Top, QCD, Flavor, Precision Modeling Session Summary

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Conveners: Jeremy Andrea, Yasuyuki Horii, Adrian Irles, Alan Price,
Juergen Reuter, MT, Huaqiao Zhang

Top, QCD, Flavor, Precision Modeling

For future collider: New physics effects can appear in extended Higgs/Top sector
Precision measurements in top sector help to find it

We had 3 sessions, 11 talks in total.

Top properties:
- Top mass measurements : 2 talks
- Top EW couplings in SMEFT : 1 talk
- Luminosity Measurement : 1 talk
- New Physics models: 2 talks
  - Top/bottom partners → Top/bottom FCNC

Flavor discrimination:
- Fragmentation function: 1 talk
- Z coupling for each quark flavor : 1 talk

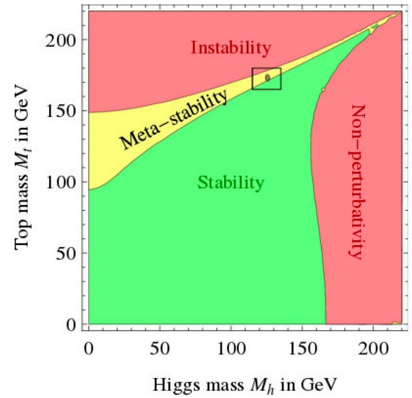
MC generators:
- Sherpa 3.0.0 (2 talks), WIZARD (1 talk)

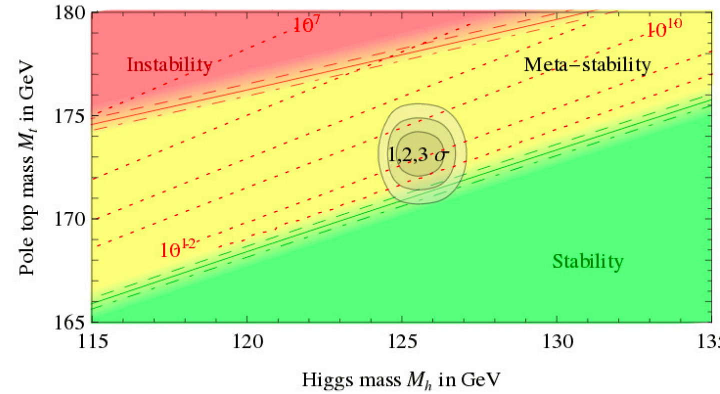
Thank you for all the contributions in the sessions!

Top mass measurements

Talk by Yaquan FANG, Marcel Vos

Top mass: important parameter for the vacuum stability



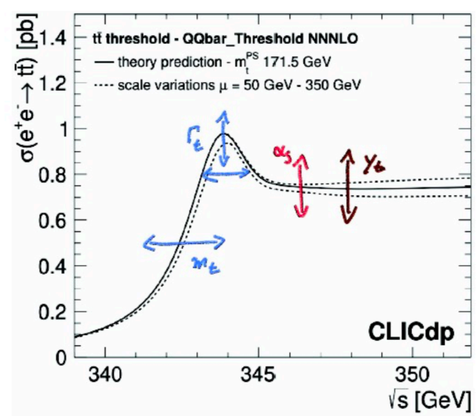


Pole mass determined at LHC

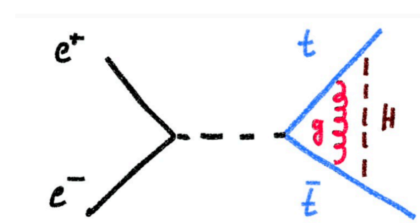
$$m_t = 172.52\text{GeV} \pm 330\text{MeV}$$

Very difficult to improve the precision (already systematics dominated)

Threshold scan at Lepton colliders can determine the mass, width, top yukawa, strong coupling.



Art-work: Frank Simon

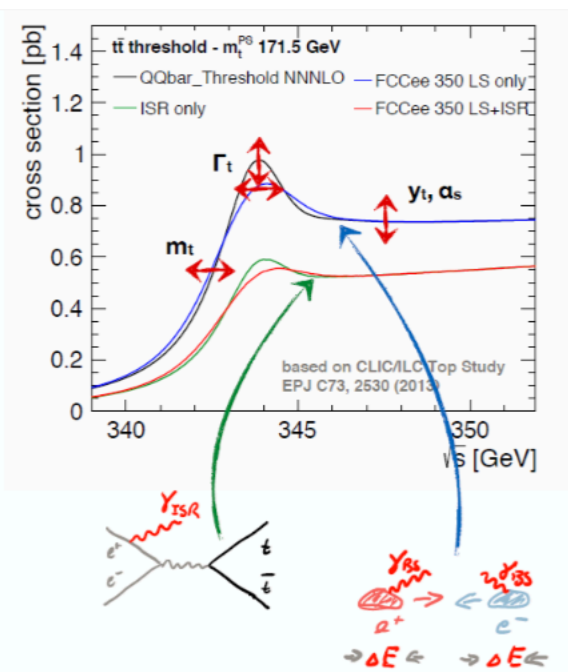


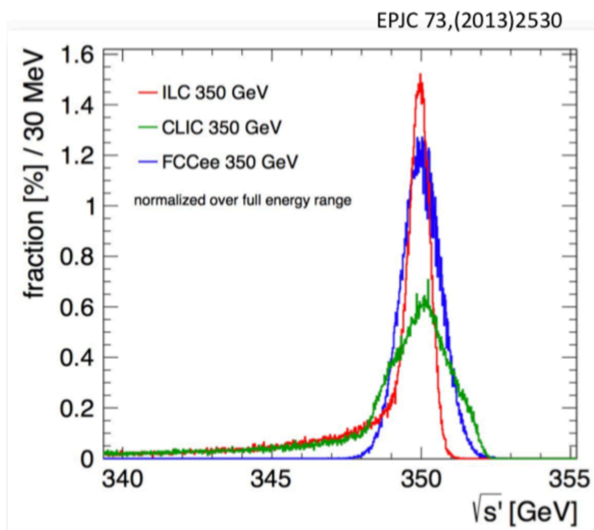
ISR effects, Luminosity spectrum

Talk by Yaquan FANG

ISR will smear the shape

Advantage of circular collider : leptons with energy loss removed ~ 500MeV beam spread



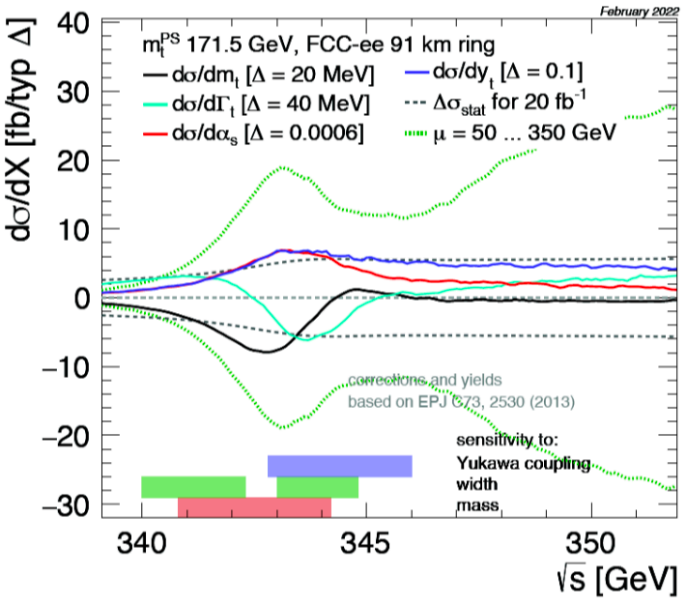


	Top mass uncertainties (MeV)	
	Optimistic	Conservative
Statistics	9	9
Theory	8	24
Quick scan	2	2
α_S	17	17
Width	10	10
Experimental efficiency	5	44
Background	2	14
Beam energy	2	2
Luminosity spectrum	3	6
Total	24	57

Estimate in CEPC: two assumptions: optimistic, conservative

uncertainty: 330 → 24 (57) MeV CEPC for fixed alpha_s and width

Top mass measurements in FCC-ee Talk by Marcel Vos



Statistical uncertainty - - - - can be made small with 1-2 years of operation

Theory uncertainty …… requires calculation beyond NNNLO (QCD) + NNLO (EW). Resummation is available and can be added.

Note: interpretation unambiguous, translation to MS scheme with O(10 MeV) QCD scale uncertainty, parametric uncertainty from α_s requires care, as well as EW corrections

Top quark mass to **approx. 50 MeV**, limited by theory uncertainty and to first order independent of collider design (luminosity spectrum has 2nd order effect)

Top quark width to 45 MeV → bounds on invisible decays+SMEFT arXiv:1907.00997
Precision for α_s ~ 0.001 and y_t ~ 12% not competitive, but good cross-checks

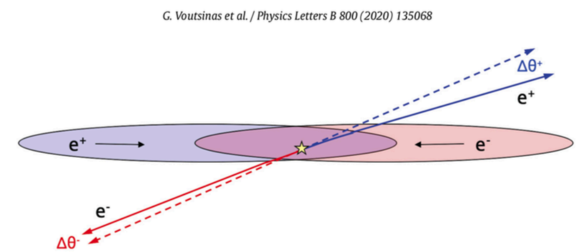
Ankita Mehta & Matteo Defranchis (preliminary):

A shape analysis may benefit from a point well above threshold, where the Yukawa coupling still has an effect, while alpha_s doesn't

Talk by Graham Wilson

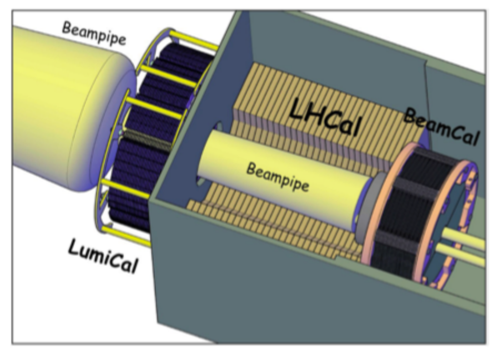
Reimagining LC Luminosity measurements

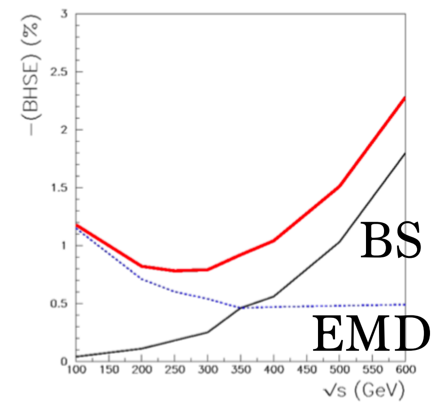
ILD forward design LumiCAL:
similar to the LEP designs like OPAL
for Small-angle Bhabah scattering, $e^+e^- \to e^+e^-$
but problematic due to beamstrahlung and
beam-induced EM deflections = Bahbha suppression

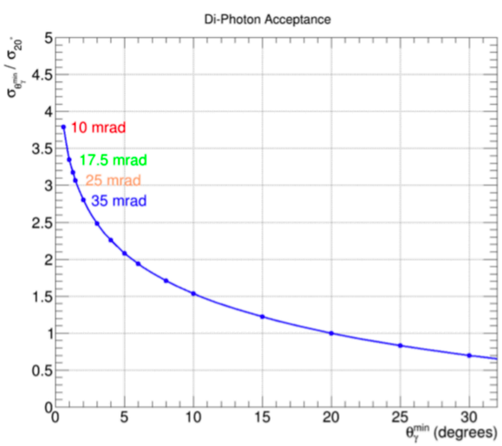


Use of $e^+e^- \to \gamma\gamma$ attractive for
absolute luminosity measurements

PLUG-CAL under consideration
(Precision Luminosity Ultra-Granular Calo.)







Targeting 10^{-4} precision. Cross-sections at $\sqrt{s} = 161$ GeV ($\sigma^U_{WW} \approx 3.5$ pb).

$\theta_{\min}$ (°)	$\sigma_{\gamma\gamma}$ (pb)	$\Delta\sigma/\sigma$ (10 μrad)	$\sigma(ee)/\sigma(\gamma\gamma)$
45	5.3	2.0×10^{-5}	6.1
20	12.7	2.2×10^{-5}	22
15	15.5	2.4×10^{-5}	35
10	19.5	2.9×10^{-5}	68
6	24.6	3.9×10^{-5}	155
2	35.7	8.1×10^{-5}	974

Bhabha rejection (e/γ discrimination) important

Top EW couplings in SMEFT

Talk by Fernando Cornet-Gomez

- top-quark Wilson coefficients of the SMEFT

2-quark operators

Couplings of the t- and b-quark to the Z

$O^3_{\varphi Q} \equiv \left(\bar{Q}\tau^I\gamma^\mu Q\right)\left(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi\right)$

$O^1_{\varphi Q} \equiv \left(\bar{Q}\gamma^\mu Q\right)\left(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi\right)$

$O_{\varphi t(b)} \equiv \left(\bar{t}(\bar{b})\gamma^\mu t(b)\right)\left(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi\right)$

EW dipole operators

$O_{uW} \equiv \left(\bar{Q}\tau^I\sigma^{\mu\nu}t\right)\left(\varepsilon\varphi^* W^I_{\mu\nu}\right)$

$O_{tB} \equiv \left(\bar{Q}\sigma^{\mu\nu}t\right)\left(\varepsilon\varphi^* B_{\mu\nu}\right)$

Chromo-magnetic dipole op.

$O_{tG} \equiv \left(\bar{Q}\sigma^{\mu\nu}T^A t\right)\left(\varepsilon\varphi^* G^A_{\mu\nu}\right)$

t-quark yukawa

$O_{t\varphi} \equiv \left(\bar{Q}t\right)\left(\varepsilon\varphi^*\varphi^\dagger\varphi\right)$

4-quark operators

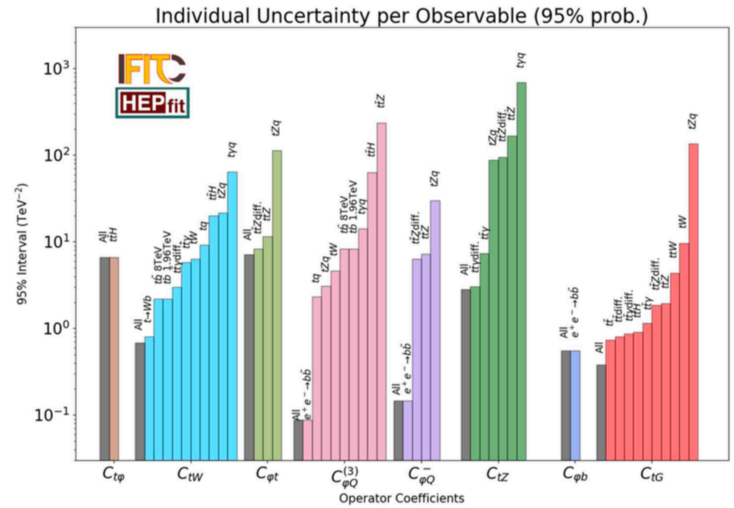
Couplings of light quarks with t- and b-quarks

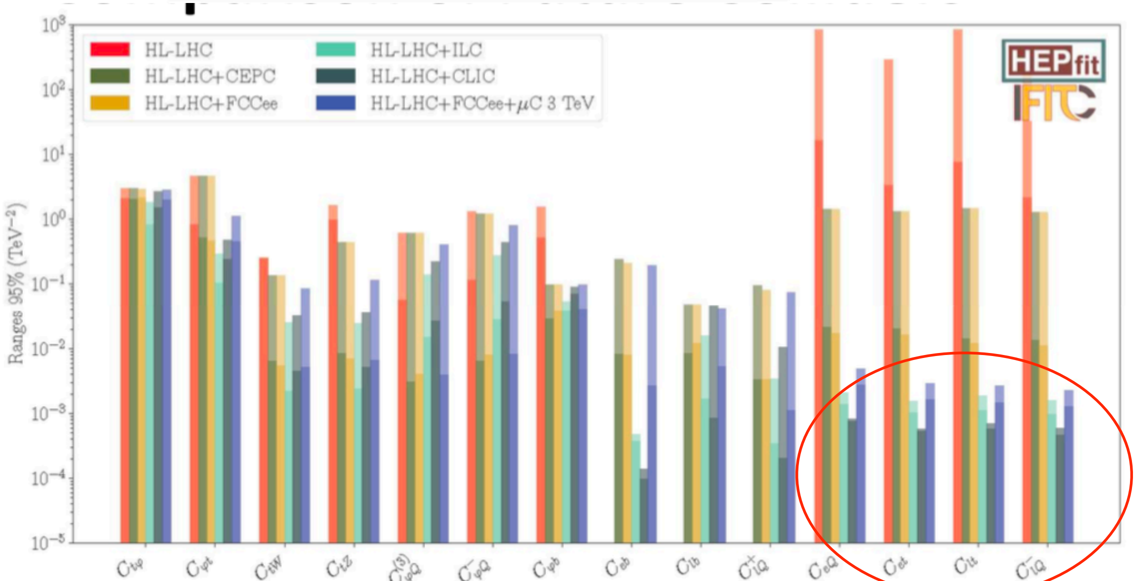
O^8_{tu} O^8_{td} $O^{1,8}_{Qq}$ O^8_{Qu} O^8_{Qd} $O^{3,8}_{Qq}$ O^8_{tq}

2-quark 2-lepton operators

Couplings of light leptons with t- and b-quarks

O_{eb} O_{lb} O_{et} O_{lt} O_{eQ} O^+_{lQ} O^-_{lQ}





HL-LHC will improve a factor 3

e+e- collider can significantly improve bounds on bottom-quark and on top-quark operators (operated above the tt threshold)

ttll operator significantly improved

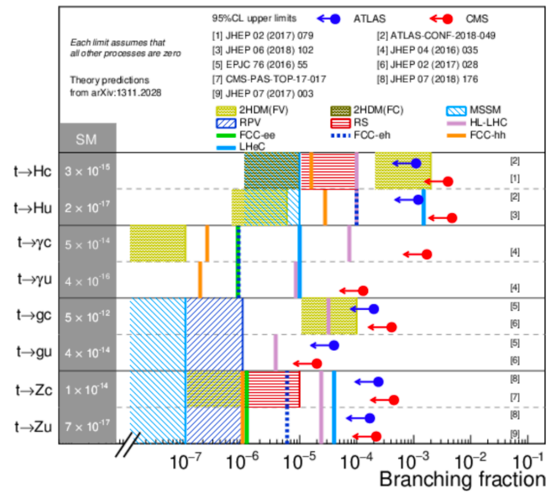
by Lepton Collider

top/bottom partners induce top/bottom FCNCs

Introducing a colored scalar particle

coupled with top and DM.

Discuss the top FCNC signature



Talk by Adil Jueid

Universal Seesaw model

Talk by Albertus Hariwangsa Panuluh

- The up quark Yukawa coupling can be explained by following approximation formula:

$$y_u^{\rm SM} \simeq \frac{y_{u_L} v_R y_{u_R}}{\sqrt{2} M_U} \simeq \frac{v_R}{\sqrt{2} M_U} \simeq 10^{-5}$$

$$v_R \ll M_U$$

$$v_L < M_T < v_R \ll M_B$$

Third gen. partners introduced

$$\mathcal{L}_{\rm mass} = -\begin{pmatrix} \overline{(\tilde{u}_L)^3} & \overline{(\tilde{u}_L)^4} \end{pmatrix} \overbrace{\begin{pmatrix} Y^3_{u_L} \frac{v_L}{\sqrt{2}} (W_{T_R})^{43} & Y^3_{u_L} \frac{v_L}{\sqrt{2}} (W_{T_R})^{44} \\ 0 & m_{u_4} \end{pmatrix}}^{\mathbb{M}_t} \begin{pmatrix} (\tilde{u}'_R)^3 \\ (\tilde{u}'_R)^4 \end{pmatrix} - h.c.$$

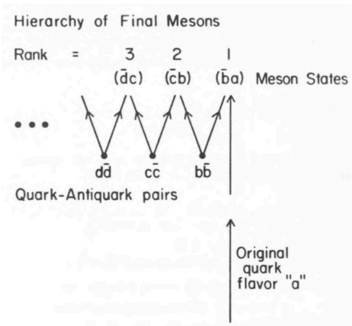
$$- \begin{pmatrix} \overline{(\tilde{d}'_L)^3} & \overline{(\tilde{d}'_L)^4} \end{pmatrix} \underbrace{\begin{pmatrix} Y^3_{d_L} \frac{v_L}{\sqrt{2}} (W_{B_R})^{43} & Y^3_{d_L} \frac{v_L}{\sqrt{2}} (W_{B_R})^{44} \\ 0 & m_{d_4} \end{pmatrix}}_{\mathbb{M}_b} \begin{pmatrix} (\tilde{d}''_R)^3 \\ (\tilde{d}''_R)^4 \end{pmatrix} - h.c..$$

Higgs FCNC in bottom sector not suppressed

Fragmentation functions af future Lepton Collider

Talk by Jun Gao

parton model [Field&Feynman]



distribution of momentum to mesons via creation of quark-antiquark pairs in cascade

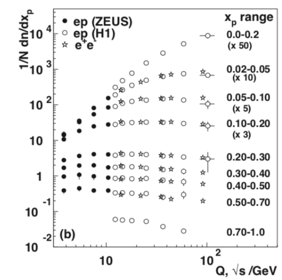
Evolution is governed by the DGLAP eq.

$$\frac{d}{d\ln\mu^2} D_1^{h/i}(z,\mu^2) = \frac{\alpha_s(\mu^2)}{2\pi} \sum_j \int_z^1 \frac{du}{u} P_{ji}(u, \alpha_s(\mu^2))\, D_1^{h/j}\left(\frac{z}{u}, \mu^2\right)$$

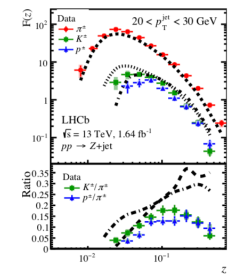
FMNLO (fragmentation at NLO in QCD)

$$u, d, s, c, b, g \to \pi^{\pm}, K^{\pm}, p$$

single incl. production of unidentified charged hadrons (SIA & SIDIS)



Jet fragmentation to light charged hadrons (LHCb)



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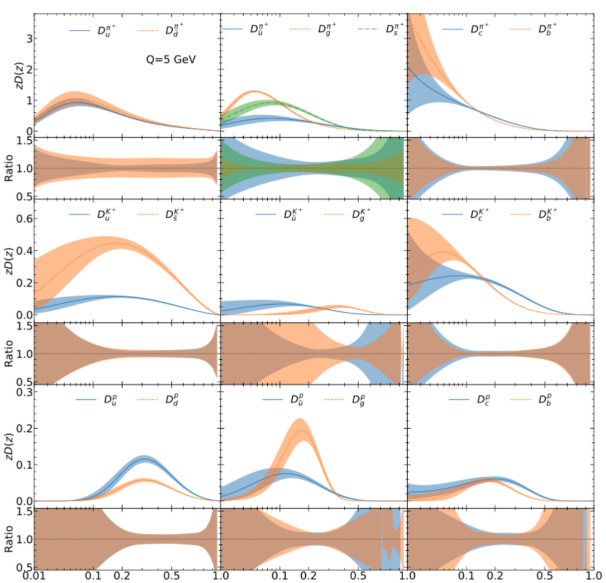
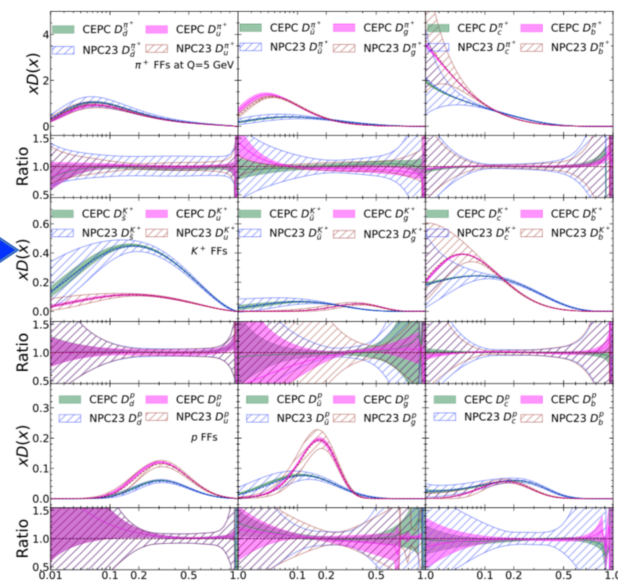


FFs (positively charged) vs. momentum fraction



FFs (positively charged) vs. momentum fraction

high precision of gluon FFs (3-4%) is mostly due to the data of jet fragmentation from the LHC (ALICE)

uncertainties are greatly reduced taking the CEPC as an example

Z coupling for each quark flavor

By Krzysztof Mękała

Z coupling measurements for each quark flavor : sensitive to New Physics

BRs to heavy quarks well constrained at ILC thanks to excellent flavor tagging

Source	$e^-e^+ \to c\bar{c}$				$e^-e^+ \to b\bar{b}$			
	$P_{e^-e^+}(-0.8,+0.3)$		$P_{e^-e^+}(+0.8,-0.3)$		$P_{e^-e^+}(-0.8,+0.3)$		$P_{e^-e^+}(+0.8,-0.3)$	
	R_c	$A_{FB}^{c\bar{c}}$	R_c	$A_{FB}^{c\bar{c}}$	R_b	$A_{FB}^{b\bar{b}}$	R_b	$A_{FB}^{b\bar{b}}$
Statistics	**0.18%**	**0.38%**	**0.27%**	**0.52%**	**0.12%**	**0.24%**	**0.23%**	**0.70%**
Preselection eff.	<0.01%	0.12%	0.02%	0.16%	<0.01%	0.08%	0.06%	0.12%
Background	0.01%	0.01%	0.02%	0.02%	0.01%	0.01%	0.06%	<0.01%
heavy quark mistag	0.11%	<0.01%	0.06%	<0.01%	0.12%	<0.01%	0.22%	<0.01%
uds mistag	0.03%	<0.01%	0.02%	<0.01%	0.08%	<0.01%	0.14%	<0.01%
Angular correlations	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
Beam Polarisation	<0.01%	<0.01%	0.02%	0.01%	<0.01%	0.01%	0.03%	0.15%
Systematics	**0.15%**	**0.16%**	**0.12%**	**0.19%**	**0.18%**	**0.13%**	**0.29%**	**0.22%**
Total	**0.24%**	**0.41%**	**0.30%**	**0.55%**	**0.21%**	**0.27%**	**0.37%**	**0.73%**

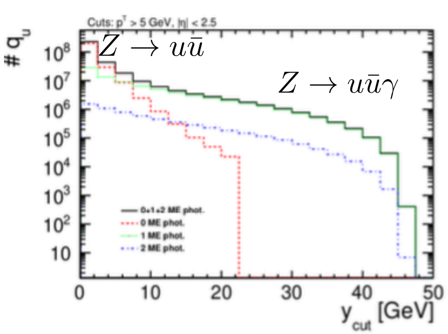
How to constrain Z coupling to light quarks?

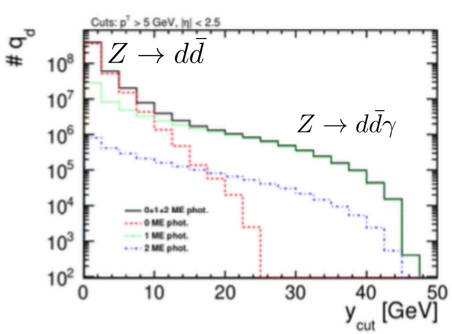
Photon in FSR can disentangle u and d

$$\sigma_{Z\to had} = C_1 \cdot (3c_d + 2c_u) \qquad c_f = v_f^2 + a_f^2$$

$$\sigma_{Z\to had+\gamma} = C_2 \cdot (3c_d + 8c_u) \qquad Q_d^2 : Q_u^2 = 1 : 4$$

Isolation criterion y_{cut}

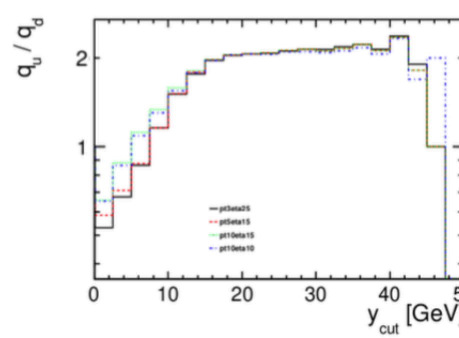




$$y_{cut} = E_\gamma \cdot \sin(\theta_{\gamma q_i}^{min})$$

preliminary, ILC@Z-pole

Isolation criterion y_{cut}



$$\frac{q_u}{q_d} = \left(\frac{Q_u}{Q_d}\right)^2 \cdot \frac{N_u}{N_d} \cdot \frac{c_u}{c_d} \approx 2.1$$

preliminary, ILC@Z-pole

Disentangling u and d possible using differential cross section of ycut

Sherpa 3.0.0 released

July 2024:
The Sherpa collaboration
proudly presents

SHERPA 3.0.0(*)

Condensing the work of the last >5 years
- new physics features
- more intuitive user interface
- more efficient CPU footprint
- modern build system
- comprehensive validation suite

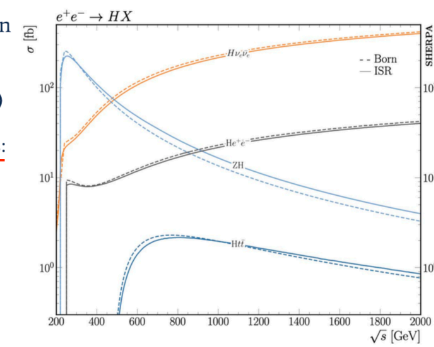
* Limited warranty applies.

https://sherpa-team.gitlab.io/

Talk by Frank Siegert

New in Sherpa 3.0: Real photon emissions in the initial state! [Krauss, Schönherr, Price 2022]

- Extension of Sherpa YFS module for soft photon resummation in final state [Krauss, Schönherr 2008]
- Supplemented with collinear logs up to $O(\alpha^3 L^3)$
- Complete treatment of muti-photon kinematics: Explicit photons, no simplified electron PDF
- Matching to full NLO EW underway [Price]

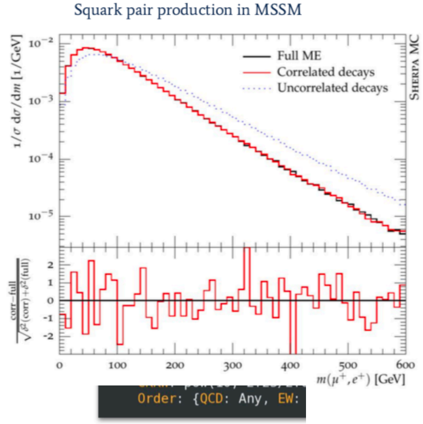


Dream of phenomenologists or experimentalists:
From a model's Lagrangian L → simulated event samples
Important ingredient: UFO standard to automatically transfer Feynman rules (from FeynRules, SARAH, ...) into event generators

Sherpa interface available for a while
[Höche, Kuttimalai, Schumann, FS 2014]

- New in Sherpa 3.0.0: UFO 2.0 interface with more flexibility, e.g. with form factors
- Automatic decay tables/chains
- Spin correlations
- Effective field theories (SMEFT, HEFT) via UFO model

Squark pair production in MSSM



Sherpa's LHC expertise carries over to LC
- Additionally dedicated developments for Linear Collider physics!

NEW: automated YFS for state-of-the-art QED corrections in the initial state [Alan Price]
NEW: photon → lepton splittings in YFS [Lois Flower]
NEW: state-of-the-art photo-production of ee → jets [Peter Meinziger]

Talk by Daniel Reichelt

New Parton Showers - NLL accuracy

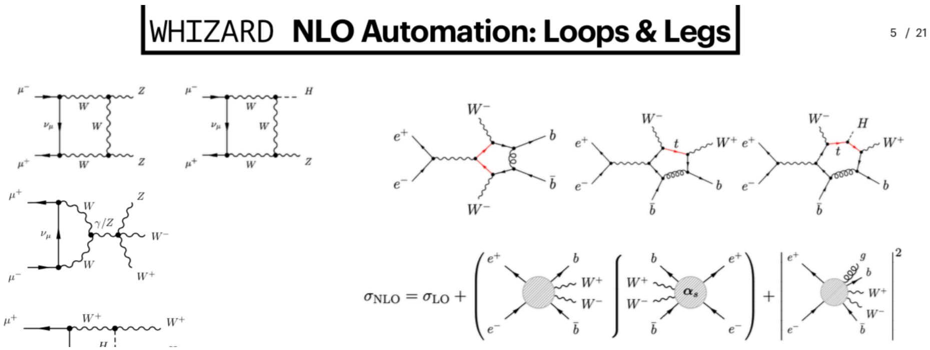
A **L**ogarithmically **A**ccurate **R**esummation **I**n **C**++

global recoil kinematics for soft splitting functions, guarantees NLL and analytic tracking of accuracy

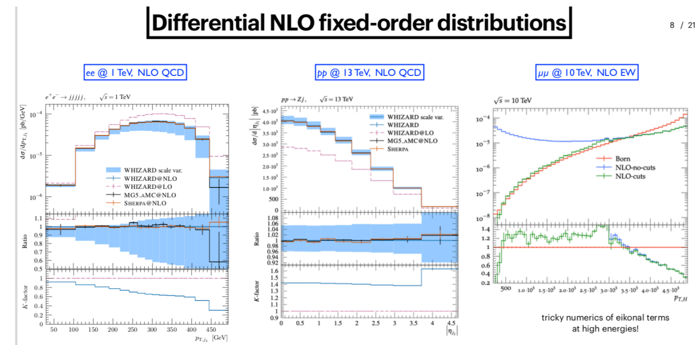
in future: spin correlations to complete radiation pattern in PS will be implemented

WIZARD

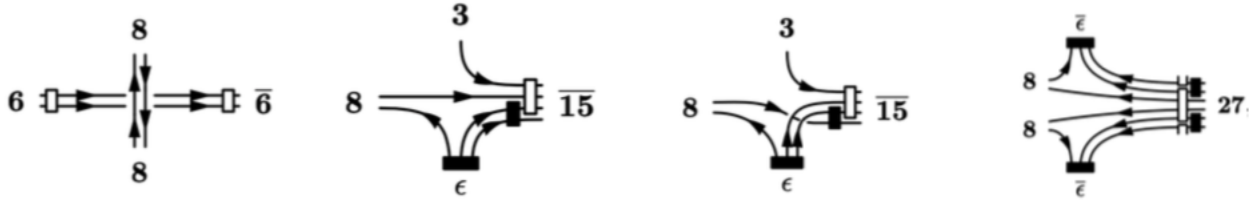
Talk by Jürgen R. Reuter



NLO SM automation for lepton-/hadron colliders completed 2022



Exotic color structure: Recent work allows to generate completely arbitrary SU(N)



Take-home message: WHIZARD is a full-fledged NLO Monte Carlo generator

Highlights: NLO EW / NLO QCD for lepton colliders, NLO EW/QCD mixed corrections at LHC

Loop-induced processes; NLO QCD for BSM models

Generic POWHEG-type matching for NLO QCD ready, for NLO QED/EW starting

Final preparations for in-house generation of exclusive coupling orders, fully general color structures

Under development: EDM4HEP interface, NLL ePDFs, EWPDFs, displaced vertices / LLP, YFS, QED shower

Caveat: many *"w.i.p"* or *"construction sites"* : limited person-power, looks more promising 2025

Summary

- Top itself plays a key role in flavor physics & Higgs physics!
- Indirect probe of NP at very high scale via FCNC and anomalous couplings
- Precision measurements is required in future and possible at Lepton colliders
- Top property measurements, flavor discrimination, MC generators for precision modeling presented.
- Thank you for all the contributions in our session