Charm production at HERA

ZEUS results

Paolo Bellan

Padova University and INFN

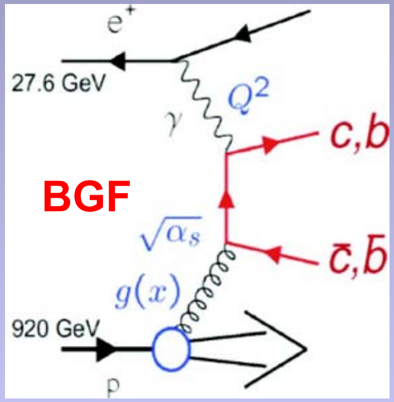
Outlook

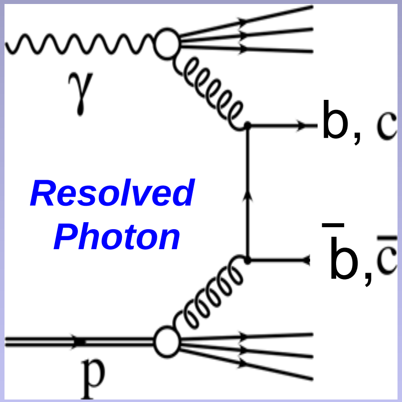
- Charm Physics: general motivations
- Charm fragmentation function, fractions and ratios
- D mesons in DIS, in photoproduction and in the transition region
- D mesons at HERA II with the lifetime method
- F_2^{cc} measurements
- Conclusions

HQ production in *ep* collisions:
the Charm Physics potentiality

- Powerful test of QCD.
- Clean measurement of the charm contribution to the structure function F_2
- Information on c quark production and fragmentation (independent, if QCD factorisation theorem holds)
- Testing different hadronisation models and fragmentation parameterisations
- Rich D mesons spectroscopy

Main processes contributing to HFL production at HERA are the boson-gluon fusion (BGF), directly sensitive to the ***p*** gluon content, and the resolved photon





Charm tagged via the reconstruction of different charmed mesons: D^*, D^+, D^0, D_s^+…

Charm fragmentation function, ratios and fractions

From the mesons to F_2^{cc}: do we have all the ingredients well measured?

- The **fragmentation functions** $f(c \to D^i)$ parameterize the energy transfer from a quark to a given meson
- Some of them not yet measured in *ep* or *pp* collisions (e.g. for D* in PHP); usually fitted from e^+e^- data
- Source of large uncertainty in the σ_{prod} calculation
- Test for the universality of charm fragmentation when compared to e^+e^- results

- **D* in photoproduction**:

$D^* \to D^0\pi$ + c.c.
$\quad \hookrightarrow K\pi\pi$

$$f(c \to D^i) = \frac{\sigma^{eq}(D^i)}{\sigma^c_{gs}}$$

σ_{gs} = all charmed ground state decaying weakly (Ω,Ξ,Λ_c corrected)

- **From D^0, D^+ and D_s in DIS:**

PS:
$D^0 \to K^-\pi^+$
$D^+ \to K^-\pi^+\pi^+$ + c.c.
$D_s^+ \to \phi\pi^+ \to K^+K^-\pi^+$

V:
$D^{*+} \to D^0\pi^+ \to K^-\pi^+\pi_s^+$

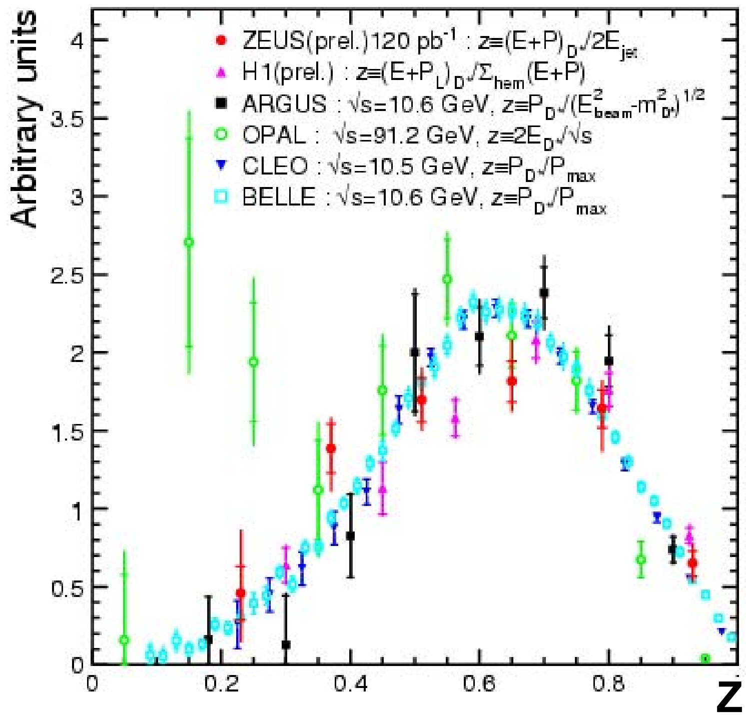
($\Lambda_c^+ \to K^- p\pi^+$ ~3σ, not used)

➔ $R_{u/d}$, γ_s, P_V^d

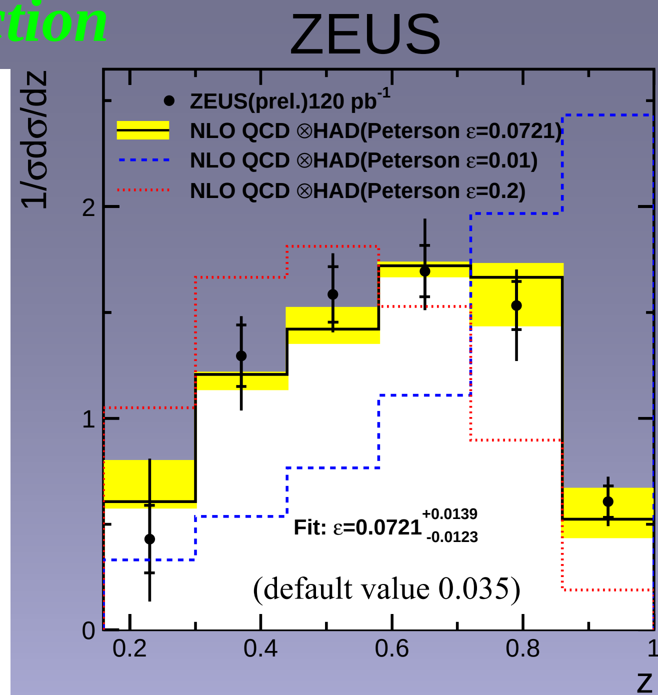
Ratios of the production rates for different D mesons → information on the quarks production (e.g. ratio charged to neutral, vector over total, strangeness suppression factor.)

(see last HERA-LHC workshop)

From D decays in photoproduction*



OPAL's points z < 0.3 not taken into account for the normalisation (higher energy, more gluon splitting)



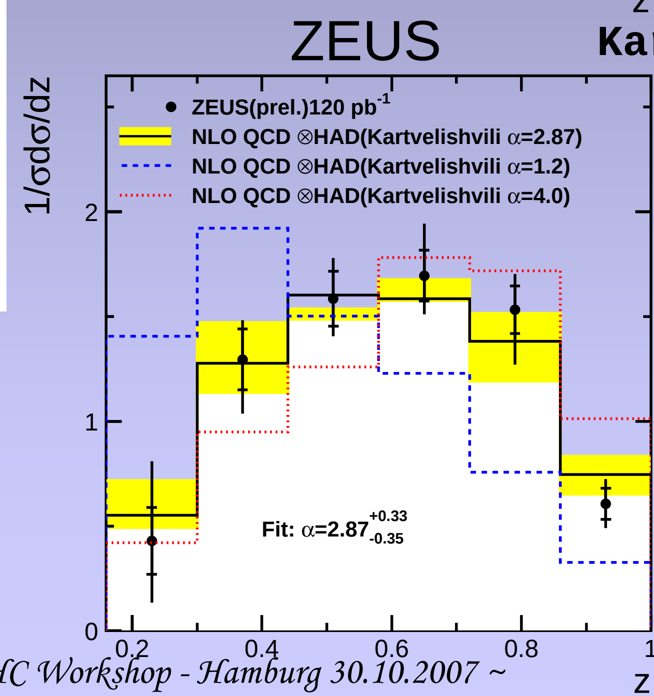
PETERSON:

$$f(z) \propto \frac{1}{\left[z\left(1-\frac{1}{z}-\frac{\varepsilon}{(1-z)}\right)^2\right]}$$

Relative syst. uncertainties smaller for α, better description with

Kartevelishvili:

$$f(z) \propto z^{\alpha}(1-z)$$



Hadronisation correction performed bin by bin with:

$$d\sigma_{|data} = d\sigma^{NLO} \cdot \frac{d\sigma_{MC}^{hadrons}}{d\sigma_{MC}^{partons}}$$

The fragmentation variable *z* computed as:

$$z = (E+p_{//})^{D^*} / (E+p_{//})^{jet}$$

D mesons ($D^{\pm}$, D^0, $D_s^{\pm}$) in DIS

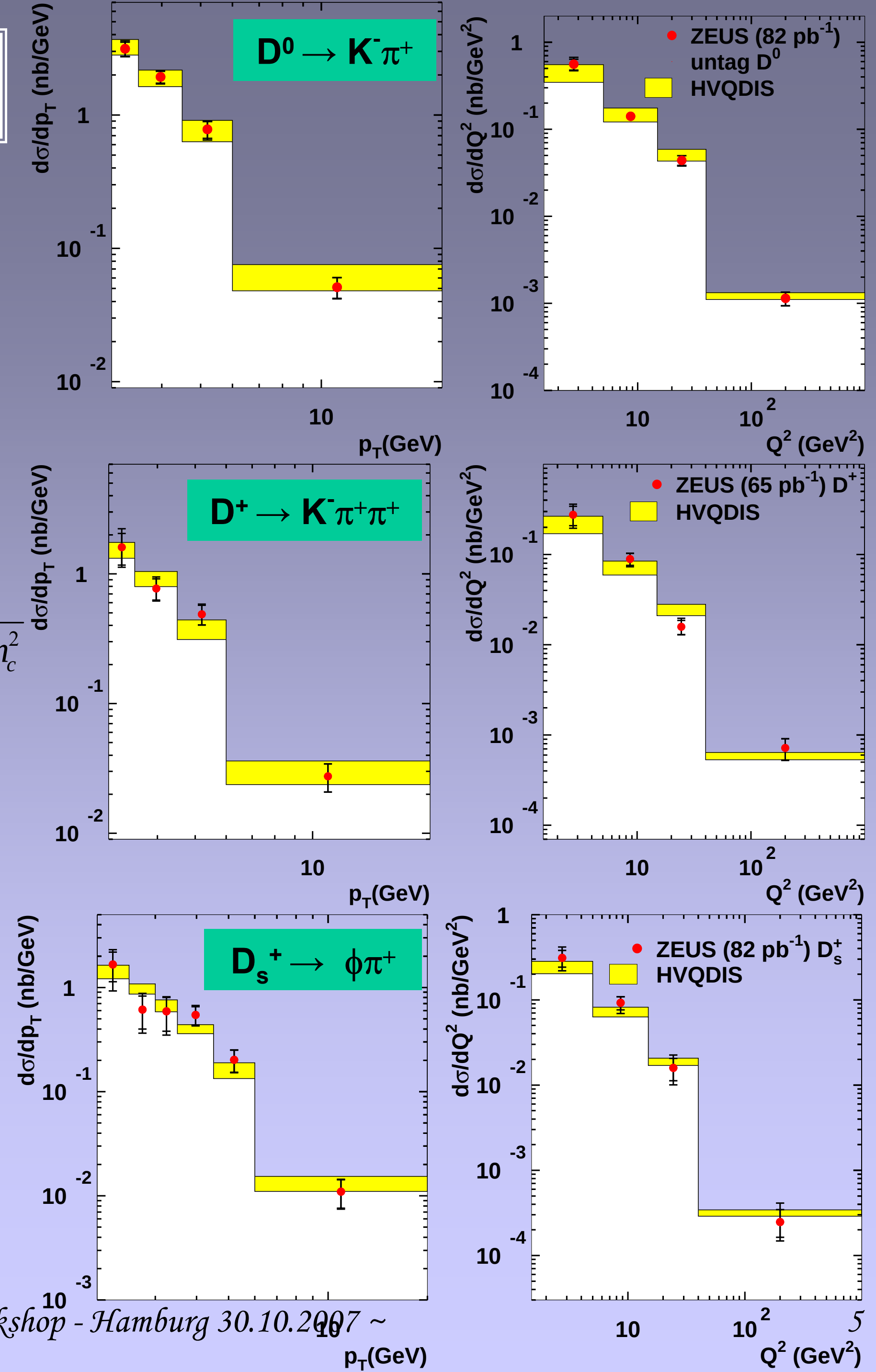
1998-2000 data, ~82 pb^{-1} $1.5 < Q^2 < 1000$ GeV^2

Data compared to

Theoretical predtion from HVQDIS:
NLO $c\bar{c}$ BGF + FFNS (lq, g evolving DGLAP, Zeus-NLO fit to F_2 for p PDF)

Peterson fragm. (ε =0.035, def. value)
Fragm fractions: the measured ones
m_c = 1.35 GeV, $\Lambda^{(3)}_{QCD}$ =363 MeV; $\mu_R = \mu_F = \sqrt{Q^2 + 4m_c^2}$

Measured: differential cross sections in Q^2, $P_T(D)$, $\eta(D)$ and x.



Main theoretical systematics:

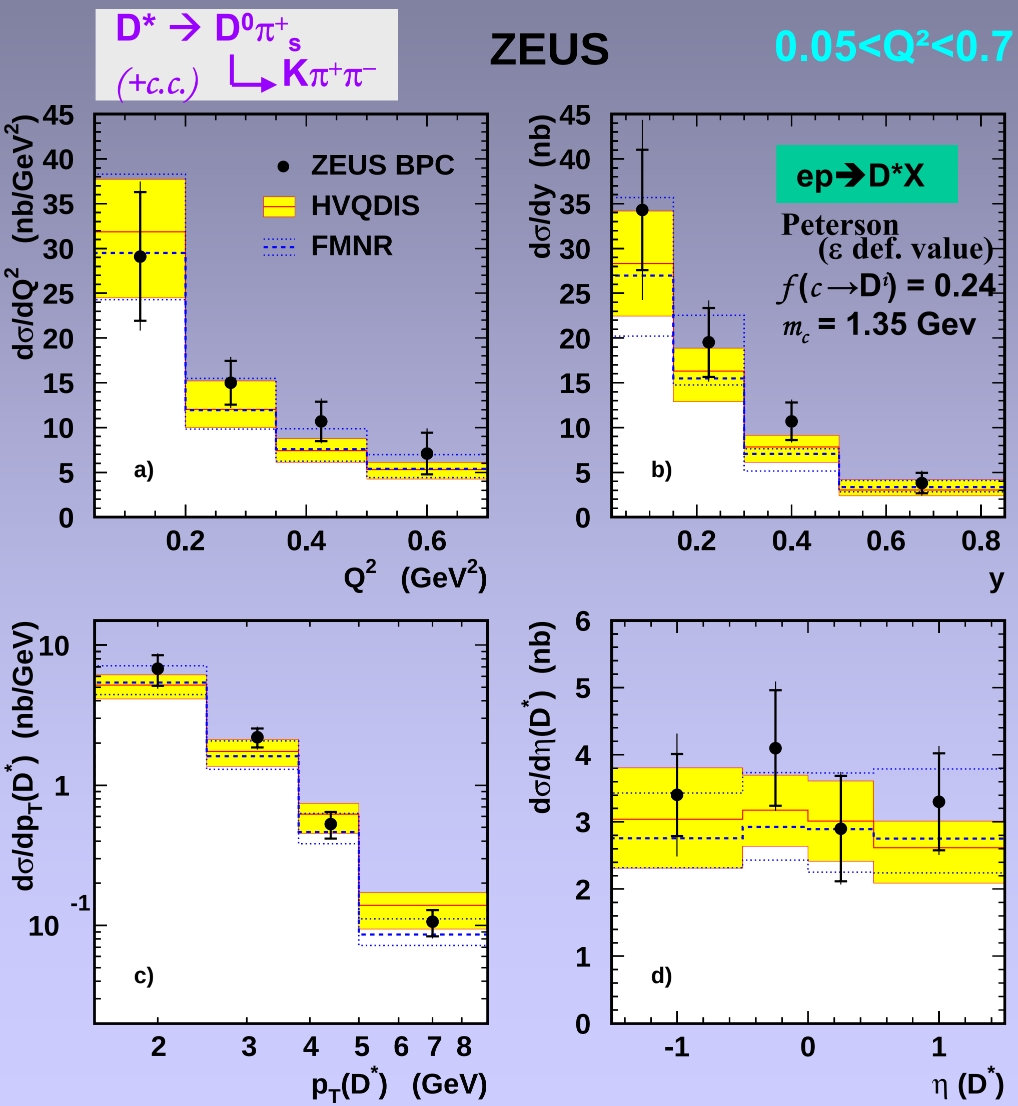
- PDF uncertainty
- Fragmentation models
- m_c

The overall agreement data-NLO calculations is good

→ cross sections used to extract F_2^{cc}

D*± Mesons at low Q2

Using low-angle calorimeter, extend measurements to low Q²



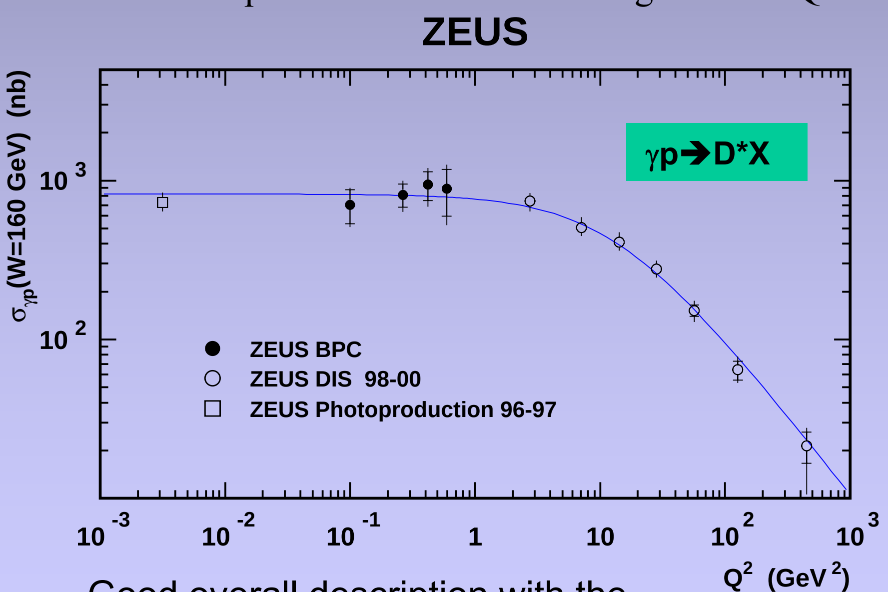
$\sigma(ep \rightarrow e D^* X)$ measurements compared with two different NLO QCD calculation:

- **FMNR** designed for PHP $\mu_R = \mu_F = \sqrt{\langle p_T \rangle^2 + 4m_c^2}$
- **HVQDIS** for DIS (no hadron-like structure for the γ) $\mu_R = \mu_F = \sqrt{Q^2 + 4m_c^2}$

Agreement with both the predictions

Results combined with the previous DIS and photoproduction measurements

ZEUS data spread over ~5 order of magnitude in Q²



Good overall description with the parameterisation: $\sigma(Q^2) = \sigma_{PHP} * M^2/(Q^2+M^2)$

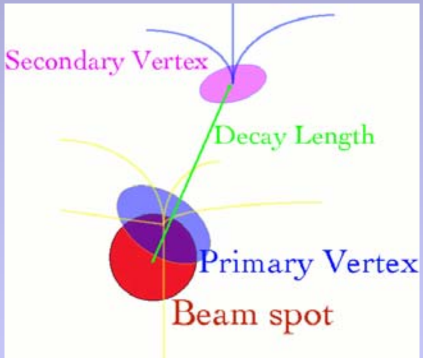
$\sigma^0_{PHP} = 823 \pm 63$ nb; $M^2 = 13 \pm 2$ GeV² ($\cong 4m_c^2$)

Not only 'old' data: D^0, D^+ at HERA II

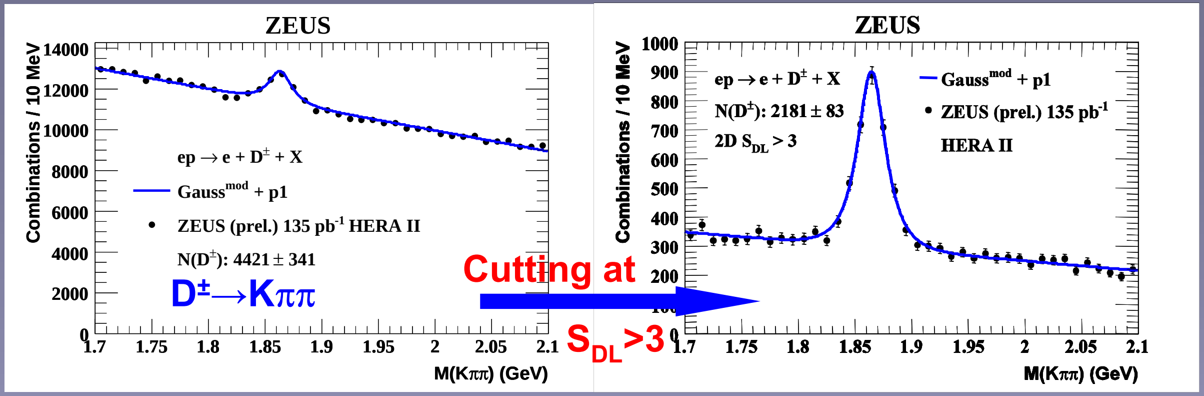
~135 pb^{-1}, 2005 data

Major upgrade: inner Si tracking system → great improvement of the tracking performances, allowing:

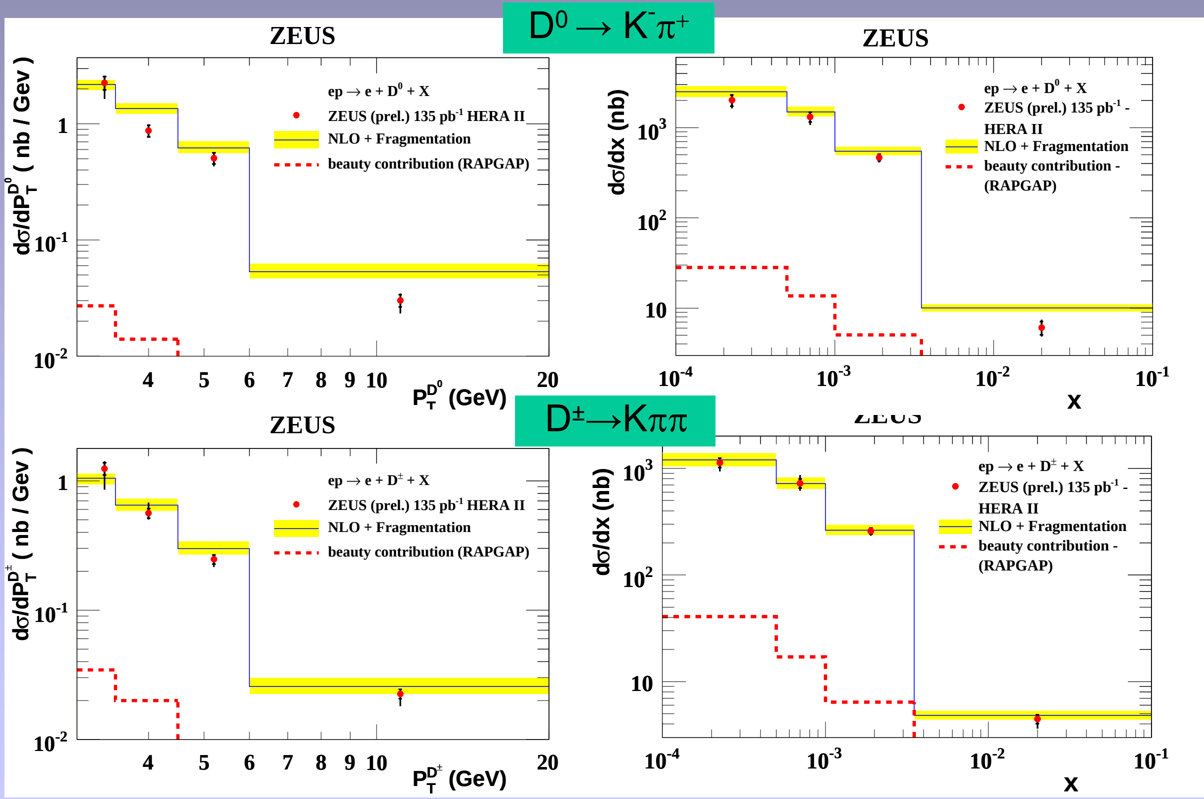
- Analysis based mainly on the tracking techniques (Impact Parameter, Decay Length.)
- Signals with high purity (~90%)



Long lived D mesons have a displaced SV which can be reconstructed by the MVD.

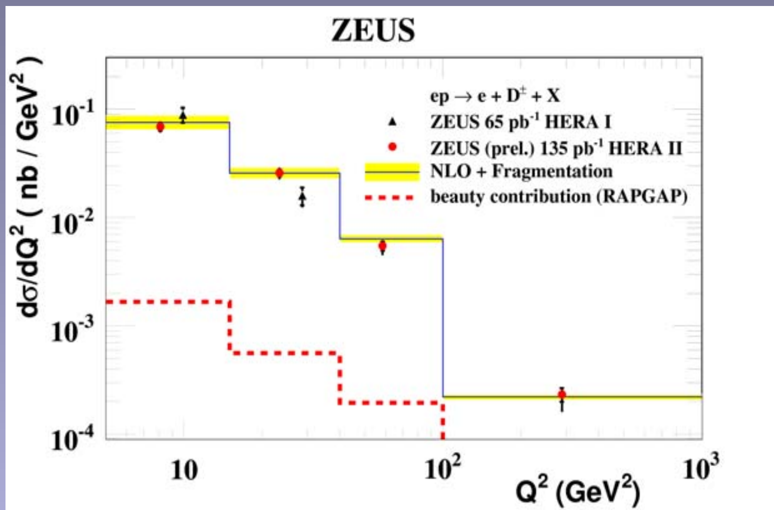


the statistical error goes from 7.7% to 3.8%

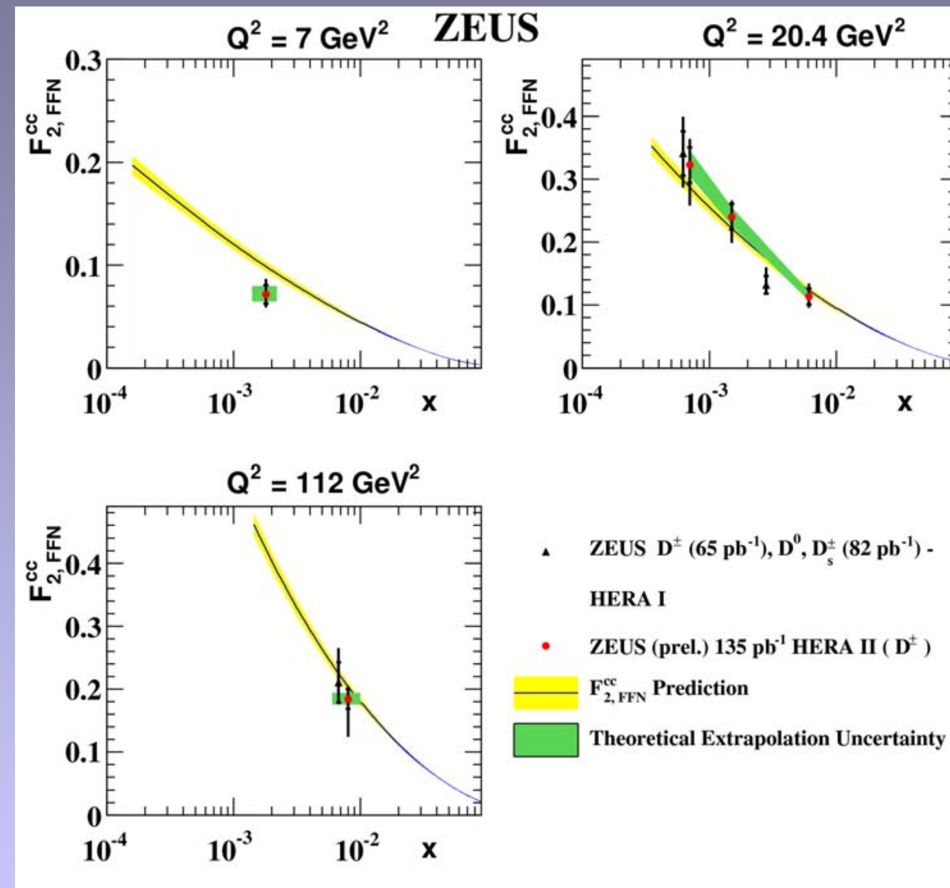


Fair agreement with NLO; F_2^{cc} extraction →

F_2^{cc} in bins of Q^2



Error reduced with respect to the previous HERAI measurement.



Precision comparable to that of the HERAI measurement with three mesons.

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

Golden mode: can be double tagged by the slow pion and the D^0 in the final state.

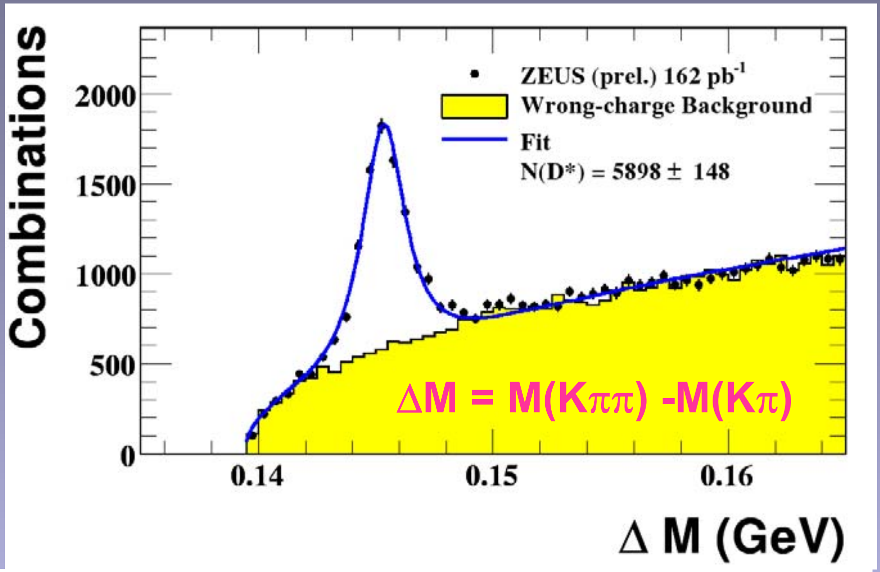
Kinematic region:

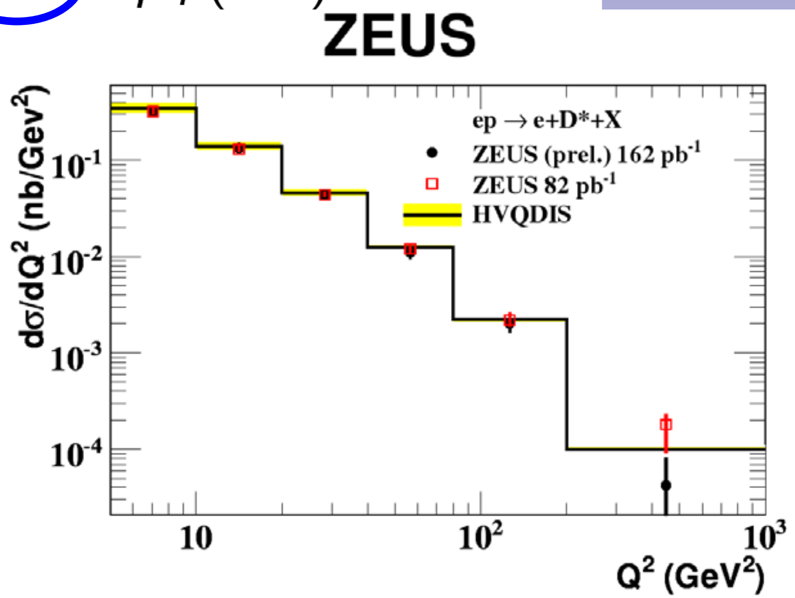
$5 < Q^2 < 1000\ \text{GeV}^2$

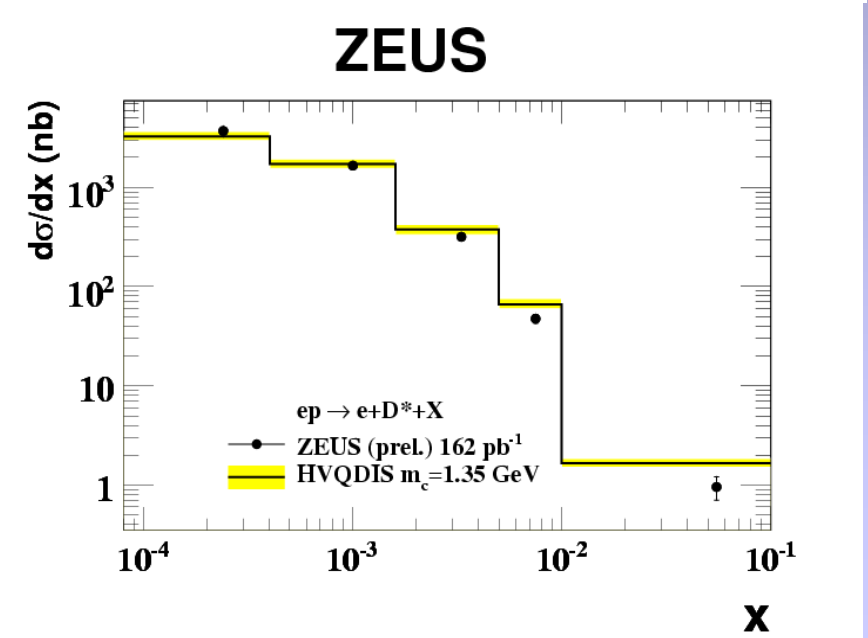
$0.02 < y < 0.7$

$|\eta(D*)| < 1.5$

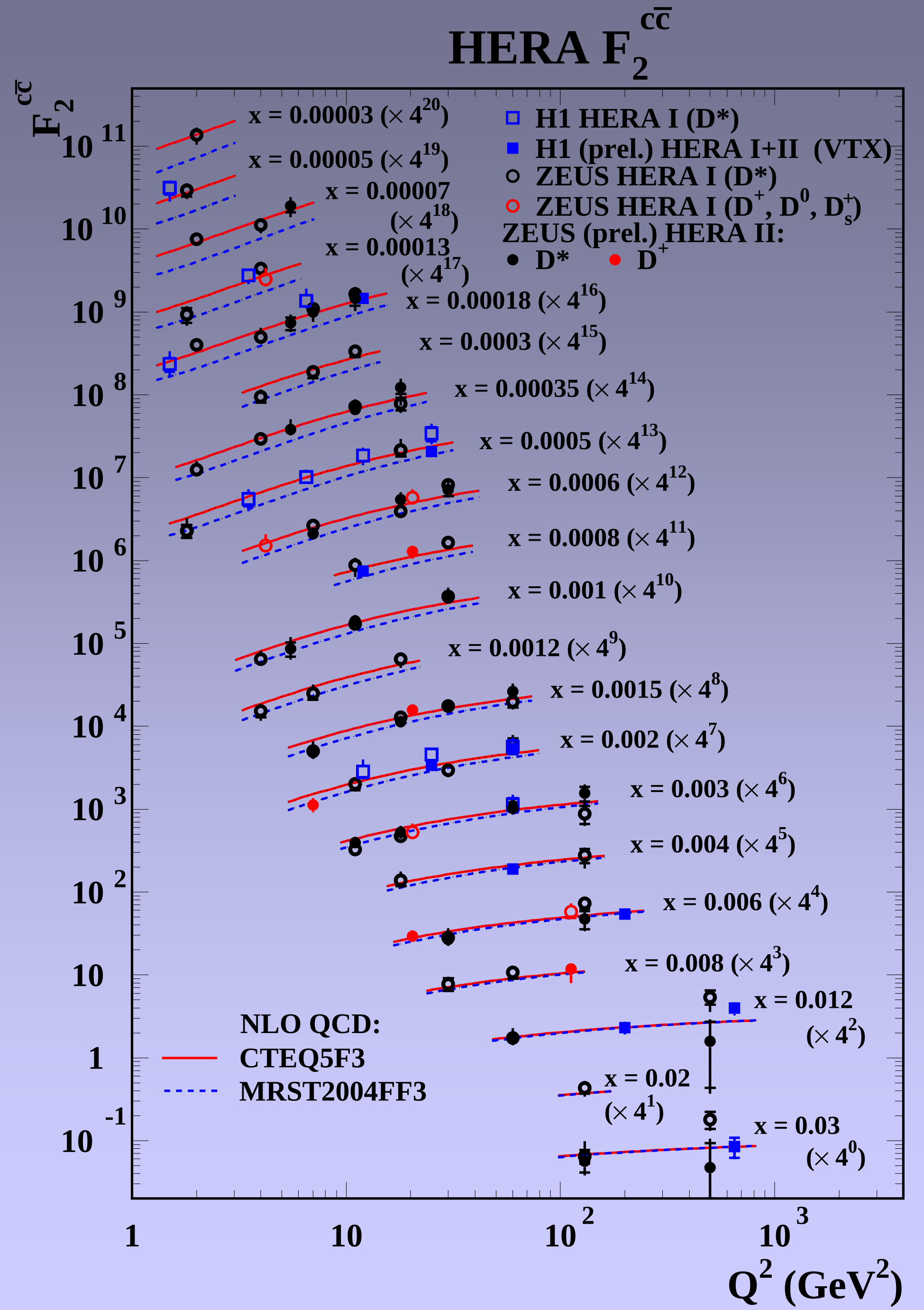
$1.5 < p_T(D*) < 15\ \text{GeV}$







Merging all the measurements



Nice agreement with the theoretical predictions (*pdf*'s coming from inclusive measurements!)

Conclusions

- Charm physics provides a lot of food for thought;
- ZEUS is extensively studying this sector: several results coming out;
- Precision competitive with other experiments (and further enhancing with new tracking tools);
- Much more to come with the new data and full statistics analysis.

BACKUP SLIDES

Theoretical models: NLO QCD

- Massive approach (Fixed Flavour Number Scheme)
- *(PHP: S. Frixione et al, FMNR, DIS: Harris and Smith, HVQDIS)*:
- heavy quark has mass, most appropriate for $Q^2 \sim M_Q^2$;
- number of active flavours in the proton is 3 (u,d,s);
- c and b are produced perturbatively in the hard subprocess;
- If $Q^2 >> M_Q^2$, large $\ln(Q^2/M_Q^2)$ appear.

Massless approach:

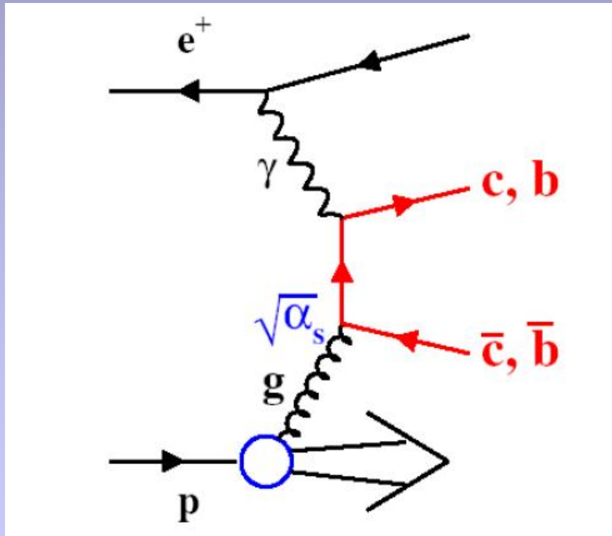
(B. Kniehl et al.)

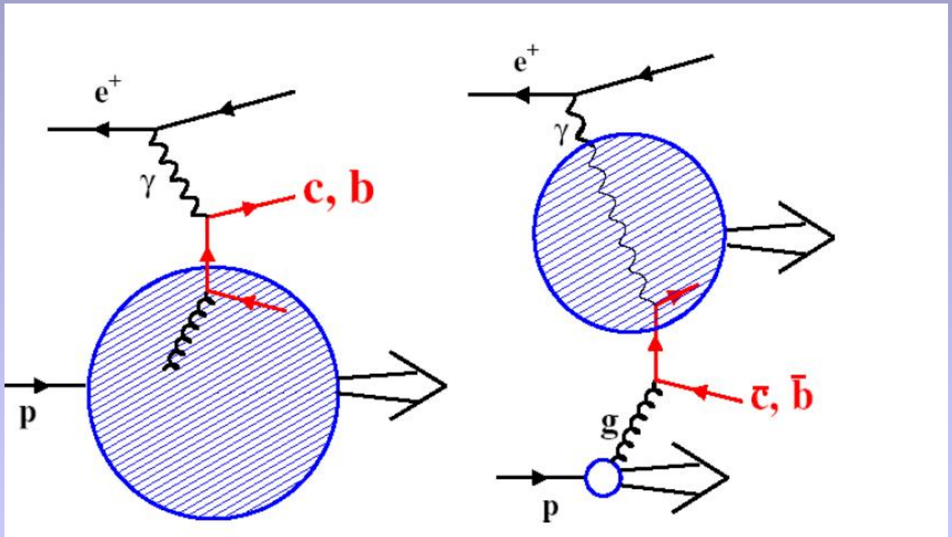
- heavy flavour masses are neglected, resummation is valid for $Q^2 >> M_Q^2$;
- number of flavours increases across threshold, HQ densities are zero below threshold.

Combined approach *(M. Cacciari et al.)*

Theoretical models: NLO QCD (cont'd)

- Variable Flavour Number Scheme:
- combines massive and massless approach;
- massive approach around threshold ($Q^2 \sim M_Q^2$), resummation of $\ln(Q^2/M_Q^2)$ at large Q^2.





D mesons ($D^{\pm}$, D^0, $D^{*\pm}$, $D_s^{\pm}$) in DIS

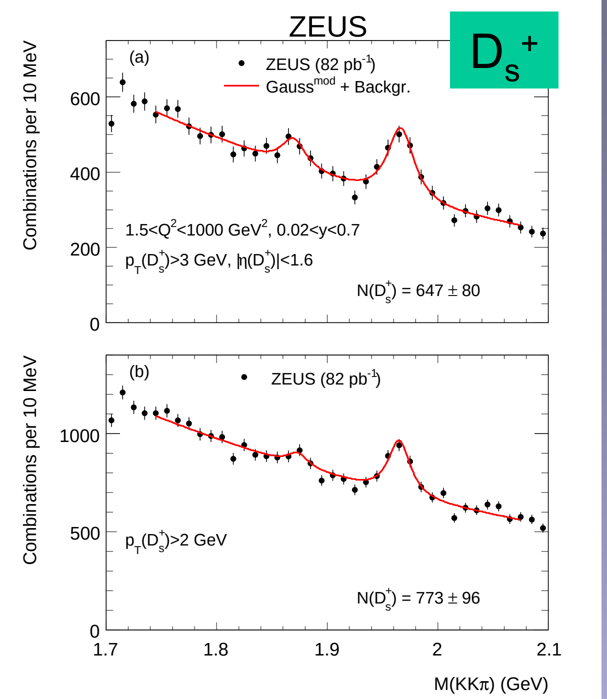
PS
- $D^0 \to K^- \pi^+$
- $D^+ \to K^- \pi^+ \pi^+$ + c.c.
- $D_s^+ \to \phi \pi^+ \to K^+ K^- \pi^+$

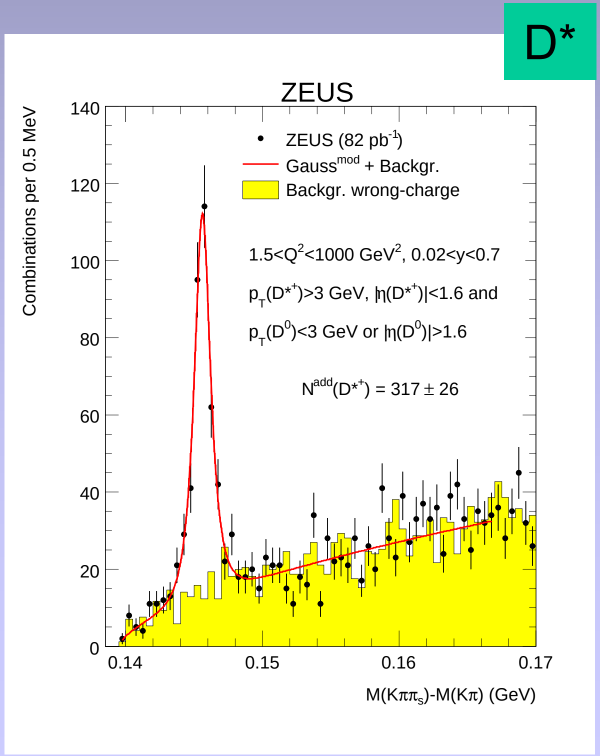
V
- $D^{*+} \to D^0 \pi^+ \to K^- \pi^+ \pi_s^+$

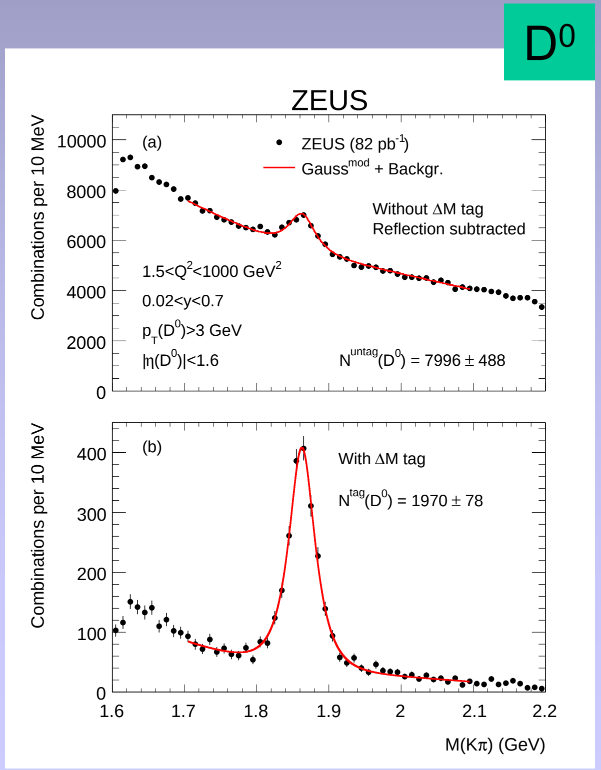
($\Lambda_c^+ \to K^- p \pi^+$ ~3σ, not used)

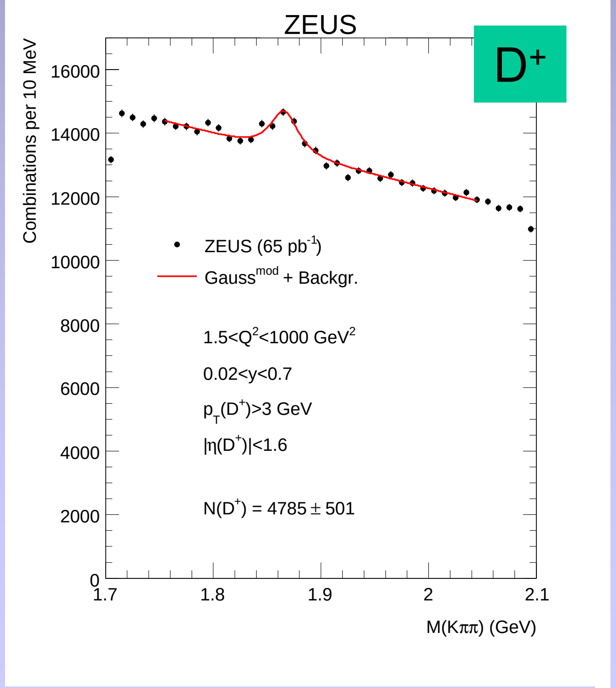
1998-2000 data, ~82 pb^{-1}

- $E(e^-) > 10$ GeV
- $1.5 < Q^2_{e\Sigma} < 1000$ GeV^2
- $40 < \Sigma_{hadr}(E-p_z) < 65$ GeV
- $y_{JB} > 0.02$ & $y_{el} < 0.95$
- $|Z_{vertex}| < 50$ cm
- |boxcut_x| < 12 cm; |boxcut_y| < 7 cm

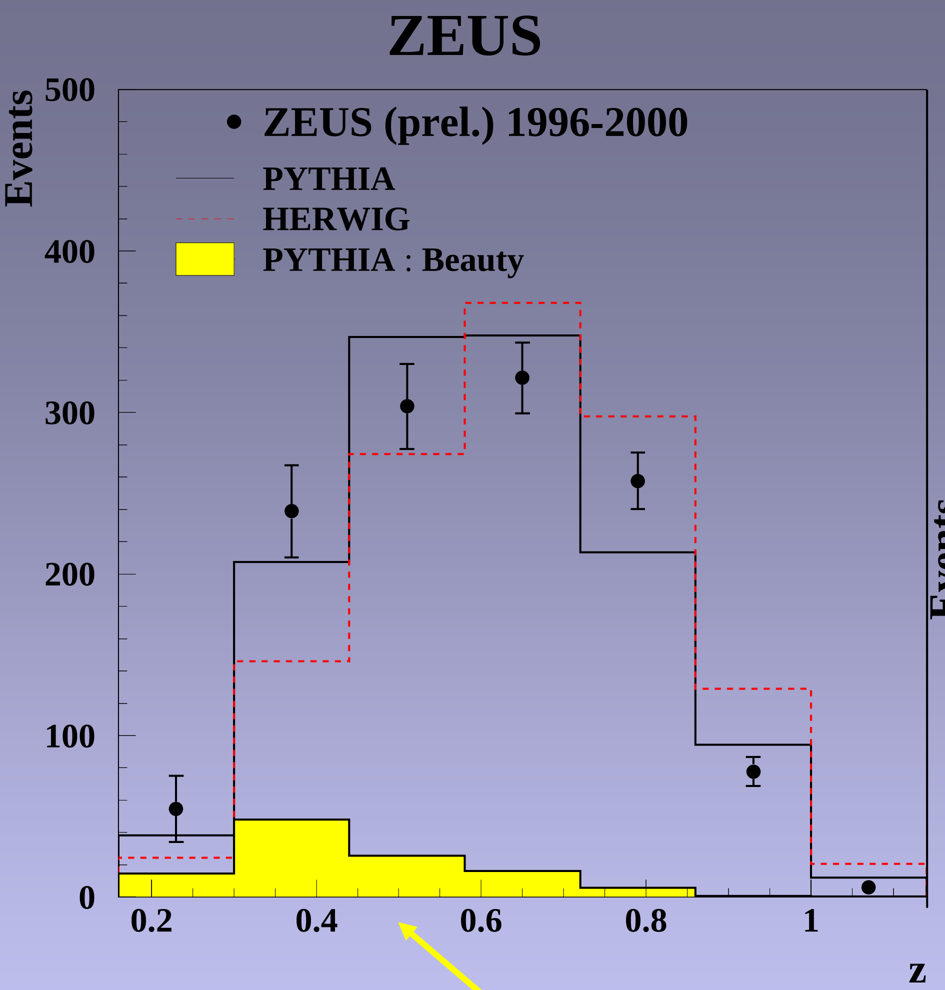




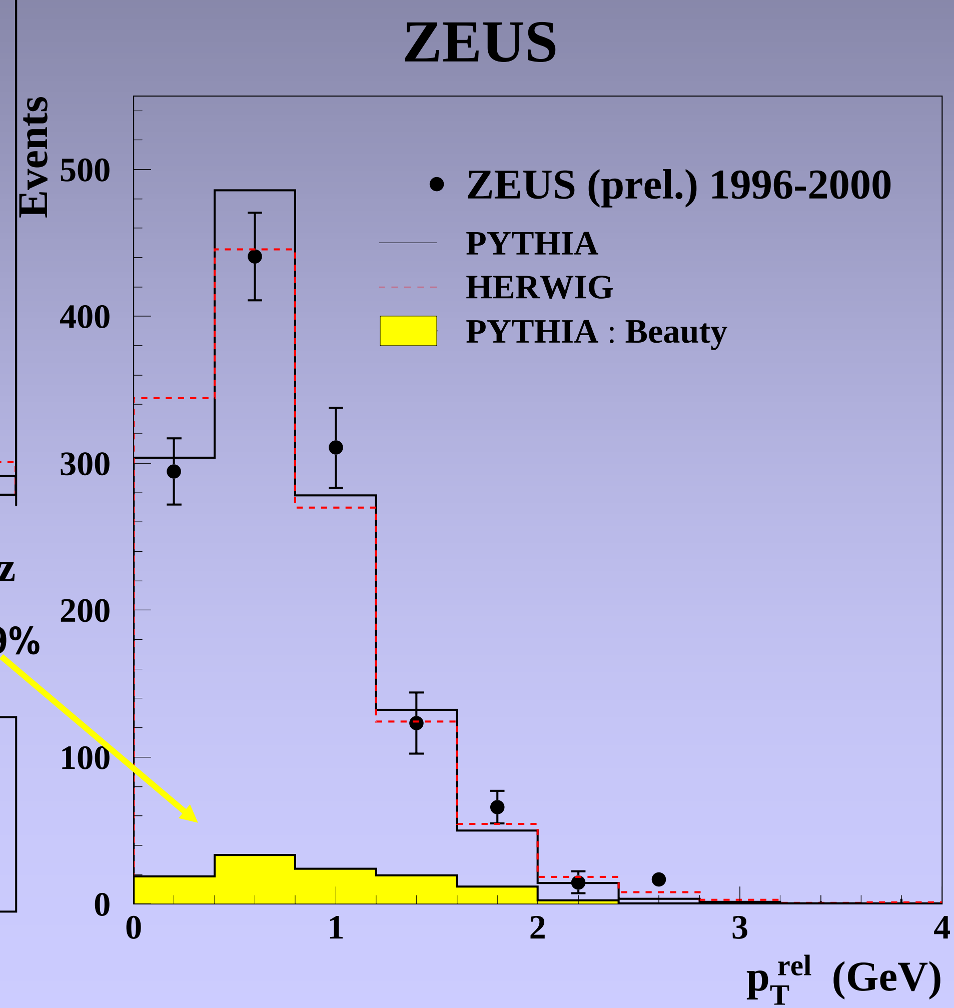




PYTHIA: Lund 'String' model
HERWIG: Cluster hadroniz.



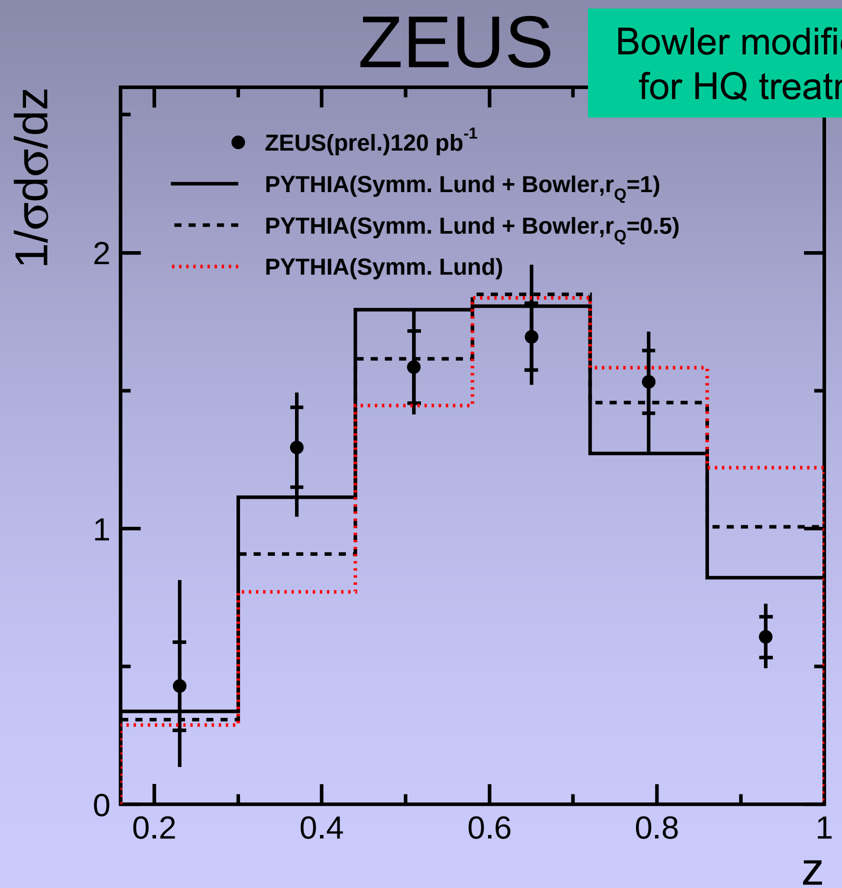
Beauty contamination ~9%



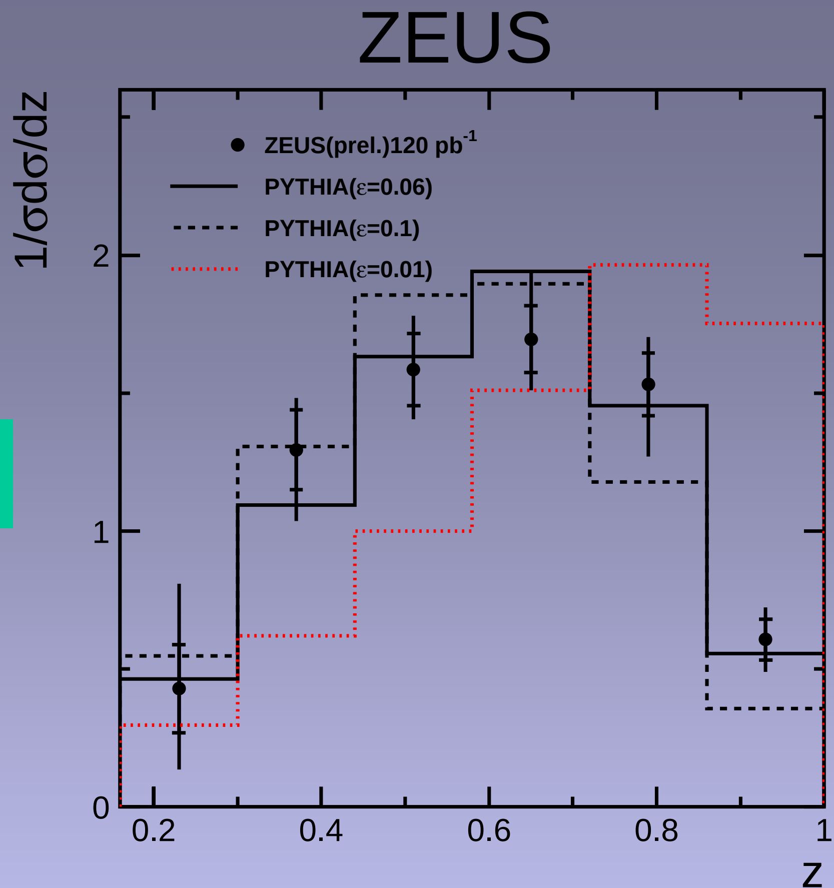
PYTHIA better agreement
→ taken for systematics and detector effic. corrections

(LUND)

$$f(z) \propto \frac{1}{z^{1+r_Q b m_Q^2}} (1-z)^a e^{(-\frac{b m_\perp^2}{z})}$$



Bowler modification for HQ treatment



$$f(z) \propto \frac{1}{[z(1-1/z-\varepsilon/(1-z))^2]}$$

(PETERSON)

Best value (χ^2min):
$\varepsilon=0.0595\pm0.0078$
(default value 0.05)

Data corrected for reconstruction accept., efficiency, migrations

RAPGAP MC+ Heracles (1° ord. EW correction) LO ME +LL PS (Lund); CTEQ5L (p) and GRV-LO(γ) PDF

HVQDIS: NLO $c\bar{c}$ BGF + FFNS (lq, g evolving DGLAP, Zeus NLO fit to F_2 for p PDF)

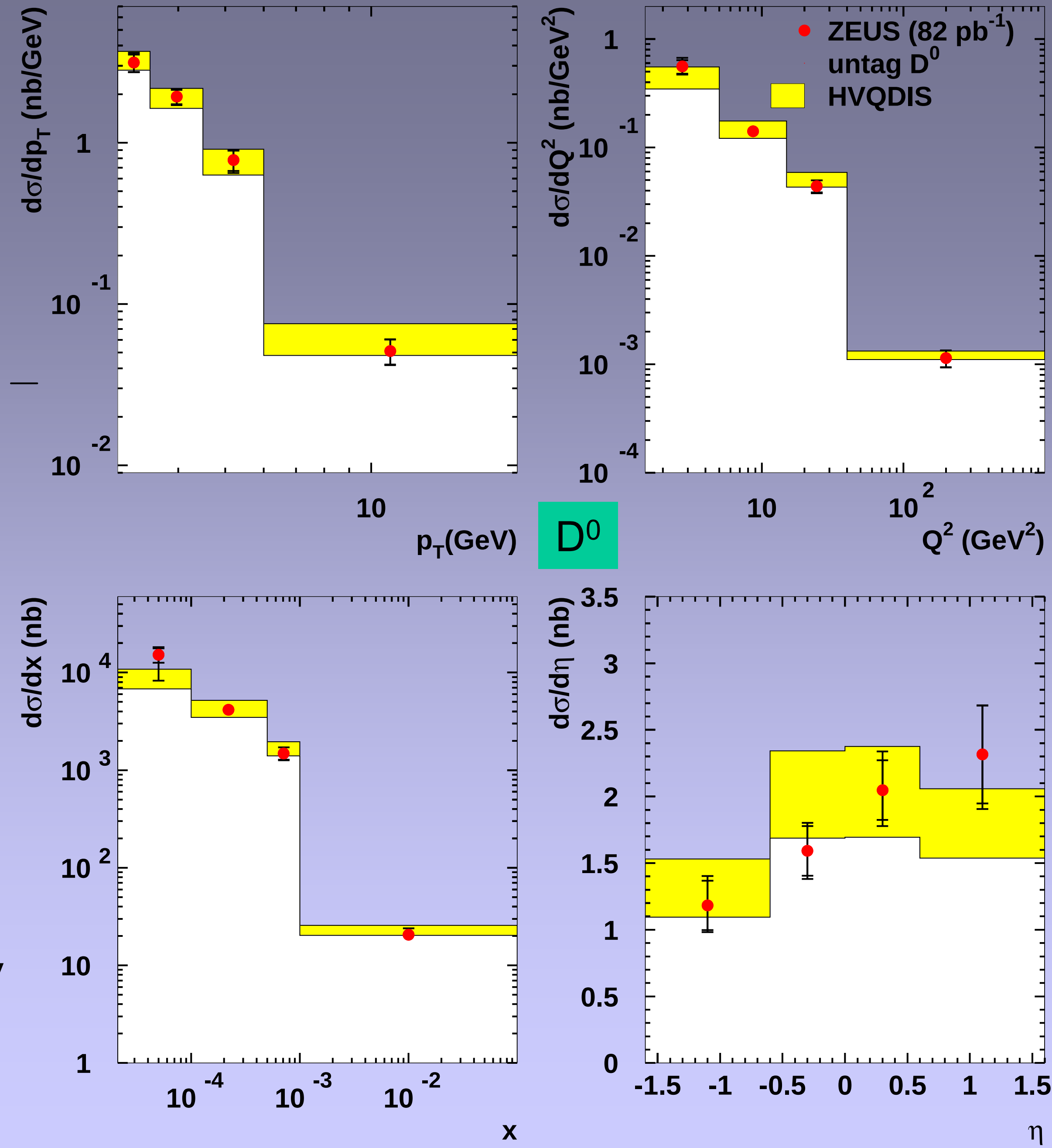
Lund string fragment.
(ε =0.035, def. value)

Fragm fractions: the measured ones

m_c = 1.35 GeV, Λ_{QCD} =363 MeV

$$\mu_R = \mu_F = \sqrt{Q^2 + 4m_c^2}$$

J/ψ negligible



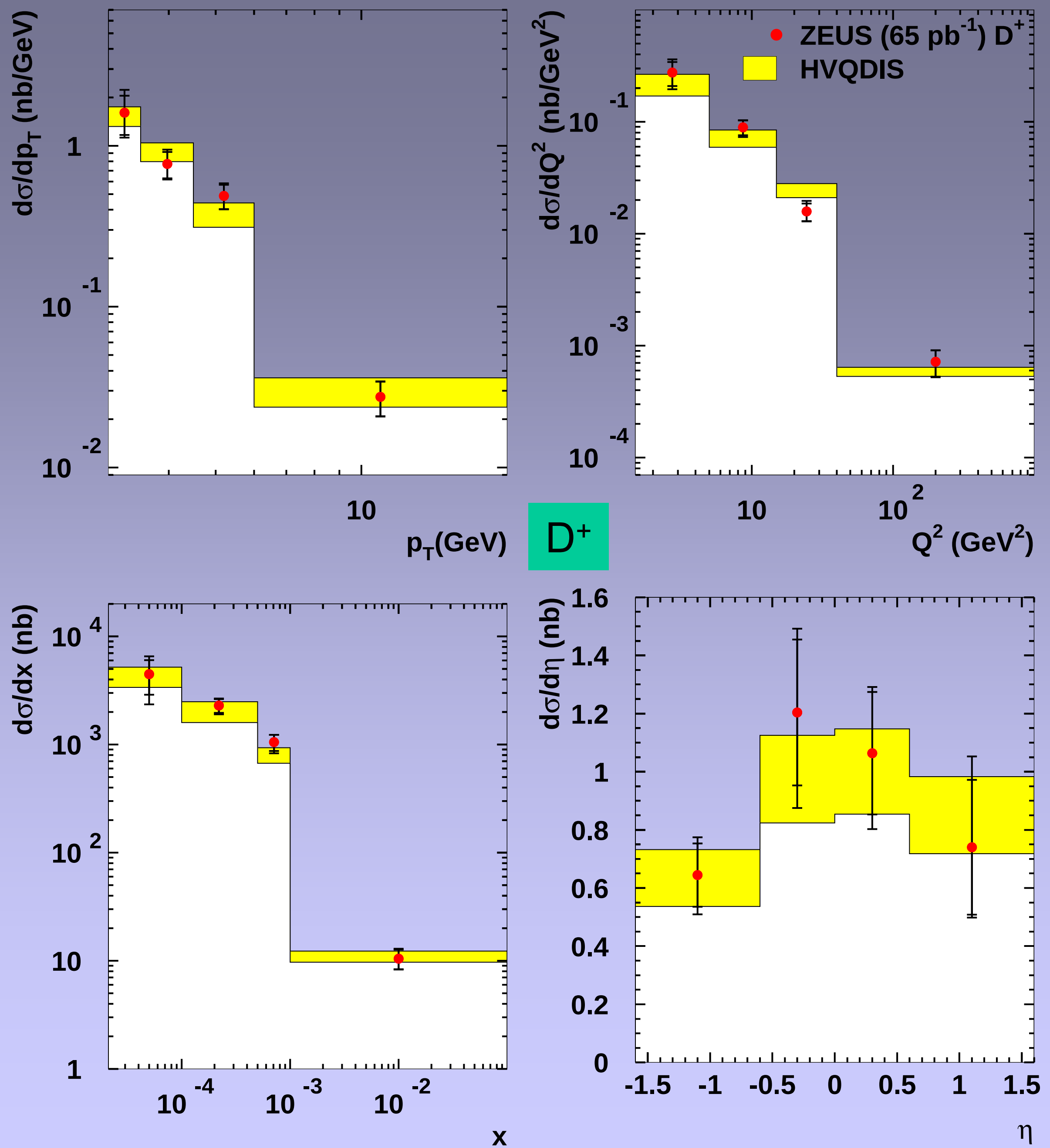
Main systematic uncertainties:

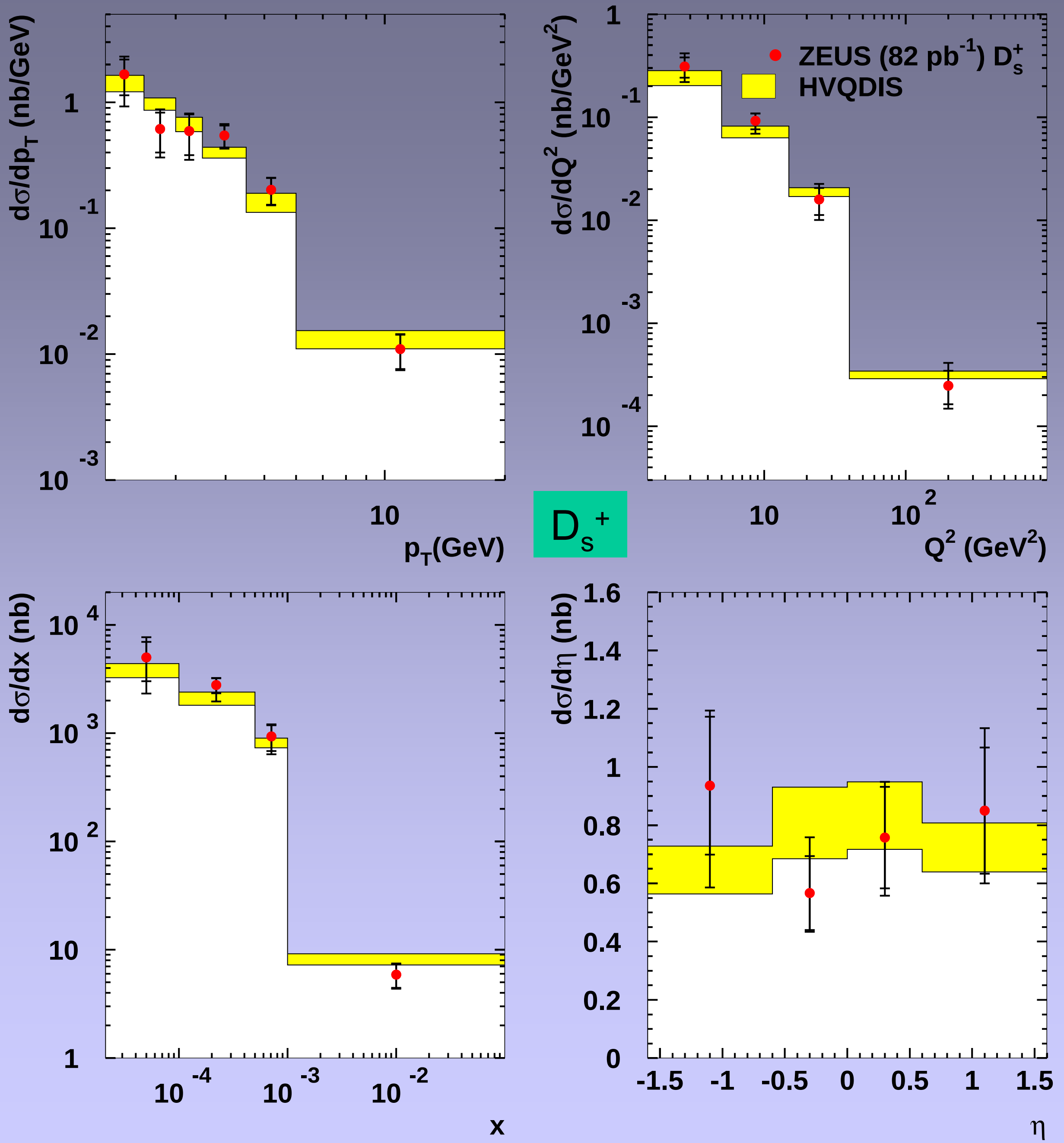
EXP.

- Beauty contribution subtraction
- signal extraction procedures
- $\sigma(\Lambda_c)$ estimation
- CAL energy scale
- Luminosity meas.

TH.

- Fragmentation models
- m_c
- PDF uncertainty





ZEUS (82 pb-1) D+s
HVQDIS
dσ/dpT (nb/GeV)
pT(GeV)
dσ/dQ2 (nb/GeV2)
Q2 (GeV2)
D+s
dσ/dx (nb)
x
dσ/dη (nb)
η