New Results from ZEUS at HERA

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on Behalf of the
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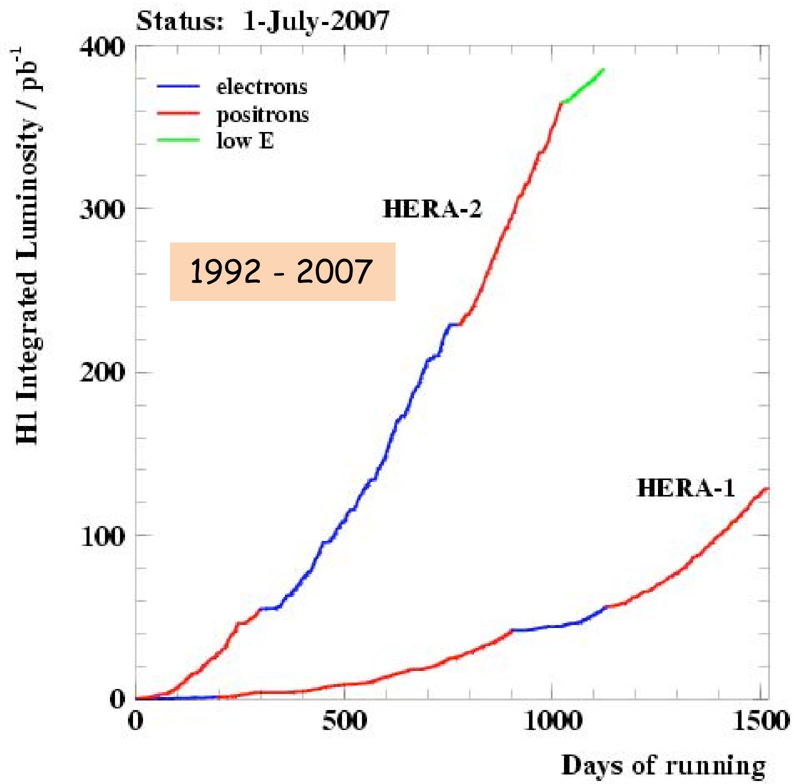
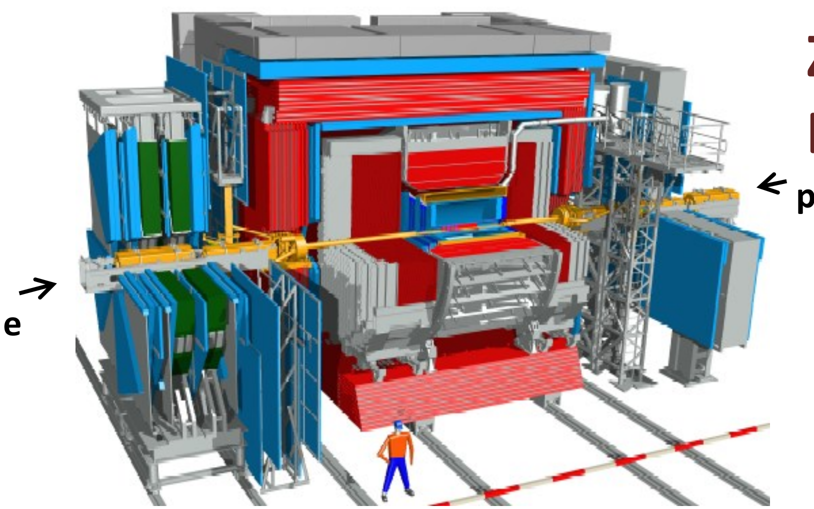
HERA Operation and the ZEUS Detector

$$E_p = 920\,\mathrm{GeV} \qquad E_e = 27.5\,\mathrm{GeV} \qquad \sqrt{s} = 4E_pE_e = 318\,\mathrm{GeV}$$





ZEUS Detector

Three periods of data taking:

HERA I : ~120 pb^{-1}

HERA II : ~380 pb^{-1}

Low proton energy: ~65 pb^{-1}

The Advantages of HERA II Data Taking Period

Upgrade of ZEUS detector for HERA II running - Silicon Micro Vertex Detector (MVD)

HERA II running period:

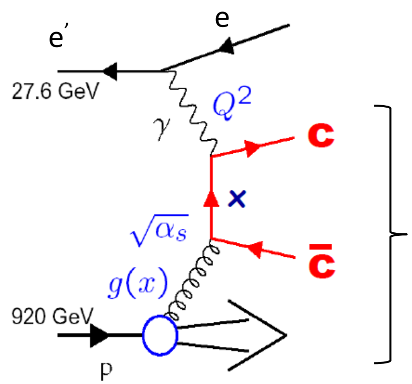
- Higher integrated luminosity ➡ improved statistical precision, some analyses became feasible only then
- Micro Vertex Detector ➡ detection of secondary vertices, new method to study heavy quark production ➡ using decay lengths of charm- and beauty mesons
- Longitudinal polarization of lepton beams study of electroweak effects with polarized beams
- Low proton-energy running ➡ measurement of longitudinal structure function F_L

Ongoing analyses:

- update previous analyses
- new high statistics analyses
- combination of H1 and ZEUS results

Combination of H1 and ZEUS Results on Charm Production

Charm production in DIS in leading order:



Boson-gluon fusion

$\longrightarrow$ $D^0 + X$, $D^+ + X$, $D^* + X$, etc.

Up to 30% of the cross-section.

- test of perturbative QCD
- gluon content of the proton: g(x)
- multiple hard scale: Q^2, m_{charm}, p_T

  -> appearance of log-terms
- procedures to treat heavy quark masses

$$Q^2 = -q^2 = (k - k')^2$$

$$x = \frac{Q^2}{2p\cdot q} \; ; \quad y = \frac{p\cdot q}{p\cdot k} \; ; \qquad z^D = \frac{p\cdot p^D}{p\cdot q}$$

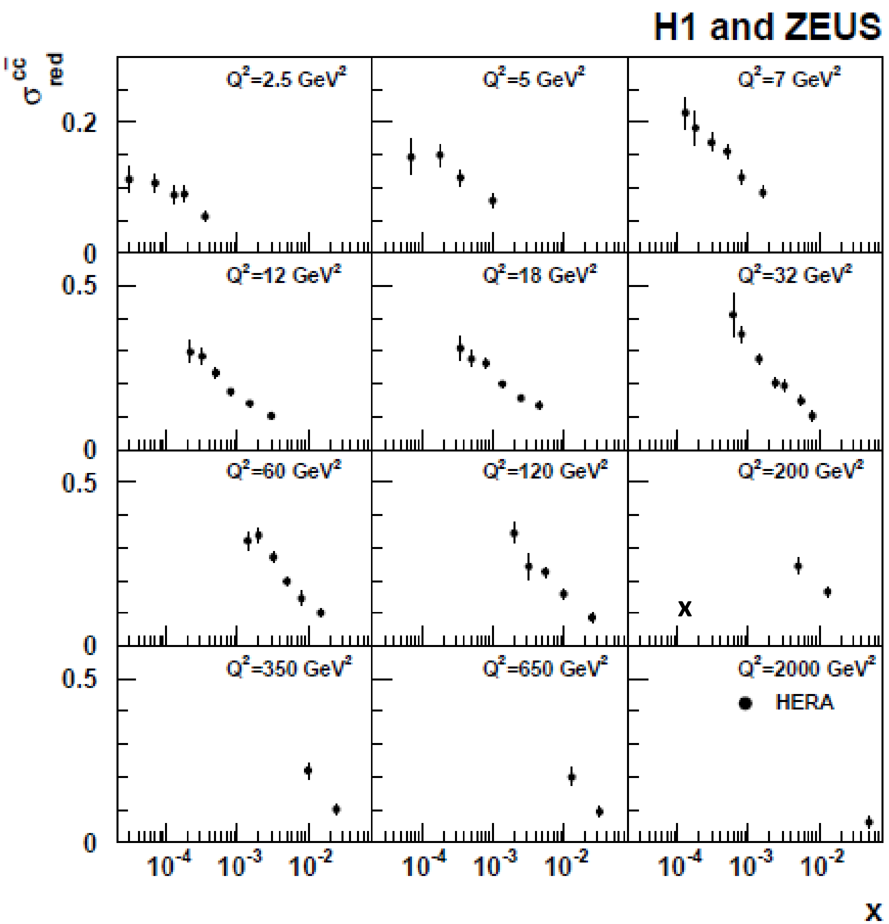
$$Q^2 = x\cdot y\cdot s$$

$$\frac{\mathrm{d}^2\sigma^{c\bar{c}}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2(Q^2)}{xQ^4}([1+(1-y)^2]F_2^{c\bar{c}}(x,Q^2) - y^2 F_L^{c\bar{c}}(x,Q^2))$$

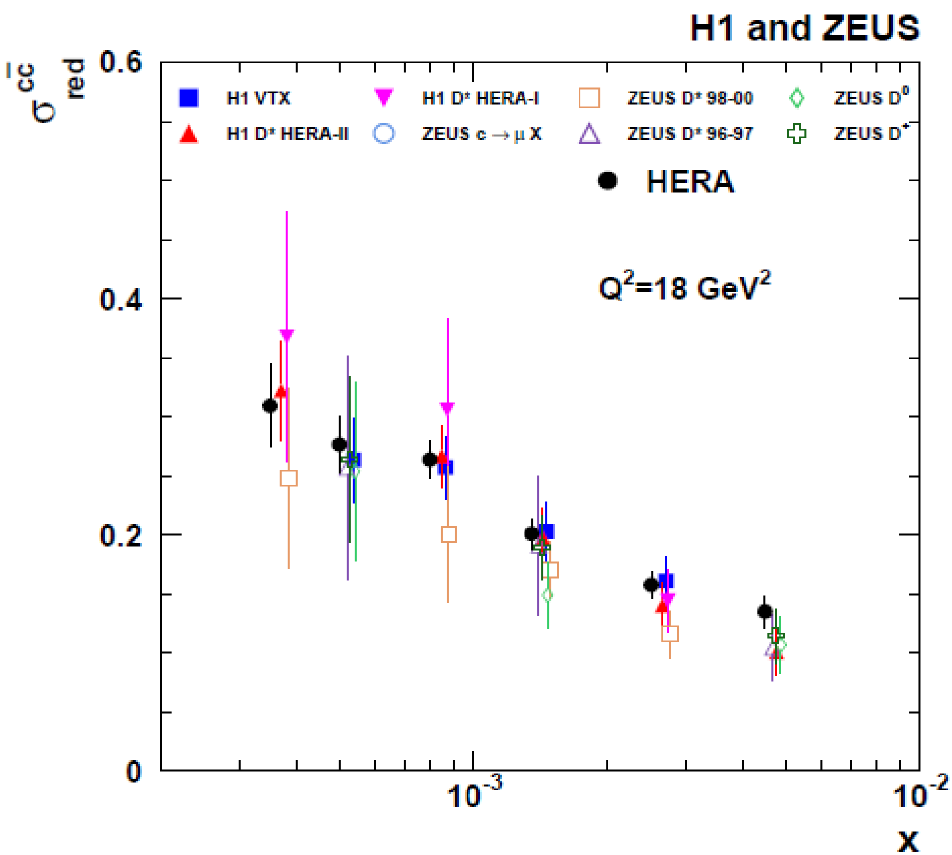
$$\sigma_{\mathrm{red}}^{c\bar{c}} = \frac{\mathrm{d}^2\sigma^{c\bar{c}}}{\mathrm{d}x\mathrm{d}Q^2}\cdot\frac{xQ^4}{2\pi\alpha^2(Q^2)\,(1+(1-y)^2)} = F_2^{c\bar{c}} - \frac{y^2}{1+(1-y)^2}F_L^{c\bar{c}}$$

H1 and ZEUS measurements of σ_{red}^{cc} projected onto a common (x,Q²) grid and combined.
For systematic errors the correlations have been taken into account.

Combined Results on Inclusive Charm Production



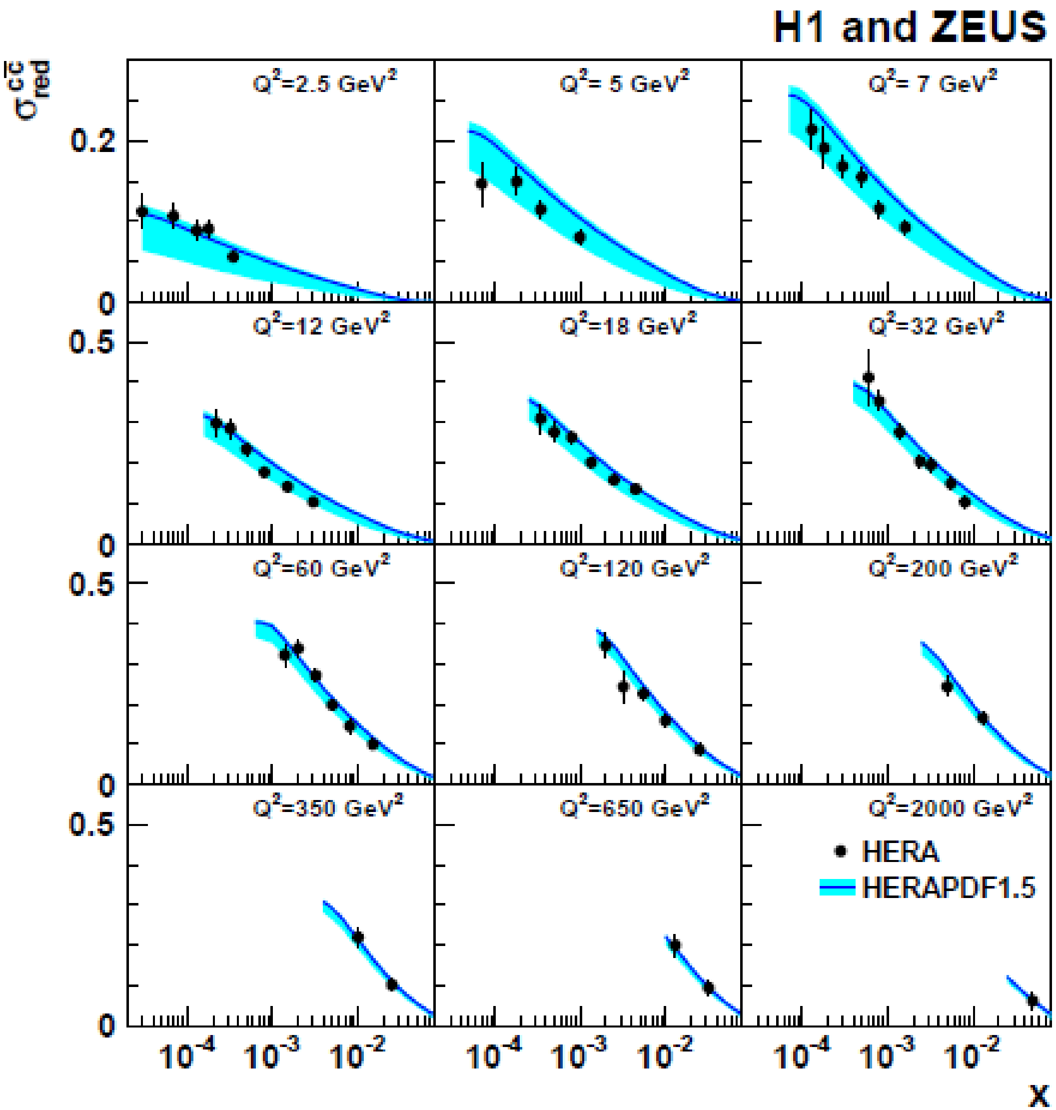
Combined H1+ZEUS result for reduced charm cross sections.



Comparison of individual measurements with different techniques to the combined reduced charm cross-section for the bin Q^2=18 GeV^2.

Improved statistical and systematic errors for combined results.

Combined Results on Inclusive Charm Production, cont.



Comparison to HERAPDF1.5 NLO predictions :

- derived from fit to inclusive DIS data (HERA I and HERA II)
- using RT standard scheme with **m_c = 1.4 GeV.**
- error bands dominated by varying **$1.35 \leq m_c \leq 1.65$ GeV.**

An issue: treatment of the charm mass in pQCD calculations.

PDFs and Treatment of Charm Mass in pQCD

In pQCD, mass obeys renormalisation equation -> it is scheme dependent.

Relation between pole mass and $\overline{MS}$ mass:

$$m_c(Q) = m_{c,\mathrm{pole}}\left[1 - \frac{\alpha_s}{\pi} - \frac{3\alpha_s}{4\pi}\ln\left(\frac{Q^2}{m_c(m_c)^2}\right)\right]$$

$$\sigma_{red}^{cc}(x,Q^2) \propto \int_0^1 d\xi \cdot \underbrace{C(\frac{x}{\xi},Q^2,\mu,\mu_f,\alpha_s(\mu^2),m_c)}_{} \otimes \underbrace{f(\xi,\mu,\mu_f)}_{}$$

DIS factorisation

hard scattering kernel:
calculable in pQCD, depends
on treatment of heavy quark mass

parton density function (PDF): has to be derived
from fitting data, depends on treatment
of heavy quark mass

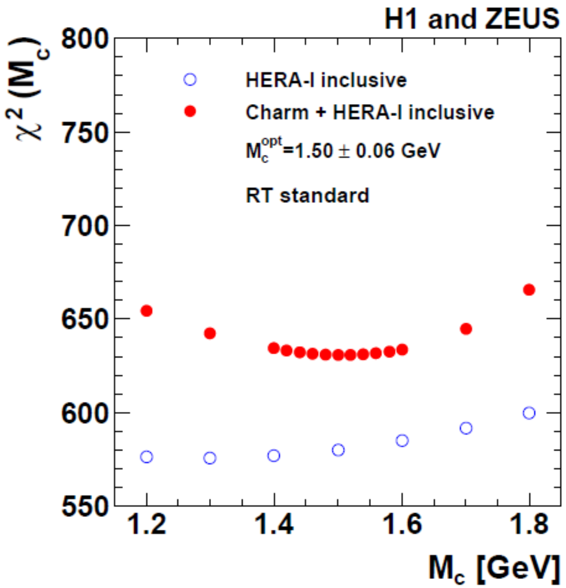
Various heavy quark mass schemes exist:

Fixed flavour number scheme (FFNS):
only light quarks in the proton, heavy quarks are massive and only produced in hard scattering.

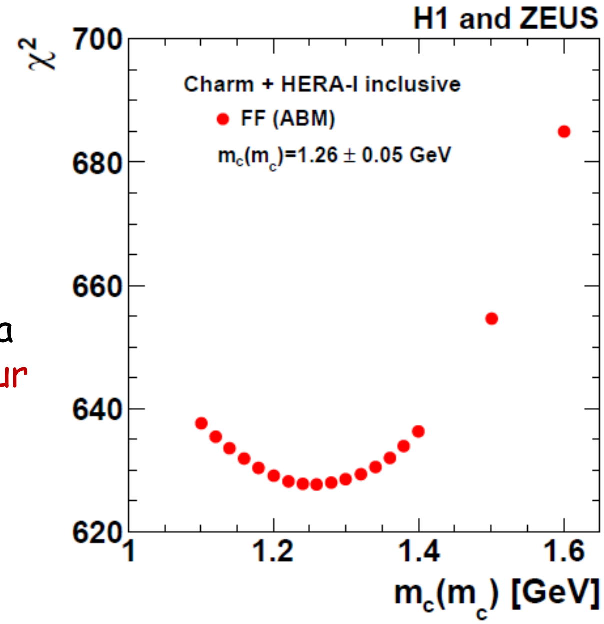
Zero mass variable flavour number scheme (ZM-VFNS):
heavy quark mass is set to zero, below threshold at $Q^2 \sim m_c^2$ charm cross-section is zero and only three active flavours in the proton. Above threshold charm is a massless active parton.

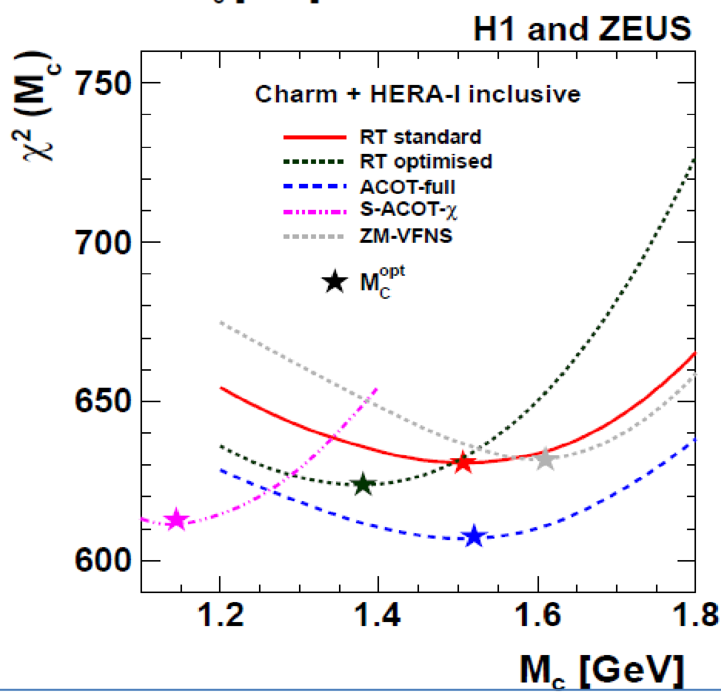
General mass variable flavour number scheme (GM-VFNS):
at low Q^2 like FFNS, at high Q^2 like ZM-VFNS, interpolation at intermediate scales, several interpolation procedures exist.

Extraction of Charm Mass from pQCD Fits



Extraction of optimal charm mass values from inclusive + charm data using different heavy flavour schemes.



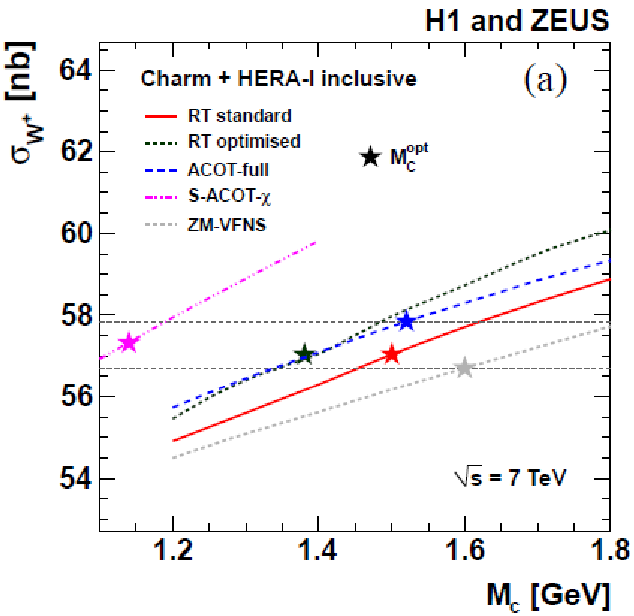


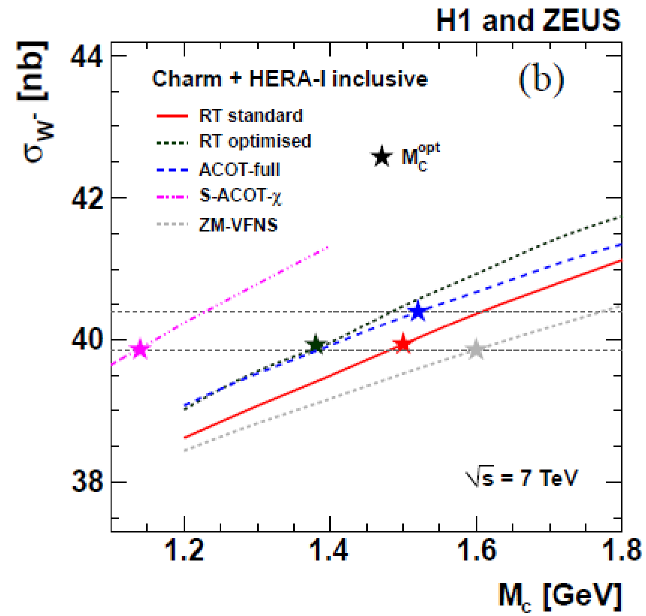
$m_c(m_c) = 1.26 \pm 0.05_{exp} \pm 0.03_{mod} \pm 0.02_{param} \pm 0.02_{\alpha_s}$ GeV

PDG : $m_c(m_c) = 1.275 \pm 0.025$ GeV

What does that mean for predictions of cross section for other processes?

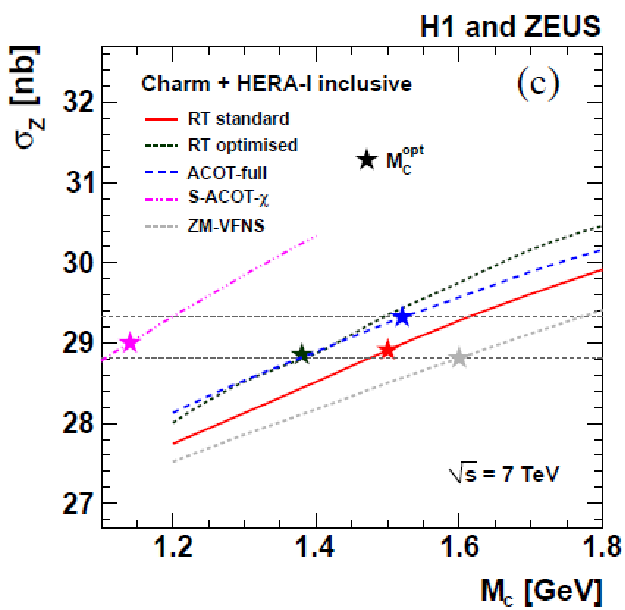
Predictions for W and Z cross-sections at LHC





Predictions as functions of the chosen charm mass in various heavy quark schemes.

Stars mark the values for the optimal charm mass in a given scheme.



<u>Conclusion:</u>

if optimal charm mass values are chosen for the different schemes, the predictions for LHC differ for

σ_{W^+} by 2%,

σ_{W^-} by 1.4 %

σ_Z by 1.8% .

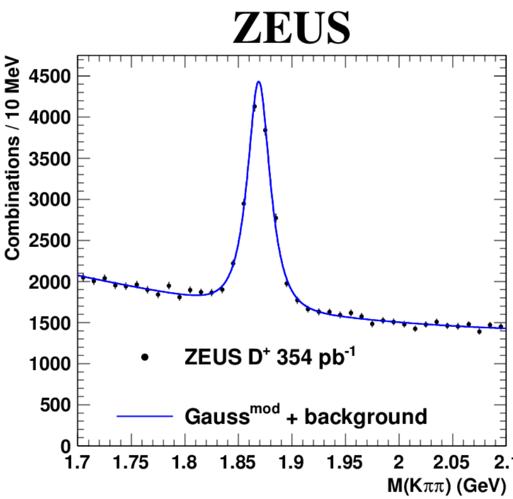
$D^{\pm}$ Production in DIS from the HERA II dataset

The HERA II dataset of 354 pb^{-1} was used to identify and reconstruct $D^{\pm}$ meson by their decay:

$$D^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}$$

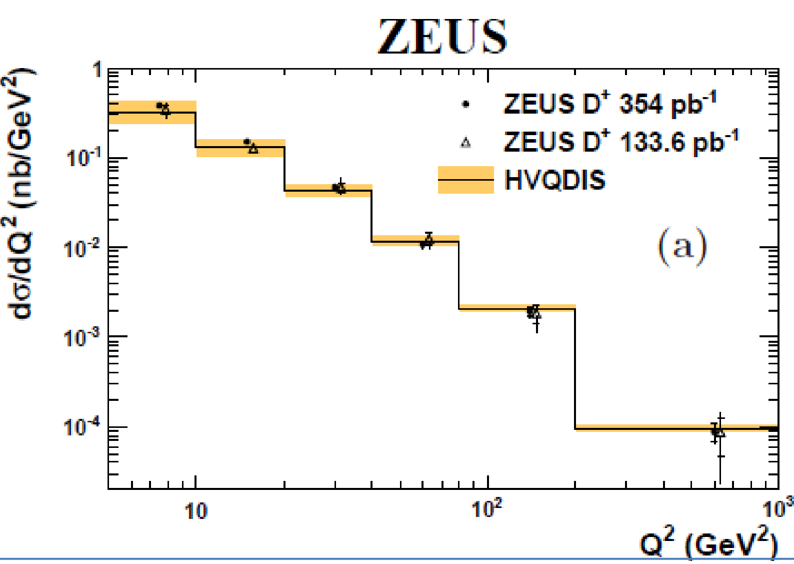
in the kinematic region

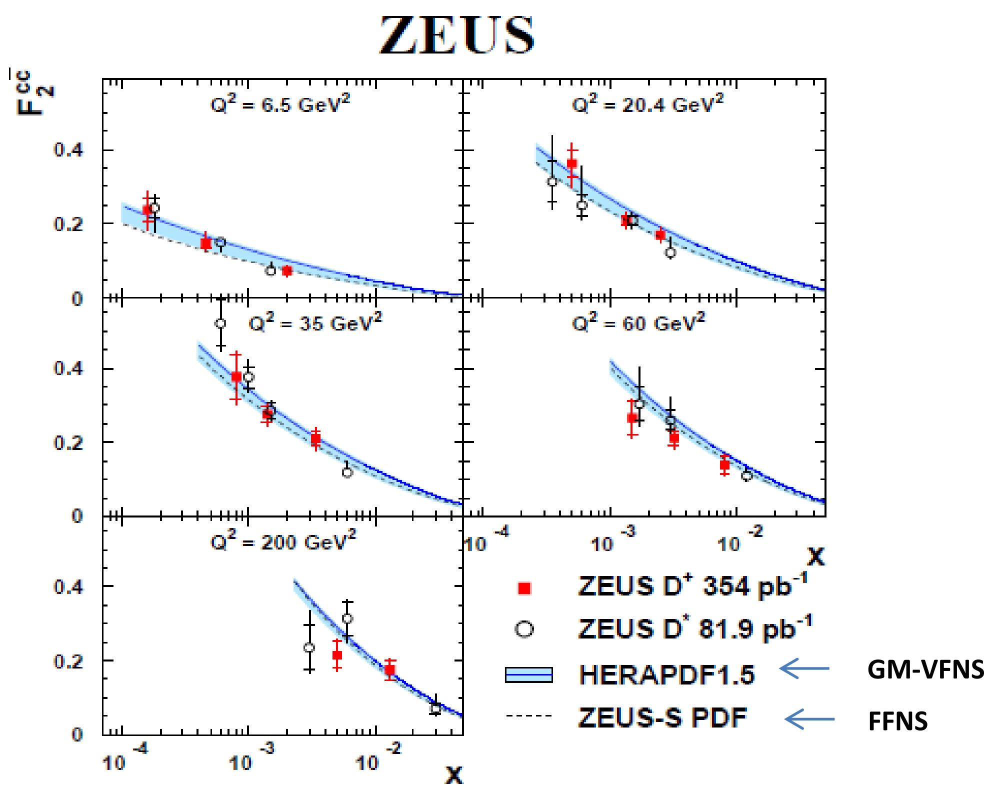
$$5 < Q^2 < 1000\ GeV^2\ ;\ 0.02 < y < 0.7$$
$$1.5 < p_T(D^{\pm}) < 15\ GeV^2\ ;\ |\eta(D^{\pm})| < 1.6$$



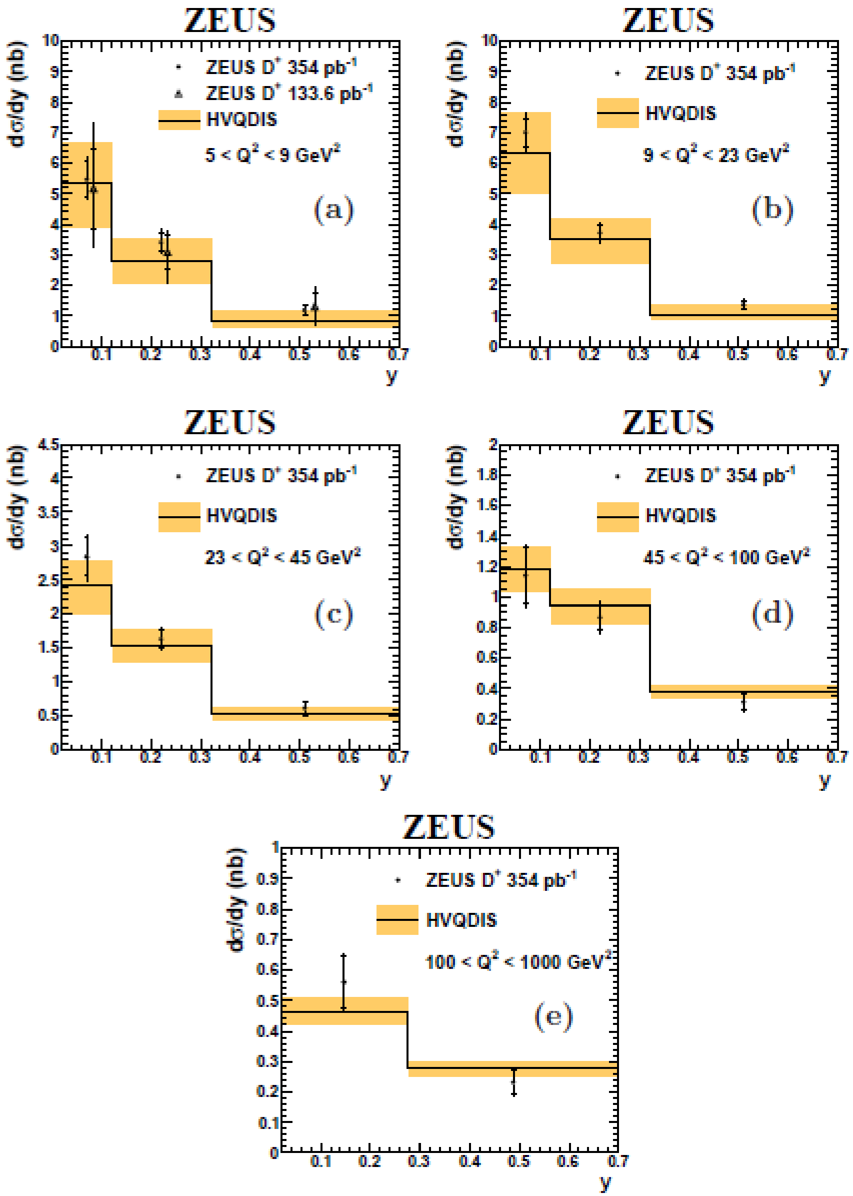
Micro-Vertex-Detector used for $D^{\pm}$ decay length measurement and selection.

Comparison to HERA I results and NLO QCD predictions.





$D^{\pm}$ Production from the HERA II dataset, continued



Due to the higher integrated luminosity w.r.t. previous analysis double differential cross sections can be calculated.

$5 < Q^2 < 9$ GeV^2 : comparison to old analysis
-> reduced statistical and systematic errors

Comparison to NLO calculations (HVQDIS)

These data are not included yet in the combination of H1 and ZEUS results on charm production.

Work is ongoing to include these data in the combination of results.

D* Production in DIS from the HERA II dataset

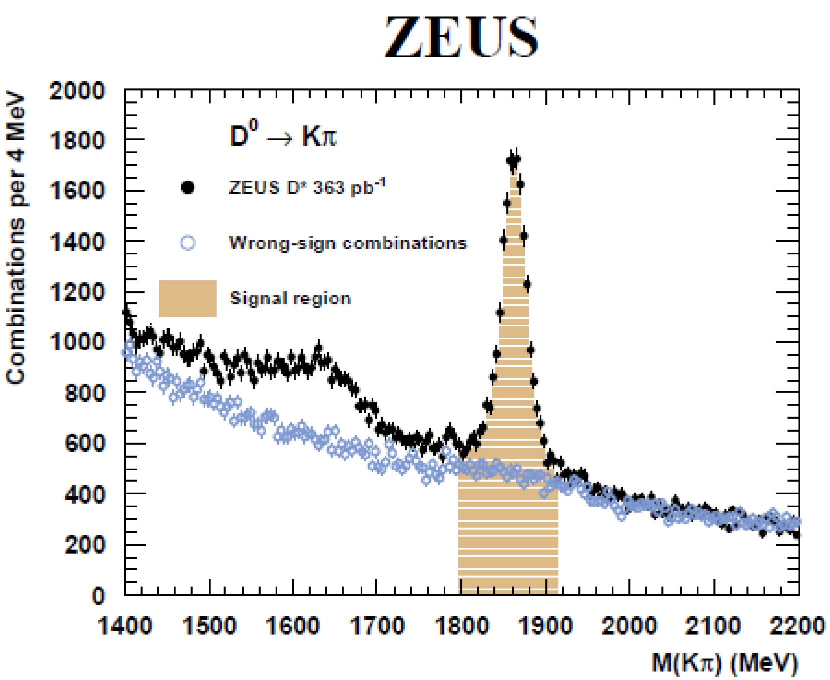
Process: $ep \rightarrow e' D^{*\pm} X$

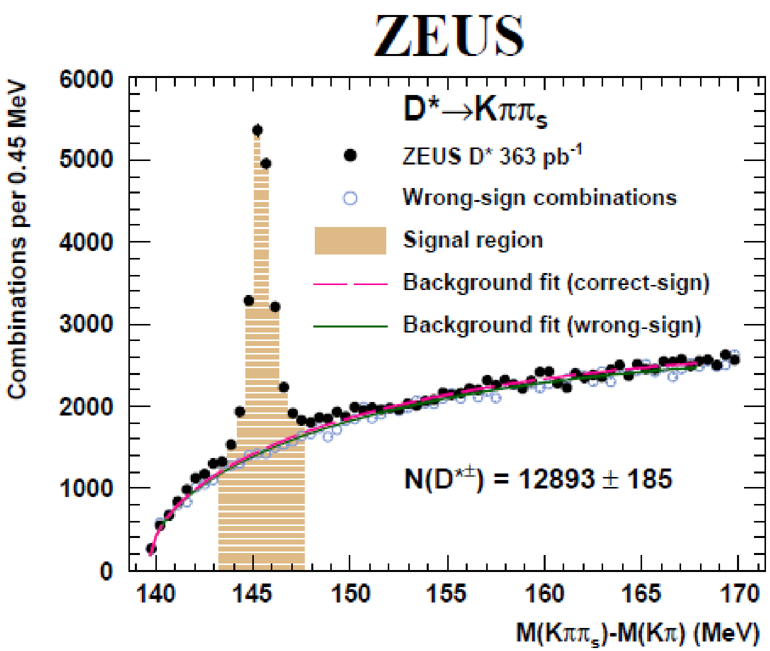
Kinematic region: $5 < Q^2 < 1000$ GeV^2 ; $0.02 < y < 0.7$; $1.5 < p_T^{D^*} < 20$ GeV ; $|\eta^{D^*}| < 1.5$

Selection of D^*: $D^{*+} \rightarrow D^0 \pi_s^+$; $D^0 \rightarrow K^- \pi^+$

Charge conjugate states are implied.

Signal region : $1.80 < M(K\pi) < 1.92$ GeV ; $143.2 < \Delta M < 147.7$ MeV ; $\Delta M \equiv M(K\pi\pi_s) - M(K\pi)$



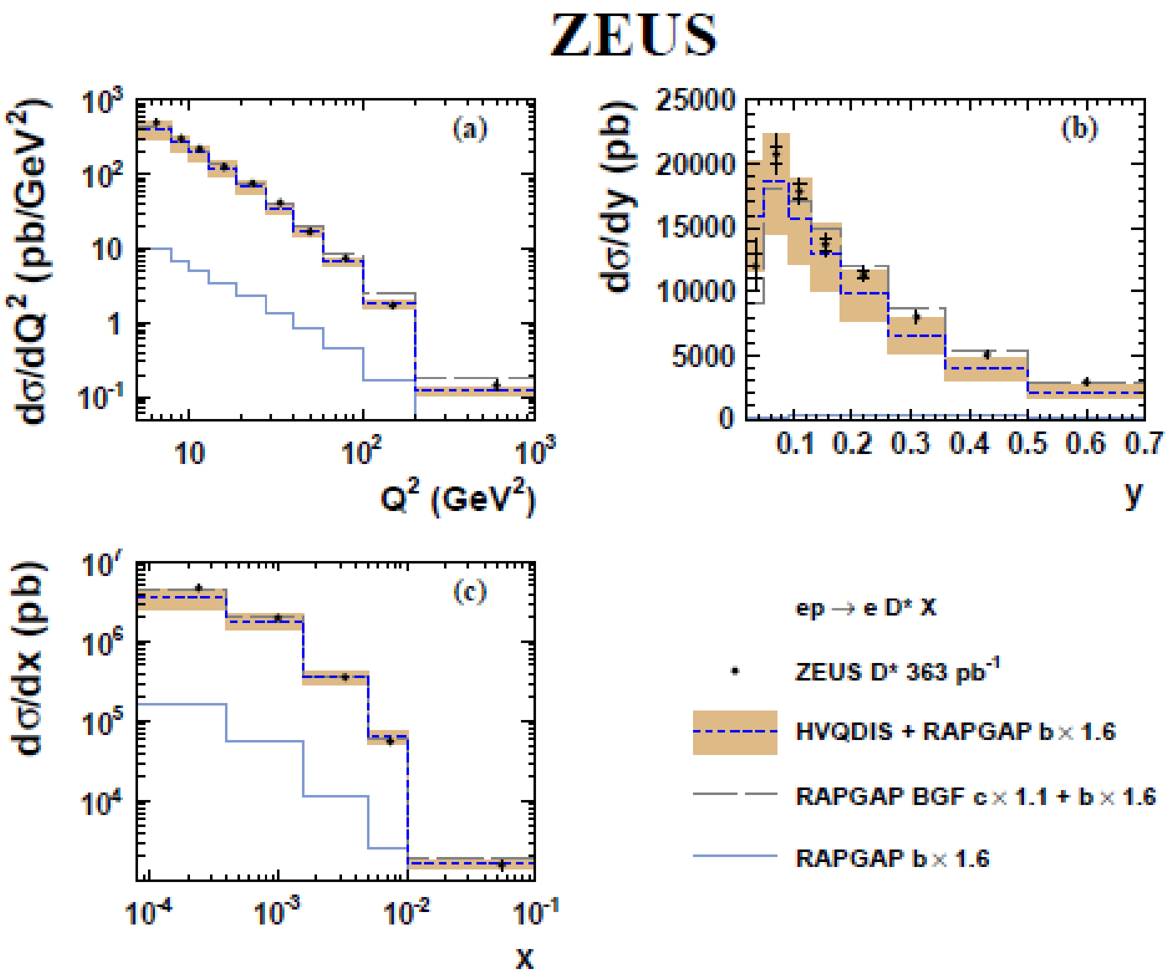


Wrong sign combination : combine tracks of same charge for K and π.

Peak below the D° position is from partly reconstructed $D^0 \rightarrow K^- \pi^+ \pi^0$.

D* Production in DIS from the HERA II dataset , cont.

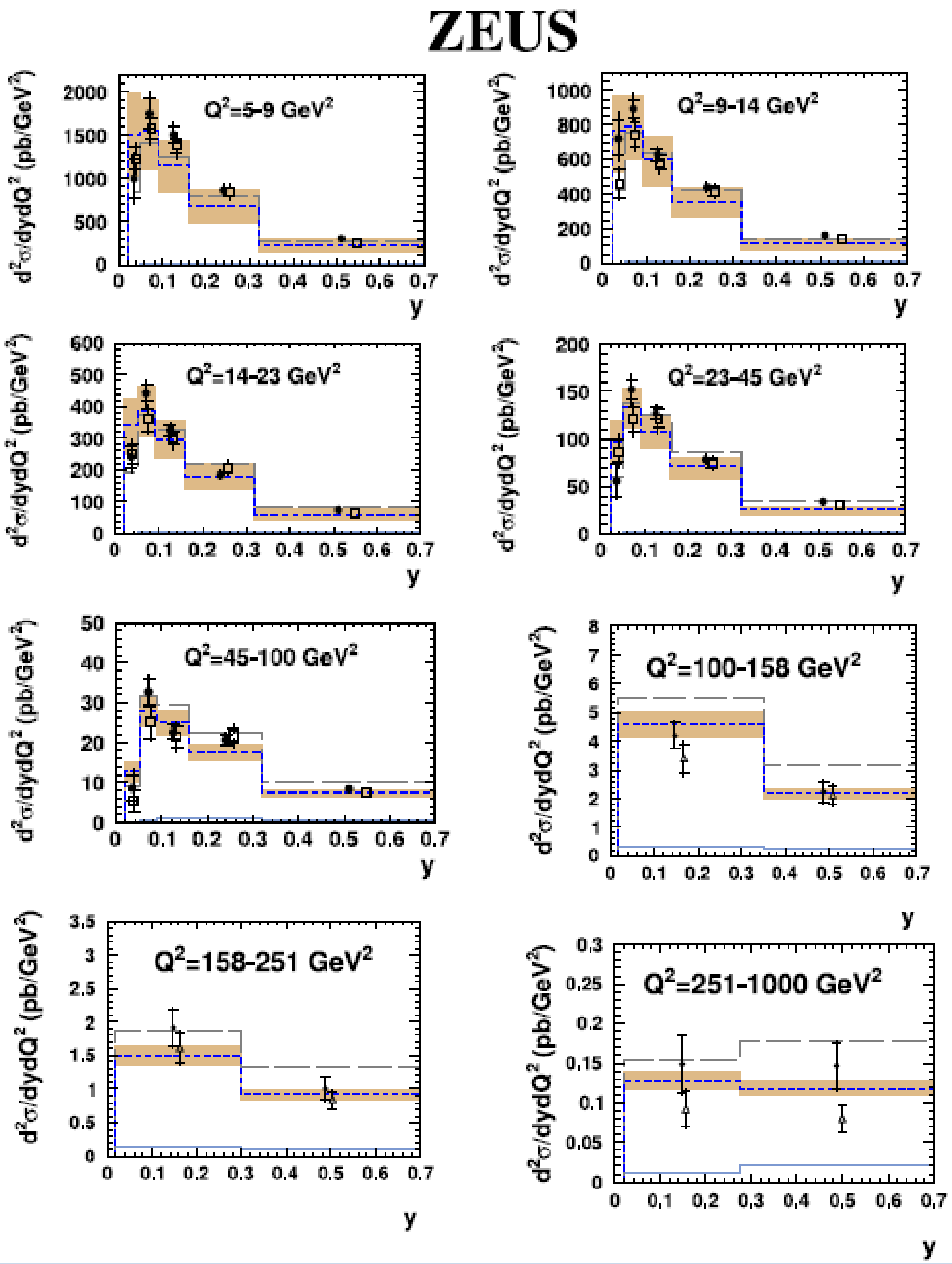
Single differential cross-sections



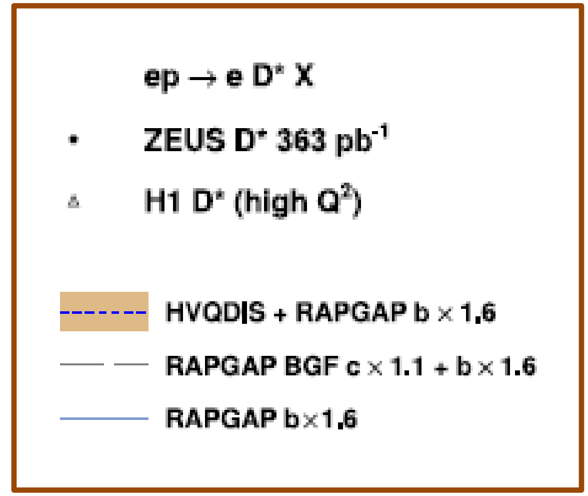
ZEUS results on D* production, comparison to NLO calculations (HVQDIS)

Fair agreement of data with NLO predictions

D* Production in DIS from the HERA II dataset , cont.



Double differential cross-sections



Comparison to NLO calculations
and to H1 results.

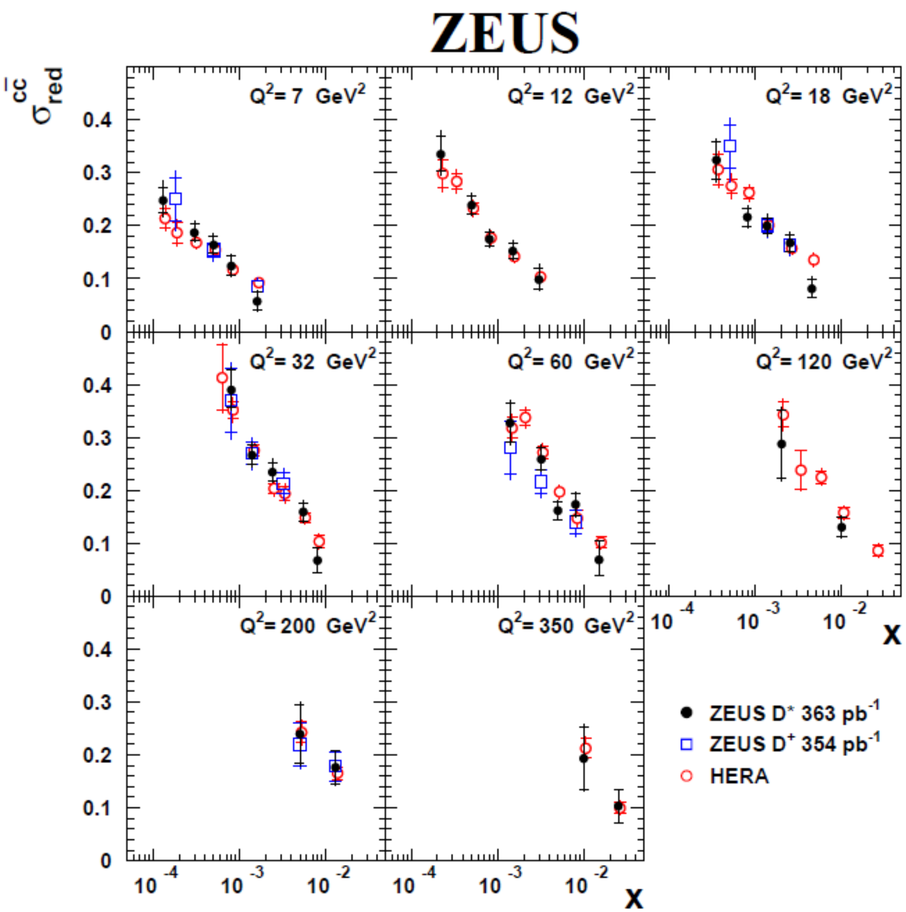
Fair agreement also for
double differential cross-sections.

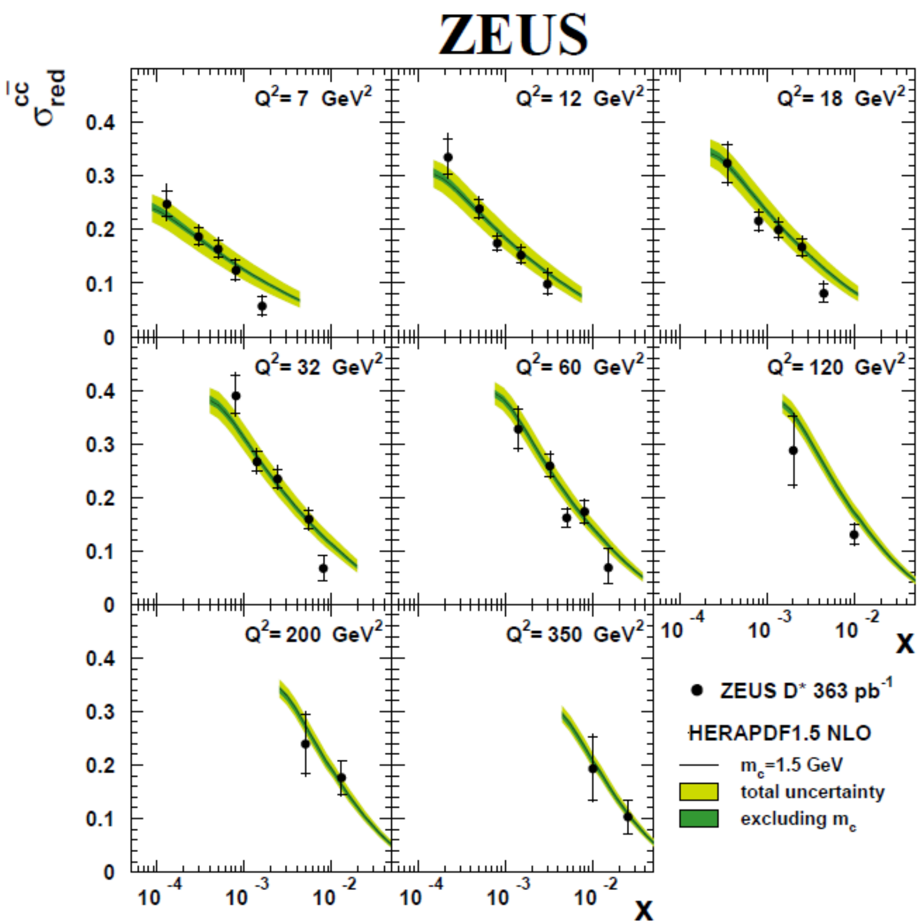
Reduced Charm Cross-sections from the HERA II dataset

Reduced charm cross-section :

$$\frac{d^2\sigma^{c\bar{c}}}{dx\,dQ^2} = \frac{2\pi\alpha_{em}^2}{xQ^4}\, Y_+\ \sigma_{\rm red}^{c\bar{c}}(x,Q^2,s)$$

$$\sigma_{\rm red}^{c\bar{c}}(x,Q^2,s) = F_2^{c\bar{c}}(x,Q^2) - \frac{y^2}{Y_+}F_L^{c\bar{c}}(x,Q^2) \qquad \text{with} \qquad Y_+ = 1+(1-y)^2$$





Good agreement with ZEUS D^+ and H1-ZEUS charm combination data.

HERAPDF1.5 (charm data not included) describes the charm data well.

Charm Fragmentation Functions from Photoproduction

Photoproduction at ZEUS: no scattered electron detected in the calorimeter -> $Q^2 \approx 0$ GeV^2

Charm fragmentation function:

$$\mathbf{f(c \rightarrow charm\ particle)} = \frac{\boldsymbol{\sigma}\mathbf{(charm\ particle)}}{\boldsymbol{\sigma}\mathbf{(total\ charm\ particles)}}$$

universal, independent of production process, needed to compute charm cross-section.

Measured signals: $D^0, D^+, D^{*+}, D_s^+, \Lambda_c^+$; charge conjugate states included

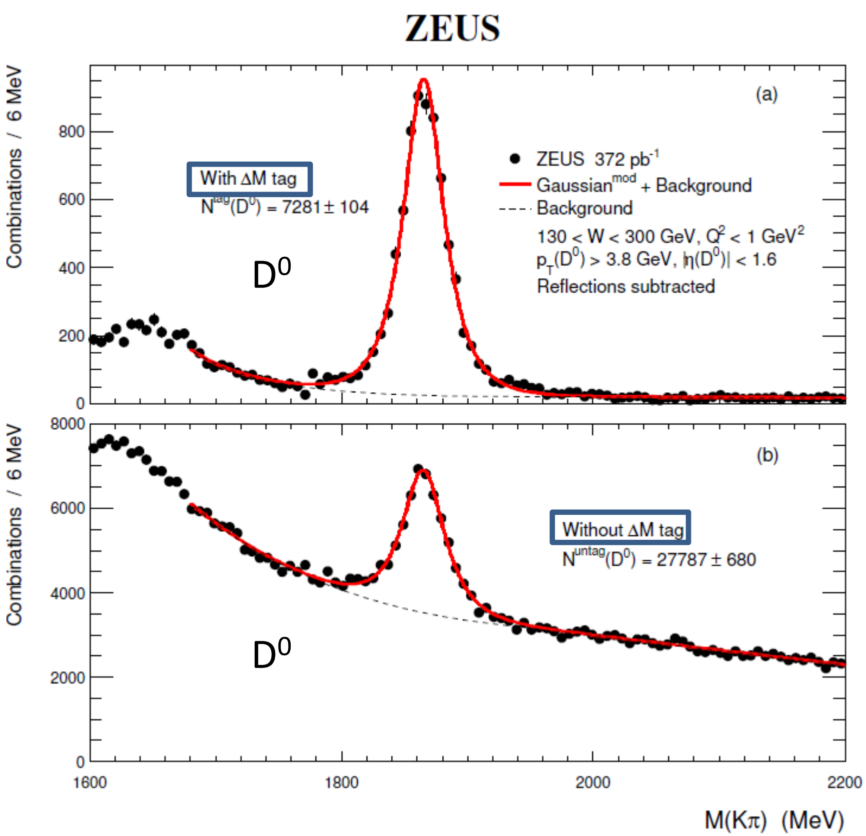
Range of γp cms energy: $130 < W_{\gamma p} < 300$ GeV

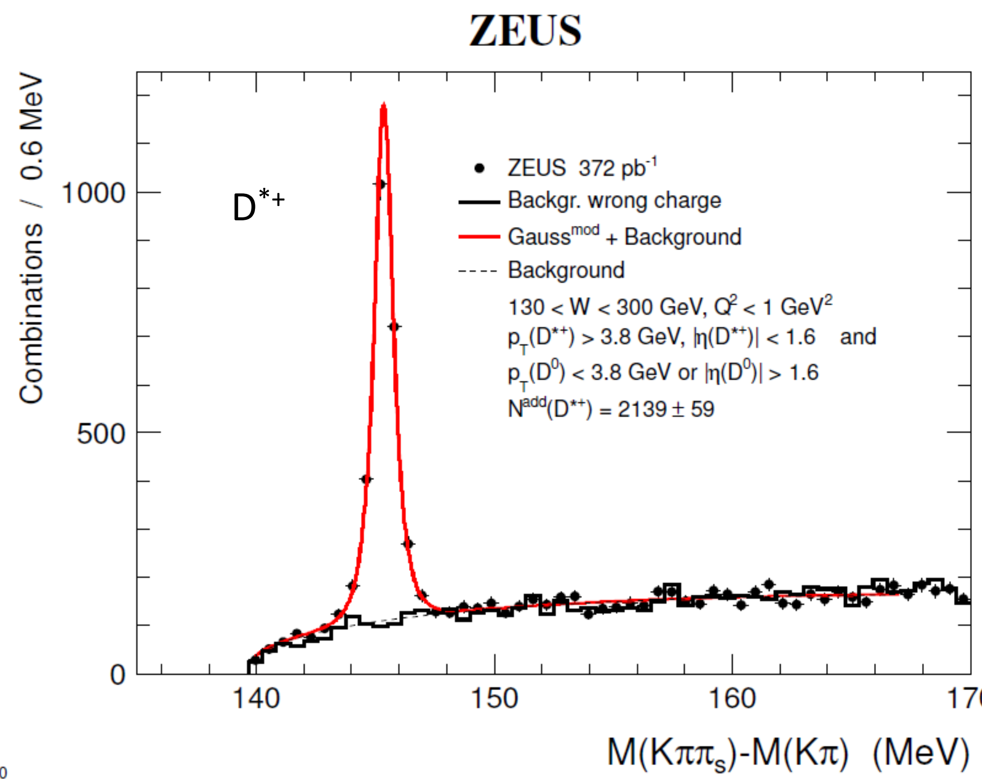
Acceptance region: $p_T > 3.8$ GeV and $\eta < 1.6$ for all charm particle candidates

$\frac{p_T}{E_T^{\theta > 10^o}} > 0.2\ (0.25)$ for $D, D^* (\Lambda_c)$ candidates

For the selection of D^o, D^+ particles the decay lengths as measured with the vertex detector have been used.

Charm Fragmentation Functions from Photoproduction, cont.



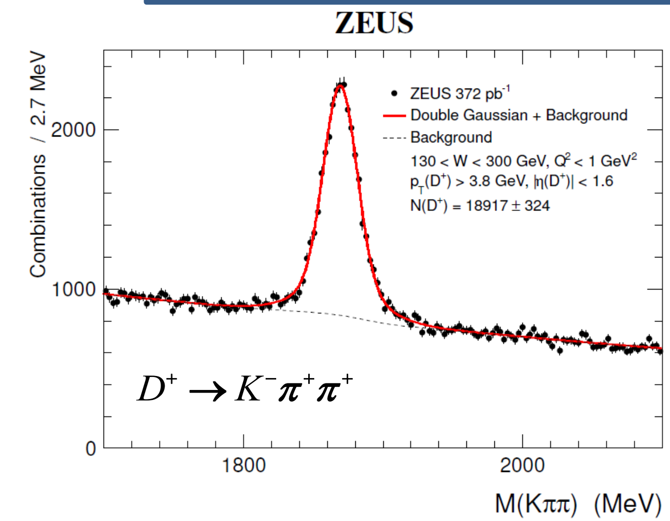


$D^{*+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+$

Additional $D^{*+} \to D^0\pi^+$ from D^0 outside kinematical region.

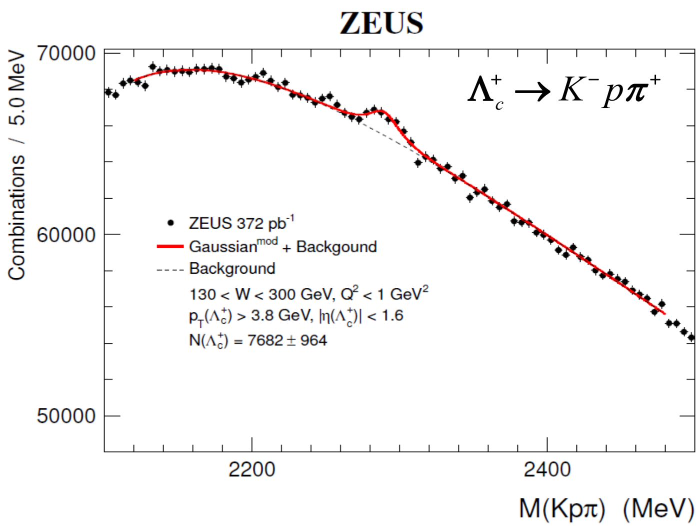
ΔM tag: $\mathbf{0.143} < M(K\pi\pi) - M(K\pi) < \mathbf{0.148\,GeV}$

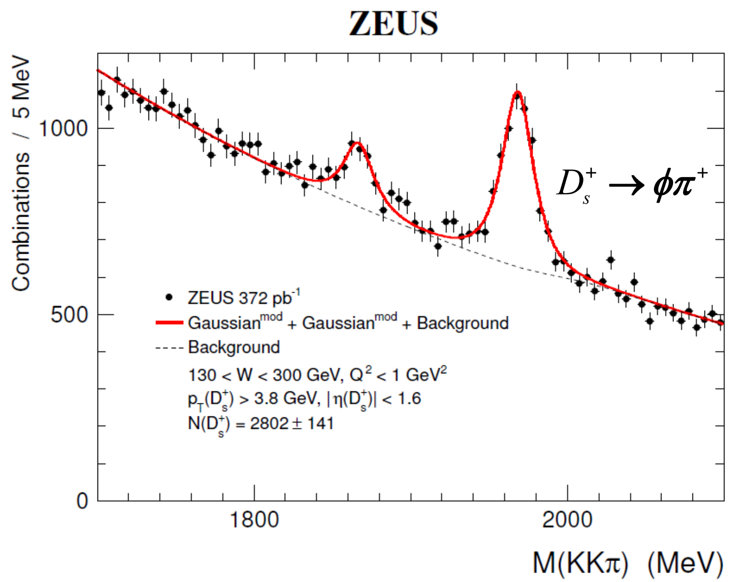
Charm Fragmentation Functions from Photoproduction, cont.



$D^+ \to K^-\pi^+\pi^+$

Appropriate mass cuts applied to remove background from D^{*+} and D_s^+ decays.





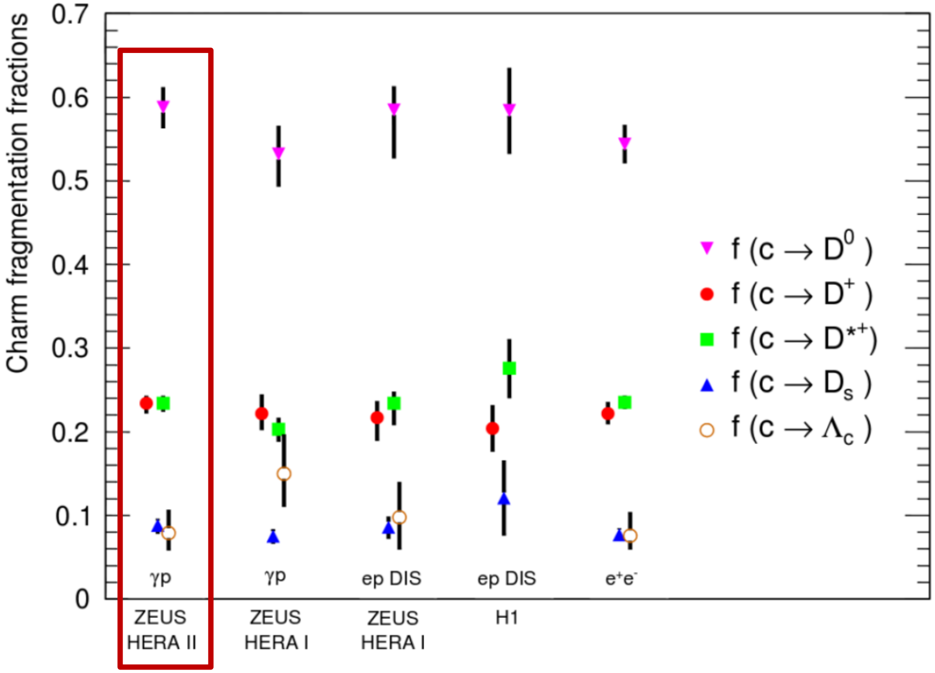
$D_s^+ \to \phi\pi^+ \quad , \quad \phi \to K^+K^-$

Lower peak at 1860 MeV is from $D^+ \to K^+K^-\pi^+$

$\Lambda_c^+ \to K^- p \pi^+$

Background from $D^+, D_s^+ \to$ 3 charged particles reflections are subtracted according to MC model.

Charm Fragmentation Functions from Photoproduction, cont.



Corrections of cross-sections for not observed states $\Xi_c^+, \Xi_c^0, \Omega_c^0$ with PYTHIA MC -> factor 1.14

Fraction of charged D mesons produced in a vector state:

$$P_V^D = \sigma(D^{*+}) / [\sigma(D^{*+}) + \sigma^{dir}(D^+)]$$

$$P_V^D = 0.595 \pm 0.020(stat.) \pm 0.015(syst.) \pm 0.011(BR)$$

naïve spin counting: 0.75 ;
string fragmentation (LUND): 0.66

Charm fragmentation functions are universal, independent of production process.

Strangeness suppression in charm production:

$$\gamma_S = 2\sigma(D_S^+) / [\sigma(D^+) + \sigma(D^0)]$$

$$\gamma_S = 0.214 \pm 0.013(stat.)\ ^{+0.006}_{-0.017}(\text{syst.}) \pm 0.012(br.)$$

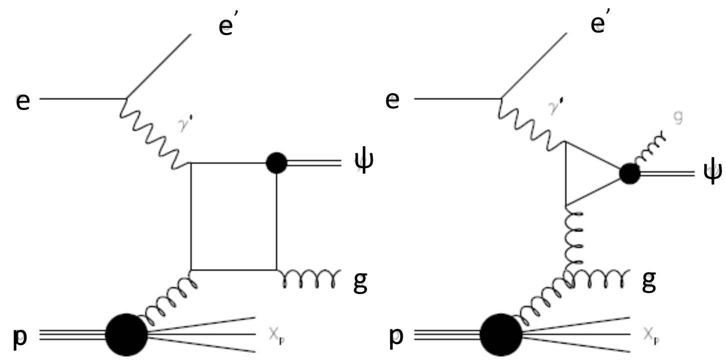
To be compared to non-charm strange particle production: 0.22-0.30

Inelastic J/ψ and ψ′ Photoproduction

$$ep \to J/\Psi\ X \quad ; \quad ep \to \Psi'\ X$$

$Q^2 \approx 0$ GeV^2

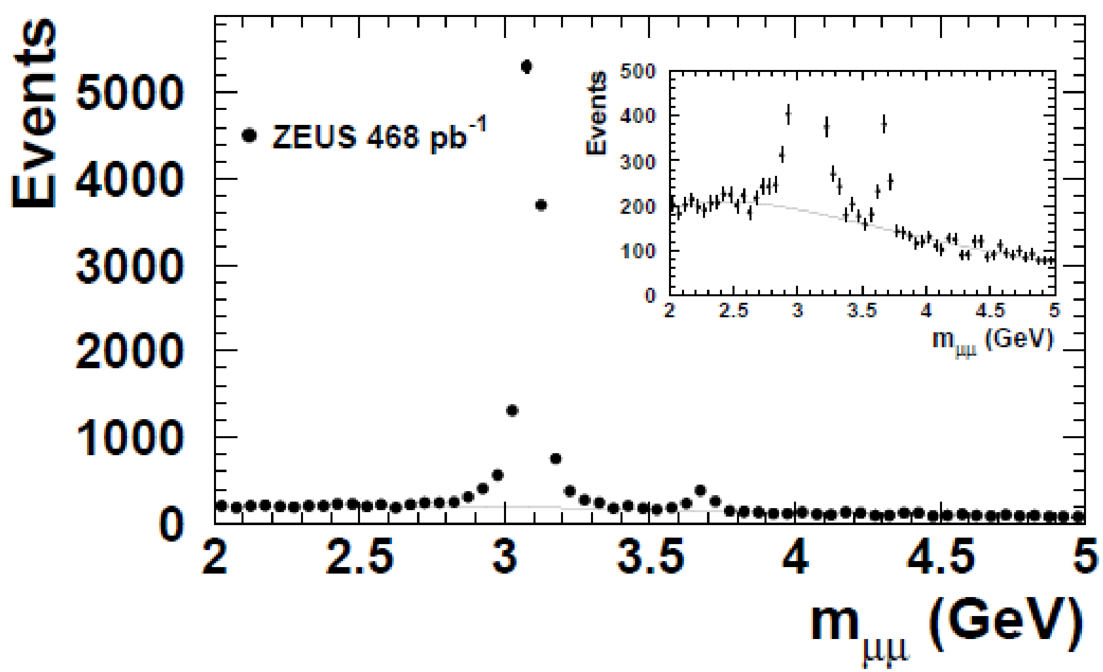
Colour singlet contribution



Colour octet contribution

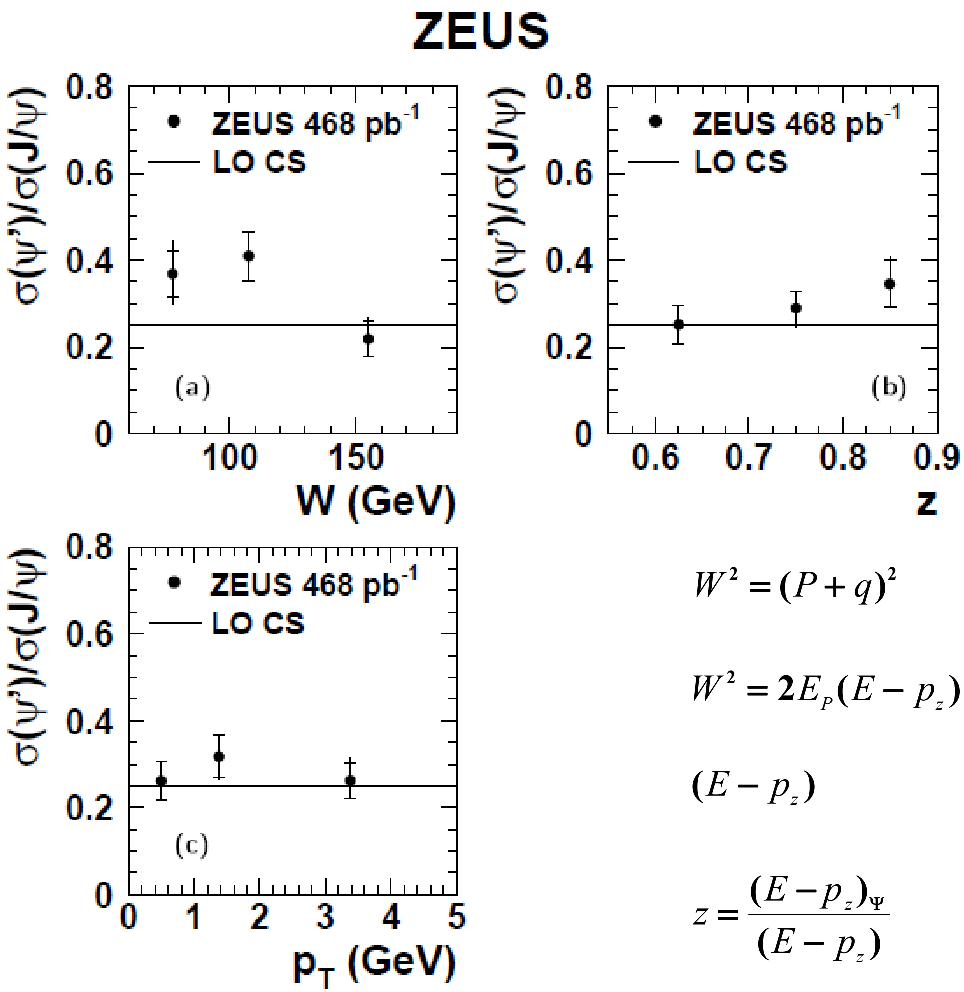
J/ψ and ψ′ detected by their decays

$$J/\Psi \to \mu^+\mu^-$$
$$\Psi' \to \mu^+\mu^-$$



Inelastic J/ψ and ψ′ Photoproduction ; continued

Ratio of J/ψ to ψ′ photoproduction



Kinematic range:

60 < W < 190 GeV ; 0.55 < z < 0.9

Reasonable agreement with leading-order colour-singlet expectation.

$$W^2 = (P+q)^2$$

Photon-proton cms energy squared

$$W^2 = 2E_p(E - p_z)$$

$$(E - p_z)$$

Difference between energy and momentum along the z-axis summed over all final state particles.

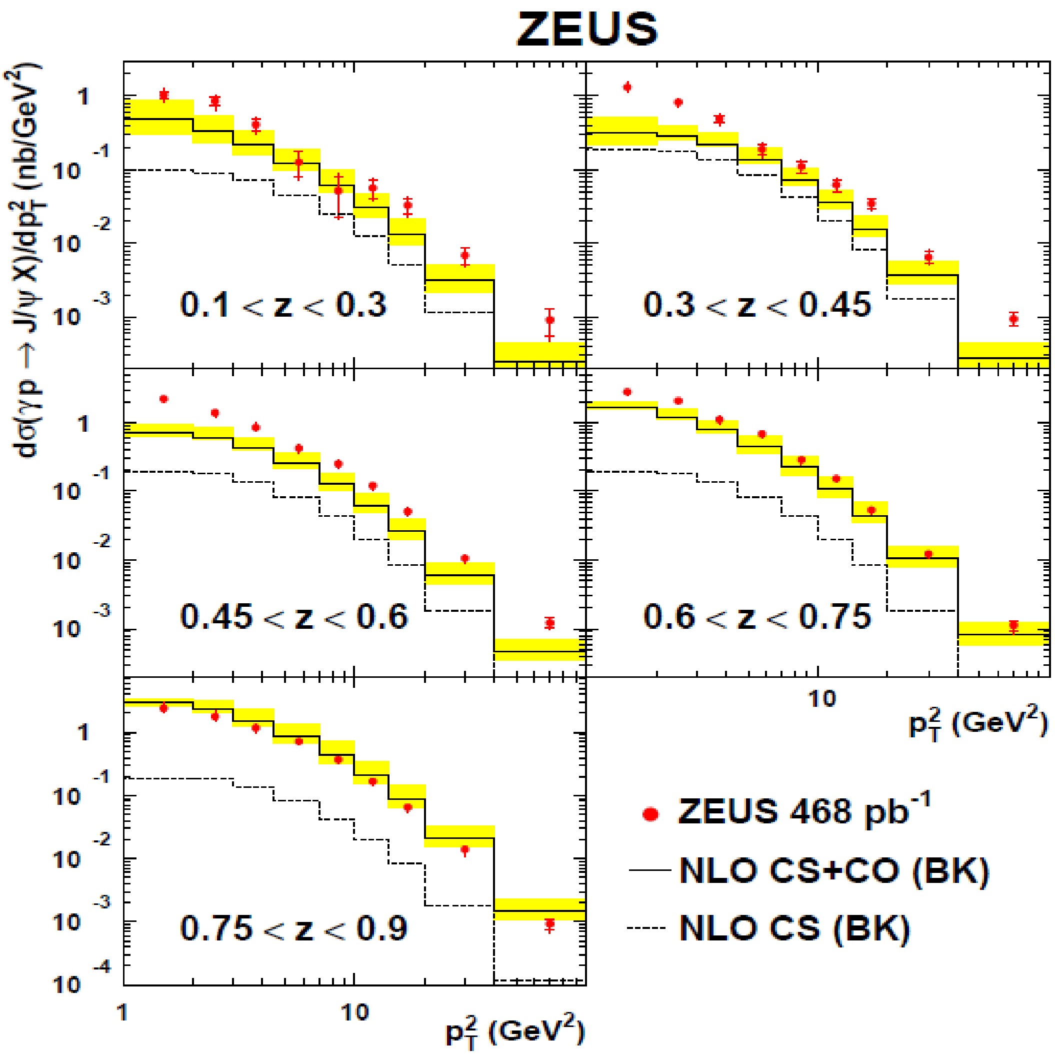
$$z = \frac{(E-p_z)_\Psi}{(E-p_z)}$$

Inelasticity: fraction of the photon energy transferred to the ψ - particle.

p_T

Transverse momentum of the ψ - particle.

Inelastic J/ψ and ψ′ Photoproduction ; continued



Differential cross-sections $\frac{d\sigma}{dp_T^2}$ measured in 5 different z ranges.

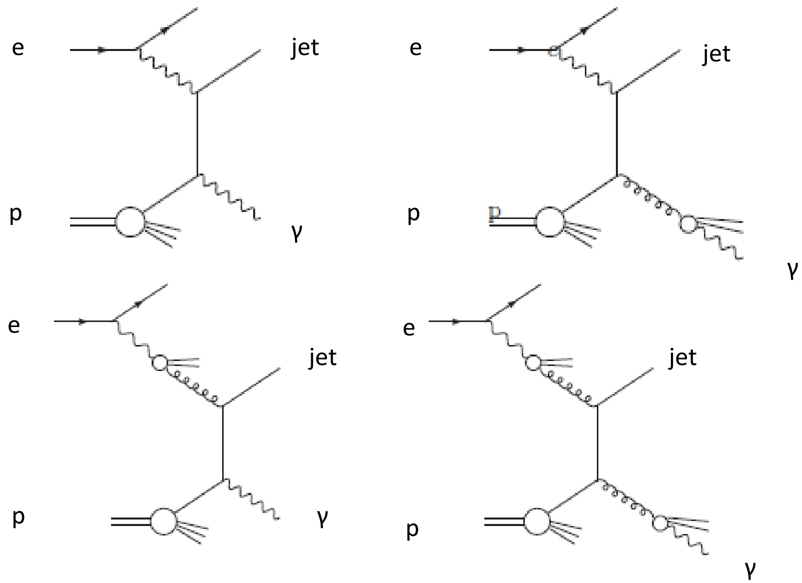
Comparison with nonrelativistic NLO CS and NLO CS+CO calculations.

Kinematic range:

60 < W < 240 GeV
p_T > 1 GeV

The colour singlet contribution alone is not able to explain the data. Addition of a colour octet contribution improves the description of the data.

Prompt Photons + Jet in Photoproduction



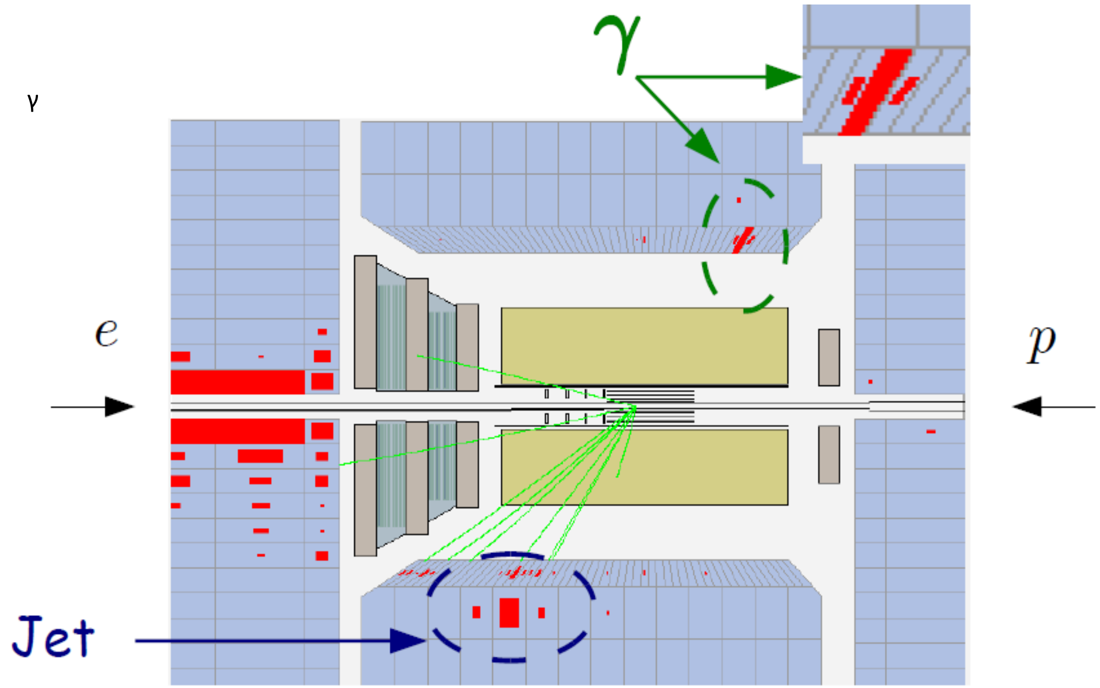
Direct photoproduction

$Q^2 \approx 0$ GeV^2

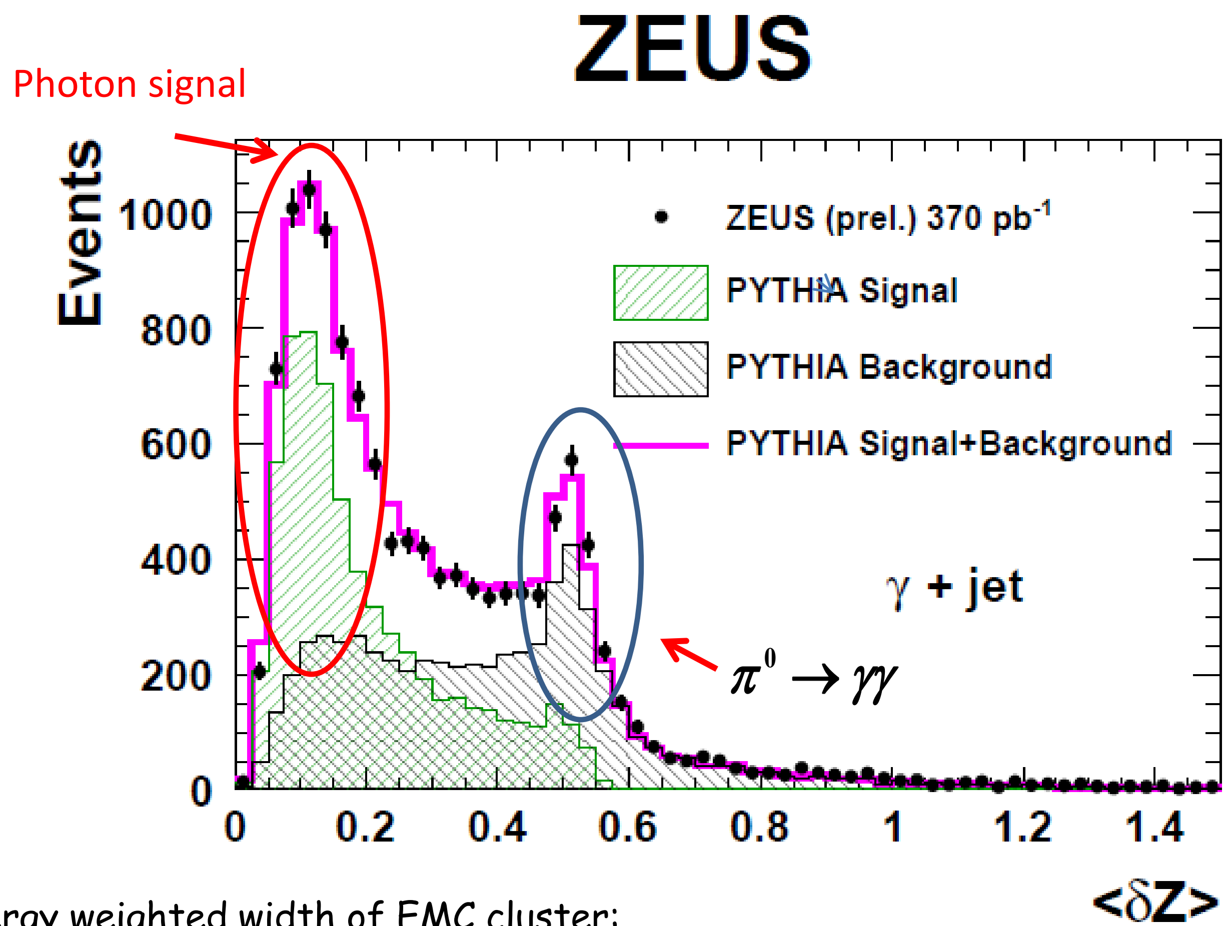
Resolved photoproduction

Prompt photon emission is not affected by problems due to hadronisation.

Sensitivity to quark charge, u/d separation.



Prompt Photons + Jet in Photoproduction, cont.



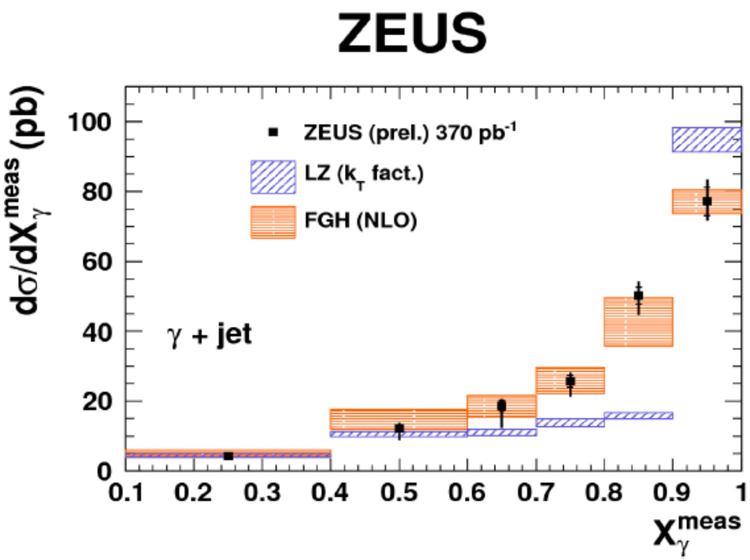
Energy weighted width of EMC cluster:

$$\langle \delta Z \rangle = \sum_i E_i |Z_i - Z_{\text{cluster}}| \; / (w_{\text{cell}} \sum_i E_i)$$

W_{cell} : width of EM calorimeter cell

Prompt photon signal extracted by template fit for δZ.

Prompt Photons in Photoproduction, cont.

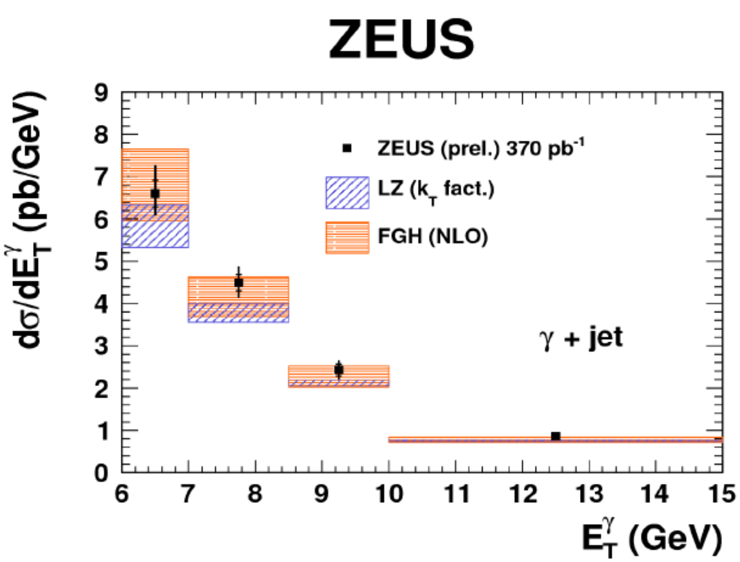


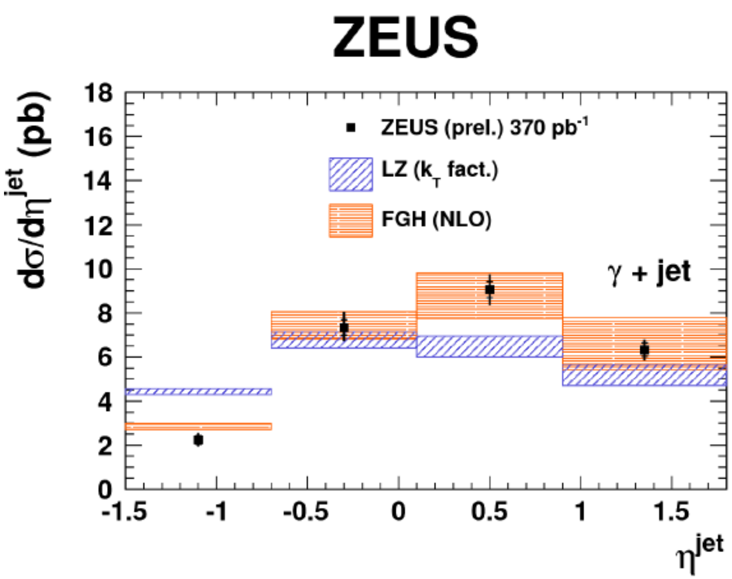
$$x_\gamma^{meas} = \frac{E^\gamma + E^{\rm jet} - p_Z^\gamma - p_Z^{\rm jet}}{E^{\rm event} - p_Z^{\rm event}}$$

Fraction of the exchanged photon energy in the hard interaction

FHG(Faontanaz,Guillet,Heinrich) NLO calculations give a good description of the data.

LZ(Lipatov,Zotov) k_T-factorisation calculations in LO describe data reasonably well. Improved predictions will come soon.





Summary

- Combination of charm results from H1 and ZEUS
  → increased precision,
  provides further constraints for the description of proton structure
  when included in the dataset for PDF fits.

- Many new results on charm production to be included in the charm combination,
  Work is underway.

- Determination of the charm pole-mass and optimal charm masses for various treatments of heavy flavours in pQCD calculations.

- Measurements of charm fragmentation fractions
  → support of fragmentation universality,
  precision is compatible with e^+e^- results.

- New data on inelastic J/Ψ photoproduction
  → evidence for the necessary colour- octet contributions.

- Updated analysis of prompt photon production provides an improved check of pQCD calculations without the complication of hadronisation corrections.