# $\alpha_s$ from event shapes in $e^+e^-$: Experimental issues and combination of results

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Precision measurements of $\alpha_s$ workshop

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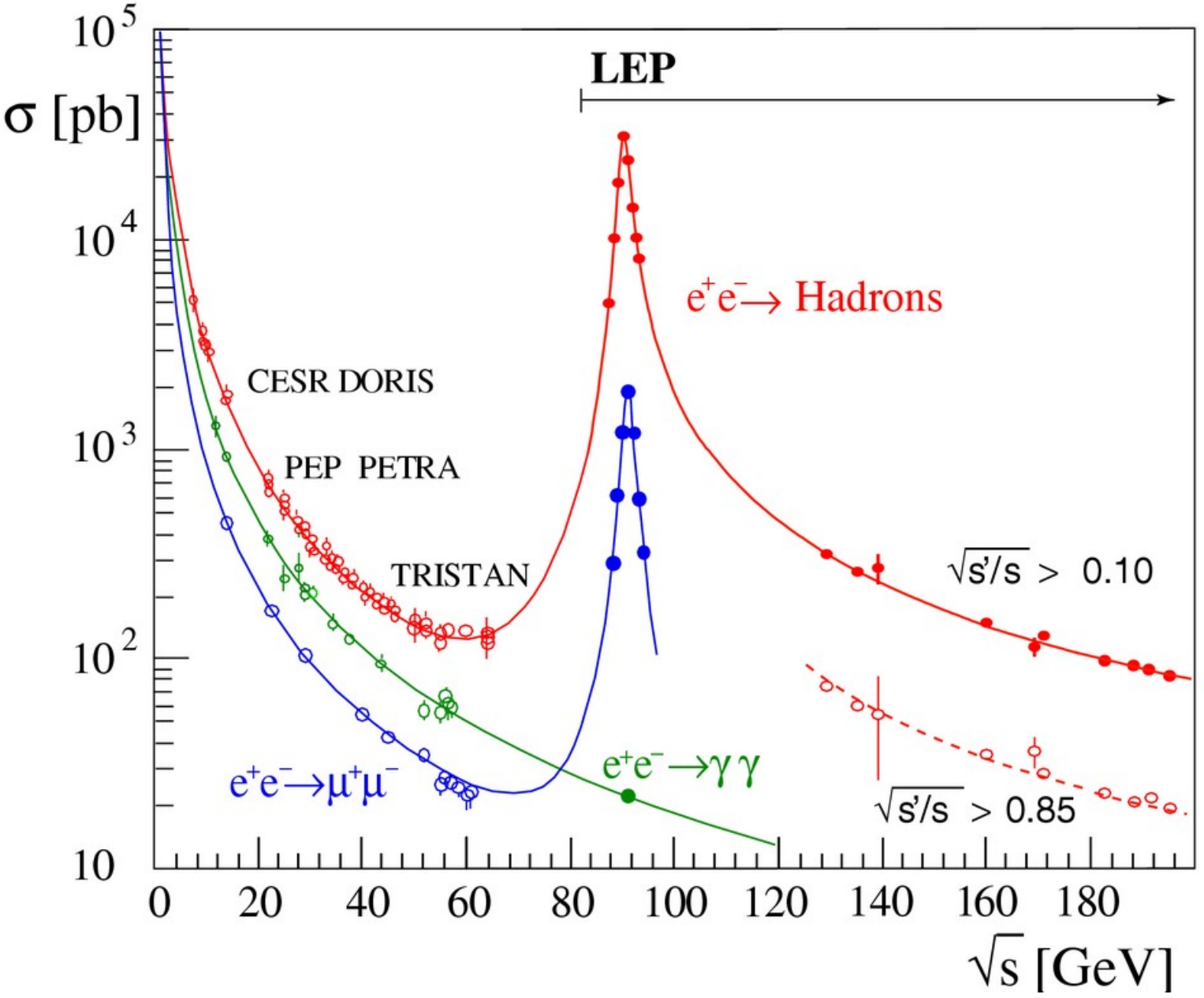
# Overview

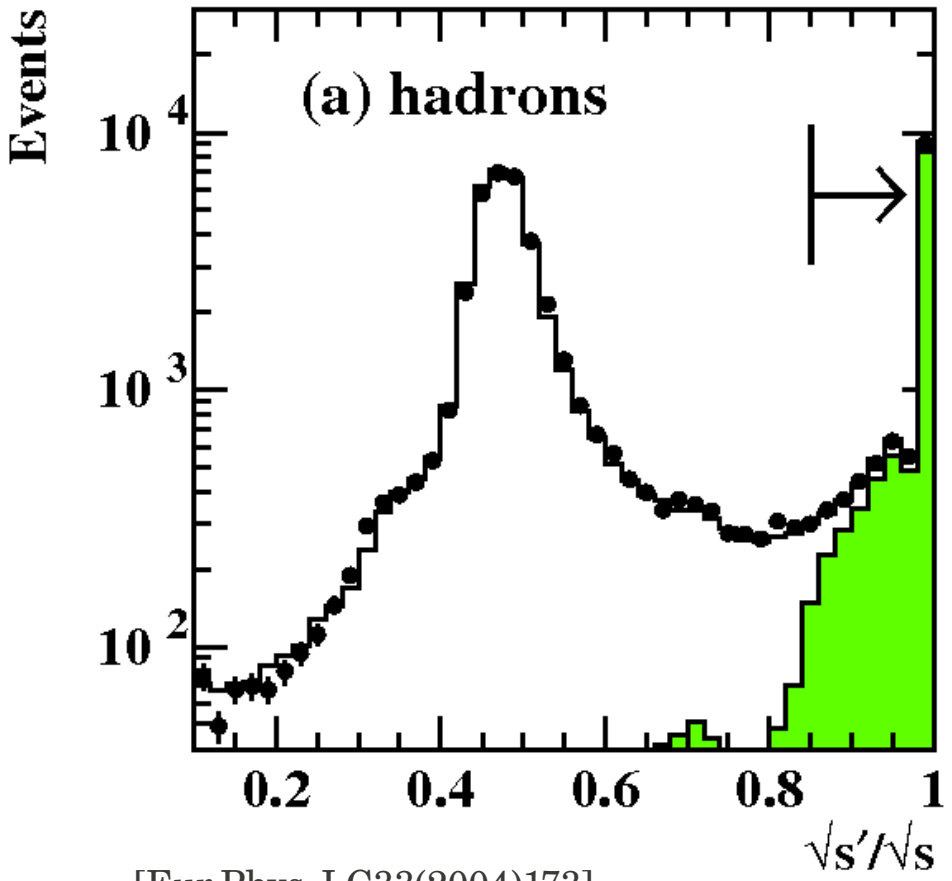

LEP
σ [pb]
$10^5$
$10^4$
$10^3$
$10^2$
10
$e^+e^- \to$ Hadrons
CESR DORIS
PEP PETRA
TRISTAN
$\sqrt{s'/s} > 0.10$
$e^+e^- \to \mu^+\mu^-$
$e^+e^- \to \gamma\gamma$
$\sqrt{s'/s} > 0.85$
0 20 40 60 80 100 120 140 160 180
$\sqrt{s}$ [GeV]

# Overview

| | PETRA | LEP 1 | LEP 2 |
|---|---|---|---|
| Rad. return | 4-mom. balance cuts<br>vary cuts | ~n.a. | 4-momentum balance, s' cuts<br>vary cuts or procedure |
| $\tau$ pair background | Multiplicity > 3<br>reject 1-3 events | Multiplicity > 6 | same |
| $2\gamma$ background | 4-mom. sum cuts<br>vary cuts | same | same |
| 4 fermion background ($W^+W^- \rightarrow$ jets) | n.a. | n.a. | "4-jet event shape" cuts<br>vary cuts and $\sigma_{bkg}$ |
| Detector corrections: acceptance, resolution, QED(ISR) | MC based unfolding<br>vary generator | same | same |

# Radiative Return

OPAL 189-209 GeV




[Eur.Phys.J.C33(2004)173]

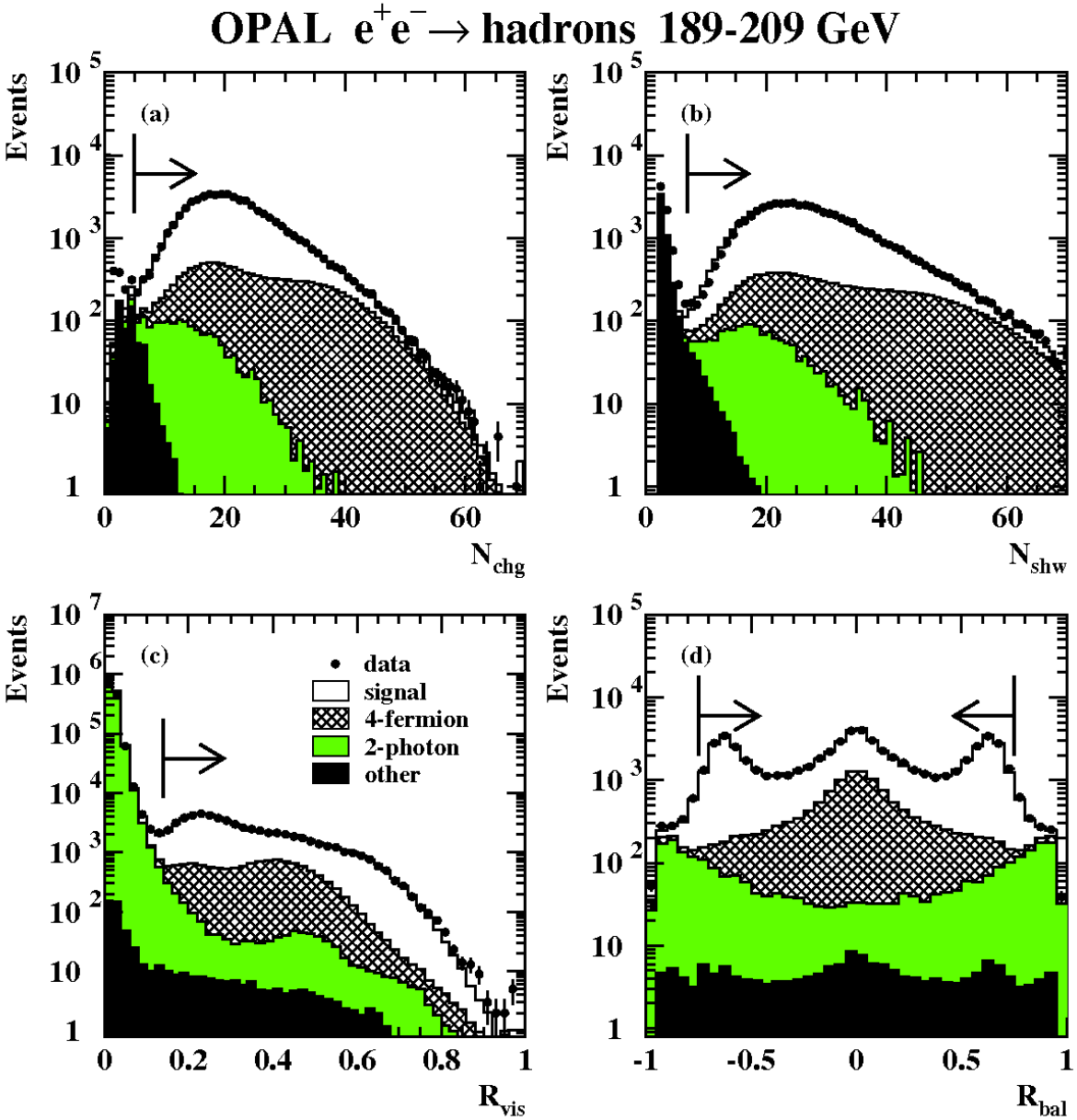
ALEPH:
make "small" jets, find EM jets, force remaining event in 2 jets

DELPHI:
kin. fit constrained to $E_{cms}$ for jet and possible missing $\gamma$ energies along beam

L3:
cuts on $E_{vis}$, $N_{cls}$, $E_{\gamma}$, $E_{||}/E_{vis}$

OPAL:
find isolated $\gamma$, force remaining event into four jets, do kin. fit constrained to $E_{cms}$ for jet and possible missing $\gamma$ energies along beam

# Two-γ and τ-pair background



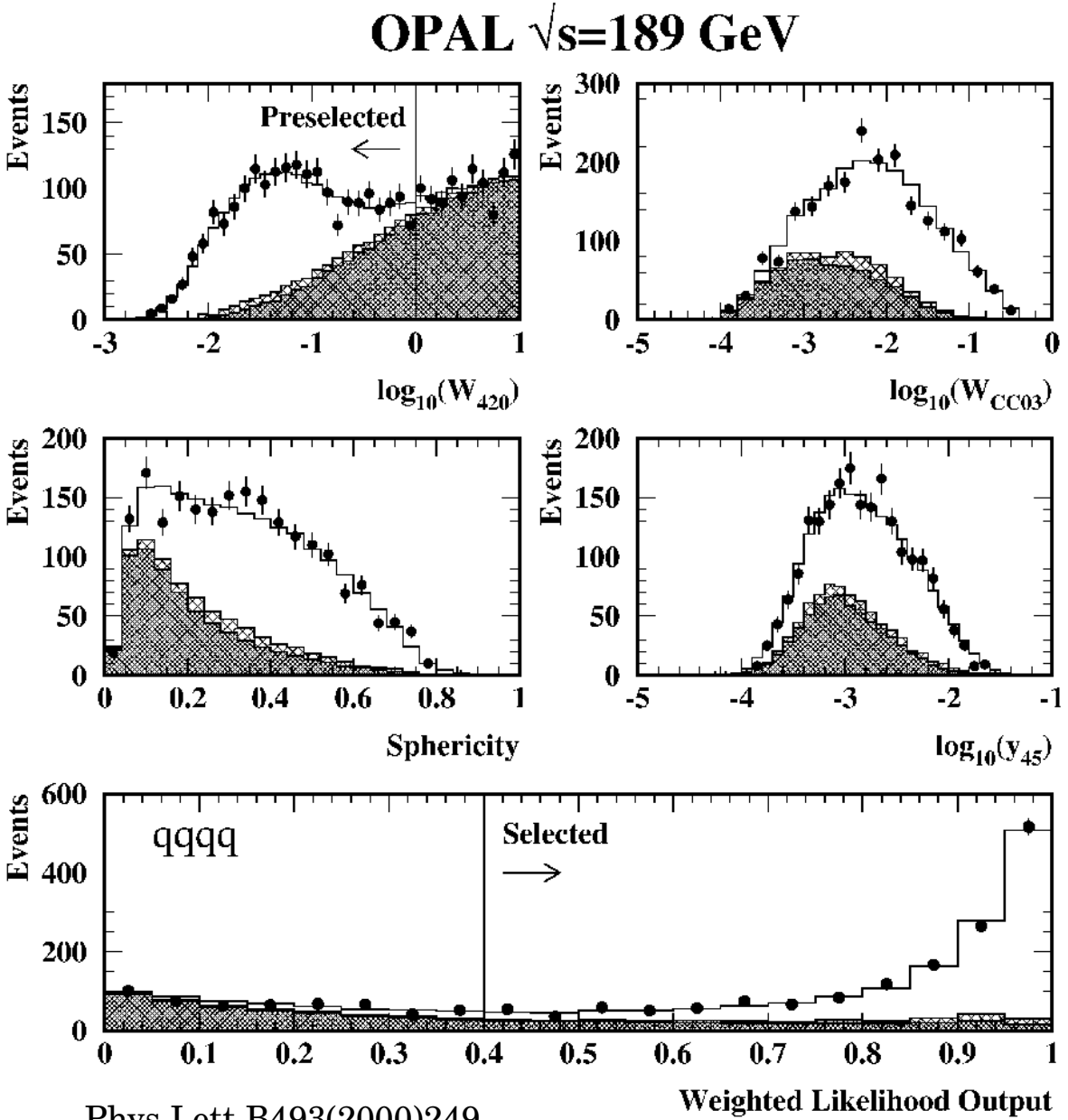

Eur.Phys.J.C33(2004)173

Background < 1% after selection

Considered neglible, no correction, no systematics

JADE/PETRA similar

# 4-fermion background




Phys.Lett.B493(2000)249

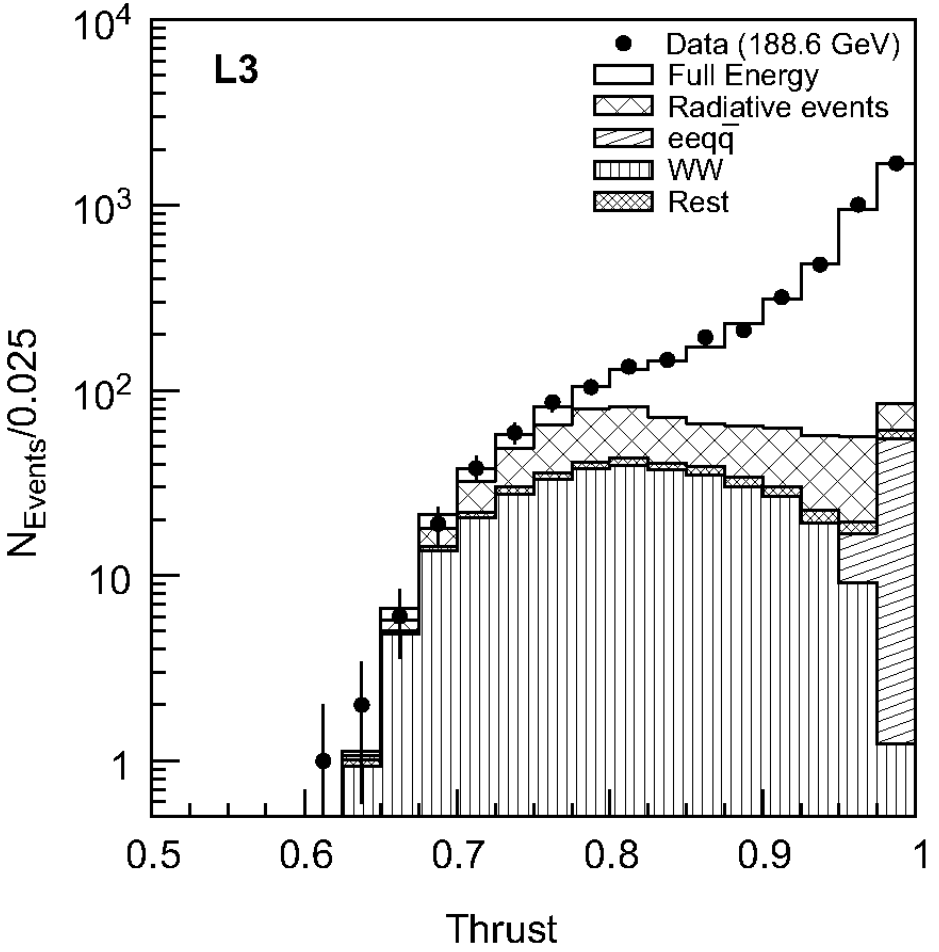
ALEPH:
4 jets: $\alpha_{34}$ and distance to $m_W$

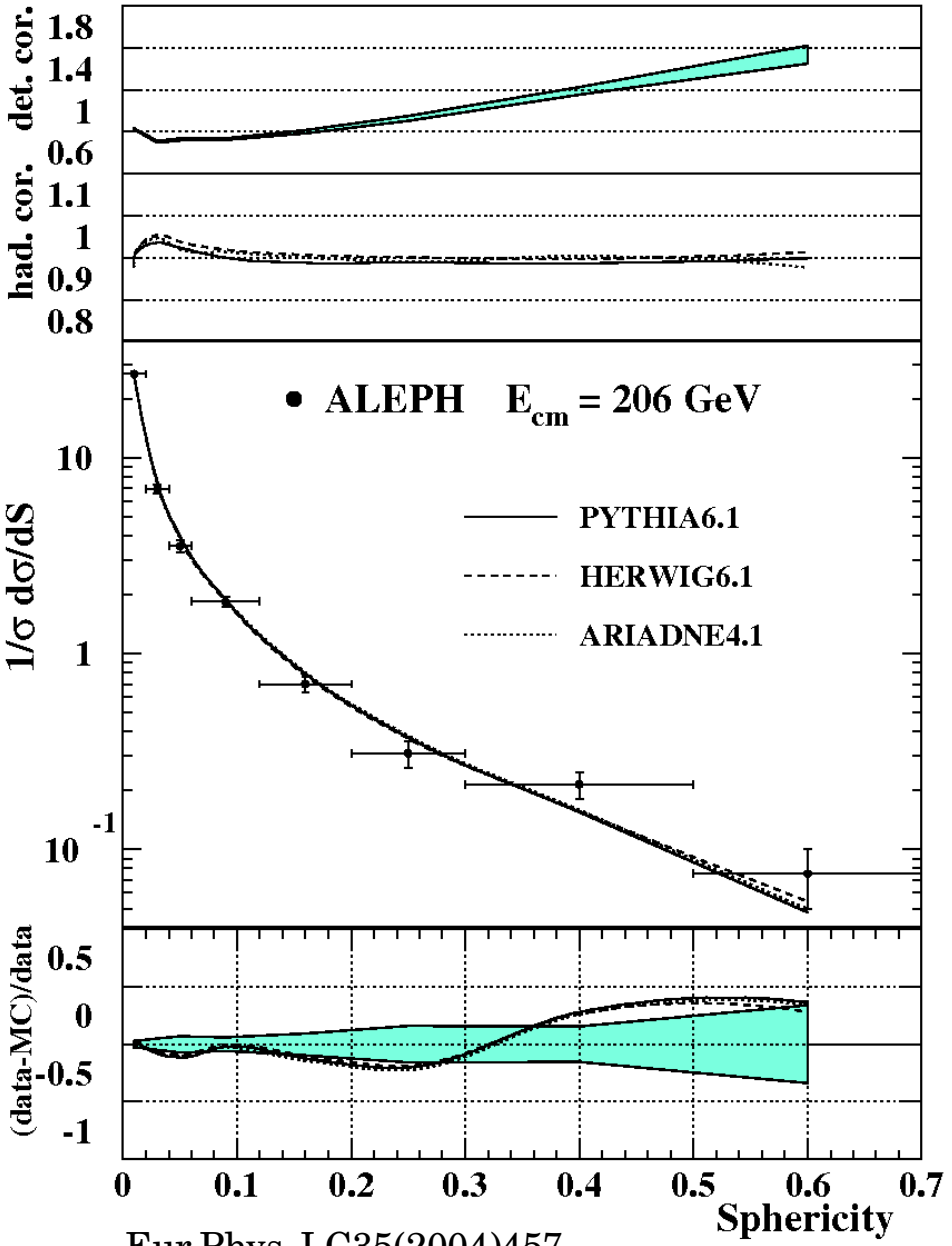
DELPHI:
2d cut in $N_{ch}$ vs $B_N$

L3:
4 jets+kin.fit: $y_{34}$, N, $E_{jet}$

OPAL:
QCD "partial NLO ME weight", $y_{34}$, Spericity, EW "partialME weight"

# Detector corrections




Detector corrections up to ~2 at high energies due to anti-WW cuts → significant systematics

[Phys.Rept.399(2004)71]

Eur.Phys.J.C35(2004)457

# Exp. Systematics overview

| | ALEPH | DELPHI | L3 | OPAL | JADE |
|---|---|---|---|---|---|
| PETRA | | | | | 0.7 – 4 % exp. corr. |
| LEP 1 | < 1 % exp. corr. | 1.6 % <br> ε=84.5% | 1.5 % exp. corr. <br> ε=98.5%*A | < 1 % exp. corr. <br> ε=88.5% | |
| LEP 2 | ~1.0 % non-rad. cuts | ~1.9 % <br> ε≈85-90%*A, $f_{bkg}$=5-14% | 1.0 - 2.5 % non-rad. cuts 4f cuts <br> ε≈85-90%*A, P≈80% | 0.8 – 4 % 4f cuts <br> ε≈80%, $f_{bkg}$=2-6% | |

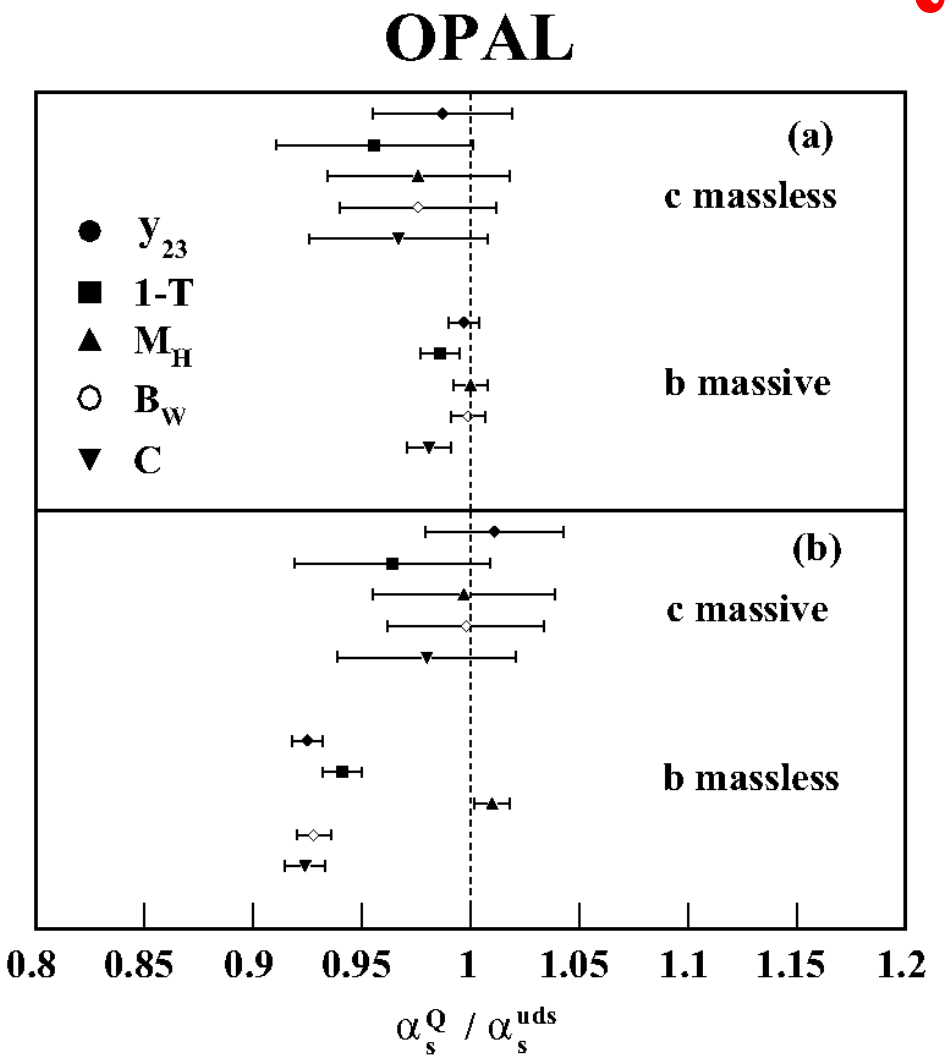
Exp. systematics not always similar along distribution,
e.g. LEP 4f cuts affect "> 3-jet region"

LEP 1 exp. systematics still to be matched by theory

LEP 2 exp. systematics reached by theory, difficult to improve with old data, hope for ILC detectors

# b Quarks

[Eur.Phys.J.C11(1999)643]




$b\bar{b}$ events bias $\alpha_S$, scales ~ $m_b^2/Q^2$ ,
~1% (incl.) at LEP 1

ALEPH:
NLO massive ME, "no corr."
systematic

DELPHI:
udsc/b had. corr., 20% systematic

L3:
NLO massive ME

OPAL:
neglect, "udsc" had. corr. systematic

JADE:
MC subtract $b\bar{b}$ from data, $\sigma_{b\bar{b}}$ ±5%
systematic

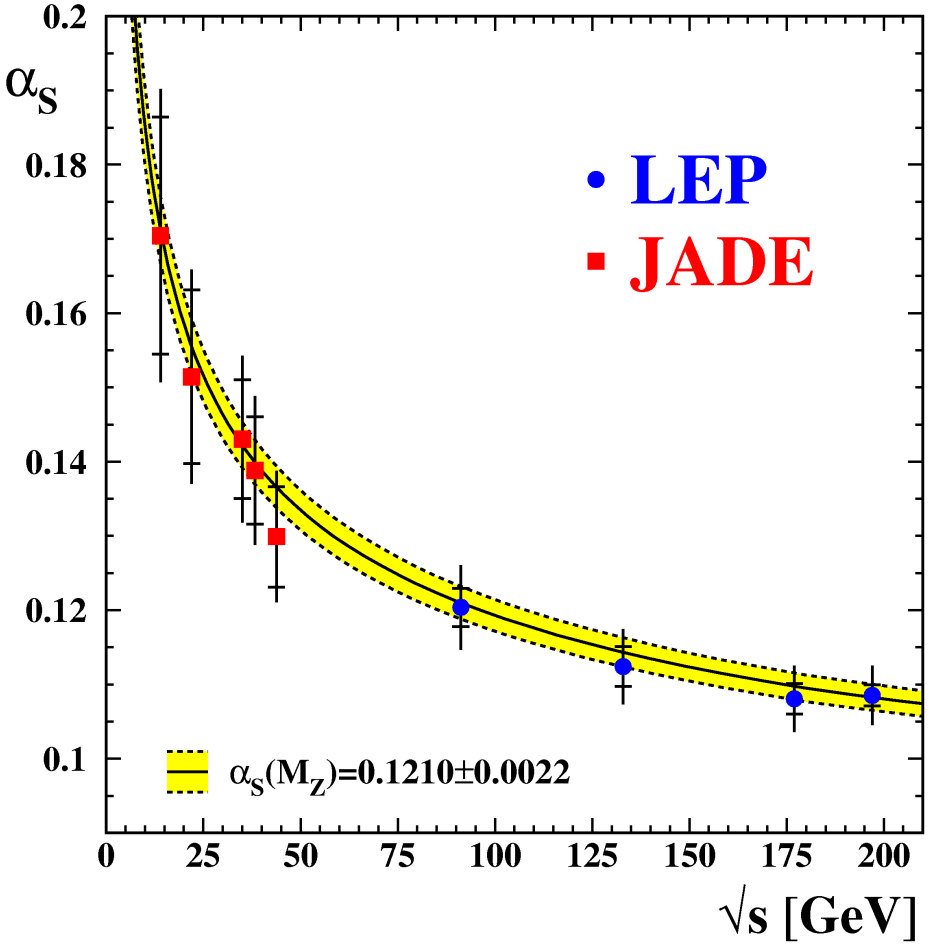
# Combination

- Find best average value of related analyses
- Event shapes highly correlated
- Systematics (exp., had., theo.) dominate
- Average from maximum-likelihood principle
  - Assume normal-distributed errors: $\chi^2$-method
  - Systematics: normal? Yes, by fiat. Correlations? Make models or repeat combinations.
- Studied by LEP QCD WG and experiments
  - LEP QCD WG method
- Always evolve to common scale before combination

# Correlations

- Statistical: measure from data or MC
- Systematic: models
  - No correlation $\rho_{ij} = 0$
  - Partial correlation $\rho_{ij} = \min(\sigma_i,\sigma_j)^2/(\sigma_i\sigma_j)$
  - Full correlation $\rho_{ij} = 1$
- Exp.
  - Partial within experiments, no corr between expts
- Had.
  - Assume no correlation, repeat for different had. models
- Theory
  - Assume no correlation, repeat for different renorm scale values

# LEP Results (pre-NNLO)




[Rept.Prog.Phys.69(2006)1771]

Consistent combination of (old) ADLO NLO+NLLA results:

LEP: $\alpha_s(m_z) = 0.1201 \pm 0.0005 \pm 0.0008 \pm 0.0019 \pm 0.0049$

LEP2: $\alpha_s(m_z) = 0.1200 \pm 0.0007 \pm 0.0010 \pm 0.0016 \pm 0.0048$

JADE: $\alpha_s(m_z) = 0.1203 \pm 0.0007 \pm 0.0017$ (NLO+NLLA) $\pm 0.0053 \pm 0.0050$

JADE: $\alpha_s(m_z) = 0.1172 \pm 0.0006 \pm 0.0020$ (NNLO+NLLA) $\pm 0.0035 \pm 0.0030$

NNLO(+NLLA) LEP not yet combined.
Same procedure? Theory variations?
Had./soft corrections?

# Other Combinations

- ALEPH, DELPHI, OPAL, JADE
  - LEP QCD WG method
- L3
  - unweighted average
- Bethke: $\chi^2$-method like LEP QCD WG
  - $\chi^2$/dof < 1: scale correlation factor
  - $\chi^2$/dof > 1: scale errors
  - Use total errors only

# Error Analysis in Combinations

$\underline{\alpha}_S = \Sigma_i\, w_i\, \alpha_S^{(i)}$ (error weighted average)

$w_i = \Sigma_j\, (V^{-1})_{ij} \,/\, \Sigma_{jk}\, (V^{-1})_{jk}$ , V is covariance matrix,

$V = V_{stat} + V_{exp} + V_{had} + V_{theo}$

$\Delta\underline{\alpha}_S = \Sigma_i\, w_i\, \Delta\alpha_S^{(i)}$

Propagate individual errors if they exist (exp., had., theo, …)
Can include correlations in $V_{xxx}$, either given, or model

$\Rightarrow \chi^2$ remains useful as hyphothesis discriminator

Please quote your error components, even if you are a theorist!

# Summary

- Investment in theory improvements might still pay at LEP 1 (and JADE)
  - Perturbative and/or non-perturbative
- Consistent combinations from JADE, LEP only for NLO+NLLA
- Now have several analyses for same data
  - ALEPH and OPAL
- How to combine?
- Reanalysis of DELPHI and L3?