Studies of Hadronic event structure in e^+e^-collisions with the L3 detector.

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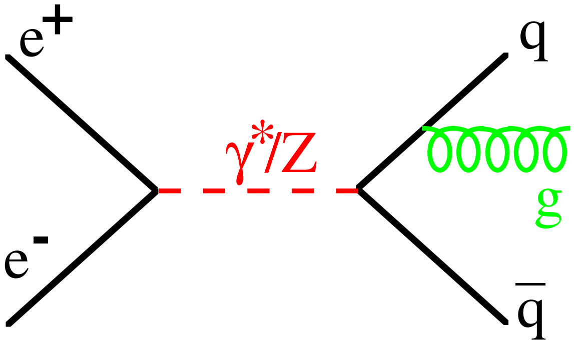
- Introduction
- Event selection
- Global Event Shape Variables
- Charged particle distributions
- Conclusions

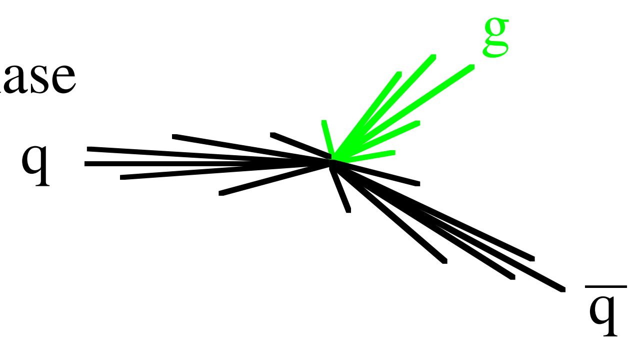
Introduction:

$e^+e^- \longrightarrow$ hadrons



After strong interactions:

-parton cascade
-hadronisation phase



→ Complex event with large number of final state particles.

→ Event structure reflects 2 aspects of gluon radiation

- Hard radiation $\Longrightarrow$ deviation from 2 jet topology

  Strong coupling: α_s

- Soft radiation $\Longrightarrow$ intrajet structure

  Soft QCD phenomena: colour coherence

LEP and QCD:

High e^+e^- CM energies:

- LEP 1 : during 5 years $\sqrt{s} \approx 91$ GeV
  $Z \rightarrow q\bar{q}\gamma$ events: $\sqrt{s'}$ from 30 to 91 GeV
- 1995 $\sqrt{s} = 130$ and 136 GeV
- 1996 $\sqrt{s} = 161$ and 172 GeV
- 1997 $\sqrt{s} = 183$ GeV

well suited for Hadronic Event Structure studies

$\Longrightarrow$ Tests of QCD models and their principles

→ useful for new particle searches, W pair studies

$\Longrightarrow$ Checks of energy dependence of observables with the same experiment

$\Longrightarrow$ Comparison with perturbative QCD calculations

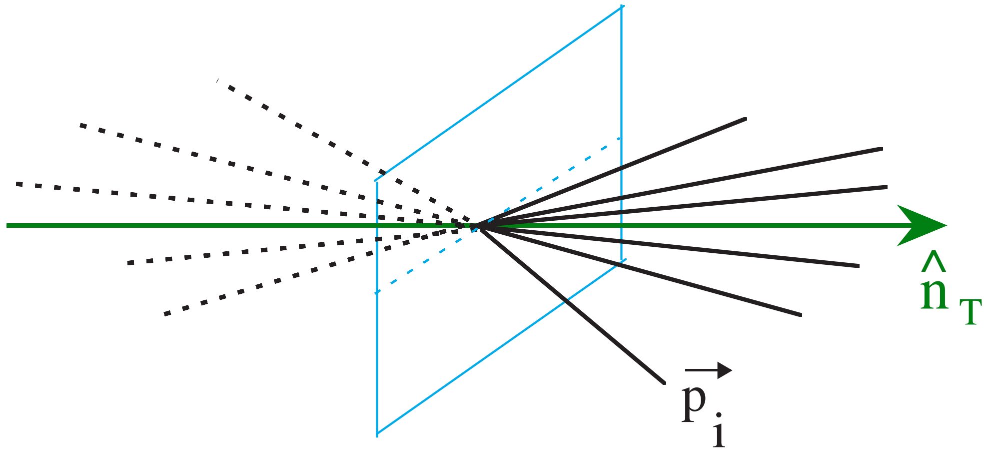
→ Complete calculations to $O(\alpha_s^2)$

→ Leading and next-to-leading terms calculated to all orders

exist for several event shape variables

Event shape variables

Definitions:



- Heavy jet mass

$$M_H \;=\; \max[M_+(\vec{n}_T), M_-(\vec{n}_T)] \;,$$

where $M_\pm$ are the invariant masses in the two hemispheres, $S_\pm$:

$$M_\pm^2 \;=\; \left(\sum_{i\in S_\pm} p_i\right)^2$$

The scaled heavy jet mass ρ is defined as:

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

- Jet broadening variables

$$B_\pm \;=\; \frac{\Sigma_{i\in S_\pm}|\vec{p}_i \times \vec{n}_T|}{2\,\Sigma_i\,|\vec{p}_i|} \;.$$

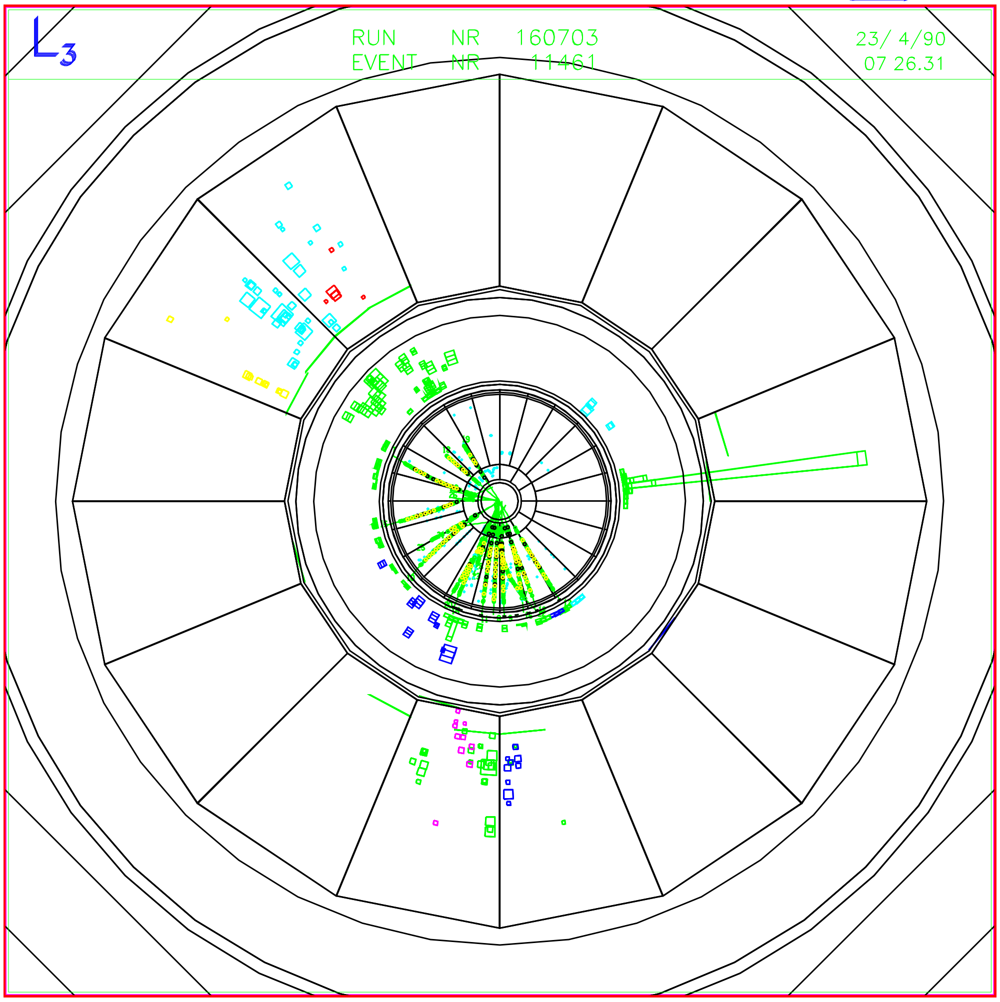
$$B_T \;=\; B_+ + B_- \qquad B_W \;=\; \max(B_+, B_-)$$

- jet rates

$$y_{ij} \;=\; \frac{2min(E_i^2, E_j^2)}{s} \cdot (1 - \cos\theta_{ij})$$

QCD tests at reduced CM energy

$e^+e^- \rightarrow \gamma^*/Z \rightarrow \text{hadrons} + \gamma$



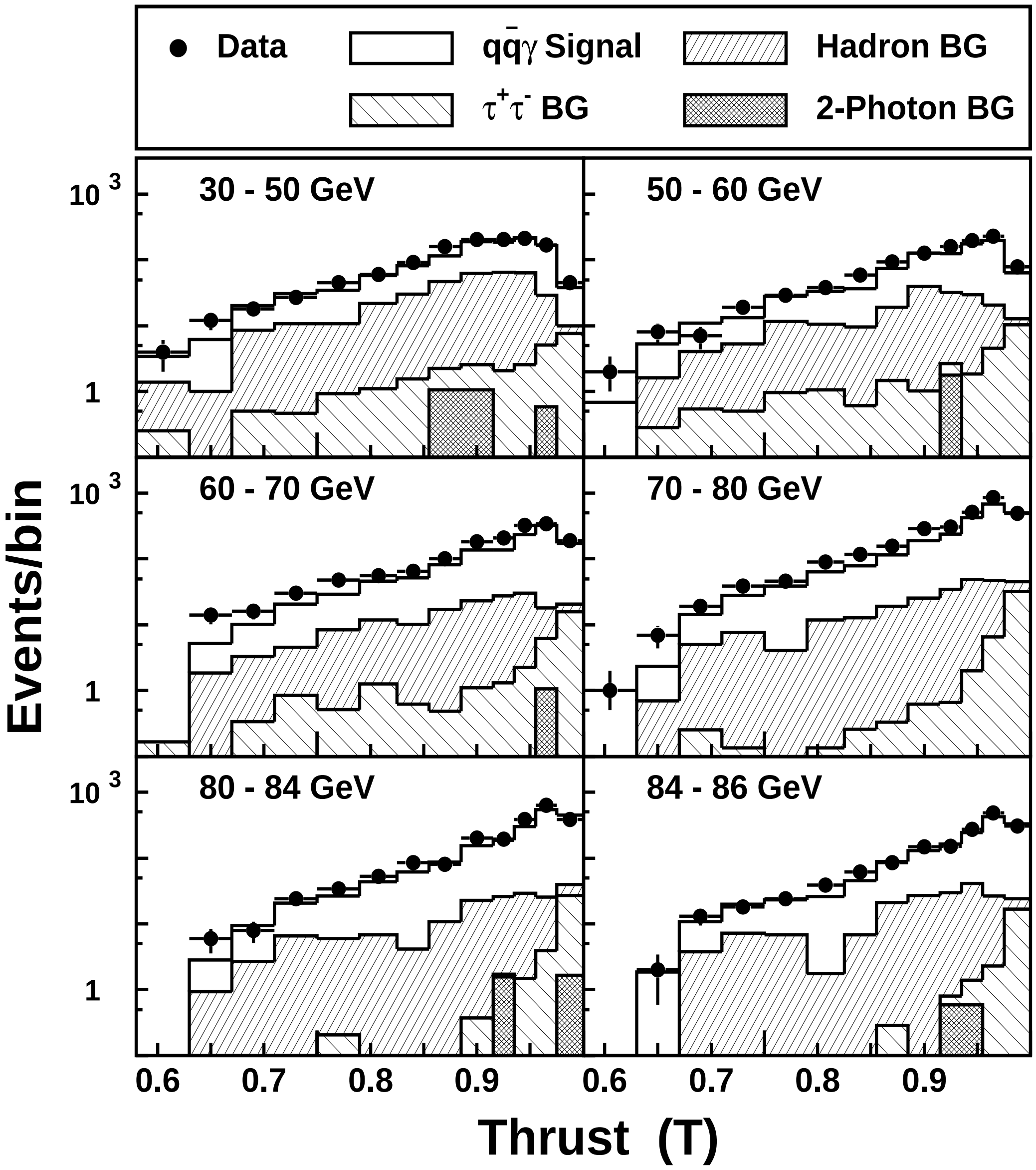
- Select isolated energetic γ in hadronic events
- Remove γ from event
- Boost the event in CM of remaining hadronic system

$$\sqrt{s'} = \sqrt{s\left(1 - \frac{2E_\gamma}{\sqrt{s}}\right)}$$

Event shape distributions at reduced CM energy

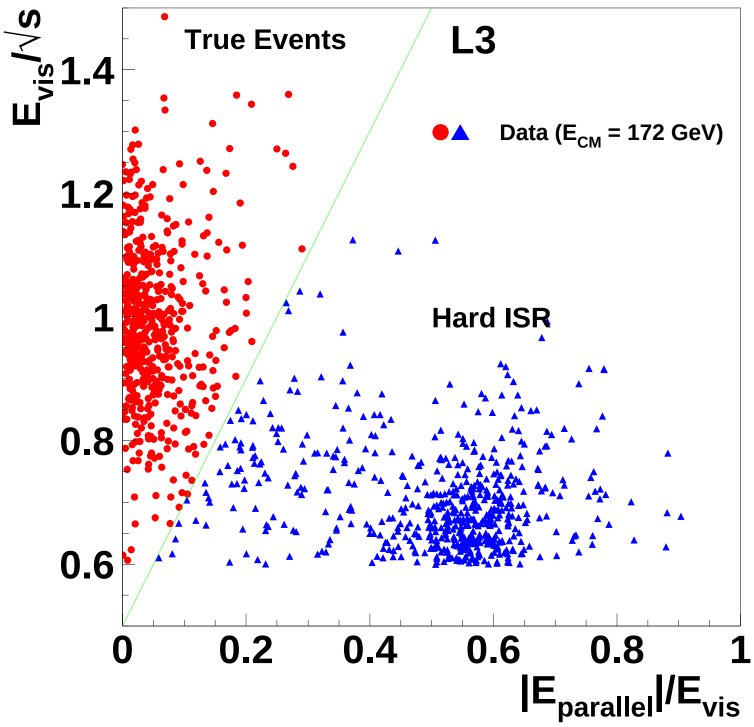
- Hadronic background: mainly π^o and η decays
- Use a neural network to estimate the background

$\sqrt{s'}$ (GeV)	30–50	50–60	60–70	70–80	80–84	84–86
# of events	1247	1047	1575	2938	2091	1607
selection eff.	48.3%	41.0%	35.2%	29.9%	27.4%	27.5%
purity	68.4%	78.0%	86.0%	89.0%	90.5%	87.0%



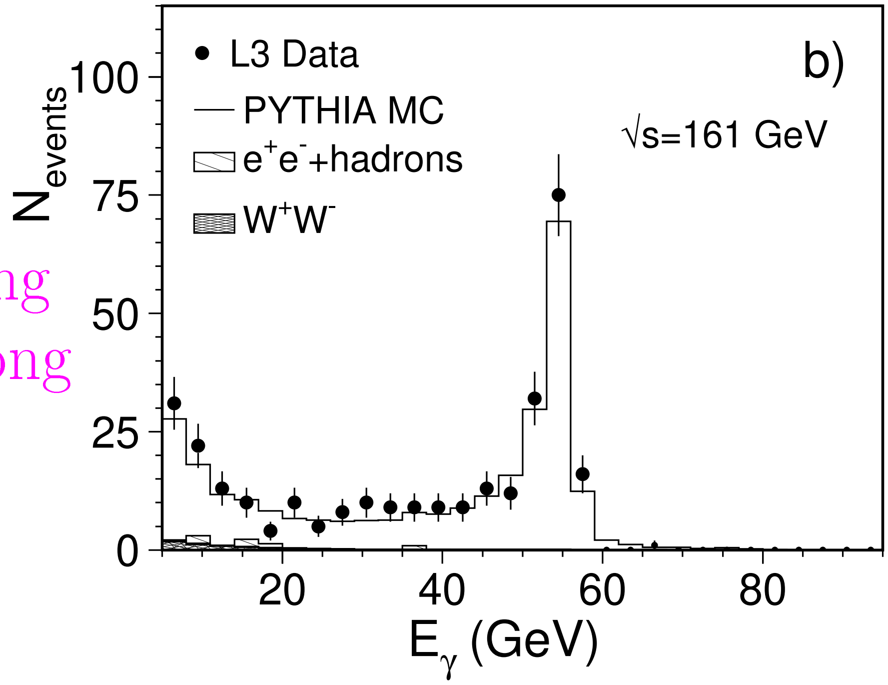
QCD tests above 91 GeV

Large contribution from radiative return to the Z



Select event if:

- No energetic γ in the detector
- No large missing momentum along beam

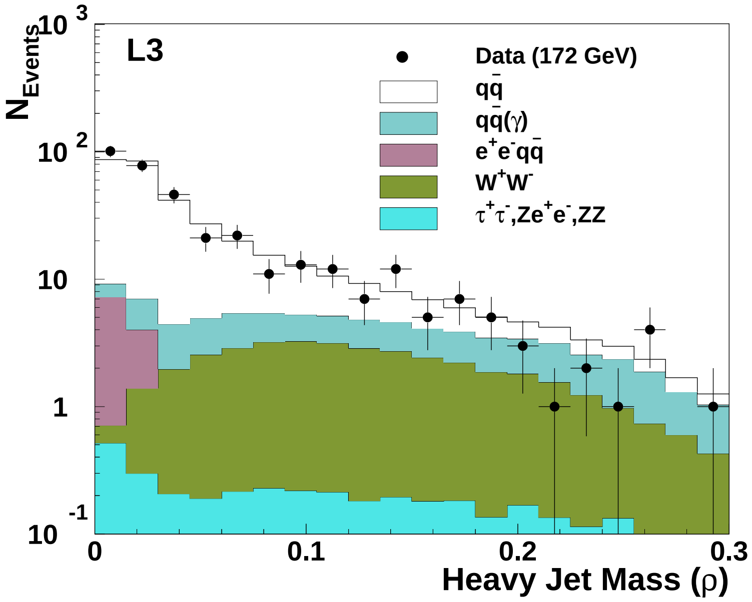


- - efficiency $\approx$ 80%
  - low contamination from hard ISR

QCD tests above 91 GeV

Since 1996: high energy runs at $\sqrt{s} > 161$ GeV

Background from WW events

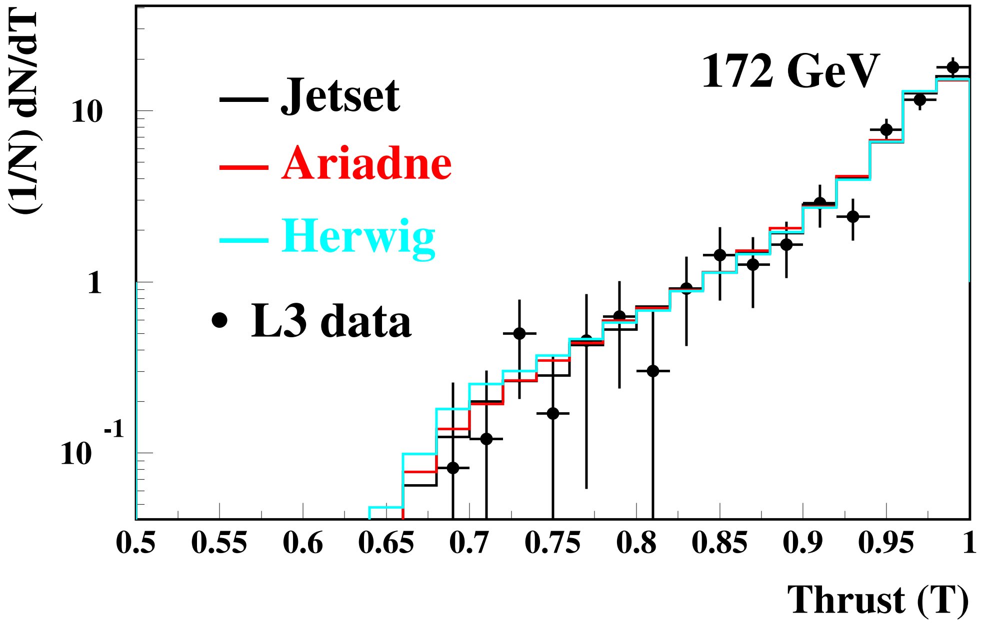


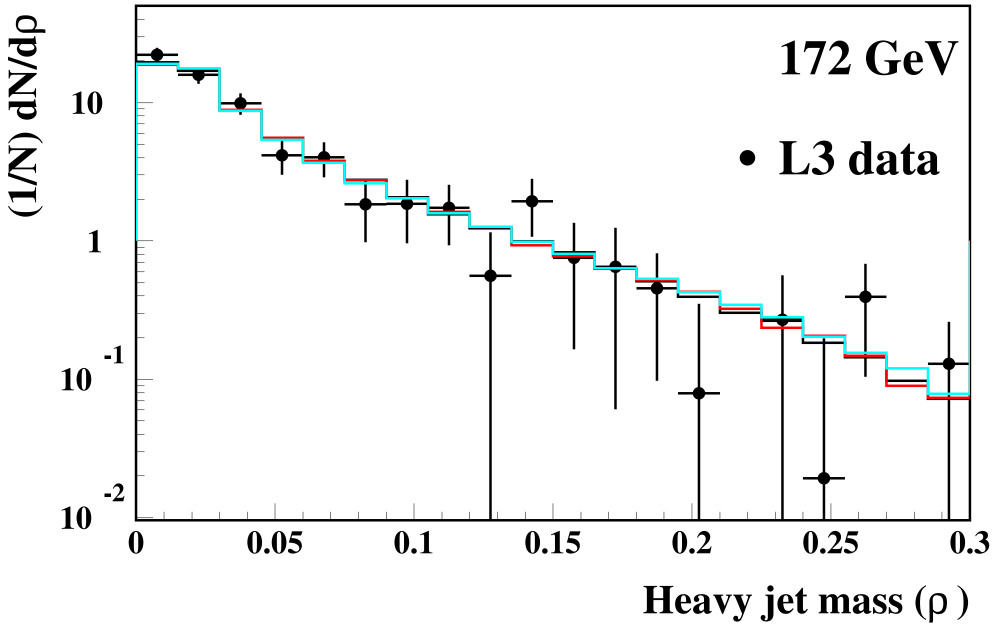
- $\sqrt{s} = 161$ GeV $\rightarrow$ 4% $\rightarrow$ subtract bin by bin
- $\sqrt{s} = 172$ GeV $\rightarrow$ 17% $\rightarrow$ identify and reject 50%
- $\sqrt{s} = 183$ GeV $\rightarrow$ 20% $\rightarrow$ identify and reject 50%

$\sqrt{s}$ (GeV)	130—140	161	172	183
$\int \mathcal{L}(\mathrm{pb}^{-1})$	5.0	11.0	10.2	52.2
# of events	402	443	341	1516
selection eff.	90%	85%	85%	84%
purity	80%	79.7%	78.7%	74.0%

Event shape variables

- Subtract remaining background bin by bin
- correct for detector effects + ISR bin by bin





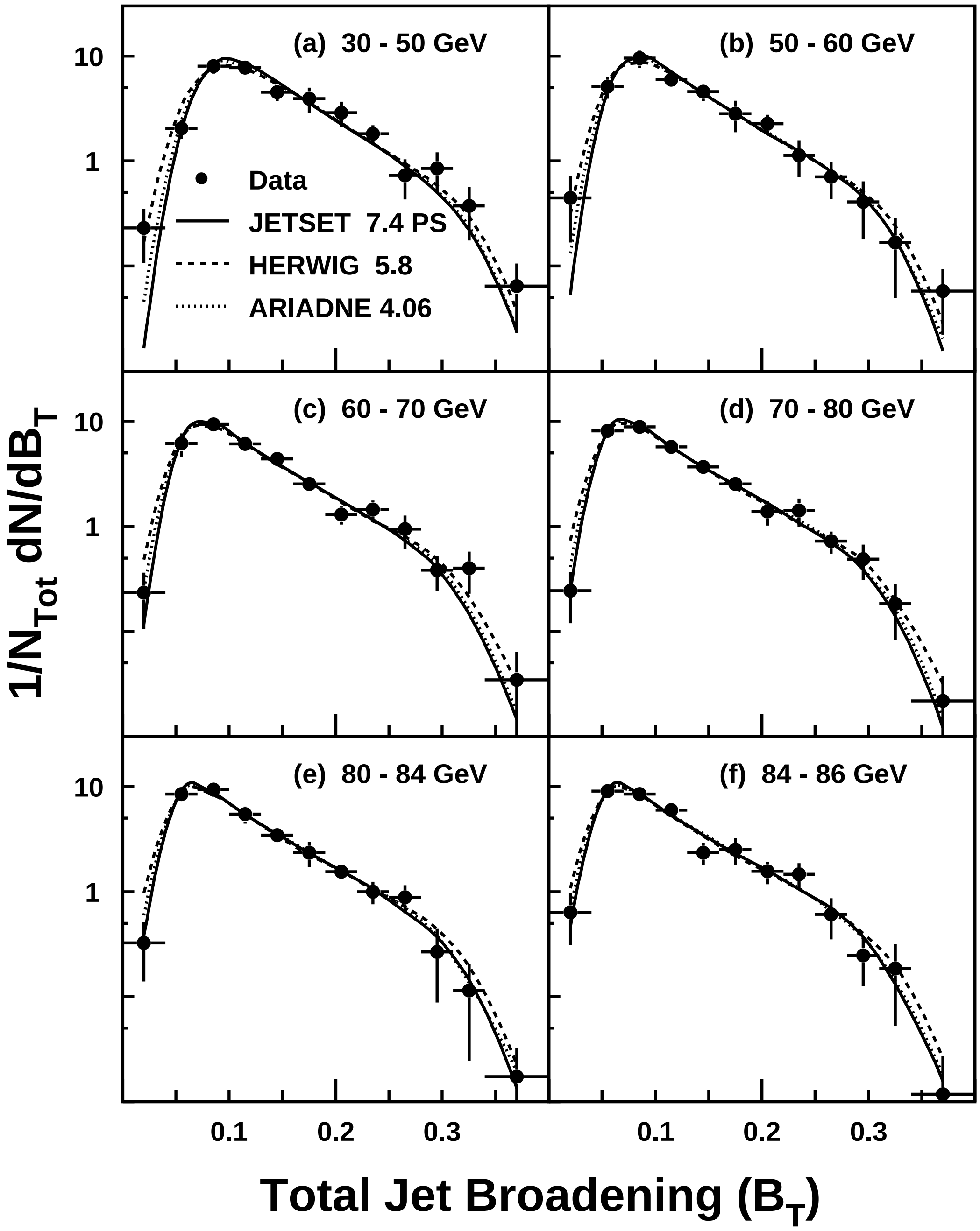
Shape distributions well described by QCD models

Typical corrections: between 0.5 and 1.5

In many cases: detector and ISR corrections compensate

Event shape at reduced CM energy

Comparison of corrected B_T distributions with QCD model predictions at the 6 energy ranges

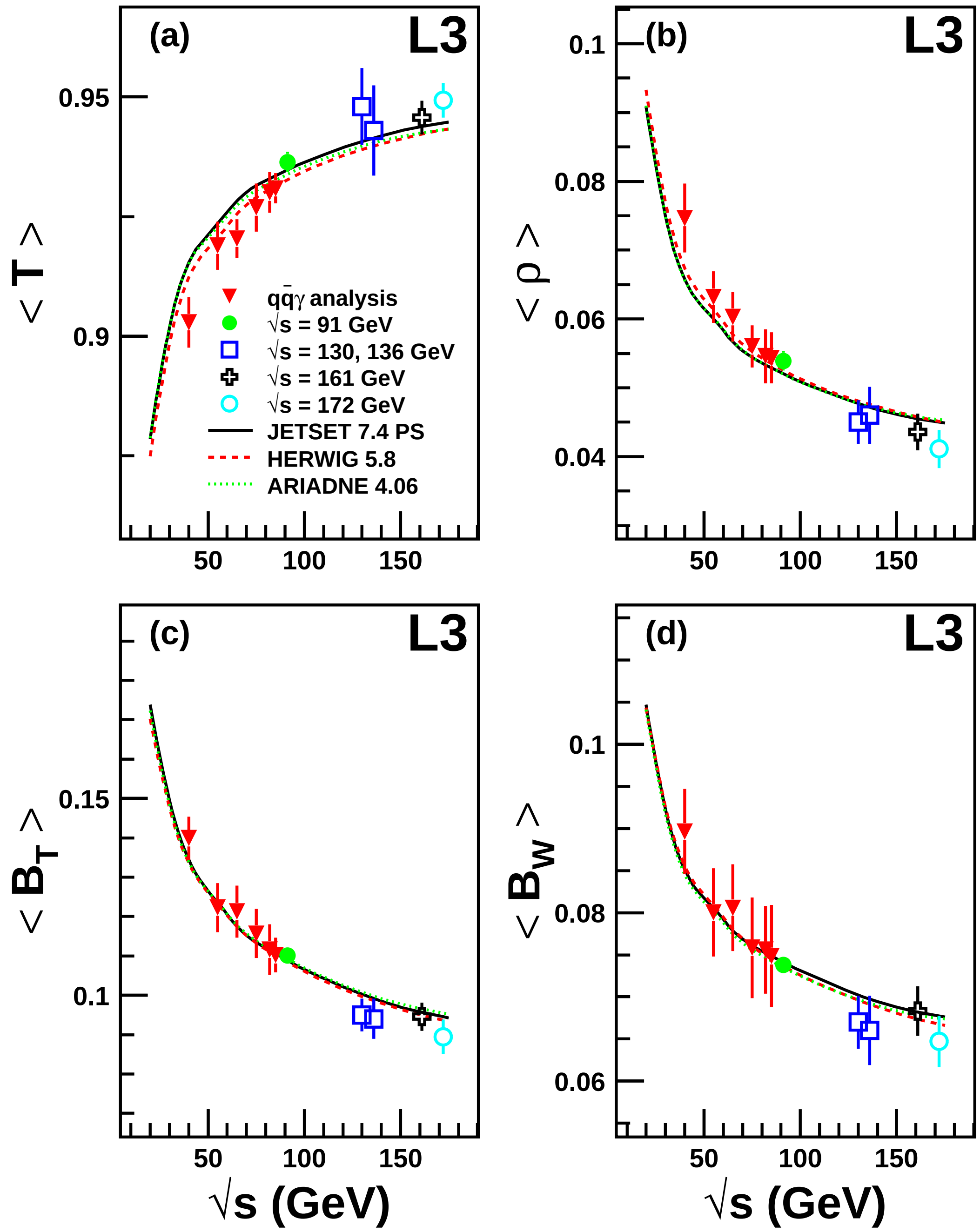


MC generated with corrected $\sqrt{s'}$ distribution and correct flavour composition (no γ radiation)

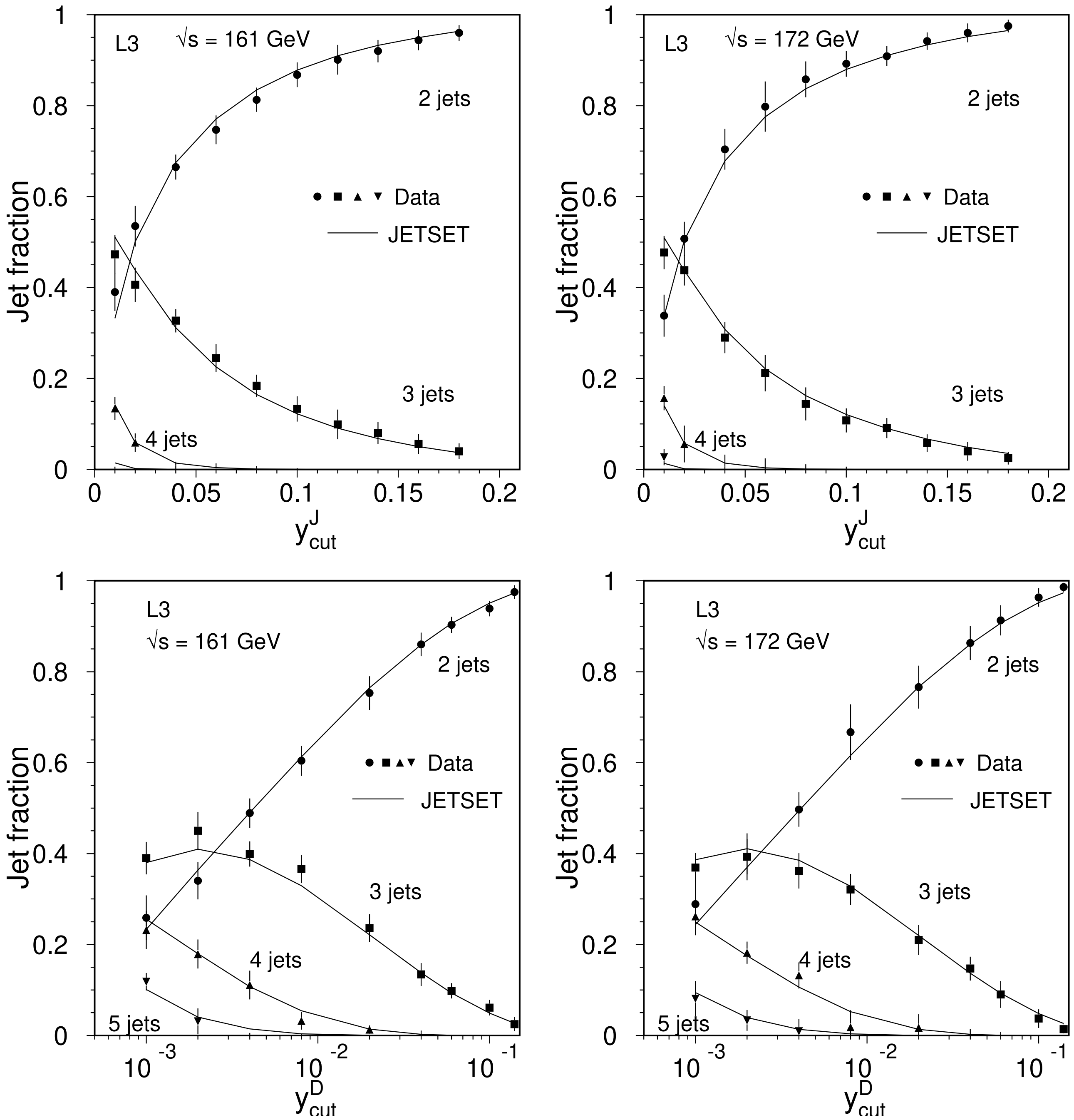
Mean event shape values

$$\langle f \rangle = \frac{1}{\sigma_{tot}} \int f \frac{d\sigma}{df} df = R_{pert} + R_{non-pert}$$

- $R_{pert} = \alpha_s(\mu)\cdot$ A $+ \alpha_s(\mu)^2\cdot$ B $+ \ldots$
- $R_{non-pert}$: non-perturbative contribution α 1/Q (hadronization + soft gluon phenomena...)



Jet rates at 161 GeV and 172 GeV



Good agreement with JETSET PS.

Inclusive charged particle distribution

QCD: coherence of soft gluon radiation

Destructive interference $\Rightarrow$ suppression of soft gluon emission

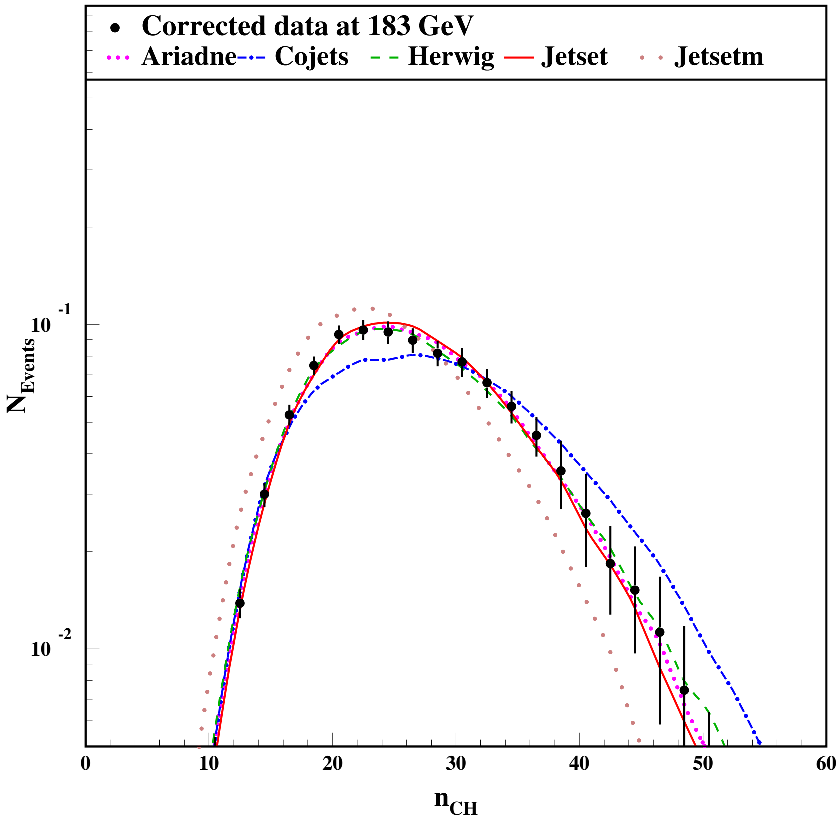
$\Rightarrow$ parton multiplicity is reduced

LPHD hypothesis:

- low energy particles are remnants of soft gluon emission
- shapes of hadron distributions and variations with energy can be predicted in the context of LLA

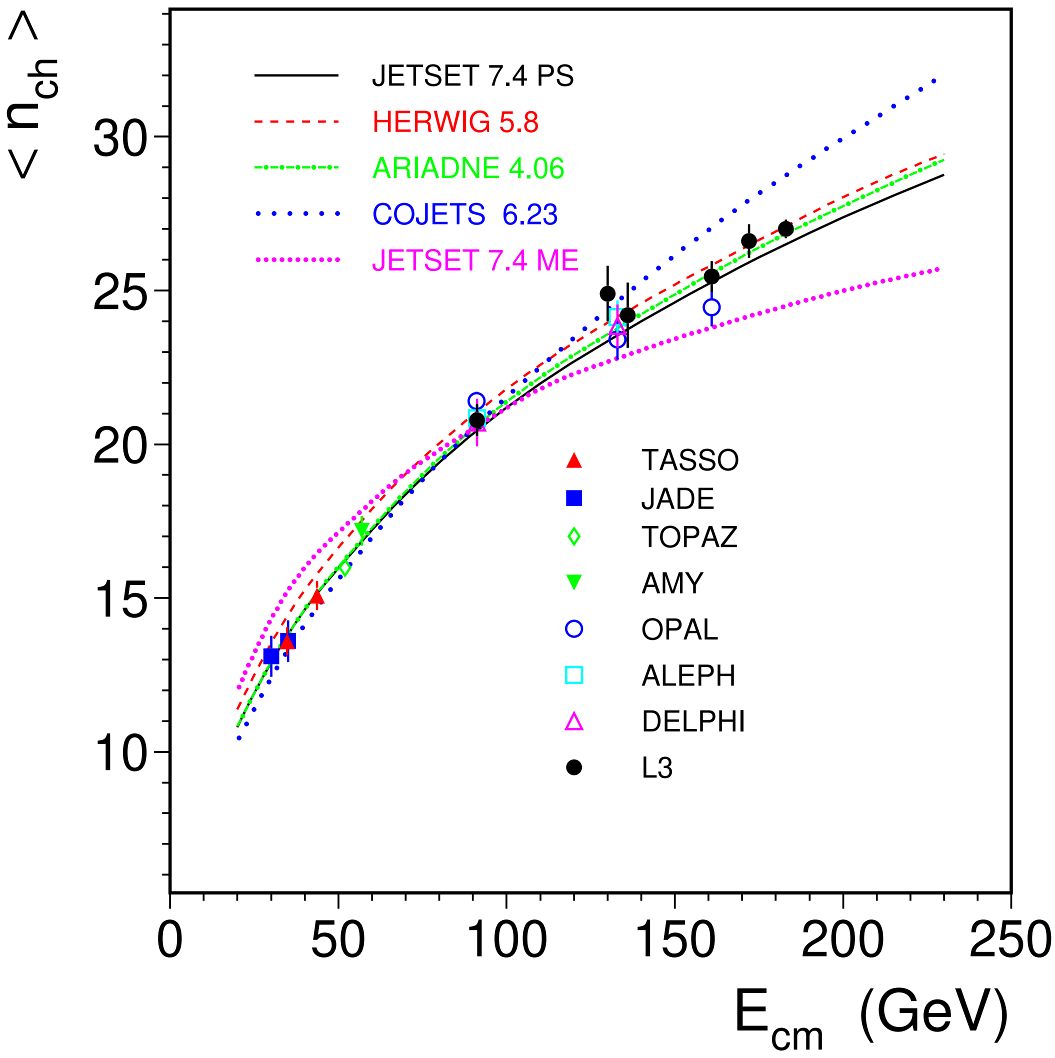
NLO QCD prediction for n_{ch} (MLLA+LPHD):

$$\langle n_{ch}(\sqrt{\mathrm{s}}) \rangle = a \cdot \alpha_s(\sqrt{\mathrm{s}})^{\mathrm{b}} \cdot \mathrm{e}^{\mathrm{c}/\sqrt{(\alpha_{\mathrm{s}}(\sqrt{\mathrm{s}})}}$$



$$< n_{ch} > = 27.0 \pm 0.2 \pm 0.2 \text{ at } 183 \text{ GeV}$$

Charged particle multiplicity: $< n_{ch} >$



$\sqrt{s}$ (GeV)	$< n_{ch} >$
130	24.9 $\pm$ 0.5 $\pm$ 0.8
136	24.2 $\pm$ 0.7 $\pm$ 0.8
161	25.5 $\pm$ 0.4 $\pm$ 0.3
172	26.6 $\pm$ 0.5 $\pm$ 0.3
183	27.0 $\pm$ 0.2 $\pm$ 0.2

Multiple gluon emission (simulated in the parton shower approach but not in ME) is necessary to describe the energy dependence of $< n_{ch} >$

Charged particle momentum spectra

QCD Coherence effects $\Rightarrow$ Suppression of soft gluon emission

$\Rightarrow$ Supression of hadron production (small $x = \frac{\mathrm{p}}{\mathrm{E_{beam}}}$)

Study $\xi = \log(1/x)$ spectra for charged particles :

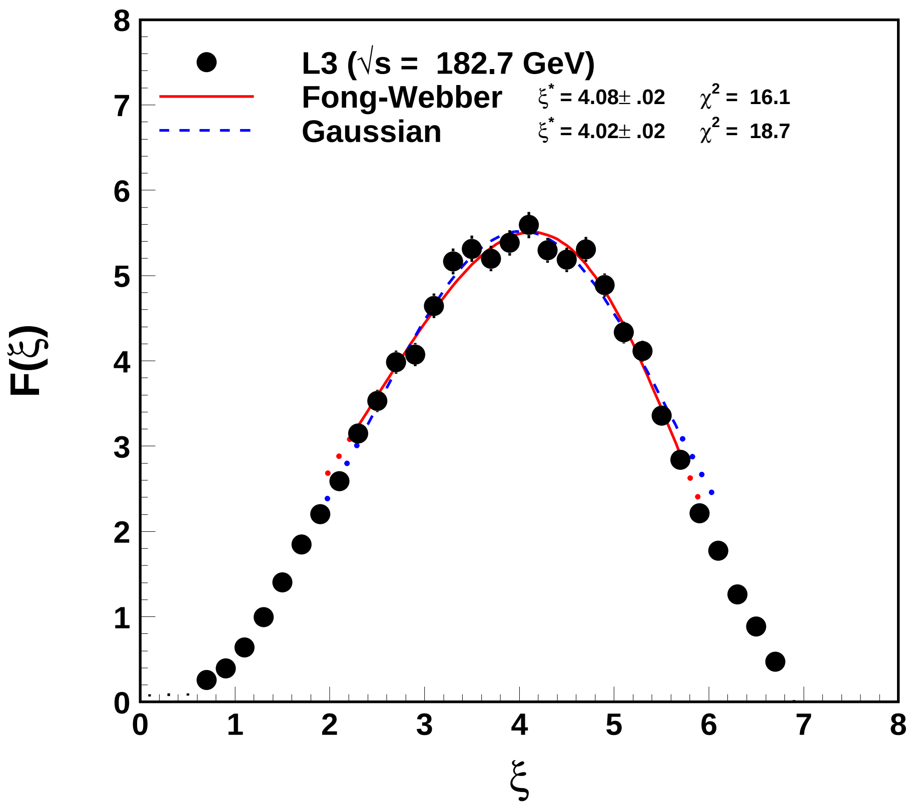
Asymptotic form of ξ spectra : *Gaussian*

Next-to-leading order corrections are important ($\mathrm{O}(\sqrt{\alpha_s})$)

$\Rightarrow$ *Platykurtic* shape (Fong-Webber Phy. Let. B229 (1989) 289.)

$$F(\xi) = \frac{< n_{ch} >}{\sigma\sqrt{2\pi}} \exp[\frac{1}{8}\mathrm{k} - \frac{1}{2}\mathrm{s}\delta - \frac{1}{4}(2+\mathrm{k})\delta^2 + \frac{1}{6}\mathrm{s}\delta^3 + \frac{1}{24}\mathrm{k}\delta^4]$$

where $\delta = (\xi - \bar{\xi})/\sigma$ and $\bar{\xi}, \sigma, s, k = f(\Lambda, \mathrm{N_f}, \mathcal{O}(1))$.



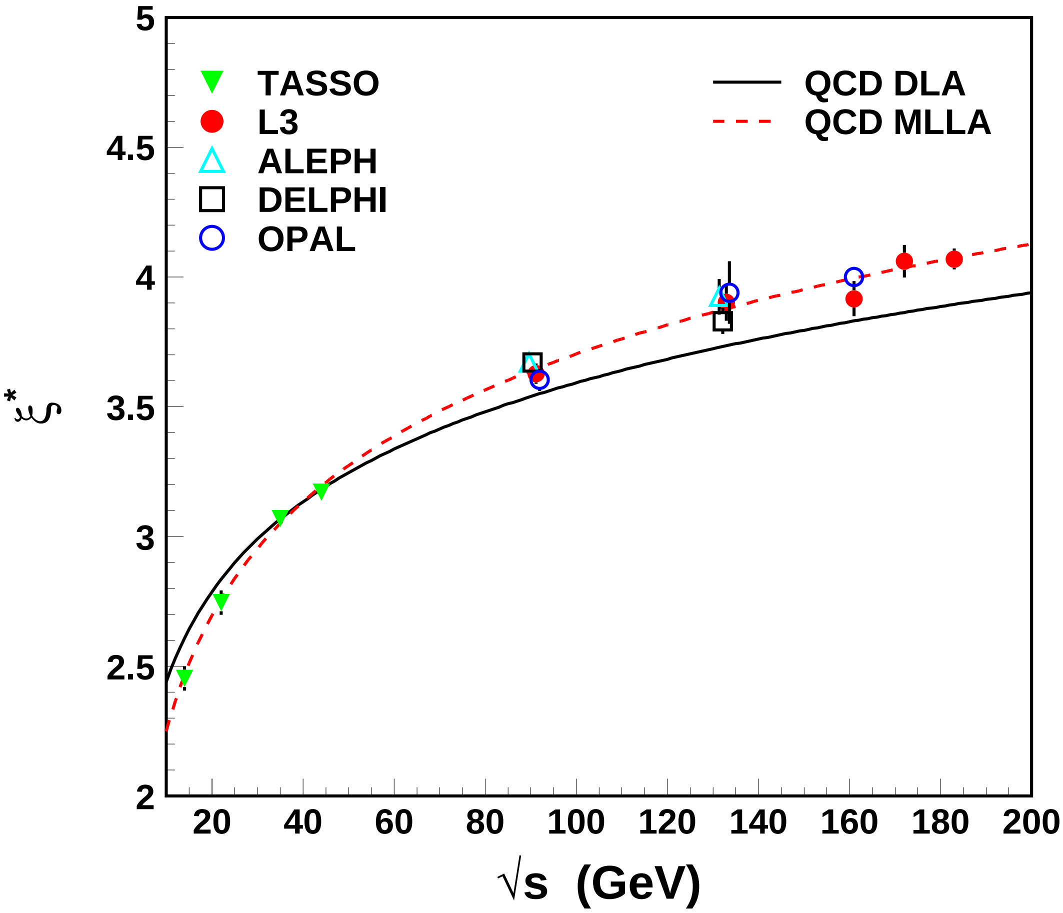
$\xi^{\star}$ (peak position) $= 4.07 \pm 0.03 \pm 0.03$ at 183 GeV

$\xi^\star$: peak position of ξ distribution

Energy evolution of $\xi^\star$:

$$\xi^\star = Y(\frac{1}{2} + a\sqrt{\frac{\alpha_s(\mathrm{Y})}{32N_c\pi}} - a^2\frac{\alpha_s(\mathrm{Y})}{32\mathrm{N}_c\pi} + \ldots), \text{where}$$

$$Y = \log(\mathrm{E_{beam}}/\Lambda), \text{ and } a = \tfrac{11}{3}N_c + \tfrac{2}{3}N_f/N_c^2.$$



$\sqrt{s}$ (GeV)	ξ^*
91,2	$3.63 \pm 0.02 \pm 0.03$
133	$3.90 \pm 0.04 \pm 0.06$
161	$3.92 \pm 0.05 \pm 0.05$
172	$4.06 \pm 0.05 \pm 0.04$
183	$4.07 \pm 0.03 \pm 0.03$

Conclusions

- Hadronic event characteristics studied from 30 GeV to 183 GeV by L3

- QCD models implementing a coherent parton shower and cluster or string fragmentation:
  $\rightarrow$ describe very well the event shape distributions (parameters tuned at 91 GeV)
  $\rightarrow$ predict the measured energy dependence of mean values

- $< n_{ch} >$ and ξ distributions show clearly a suppression effect as expected from soft gluon coherence phenomena