Measurement of the strong coupling α_s from the 3-jet rate in e^+e^- annihilation using JADE data

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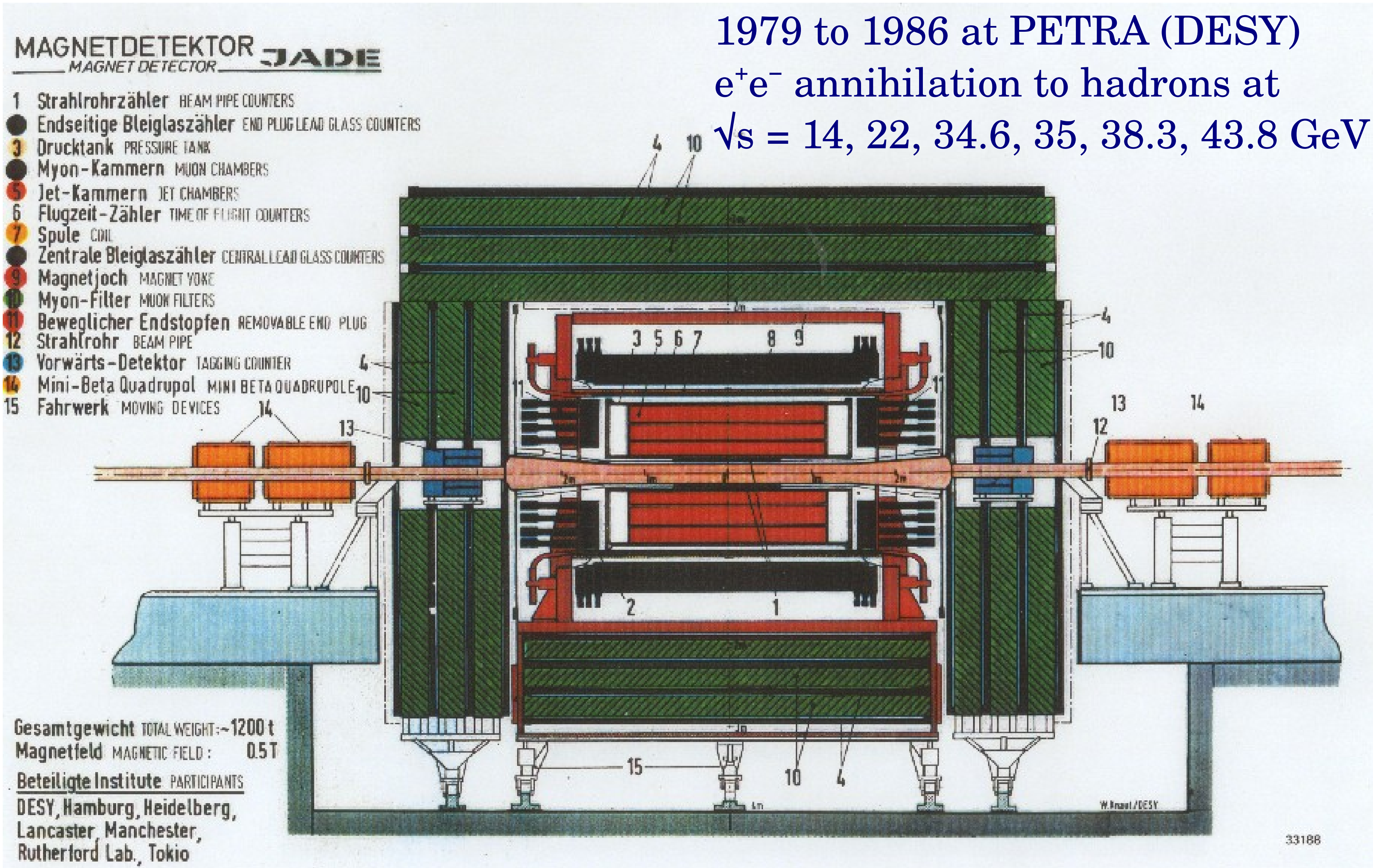
[Eur. Phys. J. C73 (2013) 2332]

Introduction

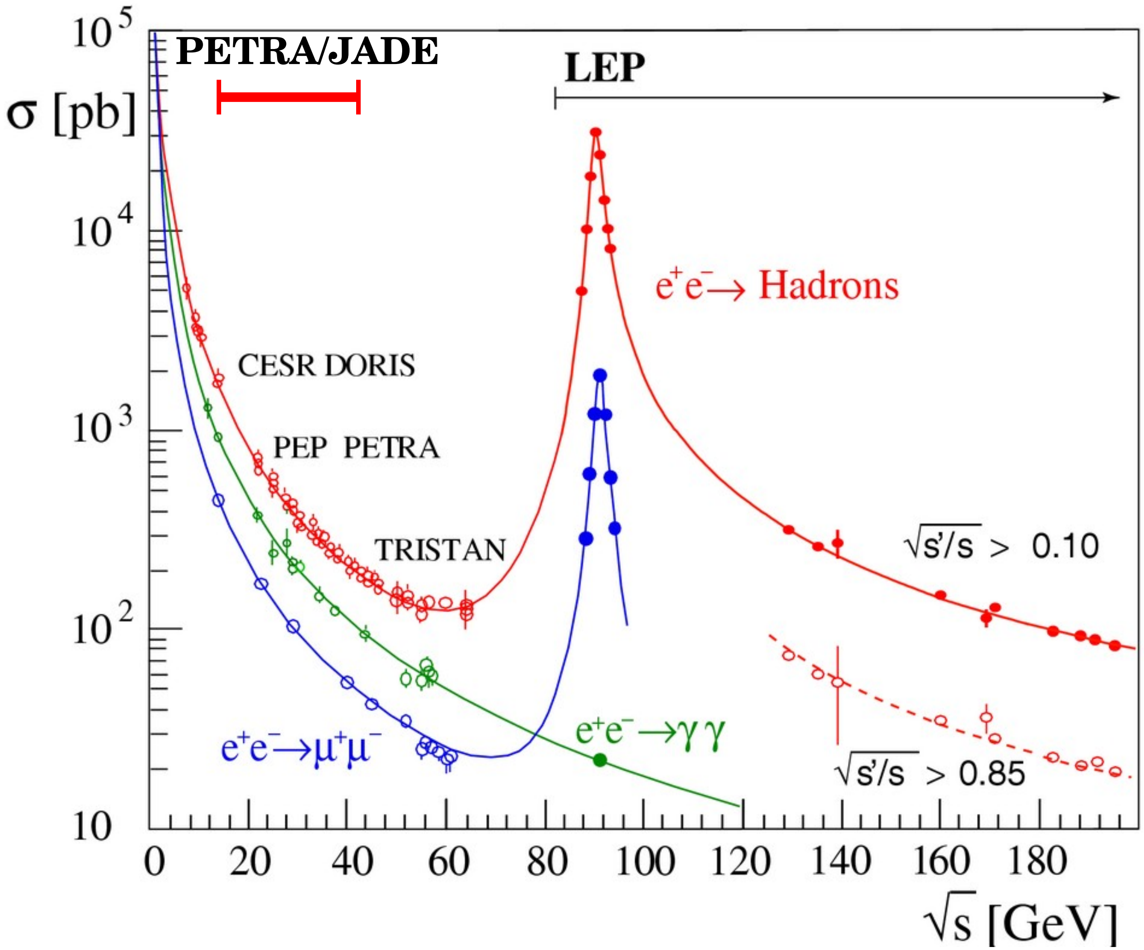
- Why study 27+ year old $e^+e^- \rightarrow$ hadrons data?
  - Theory improvements: NLO > 3 jets, NNLO, ...
  - MC generators and hadronisation models
- Test QCD calculations for LHC
  - Techniques related, crossing relations
  - Precision tests independent of pp complications
- Because we can!

The JADE experiment

1979 to 1986 at PETRA (DESY)
e^+e^- annihilation to hadrons at
$\sqrt{s}$ = 14, 22, 34.6, 35, 38.3, 43.8 GeV



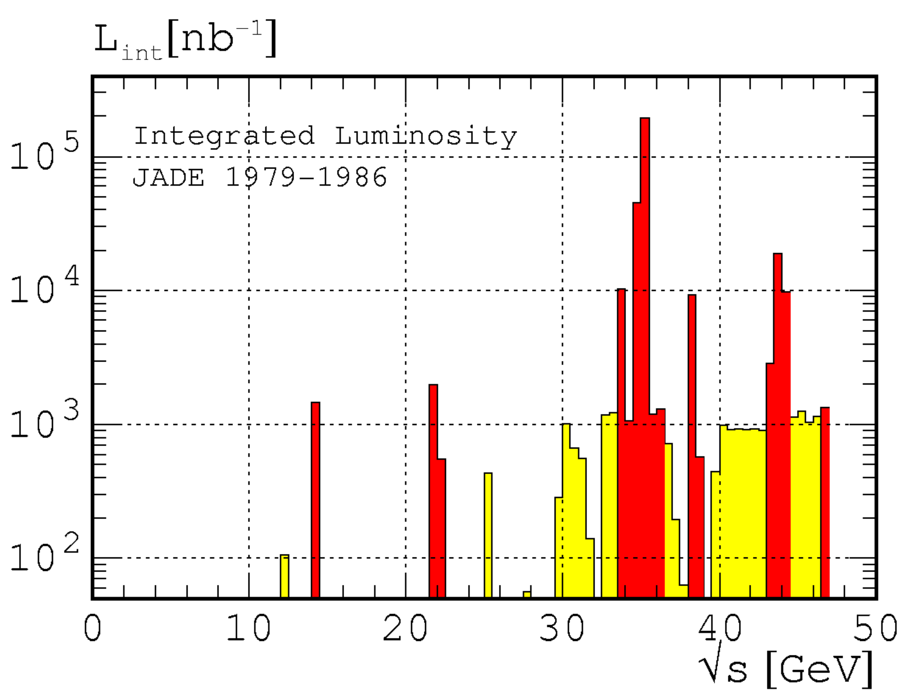
JADE data



Data samples:

O(10^3-10^4) events

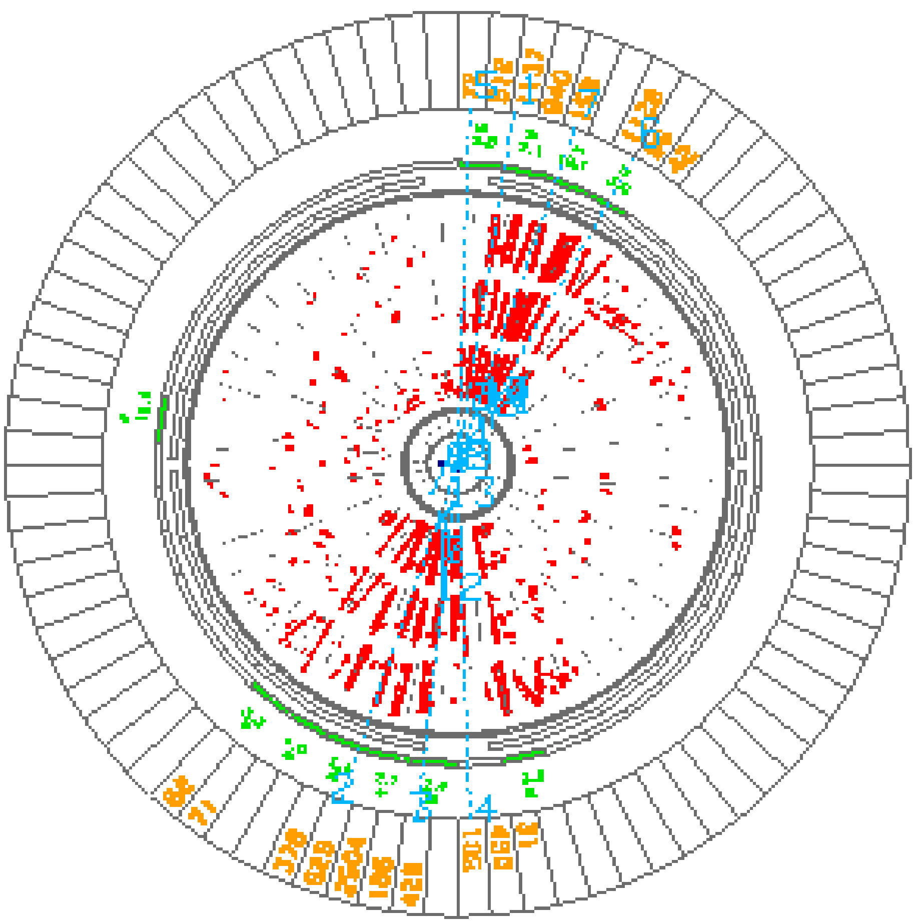
Negligible backgrounds after selection



Event selection:
momentum balance, visible energy, $N_{ch.}$

Durham jet clustering algorithm

JADE $\sqrt{s}$ = 44 GeV



1) Phase space distances

$$y_{ij} = 2\min(E_i,E_j)^2(1-\cos\theta_{ij})/s$$

2) Stop when all $y_{ij} > y_{cut}$

3) Combine pair with smallest y_{ij}

$$p_{ij} = p_i + p_j$$

4) Remove i and j, add ij, goto 1)

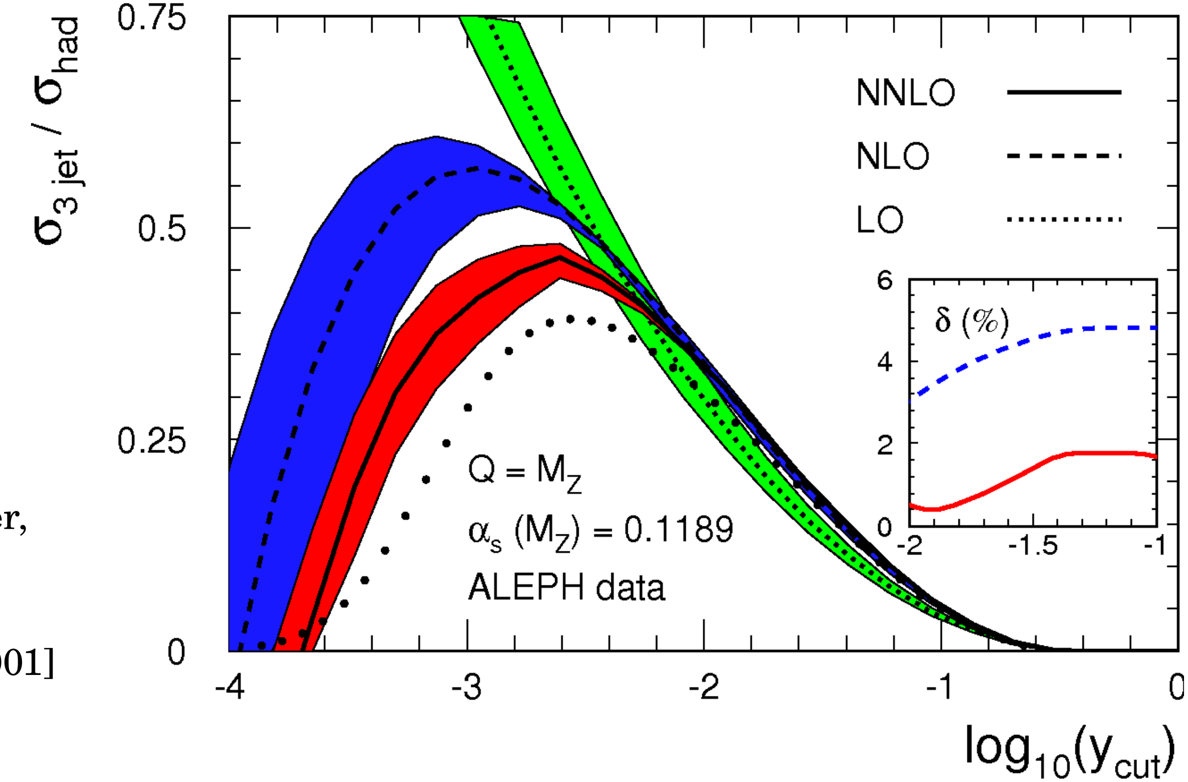
Observable: $R_3(y_{cut}, Q) = N_{3\text{-jet}}(y_{cut}, Q) / N(Q) = \sigma_{3\text{-jet}}/\sigma_{had}$

QCD predictions: fixed order

$R_{3,NNLO}(y_{cut}, Q) = \sigma_{3\text{-jet}}/\sigma_0 = A(y_{cut})\, \underline{\alpha}_S(Q) + B(y_{cut})\, \underline{\alpha}_S^{\,2}(Q) + C(y_{cut})\, \underline{\alpha}_S^{\,3}(Q)$

$\underline{\alpha}_S = \alpha_S/(2\pi)$; $\sigma_0 = \sigma_{had} / (1 + 2\underline{\alpha}_S + \ldots)$

$A(y_{cut})$, $B(y_{cut})$, $C(y_{cut})$ by numerical integration of QCD ME



Insert: rel. theory uncertainties NLO and NNLO

[Gehrmann-de Ridder, Gehrmann, Glover, Heinrich: Phys. Rev. Lett. 100 (2008) 172001]

QCD predictions: resummation

E.g. $\alpha_S \log^2(1/0.01) \approx 0.4$

→ $R_{3,NLLA}$ large for small y_{cut}

Expand known $R_{3,NLLA}$ to $O(\alpha_S^{\,3})$:

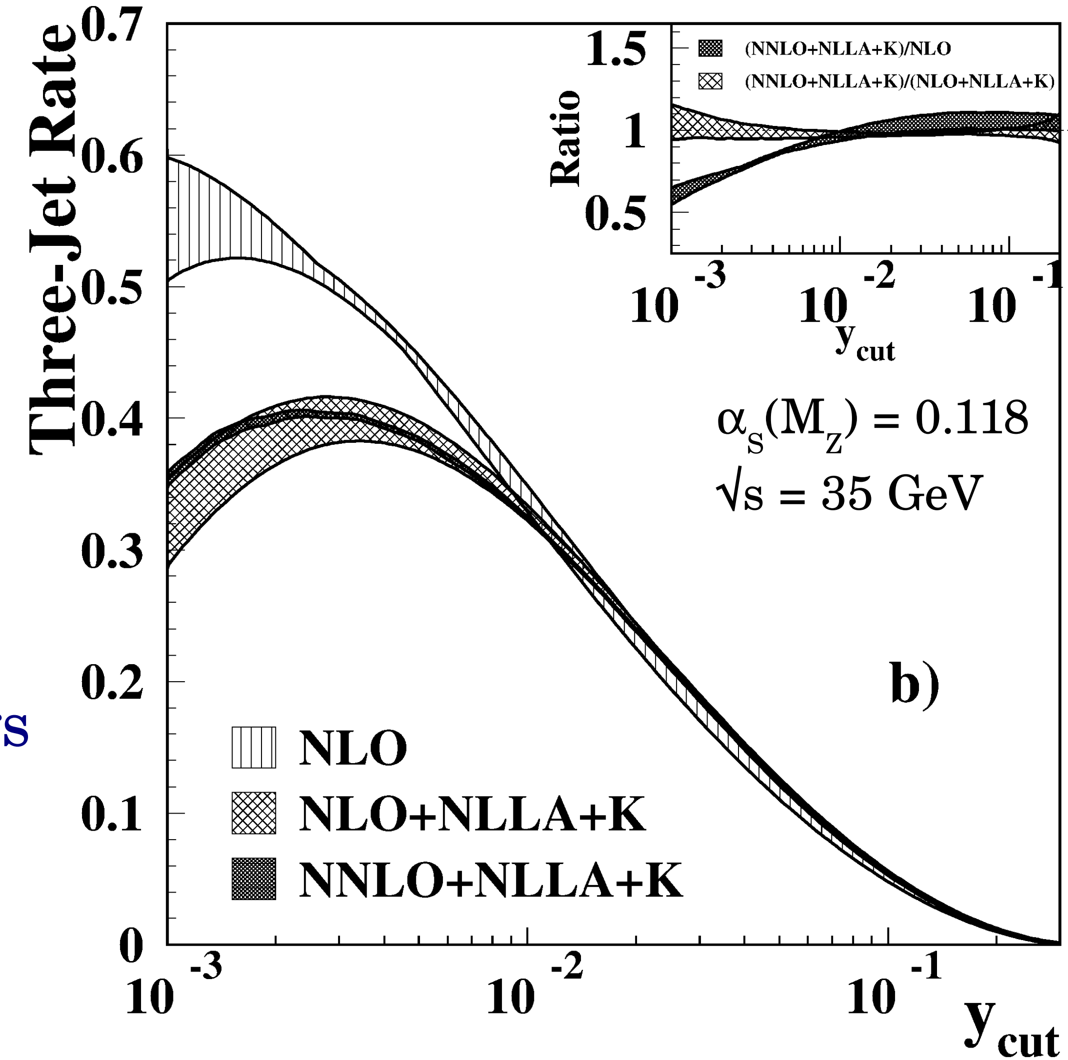
$L = \log(1/y_{cut})$

$R_{3,NLLA,exp.} = \sum_{i=1}^{3} \sum_{j=i}^{2i} \alpha_S^{\,i} L^j R_{ij}$

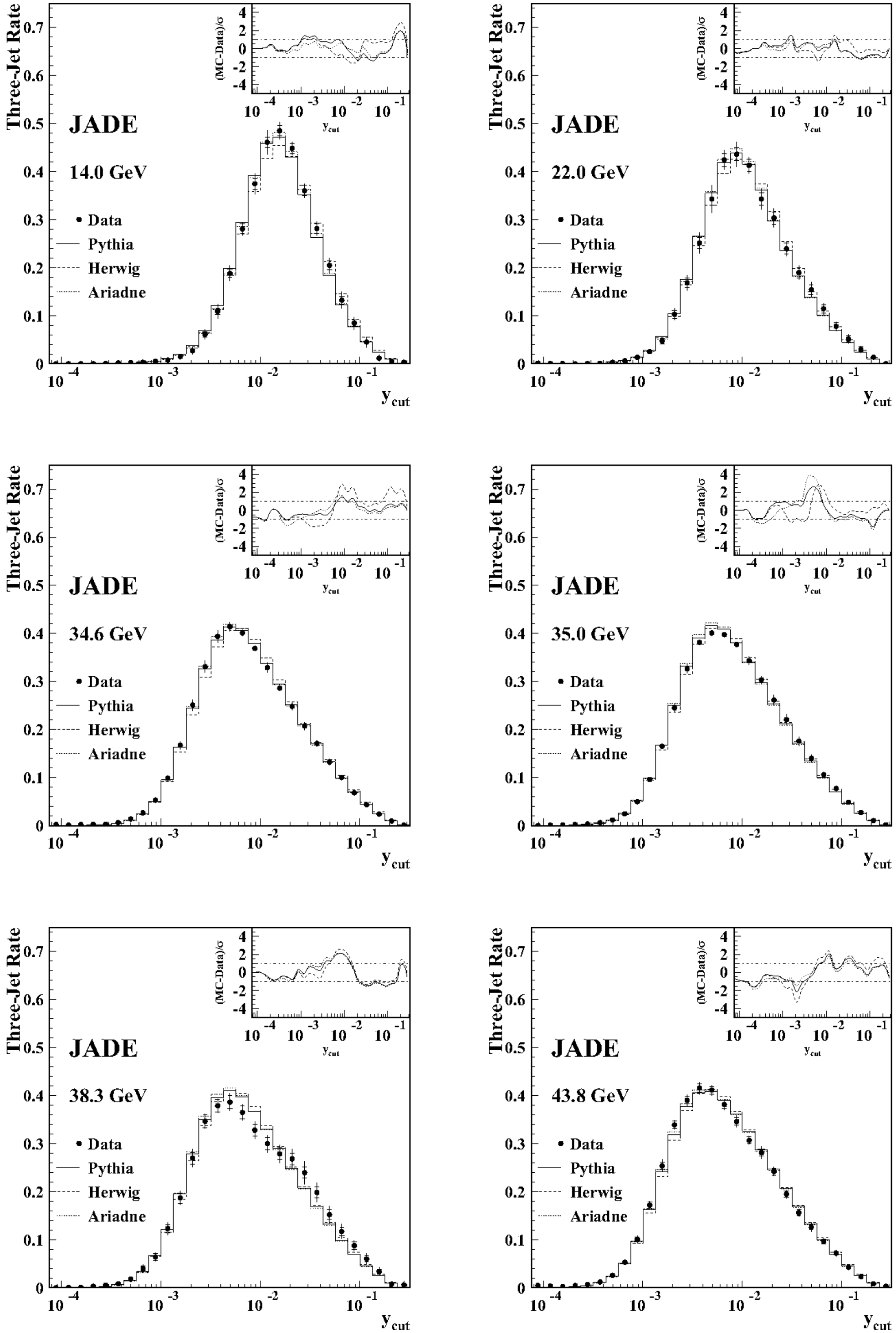
"K-term": partial subleading logs

R-matching:

$R_3 = R_{3,NNLO} + R_{3,NNLA} - R_{3,NLLA,exp.}$



Data vs MC



Data corrected to hadron-level, bb contribution subtracted

PYTHIA 5.7, HERWIG 6.2, ARIADNE 4.11

LL+LO, tuned to OPAL@LEP 1

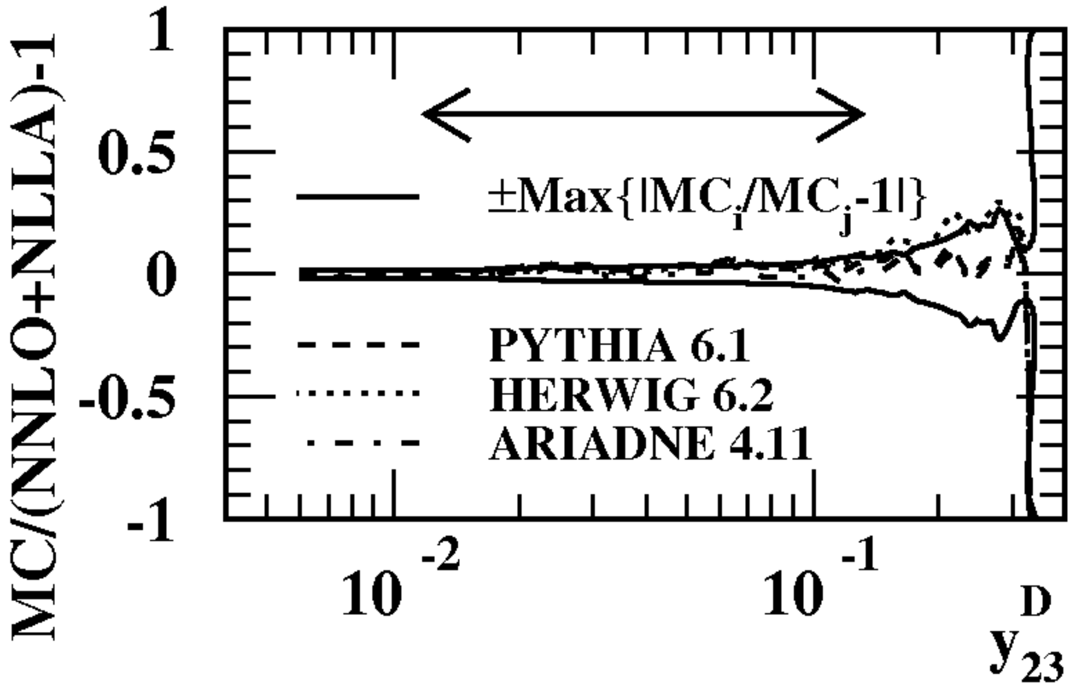
Good description of low energy data with OPAL tune

MCs ok for experimental and hadronisation corrections

Hadronisation corrections

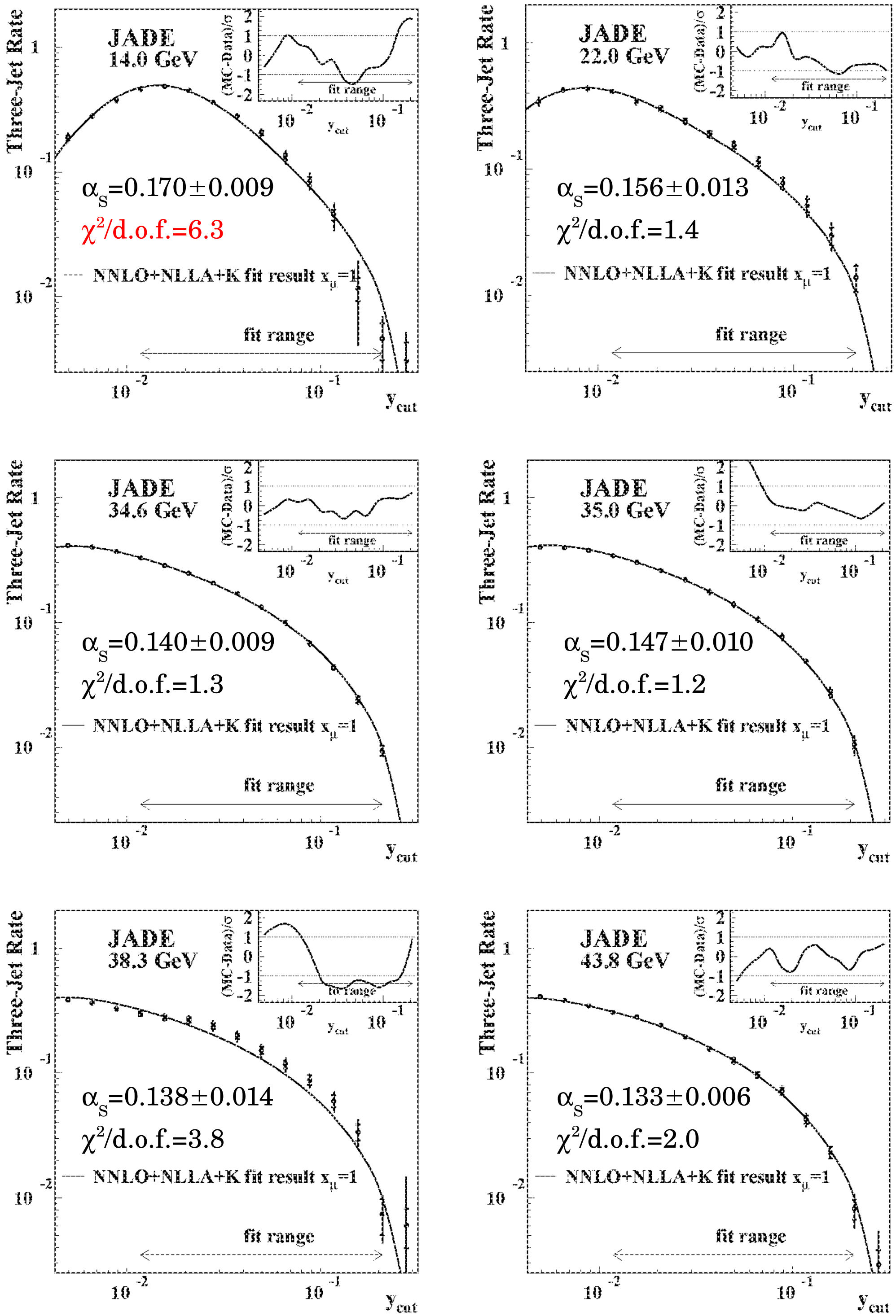
Compare MC parton-level (after parton shower) to hadron-level (particle level)

Check consistency MC LO+LL parton-level with theory NNLO+NLLA parton-level by OPAL:



Consistent within differences between MCs, covered by hadronisation correction systematic uncertainty

[OPAL: Eur. Phys. J. C71 (2011) 1733]



R_3 fits

NNLO+NLLA+K

Fit ranges: exp. and had. corrections stable and "small"

Incl. point-to-point correlations, χ^2 from stat. errors only, 1.3 < χ^2/d.o.f. < 3.8 (except 14 GeV)

Combine results 22 to 44 GeV:

$$\alpha_S(M_Z) = 0.1199 \pm 0.0010_{\text{stat.}} \pm 0.0021_{\text{exp.}} \pm 0.0054_{\text{had.}} \pm 0.0007_{\text{theo.}}$$

Systematics

- Experimental
  - Vary event selection cuts
  - Tracks + ECAL clusters vs “energy flow”
  - PYTHIA vs HERWIG exp. corrections
  - JADE detector calibration versions
  - Vary $b\underline{b}$ subtraction
  - Vary fit range
- Hadronisation
  - PYTHIA vs HERWIG vs ARIADNE
- Theory
  - Renormalisation scale factor $0.5 < x_\mu < 2.0$

Cross checks

Renormalisation scale:

Fit with x_μ free: $x_\mu = O(1)$

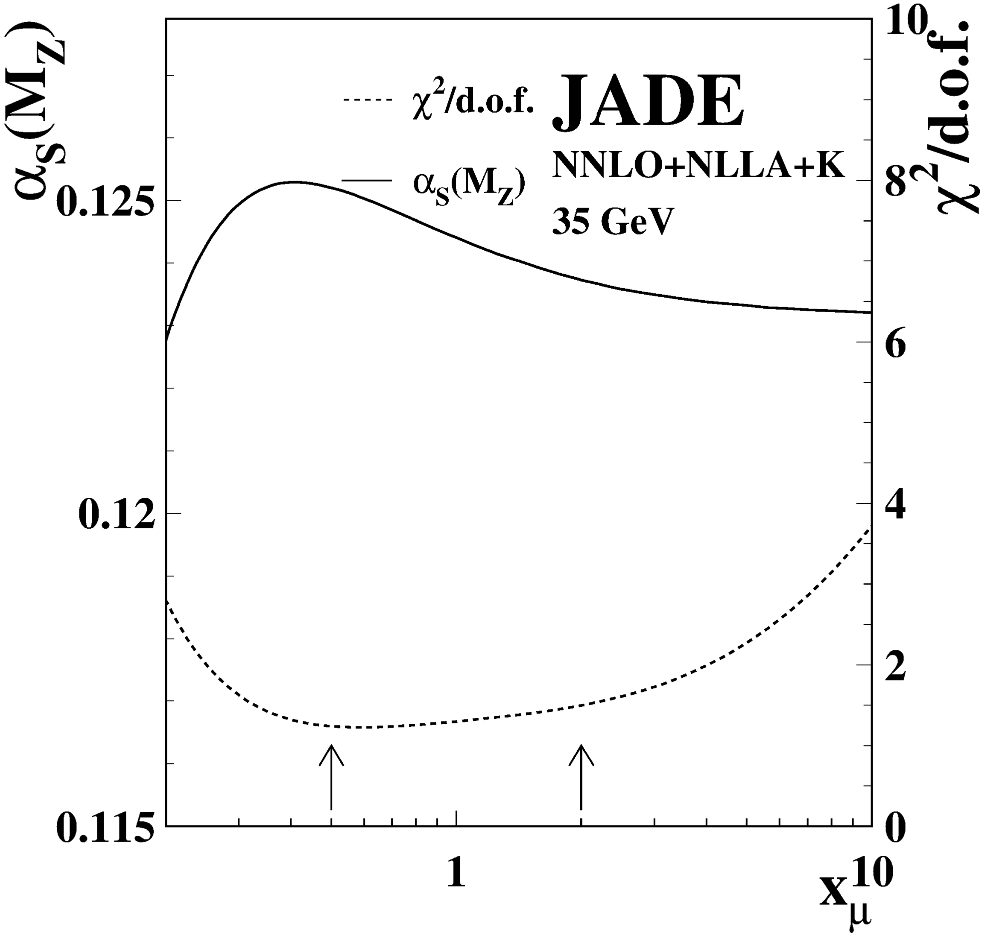
Essentially same result for $\alpha_s(m_z)$

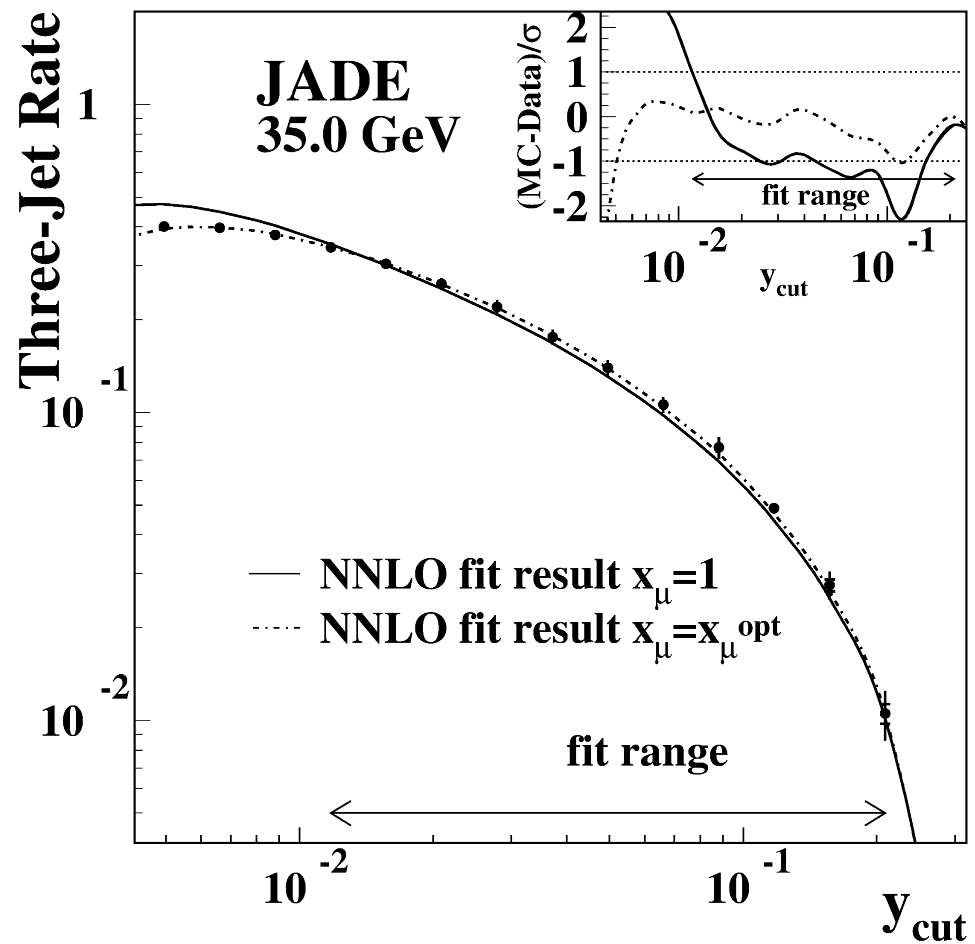
NNLO only fit:

Slope not fully described

Sensitive to fit range

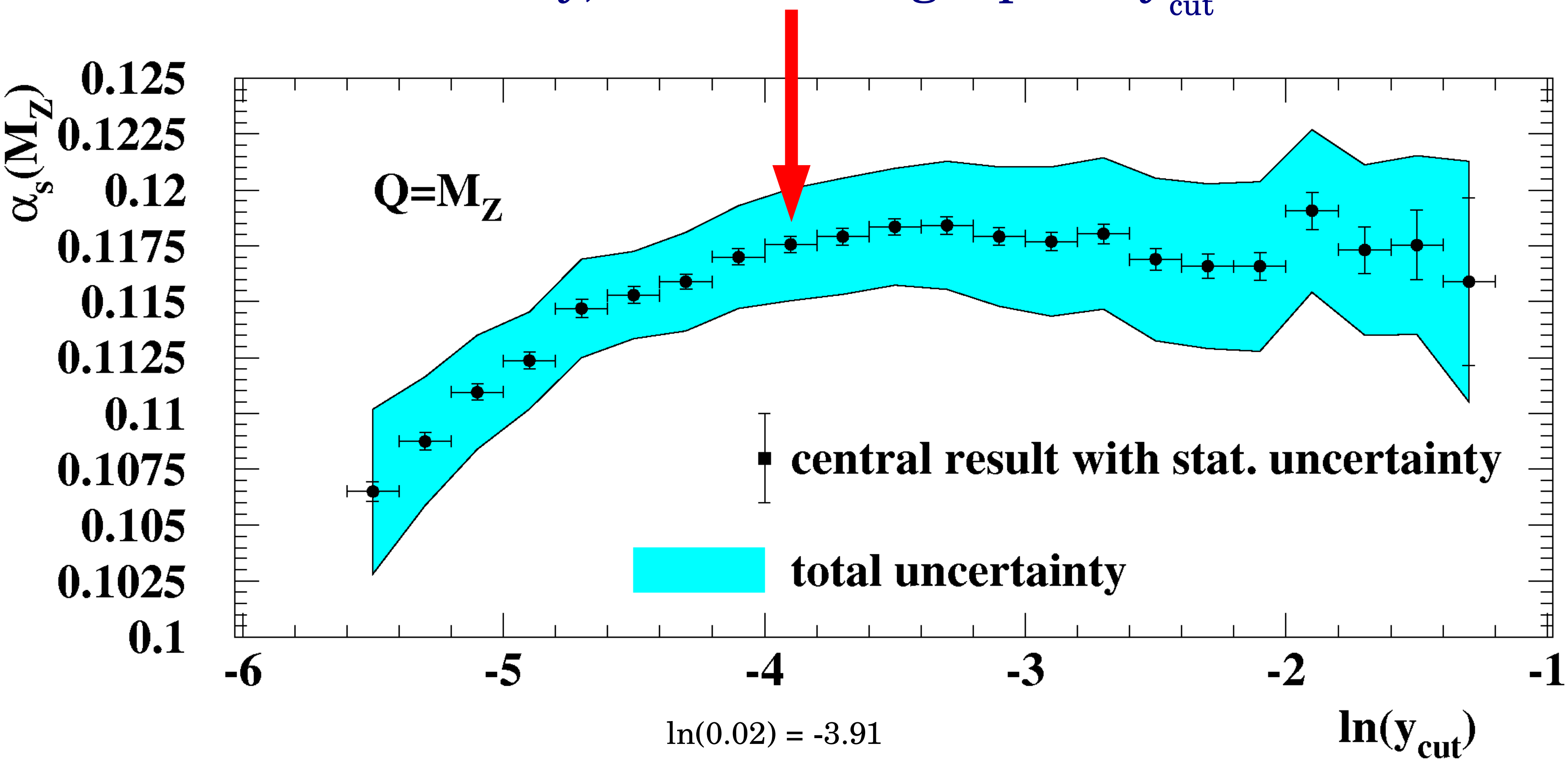
Scale uncertainty larger





DG^{3}HS/ALEPH Result

NNLO only, result at single point $y_{cut} = 0.02$

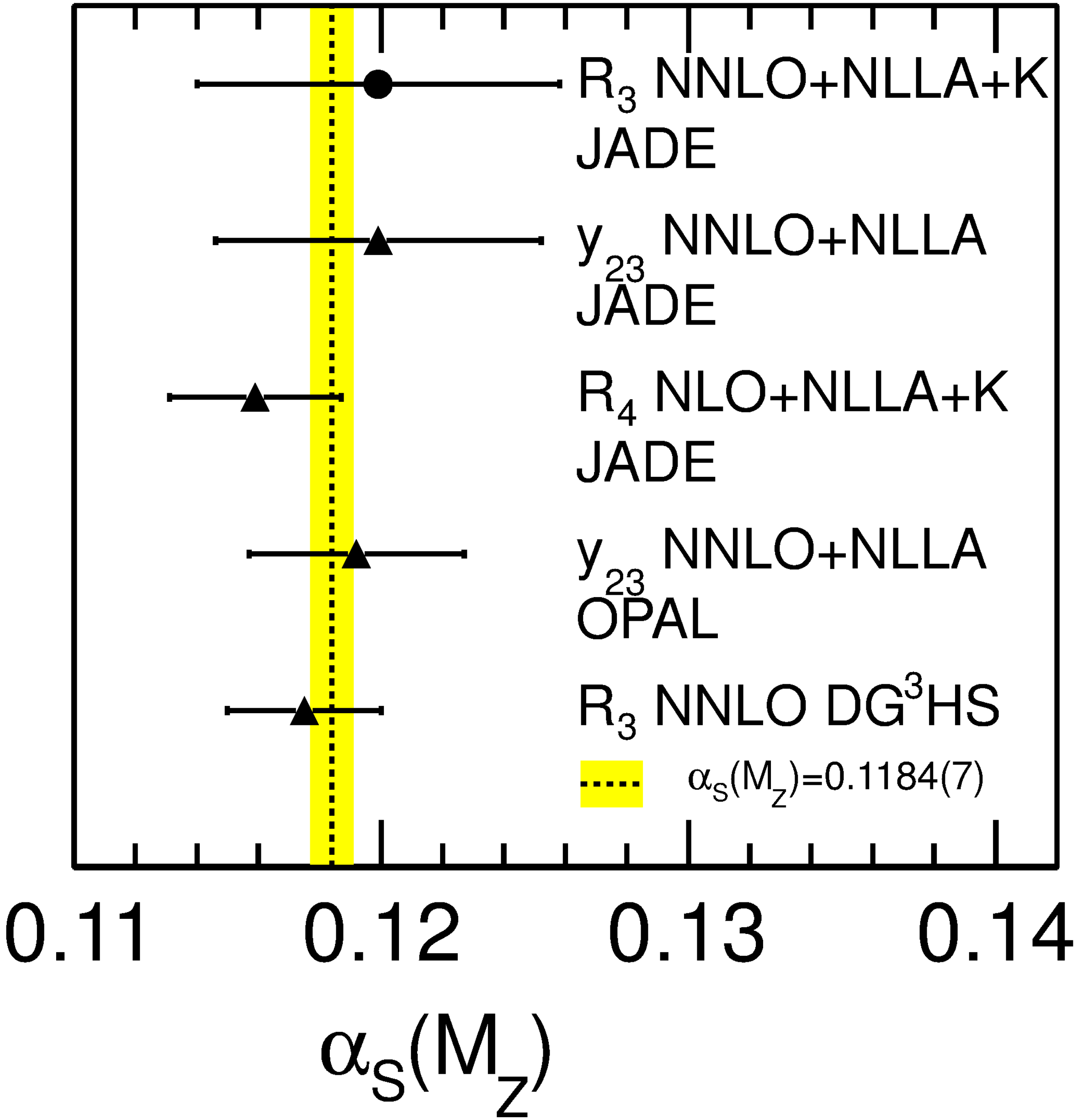


$\alpha_S(M_Z) = 0.1175 \pm 0.0004_{stat.} \pm 0.0019_{exp.} \pm 0.0006_{had.} \pm 0.0014_{theo.}$

Slope problem visible

[Dissertori et al.: Phys. Rev. Lett. 104 (2010) 072002]

Comparison to previous results



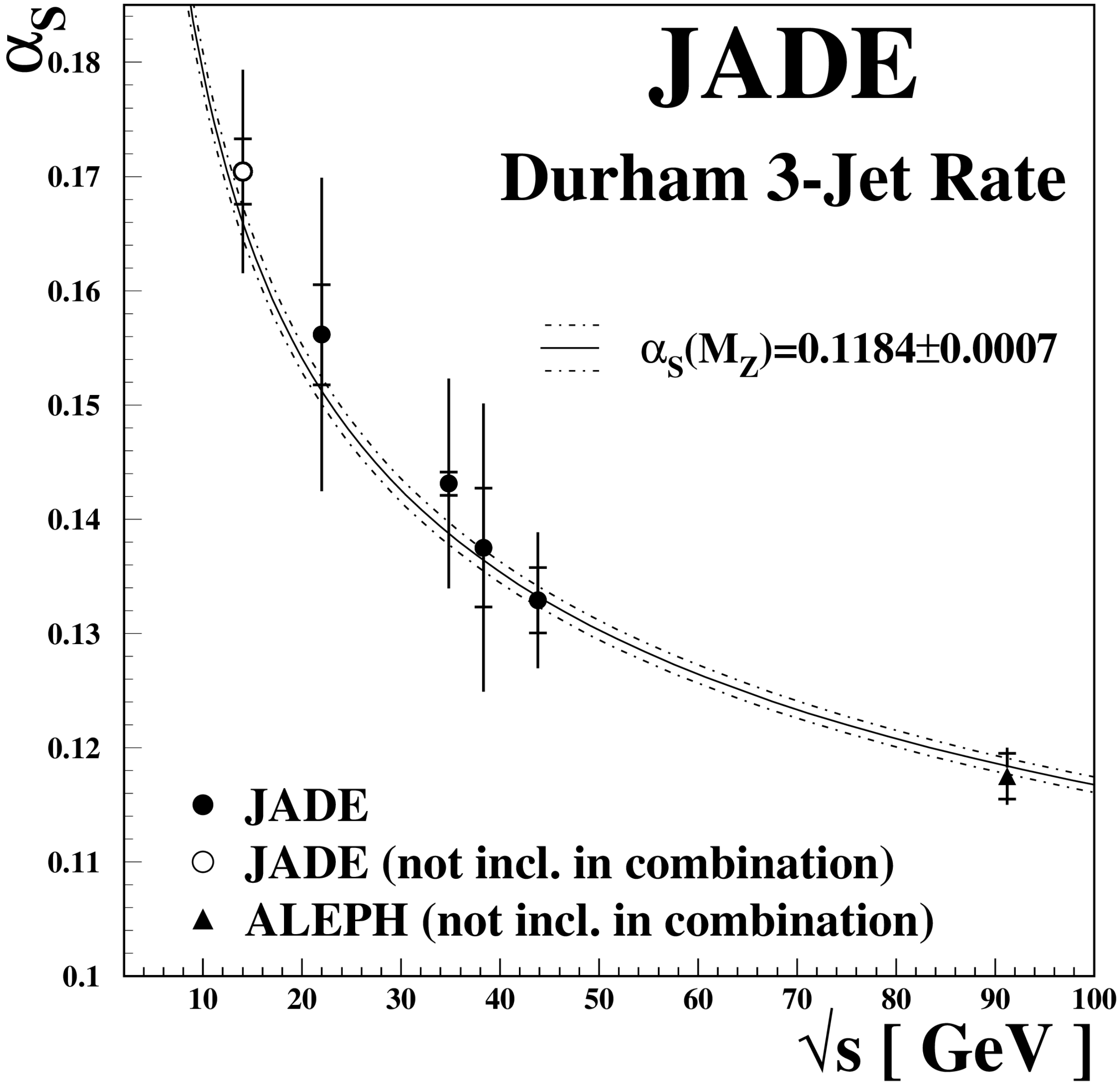
Result consistent with:

previous JADE & OPAL

DG^{3}HS/ALEPH

PDG

Running coupling



Confirm QCD running coupling prediction

14 GeV analysis (not in average) still consistent

Prediction using PDG world average

* Commercial break *
Data Preservation

JADE/OPAL Data preservation

DPHEP Study Group for Data Preservation and Long Term Analysis in High Energy Physics

Store data in computing centre (RZG)

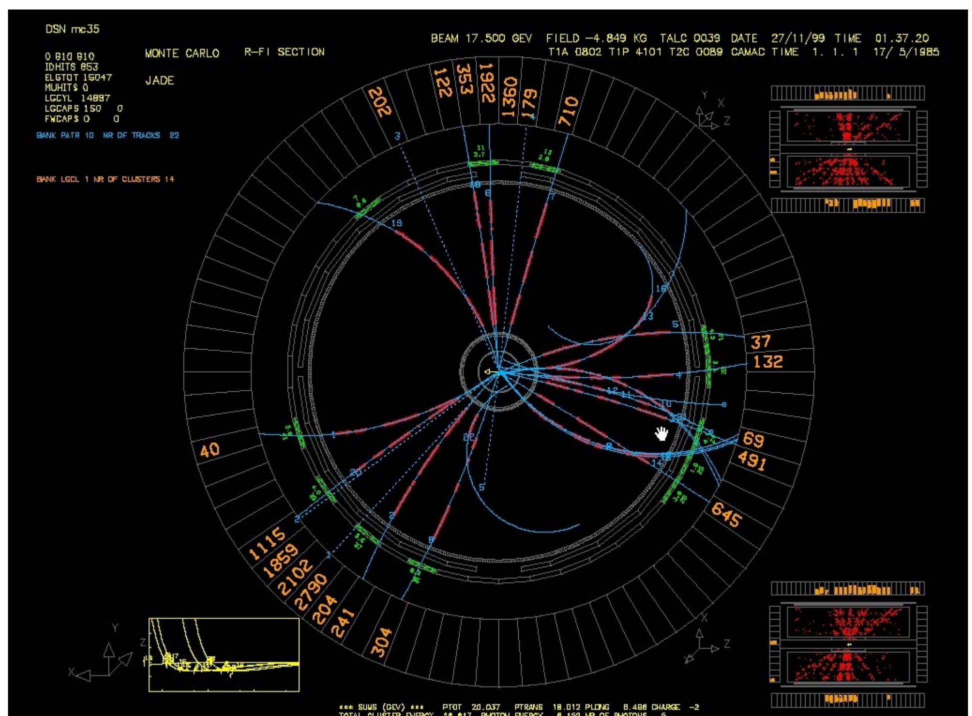
Port software on modern platforms

Replace missing libraries

Cross check analyses against previous results

9 papers, two with 50+ citations, many conference contributions, PhD and diploma theses

Why?	Physics objectives
How?	Review analysis models
How?	Soft- and hardware persistency
How?	Common specifications
Who?	Funding programs, initiatives



Summary

- First α_S from R_3 with NNLO+NLLA+K QCD
    - $\alpha_S(M_Z) = 0.1199 \pm 0.0010_{stat.} \pm 0.0021_{exp.} \pm 0.0054_{had.} \pm 0.0007_{theo.}$
- Slope of $R_3(y_{cut})$ not fully described in NNLO
    - Ok within errors with NNLO+NLLA
- Had. uncertainties dominate
    - LEP data
    - Better had. models (power corrections)?
- More new results from old data possible!