Charm Jets from ZEUS at HERA

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Heavy Quark Physics At HERA II

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T O P I C S

Charm Production

Inclusive Jets

Dijets

Summary

Charm Production in γp Interactions

HERA Collider:

Lumi $= 38\,\mathrm{pb}^{-1}$ $E_p = 820\,\mathrm{GeV}$ $E_e = 27.5\,\mathrm{GeV}$

Lumi $= 82\,\mathrm{pb}^{-1}$ $E_p = 920\,\mathrm{GeV}$ $E_e = 27.5\,\mathrm{GeV}$

Kinematics:

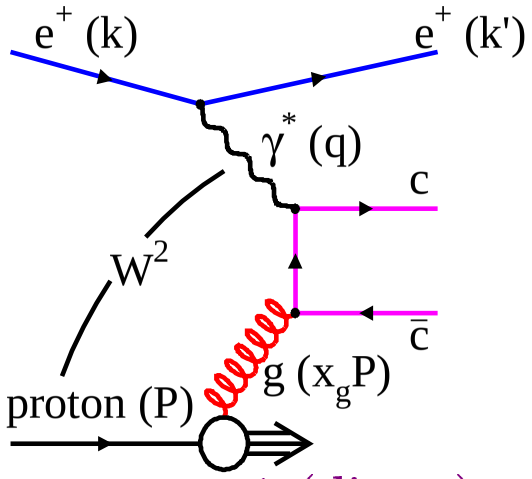
$$s = (P + k)^2$$

$$Q^2 = -q^2 = -(k - k')^2$$

$$W^2 = (P + q)^2$$

$$y = \frac{q \cdot P}{e \cdot P} \cong \frac{W^2}{s}$$

$$x_\gamma = \frac{q \cdot P_{all\ hadrons}}{q \cdot P}$$



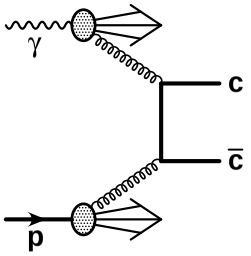
$x_\gamma = 1$ (direct)

photon gluon fusion

c quark exchange

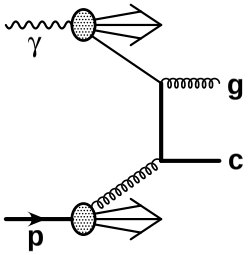
Charm Production Diagrams

Fraction of γ momentum in hard process, $x_\gamma < 1$,(resolved)



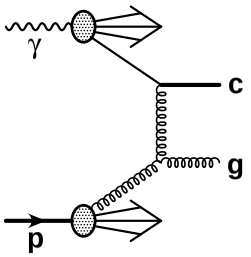
gluon gluon fusion

c quark exchange



c quark excitation

c quark exchange



c quark excitation

gluon exchange

QCD Simulations

Monte Carlo Generators

- DGLAP Initial,Final State Radiation
  - AROMA (direct only)
  - HERWIG (direct and resolved)
  - PYTHIA (direct and resolved)
- CCFM Evolution (angular ordering)
  - CASCADE (direct,evolution simulates resolved)
  - CASCADE: gluon density,hard cross section k_t dependent
  - CASCADE: m_c is only free parameter

QCD NLO Calculations

Fixed Order (massive),FMNR

(u,d,s) are active quark flavors from p and γ

c produced in hard scattering

Should be valid for $\mu^2 \leq m^2$ of charm quark

Variable Order (massless)

(u,d,s,c) are active quark flavors from p and γ

c enters hard interaction

Should be valid for $\mu^2 > m^2$ of charm quark

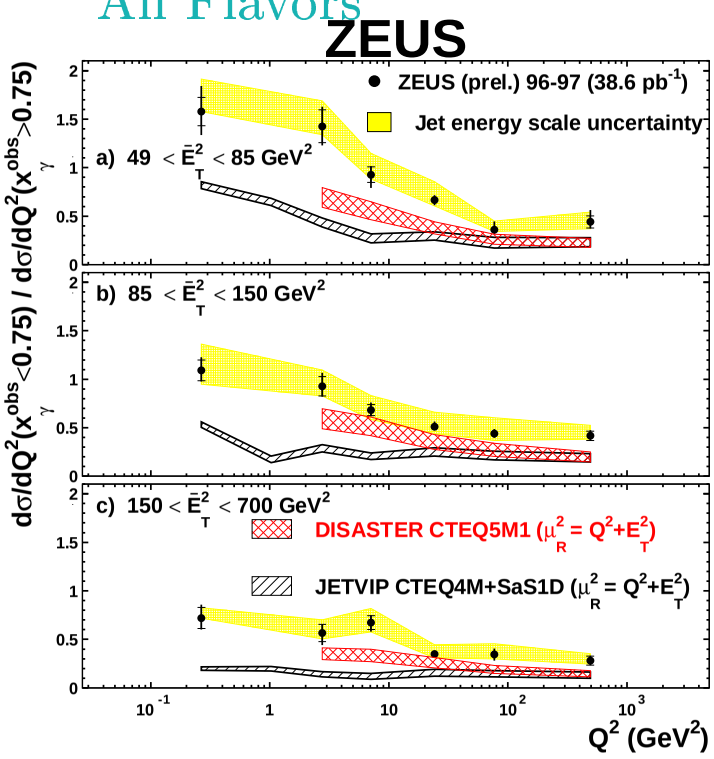
Dijet Production

$$x_\gamma^{\rm OBS} = \frac{E_T^{\rm jet1} e^{-\eta^{\rm jet1}} + E_T^{\rm jet2} e^{-\eta^{\rm jet2}}}{2yE_e}$$

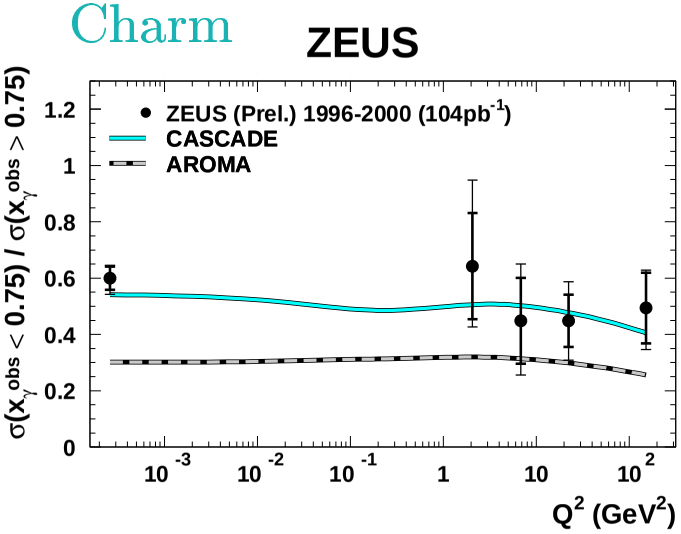
direct-enriched: $x_\gamma^{\rm OBS} > 0.75$

resolved-enriched: $x_\gamma^{\rm OBS} < 0.75$

All Flavors



Charm



Fall With Q^2

DISASTER: Direct Only

JETVIP: Direct+Resolved

No Q^2 Dependence

AROMA: Direct Only

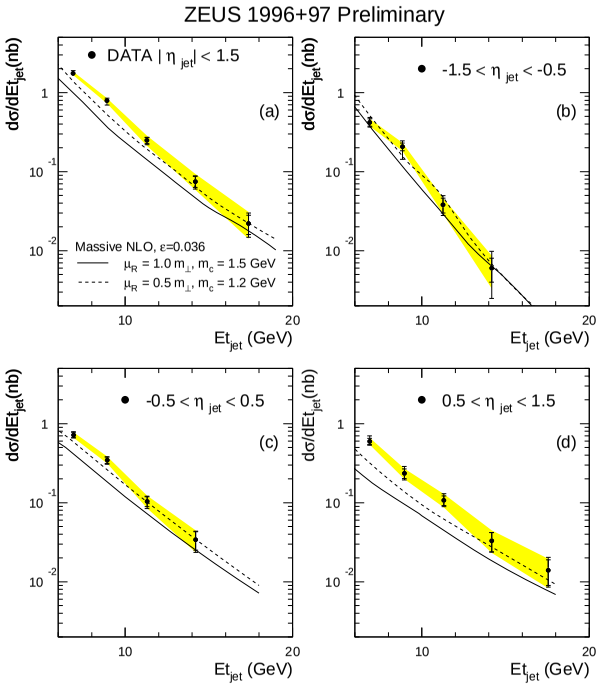
CASCADE: Direct+Resolved

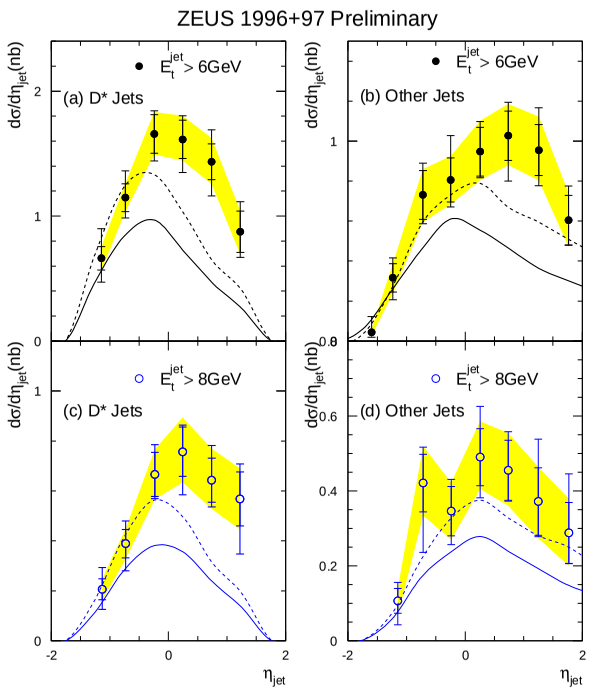
$D^{*\pm}$ Production

$Q^2 < 1\,\mathrm{GeV}^2$; $130 < W < 280\,\mathrm{GeV}$

$P_T^{D^{*\pm}} > 3\,\mathrm{GeV}$; $|\eta^{D^{*\pm}}| < 1.5$

$D^{*\pm}$ Jets





Massive NLO, $\epsilon = 0.036$

— $\mu_R = 1.0 m_\perp$

— $m_c = 1.5$ GeV

--- $\mu_R = 0.5 m_\perp$

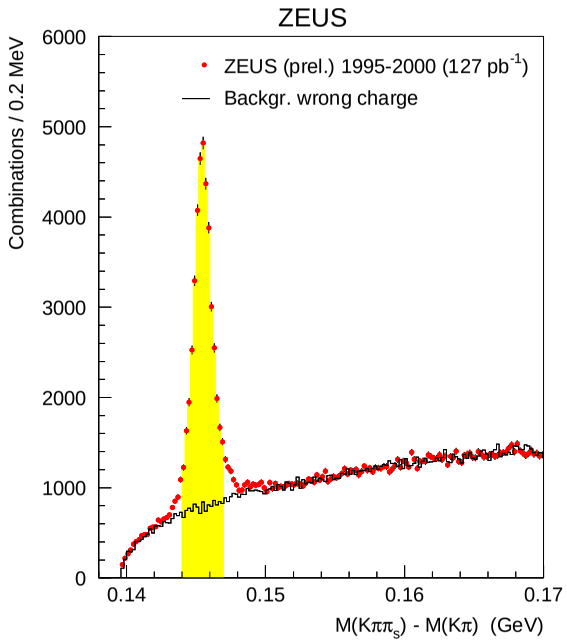
--- $m_c = 1.2$ GeV

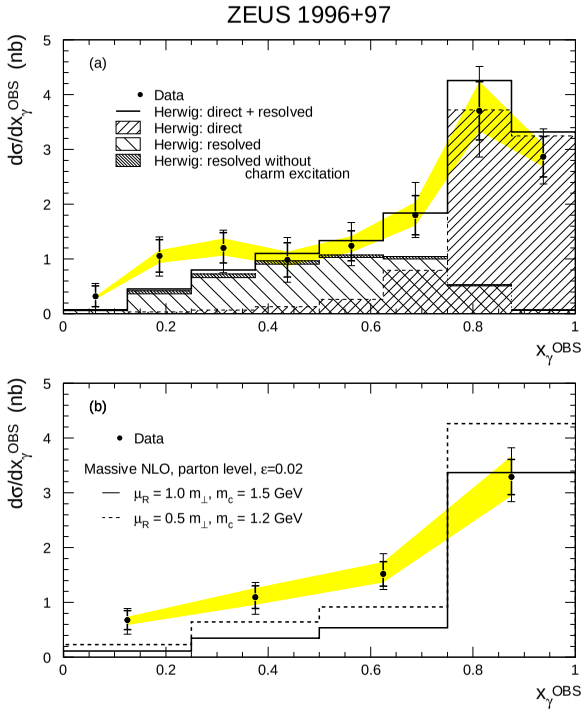
Shaded: Energy Scale

Data above NLO prediction

Charm Dijet Production

$D^{*\pm} \to D^0 \pi_s^{\pm} \to (K^{\mp}\pi^{\pm})\pi_s^{\pm}$ 2 highest E_T jets,one with a $D^{*\pm}$





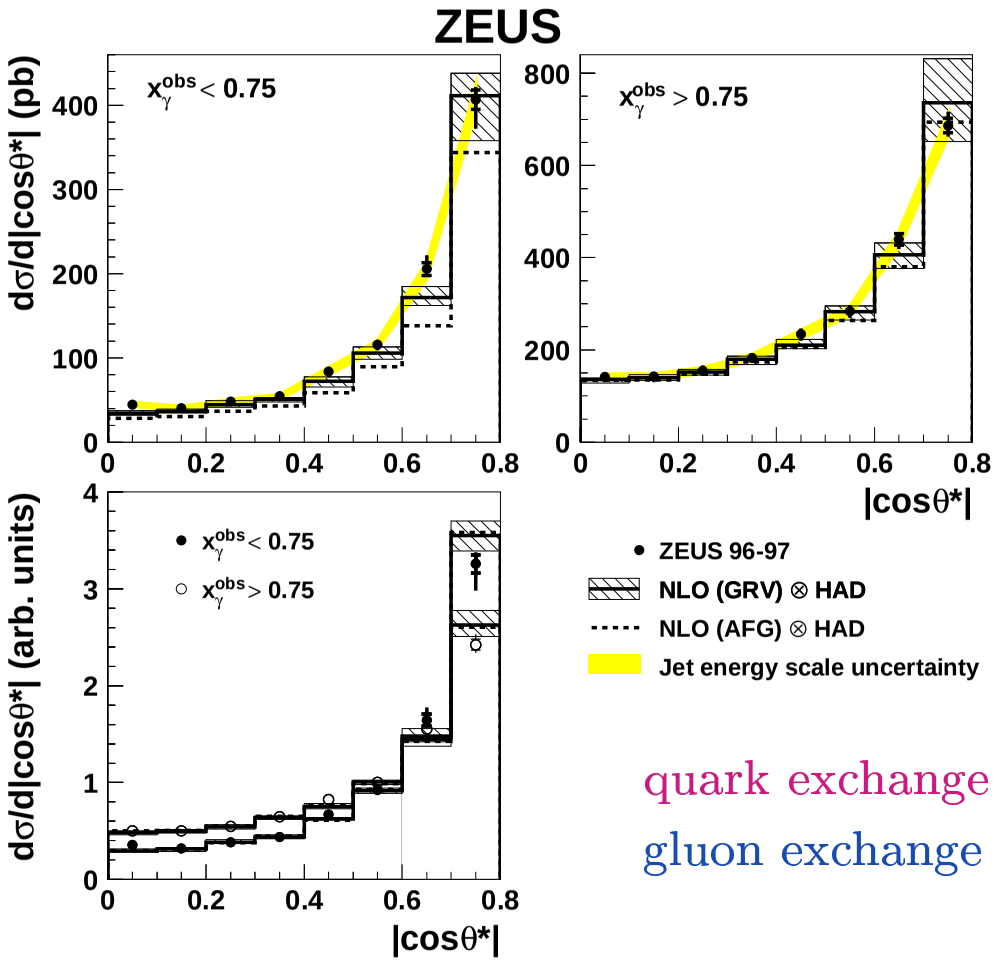
Massive(Fixed Order) NLO is too small.

Most of resolved is charm excitation.

Dijet Production

cos angle between jet-jet and beam in dijet rest frame

$\cos\theta^* = \tanh \frac{\eta^{\mathrm{jet1}} - \eta^{\mathrm{jet2}}}{2}$



All Flavors

quark exchange $\propto (1 - |\cos\theta^*|)^{-1}$

gluon exchange $\propto (1 - |\cos\theta^*|)^{-2}$

Charm Dijet Data Sample

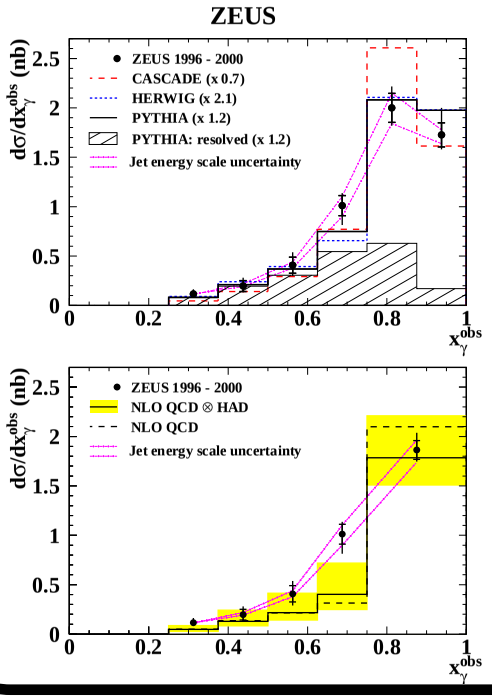
$Q^2 < 1\,\mathrm{GeV}^2$; $130 < W < 280\,\mathrm{GeV}$

$P_T^{D^{*\pm}} > 3\,\mathrm{GeV}$; $|\eta^{D^{*\pm}}| < 1.5$

$E_T^{\mathrm{jet}} > 5\,\mathrm{GeV}$ and $|\eta^{\mathrm{jet}}| < 2.4$

$M_{jj} > 18\,\mathrm{GeV}$, $|\frac{\eta^{\mathrm{jet1}} + \eta^{\mathrm{jet2}}}{2}| < 0.7$

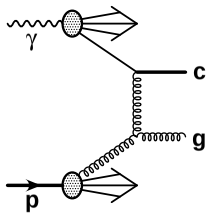
After cuts 1092 ± 43 events, 11 % have > 2 jets

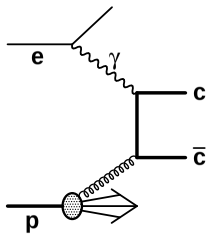


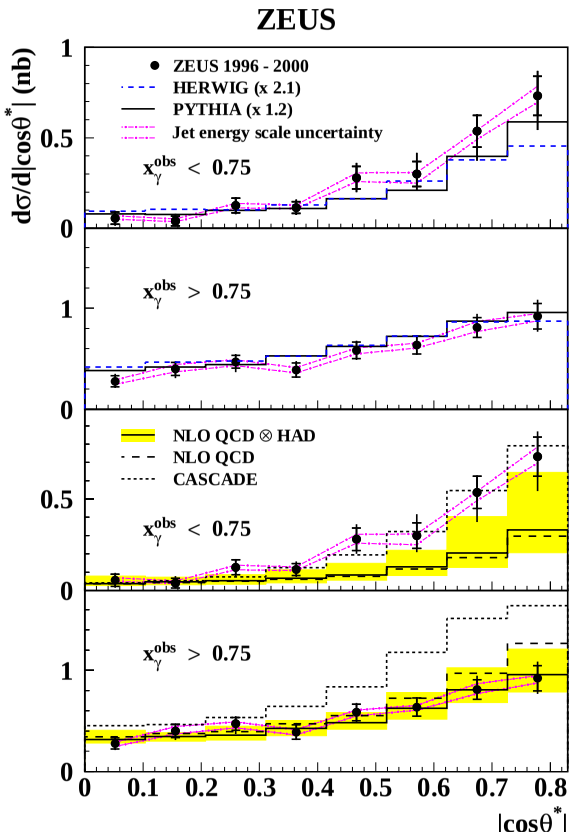
NLO: $\mu_f = \mu_r = m_T \equiv \sqrt{m_c^2 + < p_{c,T}^2 >}$

Shaded: $(m_c = 1.3\,\mathrm{GeV},\ \mu_r = m_T/2)$ and $(m_c = 1.7\,\mathrm{GeV},\ \mu_r = 2\,m_T)$

$|\cos\theta^*|$ Spectra







Data rise with $|\cos\theta^*|$ faster for $x_\gamma^{\rm OBS} < 0.75$

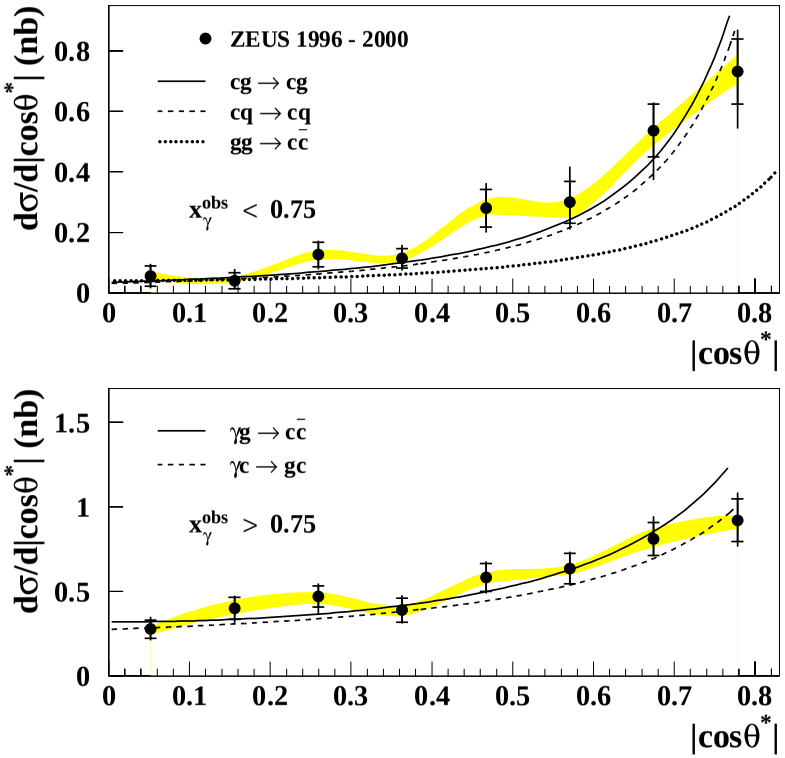
PYTHIA,HERWIG,CASCADE,NLO QCD: $\sim$ agree in shape

NLO QCD: below data for dominant resolved

CASCADE: above data for dominant direct

$|\cos\theta^*|$ Spectra

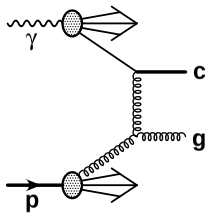
PYTHIA Monte Carlo normalized to leftmost data point

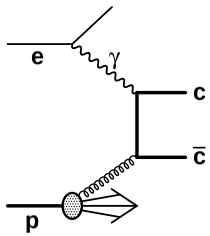


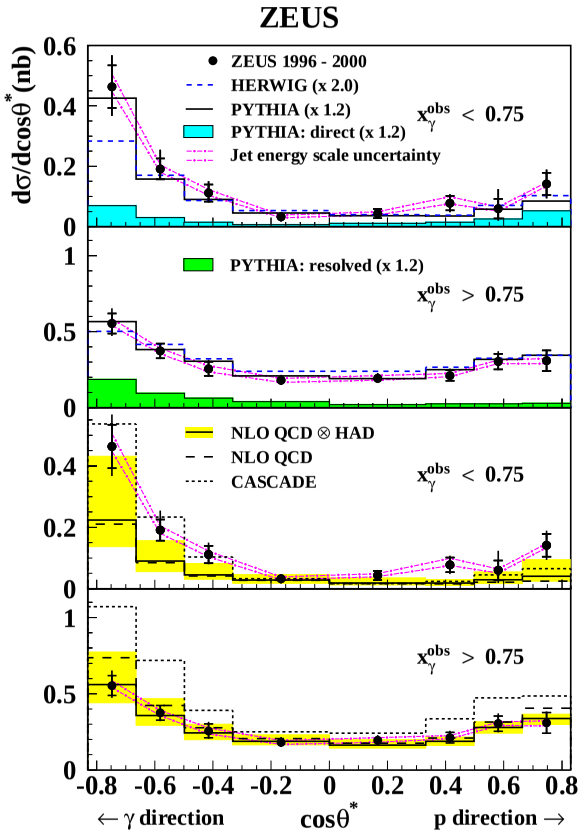
Shape of $gg \to c\bar{c}$ disagrees with data

$\cos\theta^*$ Spectra

Tag jet closest to $D^{*\pm}$ in $(\eta - \phi)$ space







$x_\gamma^{\mathrm{OBS}} < 0.75$: c from γ, no gluon gluon fusion

$x_\gamma^{\mathrm{OBS}} > 0.75$: mainly photon gluon fusion, mainly symmetric

NLO QCD: below data for dominant resolved

Summary

Inclusive Jets With Charm

- NLO: E_T^{jet} agrees in shape,too low in magnitude
- NLO: η^{jet} too low for forward (proton beam) η^{jet}

Dijets With Charm (Leading Order Production)

- $x_\gamma^{\text{OBS}} > 0.75$: Mainly photon gluon hard process,charm quark exchange
- $x_\gamma^{\text{OBS}} < 0.75$: Mainly charm gluon hard process,charm quark from photon
- $x_\gamma^{\text{OBS}} < 0.75$: Mainly gluon exchange (triple gluon vertex)

Summary

Dijets With Charm (Comparison With Predictions)

- PYTHIA,HERWIG with charm excitation describe shape
- NLO with hadronic corrections (FMNR) describes shape
- CASCADE describes shape
- NLO agrees in magnitude for $x_\gamma^{\mathrm{OBS}} > 0.75$
- NLO too low for $x_\gamma^{\mathrm{OBS}} < 0.75$
- CASCADE too high for $x_\gamma^{\mathrm{OBS}} > 0.75$

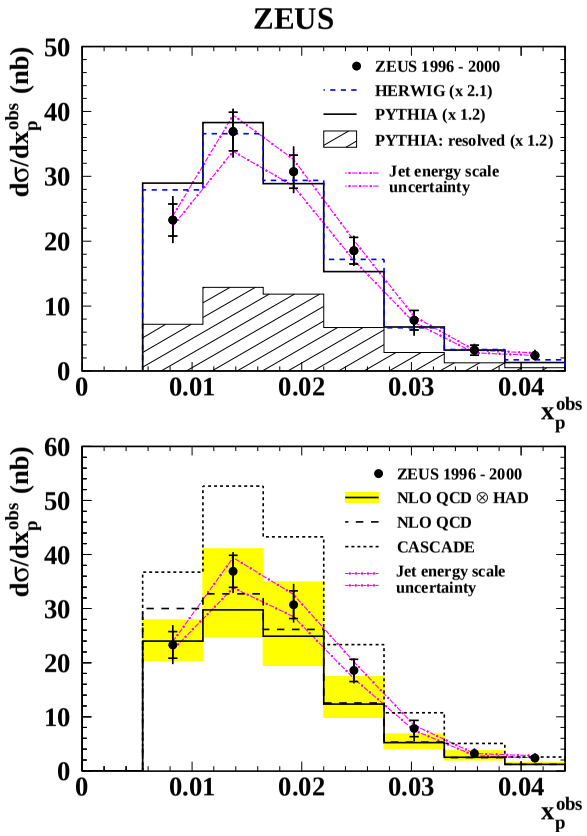
Charm Jets at HERA II

More Statistics + Microvertex Detector at HERA II

- Other Charm production channels
- Other D^0 decay channels
- Clean $D^{\pm}$ channel
- Photon remnant particles (resolved processes)
- Raise jet mass cut - insures only 2 jets
- Lower jet mass cut - study effect of 3 jets

x_p^{obs} Distribution

$$x_p^{\mathrm{OBS}} = \frac{E_T^{\mathrm{jet1}} e^{\eta^{\mathrm{jet1}}} + E_T^{\mathrm{jet2}} e^{\eta^{\mathrm{jet2}}}}{2E_p}$$



HERWIG,PYTHIA agree in shape

NLO QCD: same shape up to jet scale

CASCADE overshoots data