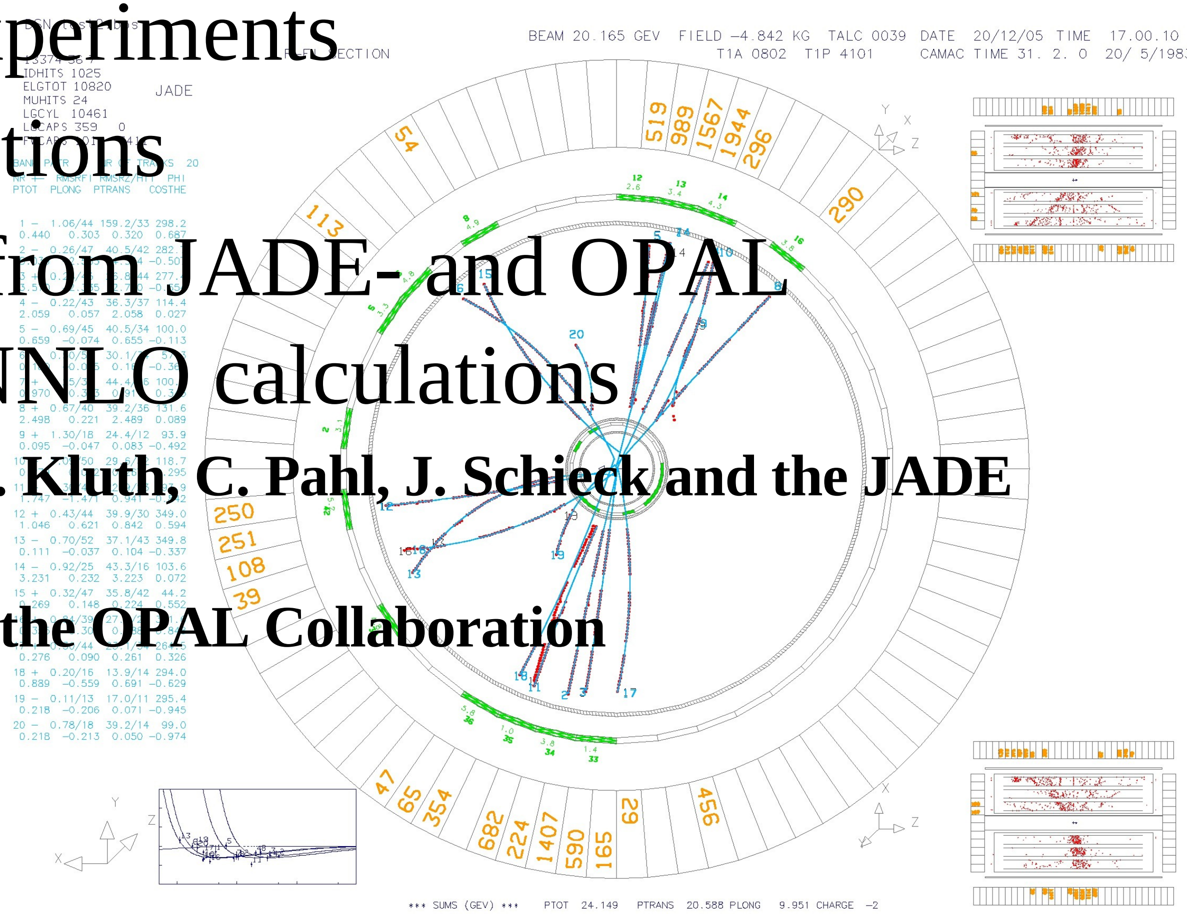
Determinations of α_s from event shapes: Results from existing data and an outlook for the ILC



– JADE and OPAL experiments

– Event shape distributions

– Measurement of α_s from JADE- and OPAL distributions using NNLO calculations

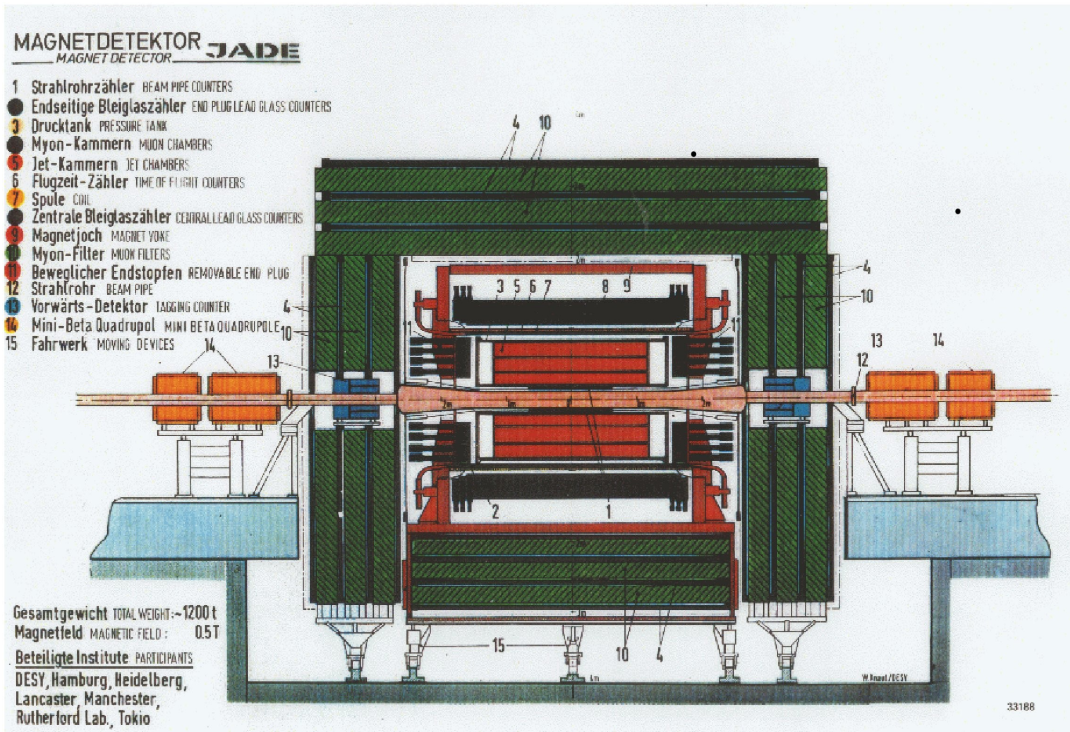
- **EPJC 64:351, S. Bethke, S. Kluth, C. Pahl, J. Schieck and the JADE Collaboration**
- **To be submitted to EPJC, the OPAL Collaboration**

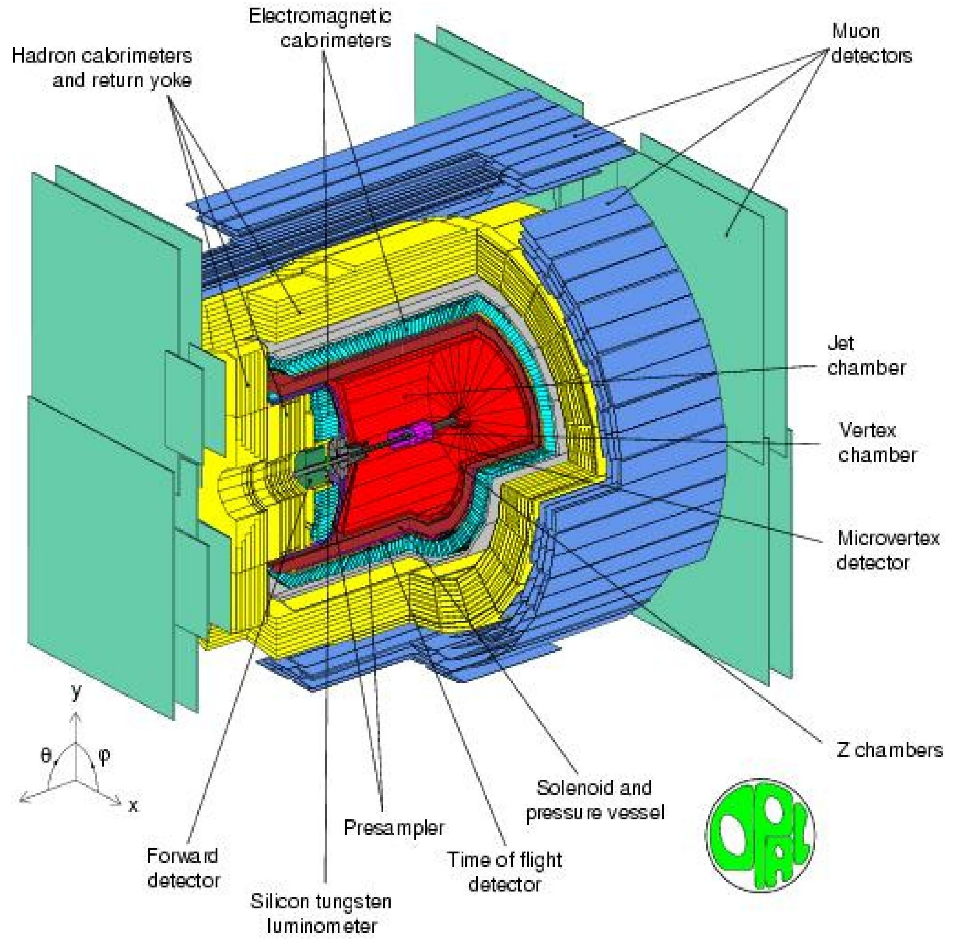
– Outlook for the ILC

Experiments

JADE: 1978-1986 at PETRA, DESY
c.m. energy Q=12-44GeV

OPAL: 1989-2000 at LEP
Q=91-209 GeV

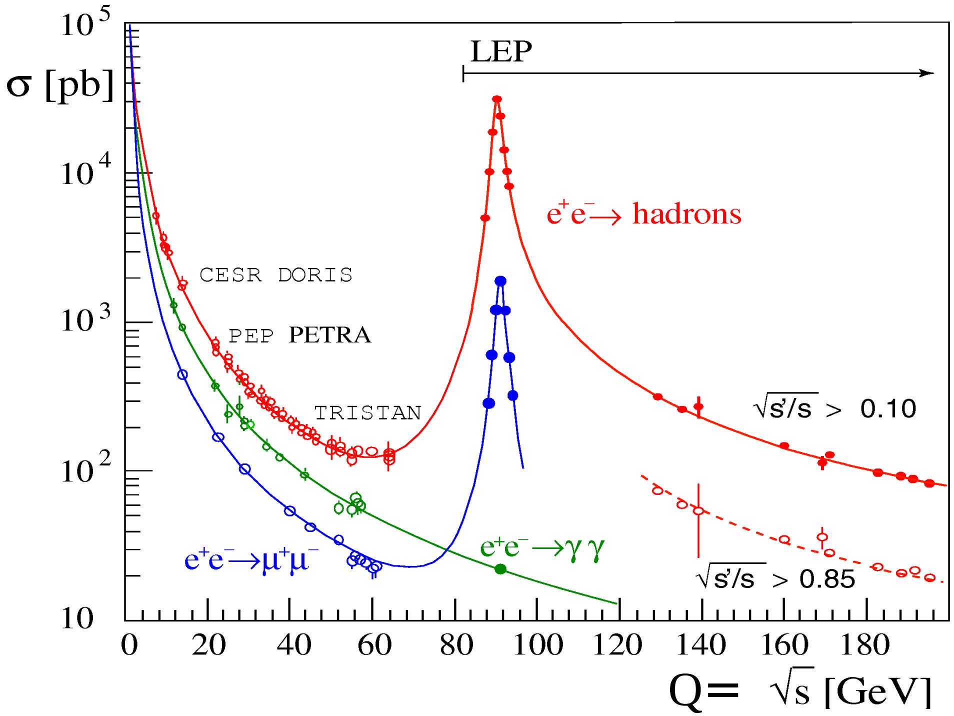




- Old data saved, software reactivated
- New Monte Carlo models

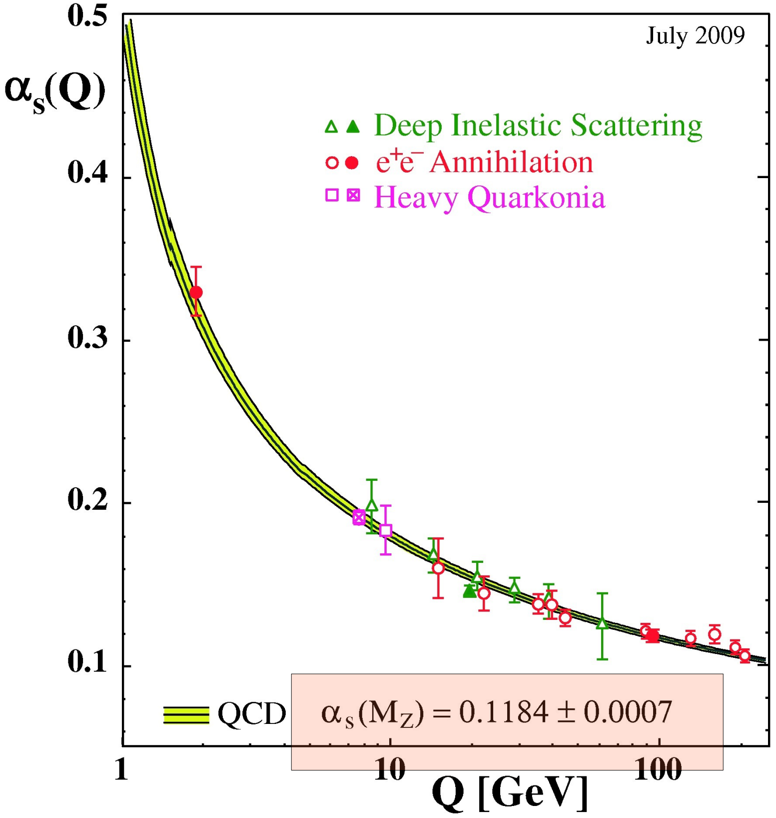
QCD up to 200 GeV

Hadronic cross section

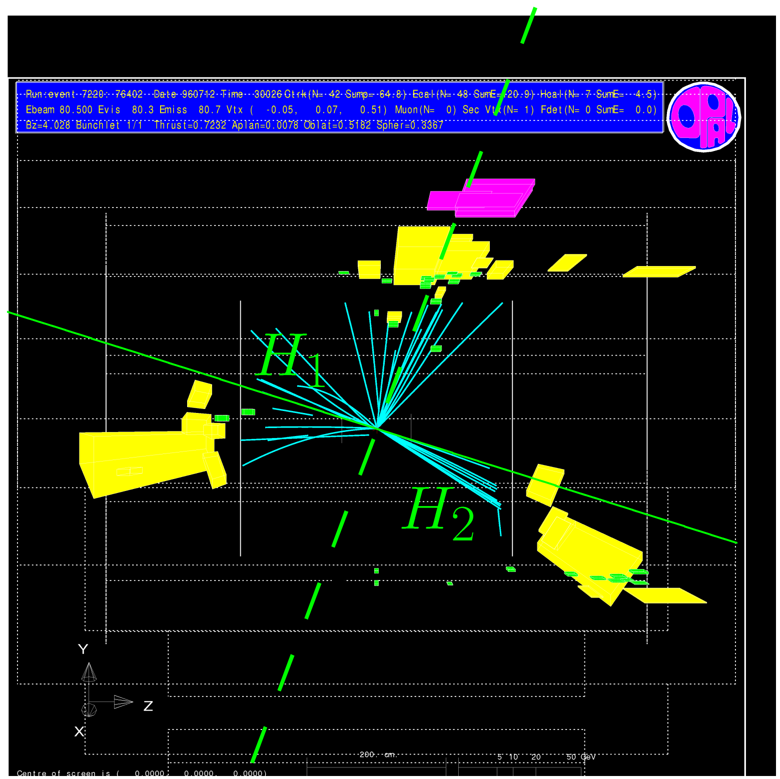


Running strong coupling

(Eur. Phys. J. C 64, 689)



Event shape variables y



Two-hemisphere variables:

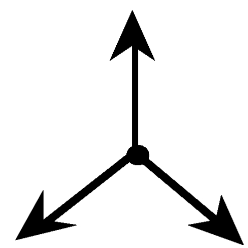
- Thrust 1-T
- C-parameter
- Total Jet Boadening B_T

One-hemisphere variables:

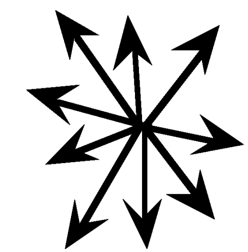
- Wide Jet Broadening B_W
- Durham 2 jet flip parameter y_{23}^D
- Heavy Jet Mass M_H

Event shape distributions

qq: 2 Jets, y≈0



qqg: 3 Jets, e.g. 1-T ≈ ⅓

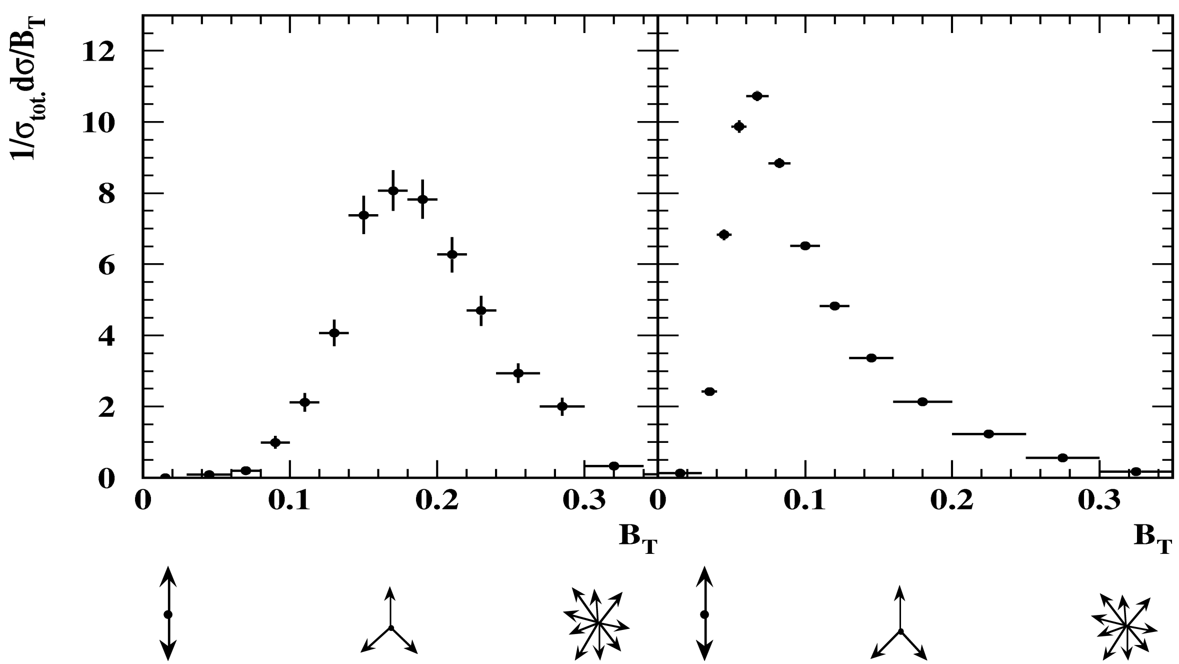


Many gluons, e.g. 1-T ≈ ½

B_T at

14 GeV:

α_s large



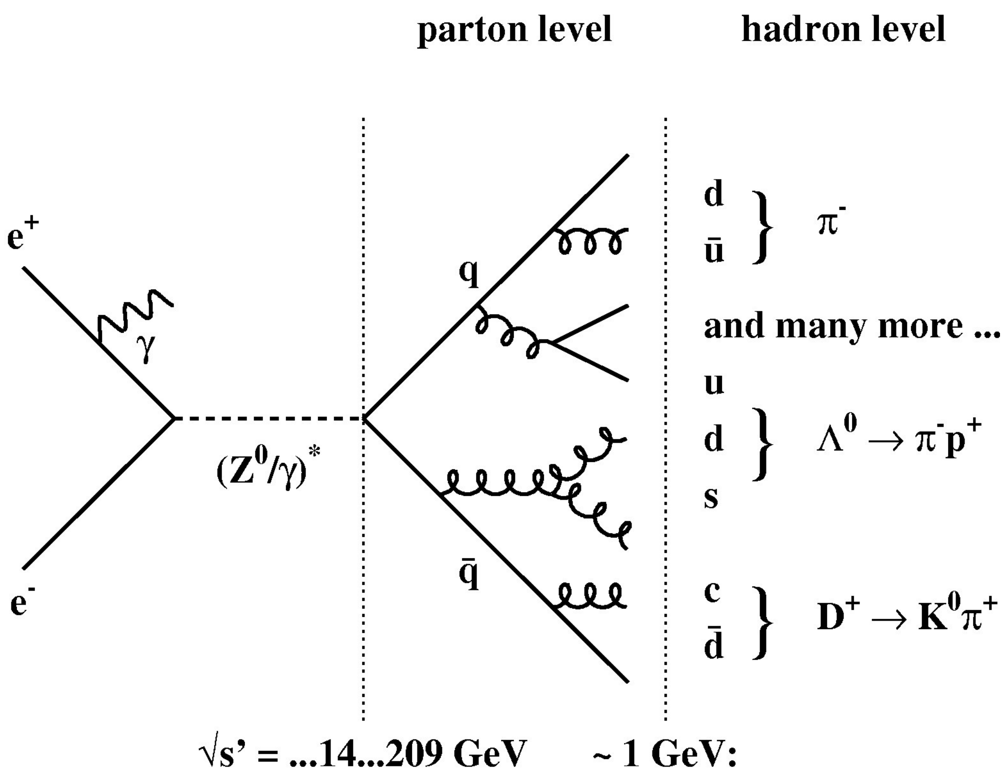
B_T at

91 GeV:

α_s small

Fits of distributions

Hadronisation: Monte Carlo models



Hadronic event in $e^+ e^-$ annihilation

Predictions: **N**ext to **N**ext to **L**eading **O**rder $O(\alpha_s^3)$

(finished 2008 after 25 years)

$$\frac{1}{\sigma}\frac{d\sigma}{dy} = \frac{dA}{dy}\frac{\alpha_s}{2\pi} + \frac{dB}{dy}\left(\frac{\alpha_s}{2\pi}\right)^2 + \frac{dC}{dy}\left(\frac{\alpha_s}{2\pi}\right)^3$$

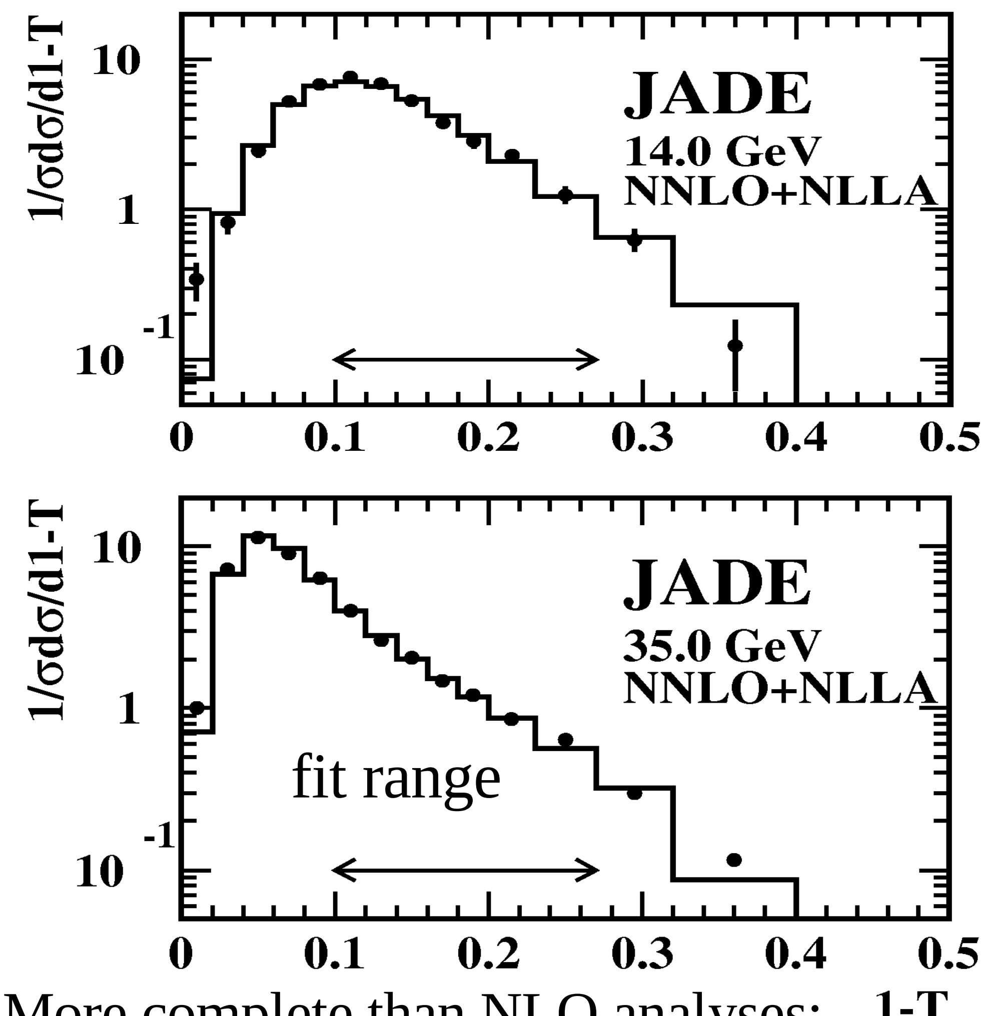
+normalization
+scale dependence (compensation in 2 loops)

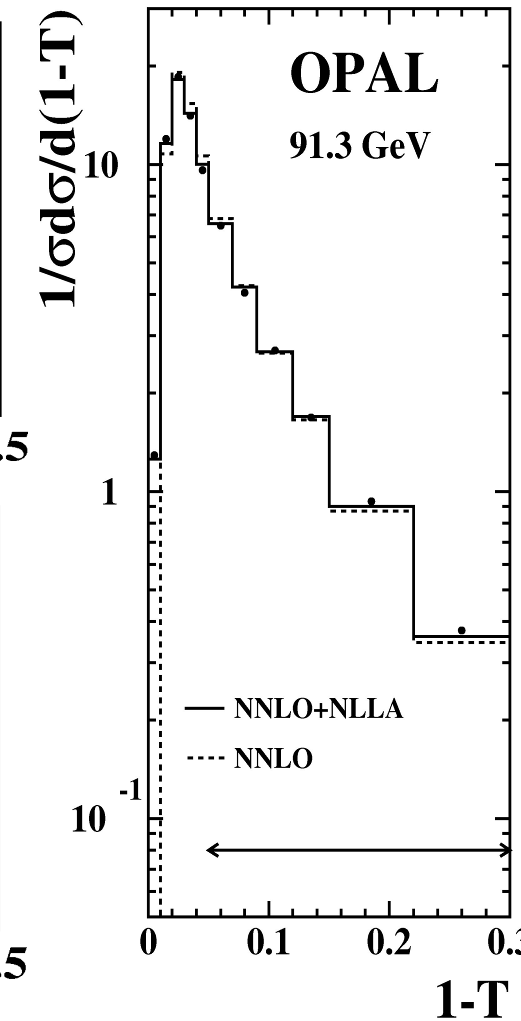
optionally:
+**N**ext to **L**eading **L**ogarithmic **A**pproximation (scale compensation in 1 loop)

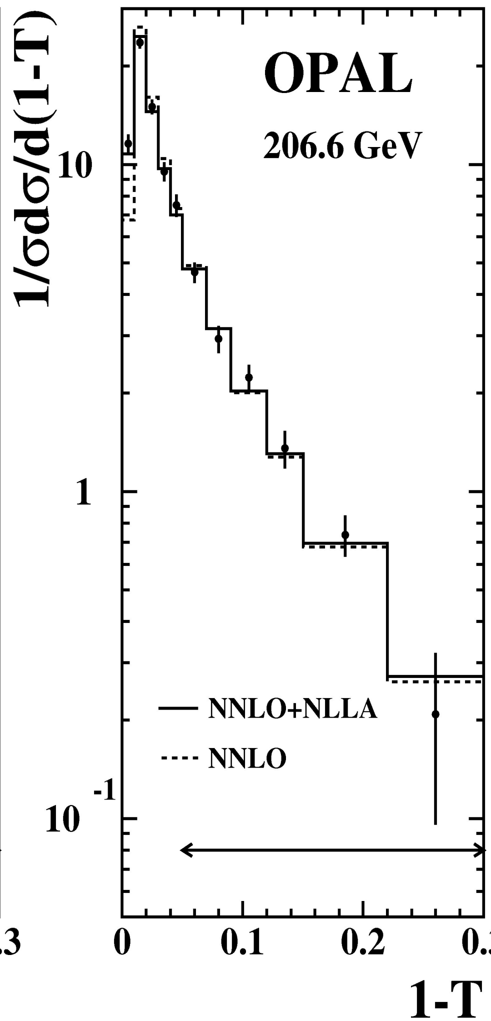
Fits of distributions

Event shape thrust

At 14, 35, 91, 207 GeV; hadron level with stat. errors



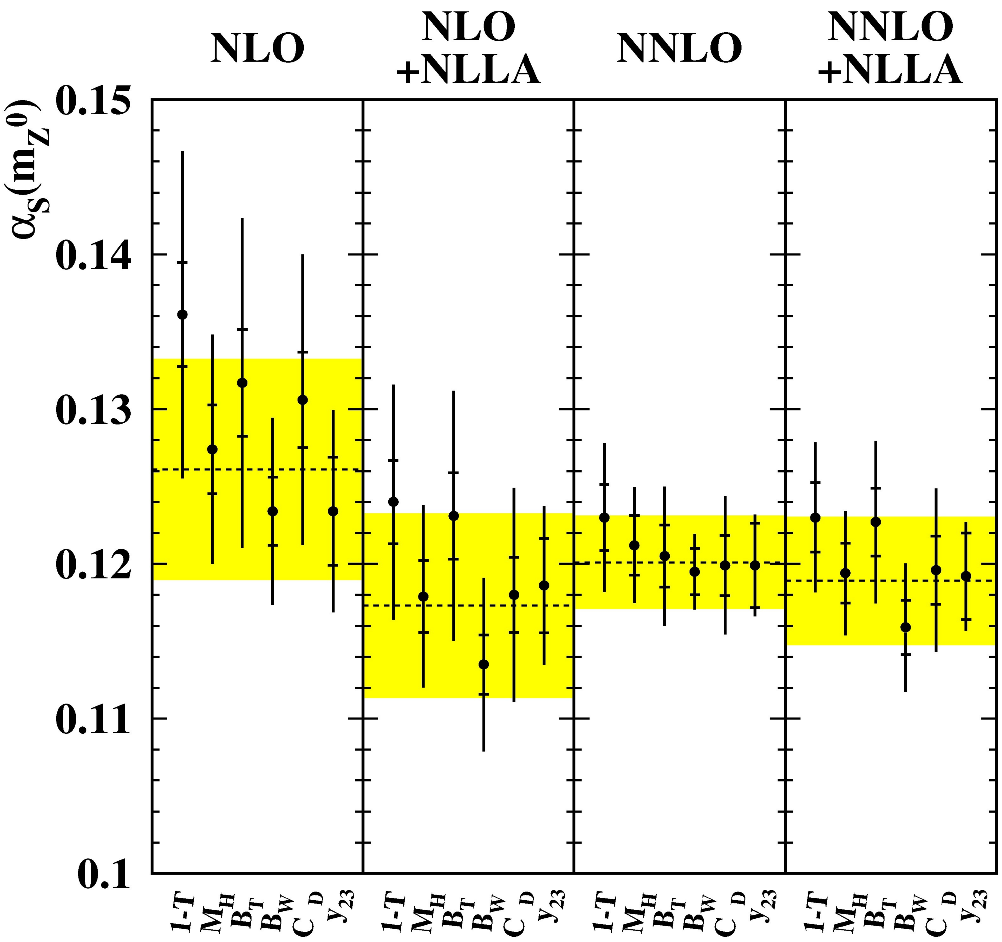




More complete than NLO analyses:
Data described well over virtually all phase space, in particular including NLLA

Determination of α_s

$\alpha_s(m_{Z^\circ})$ results, OPAL:



Errors: stat. / exp.+had.+scale

- More complete than NLO+NLLA analyses:
  - renormalisation scale uncertainty reduced
  - scatter from different variables reduced
  - in particular (OPAL) *not* including NLLA

$\alpha_s(m_{Z^\circ})$ results:

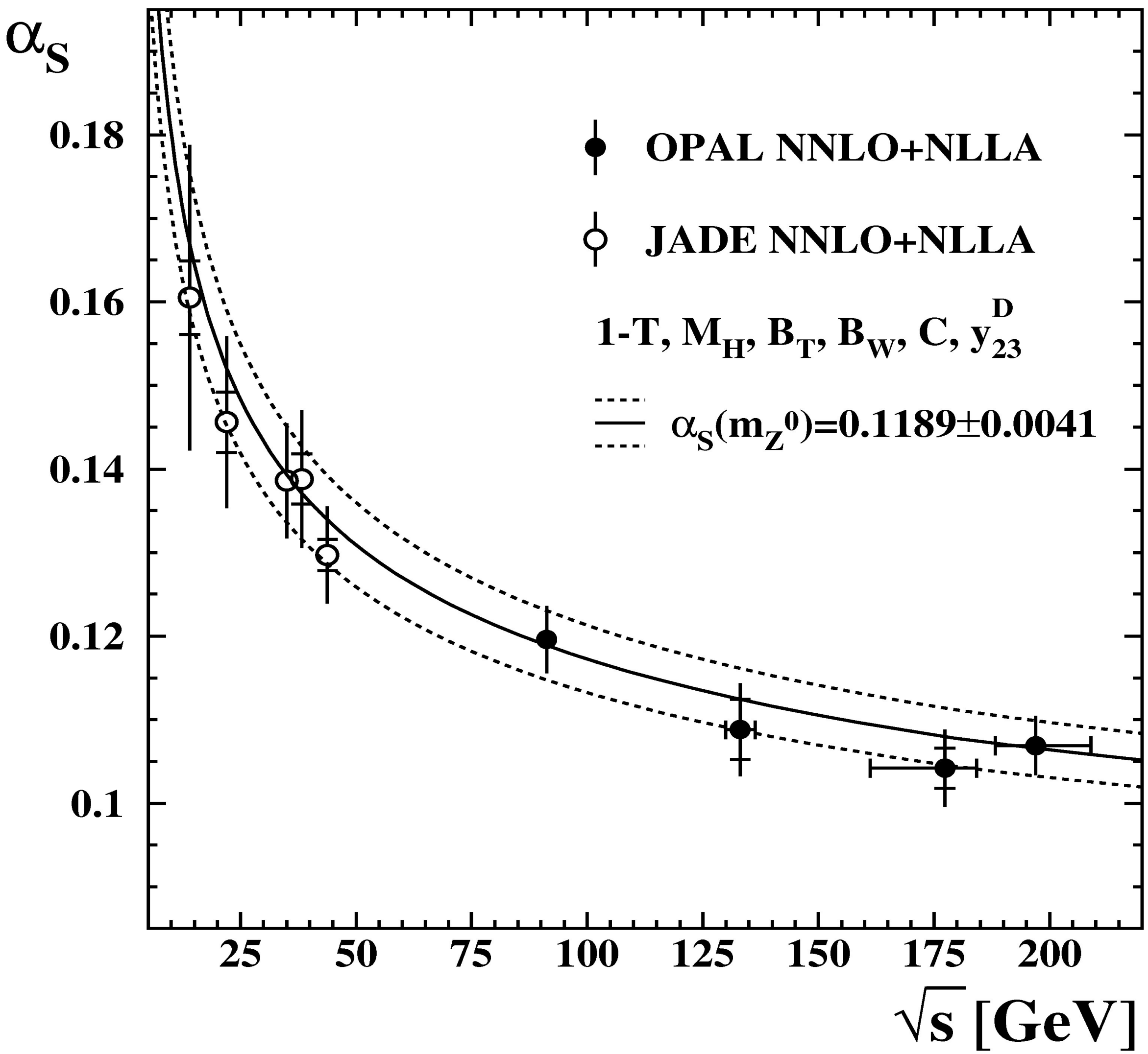
	JADE	OPAL
NNLO	0.1210±0.0061	0.1201±0.0030
NNLO+NLLA	0.1172±0.0051	0.1189±0.0041

2.6-5.0% precision, among the best measurements

Running coupling

Running $\alpha_S(Q)$ result

from event shape combination, OPAL



Errors: stat. / exp.+had.+scale

- JADE energy range 14-44 GeV: running confirmed strongly
- OPAL range 91-209 GeV: better precision

Summary, JADE & OPAL

- Analyses of data taken at the JADE and OPAL experiment are still ongoing
- Measurements not limited by statistical and experimental precision: New models and calculations allow improved determination of α_S
- Running of $\alpha_S(Q)$ confirmed strongly in the JADE energy range
- $\alpha_s(m_{Z^\circ})$ measured precisely by OPAL
- QCD precisely studied in e^+e^- important for LHC

ILC: α_s uncertainties at 500 GeV

Statistical

- $L=2 \bullet 10^{34}/cm^2 s \sim 10^3 \bullet$ LEP1
- $\sigma_{had} \sim 10^{-3} \bullet$ LEP1
- Selection efficiency slightly worse than LEP2 hep-ex/9912051
- Precision of 0.0001 in few years

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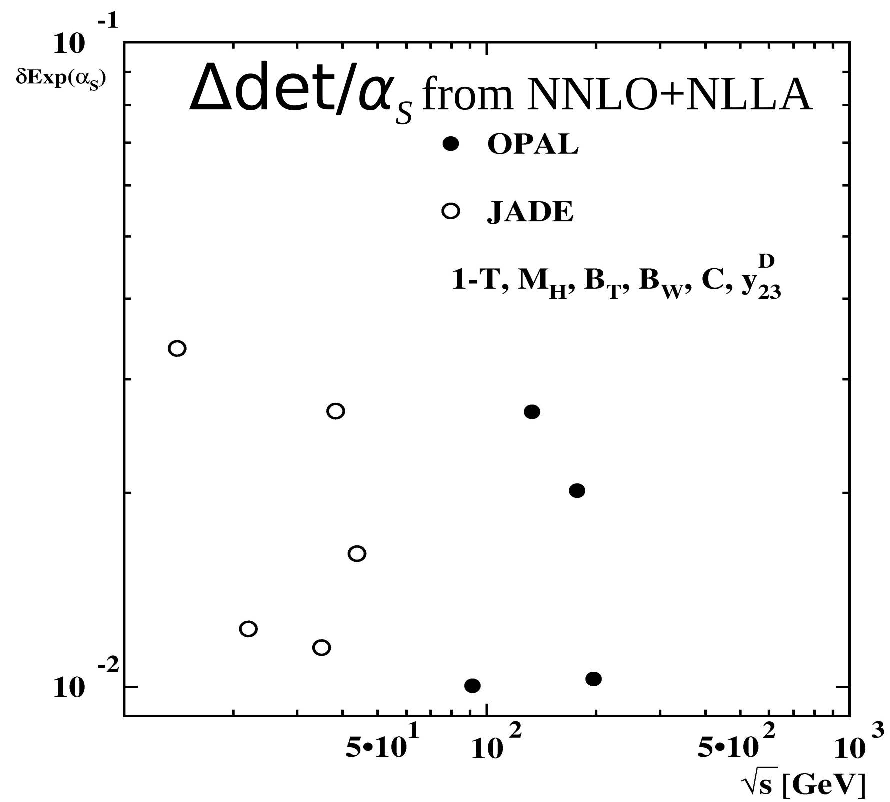
Detector uncertainties

- OPAL
  - acceptance cut
  - tracks+cluster
  - MC model
- JADE, additionally:
  - data version



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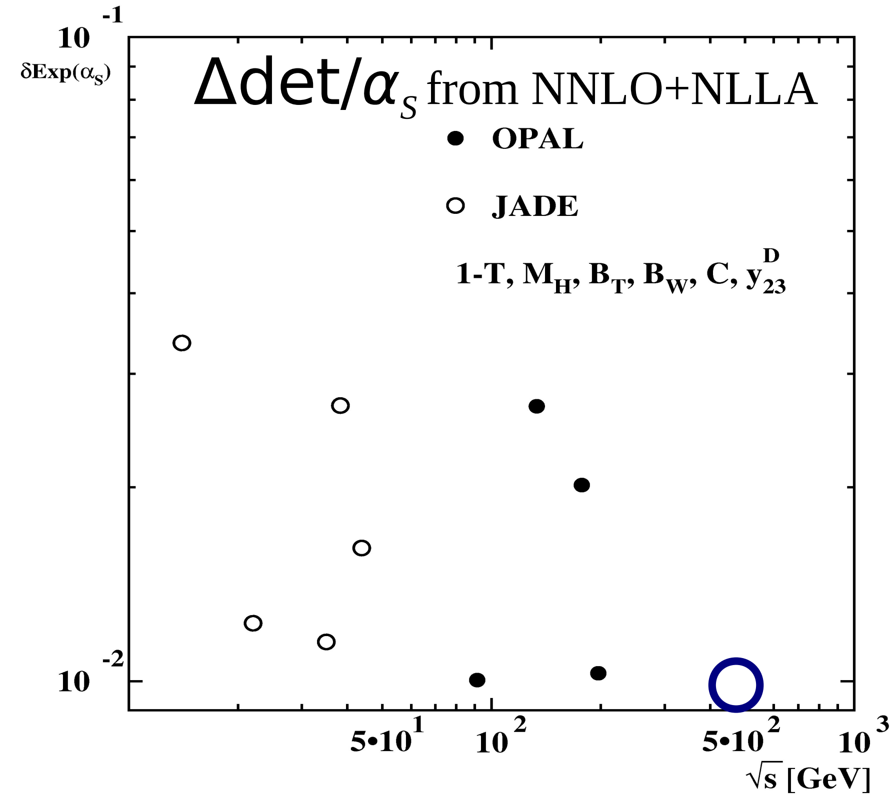


ILC detector very hermetic, good tracking & calorimetry: Detector uncertainty $\Delta det/\alpha_s \sim 0.01$ expected

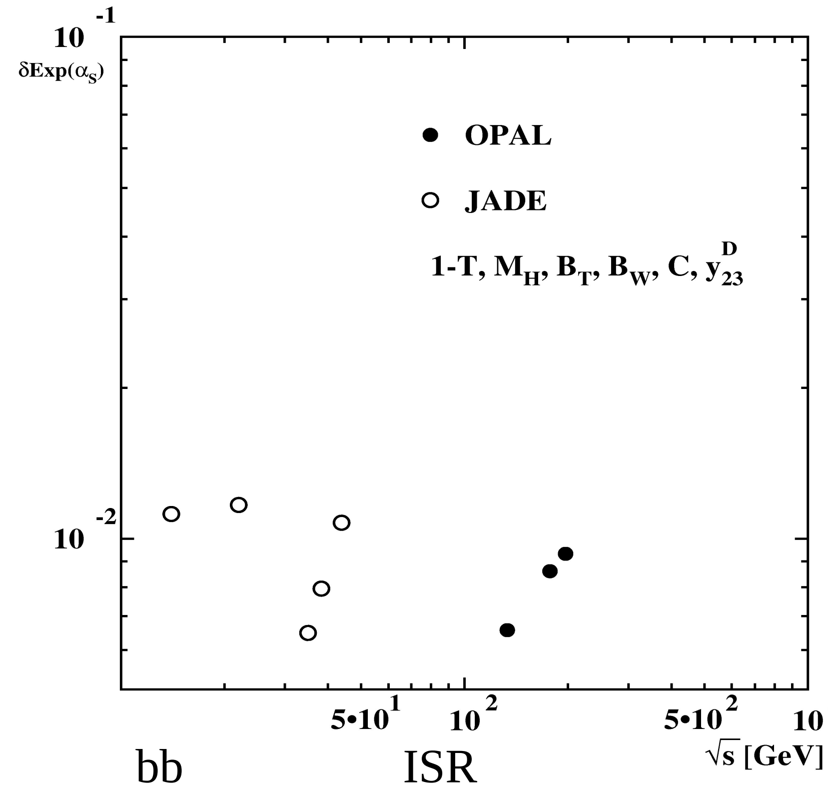
http://tesla.desy.de/new_pages/TDR_CD/PartIII/partIII.pdf

ILC: α_s *uncertainties* at 500 GeV

Residual Background

- Selection cuts varied
- JADE, additionally:
  - bb cross section ± 5%
- OPAL, additionally:
  - 4f cross section ± 5%
  - ISR algorithm varied

Δbkg/α_s from NNLO+NLLA



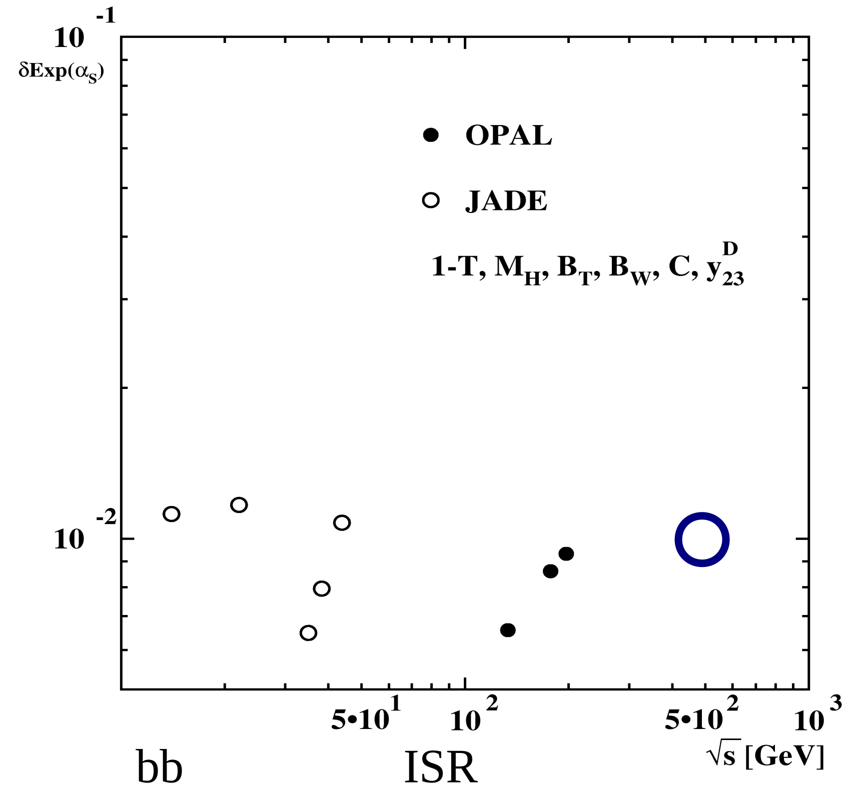
bb ISR WW,ZZ

ILC: α_s *uncertainties* at 500 GeV

Residual Background

- Selection cuts varied
- JADE, additionally:
  - bb cross section ± 5%
- OPAL, additionally:
  - 4f cross section ± 5%
  - ISR algorithm varied
- ILC: Larger background, but
  - Polarization
  - Good b-tagging
  - Bkg measured well

Δbkg/α_s from NNLO+NLLA



bb ISR

WW,ZZ,tt,beamstrahlung

500 GeV: uncertainty of
Δbkg/α_s ~ 0.01 expected

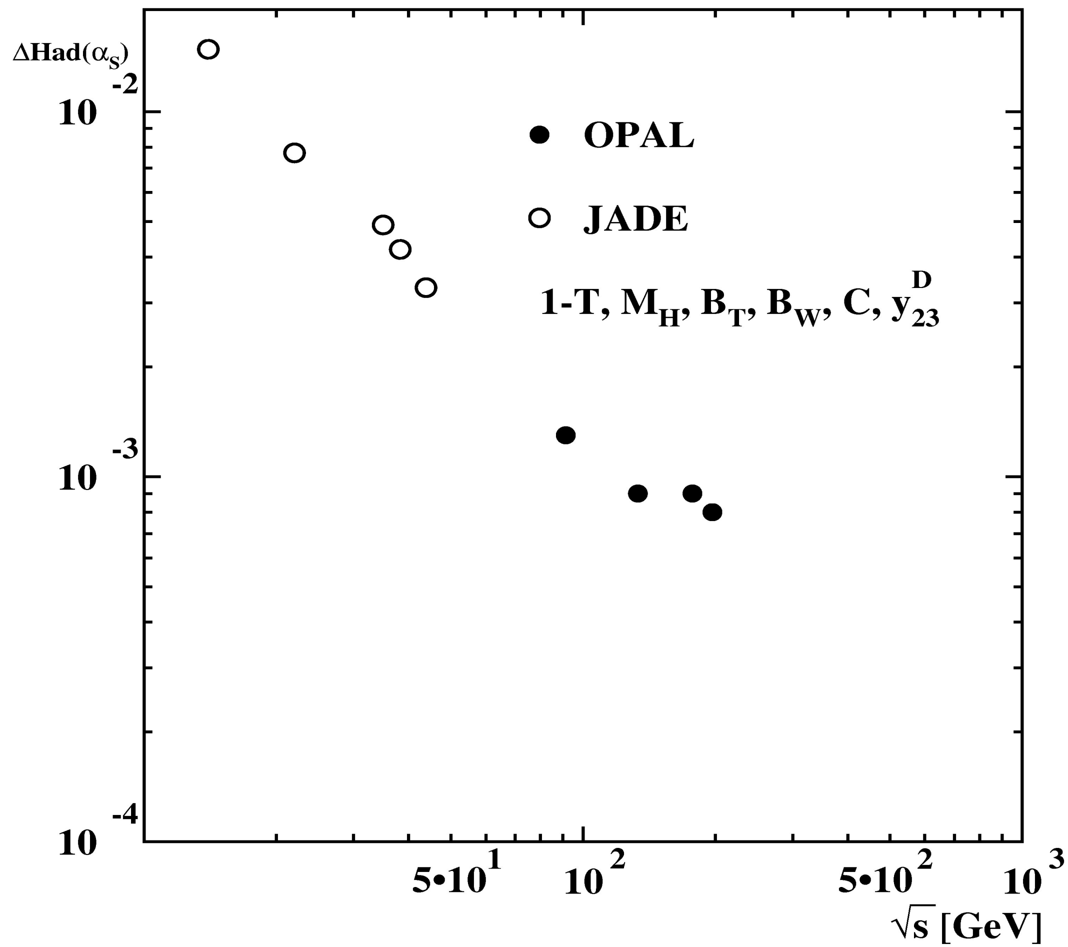
http://tesla.desy.de/new_pages/TDR_CD/PartIII/partIII.pdf

ILC: α_s *uncertainties* at 500 GeV

Hadronisation uncertainties

- JADE & OPAL: Estimated by larger difference between PYTHIA and HERWIG, ARIADNE

Δhad from NNLO+NLLA

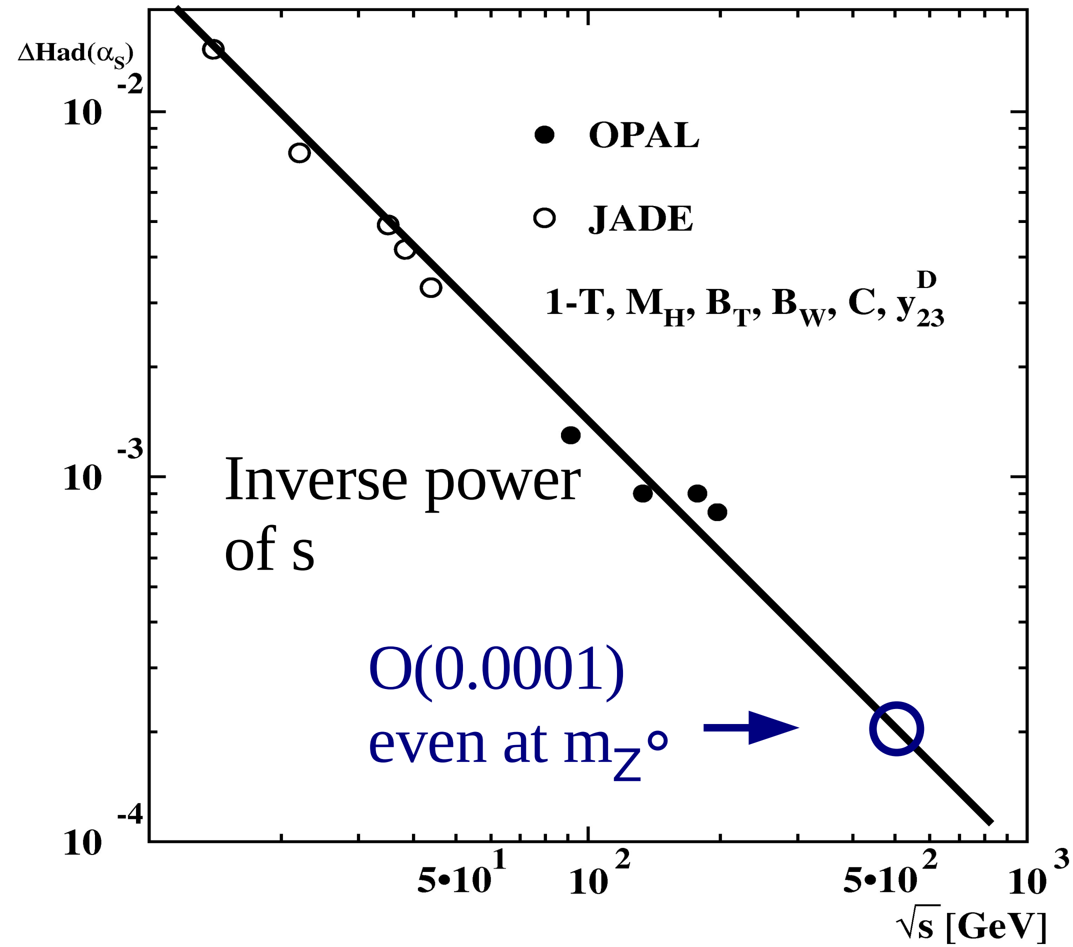


ILC: α_s *uncertainties* at 500 GeV

Hadronisation uncertainties

Δhad from NNLO+NLLA

- JADE & OPAL: Estimated by larger difference between PYTHIA and HERWIG, ARIADNE
- Agreeement with MC studies at 500 GeV.

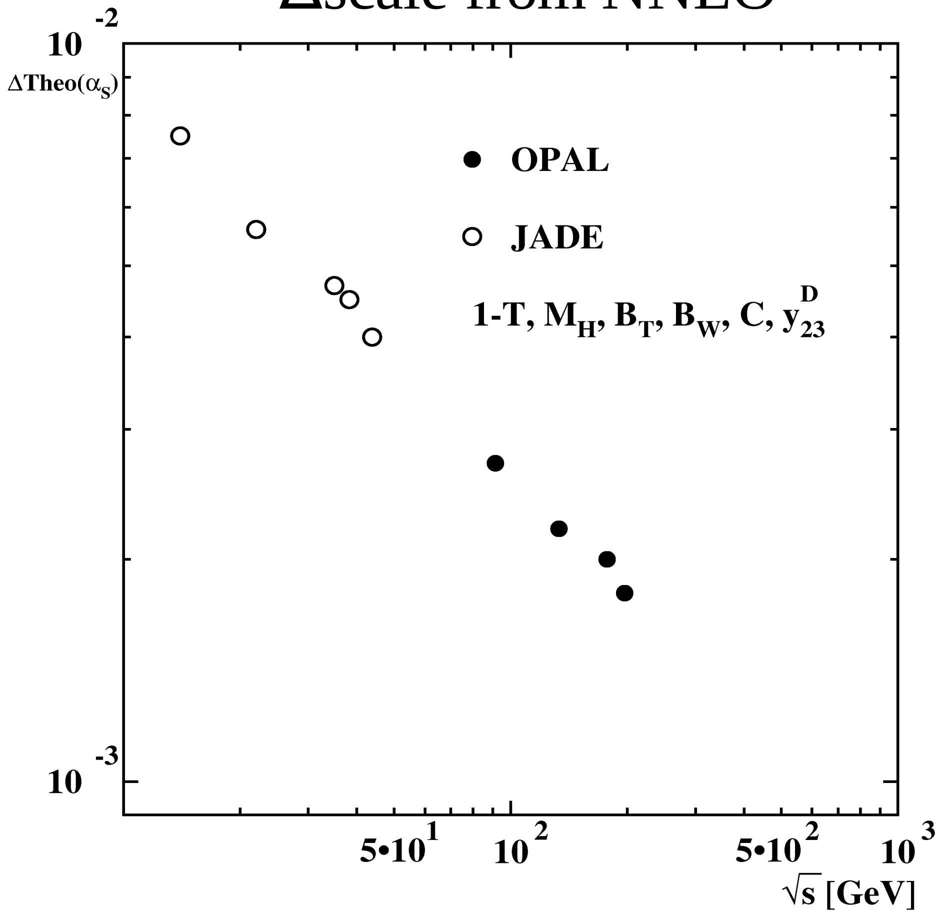


ILC: α_s *uncertainties* at 500 GeV

Uncertainty due to uncalculated higher orders

- Estimated conventionally by varying the renormalisation scale μ_R=0.5 √s ... 2.0 √s

Δscale from NNLO



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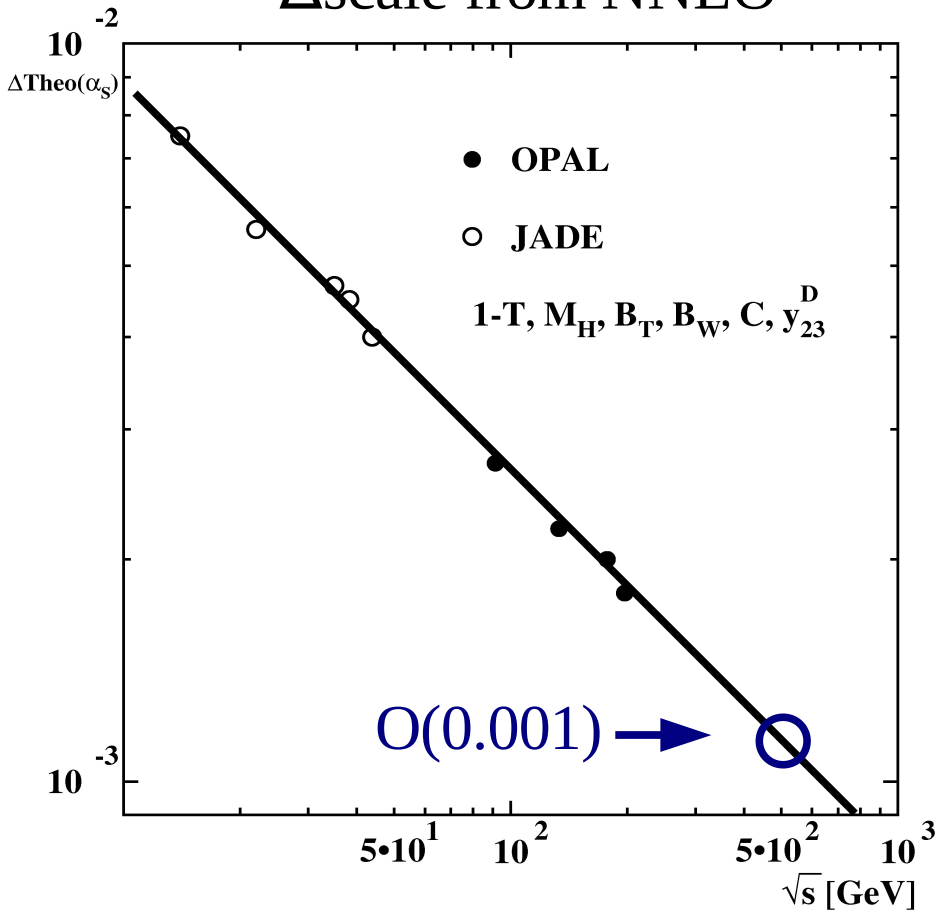

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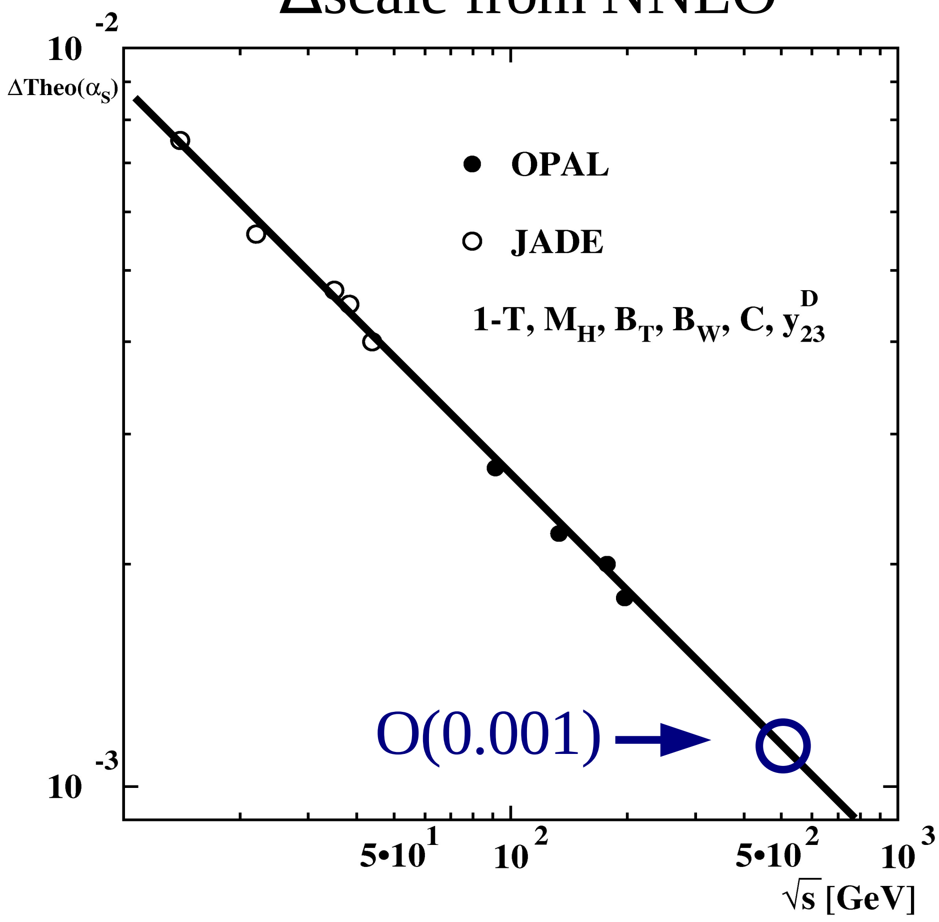


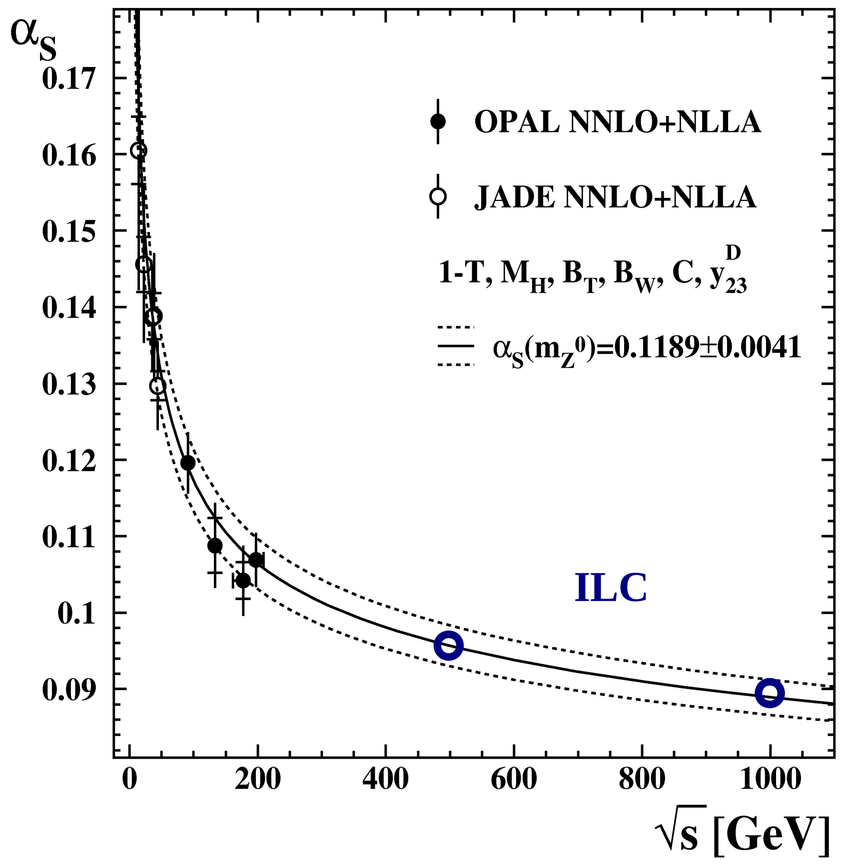
Compare scale uncertainties 500 GeV vs. 91 GeV:

	α_S measure-ment at LEP1	α_S(500GeV) estimate	$\alpha_S(m_Z\circ)$ evolved from α_S(500GeV)
NLO missing: α_S^3	0.1192 ±0.0047 (OPAL PR404)	0.0959 ±0.0024	0.1192 ±0.0038
NNLO missing: α_S^4	0.1205 ±0.0027	0.0967 ±0.0011	0.1205 ±0.0017

Scale uncertainty reduced to
NLO: 80%
NNLO: 60%.

Summary, ILC

- Uncertainties of $\alpha_s(m_{Z^\circ})$ measurement at 500 GeV:
  - Statistical ~ 0.0001
  - Detector ~ 0.001
  - Background ~ 0.001
  - Hadronisation ~ 0.0001
    partons are almost seen!
  - Scale ~ 0.001
    NNLO very important
- ILC+NNLO = precision



Test of the running of $\alpha_s(\sqrt{s})$: Extended lever arm