Determinations of $\alpha_s$ and tests of analytic hadronisation models using $e^+e^-$ annihilation data.

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– JADE experiment
– Event shape distributions and moments
– Analysis of moments from JADE and OPAL using analytic hadronisation models (arXiv:0904.0786)
– Measurement of $\alpha_s$ from JADE distributions using new NNLO calculations (arXiv:0810.1389)
– Conclusion and outlook
JADE Experiment, 1978-1986

At PETRA, DESY, c.m. energy Q=12-44GeV

hadronic cross section
JADE Experiment, 1978-1986

At PETRA, DESY, c.m. energy $Q=12-44\text{GeV}$

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- Analysis and detector simulation software reactivated
- New Monte Carlos, new calculations

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Recent world average:

$$\alpha_s(M_Z) = 0.1189 \pm 0.0010$$

(Prog.Part.Nucl.Phys.58:351)
Event shape variables $y$

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

(Two-hemisphere variables)

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

(One-hemisphere variables)

- $qq$: 2 Jets, $y \approx 0$
- $qqg$: 3 Jets, e.g. 1-T $\approx \frac{1}{3}$
- Many gluons, e.g. 1-T $\approx \frac{1}{2}$
Distributions and moments

• Distributions

\( B_T \) at

14 GeV:
\( \alpha_s \) large

91 GeV:
\( \alpha_s \) small

• Moments

\[ \langle y^n \rangle = \int y^n \frac{1}{\sigma} \frac{d\sigma}{dy} dy \]

Higher order moments probe the multi-jet region:

\( \langle (1-T)^k \rangle \)
Testing QCD: Fits to the moments

- \langle y^m \rangle, m=1...5 measured by JADE and OPAL

- Hadronisation correction by analytical “non perturbative” power correction models

- Perturbative predictions: Next to Leading Order,

\[
\langle y^n \rangle = A_n \alpha_s(Q^2) + B_n \alpha_s^2(Q^2)
\]
Testing QCD: Fits to the moments

- Dispersive model (Dokshitzer et al.):
  \[
  \frac{d\sigma_{\text{had.}}}{dy} = \frac{d\sigma_{\text{pt.}}}{dy} (y - a_y \cdot P(\alpha_0))
  \]

Dispersive model: Measurements of $\alpha_s(M_Z)$ and $\alpha_0$
Dispersive model (Dokshitzer et al.): \[
\frac{d\sigma_{\text{had.}}}{dy} = \frac{d\sigma_{\text{pt.}}}{dy} (y - a_y \times P(\alpha_0))
\]

Deficiencies of the NLO predictions lead to non universalities of the fit parameters:
- Significant rise of \(\alpha_S(M_{Z^0})\) with moment order \(n\) for two-hemisphere moments
- Higher \(\alpha_0\) for one-hemisphere moments

Dispersive model: Measurements of \(\alpha_S(M_Z)\) and \(\alpha_0\)

![Graph showing measurements of \(\alpha_S(M_Z)\) and \(\alpha_0\) with error bars and different variations indicated.](image)
Testing QCD: Fits to the moments

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  \[ \frac{d\sigma_{\text{had.}}}{dy} = \frac{d\sigma_{\text{pt.}}}{dy} (y - a_y \cdot P(\alpha_0)) \]

  Deficiencies of the NLO predictions lead to non universalities of the fit parameters:
  - Significant rise of \( \alpha_S(M_{Z_0}) \) with moment order \( n \) for two-hemisphere moments
  - higher \( \alpha_0 \) for one-hemisphere moments

- Shape Function (Korchemsky)

- Single dressed gluon approximation (Gardi et al.):
  \( \alpha_S(M_Z) = 0.1172 \pm 0.0036 \)
Predictions: $K = B_n/A_n$  

NLO calculations: Two-hemisphere moments receive large corrections in $\alpha_s^2$.  
Fit results: Trend seems to continue...
Testing QCD: Fits to the moments

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New: Theoretical explanation (JHEP 0905:106, 2009)
Measuring $\alpha_s$: New NNLO calculations

- Predictions: Next to Next to Leading Order $O(\alpha_s^3)$ (finished 2008 after 25 years) + Next to Leading Logarithmic Approximation
- Hadronisation correction by Monte Carlo models
- More complete than NLO analyses: Data described well over virtually all phase space
Measuring $\alpha_s$: New NNLO calculations

$\alpha_s(m_{Z^0})$ results

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

- Result from JADE, NNLO+NLLA:

$$\alpha_s(M_{Z^0}) = 0.1172 \pm 0.0051$$

4% precision, among the best measurements

Errors: stat. / exp. + had. + scale
Measuring $\alpha_s$: New NNLO calculations

Running $\alpha_s(Q)$ result from event shape combination

Running of $\alpha_s$ confirmed strongly in the JADE range 14—44 GeV.

NNLO: $\alpha_s(m_{Z^0}) = 0.1210 \pm 0.0061$ (tot.)

NNLO+NLLA: $\alpha_s(m_{Z^0}) = 0.1172 \pm 0.0051$ (tot.)
Conclusion

- Running of $\alpha_s(Q)$ confirmed strongly in the JADE energy range
- $\alpha_s(m_{Z^0}) = 0.1172 \pm 0.0051$ (tot.) from NNLO+NLLA at 14-44 GeV
- Event shape moments reveal shortcomings of the NLO calculations
- Outlook:
  - OPAL NNLO analysis in progress
  - Moments NNLO analysis would be interesting
  - Re-analyses of data taken at the JADE and OPAL experiment have huge potential
  - QCD precisely studied in $e^+e^-$ important for LHC