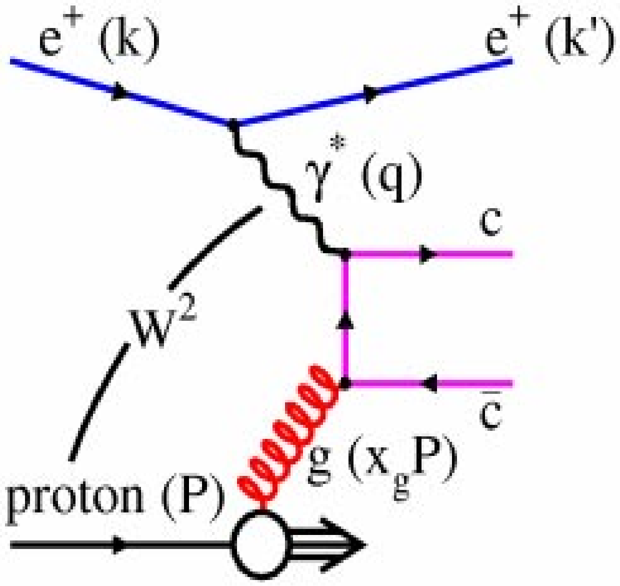
Heavy Flavoured jets at HERA

Sanjay Padhi

McGill University

- **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

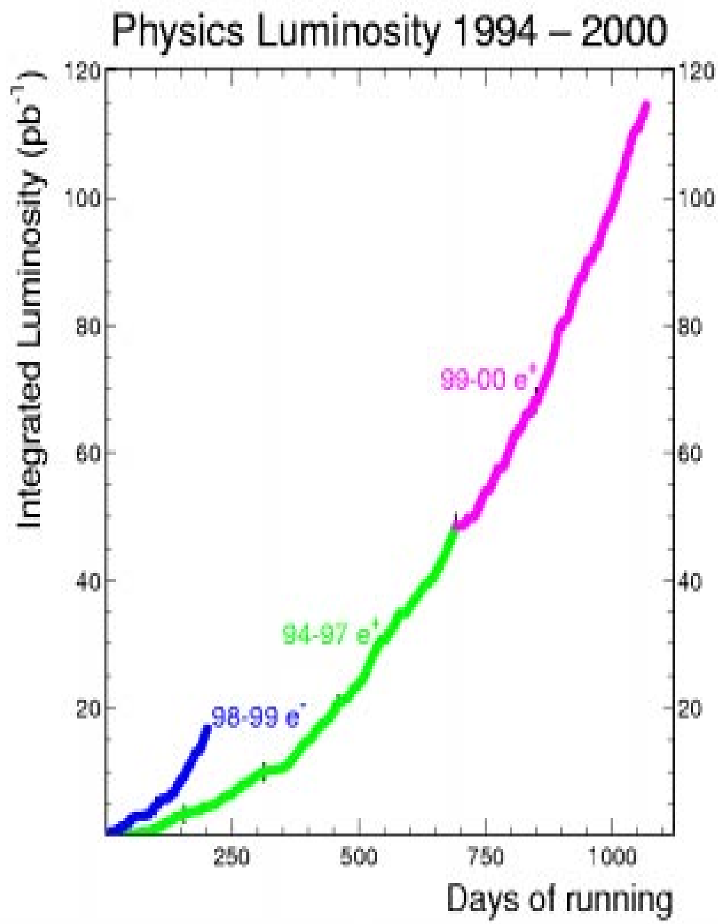


$s = (P + k)^2$

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

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

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



Photoproduction Regime:

- No scattered electrons
- $Q^2 \leq 1$ GeV^2
- 130 < W < 280 GeV

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

Sanjay Padhi

Heavy Flavour Production & Fragmentation

Experimentally ($c \rightarrow D$) Meson:

- Fragmentation Fraction

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

- Fragmentation Functions

  (e.g Peterson Fragmentation Function)

Charmed Mesons :

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

Pseudoscalar (PS) D^0 $\rightarrow$ 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) $P_v = 0.56$

Sanjay Padhi

Universality of charm fragmentation

Direct Production rates from charm fragmentation :

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

Assuming:

a) $\sigma (D^{*0}) = \sigma (D^{*\pm})$

b) No sizable distortions from excited D mesons

Decay Modes:

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

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

; π_s is a soft pion with low momentum

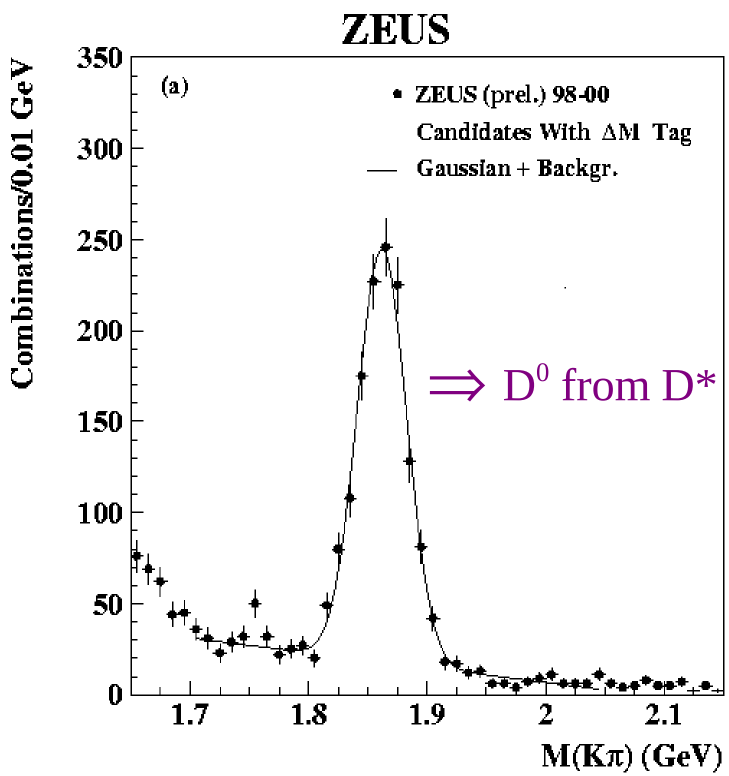
$$\sigma_{dir}(D^0) = \sigma_{tot}(D^0) - \sigma_{tot}(D^{*\pm})(1 + BR(D^{*\pm} \rightarrow D^0 \pi^\pm))$$

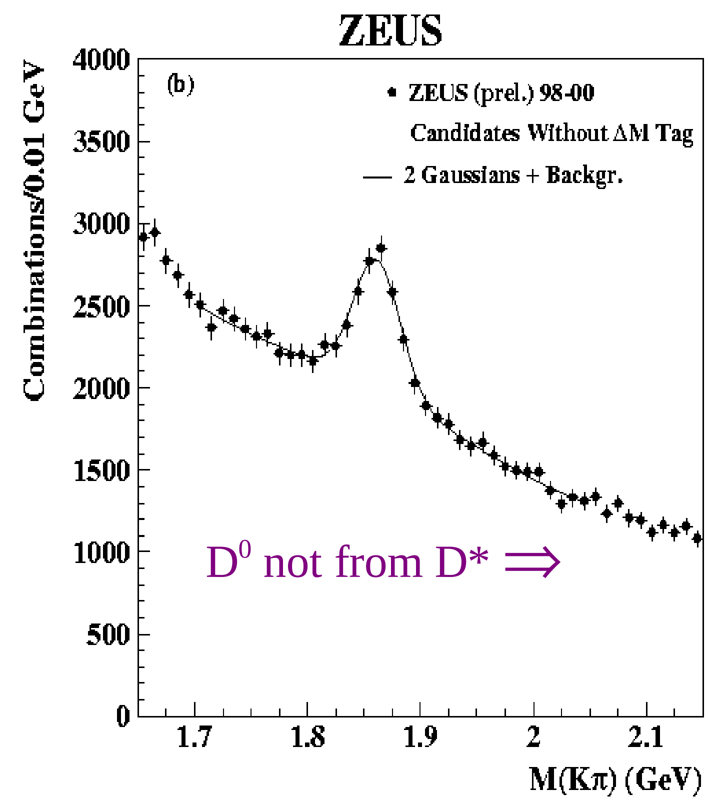
$$P_v = \frac{1}{(\sigma_{tot}(D^0)/\sigma_{tot}(D^{*\pm}) - BR(D^{*\pm} \rightarrow D^0 \pi^\pm))}$$

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

Sanjay Padhi

Universality of charm fragmentation





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

Using : $N(D^0) = 5223 \pm 185$

$N(D^{*\pm}) = 1180 \pm 39$

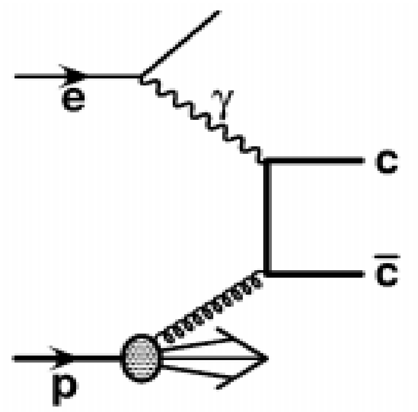
OPAL: $P_v = 0.57 \pm 0.05$

ALEPH : $P_v = 0.595 \pm 0.045$

Charm Fragmentation Fractions are Universal

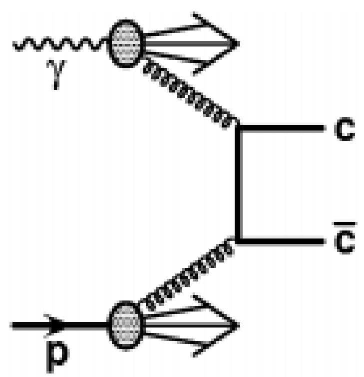
Sanjay Padhi

Charm with Jets (LO)



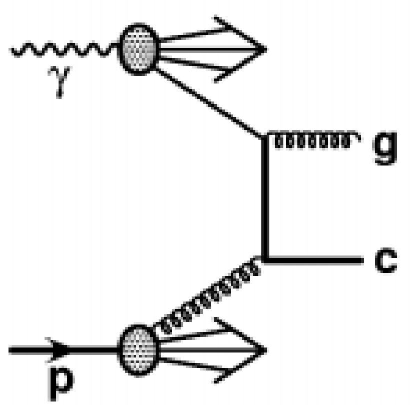
Direct−γ: γ−g fusion

q−exchange

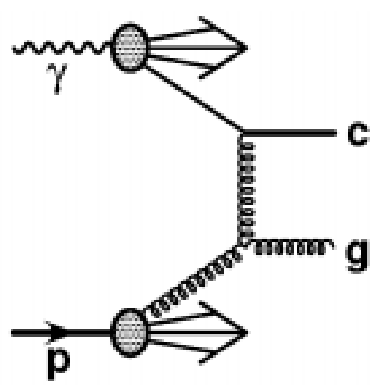


Resolved−γ: g g → c $\bar{c}$

q−exchange



q−exchange



Resolved−γ: c excitation

g−exchange

Define: Direct photon $x_\gamma = 1$

Resolved photon $x_\gamma < 1$

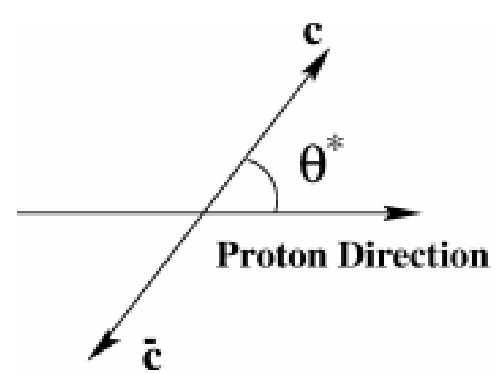
Direct and Resolved :

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

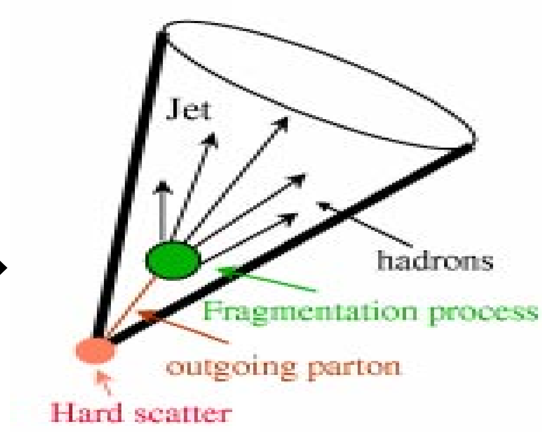


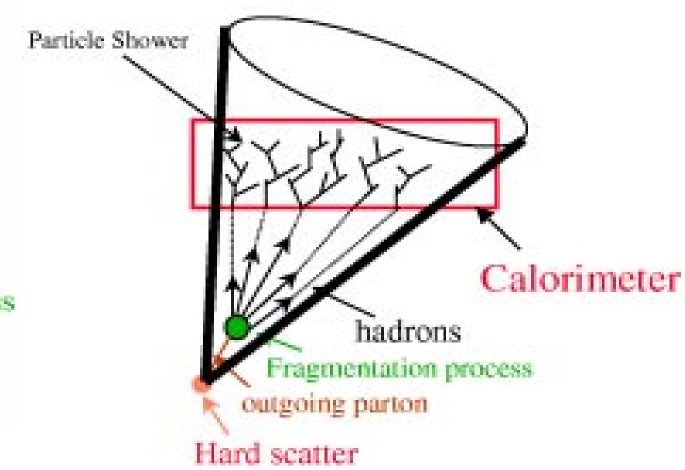
θ^* = center of mass scattering angle

Charm Jets in experiments & NLO

KTCLUS Algorithm for Jets

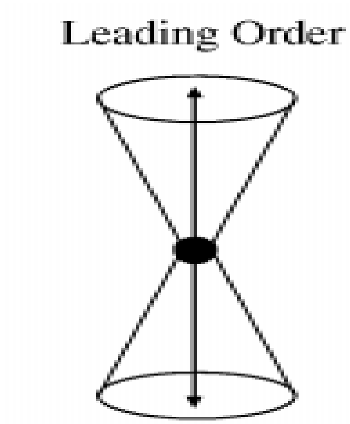
Hadron level Charm Jets ⇒





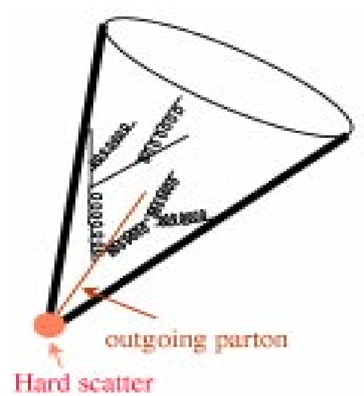
Fixed−order ("massive") NLO (Parton level Jets)

- 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



⇒

Higher Orders



Parton level Charm Jets

Sanjay Padhi

Inclusive Charm Jets Cross section

Now let's see the charm jets ...

For $Q^2 < 1$ GeV^2; $130 < W < 280$ GeV

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

NLO Fixed order **(Frixione et al.)**

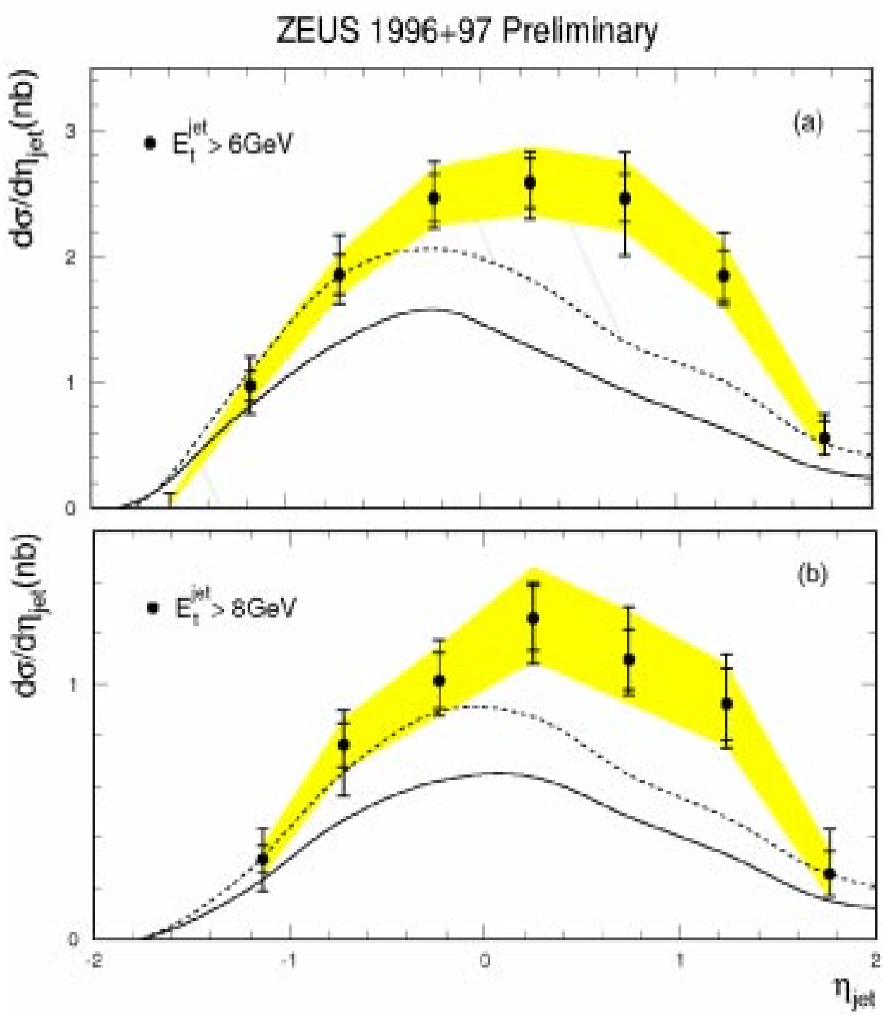
PDFs: p MRSG, γ GRV−G HO

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

dotted curves: $m_c = 1.2$ and $\mu_R = 0.5m_\perp$ ← 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

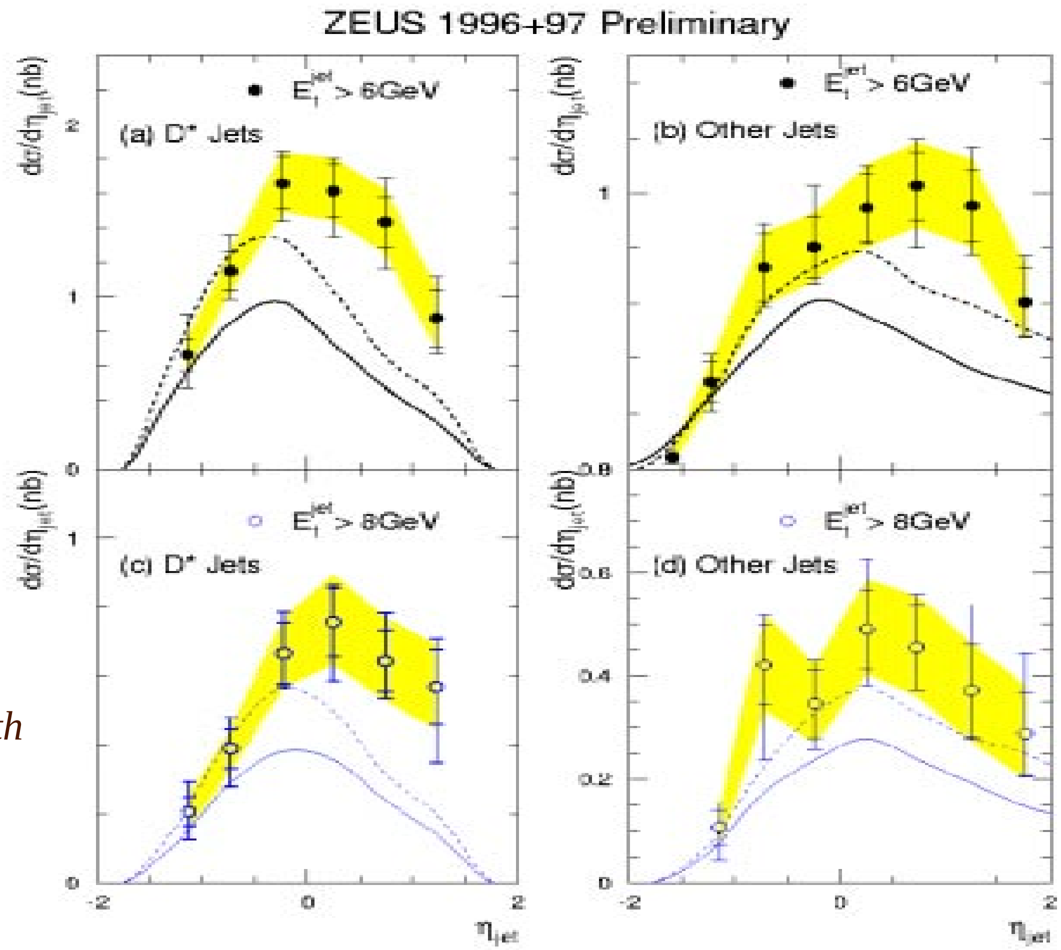
Looking at the picture from both sides:

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

⇒ 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*)



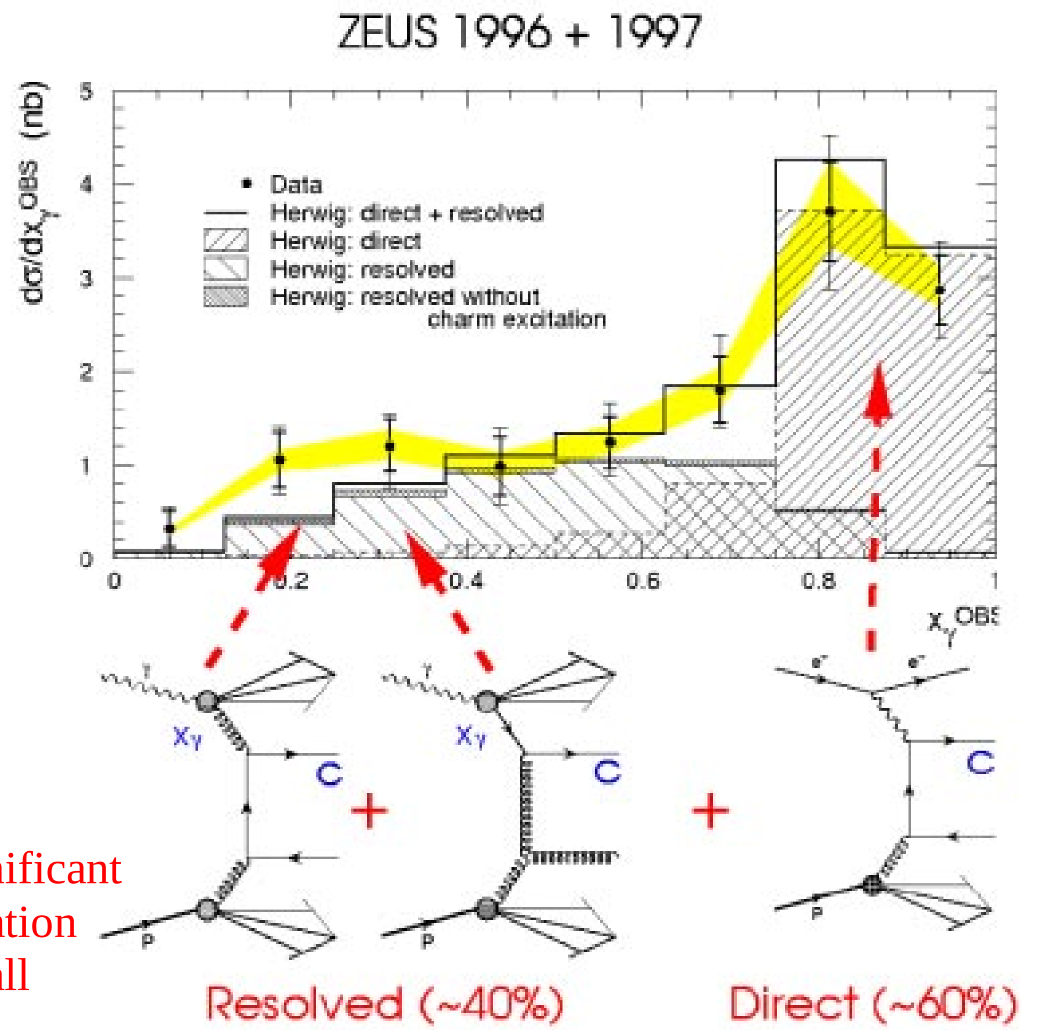
Sanjay Padhi

x_γ^{OBS} Measurements

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

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

$Q^2 < 1$ GeV^2, $130 < W < 280$ GeV
$E_T^{jet1} > 7$ GeV, $E_t^{jet2} > 6$ GeV, $|\eta^{jet}| < 2.4$
$p_\perp^{D^*} > 3$ GeV, $-1.5 < \eta^{D^*} < 1.5$

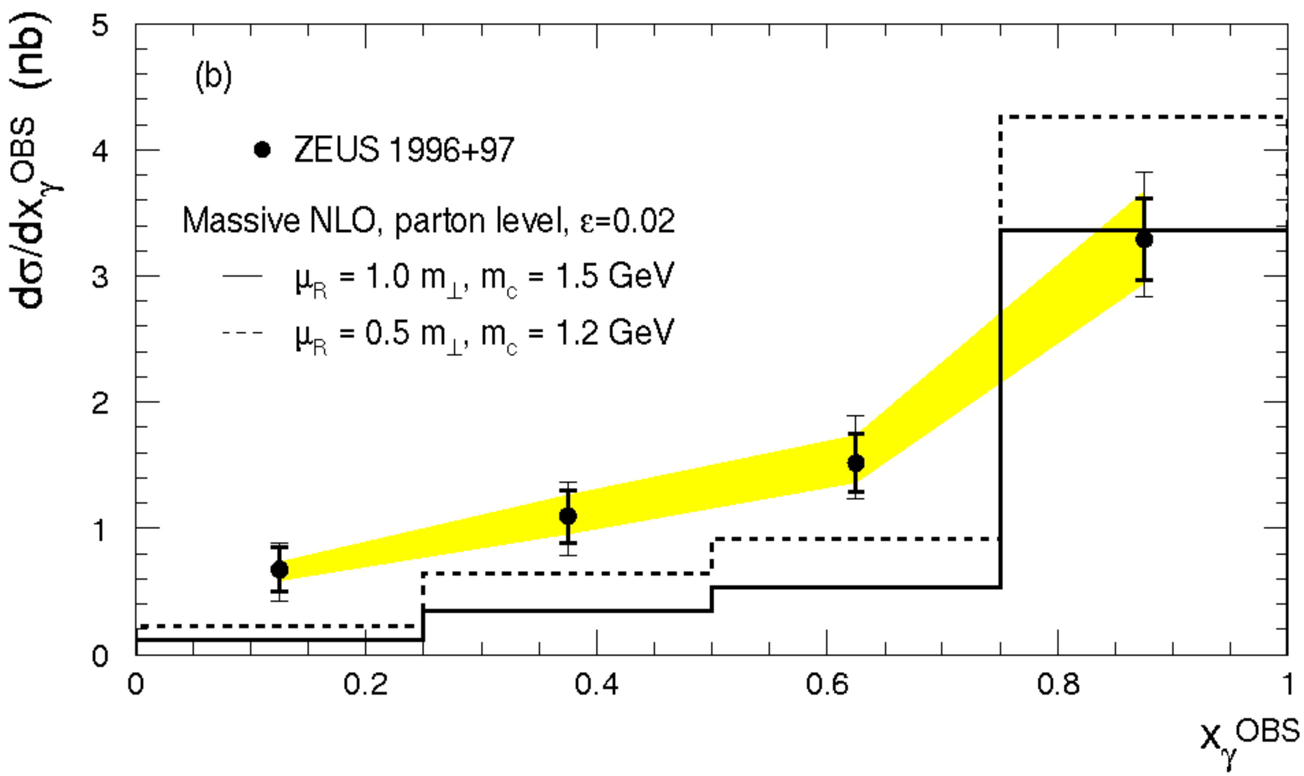


LO(DGLAP) Herwig MC :

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

Sanjay Padhi

x_γ^{OBS} Measurements



Yellow bands: Uncertainty due to Calorimeter energy scale

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

Would be interesting to see "massless" calculations ??

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

Sanjay Padhi

Dijet angular distribution in D* photoproduction

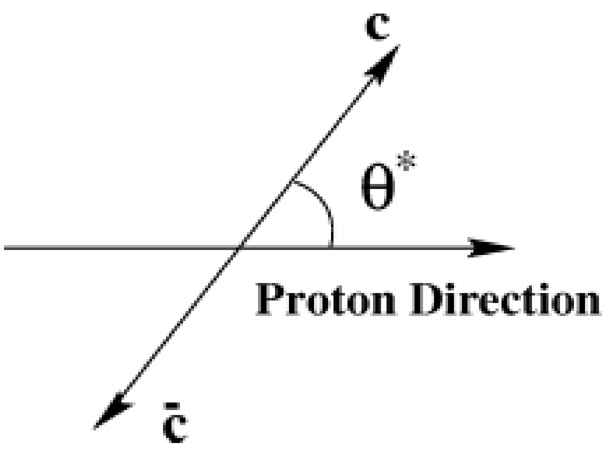
QCD (LO) predicts that the angular distribution of the outgoing partons in resolved processes will be enhanced at high $|\cos\theta^*|$ with respect to direct photon processes.

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 ?



Sanjay Padhi

Dijet angular distribution in D* photoproduction

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

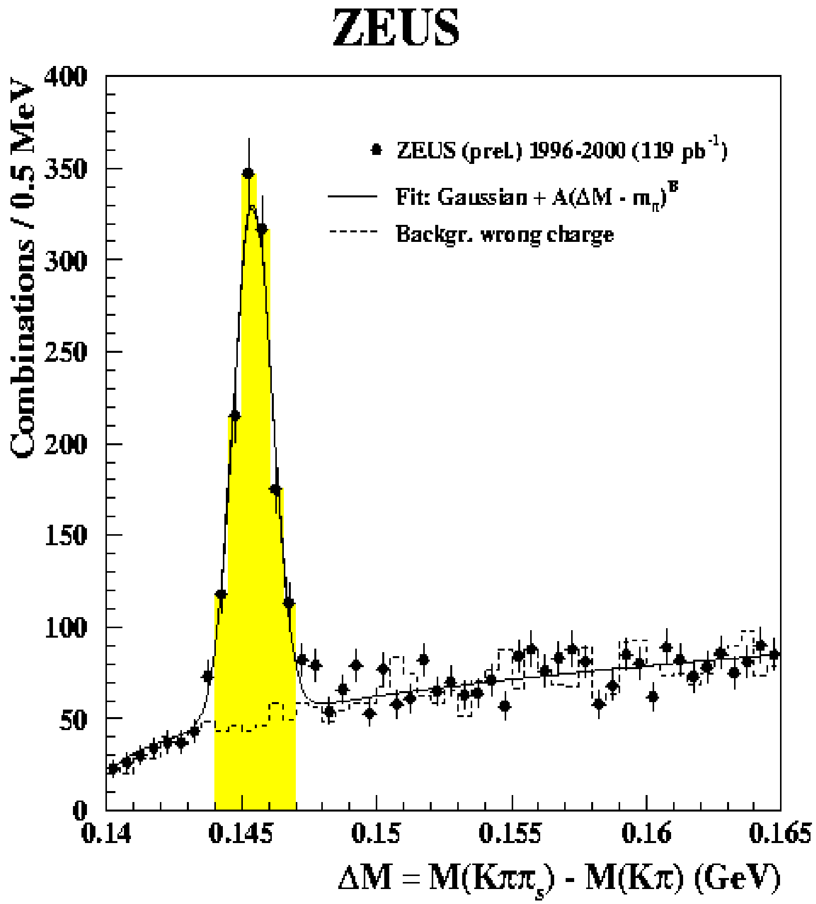
Sample Used: Photoproduction with a reconstructed D* and atleast 2 hadron jets − "dijets"

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

Kinematic region:

$Q^2 < 1$ GeV^2

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



Sanjay Padhi

Dijet angular distribution in D* photoproduction

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

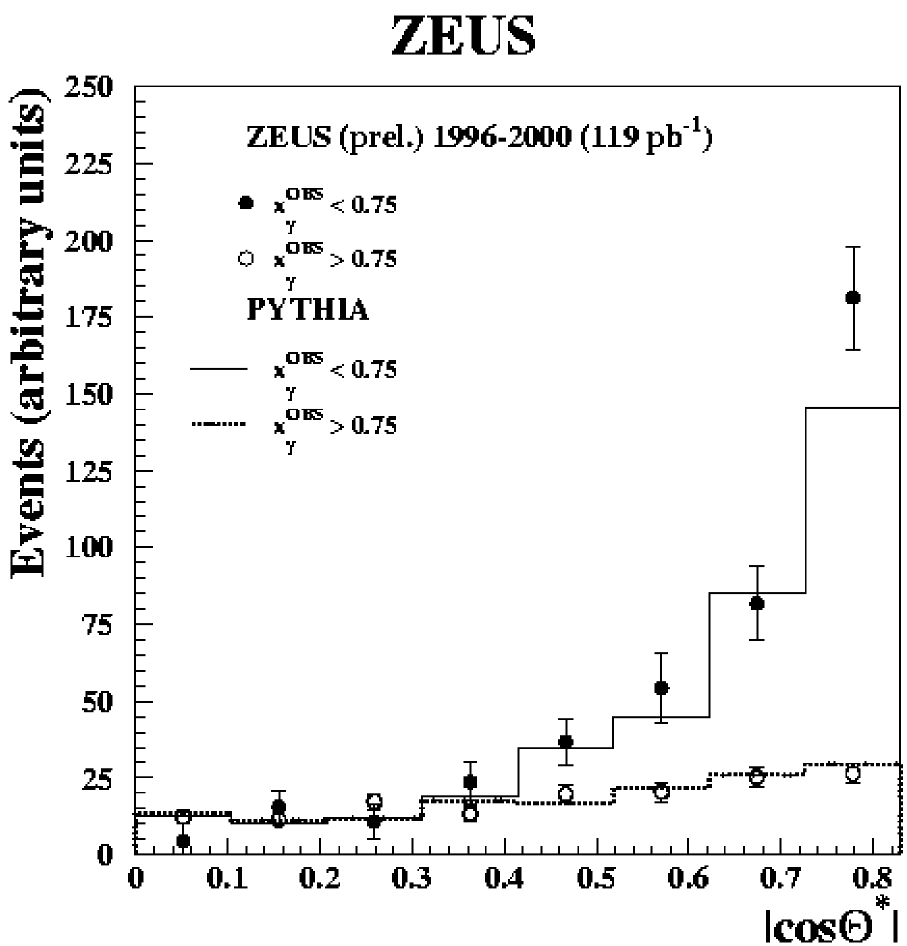
θ* = angle between jet−jet axis and beam direction in dijet rest frame

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

Pythia (LO DGLAP) describes both $x_\gamma^{OBS} > 0.75$ and $x_\gamma^{OBS} < 0.75$

A clear signature of g−exchange

CASCADE ?   NLO ?



q−exchange ∝ $(1 - |\cos\theta^*|)^{-1}$

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

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 consistant with LEP results
- Charm (and Beauty) photoproduction *cross section are underestimated by fixed−order NLO for low* x_γ^{OBS}
- The cosθ* 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): ≈ luminosity increase ($\mathscr{L}_{int} \approx 1\text{fb}^{-1}$)
- Detector upgrades
  - Si microvertex detector
  - Forward tracking ⇒ *big improvement in heavy quark tagging efficiency*

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

Sanjay Padhi