Study of Quartic Boson Coupling for Snowmass

Shih-Chieh Hsu
University of Washington Seattle
On behalf of the Snowmass EWK VBS/Triboso Group

May 30 2013
Snowmass Lunch meeting at CERN

Weekly meeting:
CERN 42-R-403 7pm on Wed (snowmass-ef-ewk-cern@cern.ch)
Project Page:
http://www.snowmass2013.org/tiki-index.php?page=Precision+Study+of+Electroweak+Interactions

Precision Study of Electroweak Interactions

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

Click here to send email to the conveners

Charge defined by the Subgroup:

(These questions will evolve over the next year.)

1. Identify the most important precision observables that can reveal deviations from the standard model.
2. Identify the thresholds of precision that needs to be achieved for each of these observables in order to be definitively sensitive to new physics.
3. 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.
4. Identify the calculational tools needed to predict standard model rates and distributions in order to perform these measurements at the required precision.

Detailed Charge:

1. Please provide a compact summary of the state of Electroweak Physics, in particular, precision measurements.
2. Please address the following goals for Electroweak physics in the future:
    1. What accuracies can be achieved on precision electroweak observables such as mW and sin^2theta_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?
    2. 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?
    3. What accuracies can be achieved in measuring the parameters of W and Z 3- and 4-boson interactions?
    4. 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?
3. Please guide your exploration of the above goals with the following considerations:
    1. Evaluate the above goals in the context of future facilities from the broad list above. (Collaboration with the Facilities Group is expected.) Pay particular attention to any benchmark energies or luminosities that enable physics goals.
    2. Are new theoretical or simulation tools (for signal or backgrounds) required in order to achieve the goals?
    3. What are the detector and computing challenges that the above goals imply? Collaboration with the Instrumentation Group is expected.

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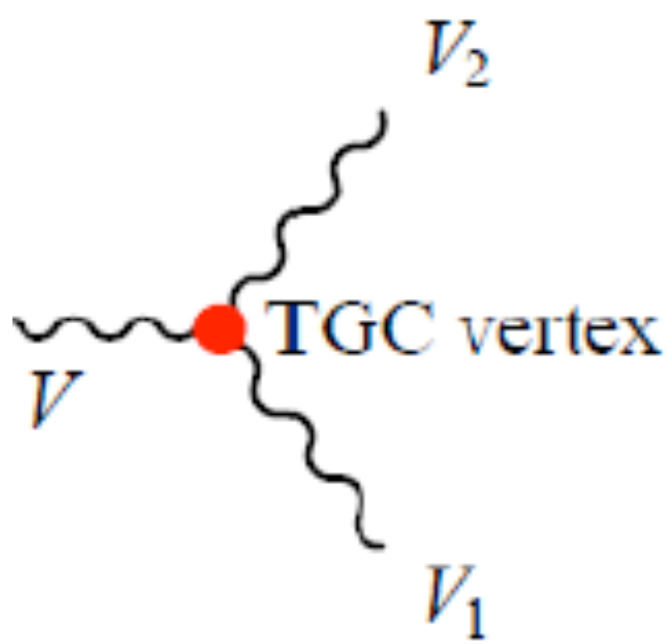
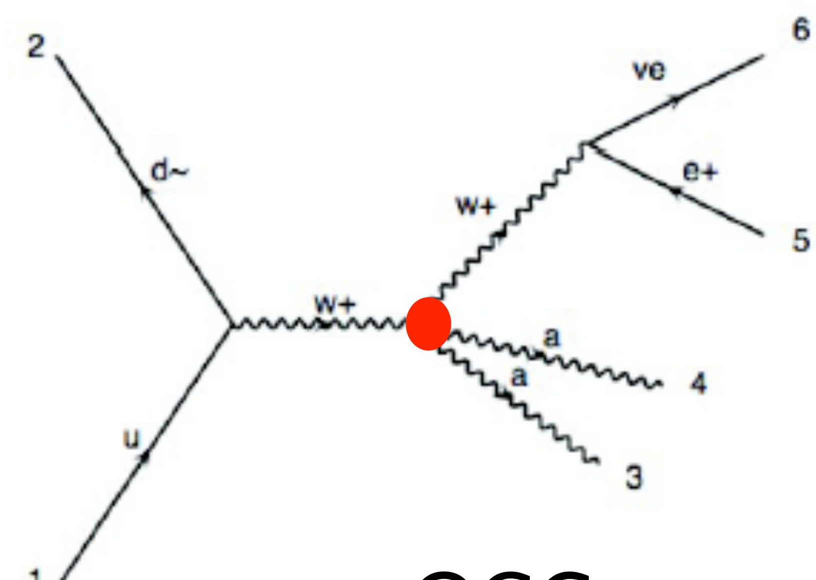
Triple and Quartic Coupling

Predicted by the SM at low energy

$$
\begin{aligned}
\mathcal{L}_{YM} = & -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}Z_{\mu\nu}Z^{\mu\nu} - \frac{1}{2}W^+_{\mu\nu}W^{\mu\nu}_- \qquad (2.3.6)\\
& +ig\sin\theta_W\left(W^+_{\mu\nu}W^\mu_-A^\nu - W^-_{\mu\nu}W^\mu_+A^\nu + F_{\mu\nu}W^\mu_+W^\nu_-\right)\\
& +ig\cos\theta_W\left(W^+_{\mu\nu}W^\mu_-Z^\nu - W^-_{\mu\nu}W^\mu_+Z^\nu + Z_{\mu\nu}W^\mu_+W^\nu_-\right)\\
& -\frac{g^2}{2}\left(2g^{\mu\nu}g^{\rho\sigma} - g^{\mu\rho}g^{\nu\sigma} - g^{\mu\sigma}g^{\nu\rho}\right)\\
& \left[W^+_\mu W^-_\nu\left(A_\rho A_\sigma\sin^2\theta_W + Z_\rho Z_\sigma\cos^2\theta_W + 2A_\rho Z_\sigma\sin\theta_W\cos\theta_W\right) - \frac{1}{2}W^+_\mu W^+_\nu W^-_\rho W^-_\sigma\right]
\end{aligned}
$$

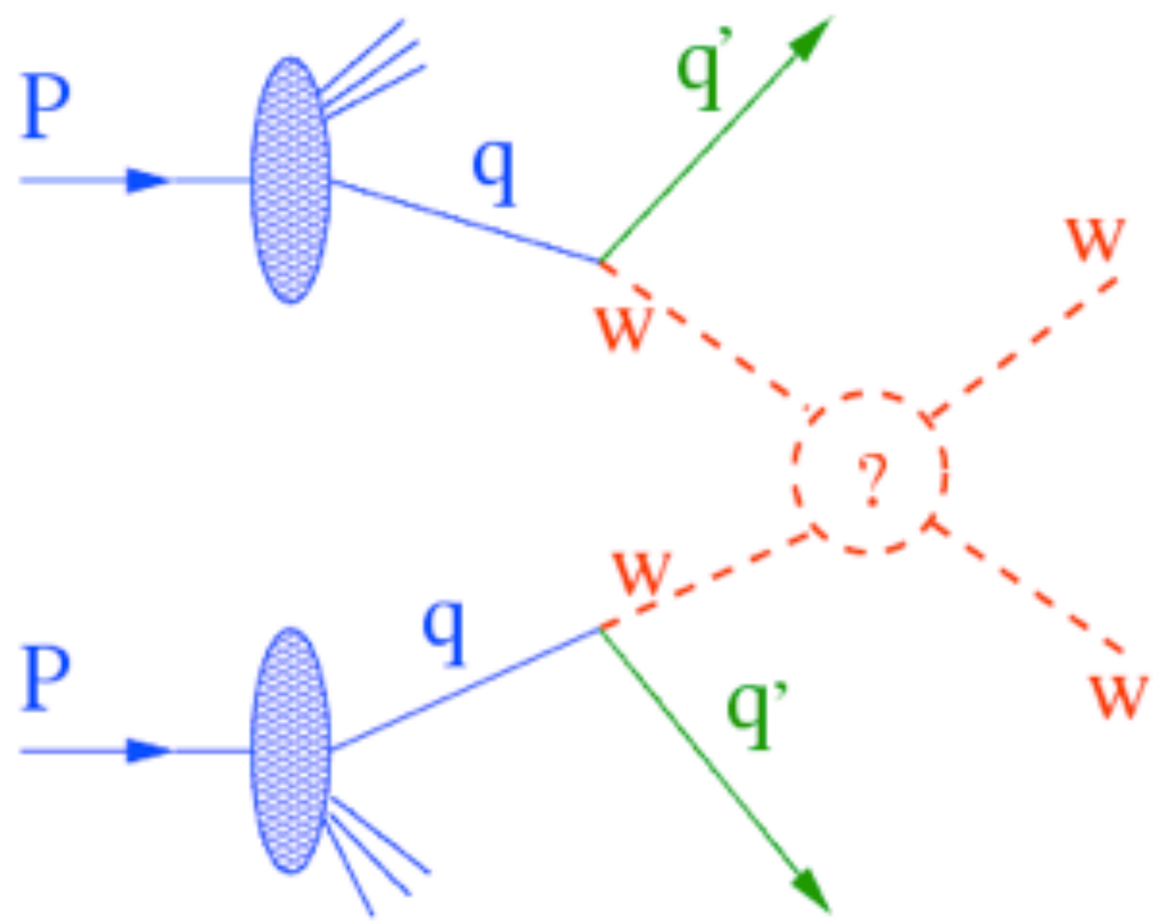




QGC vertex

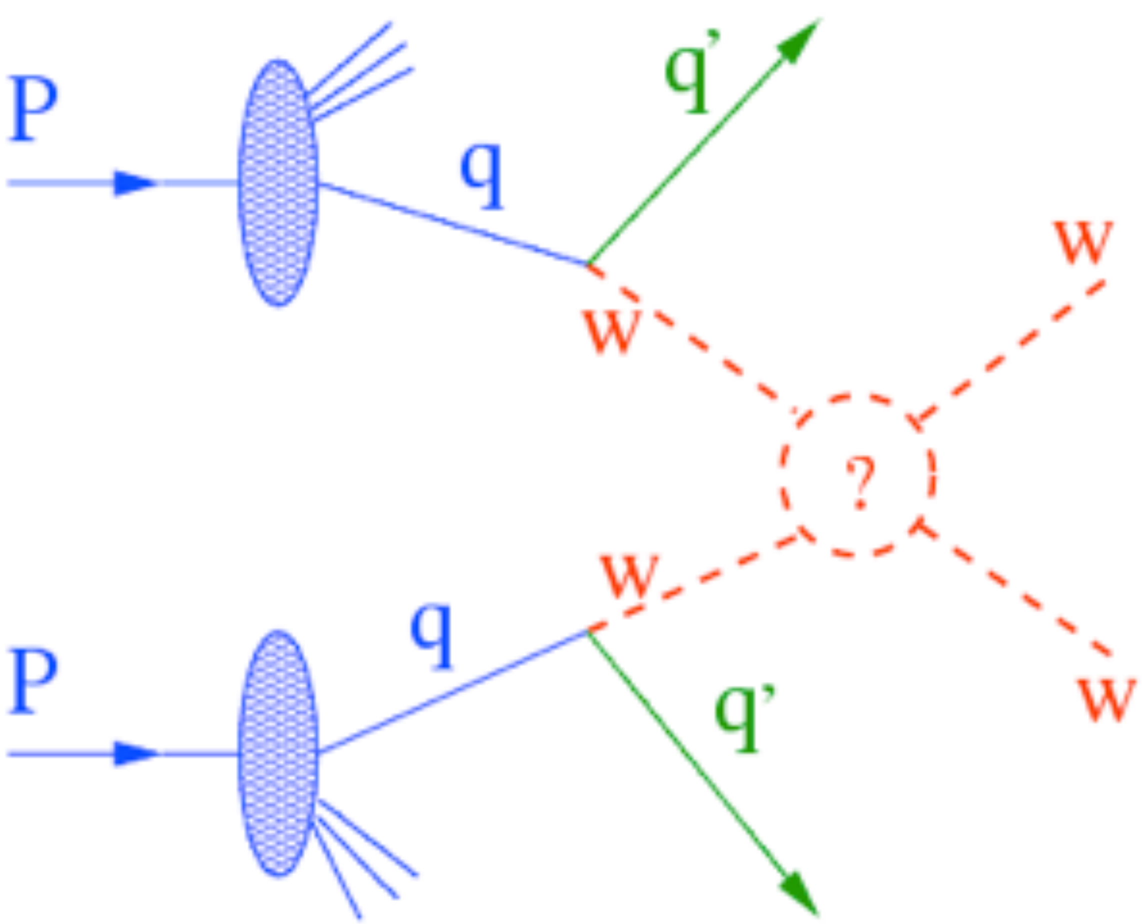
Vector Boson Scattering

- One of the primary tasks for the LHC
- Unitarity Violation at TeV scale without new particle
- Ultimate probe of the EWSB: to measure VV spectrum at TeV

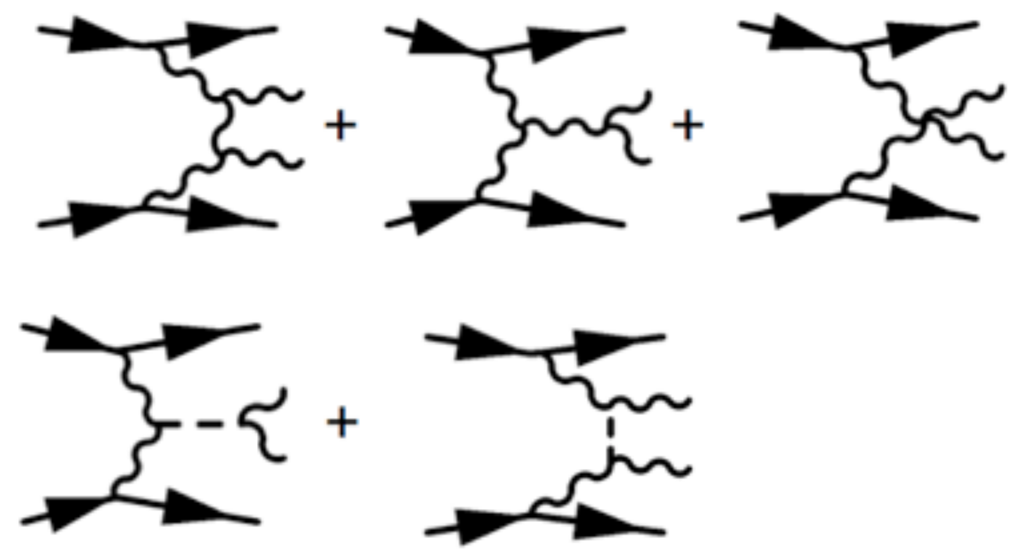


New Physics at TeV Scale

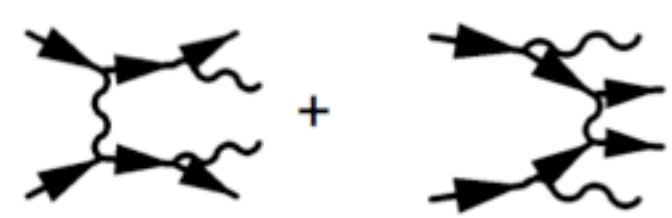
- Strongly coupling at high energy?
- Many diagrams contributing to this process



- VV Scattering (TGC, QGC, Higgs) O(EW)=6



- non-VV Scattering O(EW)=6



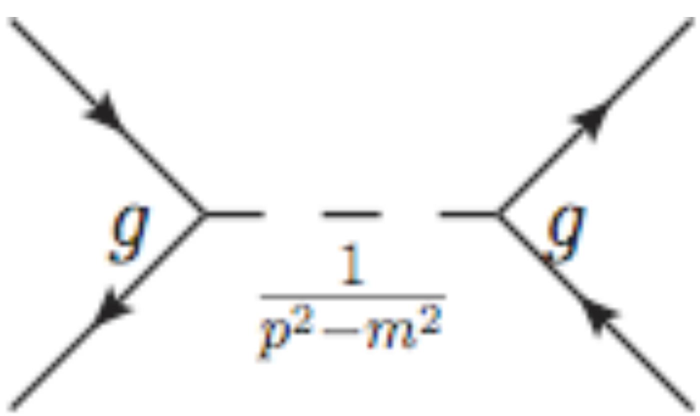
- O(EW)=4 O(QCD)=2, Other backgrounds

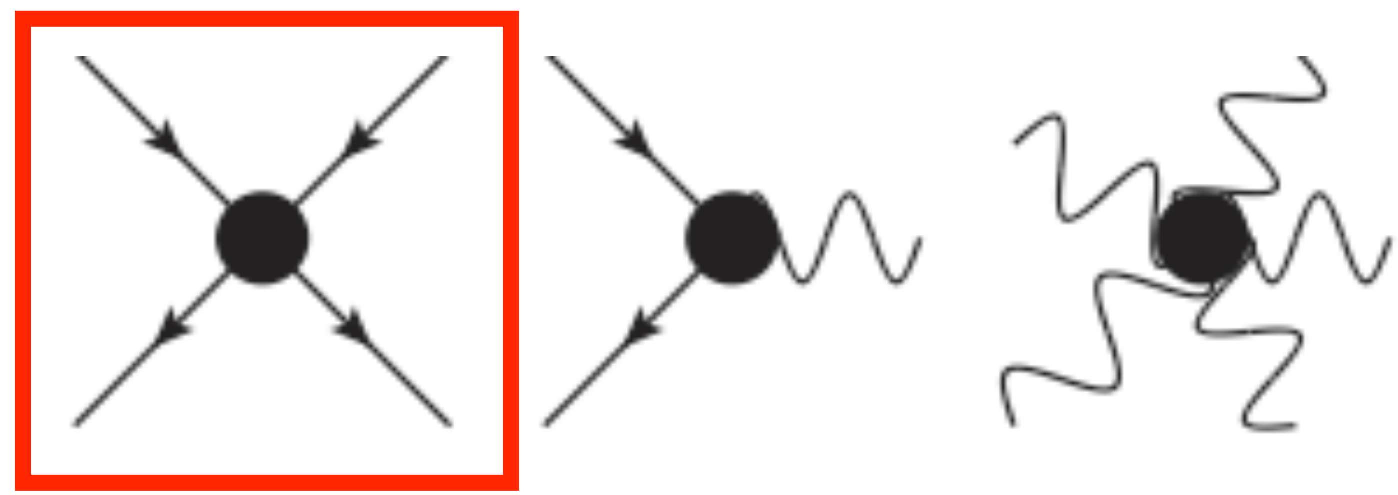
New Physics Scale is Heavy

Resonance

Effective Theory

BSM, Higgs ⟷ SM





direct search

Invariant mass

Precision measurement

Shape studies

Dim8 Operators

O.J.P. Eboli, et. al.
Phys.Rev.D74:073005,2006

$$\mathcal{L}_{S,0} = \left[(D_\mu\Phi)^\dagger D_\nu\Phi\right] \times \left[(D^\mu\Phi)^\dagger D^\nu\Phi\right]$$
$$\mathcal{L}_{S,1} = \left[(D_\mu\Phi)^\dagger D^\mu\Phi\right] \times \left[(D_\nu\Phi)^\dagger D^\nu\Phi\right]$$

$$\mathcal{L}_{M,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$
$$\mathcal{L}_{M,1} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$
$$\mathcal{L}_{M,2} = \left[B_{\mu\nu}B^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$
$$\mathcal{L}_{M,3} = \left[B_{\mu\nu}B^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$
$$\mathcal{L}_{M,4} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\mu\Phi\right] \times B^{\beta\nu}$$
$$\mathcal{L}_{M,5} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\nu\Phi\right] \times B^{\beta\mu}$$
$$\mathcal{L}_{M,6} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\nu} D^\mu\Phi\right]$$
$$\mathcal{L}_{M,7} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\mu} D^\nu\Phi\right]$$

$$\mathcal{L}_{T,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \mathrm{Tr}\left[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}\right]$$
$$\mathcal{L}_{T,1} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}\right]$$
$$\mathcal{L}_{T,2} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\beta\nu}\hat{W}^{\nu\alpha}\right]$$
$$\mathcal{L}_{T,5} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times B_{\alpha\beta}B^{\alpha\beta}$$
$$\mathcal{L}_{T,6} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times B_{\mu\beta}B^{\alpha\nu}$$
$$\mathcal{L}_{T,7} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times B_{\beta\nu}B^{\nu\alpha}$$
$$\mathcal{L}_{T,8} = B_{\mu\nu}B^{\mu\nu}B_{\alpha\beta}B^{\alpha\beta}$$
$$\mathcal{L}_{T,9} = B_{\alpha\mu}B^{\mu\beta}B_{\beta\nu}B^{\nu\alpha}$$

http://feynrules.irmp.ucl.ac.be/wiki/AnomalousGaugeCoupling

QGC Vertex

	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{L}_{S,0}$, $\mathcal{L}_{S,1}$	X	X	X	O	O	O	O	O	O
$\mathcal{L}_{M,0}$, $\mathcal{L}_{M,1}$,$\mathcal{L}_{M,6}$,$\mathcal{L}_{M,7}$	X	X	X	X	X	X	X	O	O
$\mathcal{L}_{M,2}$,$\mathcal{L}_{M,3}$, $\mathcal{L}_{M,4}$,$\mathcal{L}_{M,5}$	O	X	X	X	X	X	X	O	O
$\mathcal{L}_{T,0}$,$\mathcal{L}_{T,1}$,$\mathcal{L}_{T,2}$	X	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,5}$,$\mathcal{L}_{T,6}$,$\mathcal{L}_{T,7}$	O	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,9}$,$\mathcal{L}_{T,9}$	O	O	X	O	O	X	X	X	X

Table 1: Quartic vertices modified by each dimension-8 operator are marked with X.

Each Opeator has different effects on different quartic boson vertex

QGC Vertex

	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{L}_{S,0}$, $\mathcal{L}_{S,1}$	X	X	X	O	O	O	O	O	O
$\mathcal{L}_{M,0}$, $\mathcal{L}_{M,1}$,$\mathcal{L}_{M,6}$,$\mathcal{L}_{M,7}$	X	X	X	X	X	X	X	O	O
$\mathcal{L}_{M,2}$,$\mathcal{L}_{M,3}$, $\mathcal{L}_{M,4}$,$\mathcal{L}_{M,5}$	O	X	X	X	X	X	X	O	O
$\mathcal{L}_{T,0}$,$\mathcal{L}_{T,1}$,$\mathcal{L}_{T,2}$	X	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,5}$,$\mathcal{L}_{T,6}$,$\mathcal{L}_{T,7}$	O	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,9}$,$\mathcal{L}_{T,9}$	O	O	X	O	O	X	X	X	X

Table 1: Quartic vertices modified by each dimension-8 operator are marked with X.

Results shown today

Each Opeator has different effects on different quartic boson vertex

same-signed WWjj

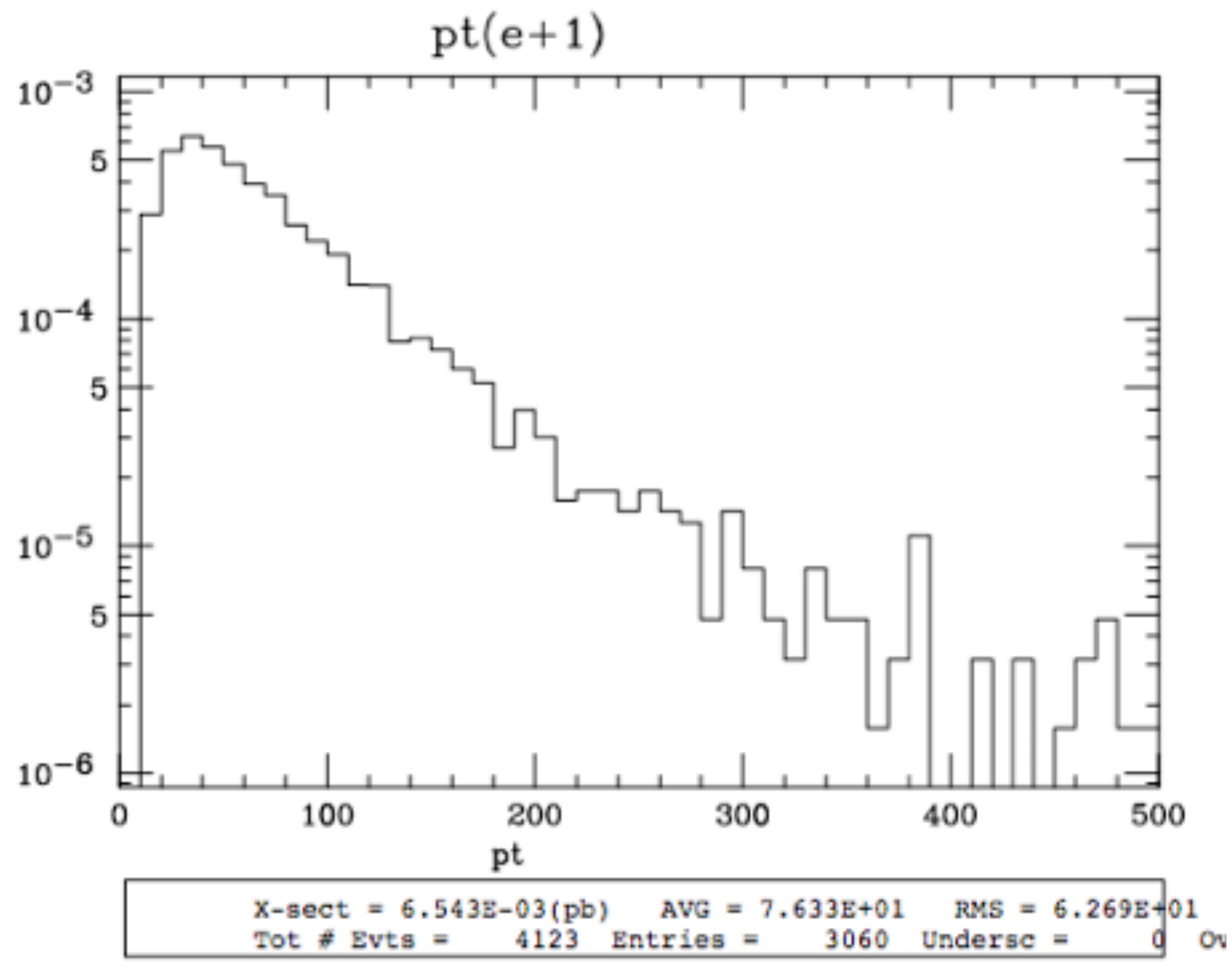
same-signed dilepton

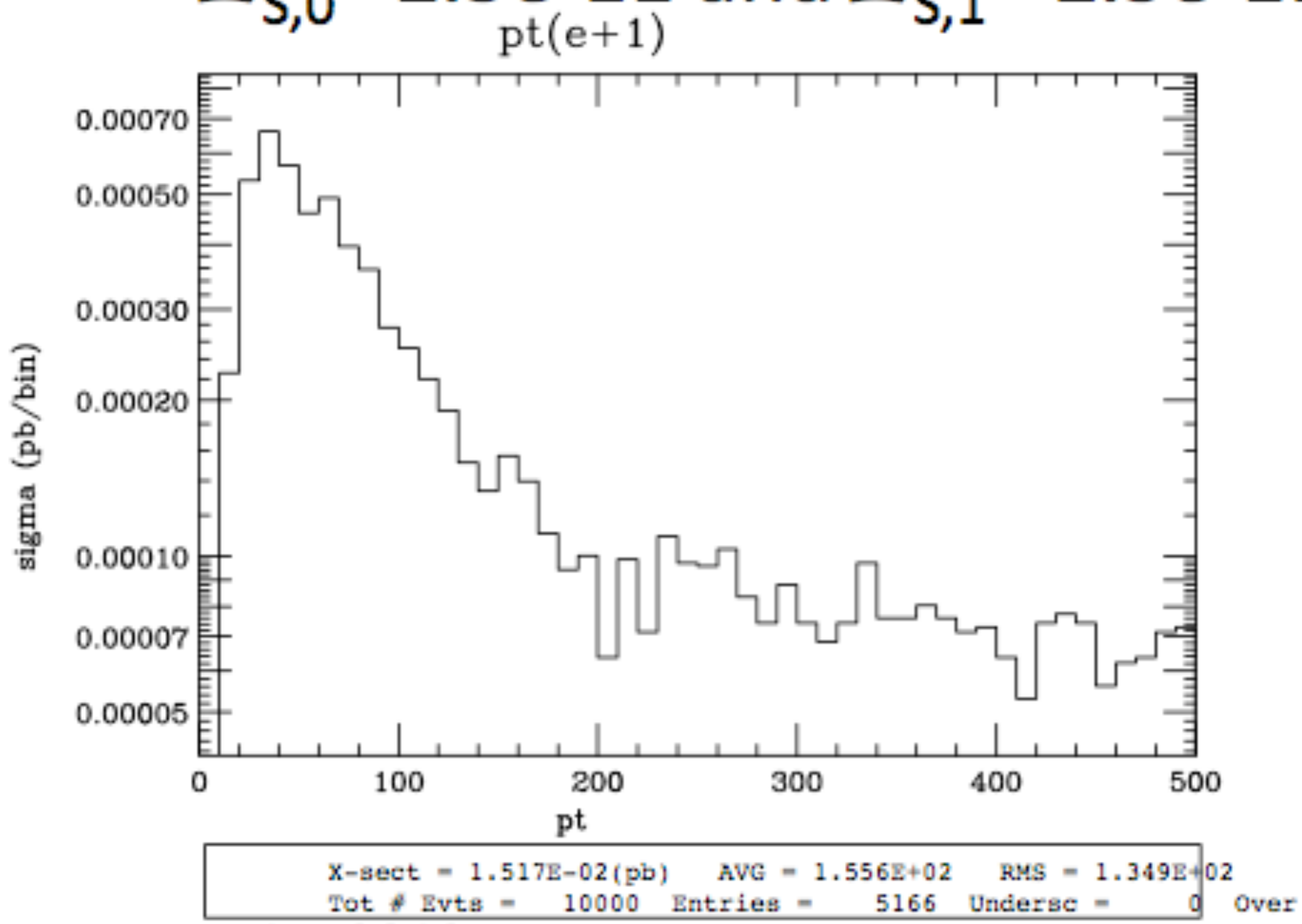
Jessica Metcalfe, Marc-Andre Pleier

$$\mathcal{L}_{S,0} = \left[(D_\mu\Phi)^\dagger D_\nu\Phi\right] \times \left[(D^\mu\Phi)^\dagger D^\nu\Phi\right]$$

$$\mathcal{L}_{S,1} = \left[(D_\mu\Phi)^\dagger D^\mu\Phi\right] \times \left[(D_\nu\Phi)^\dagger D^\nu\Phi\right]$$

$\mathcal{L}_{S,0}$ =2.5e-11 and $\mathcal{L}_{S,1}$ =2.5e-11





VVjj

$$\mathcal{L}_{S,0} = \left[(D_\mu\Phi)^\dagger D_\nu\Phi\right] \times \left[(D^\mu\Phi)^\dagger D^\nu\Phi\right]$$

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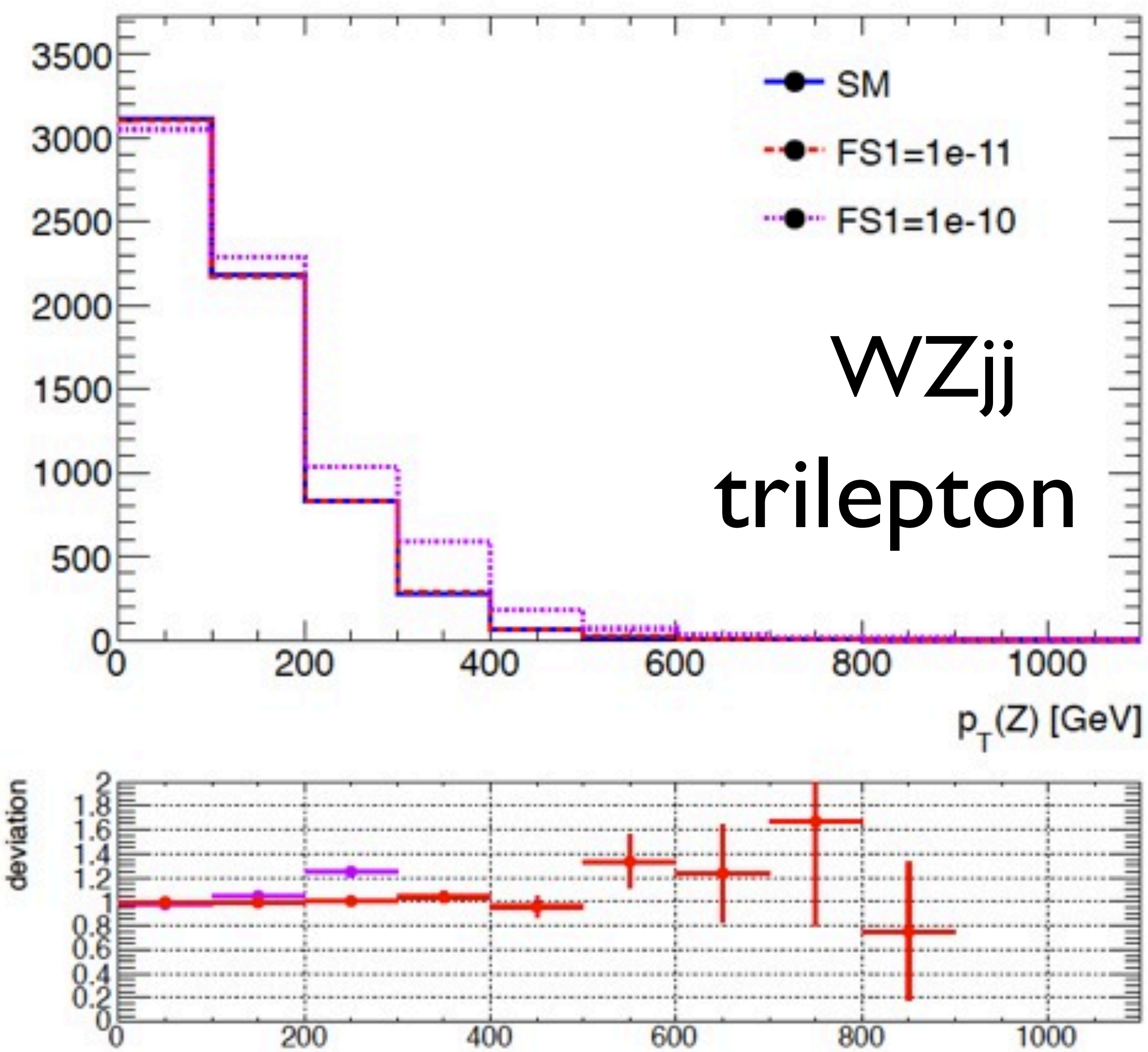
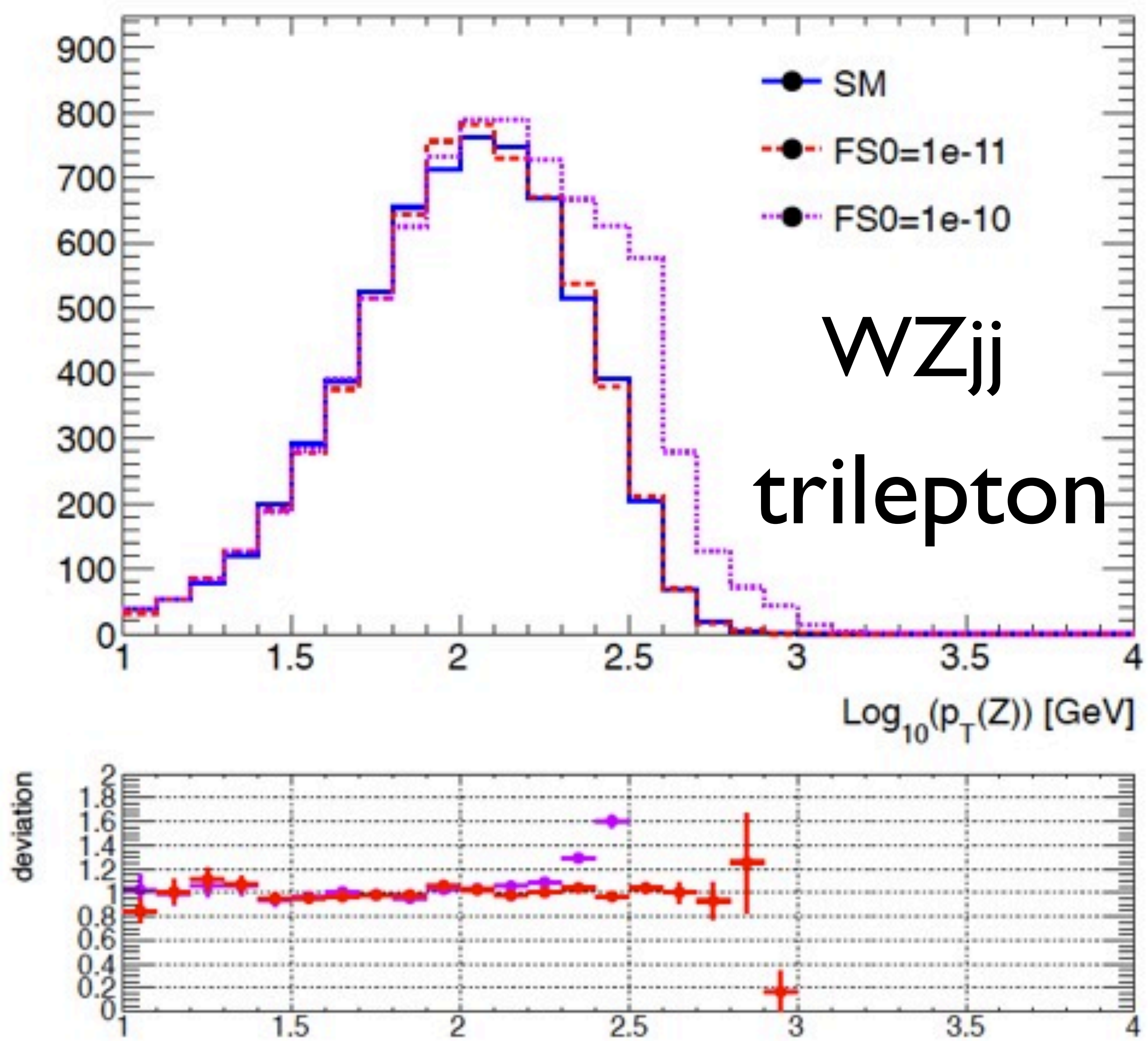
Asutosh Kotwal, Shu Li

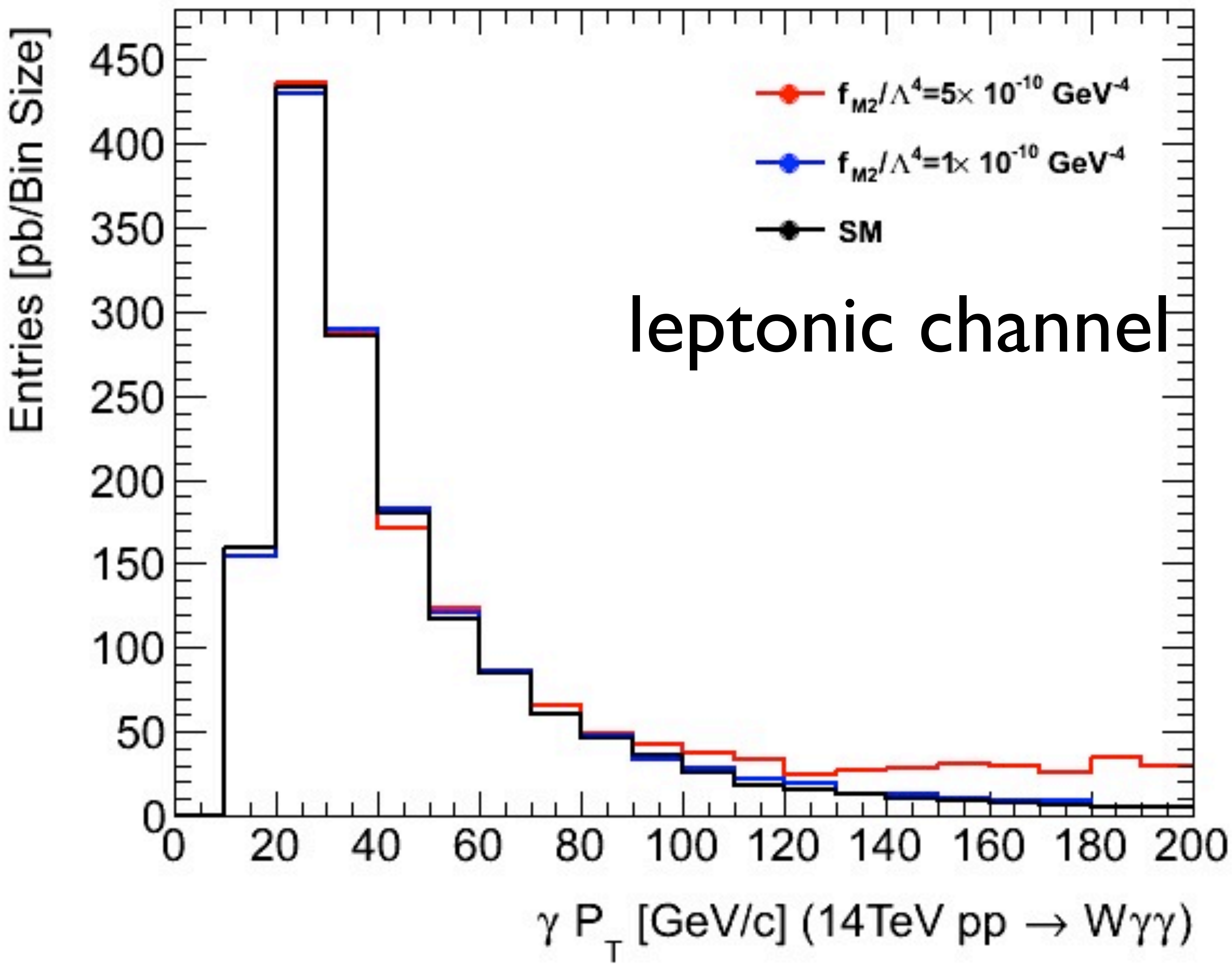




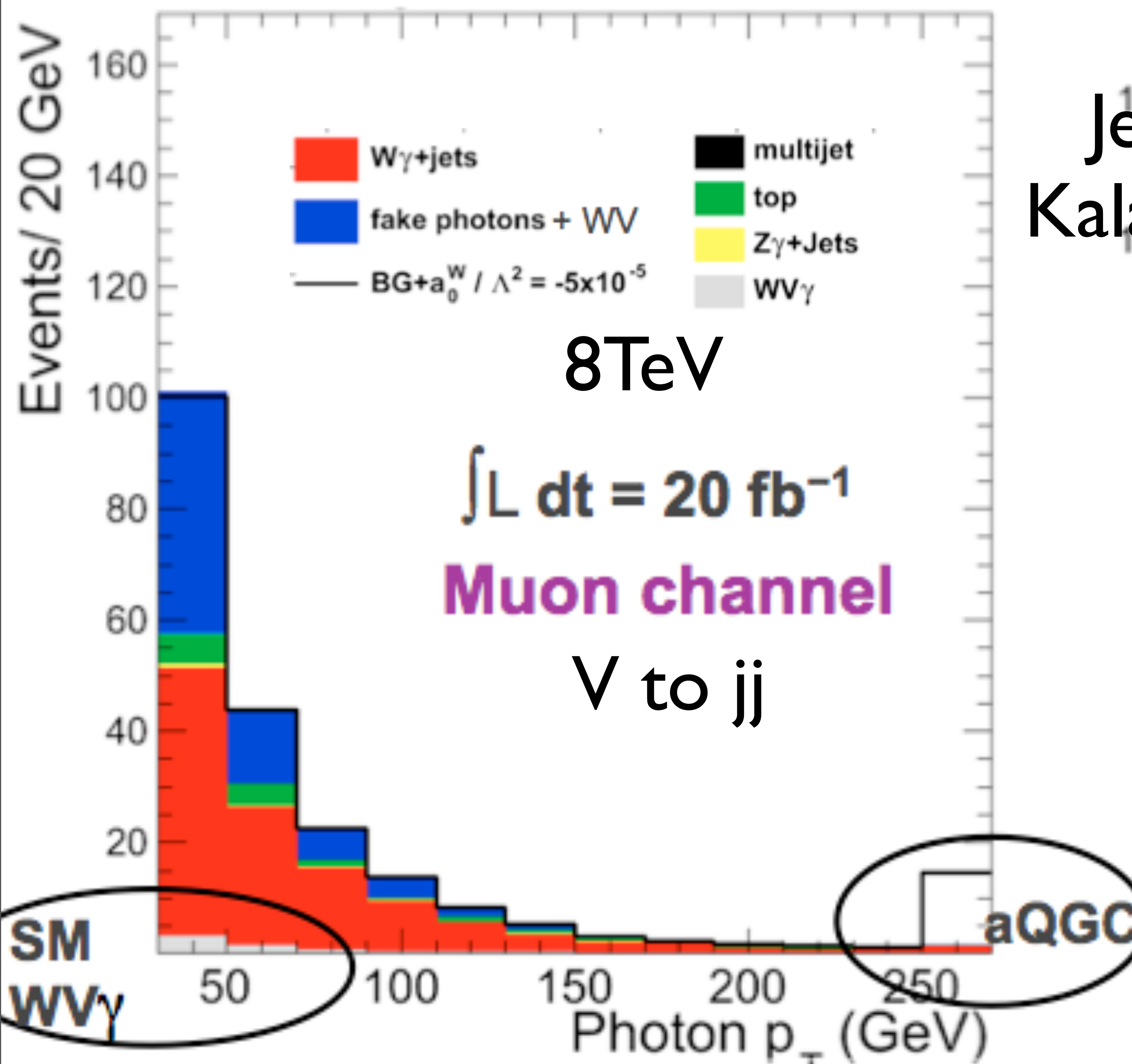
VAA

$$\mathcal{L}_{M,2} = [B_{\mu\nu}B^{\mu\nu}] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$
$$\mathcal{L}_{M,3} = \left[B_{\mu\nu}B^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$

Lindsey Gray, Shih-Chieh Hsu



VVA/VVV



Jenny Holzbauer, Shih-Chieh Hsu, Kalanand Mishra, Mandy K. Rominsky

Analysis Plan:

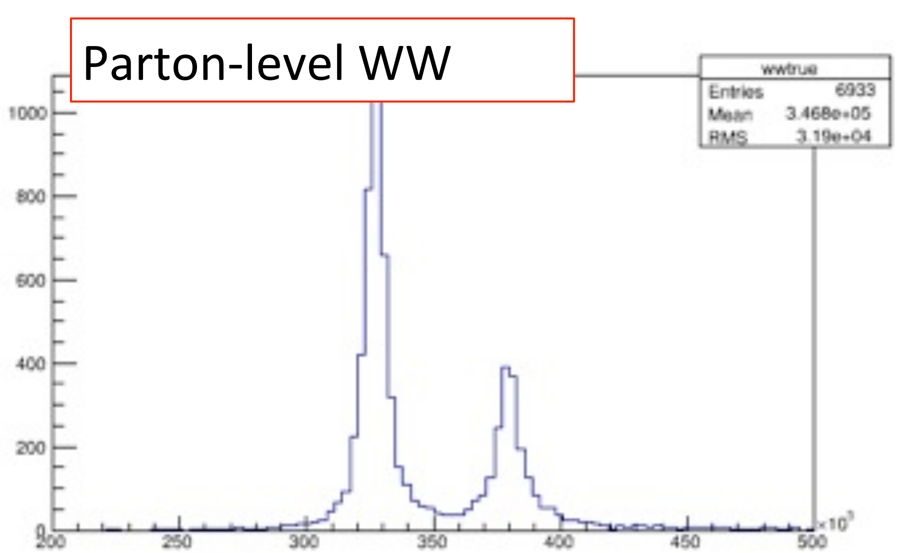
- fully leptonic channel
- WWA
- WWW/WWZ

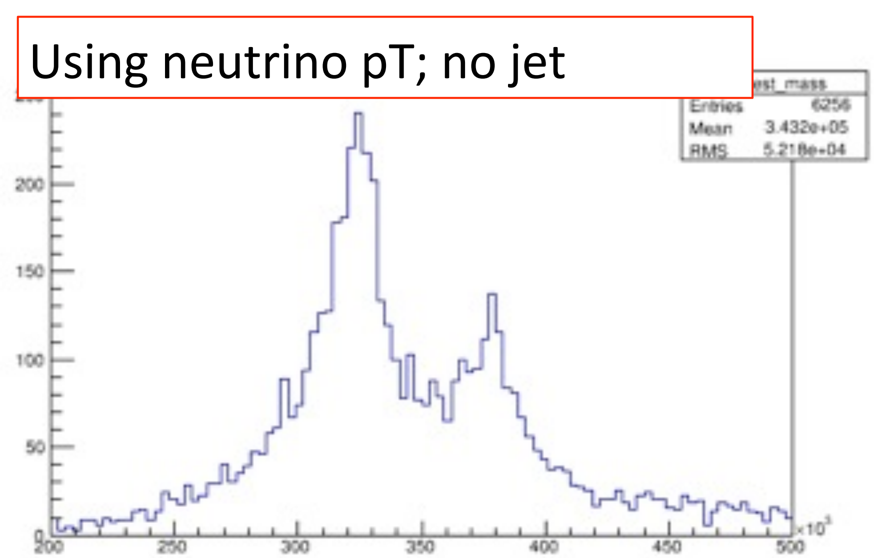
http://indico.cern.ch/getFile.py/access?contribId=24&sessionId=1&resId=0&materialId=slides&confId=245037

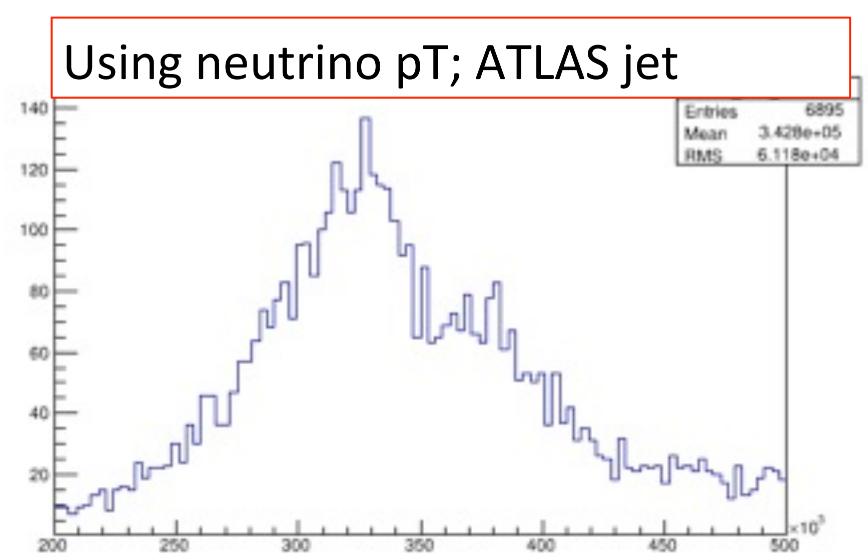
lvqq Reconstruction

Jason Nielson

- Follow-up Euro Strategy Work
  - Working on public ATLAS smearing in Delphes3 for Snowmass
  - The key of mass reconstruction comes from jet resolution (not MET)
  - The figure-of-merit for aQGC study to be defined







- 2HDM set to 325/380GeV, just for mass resolution studies

Summary

- Overview of Active Efforts
  - Focus on 4-boson coupling and VV spectrum measurements at TeV scale
  - Vector Boson Scattering /Triboson Production
  - Close ATLAS/CMS collaborations: BNL/Duke/FNAL/UCSC/UW-Seattle
- Important Schedule:
  - June 10: Internal ATLAS deadline to show preliminary results
    (Using ATLAS ESG parametrization at 14TeV-only)
  - June 30: Seattle All-hands Energy Frontier Snowmass Workshop
    https://sharepoint.washington.edu/phys/research/snowmass2013/Pages
  - July 29: Minneapolis Snowmass
    http://www.snowmass2013.org/

ToolKits to Join Us

- Generators
  - MG version : 5.1.5.10
  - Pythia version : 6.426
  - Delphes : 3.0.10
  - FeynRule UFO Files:

  http://feynrules.irmp.ucl.ac.be/wiki/AnomalousGaugeCoupling

- Limit Calculators
  - Chris Pollard's limit calculator
    (Internal ATLAS only, developed for Euro Strategy)

    https://svnweb.cern.ch/trac/atlasusr/browser/cpollard/UpgradePythia/trunk
    https://svnweb.cern.ch/trac/atlasusr/browser/cpollard/UpgradeSelector/trunk

  - Common ATLAS/CMS Higgs Statistics tools

Opportunities

- 4-boson coupling (Many tasks to be done)
  - The Standard Model background studies
  - Semi-leptonic channels, 33TeV, 100TeV, studies
  - Higgs coupling vertex (HHVV, HHHH) (synergy to **Higgs** group)
- 3-boson coupling (Completely lacking of man power)
  - Inclusive diboson channel
  - EwkDim6 operators (C. Degrande, arXiv: 1205.4231)
  - Higgs coupling vertex (HVV, HHH) (synergy to **Higgs** group)
- Strongly-coupled models (synergy to **BSM** group)
  - Strongly Interacting Light Higgs (G.F. Giudice, JHEP 0706:045, 2007)
- Welcome to contact Snowmass EWK conveners!
  - Collaborations, re-interpretations of your studies, criticism, ..., etc.
  - Conveners: kotwal@phy.duke.edu, dow@ubpheno.physics.buffalo.edu, schmittm@lotus.phys.northwestern.edu