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Studies of QCD at LEPII

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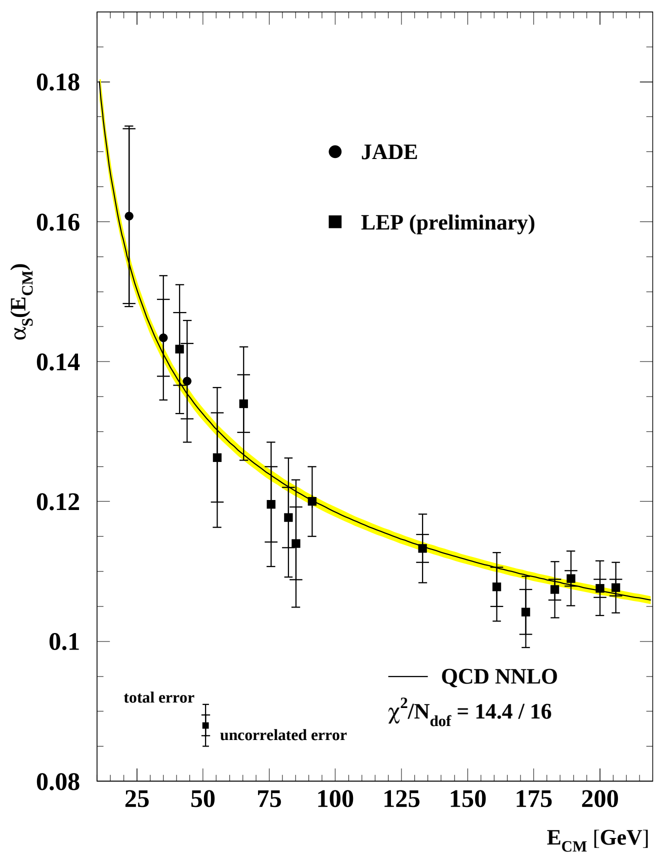
- LEP combination of α_s
- theoretical uncertainties
- power corrections
- inclusive charged particle production
- fragmentation functions

LEP Combination of α_s



- Observe the energy dependence of $\alpha_s(Q)$ at LEP
- Combination improves the statistical precision at LEPII
- Coherent analysis technique for $\alpha_s(Q)$ from event shapes
- Consistent implementation of theoretical prediction
- Common assessment of theoretical uncertainties
- Mission of the LEP QCD working group

Variables and data samples

Event-shape variables:

- Thrust T
- Heavy jet mass $\rho = M_H^2/s$
- Three-jet parameter $-\ln y_3$
- Wide jet broadening B_W
- Total jet broadening B_T
- C-Parameter C

Data samples:

- Samples with radiative events from L3
  $41.4 \leq \sqrt{s} \leq 85.1$ GeV
- LEP1 $E_{cm} = M_Z$
- LEP2 various data samples, combined to 7 nominal energies
  $133 \leq \sqrt{s} \leq 206$ GeV

In total 6 variables at 14 centre-of-mass energies yielding 194 individual measurements of $\alpha_s(Q)$ are to be combined.

Combination method

The covariance matrix $V_{(194\times 194)}$ is decomposed in four components

$$V_{ij}^{\text{total}} = V_{ij}^{\text{stat.}} + V_{ij}^{\text{exp.}} + V_{ij}^{\text{had.}} + V_{ij}^{\text{theo.}} \quad .$$

$V_{ij}^{\text{stat.}}$ uncorrelated between experiments and energies, correlation between variables for the same experiment/energy is calculated with MC

$V_{ij}^{\text{exp.}}$ uncorrelated between experiments, correlation between variables/energies assessed by 'minimal overlap'
$V_{ij}^{\text{exp.}} = \left[\min(\sigma_i^{\text{exp.}}, \sigma_j^{\text{exp.}})\right]^2$

$V_{ij}^{\text{had.}}$ correlation of hadronisation uncertainty between experiments reduced (different generator tunings) $V_{ij}^{\text{had.}} = 0,\ j \neq i$

$V_{ij}^{\text{theo.}}$ correlation of theoretical uncertainties is large ($\approx 90\%$), but difficult to assess $V_{ij}^{\text{theo.}} = 0,\ j \neq i$

The combined value of $\bar{\alpha}_s(M_Z)$ is obtained using a minimization procedure

$$\chi^2(\bar{\alpha}_s) = \sum_{ij} (\alpha_s^i - \bar{\alpha}_s)\,(V^{-1})_{ij}\,(\alpha_s^j - \bar{\alpha}_s)\ ,\ \hat{\alpha} = \sum_i w_i\,\alpha_i\ ,\ w_i = \frac{\sum_j (V^{-1})_{ij}}{\sum_{jk} (V^{-1})_{jk}} \quad .$$

Theoretical uncertainties

In a special procedure the hadronisation and perturbative uncertainties are determined.

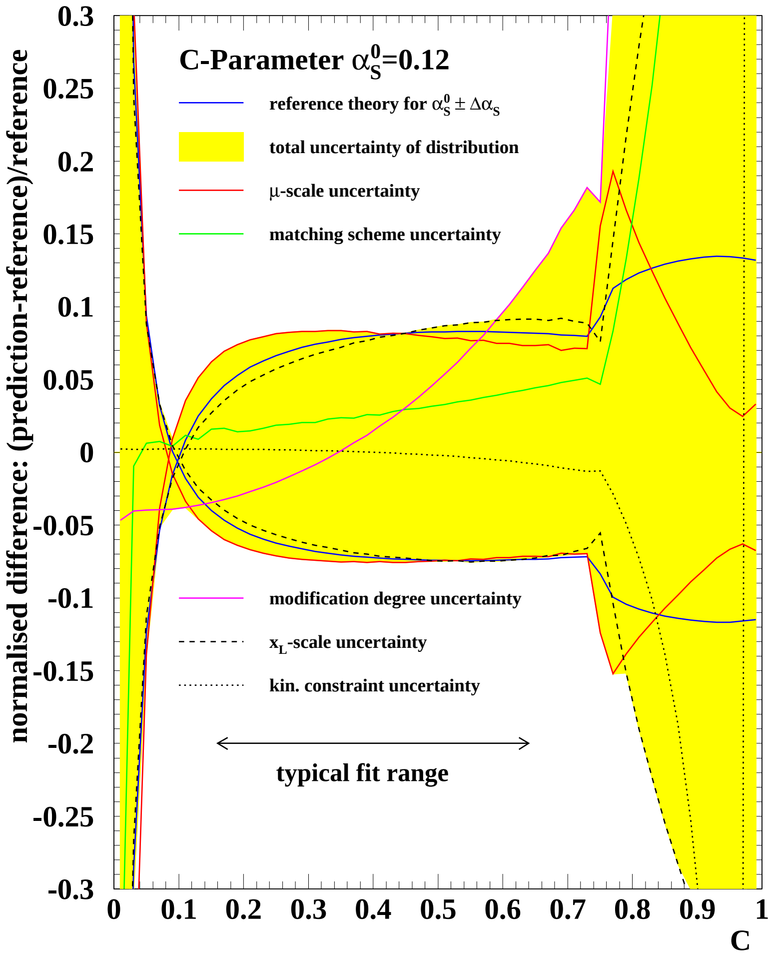
Hadronisation:

- The combination is carried out separately for each of the generators PYTHIA, HERWIG and ARIADNE.
- The hadronisation uncertainty (generator difference) is fit to a $1/Q$ form
- The RMS of the fitted difference is quoted as error.

Perturbative uncertainties:

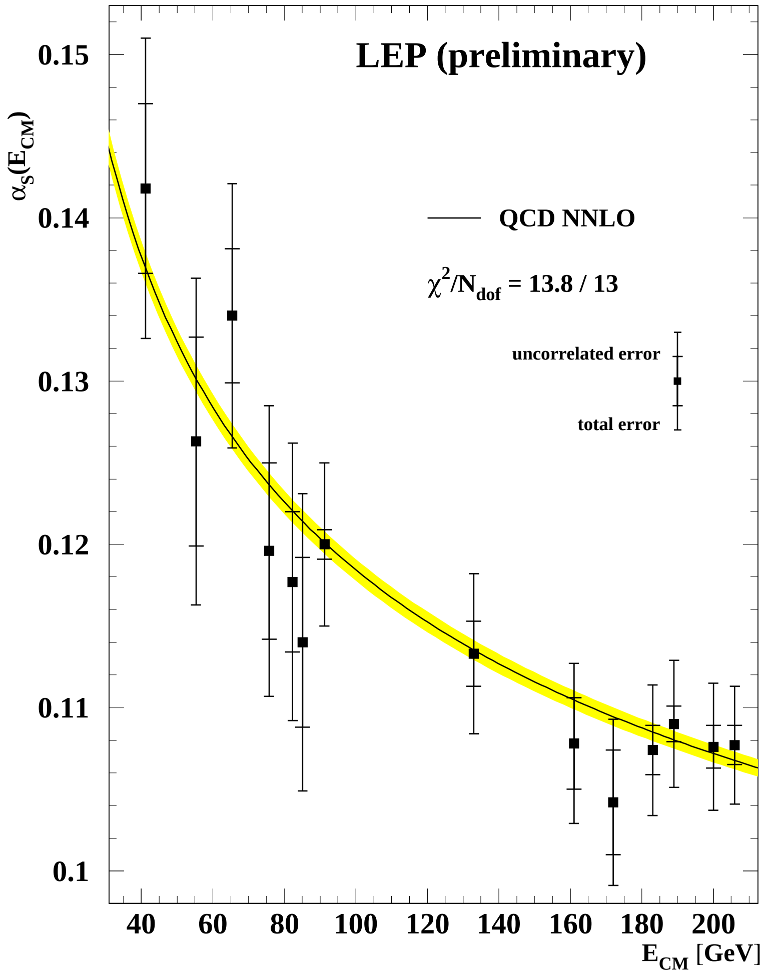
- The uncertainty band method is applied
- μ scale variation $1/2 \leq x_\mu \leq 2$
- Rescaling of resummed logs $2/3 \leq x_L \leq 3/2$
- Test with two matching schemes
- Kinematic constraint y_{max} variation
- Test with two modification schemes

The uncertainty band method



- Uncertainty evaluated centrally for the combined value of α_s
- The largest uncertainties (up/down) are kept in the uncertainty band
- The uncertainty of α_s is calculated with a reference theory
- The reference theory is requested to lie within the uncertainty band
- In a more conservative approach the reference theory can be fit to the uncertainty envelope or the range of x_L can be enlarged

LEP combined results

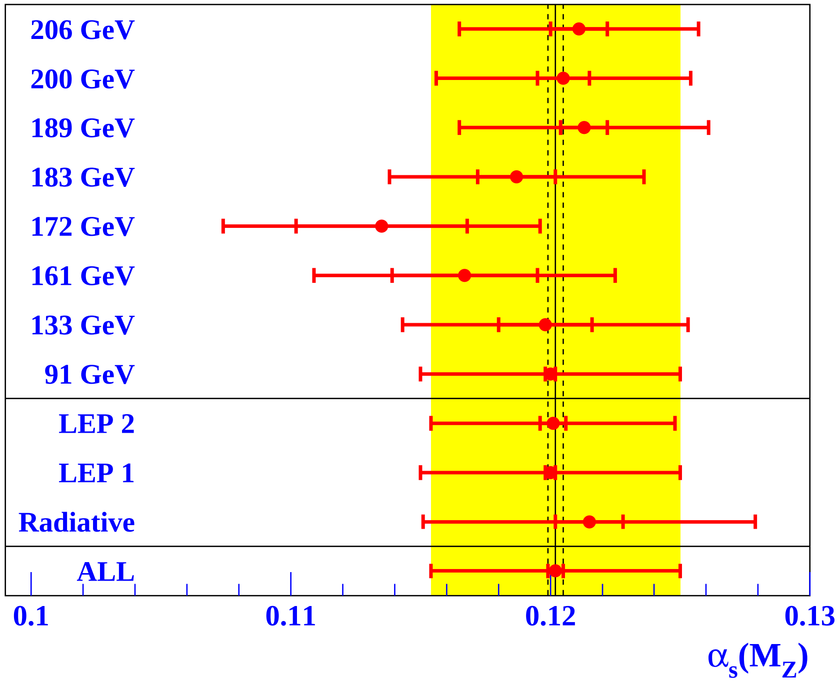


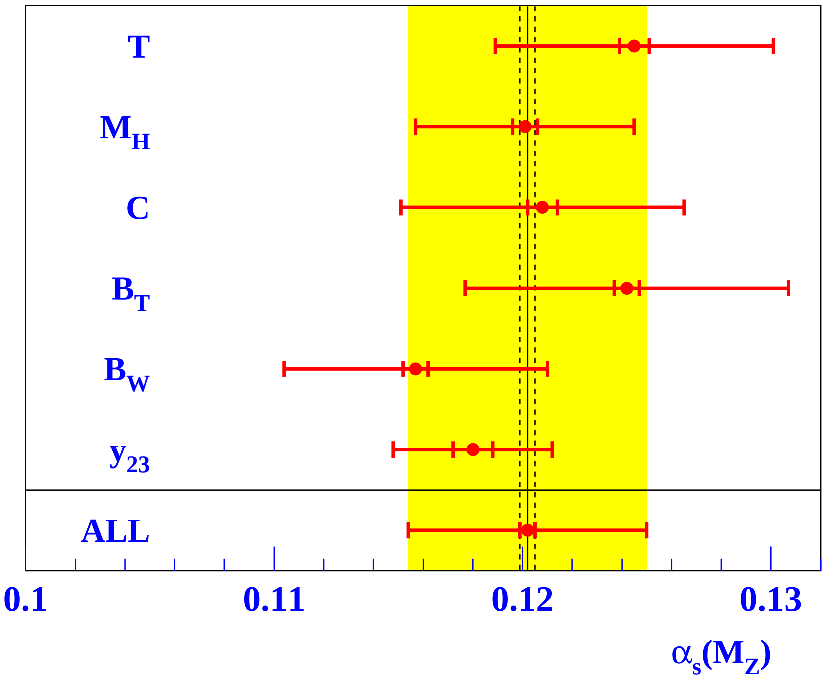
Preliminary combined LEP result:

$$\alpha_s(M_Z) = 0.1202 \pm 0.0003_{\rm stat} \pm 0.0009_{\rm exp} \pm 0.0009_{\rm had} \pm 0.0047_{\rm pert}$$

The alternative conservative uncertainty estimates yield $\Delta_{\rm pert} = \pm 0.0053$ using a larger range of x_L or a fit to the error envelope.

LEP results combined by energy and variable





Results by groups of energies:

radiative: $\alpha_s(M_Z) = 0.1215 \pm 0.0064$
LEP1: $\alpha_s(M_Z) = 0.1200 \pm 0.0050$
LEP2: $\alpha_s(M_Z) = 0.1201 \pm 0.0047$

RMS of different variables = 0.0016, maximum spread = 0.0046.

Good agreement with the combined perturbative uncertainty of ± 0.0047.

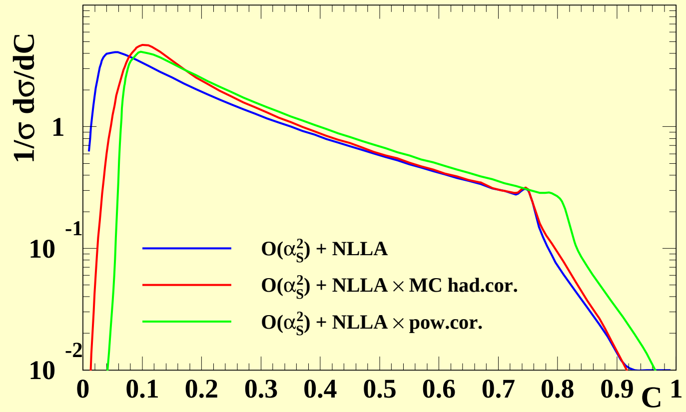
Power corrections

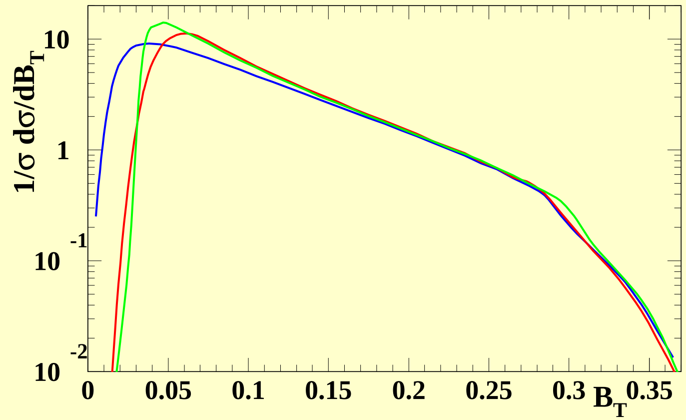
Non-perturbative effects in event-shape variables are scaling with powers of $1/Q$. The Dokshitzer-Webber model parametrise the infrared behaviour of the coupling below a matching scale μ_I by its mean.

$$\alpha_0 = \frac{1}{\mu_I}\int_0^{\mu_I} dk\alpha_s(k)$$

$$
\begin{aligned}
< y > &= < y_{\rm pert} > + < y_{\rm power} > \\
y_{\rm power} &= c_y \cdot P(\alpha_0)/Q \\
D_y(y) &= D_{\rm pert}\,(y - c_y \cdot P(\alpha_0))
\end{aligned}
$$

- Additive correction to the mean
- Shift of the distributions
- B-dependent shift for the broadenings
- A radiator correction for EEC





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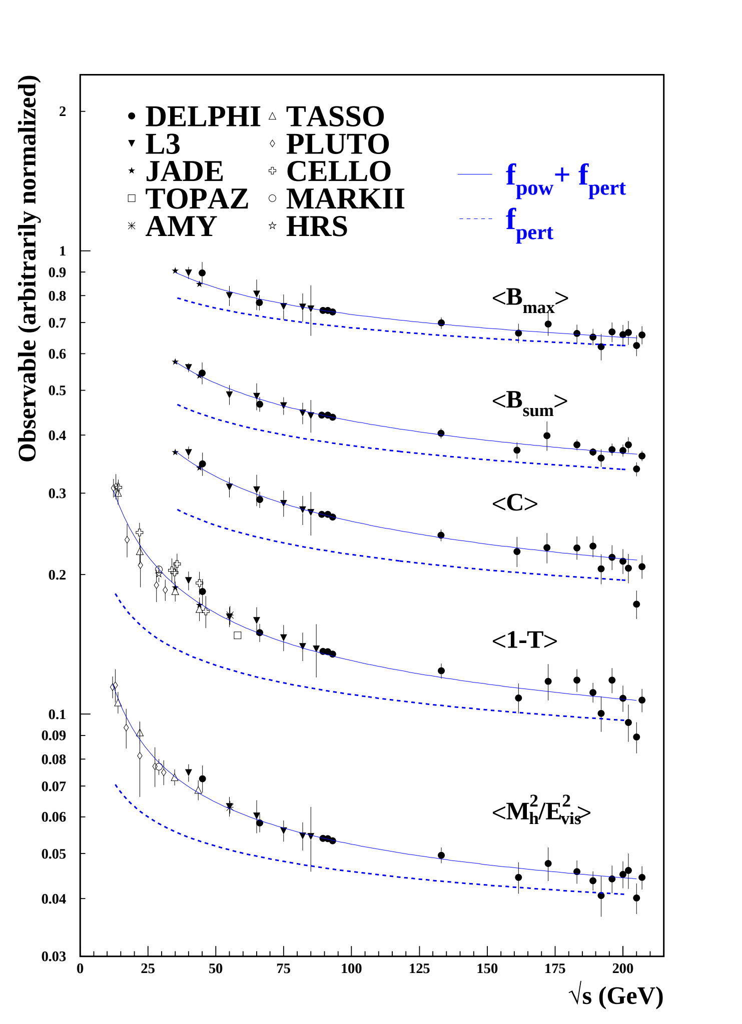
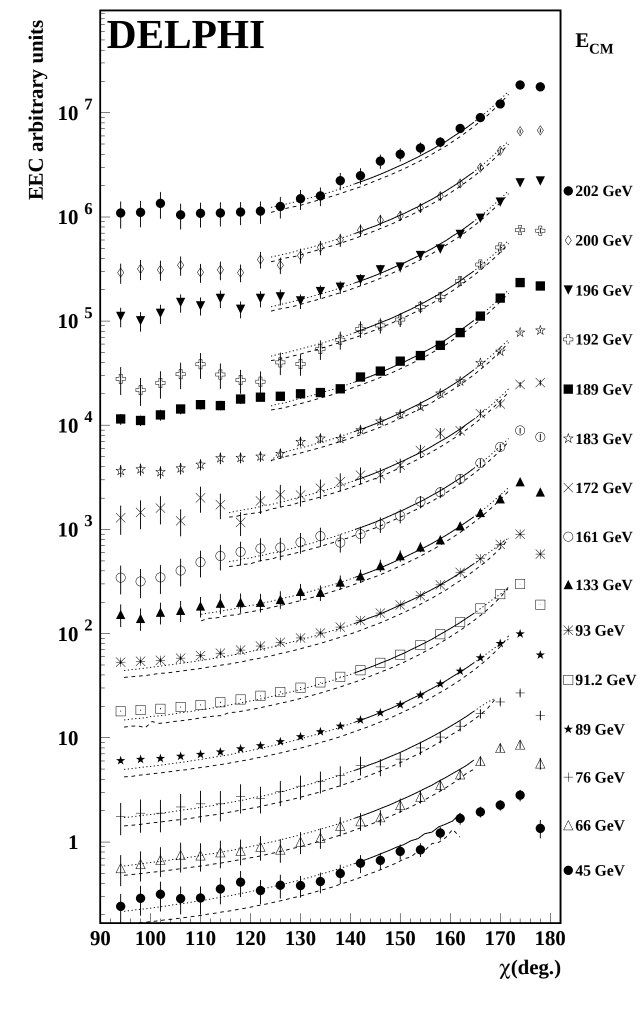
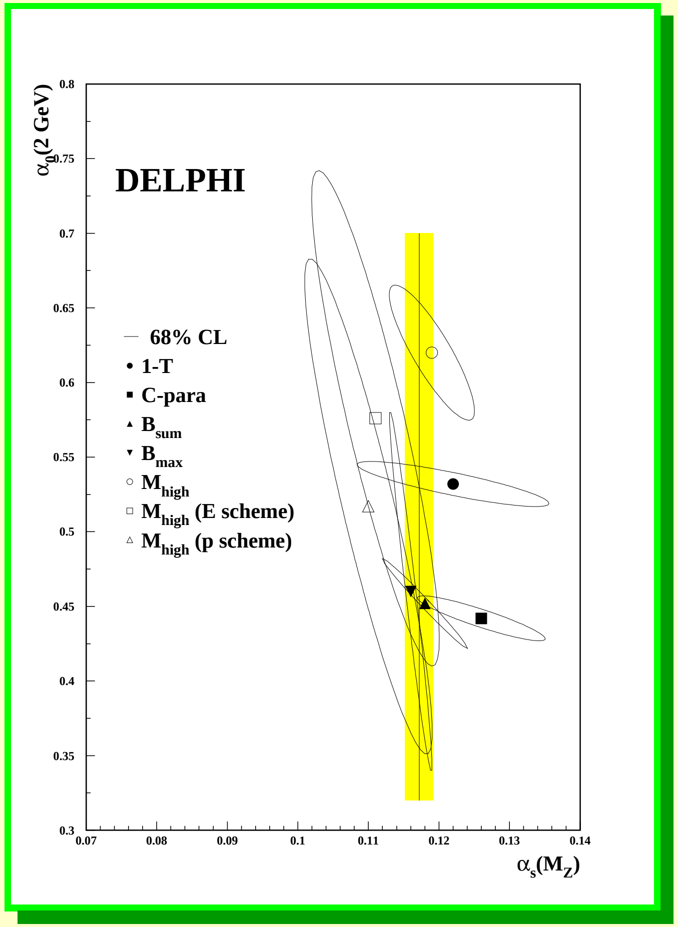
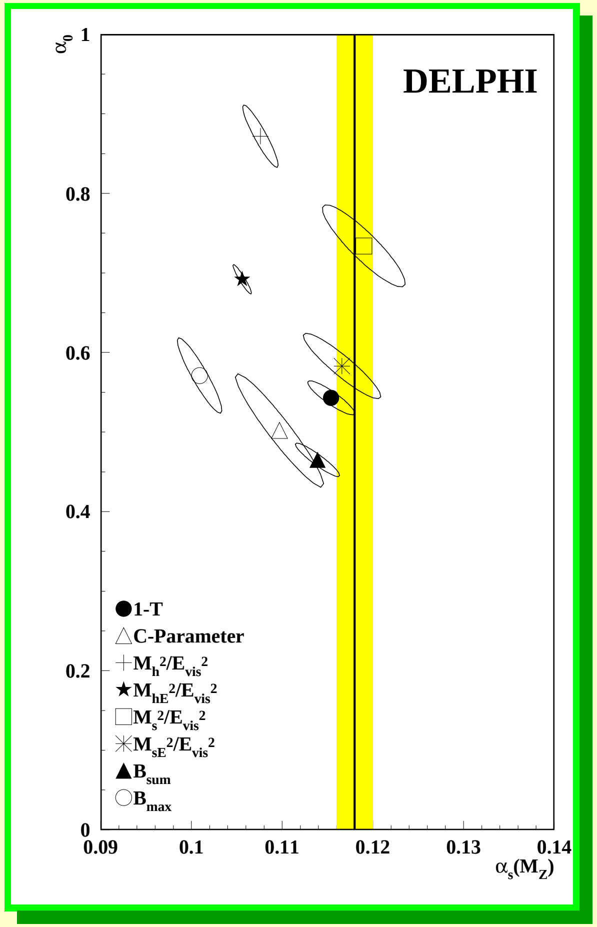
Power corrections to mean values and distributions





Results for α_s and α_0





From mean values:

$$\alpha_s(M_Z) = 0.1207 \pm .0048 \pm .0026$$

$$\alpha_0(2\mathrm{GeV}) = 0.468 \pm 0.080 \pm 0.008$$

From distributions:

$$\alpha_s(M_Z) = 0.1078 \pm .0005 \pm .0013$$

$$\alpha_0(2\mathrm{GeV}) = 0.546 \pm 0.005 \pm 0.022$$

Inclusive charged particle production

Study of color coherence and interference phenomena through particle production by multiple gluon radiation.

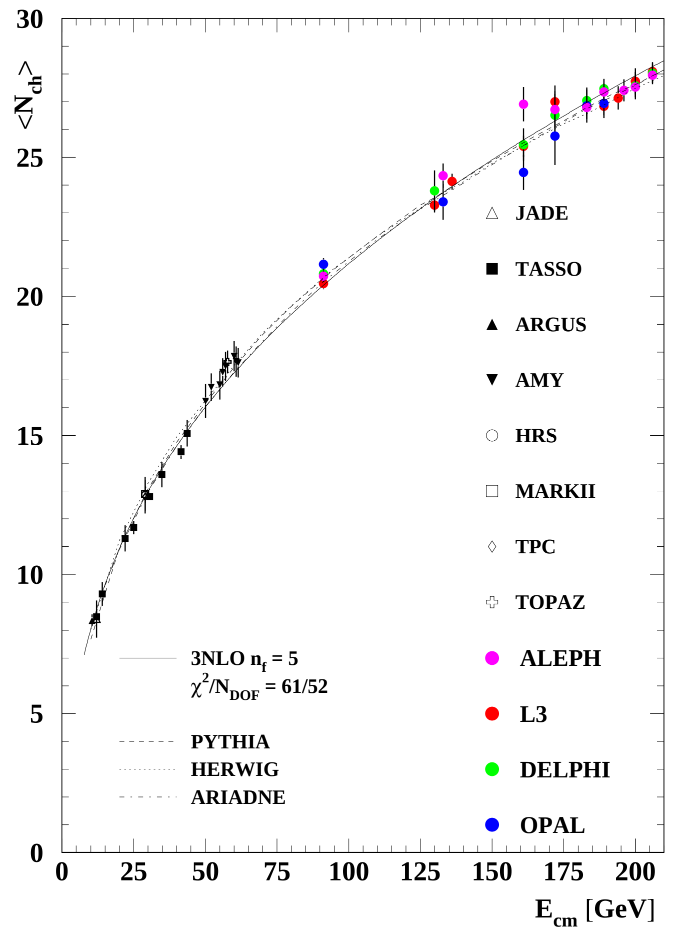
- Mean charged particle multiplicity
- Multiplicity difference light/heavy quarks
- Charged particle momentum spectrum $\xi = -\ln x_p$
- Evolution of peak position $\xi^\star$
- Fragmentation functions

Comparison to QCD generators, analytic MLLA calculations and DGLAP evolution.

Mean charged particle multiplicity

Energy evolution of $< N_{ch} >$

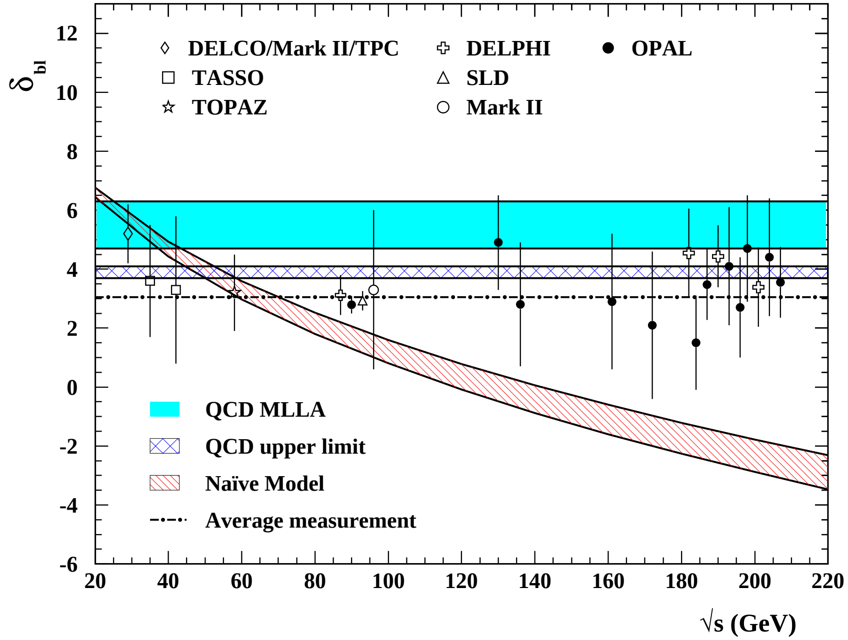
- Description by QCD generators
- Predictions of MLLA+LPHD
- $< N_{ch} >= K_{LPHD} \cdot \alpha_s(Q)^a \cdot e^{\frac{b}{\sqrt{\alpha_s(Q)}}}$
- Higher order corrections 3NLO
- Flavour composition corrections



Multiplicity difference $\delta_{\rm bl} = N_{ch}^{b}(Q) - N_{ch}^{uds}(Q)$

Energy evolution of $\delta_{\rm bl}$

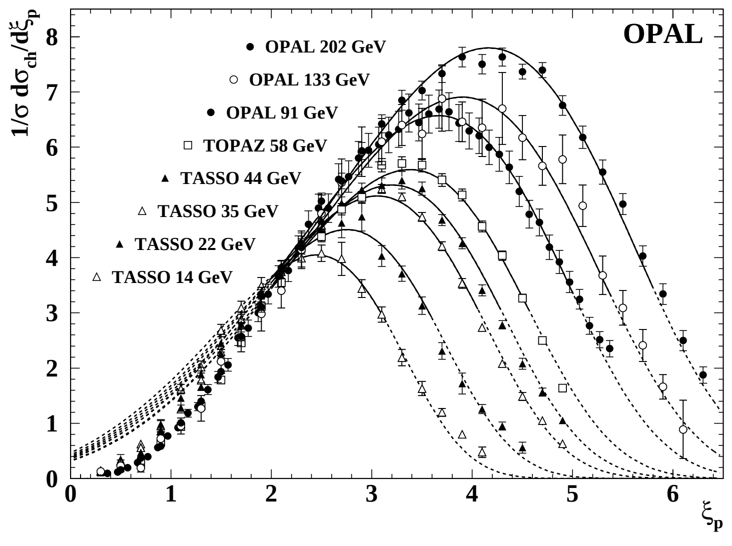
- Multiplicity in $b\bar{b}$-events is reduced by 'dead cone' effect
- Decay multiplicity $N_b^{\rm decay}\,5.5 \pm 0.2$
- MLLA predicts $\delta_{\rm bl} \approx$ const.
- Naive incoherent model predicts decreasing $\delta_{\rm bl}$ with increasing energy
- Combined result: $\delta_{\rm bl} = 3.05 \pm 0.19$

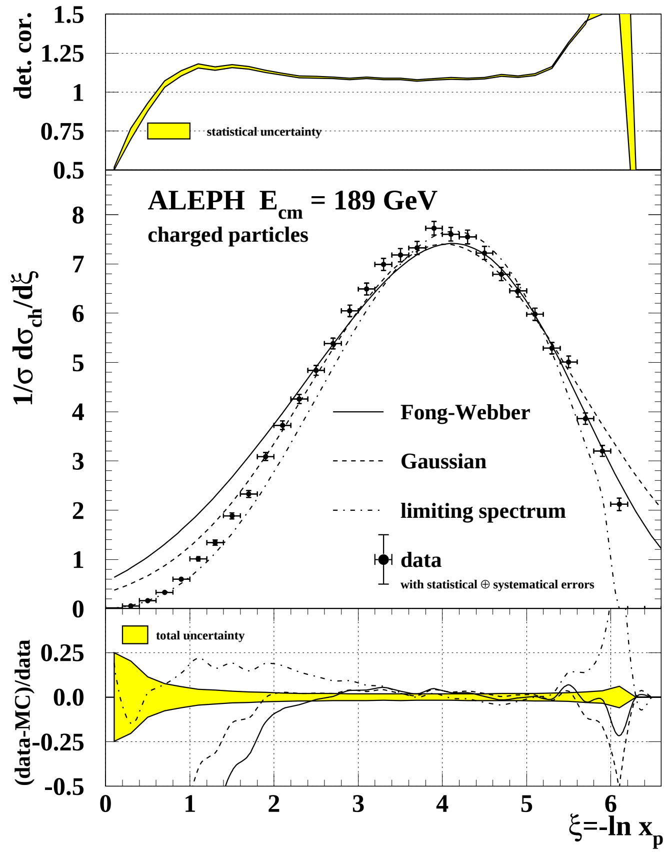


Scaled momentum distribution

Three predictions for the spectrum of $\xi = -\ln x_p,\ x_p = p/p_{\mathrm{beam}}$

- Gaussian HE approximation (3 param.)
- Limiting spectrum (2 param)
- Distorted Gaussian, Fong-Webber (3 param)
- Good description of the peak region
- Used to determine the peak position

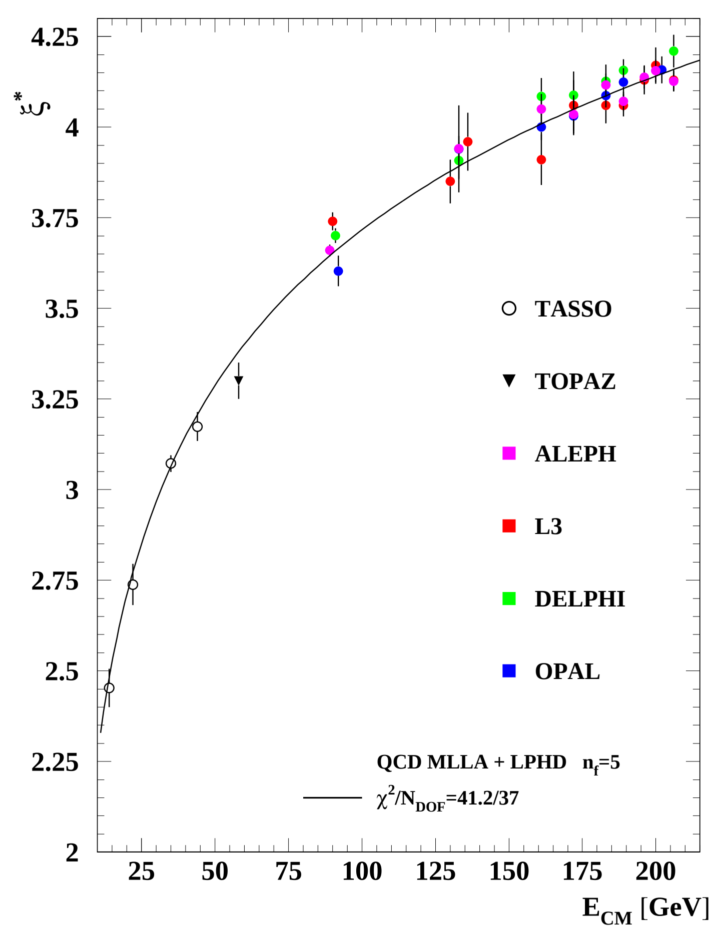




Evolution of peak position ξ^*

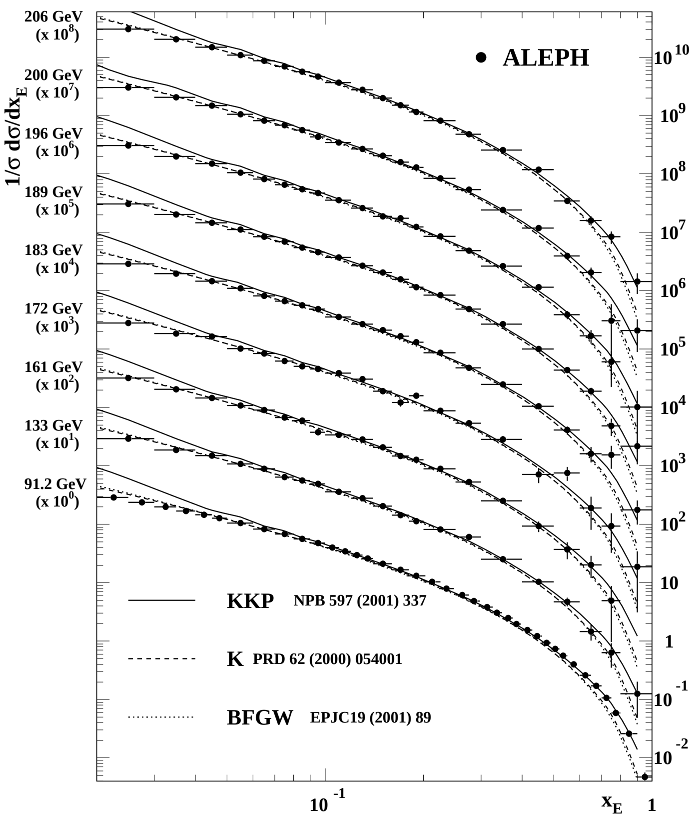
The peak position is determined from a fit to the ξ spectra.

- MLLA evolution prediction
- $\xi^* = Y\left(\frac{1}{2} + \sqrt{\frac{c}{Y}} - \frac{c}{Y}\right)$
  $Y = \ln Q/2\Lambda$
- Fit includes flavour corrections
- $\Lambda_{MLLA} = 215 \pm 8$ MeV for $n_f = 5$



Fragmentation functions

Fragmentation functions $D(x,Q^2)$ are extracted from the scaled-energy distributions. Scaling violations The energy evolution of FF's are observed by measuring x_E distributions at different $E_{\rm cm}$.



- Parametrisation $D_i^h(x,Q_0^2) = N_i(1-x)^a x^b$

- Cross section
  $\frac{1}{\sigma}\frac{d\sigma}{dx} = \int_x^1 \frac{dz}{z} \sum_f C_f(z,Q^2) D_f^h(x/z,Q^2)$

- DGLAP evolution
  $\frac{dD_i^h(x,Q^2)}{d\ln Q^2} = \frac{\alpha_s}{2\pi}\sum_f \int_x^1 P_{if}(z,\alpha_s) D_f^h(x/z,Q^2)\frac{dz}{z}$

- Global fits to various e^+e^- data carried out by three different groups
  1. Kniehl, Kramer and Pötter (KKP)
  2. Kretzer (K)
  3. Bourhis, Fontannaz, Guillet and Werlen (BFGW)

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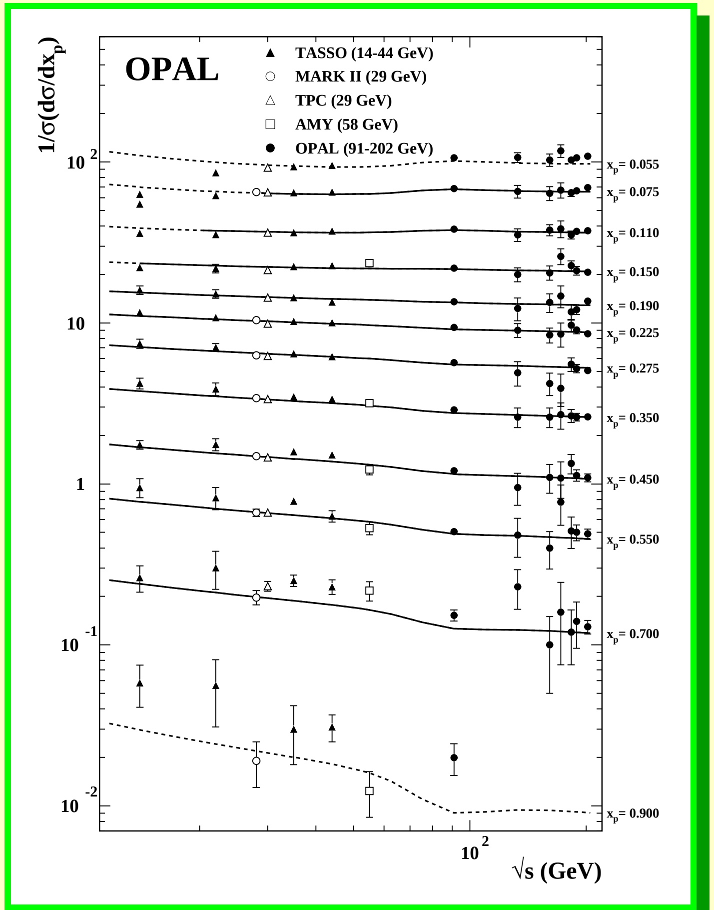
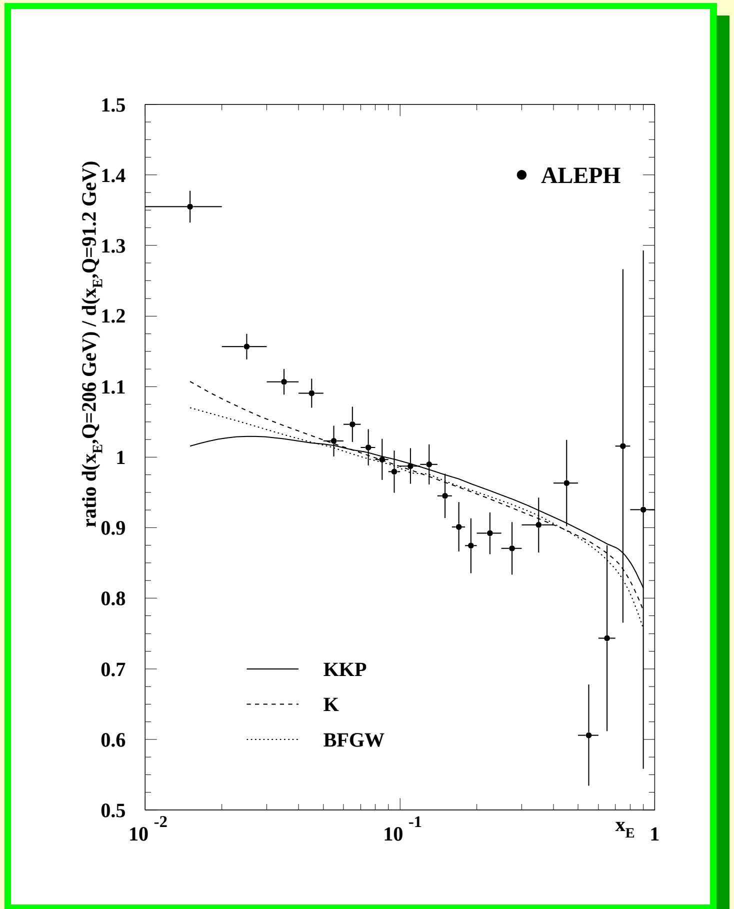
Scaling violations in fragmentation functions





Global fit by OPAL:
$\alpha_s(M_Z) = 0.113 \pm 0.005 \pm 0.007$

ALEPH ratio 206/91 GeV:
good description of data at central x by global fits

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Conclusions

- Preliminary combined LEP measurement
  $\alpha_s(M_Z) = 0.1202 \pm 0.0048$
- New method for theoretical uncertainties α_s
- Extended tests of power corrections
- Inclusive charged particle distributions overall in good agreement with QCD generators and MLLA predictions
- Fragmentation functions measured and scaling violations observed over a large range of energies