Heavy Flavours in DIS

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Outline:

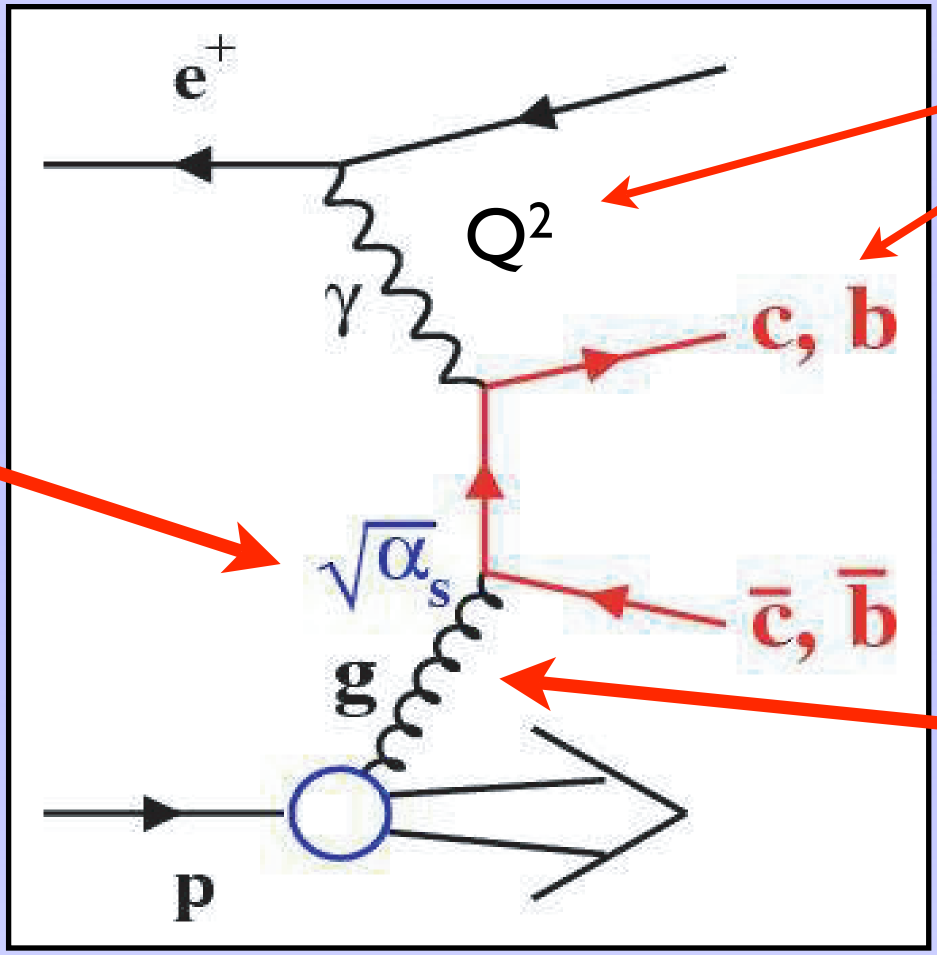
- Introduction
- Charm Production
- Beauty Production
- Structure Functions
- Summary

Heavy Flavour Production

Main Process:

Boson Gluon Fusion

- at least one hard scale
→ α_s small
- test different pQCD models and schemes



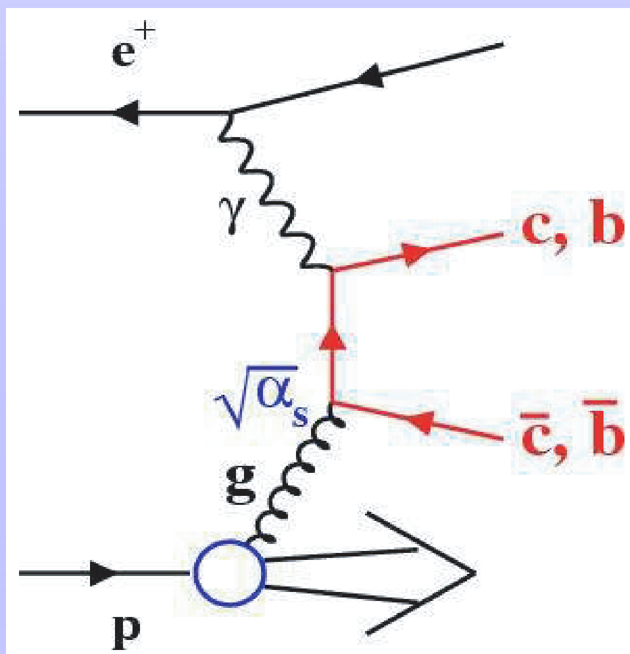
investigate multi-scale problem

sensitive to gluon density of the proton

Theoretical Approches

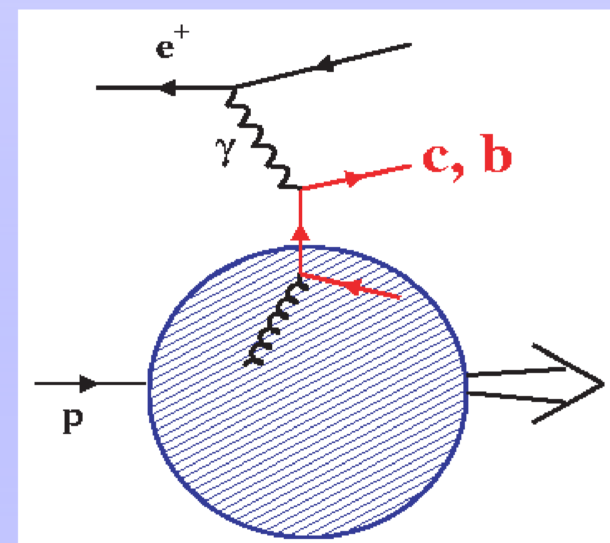
massive scheme (FFNS)

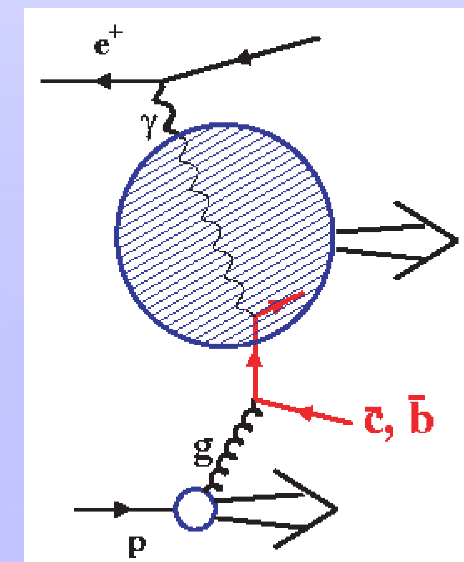
- fixed order calculation
- heavy quarks are produced in the hard process
- neglecting: $\left[\alpha_s \ln(Q^2/m_c^2)\right]^n$
- valid at: $m^2_{c/b} \sim Q^2$



massless scheme

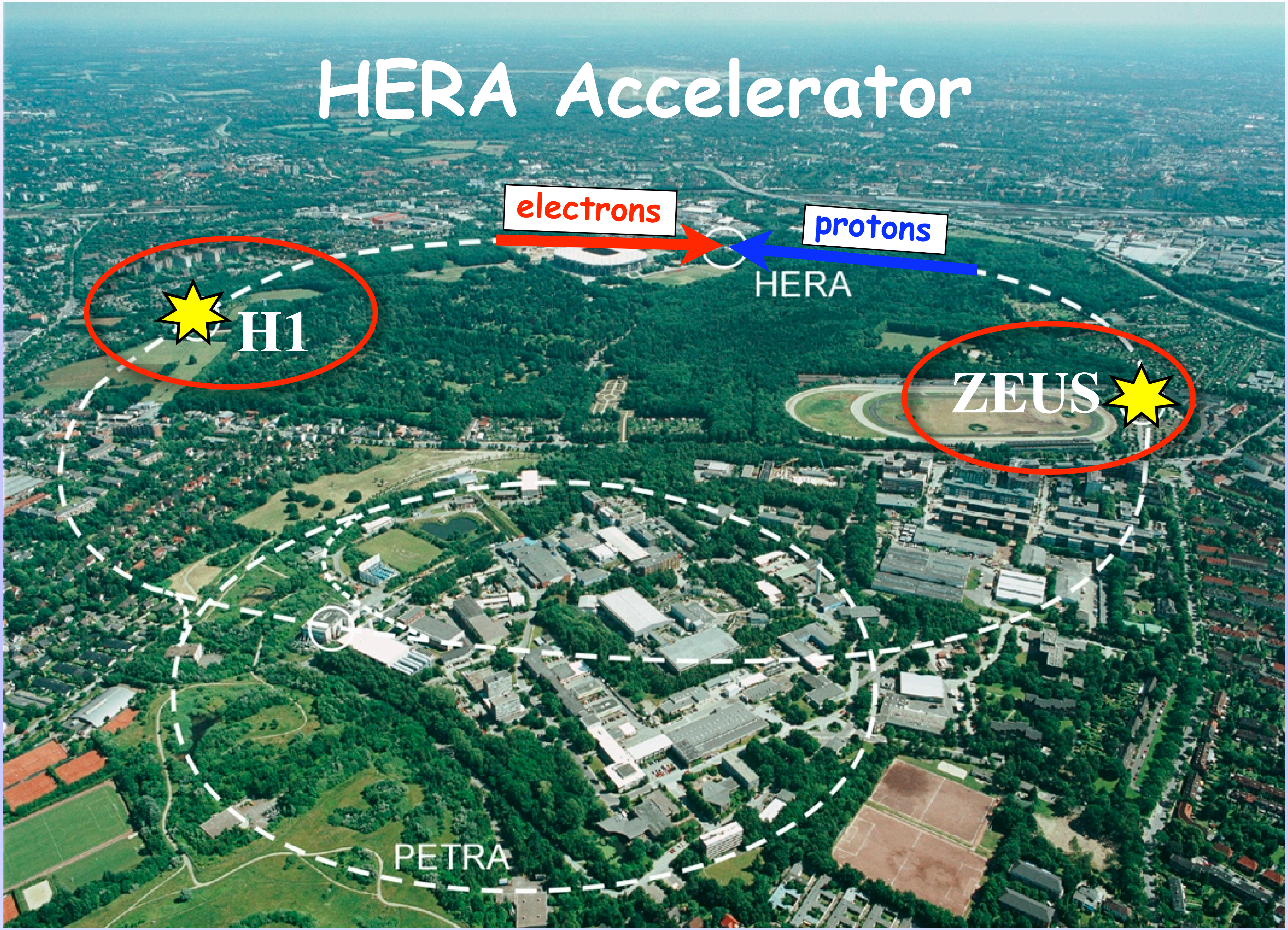
- neglect masses in hard interaction
- heavy quarks intrinsic content of proton/photon
- Resums: $\left[\alpha_s \ln(Q^2/m_c^2)\right]^n$
- valid at: $m^2_{c/b} << Q^2$





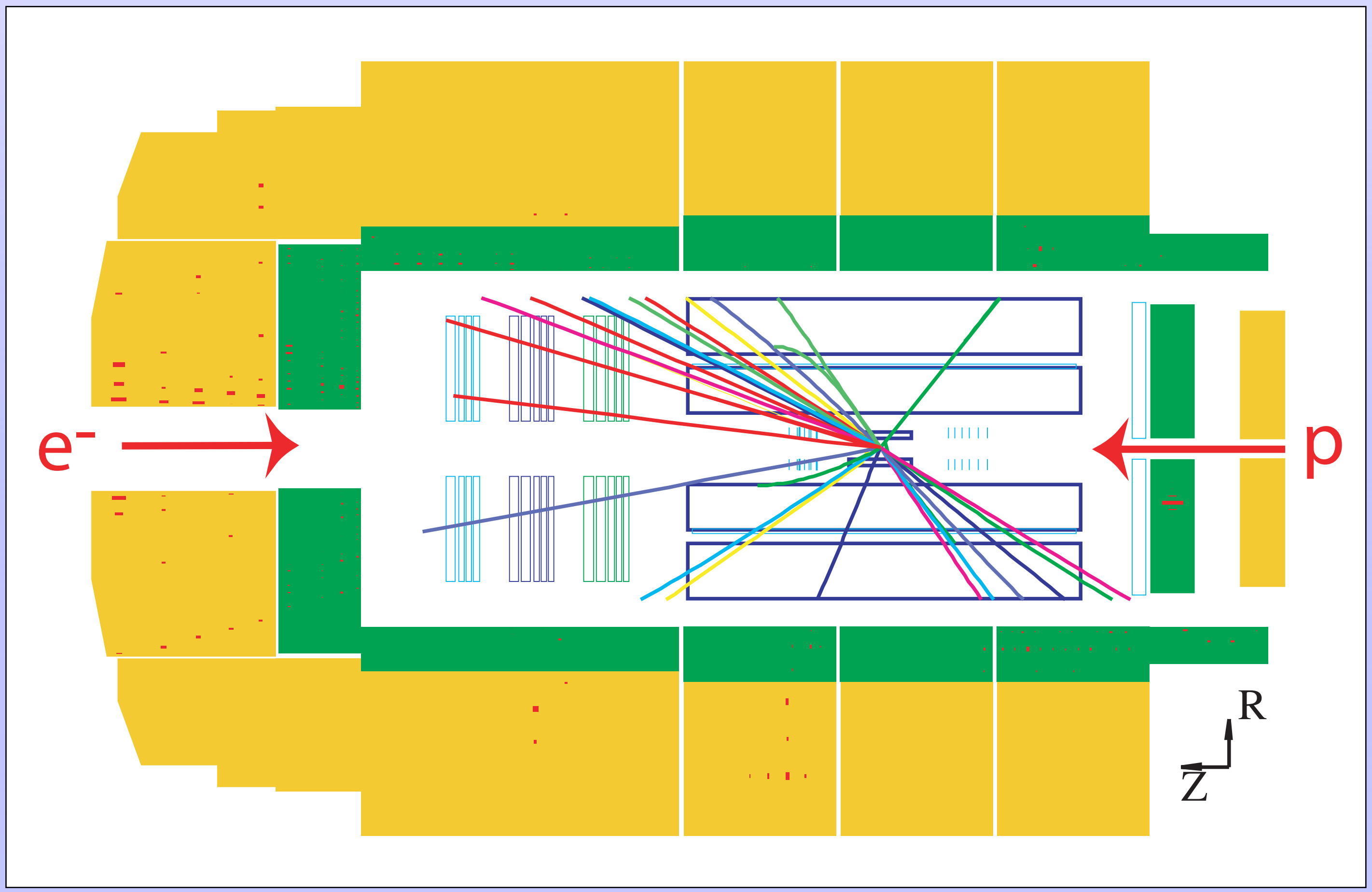
intermediate (variable) scheme (VFNS)

- low Q^2: massive scheme
- intermediate Q^2: interpolation
- high Q^2: massless scheme

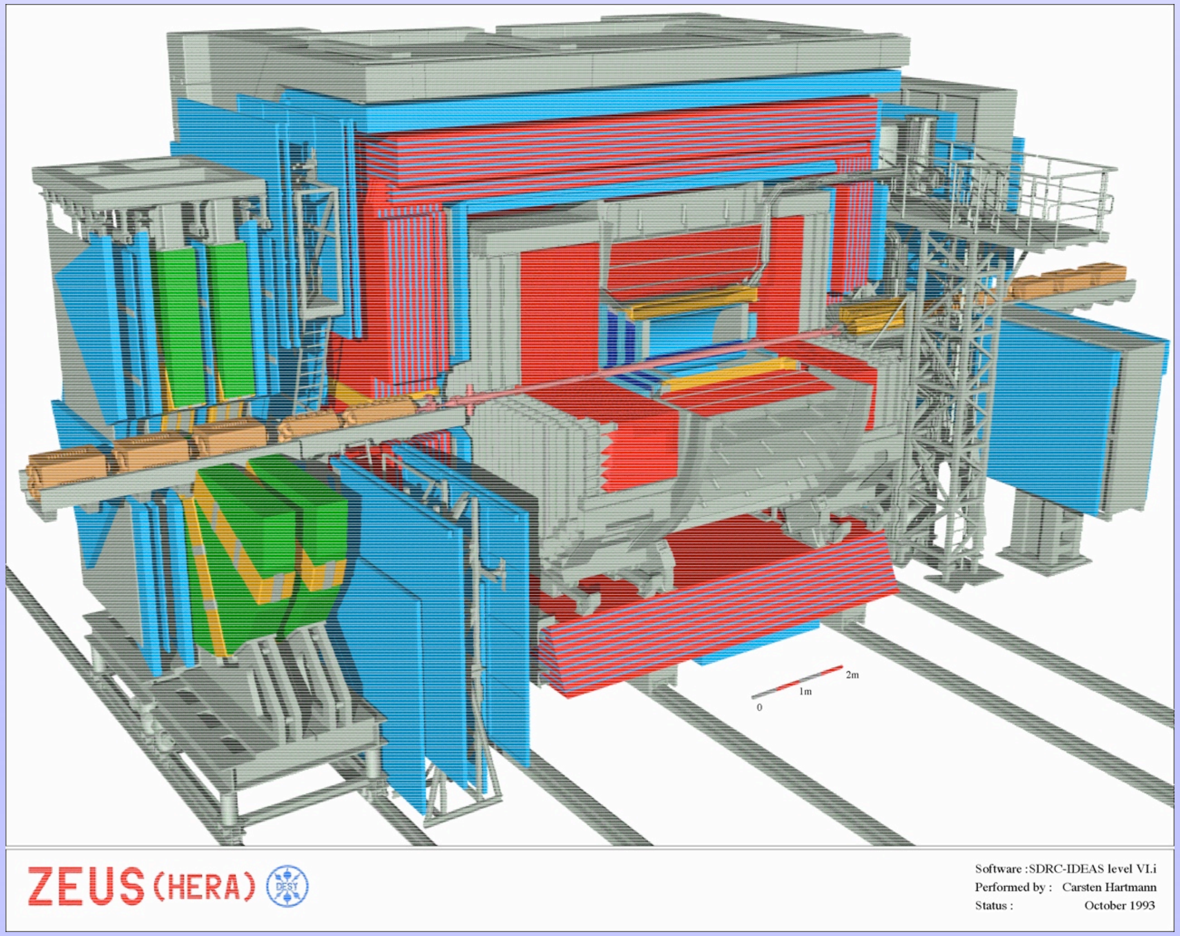

HERA Accelerator
electrons
protons
HERA
H1
ZEUS
PETRA

The Detectors

H1



ZEUS



- 27.6 on 920 GeV -> $\sqrt{s}$ = 319 GeV
- multi purpose detectors
- 4 π coverage

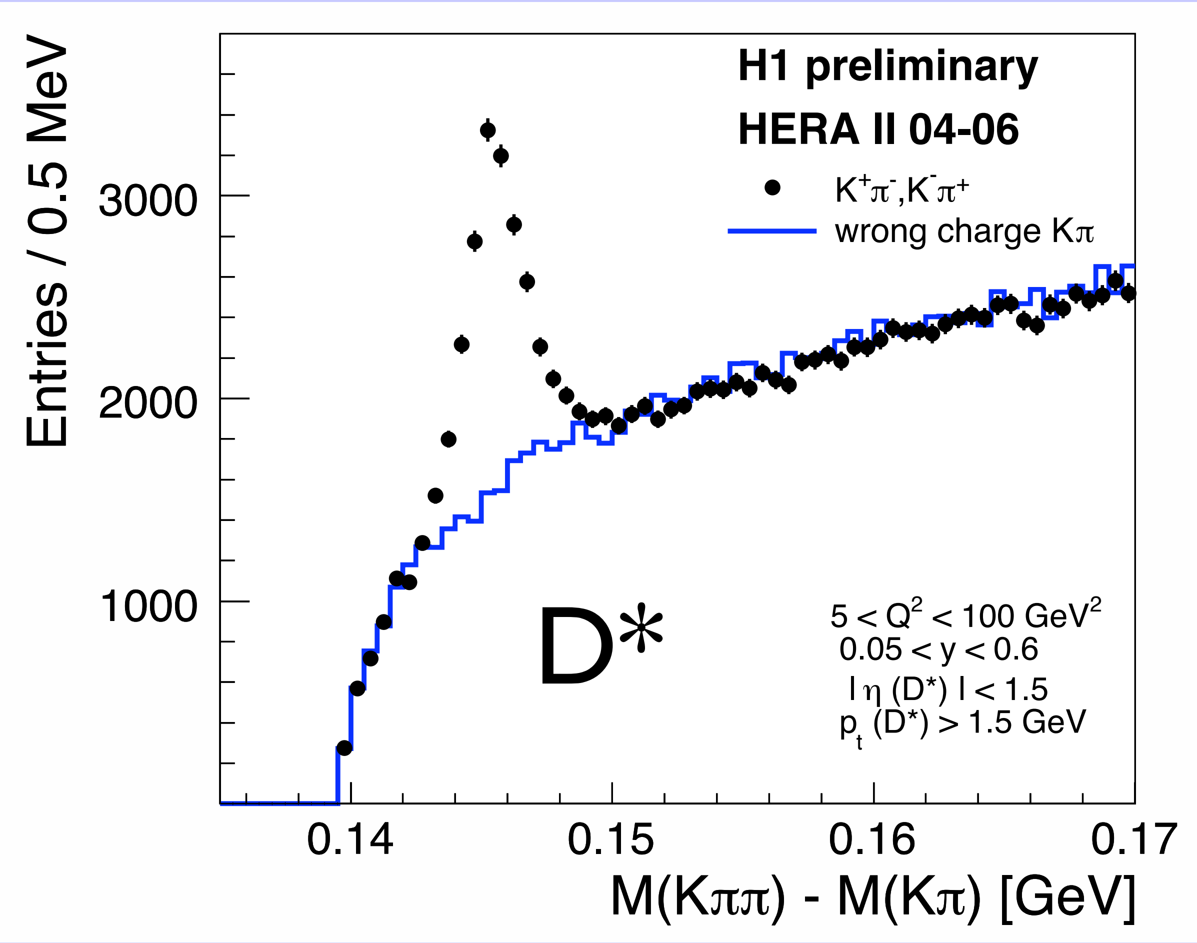
- onion shape layout:
  - vertexing
  - tracking
  - calorimeters
  - muon chambers

Charm Tagging

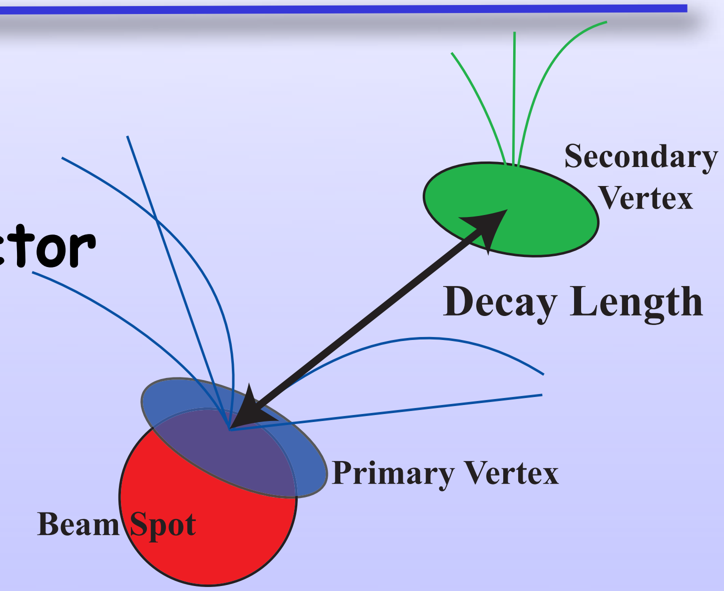
1.) via resonance decay

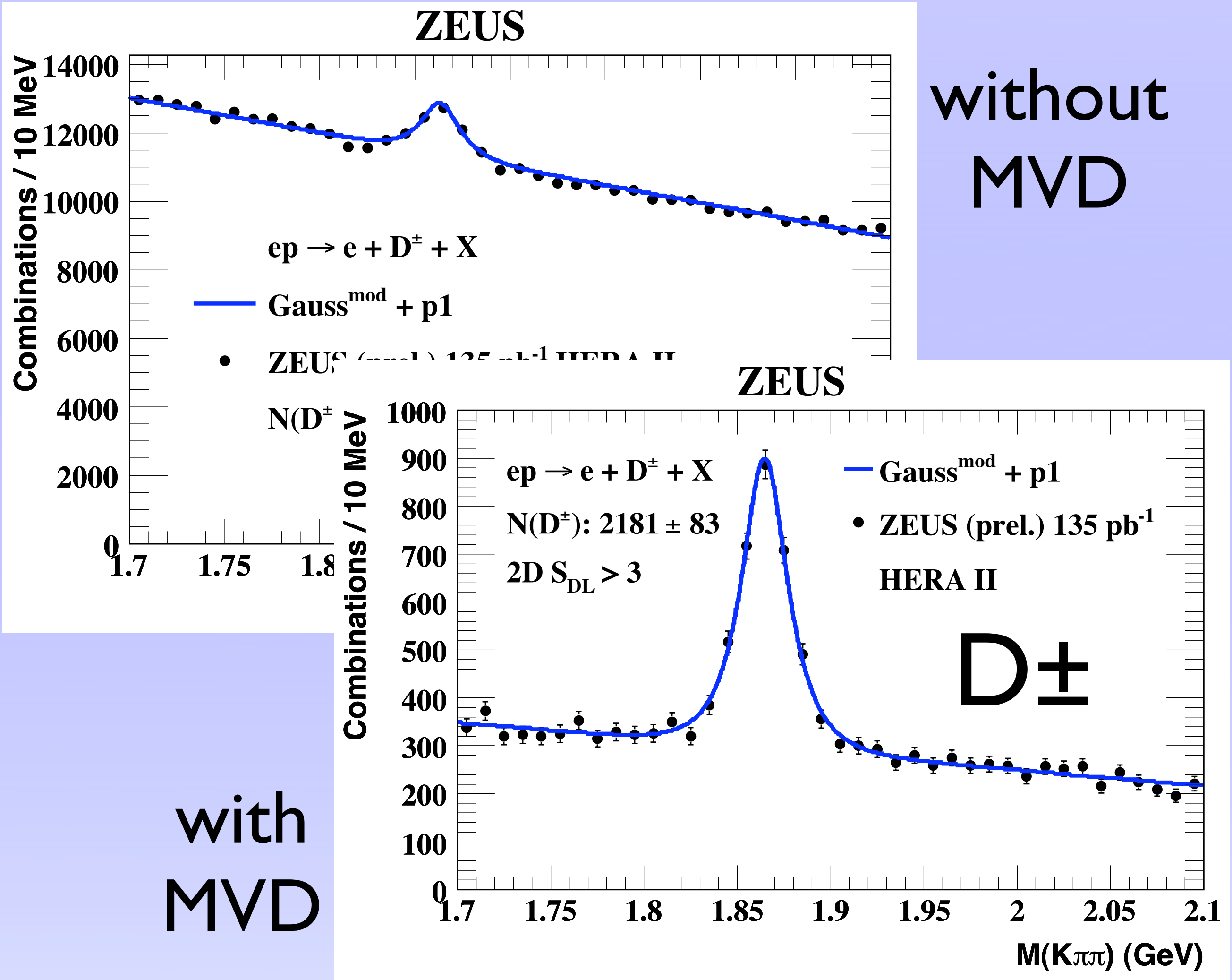
$$D^{\star} \rightarrow D^{0}\,\pi_{slow} \rightarrow K\,\pi\,\pi_{slow}$$

Plot: $\Delta M = M\,(K\,\pi\,\pi_{slow}) - M\,(K\,\pi)$



2.) via lifetime using a silicon vertex detector



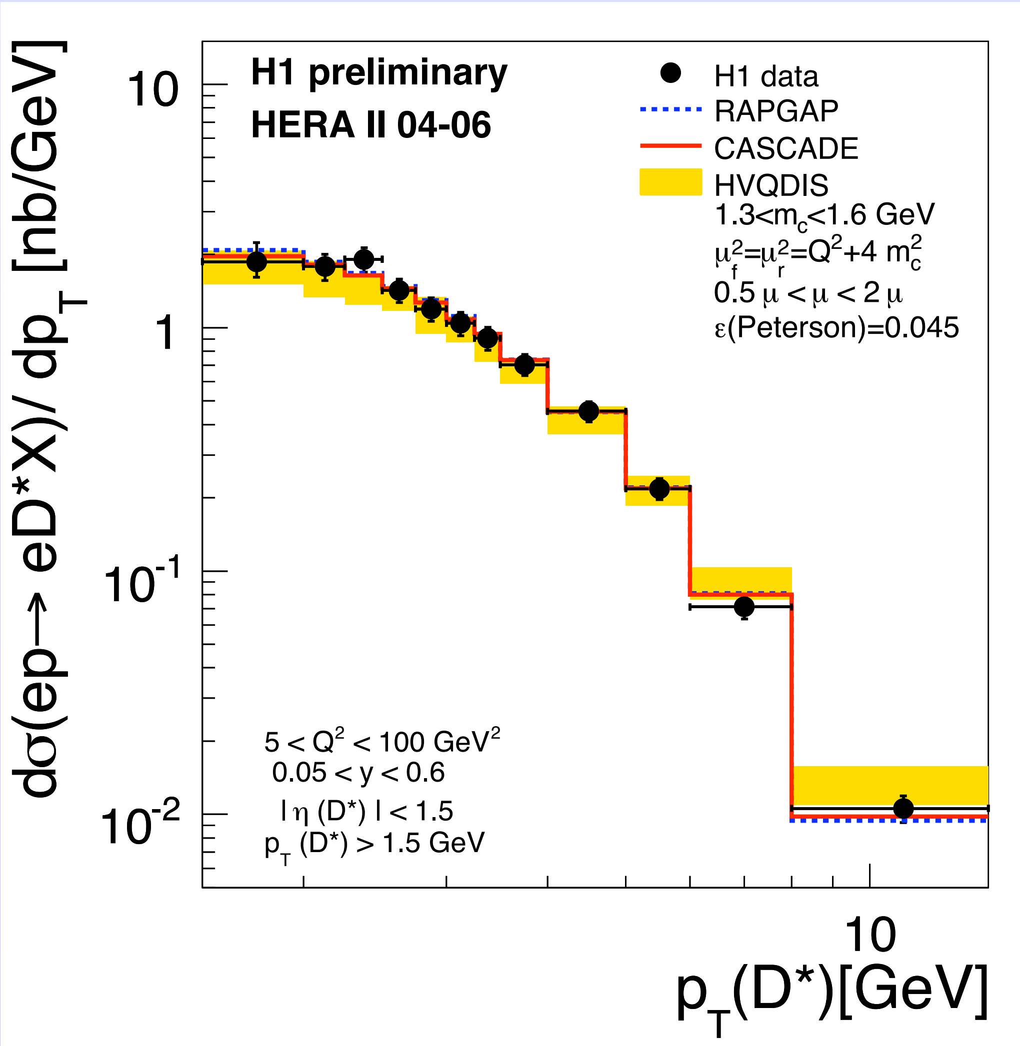


without MVD

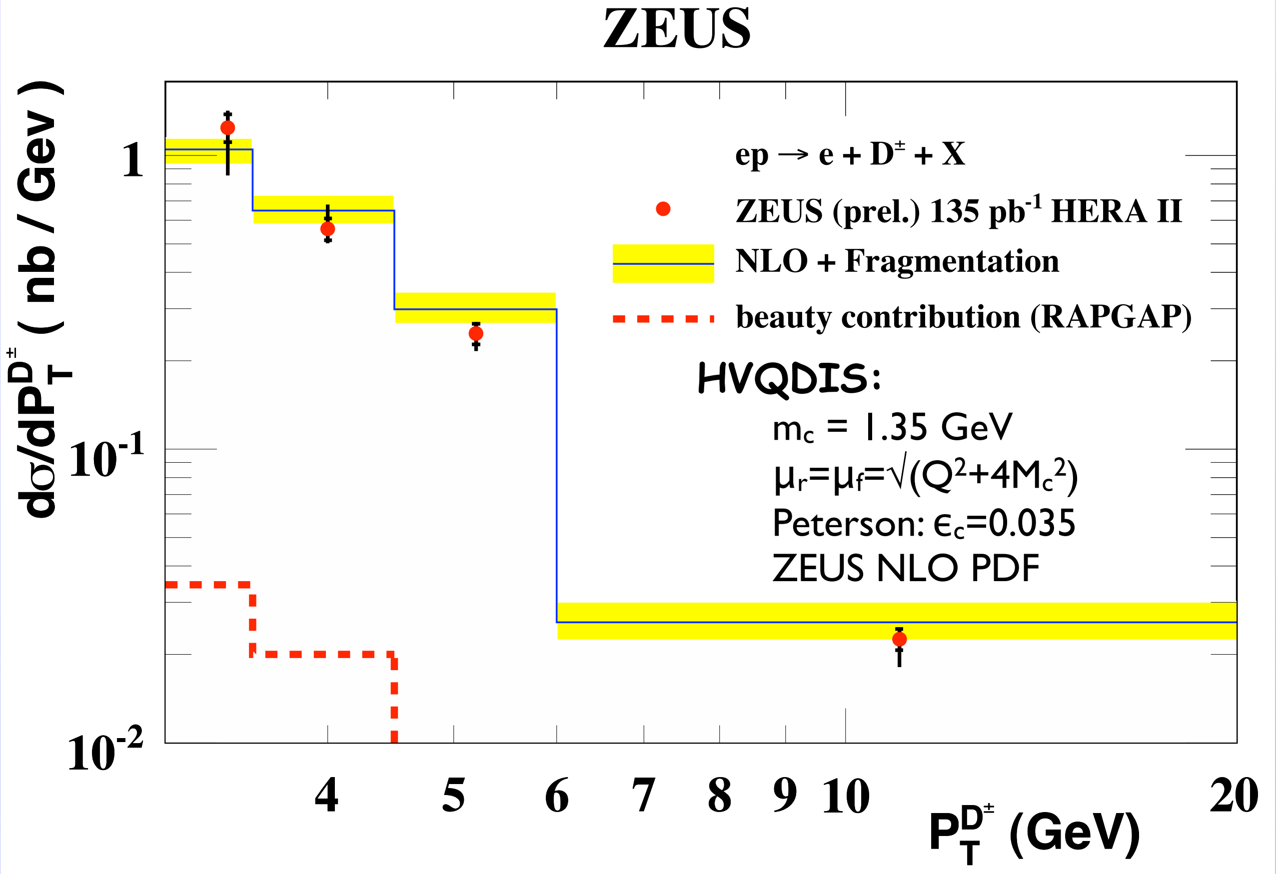
with MVD

Charm Cross Sections

D* data



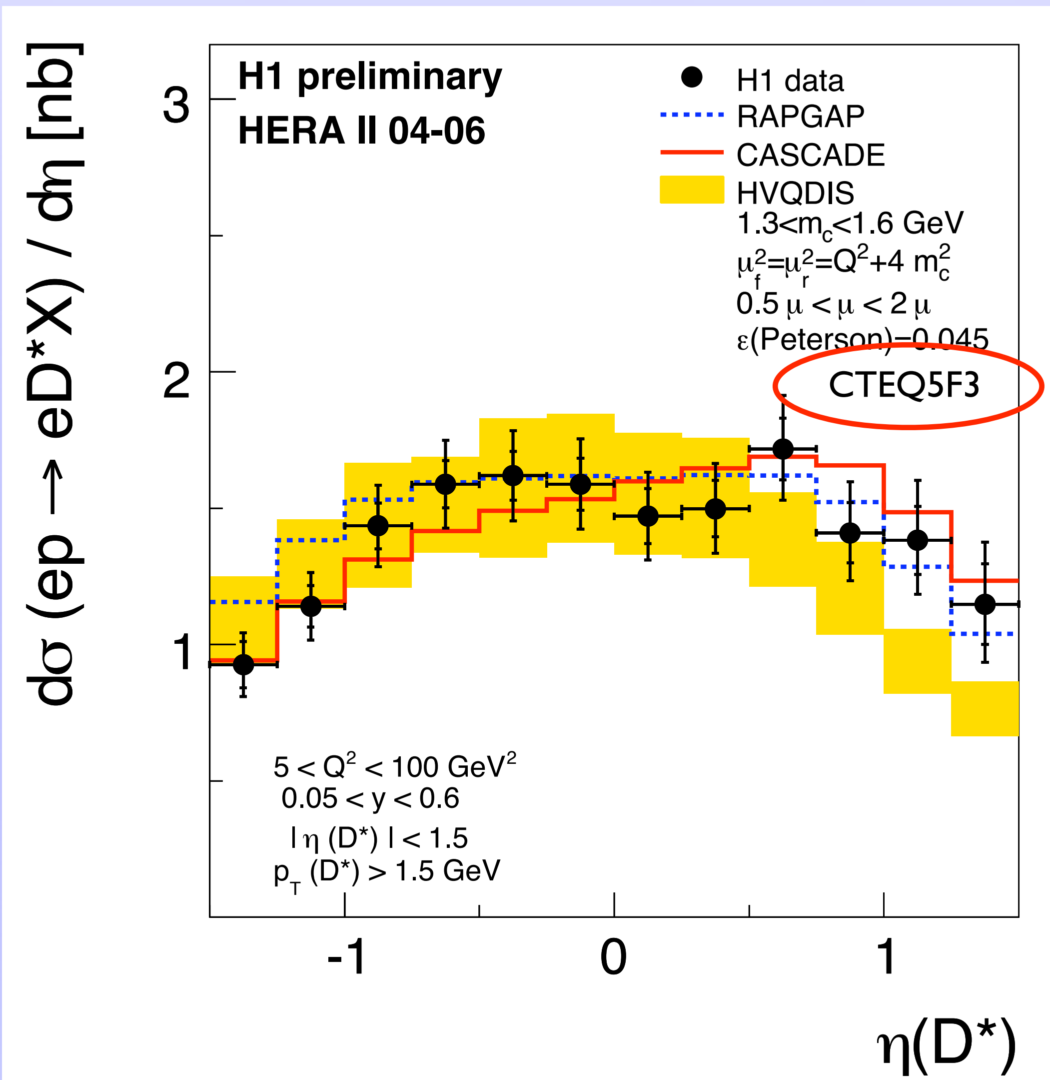
D± data



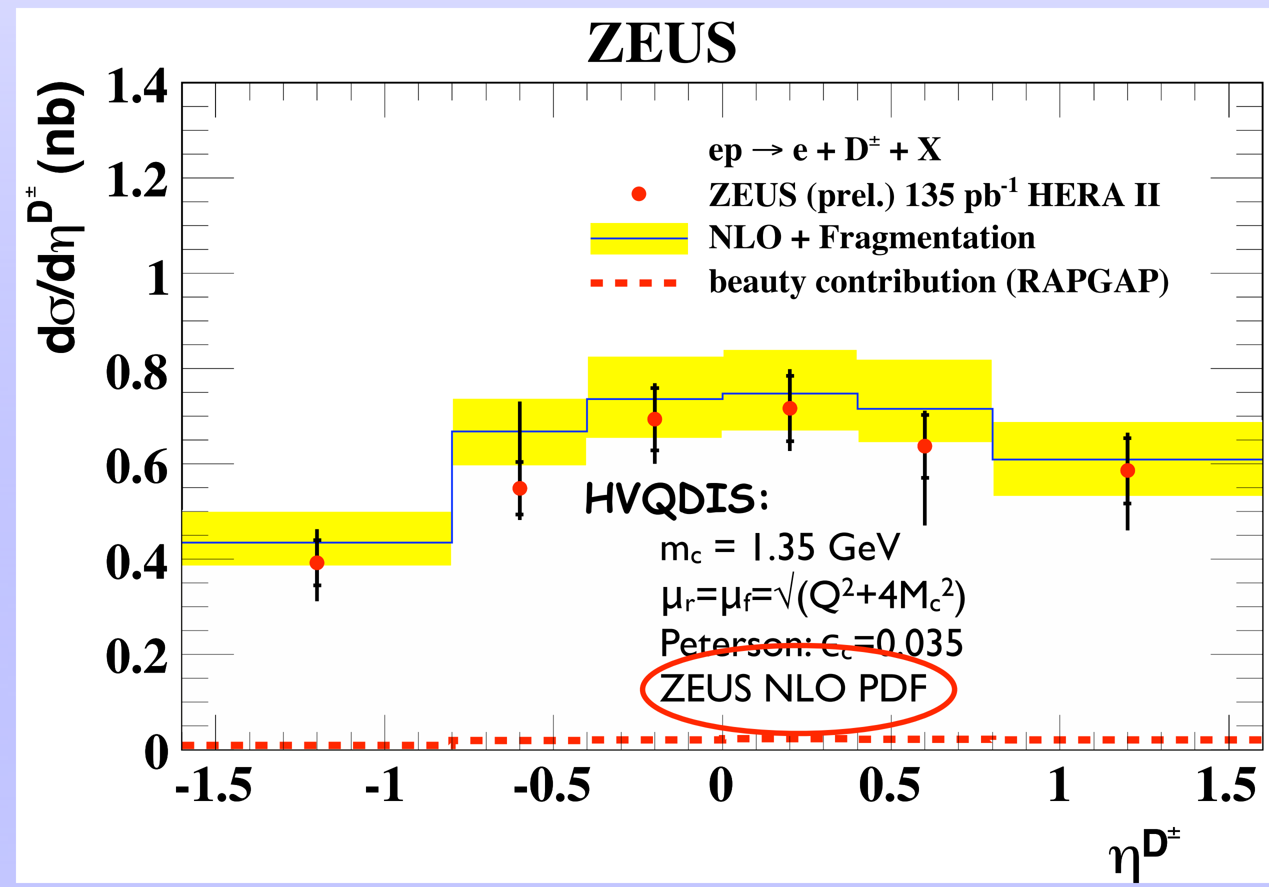
- uncertainty reduced compared to HERA I analysis
- data described by the MC & NLO prediction:
  HVQDIS: massive NLO calculation (FFNS)
- HVQDIS seems to be slightly too flat
- **H1:** HVQDIS tends to be too low (different charm mass)

Charm Cross Section (ii)

D* data



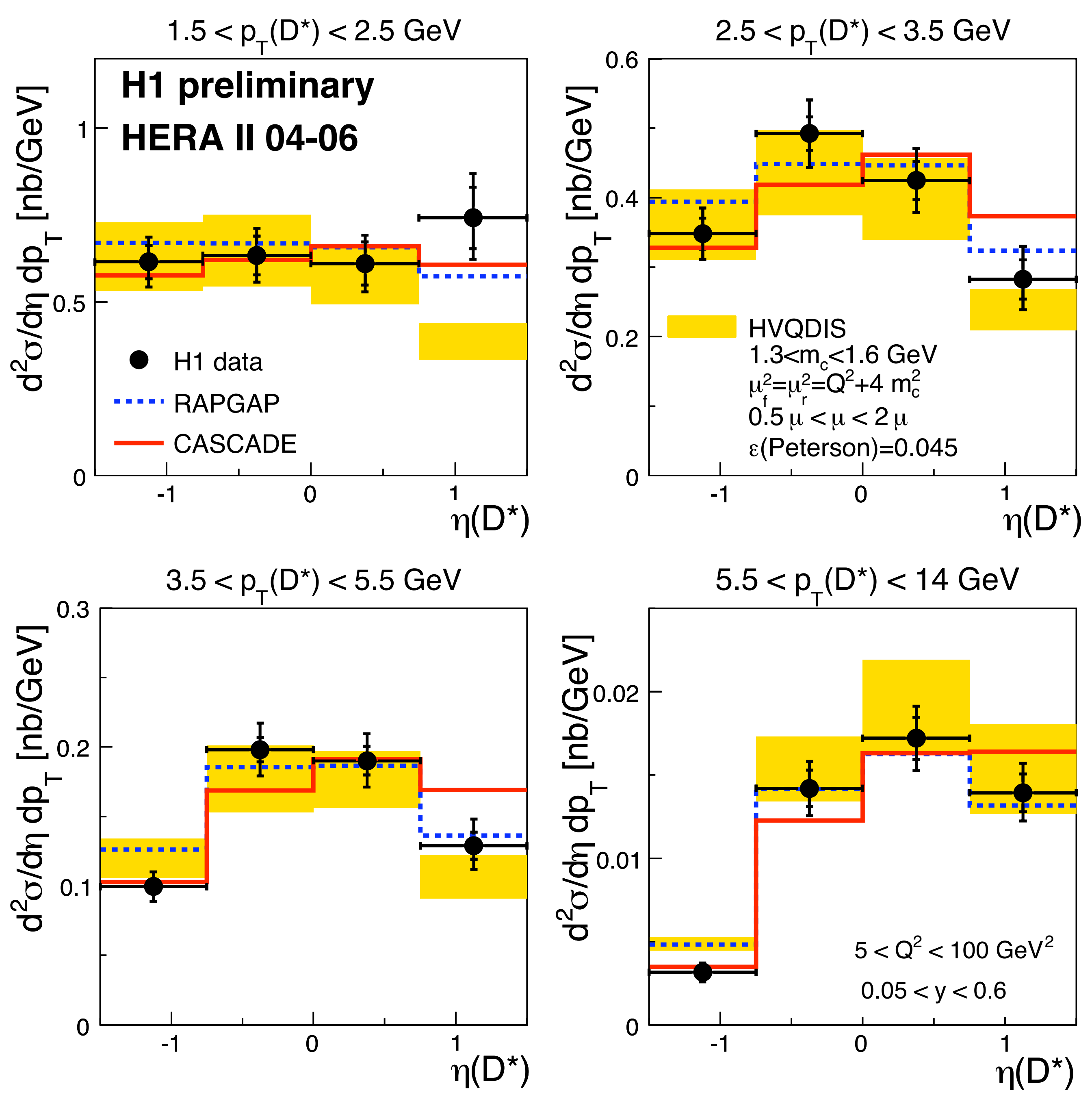
D± data



- MC describes the data
- HVQDIS fails in forward direction
- perhaps due to different Proton PDF

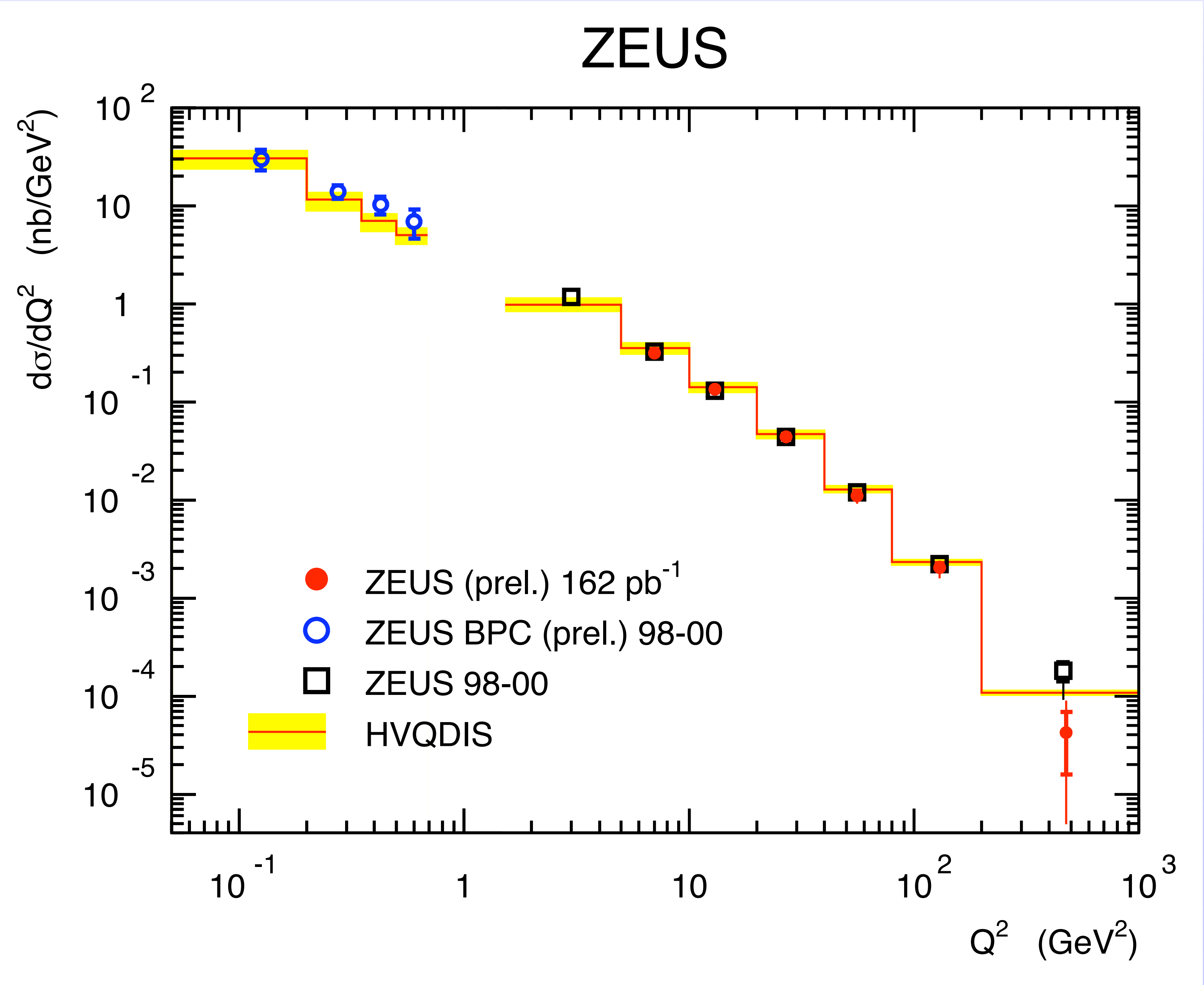
- well described by HVQDIS

D* Cross Section (ii)



- deviation in forward η localised at low p_t
- otherwise HVQDIS describes the data

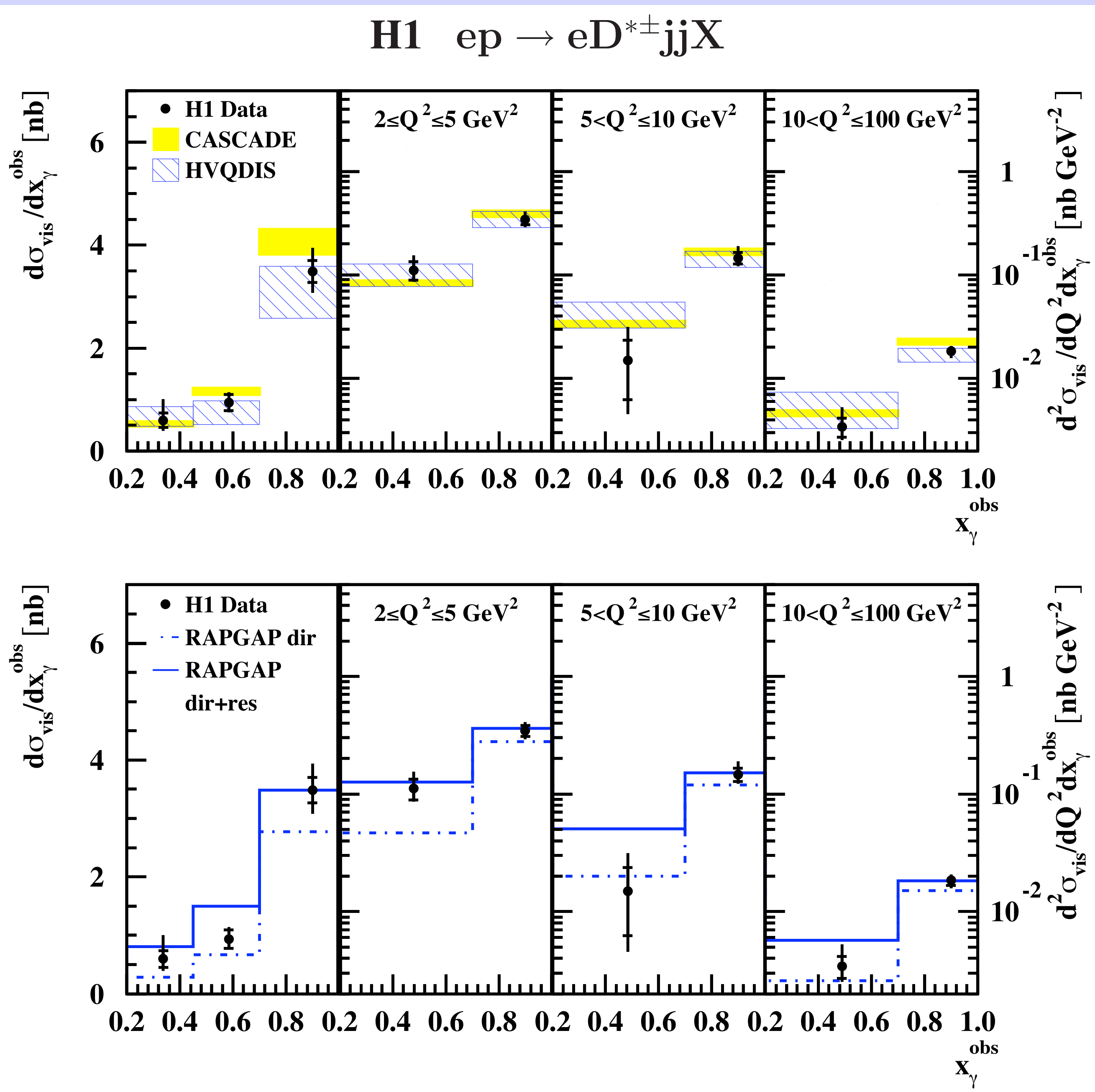
D* production

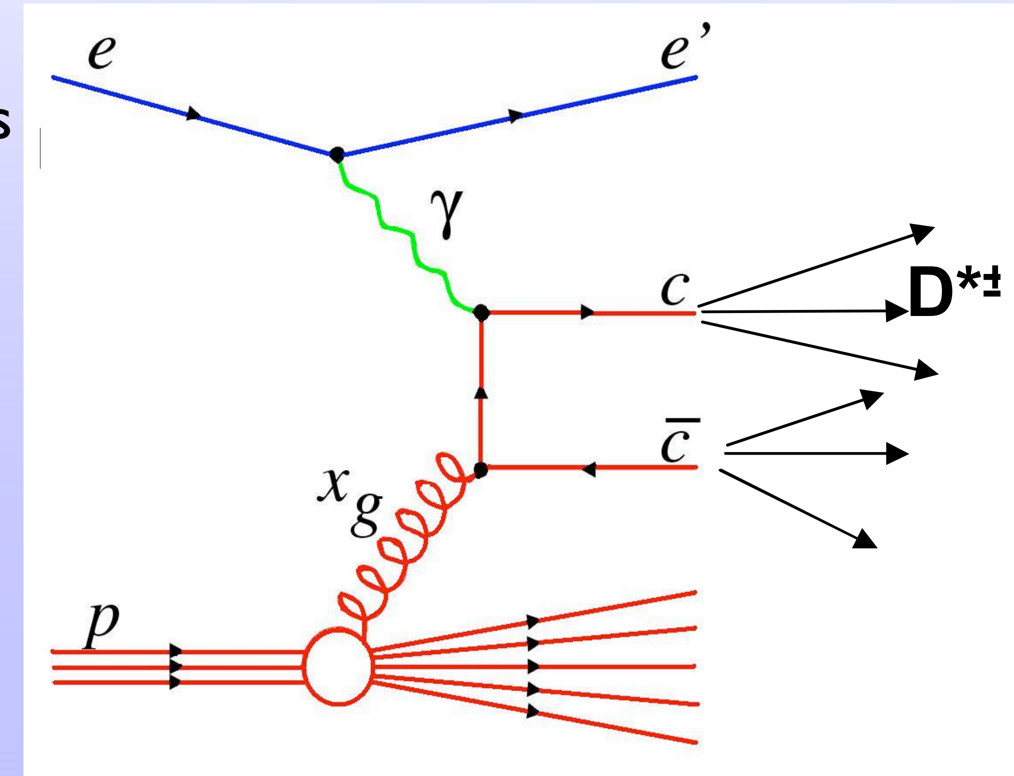


very nice agreement over 4 orders of magnitude in Q^2

D* + dijet production

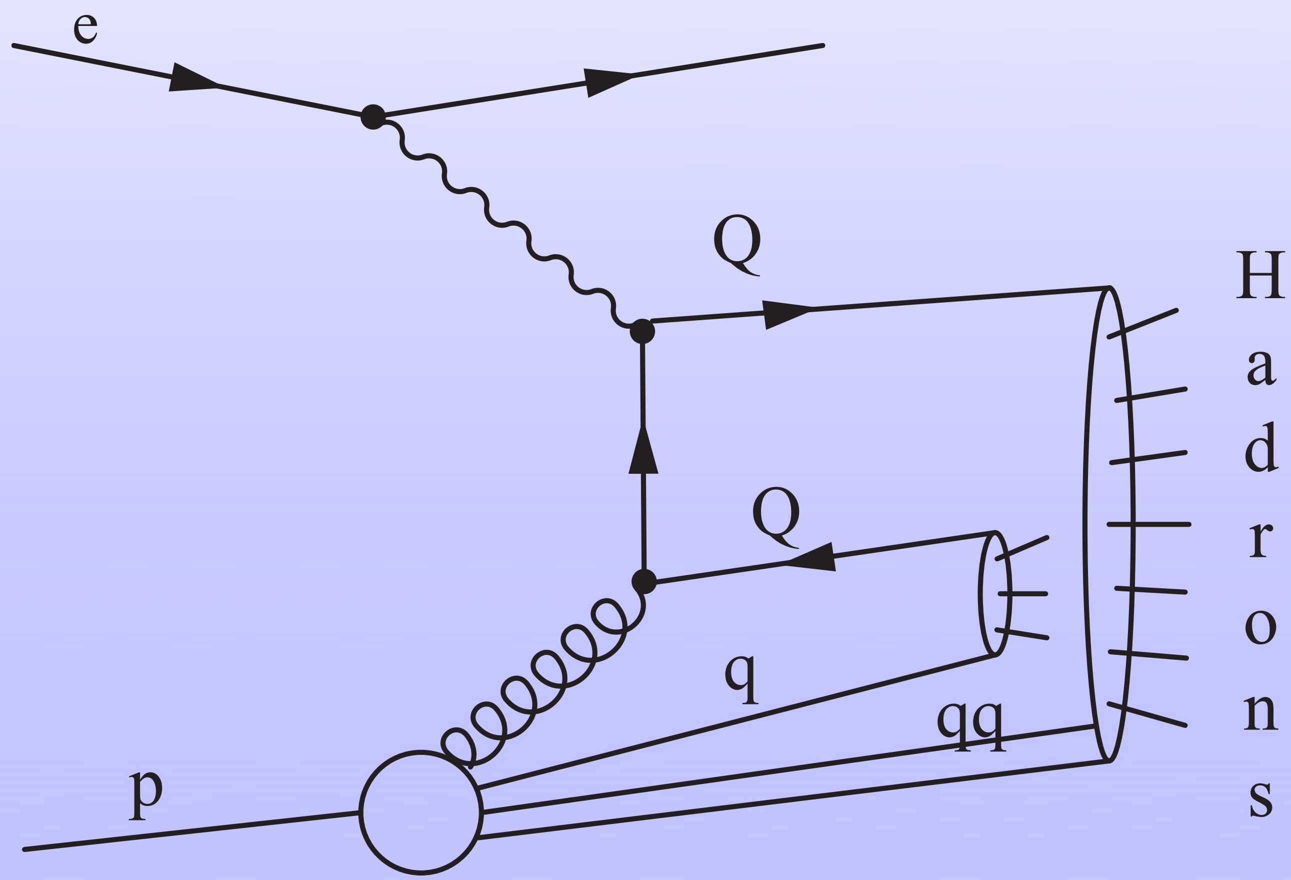
- charm tagging with D* mesons
- use the two jets to fully reconstruct the two charm quarks
- x_γ^{obs}: momentum fraction of photon entering hard process





- HVQDIS agrees with the data
- no additional resolved photon contributions needed
- CASCADE equally good
- RAPGAP needs resolved photon contributions at **low Q^2 only**

Charm Fragmentation



- charm production well described by pQCD
- transition from quarks to hadron often use non-perturbative fragmentation functions
- expected to be universal
- Peterson FF: $D_Q^H = \dfrac{N}{z\left[(1-(1/z))-\epsilon(1-z)\right]^2}$
- free parameter ε_Q "hardness" of fragmentation
- z: energy fraction of charm quark carried by charmed meson

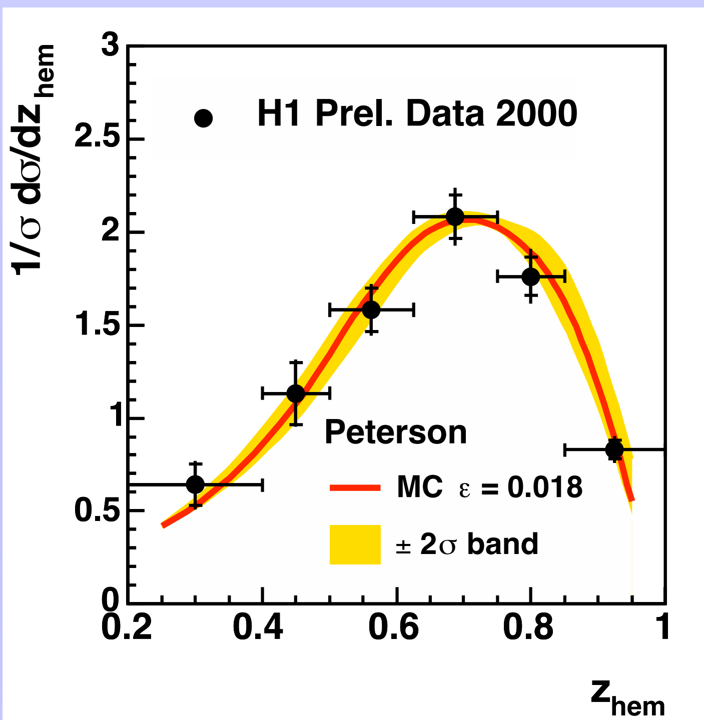
Measurement of ε_Q using D*'s

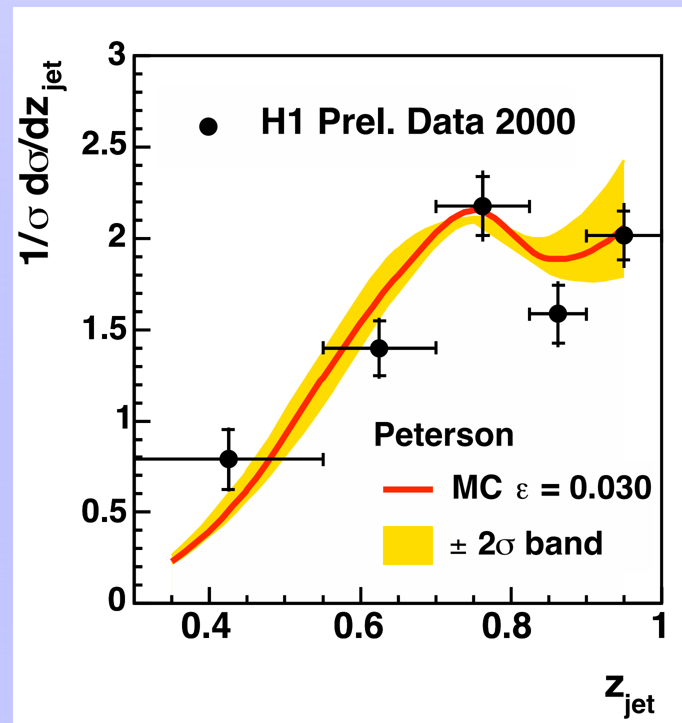
Hemisphere Method:

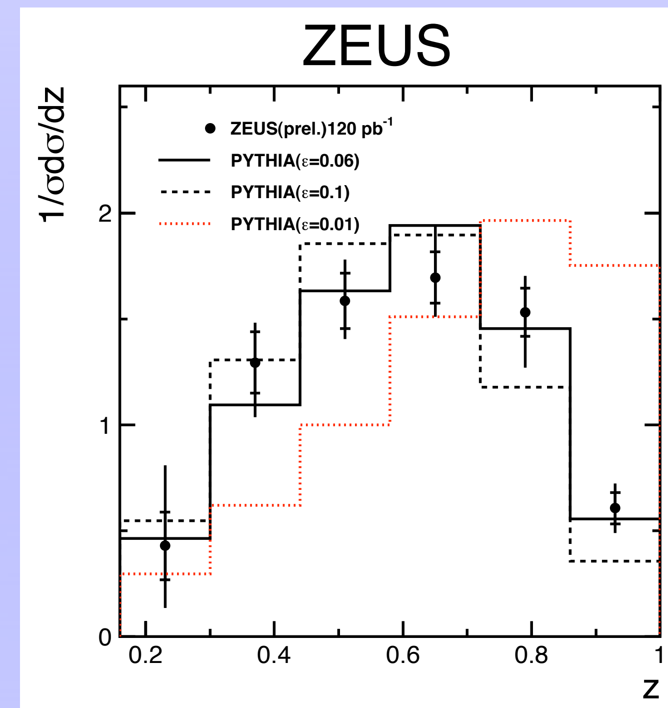
- z determination from energy in D* hemisphere
- kinematic region down to charm production threshold

Jet-Method:

- D* associated jet used for z
- due to jet → higher E_t threshold





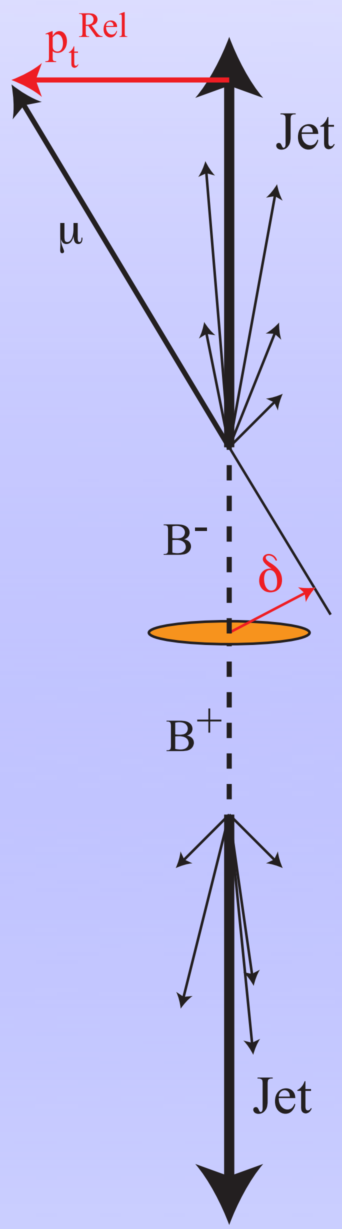


	low p_t (H1)	medium p_t (H1)	high p_t (ZEUS)
$\varepsilon_Q =$	0.018 +0.004 -0.003	0.030 +0.006 -0.005	$0.064 \pm 0.006 \,^{+0.011}_{-0.008}$

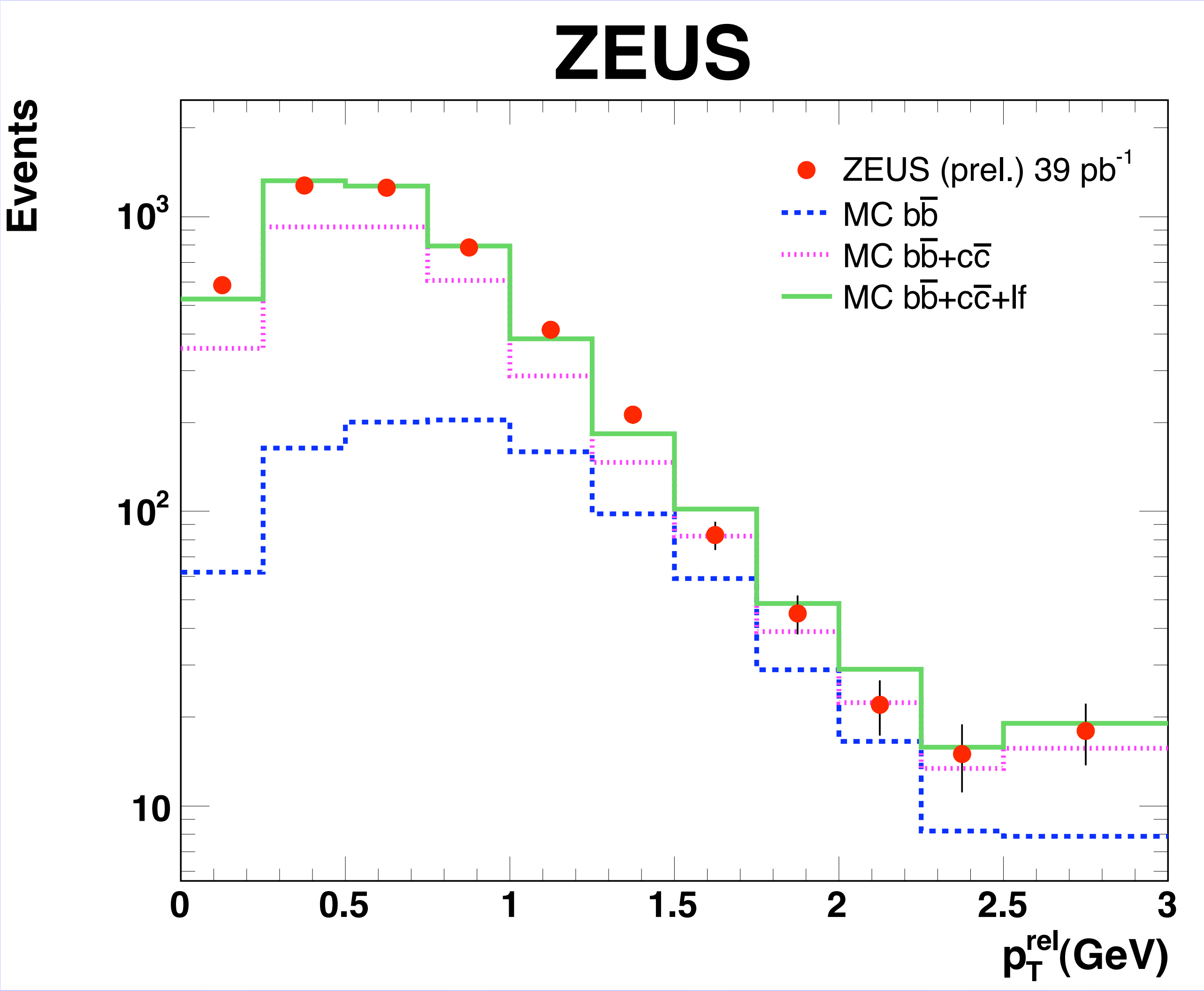
Peterson FF

Beauty with p_t^{rel}-method

process: ep→ebbX→ejjμX'

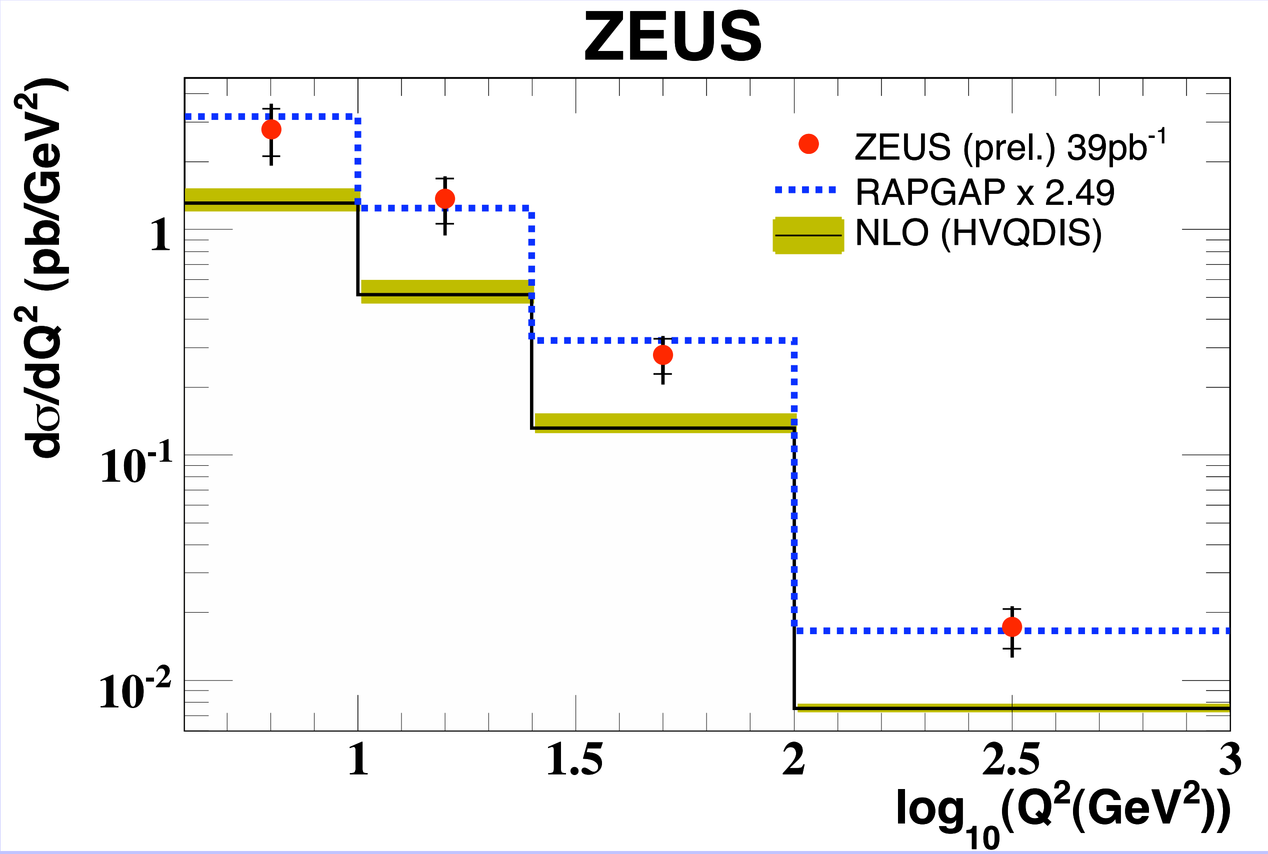


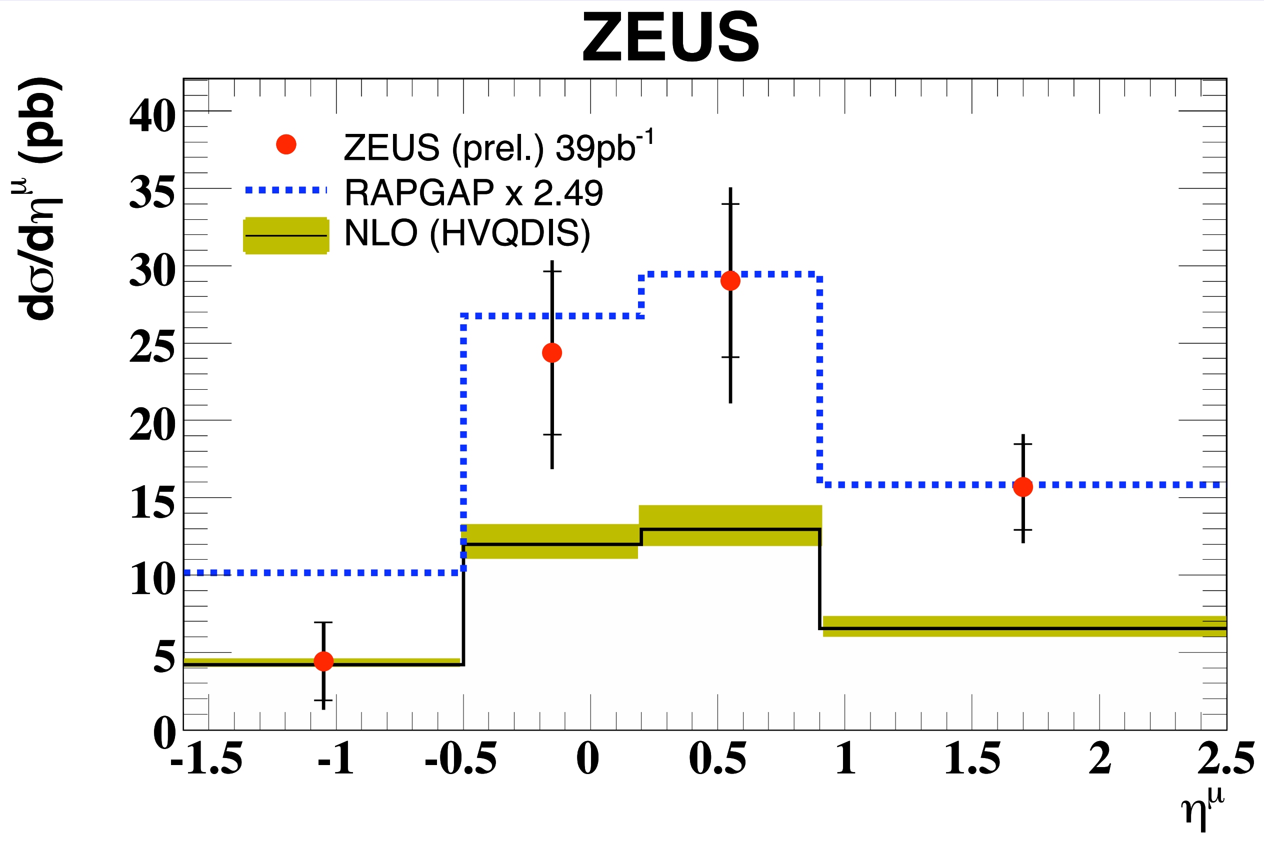
- large beauty mass → large p_t relative to corresponding jet
- light flavour: steeply falling spectrum in p_t^{rel}



- use MC simulation for the shape of the contribution by **uds**, **c** and **b** quarks
- fit the fractions of the 3 contributions such that MC describes p_t^{rel} best

Beauty with p_t^{rel} method (ii)





- data described in shape by the predictions
- but NLO calculation too low

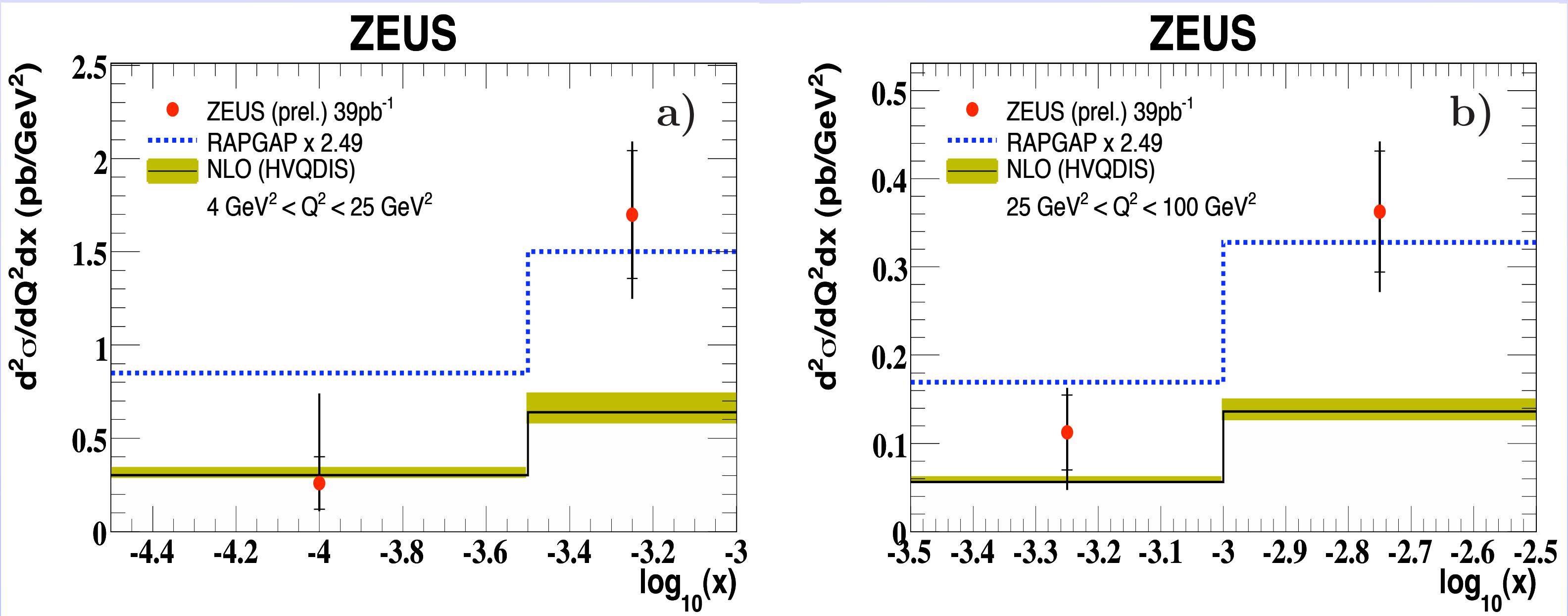
(also see the talk by A. Geiser ;-))

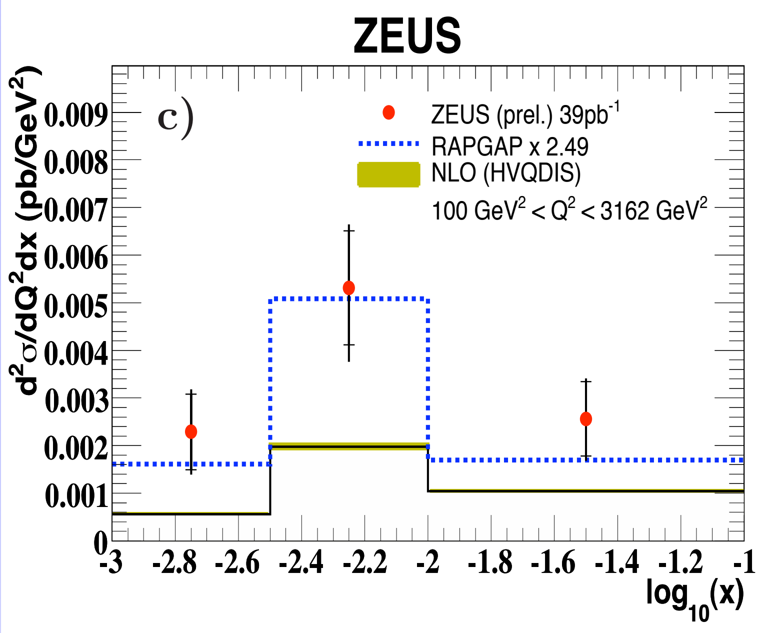
visible range:

- $Q^2 > 4$ GeV^2
- $0.05 < y < 0.7$
- $p^{\mu} > 1.5$ GeV
- $\eta^{\mu} > -1.6$
- $E_t^{jet} > 5$ GeV
- $-2 < \eta^{jet} < 2.5$

Beauty with p_t^{rel} method (iii)

double differential in x and Q^2





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- $E_t^{jet} > 5$ GeV
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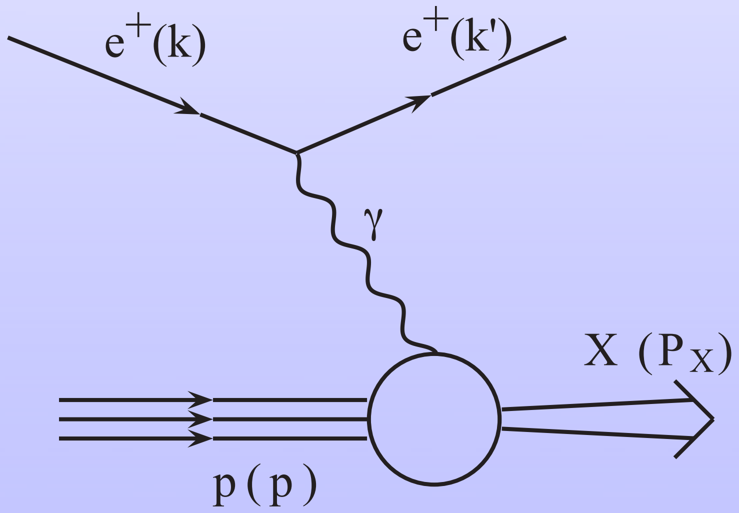
use for the extraction of the structure function F_2^{bb}

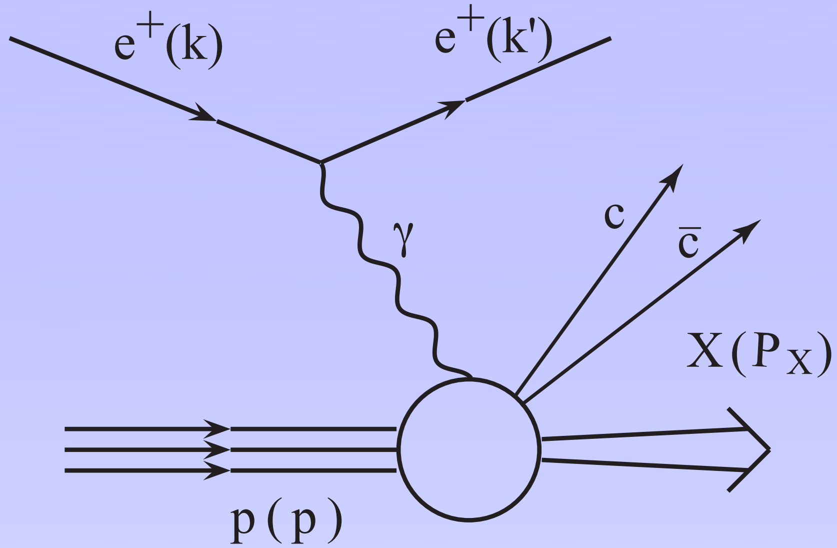
Proton Structure Function F_2

Inclusive ep scattering



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

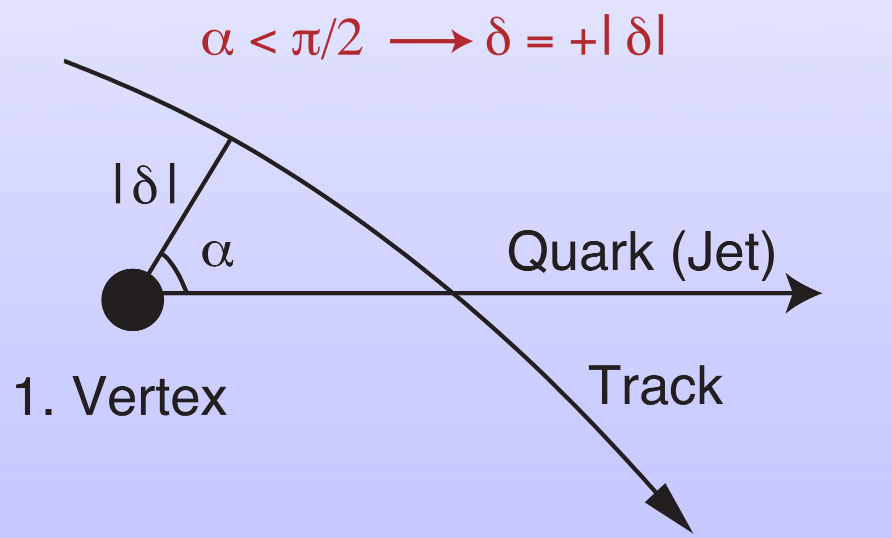
Contribution of c/b to inclusive F_2

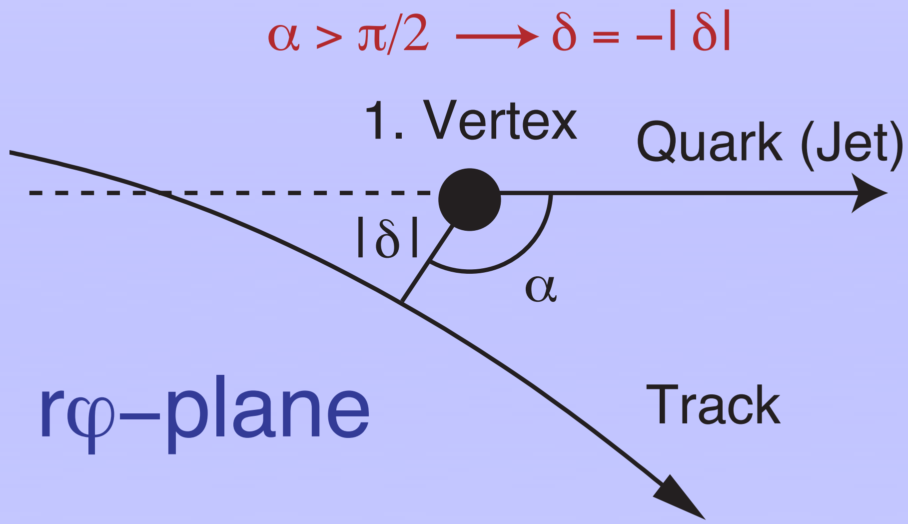


$$\frac{d^2\sigma^{ep\to c\bar{c}X}}{dQ^2dx} \propto F_2^{c\bar{c}}(Q^2, x)$$

F2cc(bb) is contribution to F2 originating from c(b) quarks

Impact parameter method

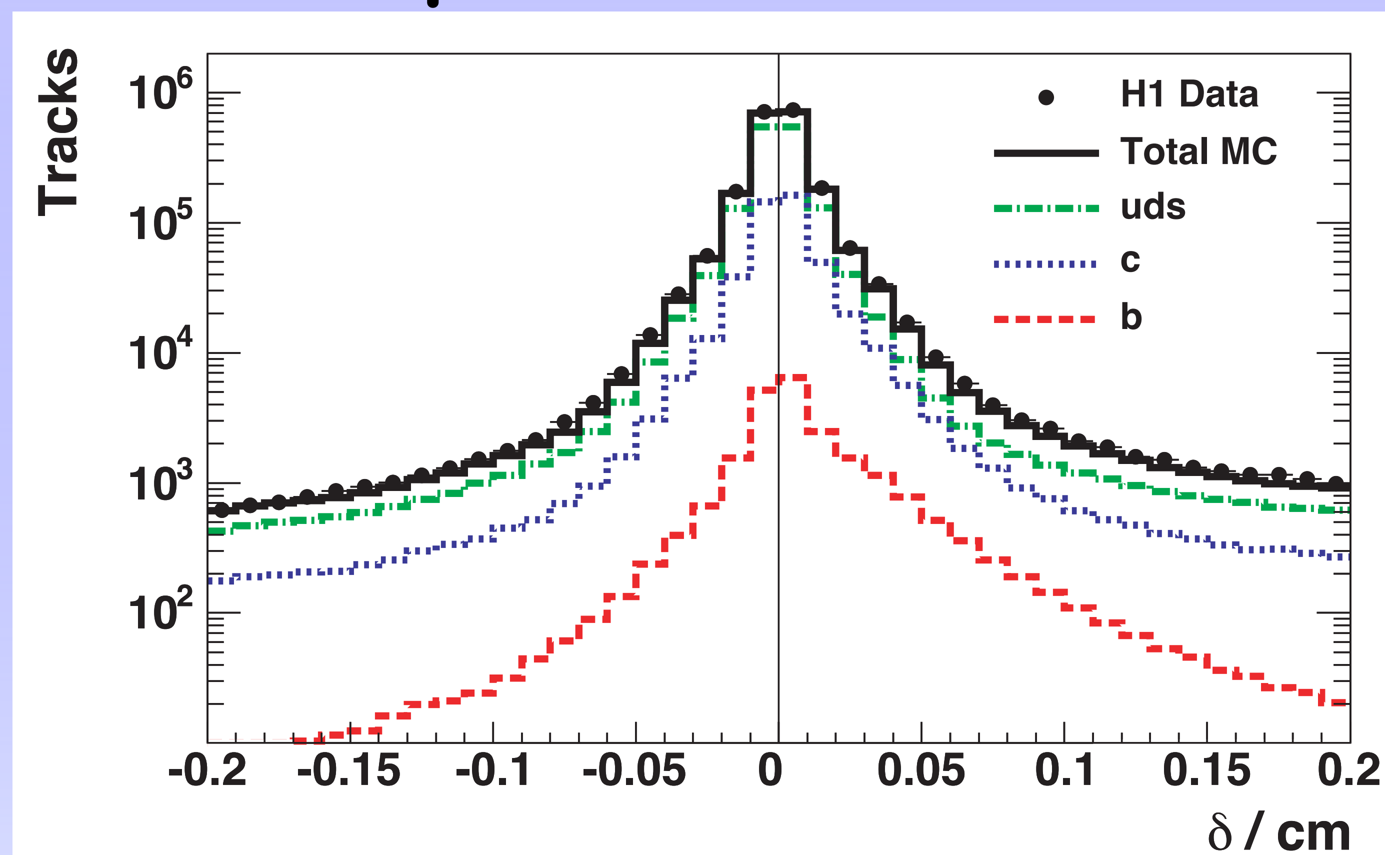




- long lifetime of the B-Mesons causes large positive impact parameter δ
- light particles → symmetric distribution around 0

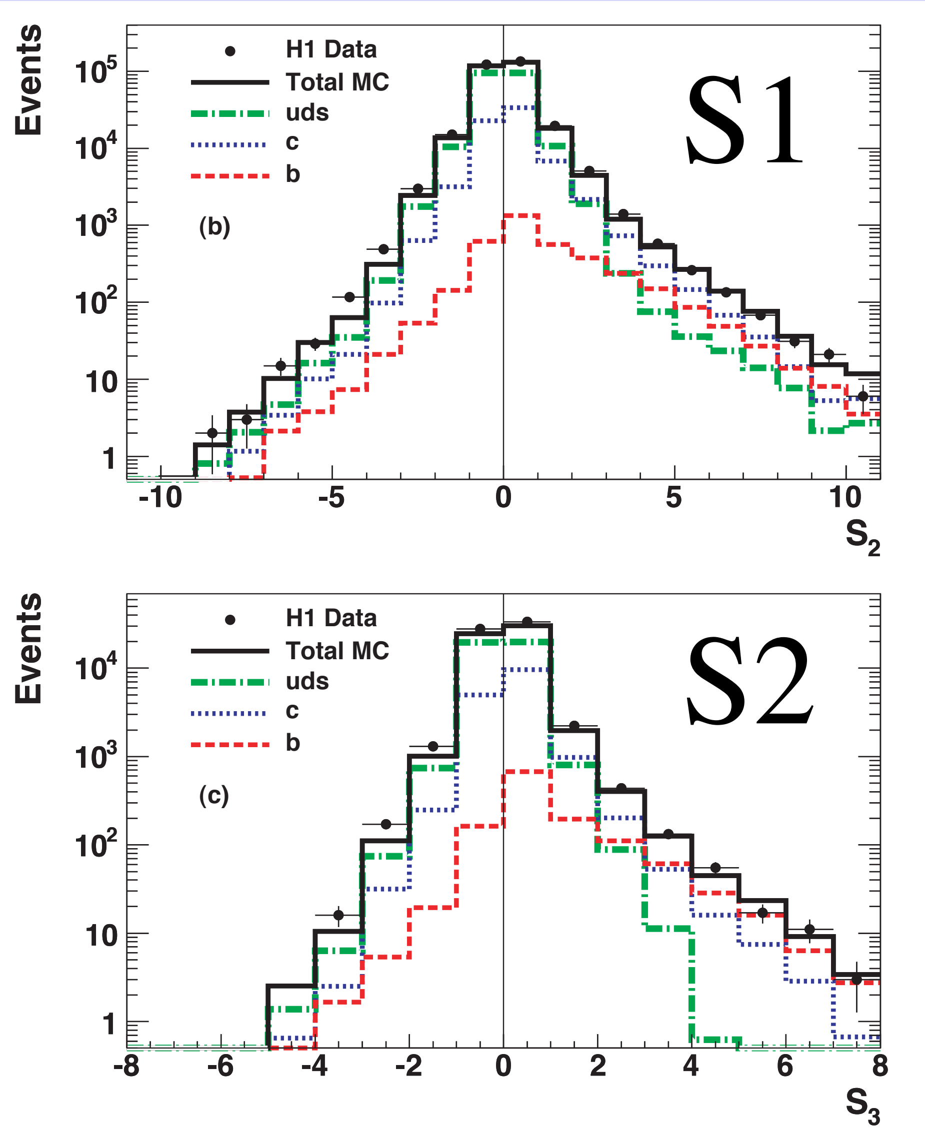
- estimate quark direction by jet,
- or by scattering angle of electron
- inclusive event selection:
  - high statistics (2 Mio events)
  - large phase space (1 track > 500 MeV)

Impact Parameter δ

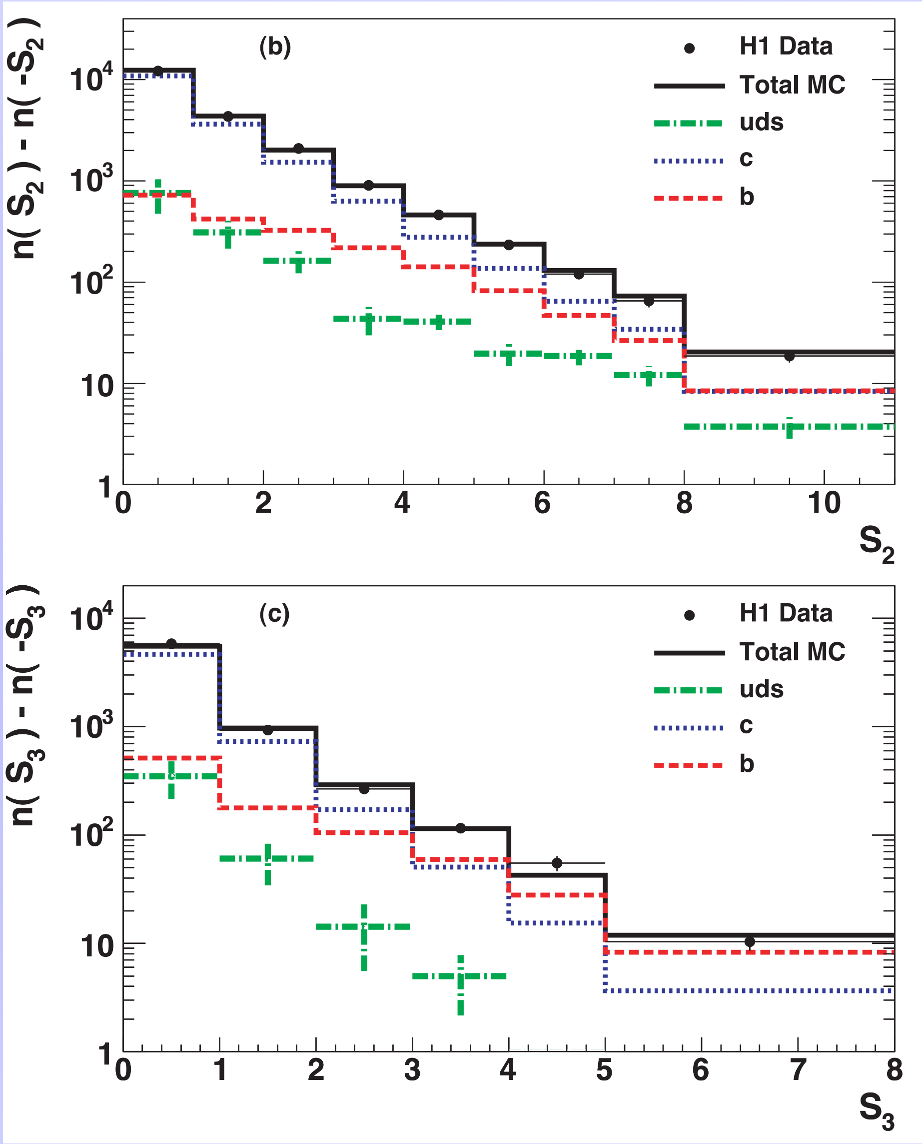


Significance Distributions

- use significance of the track: $S = \dfrac{\delta}{\sigma(\delta)}$
- S1, S2, S3 track with highest, 2nd and 3rd highest significance

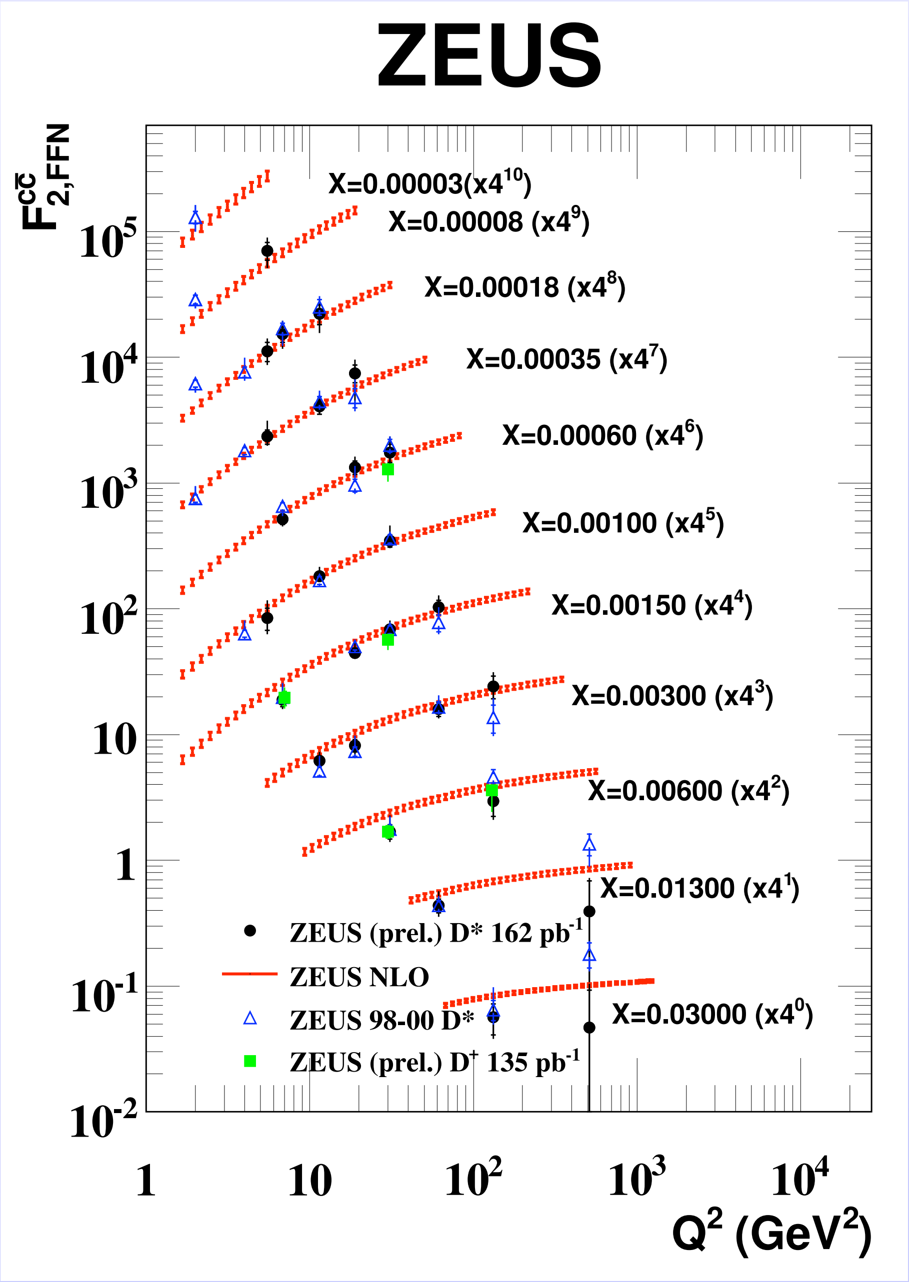


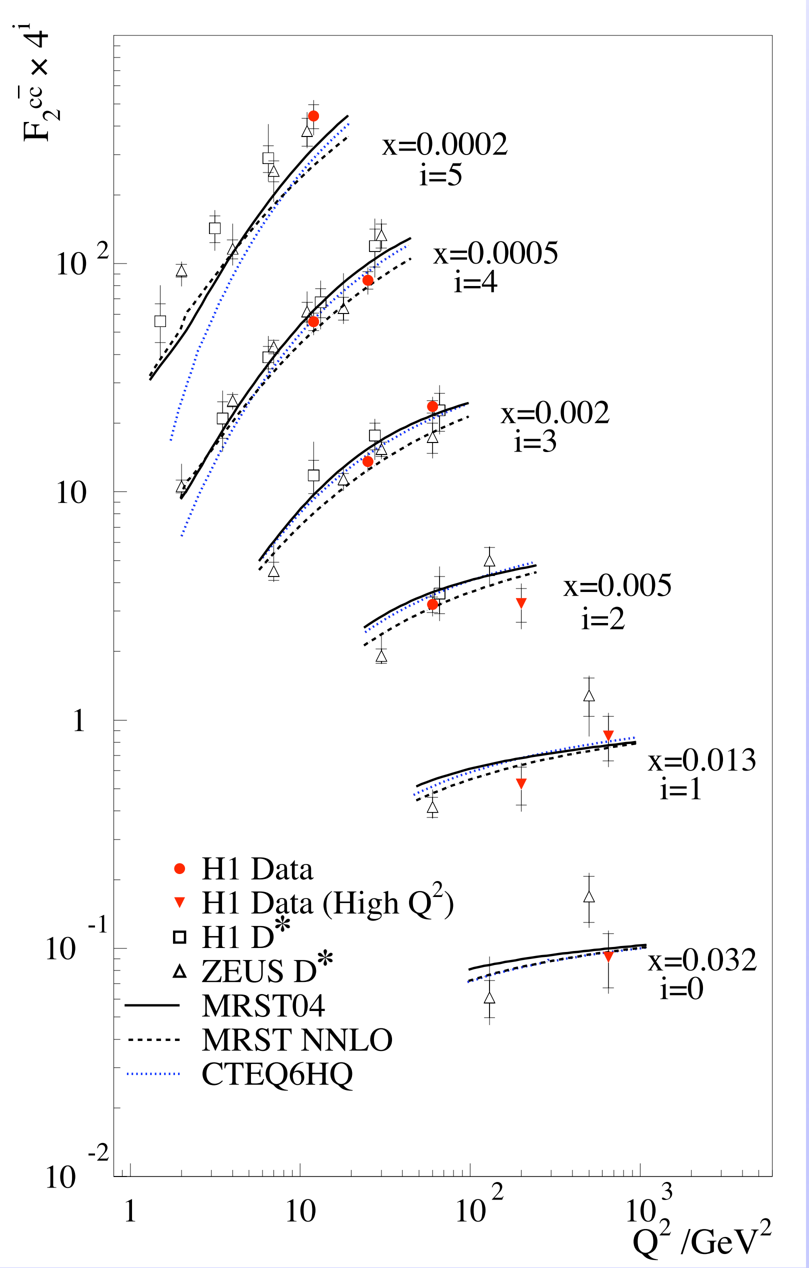
subtract negative from positive



fit of the significance distributions using the MC as a template for the shapes of the 3 contributions (uds, c, b)

F_2^{cc} from H1 & ZEUS

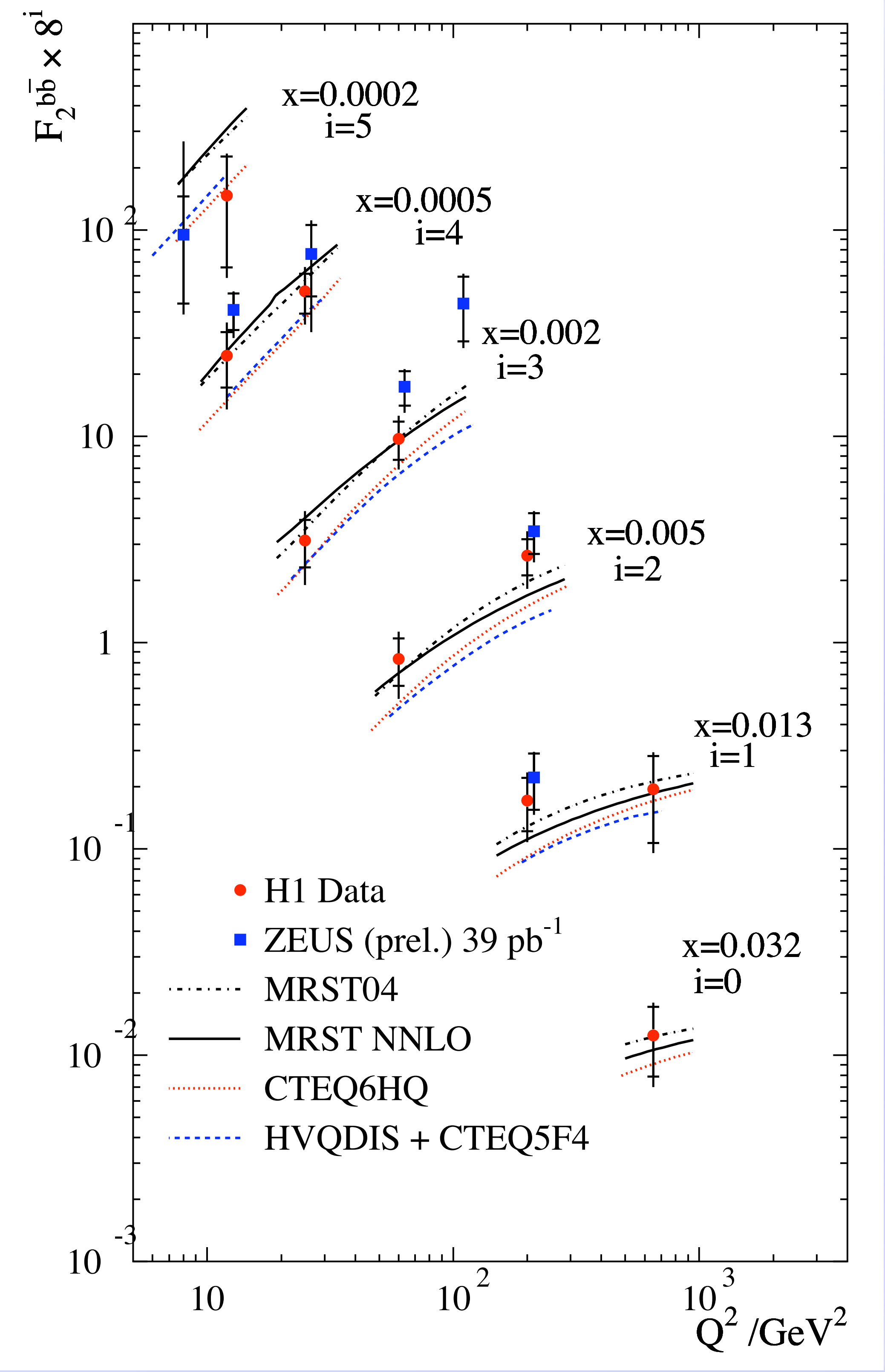




- scaling violations clearly visible
- good agreement between the different measurements

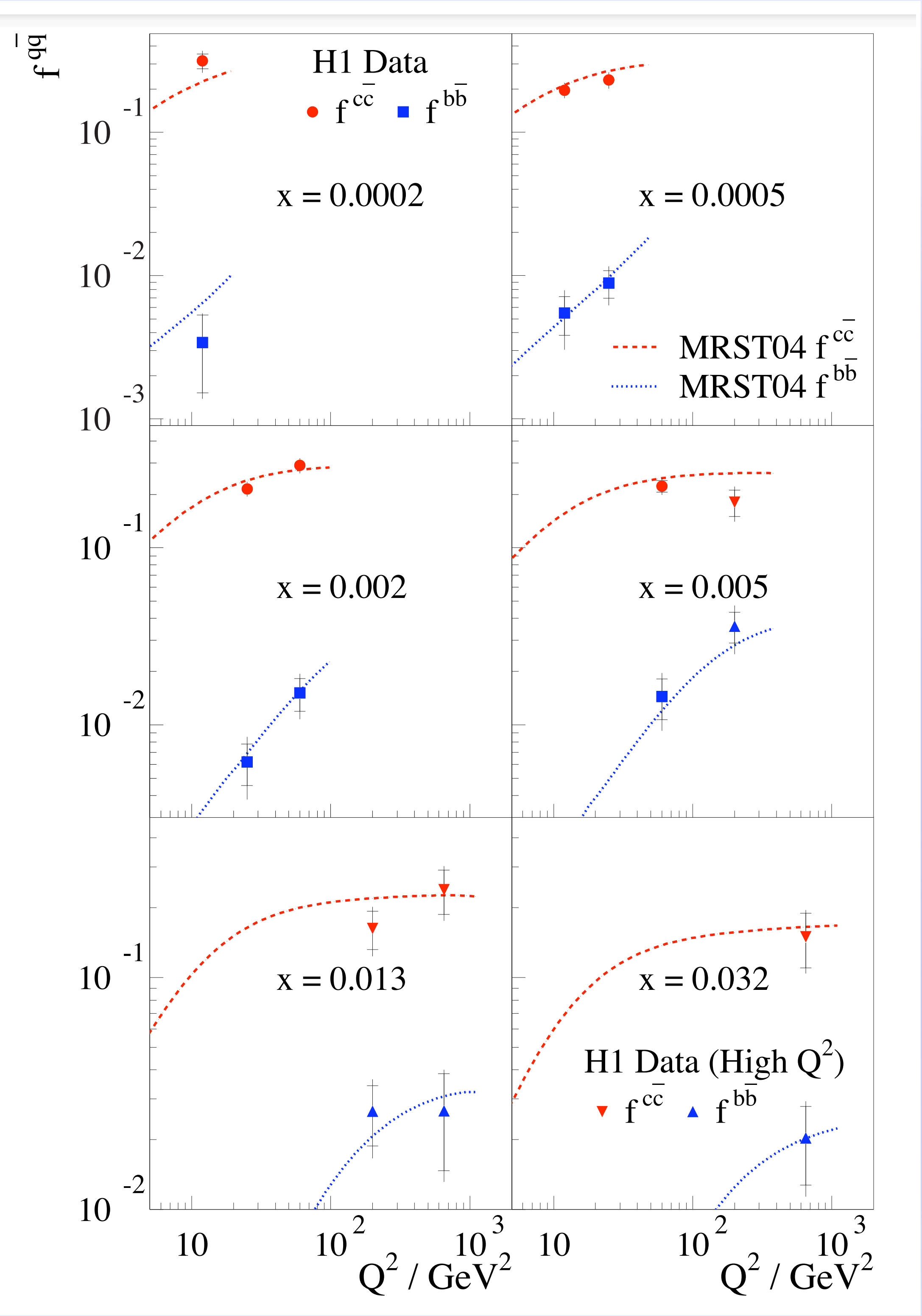
- Differences caused by matching procedure of **massive** and **massless** calculations
- high precision data → able to distinguish between predictions

F_2^{bb} Results



- first measurements of F_2^{bb}
- statistical error dominates,
- but more data is coming (factor of 5-10 more)
- data not yet decisive
- predictions differ up to a factor 2

Ratio: $F_2^{cc/bb}/F_2$



- shapes are different from F_2
- F_2^{cc} contribution to F_2 ~ 30%

→ significant effect on inclusive F_2

- F_2^{bb} contribution is small
- use to study different theoretical QCD approaches, especially in the intermediate scheme (VFNS)

Summary

Charm:

- good description achieved
- some deviations are seen

Beauty:

- reasonable agreement between data and theory
- data tends to be higher than theory

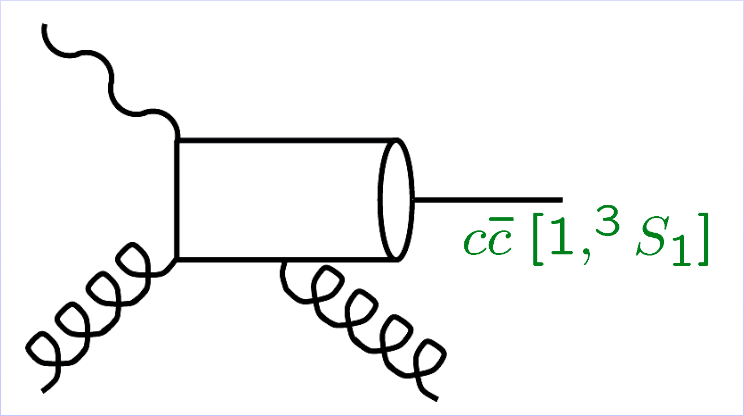
Extractions of the structure function F_2^{cc} and for the first time F_2^{bb}

- HERA I data analysis finished
- first (prel.) HERA II results are there
- much more to come

Backup Slides

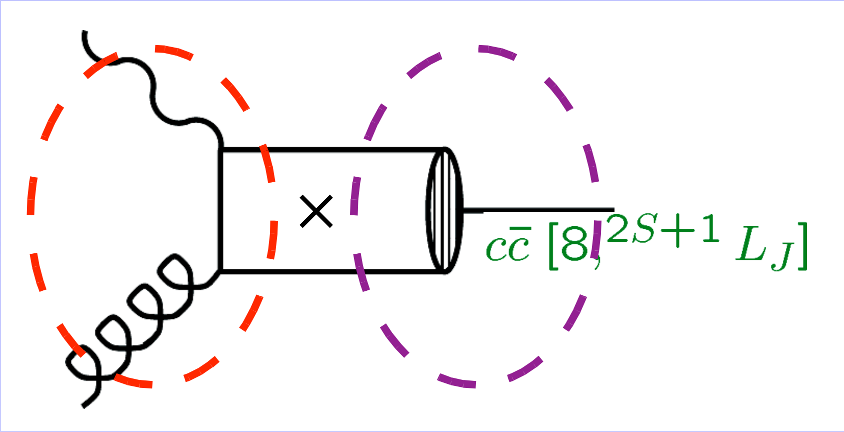
J/ψ production

Colour Singlet Model



- radiation of hard gluon
- changes also kinematics of the interaction
- implemented in EPJPSI

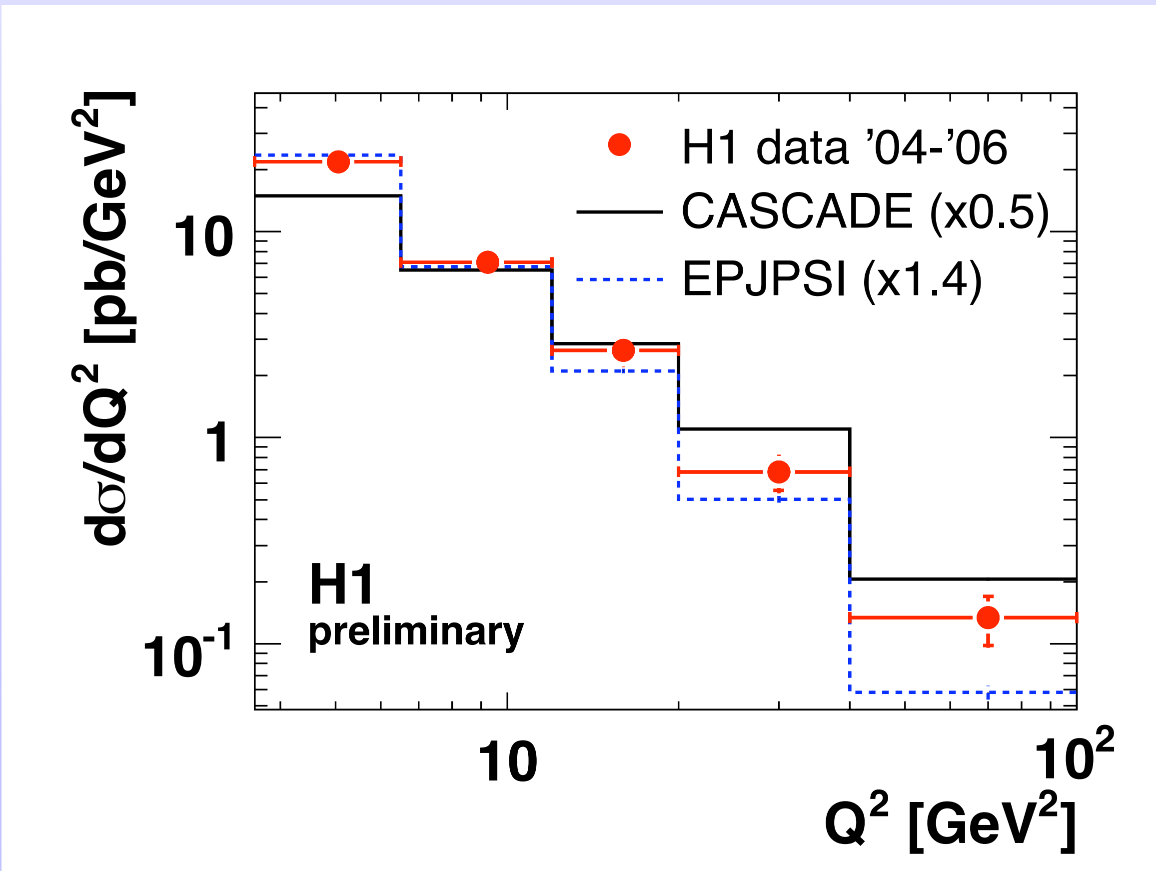
Non Relativistic QCD

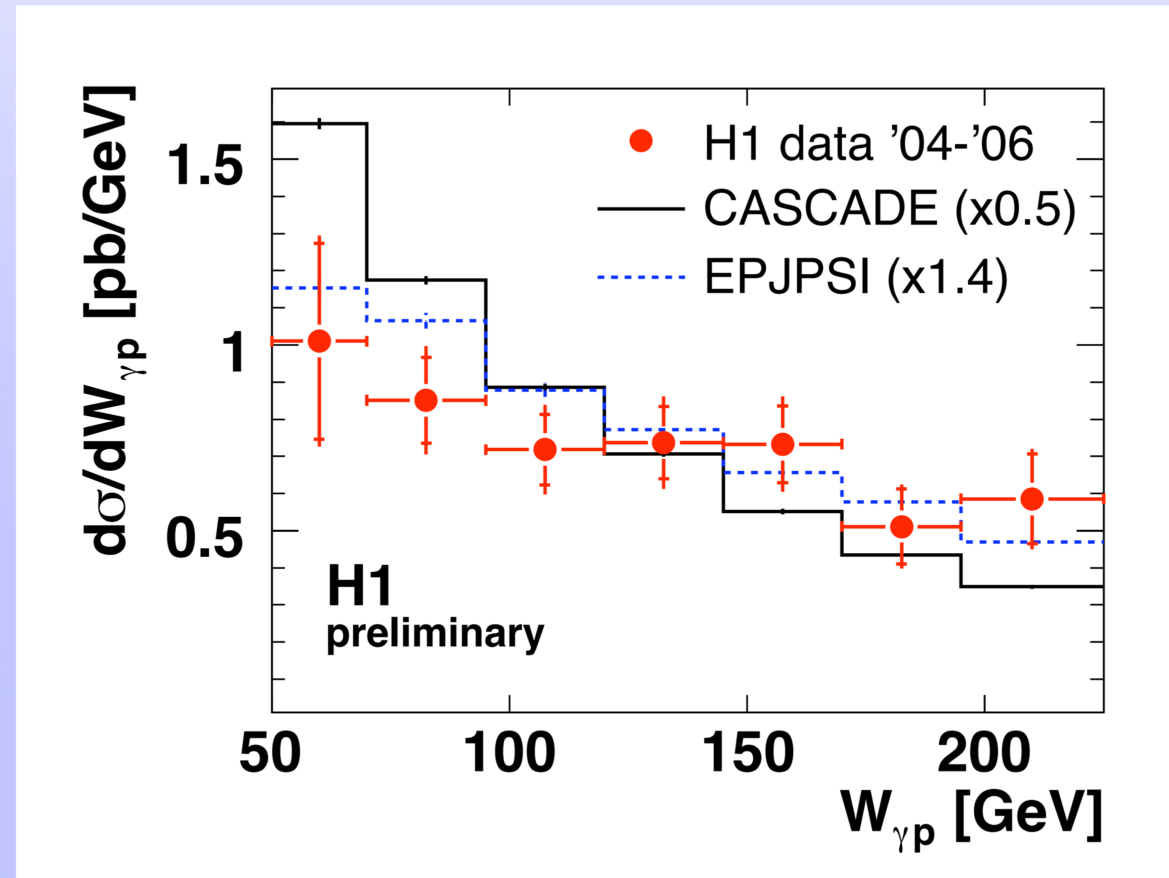


- contribution by colour octet states
- soft gluon radiation
- factorisation of
    - hard scattering process
    - transition to real J/ψ (non perturbative LDME)

Inelastic J/ψ Production

analysed channels: $J/\psi \to ee/\mu\mu$





EPJPSI:

- DGLAP
- normalisation to low
- too steep in Q^2

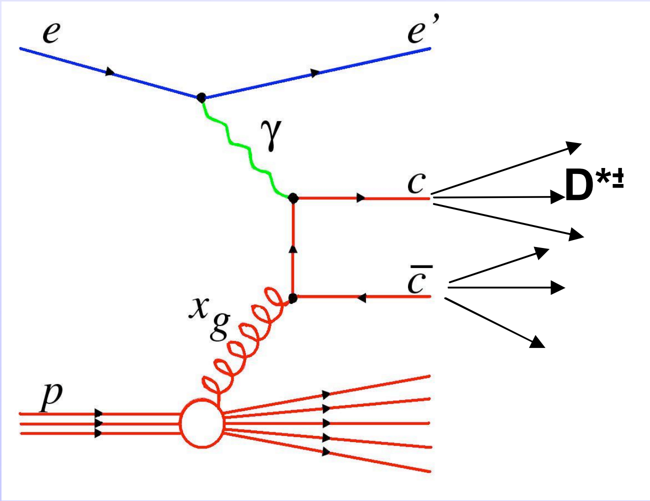
CASCADE

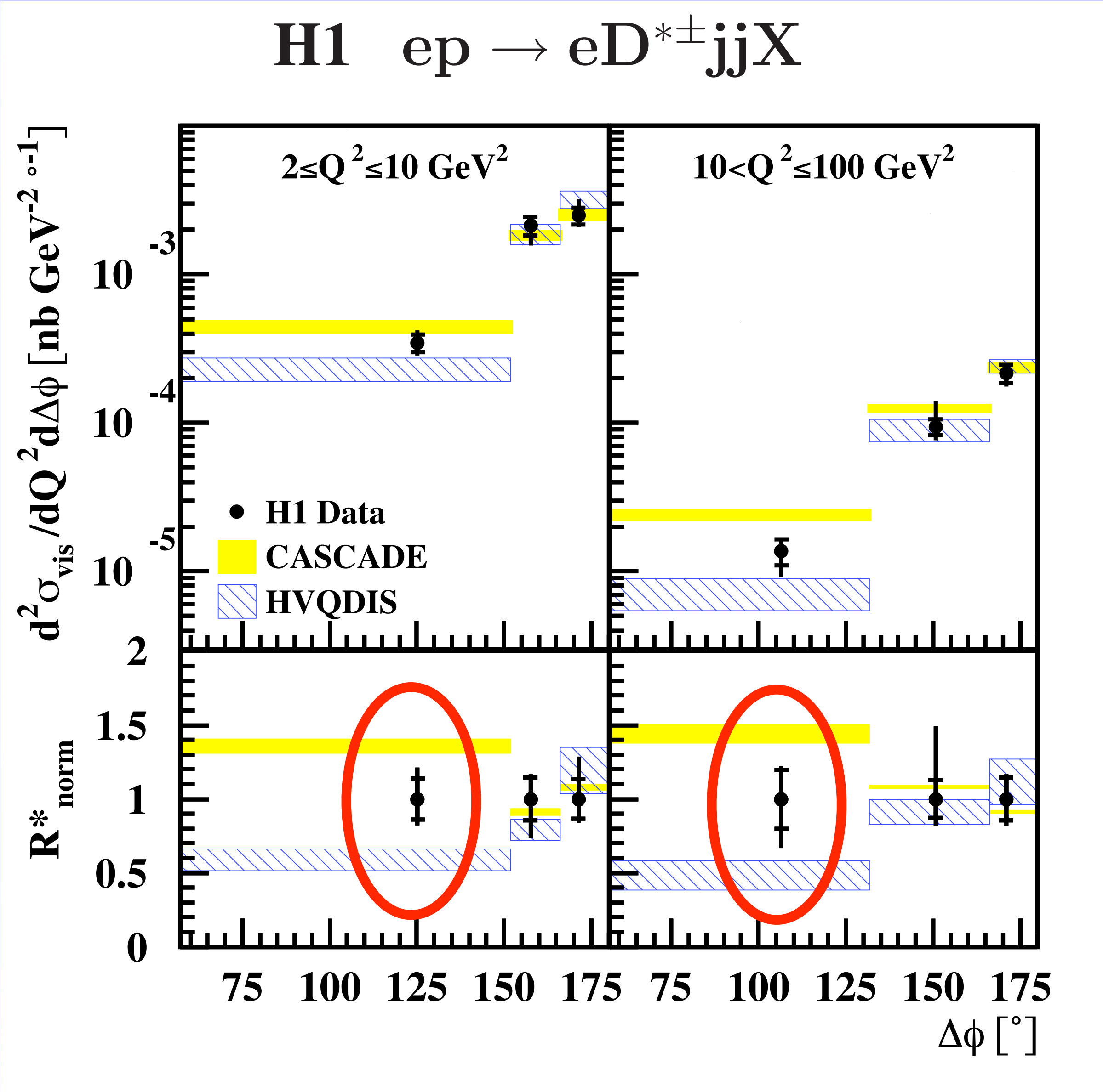
- CCFM
- normalisation to high
- too hard in Q^2
- too steep in $W_{\gamma p}$

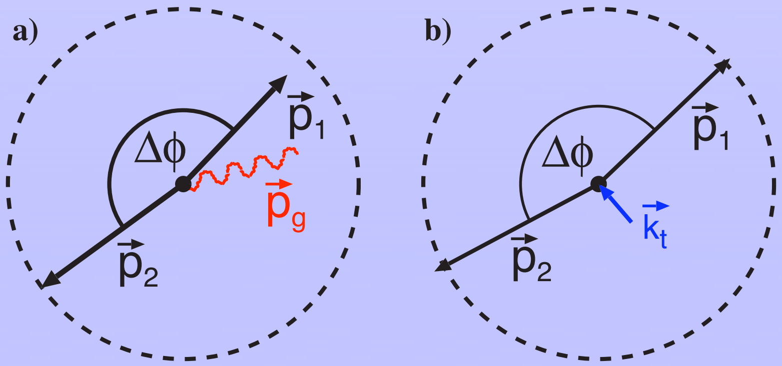
⇛ **J/ψ Production theoretically not well understood**

D* + Dijet production

- charm tagging with D* mesons
- reconstruct 2nd charm quark from the jet







gluon radiation (NLO) or initial k_t can lead to non back to back topologies

- CASCADE to broad
- some contribution missing in HVQDIS (NNLO?)

$F_2^{cc/bb}$ measurement

extrapolation to full phase space:

cross section calculation using HVQDIS

$$\sigma^{b\bar{b}}\left(x, Q^2\right) = \sigma_{\mathrm{NLO}}{}^{b\bar{b}}\left(x, Q^2\right) \frac{d^2\sigma^{b\bar{b},\mathrm{vis}}_{\mathrm{data}}}{dxdQ^2} \Big/ \frac{d^2\sigma^{b\bar{b},\mathrm{vis}}_{\mathrm{NLO}}}{dxdQ^2}$$

cross section calculation using HVQDIS in visible kinematic region

reduced cross section:

$$\frac{d^2\tilde{\sigma}^{b\bar{b}}}{dxdQ^2} = \frac{d^2\sigma^{b\bar{b}}}{dxdQ^2} \frac{xQ^4}{2\pi\alpha^2(1+(1-y)^2)}$$

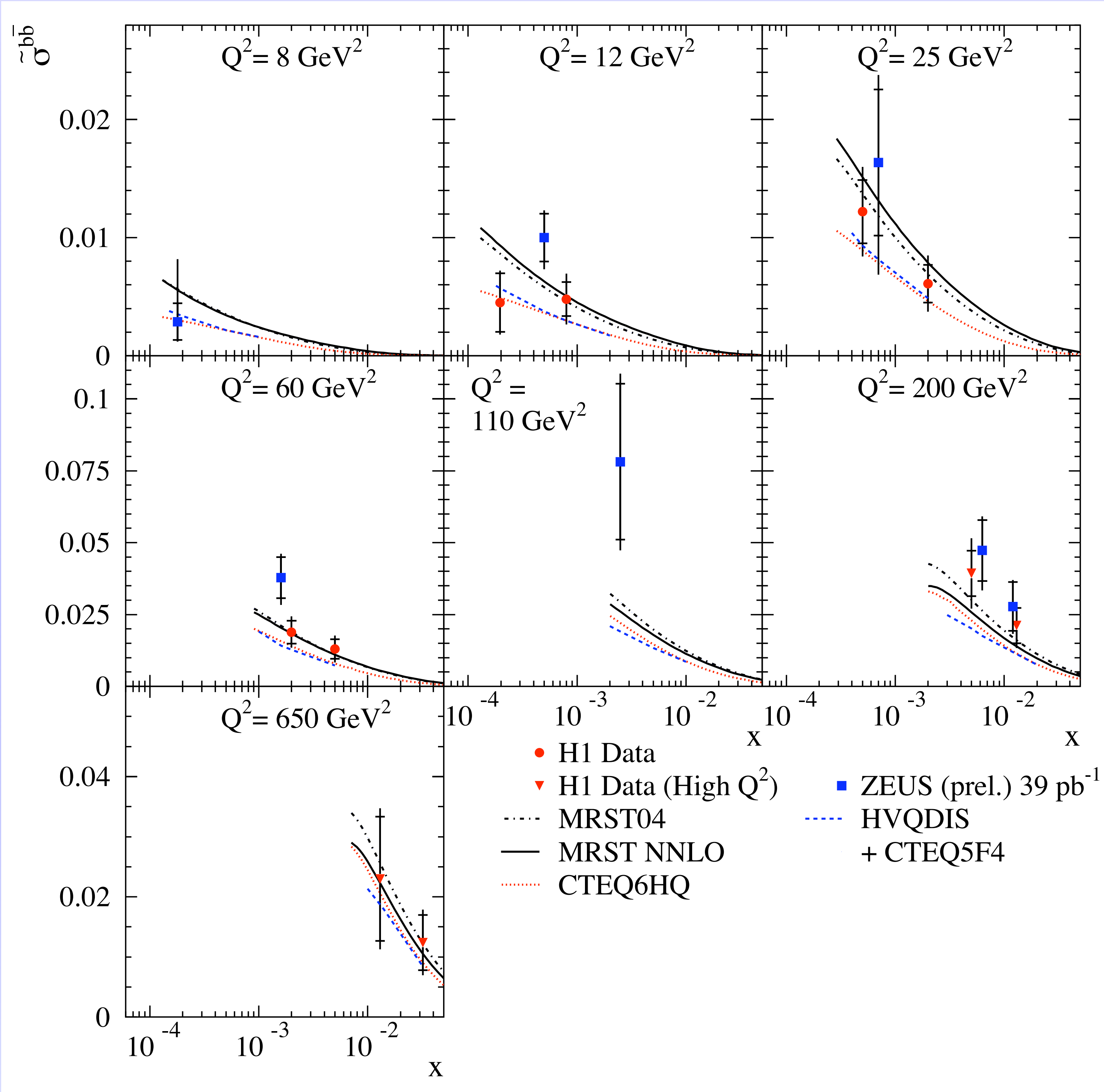
Structure Function:

$$\tilde{\sigma}^{b\bar{b}}\left(x, Q^2\right) = F_2^{b\bar{b}} - \frac{y^2}{1+(1-y)^2} F_L^{b\bar{b}}$$

$F_2^{cc/bb}$ = beauty/charm contribution to F_2

Beauty at H1 and ZEUS

reduced cross section: $\dfrac{d^2\tilde{\sigma}^{\,b\bar{b}}}{xQ^2} = \dfrac{d^2\sigma^{b\bar{b}}}{dxdQ^2}\;\dfrac{xQ^4}{2\pi\alpha^2(1+(1-y)^2)}$



- ● ▼ H1: 57.4pb^{-1} (HERA I)
- ■ ZEUS: 39pb^{-1} (HERA II)

- ZEUS data lie above H1
- still compatible within errors

- quite some spread of the theory predictions
- data will distinguish with full HERA statistic

F_2^{cc} from $D^{\pm}$