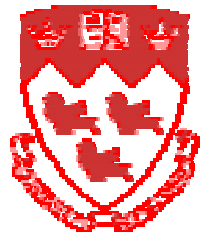


Heavy Flavoured jets at HERA

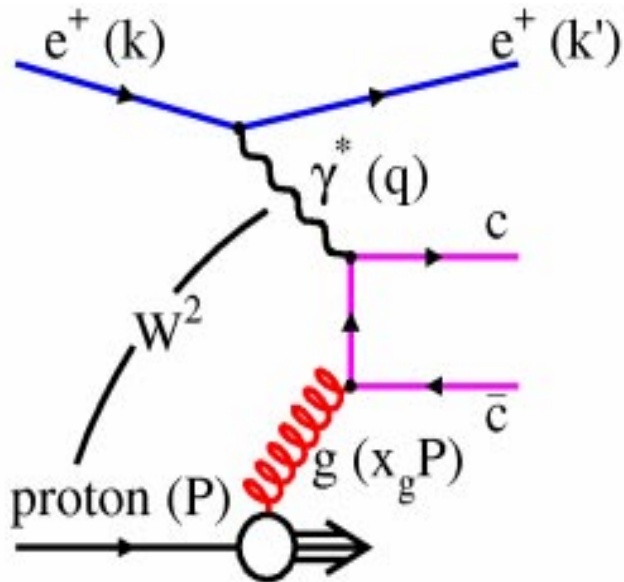


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- ◆ **Introduction**
- ◆ **Heavy Flavour Production & Fragmentation**
- ◆ **Charm with Jets**
 - ★ **Production Mechanisms**
 - ★ **Inclusive Charm Jet Cross sections**
- ◆ **Charm with Dijets**
 - ★ **x_γ measurements**
 - ★ **Dijet angular distribution in D^* Photoproduction**
- ◆ **Summary and Outlook**

Introduction



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

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

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

$$y = q \cdot P / k \cdot P \cong W^2 / s$$

Photoproduction Regime:

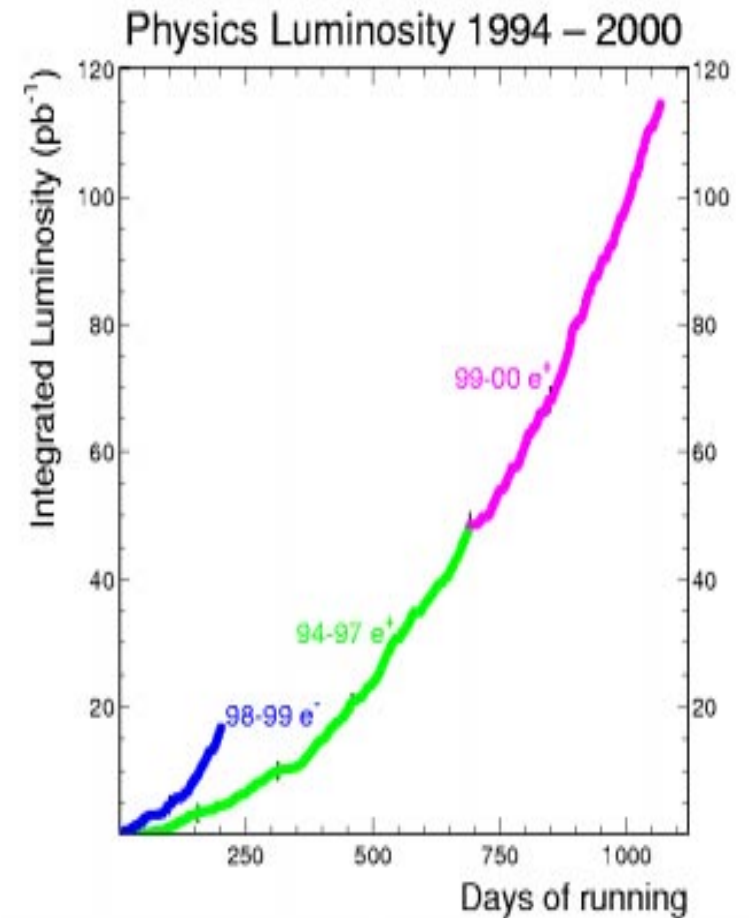
• No scattered electrons

• $Q^2 \leq 1 \text{ GeV}^2$

• $130 < W < 280 \text{ GeV}$

• 1992–1997 $E_p = 820 \text{ GeV}$ $\sqrt{s} = 300 \text{ GeV}$

• 1998–2000 $E_p = 920 \text{ GeV}$ $\sqrt{s} = 318 \text{ GeV}$



Heavy Flavour Production & Fragmentation

Experimentally ($c \rightarrow D$) Meson:

◆ Fragmentation Fraction

$$f(c \rightarrow D^{*+}) = 0.235 \pm 0.007 \text{ (LEP)}$$

◆ Fragmentation Functions

(e.g Peterson Fragmentation Function)

Charmed Mesons :

Vector State (V) $D^{*\pm} \rightarrow \text{spin } 1$

Pseudoscalar (PS) $D^0 \rightarrow \text{spin } 0$

$$P_v = V/(V + PS)$$

Simple spin counting : $P_v = 0.75$

Whether these fragmentation fractions are Universal ?

However there are several models

K. Cheung et. al. hep-ph/9505365 $P_v = 0.68$

Braaten et. al. Phys.Rev.D51(1995) 4819 $0.5 < P_v < 0.75$

Y. Q. Chen. Phys. Rev. D48 (1993) 5181 $P_v = 0.6$

Yi-Jin Pei, Z. Phys. C 72, 39 (1996) $P_v = 0.56$



Universality of charm fragmentation

Direct Production rates from charm fragmentation :

$$P_v = \sigma_{\text{dir}}(D^{*\pm}) / (\sigma_{\text{dir}}(D^{*\pm}) + \sigma_{\text{dir}}(D^0))$$

Assuming:

- a) $\sigma(D^{*0}) = \sigma(D^{*\pm})$
- b) No sizable distortions from excited D mesons

Decay Modes:

$$D^0 \rightarrow K^- \pi^+ (+\text{c.c.})$$

$$D^{*+} \rightarrow (K^- \pi^+) \pi_s^+ (+\text{c.c.})$$

; π_s is a soft pion with low momentum

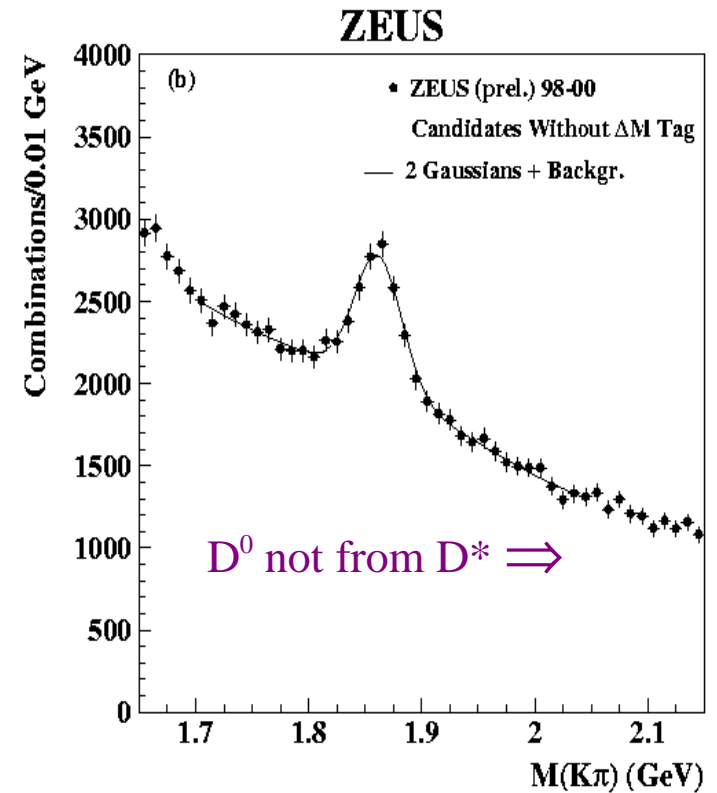
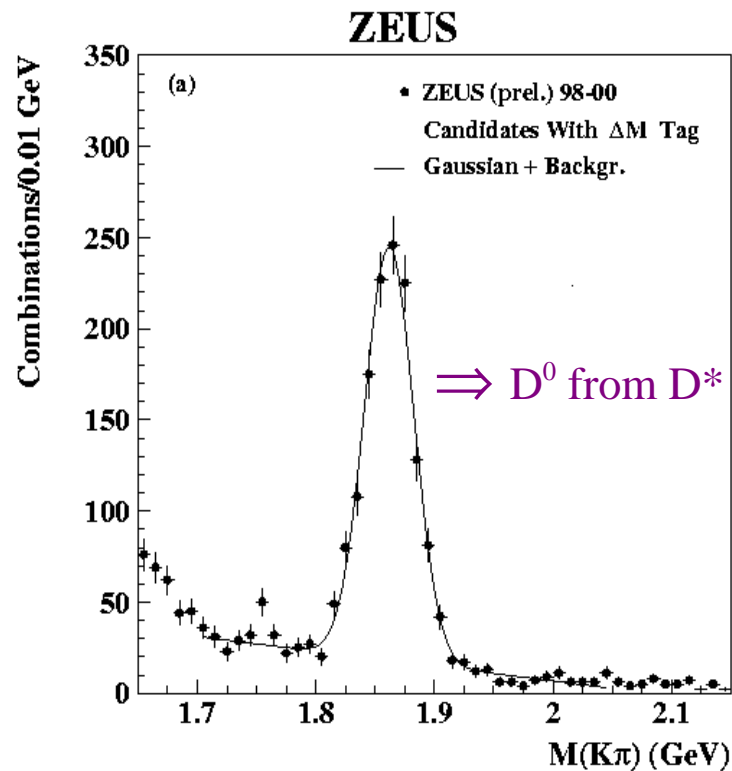
$$\sigma_{\text{dir}}(D^0) = \sigma_{\text{tot}}(D^0) - \sigma_{\text{tot}}(D^{*\pm})(1 + \text{BR}(D^{*\pm} \rightarrow D^0 \pi^\pm))$$

$$P_v = \frac{1}{(\sigma_{\text{tot}}(D^0)/\sigma_{\text{tot}}(D^{*\pm}) - \text{BR}(D^{*\pm} \rightarrow D^0 \pi^\pm))}$$

P_v measured from ZEUS data for D^* and D^0 mesons



Universality of charm fragmentation



$$P_v = 0.546 \pm 0.045(\text{stat.}) \pm 0.028(\text{syst.})$$

Using: $N(D^0) = 5223 \pm 185$
 $N(D^{*\pm}) = 1180 \pm 39$

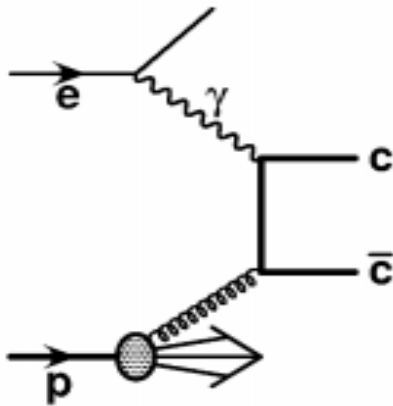
OPAL: $P_v = 0.57 \pm 0.05$

ALEPH: $P_v = 0.595 \pm 0.045$

Charm Fragmentation Fractions are Universal

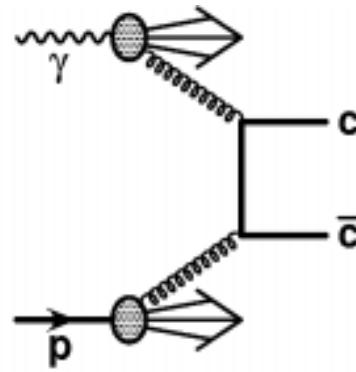


Charm with Jets (LO)



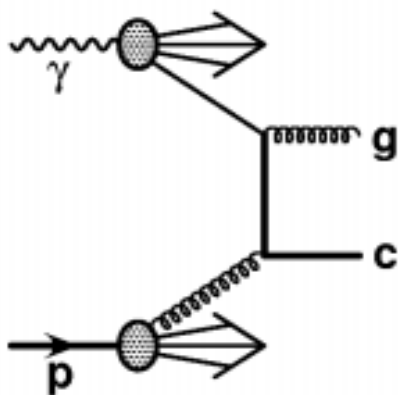
Direct- γ : γ -g fusion

q-exchange



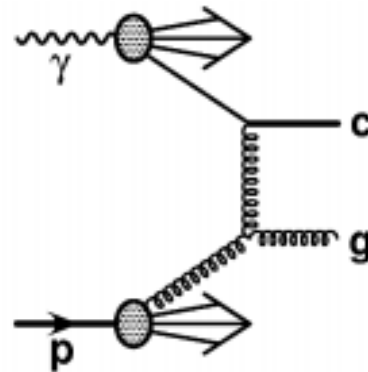
Resolved- γ : $g g \rightarrow c \bar{c}$

q-exchange



Resolved- γ : c excitation

q-exchange



g-exchange

Define: Direct photon $x_\gamma = 1$

Resolved photon $x_\gamma < 1$

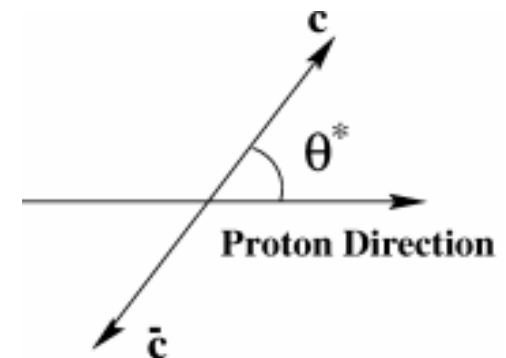
Direct and Resolved :

q-exchange $d\sigma/d\cos\theta^* \sim (1 - |\cos\theta^*|)^{-1}$

Resolved :

g-exchange $d\sigma/d\cos\theta^* \sim (1 - |\cos\theta^*|)^{-2}$

Rutherford Scattering



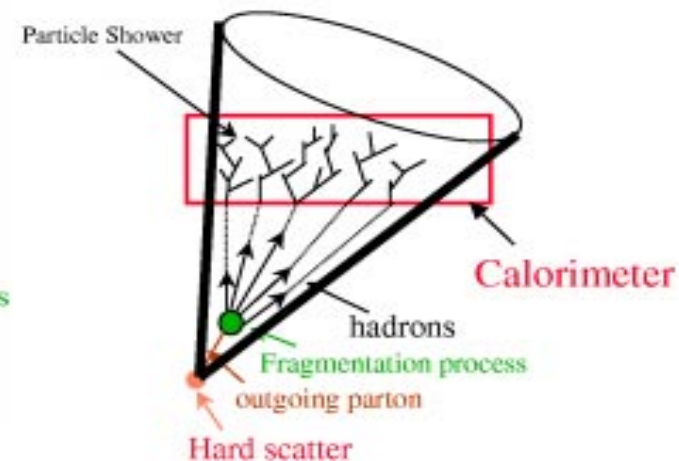
$\theta^* = \text{center of mass scattering angle}$



Charm Jets in experiments & NLO

KTCLUS Algorithm for Jets

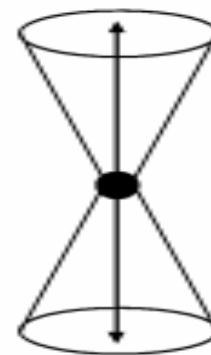
Hadron level Charm Jets



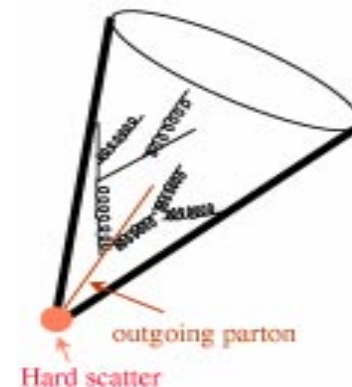
Fixed-order ("massive") NLO (Parton level Jets)

- ★ Only light quarks u, d, s are active flavours in p, γ
- ★ No explicit charm excitation component
- ★ Charm is only produced dynamically
- ★ Scheme valid for $p_{\perp}^2 \approx m_Q^2$
- ★ Only sum of dir./res contribution well defined

Leading Order



Higher Orders



Parton level Charm Jets



Inclusive Charm Jets Cross section

Now let's see the charm jets ...

For $Q^2 < 1 \text{ GeV}^2$; $130 < W < 280 \text{ GeV}$

$p_{\perp}^{D^*} > 3 \text{ GeV}$, $|\eta^{D^*}| < 1.5$

NLO Fixed order (Frixione et al.)

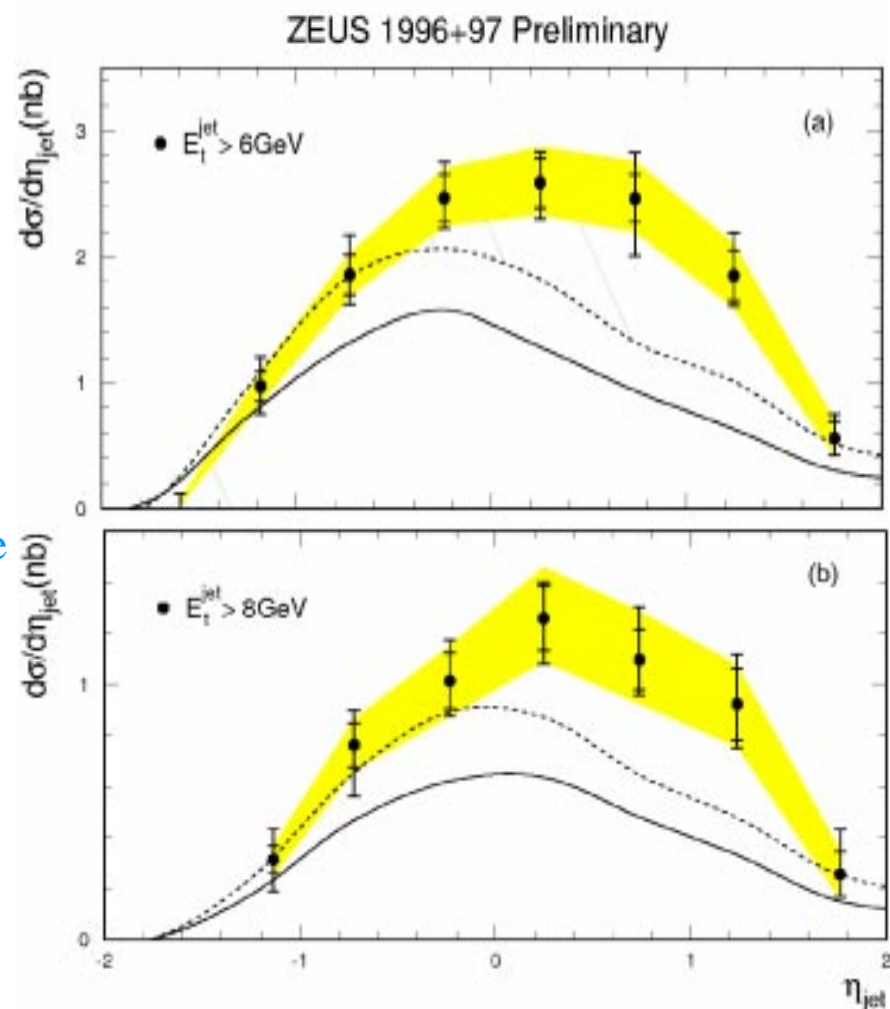
PDFs: p MRSG, γ GRV-G HO

solid curves: $m_c = 1.5 \text{ GeV}$, $\mu_R = m_{\perp}$, $\mu_F = 2m_{\perp}$

dotted curves: $m_c = 1.2$ and $\mu_R = 0.5m_{\perp} \leftarrow$ extreme case

Extreme case is still below the data, disagreement large for $\eta^{D^*} > 0$

Same trend as observed in η distribution for inclusive $D^{*\pm}$ and D_s^{\pm} cross-section



Jet distributions are not sensitive to "Beam Drag" effects !!!



Inclusive Charm Jet Cross section

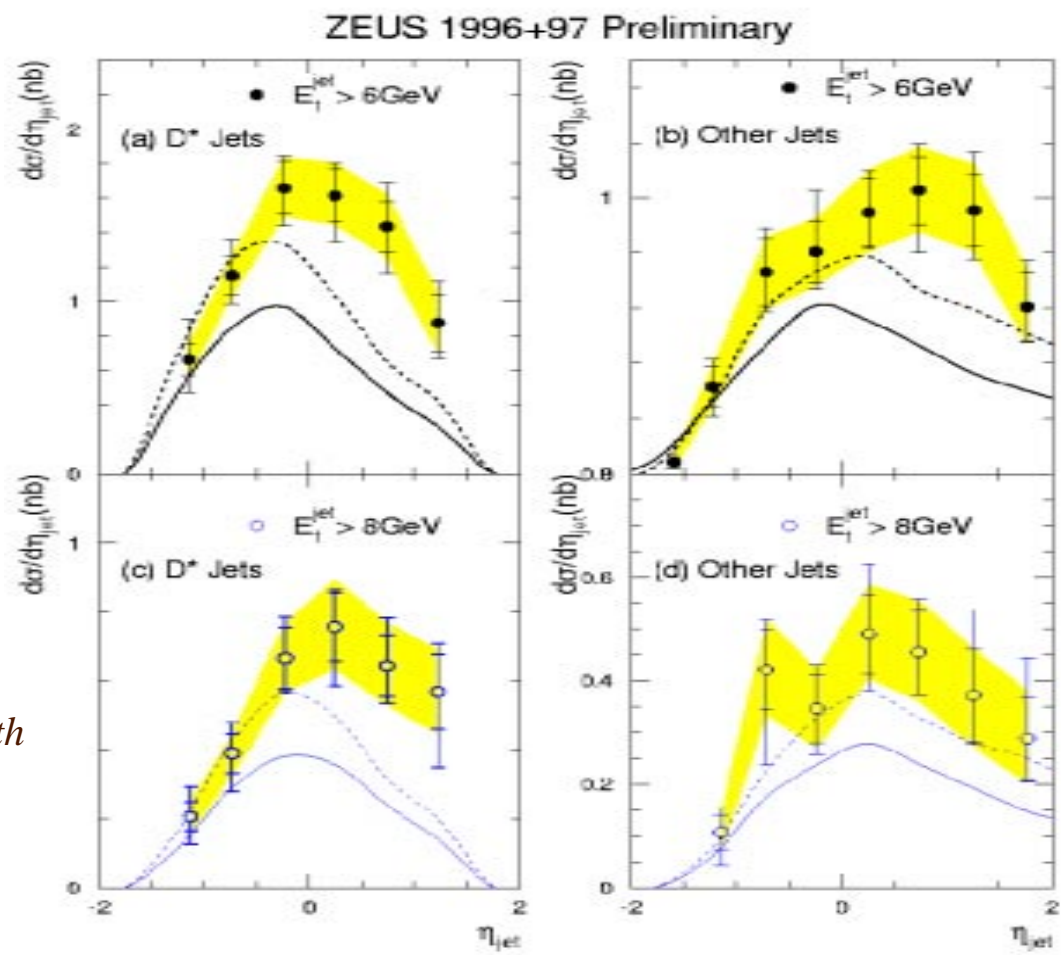
Looking at the picture from both sides:

D* jet \Rightarrow Jet nearest to D* in $\eta - \phi$ space

\Rightarrow Other Jet

NLO underestimates both non-D* cross section as well as the D* jet cross section

(Reproduces E_T^{Jet} shapes reasonably well in both cases)



x_{γ}^{OBS} Measurements

Fraction of photon energy contributing to the production of two highest E_t^{jet} jets

$$x_{\gamma}^{\text{OBS}} = \frac{\sum_{\text{jets}} E_T e^{-\eta}}{2yE_e}$$

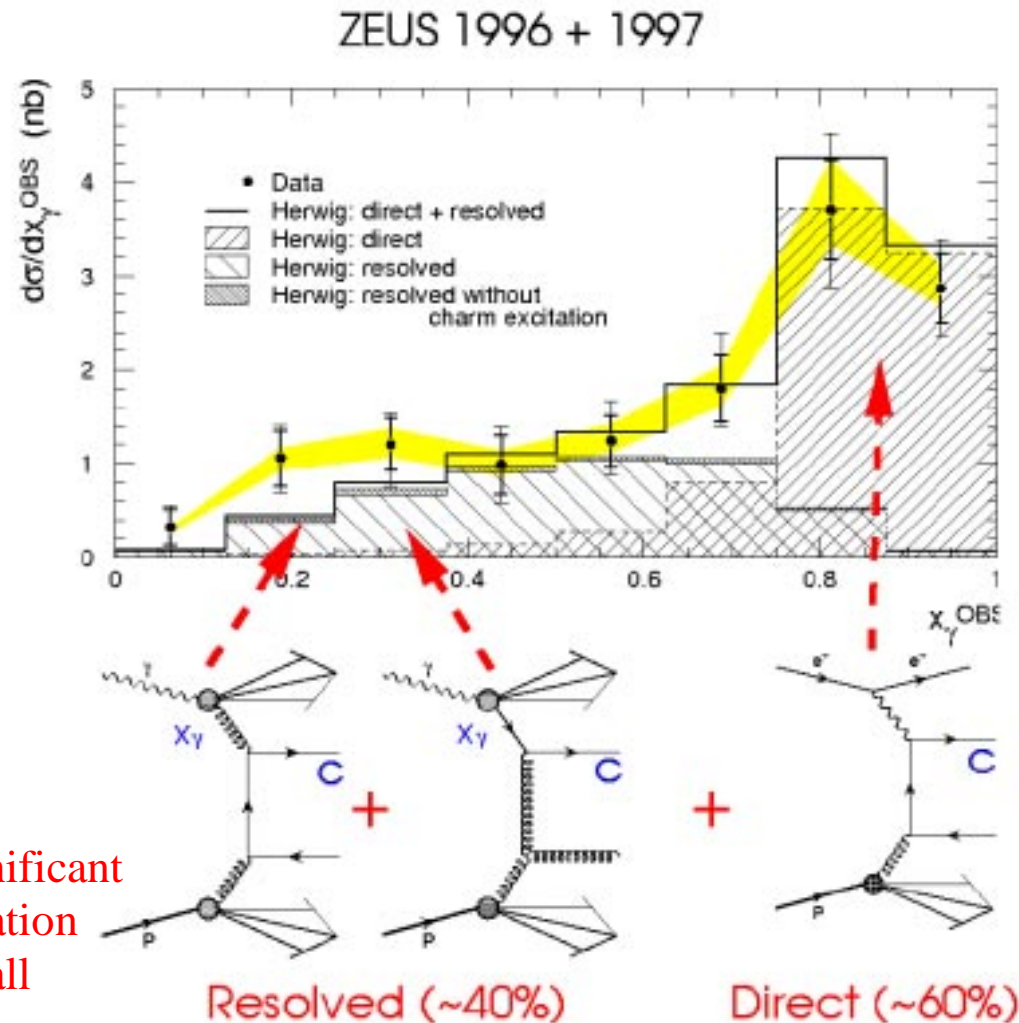
$Q^2 < 1 \text{ GeV}^2$, $130 < W < 280 \text{ GeV}$

$E_T^{\text{jet1}} > 7 \text{ GeV}$, $E_T^{\text{jet2}} > 6 \text{ GeV}$, $|\eta^{\text{jet}}| < 2.4$

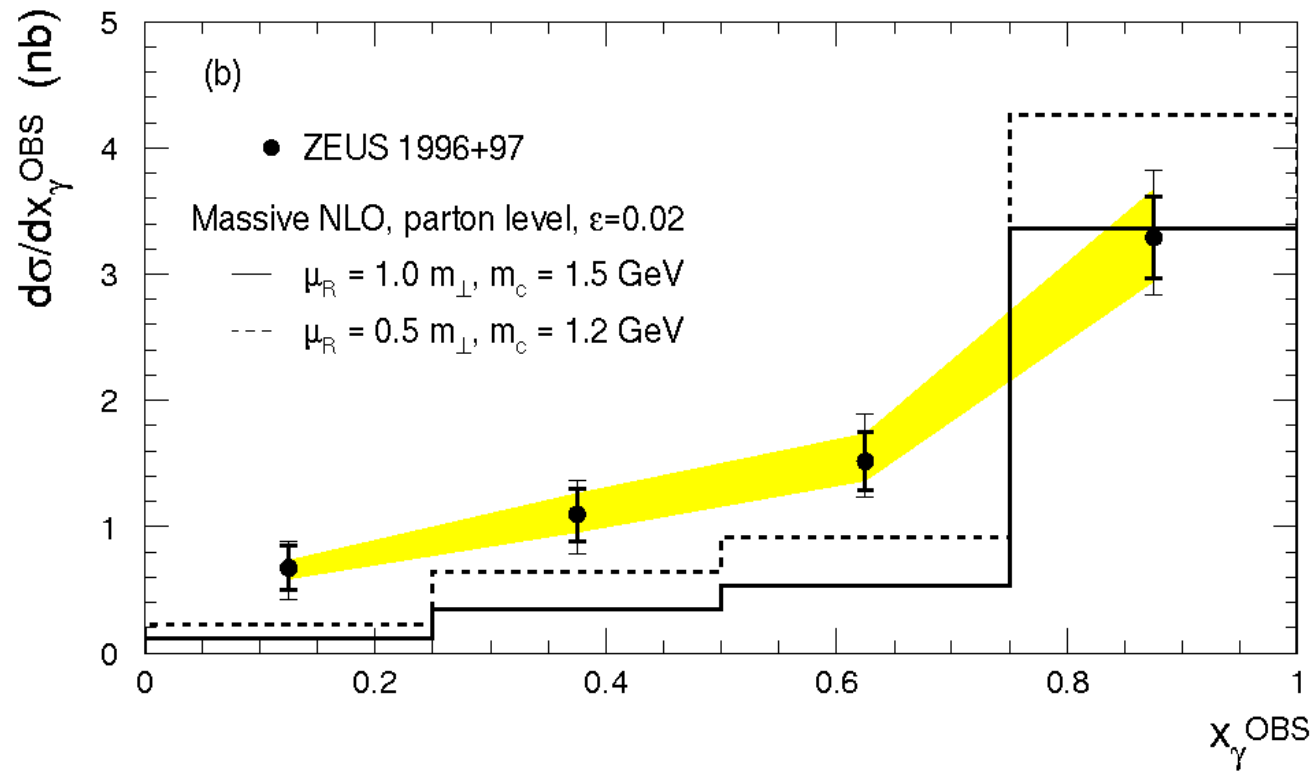
$p_{\perp}^{D^*} > 3 \text{ GeV}$, $-1.5 < \eta^{D^*} < 1.5$

LO(DGLAP) Herwig MC :

- ★ Both direct and resolved fractions are significant
- ★ Dominant part of resolved is from c excitation
- ★ Resolved without c excitation is quite small



x_{γ}^{OBS} Measurements



Yellow bands: Uncertainty due to Calorimeter energy scale

Fixed order NLO calculation below data at $x_{\gamma}^{\text{OBS}} < 0.75$

Would be interesting to see "massless" calculations ??

CASCADE \Rightarrow describes well (See B. West & H. Jung's talk)



Dijet angular distribution in D^* photoproduction

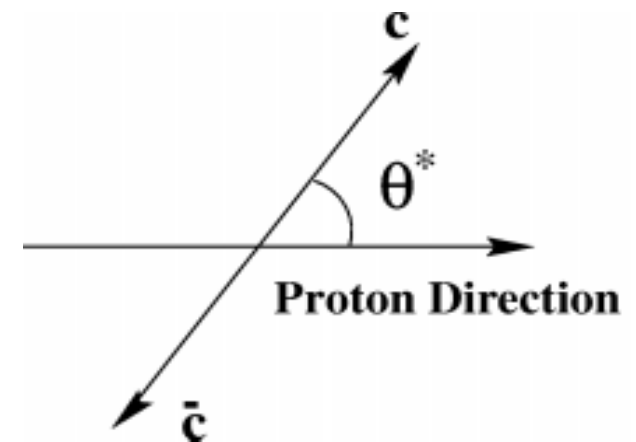
QCD (LO) predicts that the angular distribution of the outgoing partons in resolved processes will be enhanced at high $|\cos\theta^*|$ with respect to direct photon processes.

H. Baer, J. Ohnemus & J. F Owens, Phys. Rev D40 (1989) 2844

Is it really true ?

ZEUS published Phys. Lett. B 384 (1996) 401

Is it also true in case of charm ?



Dijet angular distribution in D^* photoproduction

D^* dijet events enable study of the photon structure in particular its charm content

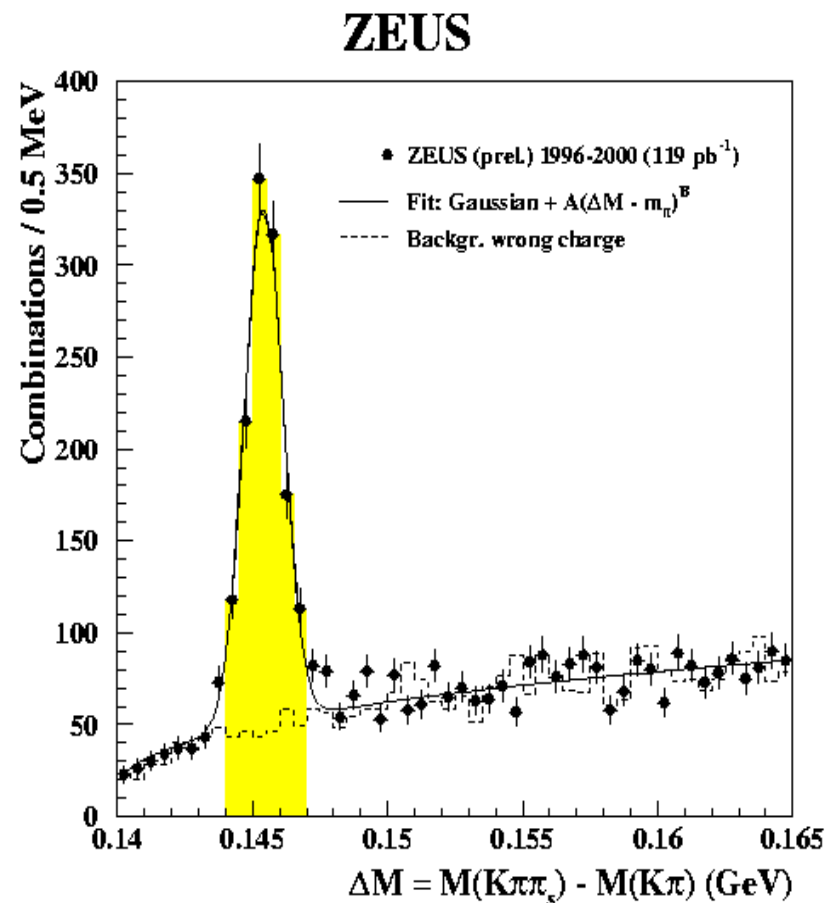
Sample Used: Photoproduction with a reconstructed D^* and atleast 2 hadron jets – "dijets"

- ★ Require D^* with $p_T^{D^*} > 3.0 \text{ GeV}$, $|\eta^{D^*}| < 1.5$
- ★ Dijets $E_t^{\text{jet}} > 5 \text{ GeV}$, $\eta^{\text{jet}} < 2.4$, $M_{jj} > 18 \text{ GeV}$
 $|\cos\theta^*| < 0.83$ | $|\bar{\eta}| < 1.2$, $\bar{\eta} = 0.5 |\eta^{\text{jet1}} + \eta^{\text{jet2}}|$
 [EPS 2001 Abstr. 499]

Kinematic region:

$$Q^2 < 1 \text{ GeV}^2$$

$$130 < W_{\gamma p} < 280 \text{ GeV}$$



Dijet angular distribution in D* photoproduction

$$\cos\theta^* = \tanh(0.5(\eta^{\text{jet1}} - \eta^{\text{jet2}}))$$

θ^* = angle between jet–jet axis and beam direction
in dijet rest frame

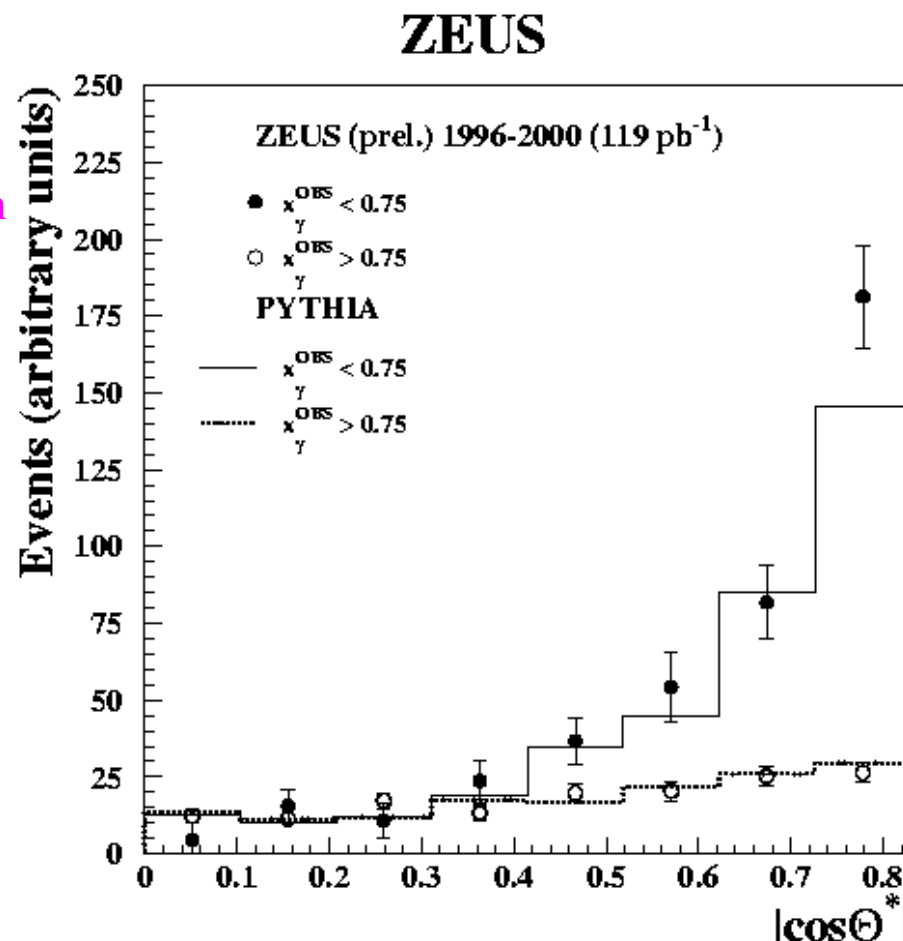
Distribution is not biased by $M_{jj} > 18$ GeV cut

Pythia (LO DGLAP) describes both

$$x_{\gamma}^{\text{OBS}} > 0.75 \text{ and } x_{\gamma}^{\text{OBS}} < 0.75$$

A clear signature of g–exchange

CASCADE ? NLO ?



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

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

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Summary and Outlook

Summary:

- ◆ HERA has provided wide spectrum of heavy flavoured (charm and beauty) Jets measurements
- ◆ Measurement of P_v (strangeness-suppression factor γ_s and excited D meson fragmentation fractions) are consistent with LEP results
- ◆ Charm (and Beauty) photoproduction *cross section are underestimated by fixed-order NLO for low x_γ^{OBS}*
- ◆ The $\cos\theta^*$ distribution for dijet events with a D^* shows a clear *signature of gluon propagator* for events with $x_\gamma^{OBS} < 0.75$

Outlook:

- ◆ Complete HERA I data (1994–2000)
- ◆ Need better theoretical input
- ◆ HERA II (2001–2006): \approx luminosity increase ($\mathcal{L}_{int} \approx 1\text{fb}^{-1}$)
- ◆ Detector upgrades
 - ➡ Si microvertex detector
 - ➡ Forward tracking \Rightarrow *big improvement in heavy quark tagging efficiency*

A lot of interesting Heavy-Flavoured Jets Physics to come from HERA

