# New results from old data -JADE and OPAL-

- QCD
- Theory: observables and calculations
- Experiments
- Analyses
  - OPAL: Event shapes NNLO+NLLA
  - JADE: Durham three-jet rate NNLO+NLLA
  - OPAL: LHC inspired jet rates

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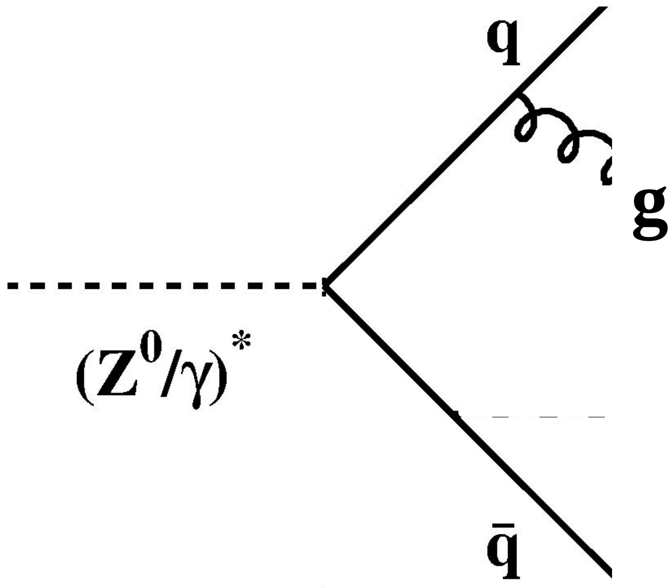
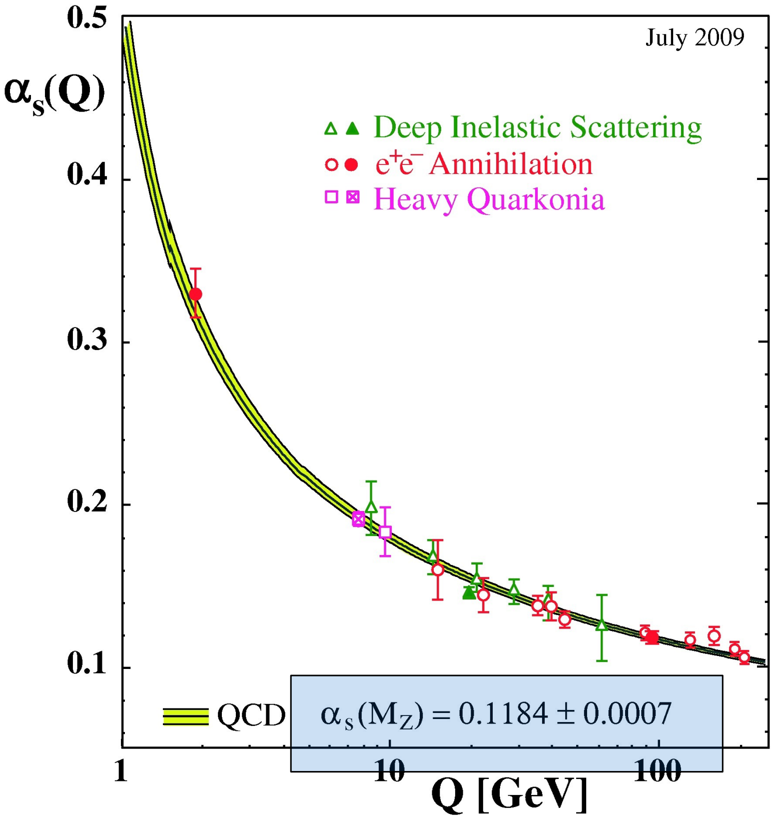
# QCD

Gluon radiation




$P(g)=C_1 \cdot \alpha_S^1$ + higher orders

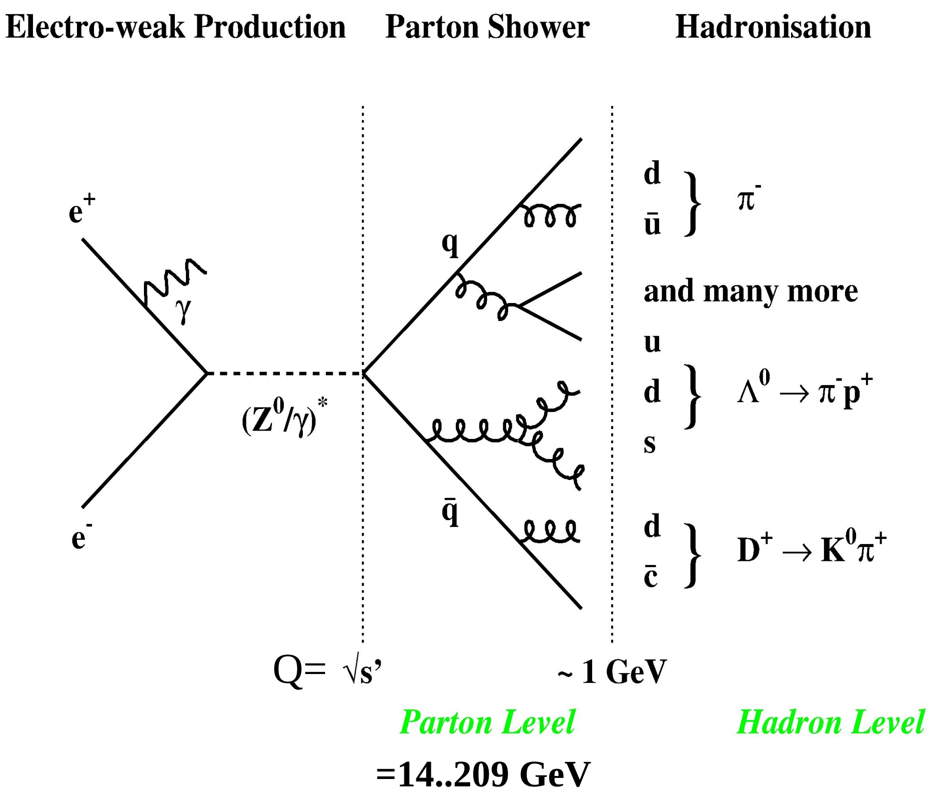
Running strong coupling
(Eur. Phys. J. C 64:689)

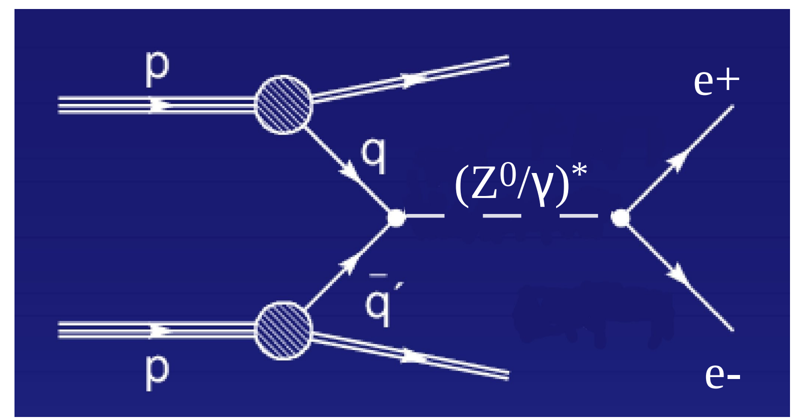


# QCD

## e⁺e⁻ collider

## pp collider

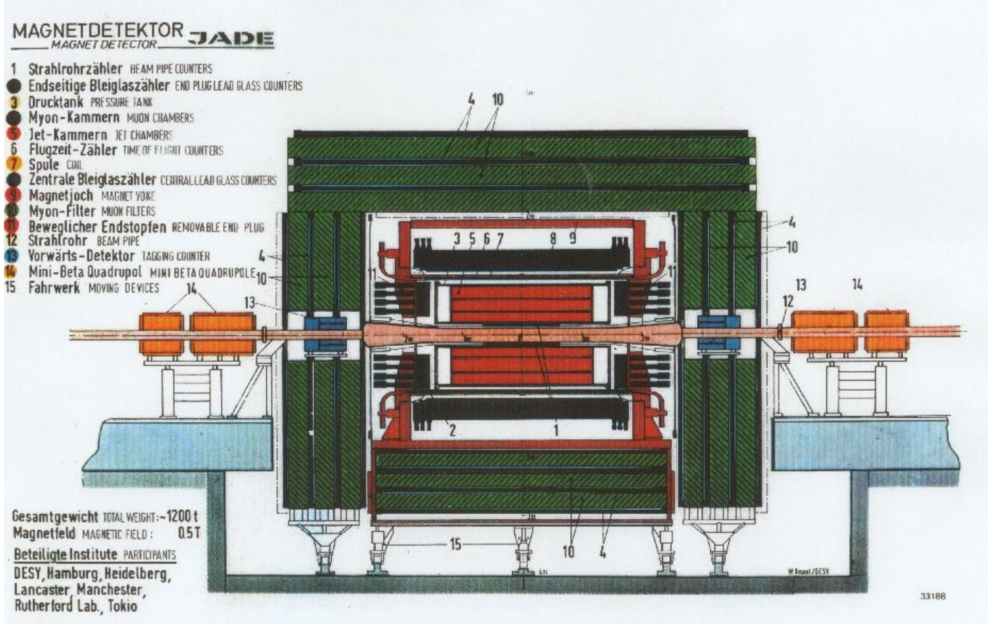



Hadronic event in $e^+e^-$ annihilation

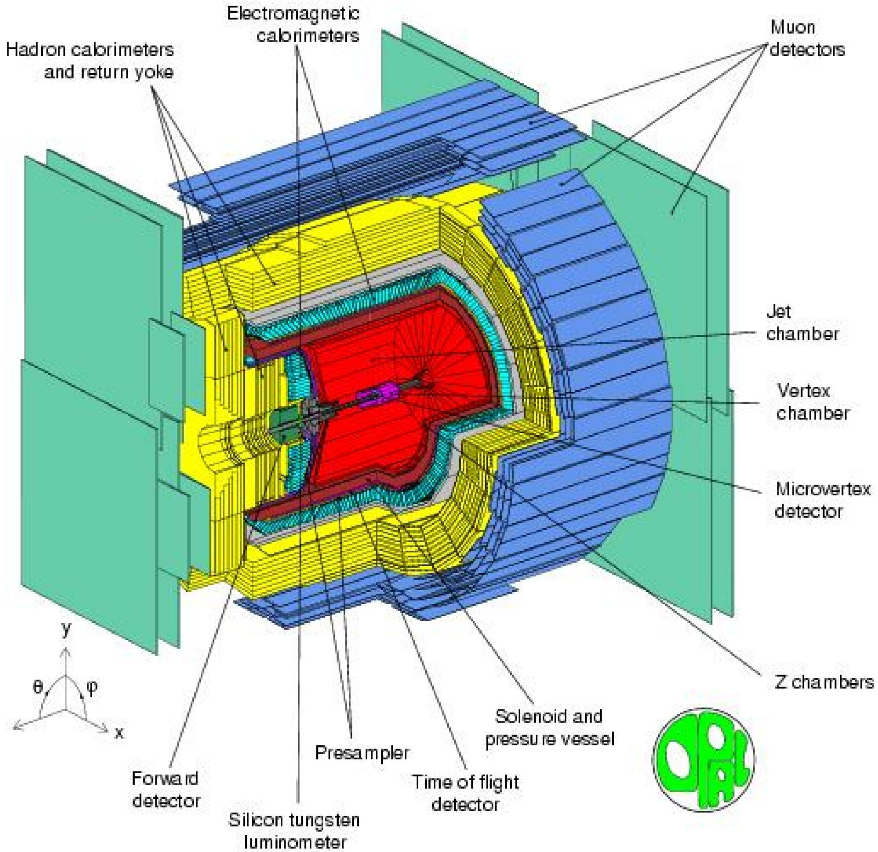
Drell-Yan production

# Experiments: JADE, OPAL

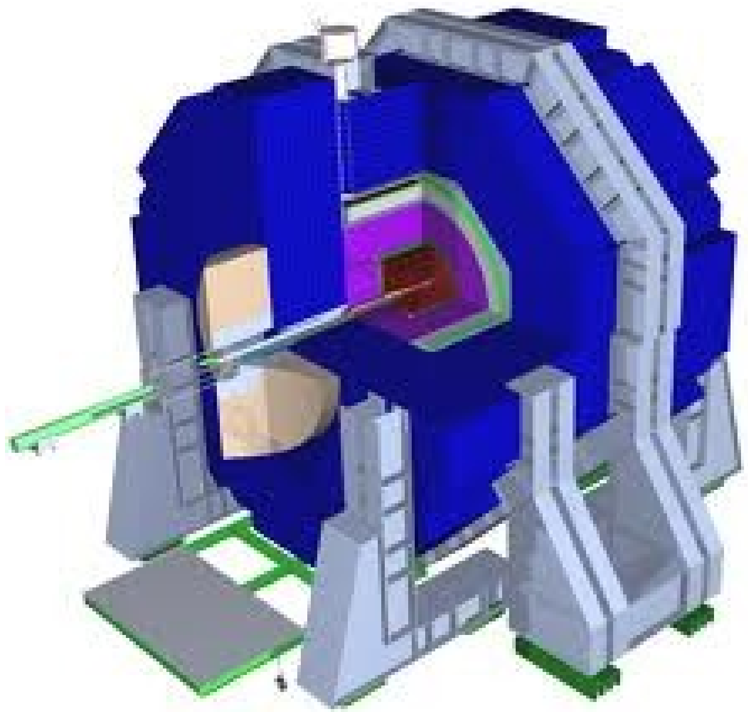



JADE: 1978-1986 at PETRA
Q=14-44 GeV
running of $\alpha_S$

OPAL: 1989-2000 at LEP
Q=91-209 GeV
$\alpha_S$ precision measurement

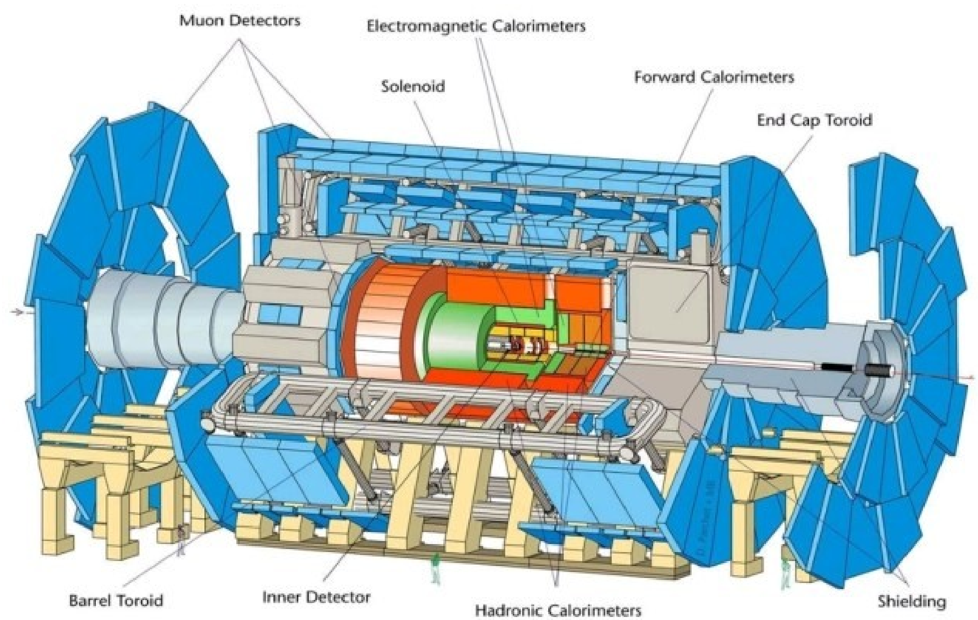


# Experiments: SiD, ATLAS



SiD: proposed at ILC
Q=500 , 1000 GeV
higher precision

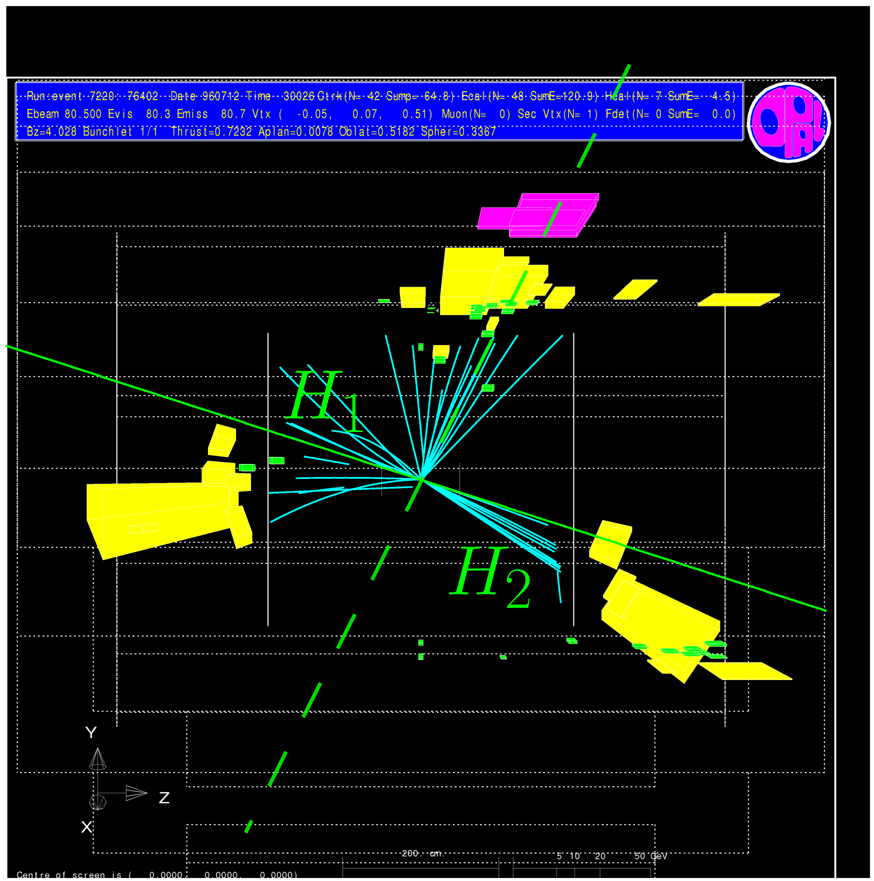
ATLAS: 2009... at LHC
Q=7...14... TeV
complex QCD



# Observables: event shape variables

<u>Two-hemisphere variables:</u>

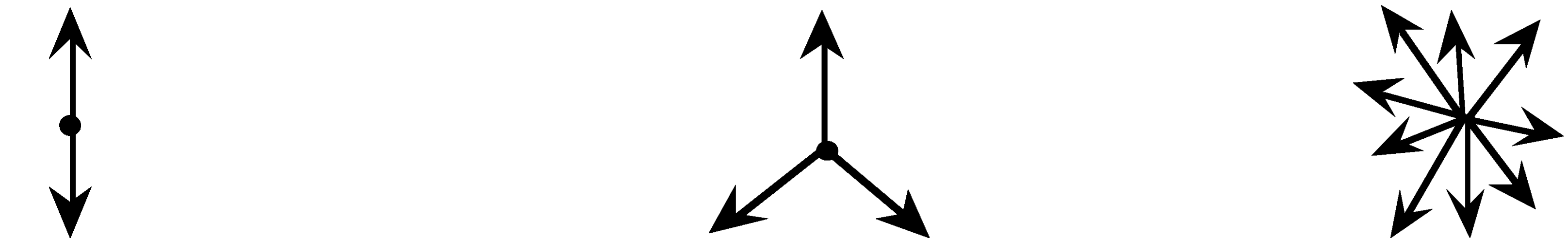
- Thrust 1-T
- C parameter
- Total Jet Broadening $B_T$




<u>One-hemisphere variables:</u>

- Wide Jet Broadening $B_W$
- Durham two-jet flip parameter $y^D_{23}$
- Heavy Jet Mass $M_H$

# Event shape distributions

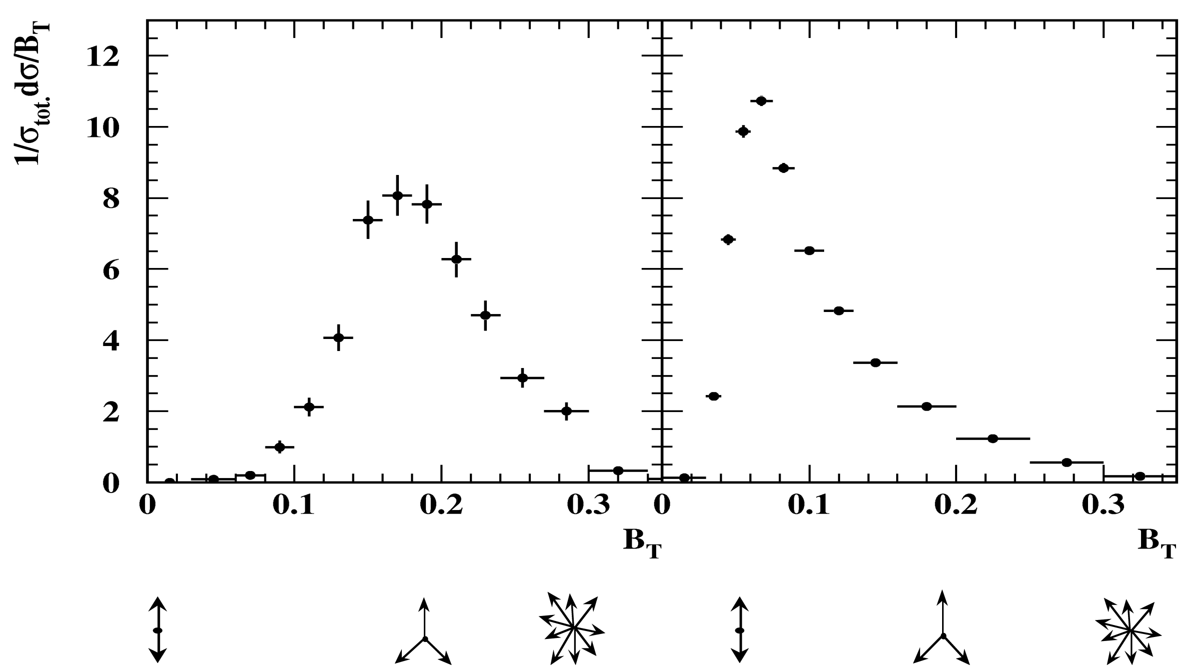


qq: 2 Jets, y≈0

qqg: 3 Jets, e.g. 1-T ≈ ⅓

Many gluons, e.g. 1-T ≈ ½

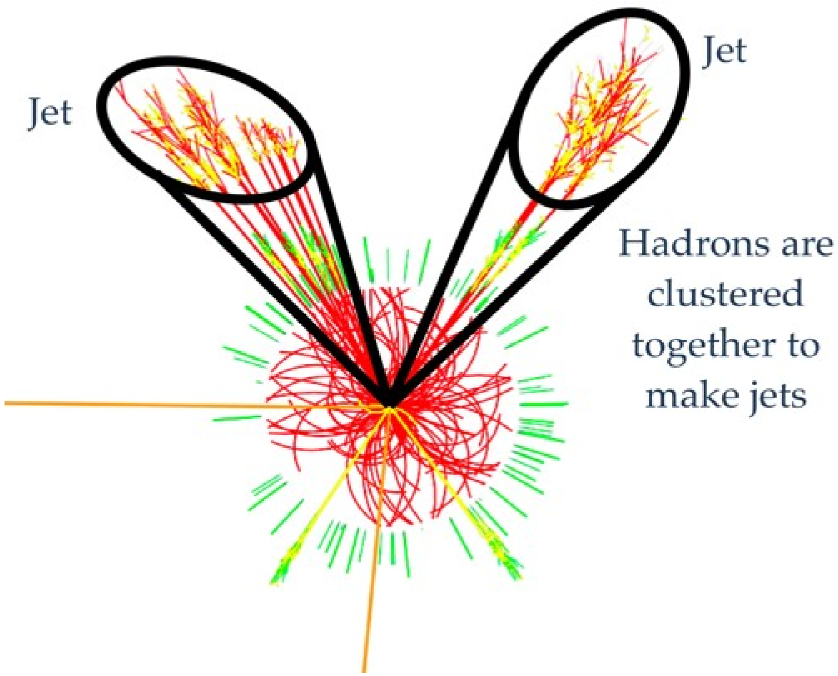
$B_T$ at 14 GeV: $\alpha_s$ large




$B_T$ at 91 GeV: $\alpha_s$ small

# Observables: jet rates

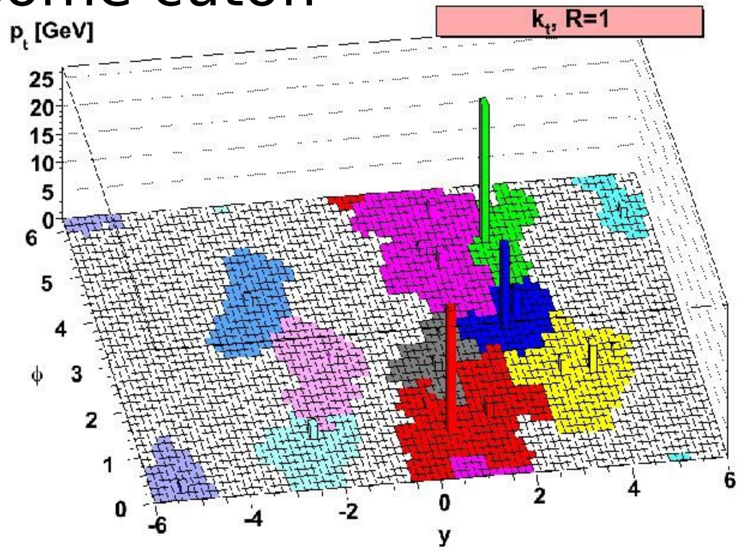
## Cone type algorithms




- Preferred in hadron collisions
- Suggested in $e^+e^-$ context 1977
- Often IR unsafe

## Durham ($k_t$-) algorithm (1992)

- $y_{ij}$=scaled relative transverse momentum between particles or jets
- combine pairs, starting from smallest $y_{ij}$ up to some cutoff

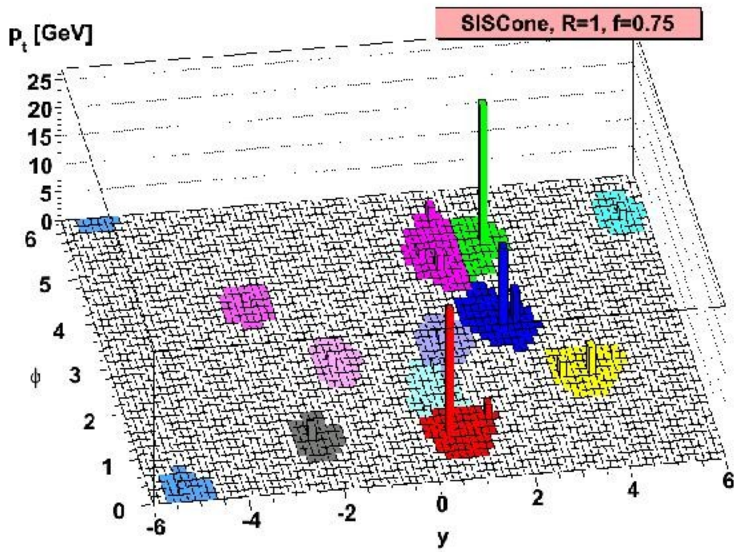



- Preferred in $e^+e^-$ collisions
- Theoretically well behaved

# Observables: jet rates

<u>SISCone algorithm (2007)</u>

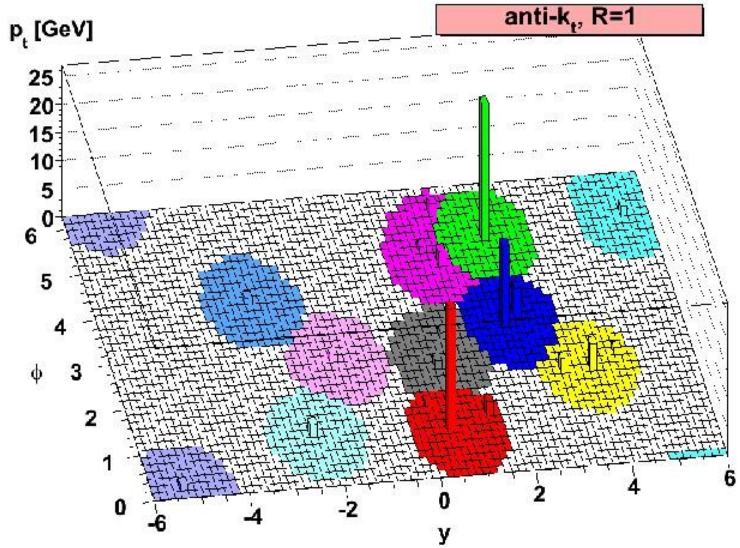
- Three parameters
- Split-merge procedure




- IR safe

<u>Anti-$k_t$ algorithm (2007)</u>

- Use $1/y_{ij}$
- Alternatively: start from highest $y_{ij}$
- Additionally: Radius parameter




- Perfect cones

# Calculations

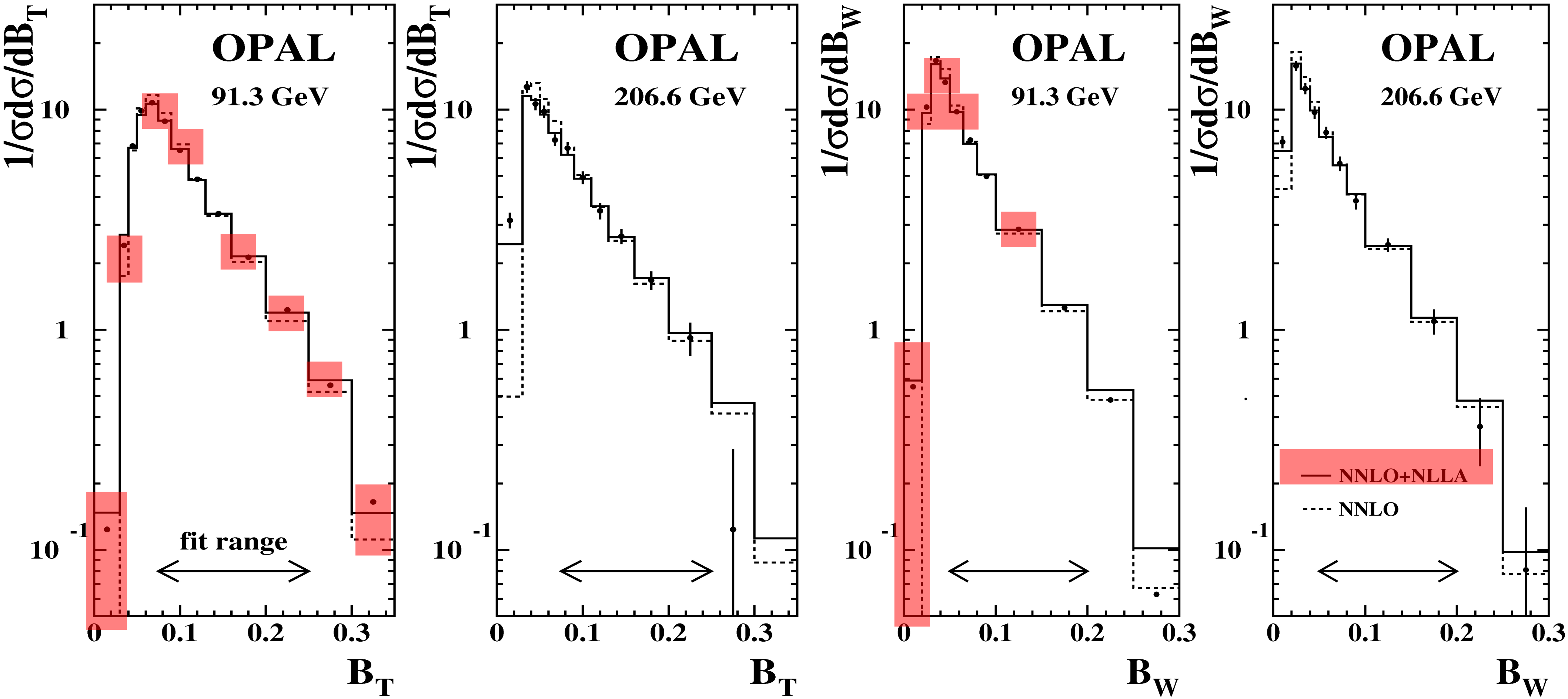
Distributions of event shape variable y or jet rate wrt. cutoff y:

- NLO: $$\frac{dR}{dy}=\frac{dA}{dy}\alpha_s+\frac{dB}{dy}\alpha_s{}^2$$ 1981
- NLO+NLLA: $$\ldots+\sum_n D_n\alpha_s{}^n\ln\left(\frac{1}{y}\right)^{n+1}+\sum_n E_n\alpha_s{}^n\ln\left(\frac{1}{y}\right)^n$$ 1991
- NNLO: $$\frac{dR}{dy}=\frac{dA}{dy}\alpha_s+\frac{dB}{dy}\alpha_s{}^2+\frac{dC}{dy}\alpha_s{}^3$$ 2007
- NNLO+NLLA: 2008

Most important error contribution results from missing higher orders.

# OPAL: Fits of event shape distributions

Event shapes total, wide jet broadening (hadron level with stat. errors)



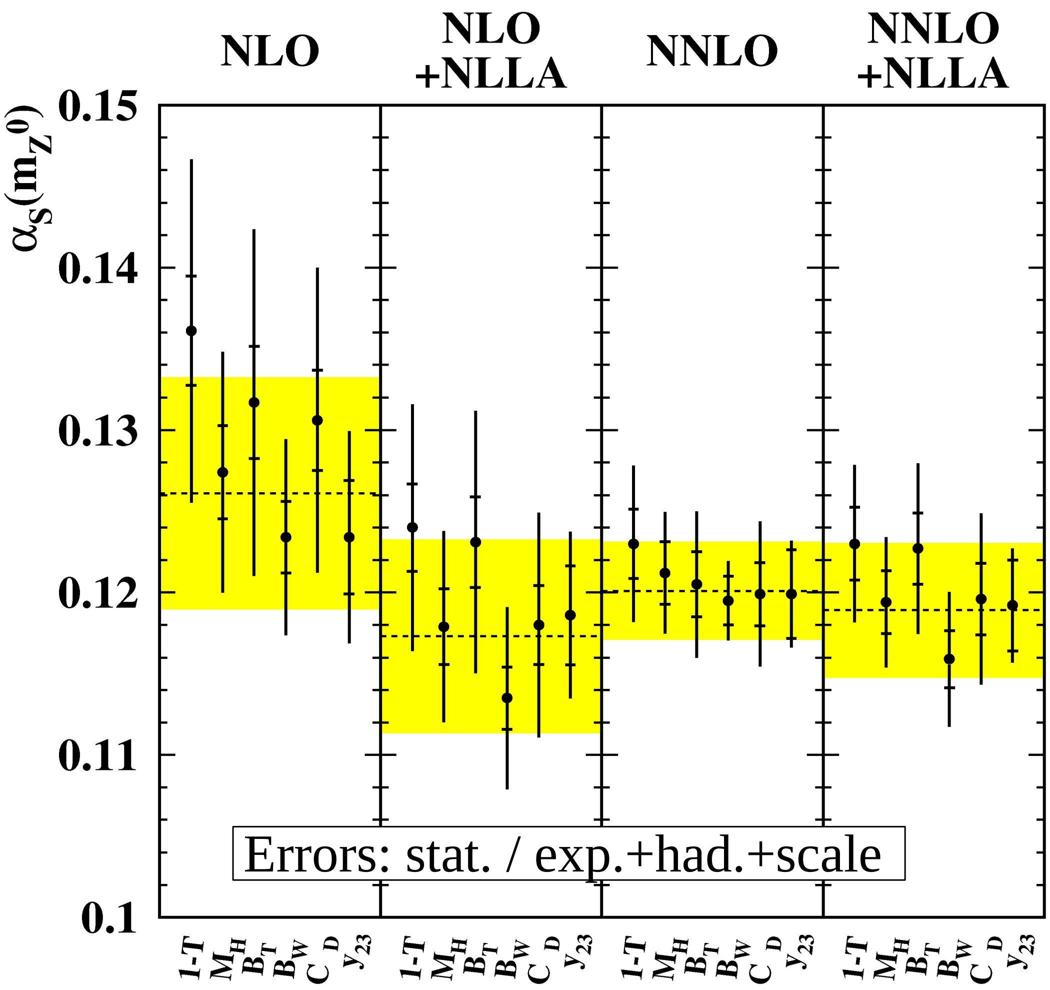

hadronisation correction factors by monte carlo models

More complete than NLO analyses:

Data described well over virtually all phase space - in particular including NLLA

# Measuring $\alpha_s$

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




- More complete than NLO+NLLA analyses:
  - renormalisation scale uncertainty reduced
  - scatter from different variables reduced

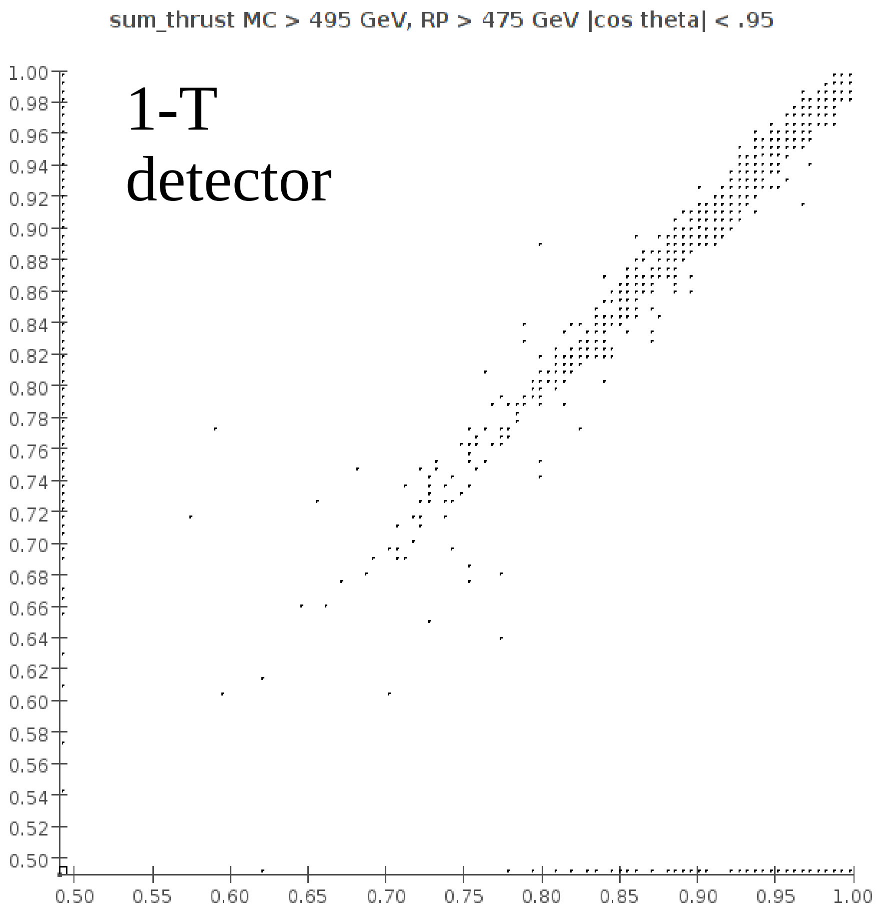
$\alpha_s(m_{Z^\circ})$ results:

| | |
|---|---|
| NNLO | $0.1201 \pm 0.0030$ |
| NNLO+NLLA | $0.1189 \pm 0.0041$ |

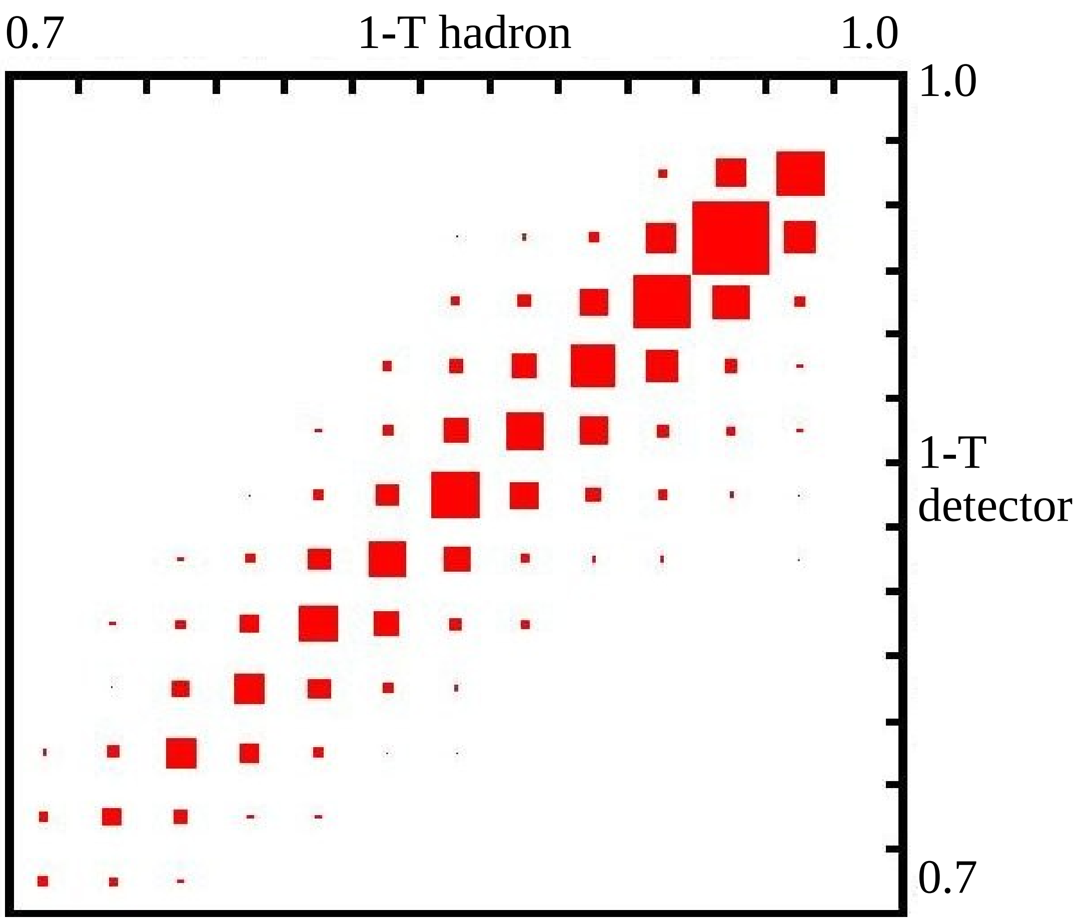
- 2.5-5.0% precision, among the best measurements

# SiD: Thrust Reconstruction

*arXiv:1110.0016*



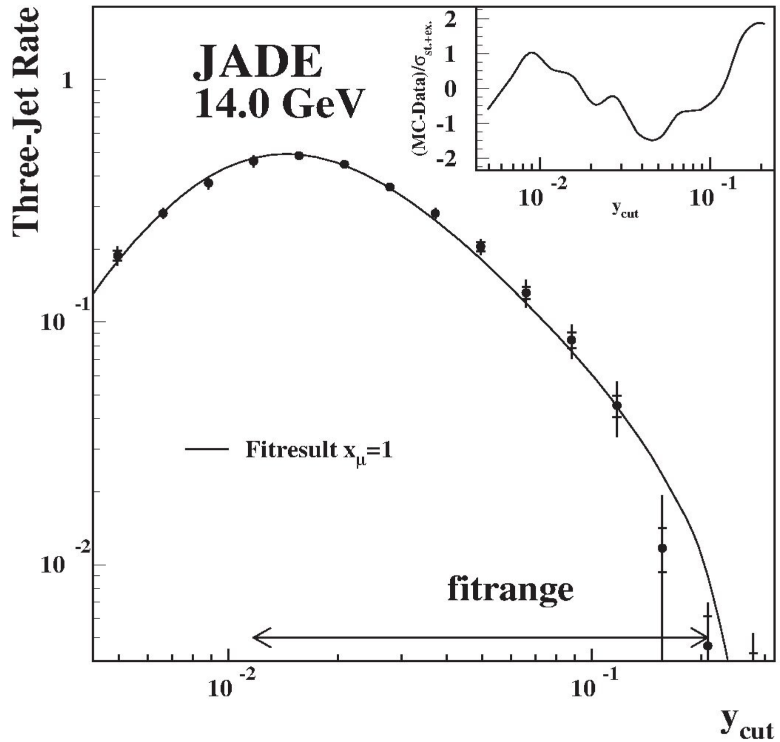

500 GeV 1-T hadron

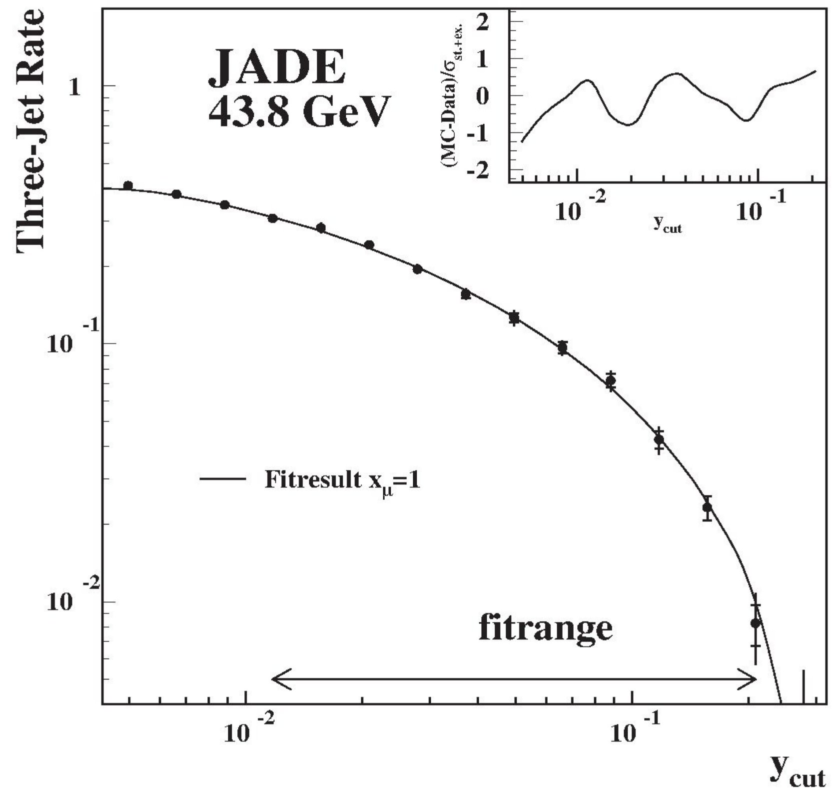



Comparison: 1-T by OPAL
at 189 GeV (M.T.Ford)

# JADE: Durham 3-JETRATE *J. Schieck*

- Detector- and hadronisation correction factors from MC models
- Prediction: NNLO, optionally + NLLA




$\alpha_s$(14 GeV)=0.1704±0.0029(stat.)± 0.0086(sys.)

$\alpha_s$(44 GeV)=0.1329±0.0029(stat.)±0.0056(sys.)

$\alpha_s(m_{Z^\circ}) = 0.1199 \pm 0.0010(\text{stat.}) \pm 0.0021(\text{exp.}) \pm 0.0054(\text{had.}) \pm 0.0007(\text{theo.})$

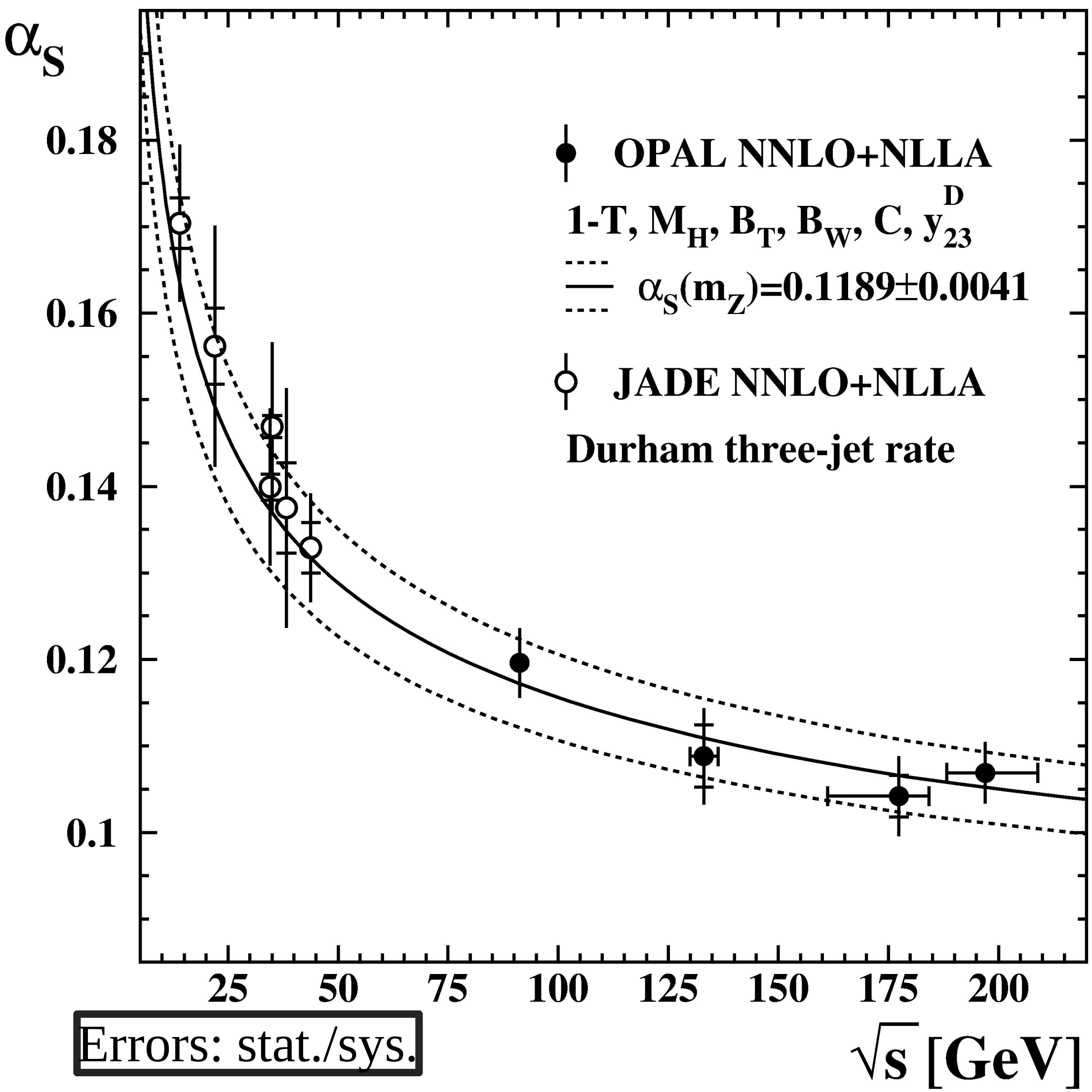
NNLA improves fits significantly:

- Much smaller $\chi^2$/dof values
- More stable wrt. fit range variations

# Running coupling

## Running $\alpha_S(Q)$ result

from event shape combination, OPAL

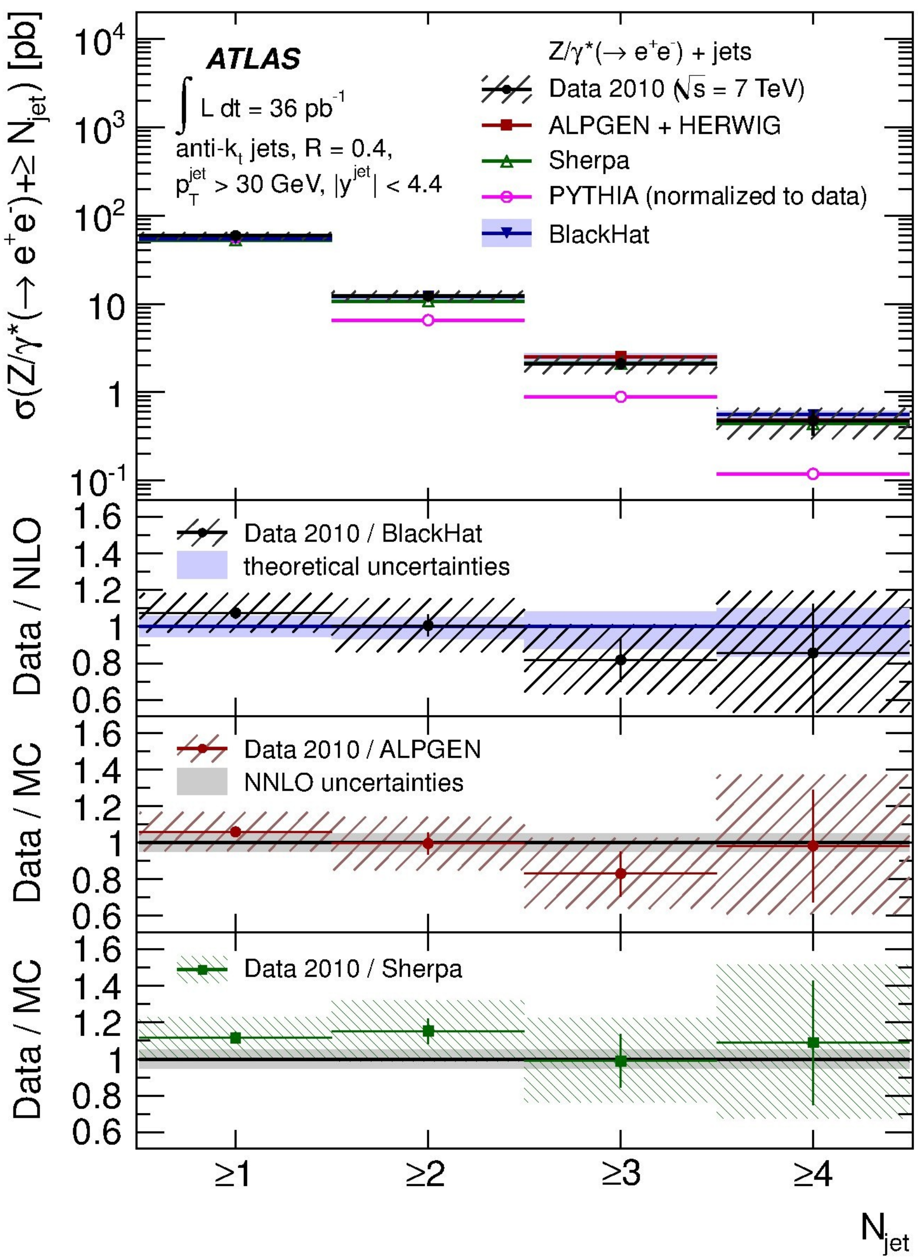



Errors: stat./sys.

= Q

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

# ATLAS: Z/γ->jets *arXiv:1111.2690*

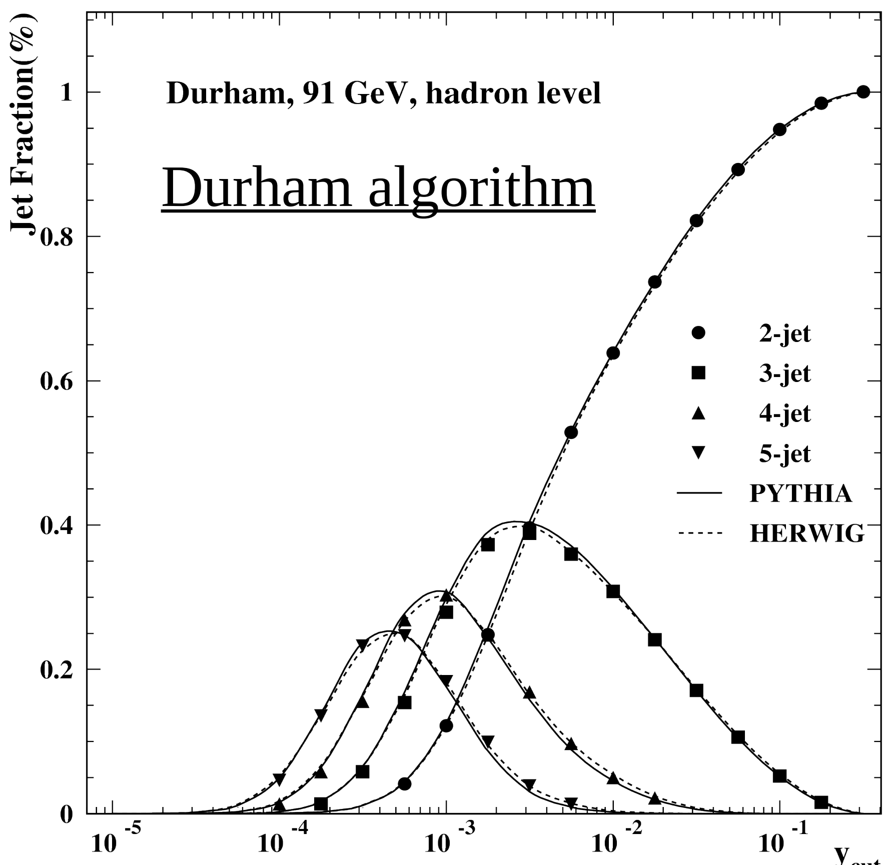


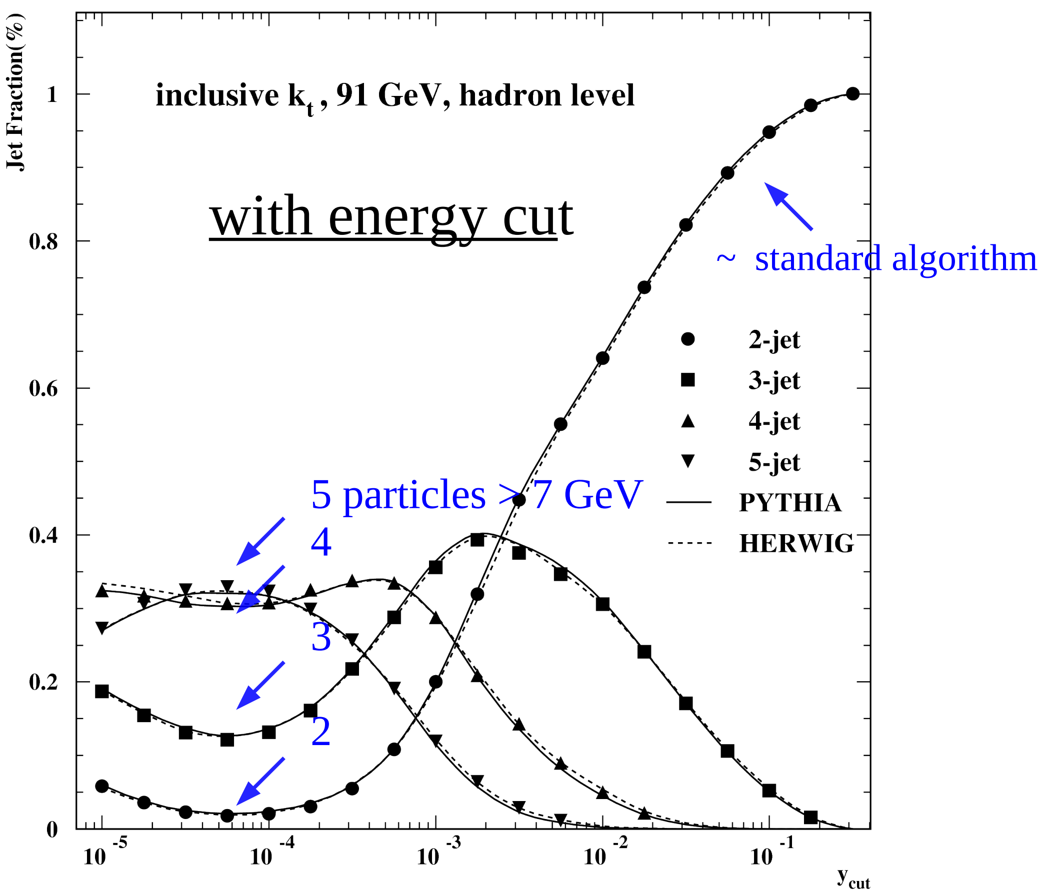

Measured cross section $\sigma_{Njet}$ for $Z/\gamma^*\to e^+e^-$+jets production as a function of the inclusive jet multiplicity, for events with at least one jet with $p_T > 30$ GeV and $|y| < 4.4$ in the final state. The error bars indicate the statistical uncertainty and the dashed areas the statistical and systematic uncertainties added in quadrature.

# OPAL: LHC inspired jet algorithms

New hadron collision jet rates can equally be formulated for $e^+e^-$ collisions, providing further insight

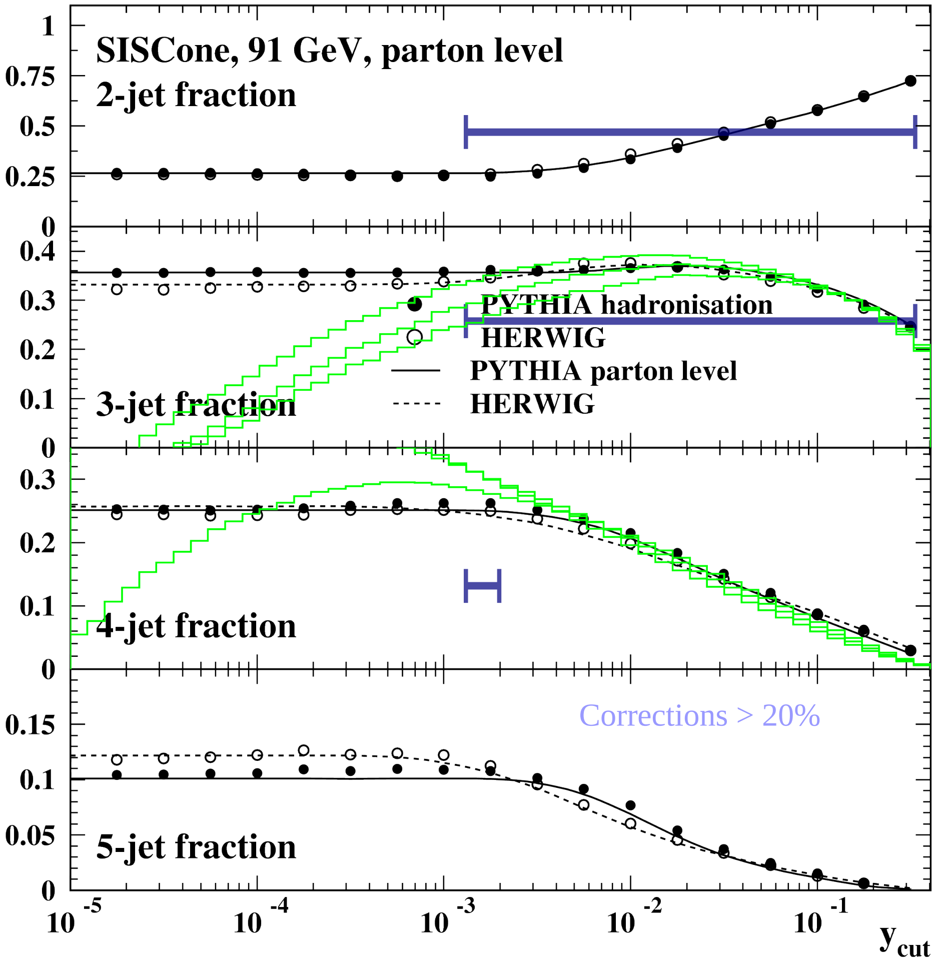
- Durham algorithm with energy cut $E_{jet} > 0.077\ E_{vis}$
- Anti-$k_t$ algorithm
- SISCone



# OPAL: LHC inspired jet algorithms

SISCone algorithmus




Theory : 3- and 4-jet rates 91 GeV.
$\alpha_S(m_Z)=0.118$, $x_\mu=0.5, 1, 2$

Anti-$k_t$ algorithmus

- Without R-parameter: ill behaviour
- Theory is recalculated

# Conclusion

- OPAL events shapes NNLO+NLLA: precise $\alpha_s(m_{Z^\circ})$ measurement, published
- Durham three-jet rate by JADE, close to publication
  - Consistent measurement
  - NLLA important
- Durham jets with energy cut, anti-$k_t$, SISCone by OPAL
  - Measured
  - Comparison with theory started

New models and calculations allow improved measurements of $\alpha_s$ with old data