Charm Physics at HERA

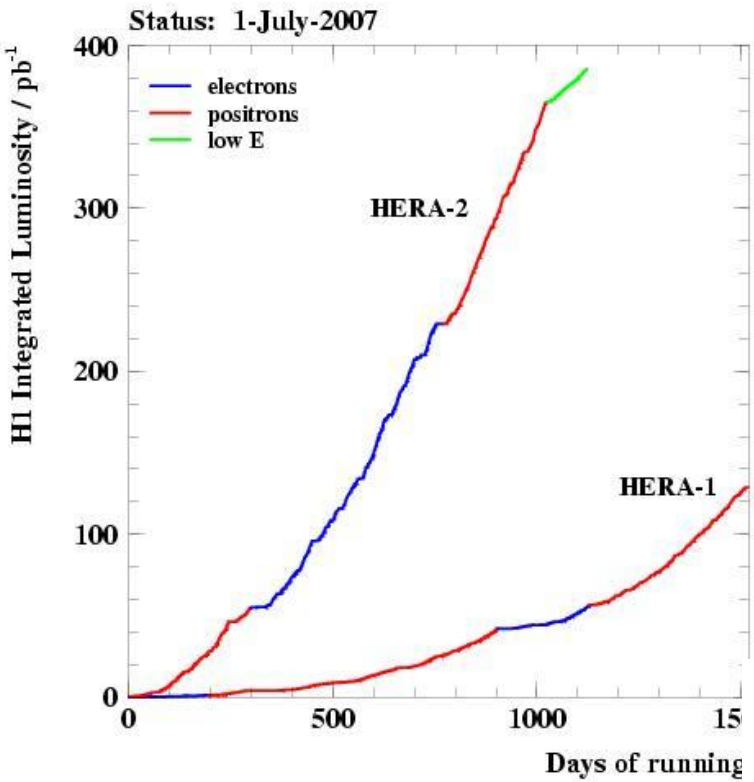
Andrew Mehta
University of Liverpool

for the H1 & ZEUS Collaborations

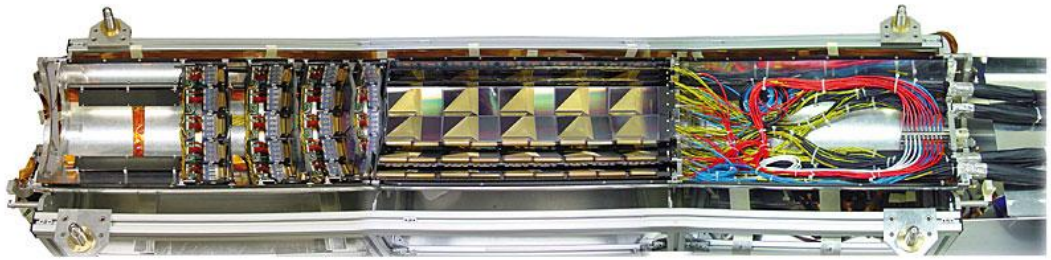
- HERA
- Charm production and theory
- D* measurements
- Measurements of F_2^{cc}
- Comparison and combination of results

CIPANP, San Diego 25th-31th May, 2009

Available Data



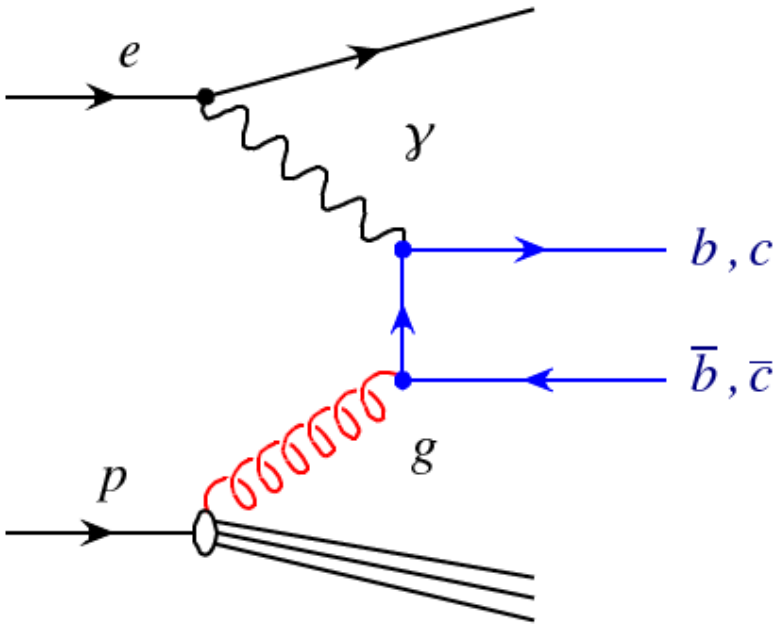
- In total ~500pb^{-1} of high energy data collected per experiment
- luminosity upgrade in 2001
- detectors upgraded
- ZEUS: micro vertex detector installed



Many analyses on full HERA II data

Working on final publication and combination of results

Production of Charm



Predominantly via boson gluon fusion

Test of perturbative QCD:

multi-scale problem (Q^2, m_c^2, p_t^2)

Directly sensitive to gluon density in the proton (PDFs)

Predictions for Heavy Quark Production

Number of theoretical approaches:

Massless (Zero Mass), massive (Fixed Flavour) and general mass (GM) flavour number schemes (combination of 2-should provide best theoretical model).

QCD Calculations:

Fixed order NLO(α_s^2), massive FFNS (HVQDIS)

GM-VFNS PDFs

MSTW08 to NLO (α_s^2) and NNLO

CTEQ 6.6 to NLO (α_s)

Monte-Carlo: LO (α_s)+Parton shower:

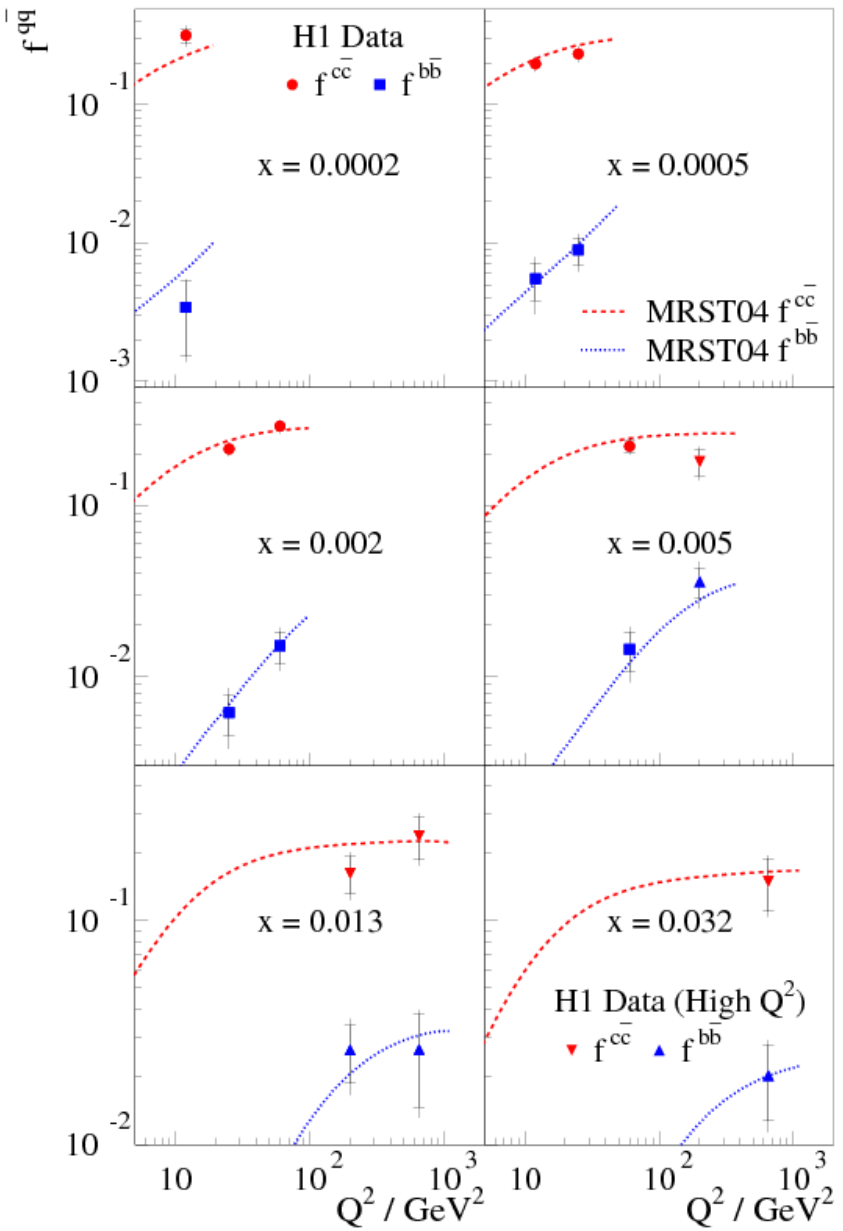
Collinear factorisation, DGLAP (RAPGAP)

K_T factorisation, CCFM (CASCADE)

Contribution to Cross Section

HERA I result:

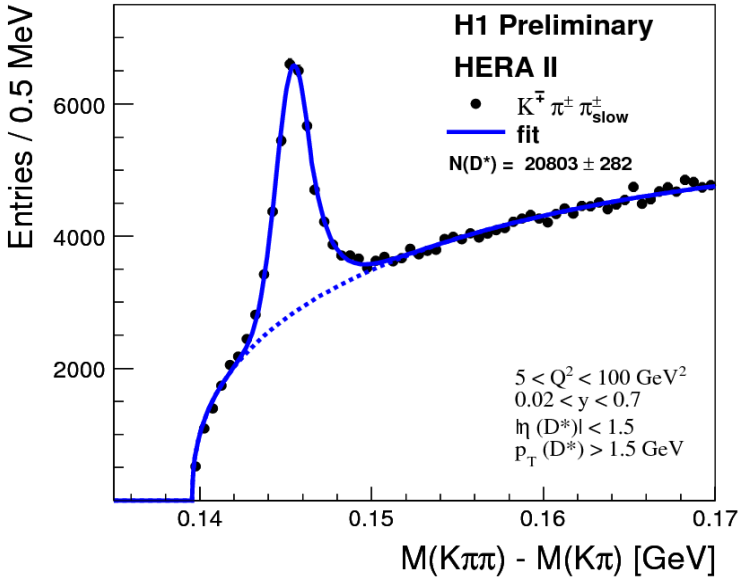
- fraction of total DIS cross section from charm and beauty
- large charm fraction (~30%)
- small beauty fraction ~% (lower at low Q^2)
- reasonable description by QCD



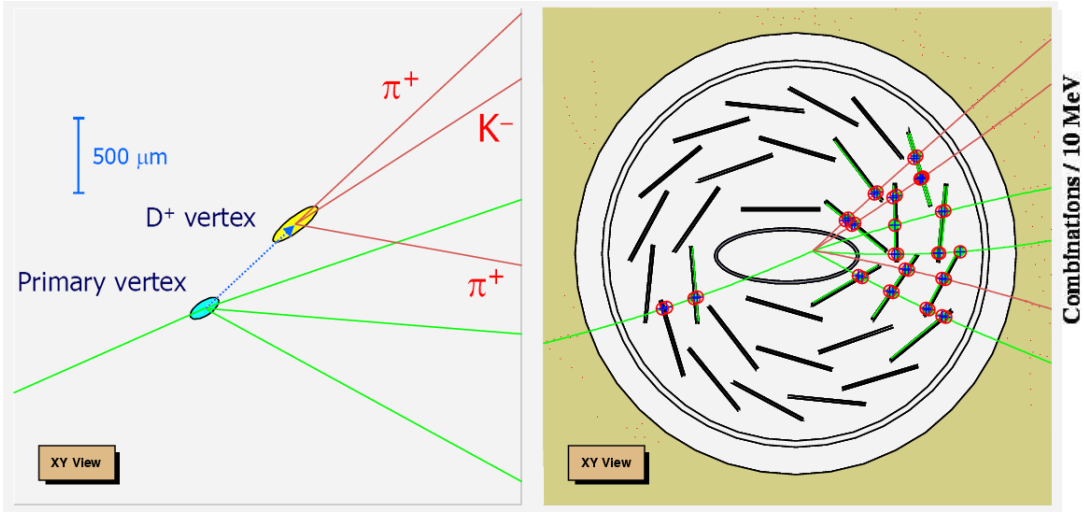
Charm Tagging using D mesons

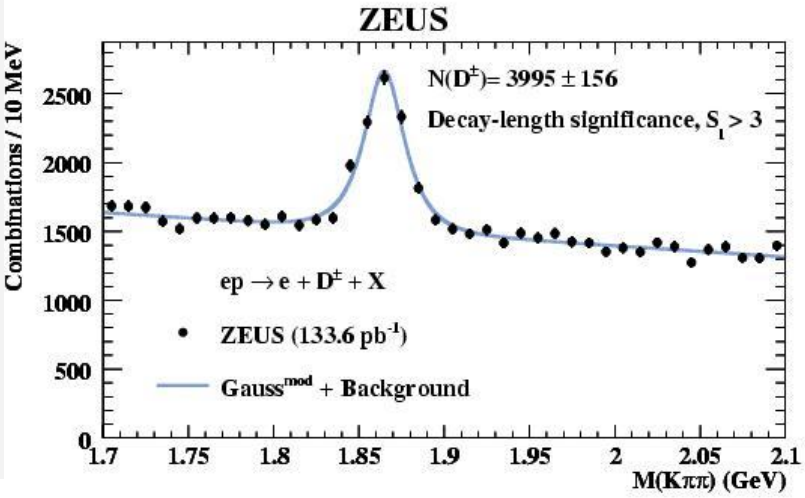
Fully reconstruct resonances D^*, D^+, D^0,…

H1 uses full HERA II statistics (~350pb^{-1})

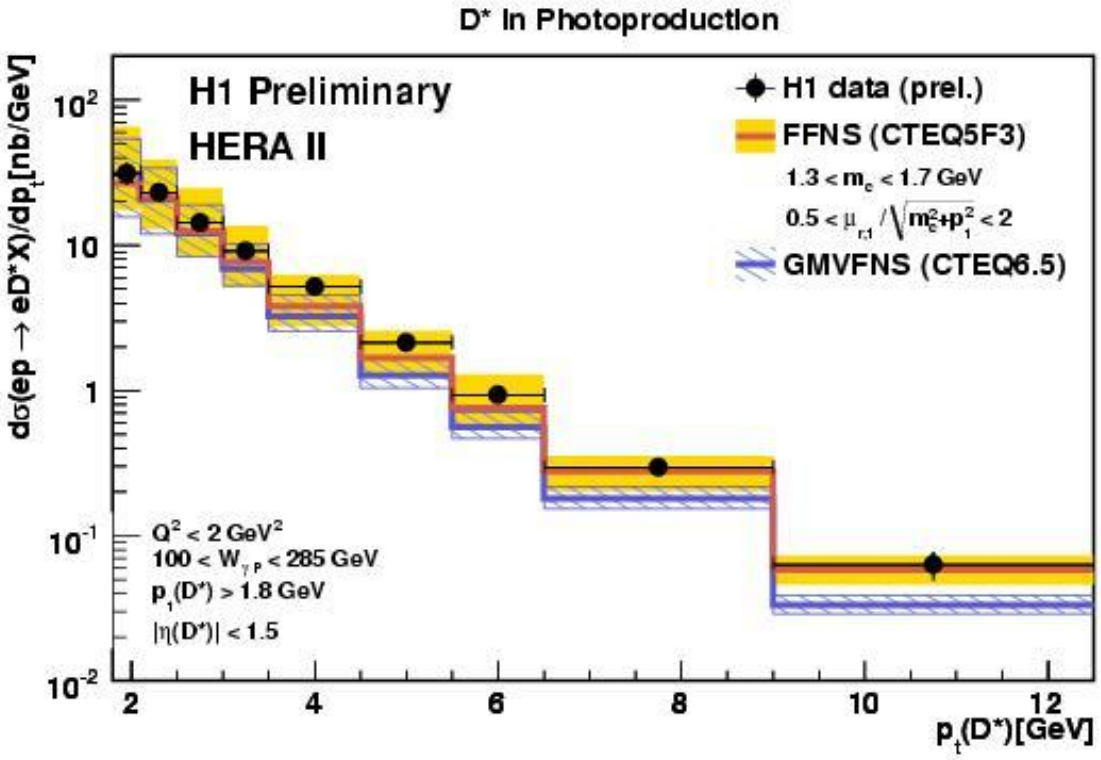


Reject background by asking for a non-zero decay length, reconstructed from vertex detectors





Charm in Photoproduction



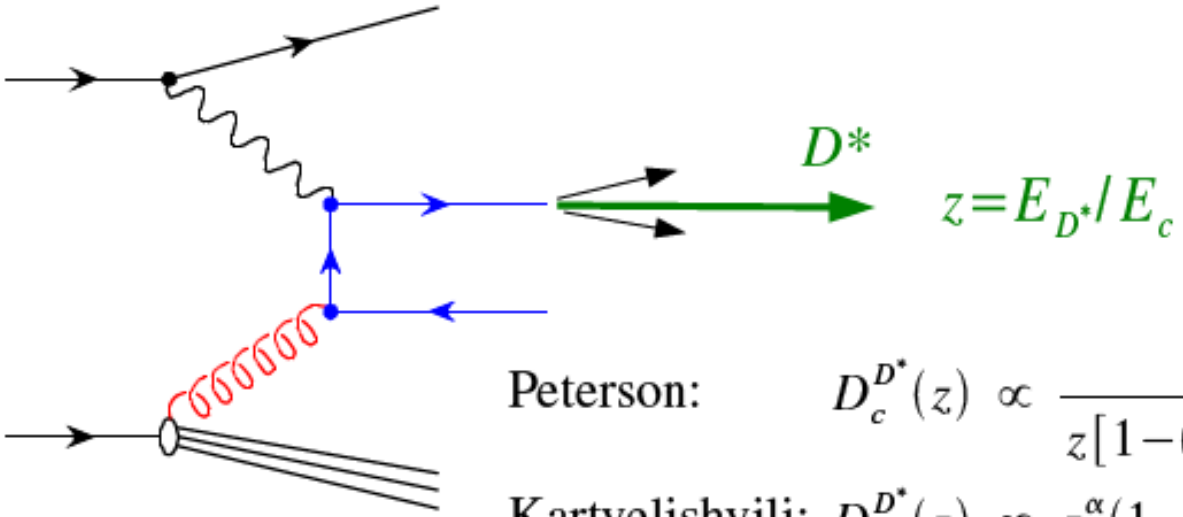
- Theoretical errors are large at low Pt(D*)
- Fixed Flavour gives a reasonable description.
- General mass flavour scheme is below data at large Pt

⇒ still some theoretical understanding needed.

D* Fragmentation

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

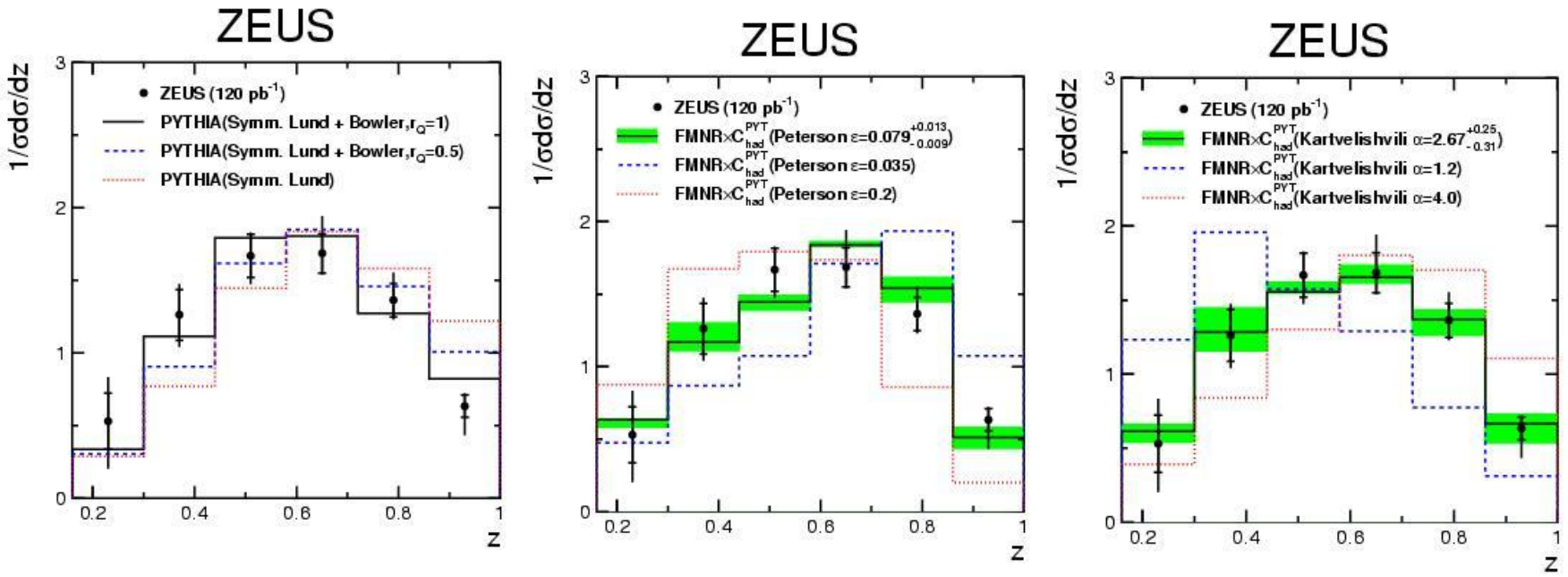
parton density function (non-perturbative)	parton scattering cross section (perturbative)	fragmentation function (non-perturbative)



Peterson: $D_c^{D^*}(z) \propto \dfrac{1}{z[1-(1/z)-\epsilon/(1-z)]^2}$

Kartvelishvili: $D_c^{D^*}(z) \propto z^{\alpha}(1-z)$

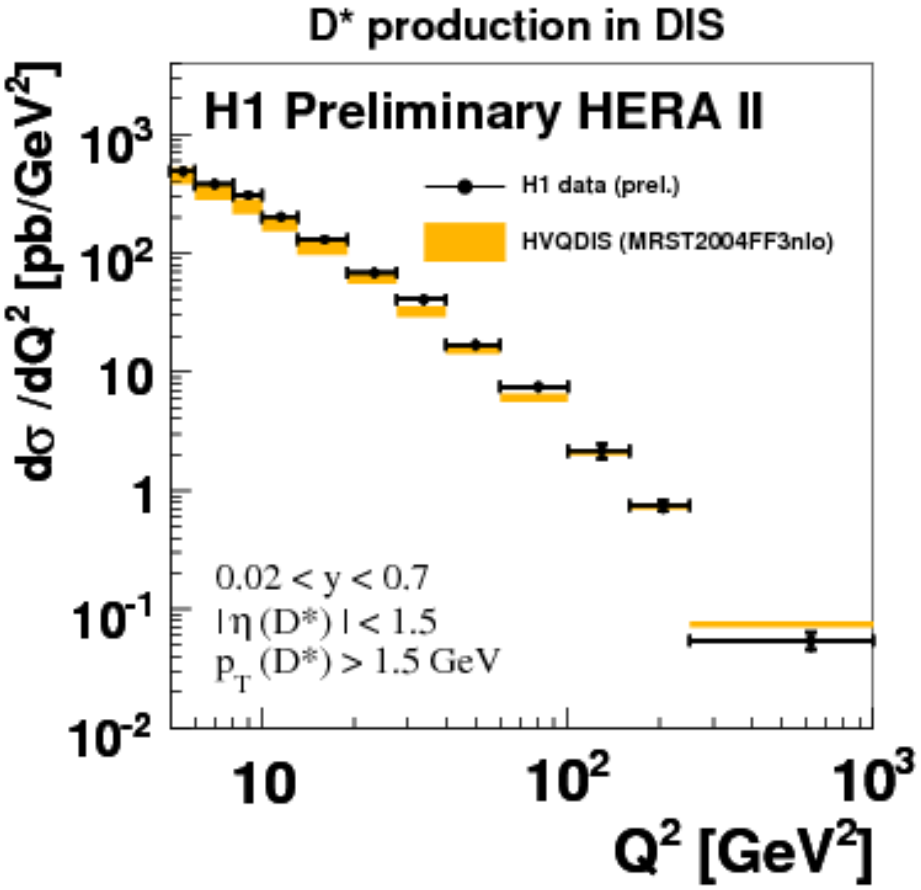
D* Fragmentation in γp

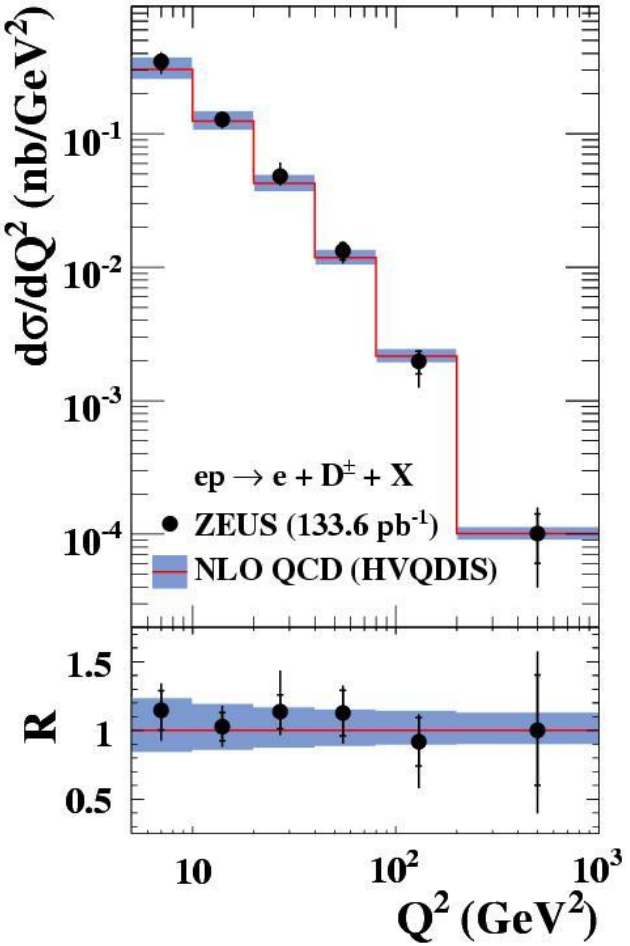


- ep data consistent with a symmetric Lund-Bowler (R_Q=1), Peterson and Kartvelishvili fragmentation functions
- Peterson parameter different from e^+e^- data, although this is expected as measurement made at different CMS energy within framework of NLO QCD
- Within the framework of PYTHIA, parameters agree with those from e^+e^-

DESY-08-080

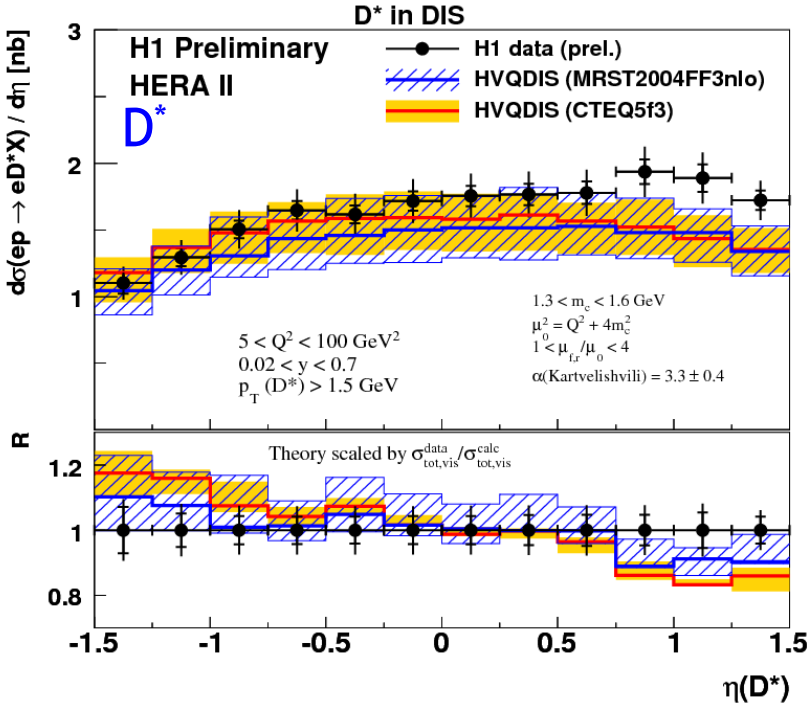
D Meson DIS Cross Section

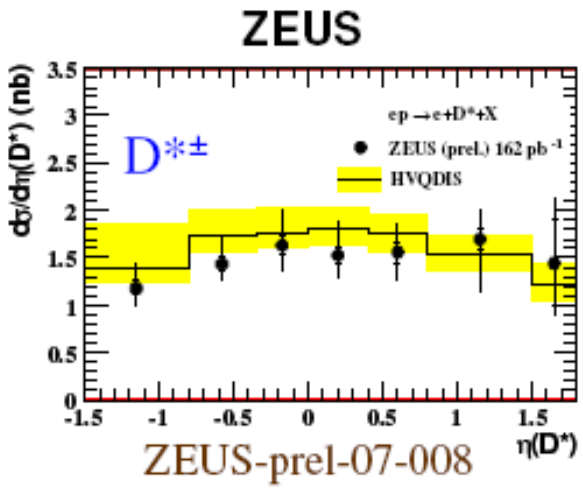




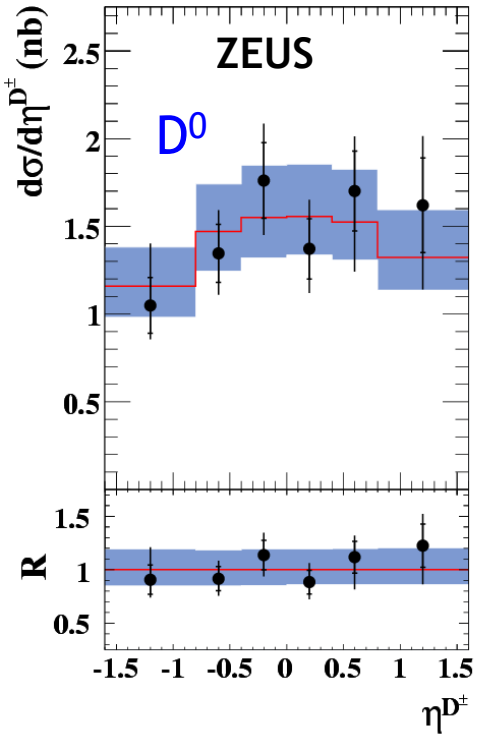
- Good description by NLO calculation (HVQDIS) in wide Q^2 range
- Also at large Q^2, where massive approach not expected to be appropriate

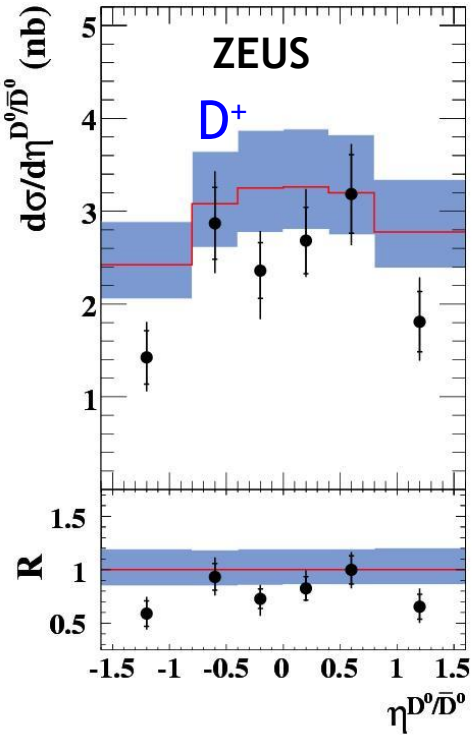
D Meson DIS Cross Sections



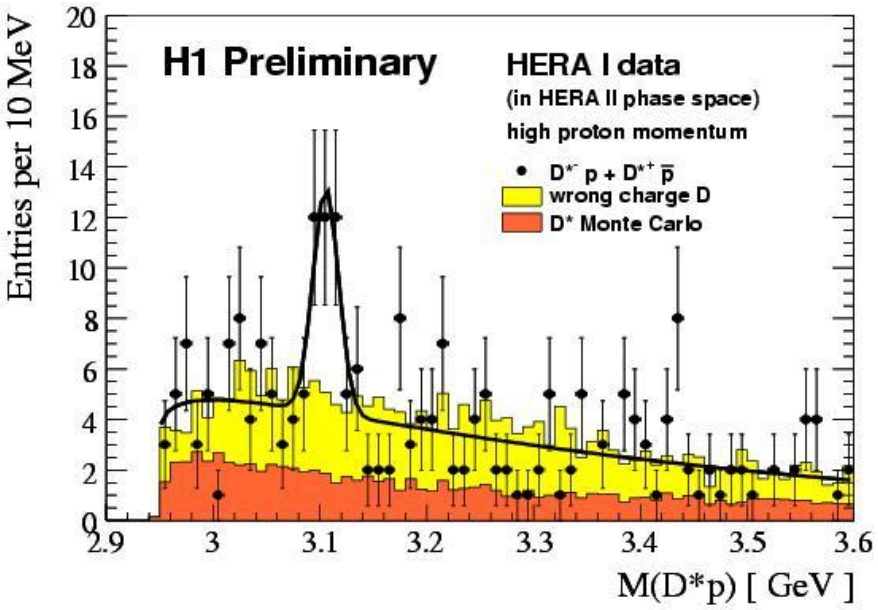


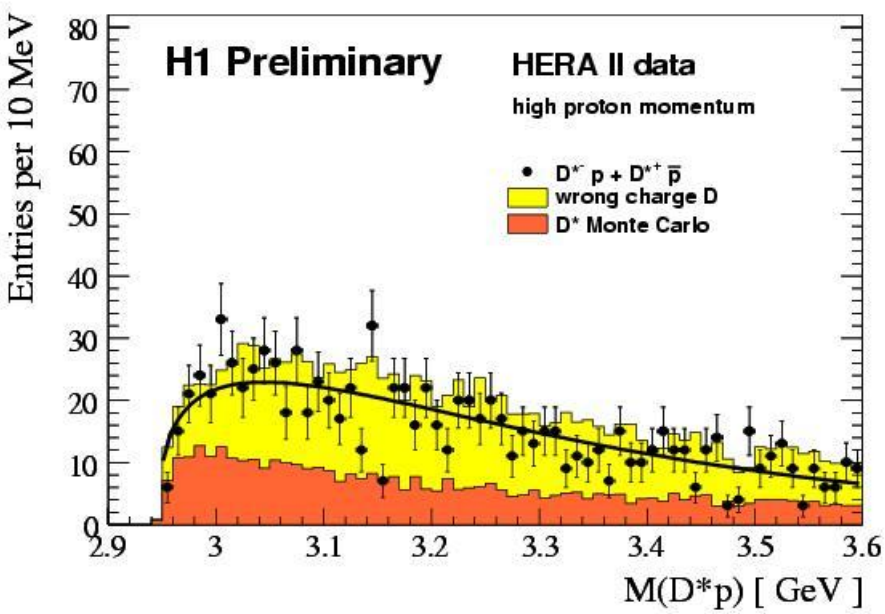
- differential cross sections of several D mesons measured
- reasonably described by NLO QCD (HVQDIS)
- double differential in x and Q^2 allows extraction of F_2^{cc} (see later)





Search for a D*p resonance





- Hint of excess of events seen in HERA I data around 3.1 GeV
- No evidence of peak seen in HERA II data (4 × statistics)

Other charm tagging techniques

Look for semileptonic decays of charm

- transverse momentum p_t^{rel} relative to jet axis

- impact parameter of muon δ

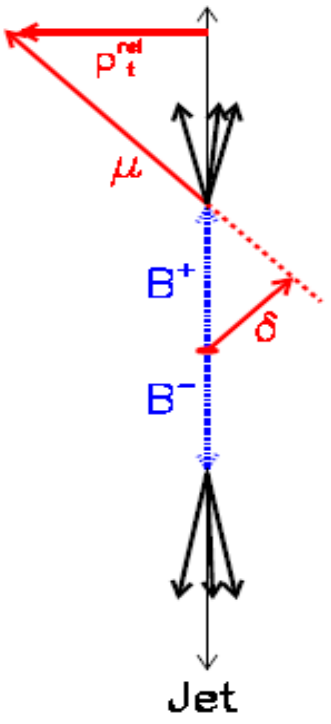
- Ptmiss relative to muon from neutrino

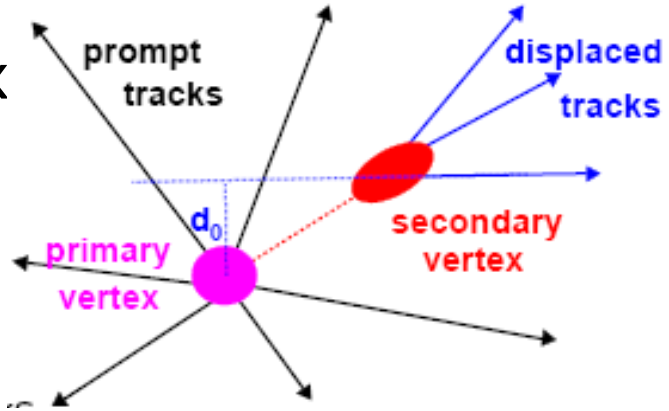
- lifetime (vertex detectors)

- reconstrucion of a secondary vertex

- impact parameter of tracks δ

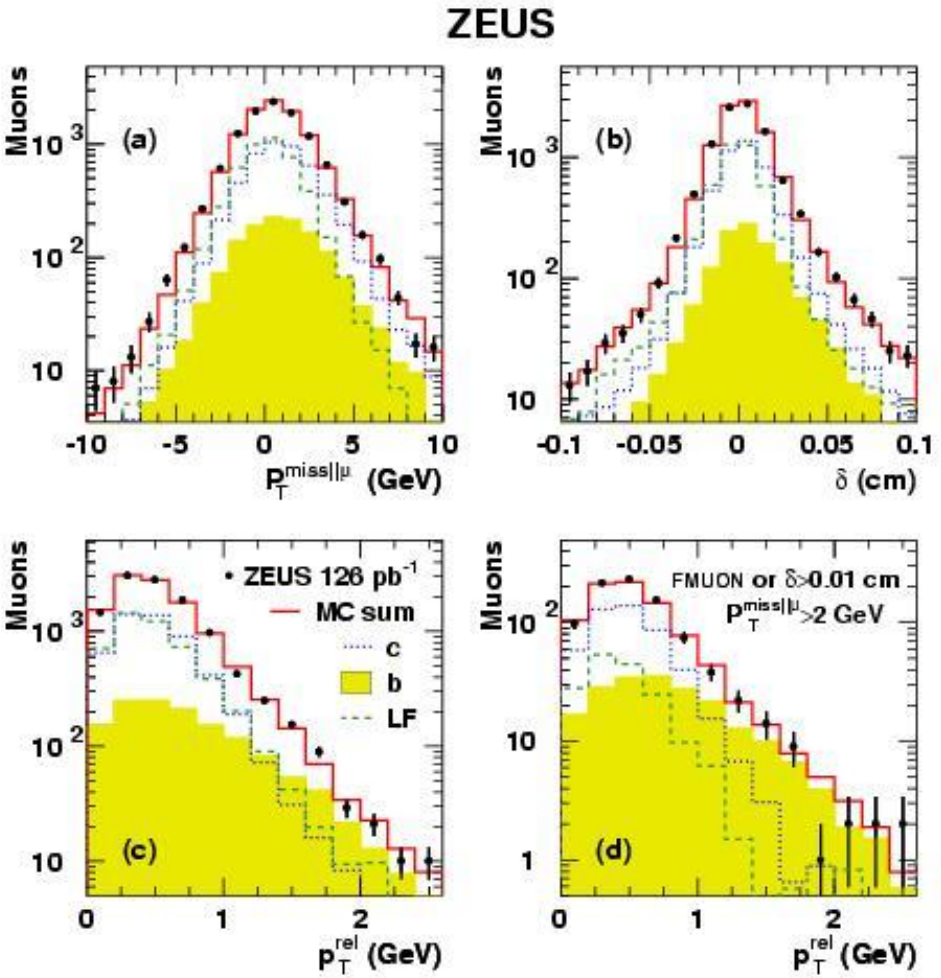
Methods are used to simultaneously tag bottom





Charm and Beauty Cross Section

- combine $p_T^{miss||\mu}$, p_T^{rel} and impact parameter distributions
- use 3D fit to decompose into beauty, charm and light flavour



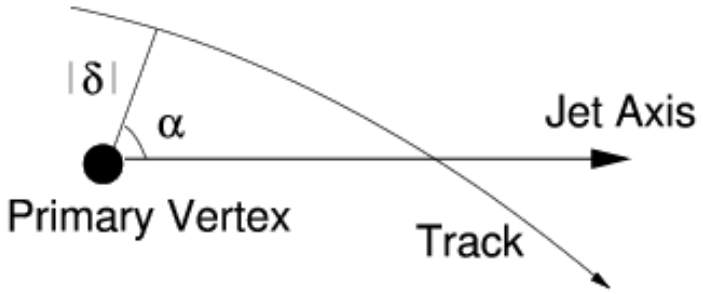
For beauty results see talk by Ana Yagues

Inclusive Analysis (lifetime)

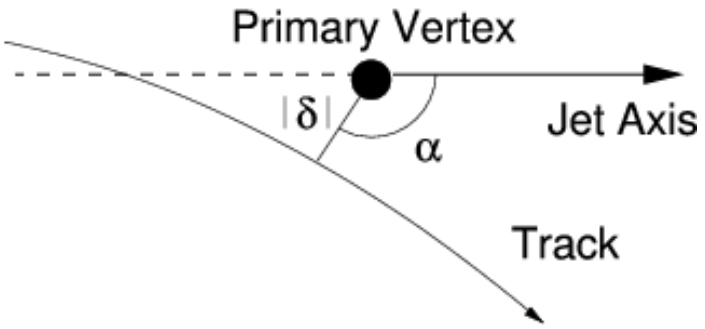
- Inclusive analysis: use all tracks with hits in silicon detector ($p_t > 0.3\ GeV$)
- H1 CST rebuilt to account for HERA II beamline
- Precise determination of impact parameter in transverse plane

Signed impact parameter δ

$\alpha < 90^o \rightarrow \delta = +|\delta|$



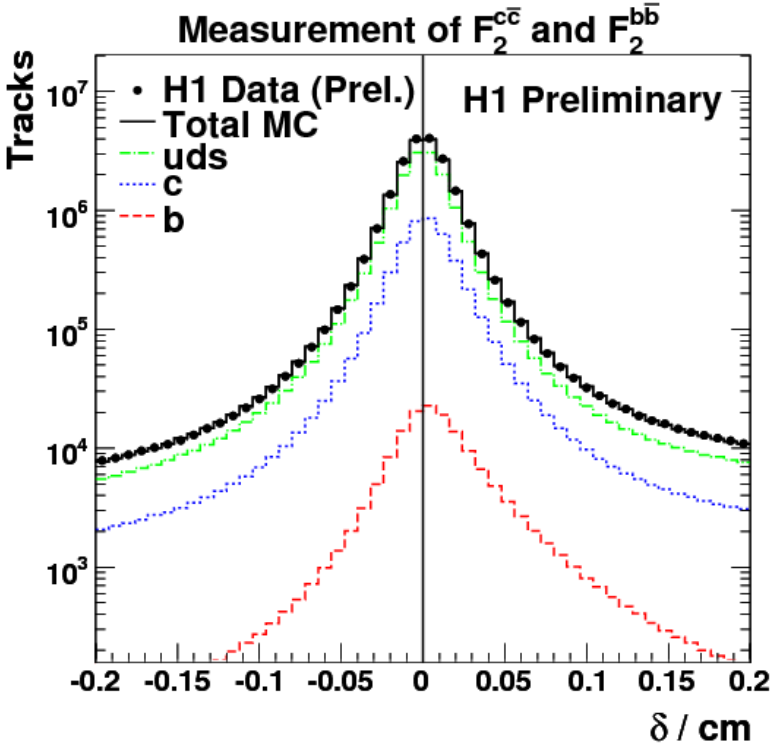
$\alpha > 90^o \rightarrow \delta = -|\delta|$



Inclusive lifetime tagging

Use all tracks with vertex hits

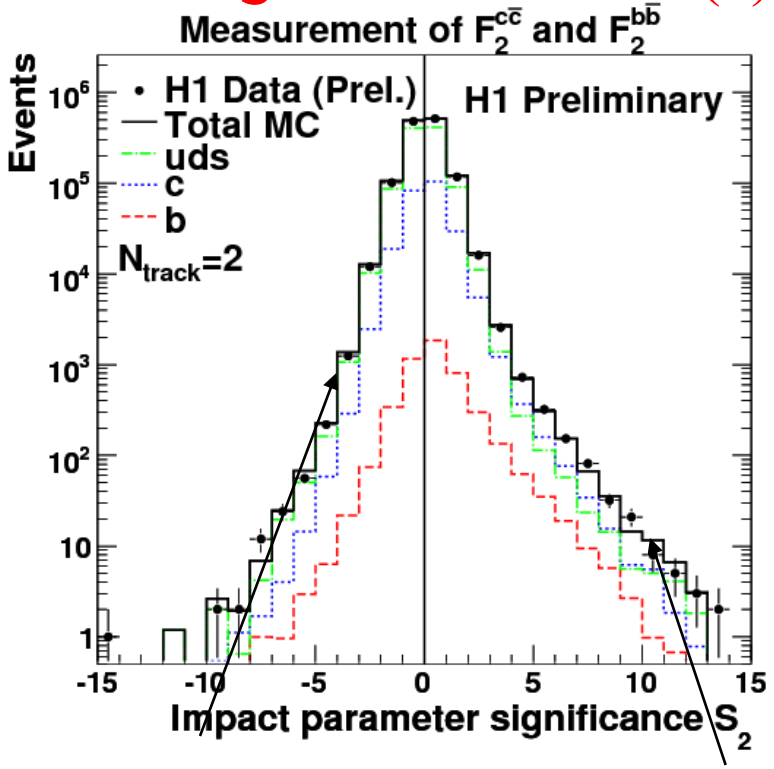
Signed Impact parameter δ



Charm and beauty asymmetric due to lifetime

Light flavours mostly symmetric

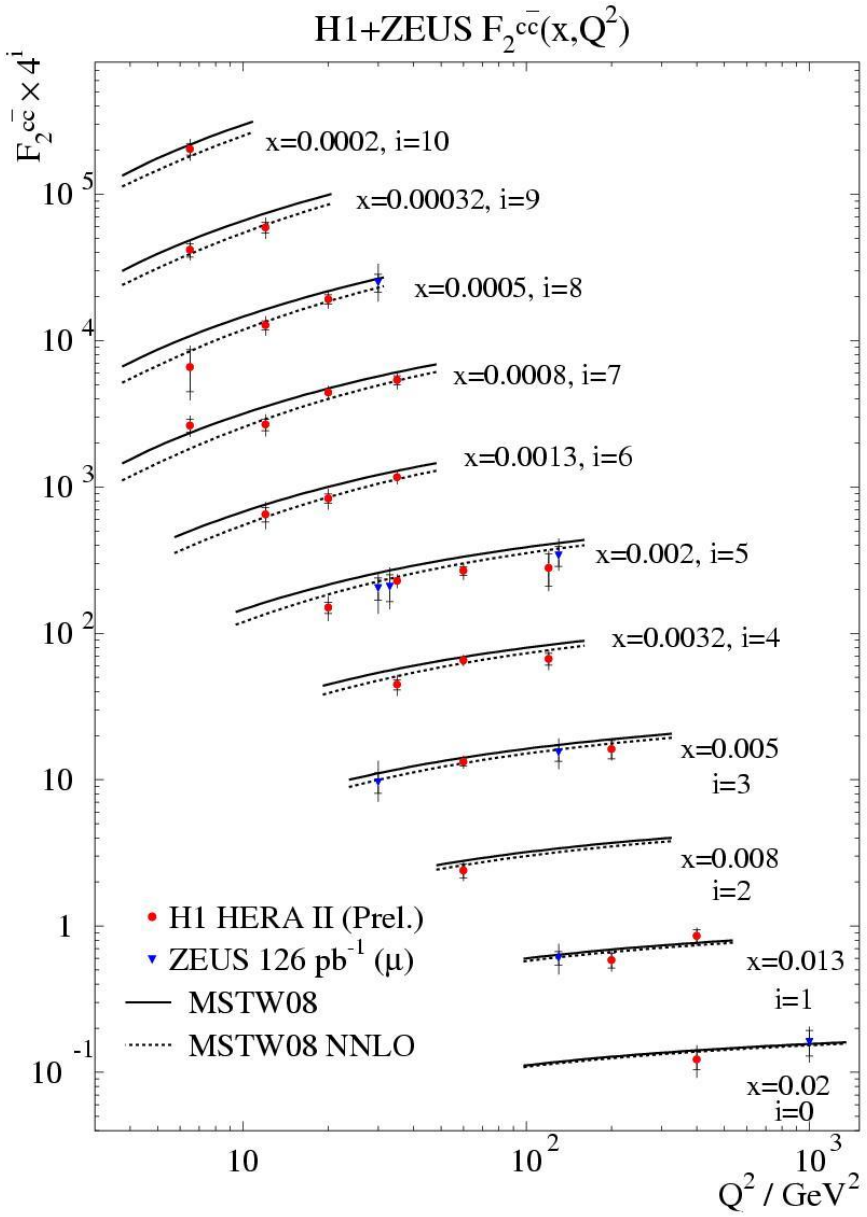
Significance = $\delta/\sigma(\delta)$



resolution

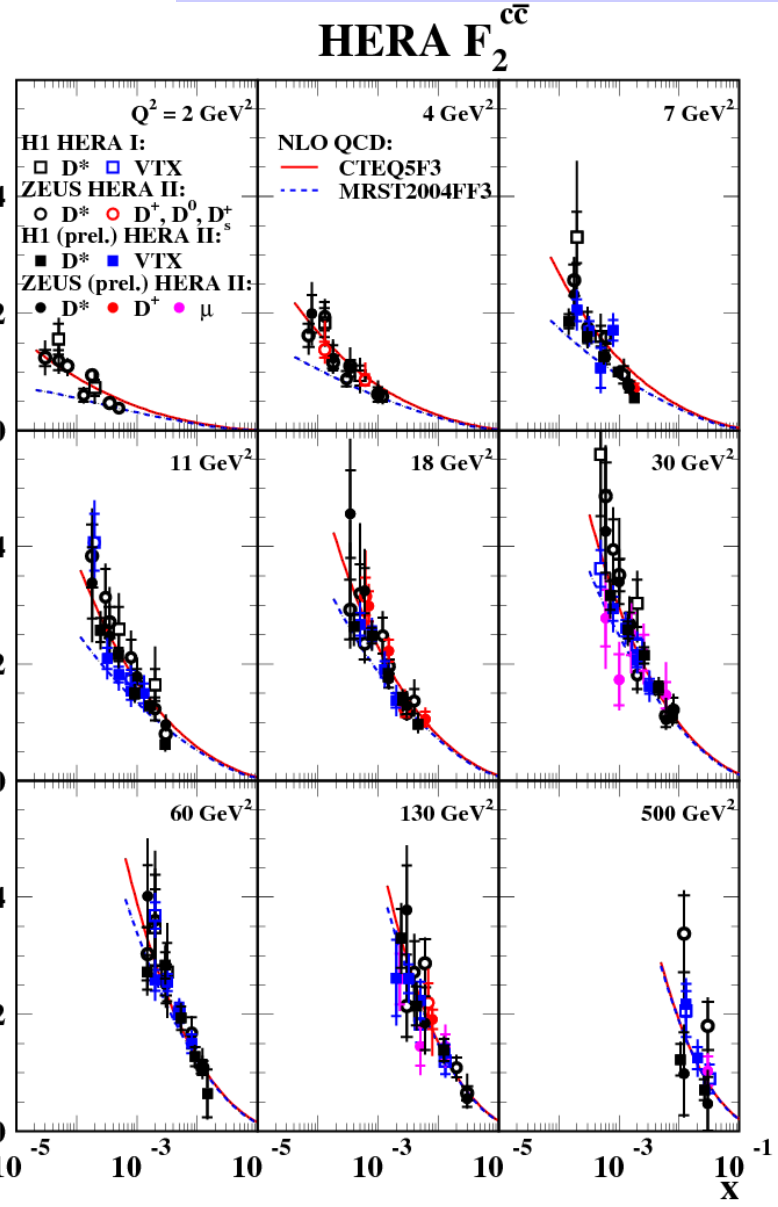
lifetime

Measurements of F_2^{cc}



- Convert double differential cross sections to F_2^{cc}
- Charm measurements span large range in Q^2 and x
- Scaling violations clearly visible
- Different measurements using different techniques agree
- Measurements sensitive to difference between theory models

Measurements of F_2^{cc}



- Many measurements with different techniques
- Comparison of different methods [acceptance]

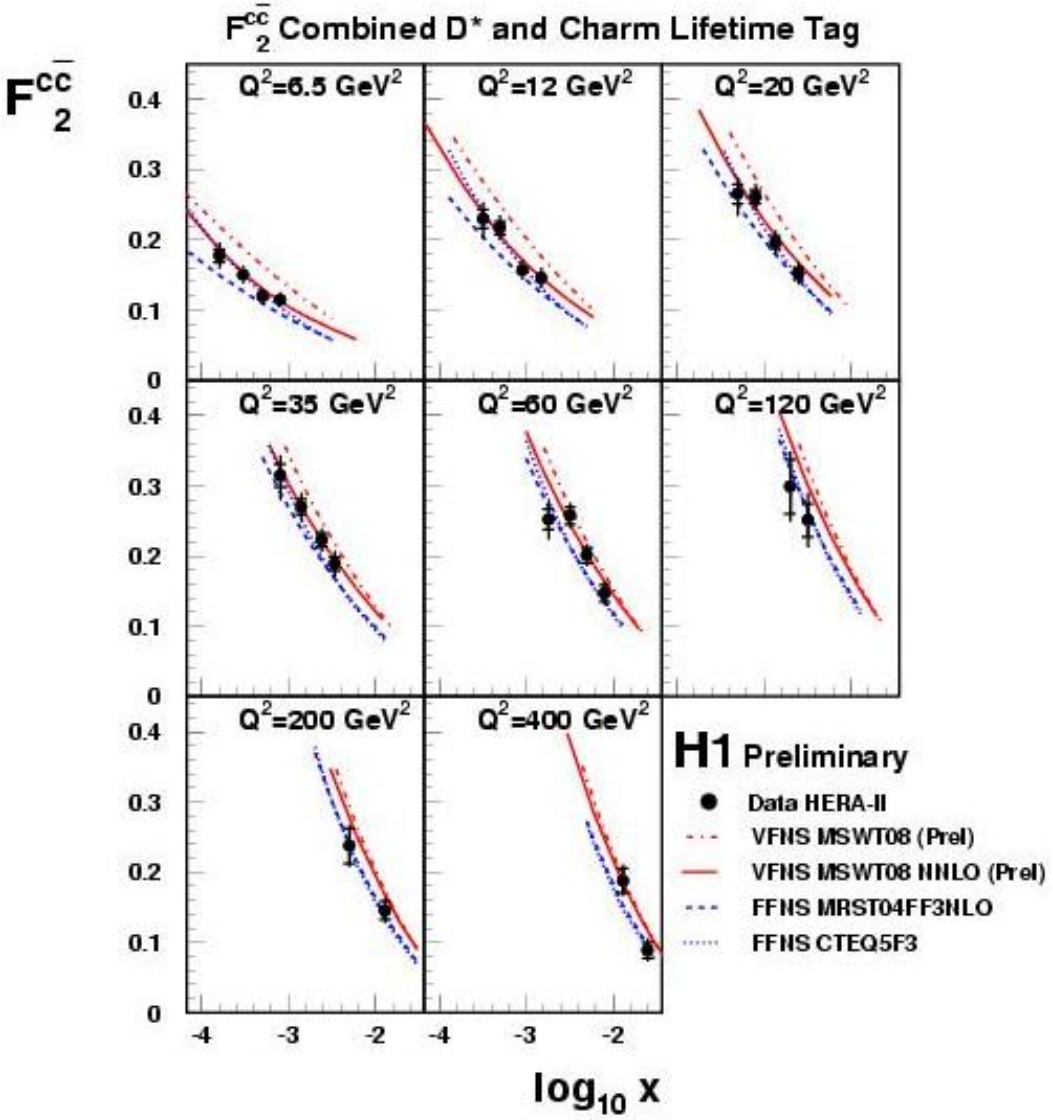
-Inclusive lifetime tagging [>70%]

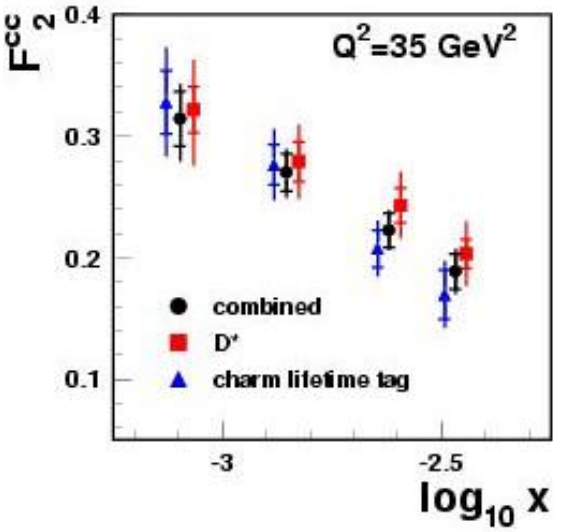
-Mu ptrel+δ [25-50%]

-D* cross sections [20-70%]

- Different methods agree well
- Combine to improve precision ⇒

Combined D* and lifetime tag





- Combine measurements, taking into account statistical and correlated systematic errors

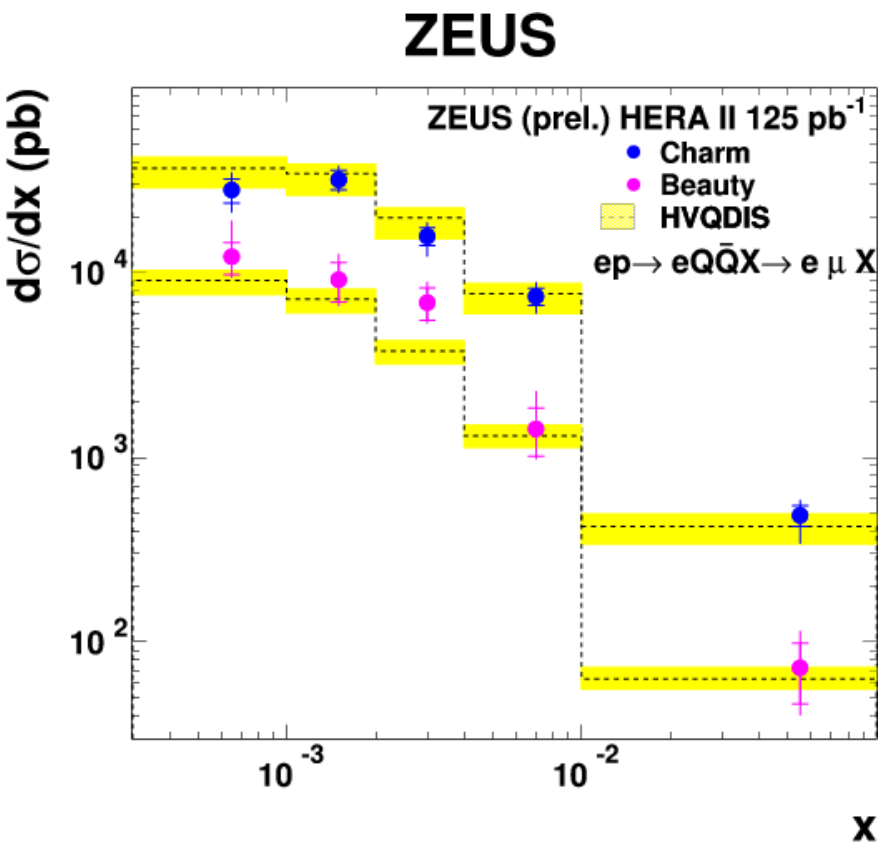
- Measurements sensitive to the different QCD predictions

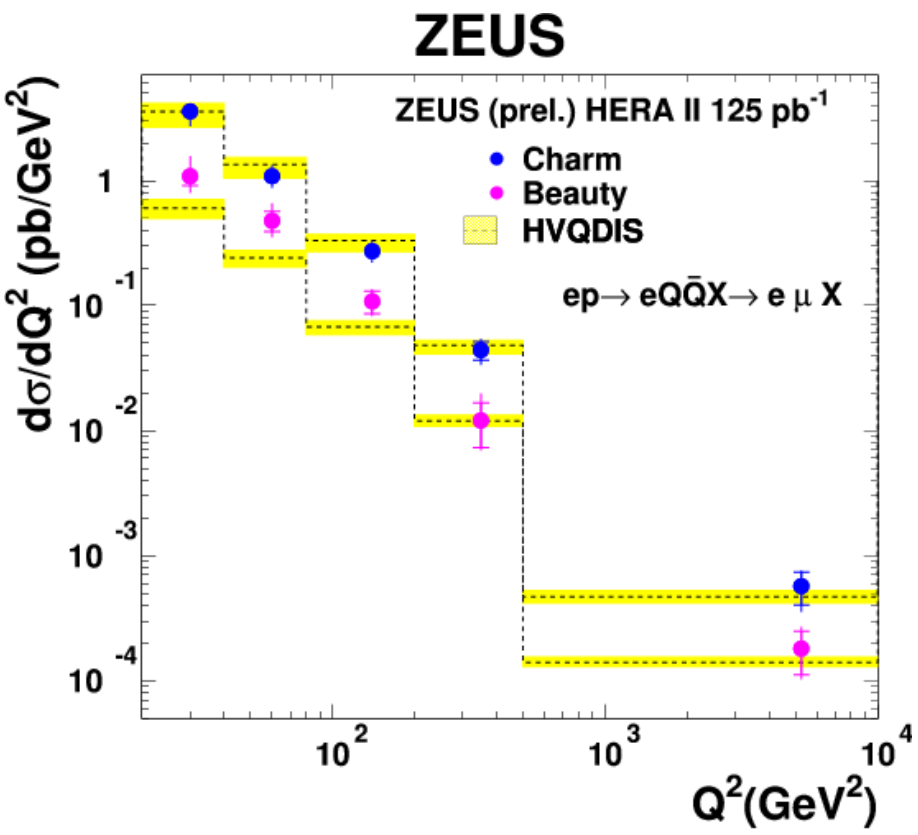
Conclusions

- Wealth of new measurements of the charm content of the proton from HERA I and HERA II data.
- Extraction of structure functions F_2^{cc} allow comparison of many different measurement techniques.
- Data are described by (N)NLO pQCD calculations.
- Data help to constrain theory mass treatments and PDFs (in time for LHC!).
- Final results to come with full HERA statistics.

Back Up

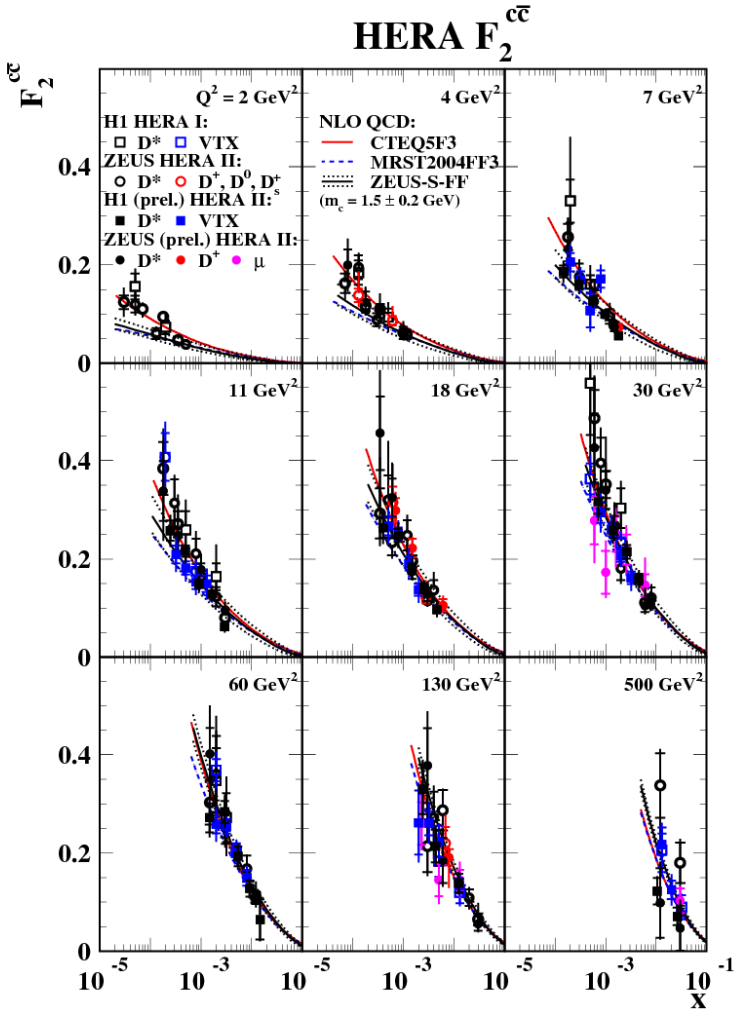
Charm and Beauty Cross Section

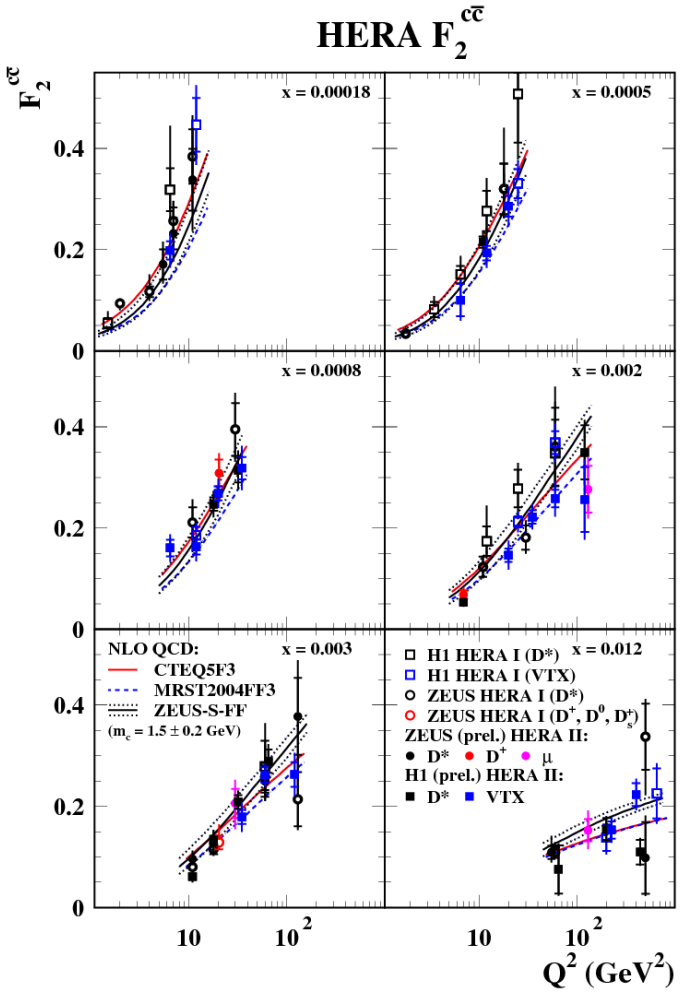




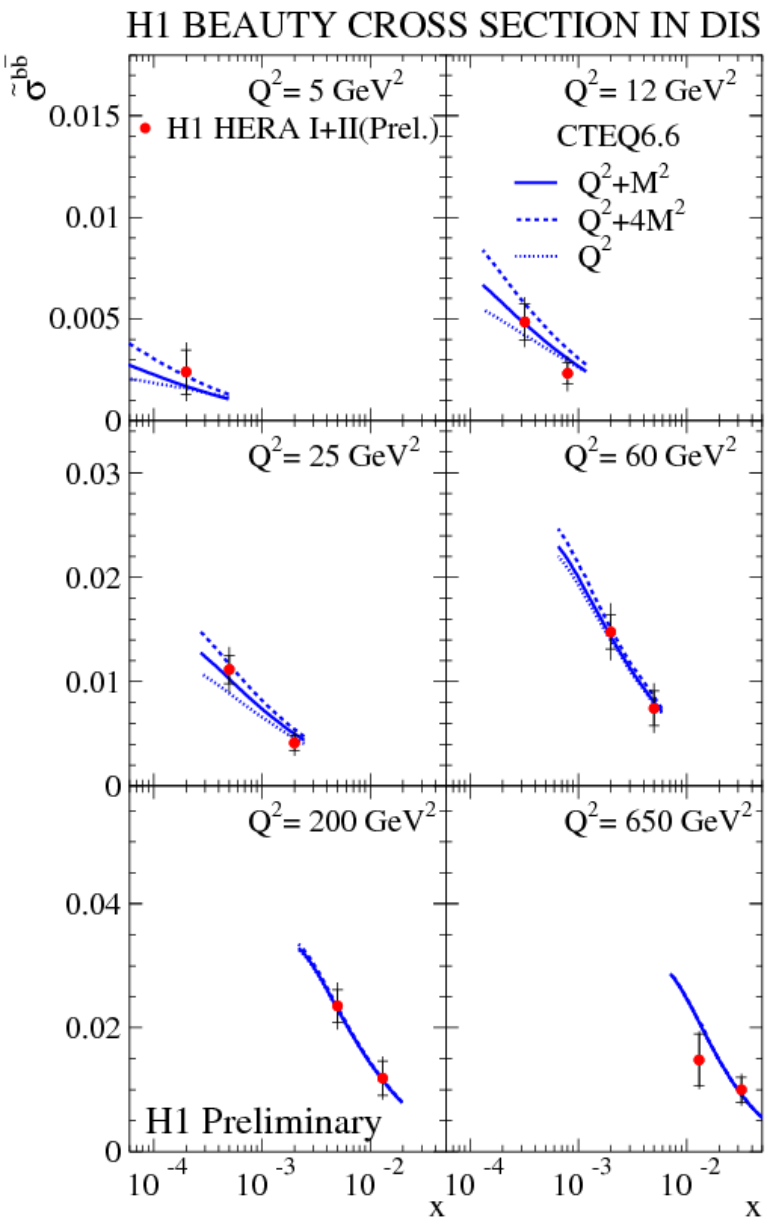
- beauty tends to be above NLO QCD at low Q^2
- may be measured double differentially in x, Q^2 and extrapolated to full phase space to compare F_2^{cc}, F_2^{bb}

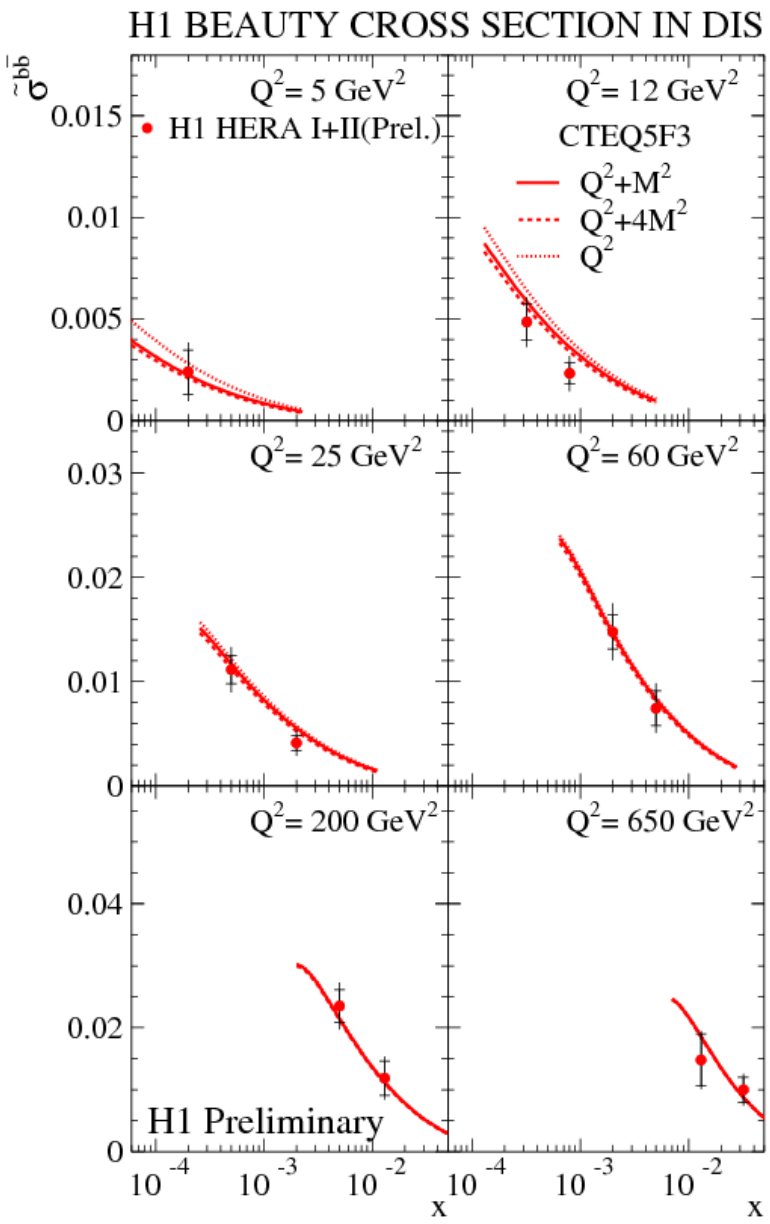
Scale Uncertainty (c)





Scale Uncertainty (b)

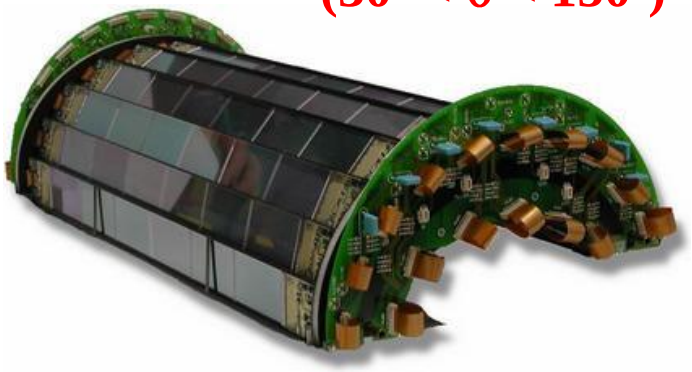




H1 Vertex Detector

CentralSiliconTracker

($30^o < \theta < 150^o$)

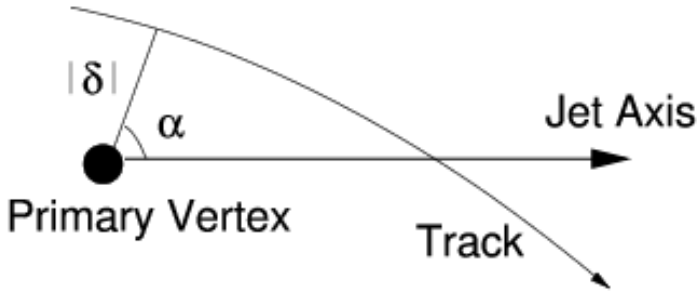


- Rebuilt to take into account HERA II beamline
- Double layer double sided strips
- Precise determination of impact parameter in transverse plane
- Resolution of $|\delta|$ for hits in both layers:

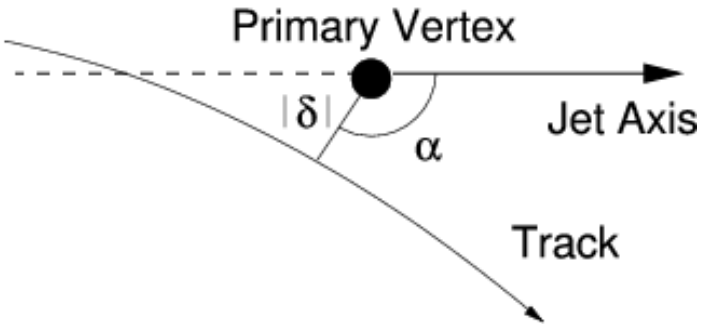
$$33\ \mu\text{m} \oplus \frac{90\ \mu\text{m}}{P_T\ /\ \text{GeV}}$$

Signed impact parameter δ

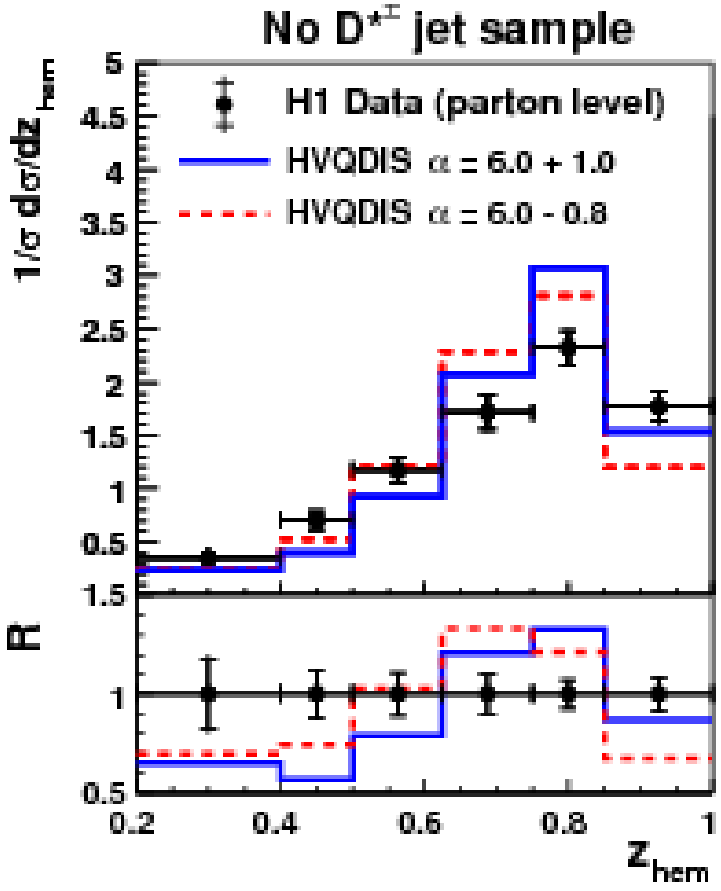
$\alpha < 90^o \rightarrow \delta = +|\delta|$



$\alpha > 90^o \rightarrow \delta = -|\delta|$



D* Fragmentation



Neural Network

- Improve separation power: use neural network for >= 3 tracks
- Inputs: S_1, S_2, S_3, S_L, track p_t, number of (SV) tracks
- Sign given by S_1. Subtract –'ve from +'ve to reduce syst. error