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

XLVIIth Rencontres de Moriond: QCD and High Energy Interactions
La Thuile, 15.03.12
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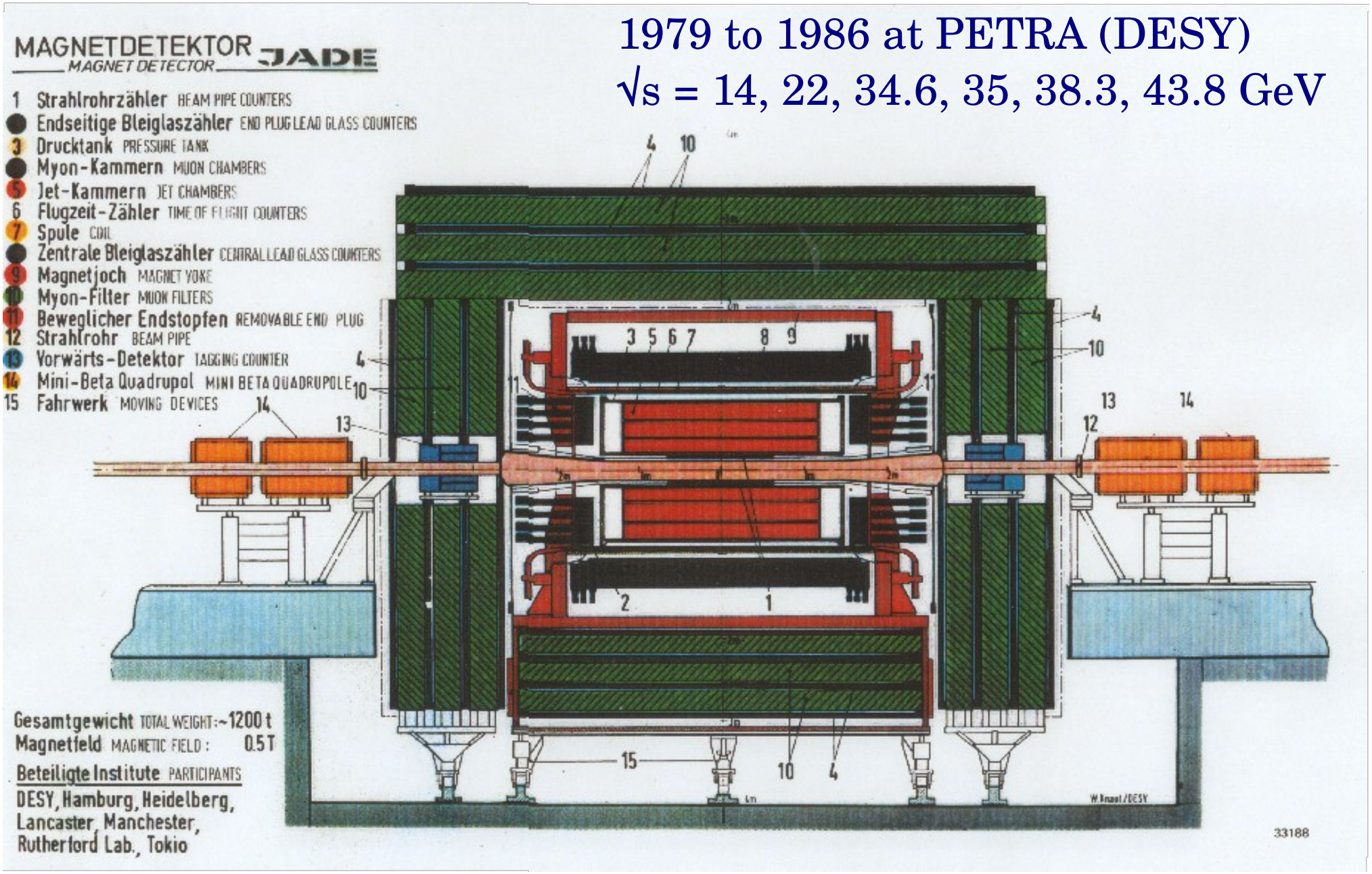
Introduction

- Why study 26+ year old e^+e^- 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!

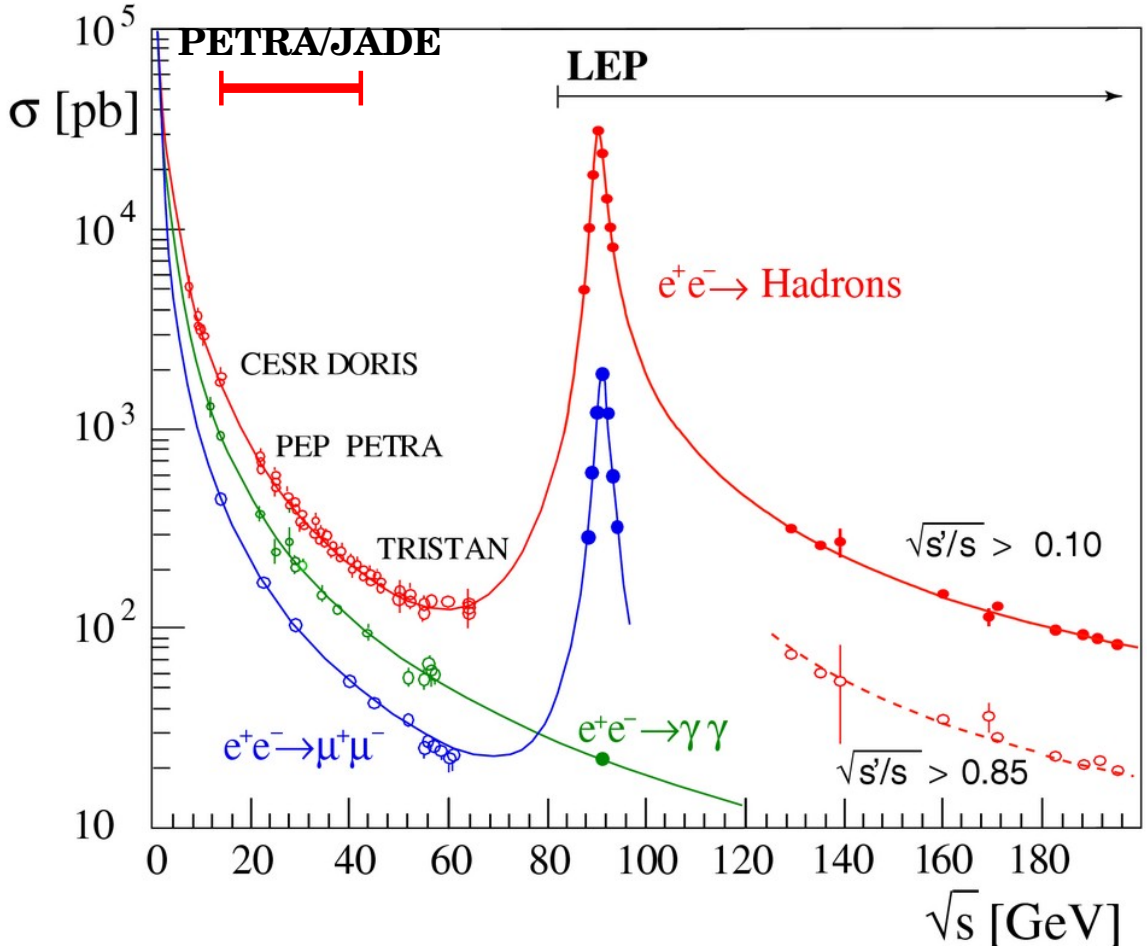
The JADE experiment

1979 to 1986 at PETRA (DESY)

$\sqrt{s}$ = 14, 22, 34.6, 35, 38.3, 43.8 GeV



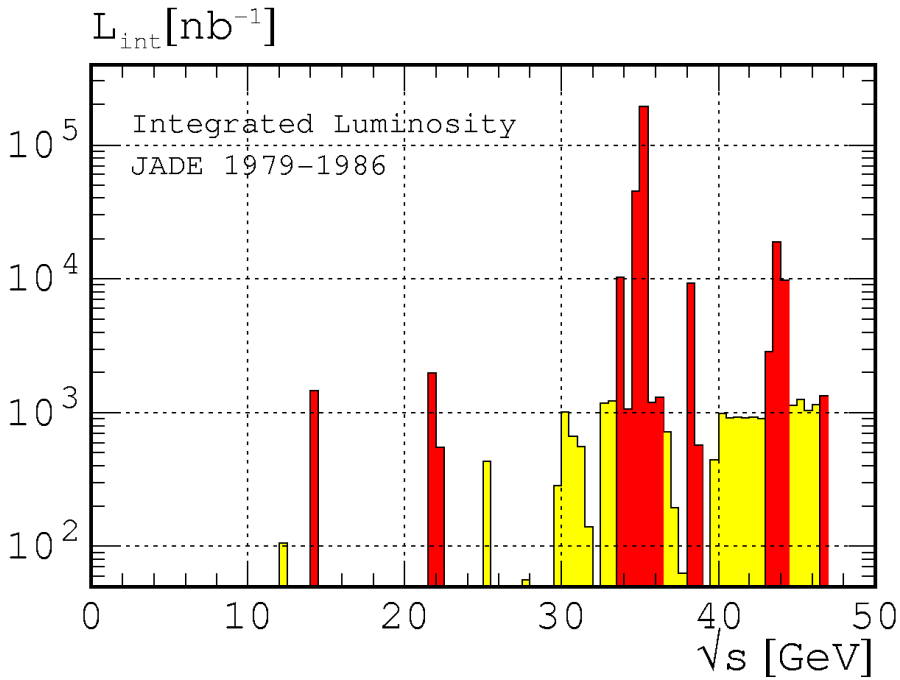
JADE data



Data samples:

$O(10^3\text{-}10^4)$ events

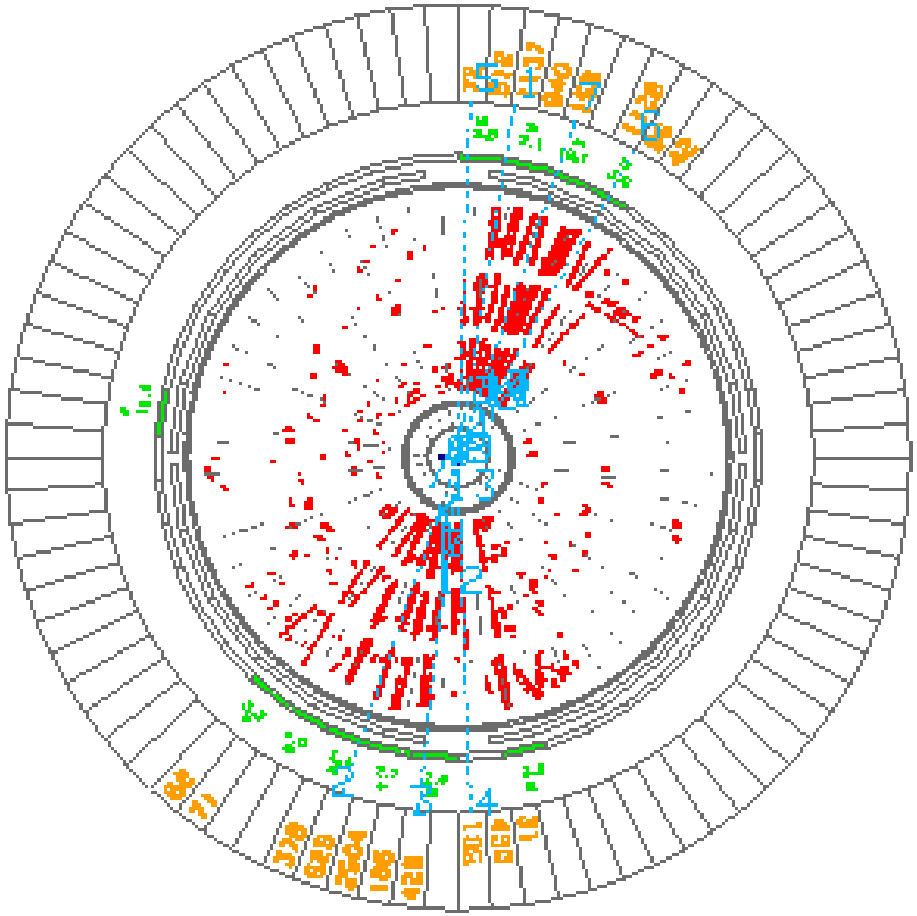
Negligible backgrounds after selection



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)

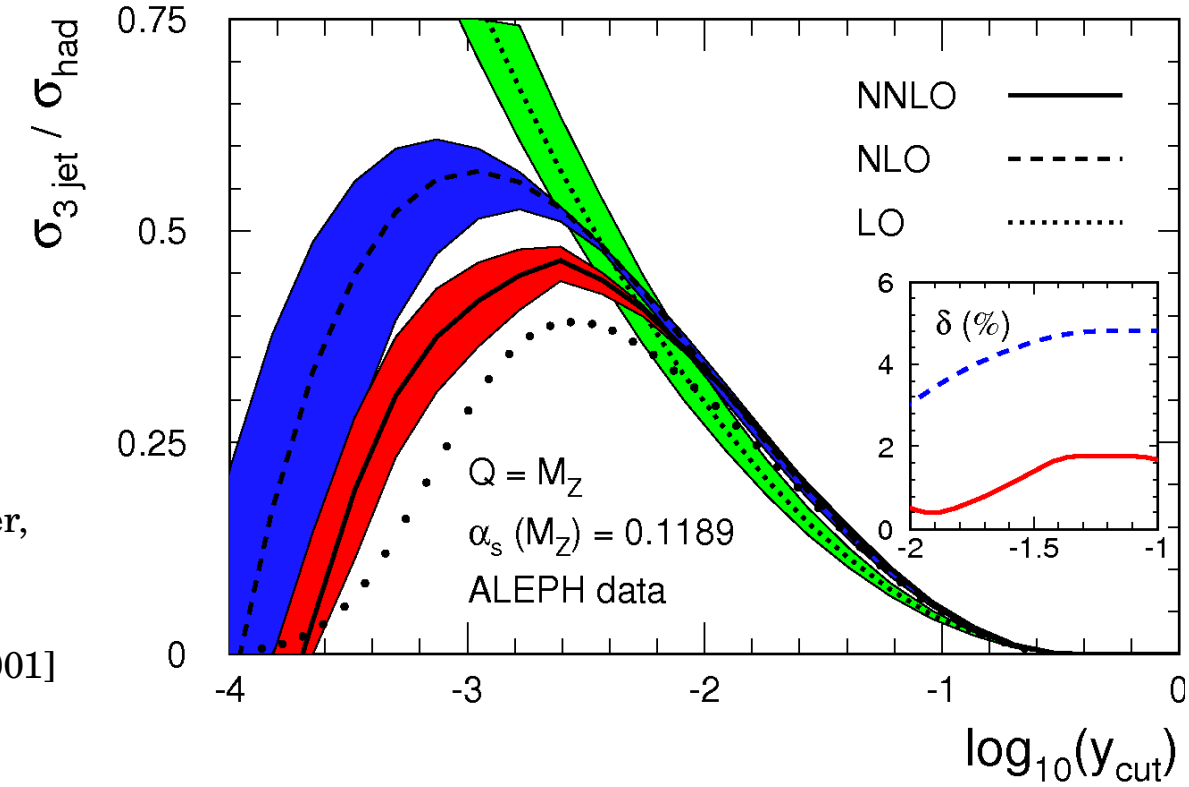
Observable: $R_3(y_{cut}, Q) = N_{3\text{-jet}}(y_{cut}, Q) / N(Q) = \sigma_{3\text{-jet}}/\sigma_{had}$

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. $\underline{\alpha}_S \log^2(1/0.01) \approx 0.4$

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

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

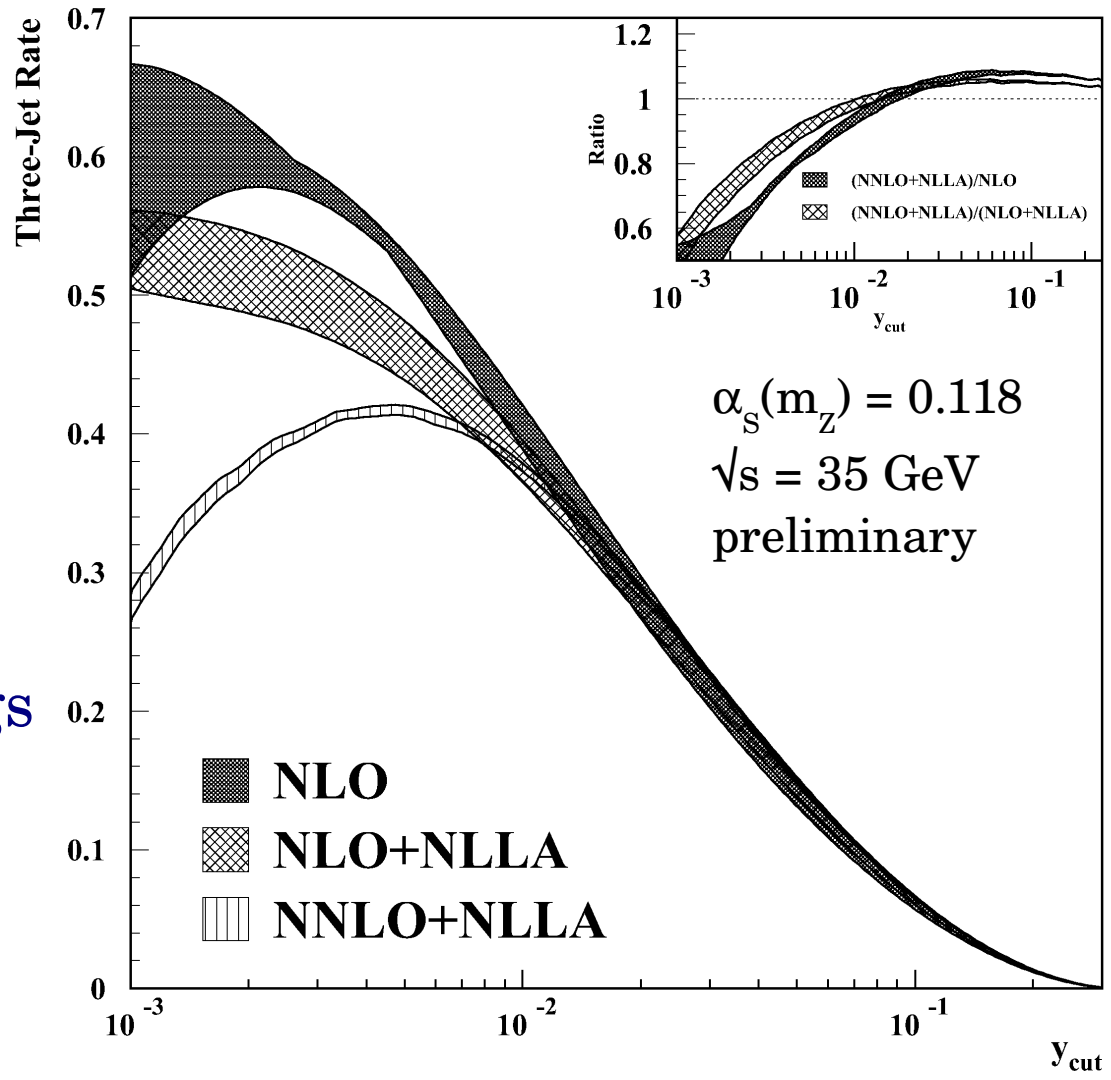
$L = \log(1/y_{cut})$

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

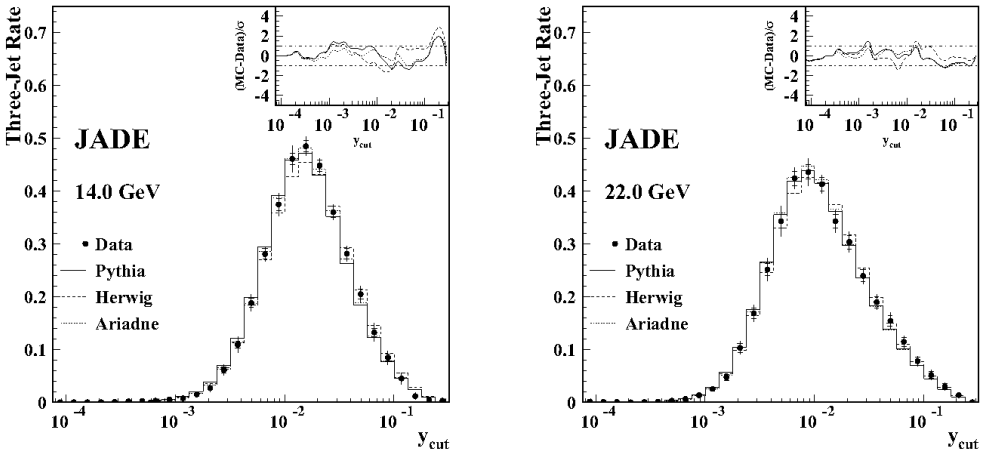
"K-term": partial subleading logs

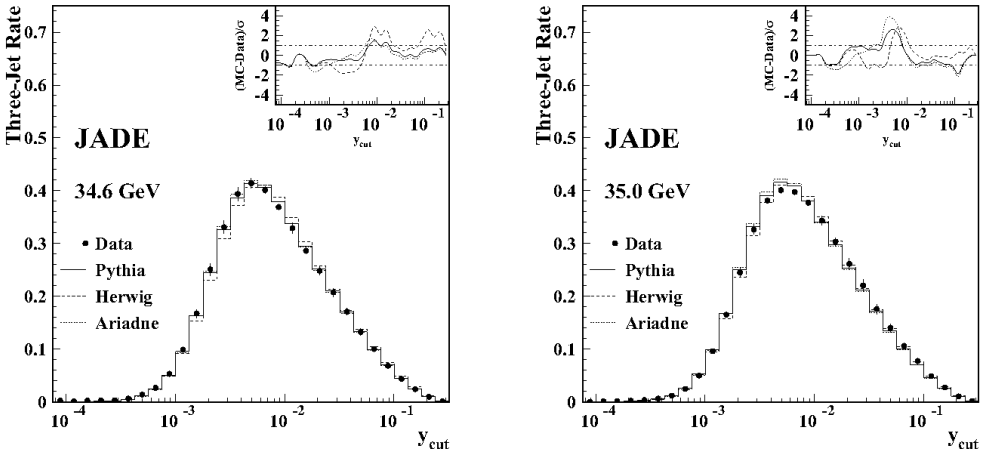
R-matching:

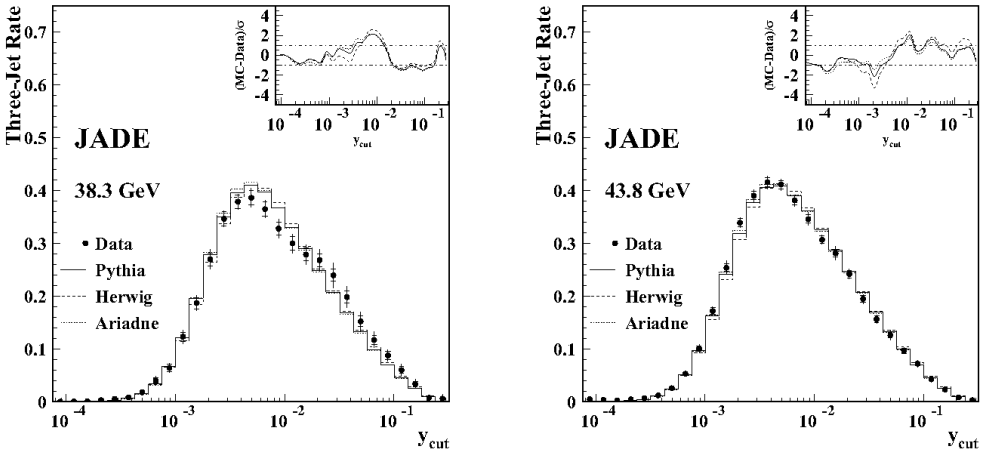
$R_3 = R_{3,NNLO} + R_{3,NNLA} - R_{3,NLLA,exp.}$



Data vs MC







preliminary

Data corrected to hadron-level, $b\bar{b}$ contribution subtracted

PYTHIA 5.7, HERWIG 6.2, ARIADNE 4.11

LL+LO, tuned to OPAL@LEP 1

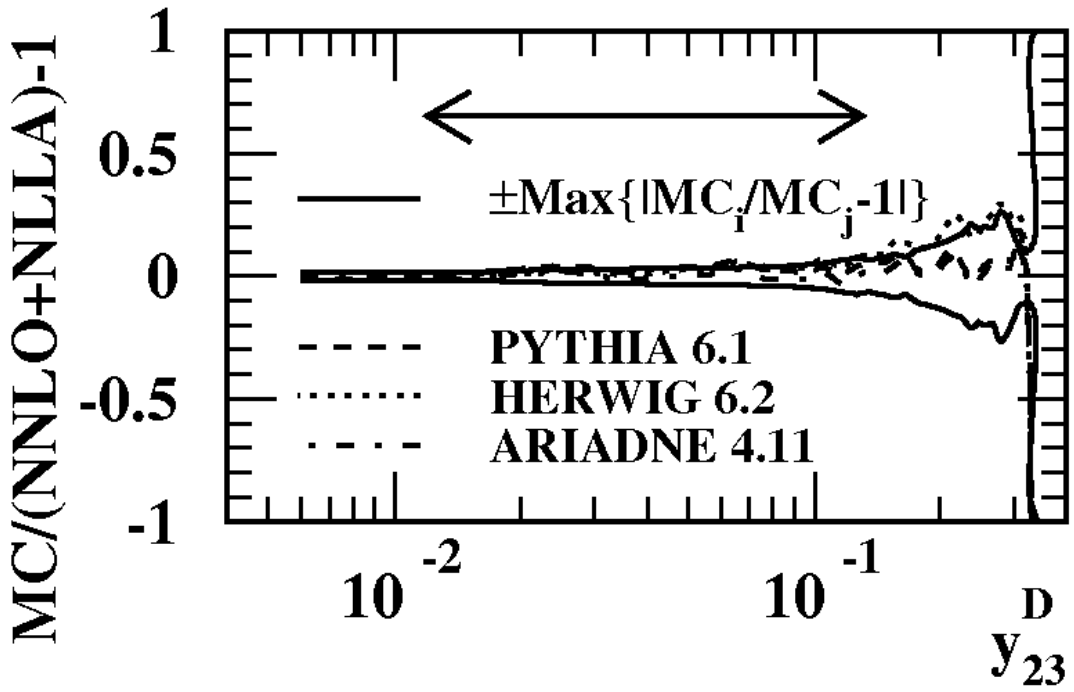
Good description of low energy data with OPAL tune

MCs ok for experimental and hadronisation corrections

Hadronisation corrections

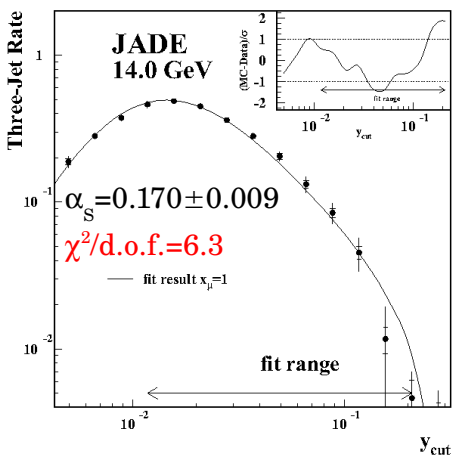
Compare MC parton-level (after parton shower) to hadron-level (particle level)

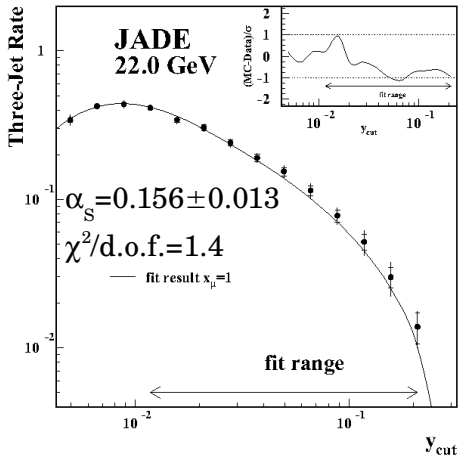
Check consistency MC LO+LL parton-level with theory NNLO+NLLA parton-level by OPAL:

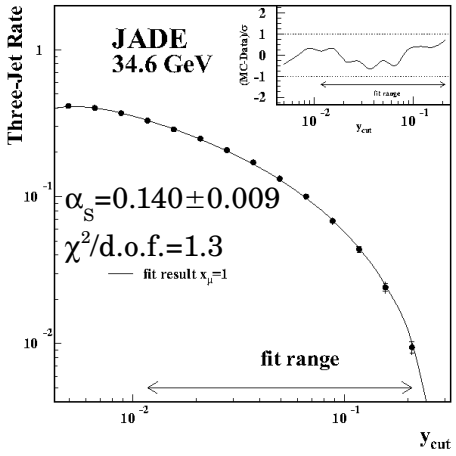


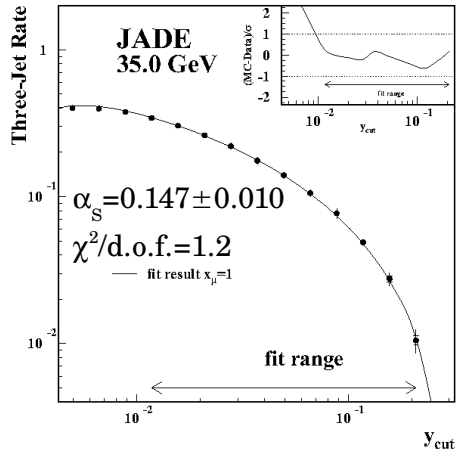
Consistent within differences between MCs, covered by hadronisation correction systematic uncertainty

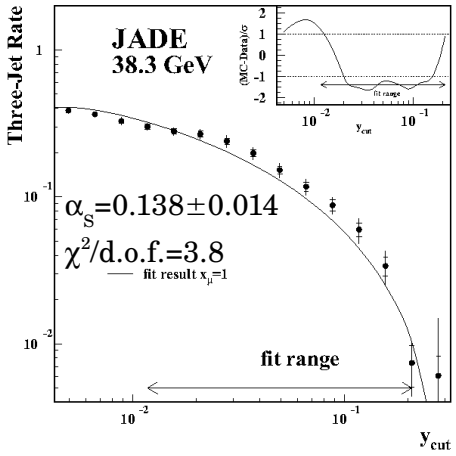
[OPAL: Eur. Phys. J. C71 (2011) 1733]

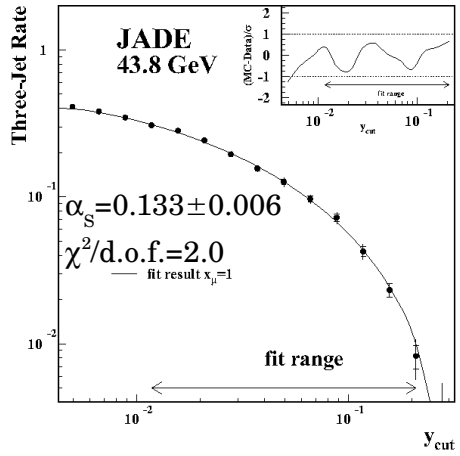












R_3 fits

NNLO+NLLA

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

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

Combine results 22 to 44 GeV:

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

preliminary

Systematics

- Experimental
  - Vary event selection cuts
  - Tracks + ECAL clusters vs “energy flow”
  - PYTHIA vs HERWIG exp. corrections
  - JADE detector calibration versions
  - Vary $b\bar{b}$ 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: $x_\mu = O(1)$

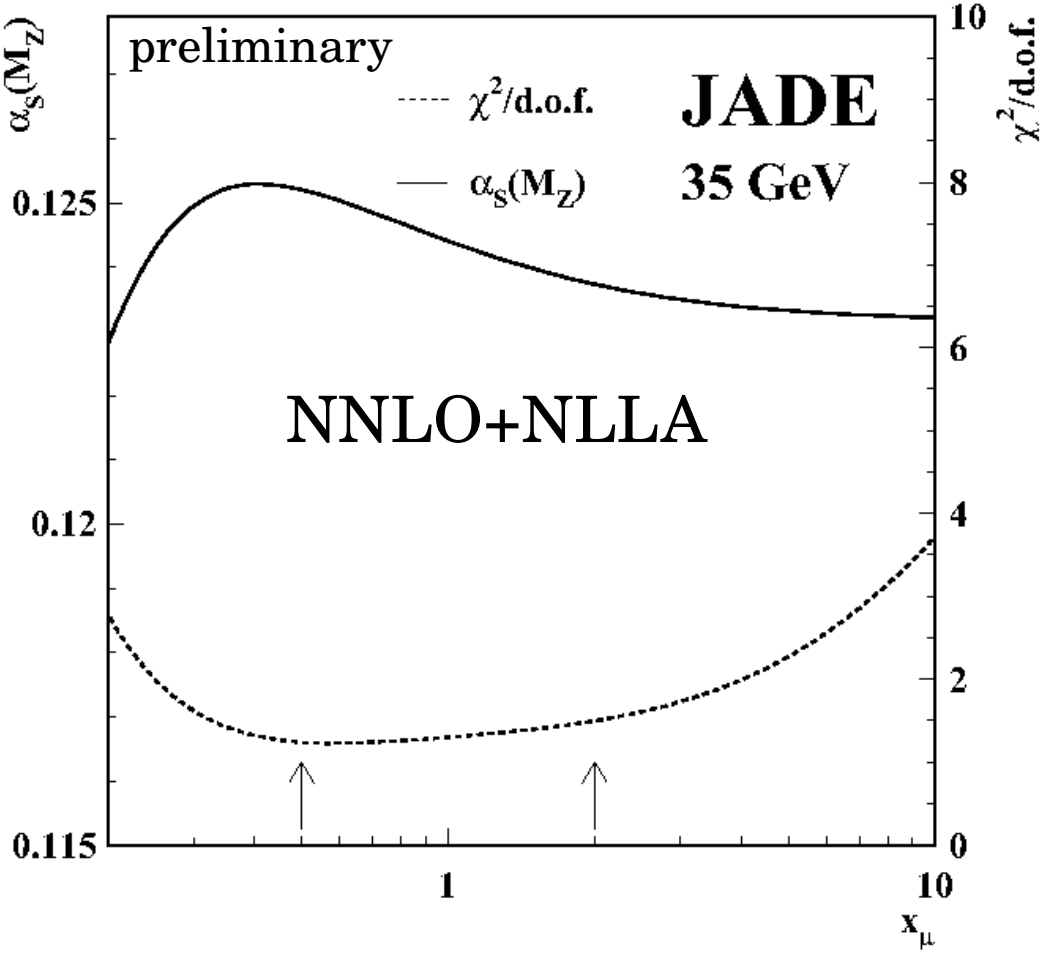
Essentially same result for $\alpha_s(m_z)$

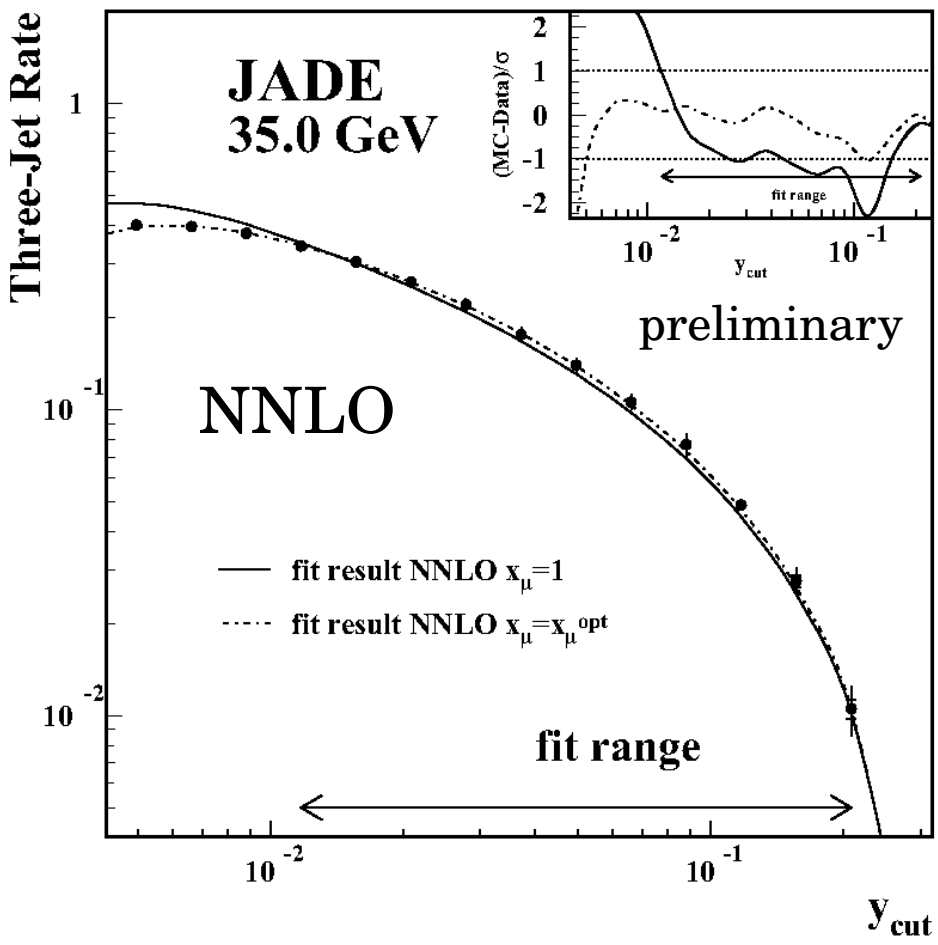
NNLO only fit:

Slope not fully described

Sensitive to fit range

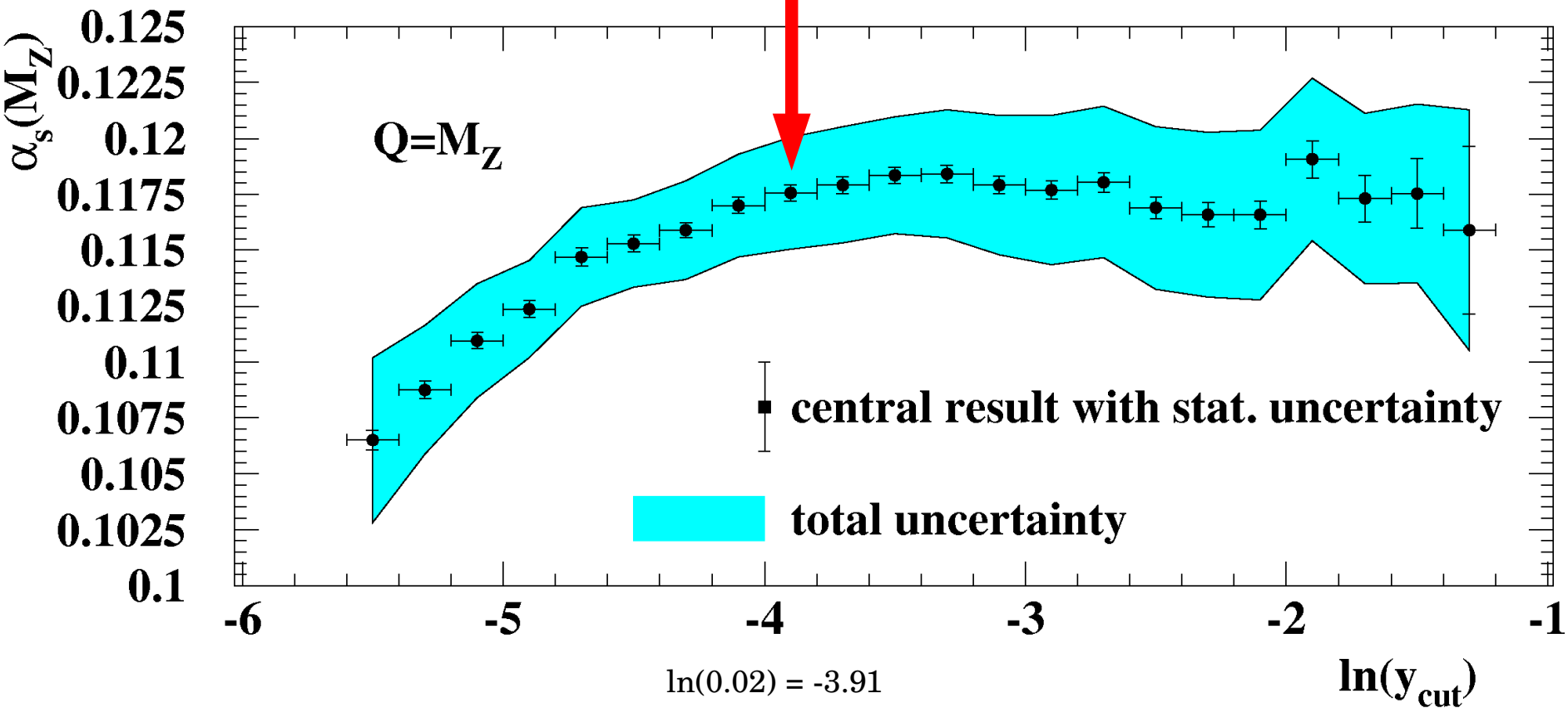
Scale uncertainty larger





DG^{3}HS/ALEPH Result

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

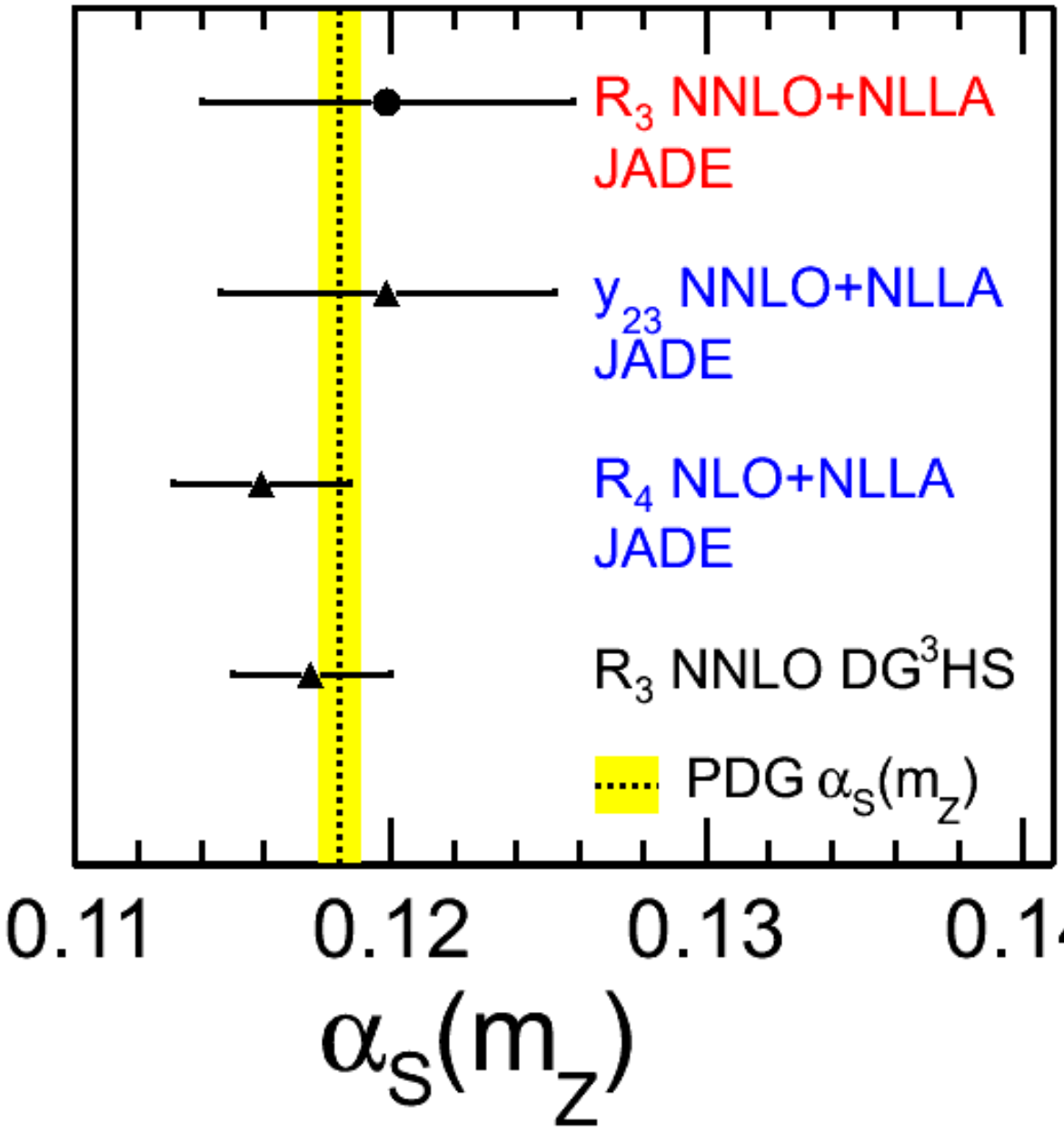


$\alpha_s(m_Z) = 0.1175 \pm 0.0004_{stat.} \pm 0.0019_{exp.} \pm 0.0006_{had.} \pm 0.0014_{theo.}$

Slope problem visible

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

Comparison to previous results



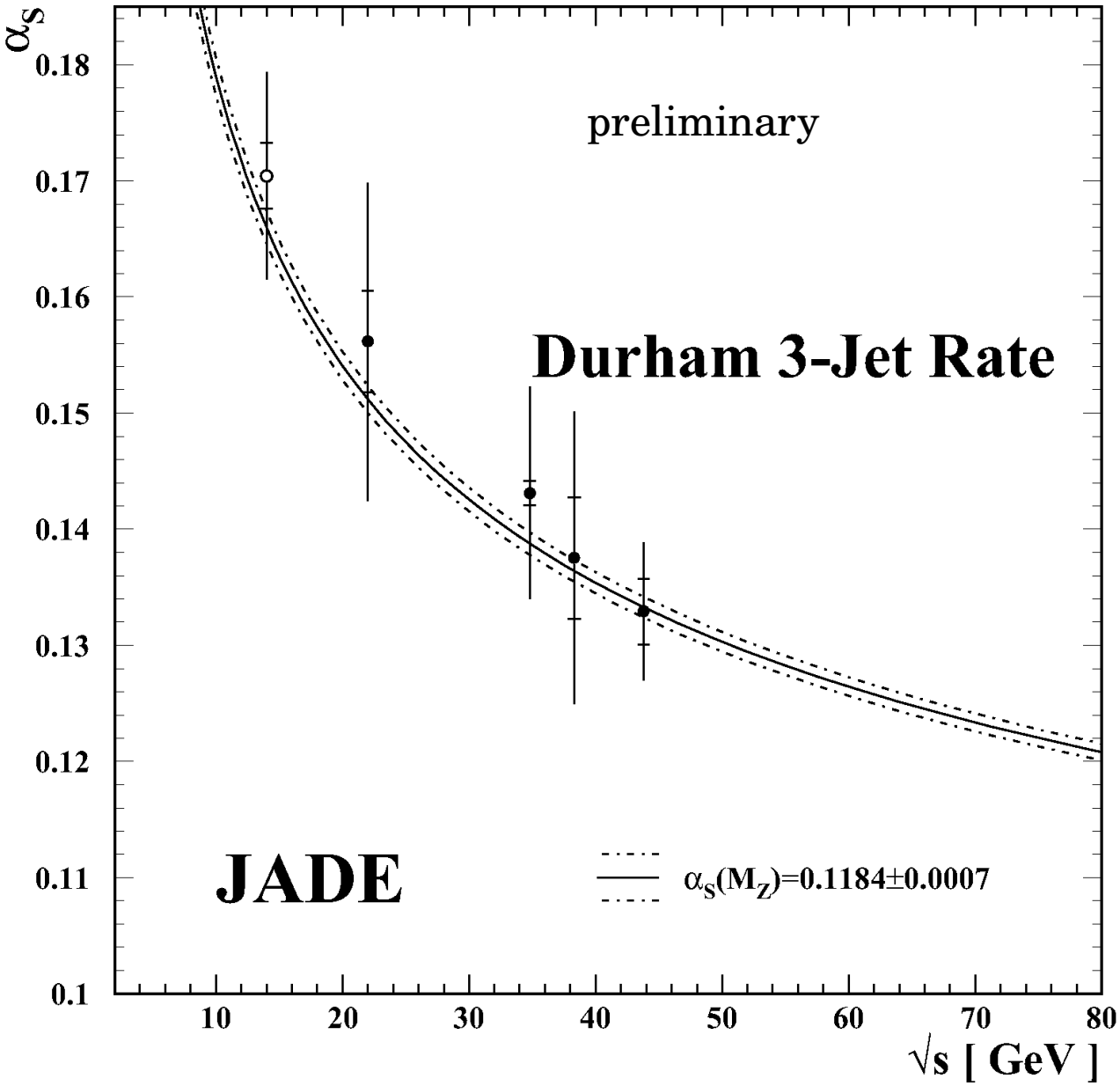
Result consistent with:

previous JADE

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

Summary

- First α_S from R_3 with NNLO+NLLA 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!