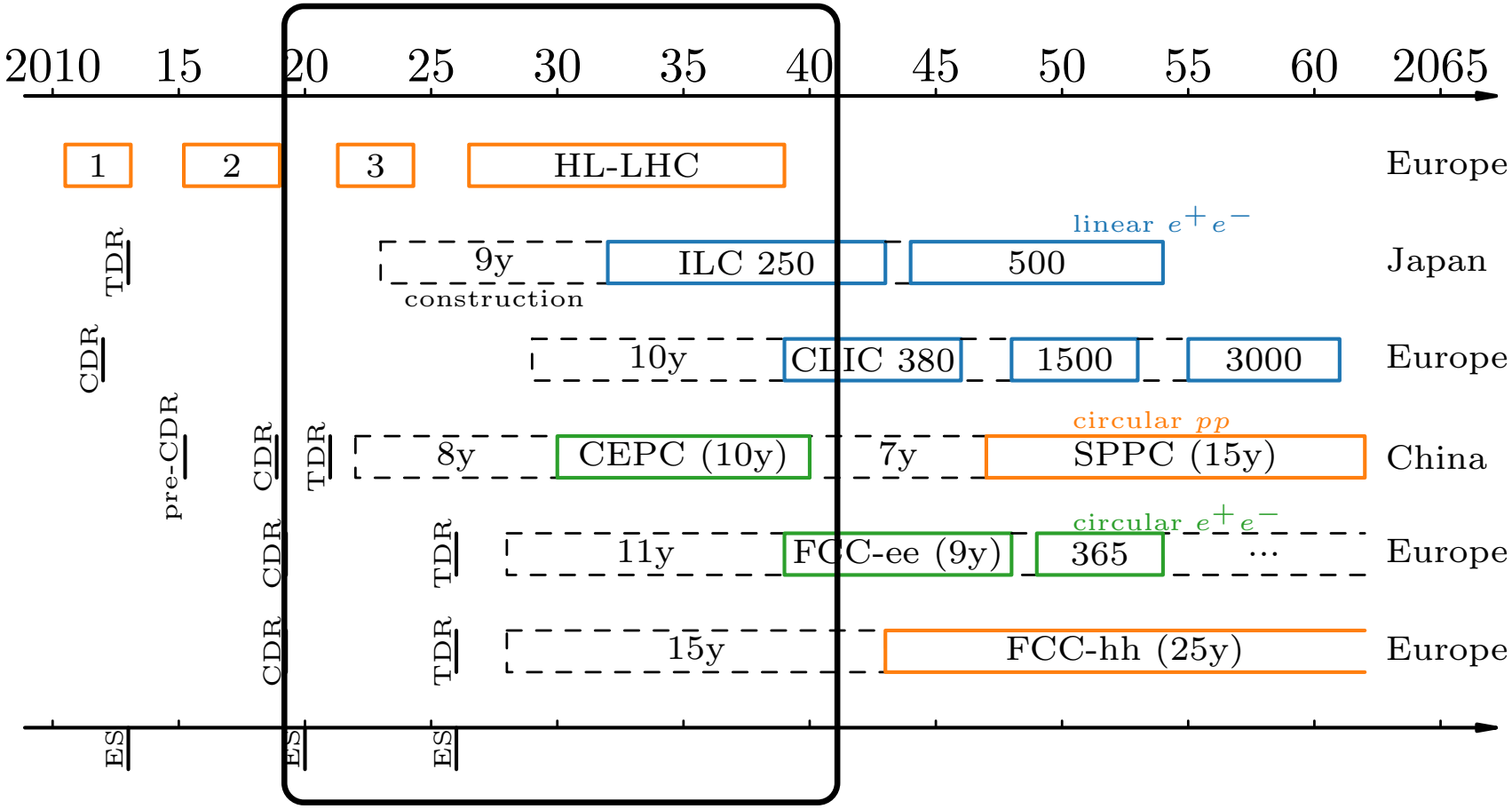
Towards global EFTs

Gauthier Durieux
(Technion)

21 July 2020
Snowmass Energy Frontier Workshop

The energy frontier in the next 20 years:

- high-luminosity LHC in Europe: 14 TeV
- future lepton colliders in Asia: 90–250 GeV
- no 100 TeV machine yet

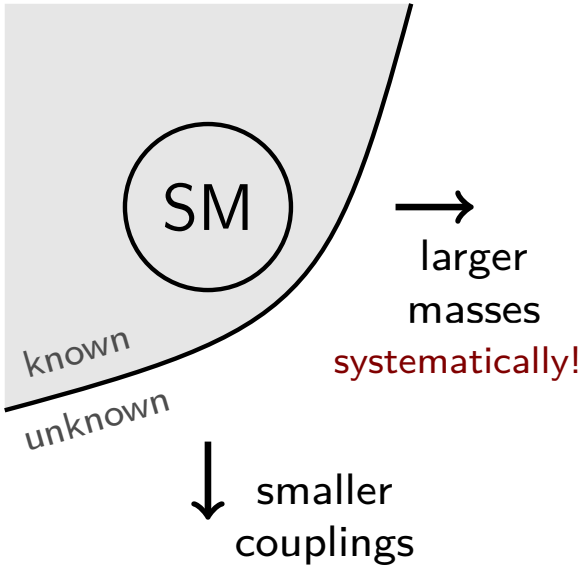


more precision than energy.

SMEFT is ideal to interpret precise measurements

remarkably parametrizes all the heavy unknown

(...) if one writes down [with given fields] *the most general possible Lagrangian, including* <u>*all*</u> *terms consistent with assumed symmetry principles, (...) the result will simply be the most general possible S-matrix consistent with analyticity, perturbative unitarity, cluster decomposition and the assumed symmetry.* [*Phenomenological Lagrangians*, Weinberg '79]

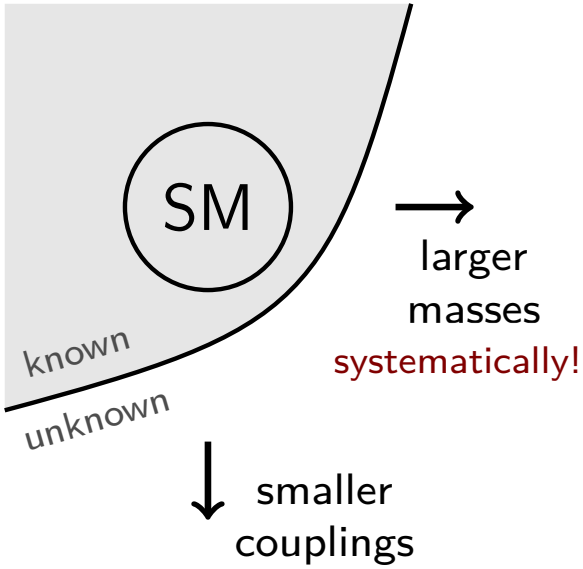


SMEFT is ideal to interpret precise measurements

remarkably parametrizes all the heavy unknown

provided it is treated globally

- considering all operators simultaneously
  - up to a given order
  - within consistent restrictive assumptions
- combining measurements



Challenges

- make precise interpretations
- cover multidimensional parameter spaces
- combine measurements (observables, processes, sectors)

vs. common experimental practice

independent physics groups
highly tailored analyses
maximally probing one or two parameters
difficult to combine cleanly (for th. and exp.)

Efforts

th more and more sophisticated interpretations

exp dedicated EFT groups, going beyond 2D analyses

th/exp crosstalk, informally and in WGs

top-quark EFT standards 1802.07237

arXiv:1802.07237v1 [hep-ph] 20 Feb 2018

CERN-LPCC-2018-01

Interpreting top-quark LHC measurements in the standard-model effective field theory

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Abstract

This note proposes common standards and prescriptions for the effective-field-theory interpretation of top-quark measurements at the LHC.

1

EFT validation agreement 1906.12310

arXiv:1906.12310v1 [hep-ph] 28 Jun 2019

CERN-LPCC-2019-02

Proposal for the validation of Monte Carlo implementations of the standard model effective field theory

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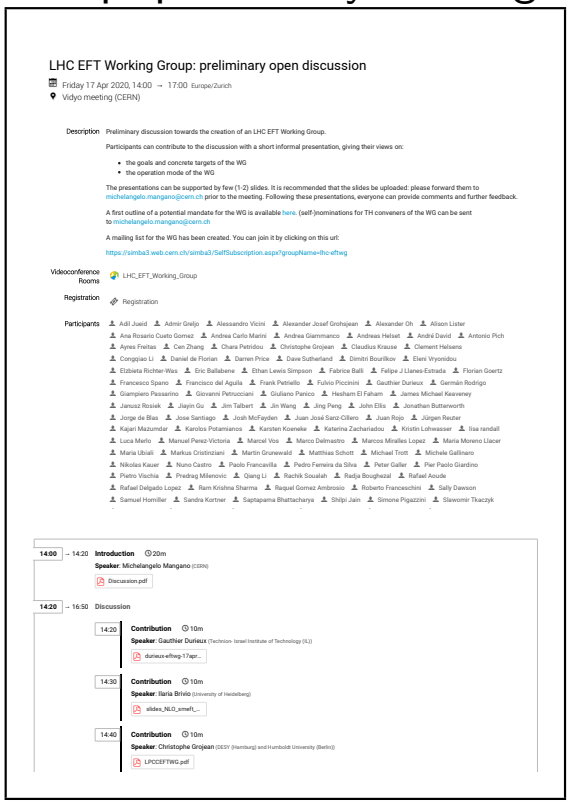
Abstract

We propose a procedure to cross-validate Monte Carlo implementations of the standard model effective field theory. It is based on the numerical comparison of squared amplitudes computed at specific phase-space and parameter points in pairs of implementations. Interactions are fully linearised in the effective field theory expansion. The squares of linear effective field theory amplitudes and their interference with standard-model contributions are compared separately. Such pairwise comparisons are primarily performed at tree level and a possible extension to the one-loop level is also briefly considered. We list the current standard model effective field theory implementations and the comparisons performed to date.

1

LHC EFT WG 17 Apr preliminary meeting



LHC EFT Working Group: preliminary open discussion

Friday 17 Apr 2020, 14:00 → 17:00 Europe/Zurich
Vidyo meeting (CERN)

Description: Preliminary discussion towards the creation of an LHC EFT Working Group.

Participants can contribute to the discussion with a short informal presentation, giving their views on:

- the goals and concrete targets of the WG
- the operation mode of the WG

The presentations can be supported by few (1-2) slides. It is recommended that the slides be uploaded: please forward them to michelangelo.mangano@cern.ch prior to the meeting. Following these presentations, everyone can provide comments and further feedback.

A first outline of a potential mandate for the WG is available here. (self-)nominations for TH conveners of the WG can be sent to michelangelo.mangano@cern.ch

A mailing list for the WG has been created. You can join it by clicking on this url:

https://simba3.web.cern.ch/simba3/SelfSubscription.aspx?groupName=lhc-eftwg

Videoconference Rooms: LHC_EFT_Working_Group

Registration: Registration

Participants: Adil Jueid, Admir Greljo, Alessandro Vicini, Alexander Josef Grohsjean, Alexander Oh, Allison Lister, Ana Rosario Cueto Gomez, Andrea Carlo Marini, Andrea Giammanco, Andreas Helset, André David, Antonio Pich, Ayres Freitas, Cen Zhang, Chara Petridou, Christophe Grojean, Claudius Krause, Clement Helsens, Congqiao Li, Daniel de Florian, Darren Price, Dave Sutherland, Dimitri Bourilkov, Eleni Vryonidou, Elżbieta Richter-Was, Eric Ballabene, Ethan Lewis Simpson, Fabrice Balli, Felipe J Llanes-Estrada, Florian Goertz, Francesco Spano, Francisco del Aguila, Frank Petriello, Fulvio Piccinini, Gauthier Durieux, Germán Rodrigo, Giampiero Passarino, Giovanni Petrocciani, Giuliano Panico, Hesham El Faham, James Michael Kearney, Janusz Rosiek, Jiayin Gu, Jim Talbert, Jin Wang, Jing Peng, John Ellis, Jonathan Butterworth, Jorge de Blas, Jose Santiago, Josh McFayden, Juan José Sanz-Cillero, Juan Rojo, Jürgen Reuter, Kajari Mazumdar, Karolos Potamianos, Karsten Koenekie, Katerina Zachariadou, Kristin Lohwasser, lisa randall, Luca Merlo, Manuel Perez-Victoria, Marcel Vos, Marco Delmastro, Marcos Miralles Lopez, Maria Moreno Llacer, Maria Ubiali, Markus Cristinziani, Martin Grunewald, Matthias Schott, Michael Trott, Michele Gallinaro, Nikolas Kauer, Nuno Castro, Paolo Francavilla, Pedro Ferreira da Silva, Peter Galler, Pier Paolo Giardino, Pietro Vischia, Predrag Milenovic, Qiang Li, Rachik Soualah, Radja Boughezal, Rafael Aoude, Rafael Delgado Lopez, Ram Krishna Sharma, Raquel Gomez Ambrosio, Roberto Franceschini, Sally Dawson, Samuel Homiller, Sandra Kortner, Saptaparna Bhattacharya, Shilpi Jain, Simone Pigazzini, Slawomir Tkaczyk

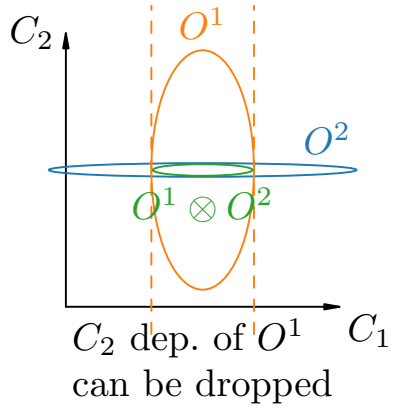
14:00	→ 14:20	Introduction	20m
		Speaker: Michelangelo Mangano (CERN)	
		Discussion.pdf	
14:20	→ 16:50	Discussion	
14:20		Contribution	10m
		Speaker: Gauthier Durieux (Technion- Israel Institute of Technology (IL))	
		durieux-eftwg-17apr...	
14:30		Contribution	10m
		Speaker: Ilaria Brivio (University of Heidelberg)	
		slides_NLO_smeft_...	
14:40		Contribution	10m
		Speaker: Christophe Grojean (DESY (Hamburg) and Humboldt University (Berlin))	
		LPCCEFTWG.pdf	

Community efforts

Top-quark EFT standards

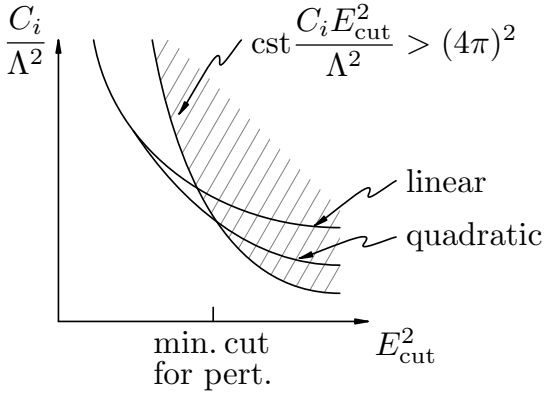
[1802.07237]

- fix reference notation and conventions
  - simplify the dependence of top processes at the LHC
  - avoid confusion, ease comparisons and combinations
  - provide benchmark dependences



- tackle the multidimensional challenge gradually
  - prioritize the exploration of flavour structures
  - define relevant contributions to observables from existing constraints
  - gather indicative limits

- discuss global analysis strategies
  - provide an example of re-interpretable approach
  - request experimental outputs, e.g.
    - both linear and linear+quadratic dim-6 results
    - as function of the energy probed



Validation agreement for EFT implementations

[1906.12310]

- protocol for precise, pairwise and decentralized comparisons
  - flexible to cover to a wide diversity of implementations
  - exploiting standard MC formats for information exchange
  - implemented in a `madgraph` plugin for UFO models
  - possible loop-level extension

- recommend establishing dictionaries between implementations

  e.g. in `rosetta` or `wcxf-python`

- reference existing implementations and public cross-validations

LHC EFT WG

Conveners

ATLAS
- Nicolas Berger (HXSWG contact)
- Nuno Castro (TOP WG contact)
- Kristin Lohwasser (EW WG contact)
- Pierre Savard

CMS
- Florencia Canelli (TOP WG contact)
- Pietro Govoni (EW WG contact)
- Andrei Gritsan
- Giovanni Petrucciani (HXSWG contact)

Theory
- Ilaria Brivio
- Sally Dawson
- Jorge de Blas (HXSWG contact)
- Céline Degrande (EW WG contact)
- Gauthier Durieux
- Admir Greljo
- Eleni Vryonidou (TOP WG contact)

Mailing list lhc-eftwg and webpage

Possible themes

disorganised set of suggestions collected at 17 Apr meeting

a. Experimental outputs & analysis strategy for re-interpretability (later/differently)
   i. See LHC re-interpretation forum: indico
   ii. Standard format/platform
   iii. Define fiducial regions across experiments, EFT-optimized
   iv. Unfolding, forward folding, recast through reweighting, etc.
b. Predictions: validation, assumptions, guidance, interplay
   i. See validation note [1906.12310]
   ii. Common MC generation / settings
c. Higher-order corrections in SM couplings: inputs, schemes, benchmarks
d. Unstable particles
e. Benchmark/compare fits
   i. TH/EXP systematics, correlations, fitting, etc.
   ii. Recommendations for inputs and outputs
   iii. Common WG fit?
f. EFT validity assessment
g. Prescription for theory uncertainties
h. Truncation quadratic dependences, double insertions, dim-8
i. Matching to specific models, BSM-driven subsets of operators, benchmarks
j. Standard basis/notation/normalization, or sets
   i. Streamline translations
   ii. Flavour assumptions, CP
   iii. Define scenarios
k. TH constraints (unitarity, positivity, etc.)
l. EFT in backgrounds: final-state driven instead of sig-bgd, statistical model
m. EFT in PDFs, alpha_s, shower and hadronization
n. Study observable & process sensitivities and complementarities
   i. Go differential, optimized observables, spin density matrices
   ii. Energy growing effects
o. Perform more global studies of pp→tth, pp→hh, etc.
p. Beyond SMEFT
   i. Pseudo-observables
   ii. Non-linear EFT
   iii. Singlet-extended, dark matter, etc.
   iv. Exotic Higgs decays (invisible, untagged, etc.)
   v. Non-decoupling (scalar, etc.)
q. EFT results for non-HEP audience

...

Higher orders

automated (mostly in QCD, matched to shower)

- $pp \to VV$ [Dixon, Kunszt, Signer '99] [Melia, Nason, Röntsch, Zanderighi '11] [Baglio, Dawson, Lewis '17, '18, '19]
- top FCNCs UFO [Degrande, Maltoni, Wang, Zhang '14] [Durieux, Maltoni, Zhang '14]
- top chromo-dipole [Franzosi, Zhang '15]
- top single production [Zhang '16] [de Beurs, Laenen, Vreeswijk, Vryonidou '18]
- $pp \to t\bar{t}Z$, $gg \to ZH$ [Bylund, Maltoni, Vryonidou, Zhang '16]
- $pp \to t\bar{t}H$, $gg \to Hj, HH$ [Maltoni, Vryonidou, Zhang '16]
- $pp \to HV$ [Degrande, Fuks, Mawatari, Mimasu, Sanz '16] [Alioli, Dekens, Girard, Mereghetti '18]
- Higgs gluon fusion [Grazzini, Ilnicka, Spira, Wiesemann '16] [Deutschmann, Duhr, Maltoni, Vryonidou '17]
- top single production with Z, H [Degrande, Maltoni, Mimasu, Vryonidou, Zhang '18]
- triple gluon UFO [Hirshi, Maltoni, Tsinikos, Vryonidou '18]
- QCD in top & EW & Higgs SMEFT@NLO [Degrande, Durieux, Maltoni, Mimasu, Vryonidou, Zhang, 'xx]
- EW top loops in Higgs & EW [Vryonidou, Zhang '18] [Durieux, Gu, Vryonidou, Zhang '18]

analytic

- $q\bar{q}q\bar{q}$ in dijet [Gao, Li, Wang, Zhu, Yuan '11]
- $q\bar{q}t\bar{t}$ in $pp \to t\bar{t}$ [Shao, Li, Wang, Gao, Zhang, Zhu '11]
- top decays [Zhang '14] [Boughezal, Chen, Petriello, Wiegand '19]
- $h \to \gamma\gamma$, VV, γZ [Hartmann, Trott '15] [Ghezzi, Gomez-Ambrosio, Passarino, Uccirati '15] [Dawson, Giardino '18] [Dedes, Paraskevas, Rosiek, Suxho, Trifyllis '18] [Dawson, Giardino '18] [Dedes, Suxho, Trifyllis '19]
- $h \to b\bar{b}$ [Gauld, Pecjak, Scott '16] [Cullen, Pecjak, Scott '19]
- Z, W decays [Hartmann, Shepherd, Trott '16] [Dawson, Ismail, Giardino '18, '18, '19]

Present constraints

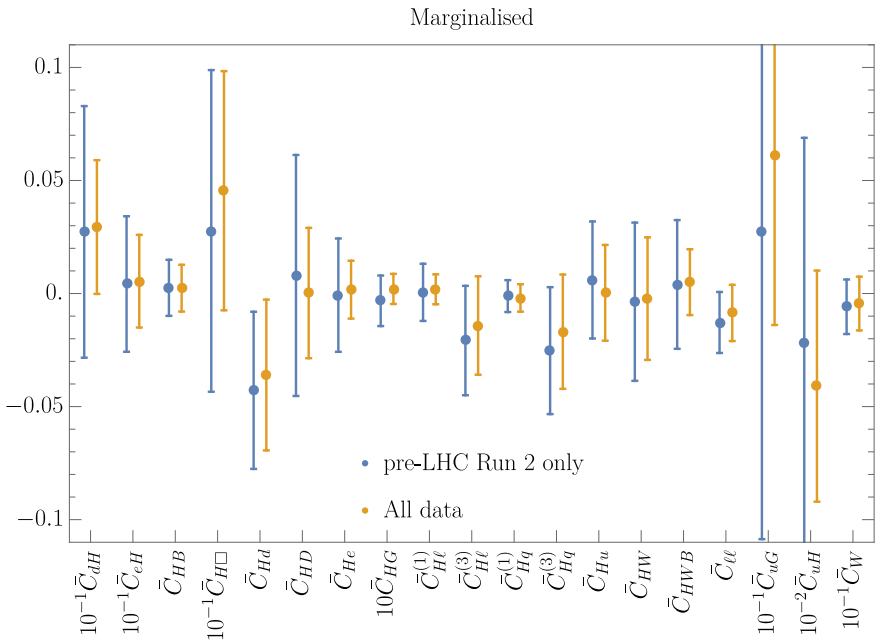
Higgs & EW (present)

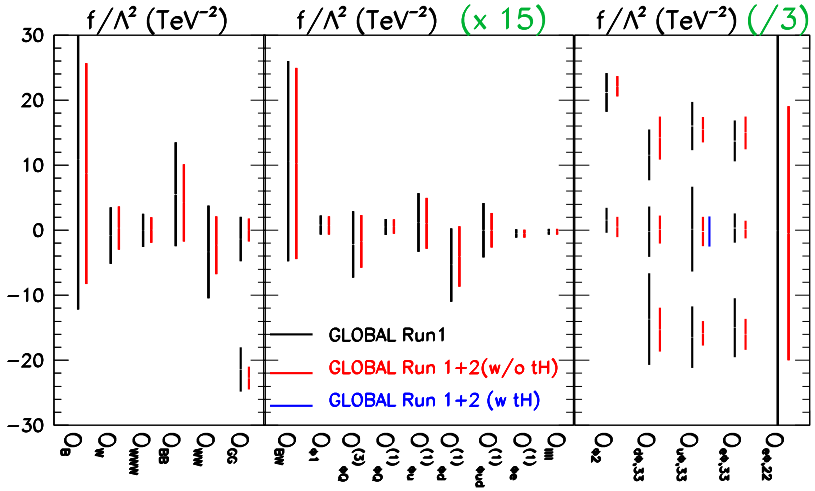
[Ellis, Murphy, Sanz, You '18]

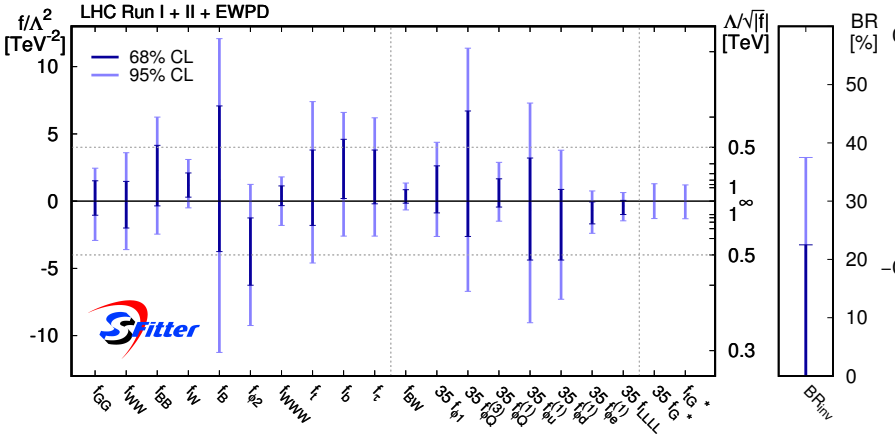
[Almeida, Alves, Rosa-Agostinho, Eboli, Gonzalez-Garcia '18]

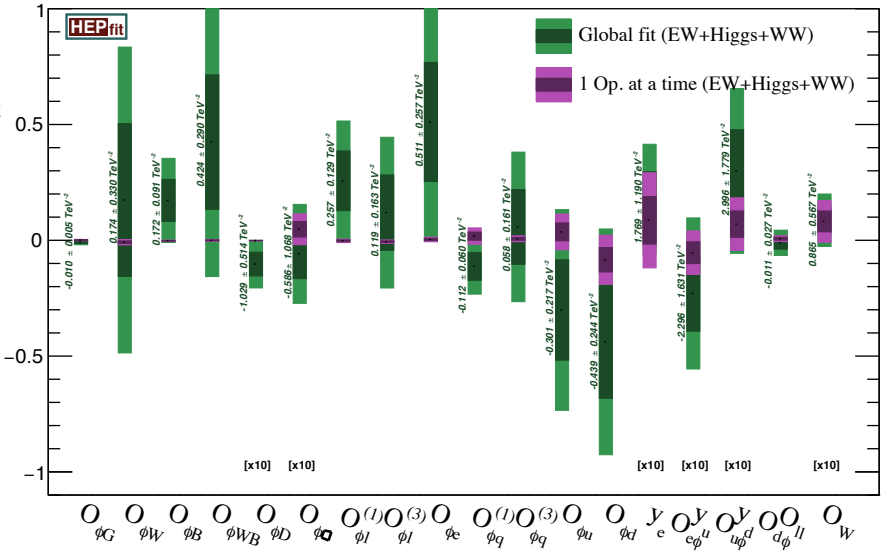
[Biekötter, Corbett, Plehn '18]

[de Blas, Ciuchini, Franco, Mishima, Pierini, Reina, Silvestrini 'xx]









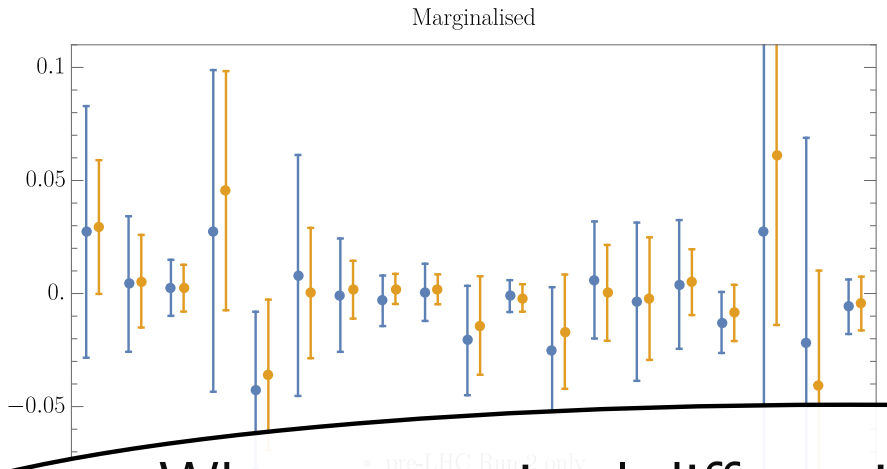
Higgs & EW (present)

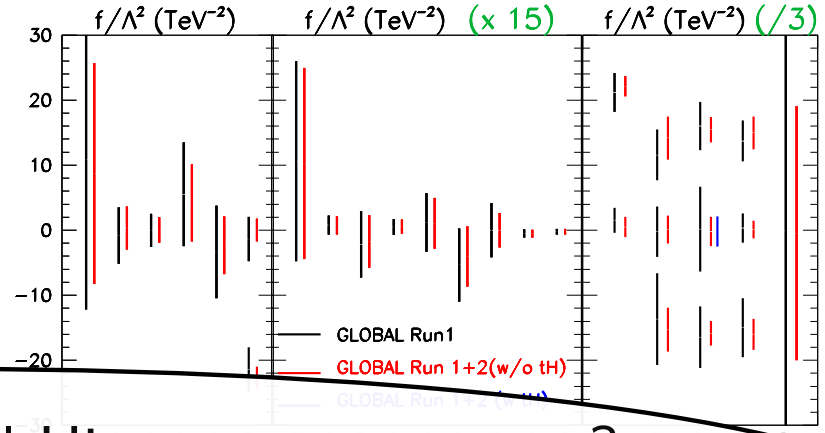
[Ellis, Murphy, Sanz, You '18]

[Almeida, Alves, Rosa-Agostinho, Eboli, Gonzalez-Garcia '18]

[Biekötter, Corbett, Plehn '18]

[de Blas, Ciuchini, Franco, Mishima, Pierini, Reina, Silvestrini 'xx]

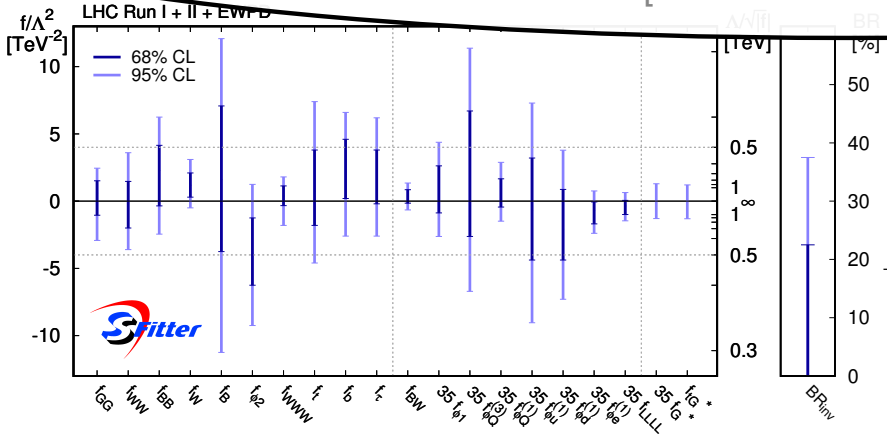


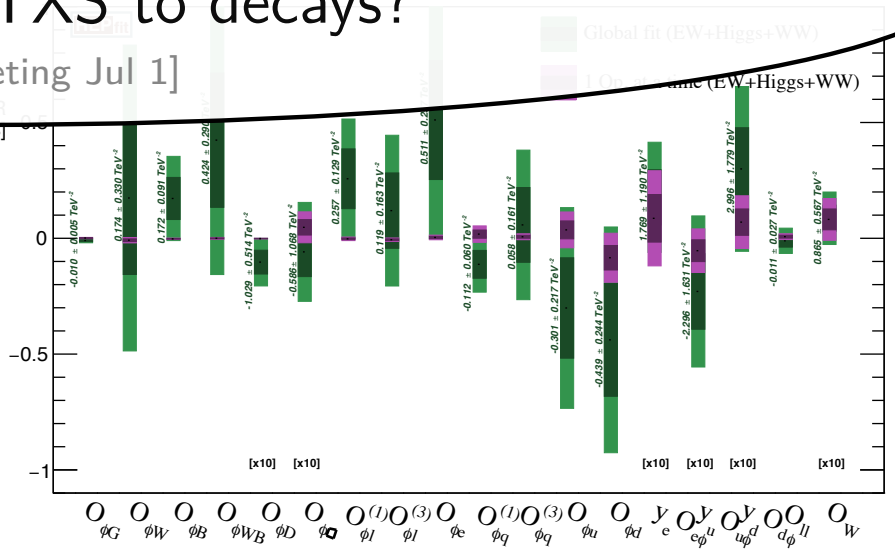


What are optimal differential Higgs measurements?

How to extend STXS to decays?

[HXSWG meeting Jul 1]



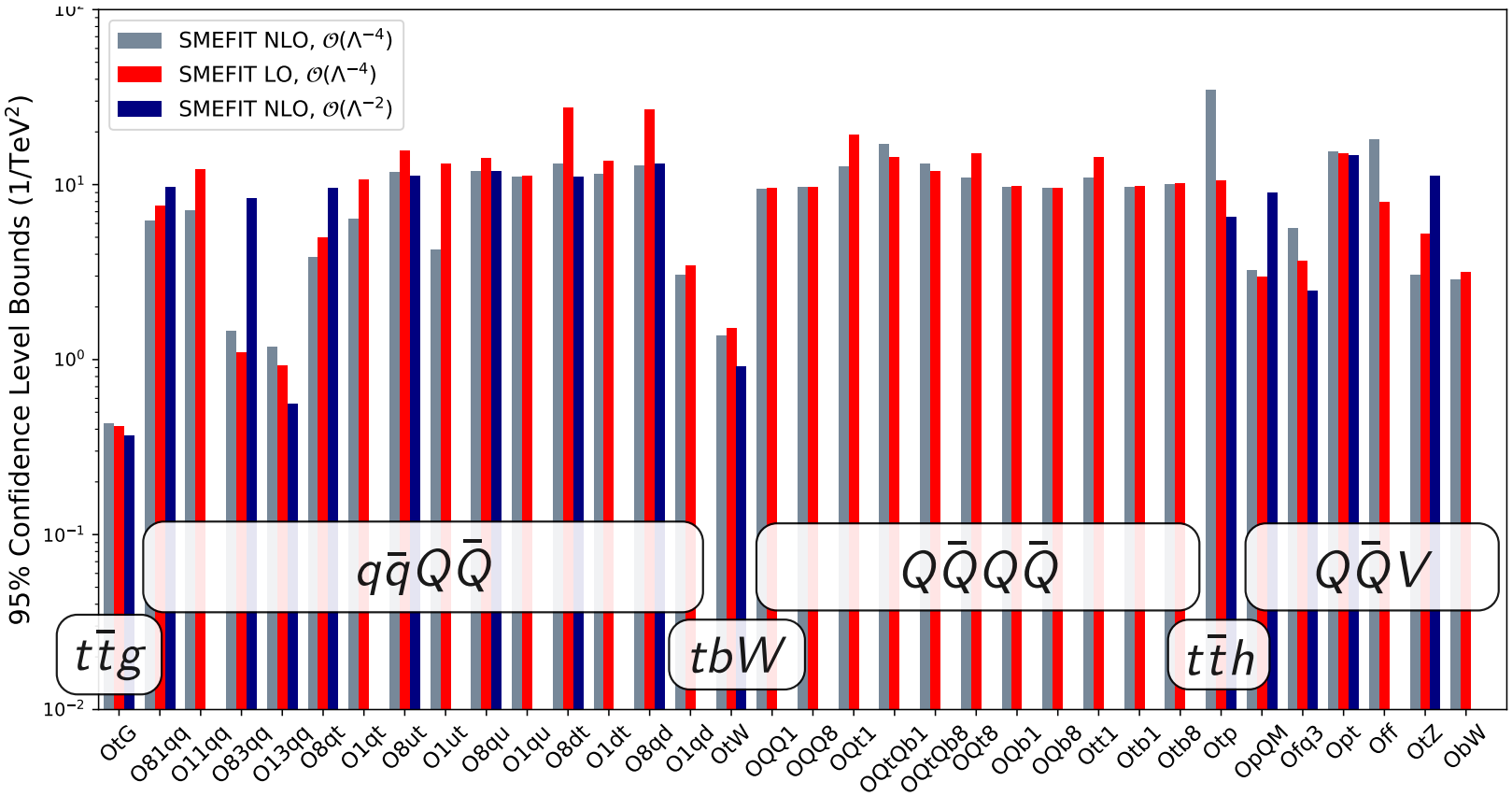


Top quark (present)

[Buckley, Englert, Ferrando, Miller, Moore, Russell, White '15]

[Hartland, Maltoni, Nocera, Rojo, Slade, Vryonidou, Zhang '19]

[Brivio, Bruggisser, Maltoni, Moutafis, Plehn, Vryonidou, Westhoff, Zhang '19]



- global constraints on 34 op. (CP-conserving, $U(2)_q \times U(2)_u \times U(2)_d$-symmetric)
- EFT predictions at NLO QCD in single & pair production, and in decay
- PDF set excluding top data
- study of $1/\Lambda^2$ and $1/\Lambda^4$ relative relevance
- variation of probed energy

Top quark (present)

[Buckley, Englert, Ferrando, Miller, Moore, Russell, White '15]

[Hartland, Maltoni, Nocera, Rojo, Slade, Vryonidou, Zhang '19]

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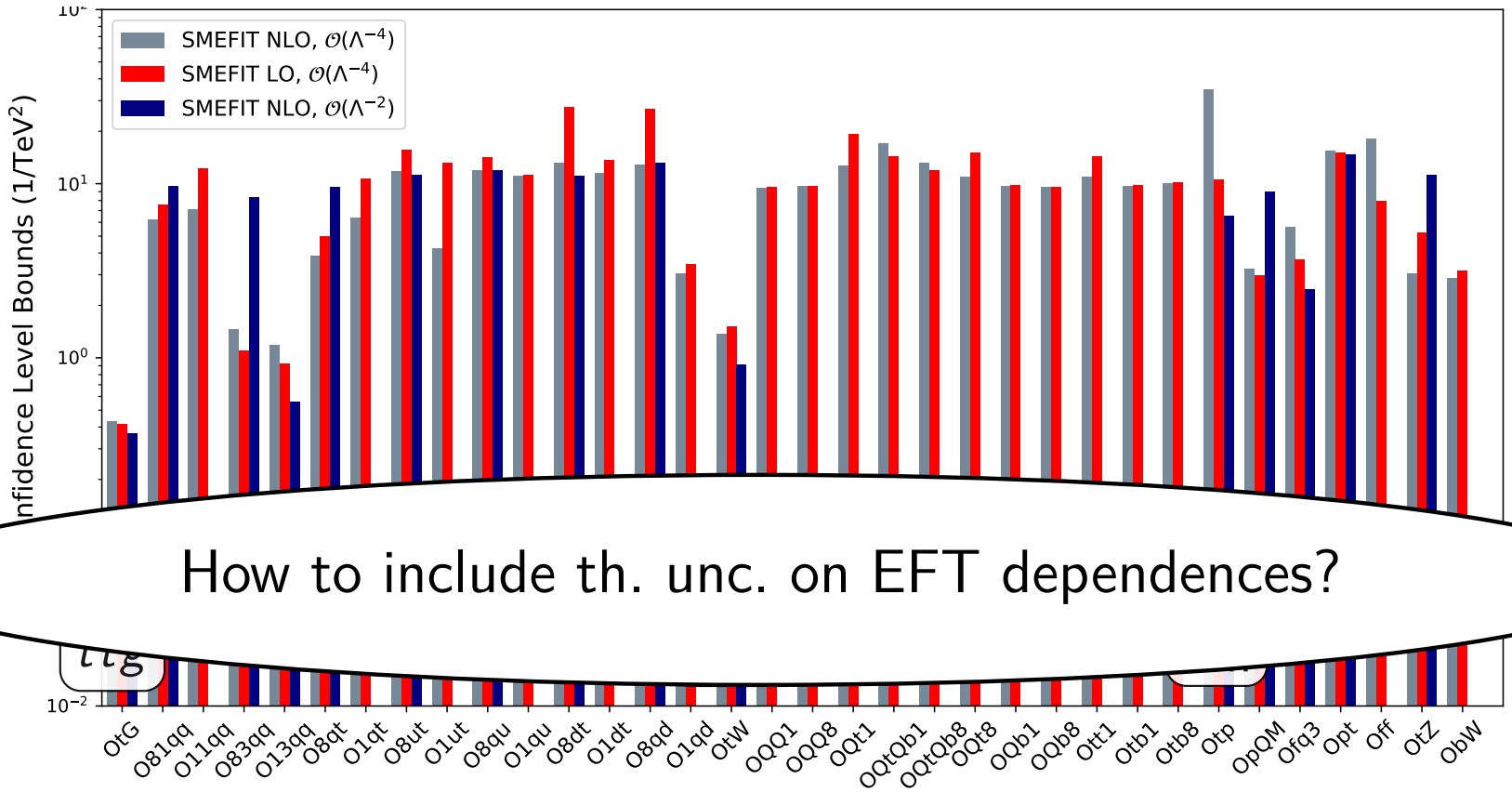
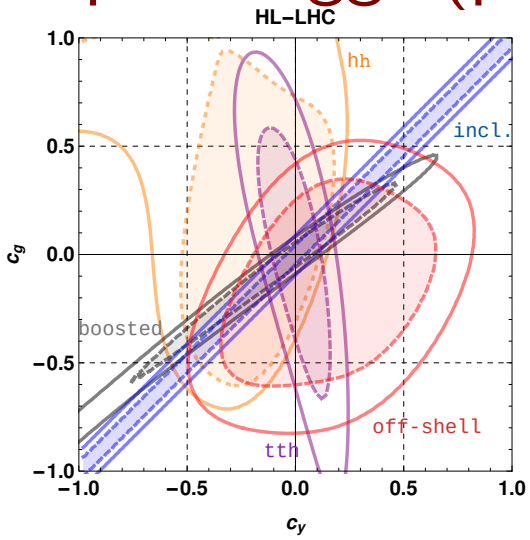


How to include th. unc. on EFT dependences?

- global constraints on 34 op. (CP-conserving, $U(2)_q \times U(2)_u \times U(2)_d$-symmetric)
- EFT predictions at NLO QCD in single & pair production, and in decay
- PDF set excluding top data
- study of $1/\Lambda^2$ and $1/\Lambda^4$ relative relevance
- variation of probed energy

Top & Higgs (present)

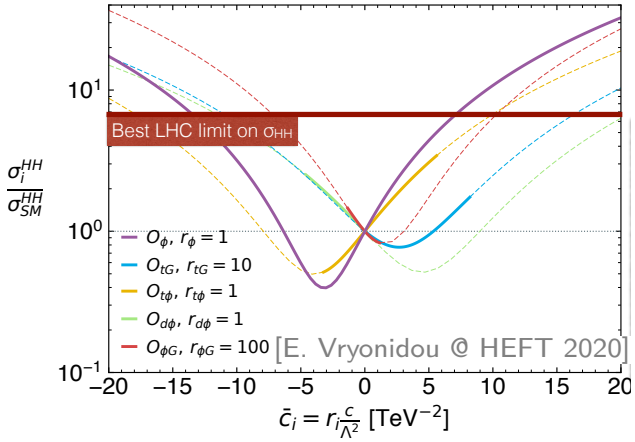


[Azatov, Grojean, Paul, Salvioni '16]

complementarities from

- $pp \to t\bar{t}h$
- $gg \to h,\ h \to \gamma\gamma$
- $pp \to hj$
- $gg \to hh$
- $gg \to (h^* \to)VV$
- $gg \to hV$ [Englert, Rosenfeld, et al. '16]

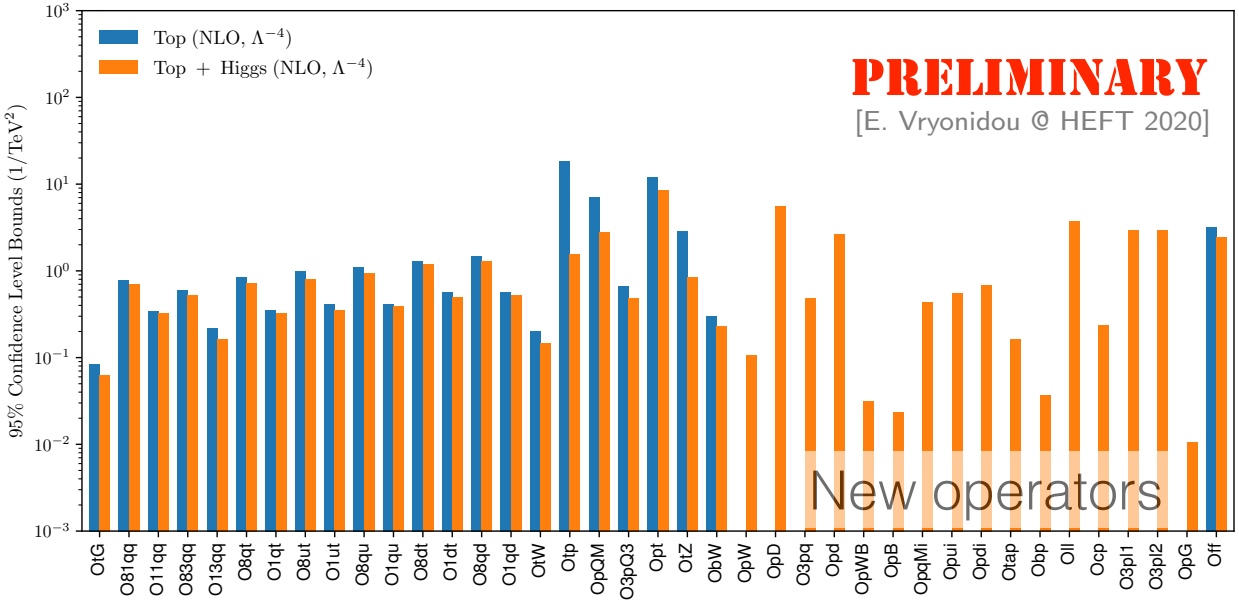
[Mimasu, Vryonidou 'xx]



[E. Vryonidou @ HEFT 2020]

EFT at NLO QCD

TBA: differential Higgs, diboson at LHC, EWPO



[Ethier, Maltoni, Mantani, Nocera, Rojo, Slade, Vryonidou, Zhang 'xx]

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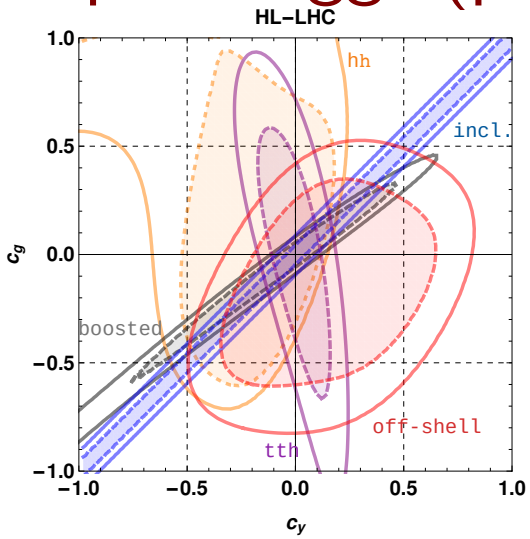

[Azatov, Grojean, Paul, Salvioni '16]

complementarities from

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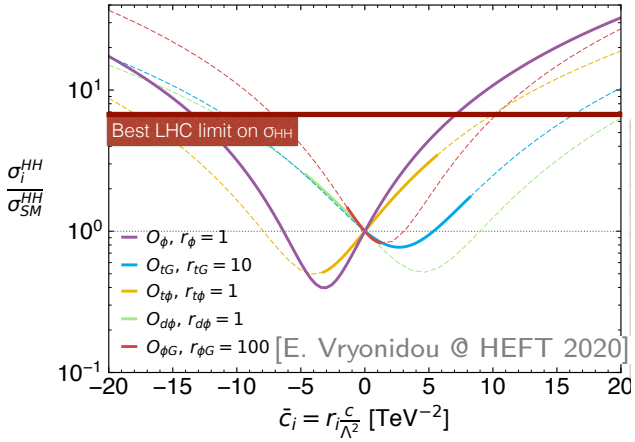

[E. Vryonidou @ HEFT 2020]

[Englert, Rosenfeld, et al. '16]

...work in progress...

EFT at NLO QCD

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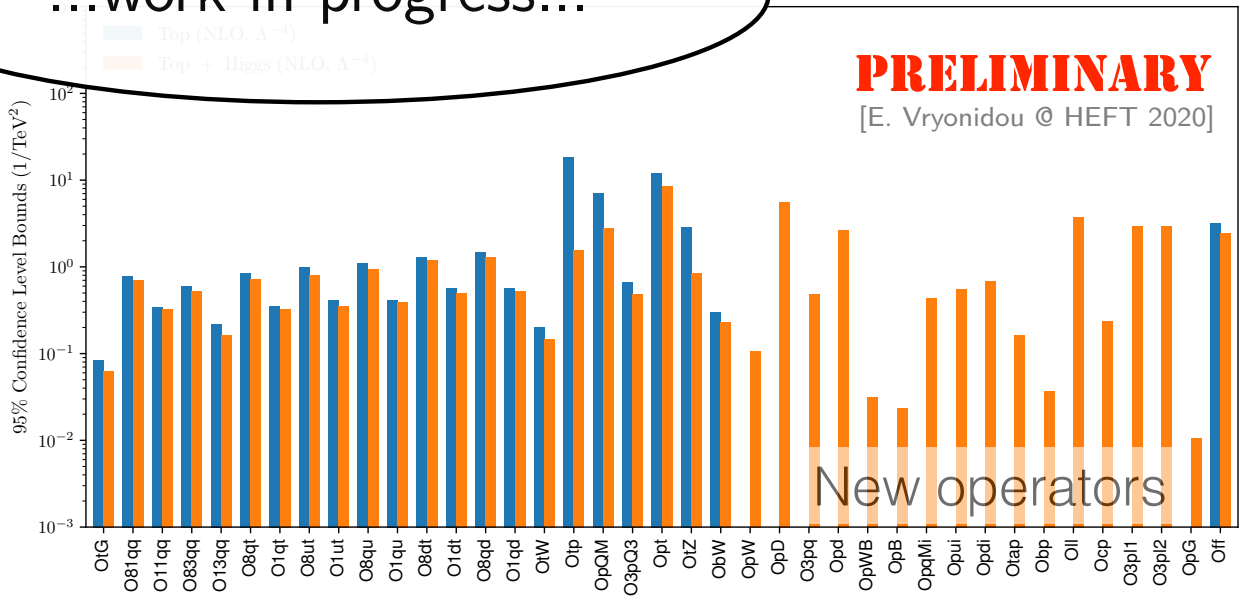


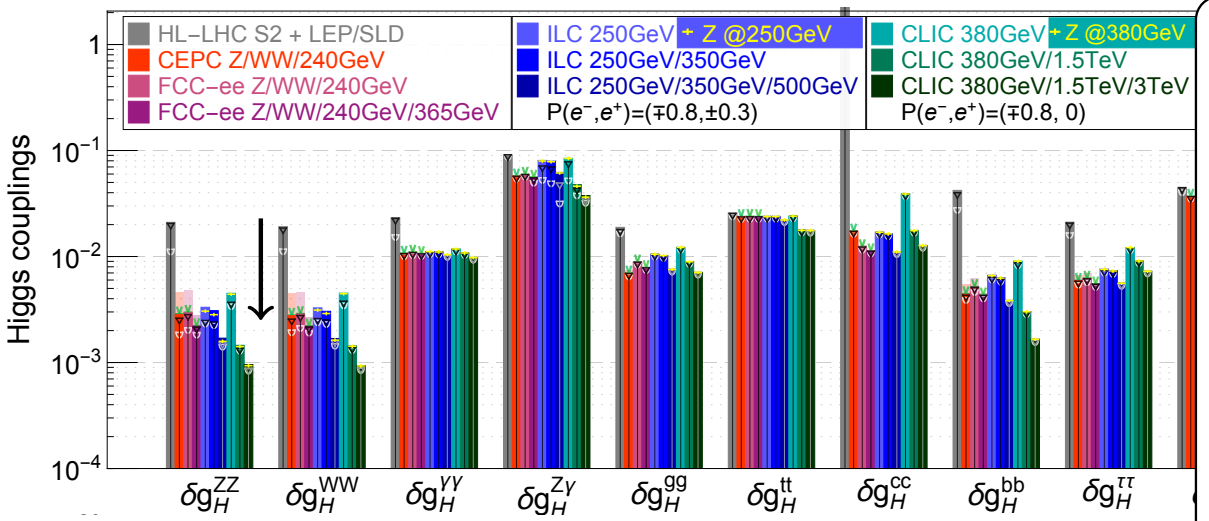
[Ethier, Maltoni, Mantani, Nocera, Rojo, Slade, Vryonidou, Zhang 'xx]

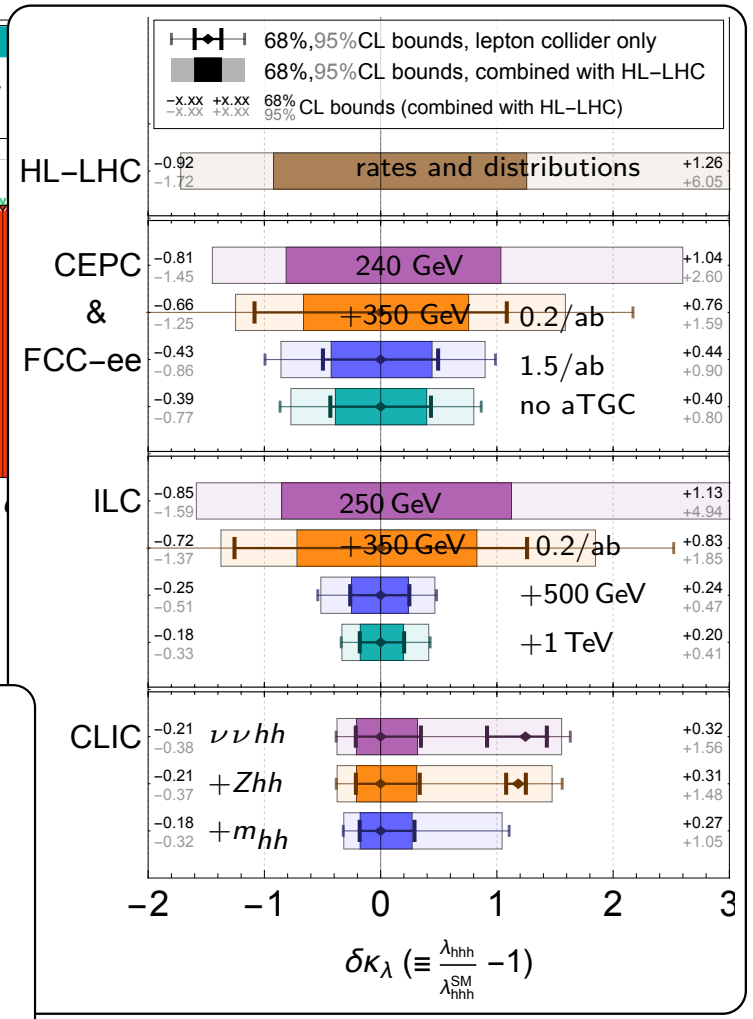
Future prospects

Higgs & EW (future)

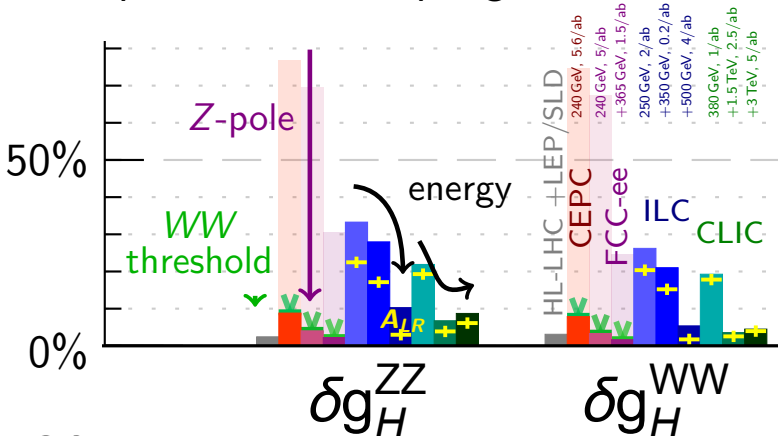
[Ellis, Roloff, Sanz, You '15; '17]
[de Blas, Ciuchini, Franco, Mishima, Pierini, Reina, Silvestrini '16]
[Barklow, Fujii, Jung, Karl, List, Ogawa, Peskin, Tian '17; '17]
[GD, Grojean, Gu, Wang '17; + Di Vita, Liu, Panico, Riembau, Vantalon '17; + de Blas, Paul '19]
[ECFA Working Group report '19]

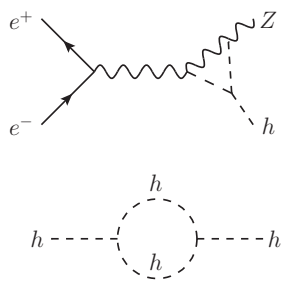
order-of-magnitude improvement wrt. HL-LHC





impact of EW coupling uncertainties





[McCullough '13]

indirect λ_{hhh} determination requires two energy runs

Higgs & EW (future)

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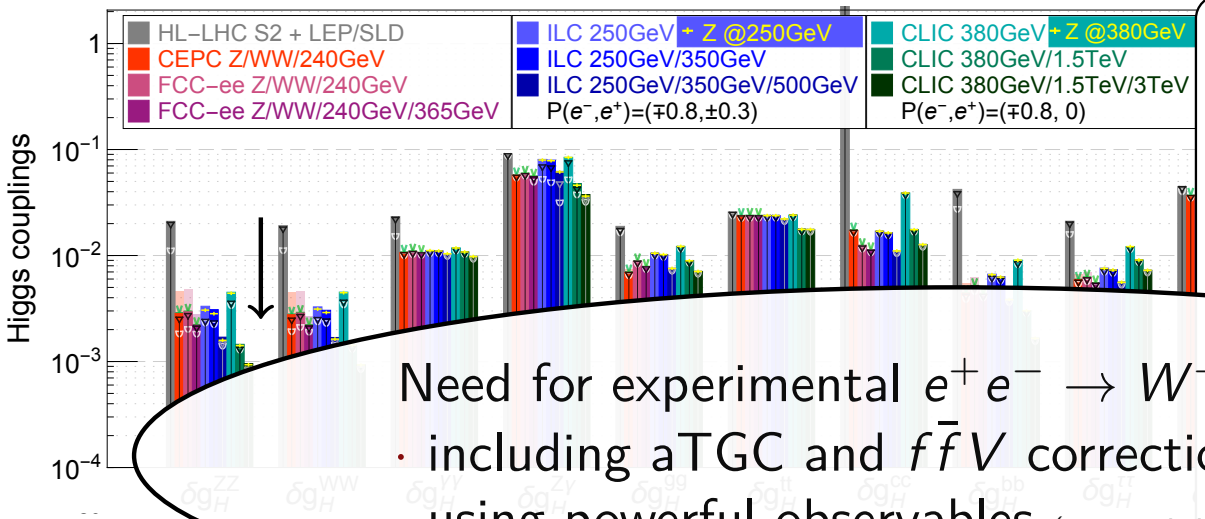
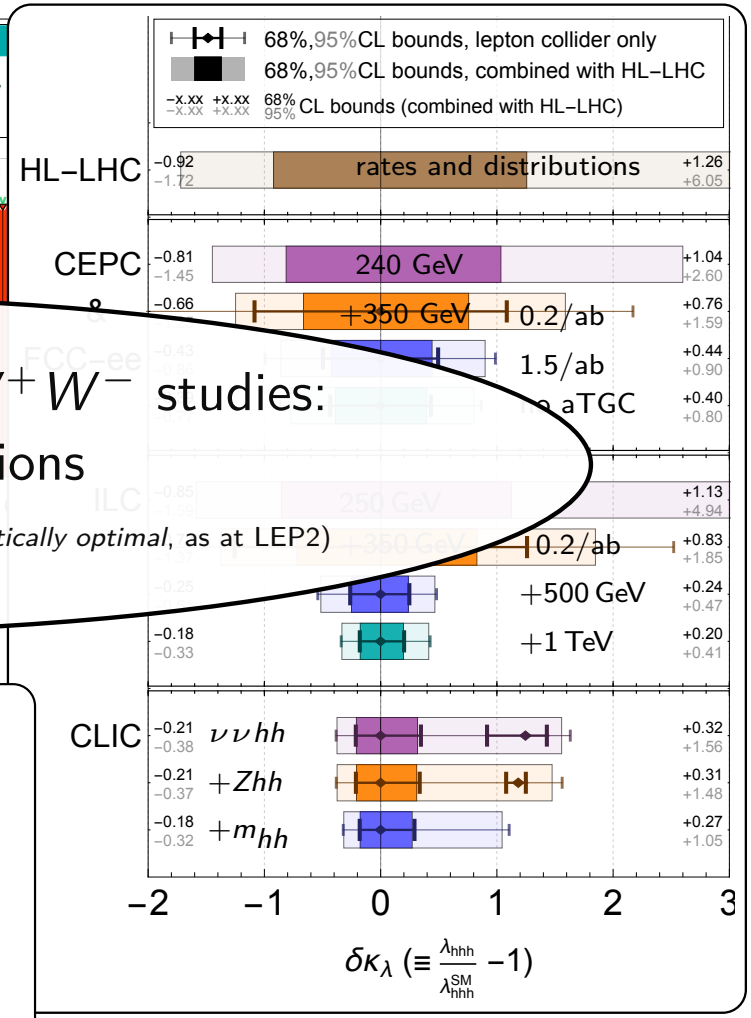
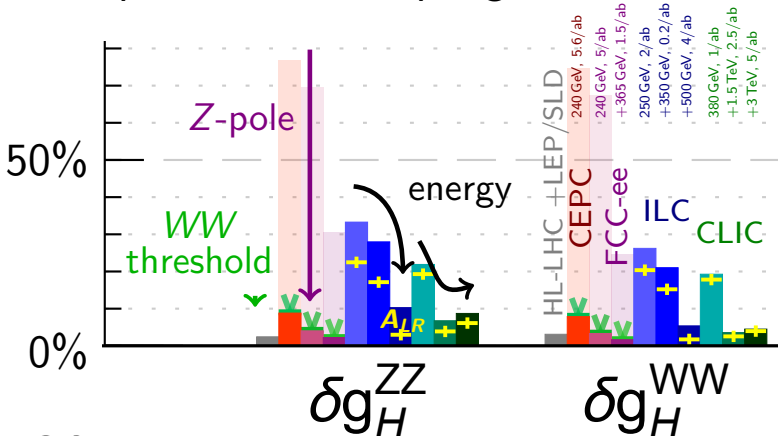


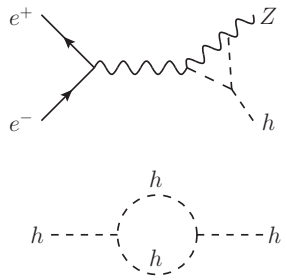


Need for experimental $e^+e^- \to W^+W^-$ studies:

- including aTGC and $f\bar{f}V$ corrections
- using powerful observables (e.g. *statistically optimal*, as at LEP2)

impact of EW coupling uncertainties





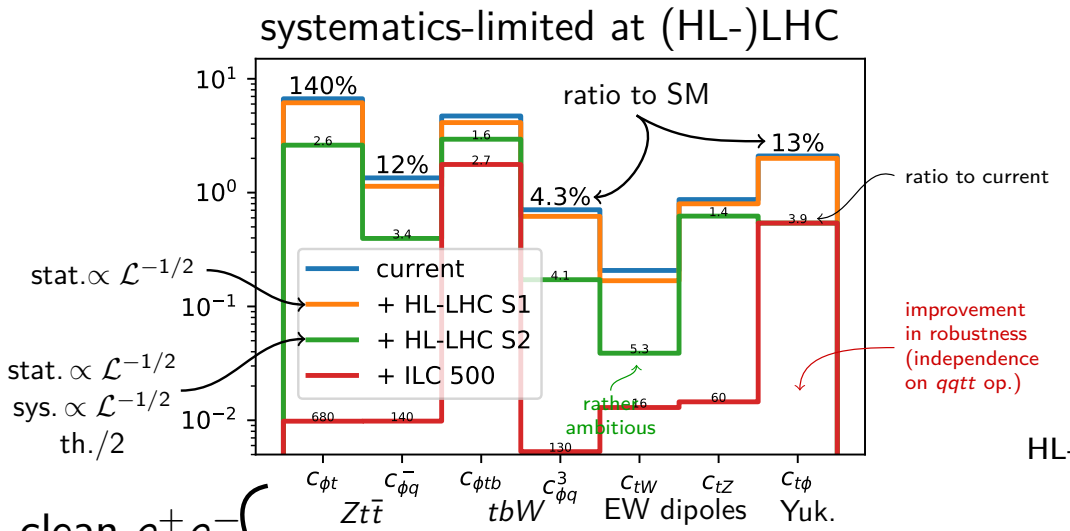
[McCullough '13]

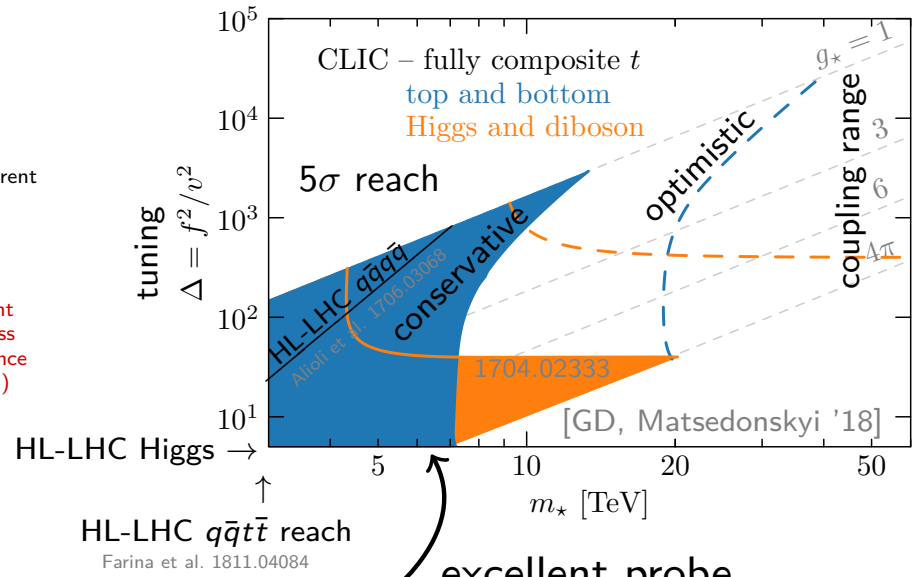
indirect λ_{hhh} determination requires two energy runs

Top quark (future)

[Grzadkowski, Hioki '00], [Janot '15]

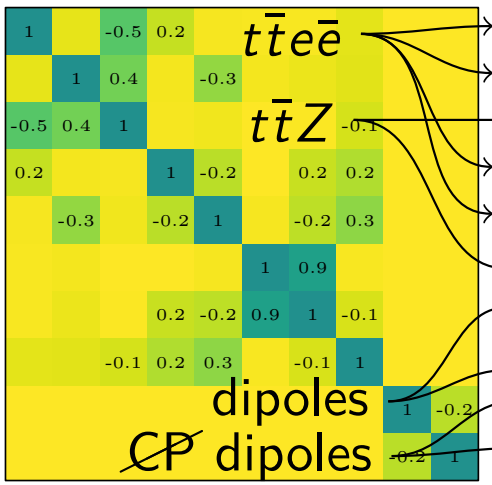
[GD, Perelló, Vos, Zhang '18; + Irles, Miralles, Peñuelas, Pöschl '19]

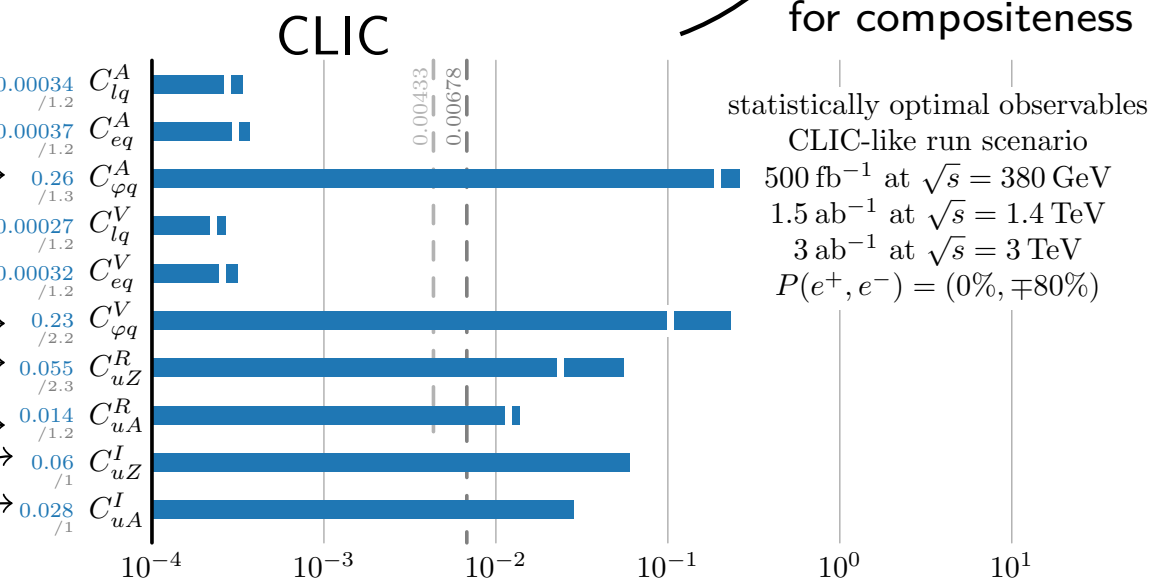




clean e^+e^- environment

excellent probe for compositeness





$e^+e^- \to t\,\bar{t}$ at two energies required to pin down both $t\bar{t}V$ and $t\bar{t}e\bar{e}$ operators

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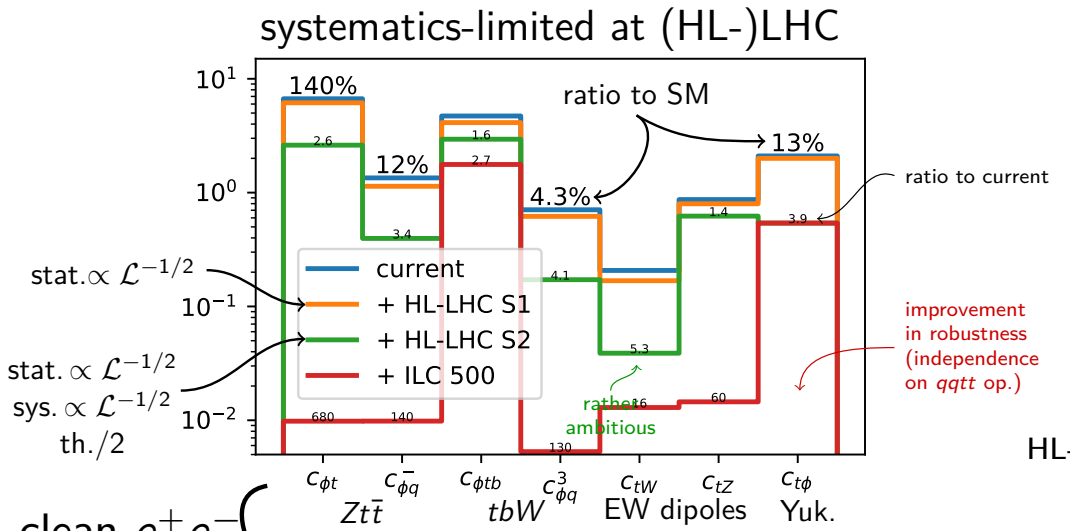

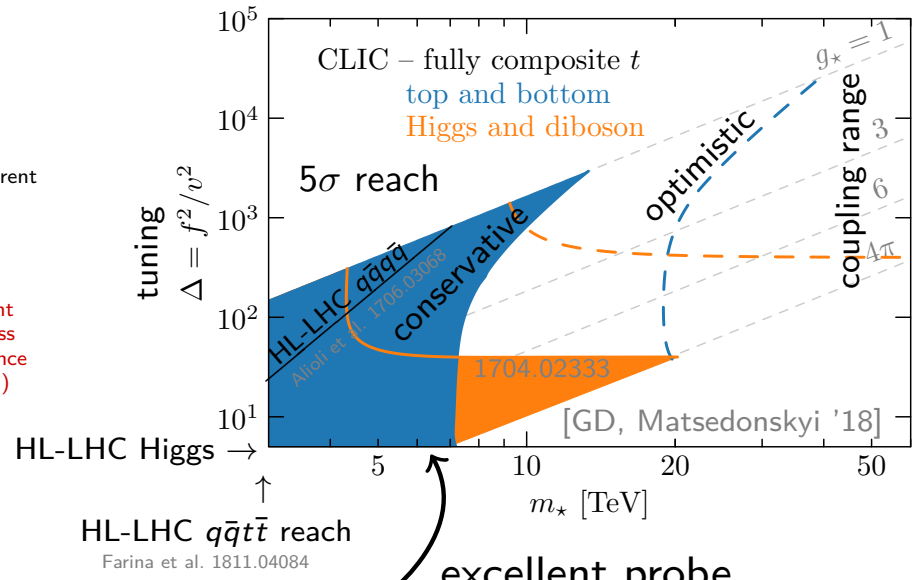

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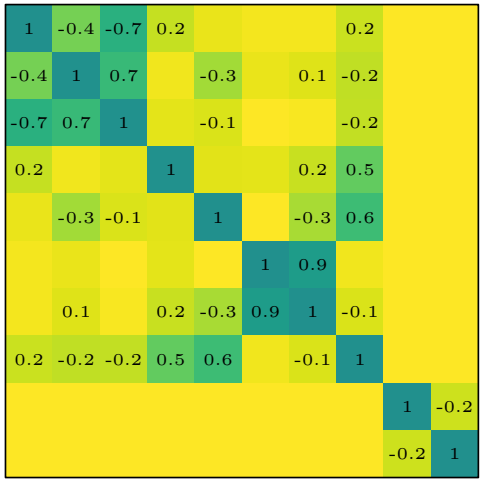

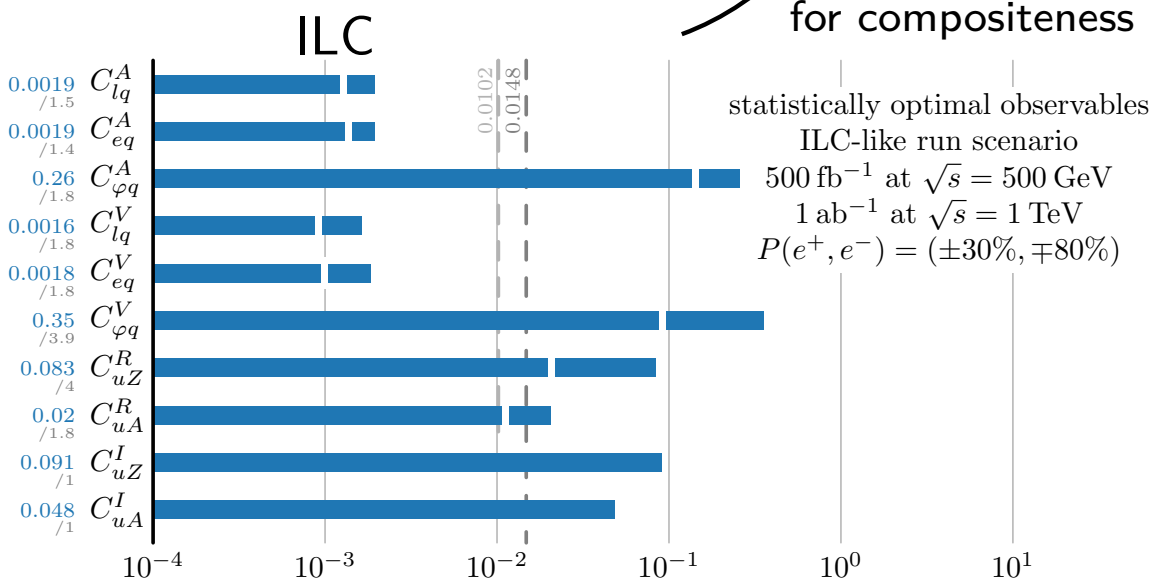

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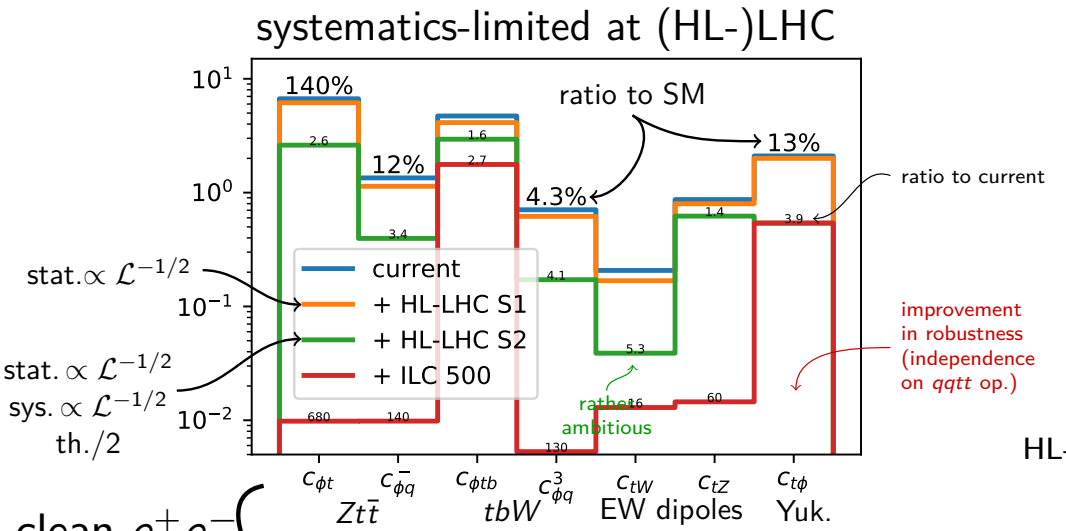

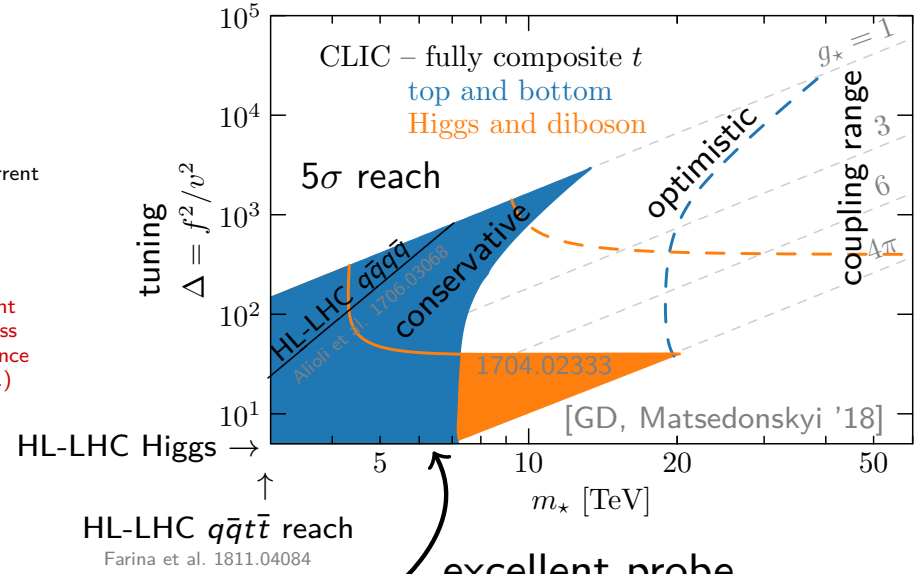

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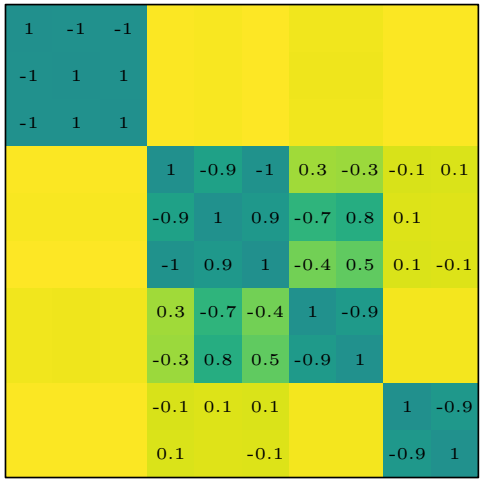

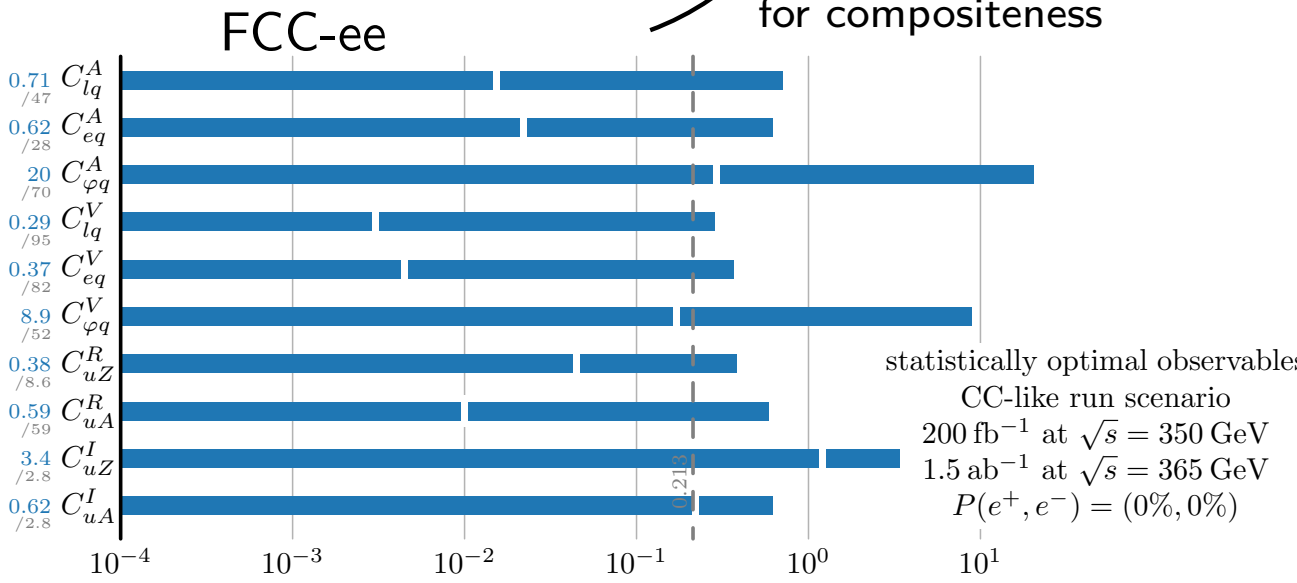

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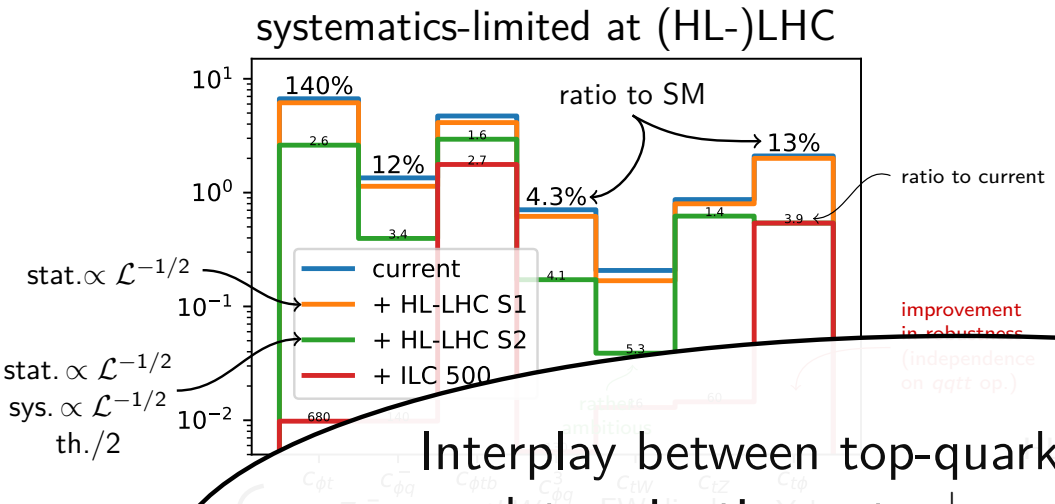
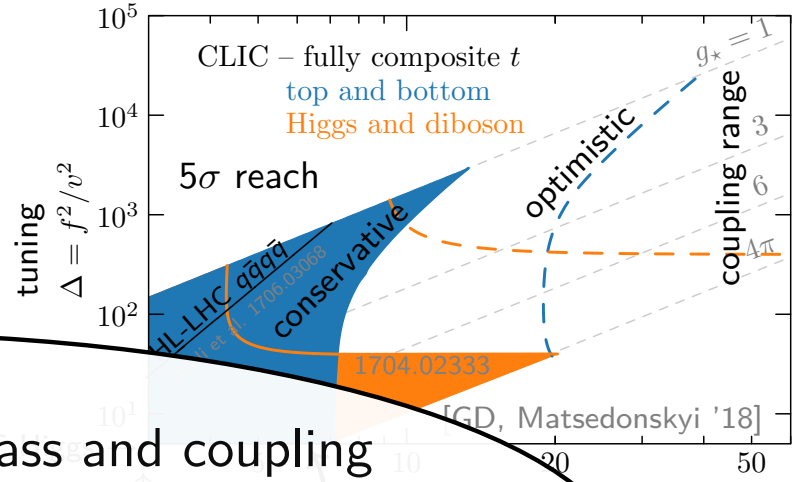


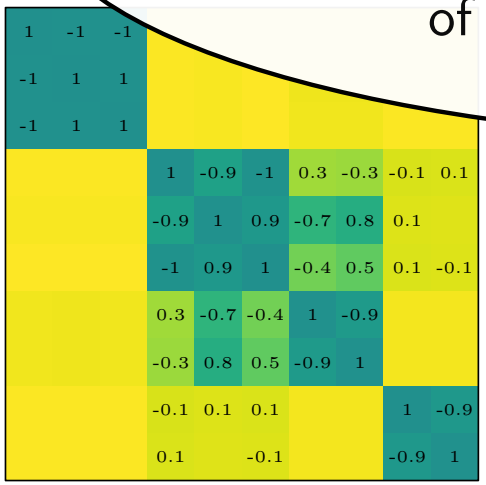


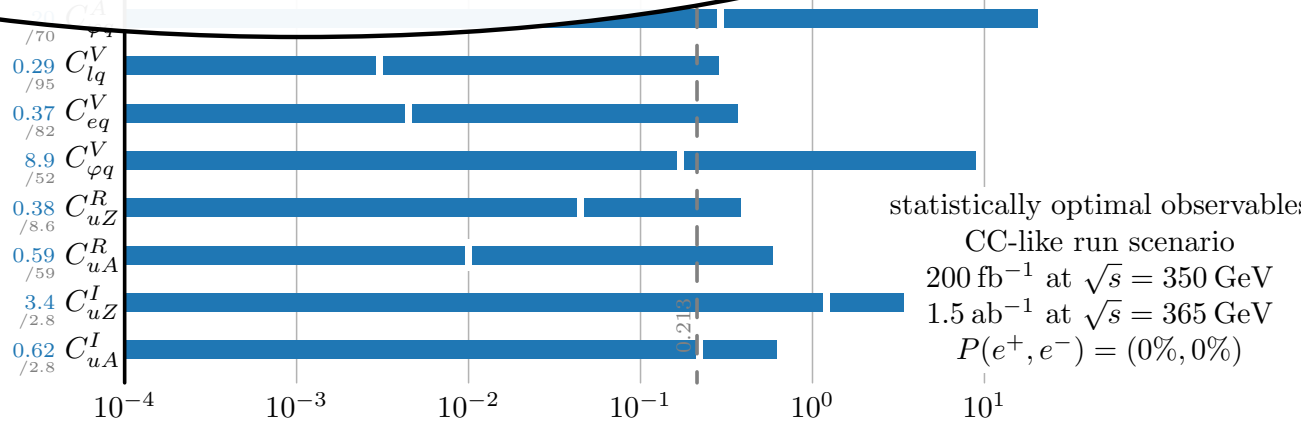
Interplay between top-quark mass and coupling determinations at $e^+e^- \to t\,\bar{t}$ threshold?

Lack of comprehensive experimental studies of top-quark prospects at HL-LHC.

clean e^+ environment

excellent probe of compositeness





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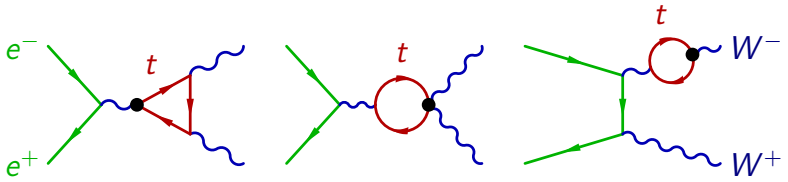
Top & Higgs (future)

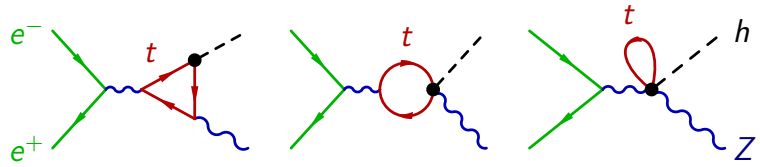
[Vryonidou, Zhang '18; + GD, Gu '18]
[Jung, Lee, Perelló, Tian, Vos '20]

- at the Z pole [Zhang, Greiner, Willenbrock '12]
- in diboson production [GD, Gu, Vrionidou, Zhang '18]



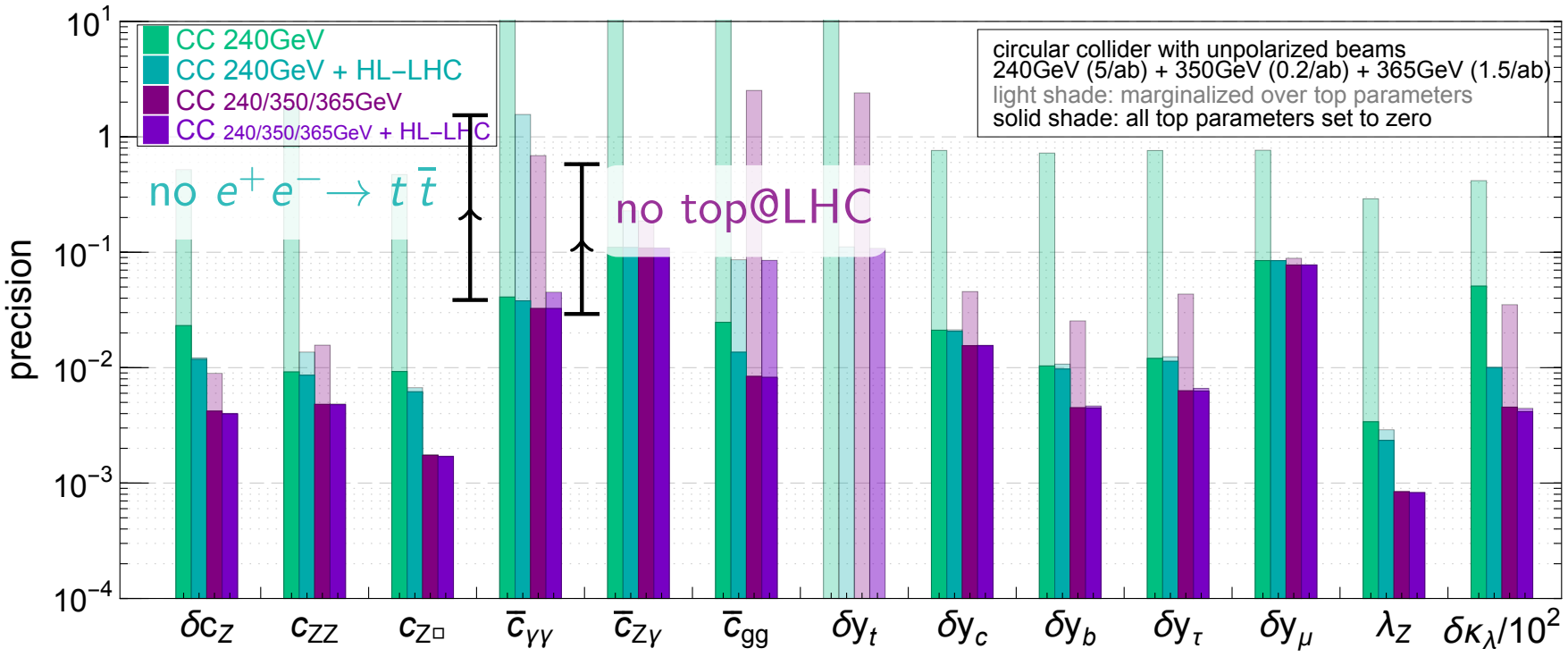
differential in the production angle

- in Higgs processes [Vrionidou, Zhang, '18] [see also Boselli et al '18]



- Higgsstrahlung and W-fusion through reweighing in MG5/aMC@NLO
- Higgs decays

(excluding four-fermion operators, no top loop included in $e^+e^- \to t\bar{t}$)



Top-quark uncertainties can impede Higgs precision!

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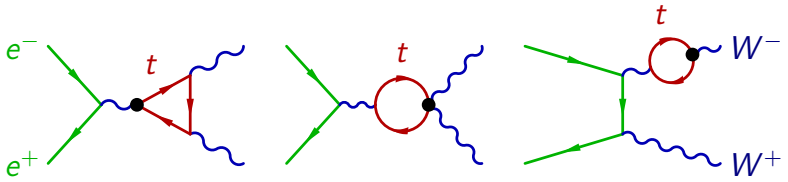

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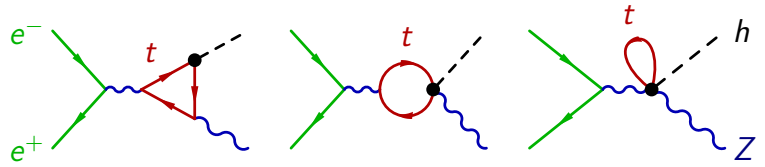

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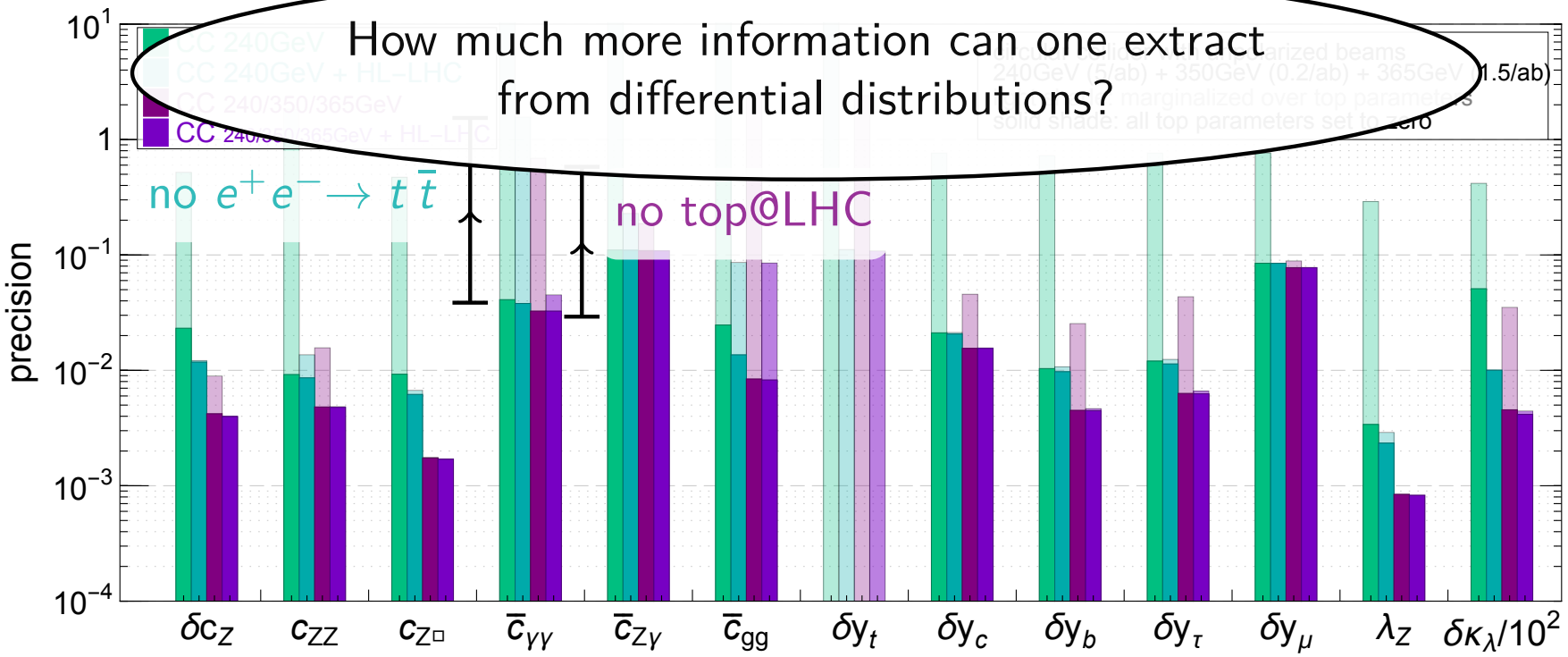

Top-quark uncertainties can impede Higgs precision!

Towards global EFTs

EFTs are ideally suited
for exploring the energy frontier in the next 20 years.

Treated globally, they systematically cover
the theory space of heavy new physics.

Challenges are significant, but the way is being paved.
So, let's get going step by step!