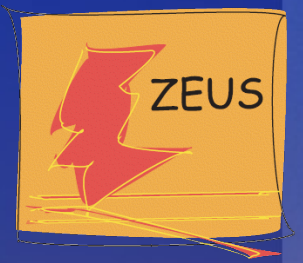
Charm and Beauty Photoproduction at HERA



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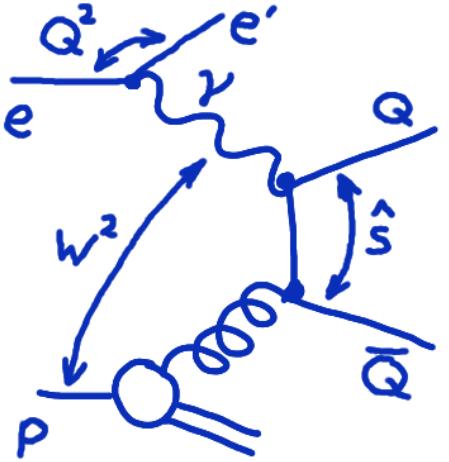
Introduction

- 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 ~ 1.5 / 5 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

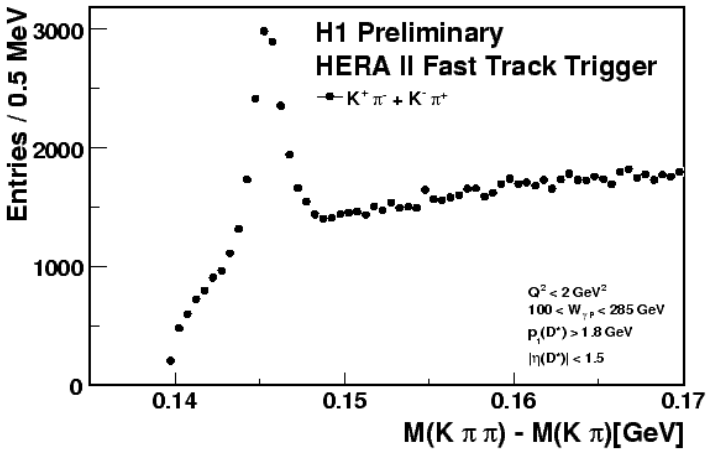
⟷

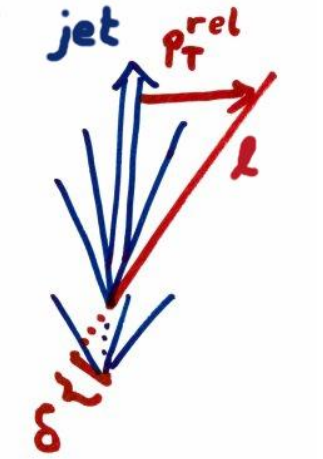
Take the gluon from elsewhere
→ Investigate accuracy of pQCD calculations

Measurements

Measurements discussed today:

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



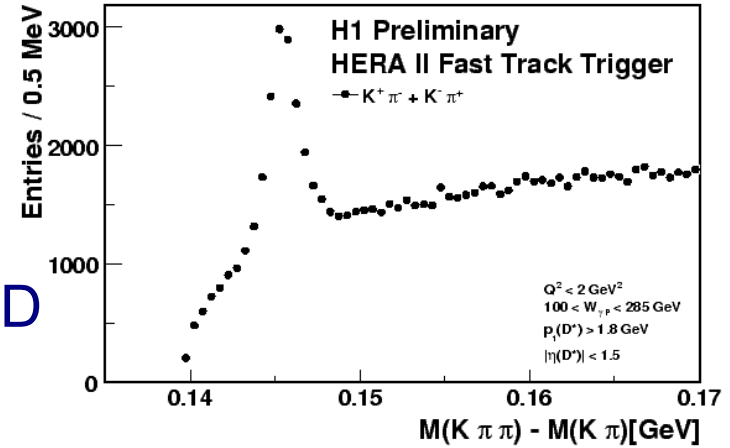


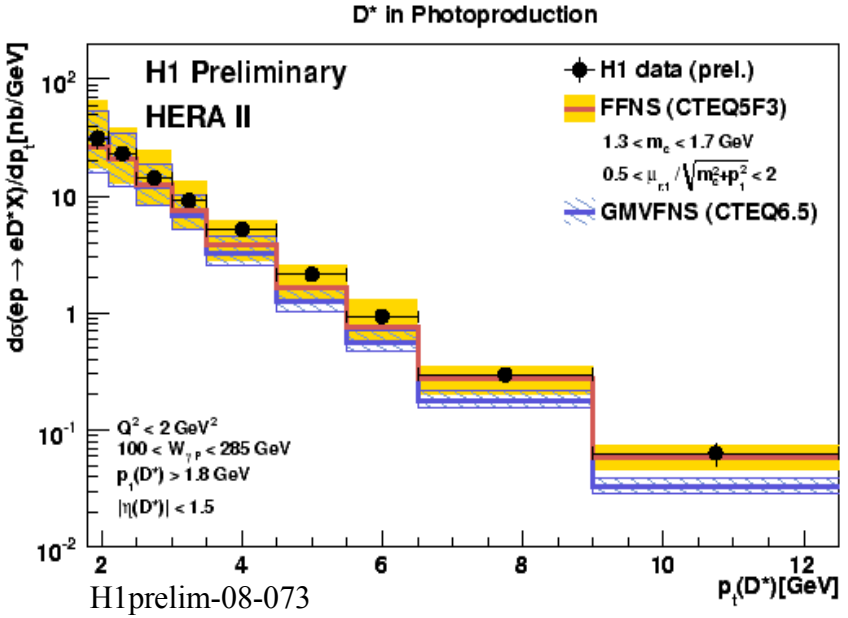
QCD Models

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





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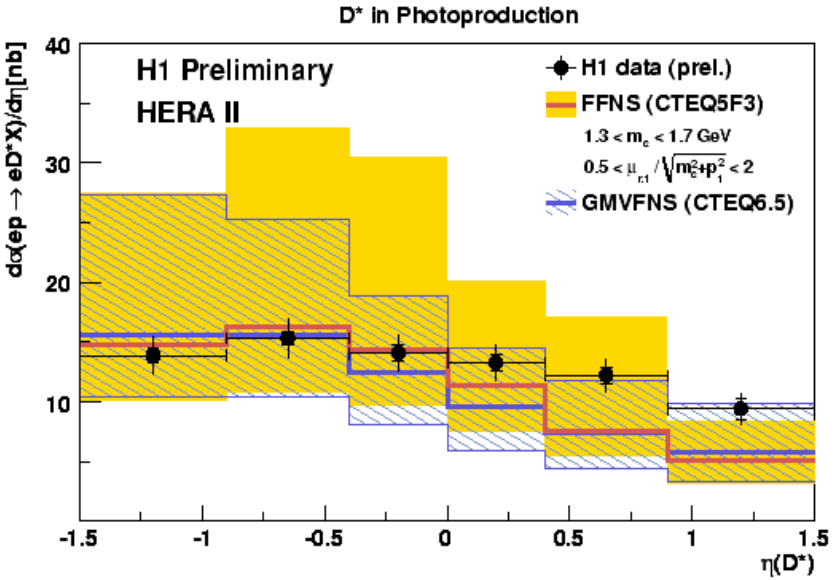
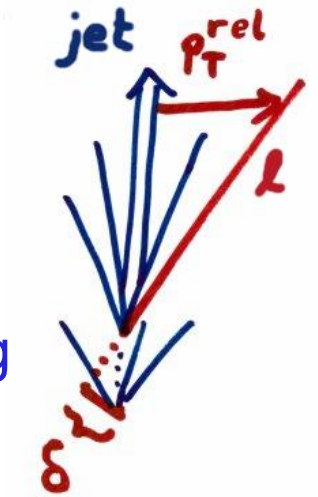


Beauty Production

- Beauty is only ~ 0.03% of total γp cross section
- Enrichment is possible with:
  - ▸ 1 high-p_T lepton (e or μ) plus 2 jets → 15-20% beauty
    Restricts measurement to small part of the phase space
    3 new measurements (2 from ZEUS, 1 from H1)
  - ▸ 2 leptons → 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^{rel} (mass of the b)
  - ▸ Impact parameter δ of lepton (lifetime)

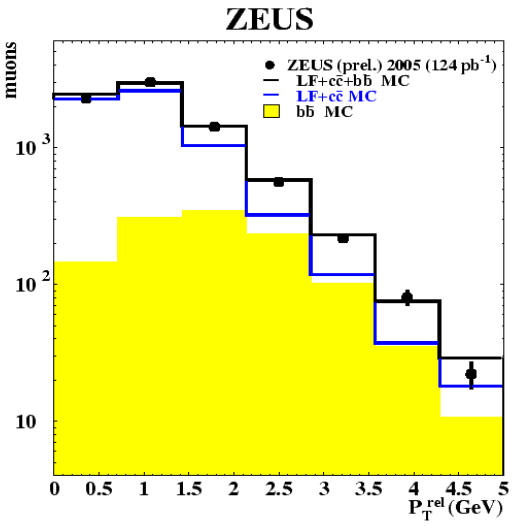
  } single tag

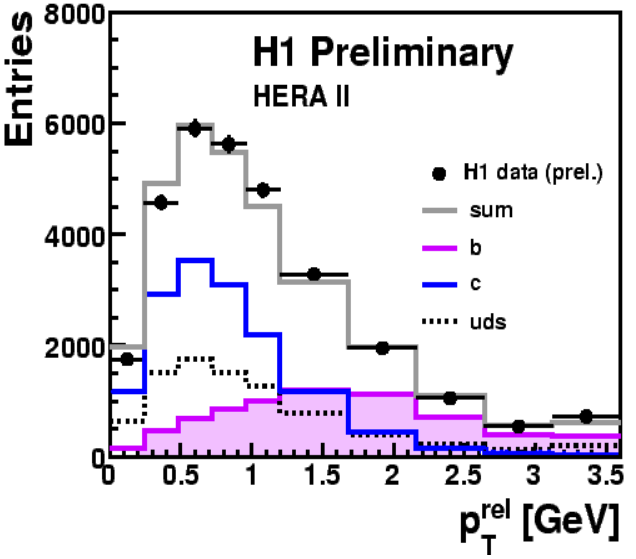
  - ▸ Charge/angle correlation for double lepton tag

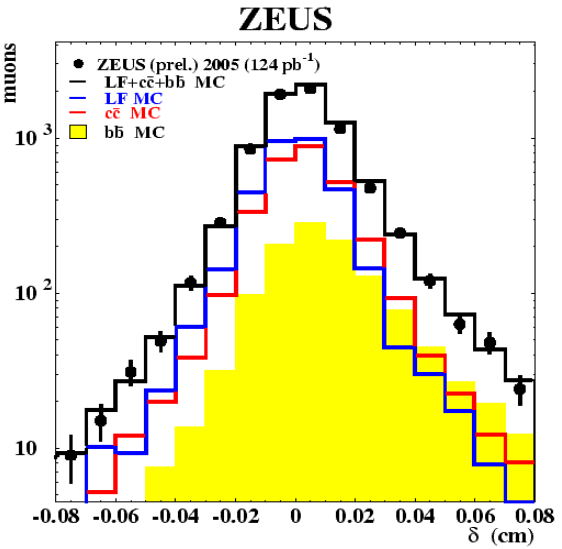


Analyses with Muons and Jets

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







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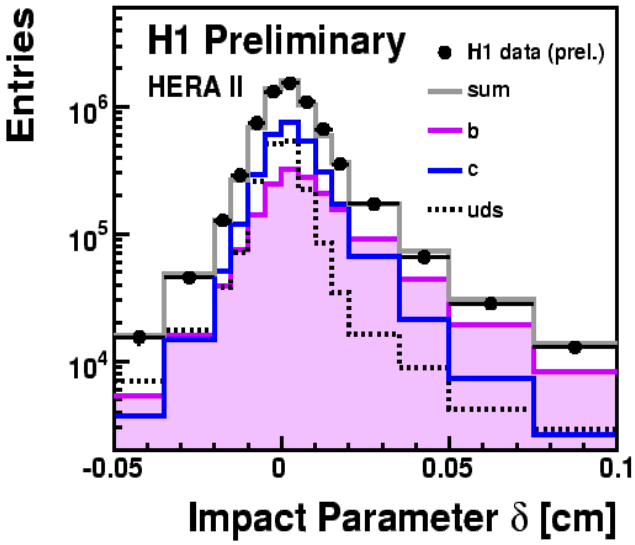

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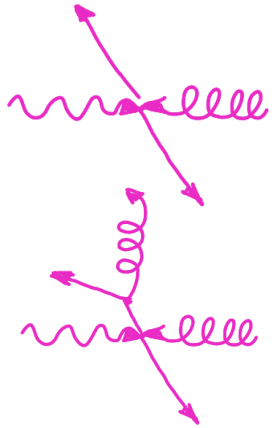
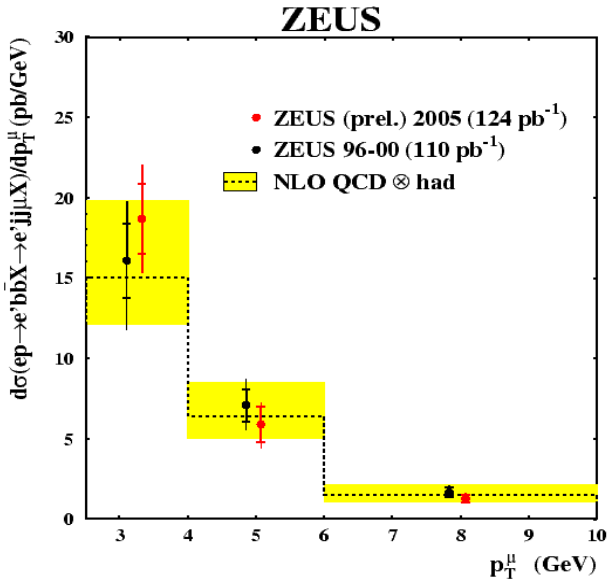
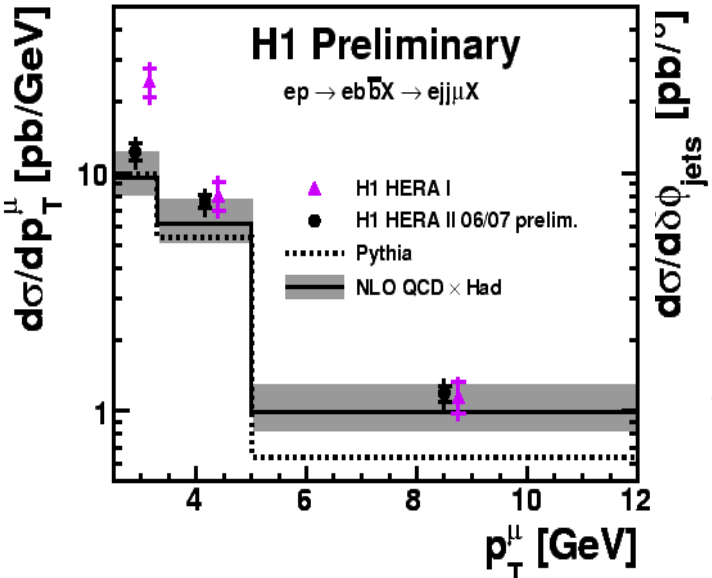
Beauty with Muons and Jets

- 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 $\delta\varphi_{jets}$: 180° at LO
  → direct sensitivity to higher orders. Well described!
- Good precision: Statistical errors 4-9%, systematics 12-15%

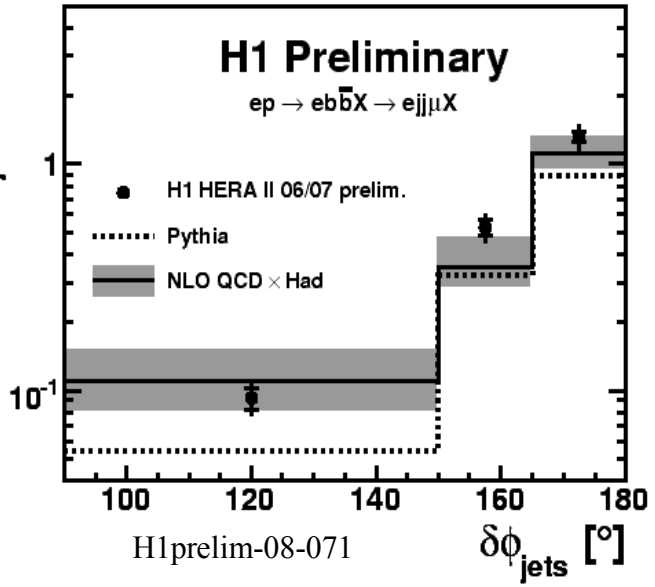




ZEUS-prel-07-020, ZEUS, PR **D70**(2004)012008



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



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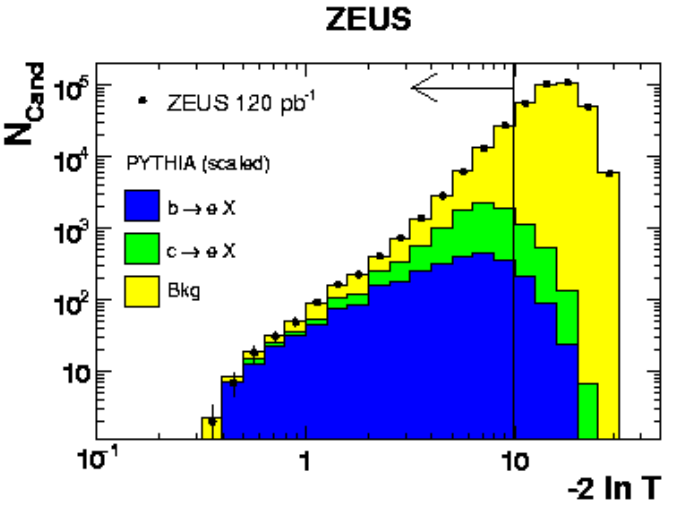
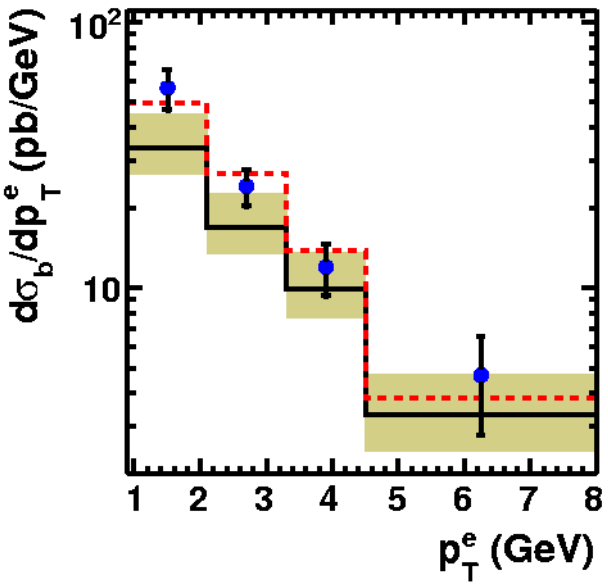
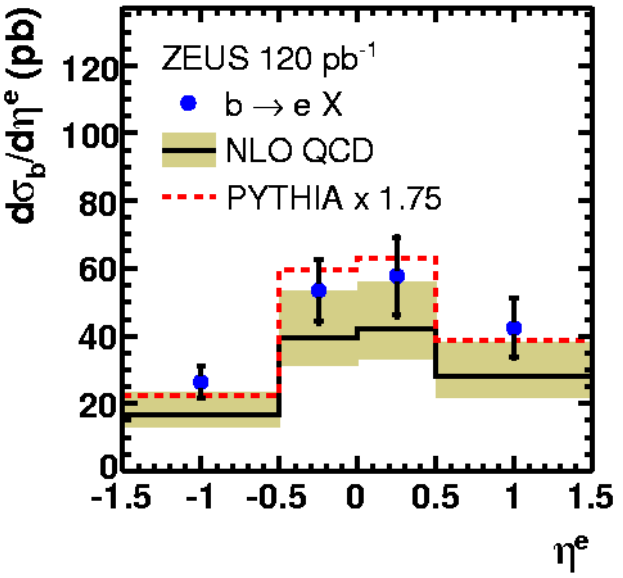
Beauty Production with Electrons and Jets

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



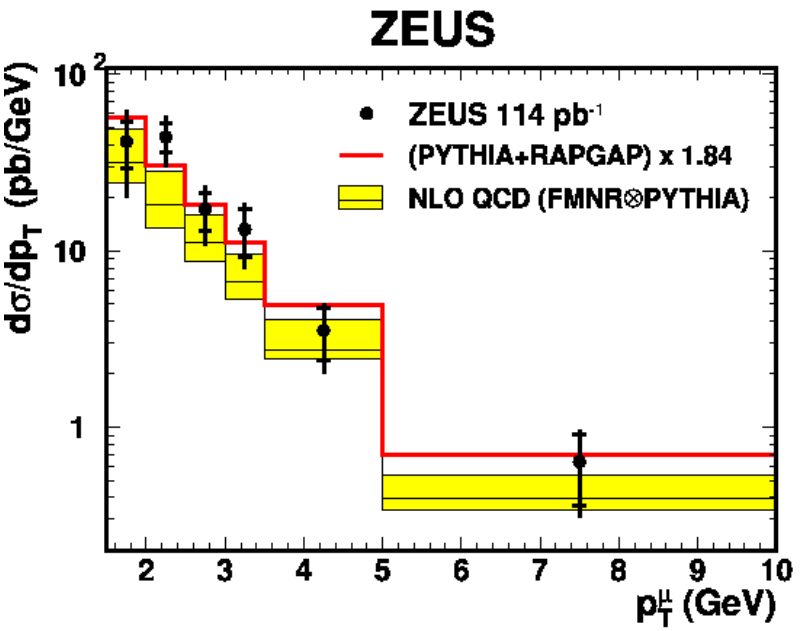
ZEUS, DESY-08-056





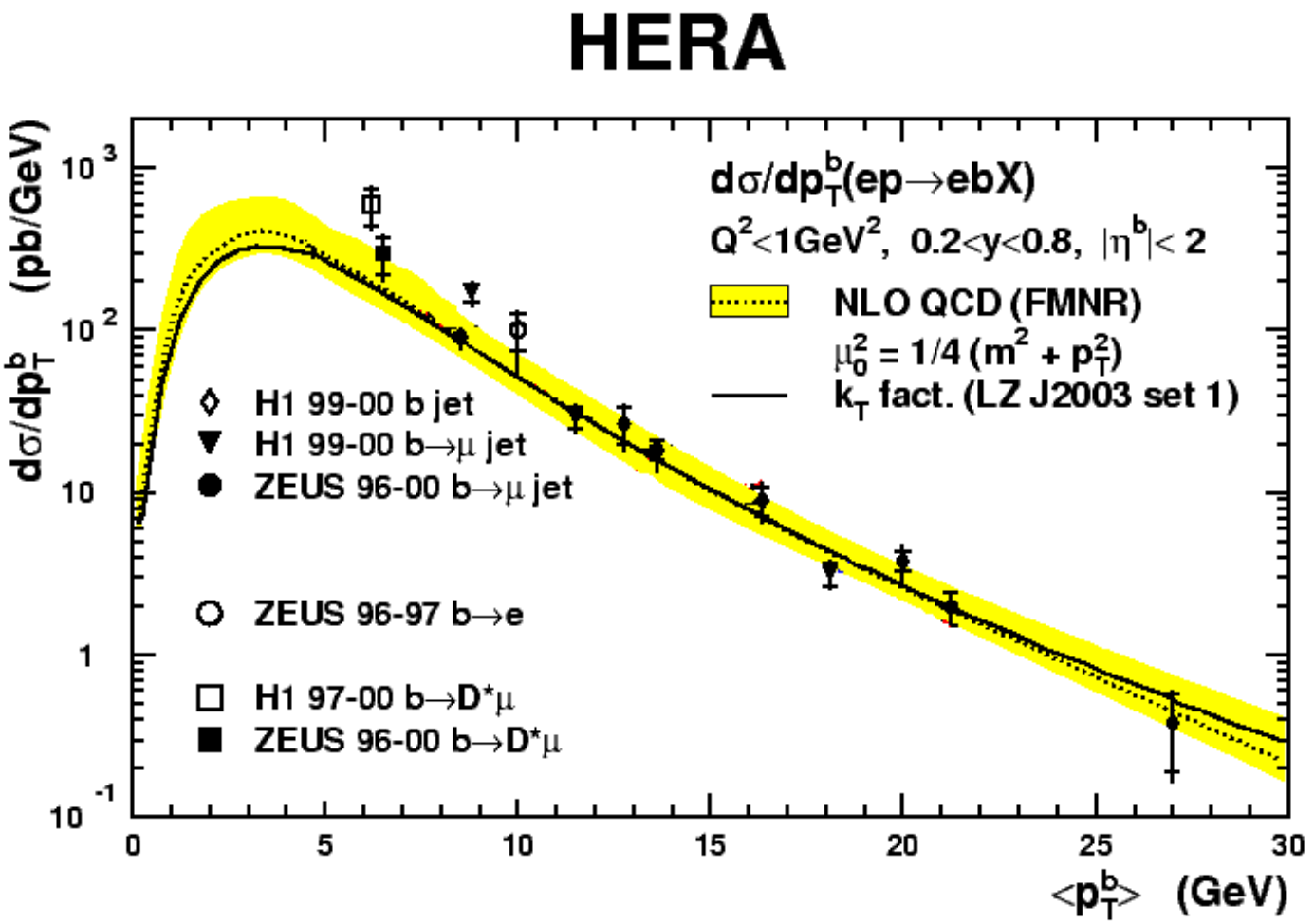
Inclusive Beauty with Dimuons

- HERA-I data, 114pb^{-1}: 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
- $\sigma_{tot}(ep\to b\bar{b}X)=13.9\pm1.5^{+4.0}_{-4.3}$ nb
  NLO QCD: $7.5^{+4.5}_{-2.1}$ nb



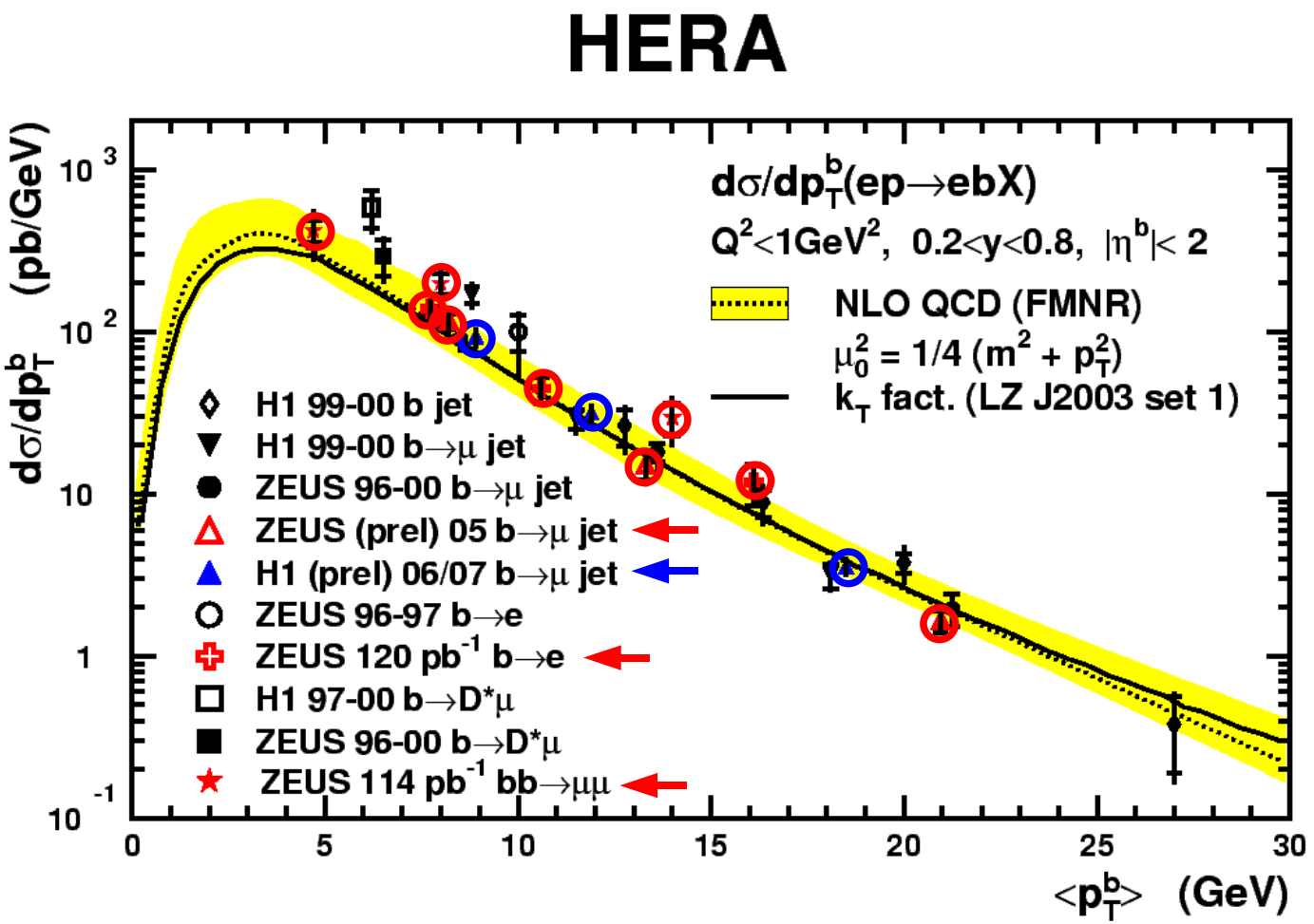
Beauty Photoproduction: Summary Plot

- Before the new data:



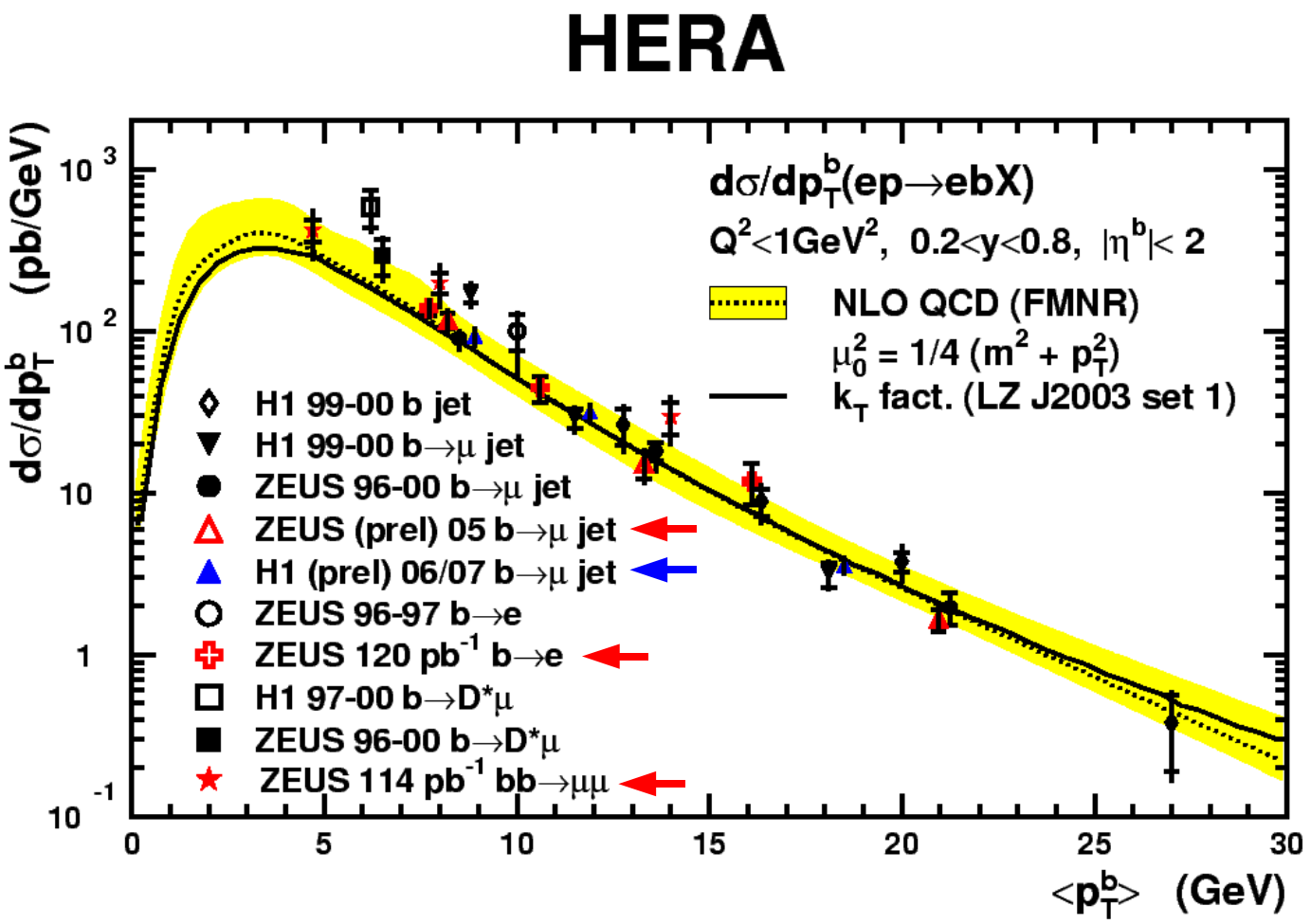
Beauty Photoproduction: Summary Plot

- Today:



Beauty Photoproduction: Summary Plot

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



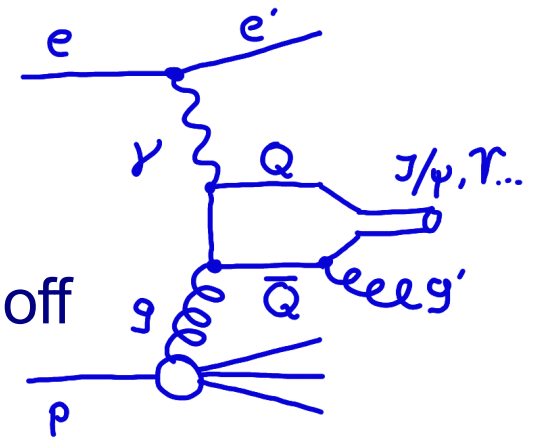
Summary and Conclusions

- 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

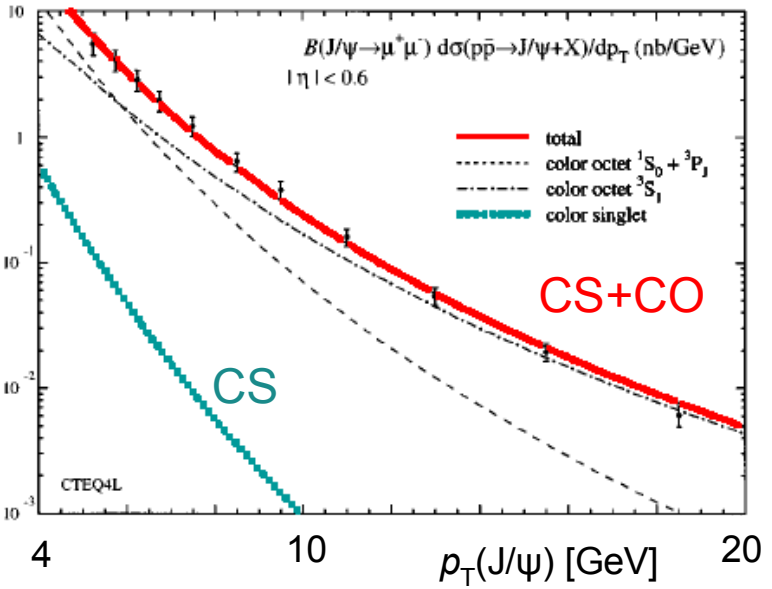
References

- Abs 253: ZEUS: *"Measurement of inelastic J/ψ helicity distributions with ZEUS at HERA"*, 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/ψ 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
- 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



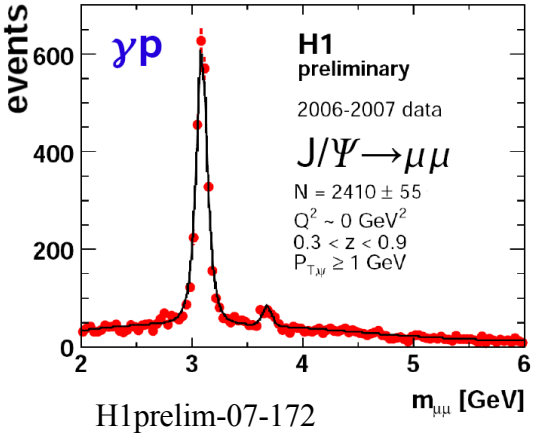
- Inelastic J/ψ production: $z=E_\psi/E_\gamma < 0.9$ (energies in γp rest frame) → non-diffractive
- J/ψ is a color singlet: a gluon must be radiated off
- Is this gluon
  - ▸ always hard? → Color Singlett Model (CS)
  - ▸ sometimes soft? → Additional Color Octett contributions (CS+CO)
- Tevatron data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



Beneke&Krämer, Phys. Rev. D55(1997)5269

Inelastic J/ψ at H1

- H1: Analysis of HERA-II data, 166pb^{-1}
- For γp 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 <u>if NLO corrections are taken into account</u>



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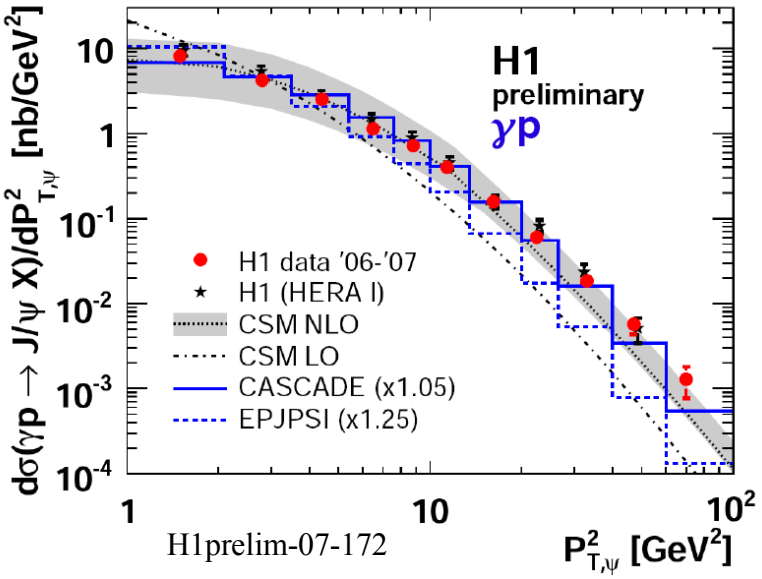

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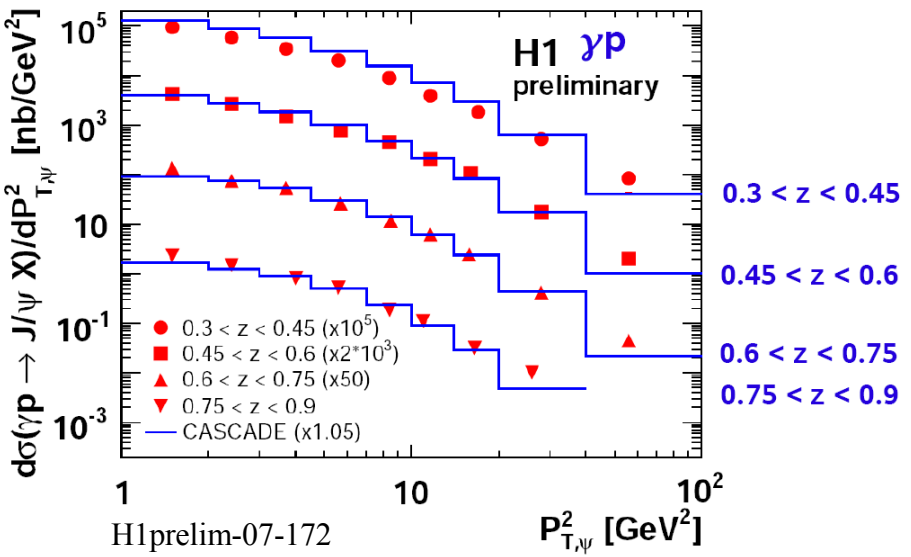

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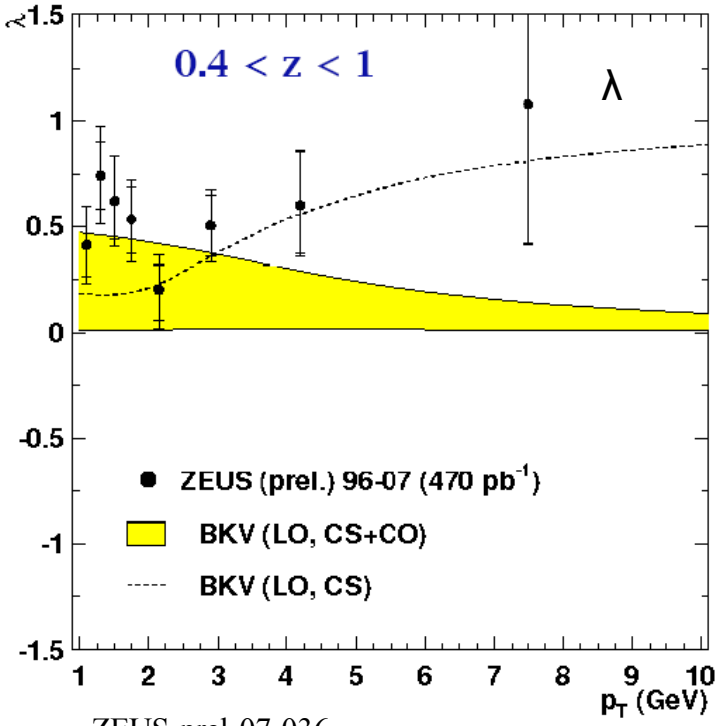
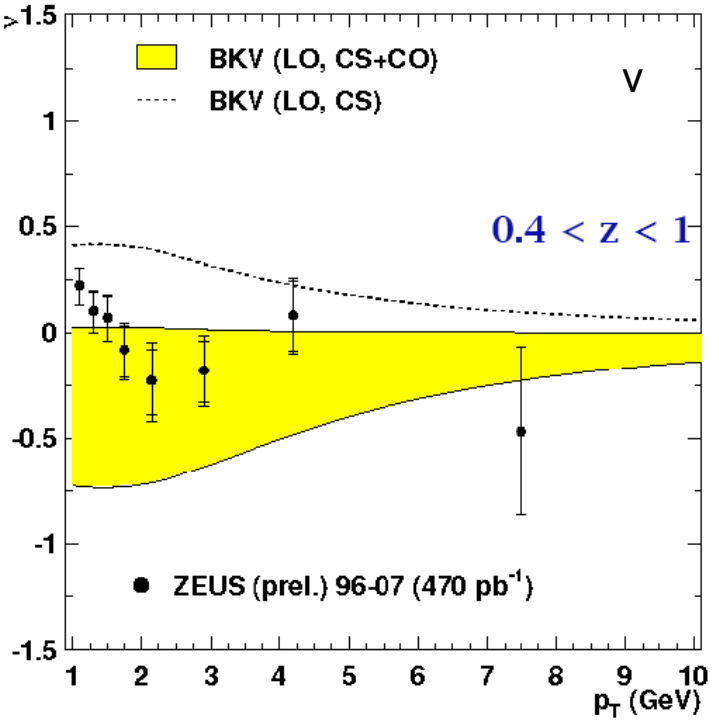
Inelastic J/Ψ at ZEUS

- ZEUS: Full HERA data set, 470pb^{-1}
- Polarization is viewed as most sensitive probe for CO contributions
- ZEUS measure θ and φ dependence for 0.4<z<1, p_T>1GeV, extract λ and ν
- Result: Scenario with Color Octett contributions slightly favoured

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

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





ZEUS-prel-07-036