QCD Studies and α_s Measurements from e^+e^- Annihilations at LEP

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on behalf of the LEP collaborations

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Beijing, China

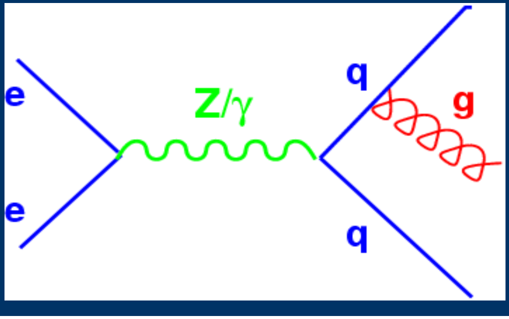
Outline:

- Event Selection and Data Samples
- Event Shapes at LEP1 and LEP2 energies
- Events Shapes using Radiative Hadronic Events
- Studies of Power Law Corrections
- Jet Rates

(charged particle multiplicity distributions omitted)

ALEPH: 5-0075, Eur. Phys, J. C35, 457 (2004)
DELPHI: 5-0748, hep-ex/0400611, accepted by EPJC
5-0731, to be submitted to EPJC
L3: 5-0235, hep-ex/0406049, submitted to Phys.Rept.
OPAL: 5-0515, OPAL Physics Note 519 (prel.)
5-0527, submitted to EPJC
5-0600, OPAL Physics Note 527 (prel.)

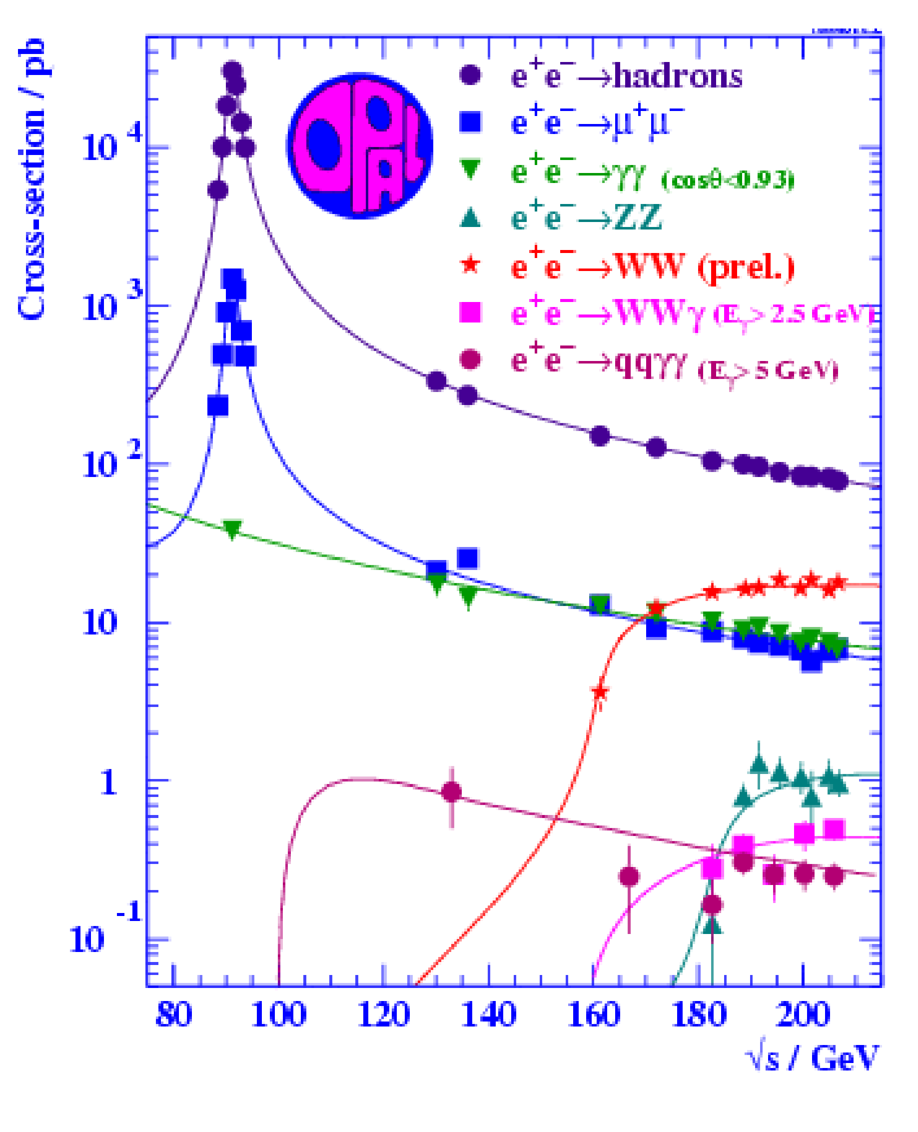
Event Selection and Data Samples



$\sqrt{s}$

typical numbers (ALEPH, 1994-2000):

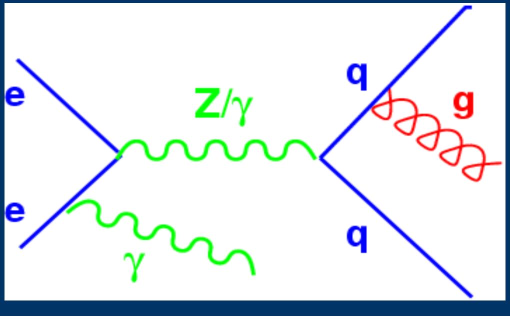
Ecm (GeV)	L (pb-1)	Events	Backg. %
91	41	>10^6	<1
133	12	806	<1
161	11	319	5
172	10	257	10
183	57	1319	12
189	174	3578	13
200	208	3528	15
206	216	3590	15



- main background from
  WW, ZZ $\rightarrow$ four fermions

- events with Intial State Radiation (ISR) need to be identified/removed

Event Selection and Data Samples



√s '

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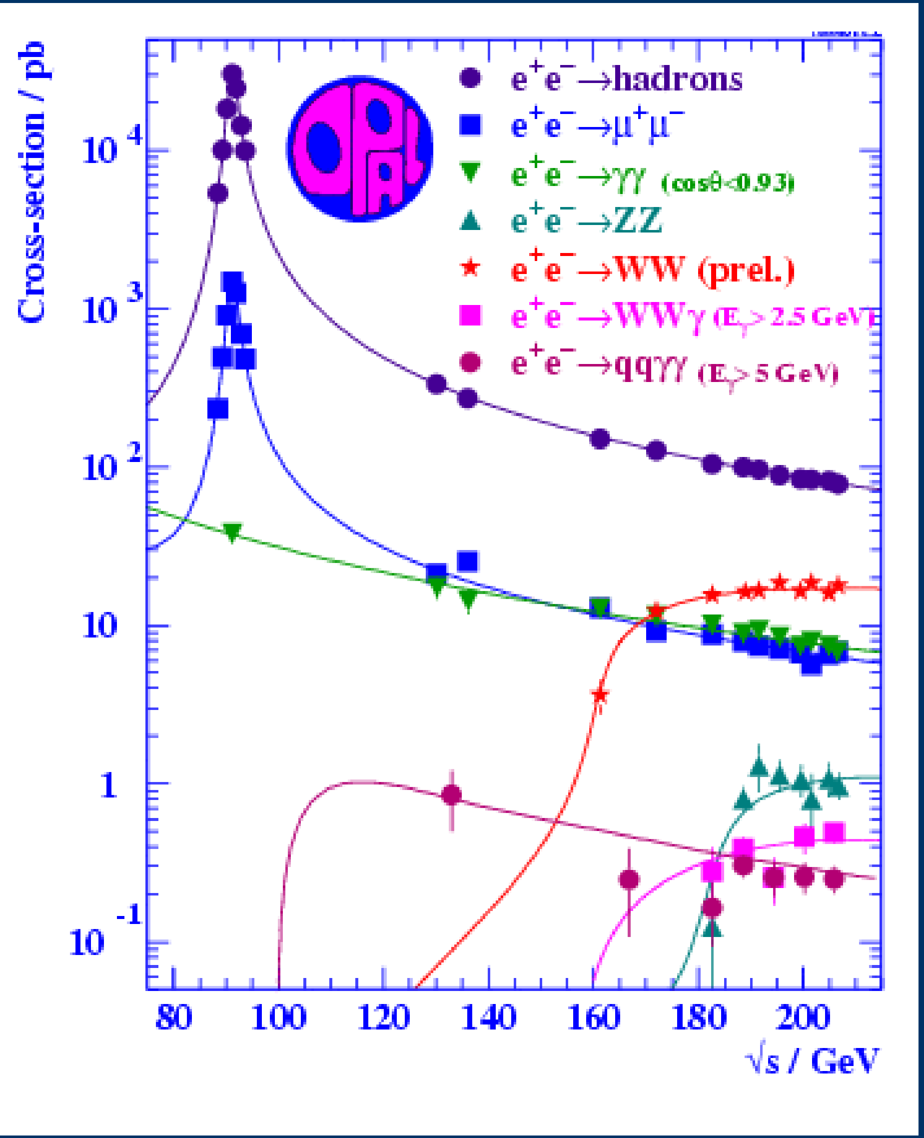

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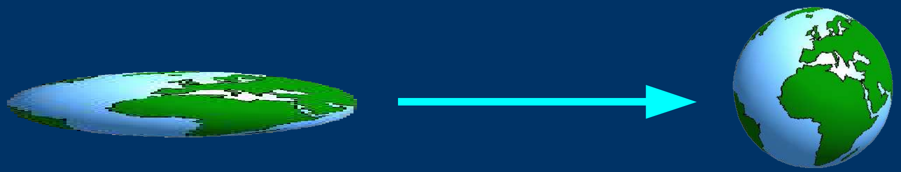
Event Shape Observables



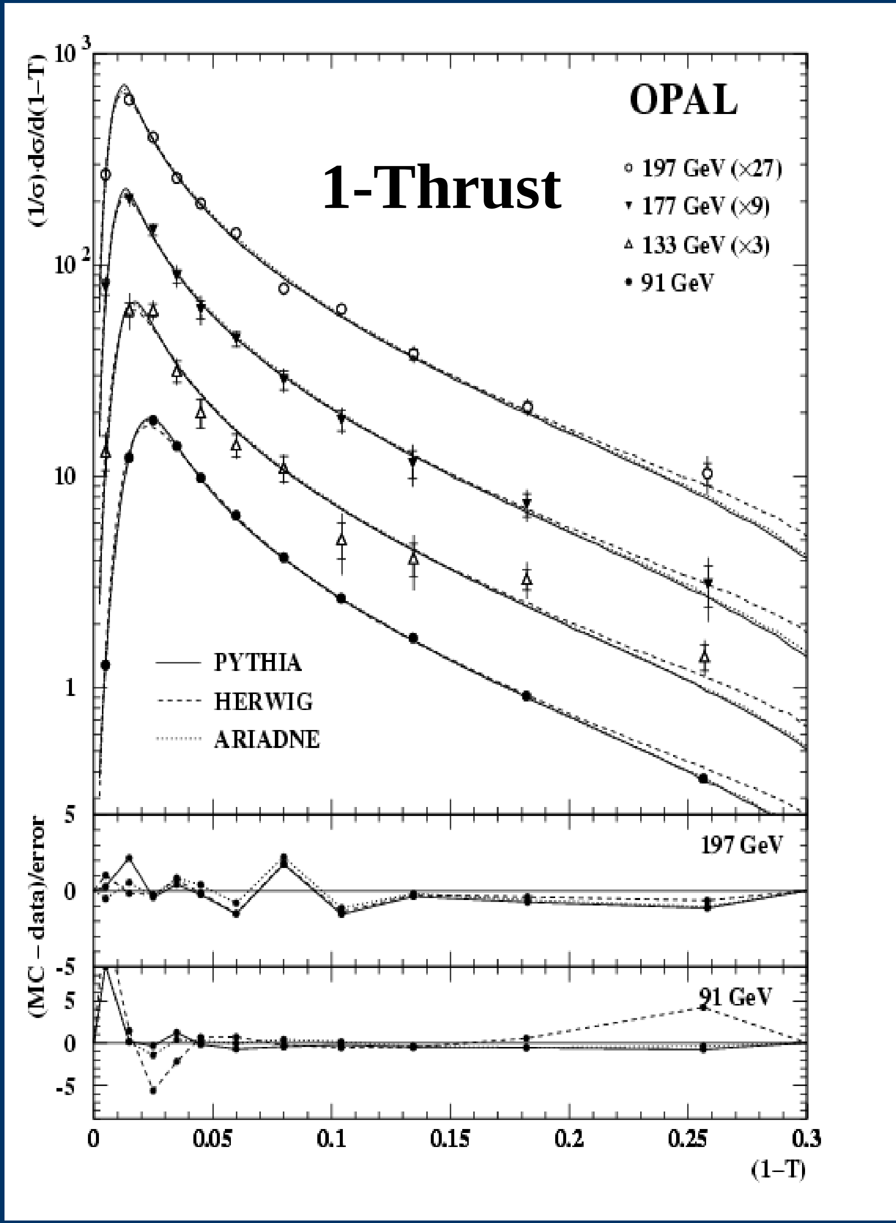
Inclusive quantities which characterize geometry of event (planar, spherical, pencil-like..)

Infra-red safe (soft gluon emission)
Collinear stable (collinear parton branchings)

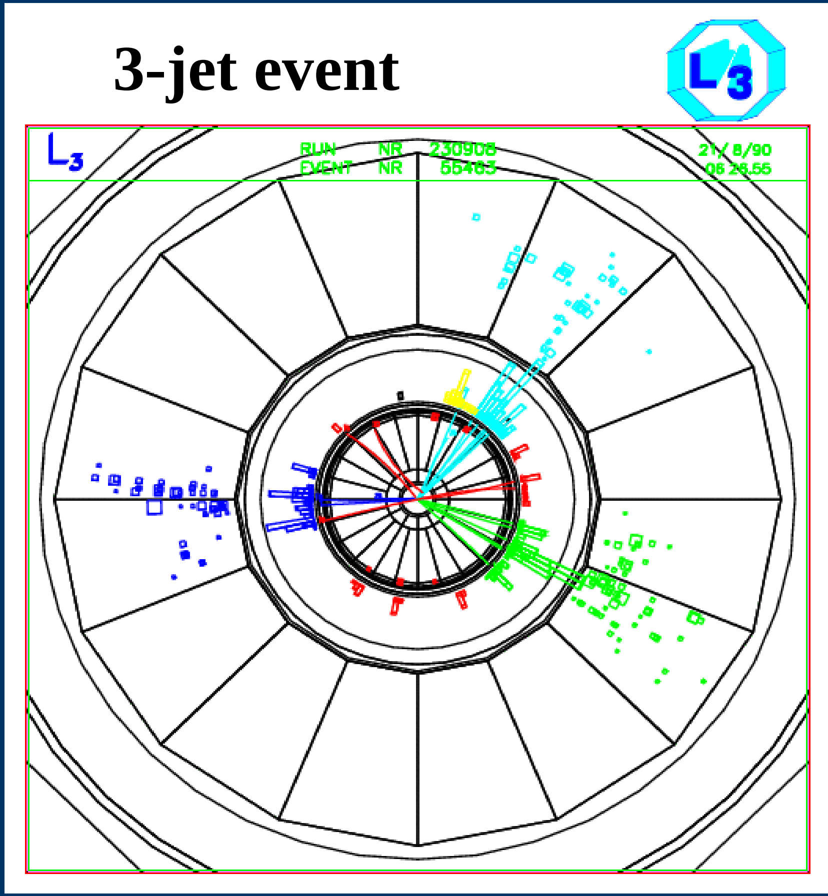
Example: Thrust (or better 1-Thrust)

Thrust axis $\vec{n}_T$ is chosen to maximize the sum of the absolute momentum components of all particles projected on that axis

$$T = \max_{\vec{n}_T}\left(\frac{\sum_i |p_i \cdot \vec{n}_T|}{\sum_i |p_i|}\right)$$



Six Standard Event Shape Observables



Thrust 1-T:

Thrust axis divides event into two hemispheres

Heavy jet mass M_H:

Heavier scaled jet mass of the two event hemisphere

C-parameter

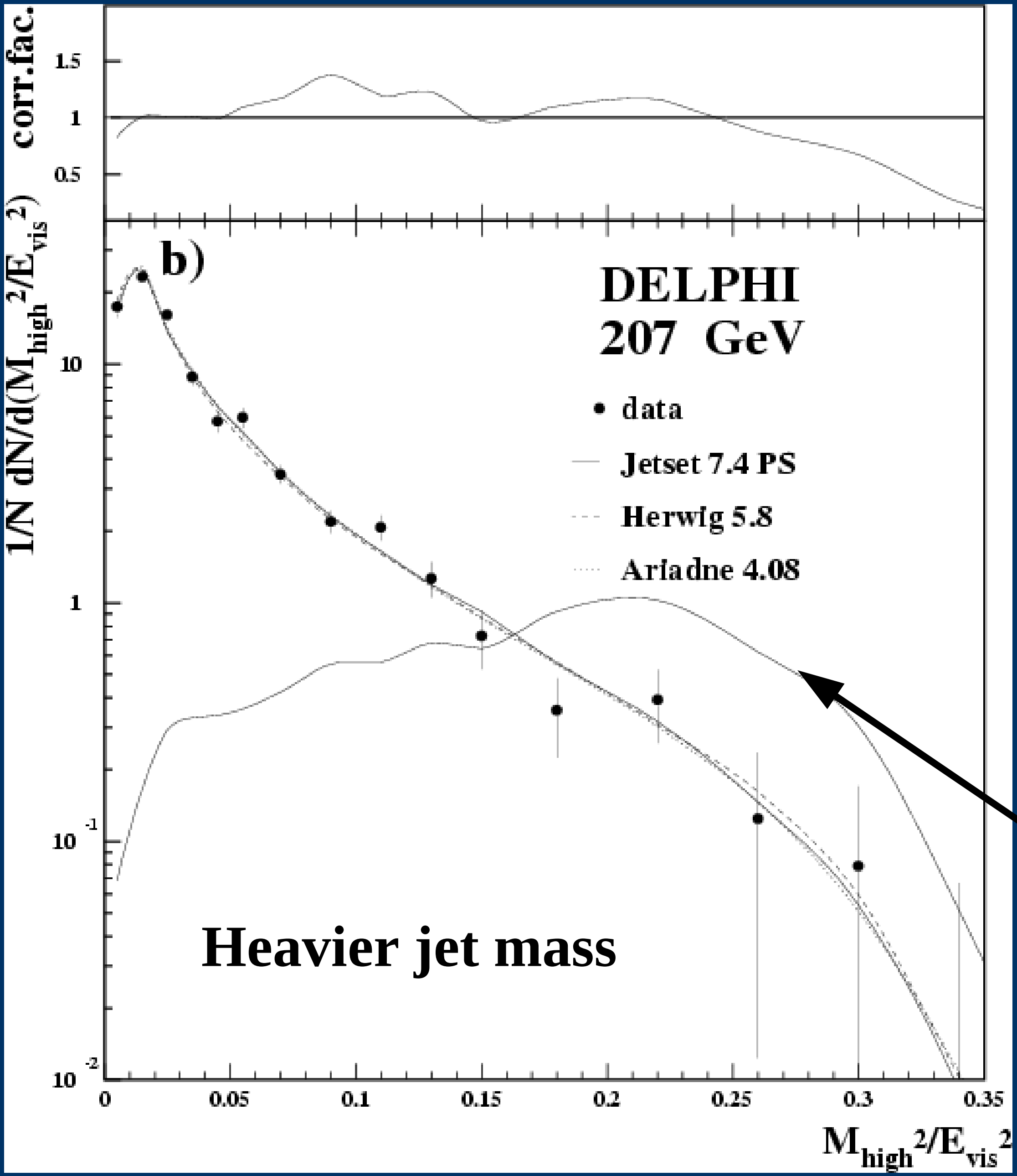
Sum of eigenvalues of the momentum tensor

Total jet broadening B_T and wide jet broadening B_W:

Sum (Maximum) of the jet broadenings of the two hemispheres

y_{23}:

Transition value between 2 and 3 jets for the Durham algorithm



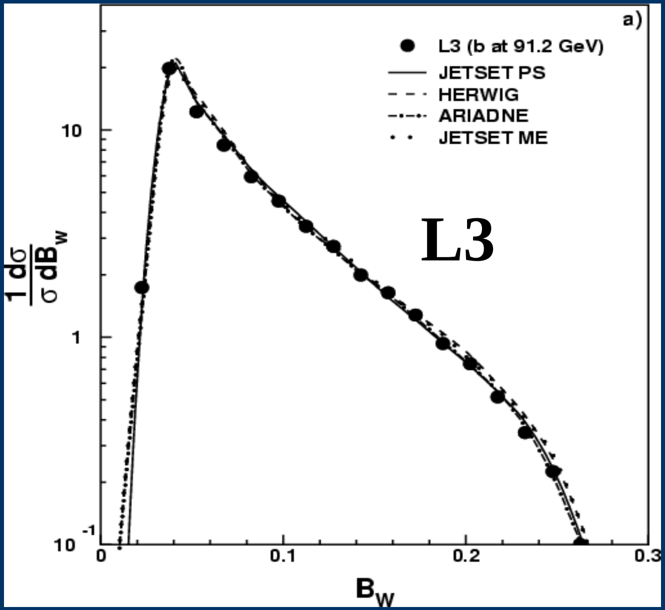
- Calculated from all neutral and charged particles in the event (tracks/clusters)

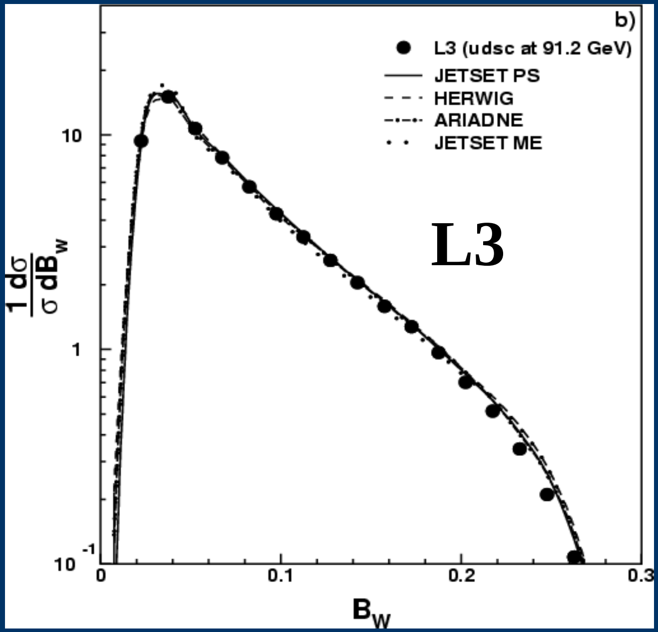
- Data and Monte Carlo are usually in very good agreement

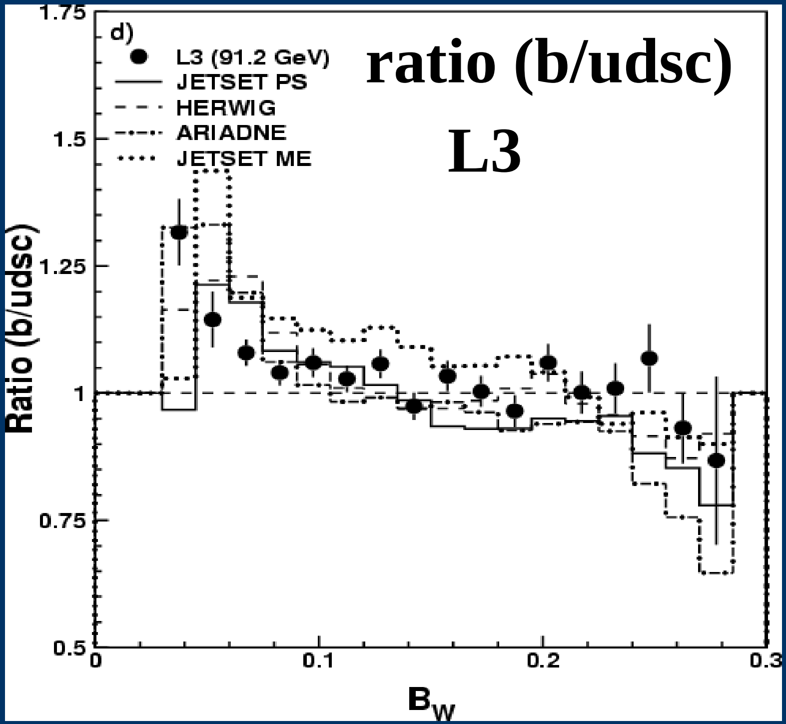
- Simple bin-by-bin unfolding methods can therefore be used

Four-fermion background subtracted (dominates at high y)

Event shape variables depend on quark mass







Wide jet broadening B_w

Two theory predictions exist for all six observables y:

$$R(y)=\int \frac{1}{\sigma}\frac{d\sigma}{dy}dy$$

1) $\mathcal{O}(\alpha_s^{\,2})$ calculation

$$R_{\alpha_s^2}(y)=A(y)\bar{\alpha}_s+B(y)\bar{\alpha}_s^2 \quad \text{with} \quad \bar{\alpha}_s=\frac{\alpha_s}{2\pi}$$

Matrix elements – best for multi-jet region (high y)

2) NLLA calculation

$$R_{NLLA}(y)=(1+C_1\bar{\alpha}_s+C_2\bar{\alpha}_s^2)e^{(Lg_1(\alpha_s L)+g_2(\alpha_s L))} \quad \text{with} \quad L=\log\frac{1}{y}$$

Summation of leading logarithms – best for two-jet region (low y)

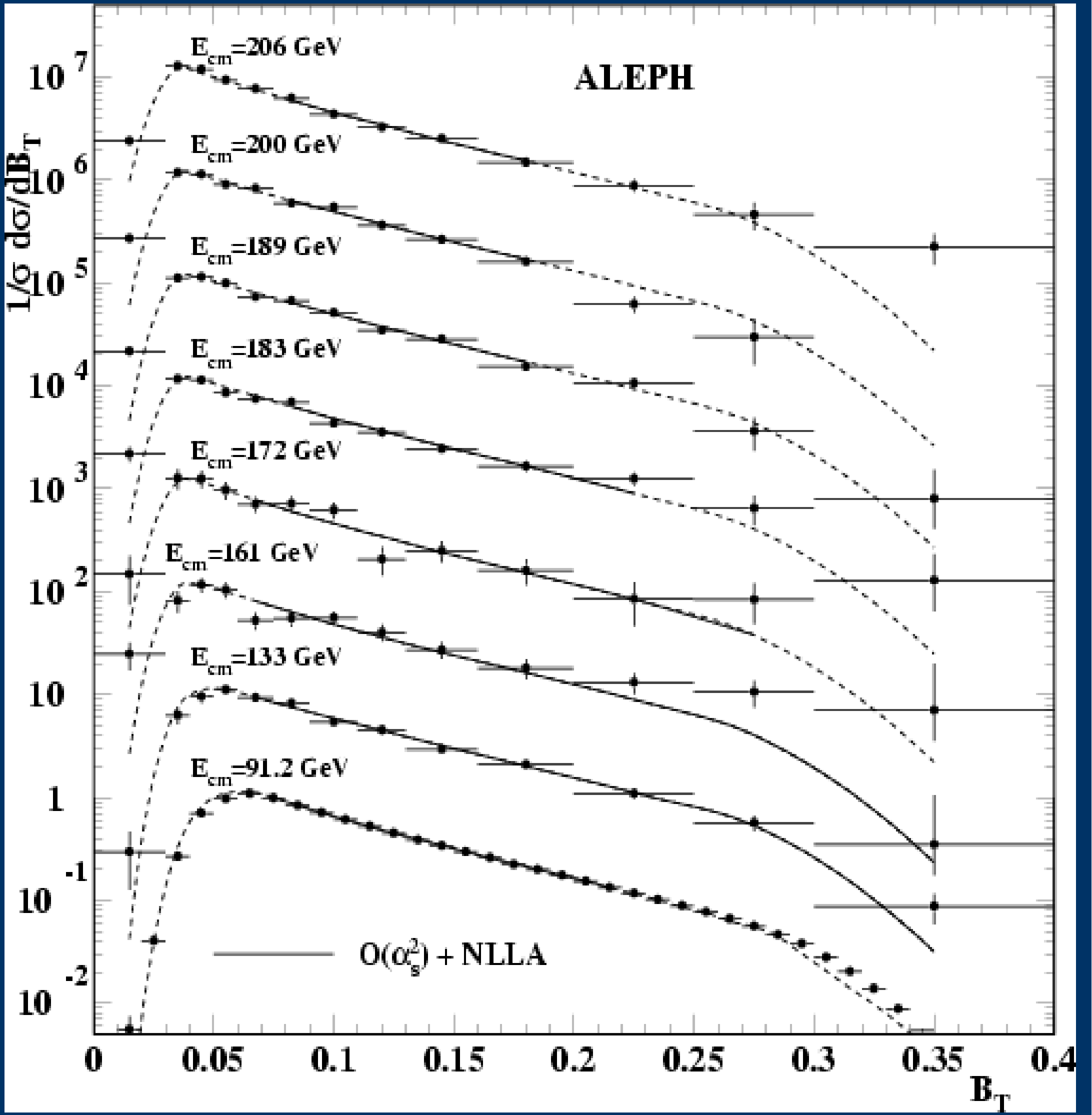
α_s is obtained by fitting the event shape distributions with theory predictions

best description if we match both calculations:

$$\log R(y) = \log R_{\alpha_s^2}(y) + \log R_{NLLA} - \textit{extra terms}$$

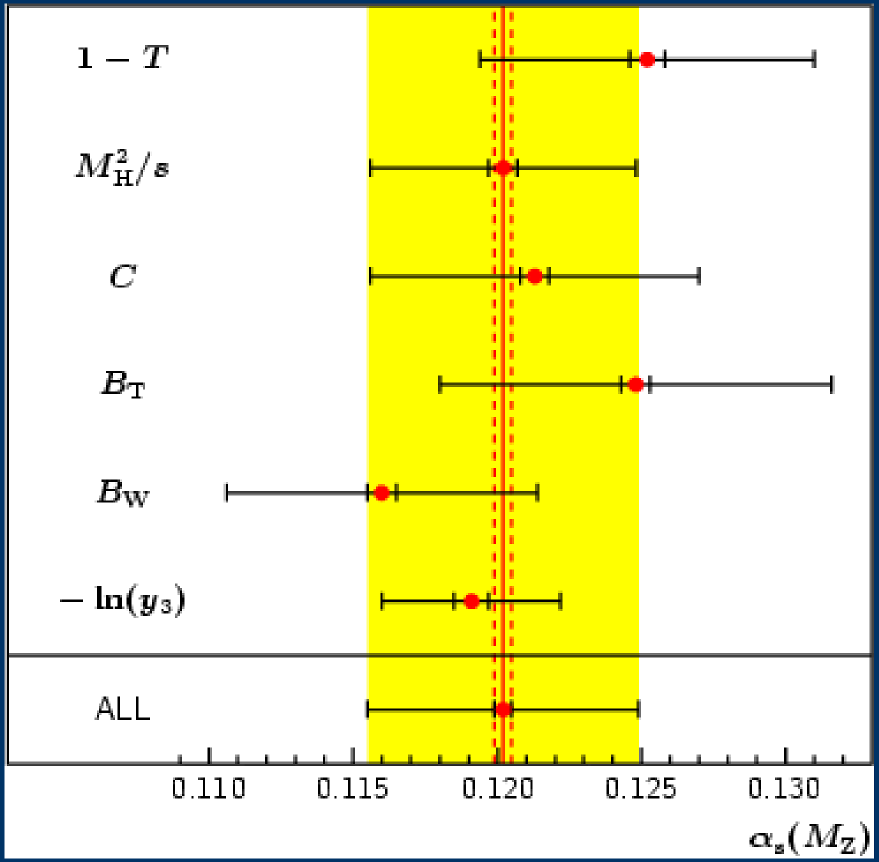
where 'extra terms' are α_s^2 terms in the NLLA calculation

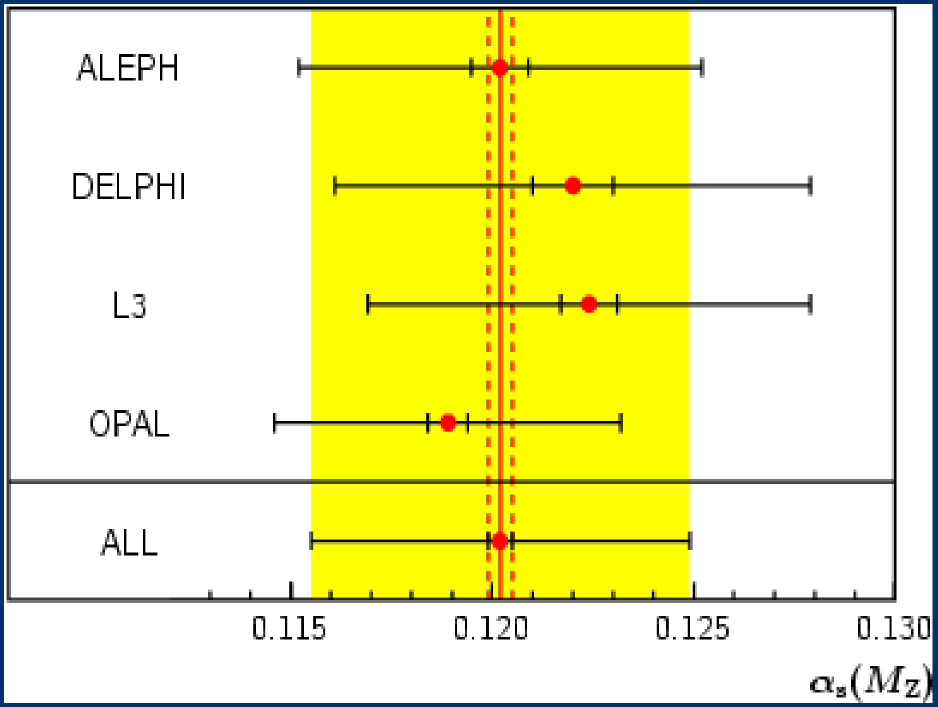
'(modified) log R matching'



Jet Broadening B_T

M. Ford, LEP-QCD WG,
prel. combination using final inputs





$$\alpha_s(M_Z) = 0.1202 \pm 0.0003(\text{stat}) \pm 0.0007(\text{expt}) \pm 0.0015(\text{hadr}) \pm 0.0044(\text{theo})$$

Sources of uncertainty

$\alpha_s(M_Z) = 0.1202 \pm 0.0003(\text{stat}) \pm 0.0007(\text{expt}) \pm 0.0015(\text{hadr}) \pm 0.0044(\text{theo})$

- Experimental

  cut variations, detector corrections etc.

- Hadronization

  comparing HERWIG, ARIADNE and PYTHIA

- Theory (see R. Jones et al, JHEP 12, 7 (2003))

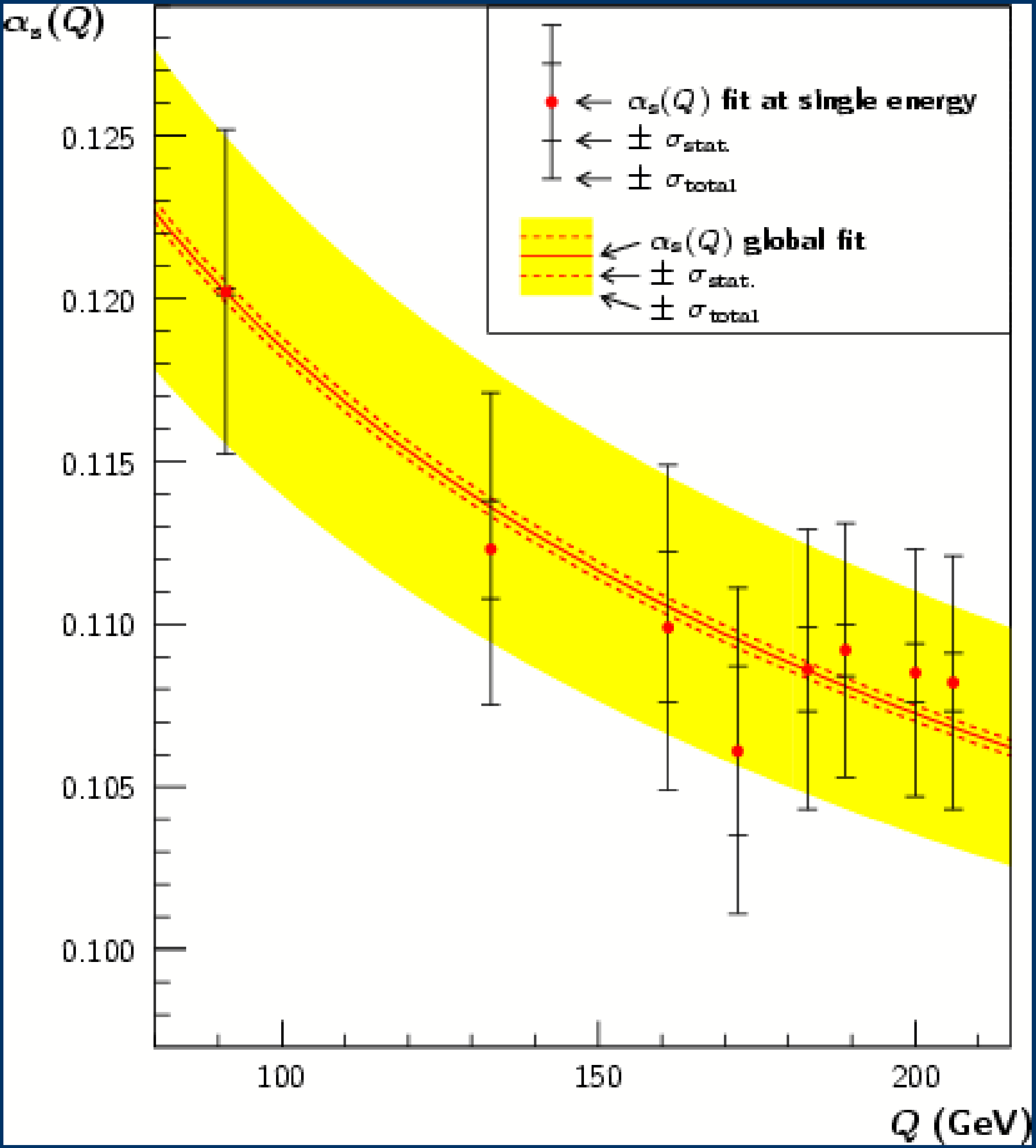
  variation of renormalisation scale $0.5 < x_\mu < 2$
  variation of logarithmic rescaling factor $2/3 < x_L < 3/2$
  'modified log(R) matching' vs 'modified R matching'
  variation of kinematic cutoffs

The running of α_s

Relative weight of results in global fit:

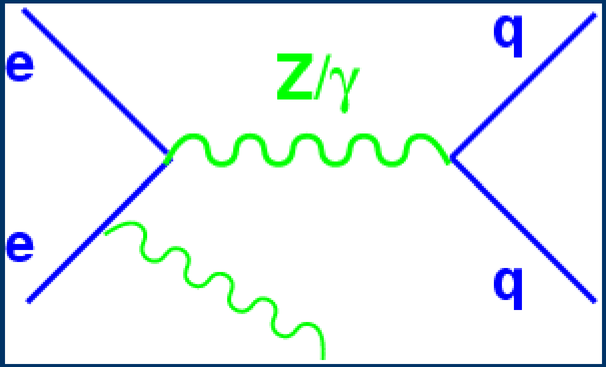
46% LEP1

54% LEP2

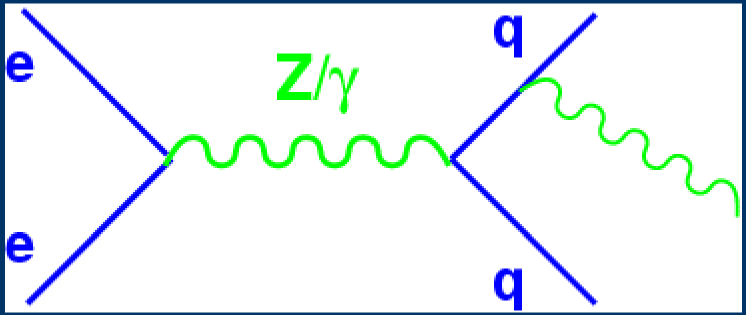


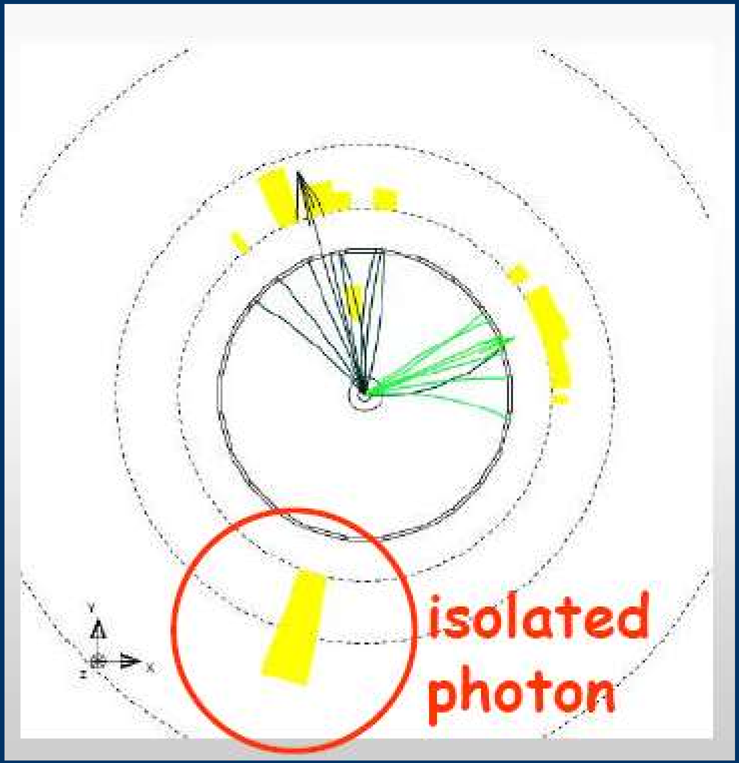
Measurement of α_s in Radiative Hadronic Events

Initial State Radiation (ISR)



Final State Radiation (FSR)





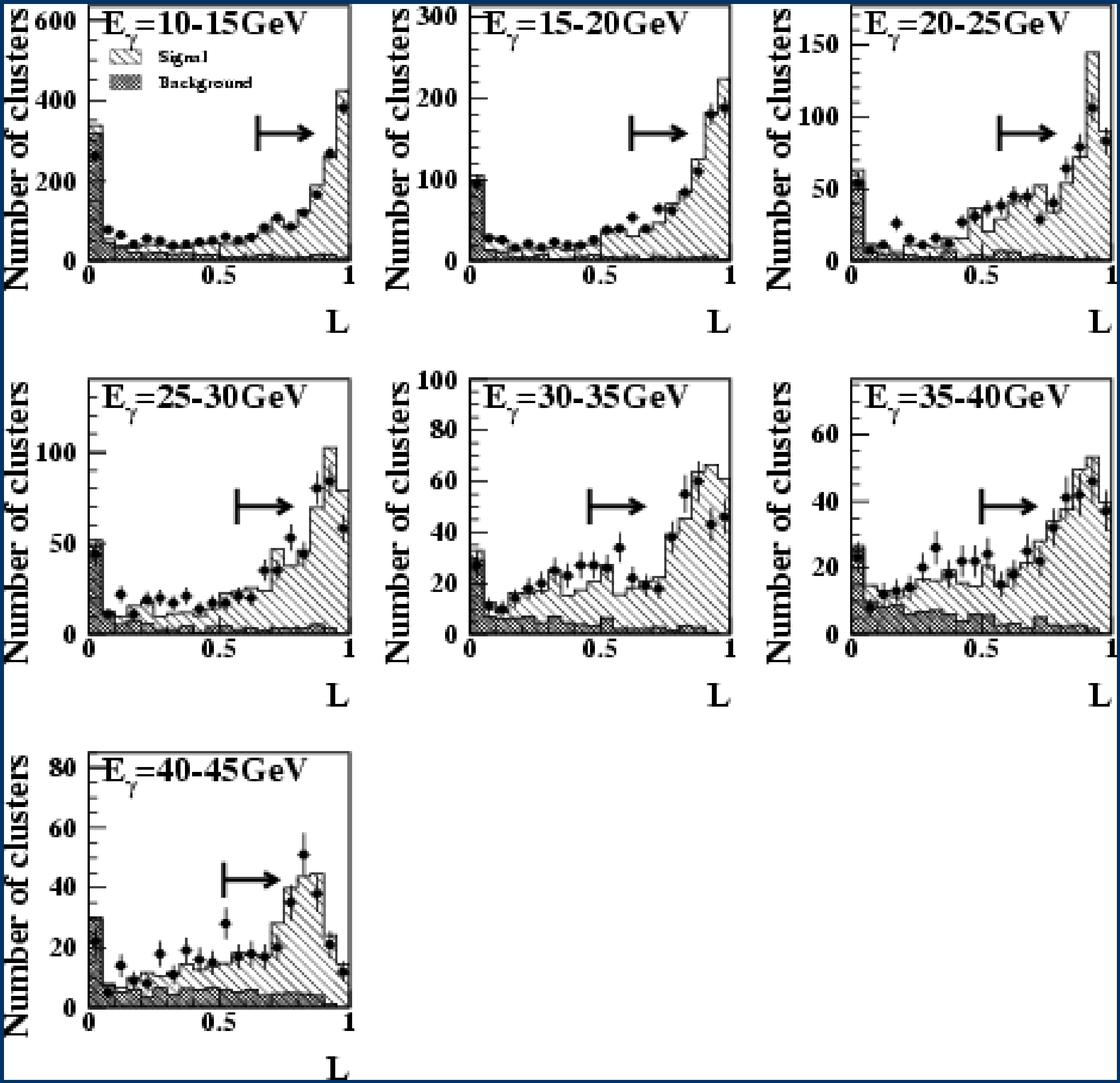
α_s at reduced scale $\sqrt{s'}$

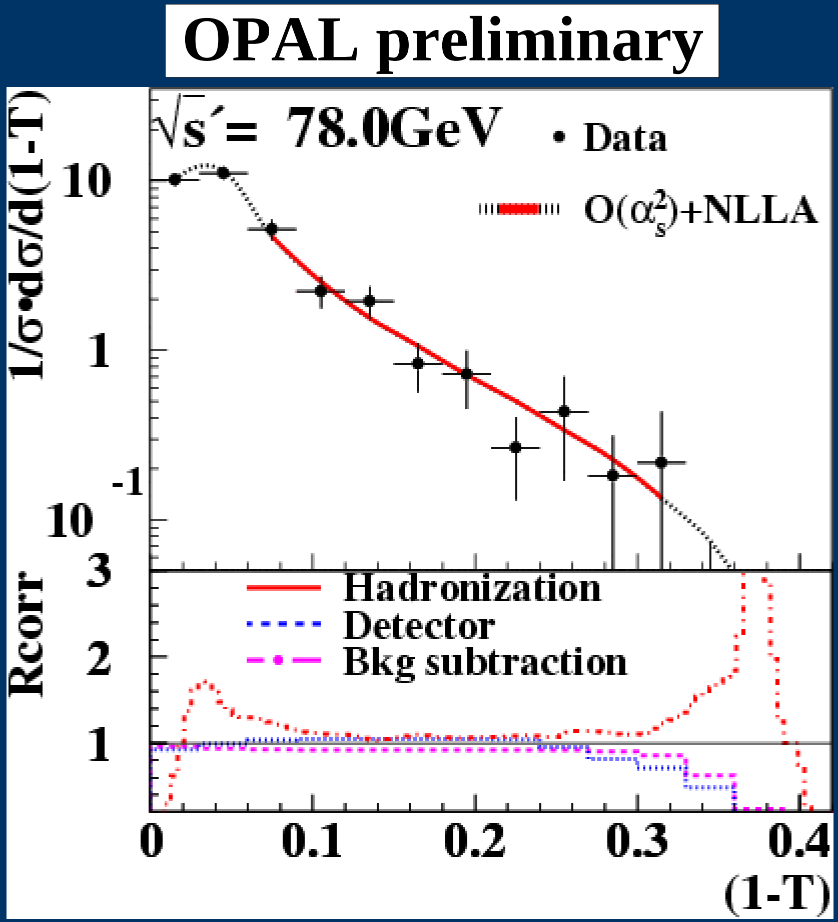
<u>Assumption:</u>
no interference between photon emission and QCD process

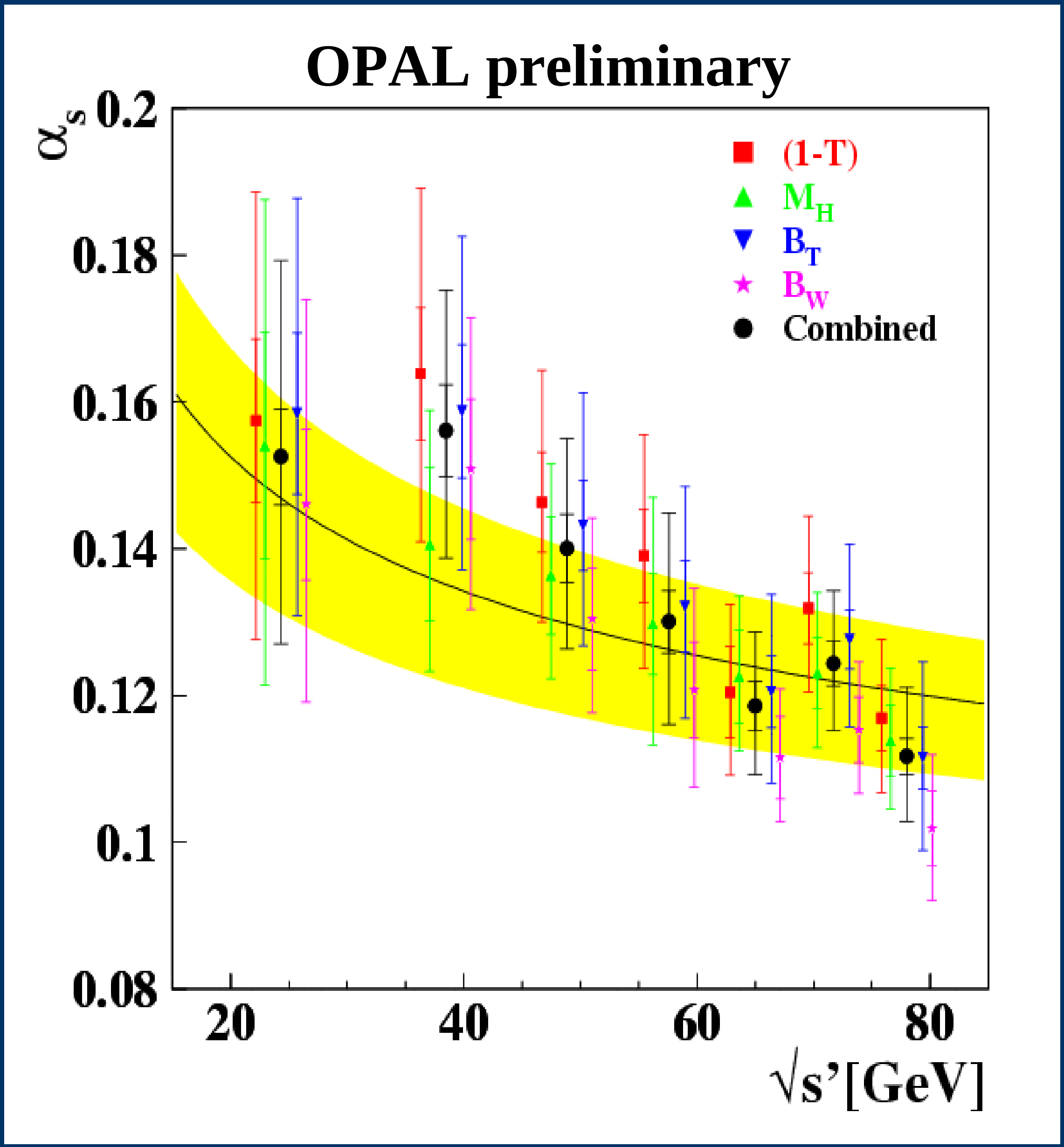
Photon Identification

Likelihood used for π^0/γ separation

based on cluster shape fit in calorimeter







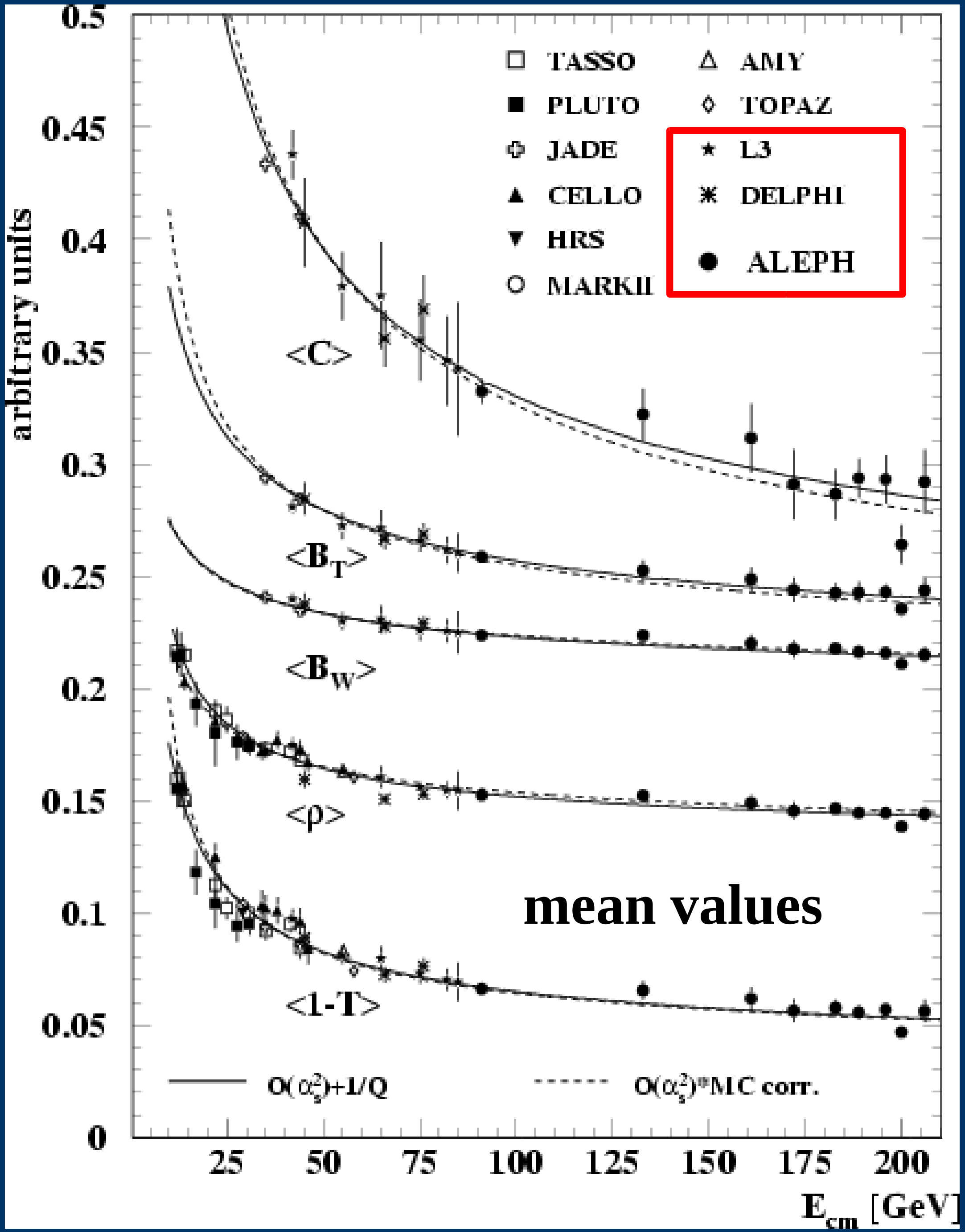
$$\alpha_s(M_Z) = 0.1176 \pm 0.0012(\text{stat})^{+0.0093}_{-0.0085}(\text{expt})$$

Power Law Corrections

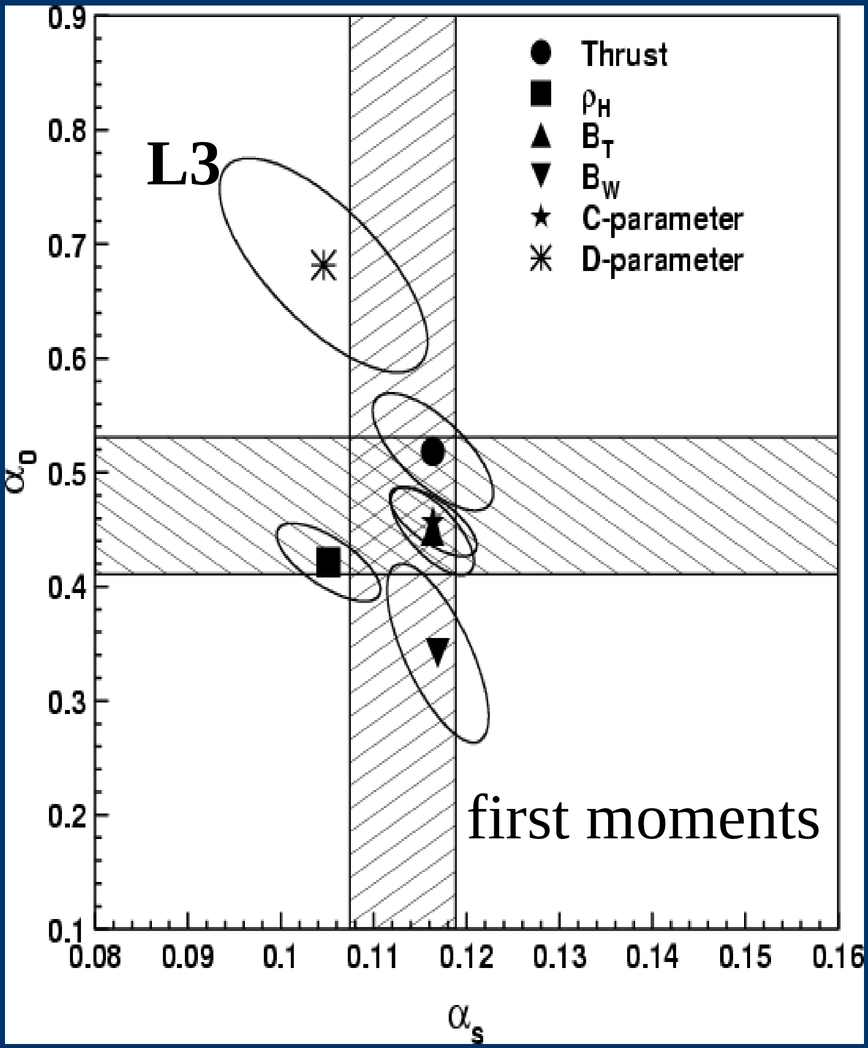
non-perturbative corrections can be derived using

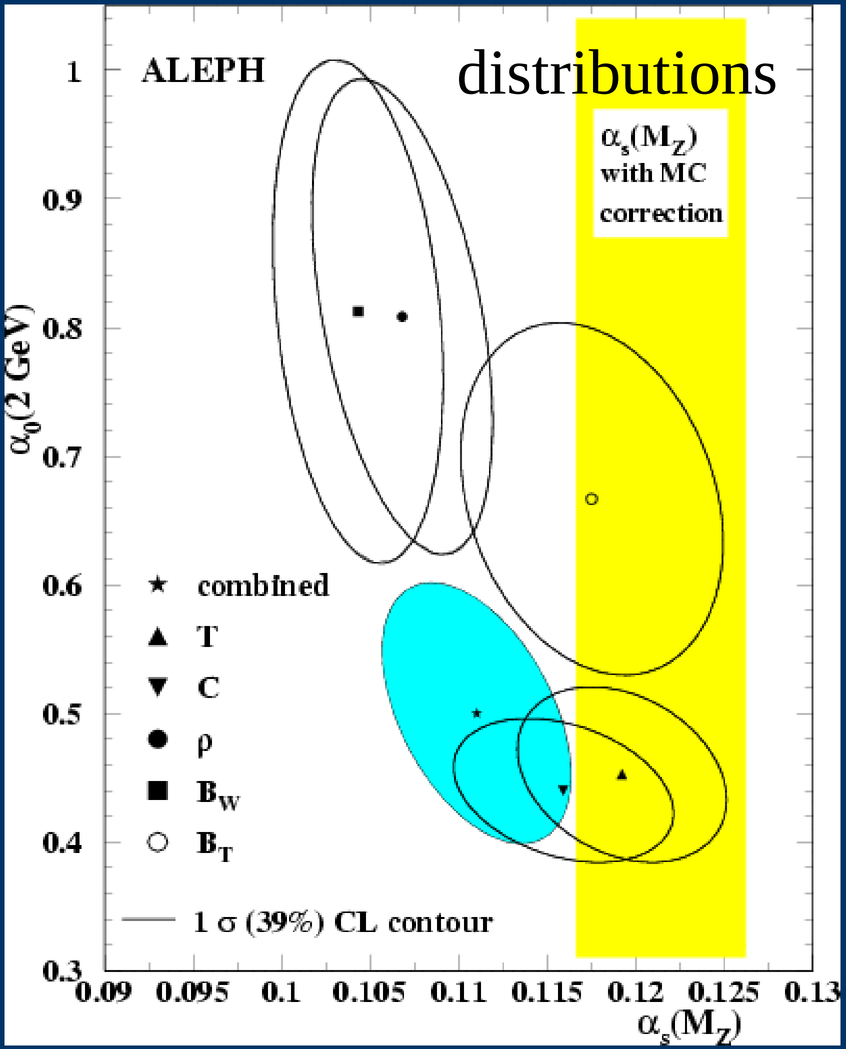
- Monte Carlo generators

- analytic power corrections (Yu.Dokshitzer, G.Marchesini, B.R.Webber)



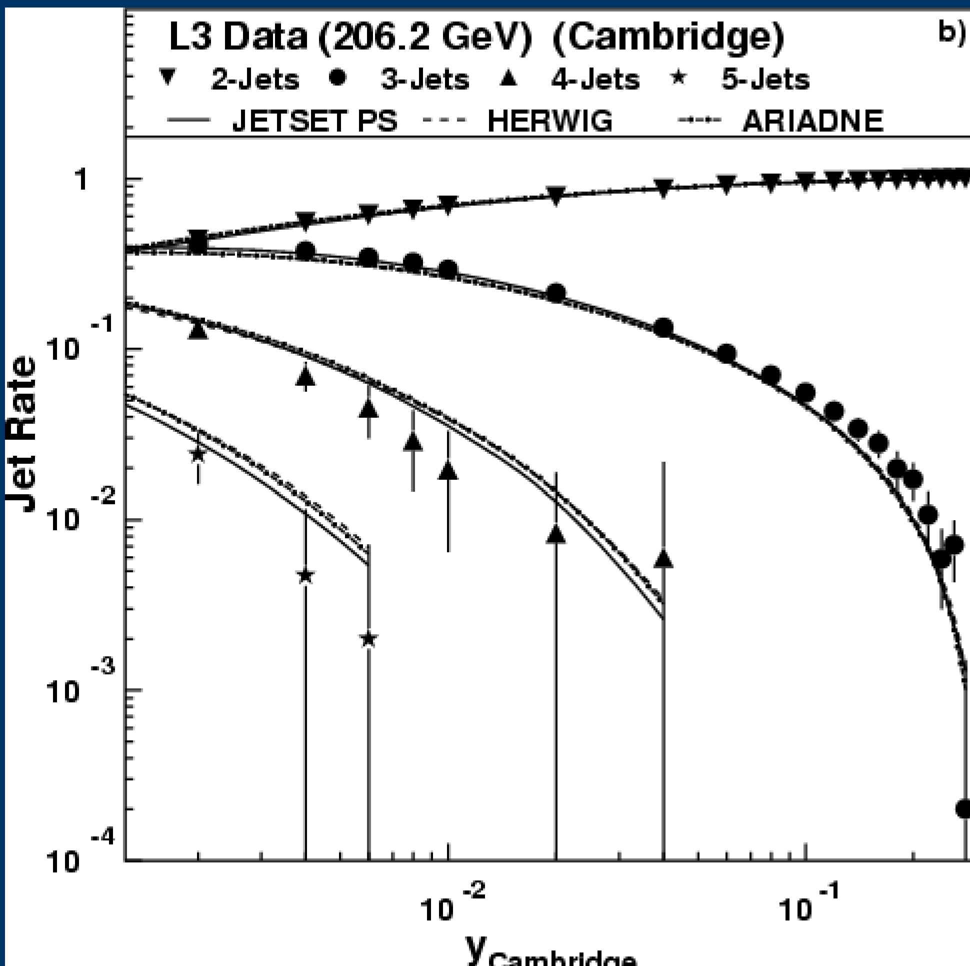
$$\alpha_0(\mu_I) = \frac{1}{\mu_I}\int_0^{\mu_I} \alpha_s(k)\,dk \quad \text{with} \quad \mu_I = \text{infrared matching scale}$$

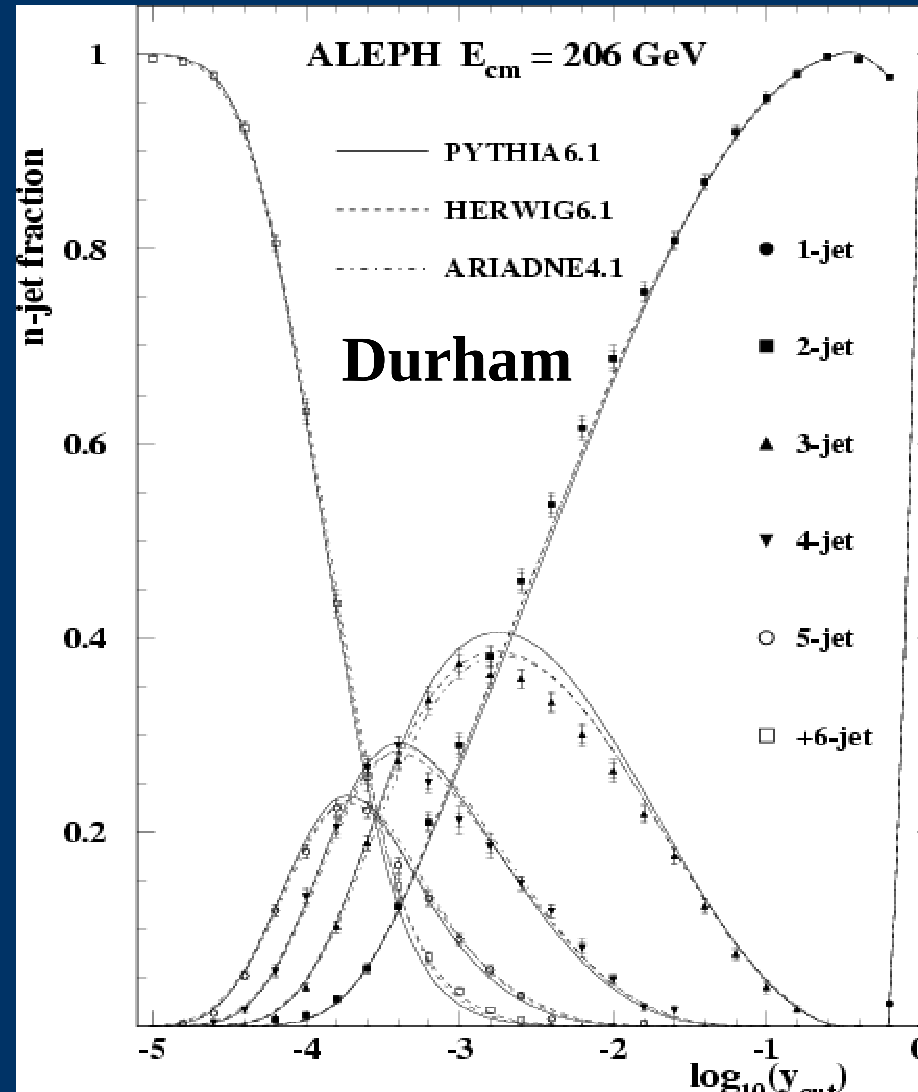




similar result from DELPHI

Different clustering algorithms (Jade, Durham, Cambridge) are used to measure jet rates





good data/MC agreement

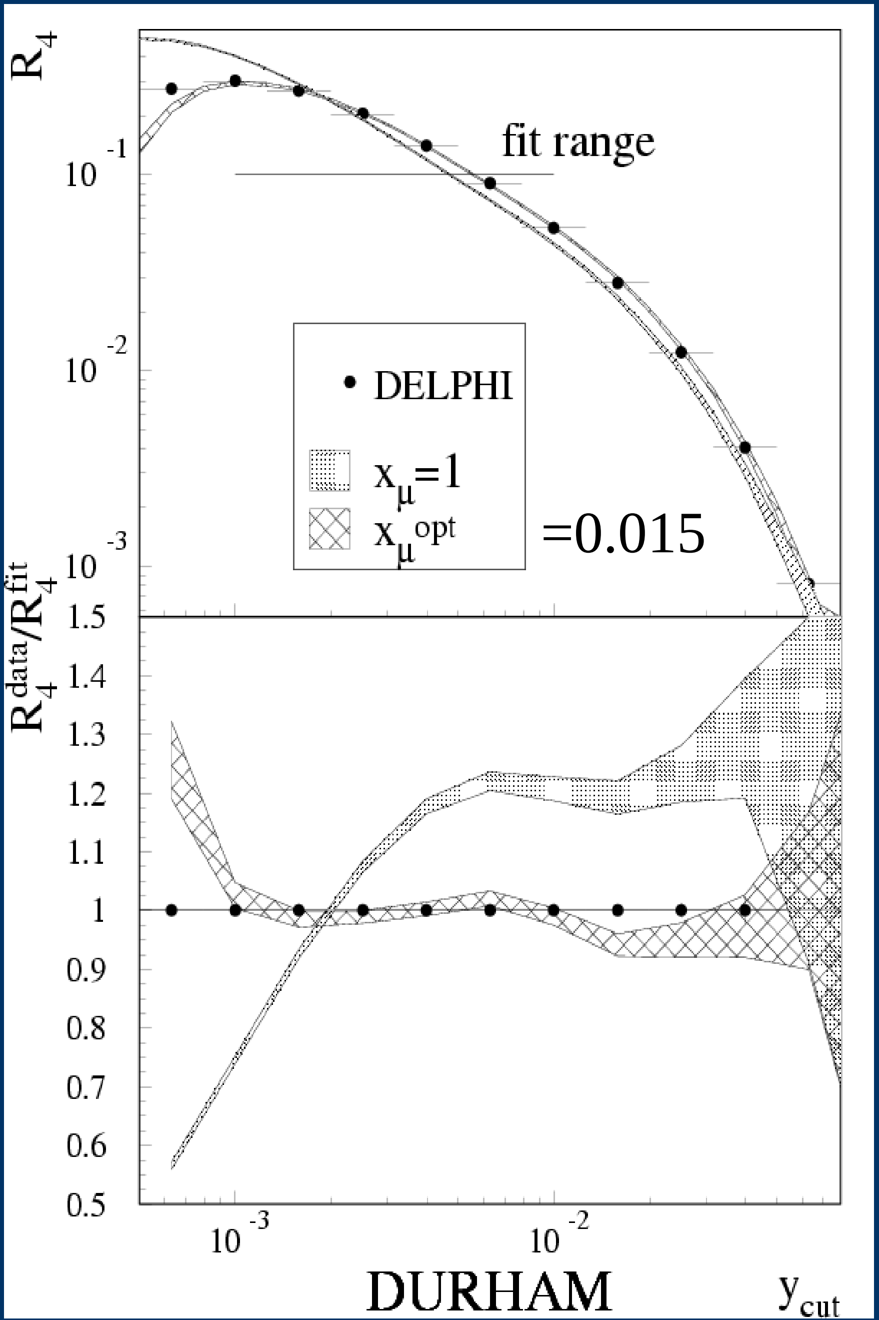
α_s Measurements from Four-jet Rates

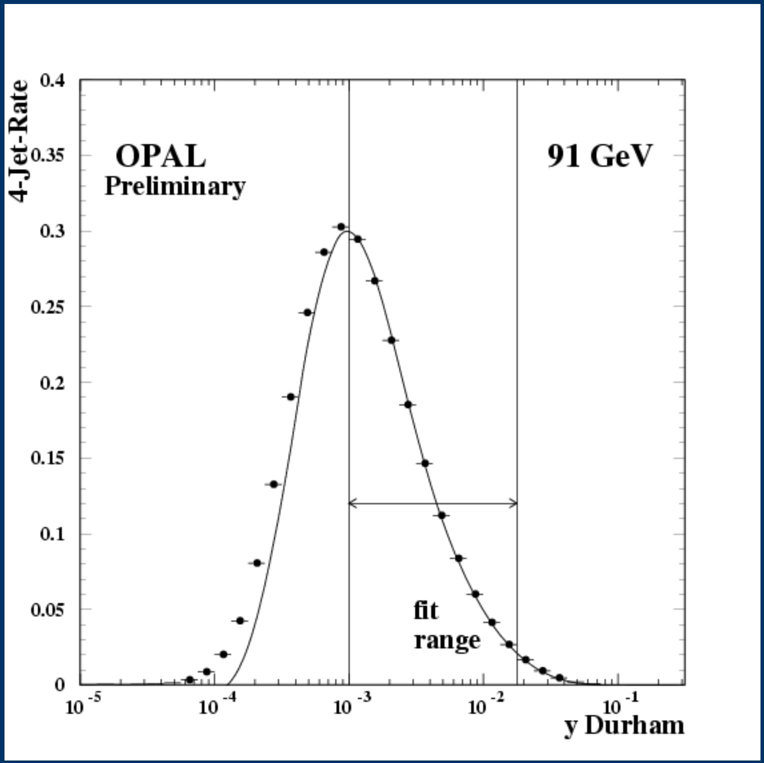
NLO expression for four-jet rate:

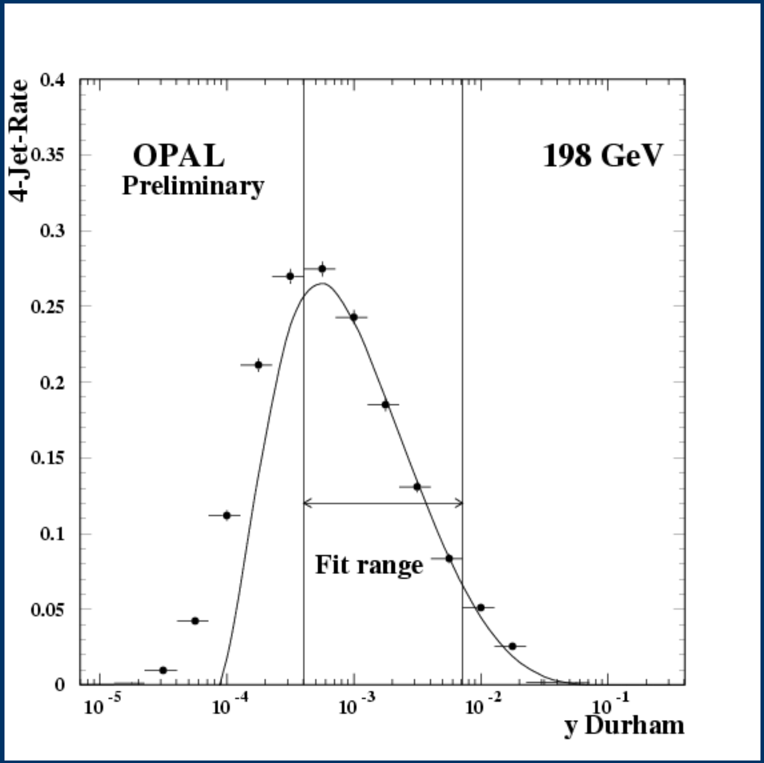
$$R_4(y) = B(y)\alpha_s^2 + (C(y) + 2B(y)b_0 \ln x_\mu)\alpha_s^3$$

$$b_0 = \frac{33 - 2n_f}{12\pi}$$

simultaneous fit to four-jet rate of optimized scale x_μ^{opt} and α_s



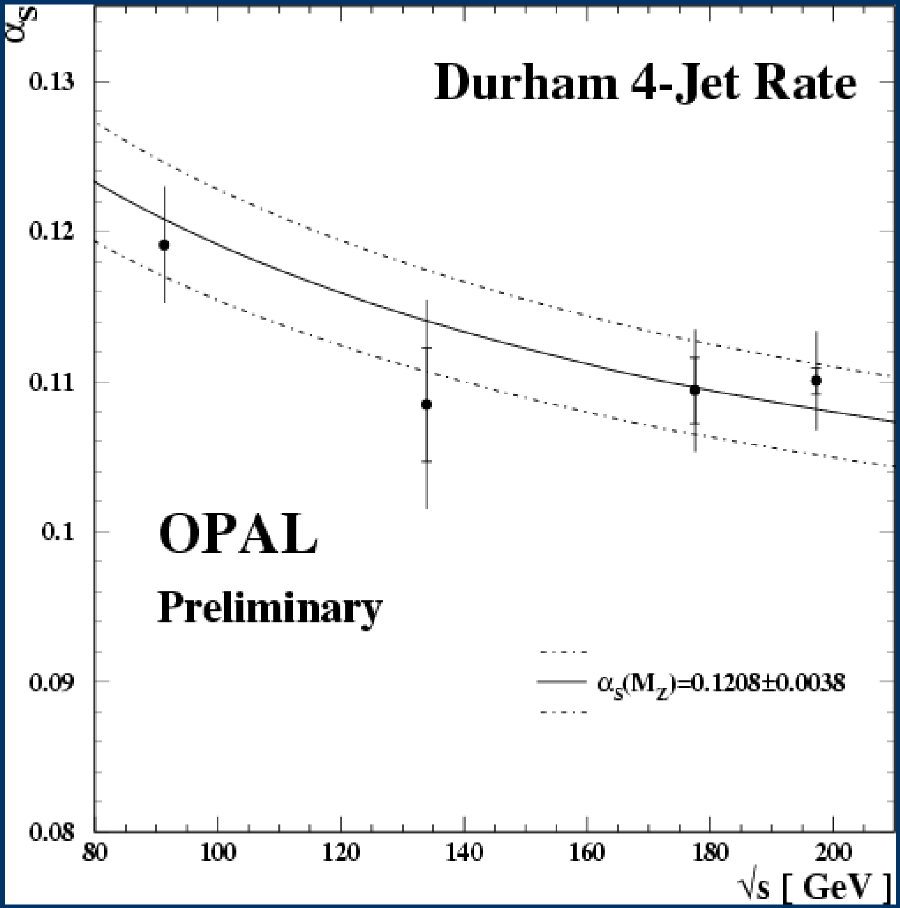


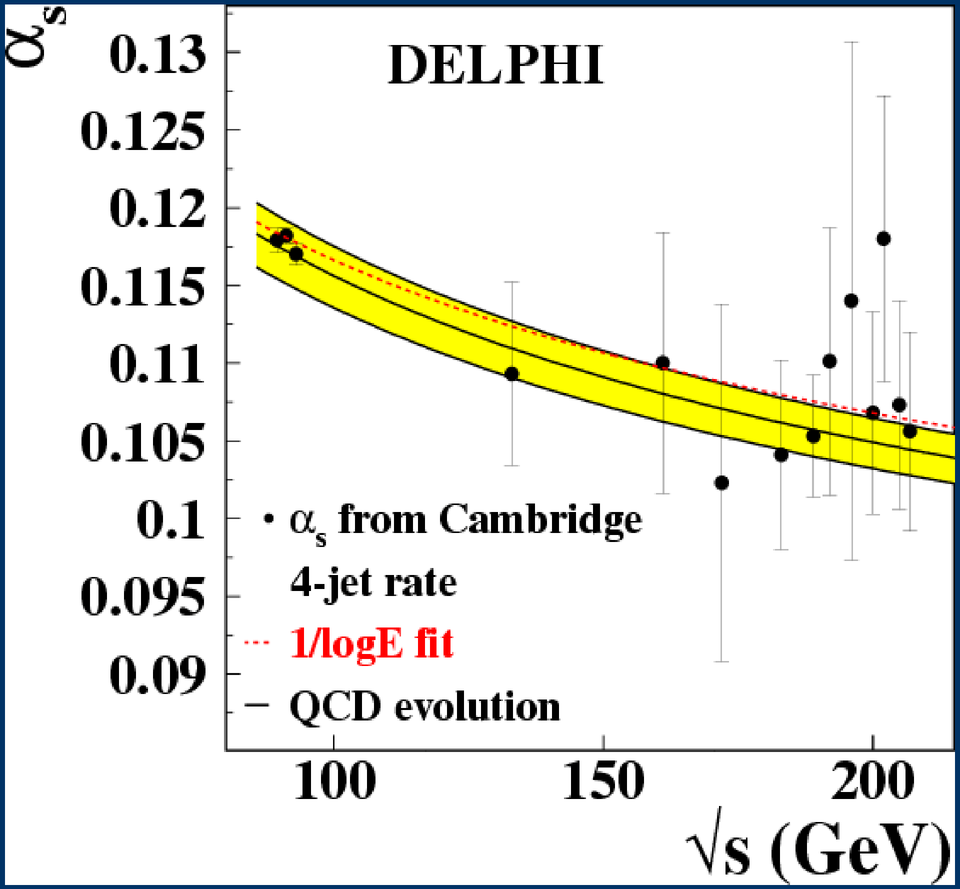


average $\sqrt{s}$ in GeV	α_s	stat.	exp.	hadr.	scale
91.3	0.1191	0.0001	0.0010	0.0023	0.0030
134.0	0.1085	0.0038	0.0039	0.0027	0.0035
177.5	0.1094	0.0022	0.0027	0.0013	0.0016
197.2	0.1100	0.0009	0.0025	0.0011	0.0017

With increasing energy

- **experimental uncertainty increases**
- **hadronisation and scale uncertainties decrease**





$\alpha_s(M_Z)$=0.1178±0.0012(stat+expt)±0.0031(hadr)±0.0014(scale) **DELPHI Durham**

$\alpha_s(M_Z,)$=0.1175±0.0010(stat+expt)±0.0027(hadr)±0.0007(scale) **DELPHI Cambridge**

$\alpha_s(M_Z,)$=0.1208±0.0022(stat+expt)±0.0019(hadr)±0.0024(scale) **OPAL Durham**

$\alpha_s(M_Z,)$=0.1202±0.0008(stat+expt)±0.0015(hadr)±0.0044(scale) **LEP Event Shapes**

Summary

All four LEP experiments have published their final event shape analysis

$\alpha_s(M_Z)$ is measured using both Monte Carlo simulations and power law corrections to take into account non-perturbative effects

A prelimininary combination of the final results has been presented

The running of α_s has been studied over a wide range of energies using radiative hadronic events

Good MC/data agreement for n-jet rates has been observed and α_s measurements have been performed using four-jet rates

thanks to Matthew Ford and Roger Jones