Anomalous Coupling Studies using a Dimension Six Electroweak Effective Field Theory in MadGraph

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Outline and Aim Of This Study

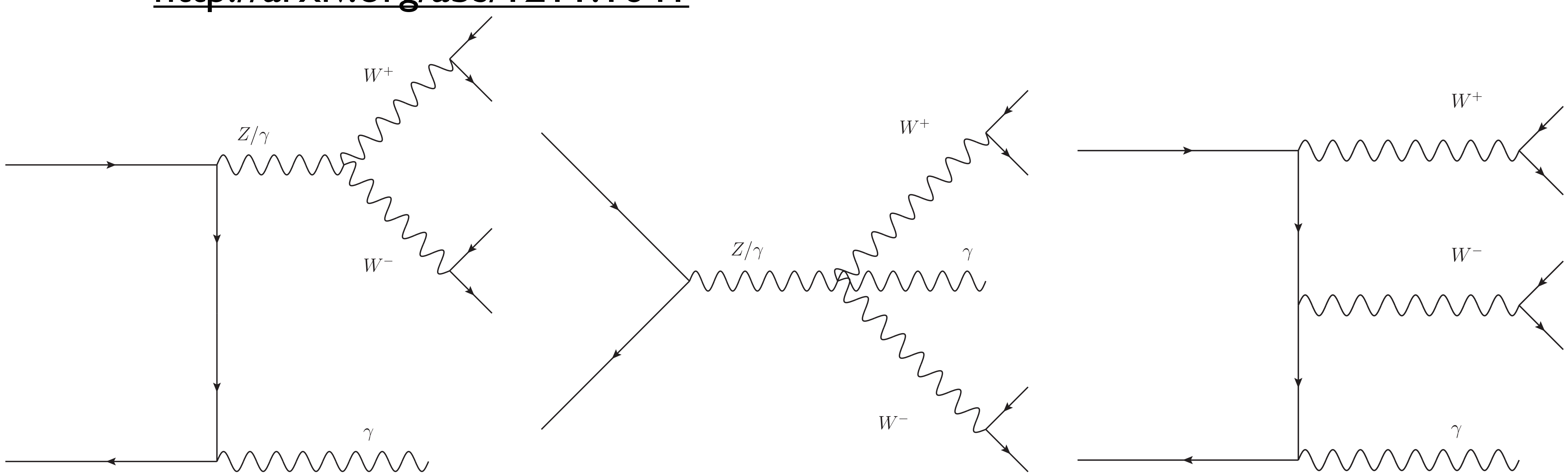
- In light of 'X' discovery, assume EWSB is real
  - Use the full SM as the starting point
    - Higgs mass still free parameter, but have a good guess
  - Assume <u>only</u> SM gauge sector
- Look for anomalous couplings of gauge bosons
  - To other gauge bosons, Higgs
- Analyze sensitivity of current & future colliders
  - Dim-6 operators scale as sqrt(s), important for future colliders
  - In previously untouched final states at LHC
    - For today: $W\gamma\gamma$ and explore variables of interest
    - Probe anomalous quartic and triple gauge, and Higgs-gauge couplings (aGC) in consistent way using EWK Eff. Field Theory (EFT)
  - Hadron collider only for today; ILC studies in the future

A Short Review of EWdim6

- For more details refer to Celine's talk
- Shortfalls of previous models $\Gamma_V^{\alpha\beta\mu} = f_1^V (q-\bar{q})^\mu g^{\alpha\beta} - \frac{f_2^V}{M_W^2}(q-\bar{q})^\mu P^\alpha P^\beta + f_3^V (P^\alpha g^{\mu\beta} - P^\beta g^{\mu\alpha})$...
  - No inclusion of Higgs or Higgs-gauge couplings
    - models from era when EWSB questionable
  - Gauge invariance and unitarity of SM often broken
    - Caused need for 'form-factors' and other assumptions to be injected in to aGC models
    - Interplay between triple, quartic and gauge-higgs interactions completely ignored
- Benefits of reformulating as EFT $\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i + \cdots$
  - No assumption of kinematic dependence of couplings
    - i.e. no need for form factors
  - Results have the same meaning at all collider types/energies
  - Builds functional and complete SM with symmetry-respecting extension

Triple Boson Final States

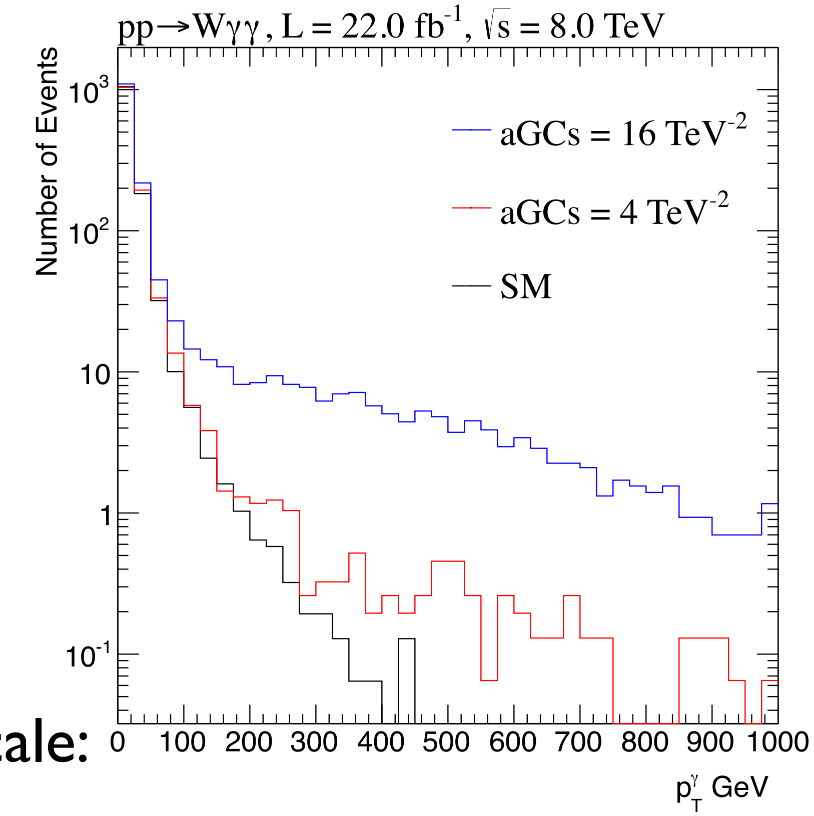
- WWγ/<u>Wγγ</u>: contributions from radiation
  - I/FSR and ISR + FSR all backgrounds
- Contains SM TGC, QGC, HGC
  - EWdim6 treats aGCs in correlated way
    - Not able to separate aQGC and aTGC, but gives consistent 'big picture' in terms of gauge sector
- Models that probe (dim8) pure quartic couplings also exist
  - Motivated if BSM physics does not show up in loops, or scale low
    - Studying EWdim6 + dim-8 models comprises a complete and general picture?
  - http://arxiv.org/abs/1211.1641

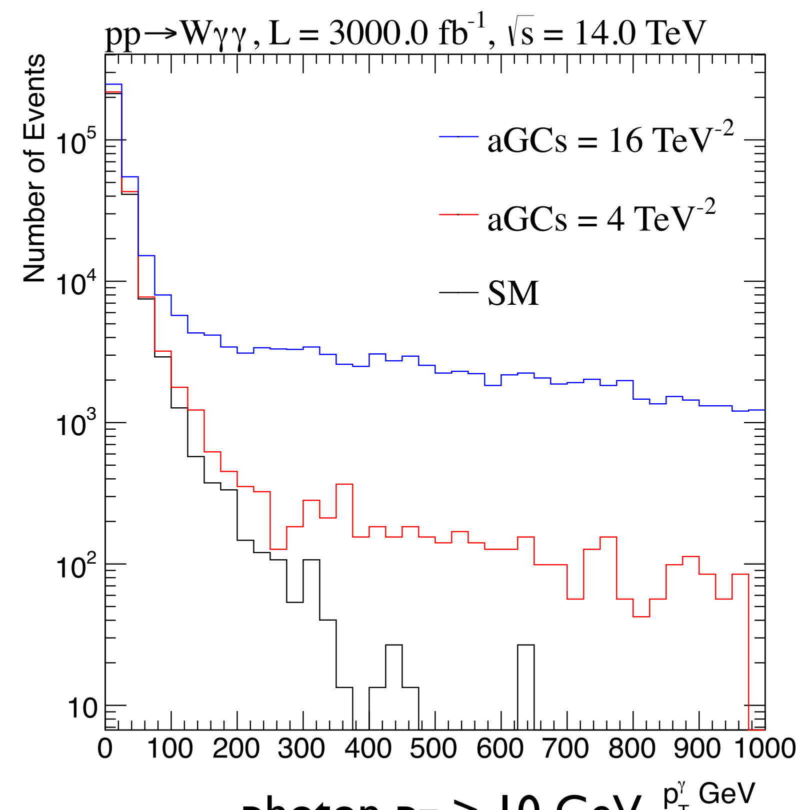


LHC 8/14 Observables: Boson p_T

- Dim-6 operator effects increase as s-hat
  - Higher center of mass leads to more energetic bosons
- Precedent in aGC analysis with photon is to use photon p_T
  - Direct probe of vertex
  - No momentum eaten up by boson mass
  - Easy to model and extract non-photon backgrounds

For a sense of scale: aGC = c/Λ^2

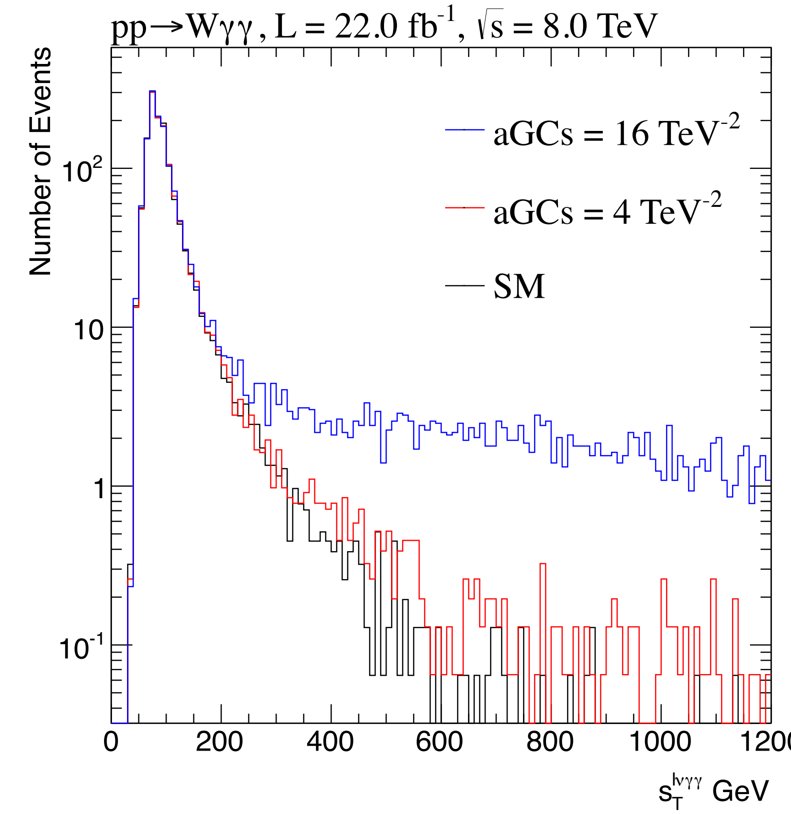


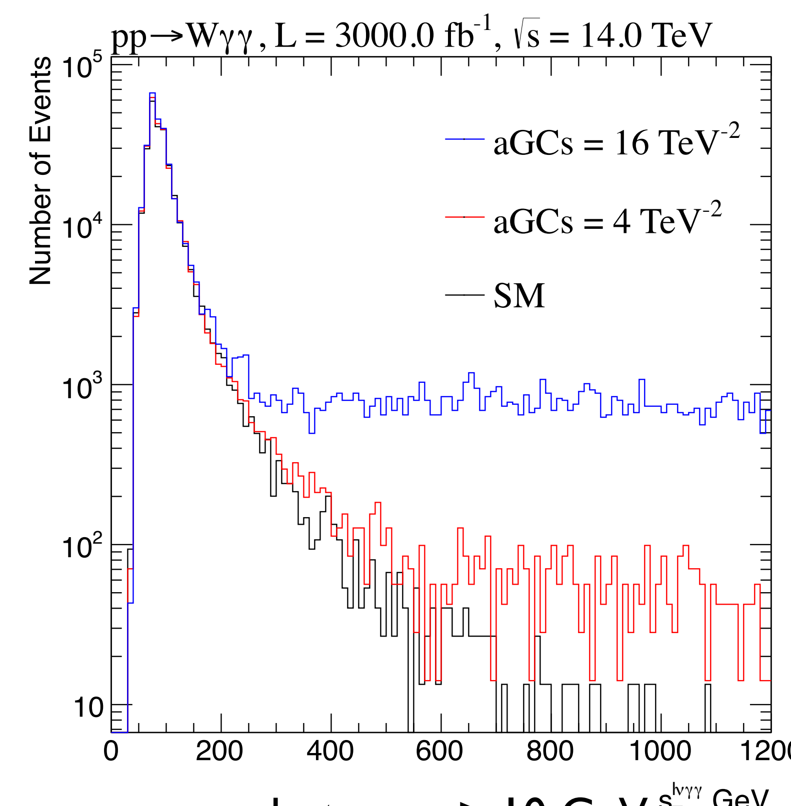


photon p_T > 10 GeV
lepton p_T > 10 GeV

LHC 8/14 Observables: s_T

- s_T, scalar-sum p_T
  - of lepton, photons, MET
- Should also exploit dimension six behavior
  - Total p_T should be larger since each p_T is larger
  - Pushes small effects from aGC significantly higher than SM
    - Technically more background free, harder to model directly

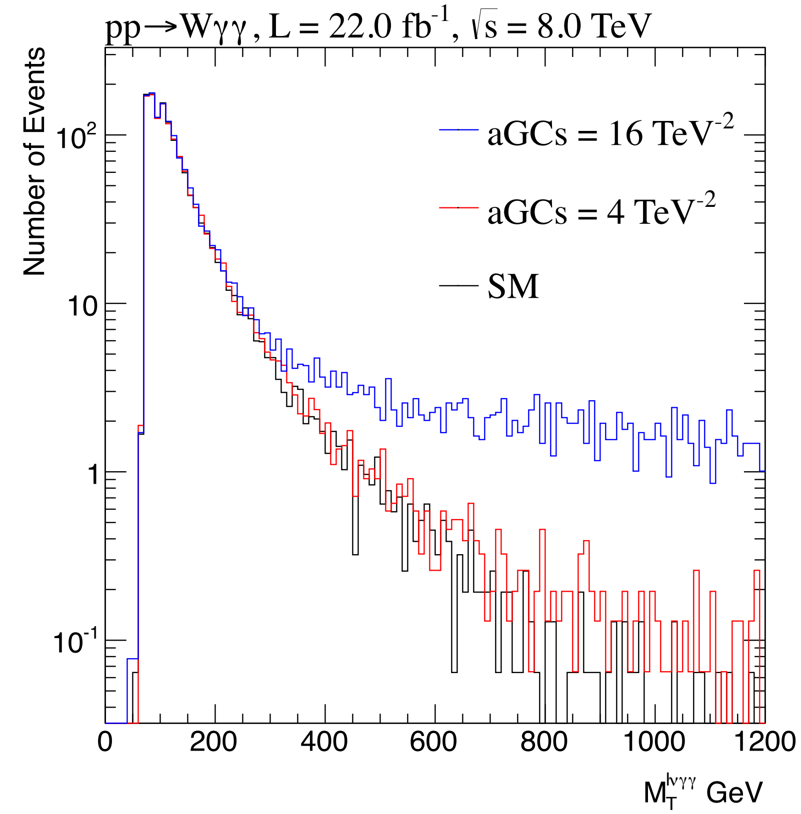


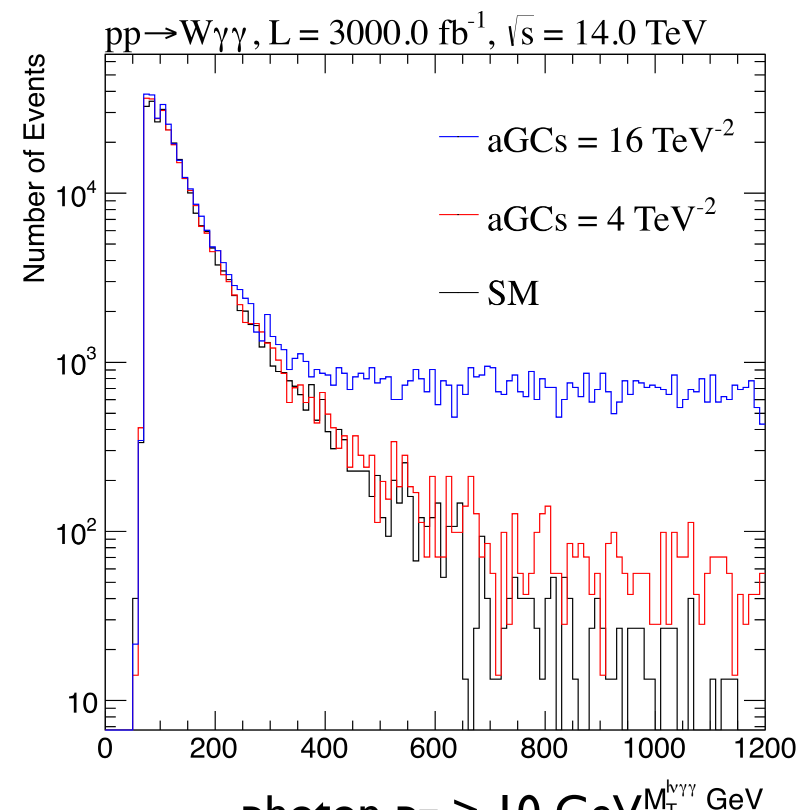


photon p_T > 10 GeV
lepton p_T > 10 GeV

LHC 8/14 Observables: Total M_T

- 4-body transverse mass
  - Again, larger s-hat means larger M_T
  - Less sensitive to boosts
    - Possibly more stable shape when considering higher-order QCD corrections
    - Harder to model backgrounds

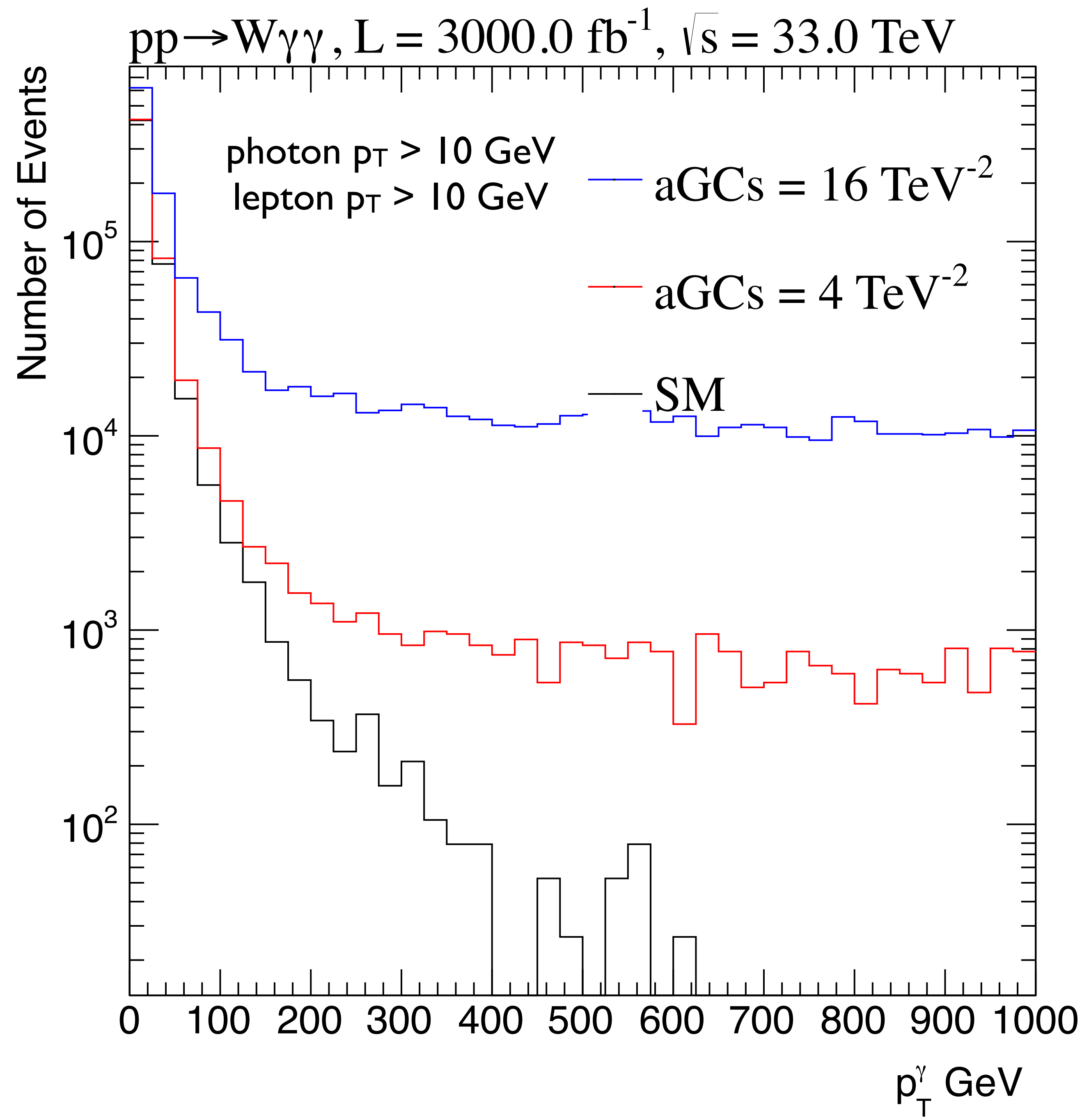




photon p_T > 10 GeV
lepton p_T > 10 GeV

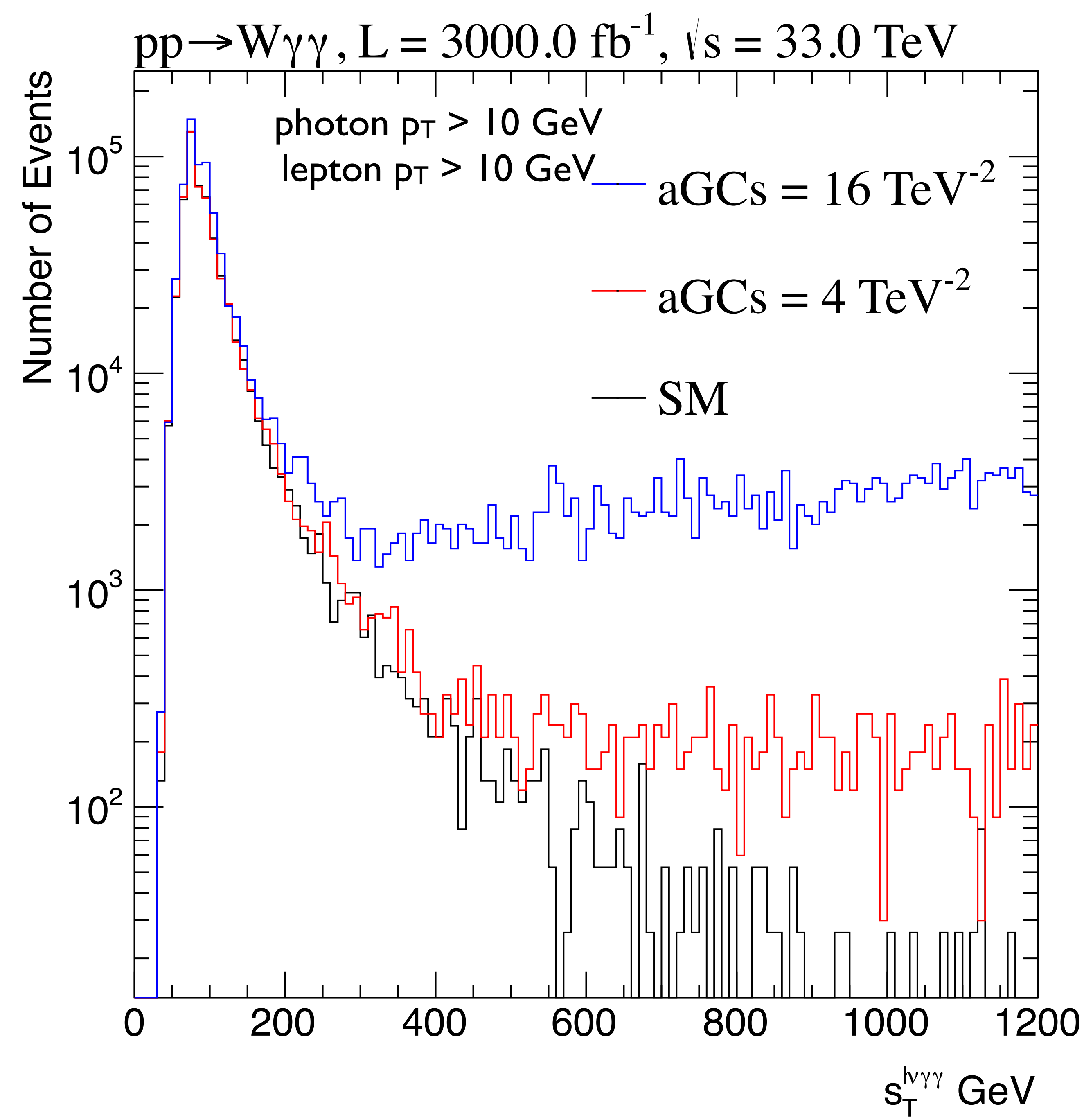
LHC 33 Observables: Boson p_T

- Sensitivity increased at 33 TeV
  - Expected due to scaling of operators
- If not already observed this would push the bounds on aGCs down by roughly a factor of 3
  - compared to 3/ab LHC
  - Driven by yield in tails



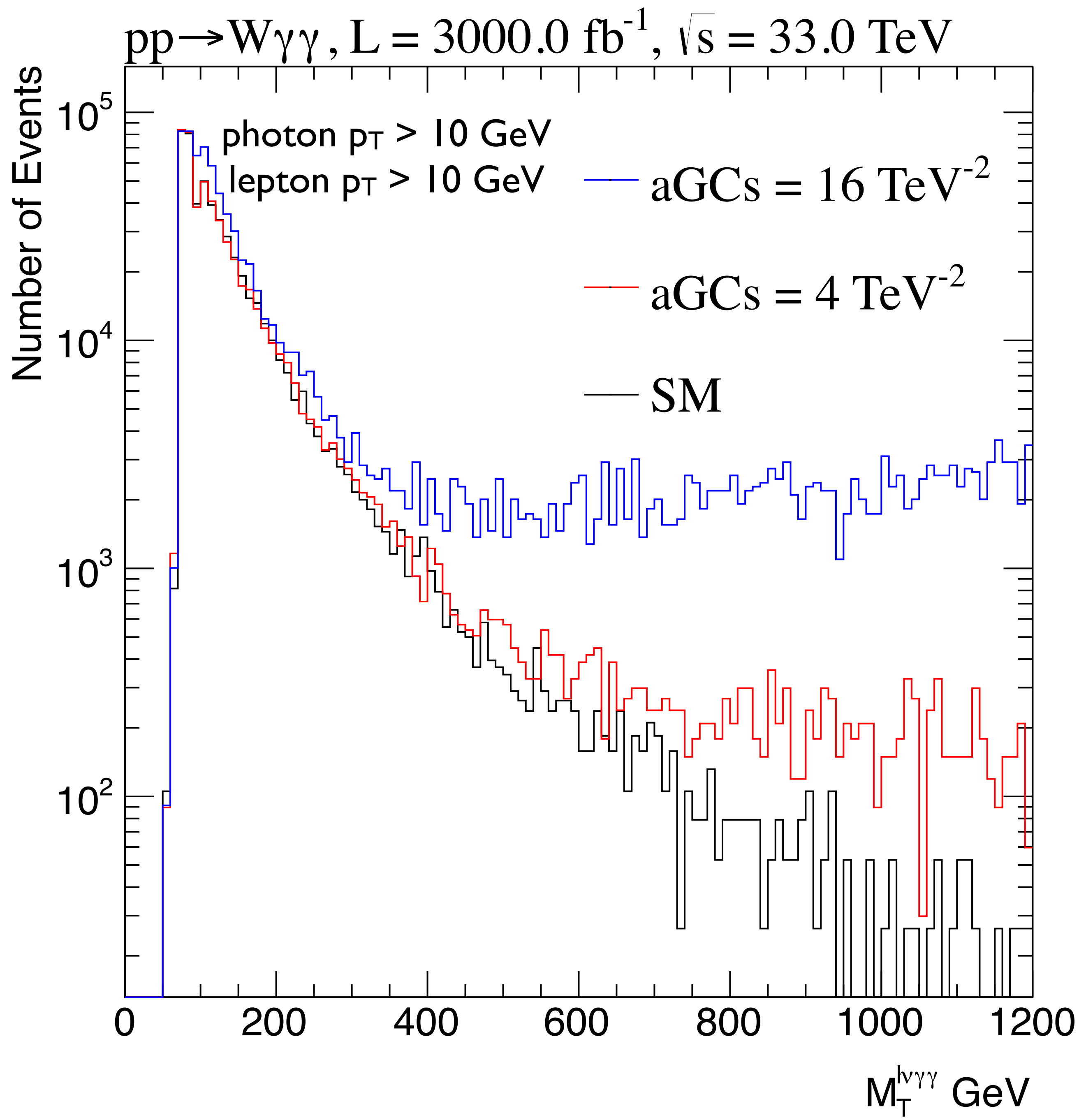
LHC 33 Observables: s_T

- s_T shows still shows reduced sensitivity to aGCs
  - Check further out in tails?



LHC 33 Observables: Total M_T

- 4-body transverse mass also shows same insensitivity
  - Should look further into this, as one would naively expect s_T and M_T to be more sensitive



A Few Points to Take

- Analyses driven by tails
  - Always statistics limited
  - Analyses are also driven by sqrt(s) (yield)
    - going to higher energy machines always better once luminosity production is constant for the machine
- Limits to not take into account NLO EW corrections to SM
  - With EWdim6 model NLO aGC corrections possible
    - should be looked at!
    - NLO EW effects already large for 14 TeV LHC
  - To maintain consistency
    - Also, never done before

Conclusions & Future Studies

- EWdim6 is a consistent framework for aGC
  - In light of ‘X’ discovery
  - Could be used in tandem with dim-8 models to provide a covering ‘picture’ of the gauge sector
- A 33 TeV LHC improves sensitivity to aGC
  - Only looked at mixture of non-zero couplings
- Future Studies
  - Photon p_T seems to be most promising observable
    - To study other, make sure there are no misunderstandings
  - Test individual anomalous couplings
  - Use more ‘realistic’ set of cuts
  - aGCs at the ILC: What can an ILC buy over a 33 TeV LHC?
  - VBF and WWγ final state topologies

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