# W, Z inclusive at the LHC.

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### Prologe: *ep* as a proton structure probe



Neutral current Deep Inelastic Scattering (DIS) cross section:

$$\frac{\mathrm{d}^2\sigma^{\pm}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x}\sigma_r^{\pm} =$$

$$= \frac{2\pi\alpha^2 Y_+}{Q^4 x} \left[ F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2) \mp \frac{Y_-}{Y_+} x F_3 \right]$$

where factors  $Y_{\pm} = 1 \pm (1 - y)^2$  and  $y^2$  define polarisation of the exchanged boson and  $y = Q^2/(Sx)$ .

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Kinematics is determined by boson virtuality  $Q^2$  and Bjorken *x*. At leading order:

$$F_{2} = x \sum e_{q}^{2}(q(x) + \bar{q}(x))$$

$$xF_{3} = x \sum 2e_{q}a_{q}(q(x) - \bar{q}(x))$$

$$\sigma_{CC}^{+} \sim x(\bar{u} + \bar{c}) + x(1 - y)^{2}(d + s)$$

$$\sigma_{CC}^{-} \sim x(u + c) + x(1 - y)^{2}(\bar{d} + \bar{s})$$

xg(x) — from  $F_2$  scaling violation, jets and  $F_L$ 



## HERA and LHC kinematics



 $x_1$ ,  $x_2$  are momentum fractions.

Factorization theorem states that cross section can be calculated using universal partons  $\times$  short distance calculable partonic reaction.

$$x_{1,2} = \frac{M}{\sqrt{S}} \exp(\pm y)$$



## Neutral Current Processes at the LHC

1000

1000

Z Boson

|YZ| Interference

Photon





Propogator for  $\gamma$  exchange:

$$P_{\gamma}(M)=rac{1}{M^4}$$

pure Z exchange:

$$P_Z(M) = \frac{k_Z^2(v_e^2 + a_e^2)}{\left(M^2 - M_Z^2\right)^2 + \Gamma_Z^2 M_Z^2},$$

where  $k_Z = (4 \sin^2 \theta_W \cos^2 \theta_W)^{-1}$ , and  $\gamma Z$  intereference:

$$P_{\gamma Z}(M) = \frac{k_Z v_e (M^2 - M_Z^2)}{M^2 \left[ \left( M^2 - M_Z^2 \right)^2 + \Gamma_Z^2 M_Z^2 \right]},$$



pp --> e<sup>+</sup>e<sup>-</sup> X at 10 TeV

cross section  $d\sigma/dM$  [nb  $GeV^1$ ]

10<sup>0</sup>

10<sup>-1</sup>

10<sup>-2</sup>

 $10^{-3}$ 

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## Z and low mass DY production flavour decomposition



Z vs  $\gamma^*$  are sensitive to U/D ratio:

 $Z \sim 0.29(u\bar{u} + c\bar{c}) + 0.37(d\bar{d} + s\bar{s} + b\bar{b})$   $\gamma^* \sim 0.44(u\bar{u} + c\bar{c}) + 0.11(d\bar{d} + s\bar{s} + b\bar{b})$ Contribution from  $\gamma - Z$  interference is small.

## $W^+$ and $W^-$ production flavour decomposition



 $W^+$  ( $W^-$ ) production is sensitive to  $u\bar{d}$  ( $d\bar{u}$ ) as well as  $c\bar{s}$  ( $s\bar{c}$ ) flavour combinations and to lesser extend to Cabbibo supressed pairs:

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





For  $W^{\pm}$  production the observalbes are lepton  $p_t$  and  $\eta$ . V-A structure of the decay modifies rapidity distribution of the lepton vs the boson.  $W^+$  production accesses higher y for a given  $\eta_e$  range.

(plots based on LO MCFM, HERAPDF1.0)



NNLO calculations agree well with NLO estimate  $\rightarrow$  perturbative convergence. NNLO is within 2% stable vs scale variation

## Early PDF constraining LHC measurements



Total cross section measurements are published by ATLAS/CMS, based on early data samples. Errors are dominated by the luminosity uncertainty (11%).

Total data samples collected in 2010 are ~ 200K W and ~ 20K Z leptonic decays. Potentially PDF constraining measurements based on W: lepton asymmetry. Interesting results from Z:  $y_Z$  and  $p_{t,Z}$ distributions are expected this winter.

## Decomposition of *U* and *D*



#### HERA fits without d = u assumption



Unconstrained fit preserves narrow  $4\bar{U} + \bar{D}$  but orthogonal combination  $\bar{U} - 4\bar{D}$  has very large spread. The only significant constraint comes from the positivity of the PDFs,  $\bar{D} > 0, \bar{U} > 0$ , which is built in the parameterisation.



Central unconstrained fit prefers solution with low  $\overline{D}$  and increased  $\overline{U}$ . The difference is dramatic at the starting scale, but it remains sizable at the  $M_W$  scale too.

LHAPDF grid file for the unconstraint fit:

https://www.desy.de/h1zeus/combined\_results/proton\_structure/Fits/HERAPDF1.0u.LHgrid.gz

#### Low mass DY vs Z for U over D decomposition



Since  $\gamma^*$  exchange has the same sensitivity to the quark flavours as the measurement of  $F_2$  at HERA, unconstrained fit agrees with HERAPDF1.0 at low  $M_{e^+e^-}$ , but sizable lower at  $M_{e^+e^-} = M_Z$ .

based on NLO MCFM

Lepton asymmetry measurement, for  $\overrightarrow{CC}$  events also provides constraint on D/U

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$$A = \frac{\ell^{+} - \ell^{-}}{\ell^{+} + \ell^{-}}$$

# Summary

- DIS cross section measurements at HERA provide PDFs for accurate predictions at the LHC
- First *W*, *Z* cross section measurements are published by the ATLAS and CMS collaborations.
- Collected data samples suggest that we may expect PDF constraining results in the near future: direct comparison/complementarity to the HERA results.