High mass Drell-Yan measurements

Ultimate Precision at Hadron Colliders
December, 2019

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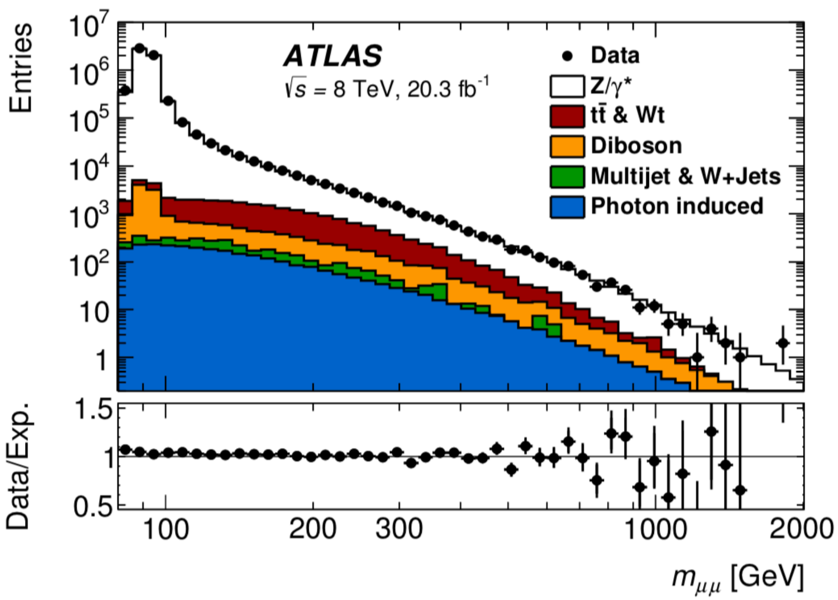
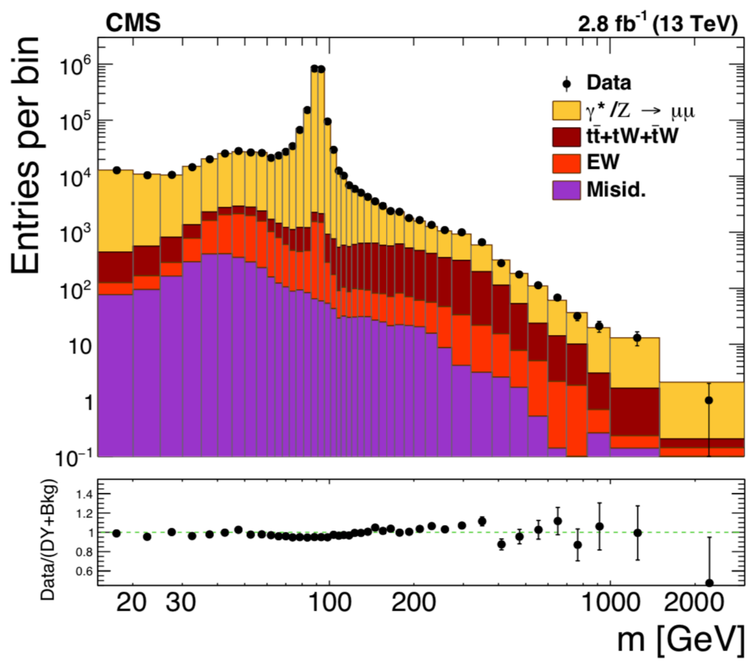
Introduction

- Measurement of the Drell-Yan production at high invariant masses (mll>116 GeV)
  - Sensitivity to PDFs at large x (current constraints are poor)
    - Some sensitivity to photon induced production (γγ->ll)
  - Constraints on BSM physics
    - Resonant or broad modifications of the spectrum





JHEP 08 (2016) 009

arXiv:1812.10529

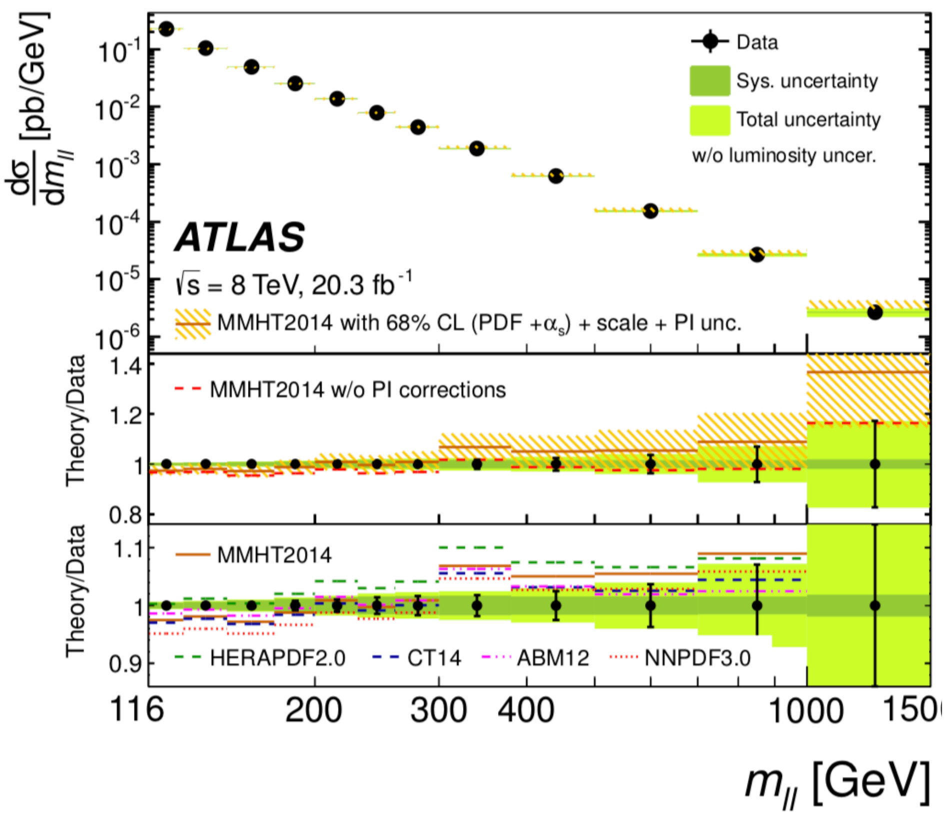
LHC measurements

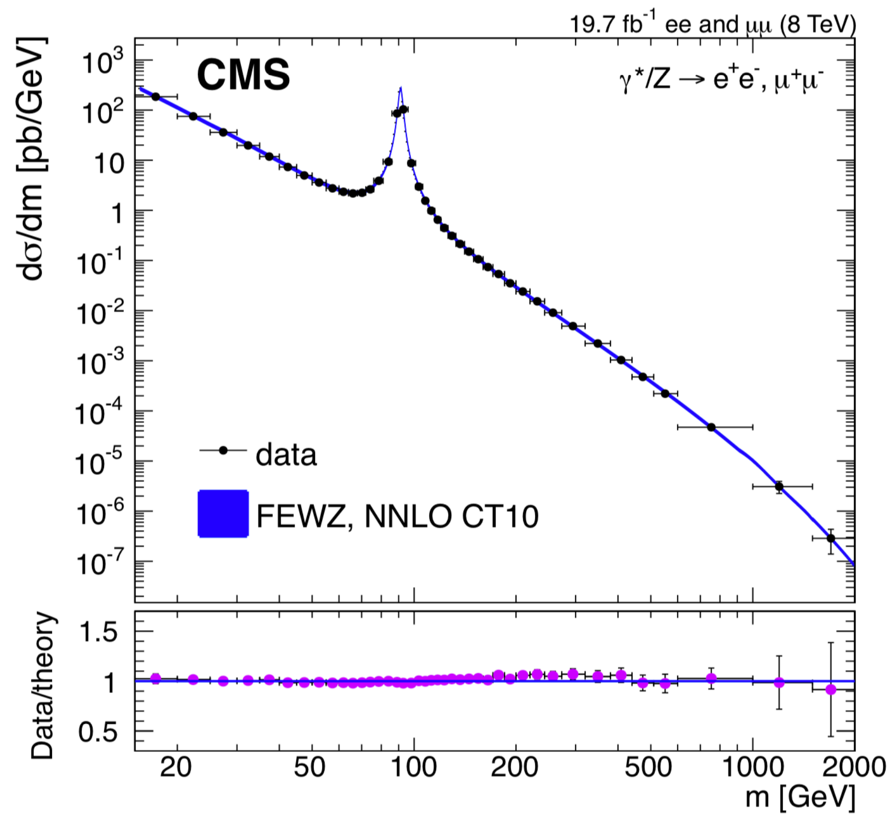
- High-mass neutral current Drell-Yan measurements at LHC
  - Clean experimental signature (electron and muon final states)

- ATLAS measurement at 8 TeV (integrated luminosity of 20.3 fb^{-1})
  - JHEP 08 (2016) 009
  - $d\sigma/dM$, $d^2\sigma/dMd|Y|$, $d^2\sigma/dMd\eta ll$
  - 116 < Mll < 1500 GeV
- CMS measurement at 8 TeV (integrated luminosity of 19.7 fb^{-1})
  - Eur. Phys. J. C 75 (2015) 147
  - $d\sigma/dM$, $d^2\sigma/dMd|Y|$
- CMS measurement at 13 TeV
  - arXiv:1812.10529, $d\sigma/dM$
  - Making use of 2015 dataset at 13 TeV (up to 2.8 fb^{-1})
  - Mll<3000 GeV

ATLAS/CMS measurements at 8 TeV

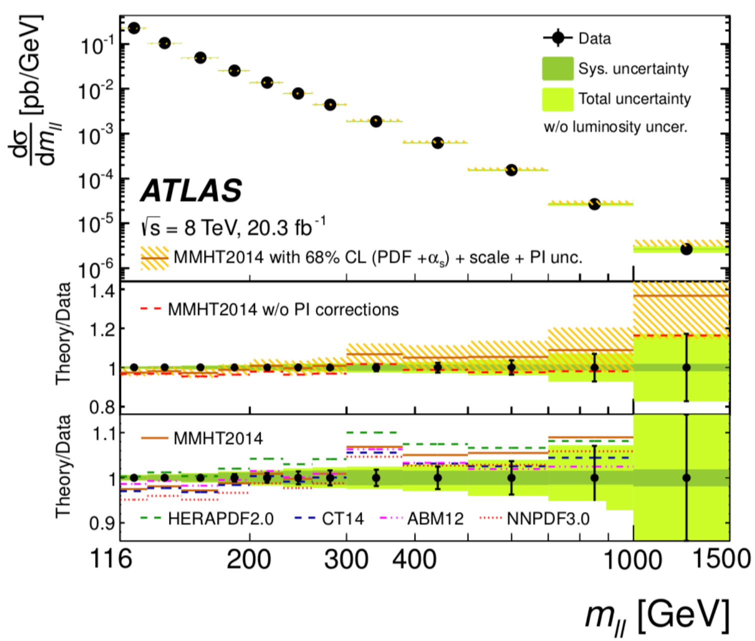
- High-mass neutral current Drell-Yan measurements at LHC
  - Measurements compared to NNLO pQCD predictions with FEWZ 3.1

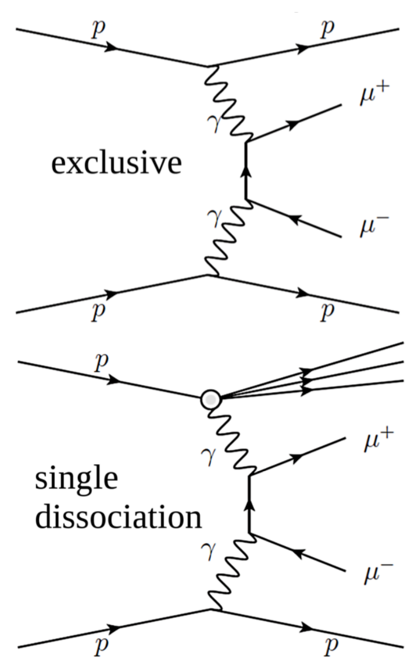




Treatment of photon-induced contribution

- CMS subtracted photon-induced contribution
- ATLAS designed the analysis to be sensitive to photon-induced (PI)
    - Constraints on photon PDF derived (sensitivity far superseded by LUXQED)
    - Contribution reaches as much as ~15-20% in the high mass region
- Recent discussion within the LHC EW precision group on the treatment of the PI contribution in the future measurement
    - https://indico.cern.ch/event/864105/





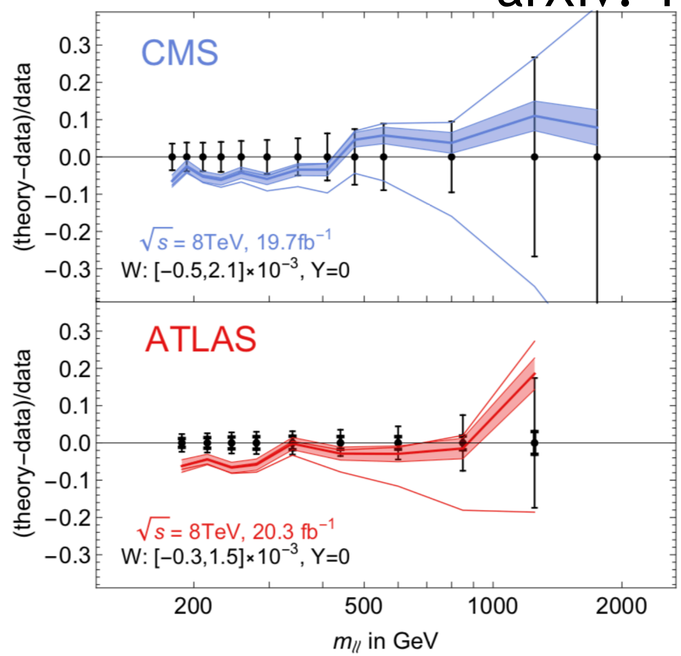
Systematic uncertainties

- Data statistical uncertainties are dominant in Run-1 for very high masses
- Experimental systematic uncertainties are up to ~5%
  - Would be interesting to understand the differences in quoted systematic uncertainties between ATLAS and CMS for the future Run-2
  - Multijet and W+jet background systematic uncertainties dominate in electron channel
- Statistical component in some of the systematic uncertainties

arXiv: 1609.08157

Sources	e^+e^-	$\mu^+\mu^-$
Efficiency	2.9, 0.5, 0.7	1.0, 0.4, 1.8
Detector resolution	1.2, 5.4, 1.8	0.6, 1.8, 1.6
Background estimation	2.2, 0.1, 13.8	1.0, 0.1, 4.6
Electron energy scale	0.2, 2.4, 2.0	—
Muon momentum scale	—	0.2, 1.7, 1.6
FSR simulation	0.4, 0.3, 0.3	0.4, 0.2, 0.5
Total experimental	3.7, 2.5, 14.0	1.6, 2.5, 5.4
Theoretical uncertainty	4.2, 1.6, 5.3	4.1, 1.6, 5.3
Luminosity	2.6, 2.6, 2.6	2.6, 2.6, 2.6
Total	6.3, 6.7, 15.3	5.1, 3.9, 8.0

Eur. Phys. J. C 75 (2015) 147



High energy probes of EW sector

- High mass Drell-Yan measurements can indirectly probe heavy new physics
- Modification of the SM in self energies of vector bosons
  - Focus on oblique corrections: S, T, W, and Y
- W and Y modify the propagators off the pole
- W and Y modify the cross section by a factor that grows with energy as q^2/mV (can be generated by dim-6 EFT operators)
  - Is the energy enhancement at hadron colliders sufficient to beat the precision at lepton colliders?
  - Look at the "tails" of charged and neutral Drell-Yan lepton pairs

	universal form factor ($\mathcal{L}$)	contact operator ($\mathcal{L}'$)
W	$-\frac{\mathrm{W}}{4m_W^2}(D_\rho W^a_{\mu\nu})^2$	$-\frac{g_2^2\mathrm{W}}{2m_W^2} J_L{}^a_\mu J_L{}^\mu_a$
Y	$-\frac{\mathrm{Y}}{4m_W^2}(\partial_\rho B_{\mu\nu})^2$	$-\frac{g_1^2\mathrm{Y}}{2m_W^2} J_{Y\mu} J_Y{}^\mu$

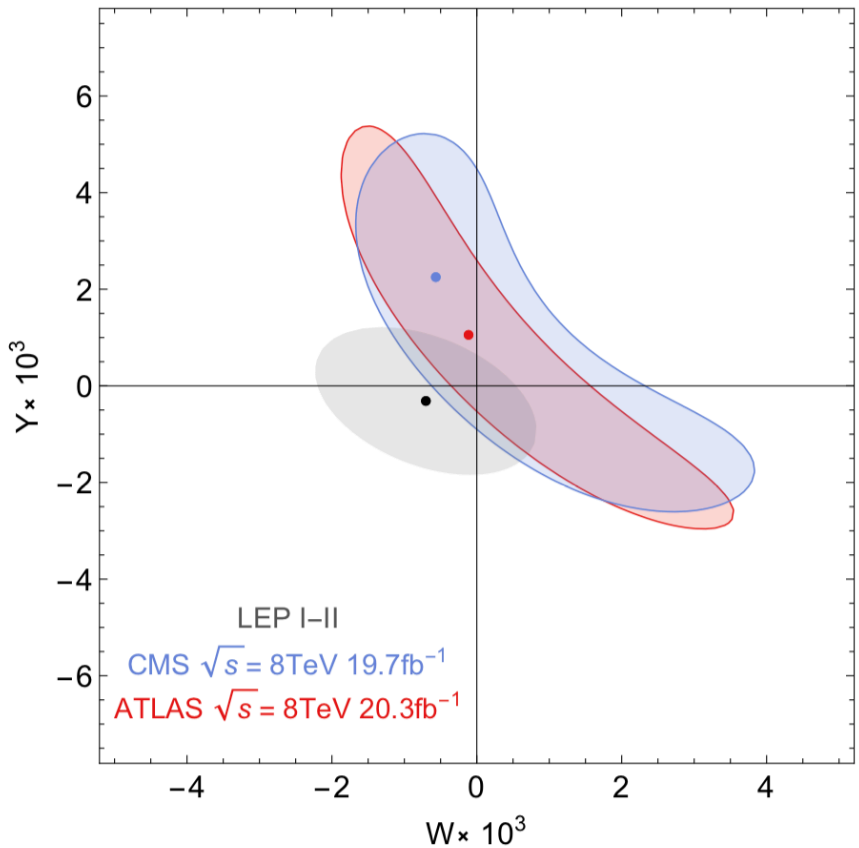
$$P_N = \begin{bmatrix} \frac{1}{q^2} - \frac{t^2\mathrm{W}+\mathrm{Y}}{m_Z^2} & \frac{t\left(\left(\mathrm{Y}+\hat{\mathrm{T}}\right)c^2+s^2\mathrm{W}-\hat{\mathrm{S}}\right)}{\left(c^2-s^2\right)\left(q^2-m_Z^2\right)} + \frac{t(\mathrm{Y}-\mathrm{W})}{m_Z^2} \\ \star & \frac{1+\hat{\mathrm{T}}-\mathrm{W}-t^2\mathrm{Y}}{q^2-m_Z^2} - \frac{t^2\mathrm{Y}+\mathrm{W}}{m_Z^2} \end{bmatrix}$$

$$P_C = \frac{1+\left(\left(\hat{\mathrm{T}}-\mathrm{W}-t^2\mathrm{Y}\right)-2t^2\left(\hat{\mathrm{S}}-\mathrm{W}-\mathrm{Y}\right)\right)/(1-t^2)}{(q^2-m_W^2)} - \frac{\mathrm{W}}{m_W^2},$$

arXiv: 1609.08157

Run-1 constraints

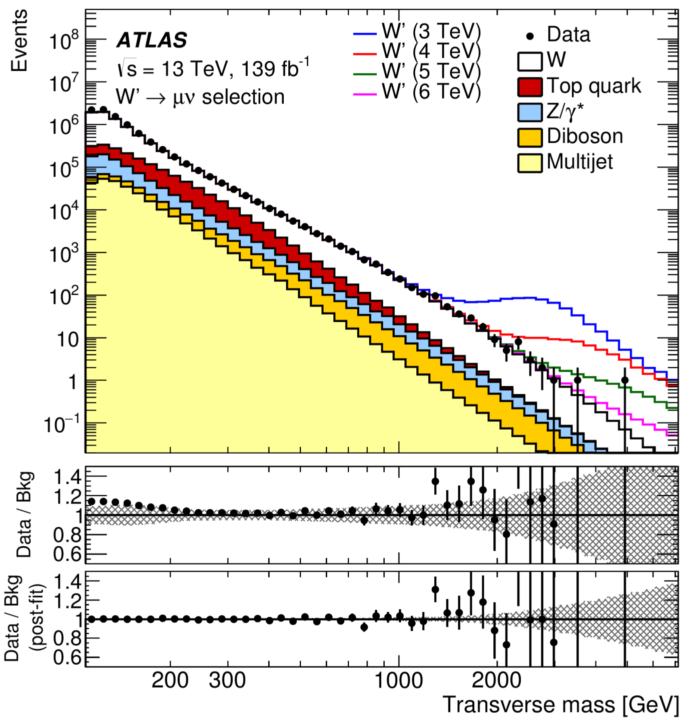
- Limits on W and Y from Run-1 neutral Drell-Yan measurements
- 95% exclusion contours obtained with ATLAS and CMS data in the W-Y plane
  - Already competitive with LEP constraints (gray region)

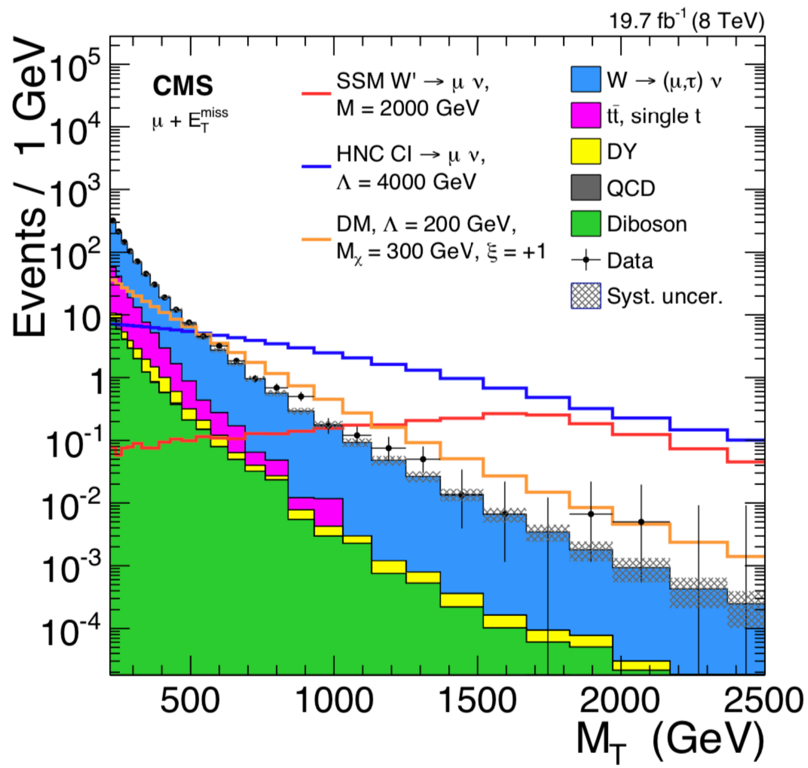


arXiv: 1609.08157

Charged current DY

- Measurements of high transverse mass W production can be used
  - Cross section measurements are not currently provided by ATLAS and CMS performed
  - The uncertainties can be estimated from W' searches (where it appears as a background process)

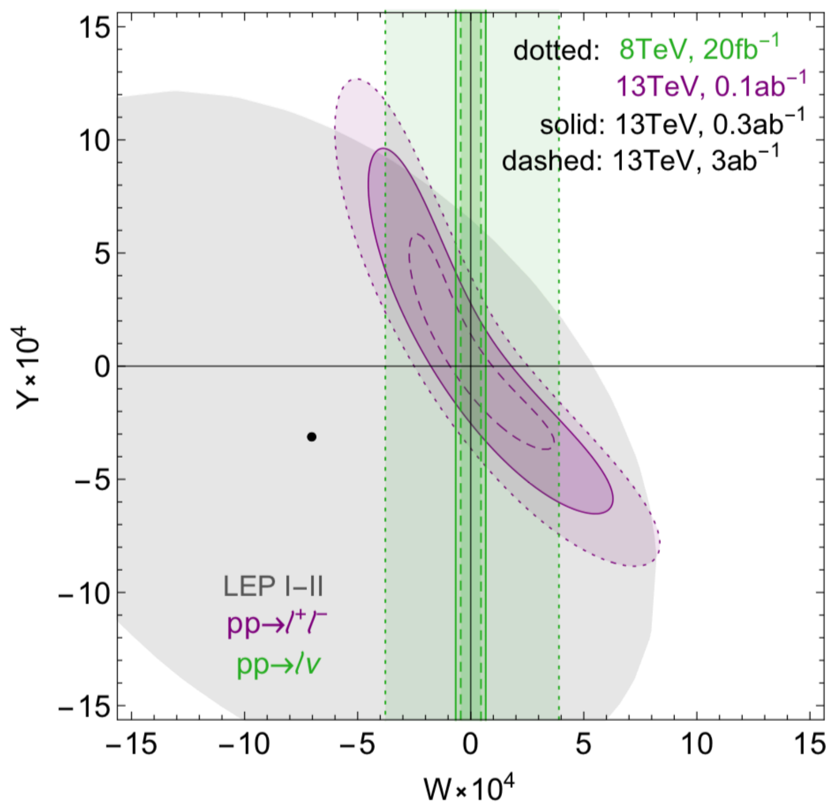




arXiv: 1606.03977 arXiv: 1408.2745

13 TeV projections (HL-LHC)

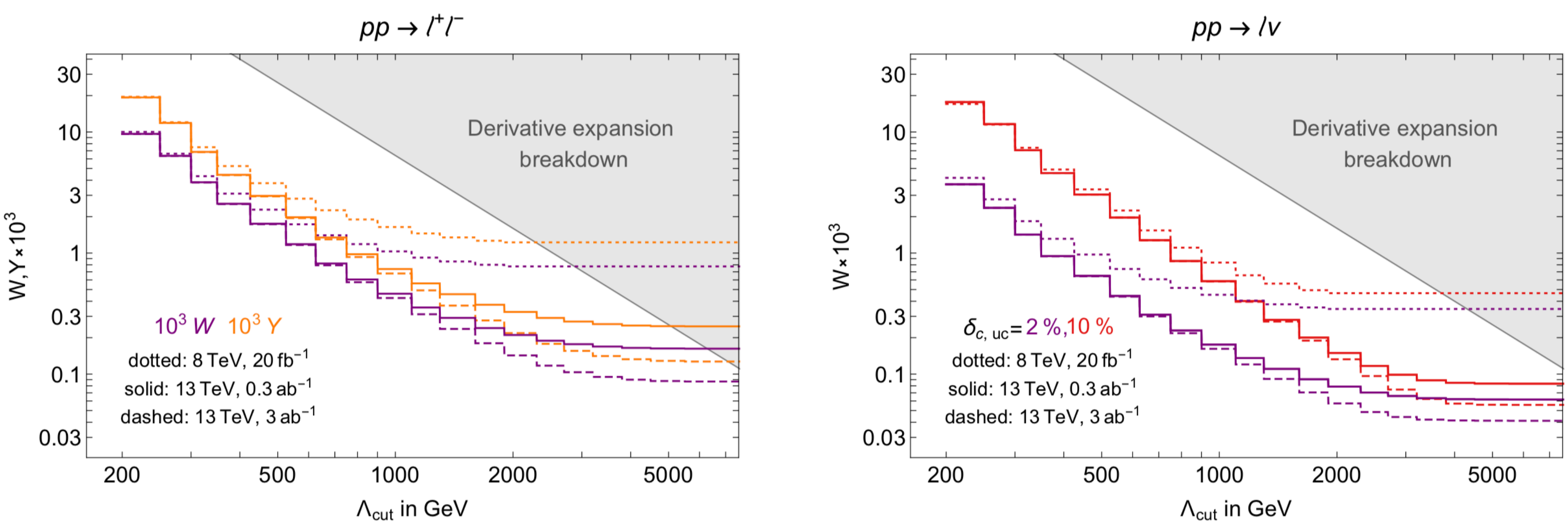
- Projected limits on W and Y from 13 TeV Drell-Yan measurements
- For neutral DY: 2% correlated and 2% uncorrelated uncertainties assumed
- For charged DY: 5% correlated and 5% uncorrelated uncertainties assumed
    - 8 TeV “projection” is also shown (dotted)



arXiv: 1609.08157

13 TeV projections

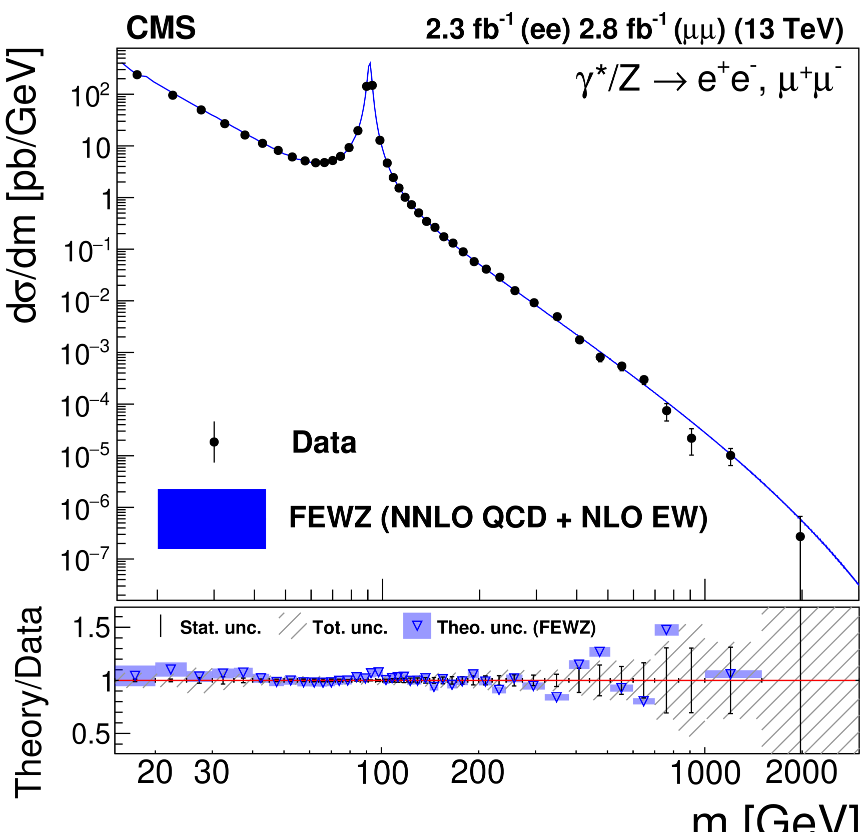
- Which mass bins give us the sensitivity to Y and W
  - Mass bins below 1 TeV for √s=8 TeV and below 2 TeV for √s=13 teV
  - Can we achieve ~1-2% experimental uncertainties at HL-LHC?

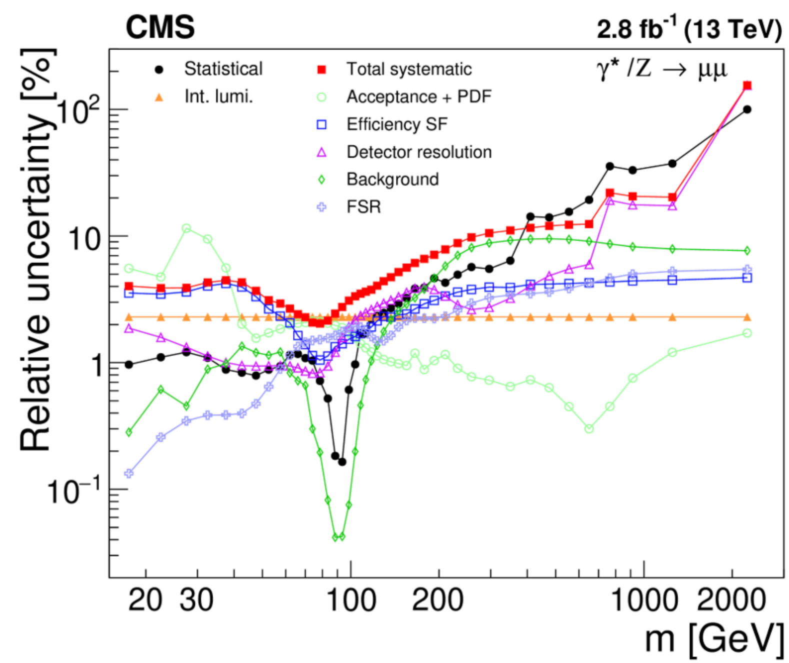


arXiv: 1609.08157

CMS 13 TeV measurement

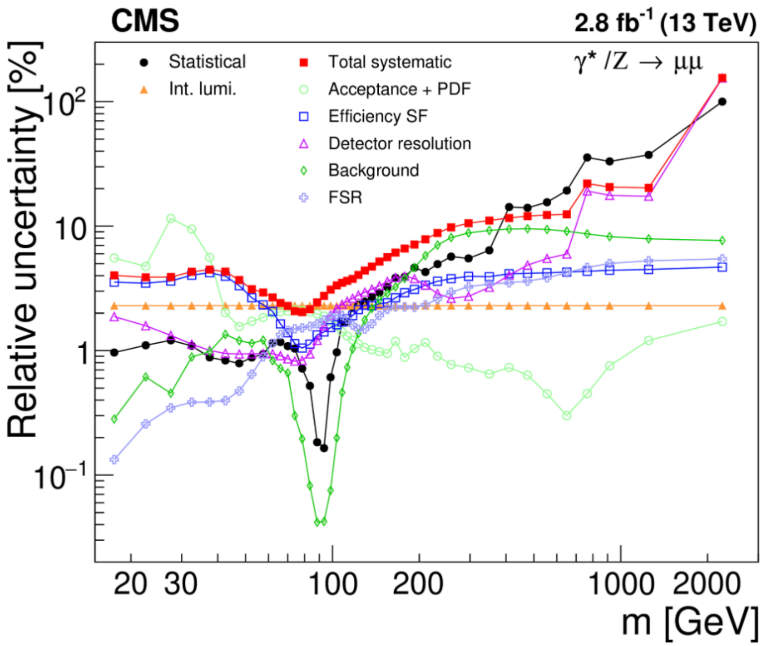
- Measurement of the differential Drell-Yan cross section at 13 TeV
  - arXiv:1812.10529, dσ/dM
  - Dilepton invariant mass in the range 15 to 3000 GeV (leading lepton pT>22 (30) GeV and sub;eading lepton pT > 10 GeV)



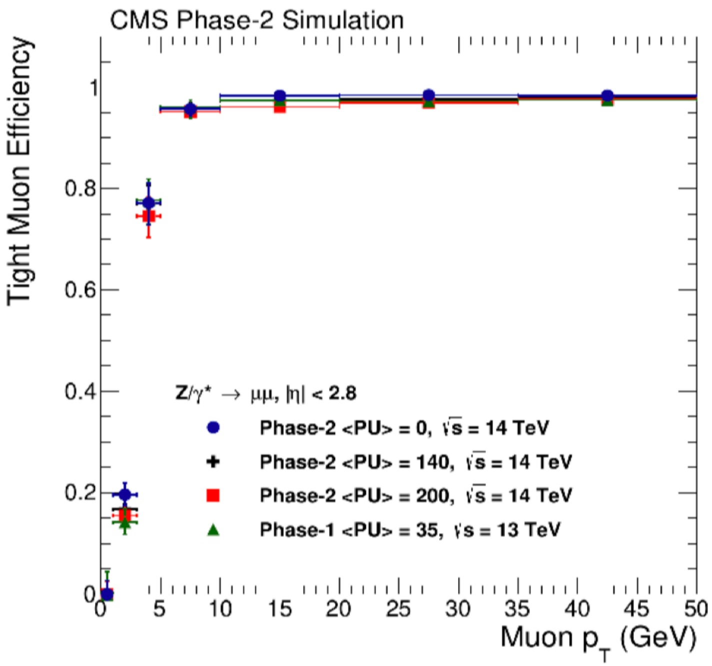


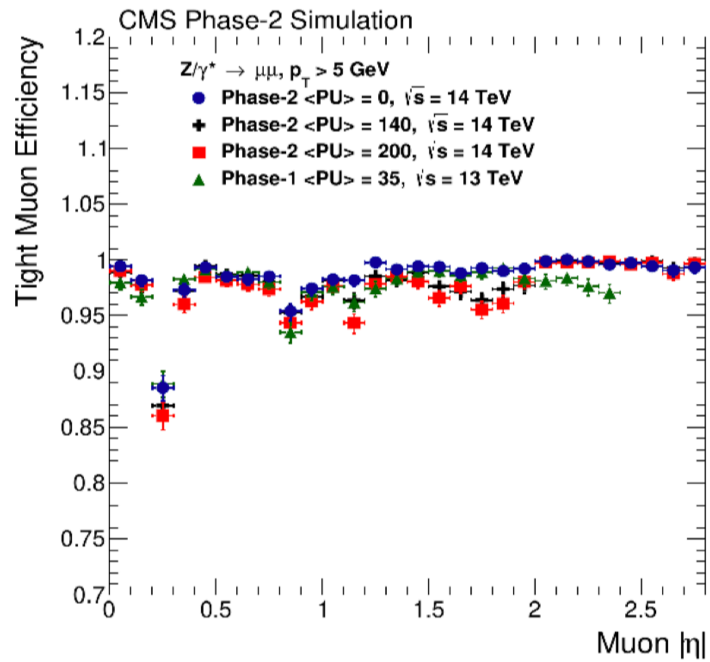
HL-LHC systematic uncertainties

- Statistical uncertainties of ~1% up to 2 TeV possible with naive extrapolation
- Upgraded detectors should maintain similar muon and electron performance (efficiency, momentum/energy scale)
- Integrated luminosity uncertainty at HL-LHC. What can be achieved?
  - Ideas of using Z counting and low pileup datasets (for absolute luminosity scale calibration) to achieve ~1-2% uncertainty:
  - arXiv:1806.02184



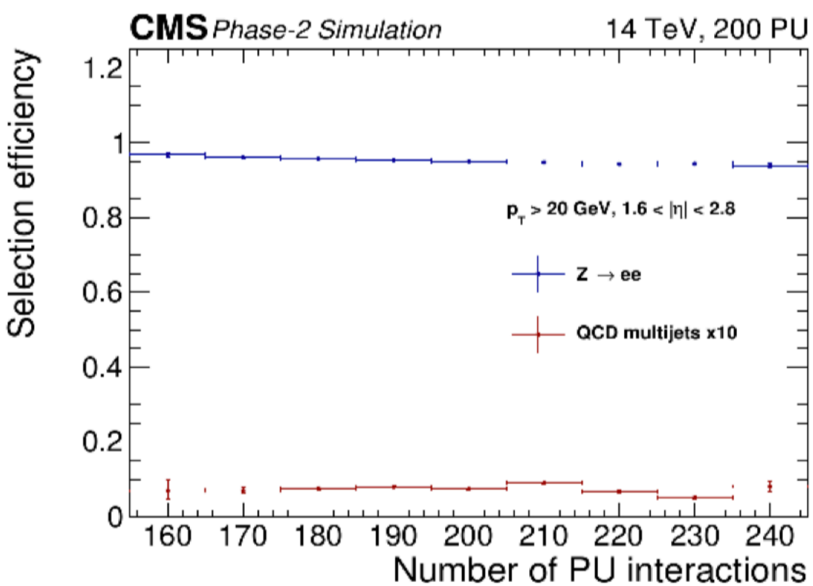
HL-LHC CMS muon performance

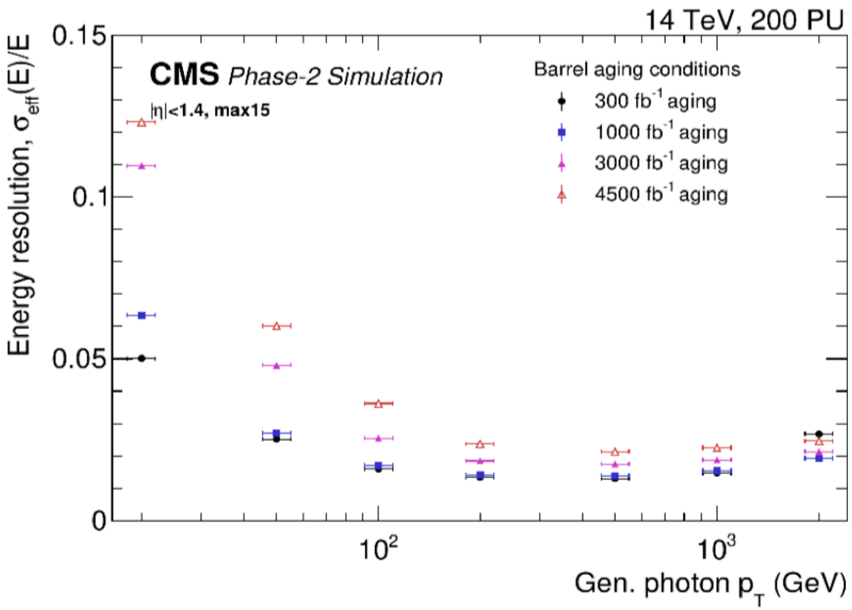




- Upgraded muon detectors maintain good performance at high pileup and extend coverage to $|\eta| = 2.8$ for CMS e.g. (albeit with challenging situation for hardware trigger beyond 2.4)

HL-LHC CMS electron performance

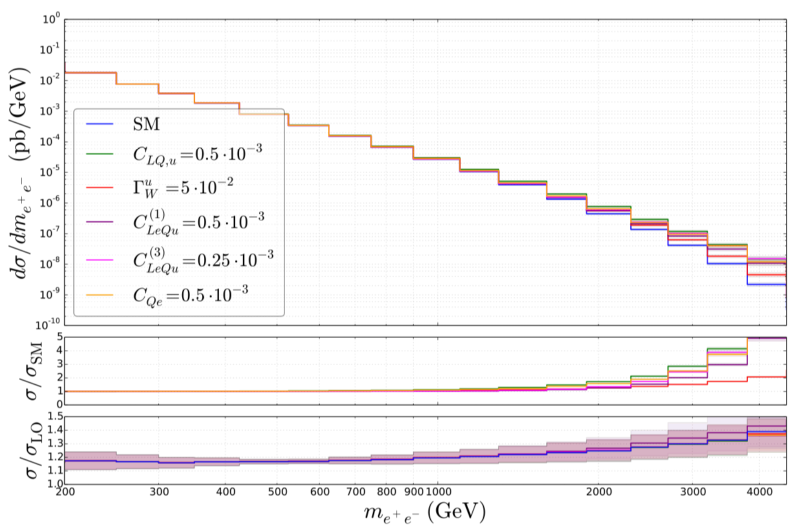


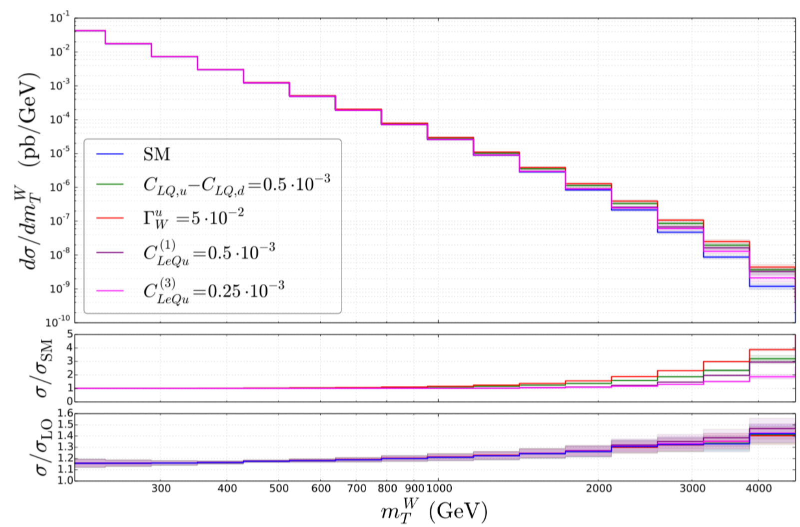


- Electron reconstruction/efficiency should be ∼ ok at high pileup
- Some radiation and pileup related challenges for energy resolution

SM-EFT contributions

- SM-EFT contributions to charged and neutral DY
  - Consider all dim-6 operators contributing at leading order
- NLO QCD corrections included (implemented in Powheg BOX V2)
  - Around ~30-40% in the highest bins
- Set bounds on effective operators using ATLAS and CMS searches
  - Angular distributions can be used to differentiate between different dim-6 operators





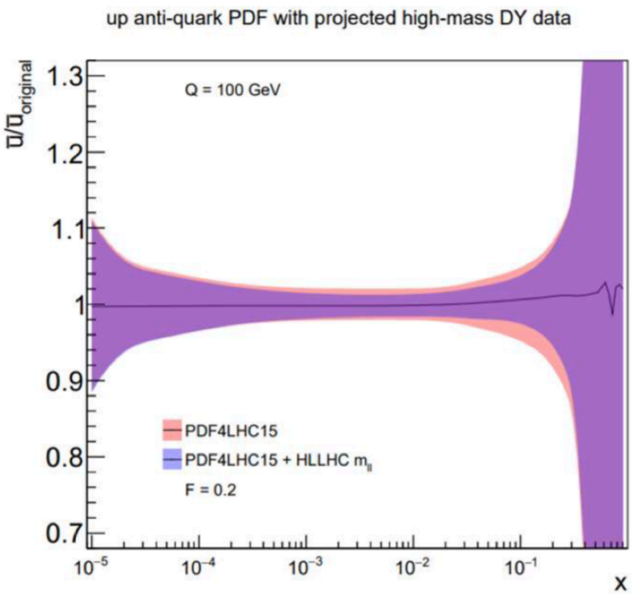
arXiv:1804.07407

$$m_T^W = \sqrt{2|p_T^\ell||p_T^\nu|(1-\cos\Delta\phi_{\ell\nu})}$$

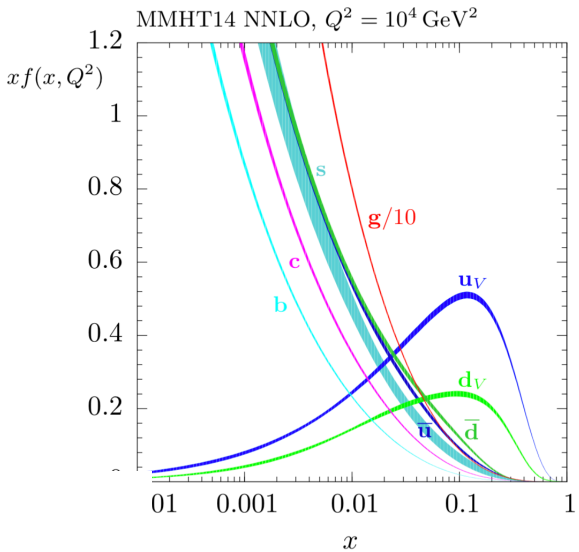
PDF constraints at HL-LHC

- Sensitivity to PDFs at large x (currently constraints are poor)
  - Poorly known large-x sea quarks
  - Projected neutral DY data

$$x_{1,2} = \frac{m_{ll}}{\sqrt{s}} e^{\pm y_{ll}}.$$



arXiv:1810.0363



LHL et al., Eur. Phys. J. C75 (2015) no.5 204

- Perform a consistent SM+EFT/BSM fit with PDFs (talk by Shayan Iranipour last week)

Summary

- High mass DY measurements as high energy probe of BSM physics
- Electroweak precision tests in high energy DY processes
  - Surpassing the LEP sensitivity to universal parameters W and Y
- Ultimate goal: Measurements of DY cross sections at dilepton masses of up to 2 TeV with O(1)% uncertainty at HL-LHC
- Detailed measurements of high mT distributions of charged DY should be performed as well
- Full Run-2 ATLAS and CMS high mass neutral DY measurements still to come
  - Stay tuned…