Oscillating H_q,
Event Shapes
and
QCD

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XXIX International Symposium
on
Multiparticle Dyanmics

11 Aug. 1999

Charged Particle Multiplicity

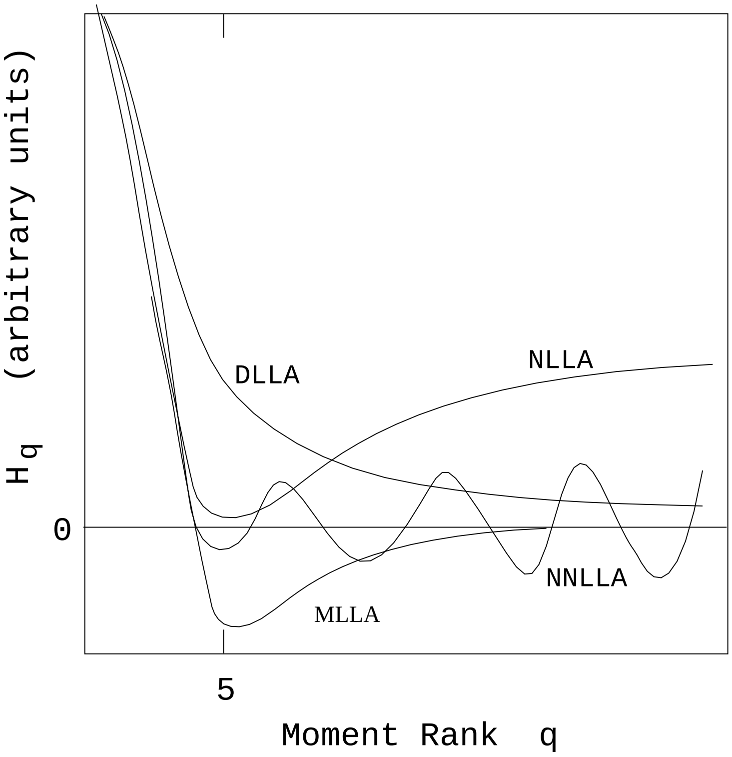
Multiplicity distribution, P_n is often analysed in terms of factorial and cumulant moments:

$$F_q = \frac{\sum_{n=q}^{\infty} \frac{n!}{(n-q)!} P_n}{(\sum_{n=1}^{\infty} n\, P_n)^q}$$

$$K_q = F_q - \sum_{m=1}^{q-1} \binom{q-1}{m} K_{q-m} F_m$$

and their ratio $$H_q = \frac{K_q}{F_q}$$

- H_q are calculable in pQCD
- assuming LPHD, can compare with H_q for charged particles



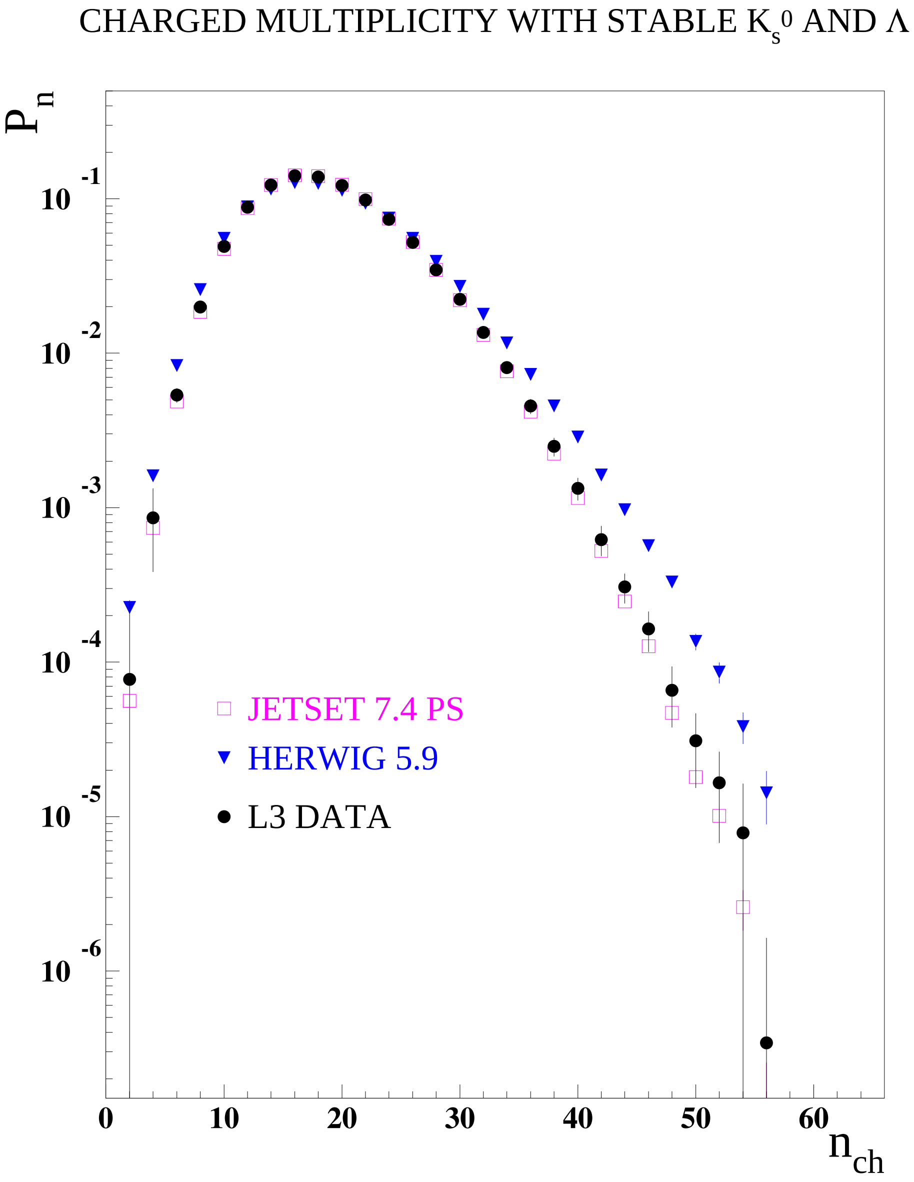
SLD observed the behaviour predicted by NNLLA, $i.e.$, min. + oscillations (P.L. B371 (1996) 149)

Multiplicity Distribution

- L3 prefers not to include K^0,Λ decay products

Unfold the mult. dist. using iterative Bayesian method with a detector response matrix determined from MC

Use 2 MCs: JETSET, HERWIG



HERWIG P_n is too broad

$\boldsymbol{H}_q$

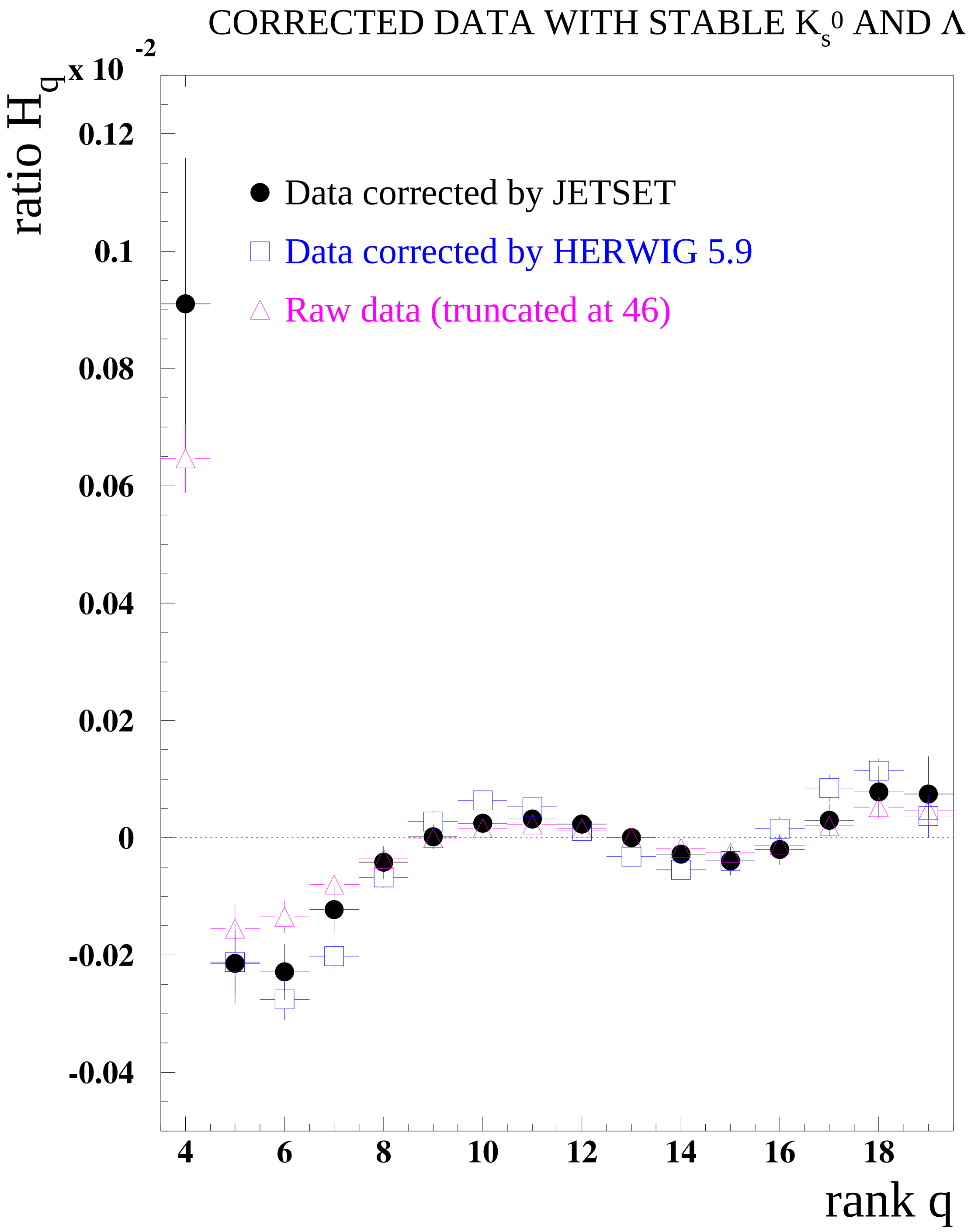
From P_n calculate H_q

- Stat. err. from propagation of covariance matrix of unfolded mult. dist.

- Syst. err. from
  - variation of selection cuts (largest)
  - JETSET/HERWIG for unfolding

- F_q is very sensitive to tails of dist.
  Truncate mult. dist. where errors become too large
  $i.e.$, events with $N_{\text{ch}} > 53$ rejected

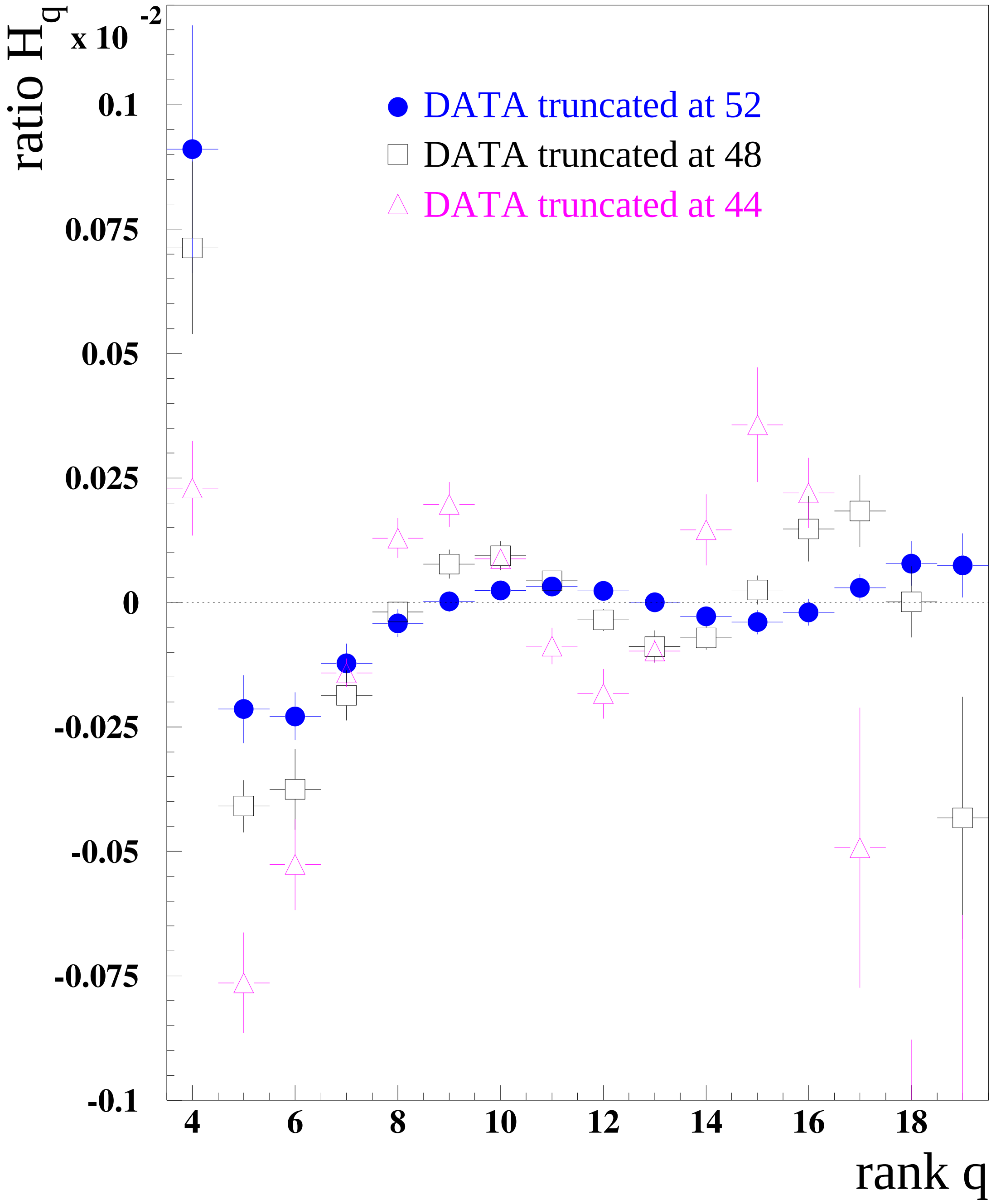
H_q L3 preliminary



H_q min. + oscillations ∼same
in raw data, data unfolded by JETSET, HERWIG
(even though generator distributions are different)

Effect of truncation

L3 preliminary



Truncation increases amplitudes

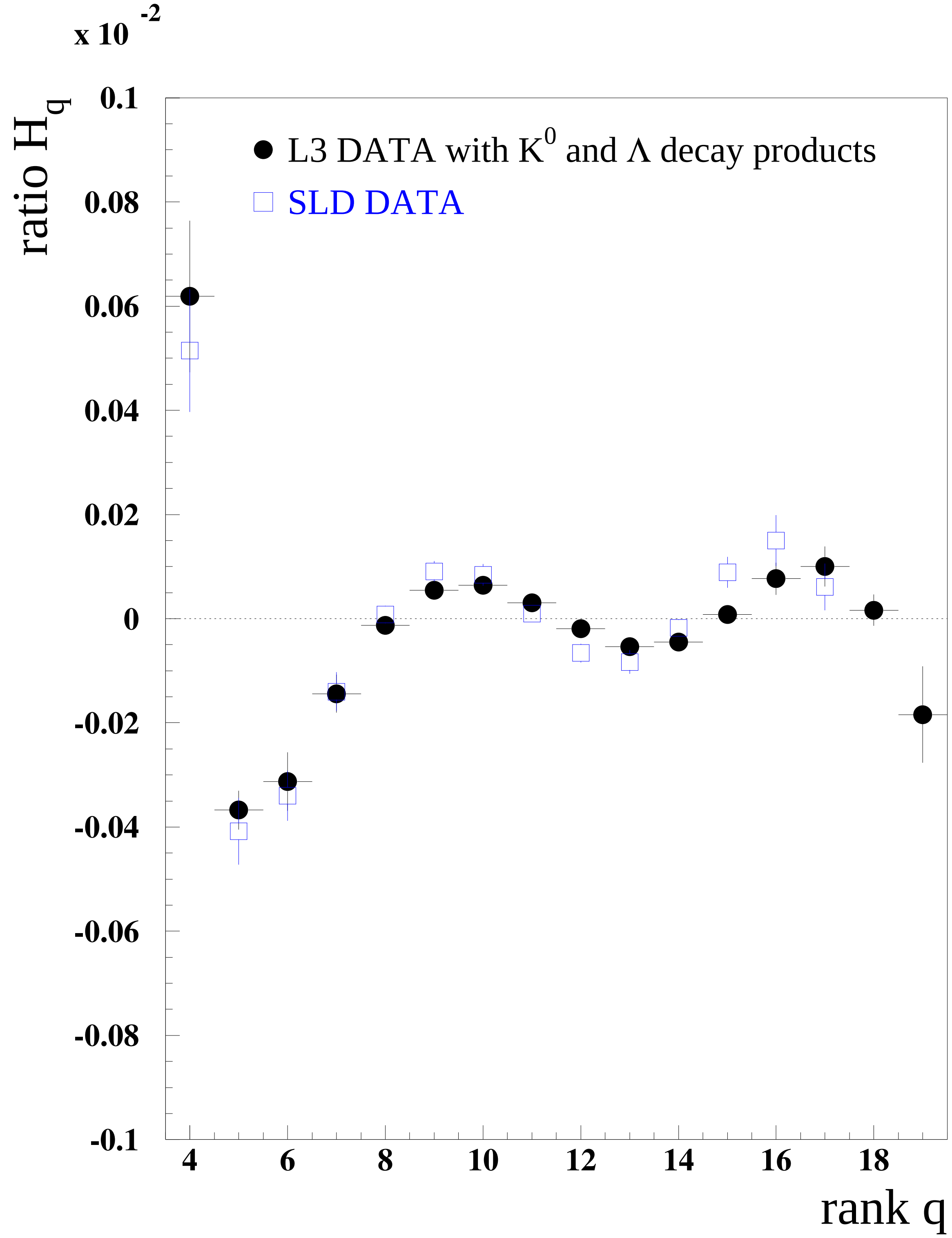
Positions of extrema shift to lower q

Period of oscillations decreases

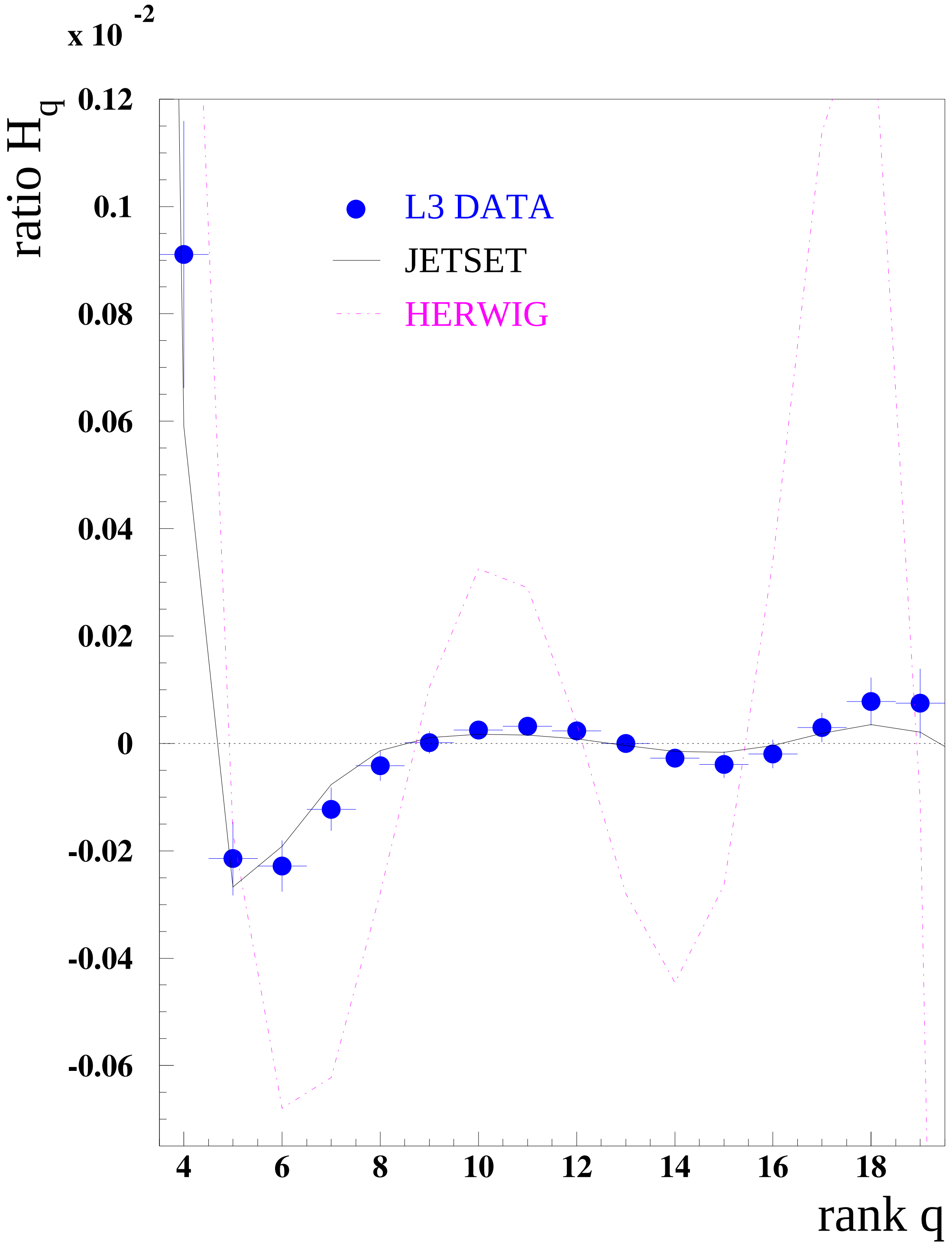
Comparison of H_q with SLD

L3 confirms the SLD result:

H_q from unfolded mult. dist. incl. K^0,Λ decay Preliminary



H_q L3 preliminary



- JETSET reproduces data
- HERWIG has min. + oscillations

  But much larger amplitude of oscillations

???

Why do MCs have oscillations?

- pQCD + LPHD has min.+osc. only at NNLLA
- MCs are only ∼MLLA

◇ Last year at Delphi (ISMD98), Dremin:
Big difference between DLA,...,NNLLA is
treatment of E-conservation.

◇ 2 years ago in Jerusalem (EPS97), Dokshitzer:
"L3 has rediscovered E-conservation"

◇ more recently, Ochs:
Ariadne parton shower to small cut-off
is similar to DLA calculation,
but with exact $E, \vec{p}$ conservation

ARIADNE without Hadronization

Lupia, Ochs, Wosiek, N.P. **B540** (1999) 405:

- 2 parameters:
  cut-off $Q_0 = 0.2\,\text{GeV}$ $\lambda = \ln \frac{Q_0}{\Lambda} = 0.015$
- $(\Lambda = 0.197\,\text{GeV})$
- no hadronization
- $N_{\text{parton}} = \frac{3}{2} N_{\text{ch}}$

	Partons	OPAL
$< N >$	30.2	30.3 ± 0.6
F_2^{hemi}	1.09	1.082 ± 0.005
F_3^{hemi}	1.30	1.28 ± 0.02
F_4^{hemi}	1.68	1.64 ± 0.05

Remarkably good agreement

ARIADNE without Hadronization

L3 does not include K^0,Λ decay products in N_{ch}

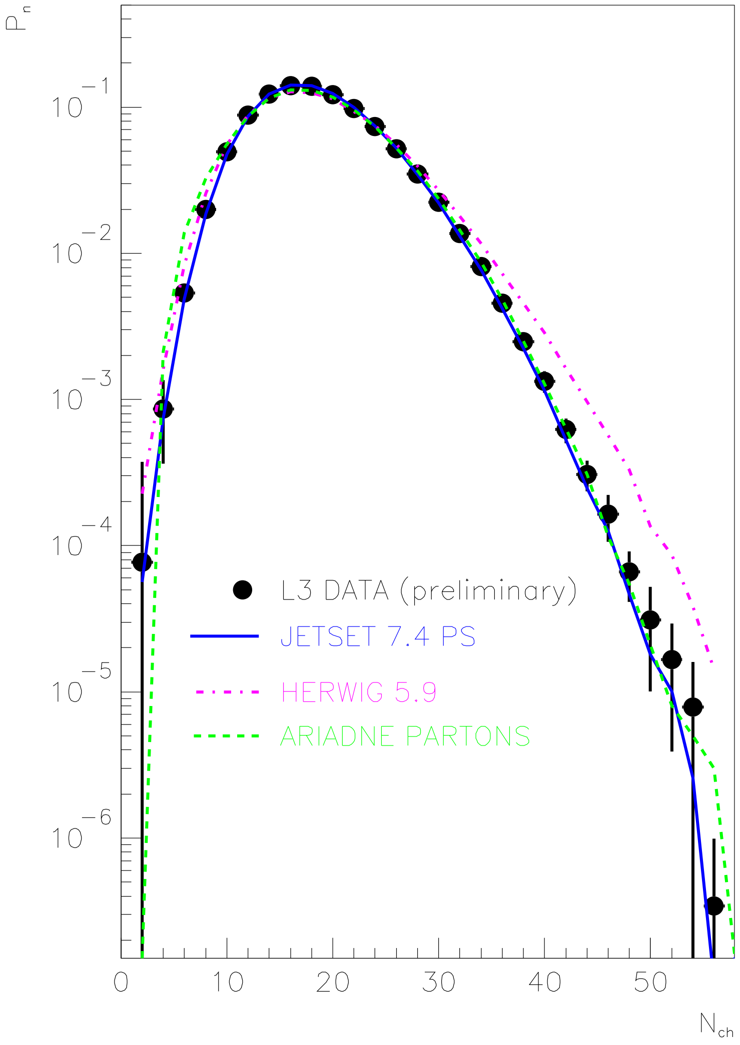
Mult. dist.

$$N_{\text{ch}} = \frac{2}{3} N_{\text{parton}}$$

rounded to even number

best described with

$$\Lambda = 0.388 \quad \text{GeV}$$
$$Q_0 = 0.38801 \text{GeV}$$

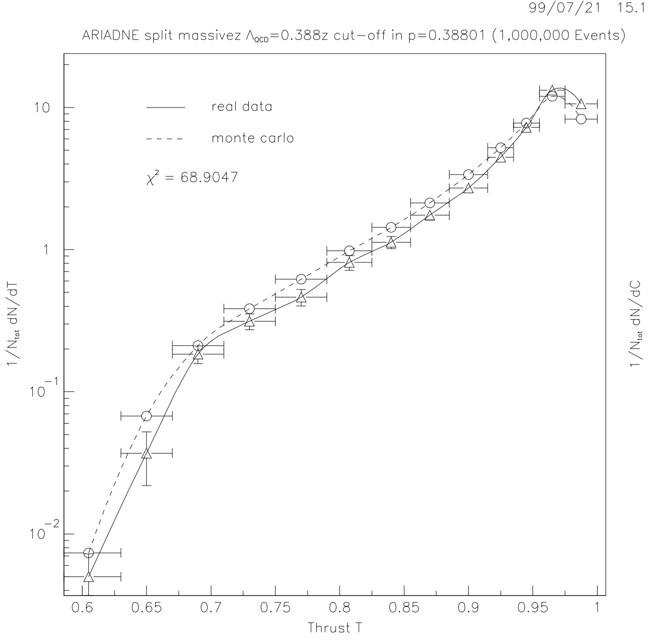


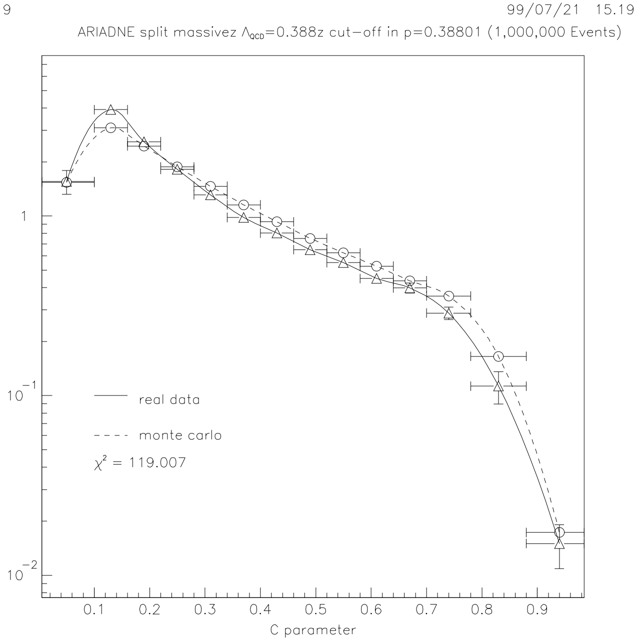
	Partons	L3
$< N_{\text{ch}} >$	18.5	18.65 ± 0.12
$< N_{\text{ch}}^2 >$	379	383 ± 5
$< N_{\text{ch}}^3 >$	8527	8559 ± 200
Dispersion	6.2	5.9 ± 0.1
$< N_{\text{ch}} > / D$	2.97	3.16 ± 0.04
skewness	0.47	0.60 ± 0.02
kurtosis	0.25	0.51 ± 0.06

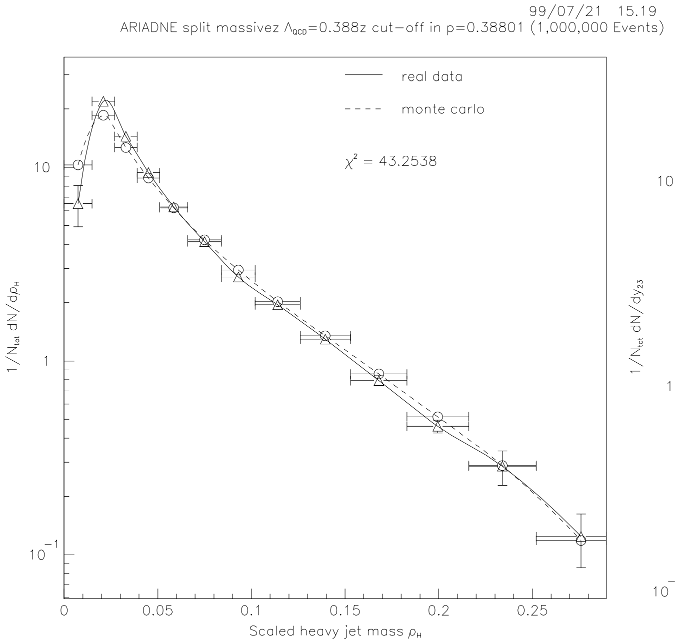
Reasonable … worse agreement

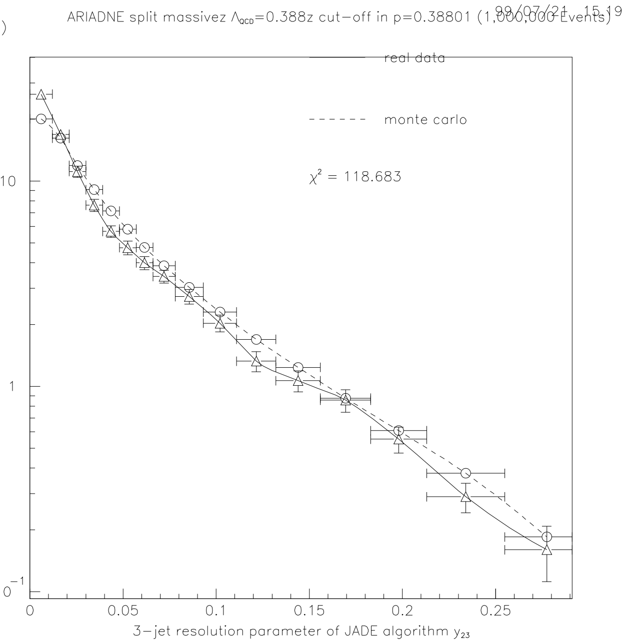
Shape variables

ARIADNE parameters optimized for N_{ch}







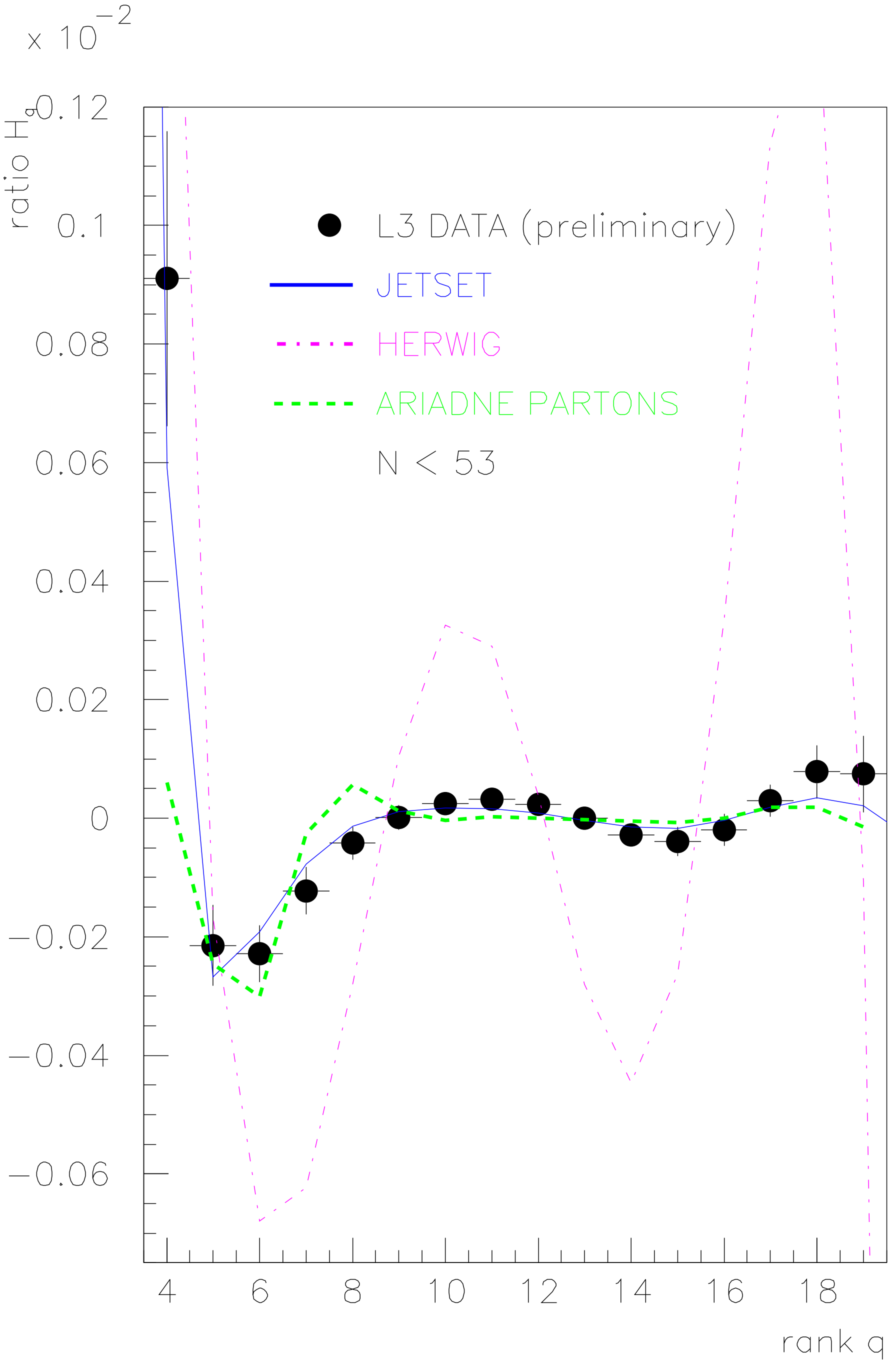


Ariadne partons qualitatively reproduce shape variables

Agreement better if use different Λ for each variable

But JETSET agrees much better Z. Phys. **C55**(1992)39

H_q L3 preliminary



- JETSET reproduces data
- HERWIG has much larger amplitude
- ARIADNE partons has min. + oscillations
  But somewhat different from data

Analytical QCD + LPHD or MC models

- QCD calculations are for partons, not particles

- to compare with data, must rely on
  - assumptions like LPHD
  - models like string fragmentation in JETSET

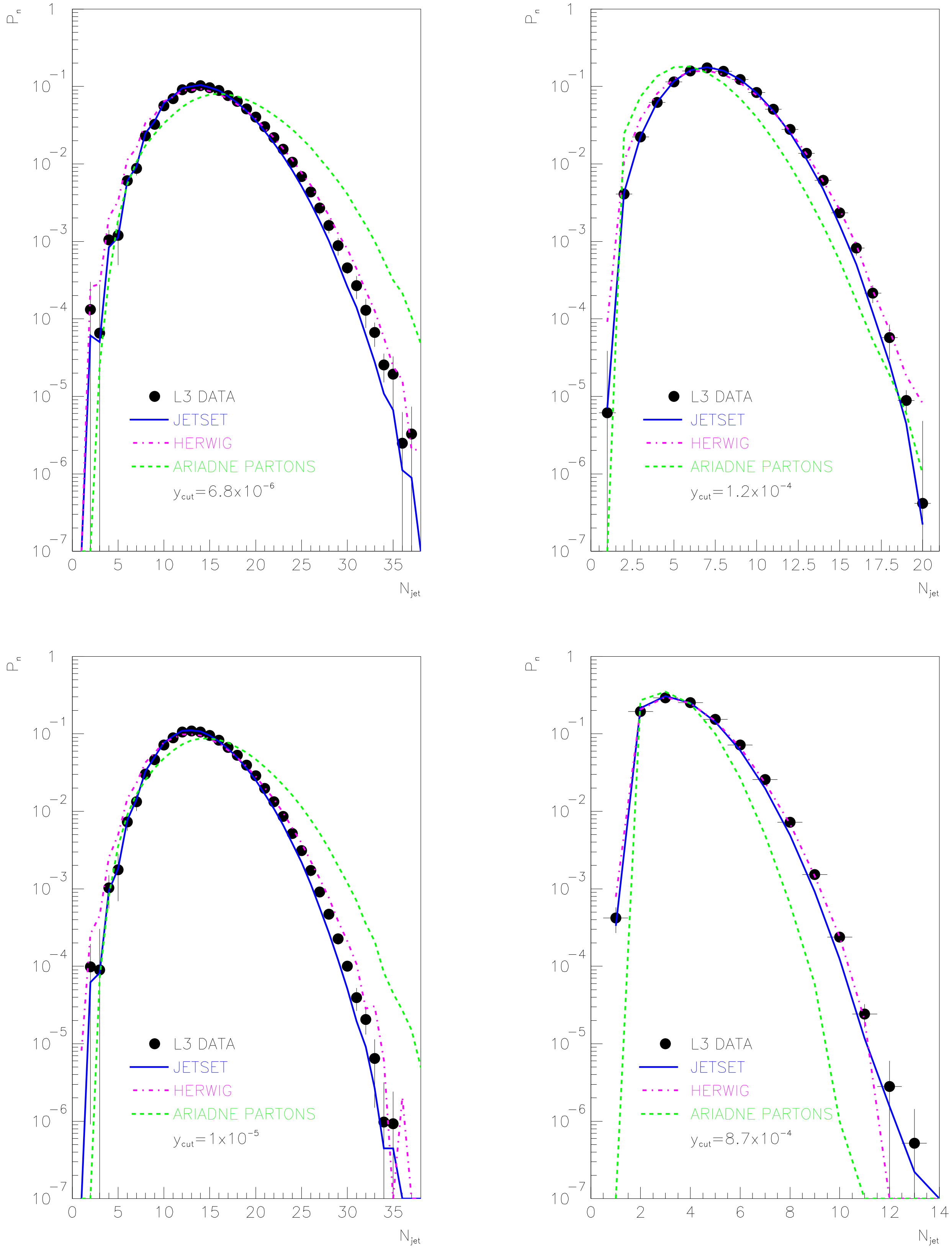
- So you do not really know if you are testing
  - QCD calculations
  - or hadronisation model
  - or hadronisation assumptions (LPHD)

◇ Are the oscillations we see a
confirmation of NNLLA pQCD
or not ???

◇ Oscillations in MCs is suspicious
– their parton showers are only ∼MLLA, not NNLLA

◇ Try to get away from LPHD and hadronisation models
by using jet multiplicity (at different scales)
instead of particle multiplicity.

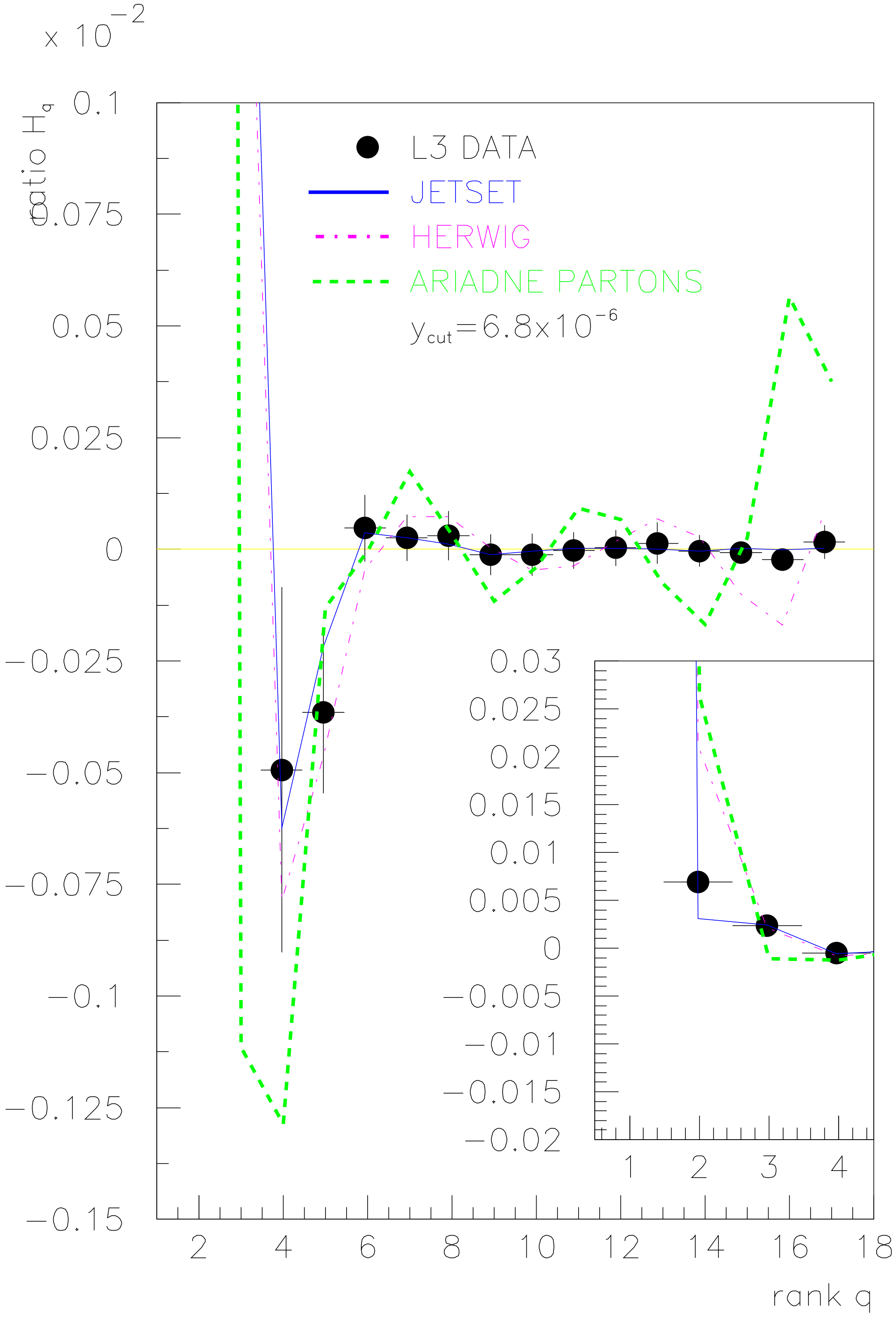
Jet (Cambridge) Multiplicity L3 preliminary



JETSET, HERWIG agree ARIADNE disagrees

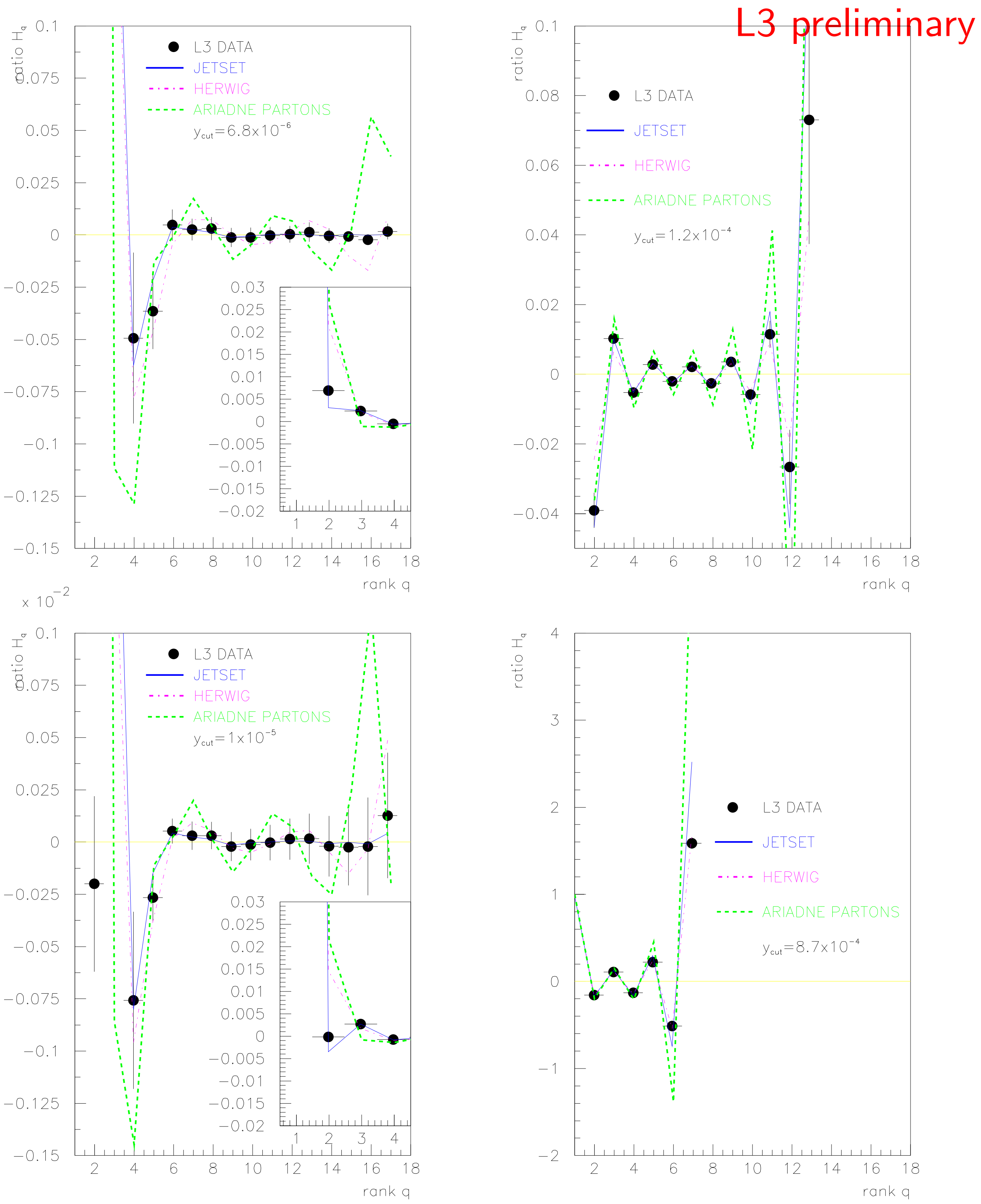
H_q from Jet (Cambridge) Multiplicity

$y_{\text{cut}} = 6.8 \times 10^{-6}$ (240 MeV) L3 preliminary



Minimum + oscillations for ‘jets’ at very small scale

H_q from Jet (Cambridge) Multiplicity



As y_{cut} (E scale) increases, min. + oscillations disappear long before pert. region

Summary

- Charged Track Multiplicities:
  - L3 confirms H_q min. + oscillations observed by SLD
  - JETSET parton shower + Lund string hadronization agrees with data
  - HERWIG parton shower + cluster hadronization shows min. + oscillations, but much larger amplitudes
  - ARIADNE parton shower + LPHD shows min. + oscillations, but different from data

- Oscillations in MCs is puzzling since MCs are only ∼MLLA, not NNLLA

- Jet Multiplicities:
  - H_q min. + oscillations disappear as $y_{\text{cut}} \to$ pert. scales

- Event shapes:
  - ARIADNE partons agree qualitatively with data.
  - JETSET agrees much better.

Conclusions

- JETSET + string, decays gives very good description
  ARIADNE + string, decays also – see last year's talk
- ARIADNE + LPHD gives qualitatively fair description for tracks, but not for jets
- Min.+oscillations are not solely due to pert. QCD.
- Non-pert. hadronisation plays a strong role.
- The contribution from pert. QCD is largely due to E,$\vec{p}$ conservation.

for transparencies:

`http://home.cern.ch/~metzger/talks.html`