Beauty in photoproduction at HERA

University of Virginia High Energy Physics Seminar

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Introduction

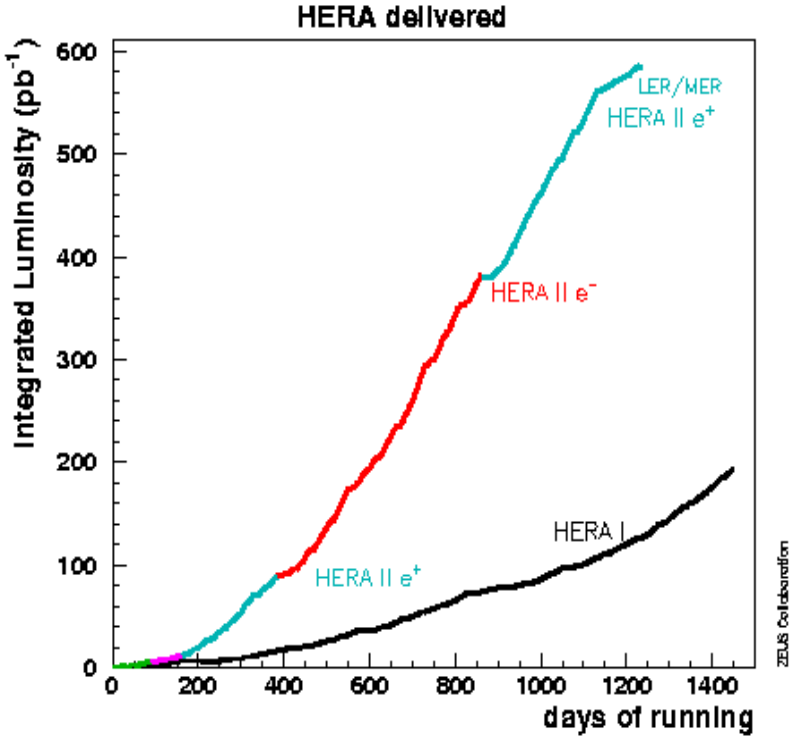
- A bit about HERA
- Reminder of HERA physics
- Beauty in photoproduction
- A short history of b measurements
- ZEUS detector
- Recent b measurement

HERA

- electron/positron – proton collider
- 10-20m underground at DESY in Hamburg, Germany
- 6.34 km in circumference
- Since 1997, centre of mass energy √s = 318 GeV
- Luminosity upgrade in 2001
- HERA delivered ~800 pb^{-1} experiments gated 500 pb^{-1}
- Designed with 4 experiment halls

1992 - June 2007

E_e = 27.6GeV E_p = 920GeV



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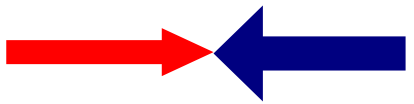
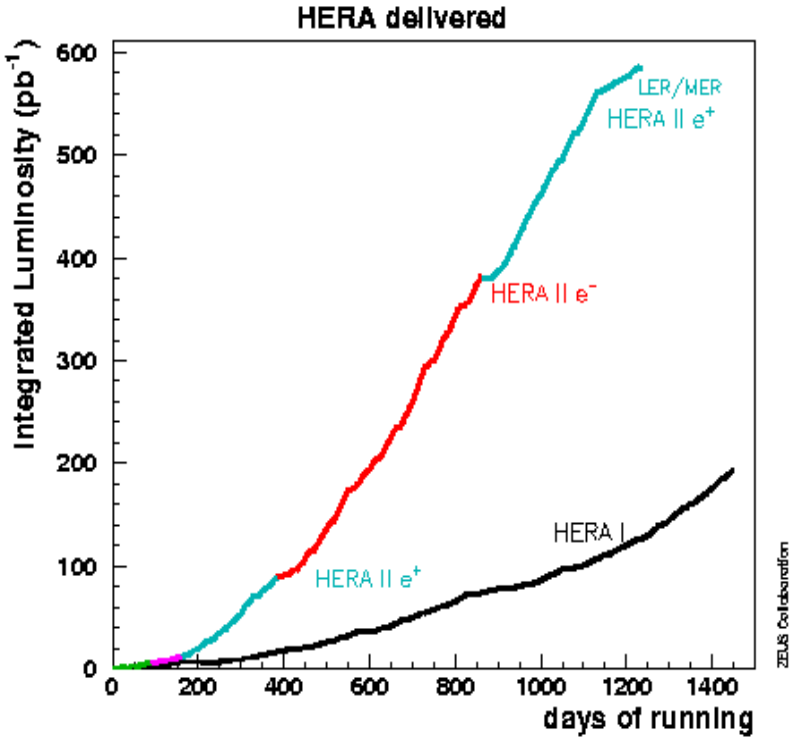
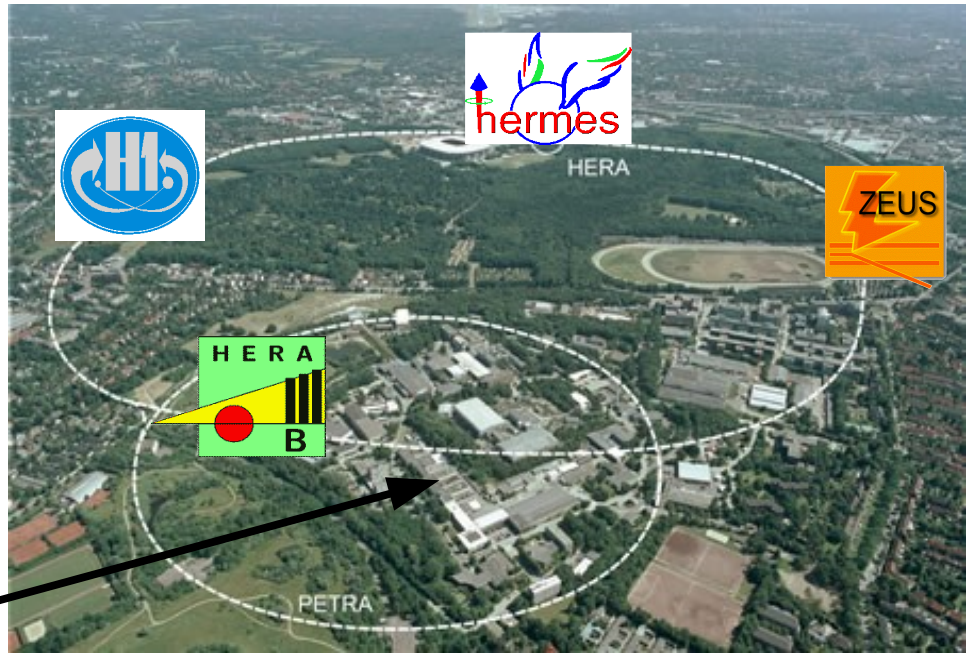
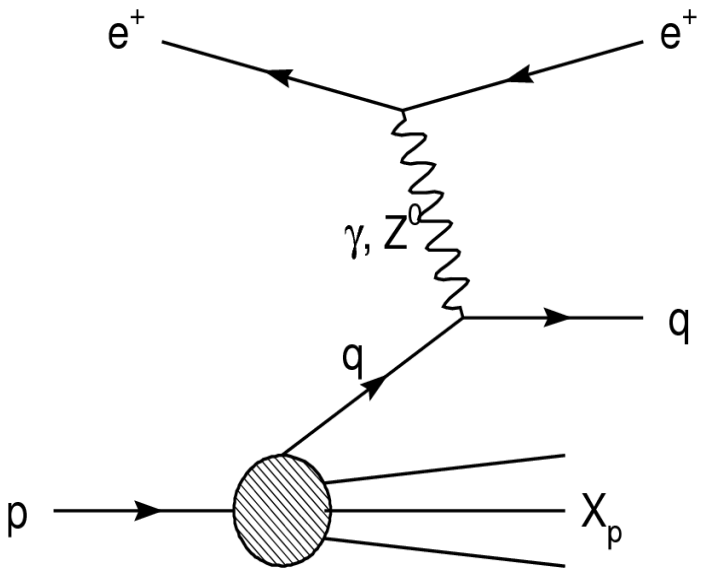




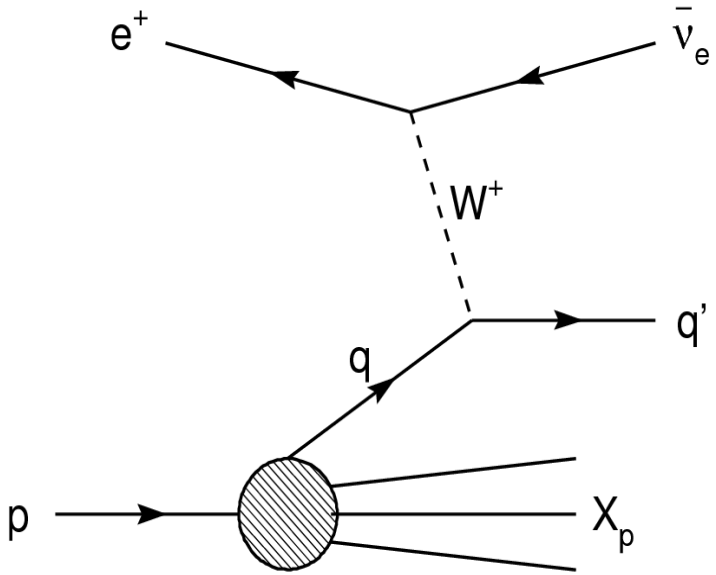


me

ep scattering

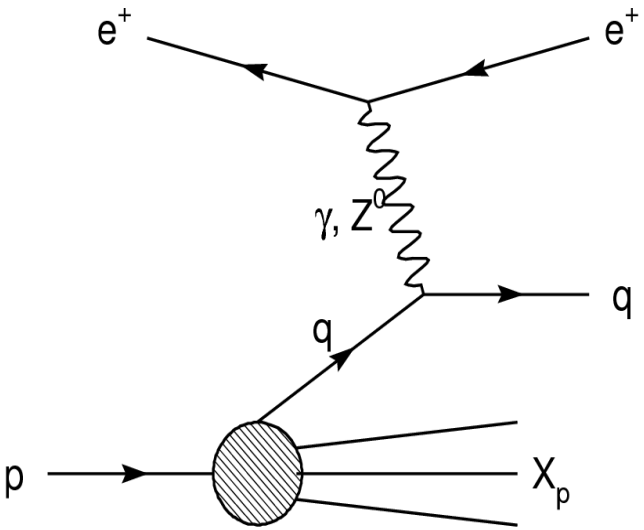


Neutral current



Charged current

ep scattering



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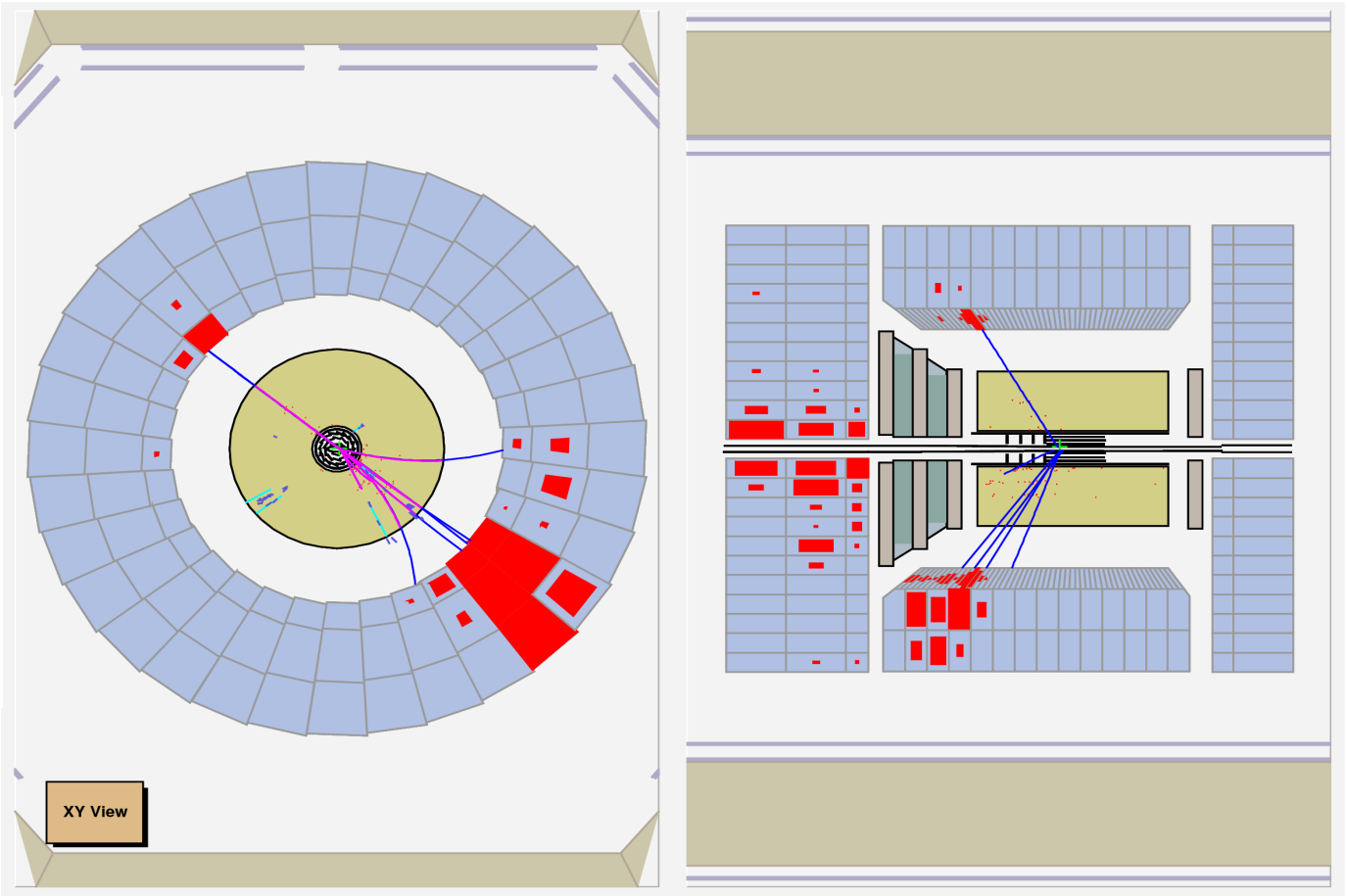

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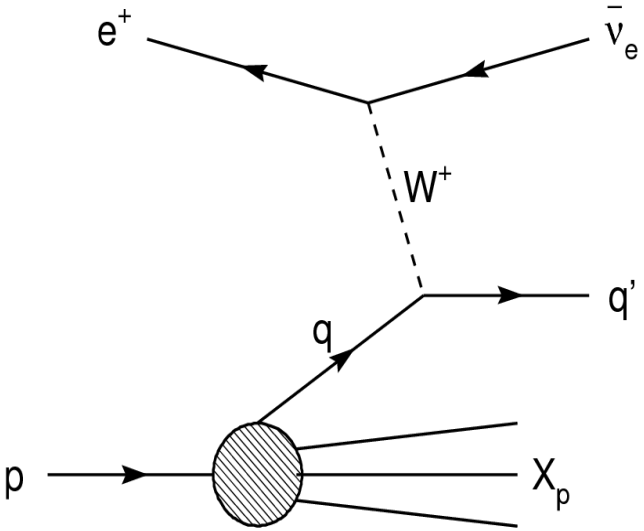

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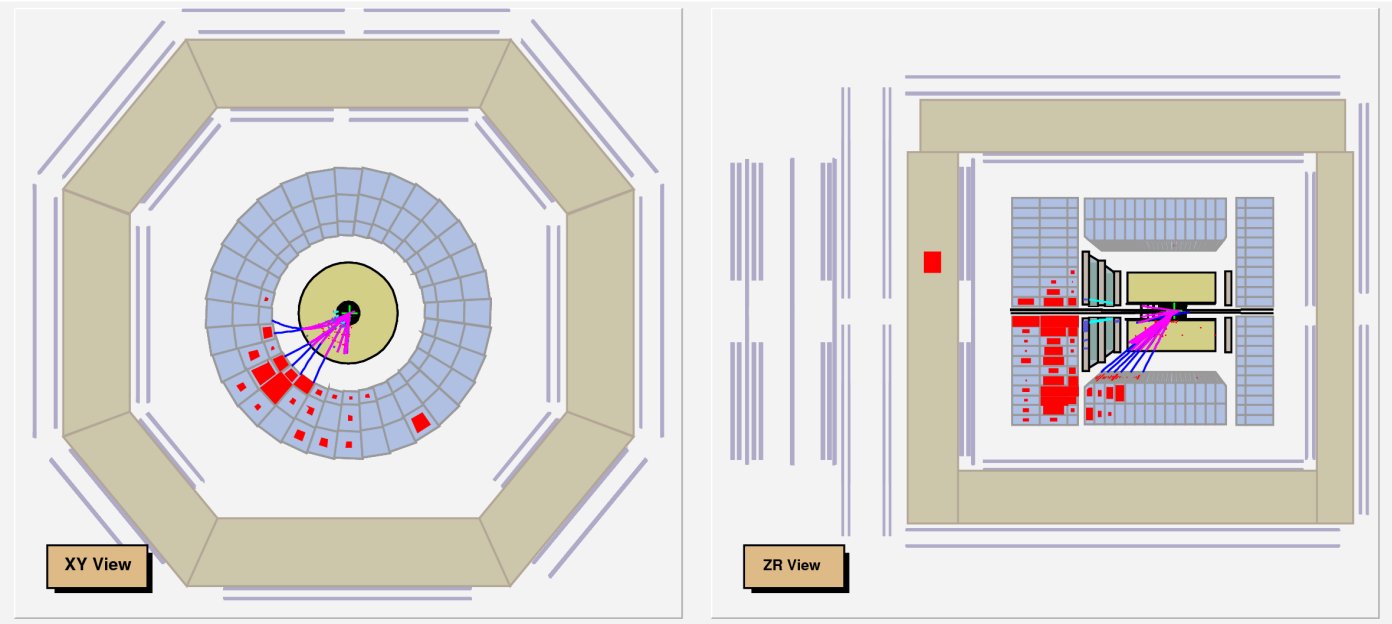
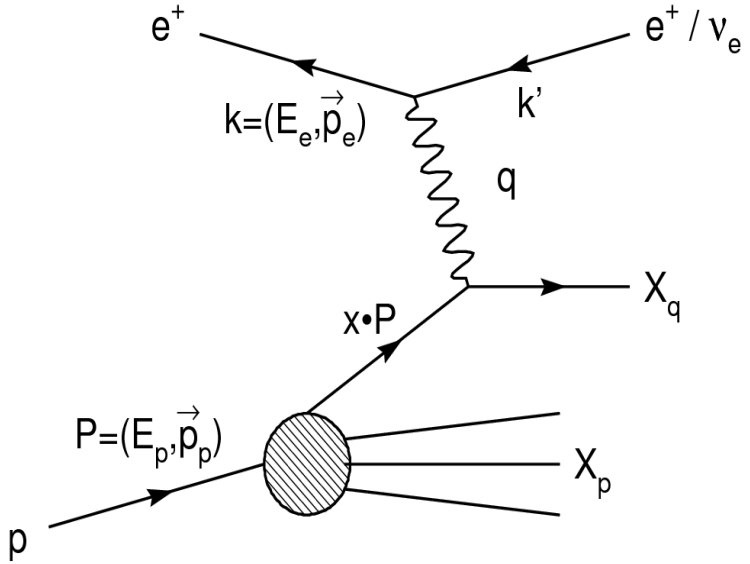


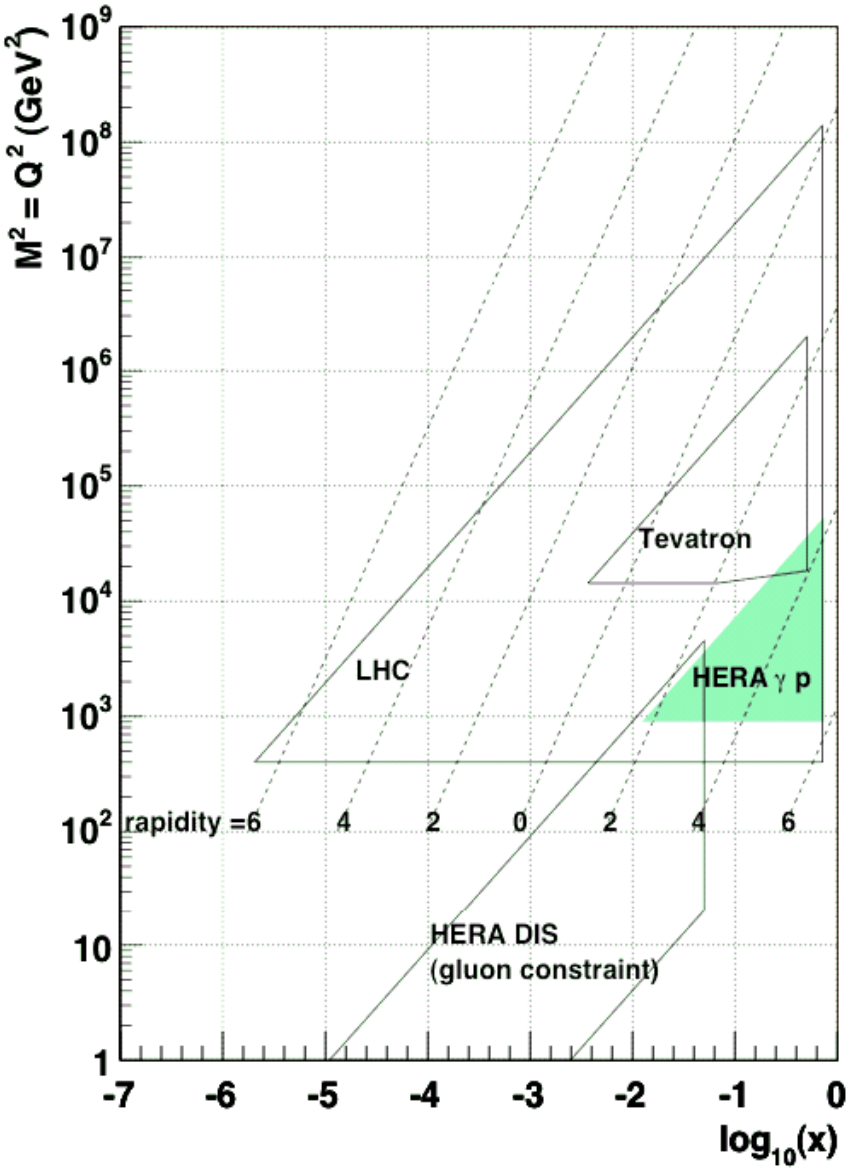
ep scattering kinematics



- $Q^2 = -q^2$ (photon virtuality)
- $x = Q^2/2p.q$
- $y = k'.p/k.p$ (inelasticity)

- Kinematic regimes:
  - $Q^2 > 1GeV^2$ Deep inelastic scattering
  - $Q^2 \sim 0GeV^2$ Photoproduction

- Measure over as large a range as possible
- Constraints important to future colliders



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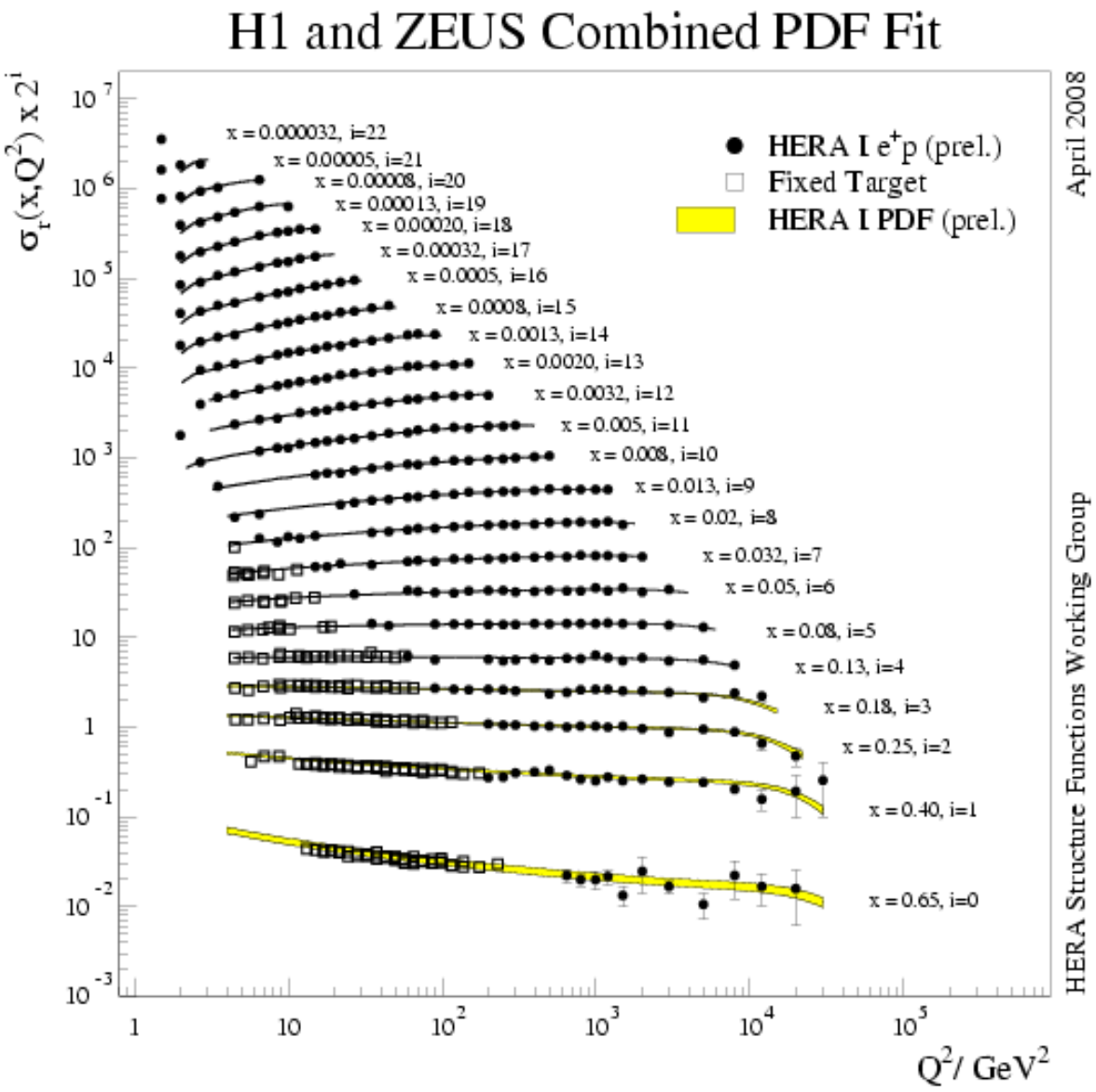
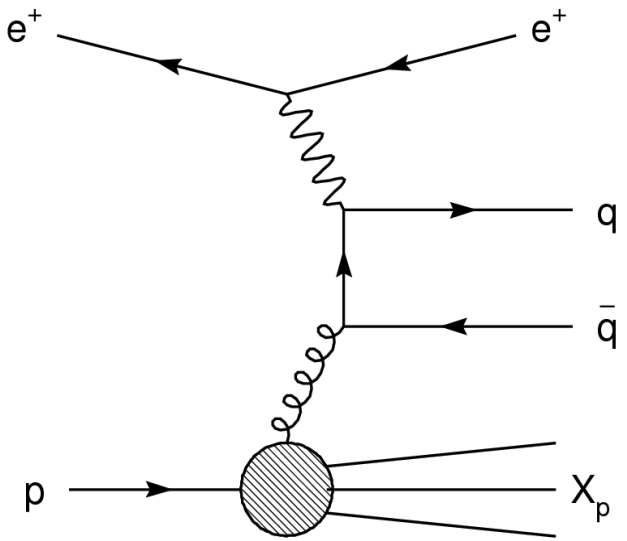


Heavy quark production

- Heavy quarks (b and c) predominantly by Boson-Gluon Fusion



PDF

Proton and Photon structure functions
Direct sensitivity to gluon density in proton

→

Hard Scatter

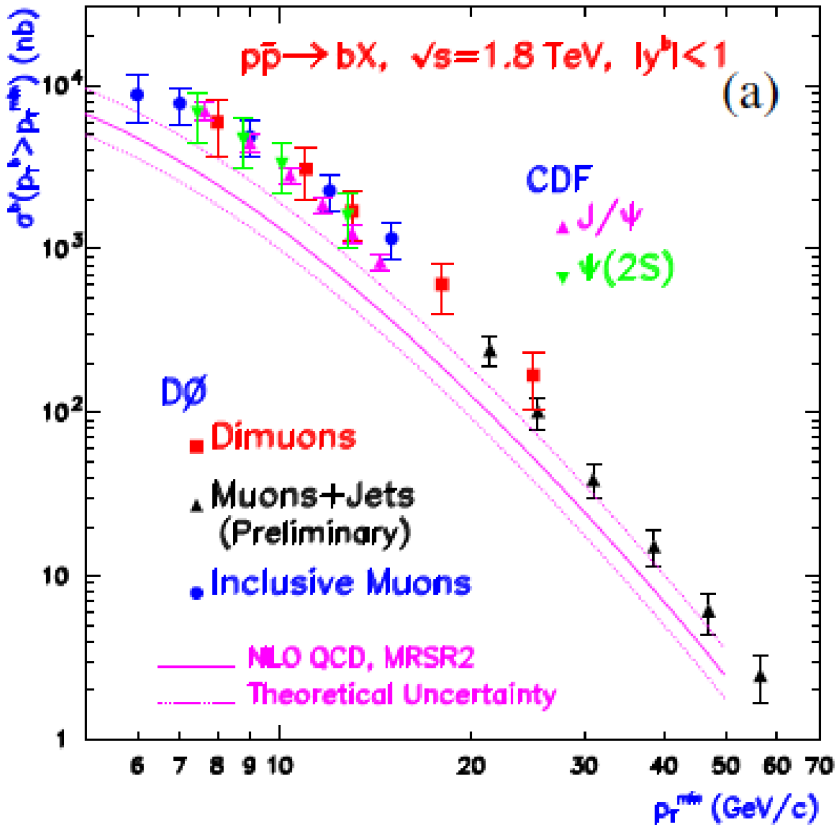
Dynamics of NLO QCD
Large quark mass allows pQCD calculations

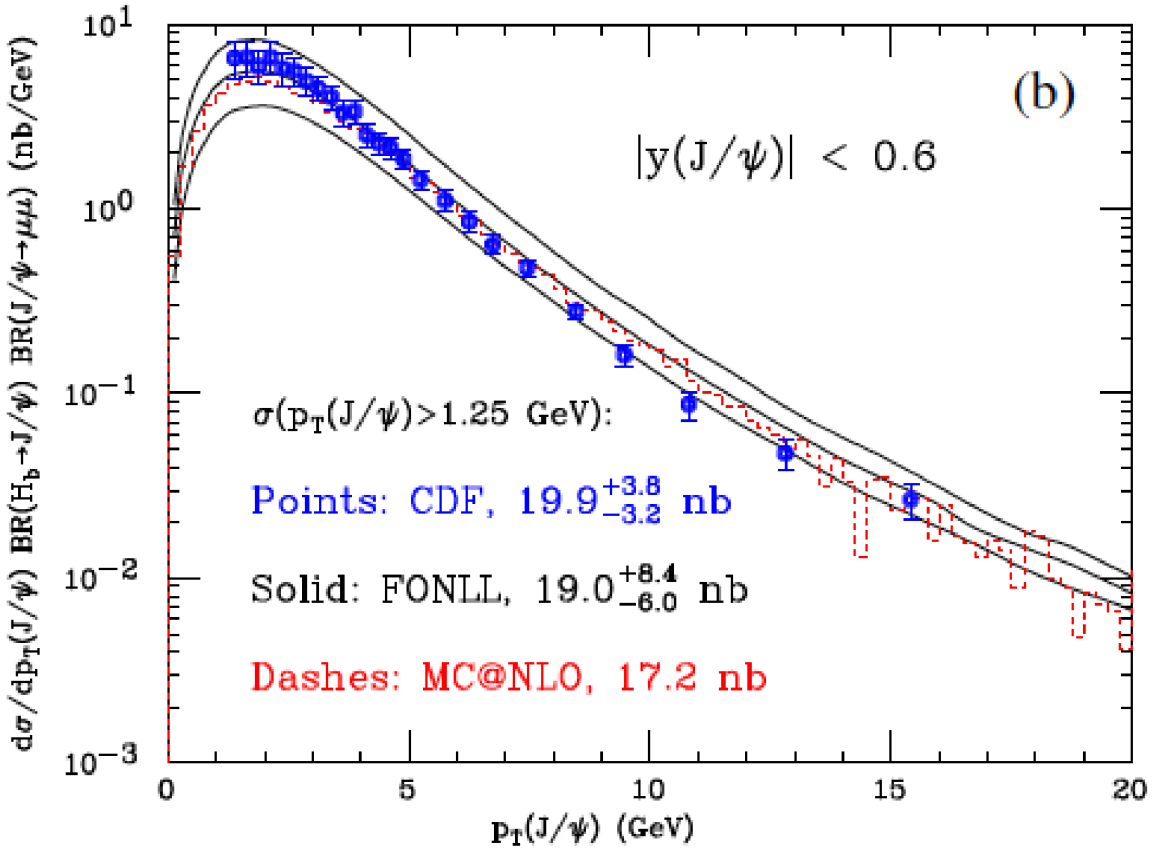
→

Fragmentation

Describes parton-hadron transition
Non-perturbative

A short history of b measurements





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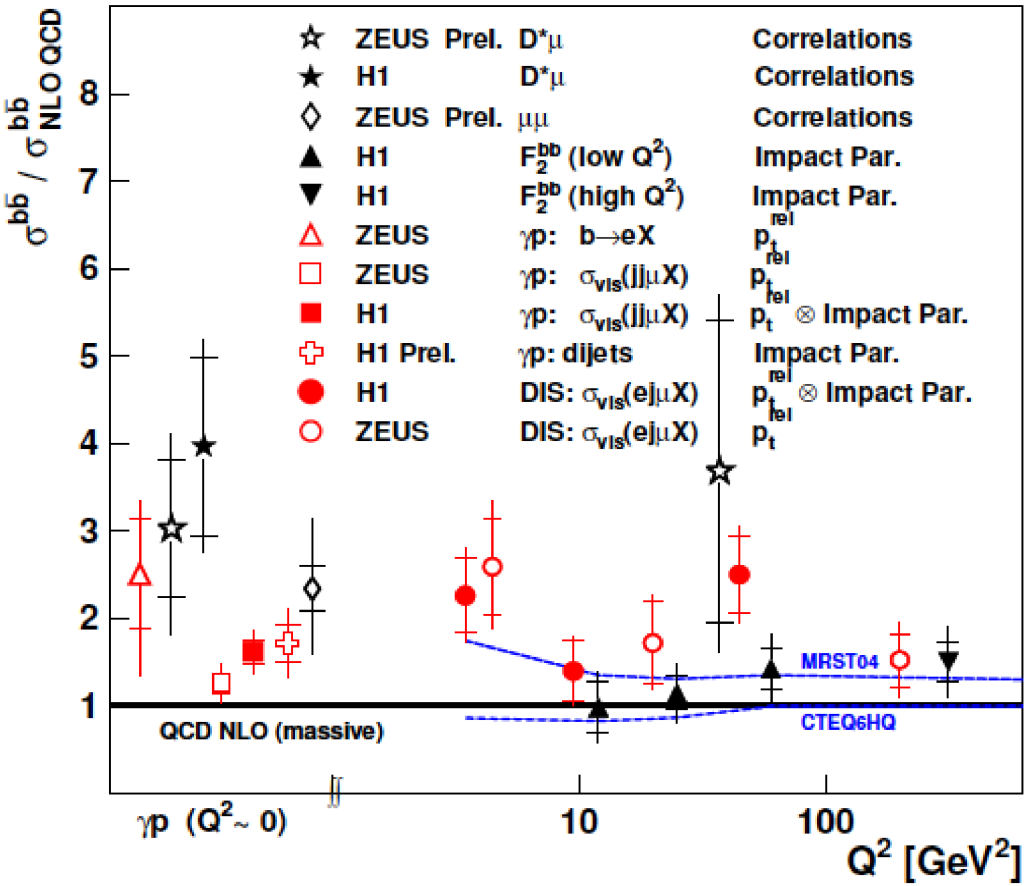

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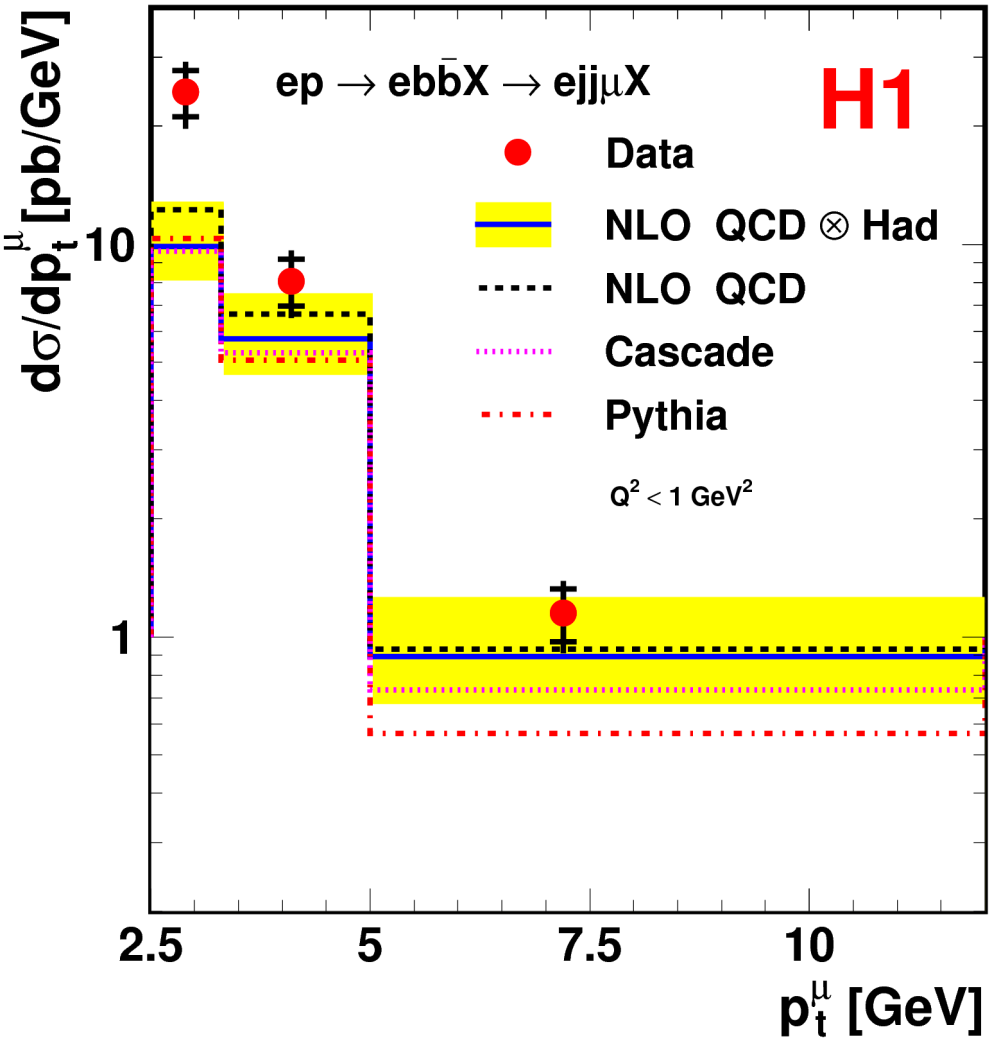
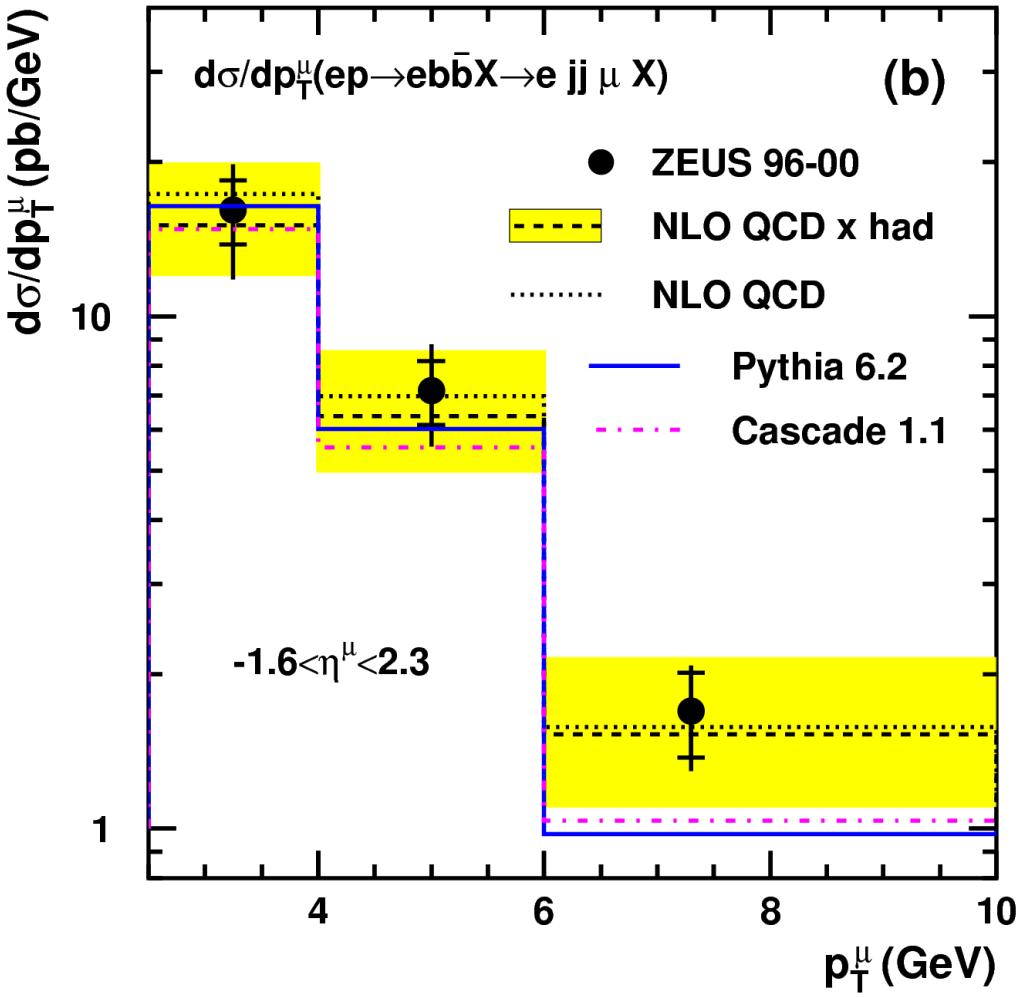


Measurement of beauty production at HERA using events with muons and jets. By H1 Collaboration (A. Aktas et al.).

Eur.Phys.J.C41:453-467,2005.

- NLO lower than the data in the lowest p_T bin by a factor of 2.5

A short history of b measurements



Bottom photoproduction measured using decays into muons in dijet events in ep collisions at $\sqrt{s}$ =318 GeV
ZEUS Collaboration; S. Chekanov et al.

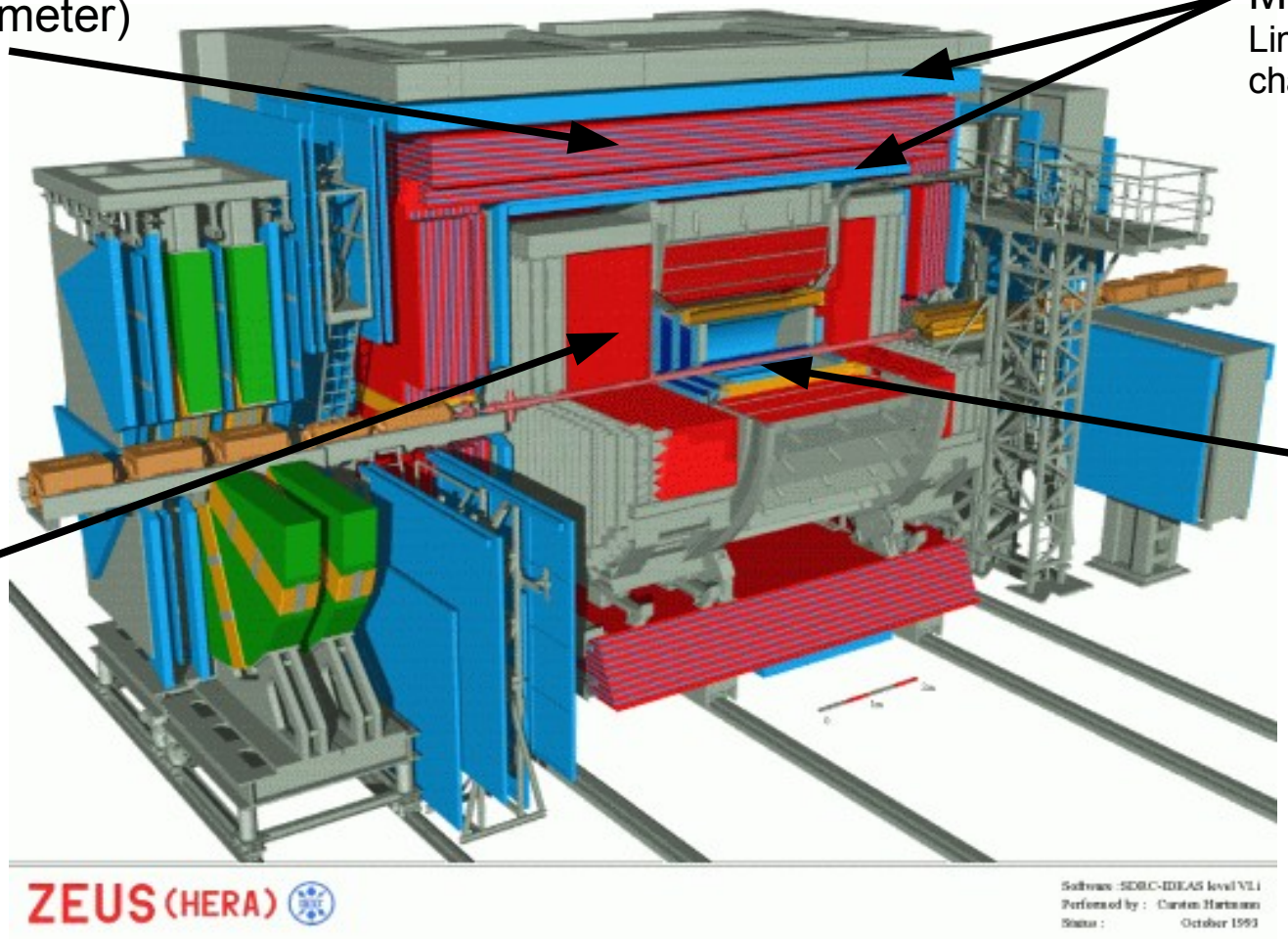
Physical Review D 70 (2004) 012008
Erratum: Physical Review D74 (2006) 059906(e)

- Good agreement with NLO observed

ZEUS detector

Yoke
(Backing calorimeter)

Muon detectors
Limited streamer tube chambers

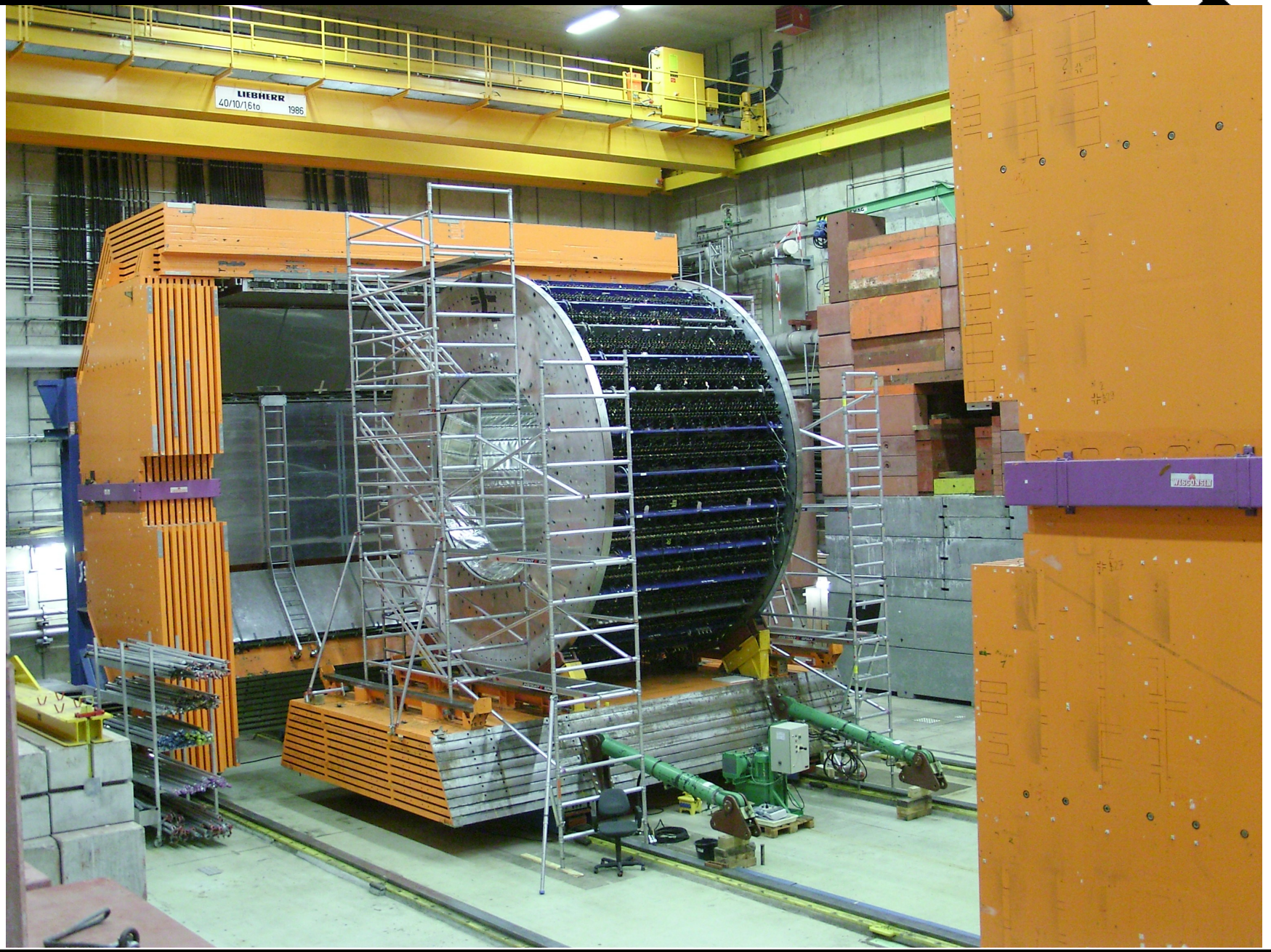


Central tracking detector
cylindrical multi-wire drift chamber inside a field of 1.8T

Uranium calorimeter
compensating calorimeter made of alternating layers of depleted uranium and scintillator

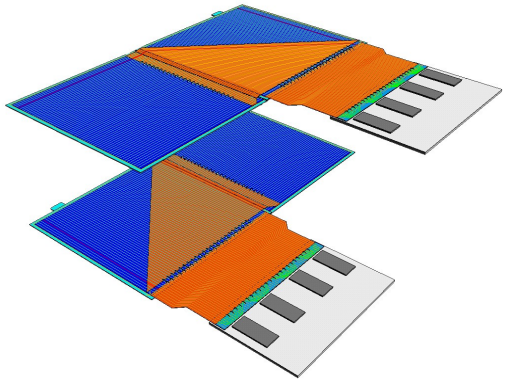
Measured 12m x 10m x 19m
Weighed 3600 tonnes

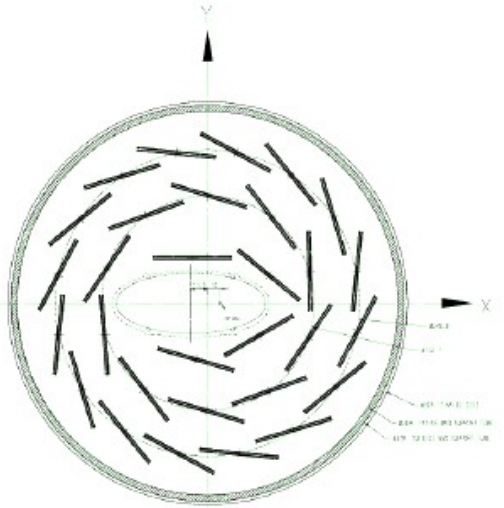
ZEUS detector

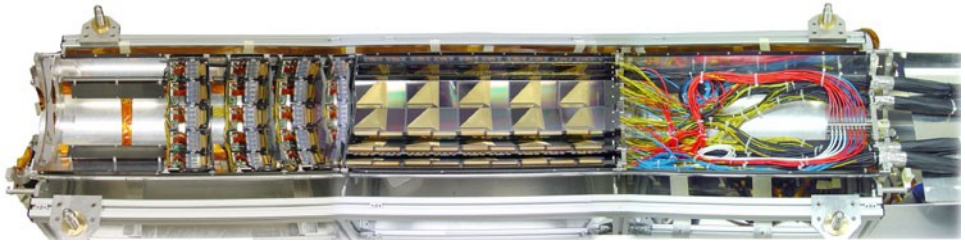


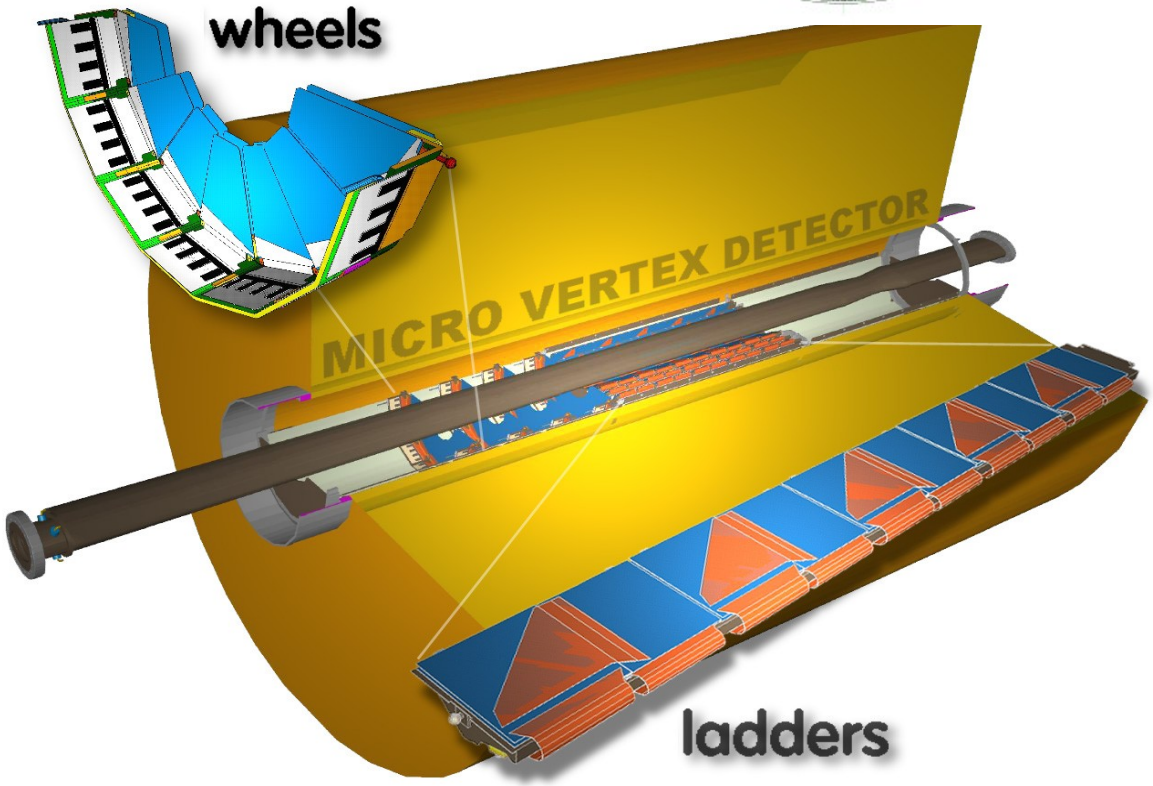
Micro Vertex Detector (MVD)

- Installed in 2001 during the HERA upgrade
- Purpose:
  - enable heavy quark tagging (secondary vertices)
  - improve tracking system
- 712 single-sided silicon strip detectors
- 2 half-modules together provided complementary r-φ and z-φ information
- 5 modules in a ladder
- 63 cm barrel comprised 30 ladders
- 4 wheels in the forward region
- Barrel half-module resolution ~13 μm
- Impact parameter resolution ~ 100 μm (3 barrel layers)





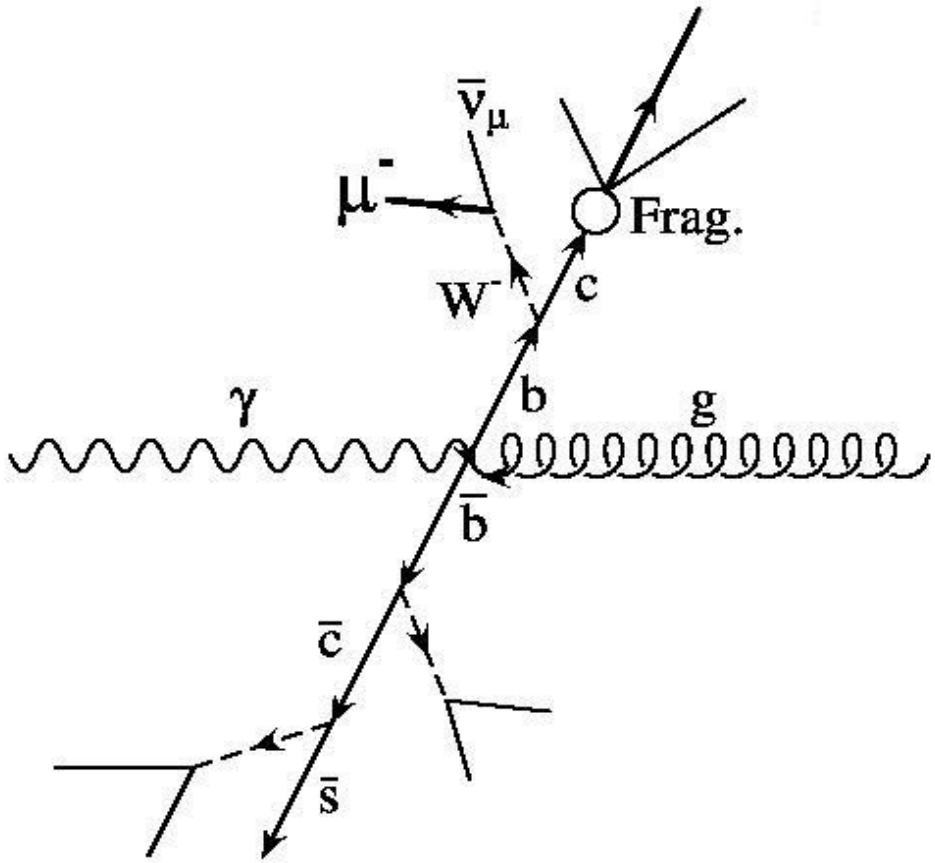




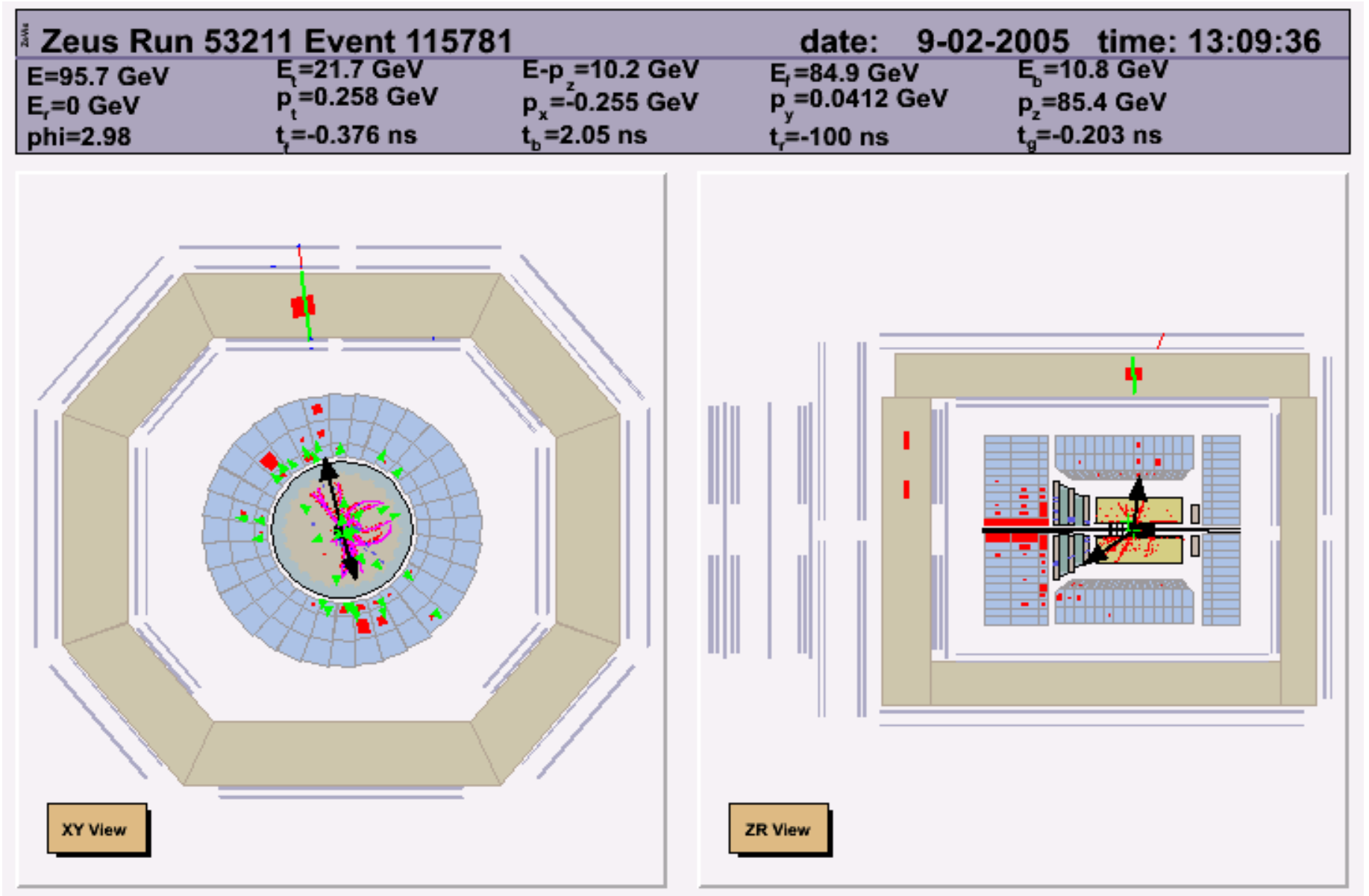
b production at HERA

- Beauty production is relatively rare at HERA $\sigma_{uds} : \sigma_c : \sigma_b \sim 2000 : 200 : 1$
  – need clean signature
- Suppression is due to kinematic threshold due to the b mass
- Predominant decay is b → c via virtual W emission
- Semi-muonic decay mode has B.R. ~10%
- Muon provides clean signature
- The two partons form two jets

→ muon + 2 jets



Experimental signature



Event Selection

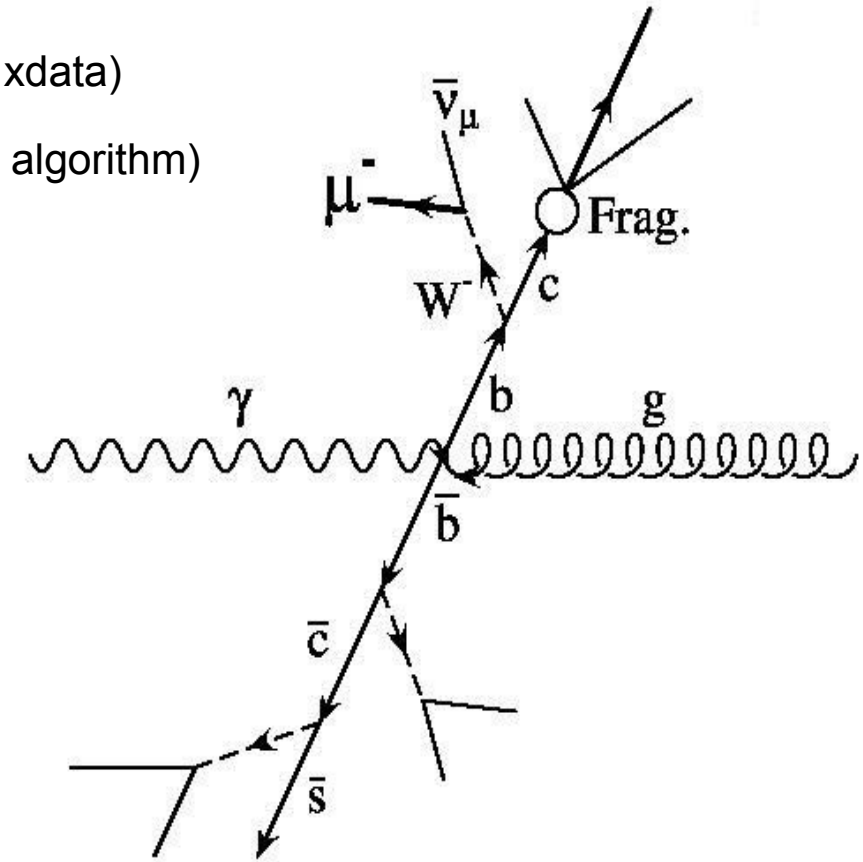
- Photoproduction: no scattered electron
- $0.2 < y_{JB} < 0.8$ to reject DIS

- This analysis uses e^-p data collected in 2005: ~$124pb^{-1}$
- Monte Carlo: PYTHIA 6.2 (bb: 9xdata, cc: 4.5xdata, LF: 1xdata)
- At least 2 jets: $-2.5 < \eta^{jet} < 2.5$, $p_T^{jet1,2} > 7{,}6$ GeV (k_T algorithm)
- At least 1 muon: $-1.6 < \eta^{\mu} < 2.3$, $p_T^{\mu} > 2.5$ GeV
- The muon must be associated with a jet (k_T algorithm)
- Photoproduction $Q^2 \sim 0 GeV^2$

→ **7351** events

- Define another sample with $p_T^{\mu} > 1.5$ GeV

→ **14172** events

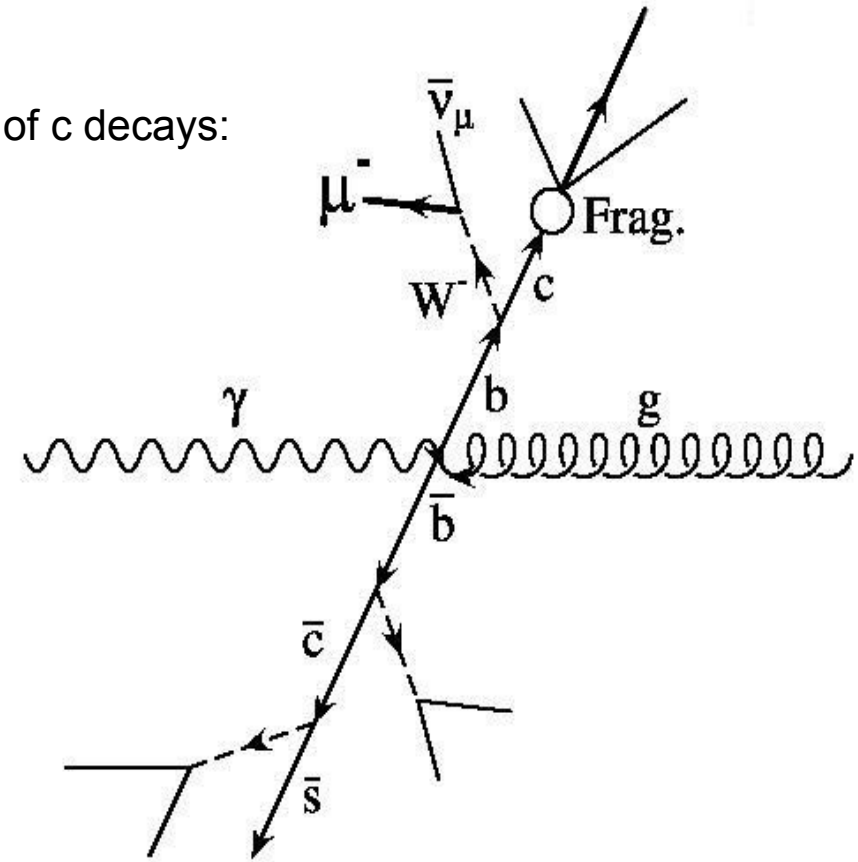


Backgrounds

- Heavy vector mesons < 1%
- Cosmic muons – negligible
- Misidentified hadrons
- Semi-muonic charm decays: VERY similar signal

Need to exploit properties of b decays which differ to those of c decays:

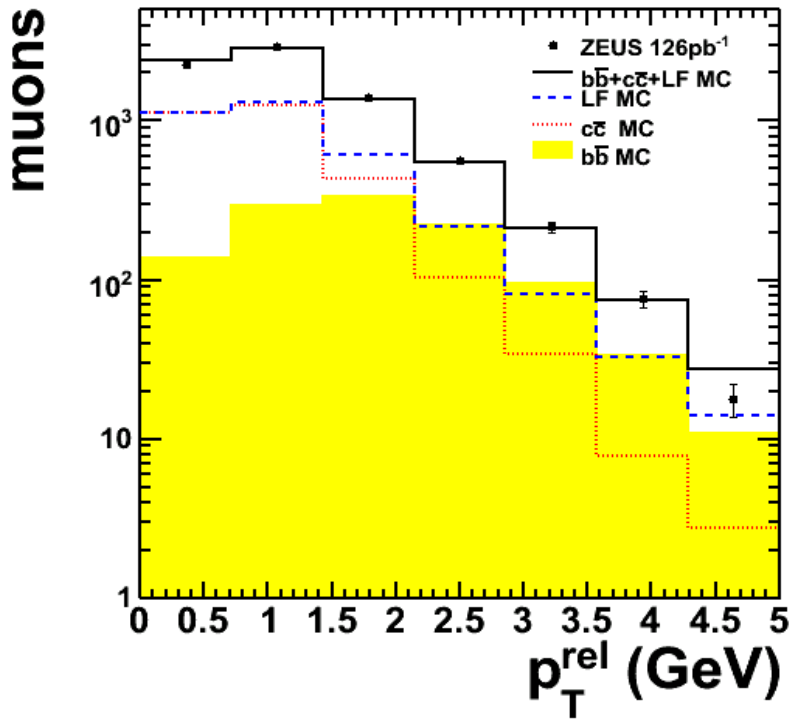
- **Larger mass**
- **Longer lifetime**

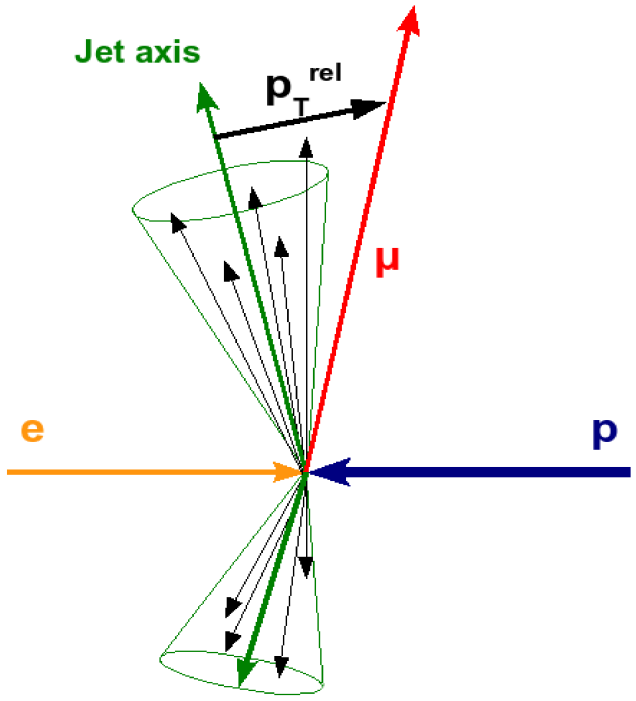


p_T^{rel} method

- Exploiting the large mass of the b quark: $m_b \approx 3 \times m_c$
- Muons from b decays will have a harder p_T spectrum than those from charm
- In particular, they have a larger p_T with respect to the mother hadron direction
- Experimentally we use the jet axis
- p_T^{rel} is the transverse momentum of the muon relative to the associated jet

$$p_T^{rel} = \frac{|p^\mu \times (p^j - p^\mu)|}{|p^j - p^\mu|}$$





Impact parameter method

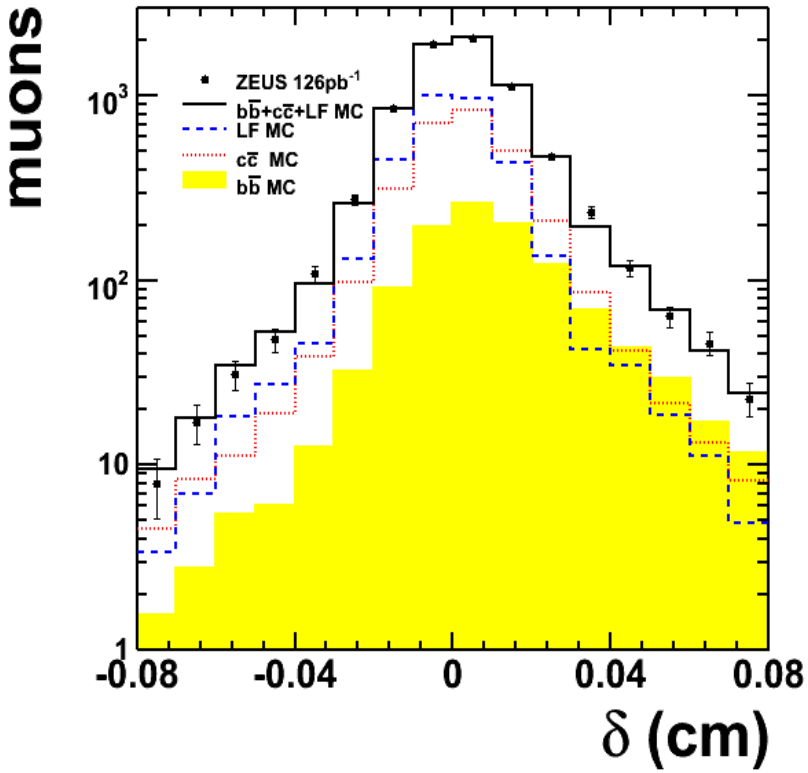
- Exploiting the long lifetime of the B hadron :

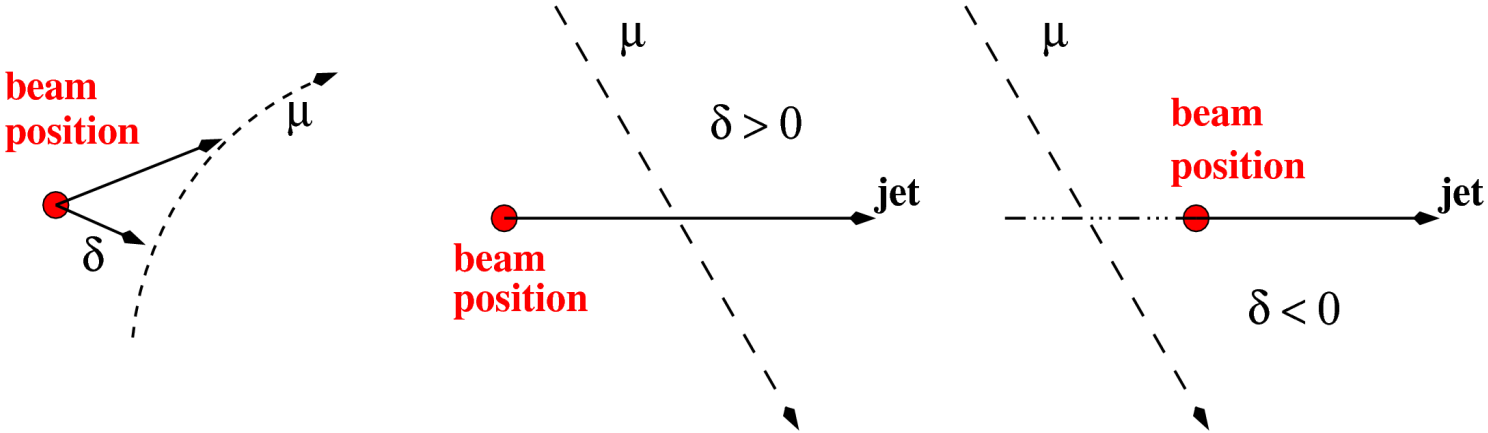
  lifetime ~ 1.5 ps ⟶ proper decay length ~ 450μm

- Charmed hadrons eg. D^0:

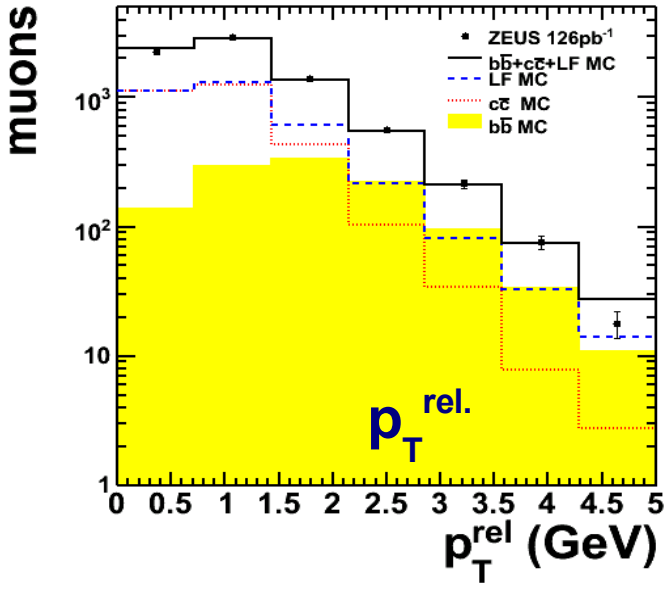
  lifetime ~ 0.4 ps ⟶ proper decay length ~ 120μm

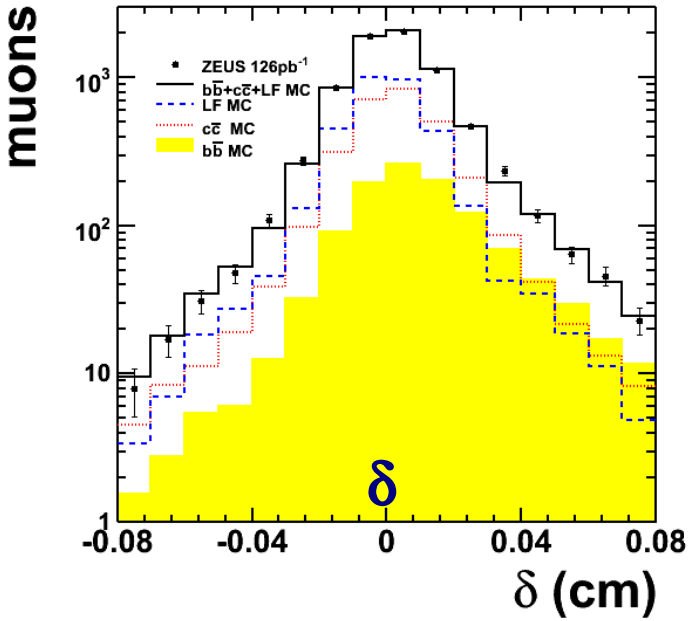
- Only decay products are experimentally accessible
- Impact parameter δ is the distance of closest approach of the muon with respect to the beam position
- Muons from b and c decays will have a large positive δ
- Light flavours have a δ distribution symmetric about zero





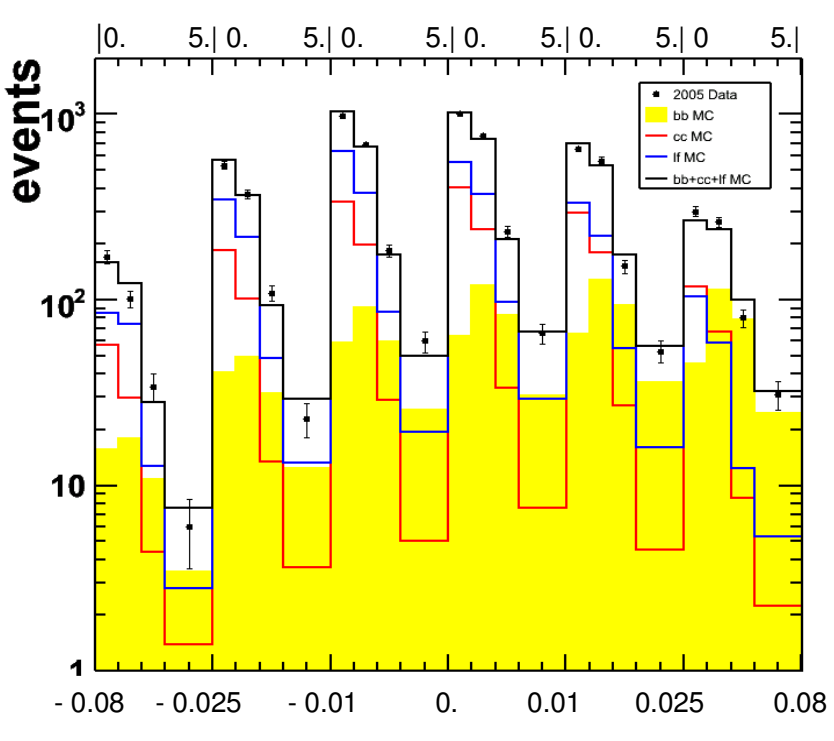
Extracting the beauty





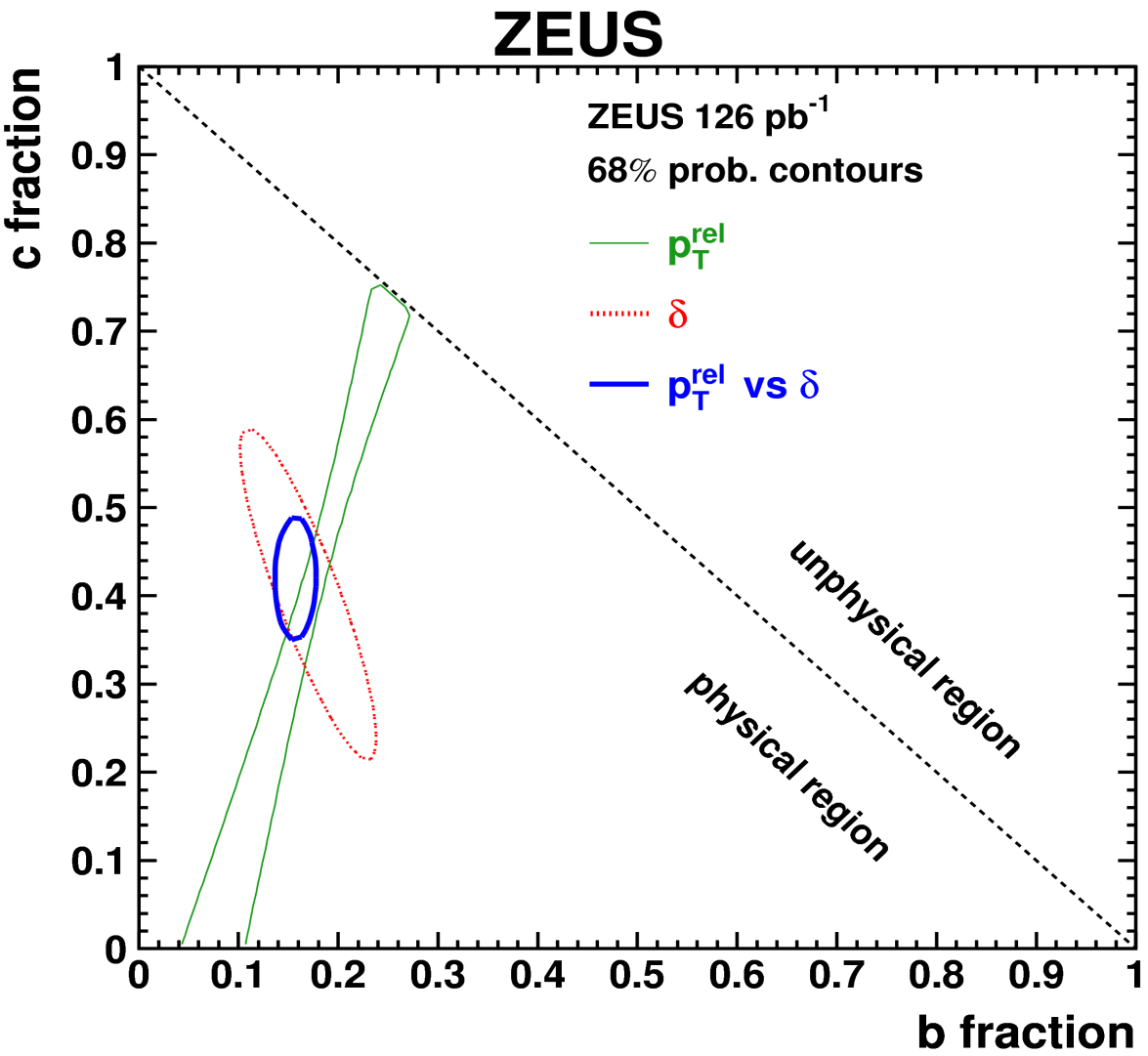
- Fraction of beauty events in the sample is extracted statistically
- Simultaneous 2-d fit of the data with the MC distributions

$$f = a_{b\bar{b}} f_{b\bar{b}} + a_{c\bar{c}} f_{c\bar{c}} + a_{lf} f_{lf}$$

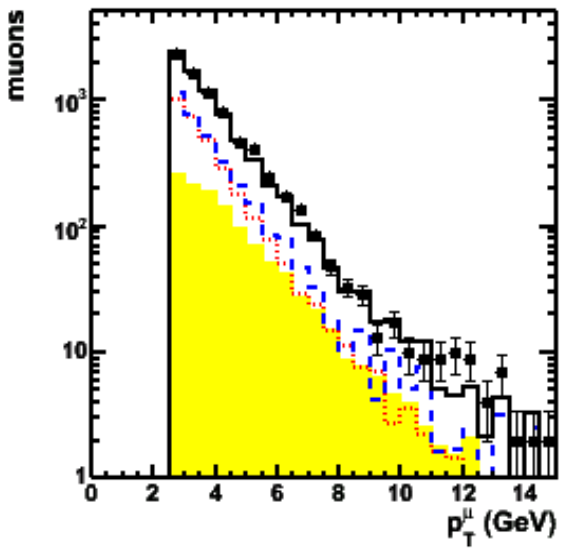


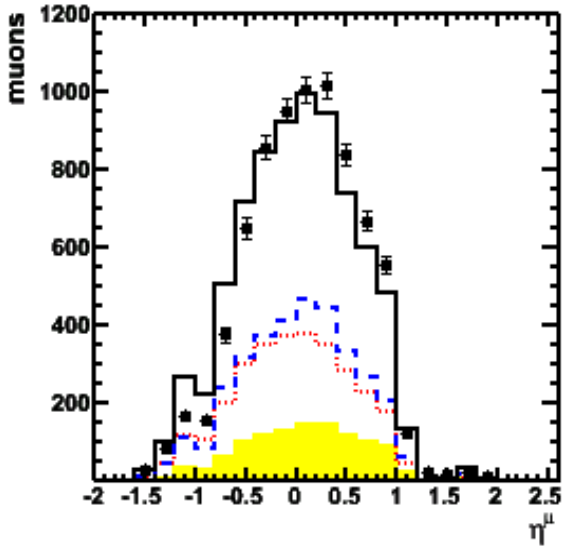
a_{bb} = 0.175 ± 0.013
a_{cc} = 0.316 ± 0.057
a_{lf} = 0.509 ± 0.055

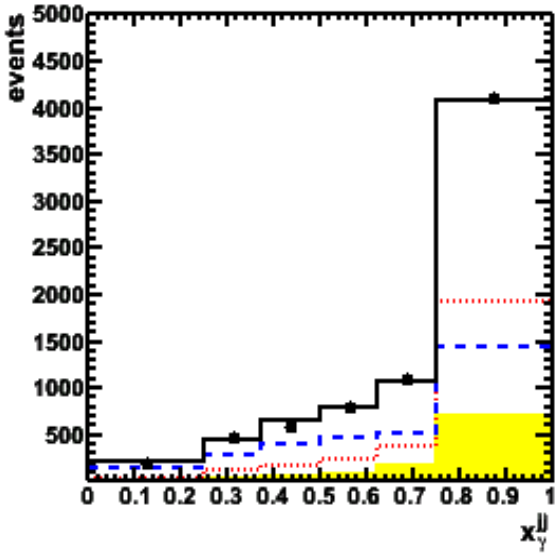
Extracting the beauty

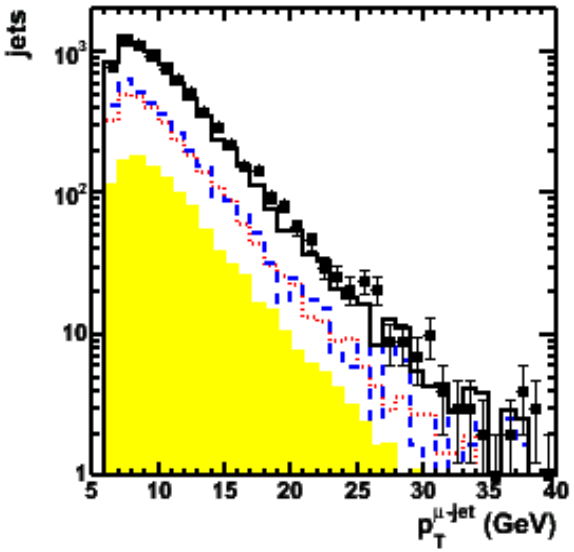


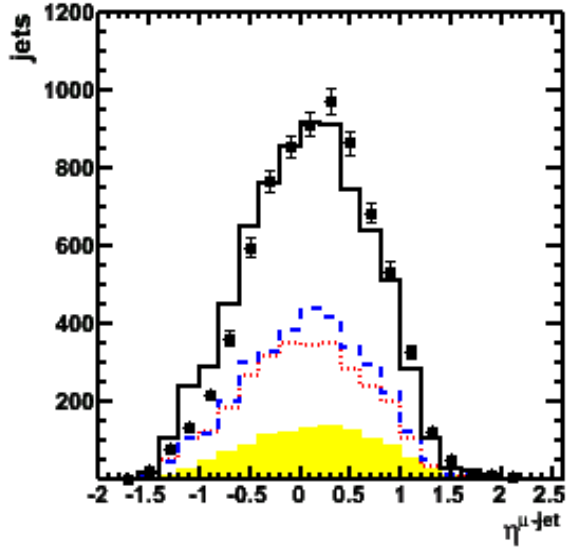
Control distributions











ZEUS 2005

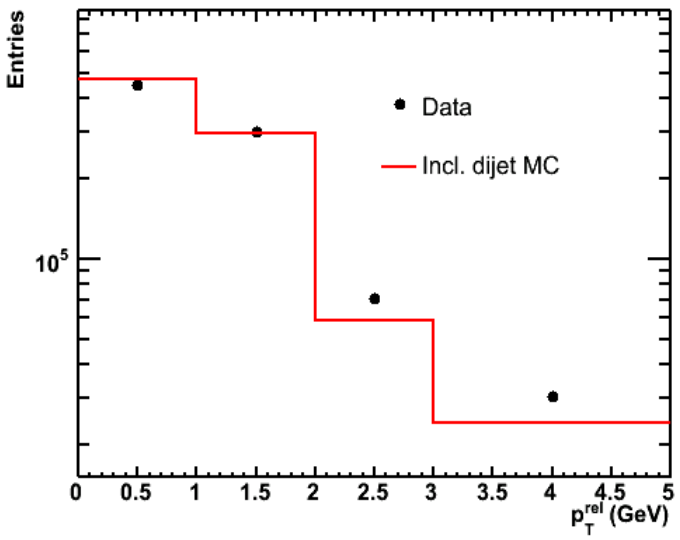
$b\bar{b}+c\bar{c}$+LF MC

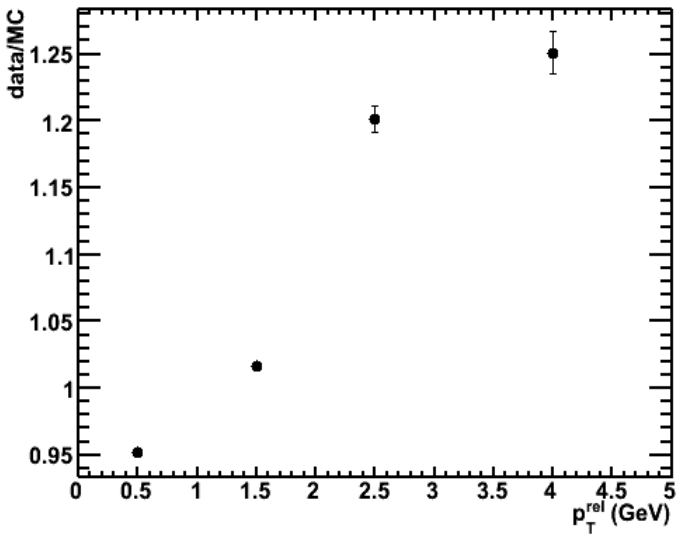
LF MC

$c\bar{c}$

$b\bar{b}$

p_T^{rel} correction





A note about the p_T^{rel} correction:

- Motivated by poor description of data by the MC seen in the p_T^{rel} distribution
- Solution is to scale the MC histograms (input to the fit) by a correction factor
- Calculated using sample of 2005 data (~80pb^{-1}) and a PYTHIA MC sample (~40pb^{-1}) with same cuts as in the analysis except muon requirement (unidentified tracks)
- Correction factor is the ratio of data/MC
- It is calculated in each bin of every cross section measured
- 100% of the correction is applied to LF
  50% is applied to charm samples

Impact Parameter smearing

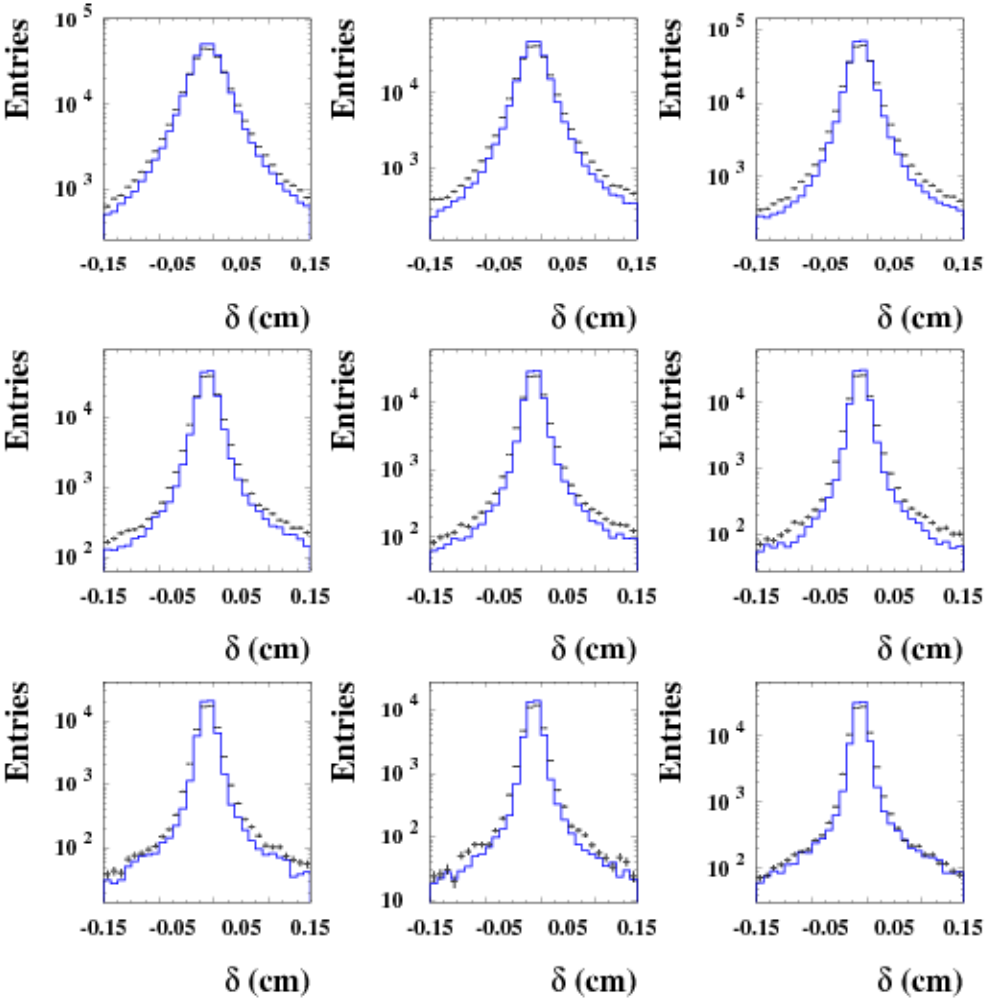
Impact Parameter distribution not well described by MC and so a smearing needed to be applied

2005 data: 30pb^{-1}

MC: inclusive dijet sample 30pb^{-1}

No muon requirement but a good quality track.

before



Impact Parameter smearing

The following smearing has been added to impact parameter of all muons selected in the MC:

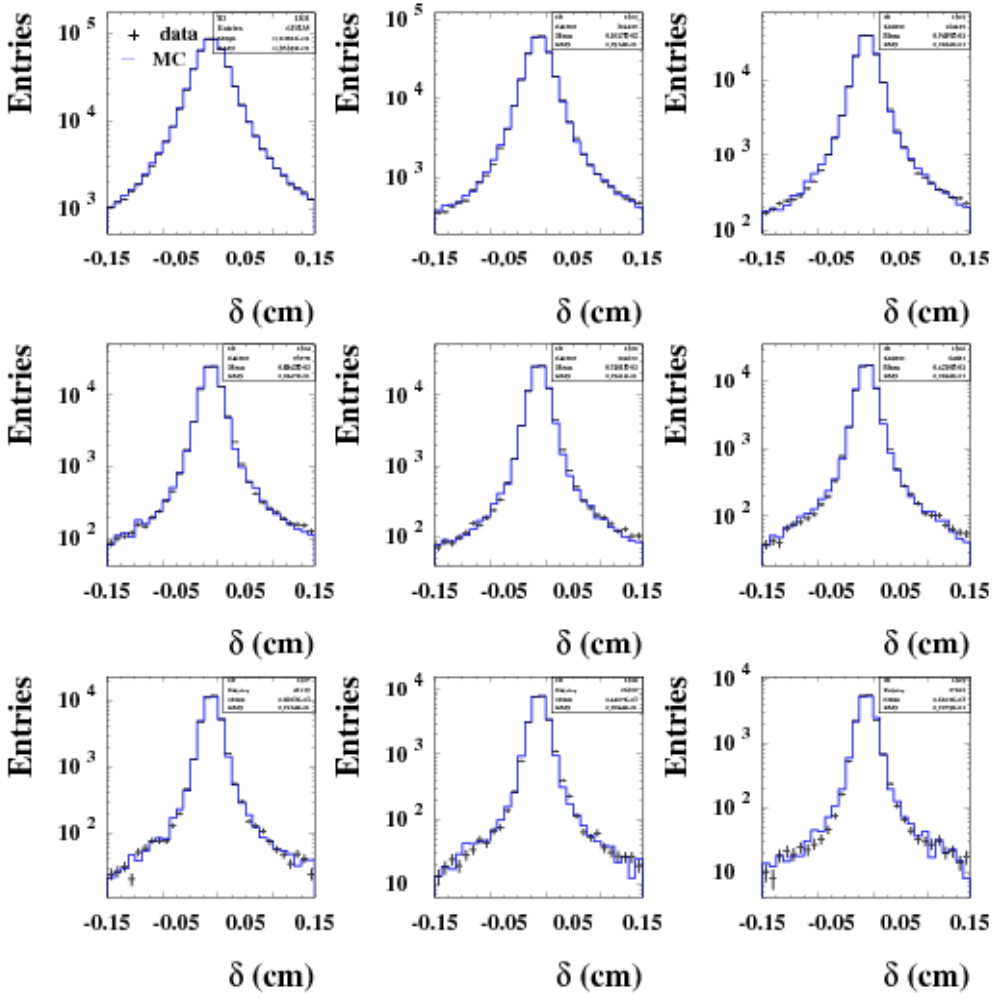
$SMR_{B.W} = N_{ran(BW)} e^{(a - b.pT_\mu)} + c) * const.$

$SMR_{GAUS} = N_{ran(gaus)} * (d + f.p_T^\mu)$

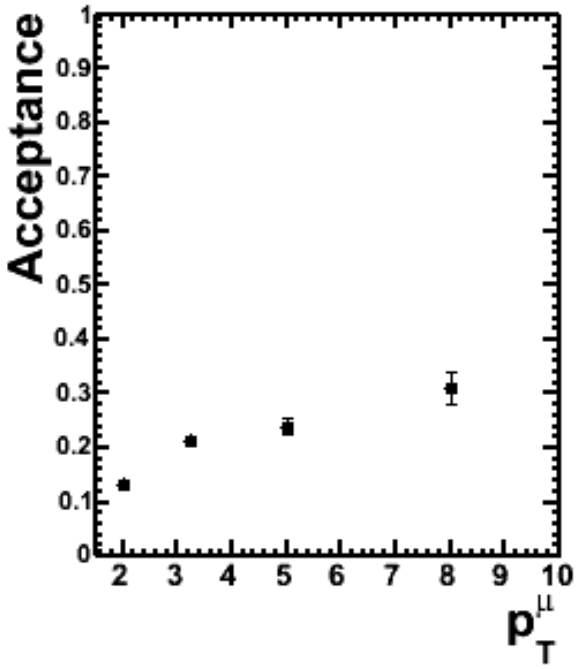
$I.P._{new} = I.P_{old} + SMR_{B.W} + SMR_{GAUS}$

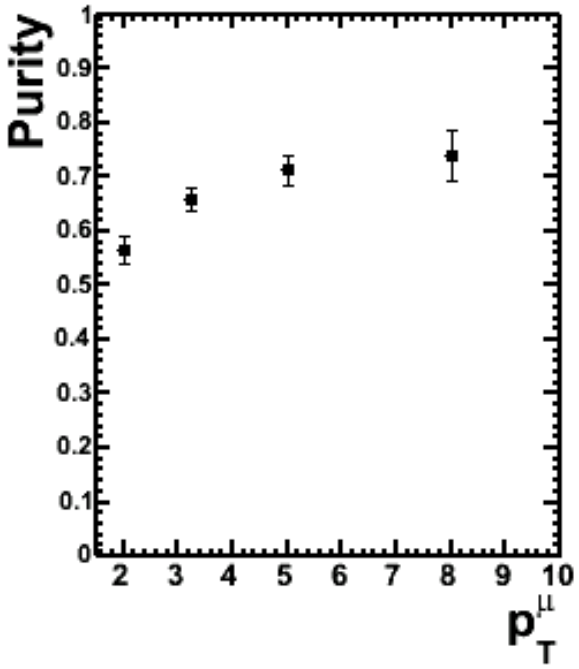
a = 1.9791
b = −0.83335
c = 2.3414
d = 0.0037817
f = 0.00039859
const. = 0.001

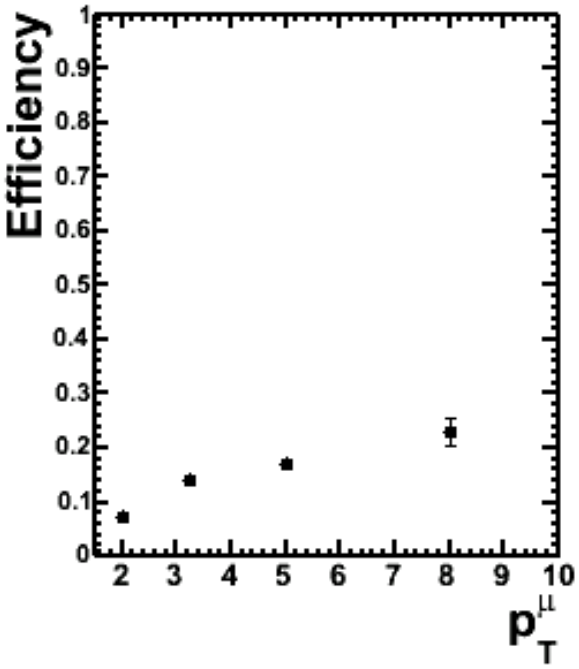
after



Acceptance





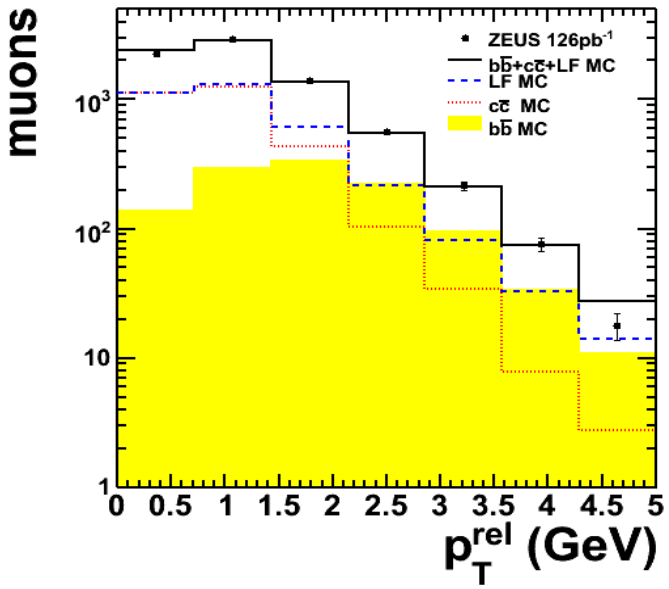


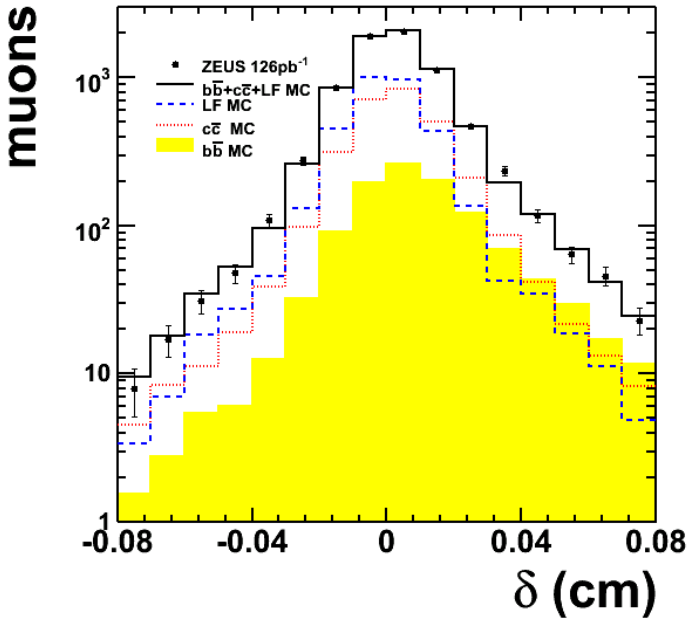
$$acceptance = \frac{efficiency}{purity}$$

$$purity = \frac{N_{rec \cap gen}}{N_{rec}}$$

$$efficiency = \frac{N_{rec \cap gen}}{N_{gen}}$$

Cross section





$$\sigma = \frac{N_{muons}\, a_{b\bar{b}}}{A\, L}$$

$$\sigma = 38.6 \pm 3.5\,(stat.) + 4.6 - 4.9\,(syst.)\ pb$$

$$\sigma_{NLO} = 39.2 + 14.4 - 6.9\ pb$$

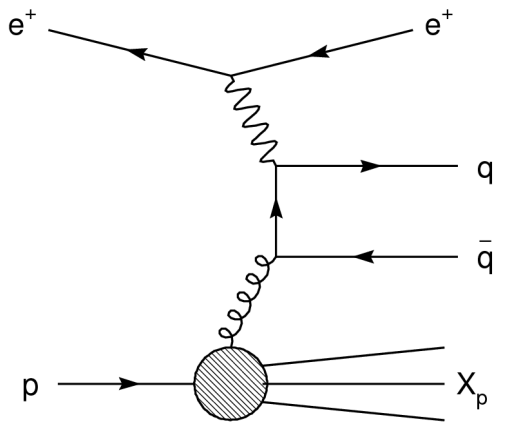
Theoretical model

- Massive approach
- Heavy quarks have mass and are not part of structure functions
- c and b are produced perturbatively in the hard interaction
- Appropriate for $Q^2 \sim M_b^2$, if $Q^2 >> M_b^2$ then large $\ln(Q^2/M_b^2)$ appear
- Program used in photoproduction is FMNR (Frixione et al.)

$\mu^2 = \mu_0^2 = (p_T^b)^2 + (m_b)^2$ $\quad 0.5\,\mu_0 < \mu < 2\mu_0$

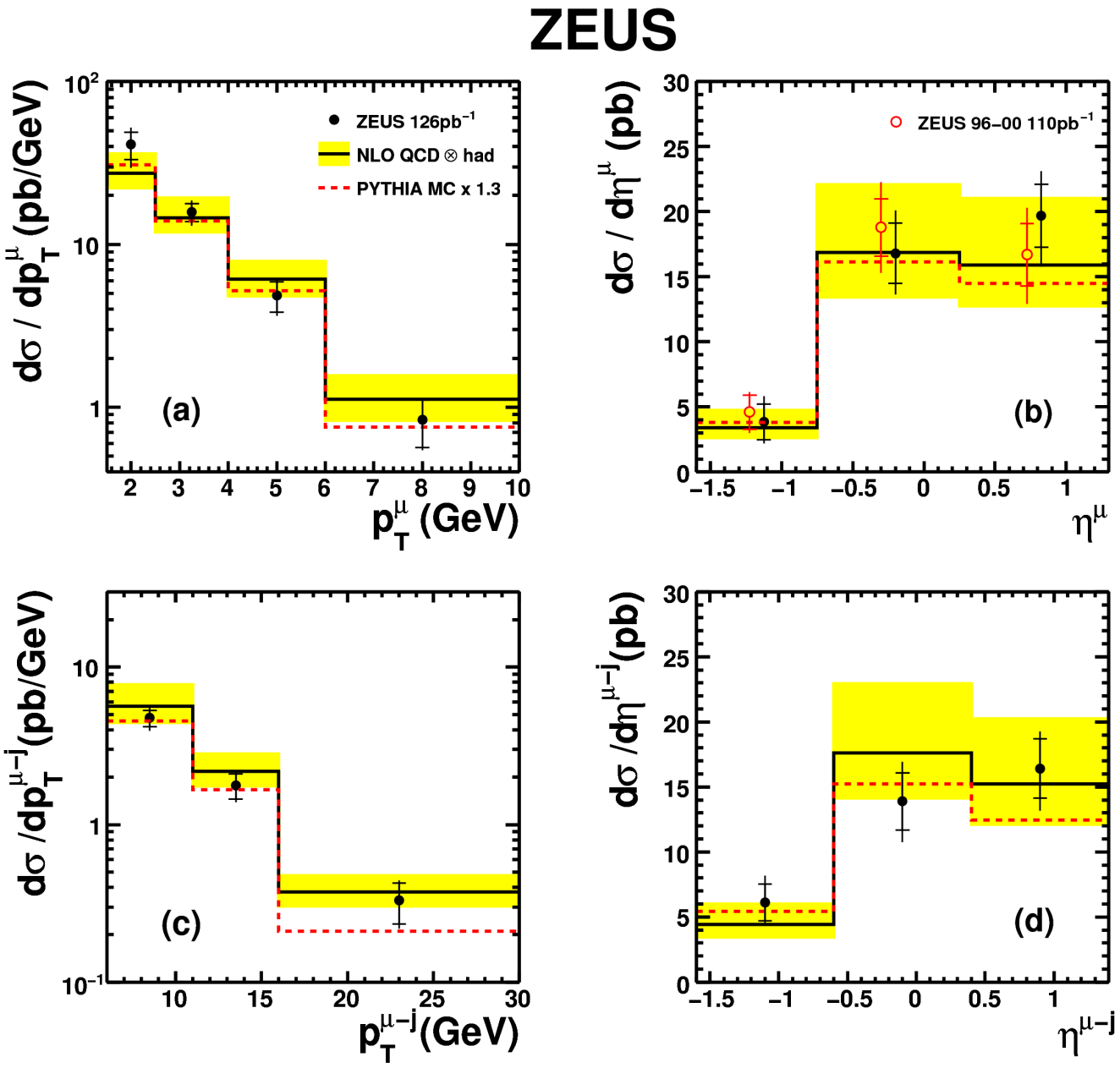
$m_b = 4.75\text{GeV}$ $\quad 4.5\text{GeV} < m_b < 5\text{GeV}$

Proton PDF: CTEQ5M, Photon PDF GRV-G HO

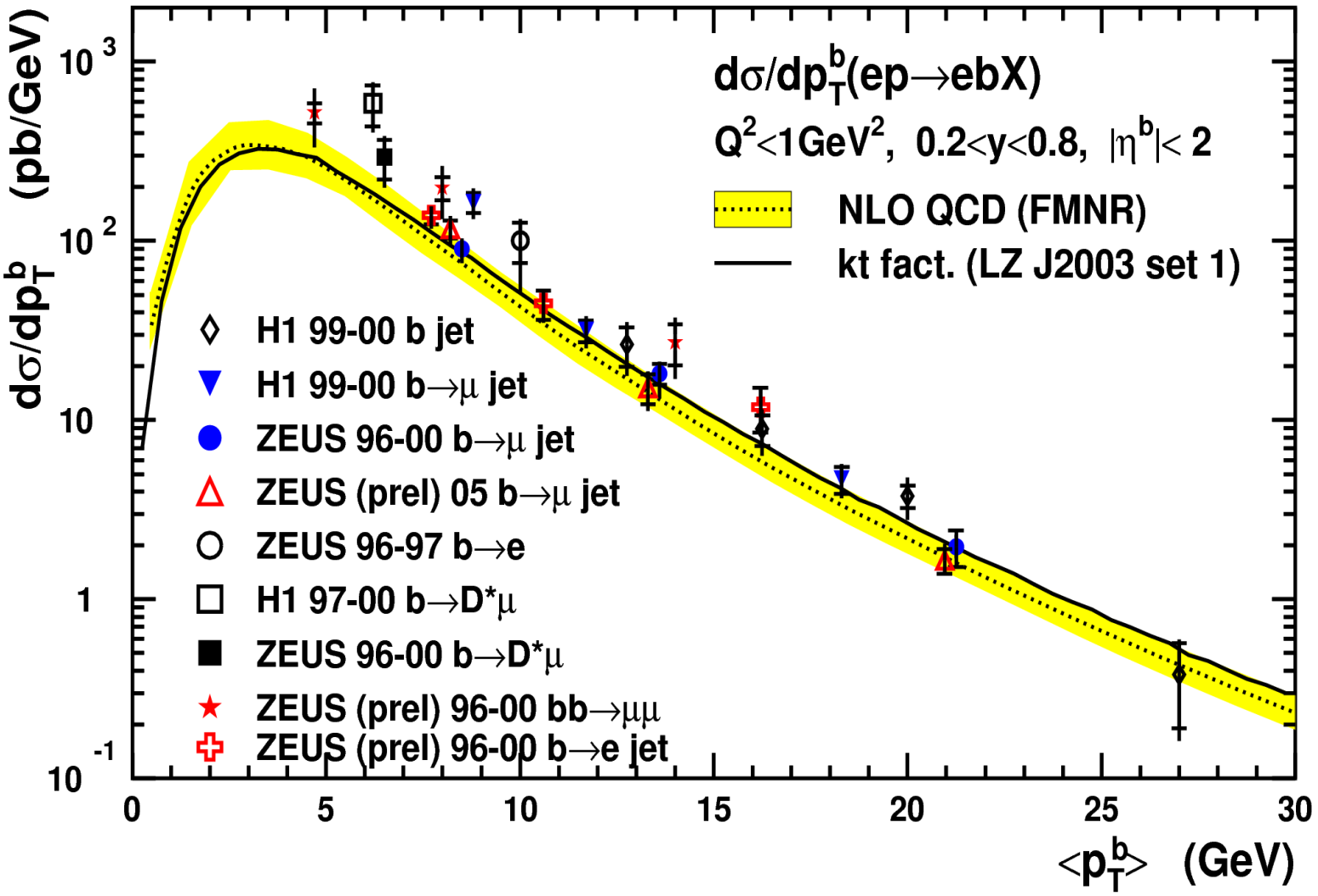


Muon and jet variable cross sections

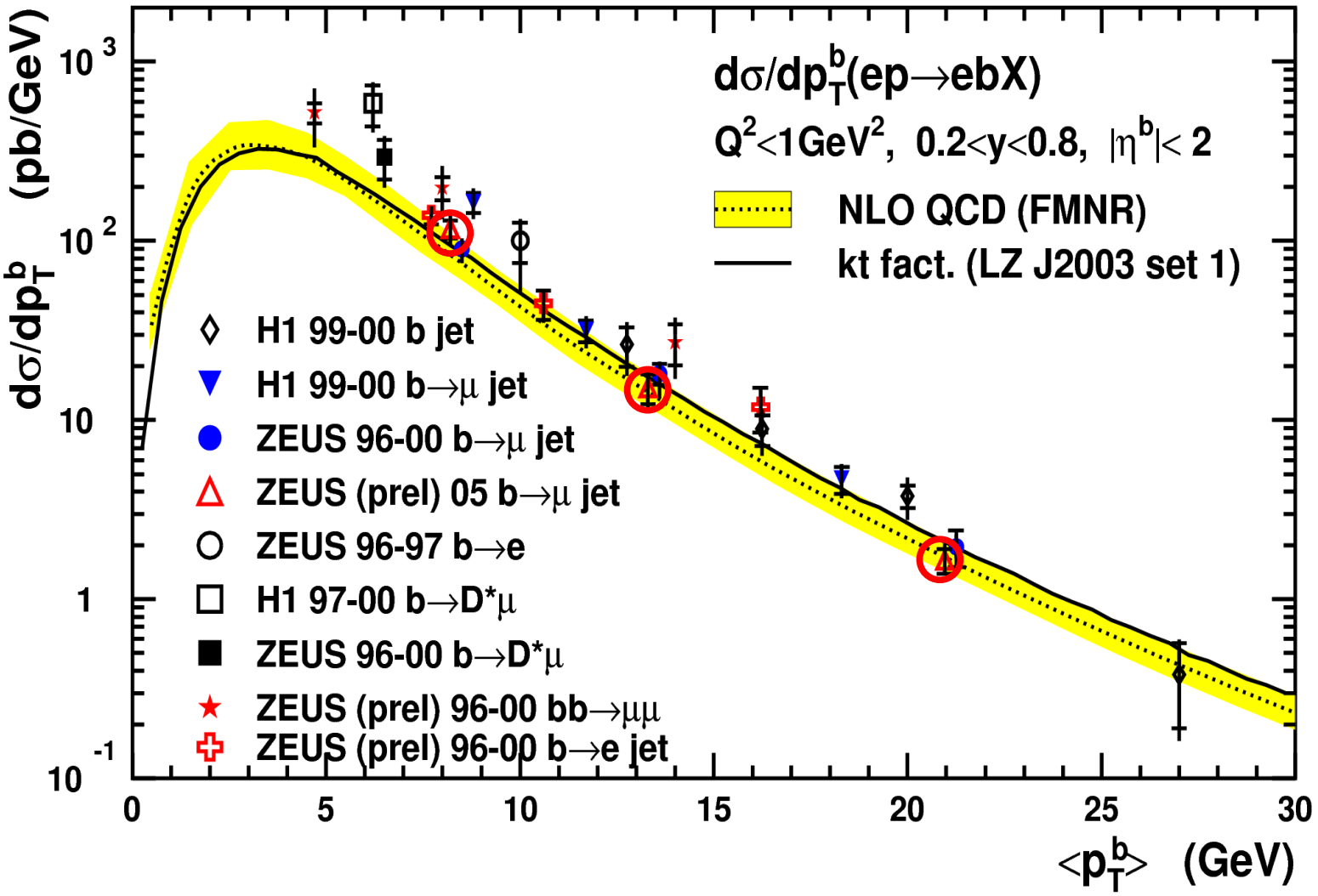
- HERA I measurement made with $p_T^{rel.}$ fit only
- Also compared to NLO QCD prediction made with FMNR program



b measurements at HERA

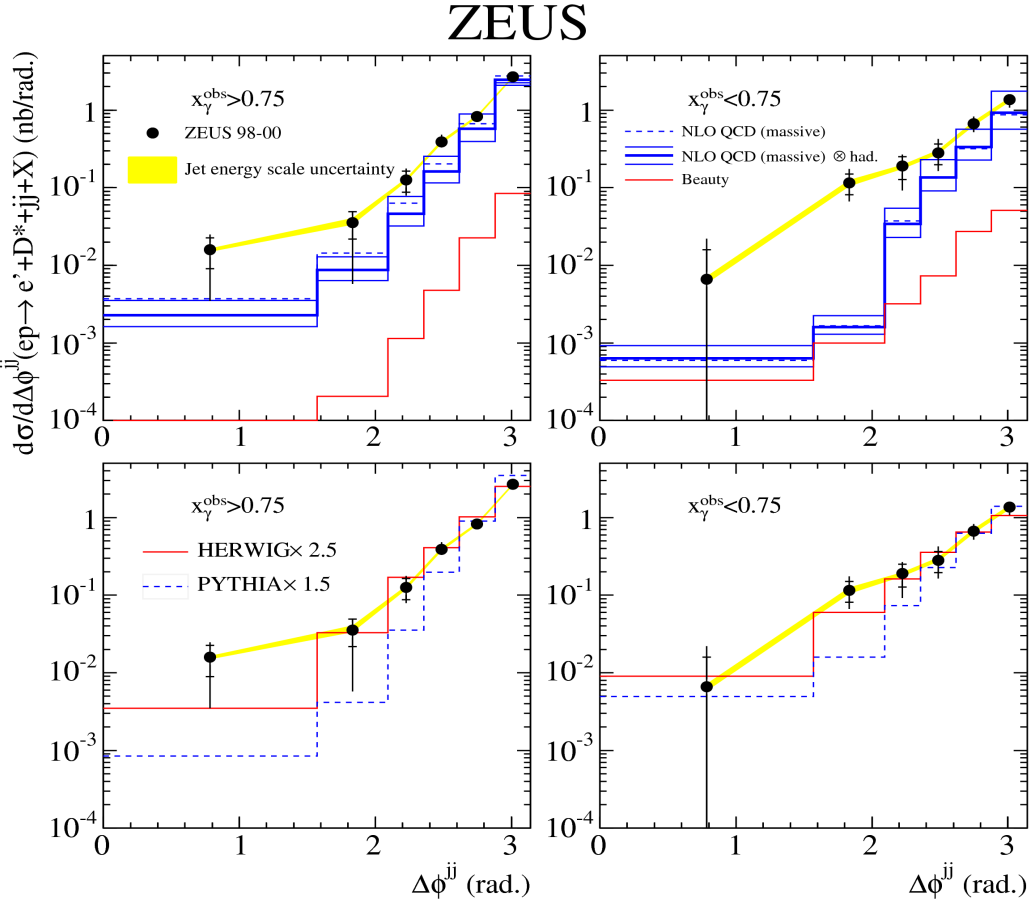


b measurements at HERA

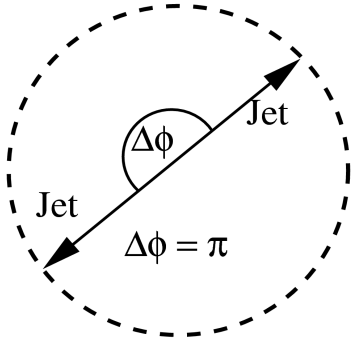


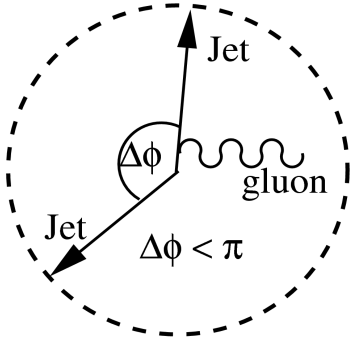
Dijet correlations in charm

- Dijet correlation cross sections, e.g. difference in azimuthal angle, have been measured in charm
- Such variables are sensitive to higher order topologies
- Discrepancies observed w.r.t NLO QCD prediction for low $\Delta\phi$
- Can we see this in beauty?



$$\Delta\phi_{jj} = \phi_{j1} - \phi_{j2}$$

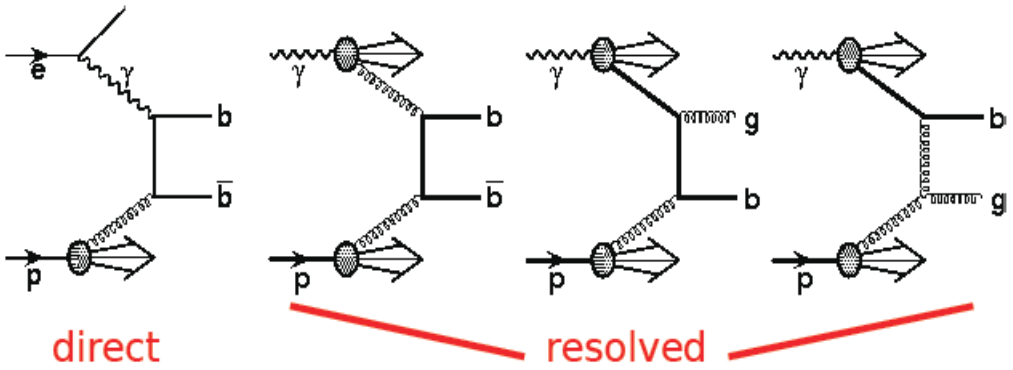




Inclusive Jet Cross Sections and Dijet Correlations in D* Photoproduction at HERA

Nuclear Physics B 729 (2005) 492-525

In LO QCD:



- DIRECT PHOTON: interacts directly with the hard subprocess
- RESOLVED PHOTON: acts as a source of partons
- Experimental separation is defined as x_γ, the photon energy fraction (summing over the partons)

$$x_\gamma = \sum_i \frac{E_T^i e^{-\eta_i}}{2 E_e y}$$

- The observable quantity x_γ^{obs}, sums over the jets instead of the partons

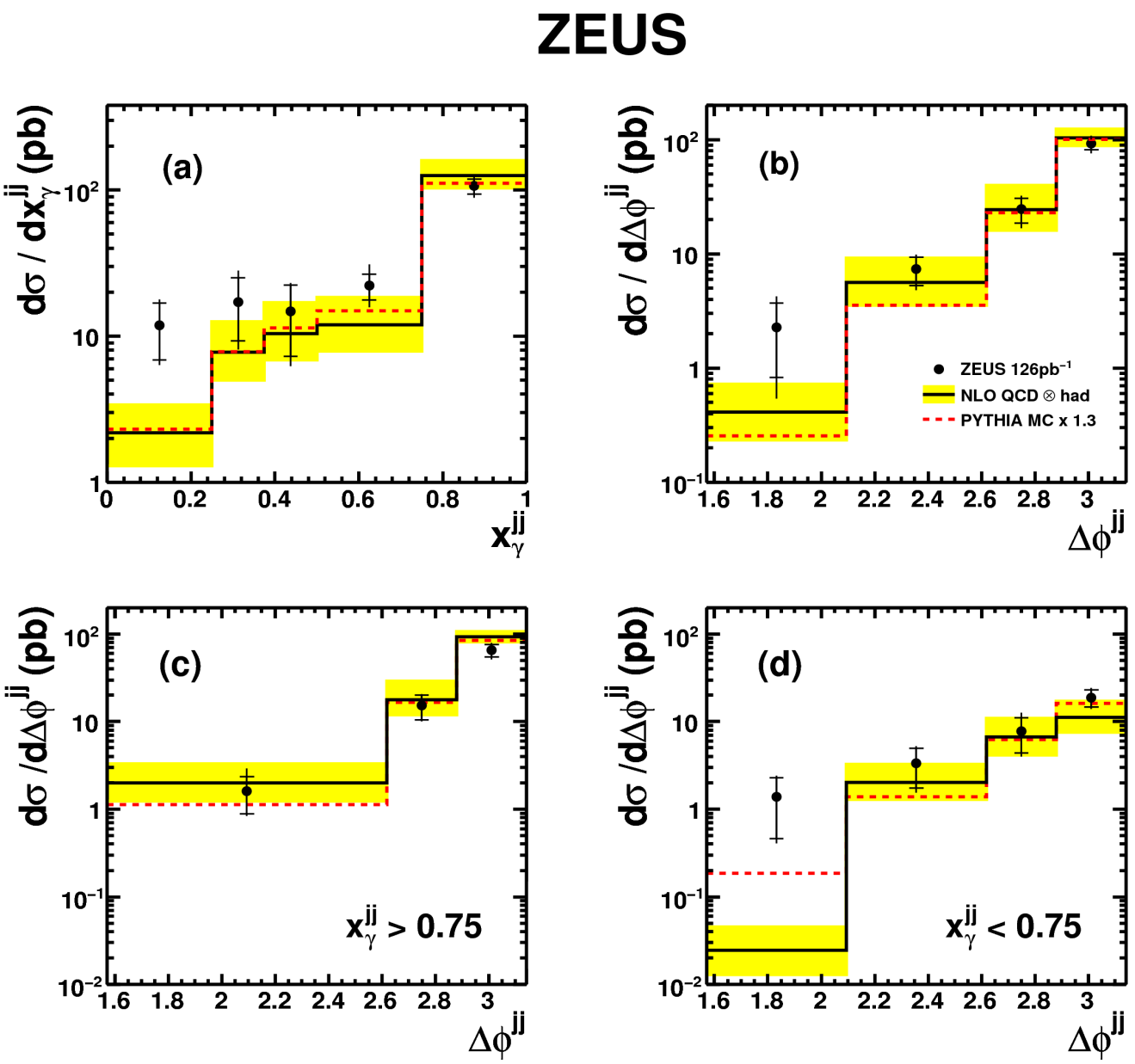
$$x_\gamma^{obs} = \frac{(E - P_z)_{j1} + (E - P_z)_{j2}}{2 E_e y}$$

- Direct processes populate the highest regions of x_γ so we define:

DIRECT: $x_\gamma^{obs} \geqslant 0.75$ RESOLVED: $x_\gamma^{obs} < 0.75$

Dijet cross sections

- x_γ cross section provides a tool to measure the relative importance of direct and resolved photon processes
- High-x_γ peak dominates
- Although resolved photon component is apparent
- $\Delta\varphi$ is sensitive to higher order topologies
- Cannot claim any disagreement
- Less apparent in beauty than charm
- $\Delta\varphi$ cross section has also been measures for direct and resolved enriched samples



Conclusions

- I have presented a recent measurement from the ZEUS collaboration
- It is the first measurement to use the Micro Vertex Detector at ZEUS
- It is also one of the most precise ever made in b-production at HERA
- Paving the way for final ZEUS analyses using complete data set
- Not much doubt that beauty production can be described by pQCD
- But it is a reassuring agreement
- Dijet correlations in beauty have been measured for the first time at ZEUS
- HERA has finished but the analyses have not!

Thank you for listening!

Sources of systematic uncertainty

HERA I

- **Muon acceptance: ~ 10%**
  - Efficiency of muon chambers
  - Reconstruction efficiency
  - Efficiency of muon-CTD info
- **p_T^{rel} correction ~ 10%**
  - Vary the charm fraction in background
  - Vary correction on LF +/- 20%
  - Vary correction on cc +/- 100%
- **Branching ratios ~ 1%**
- **Dijet selection, energy scale and trigger efficiency ~ 7%**
- **Flavour excitation contribution ~ 3%**
- **Dir/resolved contributions: not included**

HERA II

- **Muon efficiency correction ~ 7%**
  - Efficiency of muon chambers
  - Reconstruction efficiency
  - Efficiency of muon-CTD info
- **p_T^{rel} correction**
  - Vary correction on LF +/- 20% **~ 2%**
  - Vary correction on cc +/- 100% **~ 4%**
- **Smearing ~ 10%**
- **MVD efficiency ~ 3%**
- **Energy scale ~ 4%**
- **Flavour excitation contribution ~ -1.5%**
- **Dir/resolved contributions ~ +1.8%**