Analysis of the charged particle multiplicity distribution in Z decays at LEP with the L3 detector

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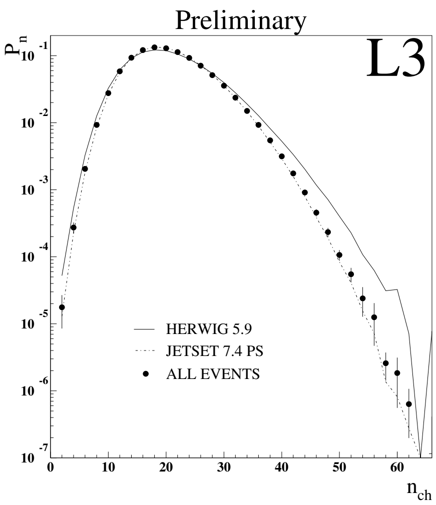
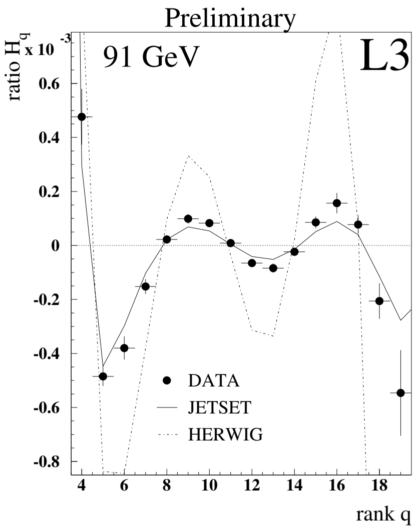
Introduction

The multiplicity distribution of the hadronic final states contains information about the dynamics of the interaction

This information can be accessed by studying the shape of the multiplicity distribution using correlation functions



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



Experimental results can be interpreted in two different ways:

- The Analytical QCD approach:
  - Predicts the shape of the parton multiplicity distribution.
  - Predictions can be extended to the hadronic final state under the Local Parton-Hadron Duality (LPHD) hypothesis.
  - LPHD assumes the shape of the multiplicity distribution is not altered by the hadronization phase.
- Phenomenological approach:
  - Assumes that the shape of the multiplicity distribution of the hadronic final state can be explained as a superposition of more simple final states related to the topology of the event
  - These final states can be interpreted using more simple parametrizations
  - Combining these parametrisation will reproduce the shape of multiplicity distribution of the hadronic final states

Experimental Data

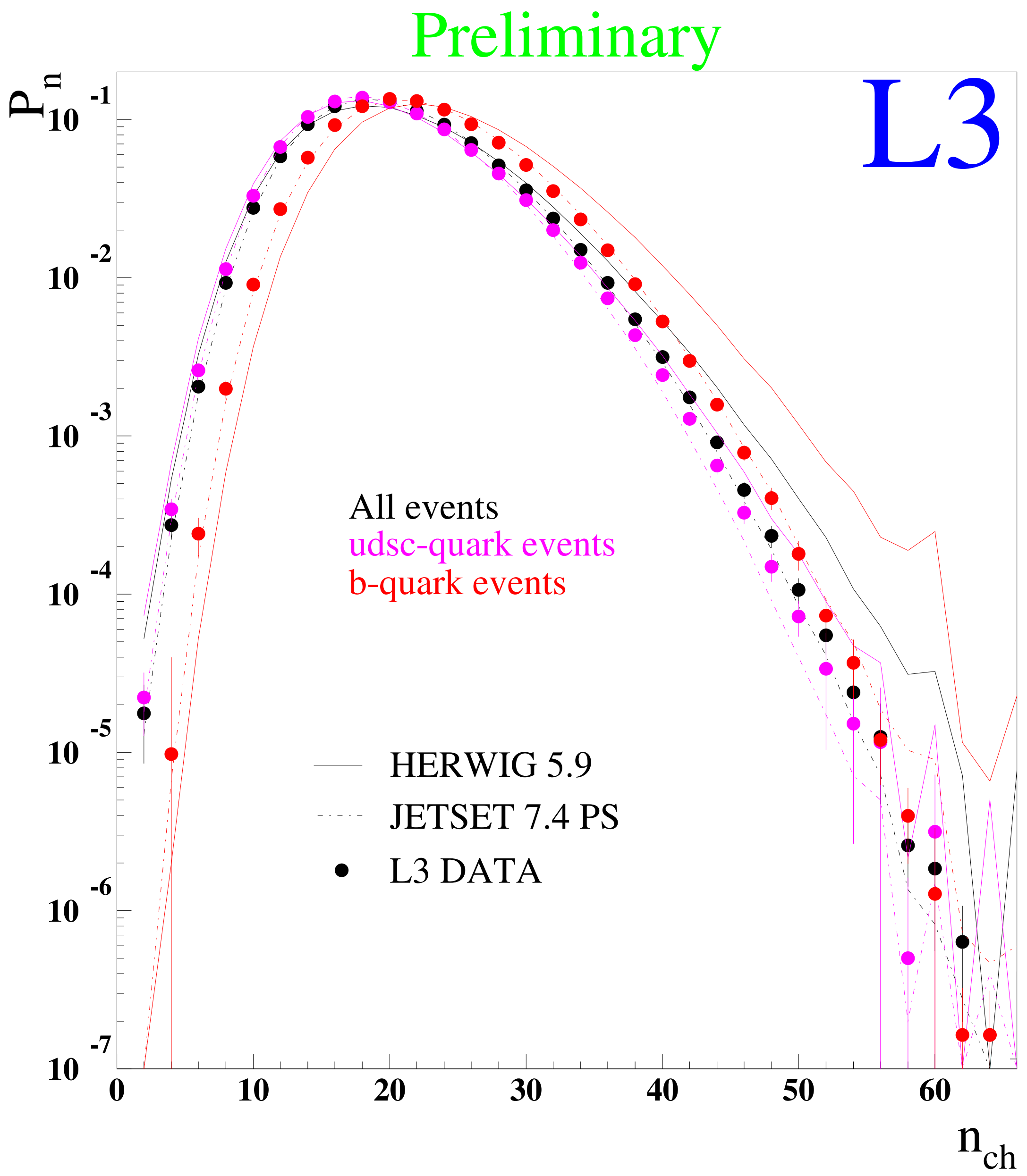
$*$ pQCD and phenomenological approaches are tested using the $e^+e^- \longrightarrow$ hadrons Charged-Particle Multiplicity Distributions (CPMD) recorded in 1994 and 1995 at LEP by the L3 experiment coming from:

- all events
- light(udsc)-quark events
  $\Longrightarrow$ Analytical QCD assumes massless quarks
- b-quark events
  $\Longrightarrow$ enable a check of the influence of heavy quark mass effect
- 2-jet and 3-jet events obtained for several y_{cut} from the three previous samples
  $\Longrightarrow$ To test the phenomenological approach

$*$ Predictions also tested using jet multiplicity distributions obtained from the charged-particle multiplicity distribution, at various energy resolution

$\Longrightarrow$ Reduces the dependence on the LPHD assumption.
Allows a direct comparison with perturbative QCD calculation.

CPMD's



Truncation of the CPMD is defined as the fraction of event removed in the tail of the full CPMD

$\Longrightarrow$ same fraction is removed from all studied CPMD's

QCD analytic predictions

- DLLA (Double Leading Logarithm Approximation)

  H_q decreases as q^{-2}

- MLLA (Modified Leading Logarithm Approximation)

  H_q has a first negative minimum for $q \approx 5$

  and increases slowly to 0 for $q > 5$

- NLLA (Next to Leading Logarithm Approximation)

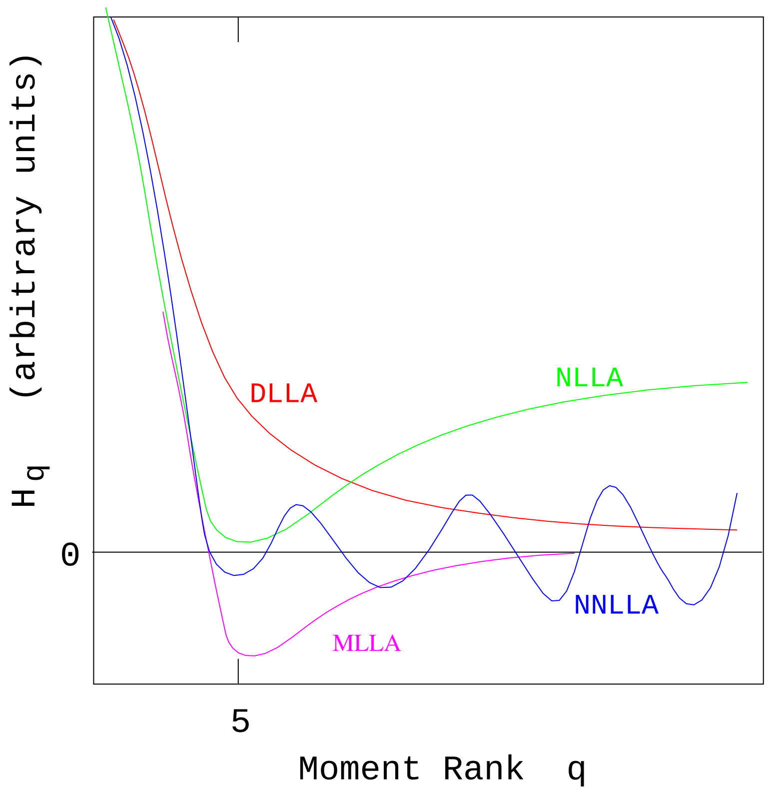
  H_q has a first negative minimum for $q \approx 5$

  a positive constant value for $q \gg 5$

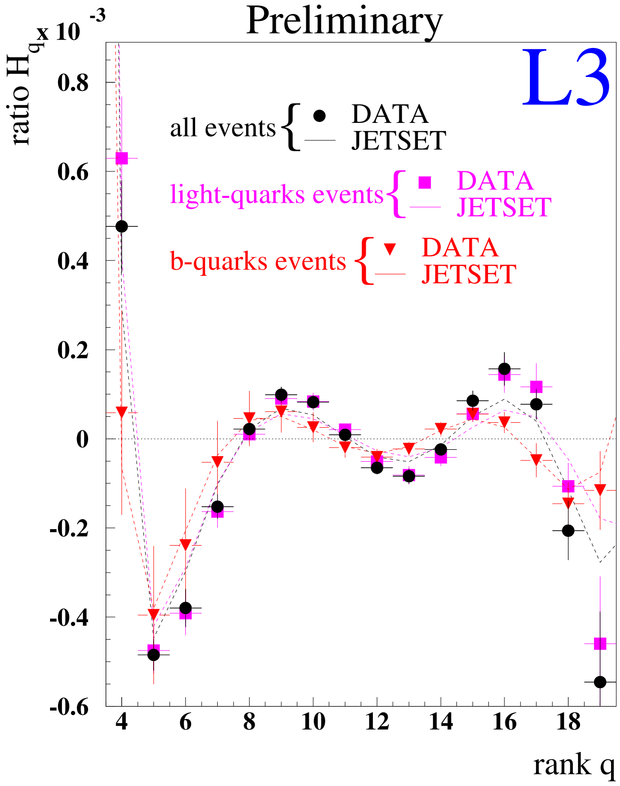
- NNLLA (Next to Next Leading Logarithm Approximation)

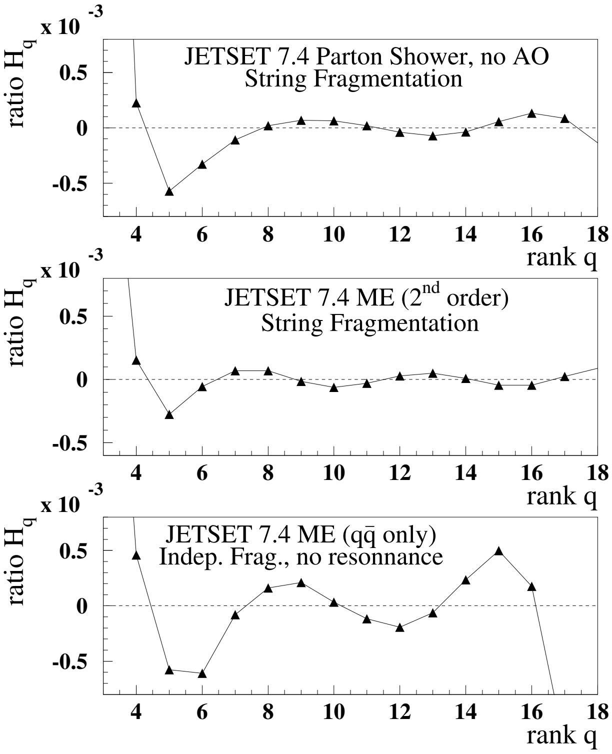
  H_q has a first negative minimum for $q \approx 5$

  quasi-oscillations about 0 for $q > 5$



H_q for the charged multiplicity





"NNLLA behaviour" seen for all events and both light- and b-quark events
Heavy-quark mass effect has only a limited influence on the H_q behaviour
Differences are seen but only for $q < 5$.

good agreement also with JETSET 7.4 PS

- JETSET PS generates partons using coherent parton showers ($\approx$ MLLA) with, in addition full energy momentum conservation
- Using various parton generations as different as:
  - ○ No Angular Ordering parton shower($\approx$ LLA)
  - ○ Matrix Elements:
    - 2^{nd} order in α_s
    - 1^{rst} order in α_s
    - $q\bar{q}$ only

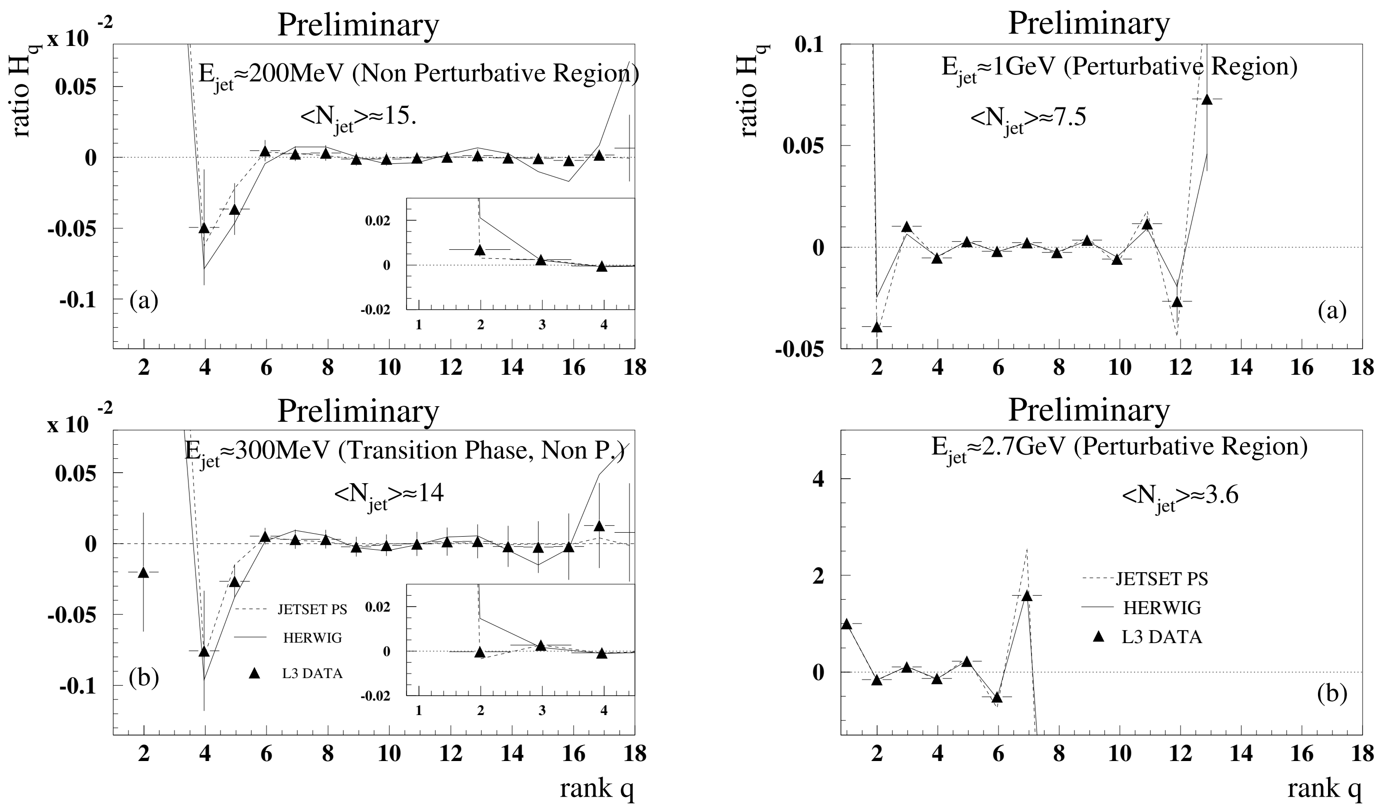
$\Longrightarrow$ The H_q oscillatory behaviour remains !!!

But energy momentum conservation is fully taken into account by Monte Carlo generator, but not by analytical QCD calculations

H_q for jet multiplicities

- Jet multiplicity is assumed to be related to the parton multiplicity at the energy scale of the jet resolution
- Using the Cambridge jet algorithm, destructive effects induced by hadronization are corrected

$\Longrightarrow$ Enables direct comparison with pQCD predictions
for $E_{\text{jet}} \gtrsim 1$ GeV $\Longleftrightarrow y_{\text{cut}} \gtrsim 1.2 \times 10^{-4}$



Good agreement between data and Monte Carlo models
But No oscillation seen in the perturbative region
Oscillation and first negative minimum appear far away from the perturbative region

phenomenological approach

The CPMD of the hadronic final states and its shape is seen as the result of the superposition of various processes as 2-jet, 3-jet, light or heavy quarks events which could be described by simple parametrizations as the NBD:

$$\mathrm{NBD}(\bar{n}, k) = \frac{(k+n-1)!}{n!(k-1)!}\left(\frac{k}{\bar{n}+k}\right)^k\left(\frac{\bar{n}}{\bar{n}+k}\right)^n$$

with k is given by $D^2/\bar{n}^2 = 1/\bar{n} + 1/k$

where $\bar{n}$ and D are the mean and the dispersion of the distribution

$*$ $\mathrm{MNBD}_{\text{full sample}} = \alpha_{\text{2jet}}\mathrm{NBD}_{\text{2jet}} + (1-\alpha_{\text{2jet}})\mathrm{NBD}_{\text{3jet}}\big|^{y_{\text{cut}}}_{\text{full sample}}$

where for given y_{cut} we have:

- α_{2jet} is the 2-jet rate
- $\mathrm{NBD}_{\text{2jet}}$ is an NBD with $\bar{n}$ and k calculated from the 2-jet CPMD
- $\mathrm{NBD}_{\text{3jet}}$ is an NBD with $\bar{n}$ and k calculated from the 3-jet CPMD

$*$ $\mathrm{MNBD}_{\text{2,3jet}} = (1-R_{\text{b}})\mathrm{NBD}_{\text{udsc-quark}} + R_{\text{b}}\mathrm{NBD}_{\text{b-quark}}\big|^{y_{\text{cut}}}_{\text{2,3jet}}$

where for given y_{cut} we have:

- R_{b} is the b-quark production rate
- $\mathrm{NBD}_{\text{udsc-quark}}$ is an NBD with $\bar{n}$ and k calculted from the 2 or 3jet, light-quark CPMD
- $\mathrm{NBD}_{\text{b-quark}}$ is an NBD with $\bar{n}$ and k calculated from the 2 or 3jet, b-quark CPMD

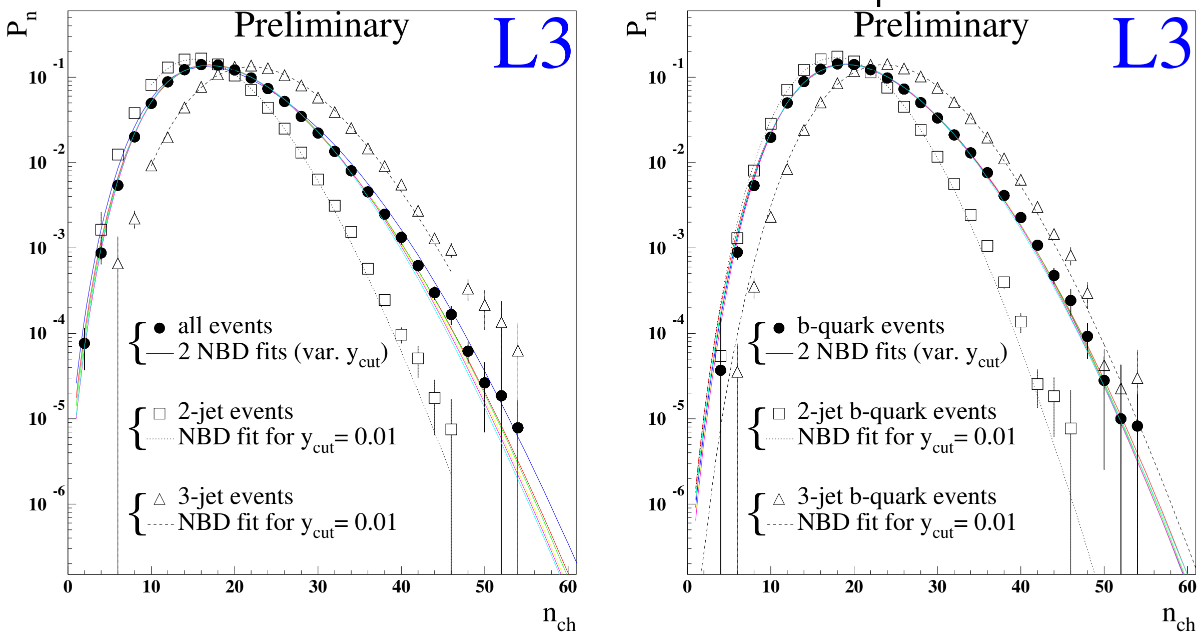
As a extension from the first parametrization, we can also get:

$*$ $\mathrm{MNBD}_{\text{flavour}} = \alpha_{\text{2jet}}\mathrm{NBD}_{\text{2jet}} + (1-\alpha_{\text{2jet}})\mathrm{NBD}_{\text{3jet}}\big|^{y_{\text{cut}}}_{\text{flavour}}$

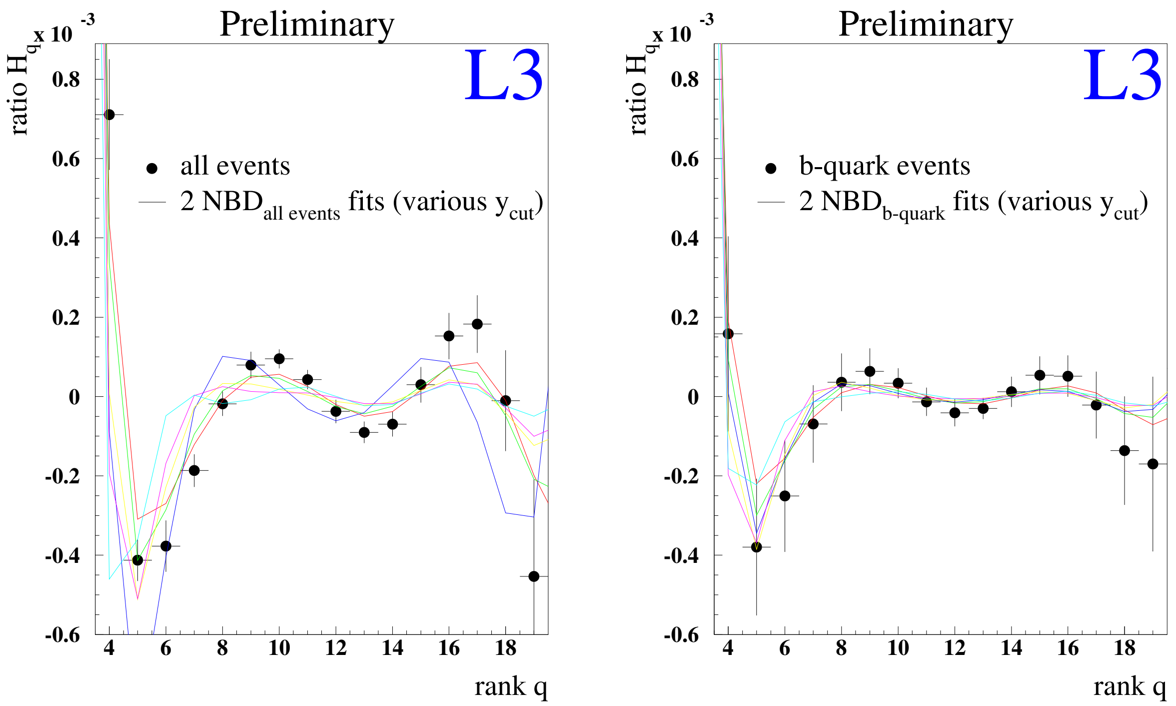
fits of the CPMD's

Good agreement with full sample, light and heavy-quark event samples with 2 NBD parametrization using 2,3 jet CPMD parameters

But single NBD are not able to describe individualy the 2,3 jet CPMD no matter the flavour of the samples



good description of the H_q by the parametrization for the full sample, even better for light and b-quark sample



No agreement at all with the 2,3 jet samples with 2 NBD parametrization using light and heavy-quark sample CPMD parameters

fits of the CPMD's

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* $\text{MNBD}_{\text{full sample}} = \alpha_{\text{2jet}}\text{NBD}_{\text{2jet}} + (1-\alpha_{\text{2jet}})\text{NBD}_{\text{3jet}}|^{y_{\text{cut}}}_{\text{full sample}}$

	χ^2/dof for all events		
y_{cut}	2 NBD (all)	NBD (2jet)	NBD (3jet)
0.03	1.4	56	8.5
0.015	0.6	36	15
0.01	20.4	8	6.3
0.006	0.7	16	36
0.004	1.5	9.4	57
0.002	5	5.5	119

* $\text{MNBD}_{\text{b-quark}} = \alpha_{\text{2jet}}\text{NBD}_{\text{2jet}} + (1-\alpha_{\text{2jet}})\text{NBD}_{\text{3jet}}|^{y_{\text{cut}}}_{\text{b-quark}}$

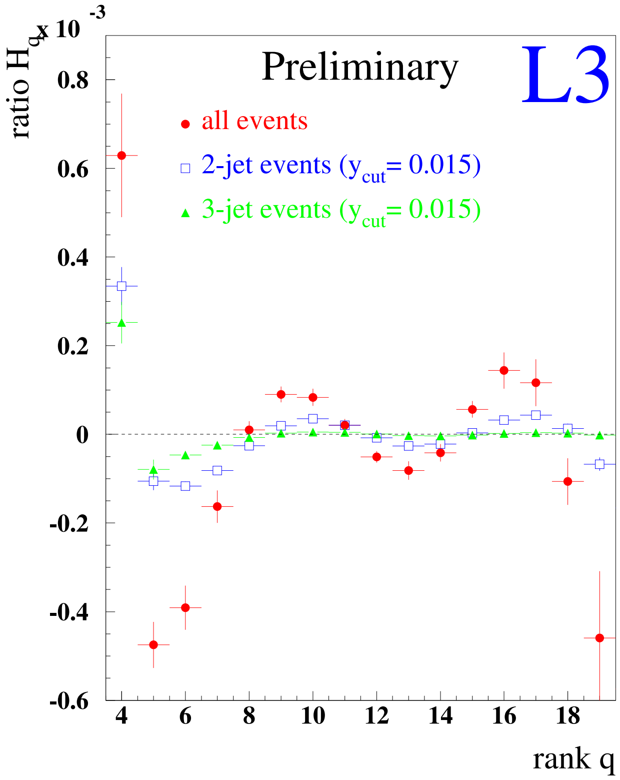
	χ^2/dof for b-quark events		
y_{cut}	2 NBD (all)	NBD (2jet)	NBD (3jet)
0.03	2.6	19	2.2
0.015	1.4	13	3.4
0.01	0.93	9.8	4.4
0.006	0.53	5.5	6.4
0.004	0.53	3.5	8.5
0.002	3	0.8	15

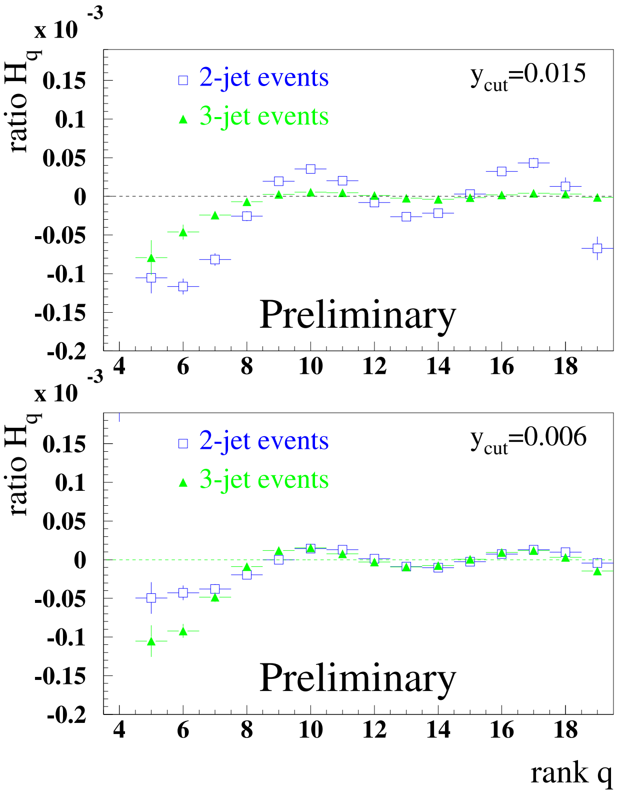
* $\text{MNBD}_{\text{2,3jet}} = (1-R_{\text{b}})\text{NBD}_{\text{udsc-quark}} + R_{\text{b}}\text{NBD}_{\text{b-quark}}|^{y_{\text{cut}}}_{\text{2,3jet}}$

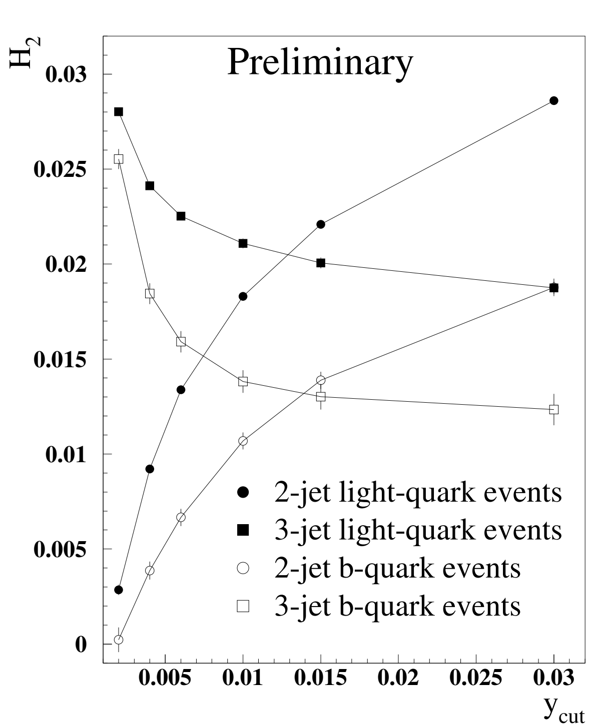
	χ^2/dof	
y_{cut}	2 NBD (2jet)	2 NBD (3jet)
0.03	74	8
0.015	46	14
0.01	39	9
0.006	23	33
0.004	14	48
0.002	5	100

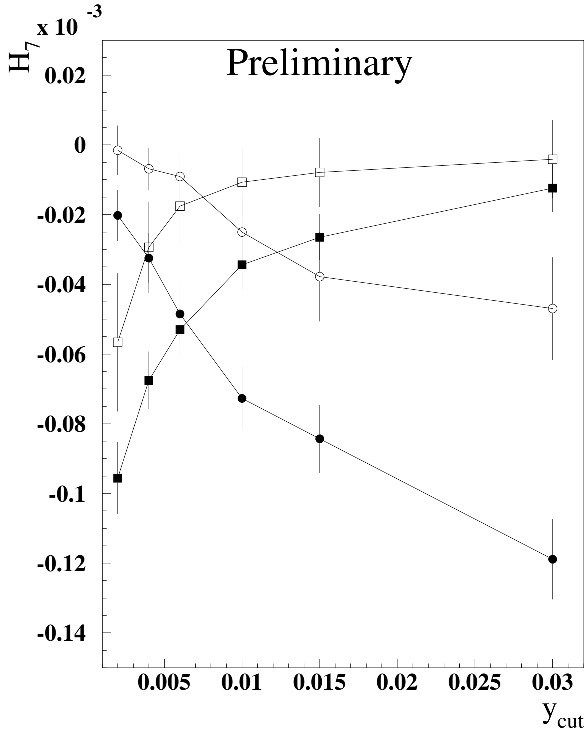
H_q for 2,3-jet events

H_q for 2,3-jet shows much smaller oscillations than the full samples
Differences are seen between 2-jet and 3-jet samples









Differences are also seen between light- and b-quark samples
$\Longrightarrow$ supports the phenomenogical approach

Conclusions

- The H_q measured from charged particle multiplicity show an oscillatory behaviour
  - Almost same behaviour seen for all events, light and b-quarks
  - slight differences between the light and b-quarks sample decreasing with rank q
- H_q for 2,3 jet sample, together with the "odd" success of the 2 NBD parametrization, suggest a reality in the phenomenological approach.
  - nevertheless single NBD fails to reproduce individually any of the 2,3-jet samples.
- H_q behaviour reproduced by Monte Carlo models independently of the pQCD order used to generate partons and of the fragmentation model used.

  $\Longrightarrow$ Could be explained, in part, by full energy momentum conservation implemented in Monte Carlo models.
- none of the pQCD calculations describe the H_q obtained from jet multiplicities obtained at perturbative energy scales

  $\Longrightarrow$ Our results do NOT favour a pQCD origin of the H_q behaviour