

Heavy Quark Results from HERA

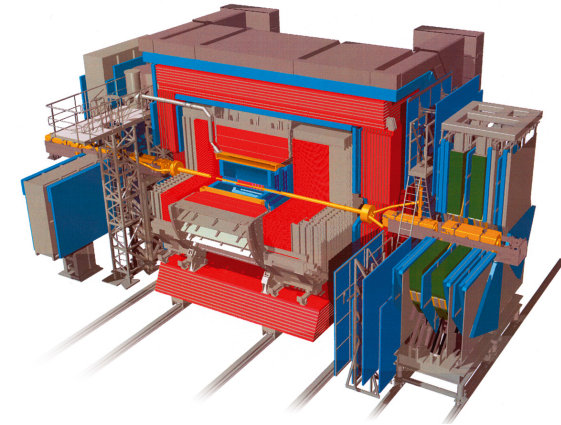
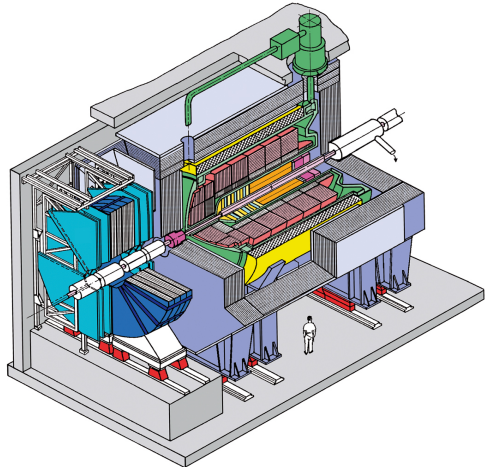


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for the H1 and ZEUS Collaborations

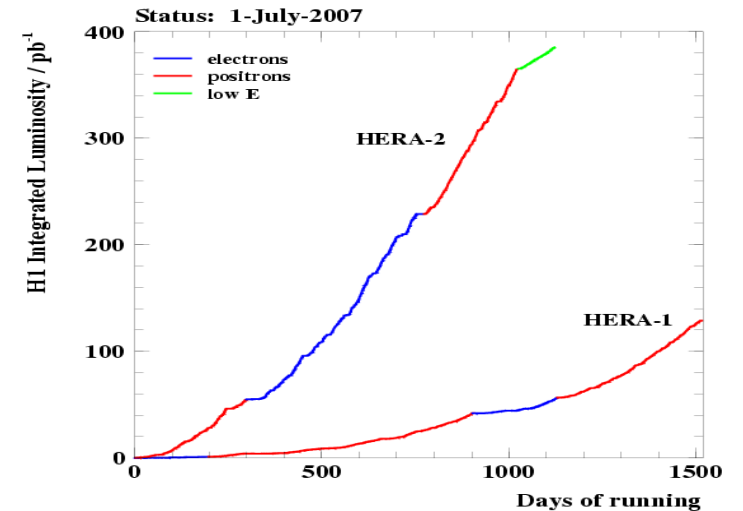


- Introduction
- Open charm results
- Open beauty measurements
- Structure Functions $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$
- Conclusion

HERA



- $27.5 \text{ GeV } e \text{ } 920 \text{ GeV } p \longrightarrow \sqrt{s} = 318 \text{ GeV}$
- HERAI: 1992-2000 and HERAII: 2003-2007
- $\sim 0.5 \text{ fb}^{-1}$ per experiment



Production of Heavy Quarks

predominantly via boson
gluon fusion

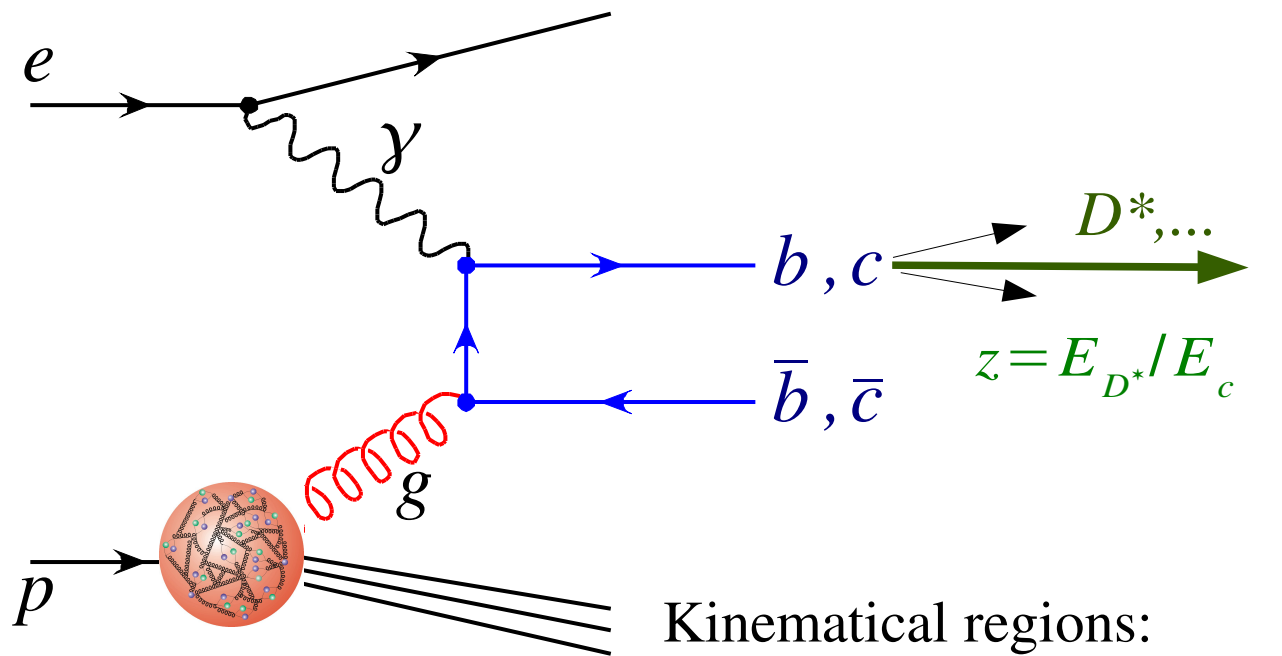
large quark mass allows
pQCD calculations

directly sensitive to gluon
density in the proton

QCD factorisation:

$$\sigma_{D^*} \propto f_{g/p} \otimes \hat{\sigma} \otimes D_c^{D^*}(z)$$

parton density function
(non-perturbative)
parton scattering cross
section (perturbative)
fragmentation function
(non-perturbative)



Photoproduction (γp) ($Q^2 \lesssim 1 \text{ GeV}^2$)

Electroproduction (DIS) ($Q^2 \gtrsim 1 \text{ GeV}^2$)

$$z = E_{D^*} / E_c$$

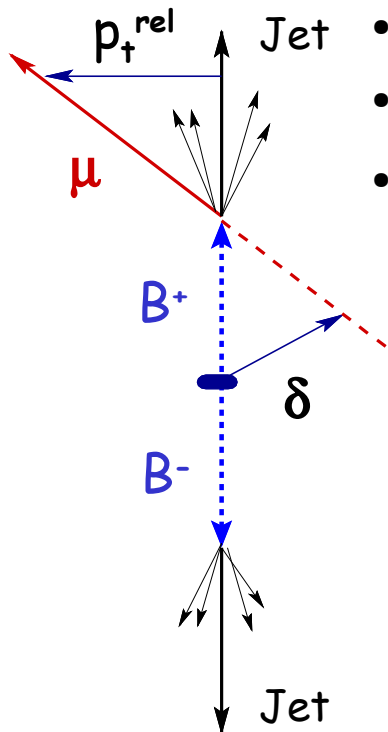
Methods for Heavy Flavour Tagging

Meson identification:

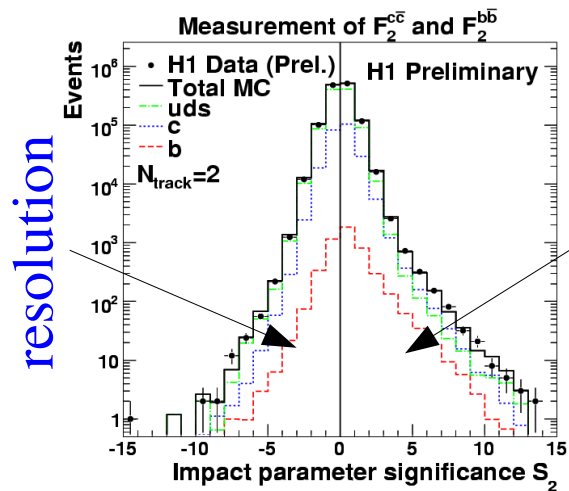
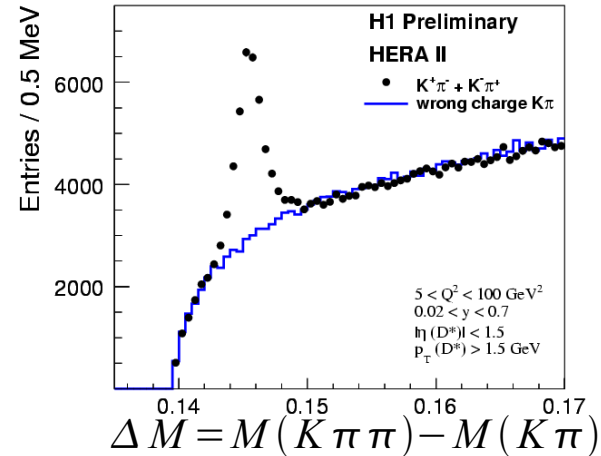
- Full reconstruction from decay tracks:

$$D^{*+/-} \rightarrow D^0 \pi_s^{+/-} \rightarrow (K^{-/+} \pi^{+/-}) \pi_s^{+/-}$$

Mass/Lifetime tag:

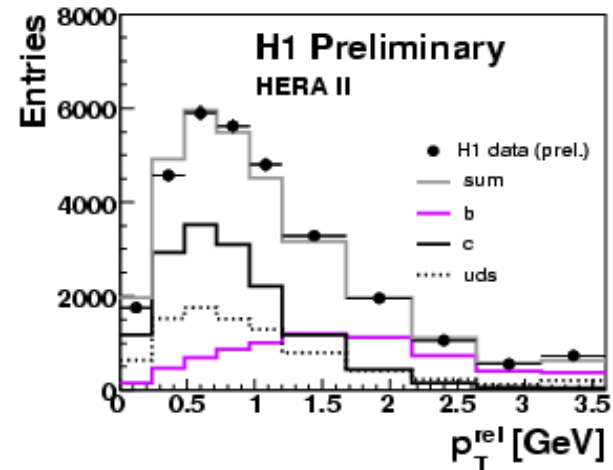


- Reconstruct secondary vertex
- Impact parameter significance: $S = \delta / \sigma(\delta)$, fit subtracted distributions
- p_t^{rel} in leptonic decays



resolution

res. & lifetime



Models of Heavy Quark Production

NLO calculation:

- **HVQDIS (DIS)**: fixed order, massive scheme (FFNS)
- **FMNR(γp)**: similar as HVQDIS, for photoproduction
- Independent fragmentation for heavy hadrons

Monte-Carlo: LO + Parton Shower:

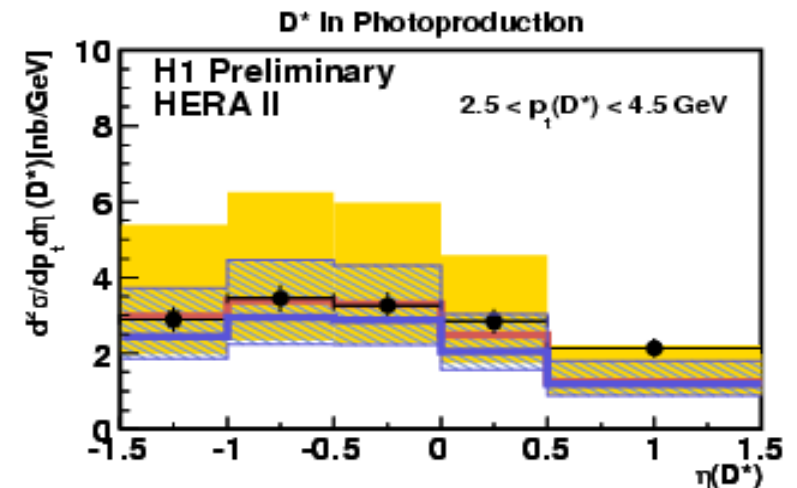
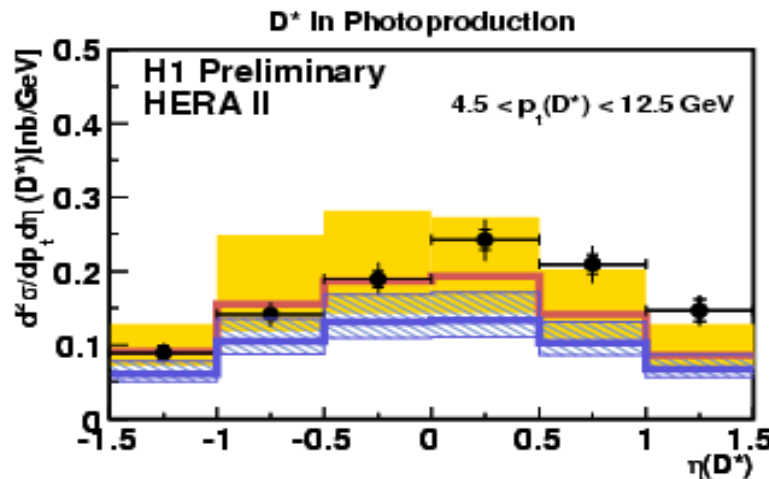
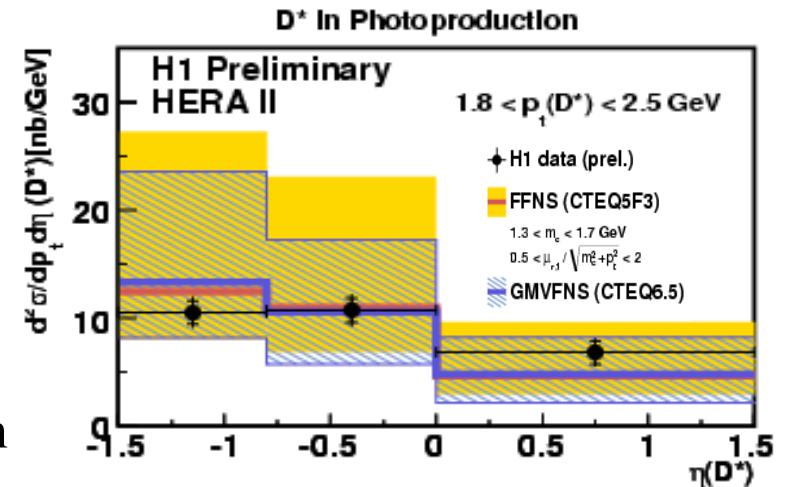
- **CASCADE(DIS, γp)**: k_T factorisation, CCFM evolution
- **RAPGAP(DIS)**: collinear factorisation, DGLAP evolution
- **PYTHIA(γp)**: similar as RAPGAP, for photoproduction
- Standard fragmentation: Lund String

Used PDFs

- From **CTEQ** and **MRST** collaborations
- Extracted from different inclusive measurements

D* Meson Cross Sections (γp)

- H1: HERA II data end 06-07, 93pb^{-1}
- Agreement with NLO QCD in double differential ($p_T(D^*), \eta(D^*)$) distributions
- High $p_T(D^*)$: GMVFNS undershoots forward η
- Large theory uncertainties due to scale variation



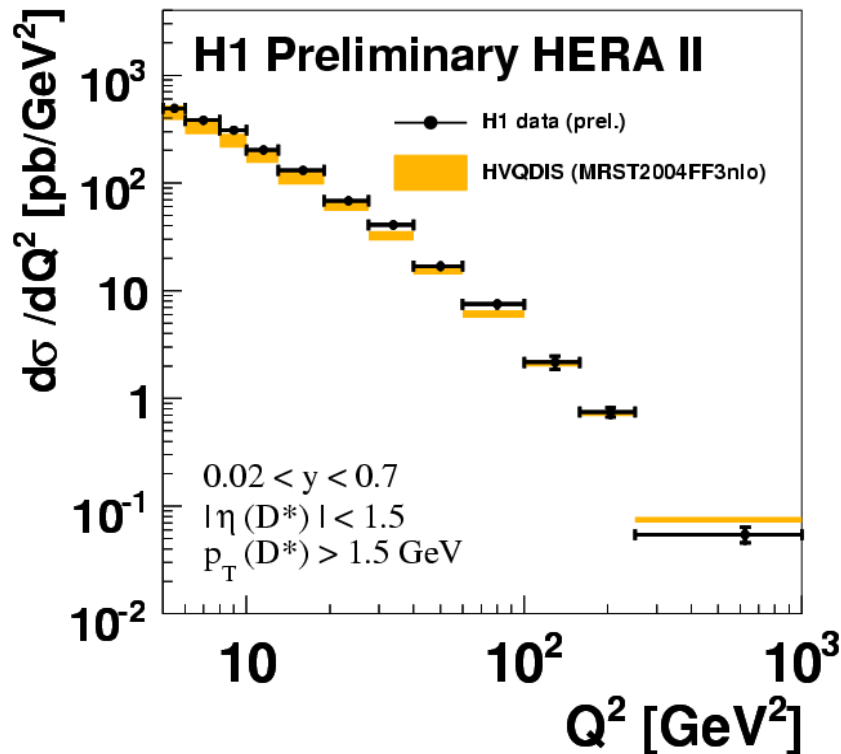
H1prelim-08-073

D* Meson Cross Sections ($d\sigma/dQ^2$)

H1prelim-08-072

H1prelim-08-074

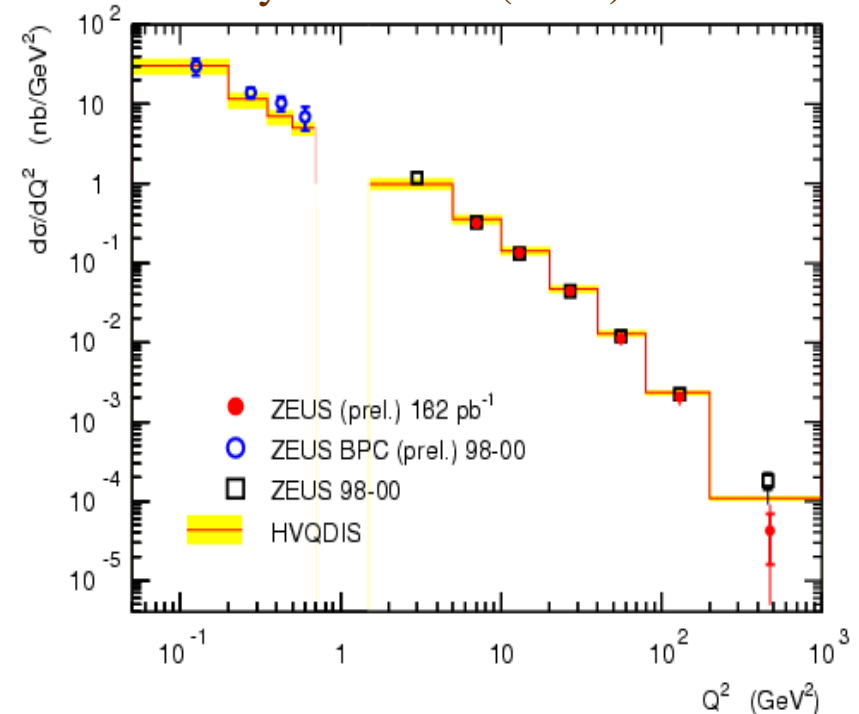
D* production in DIS



Phys.Lett.B649 (2007) 111

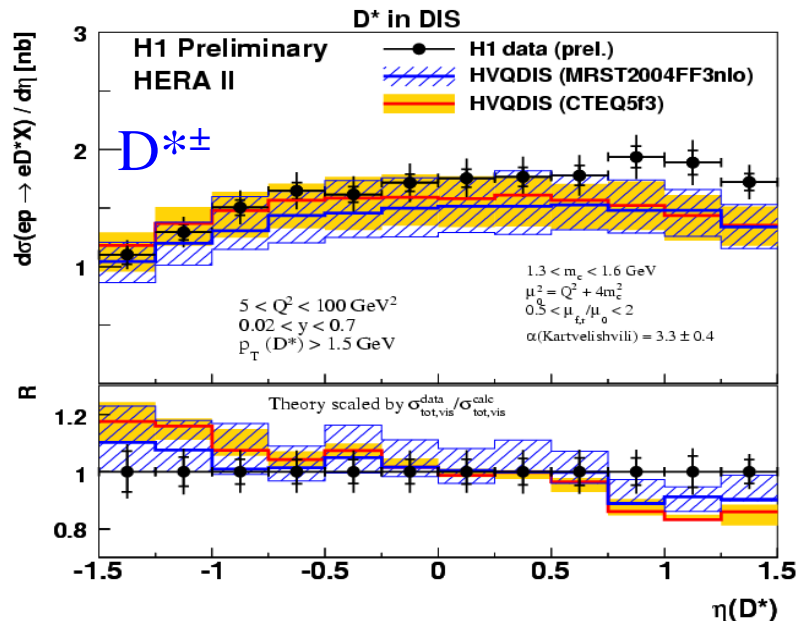
ZEUS-prel-06-021

Phys.Rev.D69 (2004) 012004

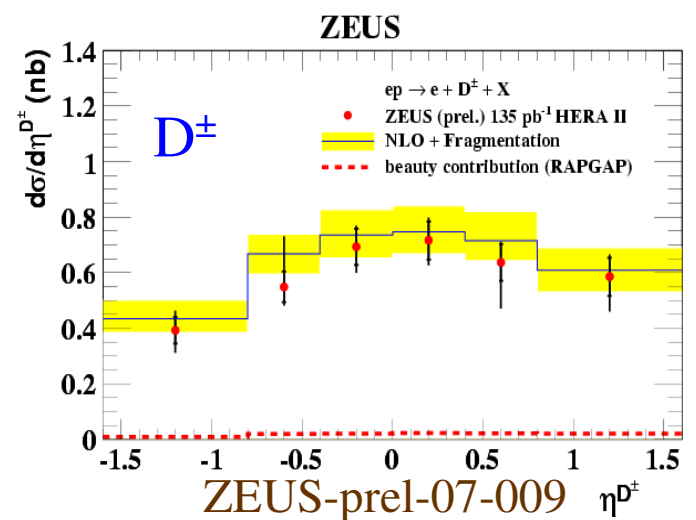
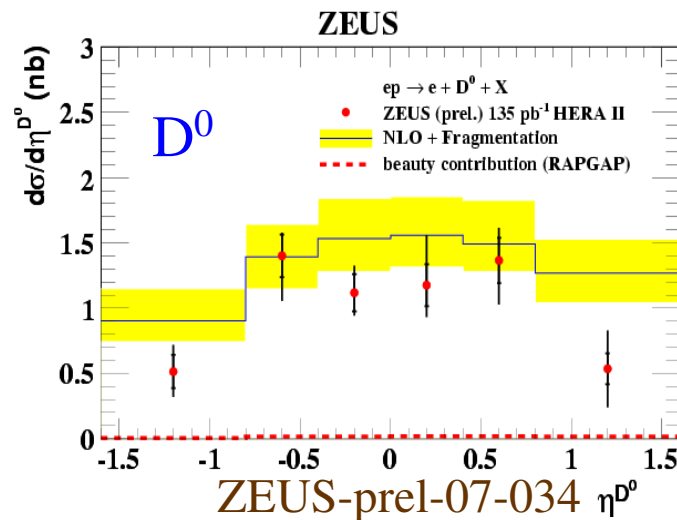
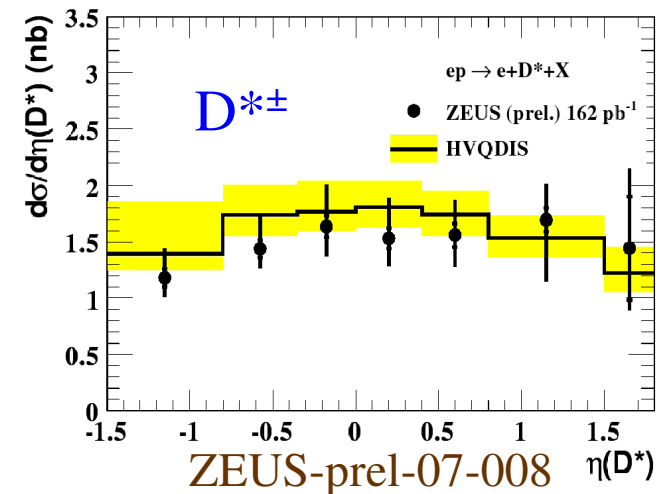


- Full HERA II statistics (~ 350 pb⁻¹)
- Very low Q^2 region accessed at ZEUS
- Good description by NLO calculation (HVQDIS) in full measured Q^2 range

D Meson Cross Sections (DIS)



- Cross sections of D - mesons measured
- Reasonably well described by HVQDIS
- Double differential cross section in x and Q^2 allows extraction of $F_2^{c\bar{c}}$



Measurements of $F_2^{c\bar{c}}$

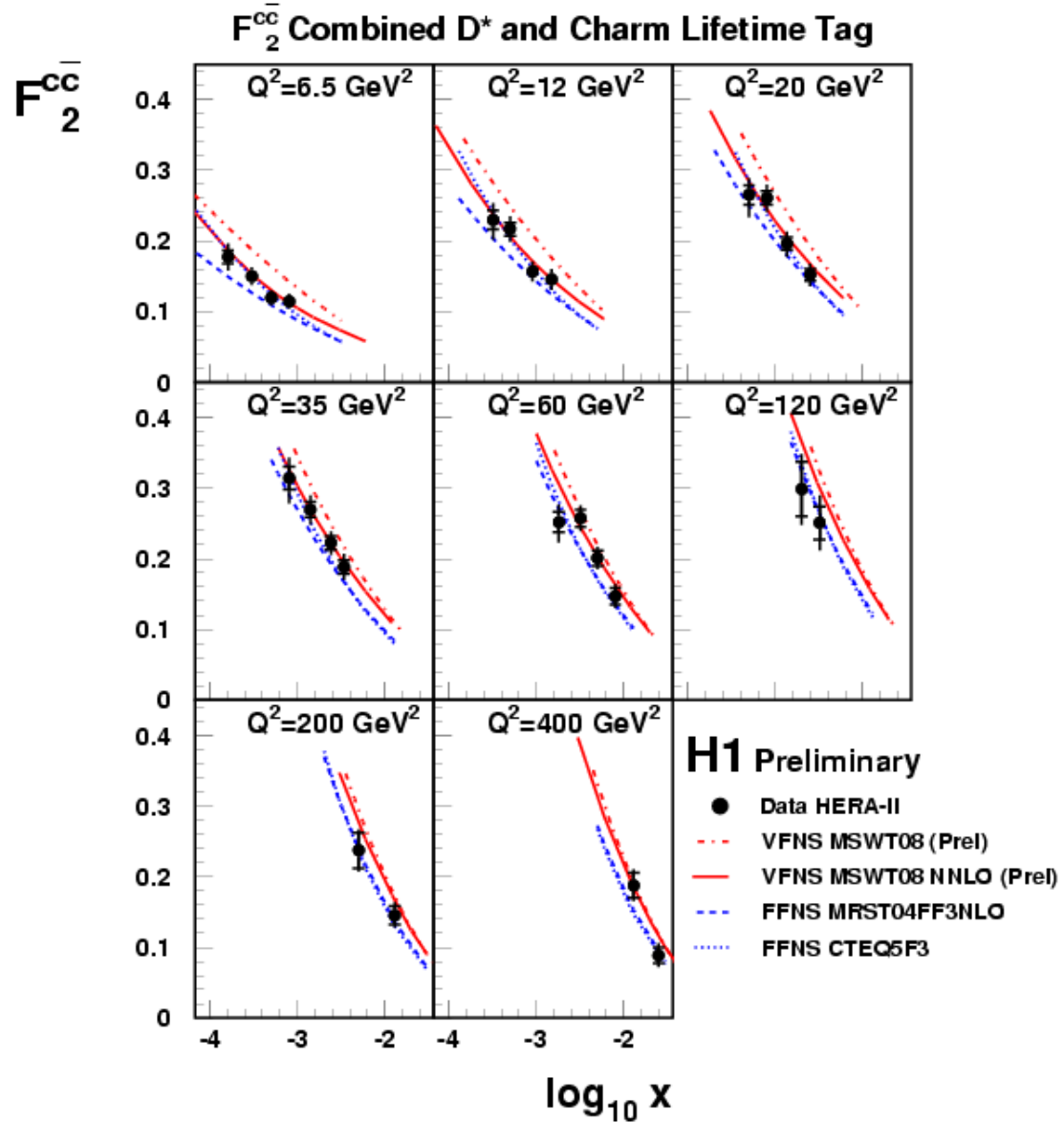
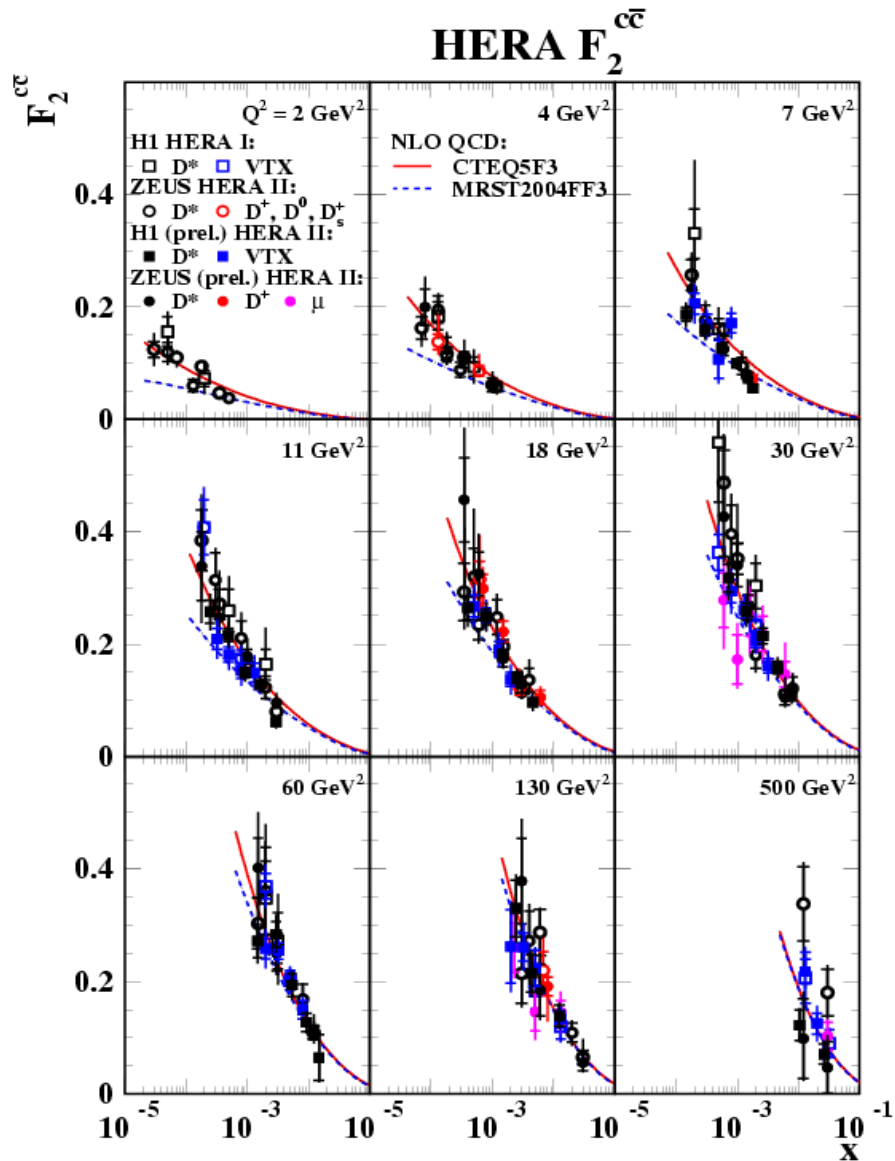
- Heavy quark contribution to F_2 :

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

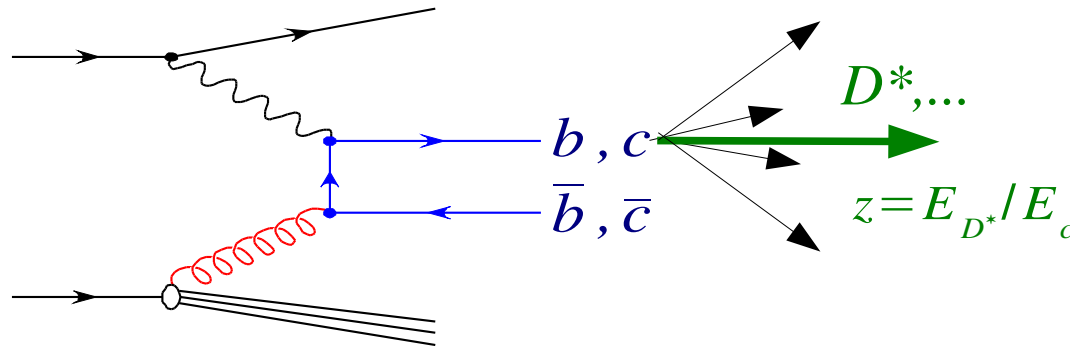
for low Q^2 with $Y_+ = (1 + (1 - y)^2)$

- Model dependence due to large extrapolation
- Extracted from different methods
- Acceptances vary:
 - > 70 % incl. Lifetime
 - 25-50 % μ p_T^{rel} + lifetime
 - 30-70 % D-mesons

Measurements of $F_2^{c\bar{c}}$

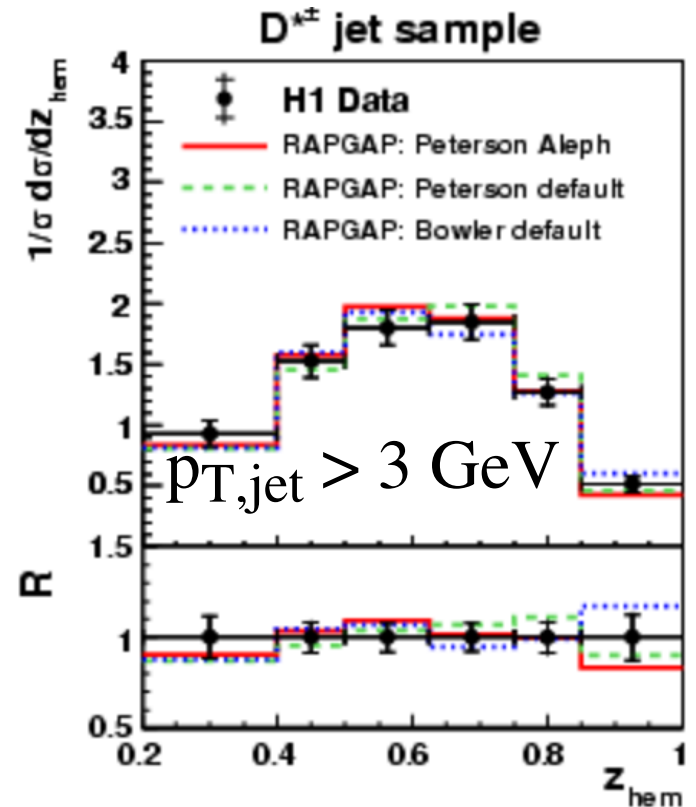


Charm Fragmentation $c \rightarrow h$



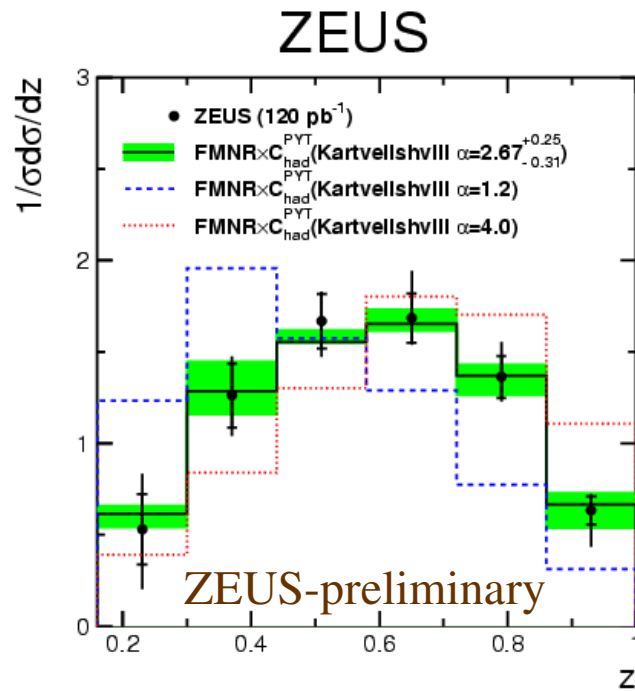
H1: arXiv:0808.1003[hep-ex]

- Approximate charm quark by
 - Jet containing D^* (far above threshold) $E_T > 3$ GeV
 - D^* hemisphere (works also close to threshold)
- Various fragmentation functions tested



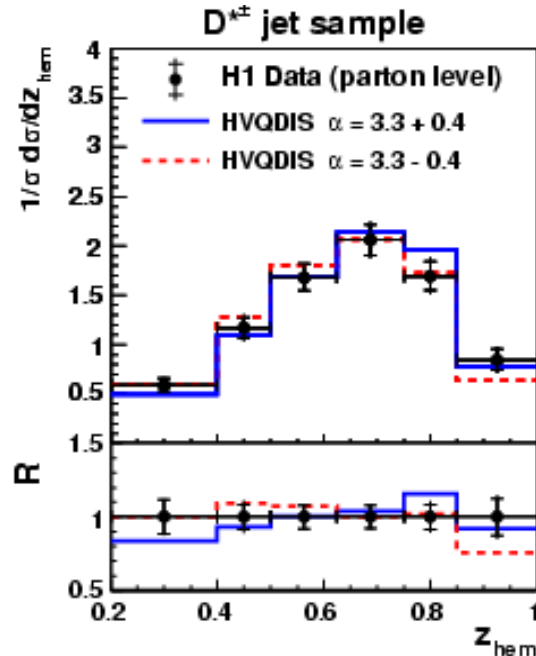
- Measured fragmentation compared with MC using LEP results
- Good agreement above threshold
 - **Universality of fragmentation**

Charm Fragmentation



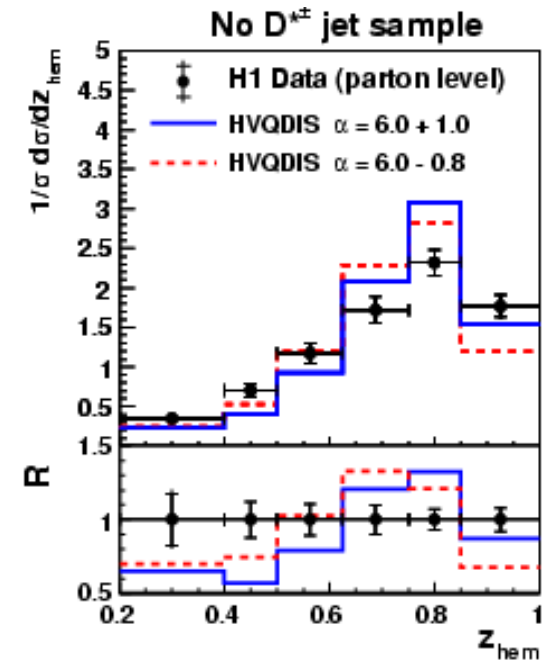
$p_{T,jet} > 9 \text{ GeV}$

H1: arXiv:0808.1003[hep-ex]



$p_{T,jet} > 3 \text{ GeV}$

H1: arXiv:0808.1003[hep-ex]

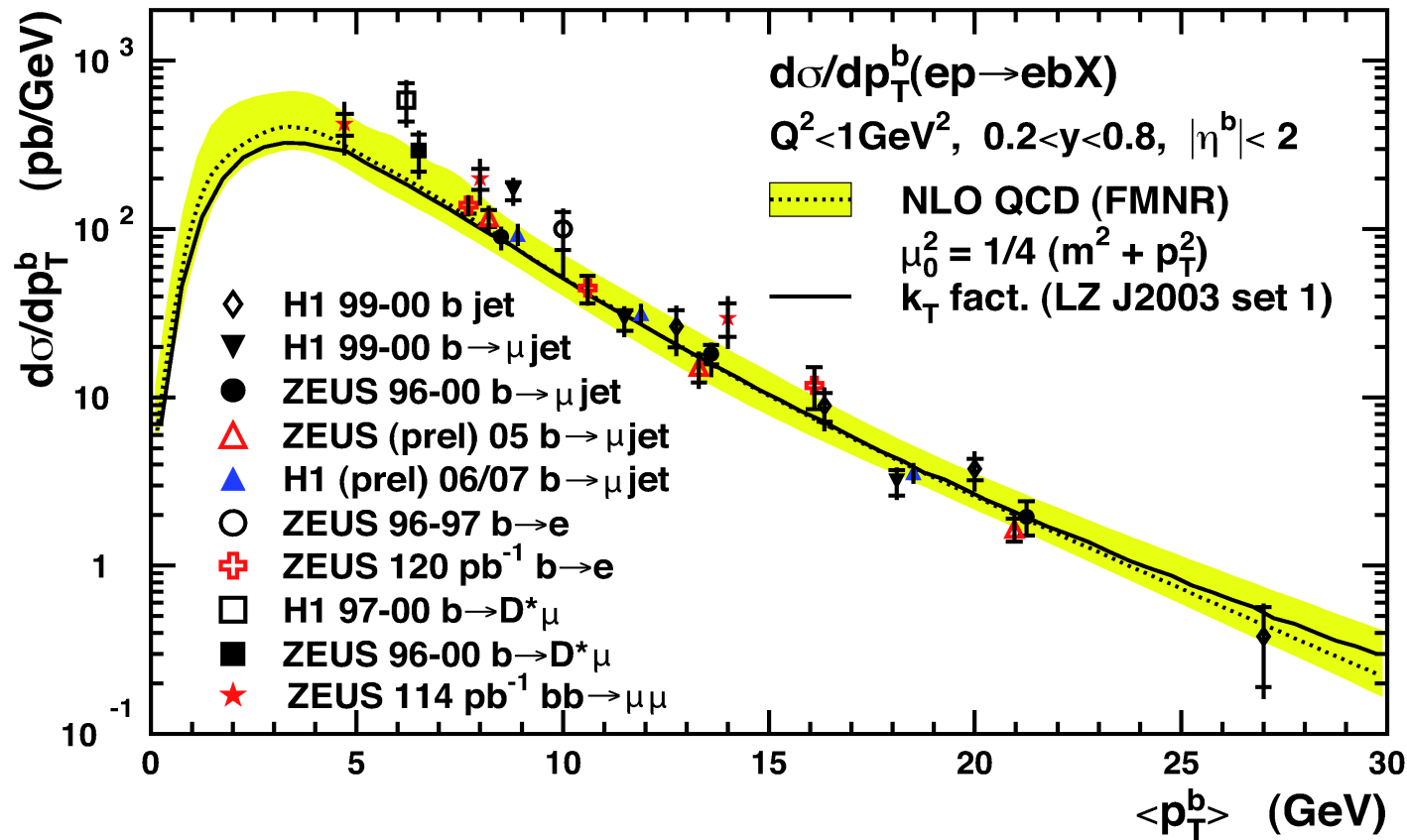


no jet

- H1 and ZEUS measurements above the threshold agree
- Close to threshold fragmentation much harder

Beauty Cross Sections(γp)

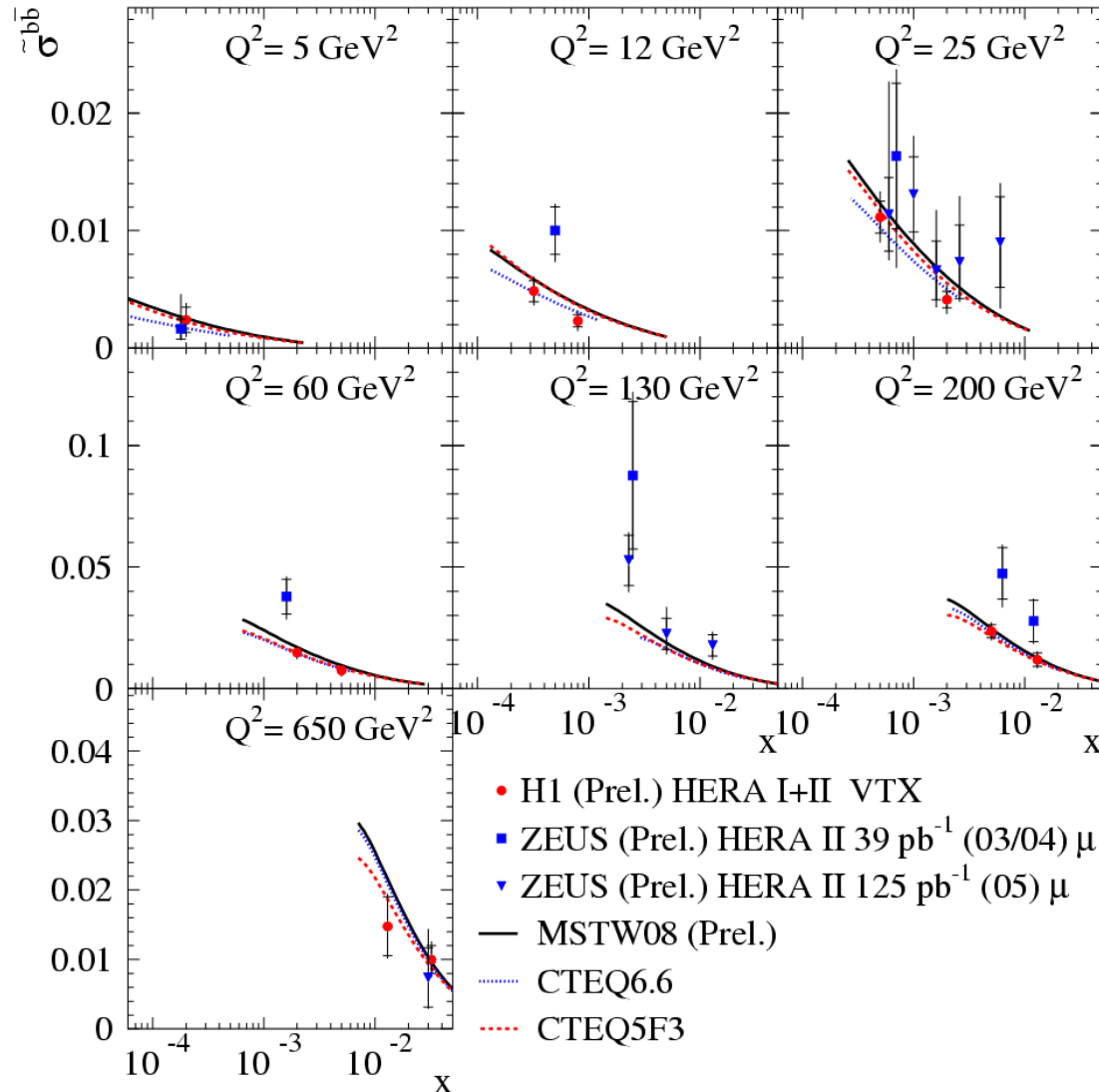
HERA



- Several measurements with different methods and systematics
- Agreement between methods and Experiments
- Good agreement with NLO prediction

Measurements of $F_2^{b\bar{b}}$

H1+ZEUS BEAUTY CROSS SECTION in DIS



- Definition analogous $F_2^{c\bar{c}}$
- Acceptances vary:
 - > 90 % incl. Lifetime
 - 20-35% μ p_T^{rel}
- Experimental uncertainties decreasing with HERA I+II statistics

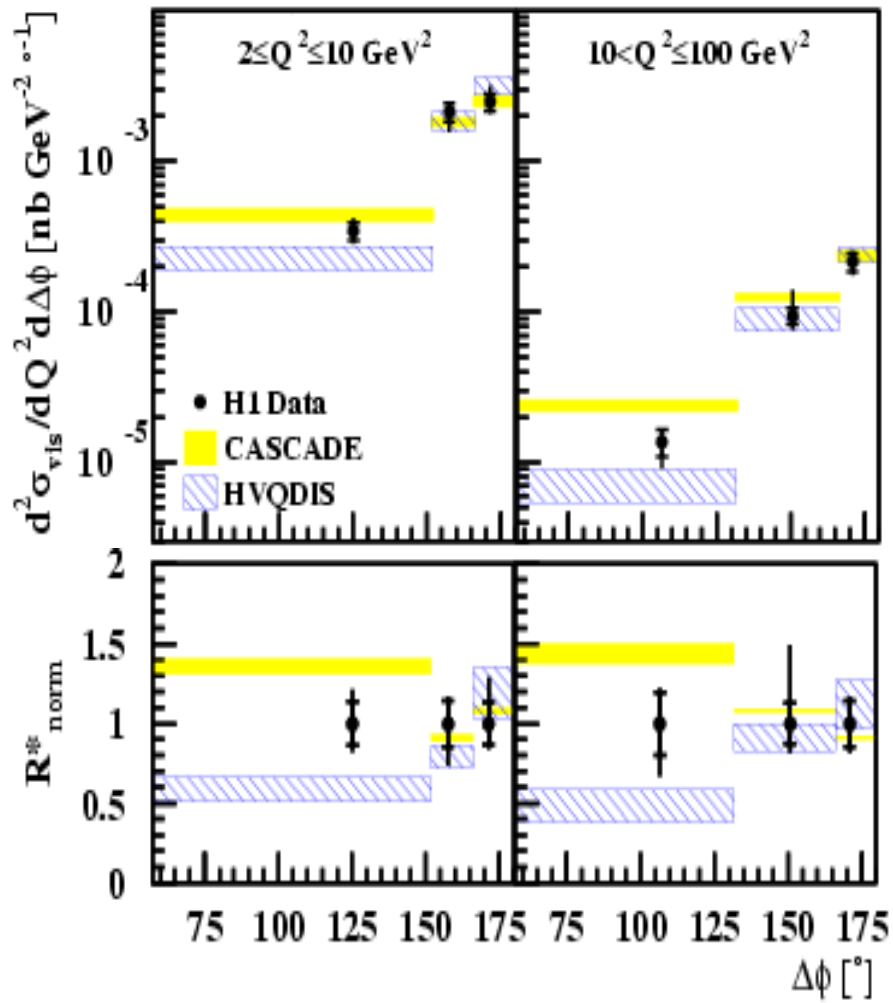
Conclusion

- Wealth of new heavy quark measurements in DIS and γp from HERA
- Data are reasonably well described by NLO pQCD calculations over wide kinematic range
- Heavy quark measurements direct sensitive to gluon density
- **Important cross check of gluon densities from inclusive measurements**
- Charm fragmentation: lack of understanding of the threshold region
- Cross sections for charm and beauty production from many different analysis techniques used to extract F_2^c and F_2^b

Backup

D* Mesons + Dijets

H1 ep \rightarrow eD*[±]jjX



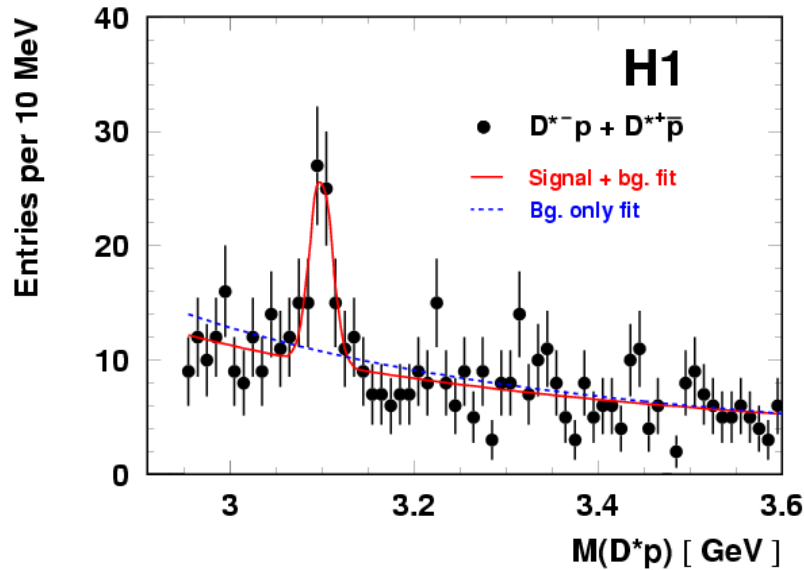
Eur.Phys.J.C51 (2007) 271

- Measurement of D* tagged dijets allows to study **both quarks simultaneously**
- Contributions at smaller $\Delta\phi(\text{jj})$ due to gluon radiation and fragmentation effects
- CASCADE (LO+PS) and HVQDIS (NLO) describe the data reasonably well
- Both have problems at small $\Delta\phi$
 - Indications for beyond NLO effects

D*_p Resonance

Analysis HERAI data ($L \approx 75 \text{ pb}^{-1}$):

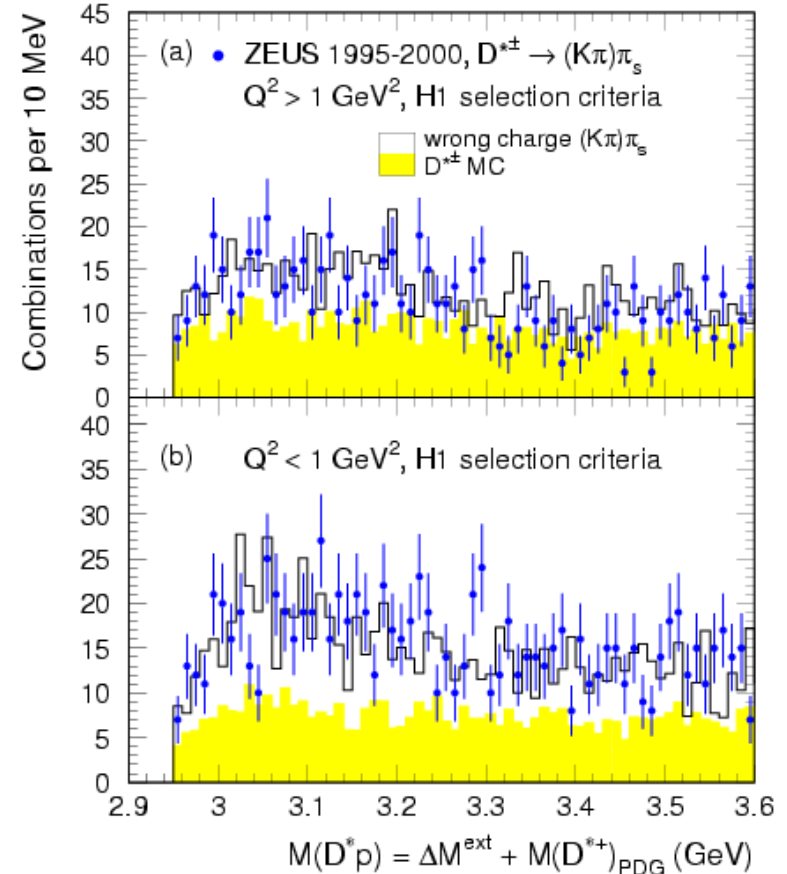
Phys.Lett.B588 (2004) 17



- **Narrow resonance observed at:**
 - $M(D^*p) = 3099 \pm 3 \text{ (stat.)} \pm 5 \text{ (syst.) MeV}$
 - Anti charm baryon with minimum quark content $uudd\bar{c}$
 - Small fraction: $\frac{N(D^*p)}{N(D^*)} \sim 1 \%$

- **No evidence in other experiments:**
 - BaBar, CDF, ZEUS, ALEPH, FOCUS

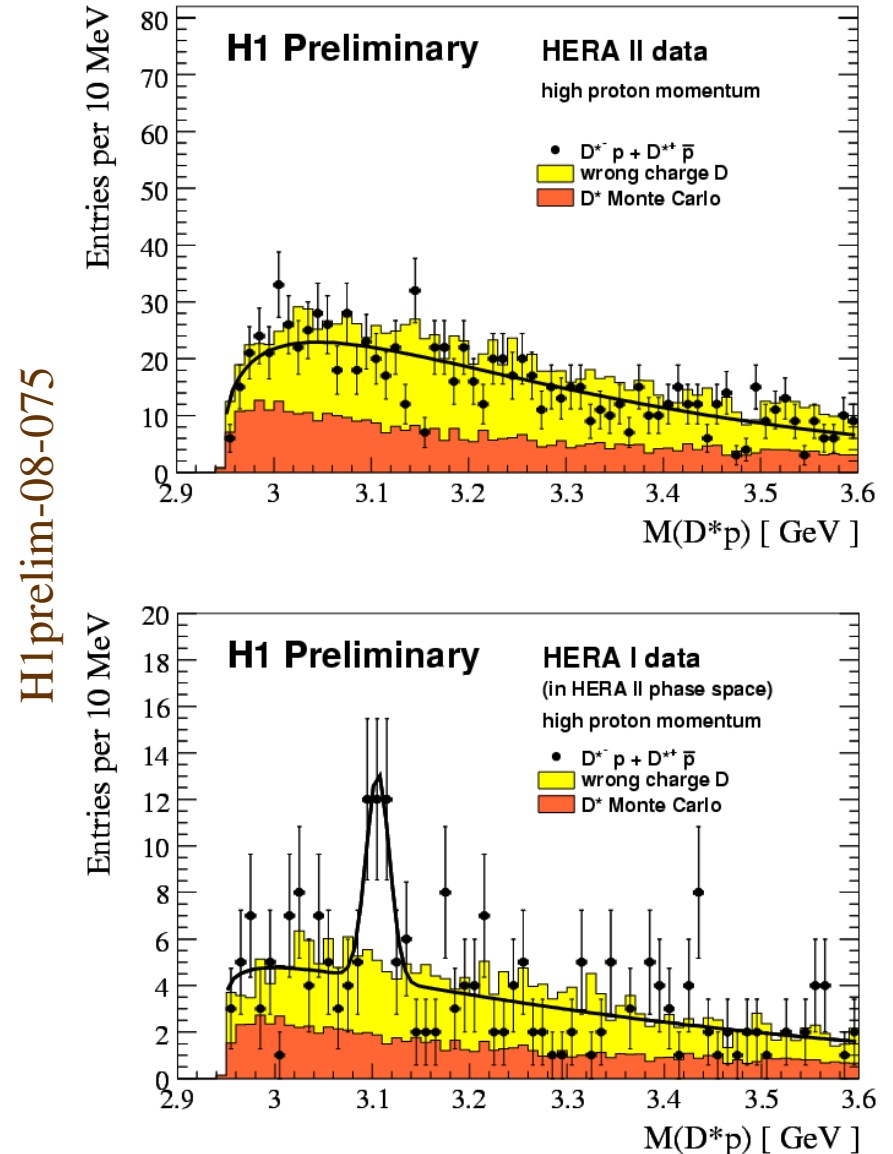
ZEUS



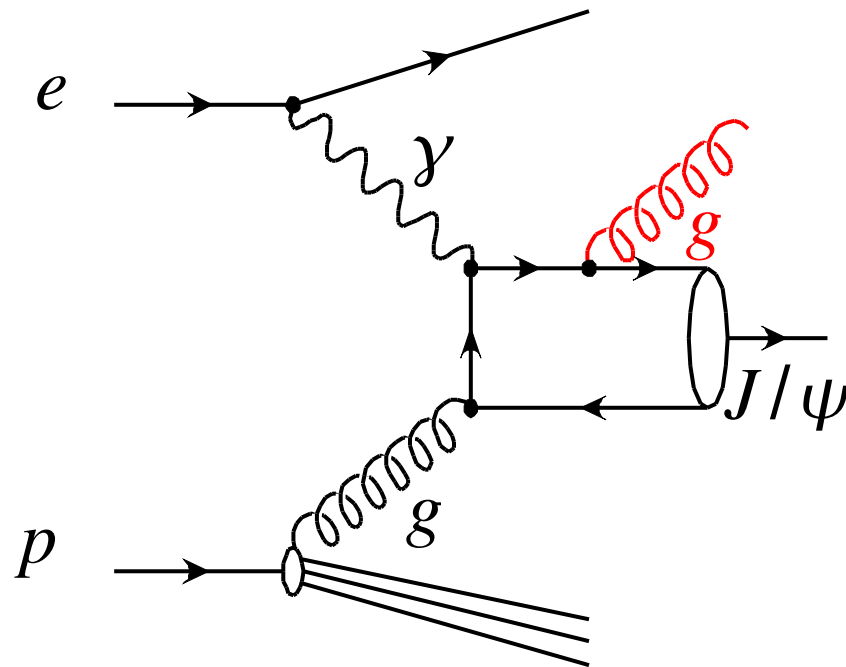
Eur.Phys.J.C38 (2004) 29

D*_s p Resonance

- HERAII data 2004-2007
($L \approx 348 \text{ pb}^{-1}$)
- **No excess in HERAII data;**
 - upper limit of $\frac{N(D^*_s p)}{N(D^*_s)} \sim 0.1 \%$
(95 % C.L.)
- Signal still there in HERAI data
(with reduced phase space)



Inelastic Electroproduction of J/ψ Mesons

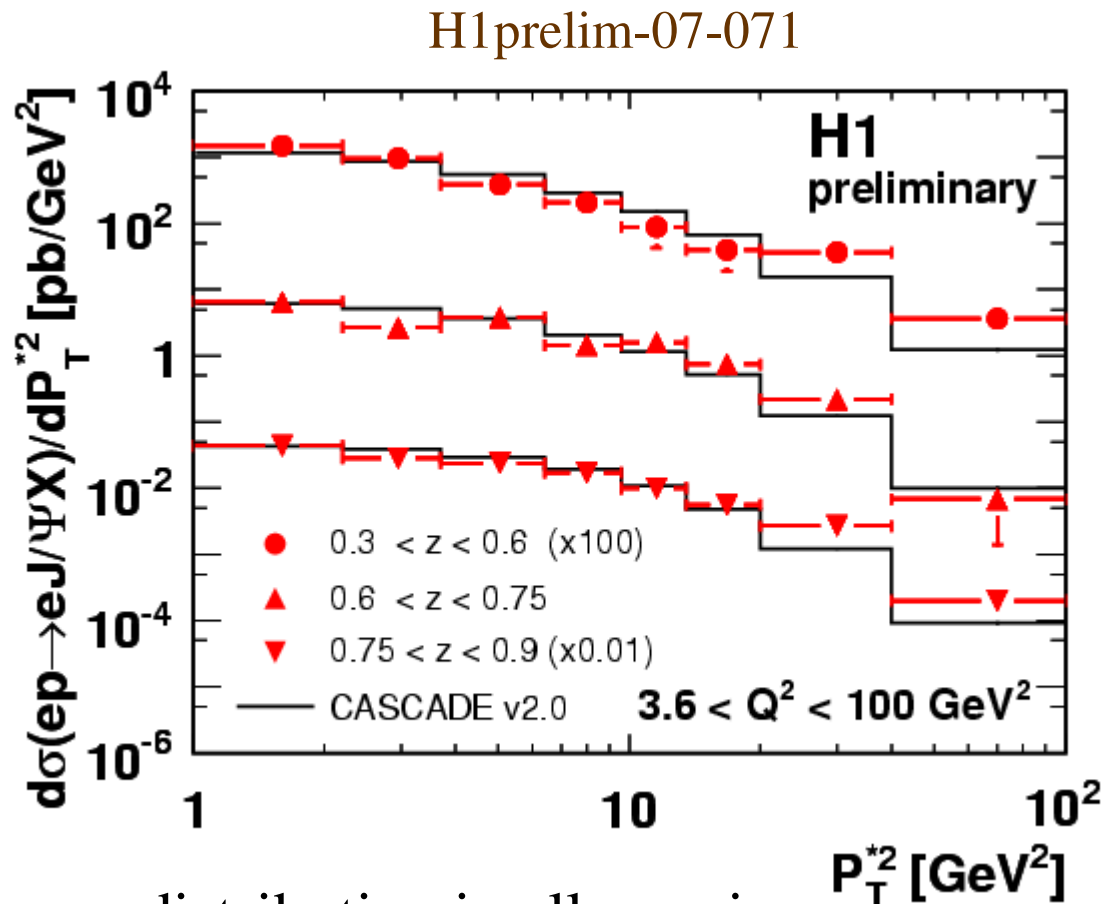


elasticity $z = \frac{E_\psi}{E_\gamma}$ in proton rest frame

several models to describe the transition $c\bar{c} \rightarrow J/\psi$

- Color Singlet Model: perturbative process („hard“ gluon)
 - MC: CASCADE
- Non-Relativistic QCD: non-perturbative process („soft“ gluons)

Inelastic Electroproduction of J/ψ Mesons (DIS)



- Similar p_T distribution in all z regions
 - all z regions well described in shape by CSM Monte Carlo
 - no additional NRQCD contributions needed

Hemisphere Method

Reconstruction of the energy of the charm quark:

- Take all particles with $\eta > 0$ in γp -frame
- Project onto plane perpendicular proton direction
- Get thrust axis
- Take all momenta of particles in D^* hemisphere

