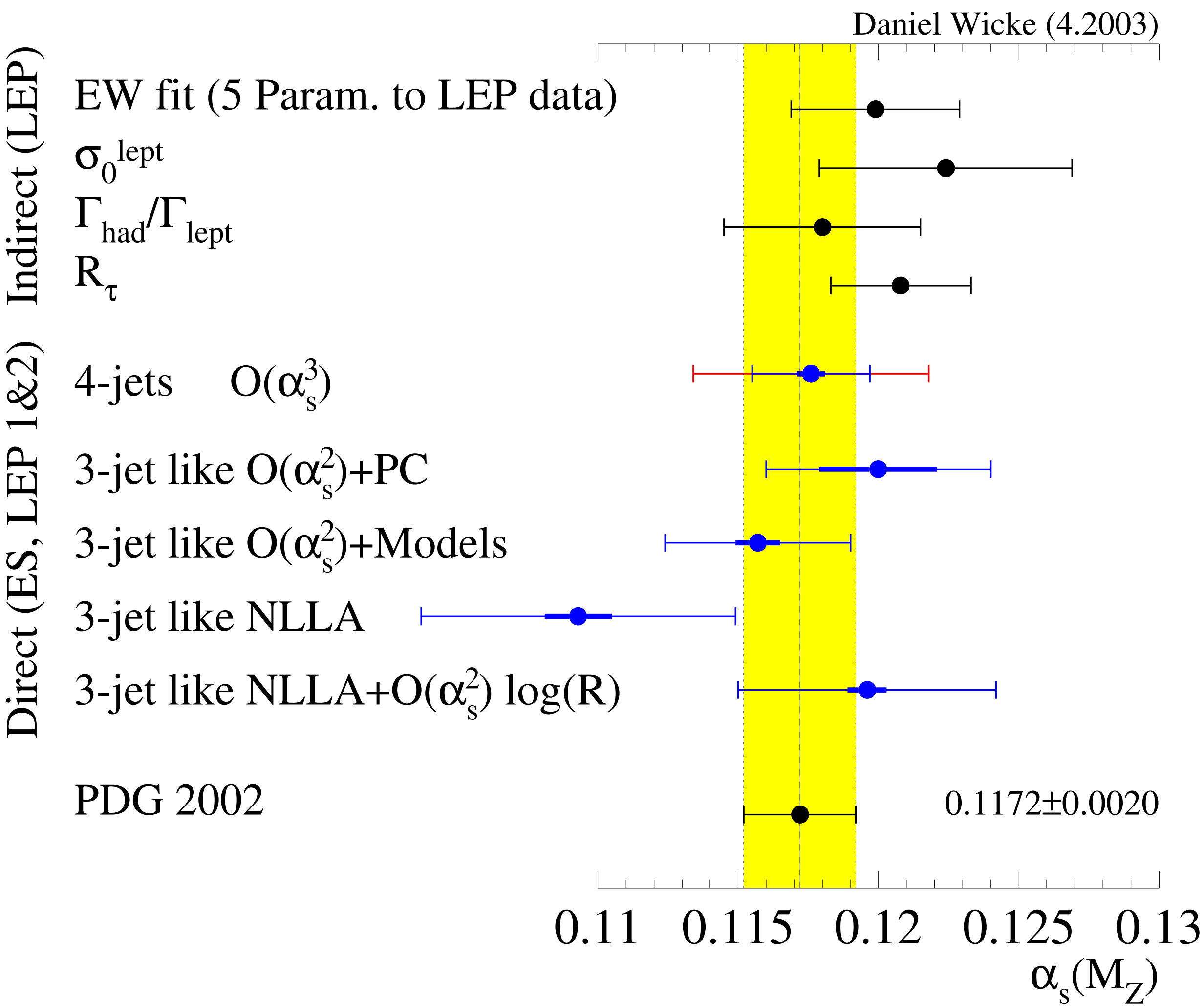
Determination of α_s with the DELPHI detector at LEP

Oliver Passon
DELPHI Coll.
Uni Wuppertal

Content

- Introduction
- The α_s combination of the LEP QCD working group
- Experimentally optimised scales
- Energy dependence of hadronic event shapes
- Summary and conclusion

Determination of α_s in e^+e^- annihilation



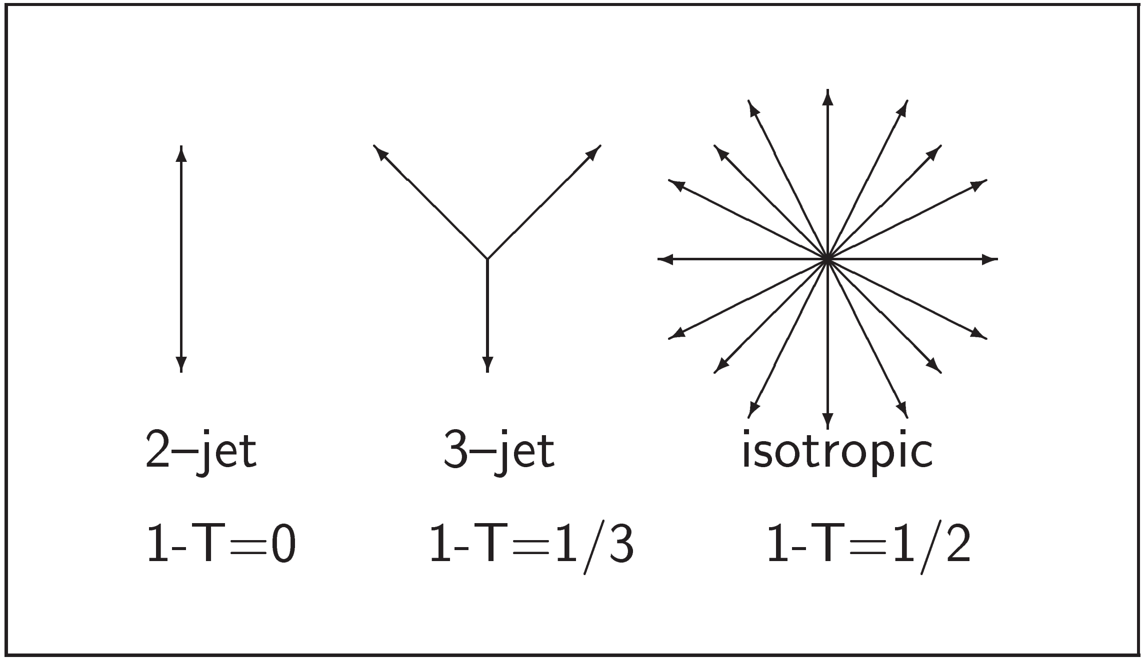
Pros and Cons

- Either the sensitivity to α_s is low, or hadronisation effects are large!
- Consistence among all methods provides a good cross check for QCD

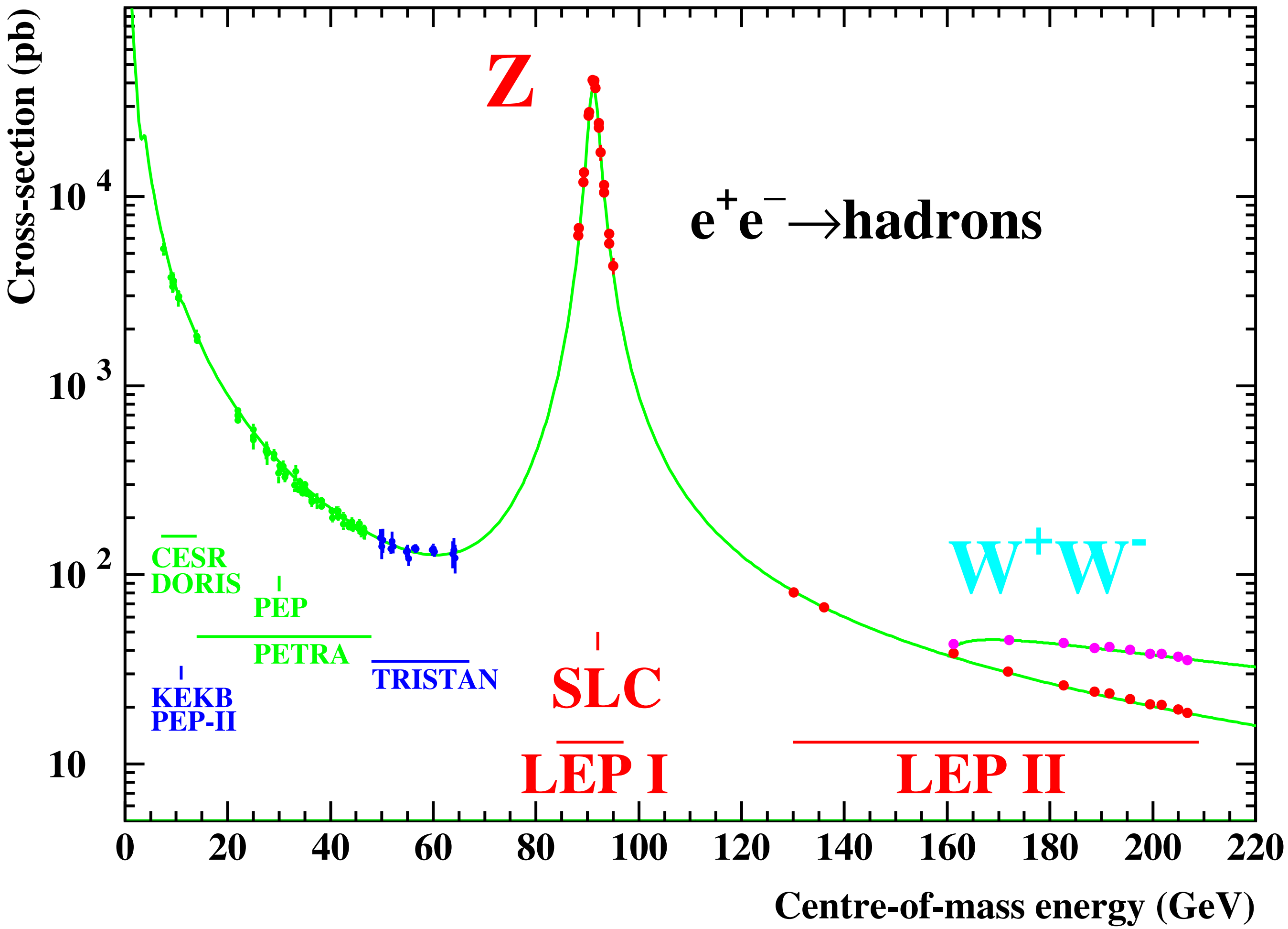
Event shape observables

Event shape observables (Thrust, C–Parameter, M_h^2/E_{vis}^2, $B_{\max}$ und B_{tot}) are dimensionless quantities which classify the topology of the hadronic final states. They are defined in the CM frame (= lab frame):

Example: Thrust $= \max_{\vec{n}} \left\{ \frac{\sum_i |\vec{p}_i \cdot \vec{n}|}{\sum_i |\vec{p}_i|} \right\} = \frac{\sum_i |\vec{p}_i \cdot \vec{n}_{\mathrm{T}hrust}|}{\sum_i |\vec{p}_i|}$



The data



LEP operated in two phases:

energy	$\frac{\#\text{events}}{\text{experiment}}$
89–93 GeV	$4{\cdot}10^6$
133–209 GeV	10^4

Background at LEP2:

$e^+e^- \rightarrow q\bar{q}\gamma_{ISR}$

$e^+e^- \rightarrow WW \rightarrow 4f$

α_s combination of the LEP QCD working group

Work done by the LEP QCD WG

- Common theory implementation, common understanding of matching schemes etc.
- Comparison of hadronisation models
- Studies on the treatment of correlation
  (between energies, experiments, observables etc.)
- Strong exchange with theoreticians on the theoretical uncertainties

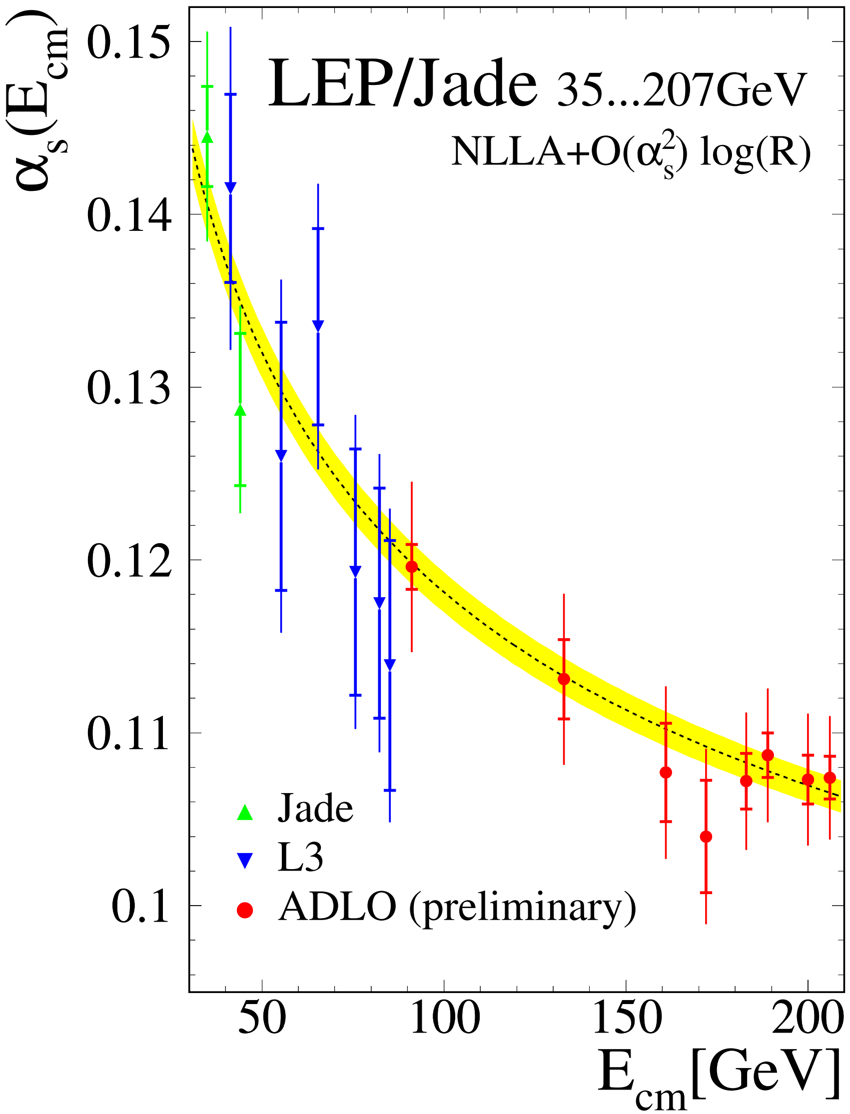
Input from ALEPH, DELPHI, L3 and OPAL:

- α_s values from event shapes in logR matching from LEP1 and LEP2
- statistical and (exp.) systemtic uncertainties
- α_s values when applying different hadronisation models

Output of the QCD working group:

- Calculation of an LEP average value of α_s
- Calculation of theoretical and hadronisation uncertainties
  (for fixed value of α_s)

α_s combination of the LEP QCD working group (ADLO)



	LEP1	LEP2
α_s	0.1197	0.1196
$\pm$stat.	0.0002	0.0005
$\pm$sys. ex.	0.0008	0.0010
$\pm$had.	0.0010	0.0007
$\pm$theo.	0.0048	0.0044
$\pm$tot.	0.0049	0.0046

$$\Delta_{\mathrm{rel}} = 4\%$$

Remarks on $\mathcal{O}(\alpha_s^2)$+NLLA calculations

$$R_{NLLA+\mathcal{O}(\alpha_s^2)} = R_{NLLA} + \alpha_s \mathcal{A} + \alpha_s^2 \mathcal{B} - \text{double counting}$$

Indications for additional theoretical uncertainties of NLLA and matched predictions

- experimental fact: χ^2 of the logR fits is poor
- α_s shows a strong fit range dependence
- E. Gardi and J. Rathsman Nucl.Phys. B638 (2002) 243 (hep-ph/0201019) have identified numerical important terms in their "dressed gluon approximation" which are sub–leading in NLLA
- The phase space condition of the NLLA calculations introduces more ambiguities.

The NLLA phase space condition

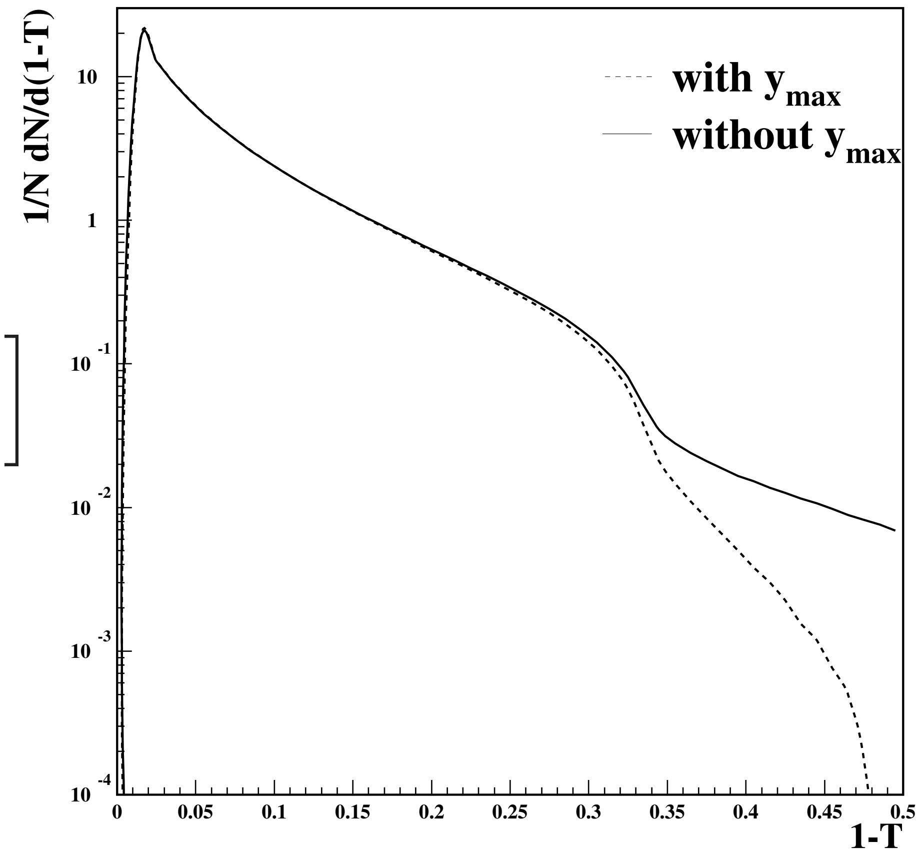
$$L = \ln\frac{1}{y} \rightarrow L' = \ln\left[\frac{1}{y} - \frac{1}{y_{max}} + 1\right]$$

Gavin Salam (hep-ph/0110213):

$$L' \rightarrow L'' = \frac{1}{p}\ln\left[\frac{1}{(x_L\cdot y)^p} - \frac{1}{(x_L\cdot y_{max})^p} + 1\right]$$

Additional arbitrary parameters p and x_L

Def. of theoretical uncertainty:
Effect of $2/3 \leq x_L \leq 3/2$ variation
Effect of $p = 1, 2$ variation
Effect of $0.5.\sqrt{s} \leq \mu \leq 2\sqrt{s}$ variation



Alternatives to logR? Fixed order perturbation theory

$$\frac{1}{\sigma_{tot}}\frac{d\sigma}{dy} = \underbrace{\underbrace{\alpha_s A}_{LO} + \alpha_s^2 \cdot [B + \underbrace{A \cdot b_0 \ln(\mu^2/Q^2)}_{\mu \text{ dependence}}]}_{NLO}$$

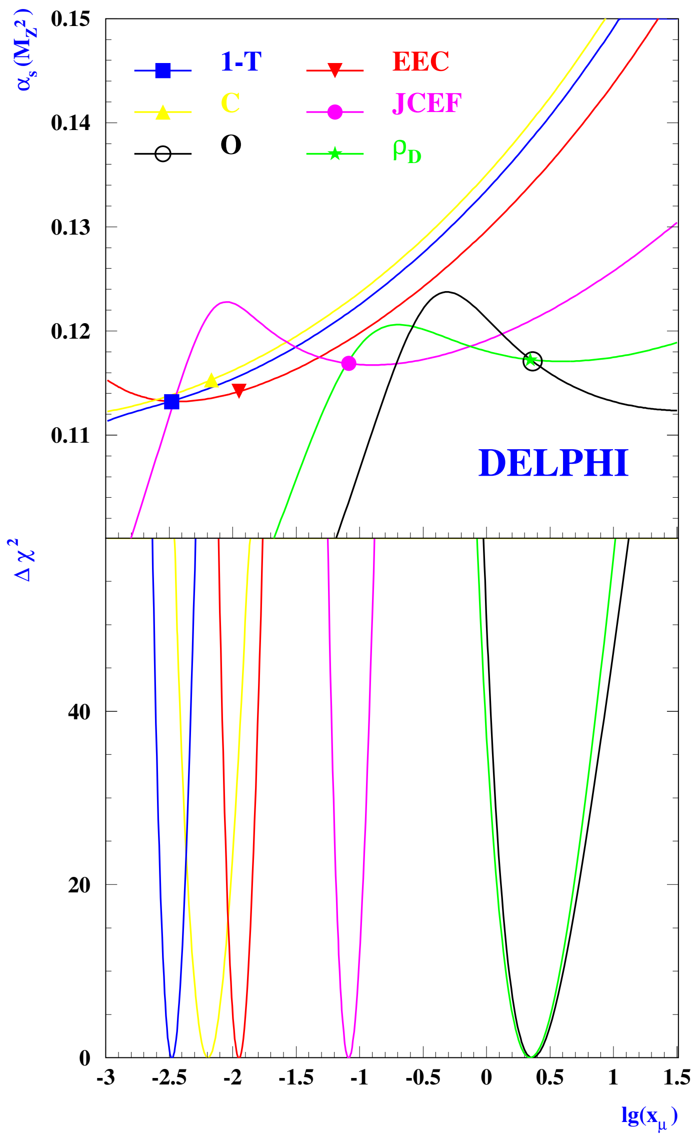
y event shape observable (1-thrust, jetmass, etc...)

- In finite order perturbation theory the results show a dependence on the unphysical renormalisation scale μ.
- $\mu = \sqrt{s}$ ("physical" scale) does not describe the data in $\mathcal{O}(\alpha_s^2)$

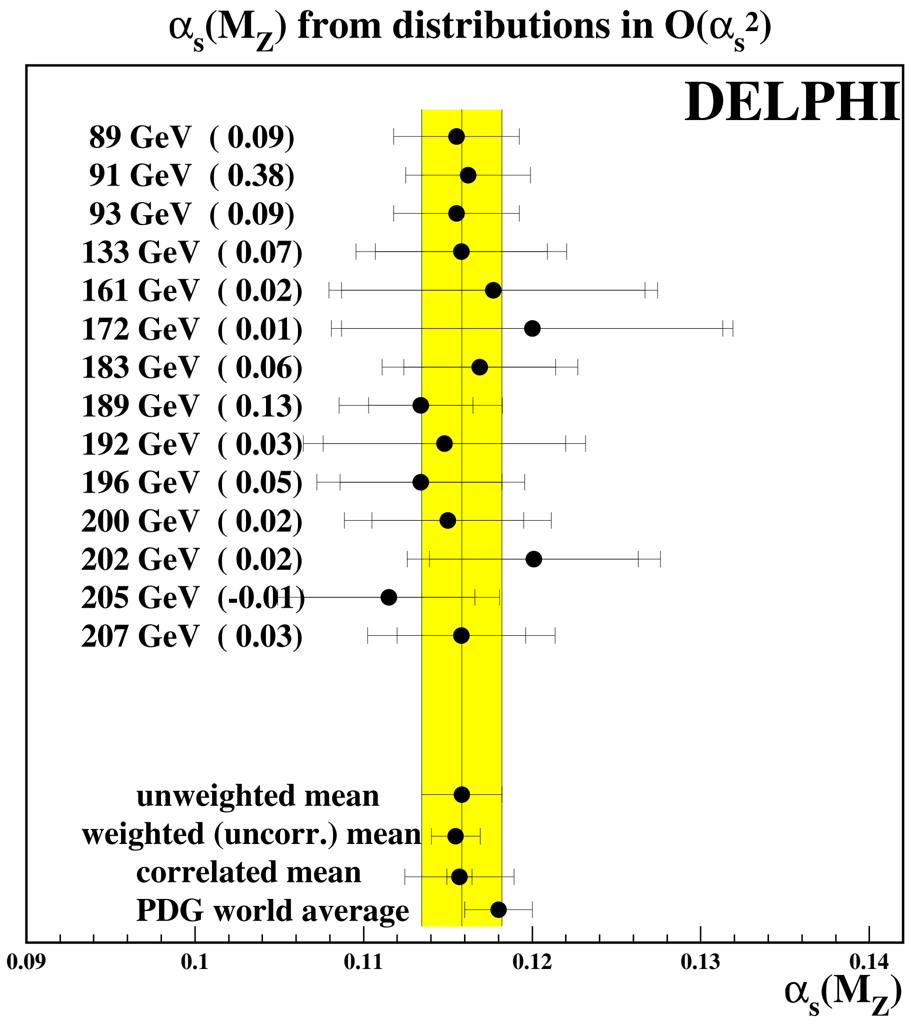
Scale choice in $\mathcal{O}(\alpha_s^n)$ and the effect of the μ variation on α_s

- Several recipes on the market: PMS, ECH, experimentally optimised scales...

- DELPHI (EPJ C14 (2000) 557) has described 18 observables in $\mathcal{O}(\alpha_s^2)$ with EOS. Consistent in α_s with a scatter of $\approx 2\%$



Combined α_s Values from 3–jet observables (DELPHI):



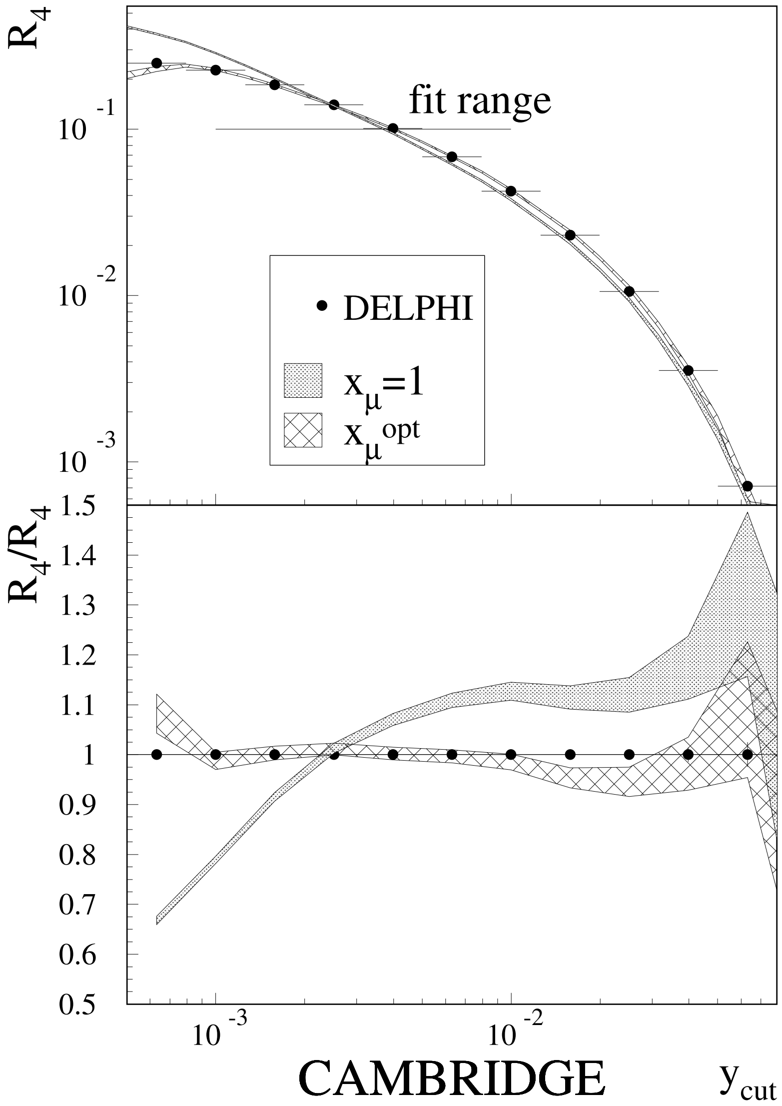
Combined α_s from Thrust, C–parameter, M_h^2/E_{vis}^2, $B_{\max}$ and B_{tot}:

	LEP1	LEP2	LEP1+LEP2
α_s	0.1162	0.1152	0.1157
$\pm$stat.	0.0002	0.0016	0.0008
$\pm$sys. ex.	0.0015	0.0022	0.0016
$\pm$had.	0.0027	0.0007	0.0016
$\pm$theo.	0.0022	0.0026	0.0022
$\pm$tot.	0.0038	0.0038	0.0033

$$\Delta_{\mathrm{rel}} = 3\%$$

But still an ad hoc error definition!

Combined α_s Values from 4–jet observables (DELPHI):



α_s from fit to 4–jet rate (Cambridge) to LEP1 data:

$$\alpha_s = 0.1175 \quad \underset{\text{ex}}{\pm 0.0010} \quad \underset{\text{had}}{\pm 0.0017} \quad \underset{\text{scale}}{\pm 0.0028}$$

$$\Delta_{\text{rel}} = 3\%$$

Energy dependence of hadronic event shapes

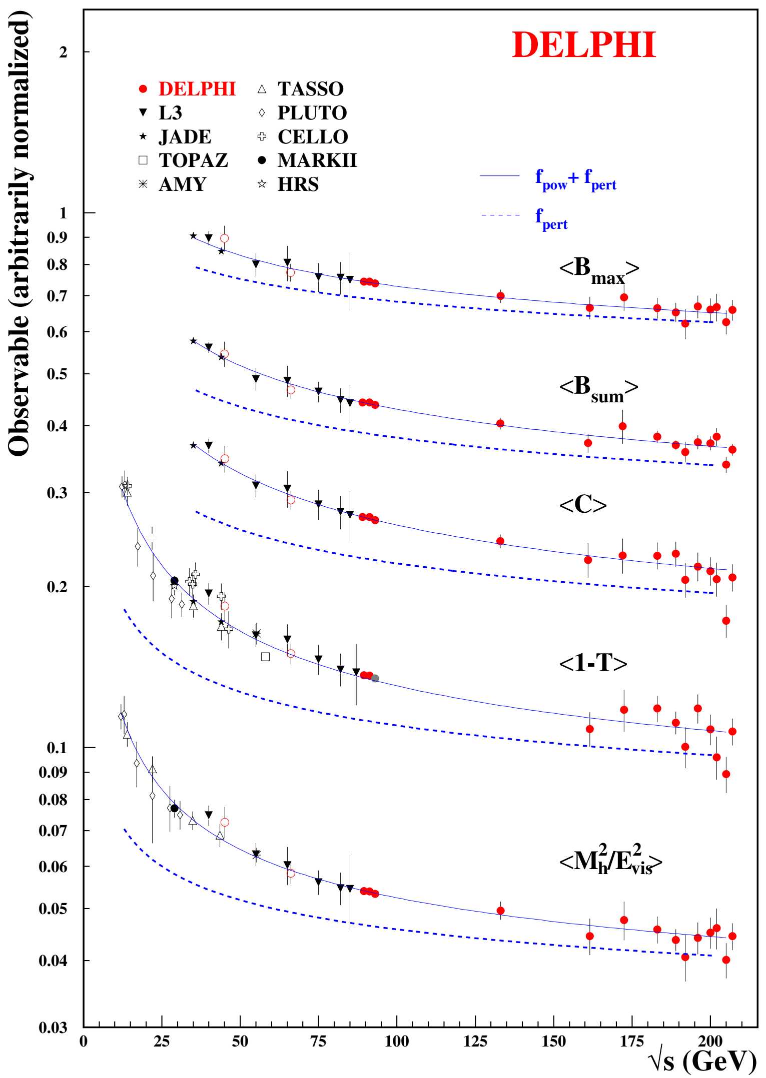
LEP has collected data from $\sqrt{s}$ =40GeV (radiative events) to $\sqrt{s}$=209 GeV

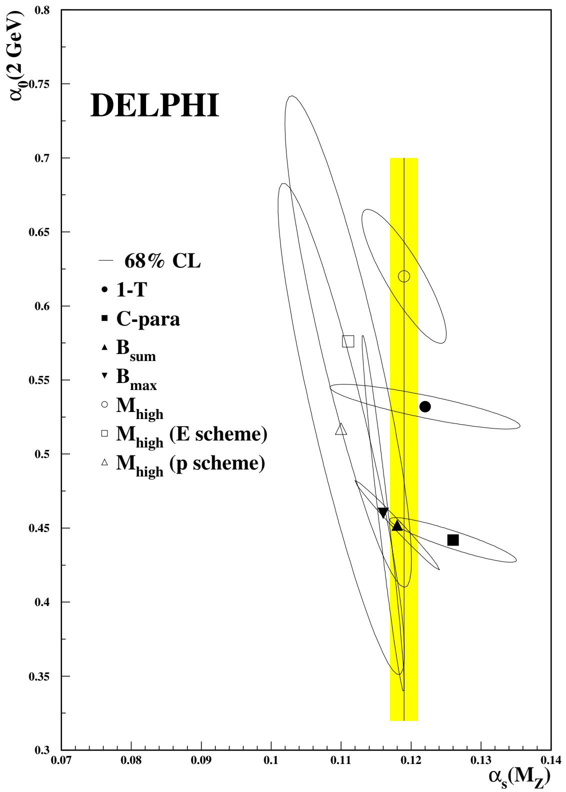
- Allows a test of power corrections (had.corr.$\propto$1/Q)
- Allows a test of the running of α_s

$$\frac{d\alpha_s}{d\log Q} = \beta(\alpha_s) = -2b_0\alpha_s^2 - 2b_1\alpha_s^3 - \cdots$$

with: $$b_0 = \frac{33-2N_f}{12\pi}, b_1 = \frac{153-19N_f}{24\pi^2}$$

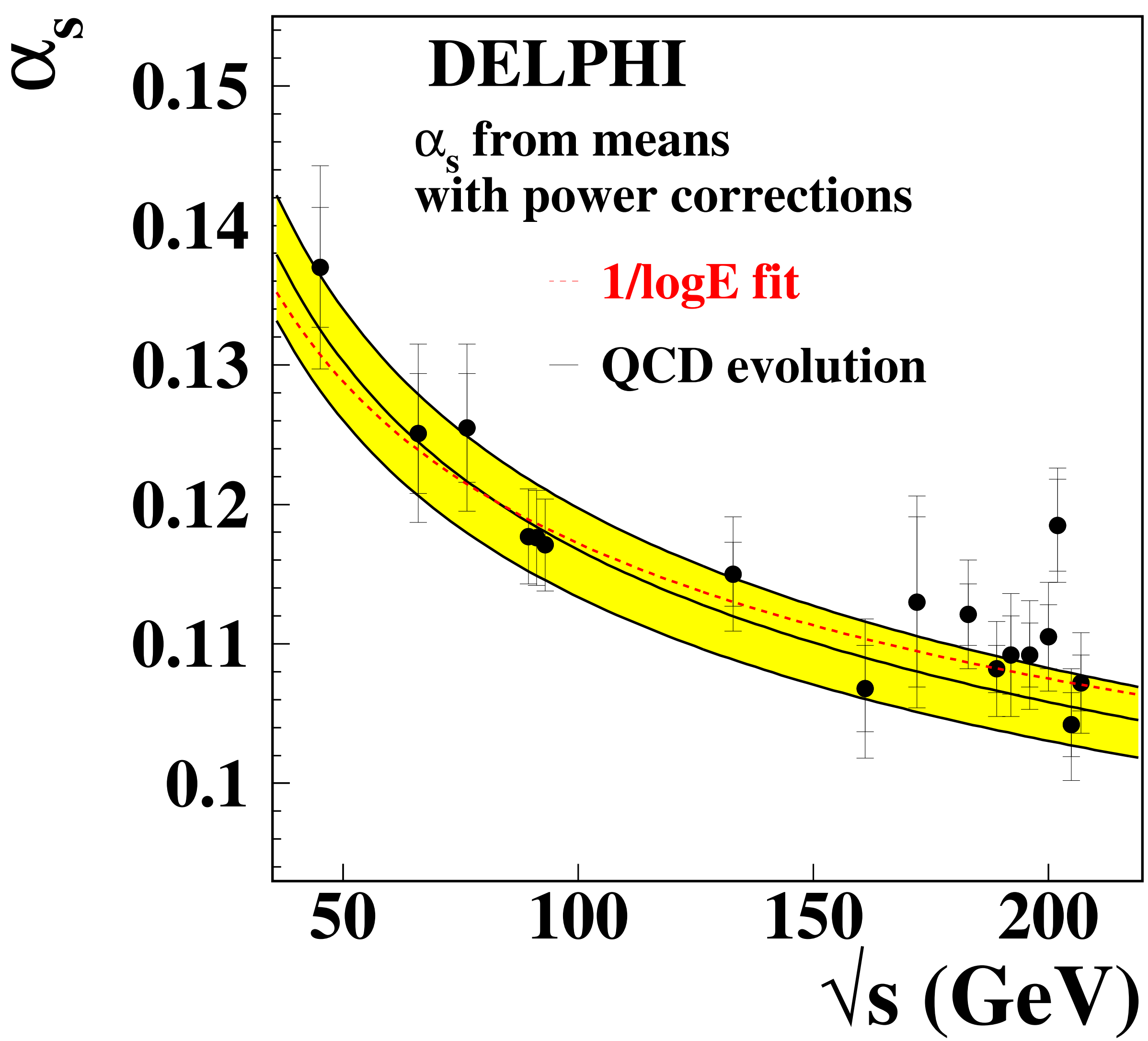
Mean values and power corrections





- Global fit yields α_s and α_0
- From α_0, α_s can be calculated for each single energy

Running of α_s



Consistent description of the data

But: power corrections are combined with $\mathcal{O}(\alpha_s^2)$ calculation in $\overline{\mathrm{MS}}$!
What about EOS, ECH etc. ?

And: This is not a proper measurement of the β function!

The Renormalisation Group Invariant (RGI) approach

The RGE governs not only the energy dependence of α_s. Thus it is possible to measure the β function without α_s!

(A.Dhar and V. Gupta (1984))

$$Q\frac{dR}{dQ} = -bR^2(1 + \rho_1 R + \rho_2 R^2 + \ldots) = b\rho(R) \quad \text{with:} \quad withe.g.R = \frac{\langle 1 - T\rangle}{A} \qquad (1)$$

equivalent to “effective charge“ (Grunberg ‘82)

ρ_i are renormalisation scheme invariant

$b = \beta_0/2$

$\rho_1 = \beta_1/2\beta_0$

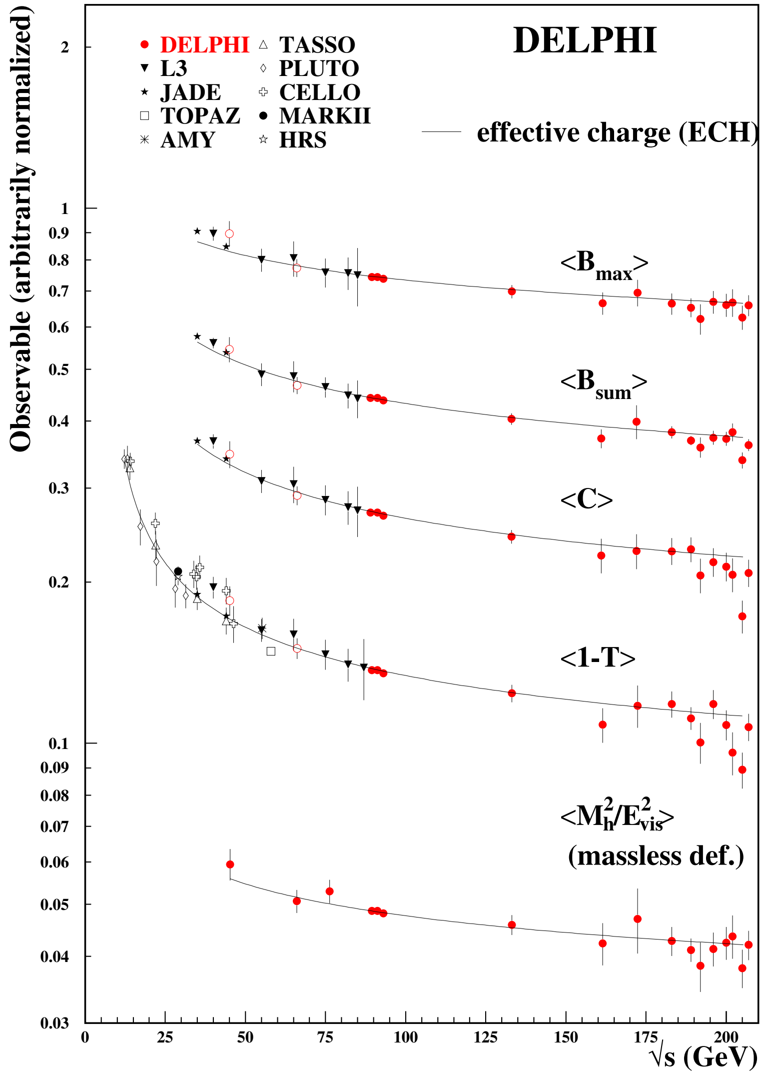
$\rho_2 = \frac{A^2\beta_2+8AC\beta_0-8AB\beta_1-8B^2\beta_0}{32A^2\beta_0}$

Solution: Λ_R

$$\frac{\Lambda_R}{\Lambda_{\overline{MS}}} = e^{r_1/b}\left(\frac{2c_1}{b}\right)^{-c_1/b}$$

Comparison with data

- pure RGI describes the data!
  (Power corrections negligible)
- The inclusive mean values seem to be less affected by hadronisation
- higher order effects better accounted for than in $\overline{MS}$



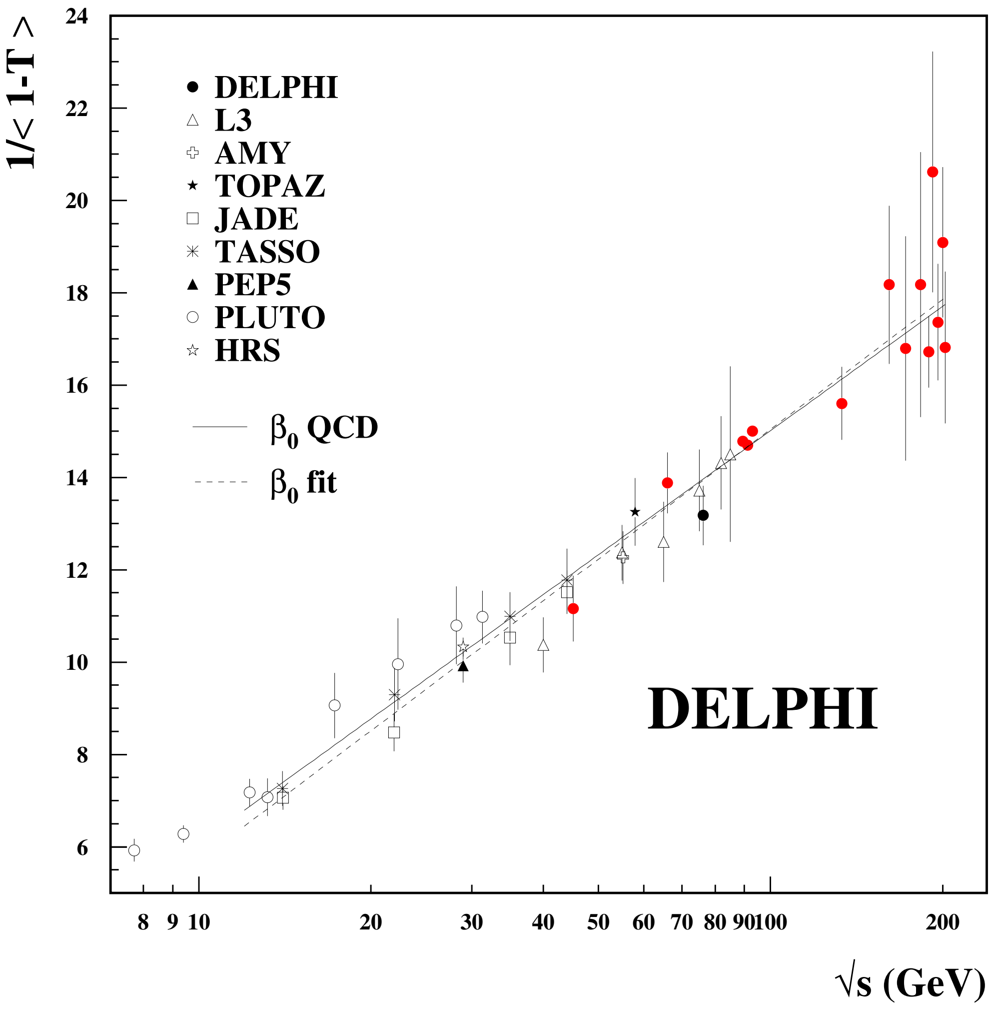
Measurement of the β function

The master equation of RGI can be converted into:

$$\frac{dR^{-1}}{d\log Q} = \frac{\beta_0}{2}\left[1 + \frac{\beta_1}{2\beta_0}R + \ldots\right]$$
$$= 4.15 \text{ (QCD)}$$
$$= 2.83 \text{ (light gluinos)}$$

$$\Rightarrow \frac{dR^{-1}}{d\log Q} = 4.35 \pm 0.16$$
$$n_f = 4.75 \pm 0.44$$

(model dependent)



Summary and Conclusion

- Various LEP measurements of α_s consistent: $\Delta_{\rm rel} = 3$–4%
  - NLLA/logR–matching affected by ambiguities (x_L, p, etc.)
  - $\mathcal{O}(\alpha_s^n)$ with experimentally optimised scale describes consistently LEP1 and LEP2 3–jet and 4–jet observables.
- Energy dependence of event shapes and α_s
  - Dokshitzer–Webber power corrections describe mean values in $\overline{\rm MS}$ scheme
  - RGI approach (in terms of α_s equivalent to ECH) describes mean values without power corrections!
    $\Rightarrow$ power corrections seem to be largely of perturbative origin
    (scheme dependence of power corrections?)

Treatment of correlation

The treatment of correlation enters at three different stages:

- Combination of α_s values at a single energy but from different observables
- Combination of α_s values at different energies
- Fit to the energy dependence of the correlated α_s values

$$\overline{\alpha} = \sum_{i=1}^{N} w_i \alpha_i, \quad \text{with:} \quad w_i = \frac{\sum_j (V^{-1})_{ij}}{\sum_{k,l} (V^{-1})_{kl}}$$

(note: w_i can turn negative) The covariance matrix has an additive structure:

$$V = V^{\text{stat}} + V^{\text{sys.exp.}} + V^{\text{had}} + V^{\text{scale}}$$

for systematic and theoretical uncertainties ("minimum overlap"):

$$V_{ij} = \min(\sigma_i^2, \sigma_j^2)$$