RGI / Effective Charges in Practise

Klaus Hamacher

Fachbereich Mathematik & Naturwissenschaften
Fachgruppe Physik
Bergische Universität Wuppertal
& DELPHI Collaboration

Workshop on 1. Principles Non–Perturbative QCD
of Hadron Jets
Paris, 12 Janvier 2006

Outline

Talk is mainly based on:

DELPHI Collab., Consistent measurements of α_s from precise oriented event shape distributions ..., (Eur. Phys. J. C14, 557)

- Standard event shapes (depending on polar angle)

DELPHI Collab., A study of the energy evolution of event shape distributions and their means ..., (Eur. Phys. J. C29, 285)

- Data
  - radiative DELPHI Z events at E_{CM} =45, 66 and 76 GeV
  - DELPHI data from LEP1 and LEP2 (E_{CM} =89 to 202 GeV)
  - low energy data from various experiments
- Observables
  - usual event shape means: $T, C, Major, B_T, B_W, (EEC, JCEF)$
  - $M^2_{h/s}/E^2_{vis}$ in alternative definitions “E/p-scheme”!

Mass Effects for Event Shapes / Means

Hadron masses influence shape observables.
Two types of observables:

- e.g. Thrust : mass–dependence via E–conservation .
- e.g. Jet Masses: direct mass–dependence;
  avoid by choosing:

(p-scheme) $(\vec{p}, E) \longrightarrow (\vec{p}, |\vec{p}|)$

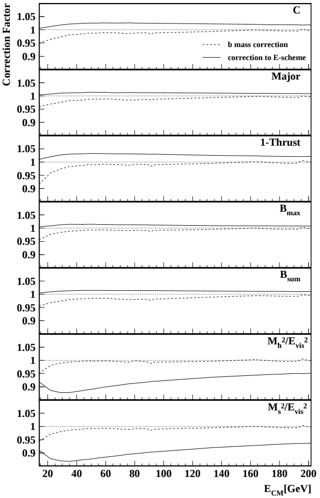
(E-scheme) $(\vec{p}, E) \longrightarrow (\hat{p}E, E)$

Furthermore:

- Transverse momentum from B–decays .

Estimate effects using Monte Carlo models;
b-correction: calculate b+udsc/udsc;

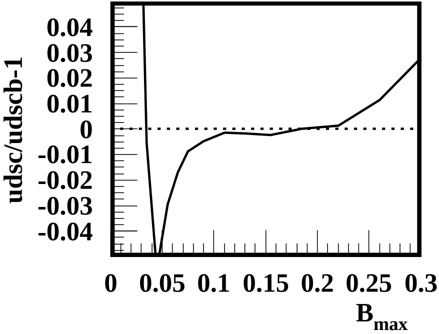
Mass Effects for Event Shape Means

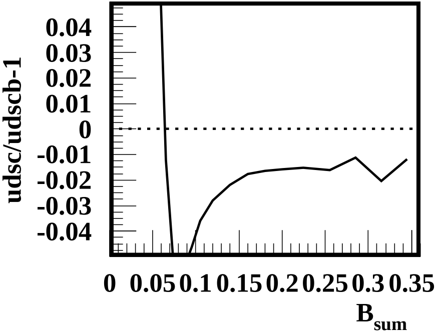


full line
correction to E–scheme
dashed line
B–correction

$\Longrightarrow$ For Jet-masses
change to E-scheme

Mass Effects for Event Shapes





Correction slightly changes slope of distributions!

Description of Event Shape Spectra

$\mathcal{O}(\alpha_s^2)$–prediction for events shape distributions

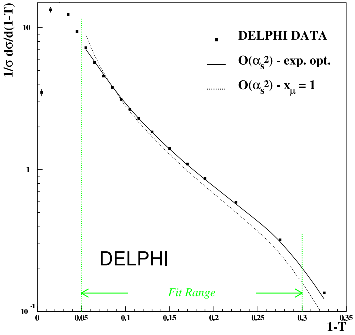
$$\frac{1}{\sigma_{tot}}\frac{d\sigma}{df} = A_f \cdot \bar{\alpha}_S(\mu) + (A_f \cdot (\beta_0 \log x_\mu - 2) + B_f)\,\bar{\alpha}_S(\mu)^2$$

- Change of $x_\mu = \mu/E_{CM}$ "turns " the prediction
- $\mathcal{O}(\alpha_s^2)$ prediction for $x_\mu = 1$ in general inconsistent with data

→ α_S results depend on fit range

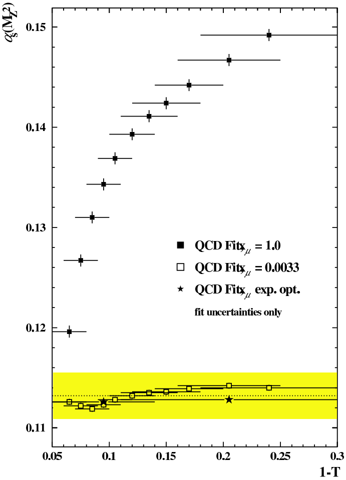
→ Good χ^2 only if x_μ is optimised !

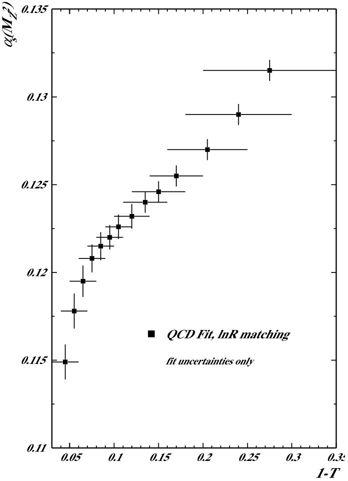
- Bad features are partly inherited to the matched predictions.



$\alpha_s = \alpha_s(T)$ – the Worst Case

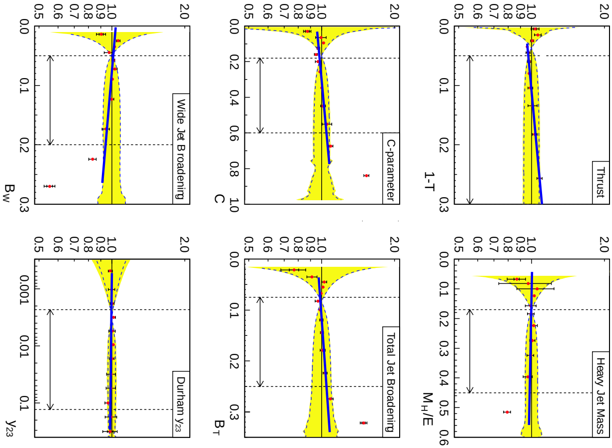
$\mathcal{O}(\alpha_s^2)$ from Siggi Hahns thesis Matched





Compare $T\,,B_T\,,C\,,M_H\,,y\,,B_W$

OPAL (Matth. Ford´s Thesis) data/fit my eye fit



note:
B/A ratios

$T\,,B_T\,,C \gtrsim 15$
$M_H\,,y$ small(er)
B_W negative

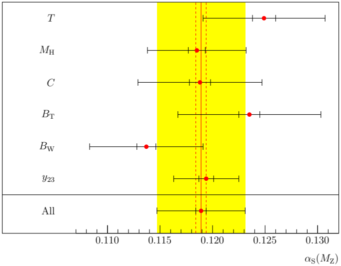
non-optimal scales $\Longrightarrow$

biases of α_s

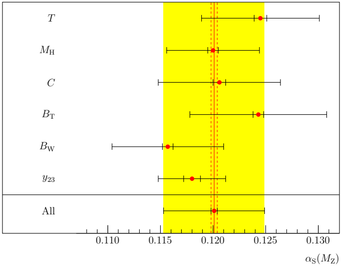
α_s Results - ln R Matched Theory

(from M.Fords thesis & LEPQCDWg info)

OPAL



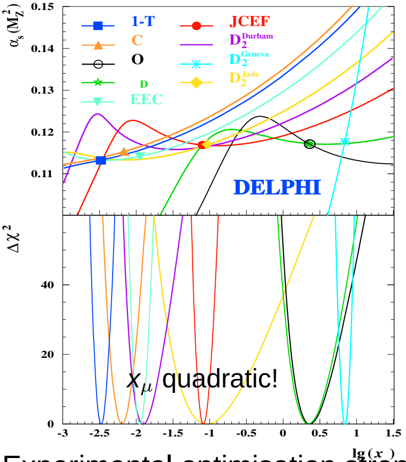
ADLO

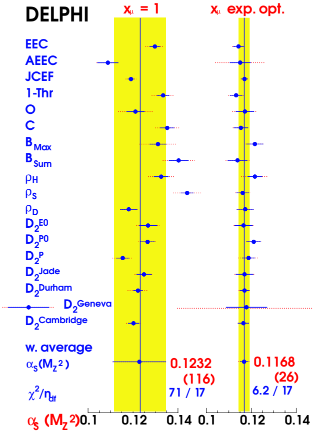


Observe the expected pattern:

$T, B_T, (C?)$ high ; M_H, y central ; B_W small

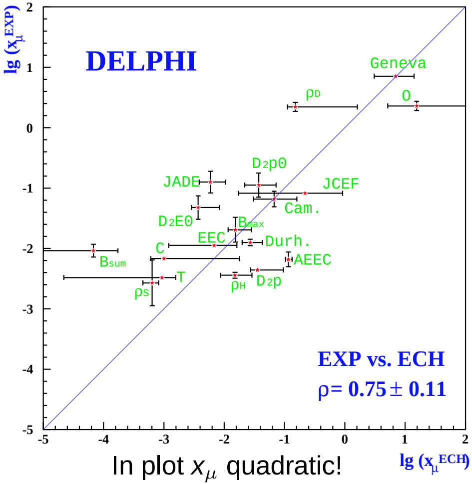
$\mathcal{O}(\alpha_s^2)$ & Experimental Optimisation





Experimental optimisation strongly improves consistency!

Experimental vs. ECH Scales



In plot x_μ quadratic!

Experimental scales correlate $\rho = 0.75$ with ECH or PMS scales

Errors:
ECH: scale variation in fit range
EXP: fit error

Influence of mass effects not considered !

$10^{\sigma(P(\lg(x_\mu^{ECH}/x_\mu^{EXP})))} \sim 2.5$
We “understand” the large range of opt. scales in $\overline{MS}$!

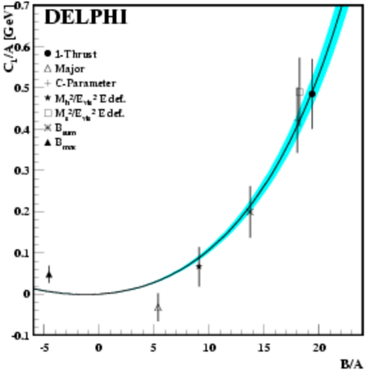
Naive Power Corrections

Assess power terms of means using:

$$\langle f \rangle = \langle f \rangle_{\mathcal{O}(\alpha_s^2)} + \langle f \rangle_{pow}$$

$$\langle f_{pow} \rangle = C_1 / E_{CM}$$

Find expected strongly differing power terms.



Surprising:
"Non–perturbative" p.t.'s correlate with perturbative ratio $B/A \Longrightarrow$.

Power terms predominantly account for higher order pert. effects?

Renormalisation Group Invariant (RGI) P.T.

Demand observable $R = \langle f \rangle / A$ to fulfil RGE:

$$Q\frac{dR}{dQ} = -bR^2(1 + \rho_1 R + \rho_2 R^2 + \ldots) = b\rho(R) \quad .$$

b, ρ_i are scheme invariant . $\Longrightarrow$

$$b \ln \frac{Q}{\Lambda_R} = \frac{1}{R} - \rho_1 \ln\left(1 + \frac{1}{\rho_1 R}\right) + \overbrace{\int_0^R dx \left(\frac{1}{\rho(x)} + \frac{1}{x^2(1+\rho_1 x)}\right)}^{\text{vanishes in second order}}$$

Simple RGI applies to observables depending on a single E scale.
Numerically RGI=ECH.

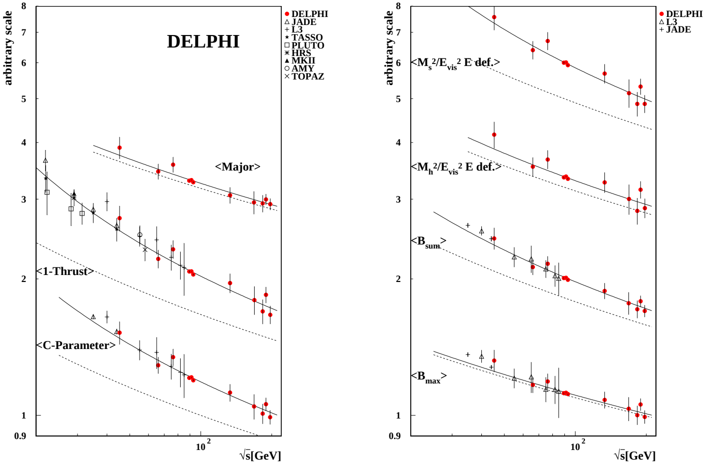
Exact conversion to $\overline{MS}$.

$$\frac{\Lambda_R}{\Lambda_{\overline{MS}}} = e^{B/2Ab}\left(\frac{2c_1}{b}\right)^{-c_1/b}$$

Include power terms by:

$$\rho(x) \rightarrow \rho(x) - \frac{K_0}{b} x^{-c_1/b} e^{-1/bx}$$

RGI – Description of Shape Observable Means

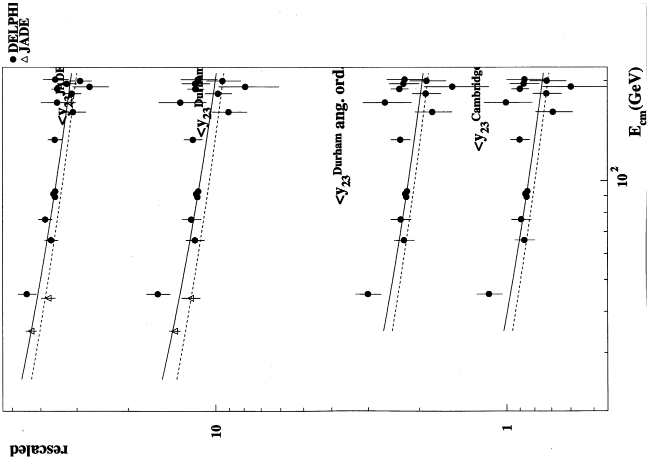


full line
RGI

dashed
$\overline{\mathrm{MS}}$
same Λ

RGI – for $\langle y \rangle$

α_s comes out somewhat lower ! $\Rightarrow$ String effect?



RGI & Means Need no Significant Power Terms

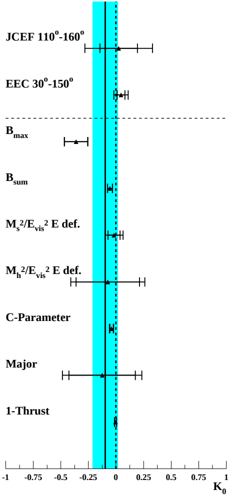
Fitting RGI with power–terms to many observable means yields:

K_0 compatible with 0 $\Leftrightarrow$ No P.C.!

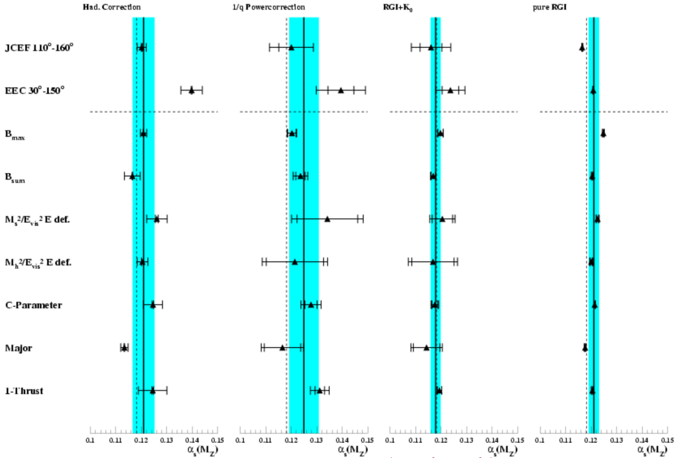
Virtue of both:
RGI and inclusiveness of mean values.

Presence of genuine power terms for means unclear !

Possible contribution:
$\mathcal{O}(\sim 2\%)$ (rel.) at the Z.



Cmp. α_s from Means Obtained with Various Methods



RGI yields smallest scatter; $\langle \alpha_s(M_Z) \rangle = 0.121 \pm 0.002$

"Predict" Power Terms using RGI

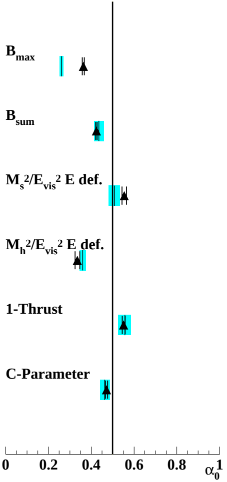
Set RGI and Power Model predictions equal:

$$\langle R \rangle_{RGI} \cdot A = \langle f \rangle_{pert} + \langle f \rangle_{pow}$$

Solve for α_0.

"Predicted" α_0 follows trend of the data.

Agrees better than any presumed universal value $\sim$ 0.5.



Measurement of the β–Function

RGI bases on the RGE ,
β–function can be measured without prior α_s determination!

$$\frac{\partial R^{-1}}{\partial \ln Q^2} = \beta_R = \frac{\beta_0}{4\pi}\left(1 + \frac{\beta_1}{2\pi\beta_0}R + \rho_2 R^2 + \dots\right)$$

$\Longrightarrow$ measure $\beta_R \approx \beta$ directly from a mean event shape.
Measurement is valid even “outside” QCD.

Got consistent results from several observables,
now use $\langle 1 - T \rangle$ (most data).

Measurement of the β–Function

Using DELPHI and low energy data:

$$\frac{\partial R^{-1}}{\partial \ln Q} = 1.38 \pm 0.05$$

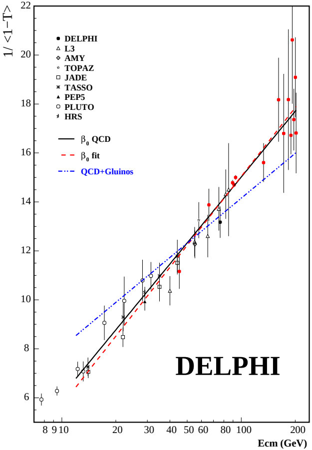
Uncertainty due to power terms small!

$$\beta_0 = 7.86 \pm 0.32 \quad n_f = 4.75 \pm 0.44$$

Compare "cross checks" via α_s:

LEP evt. shapes & world data $R_\tau, F_2, \cdots$

$$\beta_0 = 7.67 \pm 1.63 \quad \beta_0 = 7.76 \pm 0.44$$



light gluinos excluded

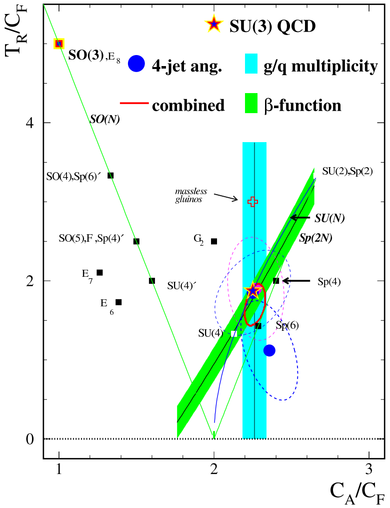
Summary

- $\mathcal{O}(\alpha_s^2)$ predictions with PMS/ECH scales
  better describe event shape distributions than $\overline{MS}$!
  χ^2/n_{df} of α_s average from 18 observabes:

$$\overline{MS} \quad : \quad \frac{71}{17} \qquad \text{ECH} \quad : \quad \frac{19}{17} \qquad \text{exp. opt.} \quad : \quad \frac{6.2}{17}$$

- Inadequate $\overline{MS}$ scales bias matched results !
- RGI can describe E dependence of means without power terms.
  $\Rightarrow$ Leads to a direct measurement of the β–function ...

Summary



RGI measurement of the
β–function
nicely confirms
the QCD gauge group!