Experimental Overview

- Photon induced processes-

— Workshop on the Modeling of Photon Induced Processes —

June 5, 2023

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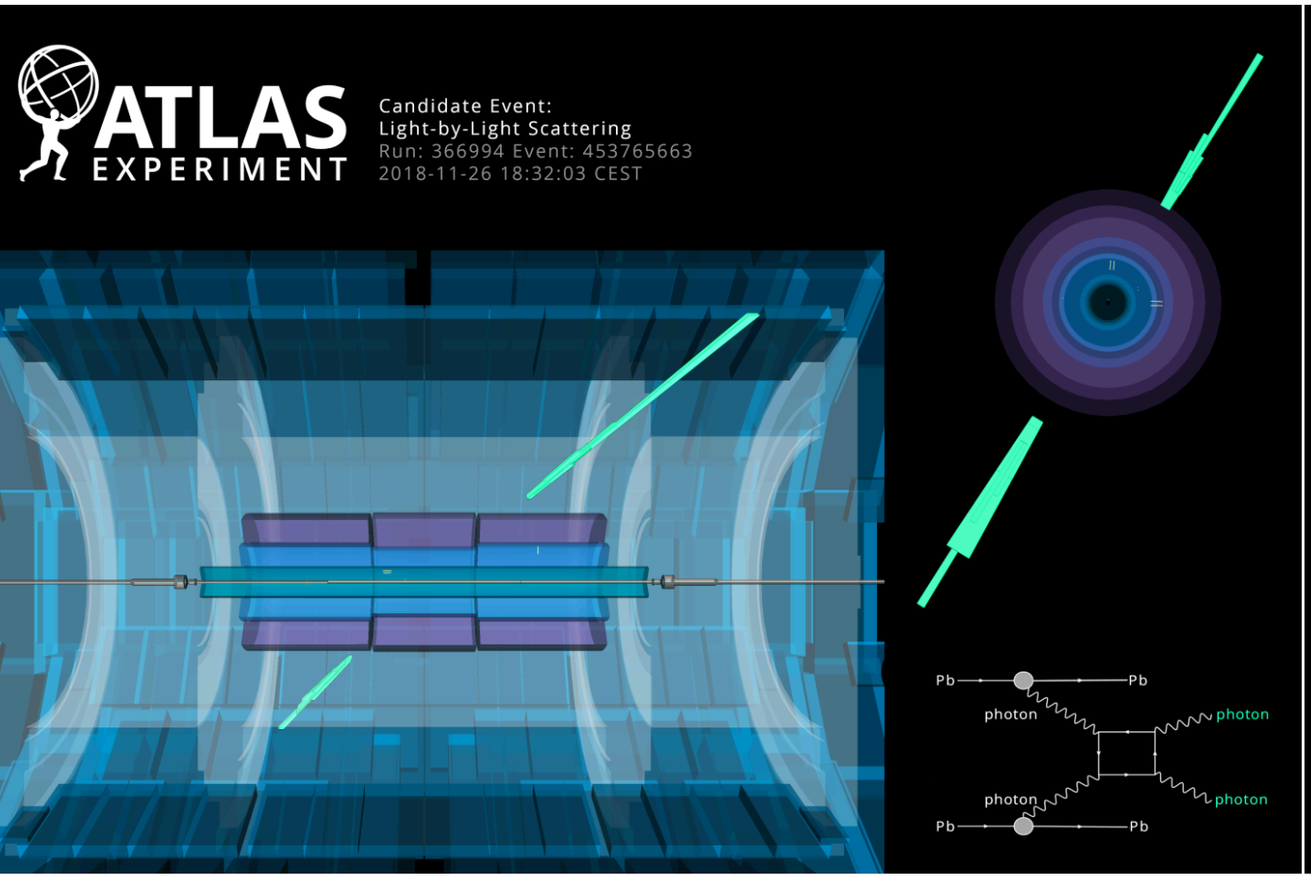
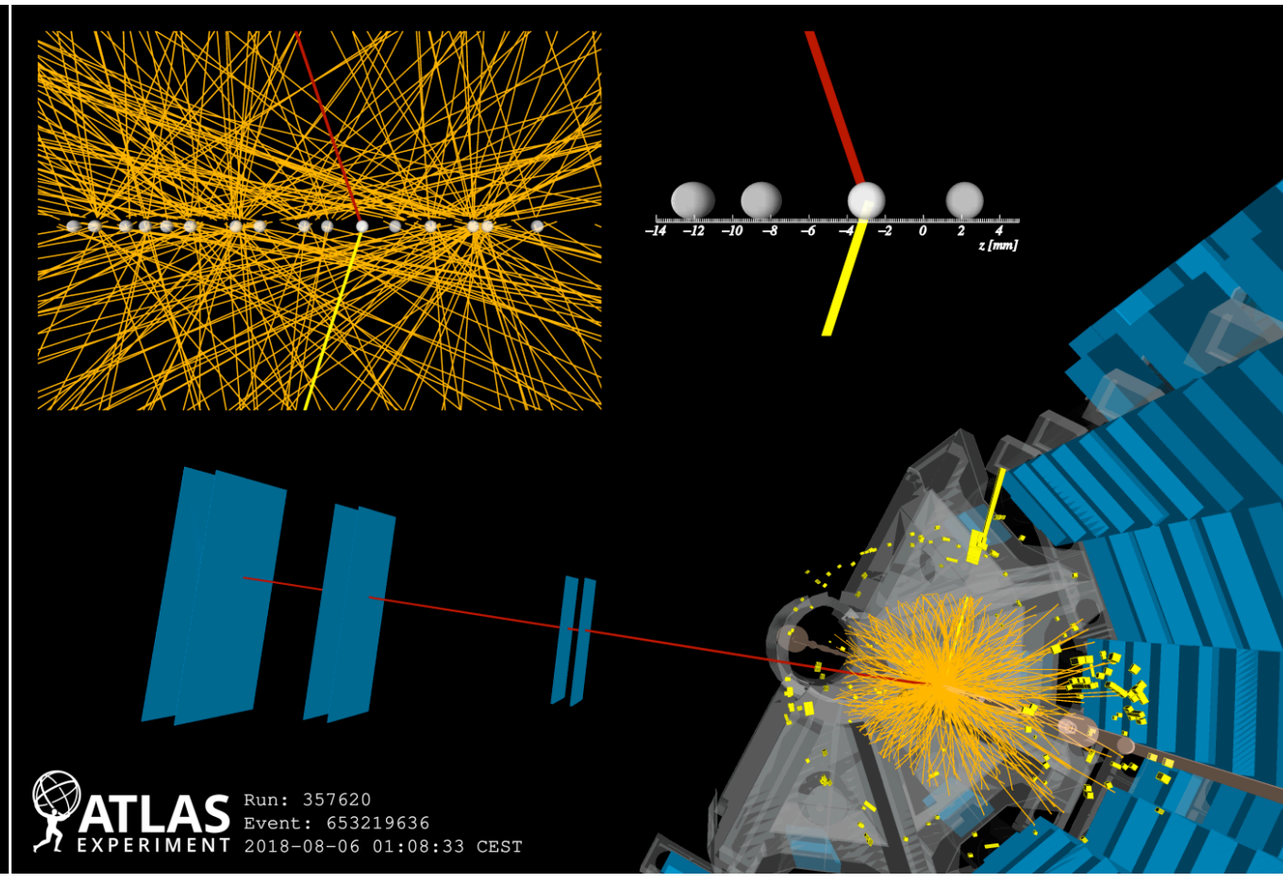
Photon Induced Processes at the LHC

- Heavy-ion collisions



- Light-by-light scattering http://dx.doi.org/10.1103/PhysRevLett.123.052001
- g-2 measurement https://arxiv.org/abs/2204.13478.
- Photon luminosity scales with Z^4

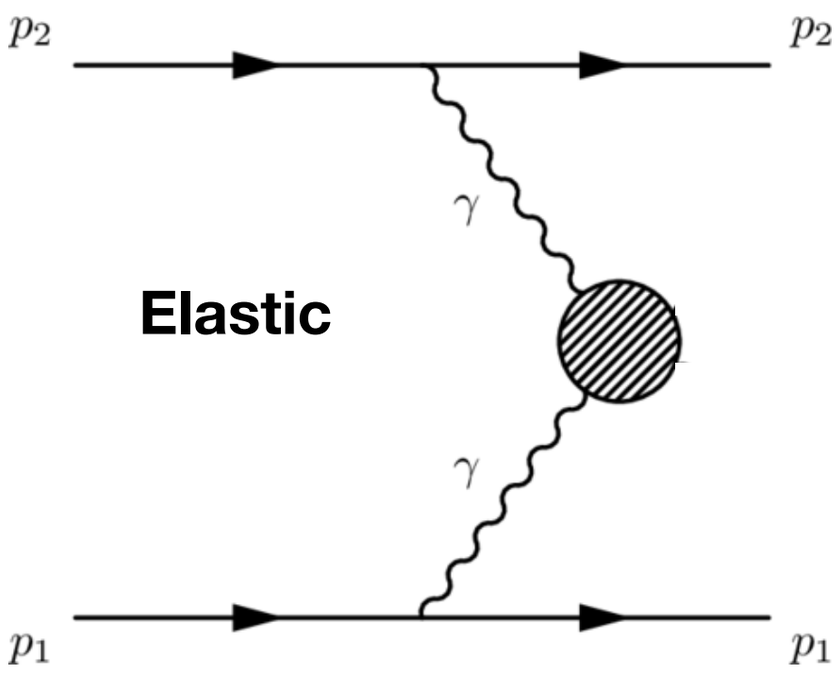
- p-p collisions



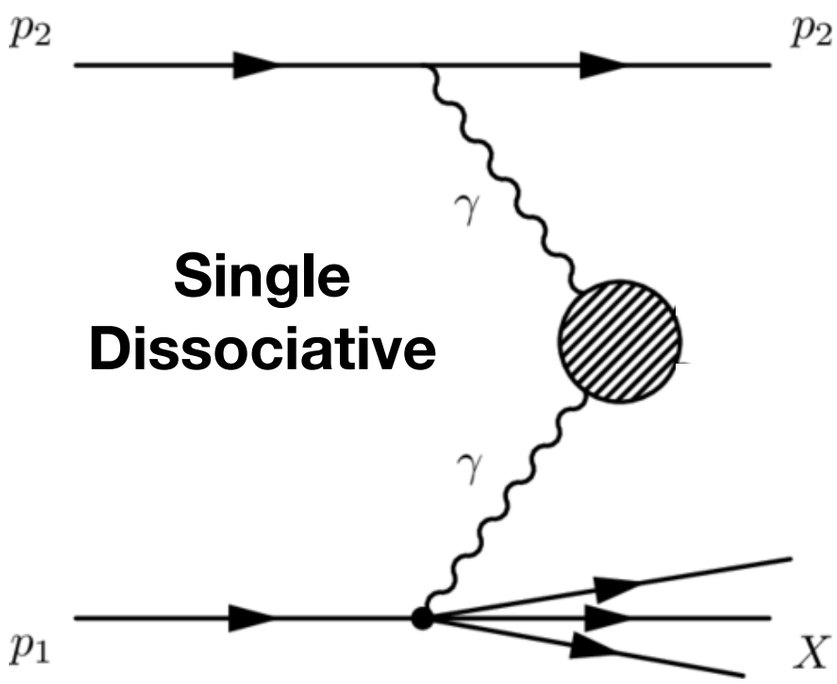
- Photon-induced di-lepton production https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.125.261801
- Observation of photon-induced WW production https://www.sciencedirect.com/science/article/pii/S0370269321001301
- better for EW scale and higher

Photon Induced Processes at the LHC

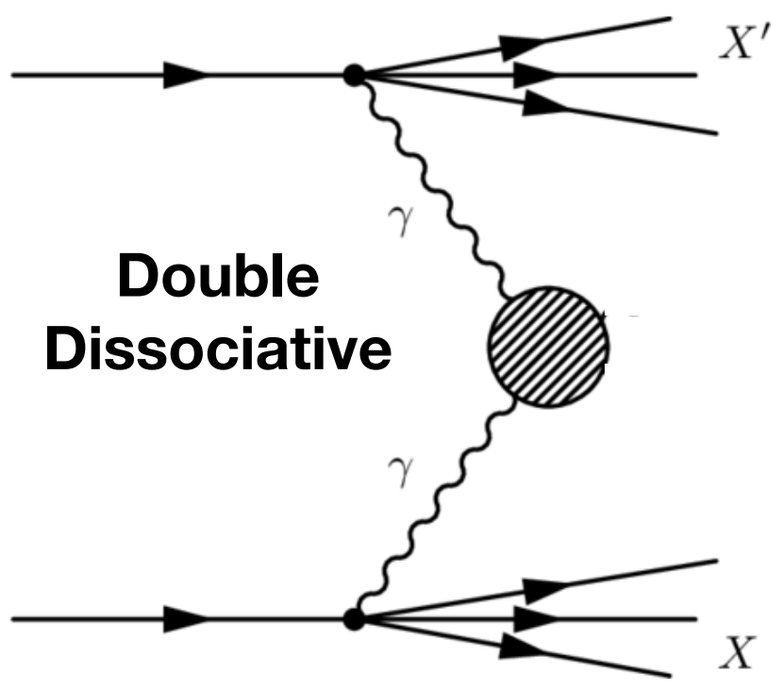
- Mechanism (in p-p):



Elastic



Single Dissociative

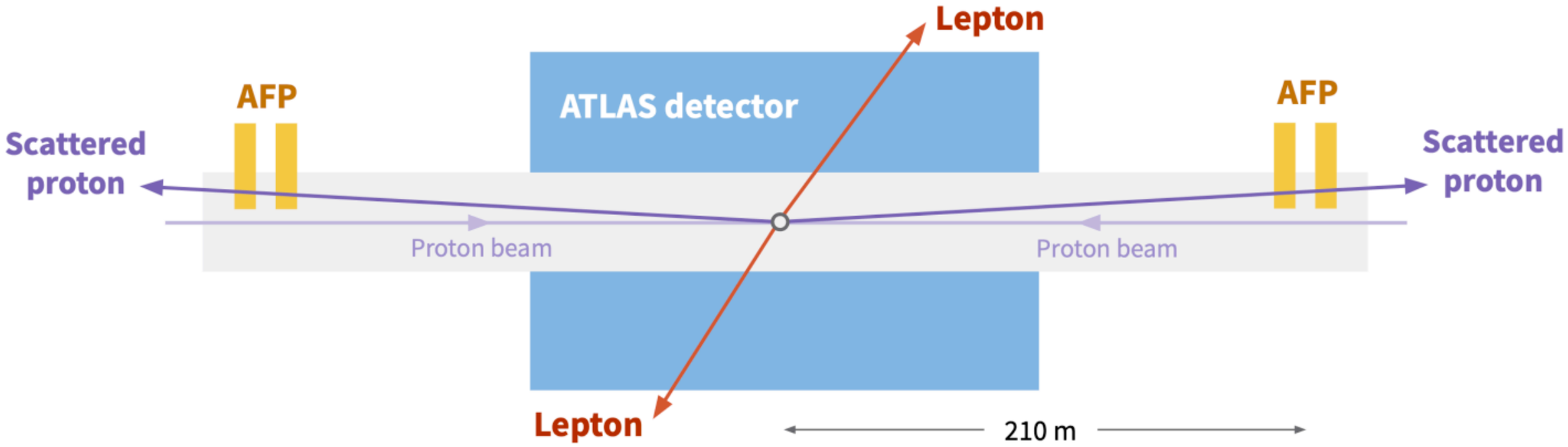


Double Dissociative

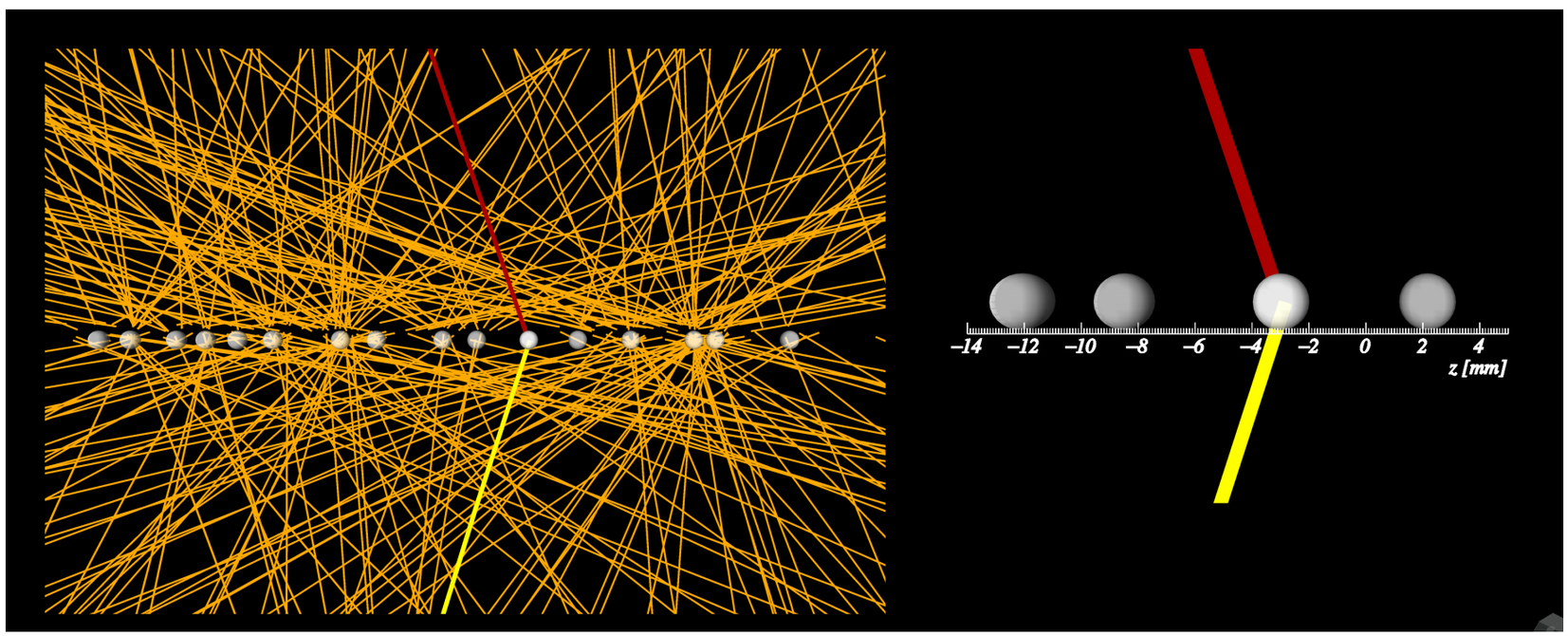
- Single-dissociative is dominant

Photon Induced Processes at the LHC

- Two ways for detection
  - **Tagging the protons in the forward detector**



- **Using the information in the central detector only**



Photon Induced Processes at the LHC

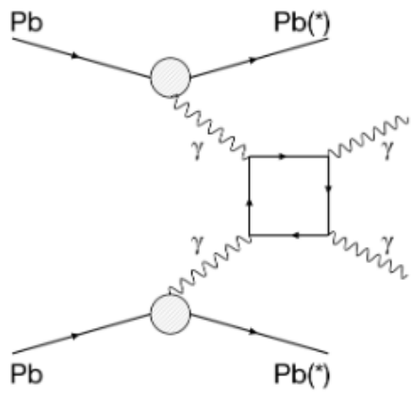
- Two ways for detection
  - **Tagging the protons in the forward detector**
    - Higher purity (S/B)
    - Smaller Acceptance and Efficiency

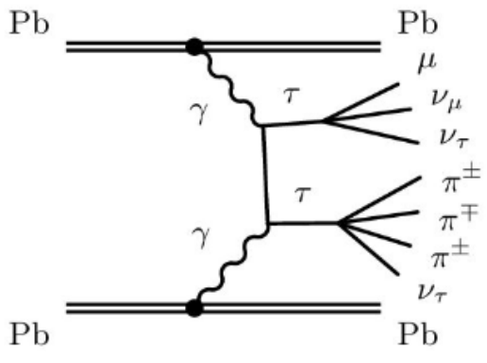
  - **Using the information in the central detector only**
    - More background: lower purity (S/B)
    - Higher Acceptance and Efficiency
    - Challenge: Background modeling
    - Challenge: Pile-up

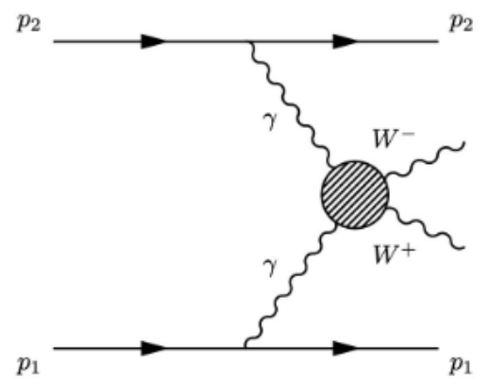
- *Ultimately we should do both and create regions with different purity*

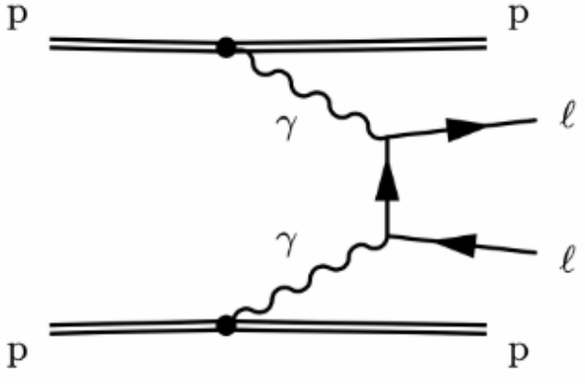
Photon Induced Processes at the LHC

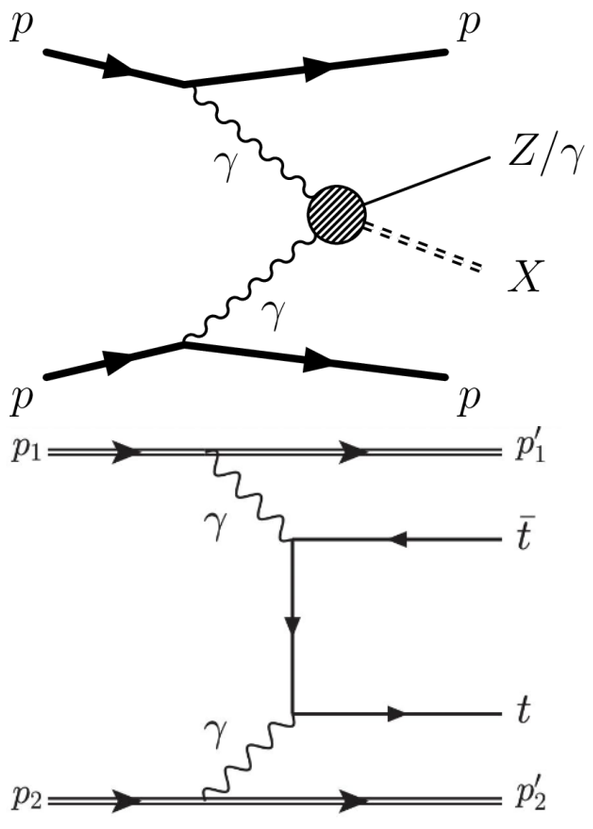
- Recent publications:
  - ✓ Light-by-light scattering http://dx.doi.org/10.1103/PhysRevLett.123.052001 https://arxiv.org/abs/1810.04602
  - ✓ g-2 measurement https://arxiv.org/abs/2204.13478 https://arxiv.org/abs/2206.05192
  - ✓ Photon-induced di-lepton production https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.125.261801 https://arxiv.org/abs/2009.14537 https://arxiv.org/pdf/1803.04496.pdf
  - ✓ Observation of photon-induced WW production https://www.sciencedirect.com/science/article/pii/S037026932100130 1
  - ✓ Photon-induced WW and ZZ in hadronic final states https://cds.cern.ch/record/2803716
  - ✓ Photon-induced tt https://cds.cern.ch/record/2803843
  - ✓ Generic search is presented for associated production of a Z boson or a photon with an additional unspecified massive particle X https://arxiv.org/abs/2303.04596





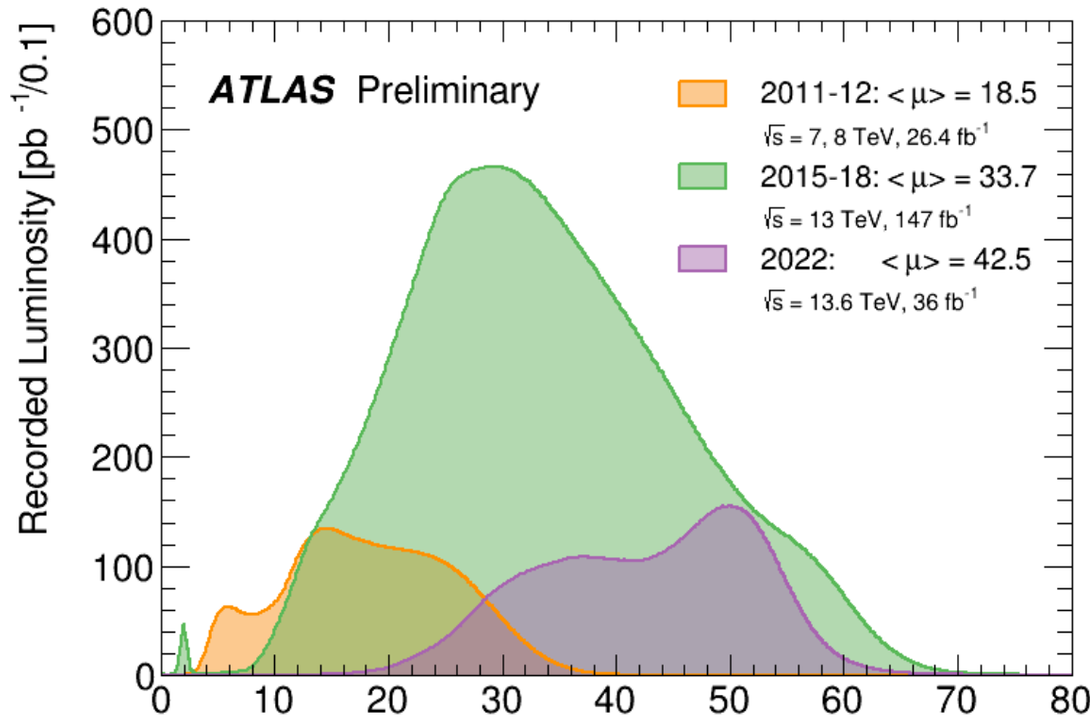


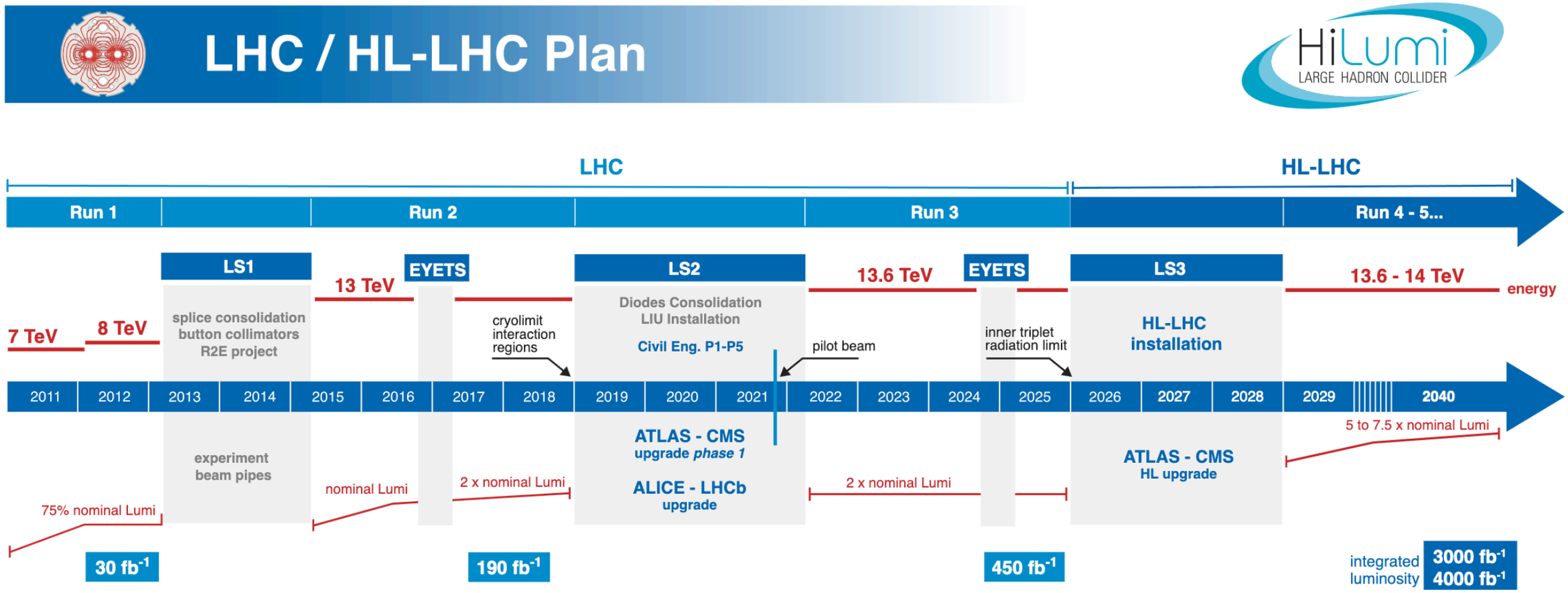




Photon Induced Processes at the LHC

- Available data at the LHC
  - Run-1 (2011-2012, 7 and 8 TeV, 25 fb^{-1})
  - Run-2 (2015-2018, 13 TeV, 140 fb^{-1})
    - Available data with fwd detectors
  - Run-3 (2022-2025, 13.6 TeV, ~300 fb^{-1})
    - Collecting data with fwd detectors
  - Run-4-6 (2029-2041, ~14TeV, ~3000 fb^{-1})
- Detectors Upgrade: |eta| < 4



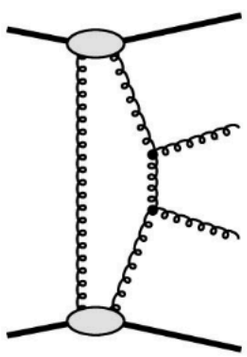


Photon Induced Processes at the LHC

[J.Liu slides]

- Plenty of opportunities

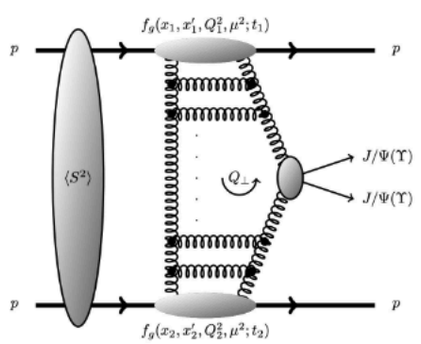
SM JETγ



Jets

ATLAS PHYS-PUB-2015-003
CMS 2002.12146

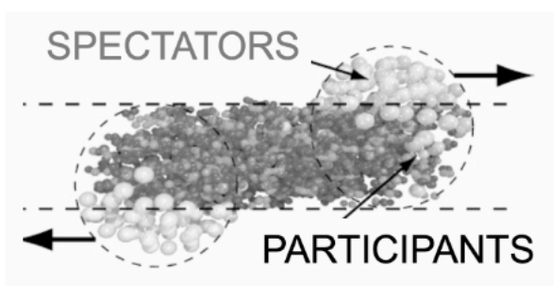
BPHY



Quarkonia

Harland-Lang et al 1508.02718
Goncalves et al 1912.02720

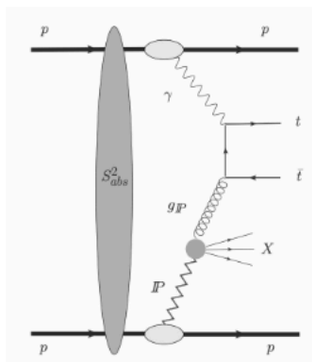
HION



Heavy ions

Oppedisano Elba Wkshp 2016
Chwastowski et al 2011.00872

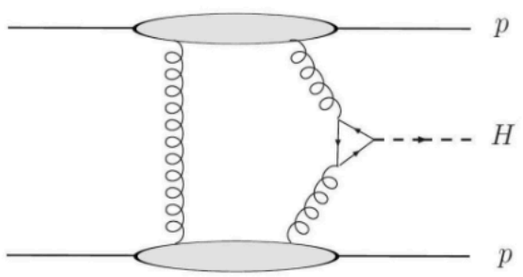
TOPQ



Top quarks

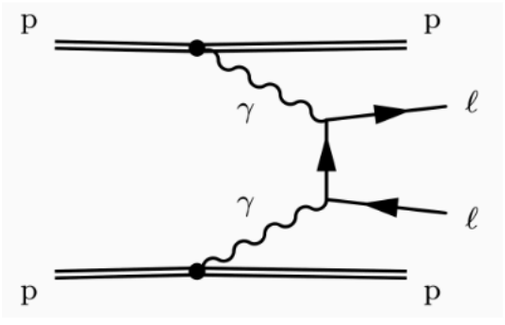
Goncalves et al 2007.04565
Howarth 2008.04249

HIGG



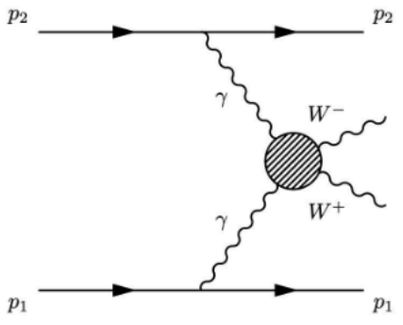
Higgs boson

Cox et al 0709.3035
Heinemeyer et al 0708.3052



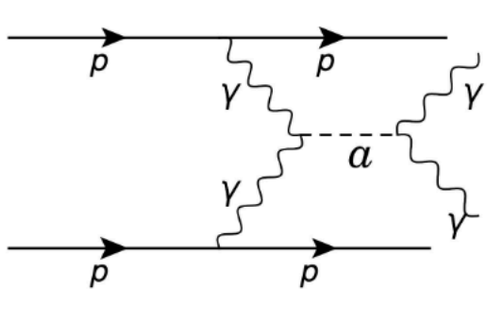
Electrons/muons

CMS+TOTEM 1803.04496
ATLAS 2009.14537



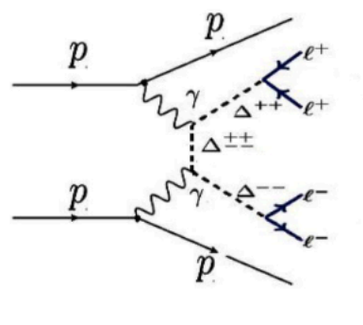
Gauge bosons

Tizchang & Etesami 2004.12203
Baldenegro et al 2009.08331



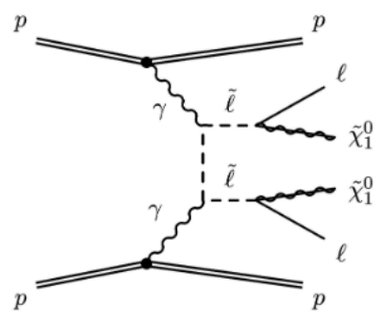
Axion-like particles

Fichet et al 1312.5153
Baldenegro et al 1803.10835



Multicharged Higgs

Babu & Jana 1612.09224
Fuks et al 1912.08975

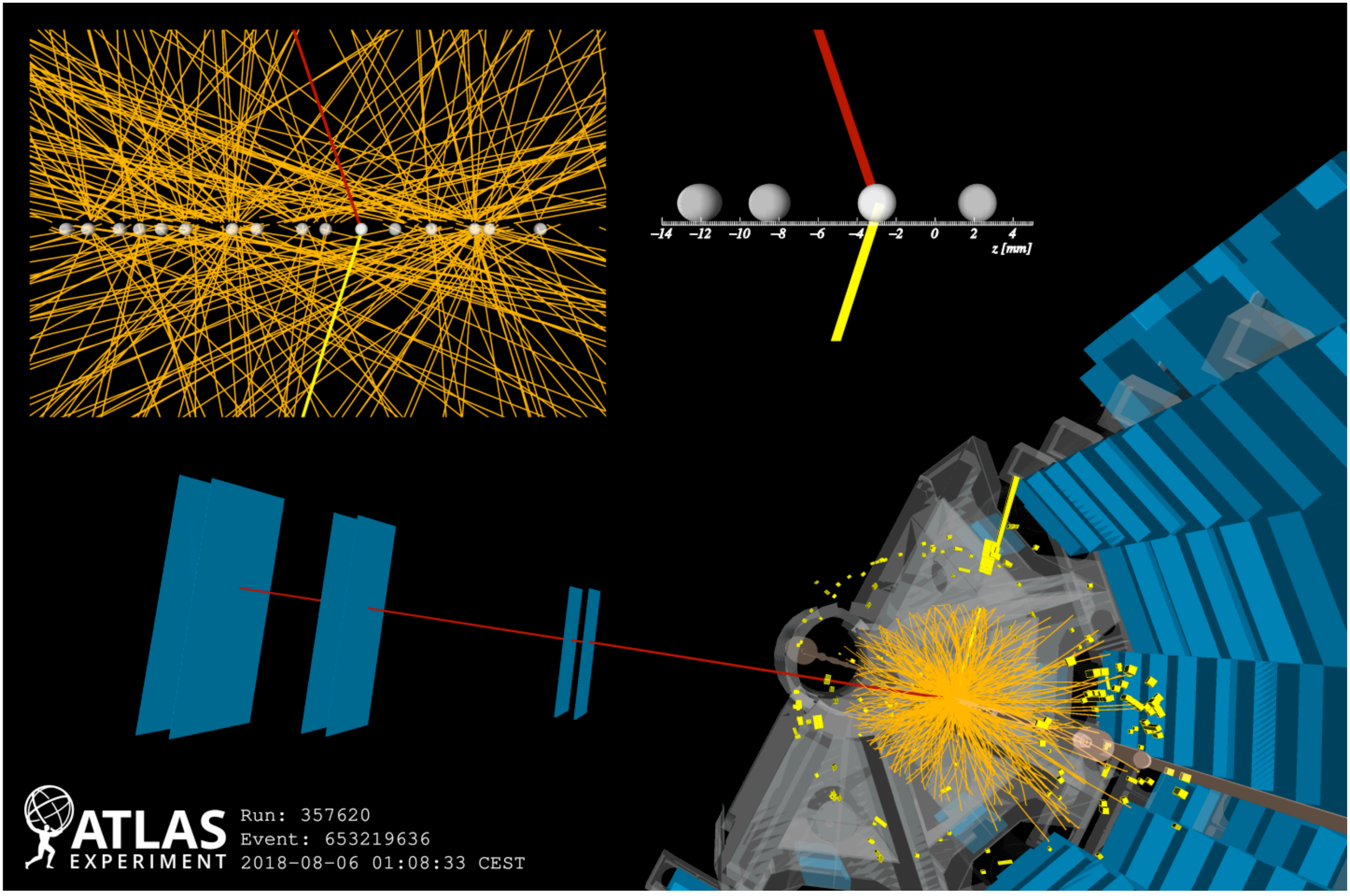


Sleptons & neutralinos

Beresford & JL 1811.06465
Harland-Lang et al 1812.04886

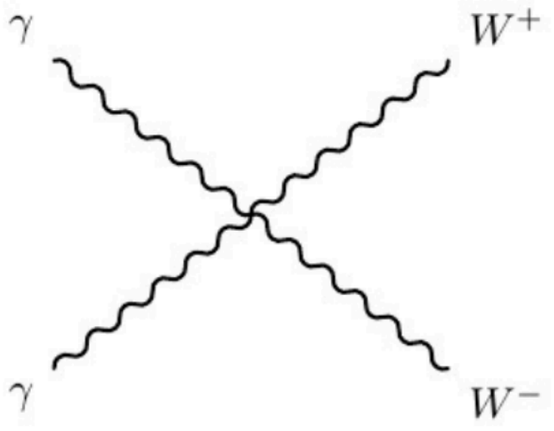
SM sQCD **SM EWK** **EXOT** **HDBS** **SUSY**

Photon-Induced WW Production

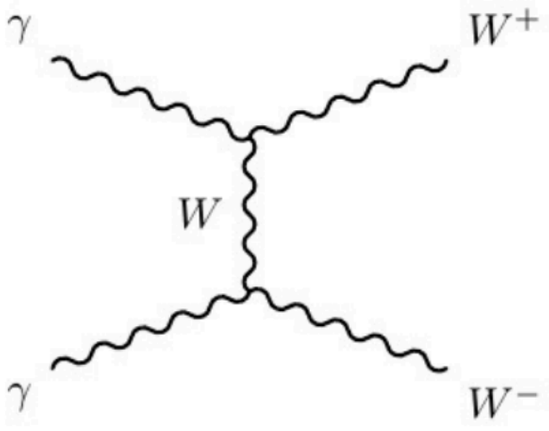


Photon Induced WW Production

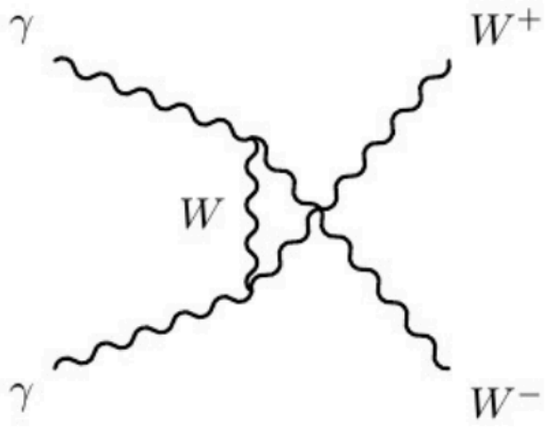
- Why is photon-induced WW interesting?



(a) QGC vertex



(b) t-channel



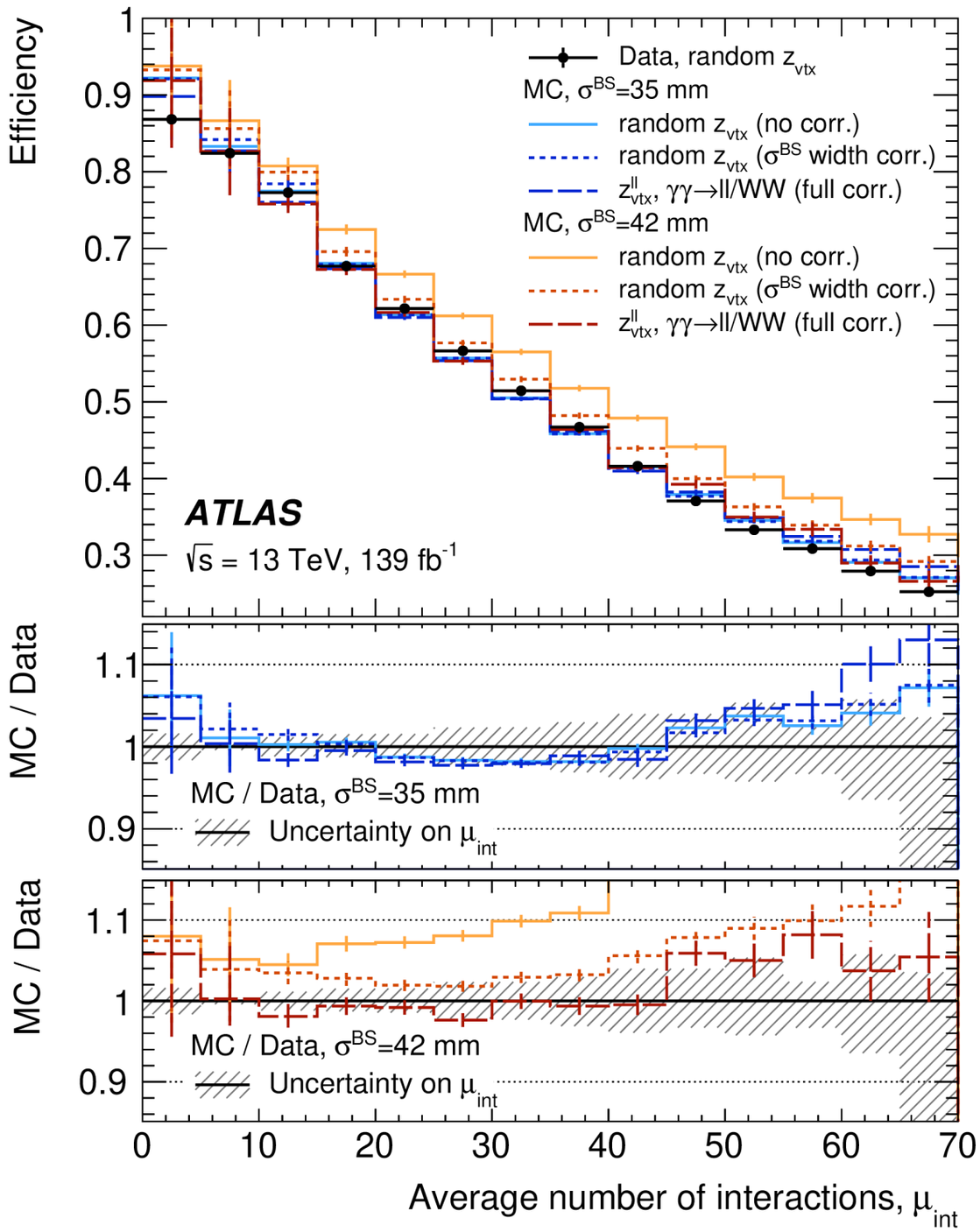
(c) u-channel

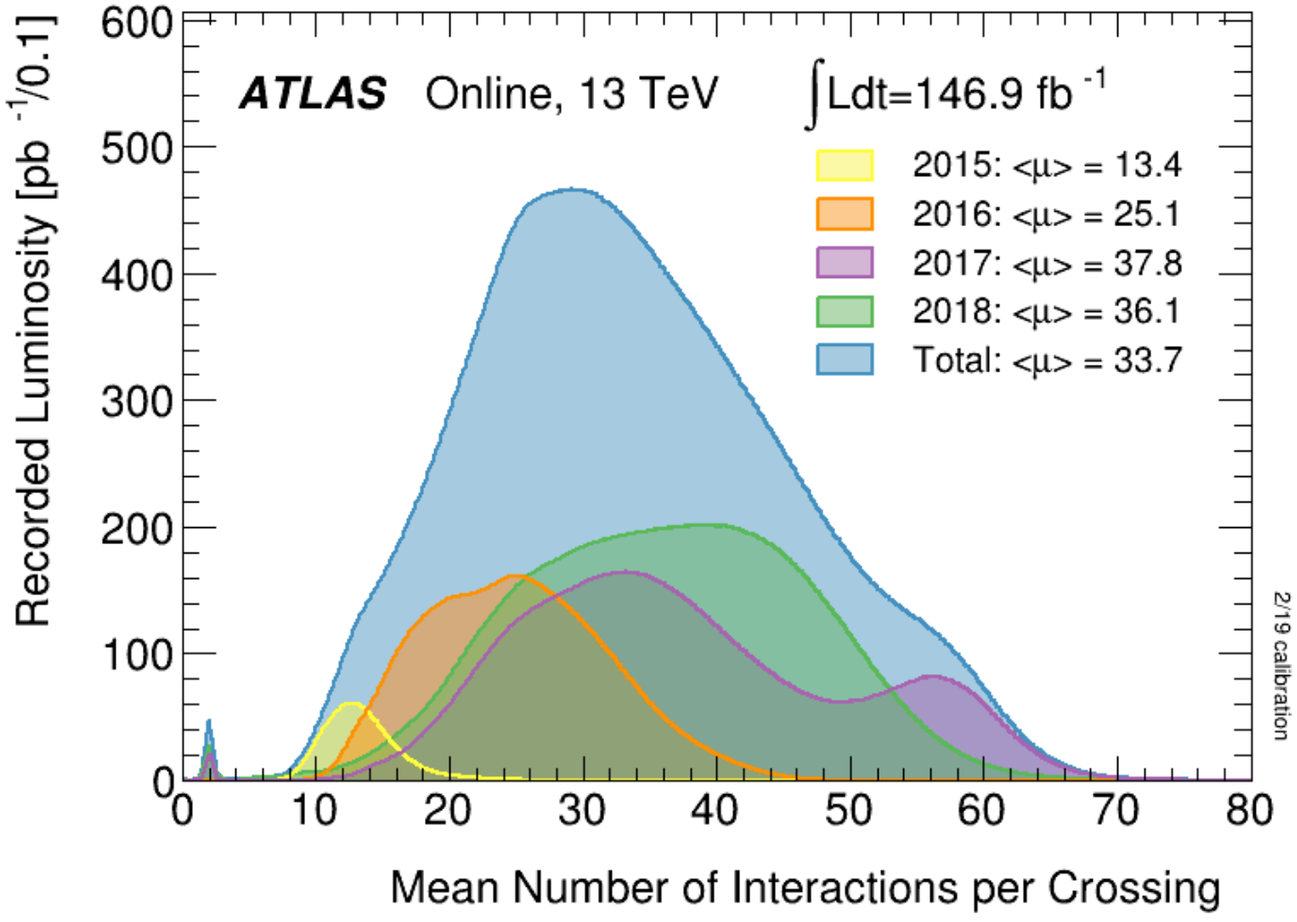
- Measure self-interaction of EW gauge bosons
  - Sensitive to triple (yWW) and quartic (yyWW) gauge coupling
  - Clean signature with very little central activity beside the products of the photon interaction

- Experimental signature:
  - one electron and one muon oppositely charged
  - no other particles around the production vertex

Photon Induced WW Production

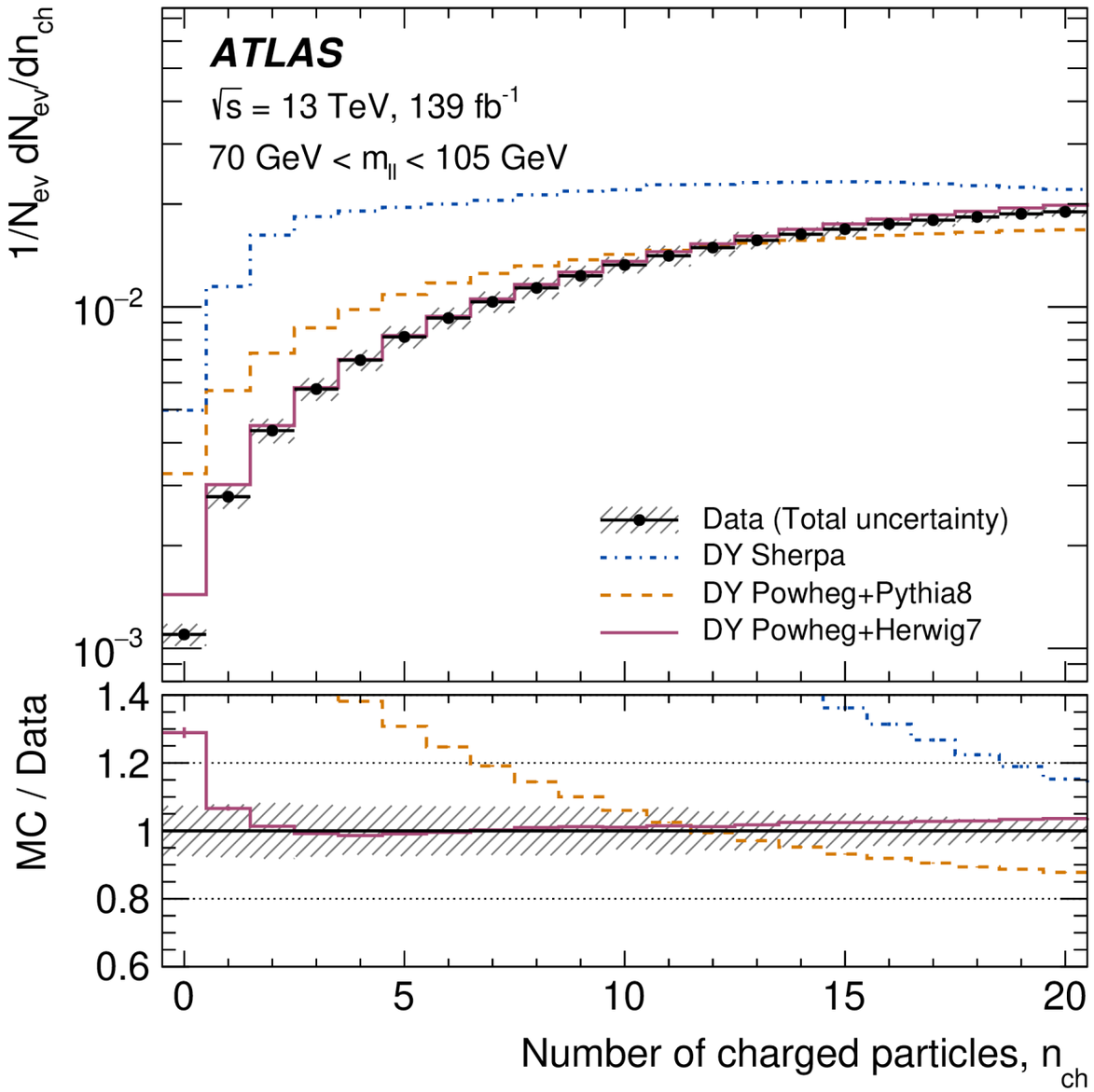
- Challenges:
  - pile-up





Photon Induced WW Production

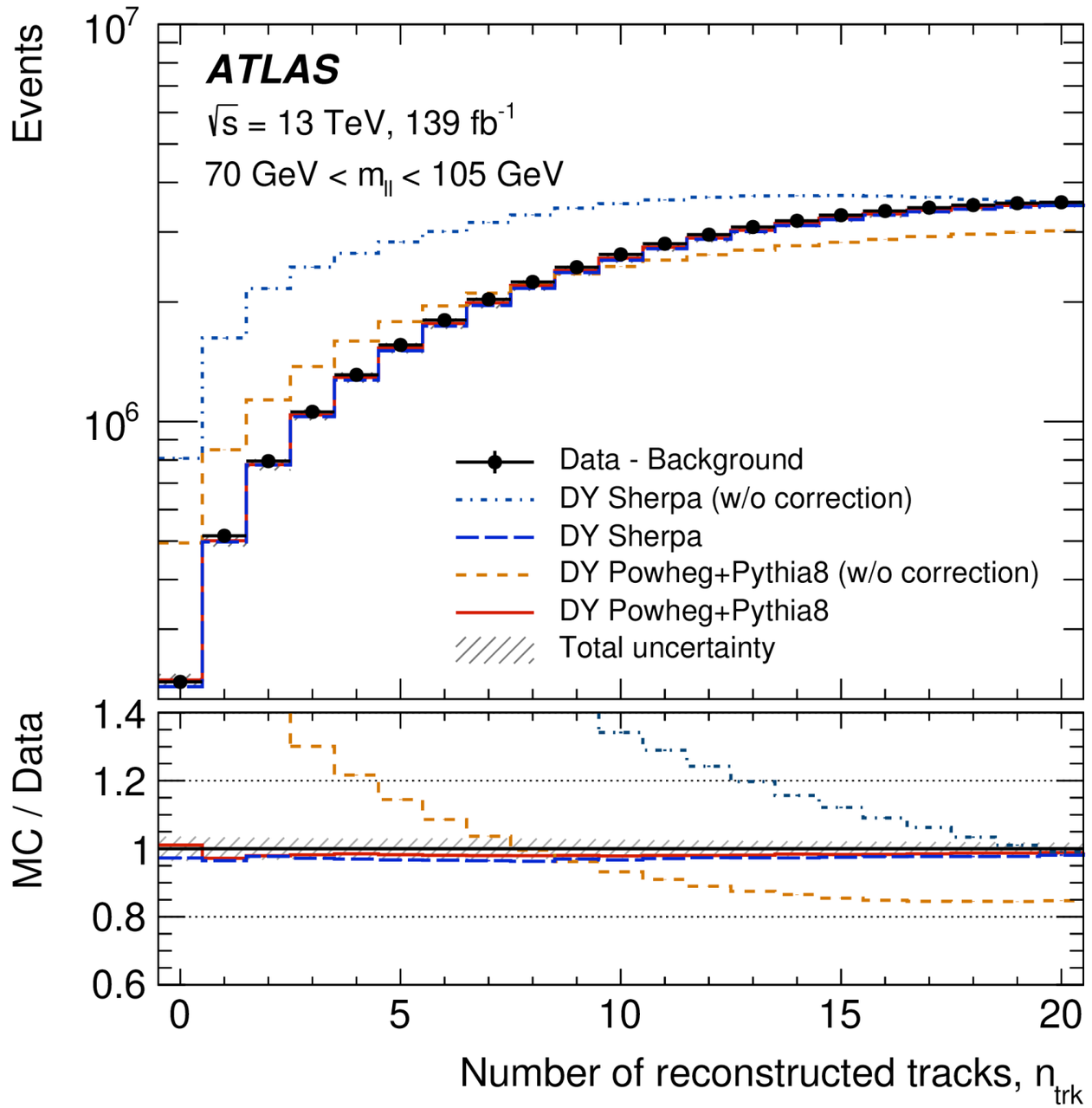
- Challenges:
  - modeling of the underlying event



  - number of charged particles is measured in Drell-Yan events

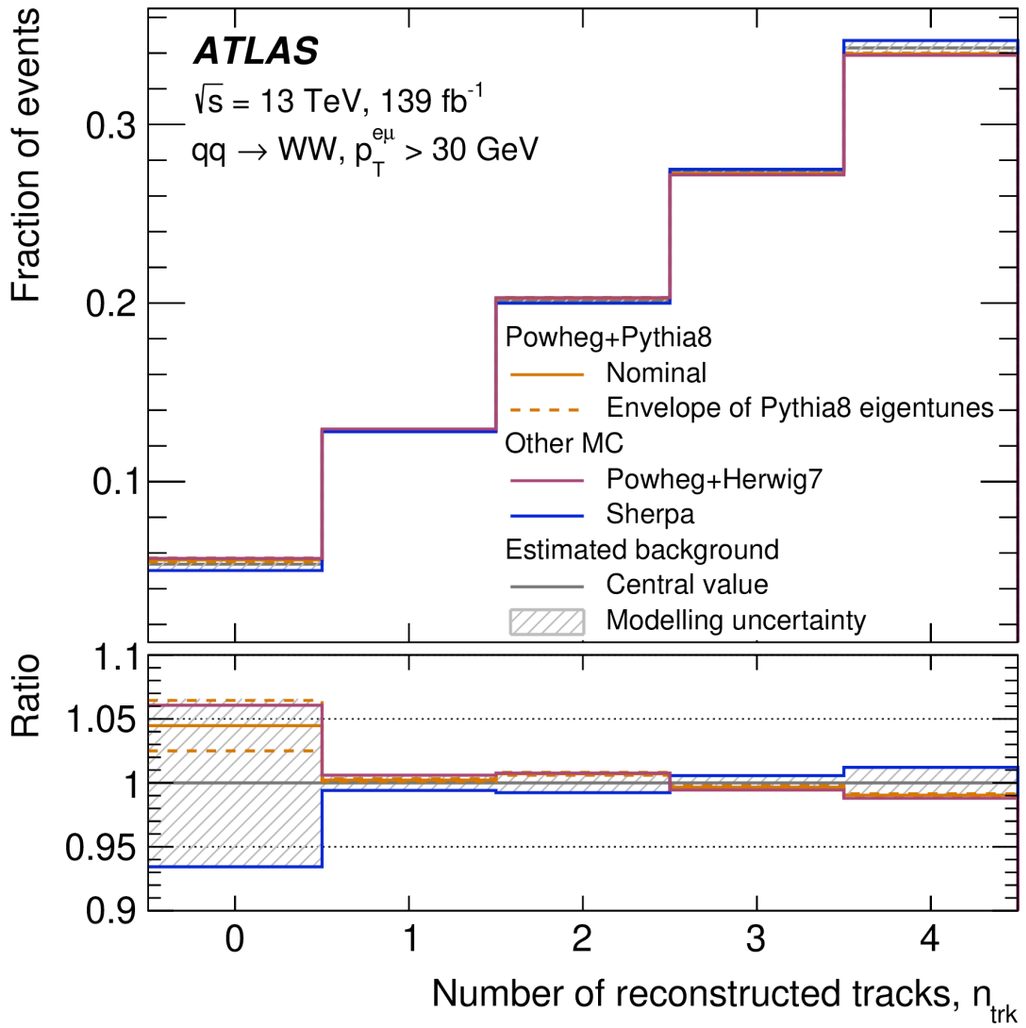
Photon Induced WW Production

- Challenges:
  - modeling of the underlying event
  - Correction derived from Drell-Yan events as a function of Nch and $p_T(ll)$



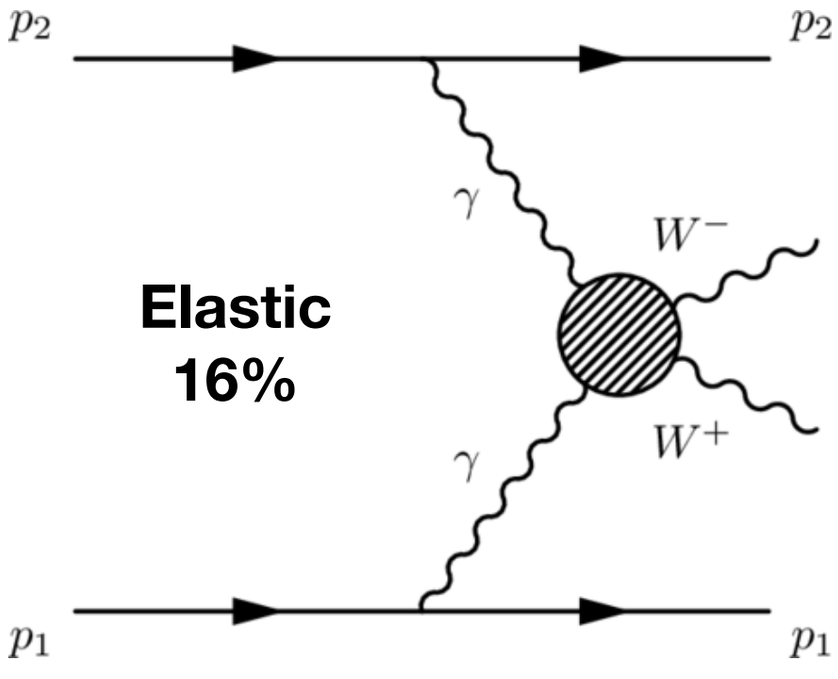
Photon Induced WW Production

- Challenges:
  - modeling of the underlying event
  - Correction applied to $qq \rightarrow WW$ function of Nch and $p_T(VV)$
  - Pythia8, Herwig7 and Sherpa parton-shower models agree within 1% except for Ntrk = 0

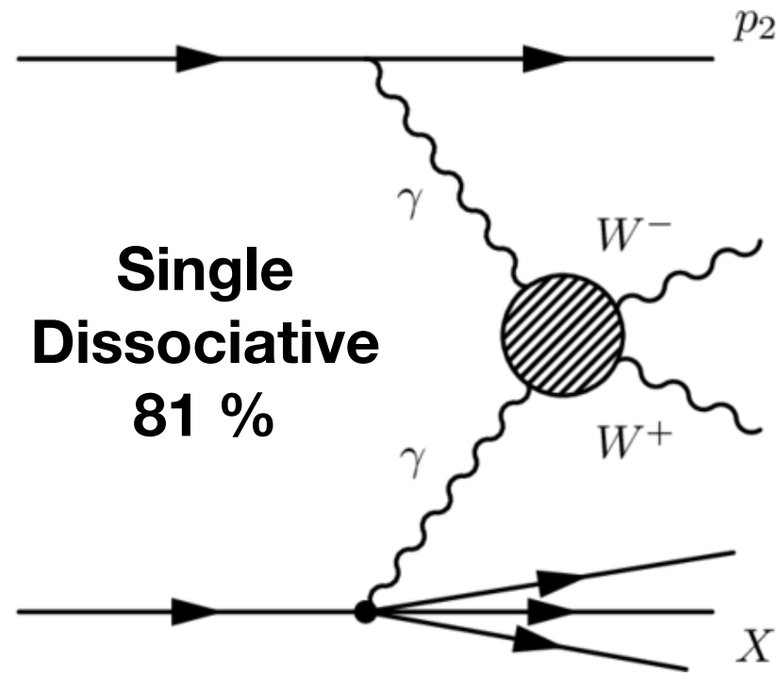


Photon Induced WW Production

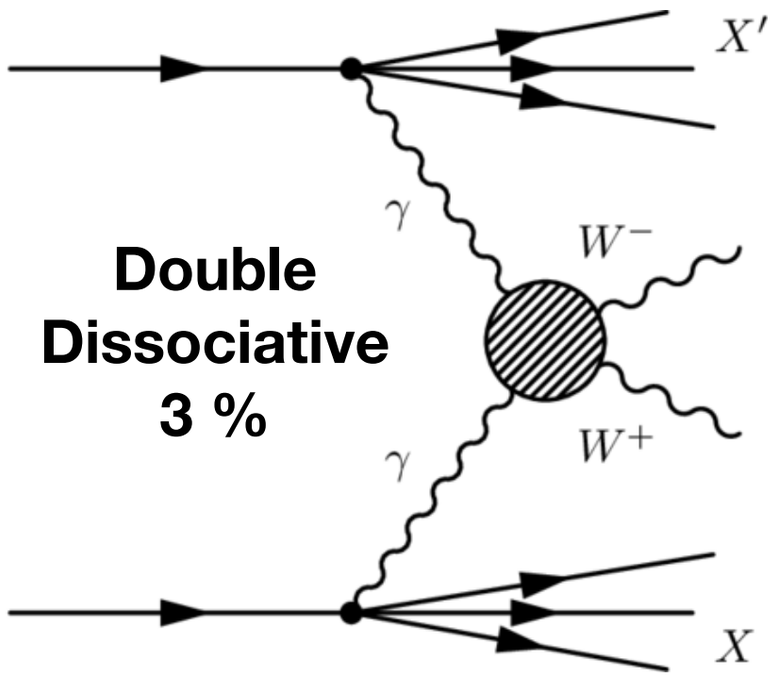
- Challenges:
  - modeling of the proton fragmentation



Elastic 16%



Single Dissociative 81 %



Double Dissociative 3 %

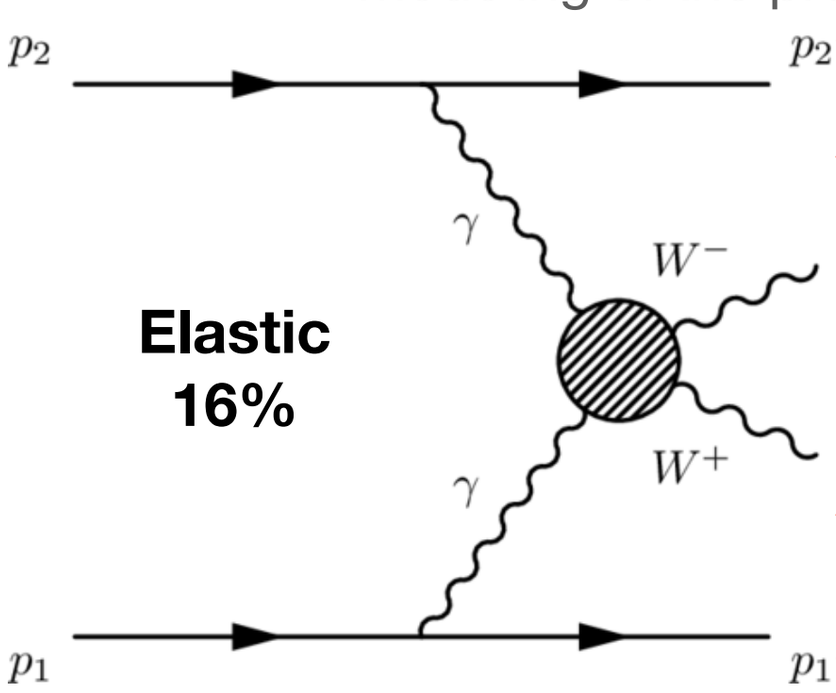
  - Available MC Samples (at the time of the publication)

Photon Induced WW Production

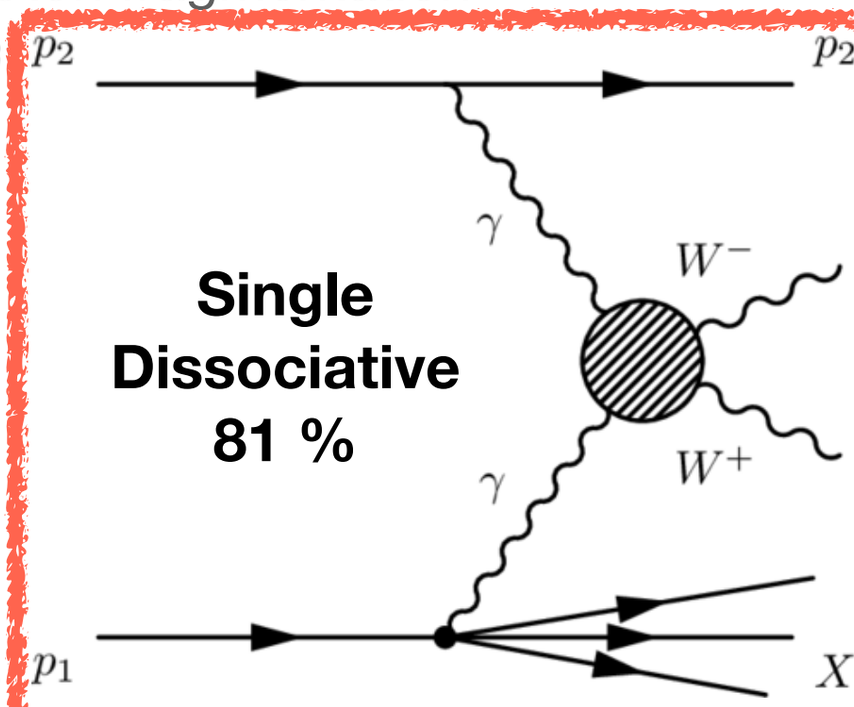
- $\gamma\gamma \rightarrow ll$
  - **Elastic**:
    - Herwig 7.1.5 interfaced with the BudnevQED photon flux
    - MadGraph 2.6.7 interfaced to Pythia 8.243
  - **Single-dissociative:**
    - LPAIR 4.0
    - MadGraph 2.6.7 interfaced to Pythia 8.243
  - **Double-dissociative**
    - Pythia 8.240 using the NNPDF3.1NLOluxQED PDF
    - MadGraph 2.6.7 interfaced to Pythia 8.243
- $\gamma\gamma \rightarrow WW$
  - **Elastic**:
    - Herwig 7.1.5 interfaced with the BudnevQED photon flux
    - MadGraph 2.6.7 interfaced to Pythia 8.243
  - **Single-dissociative:**
    - MadGraph 2.6.7 interfaced to Pythia 8.243 (re-weighted to LPAIR)
  - **Double-dissociative**
    - MadGraph 2.6.7 interfaced to Pythia 8.243

Photon Induced WW Production

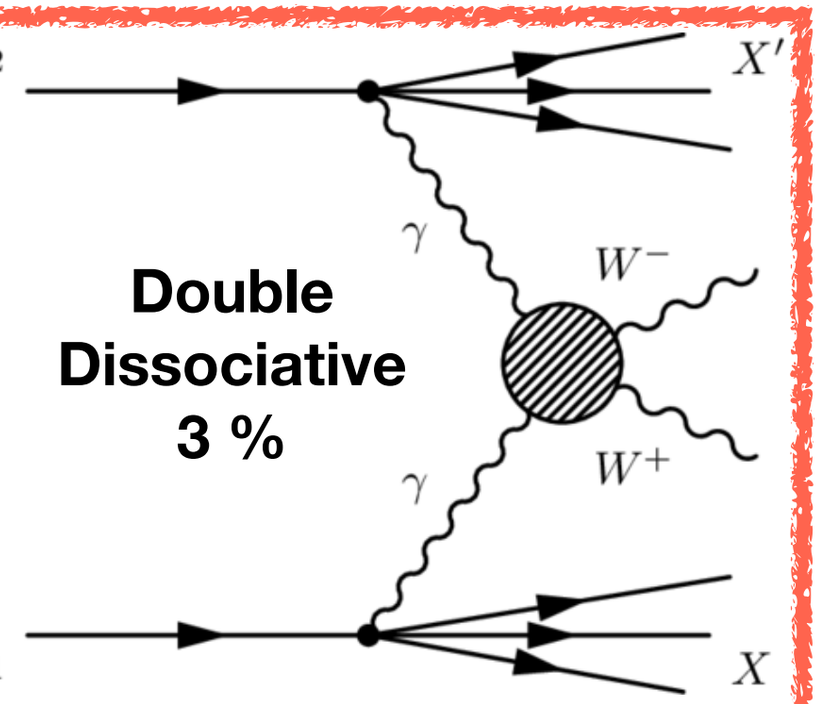
- Challenges:
  - modeling of the proton fragmentation



Elastic
16%



Single Dissociative
81 %



Double Dissociative
3 %

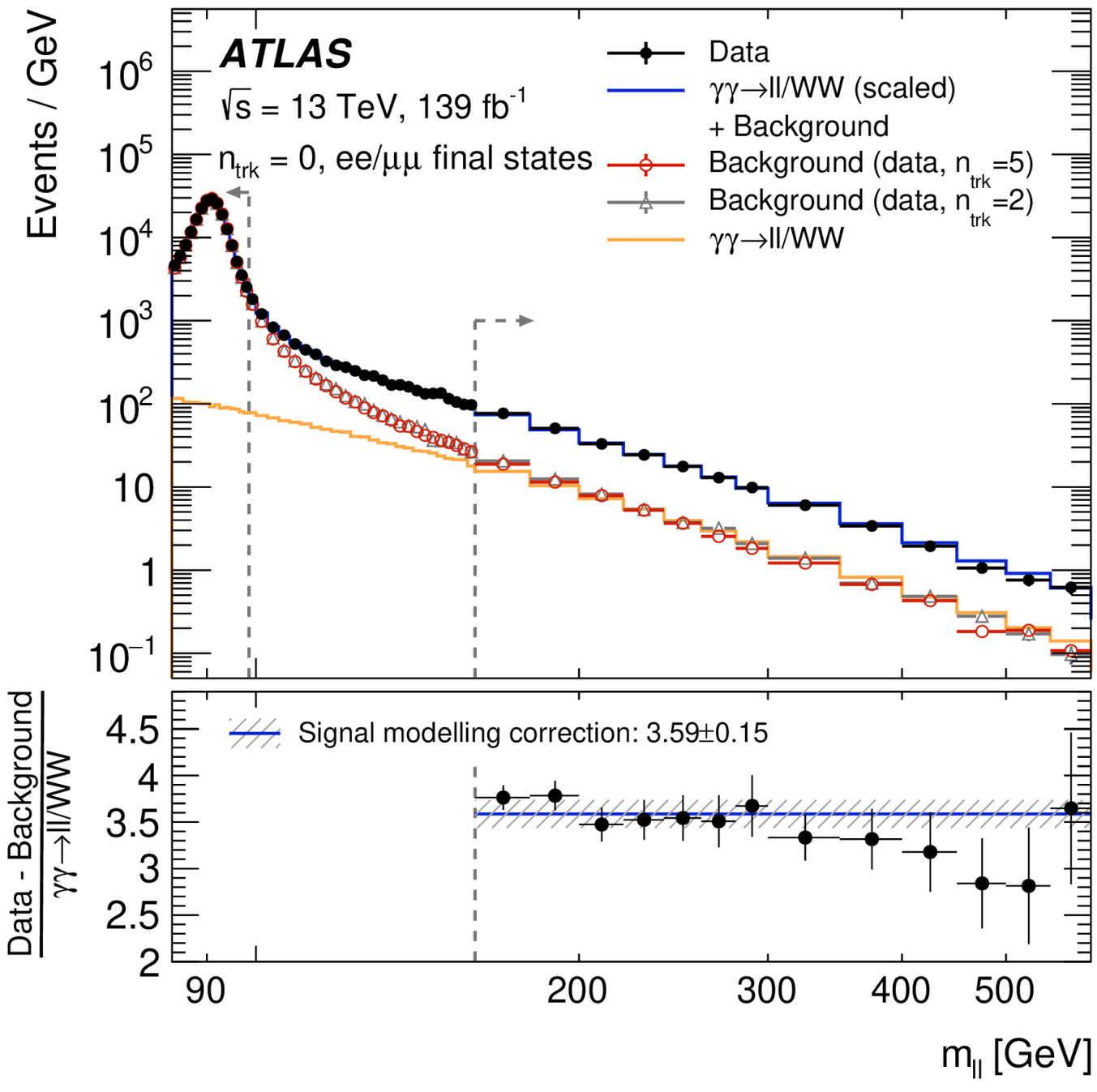
  - LPAIR (only di-lepton) describes the data the best
  - More generators available now!
  - **MadGraph (EL, SD and DD)**, **SuperChic (EL and SD)**
    (recently added $\gamma\gamma \rightarrow WW$ process)
    - Modeling of the ptll and acomplanarity ($1 - \Delta\Phi_{ll}/\pi$) distribution at the same time
    - Extra: dissociative EFT modeling

Photon Induced WW Production

- Data-driven scaling of elastic yy->WW derived from yy->ll when mll>160 GeV

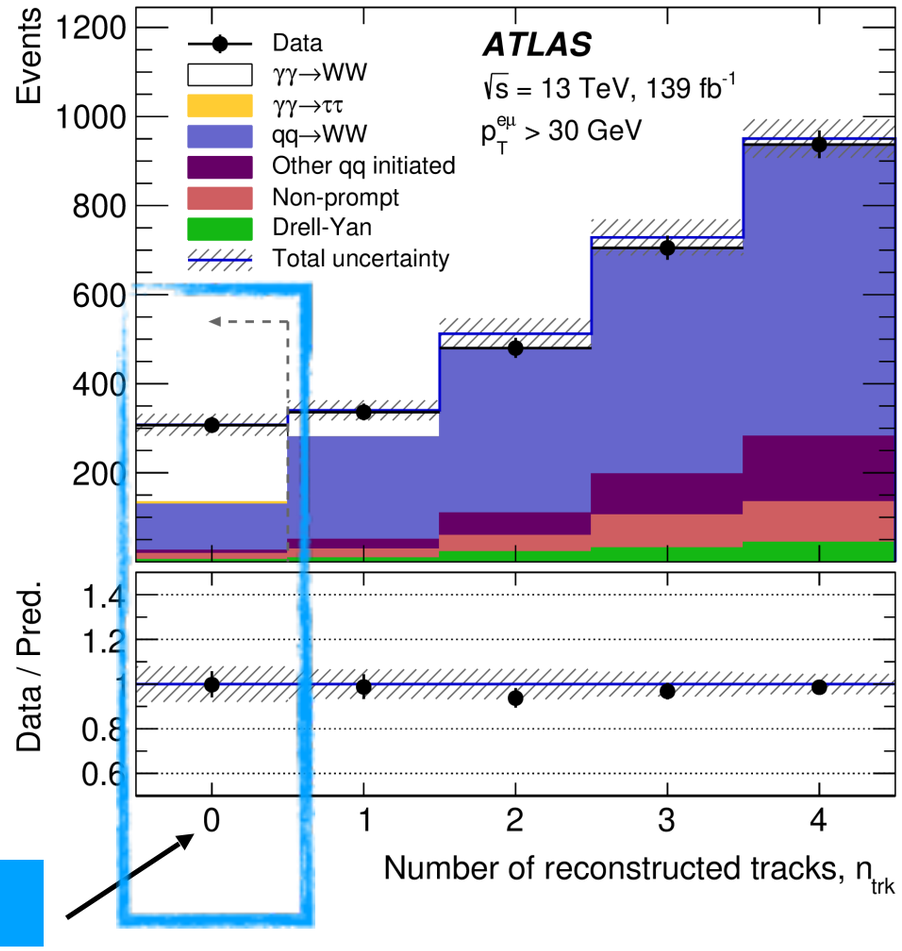
- Scale factor:
  EL/(EL+SD+DS) = 3.59 ± 0.15

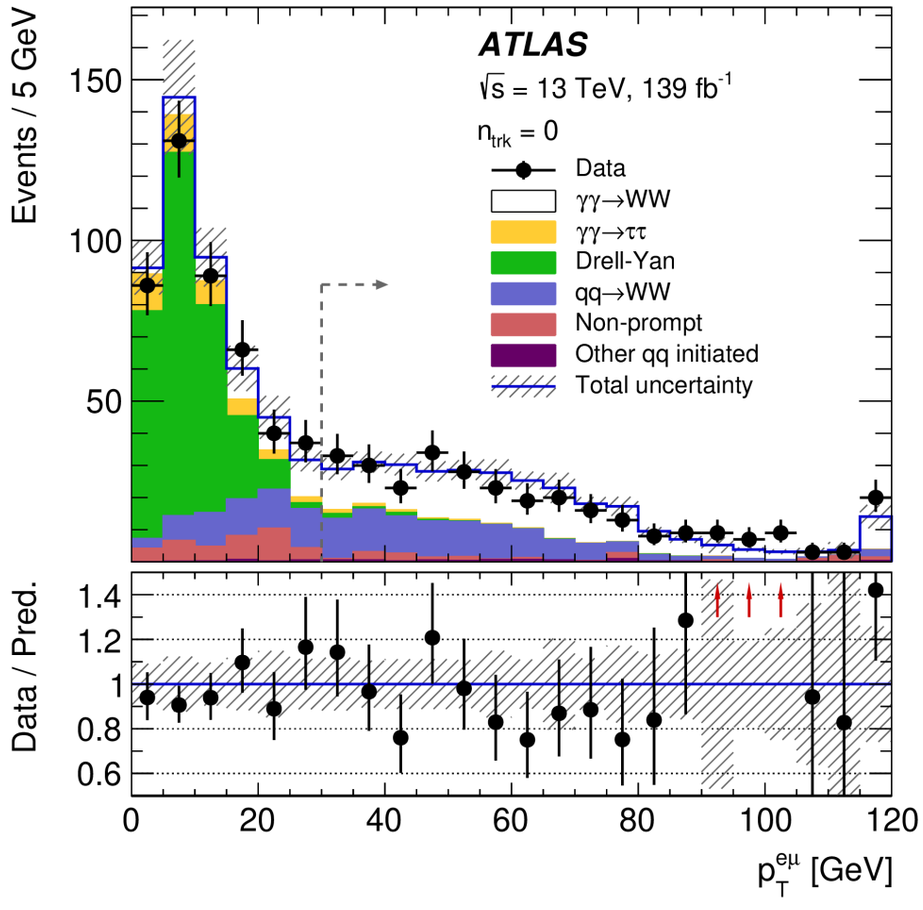
- Study from L. Harland-Lang https://arxiv.org/pdf/2201.08403.pdf:
  - Transfer factor between $\gamma\gamma \to WW$ and $\gamma\gamma \to ll$



Photon Induced WW Production

- PLB 816 (2021) 136190
- $\gamma\gamma \rightarrow WW$ is observed with significance of 8.4 (6.7) sigma





Signal Region

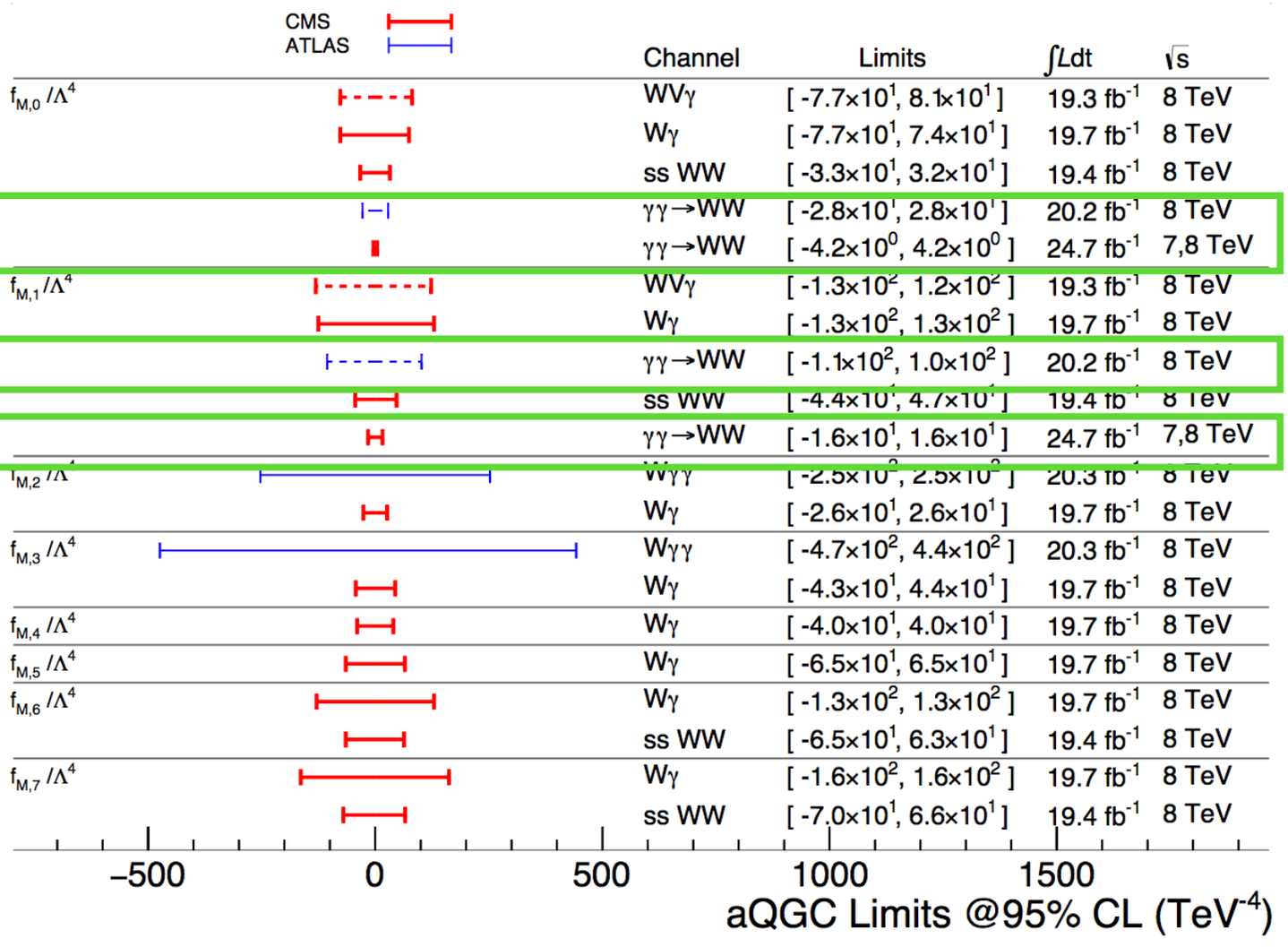
- Measured fiducial cross section:

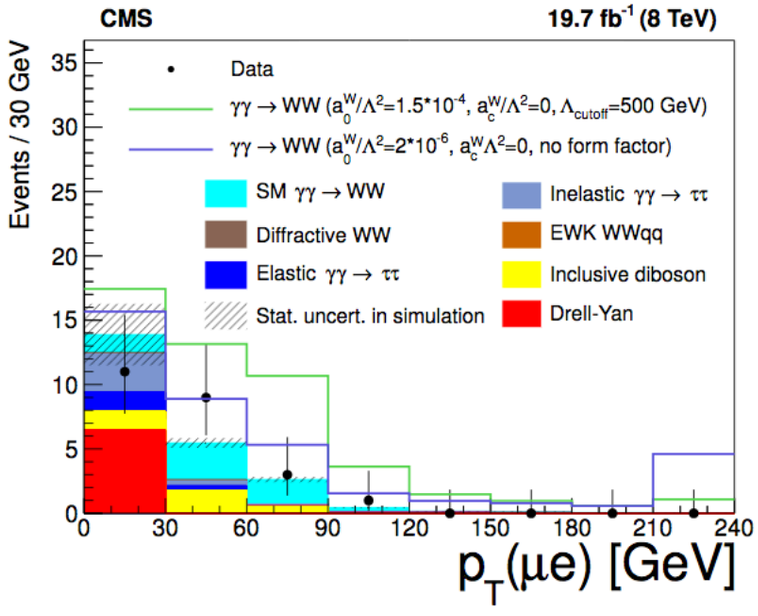
$$\sigma_{\text{meas}} = 3.13 \pm 0.31\,(\text{stat.}) \pm 0.28\,(\text{syst.})\,\text{fb}$$

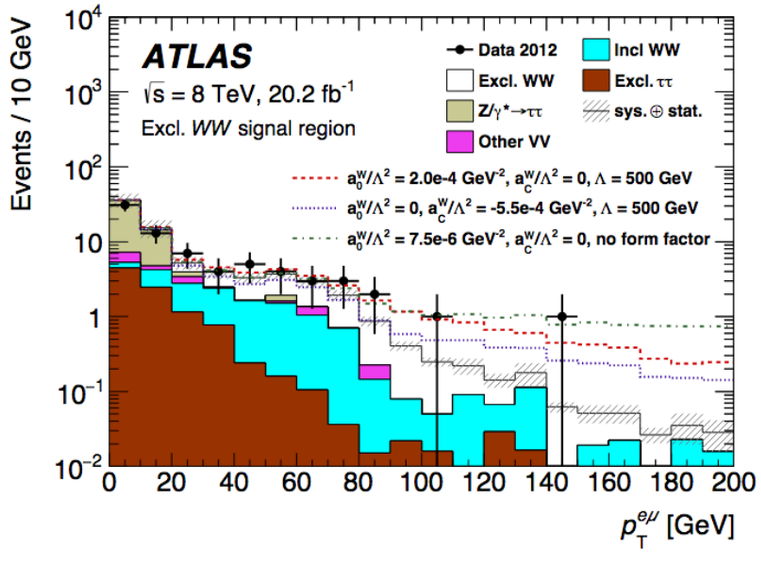
Photon-induced WW Production

- **Anomalous Triple and Quartic Gauge Coupling**
  - Models fully available within MadGraph (using SMEFT)
  - Run-1 ATLAS and CMS limits:

Comparison of the limits on the dimension-eight aQGC parameters







arxiv:1612.09256

Summary

- Identification of photon-induced process
  - With proton tagging
  - Using the central detector information only

- Lots of challenges

- Plenty of data is waiting to be analyzed!!!
  - In future precision measurements

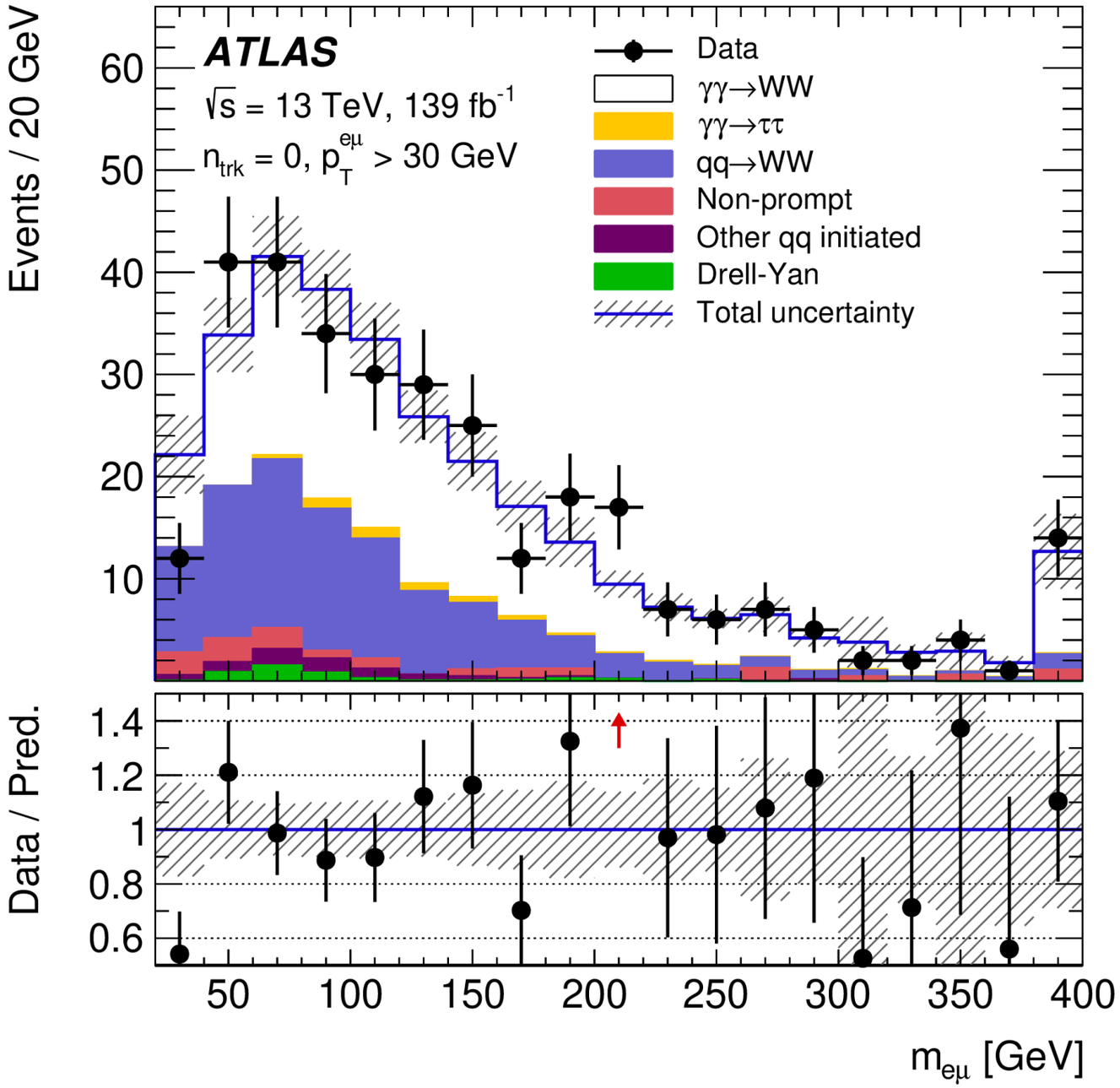
- Better modeling of the dissociative part
  - di-lepton transverse momentum
  - acomplanarity

- **Great time to ramp-up the discussion**
  how to model photon-induced processes more accurately!!!

BACKUP

Photon Induced WW Production

- di-lepton invariant mass



Photon Induced WW Production

- di-lepton transverse momentum