Experimental Status of α_s Measurments at LEP

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20.6.2001

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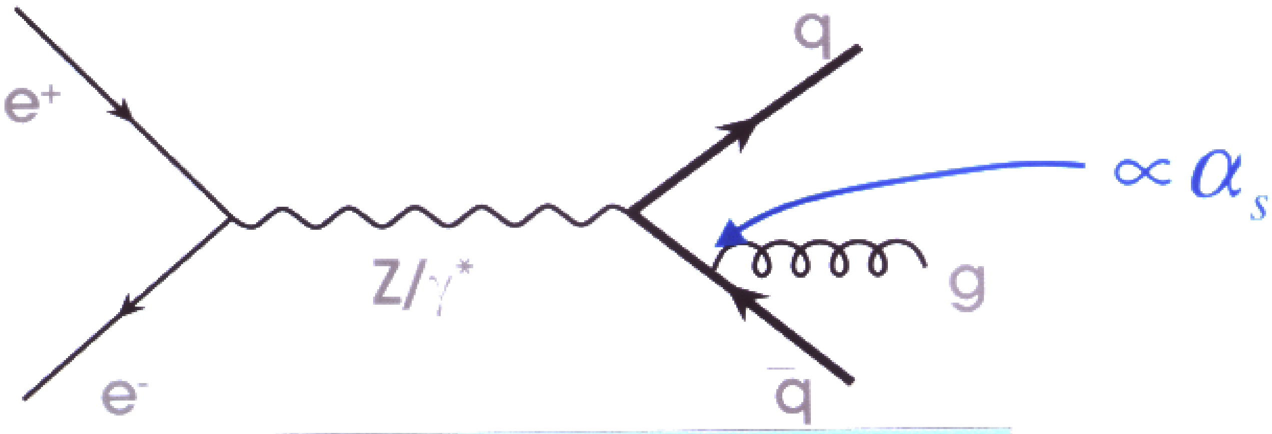
Semi-inclusive observables: Event Shapes, Jet Rates



$$\frac{d\sigma^{qqg}}{dE_{gluon}} \propto \sigma_0 \, \frac{\alpha_s}{2\pi} \frac{1}{E_{gluon}}$$

Born x-section for Z → qq

"Bremsstrahlung"

General Structure of the cross-section

In NLO:

$$\frac{1}{\sigma_0}\frac{d\sigma}{dx} = \alpha_s(\mu^2)\,A(x) + \alpha_s^2(\mu^2)\left[B(x) + 2\pi\beta_0 A(x)\ln\left(\frac{\mu^2}{E_{CM}^2}\right)\right] + O(\alpha_s^3)$$

Calculable for so-called *"infrared and collinear safe"* variables,

Cancellation of singularities in the radiative corrections

Examples: Jet Rates, Thrust, C-Parameter, ...

Perturbative Predictions

- In the 2 jet region it is necessary to re-sum all logarithms of the type $\alpha_s^n (\ln x)^{2n}, \alpha_s^n (\ln x)^n$

- A better prediction combines the NLO with the re-summed predictions

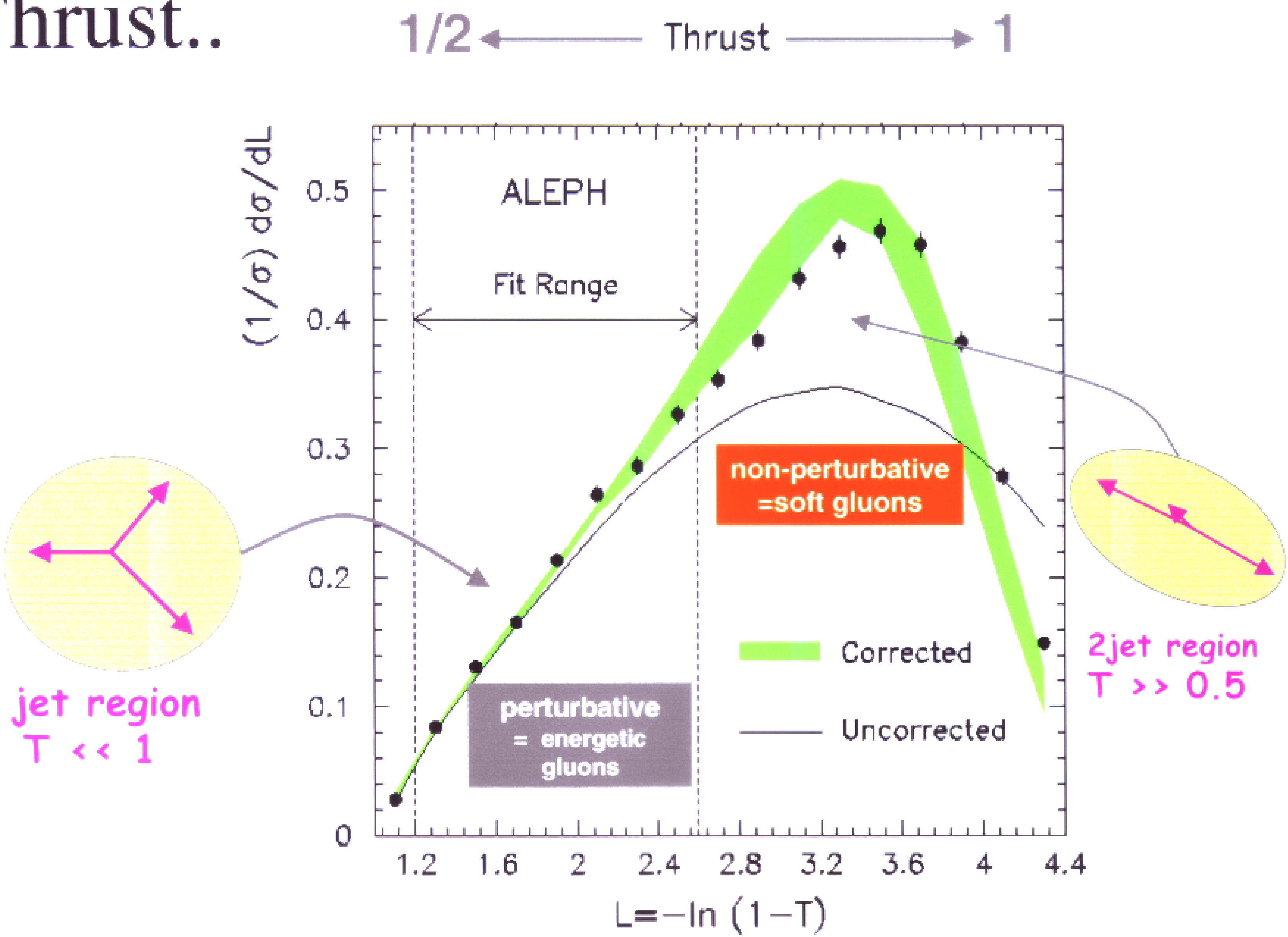
- E.g. $$\begin{aligned}\ln \sigma(x) = & \, L\, g_1(\alpha_s L) + g_2(\alpha_s L) \\ & - \alpha_s \left(G_{11} L + G_{12} L^2\right) - \alpha_s^2 \left(G_{22} L^2 + G_{23} L^3\right) \\ & + \alpha_s A(x) + \alpha_s^2 \left(B(x) - A(x)/2\right)\end{aligned}$$ $L = -\ln x$

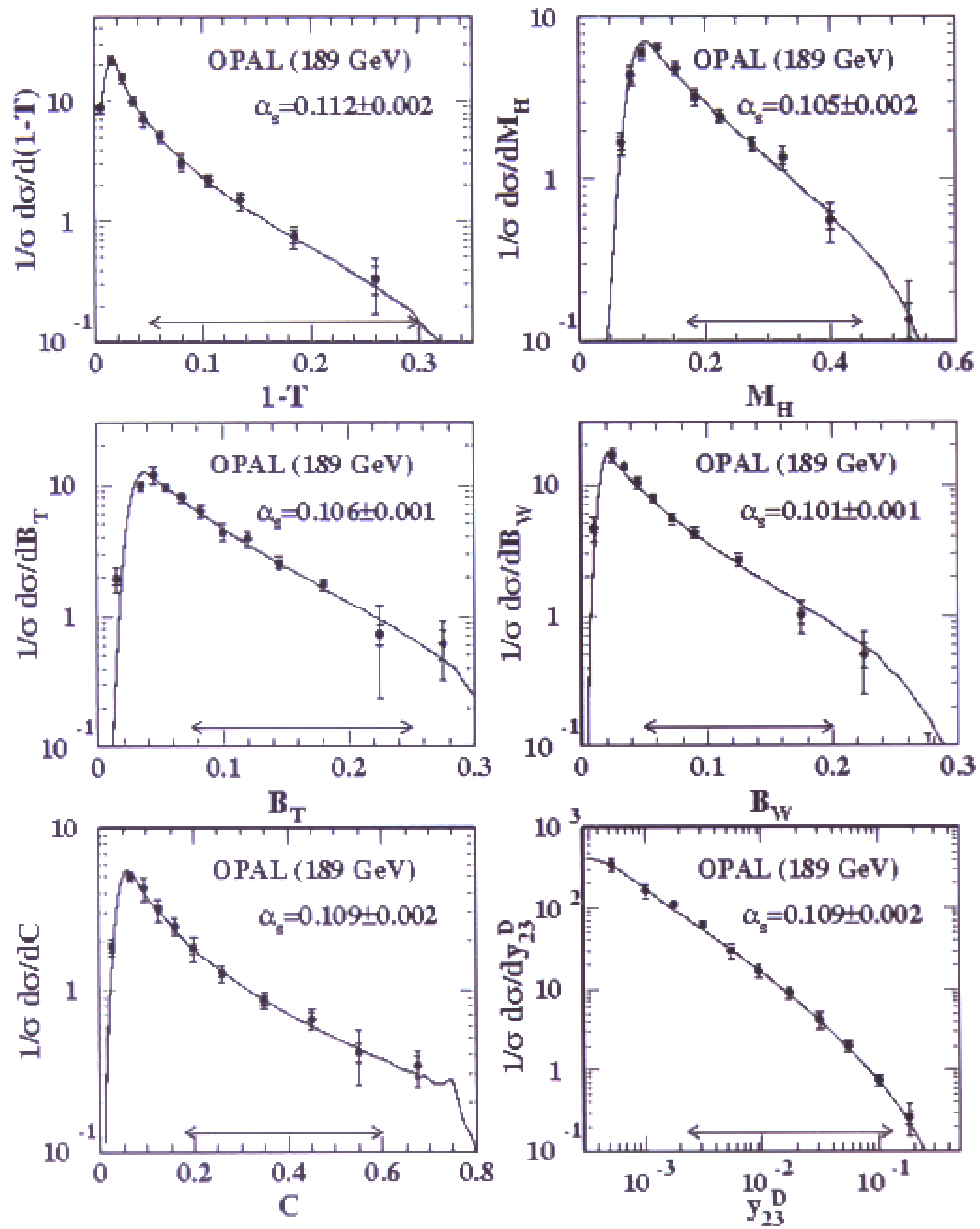
- uncertainties: matching schemes, modifications & renormalization scales $\rightarrow$ LEP QCD Working Group

Experimental Procedure

- Calculate perturbative predictions ⇨
- Calculate the hadronization corrections using Monte Carlo (JETSET, HERWIG, ARIADNE) ⇨
- Measure the distributions from data
- Correct to the hadron level accounting for acceptance, resolution, ISR etc. (`Detector corrections') ⇨
- Observables studied : Thrust, M_h^2, C_{par}, B_{tot}, B_w, $\ln y_3$, ...

Thrust..


1/2 ← Thrust → 1
(1/σ) dσ/dL
ALEPH
Fit Range
0.5
0.4
0.3
0.2
0.1
0
1.2
1.6
2
2.4
2.8
3.2
3.6
4
4.4
L=−ln (1−T)
non-perturbative
=soft gluons
perturbative
= energetic
gluons
Corrected
Uncorrected
3 jet region
T << 1
2jet region
T >> 0.5



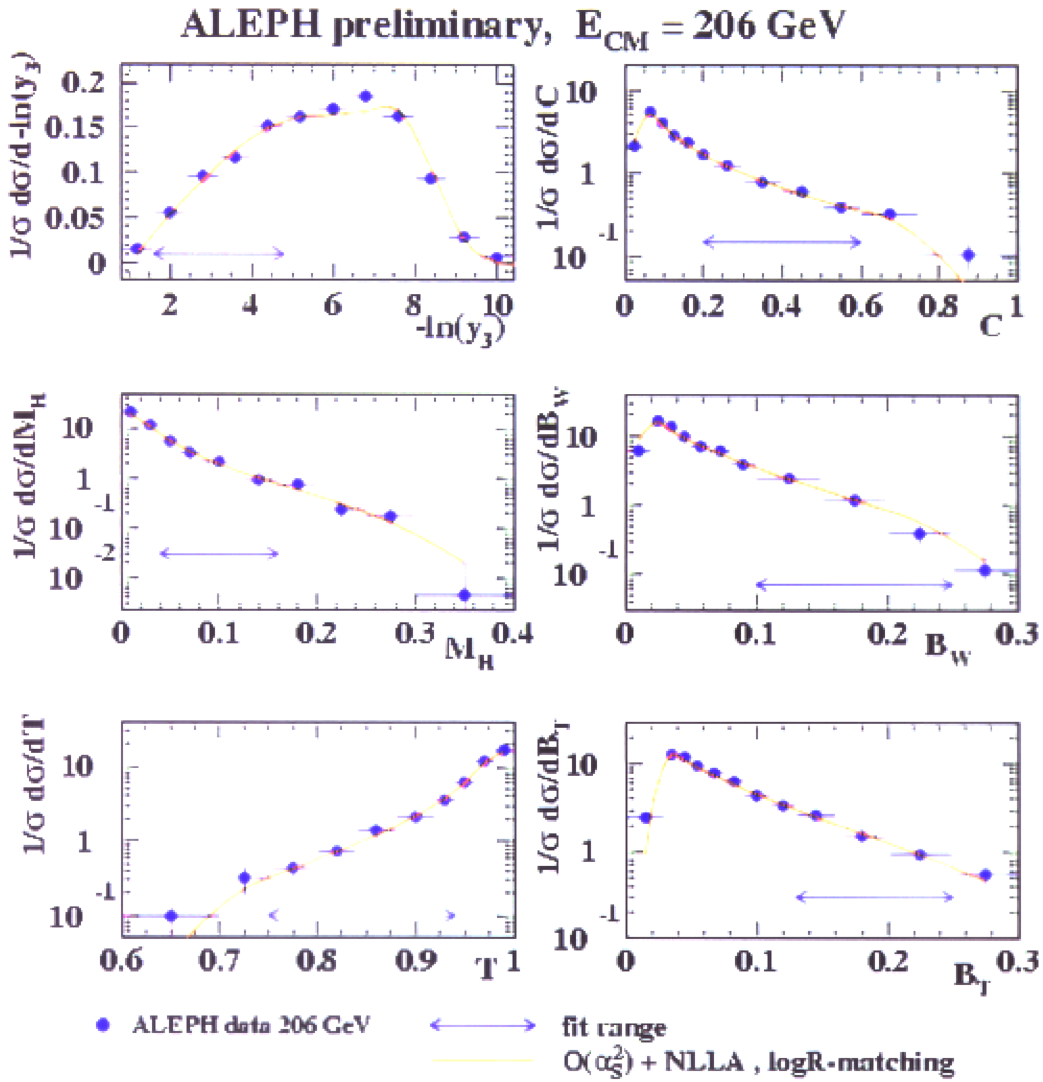
Many measurements at LEPI & LEPII

For example:

OPAL at

E_{CM} = 189 GeV

Another example :



Measurements using Data from 2000

$\alpha_s(206) = 0.1053 \pm 0.0028(\text{exp}) \pm 0.0041\ (\text{theo})$

$\alpha_s(M_Z) = 0.1181 \pm 0.0036(\text{exp}) \pm 0.0052\ (\text{theo})$

Combination of the 6 observables

Consider the various contributing uncertainties…

Uncertainties:

- Experi. : 0.0028
  - 0.0022 stat
  - 0.0017 model dep. — Use different MC To calculate acceptance etc
- Theory : 0.0041
  - 0.0016 matching
  - 0.0038 scale
  - 0.0007 hadronization
  - 0.0001 quark masses

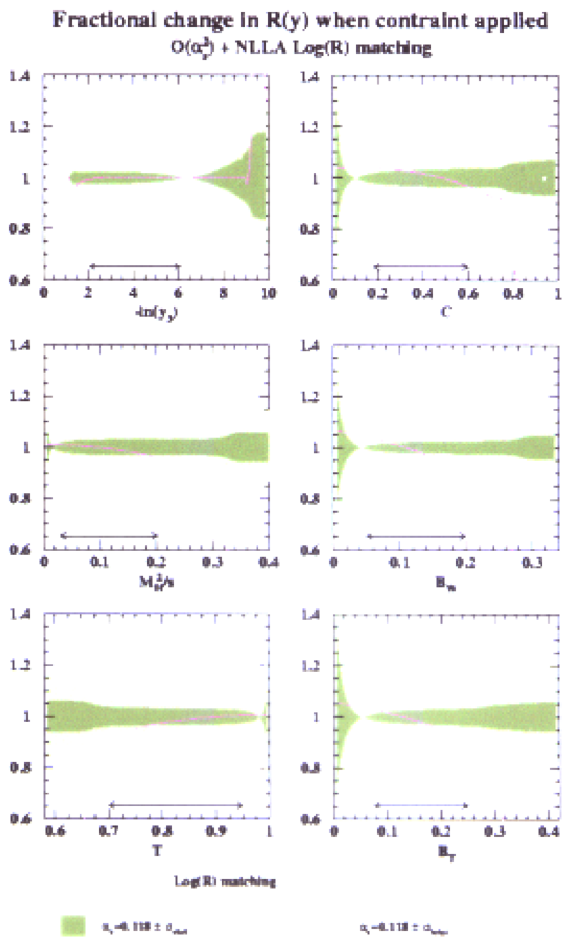
NNLO

Prego, grazie!

LEP QCD Working Group

- Ensure best combination of event shape results
- Comparable exptl. systematic estimation
- Common theory understanding – generally good agreement between experiments after ambiguities in definitions of `modified' etc
- Common treatment of scale uncertainties
- Common understanding of modification schemes and kinematic limits

Effect of modification scheme



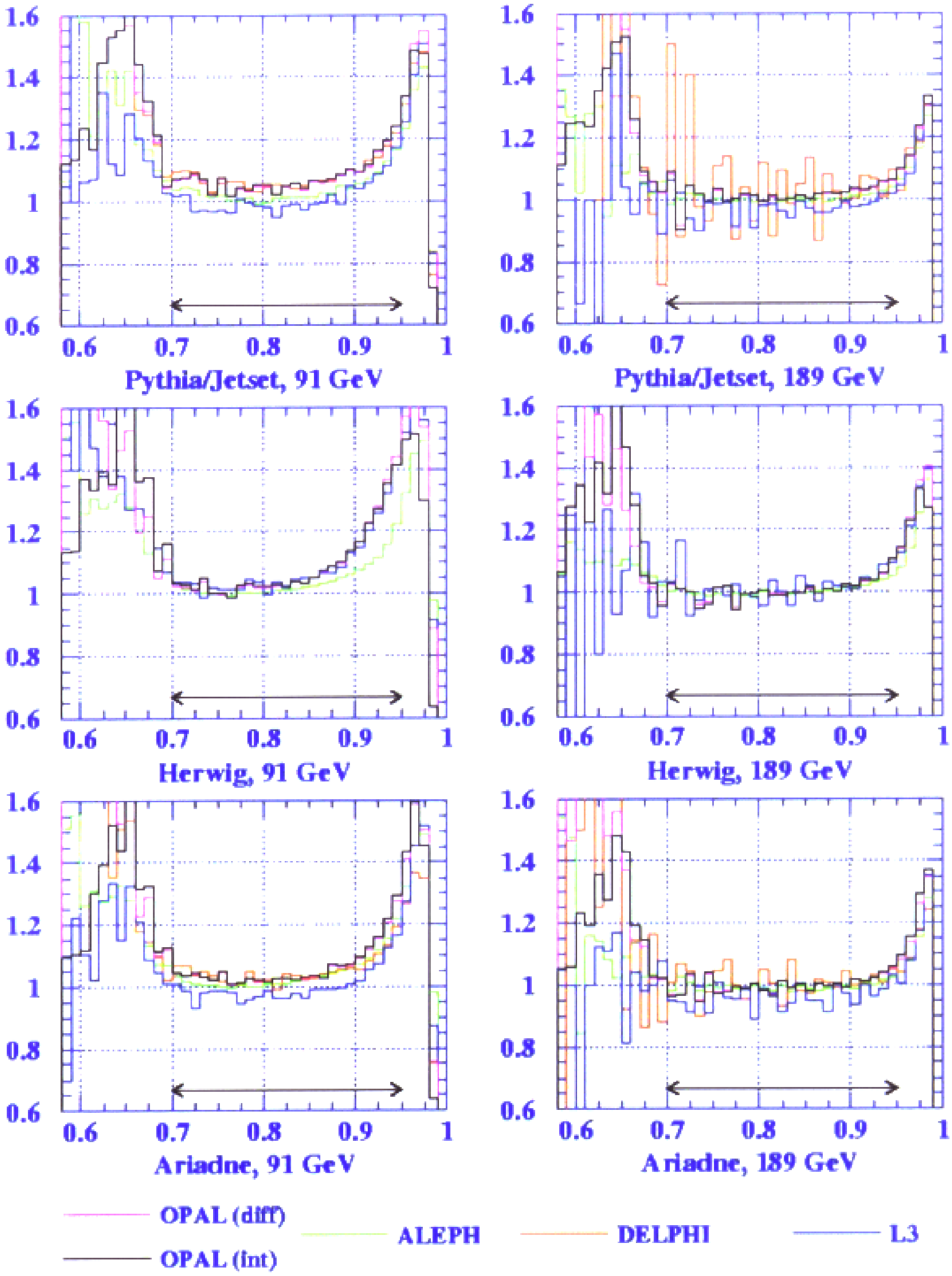
Errors typical for 1 expt. year 2000 data

- Not all experiments considered modification scheme previously
- Modification schemes varied, sometimes omitting kiniematic constraints

Hadronization uncertainties

- Hadronization differences between models and experiments large – need for more understanding
- Common definition of hadron level not yet in place (neutrinos included? Before weak decays?)

T hadronisation corrections

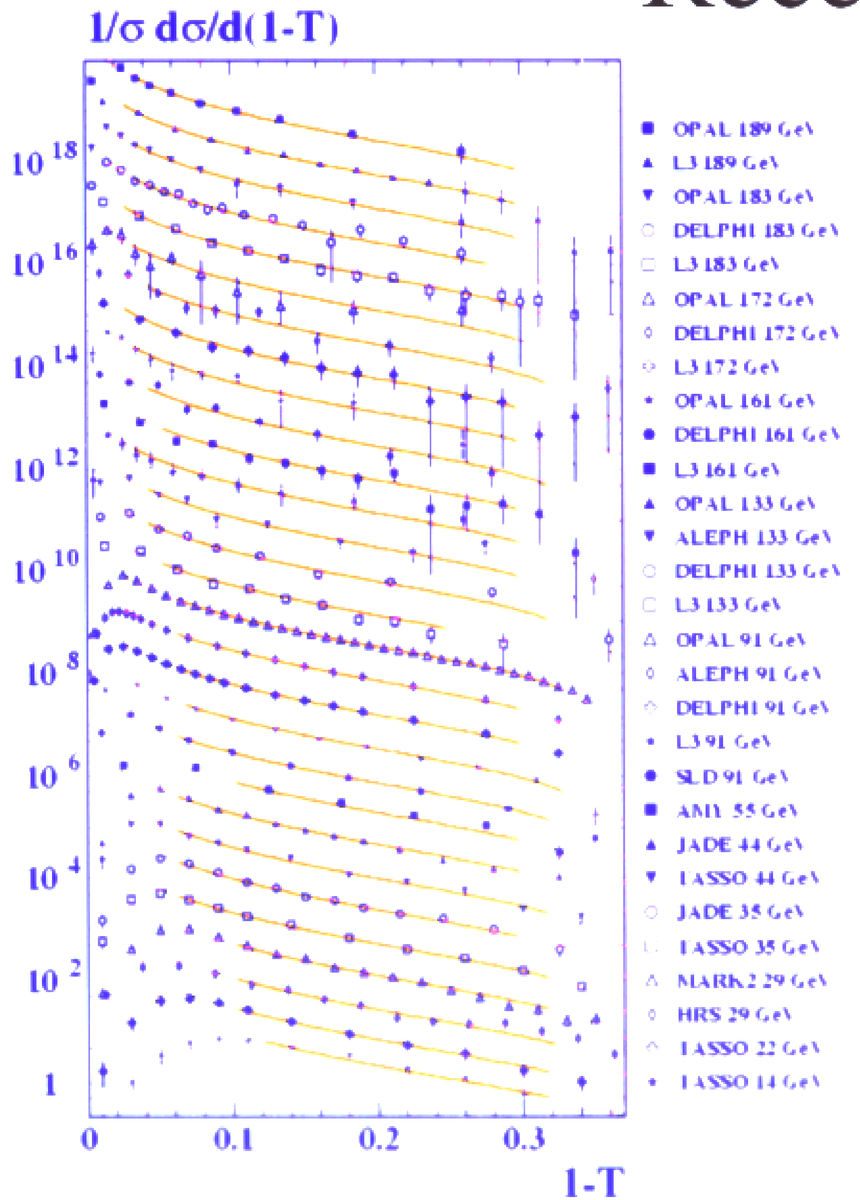


Power Corrections

- Alternative method for calculation of non-perturbative corrections to the perturbative predictions of the moments of event shapes and their ~~moments~~ distributions

- Makes the measured α_s less "model-dependent", through the introduction of a new phenomenological parameter α_0

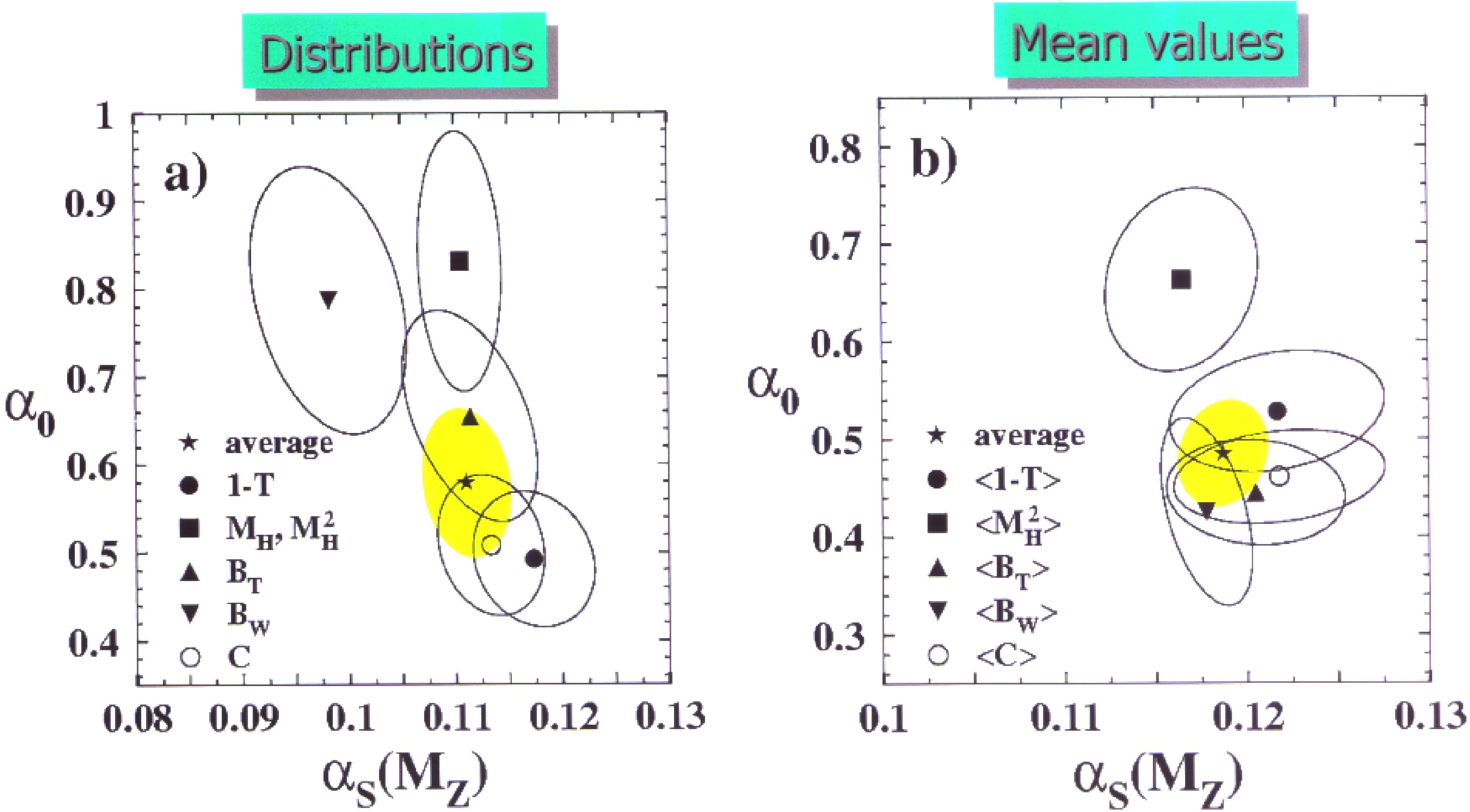
Recent analysis



- S. Kluth
  - Moriond01
  - hep-ex/0104016
  - Determination of

    α_s
    - colour factors
    - Transverse cross-section
  - uses power corrections

Results of Kluth analysis



$\alpha_0 = \alpha_0(2\ \mathrm{GeV})$ (see HEP-EX/0104016)

Comments on power corrections

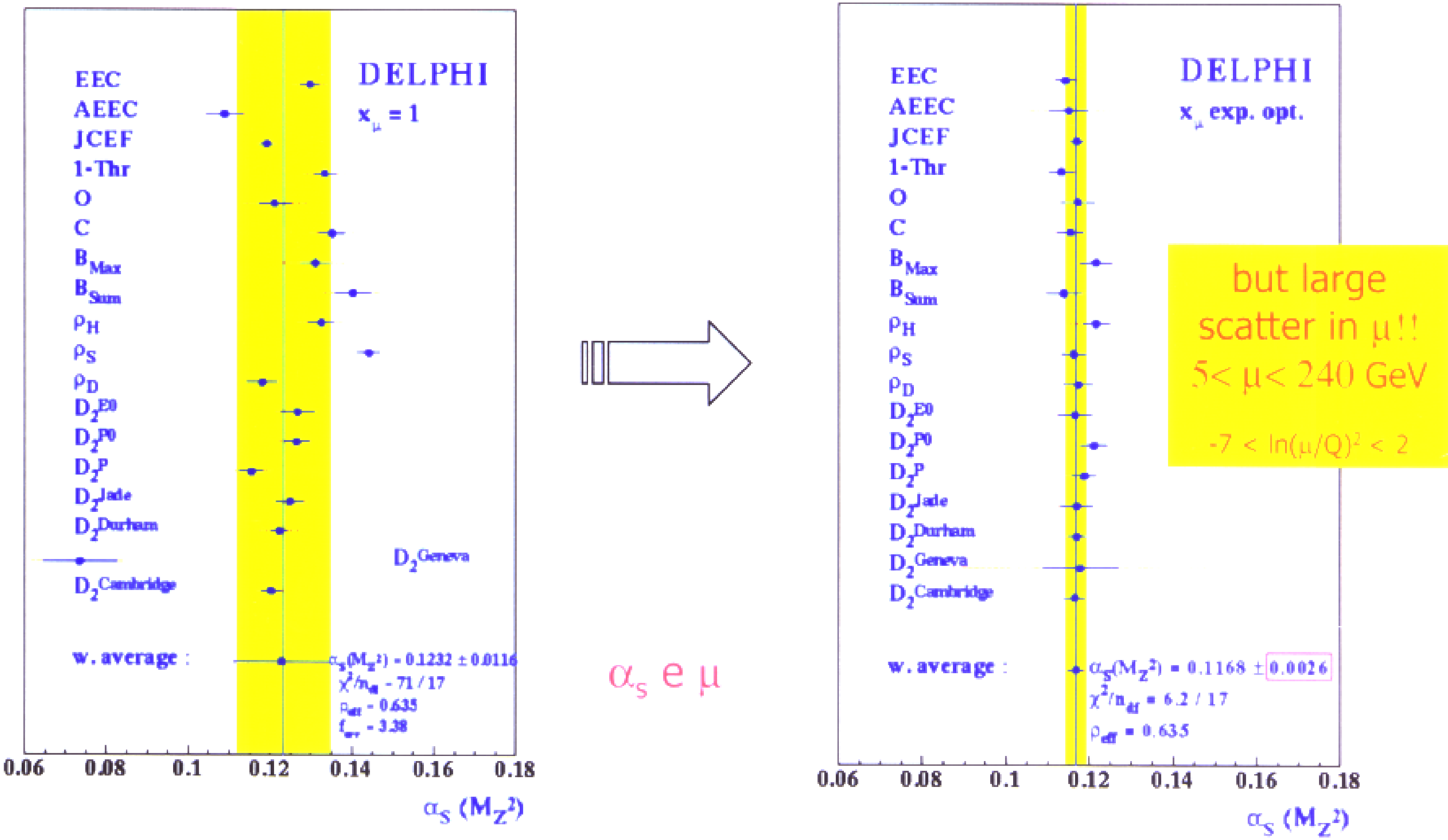
- Continuous theoretical and experimental developments

- confronting predictions with data essential
  - Nice example is broadening!

- Universality of α_0 tested at 20% level

- Still needing more detailed study:
  - Effect of hadron masses
  - Resonance decays
  - Importance of $1/Q^n$ corrections $\forall n$ as postulated by Sterman et al.

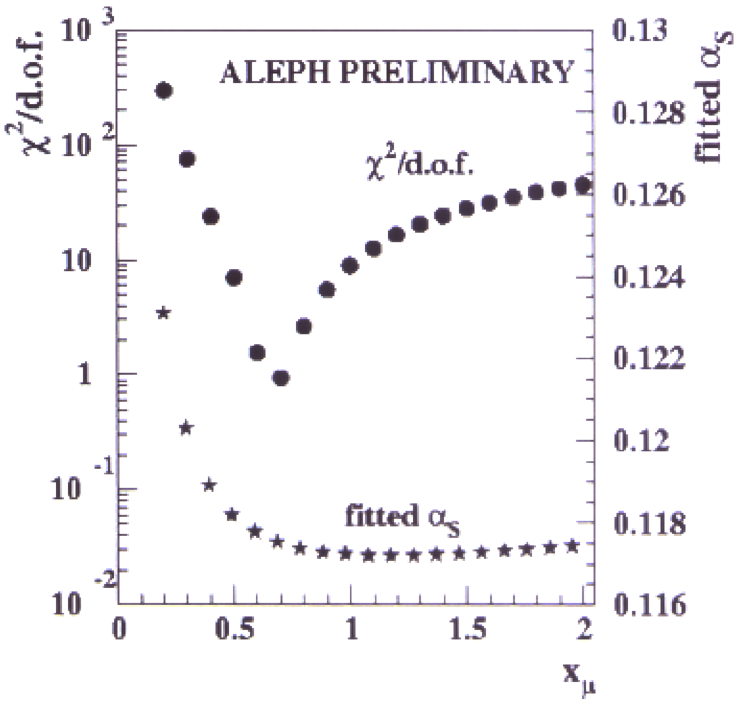
DELPHI fixed-order, fit for scale



Another indication of important NNLO contributions...

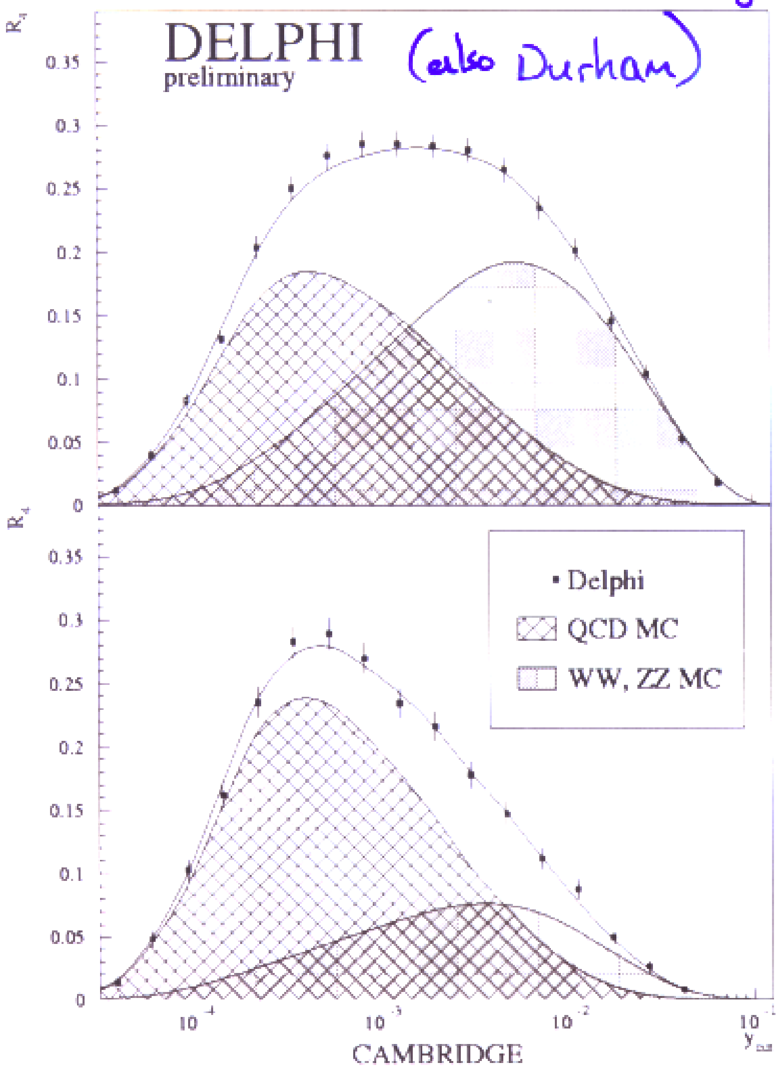
Four-jet observables

- The use of variables that start at O(α2) should have reduced higher order effects
- Evidence from reduced ~~matching~~ renormalization scale dependence etc



207 GeV (+ other energies)

before cuts



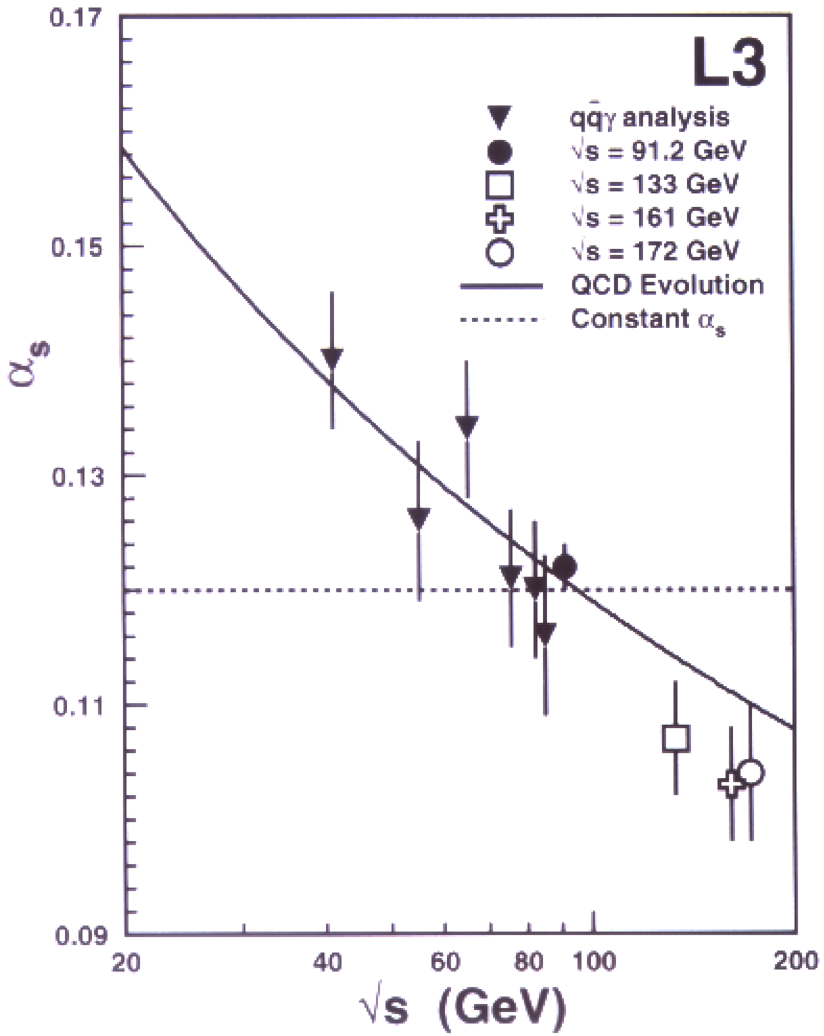
after cuts

$\Rightarrow \alpha_s(M_Z^2) = 0.1175 \pm 0.0022$

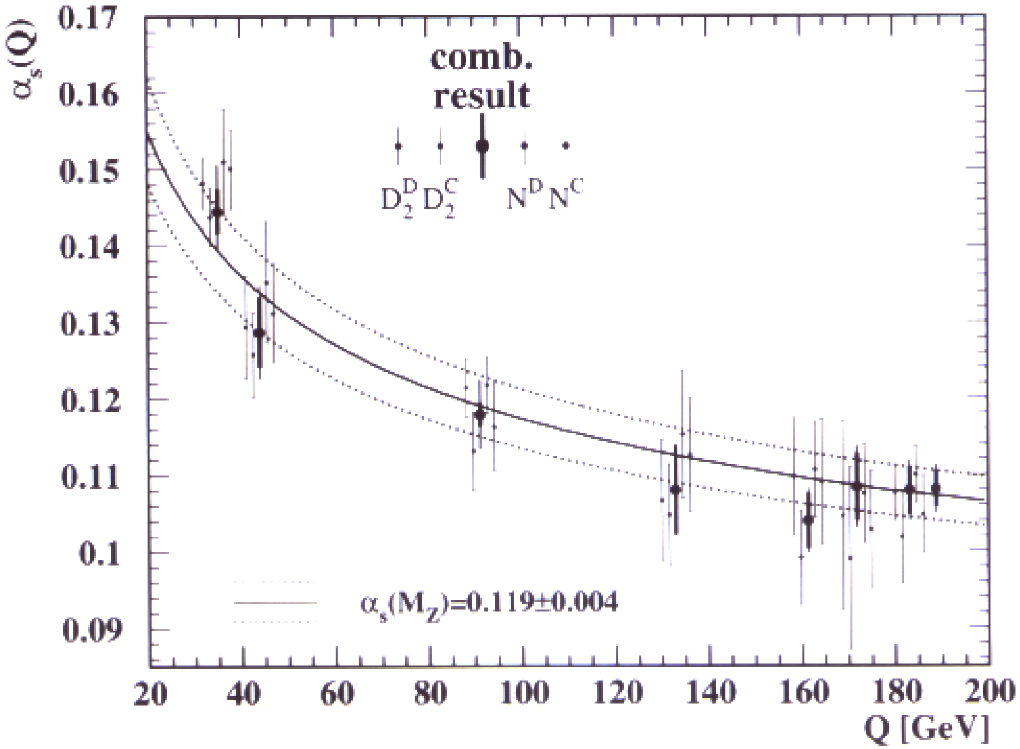
(i.e. 0.0010 stat $\pm$ 0.0017 (had) $\pm$ 0.0007 (scale))

How to study a large range in energies?

= particularly interesting for the study of non-perturbative phenomena



- The L3 approach:
  - select events with energetic initial state photon (ISR)
  - measure event shapes of the reduced mass hadronic system



- OPAL+JADE approach:
  - reanalysis of JADE data
  - Need to include some observables not originally studied at JADE
  - A good example of the need for complete analysis and effective archival of LEP data!!

Scaling Violations in fragmentation functions

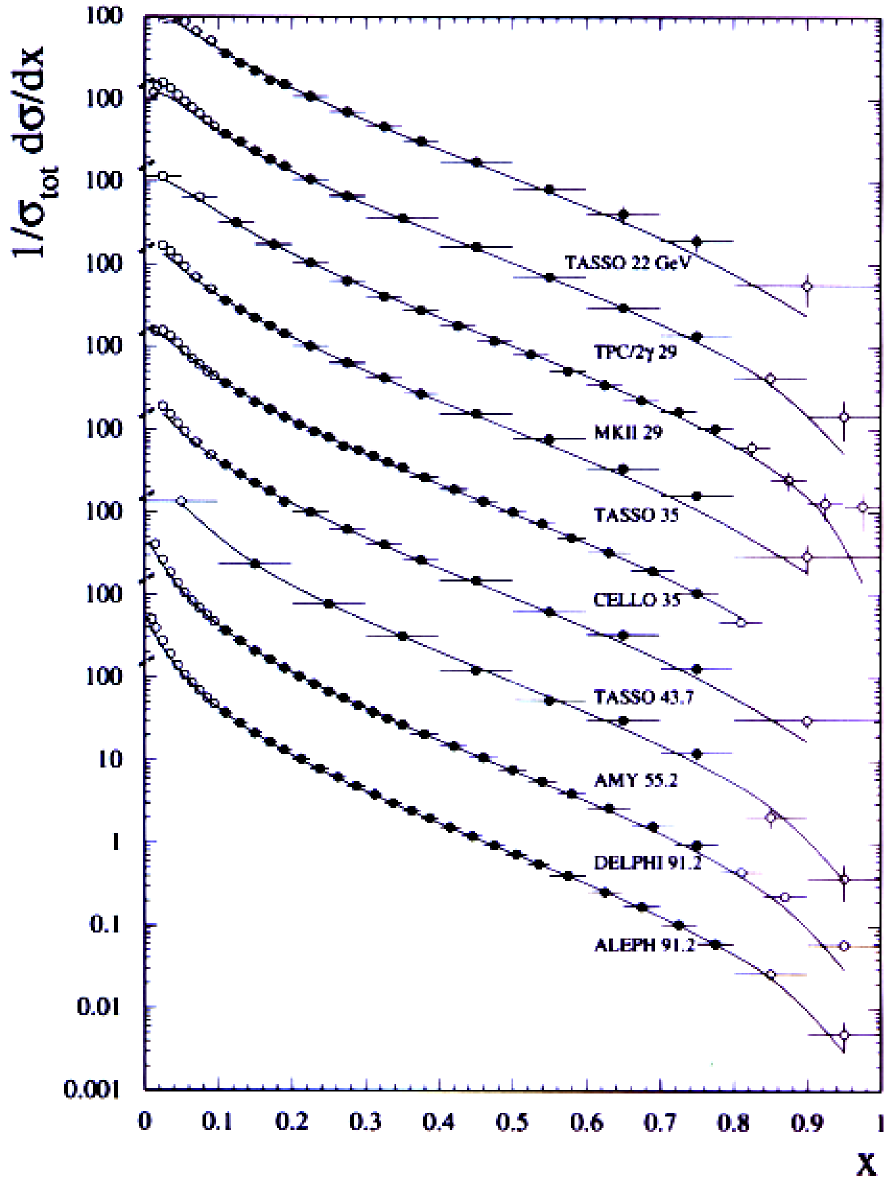
- Inclusive hadron spectra
- Shape is non-perturbative
- but pert. QCD gives the energy dependence

$$\frac{dD(x,Q)}{d\ln Q} \propto \int_x^1 \frac{dz}{z} \alpha_s P_{AP}(z) D(x/z,Q)$$

⬇

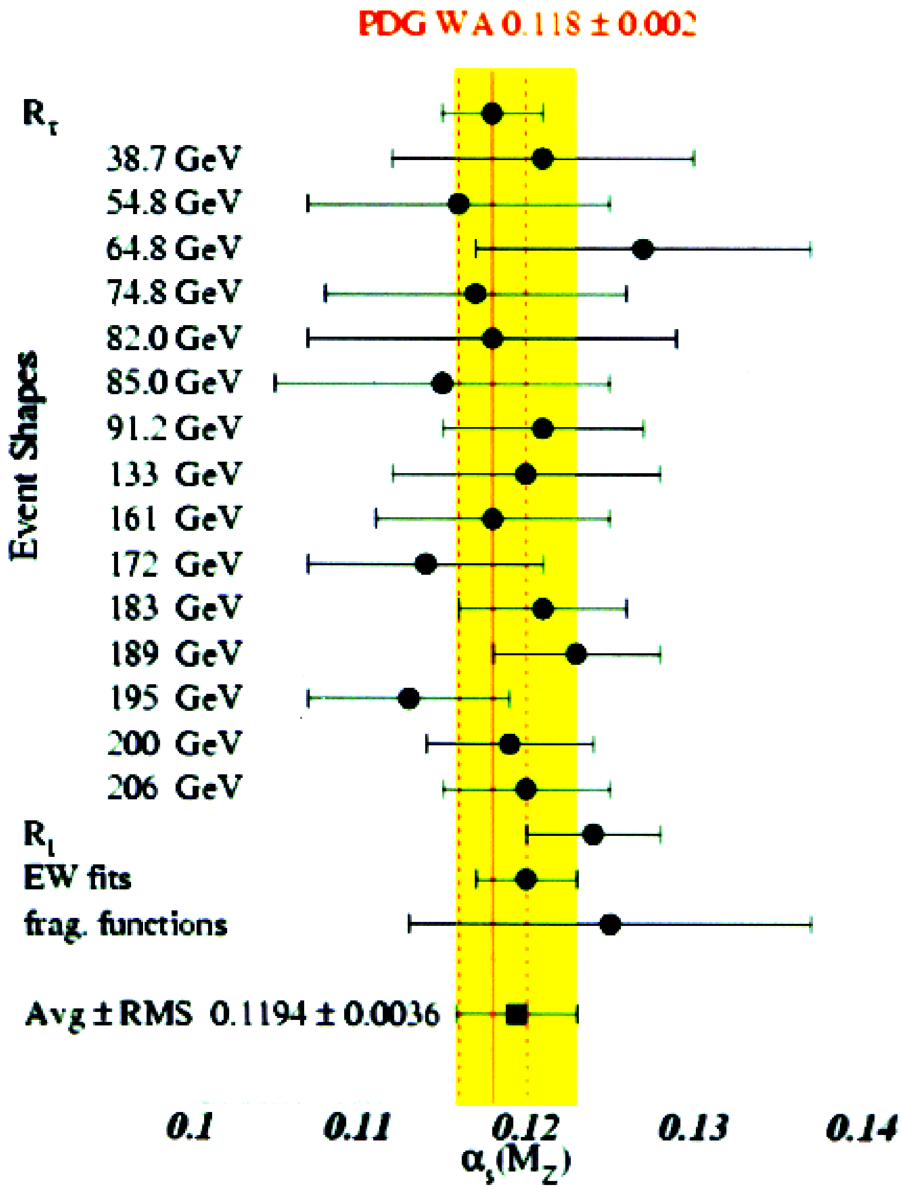
- Parameterize the shape at one energy and measure α_s from a fit to the energy evolution

$\alpha_s(M_z) = 0.126 \pm 0.007(\text{exp}) \pm 0.009\ (\text{theo})$



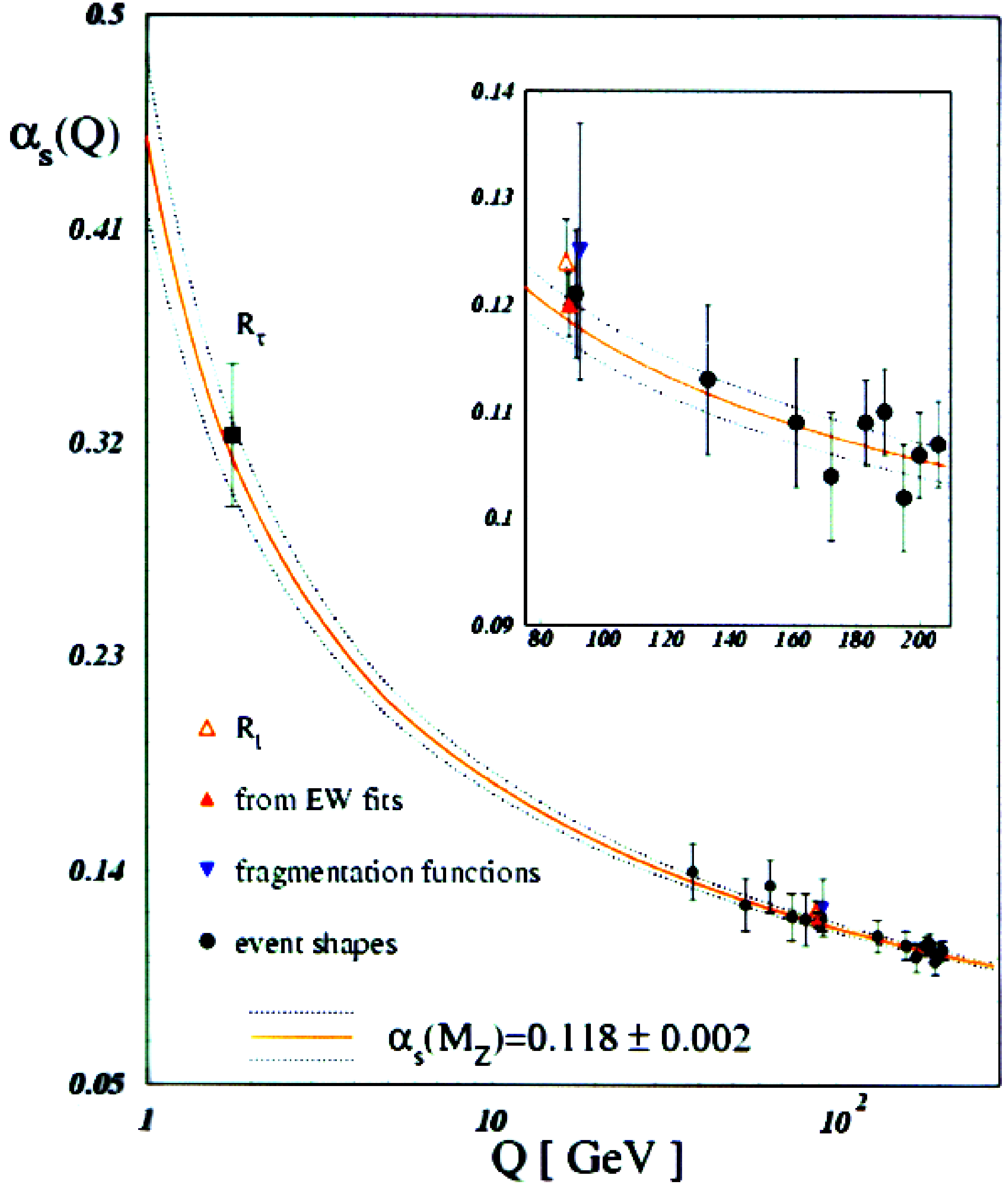
Bethke, from ALEPH and DELPHI distributions

Summary



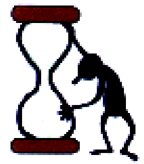
- Using only LEP measurements
- Private selection of measurements (Dissertori & Jones!)
- Several measurements preliminary
- Mean value is very stable
- Estimate of the error we leave to PDG, Bethke, LEPQCDWG,...

caution:
extractions
assume running
implicitly



Conclusions

- Each LEP (I and II) has made important contributions in measuring α_s and the current precision



- In recent years : new phenomenological developments (*power corrections*) which could
  - Make the measured α_s independent of the MC model
  - Tell us about the non-perturbative physics (maybe!)

- Hopes for the future…
  - LEP data will remain accessible for many years
  - because NNLO calculations are on the horizon..