Charm dijet angular distributions
in γp collisions with ZEUS at HERA

Leonid Gladilin

(DESY / Moscow University / Weizmann Institute)

DIS 2003

April 23 - 27, 2003, St. Petersburg, Russia

O U T L I N E :

Production mechanisms and dijet observables

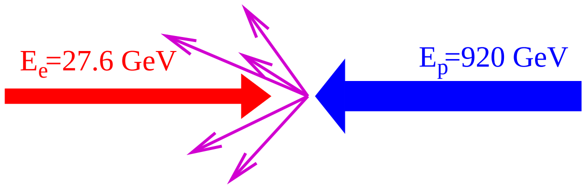
Perturbative QCD calculations

Charm tagging and dijet selection

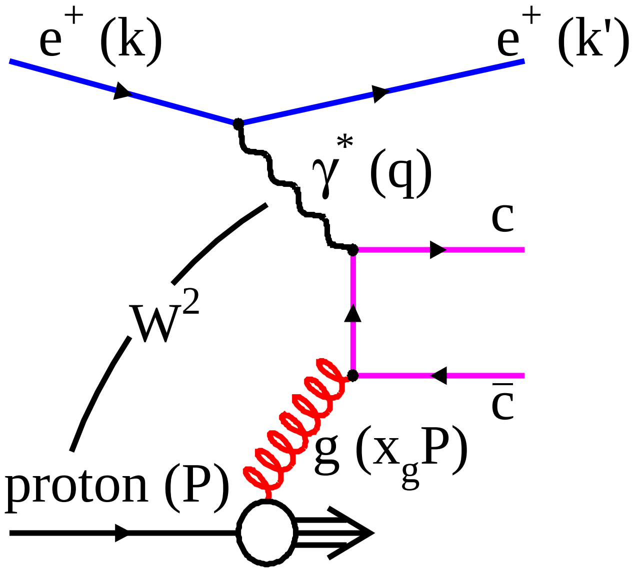
Charm dijet angular distributions

Summary

Charm production mechanisms at HERA



1992-1997 $E_p = 820\,\mathbf{GeV}$ $\sqrt{s} = 300\,\mathbf{GeV}$
1998-2000 $E_p = 920\,\mathbf{GeV}$ $\sqrt{s} = 318\,\mathbf{GeV}$



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

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

Photoproduction $Q^2 \simeq 0\,GeV^2$

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

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

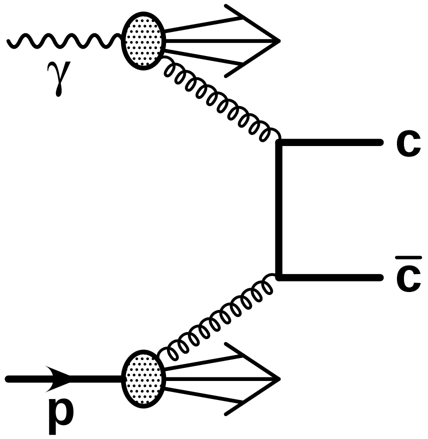
direct γ : $\gamma g \rightarrow Q\bar{Q}$, **Photon Gluon Fusion** $\longleftarrow$ **PGF**

The entire photon momentum participates in hard interaction: $x_\gamma = 1$

Propagator : c-quark, i.e. particle with spin $s = 1/2$

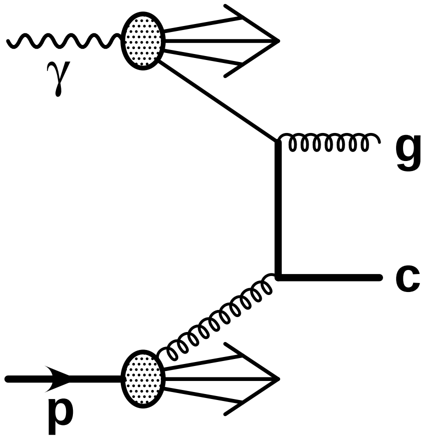
Charm production mechanisms at HERA

Resolved γ processes : $x_\gamma < 1$



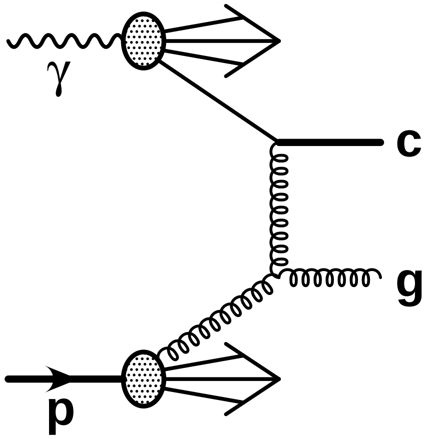
$gg \rightarrow Q\bar{Q}$

(q propagator)



$Qg \rightarrow Qg$, Q excit.

(q propagator)



$Qg \rightarrow Qg$, Q excit.

(g propagator, $s = 1$)

This is a Leading Order picture

Observables sensitive to

direct and resolved contributions

q and g propagator contributions

can be measured and defined at any order

using two highest $E_T^{\rm jet}$ jets within accepted $\eta^{\rm jet}$ range

Dijet observables

To distinguish direct and resolved contributions :

fraction of the photon momentum
participating in the dijet production

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

direct-enriched : $x_\gamma^{\text{obs}} > 0.75$

resolved-enriched : $x_\gamma^{\text{obs}} < 0.75$

To distinguish q and g propagator contributions :

angle between jet-jet and beam axis in the dijet rest frame

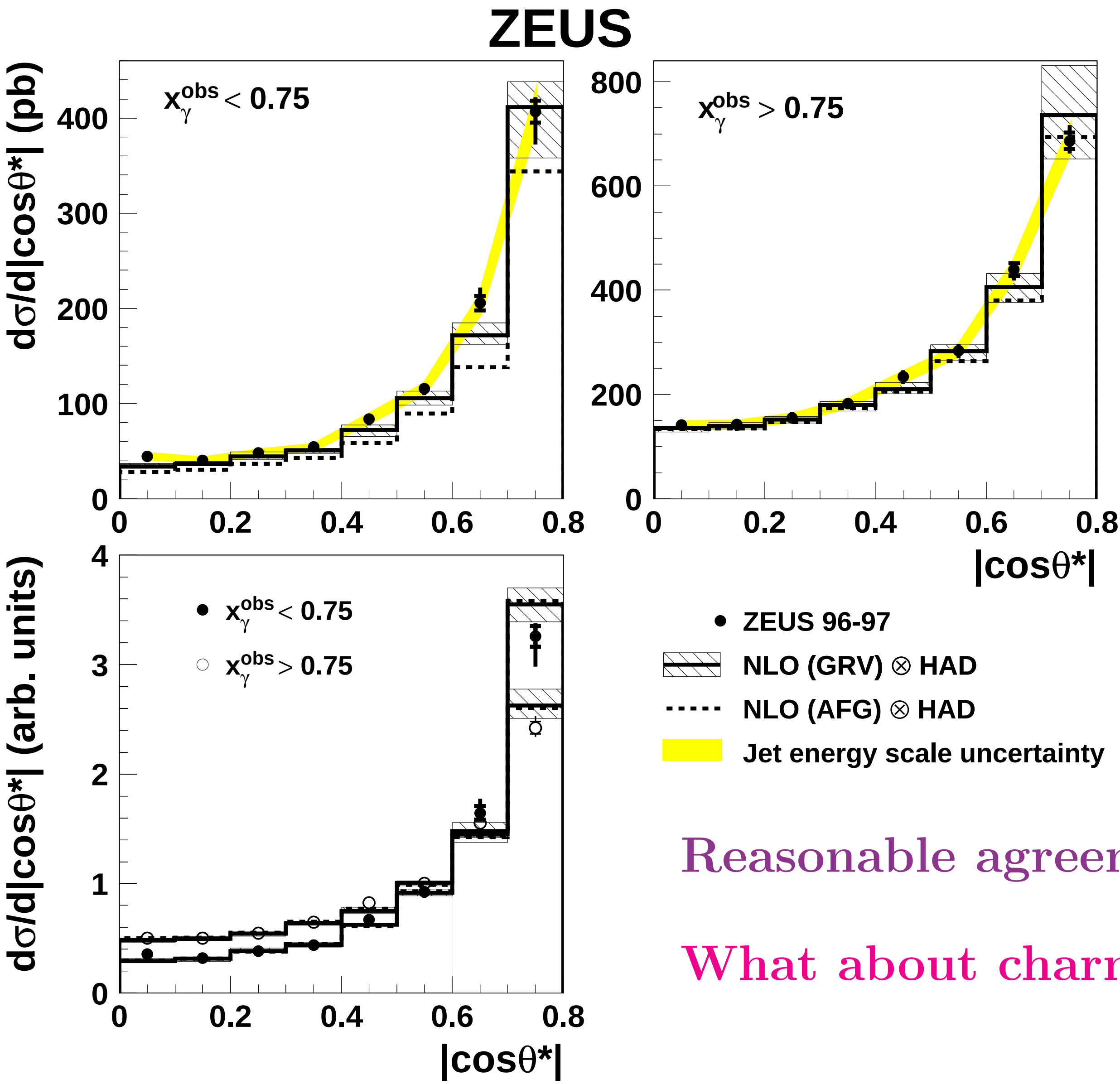
$$\cos\theta^* = \tanh\frac{\eta^{\text{jet1}} - \eta^{\text{jet2}}}{2}$$

"q propagator" $\propto (1 - |\cos\theta^*|)^{-1}$

"g propagator" $\propto (1 - |\cos\theta^*|)^{-2}$

Inclusive dijet photoproduction

"$|\cos\theta^*|$" method was used for inclusive dijet photoproduction :



Reasonable agreement with NLO QCD

What about charm case ?

Perturbative QCD calculations

collinear approach (on-shell matrix elements) :

Monte Carlo with LO matrix elements

and DGLAP initial- and final-state radiation (ISR, FSR) :

- **AROMA (only direct γ)**
- **HERWIG (direct and resolved)**
- **PYTHIA (direct and resolved)**

Fixed-order NLO QCD : FMNR, S. Frixione et al.

- $n_f = 3$: (u, d, s) **are active flavors in p and γ**
- **no explicit charm excitation component**

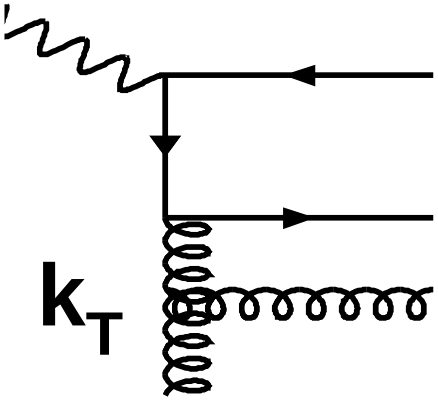
No predictions (pitifully !) for charm dijet photoproduction

from resummed NLL QCD

- $n_f = 4$: (u, d, s, c) are active flavors in p and γ
- explicit charm excitation component

Perturbative QCD calculations

k_t−factorisation (semi-hard) approach :



"unintegrated" k_t−dependent gluon density

off-shell matrix elements

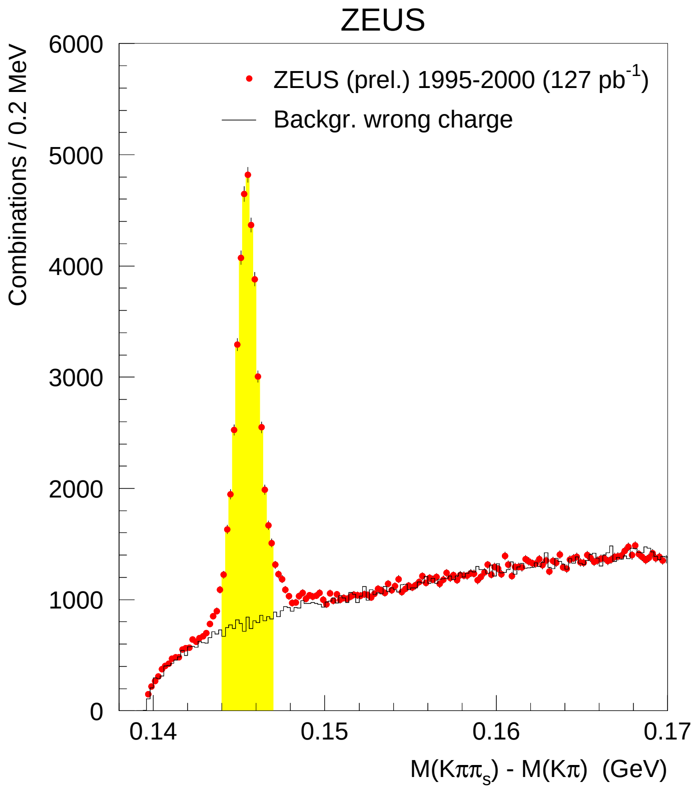
smaller NLO corrections expected

CASCADE Monte Carlo from H. Jung et al.

- LO PGF matrix element
- CCFM-like (angular ordering) evolution for ISR reproducing resolved photon processes
- gluon density tuned to describe F_2 via PGF
- no free parameters except m_c

$\boxed{m_c = 1.5\,\mathrm{GeV}}$ as central value for all predictions

Charm tagging and hadronisation description



$$D^{*\pm} \rightarrow D^0 \pi_s^{\pm} \rightarrow (K^{\mp}\pi^{\pm})\pi_s^{\pm}$$

$$\Delta M = M(K\pi\pi) - M(K\pi)$$

$$M(D^{*+}) - M(D^0) \sim m_\pi$$

$$f(c \rightarrow D^{*+}) \;=\; 0.235 \pm 0.007 \pm 0.007(br.)$$

measured in e^+e^-

used for all predictions

Hadronisation :

PYTHIA, CASCADE : LUND string model

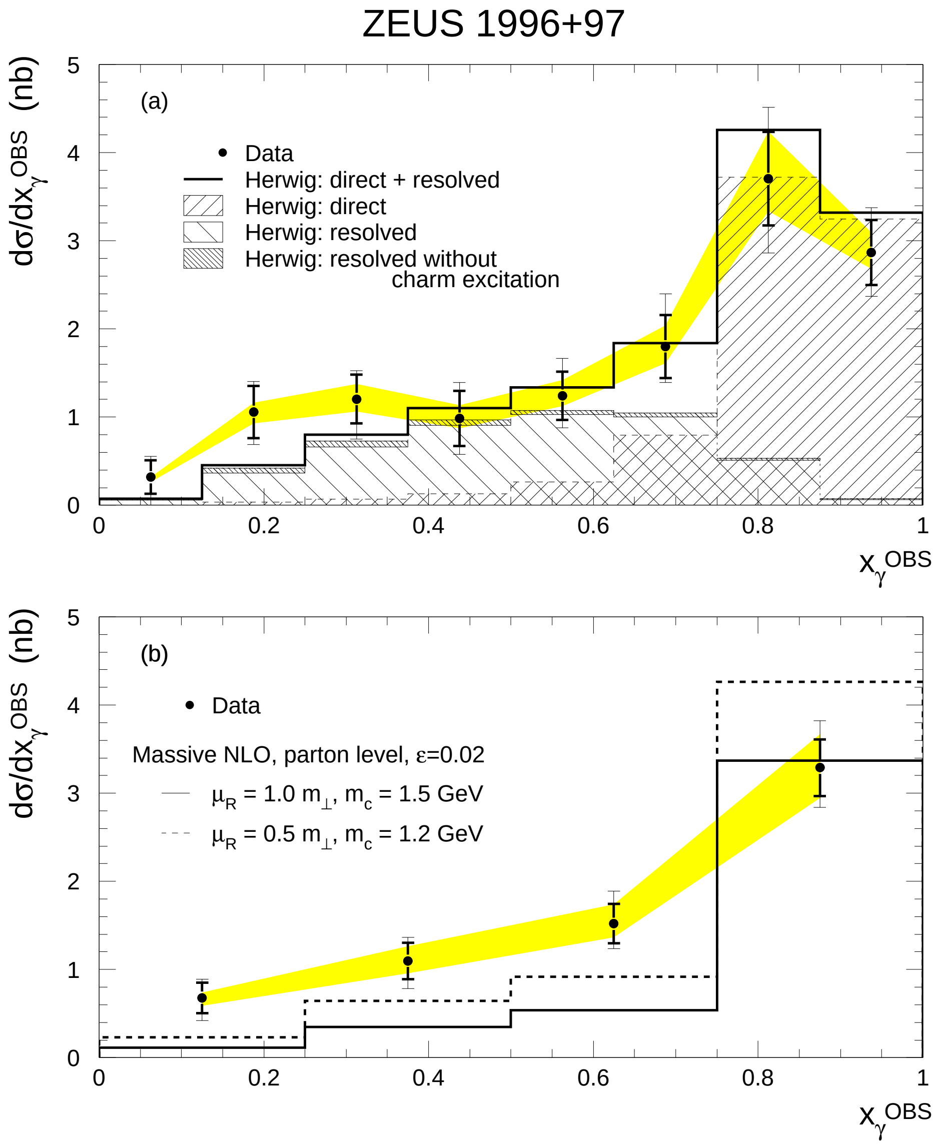
HERWIG : cluster model

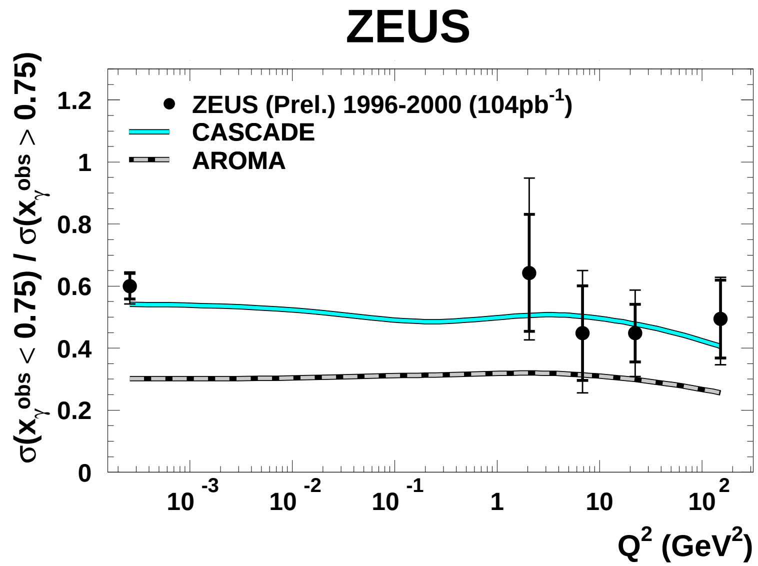
FMNR NLO : Peterson's FF : $D_c(x) = N\frac{x(1-x)^2}{[(1-x)^2+\epsilon x]^2}$ $\quad x = \frac{p_{D^*}}{p_c}$

$\epsilon = 0.035$ ARGUS data $\Leftarrow$ NLO fit of P. Nason and C. Oleari

Charm dijet photoproduction

$D^{*\pm}$ and at least two jets, $x_\gamma^{OBS} = \frac{E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}}}{2yE_e}$





Sizable LO resolved γ contribution

No strong suppression with Q^2

AROMA is too low (no resolved γ)

HERWIG, PYTHIA : charm excitation

CASCADE : CCFM ISR

$\longleftarrow$ NLO are below data at low x_γ^{OBS}

Nature of the resolved component ?

Charm dijet selection for $\cos\theta^*$ analysis

$$\boxed{\mathcal{L}_{int} = 120\,\mathrm{pb}^{-1}}$$

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

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

at least 2 jets with

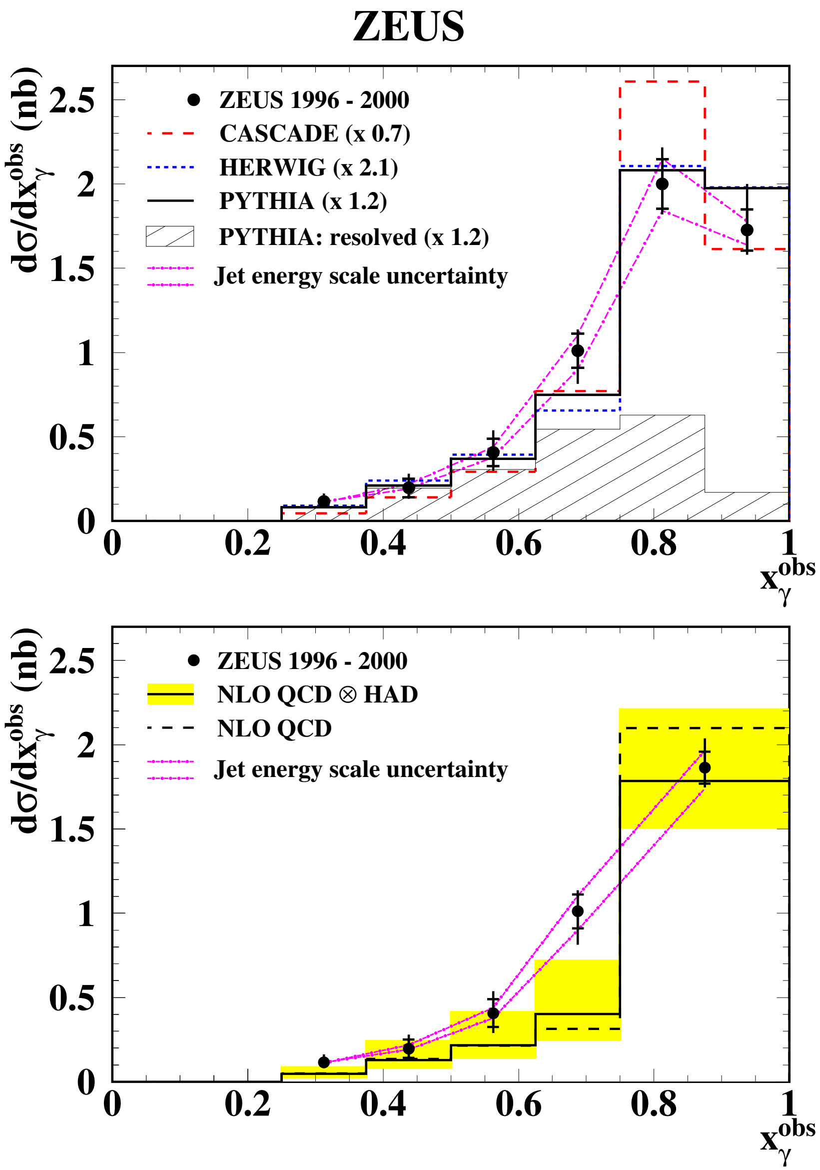
$E_T^{\mathrm{jet}} > 5\,\mathrm{GeV}$ and $|\eta^{\mathrm{jet}}| < 2.4$

<u>to reduce biases in $\cos\theta^*$</u>

from E_T^{jet} selection : $M_{jj} > 18\,\mathrm{GeV}$

from η^{jet} and $\eta^{D^{*\pm}}$: $|\frac{\eta^{\mathrm{jet1}}+\eta^{\mathrm{jet2}}}{2}| < 0.7$

$$\boxed{N(D^{*\pm}) = 1092 \pm 43}$$



NLO : CTEQ5M1 and AFGHO for p and γ

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

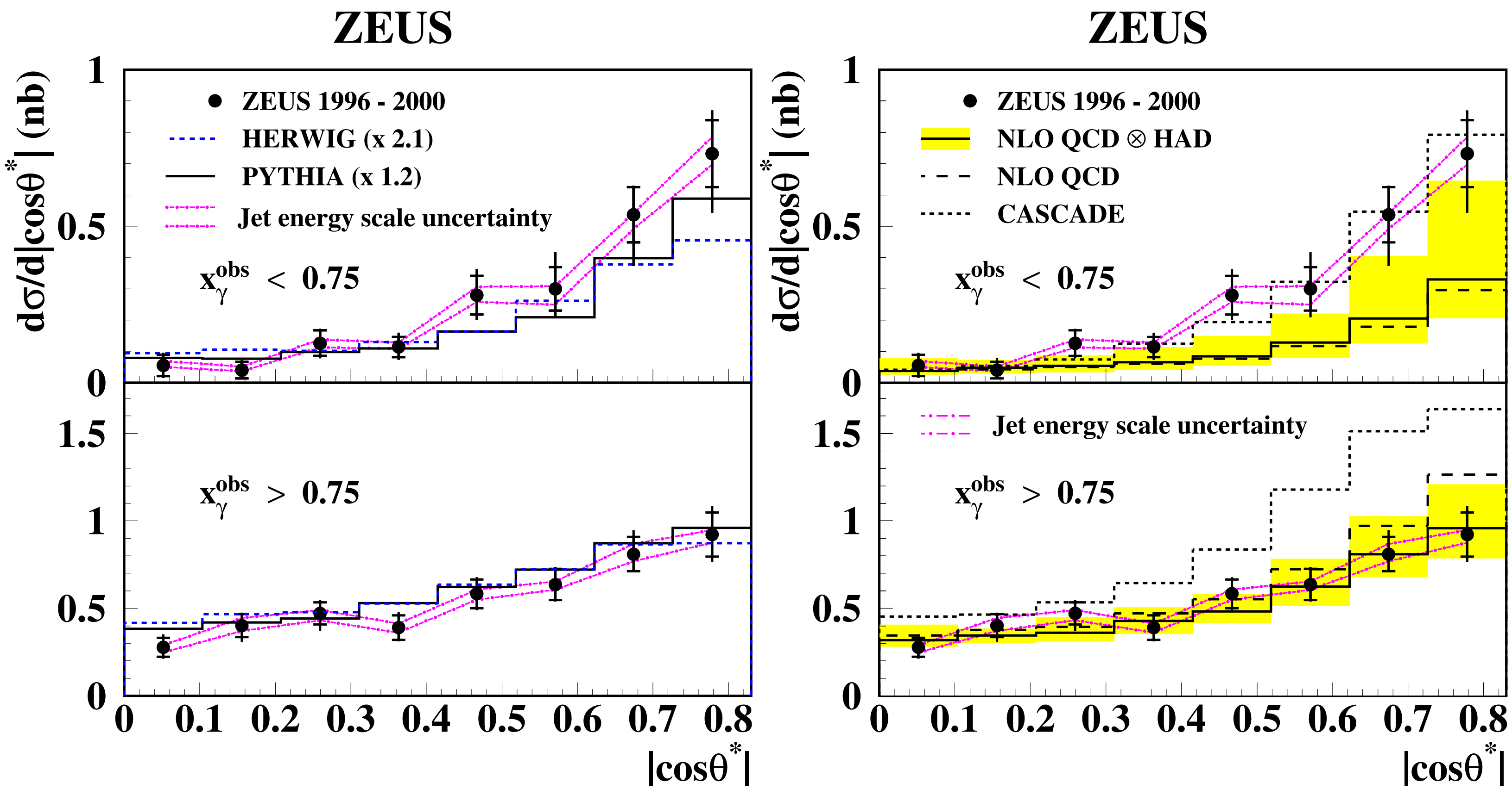
yellow band : $(m_c = 1.3\,\mathrm{GeV},\ \mu_r = m_T/2) \Longleftrightarrow (m_c = 1.7\,\mathrm{GeV},\ \mu_r = 2\,m_T)$

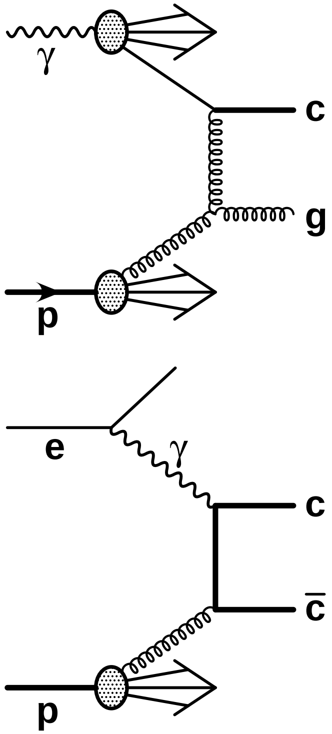
Charm dijet $|\cos\theta^*|$ distributions

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

"q propagator" $\propto (1-|\cos\theta^*|)^{-1}$

"g propagator" $\propto (1-|\cos\theta^*|)^{-2}$





$\boxed{\text{more rapid rise for } x_\gamma^{\mathrm{obs}} < 0.75 \Longrightarrow \text{a signature of } g \text{ propagator !}}$

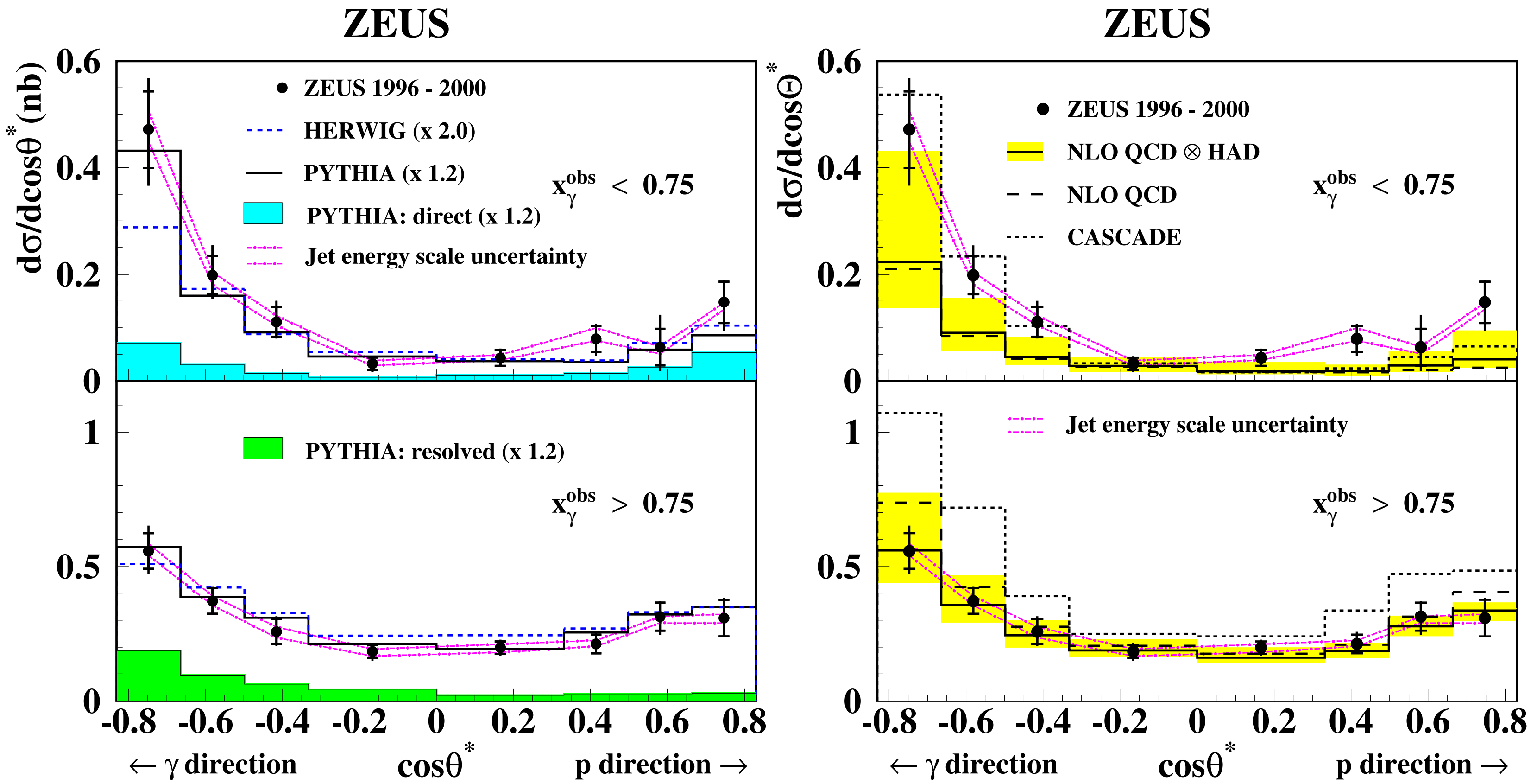
PYTHIA and HERWIG with charm excitation : adequate description

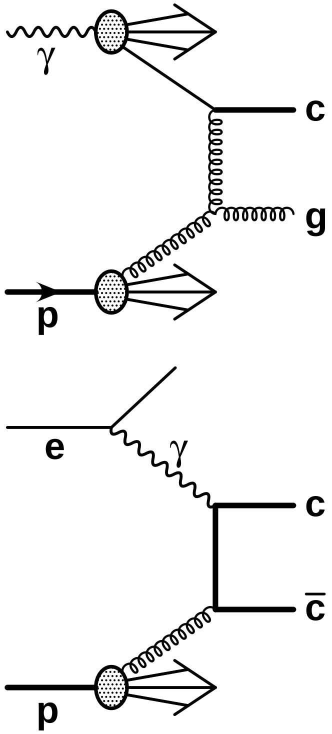
NLO QCD : too low for $x_\gamma^{\mathrm{obs}} < 0.75$; shapes are in reasonable agreement

CASCADE : too high for $x_\gamma^{\mathrm{obs}} > 0.75$; shapes are o.k.

Charm dijet $\cos\theta^*$ distributions

"jet 1" - matched with $D^{*\pm}$ in $(\eta - \phi)$ space; "jet 2" - other jet





strong rise in γ direction for $x_\gamma^{obs} < 0.75 \Longrightarrow$ dominance of $gg \to c\bar{c}$ is excluded !

dijets with $x_\gamma^{obs} < 0.75$ are mainly produced by c coming from γ side : $cg \to cg$, $cq \to cq$

PYTHIA and HERWIG with charm excitation : adequate description

NLO QCD : too low for $x_\gamma^{obs} < 0.75$ in both γ and p directions; shapes are o.k.

CASCADE : too low for $x_\gamma^{obs} < 0.75$ in p direction; shapes are o.k.

Summary

Shapes of $|\cos\theta^*|$ and $\cos\theta^*$ distributions for charm dijet events with $x_\gamma^{\rm obs} > 0.75$ and $x_\gamma^{\rm obs} < 0.75$ show :

- charm dijet photoproduction with $x_\gamma^{\rm obs} < 0.75$ cannot be dominated by $gg \to c\bar{c}$ process
- dijet system with $x_\gamma^{\rm obs} < 0.75$ is dominantly produced by charm coming from photon side : $cg \to cg$, $cq \to cq$

The shapes can be described reasonably well by :

- charm excitation in LO collinear calculations (PYTHIA, HERWIG)
- NLO corrections in collinear calculations (FMNR)
- CCFM initial-state radiation in LO k_t-factorisation calculations (CASCADE)

NLO normalisation :

- perfect for $x_\gamma^{\rm obs} > 0.75$
- too low for $x_\gamma^{\rm obs} < 0.75$ both in photon and proton directions

NNLO corrections ? resummation terms ?

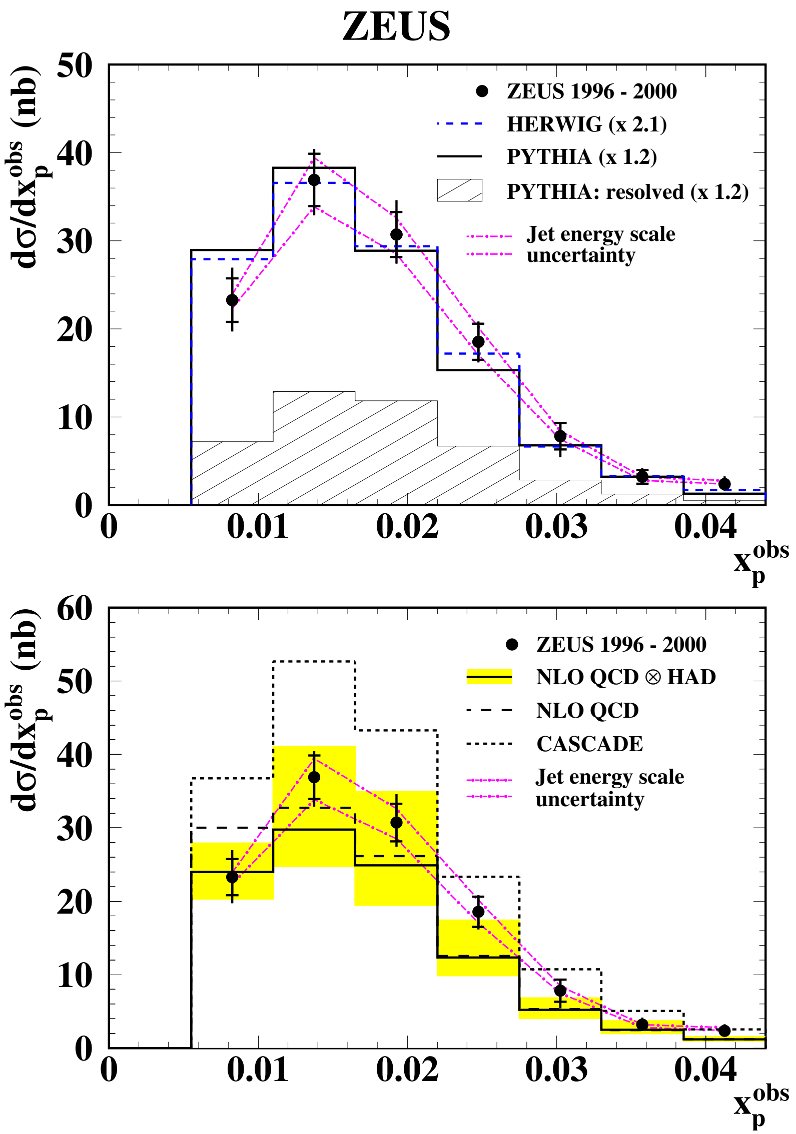
CASCADE normalisation :

- too high for $x_\gamma^{\rm obs} > 0.75$
- for $x_\gamma^{\rm obs} < 0.75$: o.k. in photon direction and too low in proton direction

surplus of proton evolution ? missing of photon evolution ?

Backup : fraction of the proton's momentum

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



$0.0055 < x_p^{\rm obs} < 0.044$

shape is reproduced

CASCADE is too high