Power Corrections and Event Shapes at LEP

XXXVth Rencontres de Moriond

QCD and Hadronic Interactions at High Energy

Les Arcs, March 2000

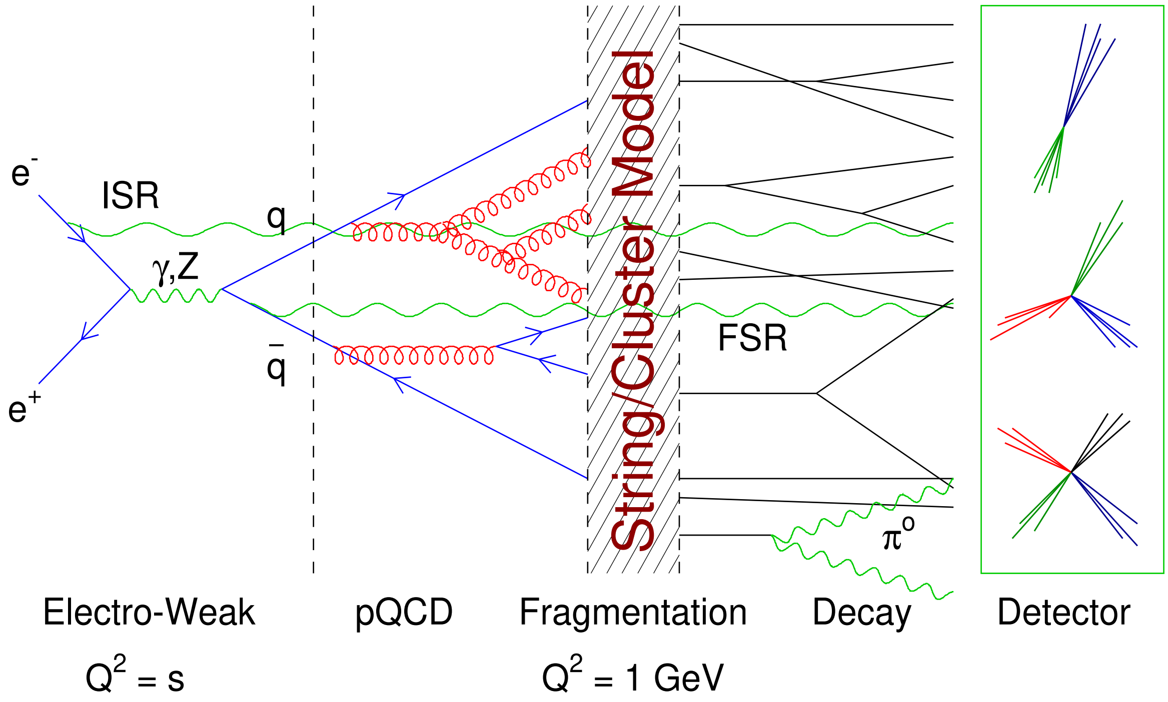
M.P. Sanders University of Nijmegen & L3

Outline

- Introduction: QCD at LEP & Data Samples
- Event Shapes
- Perturbative QCD $\Longleftrightarrow$ Event Shapes
  - Fragmentation Models ($\rightarrow \alpha_s$)
  - Power Corrections ($\rightarrow \alpha_s$)
- Conclusions

Introduction

$$e^+e^- \longrightarrow q\bar{q} \longrightarrow \text{hadrons}$$



Well defined initial state, hadronic activity in final state only

$\Longrightarrow$ Clean tests of QCD:

- running of α_s (hard core QCD)
- (energy evolution of) event shapes (soft QCD): power corrections, fragmentation models

QCD is background for WW, ZZ studies and searches

$\Longrightarrow$ Good understanding of QCD needed

Data Samples

LEP: $\sqrt{s}$ from $\approx$ 91 GeV up to 204 GeV (1999)

From $Z \longrightarrow q\bar{q}\gamma$: $\sqrt{s'}$ down to 41 GeV (DELPHI) or 30 GeV (L3)

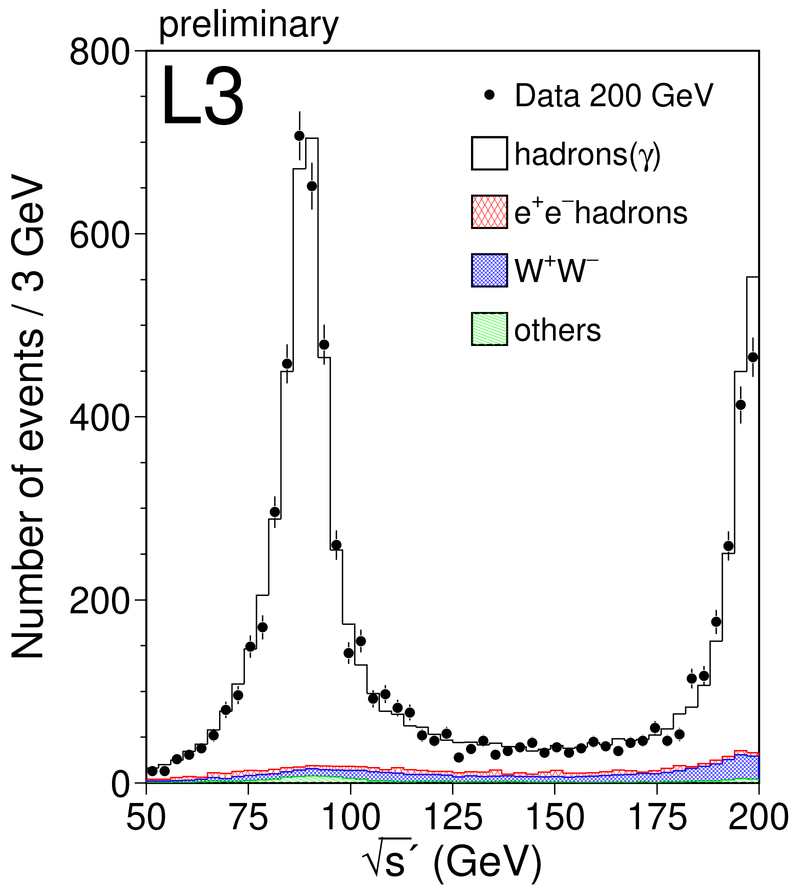
Hadronic events characterised by large visible energy, energy balance, large multiplicity

Some typical numbers for 1999 data (L3, high $\sqrt{s'}$):

$\sqrt{s}$ (GeV)	$\int \mathcal{L}\,(\mathrm{pb}^{-1})$	# Events	Eff. (%)	Pur. (%)
192	29	686	87	81
196	82	1836	87	80
200	79	1740	87	79
202	37	823	87	78

Data Samples

- $\sqrt{s} \approx \mathrm{M_Z}$: very clean, high statistics sample
- $\sqrt{s'} < \mathrm{M_Z}$: hadronic background due to π^0/η decays
- $\sqrt{s} > \mathrm{M_Z}$: background from ISR (radiative return to Z), WW

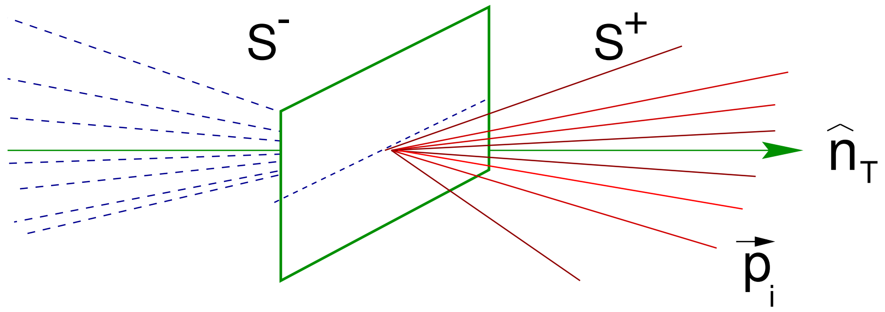


- Background subtraction with Monte Carlo models
- Correction of observables for detector acceptance, resolution, etc.

$\Longrightarrow$ Sources of systematic uncertainties

Event Shapes

Infrared & collinear safe observables $\longrightarrow$ calculable in perturbative QCD ($\mathcal{O}(\alpha_s^2)$, (next to) leading log resummations)



Thrust T:

$$T = \max_{\hat{n}_T} \frac{\sum_a |\vec{p}_a \cdot \hat{n}_T|}{\sum_a |\vec{p}_a|}$$

Scaled heavy jet mass ρ:

$$M_\pm^2 = \left(\sum_{a \in S_\pm} p_a \right)^2 , \qquad \rho = \frac{\max\left(M_+^2, M_-^2\right)}{s}$$

C-parameter:

$$C = \frac{3}{s} \sum_{i<j} |\vec{p}_i| \cdot |\vec{p}_j| \cdot \sin^2 \theta_{ij}$$

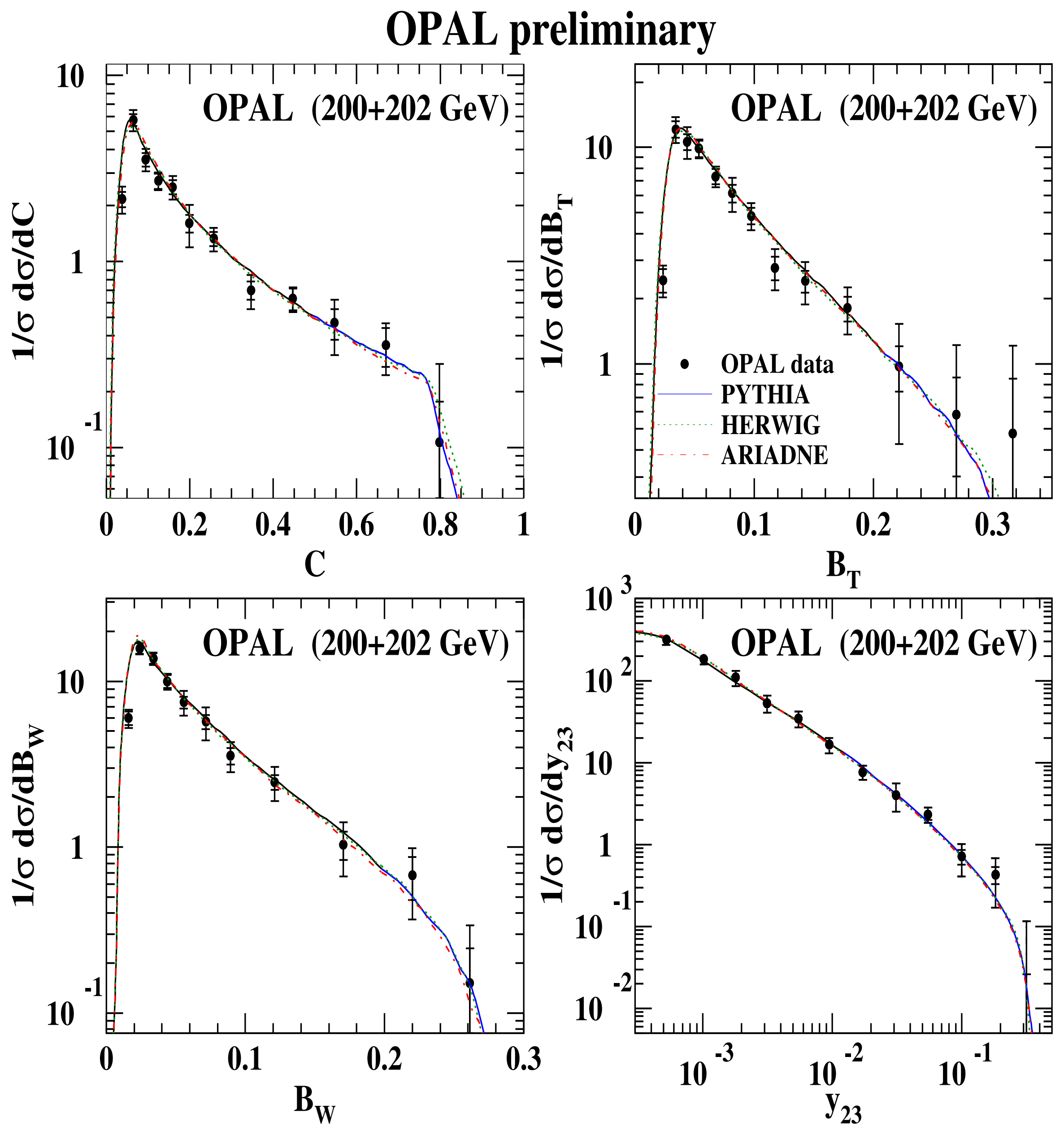
Jet broadenings variables B_T, B_W:

$$B_\pm = \frac{\sum_{a \in S_\pm} |\vec{p}_a \times \hat{n}_T|}{2 \sum_a |\vec{p}_a|}, \qquad \begin{array}{l} B_T = B_+ + B_- \\ B_W = \max(B_+, B_-) \end{array}$$

y_{23}^D: Value of y_{cut} in Durham jet algorithm at which event makes transition from 3- to 2-jet assignement

Results at $\sqrt{s} \geq 200$ GeV

Event shape distributions at $\sqrt{s} = 200 - 202$ GeV



$\Longrightarrow$ Good agreement with Monte Carlo predictions (tuned at Z)

pQCD $\Longleftrightarrow$ Event Shapes (1): MC

- Perturbative QCD ($\mathcal{O}(\alpha_s^2)$, NLLA) predicts event shapes at parton (quarks, gluons) level

- In an experiment, we see particles (π, K)

- Connection between the two (fragmentation) is non-perturbative QCD

$\Longrightarrow$ need a model to go from partons to particles

MC Model	Perturbative QCD	Fragmentation
JETSET	Parton Shower	String
HERWIG	Parton Shower	Cluster
ARIADNE	Color Dipole	String
COJETS	Incoherent Parton Shower	Independent

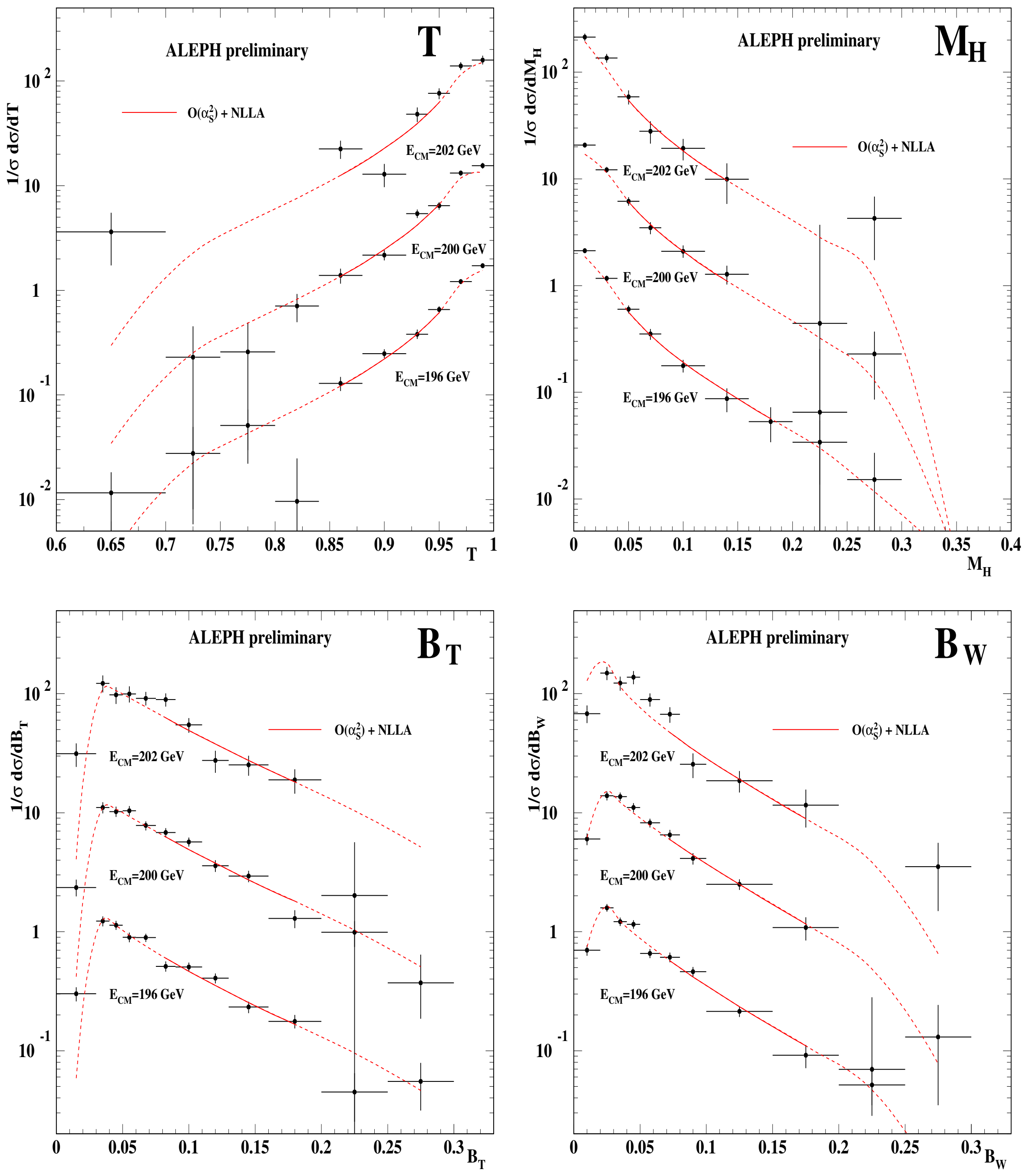
$\Longrightarrow$ α_s measurement from distribution of event shapes

However: uncertainties due to fragmentation models

Results at $\sqrt{s} \geq 196$ GeV

Fit of event shape distributions to find α_s

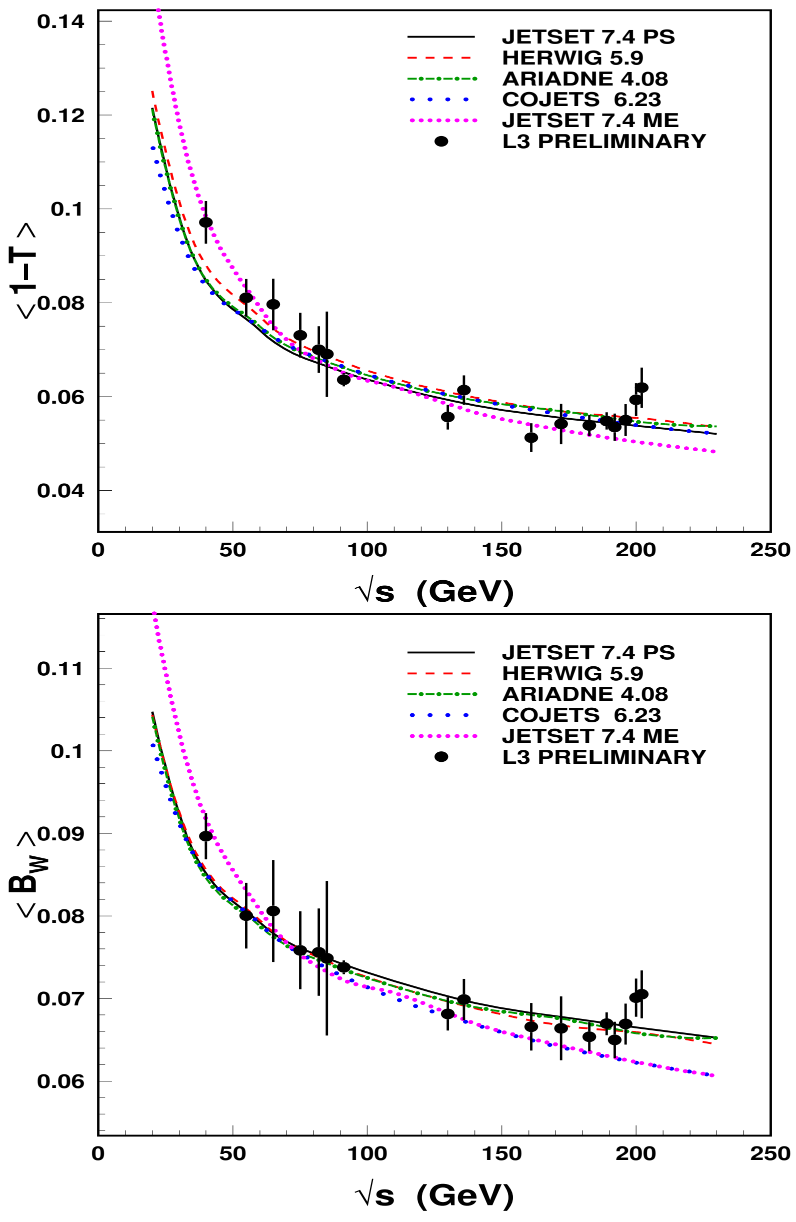
$\mathcal{O}(\alpha_s^2) + \mathrm{NLLA} \oplus \mathrm{MC}$ fragmentation



$$\Longrightarrow \alpha_s(M_Z) = 0.1212 \pm 0.0024_{\mathrm{st}} \pm 0.0023_{\mathrm{ex}} \pm 0.0046_{\mathrm{th}}$$

Results at $30\ \mathrm{GeV} \leq \sqrt{s} \leq 202\ \mathrm{GeV}$

L3 measures energy evolution of event shape mean from $\sqrt{s} = 30\ \mathrm{GeV}$ up to $\sqrt{s} = 202\ \mathrm{GeV}$ (in one experiment!)



$\Longrightarrow$ Good agreement with Monte Carlo predictions (tuned at Z), but . . .

pQCD $\Longleftrightarrow$ Event Shapes (2): Power Corrections

First and second moment of event shape variable f

$$\langle f \rangle = \langle f_{\rm pert} \rangle + \langle f_{\rm pow} \rangle$$

$$\langle f^2 \rangle = \langle f_{\rm pert}^2 \rangle + 2\langle f_{\rm pert} \rangle \langle f_{\rm pow} \rangle + \mathcal{O}\left(\frac{1}{Q^2}\right)$$

Perturbative contribution known up to $\mathcal{O}(\alpha_s^2)$:

$$\langle f_{\rm pert} \rangle = A_f\,\alpha_s \;+\; B_f\,\alpha_s^2$$

Power correction term is given by (Dokshitzer et al.):

$\star$ $f = 1 - T, \rho, C$

$$\langle f_{\rm pow} \rangle = c_f \mathcal{P}$$

$\star$ $f = B_T, B_W$

$$\langle f_{\rm pow} \rangle = c_f \mathcal{P} \cdot \left[\frac{1}{\alpha_{\rm CMW}(Qe^{-3/4})} + d_f + \mathcal{O}(\sqrt{\alpha_s})\right]$$

$\star$ $\mathcal{P}$ is universal

$$\mathcal{P} = \frac{4C_F}{\pi^2}\mathcal{M}\frac{\mu_I}{Q}\left[\alpha_0(\mu_I) - \alpha_s + \mathcal{O}(\alpha_s^2)\right]$$

$$\alpha_0(\mu_I) = \frac{1}{\mu_I}\int_0^{\mu_I} dq\, \alpha_{\rm eff}(q)$$

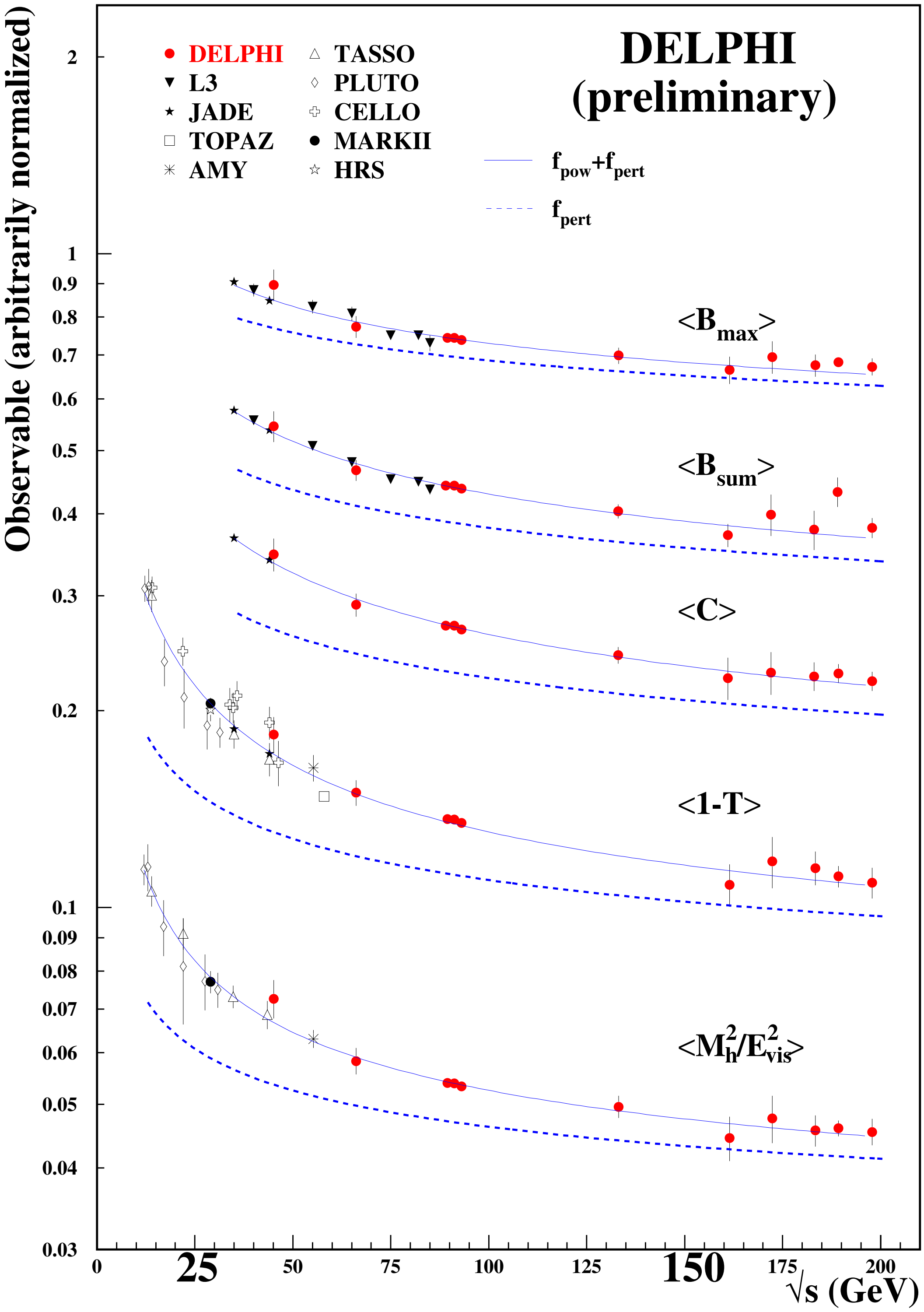
$\alpha_{\rm eff}$ = non-perturbative, universal strong coupling in infrared region ($Q < \mu_I$)

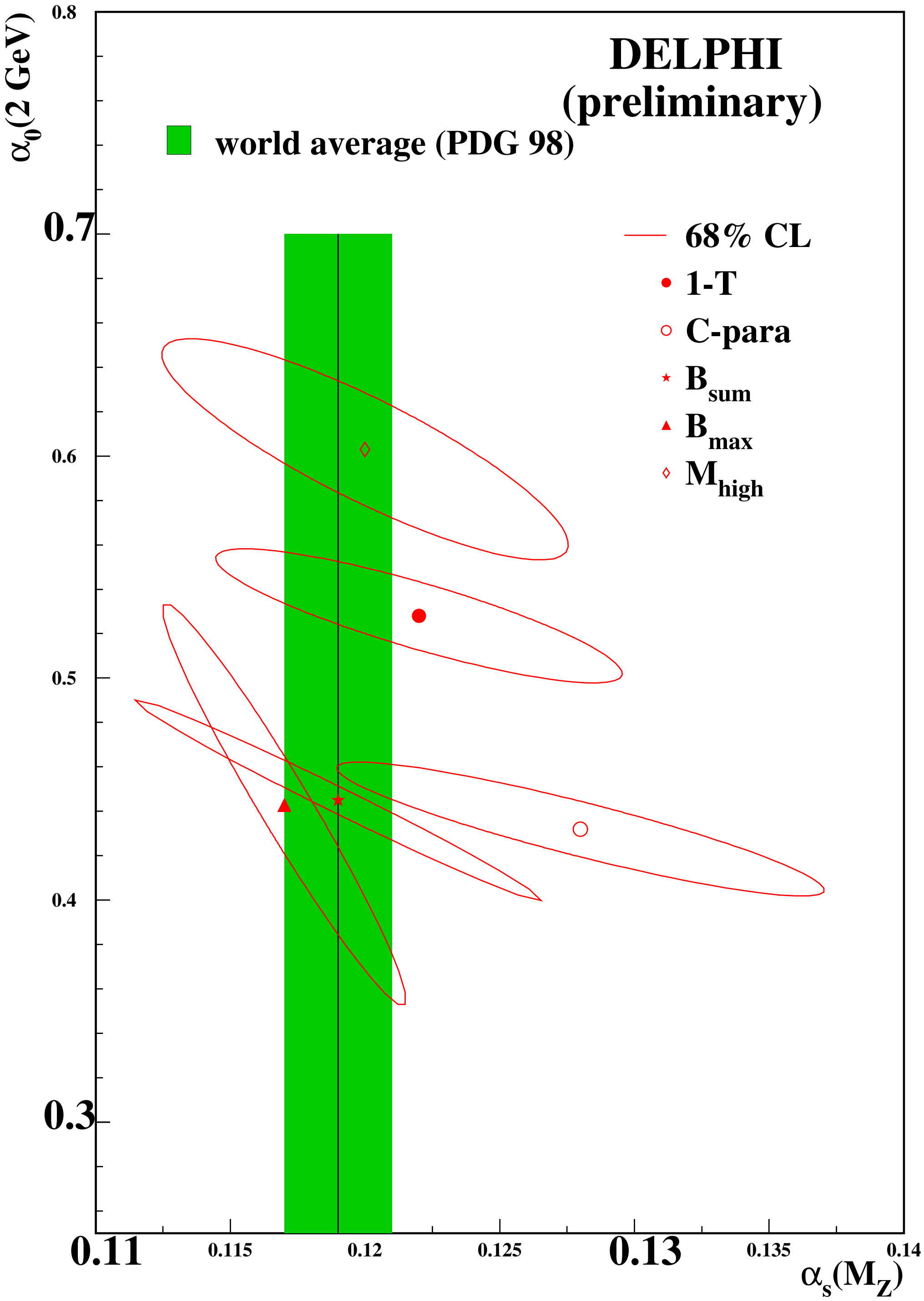
'Milan factor' $\mathcal{M} = 1.49$ (1.795 in first calculation, Dokshitzer, hep-ph/9911299)

$\Longrightarrow$ Two universal parameters to describe energy evolution of five event shape variables: α_s, α_0

Power Corrections at LEP

Combined fit of $\alpha_s(\mathrm{M_Z})$ and $\alpha_0(\,2\ \mathrm{GeV})$ to LEP data and large data set from low energy experiments



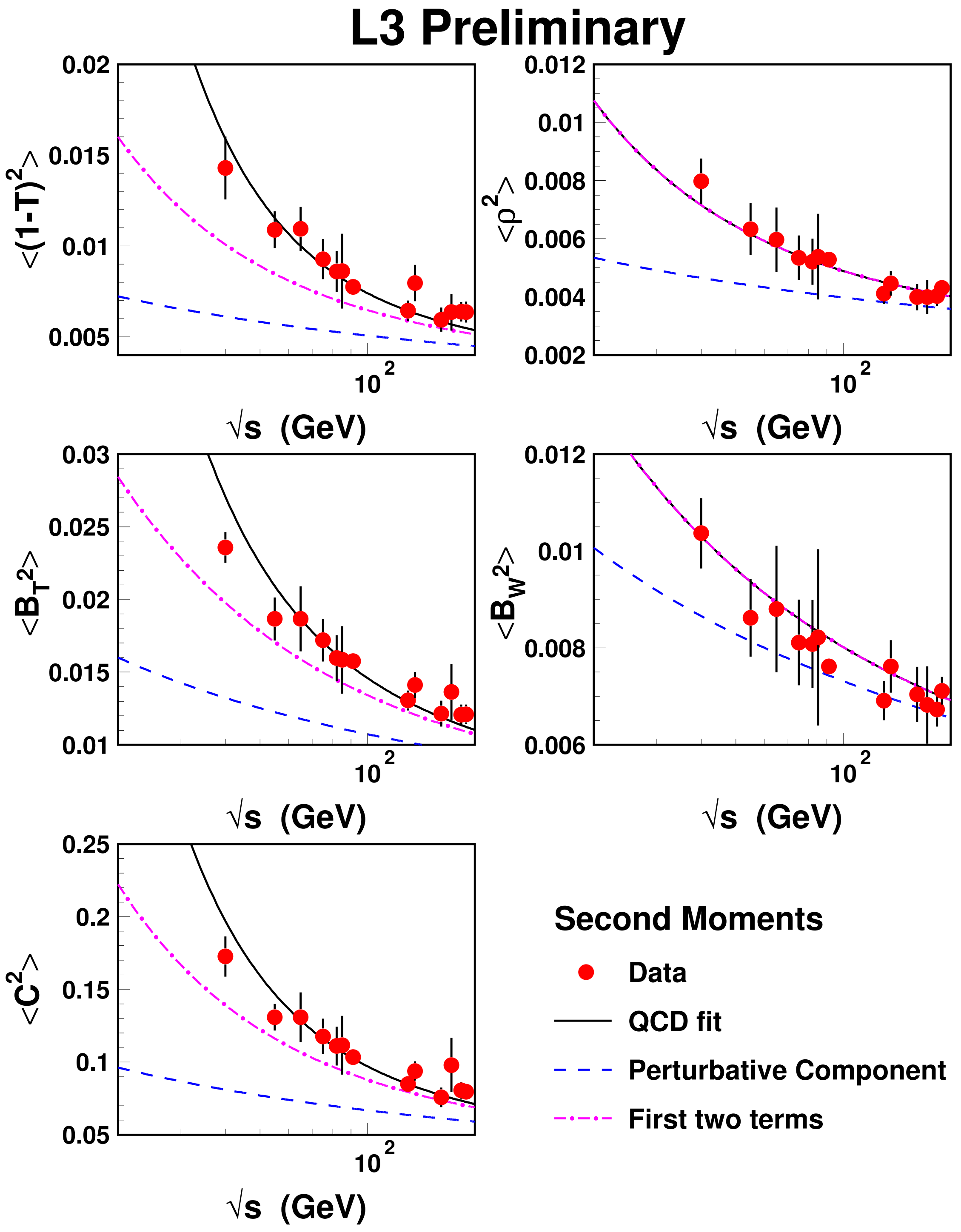


$\Longrightarrow$ Values of $\alpha_s(\mathrm{M_Z})$ consistent among each other and in good agreement with world average

$\Longrightarrow$ Predicted universality of $\alpha_0(2\ \mathrm{GeV})$ met on a 20 % level

Fits to second moments:

$\alpha_s(\mathrm{M_Z})$ and $\alpha_0(\,2\ \mathrm{GeV})$ taken from fit to first moments, $\mathcal{O}(1/Q^2)$ term parametrised as A_2/Q^2



$\Longrightarrow$ $\mathcal{O}(1/Q^2)$ term non-negligible

Power Corrections Universal?

Fit results DELPHI & low energy experiments

Observable	α_0 (2 GeV)	$\alpha_s(\mathrm{M_Z})$	χ^2/d.o.f.
$\langle 1-T \rangle$	0.528 $\pm$ 0.023	0.122 $\pm$ 0.005	54/32
$\langle \rho \rangle$	0.603 $\pm$ 0.033	0.120 $\pm$ 0.005	4.8/21
$\langle B_T \rangle$	0.445 $\pm$ 0.026	0.119 $\pm$ 0.005	21/17
$\langle B_W \rangle$	0.443 $\pm$ 0.053	0.117 $\pm$ 0.003	16.6/17
$\langle C \rangle$	0.432 $\pm$ 0.016	0.128 $\pm$ 0.006	2.6/11
my average	0.490	0.121	

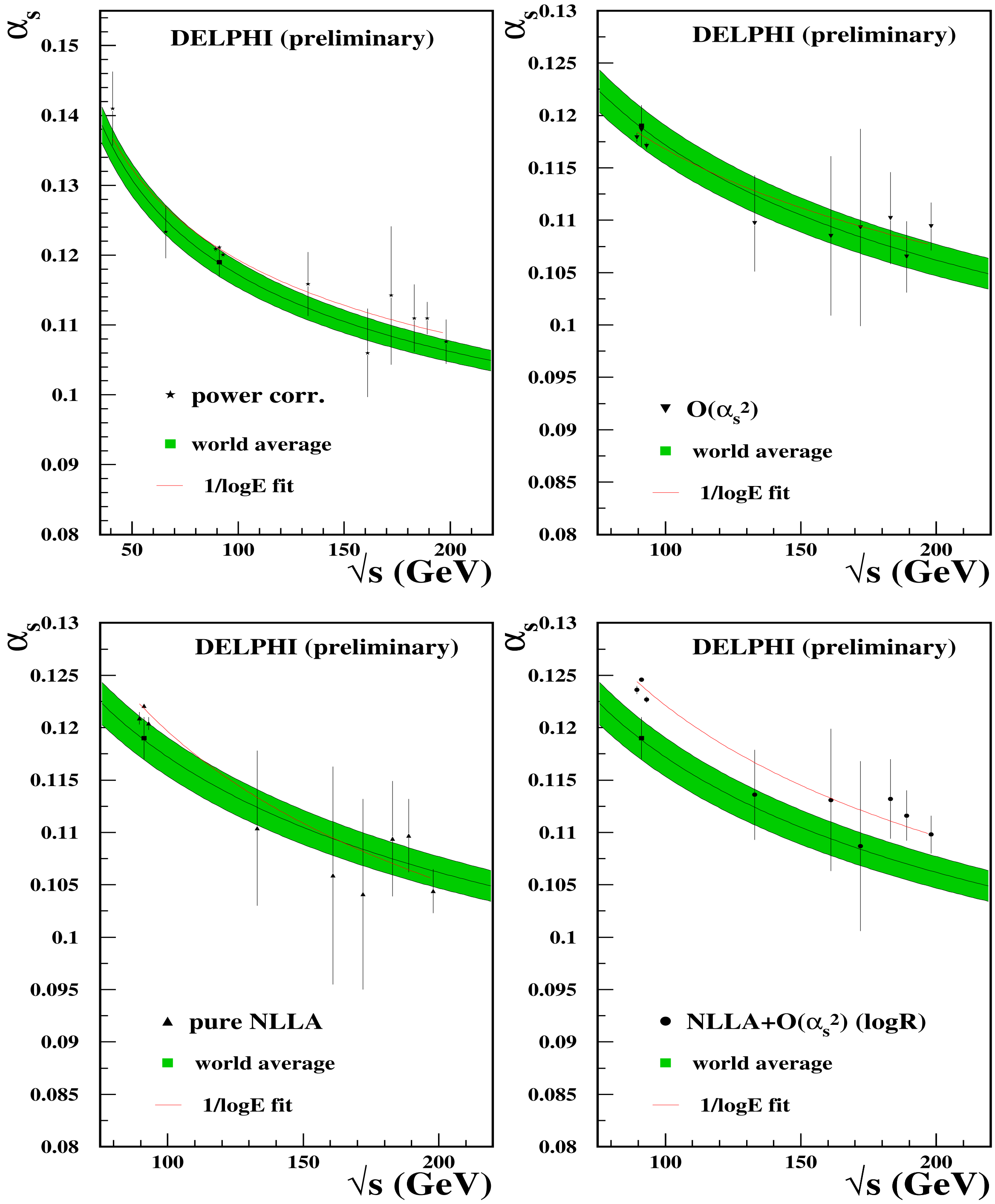
Fit results L3 ($\mathcal{M} = 1.49$, 1.795 in conference note)

Observable	α_0 (2 GeV)	$\alpha_s(\mathrm{M_Z})$	χ^2/d.o.f.
$\langle 1-T \rangle$	0.634 $\pm$ 0.092	0.110 $\pm$ 0.007	11.5/11
$\langle \rho \rangle$	0.524 $\pm$ 0.063	0.103 $\pm$ 0.005	5.5/11
$\langle B_T \rangle$	0.517 $\pm$ 0.044	0.116 $\pm$ 0.003	3.5/11
$\langle B_W \rangle$	0.476 $\pm$ 0.100	0.113 $\pm$ 0.004	4.1/11
$\langle C \rangle$	0.536 $\pm$ 0.044	0.113 $\pm$ 0.004	6.3/11
average	0.537	0.111	

$\Longrightarrow$ $\alpha_0 \simeq 0.5$, as expected by Dokshitzer et al.

Power Corrections and α_s

α_s fits with different methods, including power corrections



$\Longrightarrow$ Within statistical errors consistent results

Conclusions

- New data sample up to $\sqrt{s} = 202$ GeV
- QCD and fragmentation models, tuned at $\sqrt{s} = M_{\mathrm{Z}}$ are still healthy: event shape distributions and evolution of mean well described
- Power correction Ansatz gives good description for event shape mean over wide $\sqrt{s}$ range
- Universality of power Ansatz seen
- Power corrections seem to be powerful tool!