$W\gamma\gamma$ production in proton-proton collisions at the Large Hadron Collider with the ATLAS detector

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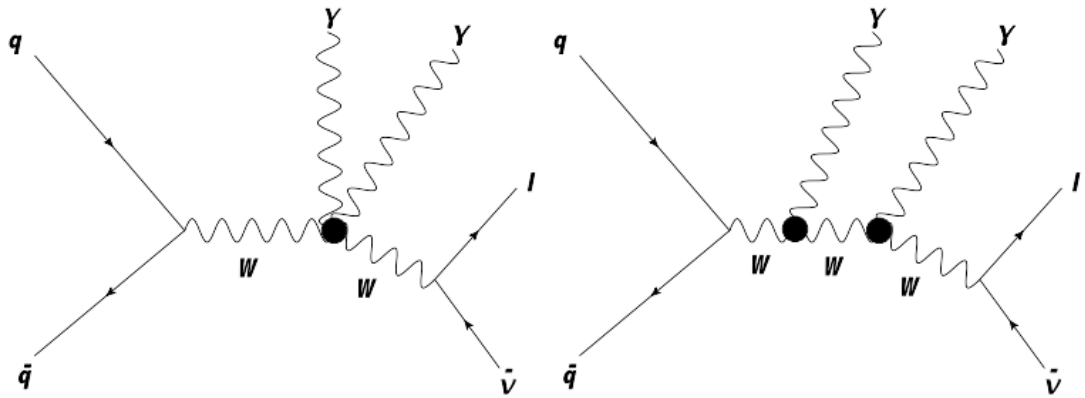
Overview

- In the Standard Model (SM), self coupling of electroweak gauge bosons entirely specified by non-Abelian SU(2)xU(1) structure
  - Deviations would indicate new physics phenomena at unprobed energy scales
- The SM process $pp \rightarrow W\gamma\gamma$ is an important test of this structure
  - Goal is to achieve first observation of this process
  - Search for hints of new physics and set limits in model independent way using effective field theory (EFT)



ATLAS Detector

- This analysis uses almost 140 fb^{-1} of data collected by the ATLAS detector at the Large Hadron Collider (LHC) during its second running period
  - The LHC is a 27 km in circumference proton-proton collider with a center-of-mass energy of 13 TeV
- ATLAS is a general purpose detector with multiple subdetectors
  - These are used for tracking, calorimetry and spectrometry using a superconducting magnet system

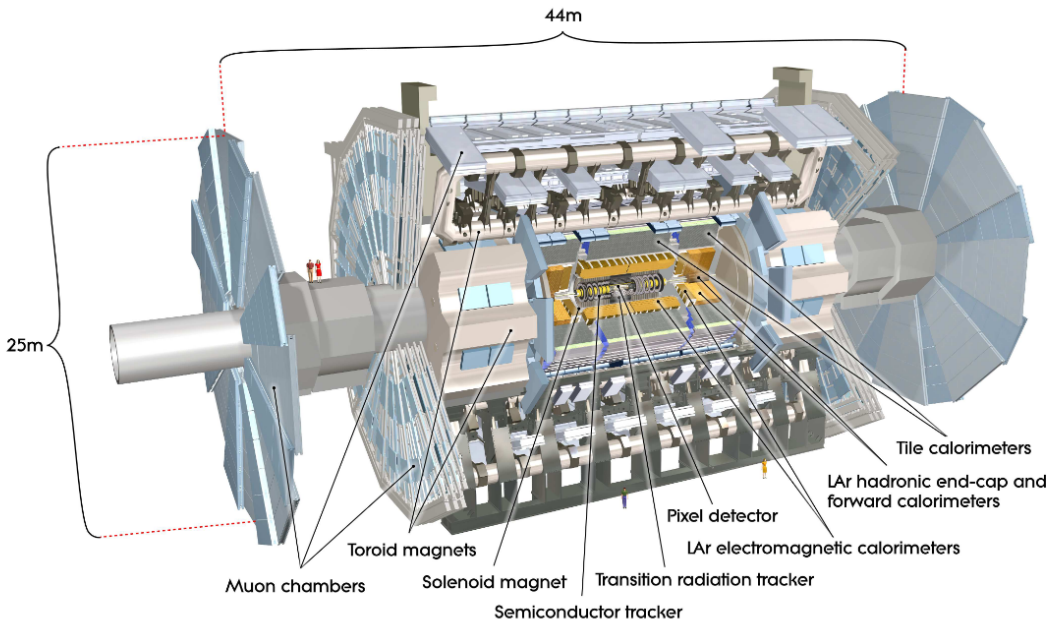


Figure: ATLAS detector. Source : cds.cern.ch

$p\ p \rightarrow W\ (\rightarrow e\nu_e\ /\ \mu\nu_\mu)\ \gamma\ \gamma$

- Typical signature given by $W(\rightarrow e\nu_e\ /\ \mu\nu_\mu)\gamma\gamma$ event in the transverse plane of the detector :

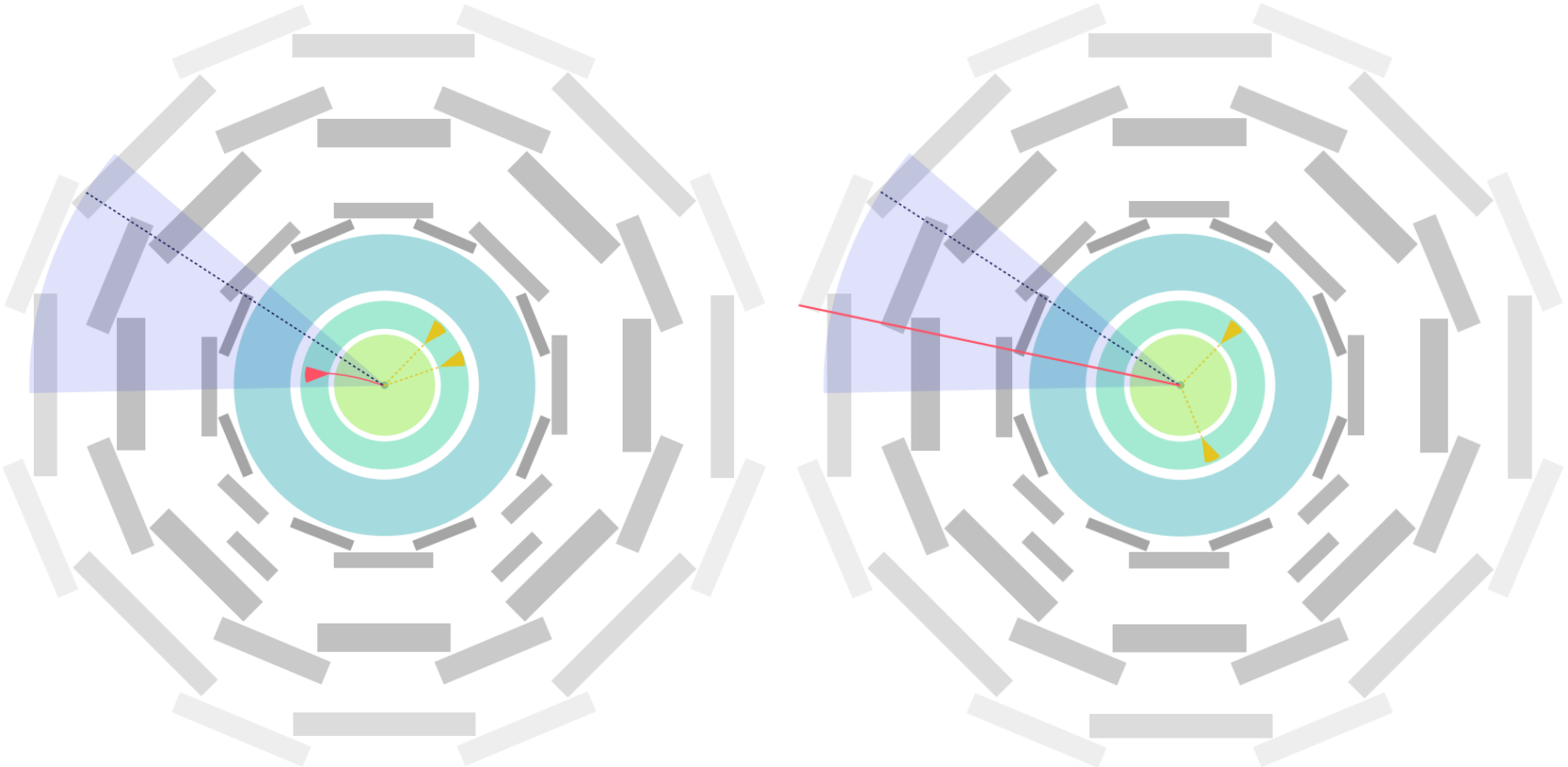


Figure: ATLAS event display : inner tracking detector in green, calorimeter in light blue and muon spectrometer in grey. Photons in yellow, electron (left) in red, muon (right) in red and neutrinos in blue. Credit : Dr. Heather Russell (McGill now CERN)

Challenges

- Most irreducible backgrounds accurately modeled in simulation
  - Some more challenging
- Main challenges of analysis : jet misidentified as lepton or photon
  - Hard to model in simulation due to numerous sources of jets and complicated detector interactions
- Must develop data-driven techniques
  - Focus of talk : jets misidentified as leptons

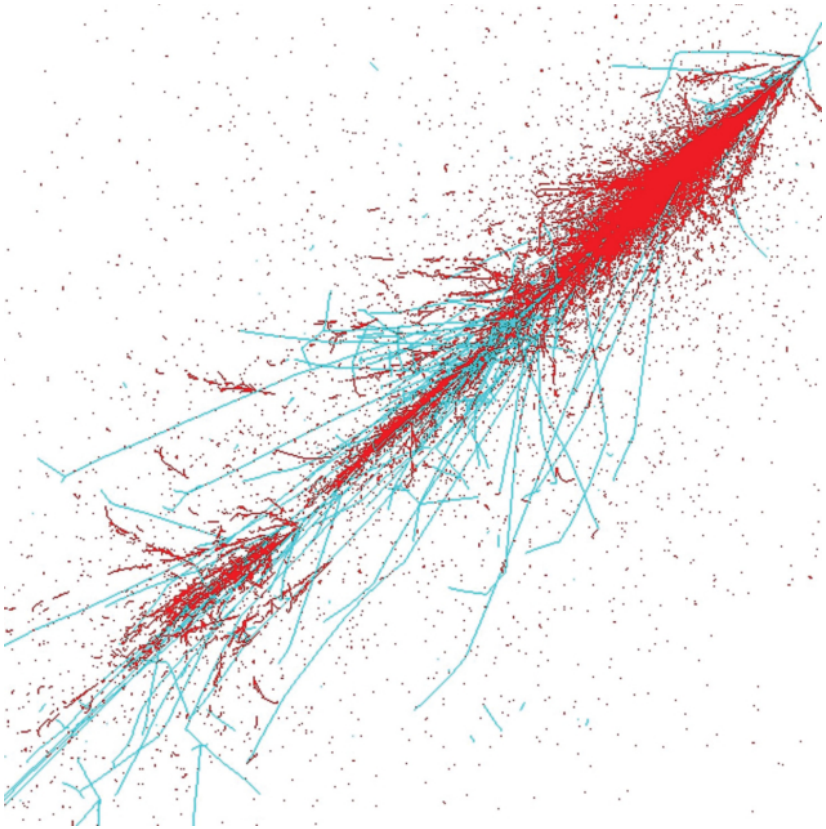


Figure: Processes at LHC are often accompanied by hadronic jets of particles originating from quark(s) or gluon(s) in hard scatter. Source : physicsworld.com

Jets Misidentified as Leptons

- Kinematic variables used to discriminate leptons from jets :
- Isolation energy
  - Discriminates against jets directly faking leptons (fakes)
- Impact parameter
  - Discriminates against leptons from heavy flavor jets (non-prompt leptons)
- Data driven method relies on inverting these requirements
  - "tight" leptons pass
  - "loose" leptons fail
  - Other requirements remain the same (based on trigger requirements, detector acceptance, tracking and particle identification)

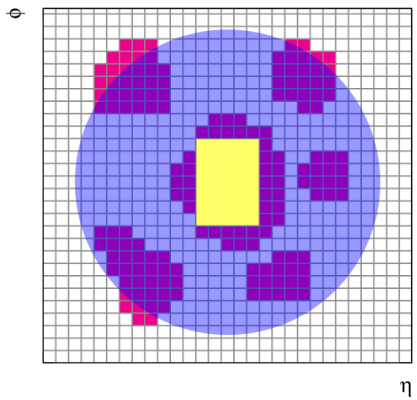


Figure: Isolation energy. Source : arXiv:1902.04655

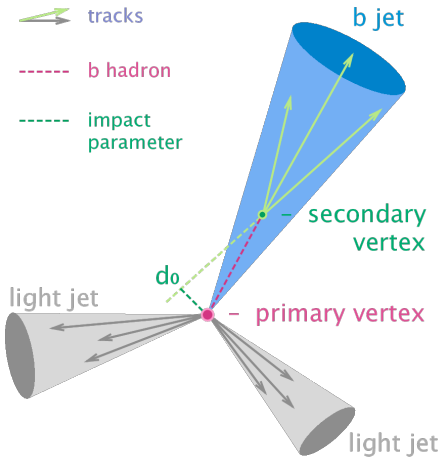


Figure: Impact parameter d_0. Source : wikipedia.org

Data Driven Method

- Goal:
  - Find a fake enriched region of phase space
  - Derive efficiency for jet / non-prompt lepton being reconstructed as lepton
- Control region (CR) : select $Z \rightarrow l^+l^- + fake$ events
  - Very clean signature
- Reconstruct Z :
  - Two "tight" same flavor opposite sign leptons near Z mass
- Third opposite flavor lepton :
  - Used to estimate fake efficiency

$$\epsilon_{fake} = \frac{N_{tight}}{N_{tight} + N_{loose}}$$

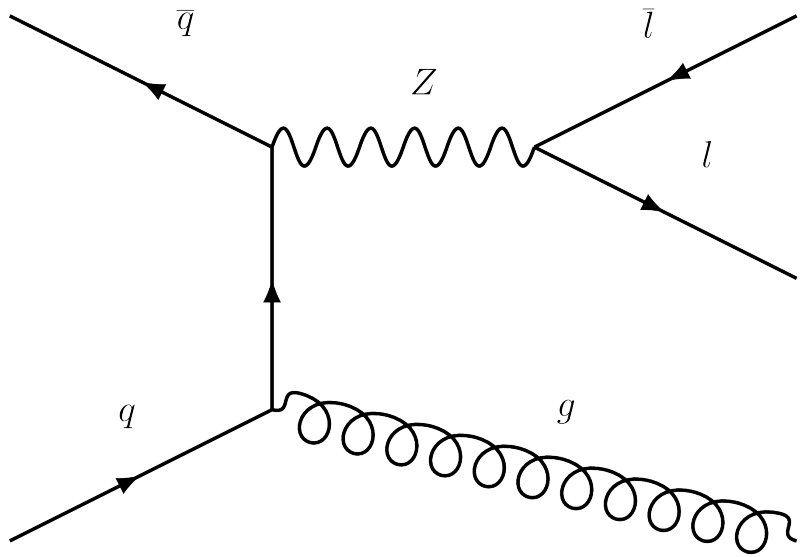
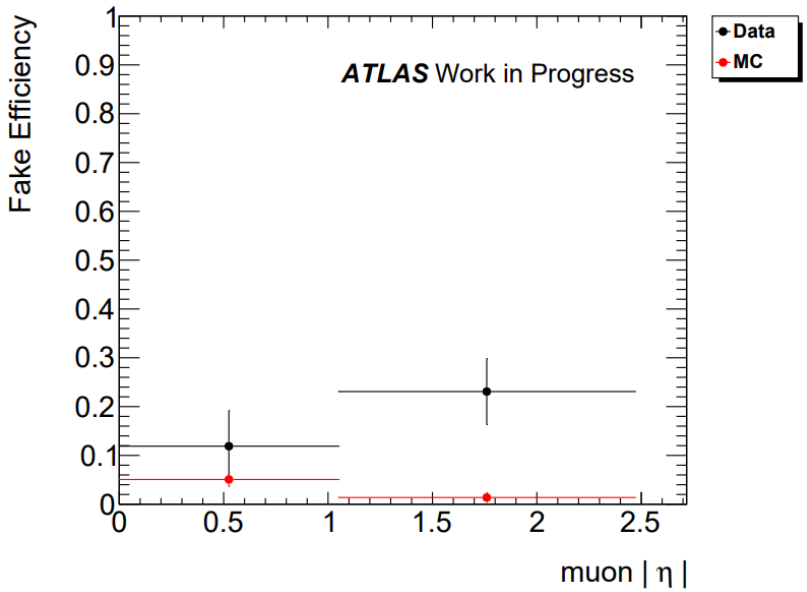


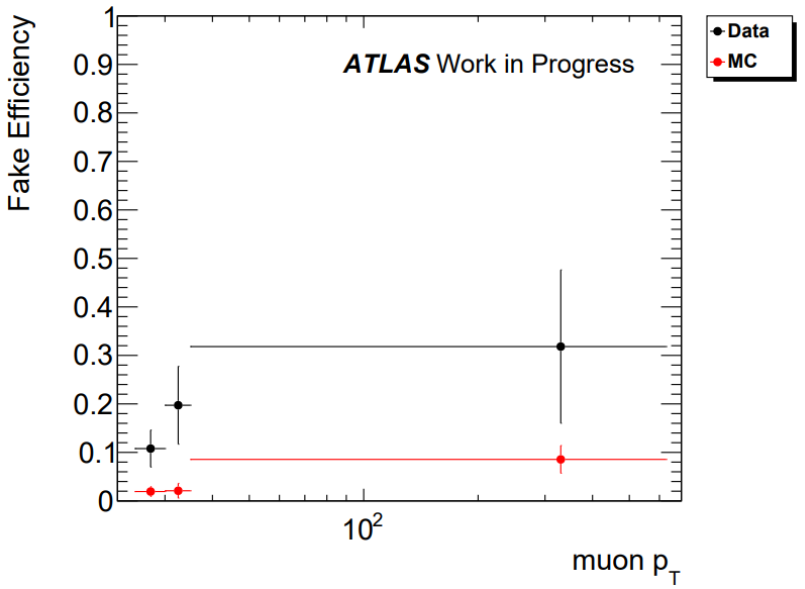
Figure: Example $p + p \rightarrow Z + jet$

- CR includes E_T^{miss} and $m_{T,W}$ cuts
  - E_T^{miss} : missing transverse energy
  - $m_{T,W}$: transverse mass of W boson
  - Reduces WZ contribution
  - Simulation used to subtract remainder

Fake Efficiencies

- Expected disagreement between data and Monte Carlo (MC) simulation
- Efficiency binned in p_T and η
  - p_T : transverse momentum
  - η : pseudorapidity, related to angle w.r.t. beam axis
- Fake "factor" derived from efficiency :
  - Applied as weight to every event based on lepton kinematics
  - Allows for analysis binned in variable like p_{T,γ_1} and $m_{\gamma\gamma}$

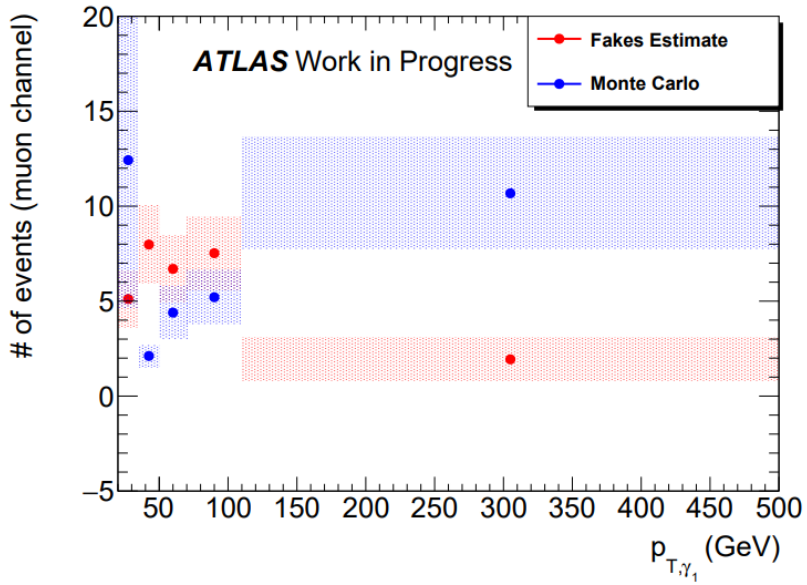


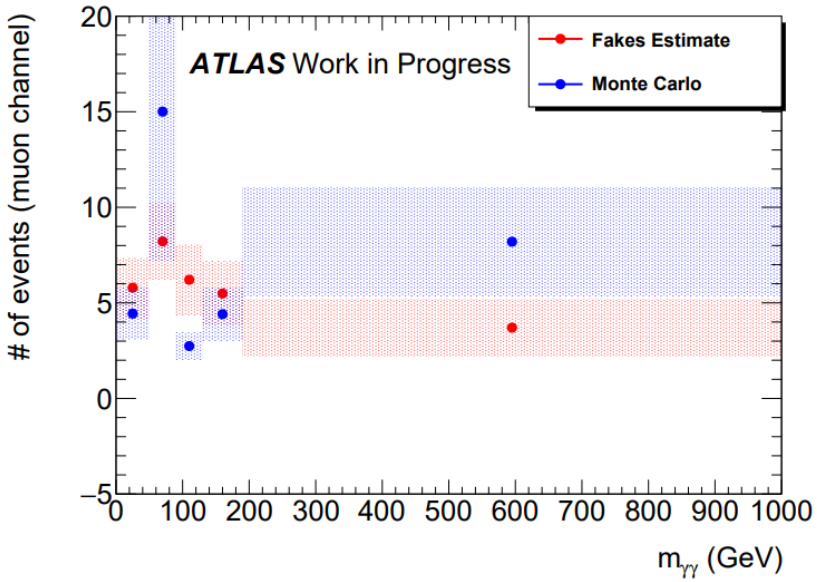


Signal Region

- Results in $W\gamma\gamma$ signal phase space :
  - Agreement in 1 bin between MC simulation and estimate
  - Binned estimates largely disagree
- Method needs validation region :
  - No overlap with signal region but with similar kinematics and fake contributions

Muon Channel	
Method	Fakes Estimate
MC simulation	35 ± 9
Fake Factor	29^{+4}_{-3}

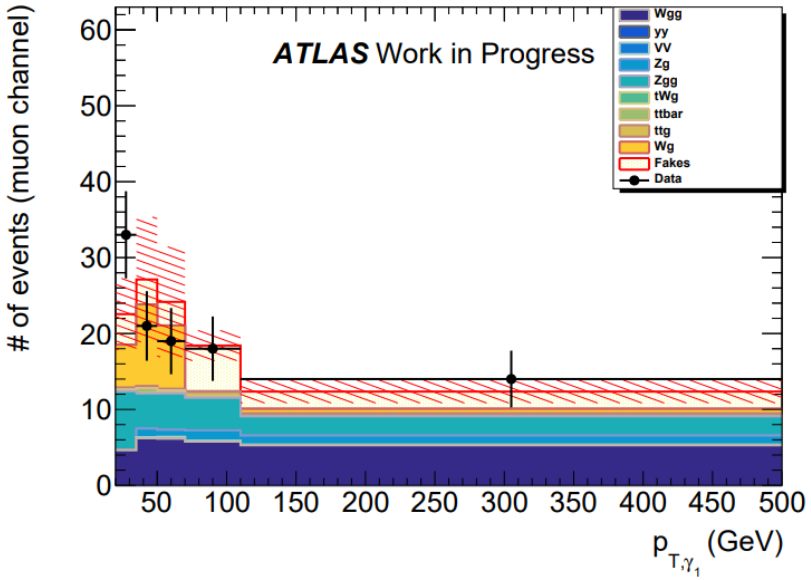


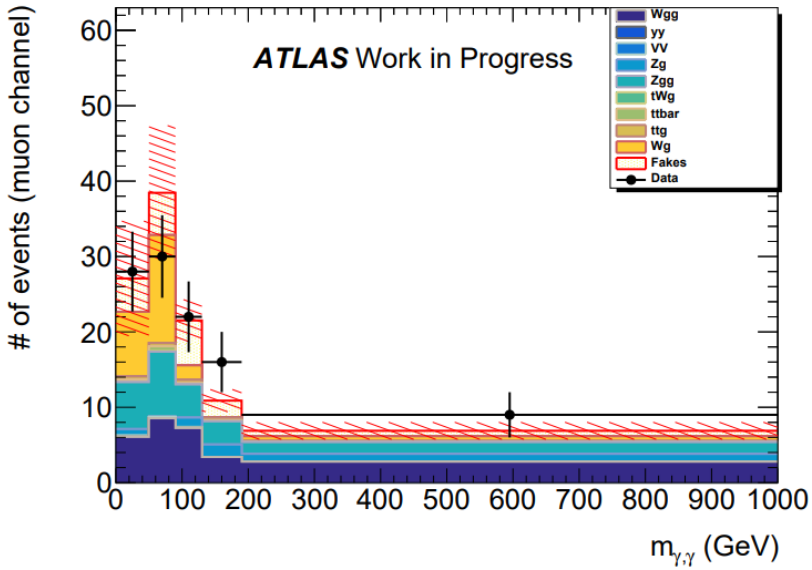


Validation Region

- Signal region has E_T^{miss} and $m_{T,W}$ cuts
  - Select for W
  - Reduce prompt background
- Validation region obtained by inverting these cuts
- Agreement between data and truth MC + fakes
  - Truth MC : reconstructed lepton must match lepton from hard scatter

Muon Channel	
Truth MC	86 ± 12
Fakes	19^{+3}_{-2}
Data	105 ± 10





Summary and Outlook

- Summary :
  - Contribution of misidentified leptons to $W\gamma\gamma$ signal has been estimated
- Outlook :
  - Estimate systematic uncertainties
  - Estimate $e \to \gamma$ fakes
  - Finalize SR fit (initial studies with MC only show $> 5\sigma$)
  - Test EFT hypothesis

$$|\mathcal{A}_{SM} + f_{T5}\mathcal{A}_{T5}|^2 = |\mathcal{A}_{SM}|^2 + 2f_{T5}\mathcal{R}e\{\mathcal{A}^*_{SM}\mathcal{A}_{T5}\} + f^2_{T5}\,|\mathcal{A}_{T5}|^2$$

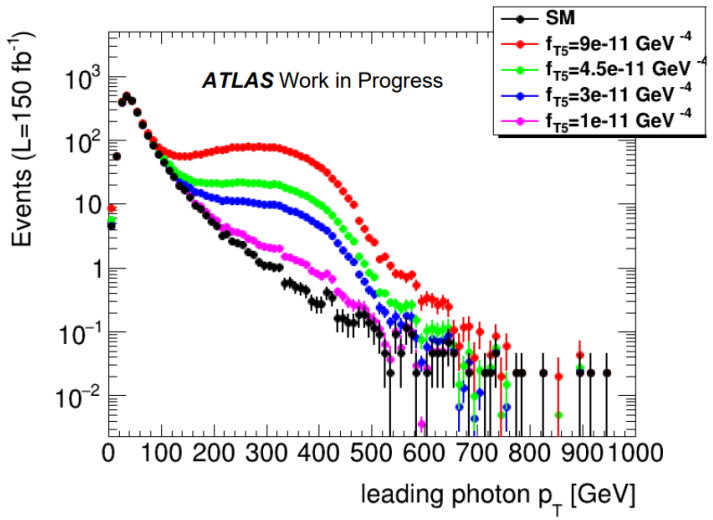


Figure: Example figure showing effect of EFT operator T_5 at different coupling strengths f_{T_5} compared to SM prediction