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Beauty Production at HERA

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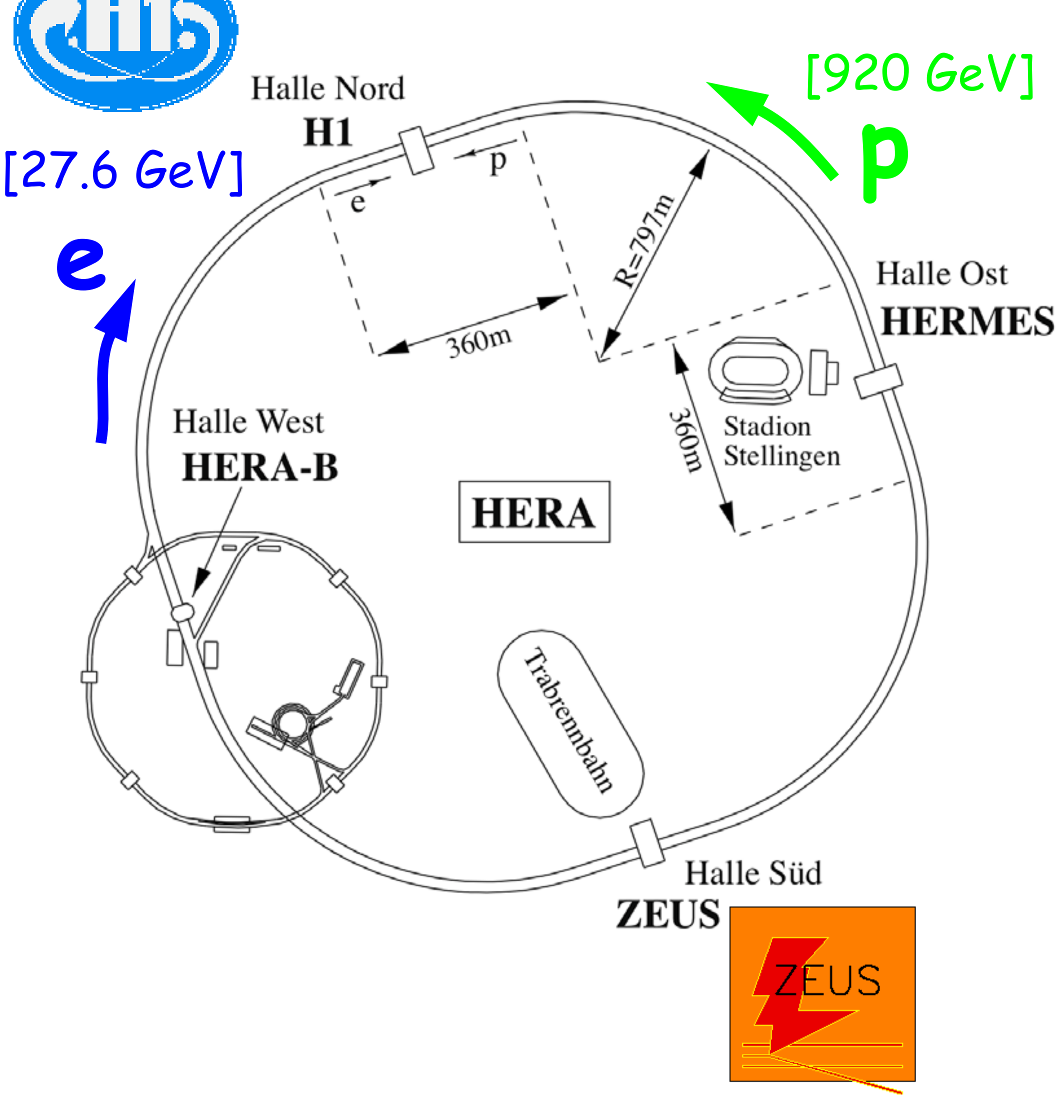
The HERA ep-Collider
@ DESY/Hamburg

$\sqrt{s}$ = 320 GeV

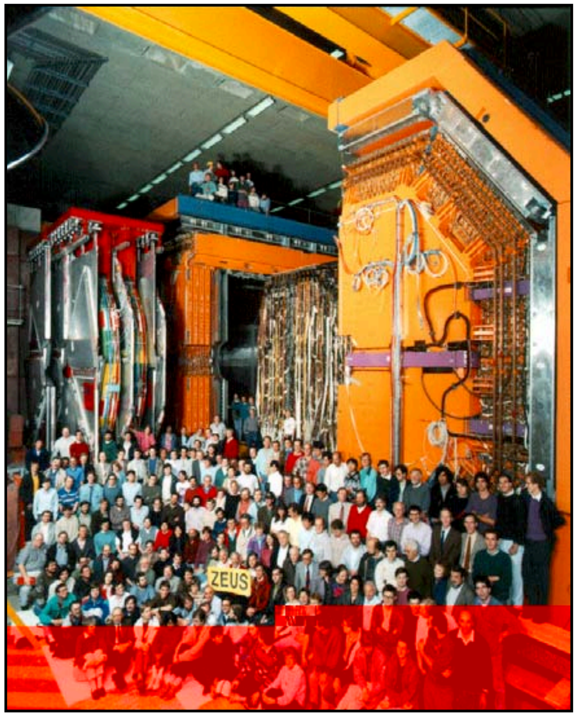


HERA I [1994 -2000]

e^+p Scattering: L ~ 100 pb^{-1}
e^-p Scattering: L ~ 15 pb^{-1}

HERA II [2003++]

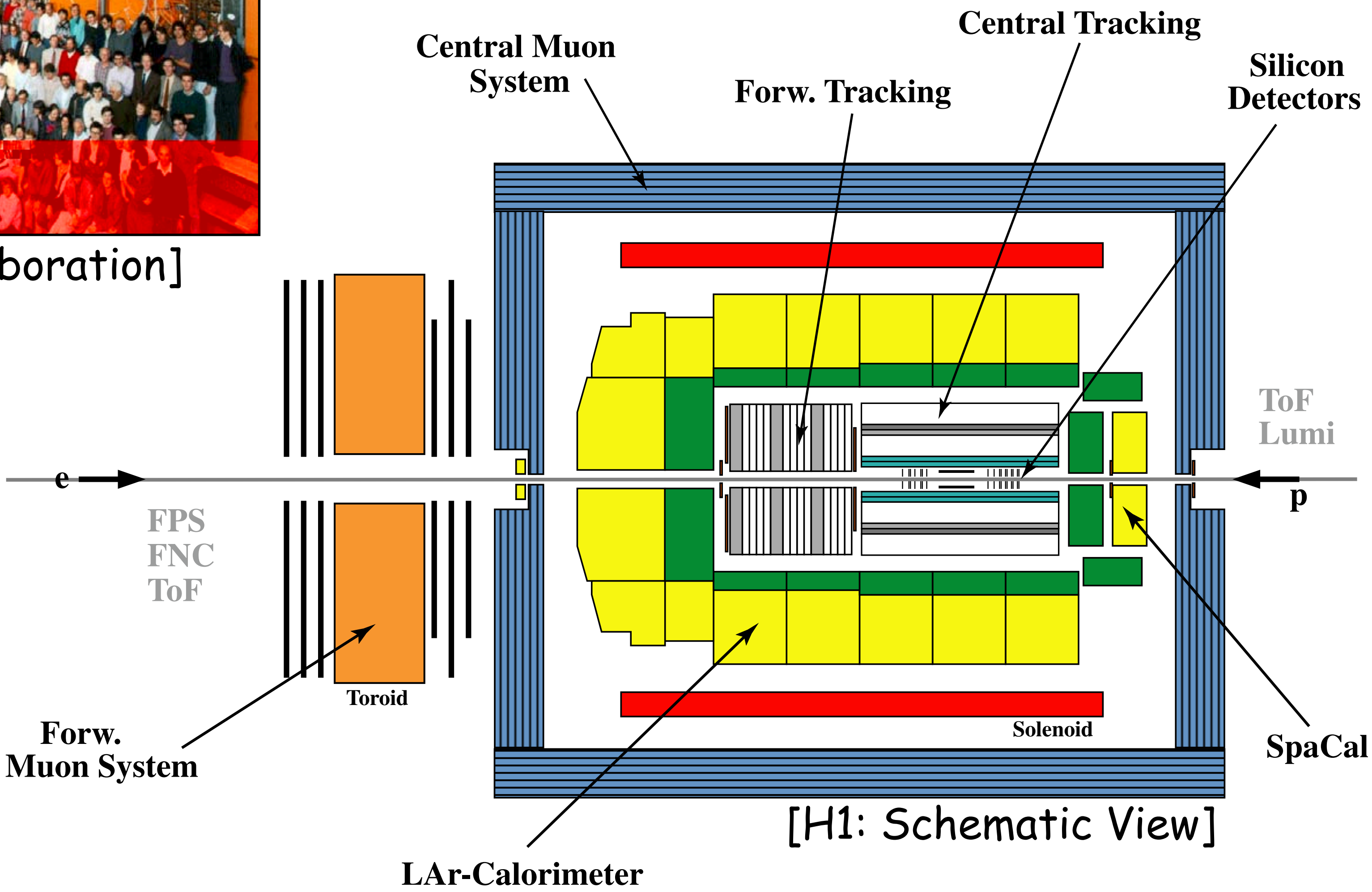
Int. Luminosity: 1000 pb^{-1}
$e^{\pm}$-Polarisation ~50%
[+ low energy ep-data]



[ZEUS Collaboration]

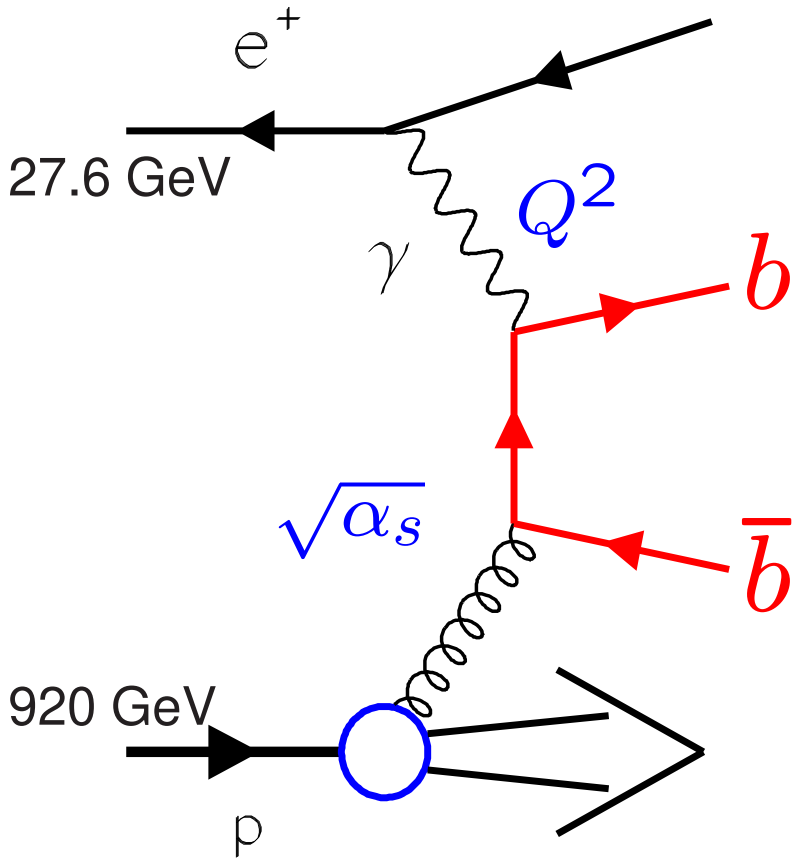
HERA Detectors

ZEUS	H1
Uranium Calorimeter	LAr Calorimeter
• $\sigma(E)/E = 18\%/\sqrt{E}$ for electrons	• $\sigma(E)/E = 12\%/\sqrt{E}$ for electrons
• $\sigma(E)/E = 35\%/\sqrt{E}$ for hadrons	• $\sigma(E)/E = 50\%/\sqrt{E}$ for hadrons
Central Tracker Resolution	Central Tracker Resolution
• $\sigma(p_t)/p_t = 0.0058\ p_t/\mathrm{GeV} \oplus 0.0065$	• $\sigma(p_t)/p_t = 0.006\ p_t/\mathrm{GeV} \oplus 0.02$



[H1: Schematic View]

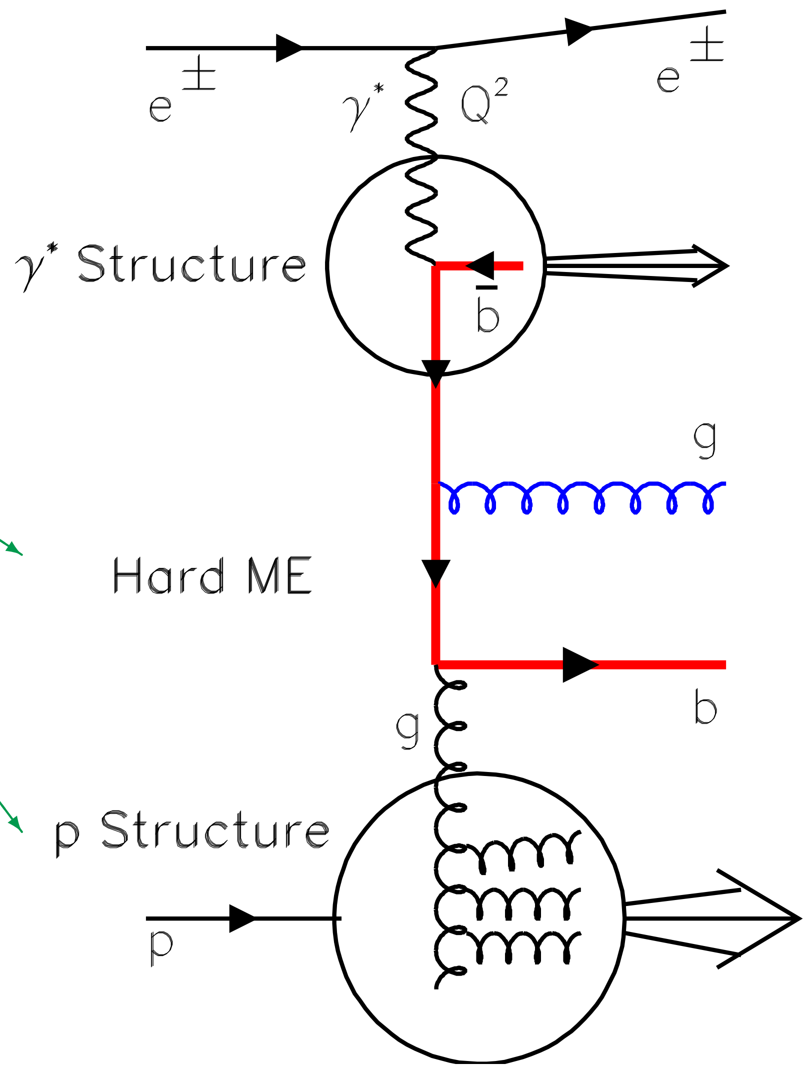
Dominant Production Process in ep: Boson-Gluon-Fusion



- Driven by gluons in the proton
- Relevant scales:
  $m_b \sim 5$ GeV
  $Q^2 < 1$ GeV^2 $\rightarrow \gamma p$
  $Q^2 > 2$ GeV^2 $\rightarrow$ DIS
  p_T^b
- Various scales available:
  pQCD should work

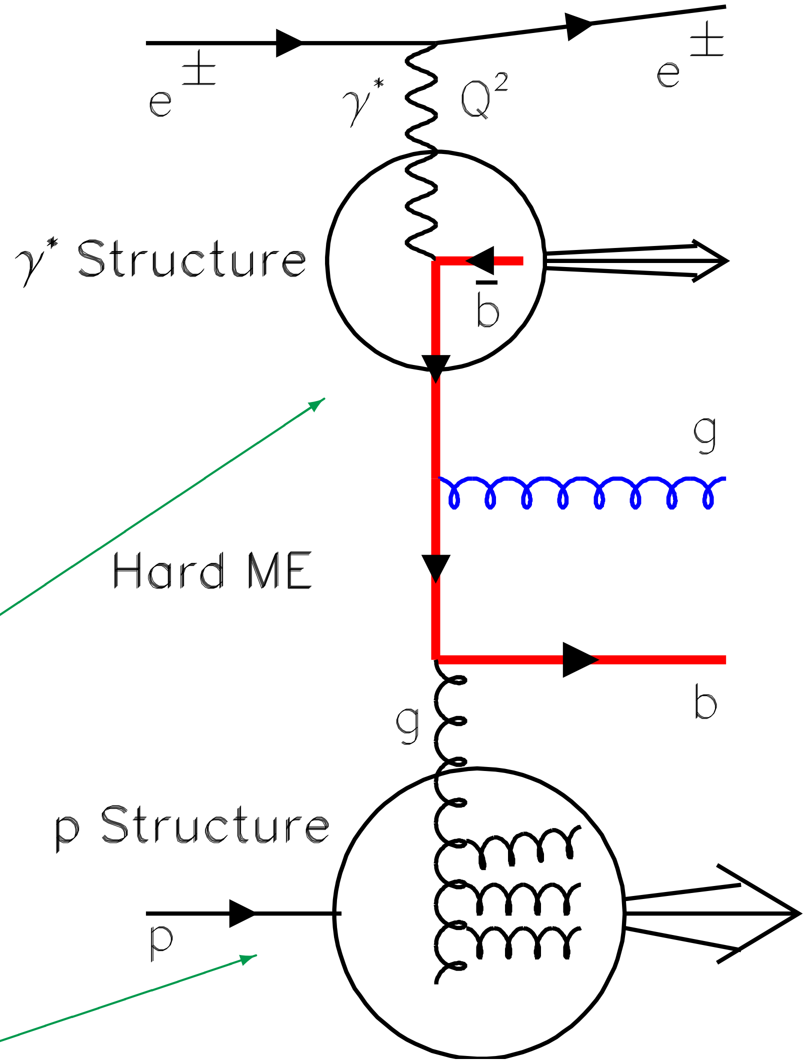
Clarify Role of Heavy Quarks in QCD

- Factorisation:
  - ⊗ Photon Structure
  - ⊗ Matrix Element
  - ⊗ Proton Structure



- Factorisation:
  - ⊗ Photon Structure
  - ⊗ Matrix Element
  - ⊗ Proton Structure

- Key Questions:
  - – Role of resolved photons for beauty production?
  - – pQCD approximation of gluon radiations (DGLAP, CCFM, BFKL)



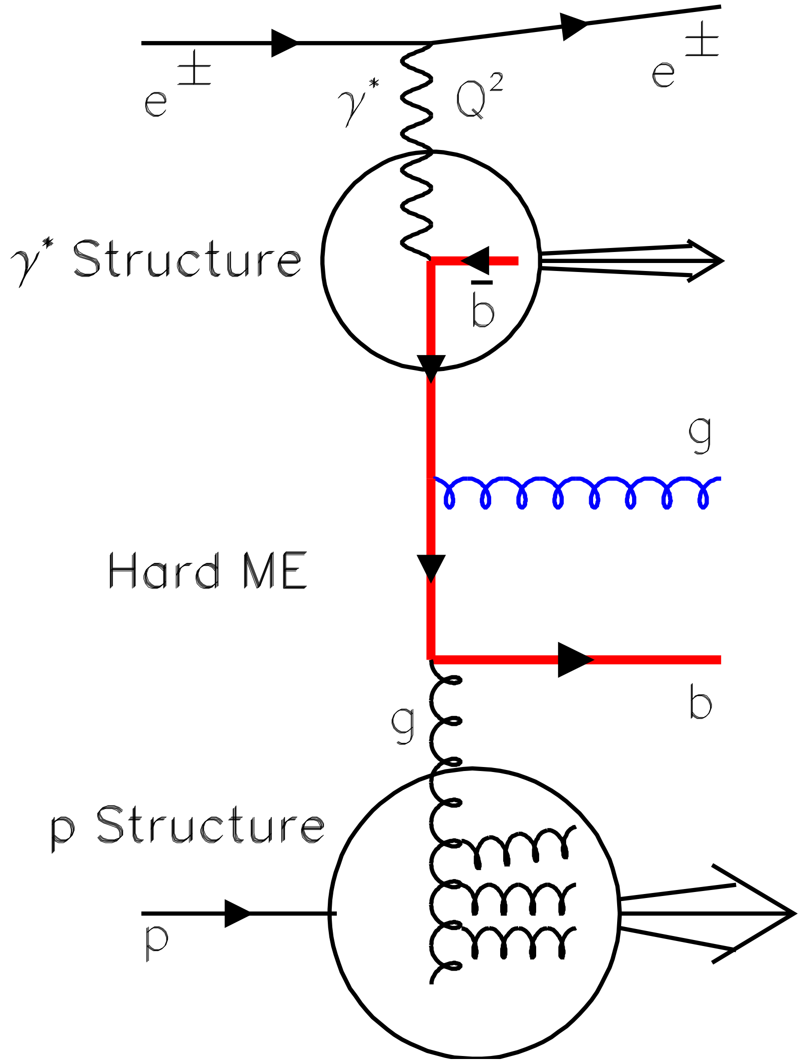
QCD models compared to data:

- NLO $\mathcal{O}(\alpha_s^2)$ calculations

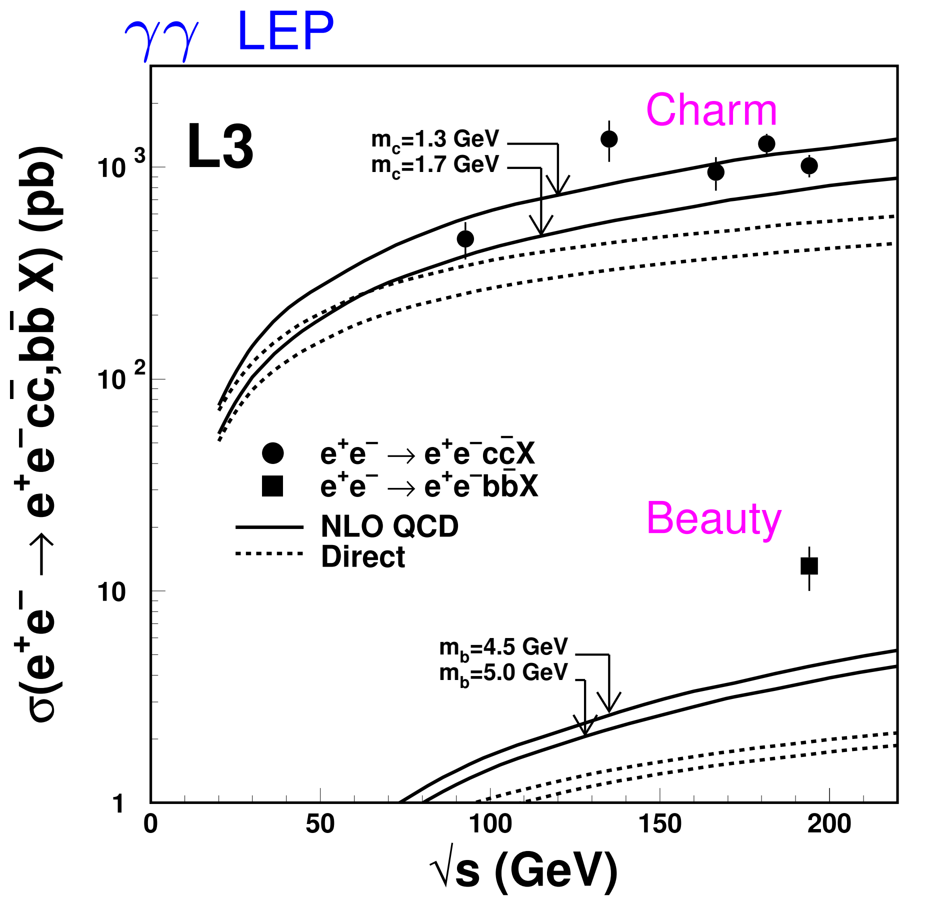
  γp: FMNR
  Frixione, Mangano, Nason, Ridolfi

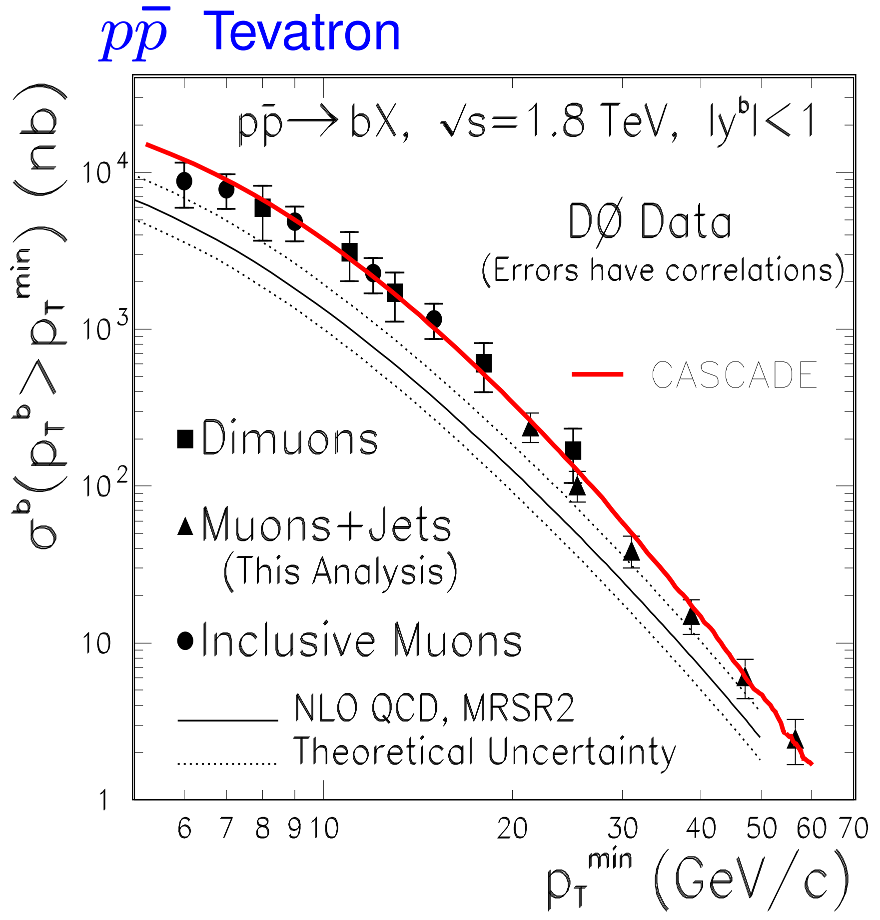
  DIS: HQVDIS
  Harris, Smith

- LO $\mathcal{O}(\alpha_s)$ + Parton shower:
  Pythia MC (DGLAP)
  Cascade MC (CCFM)



Beauty-Production at LEP and Tevatron

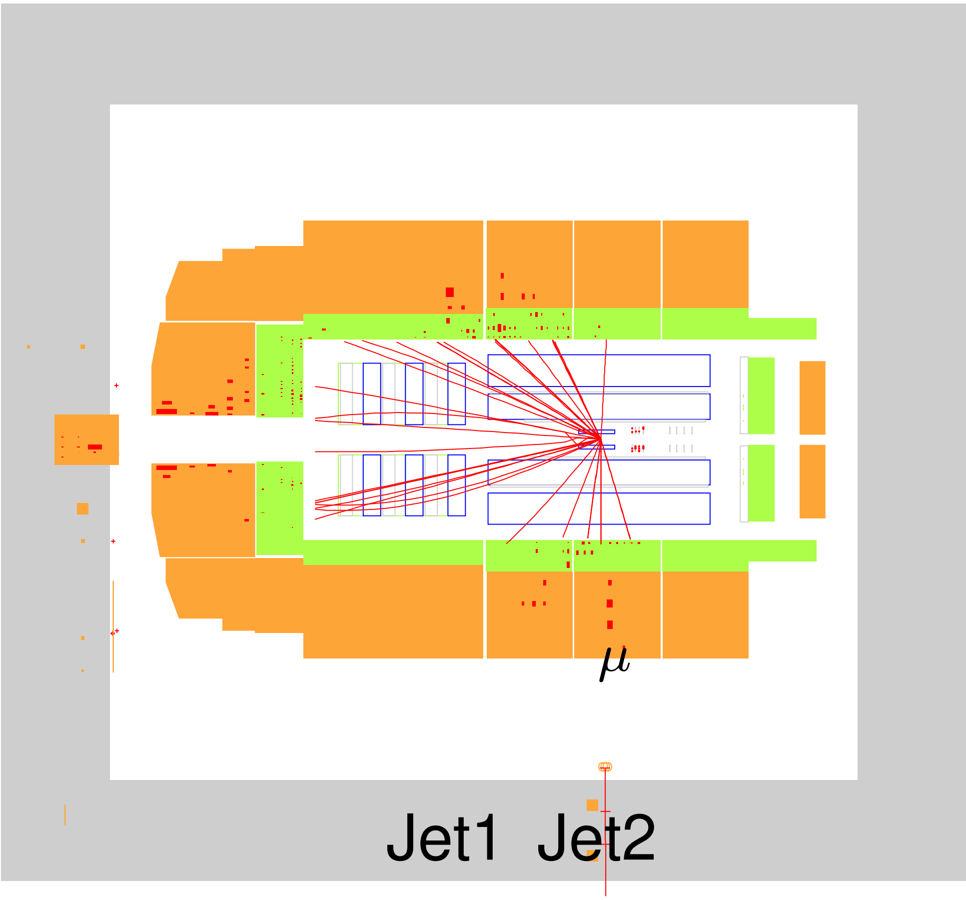


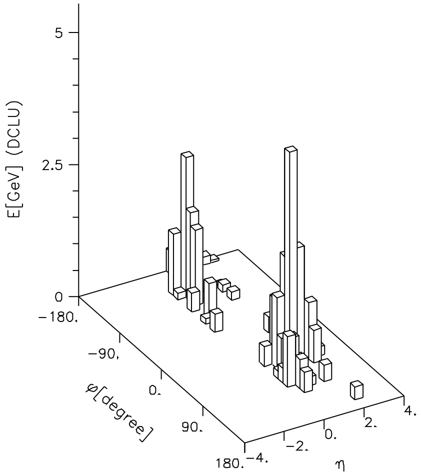


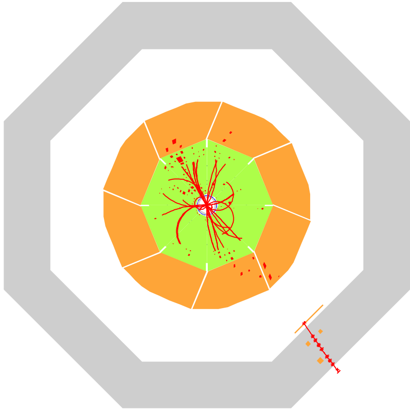
- Tevatron, LEP: NLO-expectations low compared to data
- $p\bar{p}$: Improved calculations are closer

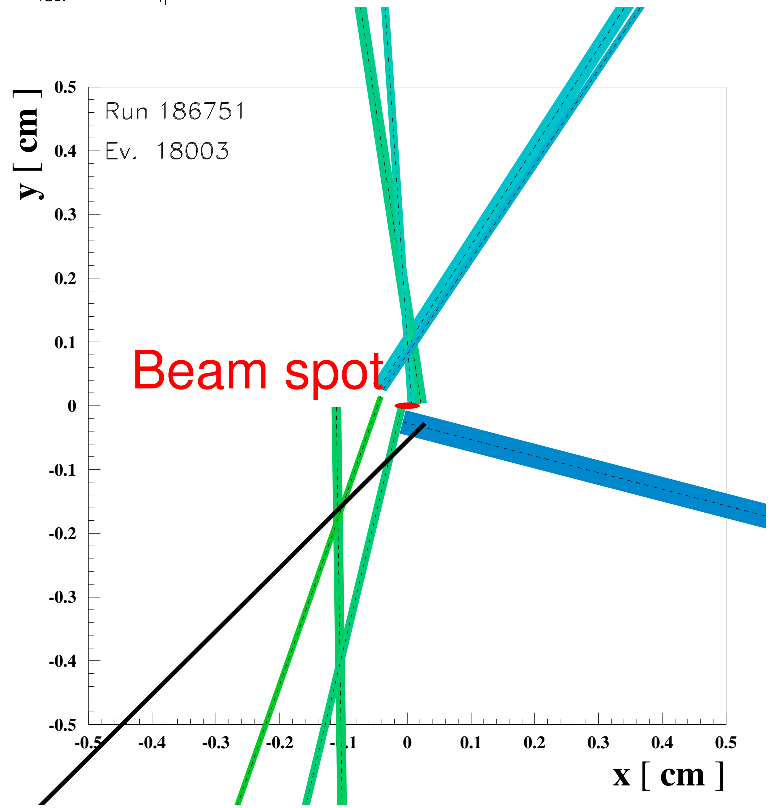
What about b at HERA?

$B \to jj\mu X$ Event Candidate







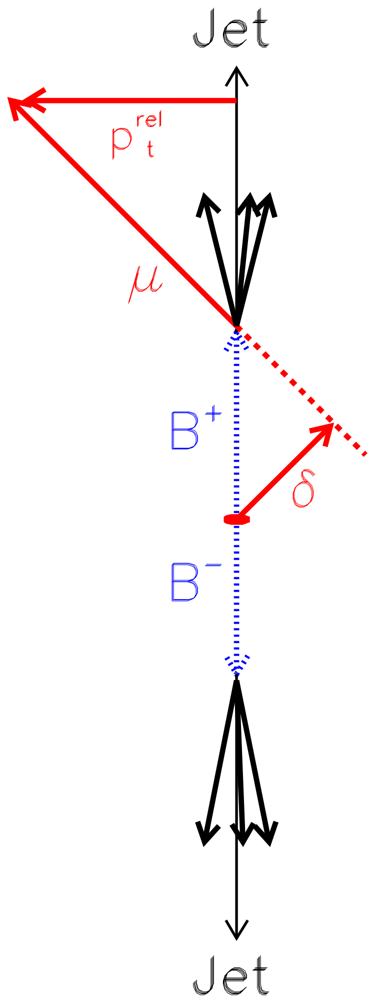


μ

μ

Tracks in vertex region ($R\phi$ plane)

Beauty Observables

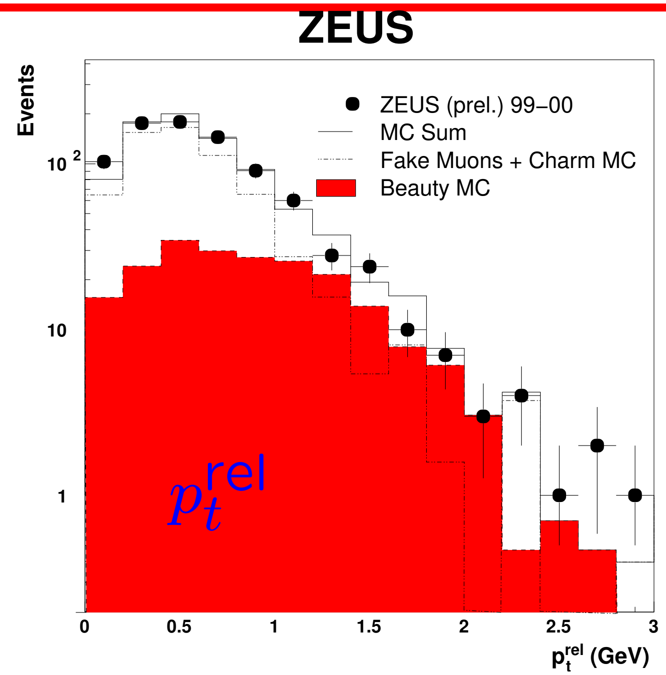


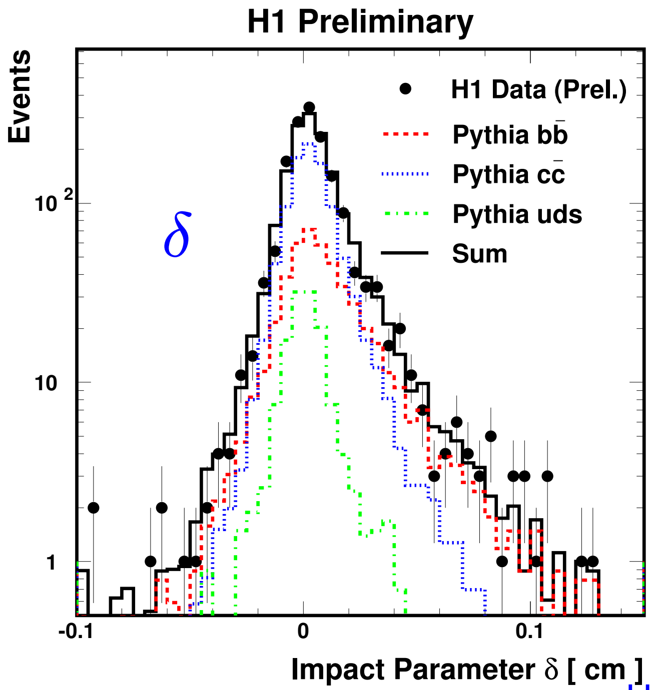
- Large B-Mass:

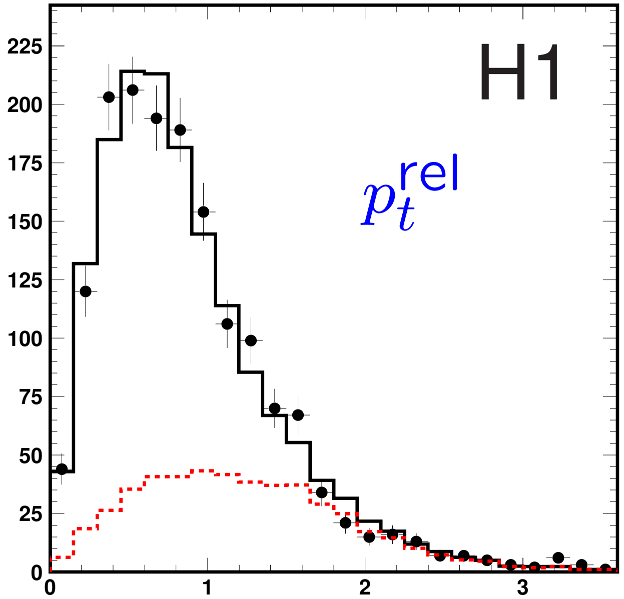
  p_t of μ relative to Jet

- Large B-Lifetime:

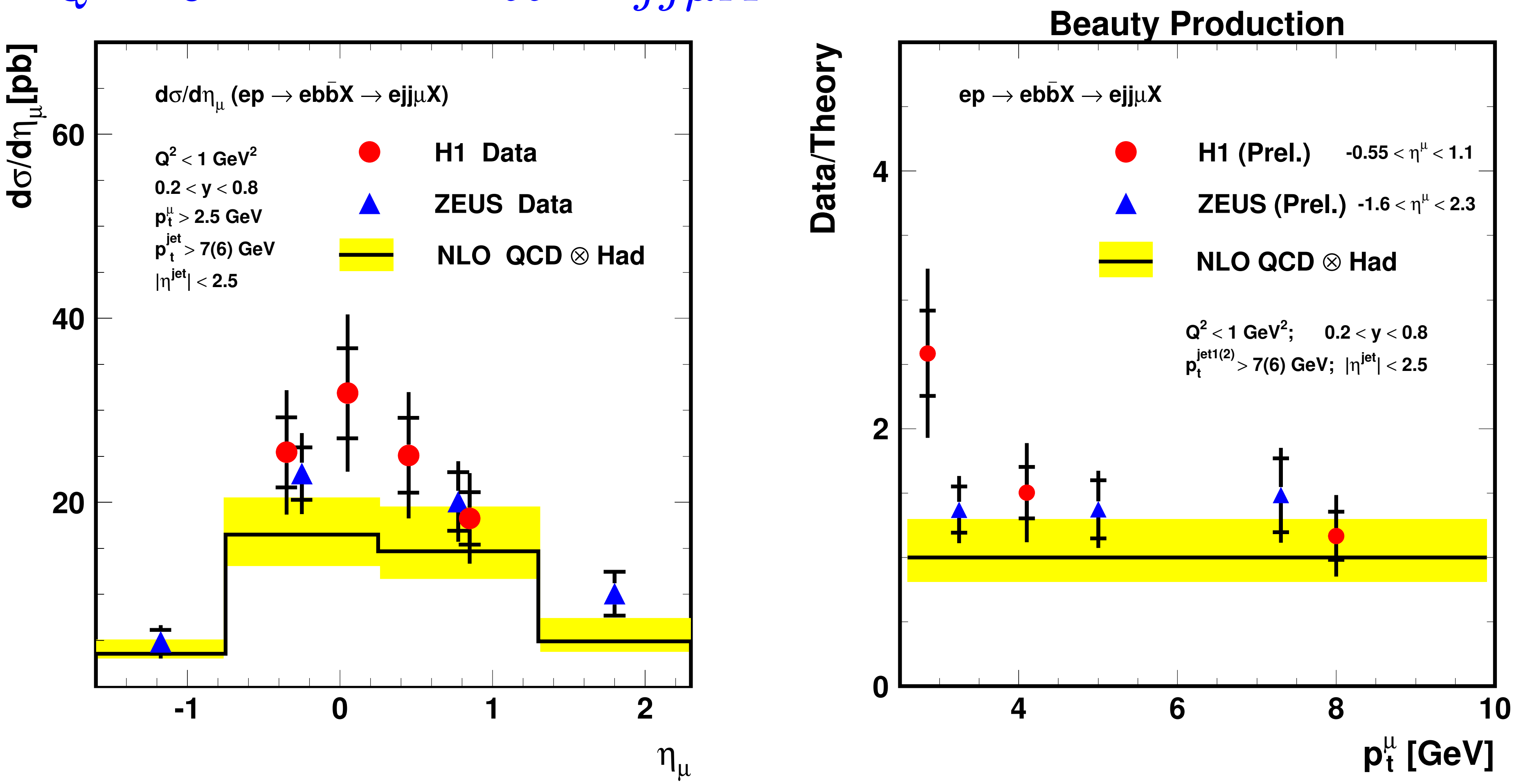
  μ Impact-Parameter







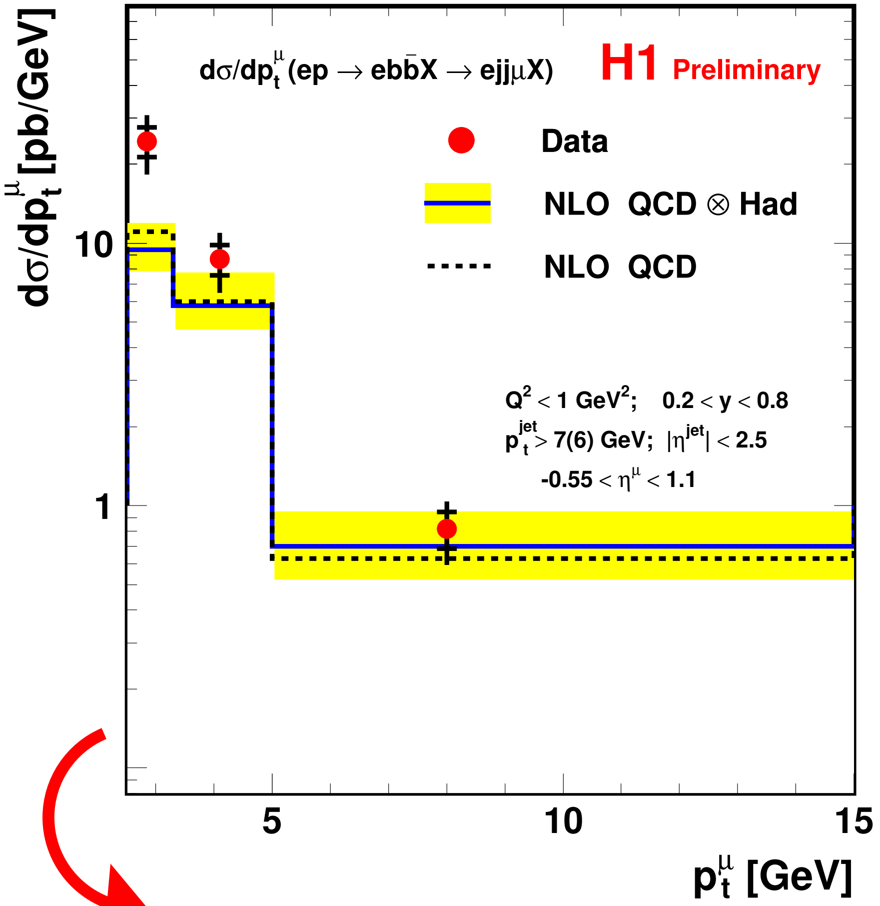
$Q^2 \sim 0$ $\qquad$ $b\bar{b} \rightarrow jj\mu X$



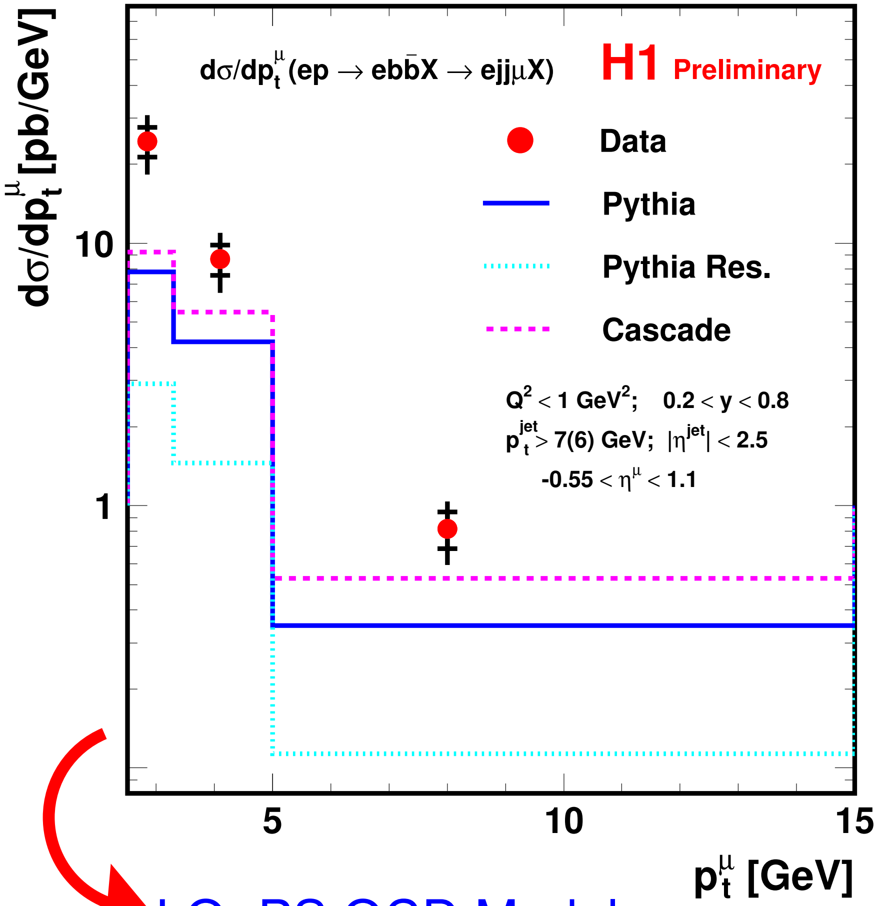
- Agreement between H1 and ZEUS
- All data points above NLO QCD
- Exp. and theory errors fairly large: Agreement within errors

$d\sigma/dp_T^{\mu}$ compared with QCD models

$Q^2 \sim 0$ $b\bar{b} \rightarrow jj\mu X$



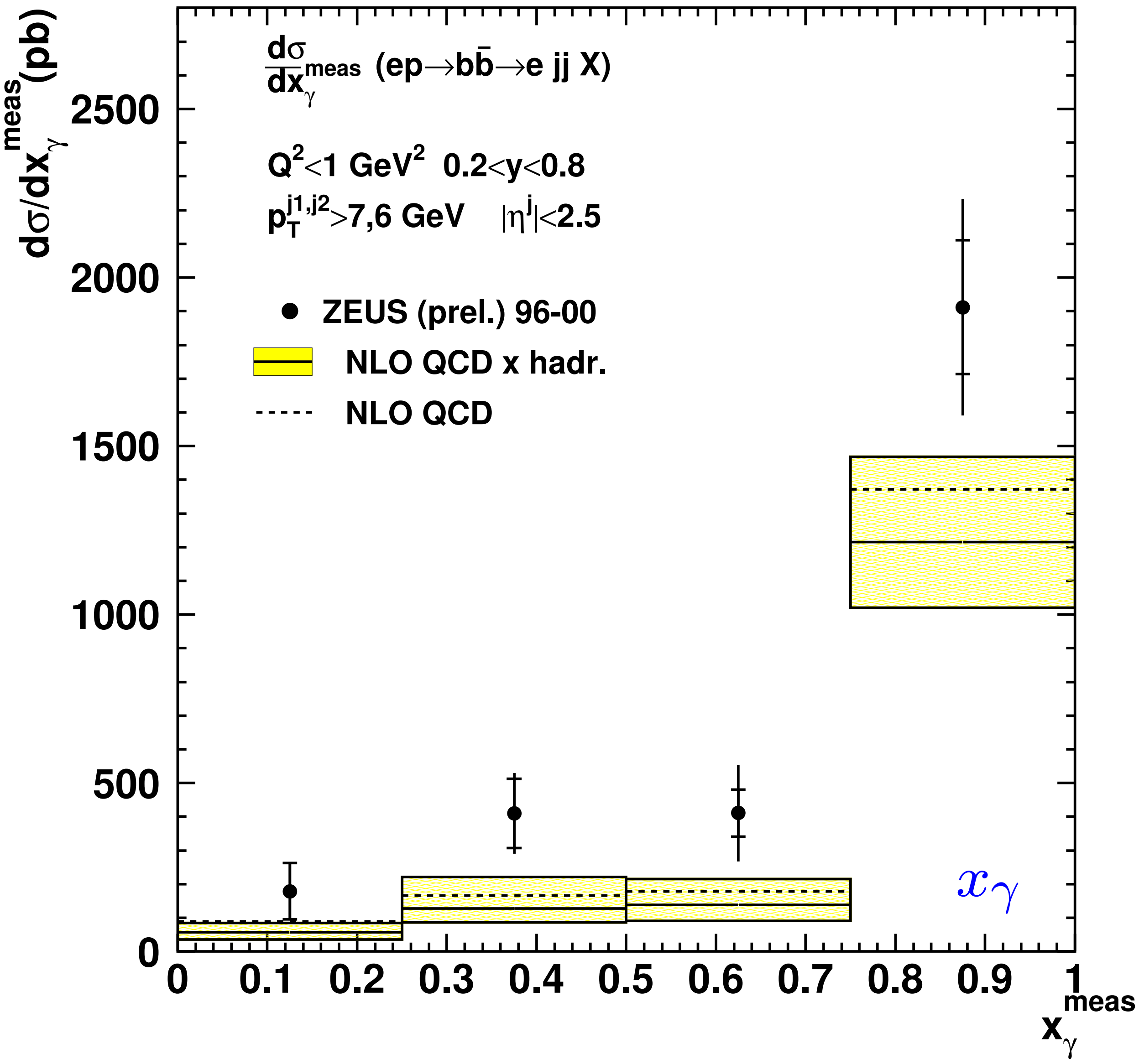
NLO QCD: Too low at low p_T^{μ}



LO+PS QCD Models

Too low in normalization

$Q^2 \sim 0$ **ZEUS** $b\bar{b} \to jjX$

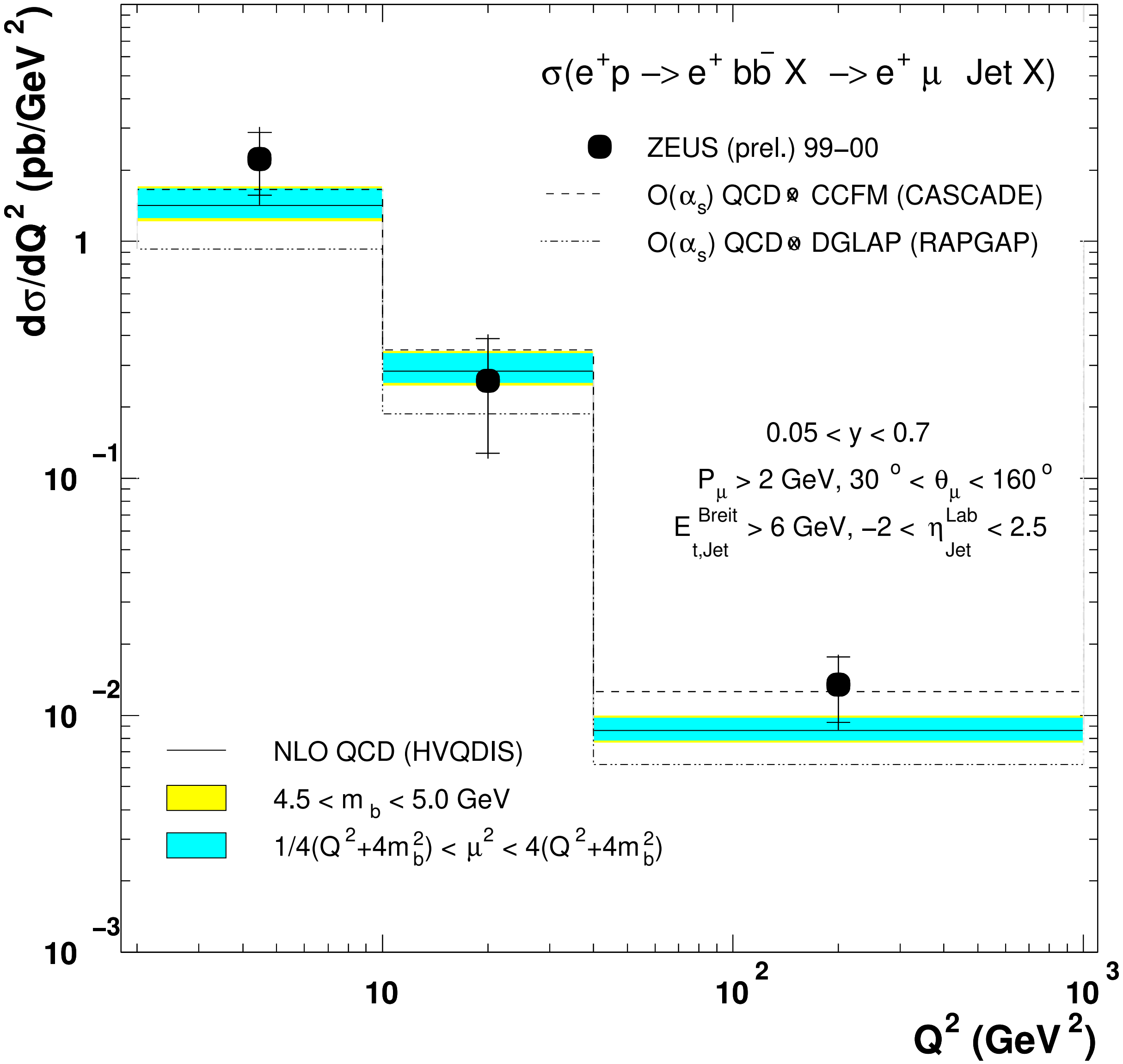


- DGLAP (NLO):
  - lower than data
  - large uncertainties

ZEUS: $\sigma^{\mathrm{vis}} = (733 \pm 61 \pm 104)$ pb
NLO (Frixione et al): $\sigma^{\mathrm{vis}} = (381^{+117}_{-78})$pb

- Significant contribution from 'Resolved-γ' $\longleftrightarrow$ Charm

$Q^2 > 2$ GeV^2 $\qquad ep \longrightarrow b\bar{b} \longrightarrow ej\mu X$



$\sigma^{\text{vis}} = (38.7 \pm 7.7^{+6.1}_{-5.0})$ pb

- DGLAP (NLO):
  - ok within errors

  NLO (Harris et al): $\sigma^{\text{vis}} = (28^{+5.3}_{-3.5})$pb

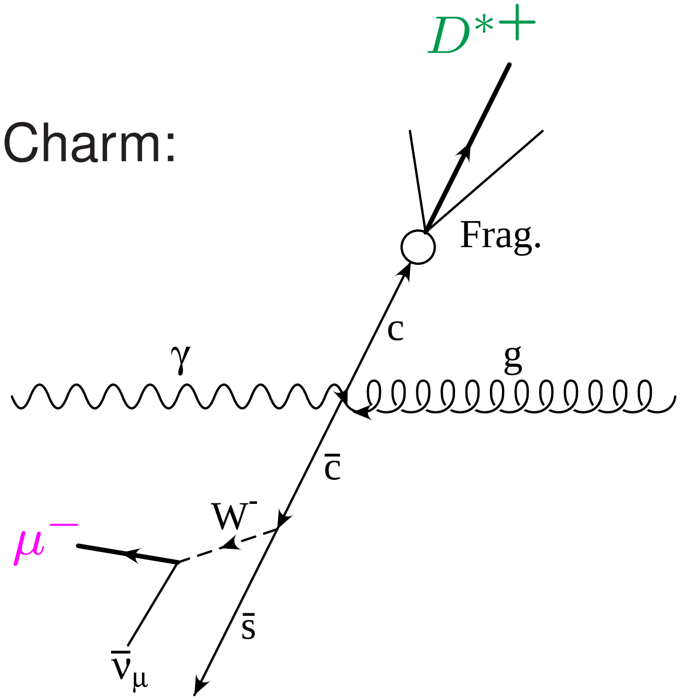
- CCFM:
  - Good description

  CASCADE-MC: $\sigma^{\text{vis}} \approx 35$pb

- DGLAP (LO+PS):
  - too low

γg-Center of Mass System:

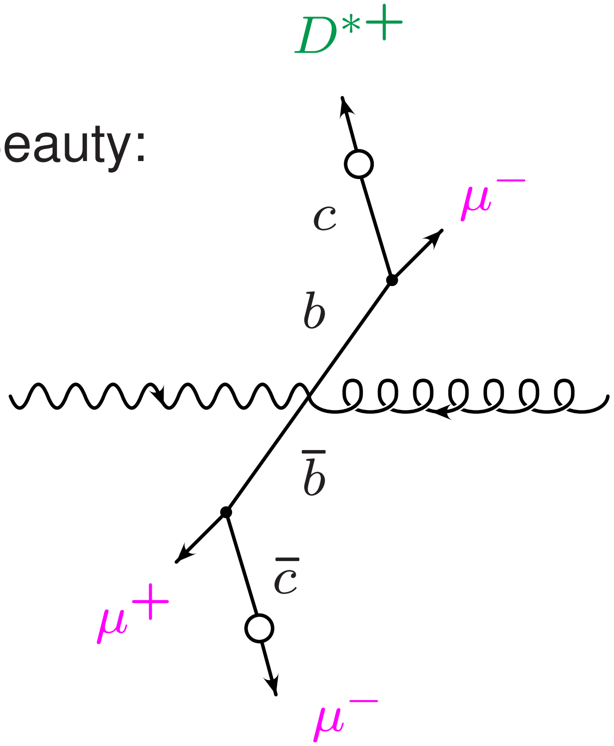
Charm:



$\Delta\Phi \approx 180^\circ$

$Q(D^*) \neq Q(\mu)$

Beauty:



$\Delta\Phi \approx 0^\circ \quad ; Q(D^*) \neq Q(\mu)$

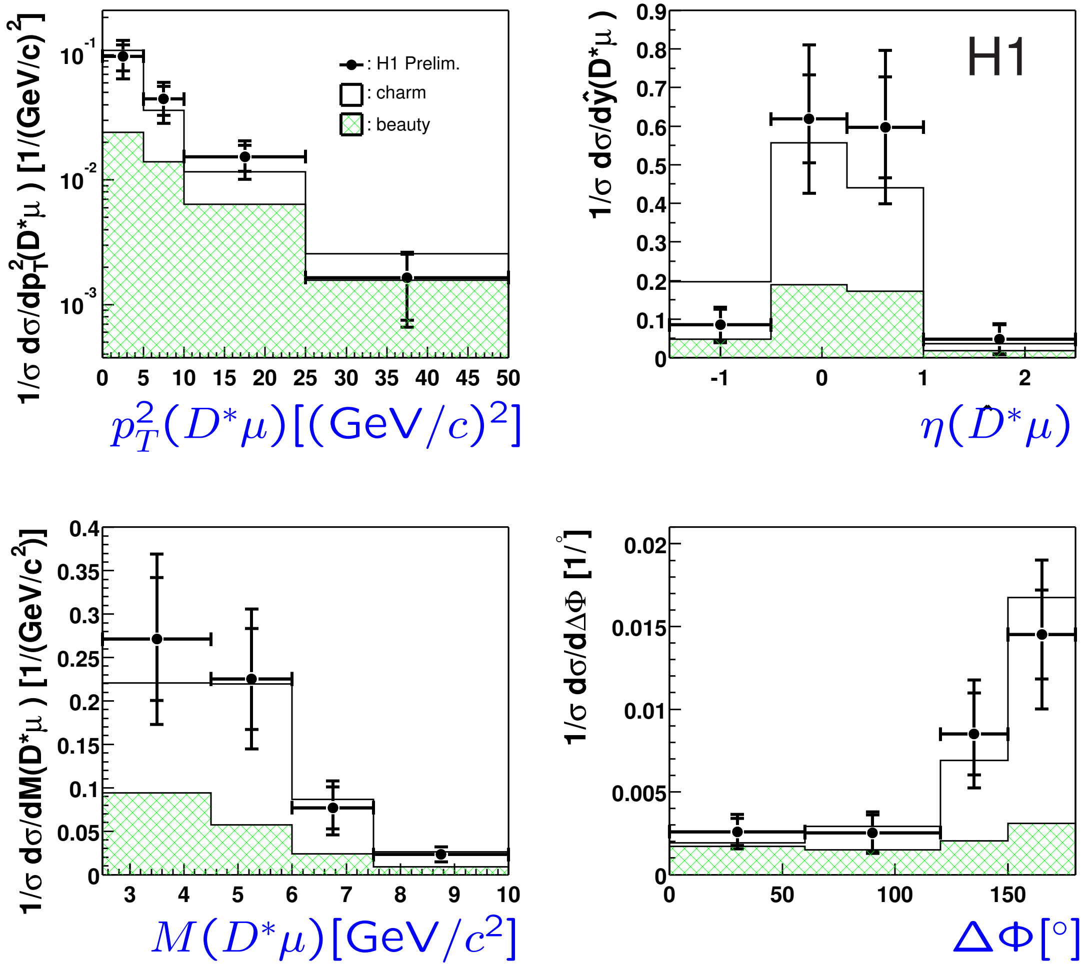
$\Delta\Phi \approx 180^\circ; Q(D^*) \neq Q(\mu)$

$\Delta\Phi \approx 180^\circ; Q(D^*) = Q(\mu)$

Separation of c and b via charge and angular correlations

$D^*\mu$ – Correlations

"Heavy-Flavour Double-Tag"



Both Quarks measured:

$\rightarrow$ Full reconstruction of event

$\rightarrow$ Higher order effects ?

$\sigma(ep \rightarrow eb\bar{b}X)$:

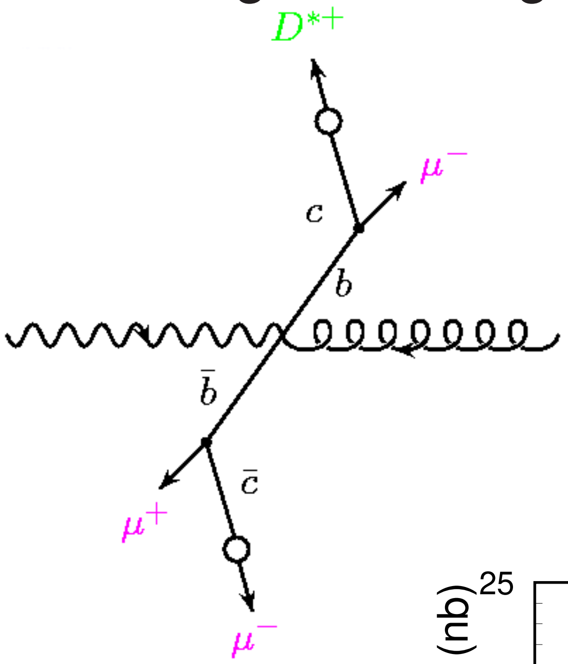
ZEUS: $15.1 \pm 3.9^{+3.8}_{-4.7}$ pb

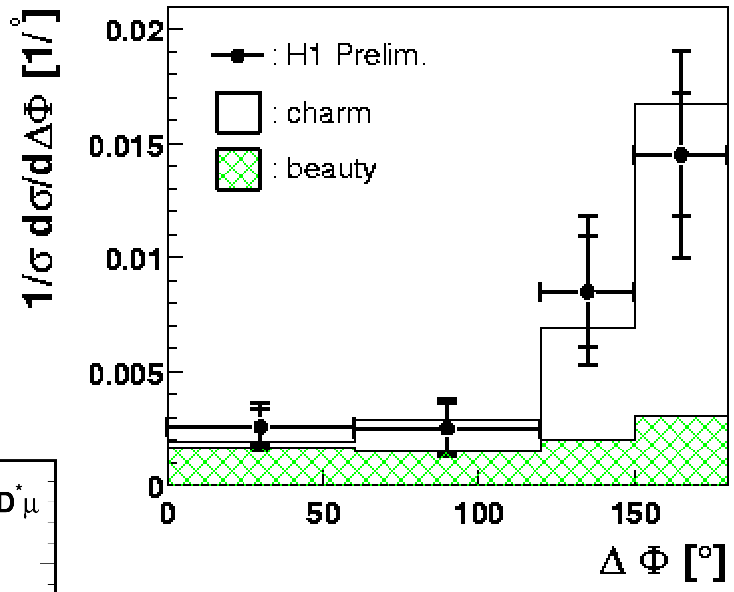
NLO (Frixione et al): $5.7^{+1.7}_{-1.1}$ pb

- Factor $\sim$ 3 above NLO-expectation
  – statistical uncertainty still large
  – confirms previous b-results

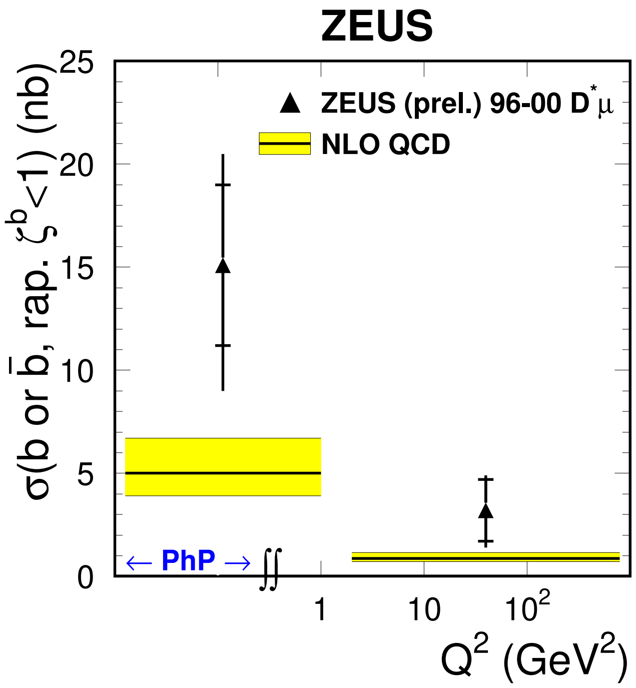
Figures: LO Monte Carlo, Cross Sections normalized

Use μ–D^* charge and angular correlations to separate charm and beauty





Data $>$ NLO QCD $\Rightarrow$



$\Rightarrow$ Large errors

Conclusions

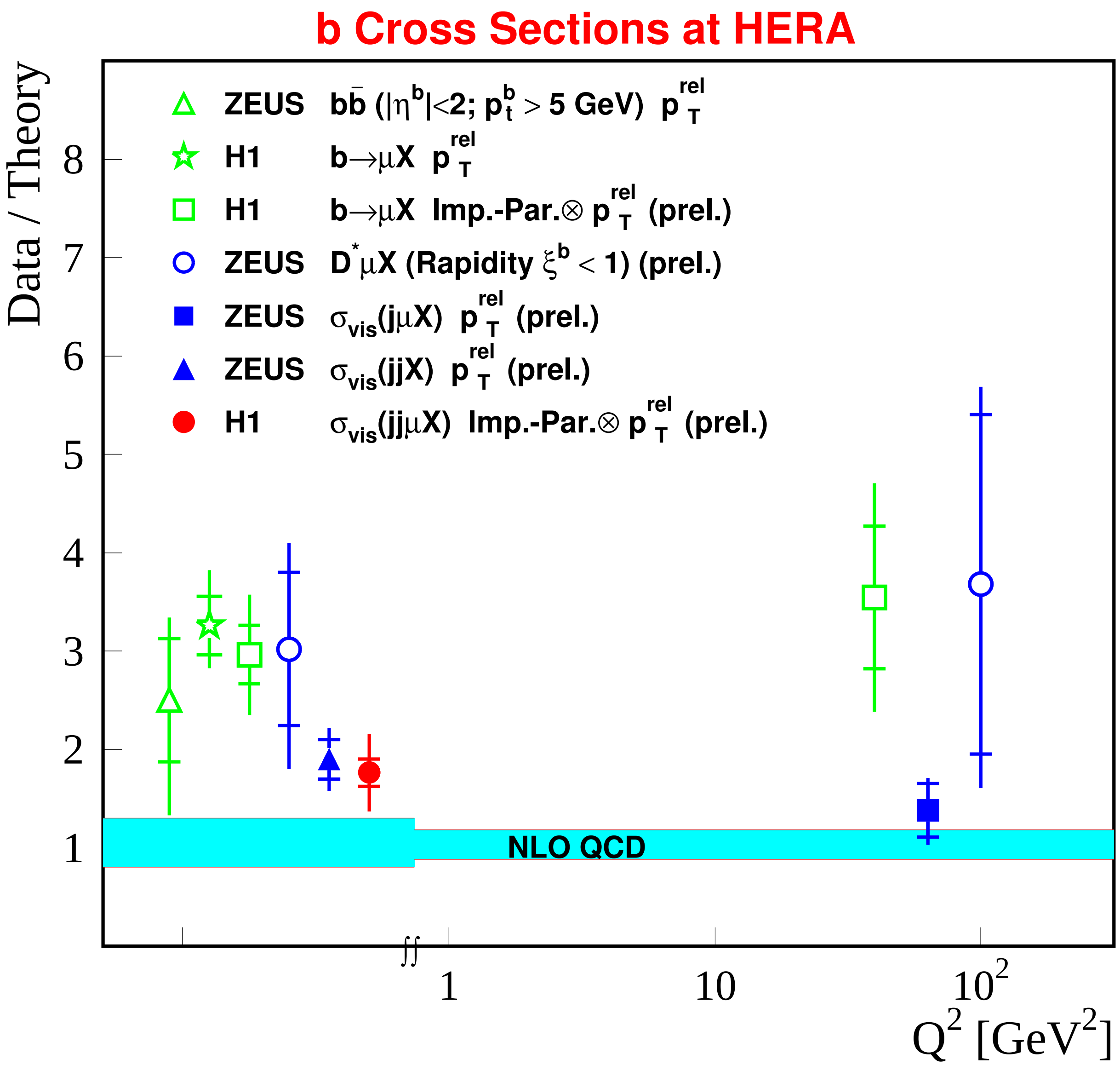
Summary: Beauty at HERA I

- New precise differential b-cross-section measurements
- H1 and ZEUS measurements agree
- Measurements are mostly above NLO QCD predictions: (Discrepancies ≤ 1.5 s.d.)
- Better description towards large Q^2, p_T^μ (?)

Outlook: Beauty at HERA II

- Go for precision answers to open questions
  - Factor of 10 in luminosity
  - Improved detectors
    (z.B. Trigger, tracking (silicon), angular coverage)

ZEUS Microvertex-Detector


b Cross Sections at HERA
ZEUS bb̄ (|η^b|<2; p_t^b > 5 GeV) p_T^rel
H1 b→μX p_T^rel
H1 b→μX Imp.-Par.⊗ p_T^rel (prel.)
ZEUS D*μX (Rapidity ξ^b < 1) (prel.)
ZEUS σ_vis(jμX) p_T^rel (prel.)
ZEUS σ_vis(jjX) p_T^rel (prel.)
H1 σ_vis(jjμX) Imp.-Par.⊗ p_T^rel (prel.)
NLO QCD
Data / Theory
1
2
3
4
5
6
7
8
1
10
10^2
Q^2 [GeV^2]