

# ***2026 European Strategy Update: Overview of WG2b Report***

**Jorge de Blas**

**University of Granada**

# ***Conclusions from the 2026 update of the European Strategy for Particle Physics***



# ***The European Strategy for Particle Physics: 2026 Update***

## ***European Strategy Group Recommendations***

### **The next CERN flagship collider project**

A. The electron–positron Future Circular Collider (FCC-ee) is recommended as the preferred option for the next flagship collider at CERN.

B. A descoped FCC-ee is the preferred alternative option for the next flagship collider at CERN.

# The European Strategy for Particle Physics: 2026 Update

## European Strategy Group Recommendations

### The next CERN flagship collider project

A. The electron–positron Future Circular Collider (FCC-ee) is recommended as the preferred option for the next flagship collider at CERN.

- Multiple considerations go into this strategic decision, with the *physics potential* being one of the main pillars:
  - ▶ *Broadest high-precision physics programme, covering the EW, Higgs, Top, Flavour (and even QCD) sectors*
  - ▶ *Paving the way towards the exploration of the high-Energy frontier by the FCC-hh (access to  $\approx 10$  TeV Parton scale)*

| Machine         | Precision Physics | BSM physics | Physics vs CEPC | Technical readiness | Constr. cost (BCHF) | Time scale | Path to $\geq 10$ TeV |
|-----------------|-------------------|-------------|-----------------|---------------------|---------------------|------------|-----------------------|
| FCC-ee          | 22                | 23          |                 |                     | 15.3                | 2046-2060  |                       |
| Descoped FCC-ee | 15                | 17          |                 |                     | 12.9                | 2046-2055  |                       |
| LCF550          | 15                | 17          |                 |                     | 14.8                | 2045-2065  |                       |
| CLIC1500        | 14                | 18          |                 |                     | 14.6                | 2045-2066  |                       |
| LCF250          | 10                | 16          |                 |                     | 9.4                 | 2045-2053  |                       |
| CLIC380         | 10                | 16          |                 |                     | 7.5                 | 2045-2054  |                       |
| LEP3            | 15                | 17          |                 |                     | 4.1                 | 2047-2062  |                       |
| LHeC            | 8                 | 7           |                 |                     | 2.1                 | 2044-2051  |                       |

# The European Strategy for Particle Physics: 2026 Update

| Machine            | Competitiveness wrt<br>CEPC running in parallel |                |                    |                        | Project estimates<br>+ exp. (CERN part) |               |                    |
|--------------------|-------------------------------------------------|----------------|--------------------|------------------------|-----------------------------------------|---------------|--------------------|
|                    | Precision<br>Physics                            | BSM<br>physics | Physics<br>vs CEPC | Technical<br>readiness | Constr.<br>cost<br>(BCHF)               | Time<br>scale | Path to<br>≥10 TeV |
| FCC-ee             | 22                                              | 23             |                    |                        | 15.3                                    | 2046-2060     |                    |
| Descoped<br>FCC-ee | 15                                              | 17             |                    |                        | 12.9                                    | 2046-2055     |                    |
| LCF550             | 15                                              | 17             |                    |                        | 14.8                                    | 2045-2065     |                    |
| CLIC1500           | 14                                              | 18             |                    |                        | 14.6                                    | 2045-2066     |                    |
| LCF250             | 10                                              | 16             |                    |                        | 9.4                                     | 2045-2053     |                    |
| CLIC380            | 10                                              | 16             |                    |                        | 7.5                                     | 2045-2054     |                    |
| LEP3               | 15                                              | 17             |                    |                        | 4.1                                     | 2047-2062     |                    |
| LHeC               | 8                                               | 7              |                    |                        | 2.1                                     | 2044-2051     |                    |

Viability  
(tech., econ., soc.)  
for transition  
to high-E frontier  
FCC-ee/LEP3 → FCC-hh  
LCF/CLIC → Plasma?  
Muon Collider?

WG2b report  
(From Briefing Book)

WG2a report



# The European Strategy for Particle Physics: 2026 Update

Competitiveness wrt  
CEPC running in parallel

| Precision Physics | BSM physics | Physics vs CEPC |
|-------------------|-------------|-----------------|
| 22                | 23          |                 |
| 15                | 17          |                 |
| 15                | 17          |                 |
| 14                | 18          |                 |
| 10                | 16          |                 |
| 10                | 16          |                 |
| 15                | 17          |                 |
| 8                 | 7           |                 |

WG2b report  
(From Briefing Book)

| Machine         | Technical readiness |
|-----------------|---------------------|
| FCC-ee          |                     |
| Descoped FCC-ee |                     |
| LCF550          |                     |
| CLIC1500        |                     |
| LCF250          |                     |
| CLIC380         |                     |
| LEP3            |                     |
| LHeC            |                     |

WG2a report

Project estimates  
+ exp. (CERN part)

| Constr. cost (BCHF) | Time scale | Path to $\geq 10$ TeV |
|---------------------|------------|-----------------------|
| 15.3                | 2046-2060  |                       |
| 12.9                | 2046-2055  |                       |
| 14.8                | 2045-2065  |                       |
| 14.6                | 2045-2066  |                       |
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| 2.1                 | 2044-2051  |                       |

# The European Strategy for Particle Physics: 2026 Update

Competitiveness wrt  
CEPC running in parallel

| Precision Physics | BSM physics | Physics vs CEPC |
|-------------------|-------------|-----------------|
| 22                | 23          |                 |
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Project estimates  
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| Machine         | Technical readiness |
|-----------------|---------------------|
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| Descoped FCC-ee |                     |
| LCF550          |                     |

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|---------------------|------------|-----------------------|
| 15.3                | 2046-2060  |                       |
| 12.9                | 2046-2055  |                       |
| 14.8                | 2045-2065  |                       |

| Project               | Scope | TRL                              | R&D | Test facilities | Performance Uncertainty | Site Preparation | Schedule Uncertainty | Cost Uncertainty | Risk |
|-----------------------|-------|----------------------------------|-----|-----------------|-------------------------|------------------|----------------------|------------------|------|
| CLIC: 380-1500 GeV    |       | 4 - 6 / 5.2                      |     |                 |                         |                  |                      |                  |      |
| FCC-ee: 91-365 GeV    |       | 4 - 7 / 6.0                      |     |                 |                         |                  |                      |                  |      |
| FCC-hh: 85 TeV        |       | 4 - 7 (Nb <sub>3</sub> Sn) / 4.3 |     |                 |                         |                  |                      |                  |      |
|                       |       | 2 - 7 (HTS) / 3.2                |     |                 |                         |                  |                      |                  |      |
| FCC-hh (SA): 85 TeV   |       | 4 - 7 (Nb <sub>3</sub> Sn) / 5   |     |                 |                         |                  | Nb <sub>3</sub> Sn   |                  |      |
| LCF: 250-550 GeV      |       | 5 - 7 / 5.5                      |     |                 |                         |                  |                      |                  |      |
| LEP 3: 91-230 GeV     |       | 3 - 6 / 4.0                      |     |                 |                         |                  |                      |                  |      |
| LHeC                  |       | 3 - 6 / 4.5                      |     |                 |                         |                  |                      |                  |      |
| Muon Collider 3-8 TeV |       | 3.2 TeV: 3 - 5<br>7.6 TeV: 2 - 5 |     |                 |                         |                  |                      |                  |      |

WG2b r  
(From Briefi

# The European Strategy for Particle Physics: 2026 Update

**Long-term vision of the field:** Strong constraints in terms of defining avenues towards exploring the high-energy frontier in the future, with the FCC-hh currently being the most clear option

Project estimates  
+ exp. (CERN part)

| Time scale | Path to $\geq 10$ TeV |
|------------|-----------------------|
| 2046-2060  |                       |
| 2046-2055  |                       |
| 2045-2065  |                       |
|            |                       |
|            |                       |
|            |                       |
|            |                       |
|            |                       |
|            |                       |

| Project               | Scope | TRL                              | R&D | Test facilities | Performance Uncertainty | Site Preparation | Schedule Uncertainty | Cost Uncertainty | Risk |
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| CLIC: 380-1500 GeV    |       | 4 - 6 / 5.2                      |     |                 |                         |                  |                      |                  |      |
| FCC-ee: 91-365 GeV    |       | 4 - 7 / 6.0                      |     |                 |                         |                  |                      |                  |      |
| FCC-hh: 85 TeV        |       | 4 - 7 (Nb <sub>3</sub> Sn) / 4.3 |     |                 |                         |                  |                      |                  |      |
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| FCC-hh (SA): 85 TeV   |       | 4 - 7 (Nb <sub>3</sub> Sn) / 5   |     |                 |                         |                  | Nb <sub>3</sub> Sn   |                  |      |
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**Long-term vision of the field:** Strong constraints in terms of defining avenues towards exploring the high-energy frontier in the future, with the FCC-hh currently being the most clear option

Project estimates  
+ exp. (CERN part)

Time  
scale

Path to  
≥10 TeV

|    |    |  |                 |  |      |           |  |
|----|----|--|-----------------|--|------|-----------|--|
| 22 | 23 |  | FCC-ee          |  | 15.3 | 2046-2060 |  |
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| 8  | 7  |  | LHeC            |  | 2.1  | 2044-2051 |  |

WG2b report  
(From Briefing Book)

WG2a report

# The European Strategy for Particle Physics: 2026 Update

| Machine         | Precision Physics | BSM physics |
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| LEP3            | 15                | 17          |
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WG2b report  
(From Briefing Book)

| Technical readiness |
|---------------------|
|                     |
|                     |
|                     |
|                     |
|                     |
|                     |
|                     |

WG2a report

| Constr. cost (BCHF) | Time scale | Path to $\geq 10$ TeV |
|---------------------|------------|-----------------------|
| 15.3                | 2046-2060  |                       |
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| 14.8                | 2045-2065  |                       |
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Project estimates  
+ exp. (CERN part)



# The European Strategy for Particle Physics: 2026 Update

| Machine         | Precision Physics | BSM physics |
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WG2b report  
(From Briefing Book)

## Report by ESG Working Group 2b: Project Comparison – Physics Potential

Jorge de Blas<sup>1</sup>, Anadi Canepa<sup>2</sup>, Cristinel Diaconu<sup>3</sup>, Monica Dunford<sup>4</sup>, Pilar Hernández<sup>5</sup>, Gino Isidori<sup>6</sup>, Ben Kilminster<sup>7</sup>, Xinchou Lou<sup>8</sup>, Fabio Maltoni<sup>9</sup>, Jocelyn Monroe<sup>10</sup>, Rogerio Rosenfeld<sup>11</sup>, and Yuji Yamazaki<sup>12</sup>

- <sup>1</sup>Universidad de Granada, Spain
- <sup>2</sup>FNAL Batavia, US
- <sup>3</sup>Aix Marseille University, CNRS/IN2P3, CPPM, Marseille, France
- <sup>4</sup>Universität Heidelberg, Germany
- <sup>5</sup>IFIC, University of Valencia and CSIC, Spain
- <sup>6</sup>Zurich University, Switzerland
- <sup>7</sup>Zurich University, Switzerland
- <sup>8</sup>IHEP Beijing, China
- <sup>9</sup>Université catholique de Louvain, Belgium; Università di Bologna, Italy
- <sup>10</sup>Rutherford Appleton Laboratory, UK; University of California, Berkeley, US
- <sup>11</sup>São Paulo State University, Brazil
- <sup>12</sup>Kobe University, Japan

Available as part of the ESG documents - CDS:

<https://cds.cern.ch/collection/European%20Strategy%20Update?ln=en>

## The WG2b task:

To synthesize the information in the Physics Briefing Book and provide a comparison of the physics capabilities of the different future collider projects

WG2a report

# ***ESG WG2b Project Comparison***

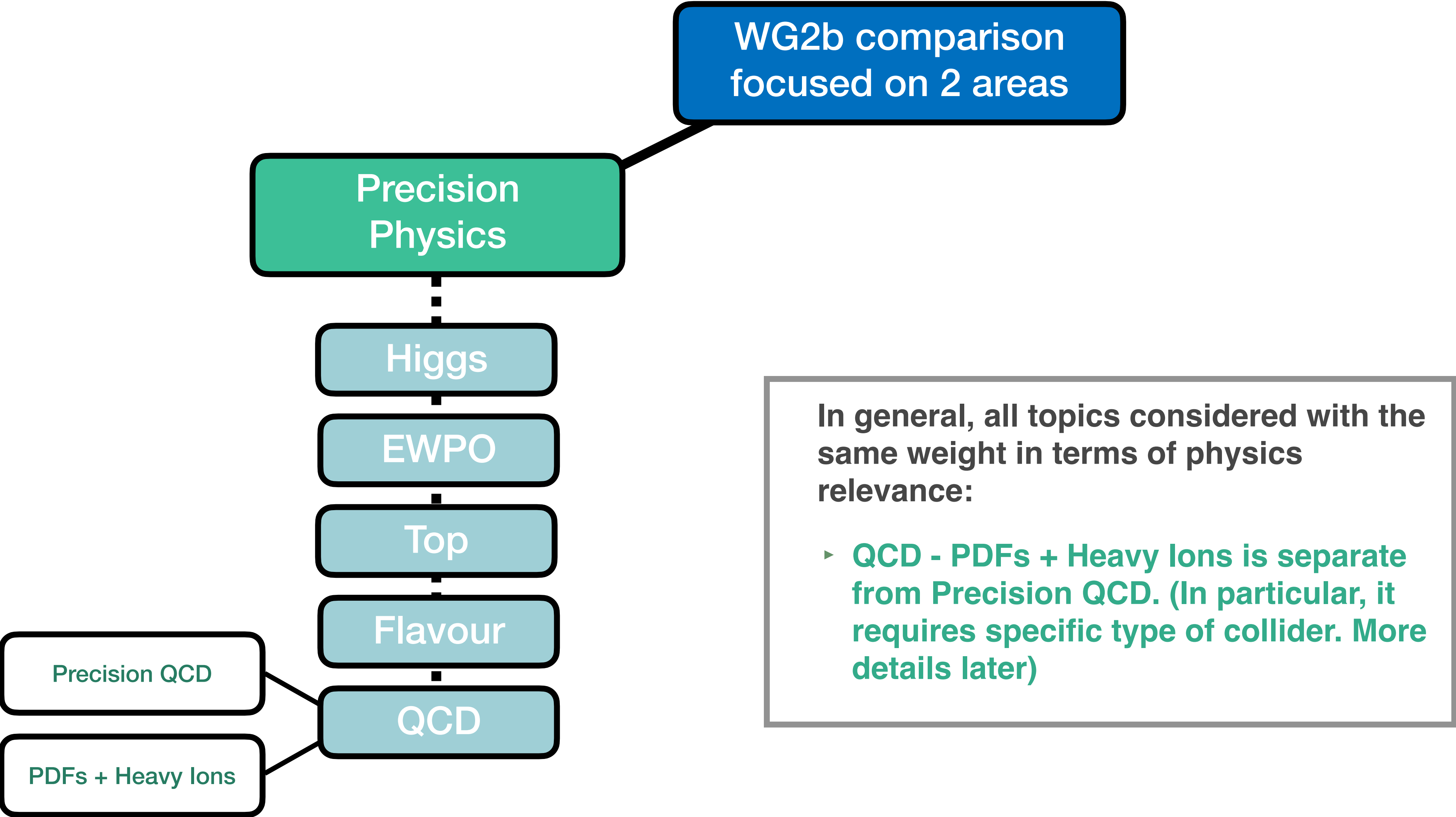
## ***Physics Potential***

# ***ESG WG2b Project Comparison: Physics Potential***

**WG2b comparison  
focused on 2 areas**



# ESG WG2b Project Comparison: Physics Potential



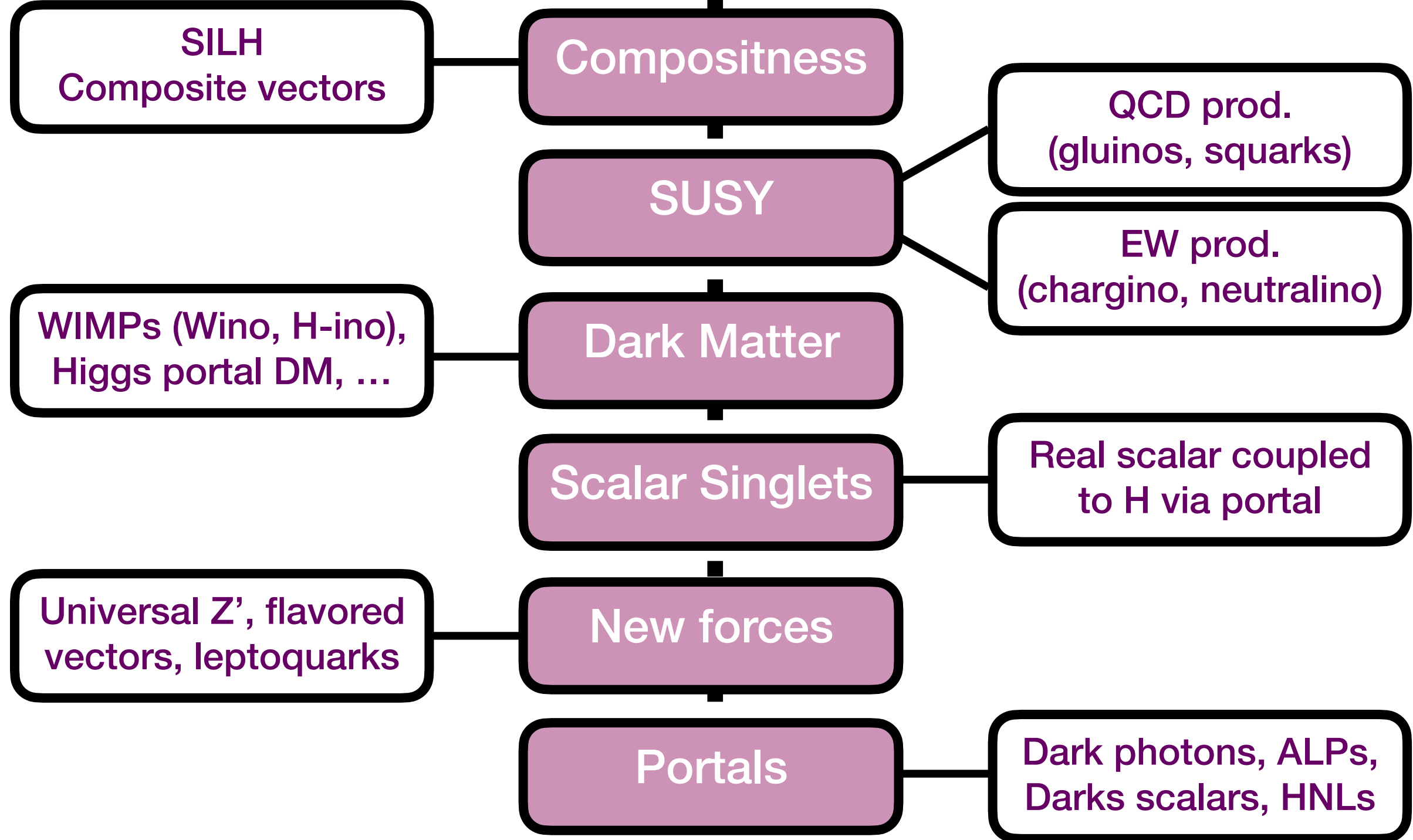
# ESG WG2b Project Comparison: Physics Potential

WG2b comparison  
focused on 2 areas

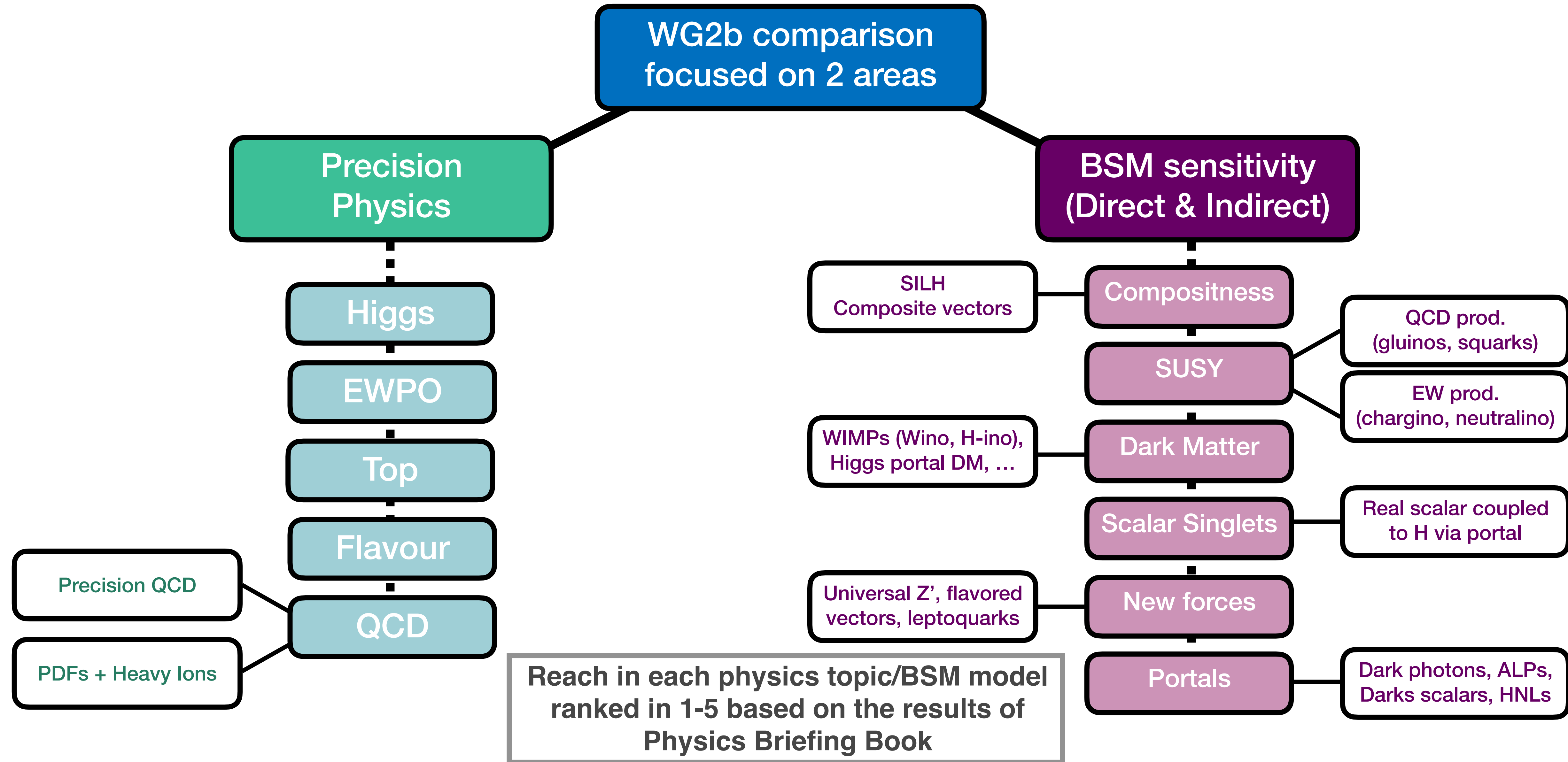
## Topics chosen based on:

- ▶ Limited set of fundamental questions that require BSM and can be addressed through collider experiments
- ▶ For each question one or two models are chosen
- ▶ Primary criterion to chose these benchmarks was simplicity

## BSM sensitivity (Direct & Indirect)



# ESG WG2b Project Comparison: Physics Potential





# Future Collider Project Comparison: Precision Physics

Precision ranking

| Project                        | Higgs                                                | EWPO           | Top | Flavour | QCD<br>(precision) | QCD<br>(PDF + HIs) |
|--------------------------------|------------------------------------------------------|----------------|-----|---------|--------------------|--------------------|
| HL-LHC                         | State-of-the-art starting point at the end of HL-LHC |                |     |         |                    |                    |
| Lepton and <i>ep</i> Colliders |                                                      |                |     |         |                    |                    |
| FCC-ee                         | 4                                                    | 5              | 3   | 5       | 5                  | 1                  |
| FCC-ee no-top                  | 2                                                    | 4              | 2   | 5       | 4                  | 1                  |
| FCC-ee descoped                | 2                                                    | 4              | 2   | 4       | 3                  | 1                  |
| LEP3                           | 2                                                    | 4              | 2   | 4       | 3                  | 1                  |
| LCF-250                        | 2                                                    | 3              | 2   | 1       | 2                  | 1                  |
| CLIC-380                       | 2                                                    | 2*             | 3   | 1       | 2                  | 1                  |
| LHeC                           | 1                                                    | 2              | 1   | 1       | 3                  | 5                  |
| Mid-Energy Lepton Colliders    |                                                      |                |     |         |                    |                    |
| LCF-550                        | 4                                                    | 4              | 4   | 1       | 2                  | 1                  |
| LCF-1000                       | 4                                                    | 4              | 4   | 1       | 2                  | 1                  |
| CLIC-1500                      | 4                                                    | 3*             | 4   | 1       | 2                  | 1                  |
| CLIC-3000                      | 4                                                    | 3*             | 4   | 1       | 2                  | 1                  |
| Energy frontier                |                                                      |                |     |         |                    |                    |
| FCC-hh                         | 3                                                    | No information |     | 3       | 2                  | 5                  |
| muC                            | 4                                                    | 3              | 5   | 3       | 1                  | 2                  |
| Precision w/ energy            |                                                      |                |     |         |                    |                    |
| LHeC + FCC-hh                  | 3                                                    | 2              | 2   | 3       | 4                  | 5                  |
| LEP3 + FCC-hh                  | 4                                                    | 4              | 3   | 4       | 3                  | 5                  |
| LEP3 + muC                     | 4                                                    | 5              | 5   | 4       | 3                  | 2                  |
| LCF-1000 + muC                 | 4                                                    | 5              | 5   | 3       | 3                  | 2                  |
| FCC-ee descoped + FCC-hh       | 4                                                    | 4              | 3   | 4       | 4                  | 5                  |
| FCC-ee + FCC-hh                | 5                                                    | 5              | 5   | 5       | 5                  | 5                  |

# Future Collider Project Comparison: Precision Physics

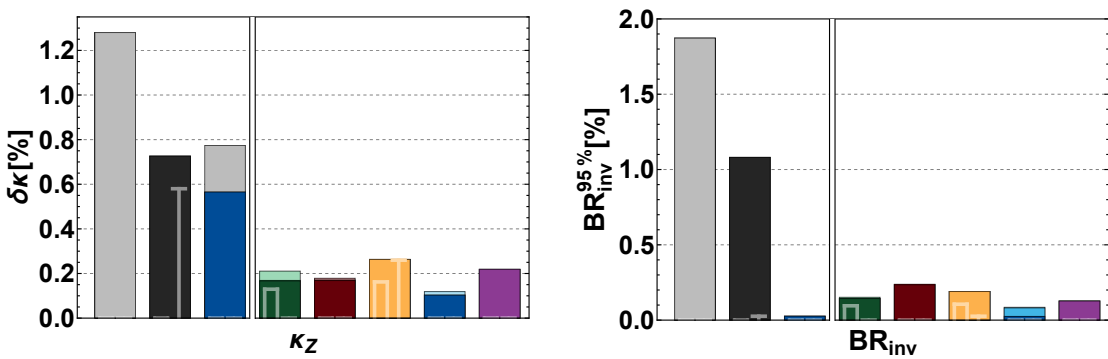
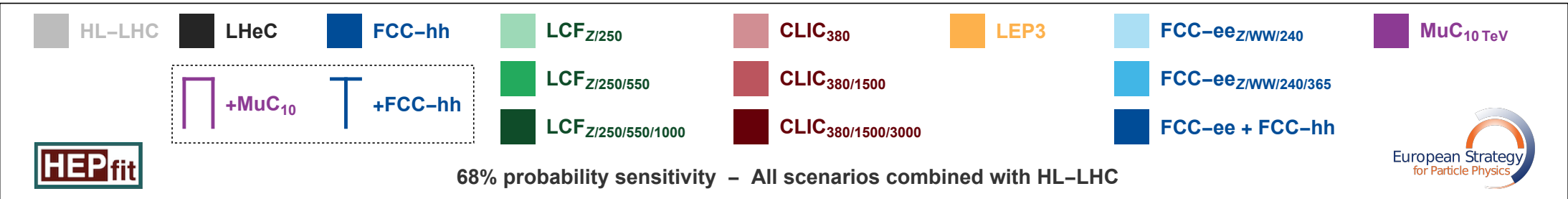
Precision ranking

| Project                     | Higgs | EWPO             |
|-----------------------------|-------|------------------|
| HL-LHC                      |       | State-of-the-art |
| Lepton and $ep$ Colliders   |       |                  |
| FCC-ee                      | 4     | 5                |
| FCC-ee no-top               | 2     | 4                |
| FCC-ee descoped             | 2     | 4                |
| LEP3                        | 2     | 4                |
| LCF-250                     | 2     | 3                |
| CLIC-380                    | 2     | 2*               |
| LHeC                        | 1     | 2                |
| Mid-Energy Lepton Colliders |       |                  |
| LCF-550                     | 4     | 4                |
| LCF-1000                    | 4     | 4                |
| CLIC-1500                   | 4     | 3*               |
| CLIC-3000                   | 4     | 3*               |
| Energy frontier             |       |                  |
| FCC-hh                      | 3     | No i             |
| muC                         | 4     | 3                |
| Precision w/ energy         |       |                  |
| LHeC + FCC-hh               | 3     | 2                |
| LEP3 + FCC-hh               | 4     | 4                |
| LEP3 + muC                  | 4     | 5                |
| LCF-1000 + muC              | 4     | 5                |
| FCC-ee descoped + FCC-hh    | 4     | 4                |
| FCC-ee + FCC-hh             | 5     | 5                |

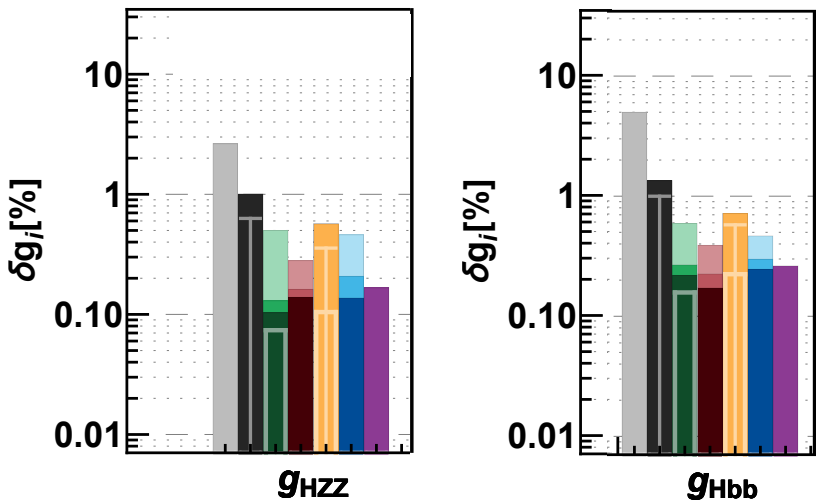
## Higgs Physics Potential

Ranking based on 2 components:

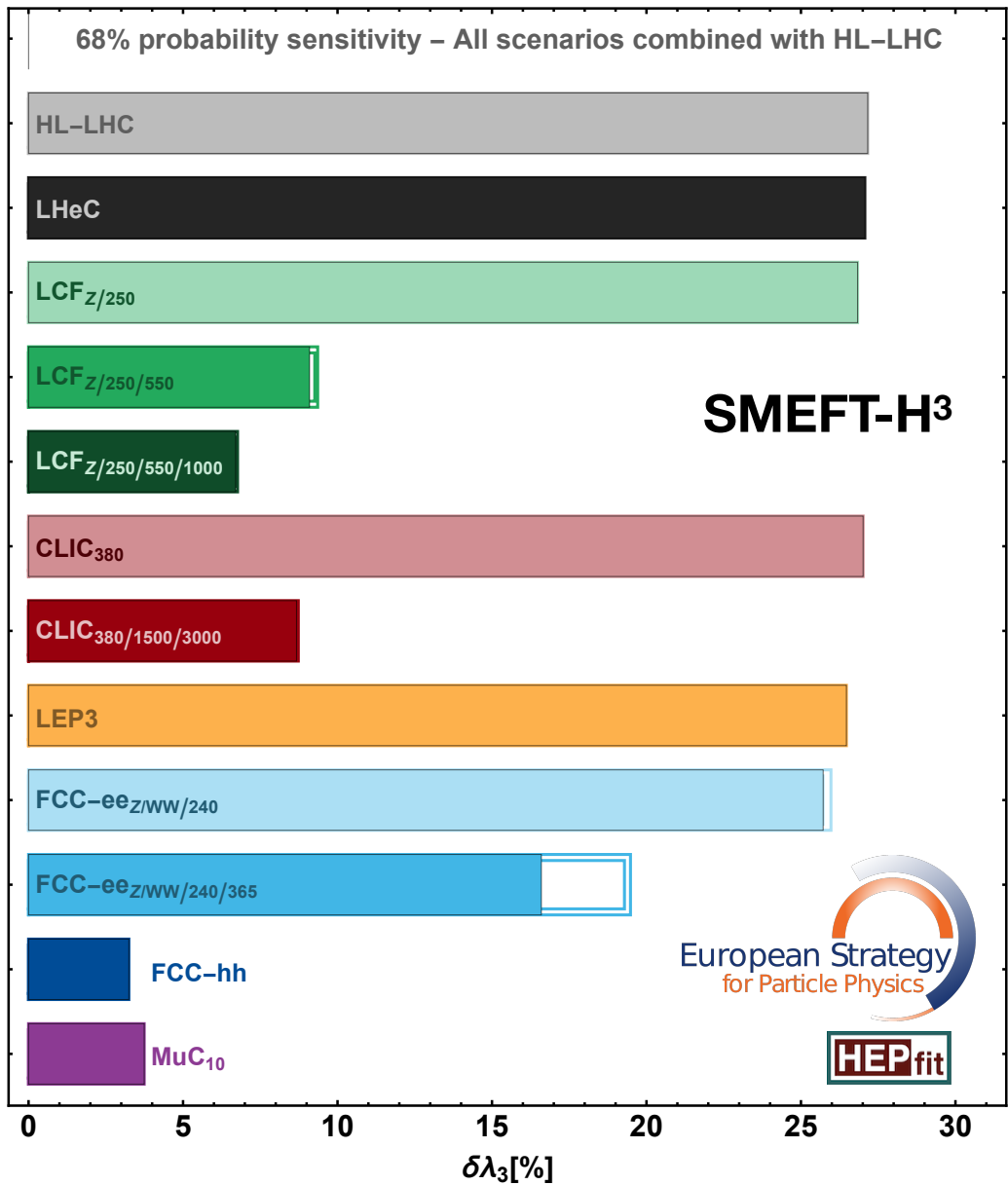
- Single Higgs boson couplings
  - Including top Yukawa and rare decays
- Higgs self-coupling



$\kappa$ -Higgs



SMEFT-Higgs



SMEFT-H<sup>3</sup>

# Future Collider Project Comparison: Precision Physics

Precision ranking

| Project                        | Higgs | EWPO             |
|--------------------------------|-------|------------------|
| HL-LHC                         |       | State-of-the-art |
| Lepton and <i>ep</i> Colliders |       |                  |
| FCC-ee                         | 4     | 5                |
| FCC-ee no-top                  | 2     | 4                |
| FCC-ee descoped                | 2     | 4                |
| LEP3                           | 2     | 4                |
| LCF-250                        | 2     | 3                |
| CLIC-380                       | 2     | 2*               |
| LHeC                           | 1     | 2                |
| Mid-Energy Lepton Colliders    |       |                  |
| LCF-550                        | 4     | 4                |
| LCF-1000                       | 4     | 4                |
| CLIC-1500                      | 4     | 3*               |
| CLIC-3000                      | 4     | 3*               |
| Energy frontier                |       |                  |
| FCC-hh                         | 3     | No i             |
| muC                            | 4     | 3                |
| Precision w/ energy            |       |                  |
| LHeC + FCC-hh                  | 3     | 2                |
| LEP3 + FCC-hh                  | 4     | 4                |
| LEP3 + muC                     | 4     | 5                |
| LCF-1000 + muC                 | 4     | 5                |
| FCC-ee descoped + FCC-hh       | 4     | 4                |
| FCC-ee + FCC-hh                | 5     | 5                |

## Higgs Physics Potential

Ranking based on 2 components:

- Single Higgs boson couplings
  - Including top Yukawa and rare decays
- Higgs self-coupling

5

Best stat. precision across all couplings (incl. rare decays, top Yukawa and self-coupling)

4

Best statistical precision in single coupling, or coverage of multiple prod. modes + access to HH

3

Improved precision in many couplings, relative to collider running at single energy point

2

Overall precision achievable at collider running at single energy point

1

Only small number of couplings improved wrt HL-LHC



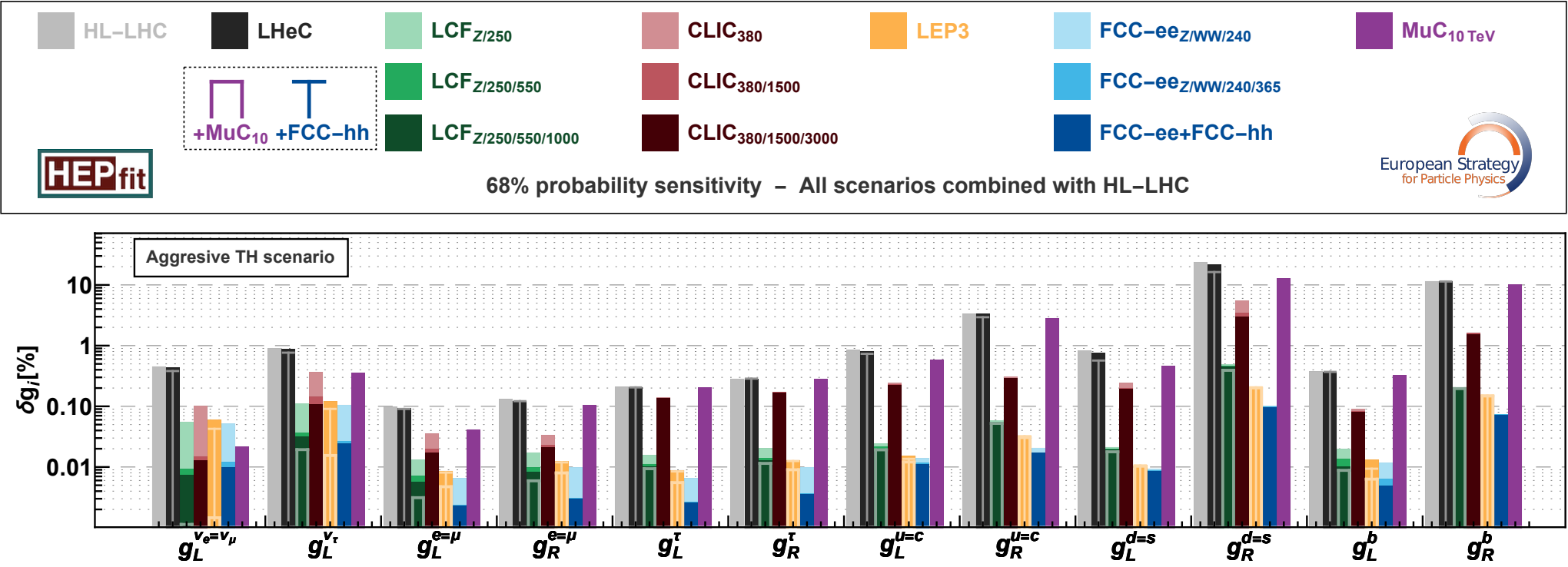
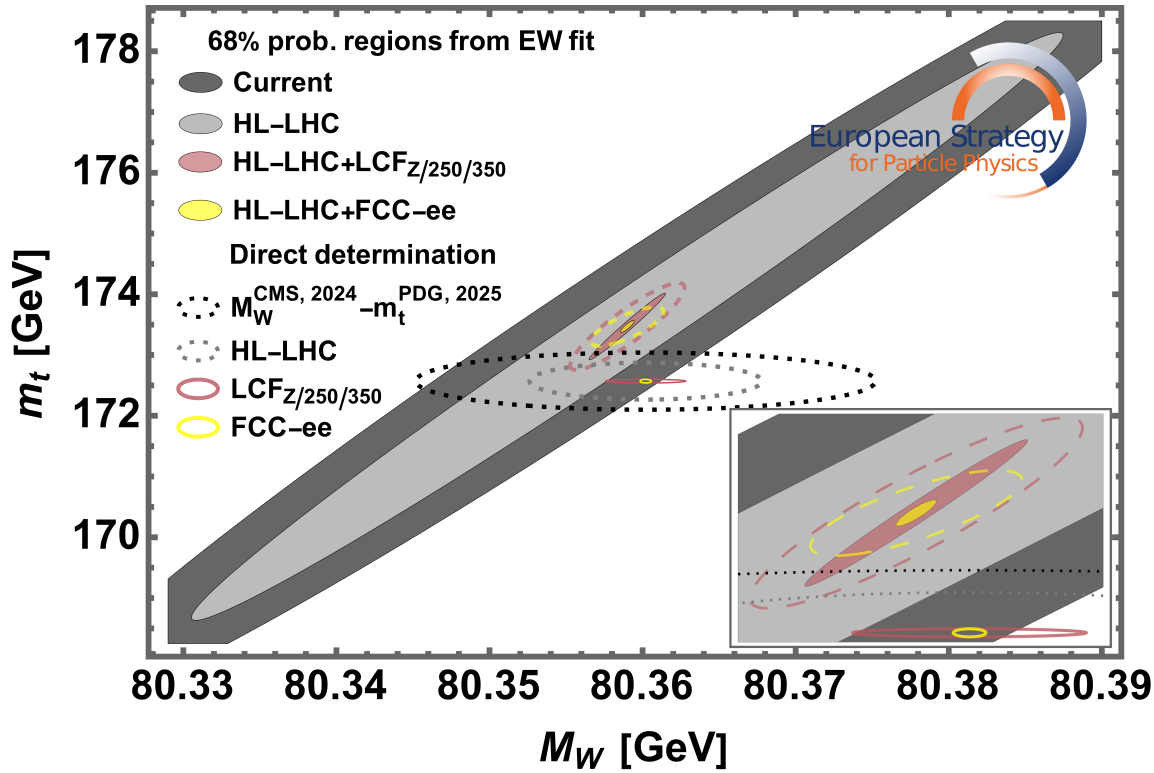
# Future Collider Project Comparison: Precision Physics

Precision ranking

| Project                     | Higgs | EWPO             |  |
|-----------------------------|-------|------------------|--|
| HL-LHC                      |       | State-of-the-art |  |
| Lepton and $ep$ Colliders   |       |                  |  |
| FCC-ee                      | 4     | 5                |  |
| FCC-ee no-top               | 2     | 4                |  |
| FCC-ee descoped             | 2     | 4                |  |
| LEP3                        | 2     | 4                |  |
| LCF-250                     | 2     | 3                |  |
| CLIC-380                    | 2     | 2*               |  |
| LHeC                        | 1     | 2                |  |
| Mid-Energy Lepton Colliders |       |                  |  |
| LCF-550                     | 4     | 4                |  |
| LCF-1000                    | 4     | 4                |  |
| CLIC-1500                   | 4     | 3*               |  |
| CLIC-3000                   | 4     | 3*               |  |
| Energy frontier             |       |                  |  |
| FCC-hh                      | 3     | No information   |  |
| muC                         | 4     | 3                |  |
| Precision w/ energy         |       |                  |  |
| LHeC + FCC-hh               | 3     | 2                |  |
| LEP3 + FCC-hh               | 4     | 4                |  |
| LEP3 + muC                  | 4     | 5                |  |
| LCF-1000 + muC              | 4     | 5                |  |
| FCC-ee descoped + FCC-hh    | 4     | 4                |  |
| FCC-ee + FCC-hh             | 5     | 5                |  |

## EWPO Physics Potential

- Ranking based on aspects like:
- Z/W statistics
  - $t\bar{t}$  threshold run (for  $m_t$  input in EW fit)
  - Access to high energies





# Future Collider Project Comparison: Precision Physics

Precision ranking

| Project                     | Higgs | EWPO             |  |
|-----------------------------|-------|------------------|--|
| HL-LHC                      |       | State-of-the-art |  |
| Lepton and $ep$ Colliders   |       |                  |  |
| FCC-ee                      | 4     | 5                |  |
| FCC-ee no-top               | 2     | 4                |  |
| FCC-ee descoped             | 2     | 4                |  |
| LEP3                        | 2     | 4                |  |
| LCF-250                     | 2     | 3                |  |
| CLIC-380                    | 2     | 2*               |  |
| LHeC                        | 1     | 2                |  |
| Mid-Energy Lepton Colliders |       |                  |  |
| LCF-550                     | 4     | 4                |  |
| LCF-1000                    | 4     | 4                |  |
| CLIC-1500                   | 4     | 3*               |  |
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| muC                         | 4     | 3                |  |
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| LEP3 + FCC-hh               | 4     | 4                |  |
| LEP3 + muC                  | 4     | 5                |  |
| LCF-1000 + muC              | 4     | 5                |  |
| FCC-ee descoped + FCC-hh    | 4     | 4                |  |
| FCC-ee + FCC-hh             | 5     | 5                |  |

## EWPO Physics Potential

Ranking based on aspects like:

- **Z/W statistics**
- **$tt$  threshold run (for  $m_t$  input in EW fit)**
- **Access to high energies**

5

**Largest Z/W statistics (Tera Z) +  $tt$  threshold run (for top mass input in EW fit)**

4

**Very large Z/W statistics (~Tera Z) WITHOUT  $tt$  threshold run OR more modest stat. (Giga Z) + high-energy run**

3

**Modest Z/W stat. (Giga Z) (with or without  $tt$  run) OR no Z/W runs but substantial high-energy coverage**

2

**No dedicated Z or WW runs but access to  $tt$  threshold run. Incremental improvement wrt HL-LHC**

1

**No substantial improvement anywhere wrt HL-LHC**

# Future Collider Project Comparison: Precision Physics

## Top Physics Potential

### Ranking based on:

- Access to  $t\bar{t}$  threshold
- Multiple energy points *above*  $t\bar{t}$  threshold
- Sensitivity via loop effects in precision obs.

5

Programme combines top-quark threshold + highest-energy measurements

4

Programme combines top-quark threshold + several high-energy points

3

Access to  $t\bar{t}$  threshold OR top measurements from  $pp$ . High sensitivity via EWPO.

2

Sensitivity only via EWPO

1

Improvement only in limited number of top couplings wrt HL-LHC

| Top                                                  | Flavour | QCD<br>(precision) | QCD<br>(PDF + HIs) | Project                     |
|------------------------------------------------------|---------|--------------------|--------------------|-----------------------------|
| State-of-the-art starting point at the end of HL-LHC |         |                    |                    | HL-LHC                      |
|                                                      |         |                    |                    | Lepton and $ep$ Colliders   |
| 3                                                    | 5       | 5                  | 1                  | <b>FCC-ee</b>               |
| 2                                                    | 5       | 4                  | 1                  | FCC-ee no-top               |
| 2                                                    | 4       | 3                  | 1                  | FCC-ee descoped             |
| 2                                                    | 4       | 3                  | 1                  | LEP3                        |
| 2                                                    | 1       | 2                  | 1                  | LCF-250                     |
| 3                                                    | 1       | 2                  | 1                  | CLIC-380                    |
| 1                                                    | 1       | 3                  | 5                  | LHeC                        |
|                                                      |         |                    |                    | Mid-Energy Lepton Colliders |
| 4                                                    | 1       | 2                  | 1                  | LCF-550                     |
| 4                                                    | 1       | 2                  | 1                  | LCF-1000                    |
| 4                                                    | 1       | 2                  | 1                  | CLIC-1500                   |
| 4                                                    | 1       | 2                  | 1                  | CLIC-3000                   |
|                                                      |         |                    |                    | Energy frontier             |
| Information                                          | 3       | 2                  | 5                  | FCC-hh                      |
| 5                                                    | 3       | 1                  | 2                  | muC                         |
|                                                      |         |                    |                    | Precision w/ energy         |
| 2                                                    | 3       | 4                  | 5                  | LHeC + FCC-hh               |
| 3                                                    | 4       | 3                  | 5                  | LEP3 + FCC-hh               |
| 5                                                    | 4       | 3                  | 2                  | LEP3 + muC                  |
| 5                                                    | 3       | 3                  | 2                  | LCF-1000 + muC              |
| 3                                                    | 4       | 4                  | 5                  | FCC-ee descoped + FCC-hh    |
| 5                                                    | 5       | 5                  | 5                  | <b>FCC-ee + FCC-hh</b>      |

# Future Collider Project Comparison: Precision Physics

## Flavour Physics Potential

Ranking based on:

- Statistical power
- Breadth of accessible channels (in  $b, c, \tau$ )

5

At least one order of magnitude wrt HL-LHC/ Belle II for all missing-energy channels + competitive CKM determination

4

Reduction by factor  $\sim 4$  of statistics wrt score of 5

3

Order-of-magnitude gain wrt HL-LHC/Belle II in fully visible  $b$  and  $c$  decays but no improvement in missing-energy channels

2

N/A

1

No improvement in  $b, c, \tau$  physics. Only CKM program from  $W$  decays

| Top                                         | Flavour | QCD<br>(precision) | QCD<br>(PDF + HIs) | Project                     |
|---------------------------------------------|---------|--------------------|--------------------|-----------------------------|
| the-art starting point at the end of HL-LHC |         |                    |                    | HL-LHC                      |
|                                             |         |                    |                    | Lepton and $ep$ Colliders   |
| 3                                           | 5       | 5                  | 1                  | FCC-ee                      |
| 2                                           | 5       | 4                  | 1                  | FCC-ee no-top               |
| 2                                           | 4       | 3                  | 1                  | FCC-ee descoped             |
| 2                                           | 4       | 3                  | 1                  | LEP3                        |
| 2                                           | 1       | 2                  | 1                  | LCF-250                     |
| 3                                           | 1       | 2                  | 1                  | CLIC-380                    |
| 1                                           | 1       | 3                  | 5                  | LHeC                        |
|                                             |         |                    |                    | Mid-Energy Lepton Colliders |
| 4                                           | 1       | 2                  | 1                  | LCF-550                     |
| 4                                           | 1       | 2                  | 1                  | LCF-1000                    |
| 4                                           | 1       | 2                  | 1                  | CLIC-1500                   |
| 4                                           | 1       | 2                  | 1                  | CLIC-3000                   |
|                                             |         |                    |                    | Energy frontier             |
| ormation                                    | 3       | 2                  | 5                  | FCC-hh                      |
| 5                                           | 3       | 1                  | 2                  | muC                         |
|                                             |         |                    |                    | Precision w/ energy         |
| 2                                           | 3       | 4                  | 5                  | LHeC + FCC-hh               |
| 3                                           | 4       | 3                  | 5                  | LEP3 + FCC-hh               |
| 5                                           | 4       | 3                  | 2                  | LEP3 + muC                  |
| 5                                           | 3       | 3                  | 2                  | LCF-1000 + muC              |
| 3                                           | 4       | 4                  | 5                  | FCC-ee descoped + FCC-hh    |
| 5                                           | 5       | 5                  | 5                  | FCC-ee + FCC-hh             |



# Future Collider Project Comparison: Precision Physics

## QCD Physics Potential

Precision ranking based on:

- Benchmarks such as  $\alpha_S$ ,  $m_t$ ,  $M_W$

**1-5** Ranked by precision in benchmarks

(Removal of top-run from FCC-ee penalized: 5→4 )

PDF + HIs ranking based on:

- Suitability for DIS
- Access to relevant kinematic regimes and observables

**5** Hadron and  $ep$  machines

**3-4** N/A

**2** Muon collider

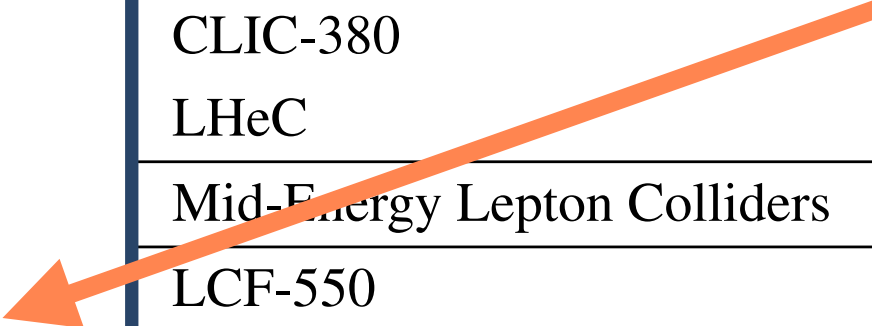
**1**  $e^+ e^-$

| Top                                         | Flavour | QCD<br>(precision) | QCD<br>(PDF + HIs) | Project                     |
|---------------------------------------------|---------|--------------------|--------------------|-----------------------------|
| the-art starting point at the end of HL-LHC |         |                    |                    | HL-LHC                      |
|                                             |         |                    |                    | Lepton and $ep$ Colliders   |
| 3                                           | 5       | 5                  | 1                  | FCC-ee                      |
| 2                                           | 5       | 4                  | 1                  | FCC-ee no-top               |
| 2                                           | 4       | 3                  | 1                  | FCC-ee descoped             |
| 2                                           | 4       | 3                  | 1                  | LEP3                        |
| 2                                           | 1       | 2                  | 1                  | LCF-250                     |
| 3                                           | 1       | 2                  | 1                  | CLIC-380                    |
| 1                                           | 1       | 3                  | 5                  | LHeC                        |
|                                             |         |                    |                    | Mid-Energy Lepton Colliders |
| 4                                           | 1       | 2                  | 1                  | LCF-550                     |
| 4                                           | 1       | 2                  | 1                  | LCF-1000                    |
| 4                                           | 1       | 2                  | 1                  | CLIC-1500                   |
| 4                                           | 1       | 2                  | 1                  | CLIC-3000                   |
|                                             |         |                    |                    | Energy frontier             |
| ormation                                    | 3       | 2                  | 5                  | FCC-hh                      |
| 5                                           | 3       | 1                  | 2                  | muC                         |
|                                             |         |                    |                    | Precision w/ energy         |
| 2                                           | 3       | 4                  | 5                  | LHeC + FCC-hh               |
| 3                                           | 4       | 3                  | 5                  | LEP3 + FCC-hh               |
| 5                                           | 4       | 3                  | 2                  | LEP3 + muC                  |
| 5                                           | 3       | 3                  | 2                  | LCF-1000 + muC              |
| 3                                           | 4       | 4                  | 5                  | FCC-ee descoped + FCC-hh    |
| 5                                           | 5       | 5                  | 5                  | FCC-ee + FCC-hh             |

# Future Collider Project Comparison: Precision Physics

| Project                        | Higgs                                                | EWPO           | Top | Flavour | QCD<br>(precision) | QCD<br>(PDF + HIs) |
|--------------------------------|------------------------------------------------------|----------------|-----|---------|--------------------|--------------------|
| HL-LHC                         | State-of-the-art starting point at the end of HL-LHC |                |     |         |                    |                    |
| Lepton and <i>ep</i> Colliders |                                                      |                |     |         |                    |                    |
| FCC-ee                         | 4                                                    | 5              | 3   | 5       | 5                  | 1                  |
| FCC-ee no-top                  | 2                                                    | 4              | 2   | 5       | 4                  | 1                  |
| FCC-ee descoped                | 2                                                    | 4              | 2   | 4       | 3                  | 1                  |
| LEP3                           | 2                                                    | 4              | 2   | 4       | 3                  | 1                  |
| LCF-250                        | 2                                                    | 3              | 2   | 1       | 2                  | 1                  |
| CLIC-380                       | 2                                                    | 2*             | 3   | 1       | 2                  | 1                  |
| LHeC                           | 1                                                    | 2              | 1   | 1       | 3                  | 5                  |
| Mid-Energy Lepton Colliders    |                                                      |                |     |         |                    |                    |
| LCF-550                        | 4                                                    | 4              | 4   | 1       | 2                  | 1                  |
| LCF-1000                       | 4                                                    | 4              | 4   | 1       | 2                  | 1                  |
| CLIC-1500                      | 4                                                    | 3*             | 4   | 1       | 2                  | 1                  |
| CLIC-3000                      | 4                                                    | 3*             | 4   | 1       | 2                  | 1                  |
| Energy frontier                |                                                      |                |     |         |                    |                    |
| FCC-hh                         | 3                                                    | No information |     | 3       | 2                  | 5                  |
| muC                            | 4                                                    | 3              | 5   | 3       | 1                  | 2                  |
| Precision w/ energy            |                                                      |                |     |         |                    |                    |
| LHeC + FCC-hh                  | 3                                                    | 2              | 2   | 3       | 4                  | 5                  |
| LEP3 + FCC-hh                  | 4                                                    | 4              | 3   | 4       | 3                  | 5                  |
| LEP3 + muC                     | 4                                                    | 5              | 5   | 4       | 3                  | 2                  |
| LCF-1000 + muC                 | 4                                                    | 5              | 5   | 3       | 3                  | 2                  |
| FCC-ee descoped + FCC-hh       | 4                                                    | 4              | 3   | 4       | 4                  | 5                  |
| FCC-ee + FCC-hh                | 5                                                    | 5              | 5   | 5       | 5                  | 5                  |

| Machine         | Precision Physics |
|-----------------|-------------------|
| FCC-ee          | 22                |
| Descoped FCC-ee | 15                |
| LCF550          | 15                |
| CLIC1500        | 14                |
| LCF250          | 10                |
| CLIC380         | 10                |
| LEP3            | 15                |
| LHeC            | 8                 |



# Future Collider Project Comparison: BSM Physics

BSM ranking

| Project                        | Comp.<br>H & V                                       | SUSY<br>(QCD) | SUSY<br>(EW) | DM | Scalar<br>Singlet | New forces | Portals |
|--------------------------------|------------------------------------------------------|---------------|--------------|----|-------------------|------------|---------|
| HL-LHC                         | State-of-the-art starting point at the end of HL-LHC |               |              |    |                   |            |         |
| Lepton and <i>ep</i> Colliders |                                                      |               |              |    |                   |            |         |
| FCC-ee                         | 4                                                    | 3             | 2            | 2  | 4                 | 4          | 4       |
| FCC-ee no-top                  | 3                                                    | 3             | 2            | 2  | 3                 | 4          | 4       |
| FCC-ee descoped                | 2                                                    | 2             | 2            | 2  | 3                 | 3          | 3       |
| LEP3                           | 2                                                    | 2             | 2            | 2  | 3                 | 3          | 3       |
| LCF-250                        | 2                                                    | 2             | 2            | 2  | 2                 | 3          | 3       |
| CLIC-380                       | 2                                                    | 2             | 2            | 2  | 2                 | 3          | 3       |
| LHeC                           | 1                                                    | 1             | 1            | 1  | 1                 | 1          | 1       |
| Mid-Energy Lepton colliders    |                                                      |               |              |    |                   |            |         |
| LCF-550                        | 2                                                    | 2             | 2            | 2  | 3                 | 3          | 3       |
| CLIC-1500                      | 3                                                    | 2             | 2            | 2  | 3                 | 3          | 3       |
| LCF-1000                       | 3                                                    | 2             | 2            | 2  | 3                 | 4          | 3       |
| CLIC-3000                      | 4                                                    | 3             | 3            | 3  | 4                 | 4          | 3       |
| Energy frontier                |                                                      |               |              |    |                   |            |         |
| FCC-hh                         | 5                                                    | 5             | 5            | 5  | 4                 | 5          | 4       |
| muC                            | 5                                                    | 4             | 5            | 5  | 5                 | 5          | 4       |
| Precision w/ energy            |                                                      |               |              |    |                   |            |         |
| LHeC+ FCC-hh                   | 5                                                    | 5             | 5            | 5  | 4                 | 5          | 4       |
| LEP3 + FCC-hh                  | 5                                                    | 5             | 5            | 5  | 4                 | 5          | 4       |
| LEP3 + muC                     | 5                                                    | 4             | 5            | 5  | 5                 | 5          | 4       |
| LCF + muC                      | 5                                                    | 4             | 5            | 5  | 5                 | 5          | 4       |
| FCC-ee descoped + FCC-hh       | 5                                                    | 5             | 5            | 5  | 4                 | 5          | 4       |
| FCC-ee + FCC-hh                | 5                                                    | 5             | 5            | 5  | 5                 | 5          | 5       |



# Future Collider Project Comparison: BSM Physics

BSM ranking

| Project                     | Comp.<br>H & V | SUSY<br>(QCD) |
|-----------------------------|----------------|---------------|
| HL-LHC                      | State-of-      |               |
| Lepton and $ep$ Colliders   |                |               |
| FCC-ee                      | 4              | 3             |
| FCC-ee no-top               | 3              | 3             |
| FCC-ee descoped             | 2              | 2             |
| LEP3                        | 2              | 2             |
| LCF-250                     | 2              | 2             |
| CLIC-380                    | 2              | 2             |
| LHeC                        | 1              | 1             |
| Mid-Energy Lepton colliders |                |               |
| LCF-550                     | 2              | 2             |
| CLIC-1500                   | 3              | 2             |
| LCF-1000                    | 3              | 2             |
| CLIC-3000                   | 4              | 3             |
| Energy frontier             |                |               |
| FCC-hh                      | 5              | 5             |
| muC                         | 5              | 4             |
| Precision w/ energy         |                |               |
| LHeC+ FCC-hh                | 5              | 5             |
| LEP3 + FCC-hh               | 5              | 5             |
| LEP3 + muC                  | 5              | 4             |
| LCF + muC                   | 5              | 4             |
| FCC-ee descoped + FCC-hh    | 5              | 5             |
| FCC-ee + FCC-hh             | 5              | 5             |

## BSM Methodology

Ranking based on two-step process:

1. Analytic and quantitative evaluation of the models discussed in Physics Briefing Book
  - ▶ When possible, the reach of each collider is characterized in terms of the underlying new-physics scale at fixed coupling
  - ▶ Sometimes, e.g. Portals, this is not representative and a case-by-case rationale is used to classify coverage of parameter space
2. Synthesis into discrete performance levels
  - ▶ The continuous estimates are mapped onto 5 discrete scores, reflecting progressive improvement in reach/sensitivity:

1

...

5

Marginal improvement  
wrt HL-LHC

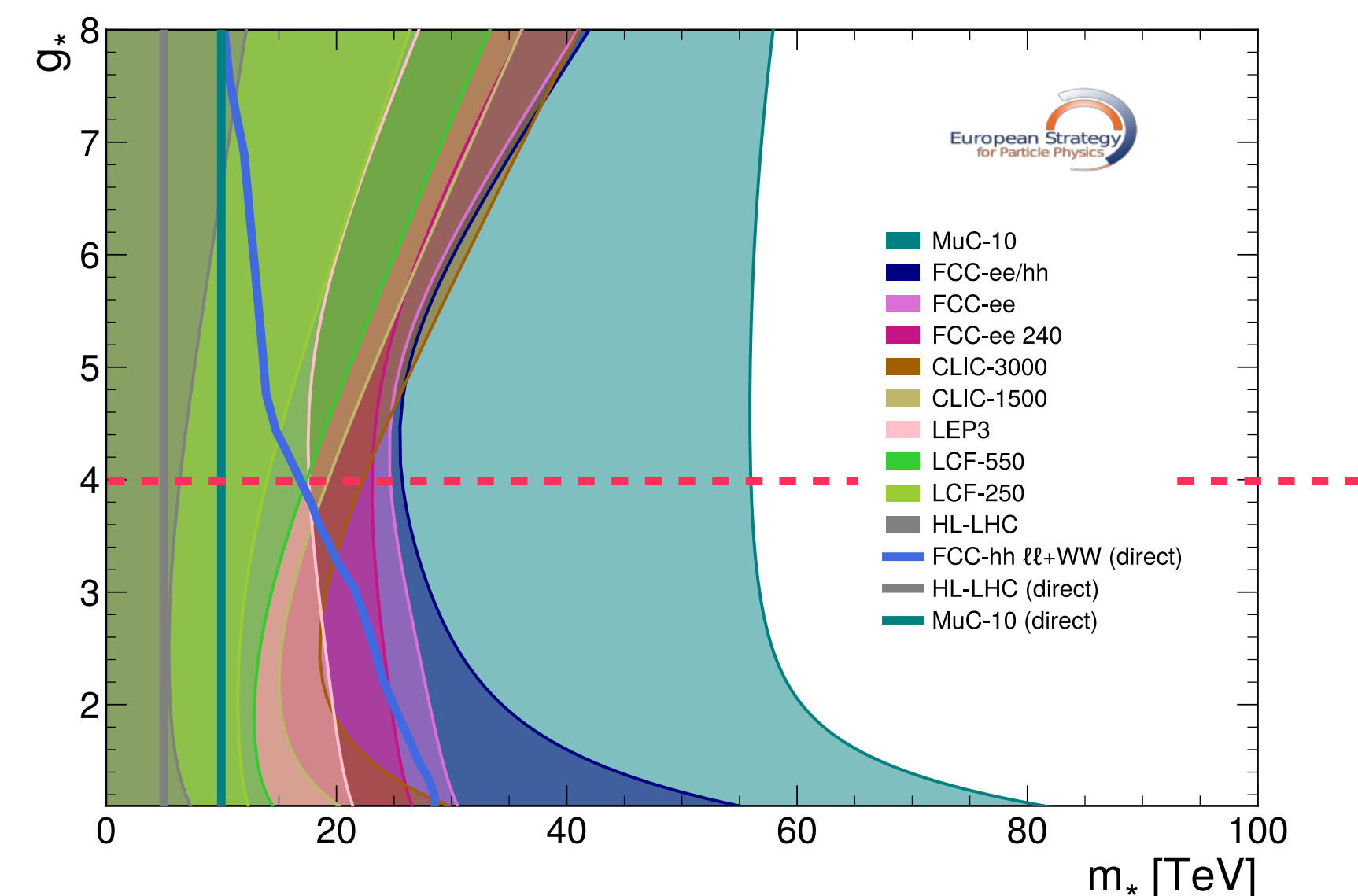
Best reach/sensitivity

# Future Collider Project Comparison: BSM Physics

BSM ranking

| Project                        | Comp.<br>H & V | SUSY<br>(QCD)             | SUSY<br>(EW) |
|--------------------------------|----------------|---------------------------|--------------|
| HL-LHC                         |                | State-of-the-art starting |              |
| Lepton and <i>ep</i> Colliders |                |                           |              |
| FCC-ee                         | 4              | 3                         | 2            |
| FCC-ee no-top                  | 3              | 3                         | 2            |
| FCC-ee descoped                | 2              | 2                         | 2            |
| LEP3                           | 2              | 2                         | 2            |
| LCF-250                        | 2              | 2                         | 2            |
| CLIC-380                       | 2              | 2                         | 2            |
| LHeC                           | 1              | 1                         | 1            |
| Mid-Energy Lepton colliders    |                |                           |              |
| LCF-550                        | 2              | 2                         | 2            |
| CLIC-1500                      | 3              | 2                         | 2            |
| LCF-1000                       | 3              | 2                         | 2            |
| CLIC-3000                      | 4              | 3                         | 3            |
| Energy frontier                |                |                           |              |
| FCC-hh                         | 5              | 5                         | 5            |
| muC                            | 5              | 4                         | 5            |
| Precision w/ energy            |                |                           |              |
| LHeC+ FCC-hh                   | 5              | 5                         | 5            |
| LEP3 + FCC-hh                  | 5              | 5                         | 5            |
| LEP3 + muC                     | 5              | 4                         | 5            |
| LCF + muC                      | 5              | 4                         | 5            |
| FCC-ee descoped + FCC-hh       | 5              | 5                         | 5            |
| FCC-ee + FCC-hh                | 5              | 5                         | 5            |

## Example: Compositeness



Ordered based on reach at ref. value  $g^* \sim 4$ :

5 FCC-hh & MuC

4 FCC-ee & CLIC-3000

2 Low-E  $e^+e^-$

3 LCF-1000 & CLIC-1500

1 LHeC

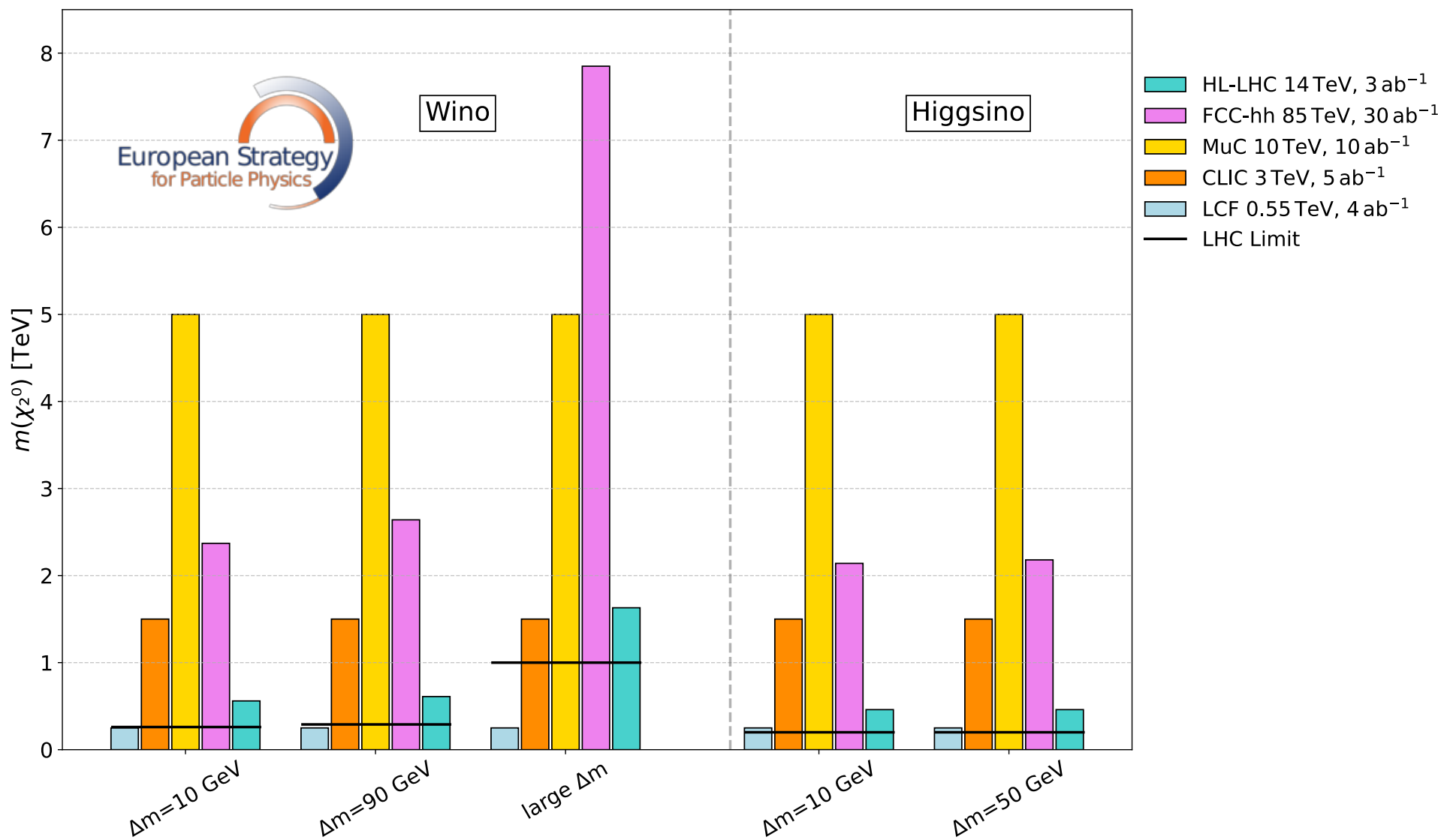


# Future Collider Project Comparison: BSM Physics

BSM ranking

| Project                        | Comp.<br>H & V | SUSY<br>(QCD)                   | SUSY<br>(EW) |  |
|--------------------------------|----------------|---------------------------------|--------------|--|
| HL-LHC                         |                | State-of-the-art starting point |              |  |
| Lepton and <i>ep</i> Colliders |                |                                 |              |  |
| FCC-ee                         | 4              | 3                               | 2            |  |
| FCC-ee no-top                  | 3              | 3                               | 2            |  |
| FCC-ee descoped                | 2              | 2                               | 2            |  |
| LEP3                           | 2              | 2                               | 2            |  |
| LCF-250                        | 2              | 2                               | 2            |  |
| CLIC-380                       | 2              | 2                               | 2            |  |
| LHeC                           | 1              | 1                               | 1            |  |
| Mid-Energy Lepton colliders    |                |                                 |              |  |
| LCF-550                        | 2              | 2                               | 2            |  |
| CLIC-1500                      | 3              | 2                               | 2            |  |
| LCF-1000                       | 3              | 2                               | 2            |  |
| CLIC-3000                      | 4              | 3                               | 3            |  |
| Energy frontier                |                |                                 |              |  |
| FCC-hh                         | 5              | 5                               | 5            |  |
| muC                            | 5              | 4                               | 5            |  |
| Precision w/ energy            |                |                                 |              |  |
| LHeC+ FCC-hh                   | 5              | 5                               | 5            |  |
| LEP3 + FCC-hh                  | 5              | 5                               | 5            |  |
| LEP3 + muC                     | 5              | 4                               | 5            |  |
| LCF + muC                      | 5              | 4                               | 5            |  |
| FCC-ee descoped + FCC-hh       | 5              | 5                               | 5            |  |
| FCC-ee + FCC-hh                | 5              | 5                               | 5            |  |

## Example: SUSY (EW)



5

FCC-hh and MuC

3

CLIC-3000 - Only  $e^+e^-$  collider  
improving substantially wrt HL-LHC

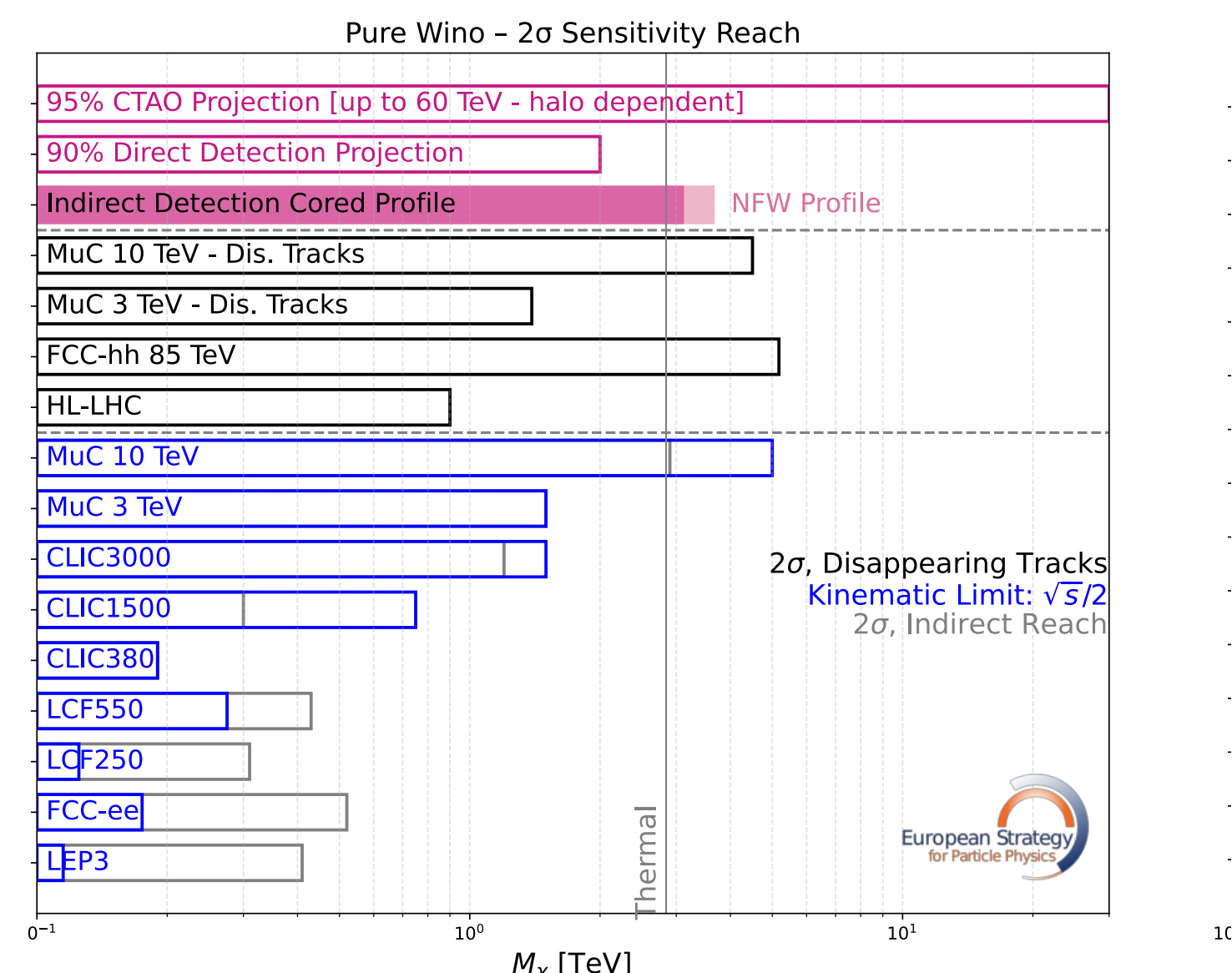
2

Other  $e^+e^-$ : no significant improvement  
wrt HL-LHC



# Future Collider Project Comparison: BSM Physics

## Example: Dark Matter



5

FCC-hh & MuC

4

N/A

3

CLIC-3000

2

LCF, LEP3 & FCC-ee

← Considering direct & indirect sensitivity

1

LHeC

USY  
(EW)

DM

Scalar  
Singlet

New forces

Portals

Project

one-art starting point at the end of HL-LHC

HL-LHC

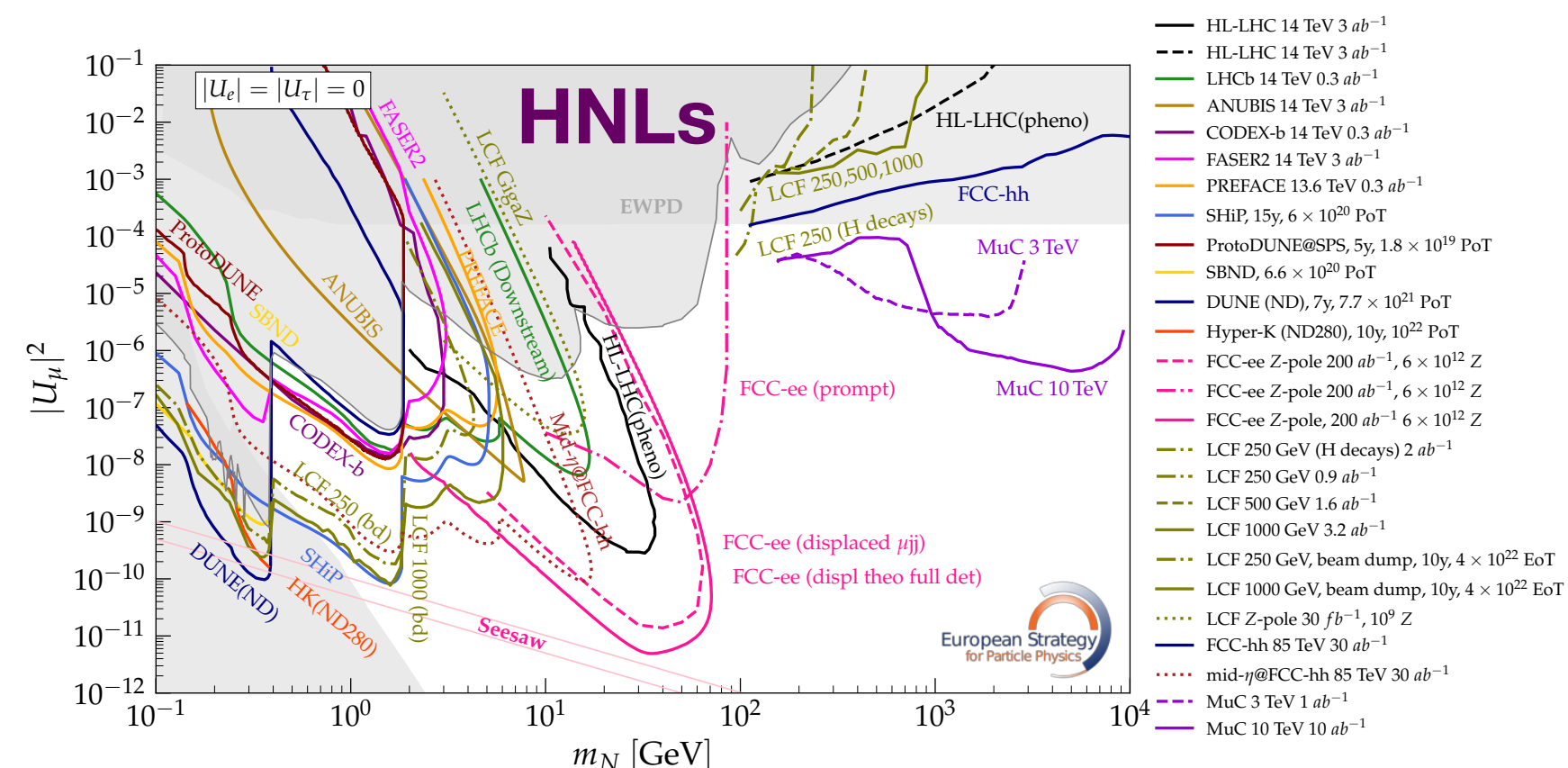
Lepton and  $ep$  Colliders

|                             |   |   |   |   |                          |
|-----------------------------|---|---|---|---|--------------------------|
| 2                           | 2 | 4 | 4 | 4 | FCC-ee                   |
| 2                           | 2 | 3 | 4 | 4 | FCC-ee no-top            |
| 2                           | 2 | 3 | 3 | 3 | FCC-ee descoped          |
| 2                           | 2 | 3 | 3 | 3 | LEP3                     |
| 2                           | 2 | 2 | 3 | 3 | LCF-250                  |
| 2                           | 2 | 2 | 3 | 3 | CLIC-380                 |
| 1                           | 1 | 1 | 1 | 1 | LHeC                     |
| Mid-Energy Lepton colliders |   |   |   |   |                          |
| 2                           | 2 | 3 | 3 | 3 | LCF-550                  |
| 2                           | 2 | 3 | 3 | 3 | CLIC-1500                |
| 2                           | 2 | 3 | 4 | 3 | LCF-1000                 |
| 3                           | 3 | 4 | 4 | 3 | CLIC-3000                |
| Energy frontier             |   |   |   |   |                          |
| 5                           | 5 | 4 | 5 | 4 | FCC-hh                   |
| 5                           | 5 | 5 | 5 | 4 | muC                      |
| Precision w/ energy         |   |   |   |   |                          |
| 5                           | 5 | 4 | 5 | 4 | LHeC+ FCC-hh             |
| 5                           | 5 | 4 | 5 | 4 | LEP3 + FCC-hh            |
| 5                           | 5 | 5 | 5 | 4 | LEP3 + muC               |
| 5                           | 5 | 5 | 5 | 4 | LCF + muC                |
| 5                           | 5 | 4 | 5 | 4 | FCC-ee descoped + FCC-hh |
| 5                           | 5 | 5 | 5 | 5 | FCC-ee + FCC-hh          |

# Future Collider Project Comparison: BSM Physics

BSM ranking

## Example: Portals\* (Dark photon, ALPs, HNL)



Difficult to define metric for comparison (2D space, widely varying coverage & detection strategies, ...)

5 FCC-ee + FCC-hh

4 FCC-hh, FCC-ee, MuC

3 LCF, CLIC, LEP3

2 N/A

1 LHeC

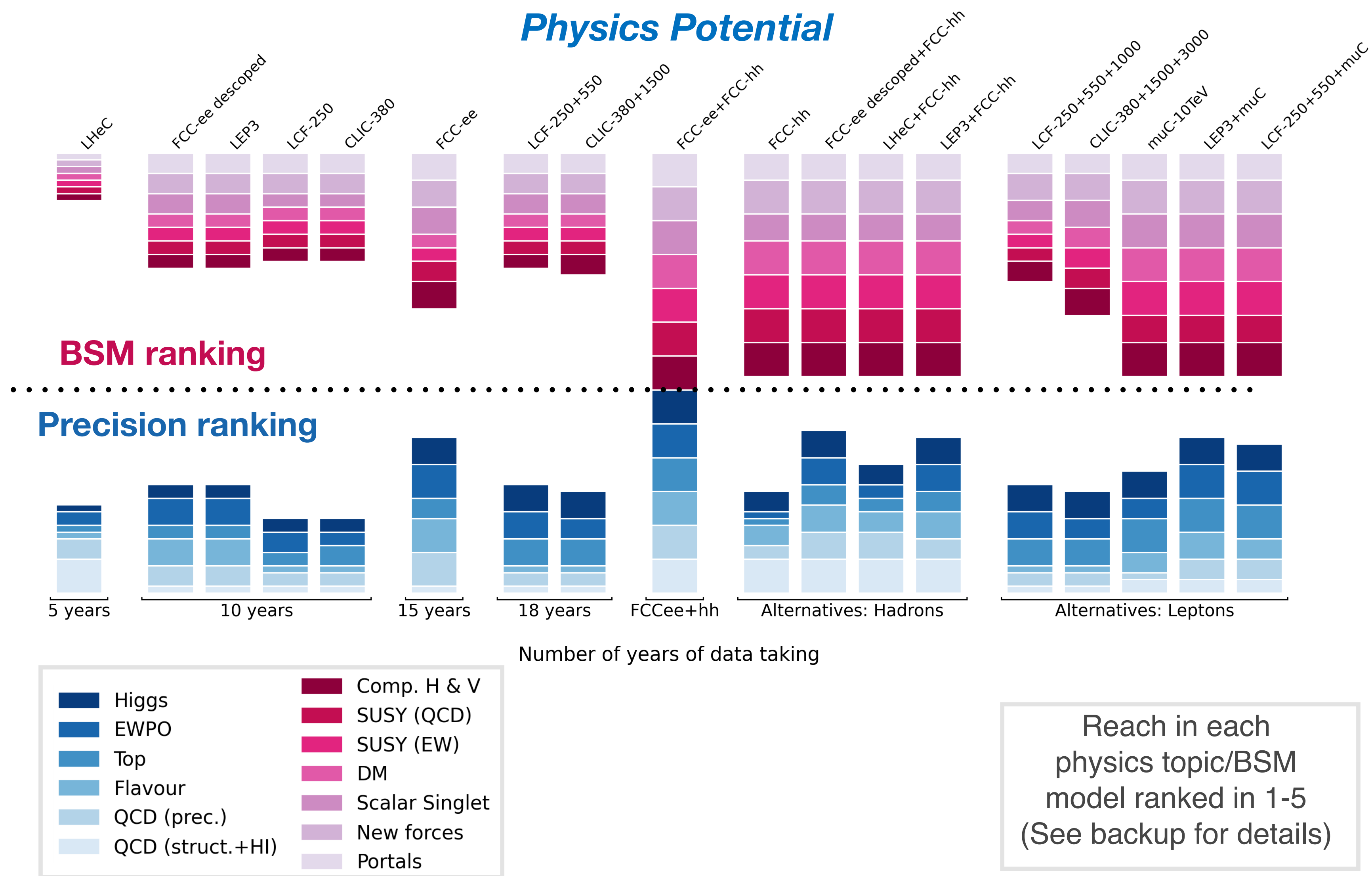
\* Dark Scalars not included, as info is only available for FCC-ee

| Scalar Singlet       | New forces | Portals | Project                        |
|----------------------|------------|---------|--------------------------------|
| at the end of HL-LHC |            |         | HL-LHC                         |
|                      |            |         | Lepton and <i>ep</i> Colliders |
|                      | 4          | 4       | <b>FCC-ee</b>                  |
| 3                    | 4          | 4       | FCC-ee no-top                  |
| 3                    | 3          | 3       | FCC-ee descoped                |
| 3                    | 3          | 3       | LEP3                           |
| 2                    | 3          | 3       | LCF-250                        |
| 2                    | 3          | 3       | CLIC-380                       |
| 1                    | 1          | 1       | LHeC                           |
|                      |            |         | Mid-Energy Lepton colliders    |
| 3                    | 3          | 3       | LCF-550                        |
| 3                    | 3          | 3       | CLIC-1500                      |
| 3                    | 4          | 3       | LCF-1000                       |
| 4                    | 4          | 3       | CLIC-3000                      |
|                      |            |         | Energy frontier                |
| 4                    | 5          | 4       | FCC-hh                         |
| 5                    | 5          | 4       | muC                            |
|                      |            |         | Precision w/ energy            |
| 4                    | 5          | 4       | LHeC+ FCC-hh                   |
| 4                    | 5          | 4       | LEP3 + FCC-hh                  |
| 5                    | 5          | 4       | LEP3 + muC                     |
| 5                    | 5          | 4       | LCF + muC                      |
| 4                    | 5          | 4       | FCC-ee descoped + FCC-hh       |
| 5                    | 5          | 5       | <b>FCC-ee + FCC-hh</b>         |

# ESG WG2b Project Comparison: Physics Potential

| Machine         | Precision Physics | BSM physics |
|-----------------|-------------------|-------------|
| FCC-ee          | 22                | 23          |
| Descoped FCC-ee | 15                | 17          |
| LCF550          | 15                | 17          |
| CLIC1500        | 14                | 18          |
| LCF250          | 10                | 16          |
| CLIC380         | 10                | 16          |
| LEP3            | 15                | 17          |
| LHeC            | 8                 | 7           |

WG2b report  
(From Briefing Book)



WG2a report



# ESG WG2b Project Comparison: Physics Potential

| Machine         | Precision Physics | BSM physics |
|-----------------|-------------------|-------------|
| FCC-ee          | 22                | 23          |
| Descoped FCC-ee | 15                | 17          |
| LCF550          | 15                | 17          |
| CLIC1500        | 14                | 18          |
| LCF250          | 10                | 16          |
| CLIC380         | 10                | 16          |
| LEP3            | 15                | 17          |
| LHeC            | 8                 | 7           |

WG2b report  
(From Briefing Book)

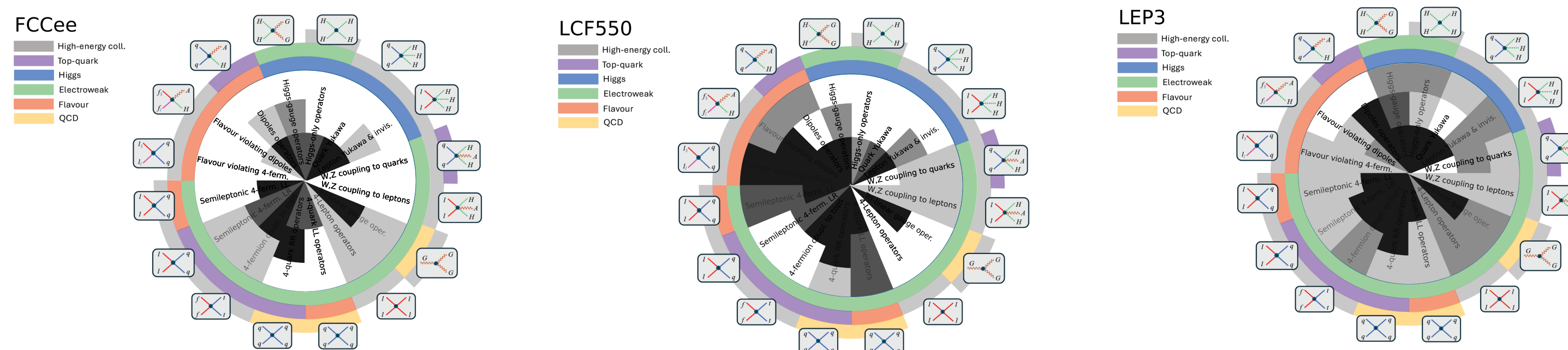
## Physics Potential

LHeC FCC-ee descoped LEP3 LCF-250 CLIC-380 FCC-ee LCF-250+550 CLIC-380+1500 FCC-ee+FCC-hh FCC-hh FCC-ee descoped+FCC-hh LHeC+FCC-hh LEP3+FCC-hh LCF-250+550+1000 CLIC-380+1500+3000 muC-10TeV LEP3+muC LCF-250+550+muC

The main driver of the physics case of the  $e^+e^-$  colliders is precision across different domains:

**Electroweak** **Higgs** **Top** **Flavour** **QCD**

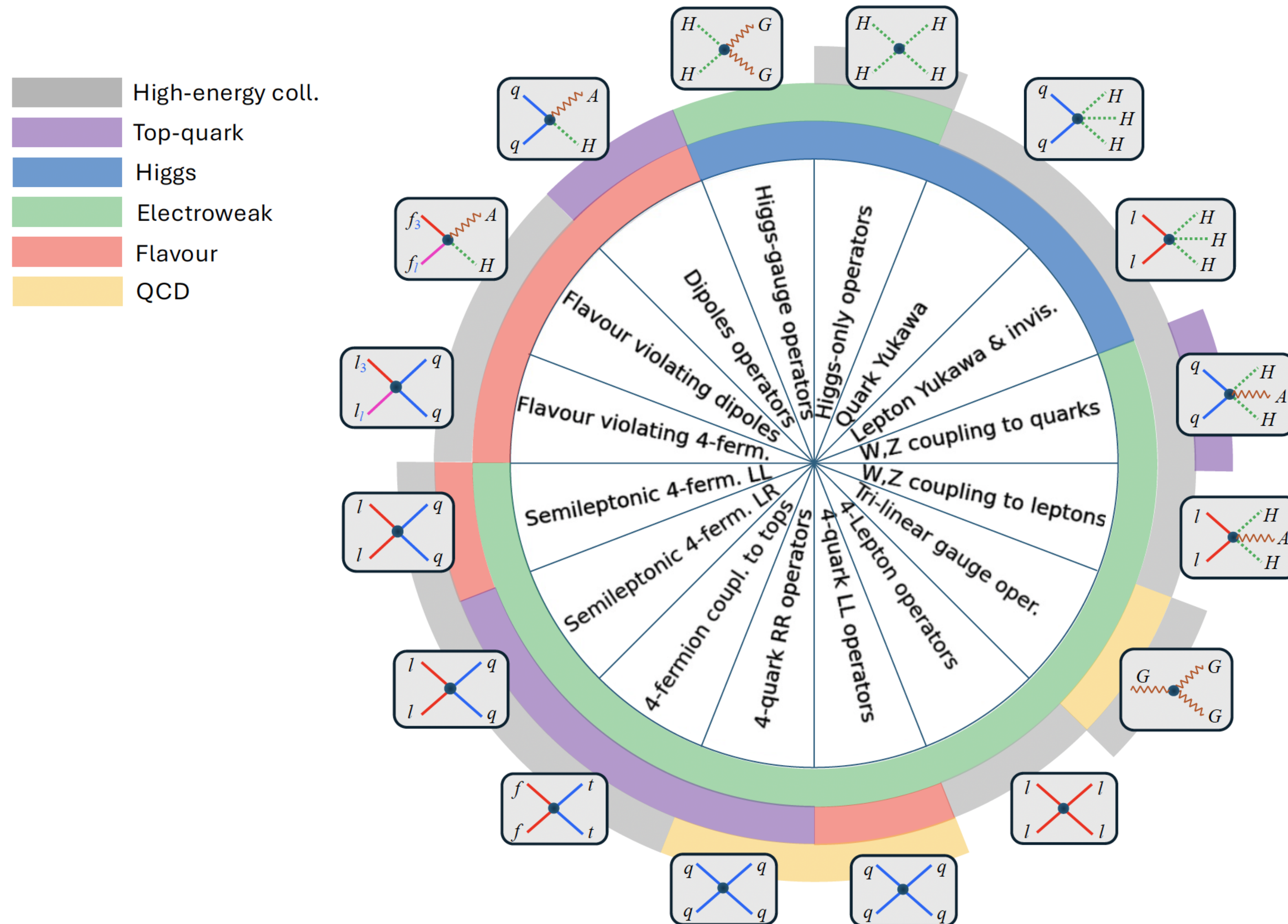
To present the ESG recommendations to CERN council, an alternative graphical comparison, including more granular information on the EW/Higgs/Top/Flavour part, was prepared:



Discussed in Appendix B of WG2b report

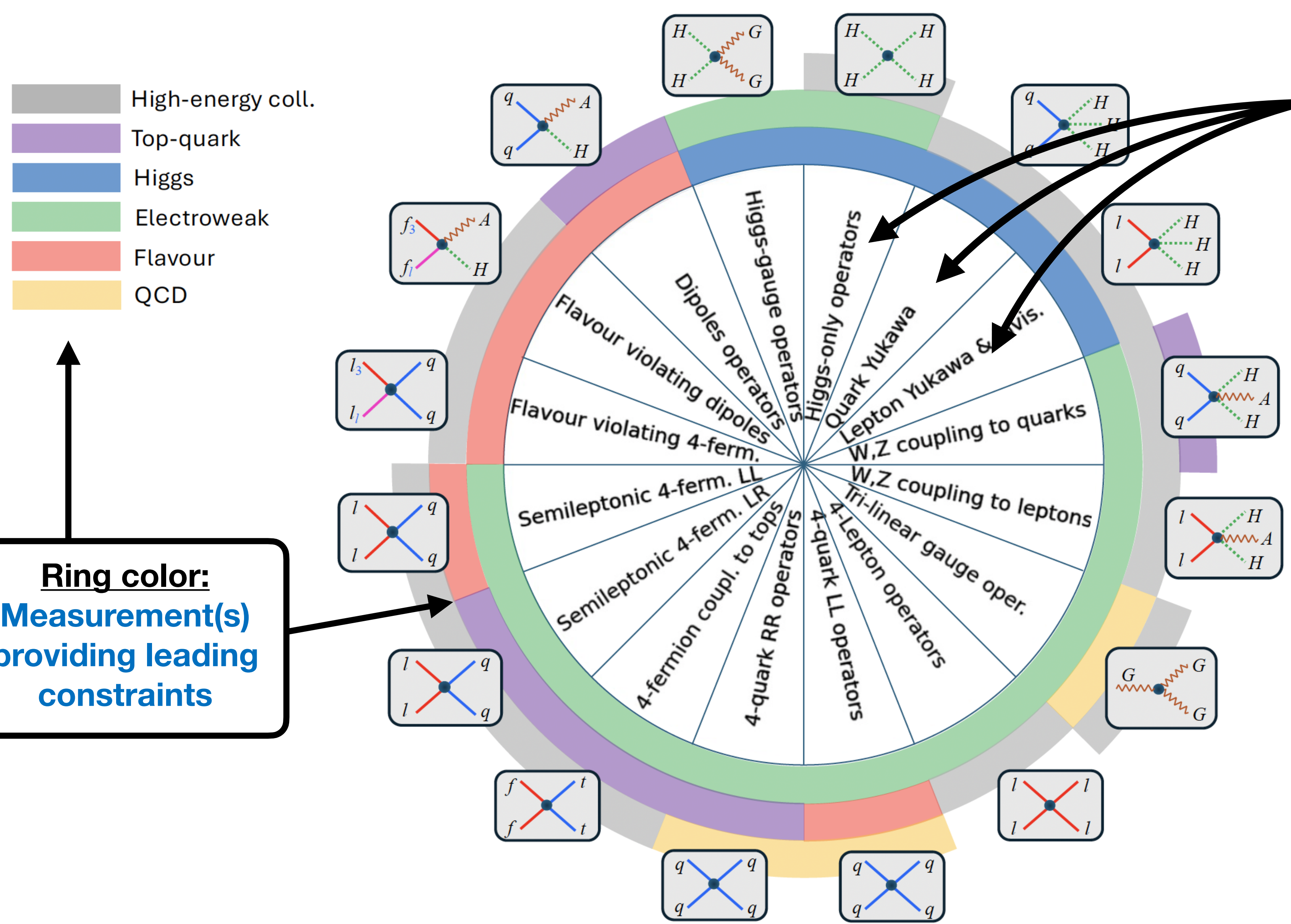
WG2a report

# ESG WG2b Project Comparison: Physics Potential





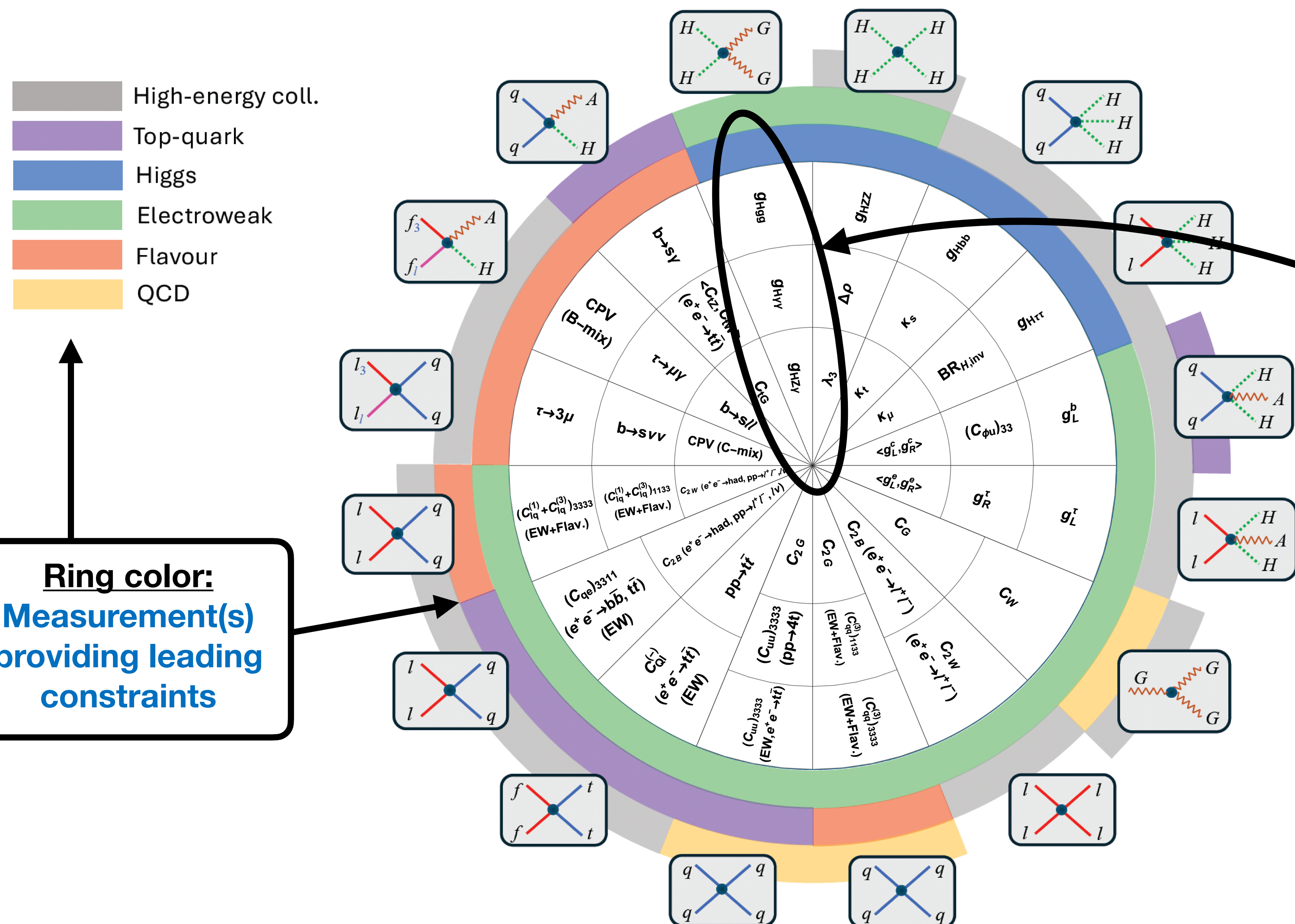
# ESG WG2b Project Comparison: Physics Potential



**Characterization of BSM physics landscape (SMEFT inspired):**  
**16 different sectors representing possible BSM deformations**

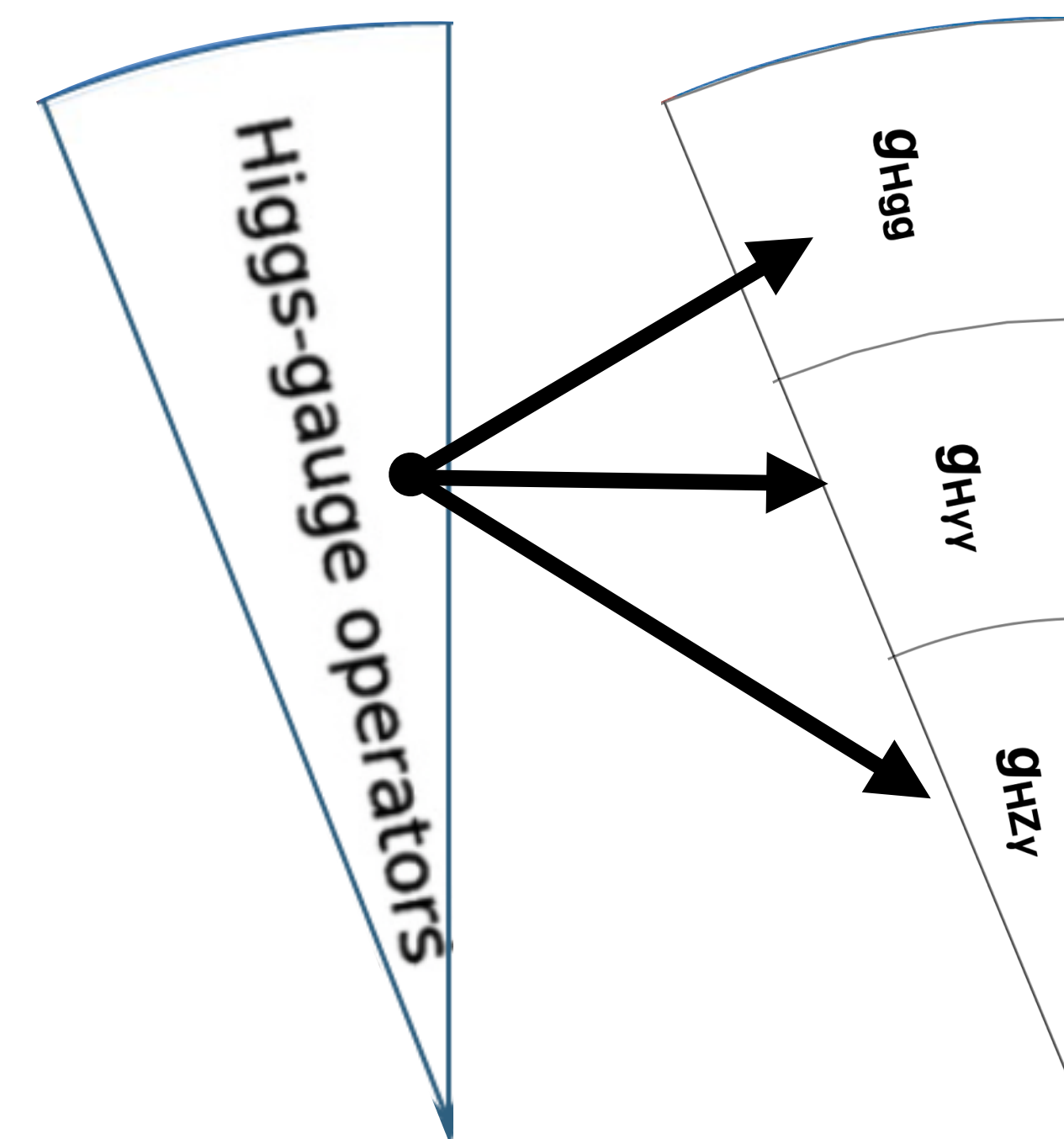


# ESG WG2b Project Comparison: Physics Potential



**Characterization of BSM physics  
landscape (SMEFT inspired):**  
**16 different sectors representing  
possible BSM deformations**

**Each sector further divided in 2-3 subsections for a more detailed characterization (44 in total)**

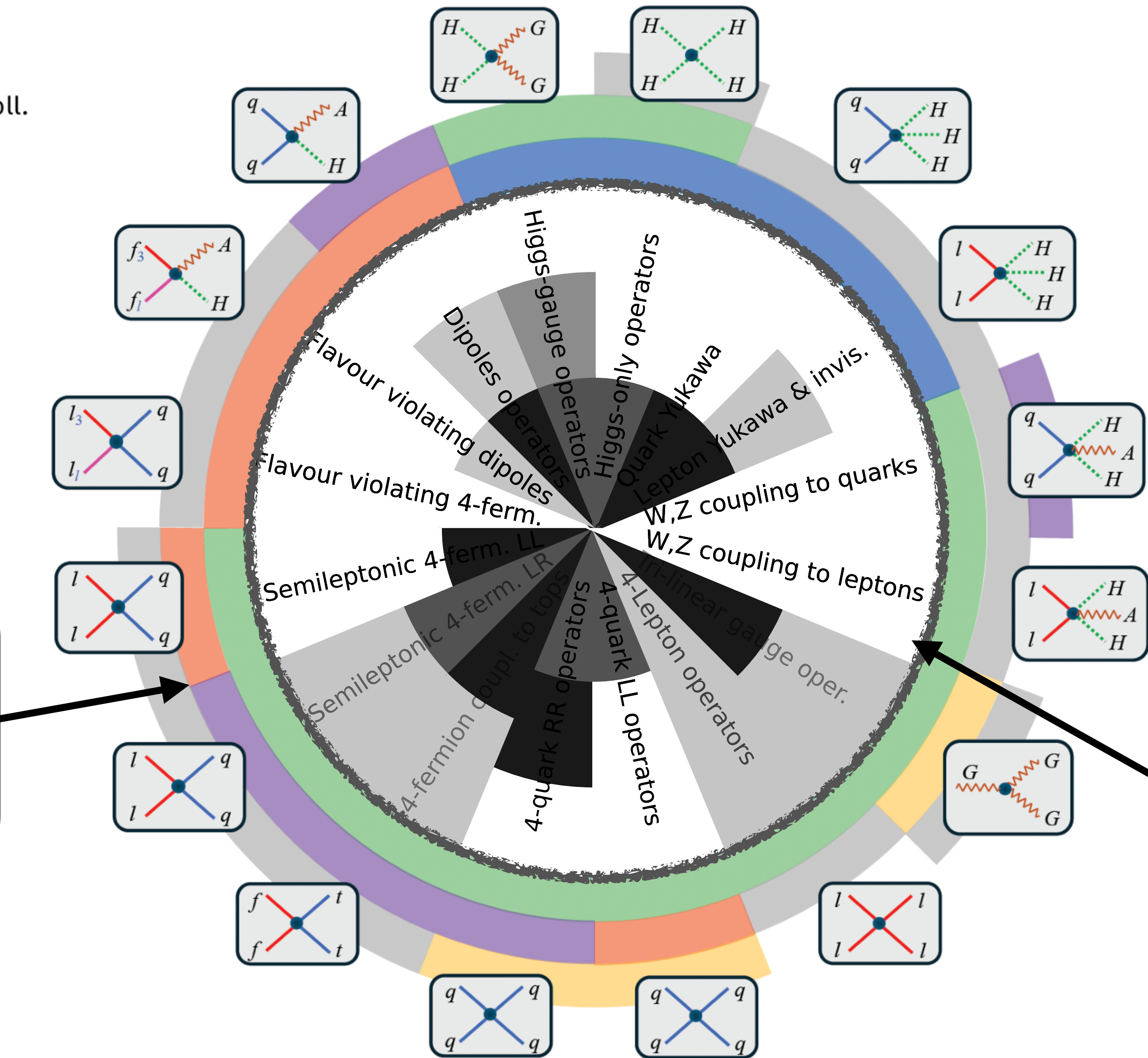




# ESG WG2b Project Comparison: Physics Potential

FCCee

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



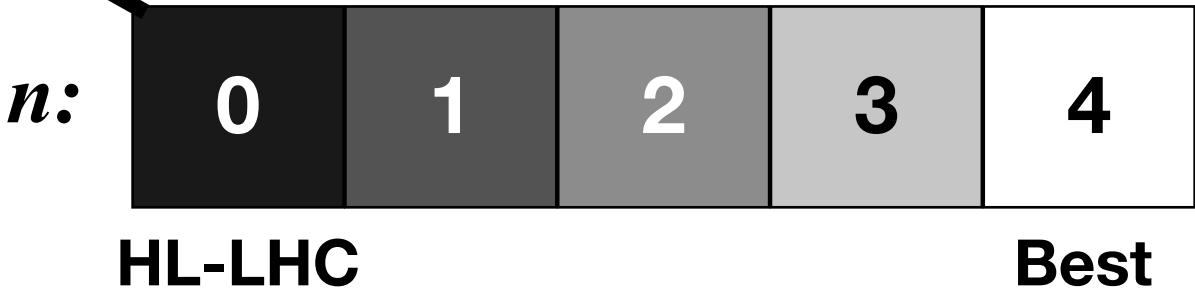
**Ring color:**  
Measurement(s)  
providing leading  
constraints

**Characterization of BSM physics  
landscape (SMEFT inspired):**  
16 different sectors representing  
possible BSM deformations

**Each sector further divided in 2-3  
subsections for a more detailed  
characterization (44 in total)**

**Collider comparison**  
For each sector, compute  
improvement,  $x$ , wrt HL-LHC  
Map into  $n \in [0,4]$  using a log scale  
 $x = p^n$

**Ranking mapped to a 5-level  
gray scale:**

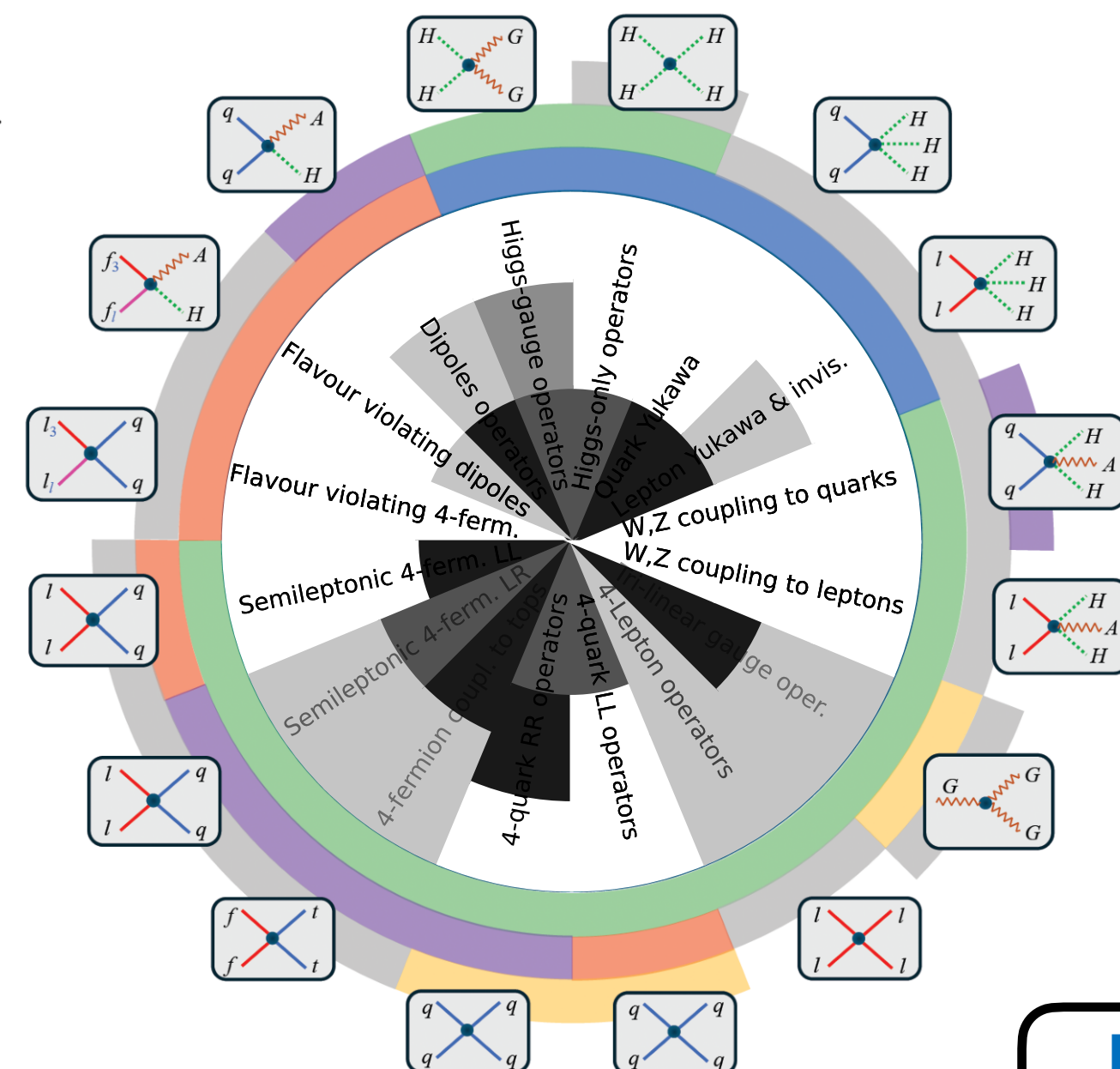




# ESG WG2b Project Comparison: Physics Potential

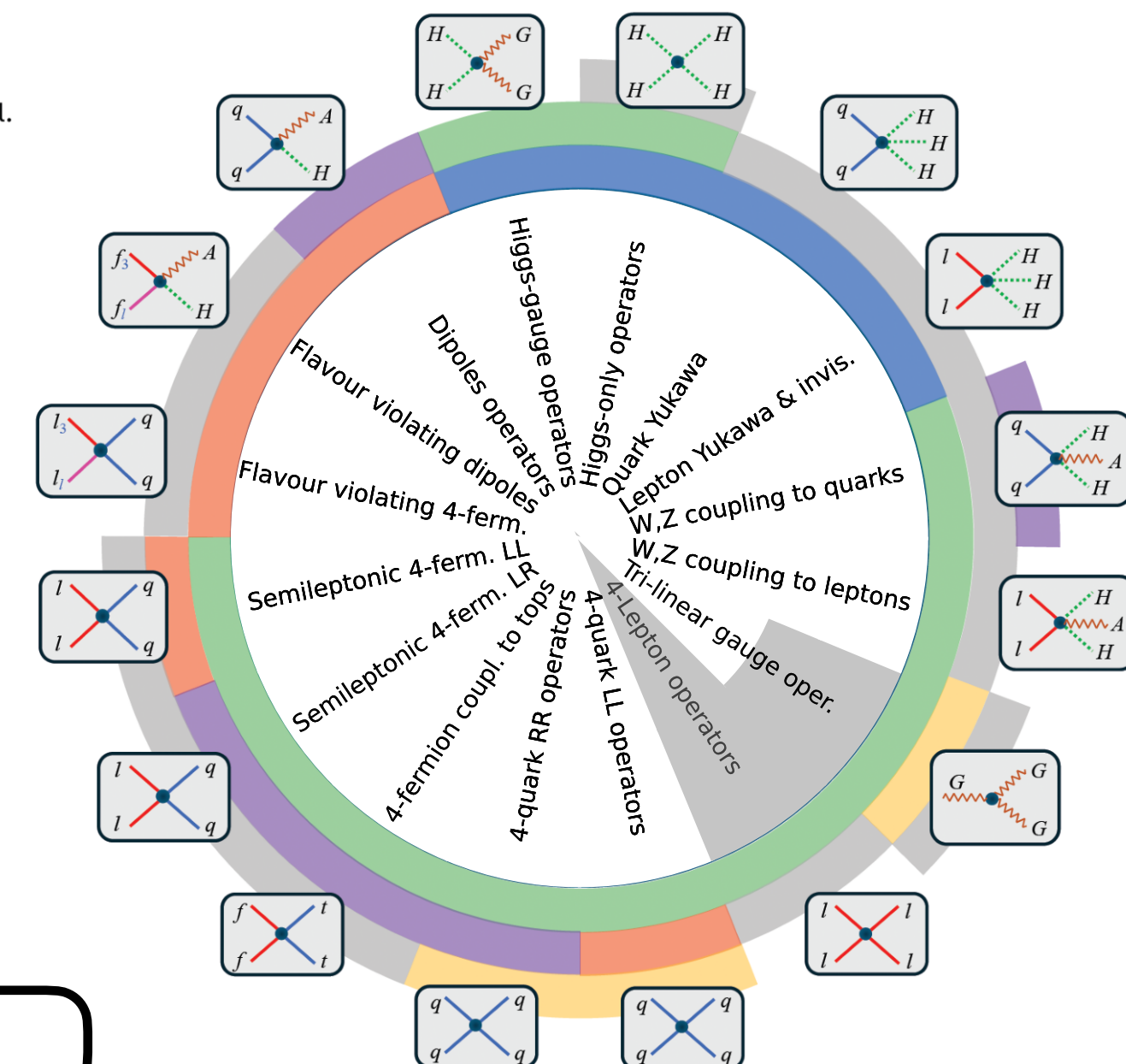
## FCCee

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



## FCCeehh

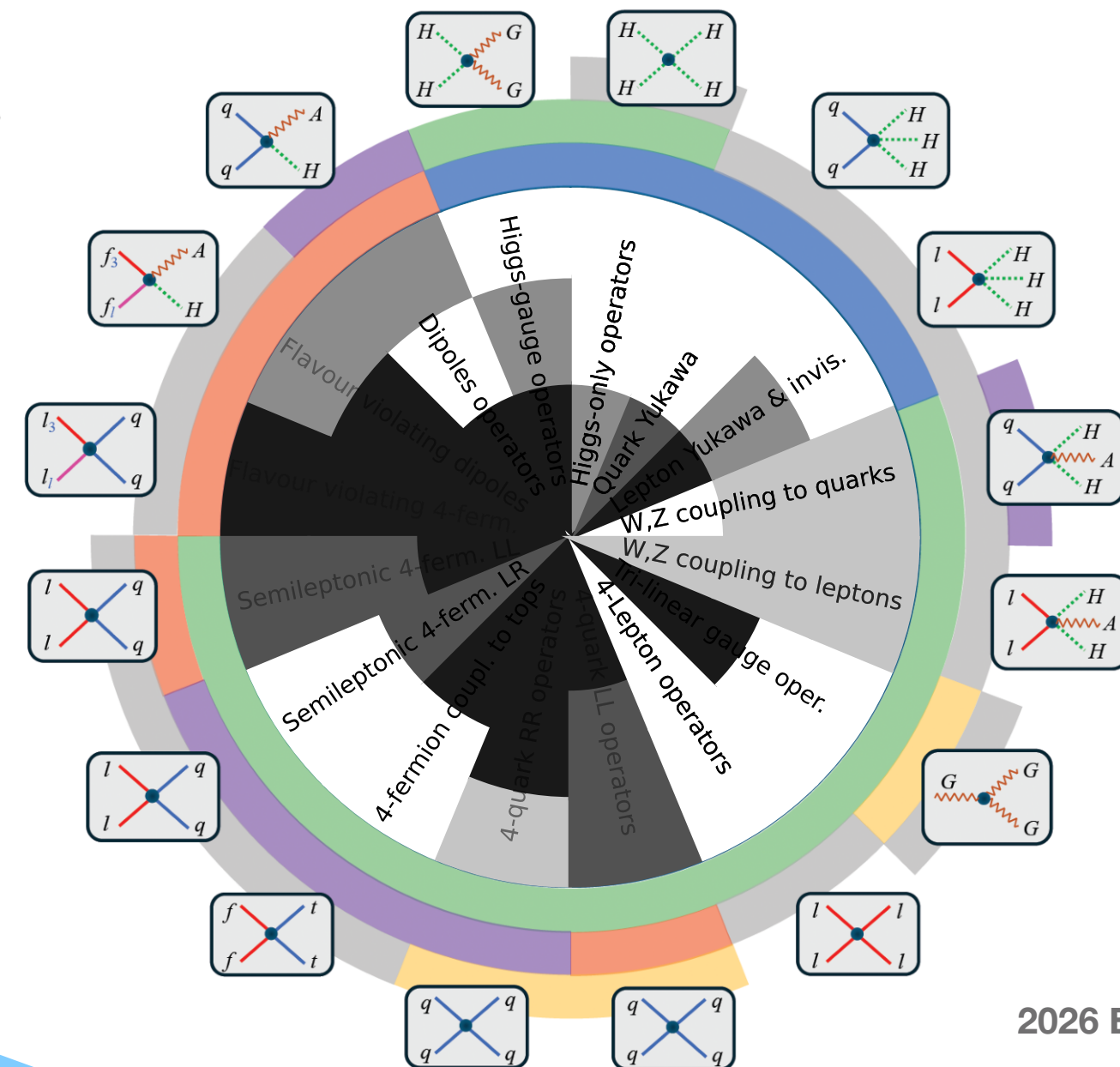
- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



FCC vs. high-Energy  $e^+e^-$

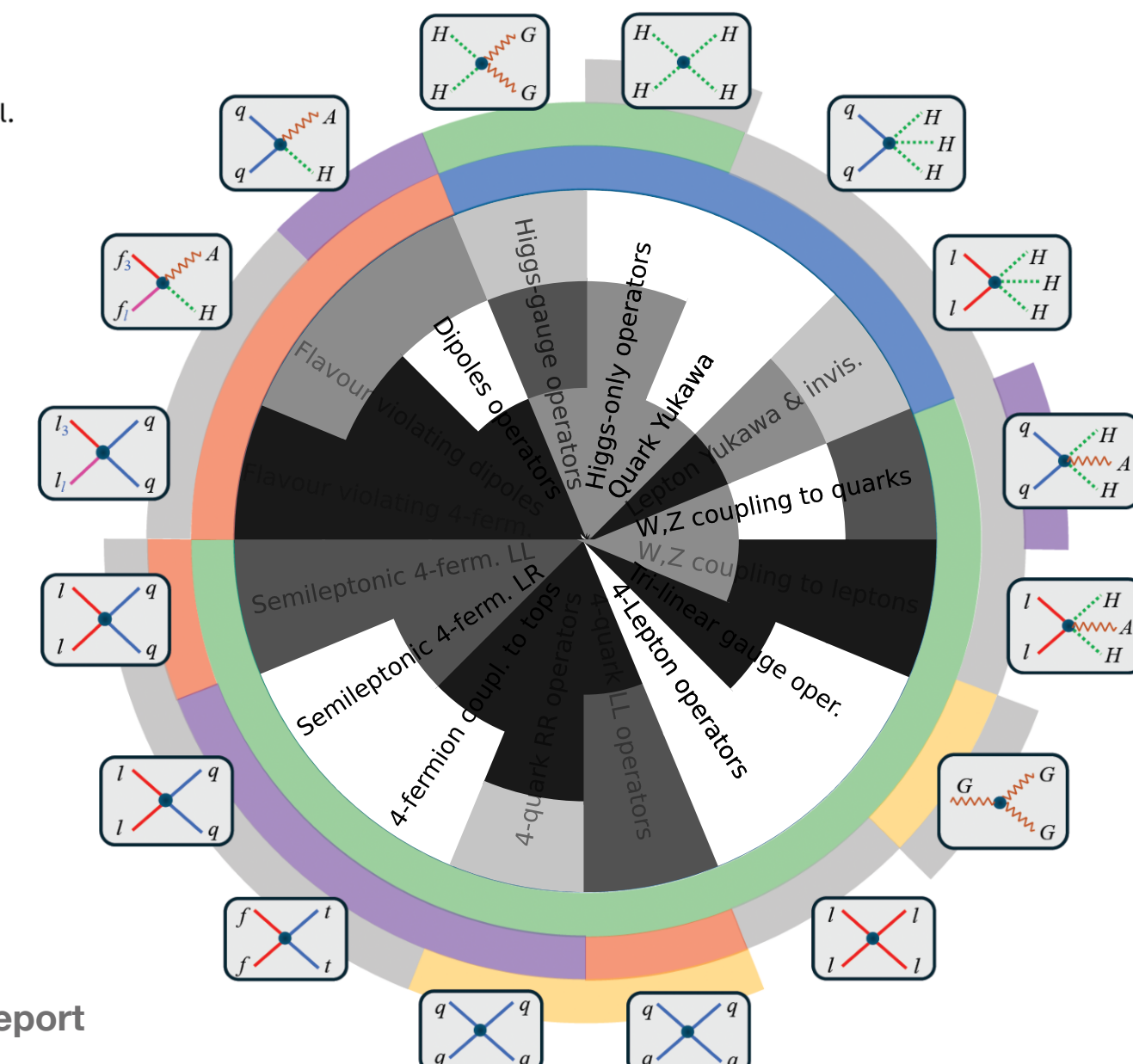
## LCF550

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



## CLIC1500

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD

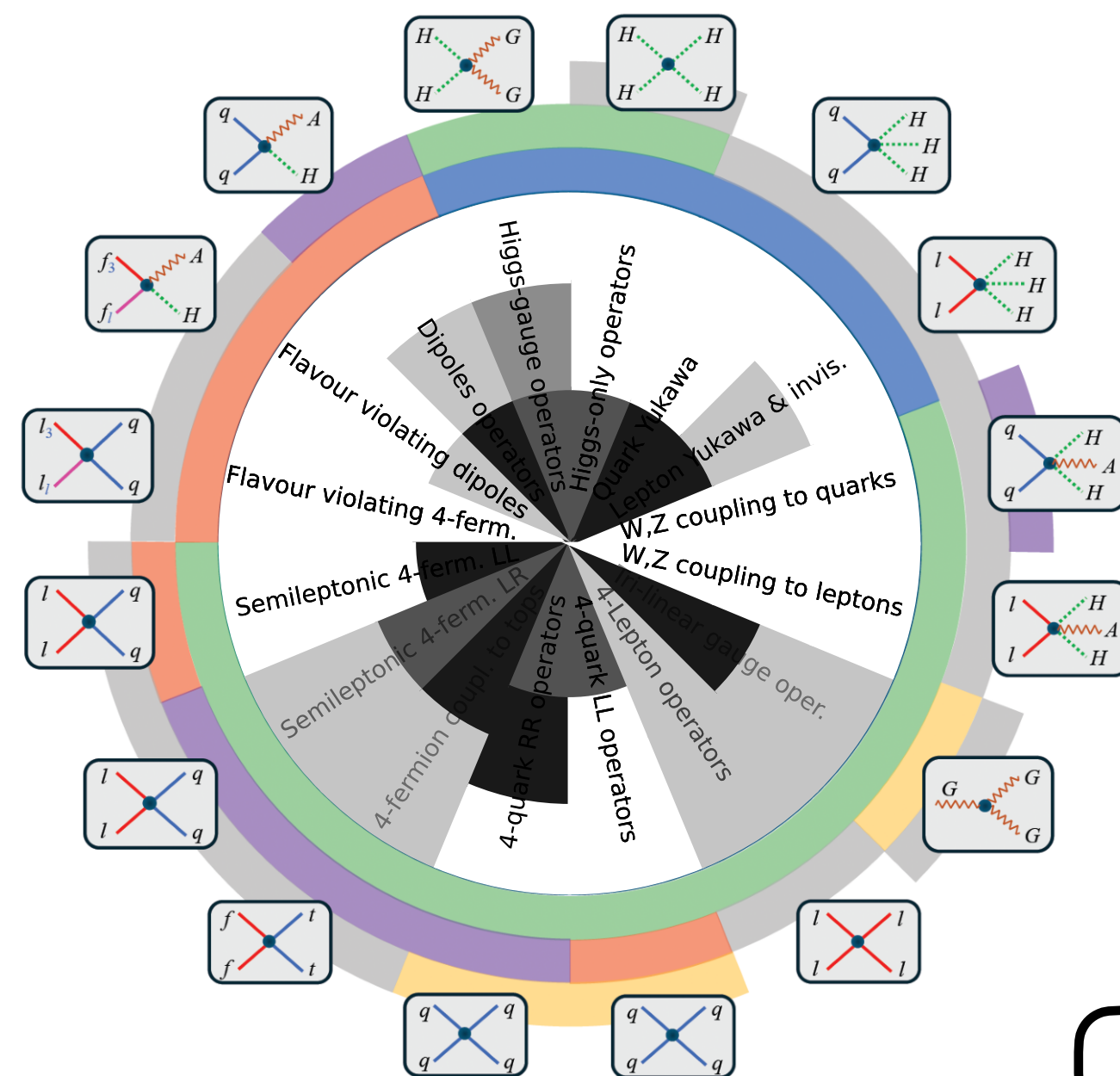




# ESG WG2b Project Comparison: Physics Potential

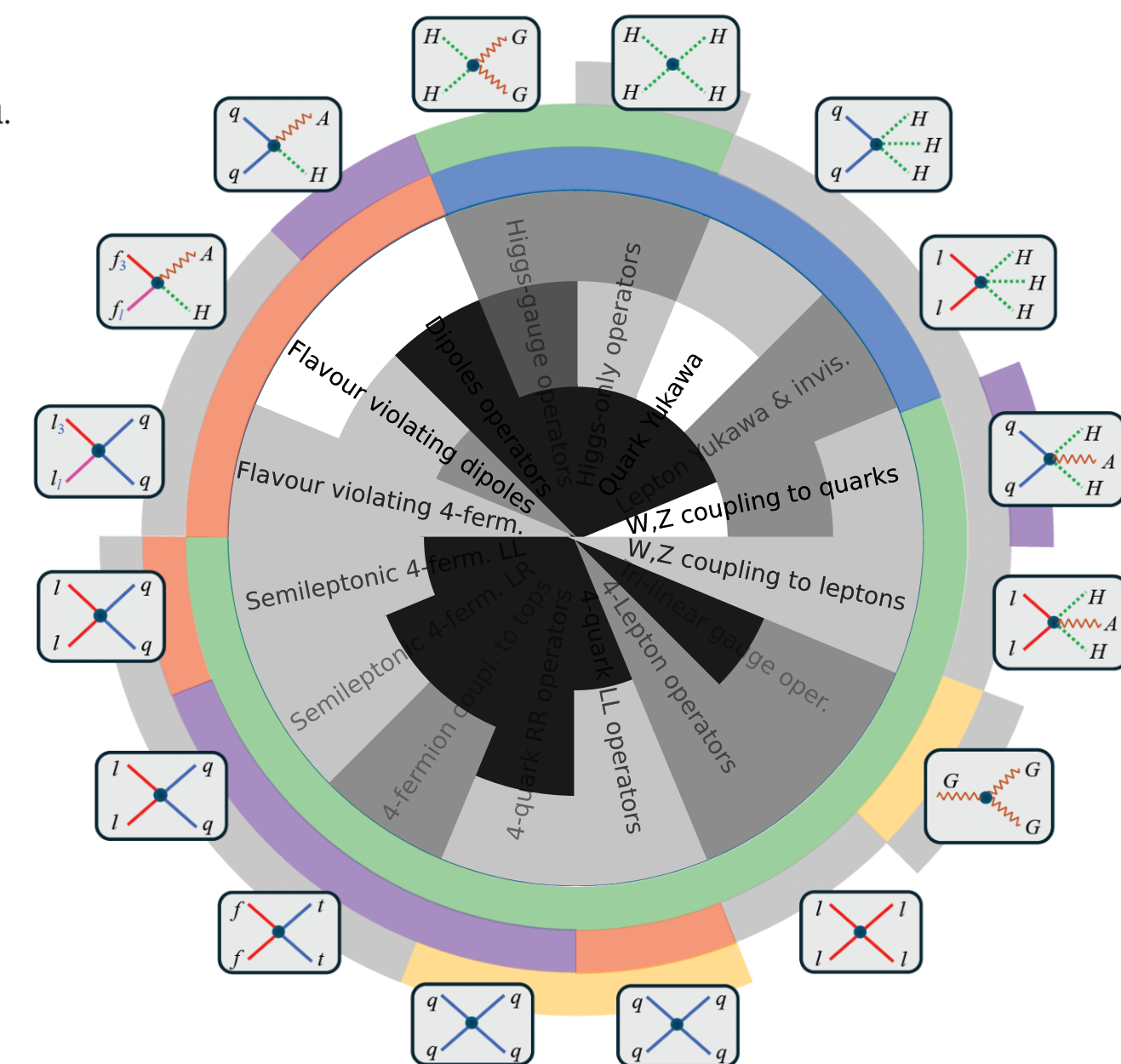
## FCCee

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



## LEP3

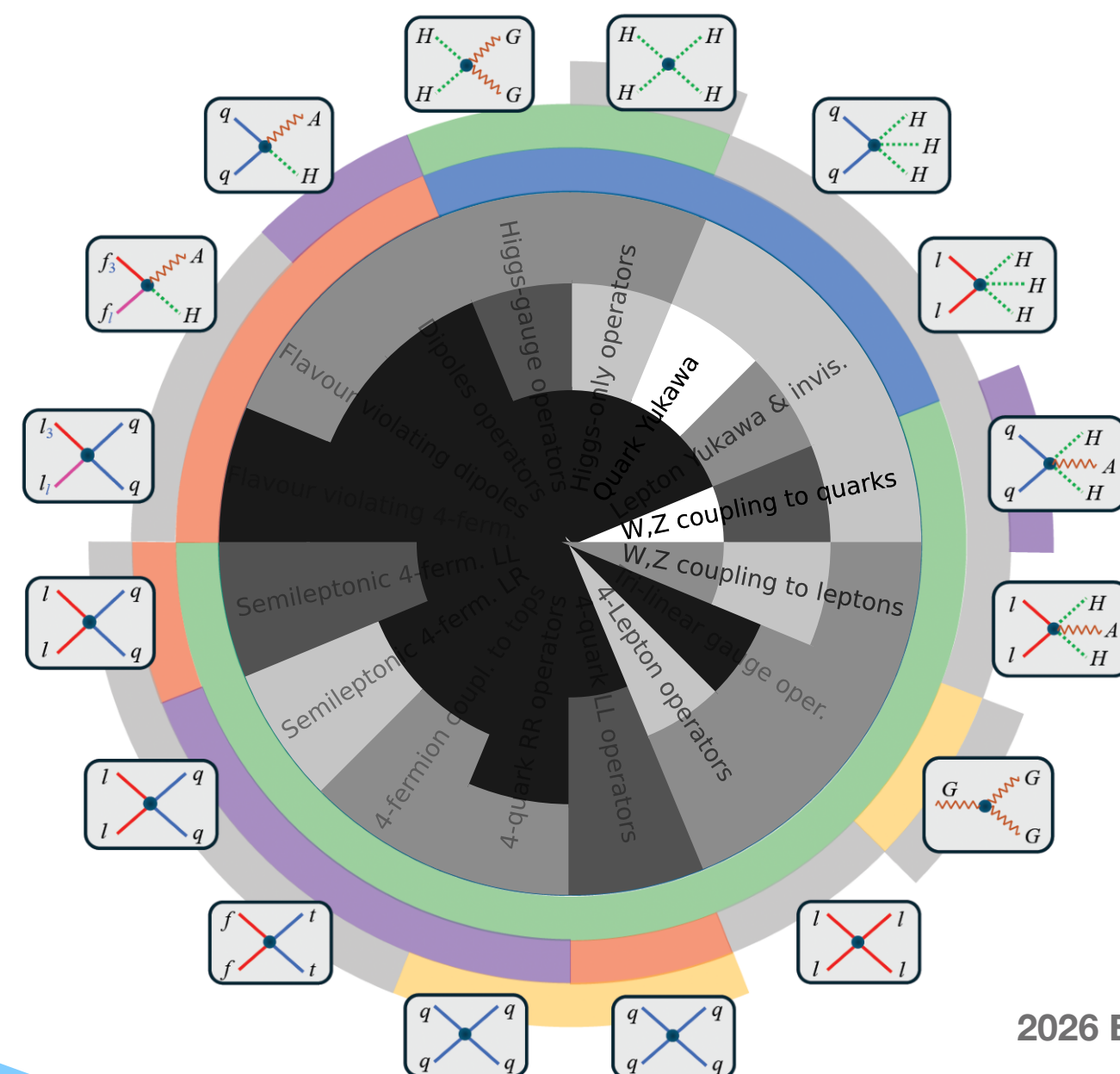
- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



First stage  $e^+e^-$

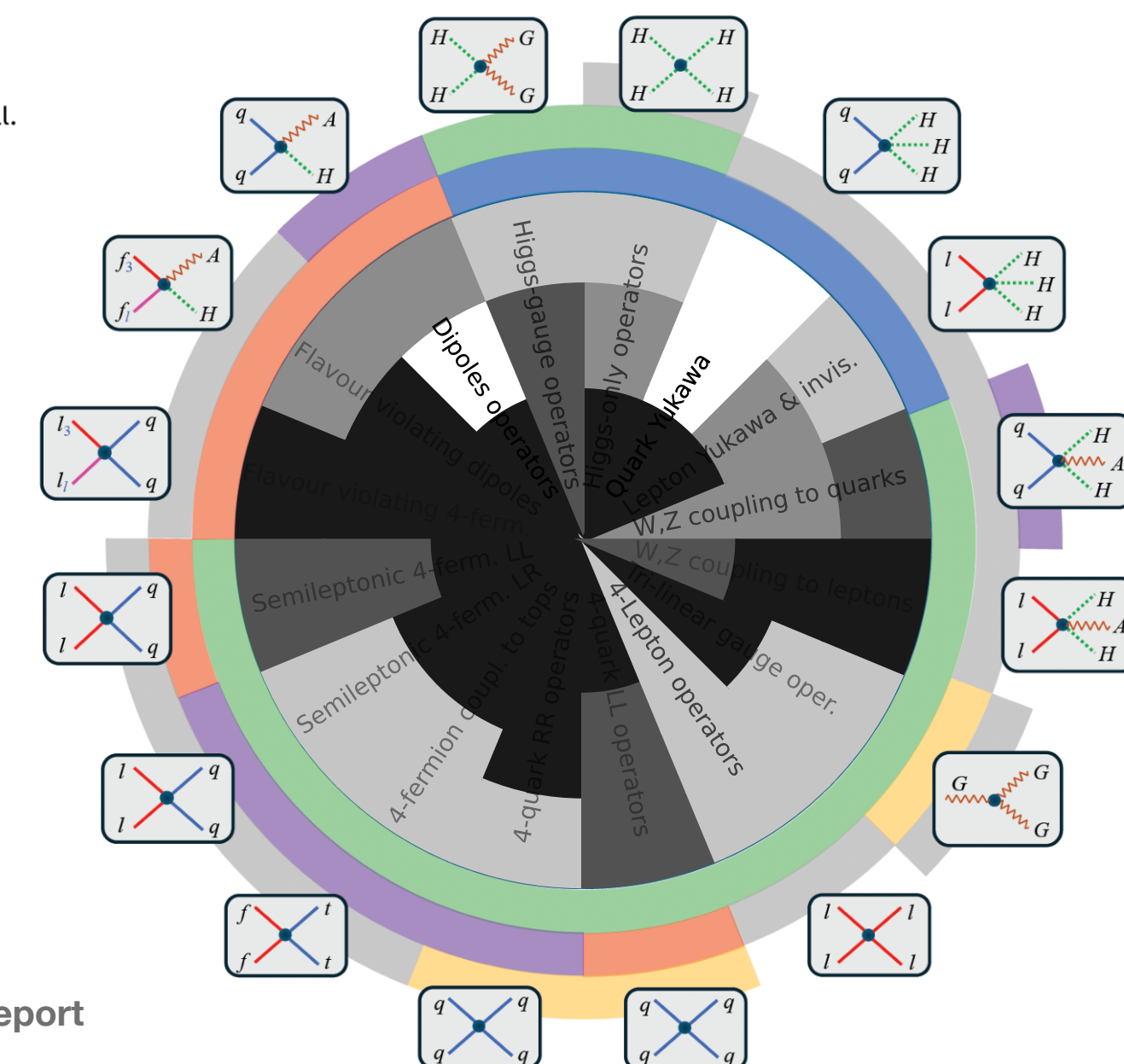
## LCF250

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



## CLIC380

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD





# ESG WG2b Project Comparison: Physics Potential

## Flavour in the global picture:

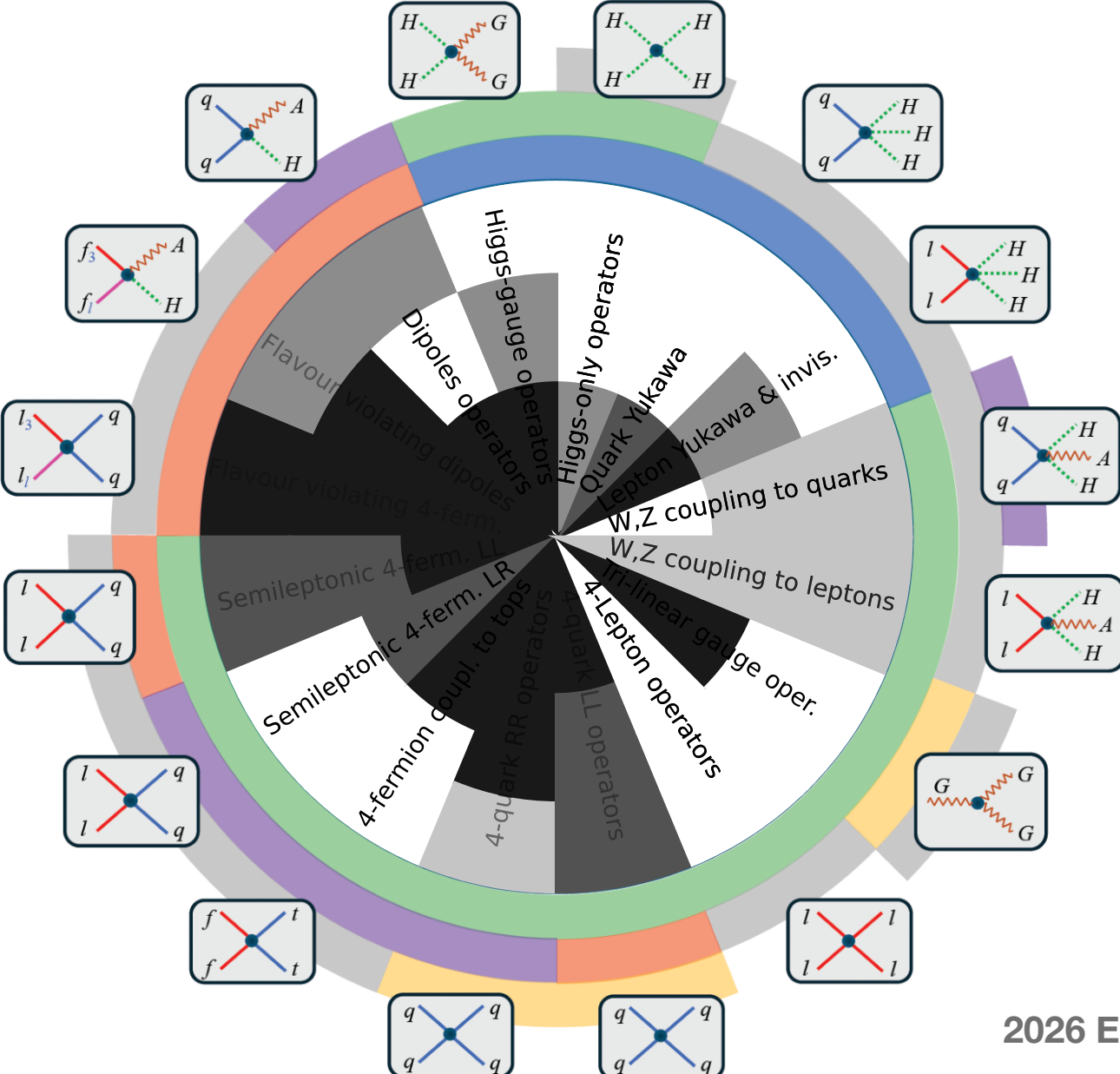
### FCCee

- High-energy coll.
- Top-quark
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- QCD



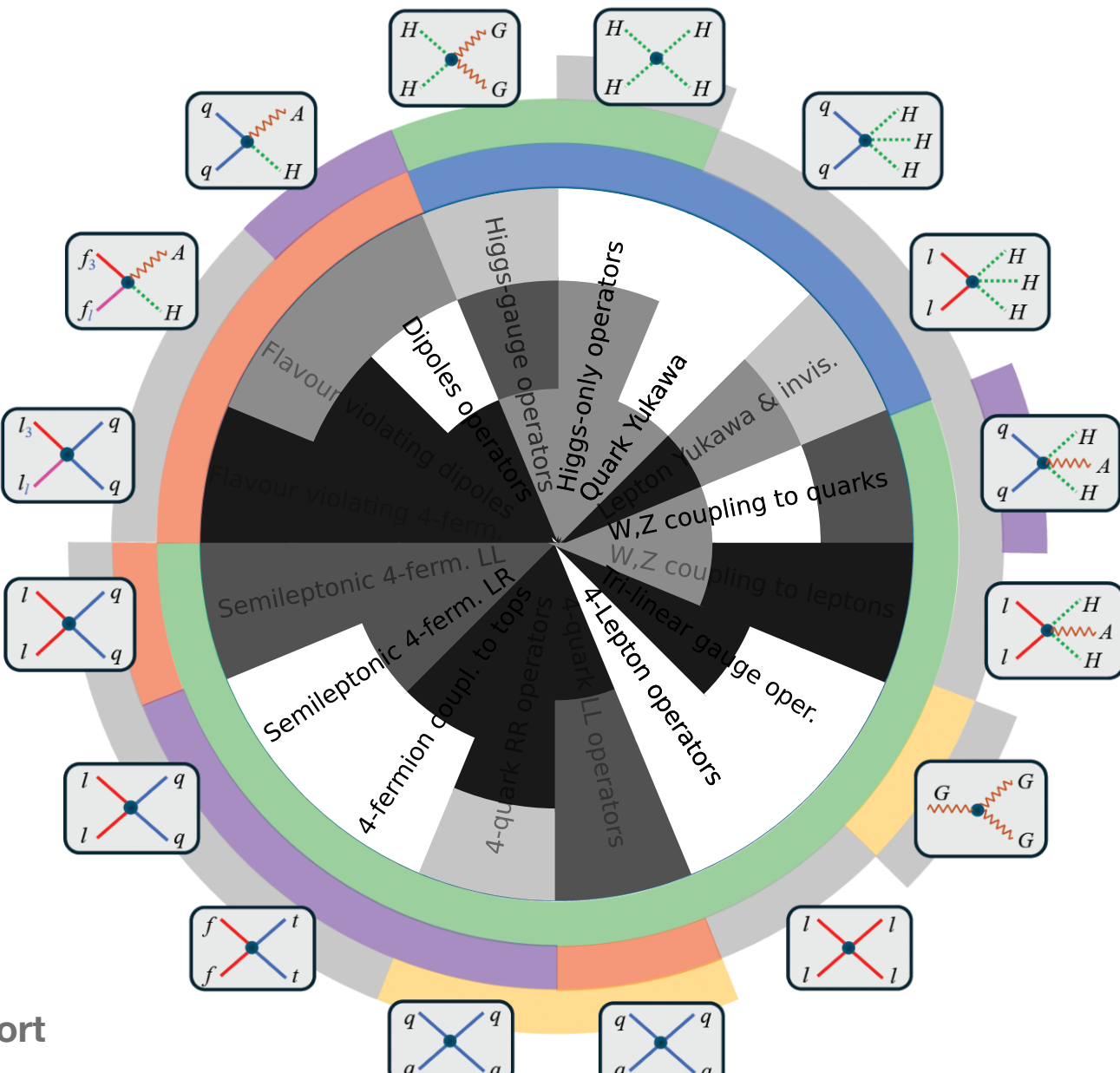
### LCF550

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



### CLIC1500

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD

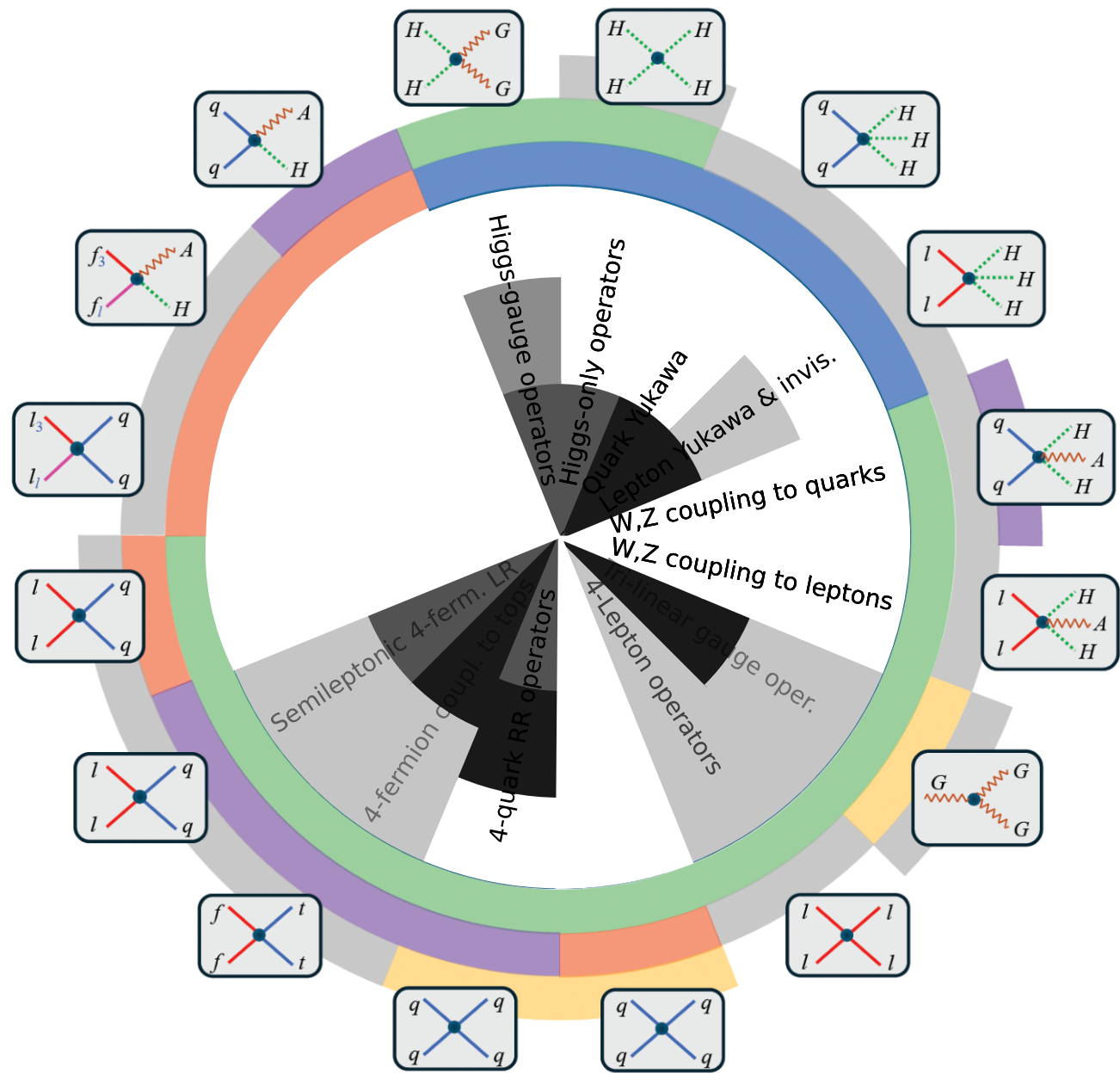


# ESG WG2b Project Comparison: Physics Potential

**Flavour in the global picture:**  
Capabilities for flavour measurement play a key role in separating FCC-ee from other  $e^+e^-$  options

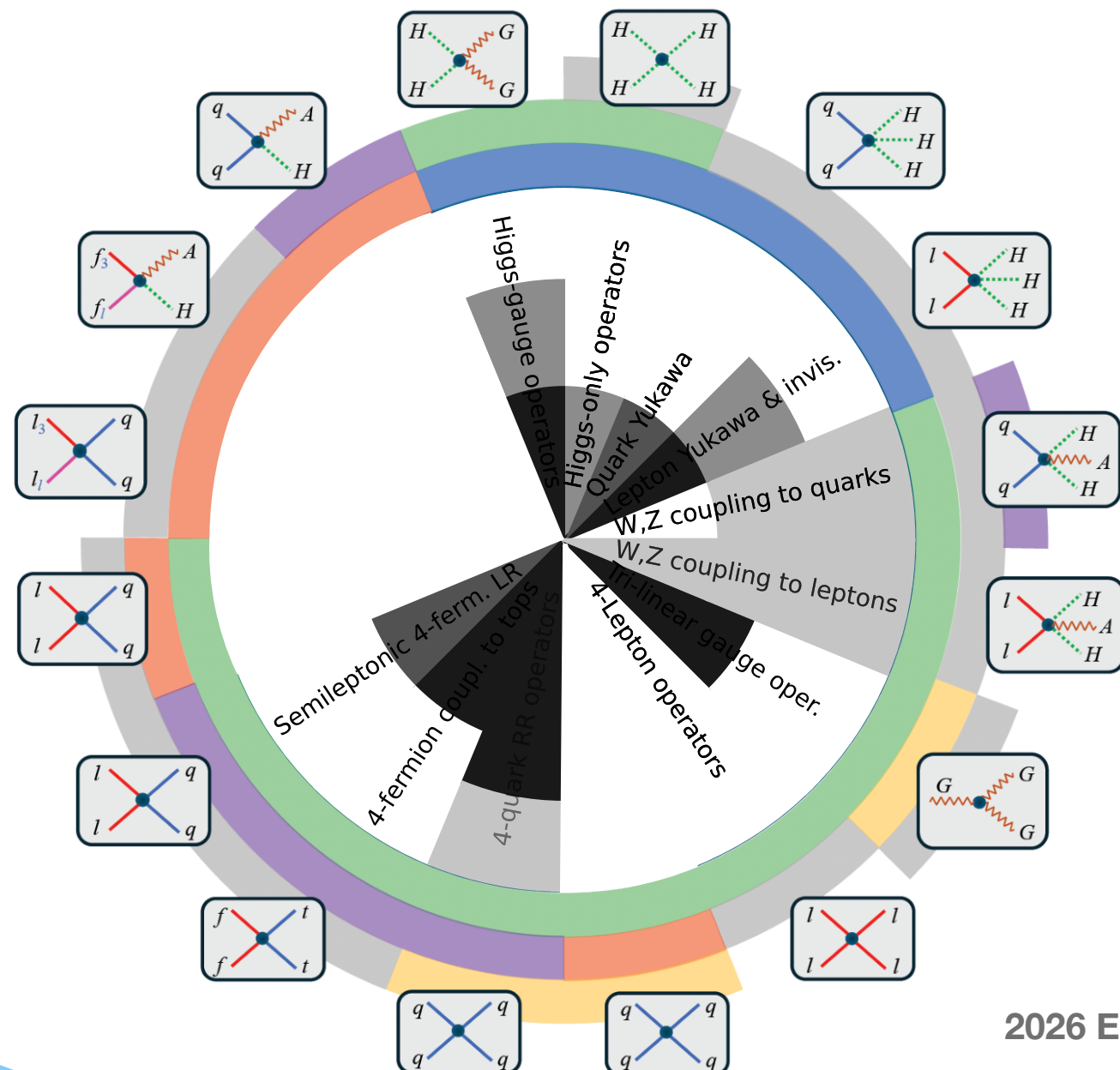
FCCee

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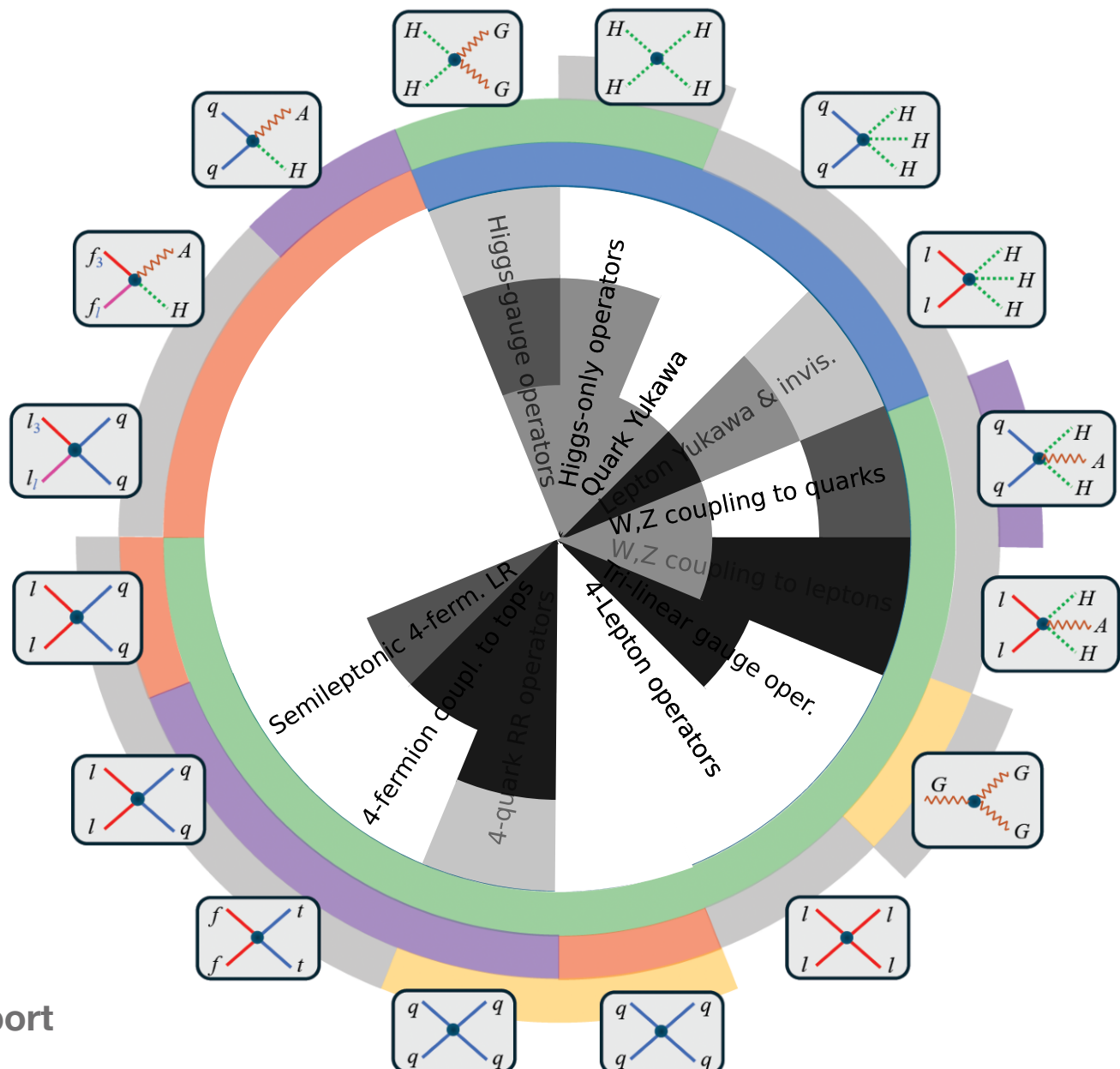
LCF550

- High-energy coll.
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CLIC1500

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD

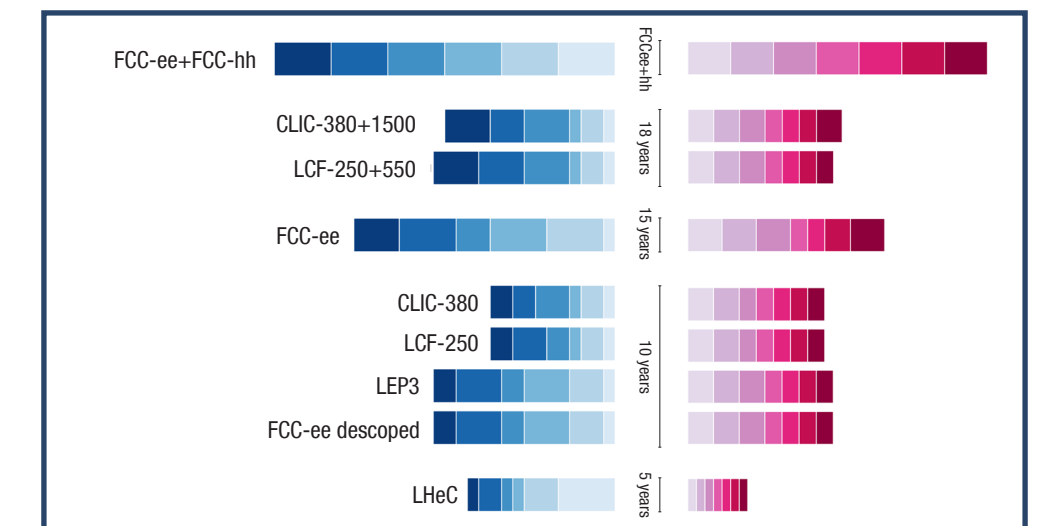


# ***Conclusions***

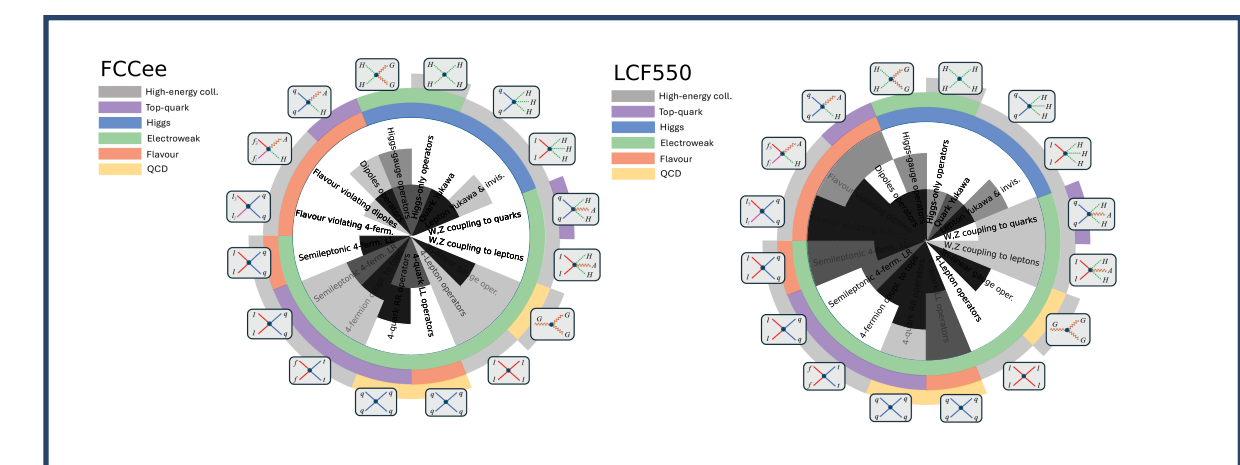


# Conclusions

- The WG2b task was to condense the information of the Physics Briefing Book and prepare a report with a quantitative classification of the collider options in a way that is:
  - ▶ Easy to digest and explain during the ESG deliberations and preparation of its recommendations
  - ▶ Easy to present to CERN council
  - ▶ (Physics potential of the “Descoped FCC-ee” scenario also estimated in App.A - See Backup)
- The methodology used was based on a discrete 1-5 ranking of the capabilities for
  - ▶ Precision Physics: EW, Higgs, Top, Flavour, QCD
  - ▶ Potential for BSM searches
- *Not unique*: any methodology to synthesize the information has limitations:
  - ▶ How to “integrate out” information, projections available for the different colliders, ...
  - ▶ Different methodologies could result in changes in the classification



⇒ **For Precision Physics, we cross checked that the main conclusions are consistent with an additional alternative ranking presented in App. B**





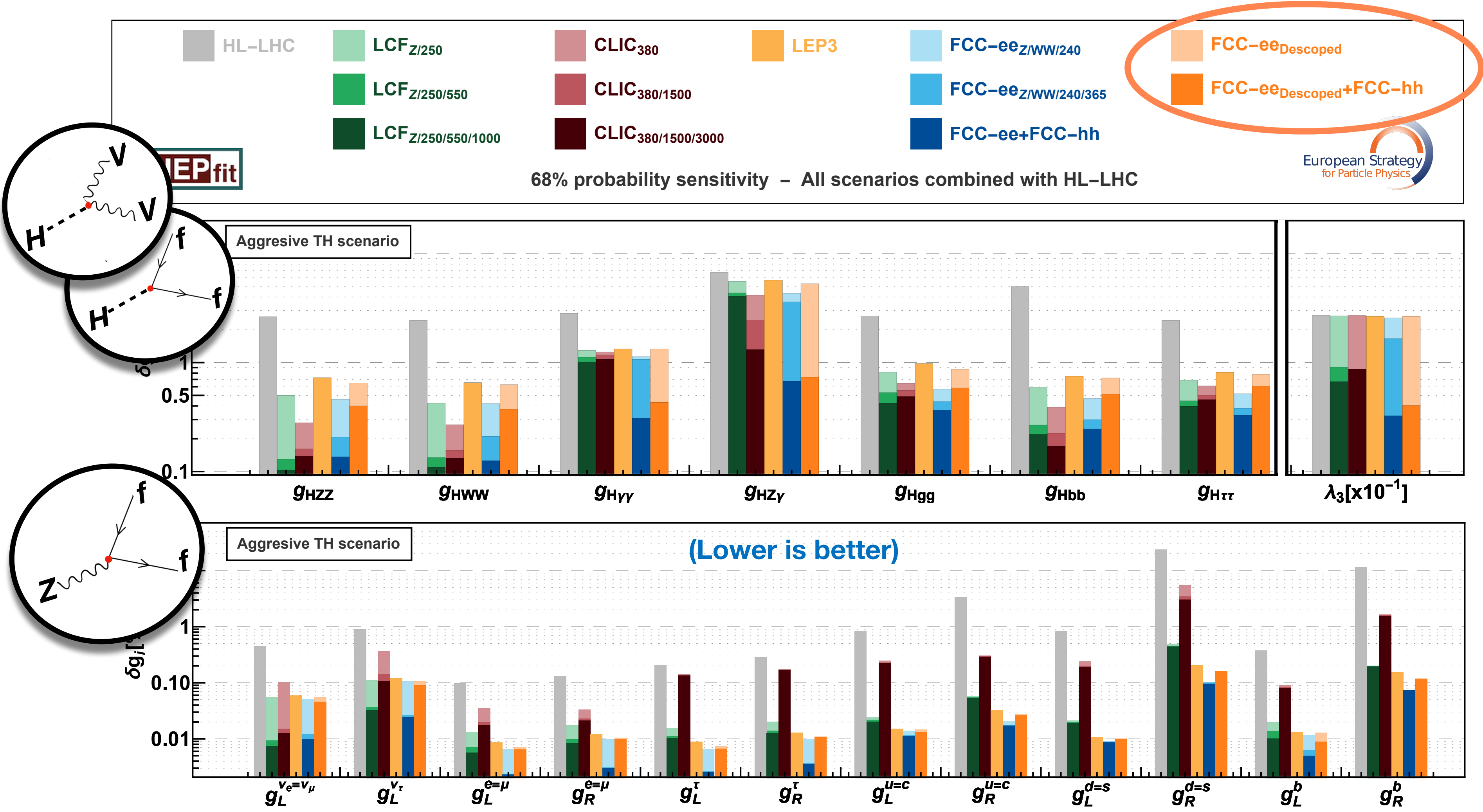
***Backup***

# WG2b Report: The descoped FCC-ee scenario physics potential

- Consider as alternative a collider based on the FCC-ee concept but at a lower cost
- Descoping scenarios:
  - ▶ Removing the top-quark runs around the  $t\bar{t}$  threshold and at 365 GeV ▶ -1.3 BCHF
  - ▶ Decreasing the synchrotron radiation (SR) power from 50 MW per beam to 30 MW ▶ -0.35 BCHF
  - ▶ Constructing only two interaction points (IPs) instead of four ▶ -0.8 BCHF
- Physics potential not discussed in Briefing Book  $\Rightarrow$  Estimates presented in WG2b report

# WG2b Report: The descoped FCC-ee scenario physics potential

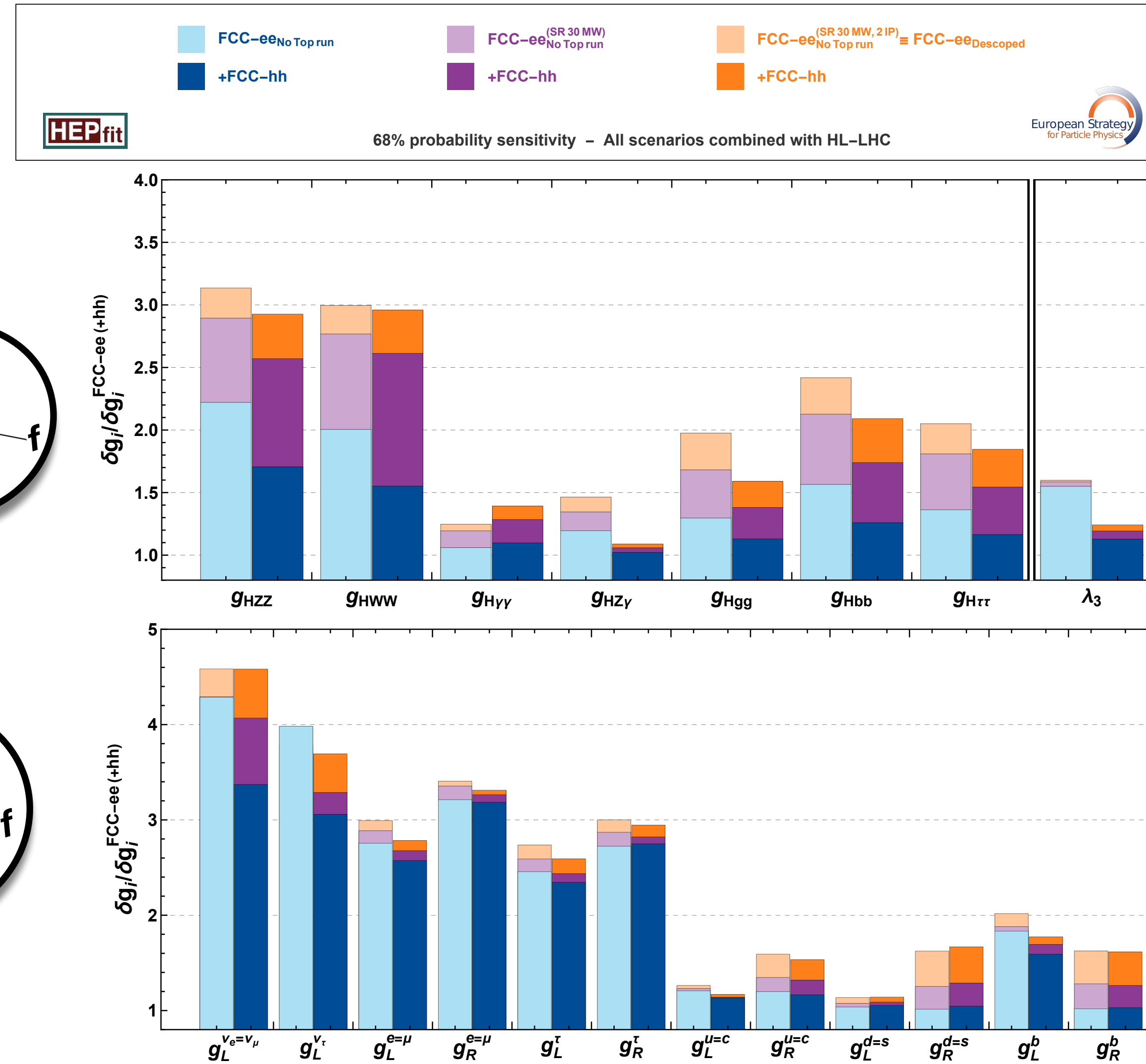
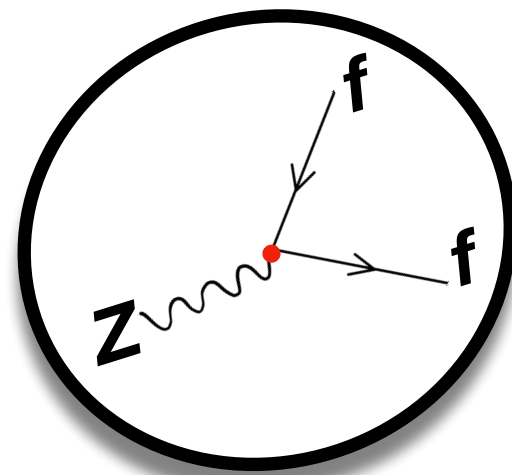
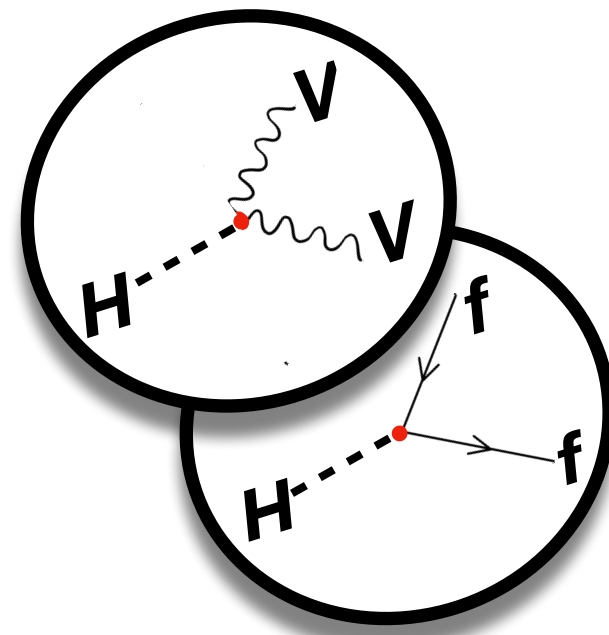
## Descoped FCC-ee EW/Higgs Physics Potential





# WG2b Report: The descoped FCC-ee scenario physics potential

## Descoped FCC-ee EW/Higgs Physics Potential - Impact of descoping





# WG2b Report: The descoped FCC-ee scenario physics potential

- Consider as alternative a collider based on the FCC-ee concept but at a lower cost
- Descoping scenarios:
  - ▶ Removing the top-quark runs around the  $t\bar{t}$  threshold and at 365 GeV ▶ -1.3 BCHF
  - ▶ Decreasing the synchrotron radiation (SR) power from 50 MW per beam to 30 MW ▶ -0.35 BCHF
  - ▶ Constructing only two interaction points (IPs) instead of four ▶ -0.8 BCHF
- Physics potential not discussed in Briefing Book  $\Rightarrow$  Estimates presented in WG2b report
  - ▶ Reduced with respect to FCC-ee but still strong physics potential
  - ▶ Still provides a convincing long-term vision for exploring the high energy frontier
  - ▶ Part of the original scope could be restored, e.g. via extended running period
  - ▶ Should additional resources become available, these descoping scenarios would be reversible
    - ▶ E.g. staging the top-quark run (important for physics programme)

# Future Collider Comparison: Precision Physics

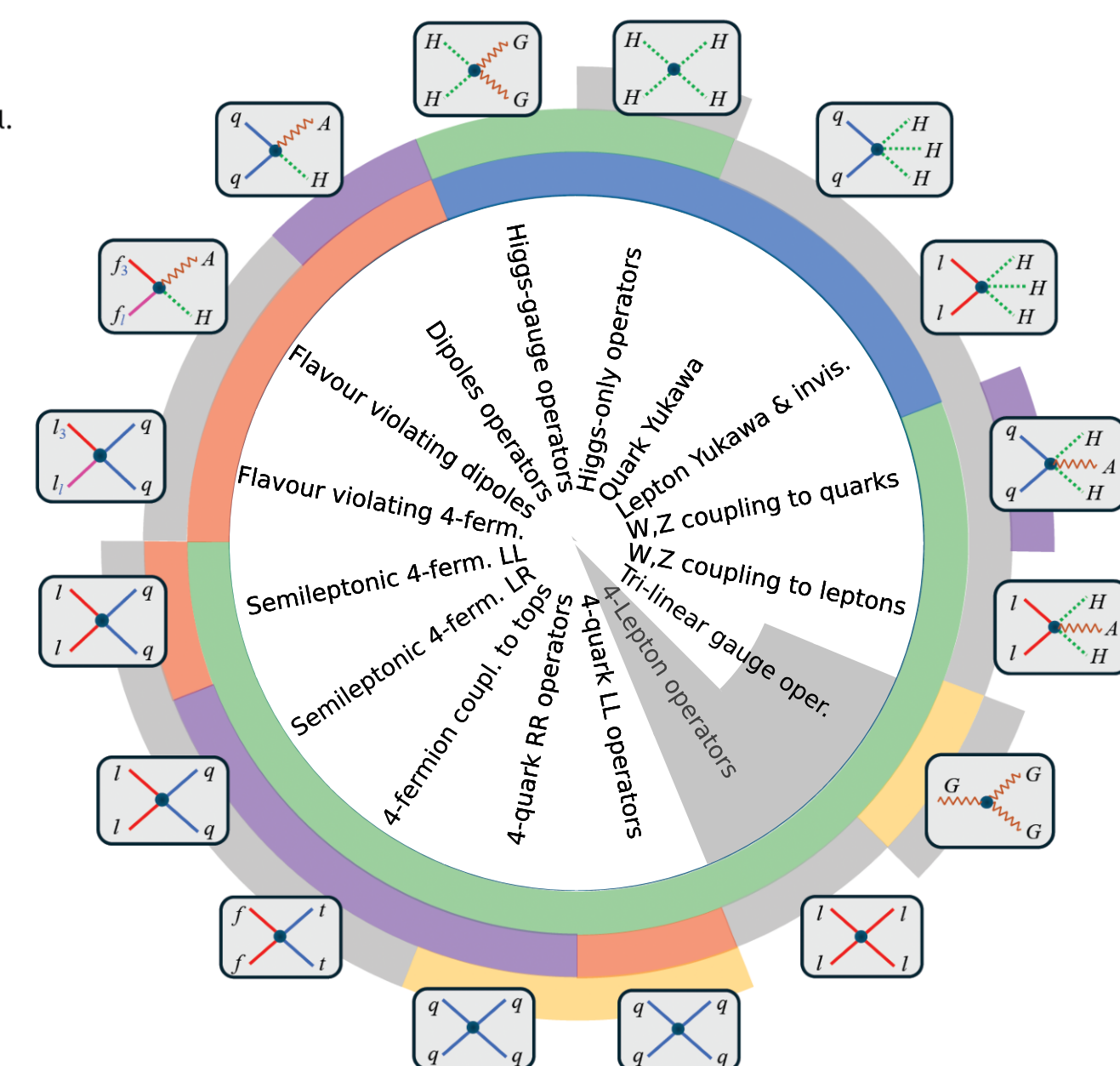
## FCCee

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



## FCCeehh

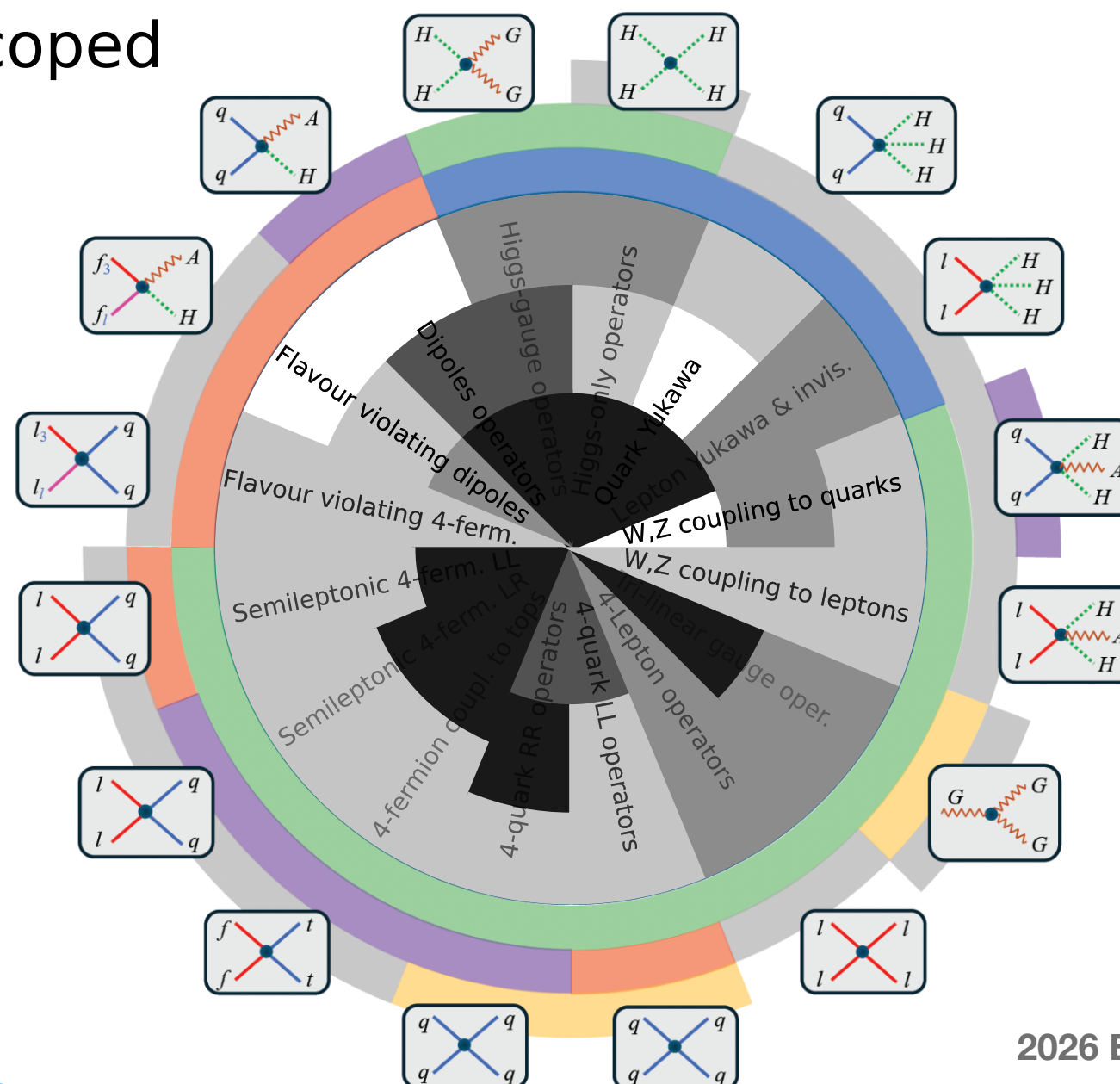
- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



## Circular Colliders

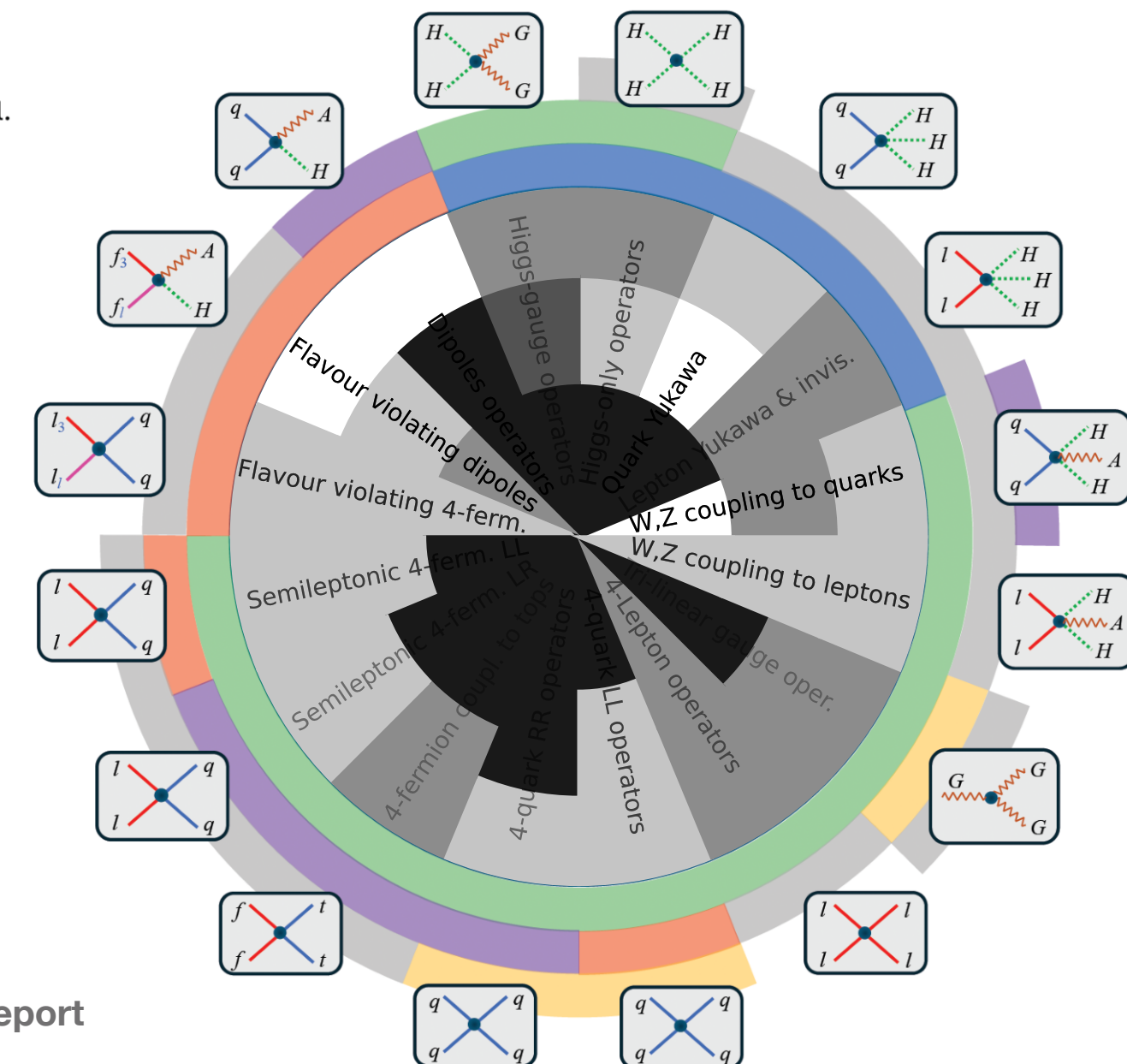
## FCCee-descoped

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



## LEP3

- High-energy coll.
- Top-quark
- Higgs
- Electroweak
- Flavour
- QCD



# Future Collider project comparison: Technical readiness

- Technical readiness and assessment of the time, cost & performance estimates studied by ESG WVG2a

| Project                   | Scope | TRL                              | R&D | Test facilities | Performance uncertainty | Site preparation | Schedule uncertainty | Cost uncertainty | Risk |
|---------------------------|-------|----------------------------------|-----|-----------------|-------------------------|------------------|----------------------|------------------|------|
| CLIC 380 GeV, 1.5 TeV     |       | 4 - 6 / 5.2                      |     |                 |                         |                  |                      |                  |      |
| FCC-ee 91-365 GeV         |       | 4 - 7 / 6.0                      |     |                 |                         |                  |                      |                  |      |
| FCC-hh 85 TeV             |       | 4 - 7 (Nb <sub>3</sub> Sn) / 4.3 |     |                 |                         |                  |                      |                  |      |
|                           |       | 2 - 7 (HTS) / 3.2                |     |                 |                         |                  |                      |                  |      |
| FCC-hh - SA 85 TeV        |       | 4 - 7 (Nb <sub>3</sub> Sn) / 5   |     |                 |                         |                  | Nb <sub>3</sub> Sn   |                  |      |
| LCF 250 - 550 GeV         |       | 5 - 7 / 5.5                      |     |                 |                         |                  |                      |                  |      |
| LEP3 91 - 230 GeV         |       | 3 - 6 / 4.0                      |     |                 |                         |                  |                      |                  |      |
| LHeC: HL-LHC + 50 GeV ERL |       | 3 - 6 / 4.5                      |     |                 |                         |                  |                      |                  |      |
| MC 3.2 TeV, 7.6 TeV       |       | 3.2 TeV: 3 - 5<br>7.6 TeV: 2 - 5 |     |                 |                         |                  |                      |                  |      |



# Future Collider project comparison: Technical readiness

- Technical readiness and assessment of the time, cost & performance estimates studied by ESG WG2a

| Project                   | Scope | TRL                              | R&D | Test facilities | Performance uncertainty | Site preparation | Schedule uncertainty | Cost uncertainty | Risk |
|---------------------------|-------|----------------------------------|-----|-----------------|-------------------------|------------------|----------------------|------------------|------|
| CLIC 380 GeV, 1.5 TeV     |       | 4 - 6 / 5.2                      |     |                 |                         |                  |                      |                  |      |
| FCC-ee 91                 |       |                                  |     |                 |                         |                  |                      |                  |      |
| FCC-hh 85                 |       |                                  |     |                 |                         |                  |                      |                  |      |
| FCC-hh - S                |       |                                  |     |                 |                         |                  |                      |                  |      |
| LCF 250 -                 |       |                                  |     |                 |                         |                  |                      |                  |      |
| LEP3 91 -                 |       |                                  |     |                 |                         |                  |                      |                  |      |
| LHeC: HL-LHC + 50 GeV ERL |       | 3 - 6 / 4.5                      |     |                 |                         |                  |                      |                  |      |
| MC 3.2 TeV, 7.6 TeV       |       | 3.2 TeV: 3 - 5<br>7.6 TeV: 2 - 5 |     |                 |                         |                  |                      |                  |      |

## Muon Colliders

- Technologies underpinning the MC design are in the early phases of exploration
- Comprehensive R&D roadmap has been defined (300 MCHF, 1800 FTEy over 10 years)
- Without such R&D effort, realistic performance, schedule and cost estimates not possible at this stage



# Future Collider project comparison: Technical readiness

- Technical readiness and assessment of the time, cost & performance estimates studied by ESG WG2a

| Project               | Scope | TRL                              | R&D | Test facilities | Performance uncertainty | Site preparation | Schedule uncertainty | Cost uncertainty | Risk |
|-----------------------|-------|----------------------------------|-----|-----------------|-------------------------|------------------|----------------------|------------------|------|
| CLIC 380 GeV, 1.5 TeV |       | 4 - 6 / 5.2                      |     |                 |                         |                  |                      |                  |      |
| FCC-ee 91-365 GeV     |       | 4 - 7 / 6.0                      |     |                 |                         |                  |                      |                  |      |
| FCC-hh 85 TeV         |       | 4 - 7 (Nb <sub>3</sub> Sn) / 4.3 |     |                 |                         |                  |                      |                  |      |
|                       |       | 2 - 7 (HTS) / 3.2                |     |                 |                         |                  |                      |                  |      |
| FCC-hh - SA 85 TeV    |       | 4 - 7 (Nb <sub>3</sub> Sn) / 5   |     |                 |                         |                  | Nb <sub>3</sub> Sn   |                  |      |
| LCF 250 - 550 GeV     |       | 5 - 7 / 5.5                      |     |                 |                         |                  |                      |                  |      |
| LEP3 91 -             |       |                                  |     |                 |                         |                  |                      |                  |      |
| LHeC: HL-             |       |                                  |     |                 |                         |                  |                      |                  |      |
| MC 3.2 TeV            |       |                                  |     |                 |                         |                  |                      |                  |      |

## FCC-hh

- Well-defined baseline scope based on Nb<sub>3</sub>Sn dipole magnets. Development ~15-20 yrs
- Alternative High Temperature Superconductor (HTS) is expected to develop over a longer timescale, with higher risk at this stage
- Large uncertainty in cost, dominated by dipole magnet cost

# Future Collider project comparison: Technical readiness

- Technical readiness and assessment of the time, cost & performance estimates studied by ESG WG2a

| Project                   | Scope | TRL                 | R&D | Test facilities | Performance uncertainty | Site preparation | Schedule uncertainty | Cost uncertainty | Risk |
|---------------------------|-------|---------------------|-----|-----------------|-------------------------|------------------|----------------------|------------------|------|
| CLIC 380 GeV, 1.5 TeV     |       | 4 - 6 / 5.2         |     |                 |                         |                  |                      |                  |      |
| FCC-hh 85                 |       | 4 - 7 (Nb-Cu) / 4.2 |     |                 |                         |                  |                      |                  |      |
| FCC-hh - S                |       |                     |     |                 |                         |                  |                      |                  |      |
| LCF 250 - 50              |       |                     |     |                 |                         |                  |                      |                  |      |
| LEP3 91 - 230 GeV         |       | 3 - 6 / 4.0         |     |                 |                         |                  |                      |                  |      |
| LHeC: HL-LHC + 50 GeV ERL |       | 3 - 6 / 4.5         |     |                 |                         |                  |                      |                  |      |
| MC 3.2 TeV                |       |                     |     |                 |                         |                  |                      |                  |      |

Evaluation of “bridge projects” (LEP3 and LHeC) also identified several concerns about the readiness of these projects

## LEP3

- LEP3 design at pre-conceptual level: No detailed lattice or beam dynamic studies
- Uncertainty on luminosity performance and schedule

## LHeC

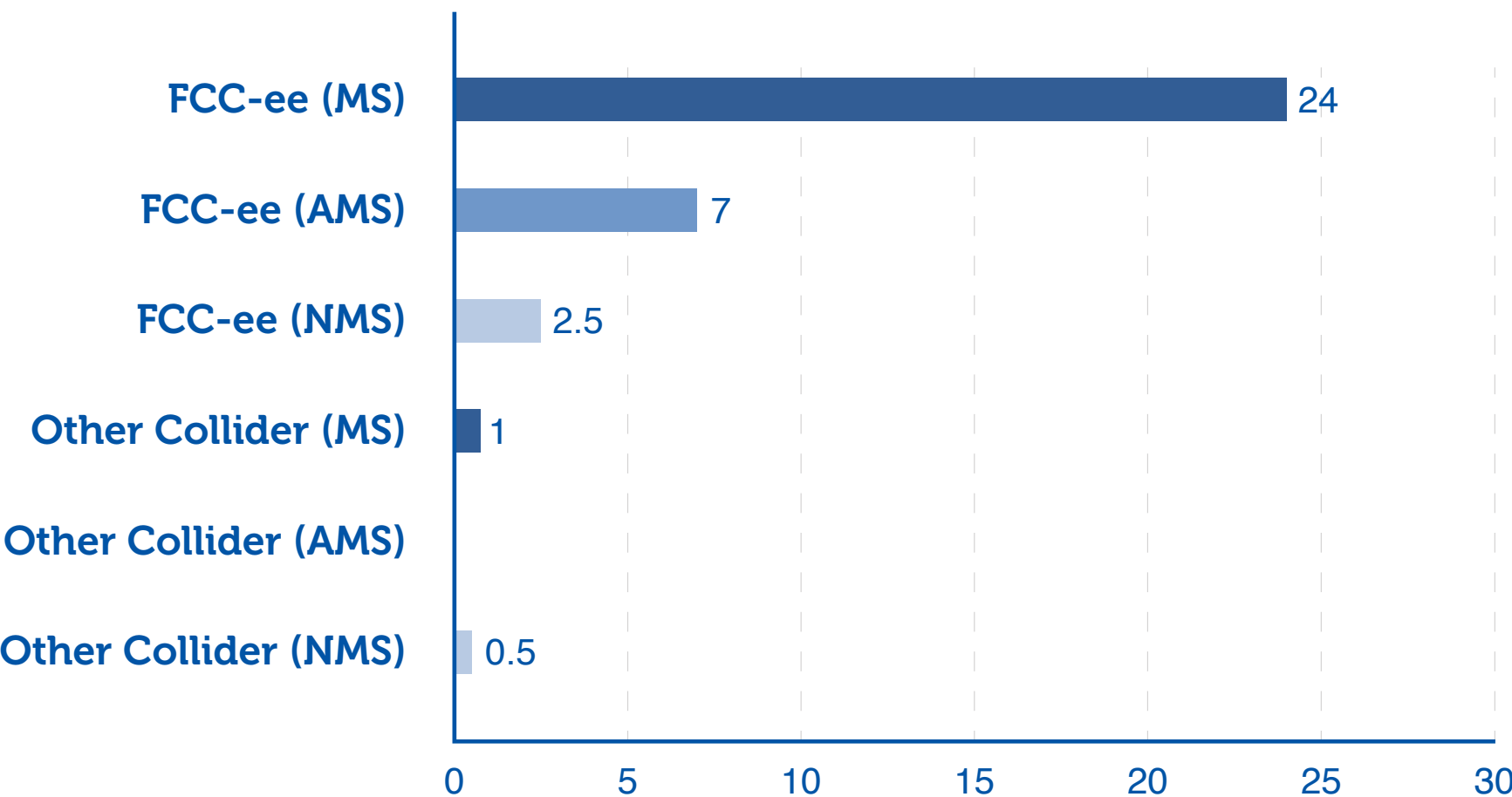
- Performance critically depends on a very high-current Energy-Recovery Linac (ERL)
  - ▶ Without ERL, luminosity would be factor of 10 smaller
- Successful demonstration of PERLE program at IJCLab is vital

# Input from national HEP communities

## ECFA questions to be considered by national HEP communities

**Q1: What is the preferred large-scale post-LHC accelerator at CERN?**

Preferred Collider Option



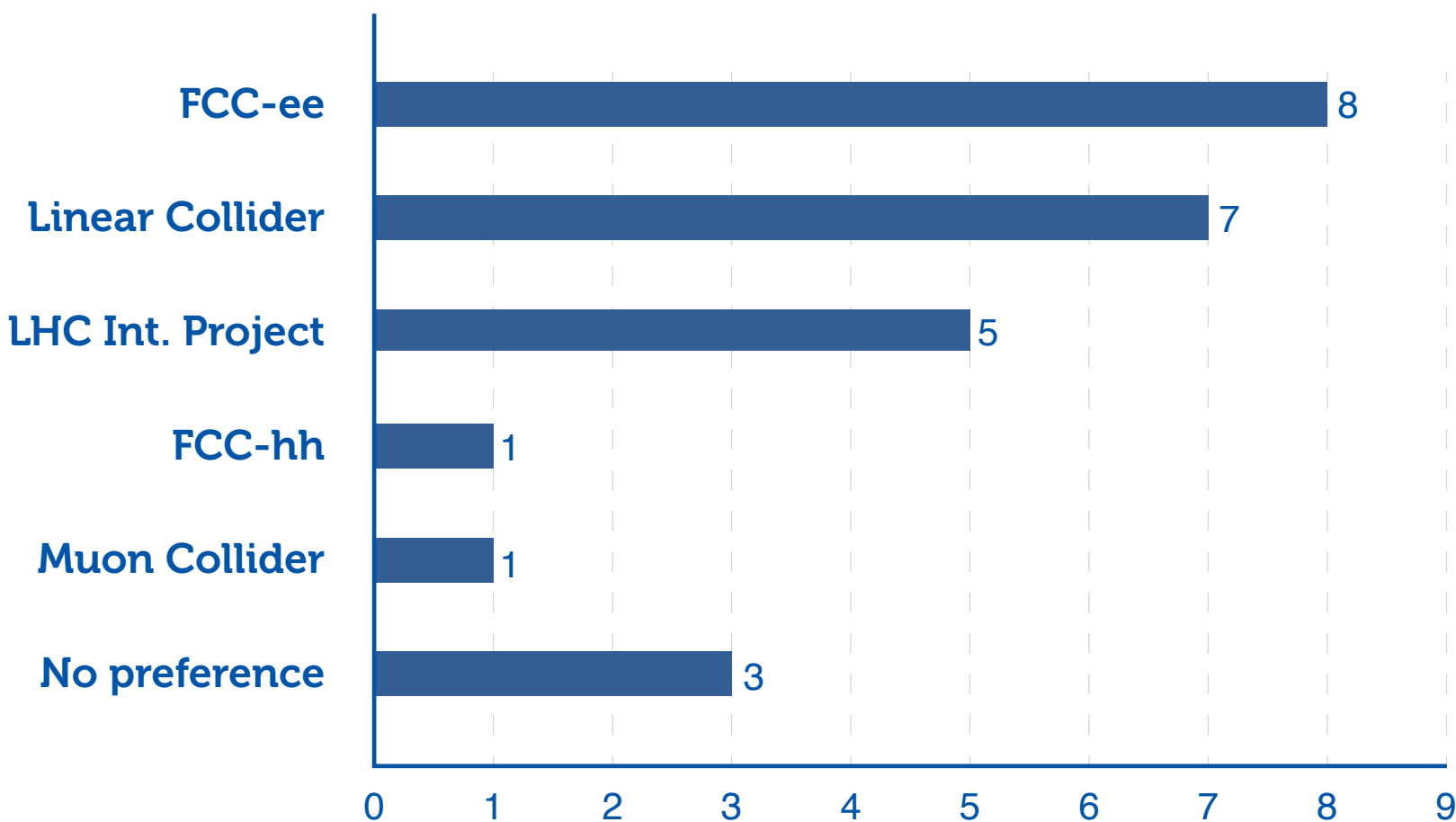
**Clear preference for FCC (physics, long-term vision):**

**FCC-ee → precision physics**

**Foundation for later transition to FCC-hh → high-E frontier**

**Q2: What is the preferred alternative if the preferred option would not be feasible?**

Preferred Alternative (Plan B)



**No clear consensus:**

**LC & intermediate projects emerge as alternatives**

**But a significant subset of communities stick to FCC-ee**



# Comparison summary

| Competitiveness wrt<br>CEPC running in parallel |                      |                |                    |                        | Project estimates<br>+ exp. (CERN part) |               |                    |
|-------------------------------------------------|----------------------|----------------|--------------------|------------------------|-----------------------------------------|---------------|--------------------|
| Machine                                         | Precision<br>Physics | BSM<br>physics | Physics<br>vs CEPC | Technical<br>readiness | Constr.<br>cost<br>(BCHF)               | Time<br>scale | Path to<br>≥10 TeV |
| FCC-ee                                          | 22                   | 23             |                    |                        | 15.3                                    | 2046-2060     |                    |
| Descoped<br>FCC-ee                              | 15                   | 17             |                    |                        | 12.9                                    | 2046-2055     |                    |
| LCF550                                          | 15                   | 17             |                    |                        | 14.8                                    | 2045-2065     |                    |
| CLIC1500                                        | 14                   | 18             |                    |                        | 14.6                                    | 2045-2066     |                    |
| LCF250                                          | 10                   | 16             |                    |                        | 9.4                                     | 2045-2053     |                    |
| CLIC380                                         | 10                   | 16             |                    |                        | 7.5                                     | 2045-2054     |                    |
| LEP3                                            | 15                   | 17             |                    |                        | 4.1                                     | 2047-2062     |                    |
| LHeC                                            | 8                    | 7              |                    |                        | 2.1                                     | 2044-2051     |                    |

Viability  
(tech., econ., soc.)  
for transition  
to high-E frontier

FCC-hh  
Muon Collider  
Plasma

WG2b report  
(From Briefing Book)

WG2a report



# Comparison summary

Competitiveness wrt  
CEPC running in parallel

Project estimates  
+ exp. (CERN part)

| Machine         | Precision Physics | BSM physics | Physics vs CEPC | Technical readiness | Constr. cost (BCHF) | Time scale | Path to $\geq 10$ TeV |
|-----------------|-------------------|-------------|-----------------|---------------------|---------------------|------------|-----------------------|
| FCC-ee          | 22                | 23          |                 |                     | 15.3                | 2046-2060  |                       |
| Descoped FCC-ee | 15                | 17          |                 |                     | 12.9                | 2046-2055  |                       |
| LCF550          | 15                | 17          |                 |                     | 14.8                | 2045-2065  |                       |
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| LEP3            | 15                | 17          |                 |                     | 4.1                 | 2047-2062  |                       |
| LHeC            | 8                 | 7           |                 |                     | 2.1                 | 2044-2051  |                       |

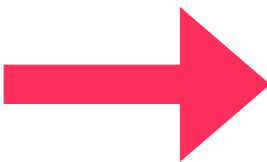
Viability  
(tech., econ., soc.)  
for transition  
to high-E frontier

FCC-hh  
Muon Collider  
Plasma

Reduced physics  
wrt FCC-ee

Technical  
readiness

Bridge projects  
(Long-term vision  
needs high-E coll.)



No flagship colliders

WG2b report  
(From Briefing Book)

WG2a report

# Comparison summary

Competitiveness wrt  
CEPC running in parallel

Project estimates  
+ exp. (CERN part)

| Machine         | Precision Physics | BSM physics | Physics vs CEPC | Technical readiness | Constr. cost (BCHF) | Time scale | Path to $\geq 10$ TeV |
|-----------------|-------------------|-------------|-----------------|---------------------|---------------------|------------|-----------------------|
| FCC-ee          | 22                | 23          |                 |                     | 15.3                | 2046-2060  |                       |
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| LEP3            | 15                | 17          |                 |                     | 4.1                 | 2047-2062  |                       |
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Viability  
(tech., econ., soc.)  
for transition  
to high-E frontier

FCC-hh  
Muon Collider  
Plasma

Reduced physics  
wrt FCC-ee  
Currently, no  
clear path  
towards 10 TeV

WG2b report  
(From Briefing Book)

WG2a report

# Comparison summary

Competitiveness wrt  
CEPC running in parallel

Project estimates  
+ exp. (CERN part)

| Machine         | Precision Physics | BSM physics | Physics vs CEPC | Technical readiness | Constr. cost (BCHF) | Time scale | Path to $\geq 10$ TeV |
|-----------------|-------------------|-------------|-----------------|---------------------|---------------------|------------|-----------------------|
| FCC-ee          | 22                | 23          |                 |                     | 15.3                | 2046-2060  |                       |
| Descoped FCC-ee | 15                | 17          |                 |                     | 12.9                | 2046-2055  |                       |
| LCF550          | 15                | 17          |                 |                     | 14.8                | 2045-2065  |                       |
| CLIC1500        | 14                | 18          |                 |                     | 14.6                | 2045-2066  |                       |
| LCF250          | 10                | 16          |                 |                     | 9.4                 | 2045-2053  |                       |
| CLIC380         | 10                | 16          |                 |                     | 7.5                 | 2045-2054  |                       |
| LEP3            | 15                | 17          |                 |                     | 4.1                 | 2047-2062  |                       |
| LHeC            | 8                 | 7           |                 |                     | 2.1                 | 2044-2051  |                       |

Viability  
(tech., econ., soc.)  
for transition  
to high-E frontier

FCC-hh  
Muon Collider  
Plasma

Similar cost as  
FCC-ee

Competitive  
Higgs & Top  
physics

Reduced EWPO  
& Flavour physics

Currently, no  
clear path  
towards 10 TeV

WG2b report  
(From Briefing Book)

WG2a report



# Comparison summary

Competitiveness wrt  
CEPC running in parallel

Project estimates  
+ exp. (CERN part)

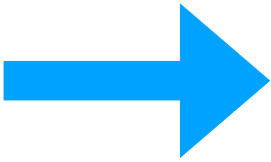
| Machine         | Precision Physics | BSM physics | Physics vs CEPC | Technical readiness | Constr. cost (BCHF) | Time scale | Path to $\geq 10$ TeV |
|-----------------|-------------------|-------------|-----------------|---------------------|---------------------|------------|-----------------------|
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| LEP3            | 15                | 17          |                 |                     | 4.1                 | 2047-2062  |                       |
| LHeC            | 8                 | 7           |                 |                     | 2.1                 | 2044-2051  |                       |

Viability  
(tech., econ., soc.)  
for transition  
to high-E frontier

FCC-hh  
Muon Collider  
Plasma

Reduced physics  
wrt FCC-ee

(Reversible if more  
resources available)



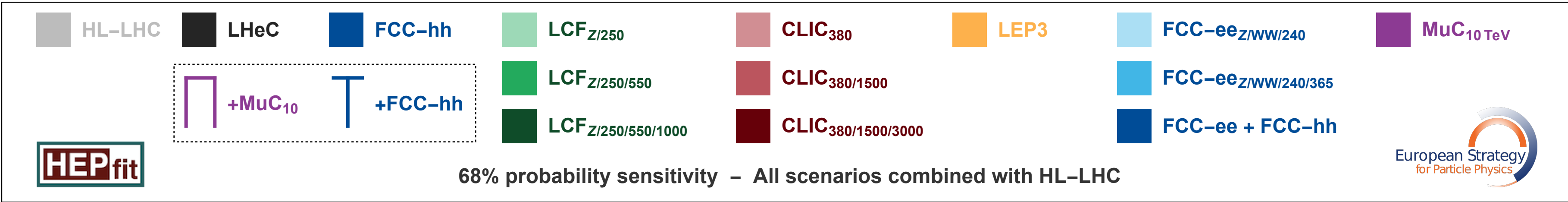
Retains path  
to 10 TeV

WG2b report  
(From Briefing Book)

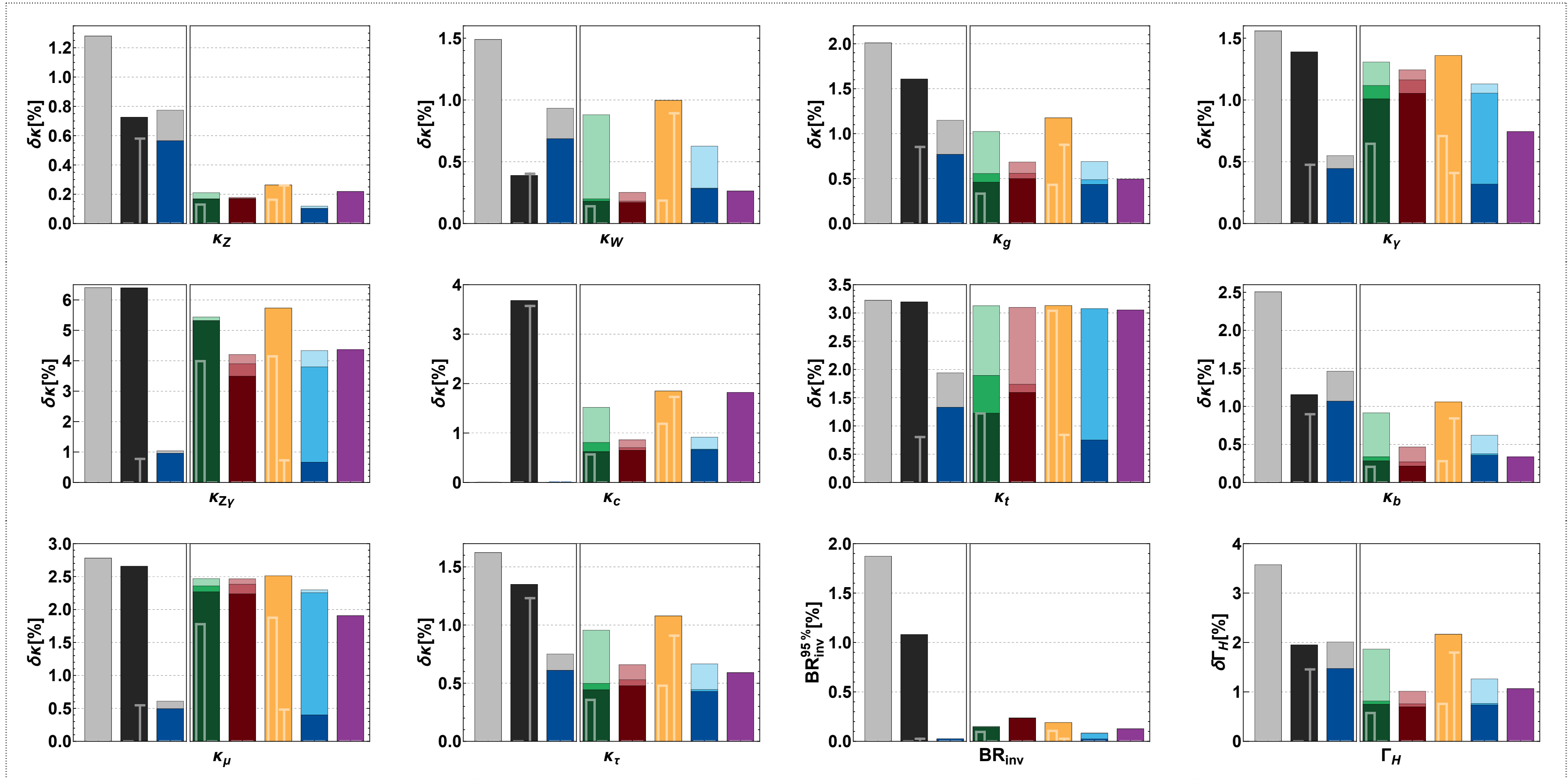
WG2a report



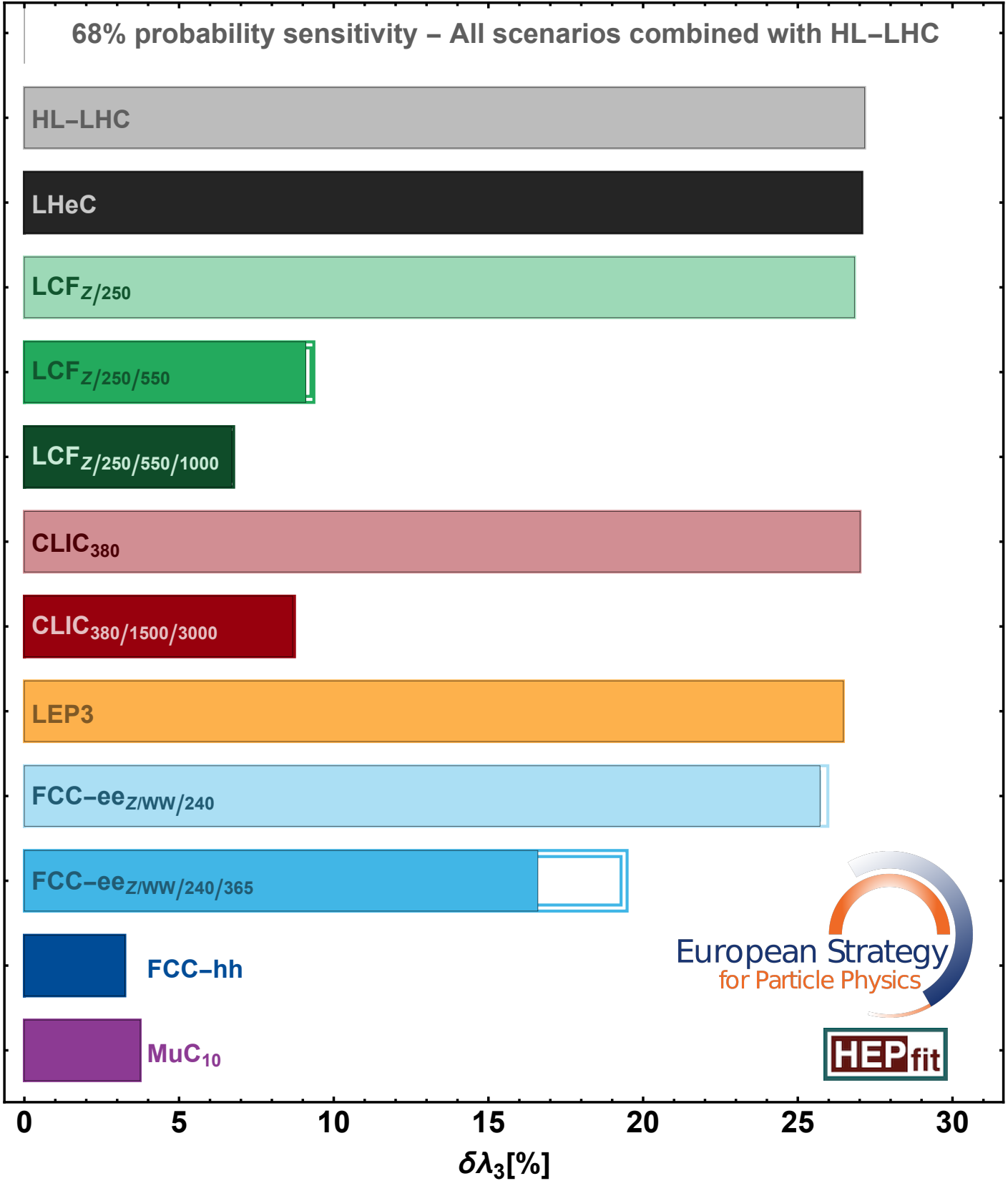
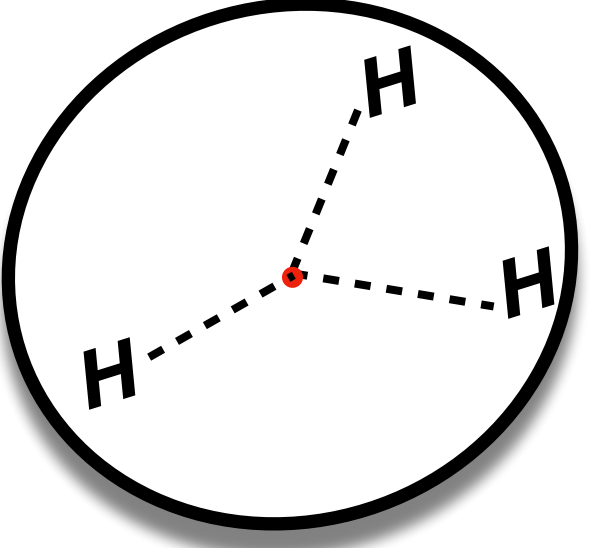
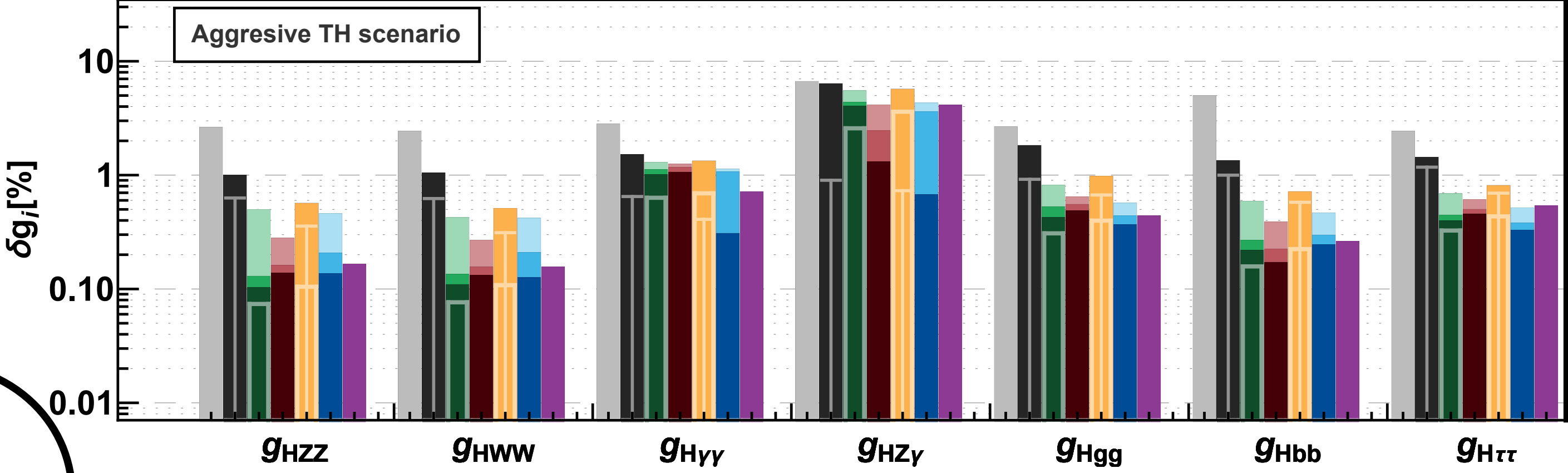
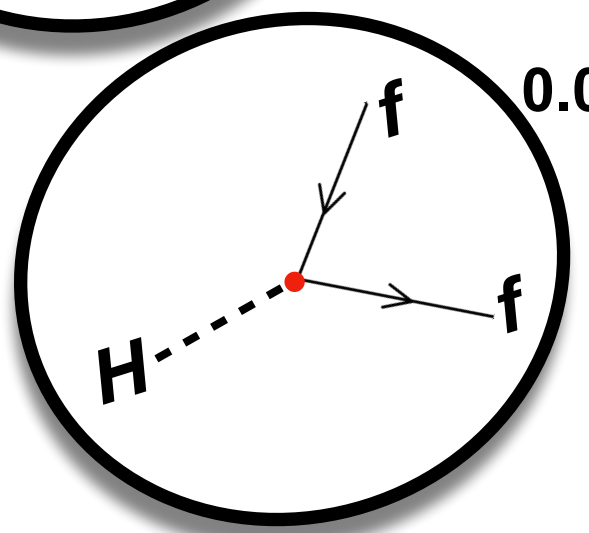
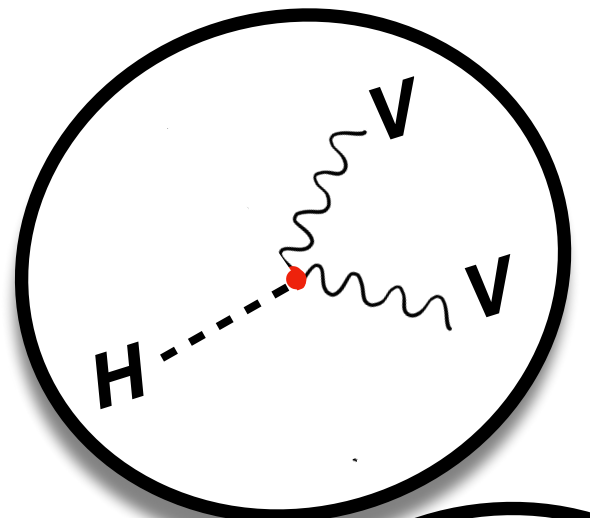
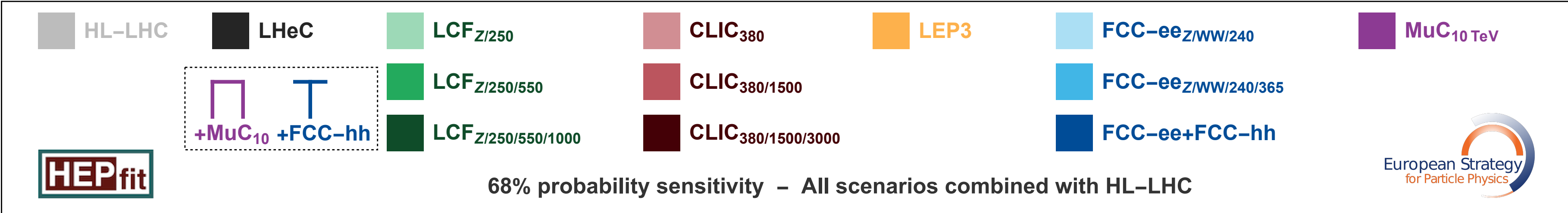
# Characterizing the Higgs boson at $e^+e^-$ Higgs factories ( $\kappa$ )



Precision Reach Higgs couplings

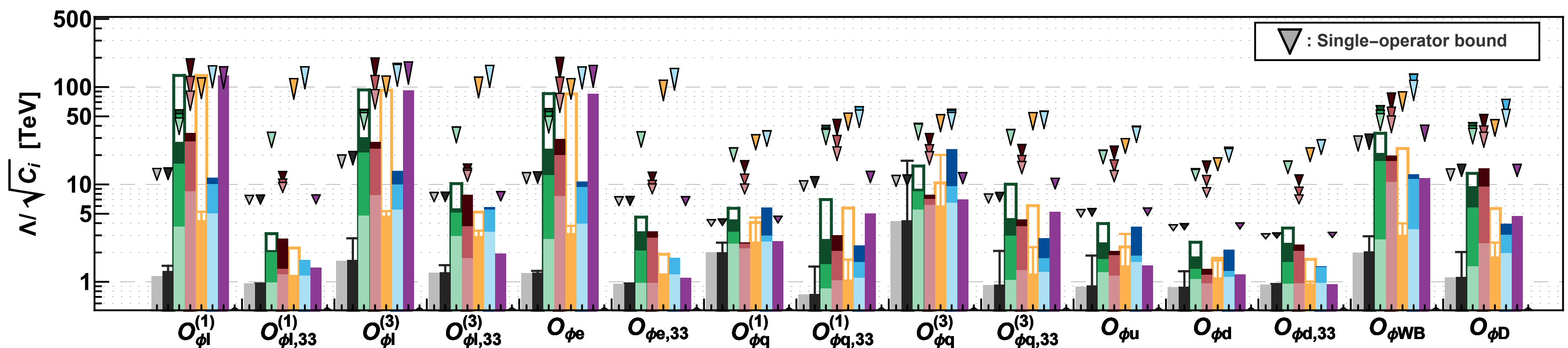
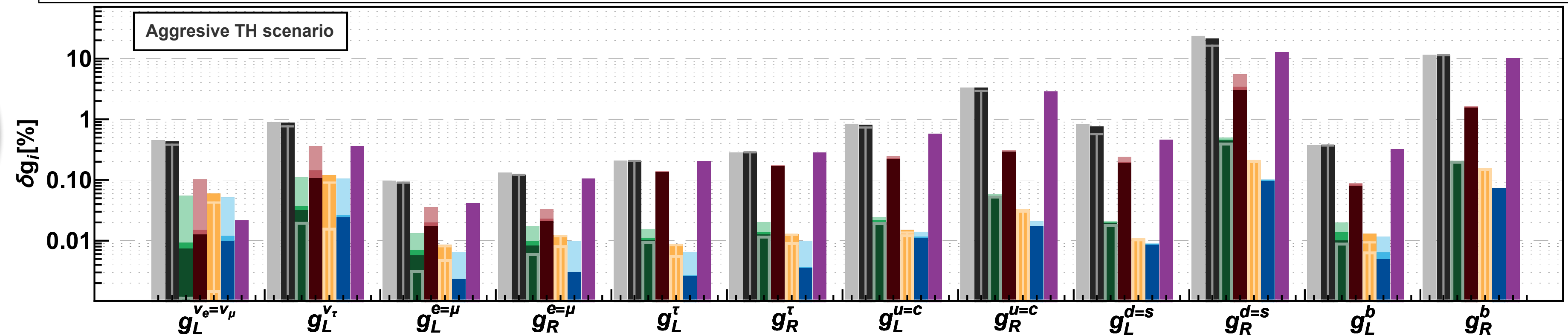
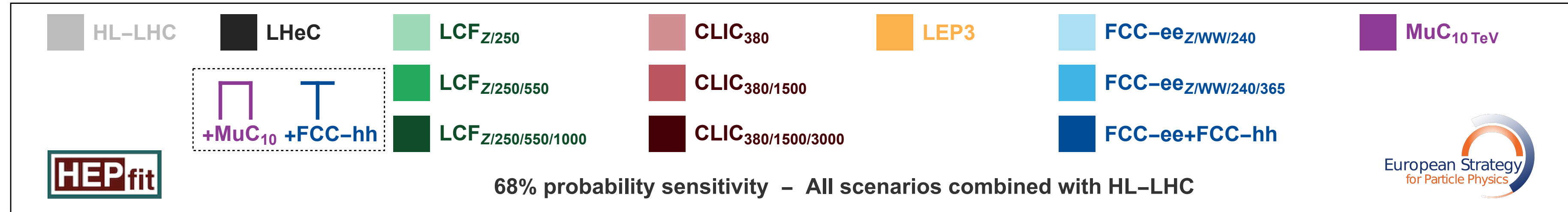
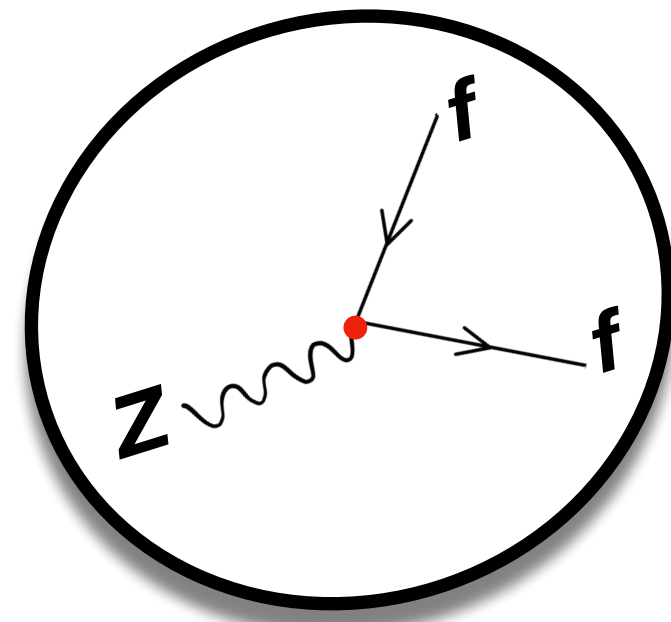


# Characterizing the Higgs boson at $e^+e^-$ Higgs factories (SMEFT)



# BSM at the Tera-Z (indirectly)

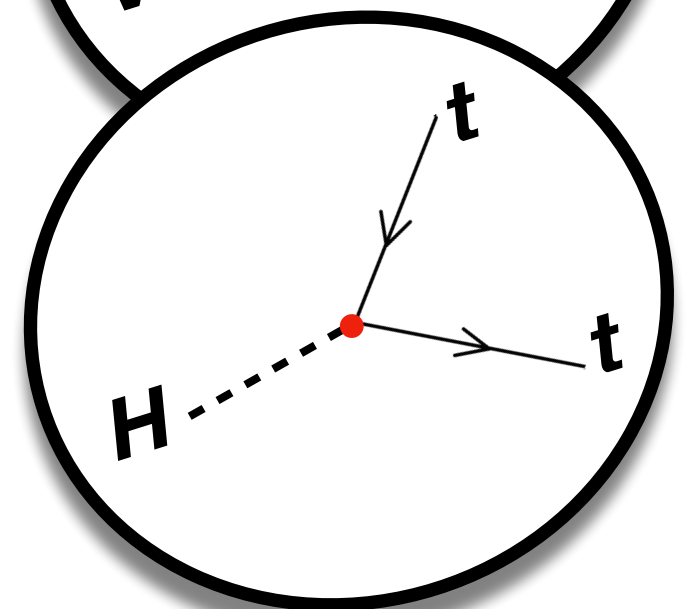
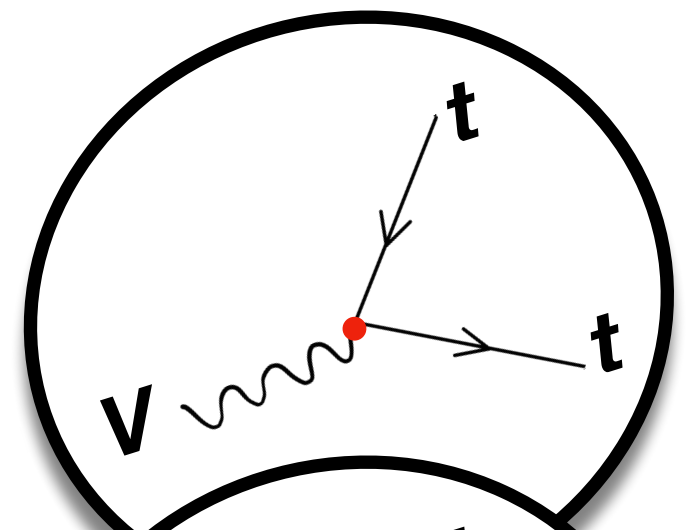
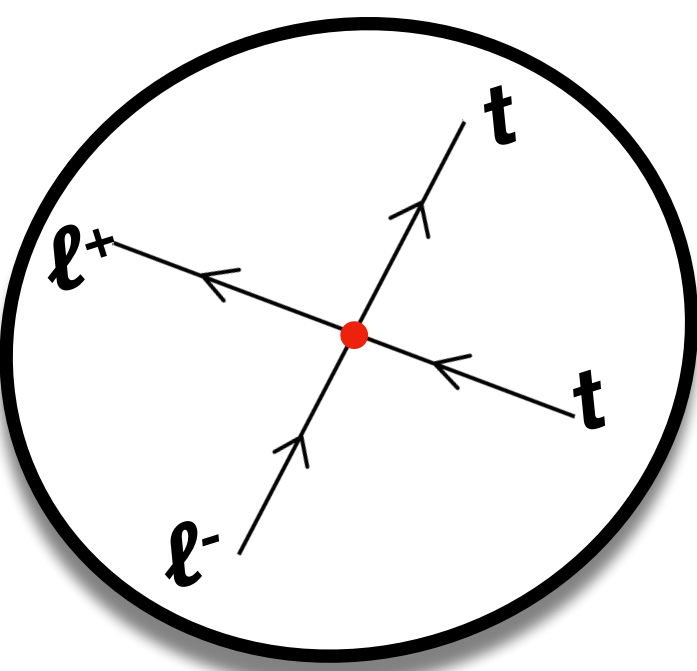
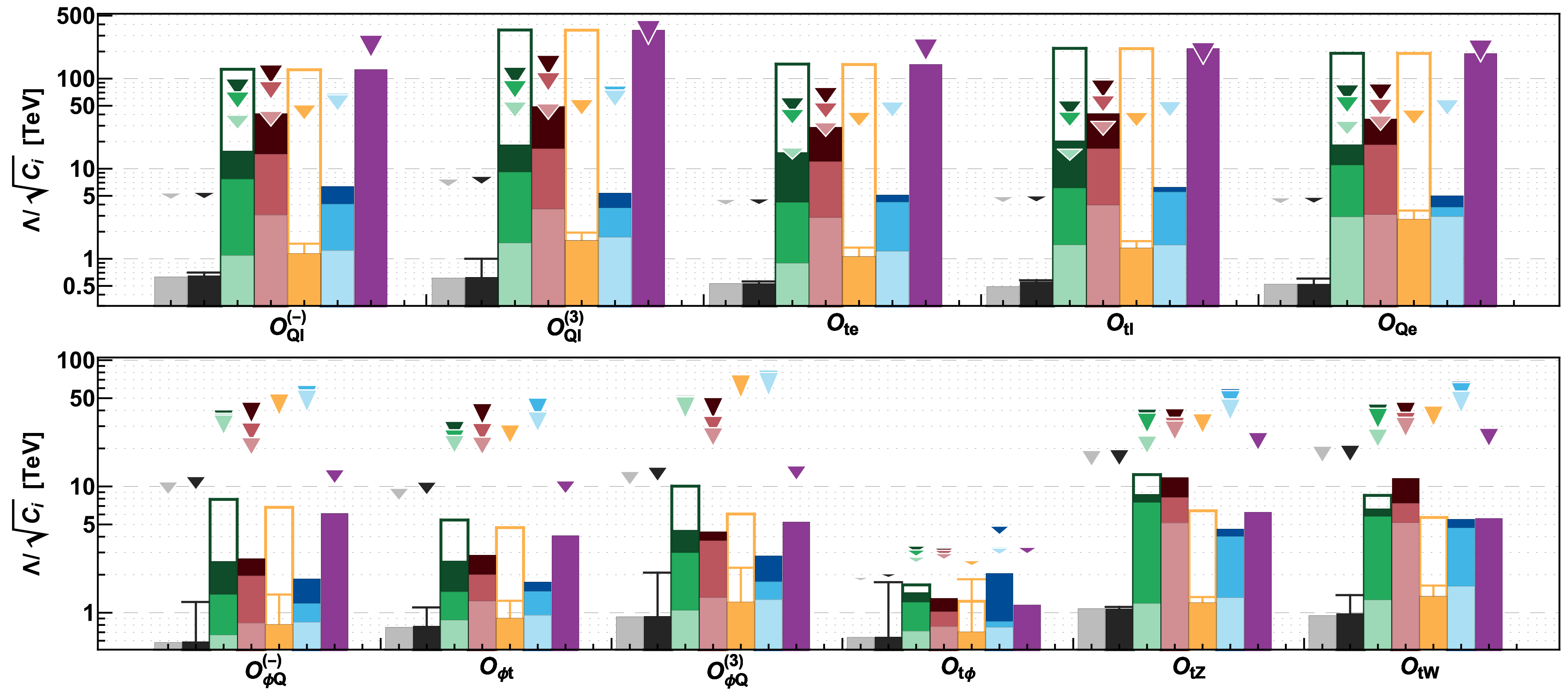
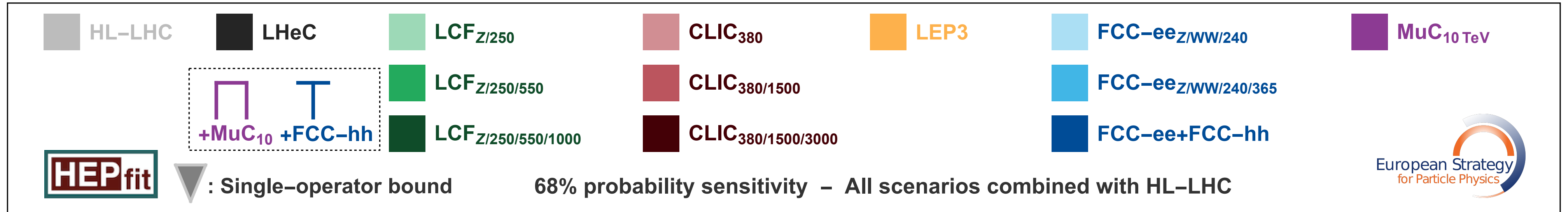
- New Physics EFT sensitivity:



Not easy to identify the actual BSM significance of these results due to large correlations...



# Characterizing the Top quark interactions





# The Flavour of New Physics

## Flavour Physics Opportunities at future colliders

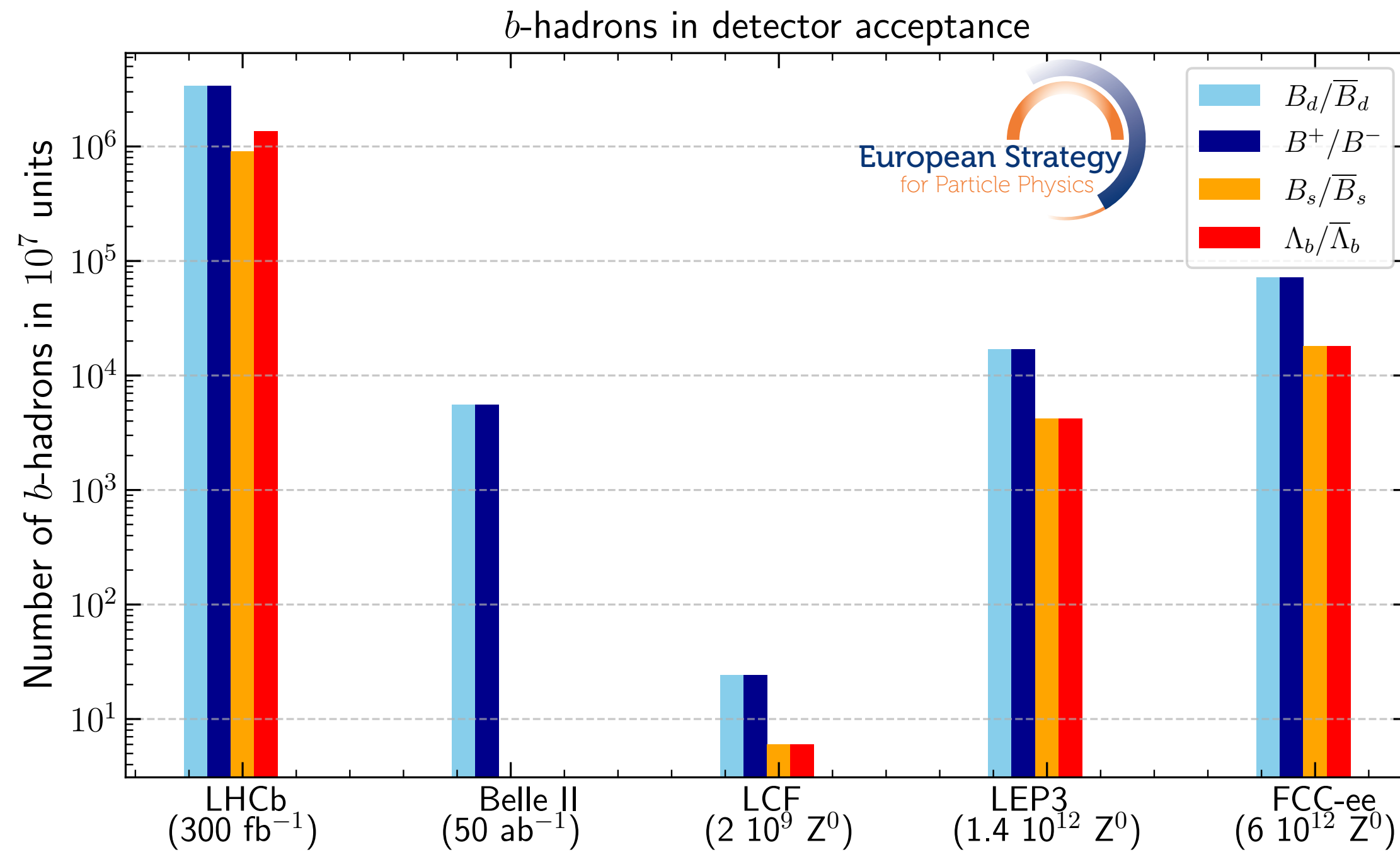
Major progress in many processes at HL-LHC & Belle II and future Z factories

| Flavour Transition                                                                                                                                                                                                                                            | Transition type                                                      |                                                                            |                                                                                                       |                                                                            |                                                                               |                                                                                    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                               | $\gamma$                                                             | quarks                                                                     | $\mu$                                                                                                 | $e$                                                                        | $\tau$                                                                        | $\nu$                                                                              |
| $3_q \rightarrow 2_q$                                                                                                                                                                                                                                         | $b \rightarrow s \gamma$ [*]                                         | $B_s \leftrightarrow \bar{B}_s$ [*]                                        | $b \rightarrow s \bar{\mu} \mu$ [*]<br>$b \rightarrow c \mu \bar{\nu}$                                | $R_{bs}(e/\mu)$ [*]<br>$R_{bc}(e/\mu)$ [•]                                 | $b \rightarrow s \bar{\tau} \tau$ [•]<br>$b \rightarrow c \tau \bar{\nu}$ [•] | $b \rightarrow s \nu \bar{\nu}$ [•]                                                |
| $3_q \rightarrow 1_q$                                                                                                                                                                                                                                         | $b \rightarrow d \gamma$ [*]                                         | $B_d \leftrightarrow \bar{B}_d$ [*]                                        | $b \rightarrow d \bar{\mu} \mu$ [*]<br>$b \rightarrow u \mu \bar{\nu}$                                | $R_{bd}(e/\mu)$ [*]<br>$R_{bu}(e/\mu)$ [•]                                 | $b \rightarrow d \bar{\tau} \tau$ [•]<br>$b \rightarrow u \tau \bar{\nu}$ [•] | $b \rightarrow d \nu \bar{\nu}$ [•]                                                |
| $2_q \rightarrow 2_q$<br>$1_q$                                                                                                                                                                                                                                | $c \rightarrow u \gamma$                                             | $D \leftrightarrow \bar{D}$ [*]                                            | $c \rightarrow u \bar{\mu} \mu$<br>$c \rightarrow s \bar{\mu} \nu$<br>$c \rightarrow d \bar{\mu} \nu$ | $R_{cu}(e/\mu)$ [*]<br>$R_{cs}(e/\mu)$ [•]<br>$R_{cd}(e/\mu)$ [•]          |                                                                               | $c \rightarrow u \nu \bar{\nu}$ [•]                                                |
| $3_\ell \rightarrow 2_\ell$<br>$1_\ell$                                                                                                                                                                                                                       | $\tau \rightarrow \mu \gamma$ [•]<br>$\tau \rightarrow e \gamma$ [•] | $\tau \rightarrow \mu \bar{q} q$ [•]<br>$\tau \rightarrow e \bar{q} q$ [•] | $\tau \rightarrow \mu \bar{\mu} \mu$ [•]<br>$\tau \rightarrow e \bar{\mu} \mu$ [•]                    | $\tau \rightarrow \mu \bar{e} e$ [•]<br>$\tau \rightarrow e \bar{e} e$ [•] |                                                                               | $\tau \rightarrow \mu \nu \bar{\nu}$ [•]<br>$\tau \rightarrow e \nu \bar{\nu}$ [•] |
| [*] = major progress @ HL-LHC, limited impact of $e^+e^-$ colliders<br>[•] = major progress @ HL-LHC & Belle II + significant further progress @ FCC-ee<br>[•] = FCC-ee allows one order of magnitude precision improvement, or more, after HL-LHC & Belle II |                                                                      |                                                                            |                                                                                                       |                                                                            |                                                                               |                                                                                    |
| $2_q \rightarrow 1_q$<br>$1_q$                                                                                                                                                                                                                                | $s \rightarrow d \gamma$                                             | $K^0 \leftrightarrow \bar{K}^0$                                            | $s \rightarrow d \bar{\mu} \mu$<br>$s \rightarrow u \mu \bar{\nu}$<br>$d \rightarrow u \mu \bar{\nu}$ | $R_{sd}(e/\mu)$<br>$R_{su}(e/\mu)$<br>$R_{du}(e/\mu)$                      |                                                                               | $s \rightarrow d \nu \bar{\nu}$                                                    |
| $2_\ell \rightarrow 1_\ell$                                                                                                                                                                                                                                   | $\mu \rightarrow e \gamma$                                           | $\mu N \rightarrow e N$                                                    |                                                                                                       | $\mu \rightarrow e \bar{e} e$                                              |                                                                               | $\mu \rightarrow e \nu \bar{\nu}$                                                  |

# The Flavour of New Physics

## Flavour Physics Opportunities at future colliders

- Tera Z:  $10^{12}$  Z bosons  $\Rightarrow$  Plenty of bottom, charm and  $\tau$  fermions for clean flavour physics



**2030s**

Belle II 10 ab<sup>-1</sup>  
LHCb 50 fb<sup>-1</sup>

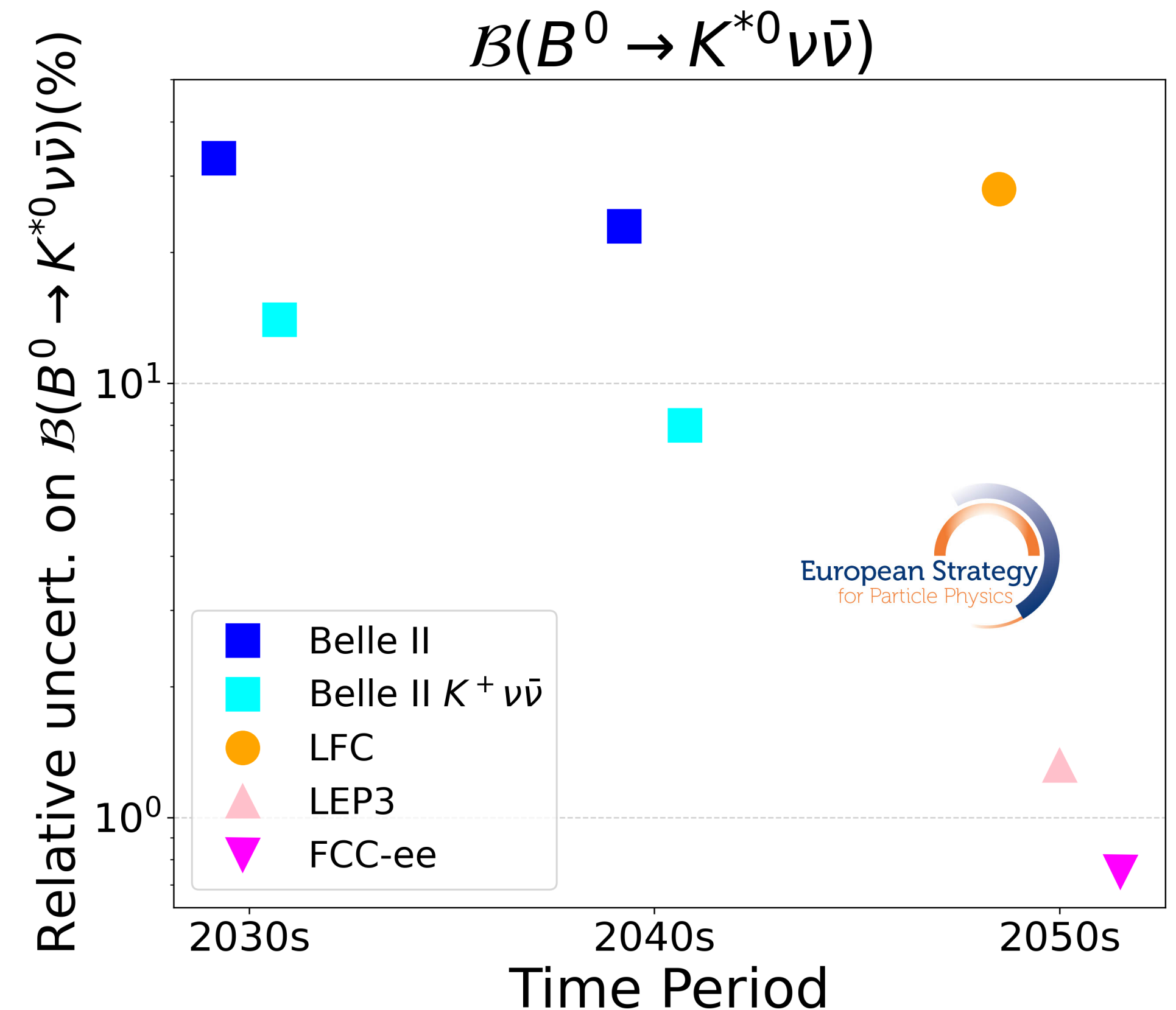
**2040s**

Belle II 50 ab<sup>-1</sup>  
LHCb 300 fb<sup>-1</sup>

**2050s**

LCF 2 10<sup>9</sup> Z<sup>0</sup>  
LEP3 1.4 10<sup>12</sup> Z<sup>0</sup>  
FCC-ee 6 10<sup>12</sup> Z<sup>0</sup>

## Opportunities for probing NP in FCNC $b \rightarrow s \nu \bar{\nu}$



**Additional opportunities from W decays (FCC-ee:  $10^8$  W pairs)  $\Rightarrow$  CKM**

# The Flavour of New Physics

## Flavour Physics Opportunities at future colliders

- Tera Z:  $10^{12}$  Z bosons  $\Rightarrow$  Plenty of bottom, charm and  $\tau$  fermions for clean flavour physics

### $\tau$ Lepton Flavour Violation

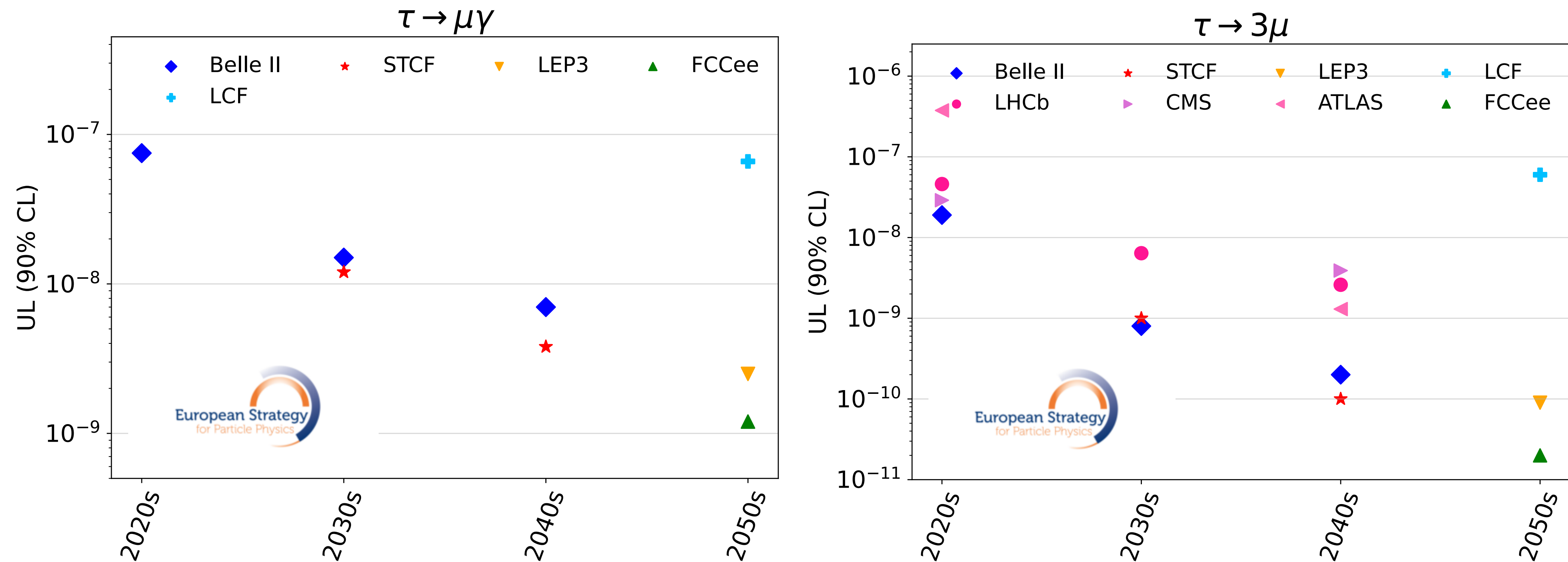


Fig. 5.7: Expected upper limits at 90% on  $\mathcal{B}(\tau \rightarrow \mu\gamma)$  and  $\mathcal{B}(\tau \rightarrow \mu\mu\mu)$ .

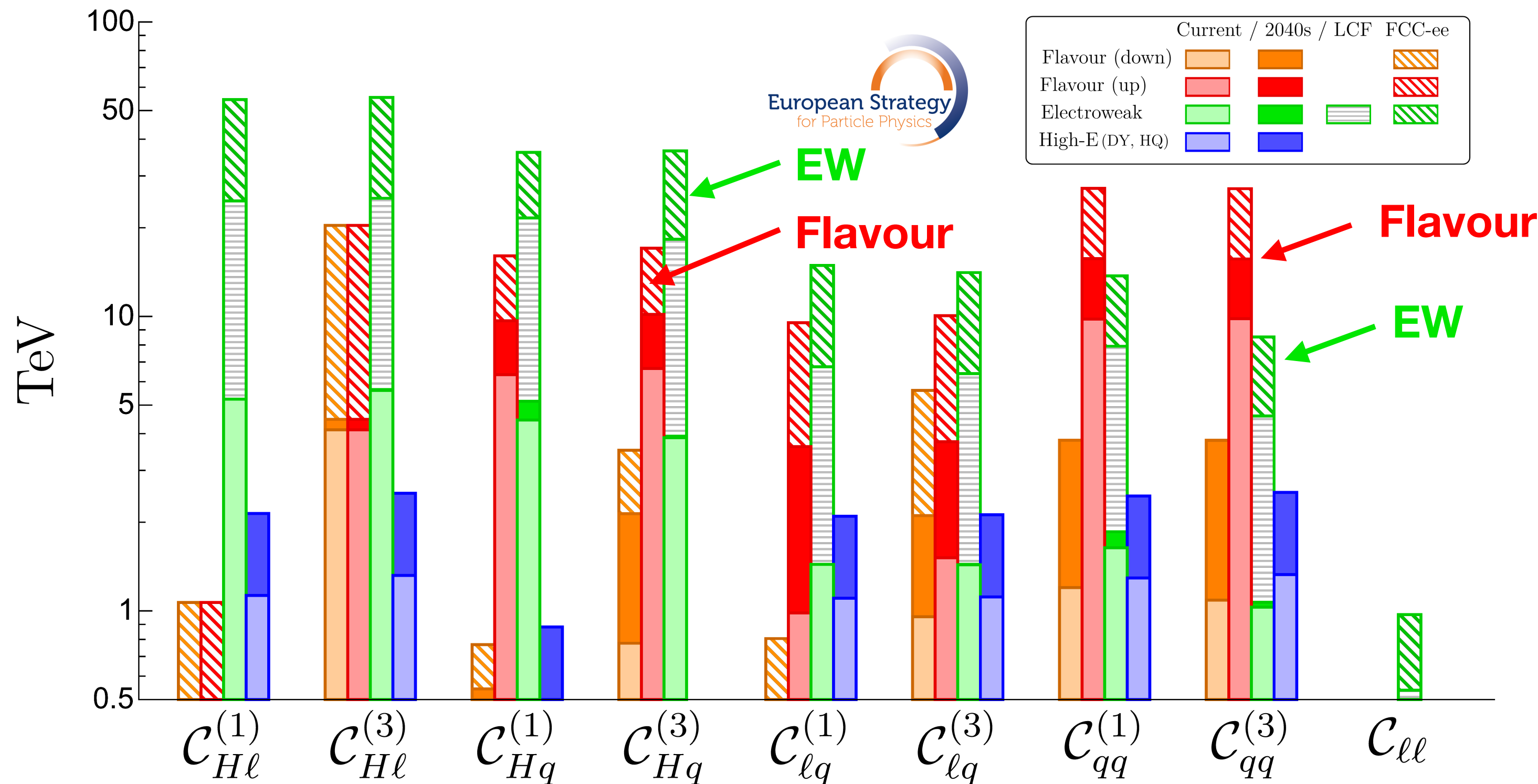


# The Flavour of New Physics

- Complementarity Electroweak/Flavour:

EFT bounds: EW vs. Flavour

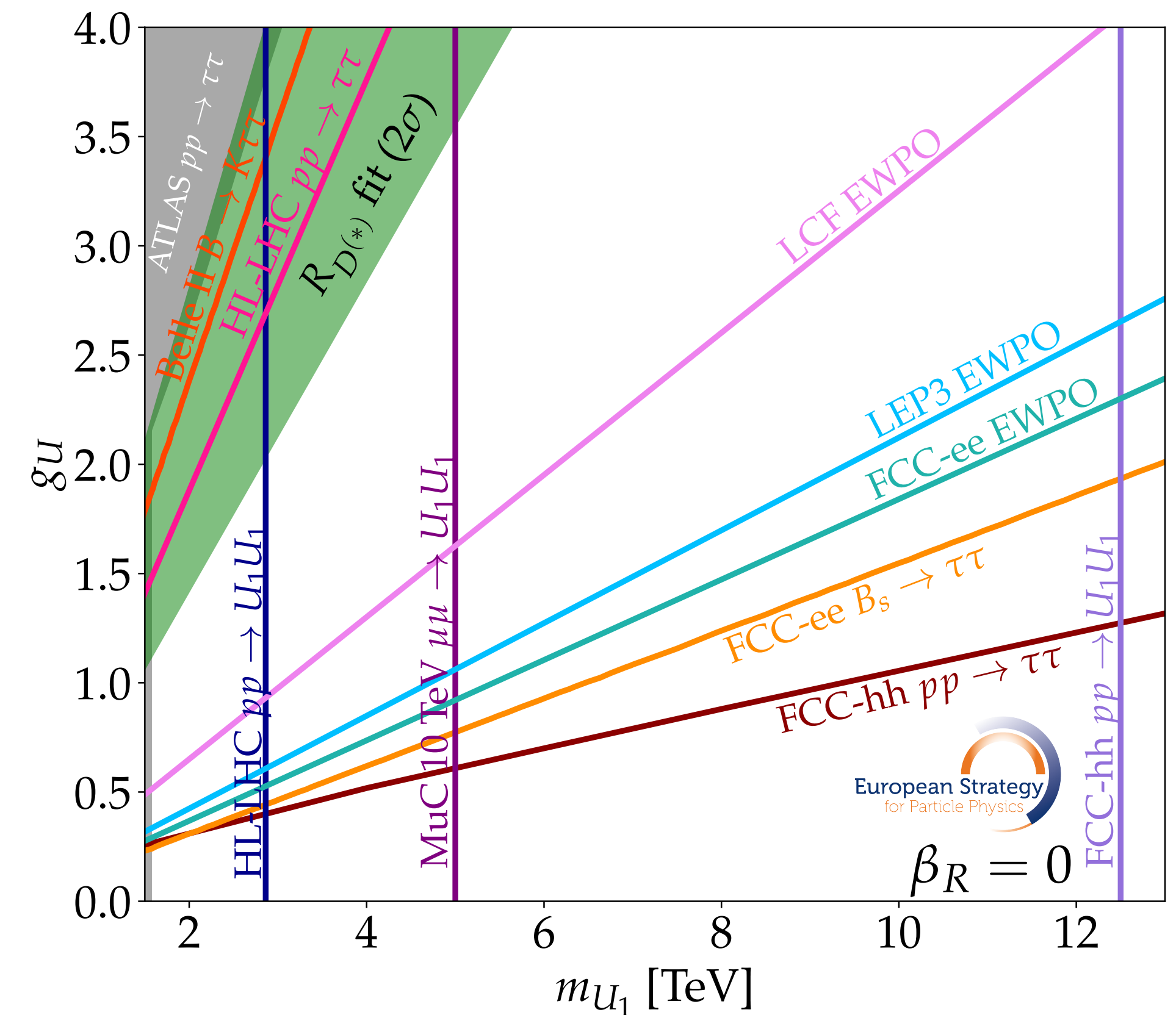
New physics in 3rd family (U(2)<sup>5</sup> flavour “protection”)



**Complementarity: Best bound depend on operator  
(and flavour assumptions of BSM)**

BSM: Vector lepto-quark (3rd gen.)

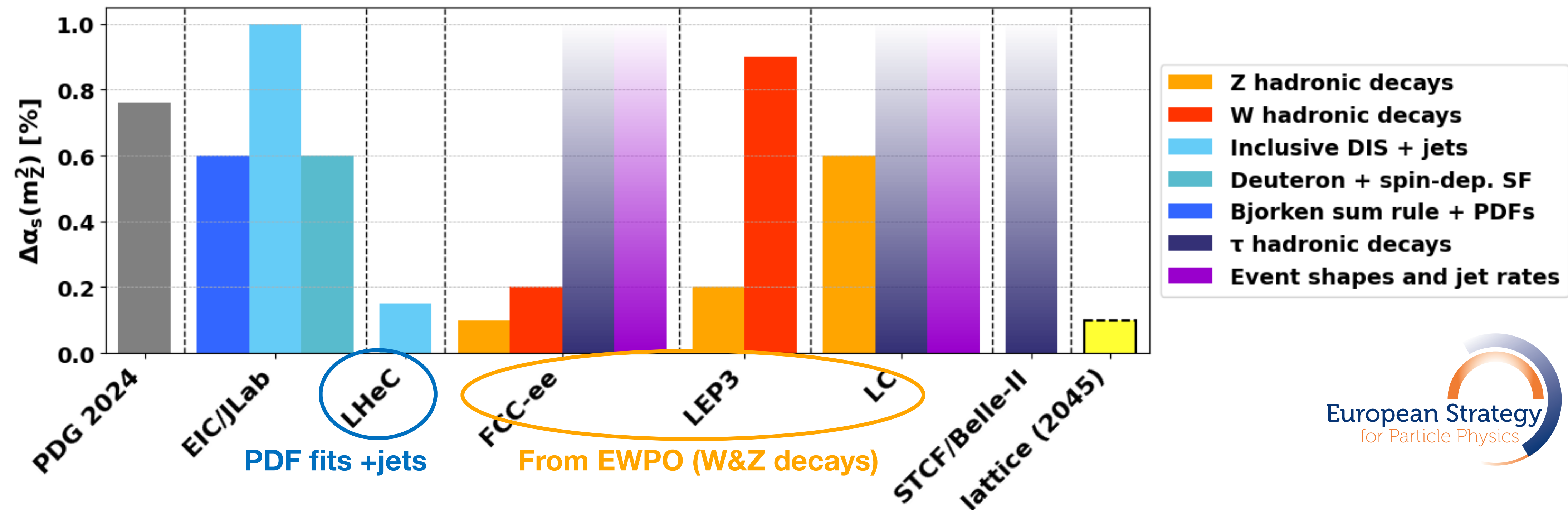
$$\mathcal{L}_{U_1} \supset \frac{g_U}{\sqrt{2}} \beta_{ij} \bar{Q}_L^i \gamma_\alpha L_L^j U_1^\alpha + h.c.$$





# QCD parameters at future colliders

## Strong Coupling Constant precision summary



LHeC & FCC-ee comparable to future Lattice QCD projections ~ 0.1%

