# Beauty and Charm Production at Hera Accelerator

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on behalf of
**Zeus** and **H1**
collaborations

Summary :

- Introduction to HERA
- Motivation and Aims
- Charm fragmentation
- Beauty Production
- PDF's
- Conclusions

# Hera accelerator


Hera is a 6 km long accelerator located in Hamburg. It collides $p^+$ at 920 GeV with $e^\pm$ at 27.5 GeV.

Experiments on the ring:

- Zeus and H1 with $\sqrt{s} = 319\, GeV$

Delivered luminosity:

- 190 $pb^{-1}$ 92-00.
- 380 $pb^{-1}$ since 2002. More to come !

# Motivation and Aims. Heavy Flavor Production.

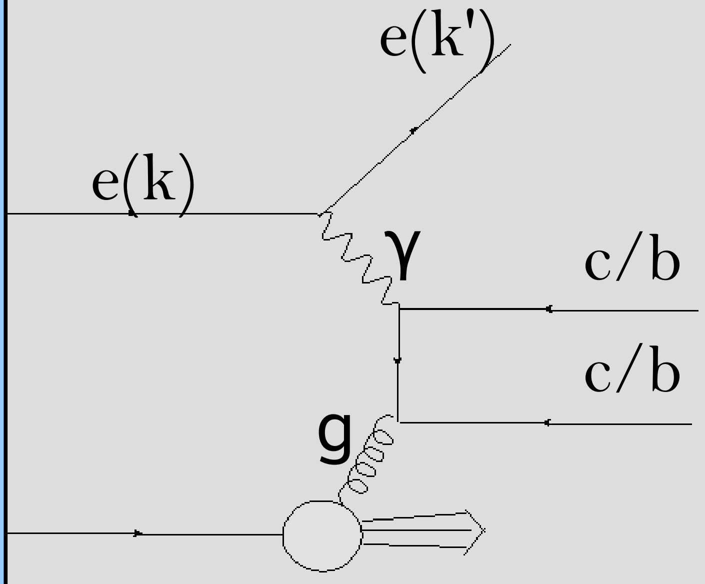
- c and b production used as good test for pQCD, due to the large mass scale
- Uderstanding heavy quark production will be useful at LHC where c and b will make up large parts of the background
- Computing the contribution from charm and beauty to proton structure functions

**Heavy flavor production dominated by boson-gluon fusion.**
**Variables used to reconstruct the event:**

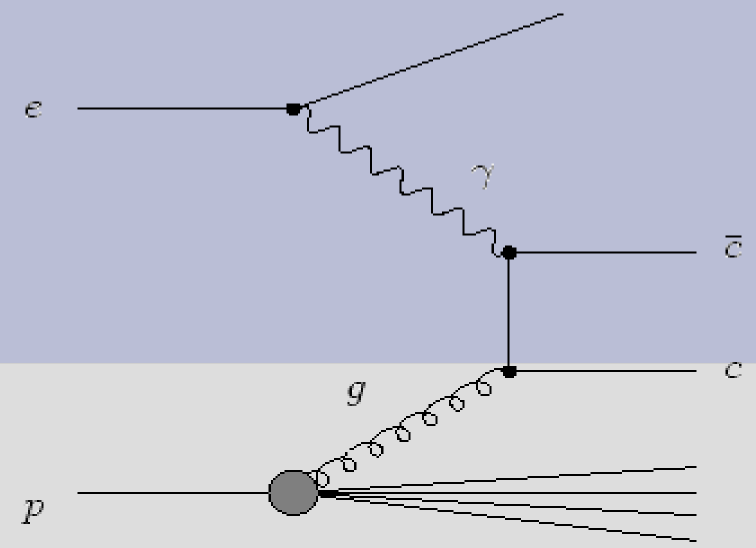
- **x** : Bjorken scaling variable
- **y** : energy fraction transferred from e to p
- $\mathbf{Q^2 = -q^2 = -(k-k')^2}$ , photon virtuality

Two kinematic regimes:

- Photoproduction , $Q^2 < 1$ GeV$^2$
- DIS , $Q^2 > 1$ GeV$^2$



# Charm Fragmentation




Reconstruct $D^0$, $D^{\pm}$, $D^{*\pm}$ and $D_s^{\pm}$ charm mesons and charm baryon $\Lambda_c$ in photo-production. Use their cross-sections to measure:

- Fragmentation fractions. Are they universal?
- Strange suppression. How often do s quarks appear in charm mesons?
- Ratio u/d. Are u and d quarks equally selected to form D mesons?

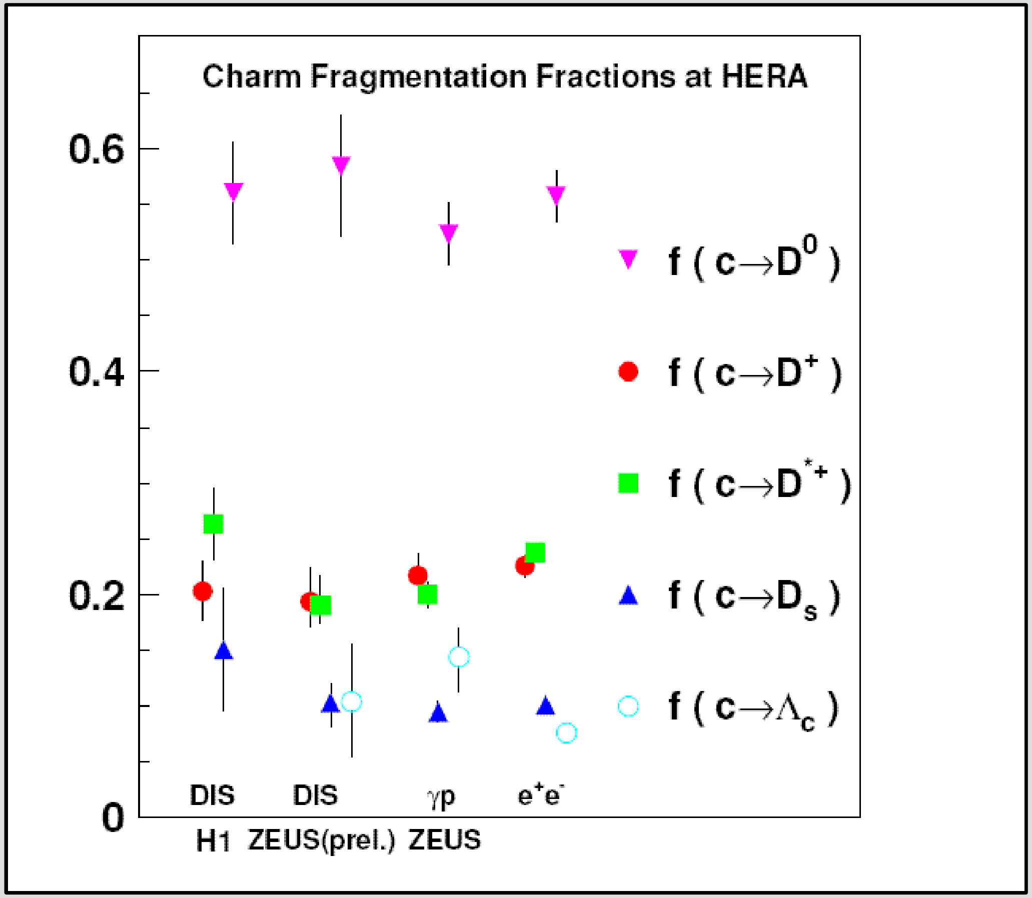
# Charm Fragmentation Fractions.

The fraction of c quarks hadronising into a particular charm hadron is given by:

$$f(c \rightarrow D, \Lambda_c) = \frac{\sigma_{D,\Lambda_c}}{Total \quad \sigma_{GS}}$$

where $Total\, \sigma_{GS}$ is a sum of all production $\sigma$'s for all c ground states that decay weakly. This is dominated by $D^0$, $D^{\pm}$, $D_S^{\pm}$ and $\Lambda_C$.

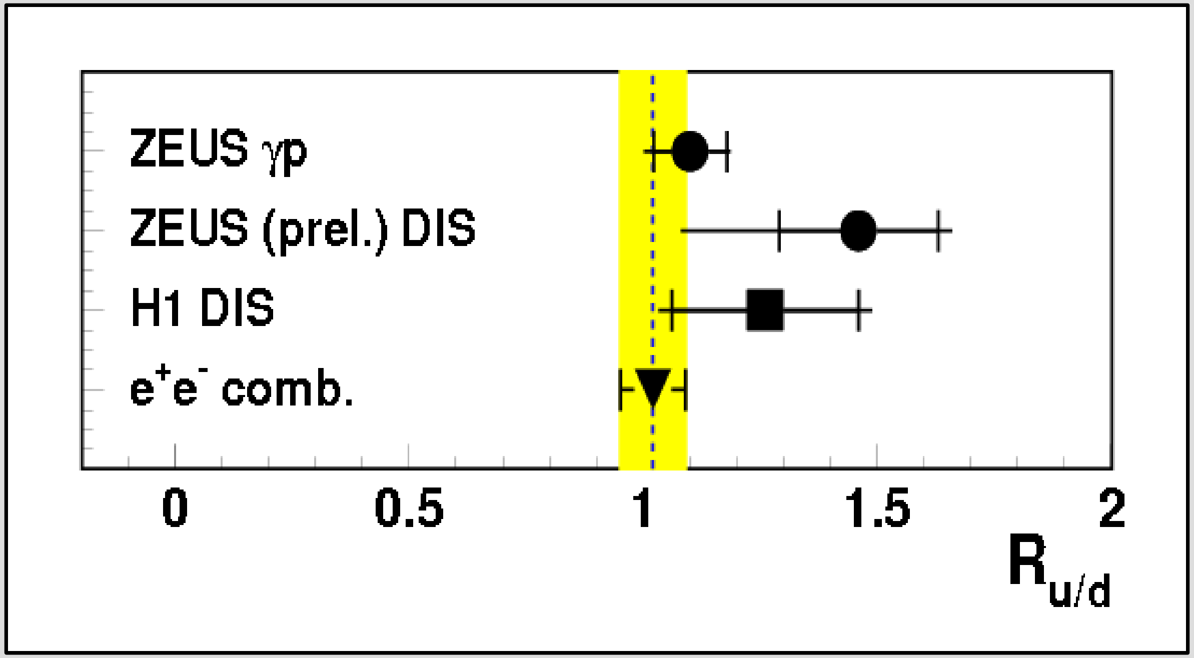
Strange Baryons $\Xi^+_C$, $\Xi^0_C$ and $\Omega^0_C$ included by estimating their contribution to $\Lambda_C$ as 14%.



# Charm Fragmentation.
# u/d Quark Production Ratio.

The ratio of direct neutral to charged D meson production is defined as:

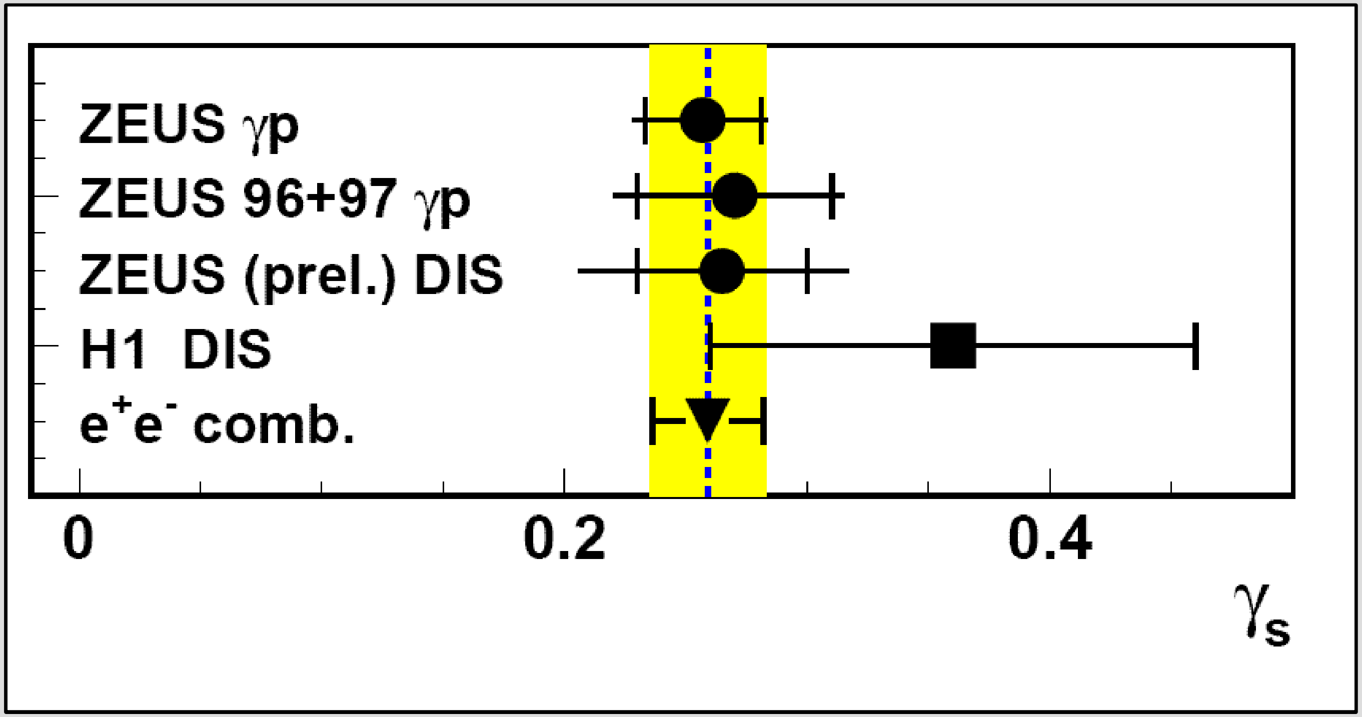
$$R_{u/d} = \frac{\sigma^{dir}(D^0) + \sigma(D^{*0})}{\sigma^{dir}(D^{\pm}) + \sigma(D^{*\pm})}$$




u and d quarks are made in equal amounts. Strong isospin invariance holds.

# Charm Fragmentation. Strangeness Suppression.

Strangeness suppression factor determines the ratio of probabilities to create an s to u/d quarks in the fragmentation process.

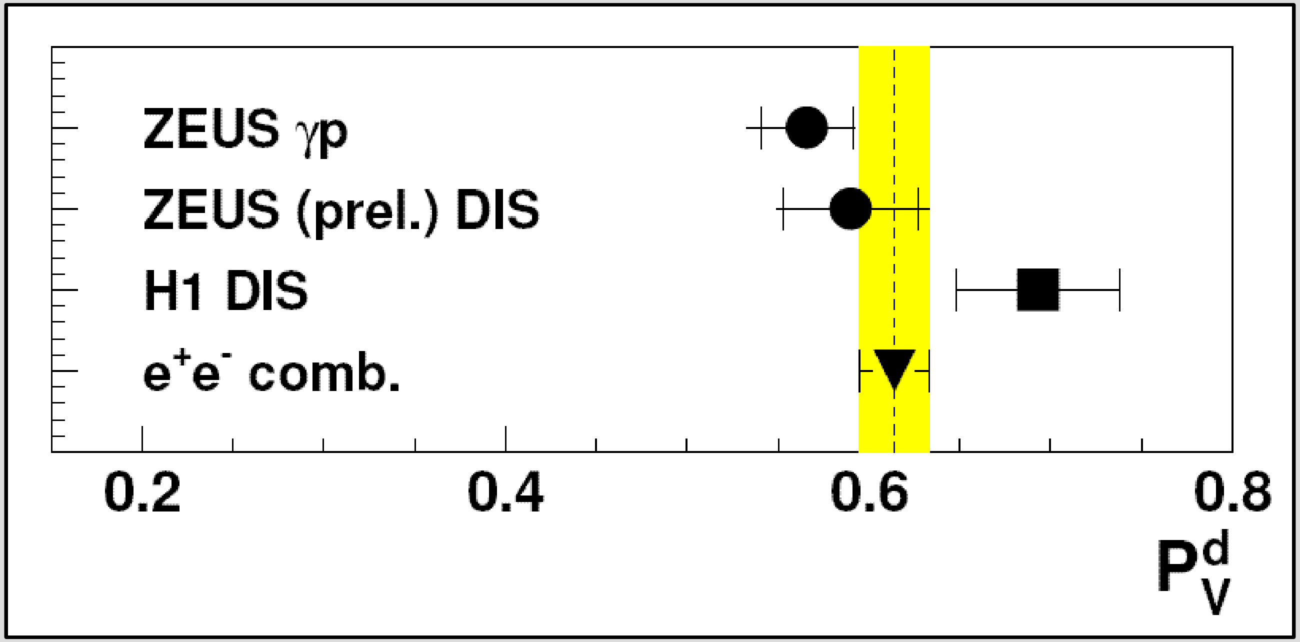



$$\gamma_s = \frac{2\sigma(D_s^{\pm})}{\sigma(D^{\pm}) + \sigma(D^0)} = 0.257 \pm 0.024(stat)$$

# Charm Fragmentation.
# Fraction of Vector Meson Production.

This measures the fraction of charm mesons produced in a vector state, $P^d_V$ .

By naive spin counting, we expect the ratio to be 75%. This can be checked by measurements of $D^{*\pm}$ and $D^{\pm}$ :



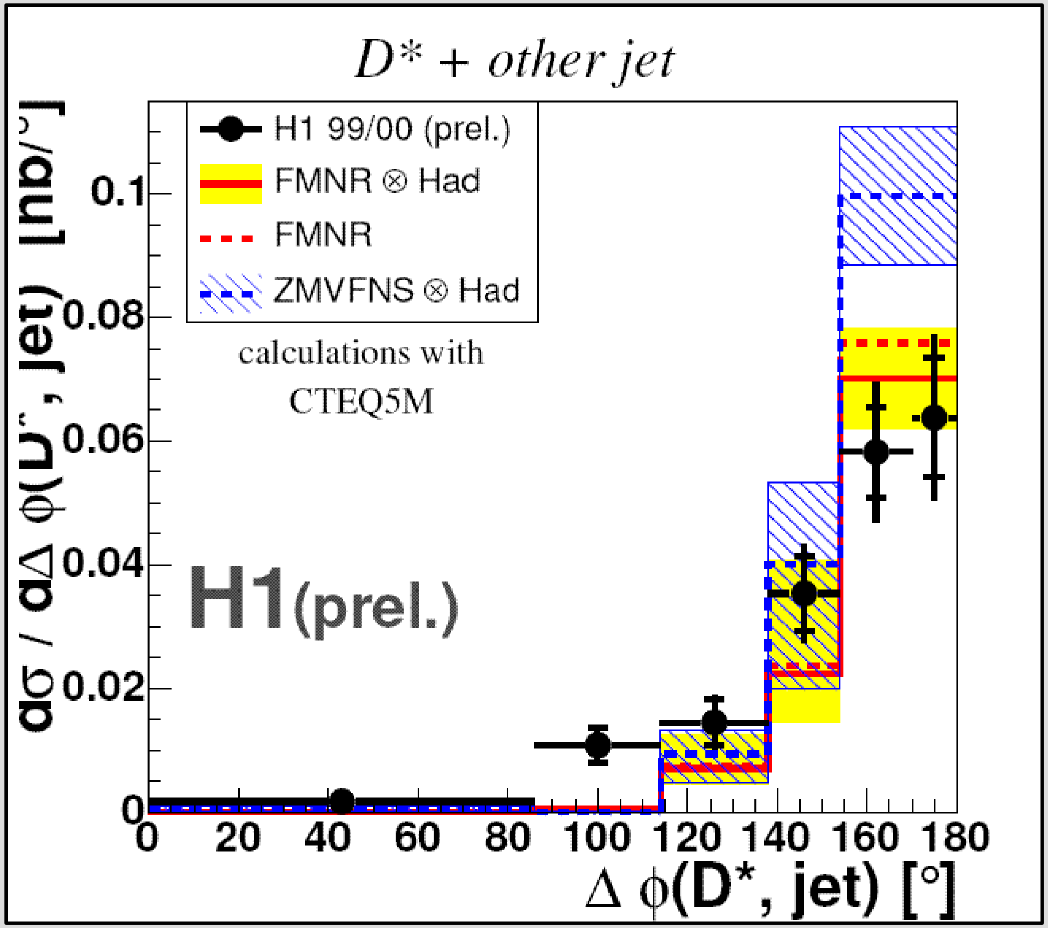

$$P^d_V = \frac{\sigma(D^{*\pm})}{\sigma(D^{*\pm}) + \sigma^{dir}(D^{\pm})} = 0.566 \pm 0.025(stat)$$

. Simple spin counting fails with charm !!!

# Testing pQCD.
# D* + Jet in PhP.

H1 measured the differential cross-section $e^- + p \rightarrow D^* + \text{Jet}$ in photoproduction.
To leading order prediction, jets should be back to back.

We see here contributions from higher order QCD radiation. The measurement is compared to both massive and massless schemes of pQCD calculations.

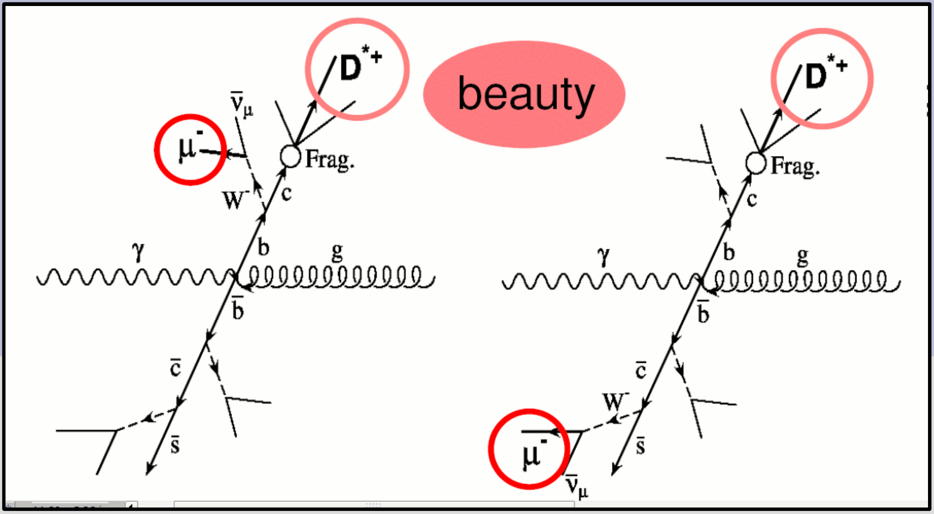



At $\Delta\phi < 120°$, NLO prediction is smaller than measured cross-section

# Beauty Production

Part II

# b tagging with D* + μ
# Total cross-section
# 96-00 data ~ 114 $pb^{-1}$




Kinematic region:

$p_T(D^*) > 1.5$ GeV  $-1.5 < \eta(D^*) < 1.5$

$p(\mu) > 2$ GeV  $-1.73 < \eta(\mu) < 1.73$

**Photoproduction only: $Q^2<1$ GeV$^2$, $0.05<y<0.85$**

H1 $\sigma_{vis}$ = 206 +- 53(stat) +- 35 (syst.) pb (published)

**ZEUS $\sigma_{vis}$ = 189 +- 48(stat) $^{+80}_{-73}$ (syst.) pb new**

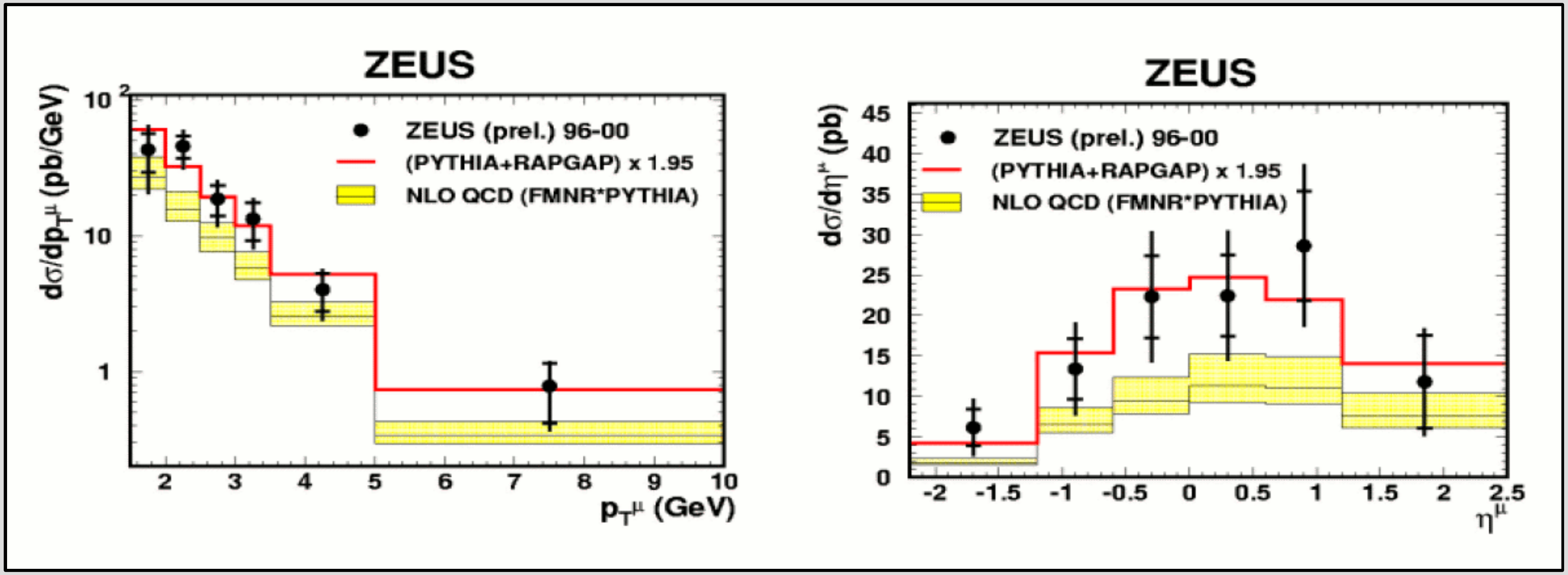
Measured Zeus and H1 cross-sections are consistent.

# b tagging with μμ
# 96-00 data ~ 114 $pb^{-1}$

Kinematic region:

$1^{st}$ μ : $p_T > 1.5$ GeV $-2.2 < \eta < 2.5$

$2^{nd}$ μ : $p_T > 0.75$ GeV $-2.2 < \eta < 2.5$




Above, differential cross-sections w.r.t. $p_T$ and η for bb → μμ.

Reasonable agreement in shape between MC, data and NLO.

# Extraction of $F_2^{QQ}$

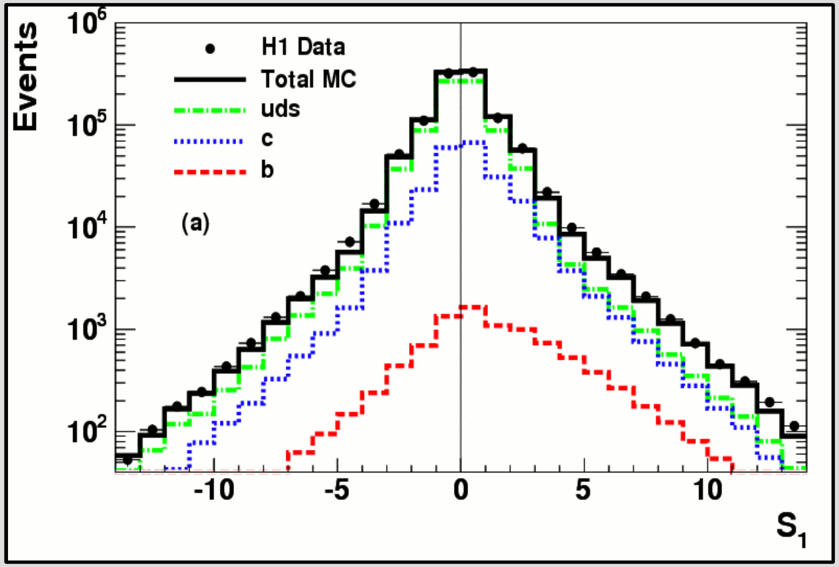
$F_2^{QQ}$ is measured from c/b double differential cross-sections:

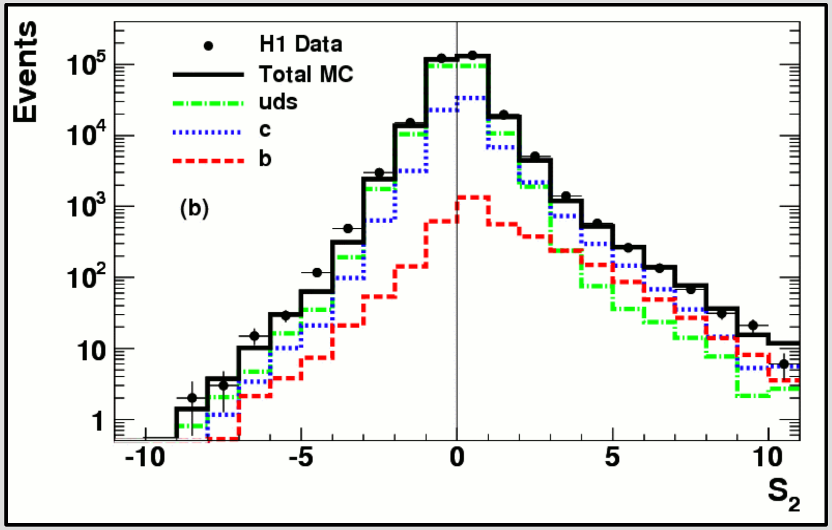
$$\frac{d^2\sigma^{q\bar{q}}(x,Q^2)}{dx\,dQ^2}=\frac{2\pi\alpha^2}{x\,Q^4}\left(\left[1+(1-y)^2\right]F_2^{Q\bar{Q}}(x,Q^2)-y^2F_L^{Q\bar{Q}}(x,Q^2)\right)$$

- Previous measurements used D* cross-sections to determine $F_2^{cc}$.
- New H1 $F_2^{cc}$ and $F_2^{bb}$ measurement uses inclusive lifetag .

# Inclusive b quarks in DIS. Lifetime Tag.

One can  use the impact parameter of any track w.r.t. the interaction point. These are the distributions of impact parameter significance  $S=\delta/\sigma(\delta)$
The upper plot shows the significance of  absolute most significant track. The positive tail shows the charm to light flavor ratio increase.  Below, the tail of second most significant track gives the beauty to light flavor ratio increase.



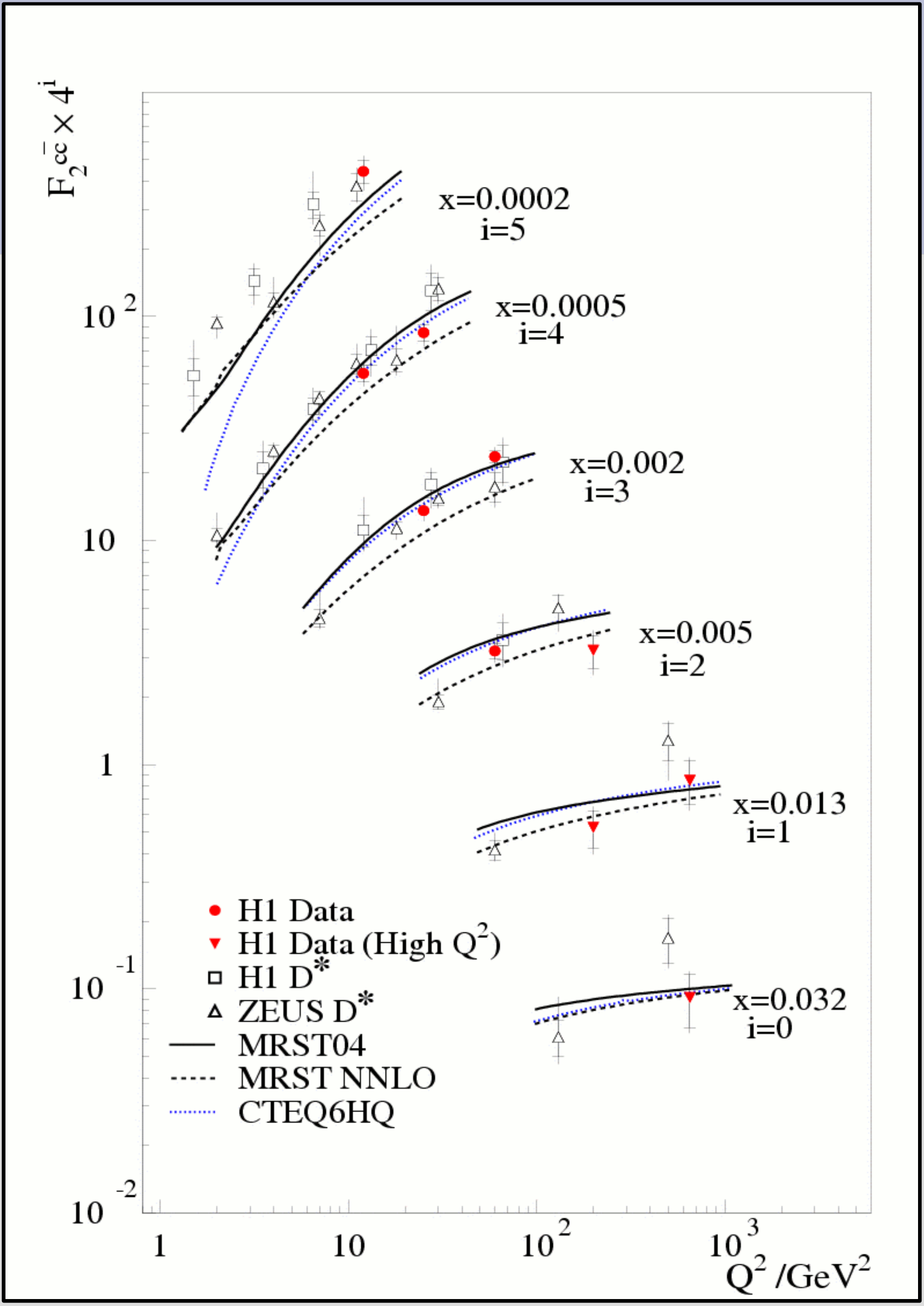




Fractions of c and b are determined from likelihood distributions to data.

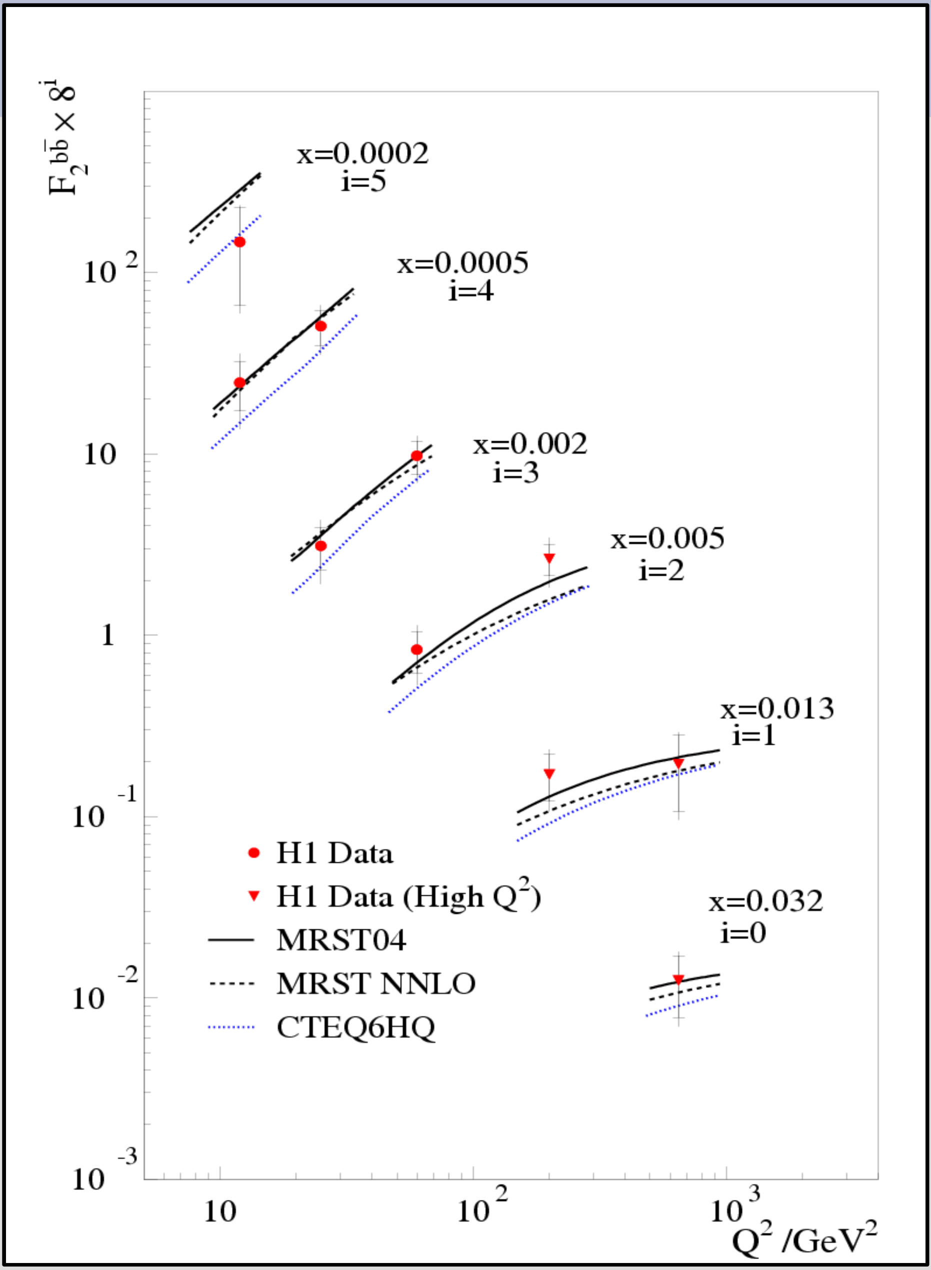
# Proton Structure Functions: $F_2^c$

H1 uses inclusive lifetime tag to measure pdfs.

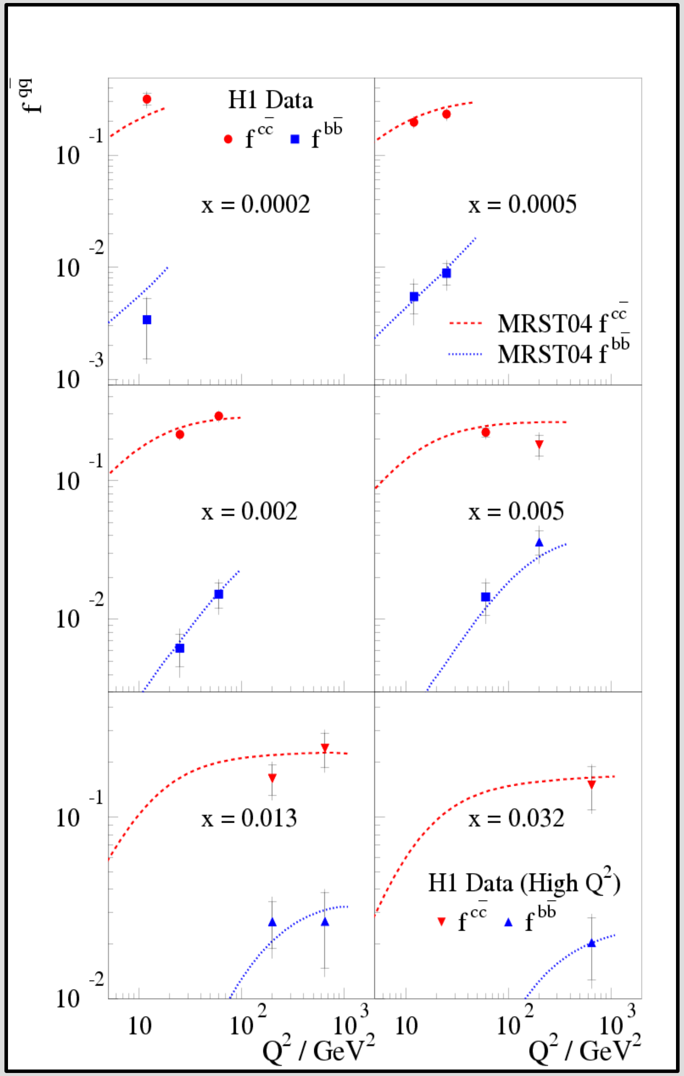
- QCD calculations fit reasonably well to data.
- NNLO calculation now available.
- Positive scaling violation increases with decreasing **x**: gluon dominates the initial state.



# Proton Structure Functions: $F_2^b$




# Beauty and Charm contributions to F2



# Dijet PhP + μ

$$e\,p \rightarrow e' + b\bar{b} + X \rightarrow e' + dijet + \mu + X$$

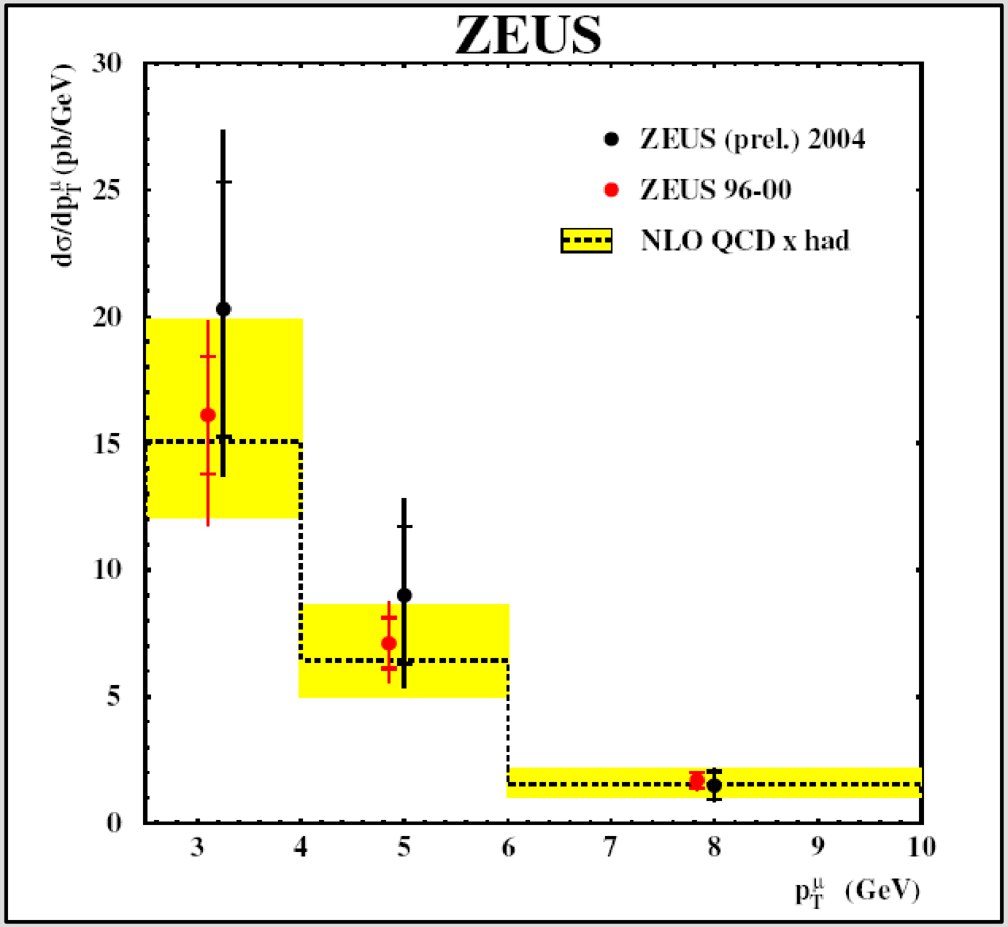
Kinematic region:
$Q2 < 1\text{GeV}2$ $\quad 0.2 < y < 0.8$
$p_\perp^{jet} > 7\text{GeV}$ $\quad |\eta^{jet}| < 2.5$
$p_\perp^{\mu} > 2.5\text{GeV}$ $\quad -1.6 < \eta^{\mu} < 2.3$

First Zeus beauty result from Hera II.

Agreement with NLO QCD prediction (FMNR)

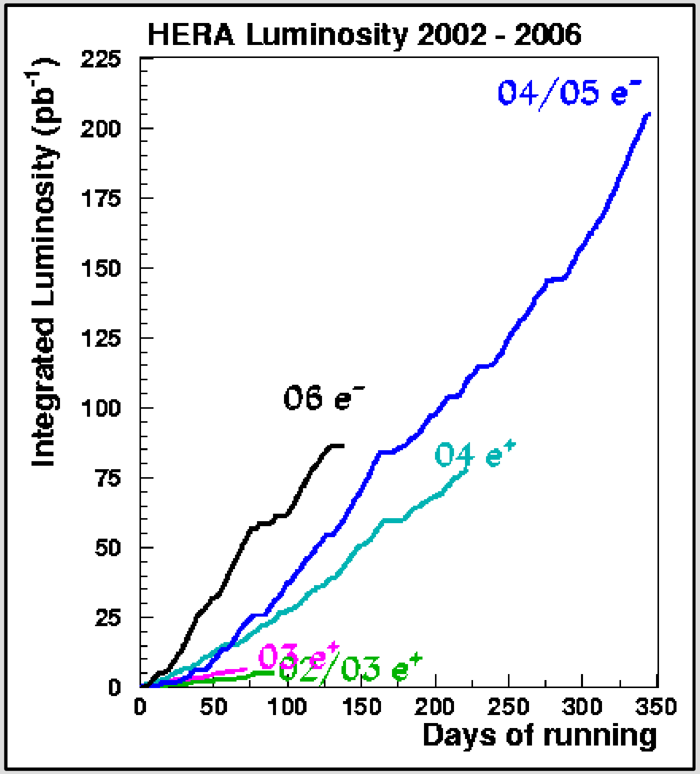
Agreement with Zeus data from Hera I ( 3x more statistics )

New results expected soon !!!



# Conclusions and Outlook

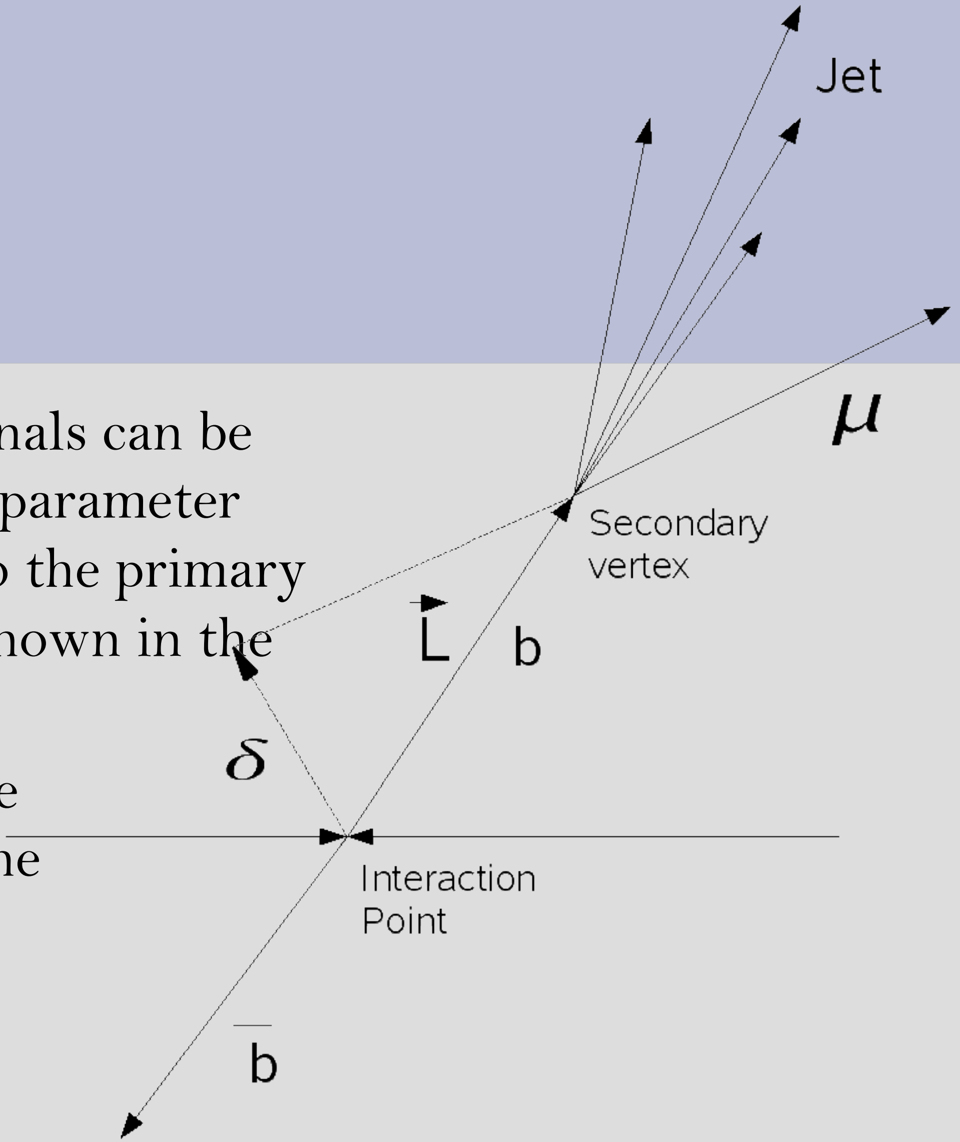

- Zeus and H1 results consistent with charm fragmentation universality. Charm fragmentation fractions are competitive with $e^+e^-$ results.
- Cross-sections well described by NLO pQCD. Nevertheless, higher order calculations are needed in some regions.
- Charm and beauty contributions to F2 have been measured.
- New techniques for tagging charm/beauty mesons have been/ are being applied.
- Most of the Hera II data still not analyzed yet.
- New results awaited as Hera II luminosity already surpassed Hera I.




- The vertex detectors of Zeus and H1 are very promising regarding new techniques for tagging charm and beauty mesons.

# Tagging b quarks.

When the resolution allows it, b signals can be enhanced by cutting on the "impact parameter significance" of the μ with respect to the primary vertex. The impact parameter δ is shown in the figure:




The impact parameter is signed. The decay length vector L points from the interaction point to the secondary vertex. Then, if

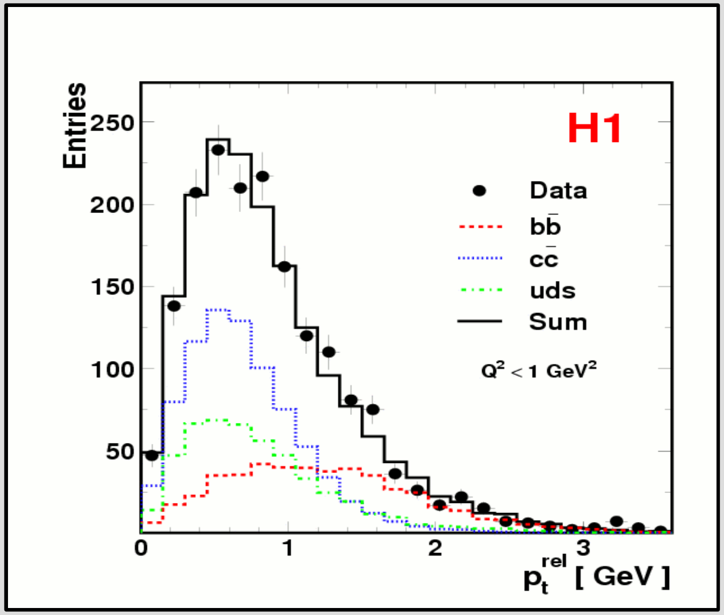
$$\vec{L}.\vec{P}(\mu)>0$$

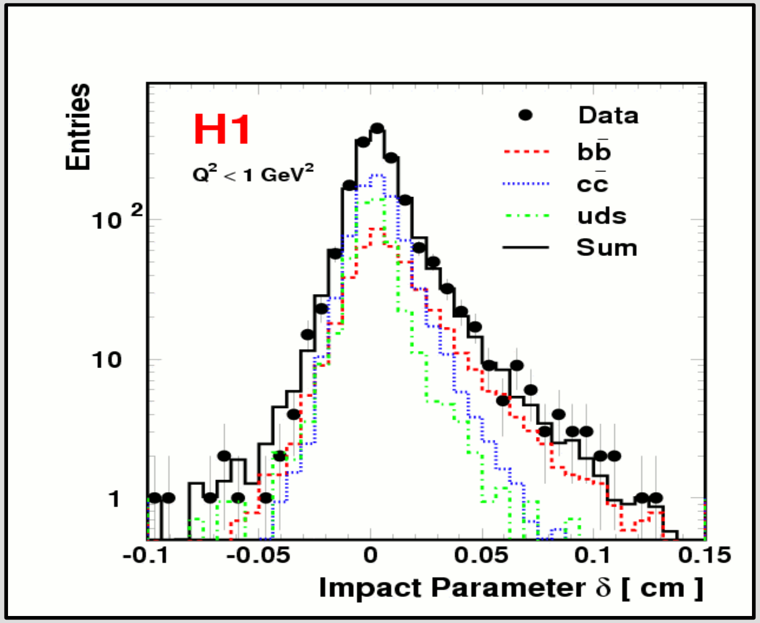
δ is positive, else negative. Due to large b mass, muons will have a high $p_T^{REL}$ .

Due to large B meson lifetime, the muons will tend to have a large impact parameter.

# b quarks from μ impact parameter and $P_T^{rel}$

H1 uses the vertex detector to tag muons in PhP.
We see that light flavors show a symmetric impact parameter distribution as long as charm and beauty have a positive excess.
At high $P_t^{rel}$, the contribution from beauty falls less rapidly than the light flavors.

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