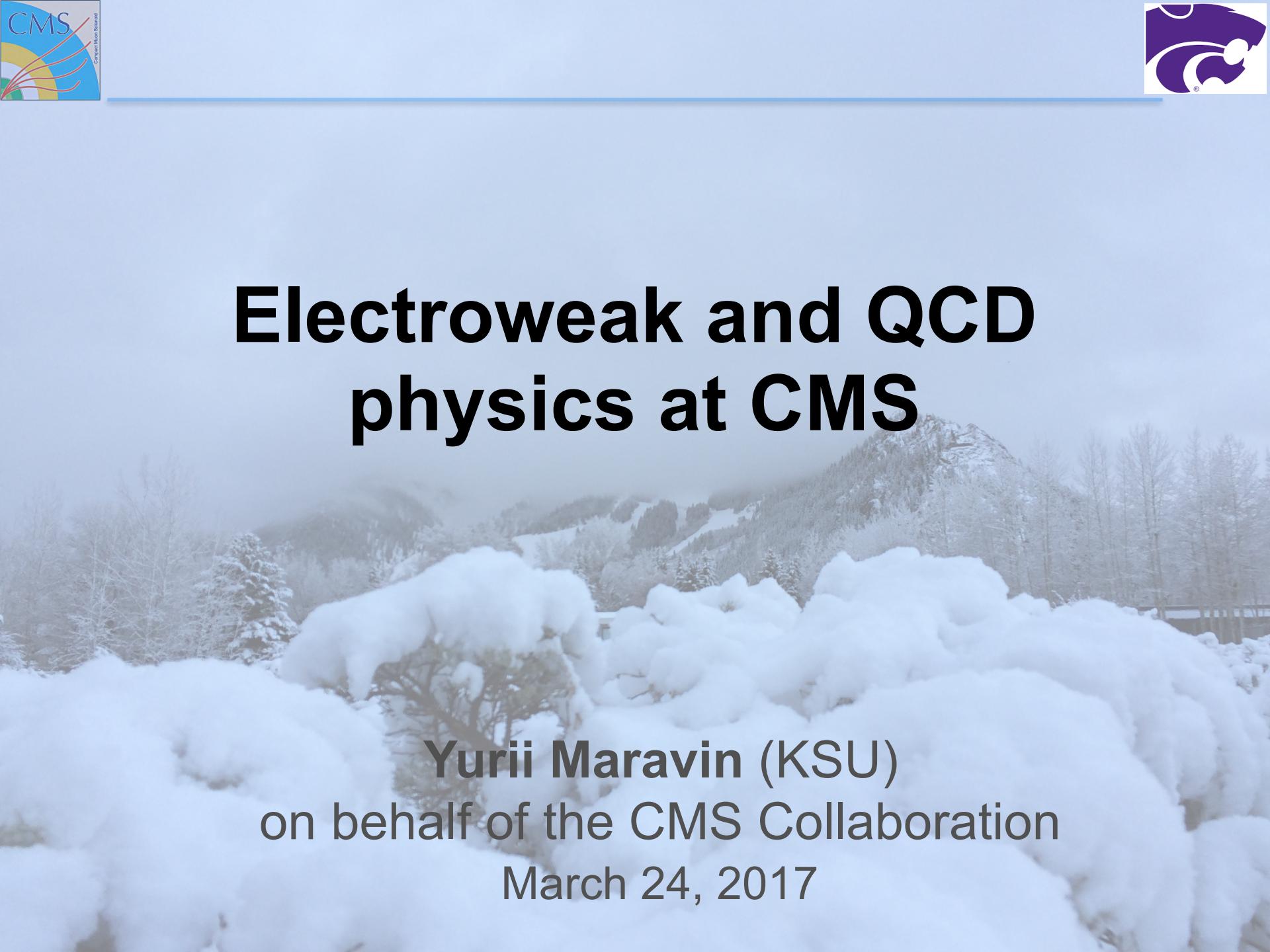


# Electroweak and QCD physics at CMS



Yurii Maravin (KSU)  
on behalf of the CMS Collaboration  
March 24, 2017



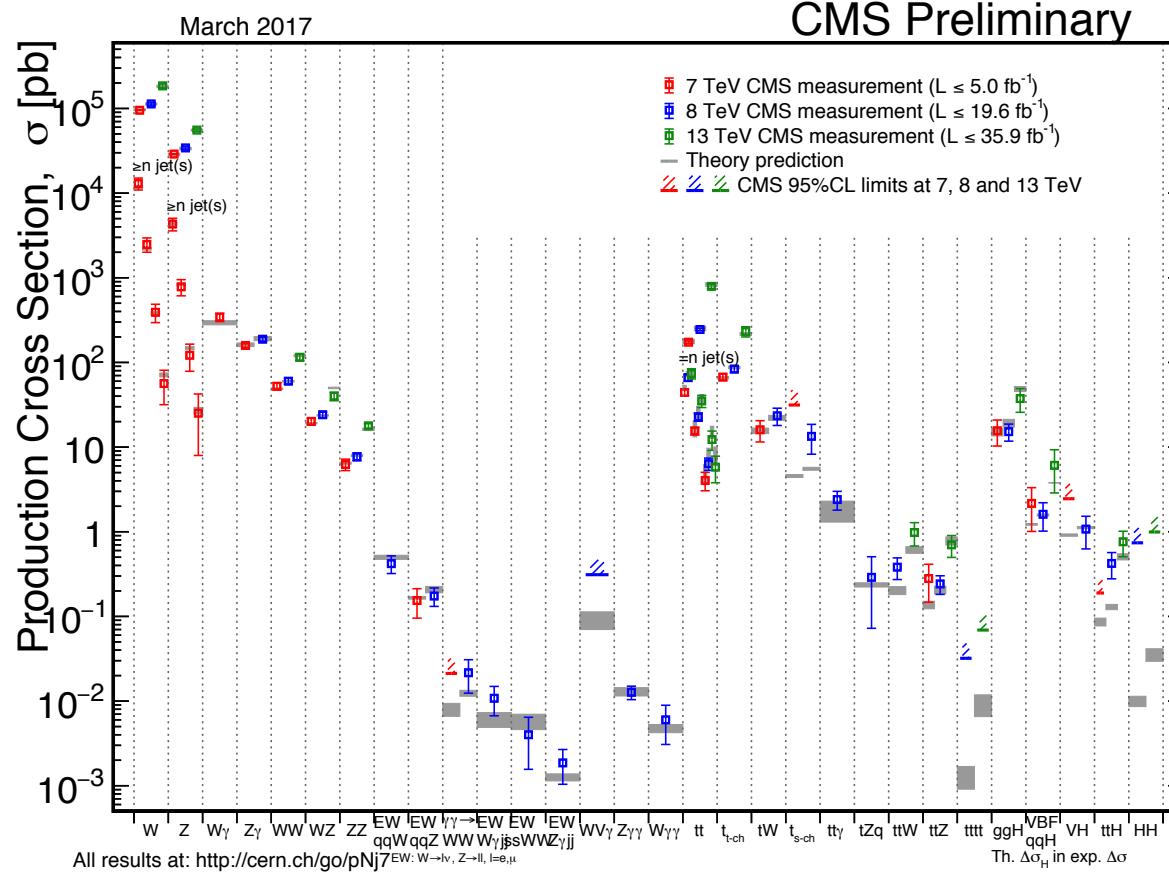
# Electroweak and QCD physics at CMS

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# Standard Model @ CMS

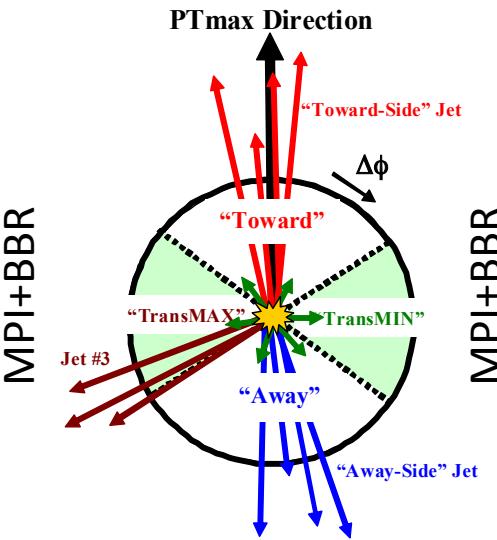
- Lack of evidence for new physics at the LHC implies that we either
  - Not looking where we should
  - Or/and new phenomena are at higher energies/small production cross section
- Precision measurements are of paramount importance as we collect more and more data
  - Improvement of modeling of non-pQCD processes as well as high order perturbative corrections
  - Improved knowledge of processes that are major backgrounds to a number of new phenomena searches
  - Tests of QCD and EWK predictions at high energy
    - (In)direct searches for new phenomena

# Quick overview



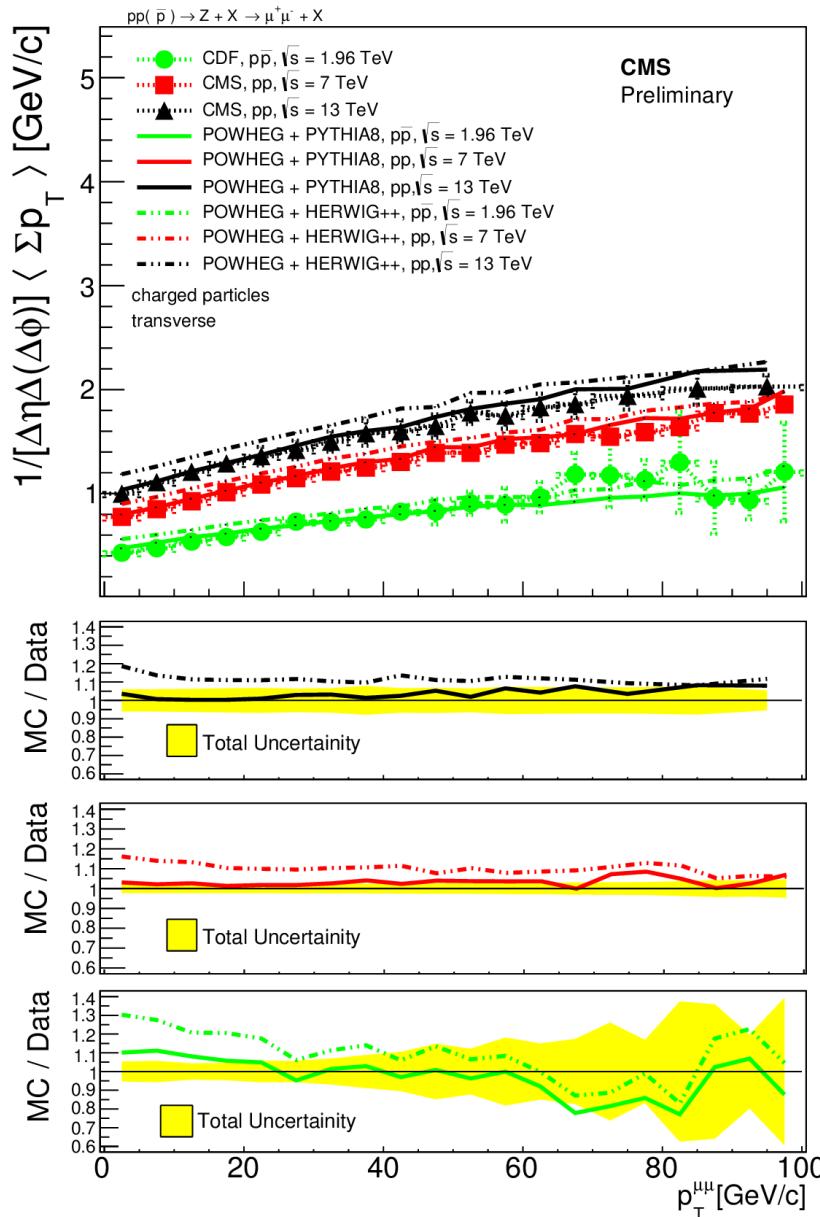
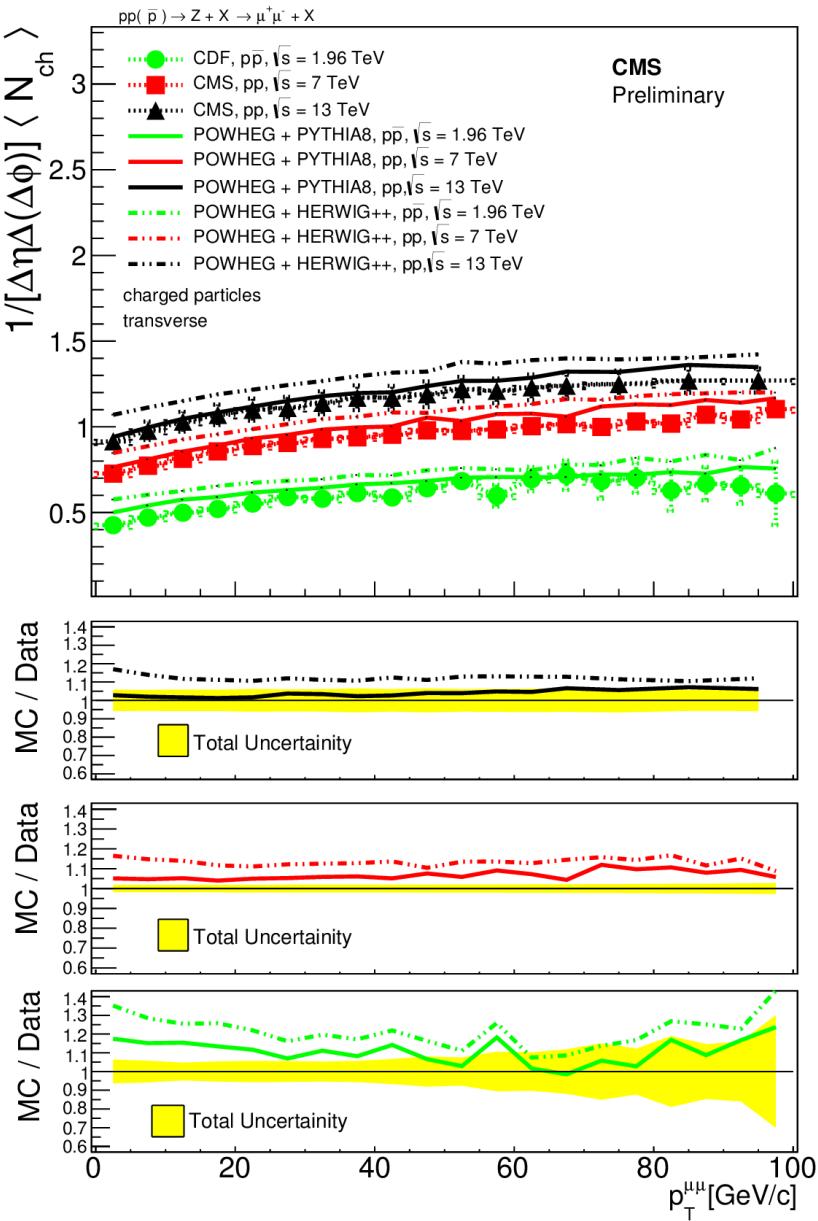
- I will focus only on new results in this talk
  - A more comprehensive link to recent CMS results can be found [here](#)

- Activity from multiple-parton interactions and beam-beam remnants.
  - Cannot be described well by pQCD, hence require phenomenological models, “tunes”
  - Affects isolation, energy scale, jet identification
    - Primary vertex for  $H \rightarrow \gamma\gamma$  analysis
  - MPI can produce high  $p_T$  leptons: background to a number of searches (same-sign dilepton SUSY)
    - Use  $Z \rightarrow \mu\mu$  process and consider standard UE observables:
      - Average charged particle density
      - Average scalar sum of the transverse momenta of tracks
    - Compare with MC predictions
      - MG+Pythia8, Powheg+Pythia8, Powheg+Herwig++



# Measurement of UE @ 13 TeV

**FSQ-16-008**

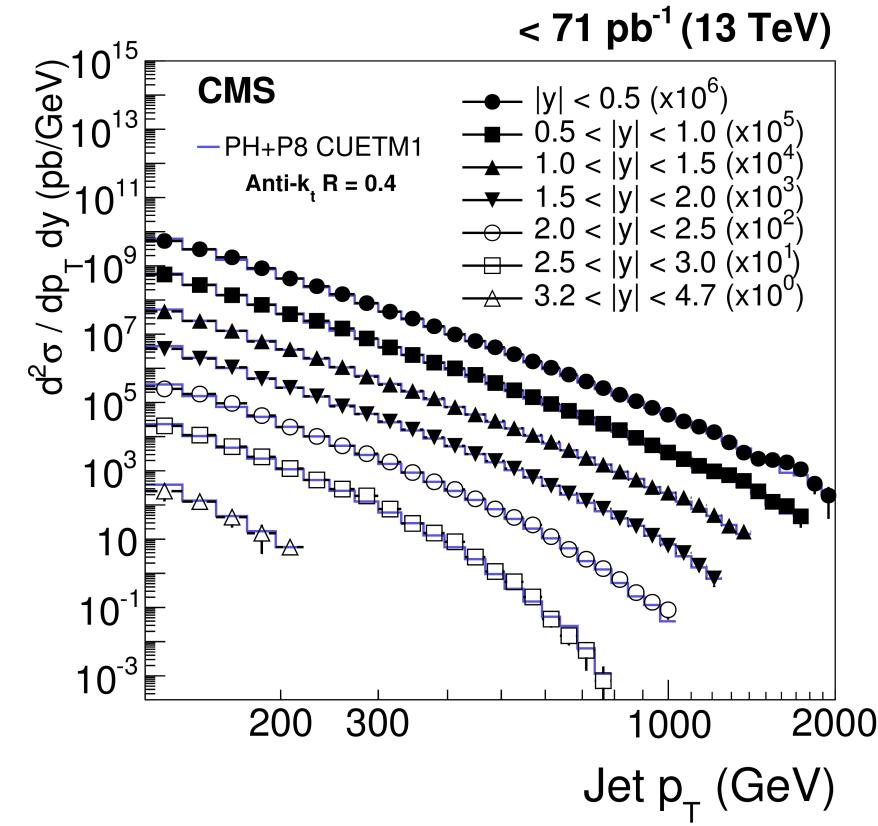
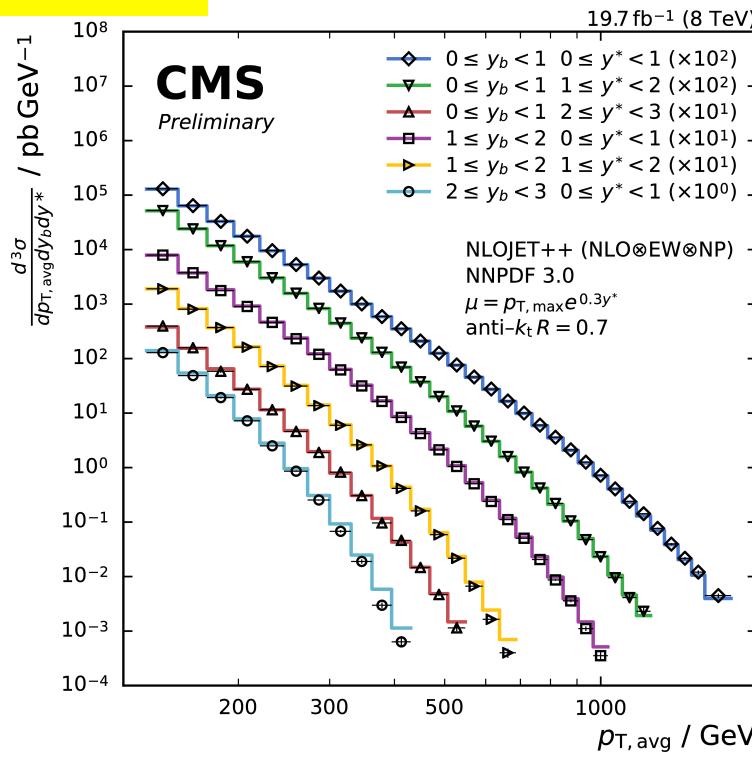


# Recent QCD results

- Double and triple-differential jet cross section measurements for 8 TeV and 13 TeV
  - Use anti- $k_T$  clustering algorithm with  $R = 0.7$  or  $0.4$
  - 7 orders of magnitude, good agreement with NLO QCD predictions + NLO EW + non-perturbative calculations

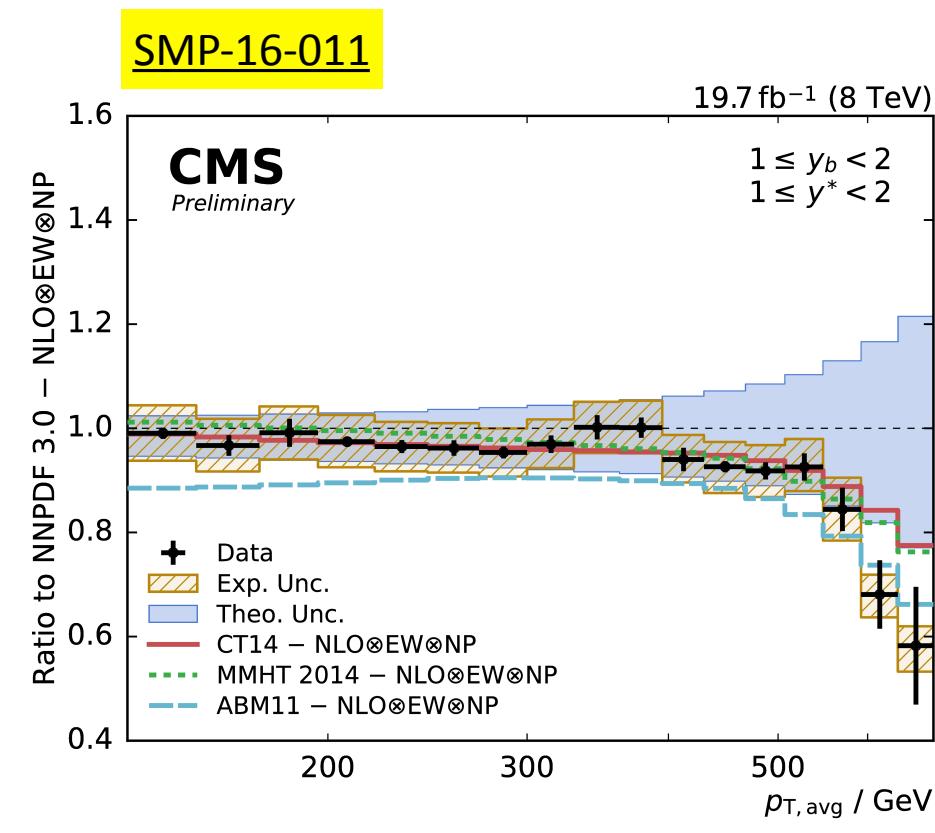
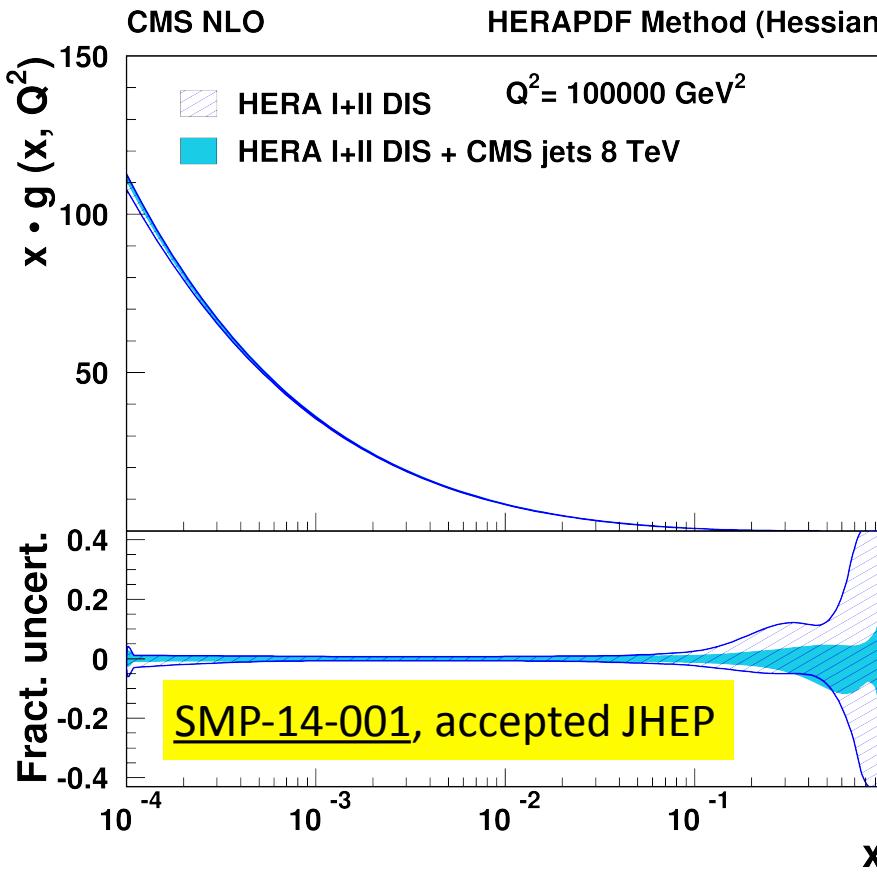
Eur. Phys. J. C 76 (2016) 451

**SMP-16-011**

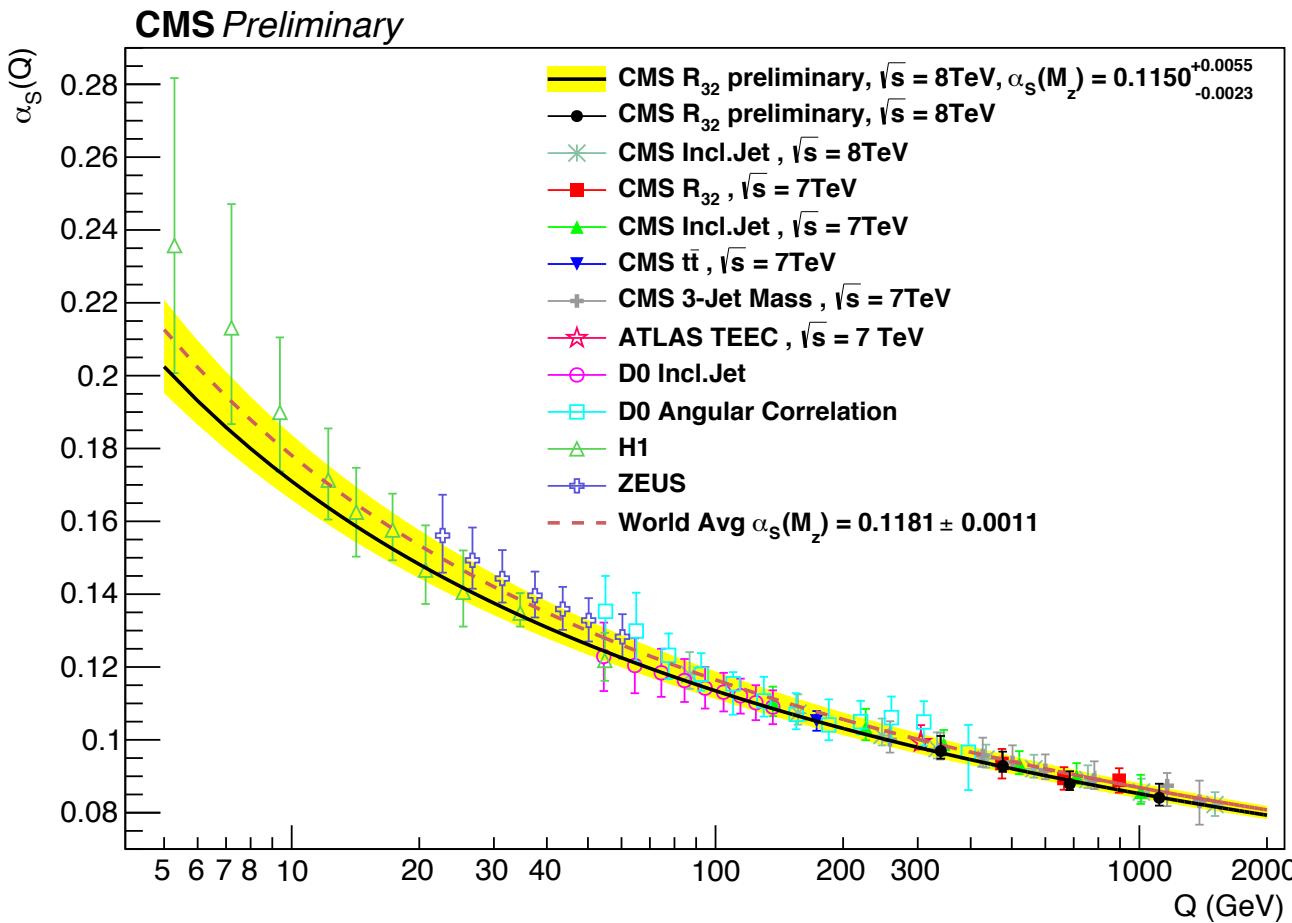


# PDF Constraints

- Considering high  $|y_1 + y_2|$ , high  $p_T$  allows access to high  $x$  values
  - Constrain PDF at high  $x$  (theory uncertainties are larger than experimental)

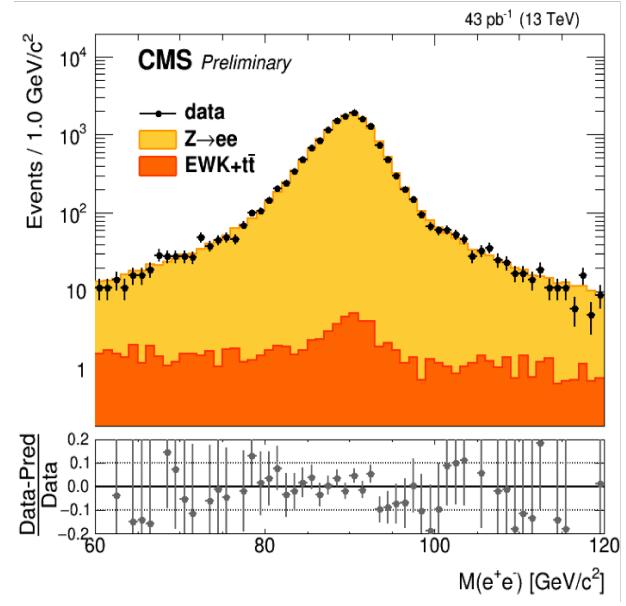
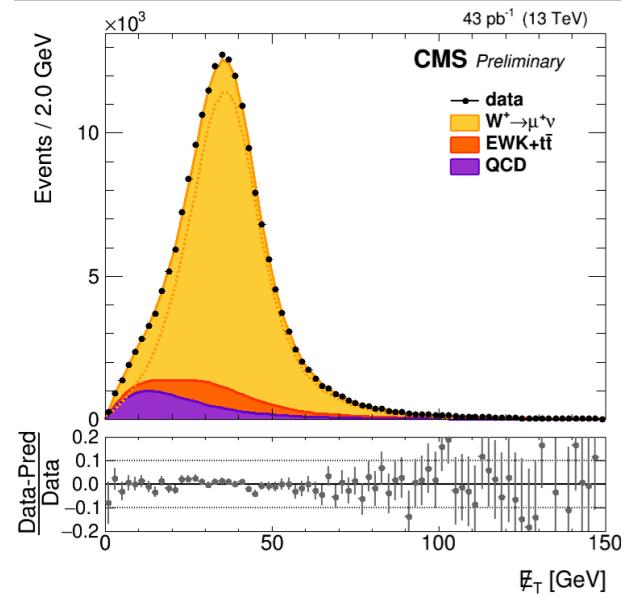
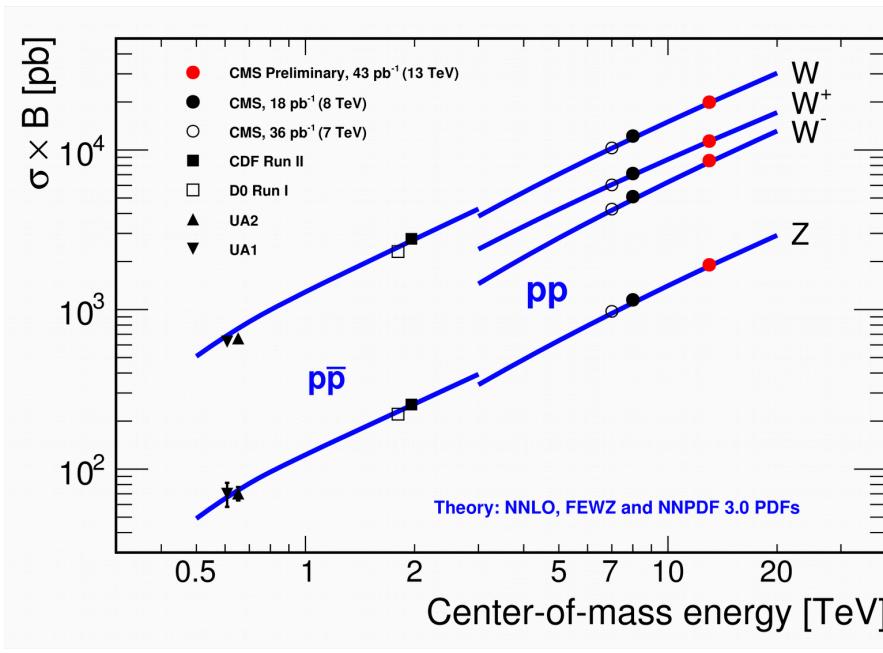


- Use inclusive two- and three-jet event cross sections to extract  $\alpha_s$  at  $M_Z$ 
  - Minimize  $\chi^2$  of the fit of theoretical predictions to data

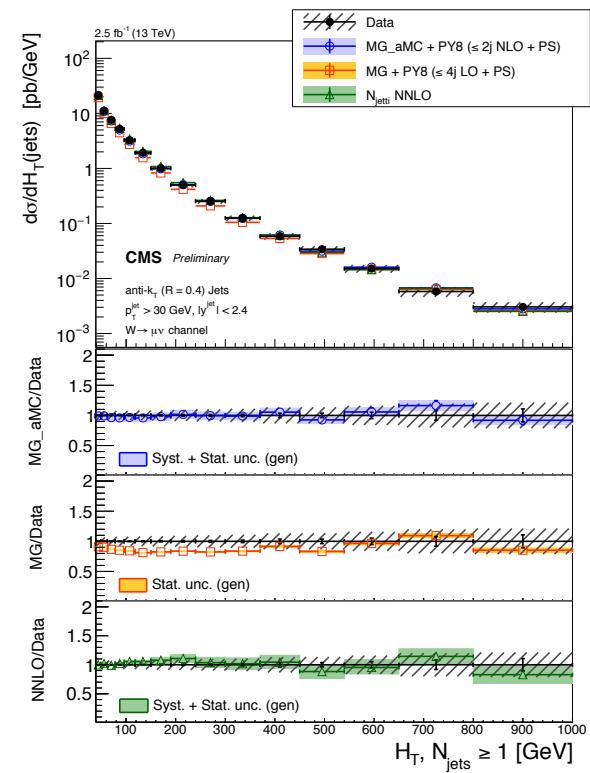
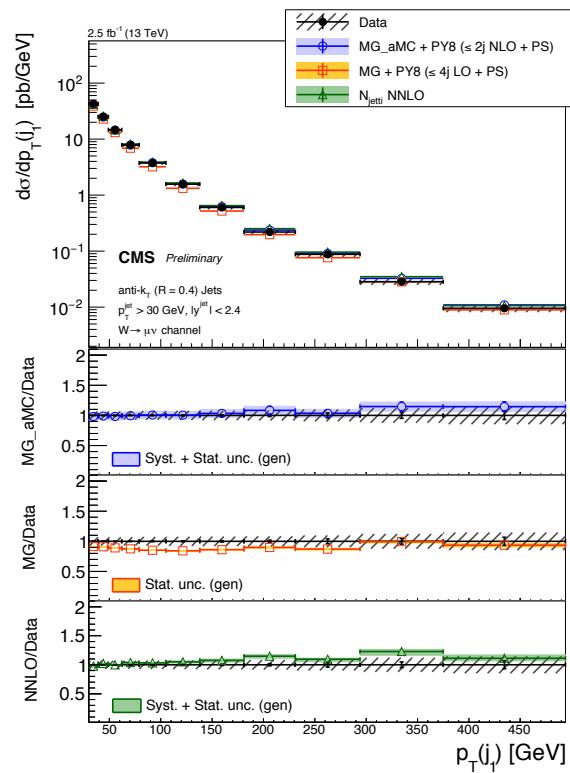
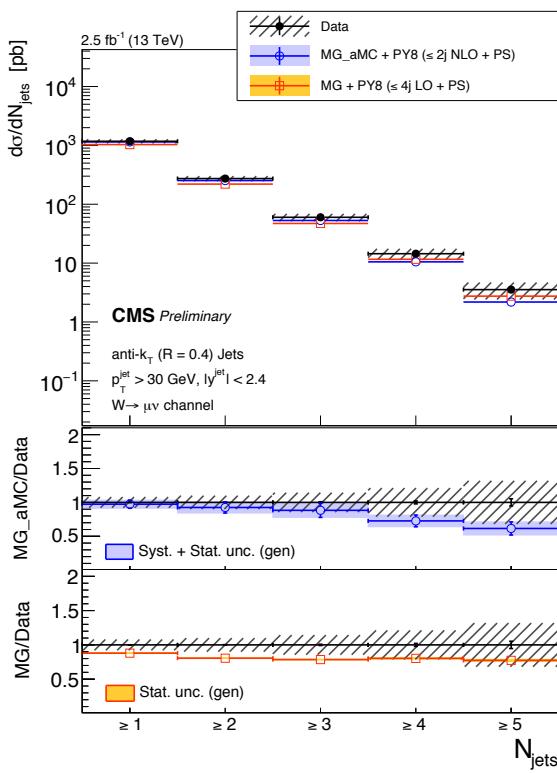


# W and Z production @ CMS

- Inclusive W and Z cross section measurements at 7, 8, and 13 TeV
  - Good agreement with NNLO
- Building blocks for a number of physics analyses
  - V+b/c, differential cross sections and many others



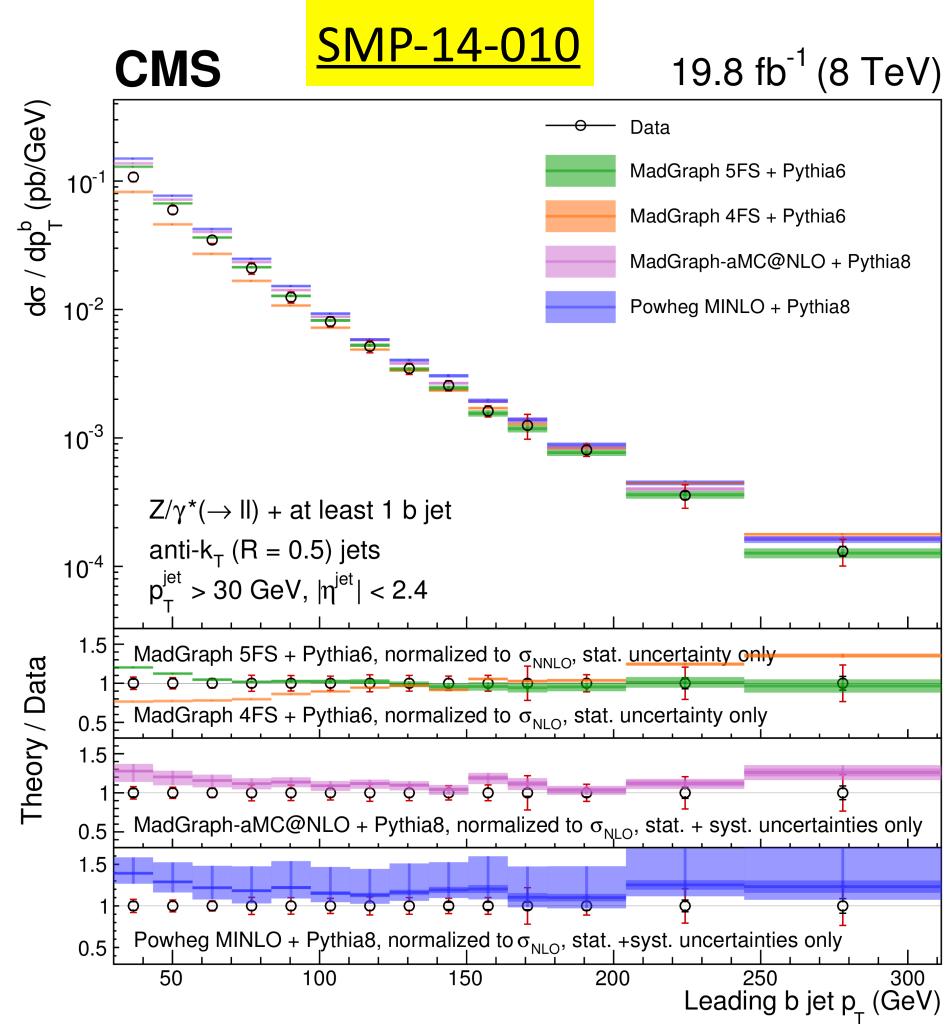
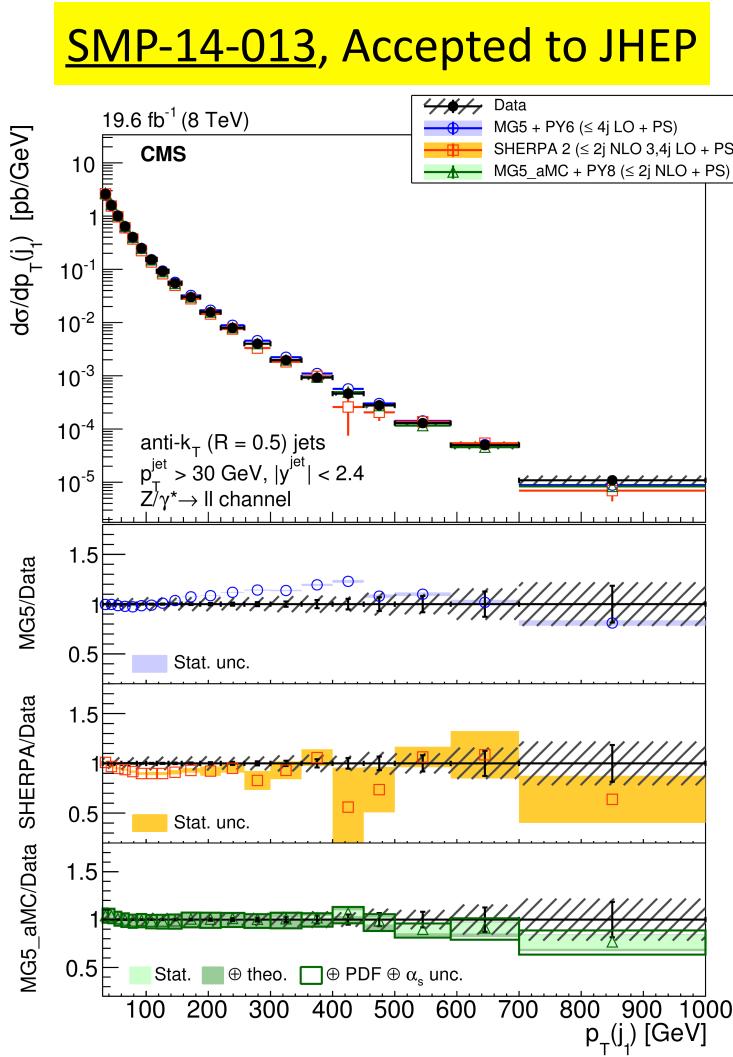
- First 13 TeV results on W+jets differential cross section
  - Sensitive to higher-order corrections but also to soft-QCD effects (PS)



- Good agreement with NLO and fixed-order NNLO predictions

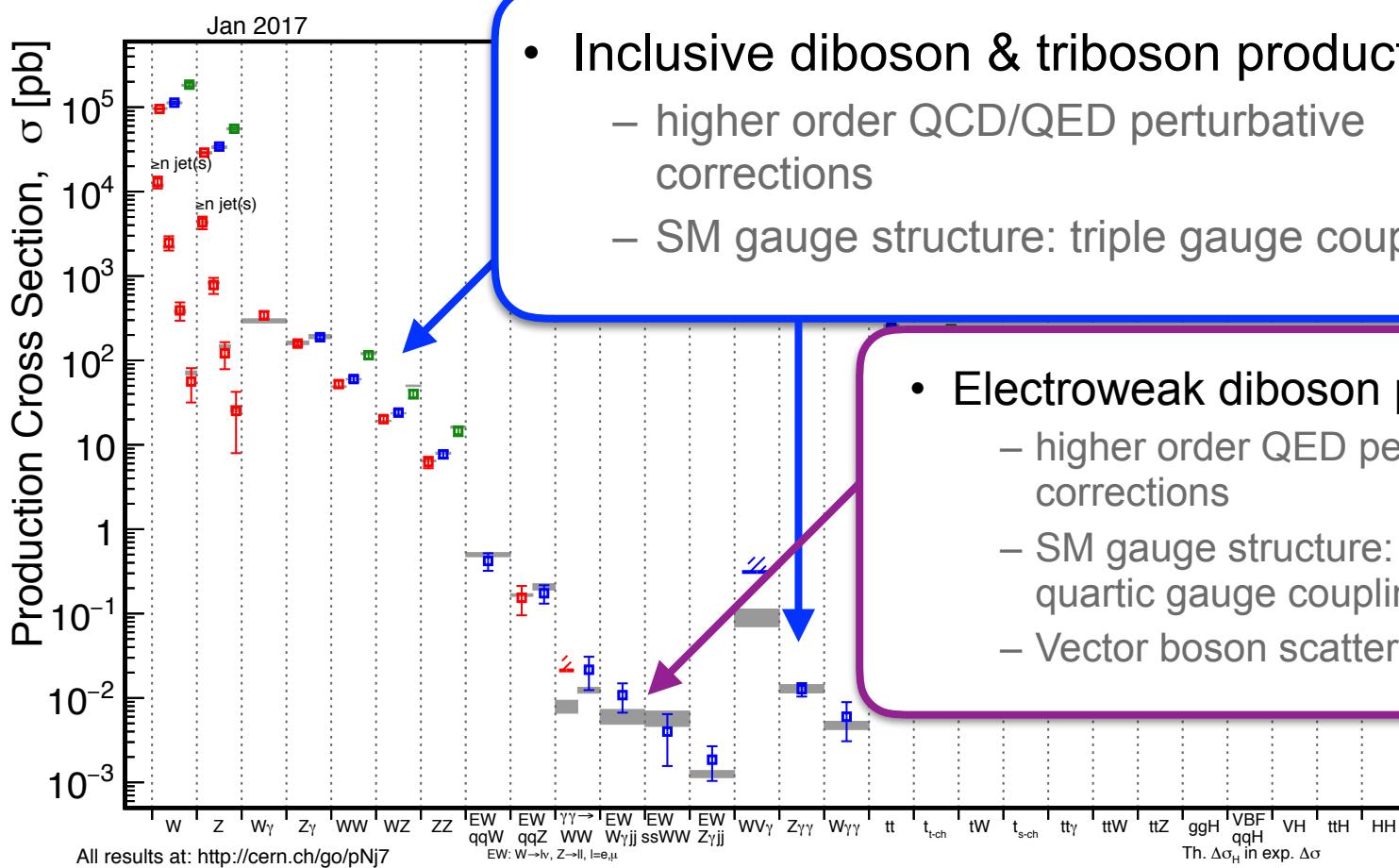
# Z+jets

- Decent agreement between data and prediction for Z+jets, but plenty of discrepancies when focusing on heavy flavor



# Multiboson physics

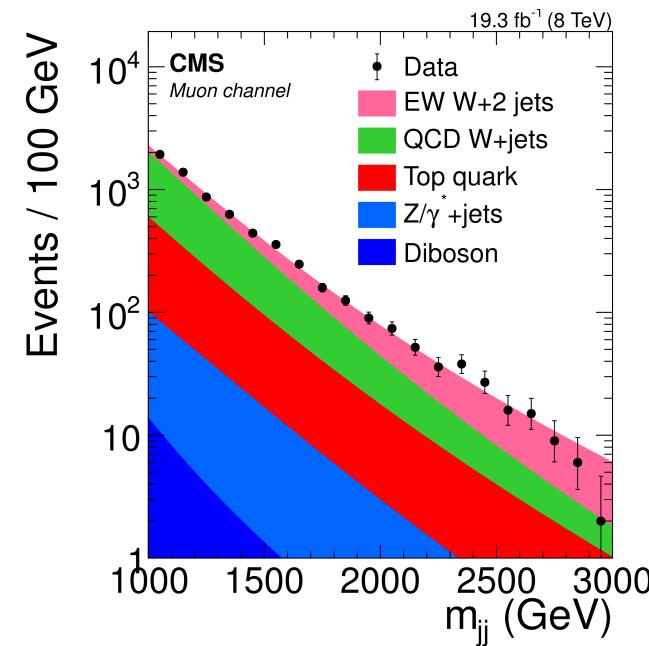
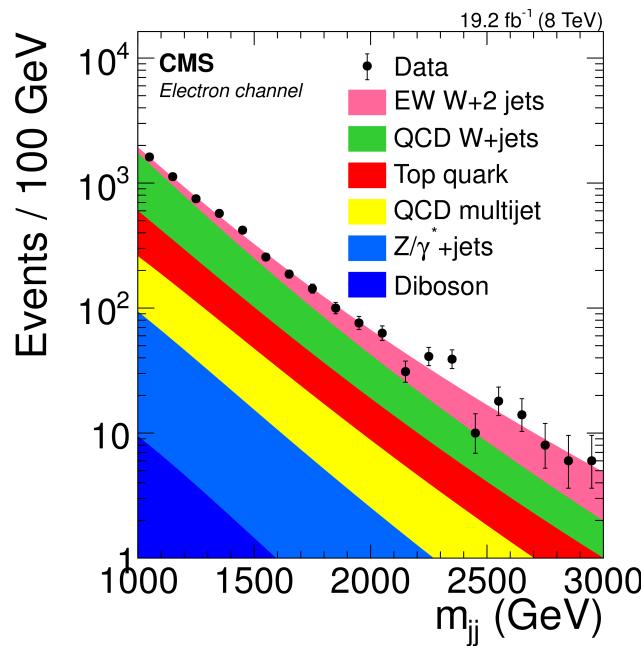
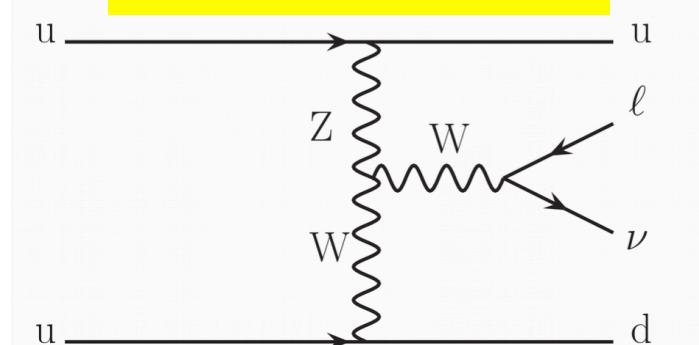
- Multiboson processes span five orders of magnitude in cross section
  - Important test of SM: gauge boson self-interaction
  - Important background for many Higgs analyses and exotica searches



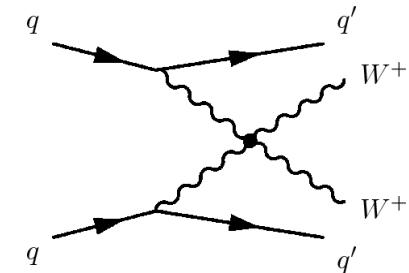
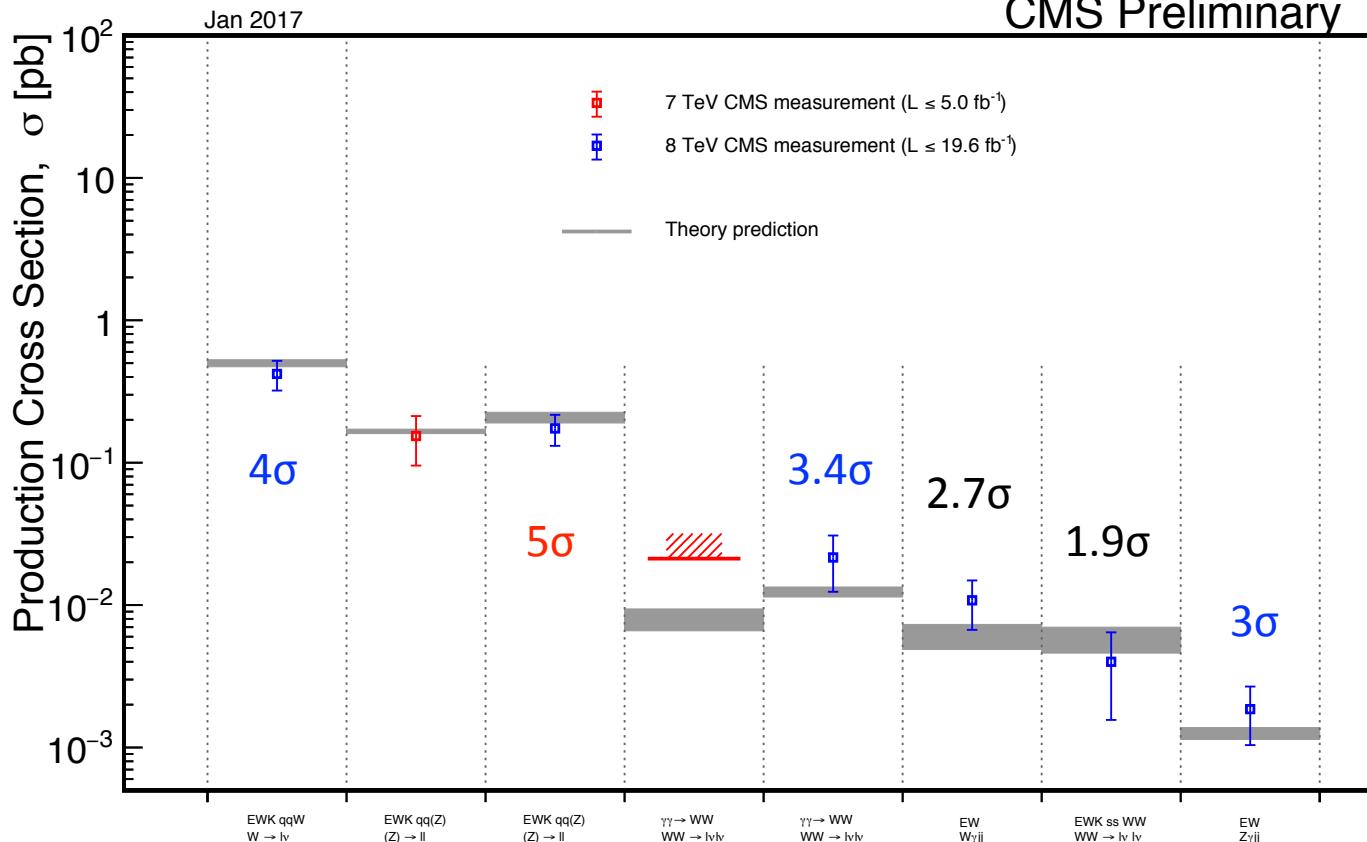
# W boson electroweak production

- Vector boson fusion signature results in two high  $|n|$  jets with large invariant mass  $m_{jj}$  and little activity in the central region
  - Probe of WWZ coupling
- Good agreement with NLO prediction
  - Evidence for signal @  $4\sigma$

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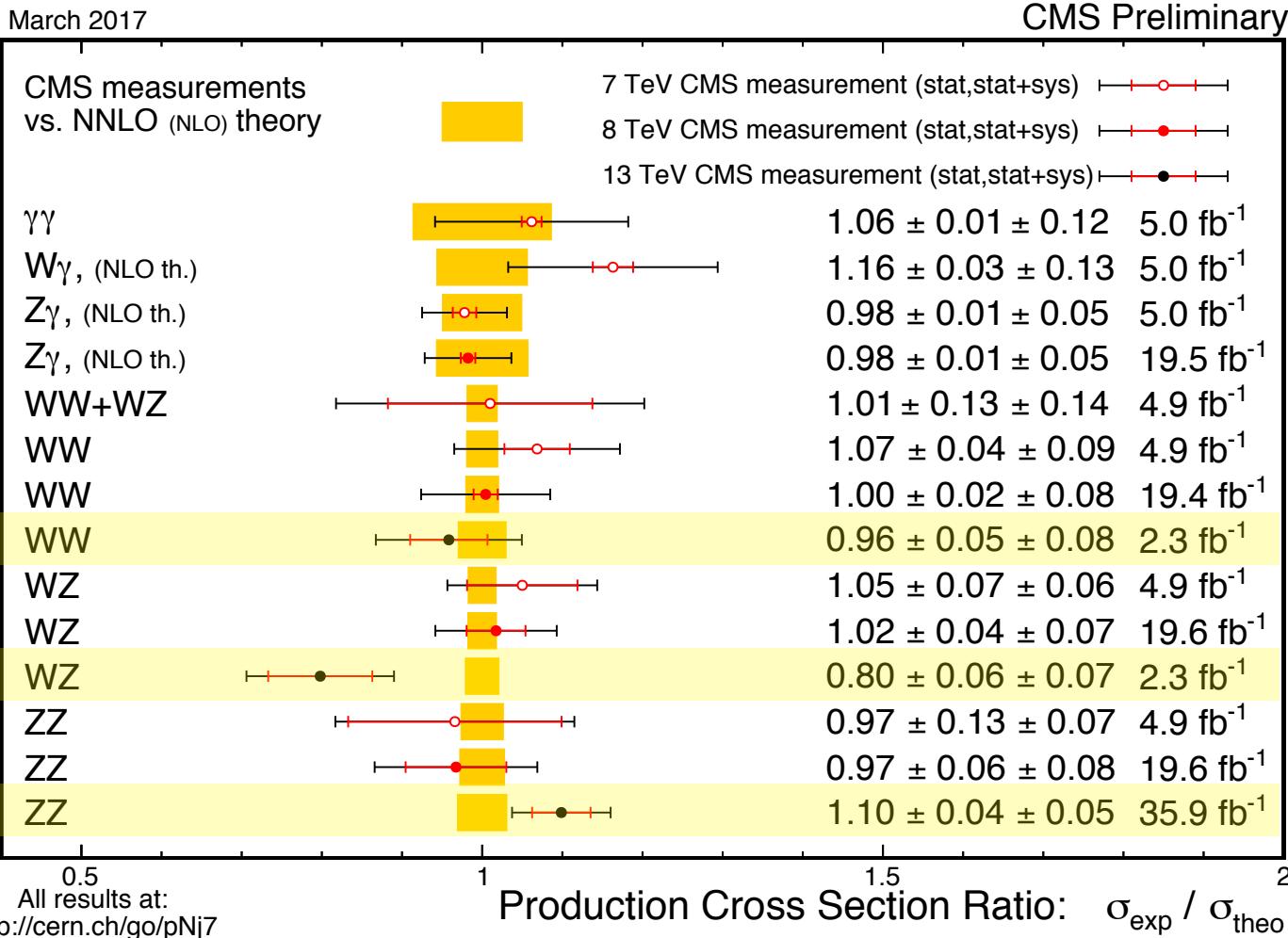


# Electroweak production summary



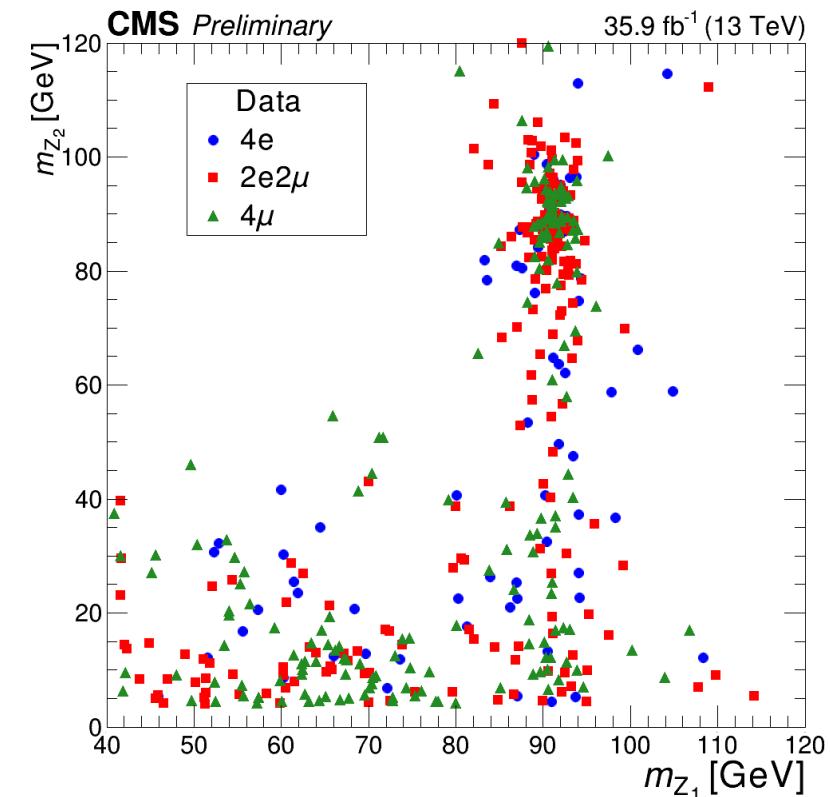
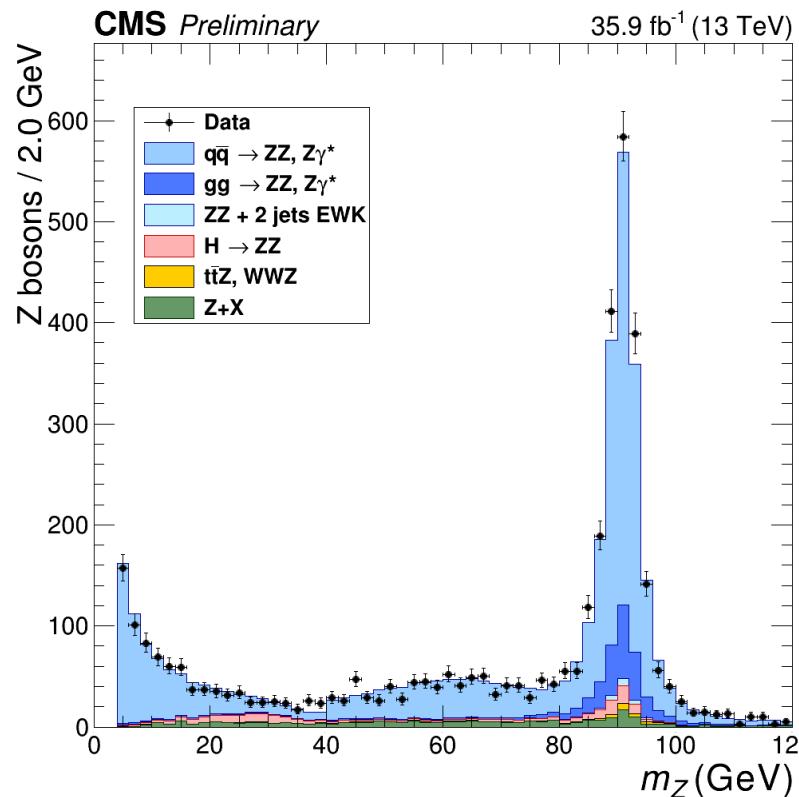
- At the moment only EWK  $Z \rightarrow \ell\ell$  is observed with  $5\sigma$  significance
  - Expect a number of new results with 13 TeV in the next several months

# Summary of diboson results

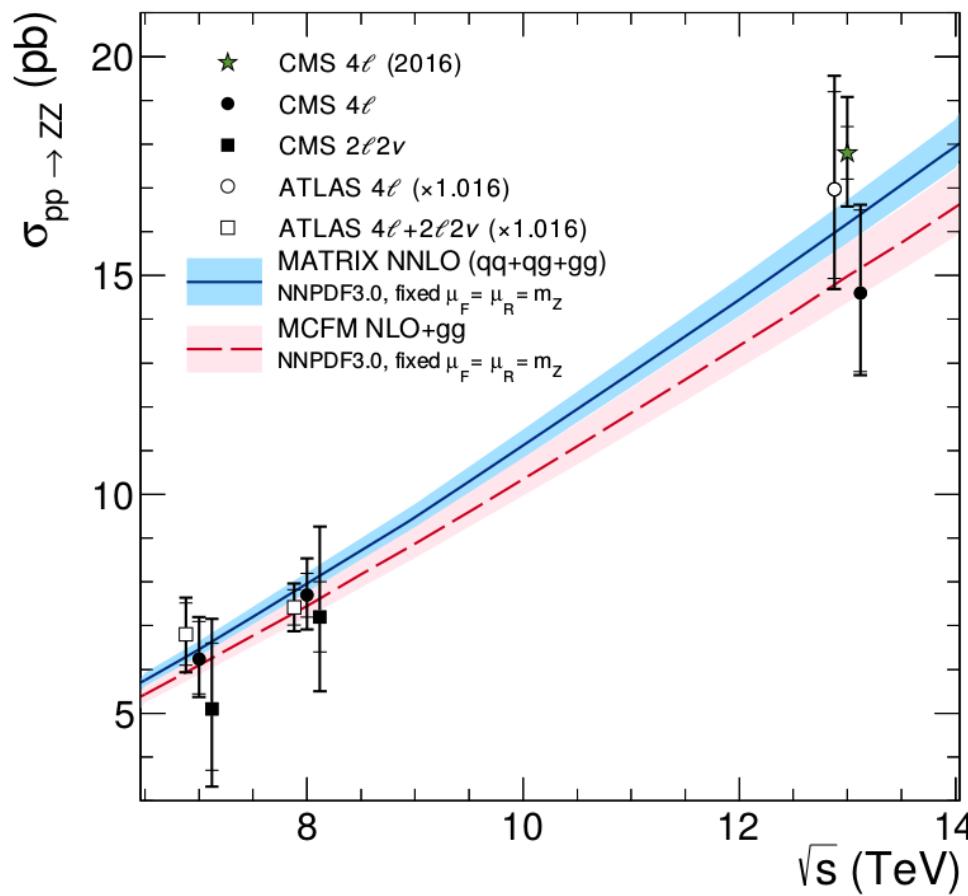


- Several results with 13 TeV data including very recent  $ZZ \rightarrow 4\ell$  with full dataset

- Select events with four charged leptons
  - About 900 candidate events in all four categories



# Z $\rightarrow$ 4 $\ell$ cross section measurement

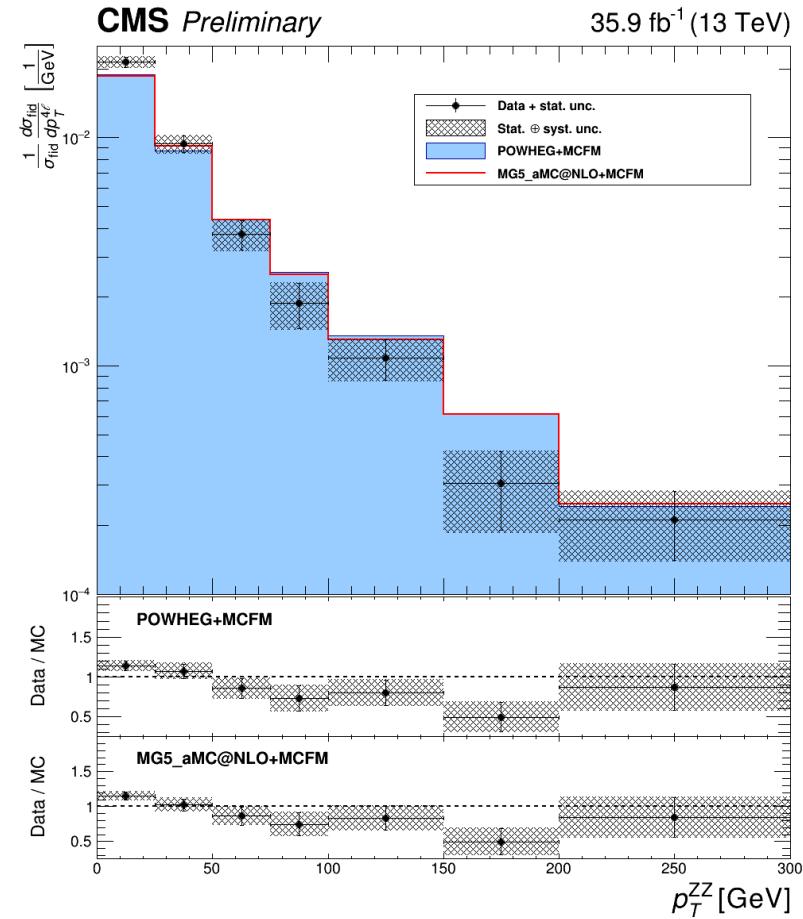
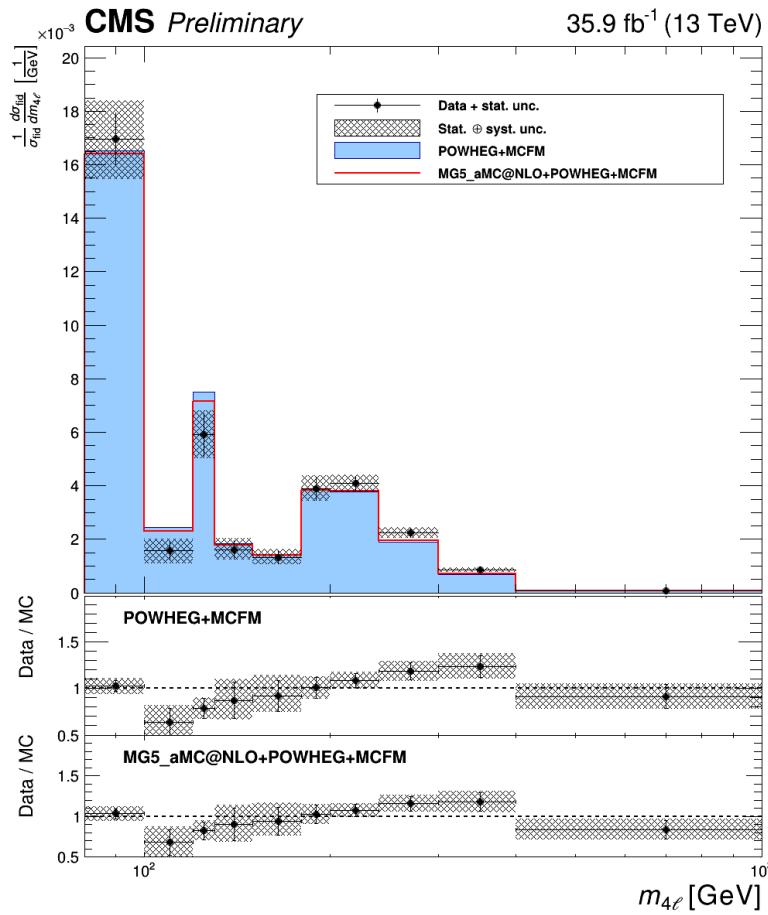


SMP-16-017

- Cross section agrees well with NNLO prediction
- Perform differential cross section as function of  $p_T(ZZ)$

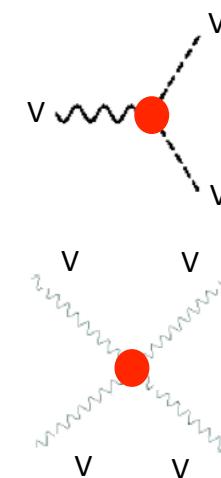
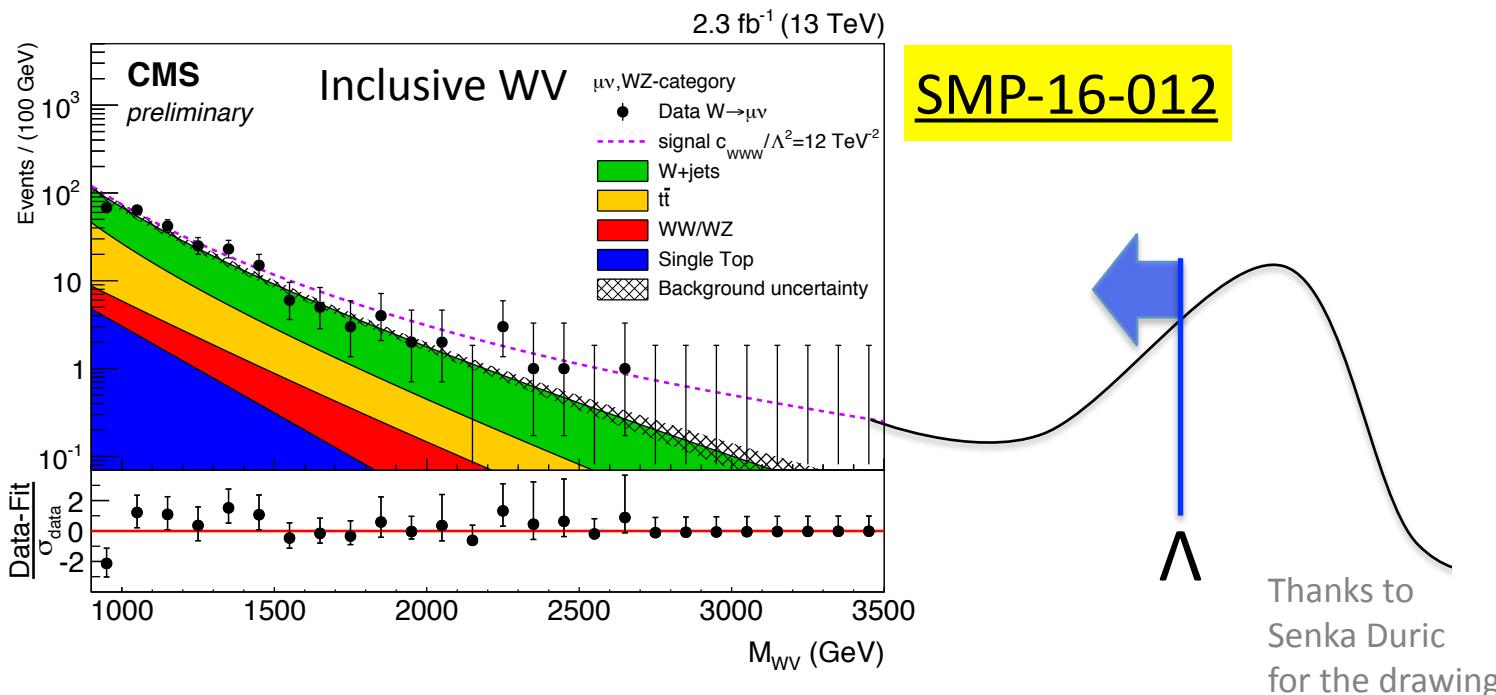
# Differential $Z \rightarrow 4\ell$ cross section SMP-16-017

- Possible indication for a softer  $p_T^{ZZ}$  than what is predicted by both Powheg+MCFM and MG+MCFM



# Search for anomalous gauge couplings

- Search for new physics by searching for deviation from SM prediction (harder recoil, excess in mass tails etc.)

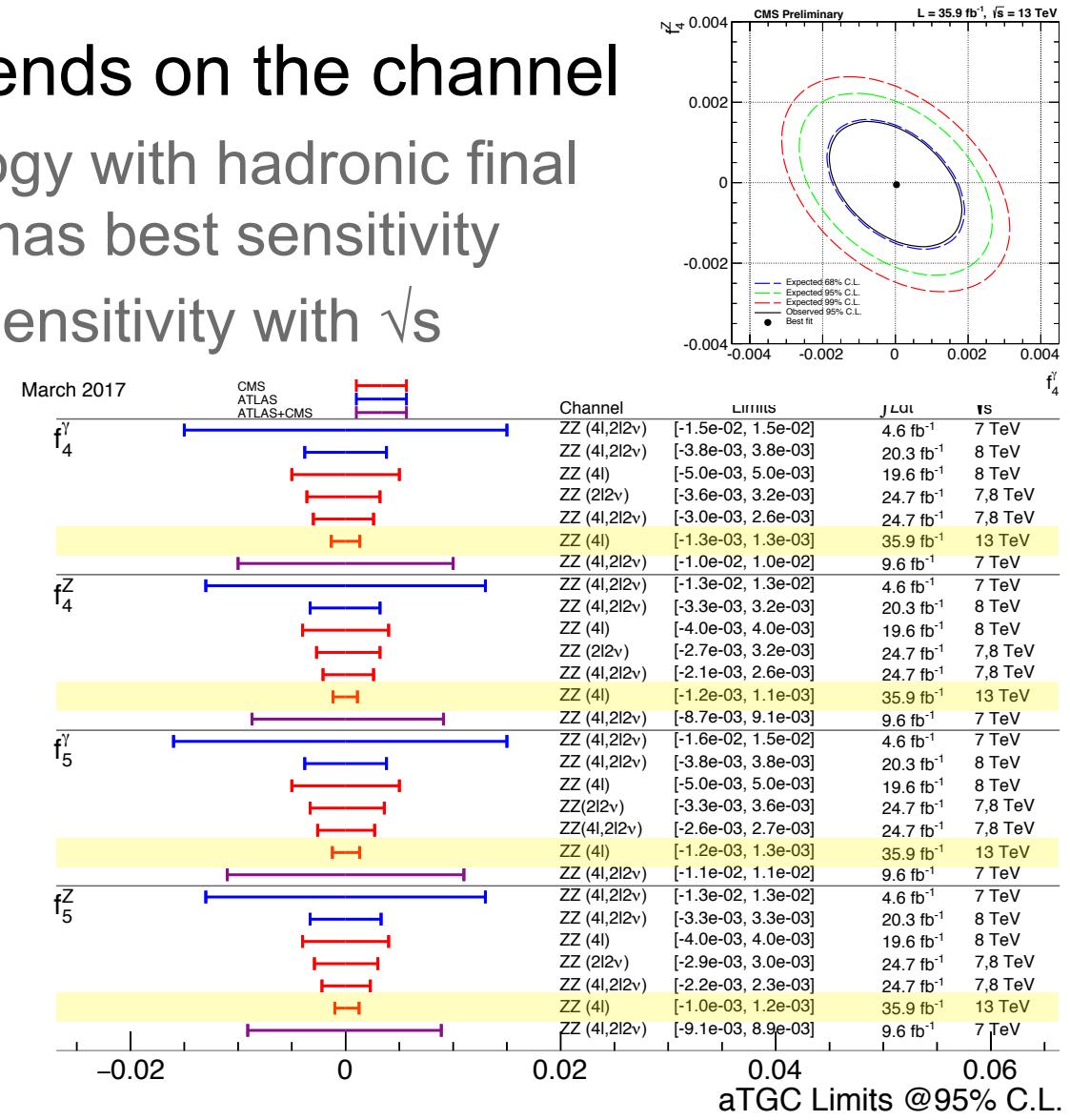
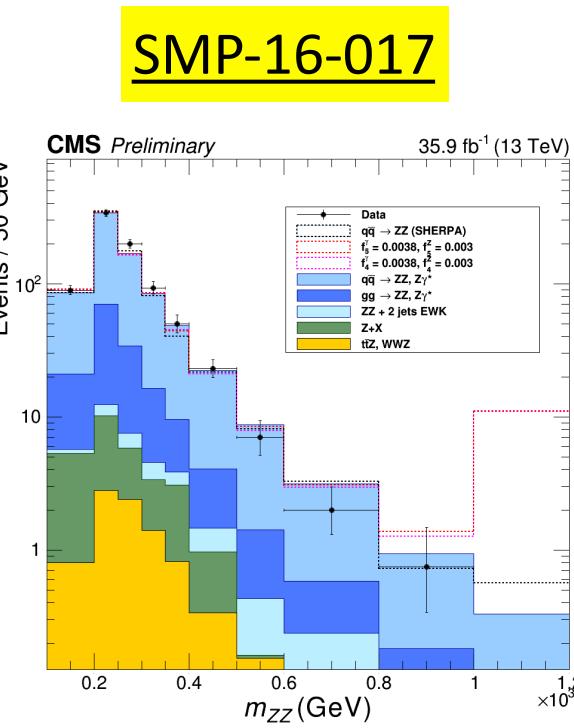


- Extend SM Lagrangian with additional operators and anomalous parameters

EFT:  $\mathcal{L}_{SM} \longrightarrow \mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{n=1}^{\infty} \sum_i \frac{c_i^{(n)}}{\Lambda^n} \mathcal{O}_i^{(n+4)}$

# Anomalous coupling results

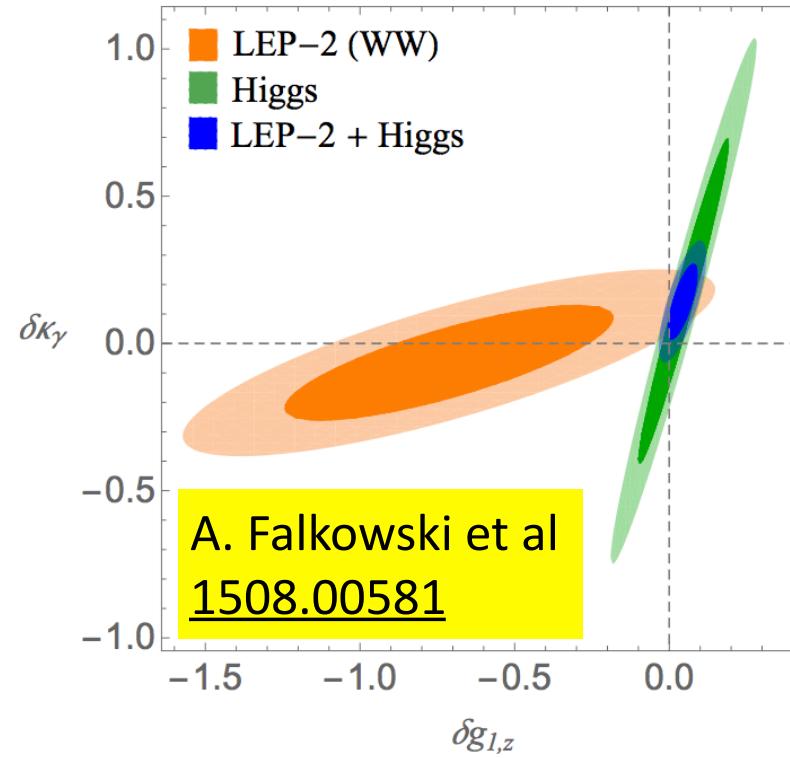
- Sensitivity depends on the channel
  - Boosted topology with hadronic final states usually has best sensitivity
  - Large gain in sensitivity with  $\sqrt{s}$



<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC>

# Future prospects

- Full 13 TeV dataset will provide significantly stronger limits due to increase in  $\sqrt{s}$
- Combination with ATLAS results as well as Higgs measurements will further improve sensitivity to anomalous gauge couplings



# Summary

- Known QCD and EW processes continue to be studied in greater detail
  - Results benefit from (and drive) the advancements in theoretical calculations and MC generators
    - NNLO or 3NLO QCD, NLO EWK...
  - A large fraction of major systematic uncertainties will go down with more data
- Enough statistics to see EW production of diboson processes: path toward  $W_L W_L$  scattering
  - Development of data analysis tools (boosted techniques, using jet substructure for hadronic W and Z decays etc.)
- Expect a significant increase in sensitivity to anomalous gauge boson self-interaction couplings
  - Await for a suite of new results by summer conferences!