Beyond the Standard Model at the Highest Energy Linear Colliders

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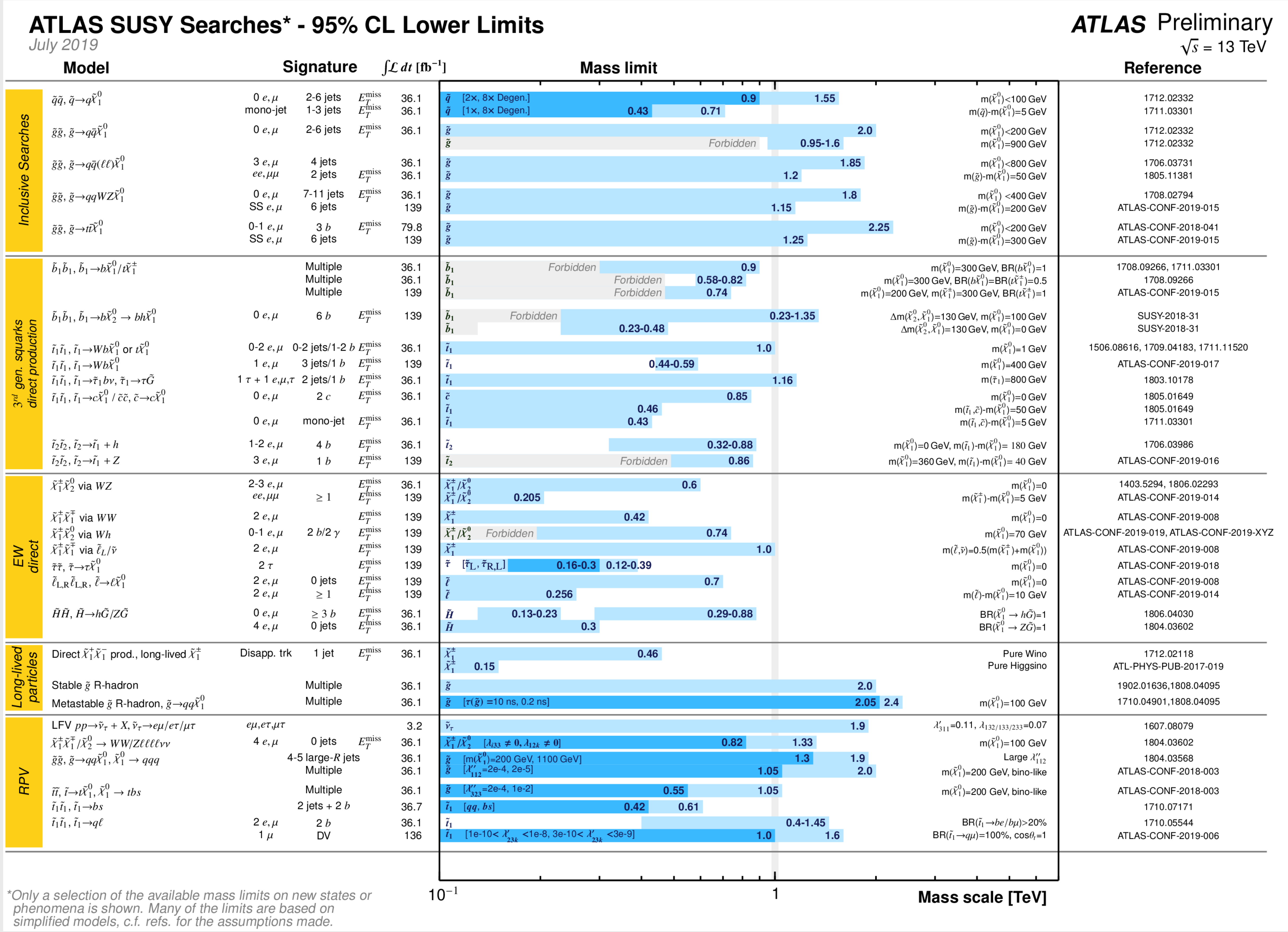
Our path to new physics in 3 steps

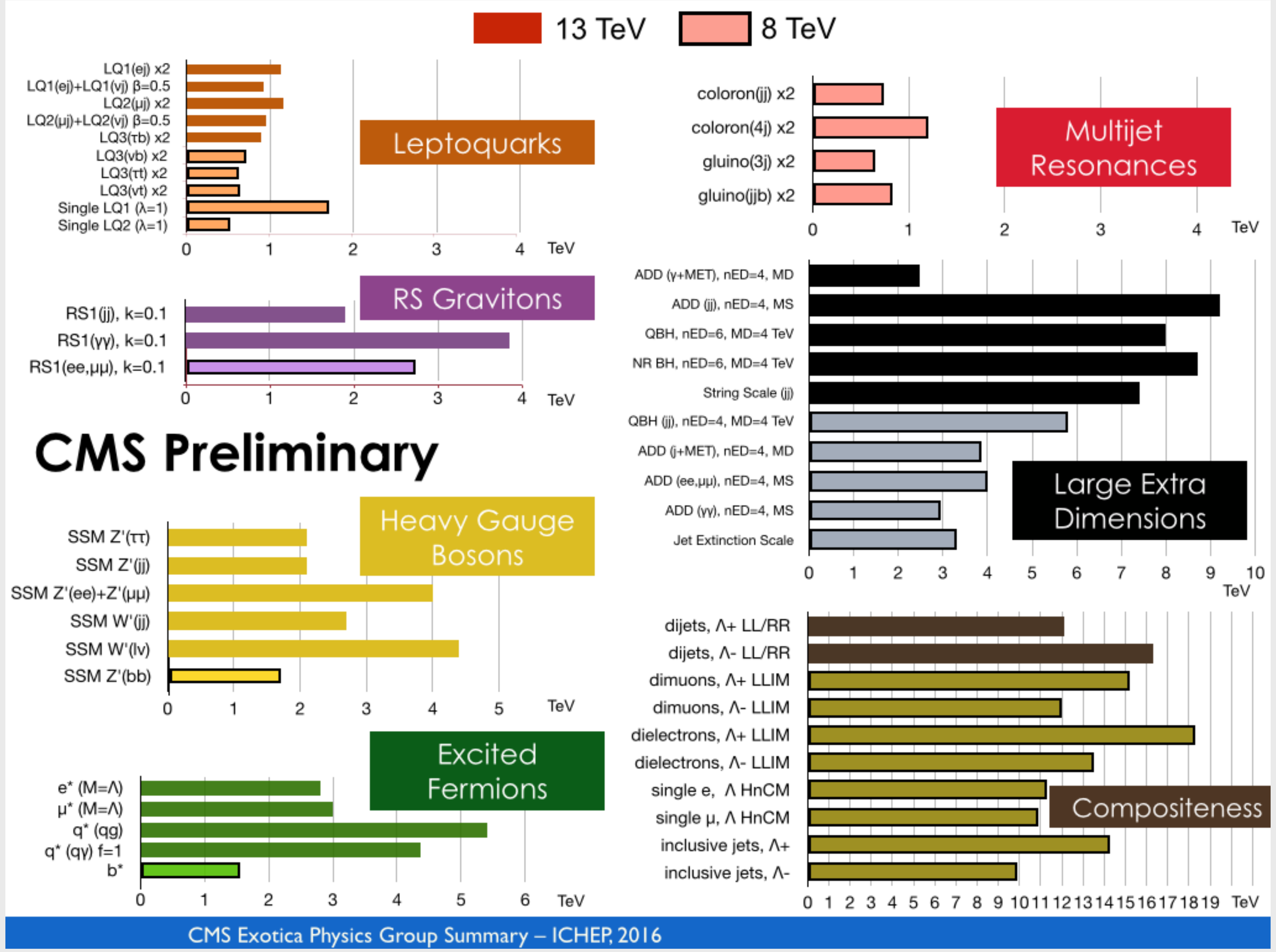
PROTON | ROAD TO DISCOVERY

- New physics is tied to the Higgs bosons, hence should appear at the TeV scale.
- Concrete models which address the peculiarly of the Higgs boson in the zoo of the SM need plenty of colored particles
- Hadron machines are the tool to discover new physics!

… then LHC came into the game

PROTON | ROAD TO DISCOVERY





Roberto Franceschini LCWS19 https://agenda.linearcollider.org/event/8217/

How deep are the consequences?

Open Questions on the "big picture" on fundamental physics circa 2020

- why QCD does not violate CP?
- how have baryons originated in the early Universe?
- ? what is the dark matter in the Universe?
- what originates flavor mixing and fermions masses?
- what gives mass to neutrinos?
- why gravity and weak interactions are so different?
- what fixes the cosmological constant?

Solutions to these puzzles involving new physics at the TeV scale are now very constrained

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end of “The Boltzmann Way”

hindering the whole paradigm of getting “macroscopic” physics from microscopic properties e.g.

$$T \propto \left\langle v^2_{\text{air molecules}} \right\rangle$$

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Foundations of reductionist physics are at stake!

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WEAK INTERACTIONS

NEW WEAKLY CHARGED PARTICLES

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WEAK INTERACTIONS

NEW WEAKLY CHARGED PARTICLES

All round exploration is needed, the field covered by LHC is not enough

The highest energy at Linear Colliders

High energy colliders for new physics

- High energy can probe directly <u>heavier new physics</u>
- High energy yields <u>largest magnification factor</u> for new contact interactions

The new 3-step recipe of new physics

EFT EPOCH

LESSON FROM LHC

- No new physics at the TeV scale
- New physics is “heavy"
- BSM can be cast in the form of an effective field theory

MAGNIFICATION FACTOR

$$\sigma = \sigma_{SM} + \boxed{\frac{E^2}{\Lambda^2}}\sigma_{BSM} + \ldots$$

- effects grow at larger energies like $\nu e^- \to \nu e^-$ in Fermi Theory

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as NP effects may grow quadratically with energy

$$\Delta O = O_{NP} - O_{SM} \sim \left(\frac{E}{v}\right)^2$$

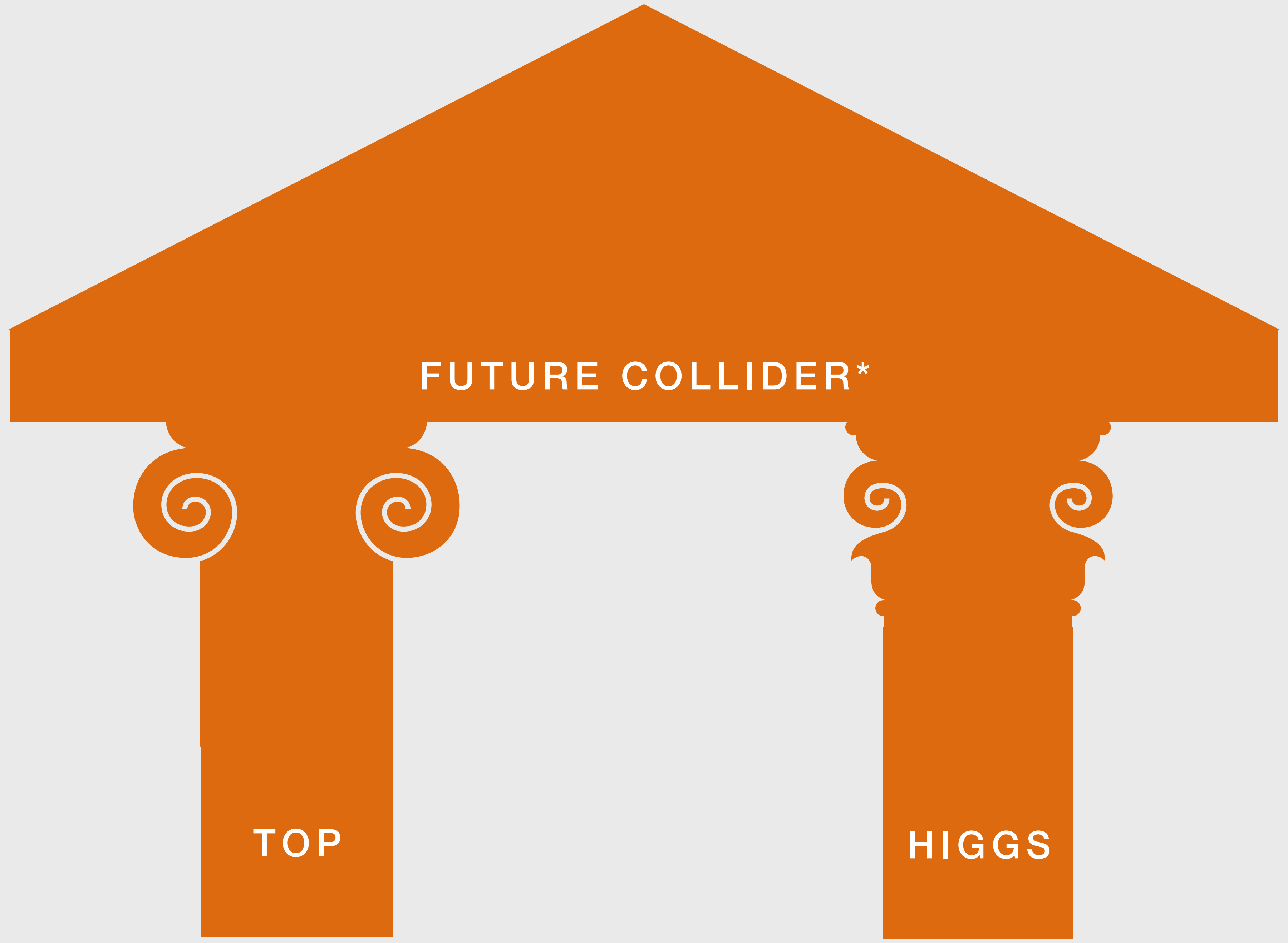
0.1% at m_Z is equivalent to 10% at 1 TeV

Which direction is “forward”?

- The “precision” study of SM interactions at the highest energies is a prime tool to discover new physics

e^+e^- colliders are unique in this sense because offer both **clean environment** and **high energy**

Which direction is “forward”?



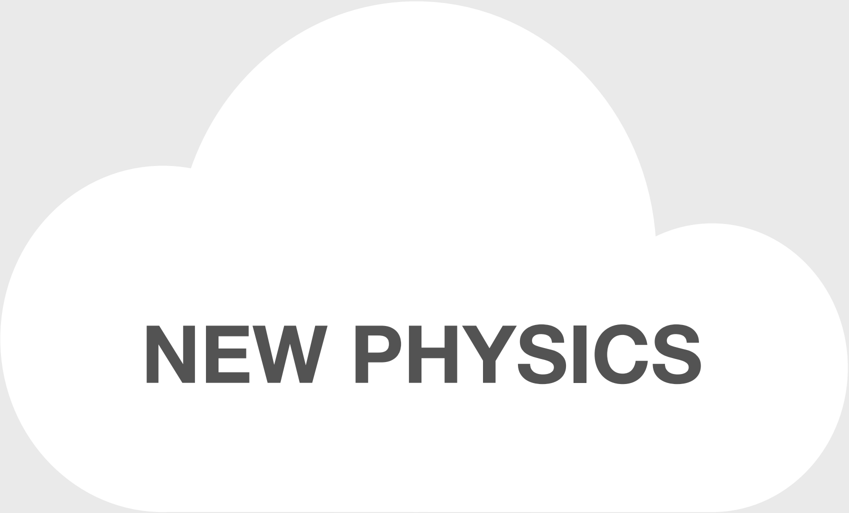
**of any shape*

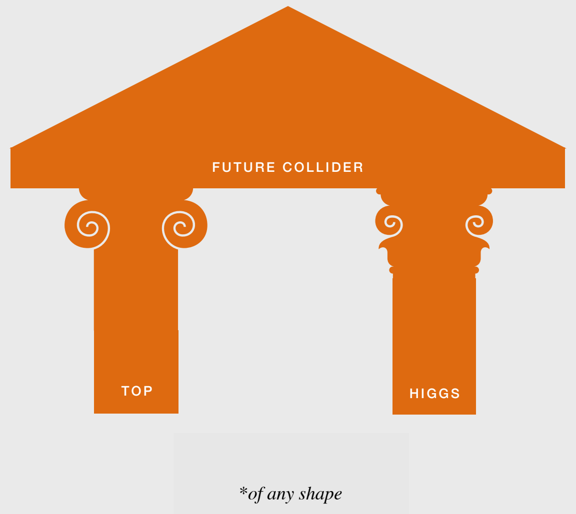
- the least well known
- the highest mass scale
- the most central to the origin of EW scale

Which direction is "forward"?

- The "precision" study of **top quark** and **Higgs boson** interactions at the highest energies is a prime tool to discover new physics

Which direction is “forward”?





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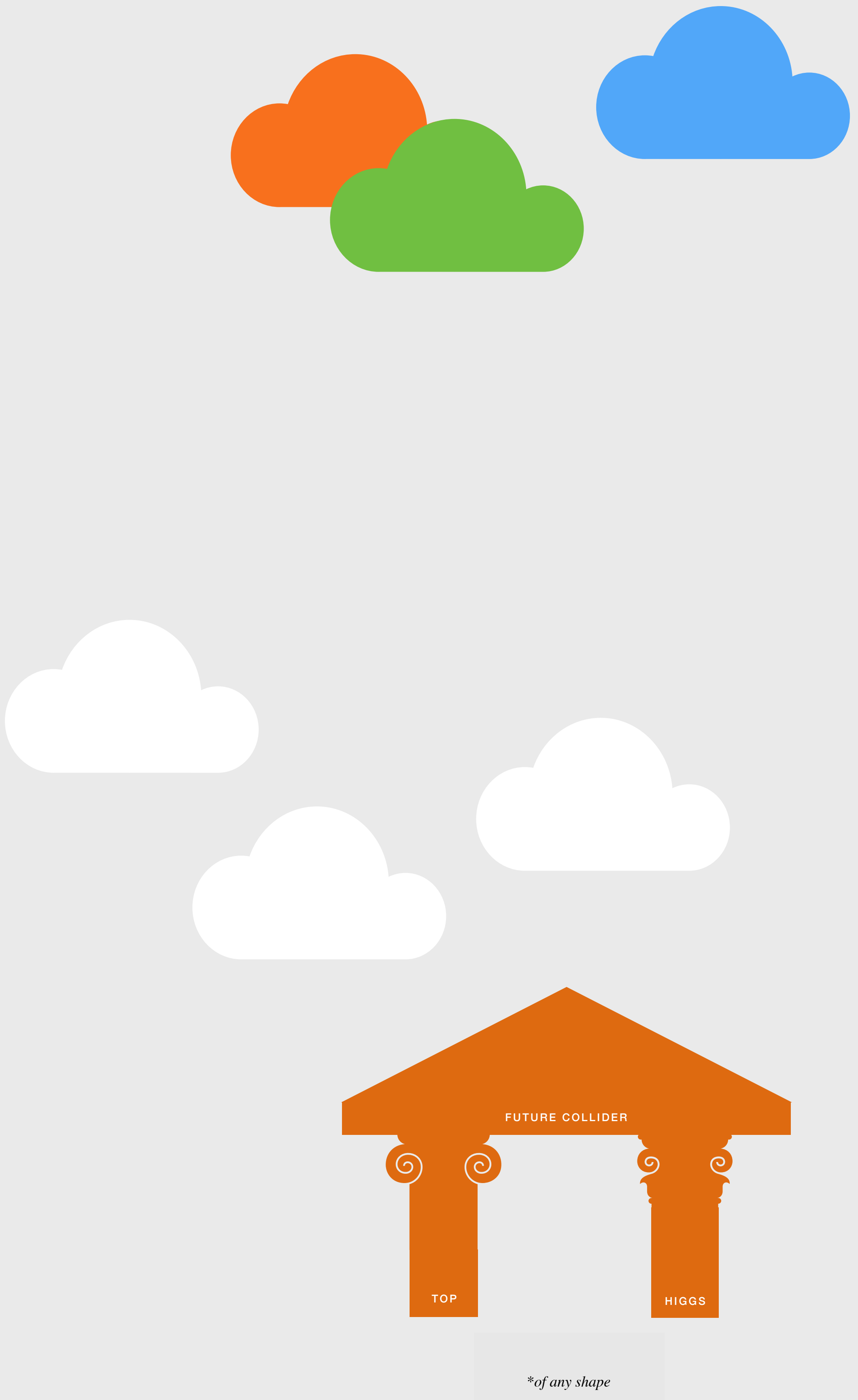

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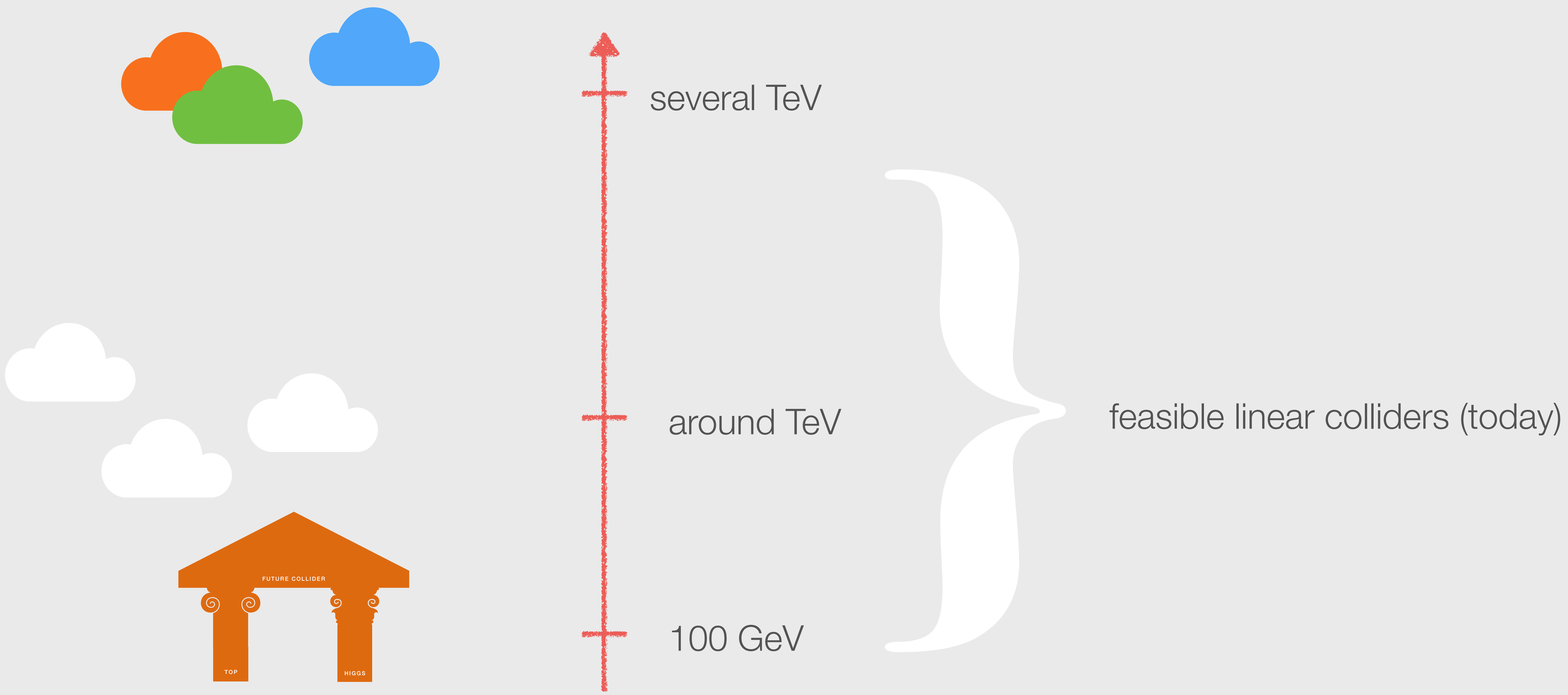

- the least well known
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Higgs Boson

“The size of the Higgs boson”

it matters because being “point-like” is the source of all the theoretical questions on the Higgs boson and weak scale

… and if it is not … well, that is physics beyond the Standard Model!


POINT
LIKE

$$\ell_{Higgs} \sim m_{\star}^{-1}$$

Effects of the size of the Higgs boson

h ~ π

STRONGLY INTERACTING LIGHT HIGGS

$$\begin{aligned}\mathcal{L}^{d=6}_{universal} &= c_H \frac{g_*^2}{m_*^2}\mathcal{O}_H + c_T \frac{N_c \epsilon_q^4 g_*^4}{(4\pi)^2 m_*^2}\mathcal{O}_T + c_6 \lambda \frac{g_*^2}{m_*^2}\mathcal{O}_6 + \frac{1}{m_*^2}\left[c_W \mathcal{O}_W + c_B \mathcal{O}_B\right] \\ &+ \frac{g_*^2}{(4\pi)^2 m_*^2}\left[c_{HW}\mathcal{O}_{HW} + c_{HB}\mathcal{O}_{HB}\right] + \frac{y_t^2}{(4\pi)^2 m_*^2}\left[c_{BB}\mathcal{O}_{BB} + c_{GG}\mathcal{O}_{GG}\right] \\ &+ \frac{1}{g_*^2 m_*^2}\left[c_{2W} g^2 \mathcal{O}_{2W} + c_{2B} g'^2 \mathcal{O}_{2B}\right] + c_{3W}\frac{3! g^2}{(4\pi)^2 m_*^2}\mathcal{O}_{3W} \\ &+ c_{y_t}\frac{g_*^2}{m_*^2}\mathcal{O}_{y_t} + c_{y_b}\frac{g_*^2}{m_*^2}\mathcal{O}_{y_b}\end{aligned}$$

$1/f \sim g_\star/m_\star$

$1/(g_\star f) \sim 1/m_\star$

$g_{SM}/(g_\star f) \sim g_{SM}/m_\star$

Effects of the size of the Higgs boson

h ~ π STRONGLY INTERACTING LIGHT HIGGS

$$\mathcal{L}^{d=6}_{universal} = c_H \frac{g_*^2}{m_*^2}\mathcal{O}_H + c_T \frac{N_c \epsilon_q^4 g_*^4}{(4\pi)^2 m_*^2}\mathcal{O}_T + c_6 \lambda \frac{g_*^2}{m_*^2}\mathcal{O}_6 + \frac{1}{m_*^2}\left[c_W \mathcal{O}_W + c_B \mathcal{O}_B\right]$$

$$+ \frac{g_*^2}{(4\pi)^2 m_*^2}\left[c_{HW}\mathcal{O}_{HW} + c_{HB}\mathcal{O}_{HB}\right] + \frac{y_t^2}{(4\pi)^2 m_*^2}\left[c_{BB}\mathcal{O}_{BB} + c_{GG}\mathcal{O}_{GG}\right]$$

$$+ \frac{1}{g_*^2 m_*^2}\left[c_{2W} g^2 \mathcal{O}_{2W} + c_{2B} g'^2 \mathcal{O}_{2B}\right] + c_{3W}\frac{3! g^2}{(4\pi)^2 m_*^2}\mathcal{O}_{3W}$$

$$+ c_{y_t}\frac{g_*^2}{m_*^2}\mathcal{O}_{y_t} + c_{y_b}\frac{g_*^2}{m_*^2}\mathcal{O}_{y_b}$$

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$1/(g_\star f) \sim 1/m_\star$

$g_{SM}/(g_\star f) \sim g_{SM}/m_\star$

$\ell_{Higgs} \sim 1/m_\star$

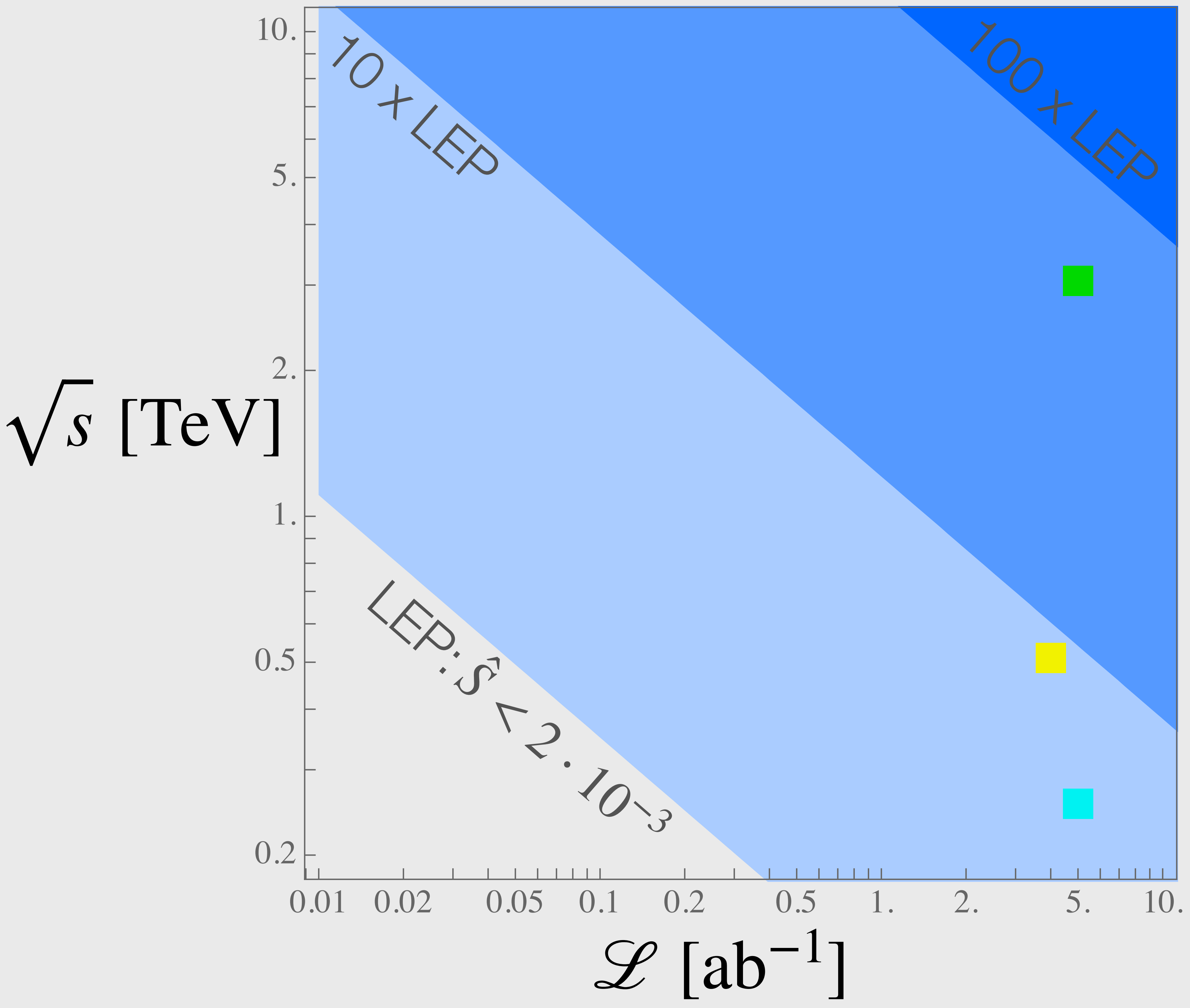
$\ell^+\ell^- \to Zh$

Ever higher energy colliders can exploit "precise" measurements at the 10% level

TOTAL RATE

$$\left|A_{SM}^{(00)}\right|^2 + A_{SM}^{00}\cdot A_{BSM}^{00} + \ldots$$

$$\hat{S}_{95\%} \lesssim 1.2\cdot 10^{-4}\,\frac{1}{E_{beam}/\mathrm{TeV}}\cdot\frac{1}{\sqrt{\mathscr{L}/\mathrm{ab}^{-1}}}$$



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TOTAL **RATE**

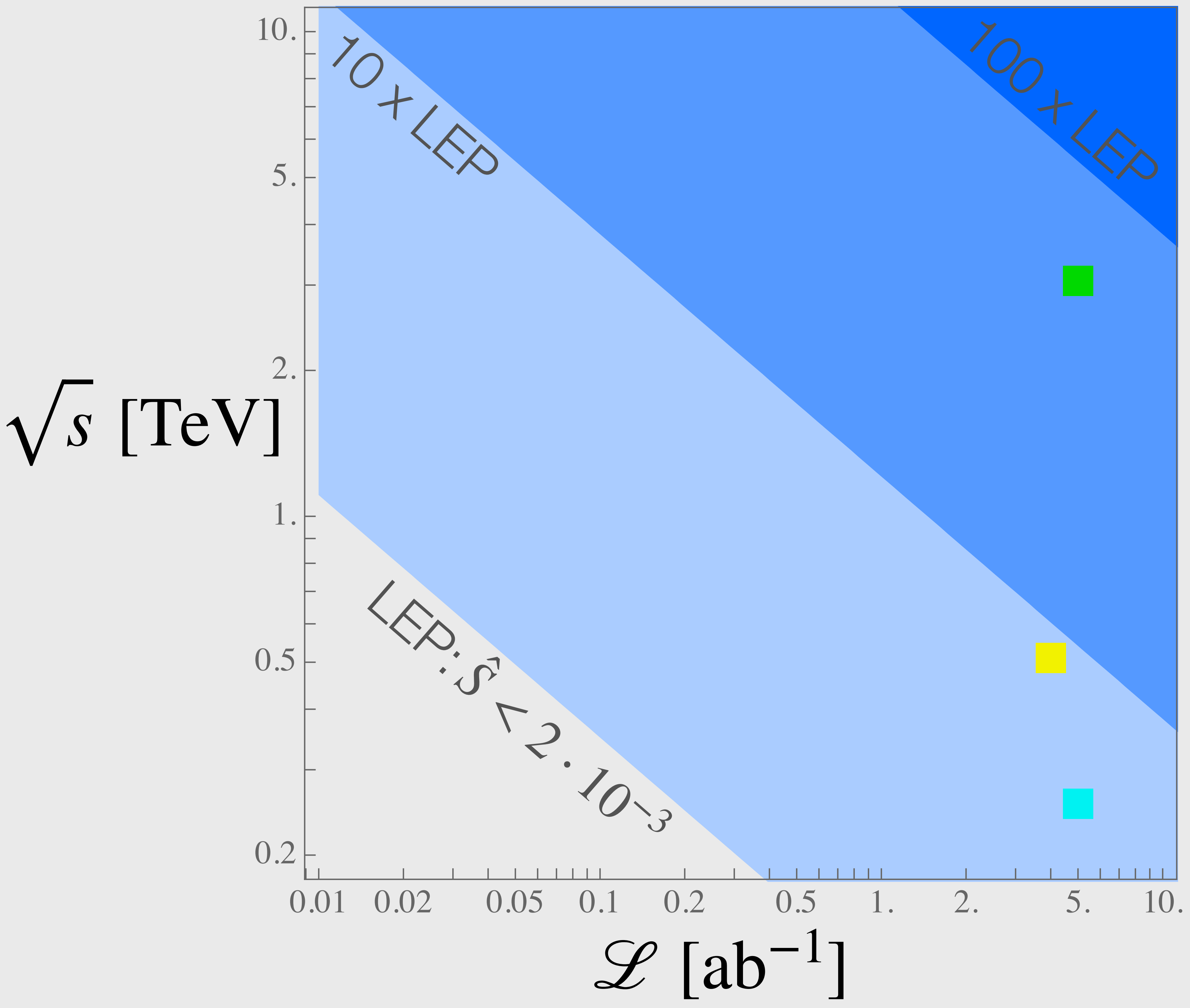
$$\left|A_{SM}^{(00)}\right|^2 + A_{SM}^{00}\cdot A_{BSM}^{00} + \ldots$$

Ever higher energy colliders can exploit "precise" measurements at the 10% level

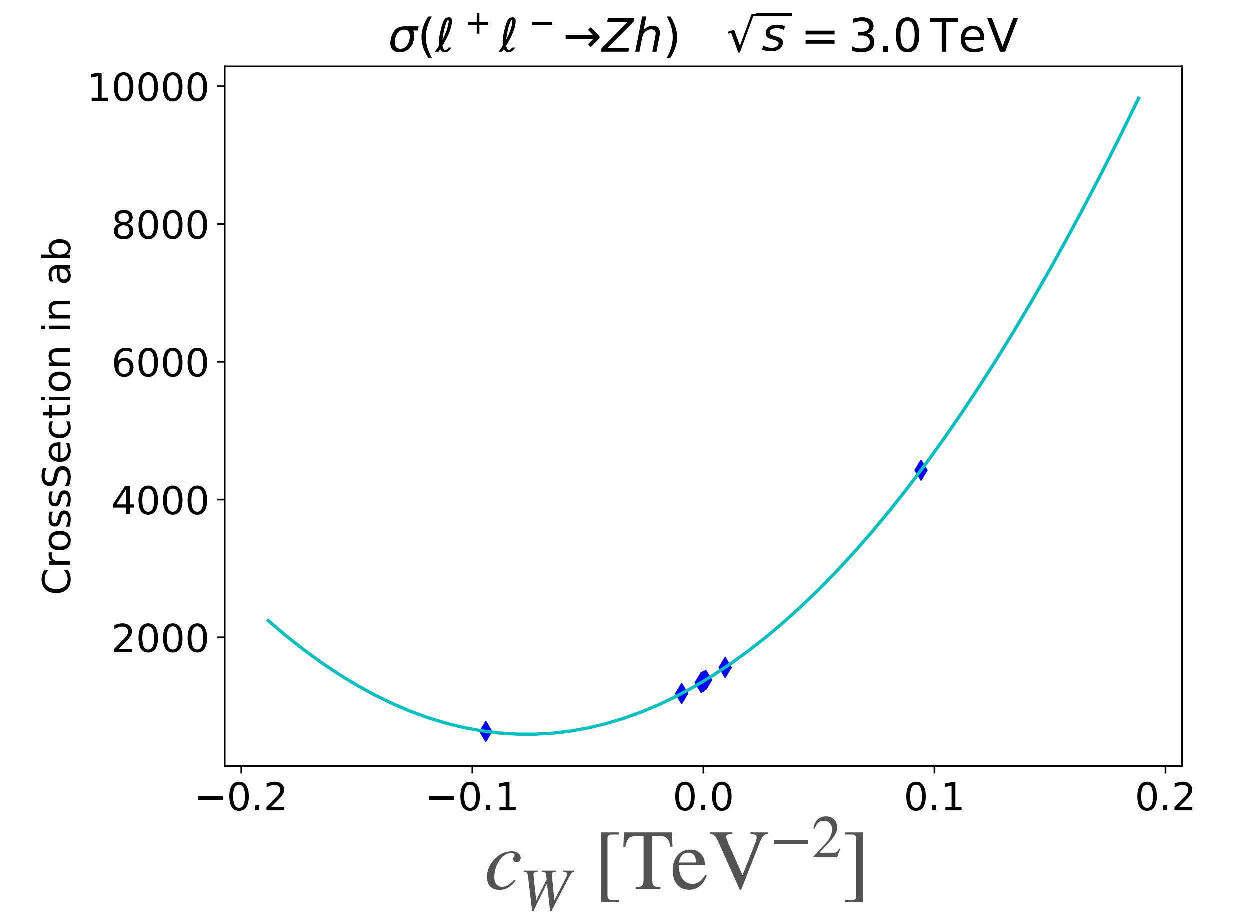
$$c_W = \hat{S}/m_W^2$$

$$c_W \lesssim 0.02\,\mathrm{TeV}^{-2}\frac{1}{E_{beam}/\mathrm{TeV}}\cdot\frac{1}{\sqrt{\mathscr{L}/\mathrm{ab}^{-1}}}$$

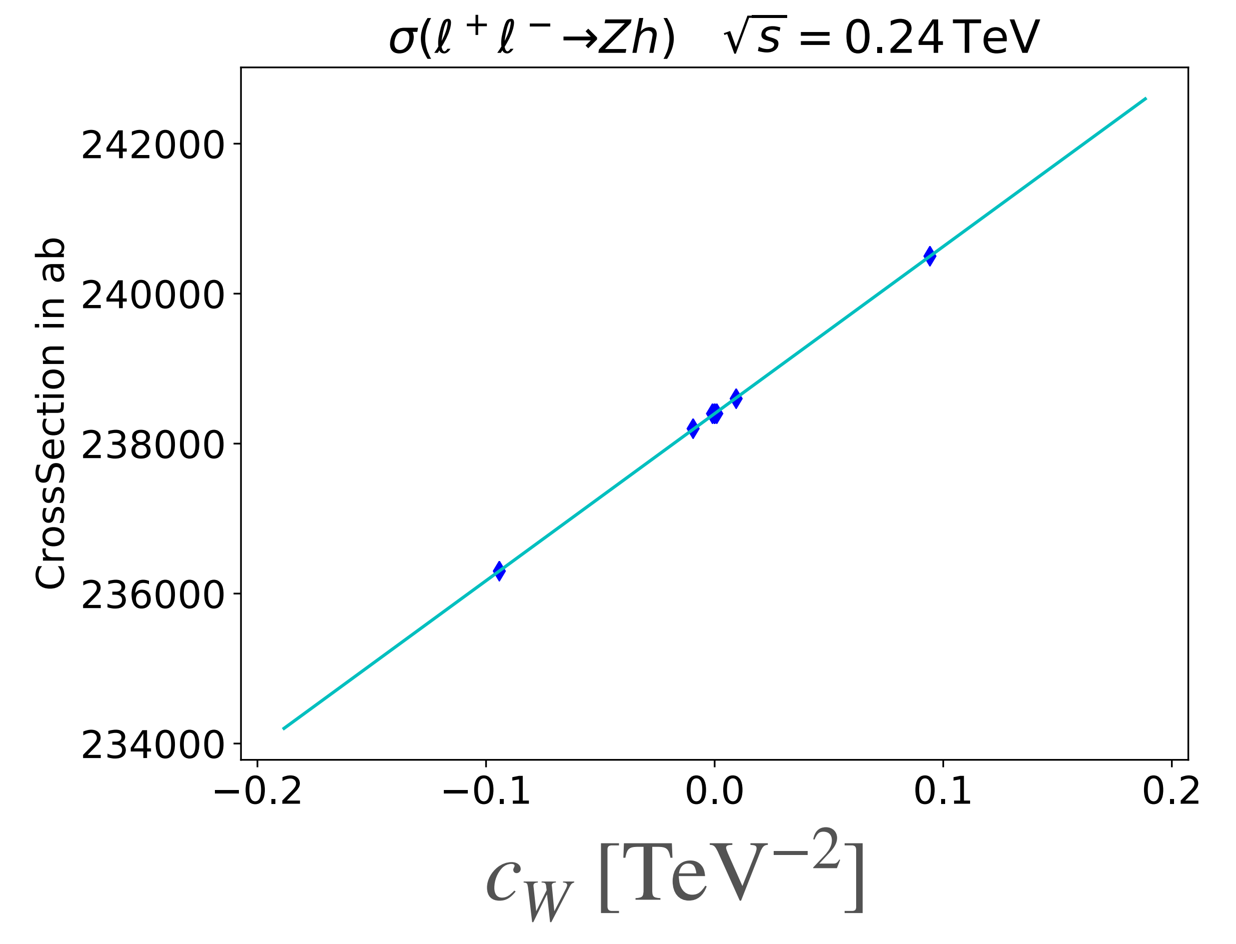
$$\hat{S}_{95\%} \lesssim 1.2\cdot 10^{-4}\frac{1}{E_{beam}/\mathrm{TeV}}\cdot\frac{1}{\sqrt{\mathscr{L}/\mathrm{ab}^{-1}}}$$



$\hat{S} < 3\cdot 10^{-5}$ (95 % CL) ⟵ $\mathscr{L} = 5\,\mathrm{ab}^{-1}$



$\hat{S} < 2\cdot 10^{-4}$ (95 % CL) ⟵ $\mathscr{L} = 5\,\mathrm{ab}^{-1}$



$\ell^+\ell^- \to Zh$

Ever higher energy colliders can exploit "precise" measurements at the 10% level

TOTAL RATE $\left|A_{SM}^{(00)}\right|^2 + A_{SM}^{00} \cdot A_{BSM}^{00} + \dots$

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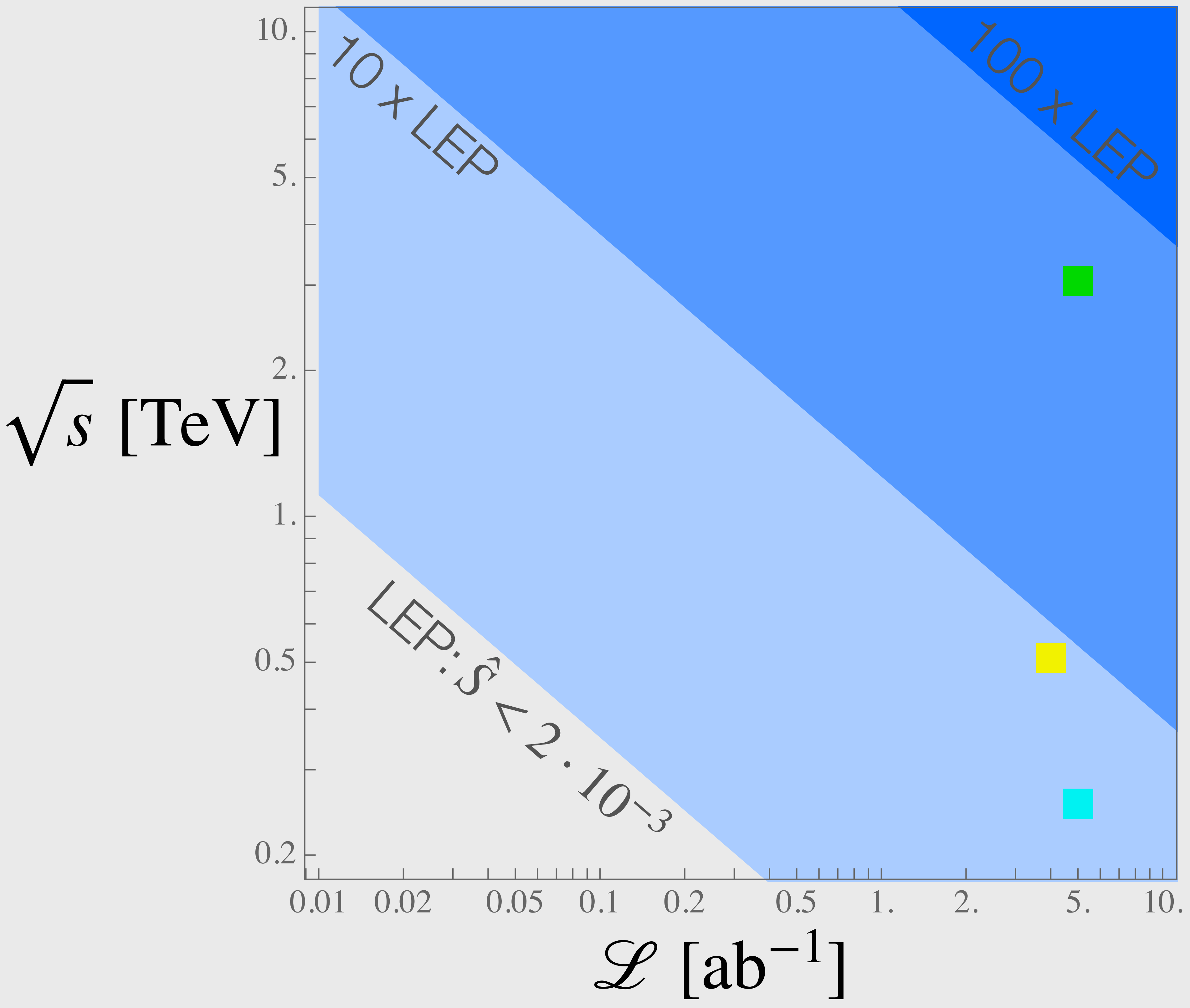

$$\hat{S} \equiv c_W / m_W^2 \simeq \frac{\delta O}{O} \text{ at Z pole}$$

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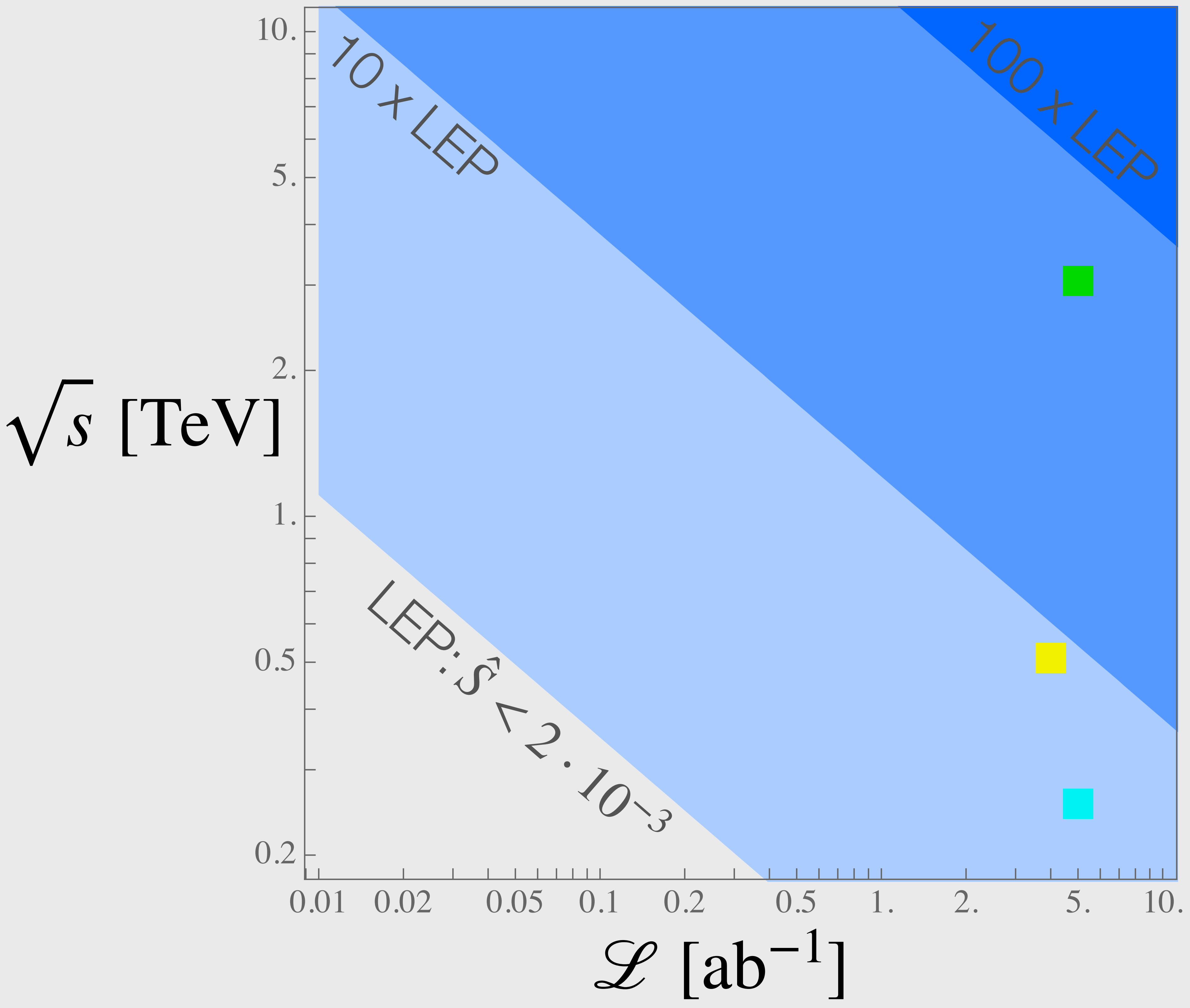
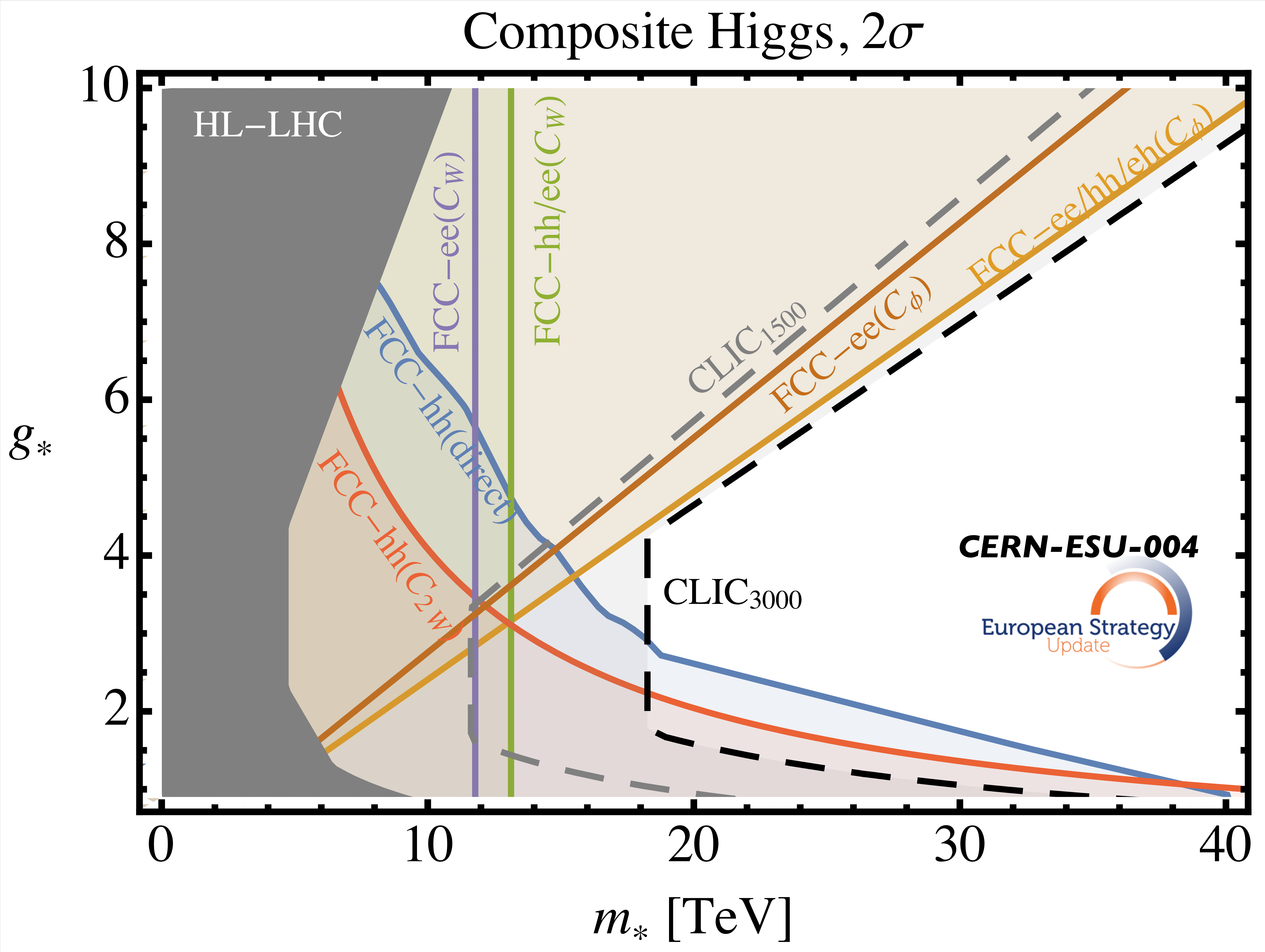
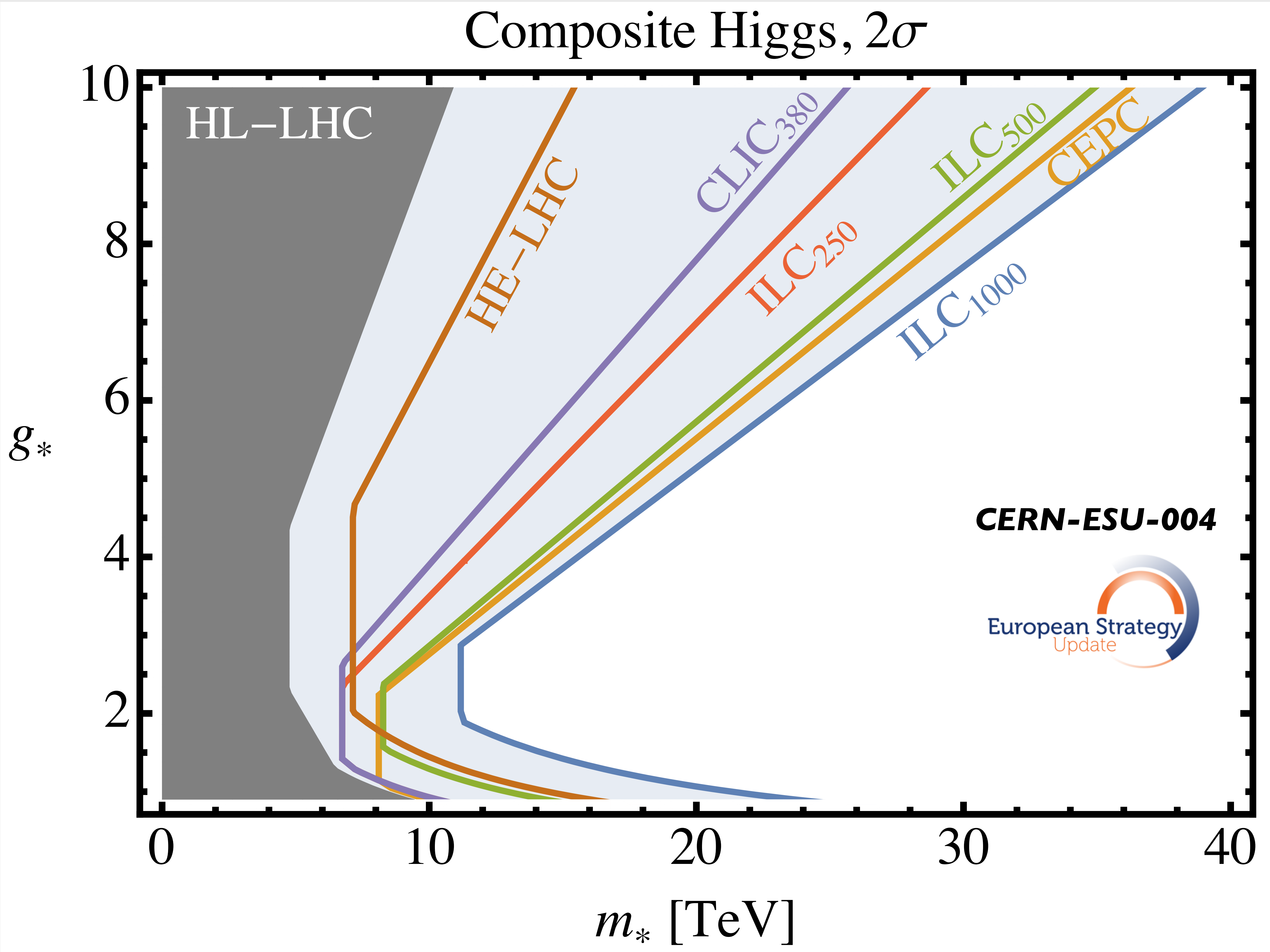


$$\hat{S} \equiv c_W / m_W^2 \simeq \frac{\delta O}{O} \text{ at Z pole}$$

GOING TO HIGHER ENERGY WE CAN EXPLOIT "PRECISE" MEASUREMENTS AT THE 10% LEVEL, AVOIDING THE BOTTLENECK OF SYSTEMATIC UNCERTAINTIES


Composite Higgs, 2σ
HL−LHC
FCC−ee(C_W)
FCC−hh/ee(C_W)
CLIC1500
FCC−ee(C_ϕ)
FCC−ee/hh/eh(C_ϕ)
FCC−hh(direct)
FCC−hh(C_{2W})
CLIC3000
CERN-ESU-004
European Strategy Update
g_*
m_* [TeV]


Composite Higgs, 2σ
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HE−LHC
CLIC380
ILC250
ILC500
CEPC
ILC1000
CERN-ESU-004
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Looking ahead

$$\underbrace{\ell_{Higgs}}_{} \sim 1/m_{\star}$$

Looking ahead

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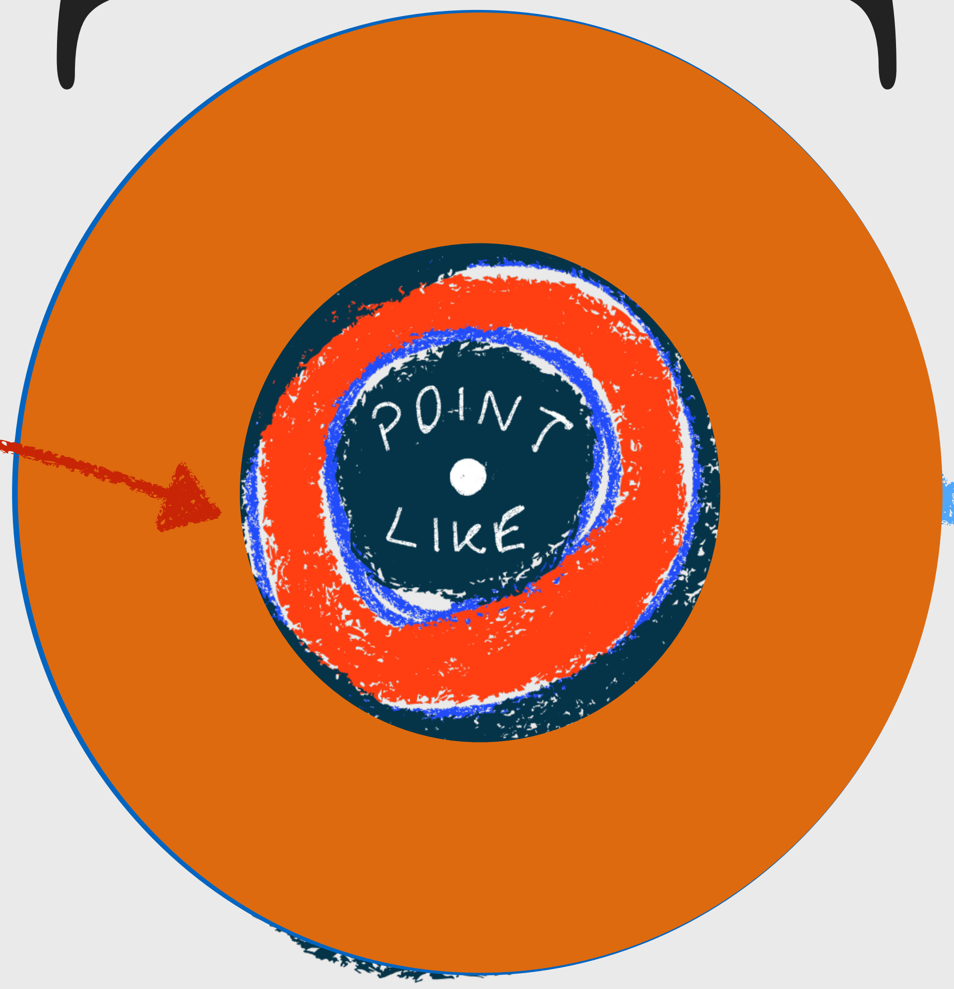
HIGH ENERGY LEPTON COLLIDER

ilc

Looking ahead

$$\ell_{Higgs} \sim 1/m_{\star}$$

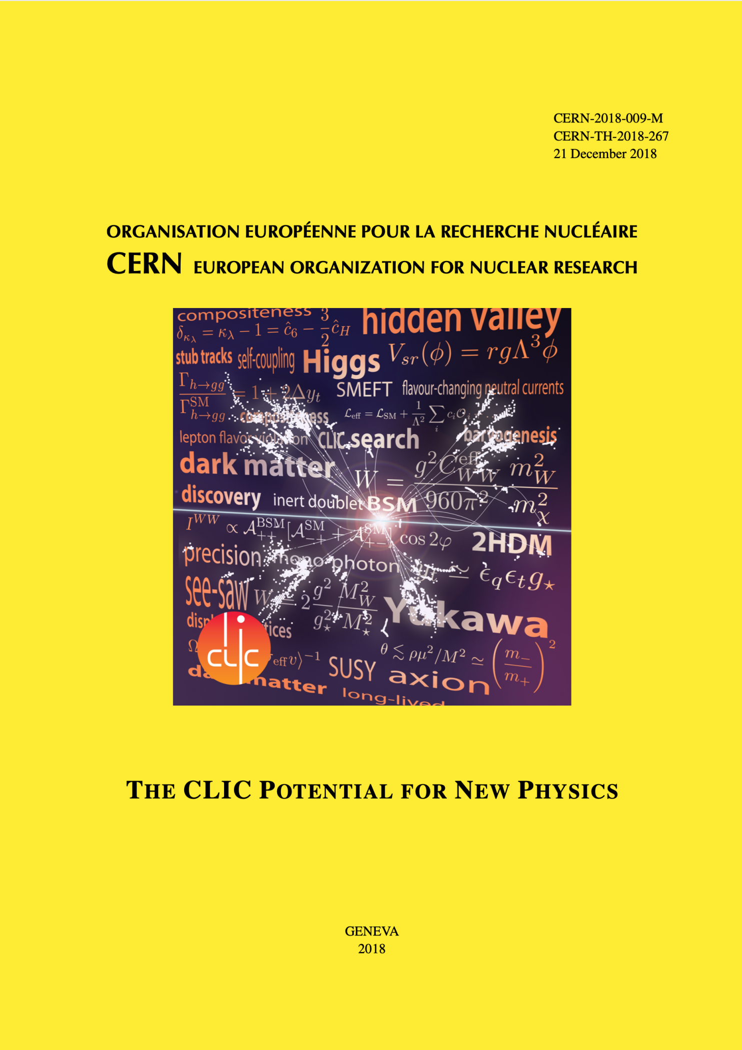
HIGHEST ENERGY LEPTON COLLIDER



HIGH ENERGY LEPTON COLLIDER

Direct

Lots of new studies!

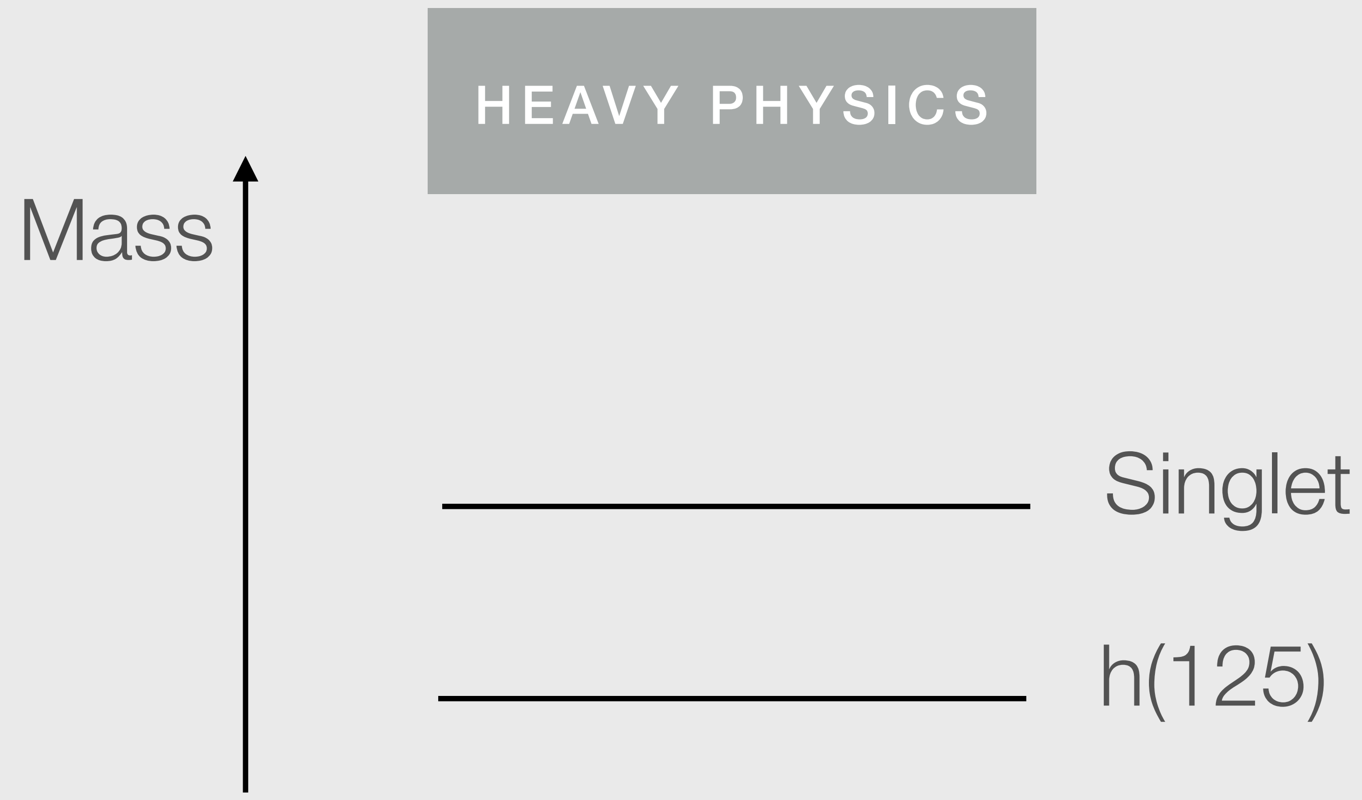


Contents

http://clicdp.web.cern.ch/content/wg-physics-potential

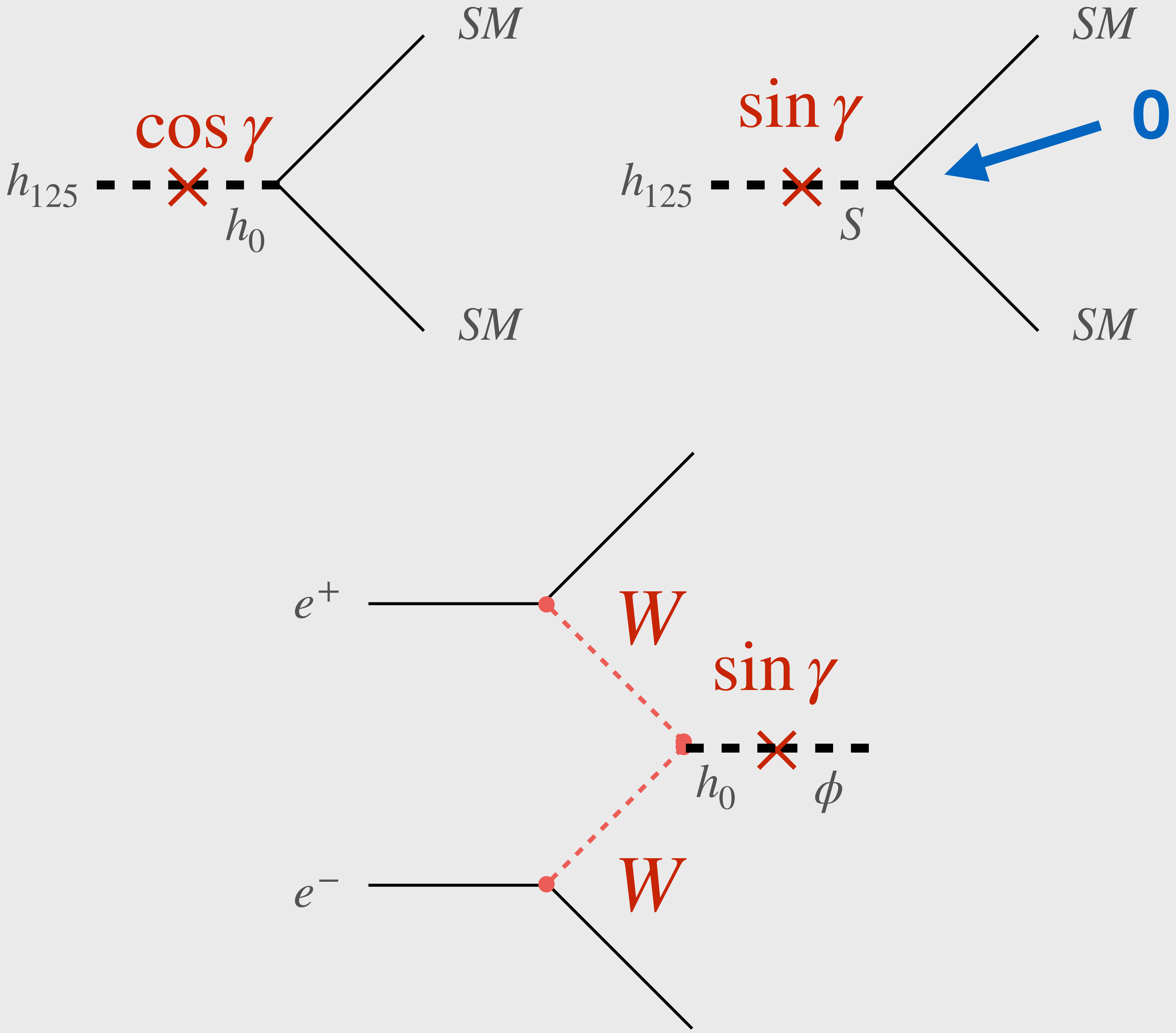
Reach on specific models

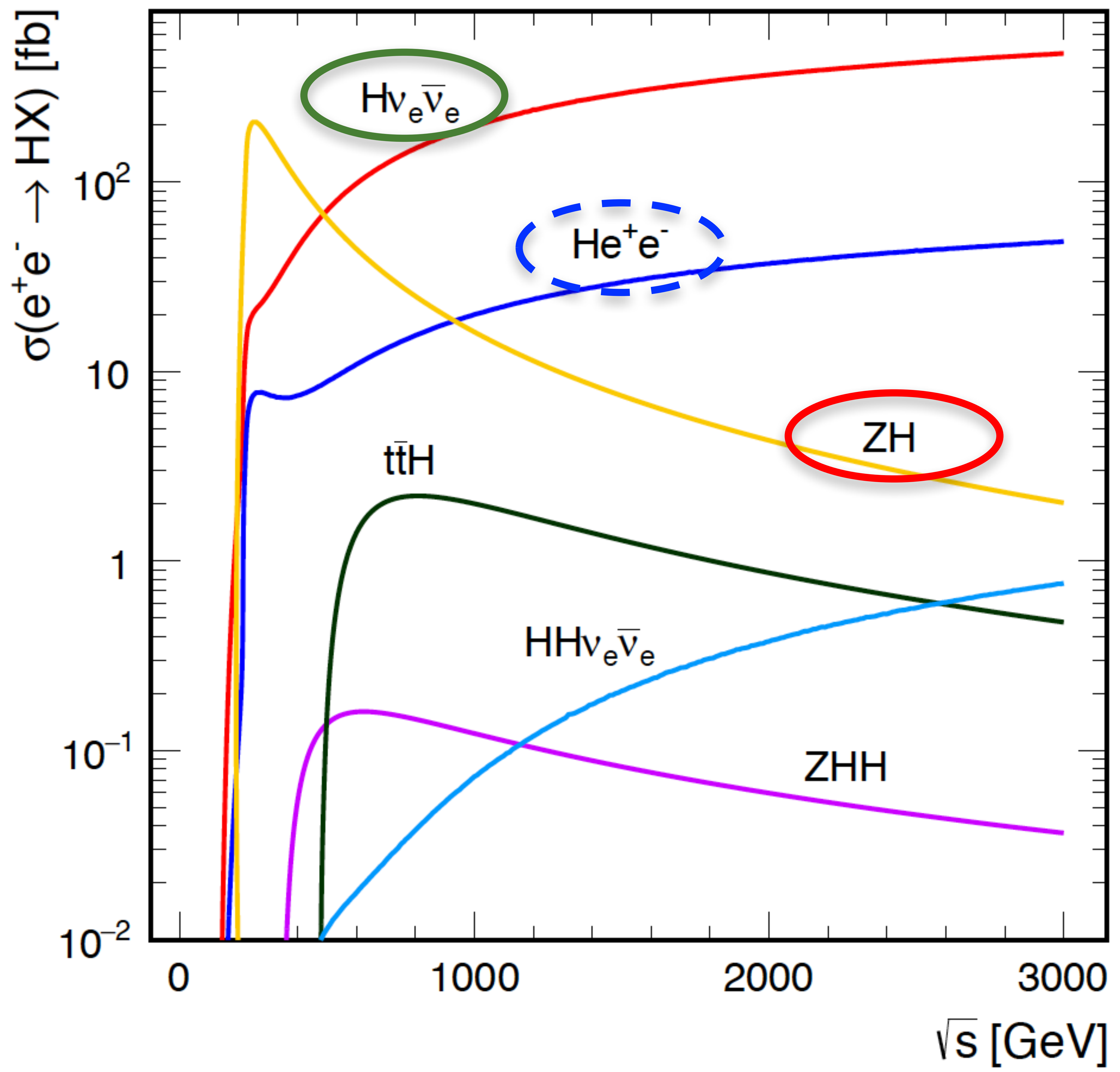
Higgs + Singlet



- Broad coverage of BSM scenarios: *(N)MSSM, Twin Higgs, Higgs portal, modified Higgs potential (Baryogenesis)*
- Phenomenology is also useful as “simplified model”

Higgs + Singlet





Qualitative new feature: W boson luminosity

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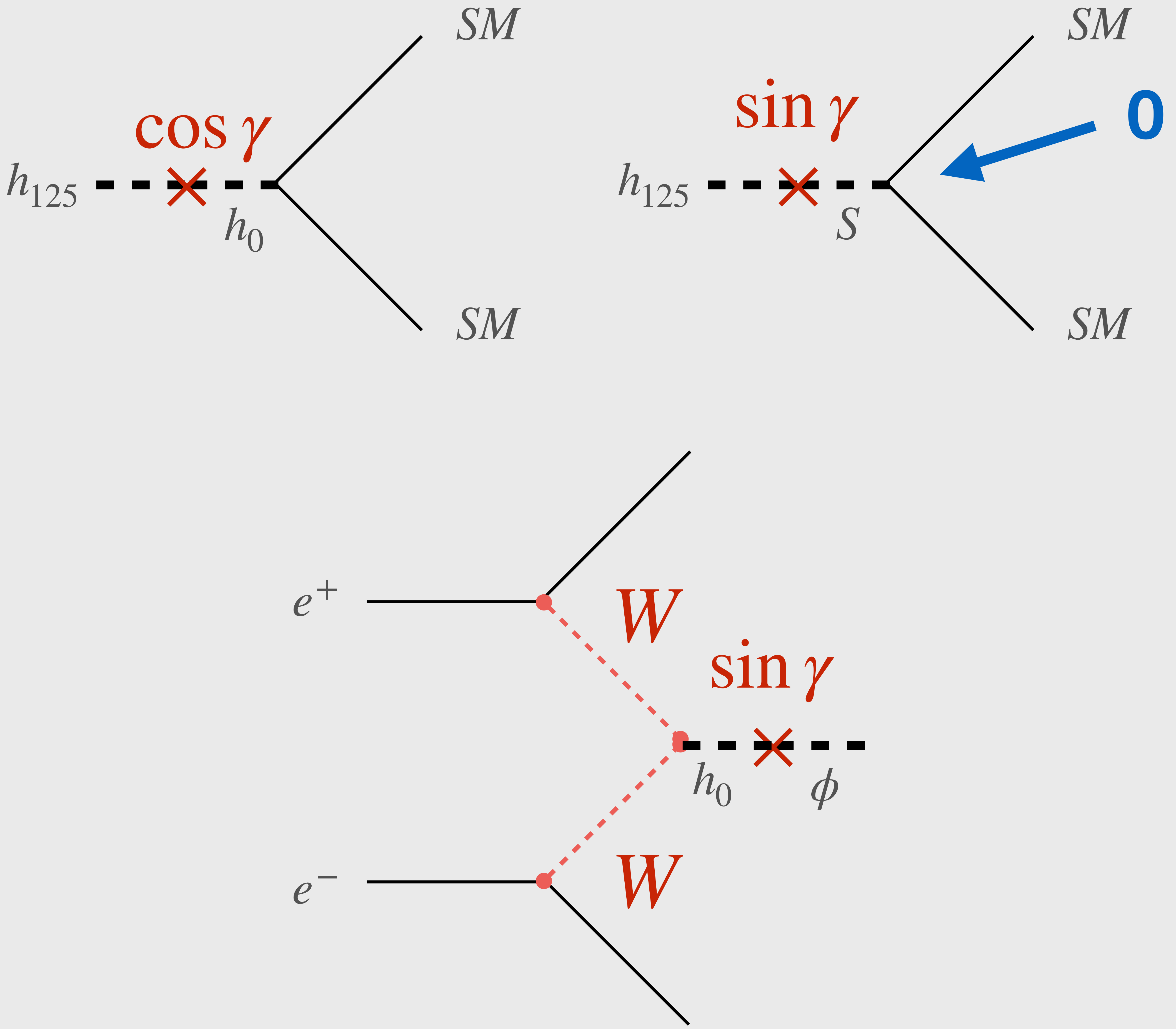
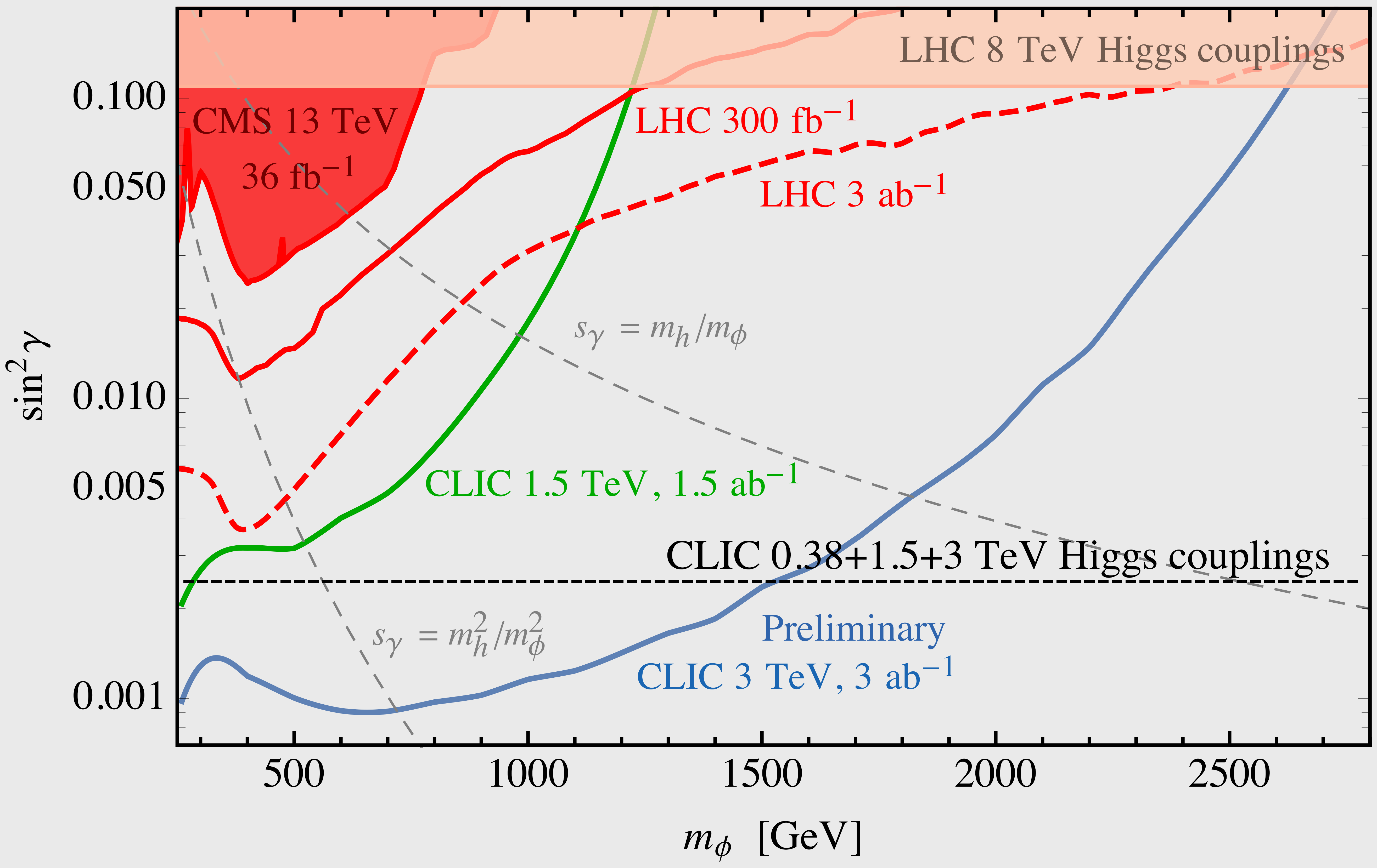
Higgs + Singlet



Interplay between direct S search and H coupling indirect sensitivity



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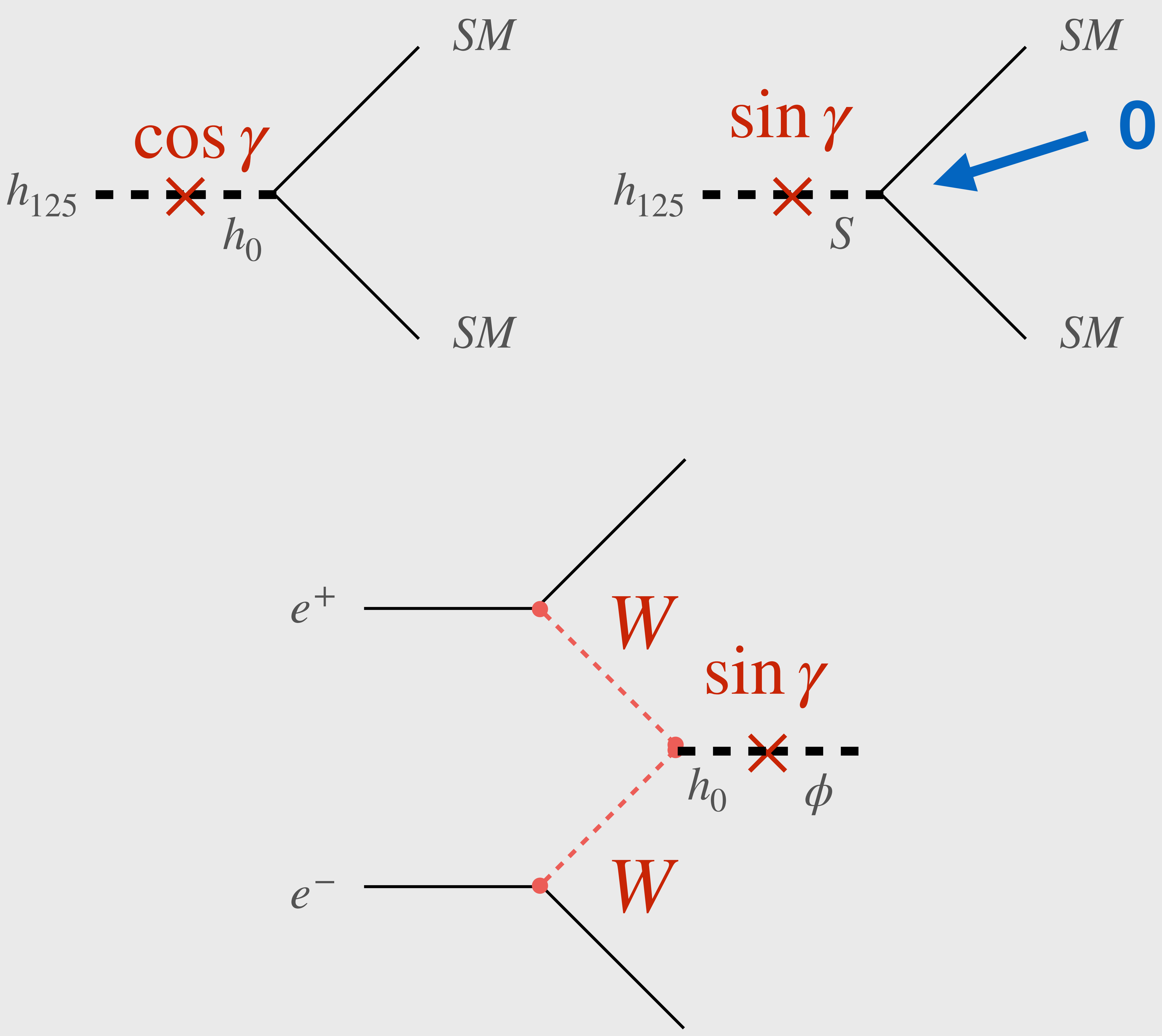

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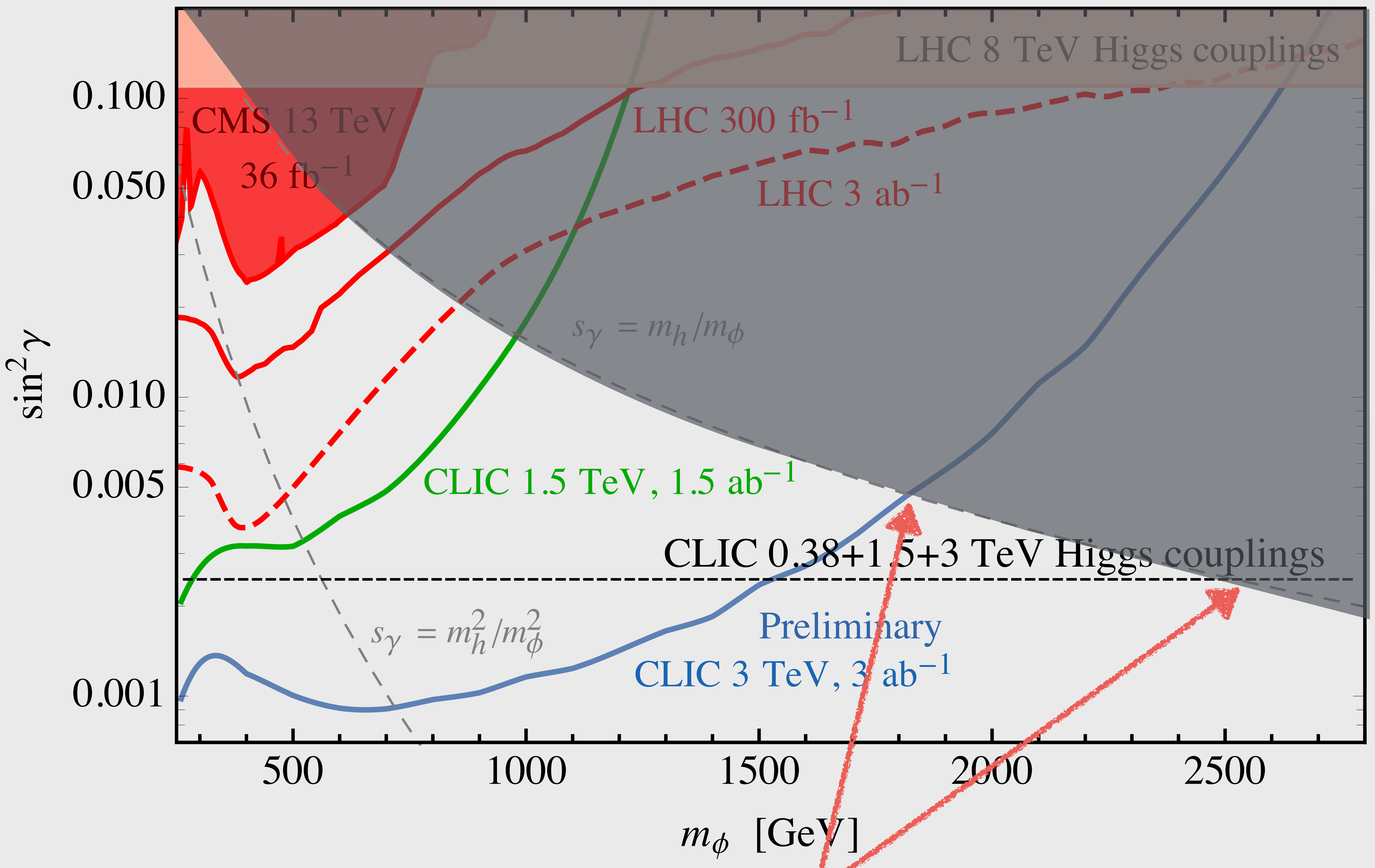
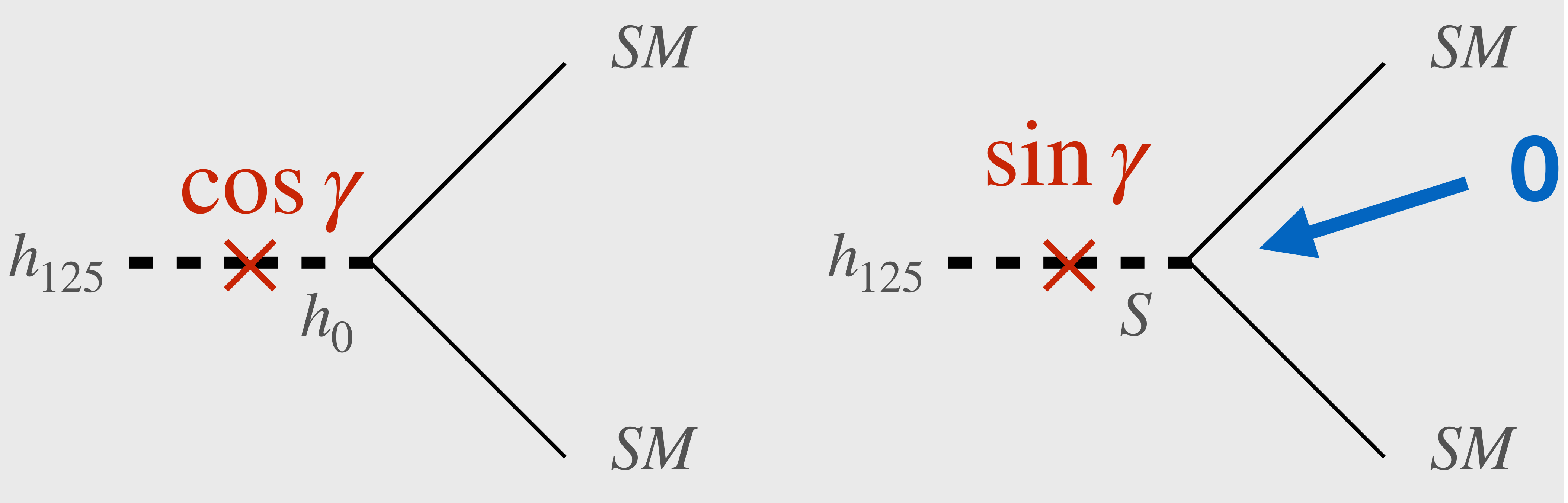
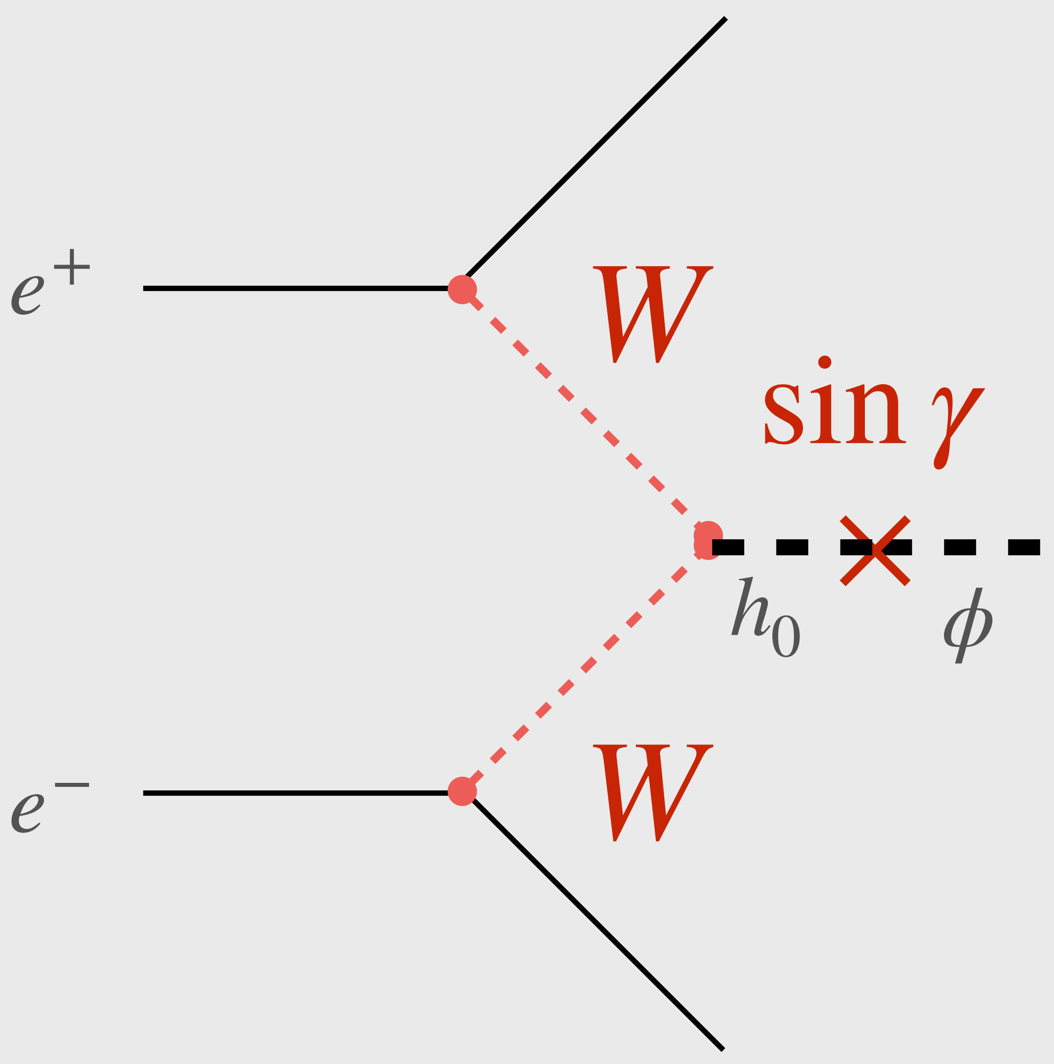


Test motivated values of the mixing beyond TeV singlet mass

Higgs + Singlet





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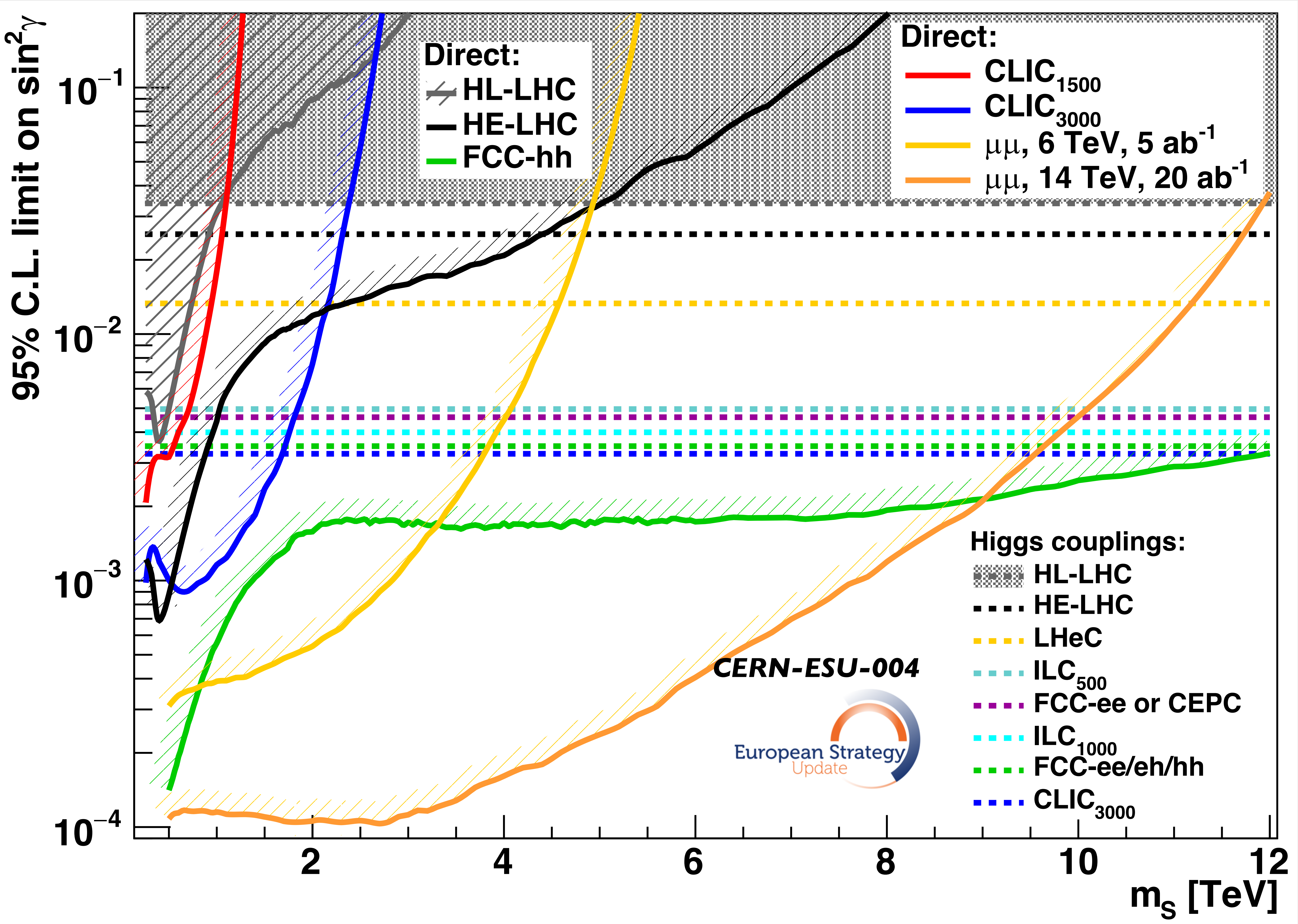

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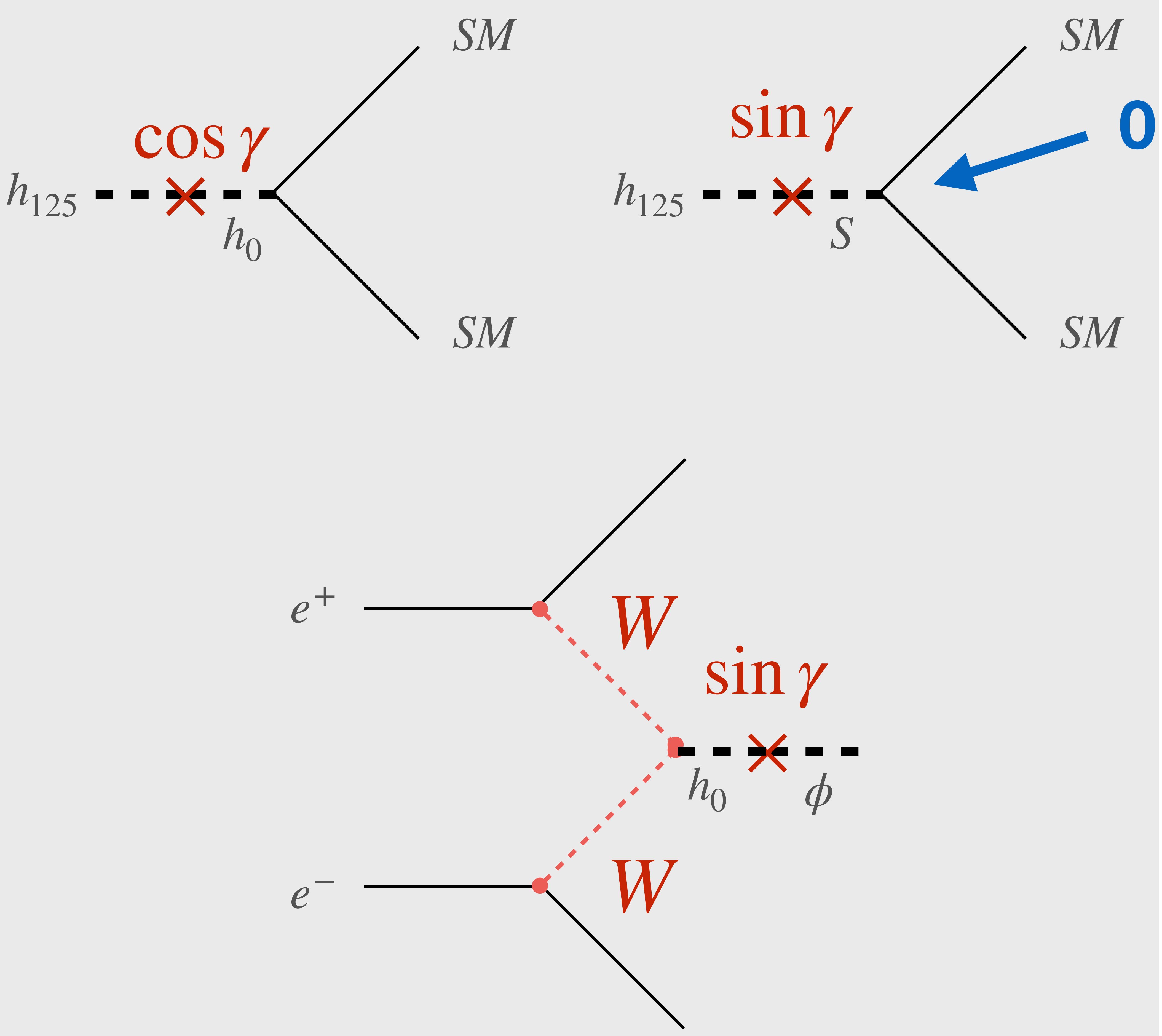

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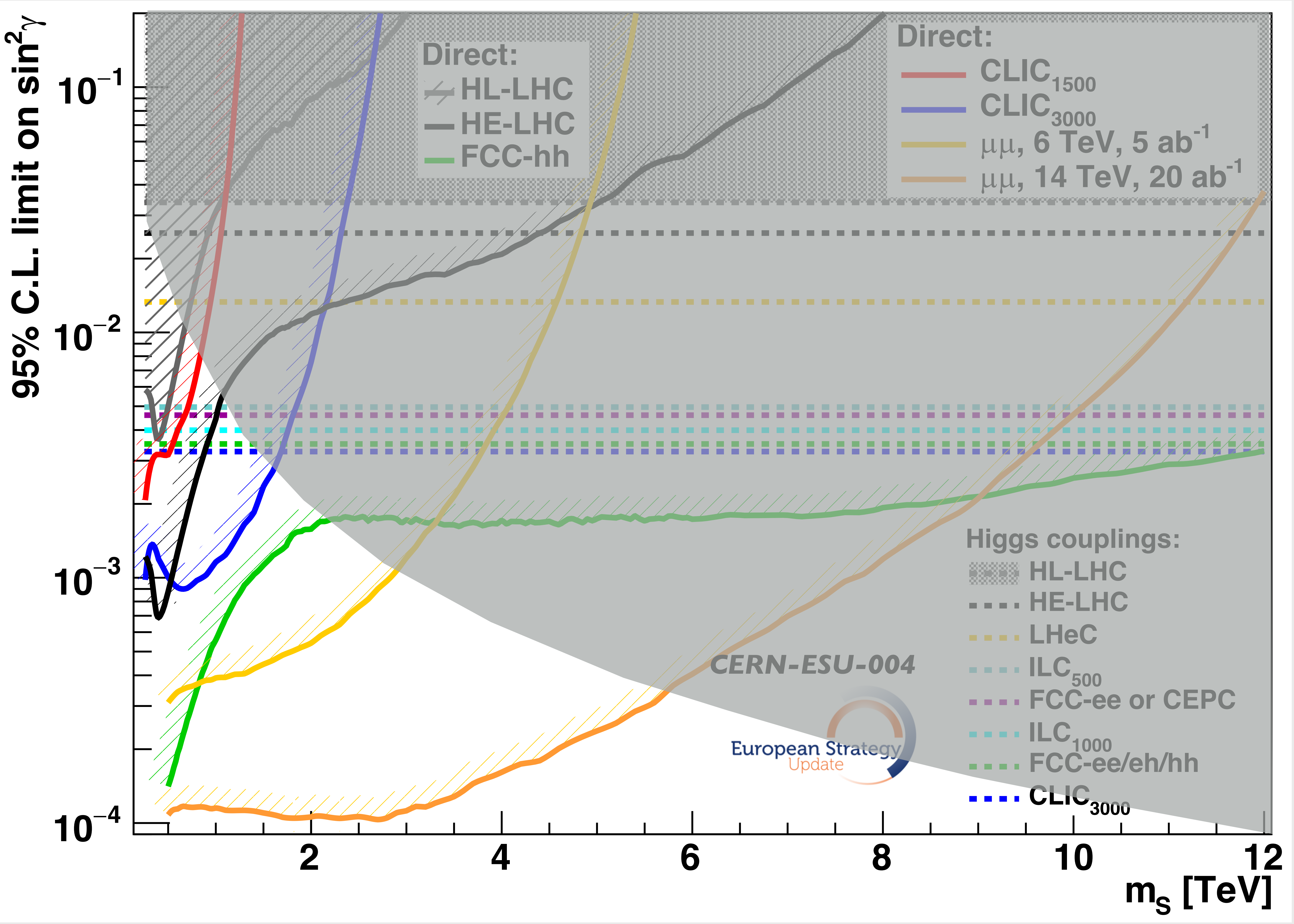

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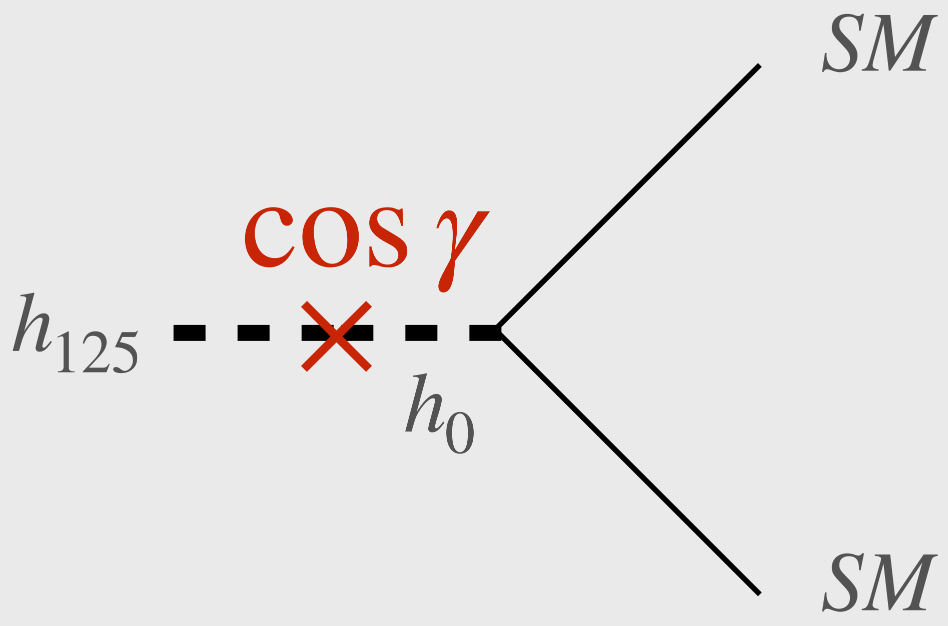
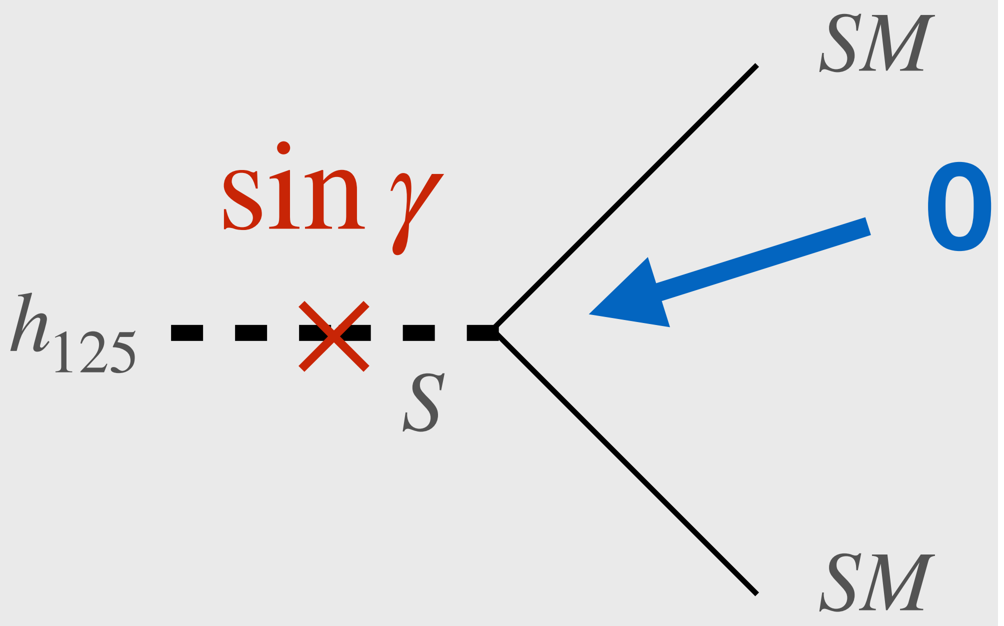
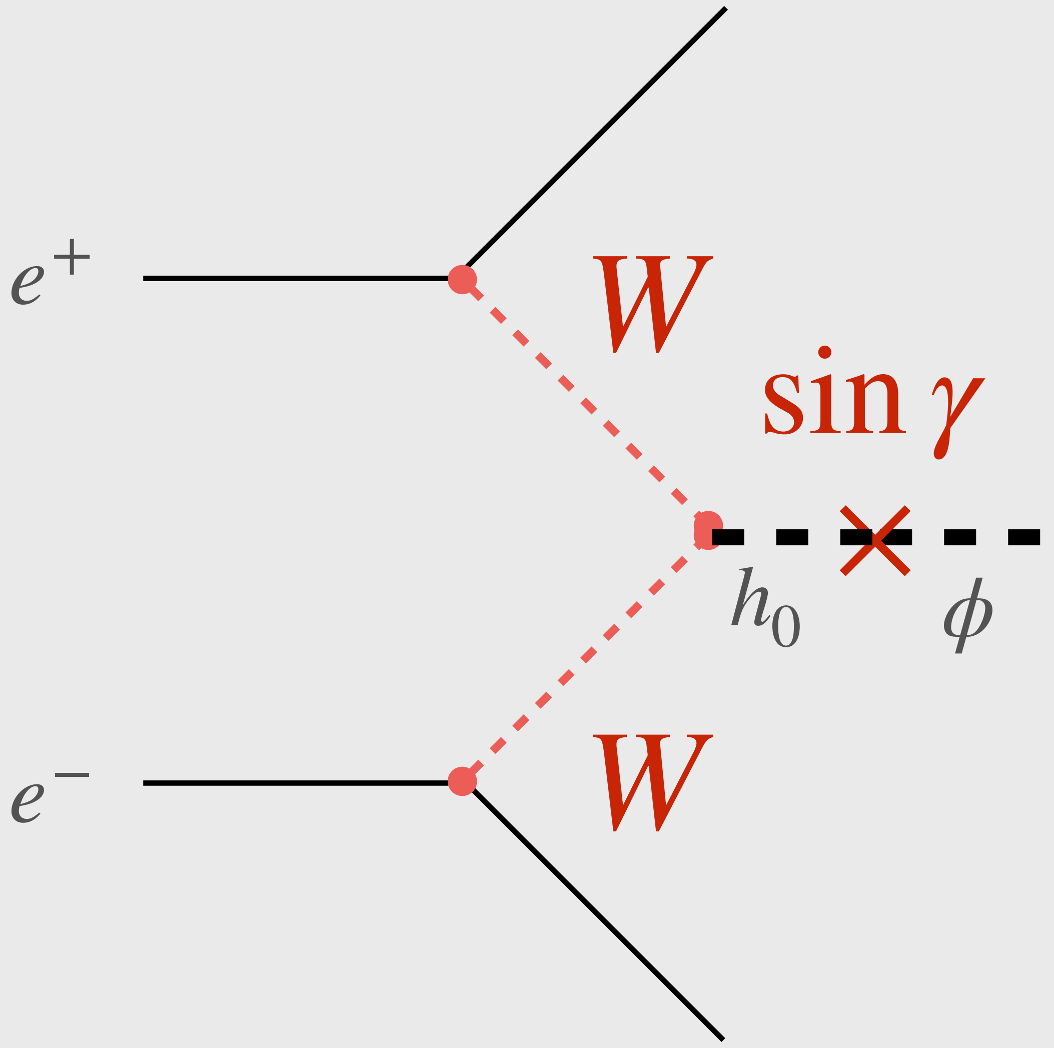
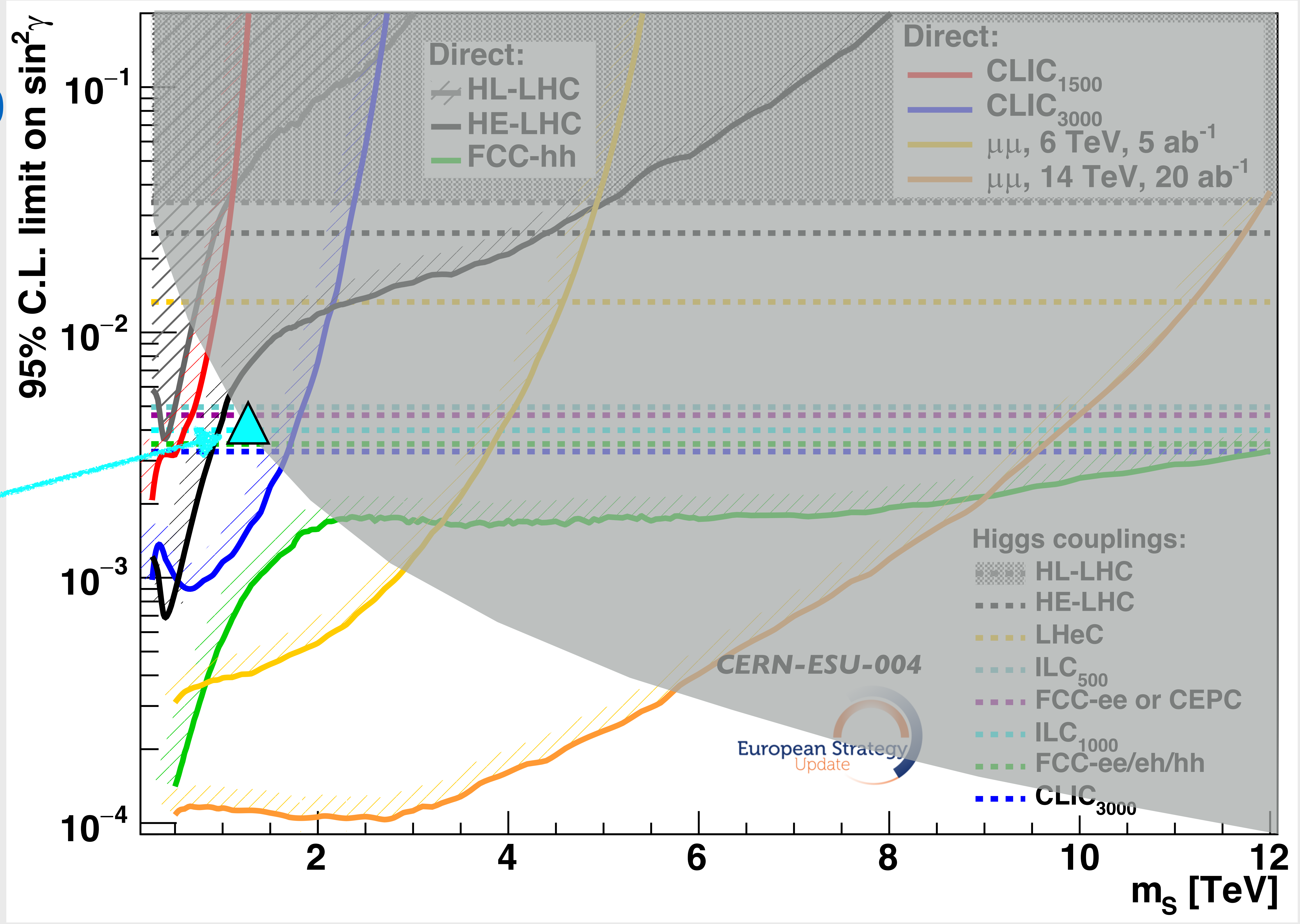






ILC

Interplay between direct S search and H coupling indirect sensitivity



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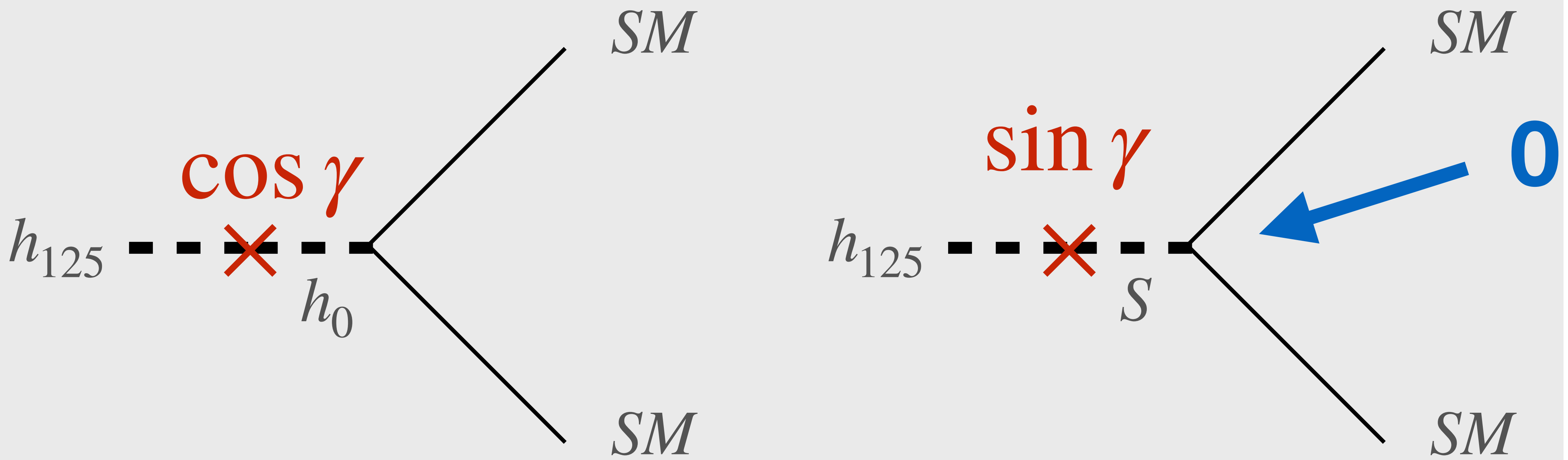

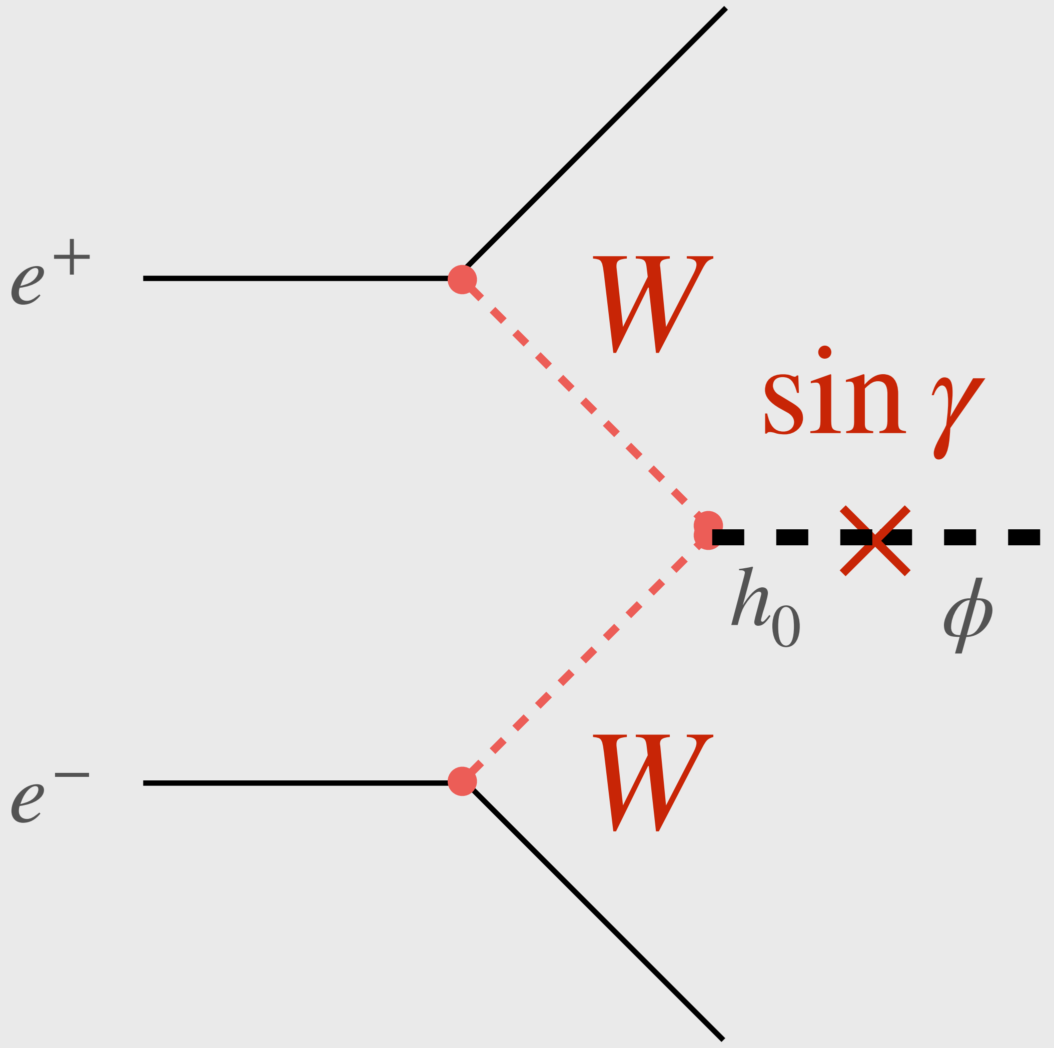

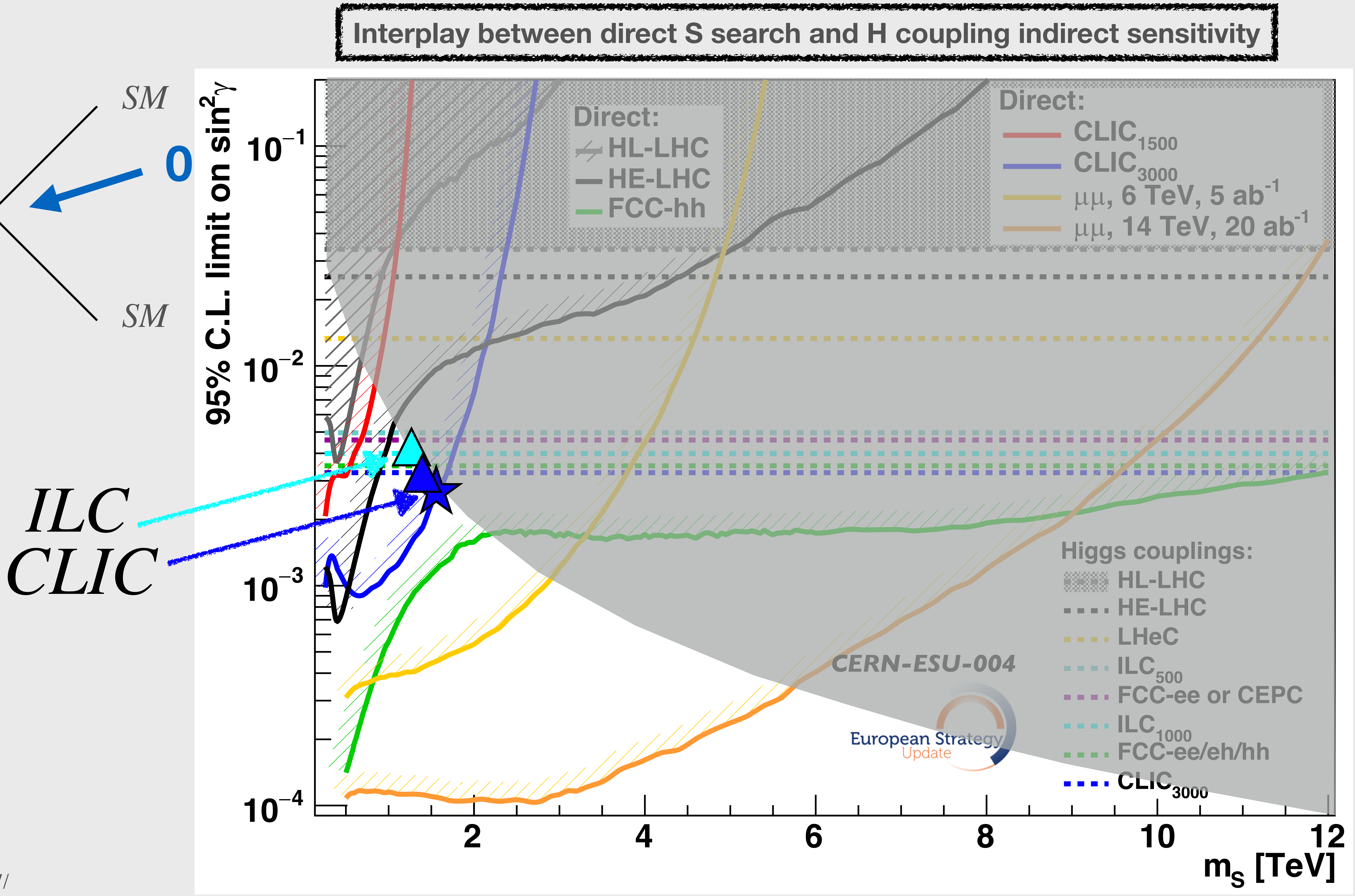

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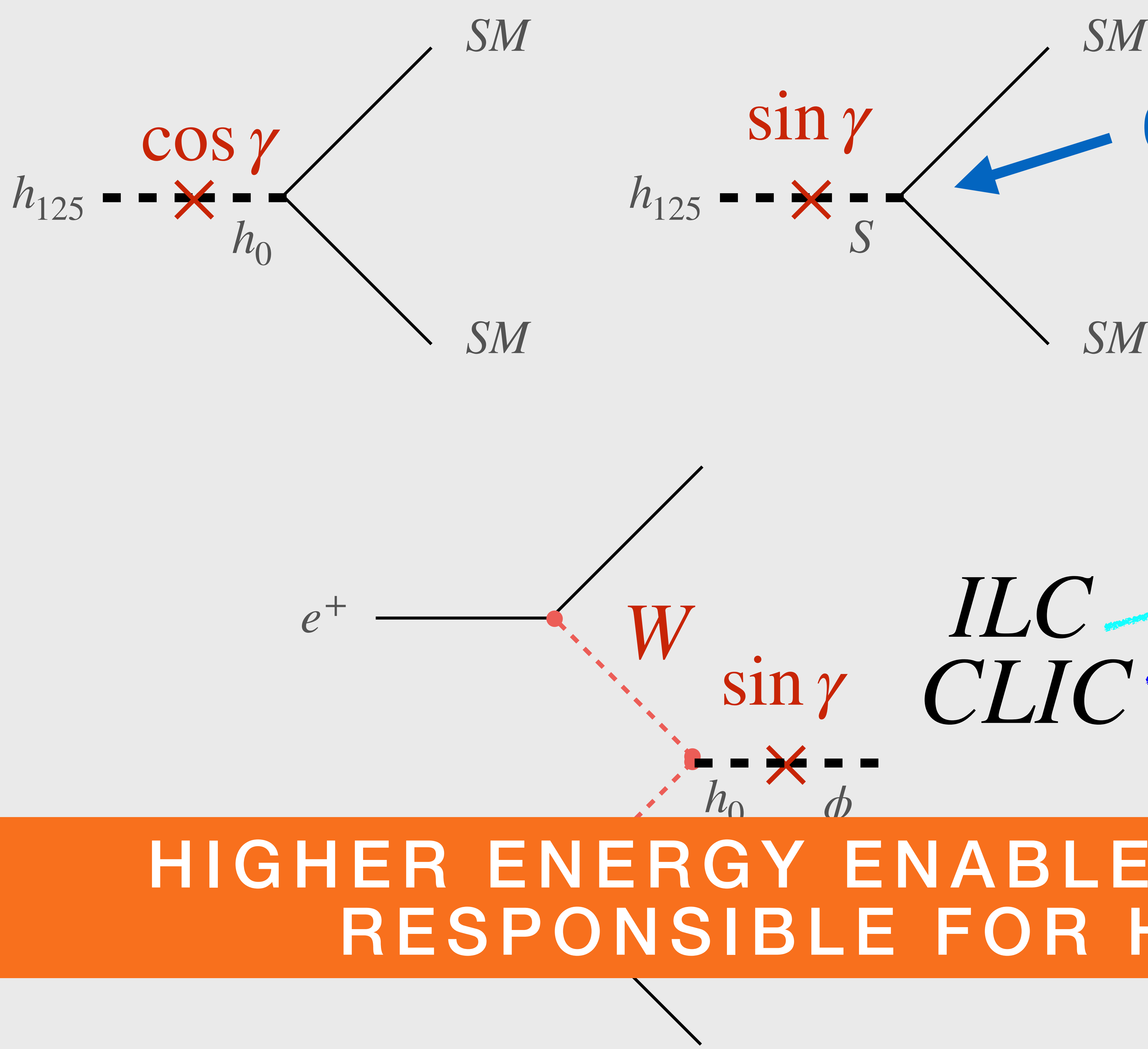

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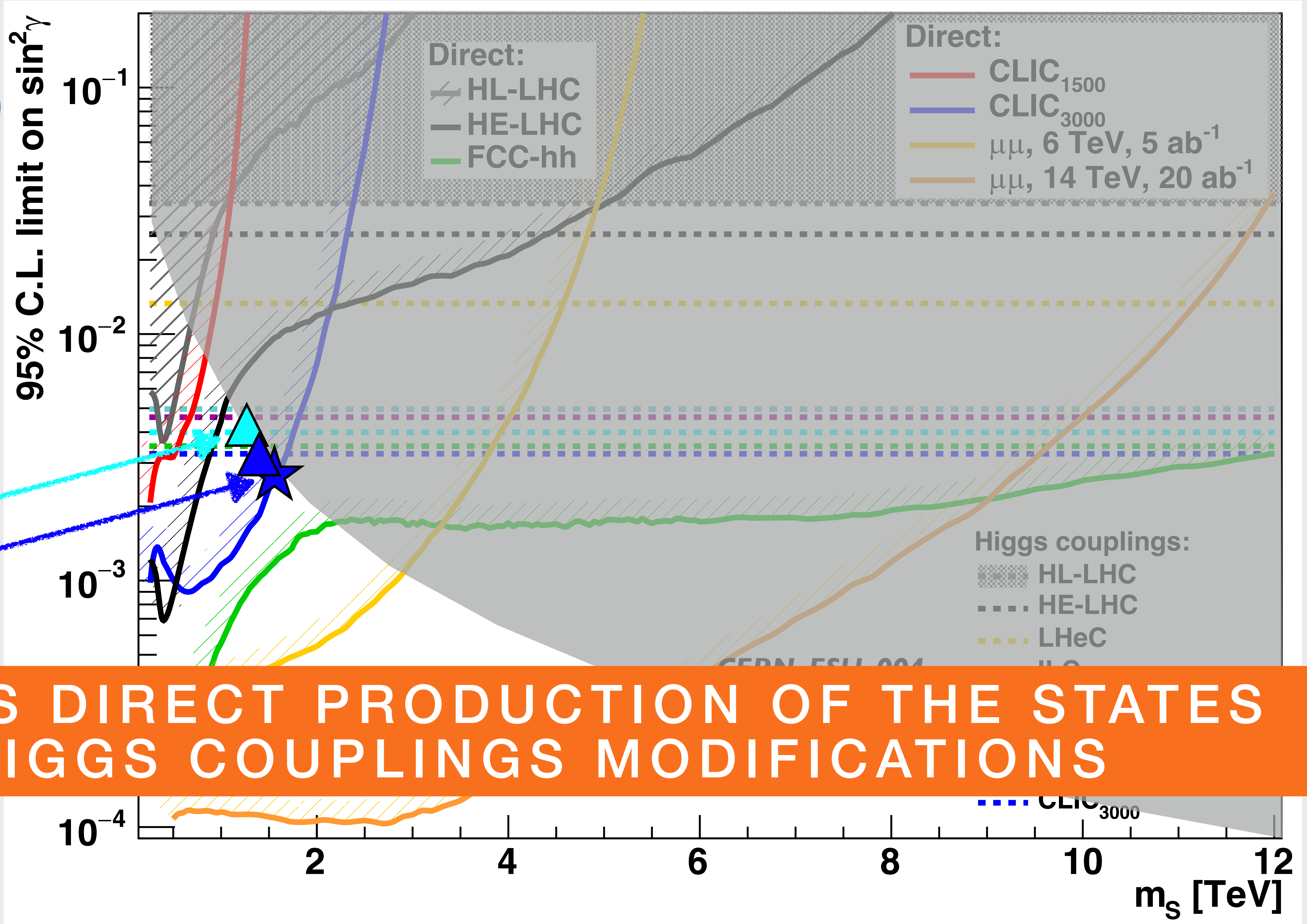
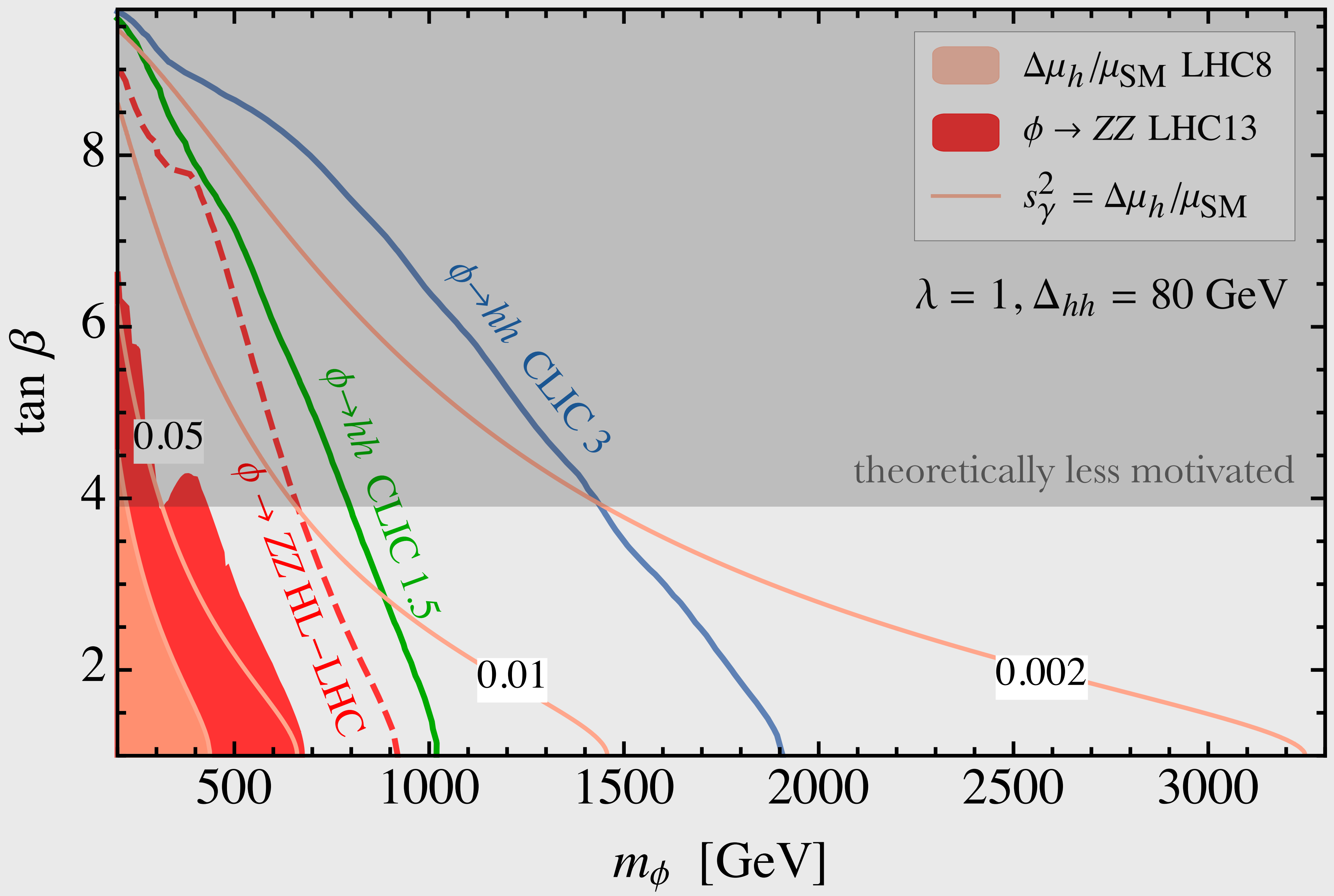


HIGHER ENERGY ENABLES DIRECT PRODUCTION OF THE STATES RESPONSIBLE FOR HIGGS COUPLINGS MODIFICATIONS

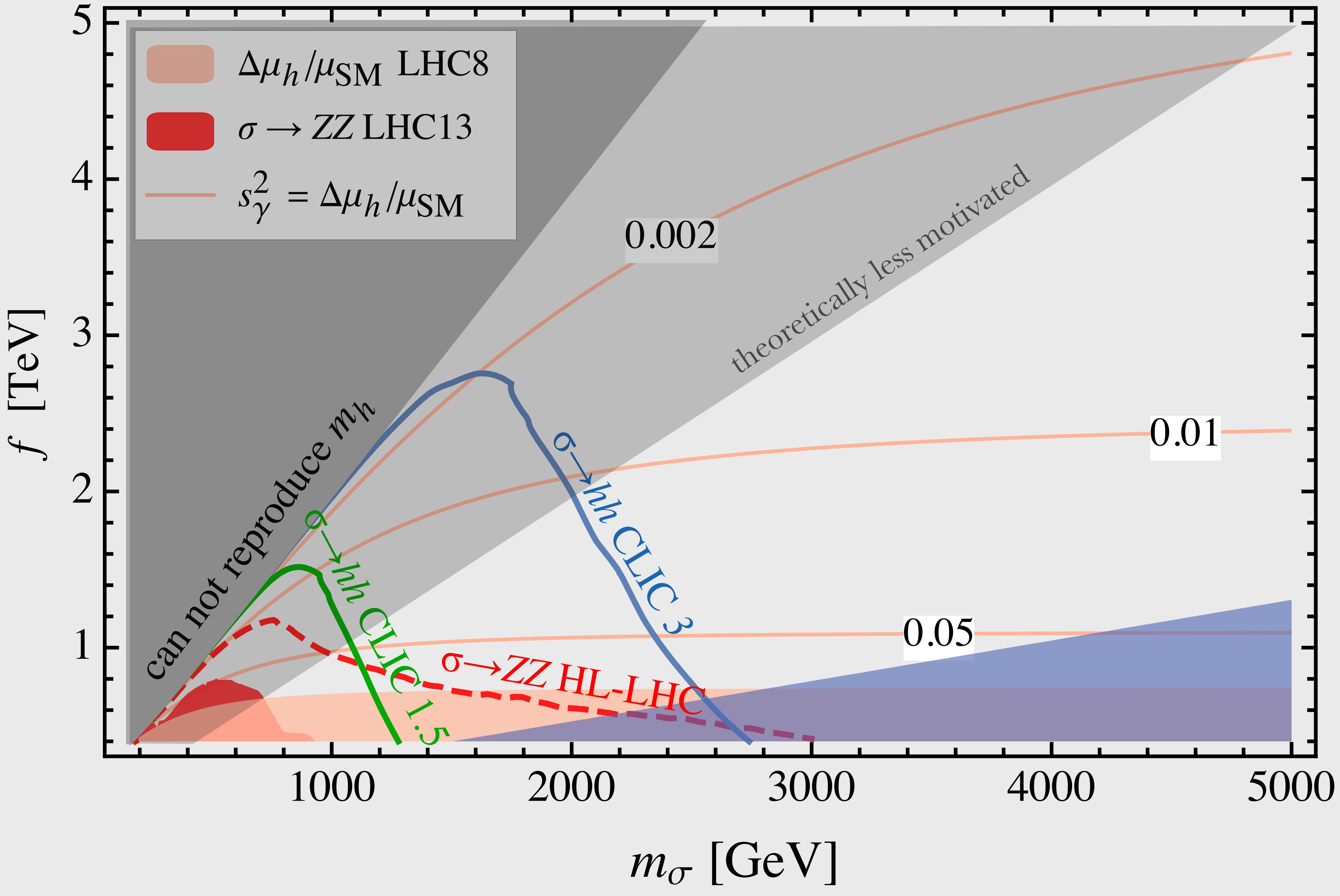
Higgs + Singlet

NMSSM



mϕ > 1.5 TeV for tanβ < 4 (most motivated range of the model)

TWIN HIGGS



mσ < 5 TeV can be excluded for mσ/f > 1 (most motivated range of the model)

Electroweak Dark Matter: LSP (+NLSP)

Δm

Wide open spectra		Generic leptons+missing momentum
Co-annihilation		Soft-objects + missing momentum
	GeV	
WIMP-like multiplet Accidental Dark Matter		Short (disappearing) tracks
DM SM singlet $e^+e^- \to Z' \to \chi\,\chi$	0	Mono-photon

Electroweak Precision Tests

Electroweak Dark Matter: LSP (+NLSP)

Δm

Wide open spectra		Generic leptons+missing momentum
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Electroweak Precision Tests

Roberto Franceschini LCWS19 https://agenda.linearcollider.org/event/8217/

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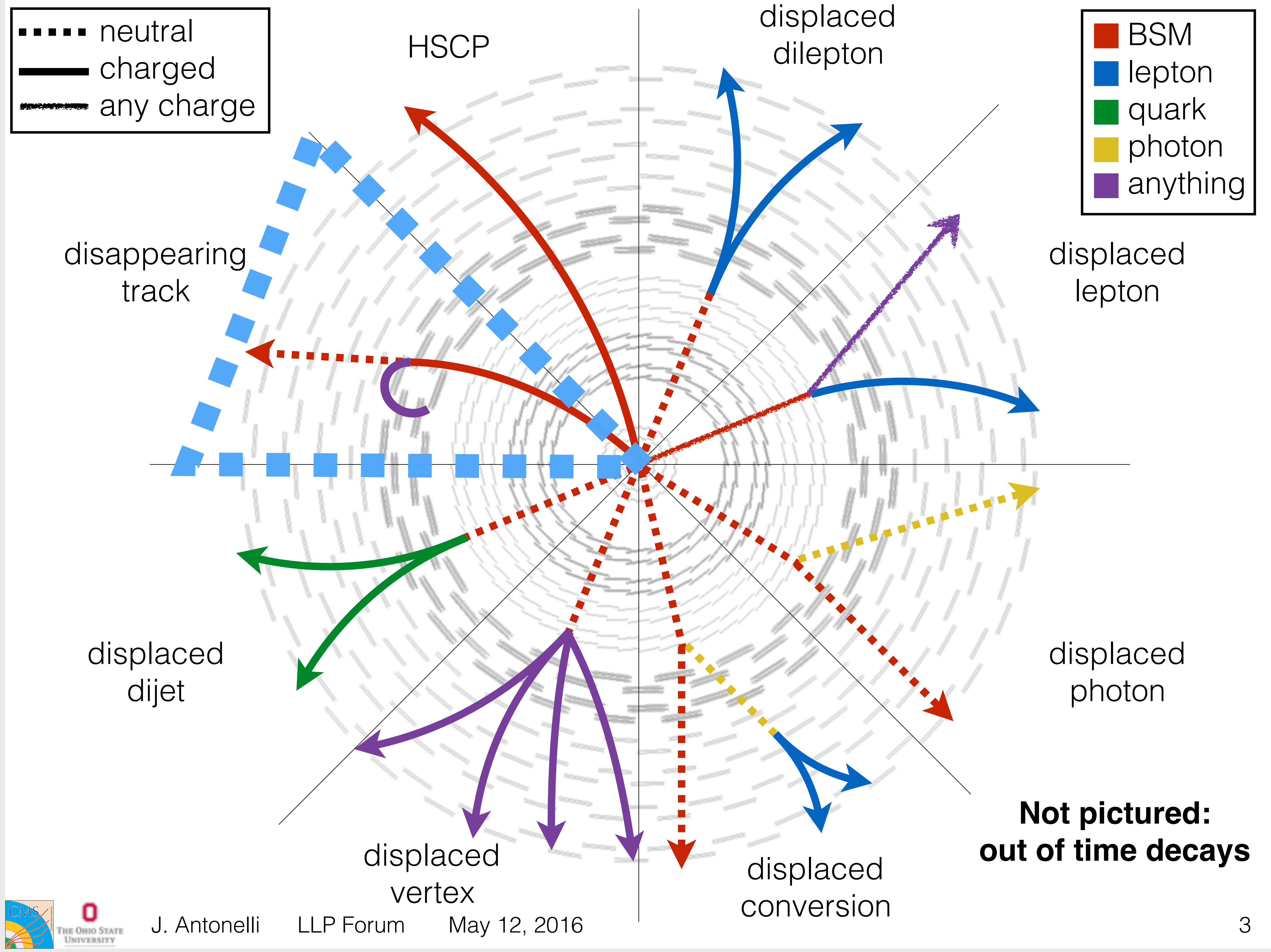
U. SCHNOOR WED. ~3PM

Electroweak Precision Tests

Short (disappearing) tracks

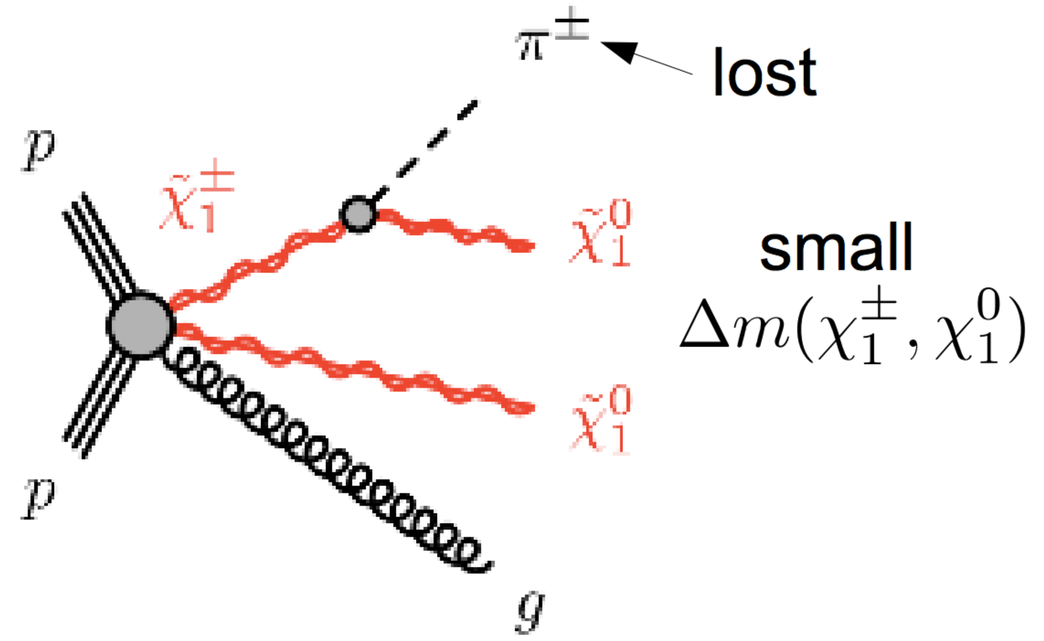
HIGGSINO DM

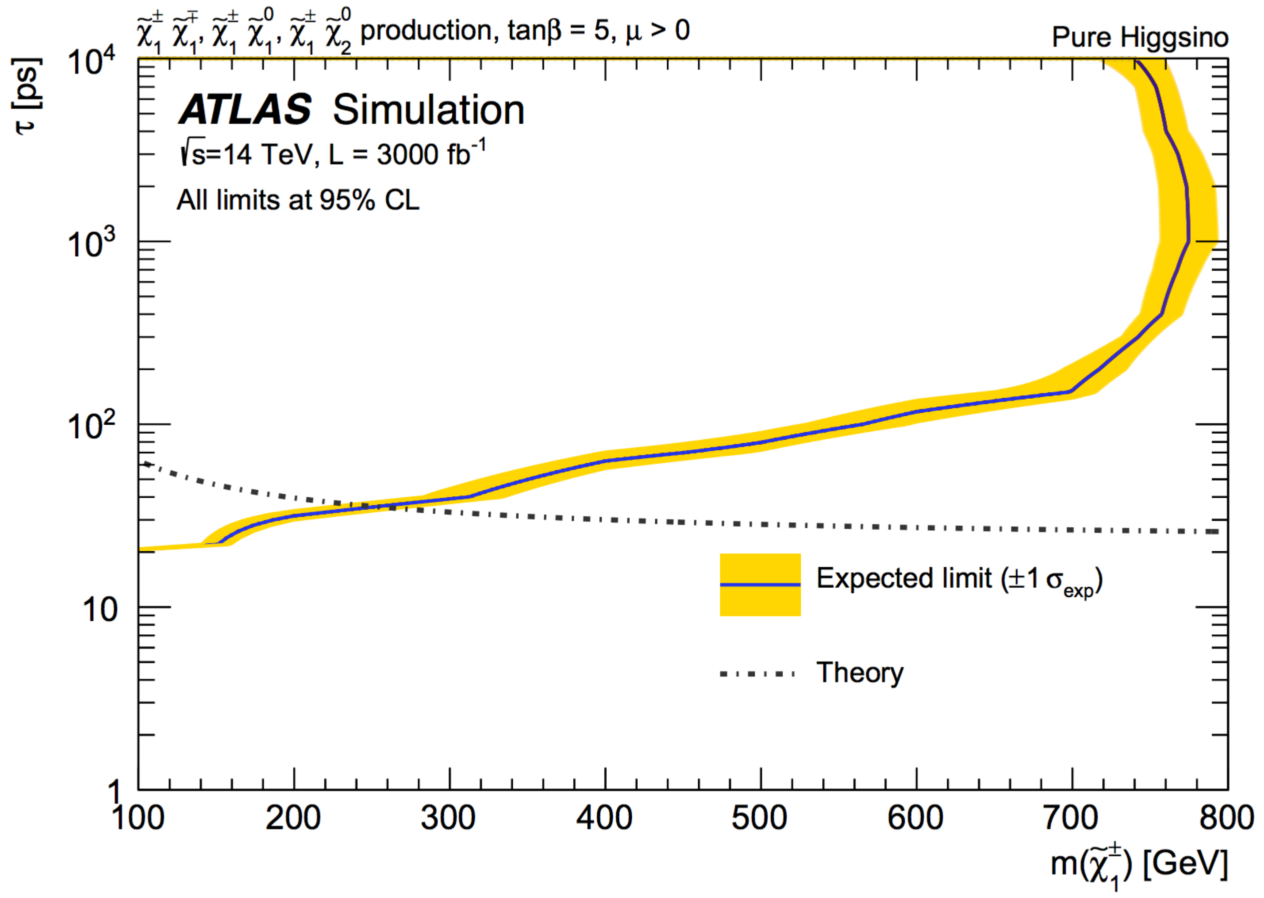
O(CM) DISAPPEARING TRACKS



Higgsinos with disappearing tracks

- Higgsino LSP → nearly degenerate χ^0 and $\chi^\pm$
- Results in track stub in detector
- Relies on accurate, multi-layer tracking to identify tracks that "disappear"
- Good reconstruction efficiency down to ~20 cm
- Main challenge measuring detector-induced fake track stubs
  - Further study will improve limits





https://cds.cern.ch/record/2285585/files/ATLAS-TDR-030.pdf

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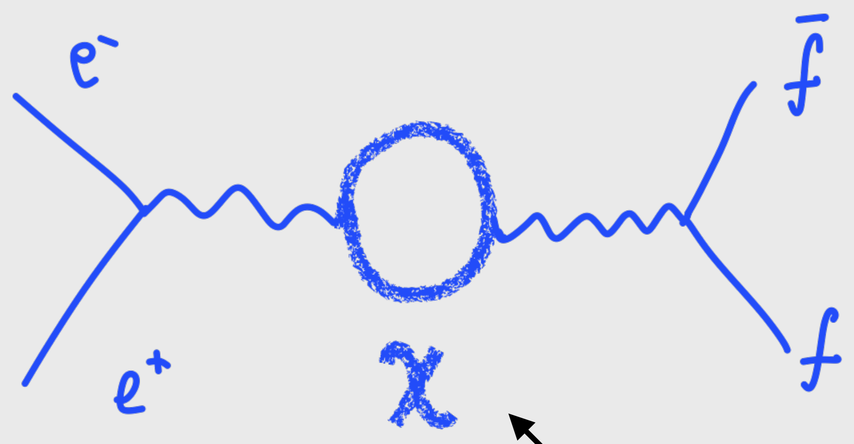
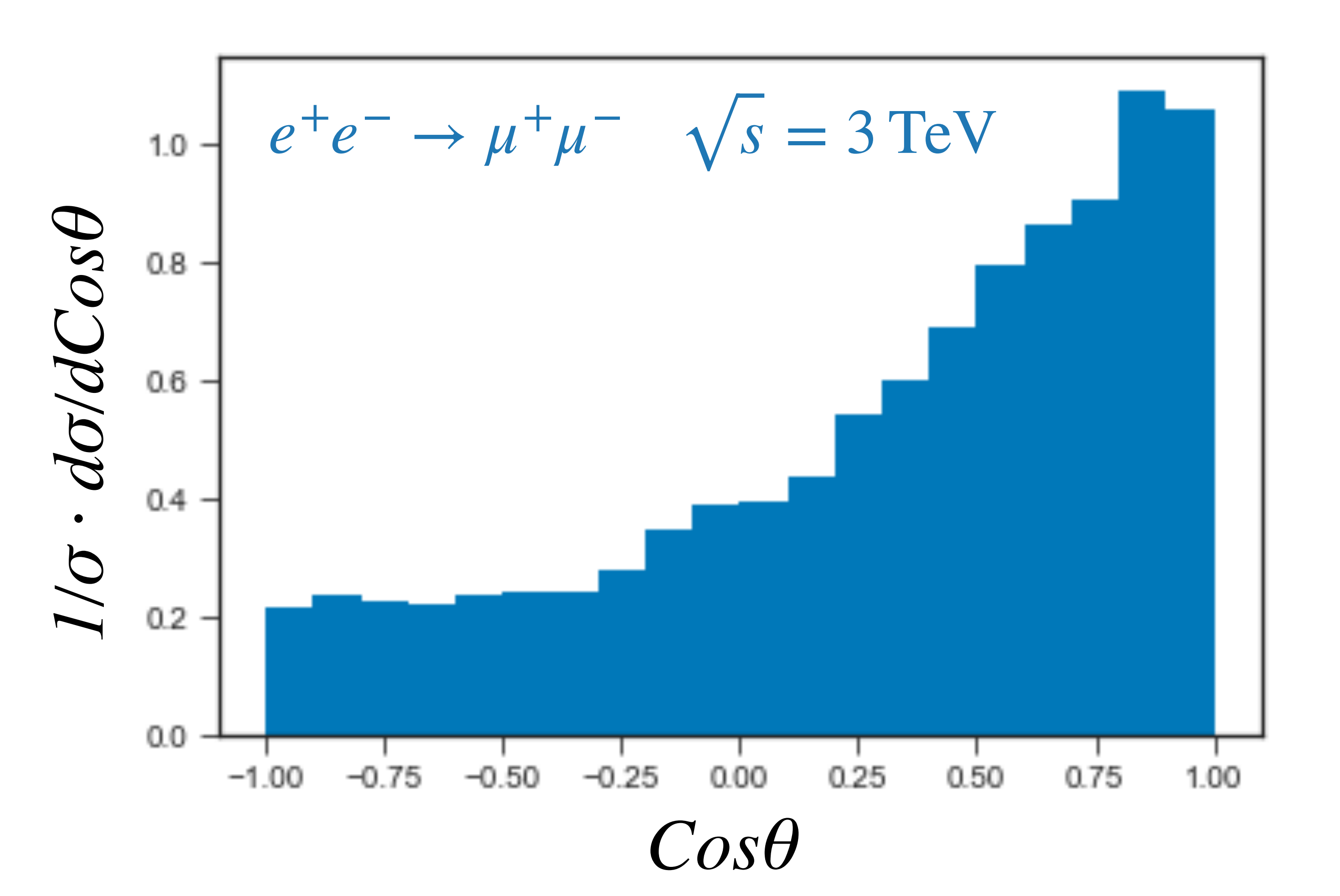
0		

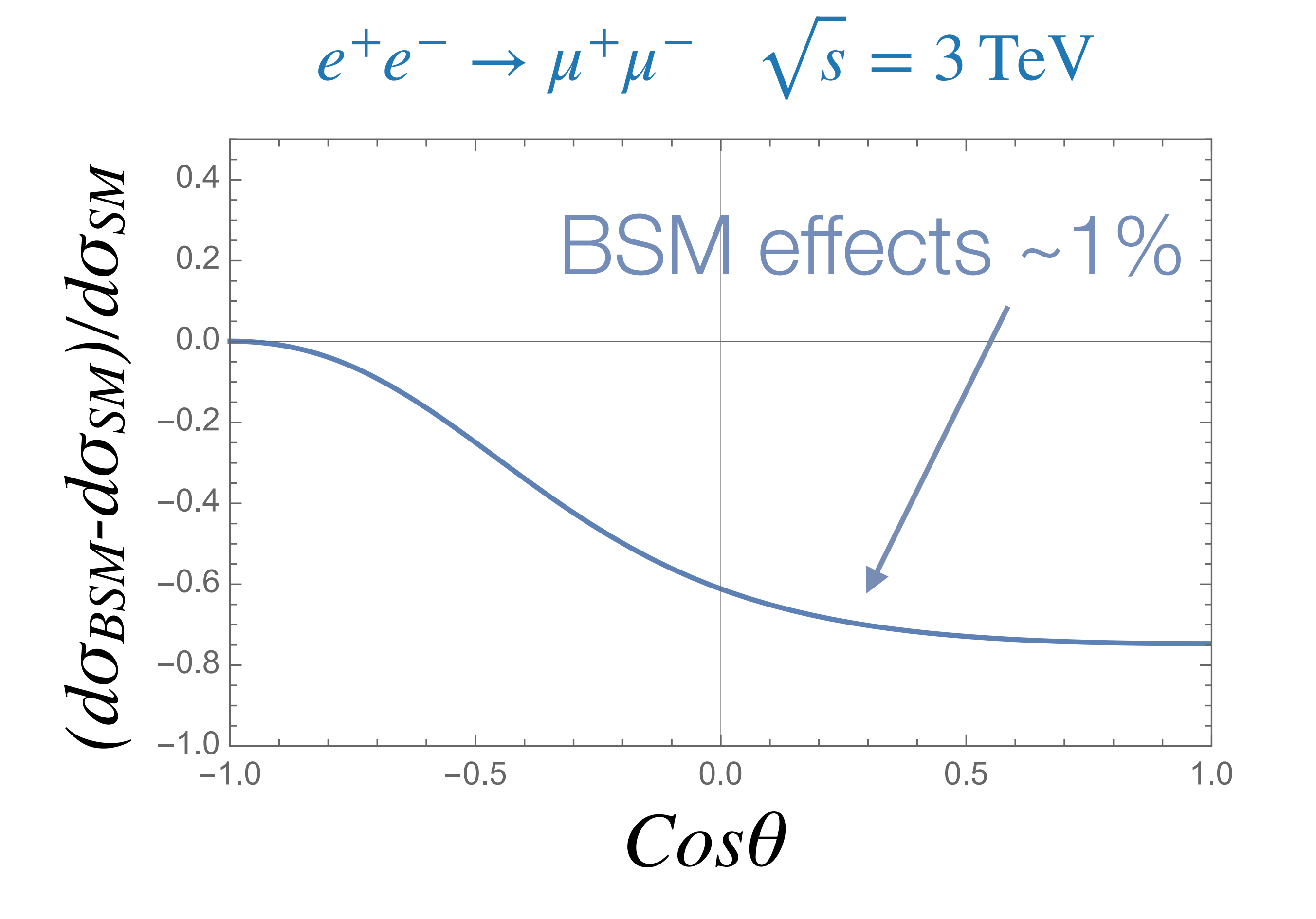
$e^+e^- \to f\bar{f}$

PRECISION ANGULAR DISTRIBUTION



χ is heavy/light new physics





beams polarization is beneficial to increase NP effects

$e^+e^- \longrightarrow f\bar{f}$

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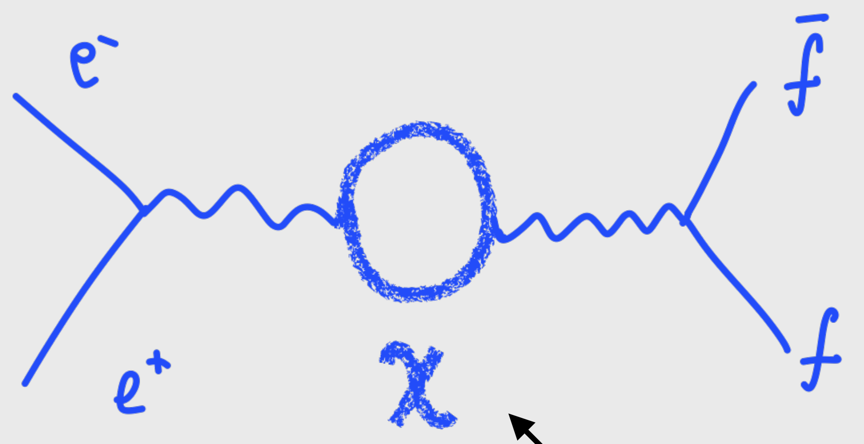

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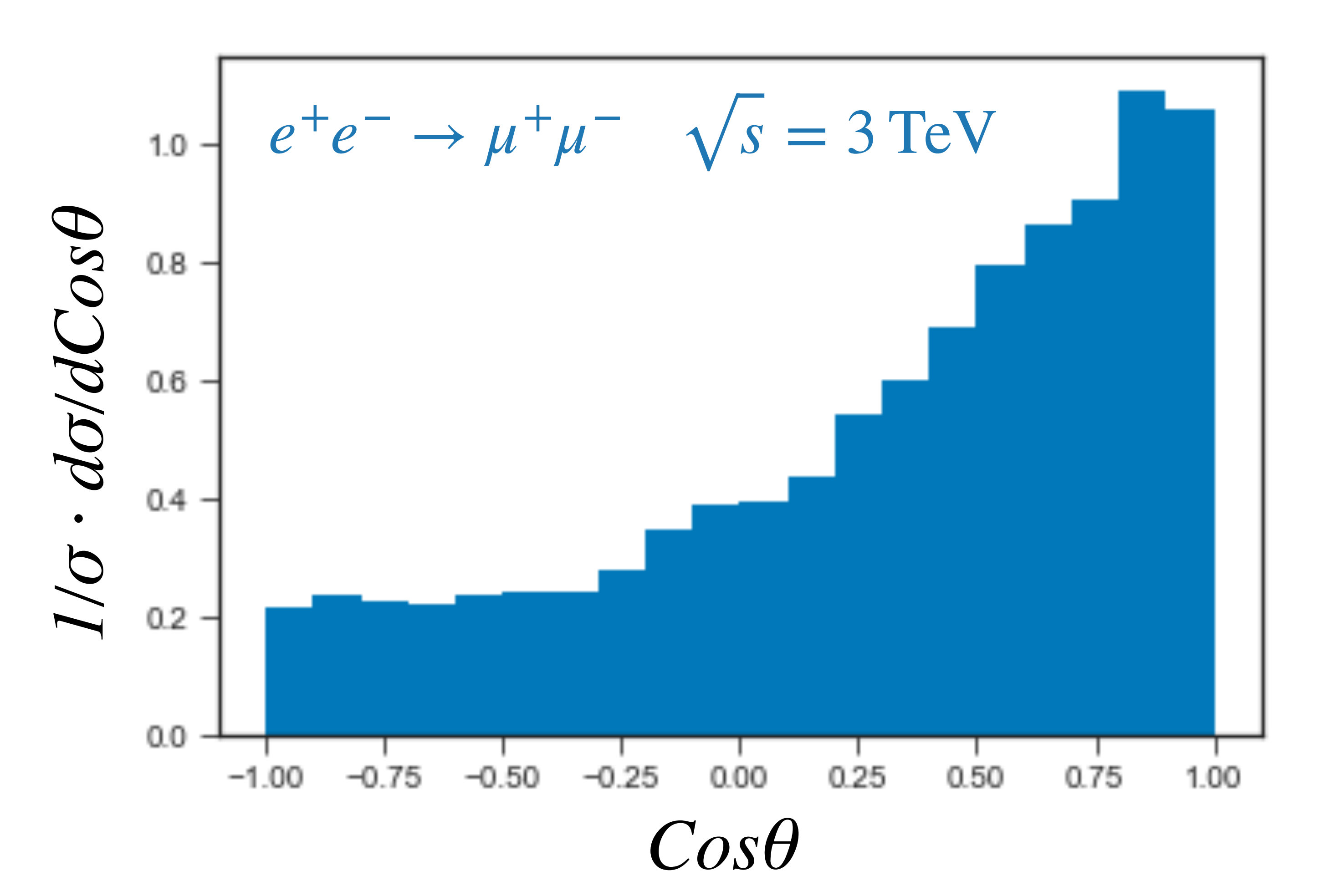

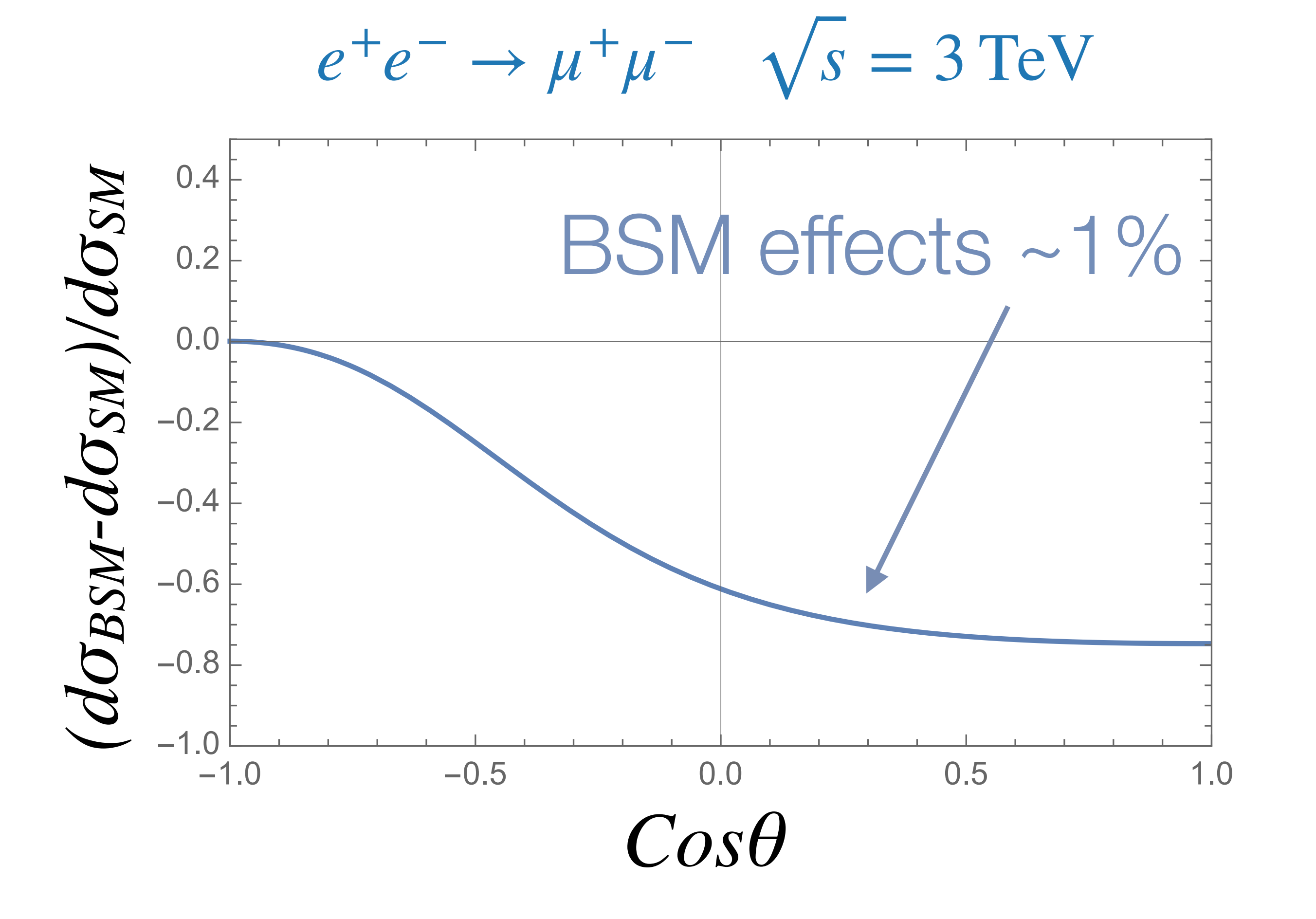

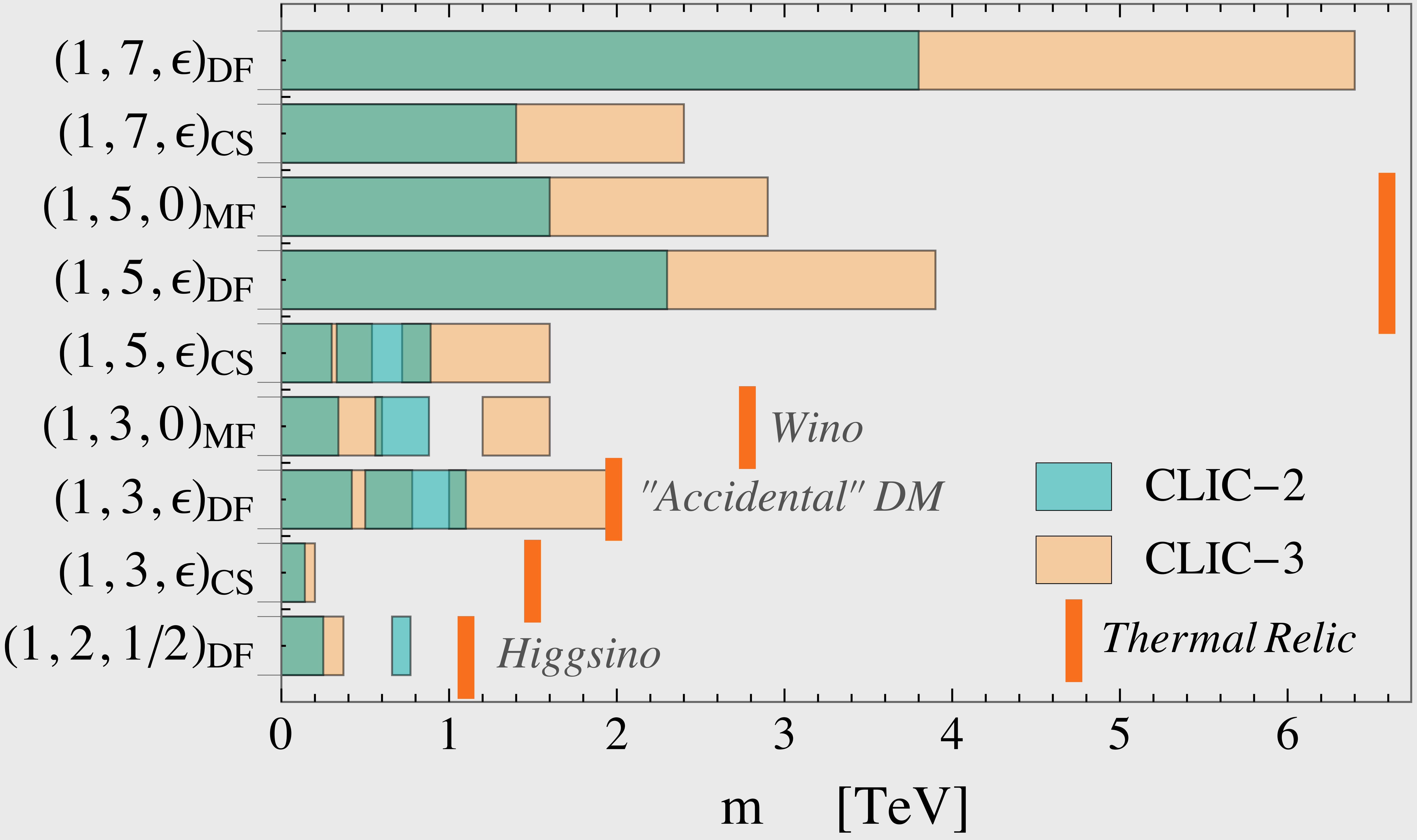

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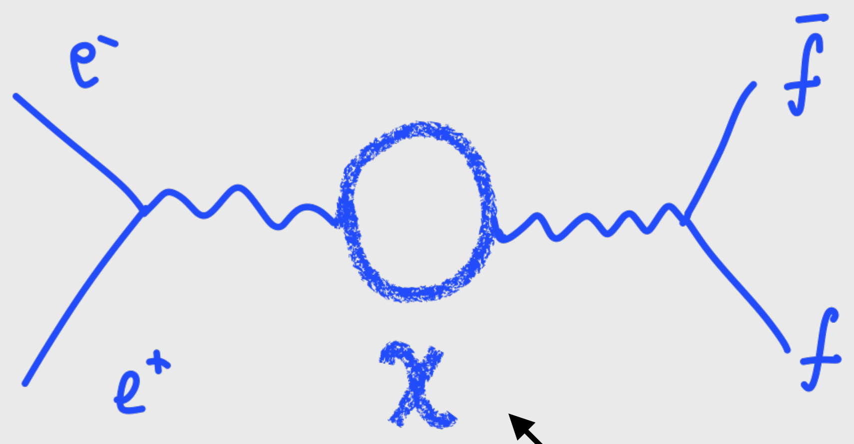

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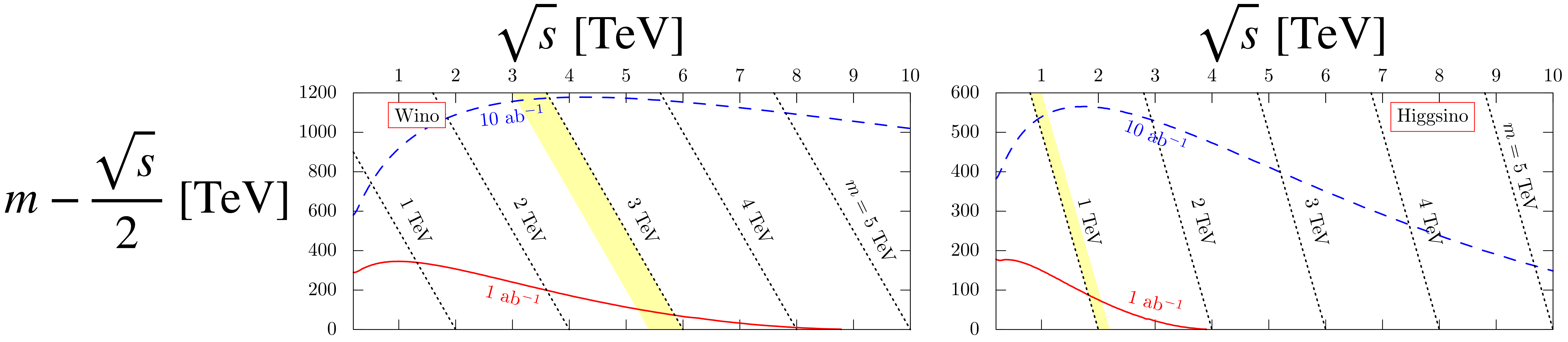

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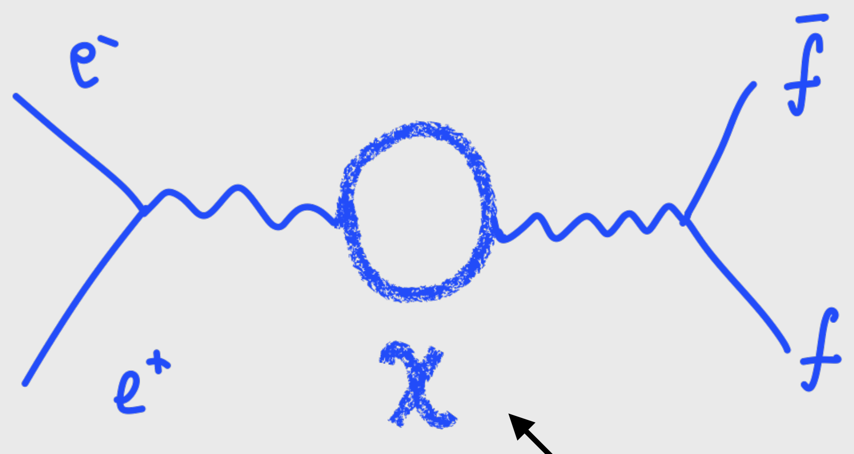

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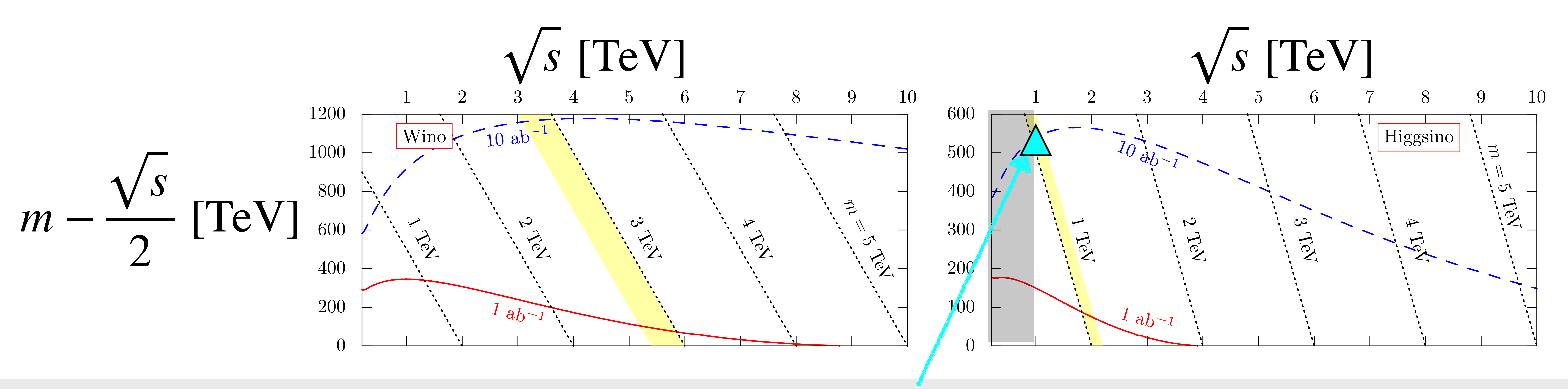

ILC_{1000}

$e^+e^- \to f\bar{f}$

PRECISION

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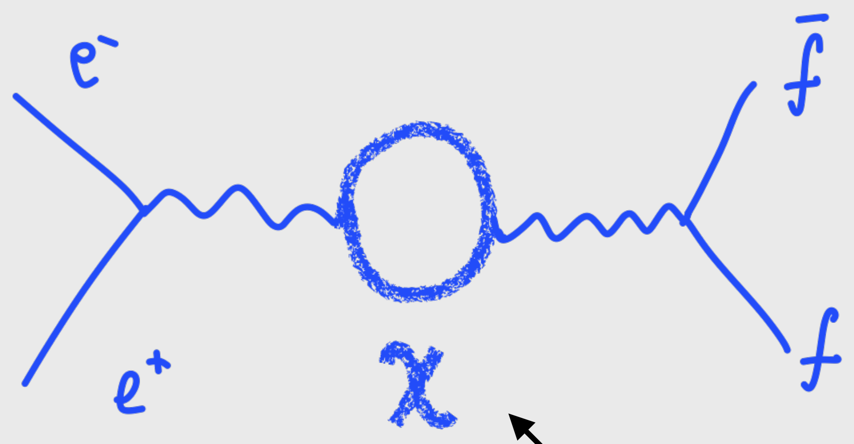

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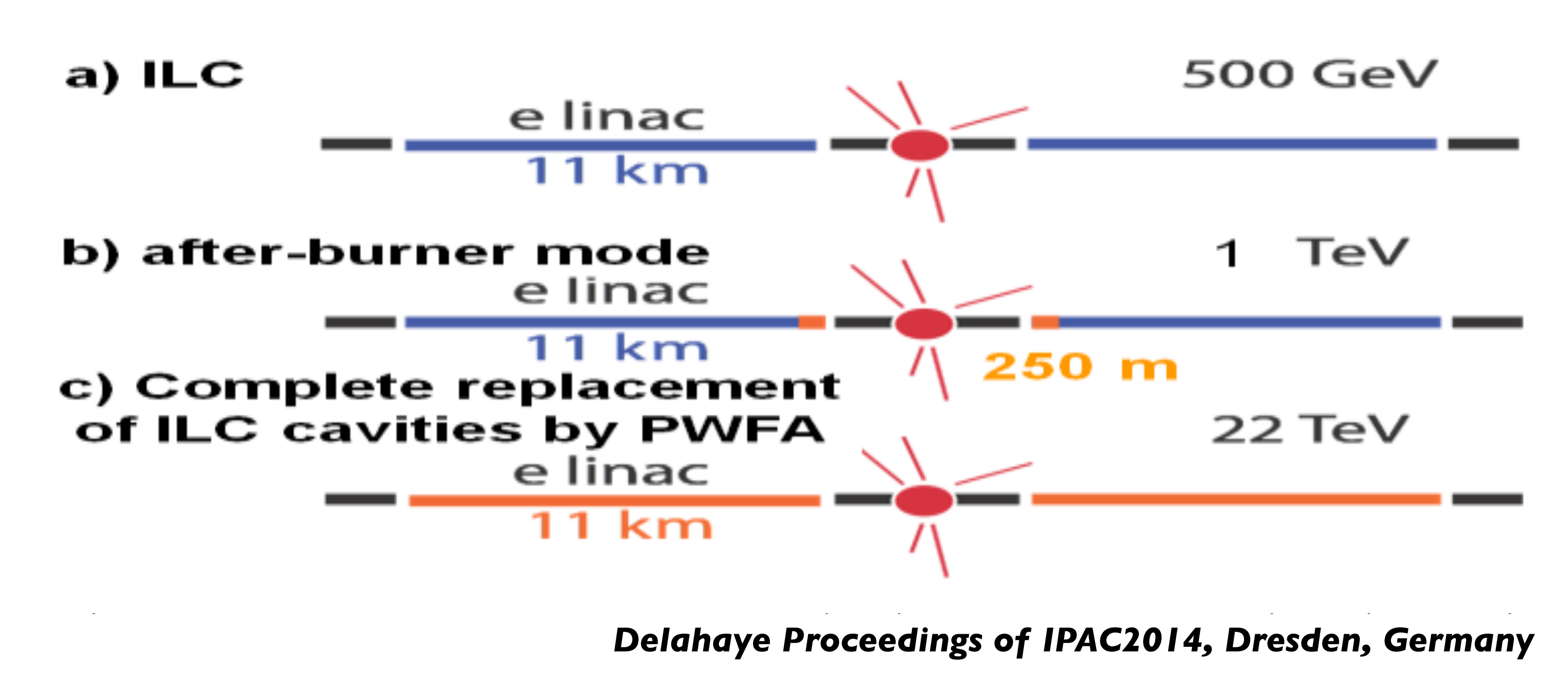

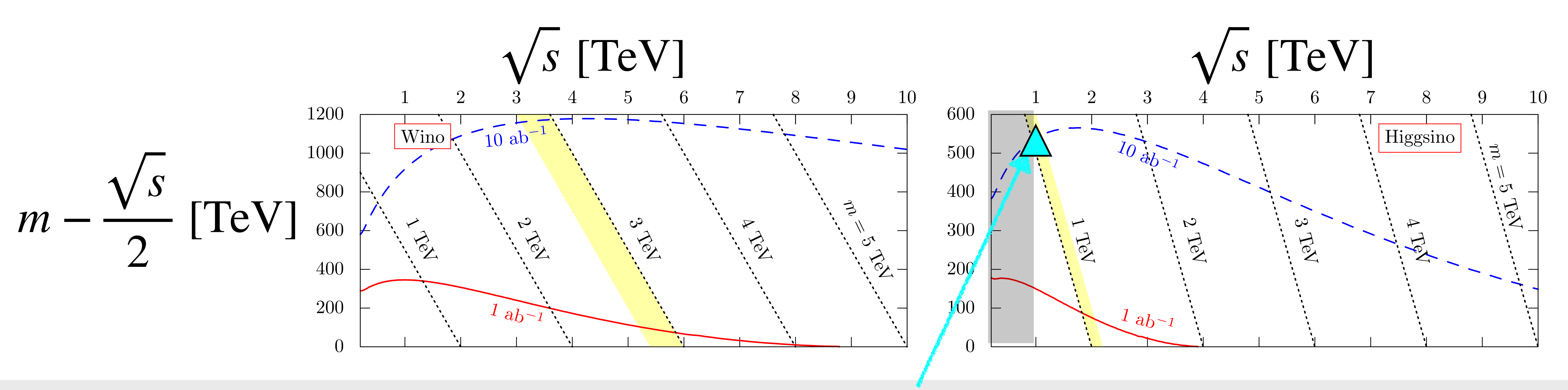

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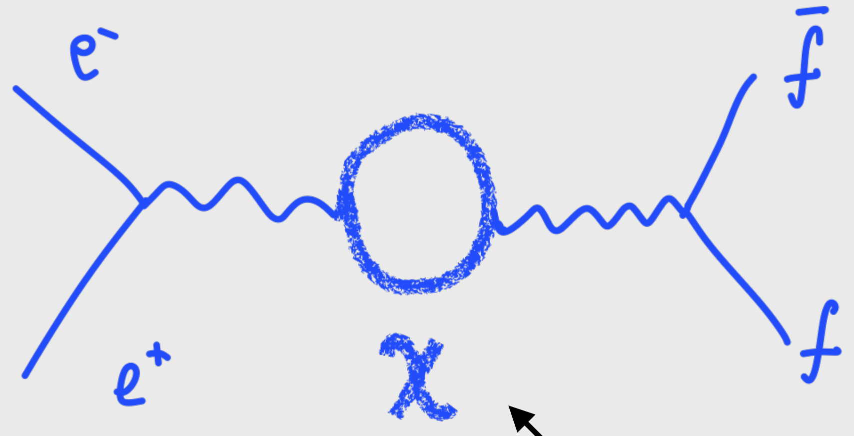

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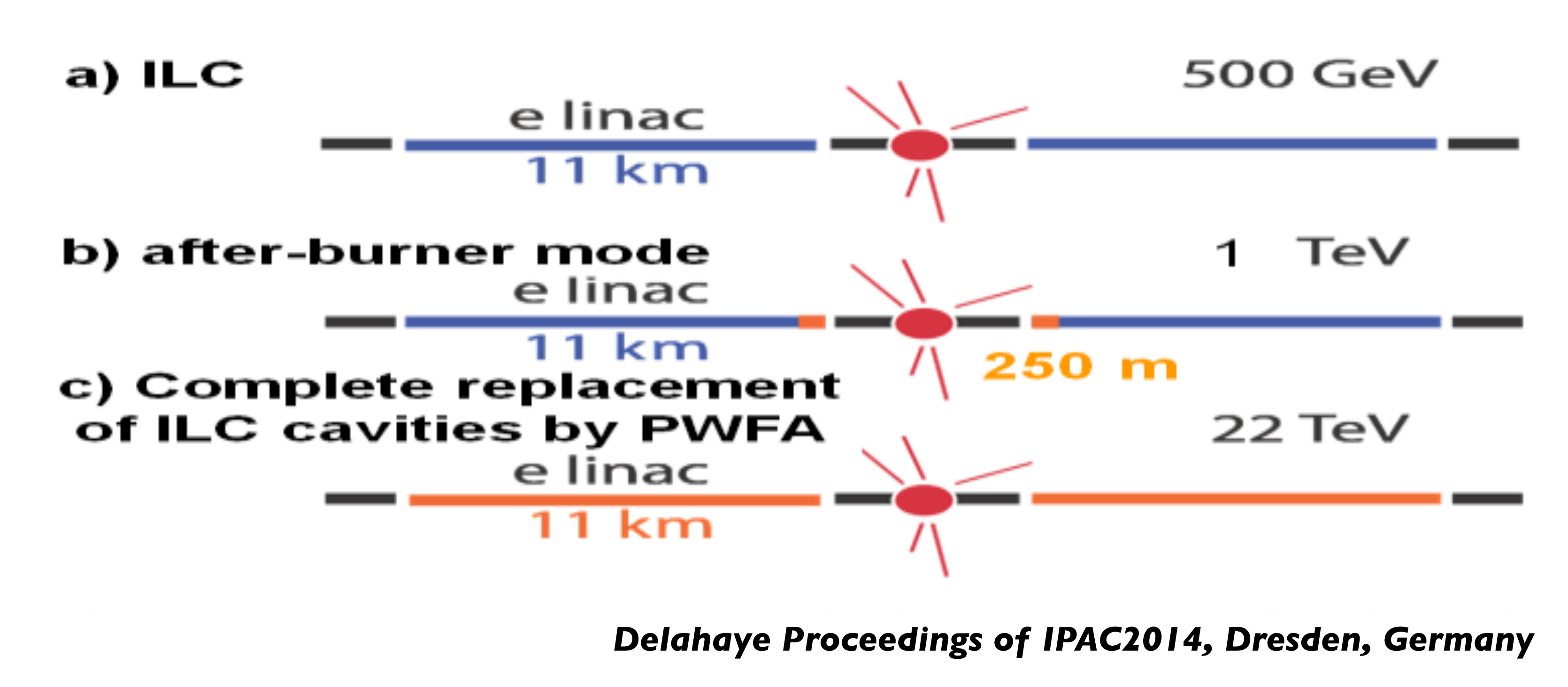
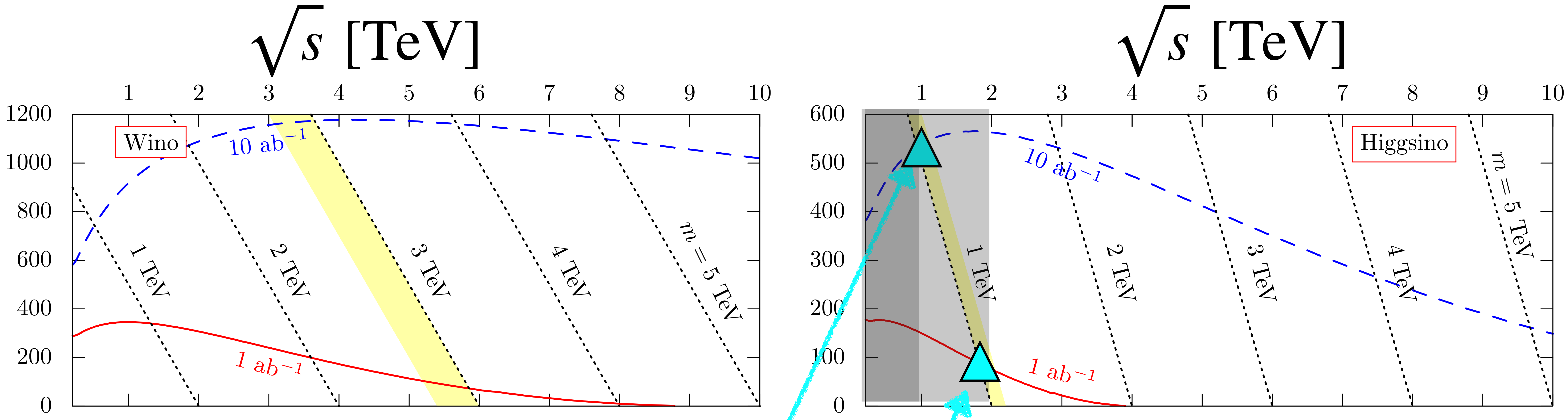


$$m - \frac{\sqrt{s}}{2}\ [\mathrm{TeV}]$$



$$ILC_{1000}$$

$$HE - LC_{2000} = \begin{cases} PWFA \\ CLIC - like \end{cases}$$

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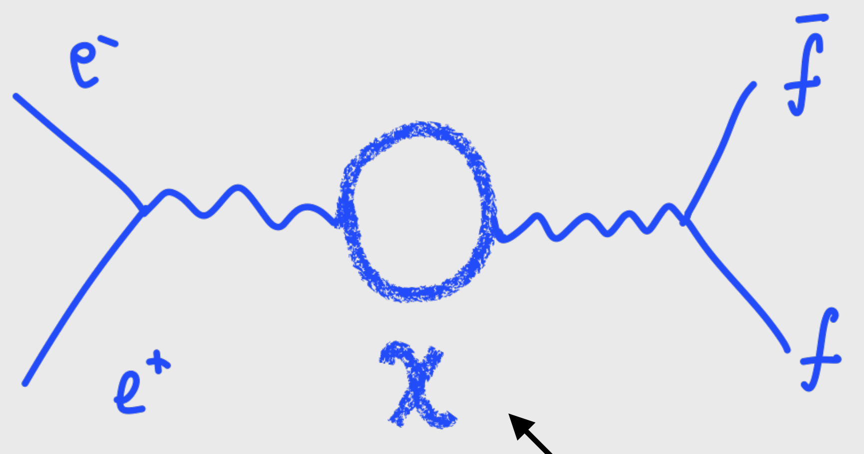
PRECISION | ANGULAR DISTRIBUTION



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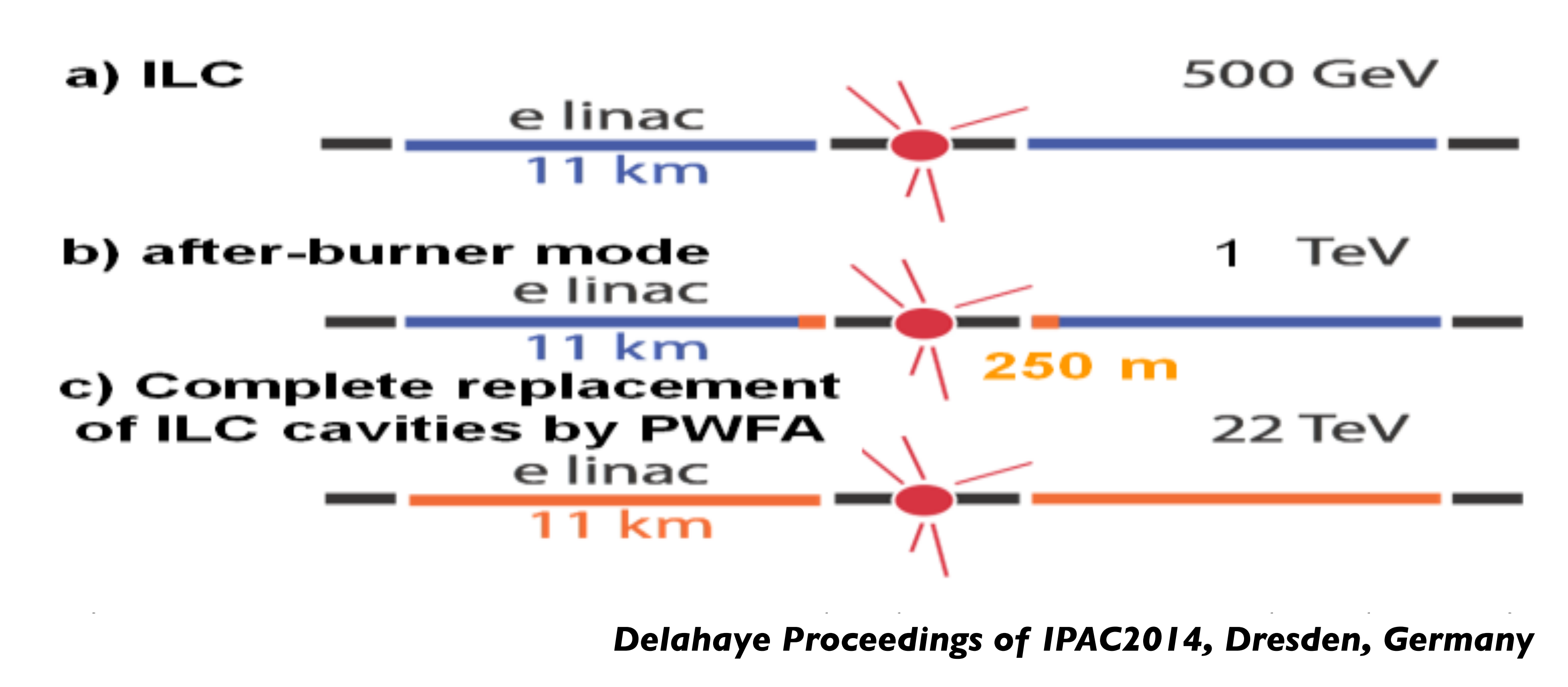

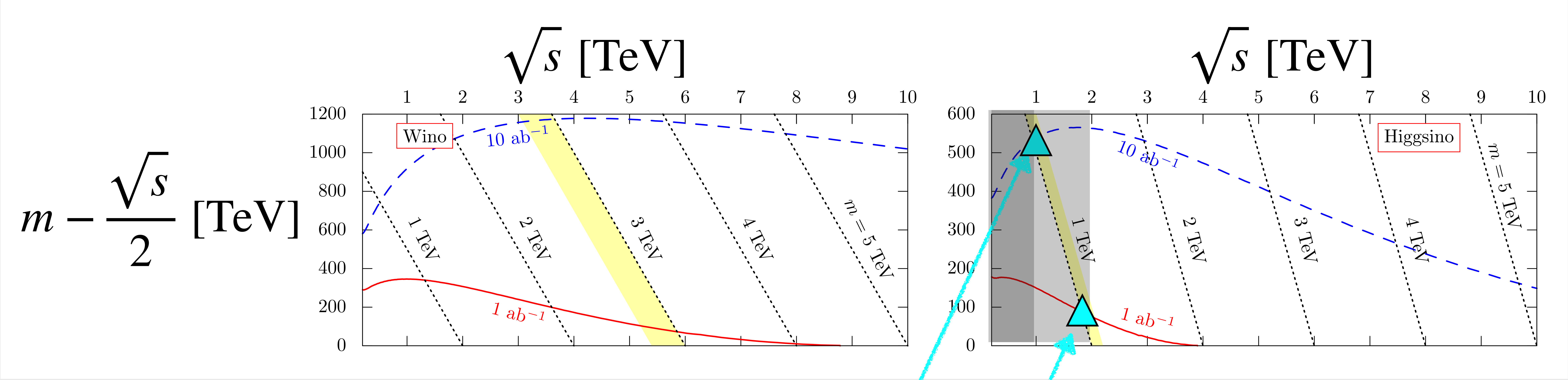

"MODEST" GAIN IN ENERGY CAN REDUCE SIGNIFICANTLY THE LUMINOSITY NEEDED TO PROBE DARK MATTER

$$ILC_{1000}$$

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Dark Matter

Neutrinos

Baryogenesis

Long Lived

$e^+e^- \to f\bar{f}$

PRECISION

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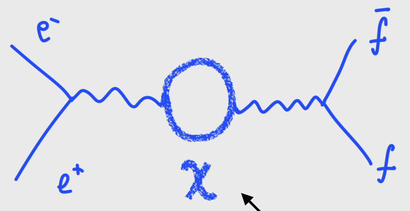

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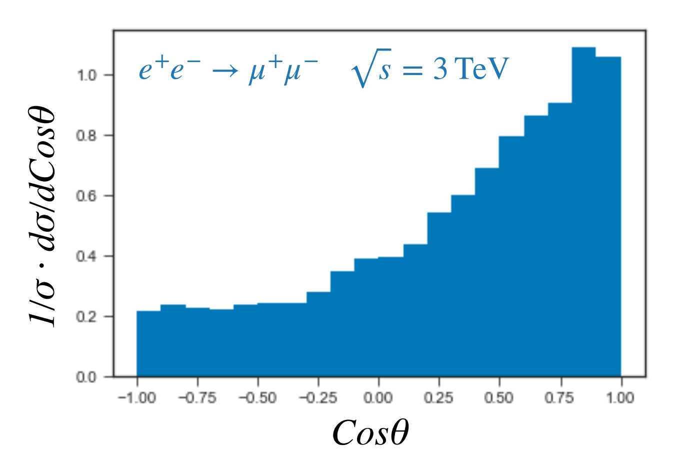

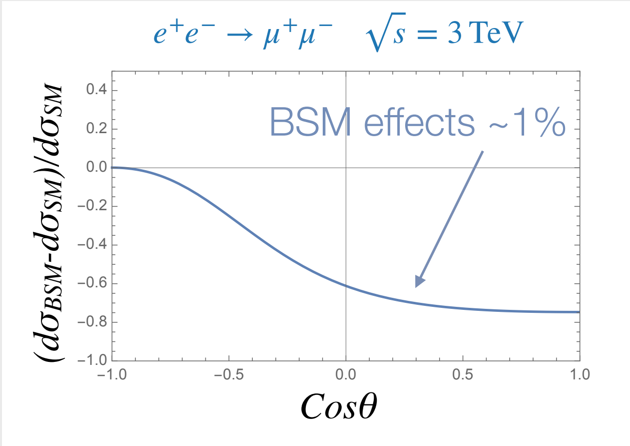

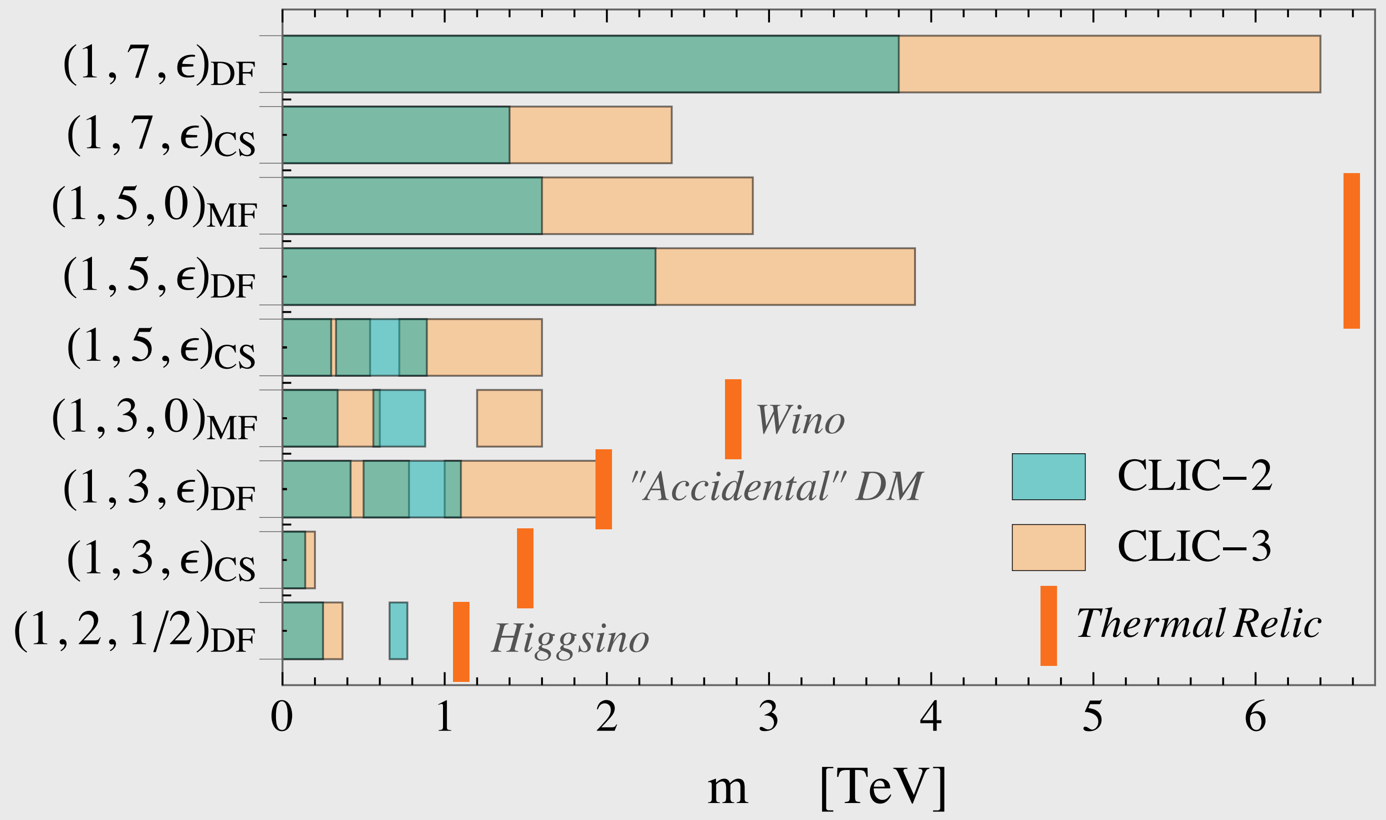

beams polarization is beneficial to increase NP effects

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Long Lived

Rober

1810.10993 - Di Luzio, Grober, Panico

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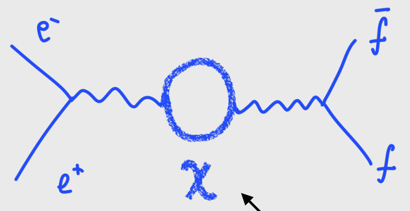

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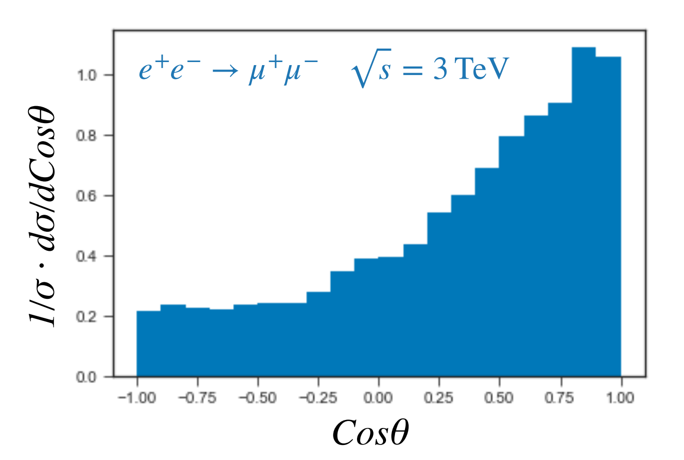

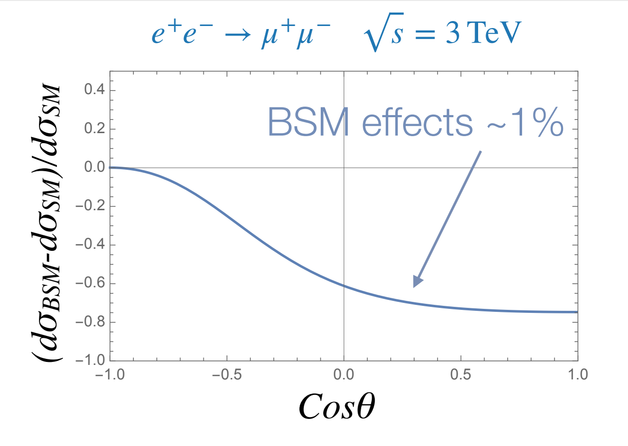

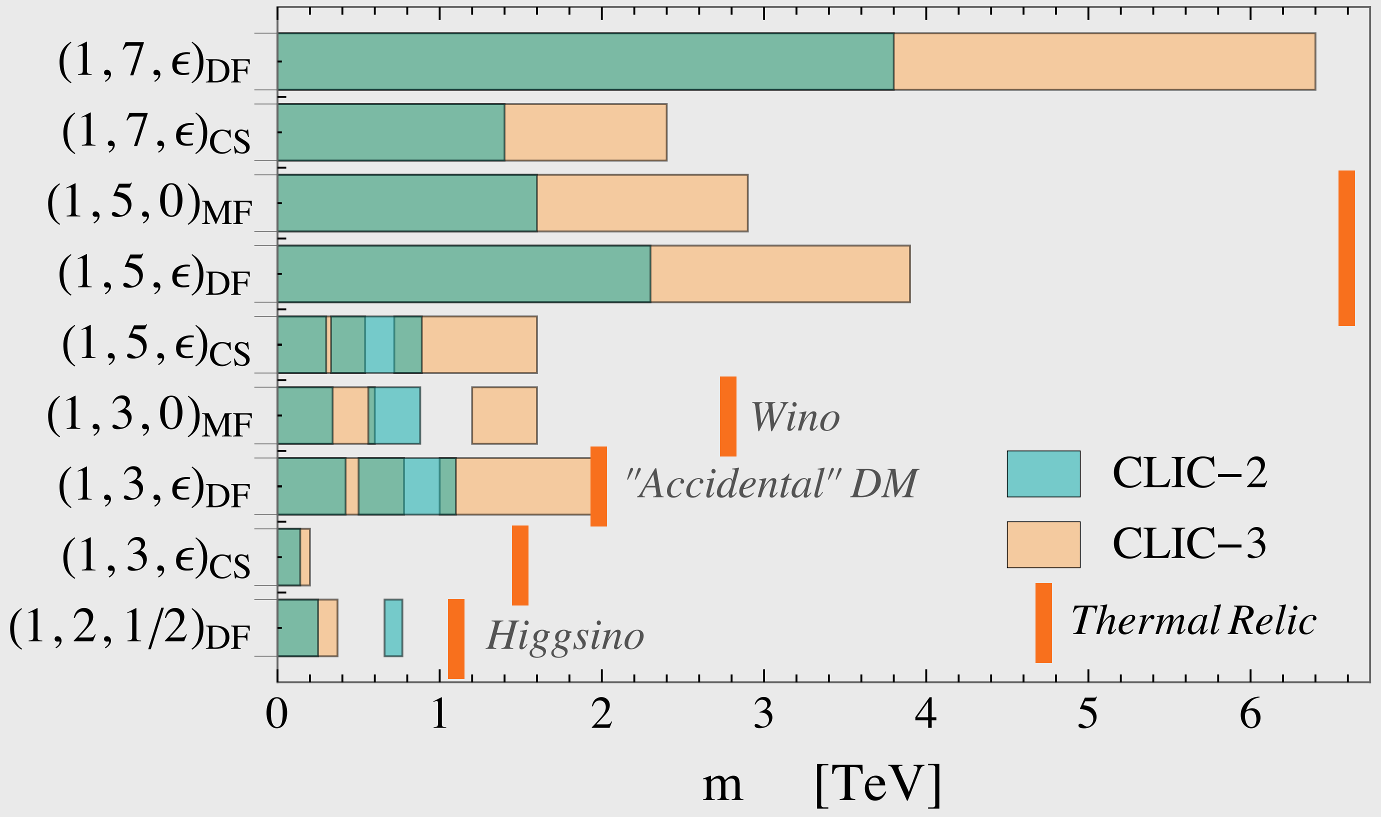

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Plenty of neutrino mass models in reach

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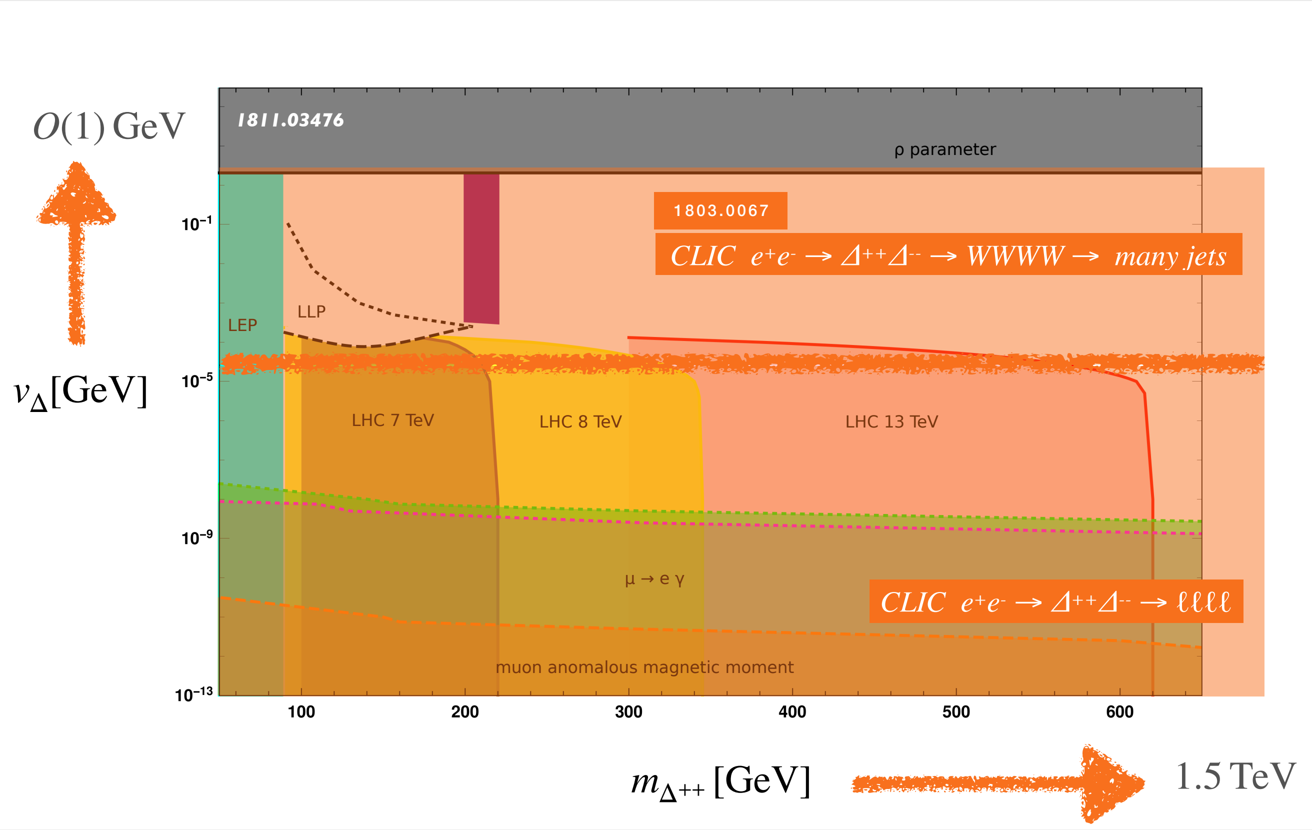
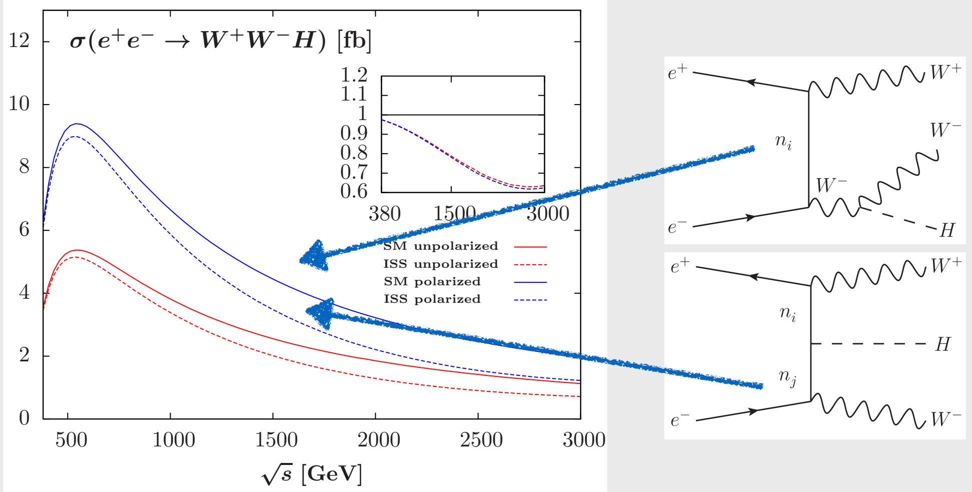
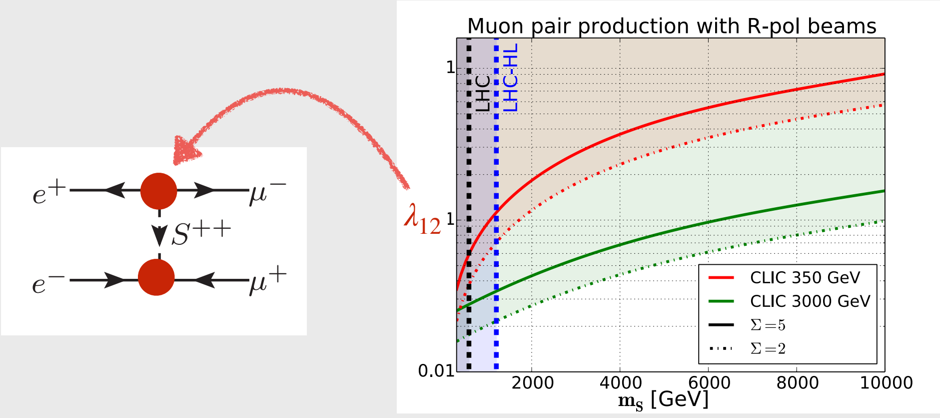


Inverse See-Saw **1712.07621 - Baglio, Pascoli, Weiland**



Exclude ISS RH Neutrino up to 10 TeV for Yukawa ~1

1807.10224 - Crivellin, Ghezzi, Panizzi, Pruna, Signer



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Long Lived

1810.10993 - Di Luzio, Grober, Panico

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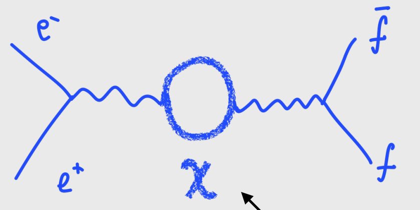
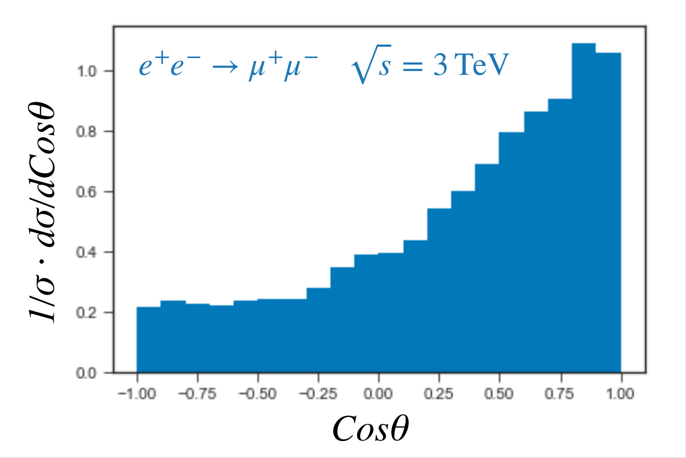
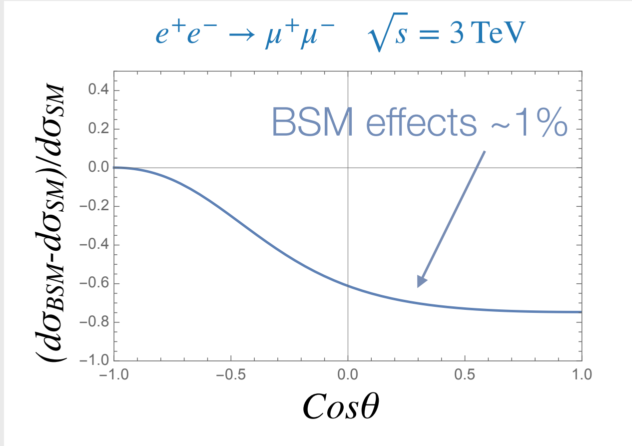
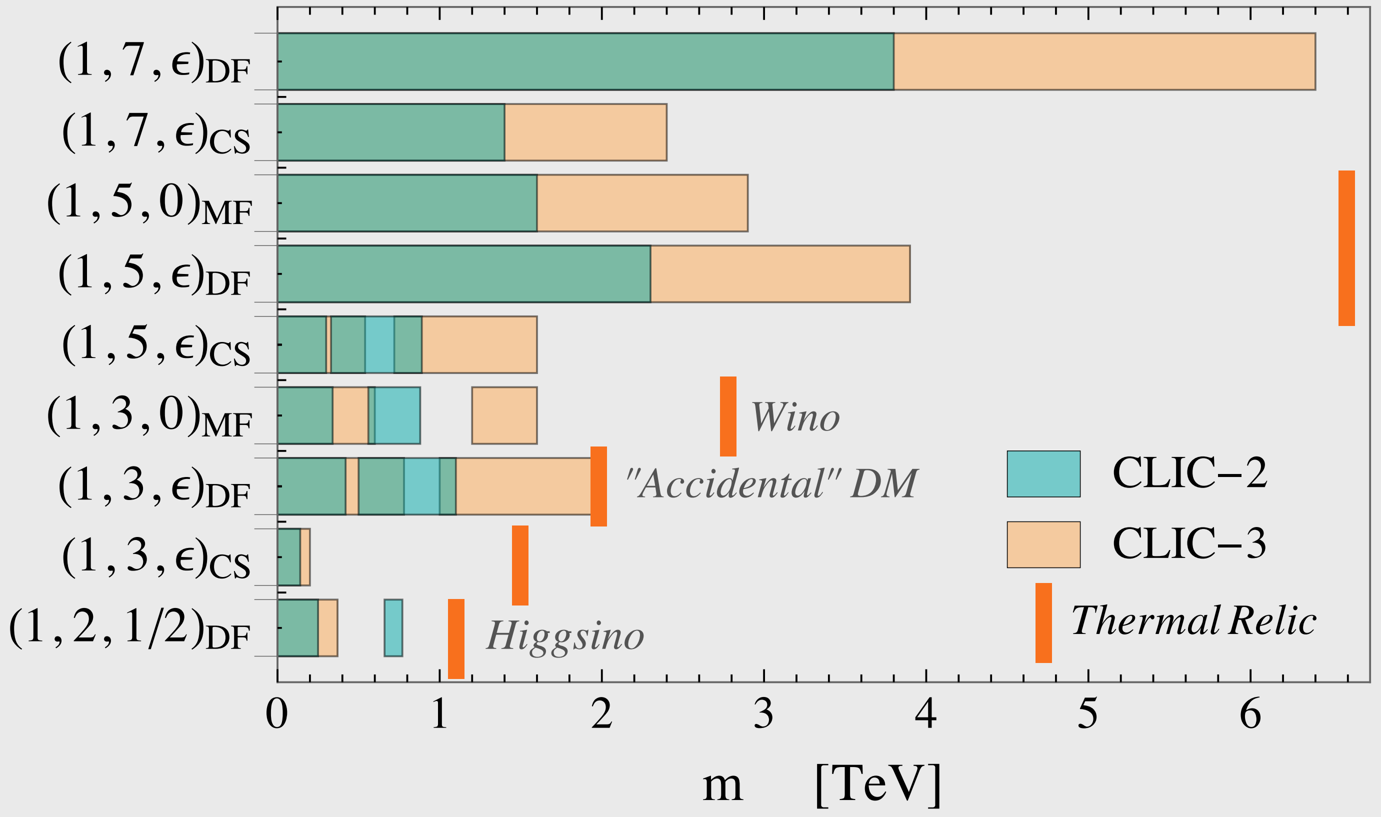
PRECISION | ANGULAR DISTRIBUTION









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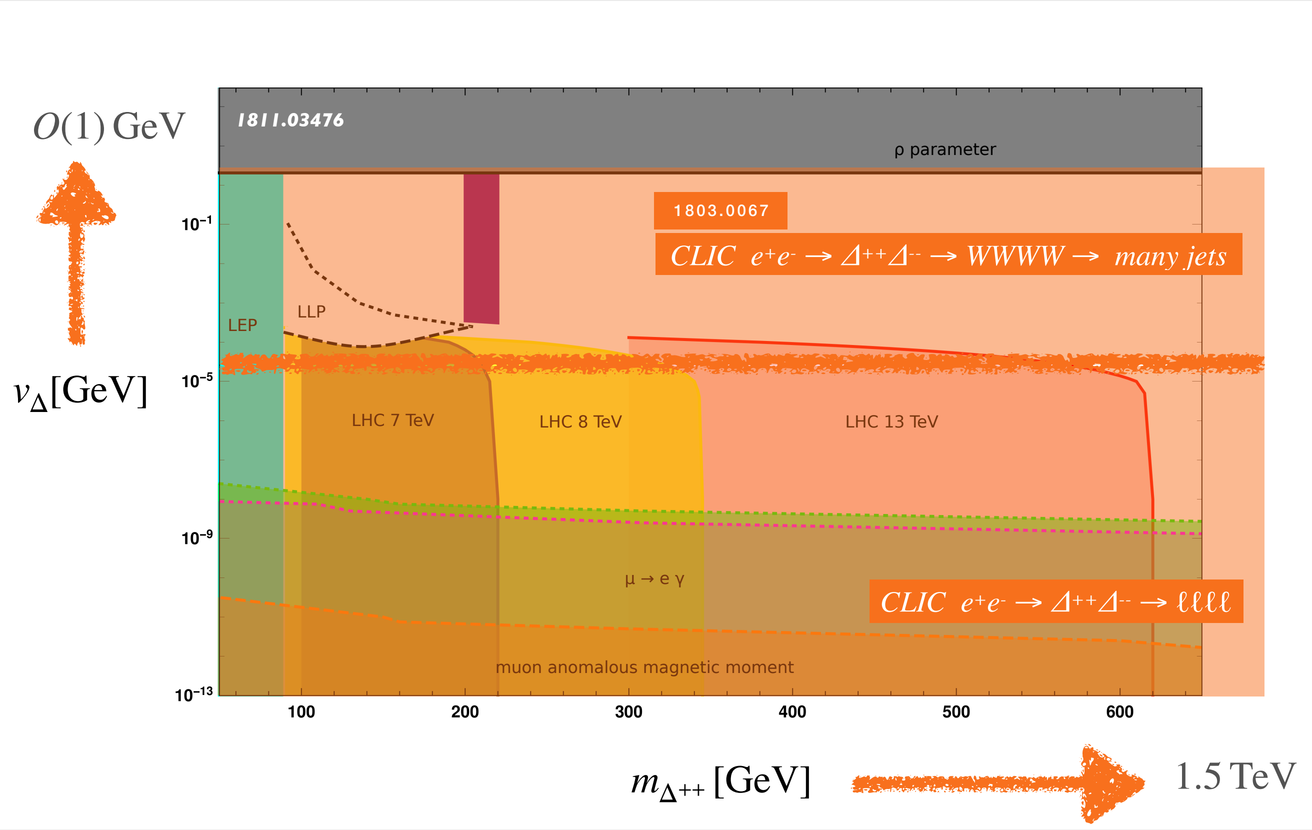

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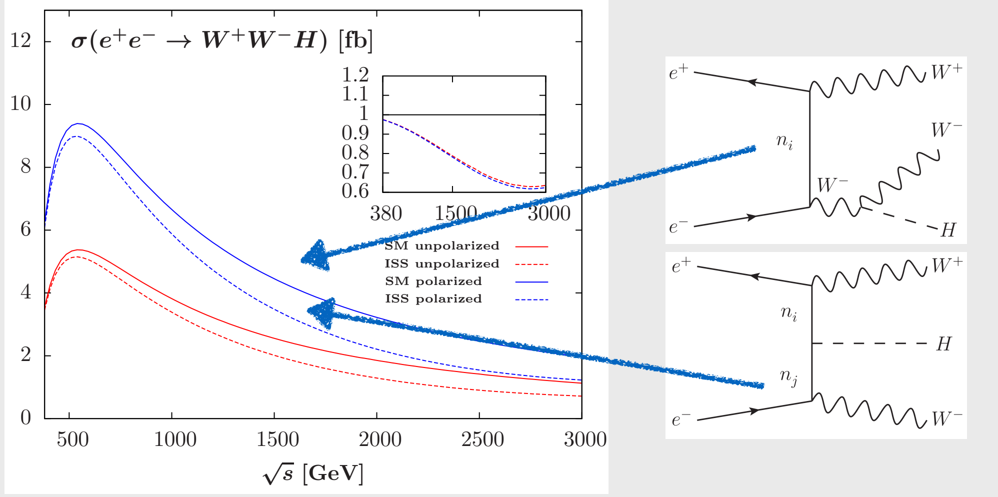

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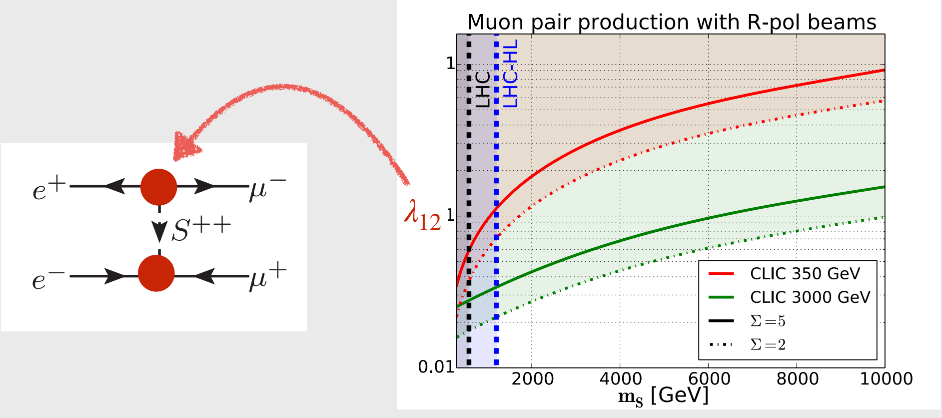

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Roberto Franceschini

1807.04284 - No and Spannowsky

Mixed Singlet for EW phase transition

EW PHASE TRANSITION | IS IT FIRST ORDER?

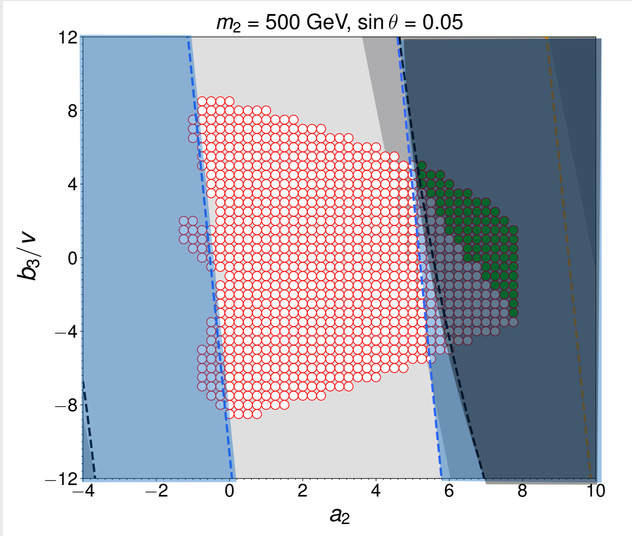
$$V(\Phi,S) = -\mu^2\left(\Phi^\dagger\Phi\right) + \lambda\left(\Phi^\dagger\Phi\right)^2 + \frac{a_1}{2}\left(\Phi^\dagger\Phi\right)S + \frac{a_2}{2}\left(\Phi^\dagger\Phi\right)S^2 + b_1 S + \frac{b_2}{2}S^2 + \frac{b_3}{3}S^3 + \frac{b_4}{4}S^4.$$

independent parameters

$\{v,\ m_1,\ m_2,\ \theta,\ a_2,\ b_3,\ b_4\}.$

fixed sampled y-axis scanned x-axis [0, 4π/3]

- "healty" potential (no runaway, minimum v=246 GeV, perturbative)
- 1st order phase transition
- HL-LHC sensitivity (from pp → S→ ZZ)
- CLIC380/3TeV Single Higgs couplings
- CLIC 1.4 TeV 3 TeV WBF S → h h → 4b
- CLIC hhh 20% @ 95% CL coupling measurement



parameters space of 1st order phase transition accessible by several probes

Long Lived

1810.10993 - Di Luzio, Grober, Panico

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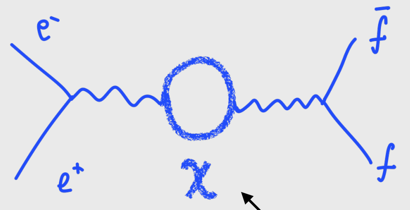
PRECISION | ANGULAR DISTRIBUTION



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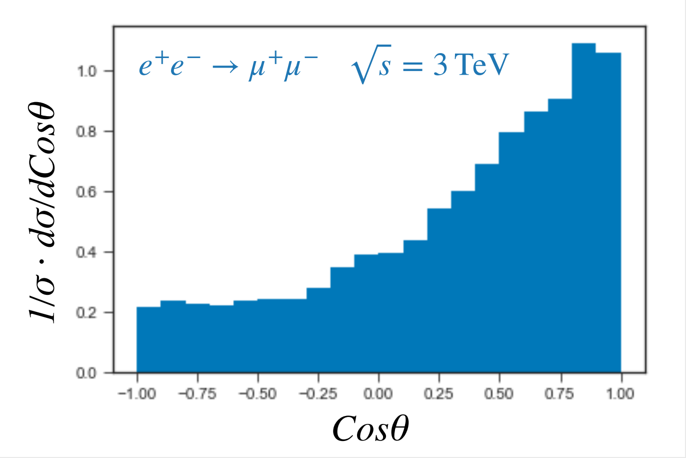

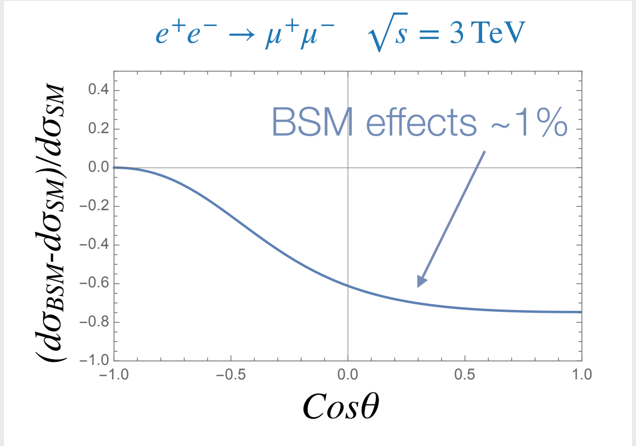

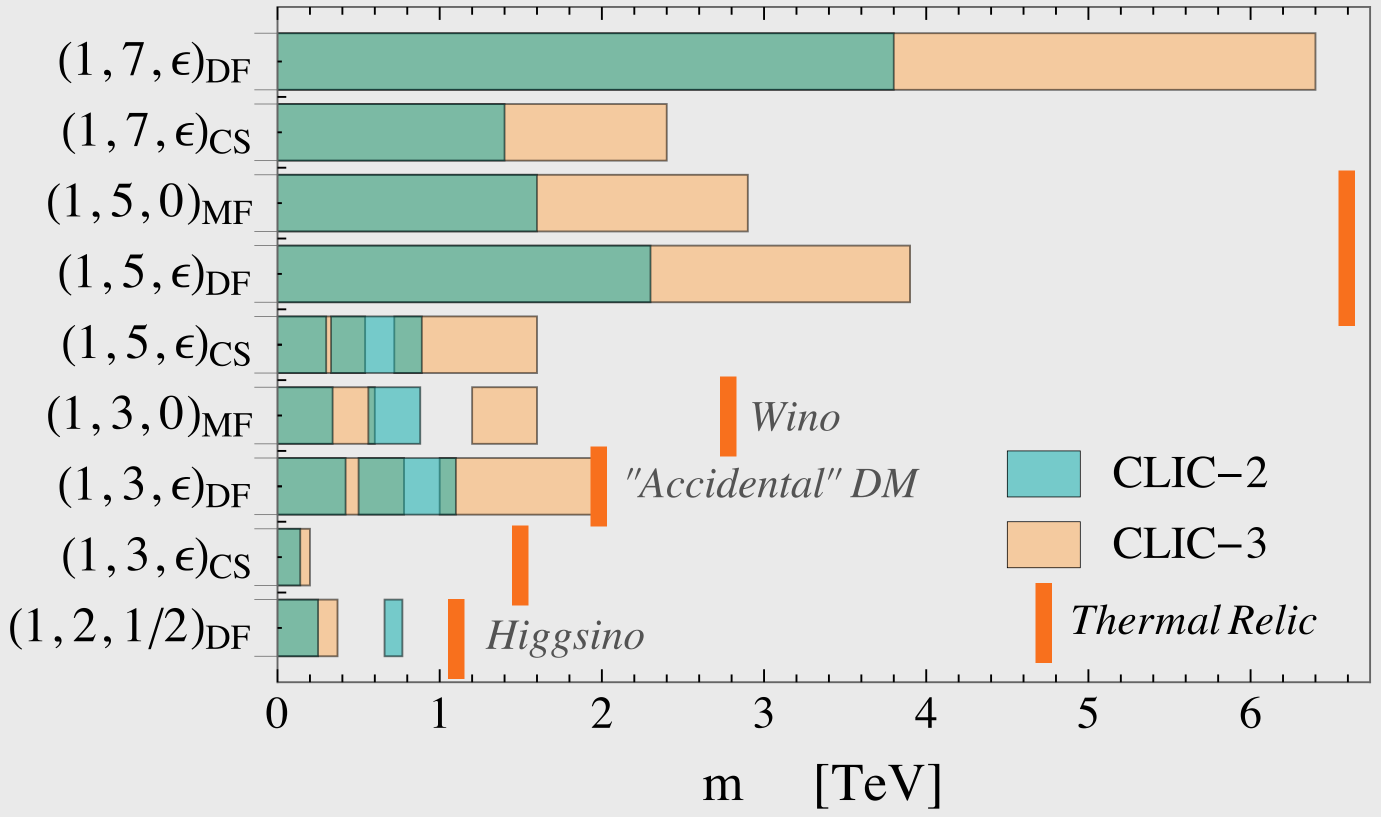

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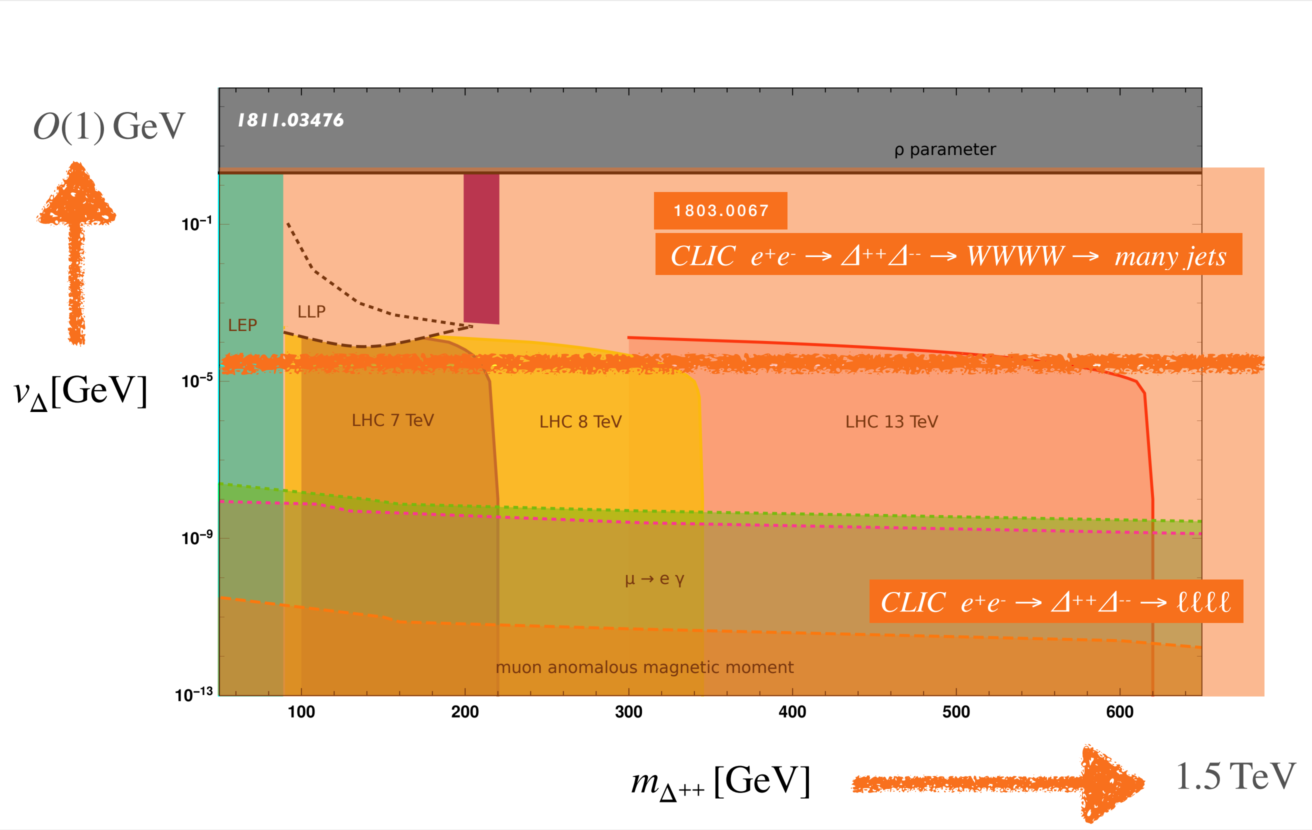

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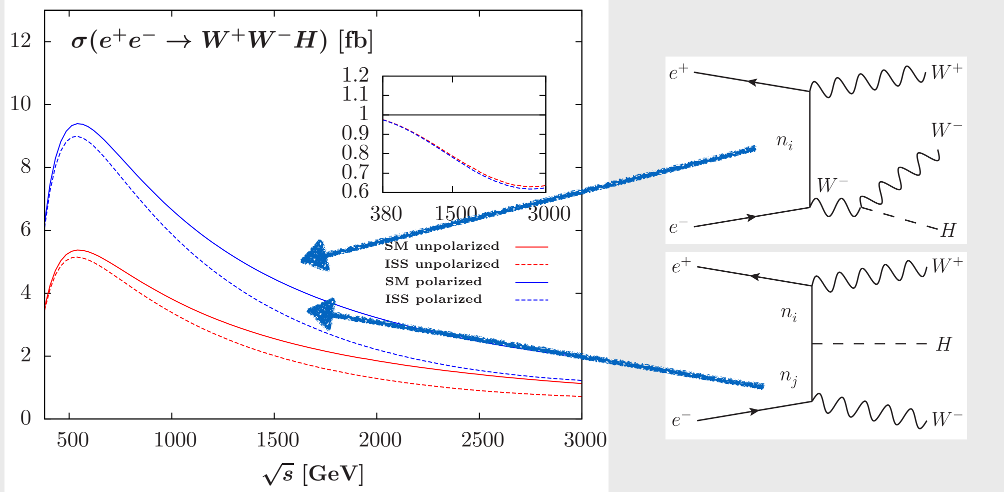

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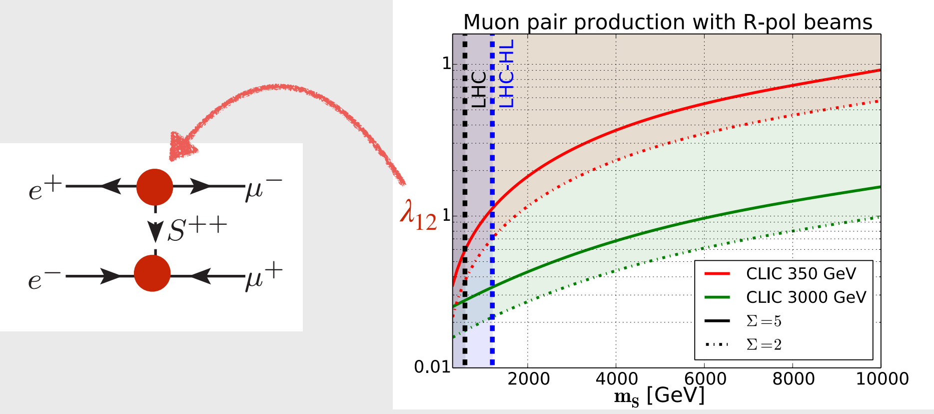

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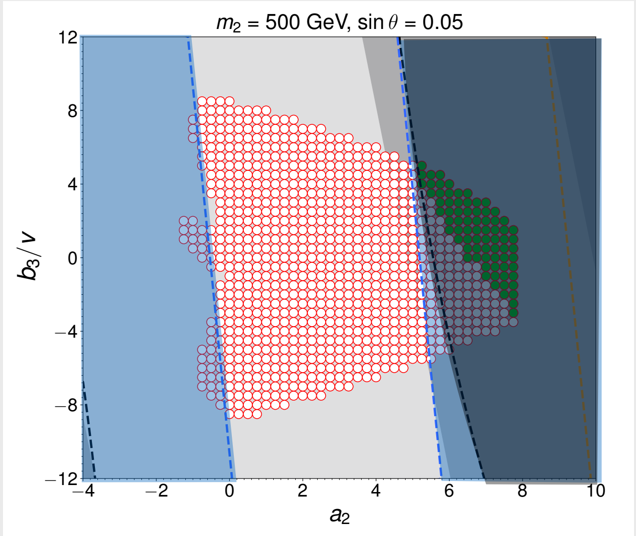


parameters space of 1st order phase transition accessible by several probes

CLICdp Full Simulation

Hidden Valley Displaced Vertex

CLICDP-NOTE-2018-001 | $e^+e^- \to h\,\nu\nu$ | $h \to \pi_V\,\pi_V$ $\xrightarrow{c\beta\gamma\tau_0}$ $\pi_V \to bb$

$BR(h_{125} \to LLP) < 10^{-4}$

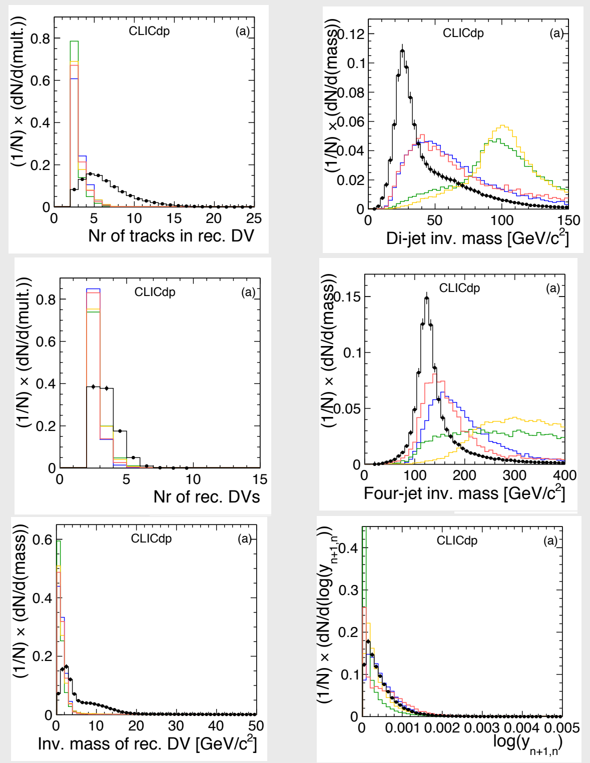
N=4 exclusive k_T jets

qq qqνν qqqq qqqqνν

# of tracks

# of DV

Mass of DV

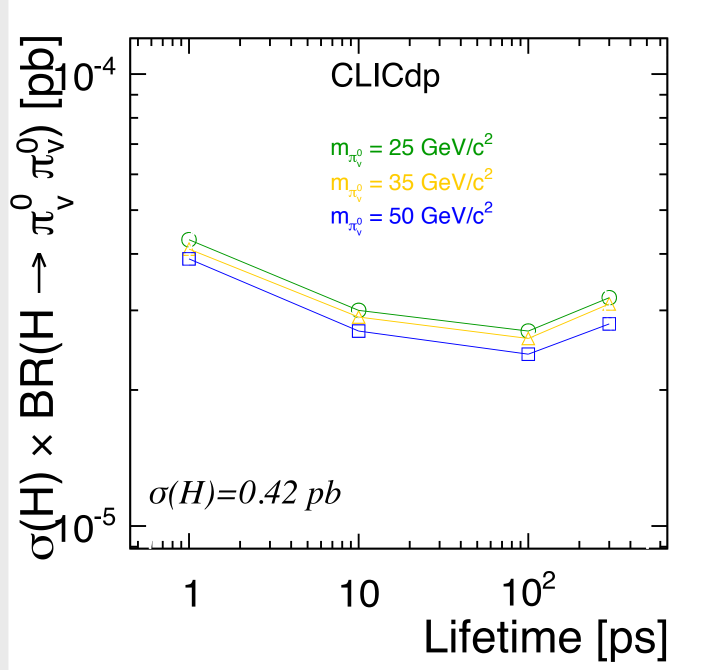


Mass of jj

Mass of 4j

Jets y_{34} and y_{23}

Boosted Decision Tree: $\varepsilon_S \geq 0.1$



Roberto Franceschini

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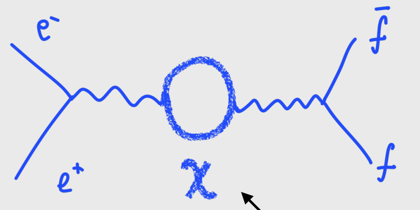
PRECISION | ANGULAR DISTRIBUTION



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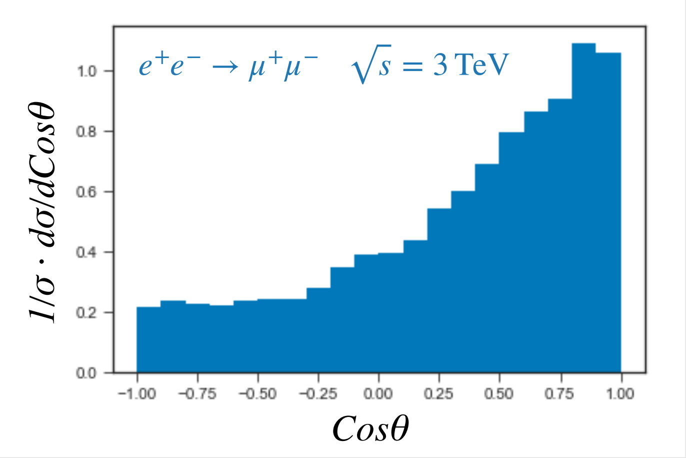

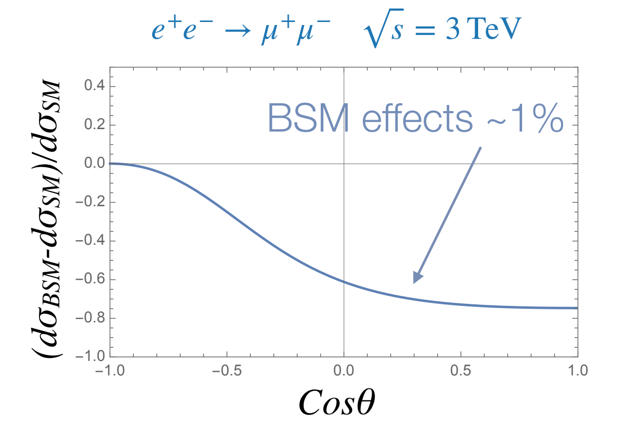

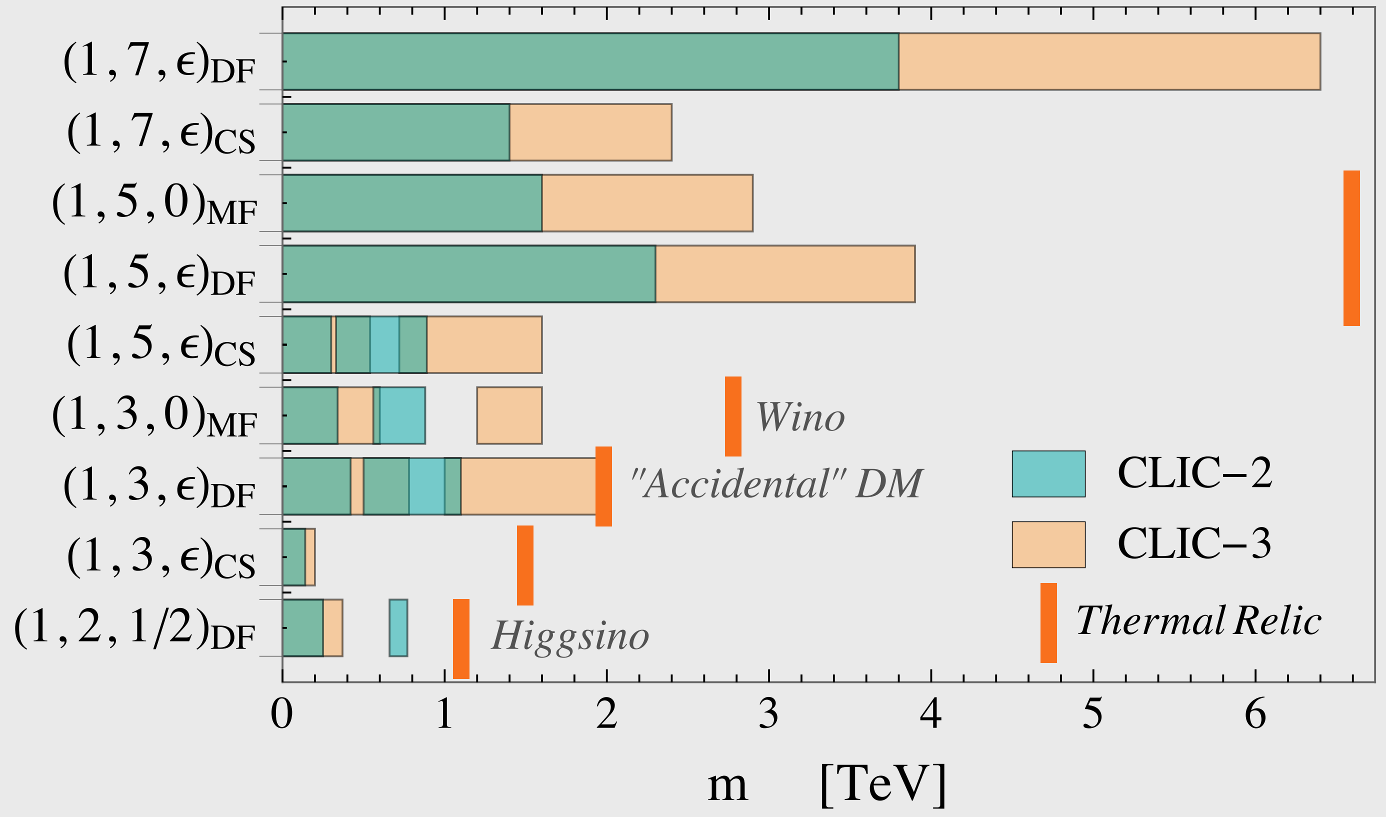

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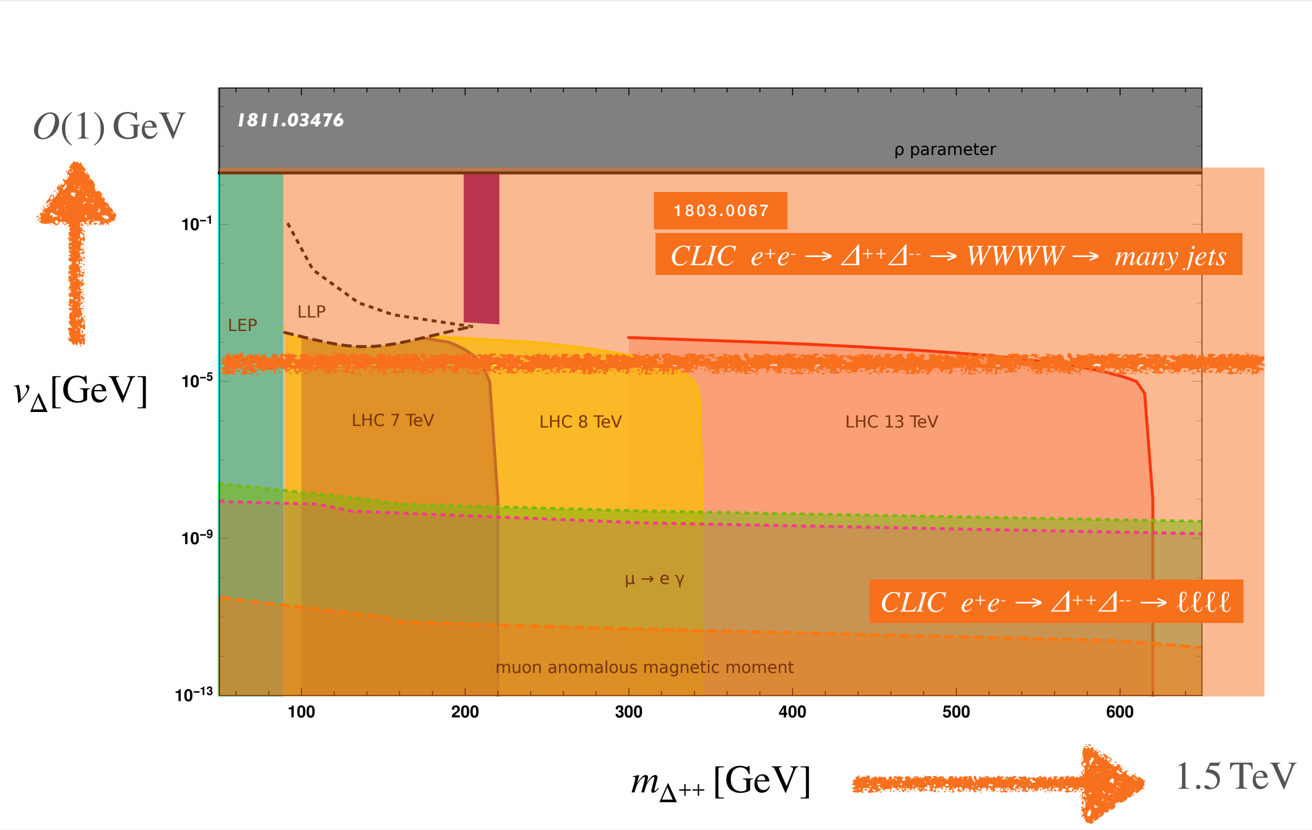
Type-2 See-Saw **1803.00677 - Agrawal, Mitra, Niyogi, Shil, Spannowsky**



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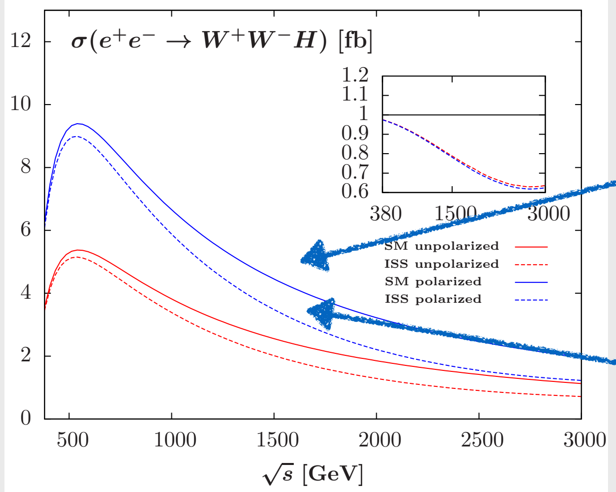
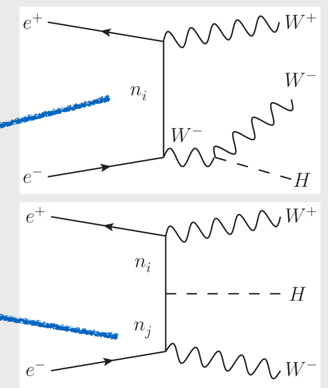
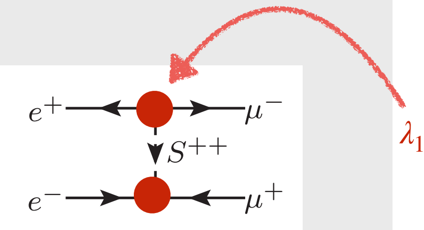
Inverse See-Saw **1712.07621 - Baglio, Pascoli, Weiland**

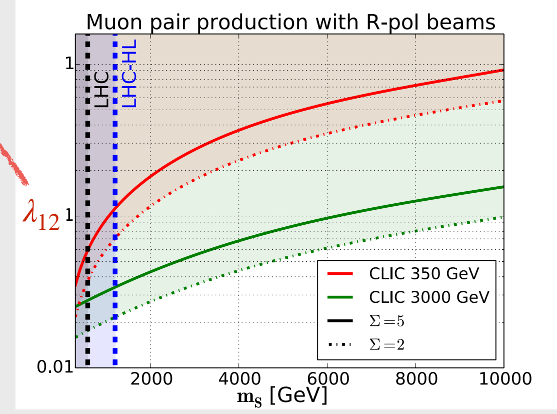




Exclude ISS RH Neutrino up to 10 TeV for Yukawa ~1

1807.10224 - Crivellin, Ghezzi, Panizzi, Pruna, Signer





Exclude S++ up to 10 TeV for triplet Yukawa ~0.1

1807.04284 - No and Spannowsky

Mixed Singlet for EW phase transition

EW PHASE TRANSITION | IS IT FIRST ORDER?

$$V(\Phi,S) = -\mu^2\left(\Phi^\dagger\Phi\right) + \lambda\left(\Phi^\dagger\Phi\right)^2 + \frac{a_1}{2}\left(\Phi^\dagger\Phi\right)S + \frac{a_2}{2}\left(\Phi^\dagger\Phi\right)S^2 + b_1 S + \frac{b_2}{2}S^2 + \frac{b_3}{3}S^3 + \frac{b_4}{4}S^4.$$

independent parameters

$\{v,\ m_1,\ m_2,\ \theta,\ a_2,\ b_3,\ b_4\}.$

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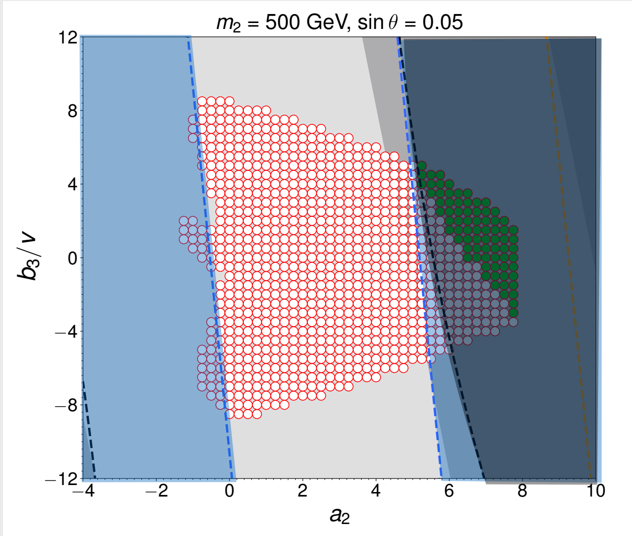
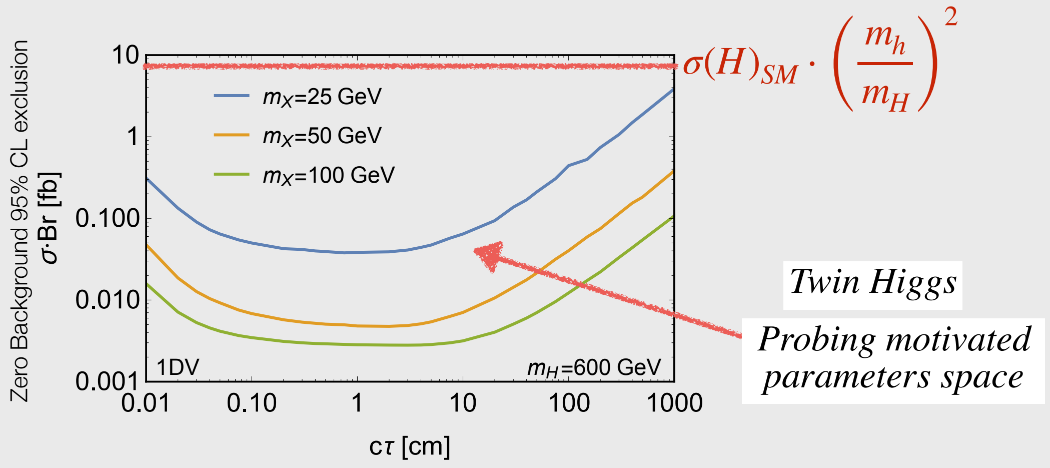


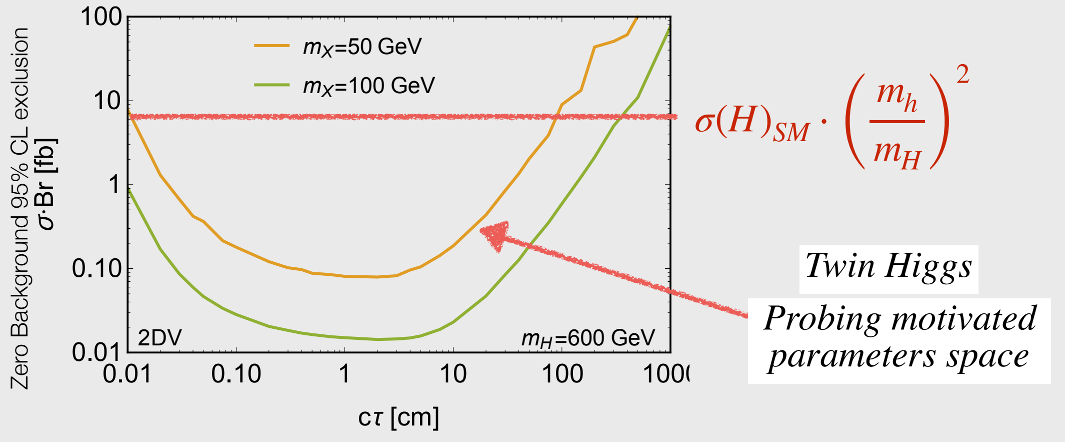
parameters space of 1st order phase transition accessible by several probes

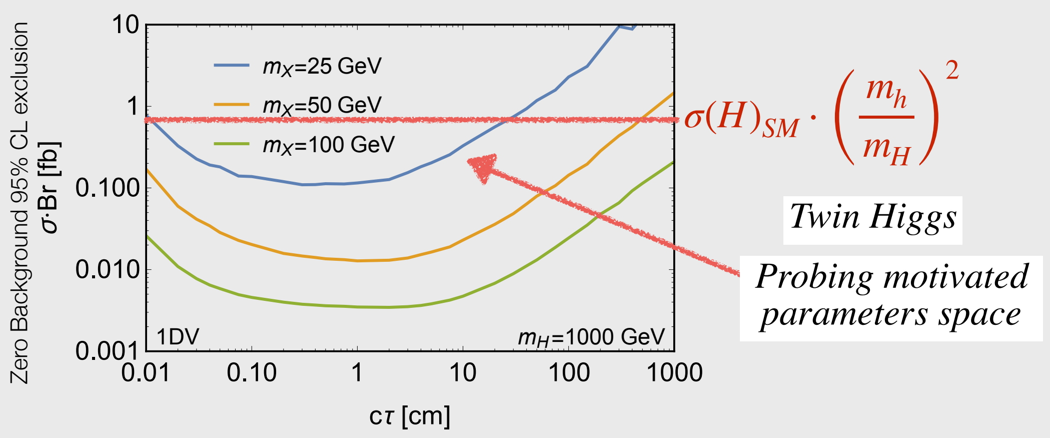
Alipour-Fard, Craig

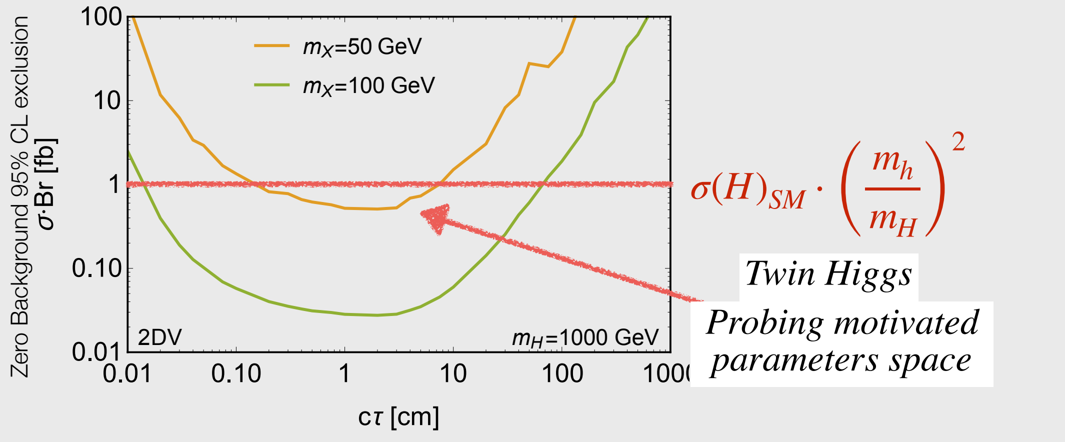
Heavy Higgs Displaced Decay

BASED ON CLICDP-NOTE-2018-001 | $e^+e^- \to H\,\nu\nu$ | $H \to LLP\ LLP$ | $c\beta\gamma\tau_0$ | $LLP \to bb$









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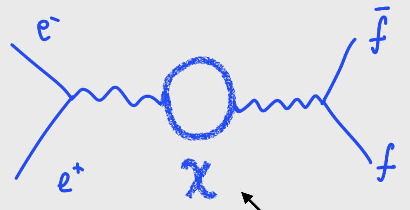
1810.10993 - Di Luzio, Grober, Panico

$e^+e^- \to f\bar{f}$

PRECISION | ANGULAR DISTRIBUTION



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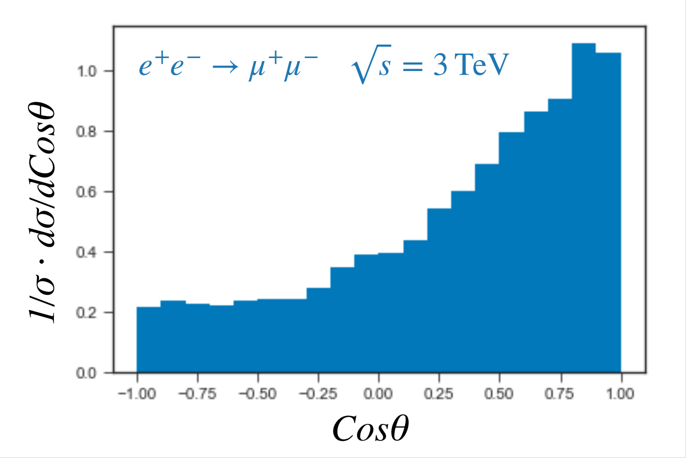

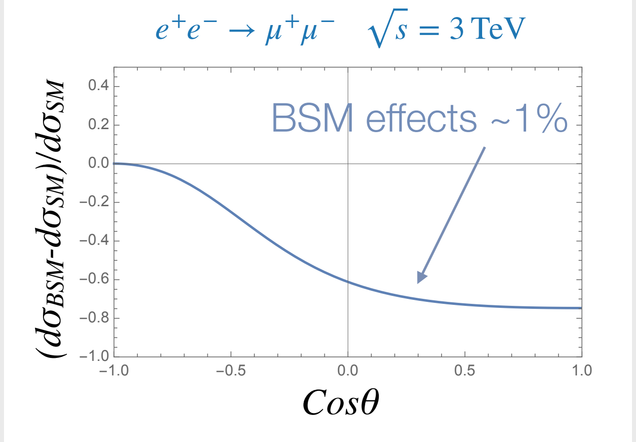

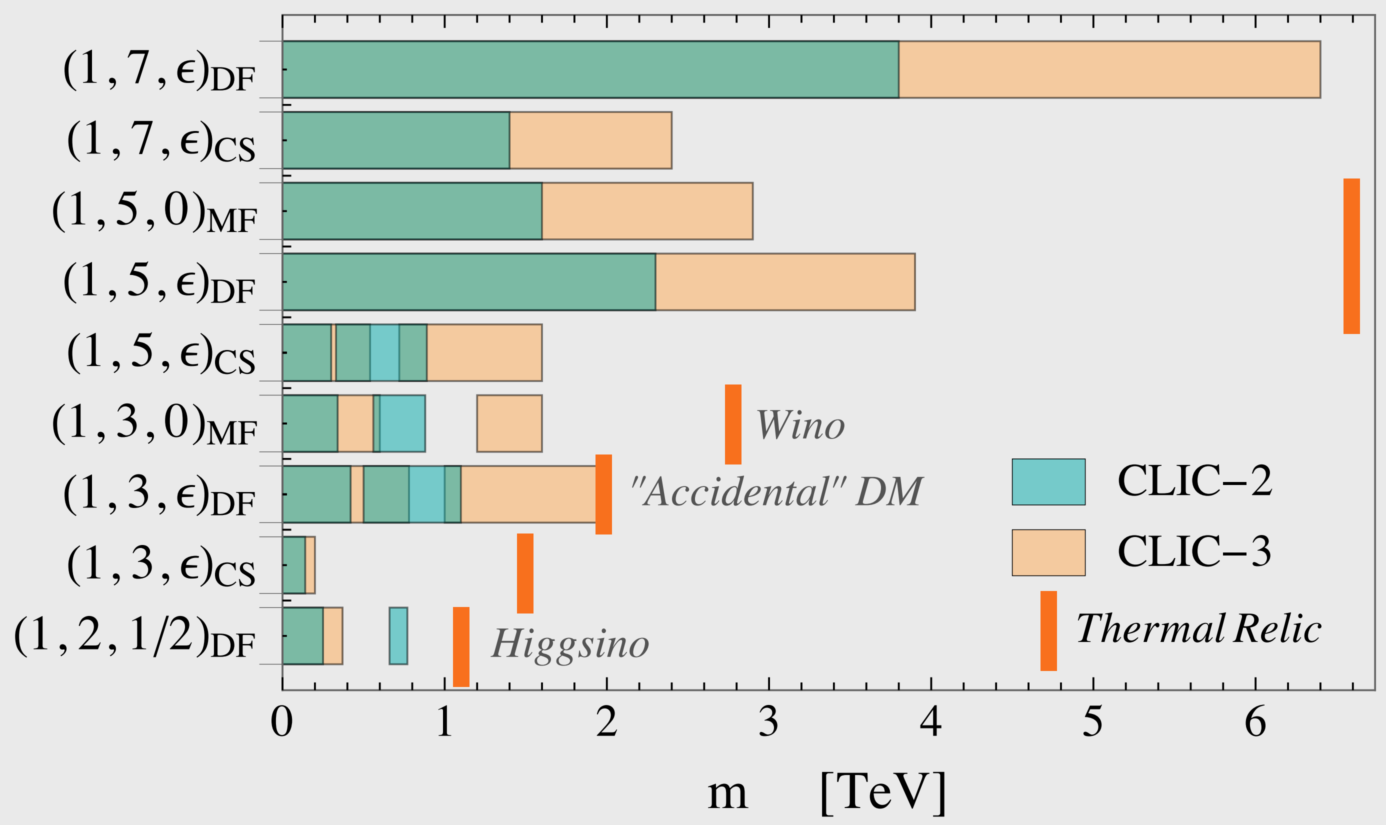

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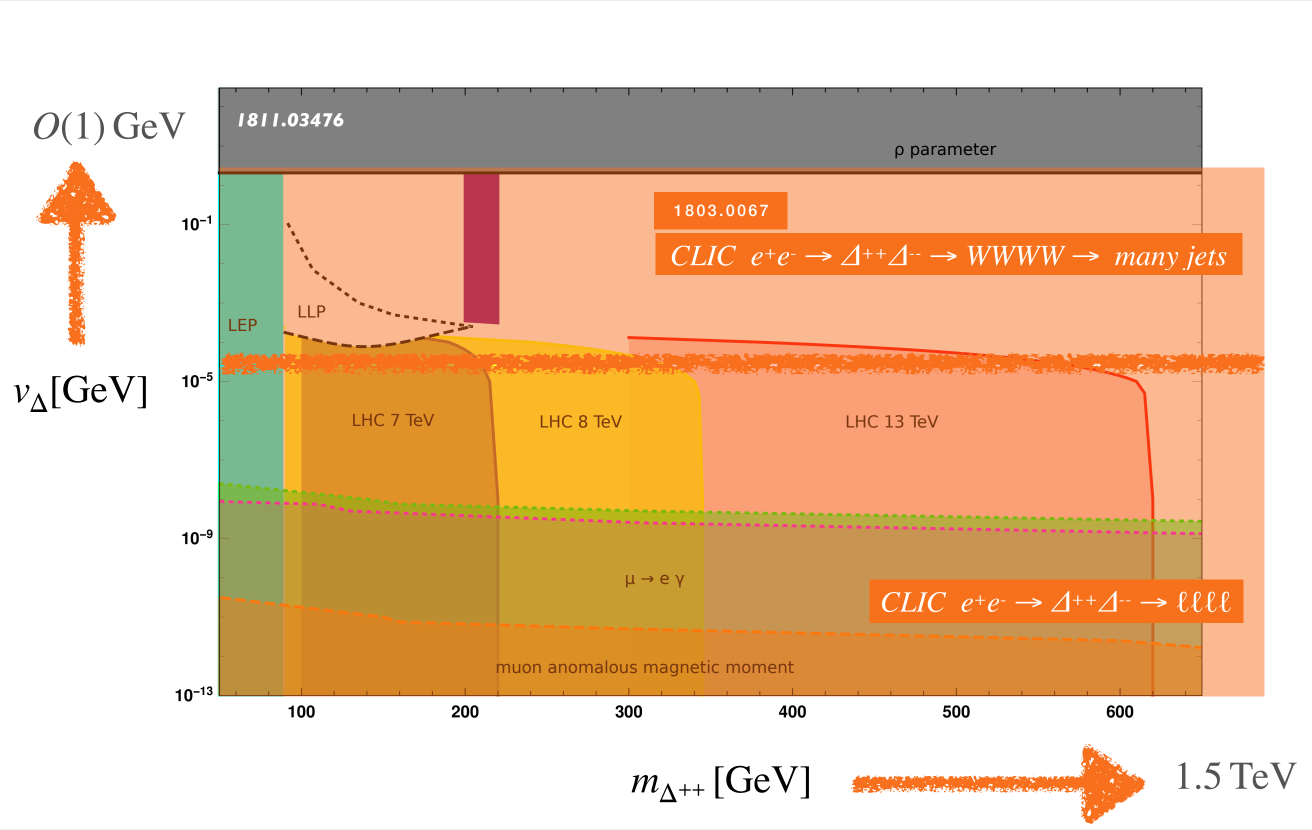

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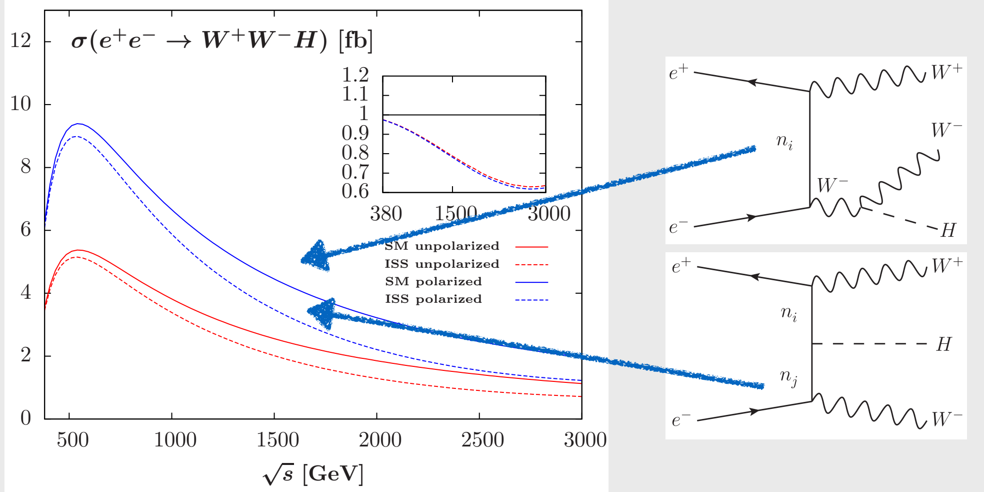

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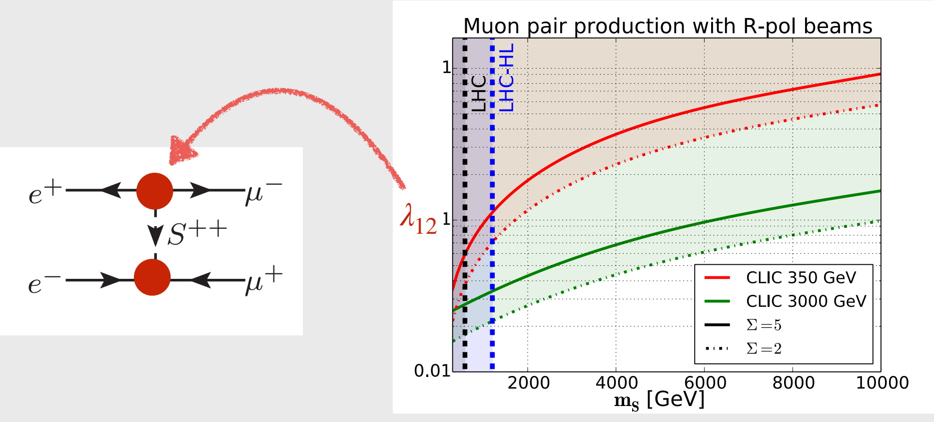

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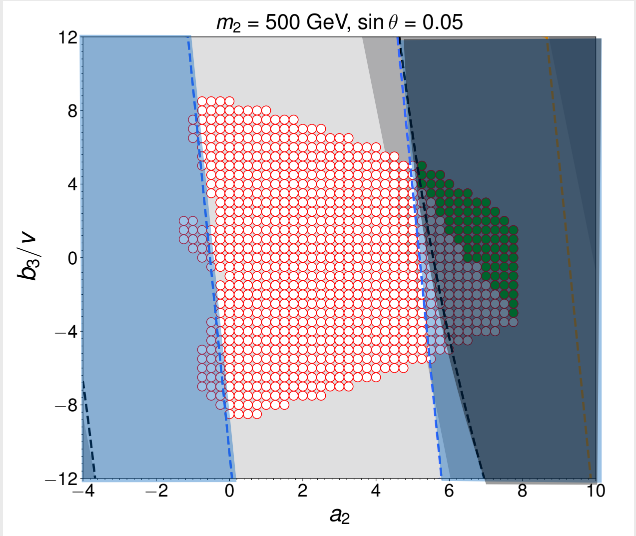

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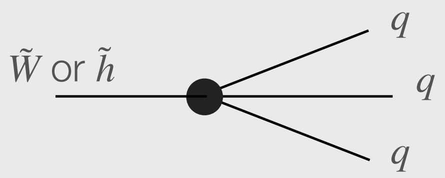
Cui, Joglekar, Liu, and Shuve

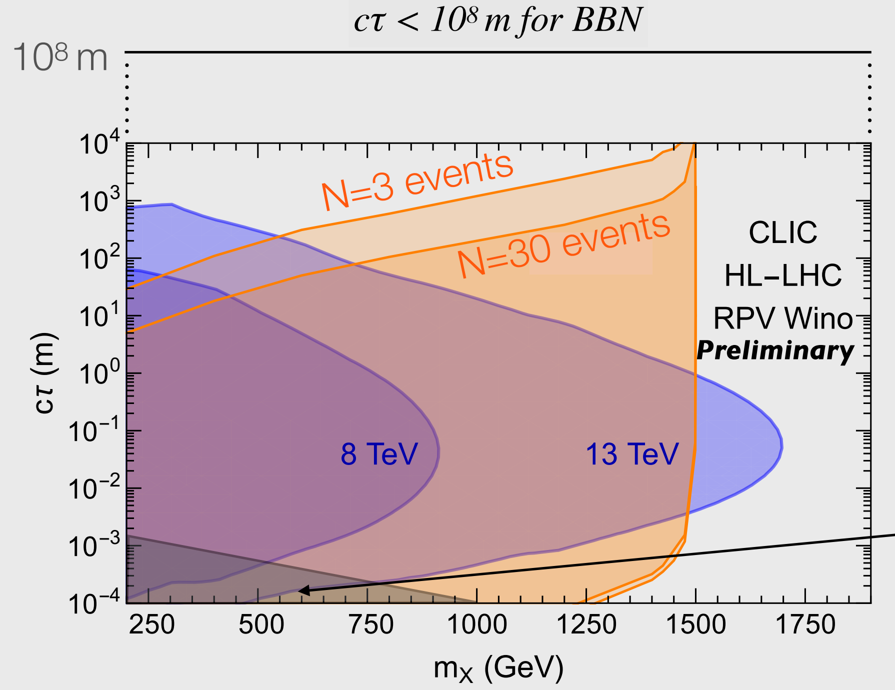
WIMP Baryogenesis



BASED ON CLICDP-NOTE-2018-001 | DISPLACED DECAYS TO HADRONS

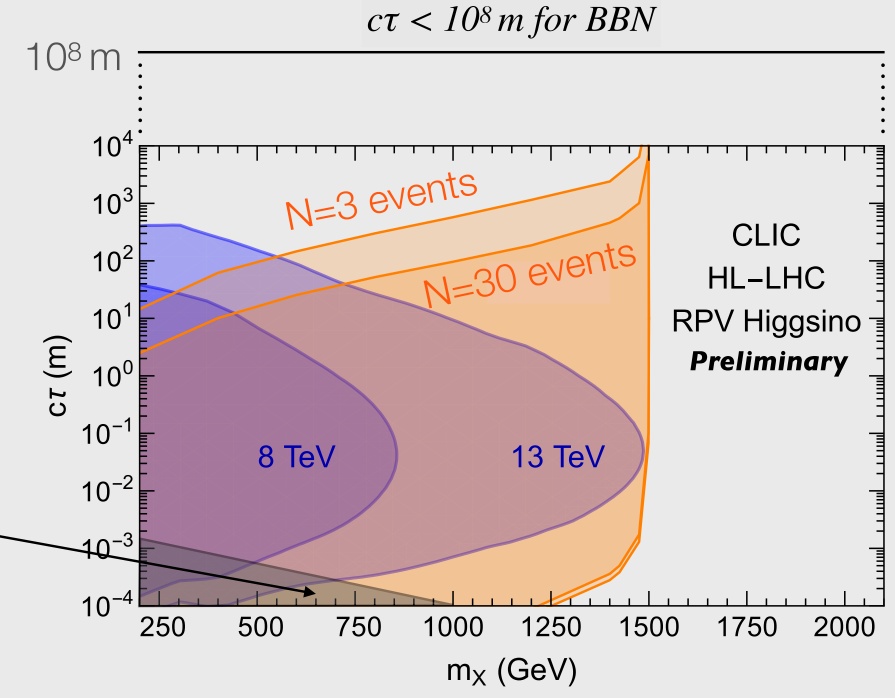
$$e^+e^- \to \chi\chi\,\nu\nu \to \nu\nu + 2\,(DV \to jjj)_\chi$$

assume 100% efficient vertex finder in 3·10⁻³ m < cτ < 0.1 m (CLICdp-Note-2018-001)



Cosmology requires

- before nucleo-synthesis $c\tau_\chi < 10^8 m$
- out-of-equilibrium $\tau_\chi > 1/H(T \sim m_\chi)$



Roberto Franceschini

Conclusions

High energy lepton colliders and new physics

- Higher energy can magnify considerably indirect effects of new physics, allowing to overcome the limitations from systematics in low-energy high intensity experiments

- Indirect and direct probes from TeV scale electroweak new physics are in the reach of high energy lepton colliders

- Luminosity can be traded for energy: more than one “working point” to probe new physics in the $\mathscr{L} - \sqrt{s}$ plane

- Thorough exploration of TeV scale physics and possible extension to even higher energy with novel acceleration techniques

About to flip page…

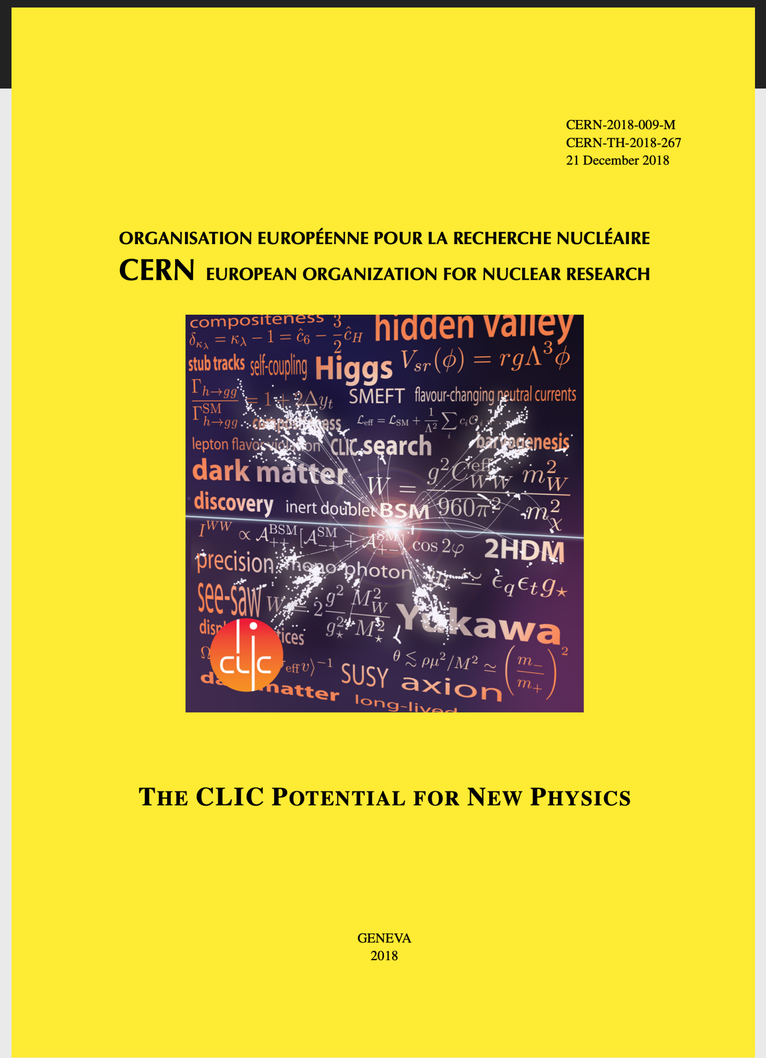
- The traditional paradigm where *pp* are discovery machines and $\ell^+\ell^-$ are measurement machines may be close to break down.

- Leptons beam quality and quantum structure enables *qualitatively new investigations* of the electroweak/Higgs sector

- Probes at high momentum transfer hugely enhanced by large available energy: e.g. Higgs compositeness at tens of TeV (similar advantage for any EFT)

- Direct reach for "anything" with electroweak charge or coupled to the Higgs boson in the kinematic reach

Thank you!


CERN-2018-009-M
CERN-TH-2018-267
21 December 2018

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

THE CLIC POTENTIAL FOR NEW PHYSICS

GENEVA
2018

Thank you!

1812.02093 - The CLIC potential for new physics - CERN Yellow Rep. Monogr. Vol. 3 (2018)

Contributors: *S. Alipour-Fard* [1], *W. Altmannshofer* [2], *A. Azatov* [3,4], *D. Azevedo* [5,6], *J. Baglio* [7], *M. Bauer* [8], *F. Bishara* [9,10], *J.-J. Blaising* [11], *S. Brass* [12], *D. Buttazzo* [13], *Z. Chacko* [14,15], *N. Craig* [1], *Y. Cui* [16], *D. Dercks* [9,17], *L. Di Luzio* [8,13,18], *S. Di Vita* [19], *G. Durieux* [9,20], *J. Fan* [21], *P. Ferreira* [5,22], *C. Frugiuele* [23], *E. Fuchs* [23], *I. García* [24,25], *M. Ghezzi* [7,26], *A. Greljo* [25], *R. Gröber* [8,27], *C. Grojean* [9,27], *J. Gu* [28], *R. Hunter* [29], *A. Joglekar* [16], *J. Kalinowski* [30], *W. Kilian* [12], *C. Kilic* [31], *W. Kotlarski* [32], *M. Kucharczyk* [33], *E. Leogrande* [25], *L. Linssen* [25], *D. Liu* [34], *Z. Liu* [14,15], *D. M. Lombardo* [35], *I. Low* [34,36], *O. Matsedonskyi* [23], *D. Marzocca* [4], *K. Mimasu* [37], *A. Mitov* [38], *M. Mitra* [39], *G. Moortgat-Pick* [9,17], *M. Mühlleitner* [40], *S. Najjari* [41], *M. Nardecchia* [4,25], *M. Neubert* [28,42], *J. M. No* [43], *G. Panico* [9,44,45,46], *L. Panizzi* [47,48], *A. Paul* [9,27], *M. Perelló* [24], *G. Perez* [23], *A. D. Plascencia* [8], *G. M. Pruna* [49], *D. Redigolo* [23,50,51], *M. Reece* [52], *J. Reuter* [9], *M. Riembau* [36], *T. Robens* [53,54], *A. Robson* [25,55], *K. Rolbiecki* [31], *A. Sailer* [25], *K. Sakurai* [31], *F. Sala* [9], *R. Santos* [5,22], *M. Schlaffer* [23], *S. Y. Shim* [56], *B. Shuve* [16,57], *R. Simoniello* [25,58], *D. Sokołowska* [30,59], *R. Ström* [25], *T. M. P. Tait* [60], *A. Tesi* [46], *A. Thamm* [25], *N. van der Kolk* [61], *T. Vantalon* [9], *C. B. Verhaaren* [62], *M. Vos* [24], *N. Watson* [63], *C. Weiland* [8,64], *A. Winter* [63], *J. Wittbrodt* [9], *T. Wojton* [33], *B. Xu* [38], *Z. Yin* [36], *A. F. Żarnecki* [30], *C. Zhang* [65]

J. De Blas, R. Franceschini, F. Riva, P. Roloff, U. Schnoor, M. Spannowsky, A. Wulzer, J. Wells, J. Zupan

http://clicdp.web.cern.ch/content/wg-physics-potential

Lumi vs. Energy

EFT EPOCH

LESSON FROM LHC

New Physics may fit well in a EFT (new contact interactions)

- effects grow at larger energies like νe⁻→νe⁻ in Fermi Theory

$$m_W, m_Z, \sin\theta_W, A_{FB}^{whatever}, h \to Z\gamma, h \to ZZ, t \to b\tau\nu$$

measurements dominated by a single mass scale

- dominant energy scale is low
- measurement is simple to grasp
- progress is easy to measure (in)significant digits

$$\frac{d\sigma}{dp_T}$$

measurements sensitive to a range of mass scales

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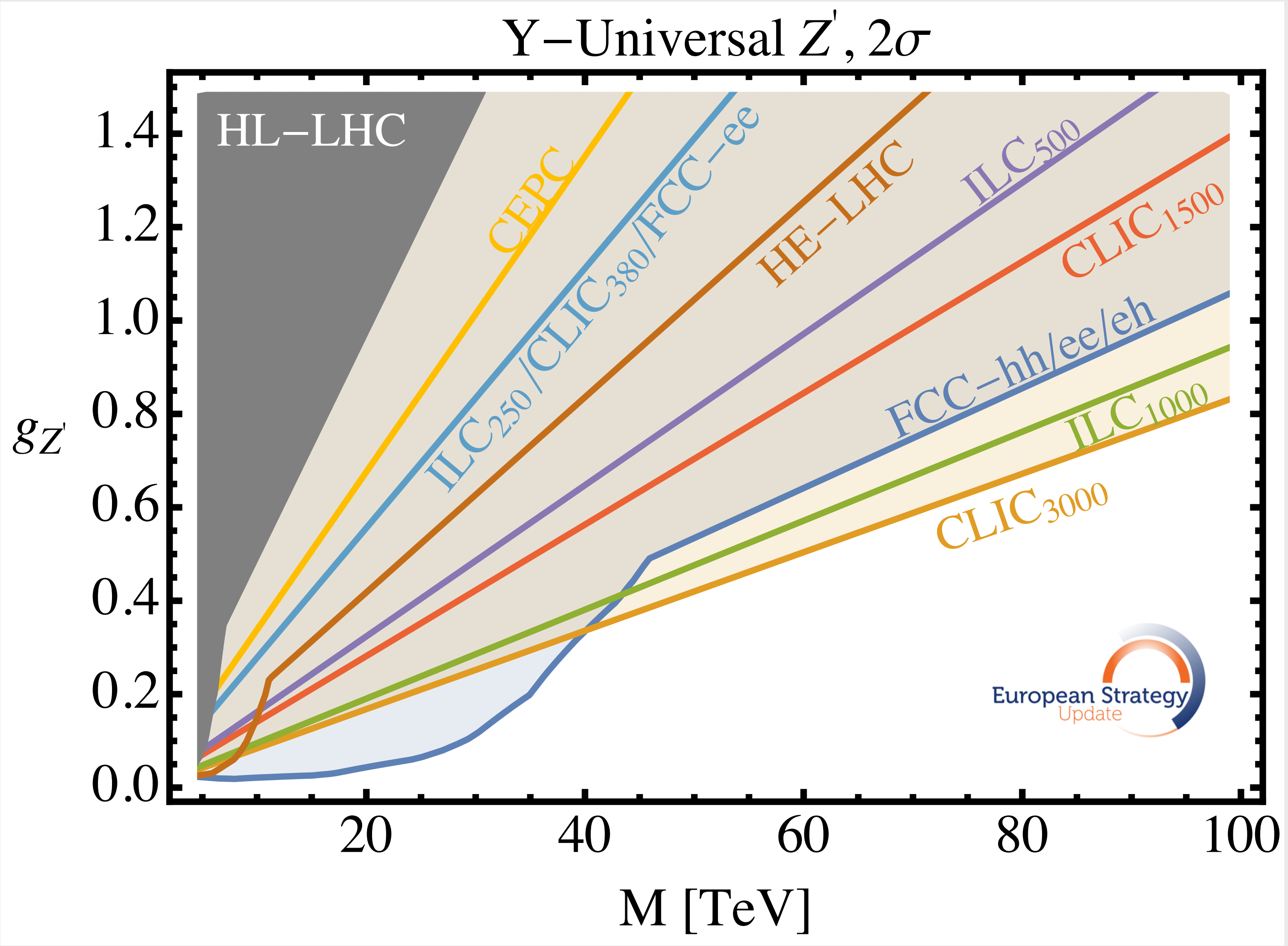
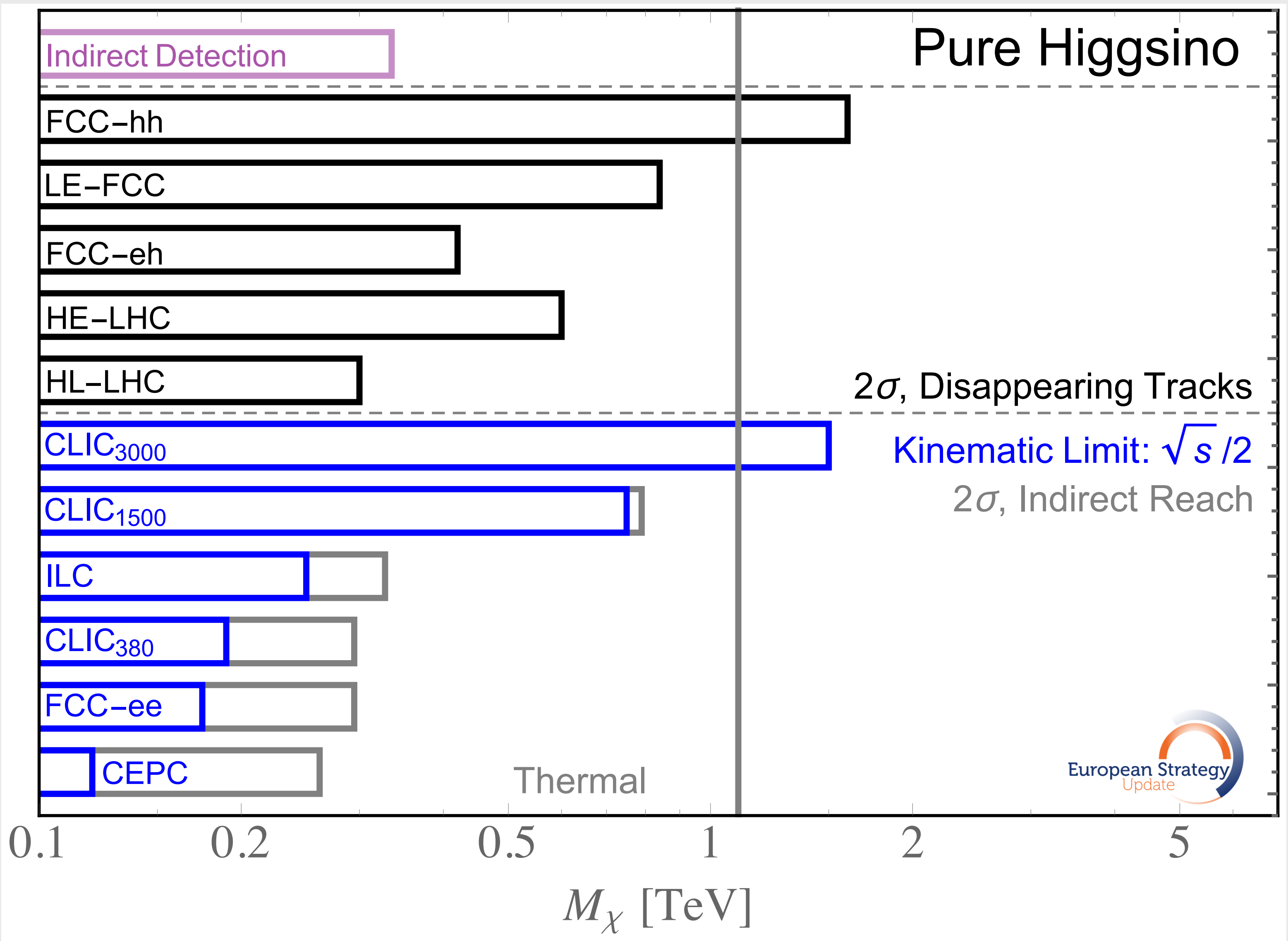
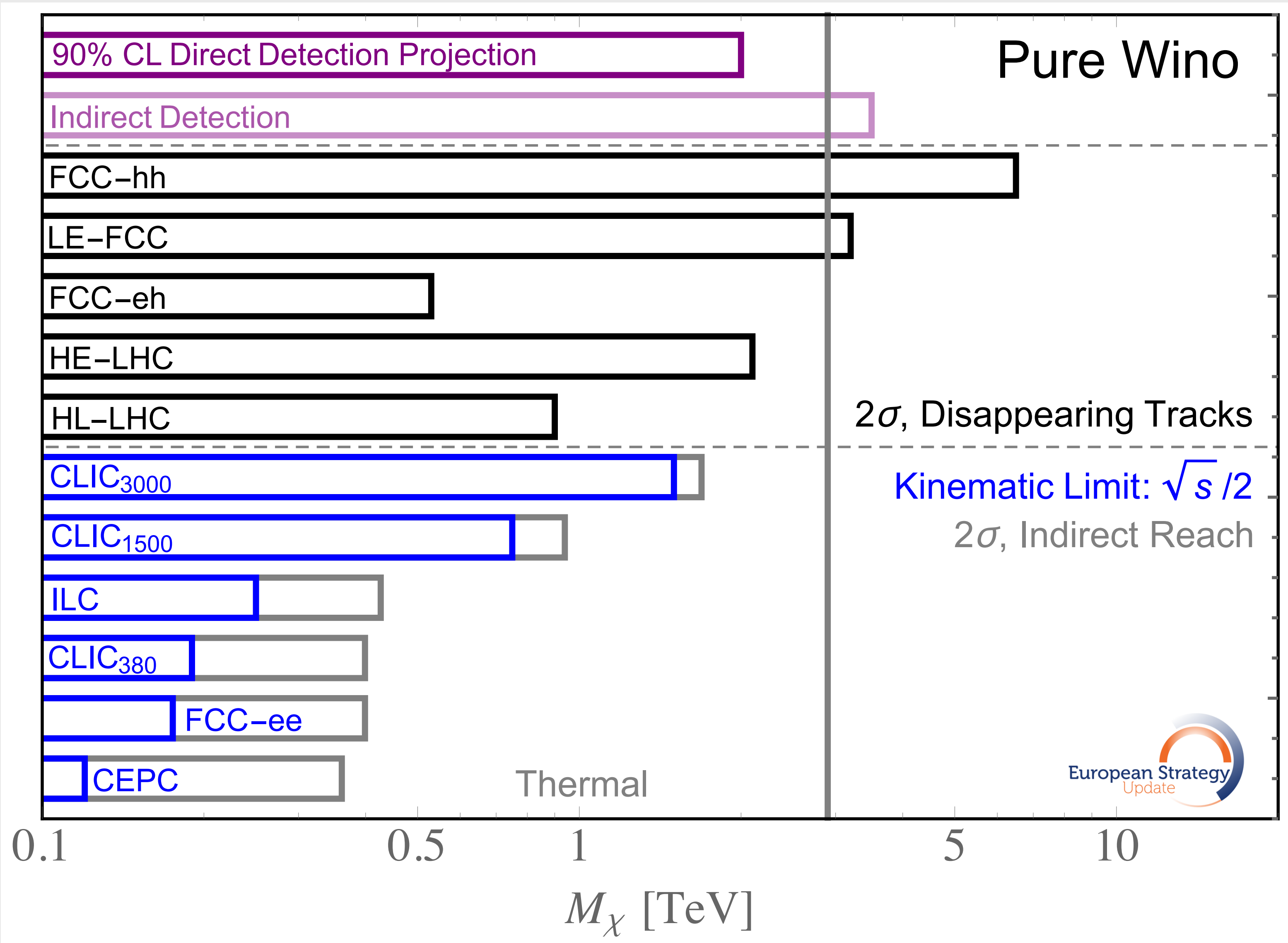
as NP effects may grow quadratically with energy

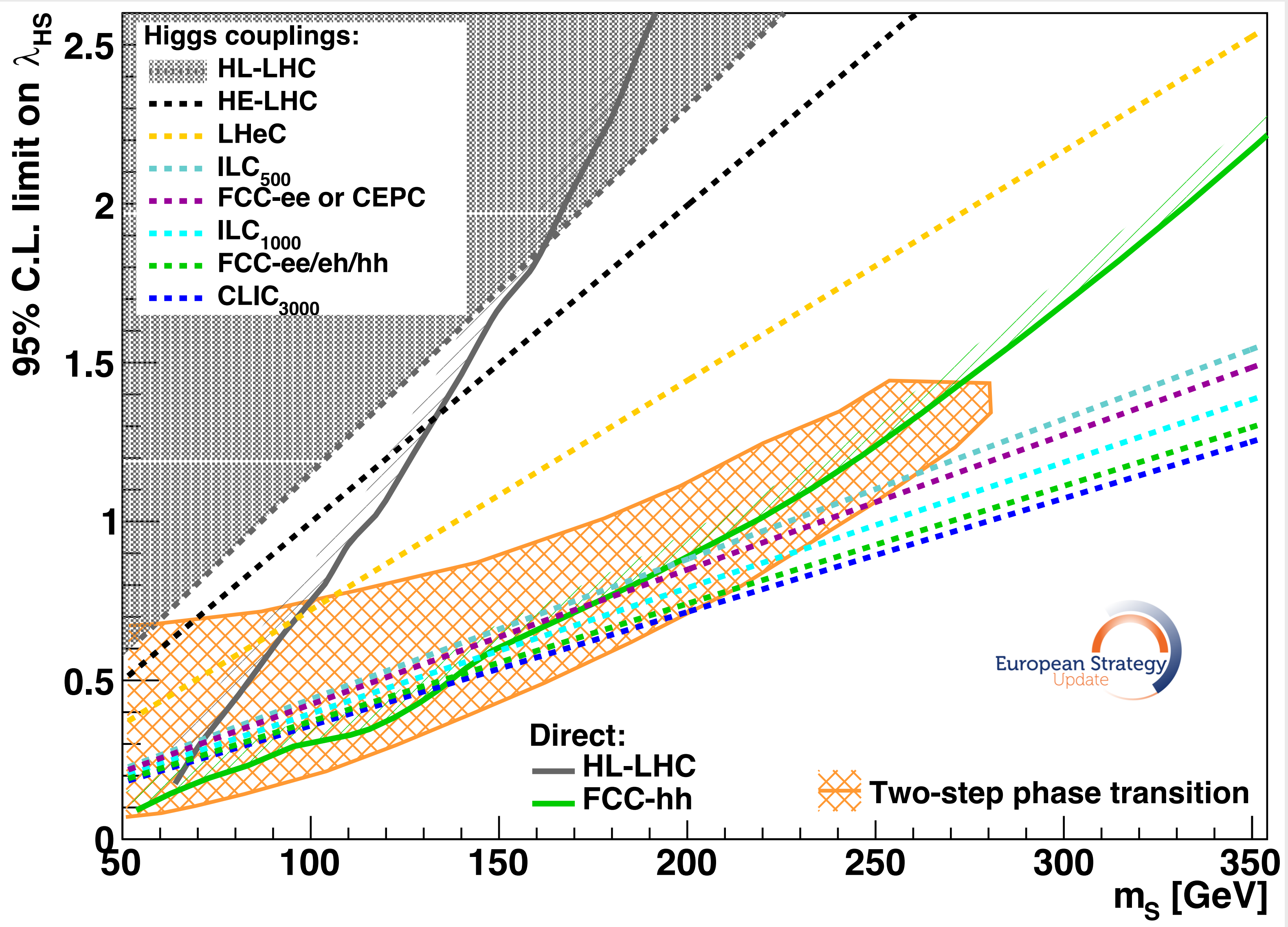
$$\Delta O = O_{NP} - O_{SM} \sim \left(\frac{E}{v}\right)^2$$

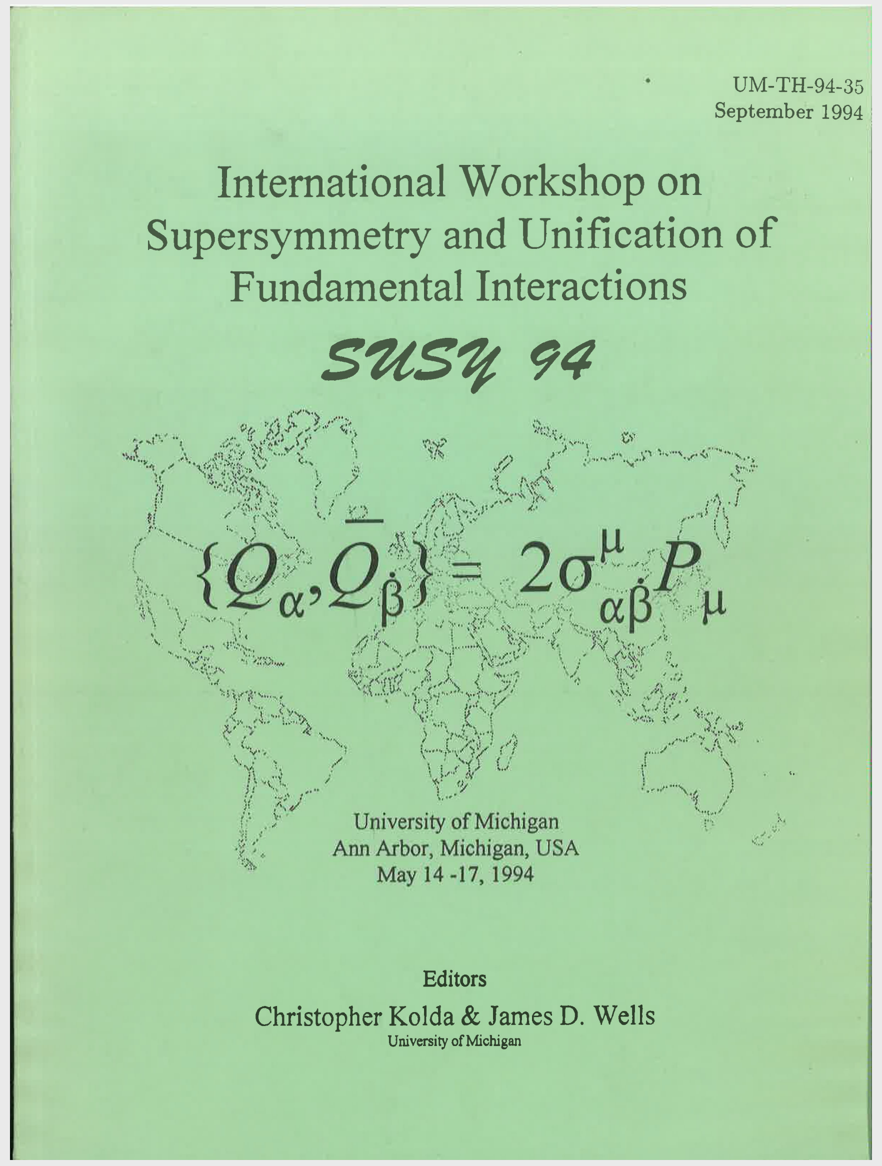
1% at m_Z is worse than 10% at 1 TeV










UM-TH-94-35
September 1994

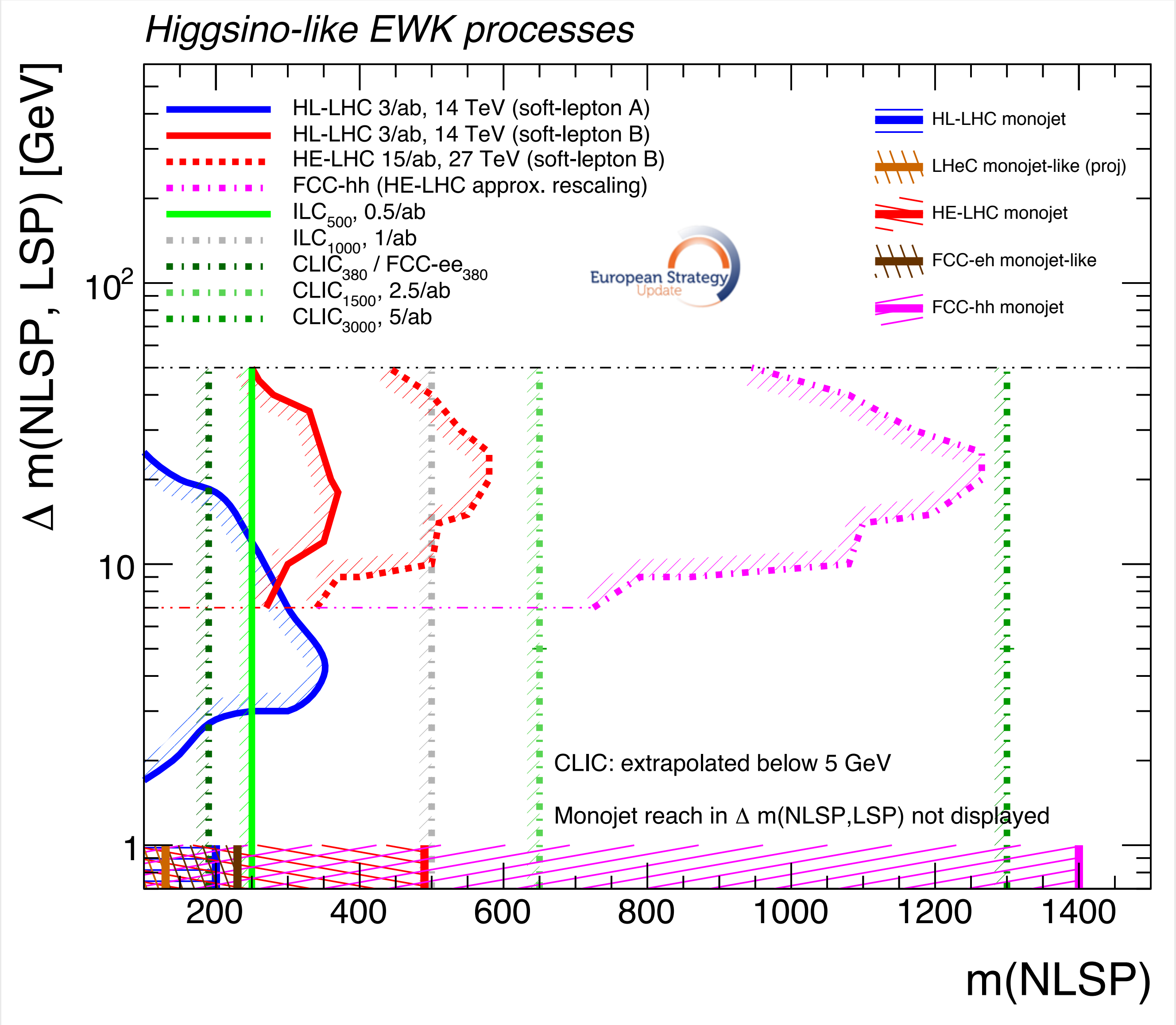
International Workshop on
Supersymmetry and Unification of
Fundamental Interactions

SUSY 94

$\{Q_\alpha, \bar{Q}_{\dot\beta}\} = 2\sigma^{\mu}_{\alpha\dot\beta} P_\mu$

University of Michigan
Ann Arbor, Michigan, USA
May 14 -17, 1994

Editors
Christopher Kolda & James D. Wells
University of Michigan



$e^+e^- \to f\bar{f}$

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χ	$m_\chi^{(\mathrm{DM})}$ [TeV]	$m_\chi^{(\mathrm{CLIC-3})}$ [TeV]
$(1,2,1/2)_{\mathrm{DF}}$	1.1	1.5
$(1,3,\epsilon)_{\mathrm{CS}}$	1.55	-
$(1,3,\epsilon)_{\mathrm{DF}}$	2.0	2.1 ✷
$(1,3,0)_{\mathrm{MF}}$	2.8	1.7
$(1,5,\epsilon)_{\mathrm{CS}}$	6.6	1.7
$(1,5,\epsilon)_{\mathrm{DF}}$	6.6	4.1
$(1,5,0)_{\mathrm{MF}}$	11	3.0
$(1,7,\epsilon)_{\mathrm{CS}}$	16	2.5
$(1,7,\epsilon)_{\mathrm{DF}}$	16	6.8

Higgsino of split-SUSY (heavy sfermions)

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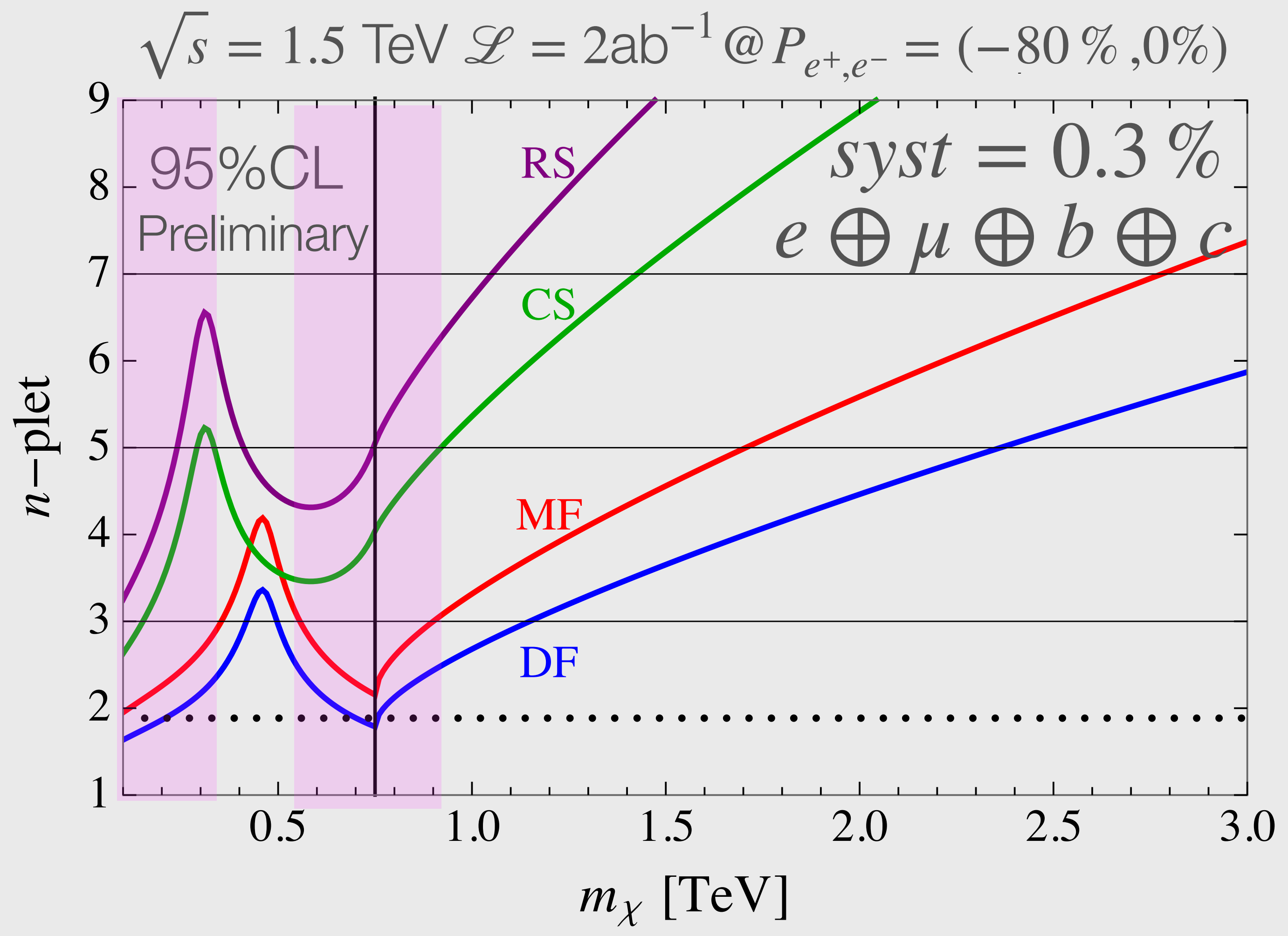
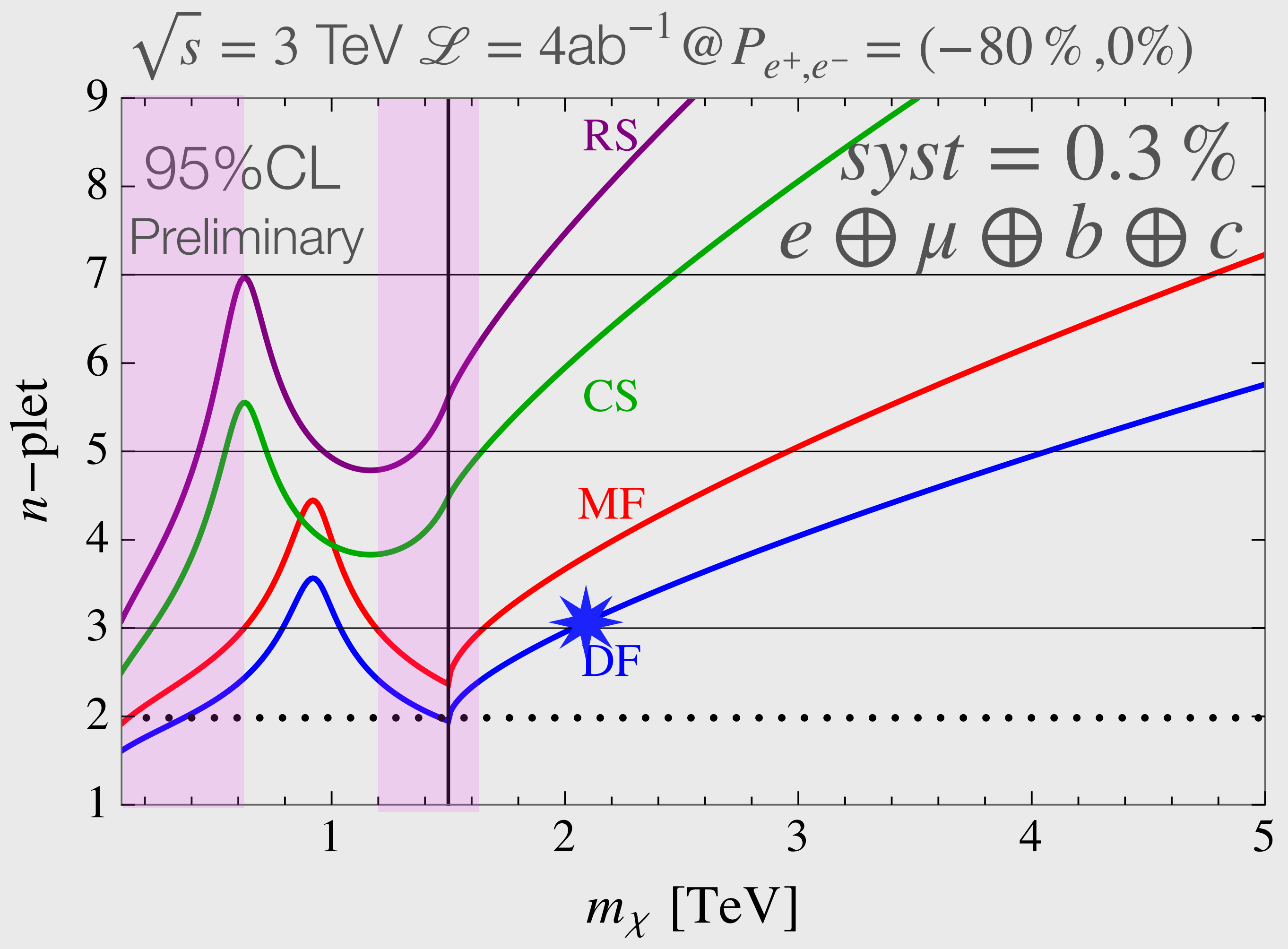
Accidental Dark Matter 3-plet Dirac Fermion





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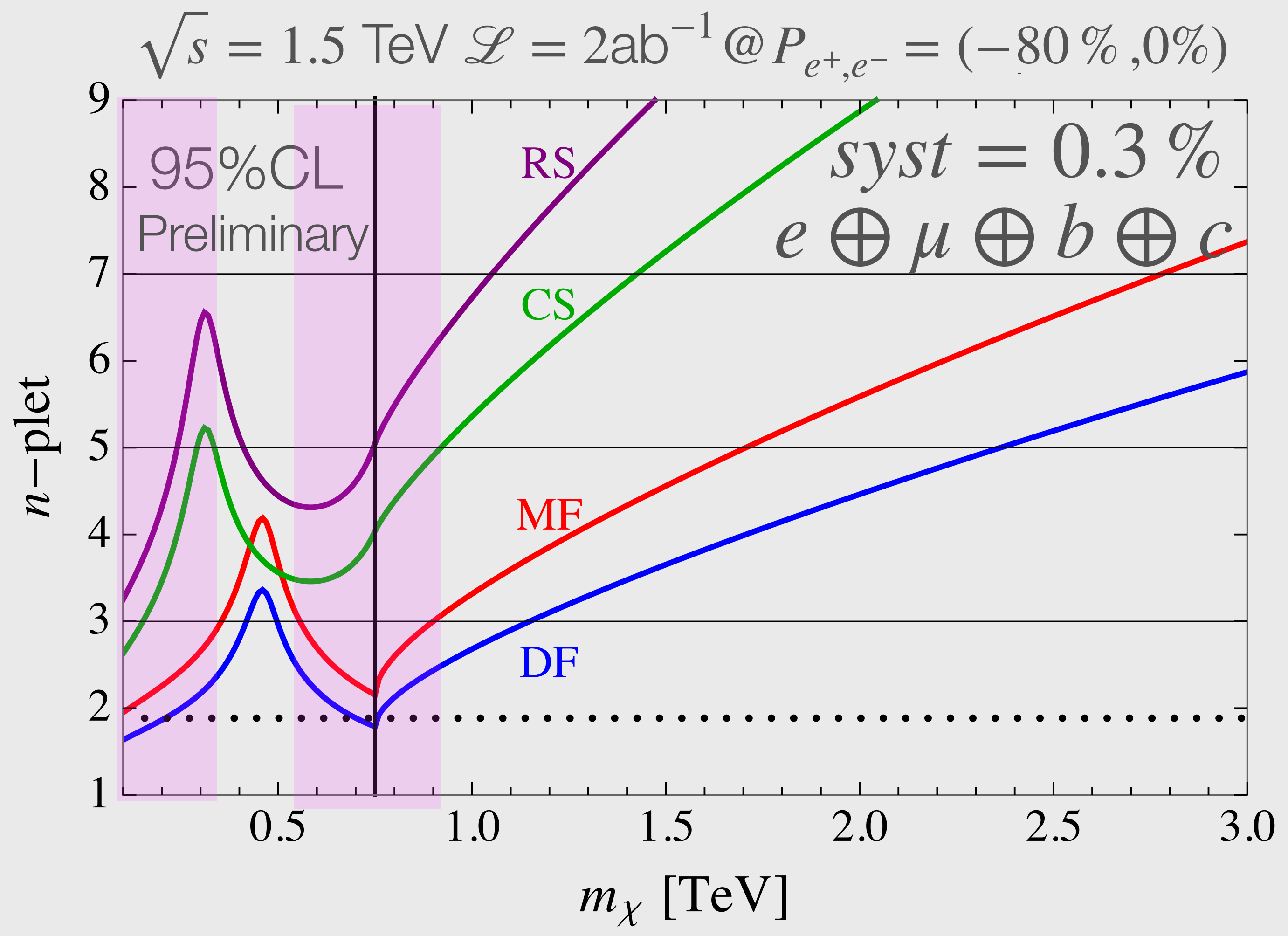

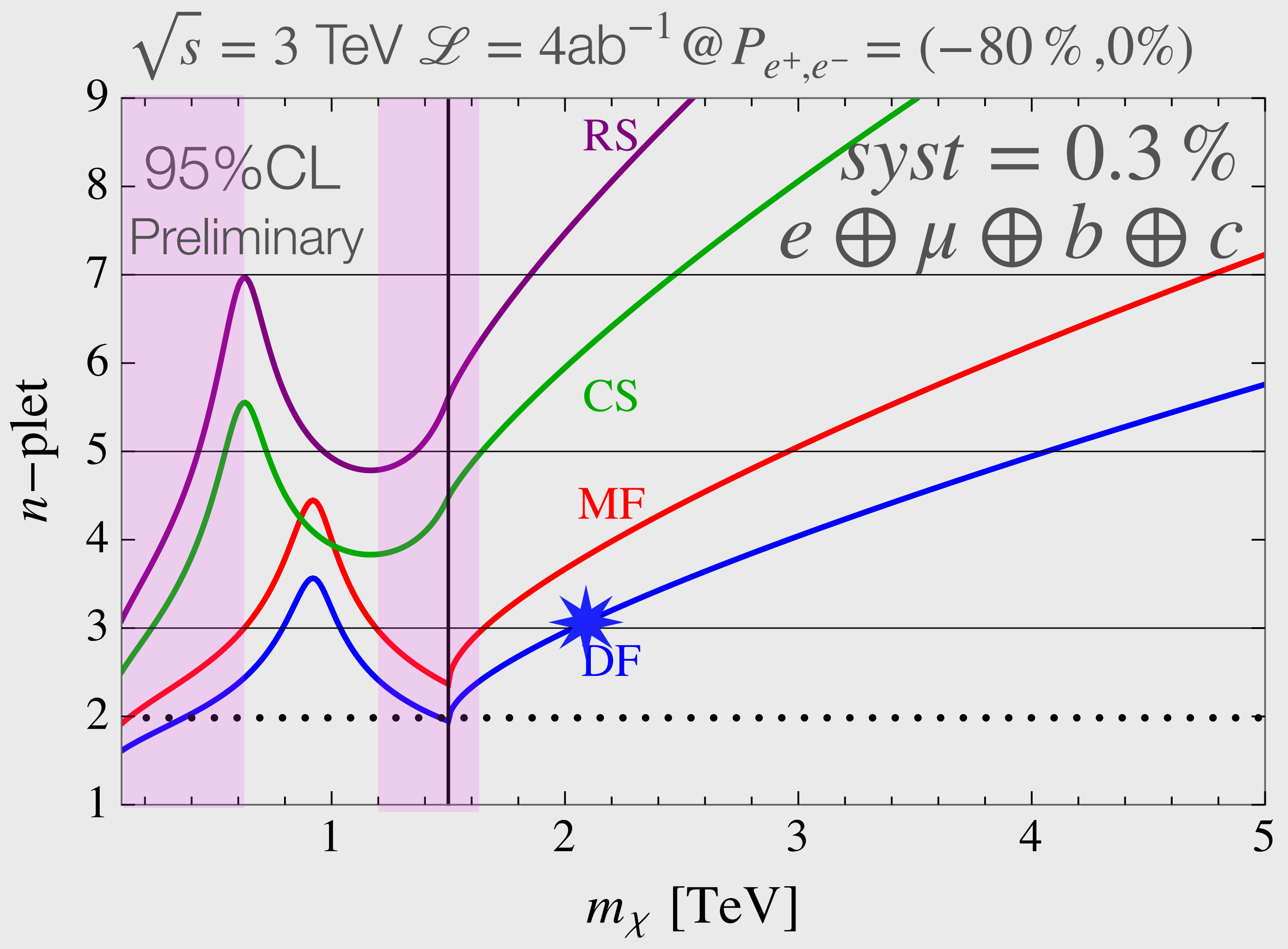

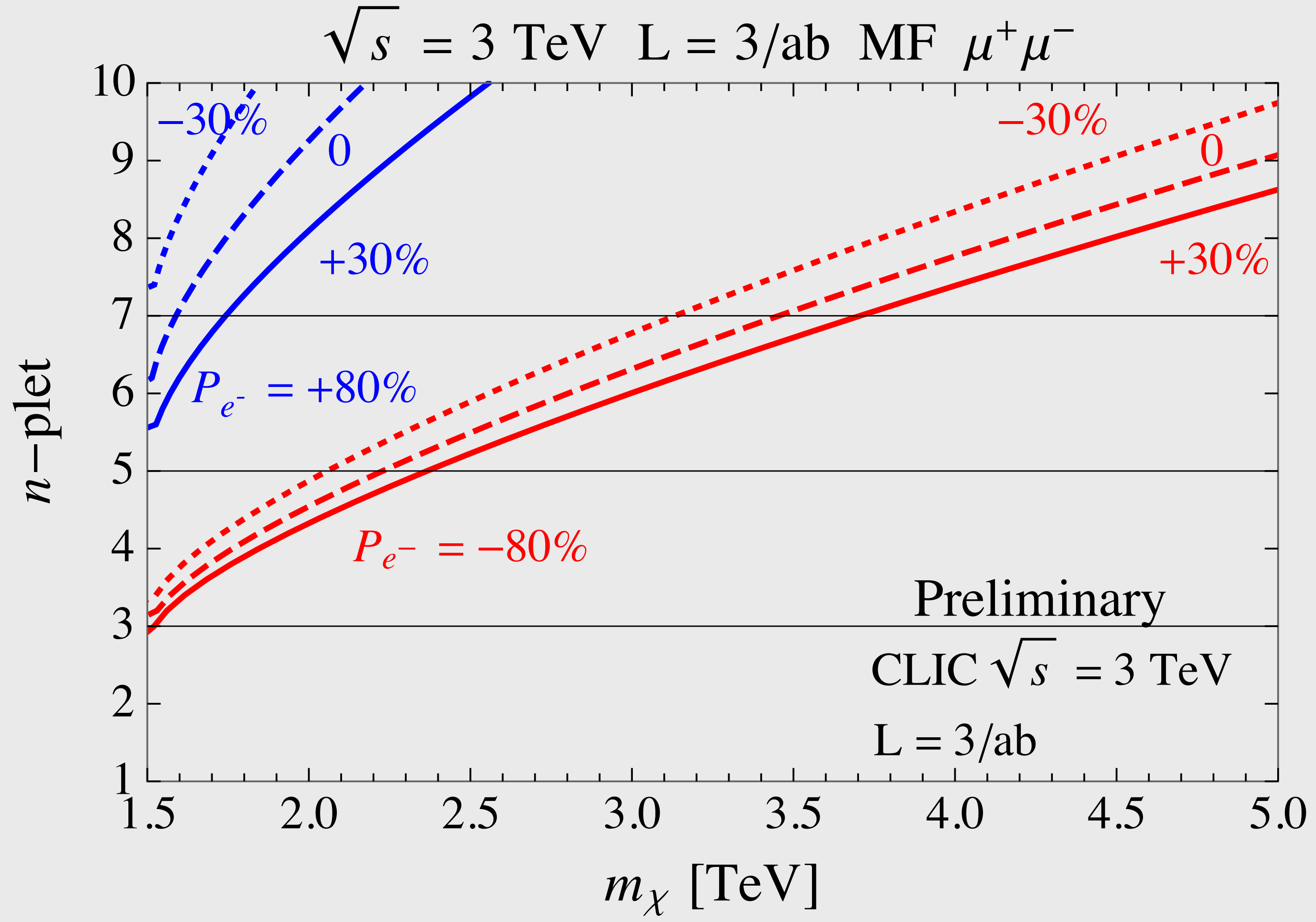

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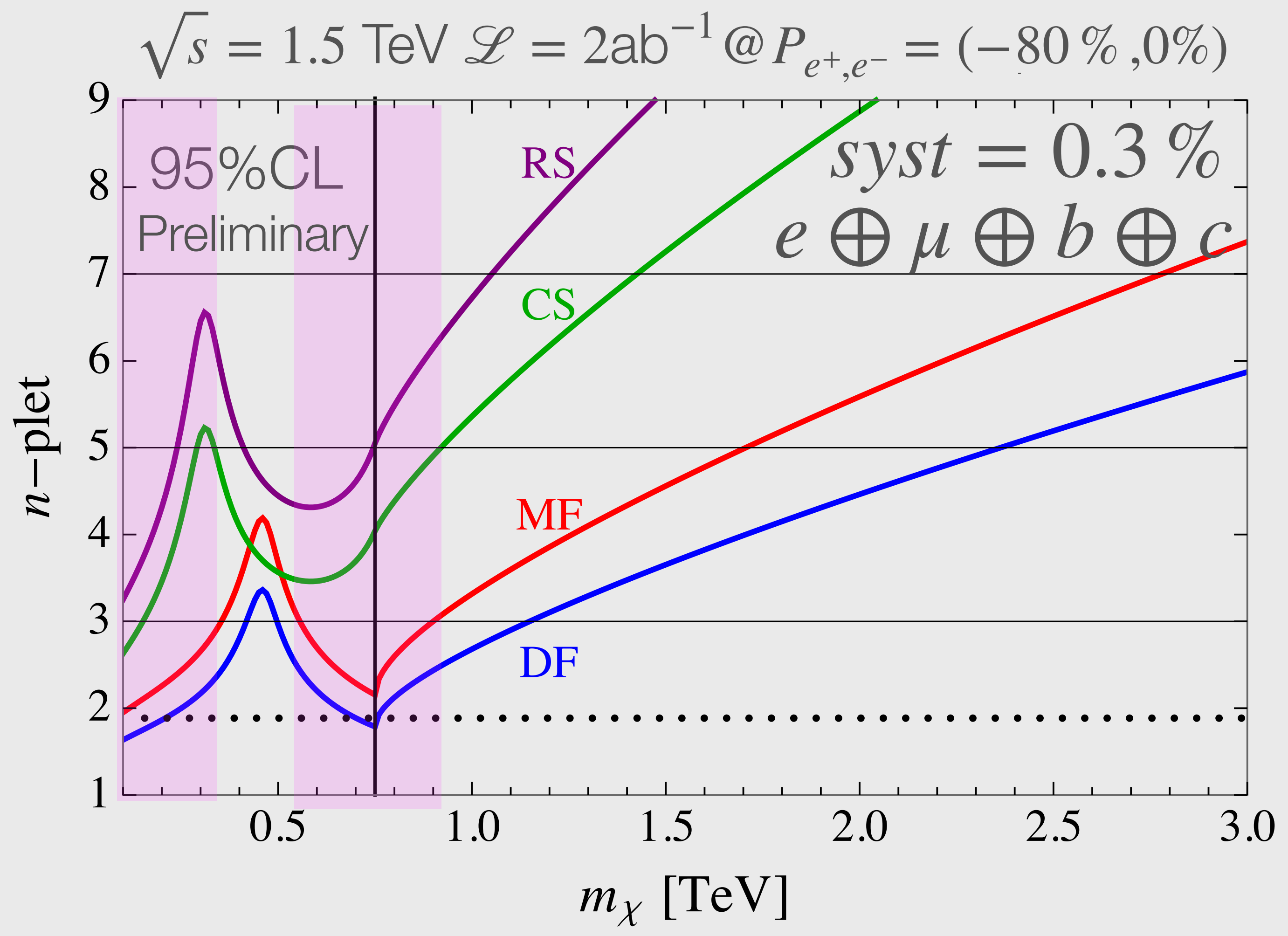
$(1,3,0)_{\mathrm{MF}}$	2.8	1.7
$(1,5,\epsilon)_{\mathrm{CS}}$	6.6	1.7
$(1,5,\epsilon)_{\mathrm{DF}}$	6.6	4.1
$(1,5,0)_{\mathrm{MF}}$	11	3.0
$(1,7,\epsilon)_{\mathrm{CS}}$	16	2.5
$(1,7,\epsilon)_{\mathrm{DF}}$	16	6.8

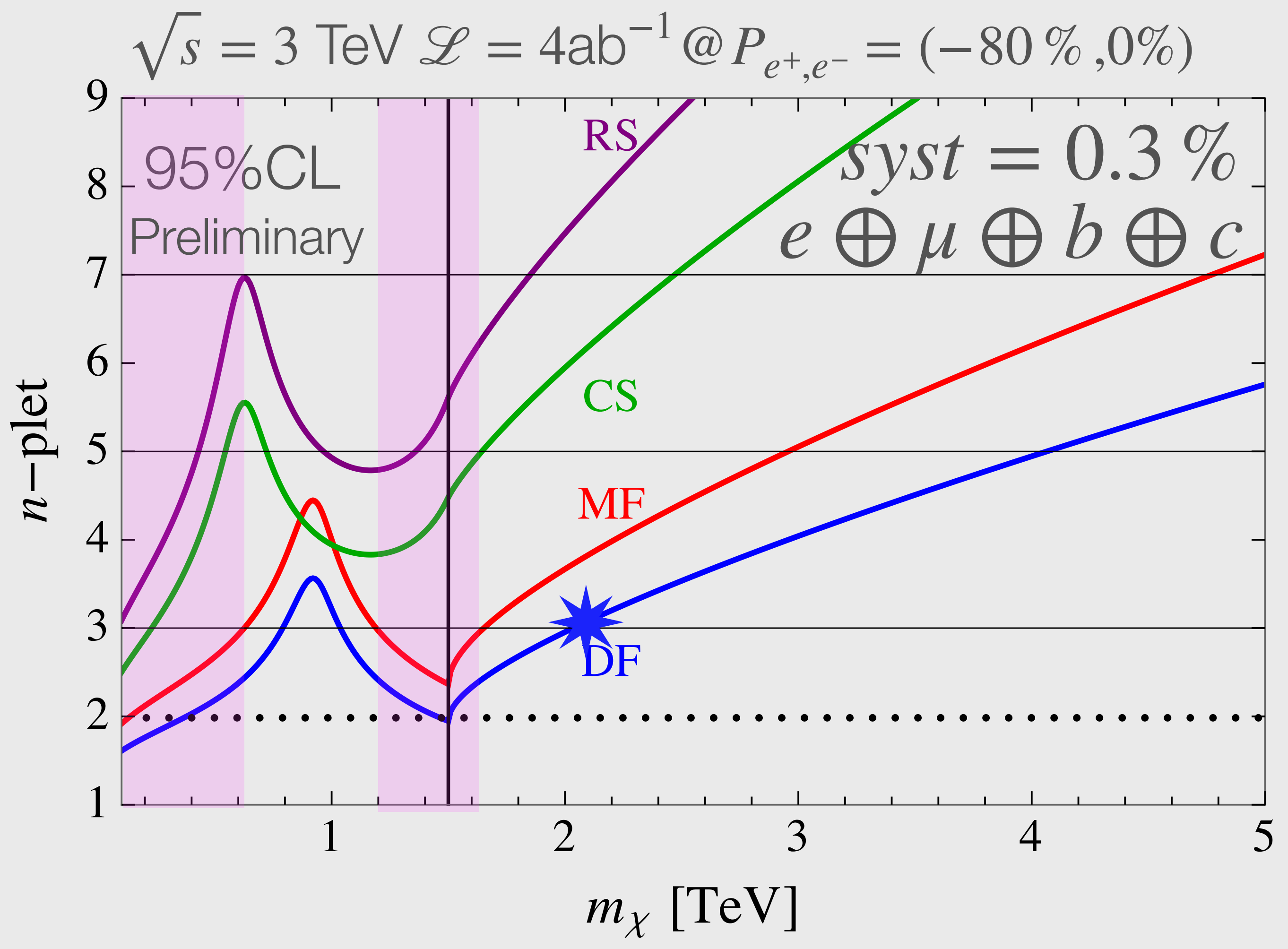
Higgsino of split-SUSY (heavy sfermions)

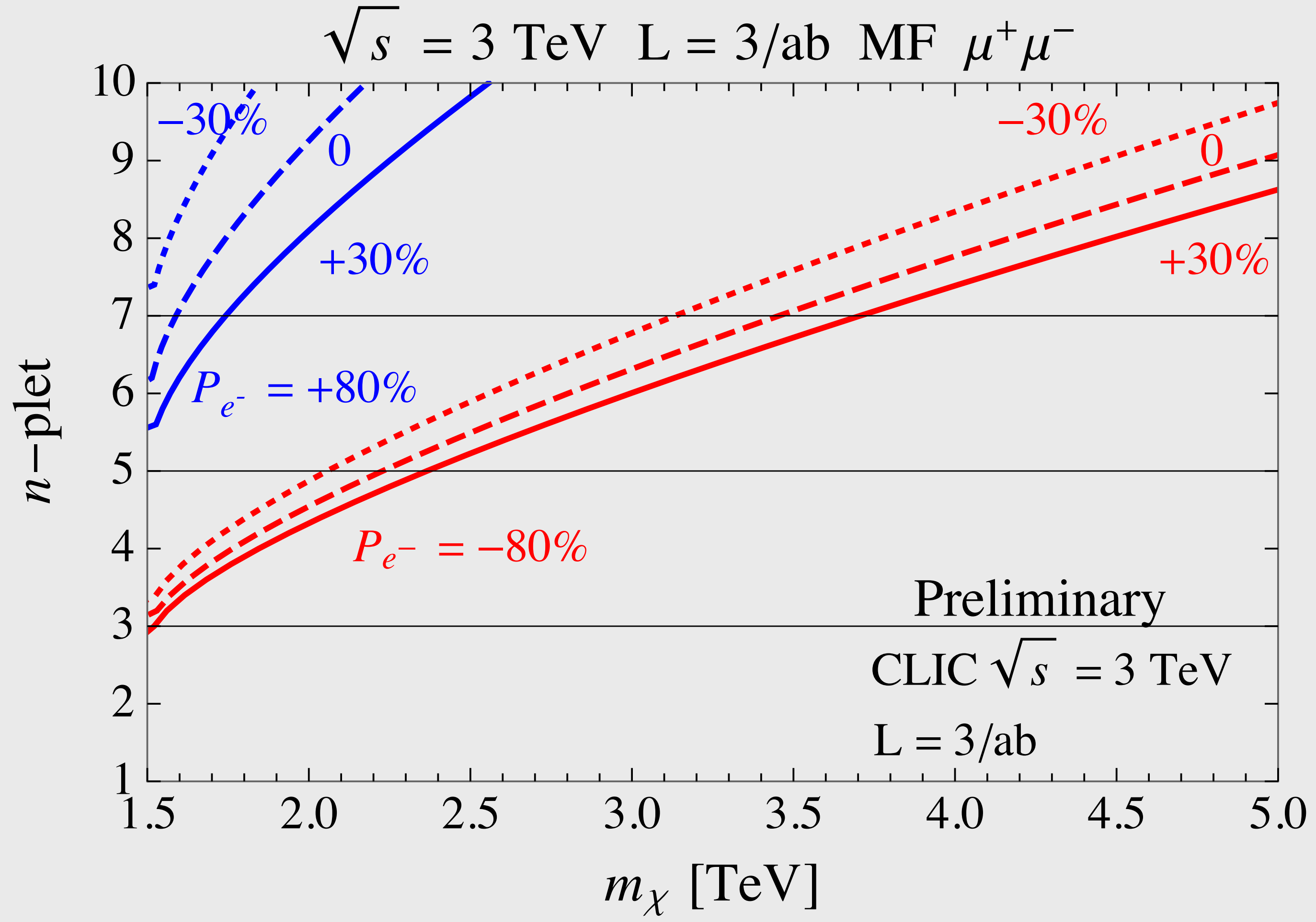
Wino of split-SUSY (heavy sfermions)

Accidental Dark Matter 3-plet Dirac Fermion

Polarization is very advantageous







$e^+e^- \to f\bar{f}$

PRECISION

ANGULAR DISTRIBUTION

χ	$m_\chi^{(DM)}$ [TeV]	$m_\chi^{(CLIC-3)}$ [TeV]
$(1,2,1/2)_{DF}$	1.1	1.5
$(1,3,\epsilon)_{CS}$	1.55	-
$(1,3,\epsilon)_{DF}$	2.0	2.1 ✷
$(1,3,0)_{MF}$	2.8	1.7
$(1,5,\epsilon)_{CS}$	6.6	1.7
$(1,5,\epsilon)_{DF}$	6.6	4.1
$(1,5,0)_{MF}$	11	3.0
$(1,7,\epsilon)_{CS}$	16	2.5
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