International Conference "Heavy Quarks and Leptons"

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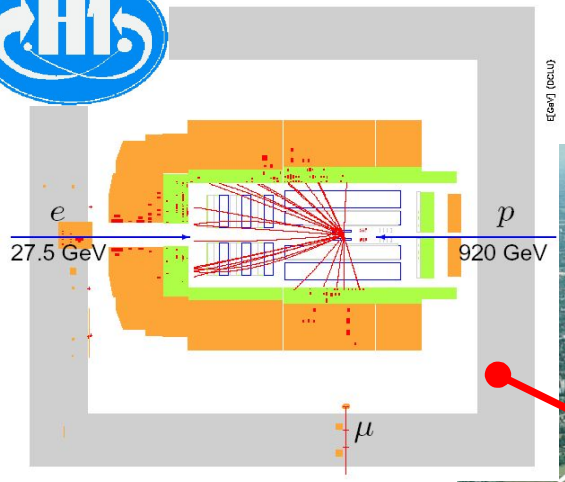
on behalf of the
H1 and ZEUS Collaborations

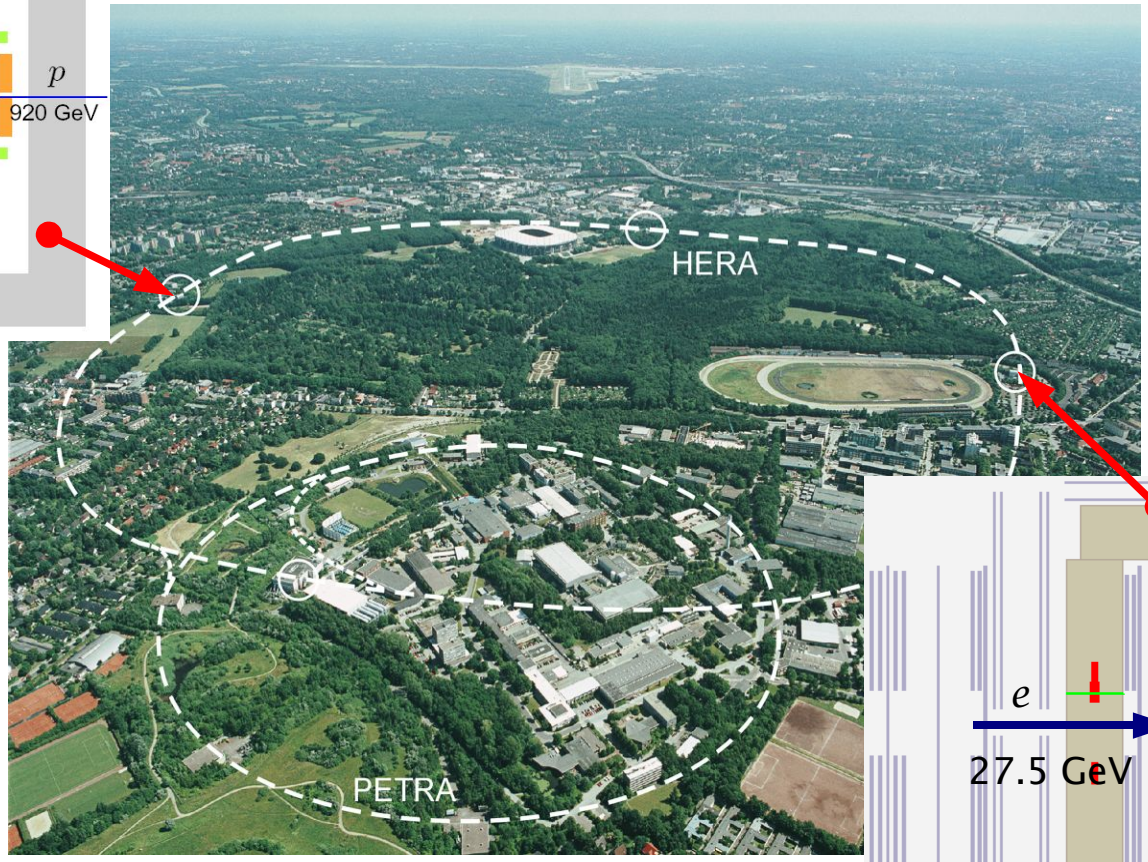
Charm and Beauty Structure of the proton

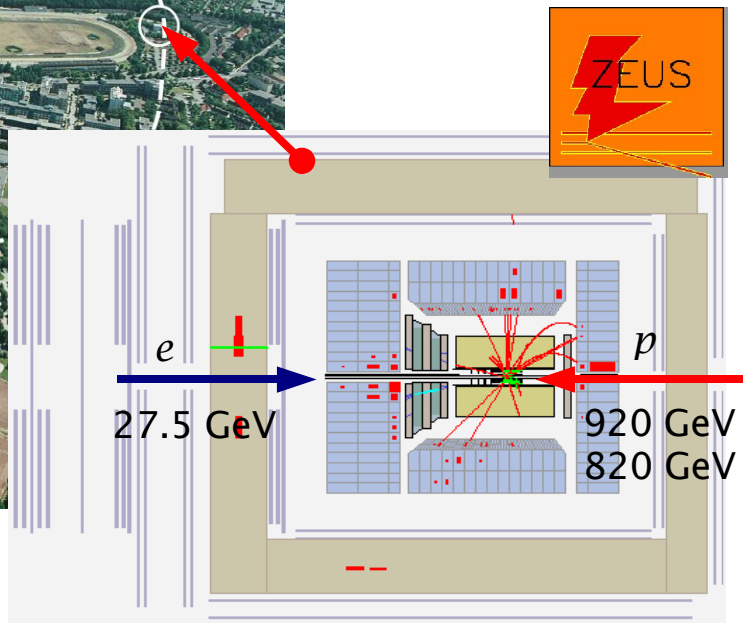
Outline:

- Introduction
- Charm
- Bottom
- F_2^{cc}, F_2^{bb}
- $\Delta G/G$ from COMPASS
- Conclusions

HERA: ep collisions within H1 & ZEUS







HERA I

- 820/920 GeV p beam
- 27.5 GeV $e^{\pm}$ beam
- Beam spot 150×30 μm^2
- Integrated Lum. 135 pb^{-1} (94–00)

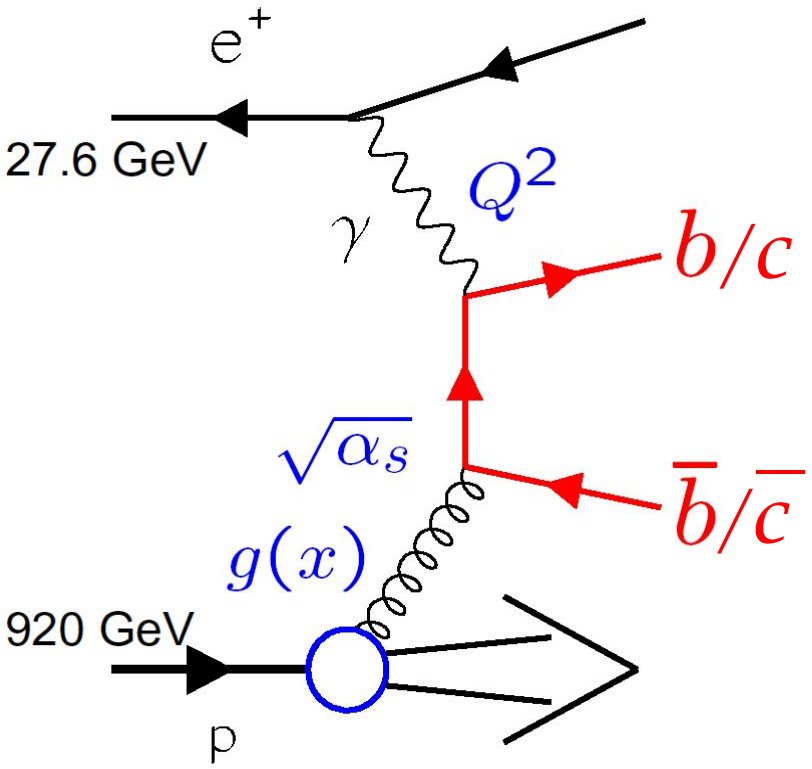
HERA II

- 920 GeV p beam; 27.5 GeV $e^{\pm}$ beam
- Beam spot 80×20 μm^2
- Integrated Lum. 180 pb^{-1} (03–05; more to come!)
- $e^{\pm}$ beam long. Polarized (≈ 30%)

Heavy Quark Production in *ep* collisions

Dominant Process in *ep* collisions:

Boson–Gluon Fusion



Multiple scales:

$m_{c/b} \sim 1.5 \; / \; 5$ GeV

$p_{T,\,c/b}$ ~ typically few to 50 GeV

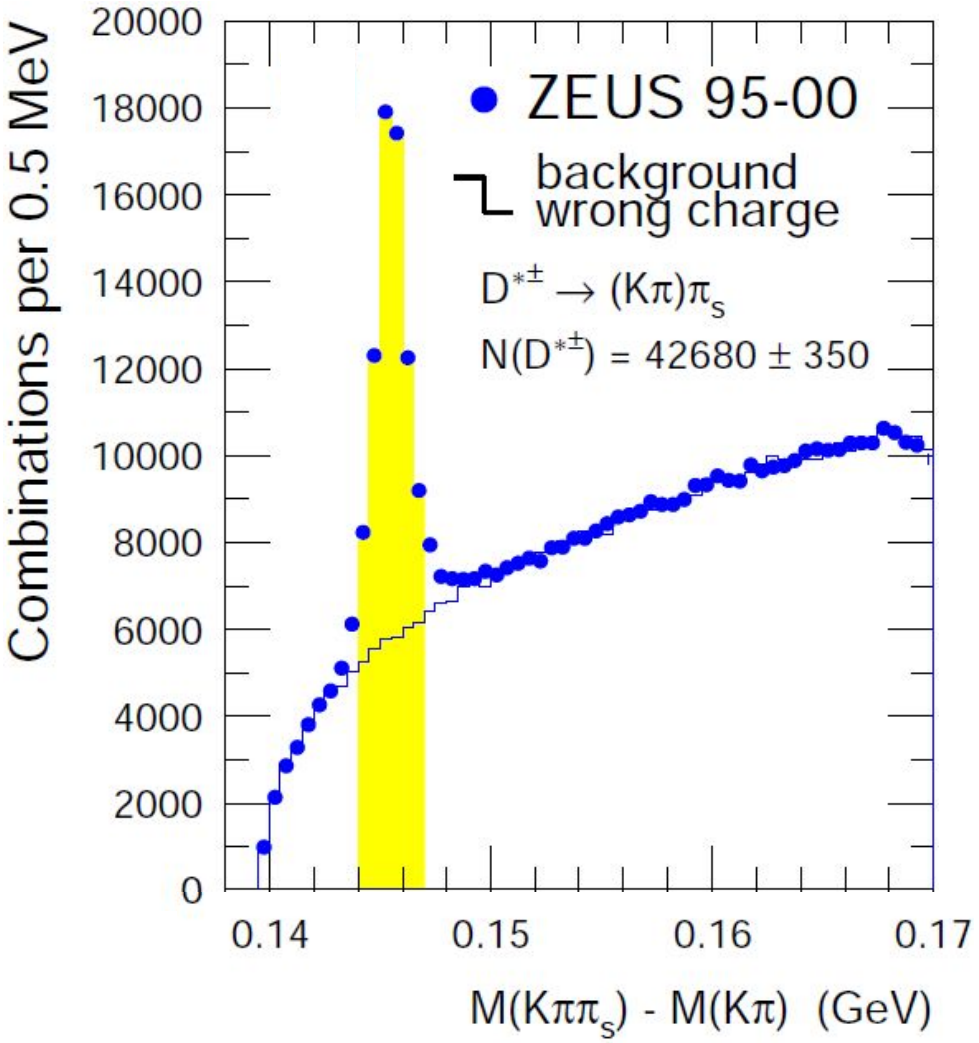
$Q^2 \lesssim 1$ GeV^2 Photoproduction (γp)

$\gtrsim 1$ GeV^2 Deep inelastic scattering (DIS)

NLO calculations with different schemes **depend on dominant scale:**

- *"massive scheme"* **FFNS:**
  $Q^2,\; p_{T,\,c/b}{}^2 \approx m_{c/b}{}^2$
- *"massless scheme"* **ZM–*V*FNS:**
  $Q^2,\; p_{T,\,c/b}{}^2 \gg m_{c/b}{}^2$
- combined massive ⊗ massless: **VFNS**

Charm production: D* tag



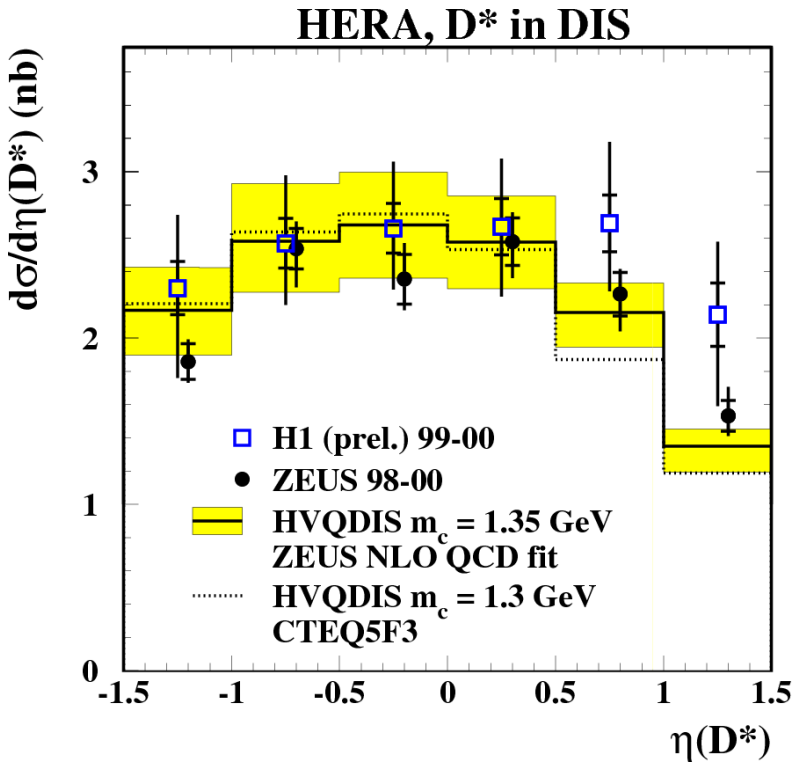
- Exclusive final hadronic decay

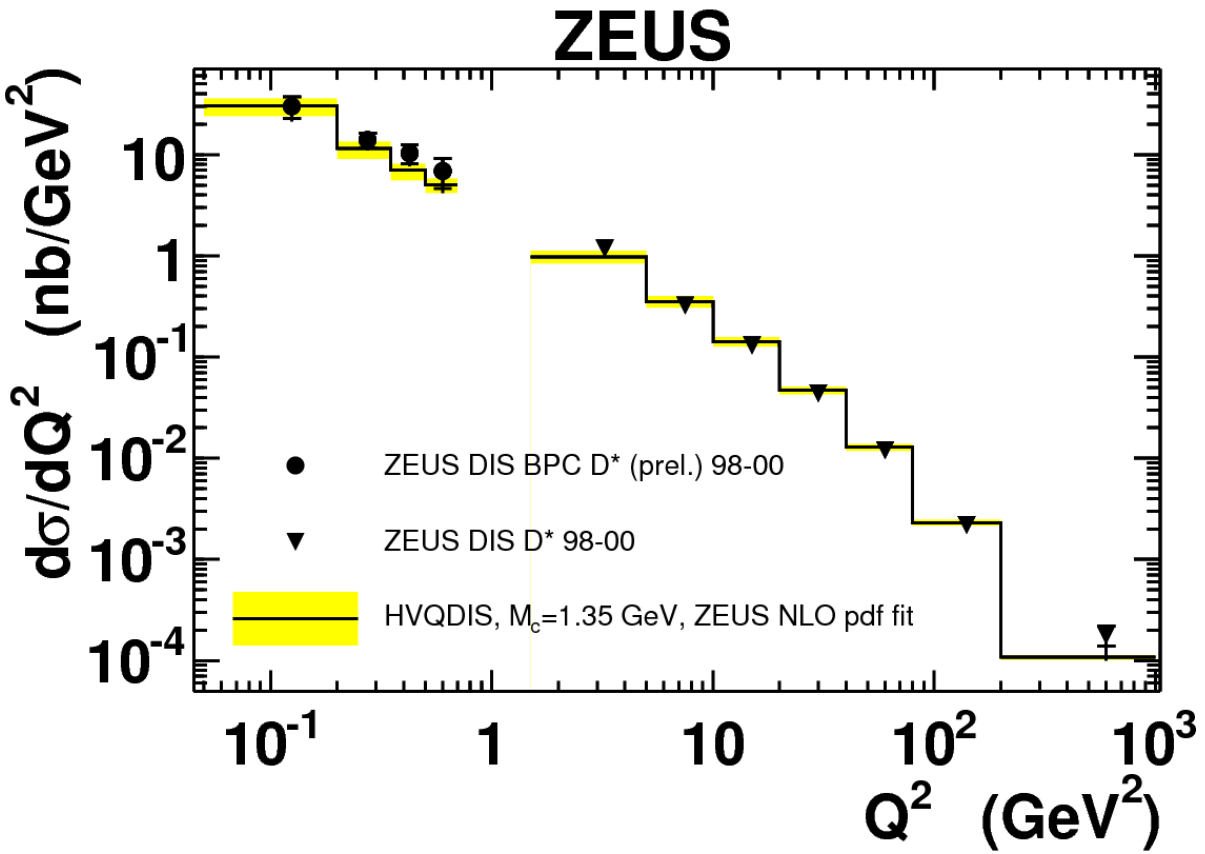
$$c \rightarrow D^*X \rightarrow D^0\pi_s X \rightarrow (K\pi)\pi_s X$$

- Impact parameter
- ... but also used other charm hadrons: D^+,D_s, Λ_c and semileptonic decays ($c \rightarrow \mu X$)

Clean signal tag with large statistics.

Charm production: D* tag

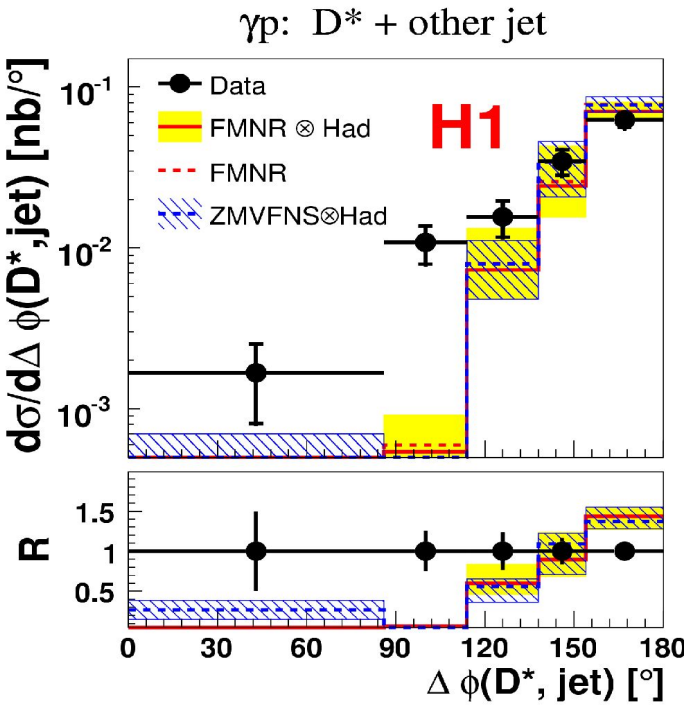




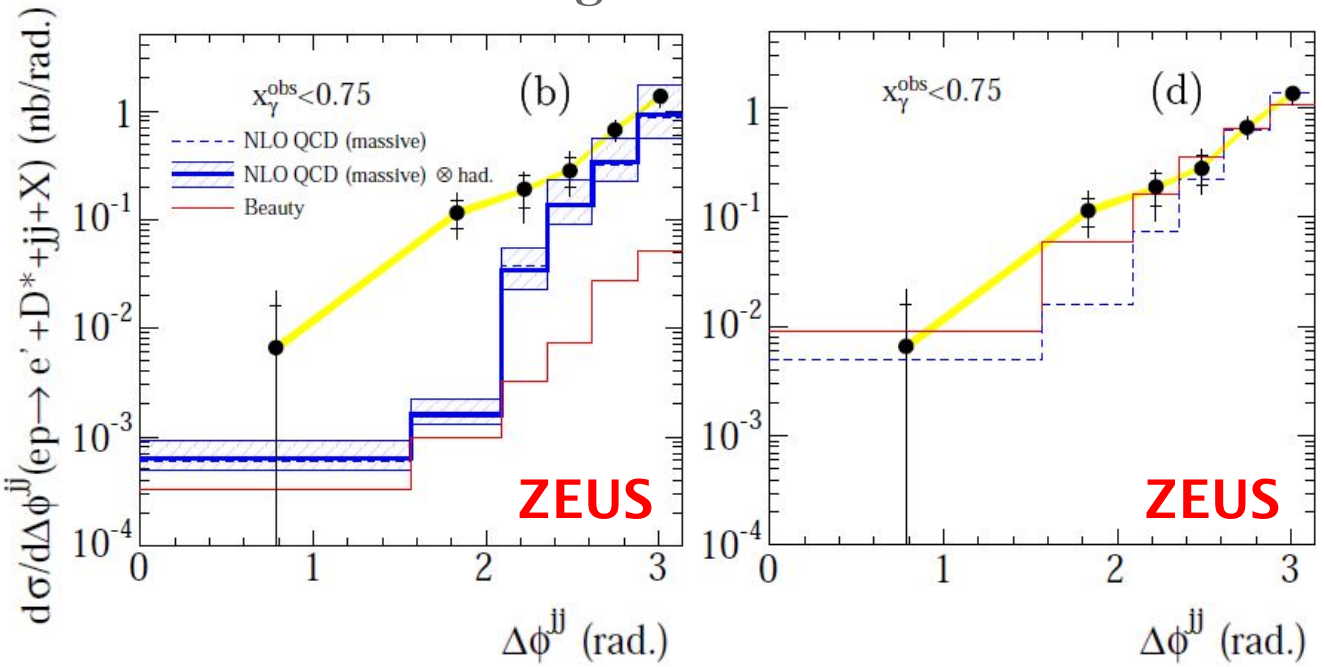
$\eta = -\ln(\tan(\theta/2))$

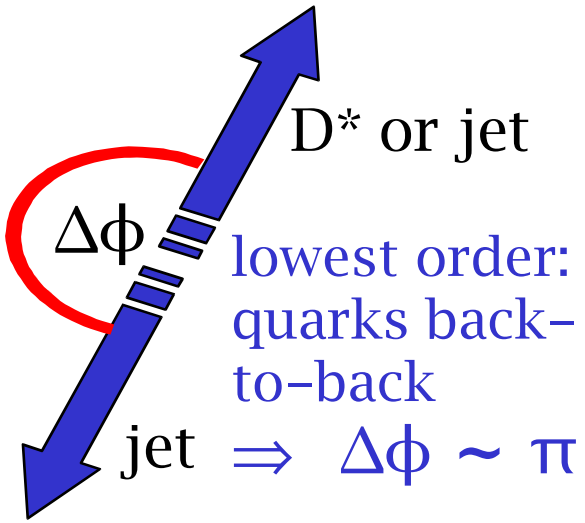
Data described by NLO QCD over 5 orders of magnitude.

Charm production, D*+jet(s) – higher order events



Enriched in higher–order like events





lowest order: quarks back–to–back

$\Rightarrow \Delta\phi \sim \pi$

NLO: Shape not well reproduced.

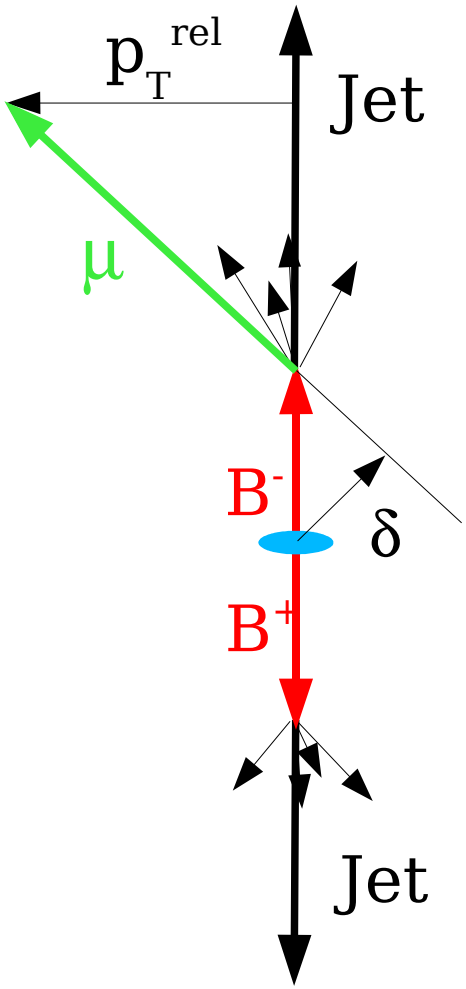
LO+PS:
Describes shape.
Normalisation too low.

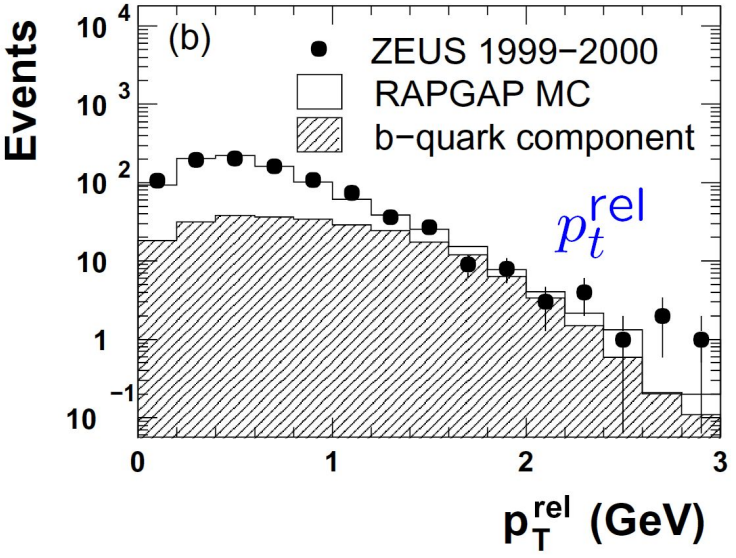
For high precision:
Need parton showers in NLO (e.g. MC@NLO) or NNLO.

Measurement techniques – μ+jets

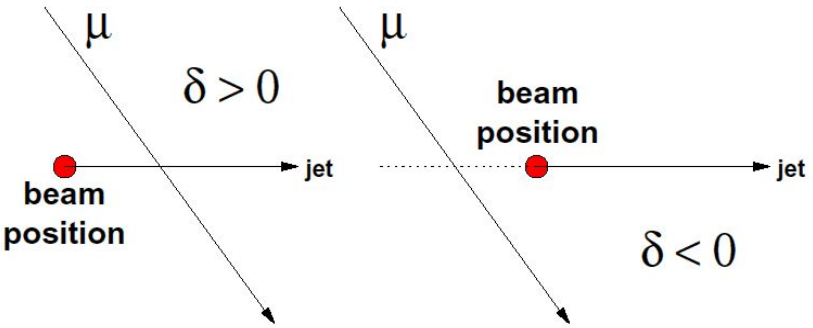
Tag μ+jets Beauty (Charm) events by exploiting:

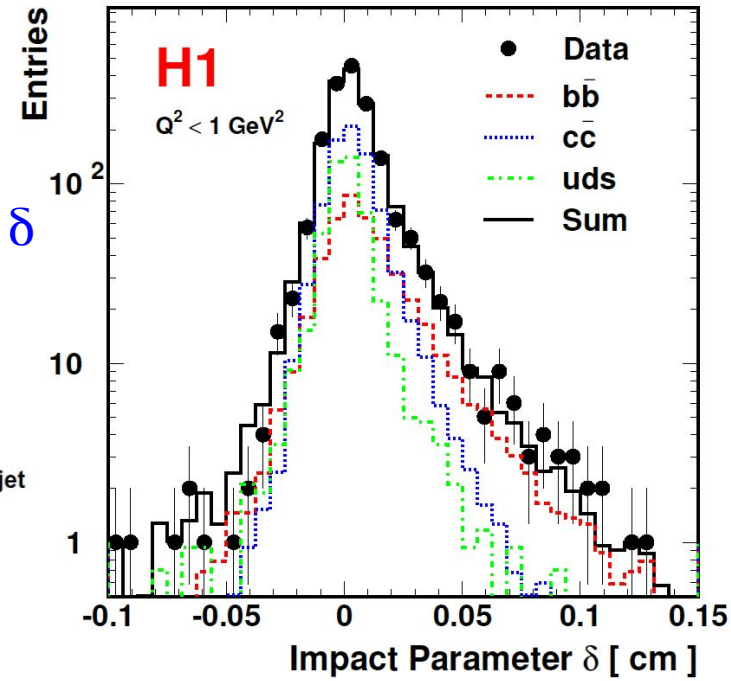
large B mass – μ–momentum relative to associated jet, $\mathbf{p_T^{rel}}$





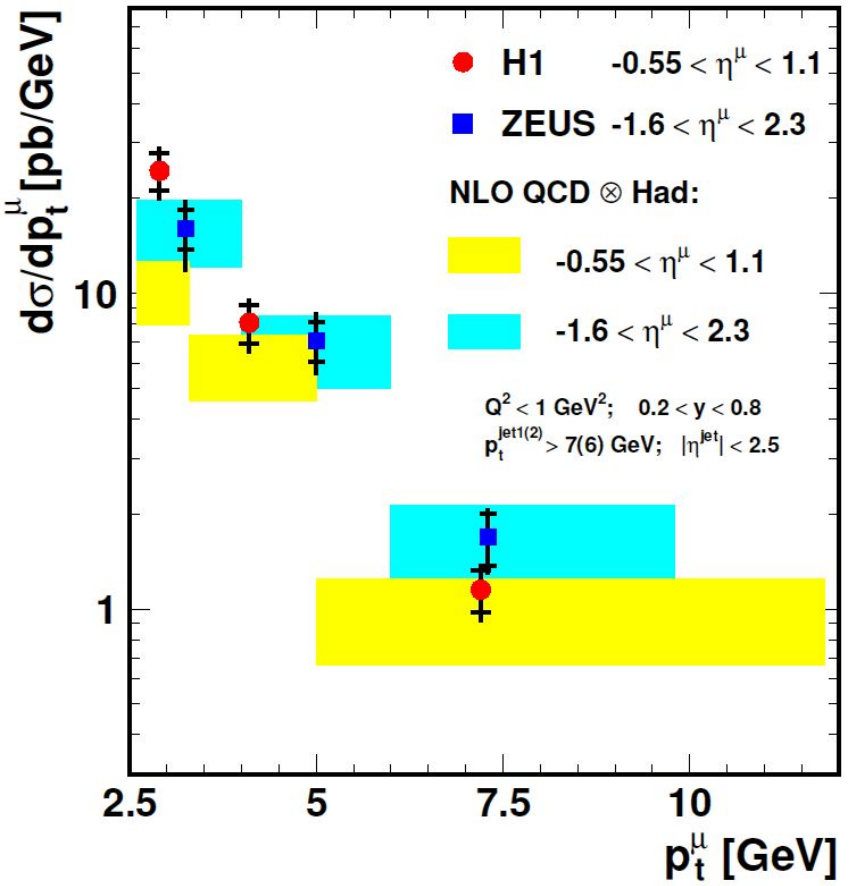
"long" lifetime (both b and c) – signed impact parameter relative to vertex/beamspot, δ

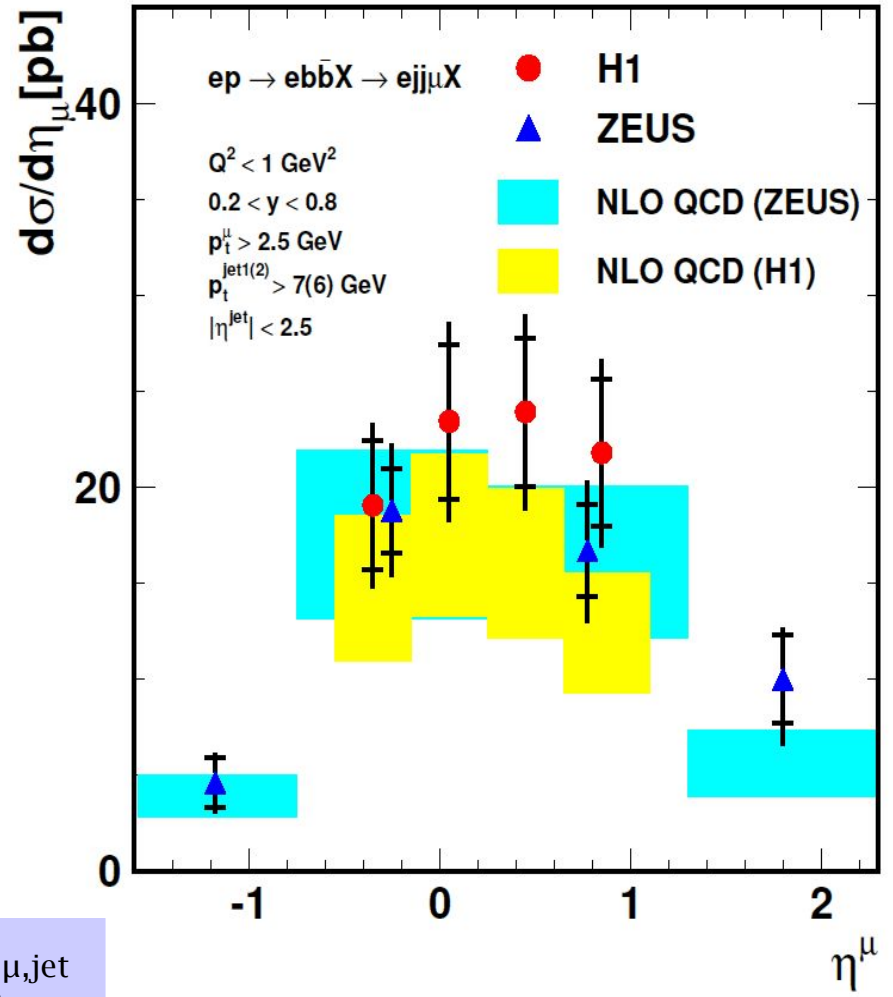




Beauty in γp, μ+jets and δ

Typical $p_T^b \sim 10$ GeV

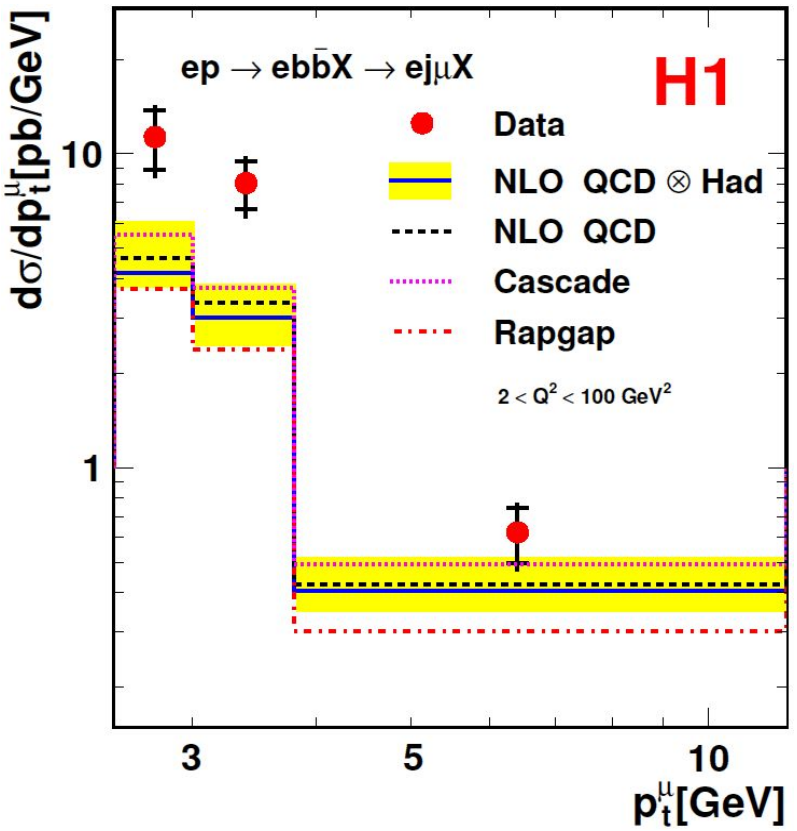




NLO agrees, H1 data slightly steeper in $p_t^{\mu,jet}$

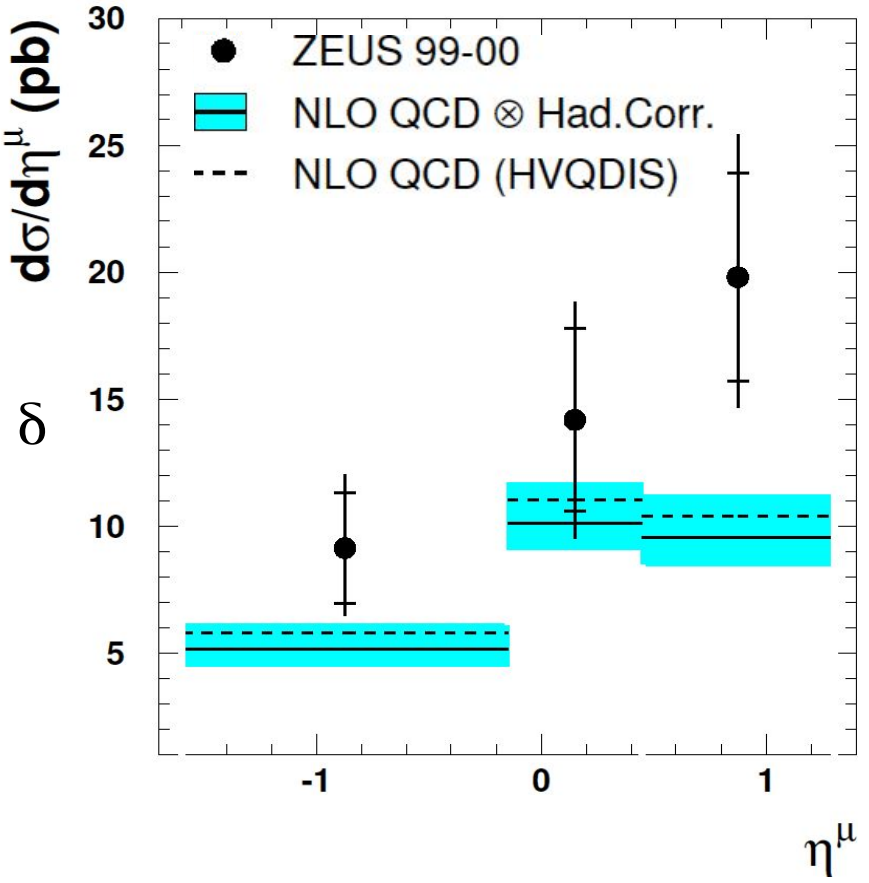
Agreement within errors of H1 and ZEUS

Beauty in DIS, μ+jets and δ



H1: $p_T^{rel} + \delta$

ZEUS: p_T^{rel}



H1

$Q^2 \in [1, 100]\ GeV^2$

$y \in [0.1, 0.7]$

$p_T^\mu > 2.5\ GeV$

$\eta^\mu \in [-0.75, 1.15]$

Data higher at low p_T^μ as for the H1 γp measurement.
Higher data **also in forward η**.

A trend? Extend η and p_T range:

ZEUS

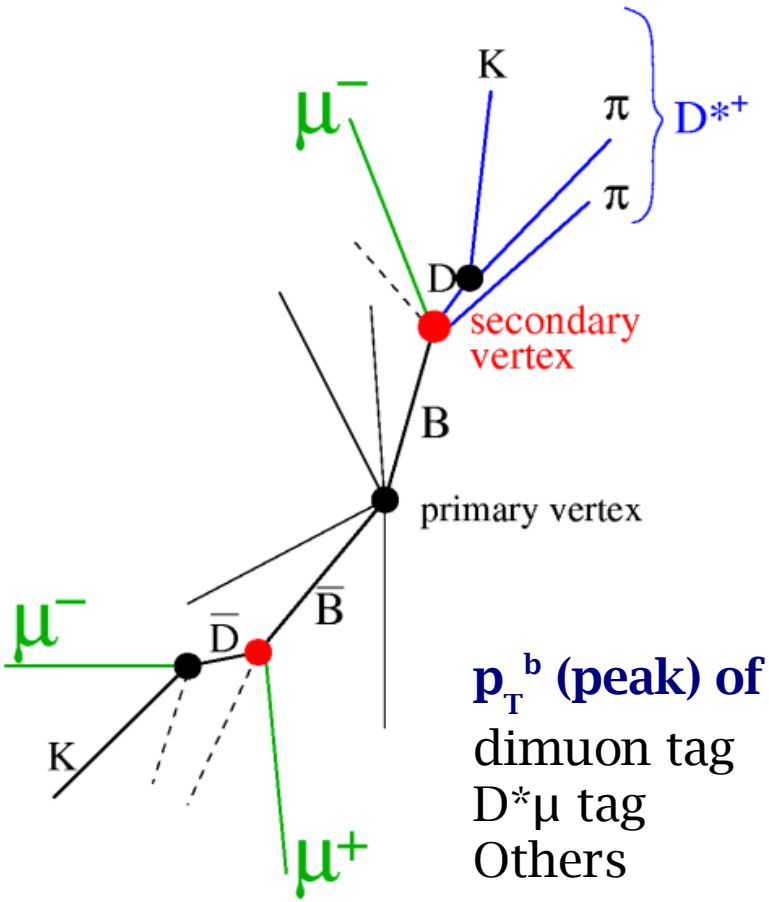
$Q^2 \in [1, 1000]\ GeV^2$

$y \in [0.05, 0.7]$

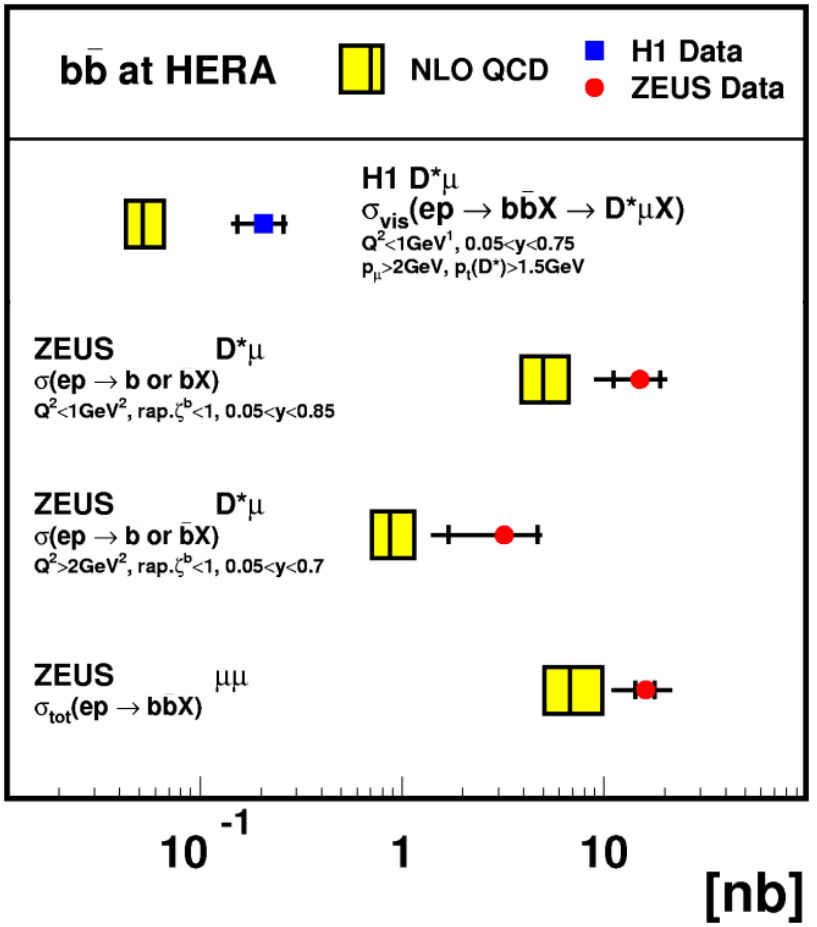
$p_T^\mu > 2.0\ GeV$

$\eta^\mu \in [-1.6, 1.3]$

b→D*μ and b→μμ measurements: sensitive to low p_T^b



Exploit correlations, no jet cuts, threshold prod.



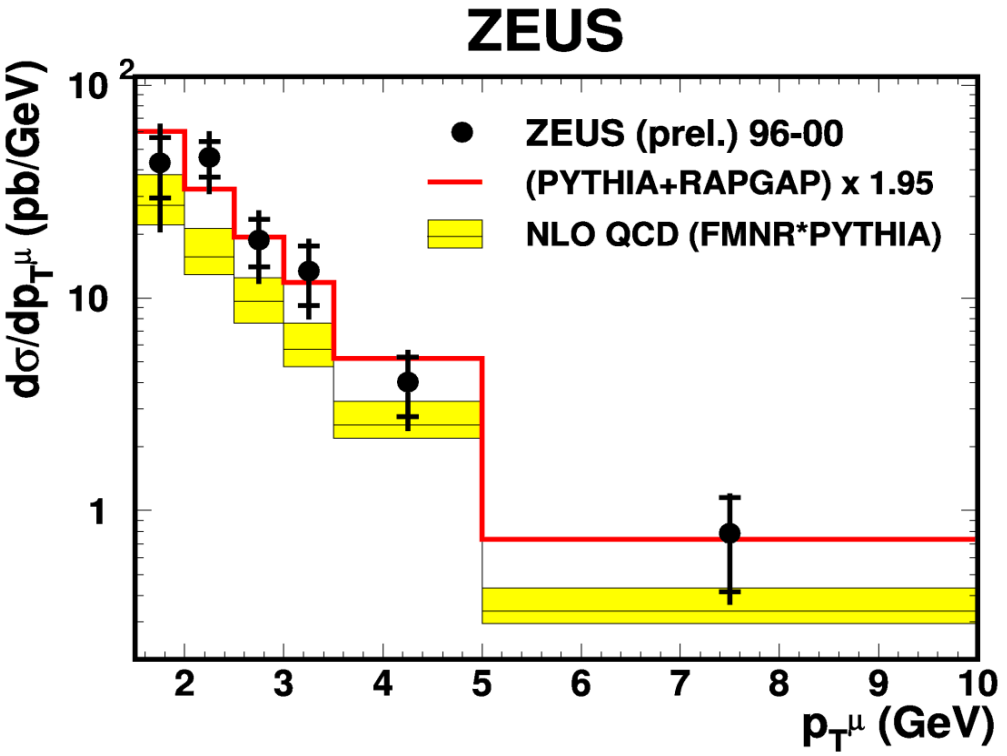
p_T^b (peak) of tagged b–quarks:

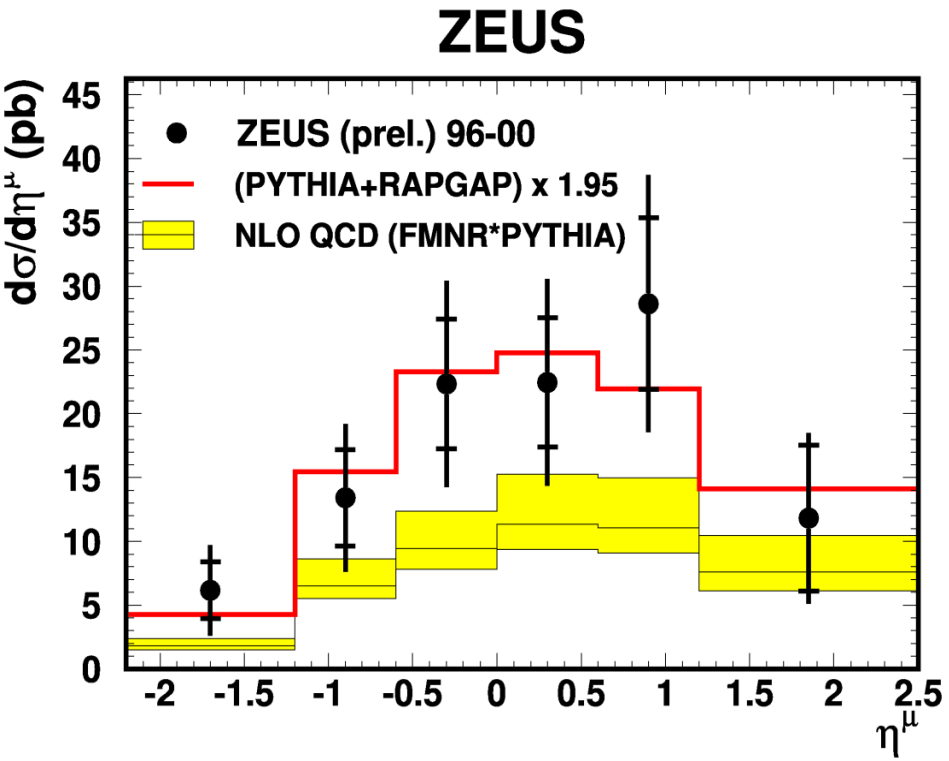
dimuon tag	~ **4 GeV**
D*μ tag	~ **6 GeV**
Others	**> 6 GeV**

At low p_T – same trend: Massive **NLO underestimates data,**
ZEUS: NLO compatible within errors.

Trend at forward η and low p_T?

Low p_T^b b→dimuon cross sections:



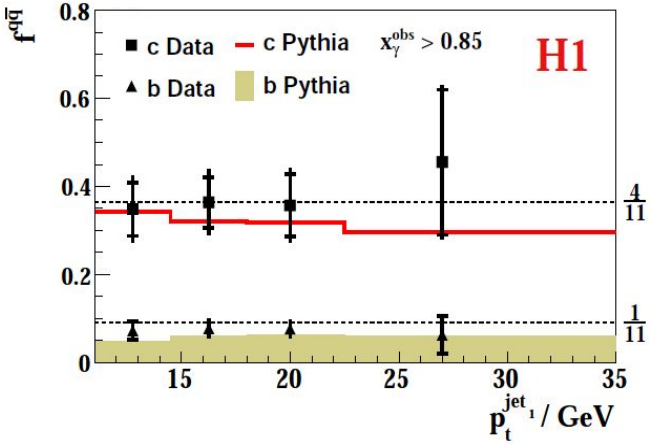


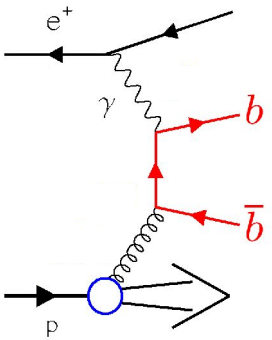
No evidence for trend at low p_T and forward η **to continue.**

Beauty and Charm – δ+jets (High p_T, γp)

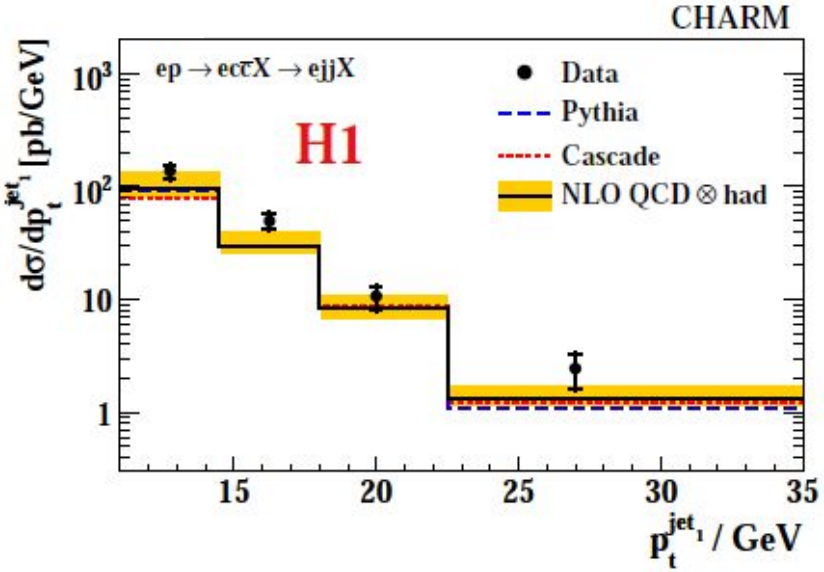
Inclusive final state, **simultaneous determination of Beauty and Charm.**

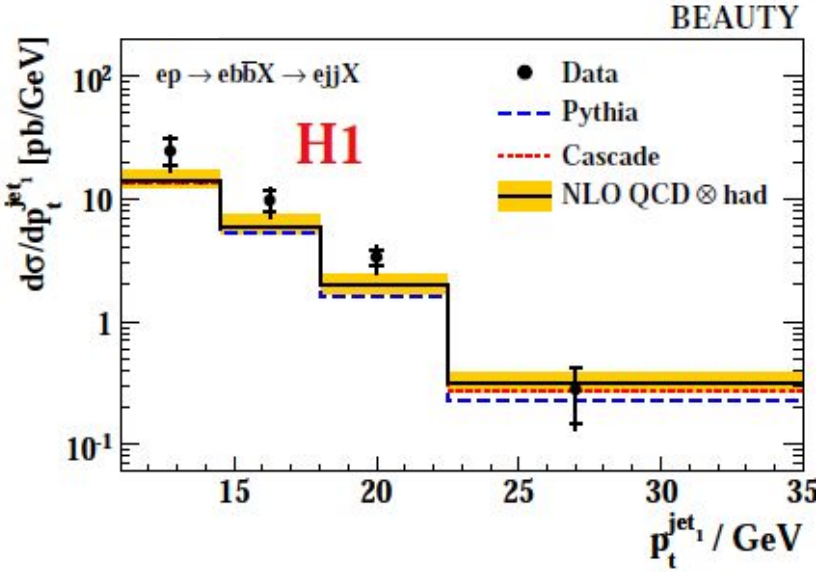
f^{qq}: c or b fraction of total ep→ejjX cross section.





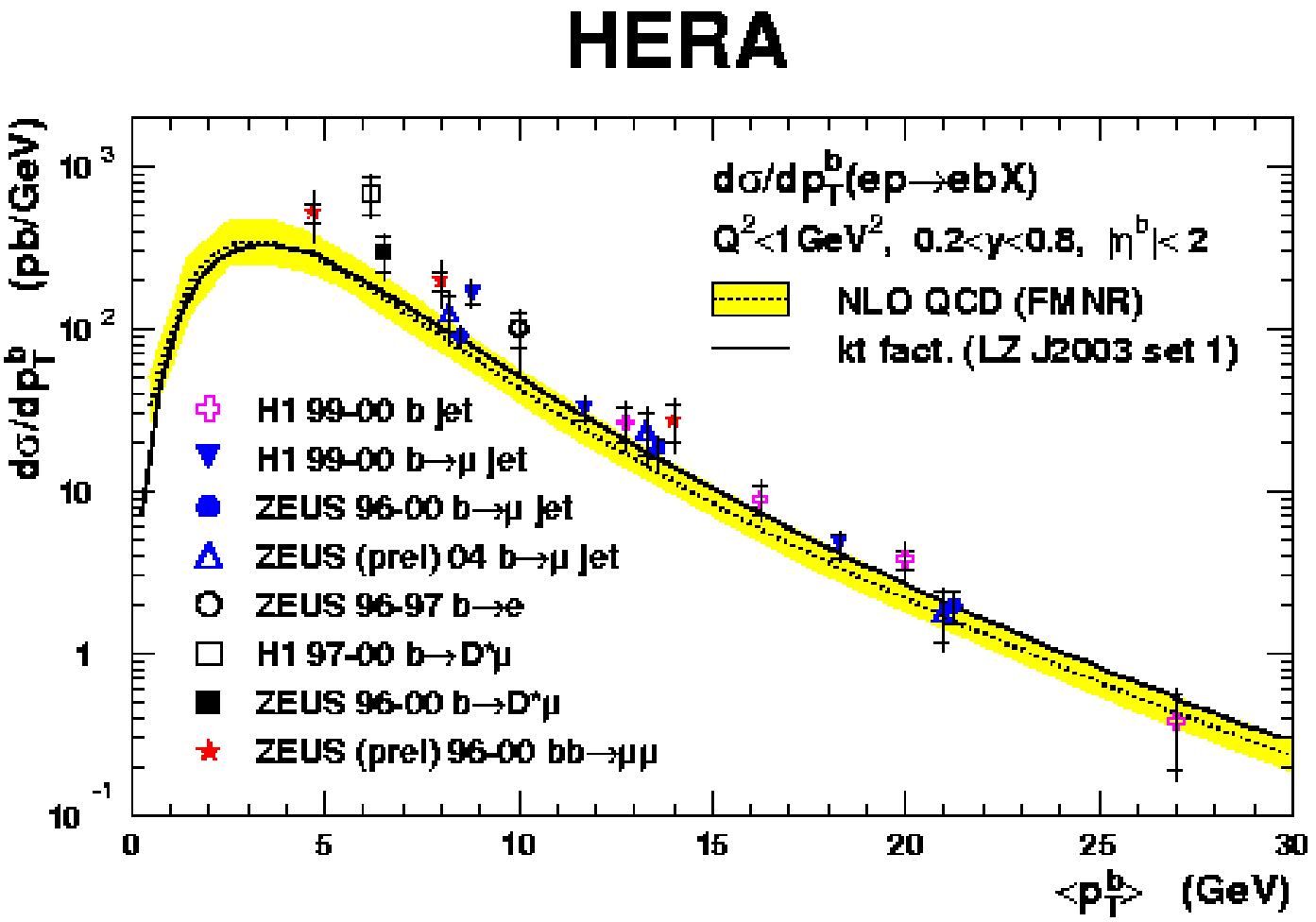
Simple quark charge counting:
$f^{cc} = 4/11$,
$f^{bb} = 1/11$





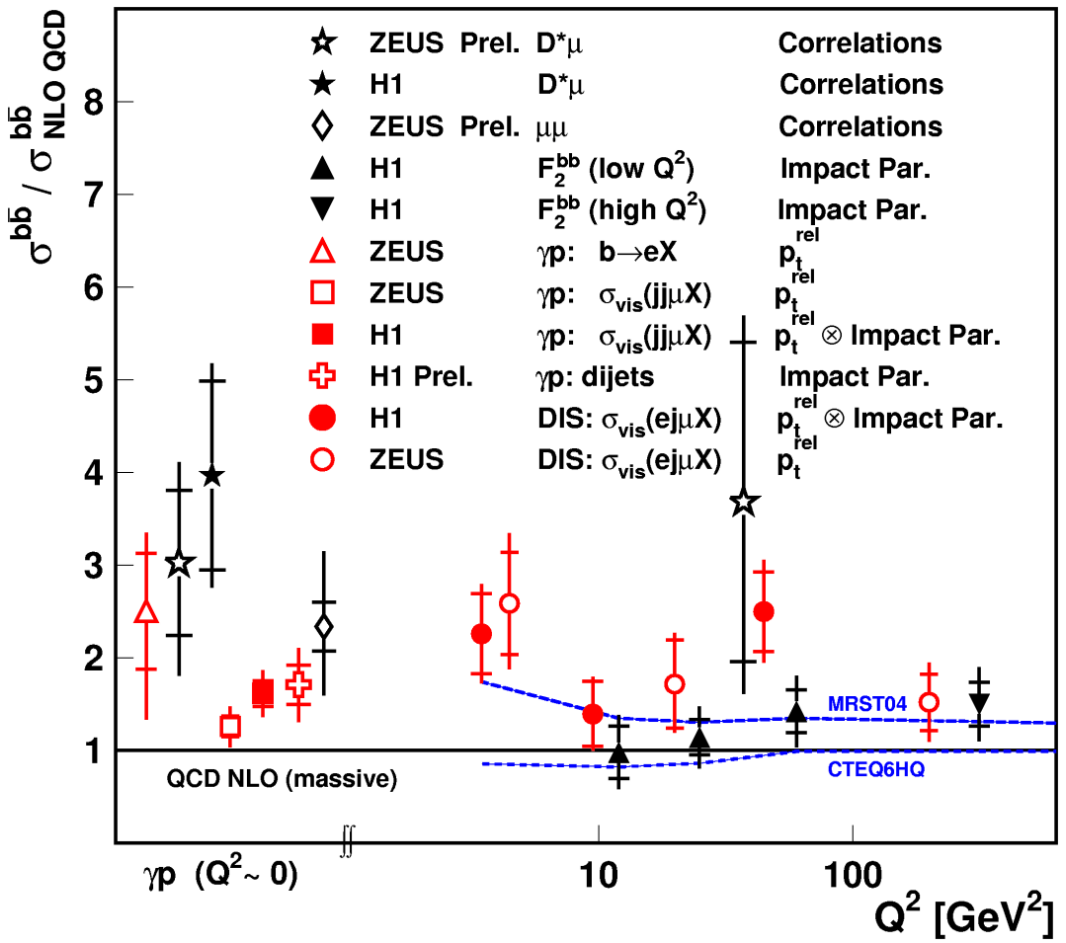
Overall good description of the data at high p_T^b.

b photoproduction at HERA



description of data not perfect,
NLO and k_t factorization agree

b cross sections vs Q^2

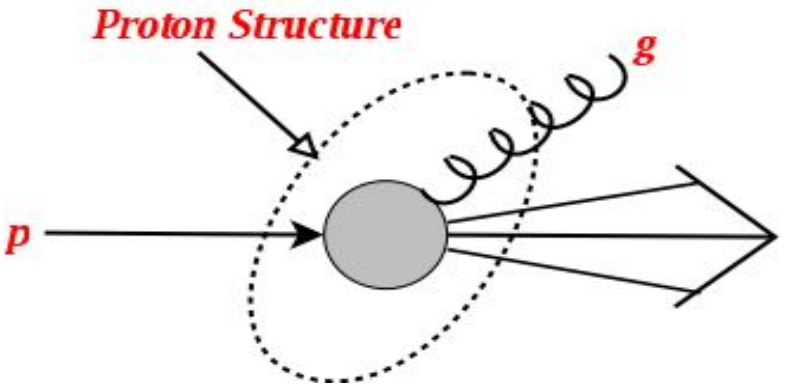


This is just a rough comparison. Q^2 is not the driving scale in the whole range!

Main caveats:

- NLO has been extrapolated to hadron level using different approaches
- NLO has been calculated for different sets of scales and parameters, same for the uncertainty
- Cross section definitions and kinematic ranges somewhat different

Extraction of $F_2^{Q\bar{Q}}$

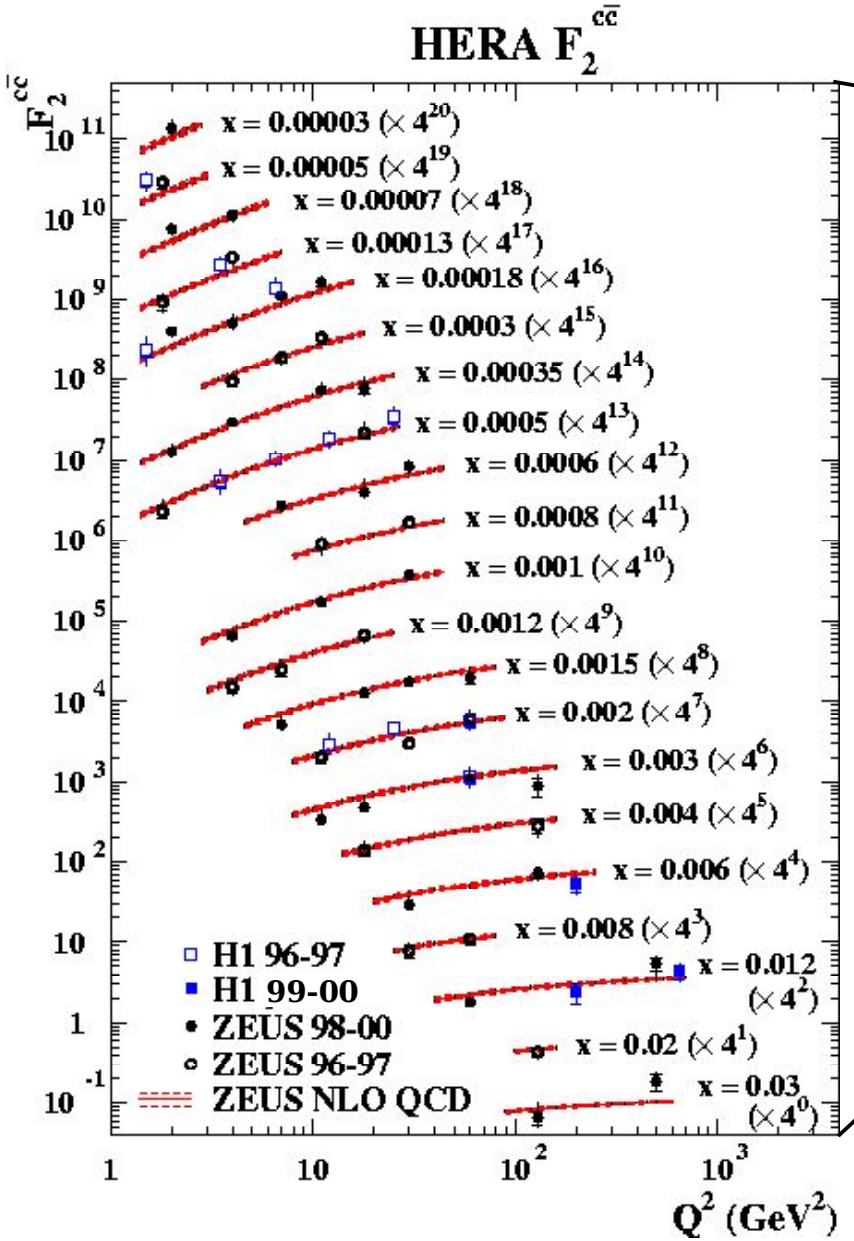


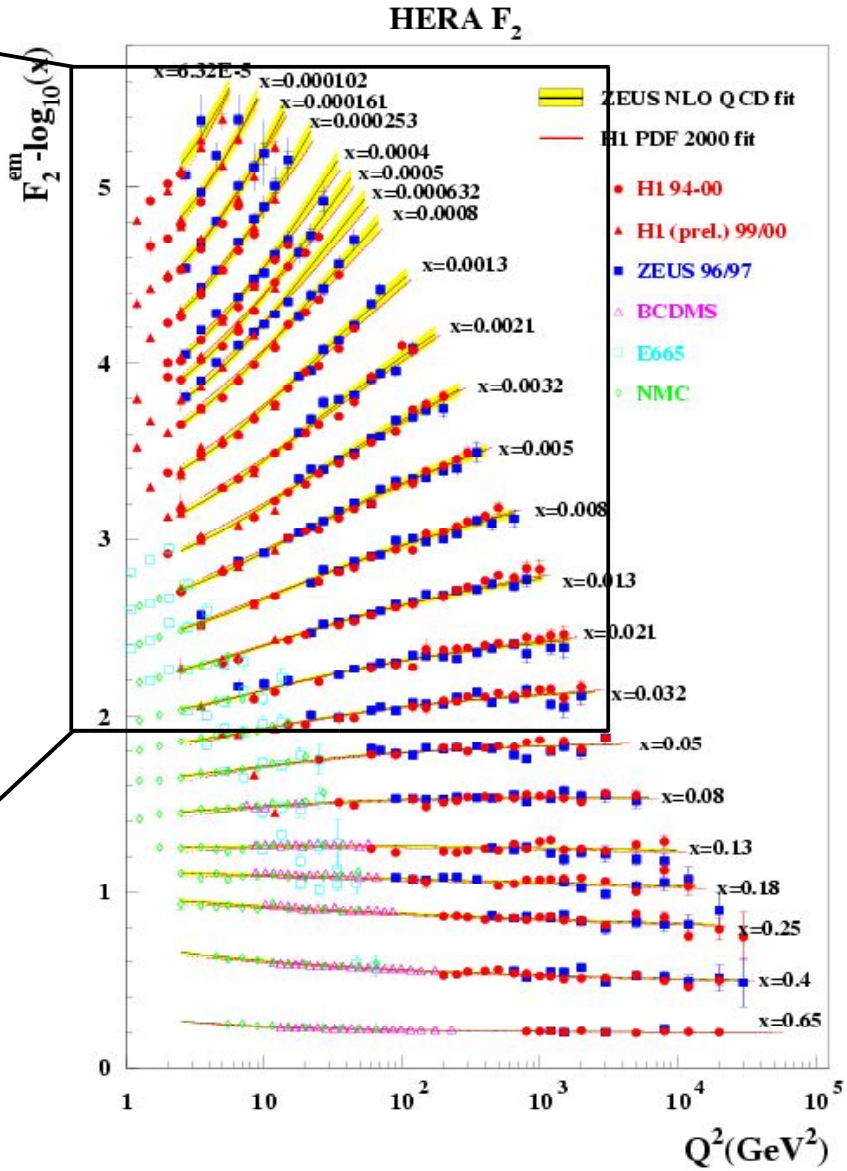
F_2^{QQ} is extracted from the charm/beauty double differential cross sections:

$$\frac{d^2\sigma^{Q\bar{Q}}(x,Q^2)}{dx\,dQ^2}=\frac{2\pi\alpha^2}{xQ^4}\left([1+(1-y)^2]F_2^{Q\bar{Q}}(x,Q^2)-y^2F_L^{Q\bar{Q}}(x,Q^2)\right)$$

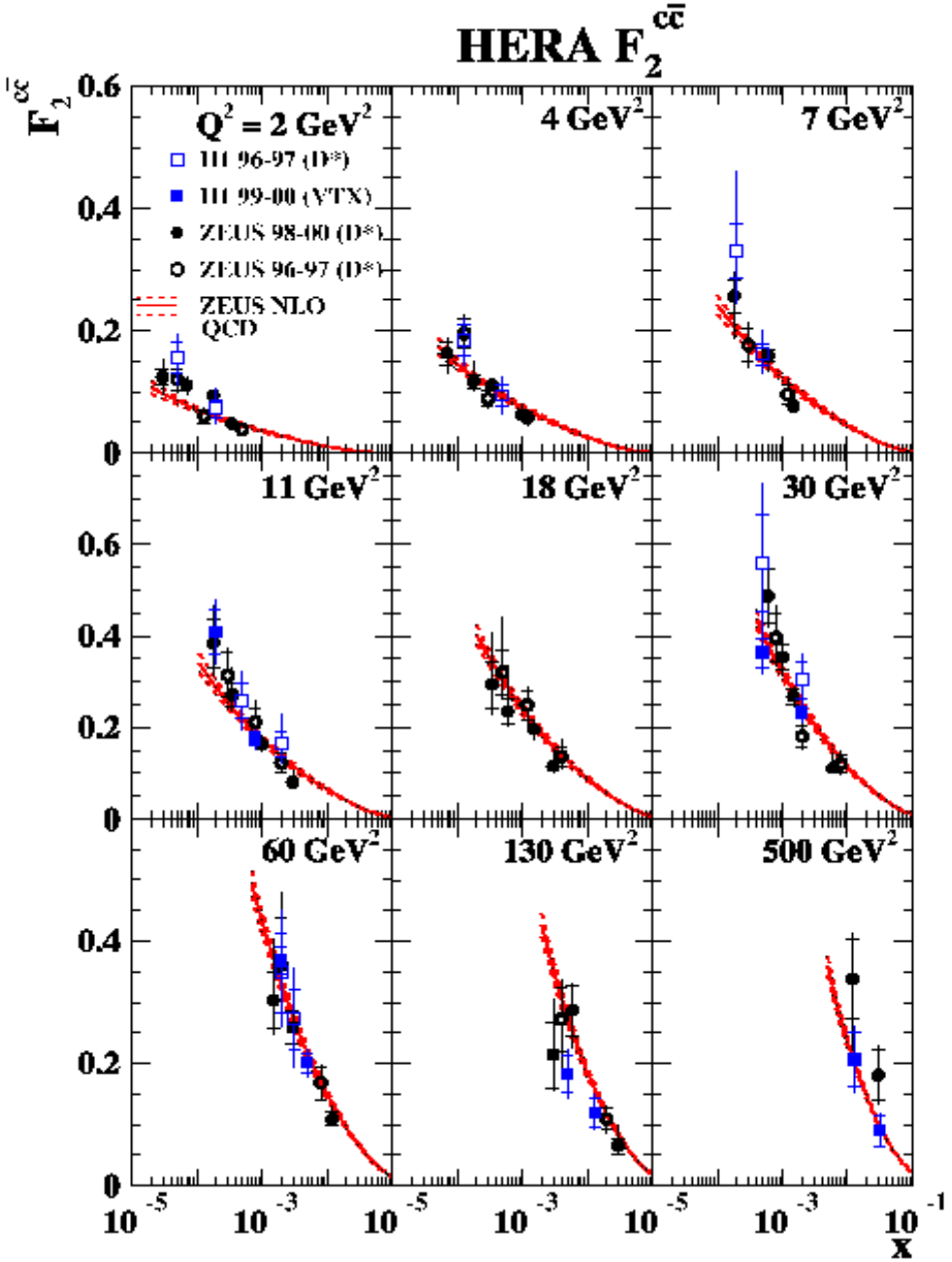
- F_L only significant at large y
- F_2 depends on Q^2 only because gluons are present in the proton
- Previous measurements used D^* cross sections to determine F_2^{cc}
- New (H1) F_2^{cc} measurement uses inclusive lifetime tag
- F_2^{bb} uses inclusive lifetime tag measurements

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



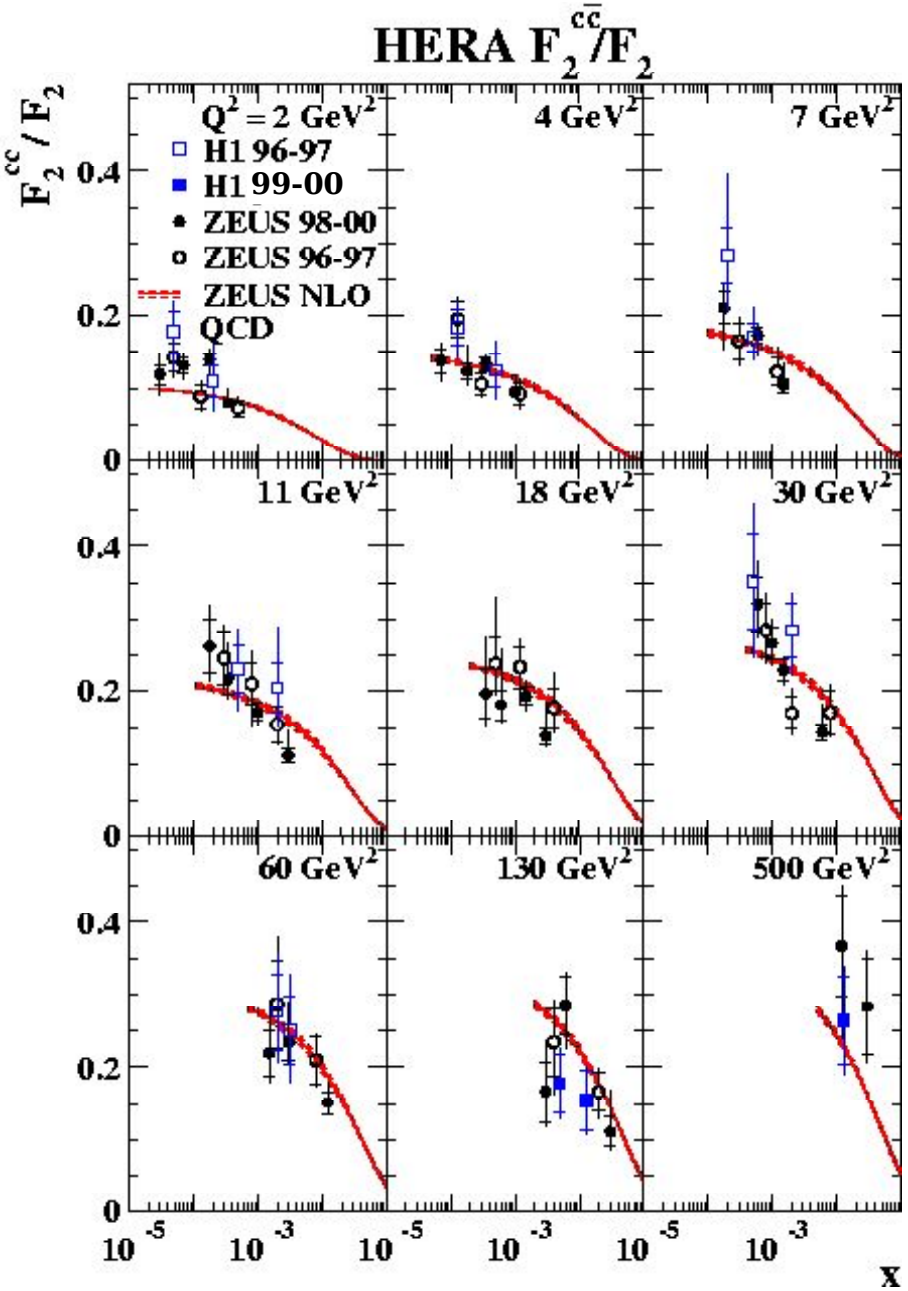


Measurement of $F_2^{c\bar{c}}$



- Data precision reaches 7%.
- Good agreement between D* and impact parameter methods.
- Strong rise towards low x driven by gluon density in the proton.
- Well described by NLO QCD fit.

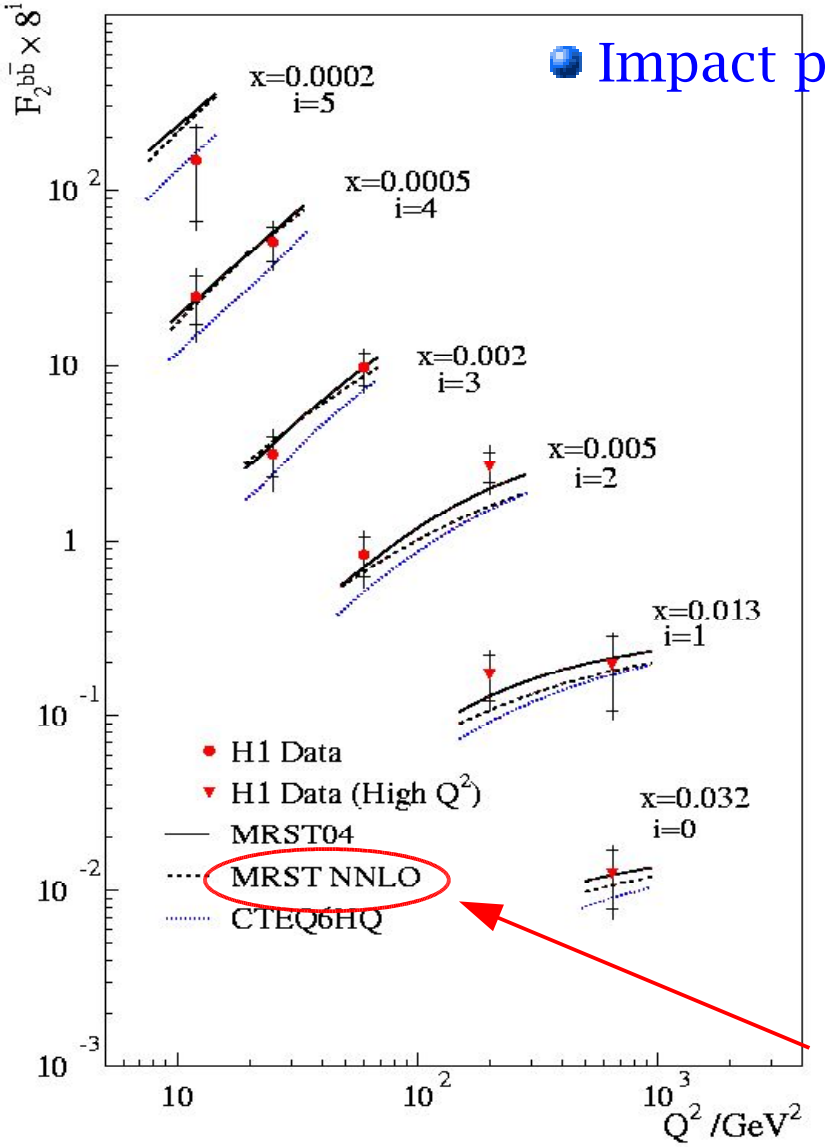
Measurement of $F_2^{c\bar{c}}$



- Charm contribution to F_2 rising towards 30% at low x and medium Q^2 .
- Flavour–democratic limit would be 4/11 = 36%

First measurement of $F_2^{b\bar{b}}$

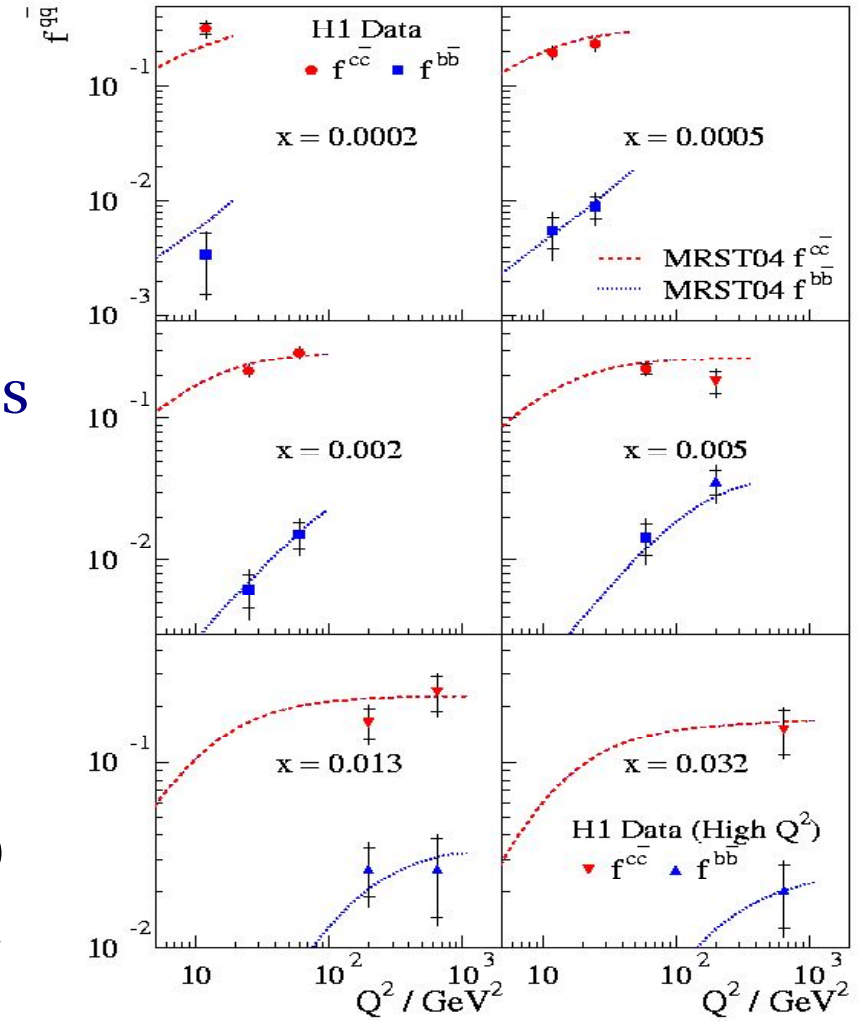
- Impact parameter method.



Beauty contributes up to 3%

First NNLO calculation

F_2^b/F_2



$\Delta G/G$ from photon gluon fusion reactions

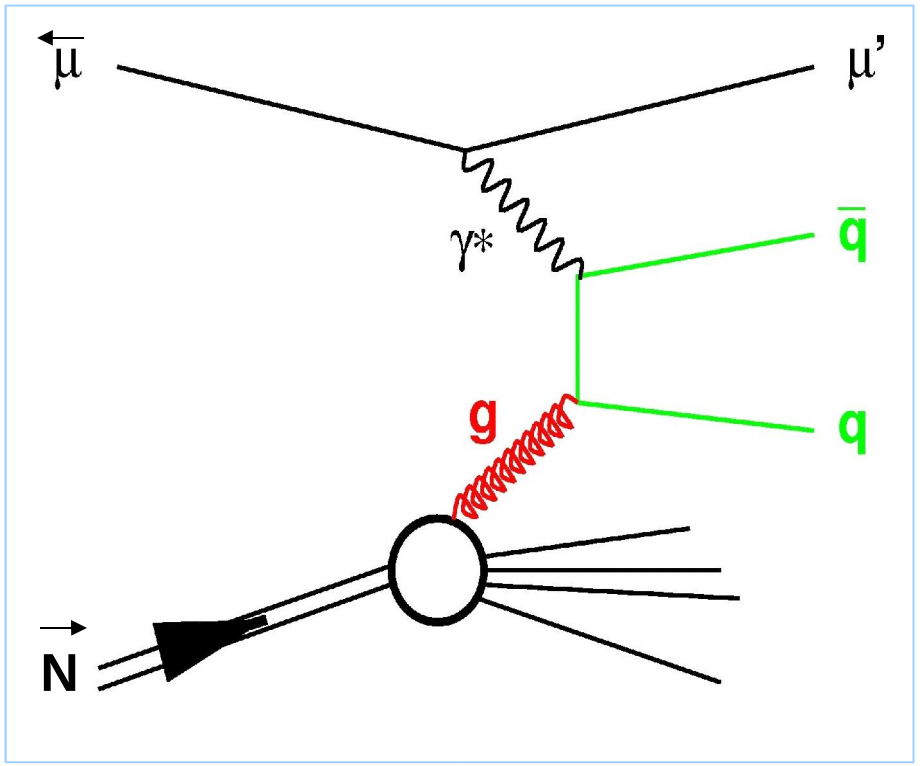
Nucleon Spin

$$\tfrac{1}{2} = \tfrac{1}{2}\,\Delta\Sigma + \Delta G + L_q + L_g$$

quark gluon orb. mom.

Photon Gluon Fusion

$\gamma g \longrightarrow q\bar{q}$



Open charm production:

q = c; $c \to D^0 \to K\pi$ (BR 4%)

$c \to D^* \to D^0\pi$ (BR 68%)

$\to K\pi\pi$

$\Delta G/G \sim$ cross section difference in charmed meson production

→ clean channel:

no background asymmetries

only charged tracks

Alternative: High p_t events

q = u,d,s; $\bar{q}q \to h^+h^-$

$\Delta G/G \sim$ cross section difference in production of jets with high-p_t

The COMPASS spectrometer at CERN

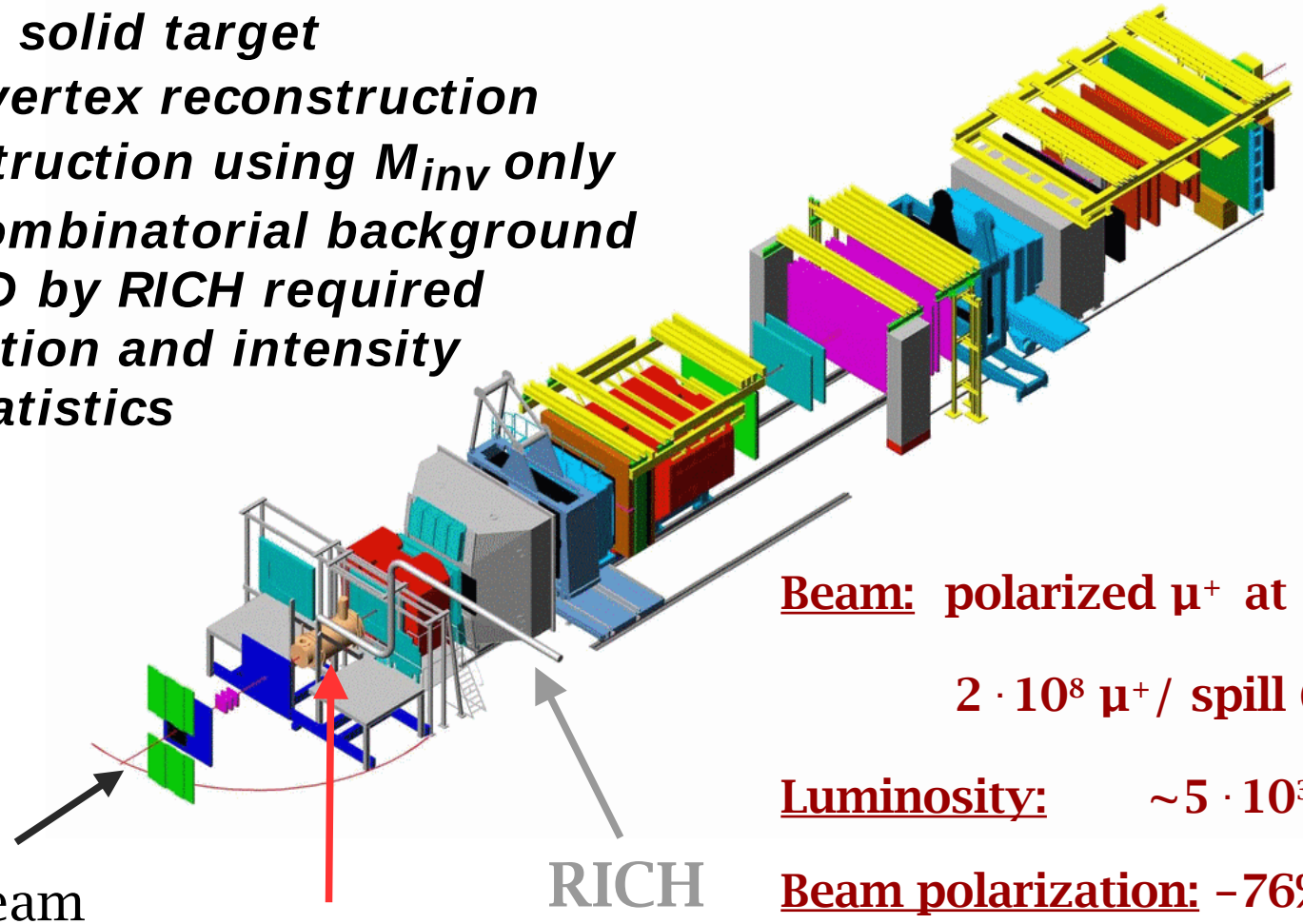
Experimental challenge:

2 * 60 cm long solid target

- → ***no D^0 vertex reconstruction***
- → ***reconstruction using M_{inv} only***
- → ***high combinatorial background***
- → ***Kaon ID by RICH required***

Low cross- section and intensity

- → ***Low statistics***



Beam: polarized μ^+ at 160GeV/c

$2 \cdot 10^8$ μ^+/ spill (4.8s/16.2s)

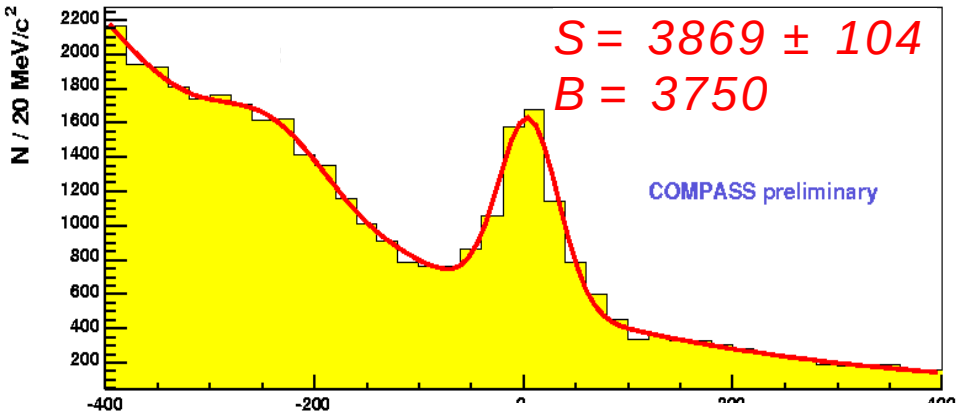
Luminosity: $\sim 5 \cdot 10^{32}$ cm^{-2} s^{-1}

Beam polarization: –76%

COMPASS results (2002–2004 data)

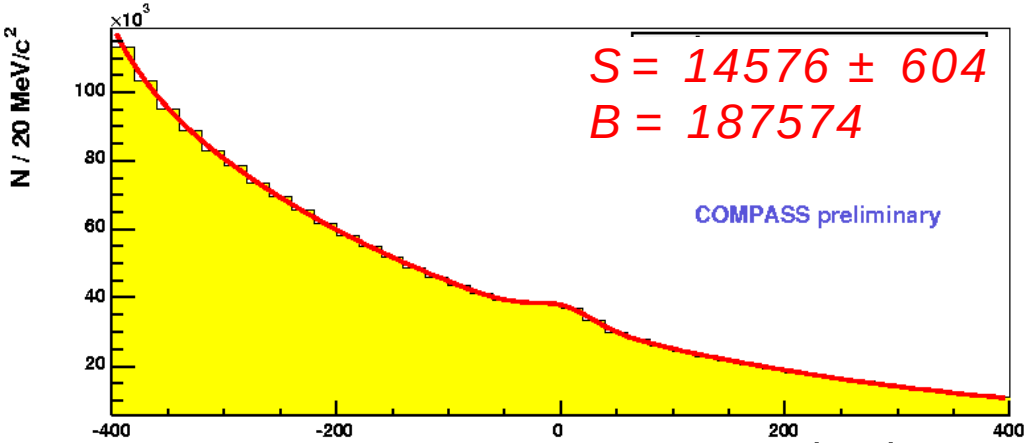
D^0 tagged by D^*

$c \rightarrow D^* \rightarrow D^0\pi_s \rightarrow K\pi\pi_s$



D^0 untagged

$c \rightarrow D^0 \rightarrow K\pi$



$$A_{LL}/D = \frac{S}{S+B}\,\tilde{a}_{LL}\,\frac{\Delta G}{G}(x_g)$$

A_{LL} measured asymmetry

$\tilde{a}_{LL}$ parametrized using MonteCarlo

$\Delta G/G = -0.57 \pm 0.41_{stat}$

σ_{syst} smaller than σ_{stat}

$x_g = 0.15$ scale $\mu^2 = 13$ GeV^2

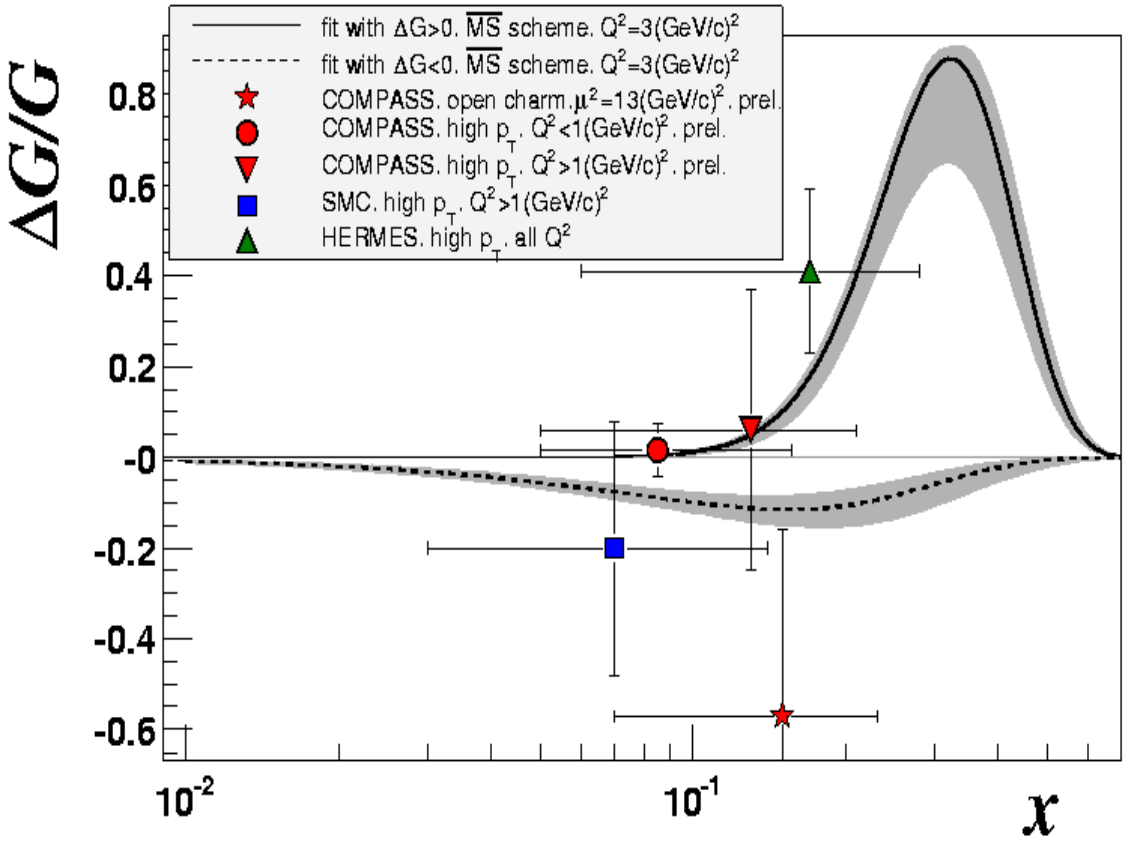
Conclusions

- **H1** and **ZEUS** heavy flavour measurements agree.
- Beauty and Charm data in general agreement with NLO
- Beauty data partially slightly higher
- Charm production gives a large contribution to the inclusive DIS cross section.
  - Measured with good precision at HERA in a large part of phase space.
  - NLO QCD calculations describe the data within accuracy
- Beauty production: first F_2^{bb} measurements.
- Exploiting the full statistics of HERA with silicon detectors will give precision results on beauty production.

- **COMPASS**: measurement of $\Delta G/G$ made with open charm in agreement with the outcome from other experimental methods (QCD evolution of g_1 and with high p_t hadron pair):
  - ΔG small or $\Delta G(x_g)$ has a node at $x_g \sim 0.1$

Other slides

COMPASS: $\Delta G/G$



The two fits are solutions of a QCD analysis of all world data about g_1 (spin-dependent structure function).

Inclusive b quarks in DIS. Lifetime Tag

- Silicon vertex detector.
- Signed impact parameter.
- Rank tracks by significance.
- Subtract negative part.
- Extract c and b fractions.
- Small phase space extrapolation.