



EF04 EW precision physics and constraining new physics

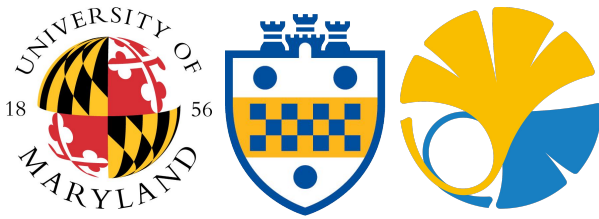
A. Belloni - University of Maryland

A. Freitas - University of Pittsburgh

J. Tian - University of Tokyo

Snowmass Energy Frontier Kick-off Workshop

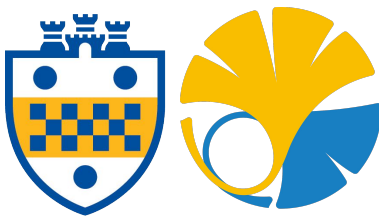
May 21, 2020



Group Mandate

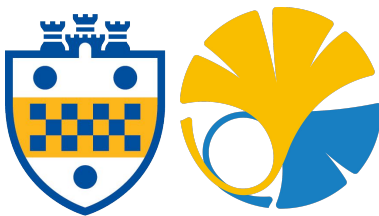
The dominant theme of topics covered in this topical group is constraining new physics by performing precision fits of standard model (SM) observables. The ingredients of the fit are electroweak observables, which are a direct component of the mandate of this group, and Higgs and top observables, which establish a tight link between this group and other EF topical groups (in particular, EF01, EF03, and EF05).

The mandate of this group includes the study of multi-boson signatures, and vector-boson fusion and scattering processes. Constraints to the SM are obtained within the EFT framework, and specific SM-extension models that are of particular relevance to electroweak precision physics. This group also investigates the impact of correlations among experimental and theoretical uncertainties, and discusses state-of-the-art theoretical modeling of EW and QCD uncertainties, and their combination.



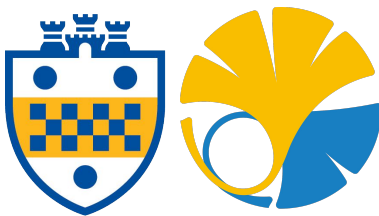
The Big Questions

- What is the scale of NP that can be probed with precision measurements?
- What is the value of new colliders? What is the motivation to do physics there?
 - Future colliders are presented in stages: why and how are these stages necessary?
- How can theoretical precision match the experimental precision?
 - What kind of precision do we need to achieve to overcome degeneracies?
- What are the correlations among experimental observables and theoretical models?
- What are the needs of theory and MC tools?
- What are the new analysis strategies?
- Ultimate goal is global fit of SM parameters, and evaluation of SMEFT constraints
 - Overall coherence of EFT interpretations



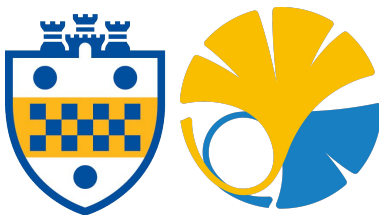
Analysis Topics (1)

- Multi-boson final states: VV , VVV
 - Inclusive and fiducial cross sections; differential cross sections
 - Limits to anomalous TGC and QGC (EFT framework)
- Vector-boson fusion and scattering
 - Electroweak production of vector bosons
 - Scattering amplitude polarization
 - Theoretical validity of EFT framework
- Measurement of W mass and A_{FB} at hadron colliders
 - Input from QCD (e.g. PDFs)
- QED and QCD corrections
 - Investigate state of the art of combination of corrections, and effect on global fits
 - ISR, IFI, FSR
 - MC tools



Analysis Topics (2)

- EWPOs at future colliders
 - SM precision fit: $m_W, m_Z, \Gamma_W, \Gamma_Z, A_{LR}^f$ ($f=e/\mu/\tau/b/c$), $A_{FB}, \alpha_{EW}, \sigma_{had}, \dots$
 - Inputs from Higgs (mass), top (mass), QCD (α_s)
 - Theoretical calculations and uncertainties (NNLO and beyond)
 - Oblique parameters S, T, U
- Global fit in SMEFT
 - Formalism: T/QGCs + EWPOs + Higgs Obsv + Top-quark Obsv; LO & NLO
 - Input observables from Higgs (EF01) and top (EF03)
 - Provide fit results on Higgs coupling precisions (collaboration with EF01)
 - Correlations among experimental uncertainties
 - Roles of EWPOs & Top couplings on Higgs couplings
 - new physics scales inferred from EFT operators
 - Evaluate reach of future colliders

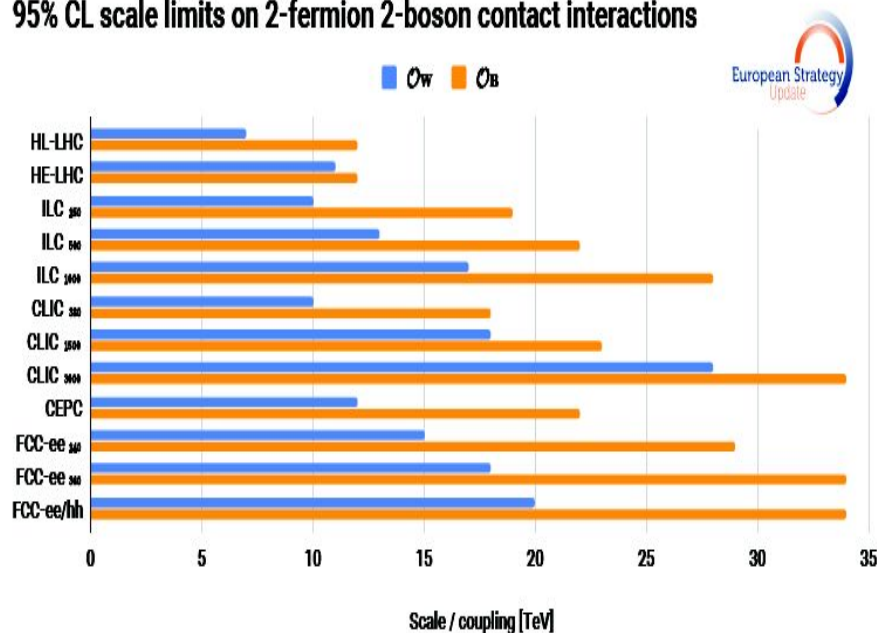


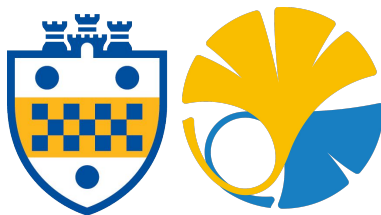
ESG Summary (1)

[[ESG Physics Briefing Book, 2019](#)]

- EWPOs: only in S/T/U framework
 - use SMEFT
 - critical analysis of sys. uncertainties
- VV production: two SMEFT operators
 - complete set of ops.
 - include vector boson fusion+scattering
 - EFT consistency and validity
 - differential observables
 - VVV processes

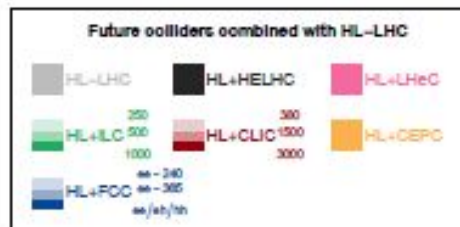
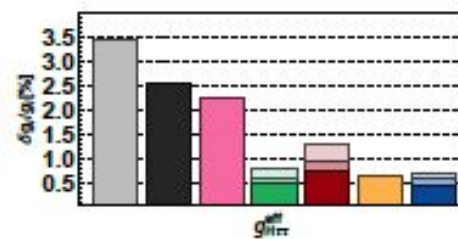
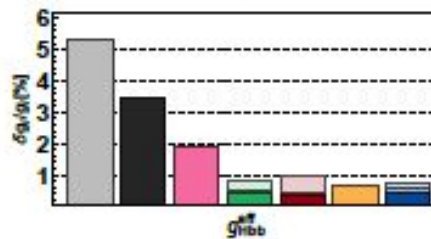
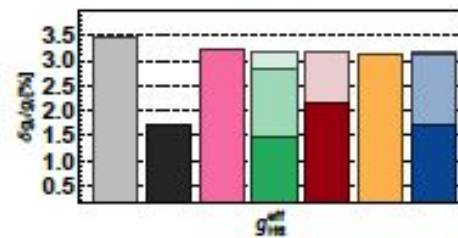
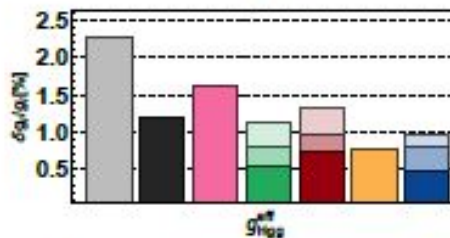
95% CL scale limits on 2-fermion 2-boson contact interactions

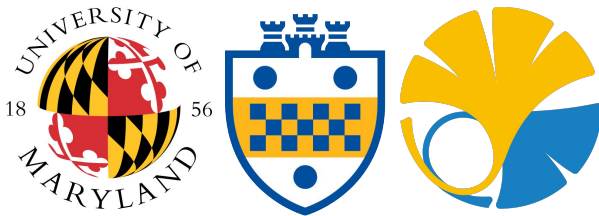




ESG Summary (2)

- Global fit:
In [Physics Briefing Book](#) only for Higgs sector
 - In supporting docs [[1905.03764](#)] global fit of Higgs rates, EWPOs + di-boson observables
- consider top-quark and 4-fermion operators, diff. observables, low-energy experiments





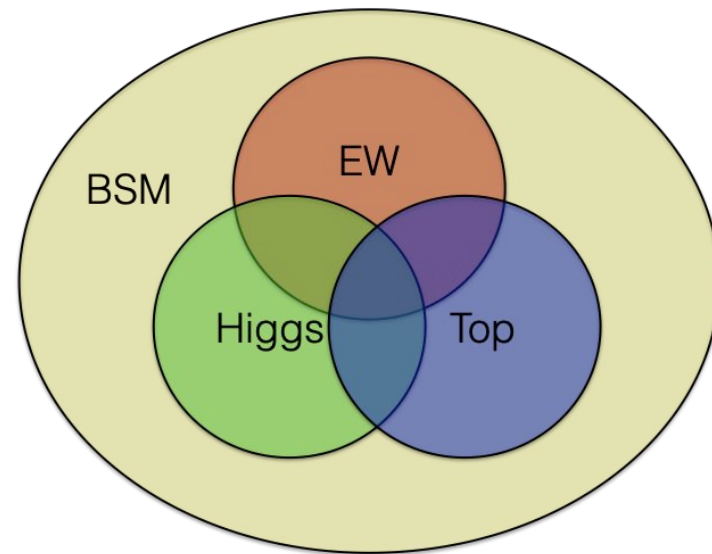
Community Input

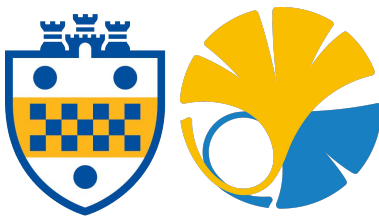
- VV(V) processes at hadron colliders [EXP]
 - VBS, polarization observables, tri-boson production
 - complete set of relevant EFT operators, QGC
 - detector performance, machine learning
- Precision obs. at e+e- colliders [EXP]
 - W mass; interplay with other precision obs.
- Higher-order corrections [TH]
 - for EWPOs; implications for global fits
 - QCD+EW corrections for VV and V+jets processes at hadron colliders
- Implications for new physics [TH]
- EFT fit
 - full EFT for VV processes
 - interplay of Higgs and top sectors
 - Statistical treatment of theory errors



Discussion: Global SMEFT Fit

- Precision measurements in EW/Higgs/Top
 - opportunity to first find BSM effects (deviations w.r.t. SM)
- Global SMEFT fit
 - opportunity to identify where the BSM effects exactly are, i.e. in W/Z couplings, Higgs couplings, or Top-quark couplings
 - thus to help identify **the** BSM model that is responsible for the deviations

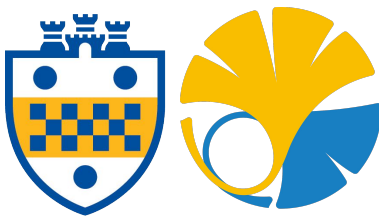




Discussion: Global SMEFT Fit

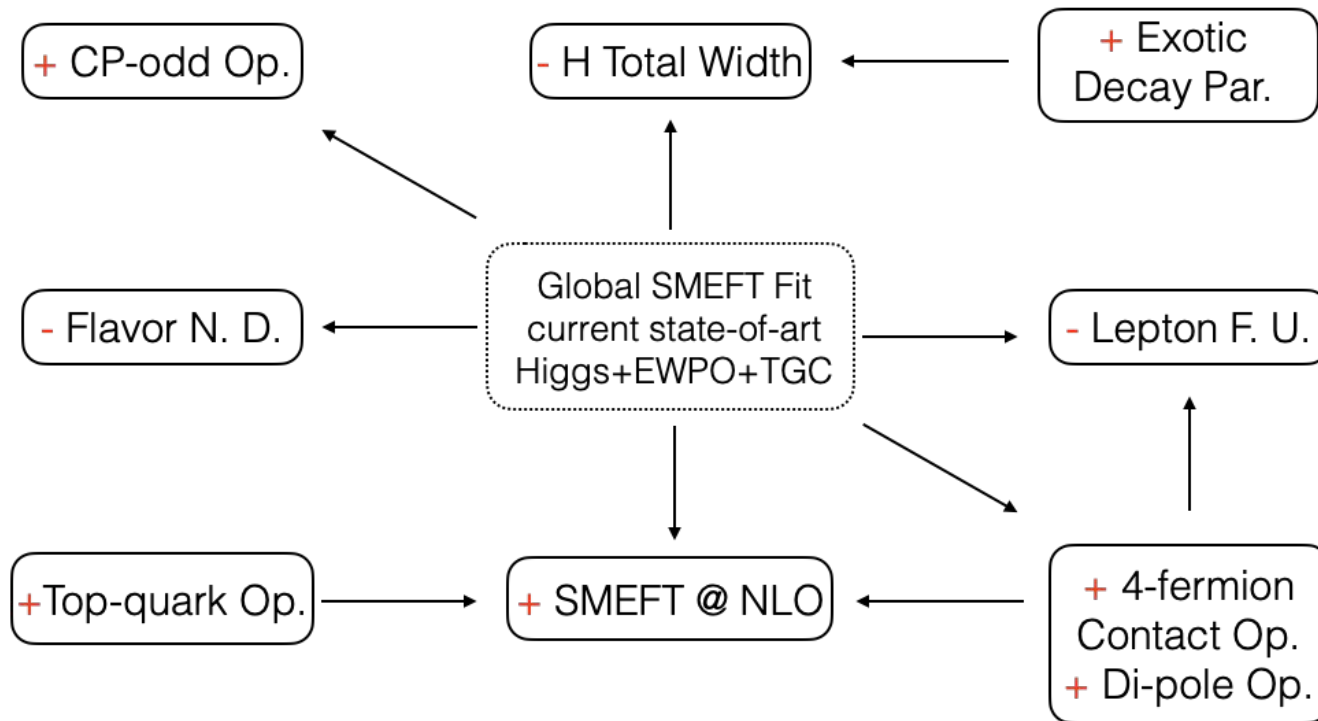
example: new questions / studies

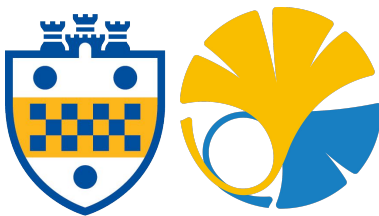
- Include more operators?
 - Achieve more model-independent test of BSM effects
- Include more observables and more differential?
 - Help lift more degeneracies
- Improve projections of existing observables?
 - Experimental sys. Errors
 - Theoretical uncertainties
 - Better strategies for measurements



Discussion: Global SMEFT Fit

example: include more operators?

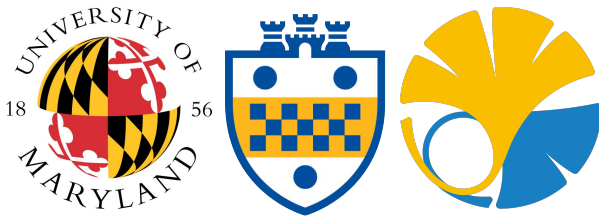




Interest behind Questions

Keep in mind: interest is what EW physics to do in next decades;
how technically to do so is a side question

- Synergies between LHC & future e^+e^- colliders?
- e^+e^- : in addition to run at $\sim ZH$ threshold, values of data from Z-pole run? Run $\geq t$ t -bar threshold? Run $\geq ZHH$ / ttH threshold? Run ≥ 1 TeV? Values of beam polarizations?
- pp: values from high energy pp / ep collisions?
- Synergies with low-energy experiments?



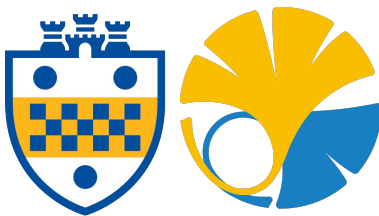
Organization

- Communication
 - Slack: [ef04-ewk_constraints](#)
 - Mailing list: SNOWMASS-EF-04-EWK_CONSTRAINTS [at] FNAL.GOV
 - Indico meetings: <https://indico.fnal.gov/category/1138/>
- Bi-weekly community meeting (next on Thursday June 4 EFT-themed)
 - Alternating Thursday and Friday, at 10am EDT
- Call for input from community
 - LOIs, contributed papers
 - Feedback on big questions
 - Survey to collect (non-committal) interests in EF04 topics
 - <https://forms.gle/rVsEs5ZX4XUQCCfW9>



Collaboration

- Global SMEFT fit:
 - Higgs properties and couplings [EF01]
 - Top measurements [EF03]
 - W/Z (+jets) production; α_s and quark masses [EF05]
 - Low-energy precision measurements [RF]
 - Interpretation in terms of BSM models [EF08/EF09]
- Higher-order corrections:
 - Interplay of EW and QCD corrections [EF05]
 - Methods and techniques [TF]
- Simulation:
 - Large MC production for precision measurements [CF]
 - Detector requirements (radiation tolerance, granularity, particle ID) [IF]

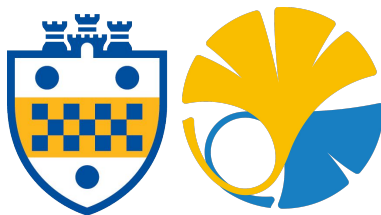


Conclusion

- The big questions and analysis topics for EF04 TG have been set; a central task will be global EFT fit
- Very rich opportunities for EW precision physics at LHC & future colliders will be addressed by EF04 in collaboration with other groups
- Many new studies are expected to happen
- Welcome feedback and input from community and join us



Additional Material

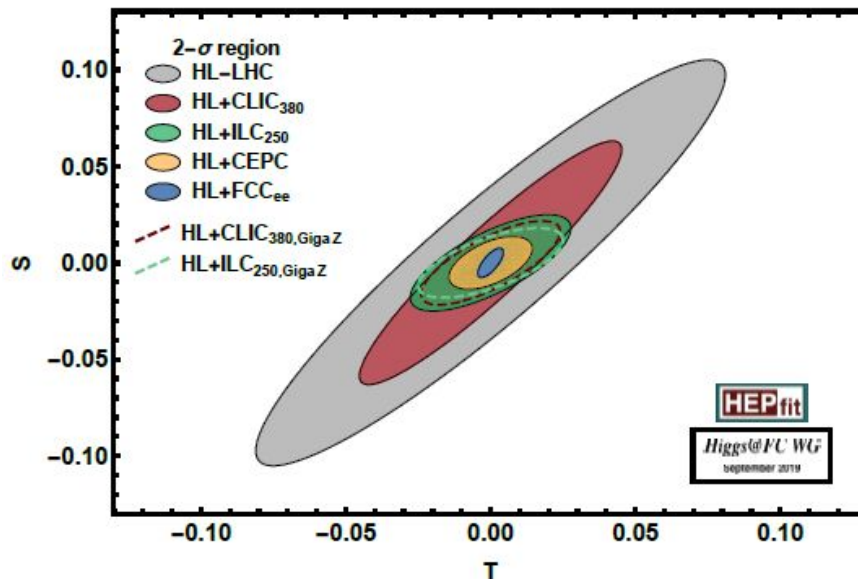
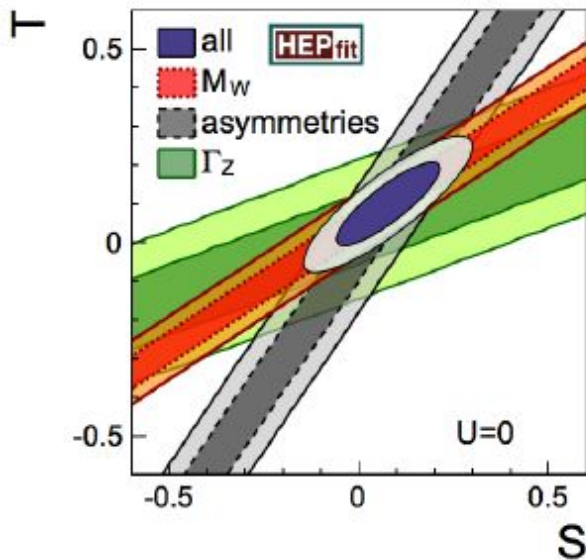


ESG Summary

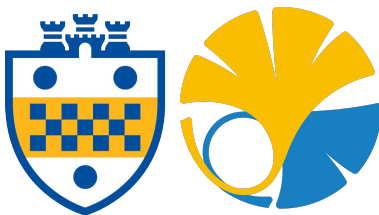
[[ESG Physics Briefing Book, 2019](#)]

- Electroweak precision tests
 - Discussed mainly in terms of oblique parameters $S/T/U$

Present



Future

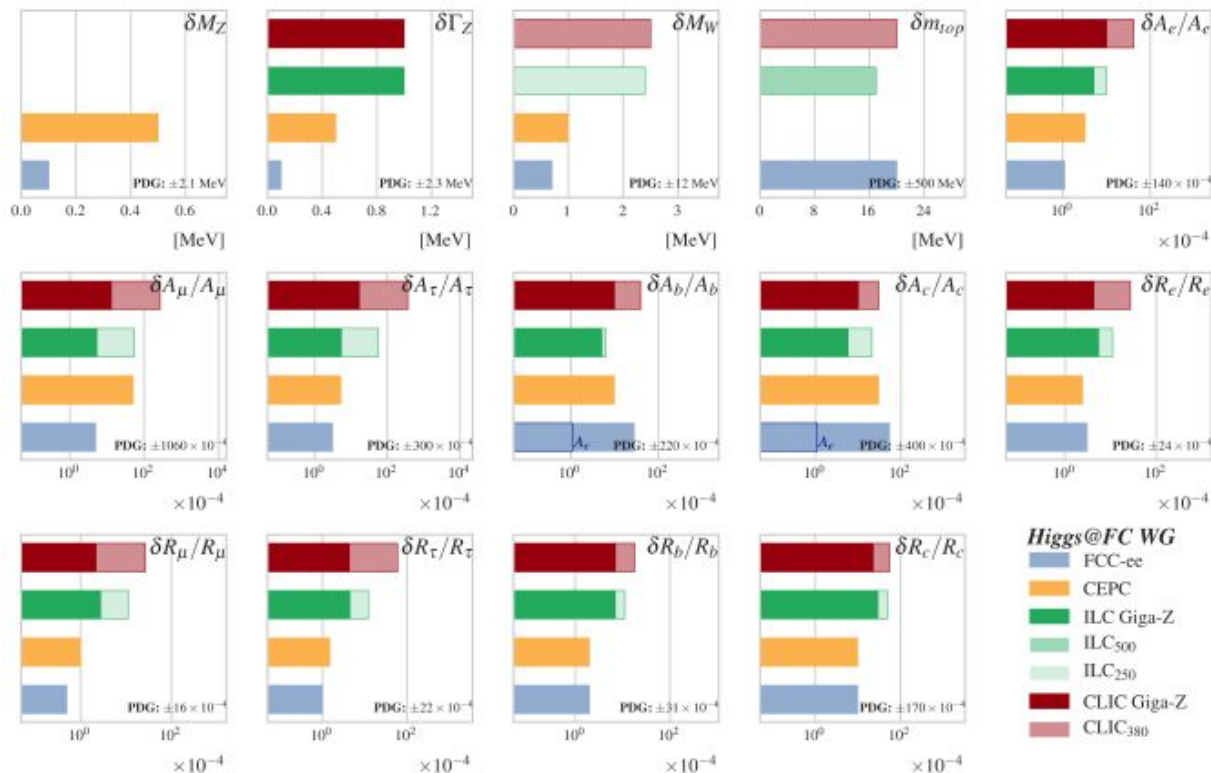


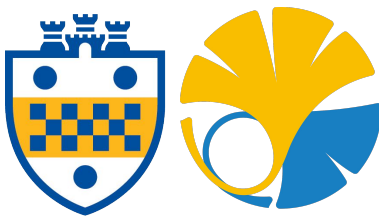
ESG Summary

[ESG Physics Briefing Book, 2019]

- Electroweak precision observables

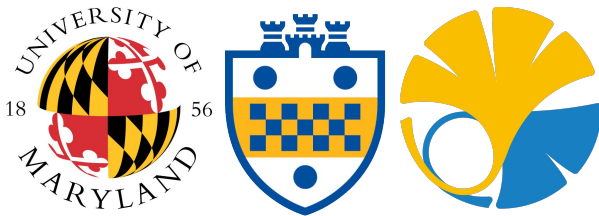
- Various observables at future lepton collider
- Very limited discussion of systematics





ESG Summary

- Theory needs for EW precision tests [[ESG Physics Briefing Book, 2019](#)]
 - Enumerate expected need for multi-loop orders for $ee \rightarrow Z$ on-shell and off-shell, $ee \rightarrow WW$, $ee \rightarrow HZ$, $ee \rightarrow \nu\nu H$
 - pp colliders: need for higher orders (without specifics) and PDF improvements
 - Factor 2-4 improvement
 - Input parameters: m_t , m_b , α_S , $\alpha(m_Z)$, ...
 - Need perturb. and lattice theory



ESG Summary

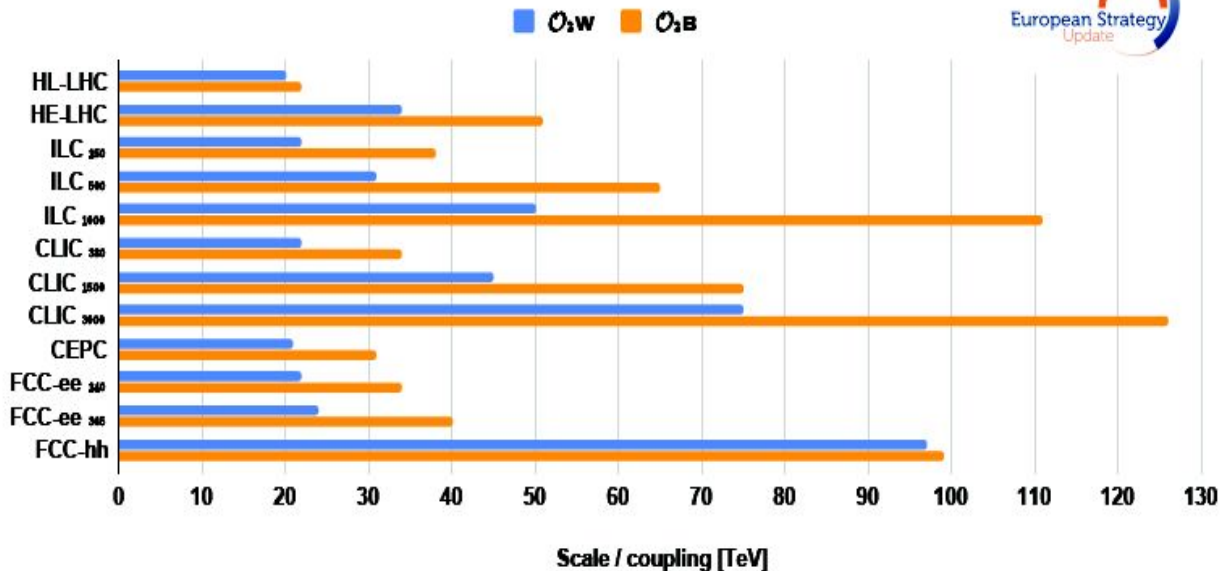
[[ESG Physics Briefing Book, 2019](#)]

- High-energy EW physics
 - 4-fermion contact interaction
 - Only two operators, related to 4f interaction through e.o.m.s

$$O_{2W} = (D^\mu W_{\mu\nu})^i (D_\rho W^{\rho\nu})^i$$

$$O_{2B} = (\partial^\mu B_{\mu\nu})(\partial_\rho B^{\rho\nu})$$

95% CL scale limits on 4-fermion contact interactions





ESG Summary

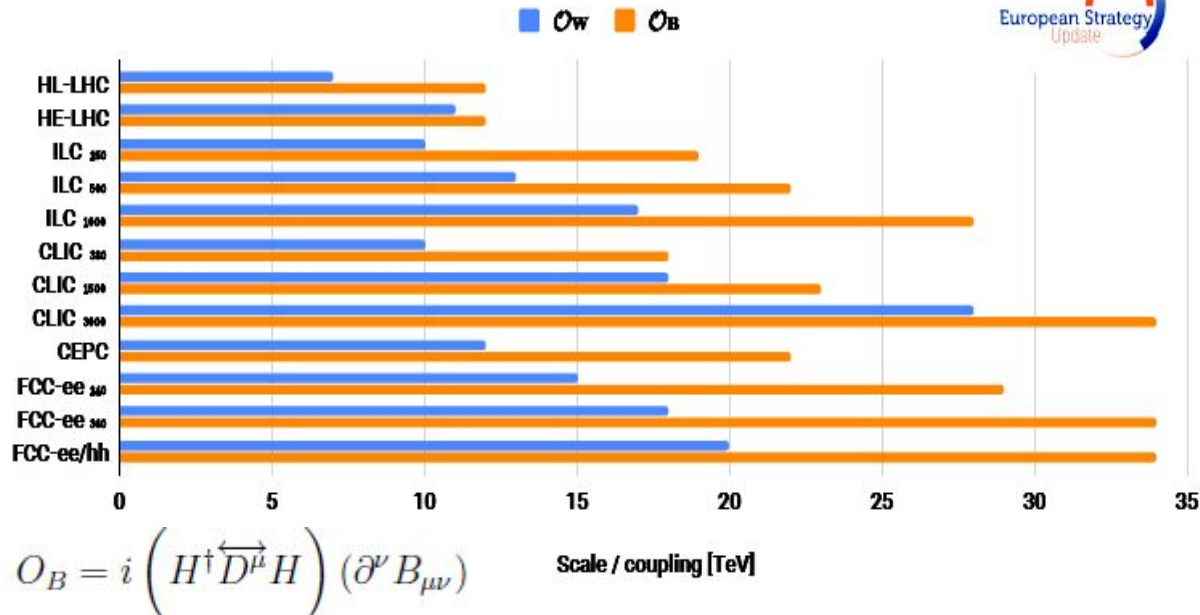
[[ESG Physics Briefing Book, 2019](#)]

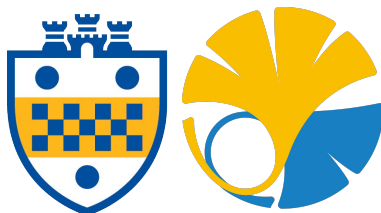
- High-energy EW physics

- 2-fermion 2-boson contact interaction, probed by di-boson production, e.g. $ee \rightarrow WW, ee \rightarrow HZ, pp \rightarrow WZ$
- Only two operators, related to contact interactions through e.o.m.s

$$O_W = i \left(H^\dagger \sigma^i \overleftrightarrow{D}^\mu H \right) (D^\nu W_{\mu\nu})^i$$

95% CL scale limits on 2-fermion 2-boson contact interactions

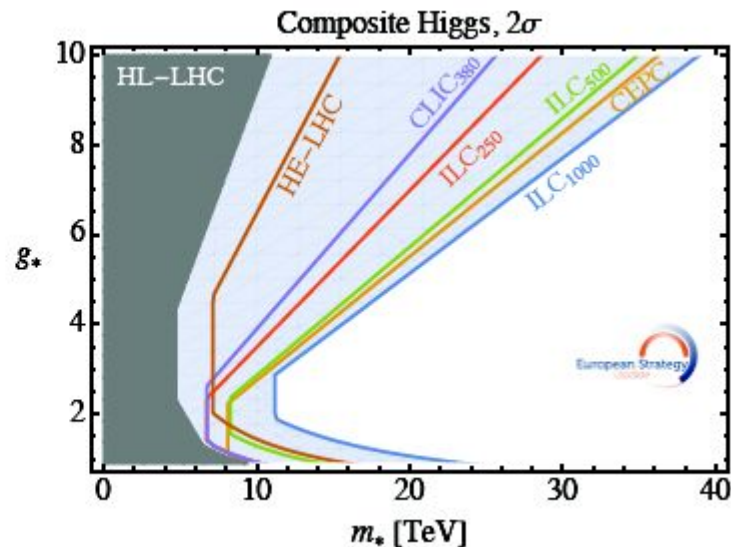
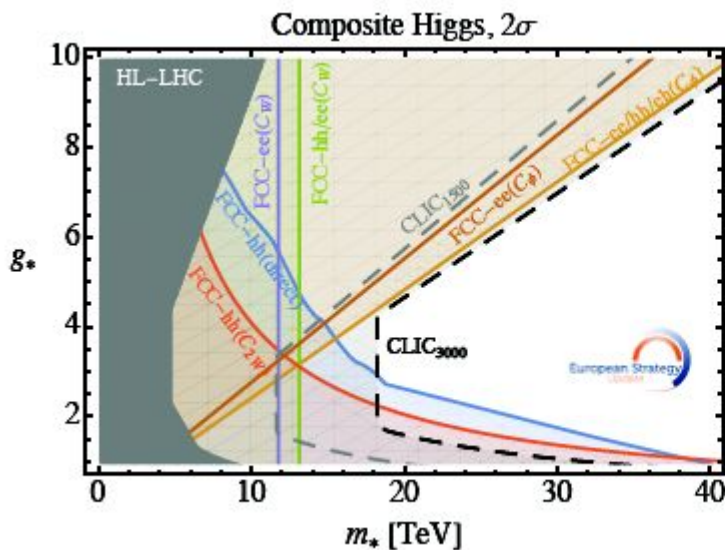


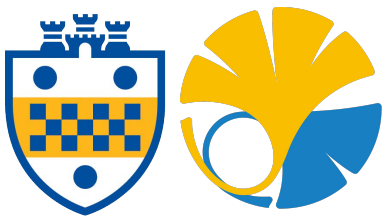


ESG Summary

[\[ESG Physics Briefing Book, 2019\]](#)

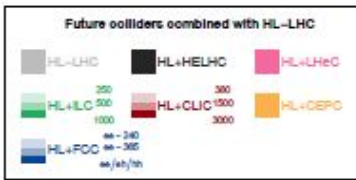
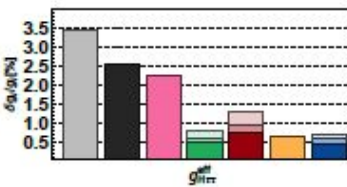
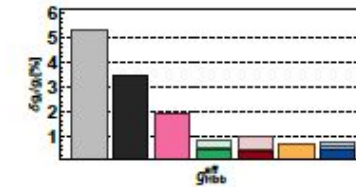
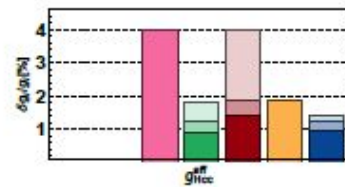
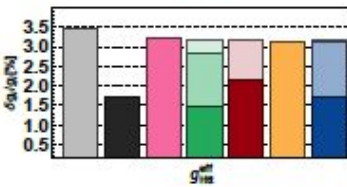
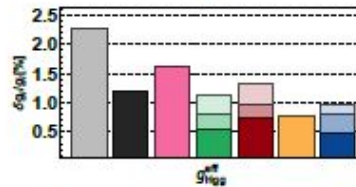
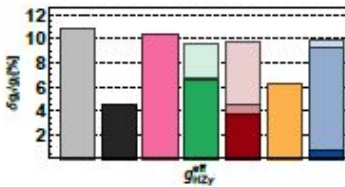
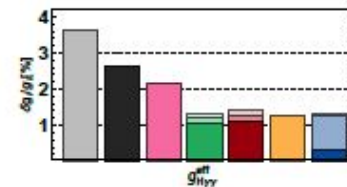
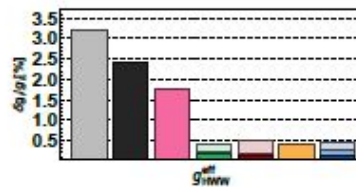
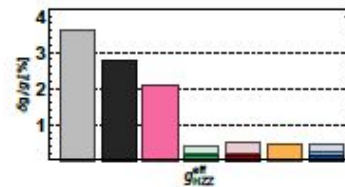
- High-energy EW physics
 - Interpretation of contact interactions in composite Higgs scenario

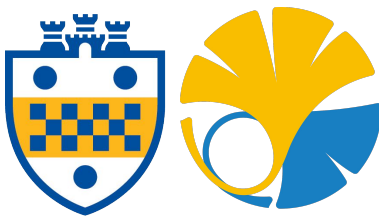




ESG Summary

- Global fit:
 - In [Physics Briefing Book](#) only for Higgs sector in κ and EFT framework
 - In supporting docs [[1905.03764](#)] global fit of Higgs rates, EWPOs and di-boson observables

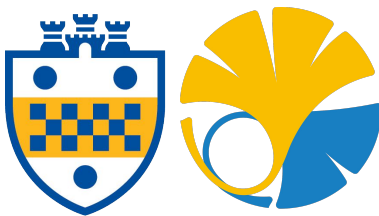




ESG Summary

- Missing elements

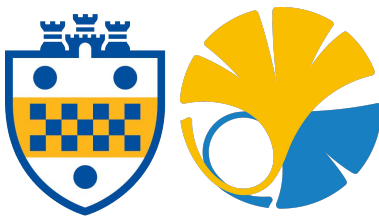
- Broader discussion of multi-boson processes (opportunities, challenges)
- Vector-boson fusion+scattering
- Critical analysis of systematic uncertainties for EWPOs
- Role of differential observables
- Role of low-energy experiments
- Global SMEFT fit, including high-energy obs., VBS, etc.
- EFT consistency and validity considerations
- SMEFT fit for top-quark operators, interplay with Higgs op.
- ...



community feedback

[suggested topics from Google Form]

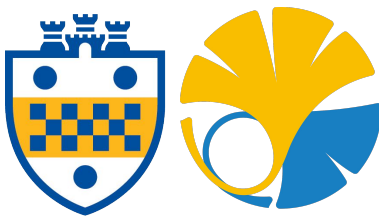
- Implications of precision measurements for new physics [T. Rizzo]
- SM corrections for EWPOs and global fits [J. Gluza]
- Case studies with concrete simple BSM models [J. Gluza]
- Optimization of different accelerators and detector for EWK observables and QGC [J. Metcalfe]
- Polarized cross-sections and EFT sensitivity of WW VBS [J. Berryhill]
- Tri-boson production [J. Berryhill]
- QCD NNLO and EW NLO corrections to multi-boson processes (SM and SMEFT) [M. Herndon]
- Application of machine learning in multi-boson analysis [S. Ganguly]



community feedback

[suggested topics from Google Form]

- Combination of EW/QED corrections with QCD corrections, for V+jets [G. Sborlini]
- [Measurement of W mass and other precision obs. at e+e-, and their interplay \[G. Wilson\]](#)
- Full EFT studies for WW production at future colliders and integration in global fits [J. de Blas]
- SMEFT global fit for Higgs and Top [S. Jung]
- Statistical treatments when SMEFT theory errors are strongly dependent on single parameter [W. shepherd]
- [welcome more feedback by filling in our survey](#)
 - <https://forms.gle/rVsEs5ZX4XUQCCfW9>



EFT Discussion

- Unified description for all measurements
 - Synergies between LHC, future ee / pp / ep , low-energy measurements
- EFT as a common theoretical tool to evaluate experimental sensitivities
 - NP scales (individual operators with assumption on Wilson coefficient)
 - Higgs / Top-quark / EW couplings (projections in multi-operators space)
- Validity in various EFT applications
 - Impact of ignored higher dimensional operators (i.e., D-8, or not completed D-6 set)
 - Uncertainty in NLO EFT calculation
 - Still making sense at $O(1)$ TeV $e+e-$ / $O(100)$ TeV pp ?
- Joint coordination with EF01 TG on Higgs couplings by global SMEFT fit
 - A lot of existing work done by ESG
 - Advantages over k fit?
 - Relax assumption: way to accommodate Higgs exotic decays?
 - Impact from Top-quark loop? Higgs self-coupling in single Higgs process?
 - Next talk by EF01 conveners