Event Shapes in e^+e^- annihalation

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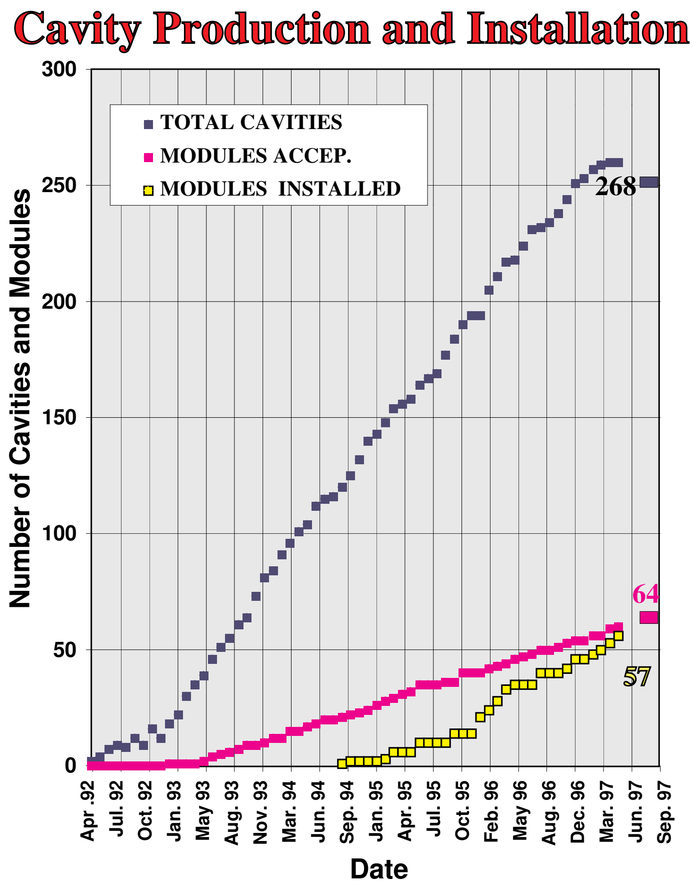
Outline:

- LEP
- Energy dependence of the charged multiplicity distribution and momentum spectra
- Event Shape distributions and the running of α_s

LEP II Energy Upgrade

Production of superconducting RF cavities



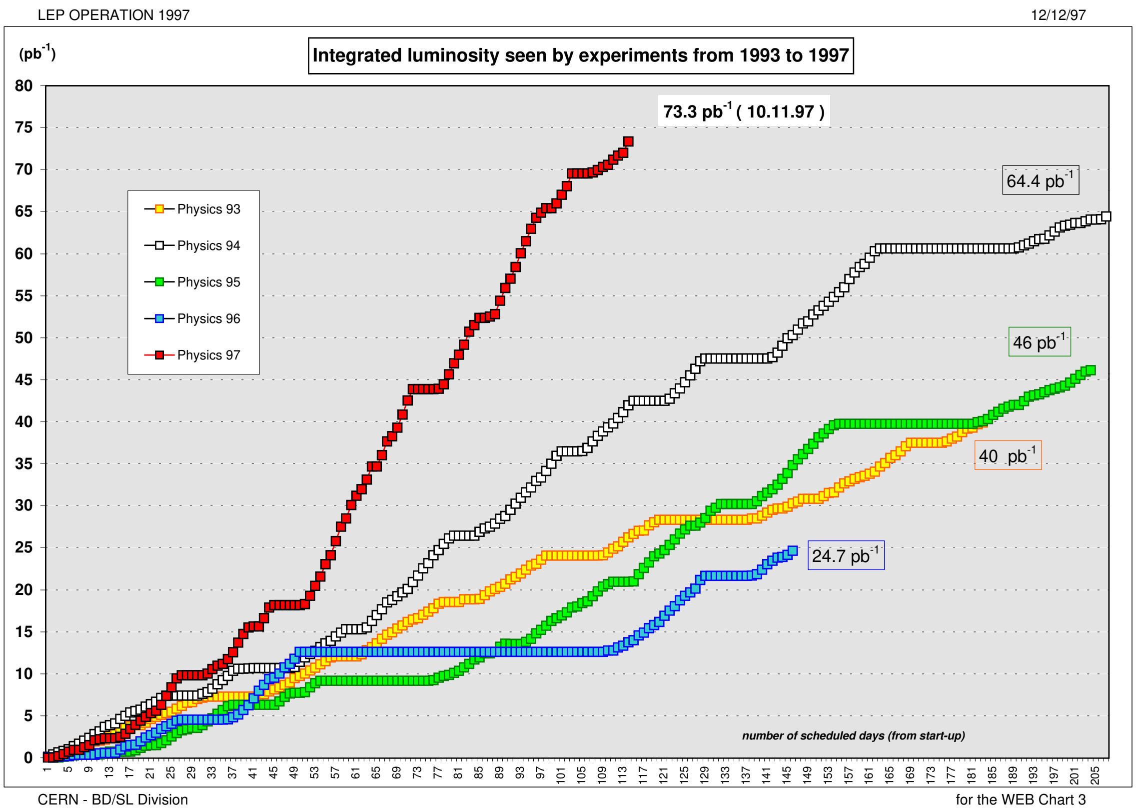
Installation in LEP

Year	SC-Cavities	Energy (GeV)
Fall 1995	64	130-136
Spring 1996	144	161
Fall 1996	176	172
1997	240	183
1998	272	189
1999	288	195
2000	288	195

1998 limited by cryogenics power
1999 onwards: Push RF to 7 MV/m to achieve close to 200 GeV
LEP II requirements (200 GeV, 500 pb^{-1}) within reach

Delivered Luminosity

1997 integrated luminosity is the largest delivered in a single year



4 Experiments at LEP

- Detectors cover 99% of 4π
- Hadronic events identified with small systematic errors
- Energy and direction of jets precisely measured

Data

Data for event shapes come from three sources :

- Z peak
- High energy runs of LEP
- $\sqrt{s} < m_Z$ Newanalysis of JADE data and hadronic Z decays with hard isolated photons (L3)

Hadronic events characterised by

- Large visible energy
- High multiplicity of final state particles

High Energy Data (L3):About 3100 Hadronic events at High Energy (4 million at Z peak)

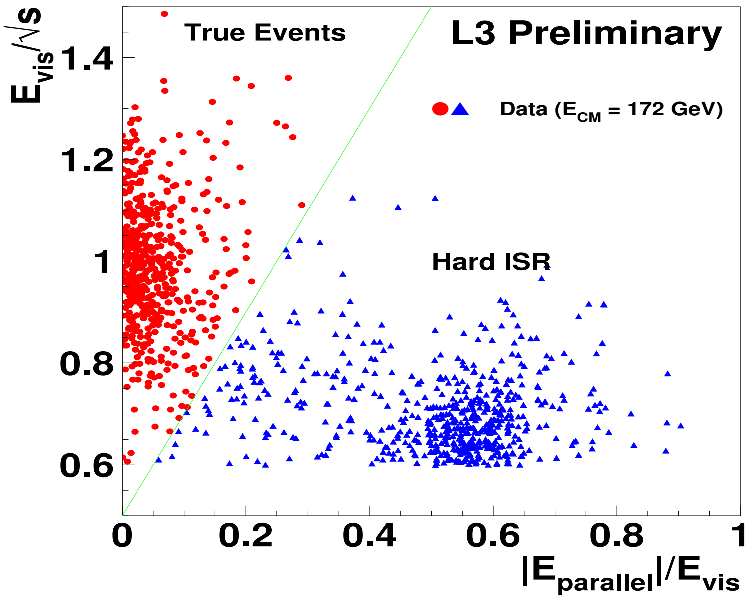
$\sqrt{s}$ (GeV)	$\int \mathcal{L}$(pb^{-1})	# of Events
130—140	10	0.80k
161	11	0.44k
172	10	0.34k
183	52	1.52k

Large contamination due to

- Radiative return to Z
- Hadronic decays of W's

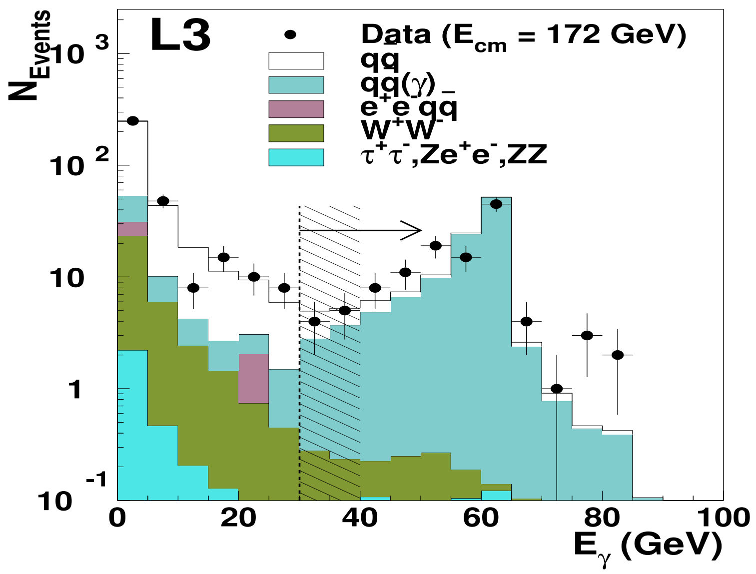
Data

Reject radiative returns to Z by demanding



low longitudinal energy imbalance :

$$(E_{vis}/\sqrt{s}) > \mathbf{2.0}\ (|\ E_{\|}\ |\ /E_{vis}) + \mathbf{0.5}$$



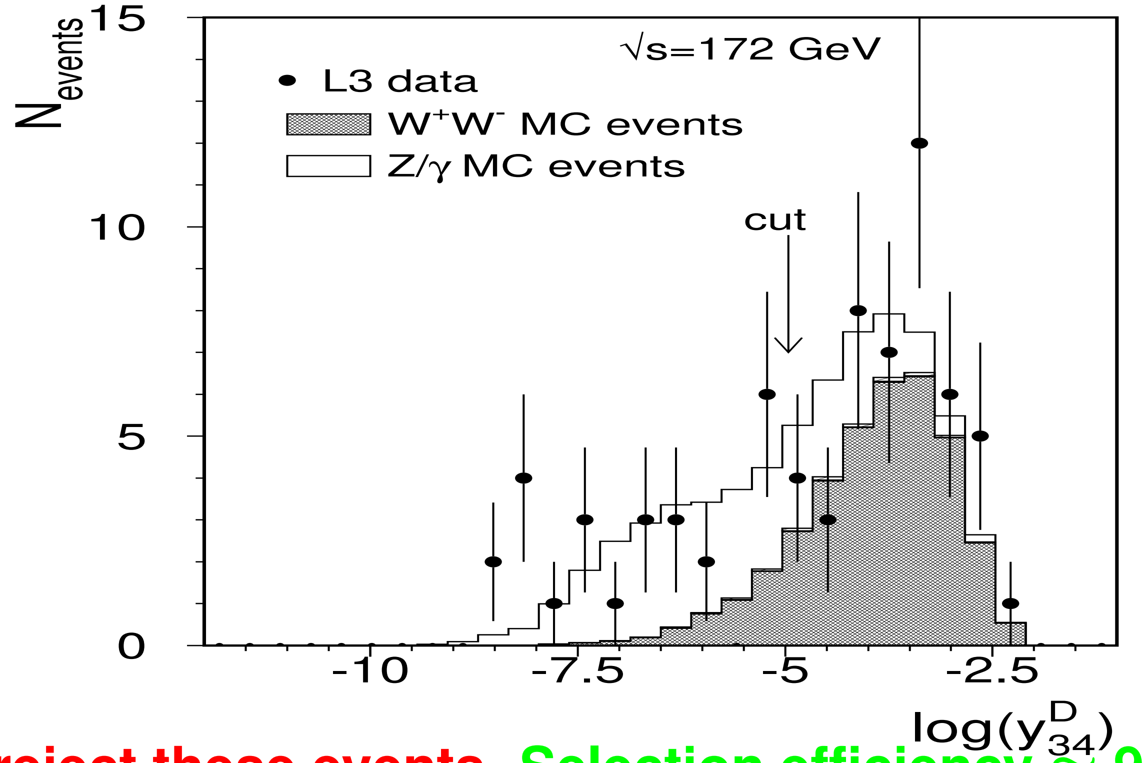
no energetic photon seen in the detector : $E_\gamma < \mathbf{30}$ **GeV**

Data

Large contribution from WW events for $\sqrt{s} > 161$ GeV

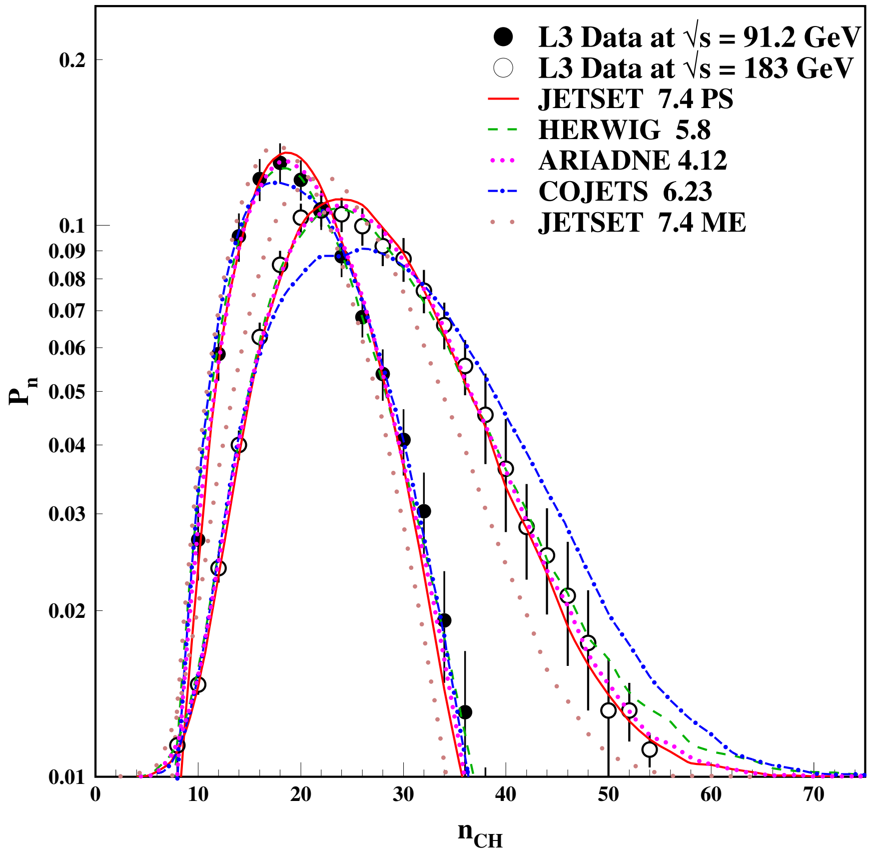
Select W-pair events by (L3)

- **Finding high multiplicity events**
- **Forcing them into four jet configuration ($k_\perp$ algorithm)**
- **Select good four jet candidates by imposing cuts on most and least energetic jets**
- **Cut on jet resolution parameter y_{34}^D**



and reject these events. Selection efficiency $\approx$ 90%

Charged Multiplicity Distribution



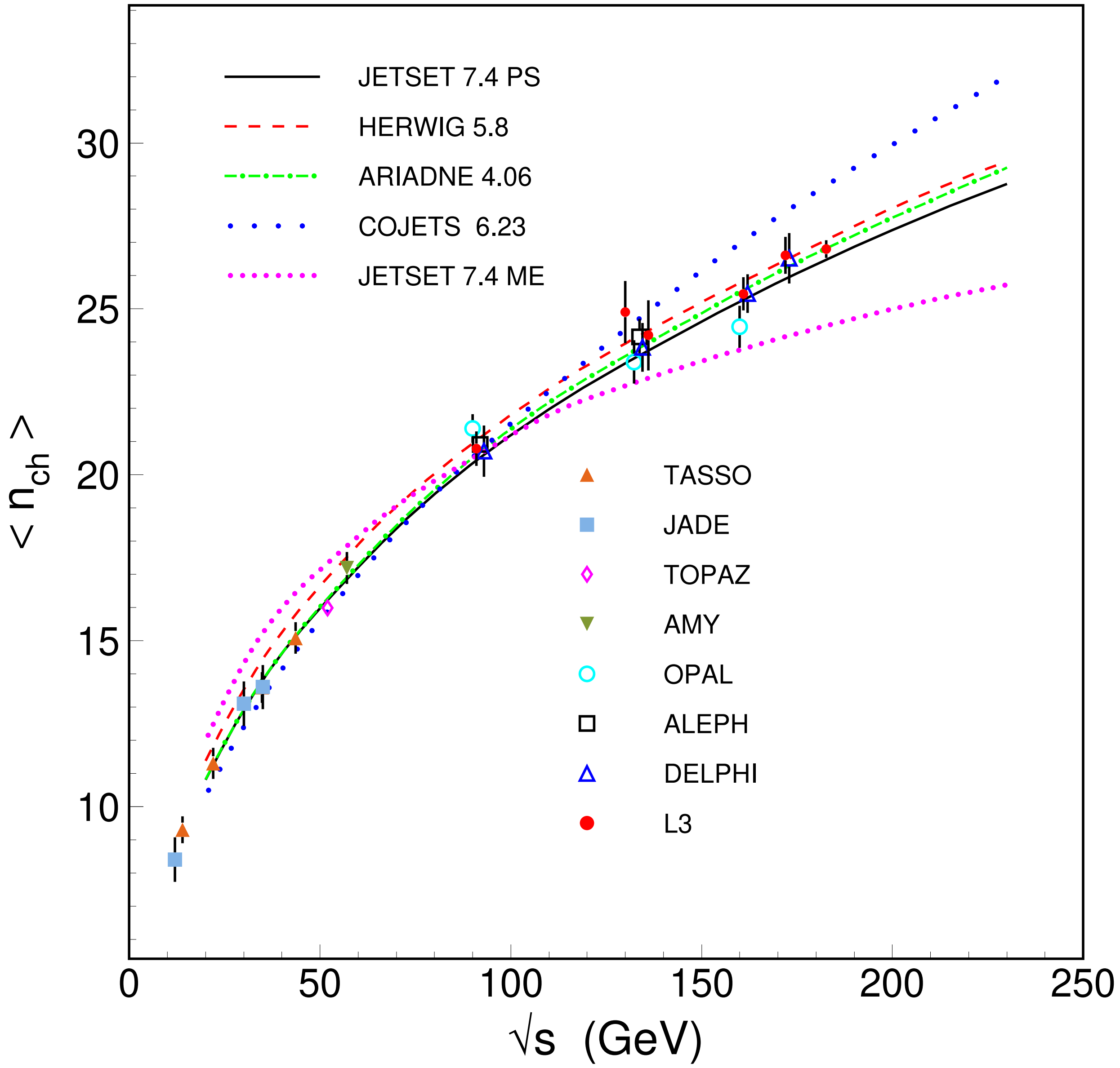
QCD Models

QCD Model	Shower Development	Fragmentation
JETSET	Parton Shower	String
HERWIG	Parton Shower	Cluster
ARIADNE	Colour Dipole	String
COJETS	Incoherent Parton Shower	Independent

The “default” parameters of the models are chosen by tuning on LEP I data

	$< n_{ch}(\sqrt{(s)} = 183)$ GeV
ALEPH	$26.44 \pm 0.33 \pm 0.50$
DELPHI	$26.58 \pm 0.24 \pm 0.54$
L3	$26.80 \pm 0.23 \pm$ ui
OPAL	$26.61 \pm 0.27 \pm 0.32$

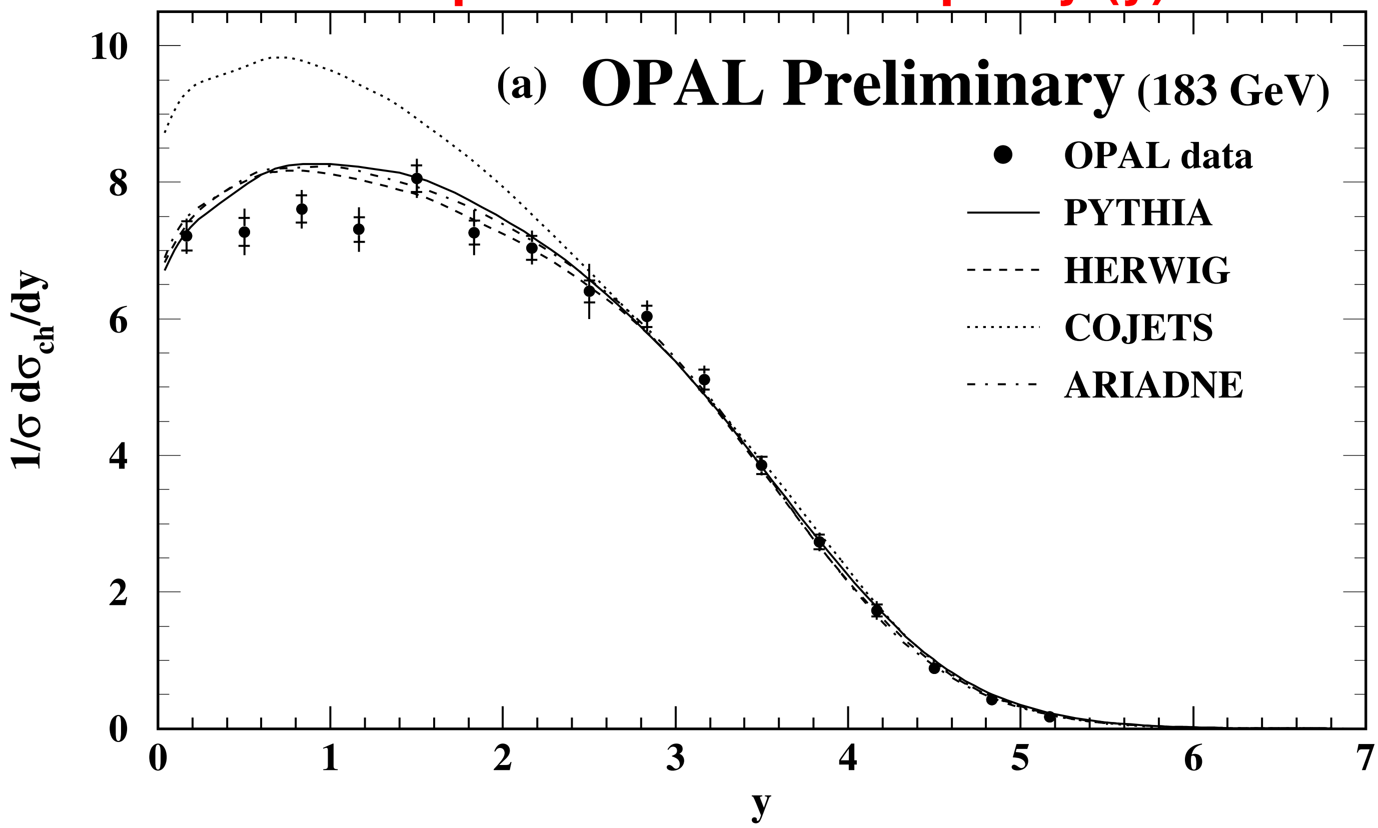
Averaged Charge Multiplicity



Good description of the energy dependence of the averaged charged multiplicity by PS models tuned at 91 GeV except for COJETS (based on incoherent gluon emission) which predict TOO MANY particles on average.

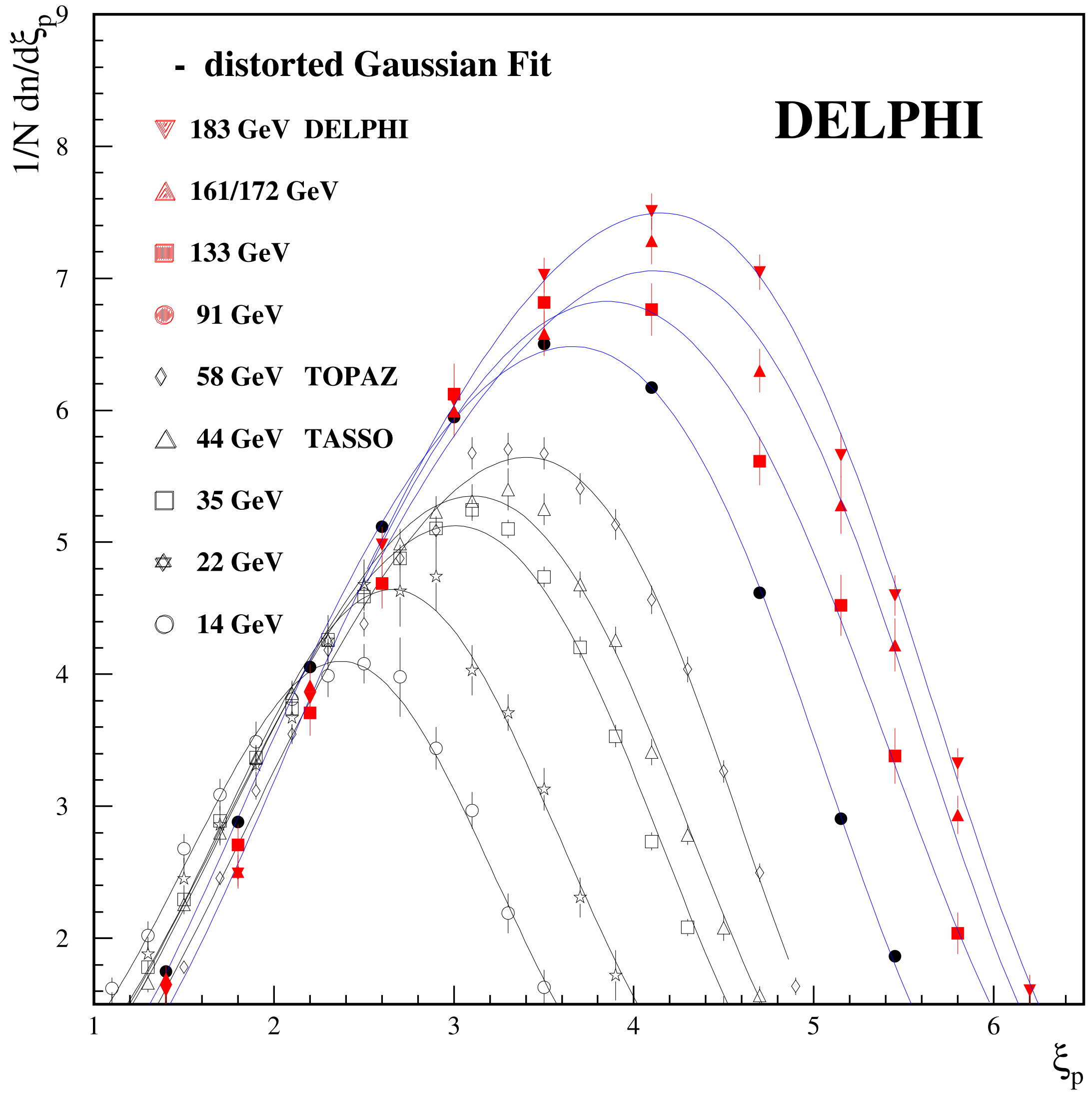
Averaged Charge Multiplicity

excess is produced at low rapidity (y)



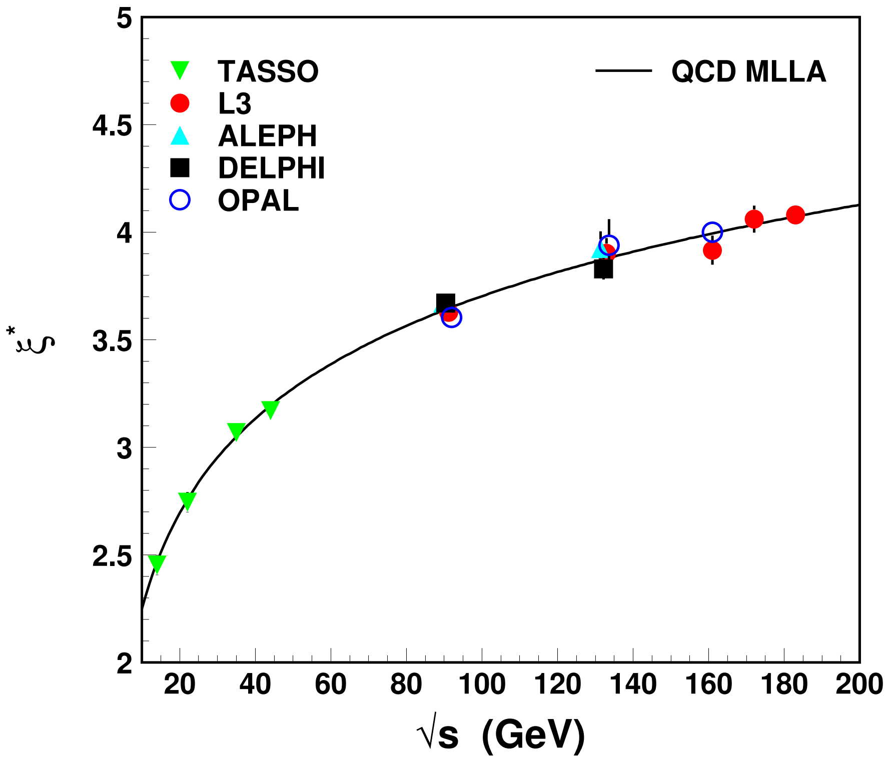
Charged Particle Spectra

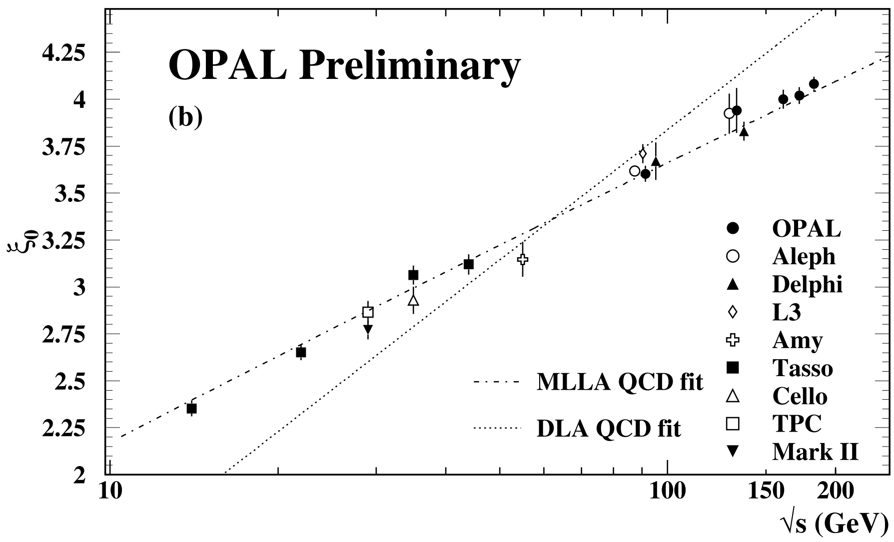
$\xi_p = \ln(1/x_p), x_p = 2p/\sqrt{(s)}$ **,p the track momentum**



From $\sqrt{(s)}$ =14 to 183 GeV, the measured spectra are well described by a distorted Gaussian from 14 to 183 GeV as expected from the partonic MLLA calculation and LPHD hypothesis

ξ_p Energy Evolution





	ξ $(\sqrt{(s)} = 183)$ GeV
ALEPH	$4.11 \pm 0.03 \pm 0.11$
DELPHI	4.13 ± 0.04
L3	$4.07 \pm 0.03 \pm 0.03$
OPAL	$4.06 \pm 0.01 \pm 0.02$

Event Shape Variables

- **Thrust**
  $T = \max \frac{\sum_a |\vec{p_a} \cdot \vec{n_T}|}{\sum_a |\vec{p_a}|}$

- **Scaled Heavy Jet Mass**

$$M^2_\pm = \left(\sum_{a \in S_\pm} p_a \right)^2$$

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

$$\rho = M^2_H / s$$

- **Jet Broadening Variables**

$$B_\pm = \frac{\sum_{a \in S_\pm} | \vec{p_a} \times \vec{n_T} |}{2 \sum_a | \vec{p_a} |}$$

  - **Total Jet Broadening** $B_T = B_+ + B_-$
  - **Wide Jet Broadening** $B_W = \max(B_+, B_-)$

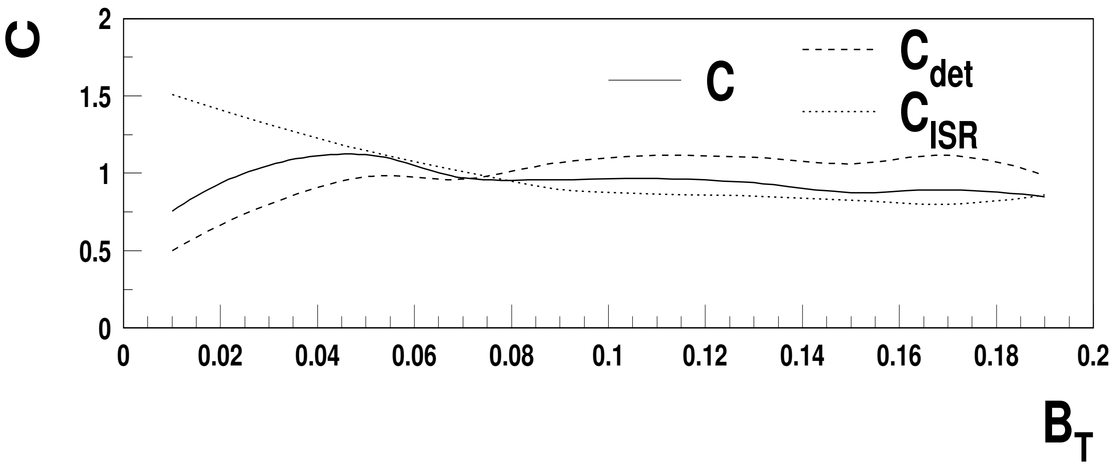
- **Differential 2-jet rate D_2 in Durham scheme**

Complete calculations to $\mathcal{O}({\alpha_s}^2)$ describe the data well in the multi-jet region, but fail in the two-jet region. However, the theoretical description of these five variables is complete, allowing the use of $\mathcal{O}({\alpha_s}^2)$ + NLLA QCD calculations. There is a new calculation for the C-parameter that has been used by ALEPH

Event Shape Variables

Distributions at detector level corrected bin-by-bin to particle level for

- **Remaining background**
- **Finite detector resolution**
- **Acceptance**
- **Initial and final state radiation**



- **Correction factors typically between 0.5 and 1.5**
- **Detector and ISR corrections compensate each other**

Summary of α_s at $\sqrt(\mathrm{s})$ = 91 GeV From Event Shape Variables

Published Results for $\alpha_s(m_Z)(\sqrt(s) = 91$ GeV) using $\mathcal{O}({\alpha_s}^2)$ + NLLA QCD calculations:

	$\alpha_s(m_Z)(\sqrt(s) = 91$ GeV)	Variables used
ALEPH	0.1251 $\pm$ 0.0023 $\pm$ 0.0039	T,ρ,$-\ln(y_{23}$
DELPHI	0.123 $\pm$ 0.002 $\pm$ 0.005	T,ρ,B_T,B_W,EEC
L3	0.1221 $\pm$ 0.0020 $\pm$ 0.0066	T,ρ,B_T,B_W
OPAL	0.120 $\pm$ 0.006	T,ρ,B_T,B_W,EEC,D2,N_jet

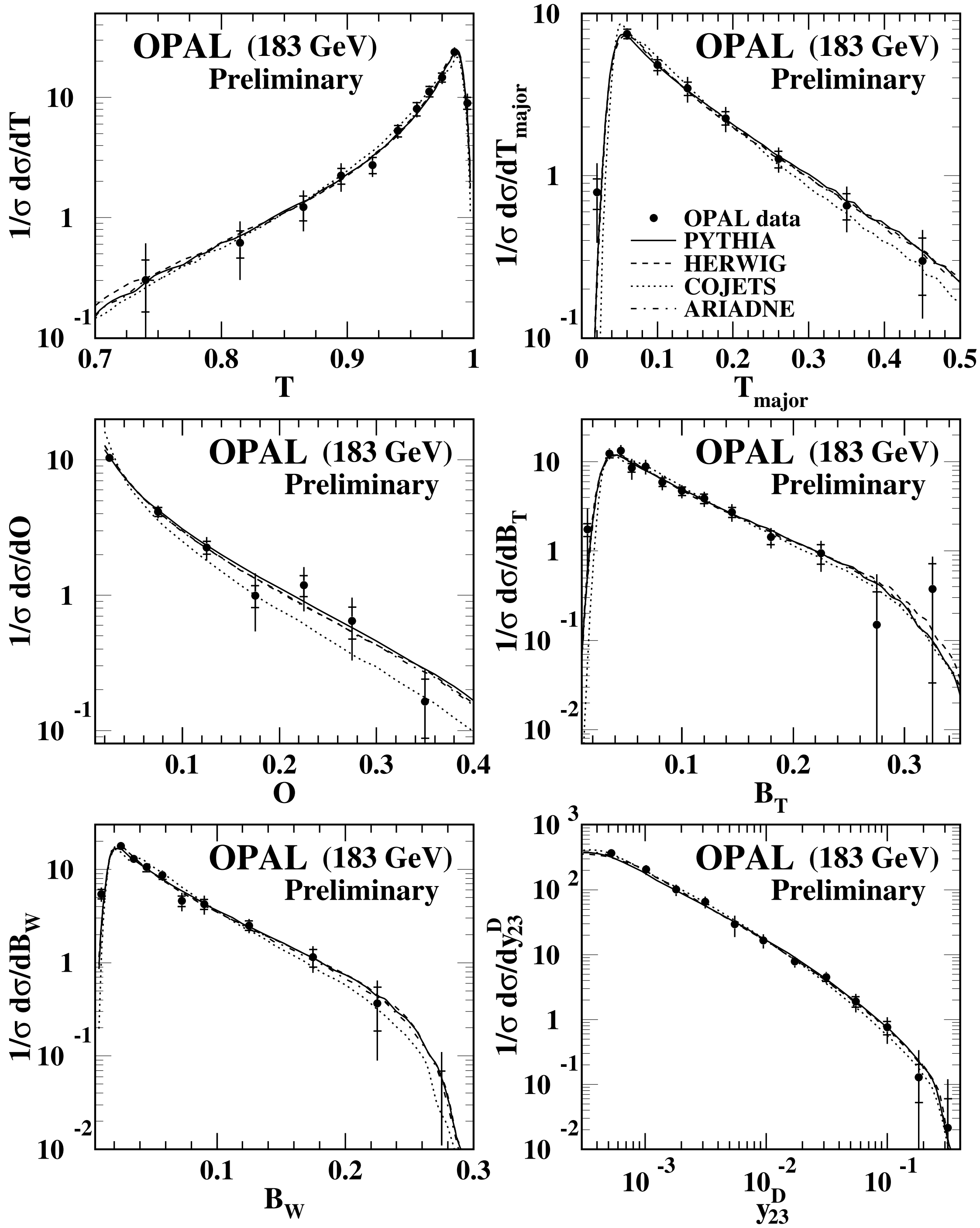
To be compared with $\alpha_s(m_Z)$ from electroweak fits:

$$\alpha_s(m_Z) = 0.120 \pm 0.003\,(\mathrm{stat}) \pm 0.002\,(\mathrm{syst})$$

and from R_τ :

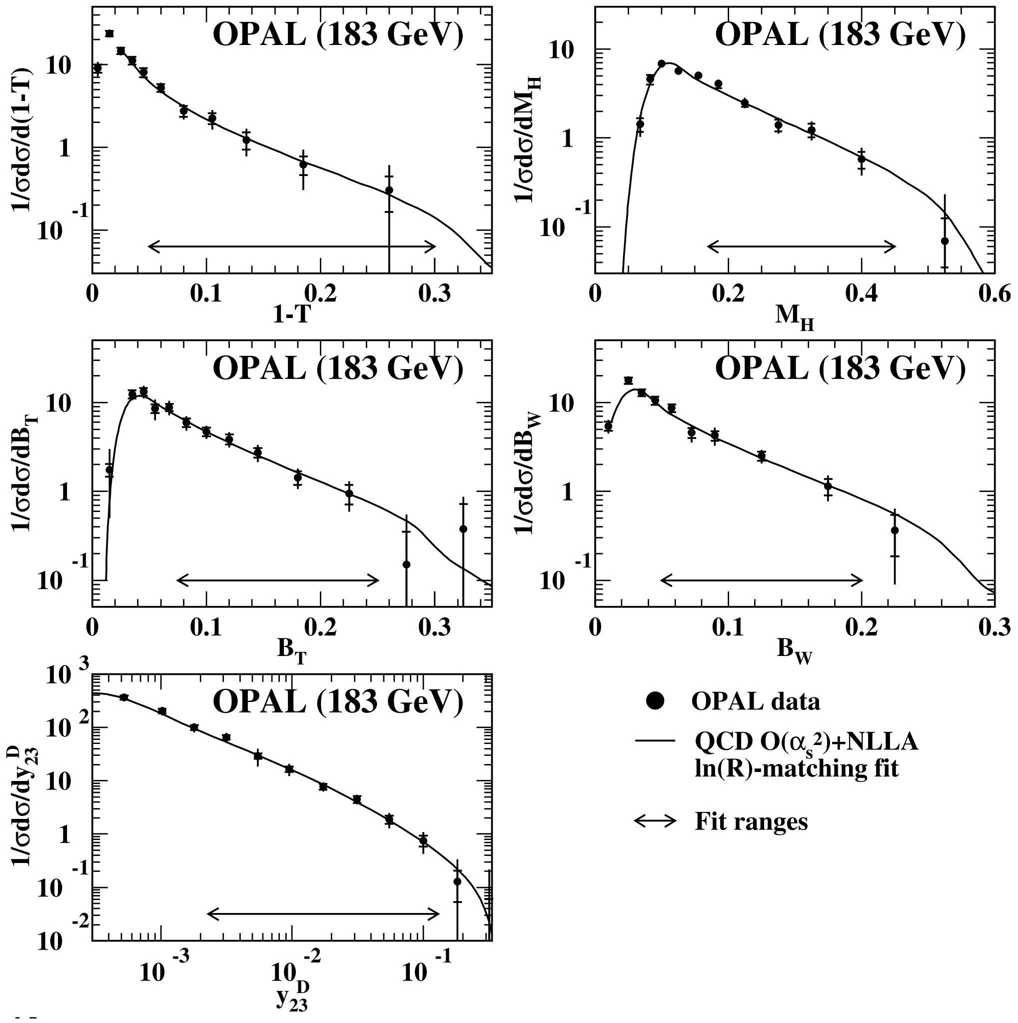
$$\alpha_s(m_Z) = 0.119 \pm 0.001\,(\mathrm{stat}) \pm 0.004\,(\mathrm{syst})$$

Data vs MC Comparison at 183 GeV (OPAL)



α_s fit to Event Shape Variables at 183 GeV (OPAL)

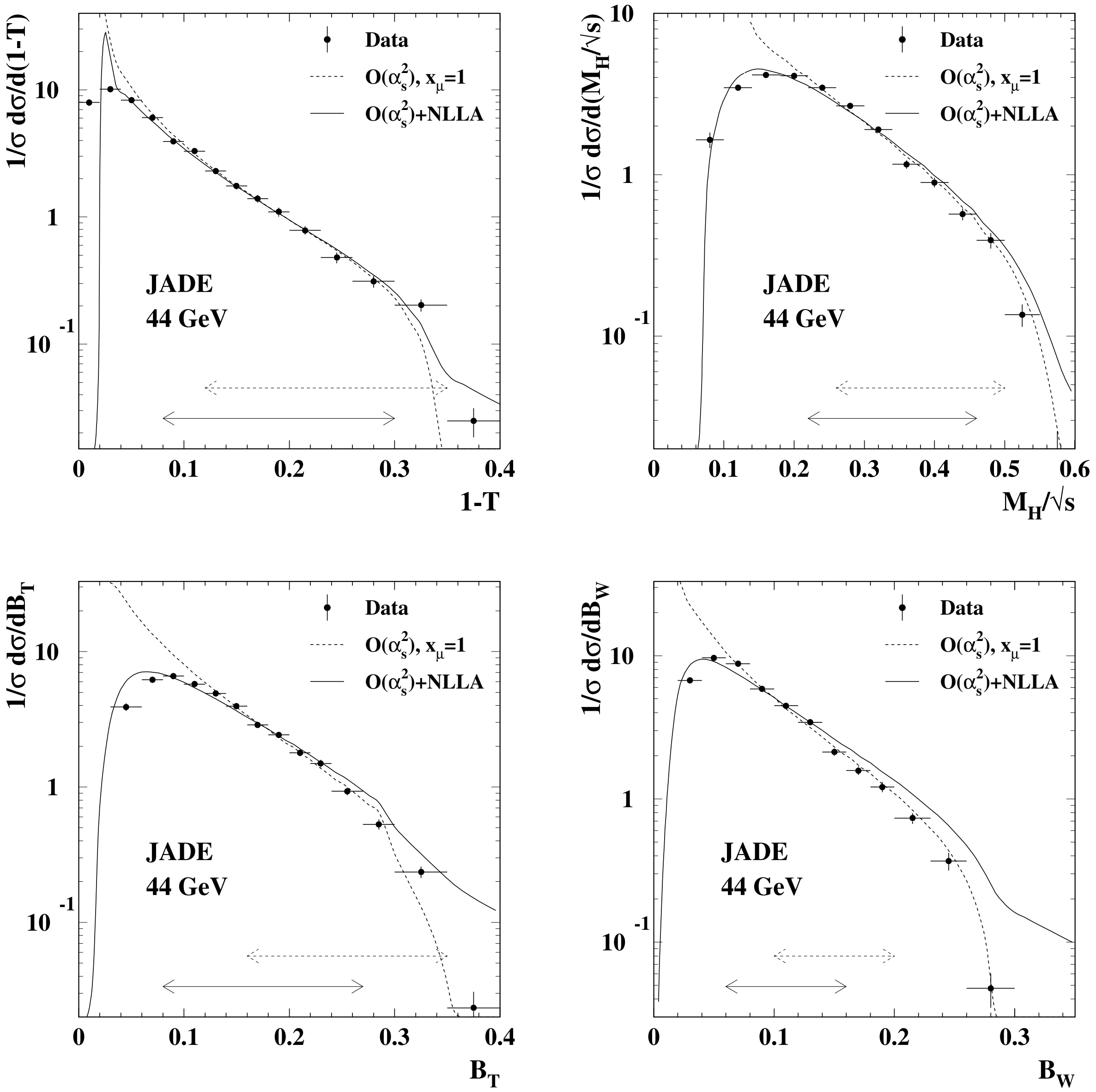
Preliminary



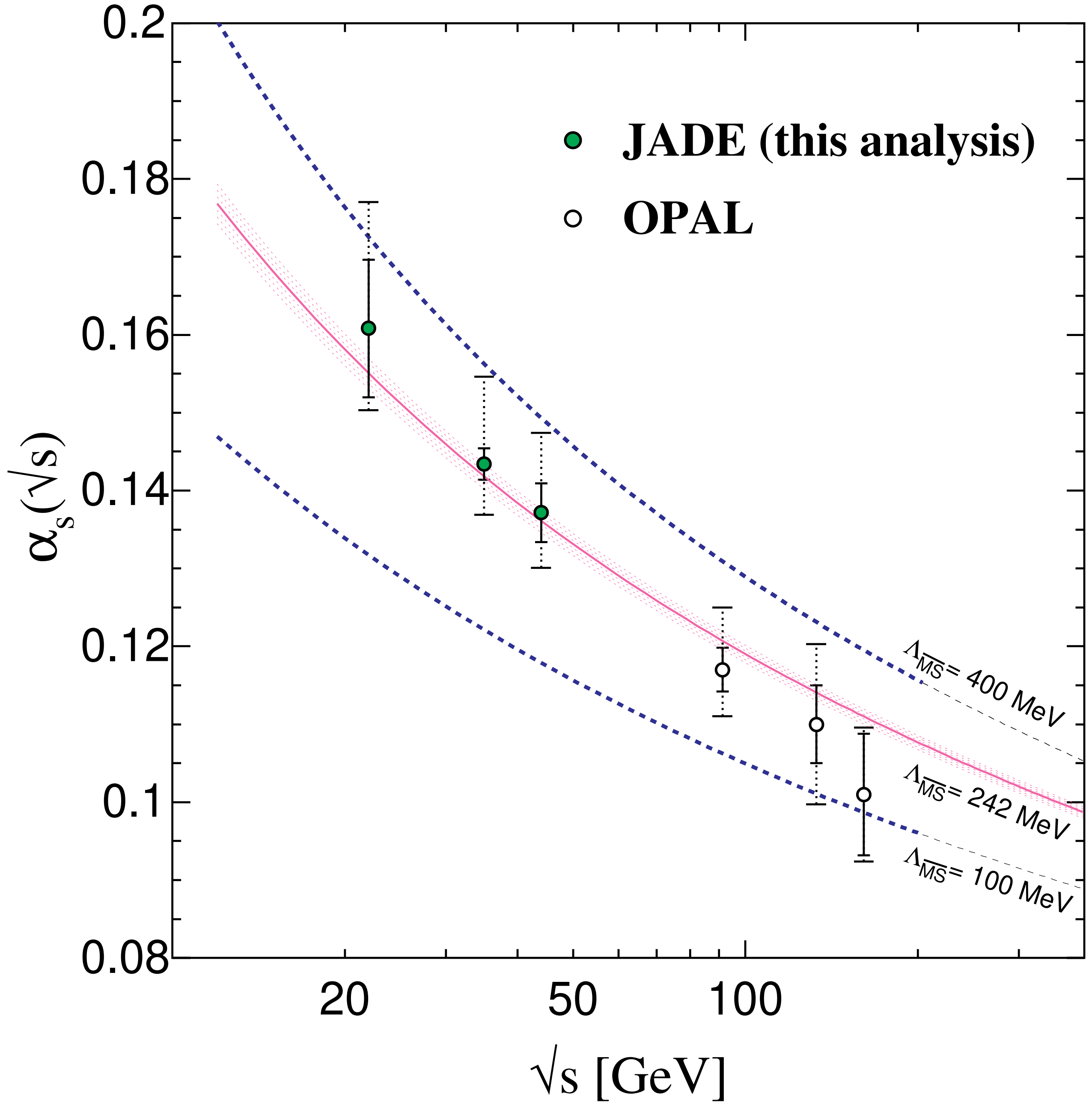
$$\alpha_s(183\ \text{GeV}) = 0.104 \pm 0.003\ (\text{stat}) \pm 0.005\ (\text{syst})$$

Running of the Strong Coupling Constant (JADE+OPAL)

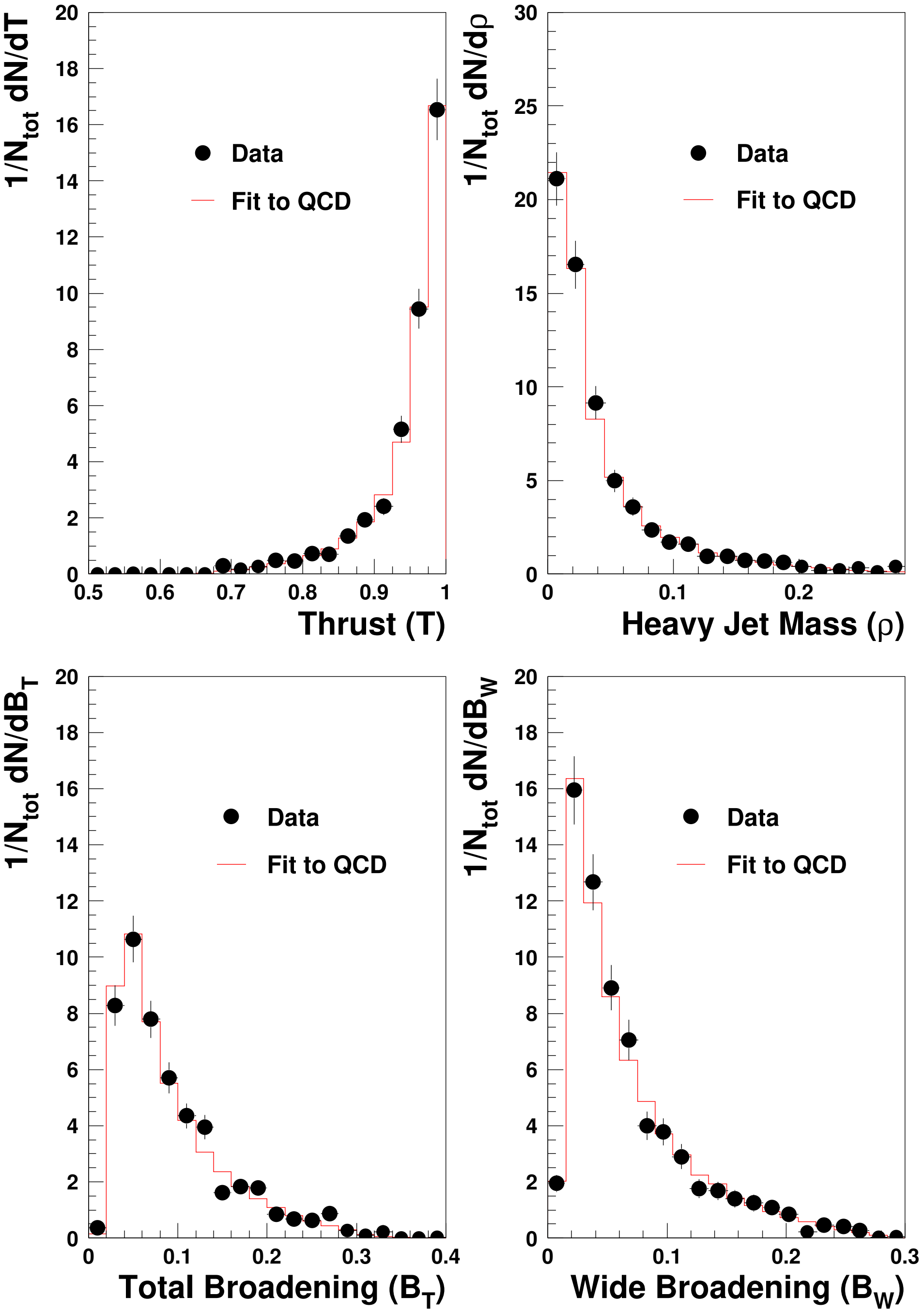
Recently the JADE data from PETRA have been analysed in order to provide data for the 5 event shape variables. Eur. Phys. J. C1 (1998) 461-478



Running of the Strong Coupling Constant (JADE+OPAL)

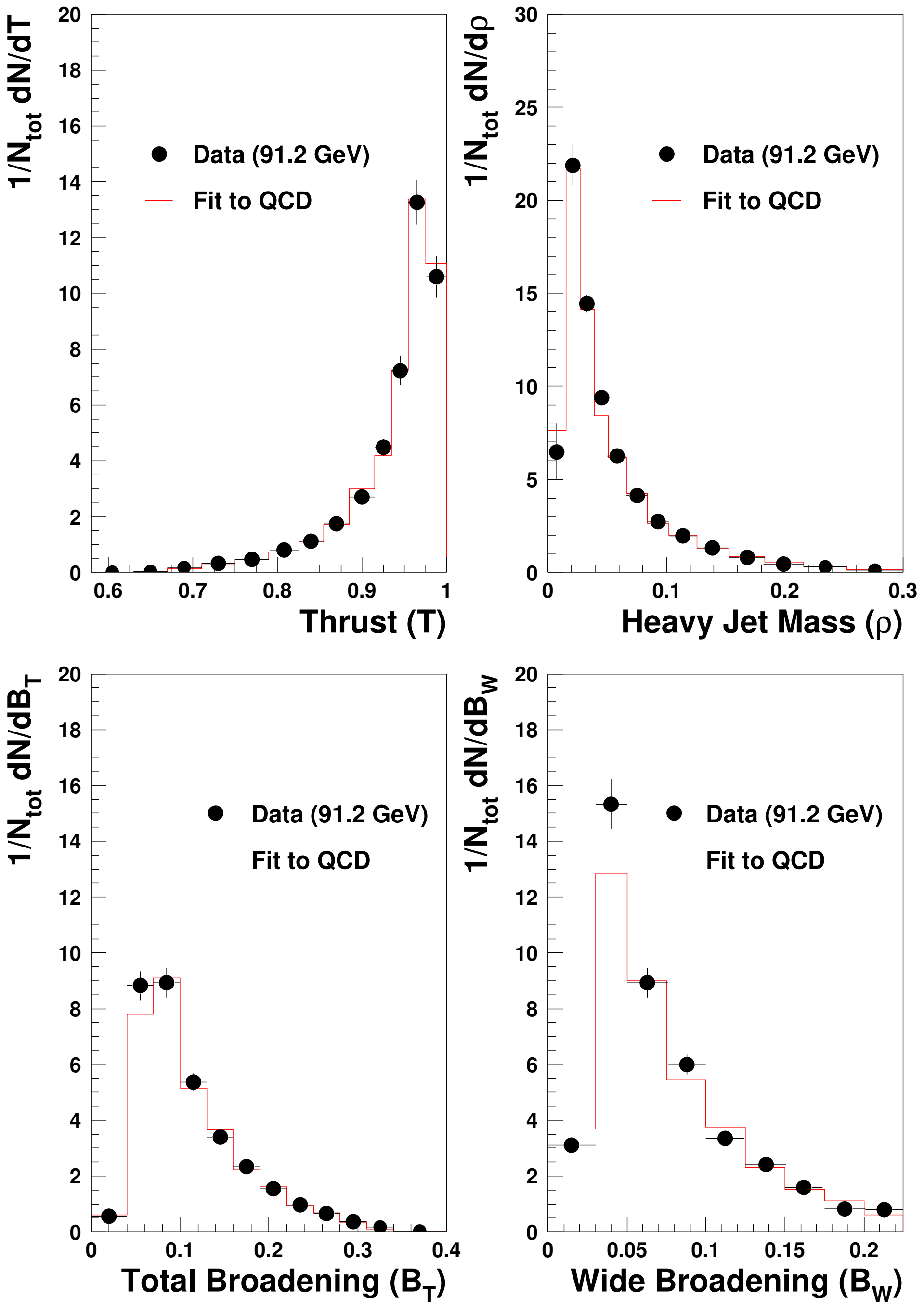


α_s fit to Event Shape Variables at 183 GeV (L3)



$$\alpha_s(183\ \text{GeV}) = 0.109 \pm 0.002\,(\text{exp}) \pm 0.005\,(\text{th})$$

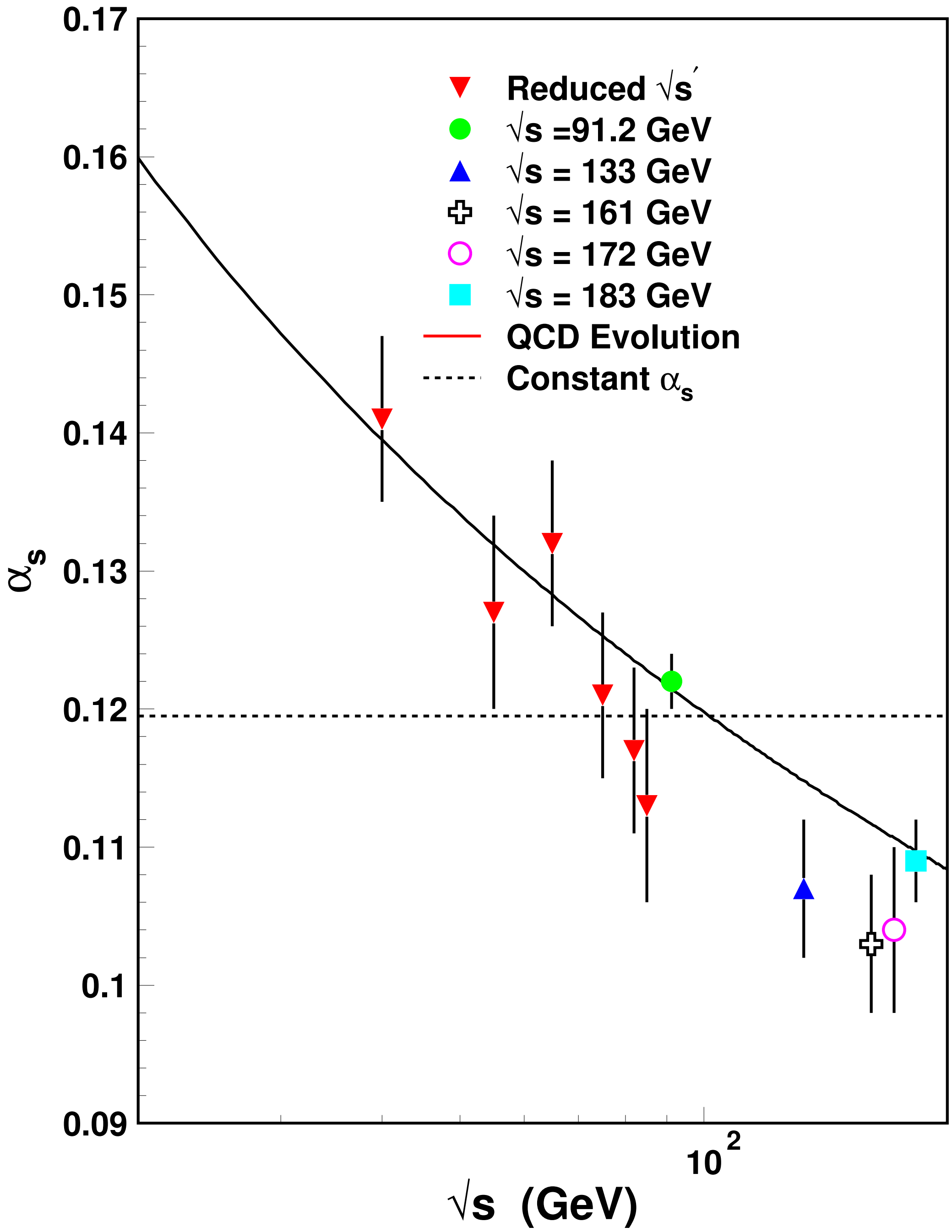
α_S fit to Event Shape Variables at 91 GeV (L3)



$$\alpha_s(91\ \text{GeV}) = 0.122 \pm 0.002\,(\text{exp}) \pm 0.007\,(\text{th})$$

Running of the Strong Coupling Constant (L3)

L3 Preliminary **Experimental errors only**

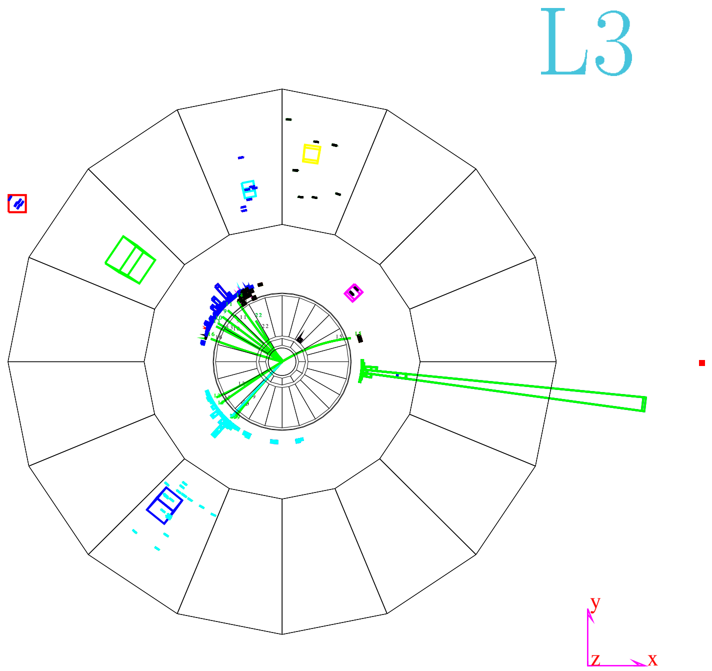


From fit to 11 measurements

$$\alpha_s(m_Z) = 0.1215 \pm 0.0016\,(\mathrm{exp}) \pm 0.0066\,(\mathrm{th})$$

$\boxed{\sqrt{s} < m_Z}$ Analysis of $e^+e^- \longrightarrow$ hadrons $+ \gamma$

γ from ISR/quark bremsstrahlung - long before hadronisation.
$\longrightarrow$ system recoiling against γ is at reduced energy $\sqrt{s'}$.
Checked by comparison with JETSET generator at reduced $\sqrt{s}$.



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

Isolated photon candidates are selected:

- neutral electromagnetic shower with $E > 5$ GeV
- isolated: no other cluster $< 15°$ & $> 20°$ from nearest jet
- neural network π^0/γ (multi-γ/single-γ) discriminator

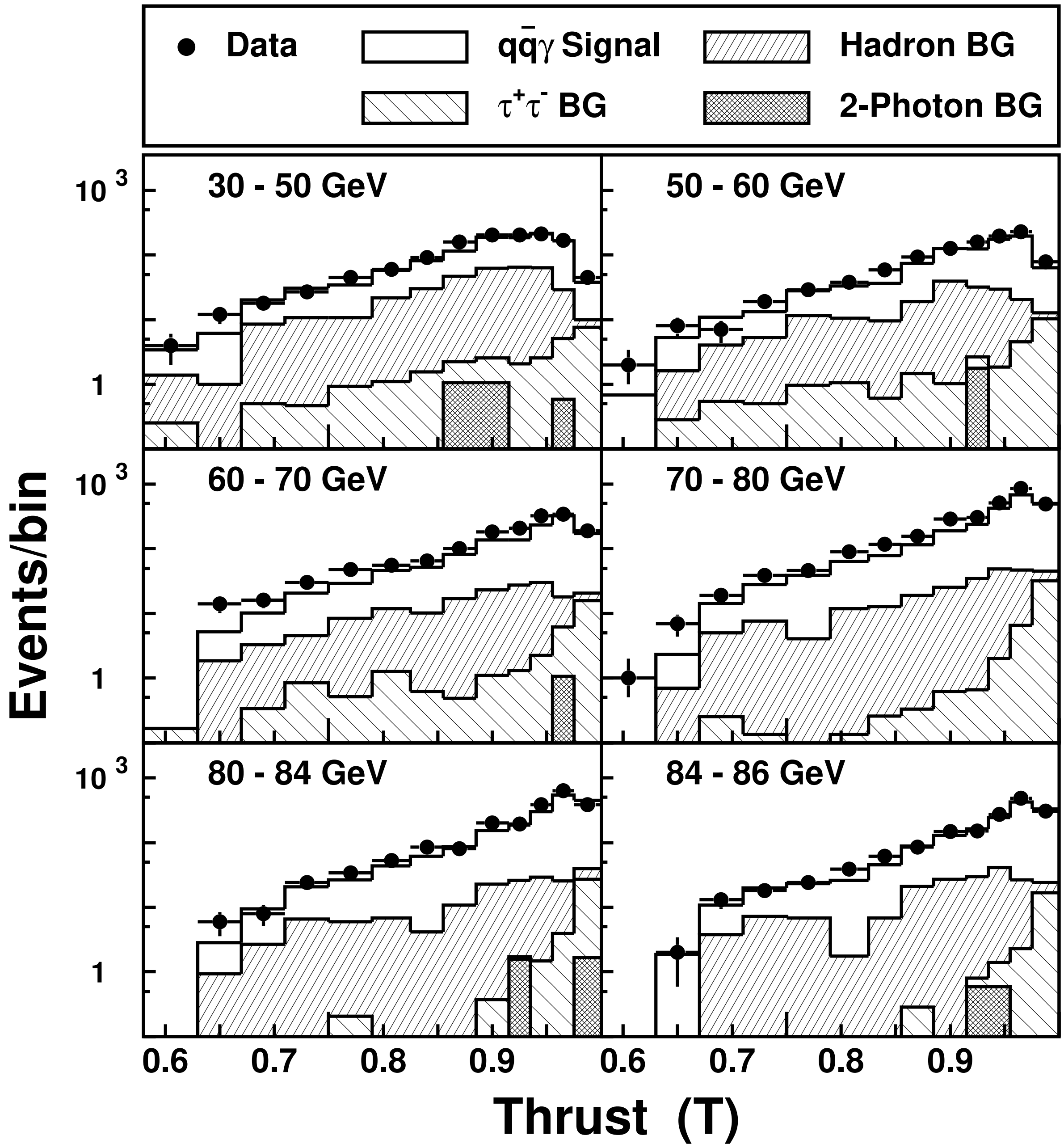
$\sqrt{s'}$ (GeV):	30-50	50-60	60-70	70-80	80-84	84-86
# $q\bar{q}\gamma$ events:	1247	1047	1575	2938	2091	1607
hadronic bgd. (%):	29.3	19.2	11.6	9.2	7.7	11.6
purity (%):	68.4	78.0	86.0	89.0	90.5	87.0

Remove γ & boost event into recoiling system, then compute event shape variables for QCD fits.

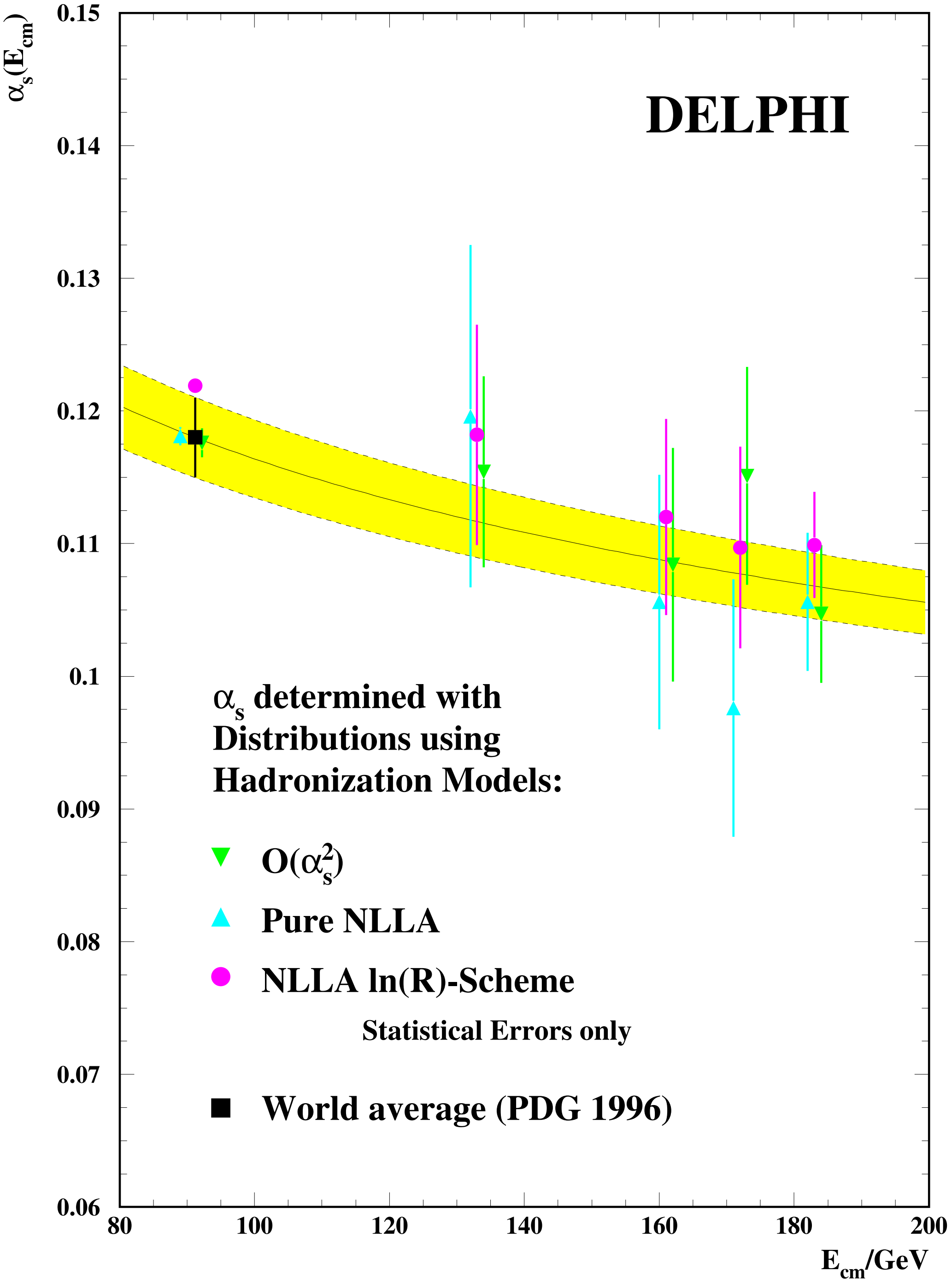
$\longrightarrow$ Measurements of α_s for each energy bin.

Thrust Distributions at $\sqrt{s} < m_Z$

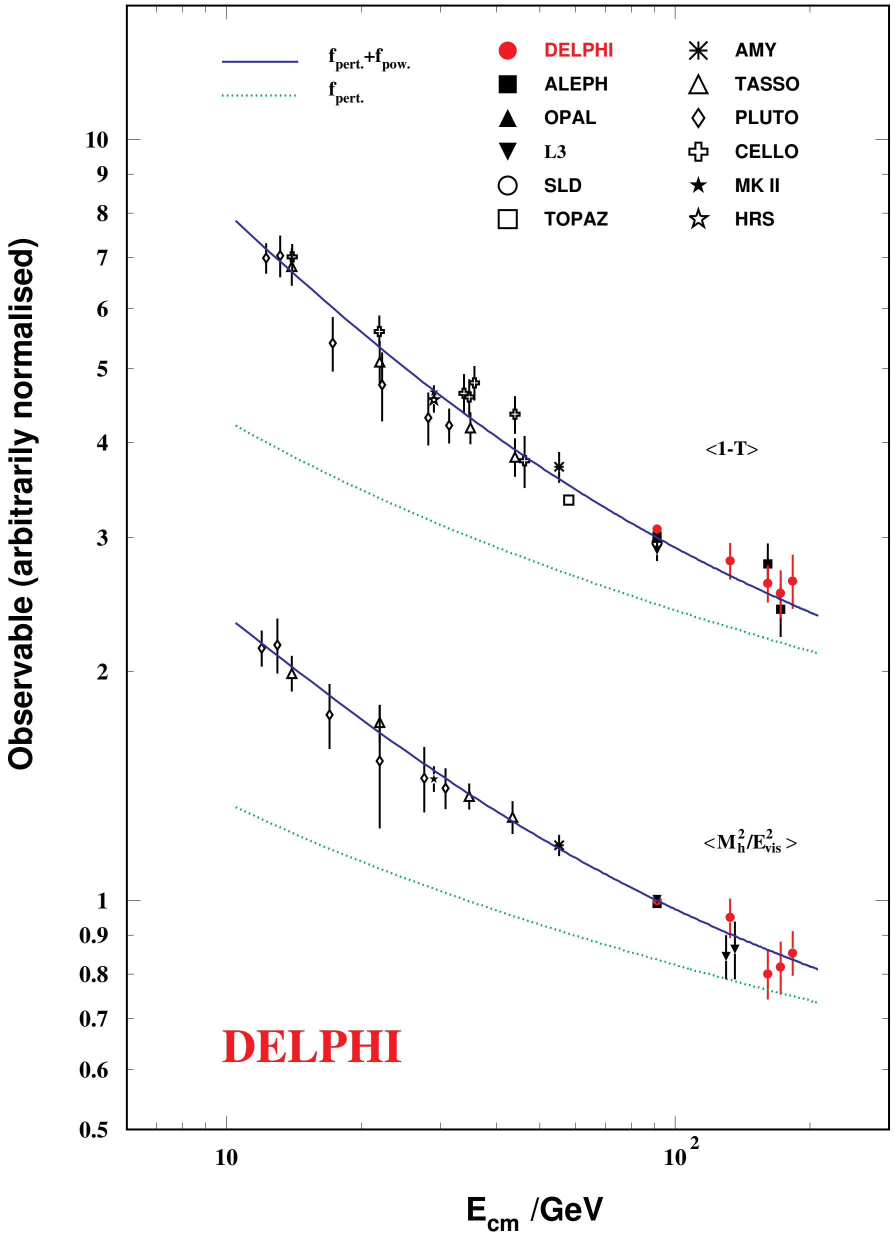
The $\sqrt{s} < m_Z$ data have purity between 68% and 90% , to be compared with a purity of about 80% for the High Energy data



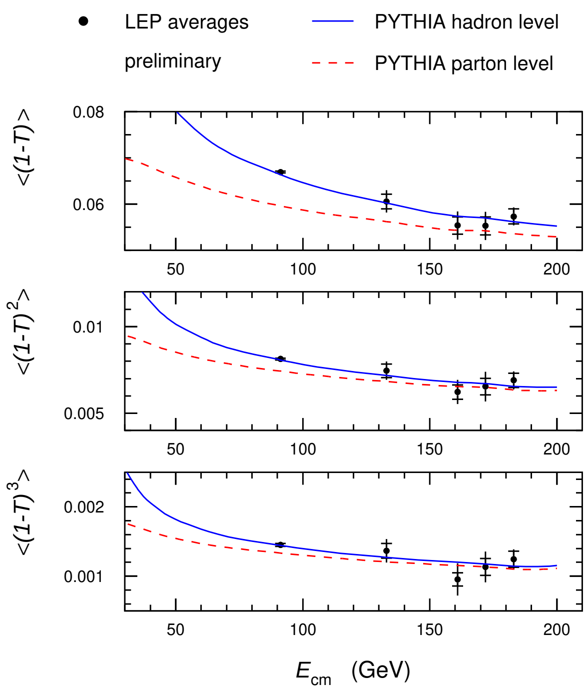
Running of the Strong Coupling Constant (DELPHI)



α_S from mean Event Shapes



α_S from mean Event Shapes



Comparison with

MC model

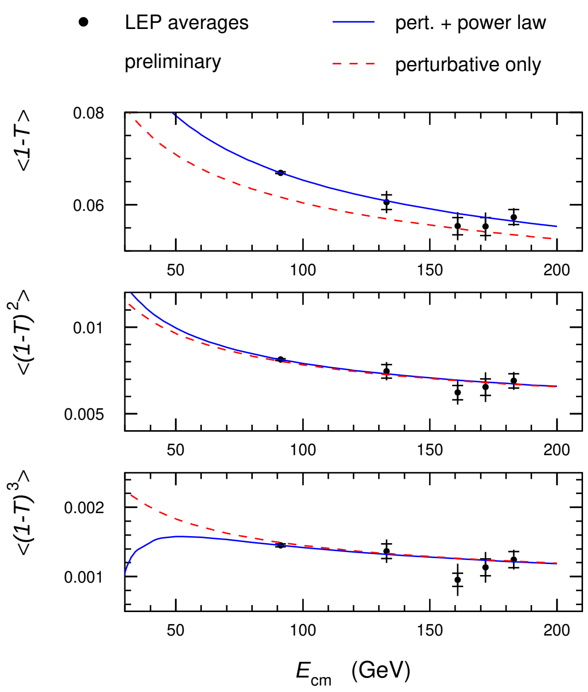
Comparison with

$O(\alpha_s^2)$ QCD +

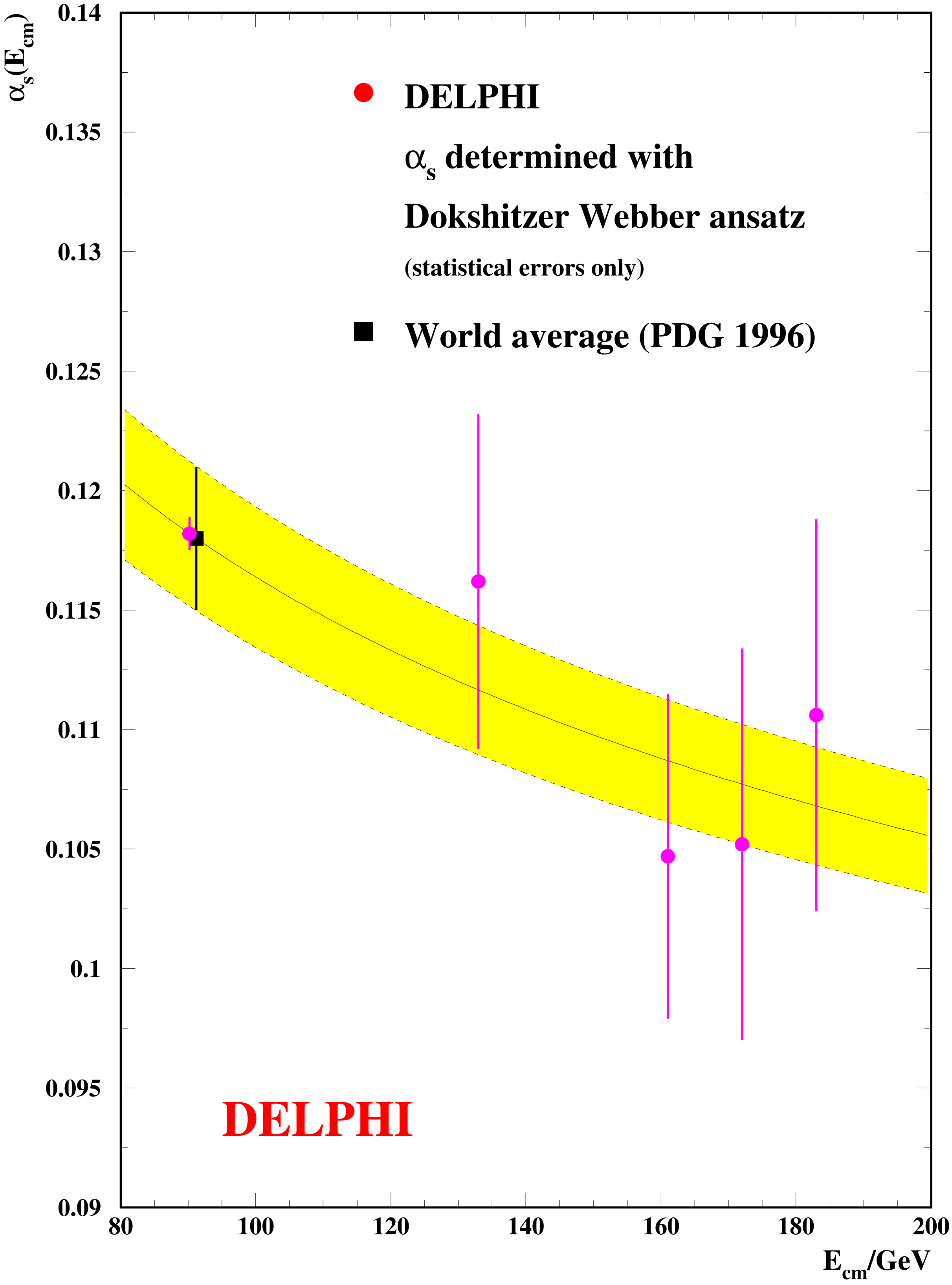
power law correction

Dokshitzer and Webber,

PLB 352 (1995) 451



α_S from mean Event Shapes



Conclusions

- About 3.1k hadronic events collected per experiment at LEP at high energy allow already for interesting consistency tests of QCD

- coherent PS models, tuned to Z data reproduce well the overall properties of hadronic events at high energy

- New α_s measurements increase our confidence in it's running character at high energy

- Looking forward to more high energy, high luminosity running of LEP II