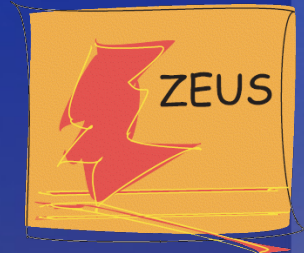


# Charm and Beauty Photoproduction at HERA



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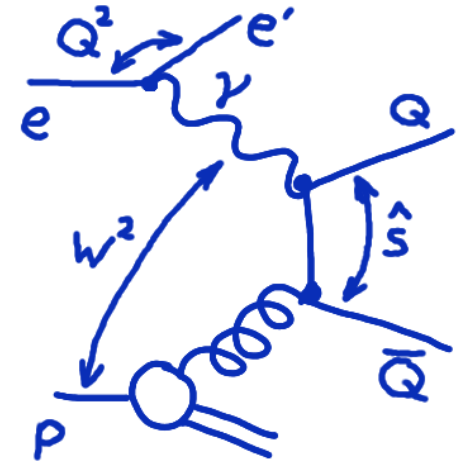
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# Introduction

- Charm and beauty quarks at HERA are mainly produced in Photon-Gluon-Fusion → sensitive to the **gluon** in the proton
- Photoproduction: Virtuality  $Q^2$  of the photon is small ( $Q^2 < 1\text{GeV}^2$ )
- Hard scales for perturbative QCD:  $m_Q \sim 1.5 / 5 \text{ GeV}$ ,  $p_T$  of quarks/jets → usually combined to  $\mu_0 = \sqrt{(m_Q^2 + p_T^2)}$
- Interpretation of Heavy Flavour Measurements:



Trust the pQCD calculations  
→ Constrain the gluon density of the proton

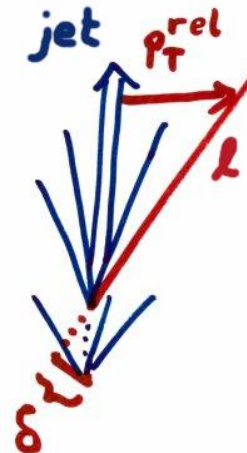
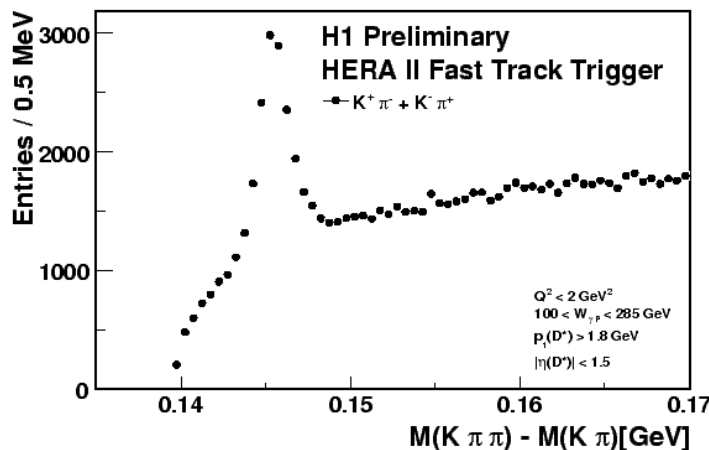


Take the gluon from elsewhere  
→ Investigate accuracy of pQCD calculations

# Measurements

Measurements discussed today:

- Open charm: Measurements of  $D^*$  production
- Open beauty: Measurements with leptons
  - ▶ Events with 2 jets and a lepton  $\rightarrow$  restricted phase space
  - ▶ Events with 2 leptons  $\rightarrow$  fully inclusive b cross section
- For Hidden charm: Production of  $J/\psi$  Mesons:  
cf. Talk by M. Jüngst, Friday 11:30, Heavy Flavour Session



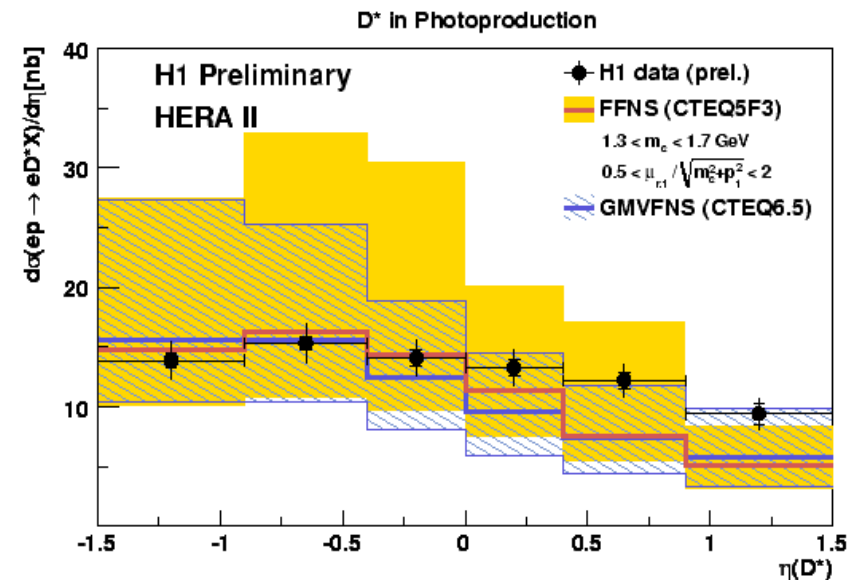
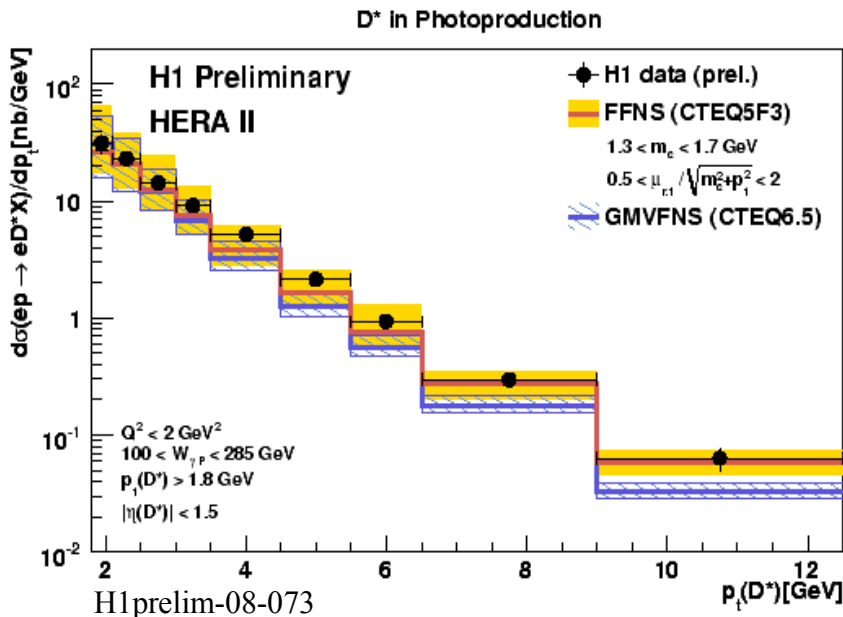
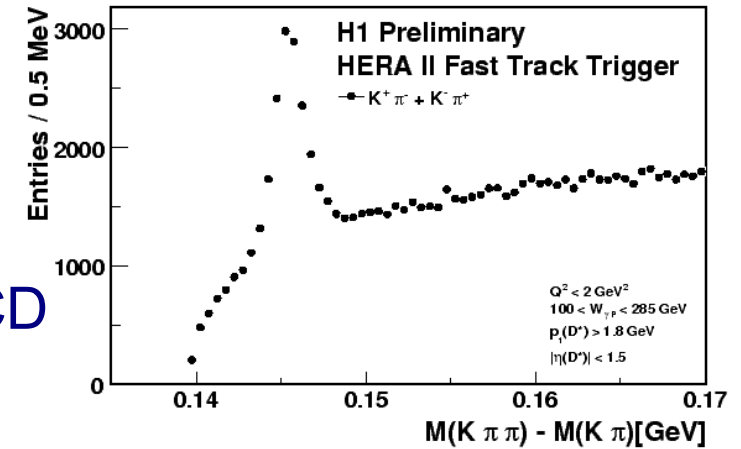
# QCD Models

- Leading Order Monte Carlo Generators:
  - ▶ Pythia: Based on collinear factorization / DGLAP evolution
  - ▶ Cascade:  $k_T$  factorization / CCFM evolution
  - ▶ Both used for data correction and model comparisons
- Next to Leading Order Calculation:
  - ▶ FMNR: Calculation in a massive scheme
  - ▶ No parton showers, independent fragmentation
  - ▶ New development FMNR x Pythia: hadronization done with PYTHIA
- Comparison to different models yields important insights
- Today: focus on comparison to NLO calculation, i.e. massive calculation using FMNR
- Have to skip over important technical issues (massive vs. massless, treatment of scales and masses, fragmentation)

# Open Charm: $D^*$ Production at H1

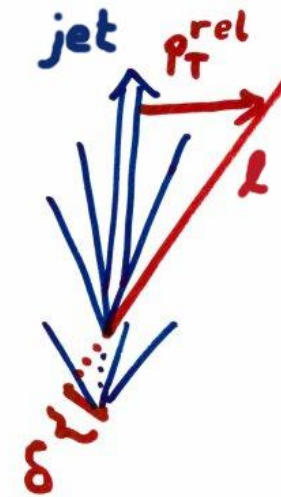


- HERA-II data,  $93\text{pb}^{-1}$   
Trigger on  $D^*$  mesons:  
 $D^*$  mass reconstruction in  $100\mu\text{s}$ !
- $p_T(D^*)$  spectrum well described by NLO QCD
- $\eta(D^*)$  shape not well reproduced:  
 $\eta$  depends on gluon density, but also on fragmentation model  
→ needs a fully fledged NLO Monte Carlo program with parton showers

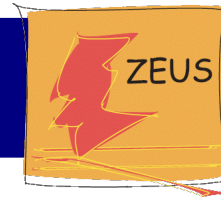


# Beauty Production

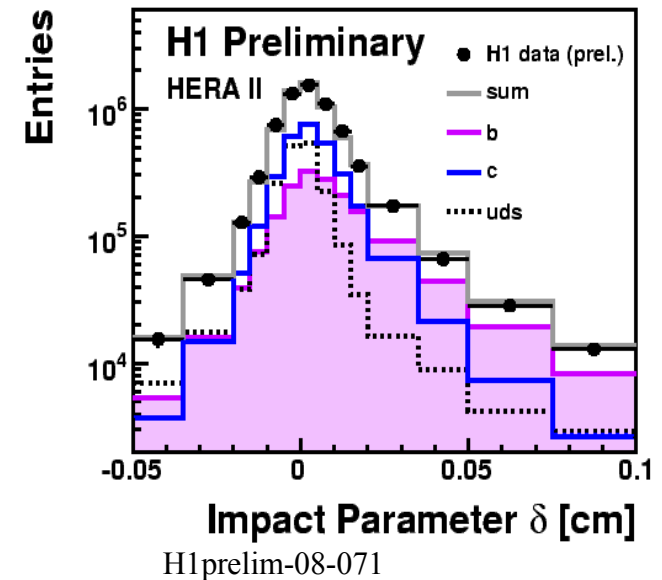
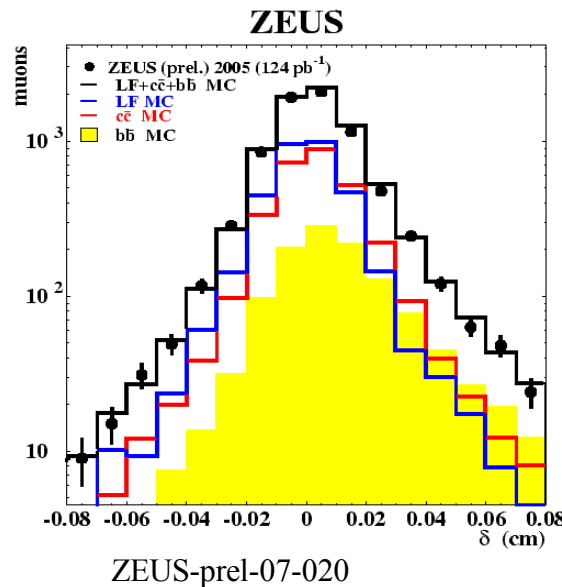
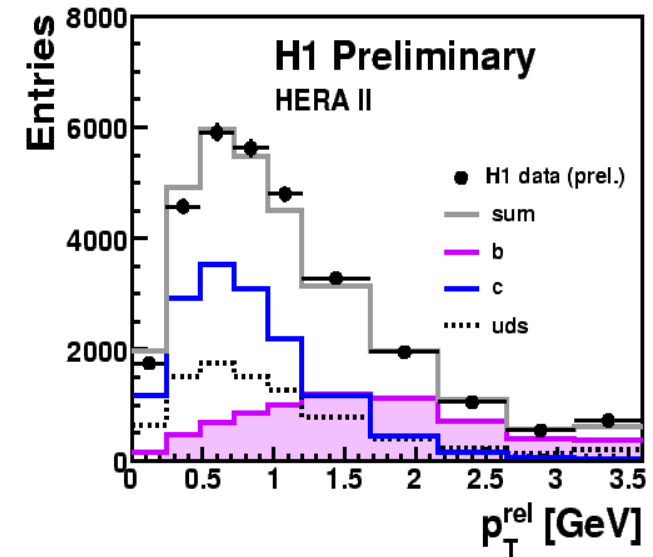
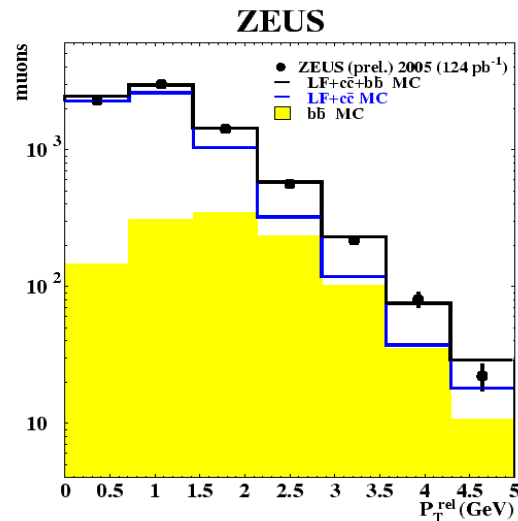
- Beauty is only  $\sim 0.03\%$  of total  $\gamma p$  cross section
- Enrichment is possible with:
  - ▶ 1 high- $p_T$  lepton (e or  $\mu$ ) plus 2 jets  $\rightarrow$  15-20% beauty  
Restricts measurement to small part of the phase space  
3 new measurements (2 from ZEUS, 1 from H1)
  - ▶ 2 leptons  $\rightarrow$  50% beauty  
Sensitive to almost full phase space: measures total cross section  
1 new measurement from ZEUS
- Main observables for determination of beauty fraction:
  - ▶  $p_T$  of lepton w.r.t jet:  $p_T^{\text{rel}}$  (mass of the b) } single tag
  - ▶ Impact parameter  $\delta$  of lepton (lifetime) }
  - ▶ Charge/angle correlation for double lepton tag



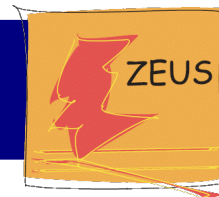
# Analyses with Muons and Jets



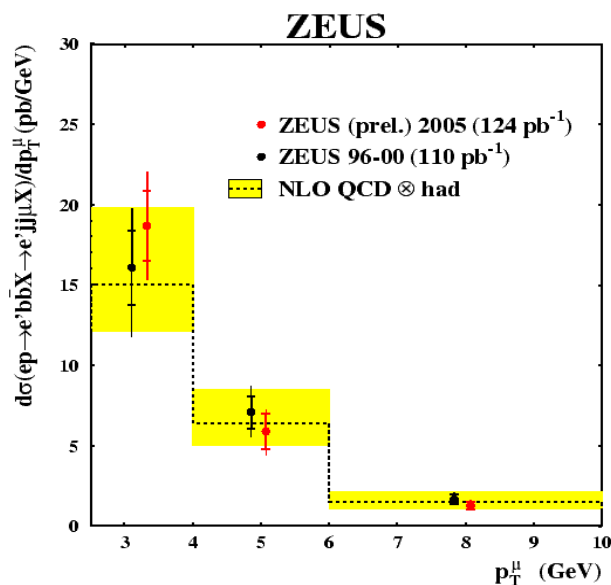
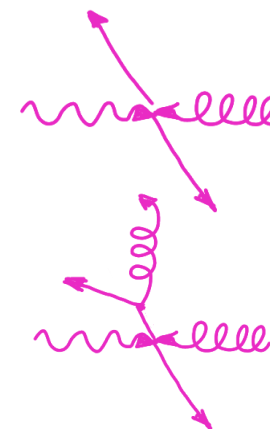
- New HERA-II analyses
- ZEUS:  $124\text{pb}^{-1}$ ,  
H1:  $171\text{pb}^{-1}$
- Similar visible range:  
 $0.2 < y < 0.8$ ,  
2 jets,  $p_{T} > 7$  (6) GeV
- Combine  $p_{T}^{\text{rel}}$  and  $\delta$   
in 2 dimensional fit
- $p_{T}^{\text{rel}}$  constrains b
- $\delta$  allows c / uds  
separation  
→ reduced systematics



# Beauty with Muons and Jets

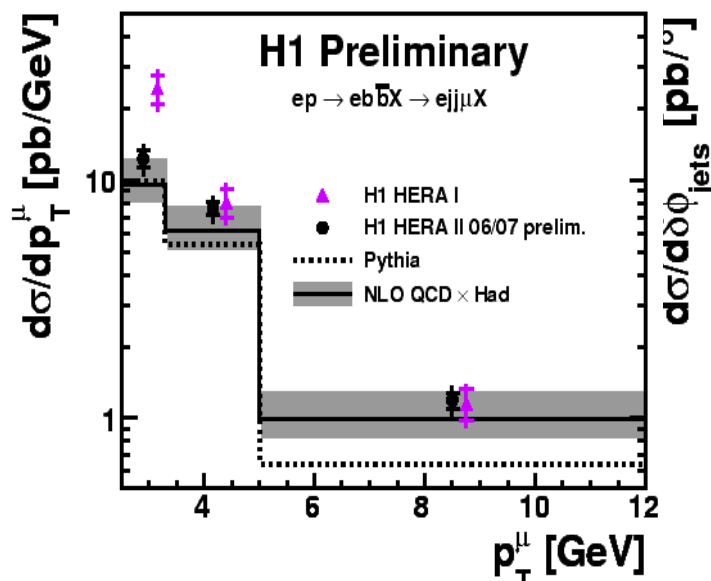


- Phase space: Similar, but not equal → different NLO predictions
- Main result: Measurements consistent with NLO calculation (excess of H1 analysis at HERA-I at low  $p_T$  not confirmed)
- Azimuthal angle difference of jets  $\delta\phi_{\text{jets}}$  :  $180^\circ$  at LO → direct sensitivity to higher orders. Well described!
- Good precision: Statistical errors 4-9%, systematics 12-15%



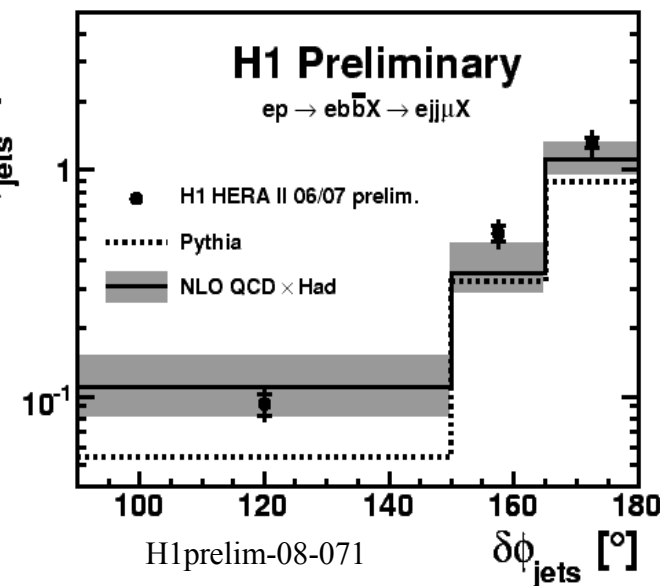
ZEUS-prel-07-020, ZEUS, PR **D70**(2004)012008

Benno List



H1prelim-08-071, H1, EPJ **C41**(2005)453.

Charm and Beauty Photoproduction at HERA

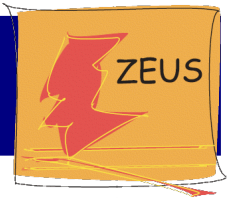


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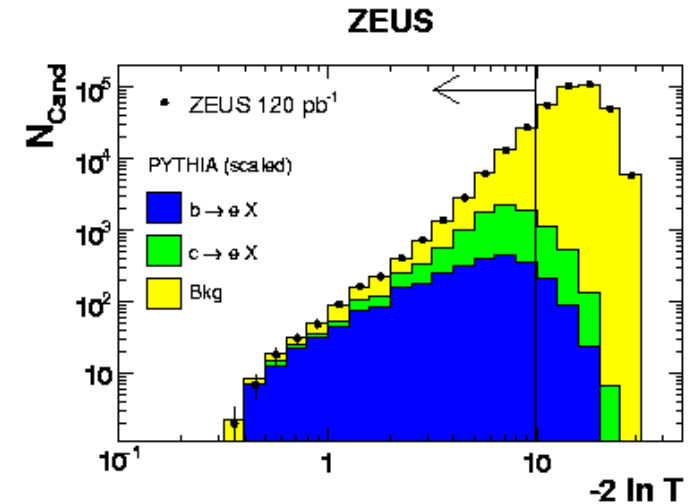
ICHEP'08, 31.7.2008, page 8



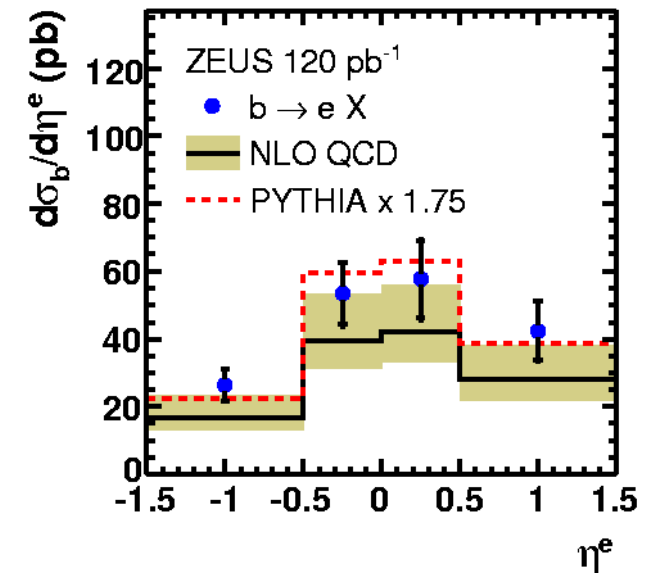
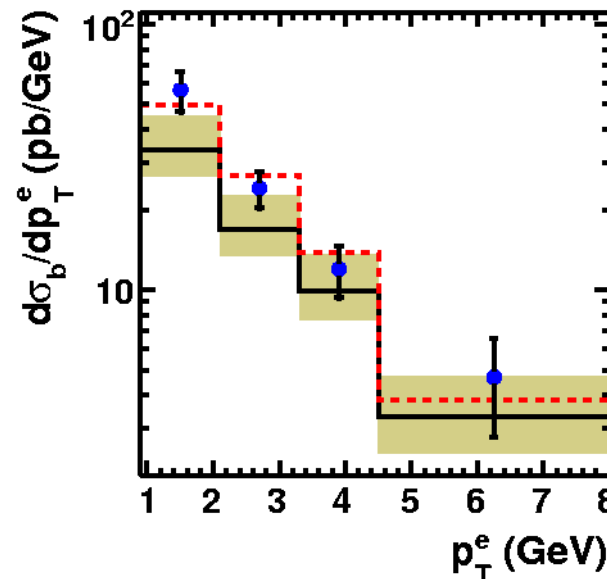
# Beauty Production with Electrons and Jets



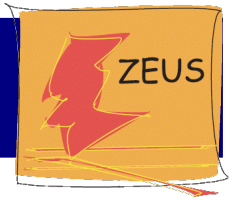
- Recent publication by ZEUS:  
HERA-I, 120pb<sup>-1</sup>
- Uses likelihood analysis to separate  
b→e from c→e and uds:  
main observable:  $p_T^{\text{rel}}$
- Low systematics (9%)
- Similar jet cuts as for muon analyses:  
 $E_T^{\text{jet}} > 7$  (6) GeV
- Result:  
NLO gives good description, but  
is on the low side



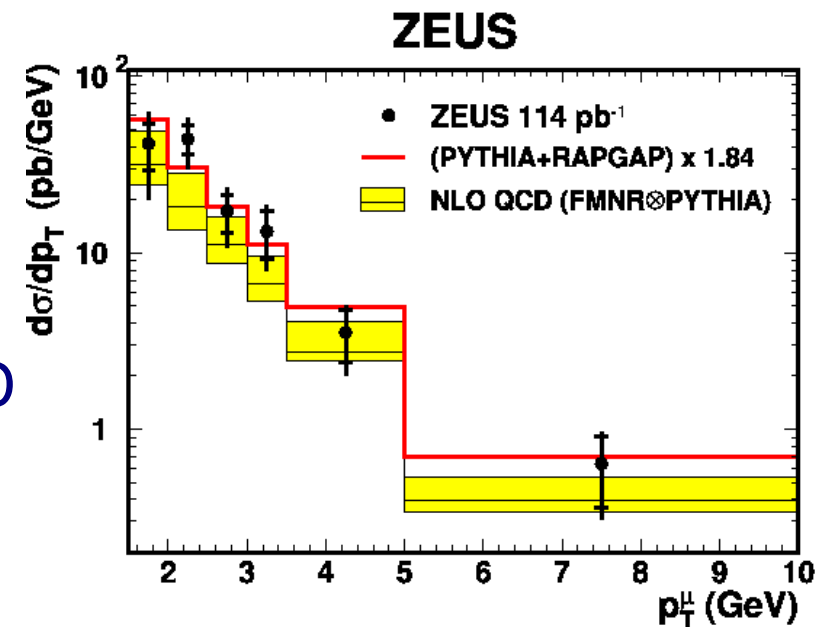
ZEUS, DESY-08-056



# Inclusive Beauty with Dimuons



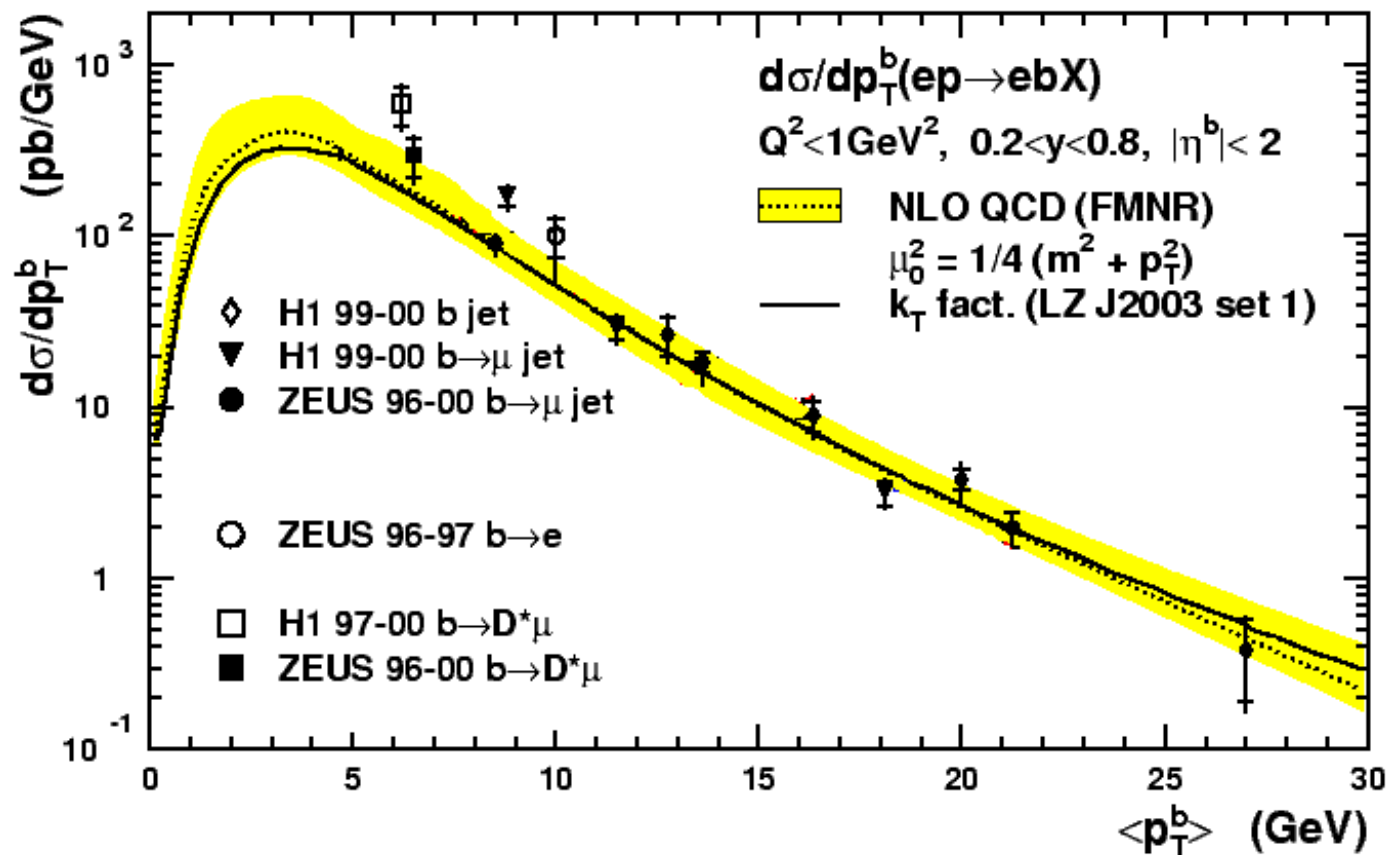
- HERA-I data, 114pb<sup>-1</sup>: Upcoming publication
- Dimuon sample is highly beauty enriched,  
→ no jet requirement needed  
charge and angle correlations allow b/c separation
- Sensitive down to threshold:  $p_T(b) \sim 0$  → allows total cross section measurement!
- New interface of NLO calculation (FMNR) with Pythia improves hadronisation modeling drastically
- Again: Good description by NLO QCD
- $\sigma_{\text{tot}}(ep \rightarrow b\bar{b}X) = 13.9 \pm 1.5^{+4.0}_{-4.3}$  nb  
NLO QCD:  $7.5^{+4.5}_{-2.1}$  nb



# Beauty Photoproduction: Summary Plot

- Before the new data:

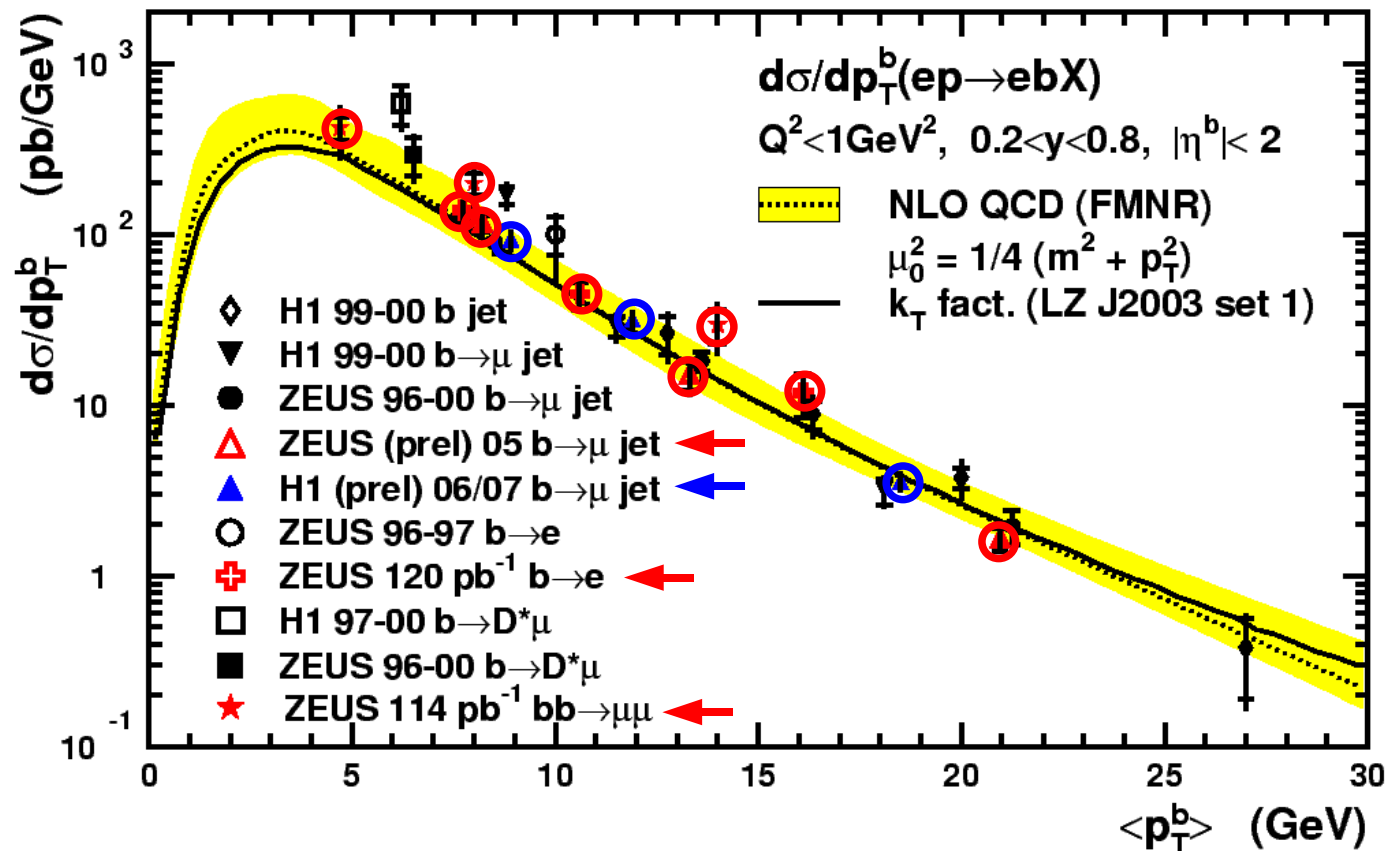
## HERA



# Beauty Photoproduction: Summary Plot

- Today:

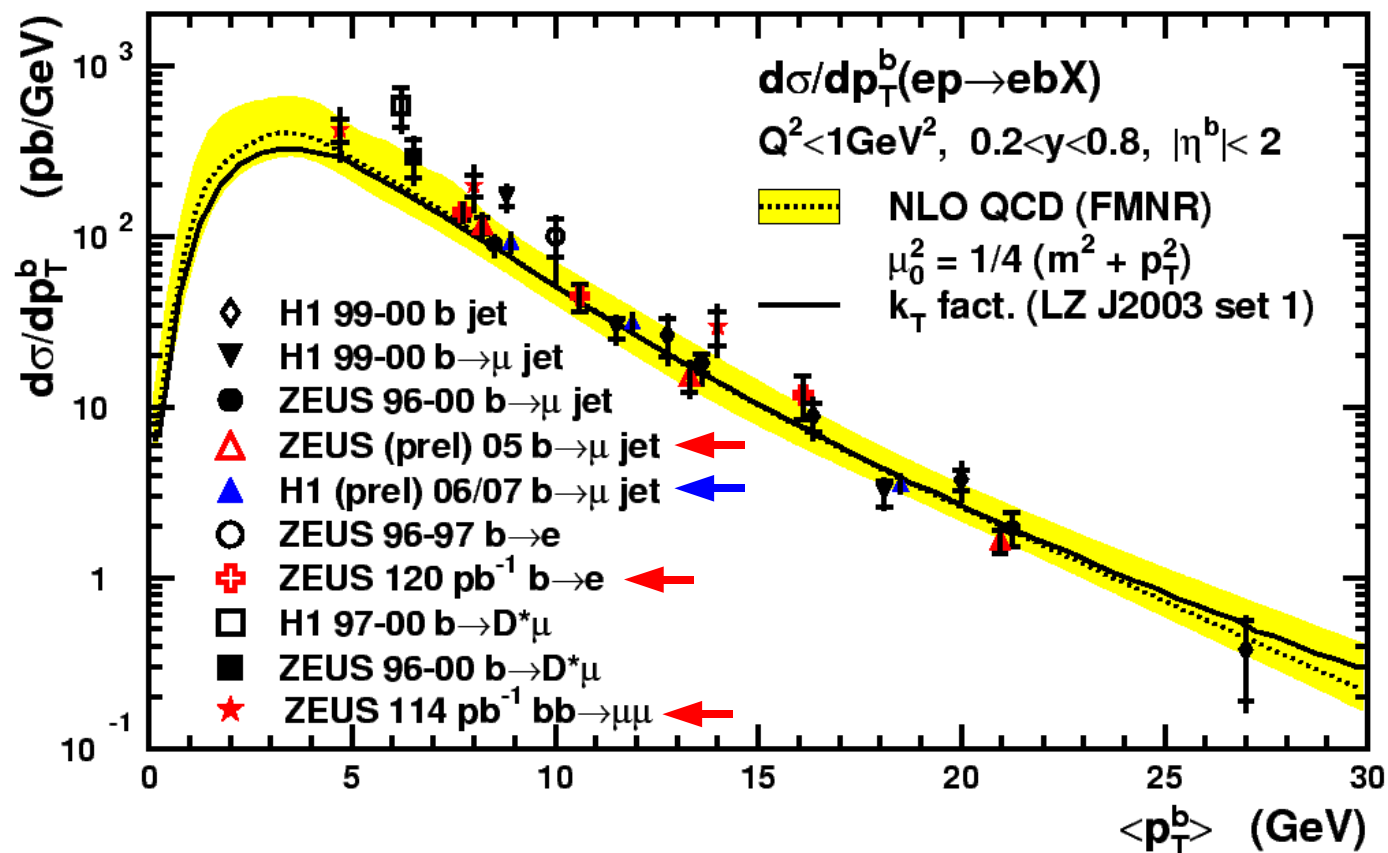
## HERA



# Beauty Photoproduction: Summary Plot

- Improved precision of the data (<20 % total error)
- Data agree well with (and are more precise than) NLO QCD!

## HERA



# Summary and Conclusions

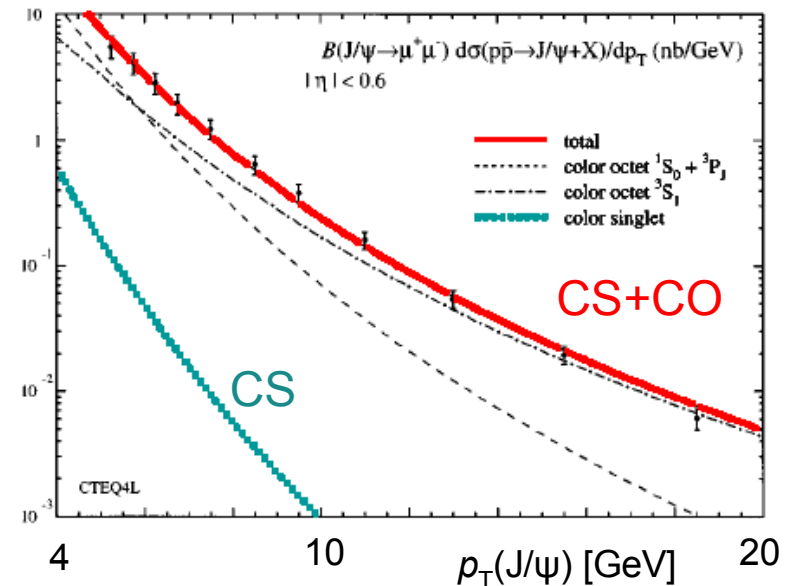
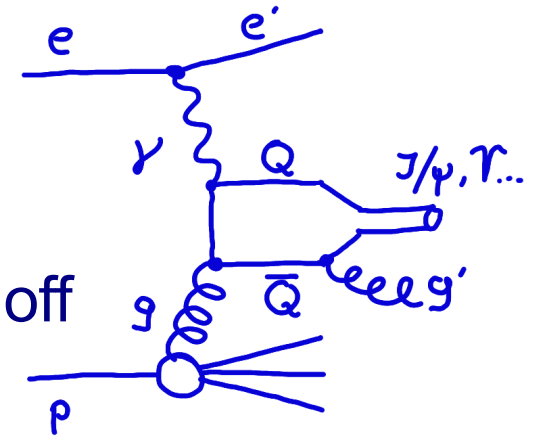
- Open charm and beauty production:
  - ▶ Overall good description of data by NLO QCD
  - ▶ Mass and scale uncertainties are larger than experimental errors  
→ theory uncertainties limit the interpretation of the data
  - ▶ NLO predictions generally on the low side,  
charm and beauty data prefer low masses and/or scales
- HERA-II analyses are in full swing,  
single/double differential measurements show precisely  
where QCD predictions have problems

# References

- Abs 253: ZEUS: “*Measurement of inelastic  $J/\psi$  helicity distributions with ZEUS at HERA*”, ZEUS-prel-07-036.  
[http://www-zeus.desy.de/public\\_results/functiondb.php?id=ZEUS-prel-07-036](http://www-zeus.desy.de/public_results/functiondb.php?id=ZEUS-prel-07-036)
- Abs. 835: H1: “*Inelastic Photo-Production of  $J/\psi$  Mesons at HERA,*” H1prelim-07-172.  
<http://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-07-172.long.html>
- Abs. 858: H1: “*Measurement of the  $D^*$  production cross section in photoproduction with the H1 detector using HERA II data,*” H1prelim-08-073.  
<http://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-08-073.long.html>
- Abs. 237: ZEUS: “*Measurement of beauty production using dimuon events with ZEUS at HERA,*” to be published.
- Abs. 238: ZEUS: “*Measurement of beauty photoproduction using dijet events with decays electrons with ZEUS at HERA,*” DESY-08-056, arXiv:0805.4390.
- Abs. 240: ZEUS: “*Measurement of beauty photoproduction using dijet events with a muon with ZEUS at HERA,*” ZEUS-prel-07-020.  
[http://www-zeus.desy.de/public\\_results/functiondb.php?id=ZEUS-prel-07-020](http://www-zeus.desy.de/public_results/functiondb.php?id=ZEUS-prel-07-020)
- Abs. 852: H1: “*A Measurement of Beauty Photoproduction Through Decays to Muons at HERA-II,*” H1prelim-08-071.  
<https://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-08-071.long.html>

# Inelastic J/ψ Production

- Inelastic J/ψ production:  $z = E_{\psi} / E_{\gamma} < 0.9$   
(energies in  $\gamma p$  rest frame)  $\rightarrow$  non-diffractive
- J/ψ is a color singlet: a gluon must be radiated off
- Is this gluon
  - ▶ always hard?  $\rightarrow$  Color Singlet Model (CS)
  - ▶ sometimes soft?  $\rightarrow$  Additional Color Octet contributions (CS+CO)
- Tevatron data on J/ψ hadroproduction seem(ed) to indicate need for large Color Octet contributions
- What does HERA say?

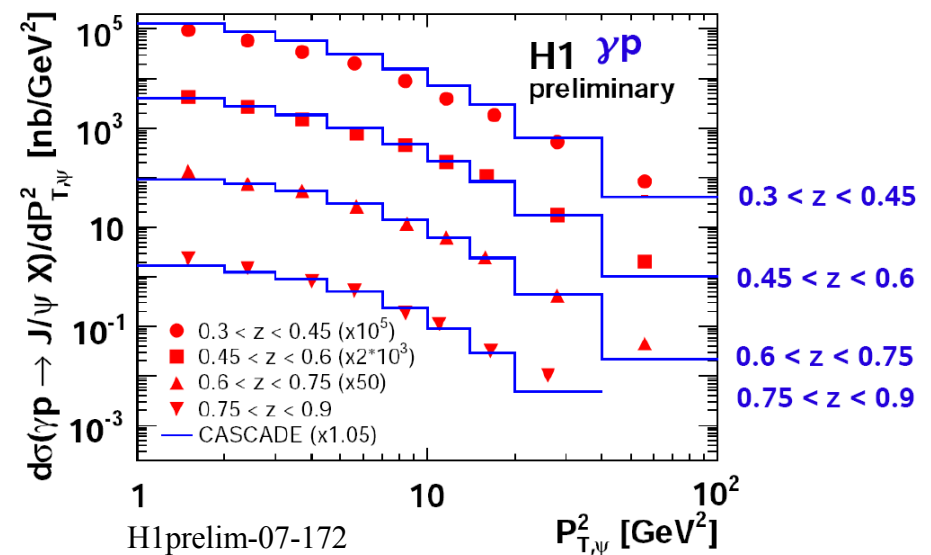
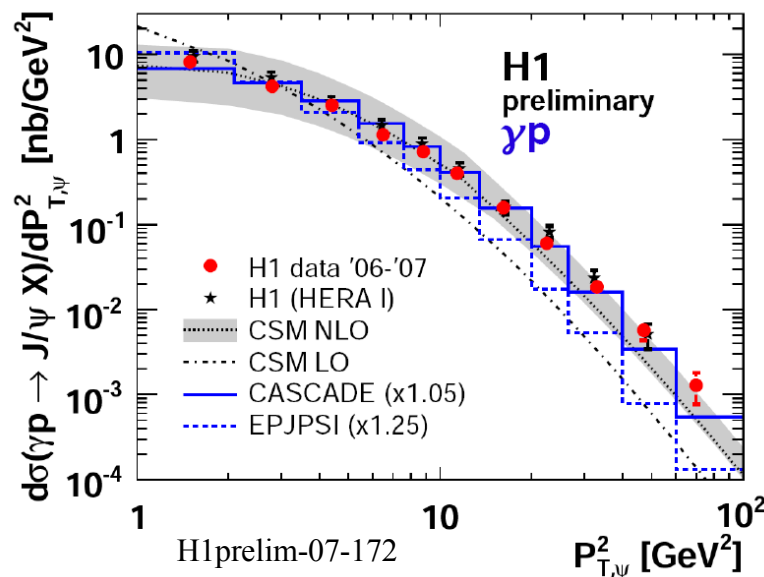
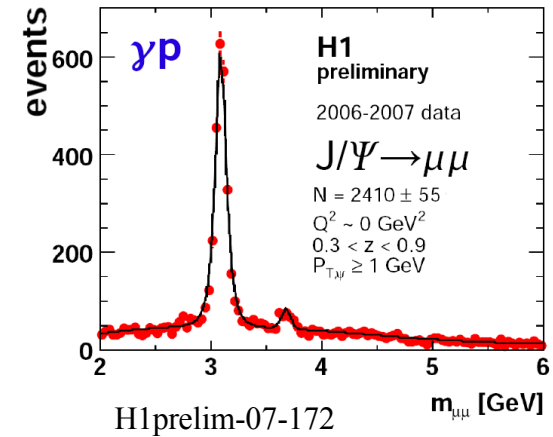




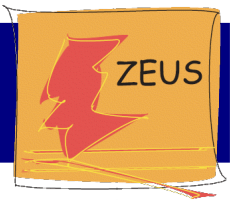
# Inelastic $J/\psi$ at H1



- H1: Analysis of HERA-II data,  $166\text{pb}^{-1}$
- For  $\gamma p$  at HERA: NLO Calculation for Color Singlett Model available, describes the data (LO does not!)
- LO Monte Carlo (Cascade) with only CS describes even double differential distributions
- Conclusion: No need for large Color Octett contributions if NLO corrections are taken into account



# Inelastic J/Ψ at ZEUS



- ZEUS: Full HERA data set, 470pb<sup>-1</sup>
- Polarization is viewed as most sensitive probe for CO contributions
- ZEUS measure  $\theta$  and  $\phi$  dependence for  $0.4 < z < 1$ ,  $p_T > 1$  GeV, extract  $\lambda$  and  $v$
- Result: Scenario with Color Octett contributions slightly favoured

$$\frac{1}{\sigma} \frac{d^2\sigma}{d\cos\theta dy} \propto 1 + \lambda(y) \cos^2\theta$$

$$\frac{1}{\sigma} \frac{d^2\sigma}{d\phi dy} \propto 1 + \frac{\lambda(y)}{3} + \frac{v(y)}{3} \cos^2\phi$$

