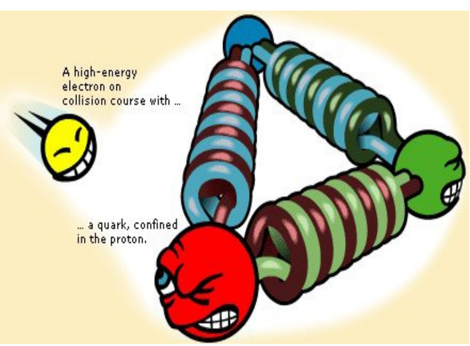
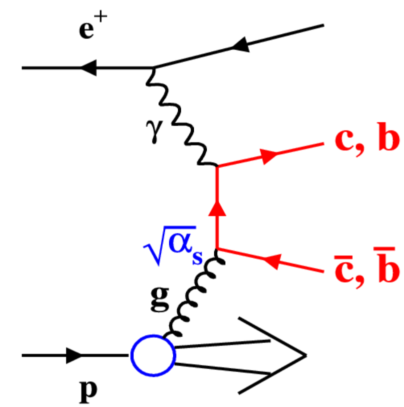
Beauty and charm production at HERA



Outline

- Heavy flavour physics at HERA
- Experimental techniques
- Recent beauty and charm results



Vladyslav Libov (DESY)

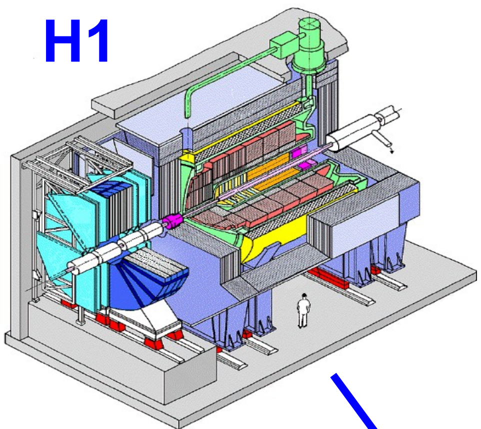
on behalf of H1 and ZEUS collaborations

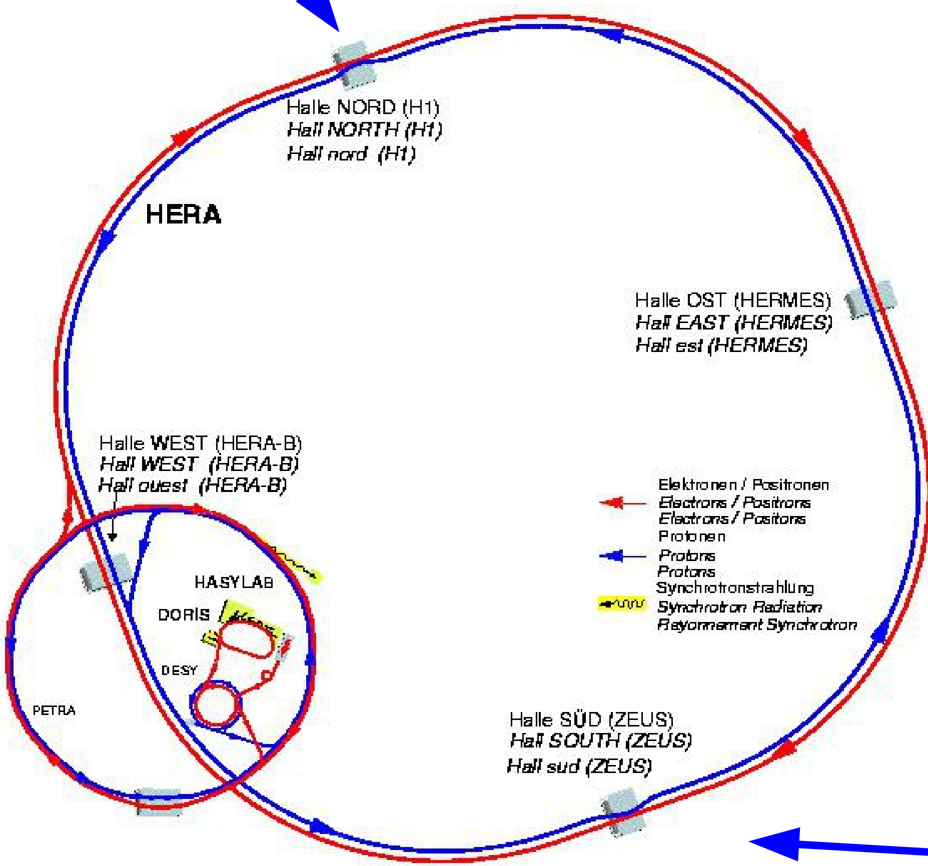
NEW TRENDS IN HIGH-ENERGY PHYSICS

Alushta, Ukraine, 23 – 29 September 2013

HERA collider

H1

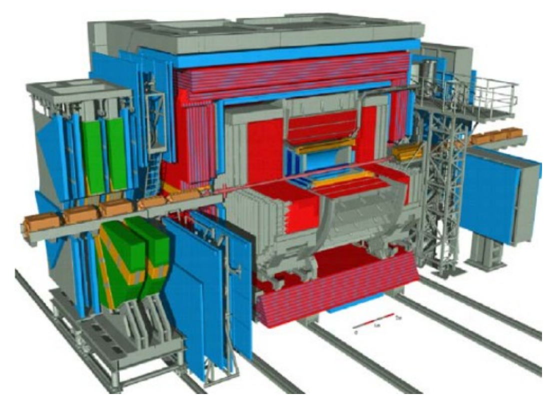




- Protons 920 GeV
- Electrons 27.6 GeV

$$\sqrt{s} = 318 \text{ GeV}$$

- Operational: 1992-2000 (HERA I)
  2003-2007 (HERA II)
- H1 and ZEUS – general purpose hermetic detectors
- ~0.5 fb^{-1} per experiment
- In the **precision era** now: finalising HERA II, combining ZEUS and H1
- **Physics**: proton structure, EW, QCD, diffraction, BSM searches, ...

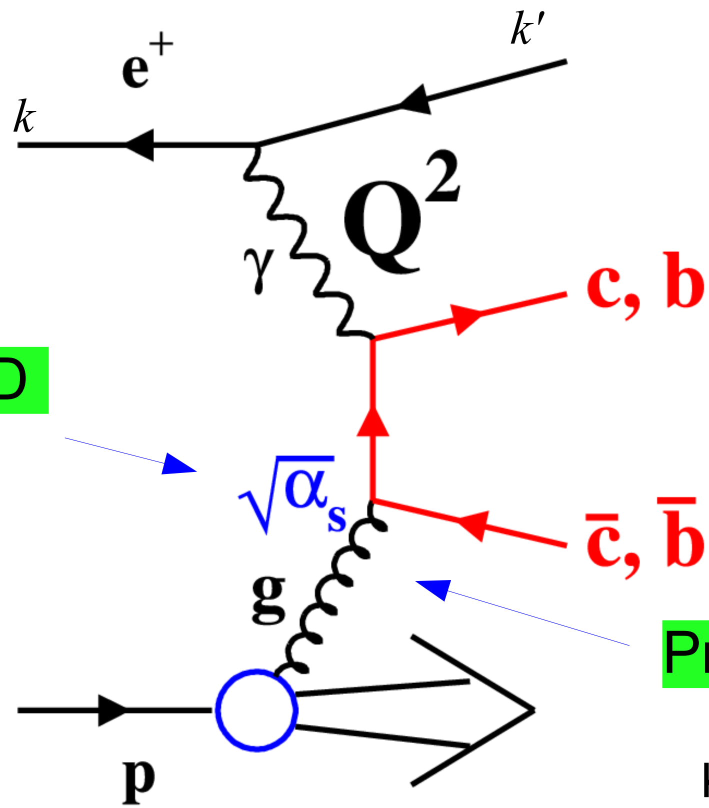


ZEUS

Heavy flavour physics at HERA

- Beauty and charm quarks are produced in LO via Boson-Gluon Fusion:

Provides tests of QCD



Sensitive to the quark masses

Probes gluons in the proton

- Charm contributes up to 30% to inclusive DIS at high Q^2

Impact on Parton Density Functions (PDF)!

Kinematic variables:

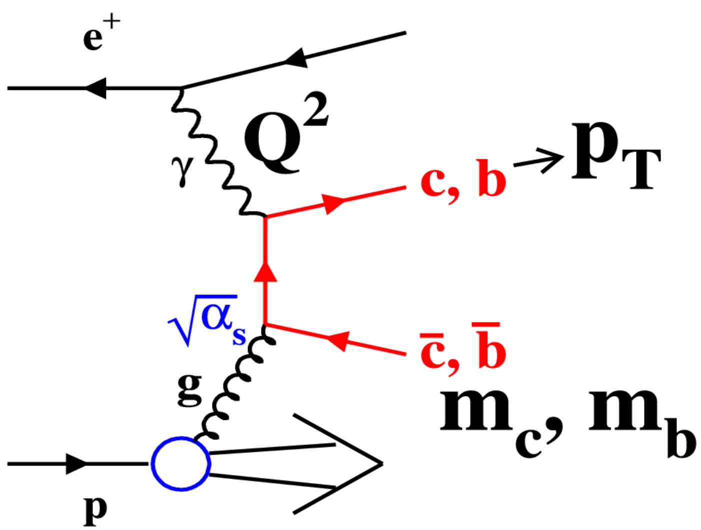
$Q^2 = -q^2 = -(k - k')^2$	Photon virtuality
$x = \dfrac{Q^2}{2p \cdot q}$	Bjorken variable
$y = \dfrac{p \cdot q}{p \cdot k}$	Inelasticity

Mass treatment in QCD

- Multi-hard-scale problem ($m_{b,c}$, p_T, Q^2) → several calculation schemes exist

Massive scheme (FFNS)

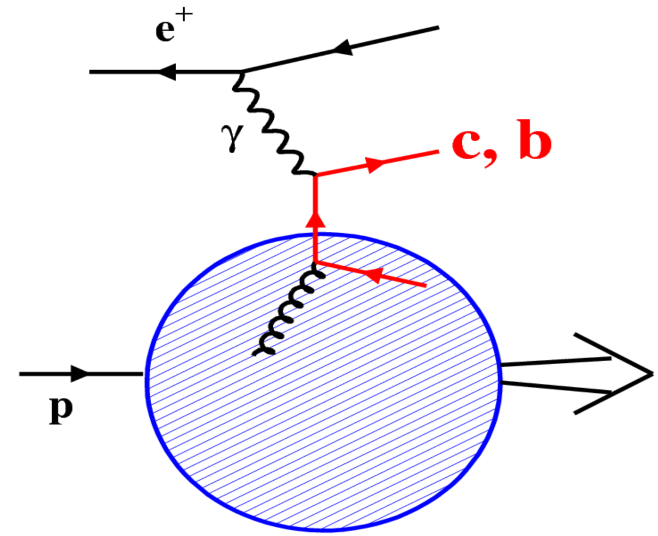
- ➔ Rigorous, fully massive treatment



- Expected to be valid at scales ~ $m_{b,c}$
- Programs exist to calculate fully differential cross sections (HVQDIS, FMNR)

Massless scheme (ZM-VFNS)

- ➔ Neglects heavy quark masses



- Allows resummation of terms proportional to $\log(Q^2/m_{b,c}^2)$
- Expected to be valid at scales $\gg m_{b,c}$

Mixed schemes (GM-VFNS)

➔ Employ both FFNS and ZM-VFNS

- Interpolation is ambiguous → various approaches (RT, ACOT etc.) exist
- No clear interpretation of the quark mass (consider it as an effective parameter)

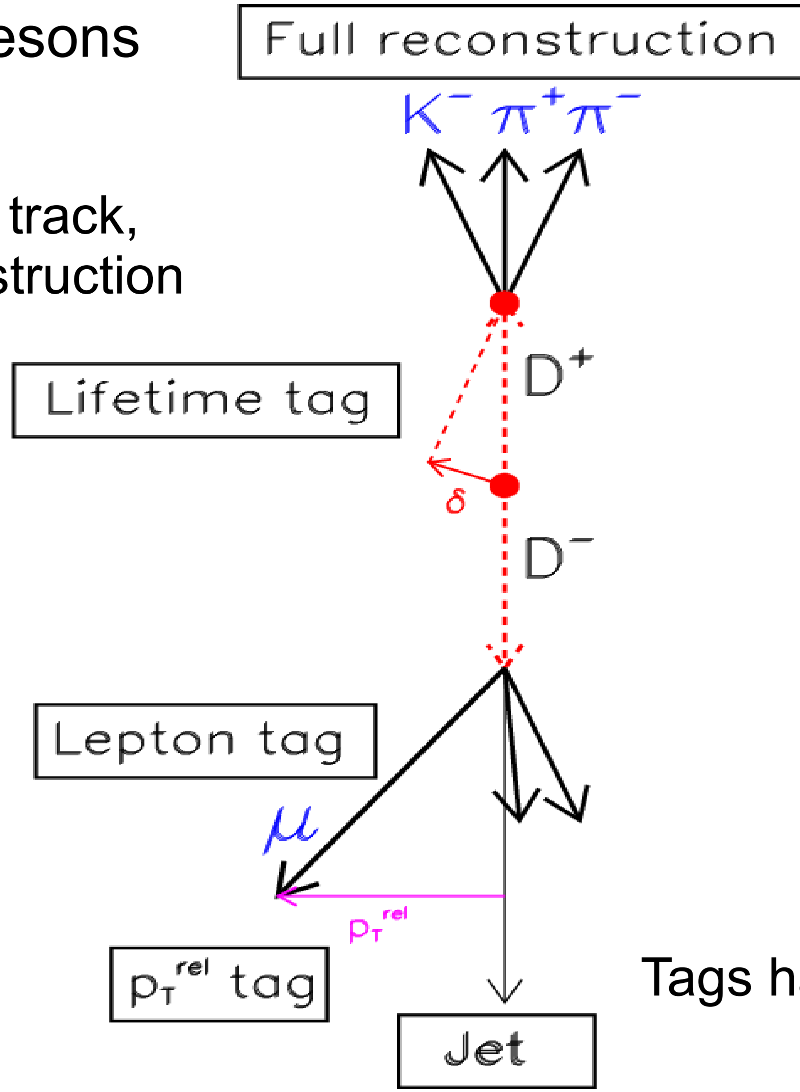
Heavy flavour measurements can help to test and improve the schemes

Experimental methods

D^+, D^*, D^0 mesons

Impact parameter of the track,
secondary vertex reconstruction

Semileptonic decays



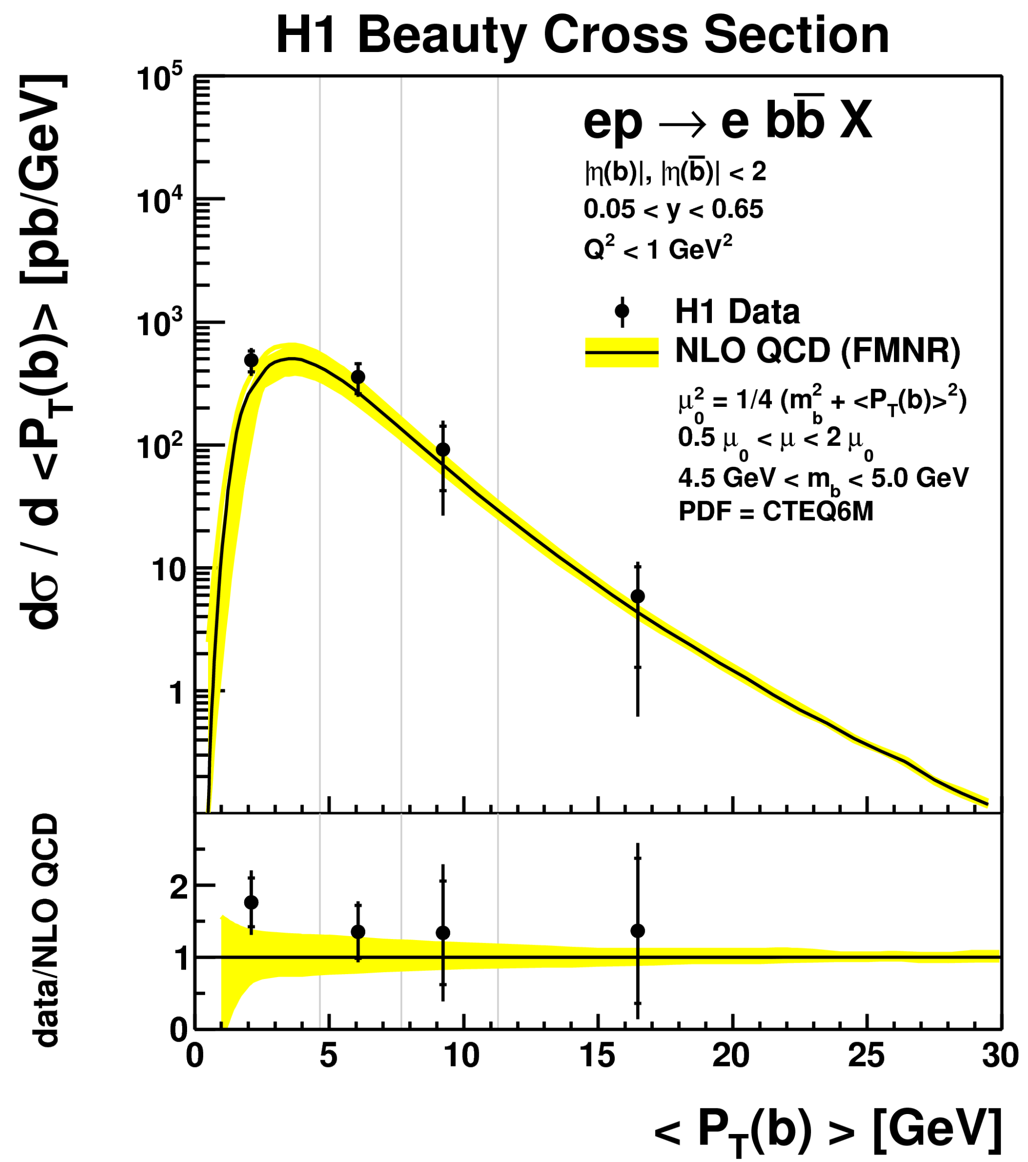
Tags hard parton

- Methods can be combined (e.g. lepton+jet, secondary vertex+jet, etc.)
- Can be used for *single* or *double* tagging

Only few results can be shown in this talk, many more to be found on H1 and ZEUS webpages

Beauty Photoproduction: lepton tag

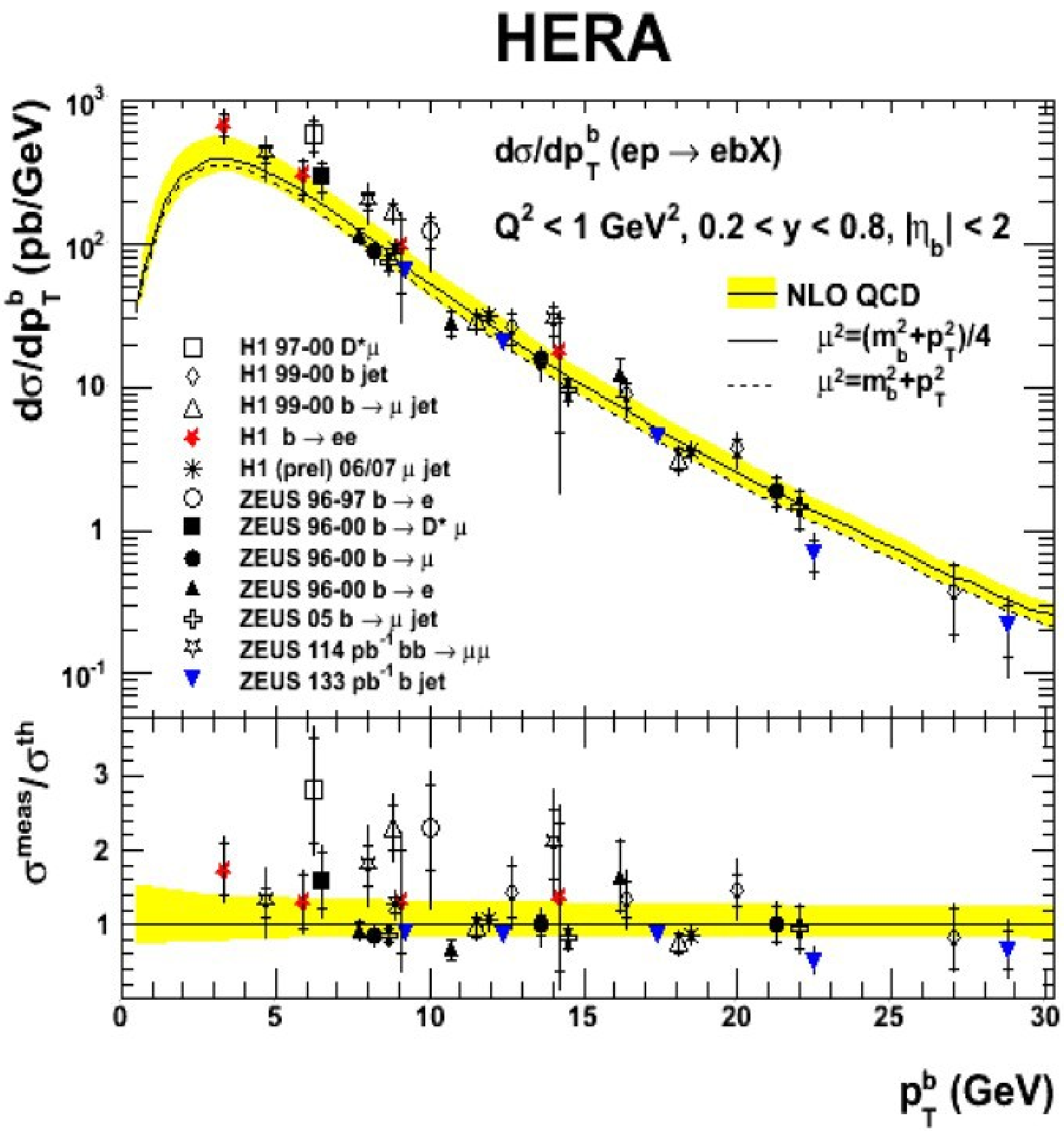
- $Q^2 < 1\ GeV^2$, $0.05<y<0.65$
- $|\eta|<2$
- Two electrons from semileptonic b-decays are exploited
- Gives access to very low $p_T(b)$ values



- **FFNS** describes beauty photoproduction well

Eur. Phys. J. **C72** (2012) 2148

Beauty Photoproduction: summary

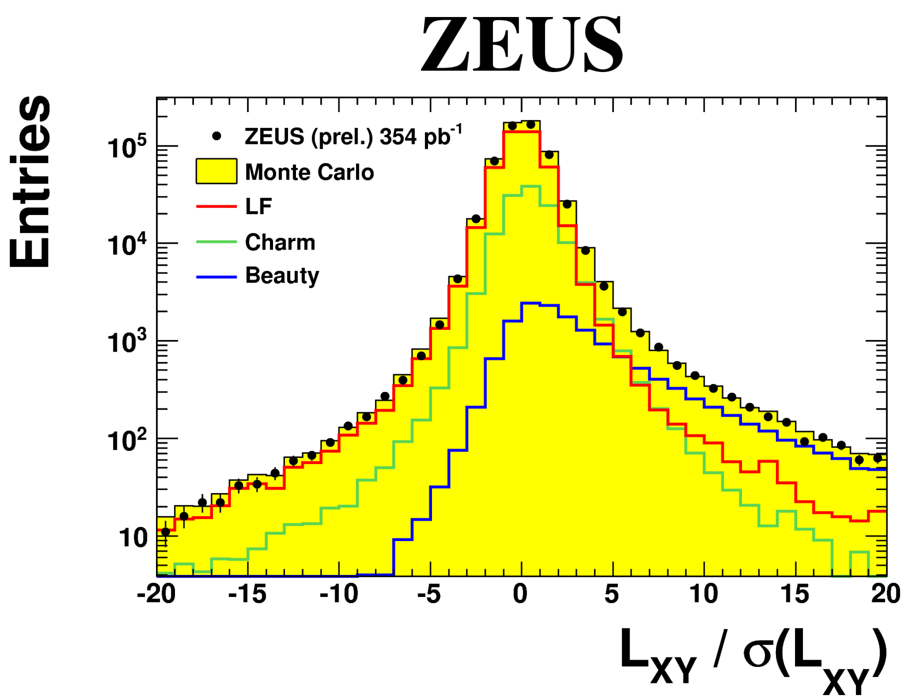


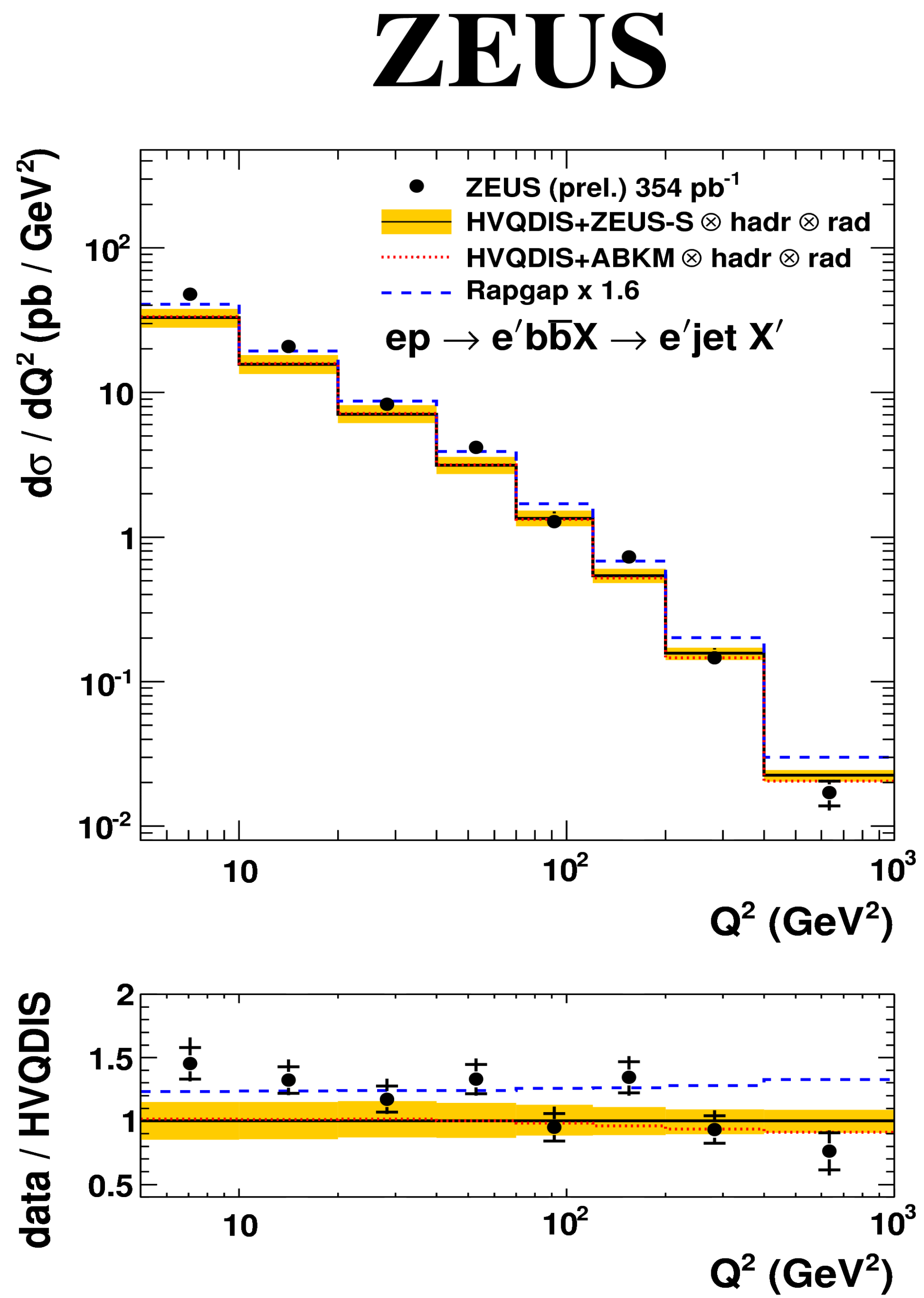
- **FFNS** describes beauty photoproduction well in full range $3<p_T<30$ GeV

Beauty in DIS: lifetime tag

- $5 < Q^2 < 1000$ GeV^2, $0.02<y<0.7$
- $E_T^{jet}>5$GeV, $-1.6<\eta^{jet}<2.2$

- Secondary vertices due to decays of beauty hadrons are reconstructed in association with jets

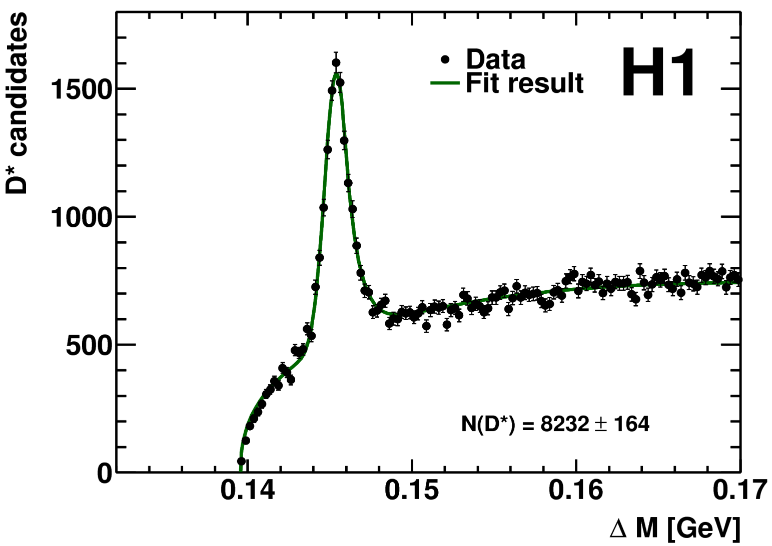


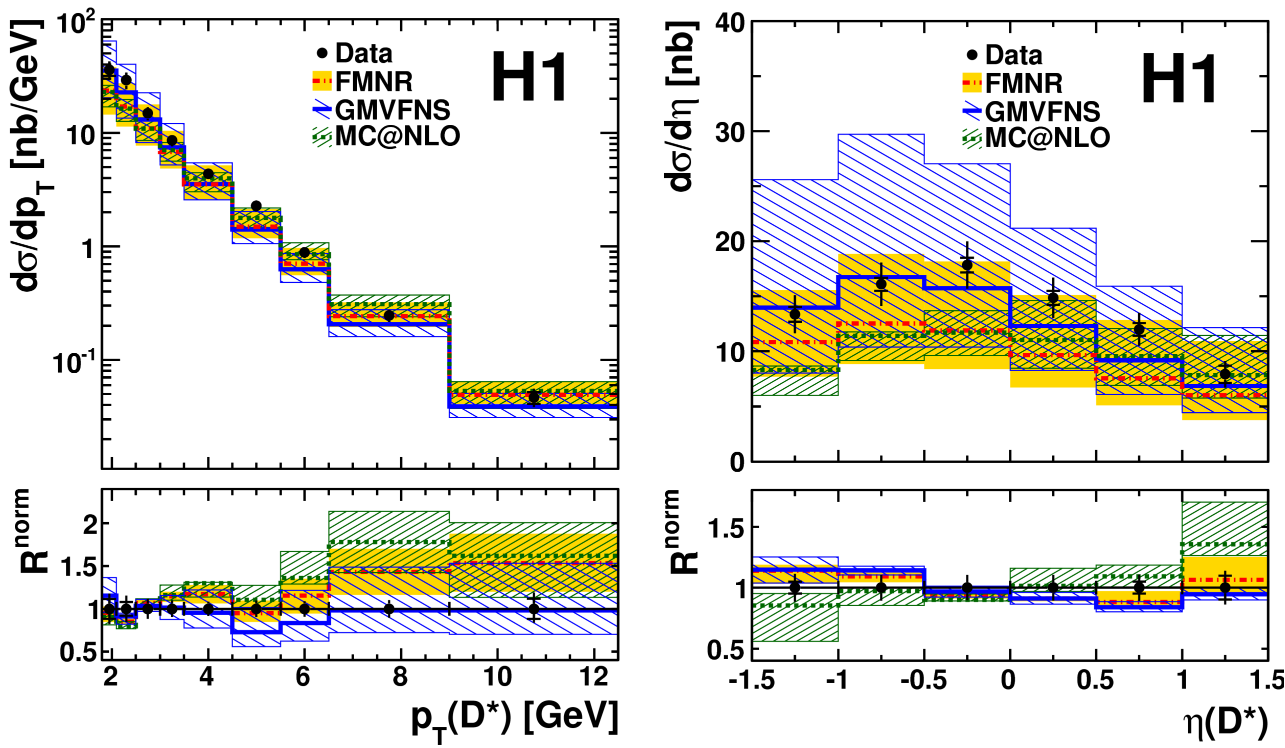


- **FFNS** describes beauty in DIS well

Charm Photoproduction: D* tag

- $Q^2 < 2$ GeV^2, $0.02<W_{\gamma p}<0.7$
- $p_T>1.8$ GeV, $|\eta|<1.5$



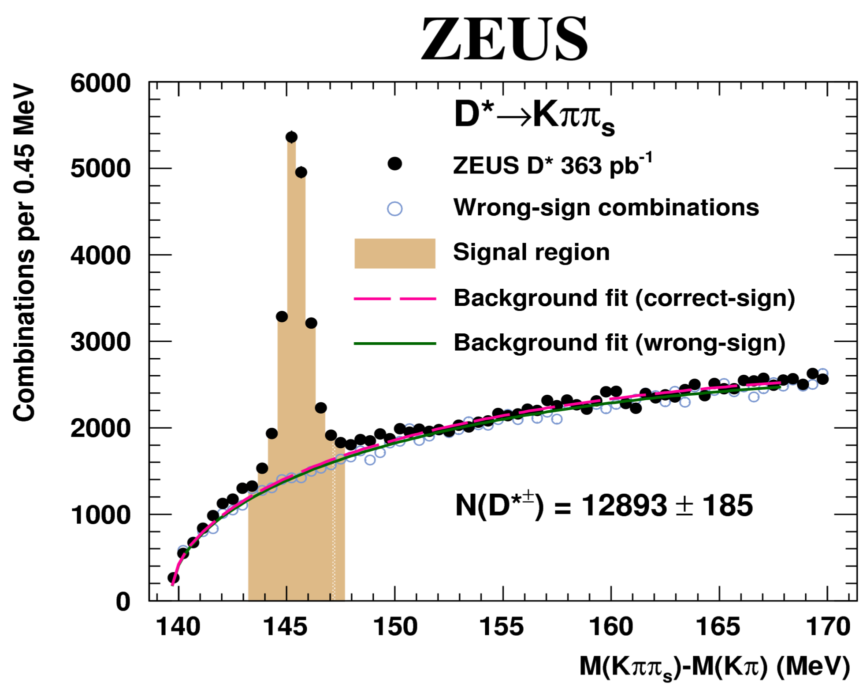


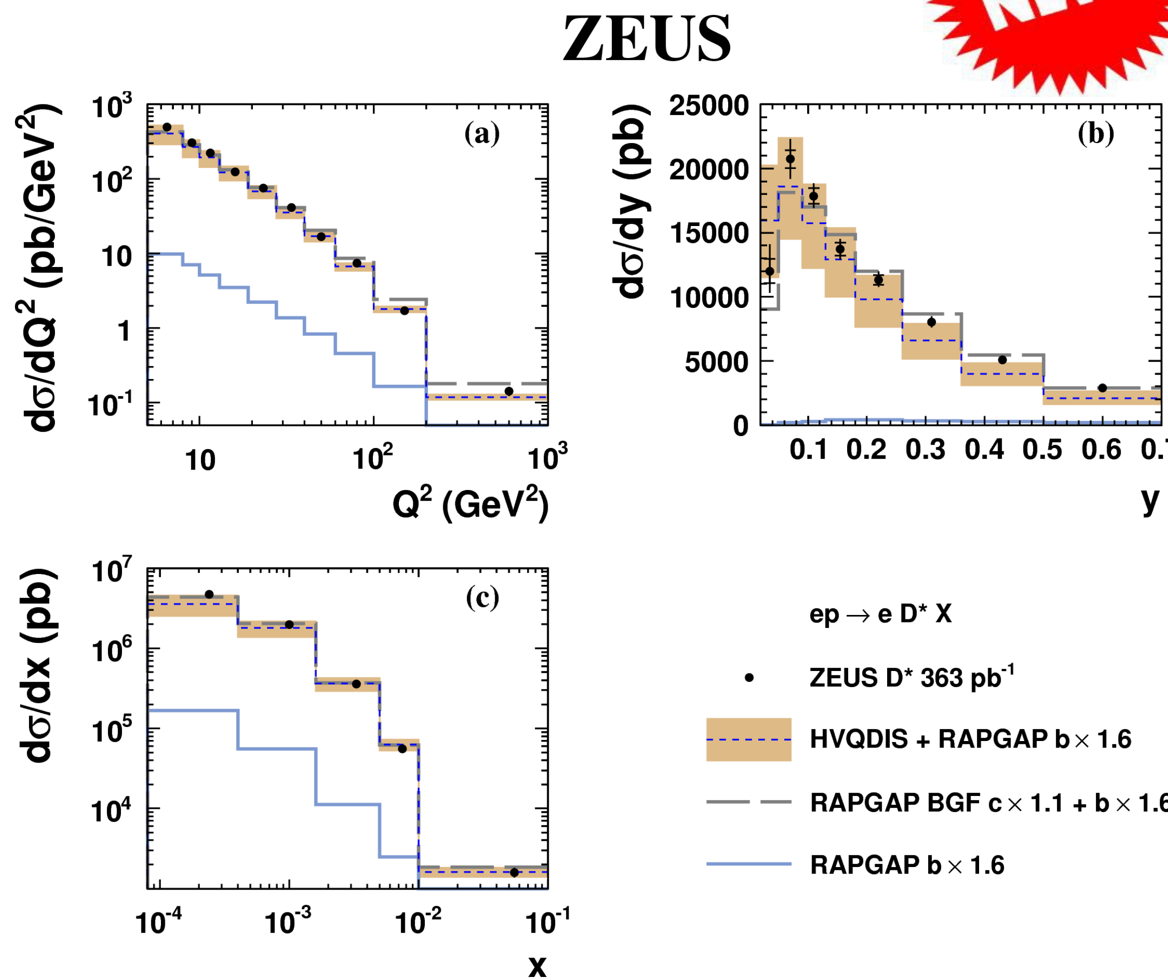
- **FFNS** and **GM-VFNS** describe data well, however uncertainties are significantly larger than the experimental uncertainties

Eur. Phys. J. **C72** (2012) 1995

Charm in DIS: D* tag

- $5 < Q^2 < 1000$ GeV^2, $0.02<y<0.7$
- $1.5<p_T<20$ GeV, $|\eta|<1.5$





- **FFNS** works up to highest Q^2

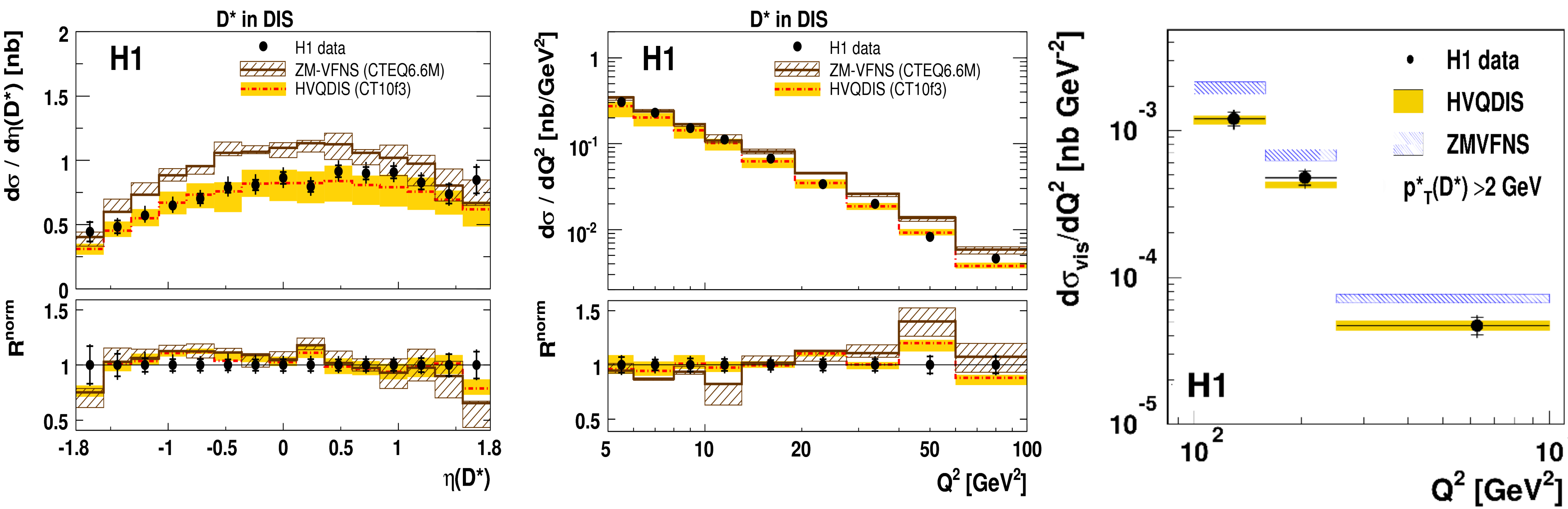
JHEP **05** (2013) 097

Charm in DIS: D* tag

DESY-11-066
DESY-09-165

- $5 < Q^2 < 100$ GeV^2, $0.02<y<0.7$
- $p_T>1.25$ GeV, $p_T^*>2$ GeV, $|\eta|<1.8$

- $100 < Q^2 < 1000$ GeV^2, $0.02<y<0.7$
- $p_T>1.5$ GeV, $p_T^*>2$ GeV, $|\eta|<1.5$



- **ZM-VFNS** overshoots the data (even at high Q^2!)

Eur. Phys. J. **C 71** (2011) 1769

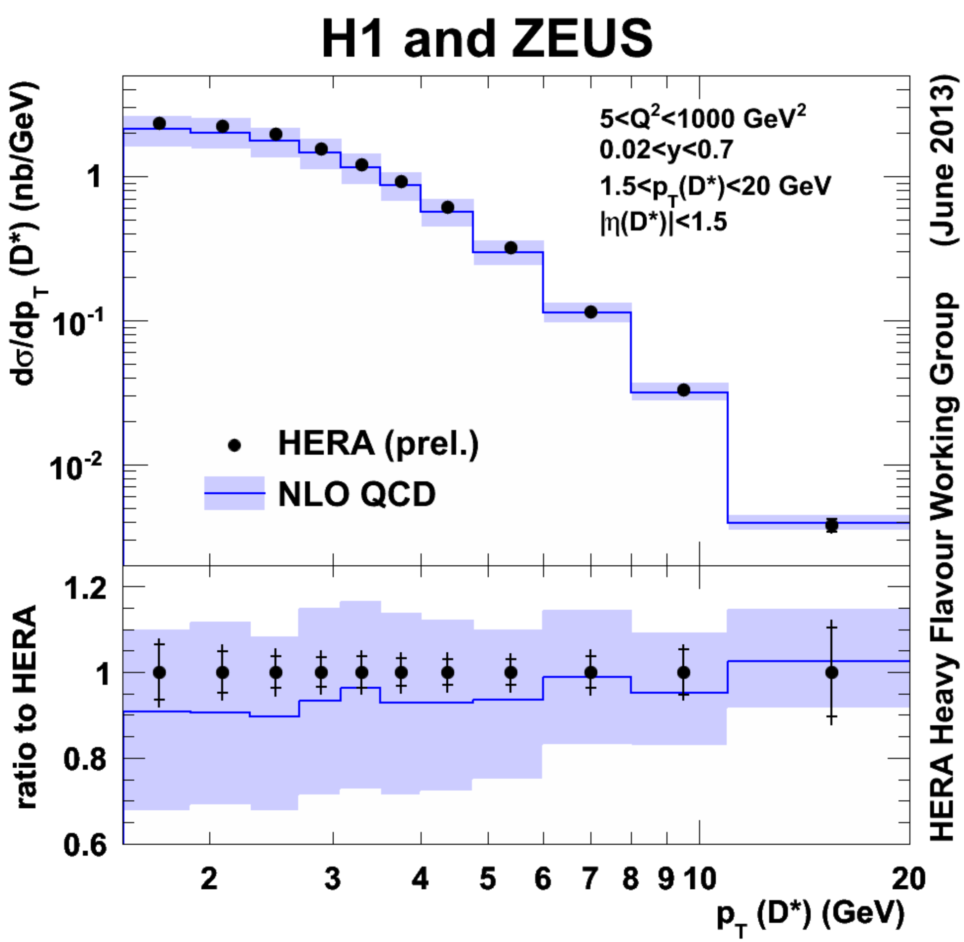
Phys. Lett. **B 686** (2010) 91

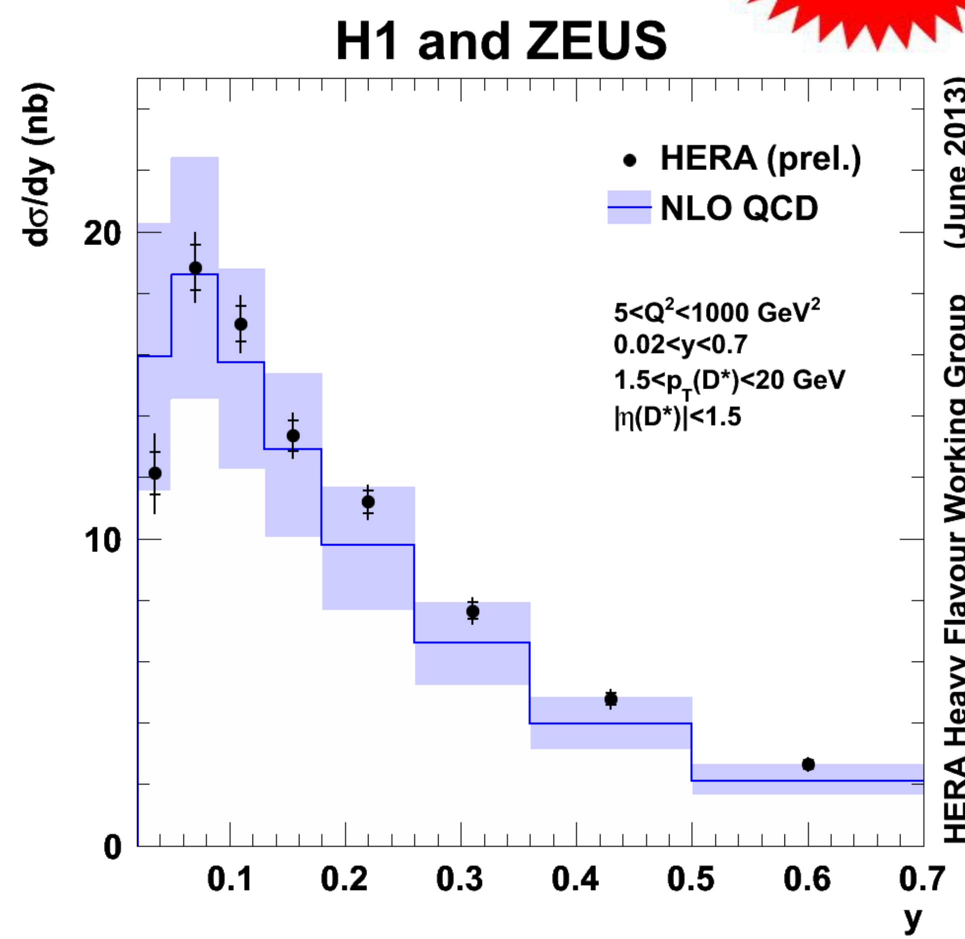
Combination of the D* cross sections

ZEUS-prel-13-002

NEW!

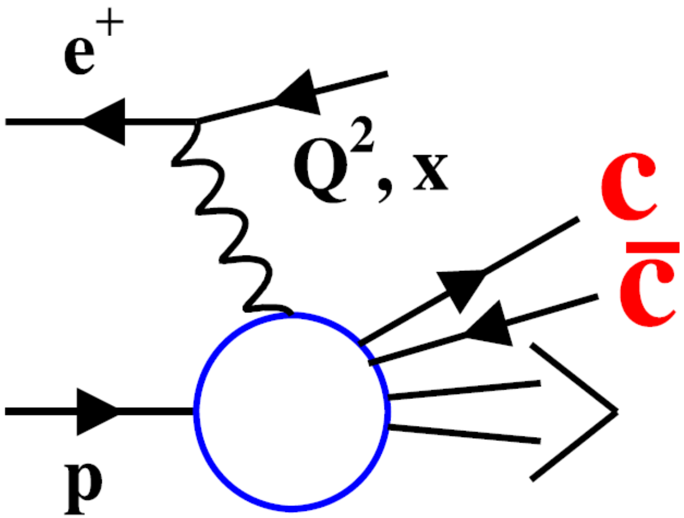
- H1 and ZEUS D* in DIS cross sections were combined to increase the precision





- **FFNS** agrees to data well

Charm in DIS: inclusive production



Charm contribution to the proton structure function F_2:

$$\frac{d^2\sigma^{ep\to c\bar{c}x}}{dQ^2dx} \propto F_2^{c\bar{c}}(x,Q^2)$$

$$\frac{d^2\sigma^{ep\to c\bar{c}x}}{dQ^2dx} = \frac{2\pi\alpha^2}{xQ^4}\left[\left(1+(1-y)^2\right)\cdot F_2^{c\bar{c}}(x,Q^2) - y^2 F_L^{c\bar{c}}\right]$$

- Reduced charm cross sections:

$$\sigma_{red}^{c\bar{c}} = \frac{xQ^4}{2\pi\alpha^2\left(1+(1-y)^2\right)}\frac{d^2\sigma^{ep\to c\bar{c}x}}{dQ^2dx} = F_2^{c\bar{c}}(x,Q^2) - \frac{y^2}{1+(1-y)^2}F_L^{c\bar{c}}$$

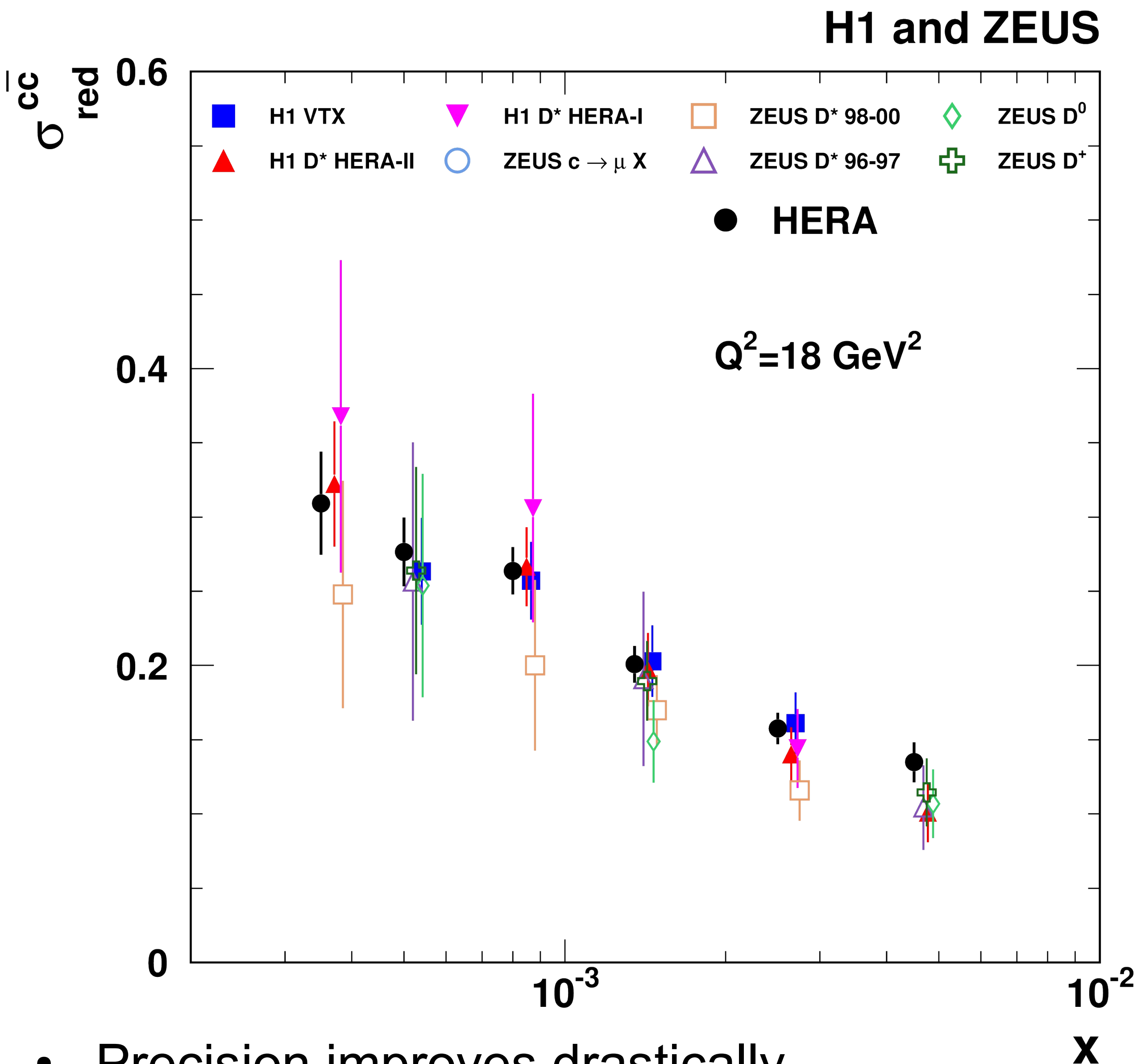
- NLO QCD used to extrapolate from *visible* double-differential cross-sections to *full phase space*:

$$\sigma_{red}^{c\bar{c}}(\exp) = \frac{\sigma_{vis}(\exp)}{\sigma_{vis}(theory)}\sigma_{red}^{c\bar{c}}(theory)$$

Charm in DIS: combination

DESY-12-172

- All available charm measurements by ZEUS and H1 were combined



$$\sigma_{red}^{c\bar{c}} = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma^{c\bar{c}}}{dxdQ^2}$$

- Reduced charm cross sections were extracted in a coherent manner for every measurement before the combination

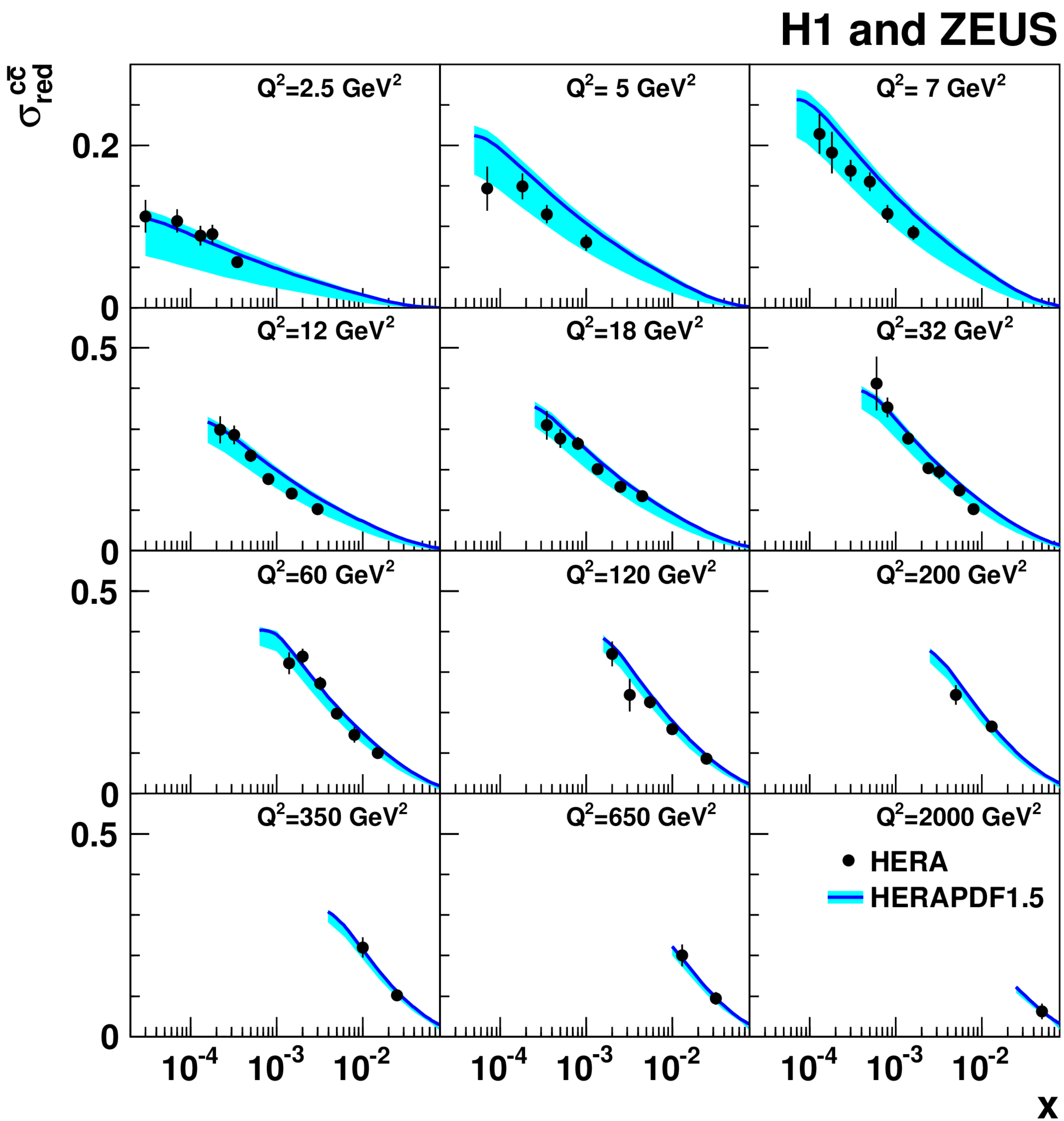
Example:
Q^2=18 GeV ^{2}

- Precision improves drastically

→ a factor of two compared to the most precise individual measurement!

Combined charm cross sections

DESY-12-172



- Theory describes data well
  - ➔ Note that these data are not included in the PDF used for predictions

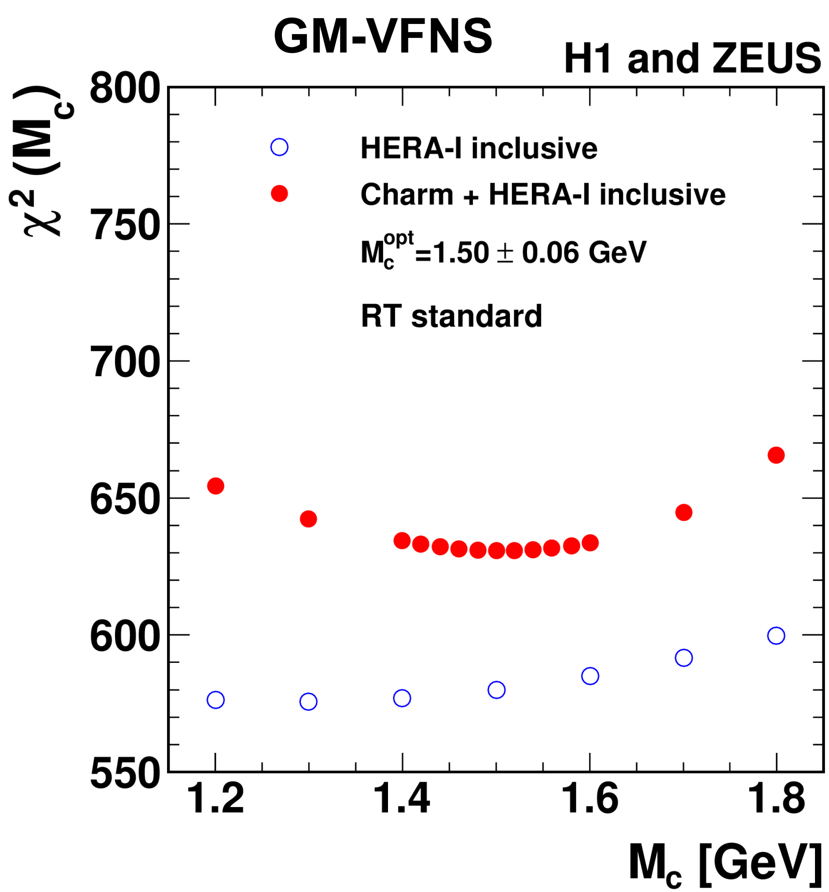
    → supports gluon PDF universality

- Theory uncertainty is dominated by charm mass (parameter) M_c variation
- Data are more precise than theory

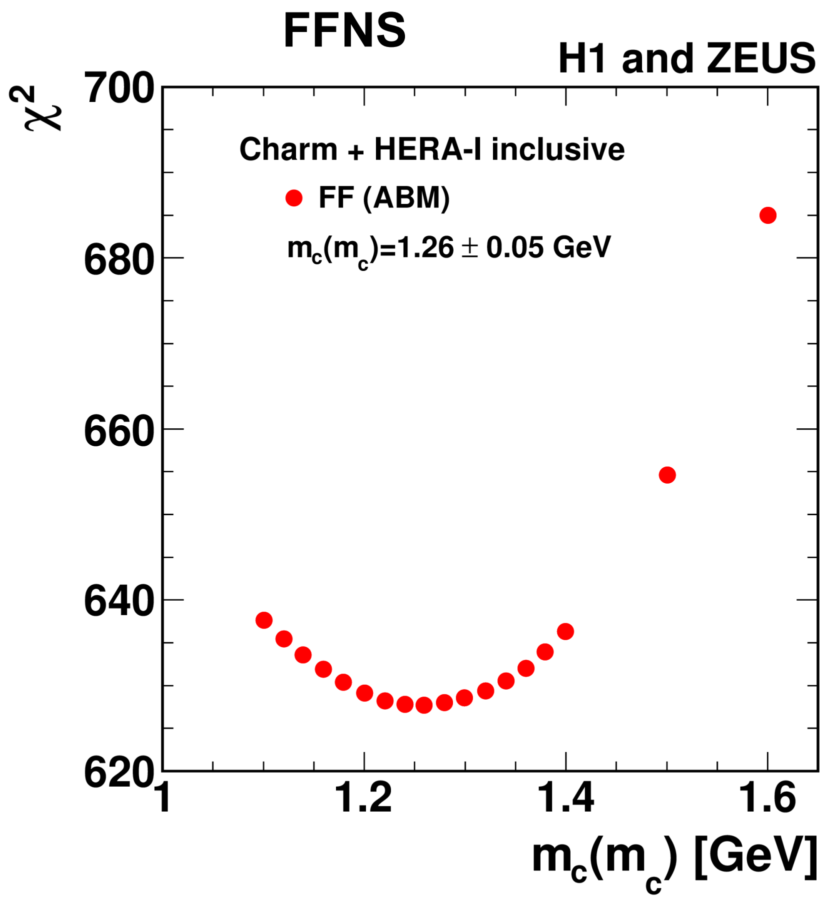
  → have constraining power on M_c

Charm mass determination

Charm data provides sensitivity to charm mass (parameter) M_c



Charm running mass ($\overline{MS}$) m_c scan

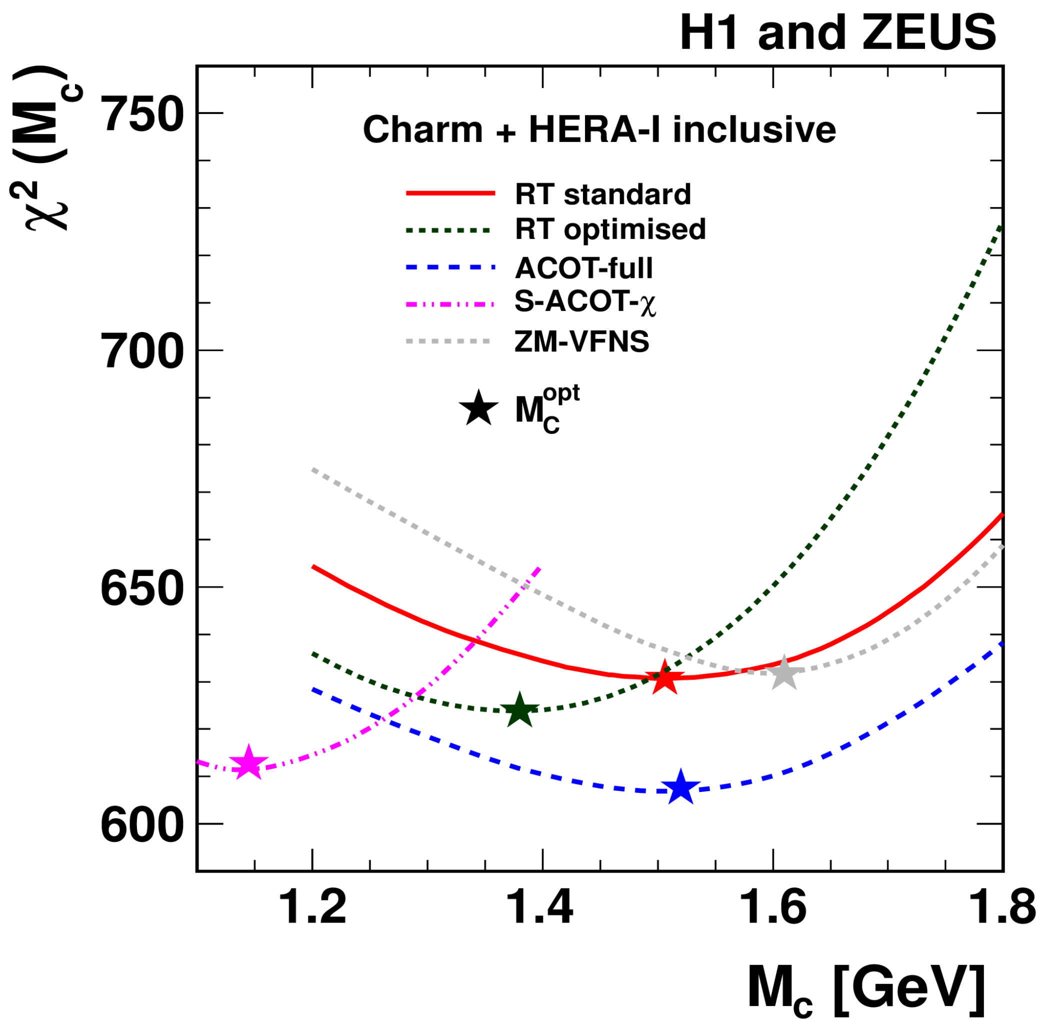


$$m_c(m_c) = 1.26 \pm 0.05_{exp} \pm 0.03_{mod} \pm 0.02_{param} \pm 0.02_{\alpha_s}\,\mathrm{GeV}$$

Consistent with the world average of $m_c(m_c)$=1.275±0.025 GeV

Charm mass parameter in **VFNS**

Charm mass parameter scan was performed in various **VFNS** schemes



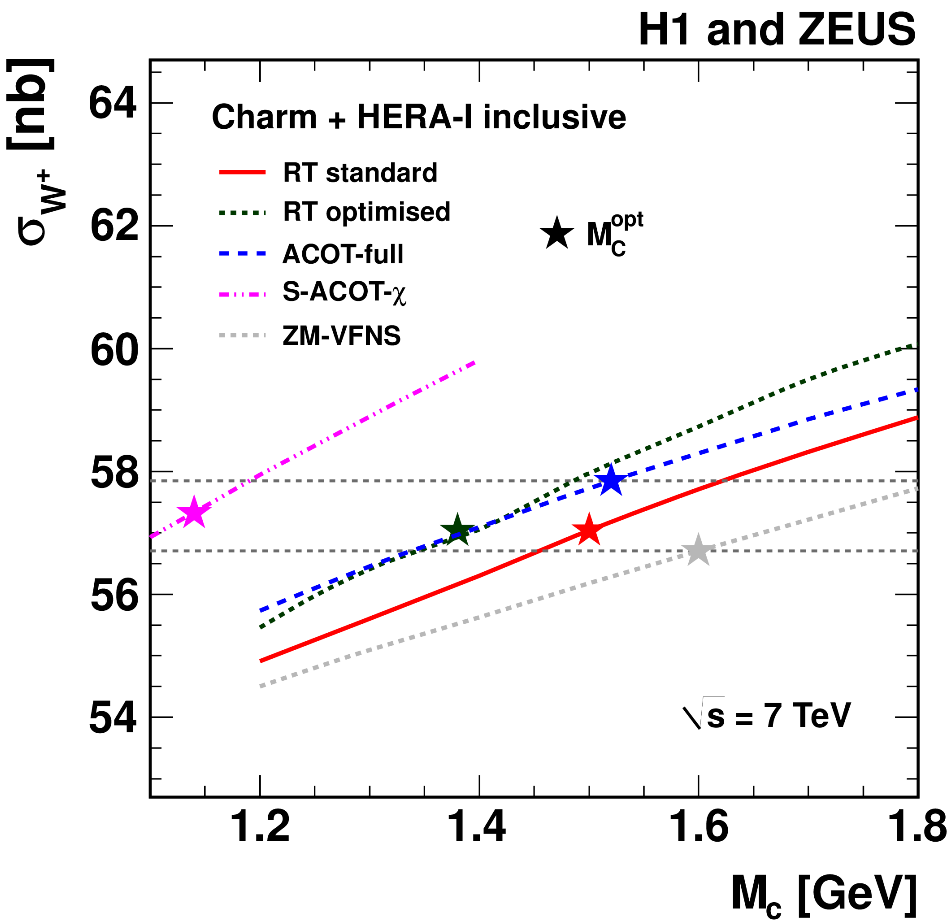
→ Optimal M_c depends on particular scheme!

Implications for LHC

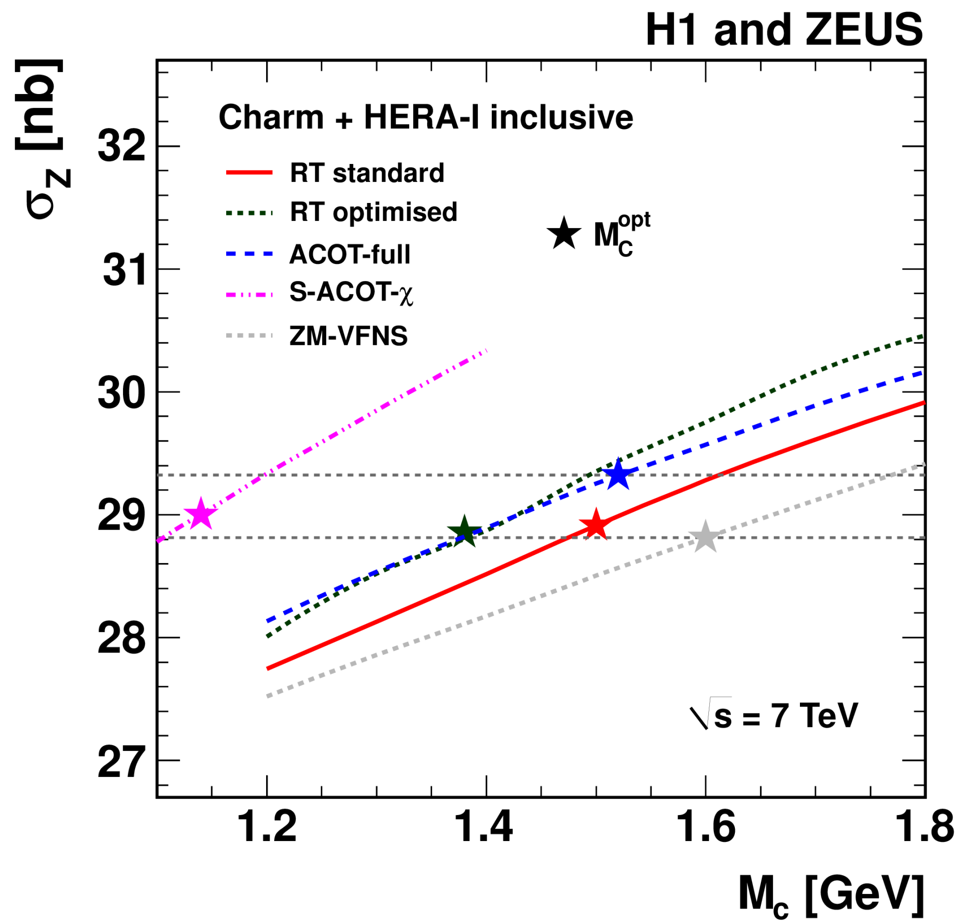
- Predictions depend strongly on M_c

VFNS

W production @ 7 TeV

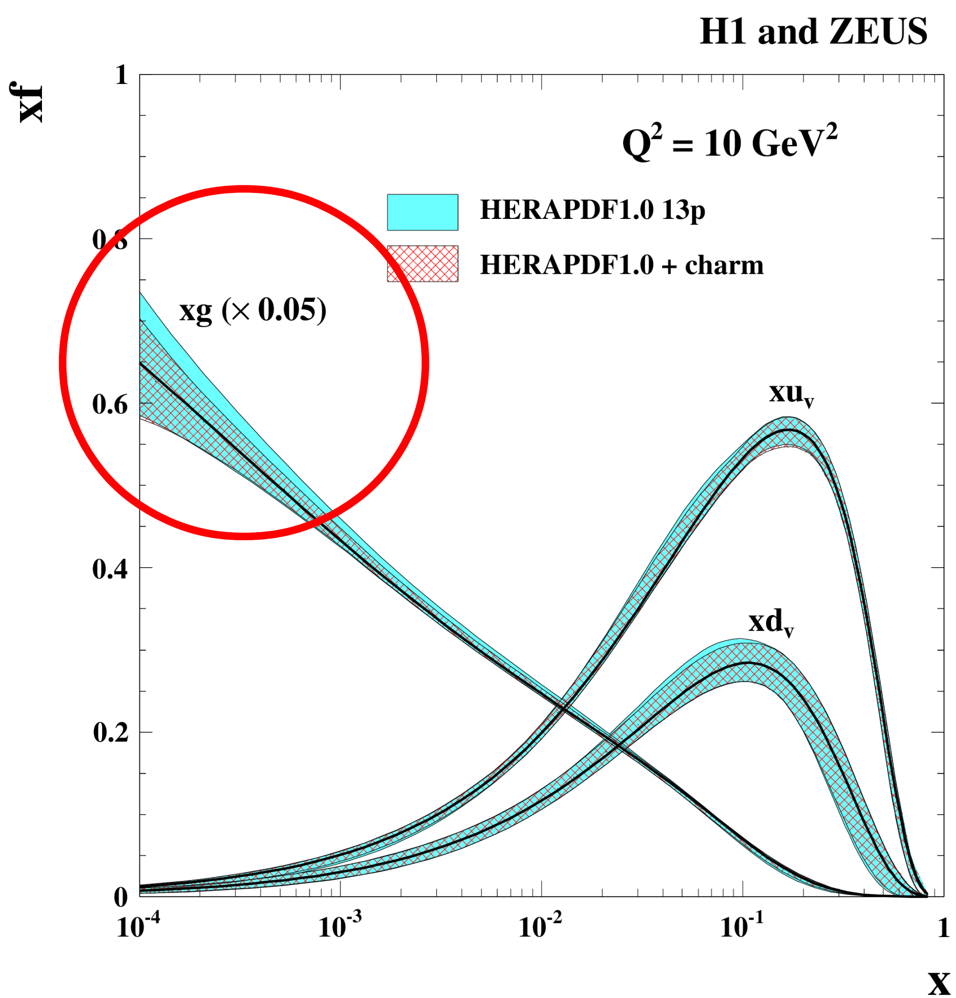


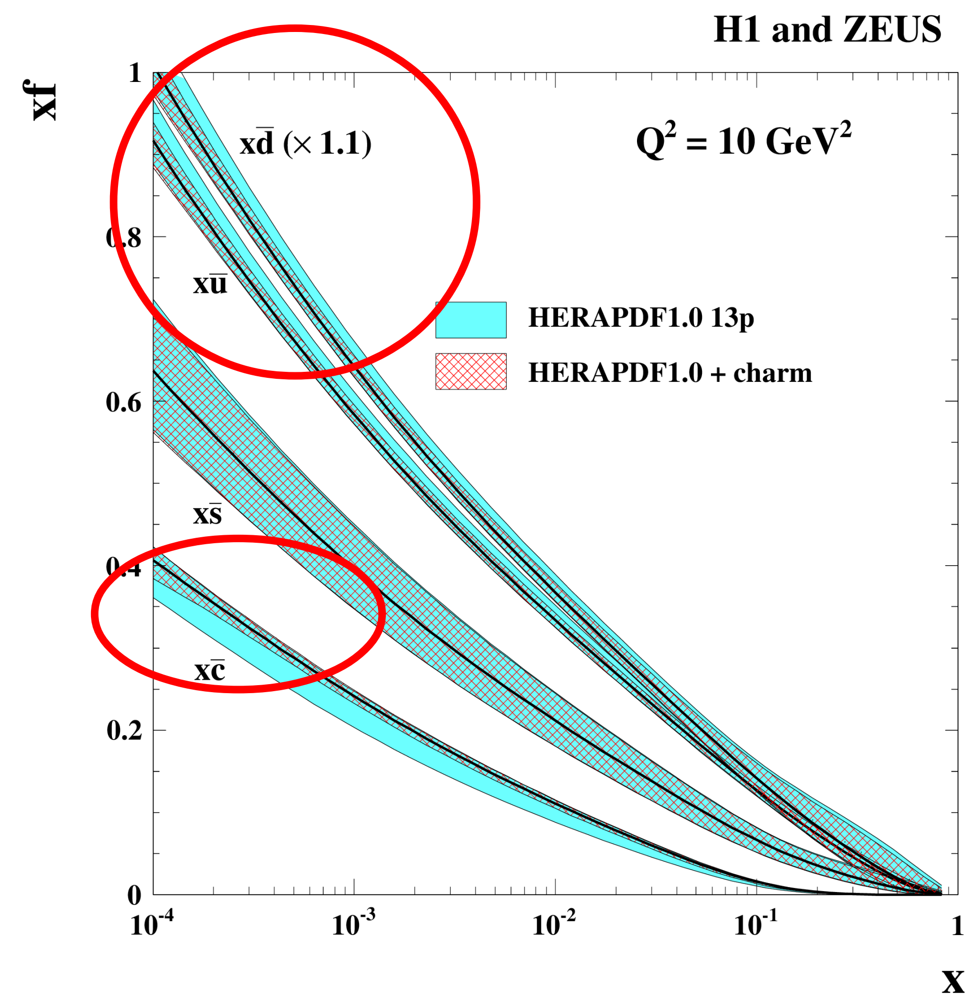
Z production @ 7 TeV



Using optimal M_c for each of the **VFNS** schemes stabilises predictions!

Impact on PDFs

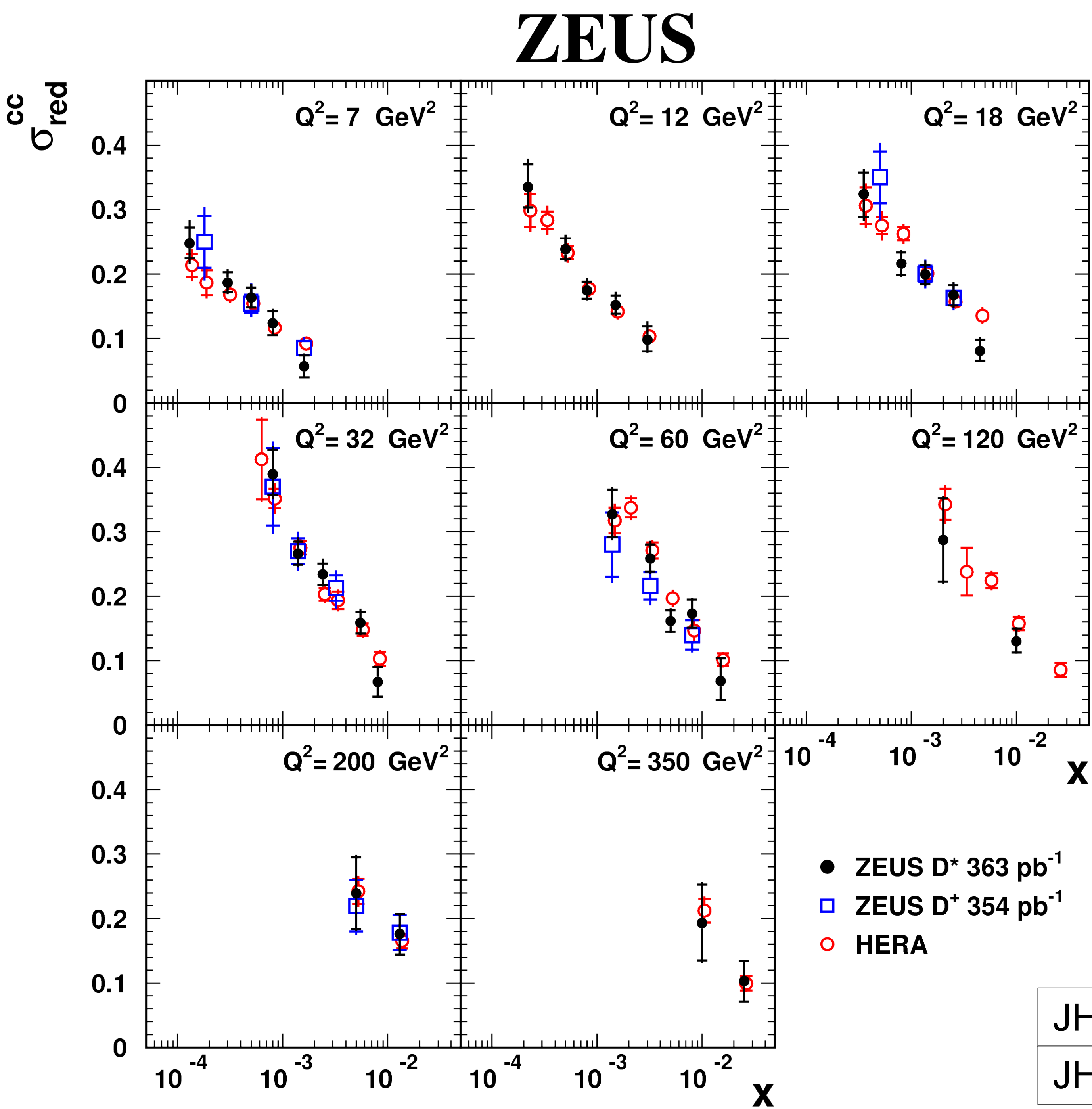




- Central values don't change significantly
- Uncertainties on PDFs reduce (xg, $x\bar{c}$, $x\bar{d}$, $x\bar{u}$)!

New measurements (not in the combination yet)

DESY-13-054
DESY-13-028



- New measurements are consistent with HERA combined
- Will improve the combination!

JHEP **05** (2013) 097

JHEP **05** (2013) 023

Summary

- HERA community is finalising data analyses – still very active six years after the accelerator shutdown!

- Quantum Chromodynamics describes heavy flavour production at HERA well
- Experimental precision in general significantly better than theory uncertainties

- Charm data combination was performed – significant improvement of precision compared to individual measurements

  → Charm running mass was determined with good precision

  → PDF uncertainties reduce
- More charm data are available for future combinations

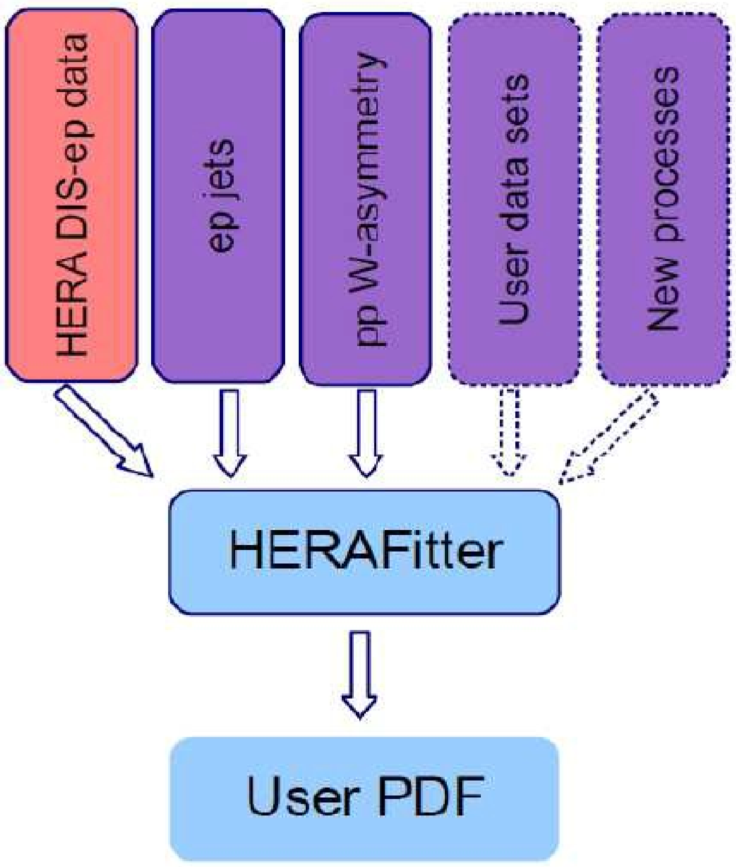
Thanks a lot for your attention!

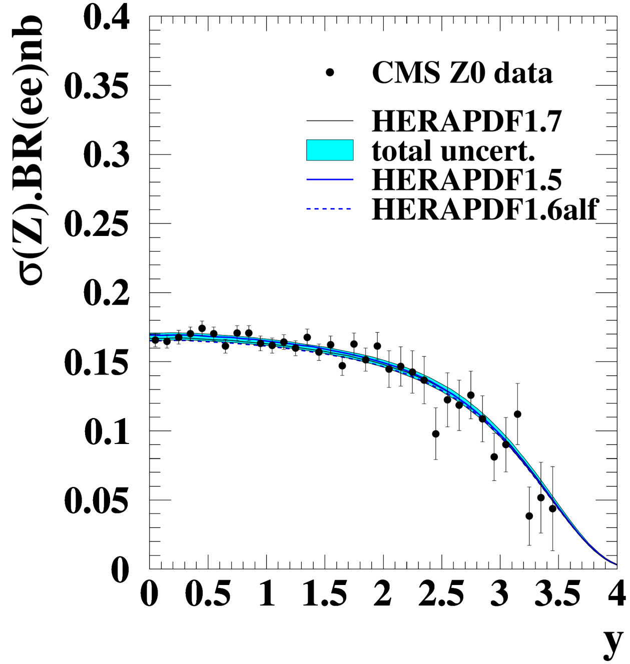
B A C K U P
slides

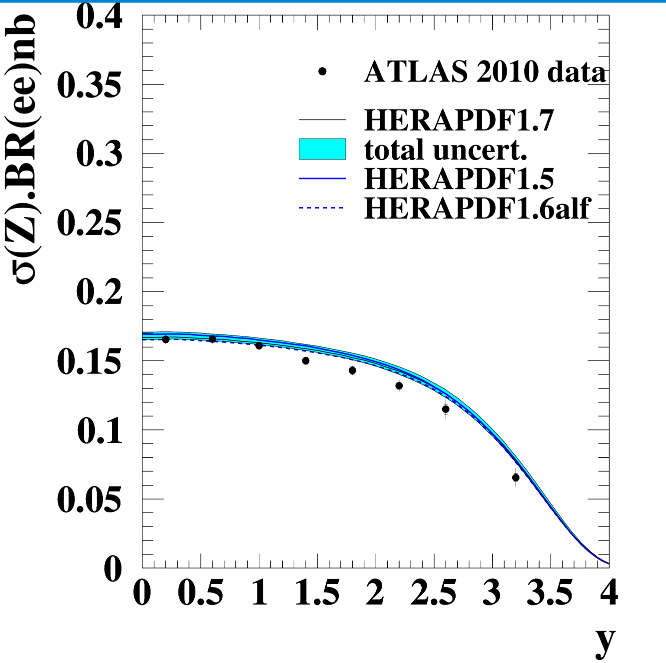
HERAPDF and HERAFITTER

- HERAFITTER – an open source tool for PDF analyses

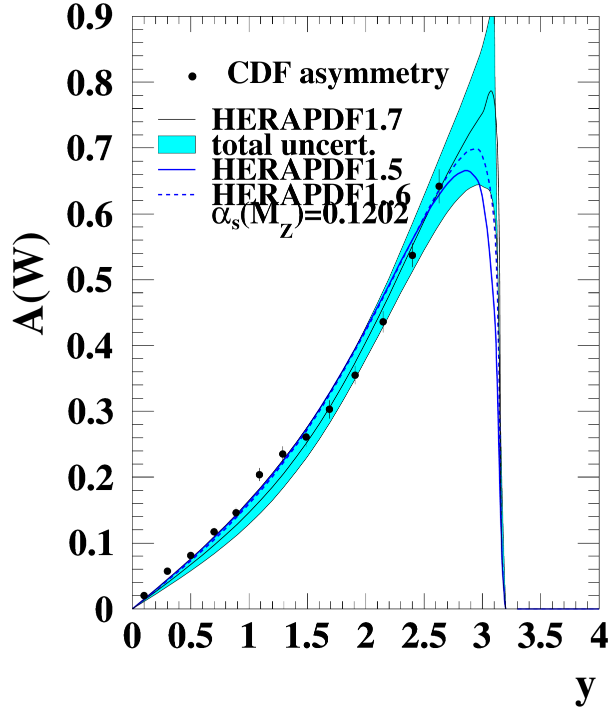
http://herafitter.hepforge.org/



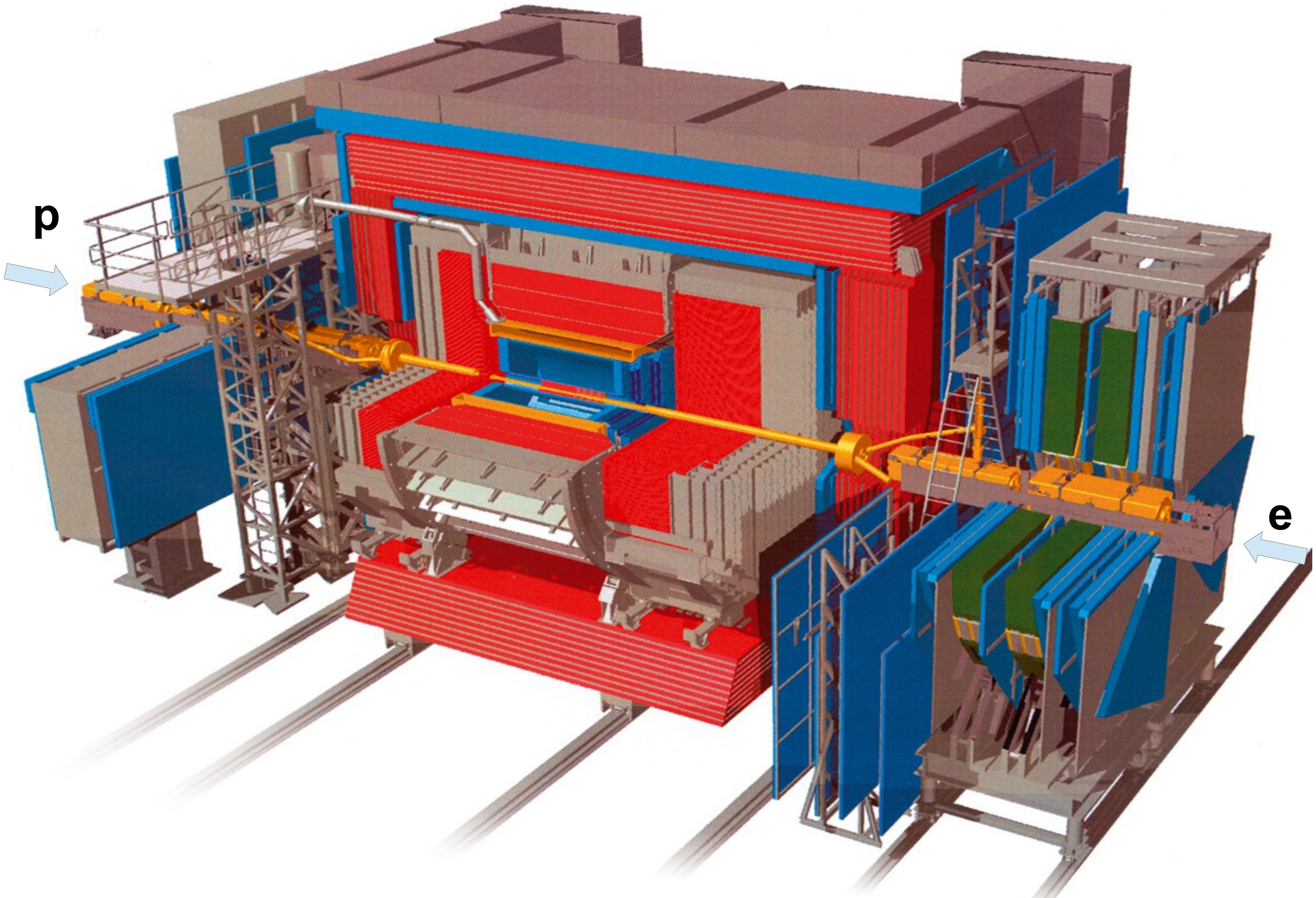




Good description of LHC/Tevatron data



ZEUS Detector at HERA



- **M**icro**v**ertex **D**etector (MVD) – silicon strip detector
- **C**entral **T**racking **D**etector (CTD) – drift chamber
- Solenoid magnet, 1.43T
- Electromagnetic and Hadronic Calorimeters
- Muon Chambers

- Almost hermetic
- General purpose

Data taking:

- 1992-2000 (HERA I): 126 pb^{-1}
- **2003-2007 (HERA II): 354 pb^{-1}**