Photon 2001
Jet Production Session, 03.09.2001
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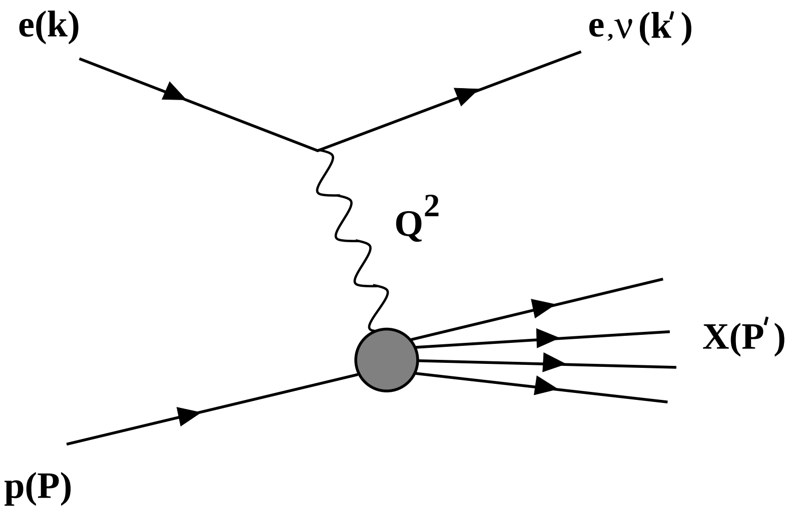
Substructure of jets at HERA (ZEUS collaboration)

- **Introduction**
- **Photoproduction regime ($Q^2 \sim 0$)**
  - exclusive dijets
  - charm-initiated jets
- **Deep Inelastic regime ($Q^2 \gg 0$)**
  - inclusive jets in Charged Current and Neutral Current Processes
- **Gluon-initiated jets**
- **Summary**



Jet internal structure

- The **internal structure of jets** gives insight into the **transition from partons to hadrons**

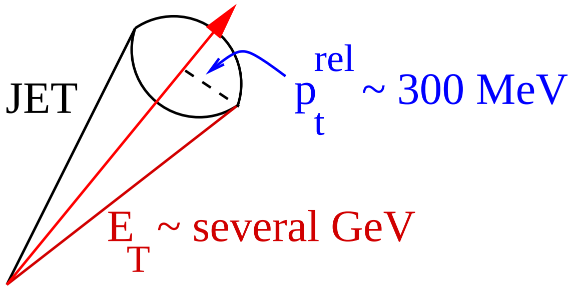
- **Quark initiated jets** are predominant in **DIS (CC,NC)** scattering. The study of the internal structure of jets and comparisons with the **Photoproduction** regime give information on the **differences** between **quark** and **gluon jets**.

The **internal structure** of jets is determined by :

- the type of primary parton (quark or gluon)
- hadronization processes

and to a lesser extent on the particular scattering process.

At **high jet energy** fragmentation effects are negligible and the jet internal structure can be studied with **perturbative QCD**.

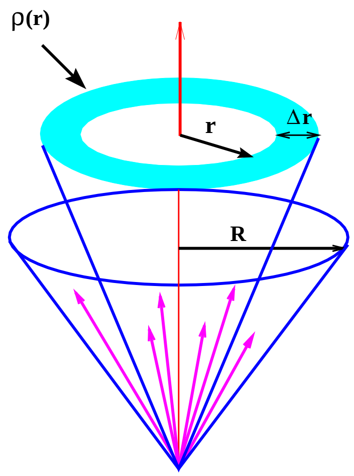


pQCD predicts :

- **gluon jets** are **broader** than **quark jets** (gluon-gluon coupling strength is larger than quark-gluon coupling).

Definition of Jet Shapes

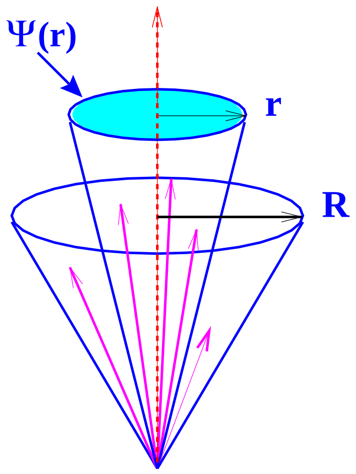
- Differential jet shape $\rho(r)$



Average fraction of the jet's transverse energy inside an annulus in the η - ϕ plane of radius $r \pm \Delta r/2$ concentric with the jet axis

$$\rho(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{E_T(r - \Delta r/2, r + \Delta r/2)}{E_T(0,R)}$$

- Integrated jet shape $\Psi(r)$

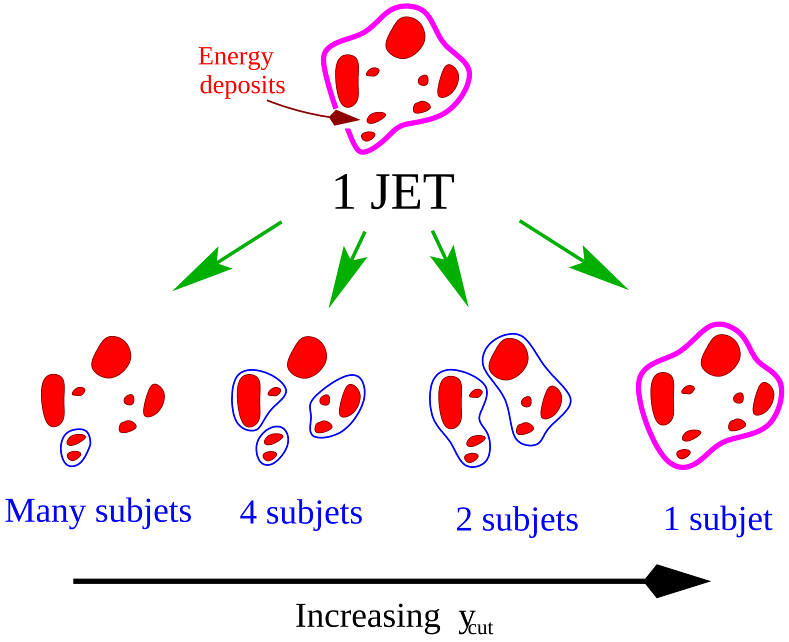


Average fraction of the jet's transverse energy inside a cone in the η - ϕ plane of radius r concentric with the jet axis

$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{E_T(0,r)}{E_T(0,R)}$$

pQCD predicts : $\Psi_{quark}(r) > \Psi_{gluon}(r) \quad \forall r < R$

Definition of subjets



The **“subjets”** are **jet-like structures** within a given jet.

- The K_T **algorithm** is applied to all the particles of a given jet until the distances between clusters, $d_{ij} = min\{E^2_{T_i}, E^2_{T_j}\} \cdot (\Delta\eta^2 + \Delta\phi^2)$, for a given **resolution scale** (y_{cut}) verify :

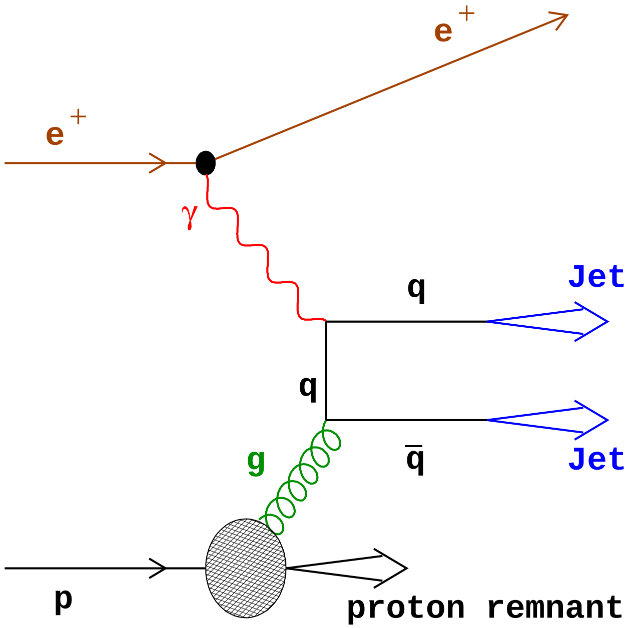
$$d_{ij} > y_{cut}(E_T^{jet})^2$$

- At each y_{cut} the final clusters found inside a jet are called **“subjets”**.
- The mean number of subjets inside a jet, $\langle n_{sbj} \rangle$, or **“mean subjet multiplicity”** can be compared with pQCD.

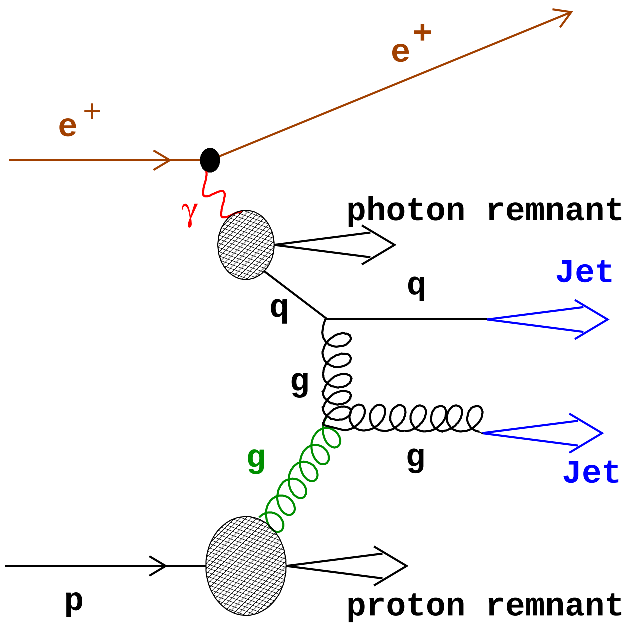
pQCD predicts : $\langle n_{sbj} \rangle_{gluon} > \langle n_{sbj} \rangle_{quark} \quad \forall y_{cut} \ll 1$

Jet production at LO QCD in Photoproduction

Dominant partonic subprocesses :



Direct process : $\gamma g \rightarrow q\bar{q}$



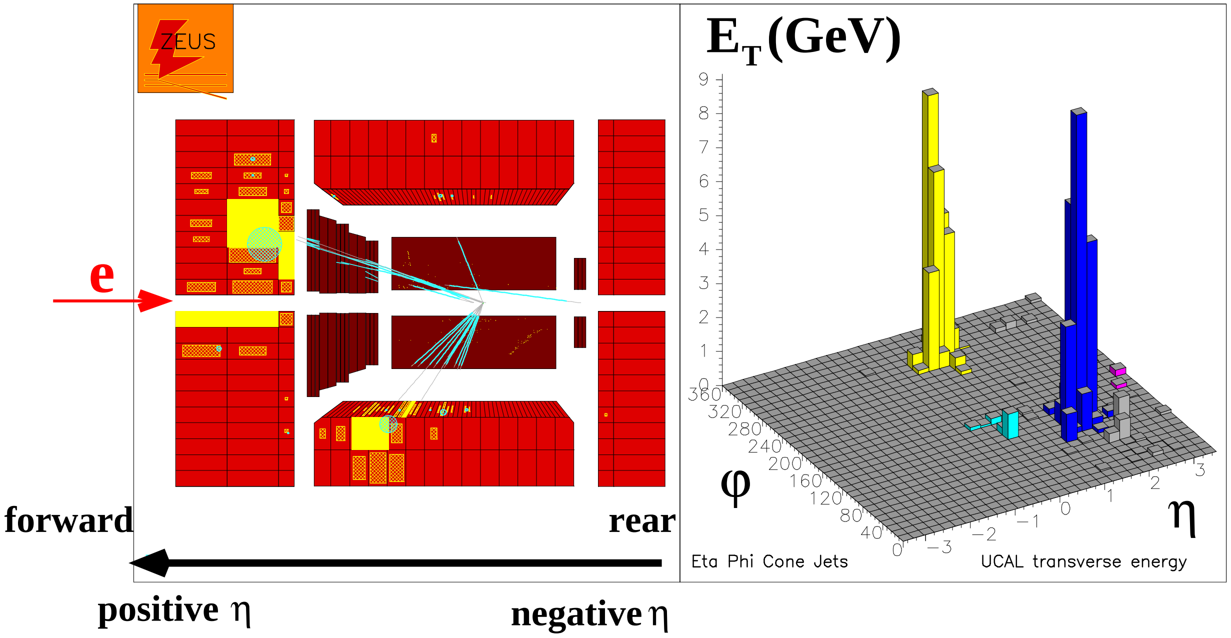
Resolved process : $q_\gamma g_p \rightarrow qg$

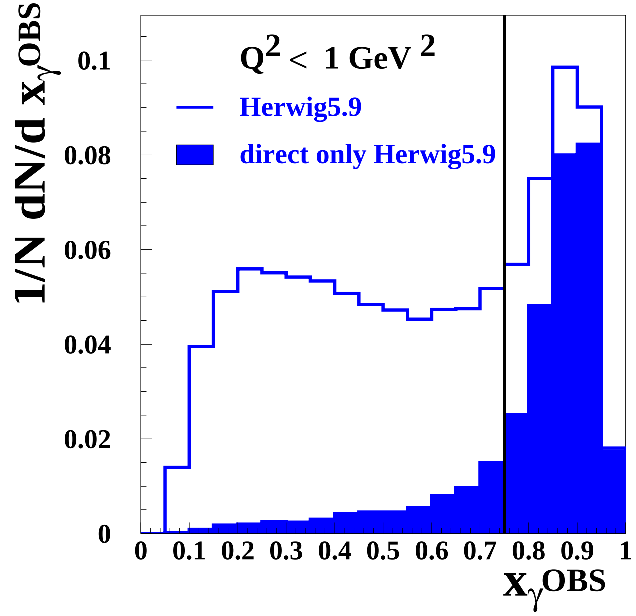
From the kinematics of the dominant processes:

- the majority of the jets in $\eta^{jet} < 0$ are **quark-initiated** jets
- the fraction of gluon jets, f^{jet}_{gluon}, **increases** as η^{jet} **increases**

Selection of exclusive dijets in Photoproduction

- $Q^2 \le 1$ **GeV**^{2}
- $0.2 < y < 0.85$
- $E_T^{jet1,2} > 7, 6$ **GeV**
- $-1 \le \eta^{jet} \le 2$



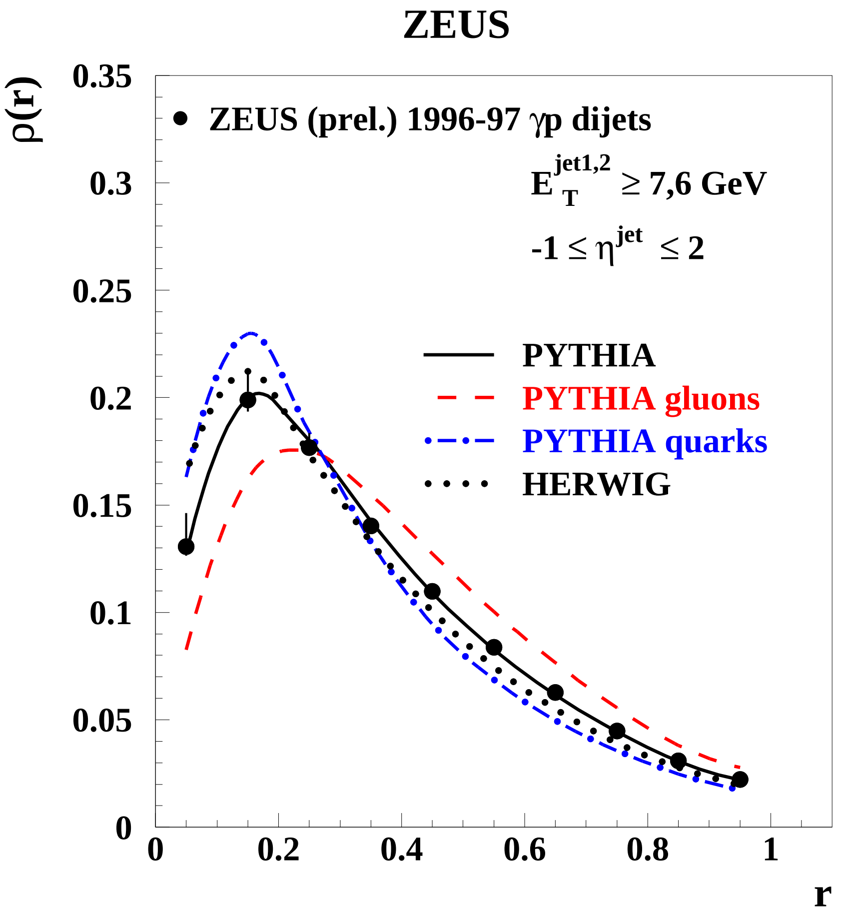


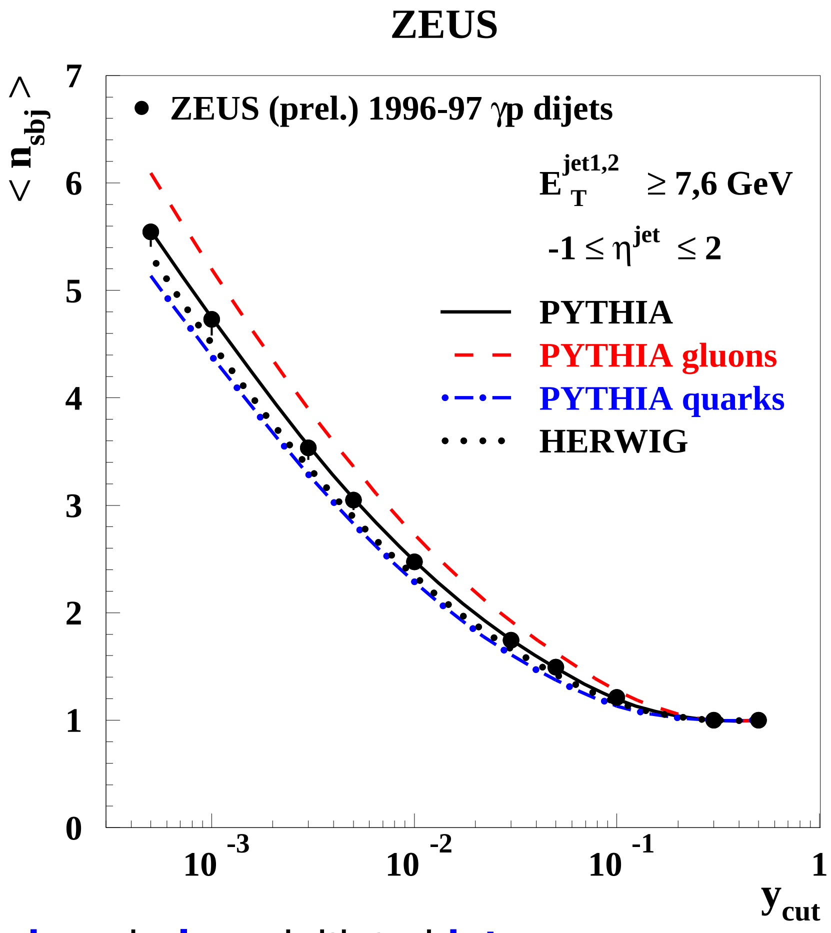
$$x_\gamma^{OBS} = \sum_{jets} \frac{E_T e^{-\eta}}{2yE_e}$$

Direct and resolved components scaled according to the x_γ^{OBS} spectrum

Jet substructure of γp exclusive dijets

$Q^2 \leq 1$ GeV^2 ; $0.2 < y < 0.85$; $E_T^{jet1,2} > 7,6$ GeV ; $-1 \leq \eta^{jet} \leq 2$





- Dijet sample is a **mixture** of **quark** and **gluon** initiated **jets**
- **PYTHIA describes** the data well

Selection of charm initiated jets in Photoproduction

- **Charm** is tagged identifying $D^{*\pm}(2010)$ mesons
- D^* selection : $K2\pi$ **decay mode**

$$\boxed{D^{*\pm} \to D^0(\overline{D^0}) + \pi^{\pm}_{\mathbf{slow}} \to \mathbf{K}^{\mp} + \pi^{\pm} + \pi^{\pm}_{\mathbf{slow}}}$$

$$f(c \to D^* \to K^-\pi^+\pi^+_{slow}) = 0.584 \pm 0.055\%$$

- D^* search : Δm **method**

combination of pairs of tracks to form $D^0(1864)$

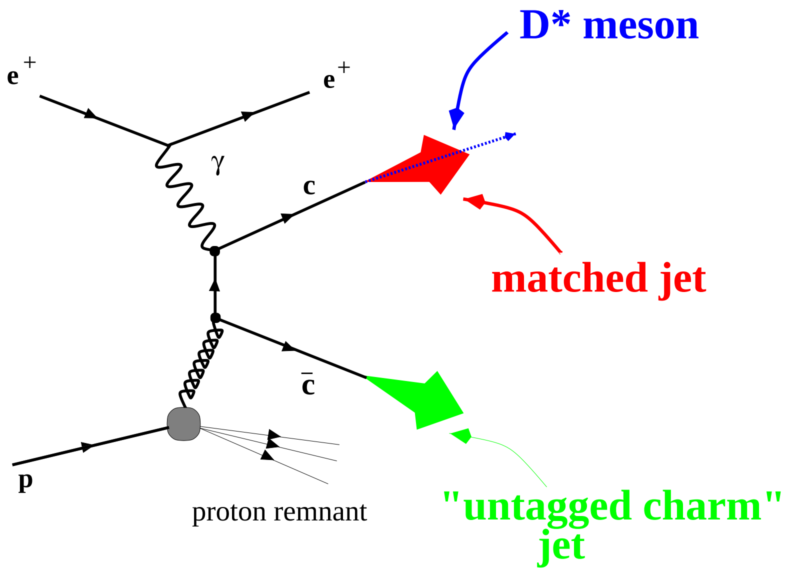
$$1.82 < M(D^0) < 1.90 \text{ GeV}$$

combination of the D^0 with a third track (slow pion)

$$0.144 < M(K\pi\pi) - M(K\pi) < 0.147 \text{ GeV}$$

- D^* - **jet** matching :

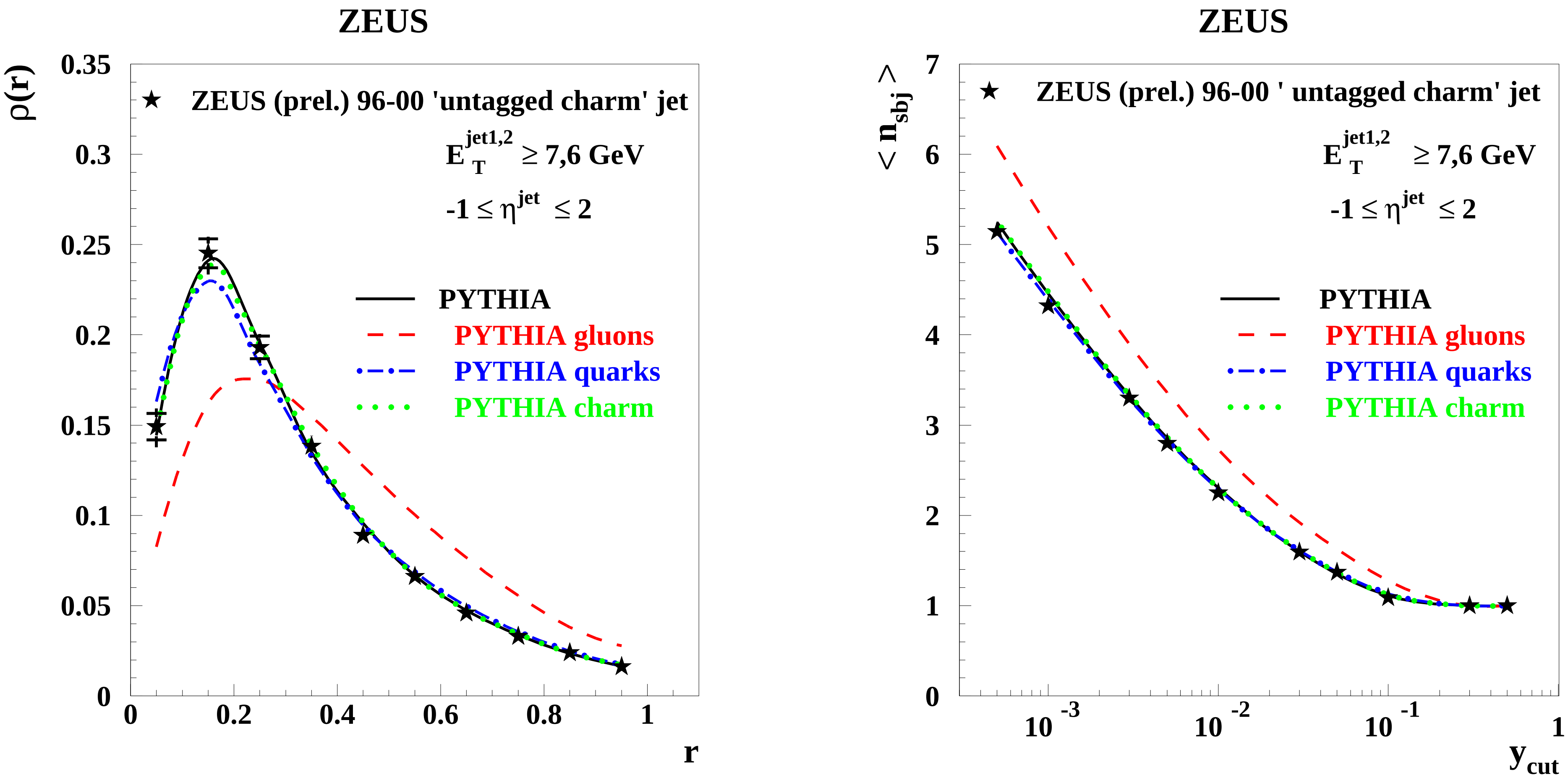
$$\boxed{\Delta\phi \equiv |\phi_{\mathbf{D}^*} - \phi_{\mathbf{jet}}| \leq \pi/4}$$



The **"untagged charm" jet** is studied for an unbiased measurement

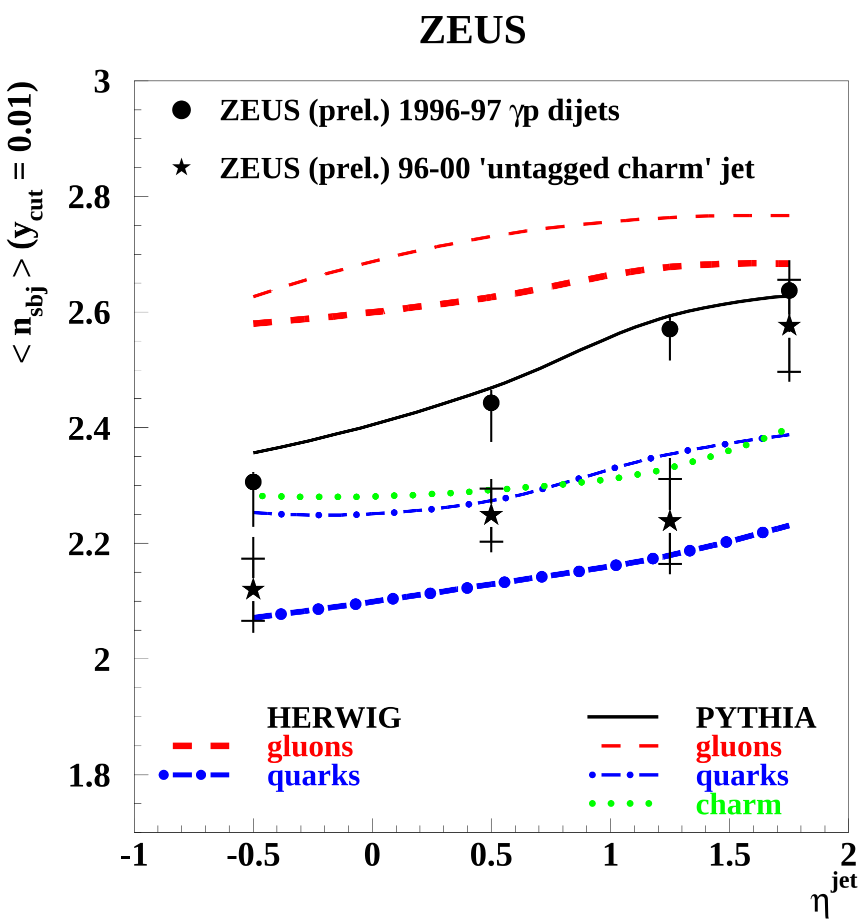
Jet substructure of 'untagged charm' jets

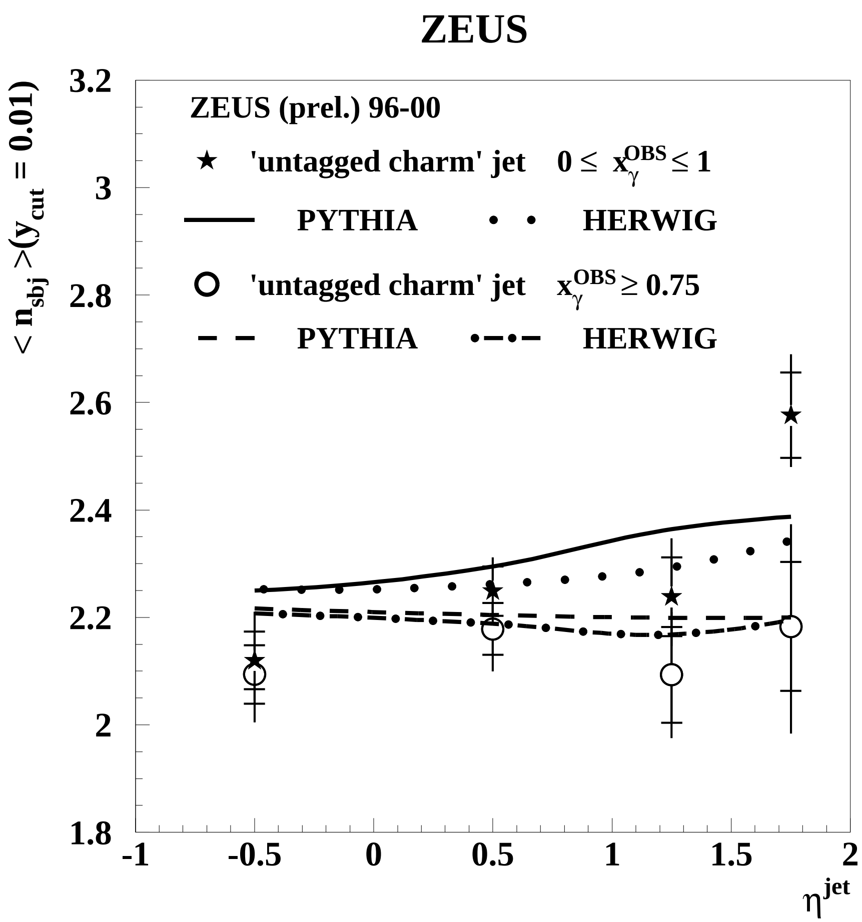
$Q^2 \leq 1$ **GeV**^{2} ; $0.2 < y < 0.85$; $E_T^{jet1,2} > 7,6$ **GeV** ; $-1 \leq \eta^{jet} \leq 2$



- The jet substructure of the **'untagged charm'** jets is consistent with a **quark-initiated** jet sample

Jet substructure dependence on η^{jet}



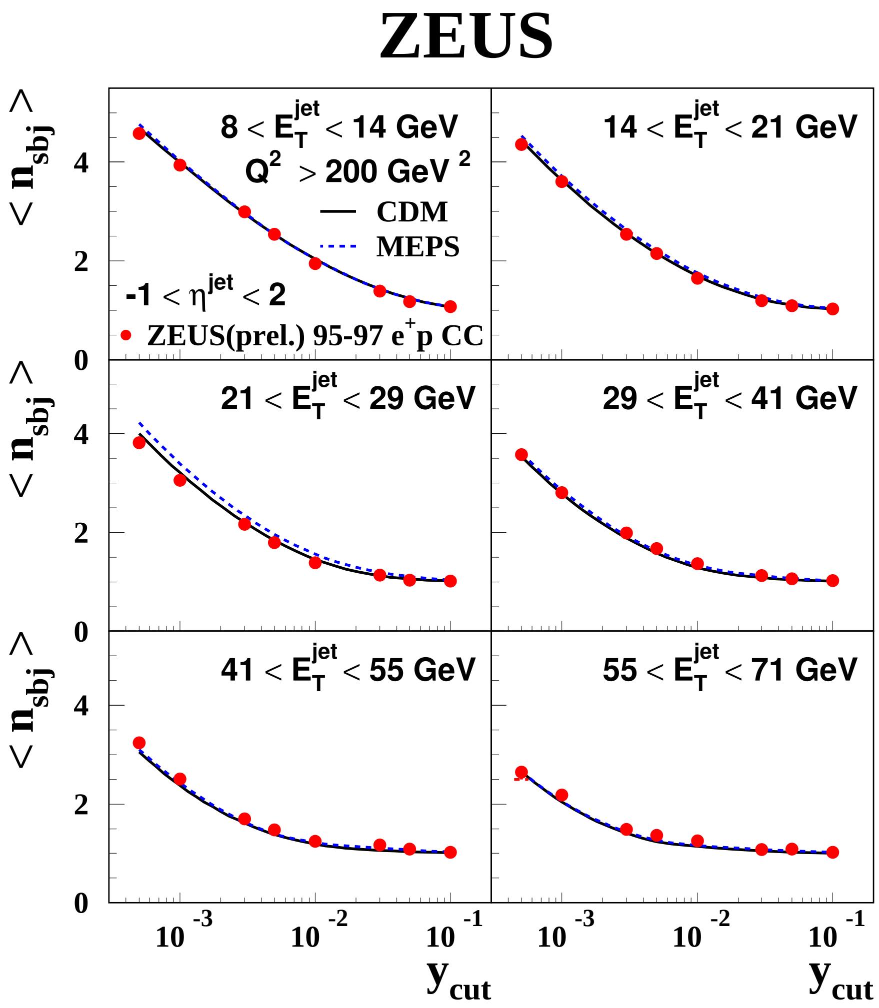


- **dijets** :
  $< n_{sbj} >$ **increases** as η^{jet} increases $\rightarrow$ f^{jet}_{gluon} increases

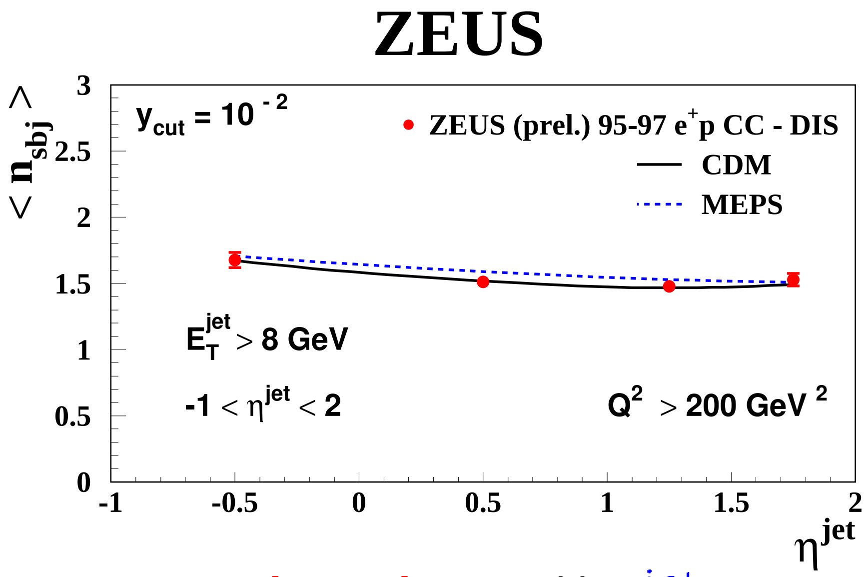
- **'untagged charm'** jets become **broader** in the **forward region** $\rightarrow$ contribution from **resolved processes**

Substructure of jets in CC - DIS

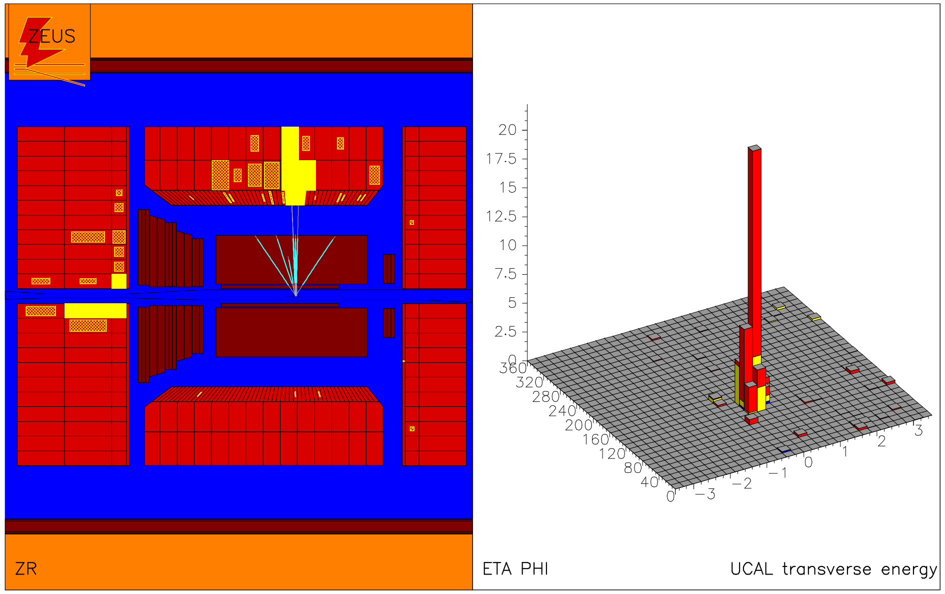
$Q^2 > 200$ **GeV**^{2} ; $E_T^{jet} > 8$ **GeV** ; $-1 \leq \eta^{jet} \leq 2$



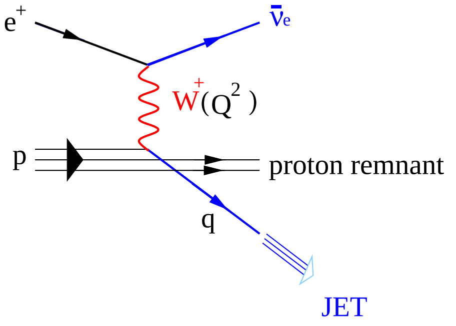
Both Monte Carlo models describe the data well



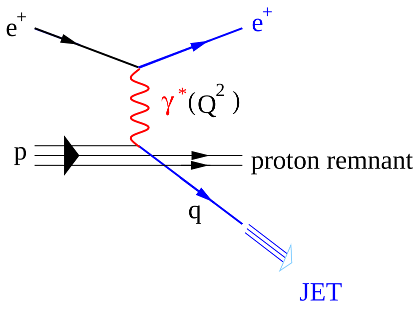
no dependence with η^{jet}



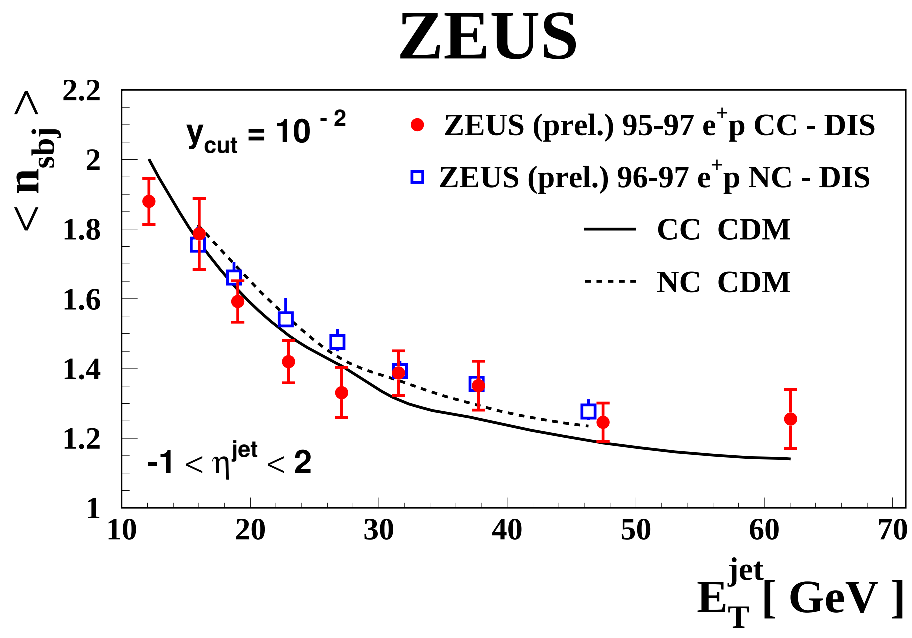
CC - DIS, NC - DIS and 'untagged charm' jets

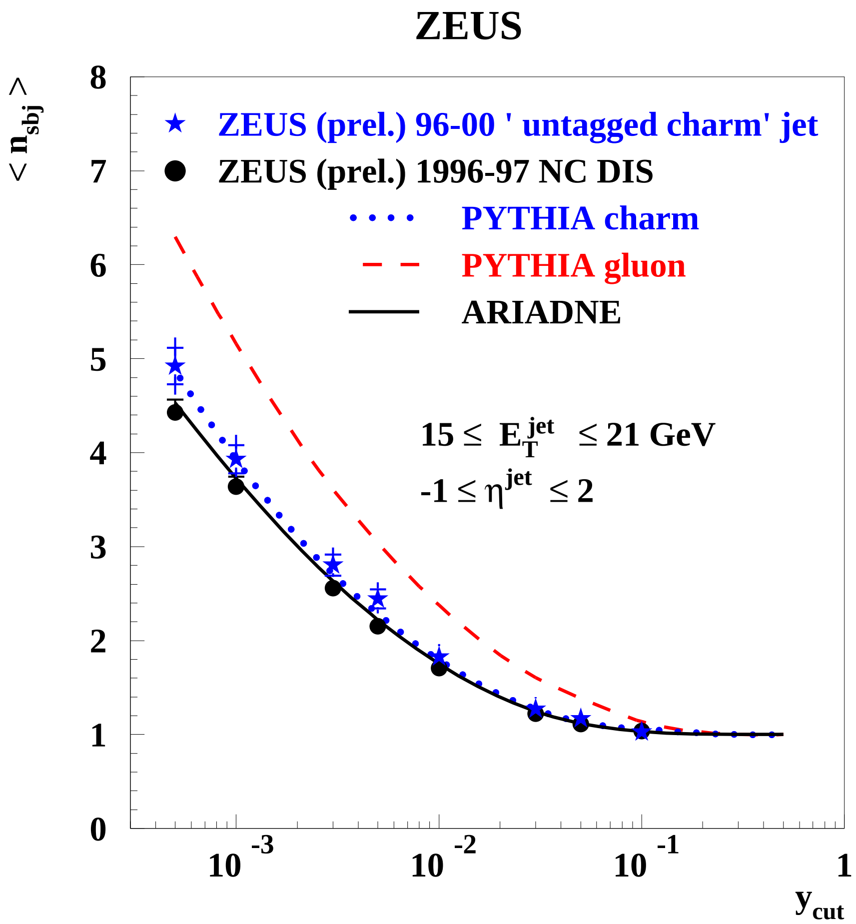


CC event



NC event



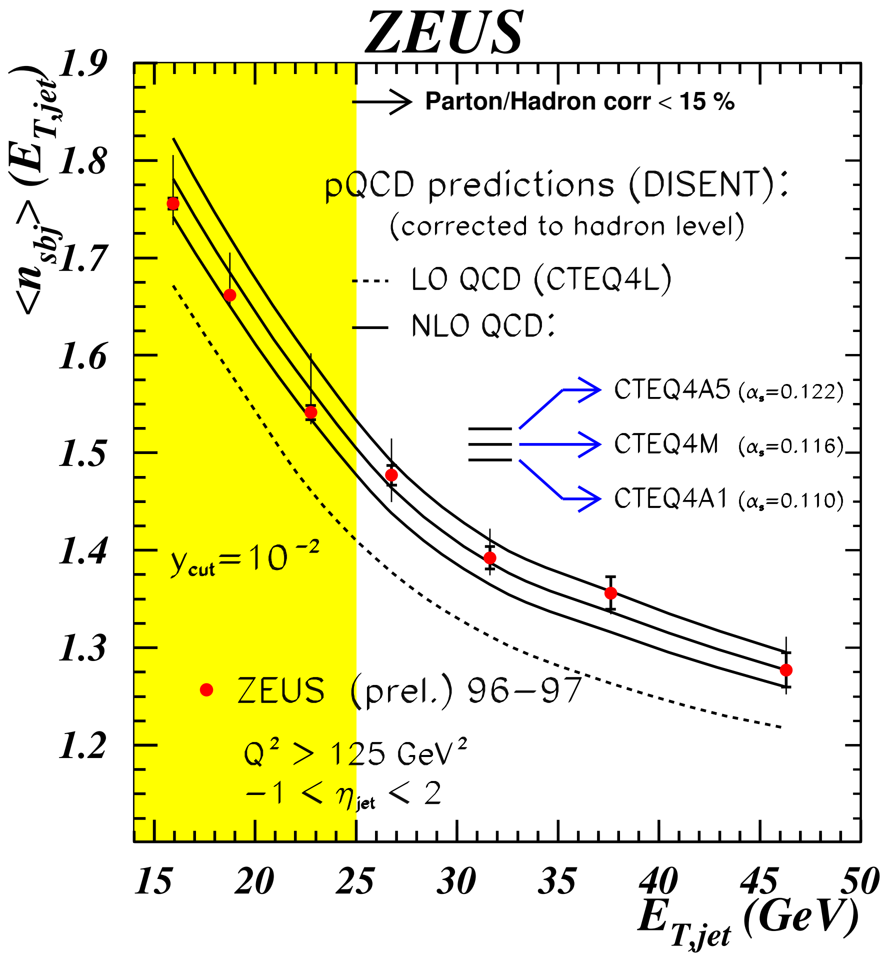


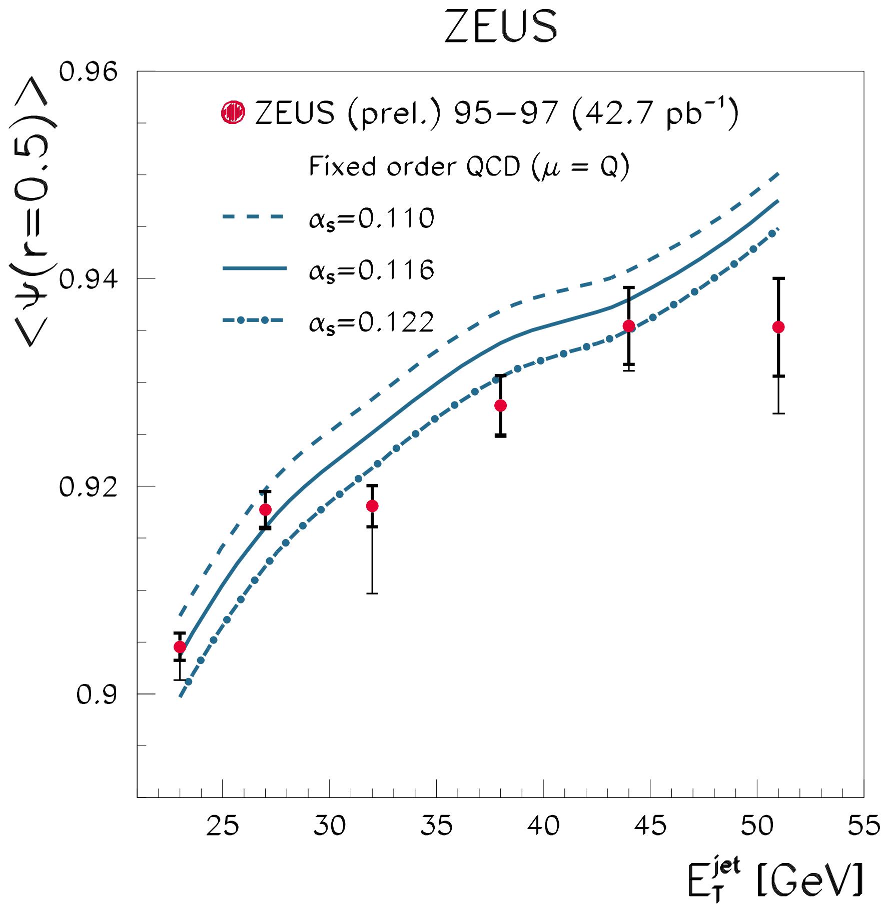
- jets become **narrower** as E_T^{jet} **increases**
- **agreement** between **NC** and **CC** (**quark jets**)

- **Charm-initiated** jets are very **similar** to **light quark-initiated** jets (**NC** and **CC**)
- $y_{cut} \leq (\frac{m_c}{E_T^{jet}})^2 \sim 0.01$ charm mass effects

Jet substructure in NC DIS : extraction of α_S

$Q^2 > 125$ **GeV**^{2} ; $E_T^{jet} > 15$ **GeV** ; $-1 < \eta^{jet} < 2$





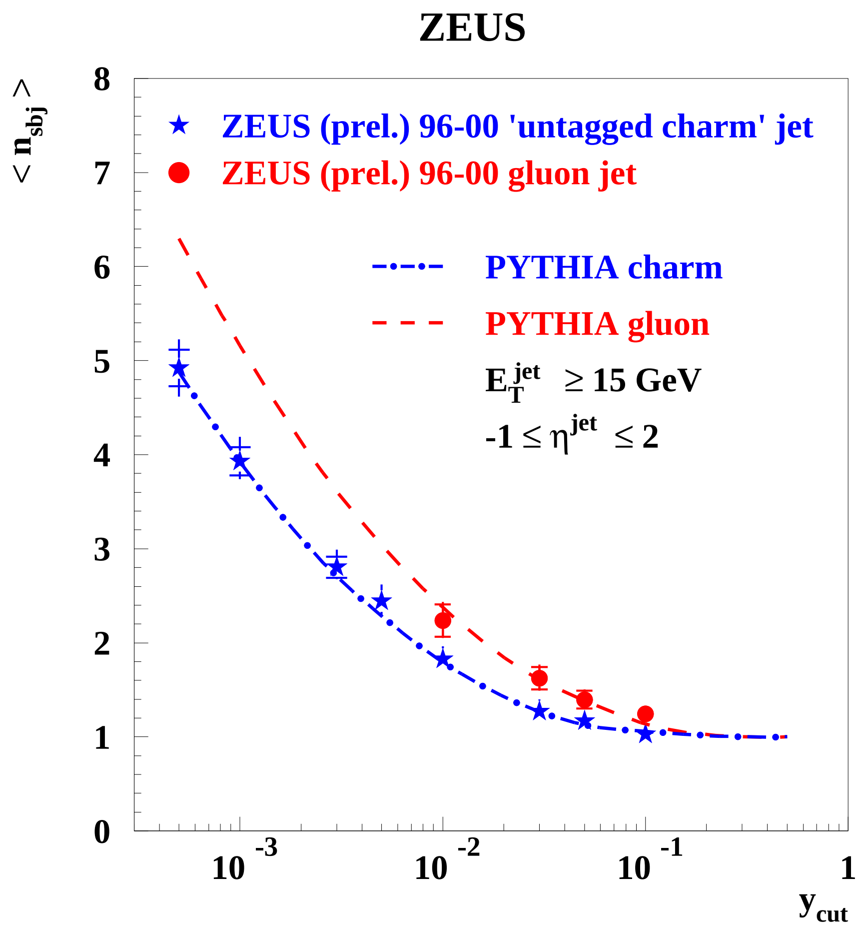
$< n_{sbj}(y_{cut} = 0.01) >$: $\alpha_S(M_Z) = 0.1185 \pm 0.0016(stat)^{+0.0067}_{-0.0048}(exp)^{+0.0089}_{-0.0071}(th)$

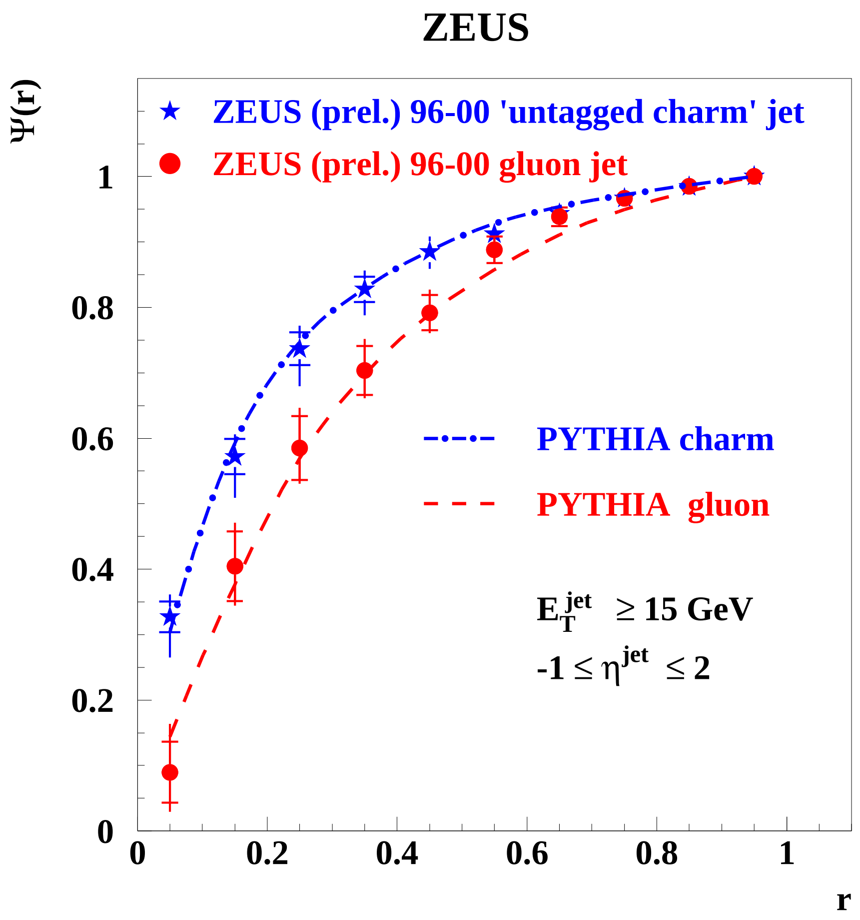
$< \Psi(r = 0.5) >$: $\alpha_S(M_Z) = 0.1179 \pm 0.0017(stat)^{+0.0054}_{-0.0065}(exp)^{+0.0094}_{-0.0073}(th)$

Extraction of the gluon jet substructure in Photoproduction

$$\boxed{\mathcal{O}_{\mathtt{dijet}} = \mathtt{f}_{\mathtt{q}}\,\mathcal{O}_{\mathbf{quark}} + \mathtt{f}_{\mathtt{g}}\,\mathcal{O}_{\mathbf{gluon}}}$$

($\mathtt{f}_{\mathtt{q}}, \mathtt{f}_{\mathtt{g}}$ from LO MC)





The extracted **structure** of **gluon-initiated jet** is **consistent** with the predictions of pQCD

Summary

- **Jet shapes**
- **mean subjet multiplicities**

in Photoproduction, Charged Current and Neutral Current DIS have been measured

- The measured **internal structure of jets** (jet shapes, subjet multiplicities) is well **described** by **LO Monte Carlo** models which include QCD radiation

The substructure of jets in CC, NC and 'untagged charm' in Photoproduction is very similar
$\longrightarrow$ parton evolution is independent of the hard scattering process

Studies of the substructure in **NC** $\longrightarrow$ **precise determination of α_S**

Characterization of gluon jets using Photoproduction data $\longrightarrow$ extracted values **consistent** with pQCD predictions