Open Charm and Beauty Production at HERA

PHOTON2000 *Ambleside, 29.08.2000*

On behalf of the  *Collaboration*

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Outline

- **Motivation**
- **Open Charm Production in DIS**
- **Charm Contribution to the Proton Structure F_2^c**
- **Open Beauty Production in γp**
- **Summary**

Results from 1996 + 1997 data

Motivation for Heavy Flavor Physics

Tests of perturbative QCD in ep interactions at $\sqrt{s} \approx 300$ GeV

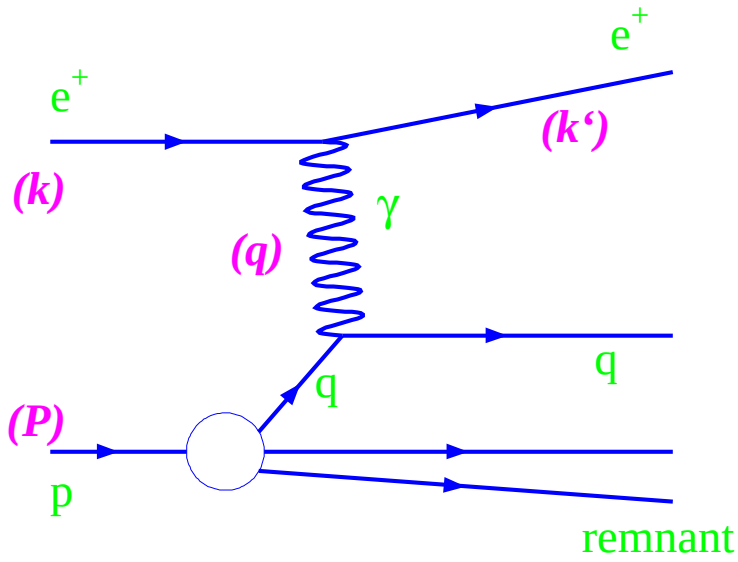
- Understanding of heavy flavour production mechanism
- Understanding of QCD evolution scheme
- Measurement of parton densities

Testing univesality of PDFs

- Charm production cross section quite large
  BUT intrinsic scale (m_c) close to pQCD limit
- Beauty production: Intrinsic scale (m_b) quite far from pQCD limit BUT cross section small

Kinematics of Deep Inelastic Scattering

$27.5\ GeV\ e^{\pm} \longrightarrow \sqrt{s} = 300 GeV \longleftarrow p\ 820\ GeV$



$Q^2 = -q^2 = -(k - k')^2$ 4-momentum transfer^2

$x = Q^2/2P \cdot q$ fraction of p momentum carried by the struck quark

$y = (p \cdot q)/(p \cdot k)$ relative energy transfer in the p rest frame

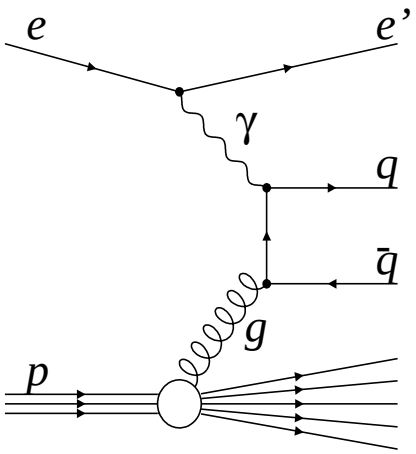
$W^2 = (q + P)^2$ mass ^{2} of the hadronic final state

$$Q^2 = sxy$$

$\eta = -ln(tan\frac{\theta}{2})$

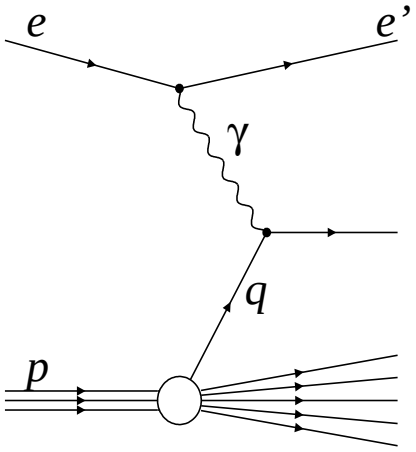
Heavy Flavor Production

- At low Q^2: Boson Gluon Fusion



Fixed Flavour Number Scheme (FFNS)

- At $Q^2 \gg m_c^2$: Flavor Excitation
  (Heavy quark treated as active parton in the proton)



At large Q^2
Deviation from BGF

Variable Flavour Number Scheme (VFNS)

DGLAP evolution should break down at small x

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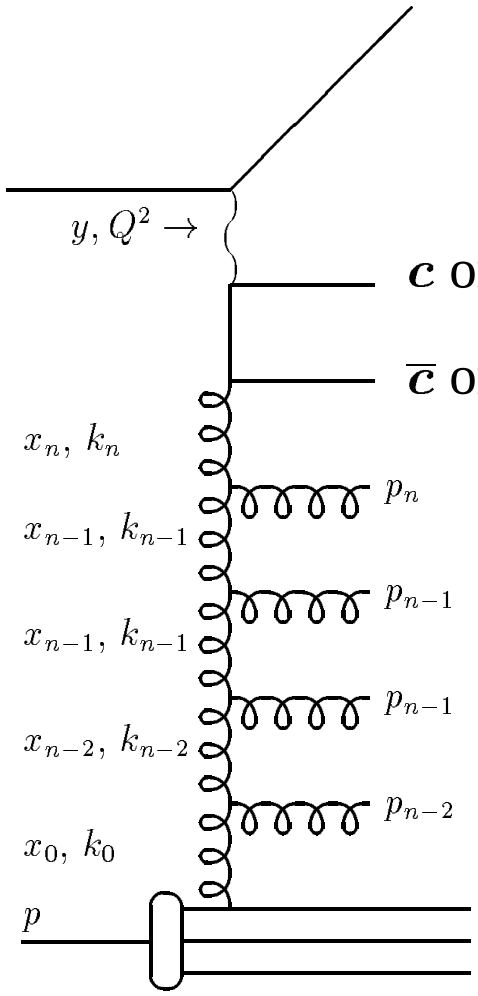
Heavy Flavor Production in the CCFM Scheme

(Ciafaloni, Catani, Fiorani and Marchesini)



Ordered in

Q^2 x η

DGLAP BFKL CCFM

BFLK $\xleftarrow{x \to 0}$ CCFM $\xrightarrow{x \to 1}$ DGLAP

Unintegrated Gluon Density

$$\int_0^{\mu^2} \mathcal{G}\left(x, k_\perp^2, \eta, Q_0^2\right) \mathrm{d}k_\perp^2 = x\,G\left(x, \mu^2, Q_0^2\right)$$

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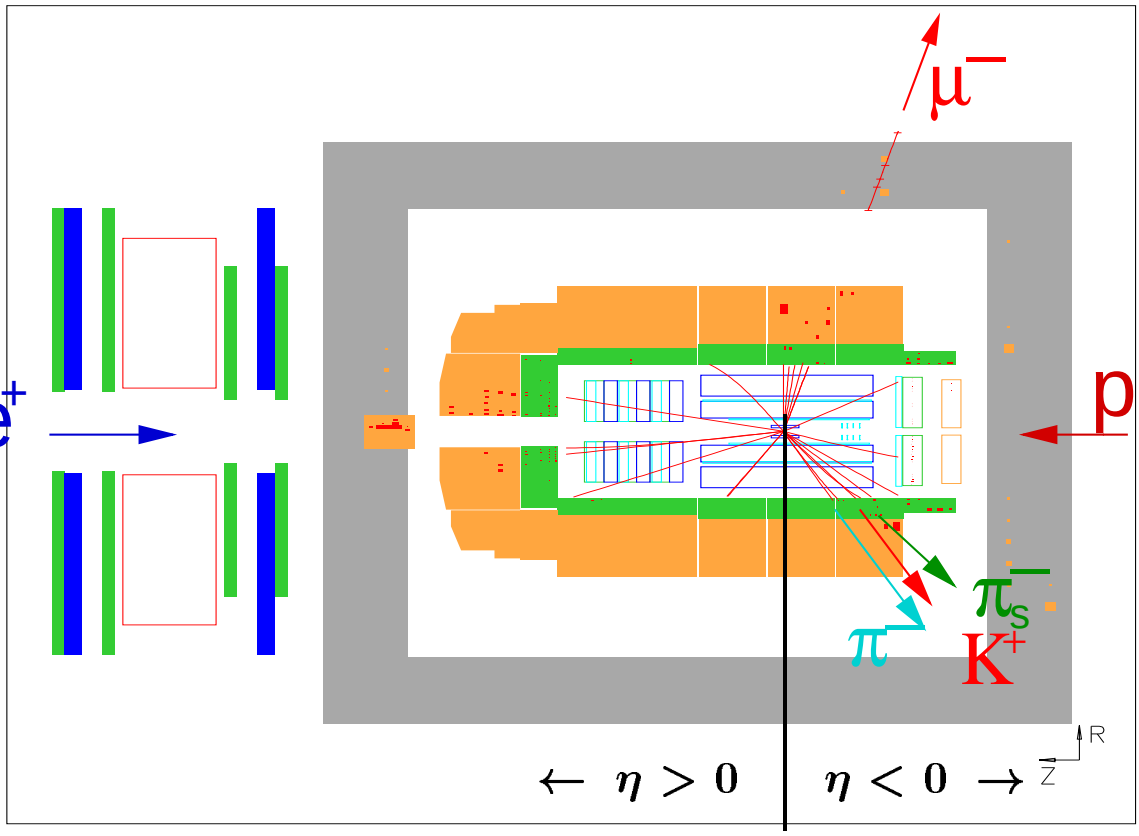
An Event in H1



$e^+ p \rightarrow \bar{b}\, b$ + remnant

$\rightarrow \mu^- \bar{\nu}_\mu X$

$\rightarrow D^{*-} Y$

$\rightarrow \bar{D}^0 \pi_s^-$

$\rightarrow K^+ \pi^-$

$\Delta m = 0.146$ GeV

$M_{\bar{D}^0} = 1.855$ GeV

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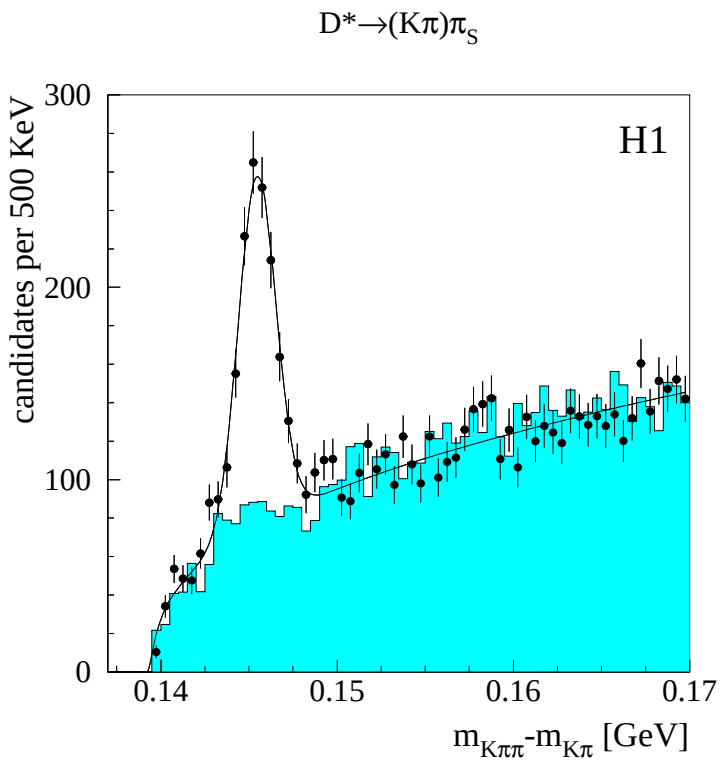
Inclusive D^* Cross Section in DIS



kinematic region

$1 < Q^2 < 100\ GeV^2$

$0.05 < y < 0.7$

$p_{T\ D^*} > 1.5\ GeV$

$|\eta_{D^*}| < 1.5$

H1 prel.

$$\sigma(e^+p \to e^+D^{*\pm}X) = 8.37 \pm 0.41(stat.)^{+1.11}_{-0.82}(syst.)^{+0.64}_{-0.39}(theo.)\ nb$$

HVQDIS: (NLO DGLAP) G from GRV98HO, $5.0 - 6.6$ nb

$m_c = 1.3\ GeV\ \epsilon = 0.035$

$m_c = 1.5\ GeV\ \epsilon = 0.100$

CASCADE: (CCFM) $\mathcal{G}$ from fit to H1 F_2 $8.5 - 10$ nb

$m_c = 1.3\ GeV\ \epsilon = 0.078$

$m_c = 1.5\ GeV\ \epsilon = 0.078$

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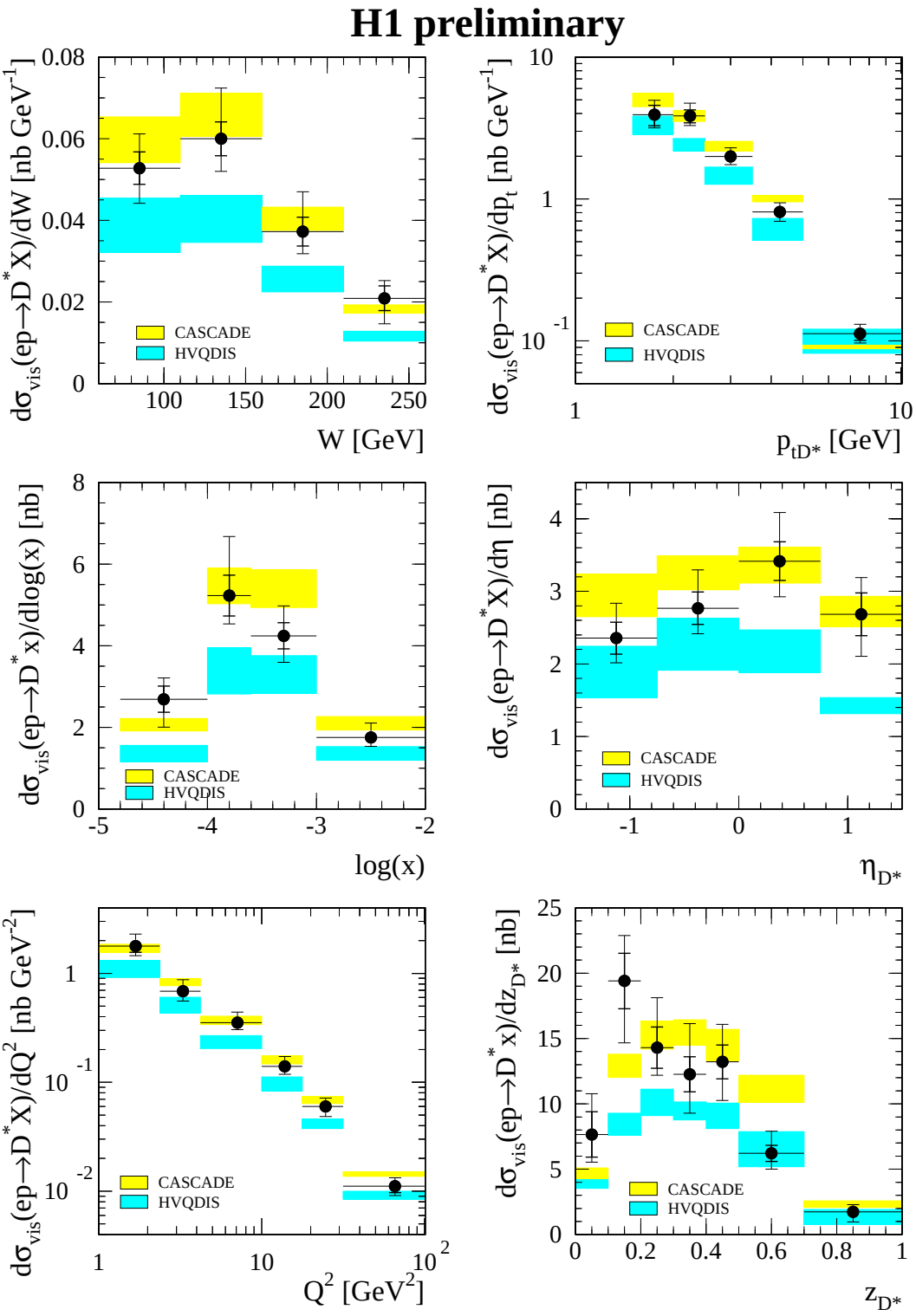
Single Differential D^* Cross Sections in DIS



Data favour CCFM

DGLAP fails at large η

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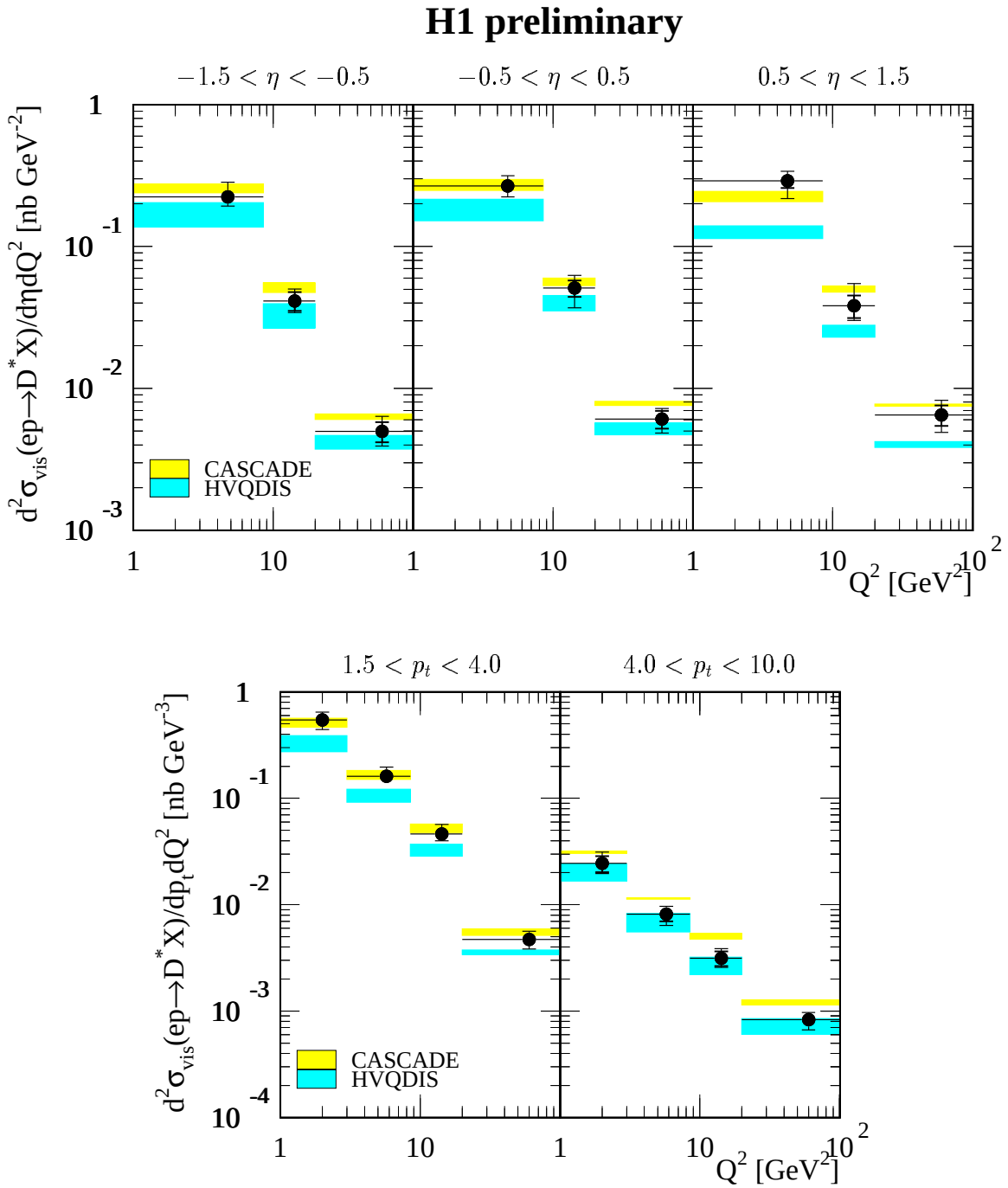
Double Differential D^* Cross Sections in DIS



Large η problem of HVQDIS not due to discrepancies at large Q^2
$\rightarrow$No sign for a transition from BGF to FE at large Q^2

CCFM better at small p_t NLO DGLAP better at large p_t

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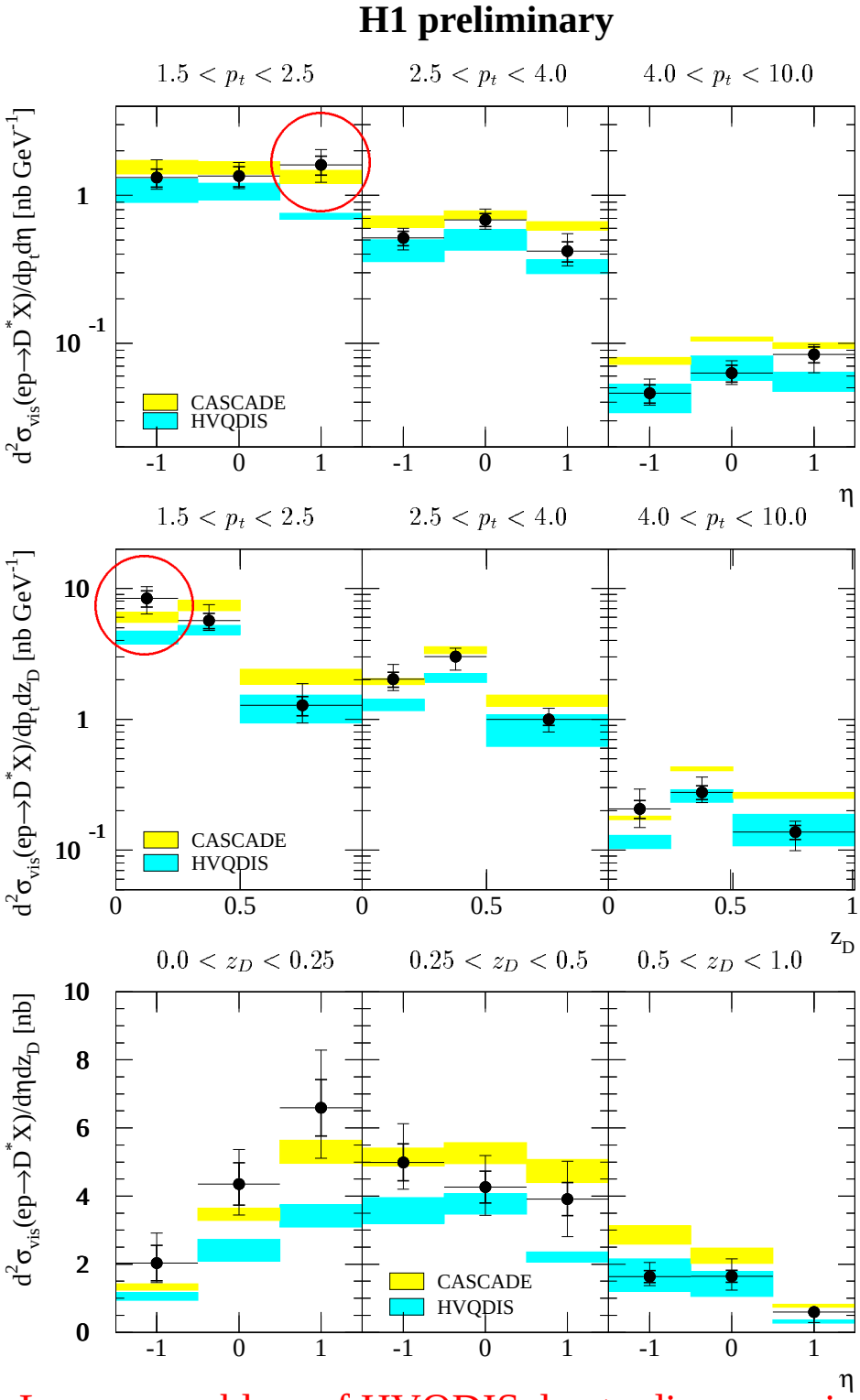
Double Differential D^* Cross Sections in DIS



Large η problem of HVQDIS due to discrepancies at small p_t and small inelasticity z_D

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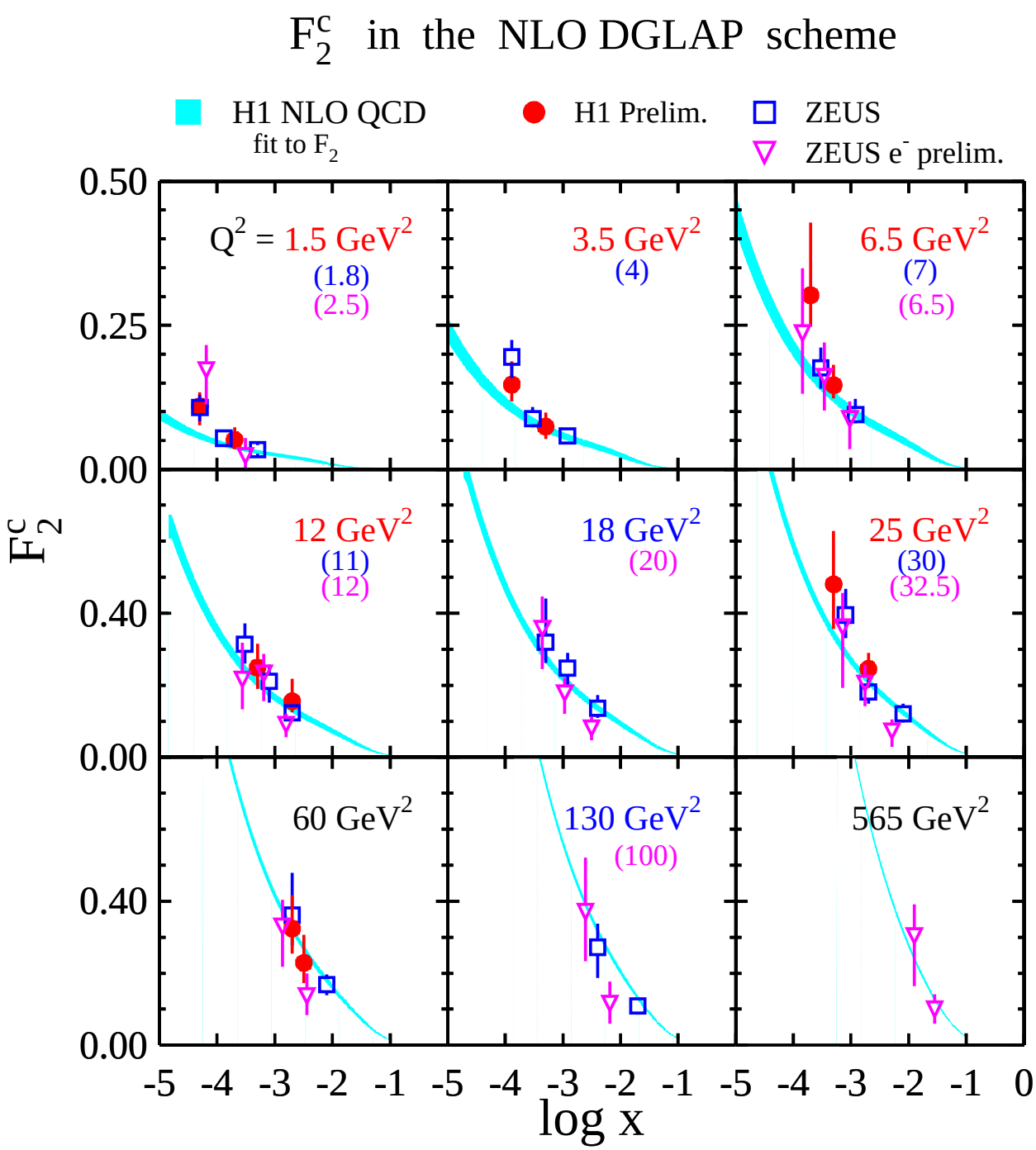
$F_2^c(x, Q^2)$



F_2^c measurements of H1 and ZEUS consistent

F_2^c agrees with NLO DGLAP prediction from F_2

some deviation at small x and small Q^2

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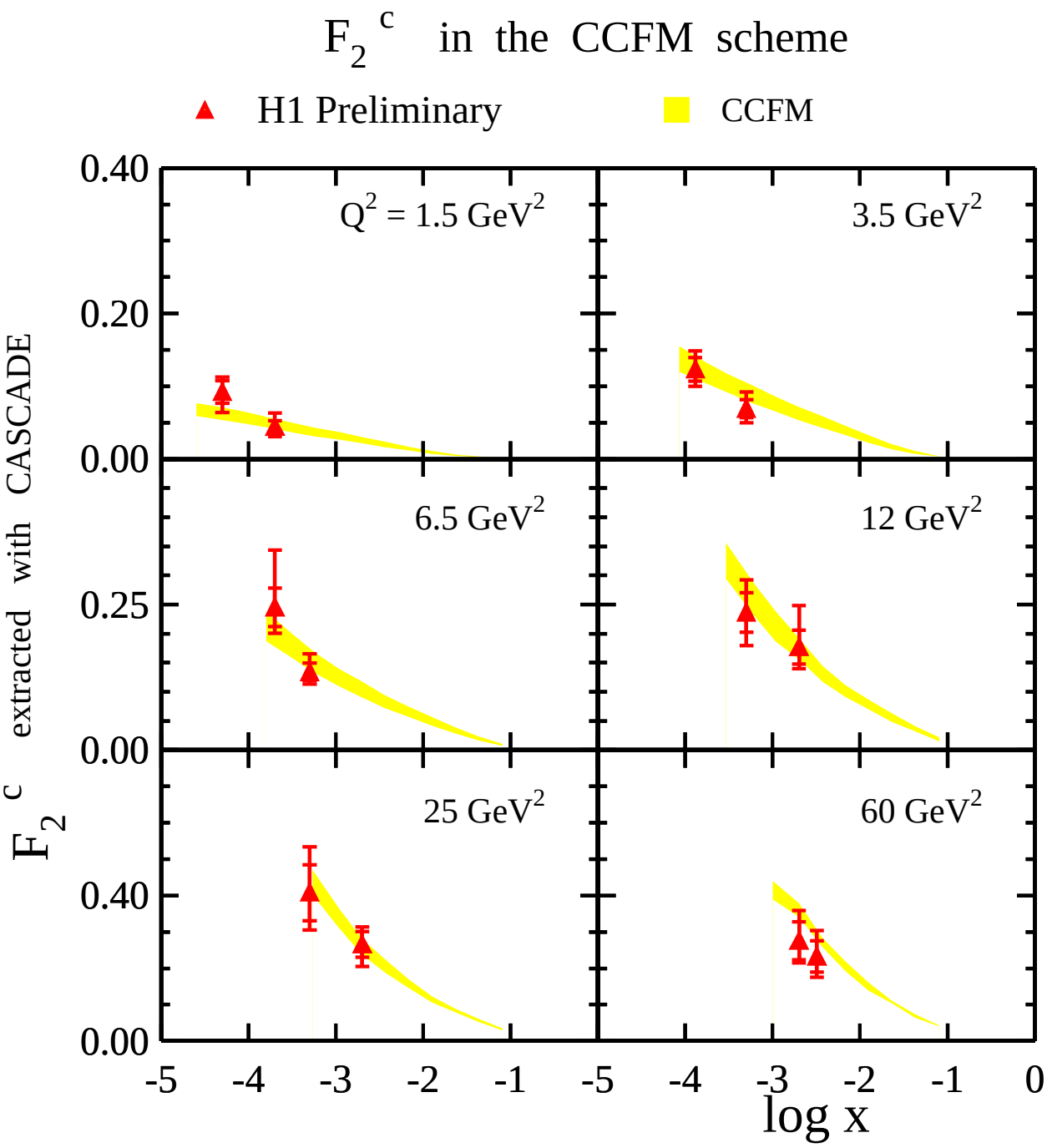
$F_2^c(x, Q^2)$ in the CCFM Scheme



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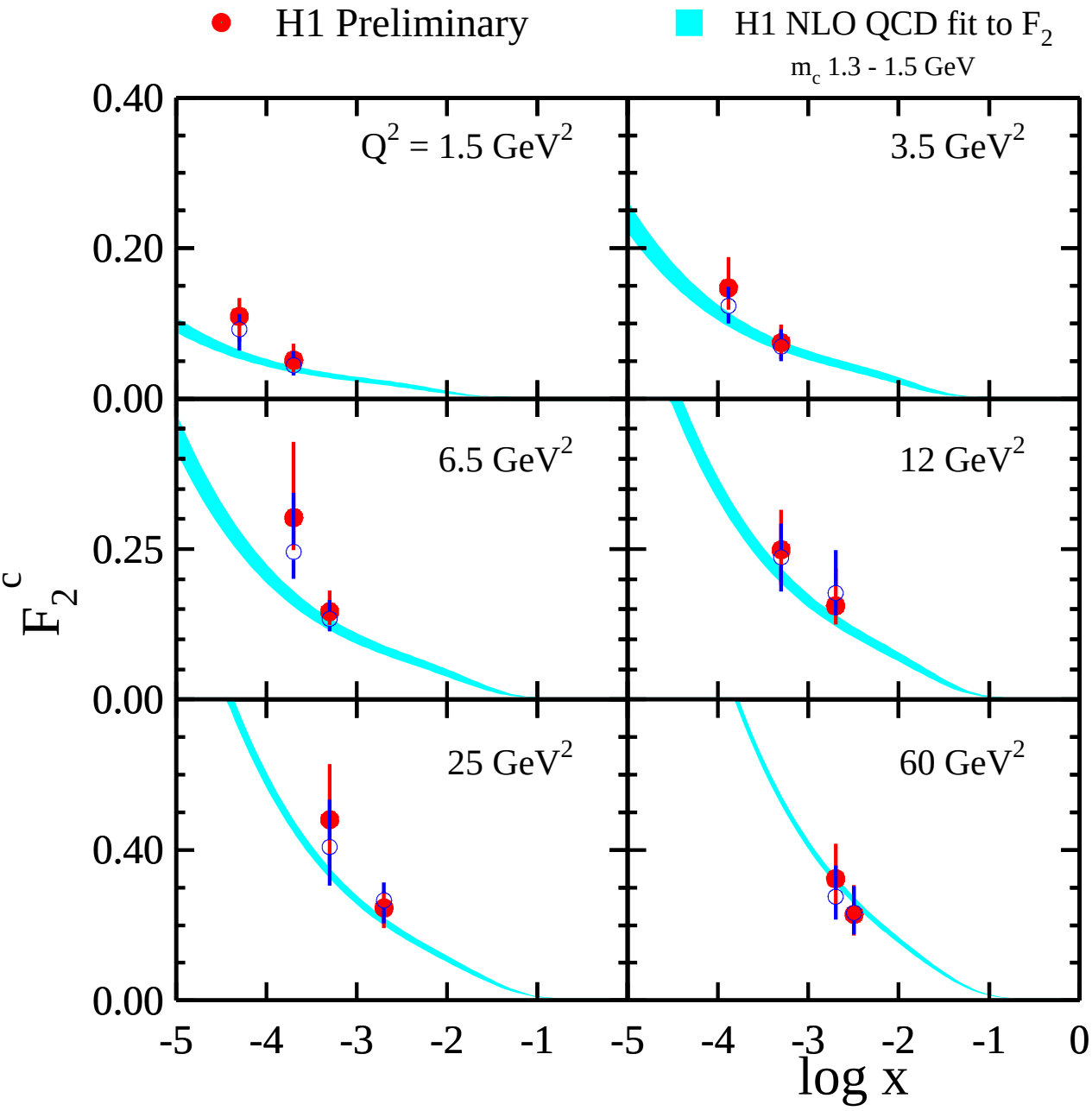
$F_2^c(x, Q^2)$



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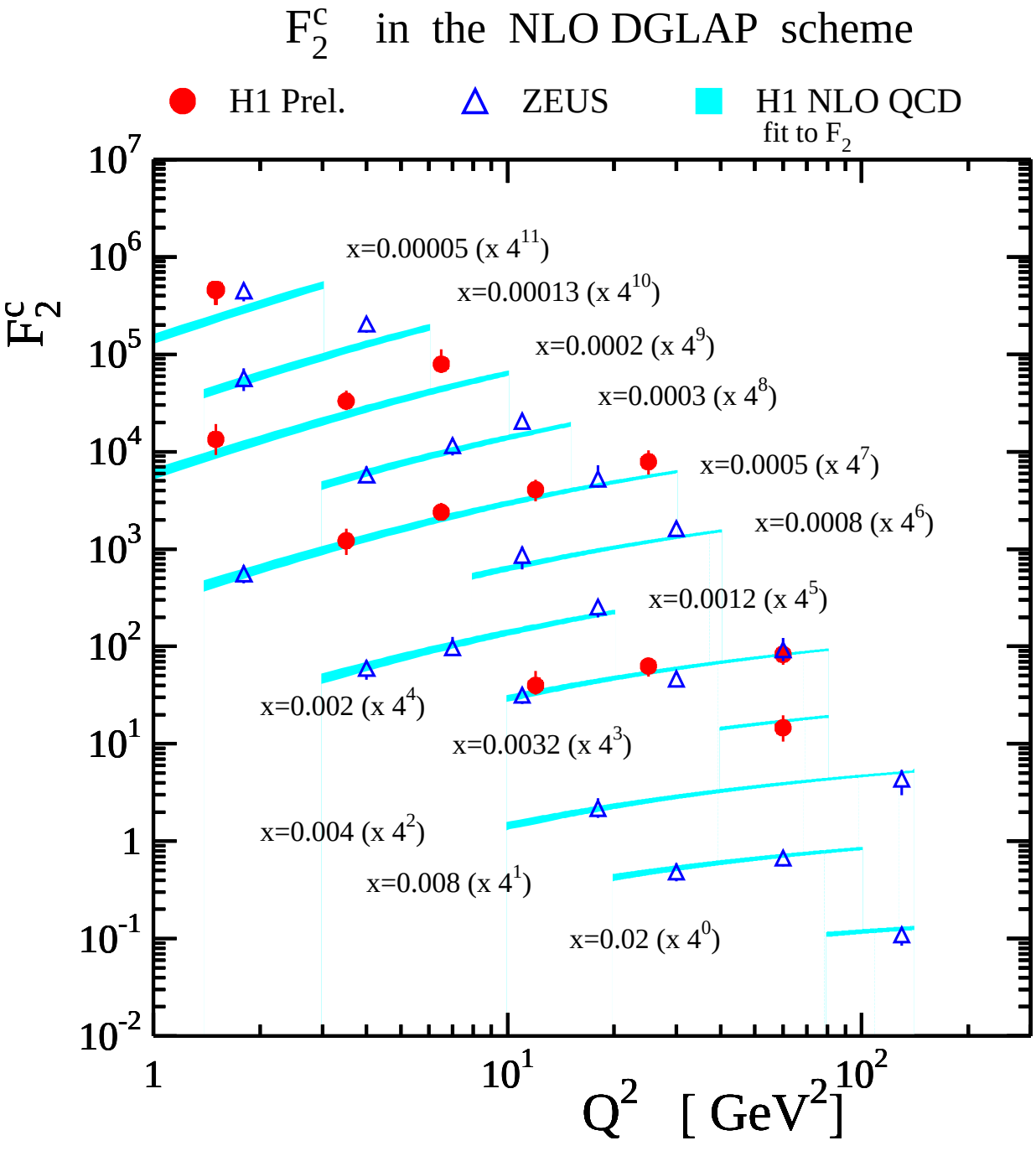
Scaling Violation in Open Charm Production



Charm data show large scaling violations

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Beauty Tagging - I

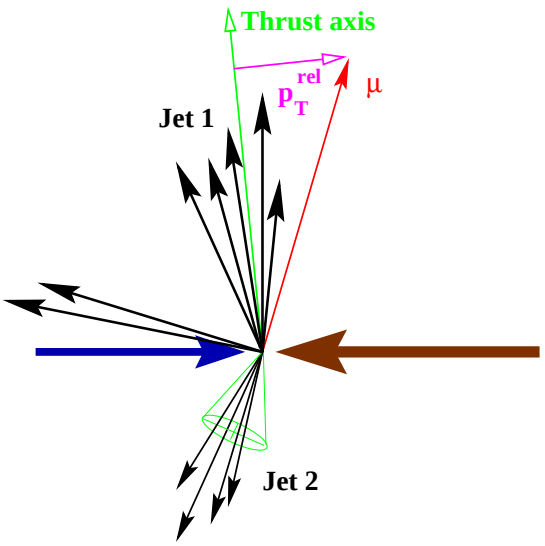
Semi-leptonic B-decays with large $p_\perp^\mu$ wrt jet

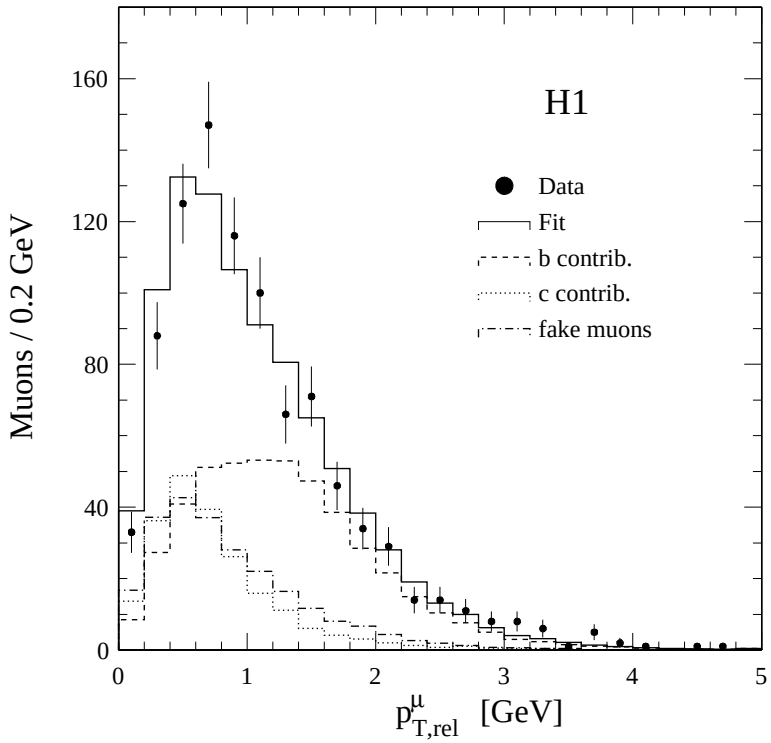
2-Jet events Cone algorithm $R = 1$

$|\eta^{jet}| < 2.5 \quad E_\perp^{jet} > 6$ GeV

+ 1 muon

$p_{\perp,lab}^{\mu} > 2.0$ GeV $\quad 35° < \Theta^\mu < 130°$





Phys. Lett. B467 (1999) 156

$$\sigma_{vis}(ep \to eb\bar{b}X \to \mu X) = 176 \pm 16(stat.)^{+26}_{-17}(syst.)\text{pb}$$

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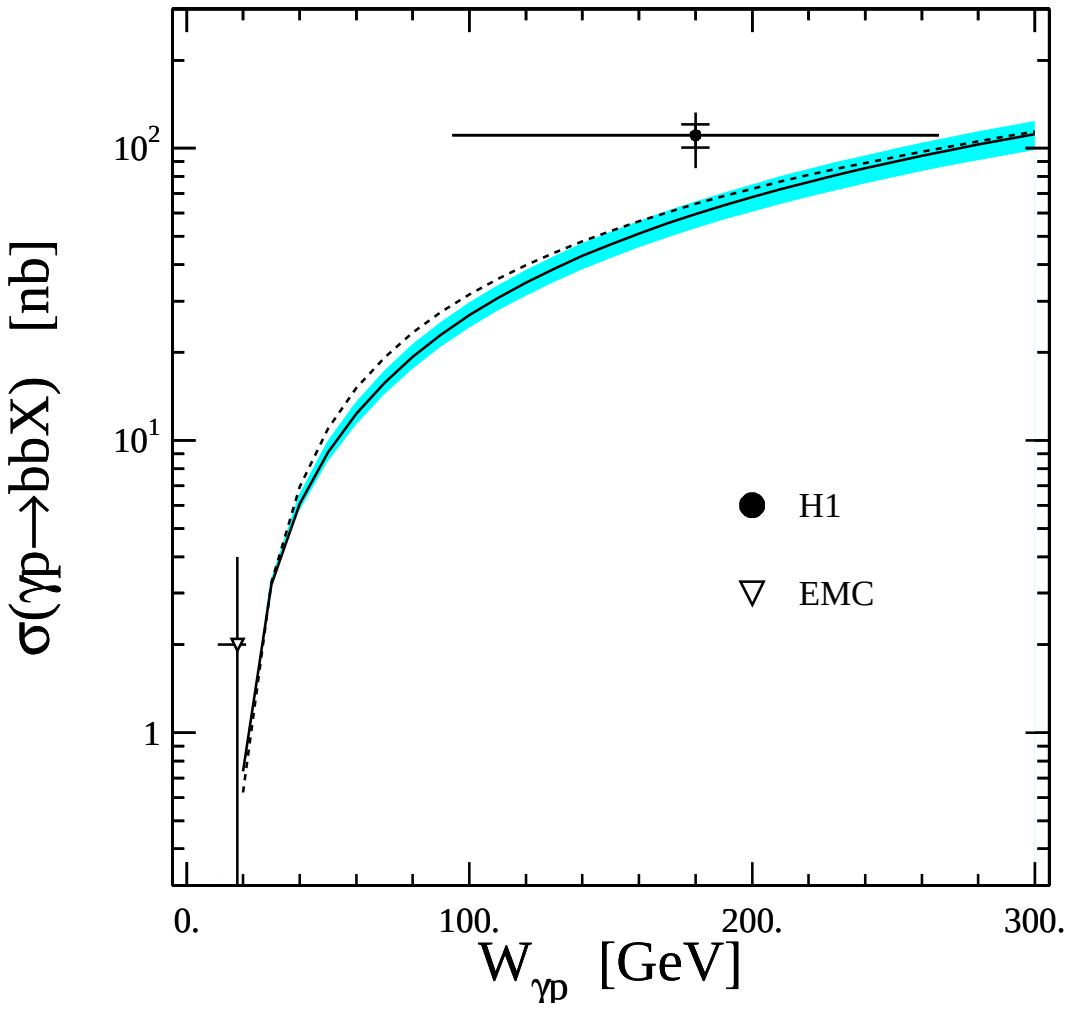
Beauty Cross Section vs. NLO QCD



Phys. Lett. B467 (1999) 156 $\langle W_{\gamma p} \rangle \approx 180$ GeV

$$\sigma(\gamma p \to b\bar{b}X) = 111 \pm 10(stat.)^{+23}_{-20}(syst.)\text{nb}$$

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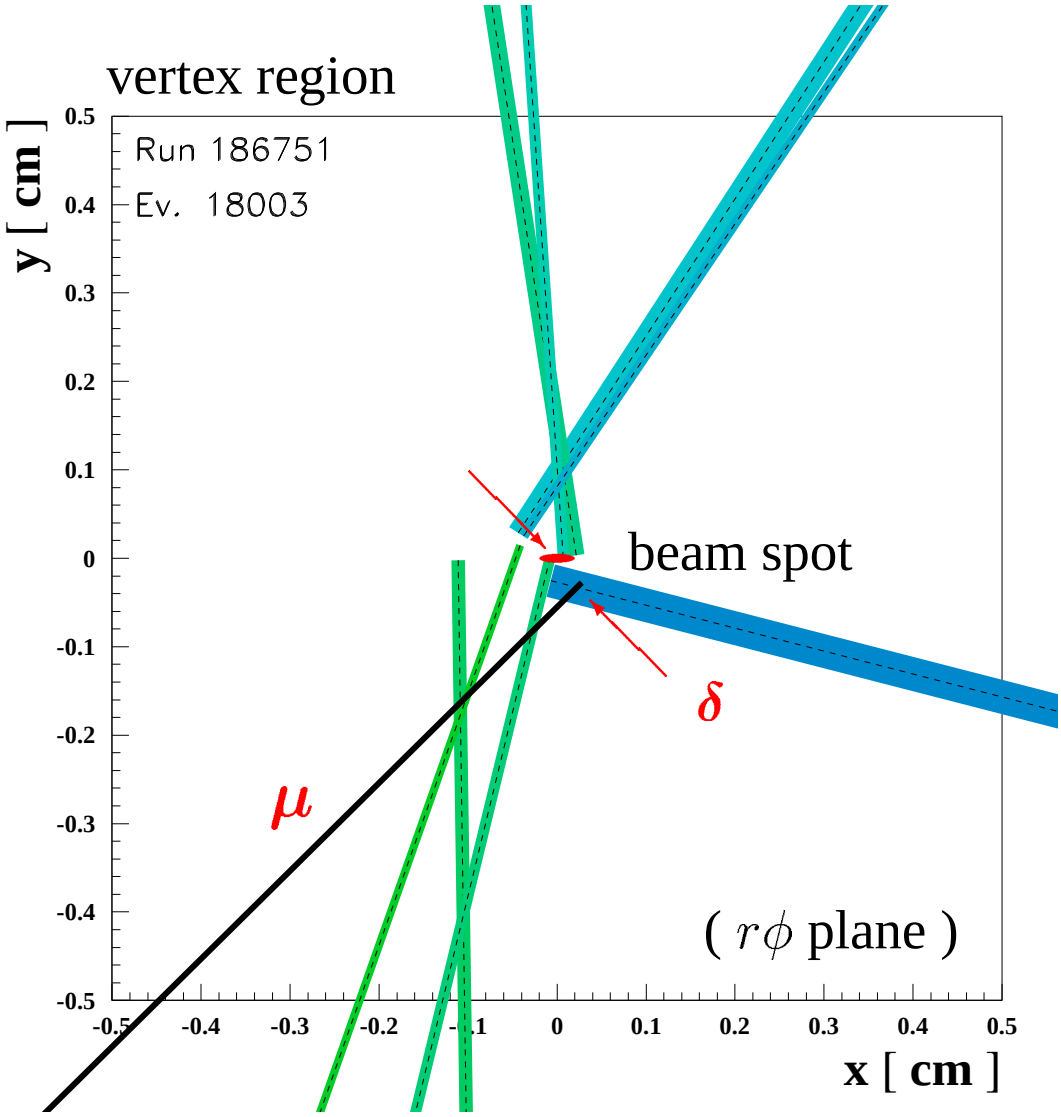
Beauty Tagging - II

Semi-leptonic B-decays with lifetime tag

→ impact parameter δ



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Impact Parameter

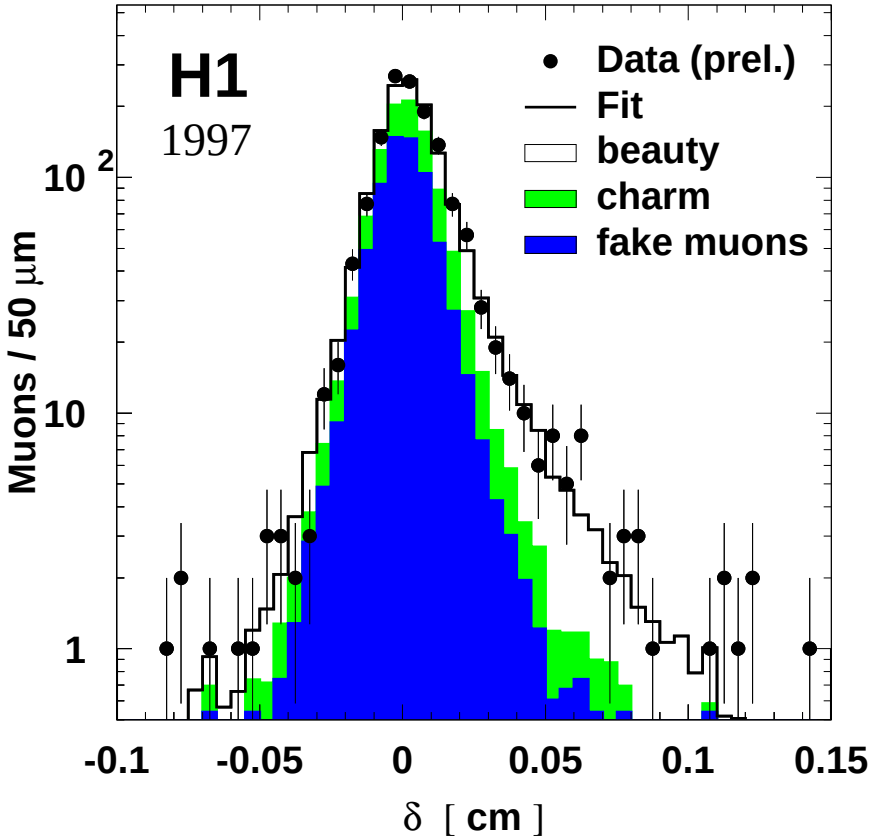
2-Jet events Cone algorithm $R = 1$

$|\eta^{jet}| < 2.5 \quad E_{\perp}^{jet} > 5$ GeV

+ 1 muon

$p_{\perp,lab}^{\mu} > 2.0$ GeV $\quad 35° < \Theta^{\mu} < 130°$

b production: impact parameter



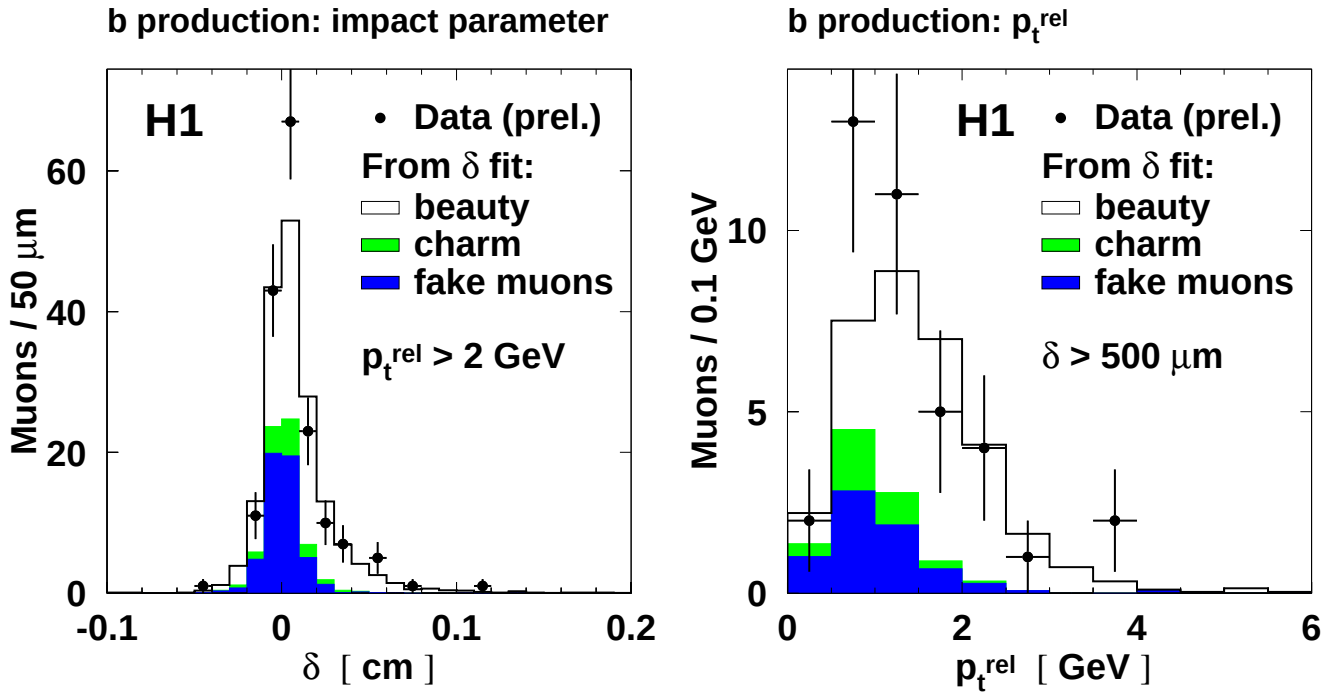
H1 preliminary

$\sigma_{vis}(ep \to eb\bar{b}X \to \mu X) = 159 \pm 30(stat.) \pm 29(syst.)$pb

Confirms P.L. B467(1996)156

Combining Impact Parameter δ with $p_\perp^{rel}$

High b purity regions



- Combined likelihood fit in $(\delta, p_\perp^{rel})$ plane:

H1 preliminary

$$\sigma_{vis}(ep \to eb\bar{b}X \to \mu X) = 160 \pm 16(stat.) \pm 29(syst.)\text{pb}$$

- Average with publ. H1 result: $\sigma_{vis} = (170 \pm 25)$ pb
- NLO pQCD (FNMR): $\sigma_{vis} = (104 \pm 17)$ pb

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Summary

- Charm DIS data seem to favour CCFM based calculations over predictions in the NLO DGLAP scheme

- Significant scaling violations are observed in F_2^c

- First measurement of Beauty photoproduction cross section confirmed by independent data using lifetime tags

- Beauty photoproduction cross section larger than NLO QCD prediction

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