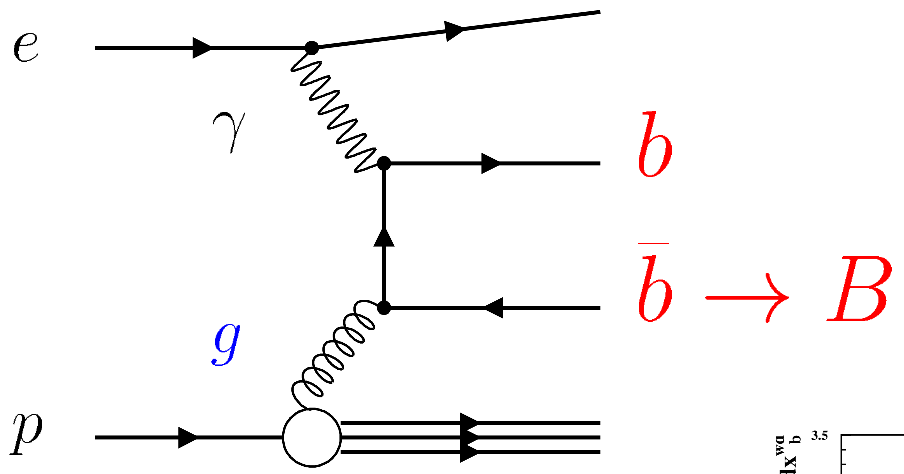
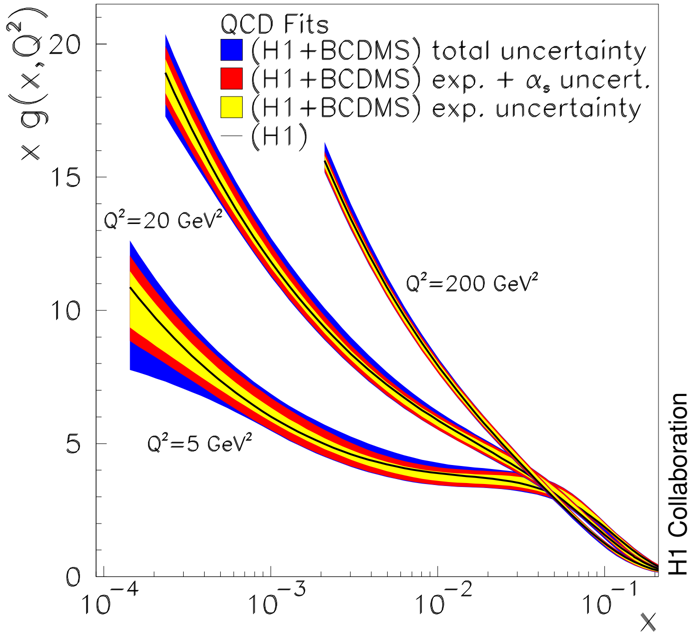
Open Beauty Production

Felix Sefkow
Universität Zürich

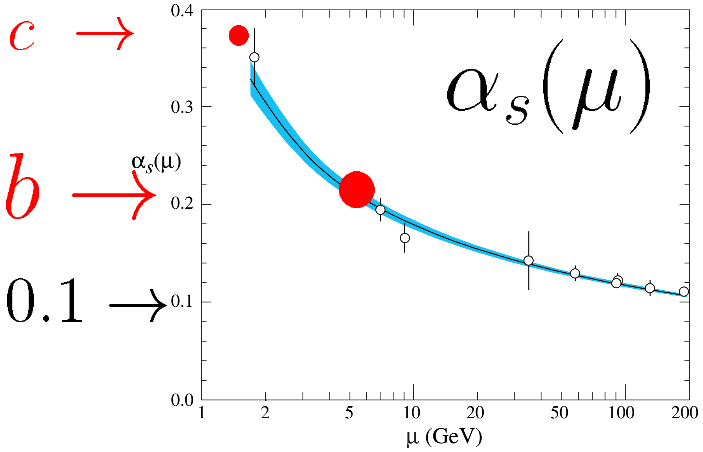
New Measurements at HERA,
Elsewhere,
and in Future

HERA's Beauty Case

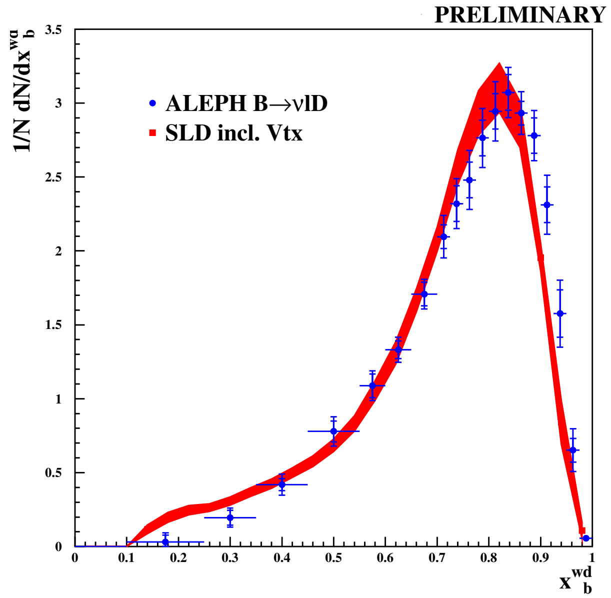




x_g



μ



x_B

- QCD testing ground *par excellence*
- Understanding mandatory to interprete proton SF data

QCD Tools

- NLO Fixed Order Calculations; "Massive" 3 Flavour Scheme

$$\sigma = g(x) \otimes \hat{\sigma}_{BGF} \otimes D_{non-pert}(z) \; (\otimes \text{ semilept. decay })$$

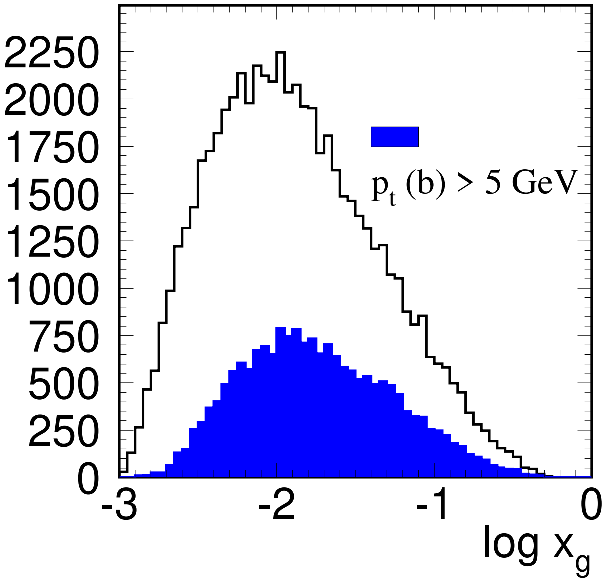
$D(z)$ Peterson Fragmentation Function

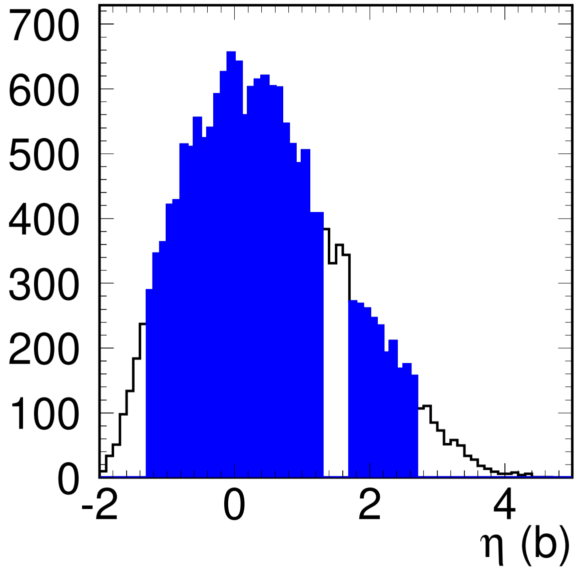
- γp: "FMNR" Frixione *et al.*
- DIS: "HVQDIS" Harris & Smith

- K-Factors $\sim$ 1.4

Experimental Signature

- Low rate: $\sigma_b/\sigma_c \sim 10^{-2}$
- Mostly photoproduction
- Steeply falling p_T spectrum
- $x_g \sim 10^{-2}$ central rapidities

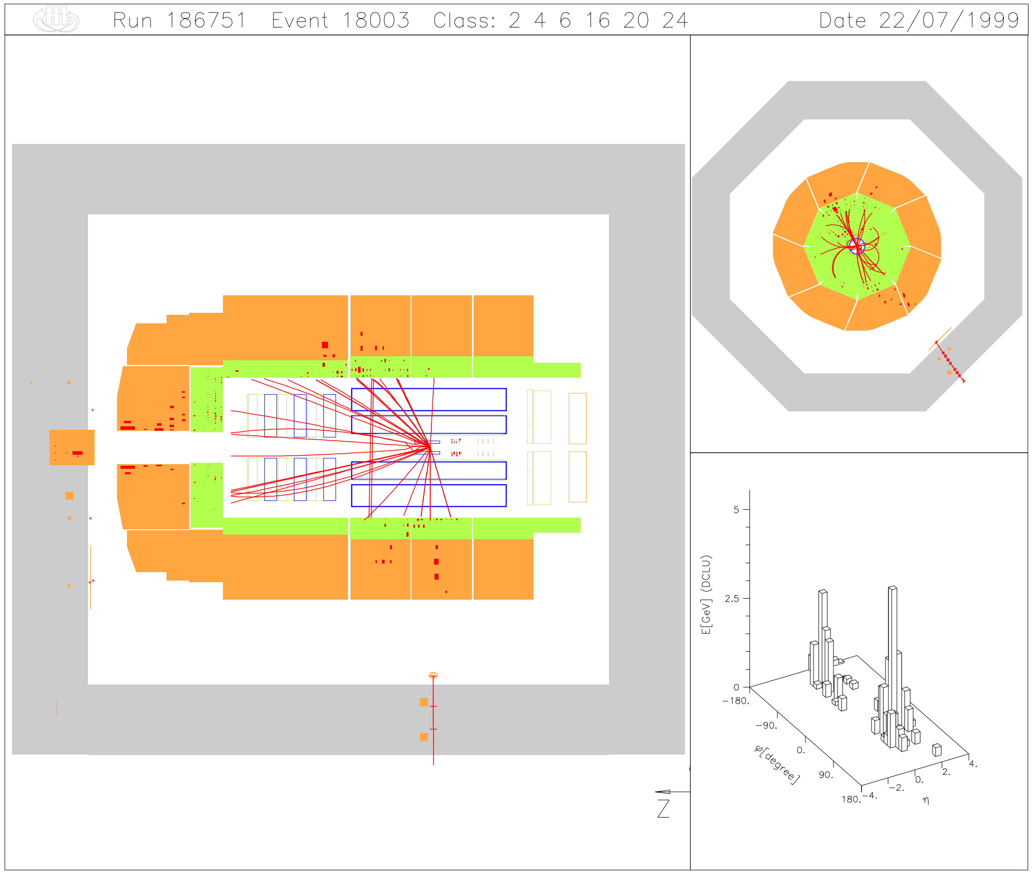




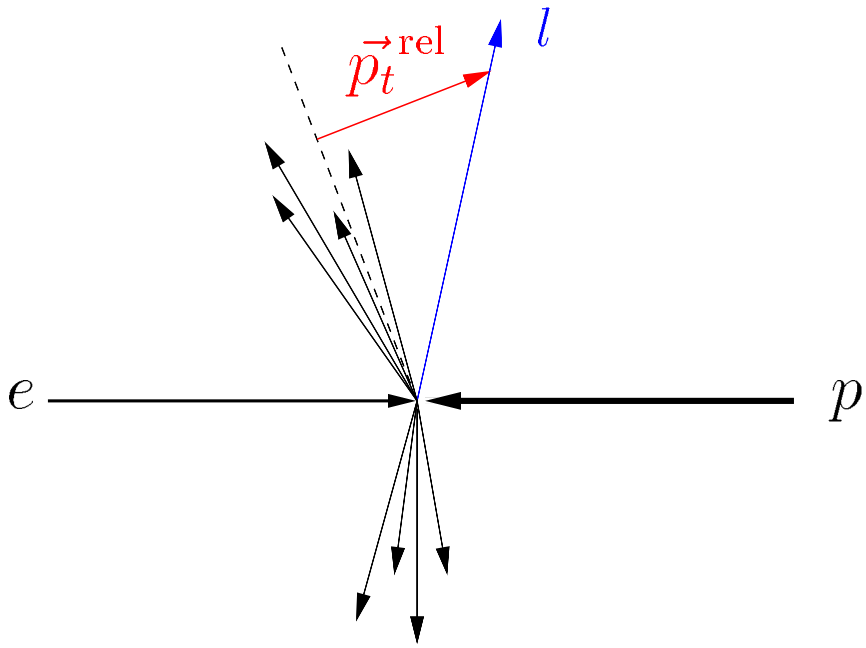
Silicon tracking

Signs of Beauty (1): Mass

- Semileptonic decay

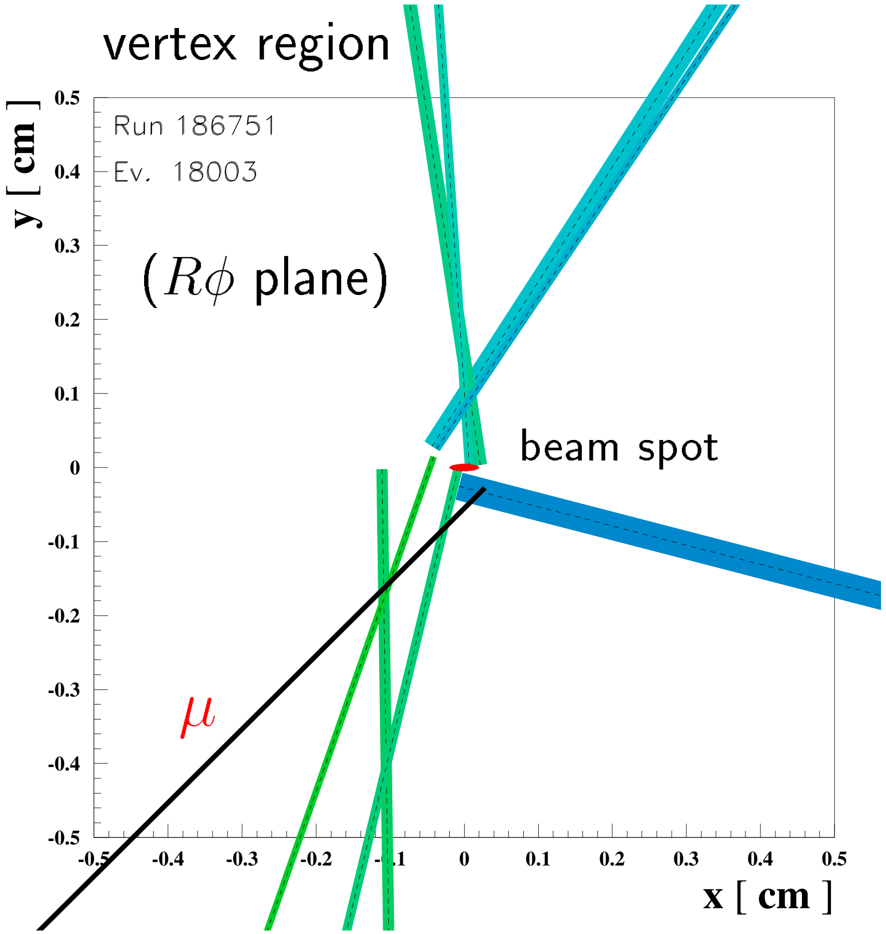


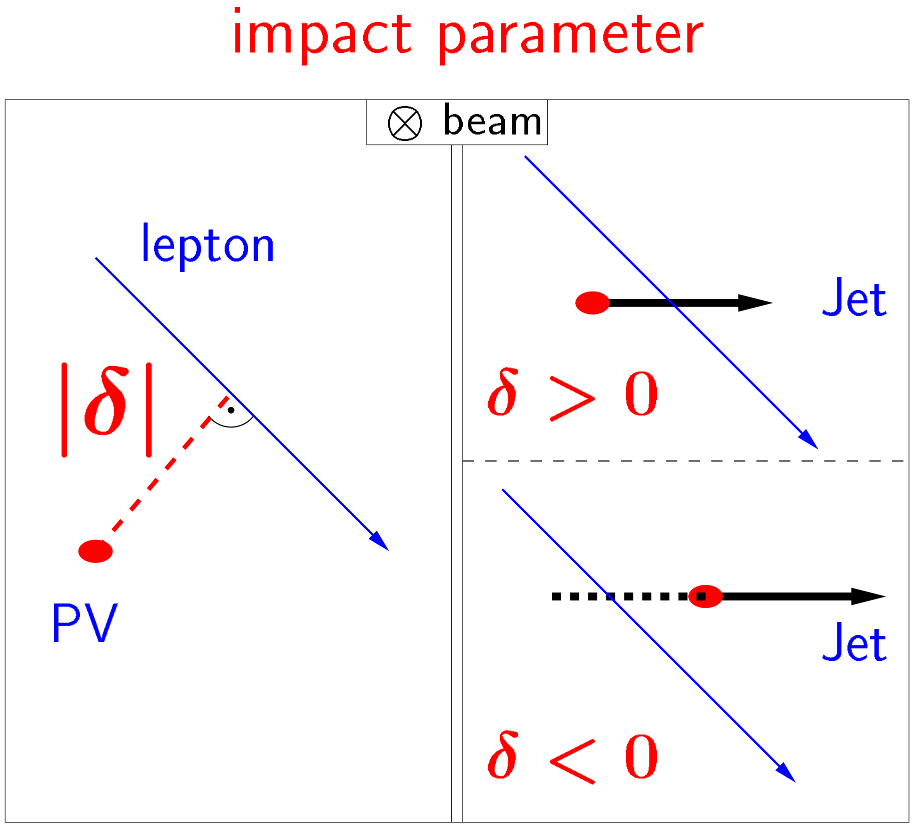
lepton p_t w.r.t. jet



$\rightarrow$ ZEUS, H1

Signs of Beauty (2): Lifetime

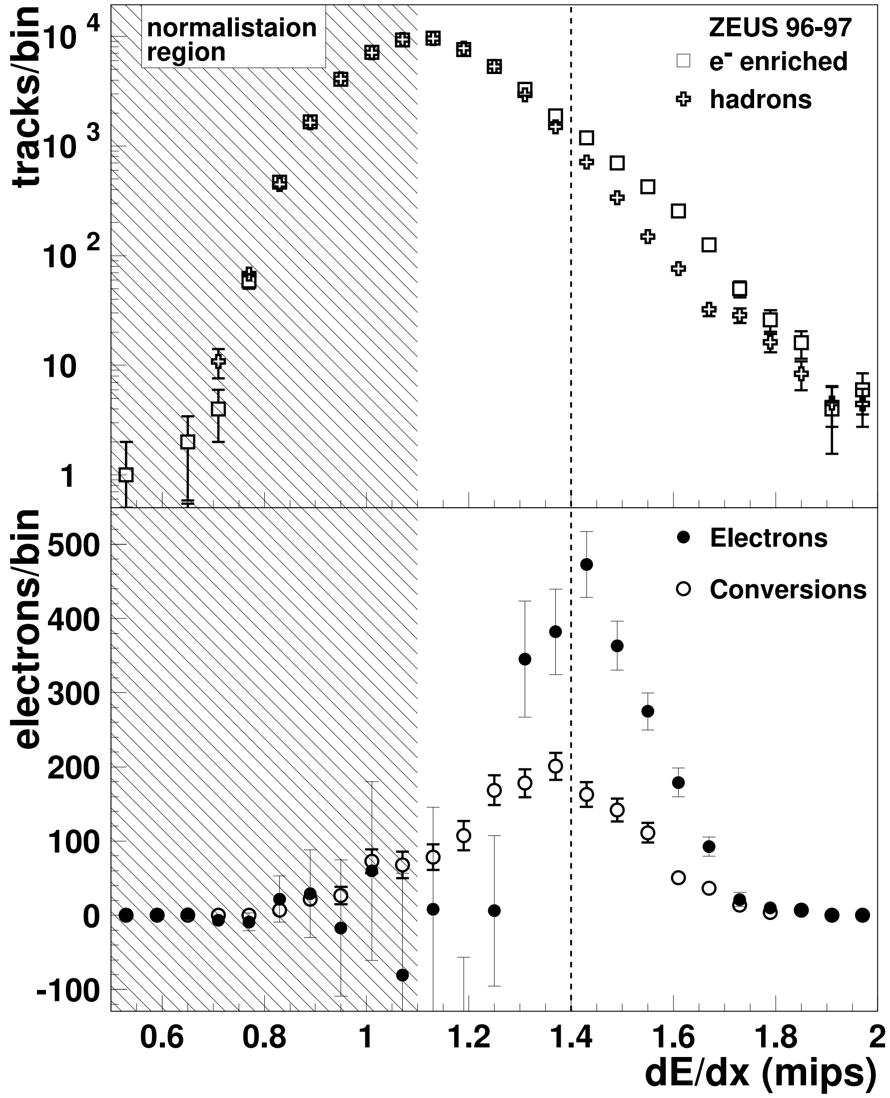




$\rightarrow$ H1 (vertex detector)

ZEUS Electron Analysis

- $\rightarrow$ Ringberg '99
  publ.: EPJ 18, 625 (2001)
- Electron ID using
  calo and dE/dx
- Identify $\gamma \rightarrow e^+e^-$
  by topology and mass
- Luminosity $\int \mathcal{L} = 38.5$ pb^{-1}
- Signal $943 \pm 69\ e^-$



Resolved γ in Charm and Beauty Production

$$x_\gamma = \frac{\sum_{\text{jet } 1,2} E_\perp^j e^{-\eta^j}}{2yE_e}$$

- x_γ fit:

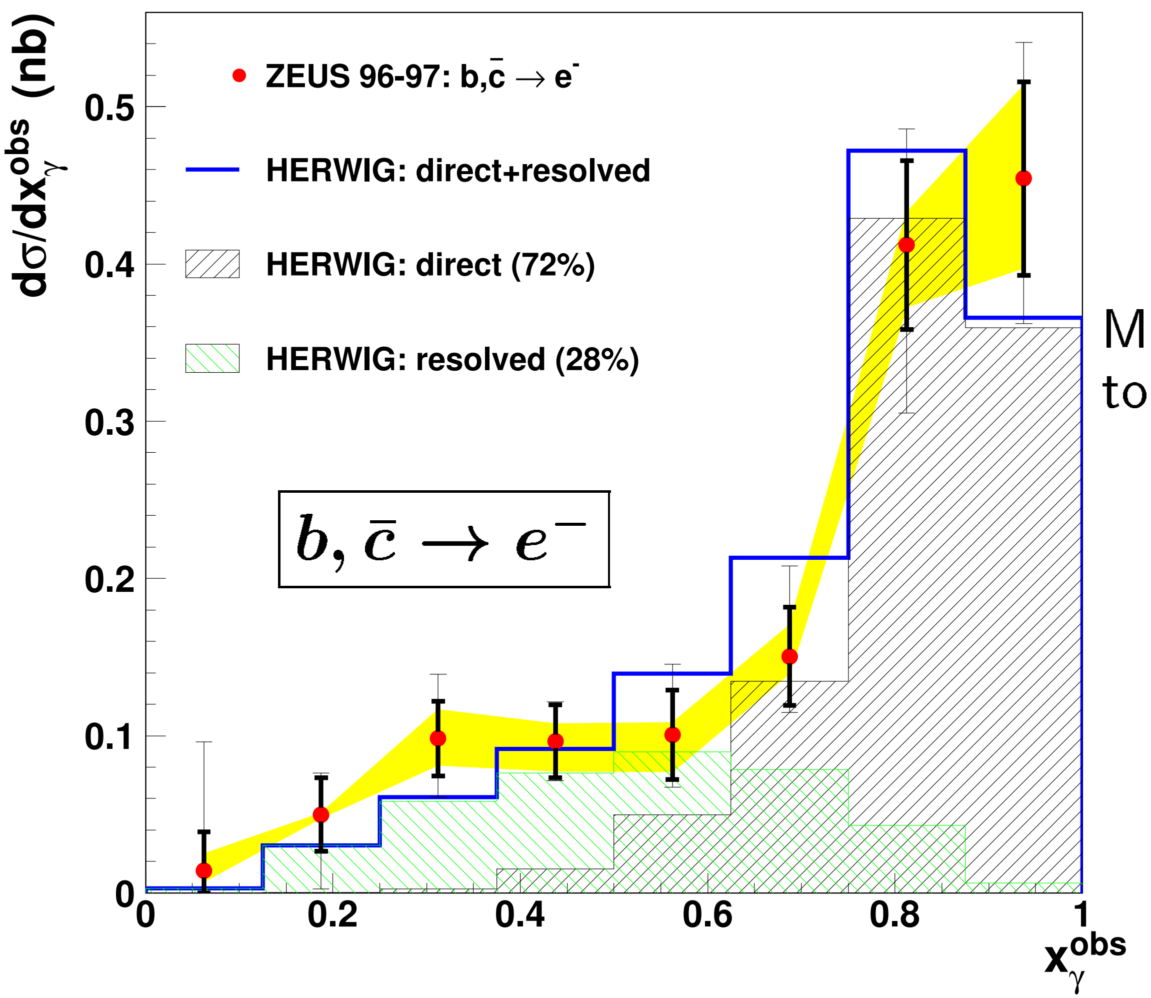
resolved contribution

$(28 \pm 5(stat.))$ %

HERWIG prediction: 35%

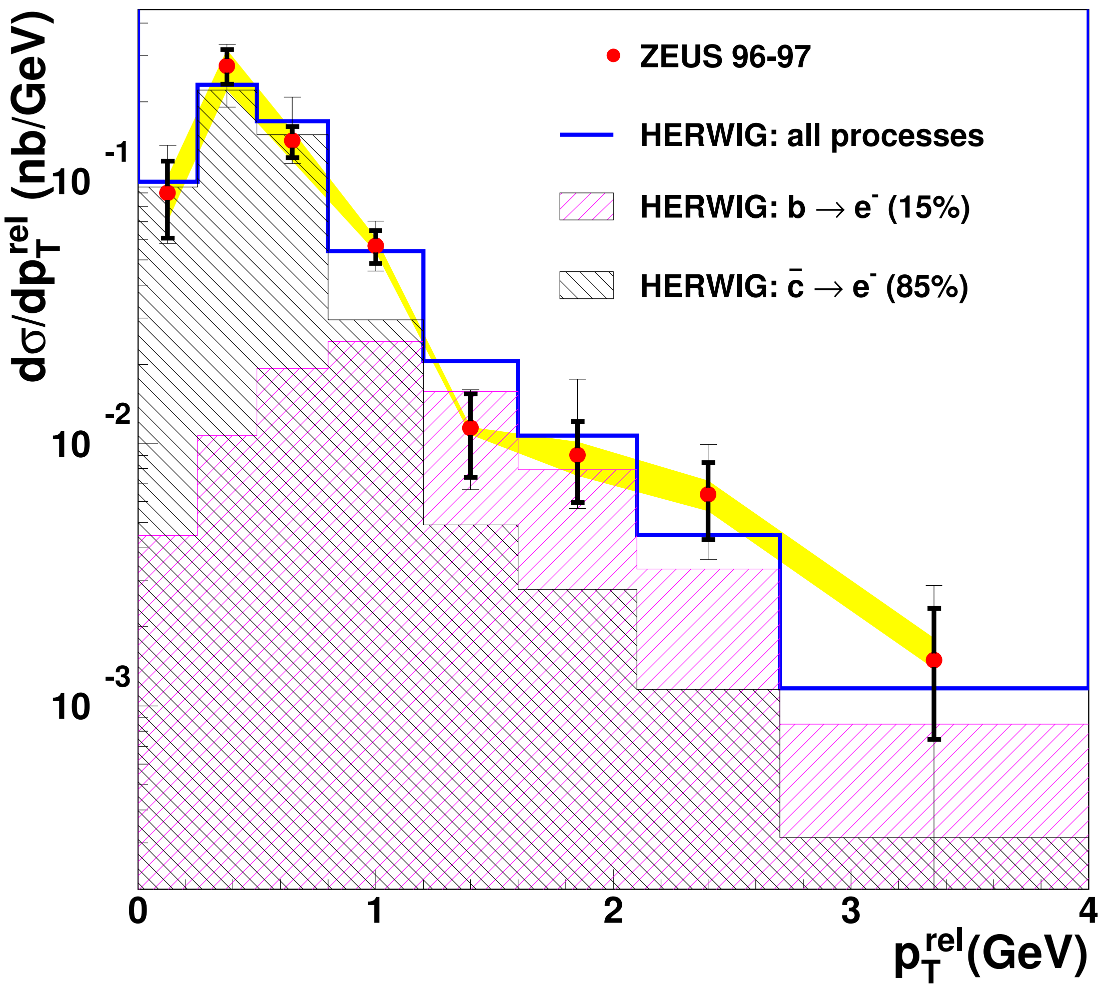
(mostly flavour excitation)

resolved γ $\longleftarrow\longrightarrow$ direct processes



MC norm.
to data

p_T^{rel} Fit: Extract the Beauty Fraction



$f_b = (14.7 \pm 3.8)\,\%$

(HERWIG: 16 %)

Kinematic range:

$Q^2 < 1$ GeV^2, $0.2 < y < 0.8$

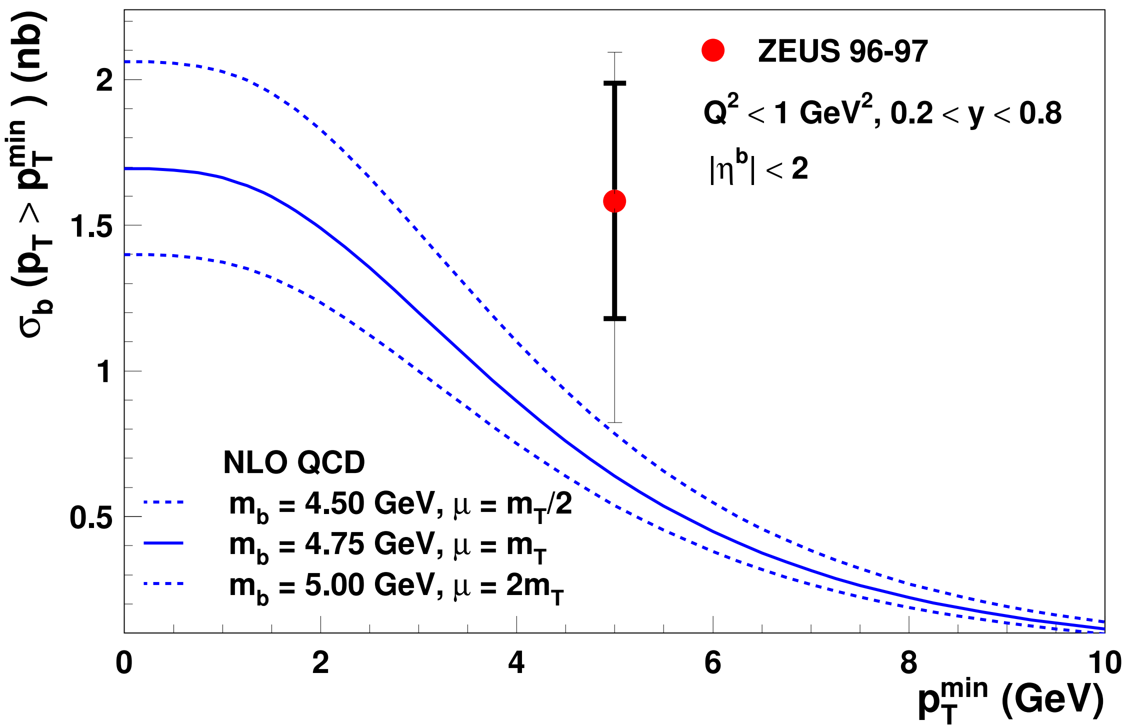
$E_T^{\text{Jet}} > 7(6)$ GeV, $|\eta| < 2.4$

$p_T^{\text{e}} > 1.6$ GeV, $|\eta| < 1.1$

- Visible cross section $\sigma^{b\to e^-}_{e^+p\to e^+ + \text{dijet} + e^- + X} = 24.9 \pm 6.4^{+4.2}_{-7.3}$ pb

b Quark Cross Section

- Use MC to extrapolate



Kinematic range:

$Q^2 < 1$ GeV^2, $0.2 < y < 0.8$

$p_T^{\text{b}} > 5$ GeV, $|\eta^{\text{b}}| < 2$

$$\sigma^{\text{ext}}_{ep\to e^+bX} = 1.6 \pm 0.4(stat.)^{+0.3}_{-0.5}(syst.)^{+0.2}_{-0.4}(ext.)\ \text{nb}$$

- Earlier prelim. ZEUS μ results consistent

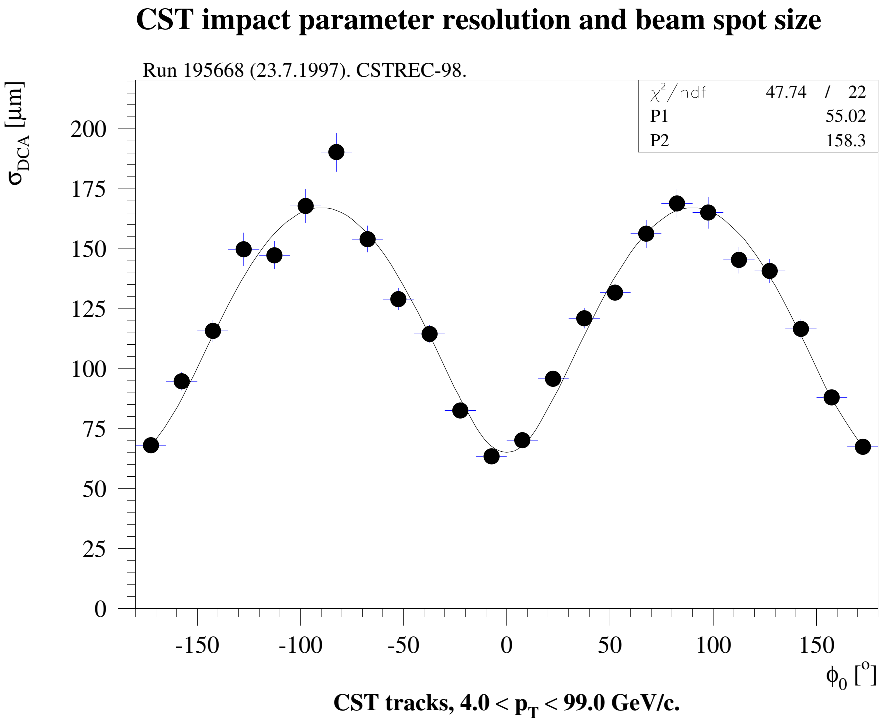
H1 Muon Analyses

- First observation, based on p_T^{rel}
  $\rightarrow$ Ringberg '99, publ.: PLB 47, 156 (1999)
- New: Lifetime signature
  - ▷ Establish impact parameter technique
    $\rightarrow$ similar selection, same kinematic range
  - ▷ Improve result
  - ▷ Explore new territory

H1 Silicon Tracker Resolution

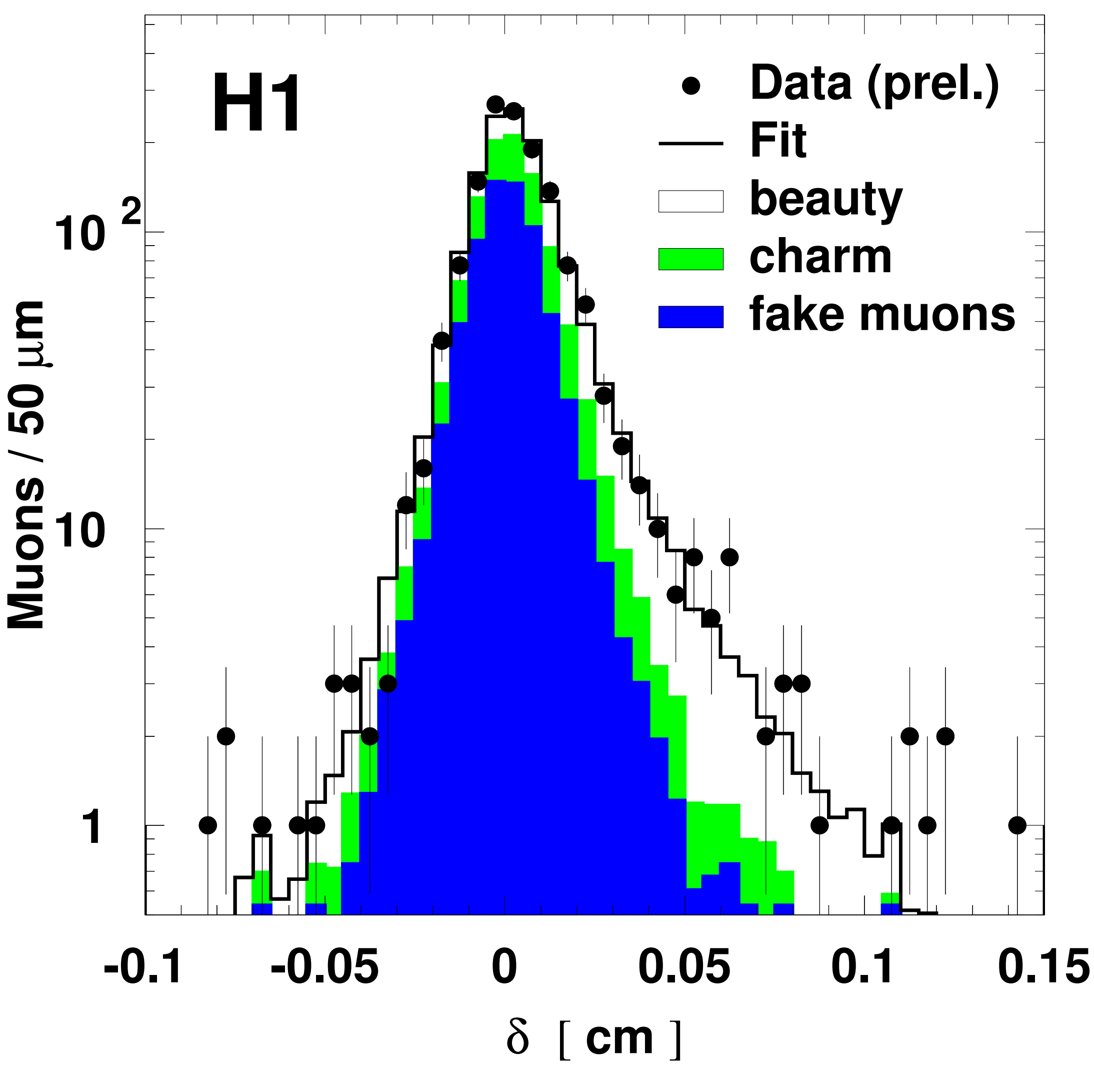
- 2 double-sided layers $R = 6\ (10)$ cm, $L = 36$ cm
  Hit resolution $12\ (25)\ \mu$m in $R\phi\ (z)$
- Up to now, work in transverse plane
- Impact parameter resolution $\sigma_\delta = 40\ \mu\mathrm{m} \oplus 100\ \mu\mathrm{m}/p_T$

Width of impact param. distribution vs. ϕ



Beam spot $150 \times 30\ \mu$m

Lifetime Based Measurement

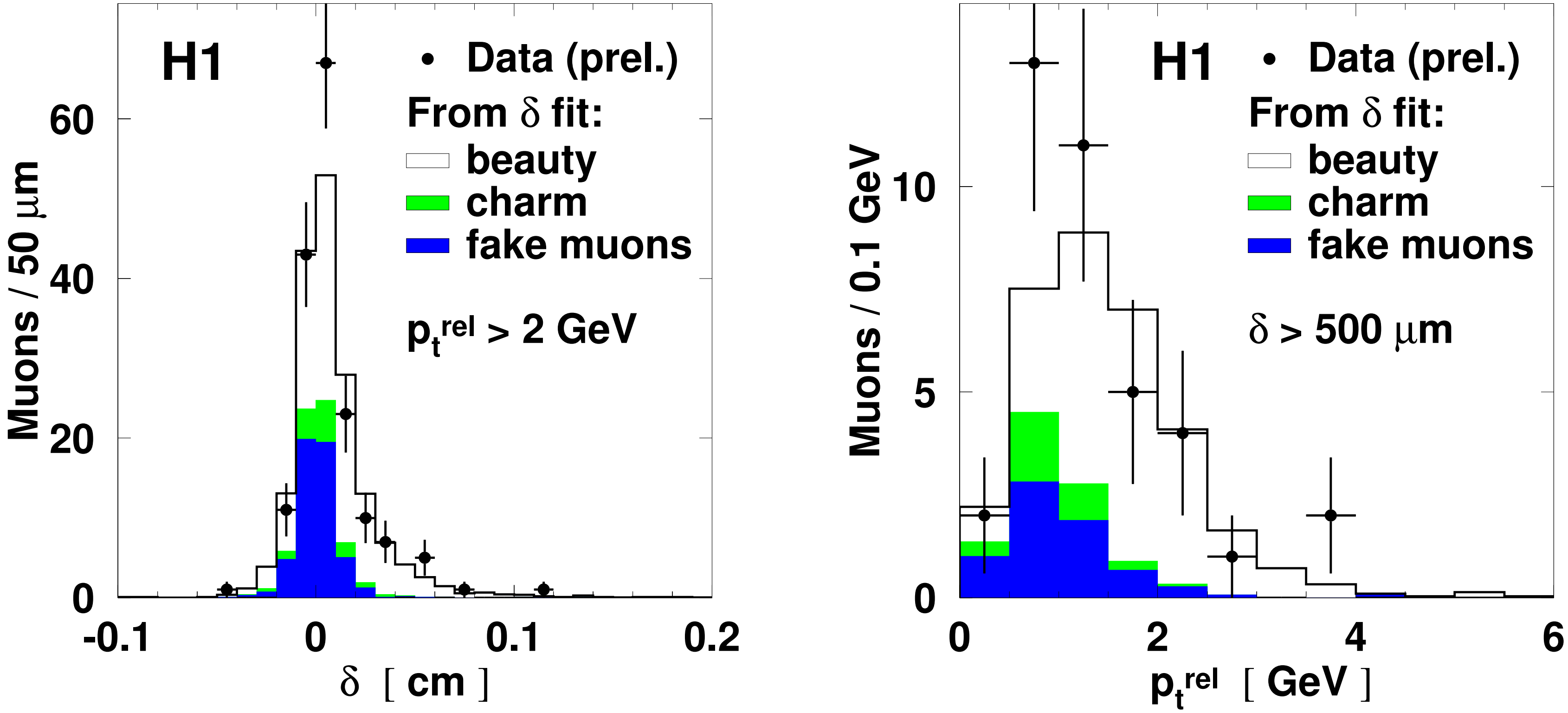


- Photoproduction,
  ≥ 2 jets $E_T > 5$ GeV,
  ≥ 1 μ in Si tracker
- Kinematic range
  $Q^2 < 1$ GeV^2, $0.1 < y < 0.8$,
  $p_T(\mu) > 2$ GeV, $35^\circ < \theta < 130^\circ$
- Likelihood fit to μ impact param. spectrum
- Beauty fraction:
  $f_b = 26 \pm 5$ %

- Visible Cross section $\sigma_{vis}^{ep \to b\bar{b}X \to \mu X} = [159 \ \pm \ 30 \pm 29\ ]$ pb
- Confirms published H1 result $(176 \pm 16\ ^{+27}_{-17})$ pb

Combine Impact Parameter δ and p_T^{rel}

- High b purity regions

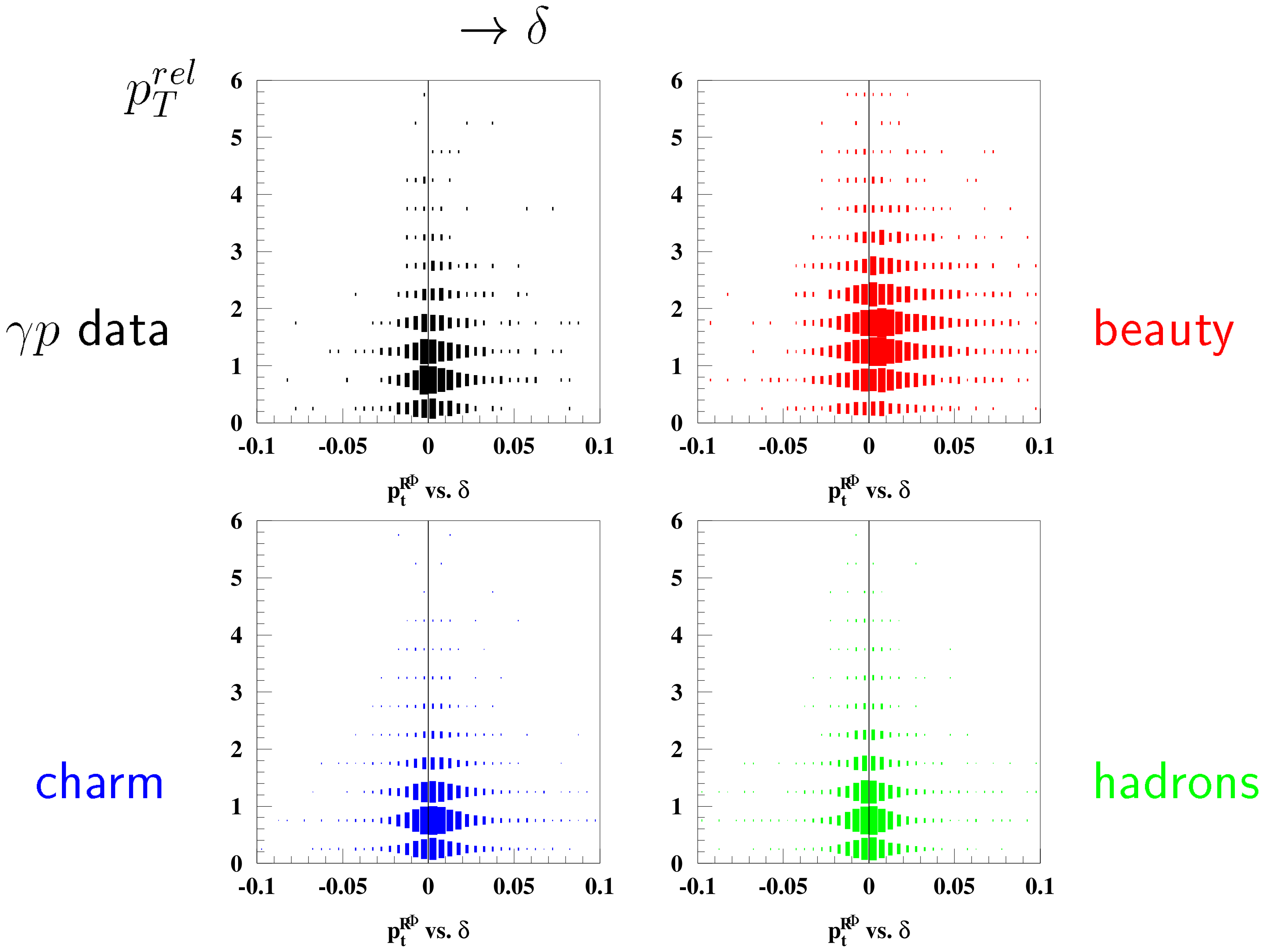


- Combined likelihood fit in (δ, p_T^{rel}) plane:

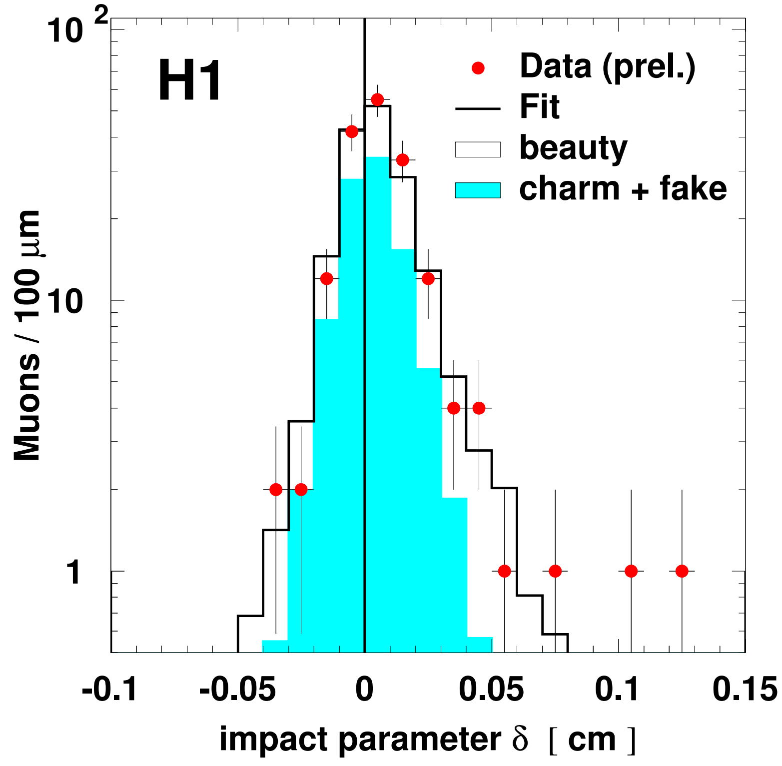
  $\sigma_{vis}(ep \to b\bar{b}X \to \mu X) = [160\ \pm\ 16\,(stat.)\ \pm 29\,(syst.)\,]$ pb

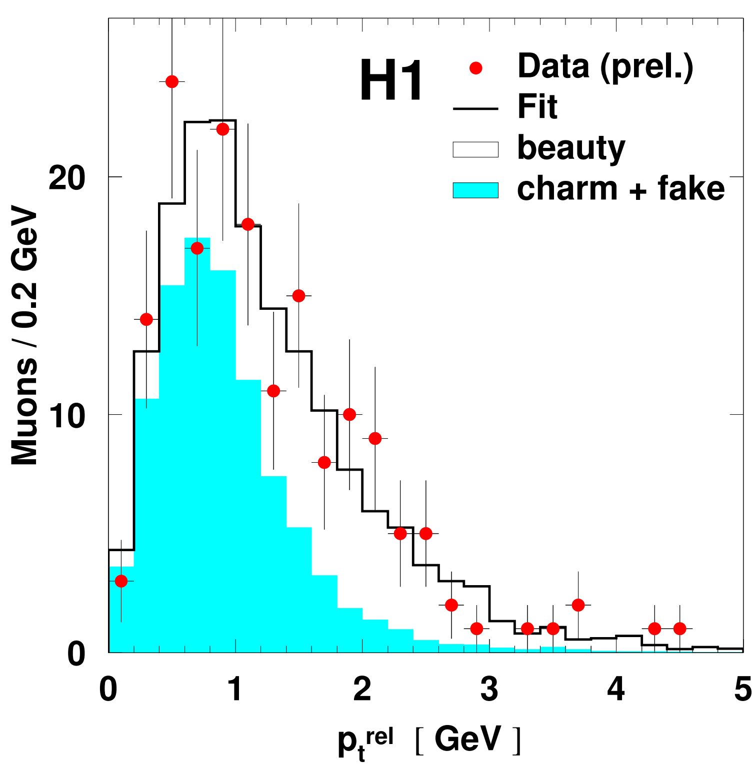
- Average with publ. H1 result: $\sigma_{vis} = (170 \pm 25)$ pb
- Exceeds NLO QCD prediction

2-Dimensional Fit (δ, p_T^{rel})



First Measurement of Beauty in DIS





- Kinematic range $2\ \mathrm{GeV}^2 < Q^2 < 100\,\mathrm{GeV}^2,\ 0.05 < y < 0.7$
  (μ and jets as in γp)
  171 candidates in 11 pb^{-1}
- Combined 2D fit $\rightarrow$ $f_b = (43 \pm 8)\,\%$

Visible b Cross Section in DIS

- Kinematic range defined by Q^2, y
  and muon cuts $p_T(\mu) > 2$ GeV, $35^\circ < \theta < 130^\circ$

  $\sigma_{vis}^{ep\to b\bar{b}X\to\mu X} = (39 \pm 8 \pm 10)\ \mathrm{pb}$

- NLO QCD ($m_b = 4.75$ GeV): $\sigma = (11 \pm 2)$ pb

- LO MC: AROMA (DGLAP evolution): $\sigma = 9$ pb
  CASCADE (CCFM evolution): $\sigma = 15$ pb

Extrapolations

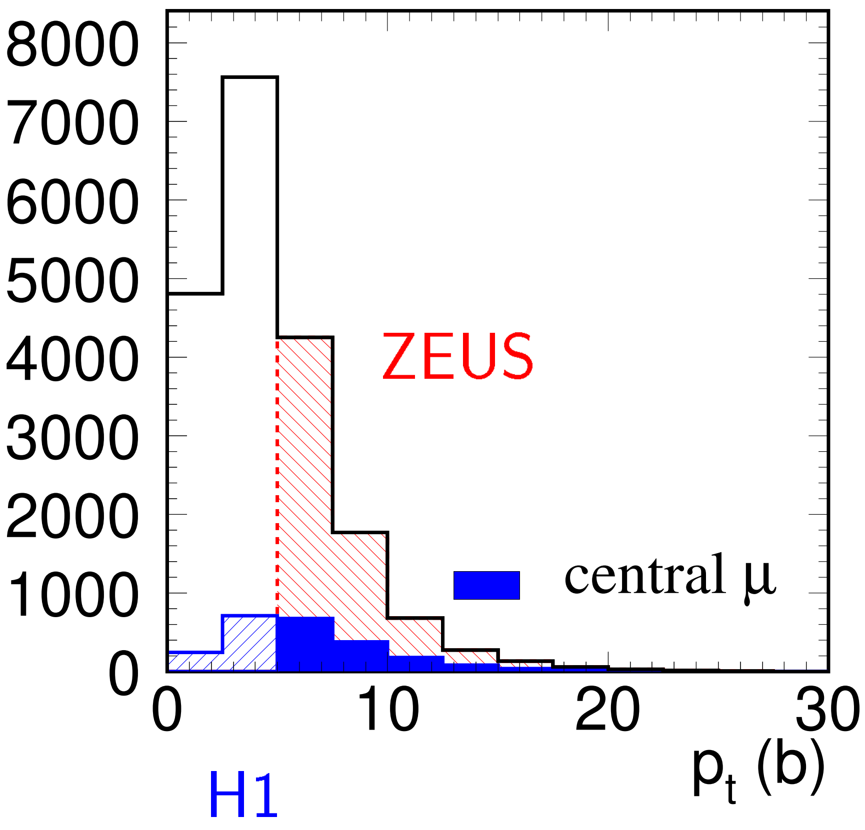
- Both experiments see only a tiny part $\mathcal{O}(0.1\%)$ of σ_{TOT}:

$$\frac{\#ev.}{\int \mathcal{L}} = \begin{array}{l} 25 \text{ pb (H1)} \\ 4 \text{ pb (ZEUS)} \\ (e^-, y, \text{jets}) \end{array}$$

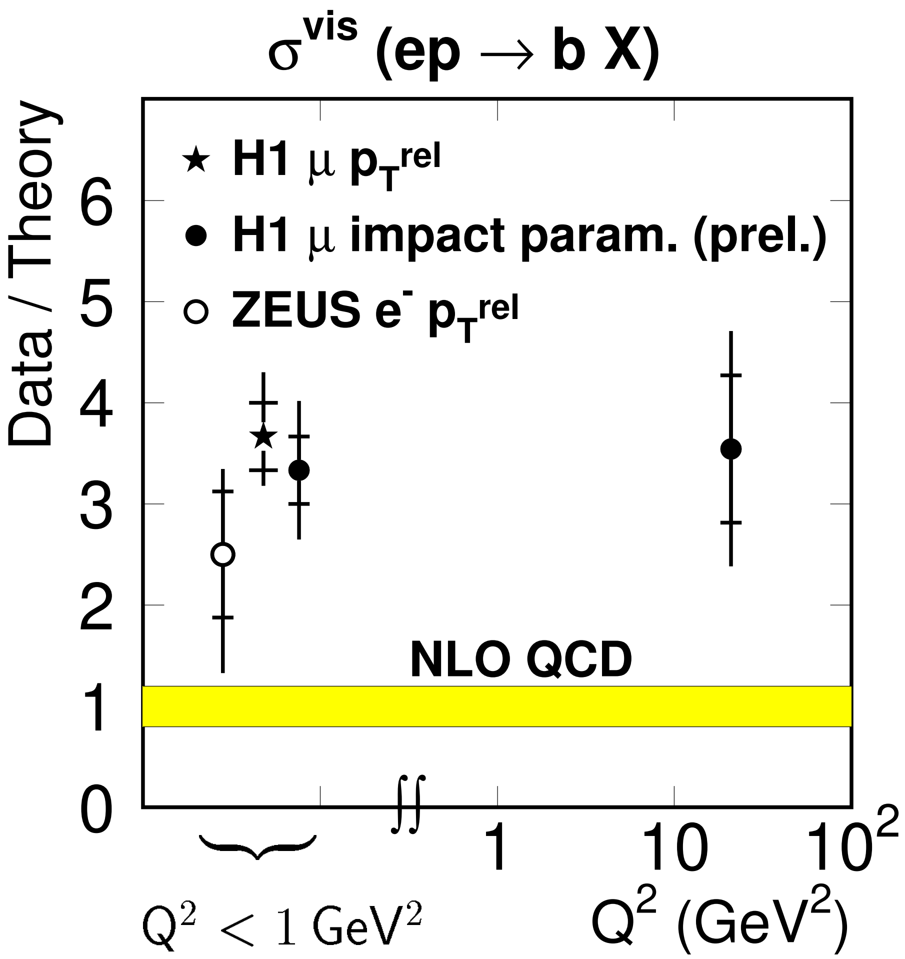
- Both extrapolate by similar factors, but in different ways $\rightarrow$

Note: σ_{H1} includes $B_{b\rightarrow\mu}$, σ_{ZEUS} does not

Simplified picture (jets $\sim$ quarks):



HERA Summary



- σ_B at HERA exceeds NLO QCD
- Seen by both experiments and with two methods:
- First measurement in DIS: Not only a γp problem

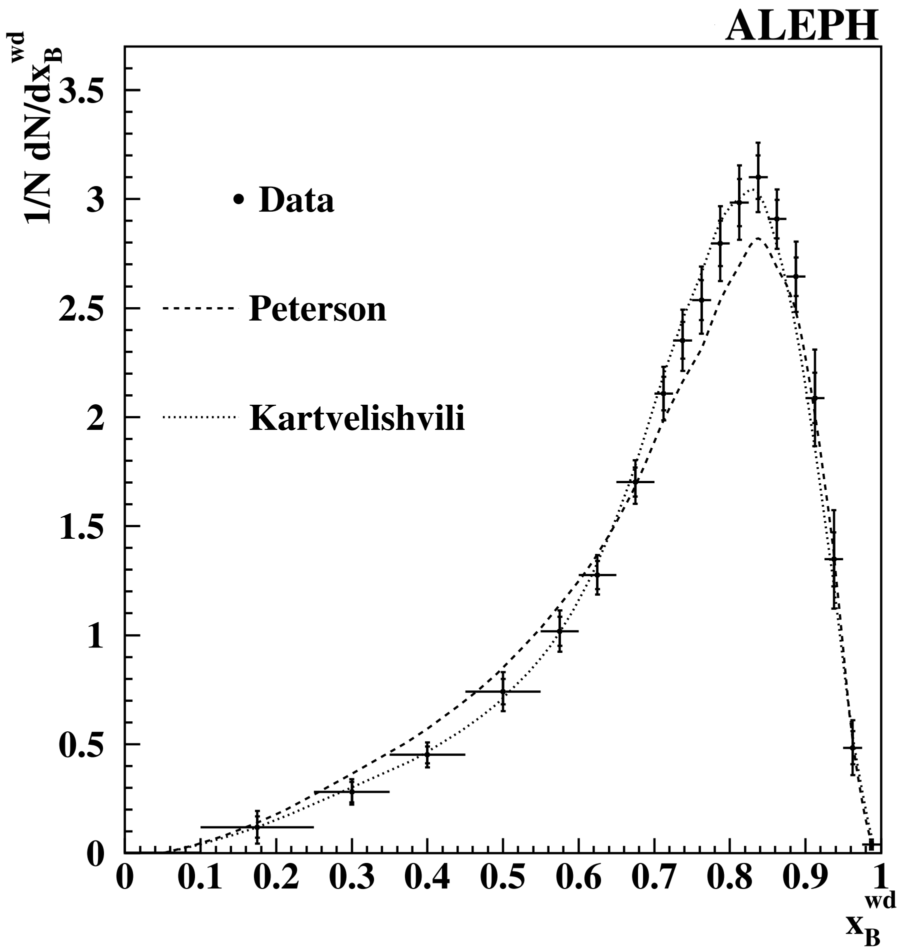
Beauty Production, Elsewhere

- A quick glance at recent developments in other production environments:
  - e^+e^-
  - $\gamma\gamma$
  - $\bar{p}p$

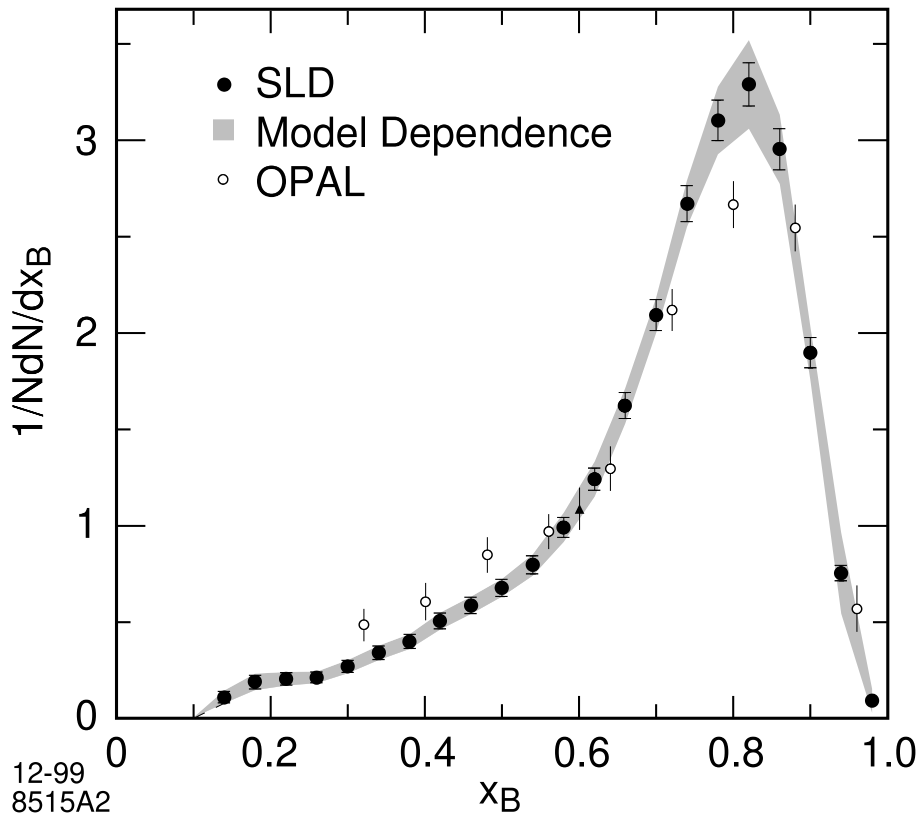
New Measurements of b Fragmentation

- $e^+e^- \to Z \to b\bar{b}$

$$x_B = \frac{E_{\text{weakly decaying hadron}}}{E_{\text{beam}}}$$

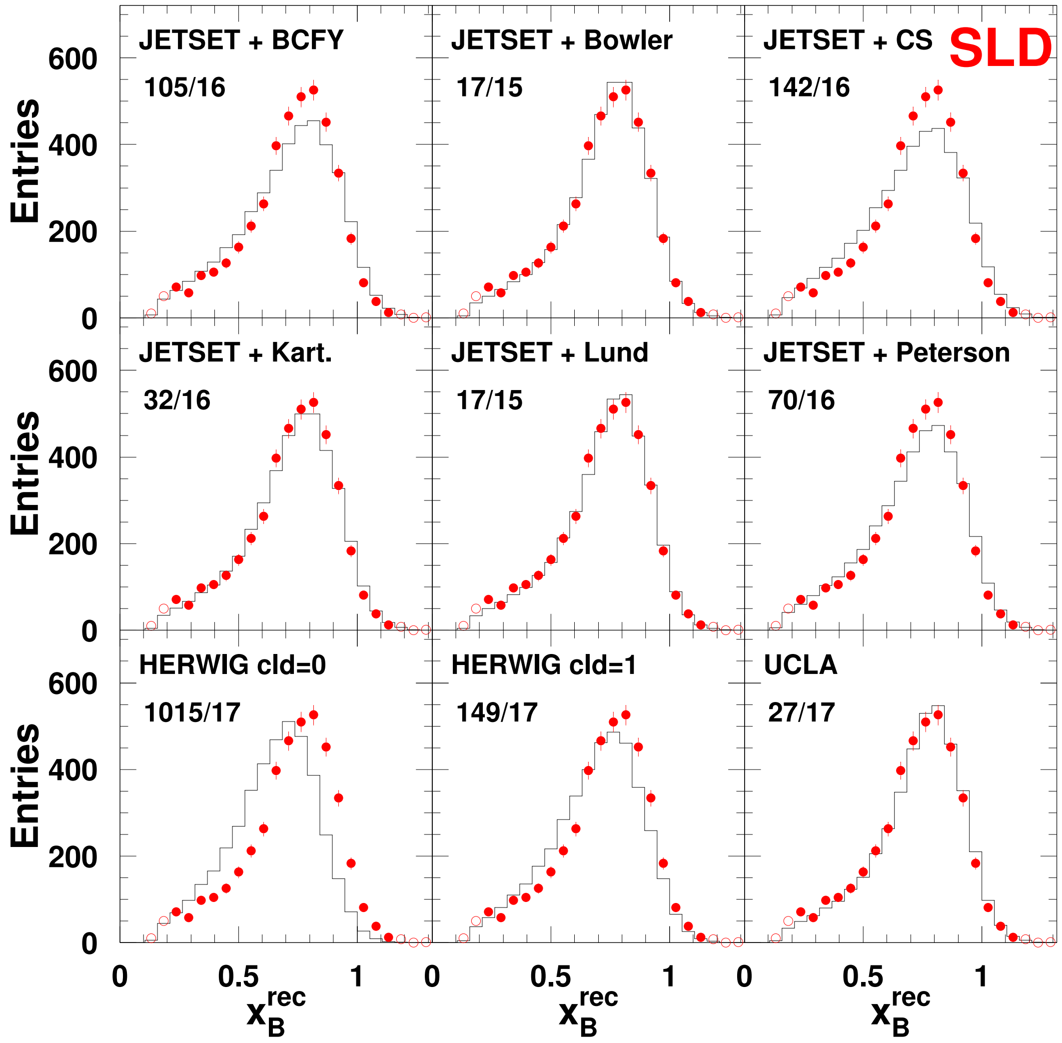


$D^{(*)}\ell$



inclusive vertexing

Peterson "Problems"



- Models include perturbative and non-perturbative effects
- Discrepancies seen for *combination* of LL MC $\otimes$ Peterson
- NLL QCD did better job

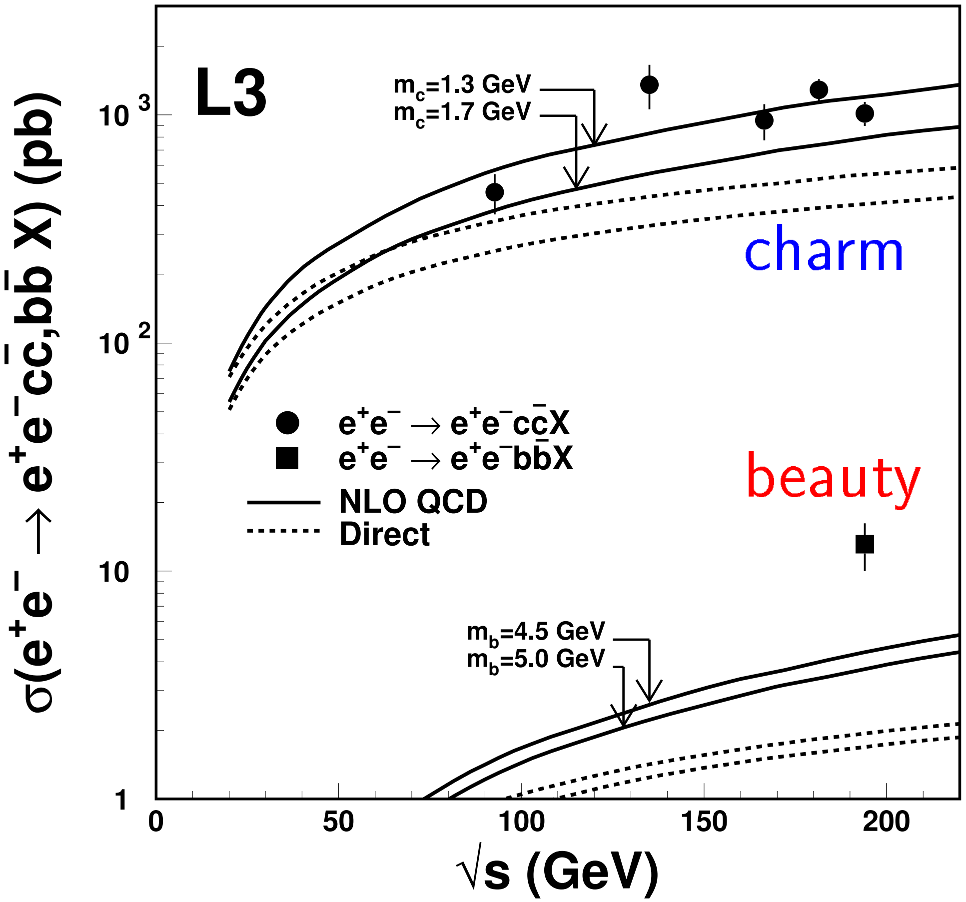
b Fragmentation Function

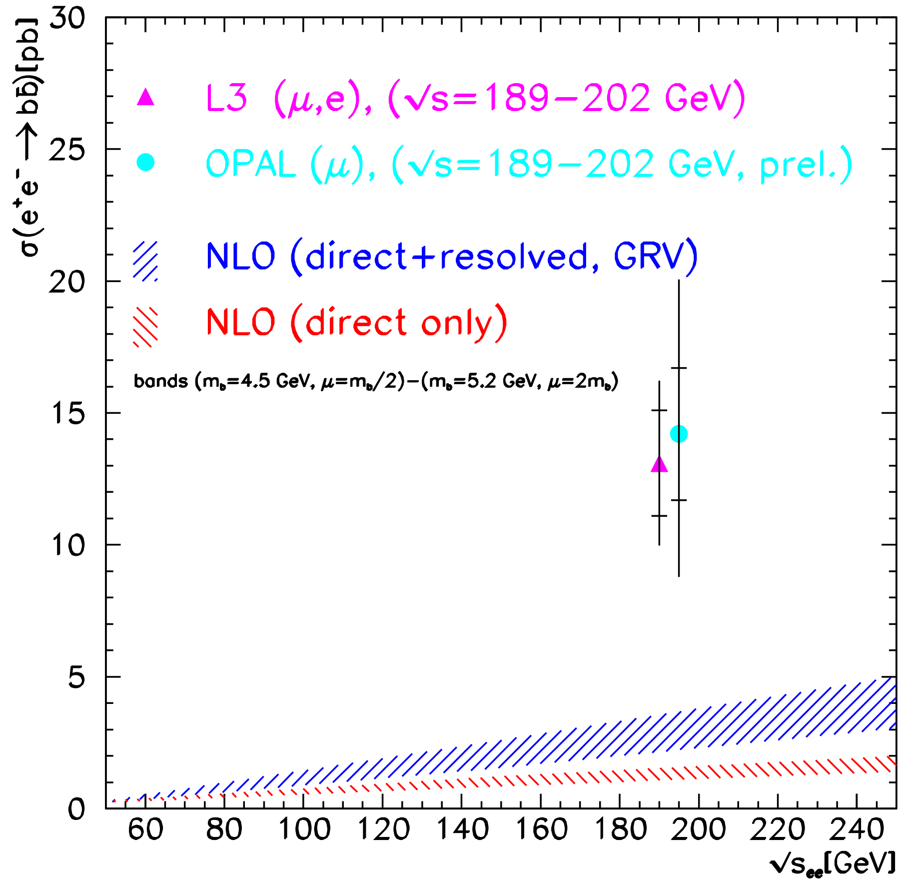
- 1. hard, and 2. well measured: little room to affect QCD predictions
- Precsion of new data challenging the different resummed NLL schemes

- N.B.: How to determine ϵ_b for Fixed Order NLO calculations?
  - ▷ Worked reasonably well for ARGUS D^*
  - ▷ But bad fits already to older LEP data (Nason, Oleari, NPB 365, 266 (2000))

Beauty in Two-Photon Collisions

- At LEP 2: direct $\gamma\gamma \to b\bar{b}$ and resolved photon interactions (γ gluon fusion)





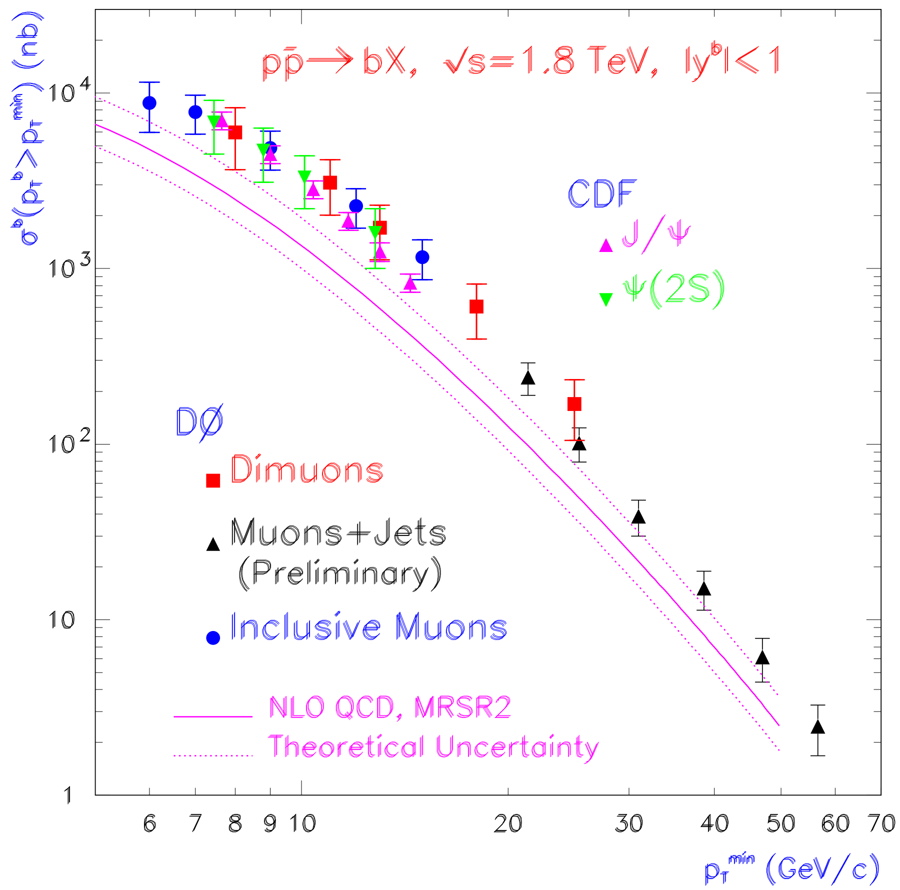
- p_T^{rel} method

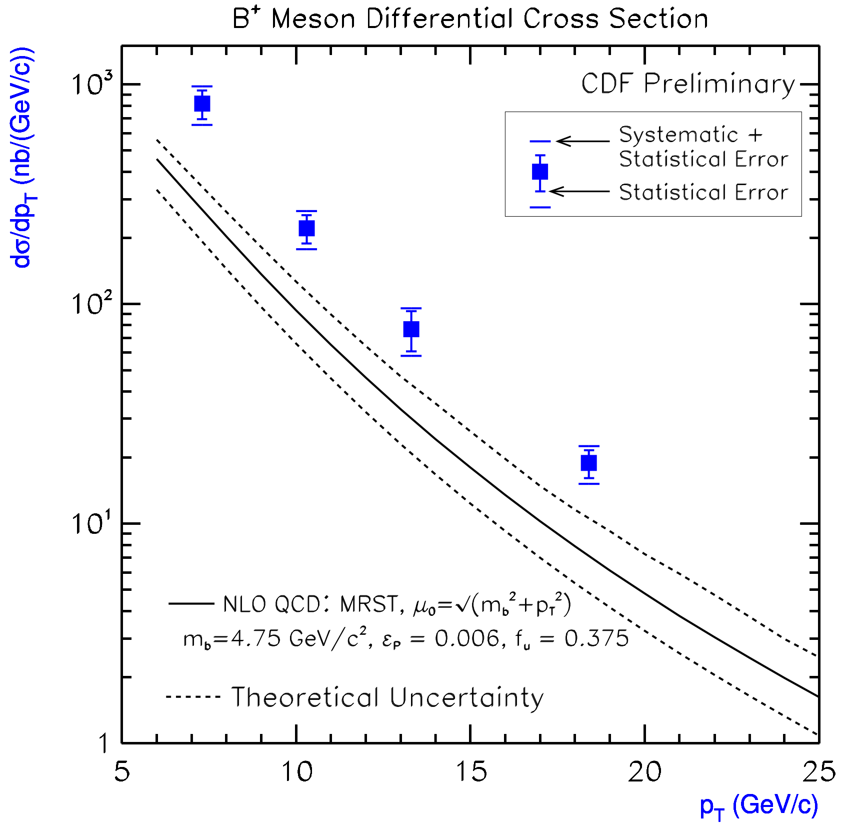
$\gamma\gamma \to b\bar{b}$

- Large excess over NLO QCD (Fixed Order) ($\sim 2.5\sigma$)
- Only for beauty – but OK for charm
- Some similarities with HERA
  - ▷ very low p_T jets ($>$ 3 GeV)
  - ▷ resolved photon contributions

New Tevatron Results

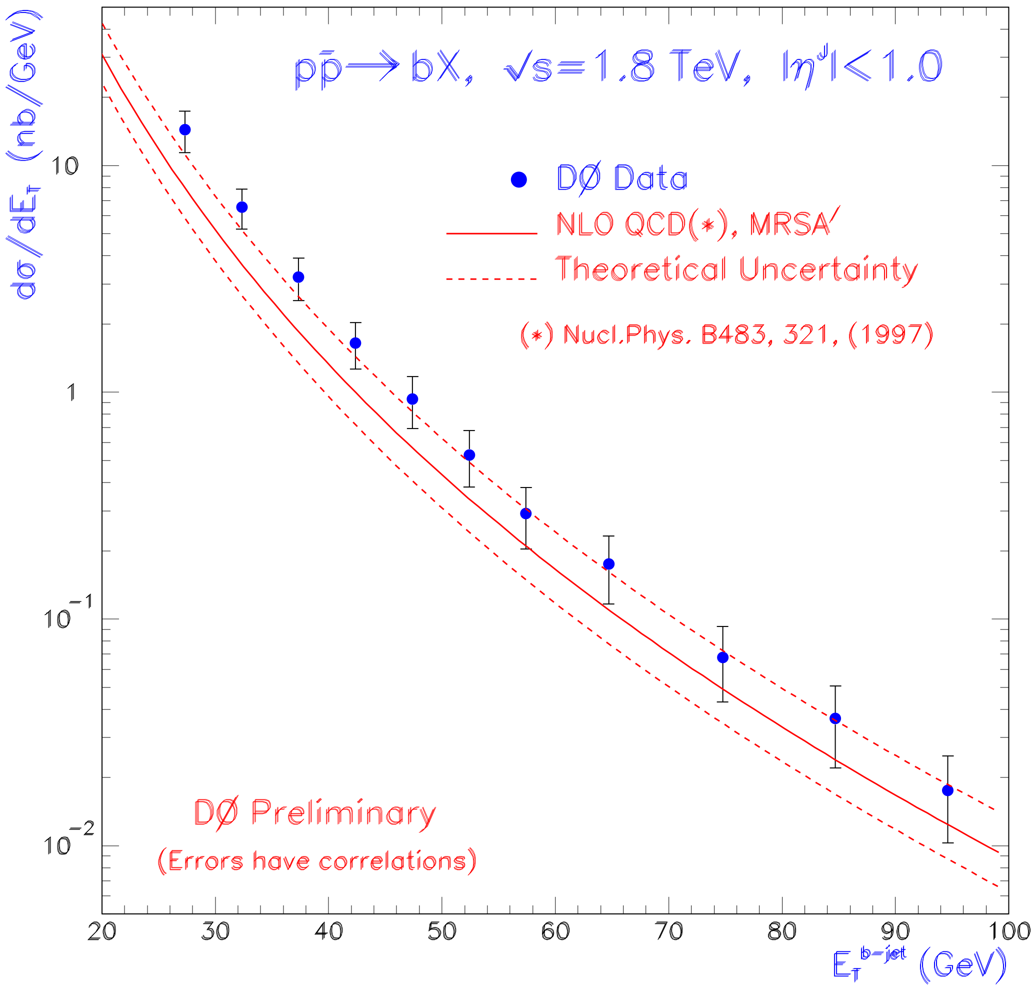
- Covering large p_T range; high precision





- CDF and D0 consistent
- *Not* a simple K factor

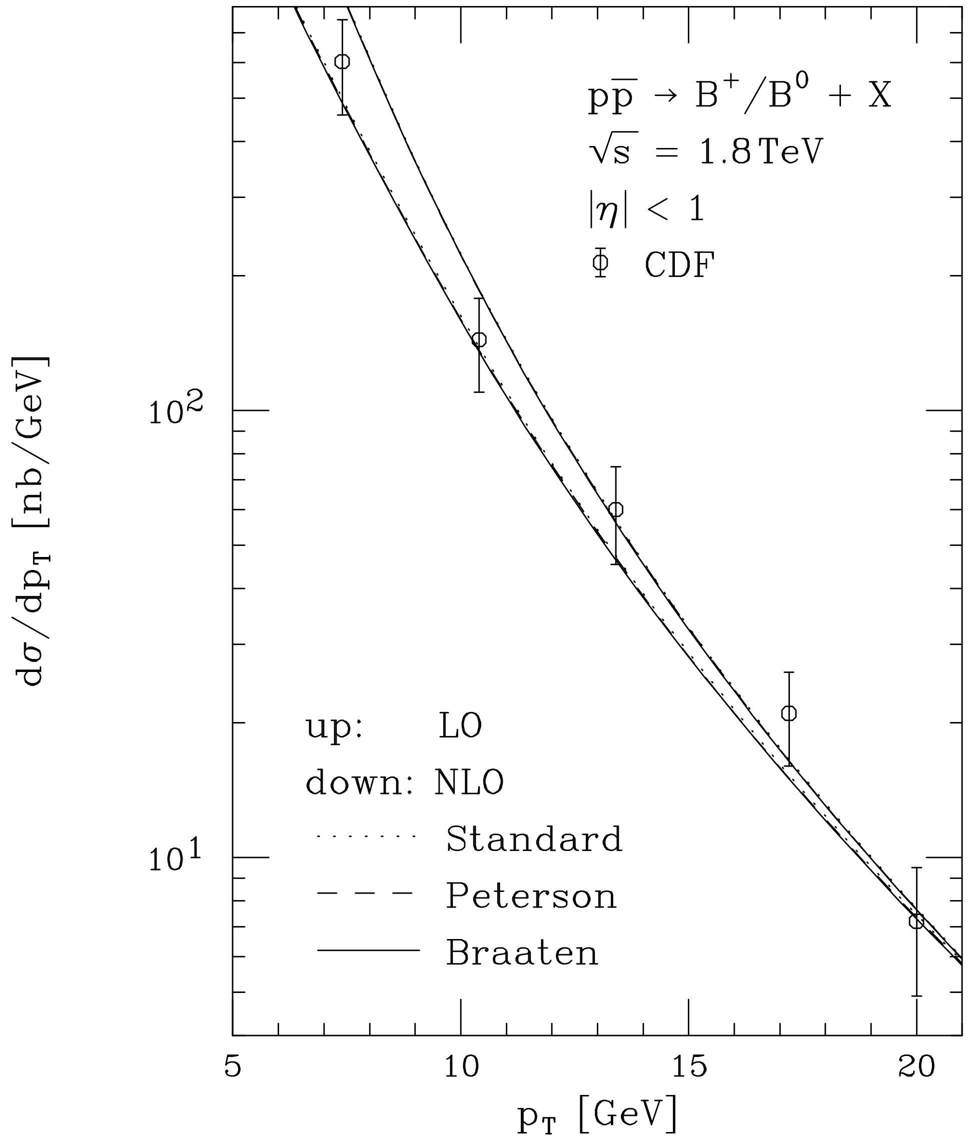
b Jet Cross Section



- Theory safer and less sensitive to non-perturbative effects
- Better agreement

Refined, Resummed Calculations

(Binnewies, Kniehl, Kramer)



- Resum NLL $\log p_T/m$ using perturbative fragmentation functions

  Cacciari, Greco:

  (also NLL, diff. scheme)

  enhance medium p_T

- Other appoach: k_T factorization

  ▷ Ball & Ellis

  ▷ Hägler *et al.*

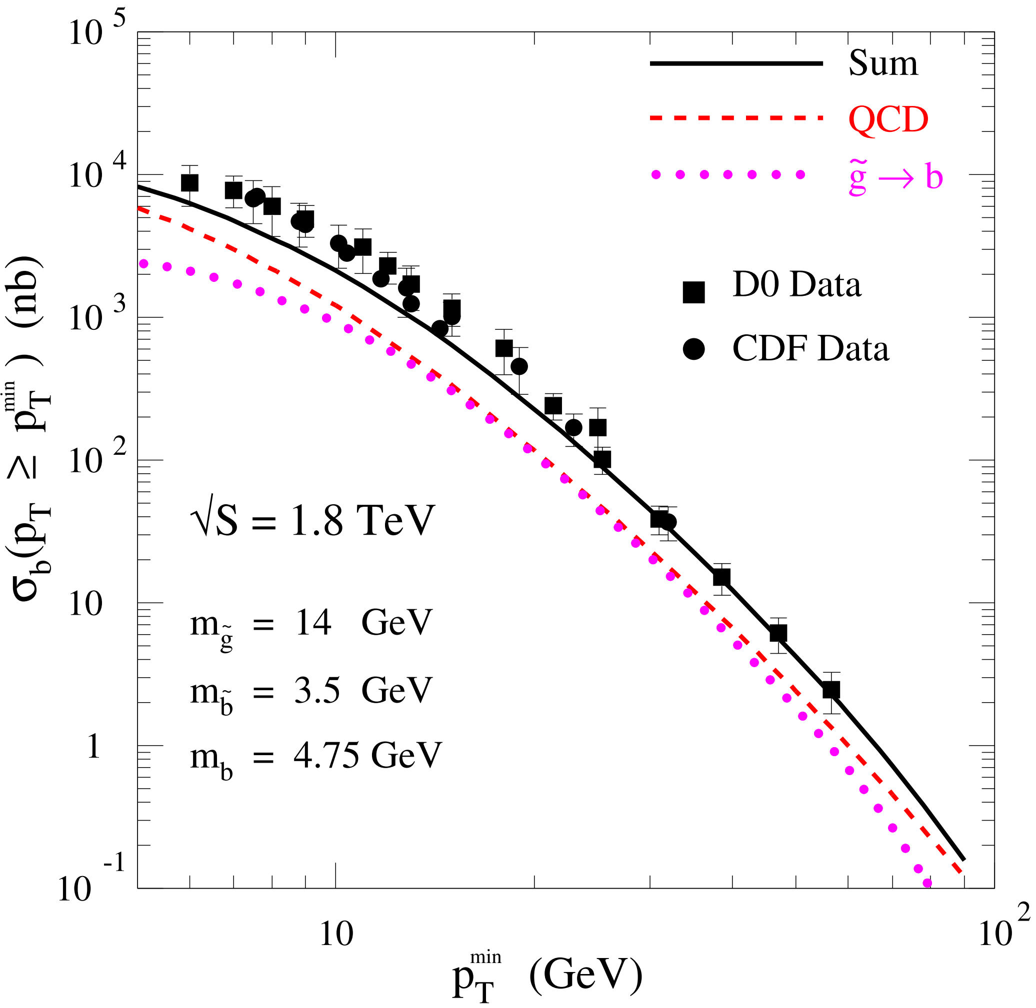
  ▷ CCFM

  $\rightarrow$ H. Jung's talk

Do We Miss Something?

"Three times is ememy action."

- SUSY contribution (Berger *et al.*)



- Not ruled out by
  - ▷ $\tilde{g}$, $\tilde{b}$ searches
  - ▷ El.weak precision tests
  - ▷ $\Upsilon(4S)$ data
- But could help also elsewhere ($R_{e^+e^-}$, ...)
- The Standard Model has an open window here.

$\bar{p}p \to b\bar{b}$

- Exotic contributions or “just” improving QCD:

- Cross checks from HERA are most vital.

HERA's Beautyful Cornucopia

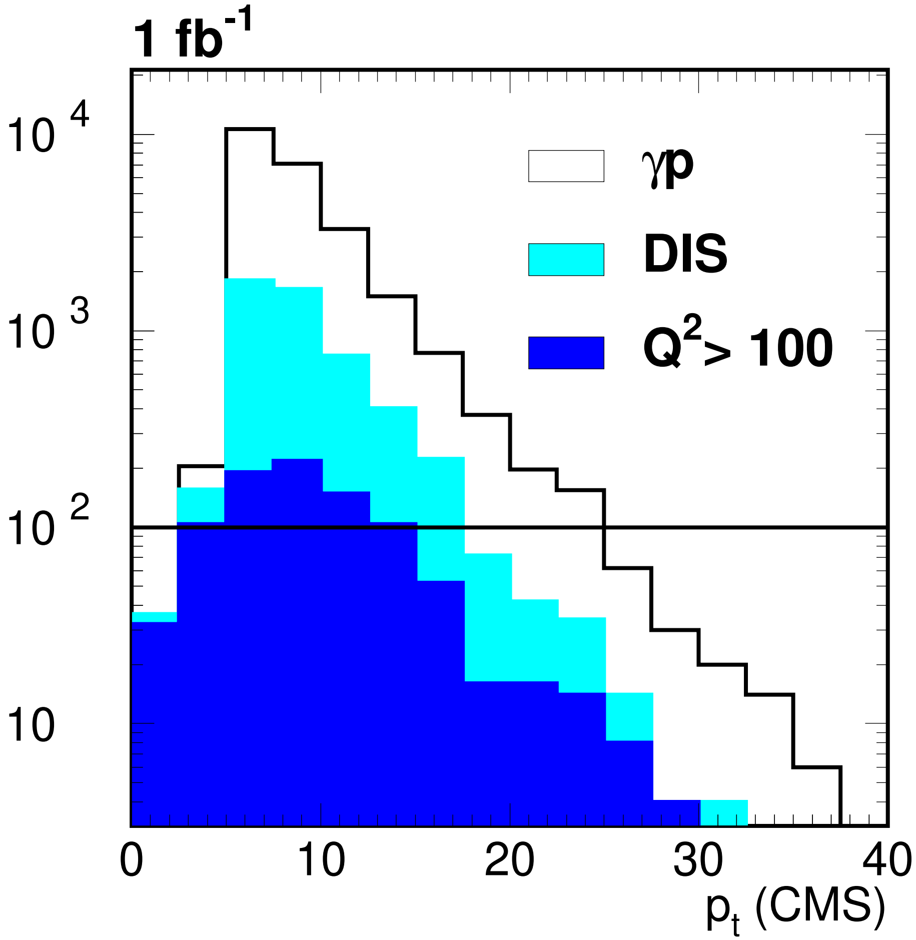
The HERA II upgrade:

- Luminosity
- Forward Tracking
- Precision Tracking
- Low p_T Triggering

Luminosity

- Can we vary the p_T^2 and Q^2 scales independently, beyond $4m_b^2$?

- Scale H1's present central μ measurement $\rightarrow$



- Yes, but high p_T and high Q^2 together may be hard.

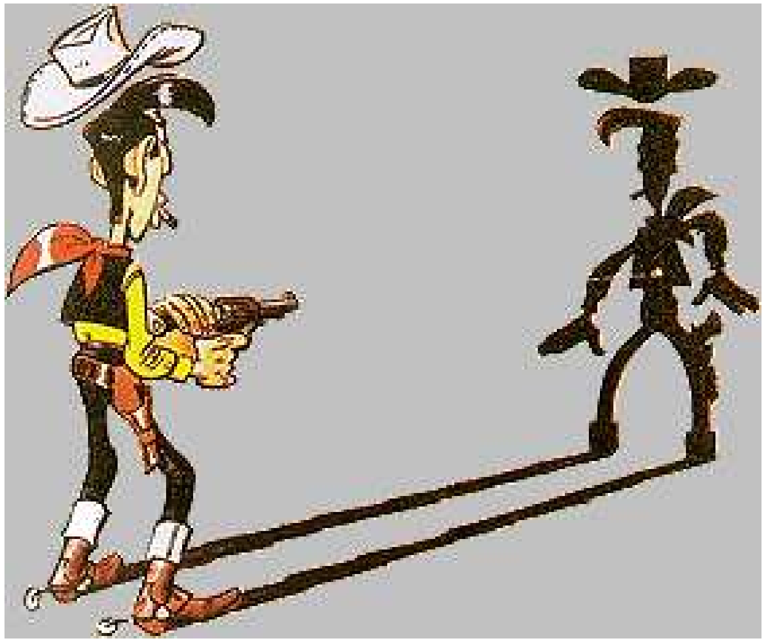
Precision Tracking

- For inclusive secondary vertex taggig (à la LEP, CDF) at high p_T
  - ▷ Impact parameter resolutions are very similar
  - ▷ Upgrade bonus: beam spot $150 \times 30\,\mu$m $\rightarrow$ $80 \times 20\,\mu$m
    $(\mathrm{LEP}\colon 110 \times 10\,\mu\mathrm{m})$
  - ▷ Efficiencies (LEP example):
    25%, 1%, and 0.1% for b, c and uds quarks
  - ▷ Efficiencies (HERA): ?, ? and ?
- Correlations may be easier to access with beauty than with charm.

Low p_T Triggering

- With (semi-) exclusive channels, e.g. $D^{(*)}\ell$, $J/\Psi X$: better handle on σ_{TOT}

- H1: Track fits after $20\,\mu$s, invariant masses after $100\,\mu$s $\longrightarrow$ D^* and J/Ψ before readout
- ZEUS: Si vertex trigger



Forward Tracking

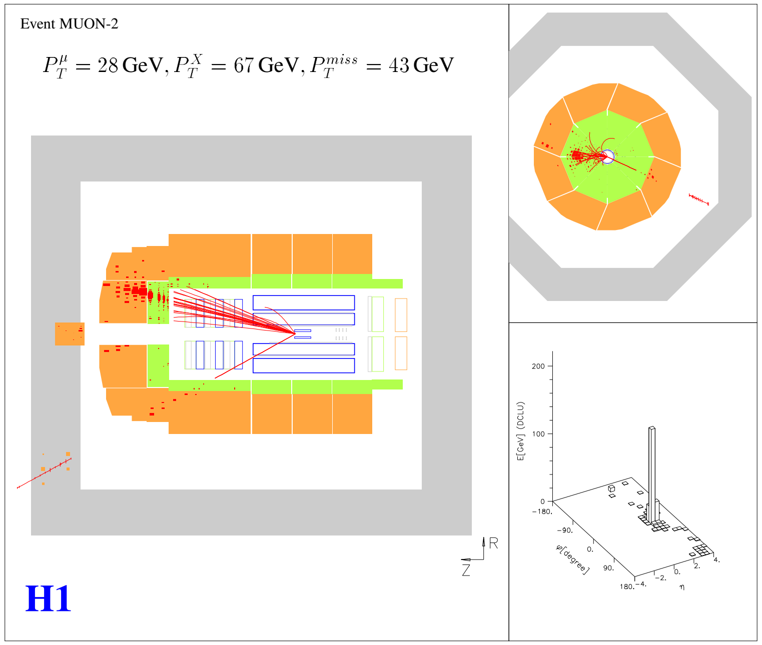
- Both H1 and ZEUS upgrade their forward track chambers and
- Install forward Si tracking

- larger x_g $(\rightarrow\sim 0.1)$

  lower x_γ

- and searches $\rightarrow$

$e^+p \rightarrow \mu^+X$



a top candidate?

Conclusion

Discovering HERA's Beauty:

- experimentally challenging
- theoretically rewarding
- potentially exciting