QCD studies with the L3 detector

Dominique Mangeol
University of Nijmegen/NIKHEF

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- Measurement of α_s from event shape variables
- Inclusive charged particle momentum distribution
- Charged particle multiplicity at 183 GeV
- Moments of the charged particle multiplicity at 91.2 GeV

Definitions:

- Thrust

$$T = \max_{\vec{n}} \left(\frac{\sum_i |\vec{p_i} \cdot \vec{n}|}{\sum_i |\vec{p_i}|} \right)$$

- Scaled heavy jet mass

$$\rho = M_H^2 / s$$

Where the heavy jet mass: $M_H = \max(M_+(\vec{n_T}), M_-(\vec{n_T}))$

And the invariant mass: $M_\pm^2 = \left(\sum_{i \in H_\pm} p_i \right)^2$

- Jet broadening variables

$$B_\pm = \frac{\sum_{i \in H_\pm} |\vec{p_i} \times \vec{n_T}|}{2 \sum_i |\vec{p_i}|}$$

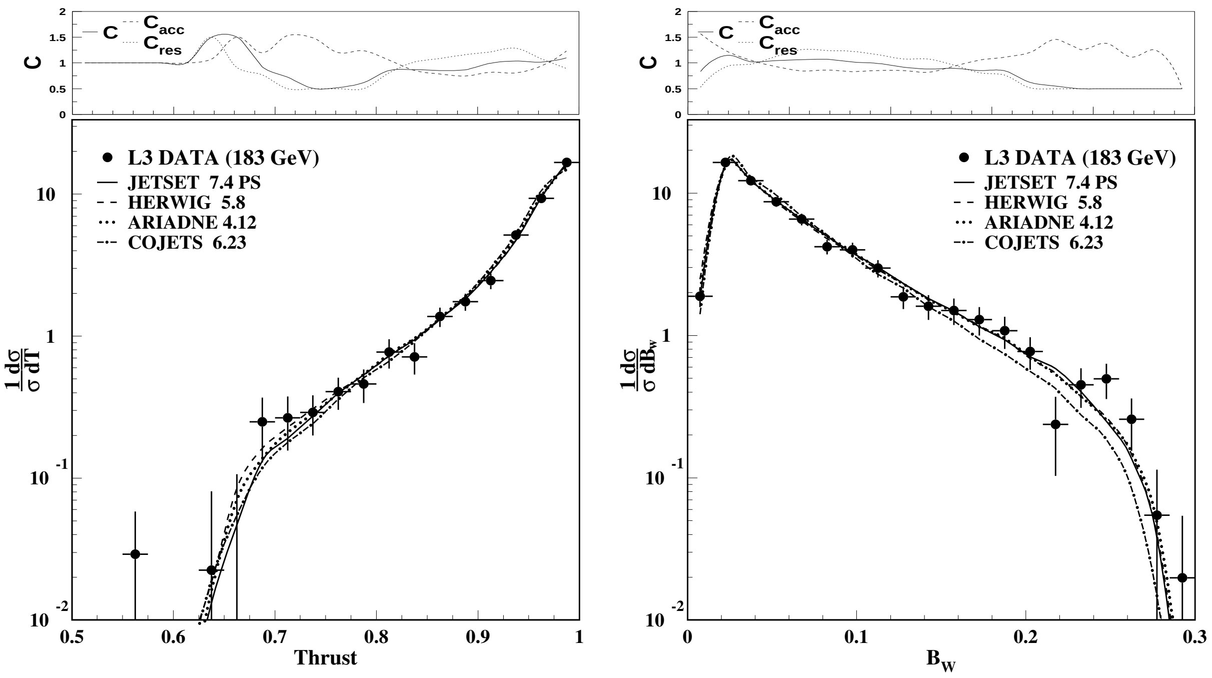
  - Total jet broadening: $B_T = B_+ + B_-$
  - Wide jet broadening: $B_W = \max(B_+, B_-)$

Event shape variables at 183GeV

- Used to described multi-jet events topology
- Show how hadronic events are affected by hard gluon radiations

  $\Longrightarrow$ Deviation from 2-jet topology

- Sensitive to strong coupling constant α_s

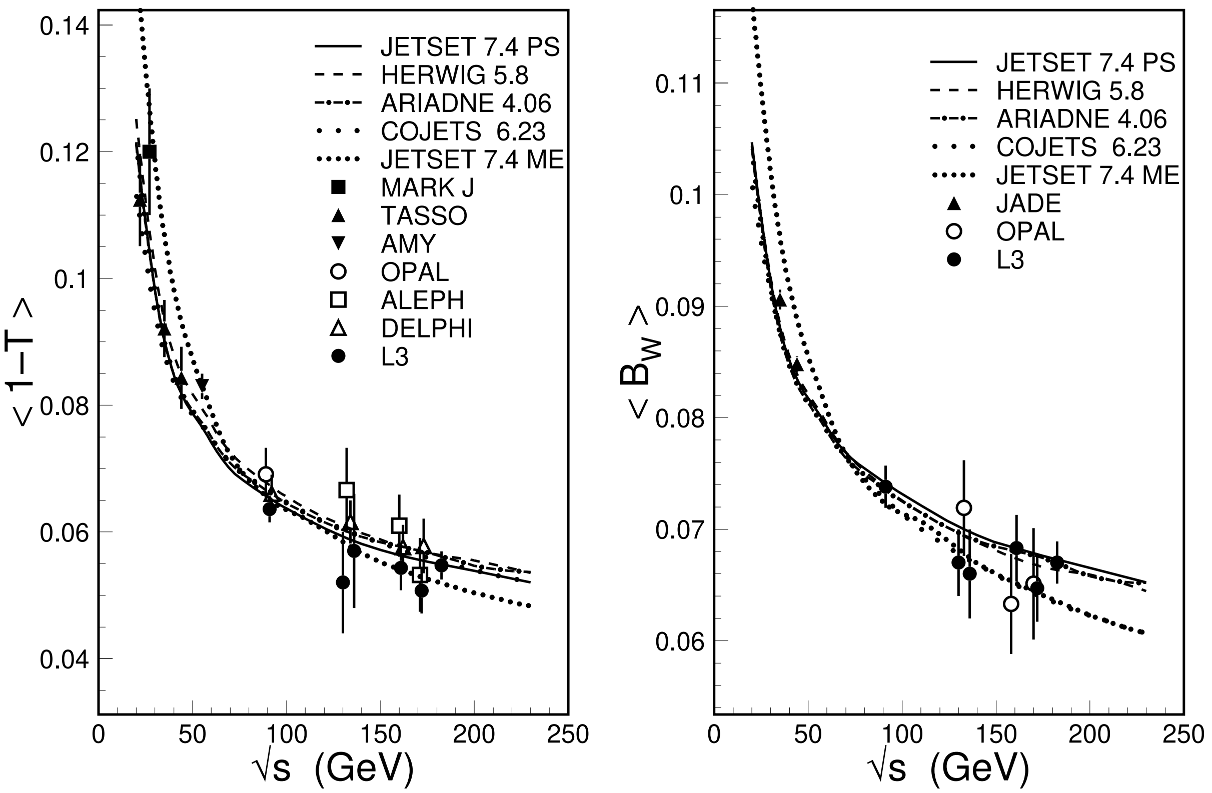


At 183 GeV:

$$< 1 - T >= 0.0547 \pm 0.0016 \pm 0.0015$$
$$< \rho >= 0.0440 \pm 0.0014 \pm 0.0009$$
$$< B_{\mathrm{T}} >= 0.0936 \pm 0.0017 \pm 0.0018$$
$$< B_{\mathrm{W}} >= 0.0670 \pm 0.0014 \pm 0.0013$$

Energy dependance of mean values

Reflects the logarithmic dependence of α_s and the power behaviour of non-perturbative effects



Good agreement with Monte Carlo
using a parton shower
Small difference with JETSET 7.4 M.E.

- Performed using fits of event shape variables for which exist improved theoretical calculations

$$\Longrightarrow T,\ \rho,\ B_{\mathrm{W}},\ B_{\mathrm{T}}$$

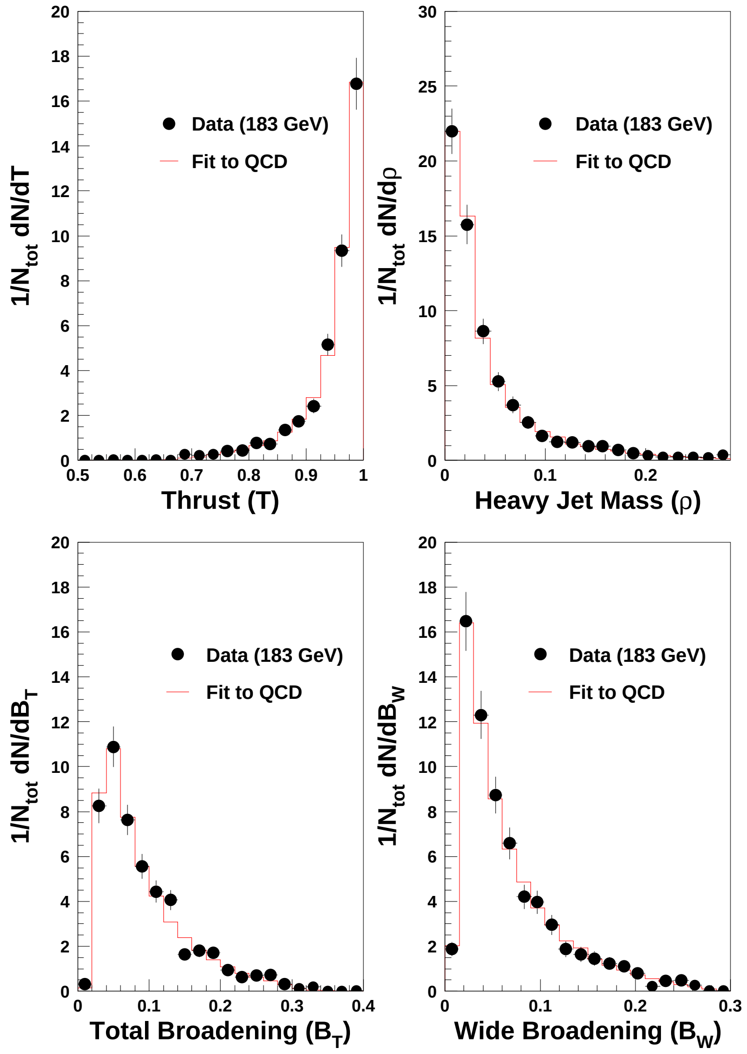
- For these event shape variables (Y)

$$F(\alpha_s, Y) \equiv \int_0^Y \frac{1}{\sigma}\frac{d\sigma}{dY'}dY'$$

- $F(\alpha_s, Y)$ based on theoretical calculation at $\mathcal{O}(\alpha_s^2)$ with resummed up to Next to Leading Log. terms

and corrected for hadronisation effects using Monte Carlo programs

α_s measurement at 183 GeV

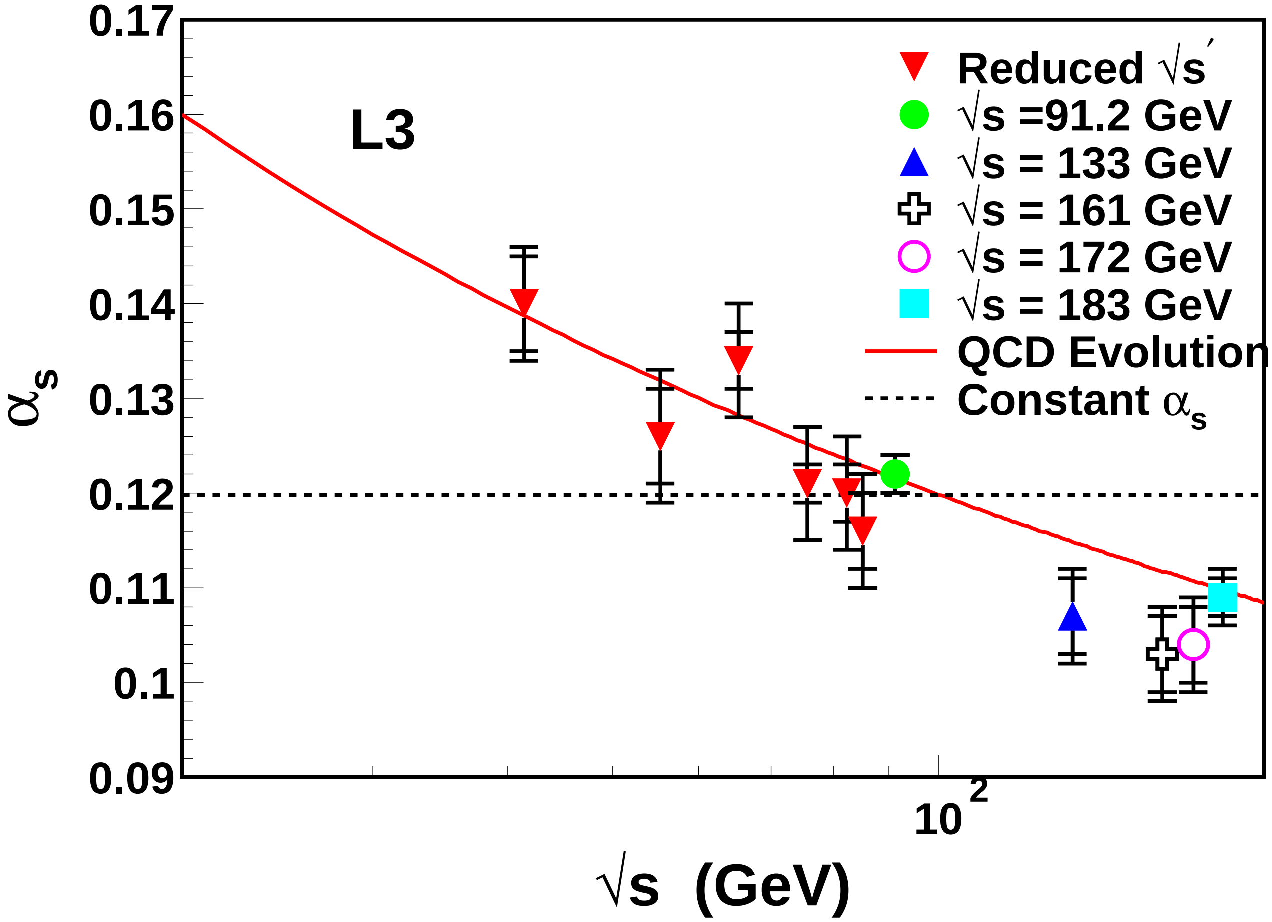


	$(1-T)$	ρ	B_T	B_W
Fit range	0.00 – 0.30	0.00 – 0.20	0.00 – 0.25	0.00 – 0.20
α_s(183 GeV)	0.1135	0.1070	0.1112	0.1028
Experimental error	±0.0030	±0.0033	±0.0022	±0.0019
Theoretical error	±0.0055	±0.0038	±0.0065	±0.0058

$$\alpha_s(183 \text{ GeV}) = 0.1086 \pm 0.0026(\text{exp}) \pm 0.0054(\text{theo})$$

Energy evolution of α_s

Using α_s values calculated by L3 at various $\sqrt{s}$



QCD evolution one parameter fit gives:

$$\alpha_s(M_z, \text{fitted}) = 0.1216 \pm 0.0017(\text{exp}) \pm 0.0058(\text{theo})$$

with $\chi^2 = 16.9$ for 10 DoF $\Rightarrow$ C.L $= 7.6\%$

$\Longrightarrow$ Good agreement with

$$\alpha_s(M_z, \text{published}^*) = 0.124 \pm 0.003(\text{exp}) \pm 0.008(\text{theo})$$

Constant α_s model gives $\chi^2 = 91.4 \Rightarrow$ C.L. $= 0.29 \times 10^{-12}\%$

*L3 collaboration, O. Adriani *et al.*, Phys. Lett. **B284** (1992) 471

Charged particle momentum spectrum

Colour coherence effect in QCD

$\Downarrow$

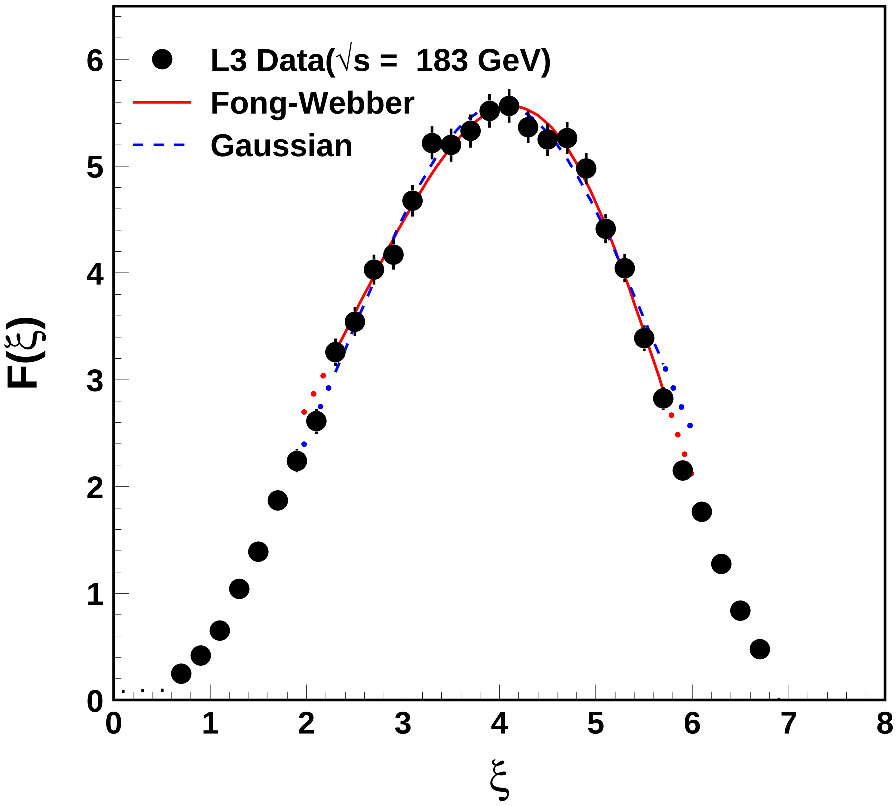
Destructive interference in soft gluon emission

$\Downarrow$

Hadron production suppression at small momenta

$$\xi = -\ln(x) \text{ where } x = \frac{|\vec{p}|}{E_{\text{beam}}}$$

$\Longrightarrow$ Colour coherence effect increases depletion a low x



Assuming LPHD, ξ distribution is fitted by:

- A gaussian expected by DLA prediction
- A skewed gaussian (Fong-Webber) expected by MLLA prediction

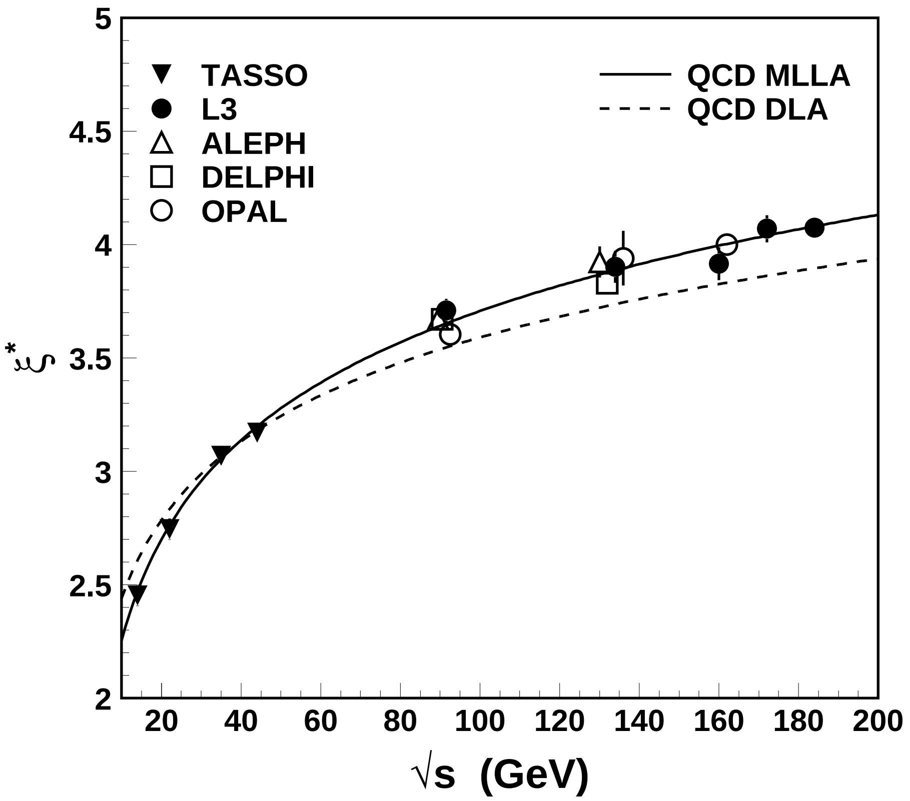
$$\xi^*(183 \text{ GeV}) = 4.075 \pm 0.022 \pm 0.038$$

Energy evolution of ξ^*

Analytical QCD calculations give:

$$\xi^* = \underbrace{\tfrac{1}{2}Y}_{\text{DLA}} + \underbrace{Y\left(a\sqrt{\frac{\alpha_s(Y)}{32\pi N_c}} - a^2\frac{\alpha_s(Y)}{32\pi N_c} + \ldots\right)}_{\text{Sub-leading contributions}}$$

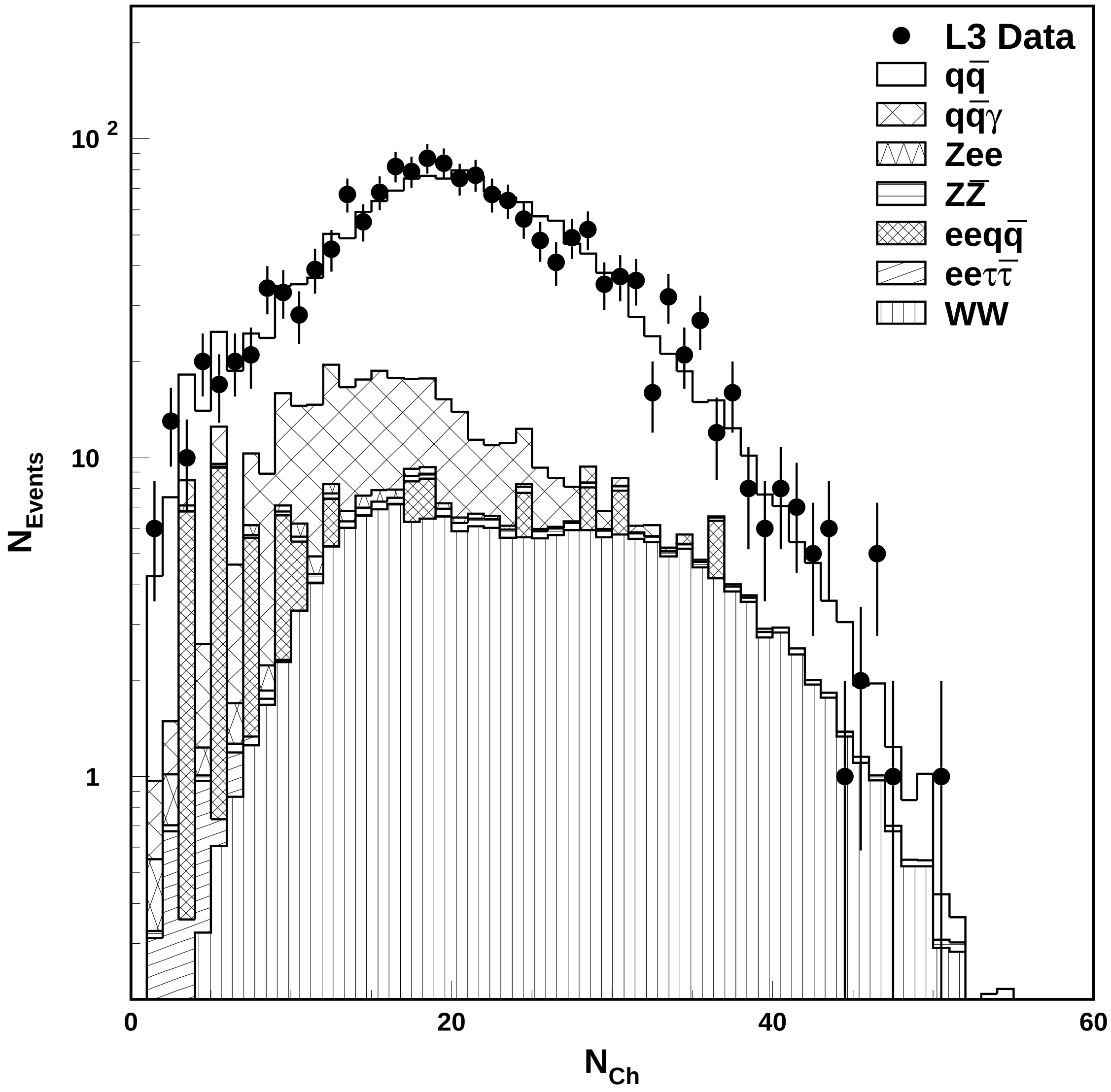
where $Y = \ln(E_{\text{beam}}/\Lambda)$ and $a = \frac{11}{3}N_c + \frac{2}{3}\frac{N_f}{32N_c^2}$



Data are well described by MLLA calculation

Charged particle multiplicity

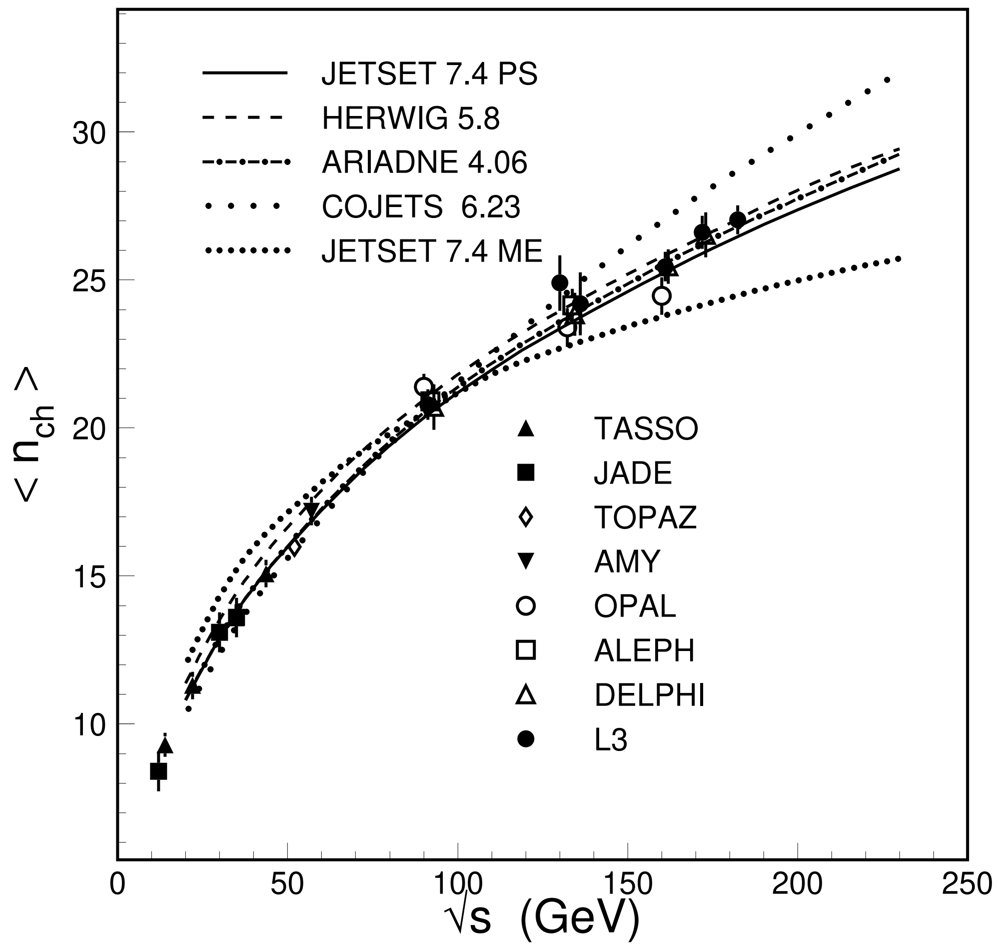
At detector level



After corrections

At 183 GeV, $< N_{\rm ch} >= 27.04 \pm 0.24 \pm 0.43$

$< N_{\rm ch} >$ energy evolution



- Good agreement with Monte Carlo models using a coherent parton shower
- Failure of JETSET 7.4 ME

  $\Rightarrow$ Fixed Number of partons generated !!!
- Failure of COJET 6.23

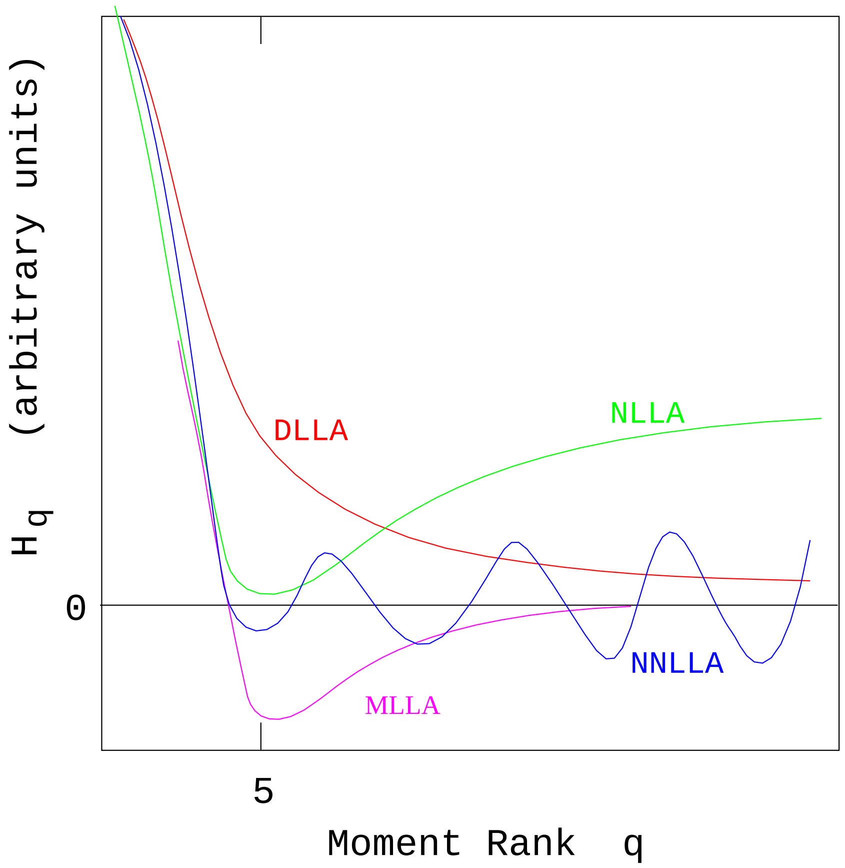
  $\Rightarrow$ Coherence effect not taken into account by LLA parton shower

H_q **moments at** 91.2 GeV

Multiplicity distribution can be analyzed in term of H_q moments, $H_q = \frac{K_q}{F_q}$

$\Longrightarrow$ q particles correlation function dependence to the whole correlation function of a M.D.

Behaviour of $H_q(q)$ predicted for partons by QCD



Assuming the validity of LPHD, same behaviour should be seen for hadrons

Using charged particle multiplicity distribution, SLD* observed the behaviour predicted by the NNLLA

$*$ Phys. Lett. **B371** (1996) 149

F_q, K_q, H_q moments

- Normalized multiplicity distribution P_n

- Normalized factorial moment F_q

$$F_q = \frac{\sum_{n=q}^{\infty} n(n-1)....(n-q+1)P_n}{\left(\sum_{n=1}^{\infty} nP_n\right)^q}$$

F_q show the correlations in the multiplicity distribution

- Normalized cumulant factorial moment K_q

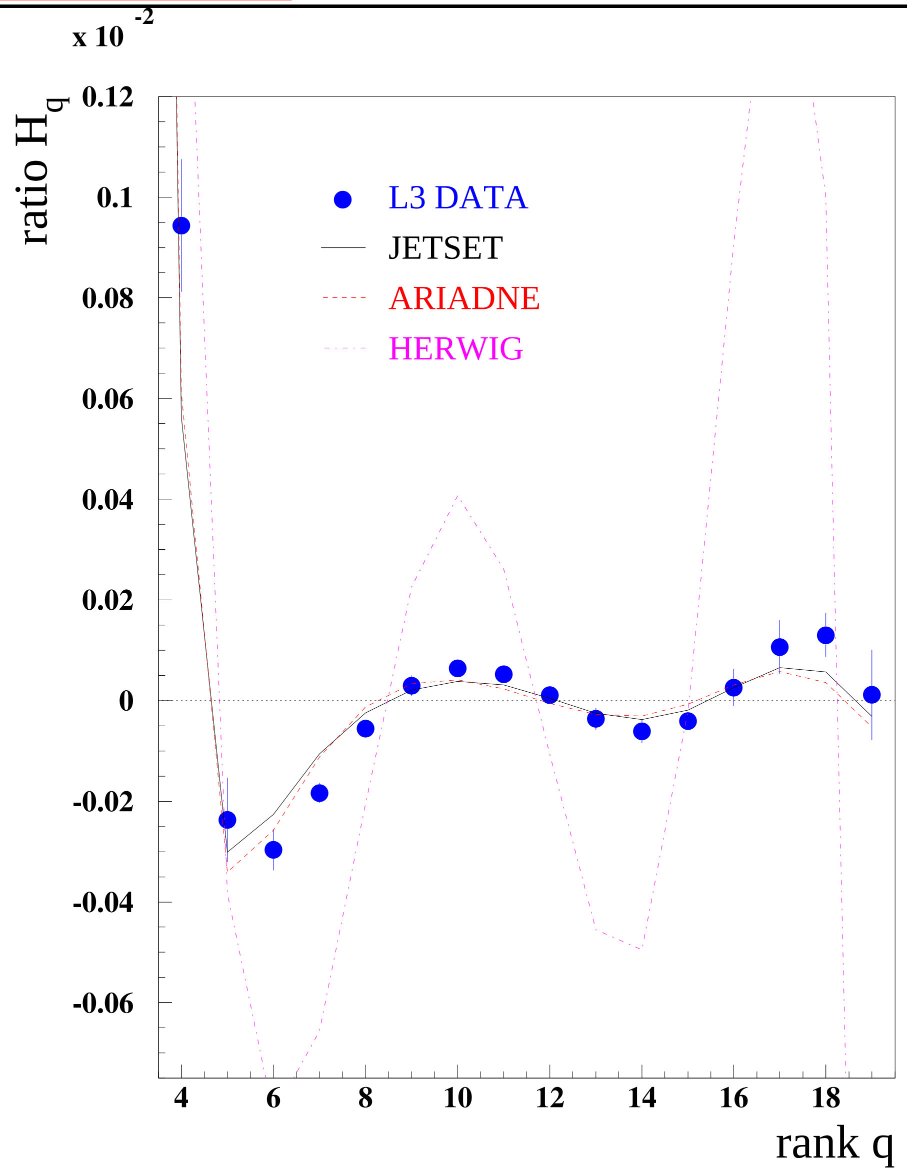
$$K_q = F_q - \sum_{m=0}^{q-1} \frac{(q-1)!}{m!(q-m-1)!} K_{q-m} F_m$$

K_q show the genuine correlation functions of q order

- Ratio of cumulant to factorial moment H_q

$$H_q = \frac{K_q}{F_q}$$

H_q for the charged multiplicity



$\Longrightarrow$ "NNLLA behaviour" also seen using L3 data
also good agreement with
JETSET 7.4 PS and ARIADNE 4.08
BUT

- JETSET PS, ARIADNE (and HERWIG) generate parton according a coherent parton shower with momentum conservation $\approx$ MLLA not NNLLA
- difference in behaviour between JETSET and HERWIG $\Longrightarrow$ difference in hadronization process

H_q for the jet multiplicity

Testing directly pQCD predictions need to reduce the dependence to the LPHD

$\Longrightarrow$ Jet defined at energy scales $\gtrsim$ 1 GeV mainly described by pQCD

$\Longrightarrow$ Close to parton level

Jet defined using $\begin{cases} \text{Durham} \\ \text{Cambridge} \end{cases}$ algorithms

with $y_{ij} = \dfrac{2\min(E_i^2, E_j^2)}{E_{\rm cms}^2}(1 - \cos\theta_{ij})$ and $y_{\rm cut} \approx \left(\dfrac{E_{\rm jet}}{\sqrt{s}}\right)^2$

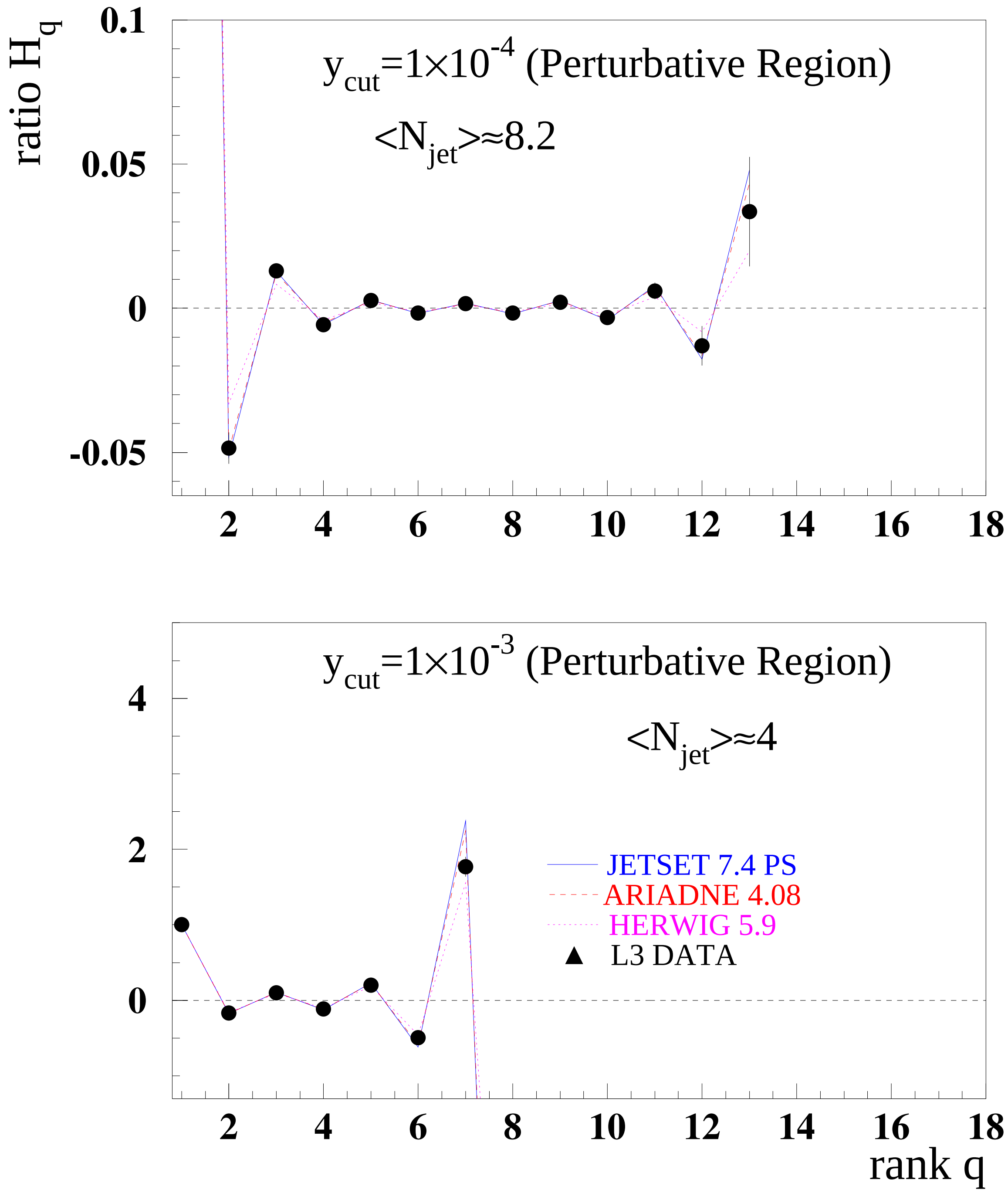
Perturbative region ($\gtrsim$ 1 GeV) $\Longleftrightarrow$ $y_{\rm cut} \gtrsim 10^{-4}$

No significative difference between Cambridge and Durham in our analysis

H_q for jet multiplicities

For jet multiplicities obtained with Durham

In the perturbative region



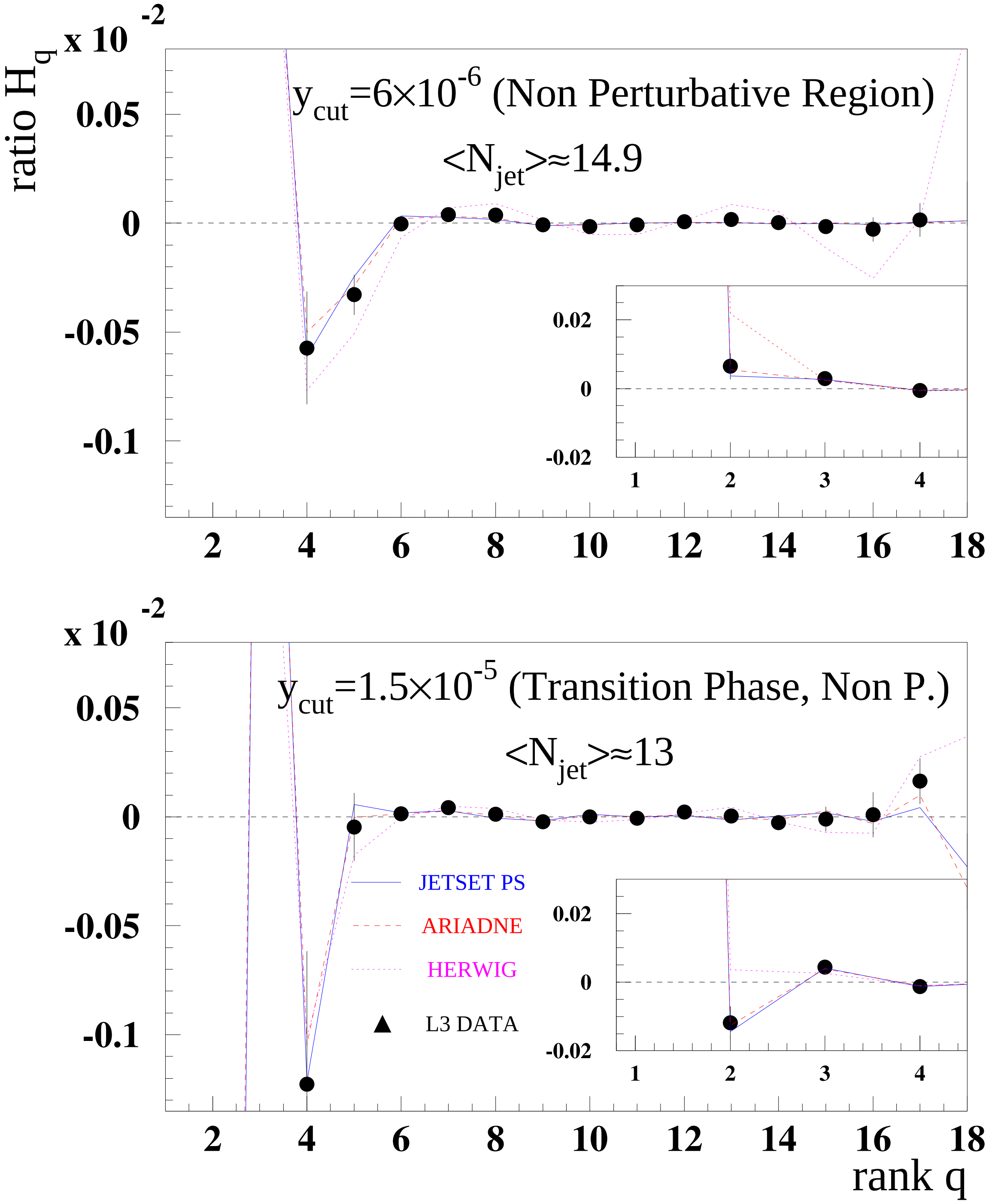
Good agreement with the data for Monte Carlo models

No oscillation seen in the perturbative region

H_q for jet multiplicities

For jet multiplicities obtained with Durham

In the non-perturbative region



Oscillation and first negative minimum appear far away from the perturbative region

Summary

- Event shape variables are seen to agree well with Monte Carlo expectations
- New high energy value measured for α_s from the fit of event shape variables:

$$\alpha_s(183\ \mathrm{GeV}) = 0.1086 \pm 0.0026(\mathrm{exp}) \pm 0.0054(\mathrm{theo})$$

- Energy evolution of α_s in agreement with the strong running coupling constant expectation
- Evidence of color coherence effect given by ξ distribution and $< N_{\mathrm{ch}} >$ energy evolution
- Success of MLLA with ξ^* energy evolution

BUT

- H_q behaviour seen for charged multiplicity unrelated to analytical QCD calculations