Single boson production with CMS

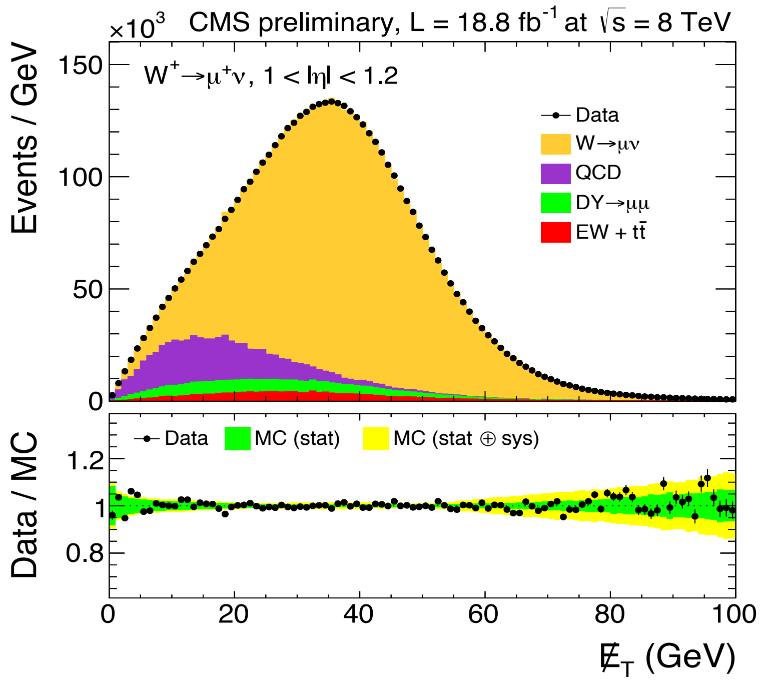
Markus Stoye on behalf of the CMS collaboration

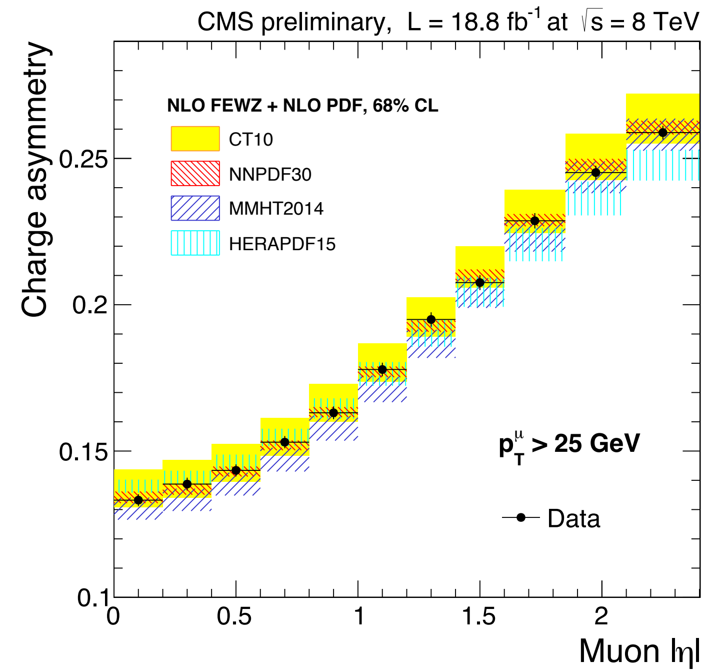
LHCP15, 31st August, St. Petersburg

Content

I will summarize recent 8 TeV results that help pushing the precision frontier and constrain pdfs

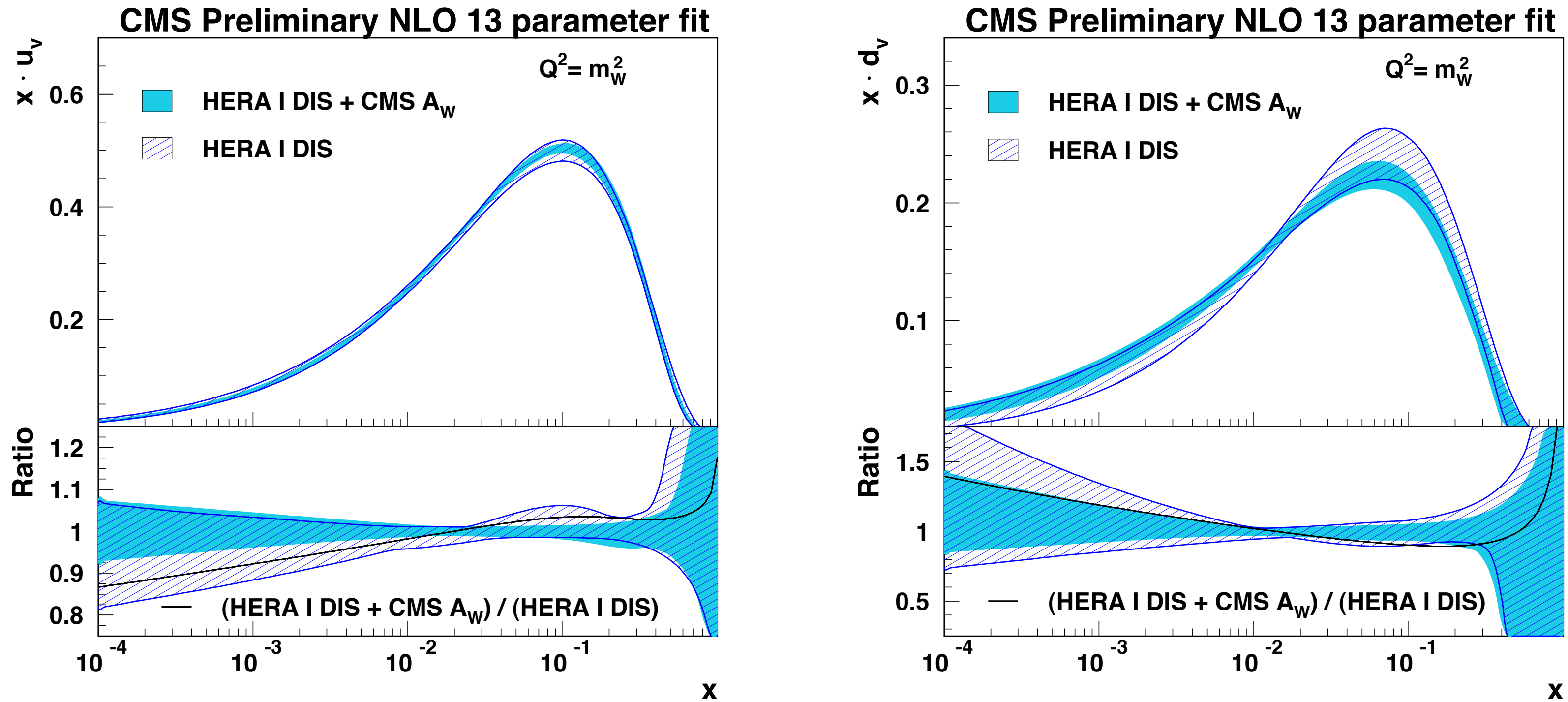
Lepton charge asymmetry in W+X at 8 TeV





- Templated fits to MET performed for e and μ for each charge in bins of η to extract W contribution to charge asymmetry
- Prediction uncertainties are dominated by pdf uncertainties
- Classical approach to constrain u_v and d_v pdfs

Impact on valence quark pdfs estimated by CMS

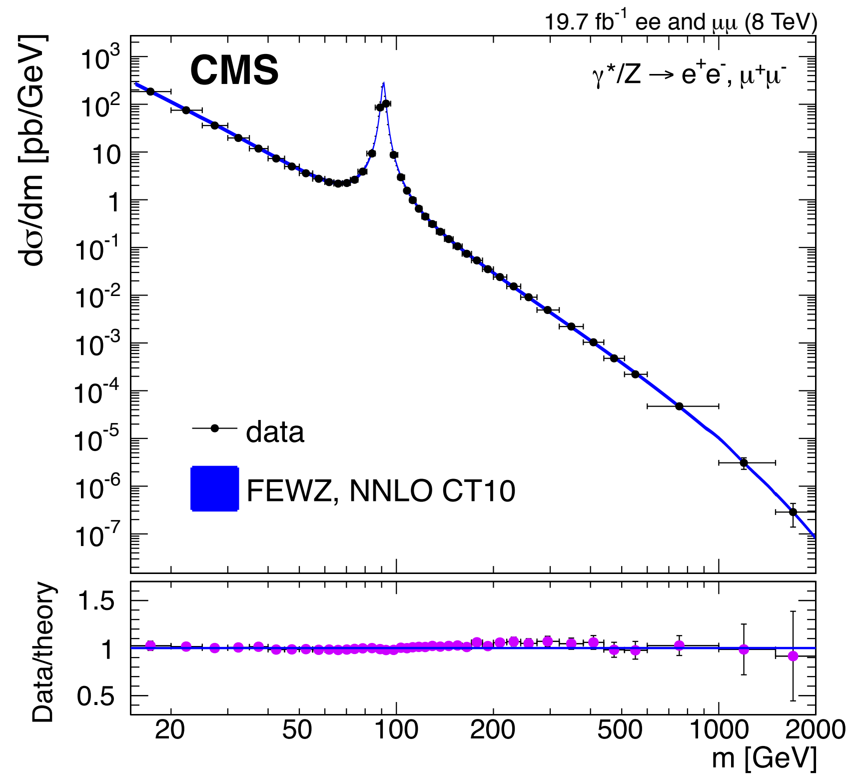


- CMS quantified the improvement by its measurement w.r.t. HERA I data
- The expected significant improvement from CMS data in u_v and d_v pdfs is confirmed

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

Double differential dσ(DY)/dY/dM

- DY lepton pairs collected starting in mass from 15 GeV
- Typical experimental uncertainties (w/o $\mathcal{L}$) about 2% at the Z peak and 1-5% for other masses
- QCD NNLO + EWK NLO leads the scale uncertainty ≤ 2%

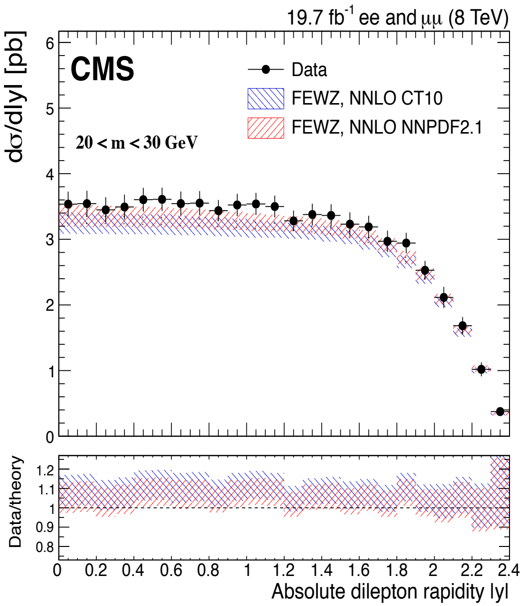


Data agrees with theory dσ(DY)/dM over ~ 9 orders of magnitudes

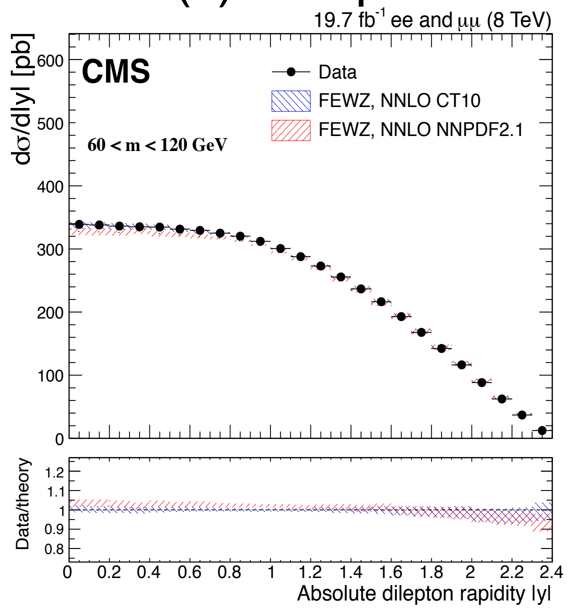
dσ(DY)/dY in bins of M(ℓℓ) can constrain quark pdfs

Expectation are shown for NNLO CT10 and NNPDF2.1 including pdf (set) uncertainties

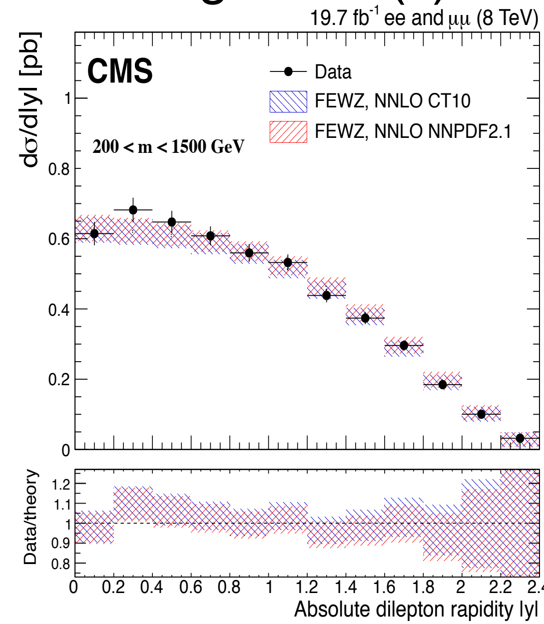
lowest M(ℓℓ)



M(ℓℓ) at Z peak



highest M(ℓℓ)



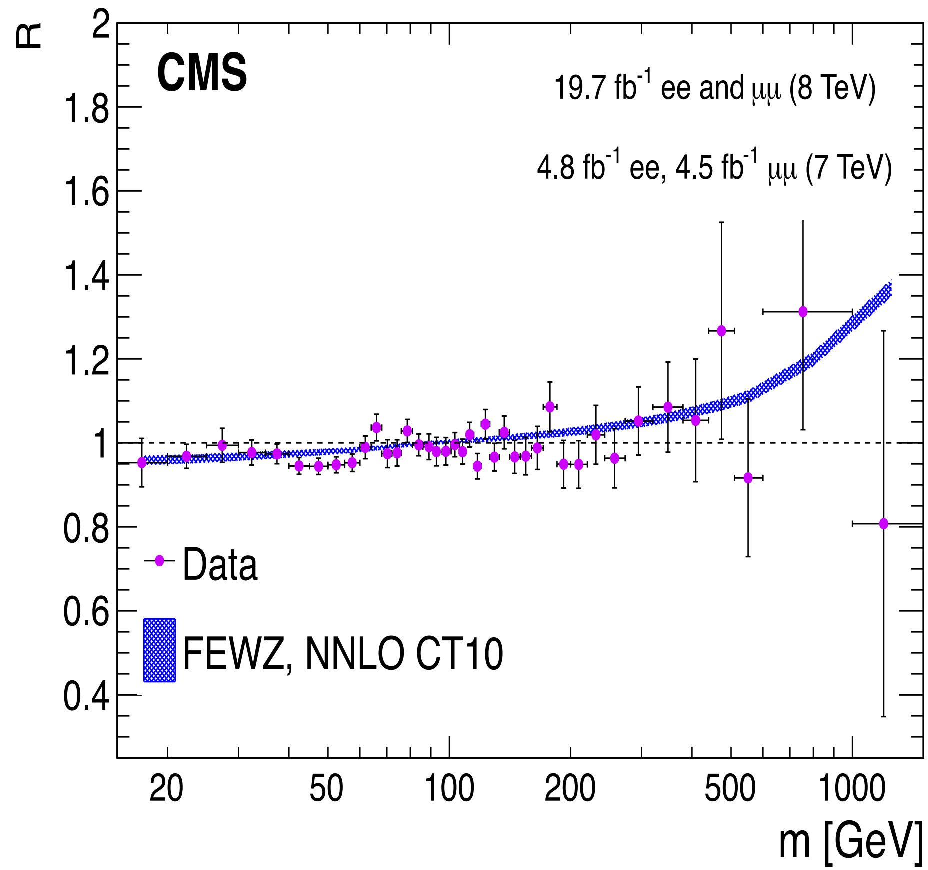
- The high center of mass energy probes a *bjorken* x range from 0.001 to 0.1
- Q^2 ranges from 600-750.000

➢ Probes pdf(quarks) in large x, Q^2 range

➢ Complementary to fixed target experiments

Normalized dσ(DY)/dM ratio of 8/7 TeV

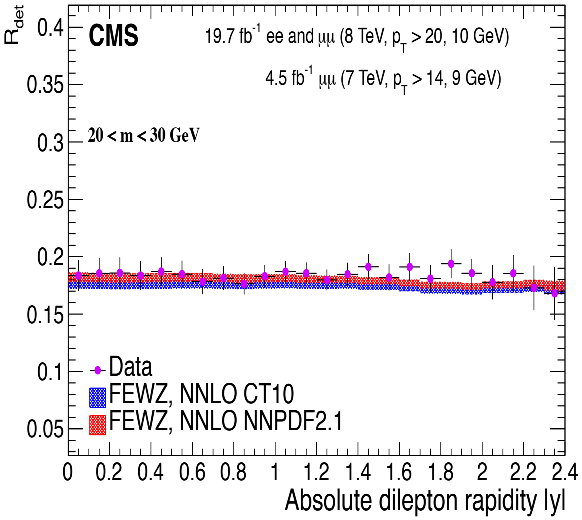
- Hard scatter σ uncertainty cancels
- FSR, scale, $\gamma\gamma$ initiated production, acceptance, … uncertainties cancel
- Shape reflects different *bjorken* x and s.



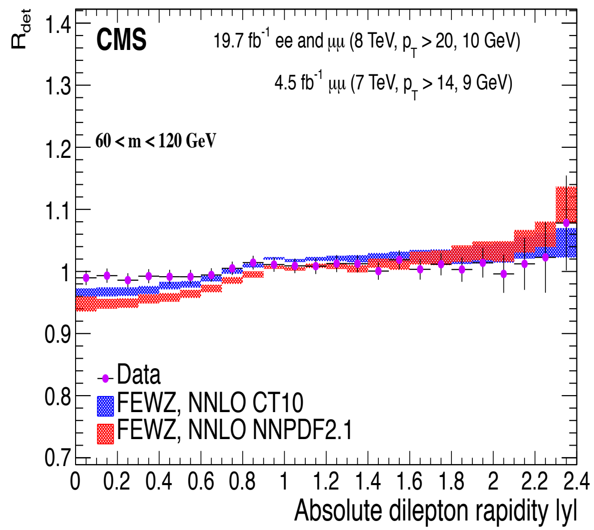
Increasing slope reflects that smaller *bjorken* x leads to higher M($\ell\ell$) for 8 TeV than for 7 TeV

Normalized dσ(DY)/dY ratio of 8/7 TeV in M(ℓℓ) bins

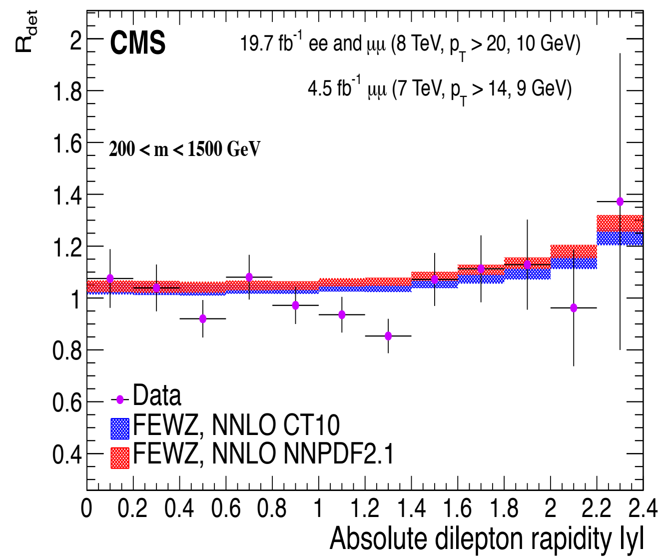
lowest M(ℓℓ)



M(ℓℓ) at Z peak



highest M(ℓℓ)



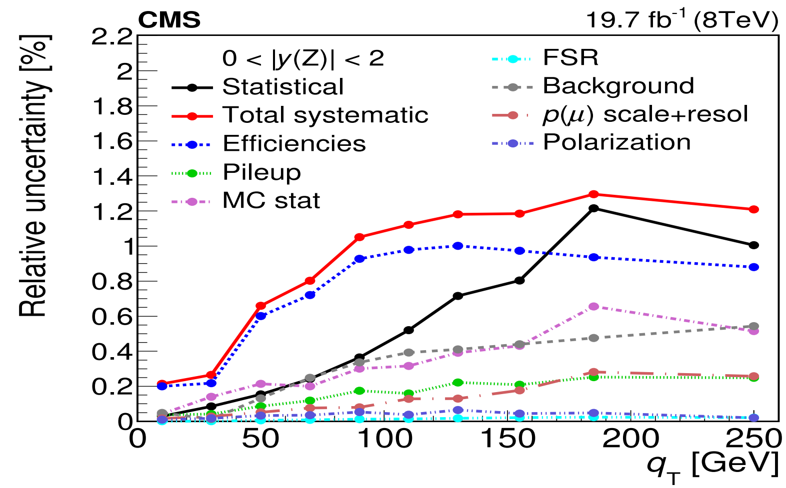
The ratio gives the opportunity to apply novel method in pdf fits

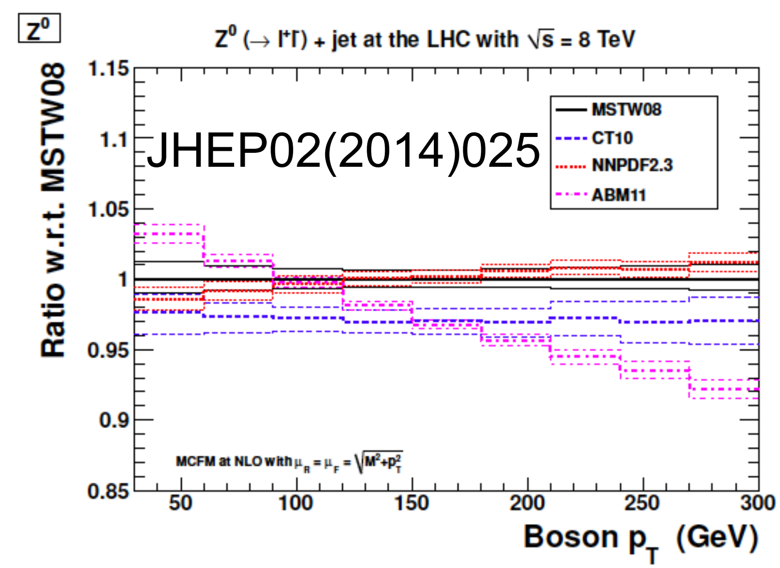
Phys. Lett. B 749 (2015) 187

Double differential $d\sigma(Z(\mu,\mu))/dY/dP_T$

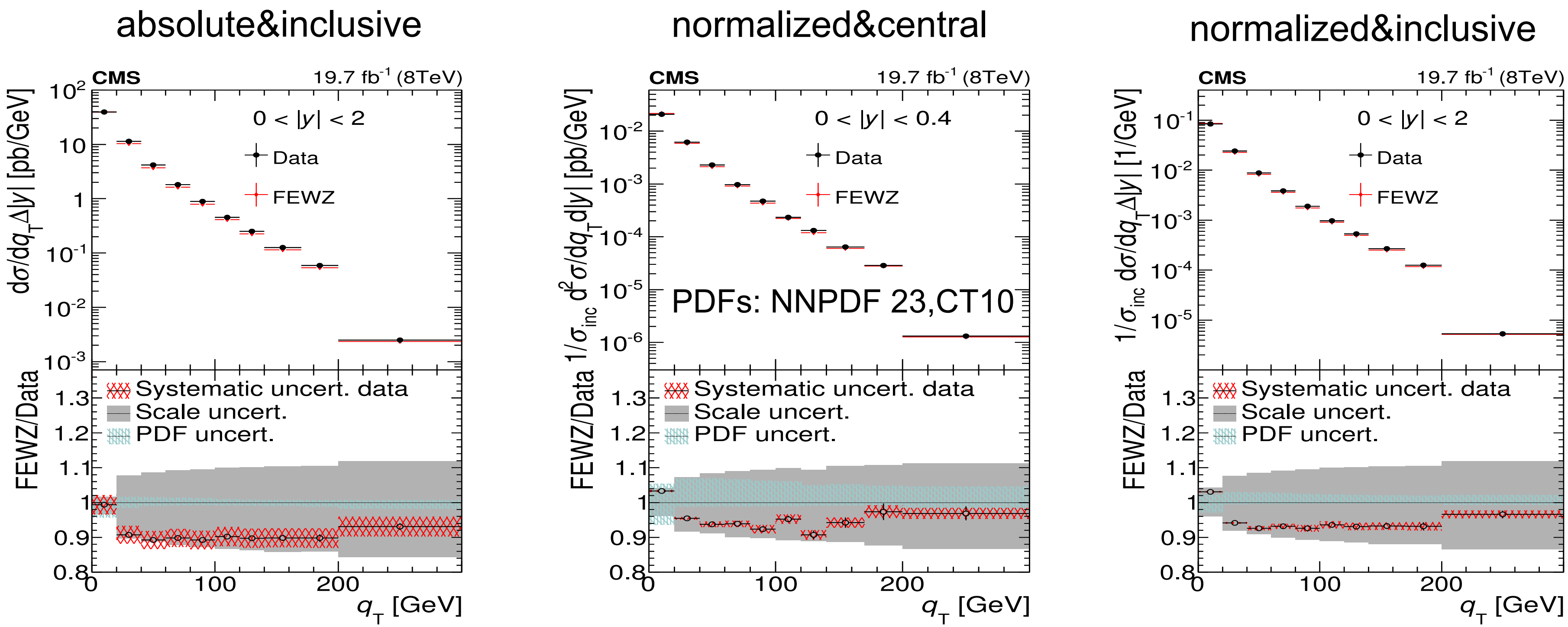
- $M(\mu\mu)$ pairs with invariant mass between 81 and 101 GeV selected
- Normalized σ experimental uncertainties ~ 1%.
- Significantly smaller than pQCD uncertainties at large $P_T(Z)$
- Exp. uncertainties smaller or similar to pdf uncertainties
- Higher $P_T(Z)$ probes gluon pdf
- Correlation of gluon pdf (Q^2=10000, x=0.01, i.e. ~Higgs regime) to $\sigma(P_T(Z)>80$ GeV) ~ 1 (J.R.)

normalized x-section



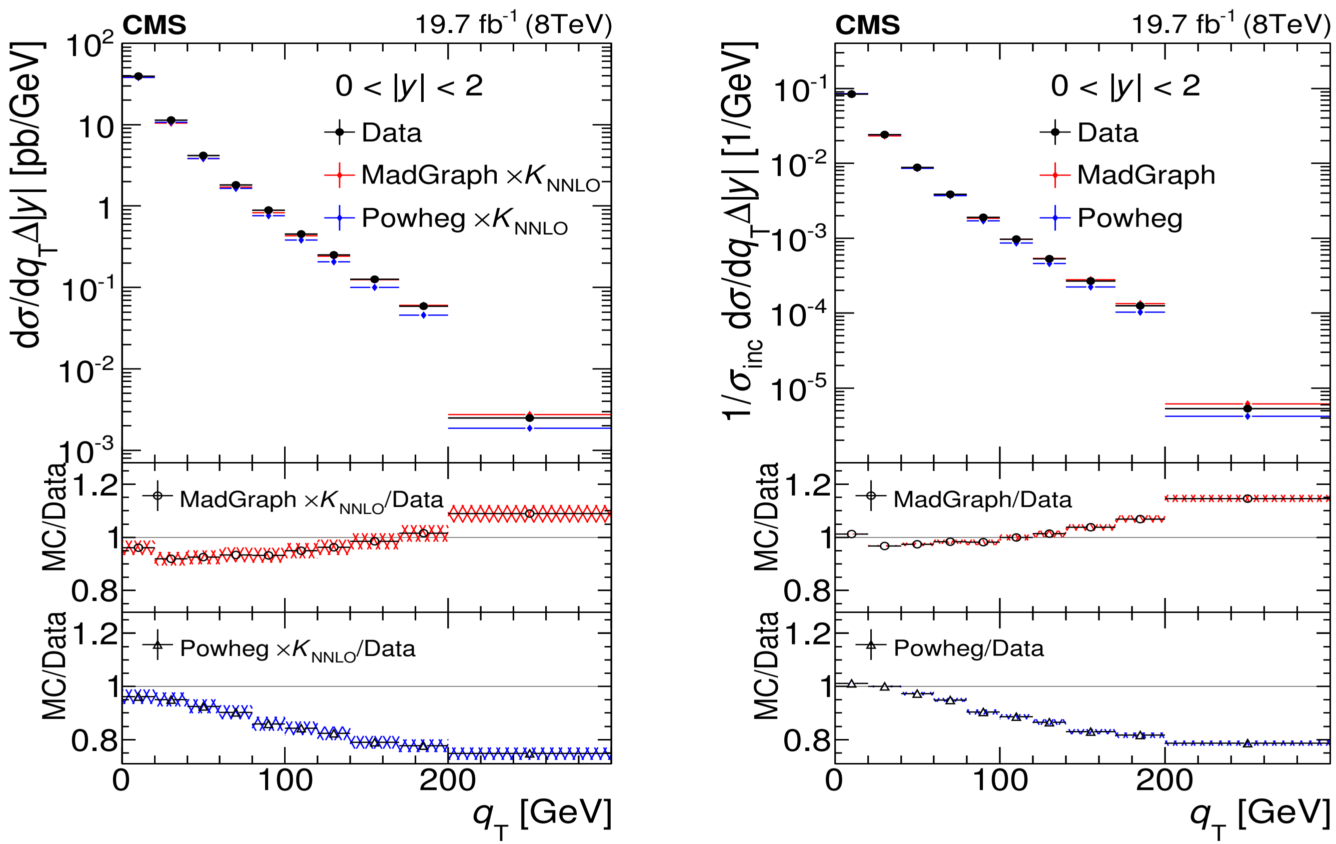


Measured dσ(Z(μ,μ))/dY/dP$_T$ compared to NNLO



- Data and prediction agrees within current (large) theory uncertainties
- Developments in the pipeline in theory sector:
    - QCD NNLO Z+jet + NLO EWK expected soon (W+jet exists already)
- CMS provided results with full covariance matrix to allow inclusion in global pdf fits once higher orders *are* available

Measured $d\sigma(Z(\mu,\mu))/dY/dP_T$ compared to (N)LO+PS

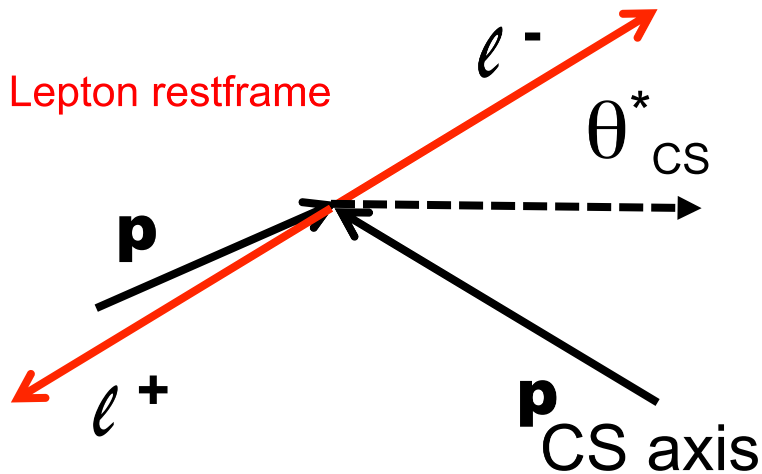


Modest shape agreement with standard CMS 8 TeV “workhorse” generators

The forward-backward asymmetry (A_{FB}) in DY events

A_{FB} probes V-A and is ideally measured by the angle between negative lepton and quark

$$A_{FB} = \frac{N(\cos(\theta) > 0) - N(\cos(\theta) < 0)}{N(\cos(\theta) > 0) + N(\cos(\theta) < 0)}$$

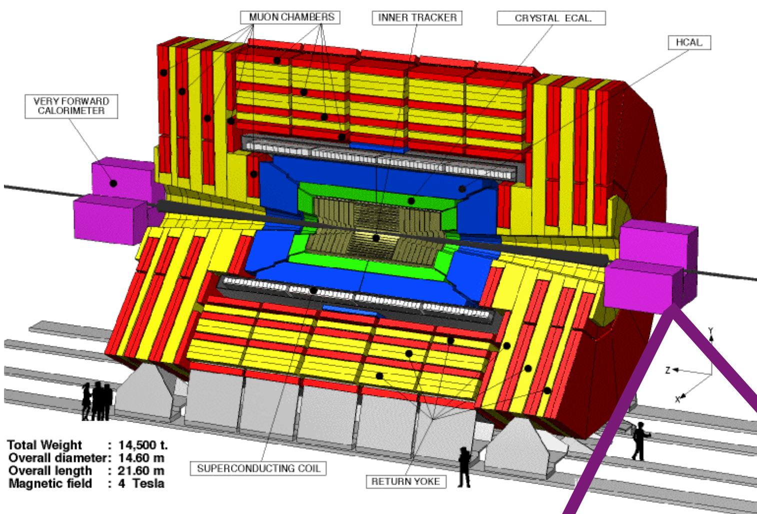


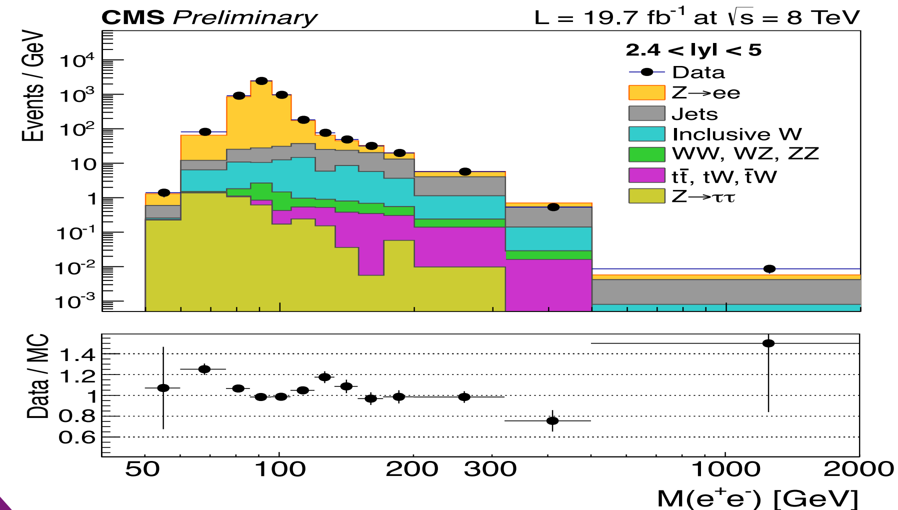
Collins Soper frame:

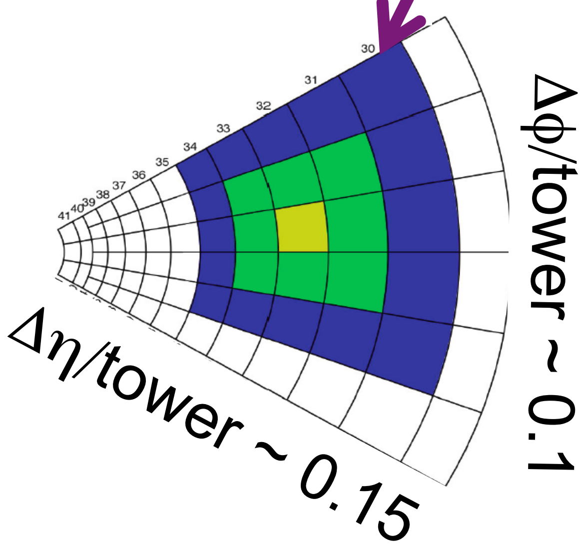
- **pp** bisector as z-axis
- Use **p** that gave stronger *boost* as “quark” direction

- For DY pairs with small rapidity A_{FB} vanishes as likely quark direction cannot be found anymore (dilution)
- ➢ DY pairs with ***large rapidity*** best to measure A_{FB}

Extended electron definition in η for 8 TeV to capture high rapidity DY pairs using the HF



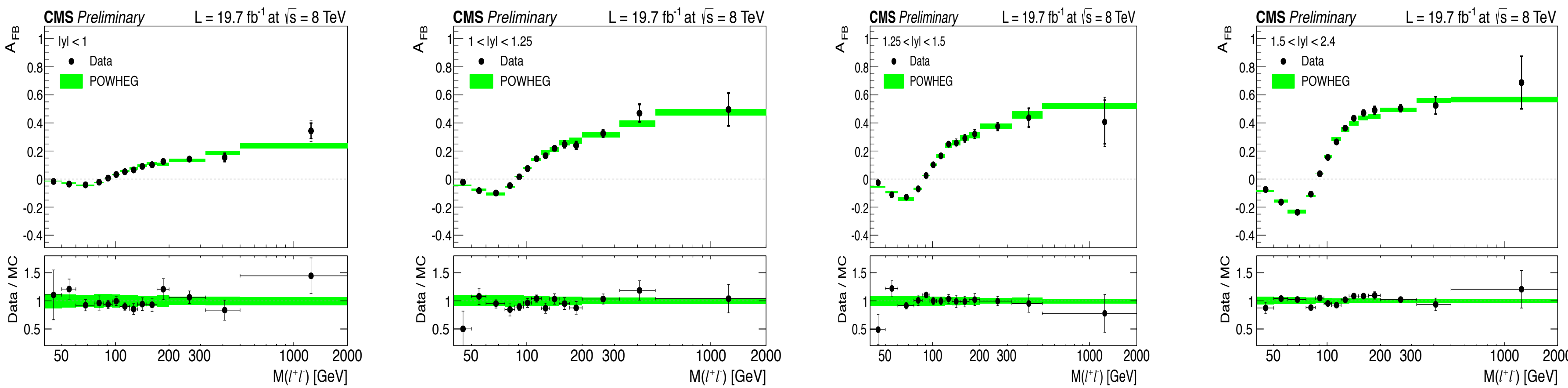




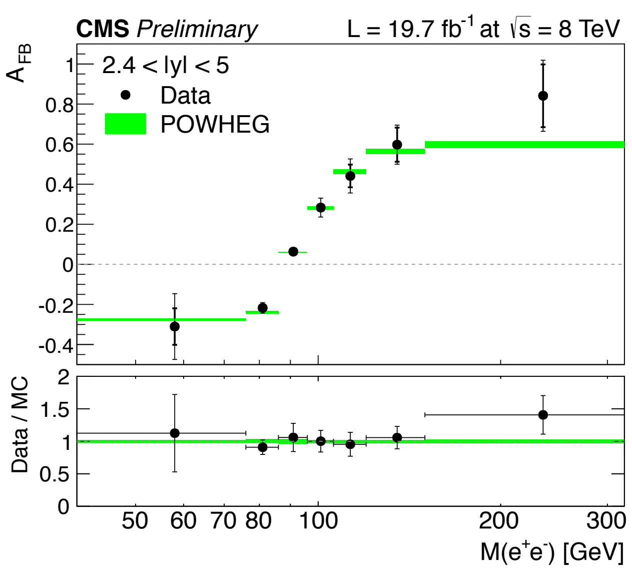
- Hadron Forward calorimeter used to identify electrons in η 3-5
- Short and long fibers sensitive shower depths
- No track, i.e. no charge assignment for forward electron

A_{FB} for several Y(ℓℓ) bins as function of M(ℓℓ)

μμ and *ee* combined



Forwards *e* + central *e*



- A_{FB} probes by the V-A structure of Z^0/γ^* and thus $\sin(\theta_W)$
- A_{FB} depends on M(ℓℓ) due to varying Z and γ^* interference
- Anomalies in A_{FB} can indicate new physics
- ➢ Very good agreement between data and theory

Accepted Phys. Lett. B arXiv:1504.03512

Z boson angular coefficients in Y(Z) and P_T(Z)

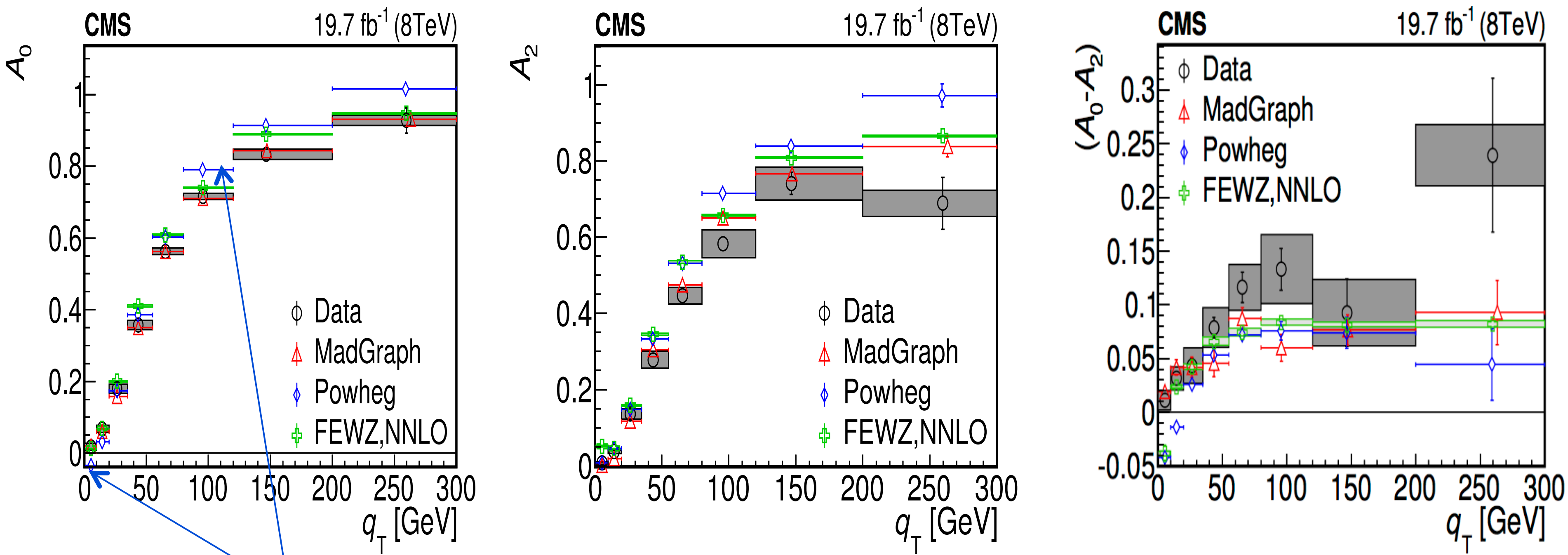
Angular momentum in the Z decay generally requires:

$$\frac{d^2\sigma}{d\cos\theta^* d\phi^*} \propto (1+\cos^2\theta^*) + A_0\frac{1}{2}(1-3\cos^2\theta^*) + A_1\sin(2\theta^*)\cos\phi^*$$
$$+ A_2\frac{1}{2}\sin^2\theta^*\cos(2\phi^*) + A_3\sin\theta^*\cos\phi^* + A_4\cos\theta^*$$
$$+ A_5\sin^2\theta^*\sin 2\phi^* + A_6\sin 2\theta^*\sin\phi^* + A_7\sin\theta^*\sin\phi^*$$

θ^* and ϕ^* are Collins Soper angles in the Z rest-frame

- First measurement of complete set of coefficients from A_0 to A_4
- First measurement of angular coefficients at high P_T(Z)
- Establishing A_i modeling in simulation is important for ***precision frontier*** measurements like W mass or acceptance effects in very precise cross-sections

Comparison to theory shows some disagreement for LO+PS, NLO+PS and NNLO



Powheg: ***negative*** at low $P_T(Z)$ and to high for high $P_T(Z)$ [source understood, see backup]

- Scale uncertainties largely cancel as coefficients are σ ratios
- Not straight forward to assign theory uncertainties
- Disagreement as shown would lead to large effects e.g. on W mass measurement

Conclusions

Recent results that will improve pdfs:

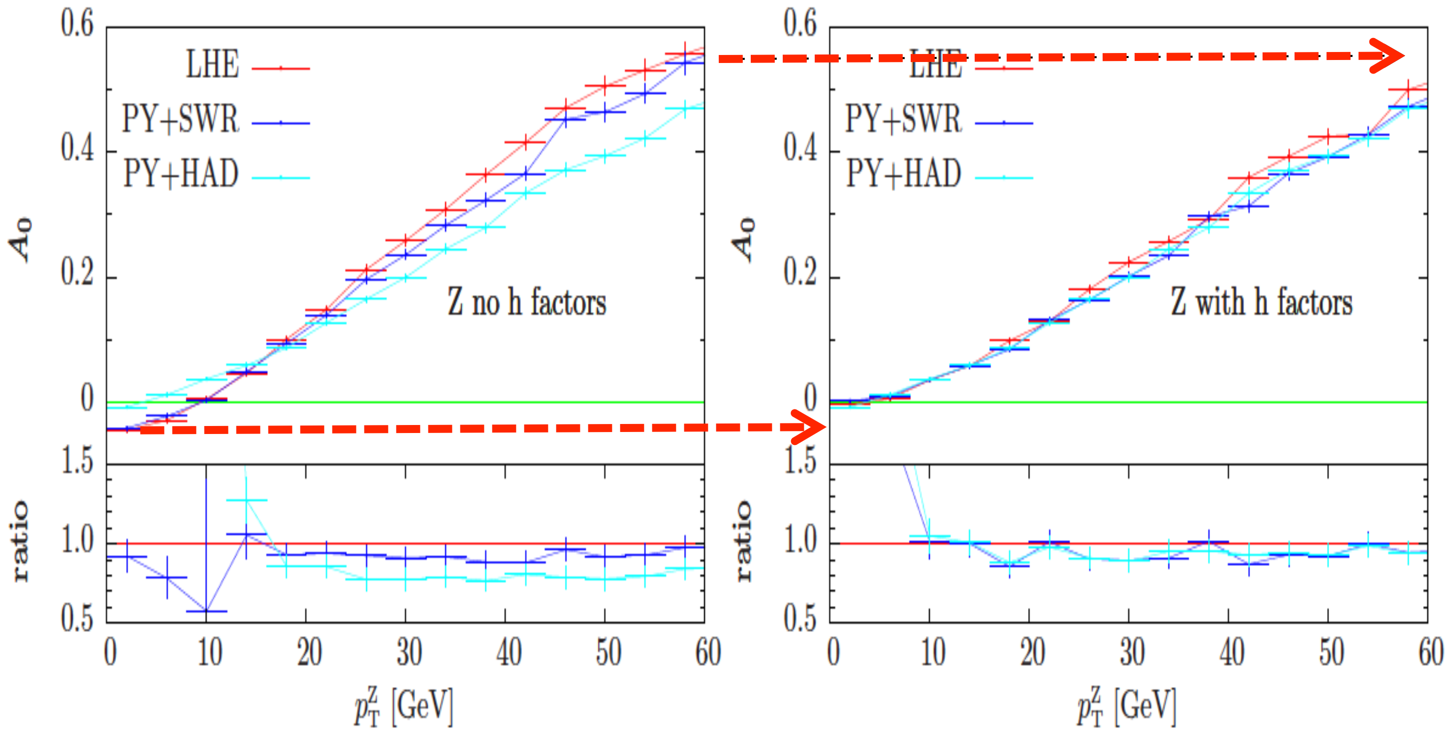
- Lepton charge asymmetry: pdf(u_v,d_v)
- σ(DY)/dY/dM: pdf(quarks)
- σ(Z)/dY/dP_T: potentially (better theory) pdf (gluon)

Recent results that allow testing/improving simulation and it's parameters:

- σ(Z)/dY/dM:
- DY angular and A_{FB}

Important steps preparing the ground for potential future discoveries

Powheg authors progressed in understanding cause of deviations



"damping" by h factors lead to right trend w.r.t. data&physics

- Partial inclusion of higher orders in Powheg affects coefficients
- Options in Powheg Box to "damp" these contributions, which improved the results at low and high $P_T(Z)$
- Recommendation to use NLO in Z+jet generators for A_x studies