


EF04 Highlights

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Energy Frontier Workshop

Open Questions and New Ideas

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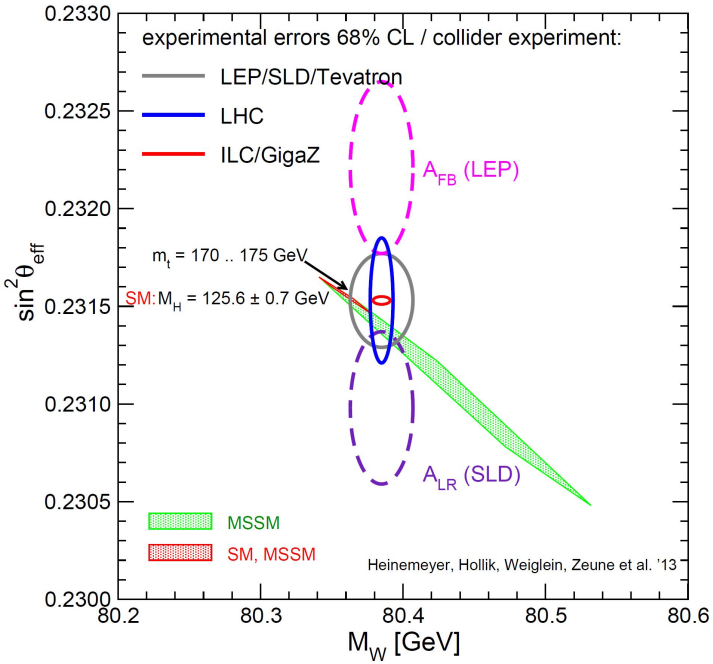
The EF04 Big Questions

- 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 are the correlations among experimental observables and theoretical models?
- What kind of precision do we need to achieve to overcome degeneracies?
- 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

Physics at New Colliders

- Unbeatable resource for Z and W precision physics
  - Baseline runs at Z pole for CEPC and FCC-ee; radiative return events at ILC, CLIC
  - Runs at WW threshold for all lepton colliders
- Polarized beams allow for significant reduction of uncertainties
  - Additional observables: LR asymmetry
  - Model-independent determination of L- and R-handed coupling
  - Suppression of background and enhancement of signals
- Multi-boson final states are key experimental ingredient for EF04
  - Multi-TeV hadron colliders provide enhanced sensitivity to anomalous TGC and QGC
  - Lepton colliders effectively act as W colliders, at c.o.m. energy above a few 100s GeV



S. Heinemeyer

Focus on Lepton Colliders

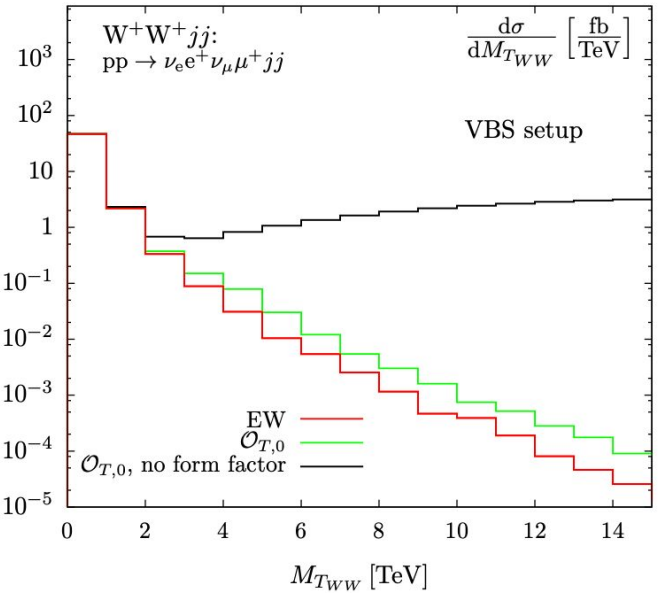
- Dedicated EF04 meeting on June 19 (and July 2) to EWPO at lepton colliders
  - Zhijun Liang (CEPC), Graham Wilson (ILC), Alain Blondel (FCC-ee), Phillip Roloff (CLIC)
- Key points and highlights from discussions
  - Electron and positron polarized beams are a unique asset
  - Let us be optimistic with systematic uncertainties: past experience teaches that one shall not underestimate creativity of dedicated physicist
  - Impact on BSM from, e.g., improving by factor of 20 the R_b measurement (with attention to hemisphere correlations)
  - Staged upgrades to O(TeV) c.o.m. energy at linear colliders
- Open questions and ideas
  - Usage of J/ψ to calibrate energy at linear colliders? Hard limit is 1.9ppm on mass
  - What is need for higher-order calculations? NNLO for 2→2 processes, N^3LO for Z pole?
  - New programs for EWK and QED effects, mixed EW-QCD effects (for *pp*)

Ayres on theory needs in yesterday's parallel session

Experimental Inputs

- Global EWK and SMEFT fits are under purview of EF04, with input from many TGs
  - Higgs couplings (EF01), heavy-quark physics (EF03), precision QCD (EF05)
- Multi-boson final states, VBF and VBS are direct parts of EF04
  - Particular interest in same-sign WW production, tri-boson final states
- Expressions of interest from experienced groups
  - Reports at EF04 meetings: FNAL (July 2), BNL and ANL (scheduled)

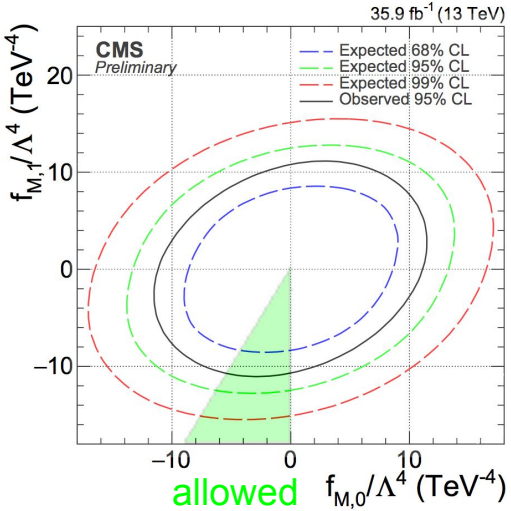
Same-sign WW @ 100TeV



A. Apyan (from 1704.04911)

Gauge Couplings

- Contributions at EF04 and EF workshop preparatory meetings
  - New method to estimate positivity bounds on aQGC (Cen Zhang)
  - Report on effect of beam polarization in charged TGC measurements (Jacob Beyer)
- Multi-boson analyses traditionally used to set bounds on new physics with language of anomalous gauge couplings
  - Shall prefer to use effective operators, and perform full analysis (i.e., without letting only one or two aGC/operator to be non-zero at the same time)
- Open questions
  - VV(V) analyses at hadron colliders with full set of EFT operators: how large are correlations?
  - How to ensure consistency of SMEFT fits? Validity of form factors is model-dependent
  - What are the prospect for HL-LHC? Baseline for future *pp* colliders



C. Zhang

Global Fits

- These are at the heart of the EF04 activities: global fit of EWK parameters, and full SMEFT fit
  - The latter providing a model-independent prescription for generic constraints on new physics
- EFT-themed EF04 session on June 4, more inputs at EF workshop preparatory meeting, and EF04 July 17
  - Overview of EFT in ESG (Jorge de Blas)
  - Theory uncertainties in EFT (William Shepherd)
  - Prospects for EFT studies at LHC (Pietro Govoni)
  - SMEFT fits and Inverse Higgs Problem (Samuel Homiller)
  - Third-generation quarks (Marcel Vos)
  - EWPOs and BSM (Sven Heinemeyer)

...and Gauthier Durieux yesterday afternoon

EFT Discussion (1)

- Some areas are lacking…
  - No full EFT treatment of WW at lepton collider available; limited exploration of top sector (only EW couplings)
  - Need *global* analysis for BSM, setting EW observable shift to zero does not give model-independent results
- Some recommendations…
  - Develop more off-shell observables, do not neglect theory uncertainties
  - Overcome traditional separation between dim-6 and dim-8 operators
  - Experimentally investigate optimal-observable method in WW

EFT Discussion (2)

- … and the open questions
  - How to include theory uncertainties on EFT dependencies?
  - Are there NLO effects contributing to SMEFT fit? E.g., NLO corrections to top-quark operators
  - How to do full EFT treatment of multi-boson and VBS/VBF results?
  - How would low-energy precision measurement help the global SMEFT fit?
  - What interplay between PDF and EFT fit? No new physics in PDF fits
  - Flavor neutrality is assumed; can we release assumption?
  - Higgs: should extra parameter be added to describe unknown exotic Higgs decays? Would differential Higgs measurements help (and how)? How to include CP-odd operators?
  - Technicality: which fitting tool can properly implement many inputs and possibly hundreds of parameters?

Executive Summary

- Ultimate goal of EF04 is global EW and SMEFT fits
  - Experimental inputs from EF04 (multi-boson, VBF, VBS), EF01 (Higgs couplings), EF03 (top observables and couplings), EF05 (precision QCD); connection with EF08 (signature-independent BSM)
  - Theory inputs: uncertainties, NnLO corrections, correlations among experimental and theoretical uncertainties
- Many links to other Frontiers as well
  - Rare Processes and Precision Measurement (low-energy EW tests)
  - Theory (HO radiative corrections; lattice results for α_S and quark masses)
  - Computational (large MC needs)
  - Instrumentation (high-granularity, particle-ID, radiation-tolerant detectors for high-η physics)
- Lively discussions coalesced in comprehensive list of (open) questions

Additional Material

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.

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)

- Global fit of electroweak parameters
  - Global fits to SM: m_W, m_Z, Γ_W, Γ_Z, A_{LR}^f (f=e/μ/τ/b/c), A_{FB}, α_{EW}, σ_{had}, …
    - Inputs from Higgs (mass), top (mass), QCD (α_S)
  - Theoretical calculations and uncertainties (NNLO and beyond)
- Global fit in SMEFT
  - Formalism: T/QGCs + EWPOs + Higgs Obvs + Top-quark Obvs; 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
  - Oblique parameters S, T, U; new physics scales inferred from EFT operators
  - Evaluate reach of future colliders

Shared Topics

- EF01: Higgs Boson properties and couplings
  - Higgs TG collaboration to EW and EFT fit
- EF03: Heavy flavor and top quark physics
  - Top inputs to EW and EFT fit
- EF05: Precision QCD
  - Correlations between EW and QCD corrections; α_S and quark masses
  - W/Z(+jets) production (entirely in purview of EF05)
- EF08/EF09: Interesting BSM models (entirely in purview of EF08/EF09)
  - Models with strong signals in VV(V) processes
  - Models that be probed in EW precision tests but are difficult to search directly

With other Frontiers

- Rare Processes & Precision Physics Frontier
  - Low-energy electroweak precision tests
- Theory Frontier
  - Higher-order radiative corrections
  - Lattice results for α_S and quark masses
- Computational Frontier
  - Large MC production for precision measurements
- Instrumentation Frontier
  - Radiation tolerance for high-rapidity physics, high granularity, particle-ID