# Precision Electroweak Measurements at the Energy Frontier

Subgroup Conveners:
Ashutosh Kotwal (Duke)
Michael Schmitt (Northwestern)
Doreen Wackeroth (SUNY Buffalo)

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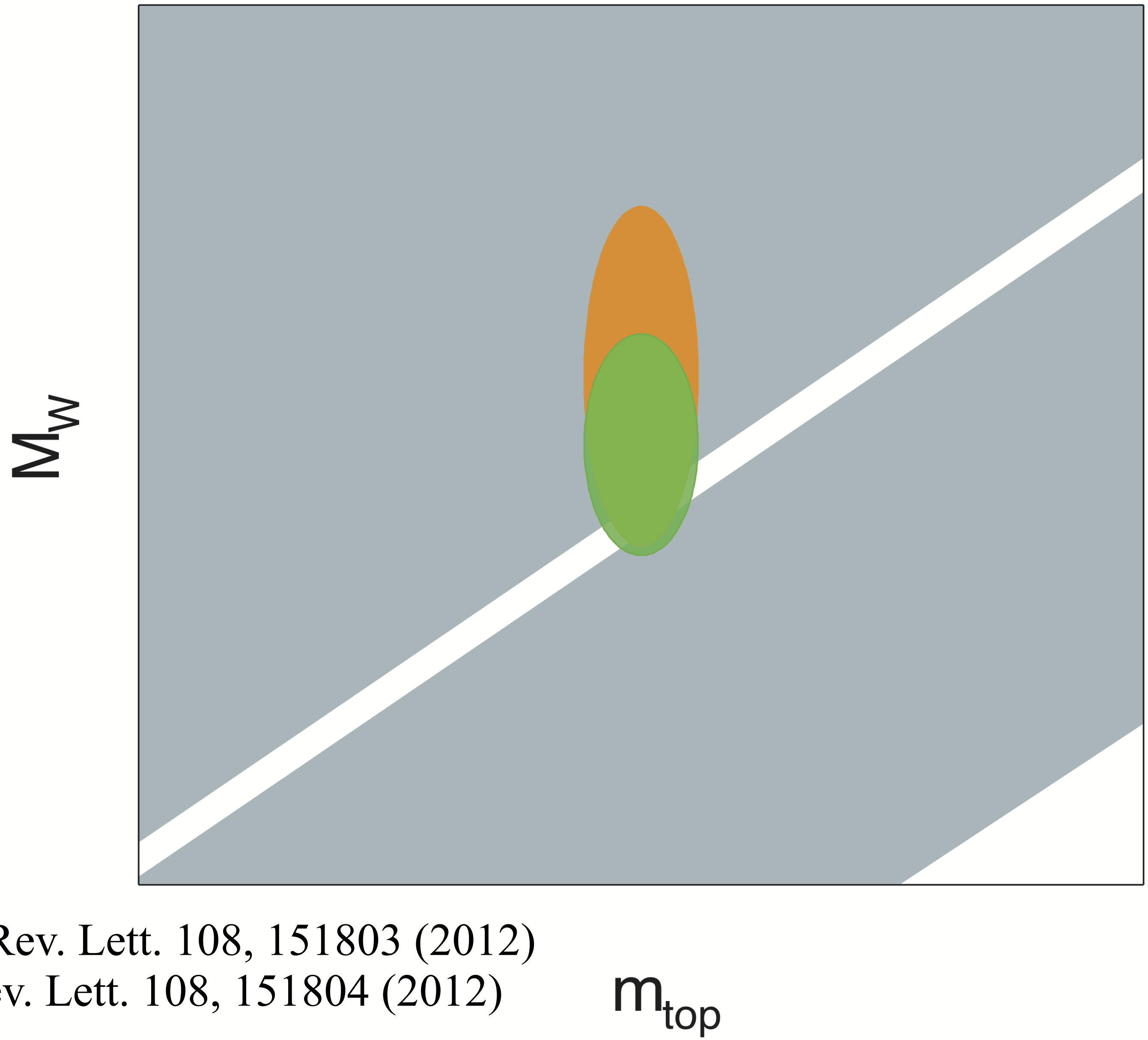
# End of an Era...Dawn of a New Era

- To a large extent, precision electroweak measurements at the energy frontier have been guided by symmetries of the standard model
  - Measurement of gauge couplings
  - Universality of electroweak interactions
  - Electroweak gauge symmetry
  - Pinpoint the mass of the Higgs boson, assuming SM Higgs mechanism

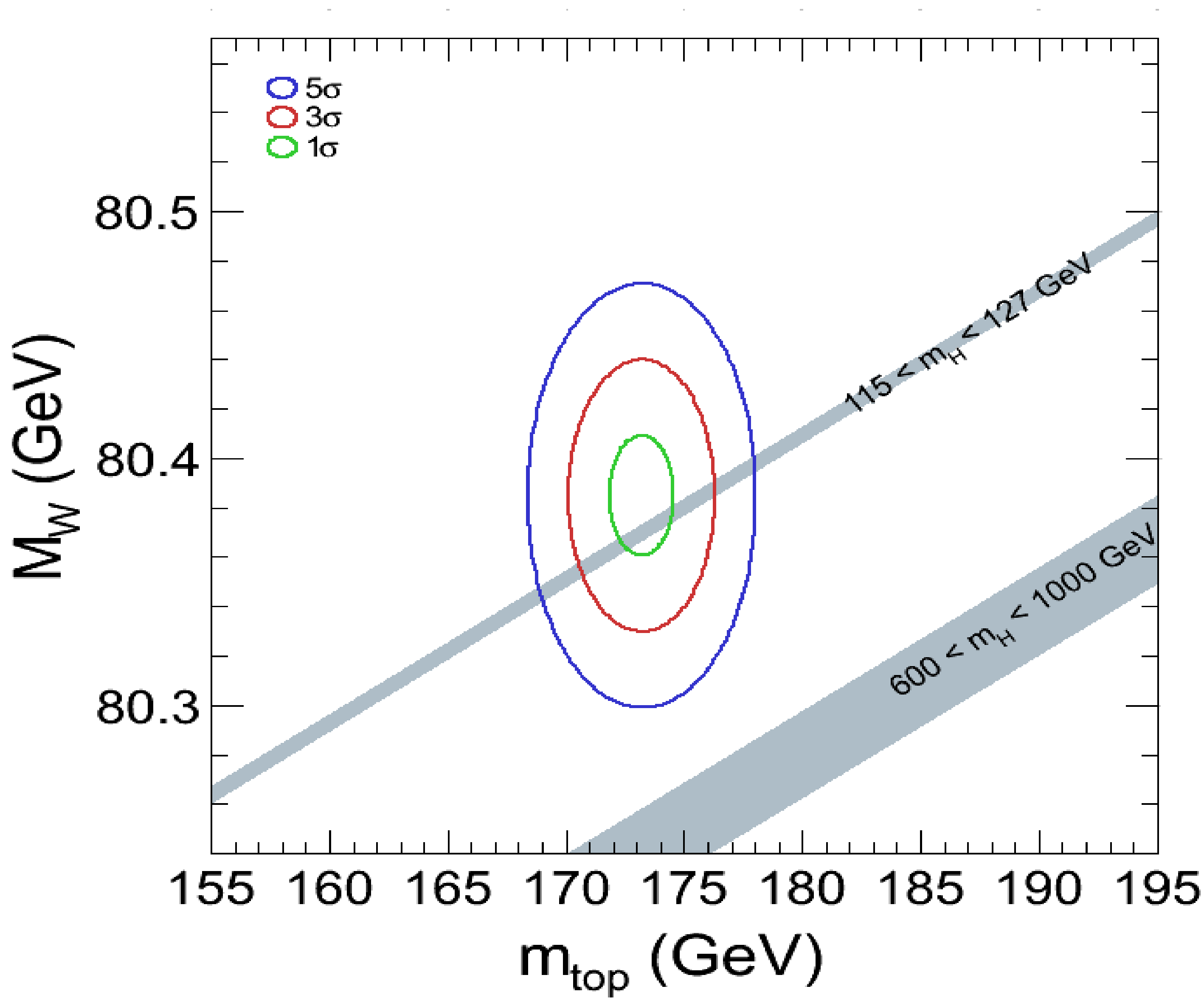
- If 126 GeV boson is the SM Higgs boson, what is the next agenda for precision electroweak measurements?

# Before Higgs Discovery

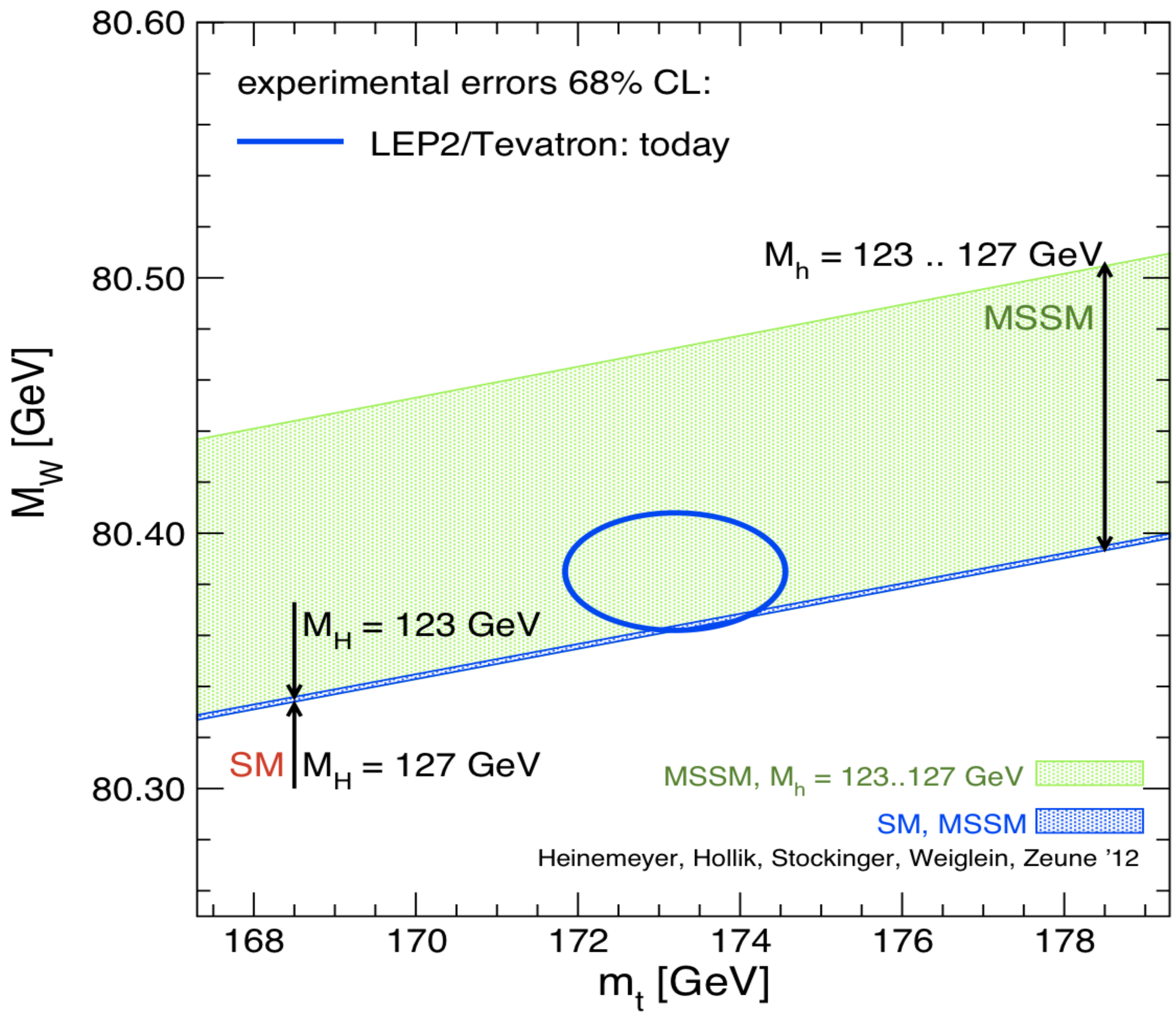



PRL cover
CDF - Phys. Rev. Lett. 108, 151803 (2012)
D0 - Phys. Rev. Lett. 108, 151804 (2012)

# Before Higgs Discovery



# After Higgs Discovery




hep-ph/0604147

# Our Charge

- Driven by the question

  "What is the energy scale of physics beyond the standard model ?"

- Can precision electroweak measurements give us guidance?

# Our Charge

- What are the important precision observables that can reveal deviations from the standard model
    - Observables that are sensitive to loop effects from eg. SUSY, extra dimensions, additional fermions, extra gauge bosons...
- Find the thresholds of precision that need to be achieved for these observables in order to be sensitive to new physics
- Study the precision that can be achieved at each proposed facility on these observables, and ask what machine and detector parameters are required to reach the discovery threshold
- Identify the calculational tools needed to predict standard model rates and distributions in order to perform these measurements at the required precision.

# Detailed Charge

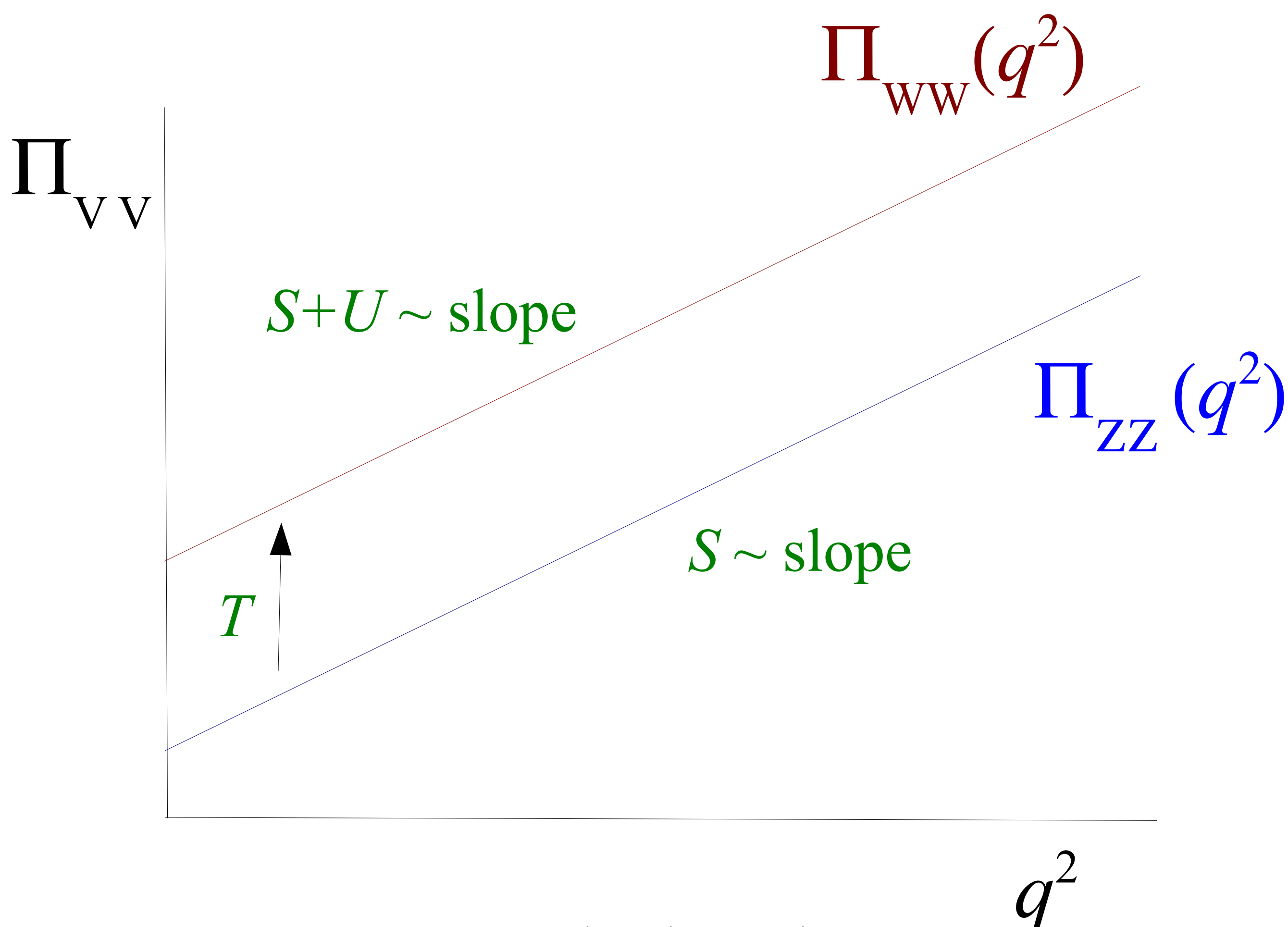
- What accuracies can be achieved on precision electroweak observables such as $m_W$ and $\sin^2\theta_W$?
- For experiments at hadron colliders, what information about QCD is needed to achieve the goals for these precision measurements?
- It is interesting to improve the *Z* pole measurements using a "giga-*Z*" facility?
- How sensitive a test of the Standard Model can be achieved by comparing electroweak observables to the measured values of the Higgs boson and top quark masses?
  - How sensitive will future measurements be to deviations from the Standard Model expected in models of new physics?

# Detailed Charge

- What accuracies can be achieved in measuring the parameters of weak-boson 3- and 4-boson interactions?
  - If there is a strongly interacting Higgs sector with a spectrum of resonances in the TeV energy region, how well might the spectrum be measured, in particular, at a high energy hadron collider?
- Exploration of the above goals to be guided by the following considerations:
  - Evaluate the above goals in the context of future facilities from the broad list above, paying attention to any benchmark energies or luminosities that enable physics goals.
  - Are new theoretical or simulation tools required in order to achieve the goals?
  - What are the detector and computing challenges that the above goals imply?

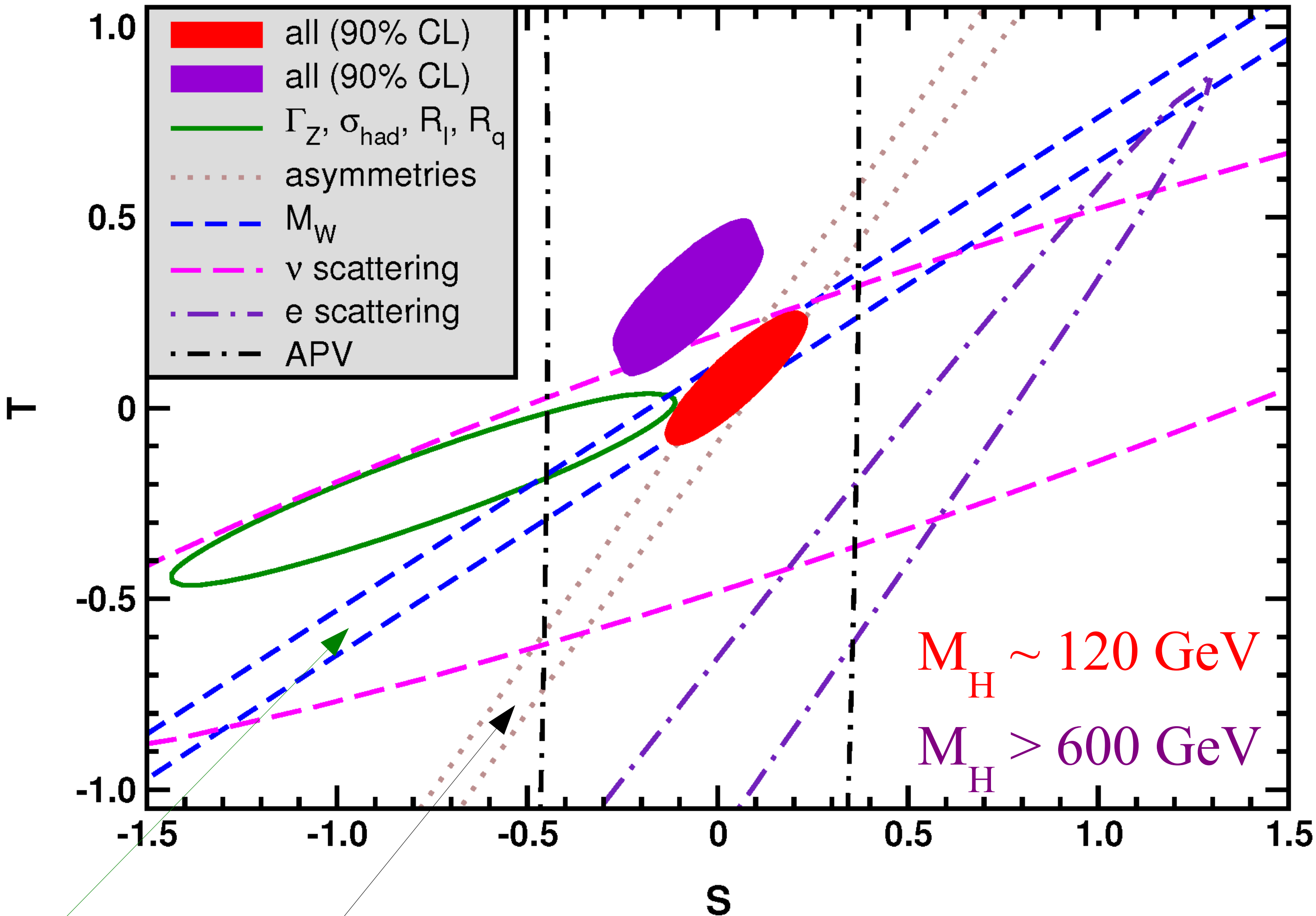
# Example: New Physics Through Propagator Corrections

- Generic parameterization of new physics contributing to W and Z boson self-energies through radiative corrections in propagators
  - *S, T, U* parameters (Peskin & Takeuchi, Marciano & Rosner, Kennedy & Langacker, Kennedy & Lynn)



# Propagator Corrections

- Generic parameterization of new physics contributing to W and Z boson self-energies: *S, T, U* parameters




Can we map models of new physics into the *ST* plane?

(from P. Langacker, 2012)

$M_W$ and Asymmetries are the most powerful observables in this parameterization

# Theory Guidance

- How well can the SM Higgs mass be predicted from electroweak precision observables (EWPOs) to compare to "126 GeV Higgs-like Boson"

- constraining SUSY: Given LHC limits on squarks and gluinos, what is needed to be able to obtain complementary information from EWPOs?

- What is the radiative correction induced in EWPOs by various technicolor models, extra-dimensional models etc?

# Example: $M_W$ Measurements at Tevatron and LHC

- Factor of 2-5 bigger samples of W and Z bosons available at Tevatron
- Huge samples at LHC
- For most of the sources of systematic uncertainties, we have demonstrated that we can find ways to constrain them with data and scale systematic uncertainties with data statistics
- Exception is the PDF uncertainty, where we have not made a dedicated effort to constrain the PDFs within the analysis: current PDF uncertainty is 10 MeV at the Tevatron, total $M_W$ uncertainty is 15 MeV
- We need to address specific PDF degrees of freedom to answer the question:
  - Can we achieve total uncertainty on $M_W$ < 10 MeV at the Tevatron? 5 MeV at the LHC ?

# PDF Uncertainties – scope for improvement

- Newer PDF sets, *e.g.* CT10W include more recent data, such as Tevatron W charge asymmetry data, to be improved with LHC data

- Dominant sources of W mass uncertainty are the $d_{\text{valence}}$ and $\bar{d}$-$\bar{u}$ degrees of freedom at the Tevatron
  - What are the important degrees of freedom for PDFs at the LHC ?
- Tevatron and LHC measurements that can further constrain PDFs:
  - Z boson rapidity distribution
  - $W \rightarrow l\nu$ lepton rapidity distribution
  - W boson charge asymmetry
- Can specialized experiments make an appreciable, additional impact on PDF knowledge?

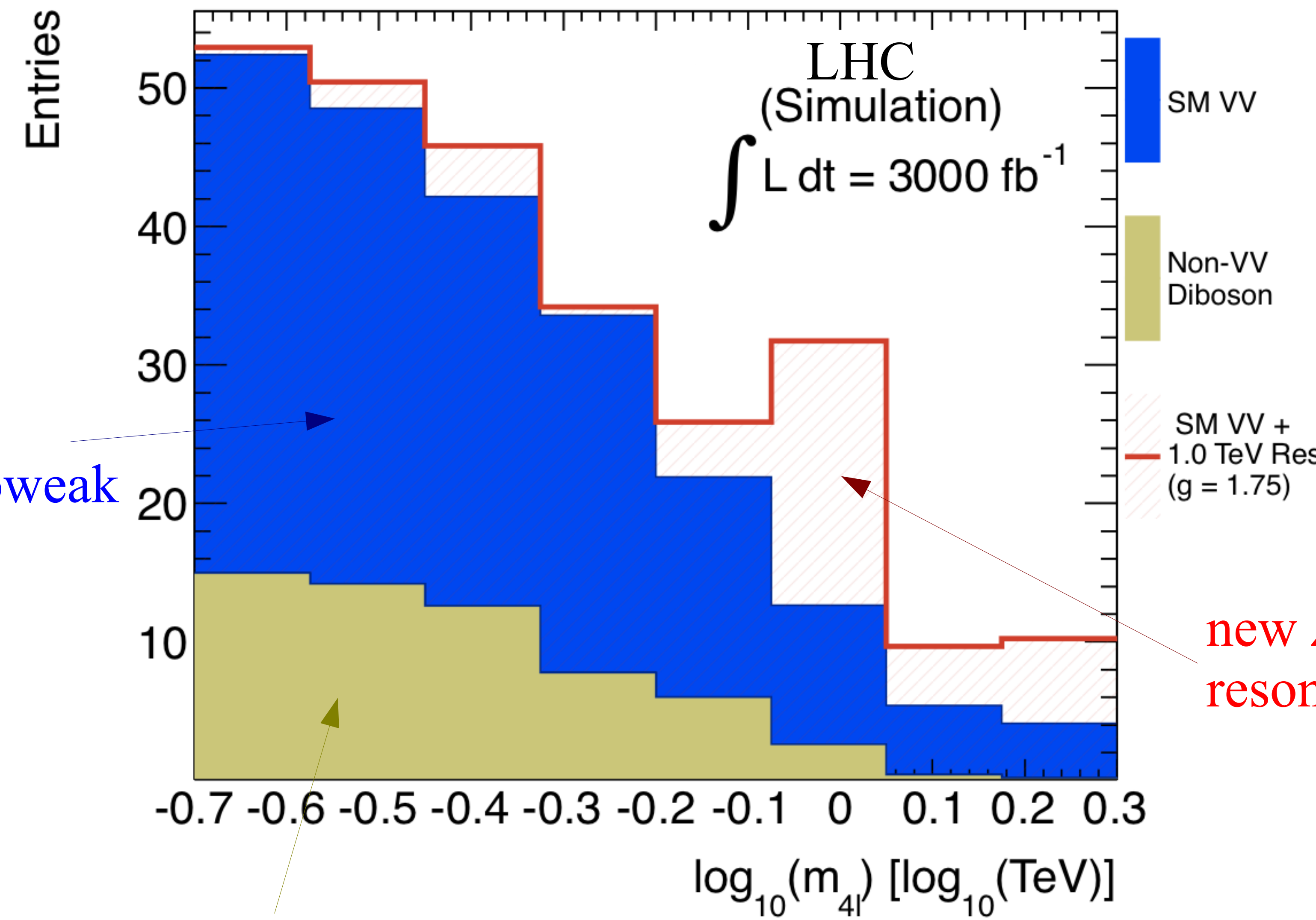
# Triple and Quartic Gauge Couplings

- Triple gauge couplings measured at the "few %" level
  - New physics sensitivity possible at the 0.1% level?
- LHC has opened new era of quartic gauge coupling measurements
  - Measurements of longitudinal vector boson scattering is of particular interest to confirm unitarization
  - the search for new resonances in vector boson scattering in multi-TeV range to probe the Higgs sector is well-motivated
    - even if SM Higgs implies that no new resonances are needed for unitarization
  - What is the needed precision in quartic coupling measurements to detect new physics?

# Developing Action Plan

- Careful study of how well W and Z and VV, VVV kinematic distributions and total rates can be measured and predicted at different colliders
  - ongoing work in the context of the LPCC EWWG and European Strategy Forum which we could use and extend
- Then the same study for the extraction of EW parameters and ElectroWeak Precision Observables, Trilinear & Quartic Gauge Couplings
  - Quite some work for the LHC and ILC has been done already
  - update past studies, in particular where new calculations became available
  - Initiate new studies, especially on quartic couplings

# Example: $ZZ$ ($\rightarrow 4l$) Scattering at LHC




VV → *ZZ*
SM Electroweak scattering

new *ZZ* resonance

Substantial *ZZ* + 2j "QCD" production background, to be calculated with ~10% accuracy

# Electron-Positron Collider

- As LEP I and LEP II demonstrated, electron-positron collider is well-suited to make very precise measurements of electroweak observables:
  - *Z*-pole observables
  - *W* boson and top quark masses (@ higher c.m.s. energy)
  - Trilinear gauge couplings
  - Quartic gauge couplings (@ higher c.m.s. energy)
  - $\mathrm{Sin}^2\theta_W$ versus c.m.s. Energy
  - *….*
- We plan to document the sensitivity achievable in the various running modes (Giga-*Z*, threshold scans, vector boson fusion, vector boson scattering...)

# Summary

- One goal at this meeting is to start discussions on what theoretical tools are available to get  answers (known unknowns) vs. what calculations we want that may not even exist (unknown unknowns)
- It will help to perform the experimental studies if we get the theory motivation and theory tools organized first
- Partial list of precision observables to be considered:
  - *W* and *Z* boson properties
  - diboson and triboson production
  - Weak boson scattering

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- Partial list of precision observables to be considered:
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- Join us and help define the new era of precision electroweak measurements