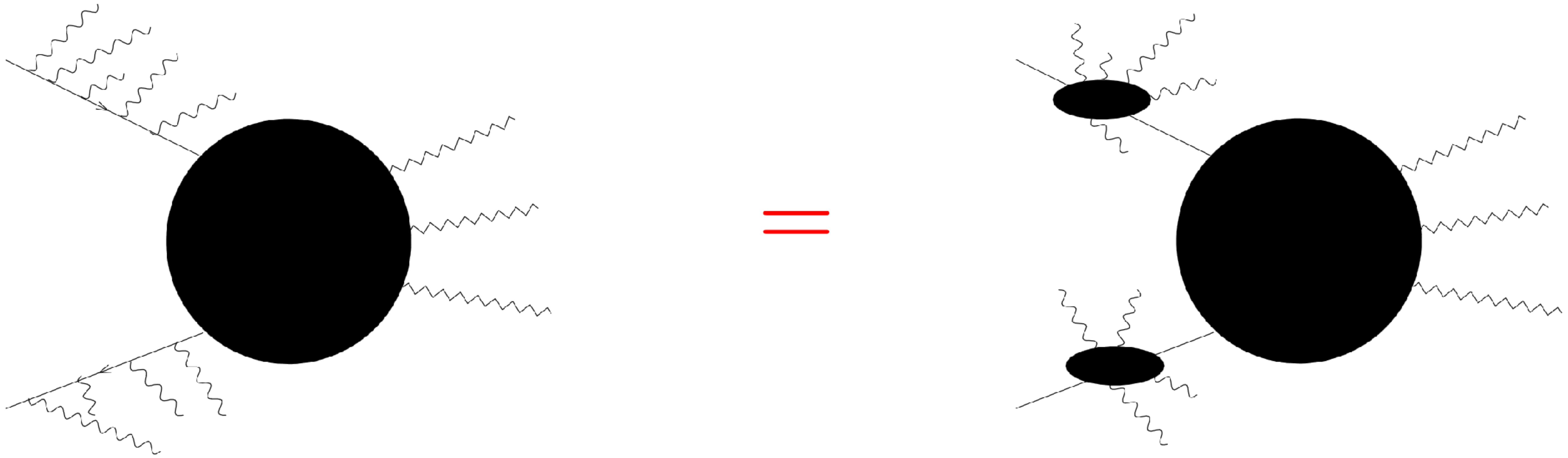
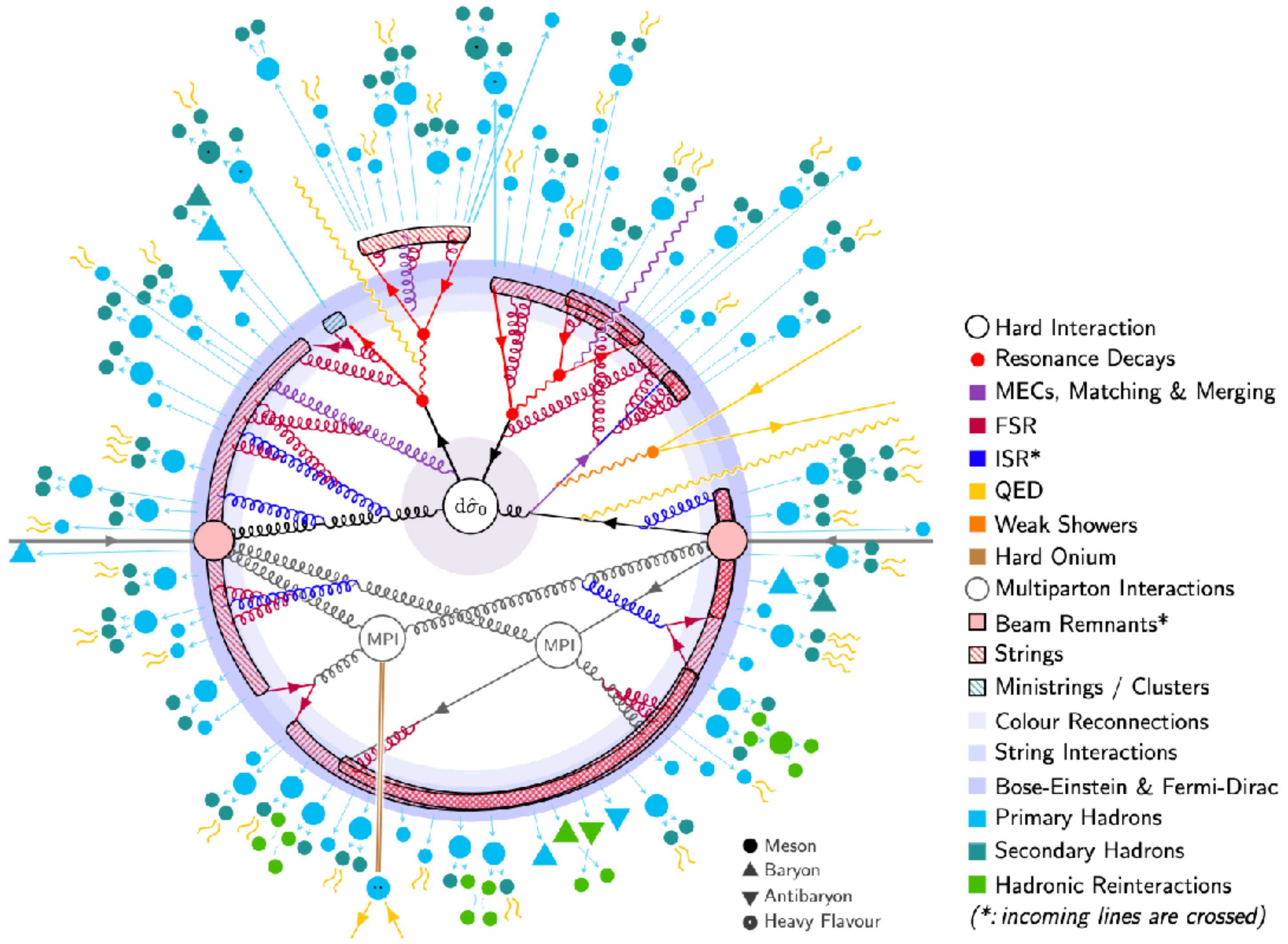
ECFA Higgs Factory 2nd Topical Workshop on Generators / Simulation



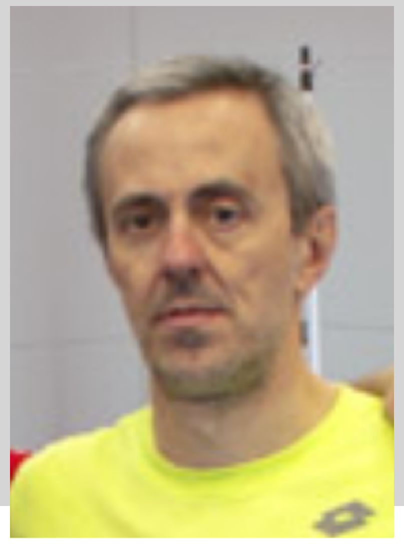


ECFA
European Committee for Future Accelerators

Jürgen Reuter

ECFA H/EW/Top Factory 2nd Topical MC Generator WS

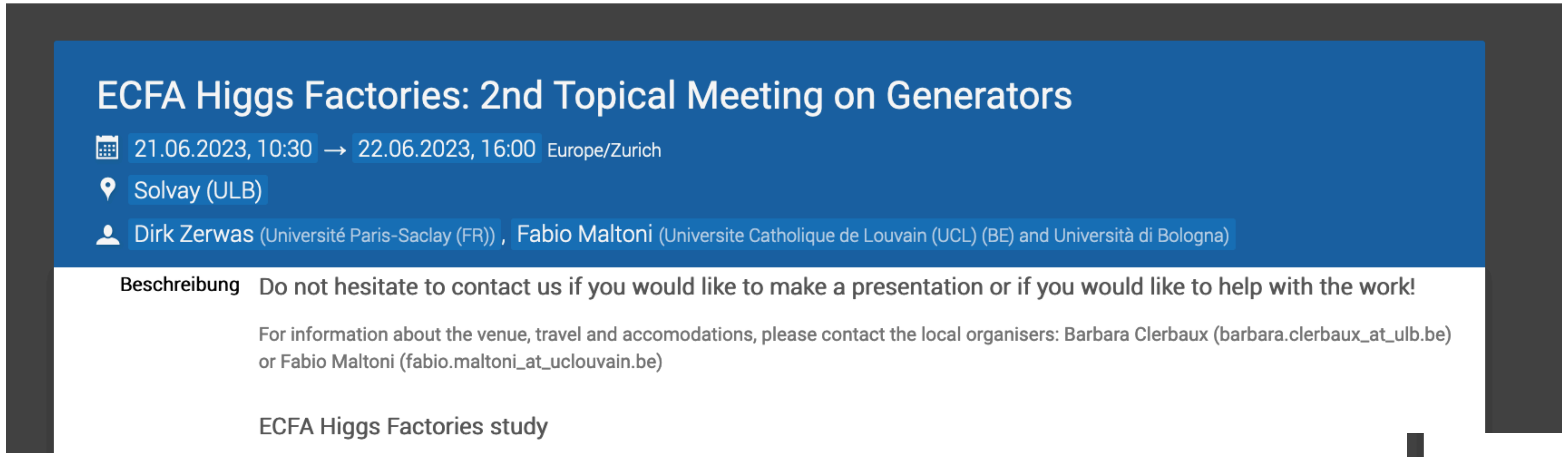
- 1st WG2 Topical WS on Generators / Simulation, @CERN: Nov. 9-10, 2021 https://indico.cern.ch/event/1078675/
- Very efficient and effective organization $\Longrightarrow$ Conveners: Patrizia Azzi Fulvio Piccinini Dirk Zerwas


- $\gtrsim$ 100 participants, roughly 30 at CERN
- Setting the stage: simulation tools, MCs, software frameworks

- 2nd WG2 Topical WS on Generators, @Brussels: June 21-22, 2023 https://indico.cern.ch/event/1266492/
- $\gtrsim$ 65 participants, roughly 15 at Brussels (U. Libre de Bruxelles & Vrije Universiteit)
- Transfers from IMCC Annual Meeting in Orsay + Les Houches
- Much more focused on MC generators: physics, beam spectra, technical details, benchmarks
- Only invited talks triggered by the conveners .... well, and some more self-suggested ones

ECFA H/EW/Top Factory 2nd Topical MC Generator WS


ECFA Higgs Factories: 2nd Topical Meeting on Generators

21.06.2023, 10:30 → 22.06.2023, 16:00 Europe/Zurich

Solvay (ULB)

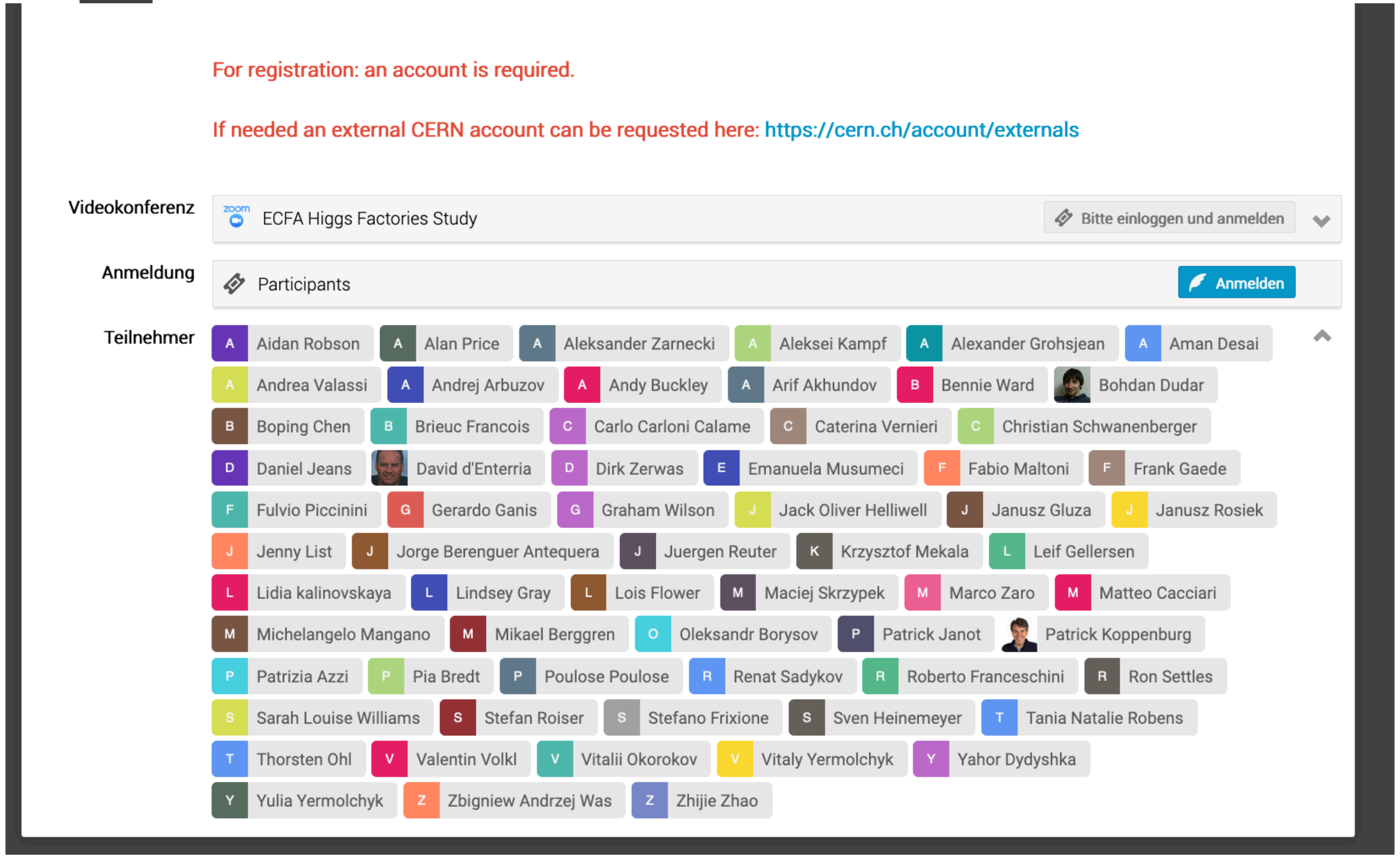
Dirk Zerwas (Université Paris-Saclay (FR)), Fabio Maltoni (Universite Catholique de Louvain (UCL) (BE) and Università di Bologna)

Beschreibung: Do not hesitate to contact us if you would like to make a presentation or if you would like to help with the work!

For information about the venue, travel and accomodations, please contact the local organisers: Barbara Clerbaux (barbara.clerbaux_at_ulb.be) or Fabio Maltoni (fabio.maltoni_at_uclouvain.be)

ECFA Higgs Factories study

- Beam simulation / luminosity spectra
- QED: ePDFs vs. YFS, collinear vs. soft resummation
- Inclusive precision vs. exclusive description
- Event formats
- Software frameworks
- QCD: parton showers & hadronization
- Performance
- Some focus topics: BSM needs, top threshold needs, Bhabha luminometry needs


For registration: an account is required.

If needed an external CERN account can be requested here: https://cern.ch/account/externals

Videokonferenz: ECFA Higgs Factories Study — Bitte einloggen und anmelden

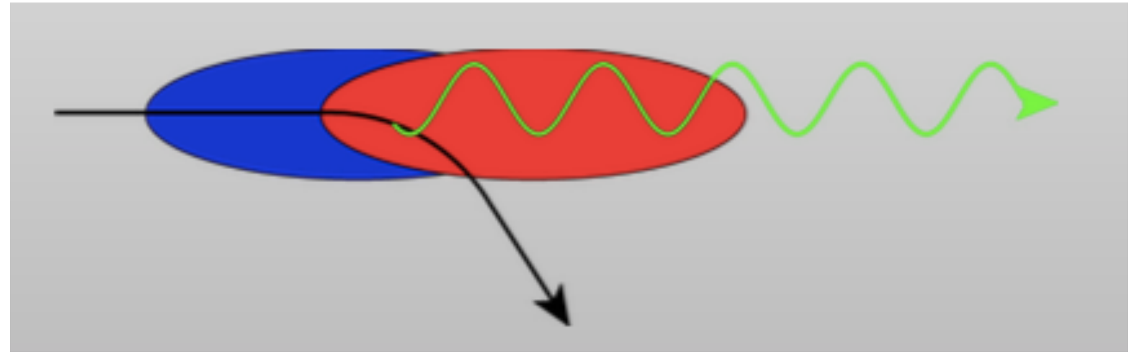
Anmeldung: Participants — Anmelden

Teilnehmer: Aidan Robson, Alan Price, Aleksander Zarnecki, Aleksei Kampf, Alexander Grohsjean, Aman Desai, Andrea Valassi, Andrej Arbuzov, Andy Buckley, Arif Akhundov, Bennie Ward, Bohdan Dudar, Boping Chen, Brieuc Francois, Carlo Carloni Calame, Caterina Vernieri, Christian Schwanenberger, Daniel Jeans, David d'Enterria, Dirk Zerwas, Emanuela Musumeci, Fabio Maltoni, Frank Gaede, Fulvio Piccinini, Gerardo Ganis, Graham Wilson, Jack Oliver Helliwell, Janusz Gluza, Janusz Rosiek, Jenny List, Jorge Berenguer Antequera, Juergen Reuter, Krzysztof Mekala, Leif Gellersen, Lidia kalinovskaya, Lindsey Gray, Lois Flower, Maciej Skrzypek, Marco Zaro, Matteo Cacciari, Michelangelo Mangano, Mikael Berggren, Oleksandr Borysov, Patrick Janot, Patrick Koppenburg, Patrizia Azzi, Pia Bredt, Poulose Poulose, Renat Sadykov, Roberto Franceschini, Ron Settles, Sarah Louise Williams, Stefan Roiser, Stefano Frixione, Sven Heinemeyer, Tania Natalie Robens, Thorsten Ohl, Valentin Volkl, Vitalii Okorokov, Vitaly Yermolchyk, Yahor Dydyshka, Yulia Yermolchyk, Zbigniew Andrzej Was, Zhijie Zhao

Beam simulations

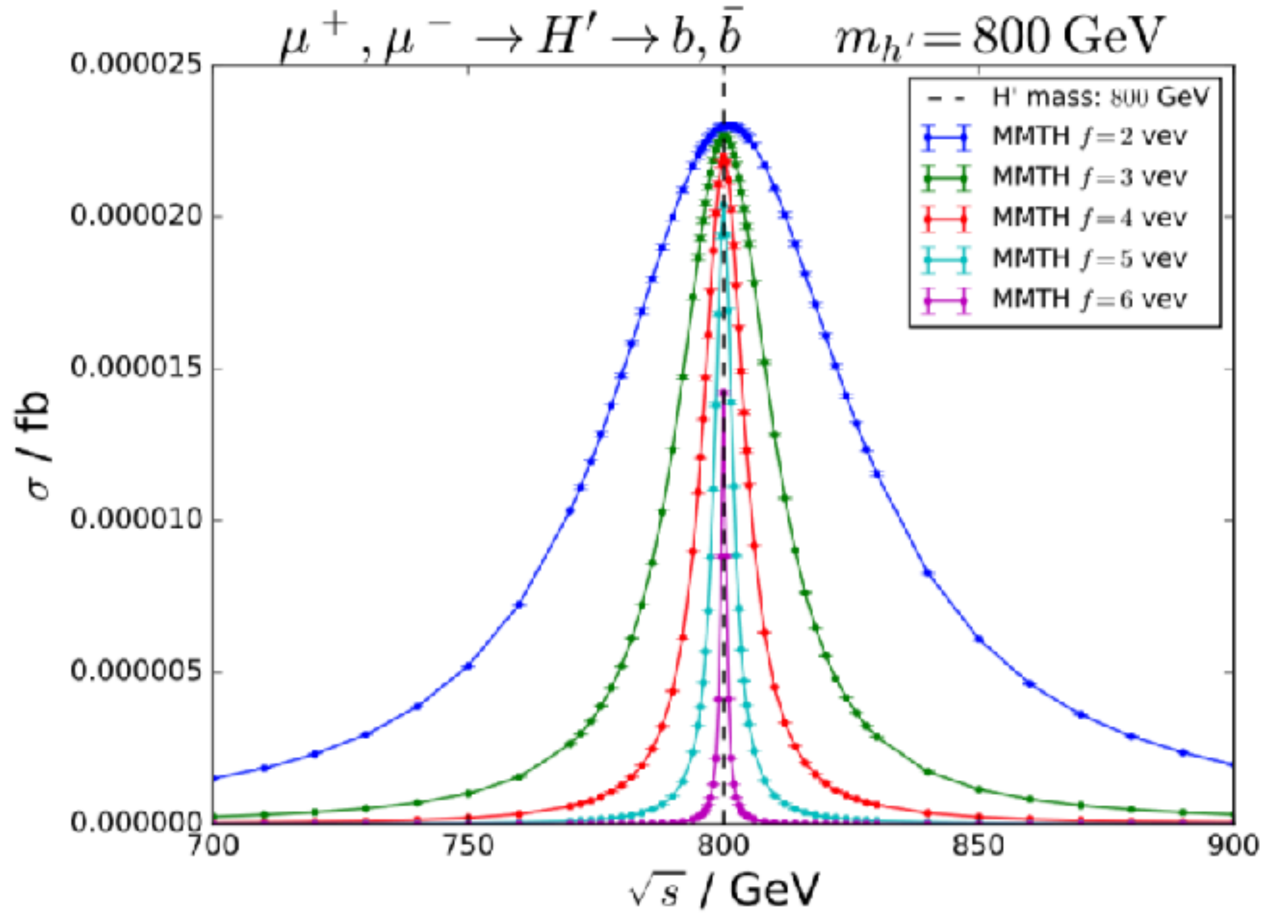
[Thorsten Ohl]

- Micro-scale bunches create beam structure/-strahlung
- Mostly Gaussian shape for circular machines, but not fully
- Machine simulation with tools like `GuineaPig(++)`, `CAIN`
- Has to be folded into realistic MC simulations



$$L \approx \frac{N}{4\pi\sigma_x\sigma_y}\frac{\eta P_{AC}}{E_{CM}}$$

1. Gaussian shape with specific spreads — Avail.: ✔
2. Parameterized (delta peak ⊕ power law) — Avail.: (✔)
3. Generator for 2D histogrammed fit — Avail.: [✔]



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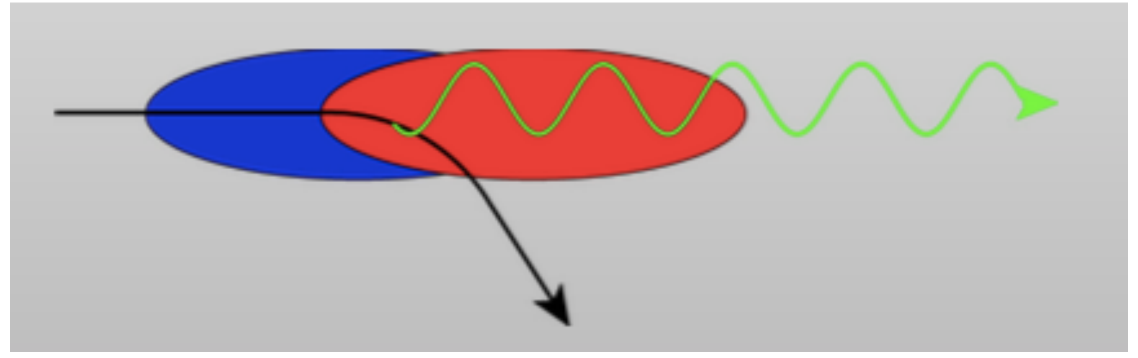

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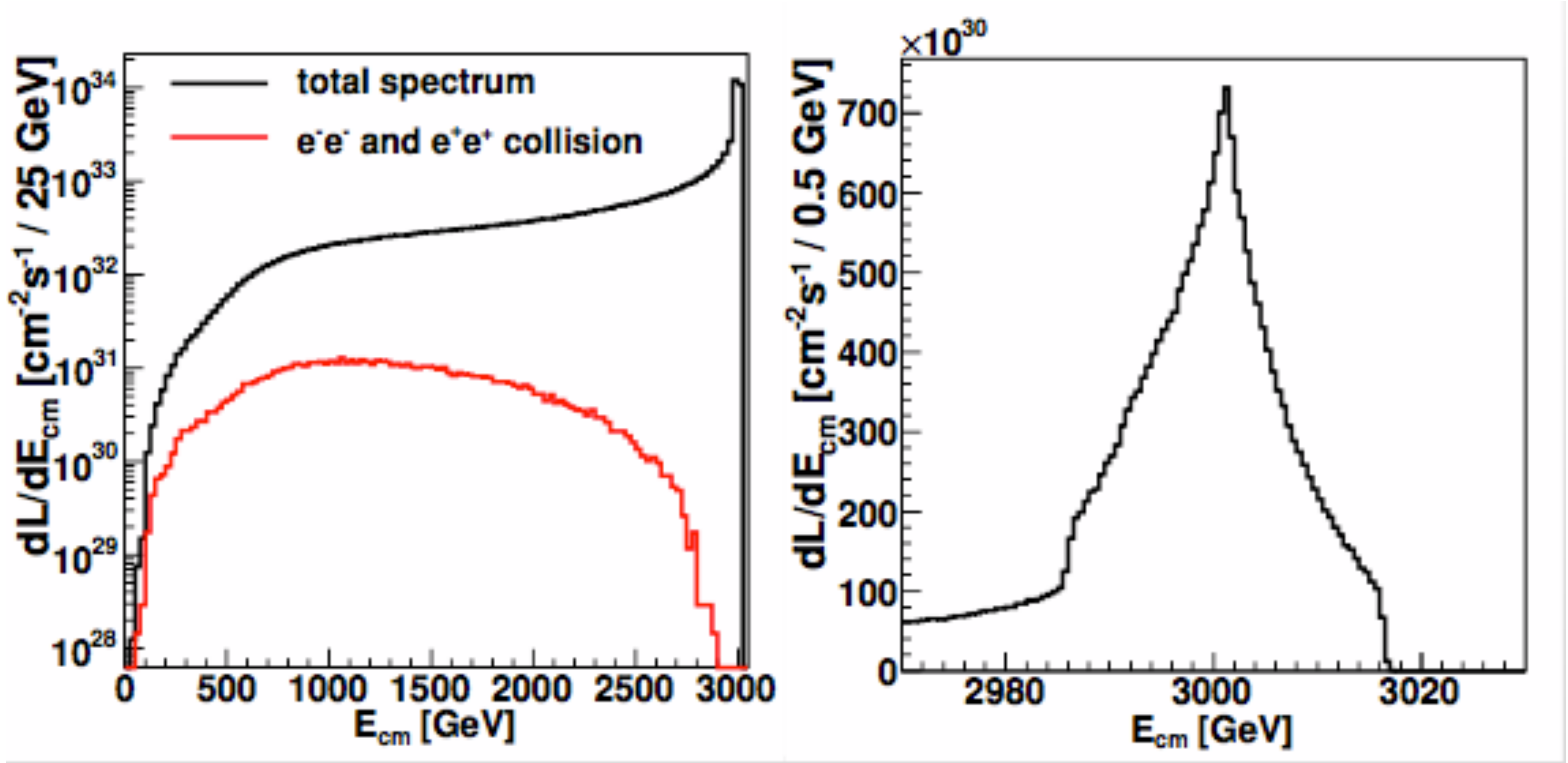

Dalena/Esbjerg/Schulte [LCWS 2011]

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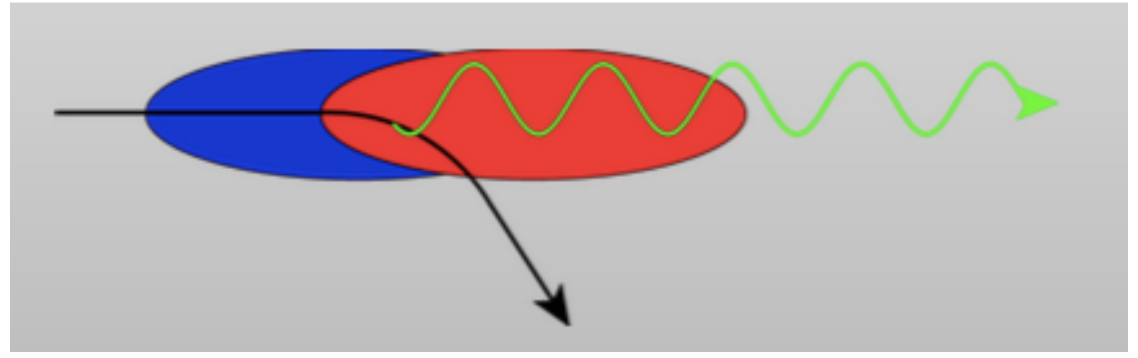

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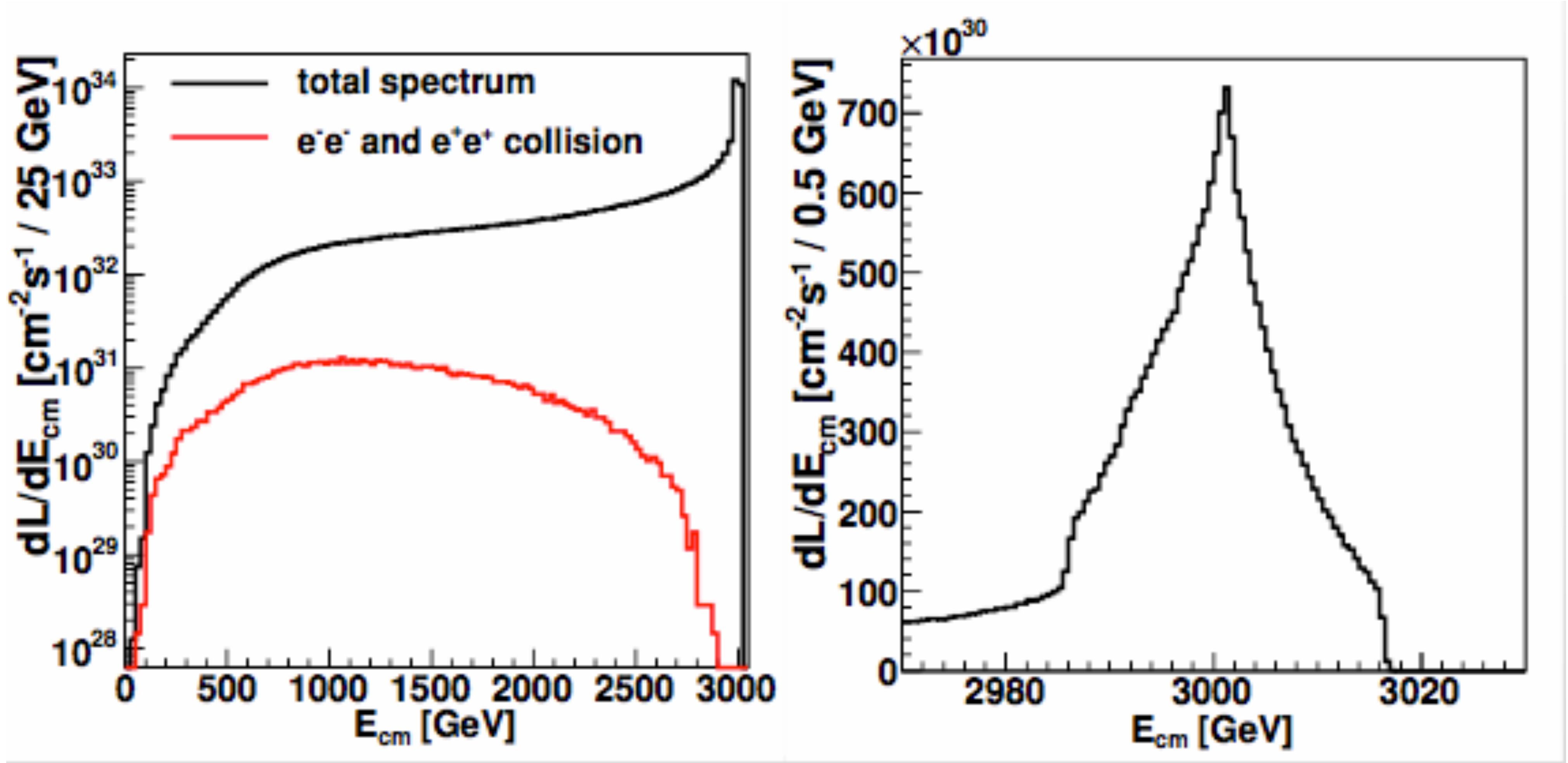


Dalena/Esbjerg/Schulte [LCWS 2011]

1. Gaussian shape with specific spreads — Avail.: ✔
2. Parameterized (delta peak ⊕ power law) — Avail.: (✔)
3. Generator for 2D histogrammed fit — Avail.: [✔]

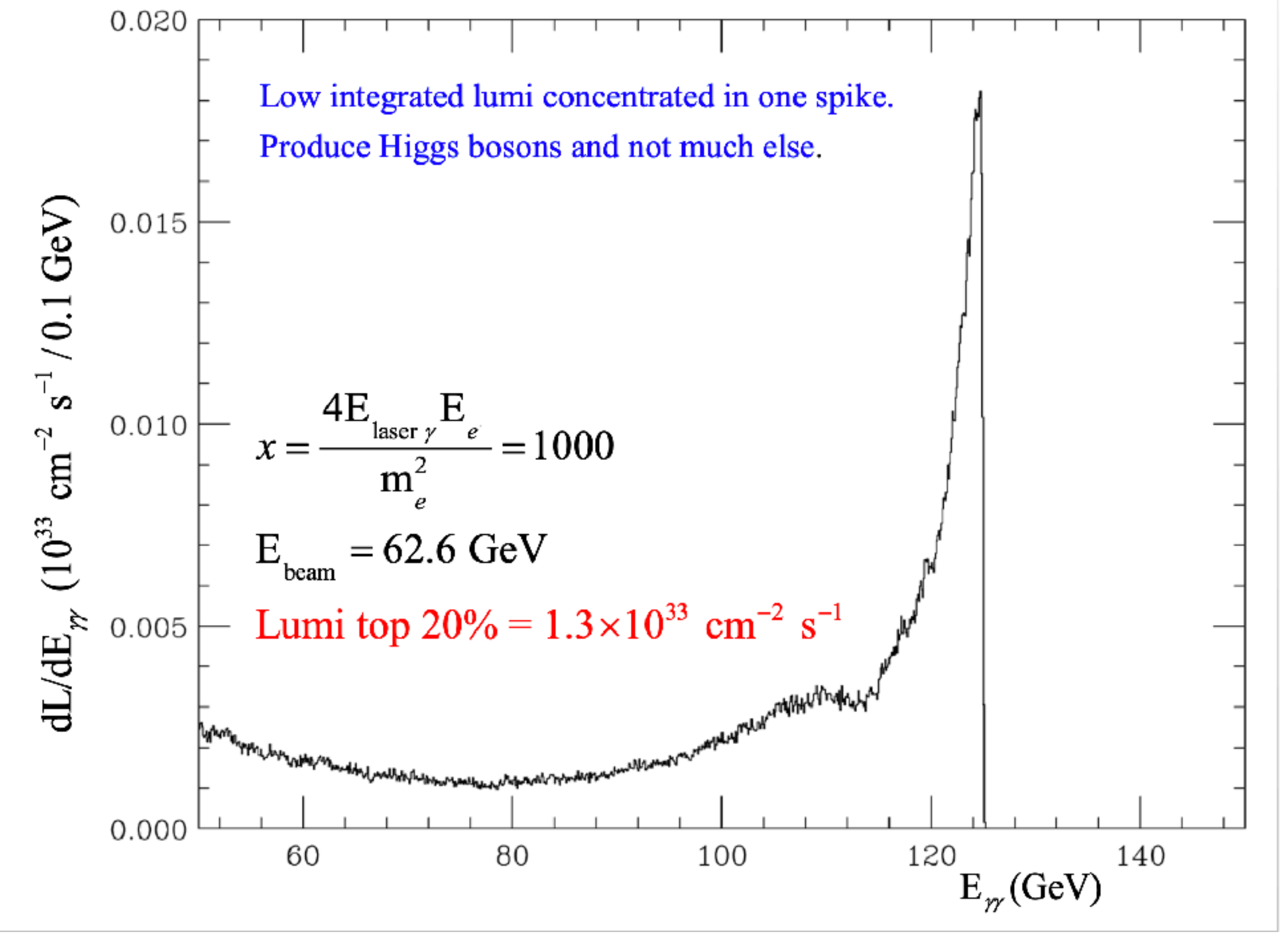
- Pro (1.): Easy implementation, covers main features
- Con (1.): Gaussian approximative, exceeds nominal collider energy
- Pro (2.): Relatively easy implementation
- Con (2.): Delta peak behaves badly in MC, beams maybe not factorizable/simple power law
- Pro (3.): most exact simulation, generator mode avoids artifacts in tails
- Con (3.): only available (yet) in dedicated tools like `LumiLinker` and `CIRCE2`

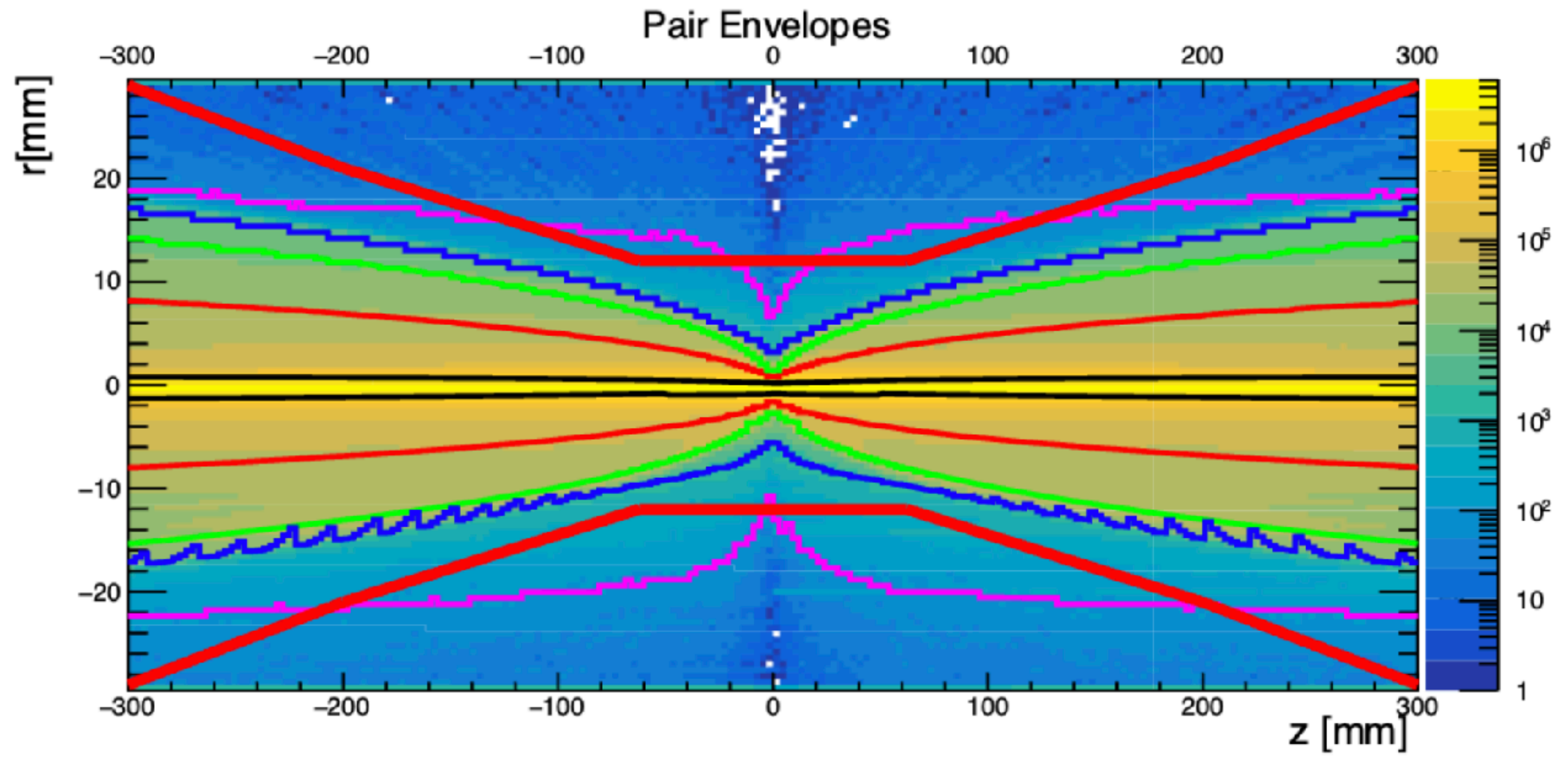
$$D_{B_1B_2}(x_1,x_2) \neq D_{B_1}(x_1)\cdot D_{B_2}(x_2)$$

$$D_{B_1B_2}(x_1,x_2) \neq x_1^{\alpha_1}(1-x_1)^{\beta_1}x_2^{\alpha_2}(1-x_2)^{\beta_2}$$

Beam simulations

- New beam simulations for FCC-ee: 4 IPs ⇒ 1.7x lumi (91 GeV) / 1.8x lumi (161/250 GeV)
- New beam simulations for CCC and XCC (photon collider simulations)
- Photon collider simulations *not* possible with parameterized spectra
- Conclusion: `CIRCE2`-like sampling most versatile/general approach

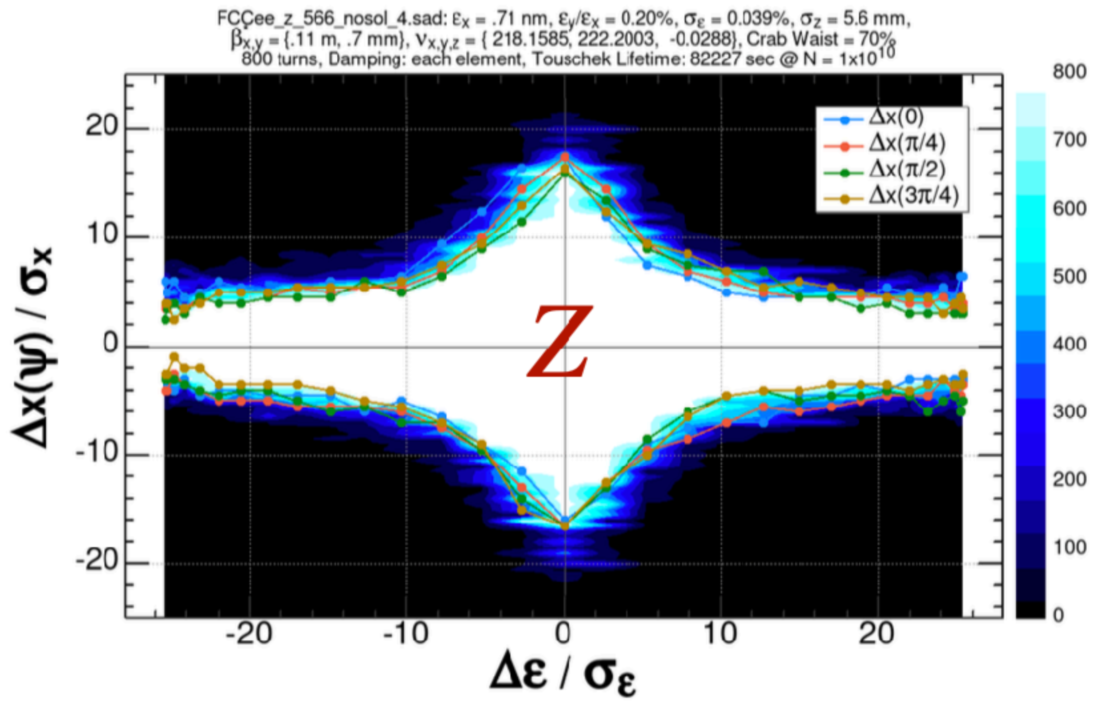




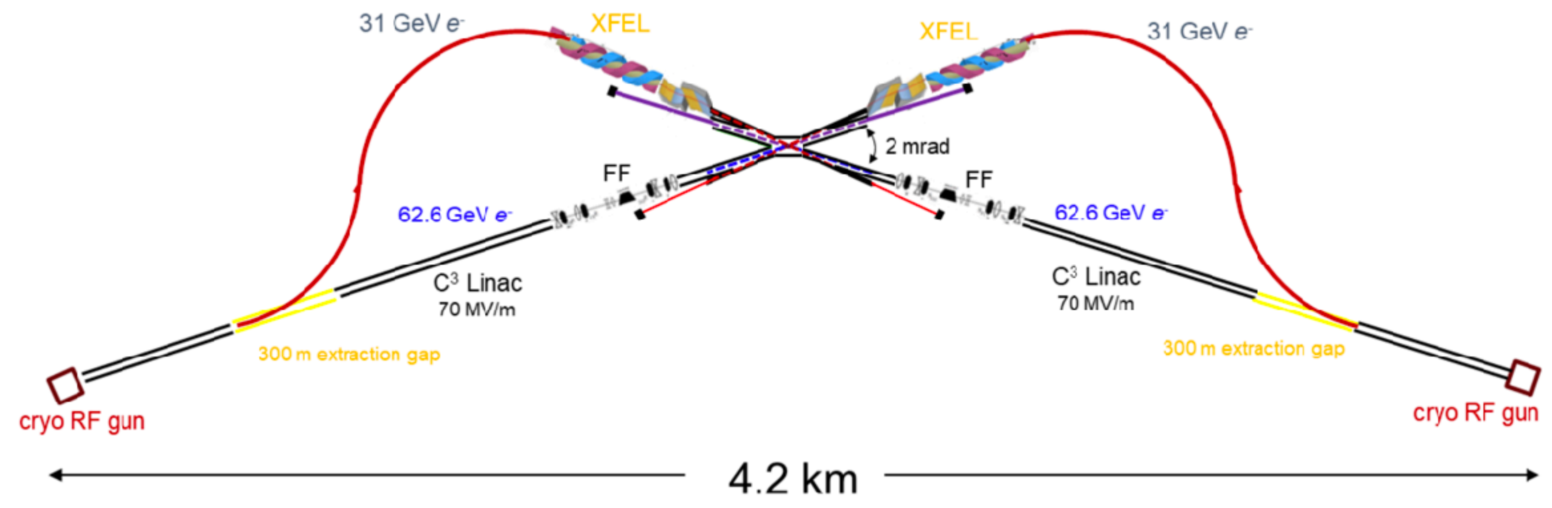
Open Issues

[Katsunobu Oide, FCC week]

Dynamic aperture (*z*-*x*)



XCC s-channel $\gamma\gamma \to H$ @ $\sqrt{s} = 125$ GeV



[Thorsten Ohl; Lindsey Gray]

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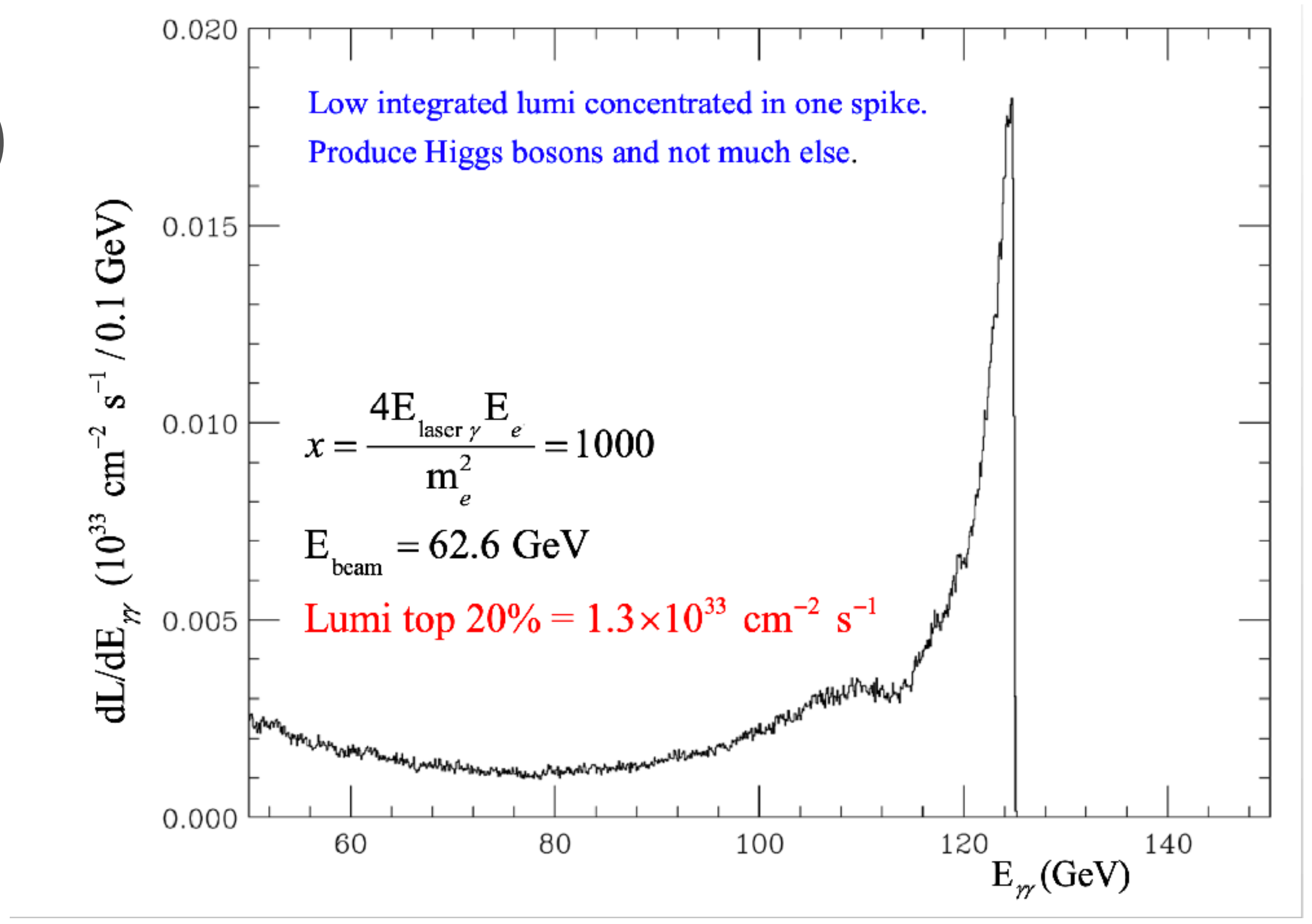

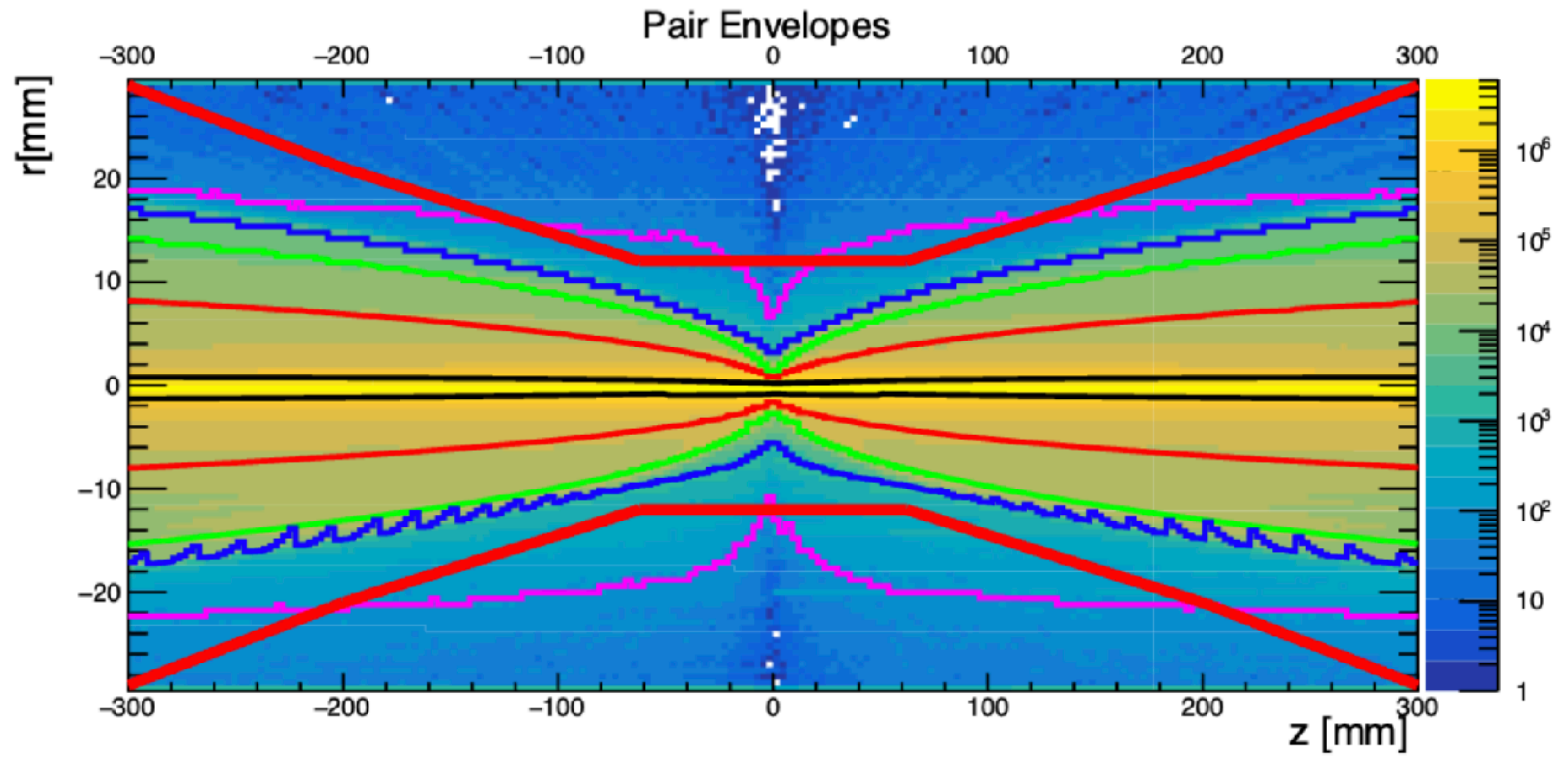

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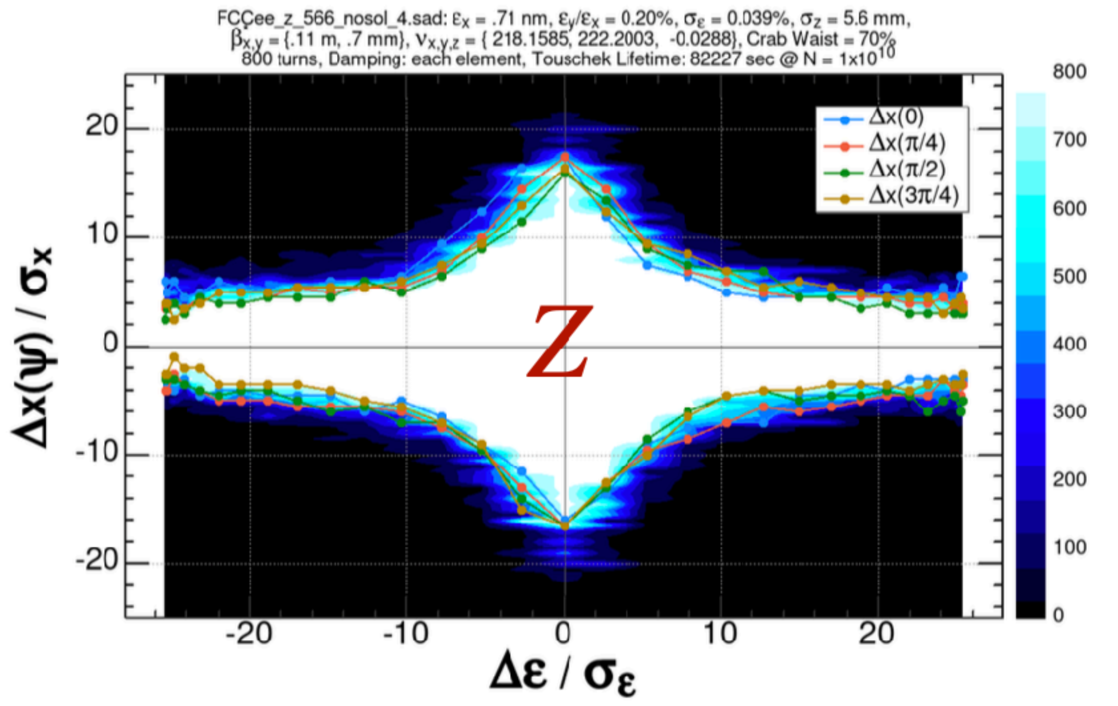
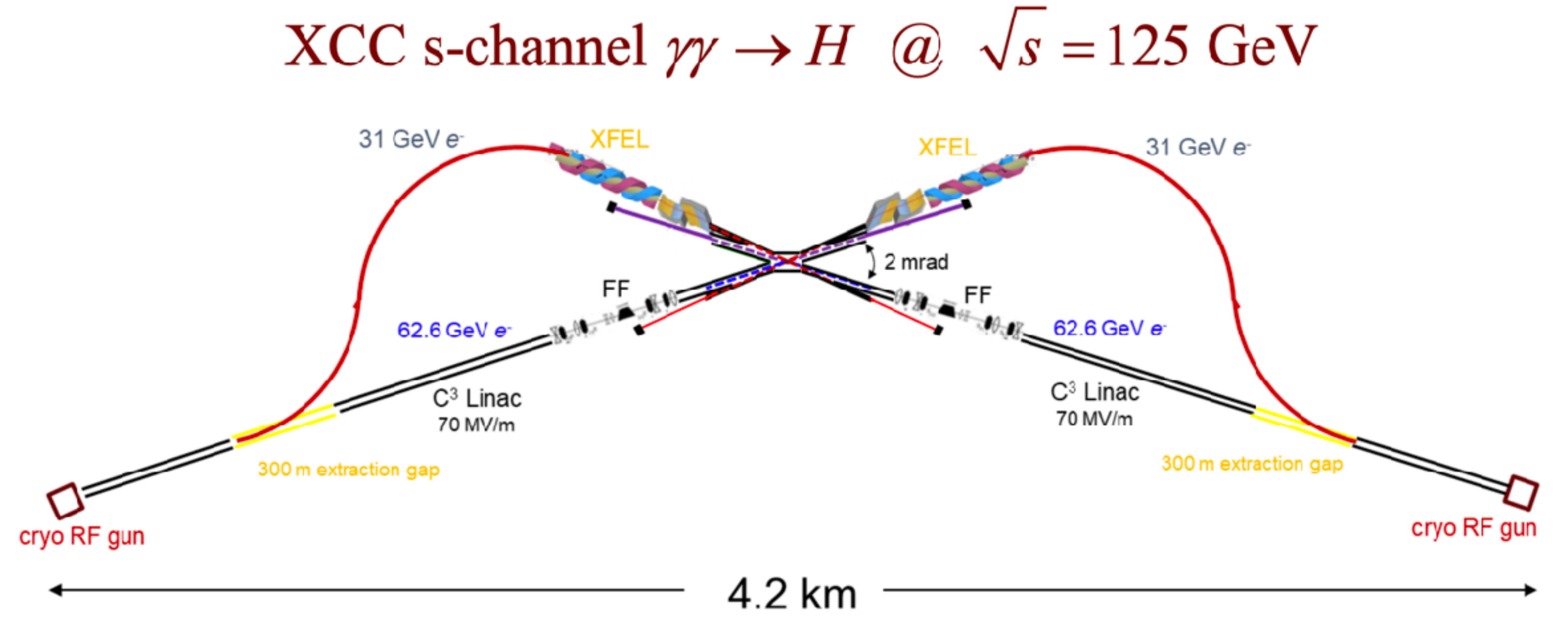
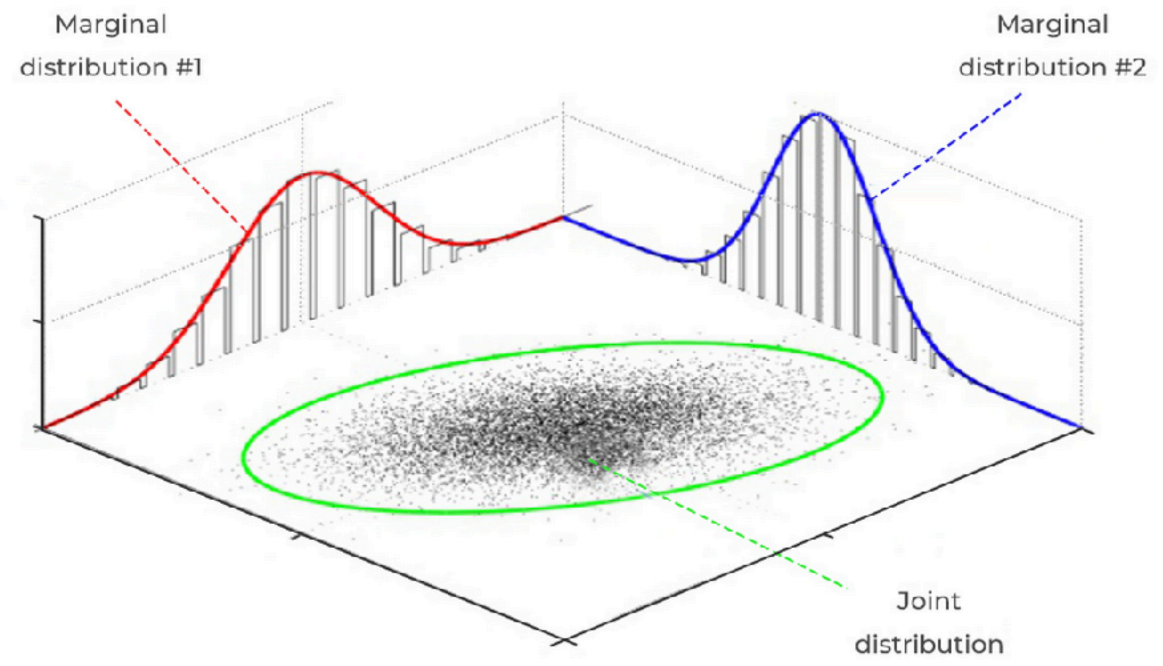


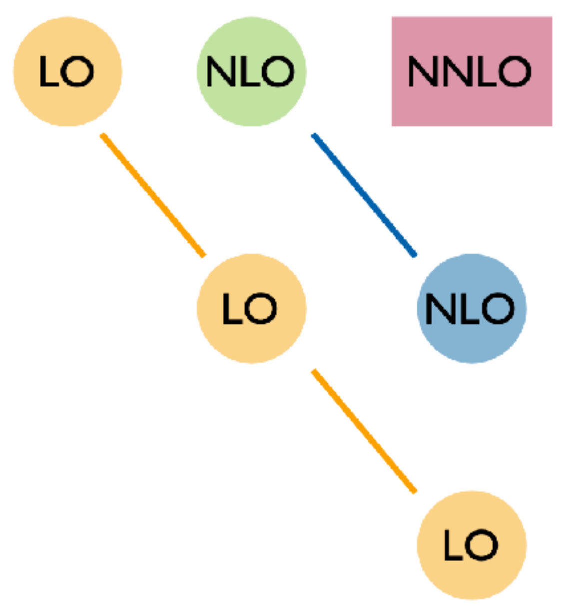


Open Issues

- Still several Higgs factories missing in general beam spectrum repository
- Machine learning for sampling beam spectra not yet started (expected performance?)
- 2D-/3D-structure of beam spectra (*z*-dependence, copulas)



QCD: parton shower / tuning / fragmentation / validation



$e^+e^- \to t\bar{t}$	166.37(12)	174.55(20)	1.05
$e^+e^- \to t\bar{t}j$	48.12(5)	53.41(7)	1.11
$e^+e^- \to t\bar{t}jj$	8.592(19)	10.526(21)	1.23
$e^+e^- \to t\bar{t}jjj$	1.035(4)	1.405(5)	1.36
$e^+e^- \to t\bar{t}t\bar{t}$	$0.6388(8) \cdot 10^{-3}$	$1.1922(11) \cdot 10^{-3}$	1.87
$e^+e^- \to t\bar{t}t\bar{t}j$	$2.673(7) \cdot 10^{-5}$	$5.251(11) \cdot 10^{-5}$	1.96
$e^+e^- \to t\bar{t}H$	2.020(3)	1.912(3)	0.95
$e^+e^- \to t\bar{t}Hj$	$2.536(4) \cdot 10^{-1}$	$2.657(4) \cdot 10^{-1}$	1.05
$e^+e^- \to t\bar{t}Hjj$	$2.646(8) \cdot 10^{-2}$	$3.123(9) \cdot 10^{-2}$	1.18
$e^+e^- \to t\bar{t}Z$	4.638(3)	4.937(3)	1.06
$e^+e^- \to t\bar{t}Zj$	$6.027(9) \cdot 10^{-1}$	$6.921(11) \cdot 10^{-1}$	1.15
$e^+e^- \to t\bar{t}Zjj$	$6.436(21) \cdot 10^{-2}$	$8.241(29) \cdot 10^{-2}$	1.28
$e^+e^- \to t\bar{t}W^\pm jj$	$2.387(8) \cdot 10^{-4}$	$3.716(10) \cdot 10^{-4}$	1.56
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- Fixed order NLO and mostly also NNLO QCD (semi-) automated and validated
- Machinery of parton showers well advanced, recap of CERN workshop 04/2023
- Possible NLL parton showers (final state only!) for e^+e^- :

[Alan Price]
[Zhijie Zhao]
[Jack Helliwell]
[Leif Gellersen]

Shower	Ordering	NLL Validation
PanScales [2002.11114]	$^1 0 \leq \beta < 1$	Fixed and all order numerical tests for a range of observables
Alaric [2208.06057]	$k_t \ (\beta = 0)$	Analytical, numerical tests for global event shapes
Deductor [2011.04777]	$k_t, \Lambda \ (\beta = 0, 1)$	Analytical and numerical tests for thrust
Manchester-Vienna [2003.06400]	$k_t \ (\beta = 0)$	Analytical for thrust and multiplicity

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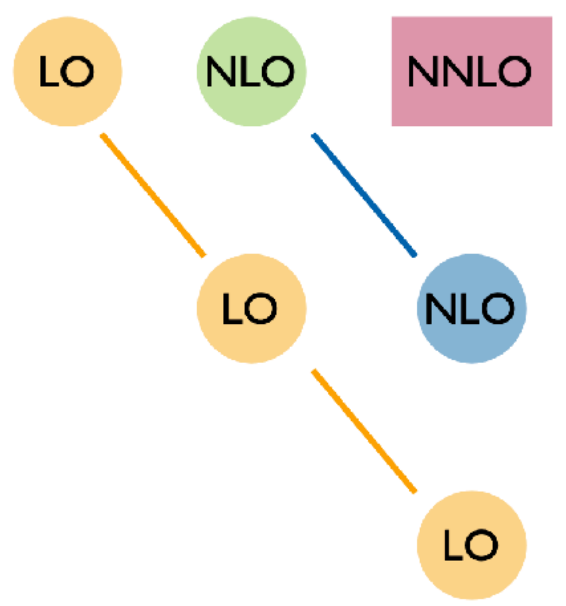

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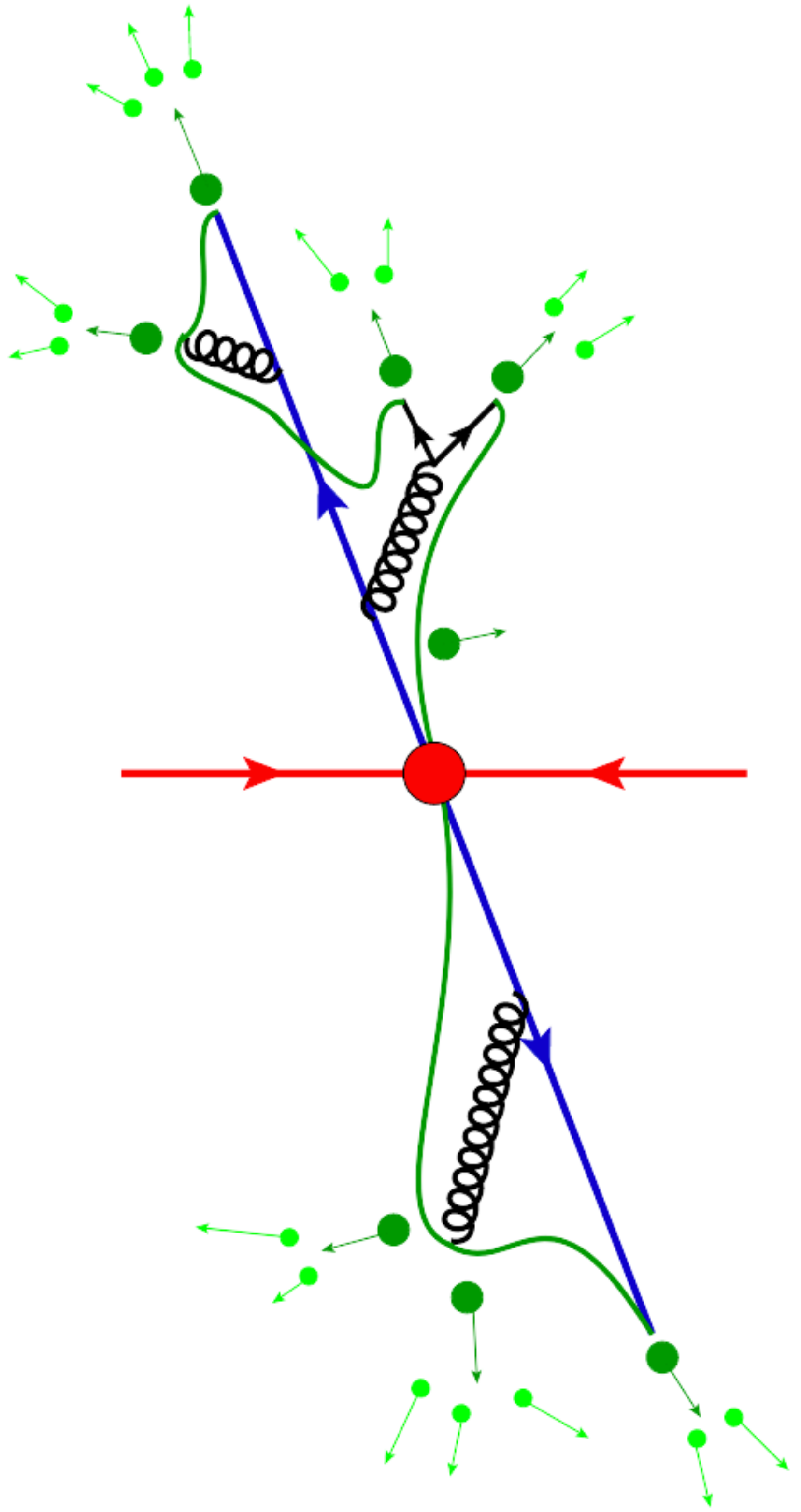

e^+e^- collision

- Ongoing work towards NNLL showers, sub-leading color (FCC = full color correlations)
- NLO matching automated, different approaches, different error estimates;
- NNLO matching still process-dependent; also does not yet preserve NNLL accuracy
- Elephant in the room: fragmentation $\Rightarrow$ no real progress in last 30 years

Gigantic clean data sets from Z pole and above will necessitate new models / theor

QCD: parton shower / tuning / fragmentation / validation

- Tuning: automated tools w/ built-in correlations (`Professor`, `AutoTunes`, `Apprentice`, ...)
- Global event shapes, α_s, charge multiplicity, hadron multiplicity
- Many different parameters: e.g. IR cutoff, string parameters vs. cluster parameters etc.

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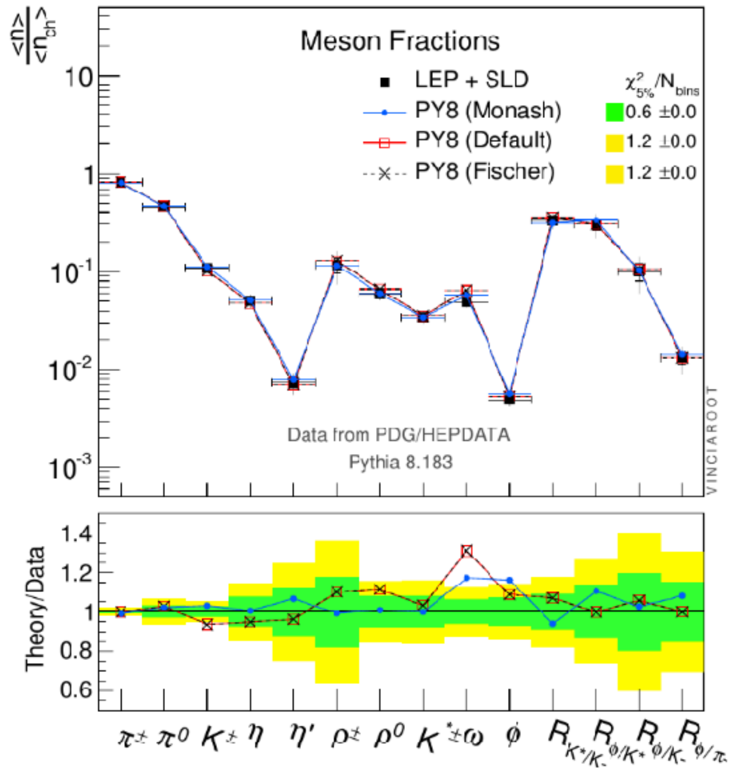
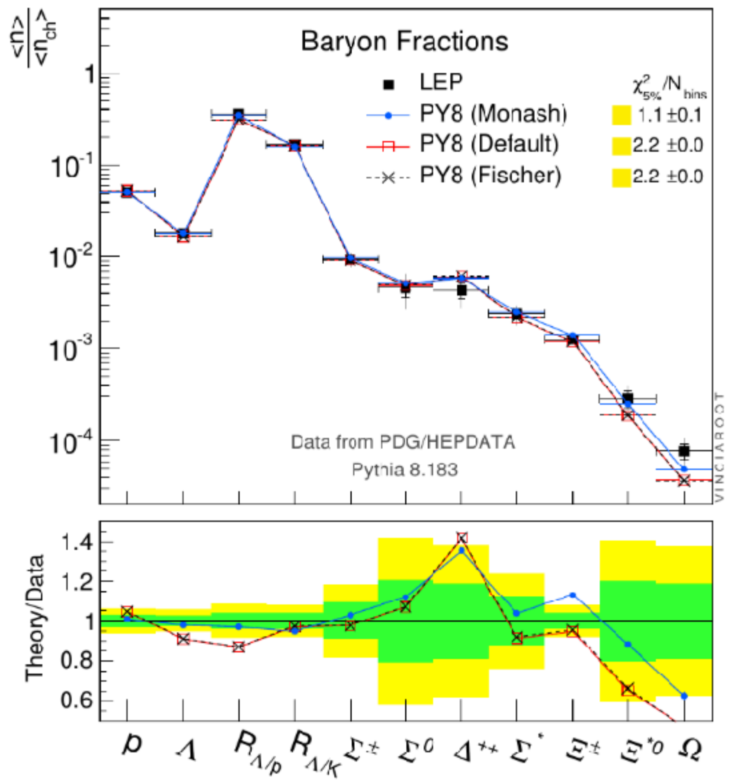
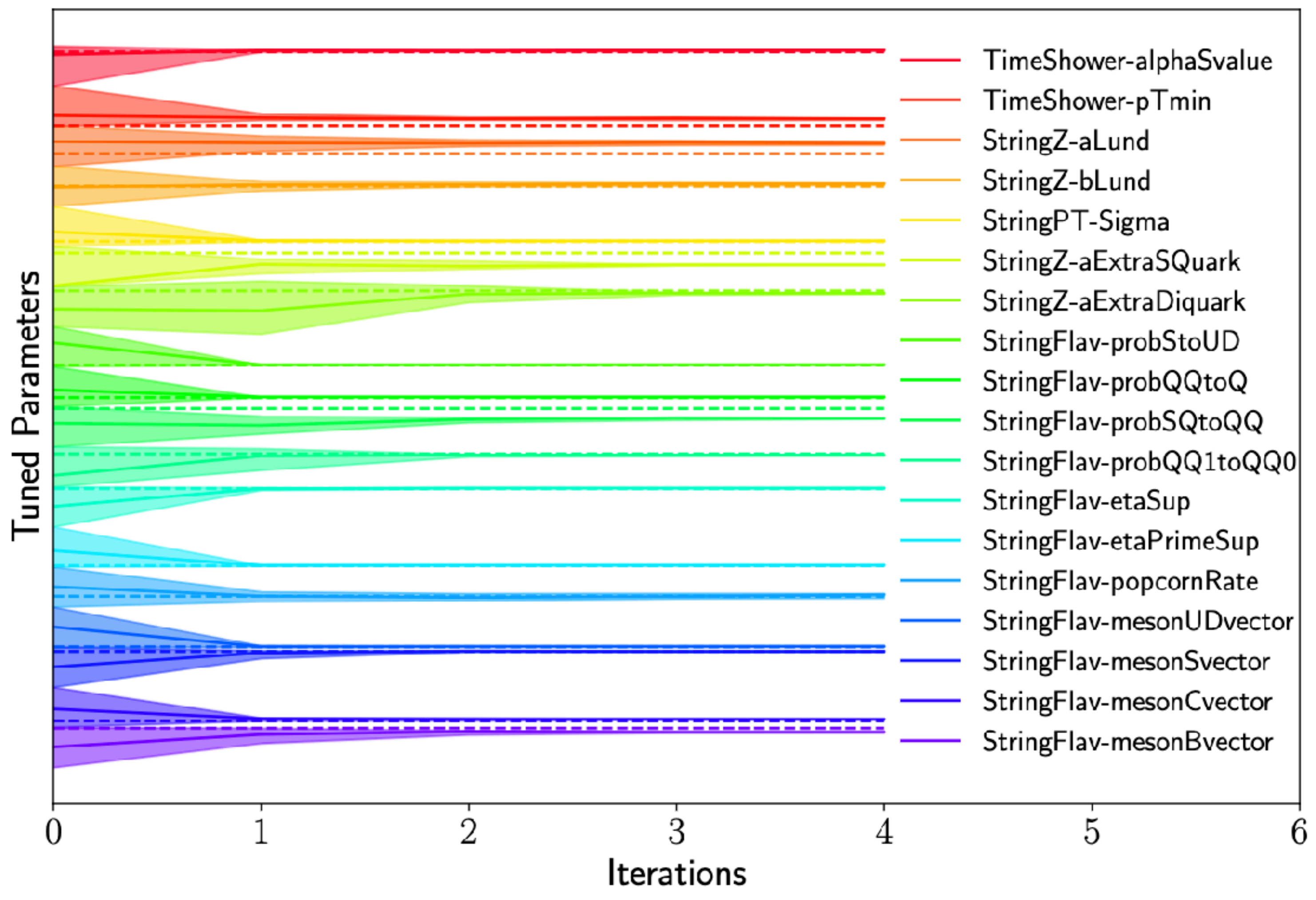
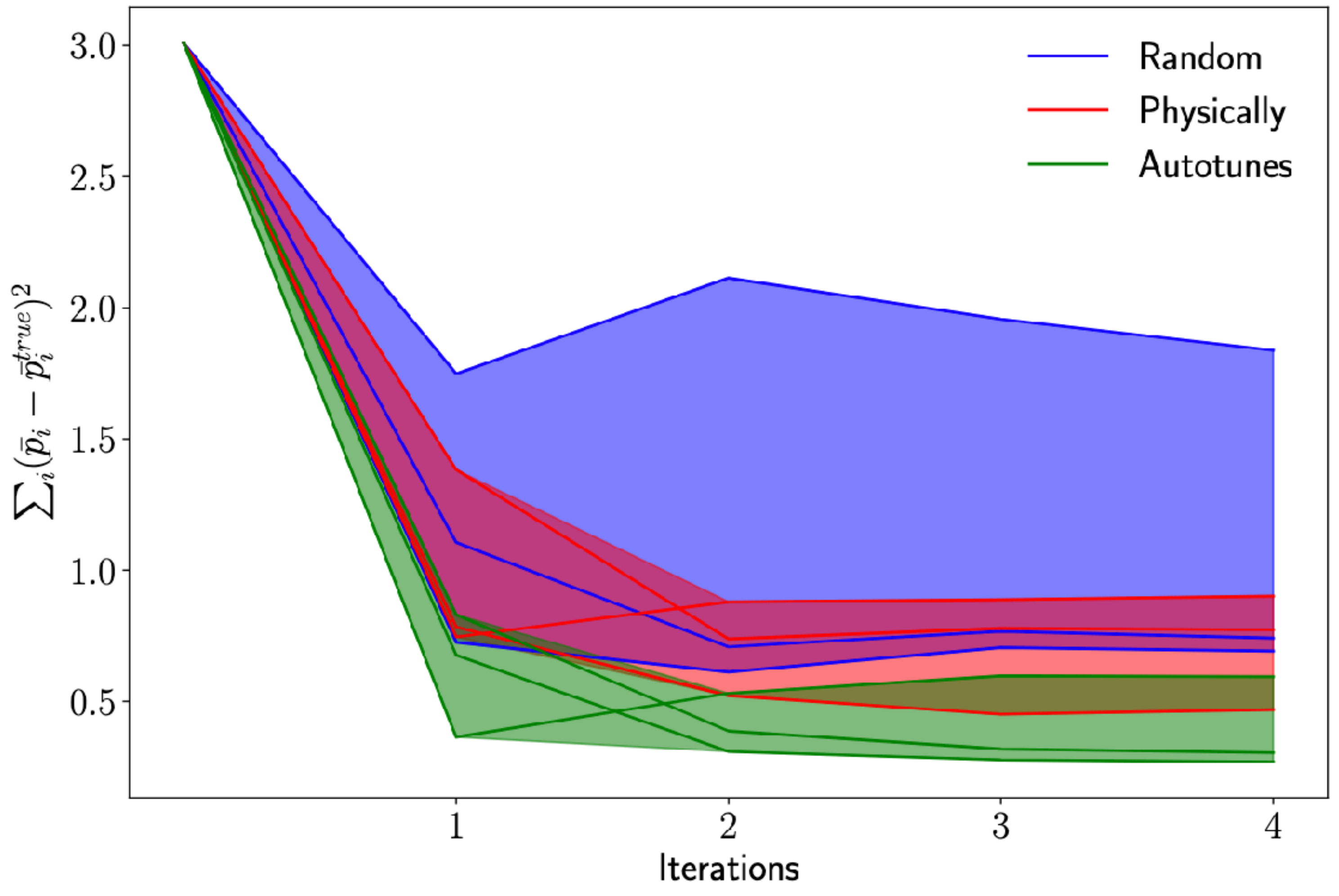
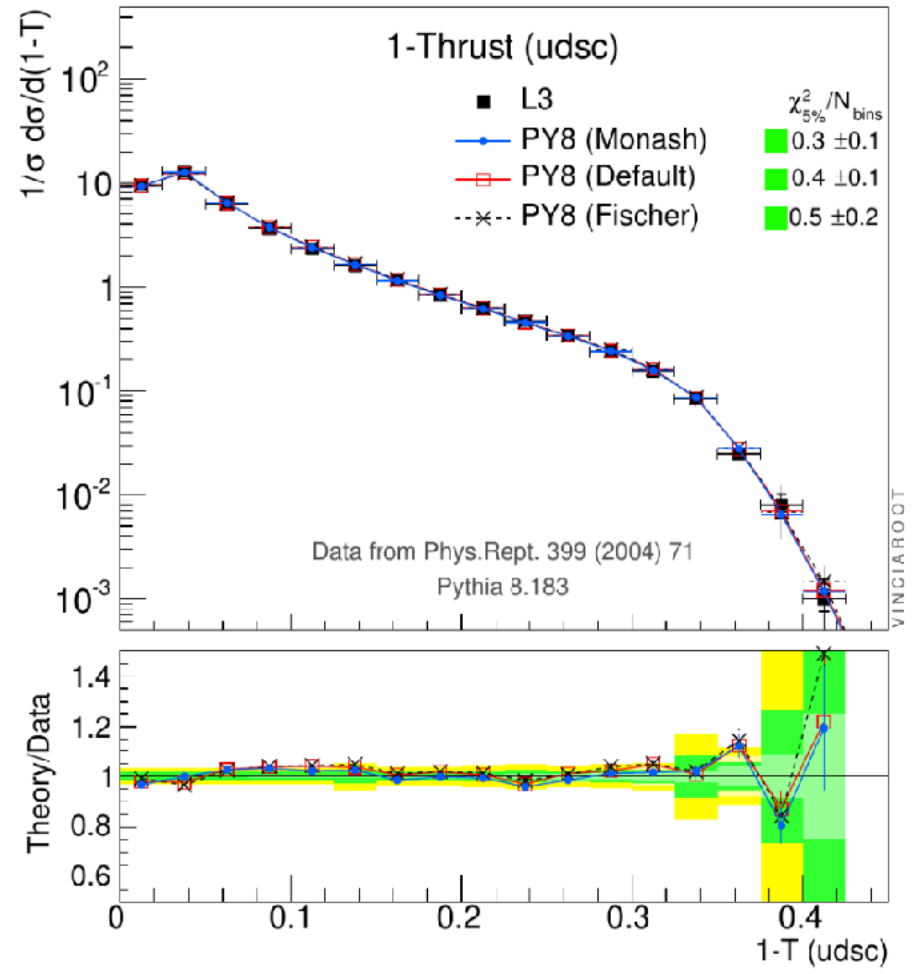




Try to reproduce — — — values, ≈ 6000 DOF & 18 parameters







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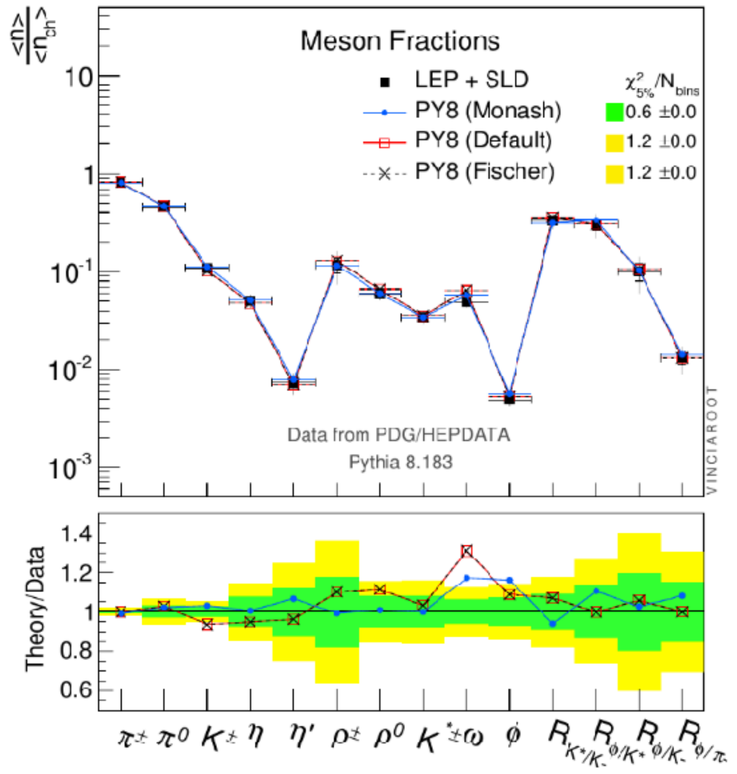

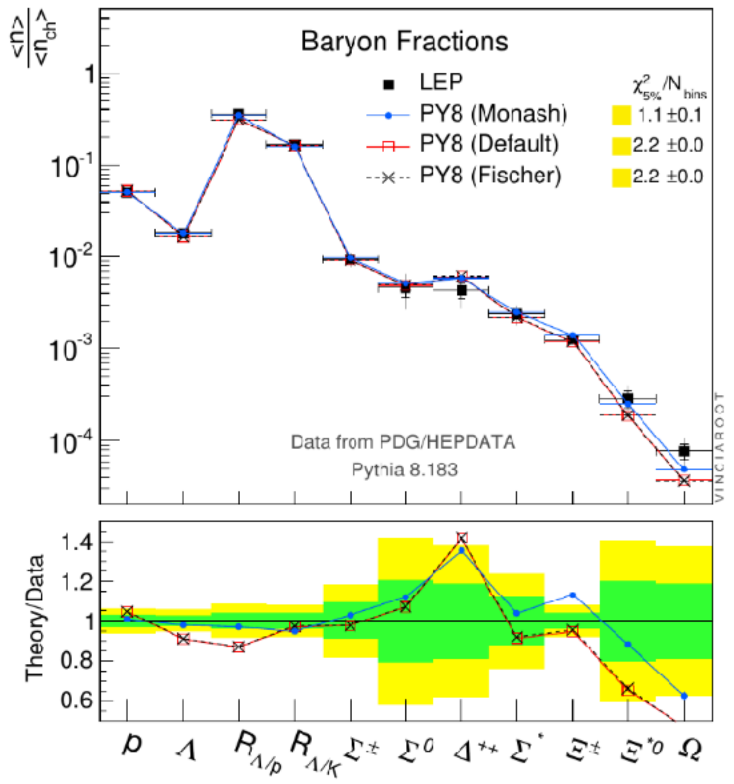

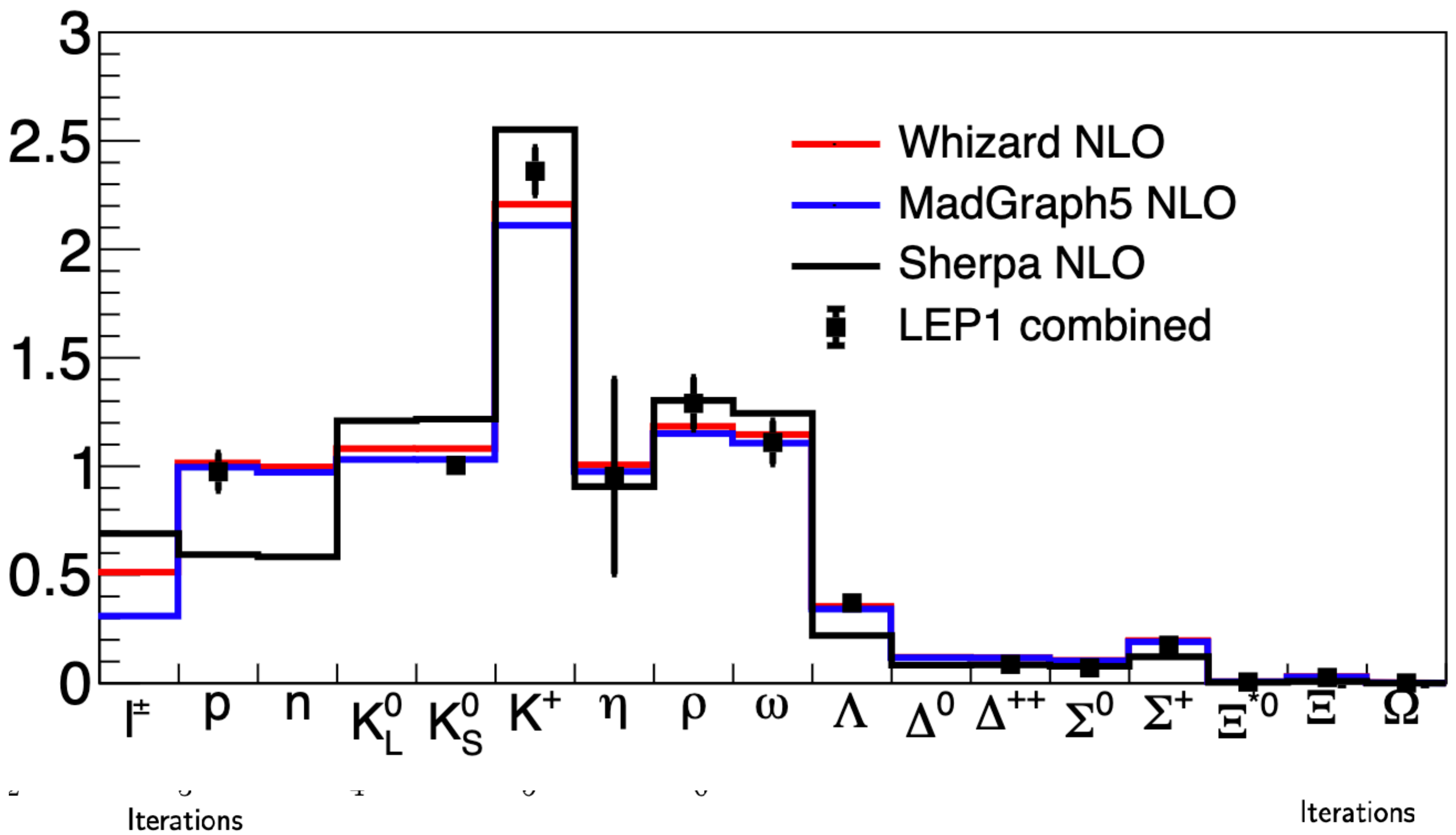

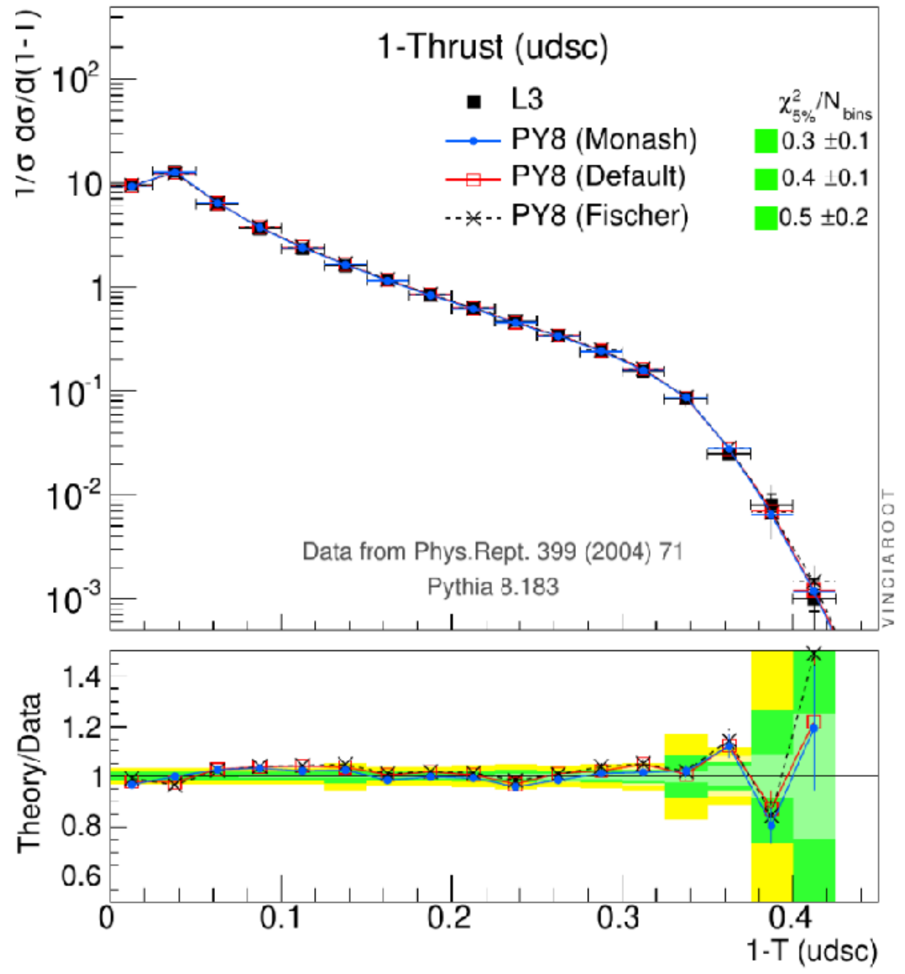

- Comparison of NLO QCD MC generators at detector level (`aSherpa`, `MG5_aMC@NLO`, `Whizard`)
- Only genuine ILD contribution to the workshop
- Event shapes and hadron level MC data

QED and EW precision: exclusive vs. inclusive

Stanisław (“Staszek”) Jadach, 1943 — 2023

RAPIDITY GENERATOR FOR MONTE-CARLO CALCULATIONS OF CYLINDRICAL PHASE SPACE

S. JADACH
Institute of Physics, Jagellonian University, Cracow, Poland

Received 1 November 1974

Quite a severe impact on the development of LEP legacy Monte Carlos,
YFS-style tools (the whole KKMC, YFS-WW/ZZ, Photos, Tauola, BHLumi/BHWide !

QED and EW precision: exclusive vs. inclusive

- **Fixed-order NLO QED/NLO EW calculations under control**
- Infinitely tough way to go to fixed-order NNLO QED/EW

[Stefano Frixione]
[Fulvio Piccinini]
[Alan Price]
[Maciej Skrzypek]
[Bennie Ward]

QED and EW precision: exclusive vs. inclusive

- **Fixed-order NLO QED/NLO EW calculations under control**
- Infinitely tough way to go to fixed-order NNLO QED/EW

[Stefano Frixione] [Maciej Skrzypek]
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[Alan Price]

Two major bottlenecks

- Virtual integrals with many mass scales/off-shell legs
  Abreu ea., Badger ea., Baglio ea., Brønnum-Hansen ea.
- IR pole treatment / subtraction
  CS, FKS, NS, Stripper, qT/sub-jettiness etc.

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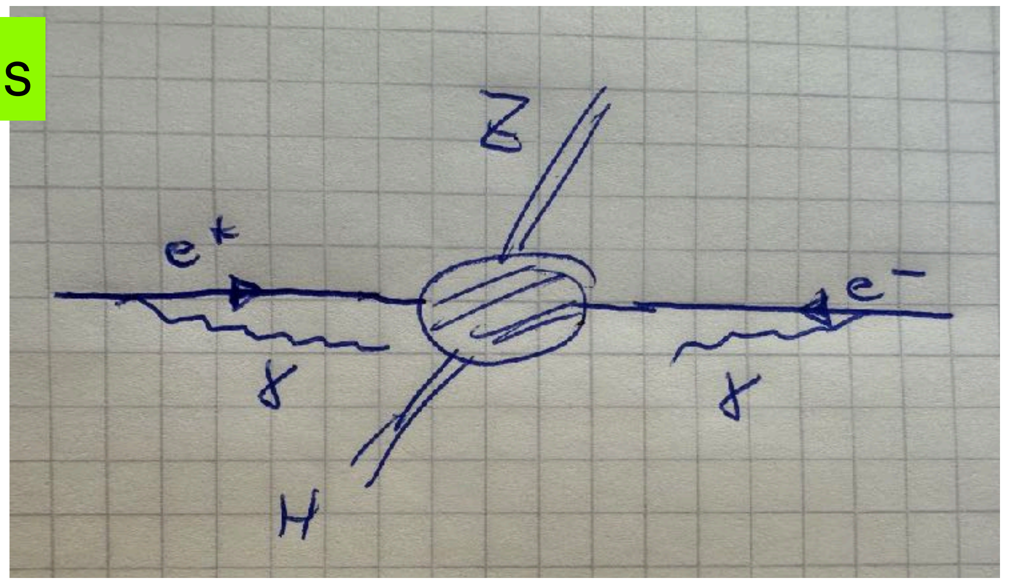
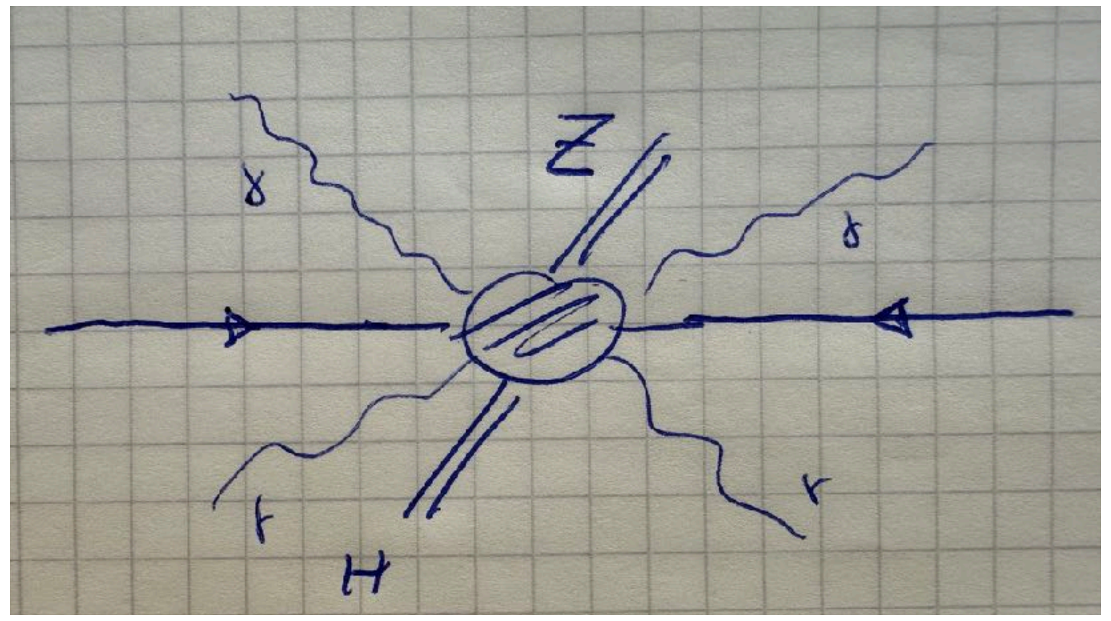
Collinear logarithms

$$L = \log \frac{Q^2}{m^2}$$



$$\sigma = \alpha^b \sum_{n=0}^{\infty} \alpha^n \sum_{i=0}^{n} \sum_{j=0}^{n} \varsigma_{n,i,j} L^i \ell^j$$



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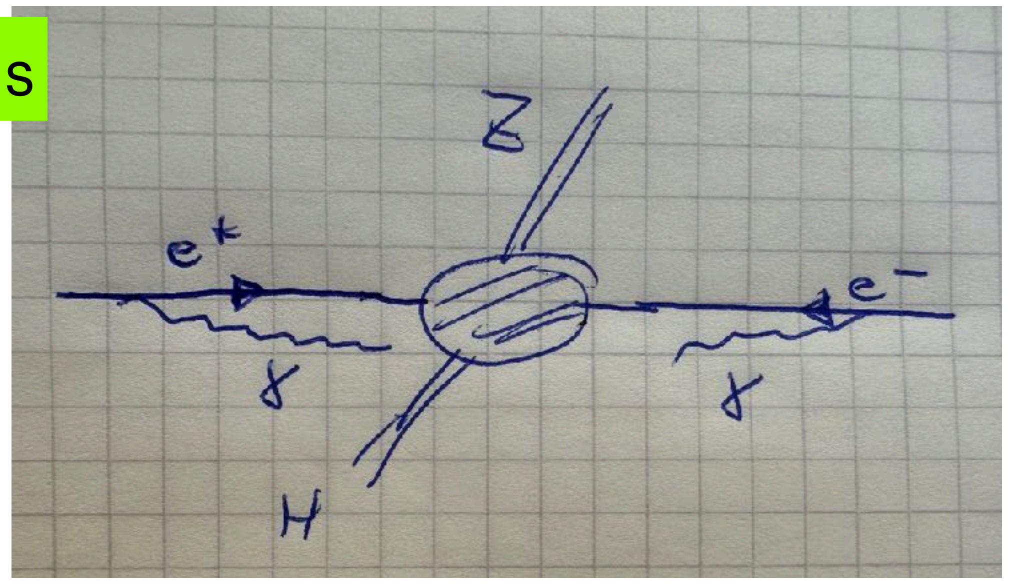

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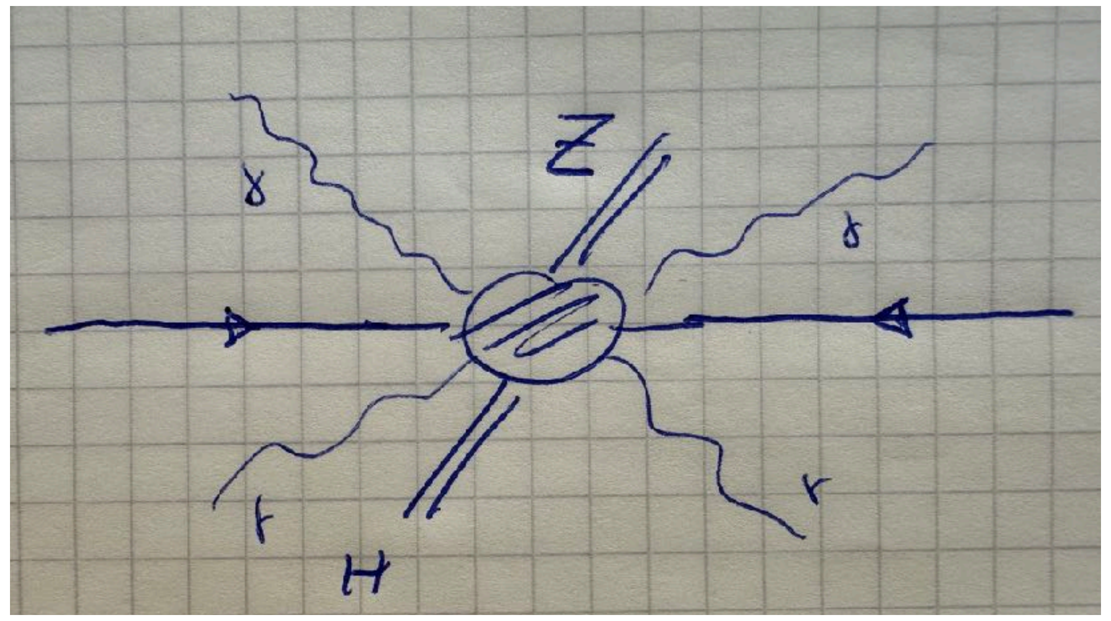

Soft logarithms

$$\ell = \log \frac{Q^2}{\langle E_\gamma \rangle^2}$$

$\sqrt{Q^2} = m_Z$

$$L = 24.18 \quad \Longrightarrow \quad \frac{\alpha}{\pi} L = 0.06$$

$$0 \leq m_{ll} \leq m_Z\,, \quad \ell = 6.89 \quad \Longrightarrow \quad \frac{\alpha}{\pi} \ell = 0.017$$

$$m_Z - 1 \text{ GeV} \leq m_{ll} \leq m_Z\,, \quad \ell = 10.60 \quad \Longrightarrow \quad \frac{\alpha}{\pi} \ell = 0.026$$

$\sqrt{Q^2} = 500$ GeV

$$L = 27.59 \quad \Longrightarrow \quad \frac{\alpha}{\pi} L = 0.069$$

$$0 \leq m_{ll} \leq m_Z\,, \quad \ell = 1.449 \quad \Longrightarrow \quad \frac{\alpha}{\pi} \ell = 0.0036$$

$$m_Z - 1 \text{ GeV} \leq m_{ll} \leq m_Z\,, \quad \ell = 1.453 \quad \Longrightarrow \quad \frac{\alpha}{\pi} \ell = 0.0036$$

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YFS (soft/eikonal factorization)

$$\left\{ e^+(p_1) + e^-(p_2) \longrightarrow X(p_X) + \sum_{i=0}^{n} \gamma(k_n) \right\}_{n=0}^{\infty}$$

$$d\sigma(L,\ell) \quad = \quad e^{Y(p_1,p_2,p_X)} \sum_{n=0}^{\infty} \beta_n \left(\mathcal{R}p_1, \mathcal{R}p_2, \mathcal{R}p_X; \{k_i\}_{i=0}^{n}\right) d\mu_{X+n\gamma}$$

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Electron PDFs (collinear factorization)

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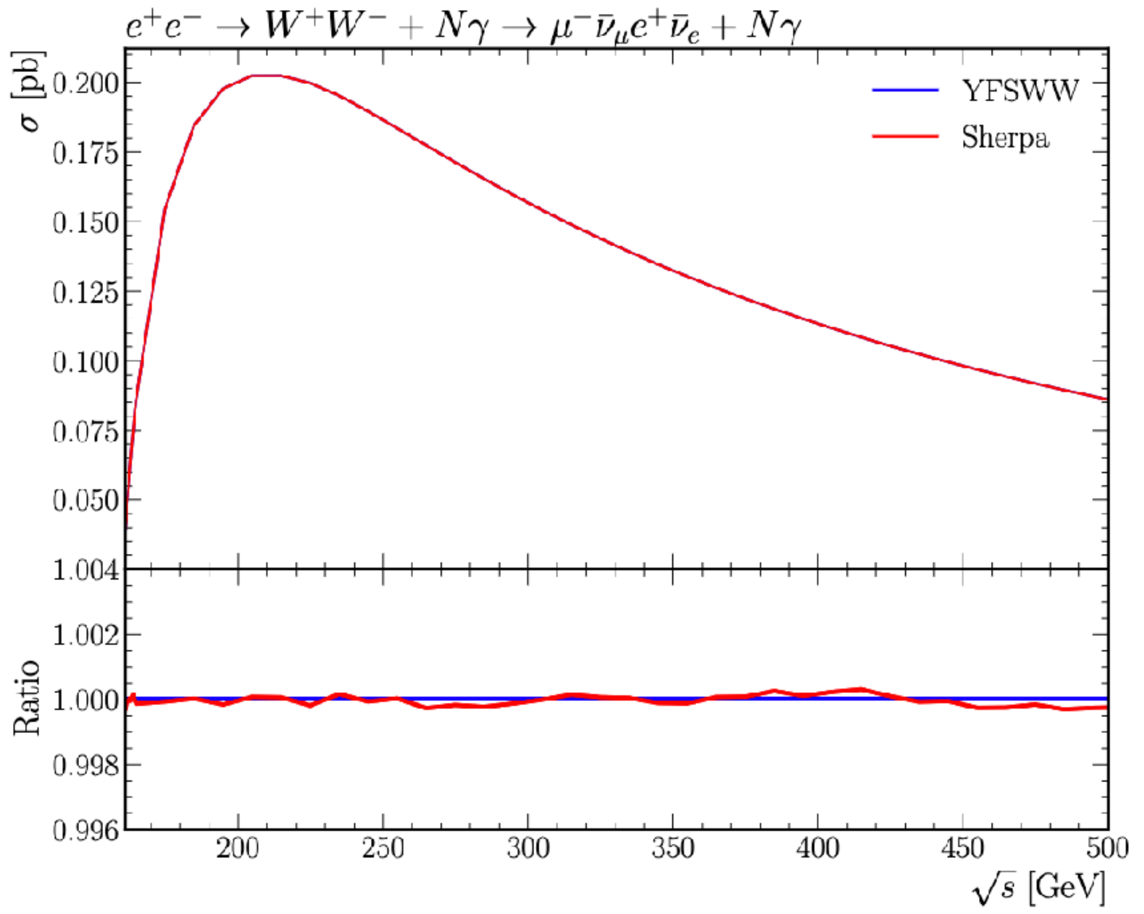

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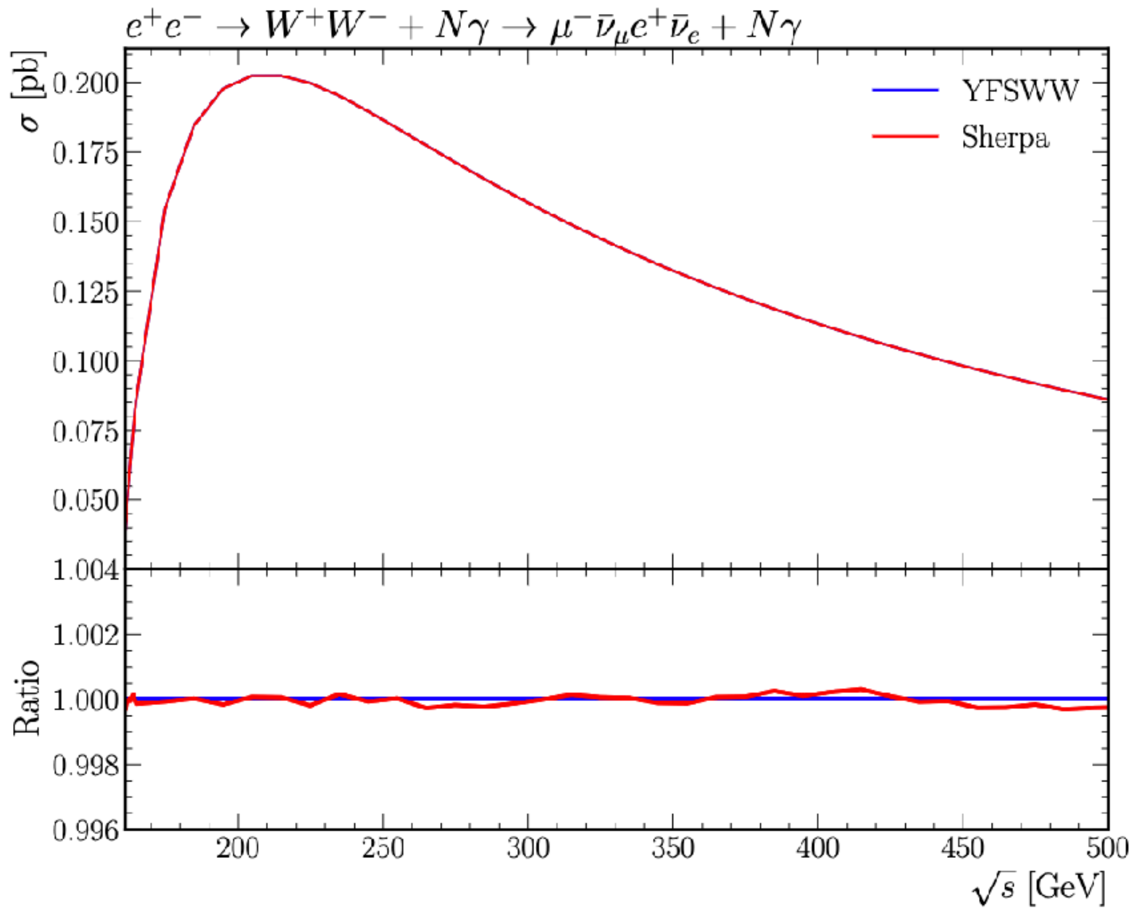

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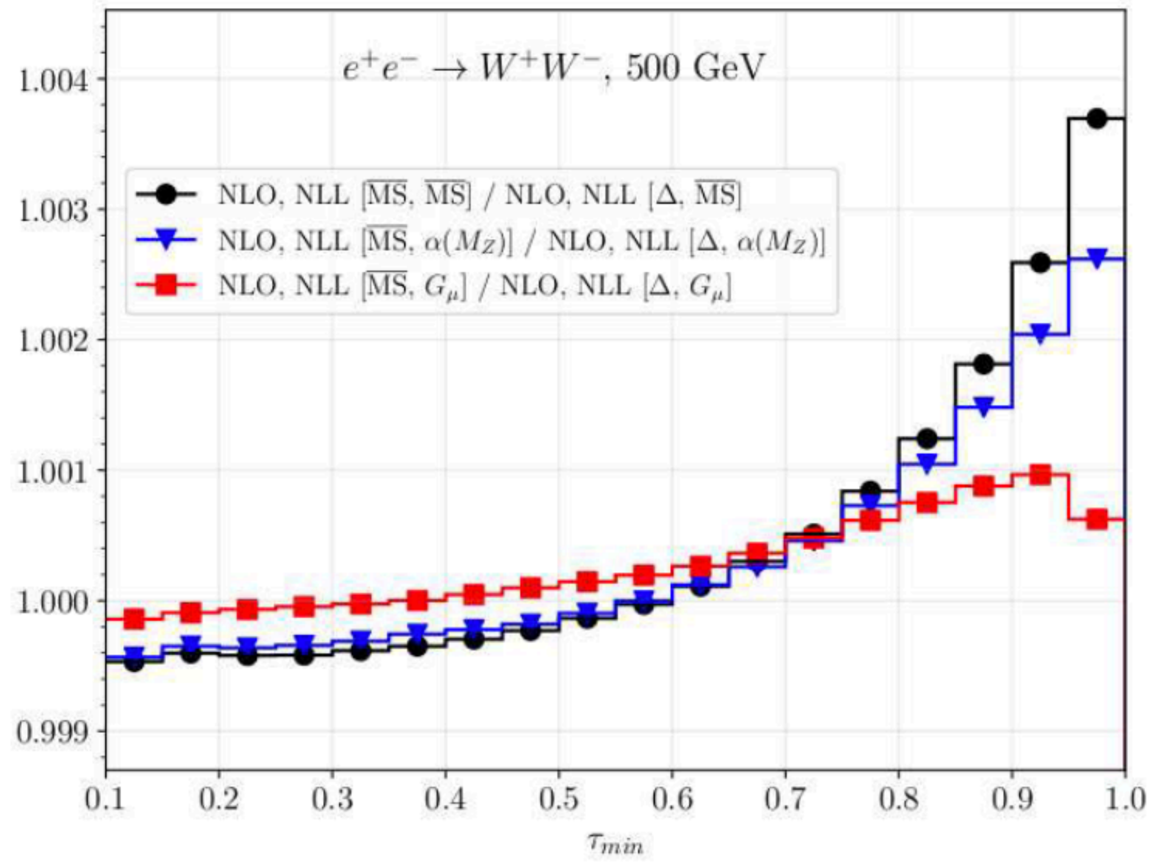

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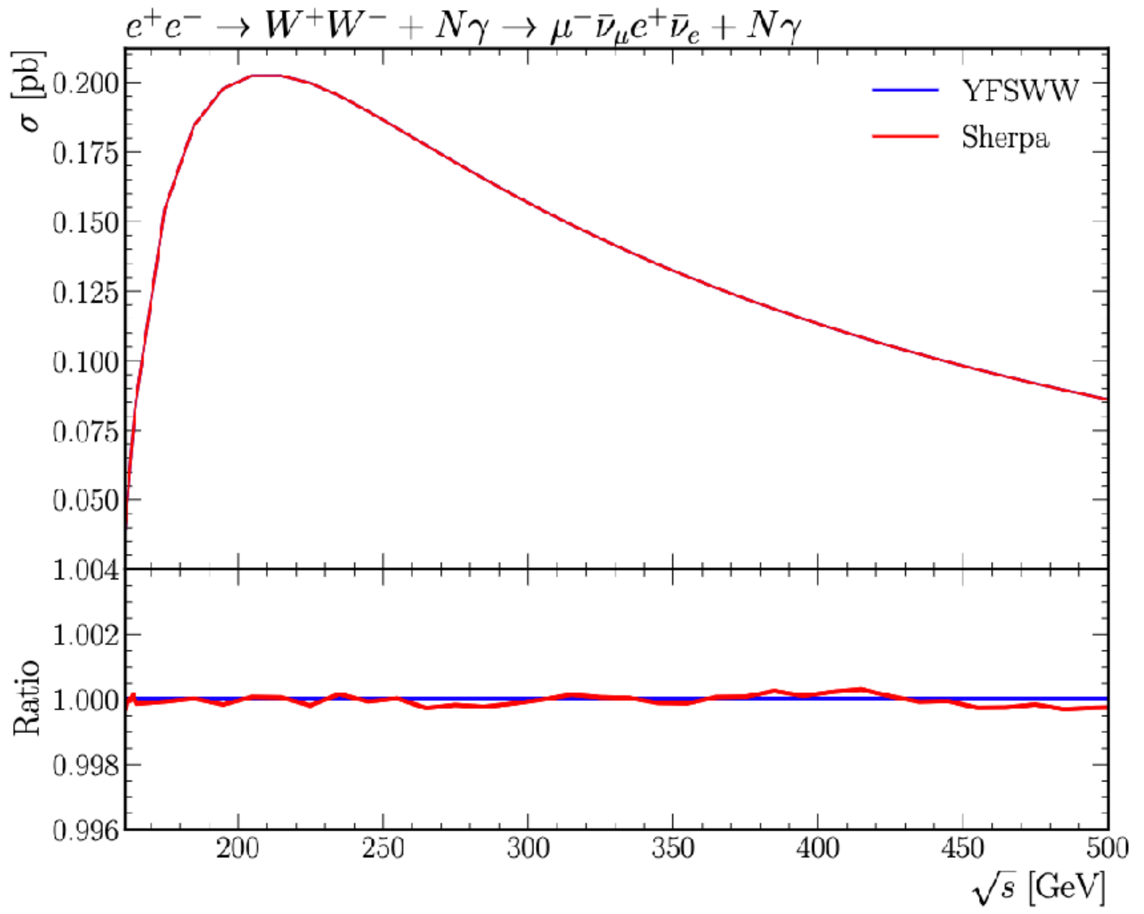

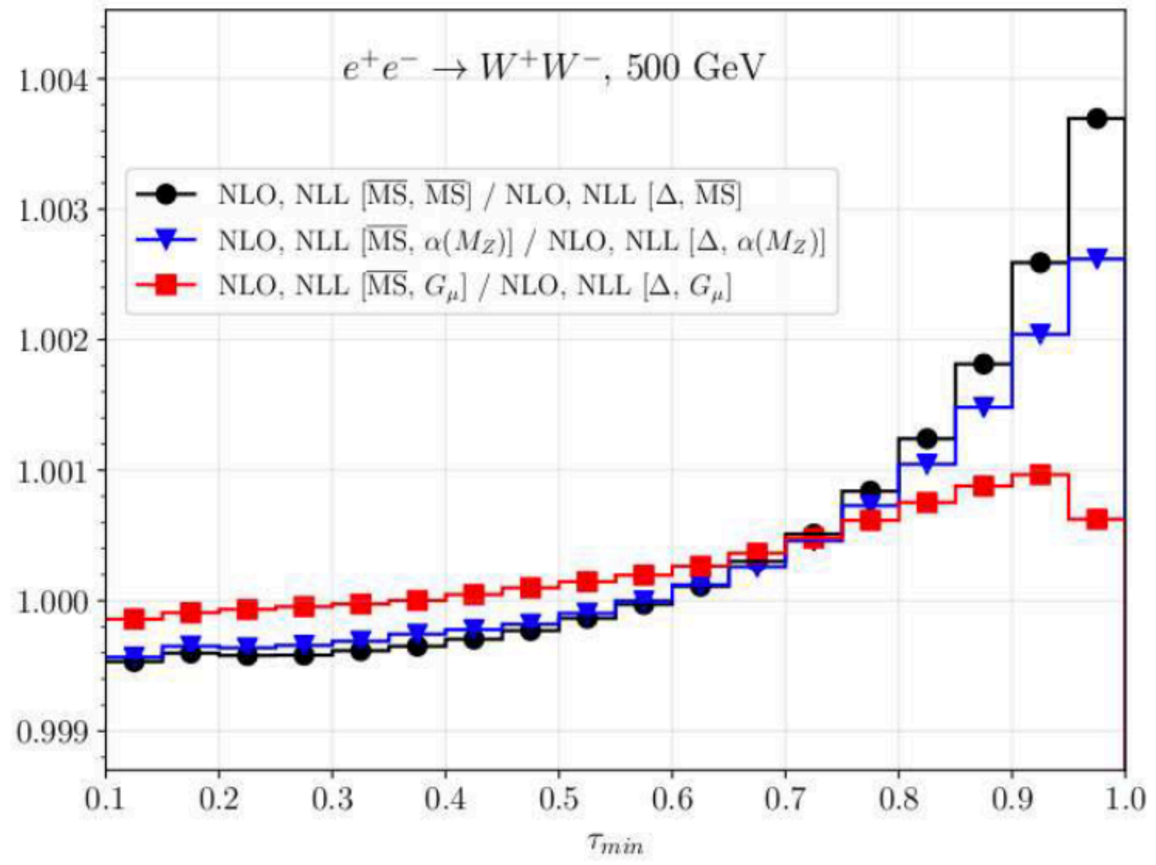

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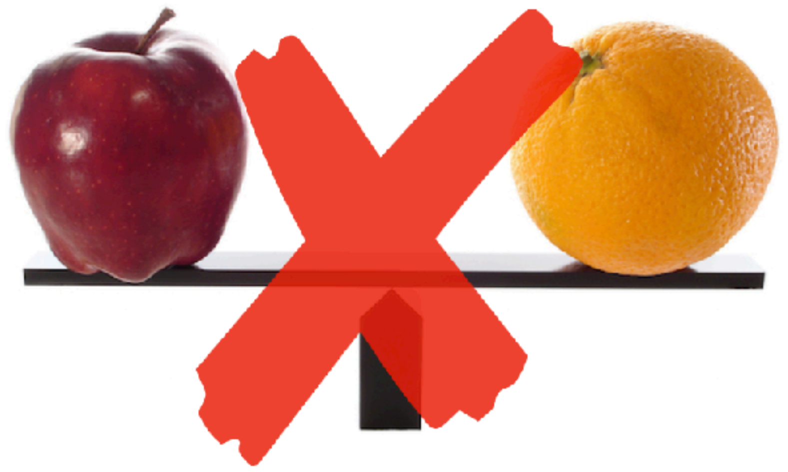
- Collinear PDFs available at NLL (`MG5_aMC@NLO`, `[Whizard]`)
- YFS available for $e^+e^- \to ff, WW, ZZ, ZH$ and in `Sherpa`
- YFS little systematic uncertainties
- Collinear PDFs much larger scheme uncertainties
- Different schemes available: $\overline{\text{MS}}$ vs. DIS
- Computation non-trivial, much less universal, but possible
- PDF calculation analogous to LHC
- Calculation allow uncertainties of 0.2-0.4 per cent

Benchmarks and lessons from LEP Yellow Report

[Alan Price]

[*all*]



Technical Benchmarks of Monte Carlo for Future Lepton Colliders

As a first step we can follow in the footsteps of LEP Reports of the Working Groups on Precision Calculations for LEP2 Physics - CERN Document Server

91.2 GeV

Also look at +- 3Gev around zpole (88GeV, 94GeV)

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

    Lep Cut Examples: **inclusive** $\sqrt{\frac{M^2}{s}} > 0.1$

    exclusive $\sqrt{\frac{M^2}{s}} > 0.85$

    First benchmarks:
    1. Total XS
    2. $\frac{d\sigma}{dcos(\theta)}$, $\frac{d\sigma}{dM}$, others?
    3. Polarised beams?
    4. LL PDF c.f input eta, beta, mixed
    5. AFB, include |cos(theta)| < 0.97
  - $e^+e^- \to e^+e^-$

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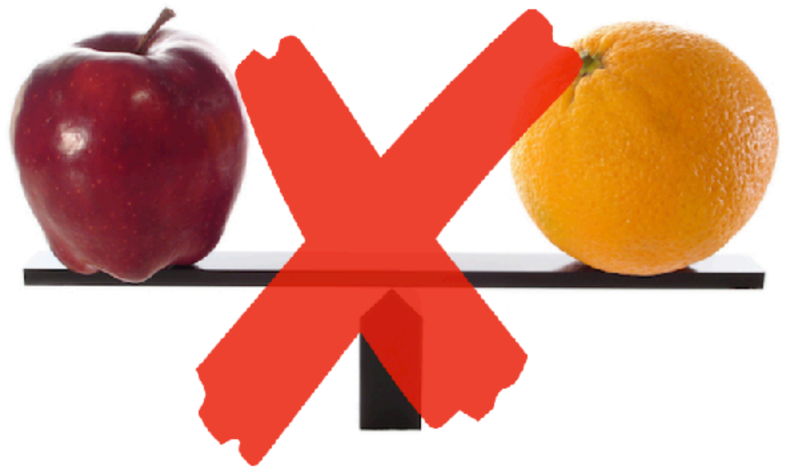

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- ☑ Reproducability & versioning
- ☑ "Theory-inspired" approach: start from simplest "parton" level upwards
- ☑ then switch on: polarization, QED ISR, parton shower, fragmentation, NLO
- ☑ Include multi-purpose tools and dedicated/specialized Monte Carlos
- ☑ Cover all energy stages: 91, 161, 240/250, 365-380 GeV (beyond?)
- ☑ Time scale: ca. end of 2025 (before CERN yellow report)
- ☑ Involve as many ECRs as possible
- ☑ Publish theory paper; CERN yellow report: only summary table

- ☑ Community input and participation *very* much welcome!

Benchmarks and lessons from LEP Yellow Report

[Fulvio Piccinini]

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- Electroweak vs QCD
  - *“EW software can be required to give relatively unambiguous answers, with high implied accuracy”*
  - *“QCD software is still descriptive rather than predictive”*

Electroweak (EW)	strong (QCD)
‘new’ phenomena	‘old’ phenomena
‘new’ software	‘old’ software
rapid evolution	moderate evolution
theory ‘solved’	theory ‘unsolved’
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- CERN Yellow Report demands on LEP1/2 MCs:

☑ Higher order QED corrections
☑ Multi-photon kinematics
☑ Implementation of weak corrections
☑ Beam polarization (sic!)
☑ Bhabha scattering mode
☑ Support (sic!)
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- it is never underestimated the importance of having predictions from different event generators, necessary for a robust assessment of the th. uncertanty

Focus topics I: Bhabha precision

[Maciej Skrzypek]

Bhabha cross sect. depends on detector acceptance angles

$$\sigma_{Bh} \simeq 4\pi\alpha^2 \left(\frac{1}{t_{\min}} - \frac{1}{t_{\max}}\right) = 4\pi\alpha^2 \left(\frac{t_{\max} - t_{\min}}{\bar{t}^2}\right), \quad \bar{t} = \sqrt{t_{\min} t_{\max}}$$

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FCCee	64÷86	M_Z	13.7×10^{-4}	3.37
FCCee	64÷86	240	13.7×10^{-4}	8.9
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Current BHLUMI precision forecast for FCCee			
Type of correction / Error	M_Z (2019) [1]	240 GeV	350 GeV [2]
(a) Photonic $\mathcal{O}(L_e\alpha^2)$	0.027%	0.032%	0.033%
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(e) Z and s-channel γ exchange	0.09%	0.25% (0.034%)	0.5% (0.07%)
(f) Up-down interference	0.009%	0.010%	0.010%
(g) Technical Precision	[0.027%]		
Total	10×10^{-4}	25×10^{-4} (6×10^{-4})	50×10^{-4} (8.7×10^{-4})

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(c) Vacuum polariz.	0.6×10^{-4}	1.0×10^{-4}	1.1×10^{-4}
(d) Light pairs	0.5×10^{-4}	0.4×10^{-4}	0.4×10^{-4}
(e) Z and s-channel γ exch.	0.1×10^{-4}	$1.0 \times 10^{-4(*)}$	$1.0 \times 10^{-4(*)}$
(f) Up-down interference	0.1×10^{-4}	0.09×10^{-4}	0.1×10^{-4}
Total	1.0×10^{-4}	1.5×10^{-4}	1.6×10^{-4}

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[Maciej Skrzypek]

Bhabha cross sect. depends on detector acceptance angles

$$\sigma_{Bh} \simeq 4\pi\alpha^2\left(\frac{1}{t_{\min}} - \frac{1}{t_{\max}}\right) = 4\pi\alpha^2\left(\frac{t_{\max} - t_{\min}}{\bar{t}^2}\right), \quad \bar{t} = \sqrt{t_{\min} t_{\max}}$$

Machine	$\theta_{\min} \div \theta_{\max}$ [mrad]	$\sqrt{s}$ [GeV]	$\bar{t}/s \simeq \bar{\theta}^2/4$	$\sqrt{\bar{t}}$ [GeV]
LEP	28÷50	M_Z	3.5×10^{-4}	1.70
FCCee	64÷86	M_Z	13.7×10^{-4}	3.37
FCCee	64÷86	240	13.7×10^{-4}	8.9
FCCee	64÷86	350	13.7×10^{-4}	13.0
ILC	31÷77	500	6.0×10^{-4}	12.2
ILC	31÷77	1000	6.0×10^{-4}	24.4
CLIC	39÷134	3000	13.0×10^{-4}	108

Current BHLUMI precision forecast for FCCee			
Type of correction / Error	M_Z (2019) [1]	240 GeV	350 GeV [2]
(a) Photonic $\mathcal{O}(L_e\alpha^2)$	0.027%	0.032%	0.033%
(b) Photonic $\mathcal{O}(L_e^3\alpha^3)$	0.015%	0.026%	0.028%
(c) Vacuum polariz.	0.009%	0.020%	0.022%
(d) Light pairs	0.010%	0.015%	0.015%
(e) Z and s-channel γ exchange	0.09%	0.25% (0.034%)	0.5% (0.07%)
(f) Up-down interference	0.009%	0.010%	0.010%
(g) Technical Precision	[0.027%]		
Total	10×10^{-4}	25×10^{-4} (6×10^{-4})	50×10^{-4} (8.7×10^{-4})

Forecast			
Type of correction / Error	FCCee$_{M_Z}$ [1]	FCCee$_{240}$	FCCee$_{350}$
(a) Photonic $\mathcal{O}(L_e^2\alpha^3)$	0.10×10^{-4}	0.10×10^{-4}	0.13×10^{-4}
(b) Photonic $\mathcal{O}(L_e^4\alpha^4)$	0.06×10^{-4}	$0.26 \times 10^{-4(a)}$	$0.27 \times 10^{-4(a)}$
(c) Vacuum polariz.	0.6×10^{-4}	1.0×10^{-4}	1.1×10^{-4}
(d) Light pairs	0.5×10^{-4}	0.4×10^{-4}	0.4×10^{-4}
(e) Z and s-channel γ exch.	0.1×10^{-4}	$1.0 \times 10^{-4(*)}$	$1.0 \times 10^{-4(*)}$
(f) Up-down interference	0.1×10^{-4}	0.09×10^{-4}	0.1×10^{-4}
Total	1.0×10^{-4}	1.5×10^{-4}	1.6×10^{-4}

- Technical precision needs 2nd code: `BHLumi` vs. `BabaYaga` (NNLO in hard process possible)
- Major ingredients: hadronic vacuum polarization, EW corrections, light fermion pairs
- Inclusion of 4f, 4f + γ, 5f, 6f backgrounds necessary at matrix element level

Focus topics II: BSM needs

[Sarah Williams]

- Focus much on LLP/displaced vertices
- Feature request for LLP in `Whizard`
- Some confusion on
  UFO vs. generator-specific models

Higgs
factory

m_H, σ, Γ_H
self-coupling
H→ bb, cc, ss, gg
H→inv
ee→H
H→bs, ..

Top

m_{top}, Γ_{top}, ttZ, FCNCs

Flavor
"boosted" B/D/τ factory:

CKM matrix
CPV measurements
Charged LFV
Lepton Universality
τ properties (lifetime, BRs..)

$B_c \to \tau\nu$
$B_s \to D_s K/\pi$
$B_s \to K^* \tau\tau$
$B \to K^* \nu\nu$
$B_s \to \varphi \nu\nu$ …

QCD - EWK
most precise SM test

m_Z , Γ_Z , Γ_{inv}

$\sin^2\theta_W$, R^Z_ℓ , R_b, R_c

$A_{FB}^{b,c}$, τ pol.

α_S ,

m_W, Γ_W

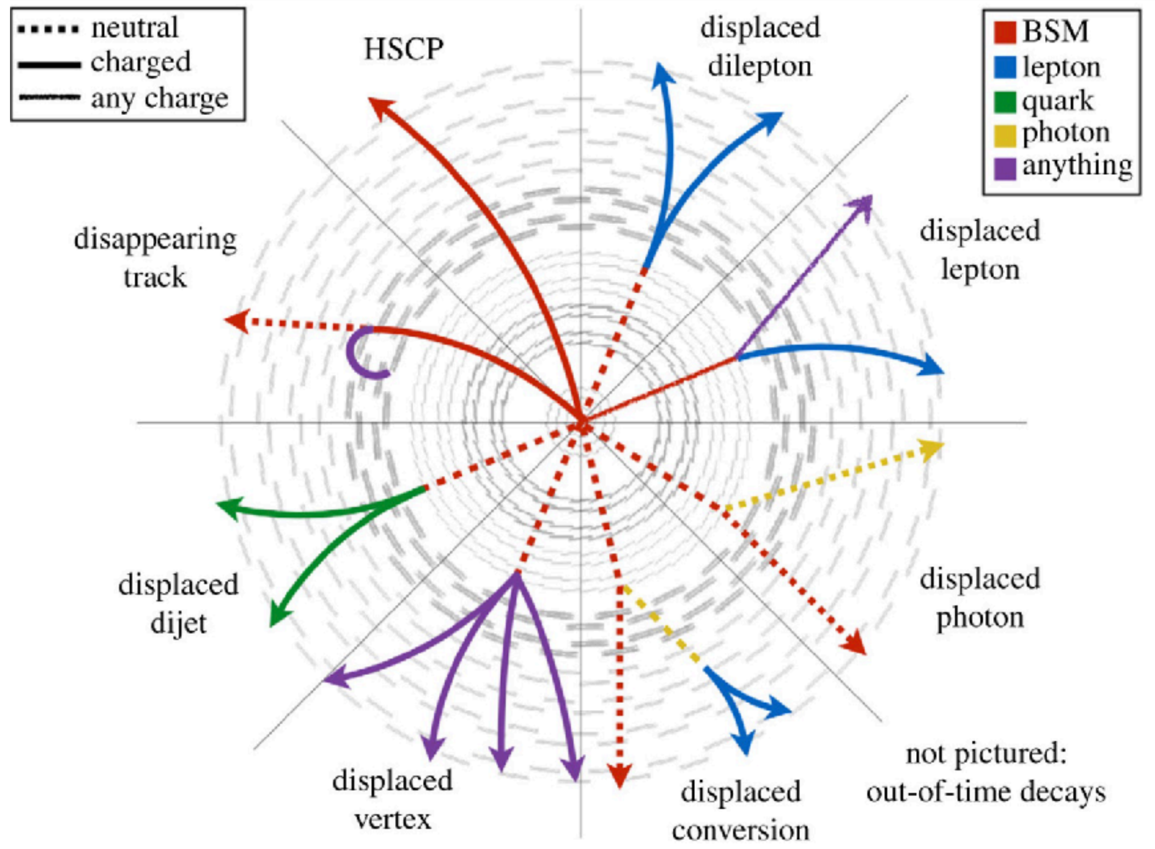
BSM
feebly interacting particles

Heavy Neutral Leptons
(HNL)

Dark Photons Z_D

Axion Like Particles (ALPs)

Exotic Higgs decays



LLPs that are semi-stable or decay in the sub-detectors are predicted in a variety of BSM models:

- Heavy Neutral Leptons (HNLs)
- RPV SUSY
- Dark photons
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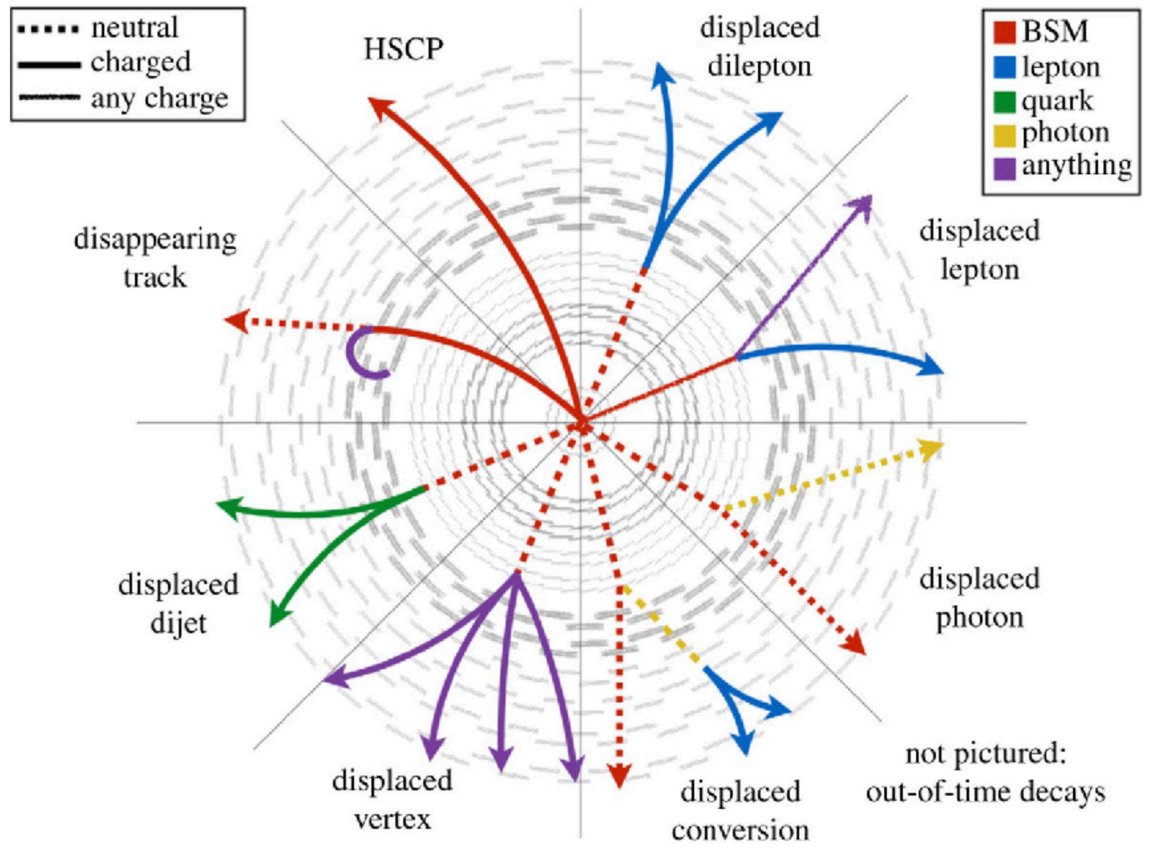

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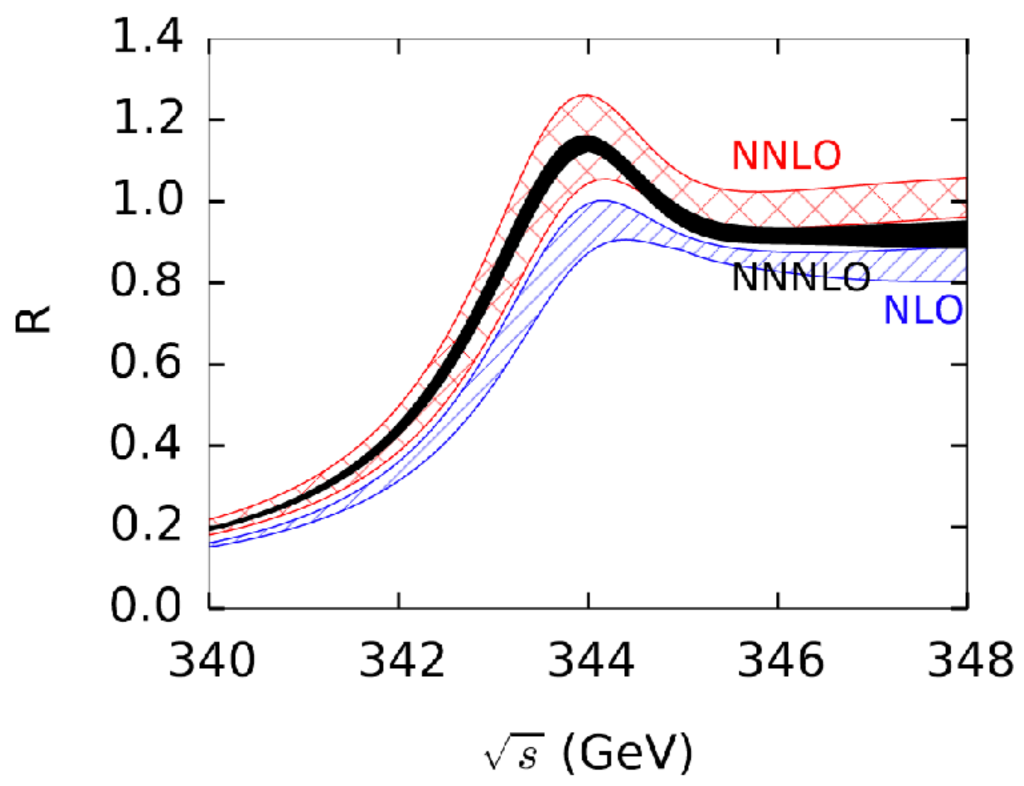
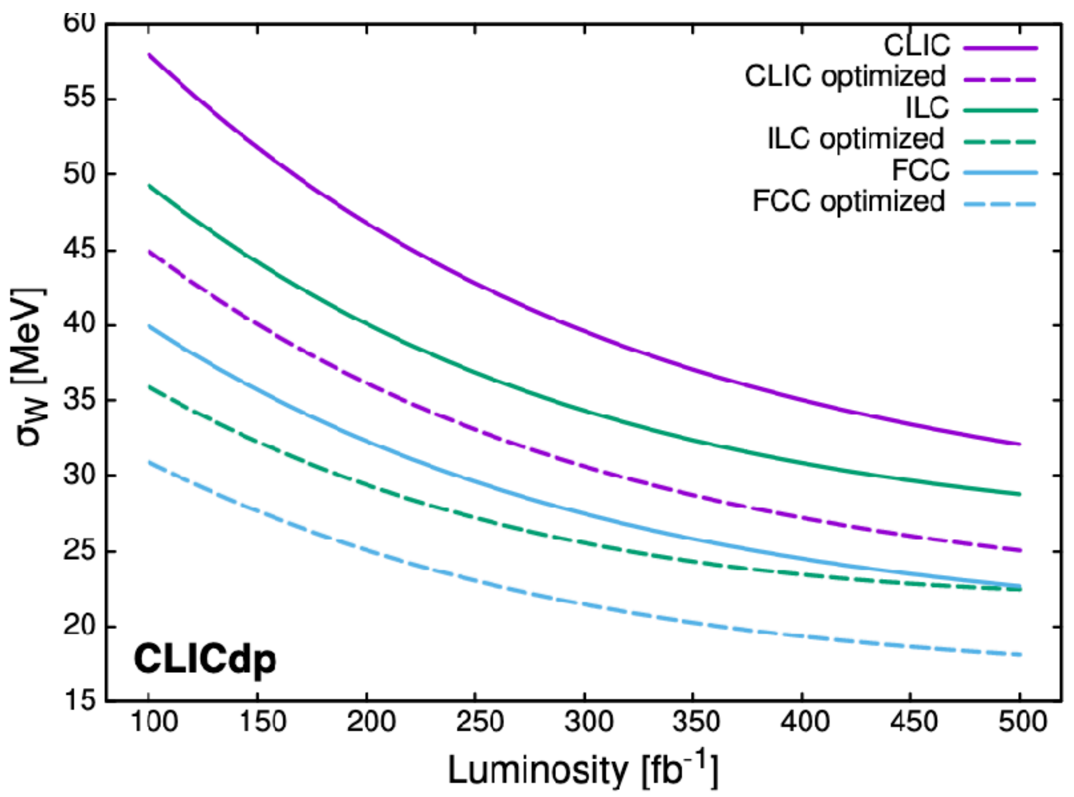
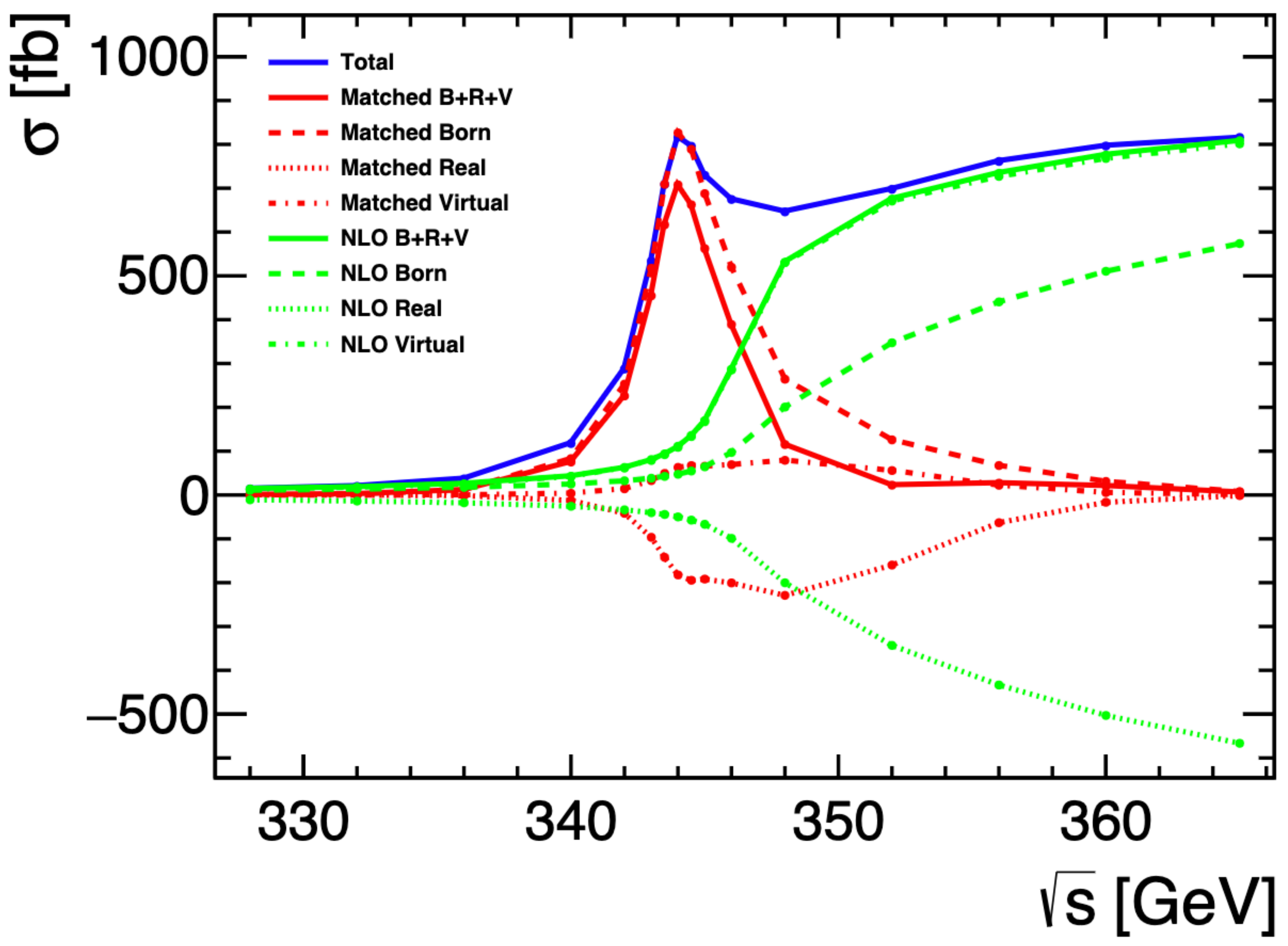
- Are there fundamental differences between generators when it comes to assumptions/frameworks used for calculating BSM processes? Can we expect ~ 100% agreement up to numerical precision when the same process is calculated?

[A. Filip Żarnecki]

Focus topics III: (exclusive) top threshold







- Top threshold cross section known to NNNLO in NRQCD and NNLL in vNRQCD
- Differential distributions are sensitive to top mass as well
- Completely unknown: theoretical uncertainties, completely unknown: systematic uncertainties
- For $e^+e^- \to W^+W^-b\bar{b}$ at NLO QCD (continuum) to NLO NRQCD⊕NLL vNRQCD matched in `Whizard`
- Implemented 2013-17 (1 postdoc, 2 Phd students left physics), recently (re-)validated in `Whizard v3.x`
- Attempt in FCC-ee by Jeremy Andrea (director at Strasbourg) and A.F. Żarnecki (student finished)
- Some purely technical problems: tested with ISR, doesn't work with beam spectrum, fails with spectrum & polarization
- Complicated procedure of six different differential cross section contributions
- Plagued by very bad number of negative weights
- No person-power in `Whizard`: open call for participation & contribution .... there are open theoretical challenges !!

Miscellaneae: event formats, computing, software frameworks

[Andy Buckley]
[Gerard Ganis]
[Andrea Valassi]

T Mandlener, Oct 2022

- Generators

babayaga*†	baurmc†	bhlumi*†	crmc†	evtgen	genie†
gosam†	guinea-pig*†	herwig3	herwigpp†	kkmcee*	madgraph5amc
photos	pythia6†	pythia8	sherpa	starlight†	superchic†
tauola†	vbfnlo	whizard			

- "Generator tools"

agile†	alpgen†	ampt†	apfel†	ccs-qcd†	chaplin†
collier†	cuba†	dire†	feynhiggs†	form†	hepmc
hepmc3	heppdt	hoppet†	hztool†	lhapdf	lhapdfsets†
looptools	openloops	professor†	prophecy4f†	qd†	qgraf†
recola†	rivet	syscalc†	thepeg	unigen†	yoda

- ☑ Software framework (Key4Hep, EDM4HEP) universally adapted by CEPC, ILC, CLIC, FCC-ee, CCC (?)
- ☑ Discussion on performance, portability, installation and deployment chains

- ☑ Generator performance: every generator has different bottlenecks, hence different needs / ways for solution
- ☑ Discussed: porting to GPUs, mentioned: vectorization, not discussed: OpenMPI / coarray etc.

- ☑ Most popular event format for MC authors: HepMC3 (HepMC2 only a "C++ version of COMMON blocks 😂)
- ☑ HepMC3 easiest way for MCs to ROOT output, soon-ish support for parallelized standardized I/O via HDF5

Conclusions & Personal Thoughts

- Three multi-purpose MCs for *e e* Higgs factories: `MG5_aMC@NLO`, `Sherpa`, `Whizard`
- Beam spectra mostly supported: Gaussian vs. parameterized vs. sampled (sampled is most versatile)
- QCD perturbatively in a very good shape (fixed-order NNLO/NNNLO, NLL showers, NNLL/NNNLL resummation)
- Fragmentation has no new ideas since decades ⇒ Will become a problem for large hadronic data sets
- No *a priori* superior framework for NLO QED: collinear vs. soft (ePDFs vs. YFS); needs work and *data* (sic!)
- Exclusive QED higher-order simulations: YFS vs. QED shower w/ matching still in infancy
- Big challenge will be NNLO QED / NNLO EW
- Dedicated MCs exist and needed for luminometry: `BabaYaga [BHLumi/BHWide]`,
- Uncertain future of Krakow / LEP legacy MCs (will there be ECRs for those? maintenance?)
- Event formats are modern and efficient; but still do not contain spin correlations
- Software frameworks in good shape; efforts on efficiency

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Deep concern that the gap until the first data is too large for theory community

A lot remains to be done (e.g. exclusive simulations), but we are a generation away: there is ~~plenty of~~ too much time