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4th October 2000

Measurement of the Beauty Production Cross Section at HERA Using Lifetime Information

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- Open Beauty Production in ep Scattering
- Muon Impact Parameter Analysis with H1

Beauty Production and QCD

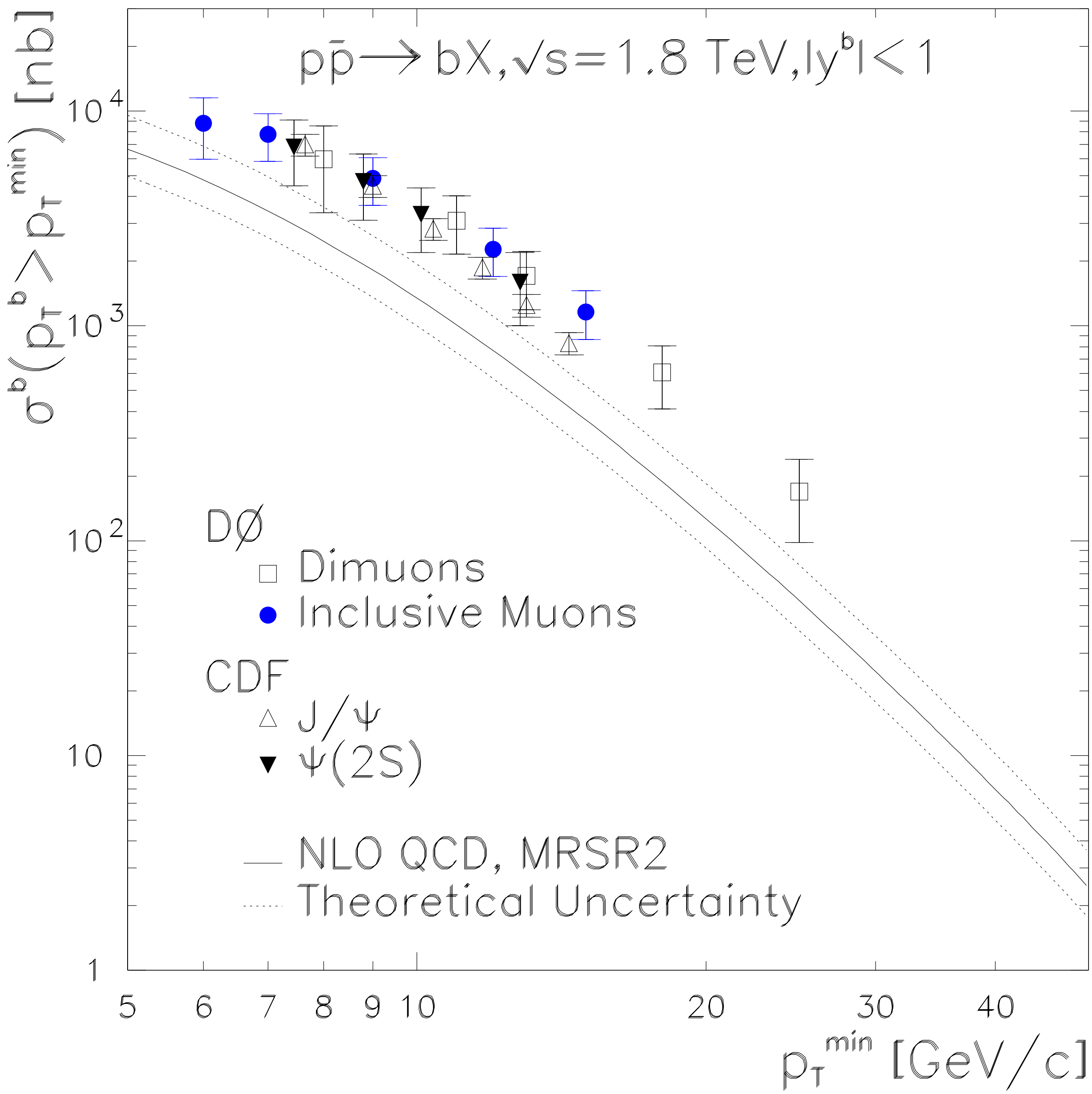
- high b mass provides hard scale

  $\rightarrow$ expect reliable pQCD calculations

however

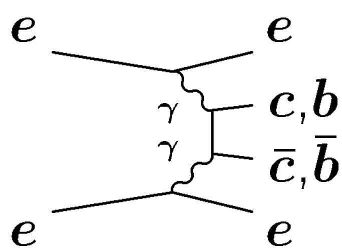
- present QCD predictions have problems describing beauty production data

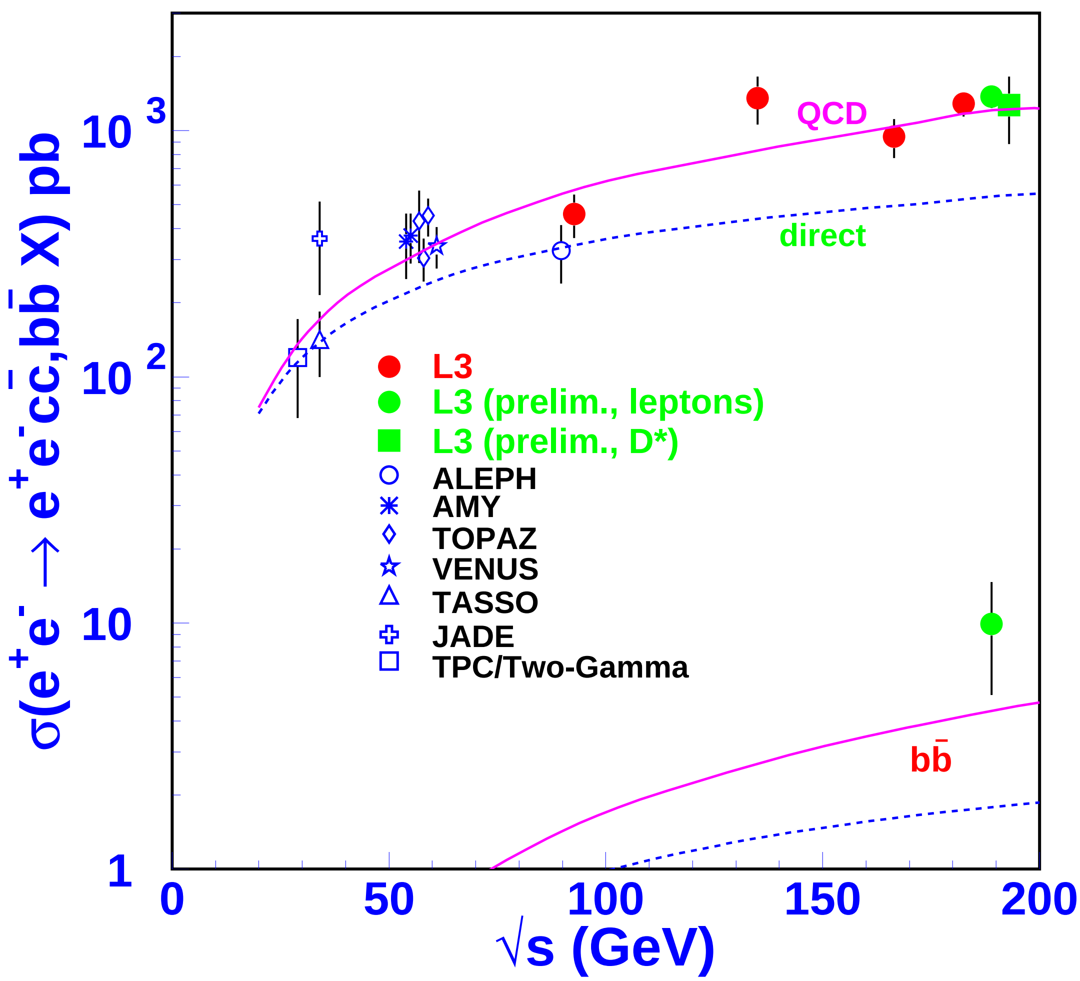
▷ need as much experimental input as possible



→ NLO QCD prediction ≈ factor 2.5 below data

LEP Results





→ $b\bar{b}$ data "somewhat above" NLO QCD prediction

Beauty Production at HERA

▷ proton structure

$\rightarrow$ gluon density

▷ photon structure

$\rightarrow$ resolve hadronic content

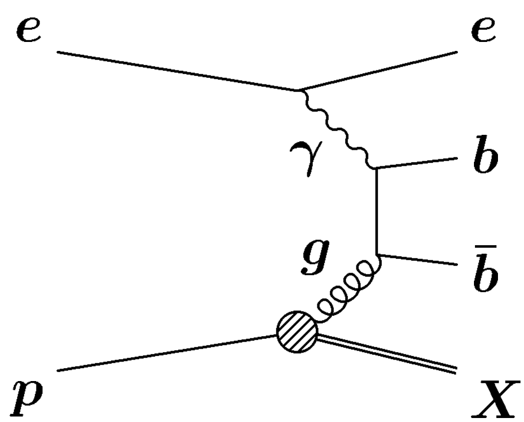
▷ production mechanism

$\rightarrow$ probe hard subprocess

. . . but not so easy to measure:

$$\sigma_b : \sigma_c : \sigma_{uds} \approx 1 : 200 : 2000$$

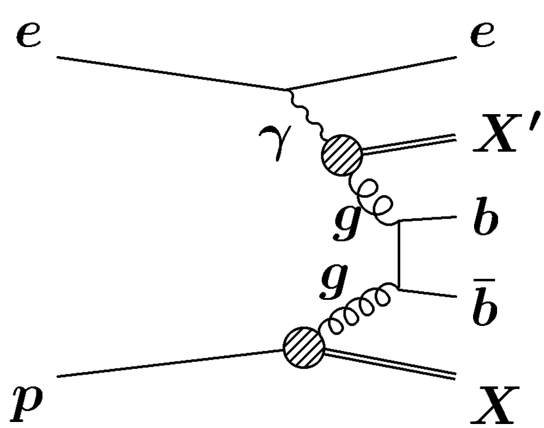
Boson-Gluon-Fusion



- main contribution in leading order QCD
- sensitive to gluon content of the proton
- exchange of quasi-real photons dominates
  $\rightarrow$ photoproduction (γp)

Resolved γ Processes

e.g.



- resolve hadronic structure of the photon

- only a fraction $x_\gamma < 1$ of the photon momentum enters the interaction

  ($x_\gamma = 1 \;\rightarrow$ "direct" process, e.g. BGF)

- significant resolved contribution to charm photo-production at HERA, for beauty not clear (yet)

NLO Processes

e.g.

- large contributions from NLO QCD:

▷ LO prediction:

$\sigma \approx 3.8$ nb

▷ NLO prediction (Frixione et al):

$\sigma \approx (5 \ldots 10)$ nb

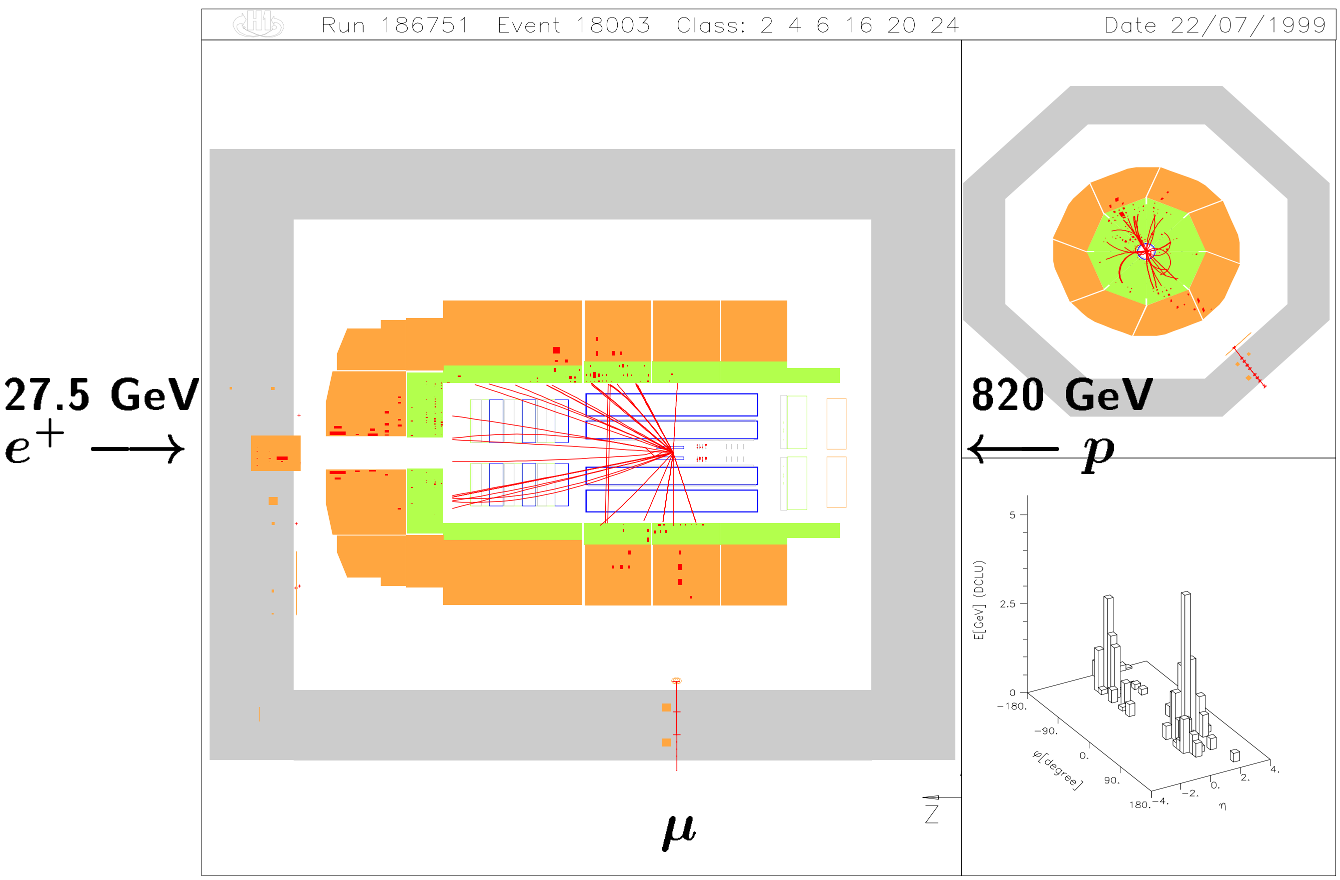
Semimuonic Decay

- branching ratio $\approx 10\%$

- clear experimental starting point:

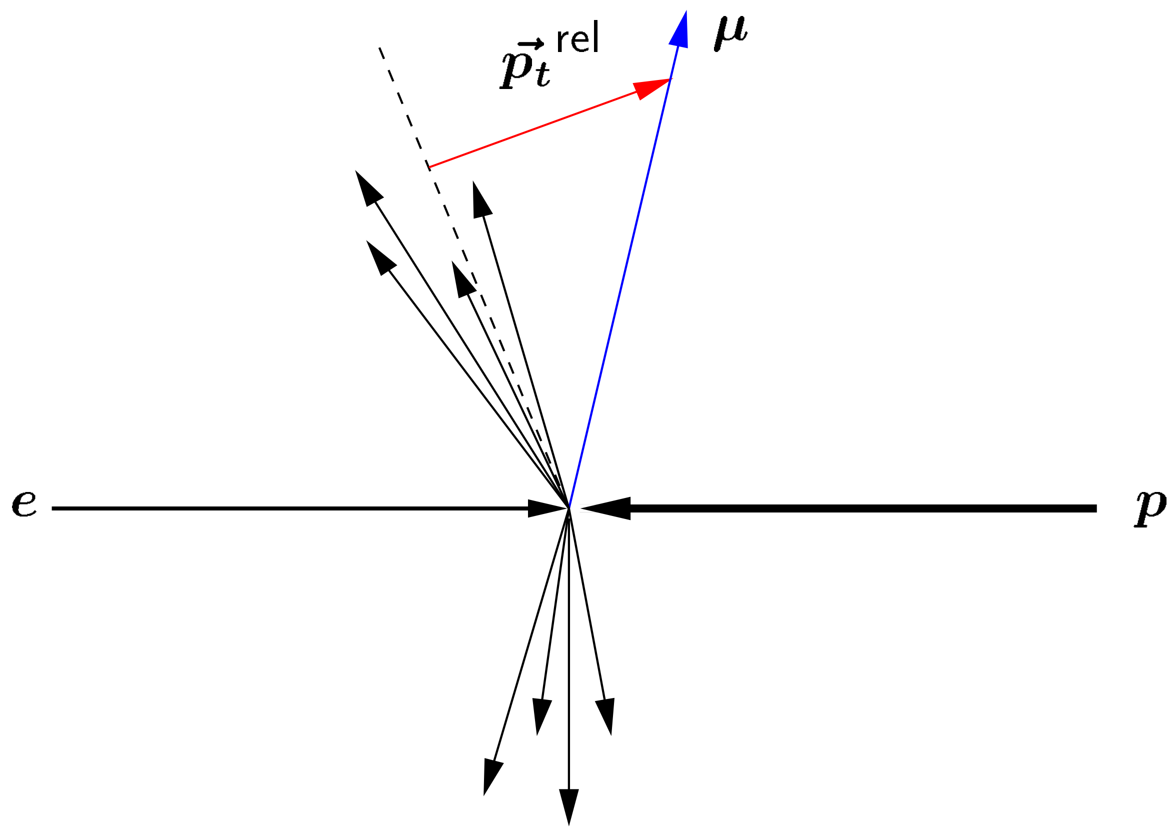
  $\mu \rightarrow$ instrumented iron + central jet chambers (CJC)

  $jets \rightarrow$ calorimeter + tracking chambers



b Signatures (1): Mass

$m_{B^\pm} \approx 5.2\,\text{GeV}$ ($\gg m_{D^\pm} \approx 1.8\,\text{GeV}$)



For muons from b decays expect high p_t^{rel}.

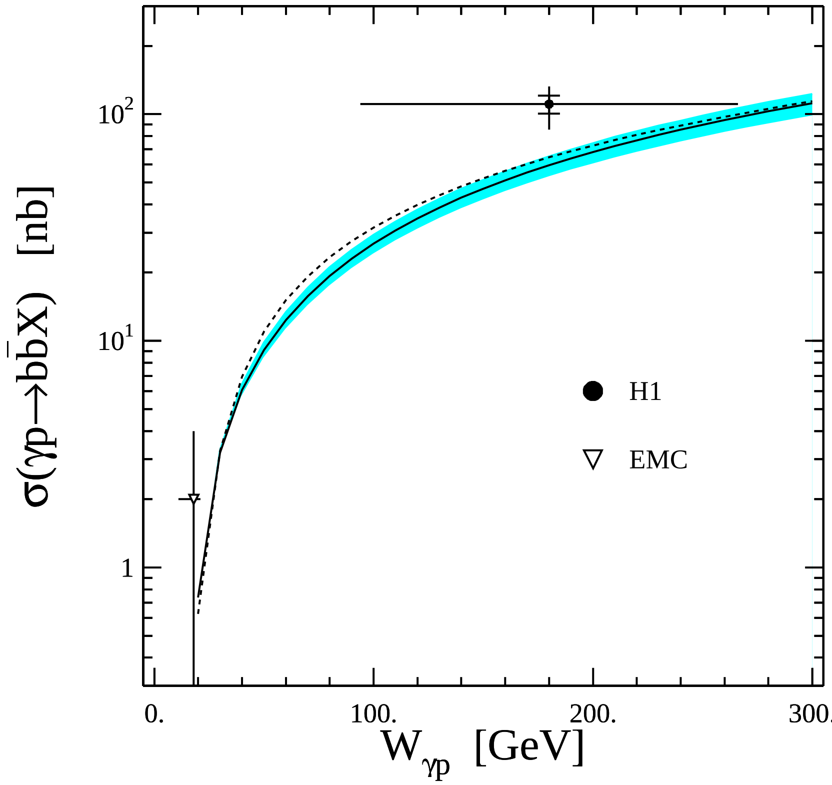
→ H1 publication (first observation of open b in ep)

→ by now also prelim. ZEUS results (using also e channel)

HERA Results

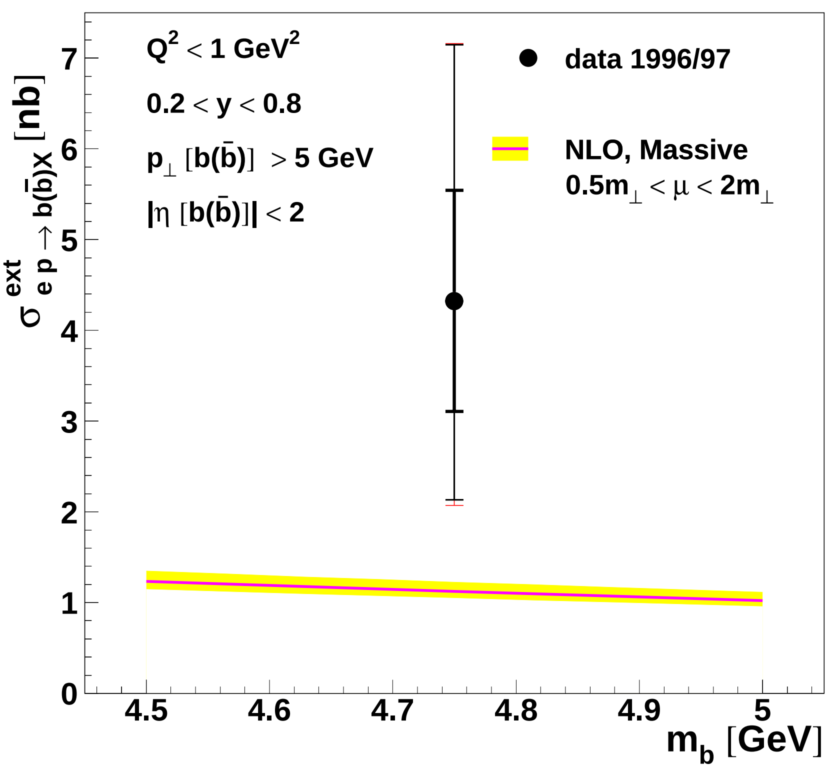
H1

(published)



ZEUS

(preliminary)



b Signatures (2): Lifetime

$c\tau_{B^\pm} \approx 500\,\mu\text{m}$ ($\gg 0$, $> c\tau_{D^\pm} \approx 315\,\mu\text{m}$)

Can be used in many different ways, e.g.:

- **impact parameter** techniques (see below)

  $\rightarrow$ one track (e.g. identified muon, see below)

  $\rightarrow$ several tracks (e.g. within one jet)

- **secondary vertex** reconstruction

- measurement of **decay length** $L = p/m_b \cdot c\tau$

$\rightarrow$ standard at Tevatron, LEP, . . .

$\rightarrow$ never been done at HERA

$\rightarrow$ possible only since installation of the H1 CST

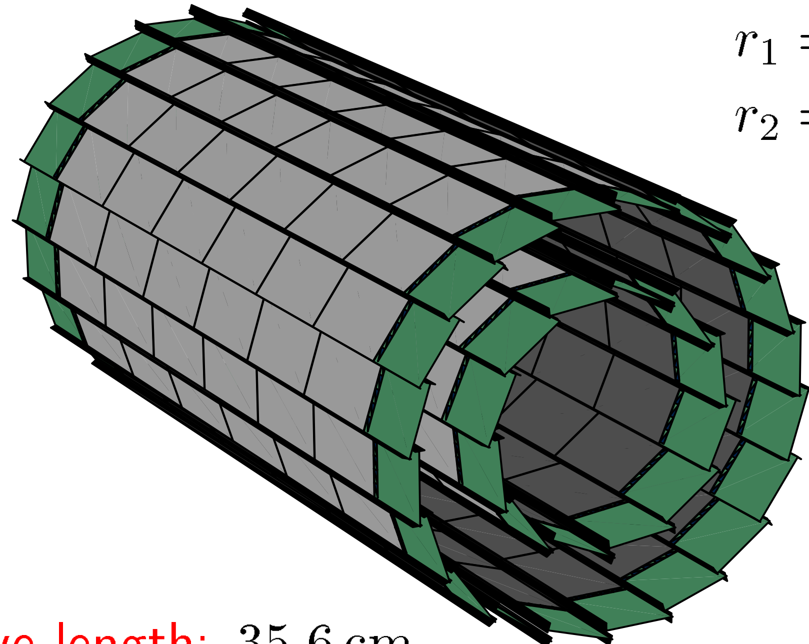
The H1 Central Silicon Tracker

(ETH ZH, Uni ZH, PSI, DESY, RAL, Uni Lund)

2 Si strip layers (double sided)

$r_1 = 5.75\,\mathrm{cm}$

$r_2 = 9.70\,\mathrm{cm}$

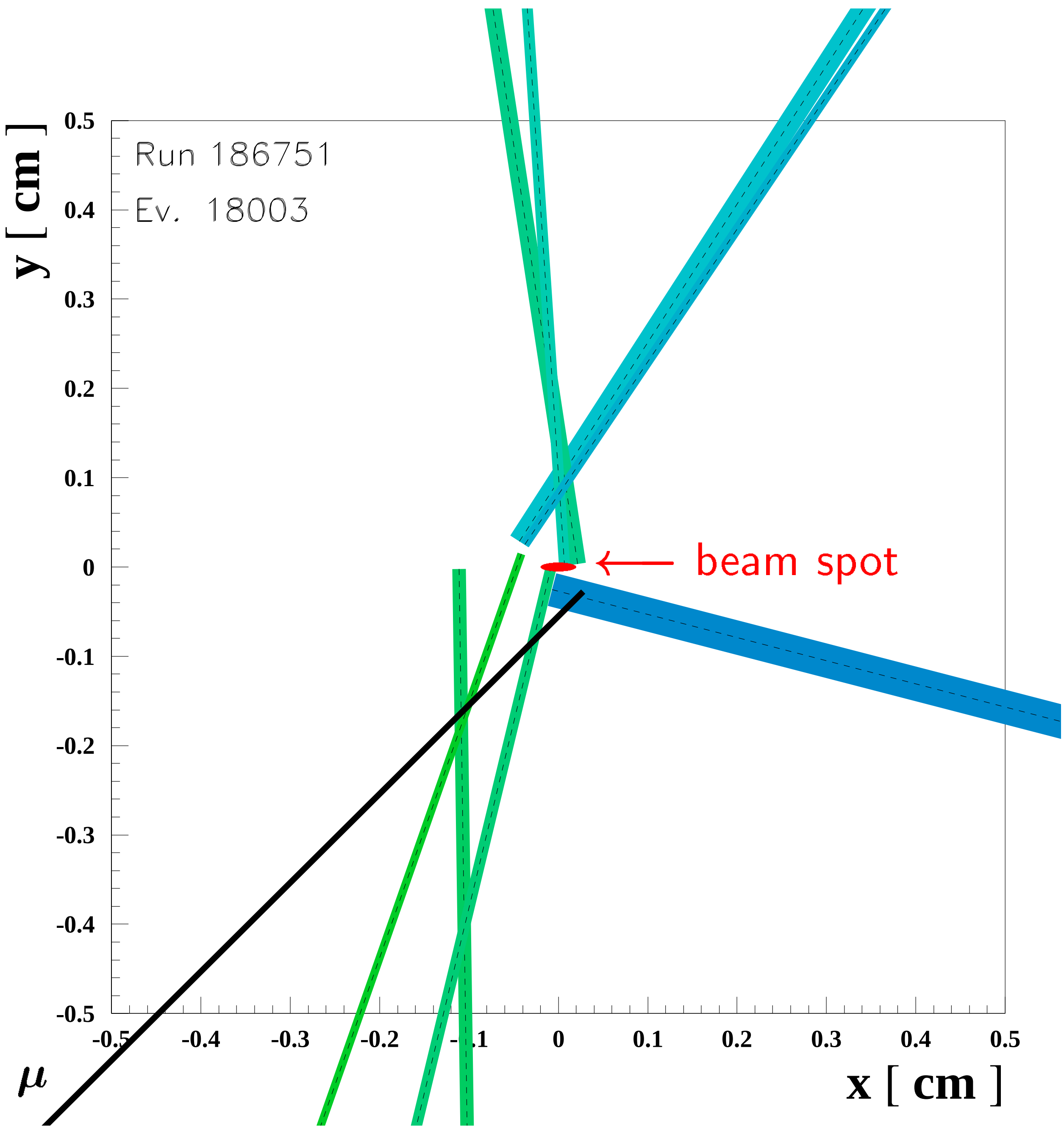


active length: $35.6\,\mathrm{cm}$

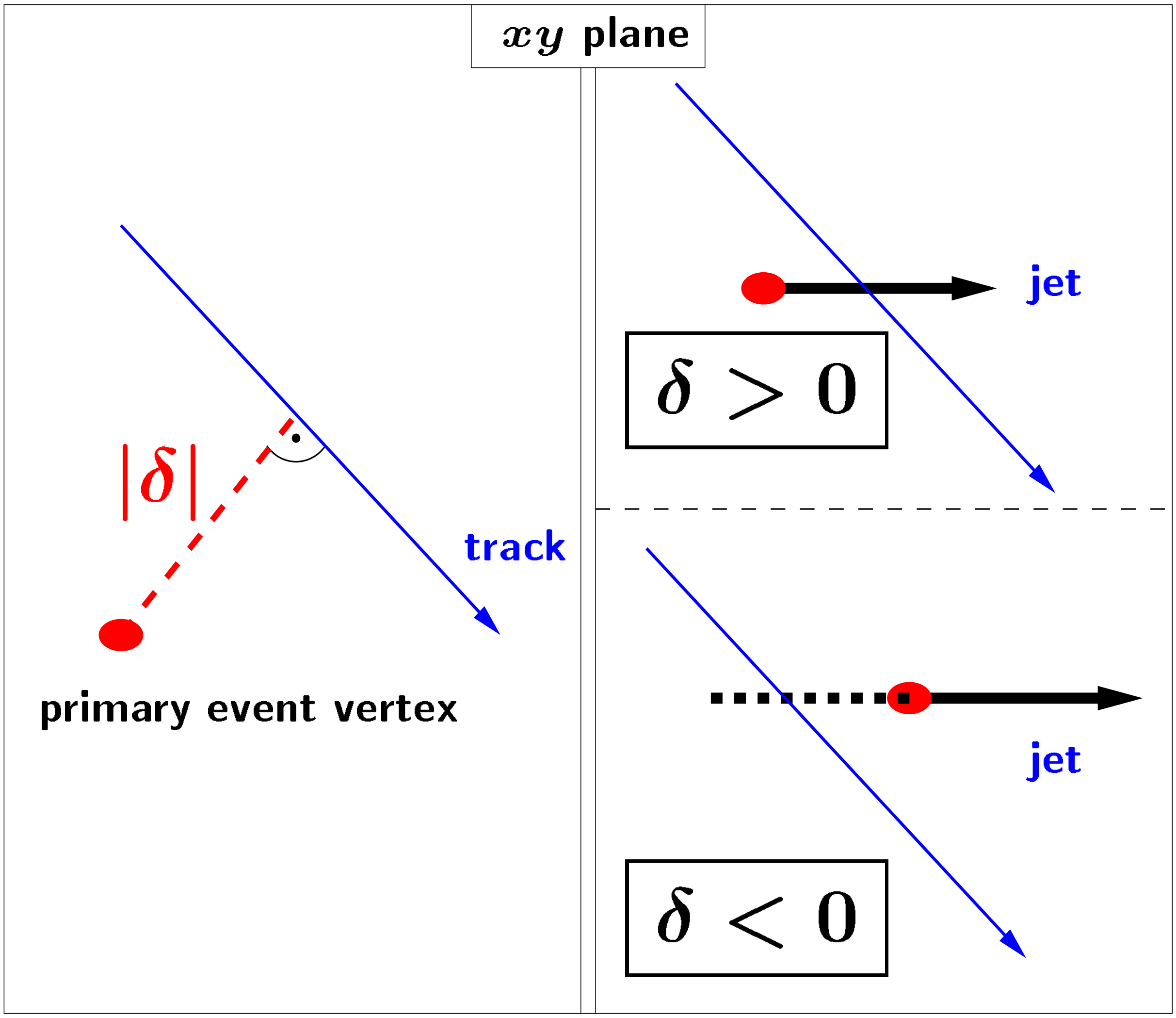
- polar acceptance: $30^\circ < \theta < 150^\circ$

- single hit resolution: $xy \approx 12\,\mu\mathrm{m}$, $z \approx 25\,\mu\mathrm{m}$

Vertex Region of Candidate Event



Signed Impact Parameter δ



primary particles:

- ideal: $\delta = 0$
- finite resolution $\rightarrow$ symmetric distribution centered at 0

b decay particles:

- enrichment at large positive δ

δ Ingredients

▷ **track**

- require high precision in vertex region
- need efficient CST–CJC combined tracking
- $\sigma_{dca} \approx 40\,\mu\mathrm{m} \oplus 100\,\mu\mathrm{m}/\mathrm{p_t}$

▷ **event vertex (xy)**

- beam spot size: $\sigma_x \approx 150\,\mu\mathrm{m}$, $\sigma_y \approx 30\,\mu\mathrm{m}$
- primary vertex fit using CST–improved tracks
- problem: avoid bias from secondary tracks
- $\sigma_x \approx 110\,\mu\mathrm{m}$, $\sigma_y \approx 30\,\mu\mathrm{m}$

▷ **jet axis**

- need good reconstruction of b hadron direction
  $\rightarrow$ sign(δ)
- problem: for typical beauty jet (broad, low E_t) not easy
- angular resolution $\approx 10^\circ$

Event Selection

- **selection**
  - muon trigger
  - γp (no e in main detector)
  - $\geq$ 2 jets ($E_t > 5\mathrm{GeV}$)
  - $\geq$ 1 muon (μ ID + CST/CJC track, $p_t > 2\mathrm{GeV}$)

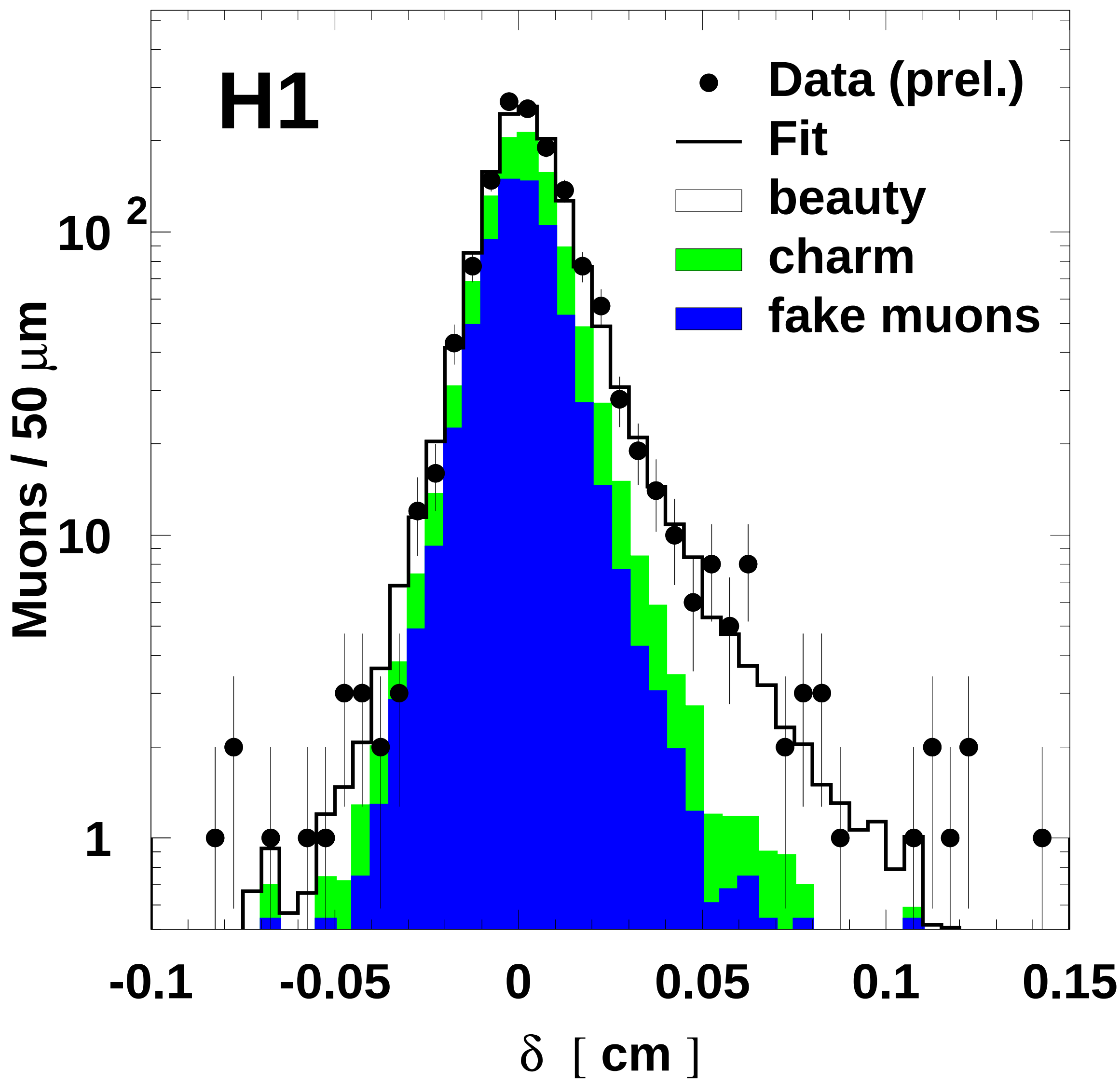
- **data sets**

1. H1 data (1997, $15\mathrm{pb}^{-1}$)
2. $b\bar{b} \to \mu X$ Monte Carlo (LO, direct only)
3. $c\bar{c} \to \mu X$ Monte Carlo
4. "fake muon" sample (H1 data, γp trigger, no μ ID)

   $\to$ background from misidentified hadrons

selection efficiency: 10% trigger efficiency: 79%

Likelihood Fit to the δ Spectrum



$\rightarrow$ sample decomposition:

$f_b = (26 \pm 5)\%$; $f_c = (24 \pm 12)\%$; $f_f = (50 \pm 10)\%$

Cross Checks of δ Fit Result

- translate **charm fraction** into total $c\bar{c}$ cross section and compare to H1 measurement of D^* photoproduction

  $\rightarrow$ consistent within (large) errors

- estimate **fraction of fake muons** from momentum and polar angle dependent misidentification probabilities: $(56 \pm 6)\%$

  $\rightarrow$ consistent within errors with δ fit result

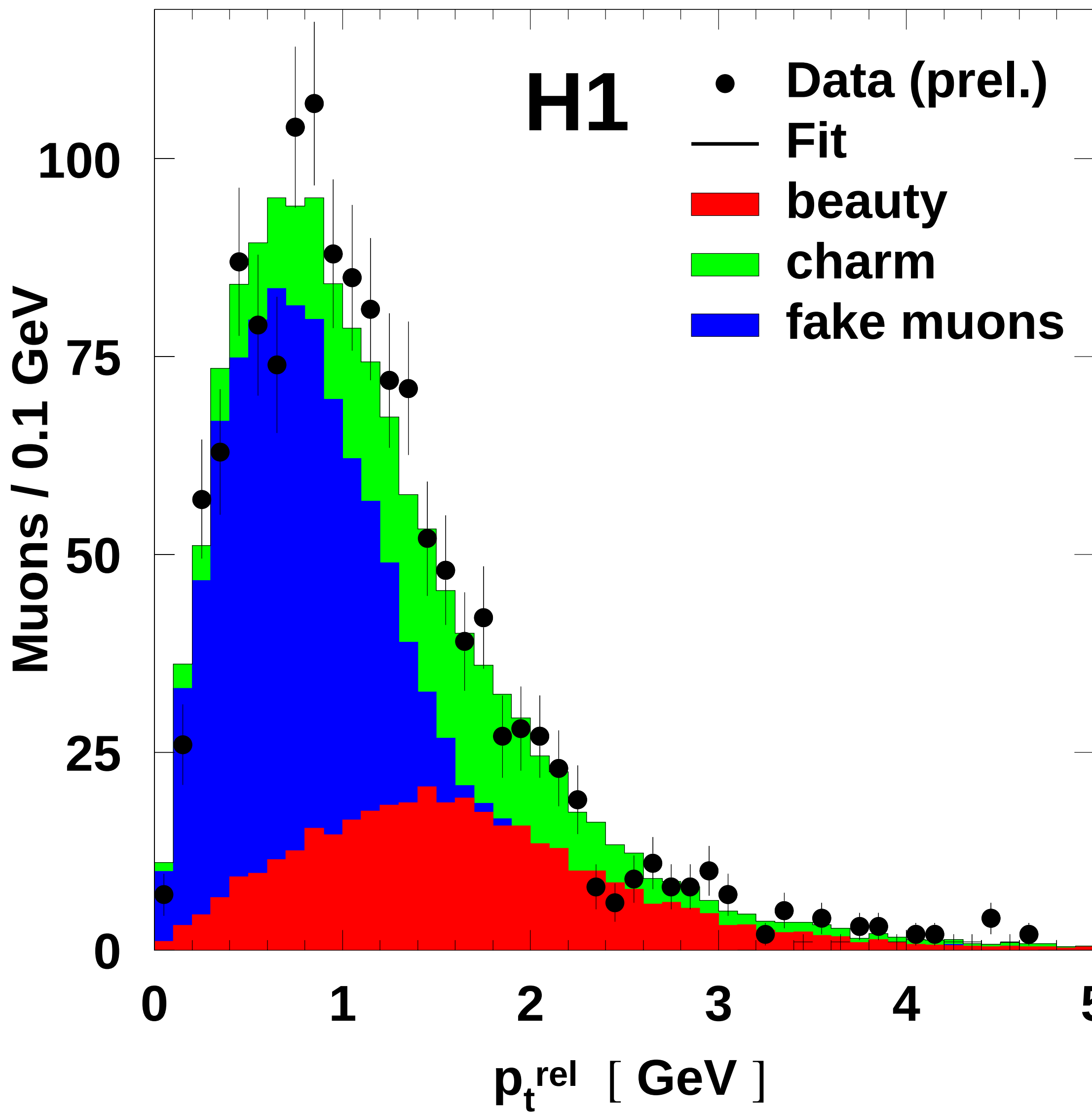
- repeat measurement using p_t^{rel} **method**

  $\rightarrow$ good agreement with δ fit result

  smaller statistical errors (better beauty discrimination) but

  fake muon contribution has to be fixed

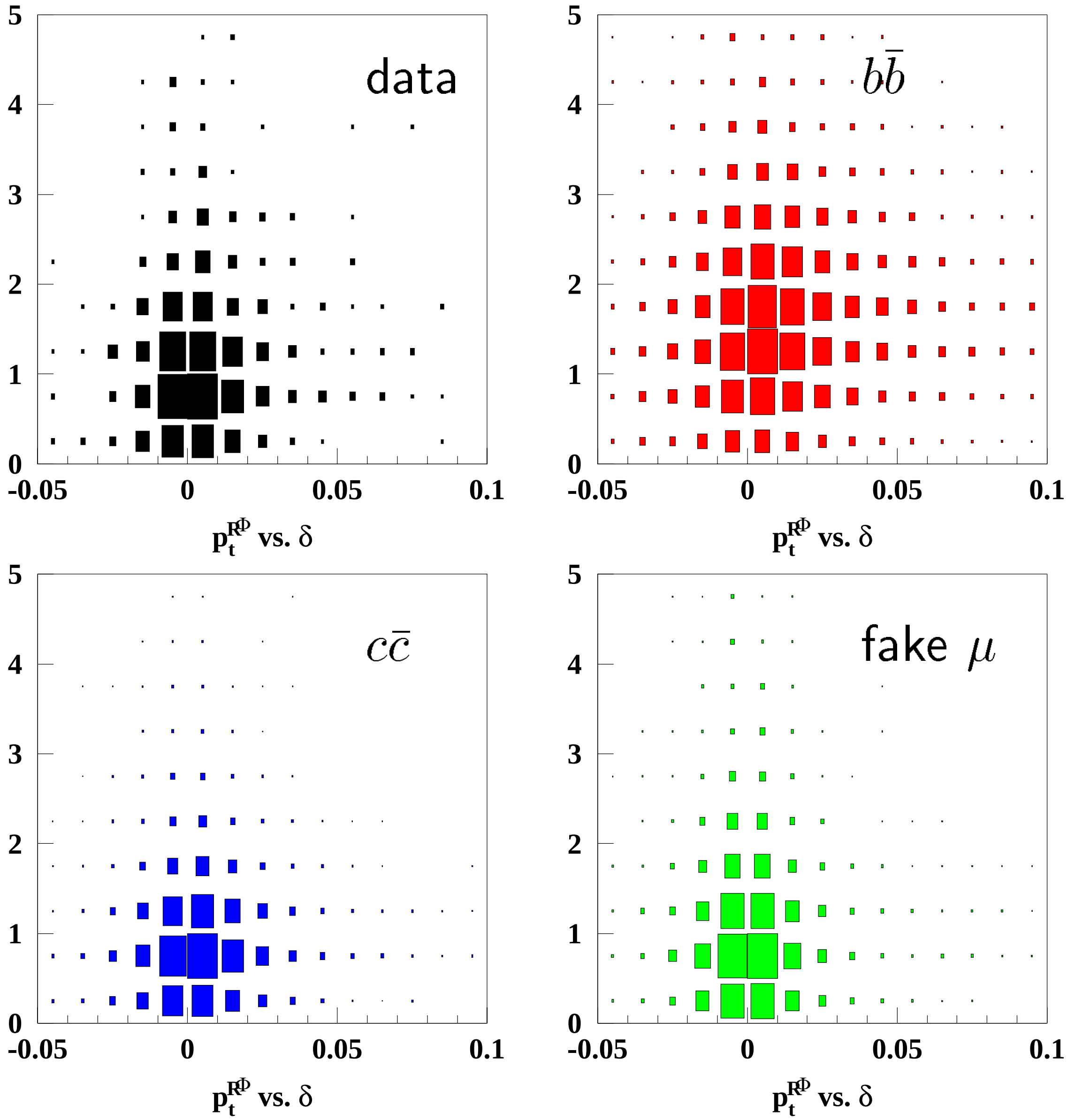
p_t^{rel} Fit



$\rightarrow f_b = (27 \pm 3)\%$

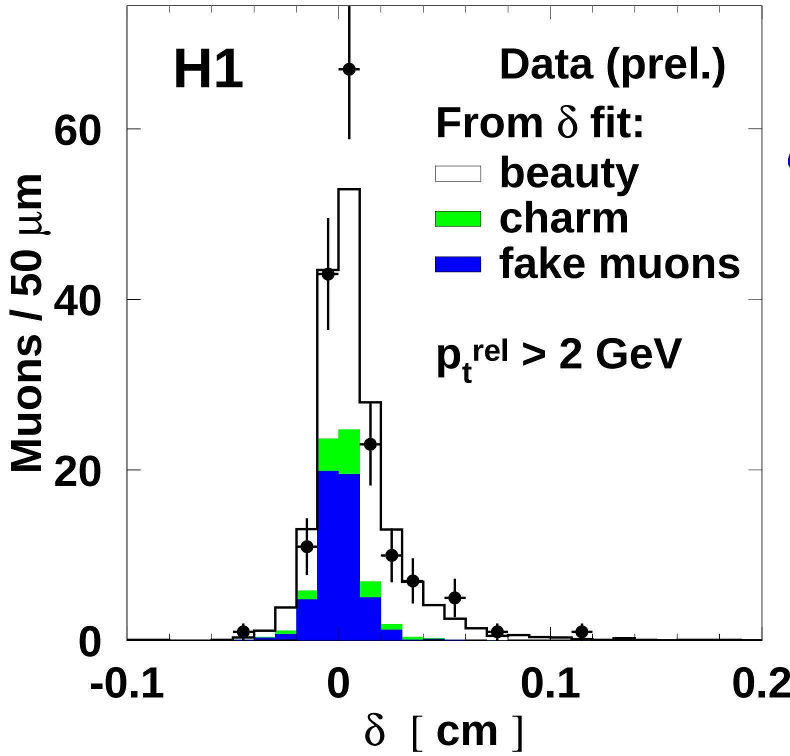
(fake muon contribution fixed at $f_f = 56\%$)

δ–p_t^{rel} Correlation



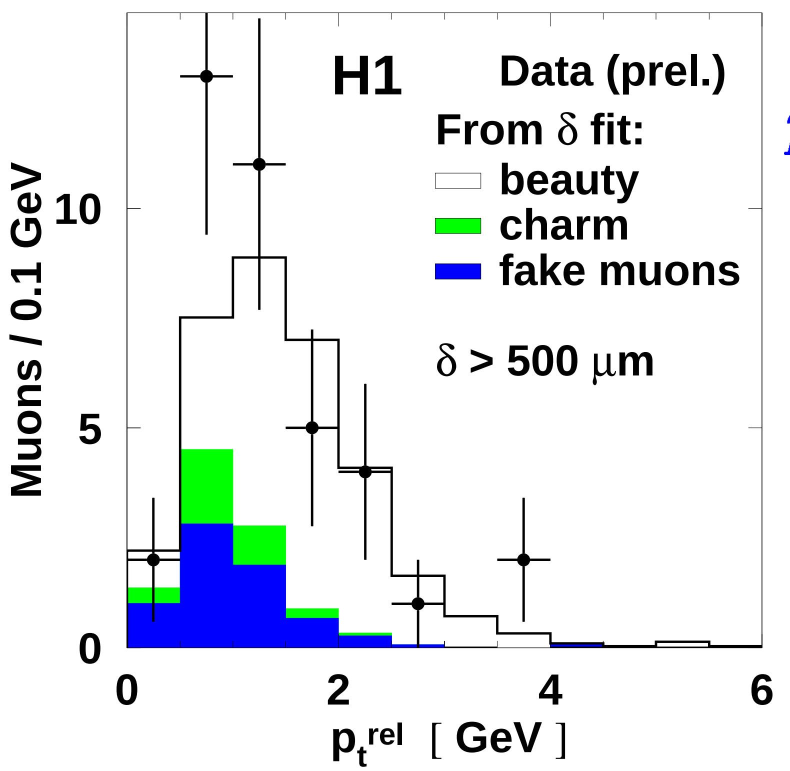
Combine separation power of both observables!

Use δ Result on High Purity Sample



δ control plot

$(p_t^{rel} > 2$ GeV$)$



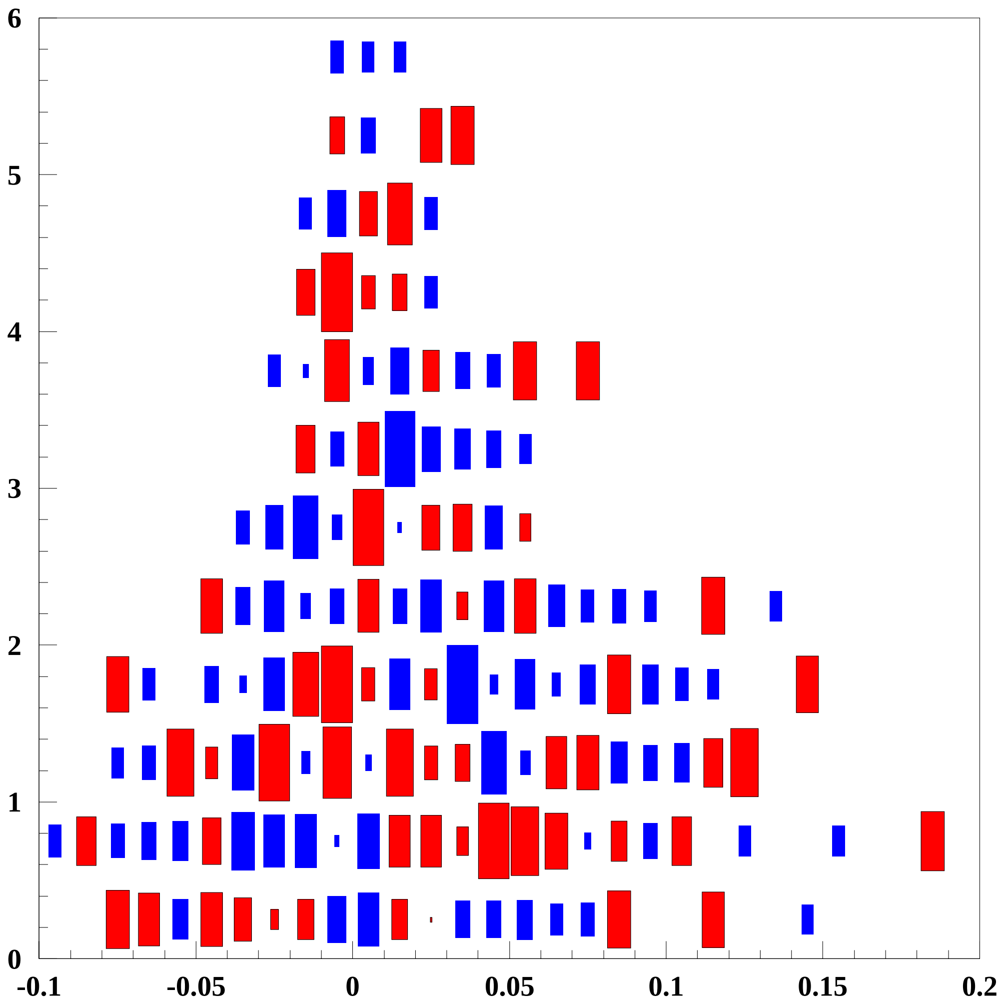
p_t^{rel} control plot

$(\delta > 500\ \mu m)$

Combined (δ, p_t^{rel}) Fit

consistent picture $\rightarrow$ go ahead with 2d fit

pull data-fit (< 0, > 0)



fit result: $f_b = (27 \pm 3)\%$

Systematics

dominating contributions:

- modeling of tracking resolution (10%)
- modeling of hadronic final state (10%)

  (use different MC, including also resolved contributions)

further contributions:

$\rightarrow$ detector description

$\rightarrow$ luminosity measurement

$\rightarrow$ ...

total systematic error: 18%

Beauty Cross Section (1)

Visible cross section for the kinematic range

$Q^2 < 1$ GeV^2, $0.1 < y < 0.8$

$p_t(\mu) > 2$ GeV, $35^\circ < \theta(\mu) < 130^\circ$

- from impact parameter fit alone:

$$\sigma_{vis}^{ep \to b\bar{b}X \to \mu X'} = [159 \pm 30\,(stat.) \pm 29\,(syst.)]\ \mathrm{pb}$$

- from two dimensional (δ, p_t^{rel}) fit:

$$\sigma_{vis}^{ep \to b\bar{b}X \to \mu X'} = [160 \pm 16\,(stat.) \pm 29\,(syst.)]\ \mathrm{pb}$$

Previously published H1 result (same kinematic range, p_t^{rel} method, different data taking period + event selection):

$$\sigma_{vis}^{ep \to b\bar{b}X \to \mu X'} = [176 \pm 16\,(stat.)\ ^{+27}_{-17}\,(syst.)]\ \mathrm{pb}$$

Beauty Cross Section (2)

- impact parameter measurement confirms previously published H1 result using an independent signature and data set
- result obtained from the 2d (δ, p_t^{rel}) fit is consistent with published cross section within the statistical uncertainty

Combining published and new result yields

$$\sigma_{vis}^{ep \to b\bar{b}X \to \mu X'} = (170 \pm 25)\ \text{pb}$$

NLO QCD prediction:

$$\sigma_{vis}^{ep \to b\bar{b}X \to \mu X'}(NLO) = (104 \pm 17)\ \text{pb}$$

$\rightarrow$ significantly below measurement

Summary

- **open beauty production at HERA**
  - valuable testing ground for QCD
  - experimental challenge

- **cross section measurement with H1**
  - analysis of muon impact parameter distribution
  - exploits lifetime signature

    (for the first time at HERA)
  - essential tool: vertex detector CST
  - result above NLO QCD prediction

    (confirming first H1 measurement)

- **discrepancy between theory and experiment**
  - established for b production in both ep and $p\bar{p}$ interactions

Outlook

various possibilities to

- ▷ **extend μ IP analysis**
  - – to different kinematic range (DIS)
  - – to new data (1998-2000)
  - – to differential cross sections
- ▷ **go beyond**
  - – towards an inclusive lifetime tag

$\rightarrow$ more fun and physics to come!