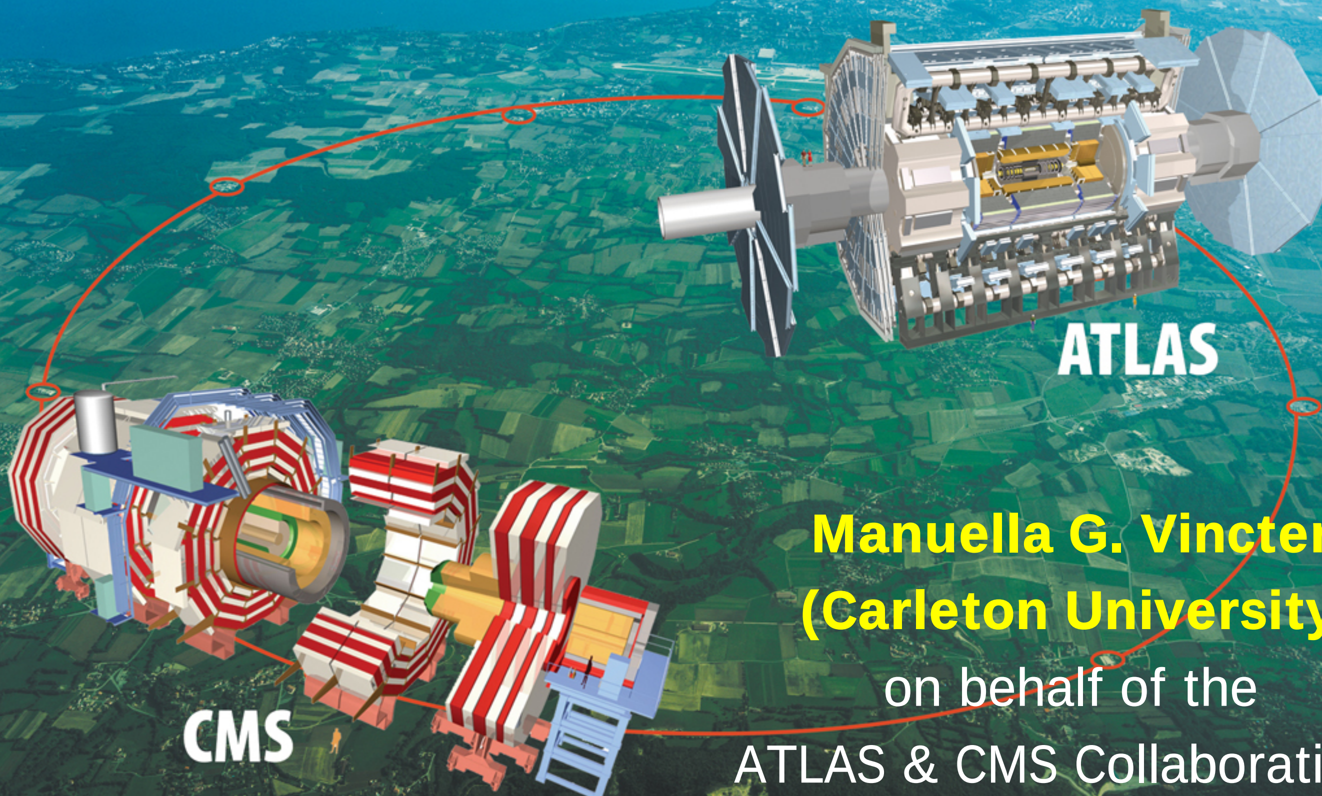
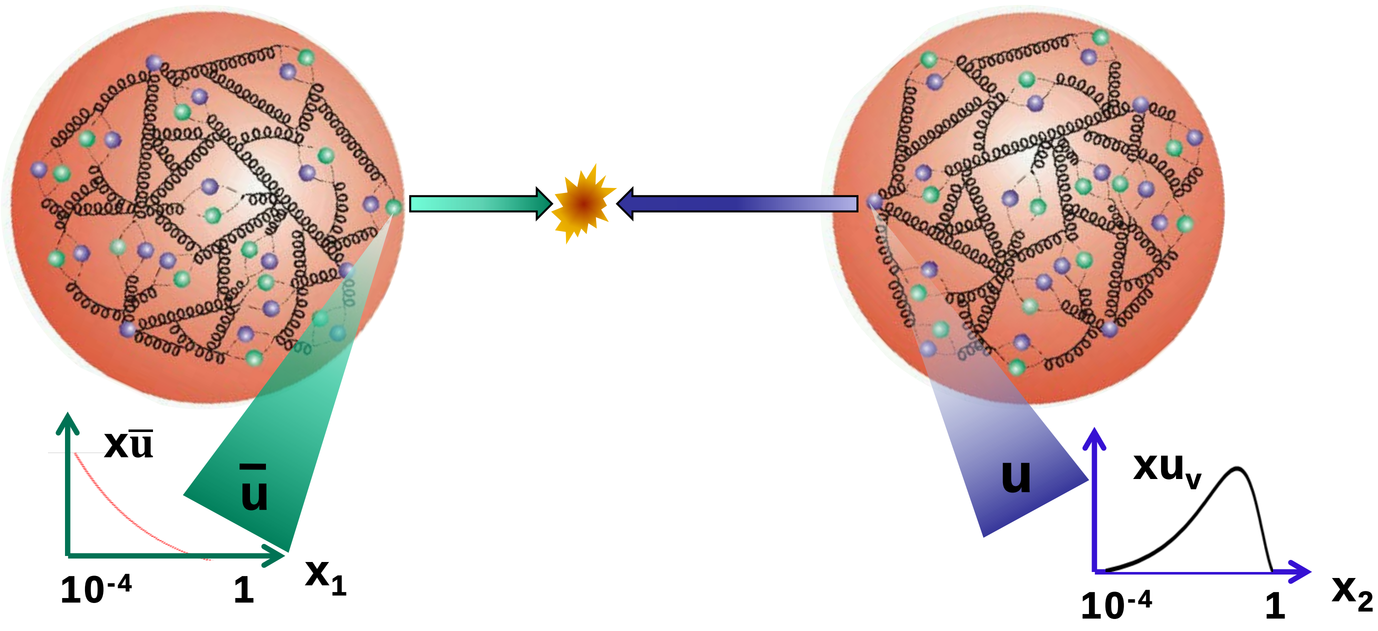
PANIC 2014 – Hamburg, Germany - August 2014

Measurements of vector-boson production in ATLAS and CMS



Manuella G. Vincter
(Carleton University)
on behalf of the
ATLAS & CMS Collaborations
at the LHC

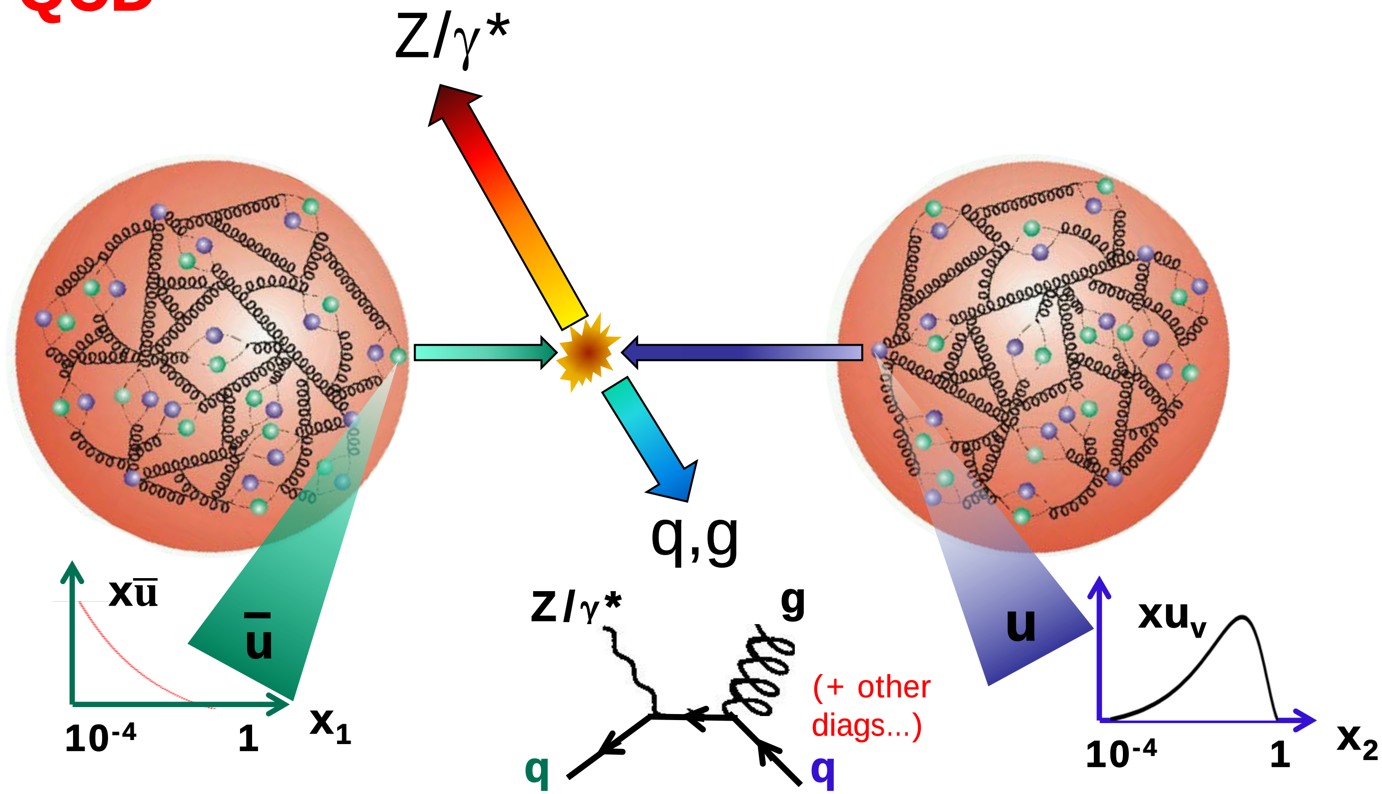


Parton distribution functions f of the proton (pdf)

x_1, x_2 = momentum fraction of partons

Thanks to:
desy.de, hepdata.cedar.ac.uk

Perturbative QCD



Parton distribution functions f of the proton (pdf)
x_1, x_2 = momentum fraction of partons

Hard scattering $\hat{\sigma}$ for k[th] sub-process between partons of flavour a and b

$$\sigma = \sum_{a,b,k} \int dx_1 dx_2 \; f_a(x_1, Q^2) \quad \hat{\sigma}_{a,b,k}(x_a, x_b) \quad f_b(x_1, Q^2)$$

Via hard scatter, can test perturbative QCD (pQCD) between initial, final states

Z balances the hadronic system

e.g. gluon hadronises/showers to jet of particles

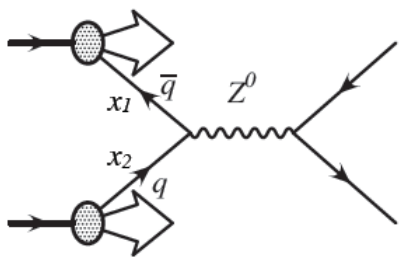
Have predictions up to NNLO

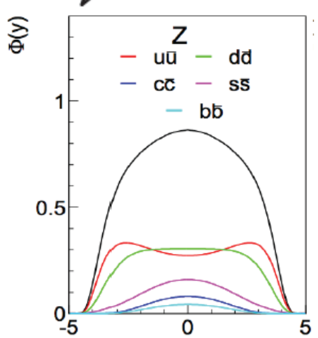
Thanks to:
desy.de, hepdata.cedar.ac.uk

Thanks to:
M. Sutton Moriond 2014, U. Klein DIS 2012

Global fits to extract PDFs

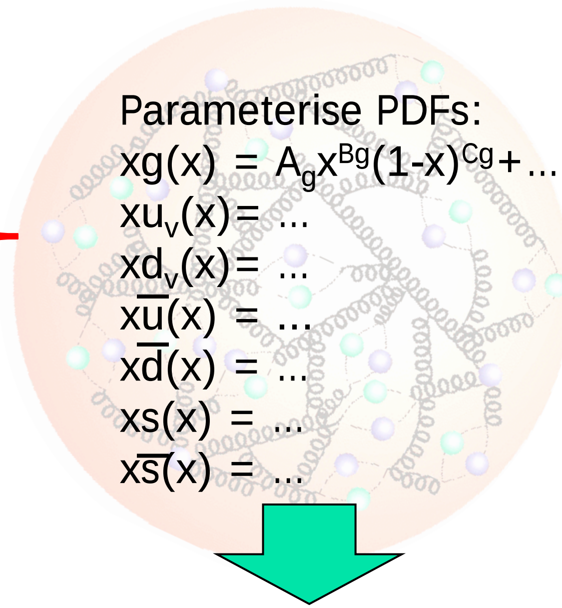
- DY production at LHC probes PDFs in the region $x \approx 10^{-4}$-10^{-1} and $Q^2 \approx 5\times10^2$-10^6 GeV^2
- Feed e.g. $W^\pm$, Z/γ^*, W+charm cross section information into global fits to extract PDFs
  - All data have differing sensitivity to different aspects of the proton's PDFs.
  - EW boson production sensitive to valence and sea quark distributions



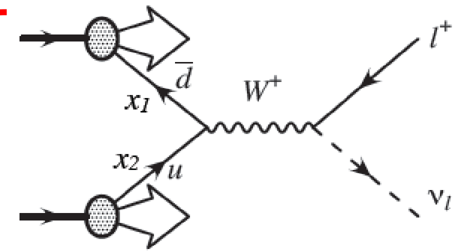


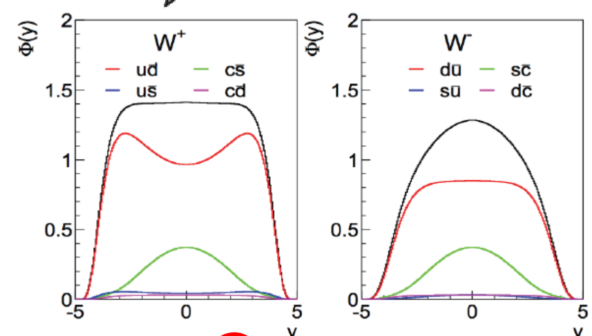
Rapidity y
(related at LO to momentum fraction x)

$$Z \sim 0.29(u\bar{u} + c\bar{c}) + 0.37(d\bar{d} + s\bar{s} + b\bar{b})$$

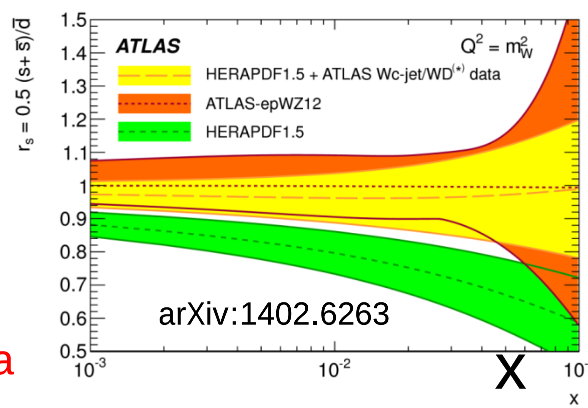


Parameterise PDFs:
$xg(x) = A_g x^{B_g}(1-x)^{C_g} + \ldots$
$xu_v(x) = \ldots$
$xd_v(x) = \ldots$
$x\bar{u}(x) = \ldots$
$x\bar{d}(x) = \ldots$
$xs(x) = \ldots$
$x\bar{s}(x) = \ldots$





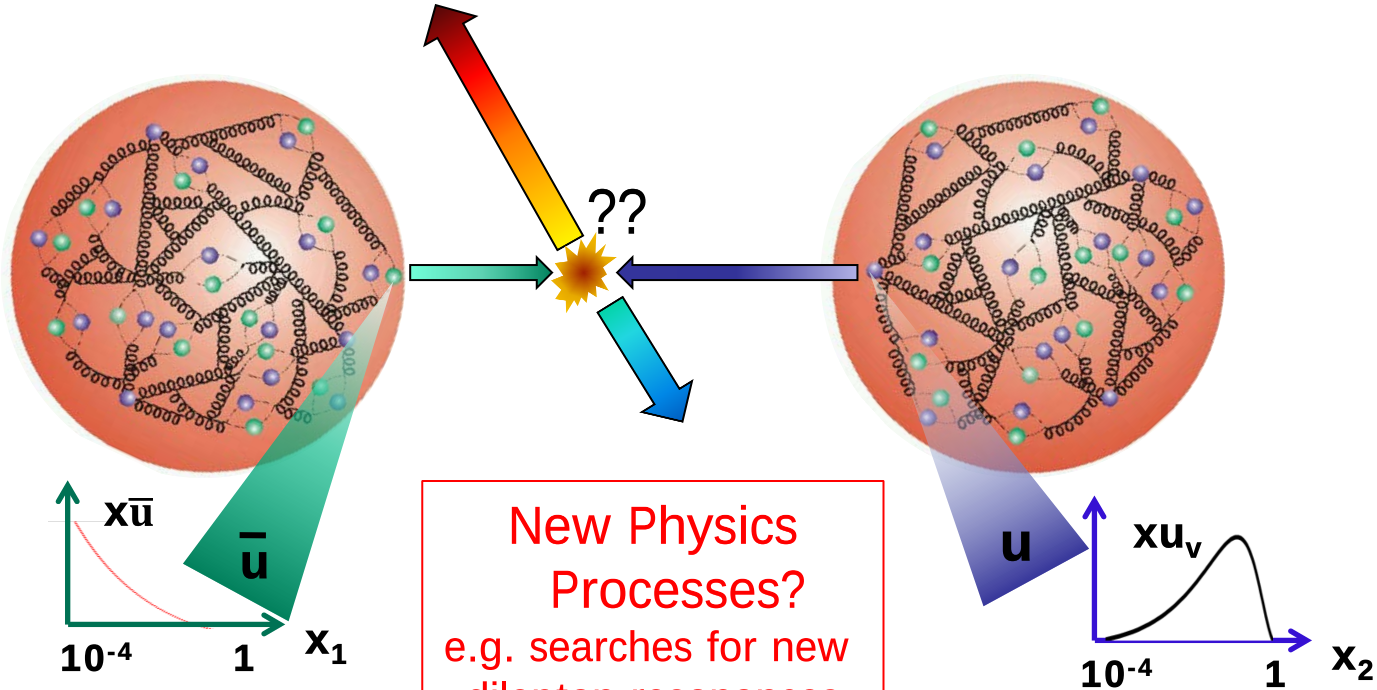
$$W^+ \sim 0.95(u\bar{d} + c\bar{s}) + 0.05(u\bar{s} + c\bar{d})$$
$$W^- \sim 0.95(d\bar{u} + s\bar{c}) + 0.05(d\bar{c} + s\bar{u})$$



$$r_s = (s + \bar{s})/2\bar{d}$$

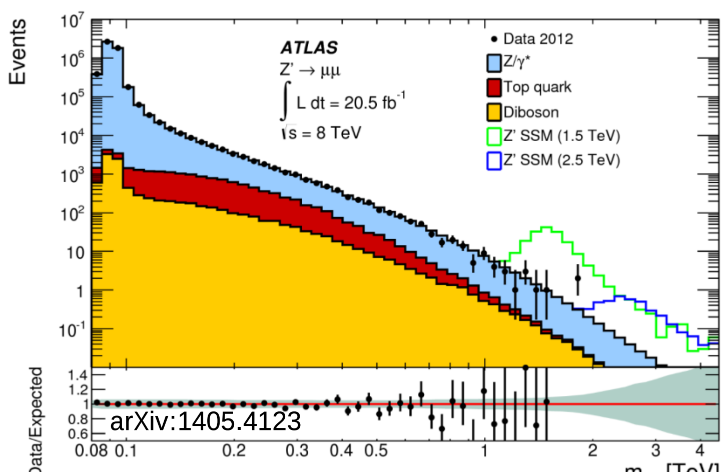
Result: e.g testing relationship between strange and down sea

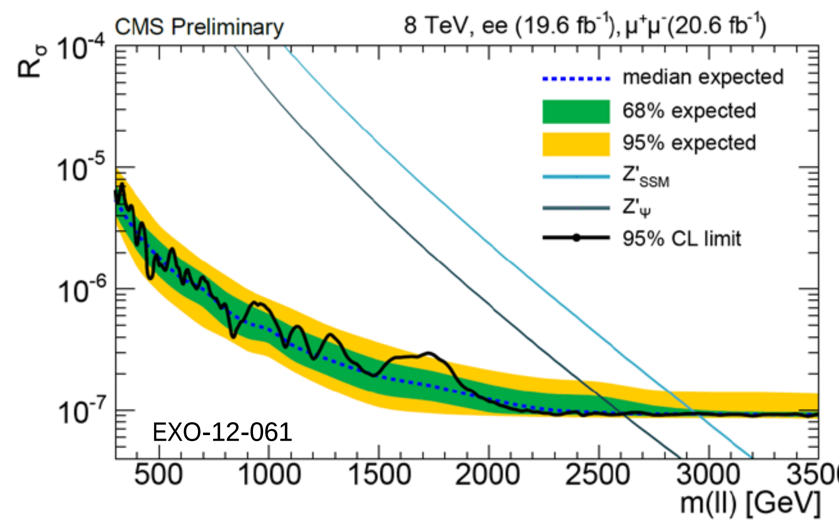
Beyond the SM?



New Physics Processes?

e.g. searches for new dilepton resonances



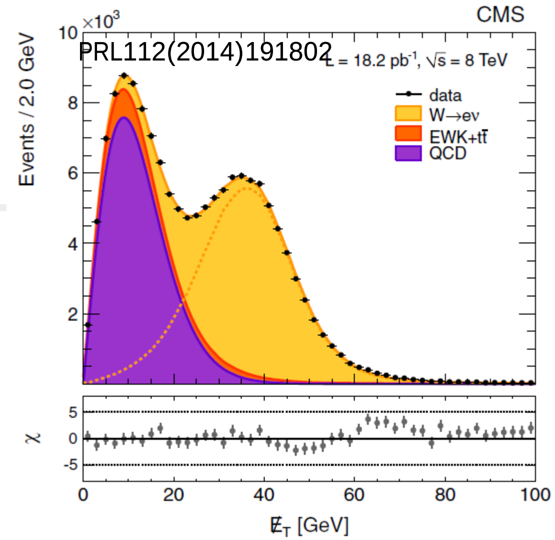


Recent measurements covered in this talk

Some of the results in these recent papers/notes are presented here:

- p_T dependence of Z/γ^* production
  - CMS@8TeV: CMS PAS SMP-13-013
  - ATLAS@7TeV: arXiv:1406.3660, Phys. Lett. B720 (2013) 32
- $m_{\ell\ell}$ dependence of Z/γ^* production
  - CMS@7 and 8TeV: JHEP 12 (2013) 030, CMS PAS SMP-14-003
  - ATLAS@7TeV: JHEP 06 (2014) 112 (low mass), Phys. Lett. B 725 (2013) 223 (high mass)
- W, Z inclusive cross sections at 8TeV
  - CMS: PRL 112 (2014) 191802
- W charge asymmetry, W+charm and QCD analysis
  - CMS@8TeV: PRD 90 (2014) 032004
  - ATLAS@7TeV: JHEP05 (2014) 068

Characteristics of leptonic decays of W,Z and their measurements

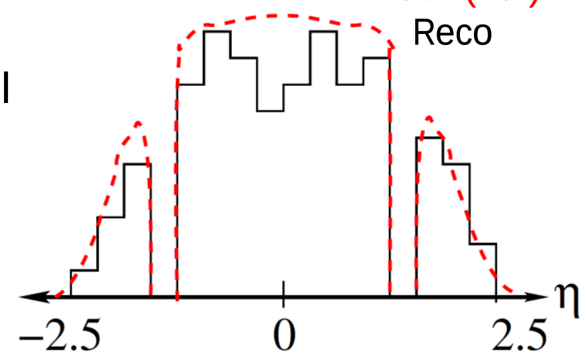


W: prompt, energetic, isolated charged ℓ + ν giving rise to E_T^{miss}

- E_T^{miss} used as a discriminant against background

Z: 2 prompt, energetic , isolated charged ℓ, same flavour, opposite sign

- Two-lepton invariant mass defines low-, high-mass and, on-peak
- Leptons reconstructed within pseudorapidity η and transverse momentum p_T ranges afforded by the detector (defines fiducial region)

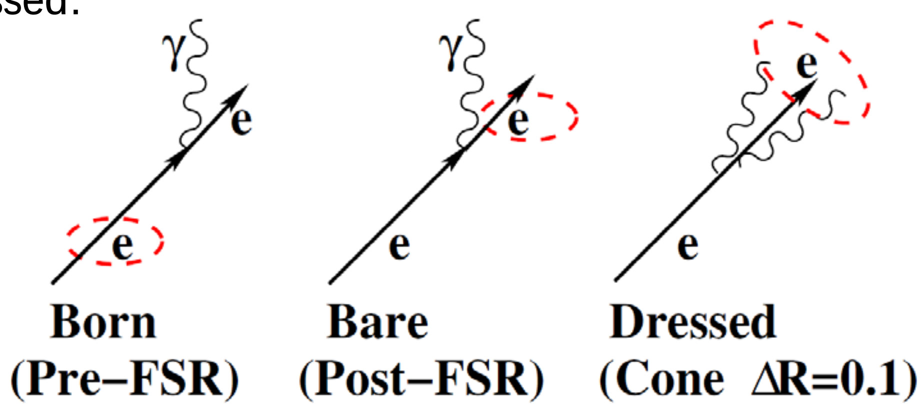


Measurements reported in fiducial or full phase-space

- Use simulation to unfold data from “reconstruction” to “truth” level
- Correction factor: reconstruction → truth level in fiducial region
- Acceptance: truth fiducial region → full truth phase-space

Cross-section measurement reported at one or more levels:

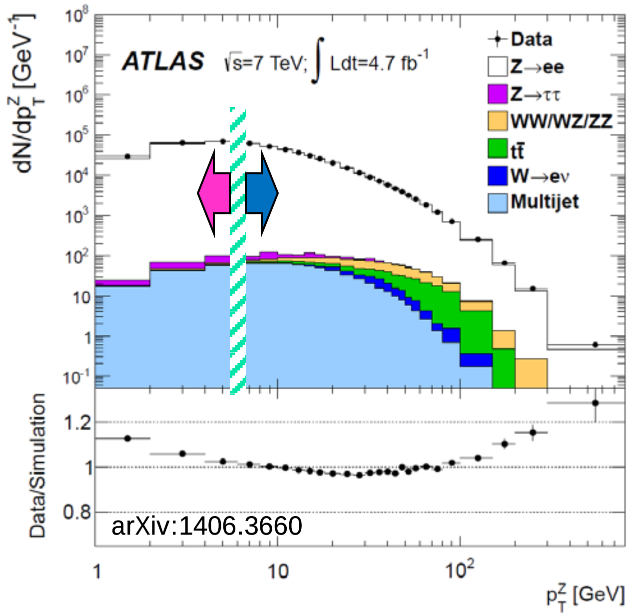
- Born, bare, dressed:



p_T dependence of Z/γ^* production

Near Z pole (ATLAS: $m_{\ell\ell}$=66-116GeV@$\sqrt{s}$=7TeV, CMS: $m_{\ell\ell}$=81-101GeV@$\sqrt{s}$=8TeV):

- $d\sigma/dp_T^{\ell\ell}$, $d^2\sigma/dp_T^{\ell\ell}d|y_{\ell\ell}|$
- Low $p_T^{\ell\ell}$: region of ISR and intrinsic k_T of partons
- modeled through soft-gluon resummation or parton showers (PS)
  - e.g. ResBos (NLO,NNLO)+NNLL



- High $p_T^{\ell\ell}$: region dominated by radiation of high p_T gluons
  - Sensitive to gluon PDF
- Modeled with fixed-order calculations like FEWZ @NLO,NNLO & DYNNLO (with NLO,NNLO EW corrs)

Measurements also compared with various generators (for a given PDF)

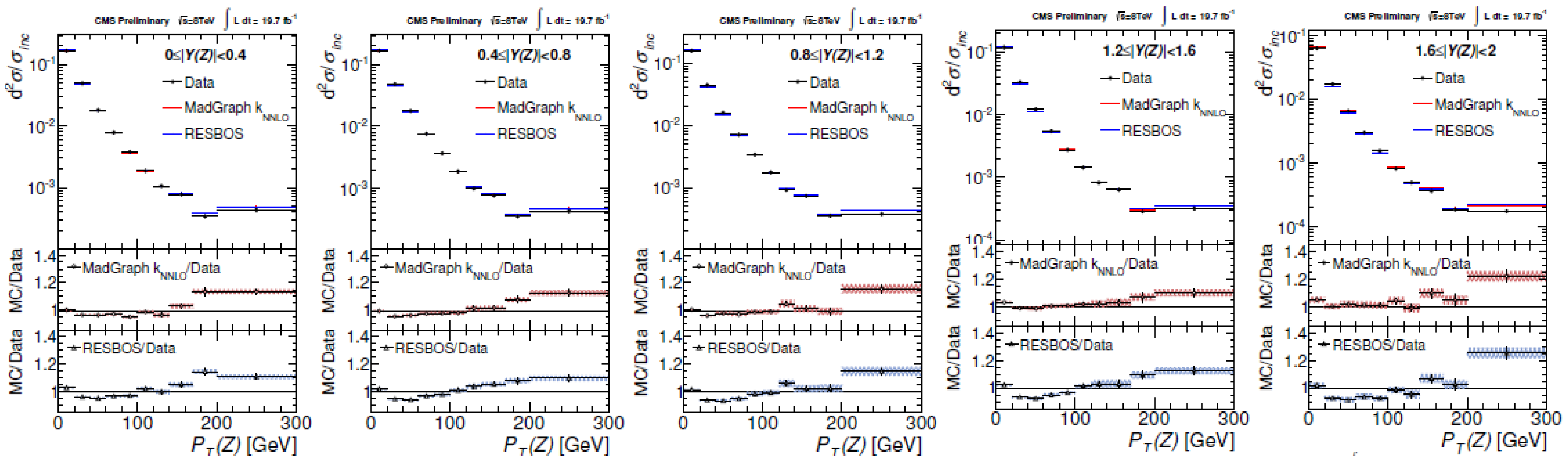
- MADGRAPH with k_{NNLO} with 0-4 additional jets interfaced to PYTHIA6
- PYTHIA & HERWIG: PS for low $p_T^{\ell\ell}$, include $O(\alpha_s)$ m^x element for 1 hard parton
- MC@NLO & POWHEG: NLO QCD m^x element into PS frameworks of HERWIG or PYTHIA
- ALPGEN & SHERPA: tree-level m^x elements for generation of multiple hard partons in association with the boson

Note: precise CMS measurement of inclusive cross section for $m_{\ell\ell}$=60-120GeV@$\sqrt{s}$=8TeV

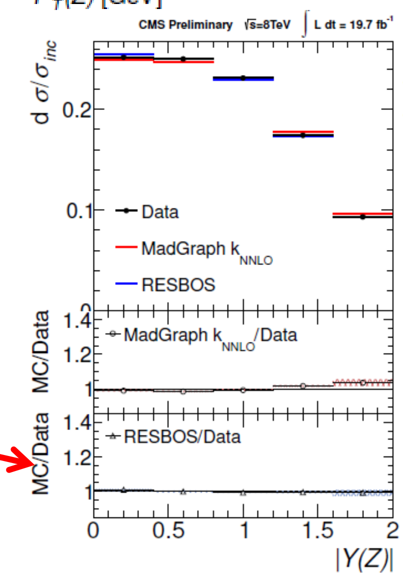
$$\sigma(pp \to ZX) \times \mathcal{B}(Z \to \ell^+\ell^-) = 1.15 \pm 0.01\,(\text{stat}) \pm 0.02\,(\text{syst}) \pm 0.03\,(\text{lum})\ \text{nb}$$ PRL112(2014)191802

CMS $p_T^{\ell\ell}$

$(1/\sigma^{fid})\ d^2\sigma^{fid}/dp_T^{\ell\ell}\ d|y_{\ell\ell}|$ @ born level (5 bins of $|y_{\ell\ell}|$, $\mu\mu$ only)



- LO MADGRAPH σ scaled to NNLO with FEWZ and ResBos in approximate NNLO
  - Both overshoot data for $p_T^{\ell\ell}$ above 80GeV
  - No y-trend observed with ResBos
    - better seen when integrating over $p_T^{\ell\ell}$



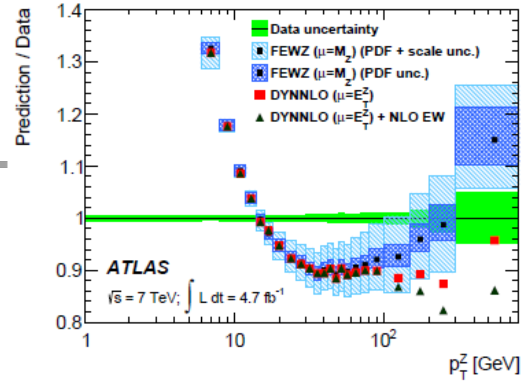
arXiv:1406.3660
Phys. Lett. B720 (2013) 32

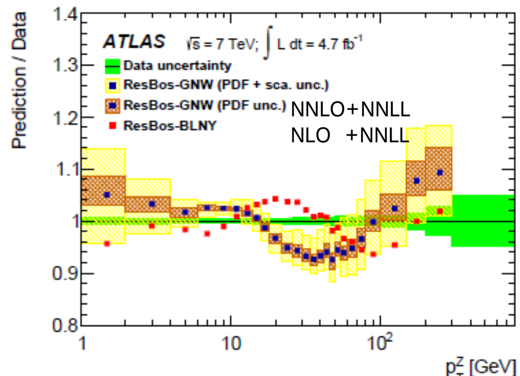
ATLAS $p_T^{\ell\ell}$

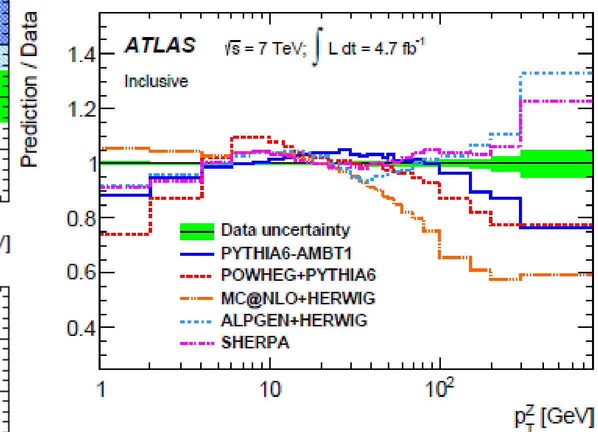
$(1/\sigma^{fid})\ d\sigma^{fid}/dp_T^{\ell\ell}$ @ born level, inclusively in $y_{\ell\ell}$ (ee and $\mu\mu$)

- FEWZ,DYNNLO (top), ResBos (bot)

Comparison to various generators, inclusive (and in 3 $|y_{\ell\ell}|$ bins not shown)





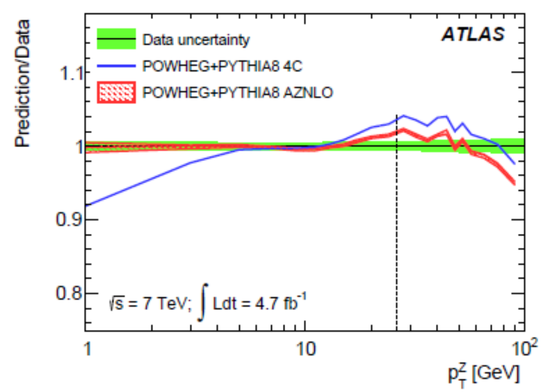


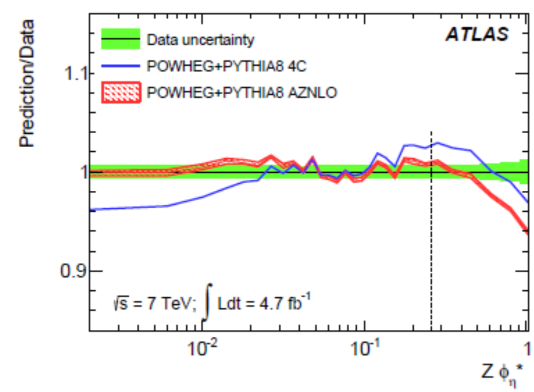
Parton-shower tunes: determine sensitivity of $d\sigma/dp_T^{\ell\ell}$ to PS models

- Include measurement of ϕ_η*****, highly correlated to p_T^Z but depends on direction of tracks (better measured than momenta)

$$p_T^Z \approx m_Z\, \phi_\eta^*$$

- e.g. compare POWHEG+PYTHIA8 new tune AZNLO with base tune 4C
  - Primordial k_T and ISR cut-off have been tuned



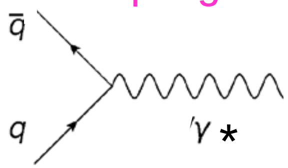


Consistent tune with $p_T^{\ell\ell}$ and ϕ_η* in agreement within 2% with data for $p_T^{\ell\ell}$<50GeV

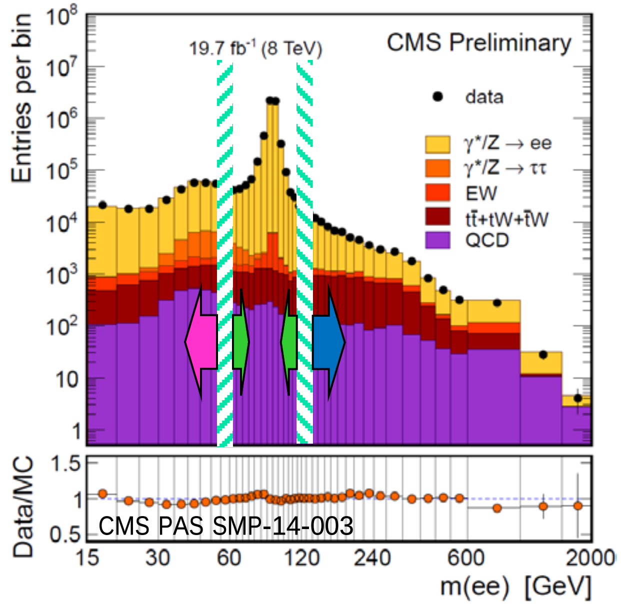
$m_{\ell\ell}$ dependence of Z/γ^* production

CMS: $m_{\ell\ell}$=15-2000 GeV@√s=7,8 TeV, ATLAS: $m_{\ell\ell}$=12-1500 GeV@√s=7 TeV

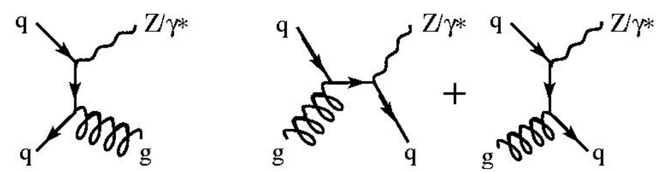
- $d\sigma/dm_{\ell\ell}$, $d^2\sigma/dm_{\ell\ell}d|y_{\ell\ell}|$
- Low-mass DY: dominated by EM coupling of γ^* to $q\bar{q}$



- Different sensitivity to u, d-type $q\bar{q}$ than on peak



- Peak region and above dominated by Z, γ^* coupling to $q\bar{q}$



- High-mass DY shape can be modified by new physics

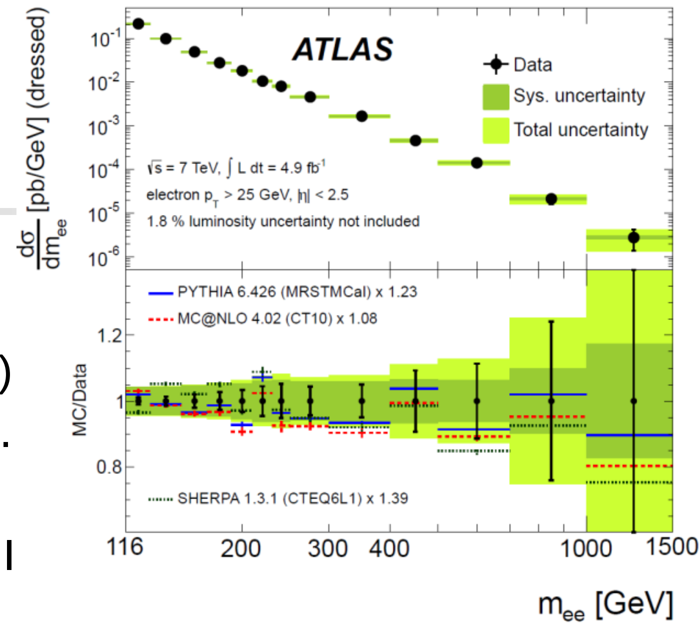
Measurements compared to FEWZ, generators, including higher-order EW corrections and γ-induced interactions (PI), and various PDFs

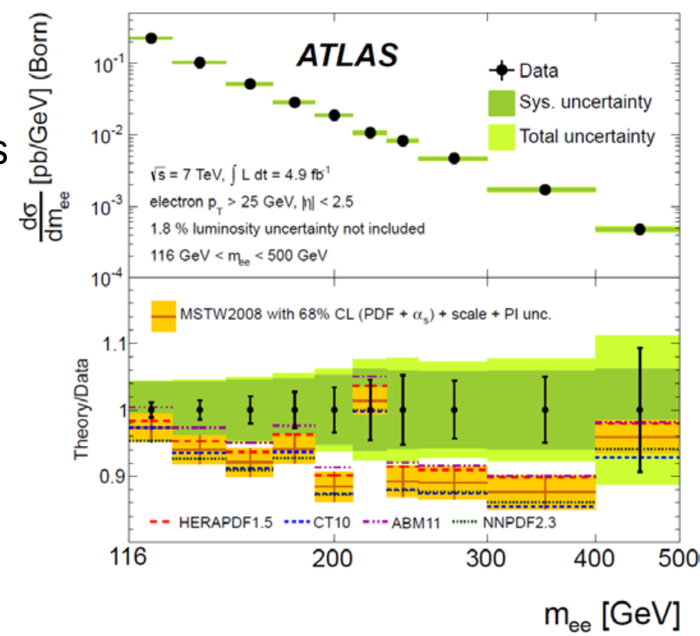
- FEWZ3.1 at NLO, NNLO
- POWHEG+PYTHIA6, corrected to NNLO with FEWZ
- POWHEG NLO calculation matched LL-resummed parton showers
- PYTHIA6, MC@NLO, SHERPA (with up to 3 additional partons)
- PDFs: MSTW2008, HERADPDF1.5, CT10, CT10W,AMB11, NNPDF2.1,2.3, JR09, ABKM09, ...

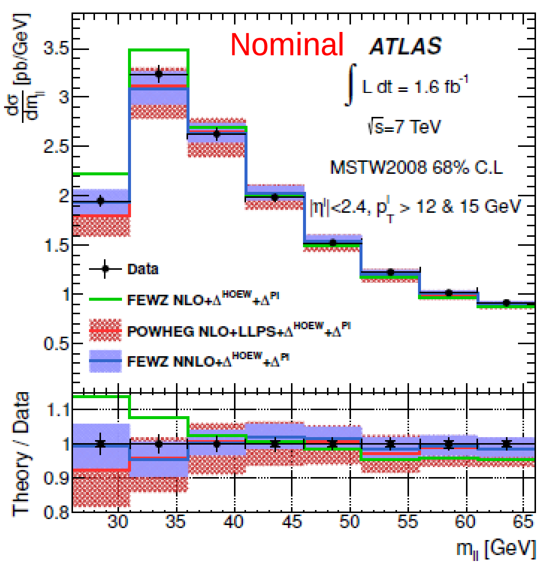
High mass: Phys. Lett. B 725 (2013) 223
Low mass: JHEP 06 (2014) 112

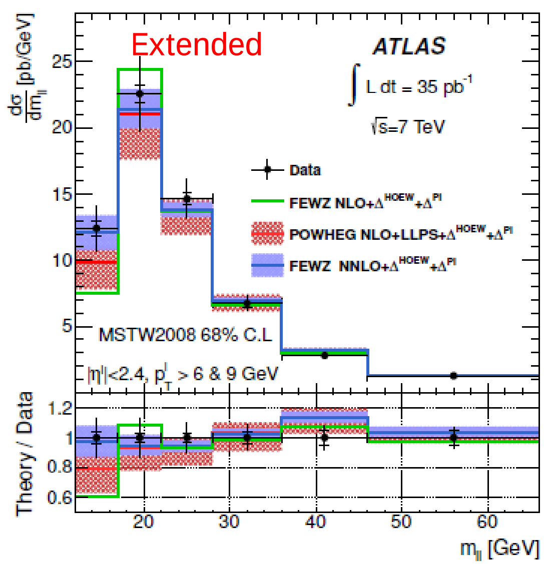
ATLAS $m_{\ell\ell}$

- High-mass DY in ee channel: born, dressed $d\sigma^{fid}/dm_{\ell\ell}$
  - Compare to 3 generators (norm. to total # of data evts)
  - Measured compared to FEWZ NNLO with NLO EW corrs.
    - Most PDFs disagree with predictions at mid-mass
      - MSTW2008 uncertainty from PDF, α_S, scale, PI
- Low-mass DY in ee+$\mu\mu$ (nominal) and use of 2010 data to go down to $m_{\ell\ell}$ = 12 GeV in $\mu\mu$ (extended): born $d\sigma^{fid}/dm_{\ell\ell}$ Comparisons to predictions, including EW corr and PI
  - χ^2 disagreement of NLO FEWZ to data at low $m_{\ell\ell}$ implies that at least NNLO is needed





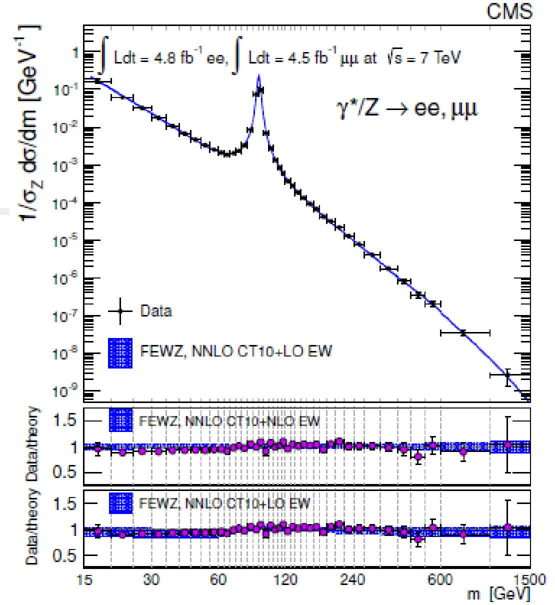


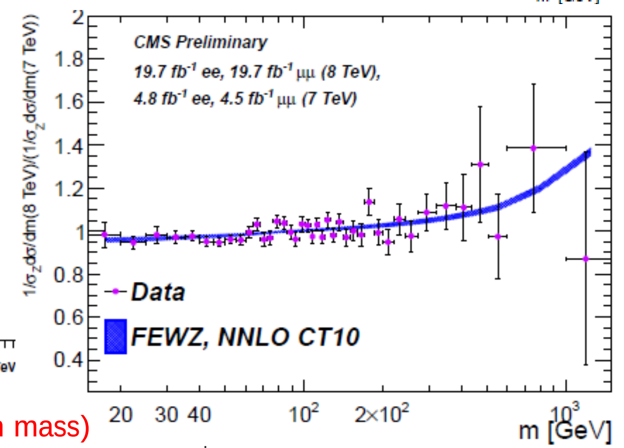


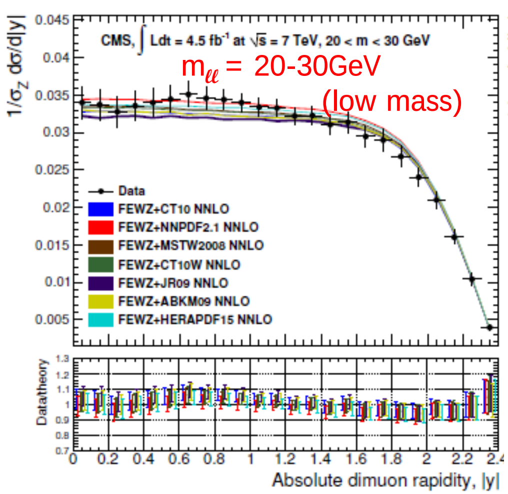
7TeV: JHEP12(2013)030
8TeV: CMS PAS SMP-14-003

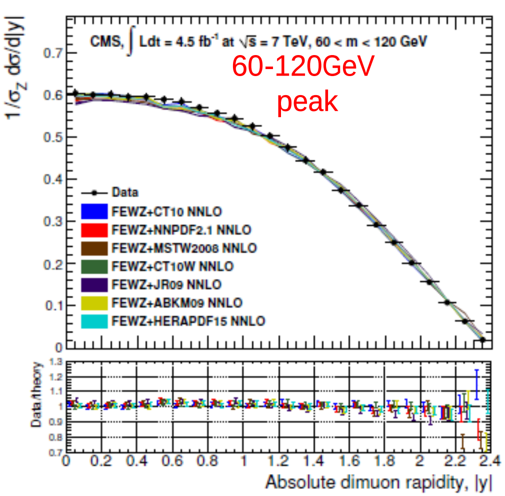
CMS $m_{\ell\ell}$

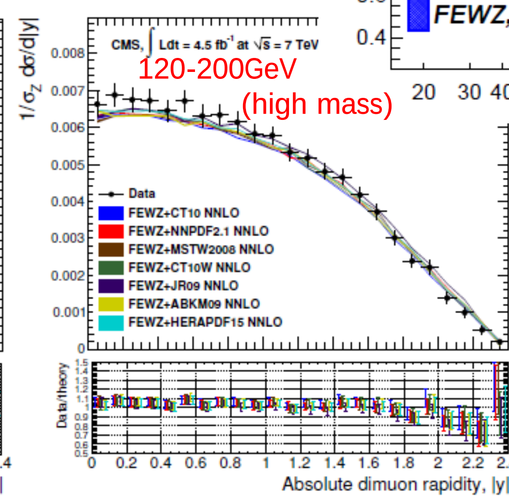
- $(1/\sigma_Z)\, d\sigma/dm_{\ell\ell}$: ee+μμ channel normalised to peak region (7TeV)
  - Comparisons including LO and NLO EW corrections
- Dimuon $(1/\sigma_Z)\, d\sigma/d|y_{\ell\ell}|$ normalised to peak region available in 6 $m_{\ell\ell}$ bins (3 shown) compared to FEWZ using various PDF sets
  - Test compatibility of PDFs with low-to-high-mass DY
- Ratio of born-level $(1/\sigma_Z)\, d\sigma/dm_{\ell\ell}$ at 8TeV to 7TeV in ee+μμ channels available in 6 $m_{\ell\ell}$ bins (inclusive shown) compared to NNLO FEWZ obtained with CT10 NNLO PDF
  - Shape driven by √s and x dependencies of PDFs
    - 1 near peak (hard scattering cancels), high mass (x>0.3) PDF at smaller √s fall steeper at large x





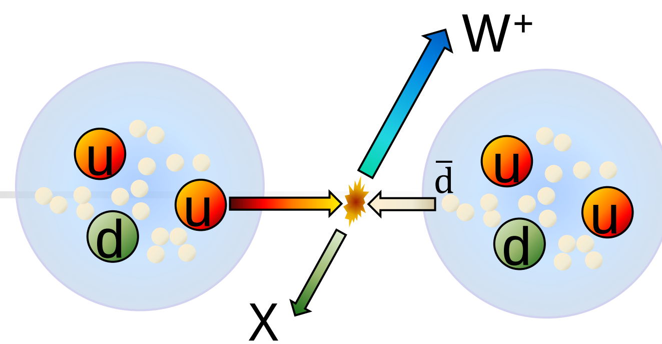






arXiv:1312.6283
PRL112(2014)191802

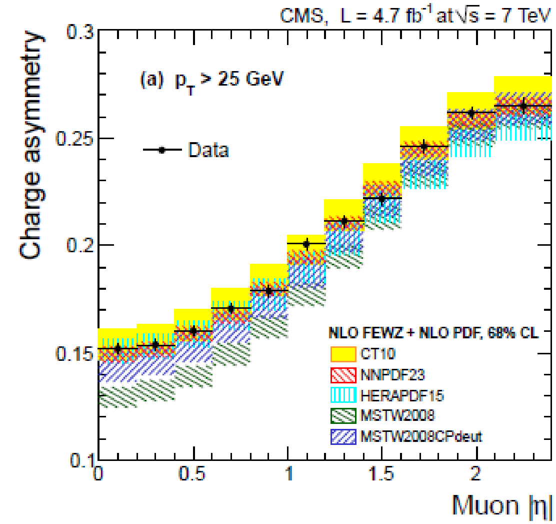
CMS W-charge asymmetry

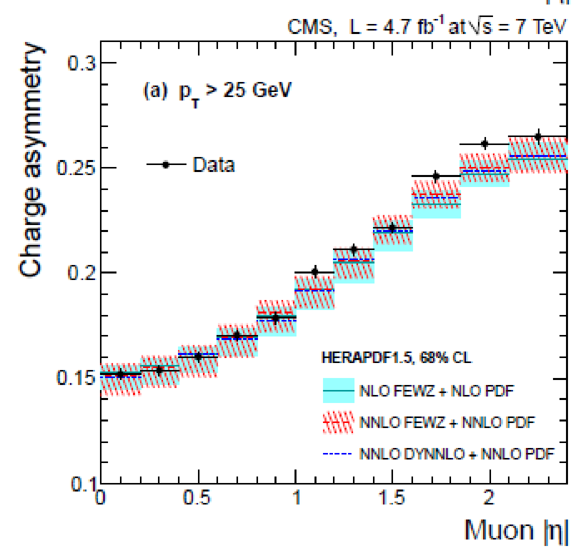


- Dominant W production mechanisms at LHC:
  - valence+sea antiquark: $d\bar{u} \rightarrow W^-$ and $u\bar{d} \rightarrow W^+$
  - W^+,W^- production asymmetry due to valence content
    - R_{W^+/W^-} $1.39 \pm 0.01(\text{stat}) \pm 0.02(\text{syst})$ (at 8TeV)
- Lepton charge asymmetry vs. pseudorapidity η can provide information on PDFs:

$$\mathcal{A}(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \ell^+\nu) - \frac{d\sigma}{d\eta}(W^- \to \ell^-\overline{\nu})}{\frac{d\sigma}{d\eta}(W^+ \to \ell^+\nu) + \frac{d\sigma}{d\eta}(W^- \to \ell^-\overline{\nu})}$$

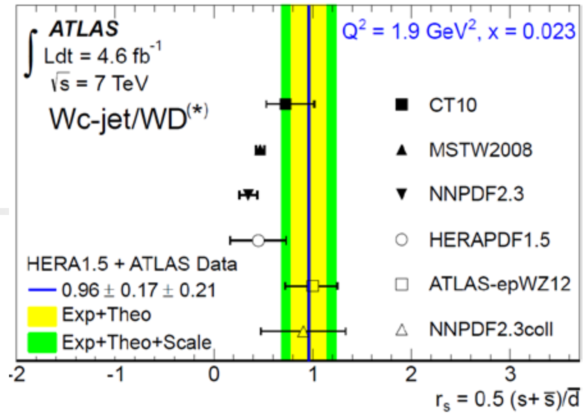
  - d/u ratio and sea antiquarks (including strangeness)
- CMS measurement at 8TeV with $W \rightarrow \mu\nu$ and p_T^ℓ>25,35GeV (probe different bkg compositions)
  - Good agreement with CT10, NNPDF2.3, HERAPDF1.5
  - Less so with MSTW2008 |η|<1 (MSTW2008CPdeut better)
  - Comparable concordance with NNLO FEWZ and DYNNLO
    - Somewhat low compared to data at high |η|



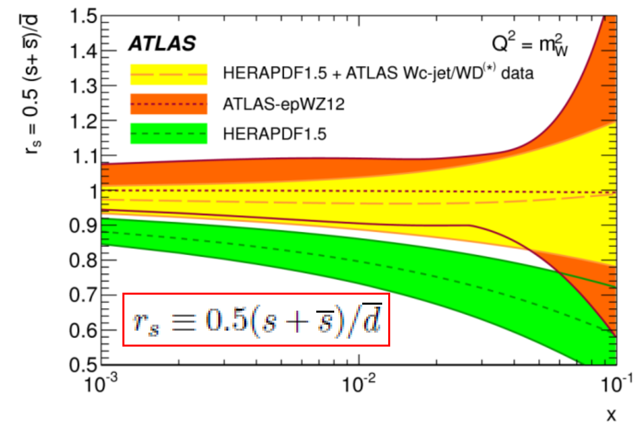


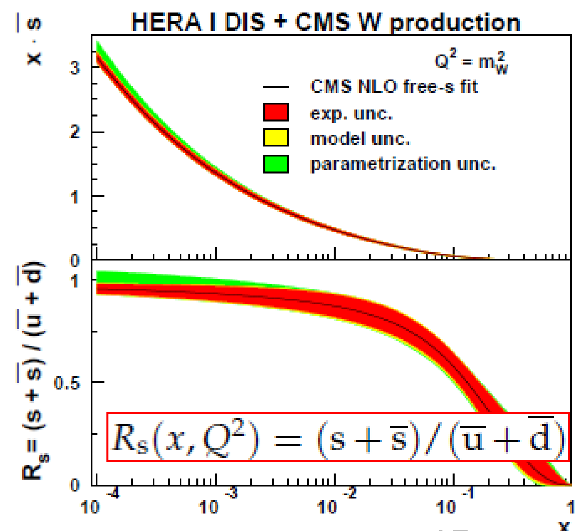
PDF extraction in the HERAFITTER framework

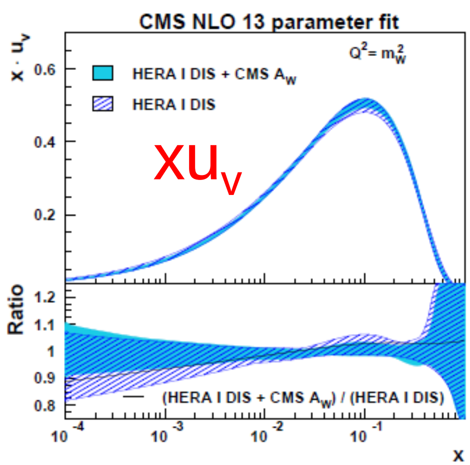
ATLAS: JHEP05 (2014) 068
CMS: arXiv:1312.6283

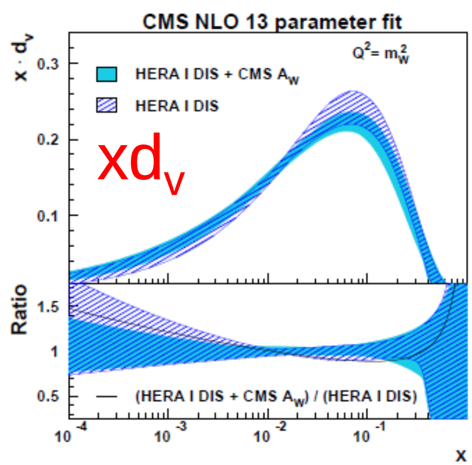


- Use HERA inclusive DIS data with LHC W data to better constrain PDFs, in particular valence and strange
- ATLAS: HERA + [W+charm]
  - Repeat HERAPDF1.5 fit making $f_s = \bar{s}/(\bar{d}+\bar{s})$ ~free while constraining other params to HERAPDF1.5 fit results
    - $r_s \equiv 0.5(s+\bar{s})/\bar{d}$ ~1 at starting scale Q^2=1.9GeV^2
- CMS: HERA + $\mathcal{A}(\eta)$ + [W+charm]
  - Adding $\mathcal{A}(\eta)$ improves valence precision, changes shape
  - Free-s fit where dbar and sbar parameterised separately
    - $R_S = (s+\bar{s})/(\bar{u}+\bar{d})$, just below 1
- Within framework, ATLAS&CMS strange fraction definition similar at starting scale… R_S & r_s can be directly compared: ~consistent









Summary

Vector-boson production at the LHC is interesting on so many levels

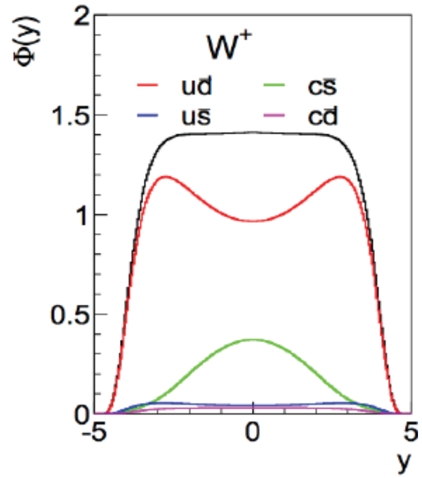
- Probe of
  - pQCD via the hard scattering process
  - PDFs, particularly valence and poorly-known strange sea
  - $m_{\ell\ell}$, $|y_{\ell\ell}|$, $p_T^{\ell\ell}$ dependence of Z/γ^* production, W charge asymmetry: CMS and ATLAS
- Underlying foundation of many new physics searches
  - e.g. can help us to better understand backgrounds and PDFs for LHC at higher energy/luminosity

ADDITIONAL MATERIAL

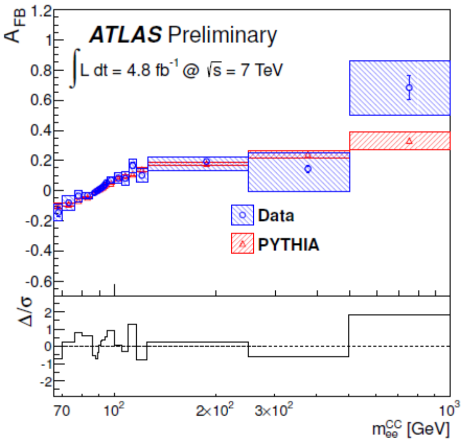
Future prospects: benefits of extending the tracking coverage?

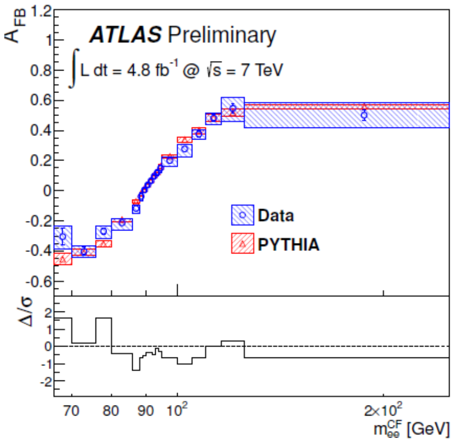
- Tracking coverage at ATLAS and CMS stops at $|\eta|\sim 2.5$
- Benefits for W,Z production to extend the coverage to $|\eta|\sim$ 4 - 5?
  - Extension of Bjorken-x coverage
  - Probe of valence PDFs
    - new physics at large $m_{\ell\ell}$ depend on PDFs at high x
  - $Z\to\ell\ell$ forward-backward asymmetry: $\sin^2\theta_W$
    - Sign for F,B measured with respect to incoming quark direction
      - Dilution of info in pp collisions: q comes from which p?
      - Quark direction misID decreases with increasing $\ell\ell$ boost
    - e.g. ATLAS extending range where electron is identified
      - Lower asymmetry dilution $\to$ increased sensitivity to $\sin^2\theta_W$
      - Can forward calo e still be identified at higher pileup?

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



Both e in tracker volume $|\eta|<2.47$ $\to$ $|y_{ee}|<2.4$





One e in tracker, one e in calo $2.5<|\eta|<4.9$ $\to$ $|y_{ee}|<3.5$

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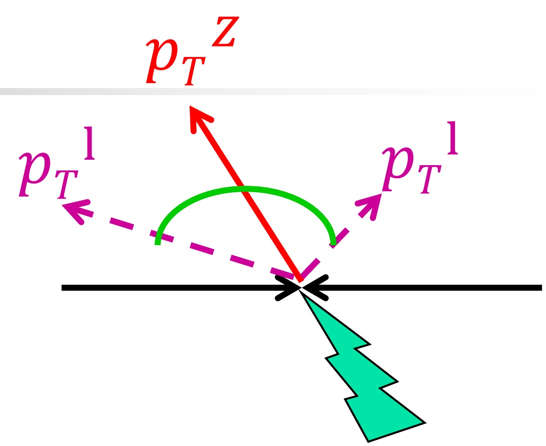
Z cross section vs. ϕ_η*



- A better variable to probe low-p_T Z: ϕ_η*

$$\phi^*_\eta \equiv \tan(\phi_{\rm acop}/2) \cdot \sin(\theta^*_\eta)$$

where $\phi_{\rm acop} \equiv \pi - \Delta\phi,$ (ϕ between 2 leptons)

and $\cos(\theta^*_\eta) \equiv \tanh[(\eta^- - \eta^+)/2]$ (η between 2 leptons)

- Probes same physics as Z p_T but with better precision

$$p_T{}^Z \approx m_Z\, \phi_\eta{}^*$$

- Depends uniquely on direction of lepton tracks (which is better measured than their momenta)
- Significant improvement in the understanding of electron track parameters in 2011/2012 really helped this analysis!