



ETH Institute for
Particle Physics



Heavy Quark Production in ep Collisions

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- o Introduction
- o Charm Production
- o Beauty Production
- o Beauty and Charm Contribution to F_2
- o Conclusion

Heavy Flavor Production

Boson-Gluon Fusion, dominant process

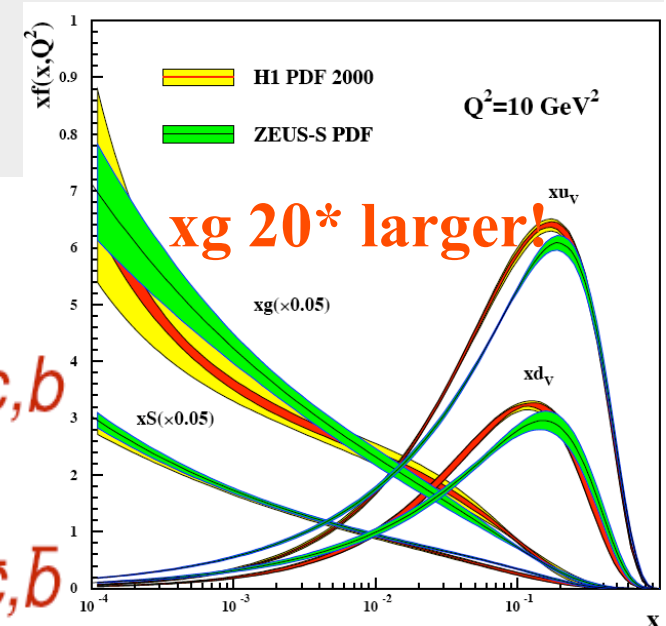
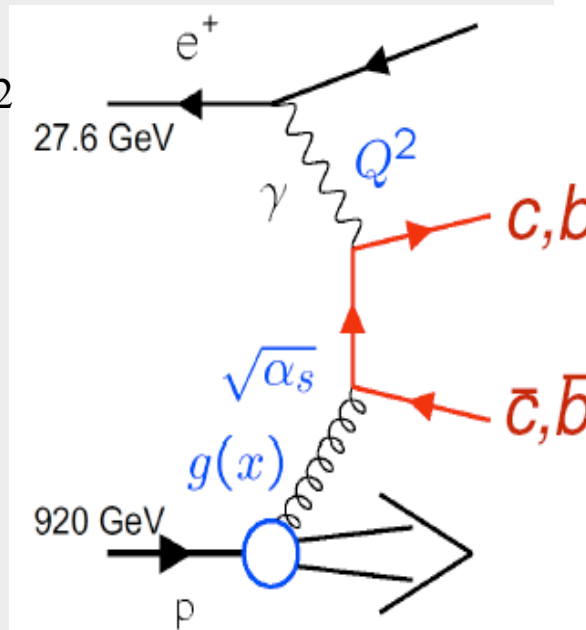
Hard scale: $m_b / m_c, Q^2, P_t^2$

pQCD applicable :

- ✓ Probe a large range of Q^2
- ✓ Study interplay of scales

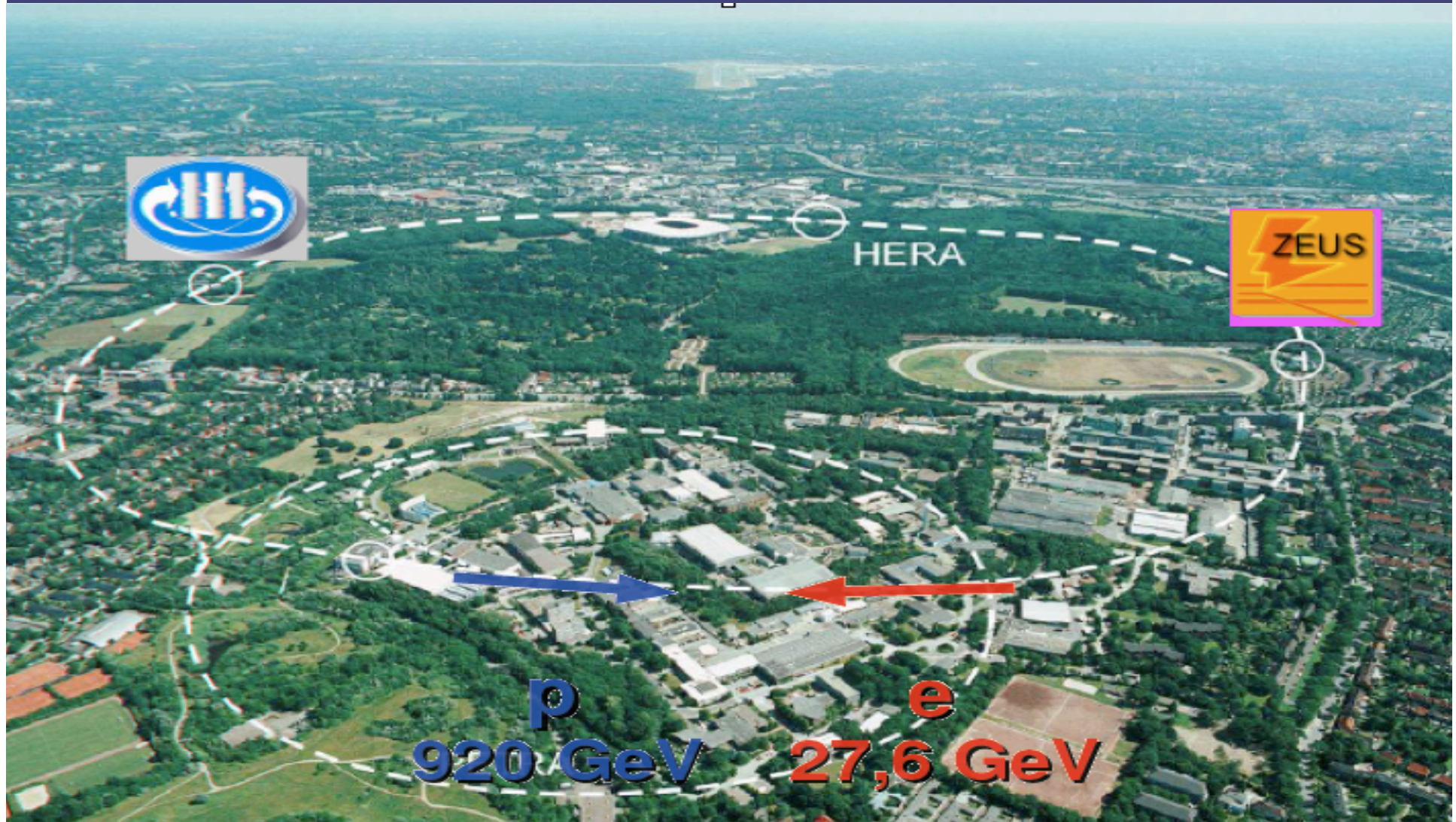
Cross section prop. to F_2 ,
structure function of the
proton:

$$\frac{d^2\sigma}{dx dQ^2} \sim \frac{2\pi\alpha}{xQ^4} F_2(x, Q^2)$$

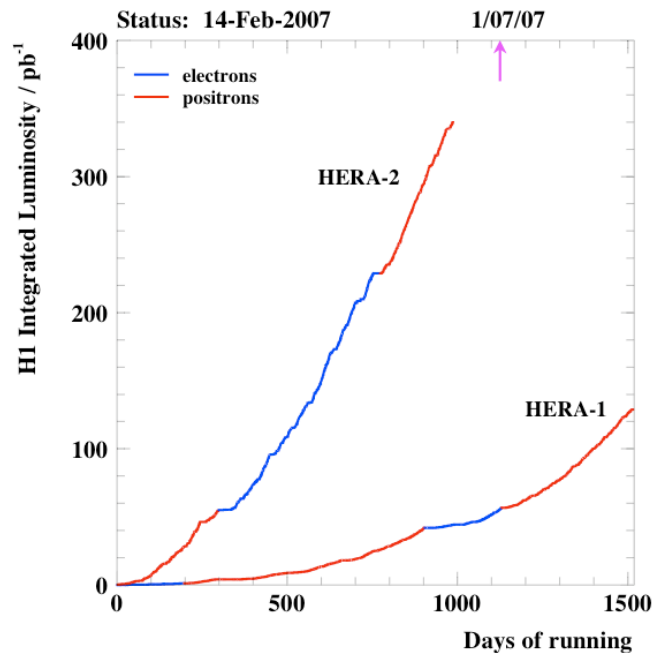


- ✓ Probing the gluon density $G(x, Q^2)$, dominant a low x

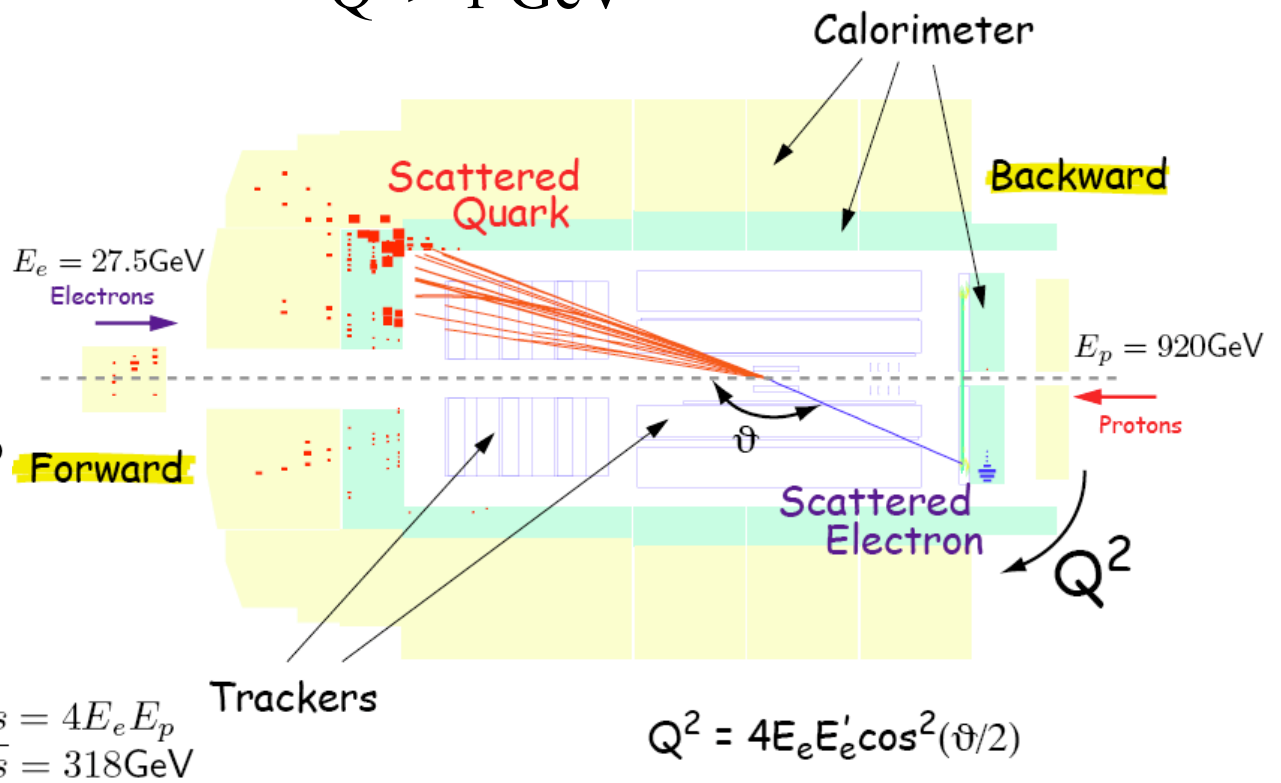
HERA, Electron-Proton Collider



The Experiments: H1 and Zeus



A Deep Inelastic ep-Scattering event (DIS)
 $Q^2 > 1 \text{ GeV}^2$:



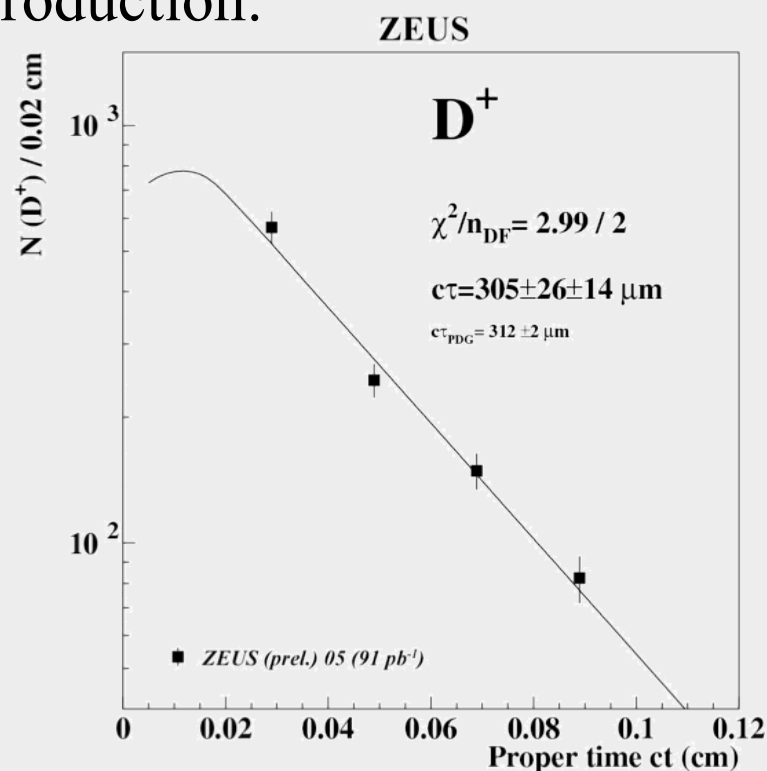
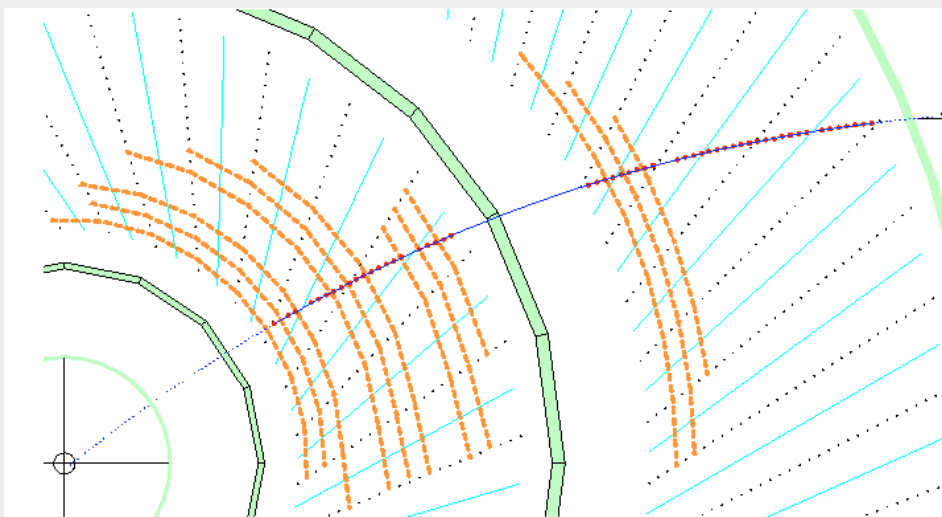
2 kinematics regimes:
 DIS
 photoproduction

Photoproduction (γp): $Q^2 < 1 \text{ GeV}^2$ (quasi real photon)

Detector Upgrade for HERA II

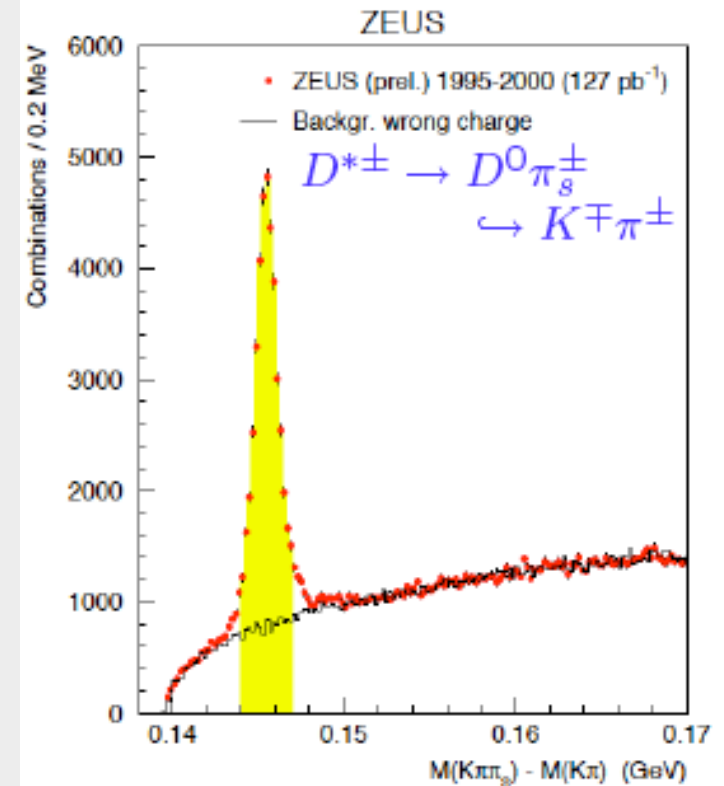
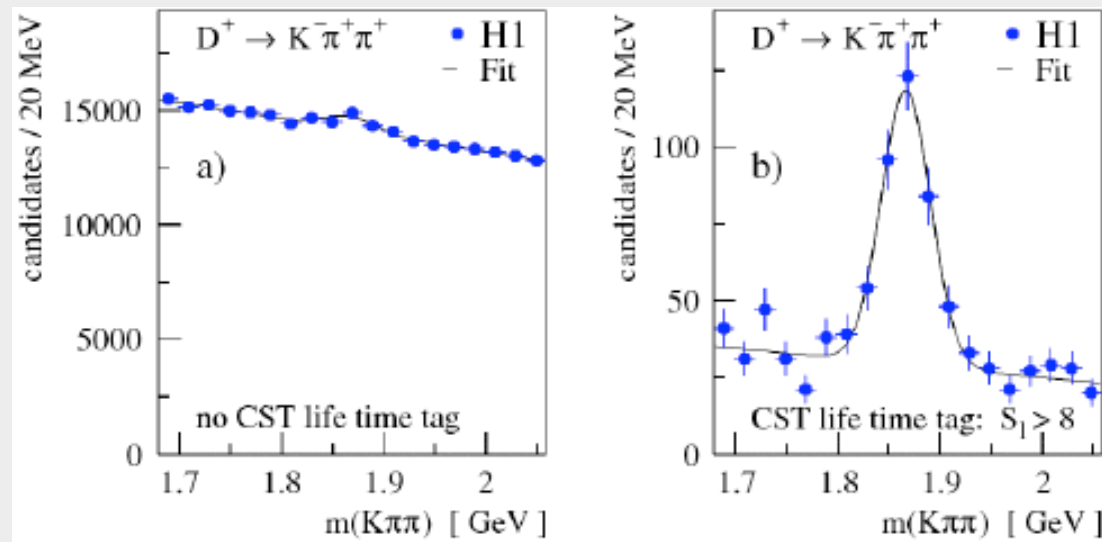
Most relevant upgrade for heavy flavor production:

- H1 Fast Track Trigger
- ZEUS Micro Vertex Detector



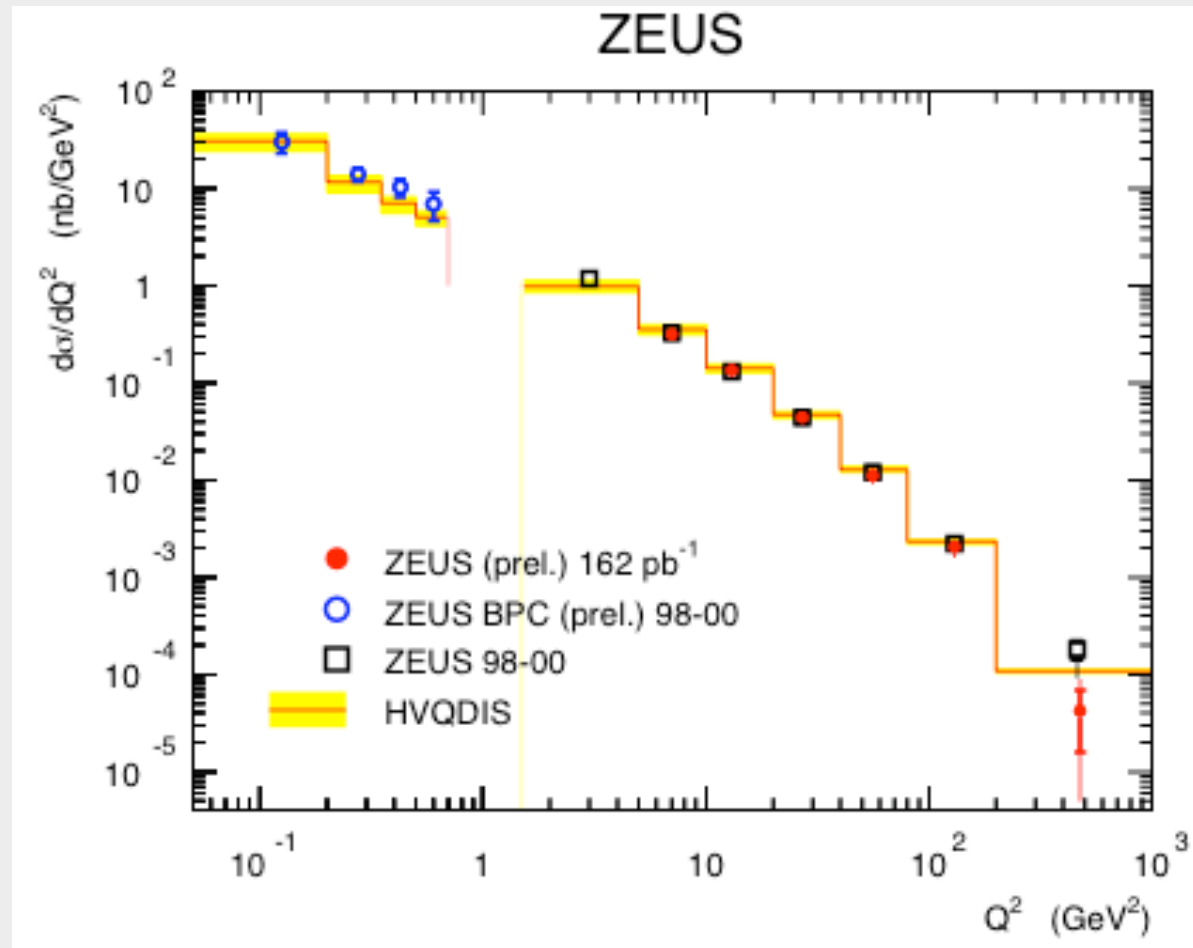
Charm Tagging

- ✓ Via D^* resonance reconstruction :
 $D^* \rightarrow K^- \pi^+ \pi^+$, knowledge of kinematics,
 signal and background
- ✓ Via lifetime tagging (vertex detector)



Large sample:
 40000 D^* (Hera I)

Charm production versus Q^2

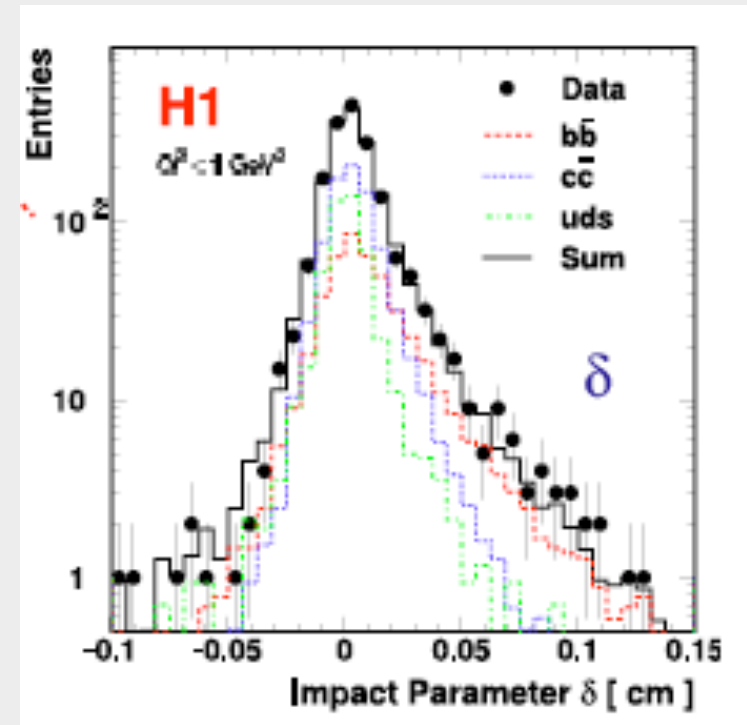
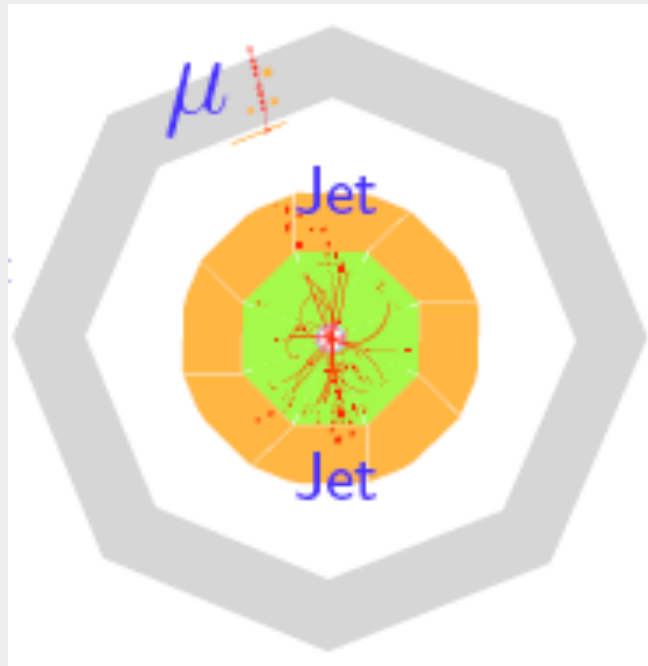
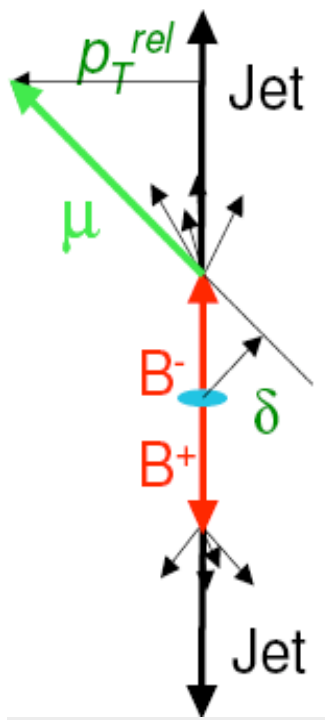


Q^2 evolution (Calculation) describes data over 6 orders of magnitude!

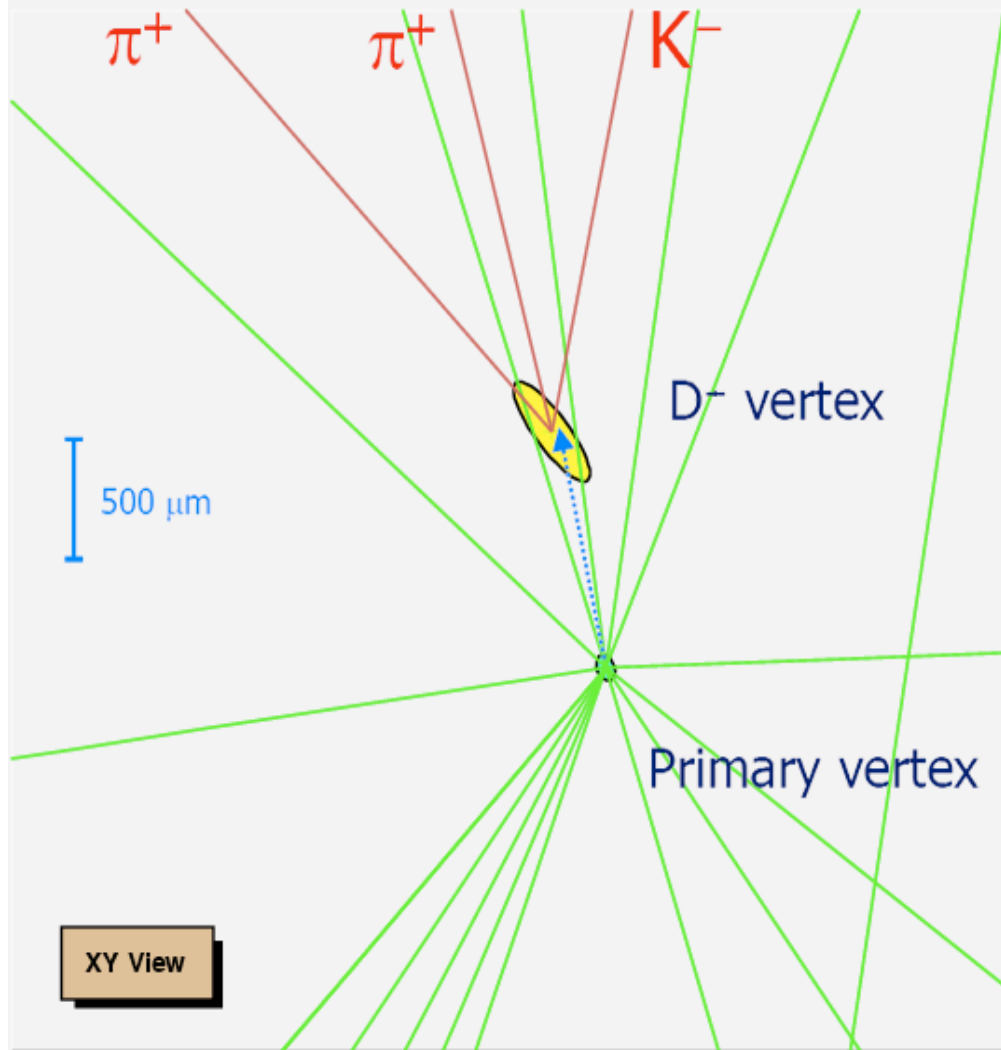
Beauty Tag

Tag the b decay, separation power from:

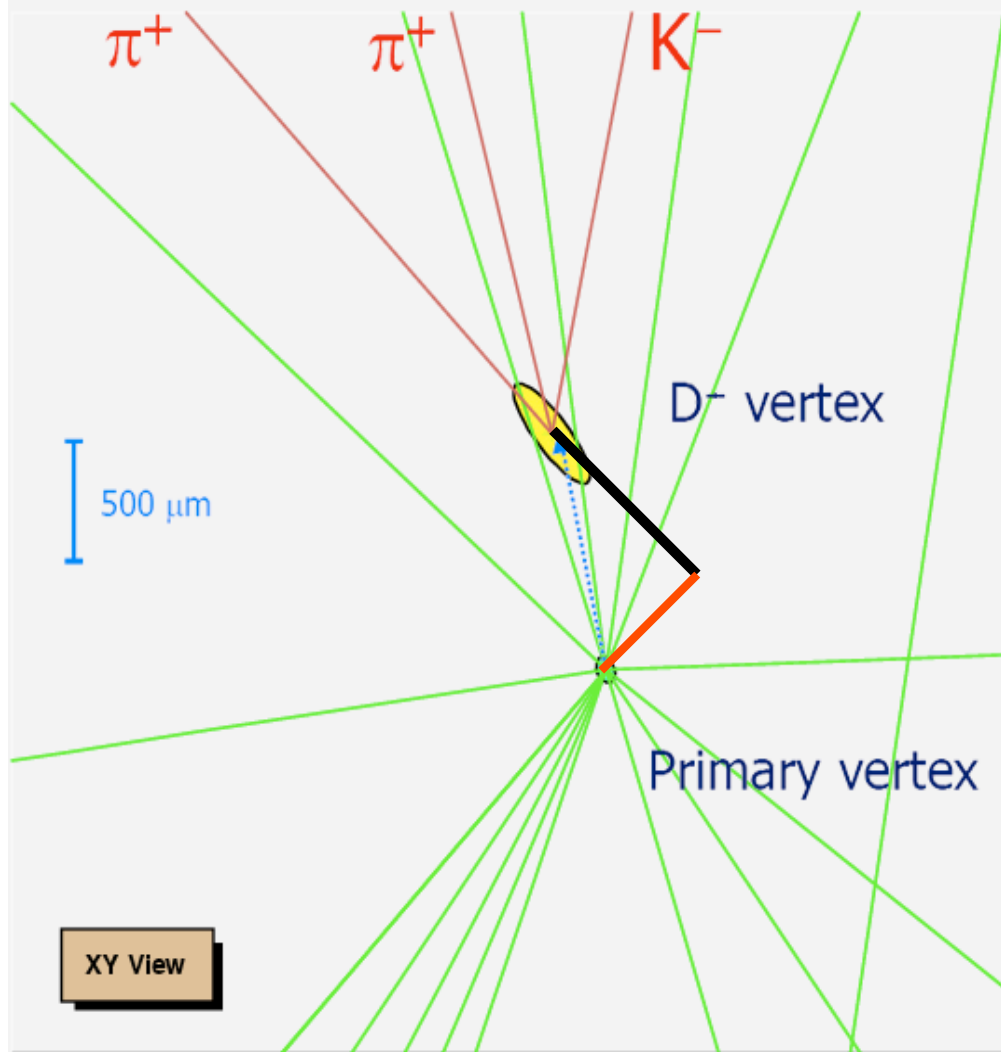
- ✓ B mass: P_t^{rel} (p_t of μ w.r.t jet axis) for semi-leptonic decay
- ✓ Large b lifetime: impact parameter δ (distance between Interaction Point and B decay products, see next slide)



Impact Parameter and Significance



Impact Parameter and Significance



-
- The diagram shows a vertical black arrow labeled 'Jet axis'. A blue dot labeled 'PV' (Primary Vertex) is located on the jet axis. A red line segment, labeled 'Imp. Par. δ', extends from the PV to a point on the jet axis. A horizontal dashed line passes through the PV. The region above the dashed line is labeled δ > 0, and the region below is labeled δ < 0.
- ✓ D⁻ meson event reconstructed (not necessary)
 - ✓ Prolong the track to the IP
 - ✓ Measure the distance between the interaction point (or primary vertex) and the distance to close approach (dca) and its error
- ⇒ Ratio = Significance

Inclusive Lifetime Analysis

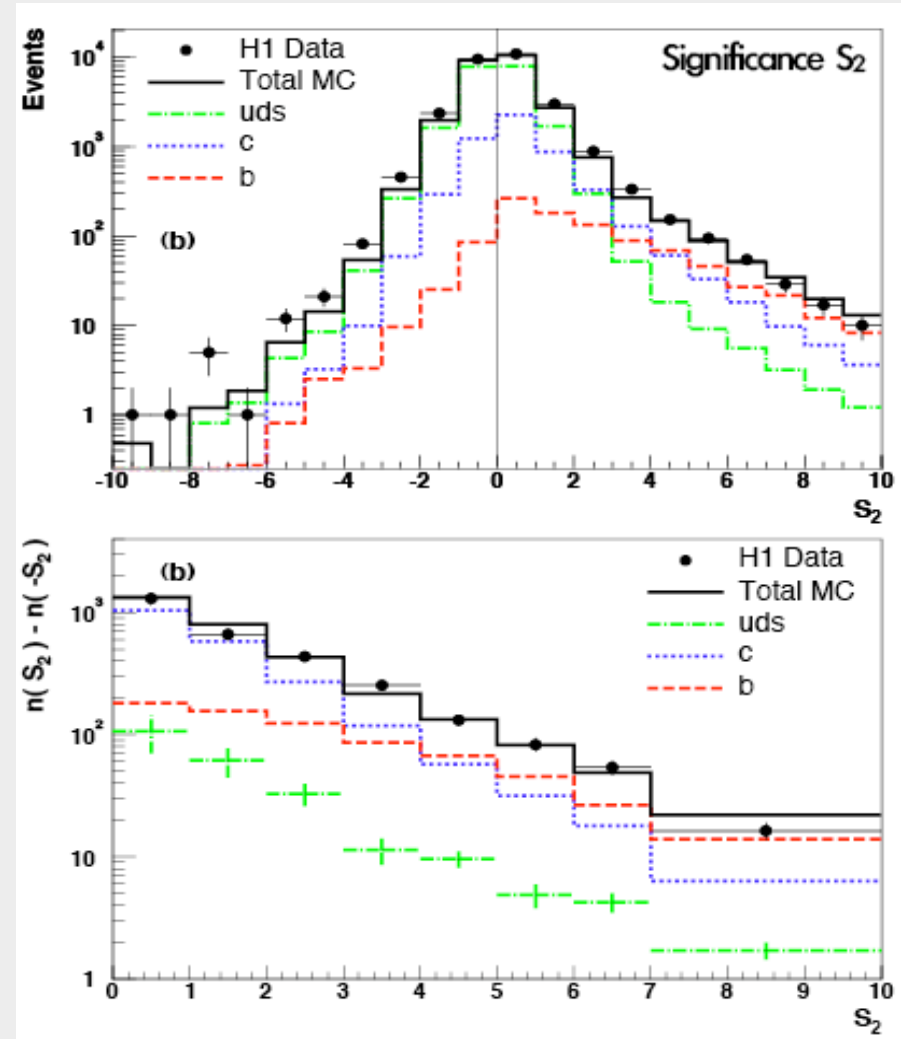
- Use all tracks ($p_t > 0.5$ GeV) with vertex detector information
- Significance of signed impact parameter:

$$S = \frac{\delta}{\sigma(\delta)}$$

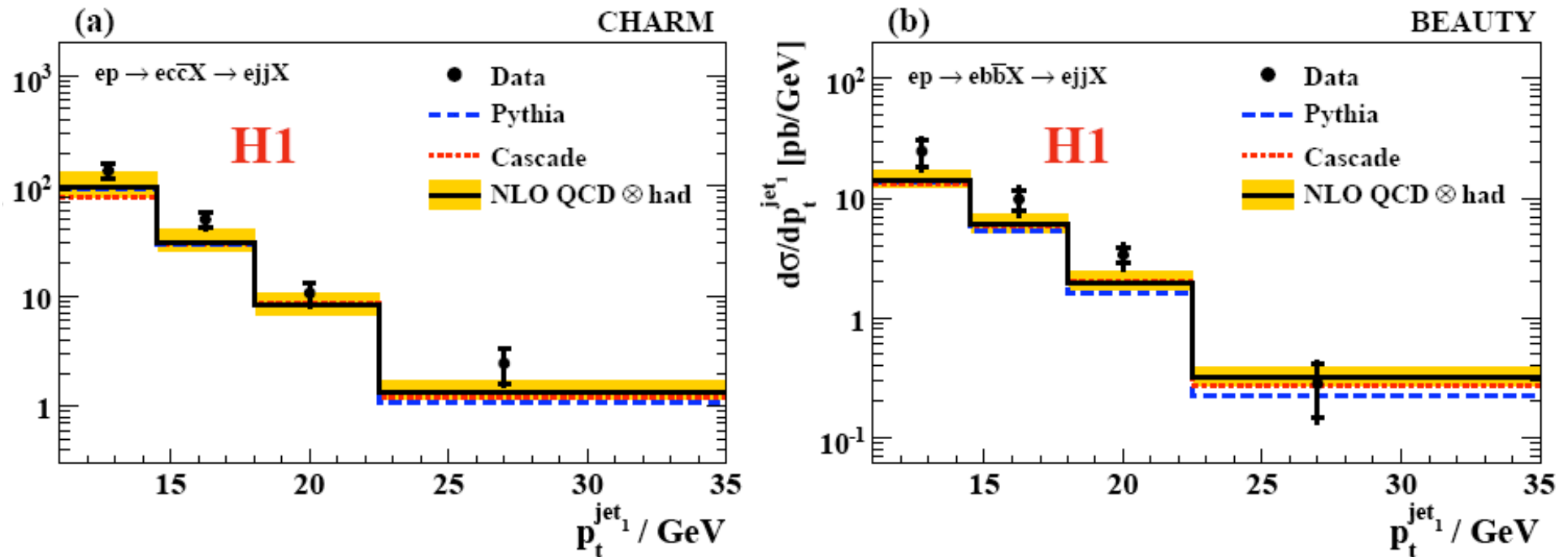
- Subtract negative side (resolution effect) from positive (contains the lifetime information)

=> enhance charm and beauty

- Example: tracks with 2nd highest significance has the highest discrimination power



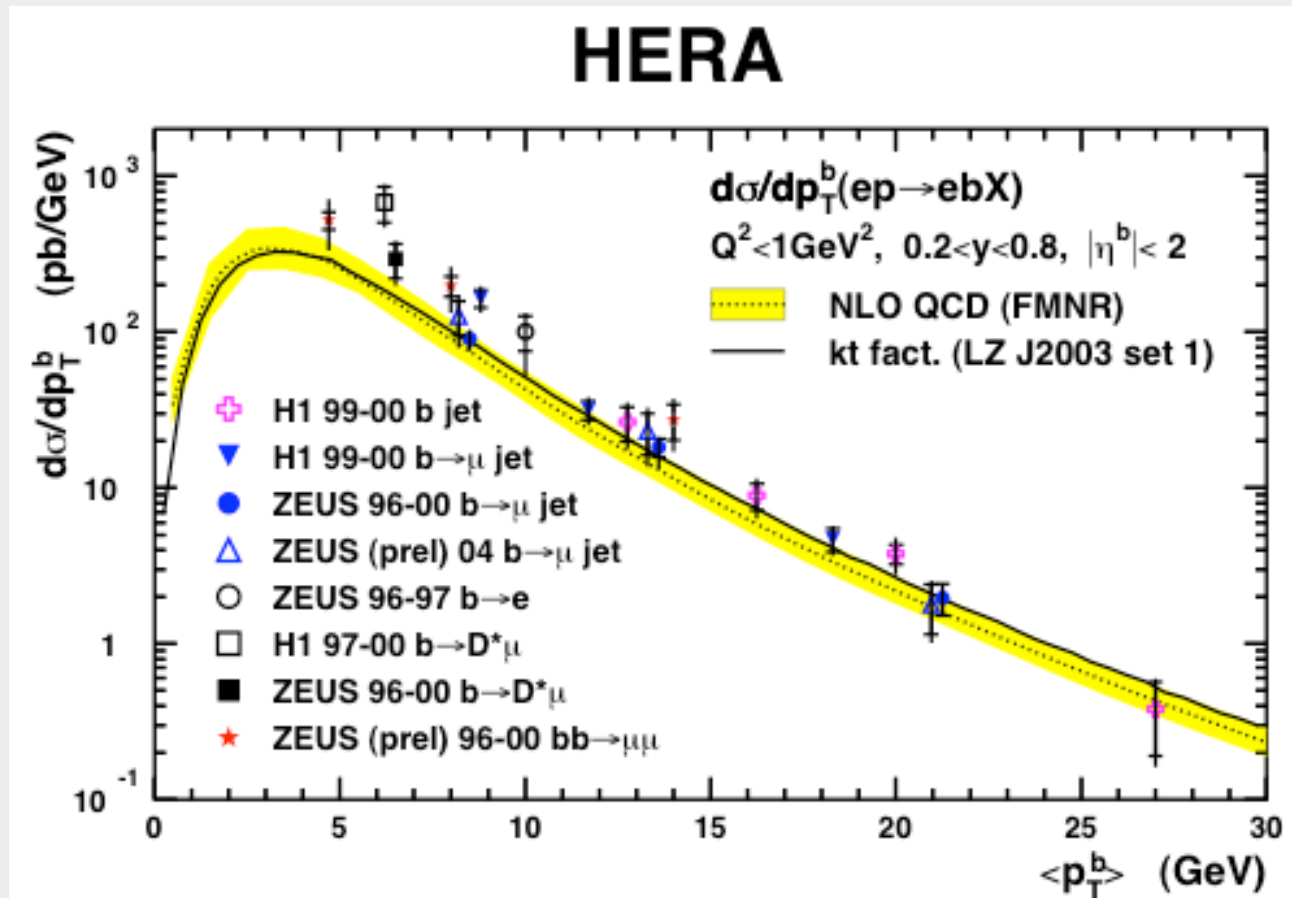
Beauty & Charm Cross Sections



First simultaneous measurement of
Charm and beauty in photoproduction
(lifetime info used as a charm/beauty tag):
NLO describe the data well for charm, less for beauty

Beauty Production Combined Results

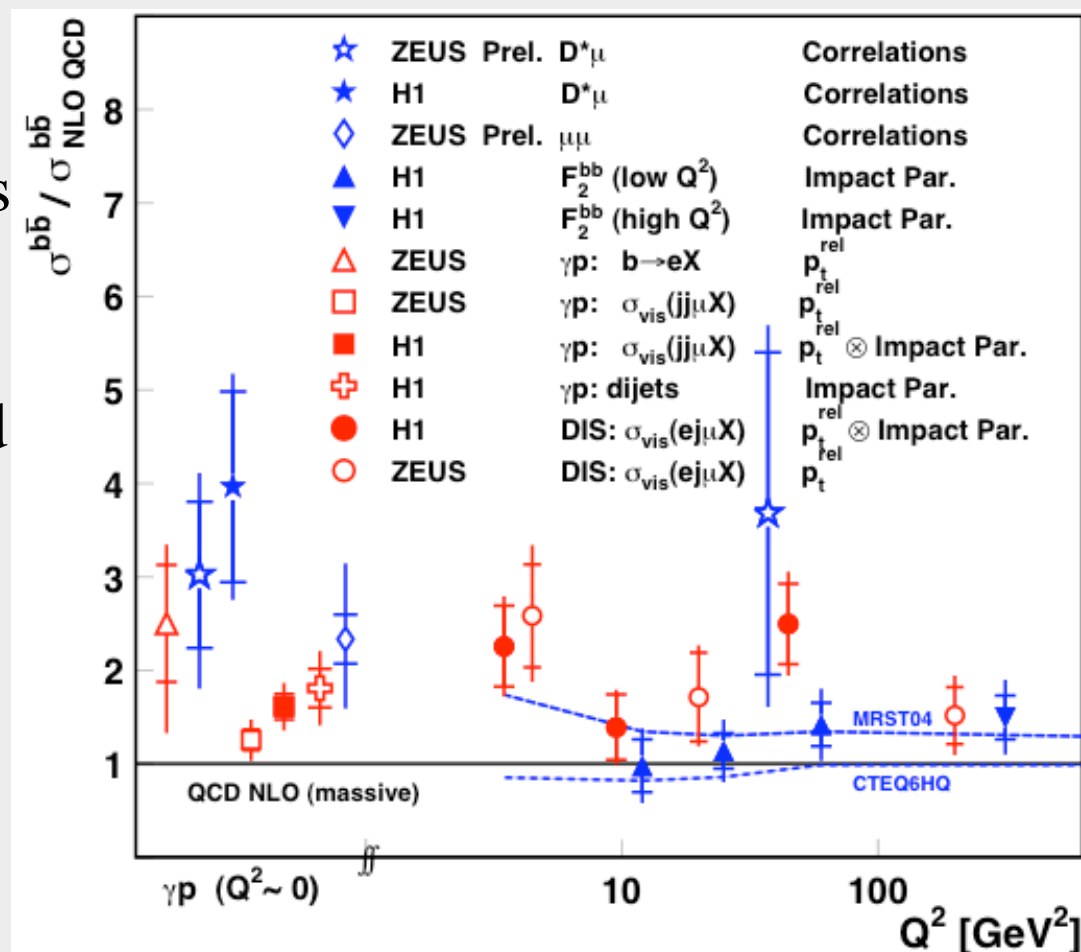
In photoproduction, Data slightly higher than prediction



With upgraded detector, hope to reach lower value of Pt

Beauty Production Summary

- General trend: slight overshoot of data versus massive NLO calculations
- difference between QCD calculations (work needed to understand different hypothesis)
- need Hera II data for improved precision



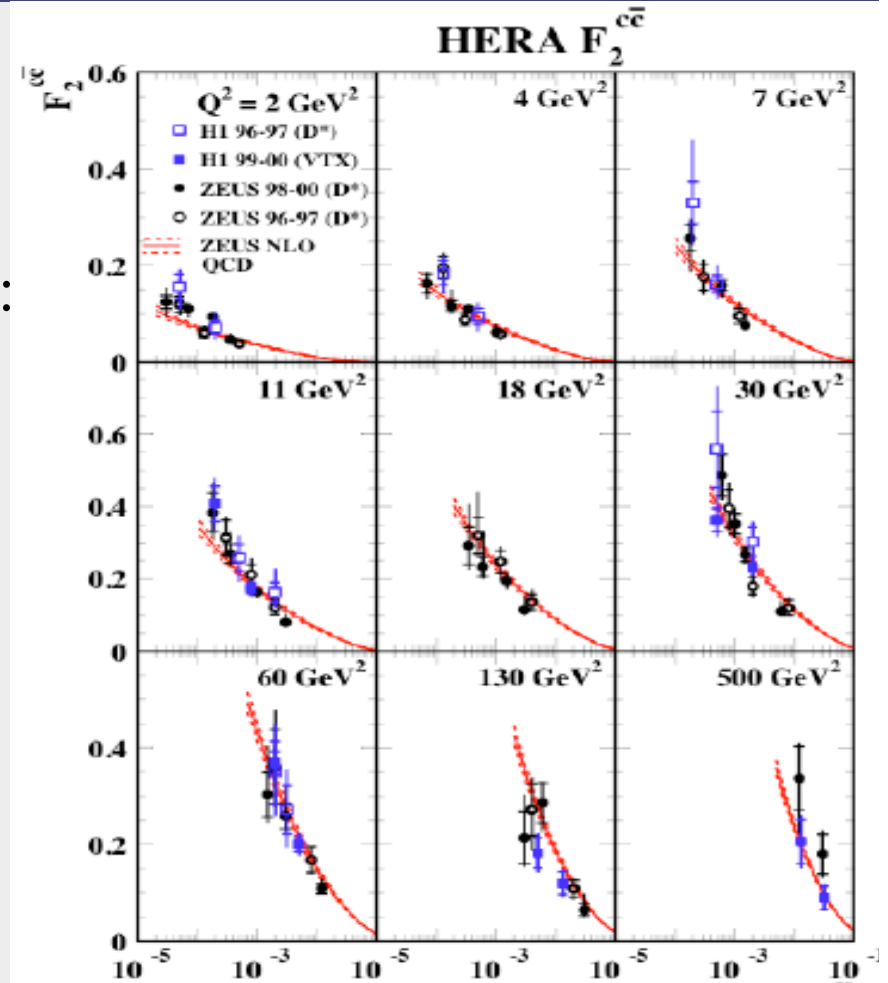
$F_2^{c\bar{c}}$

$$\frac{d^2 \sigma^{ep \rightarrow c\bar{c}X}}{dx dQ^2} \propto F_2^{c\bar{c}}(x, Q^2)$$

In analogy to the inclusive measurement:

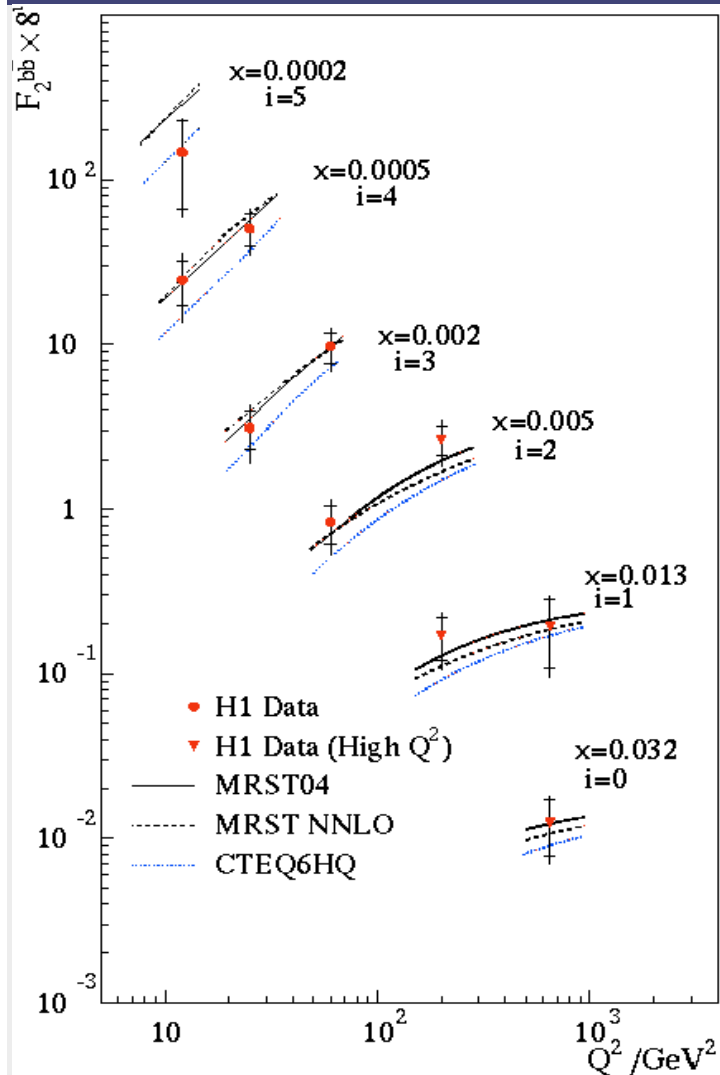
$$\frac{d^2 \sigma^{ep}}{dx dQ^2} \propto F_2(x, Q^2)$$

- ✓ Good agreement with NLO
- ✓ At low Q^2 , charm starting to help constrain gluon density

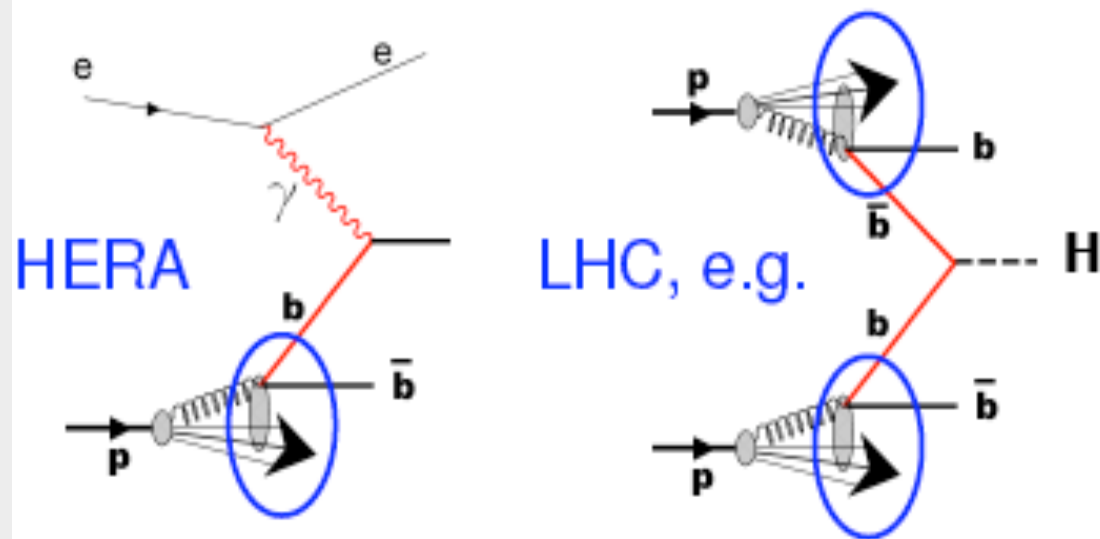


Bjorken X

Beauty Contribution to F_2



- First measurement
- Rise with $g(x)$ (smaller x and larger Q^2)
- NNLO calculation (R. Thorne) agree with HERA data



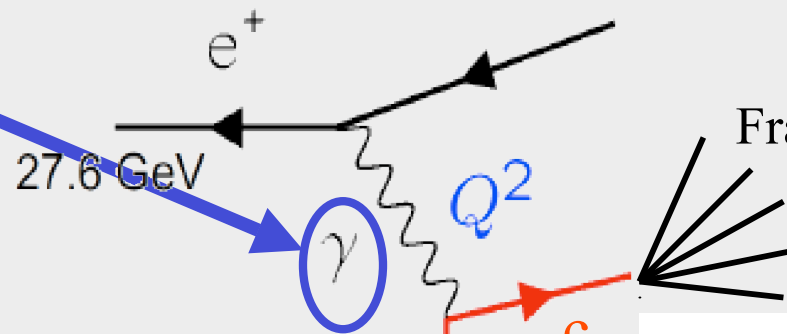
Summary

- Charm production:
High precision data described by NLO
- Beauty description:
Data tend to be higher than NLO predictions
- First measurement of F_2^{bb} Structure Functions
- Hera II: improved detector and data still coming => higher precision in view

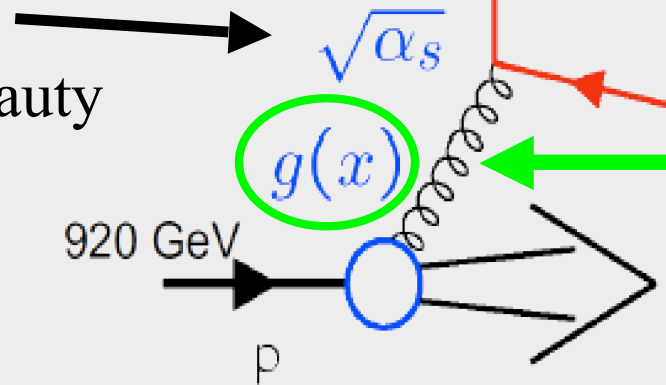
Back-up Slides

Charm Overview

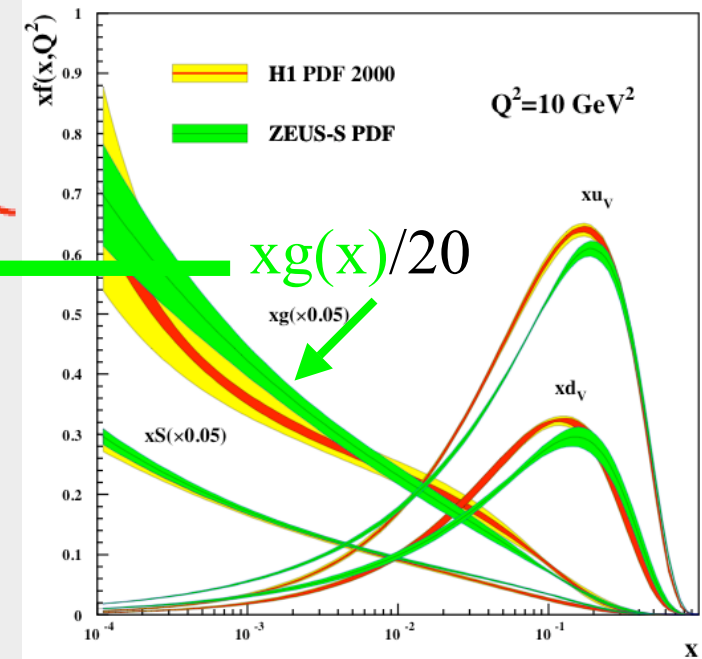
Photon structure
(photo-production,
photon quasi-real)



Strong coupling:
“small” (charm /beauty
masses)



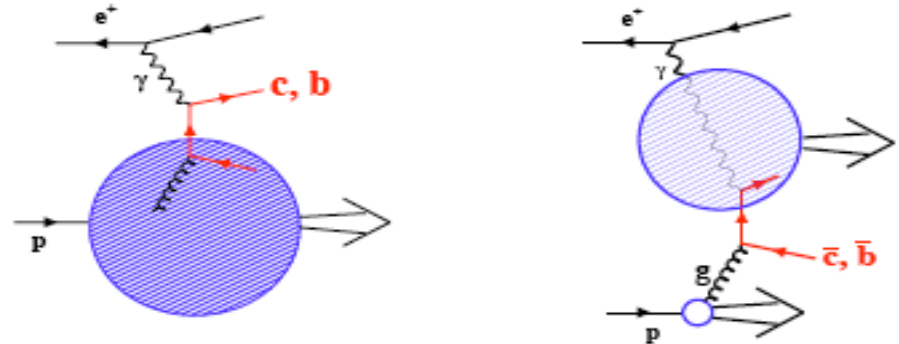
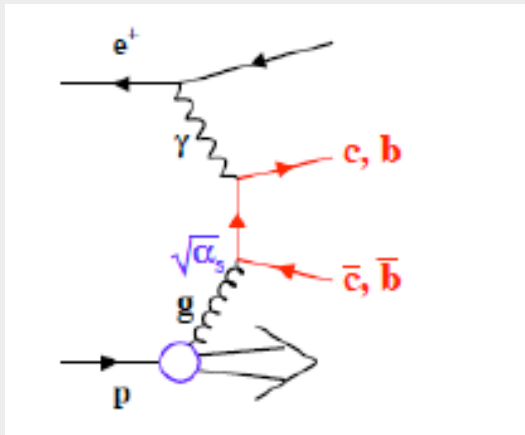
Factorization of pQCD and non perturbative
components



pQCD approximation

Massive approach:

- ❖ Fixed order calculation in α_s , with $m_q \neq 0$
- ❖ HQ produced only dynamically



Massless approach

- ❖ Resums in α_s , with $m_q = 0$ (HQ is flavor active in structure function)
- ❖ Reliable at $p_t \gg m_q$

Intermediate (or variable) scheme :
massive at low Q^2 , massless at high Q^2

Experimental Conditions

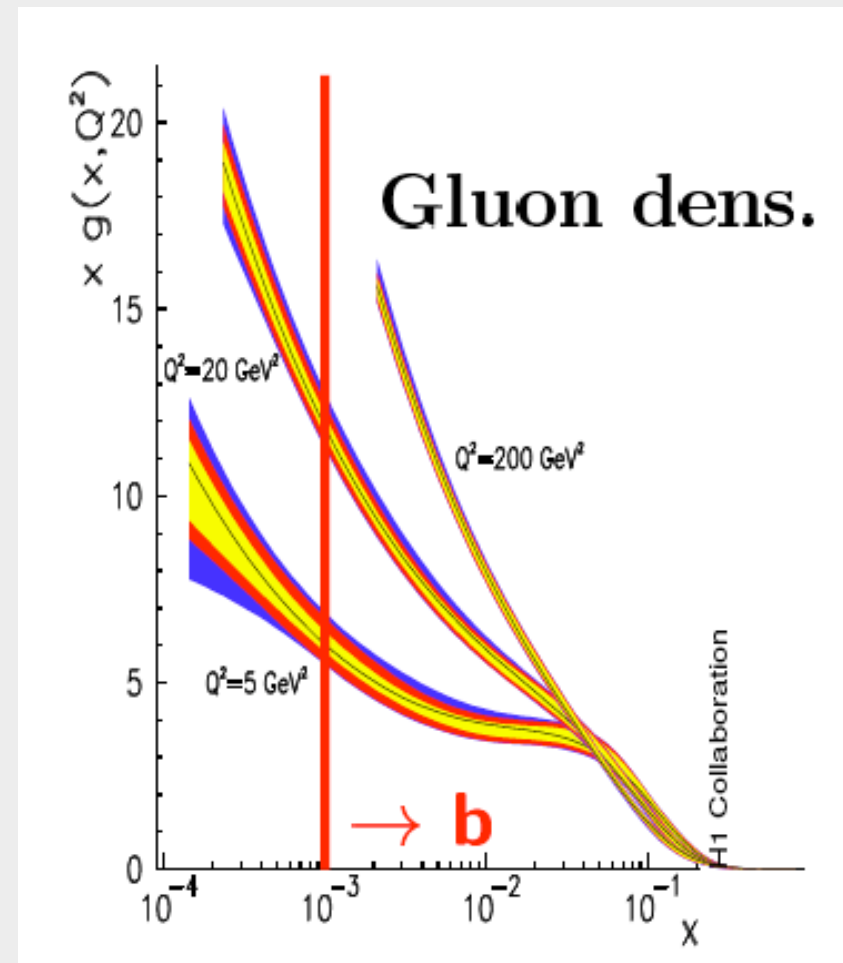
Total production rate at HERA:

$$\sigma_{\text{uds}} : \sigma_{\text{charm}} : \sigma_{\text{beauty}} \sim 2000 : 200 : 1$$

Main reason for beauty suppression:
phase space,

$$X_g \geq \frac{m_Q^2}{E_\gamma \cdot 920 \text{ GeV}}$$

...

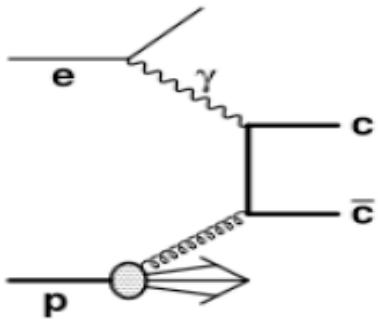


γg Charm Production at HERA

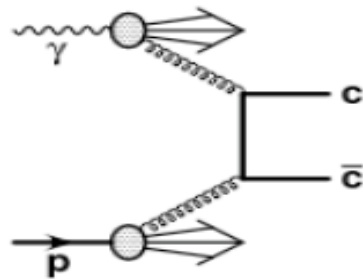
Boson Gluon Fusion Dominate (@LO) :

\Rightarrow Direct process $\gamma g \rightarrow cc$ dominates, in γp resolved contribution plays a significant role

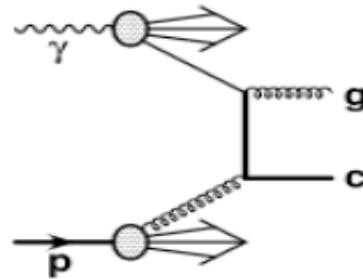
direct photon



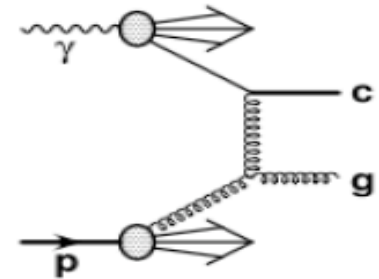
resolved photon



resolved photon
charm excitation



resolved photon
charm excitation

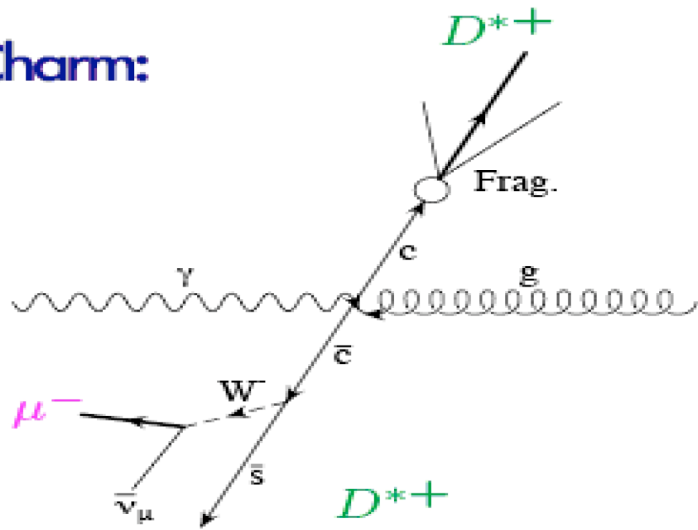


Factorisation:

$$\sigma = \text{proton PDF} \otimes \sigma_{\gamma g \rightarrow qq} \otimes \text{photon PDF} \otimes \text{fragmentation function}$$

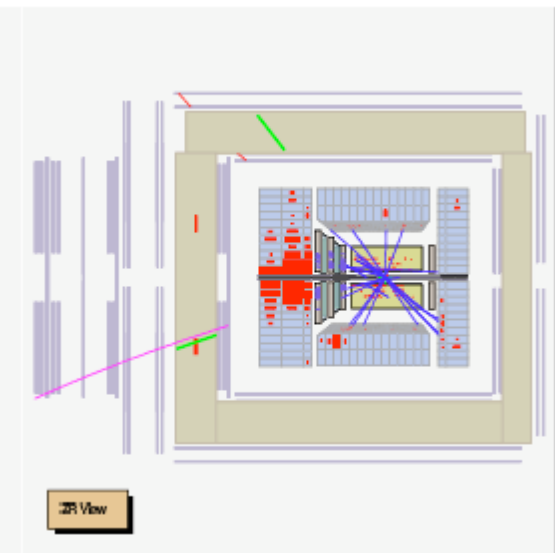
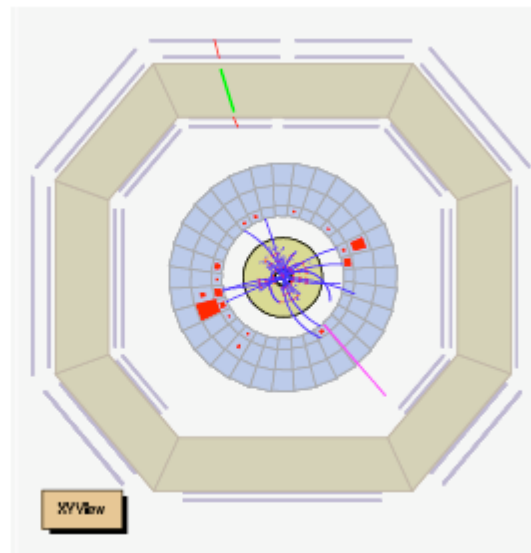
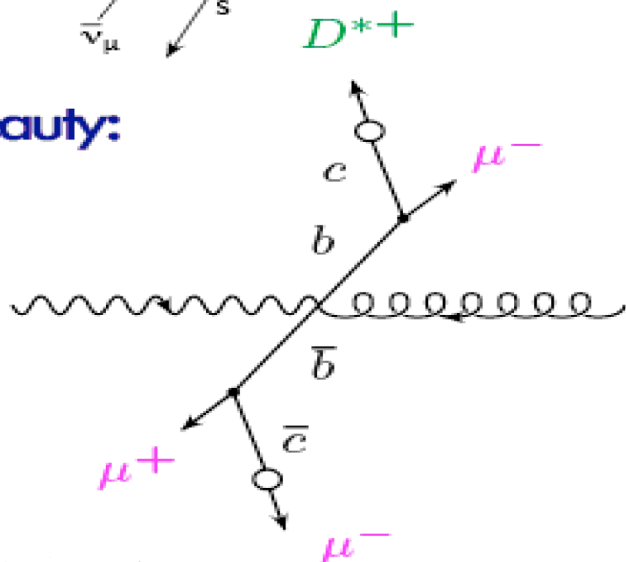
Double Tagging: $D^*\mu$ and $\mu\mu$

Charm:



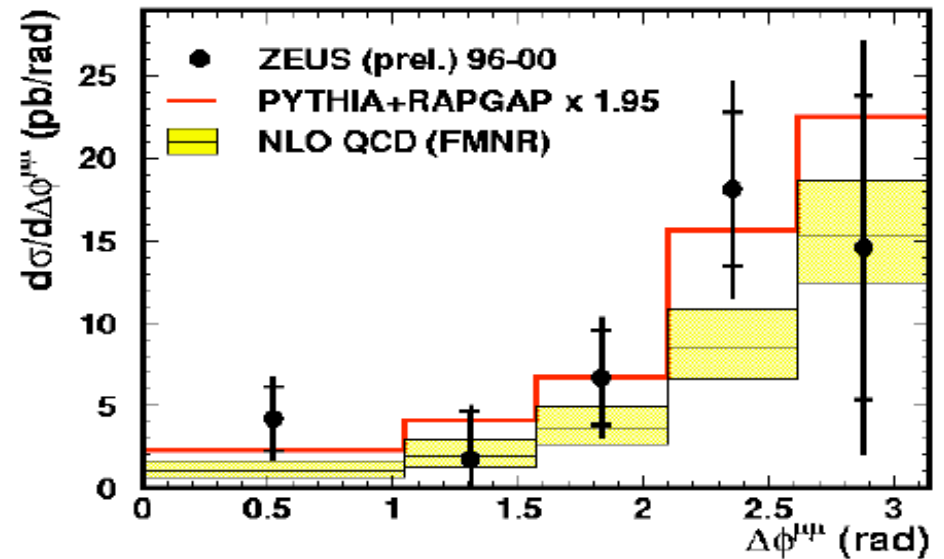
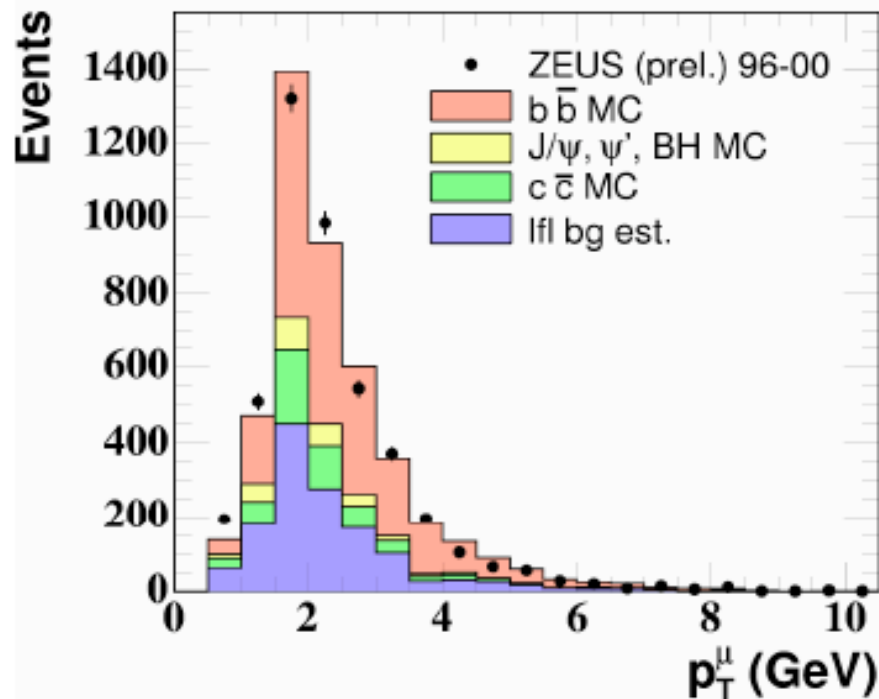
- $D^*\mu$: Separate charm and beauty with charge and/or angular correlations
- $\mu\mu$: b-contribution from excess of unlike sign muon pairs

Beauty:



$\mu\mu$ correlations @ Zeus

Exploit data for background determination / subtraction



$M_{\mu\mu} > 3.25$ GeV \Rightarrow 2 μ from different b's

LO: shape ok, norm too low

NLO: agrees within errors