Hadronic $e^+e^-$ event shapes with JADE, ALEPH and OPAL: NNLO analysis of distributions, NLO and non perturbative analysis of moments

- S. Bethke, S. Kluth, C. Pahl, J. Schieck and the JADE Collaboration, “Determination of the strong coupling $\alpha_s$ from hadronic event shapes and NNLO QCD predictions using JADE data”, to be submitted to EPHJ C.
- C. Pahl, S. Bethke, S. Kluth, J. Schieck and the JADE Collaboration, “Study of moments of event shapes and a determination of $\alpha_s$ using $e^+e^-$ annihilation data from JADE”, to be submitted to EPHJ C.

Christoph Pahl
34th International Conference on High Energy Physics
7/29-8/5 2008
• QCD concepts
• Measurement
• NNLO analyses of event shape distributions
• NLO analyses of event shape moments
• Power corrections of the moments
• Conclusion and outlook
Hadronic event in $e^+e^-$ annihilation

$$
\sqrt{s'} = \ldots 14\ldots 209~\text{GeV} \sim 1~\text{GeV}:
$$

Hadronisation:
- Monte Carlo models
- Analytical models – power corrections

Running coupling

(S. Bethke, Prog. Part. Nucl. Phys., 58:351)

$$\alpha_s(Q)$$

world average:
$$\alpha_s(M_{Z^0})=0.1189\pm0.0010$$
Experiments

JADE

12-44 GeV
1978-1986

Comparable measurement

OPAL

91-209 GeV
1989-2000

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Event shapes

Thrust $1 - T$

C-Parameter $C$

Total Jet Broadening $B_T$

(Two-hemisphere variables)

Heavy Jet Mass $M_H$

Wide Jet Broadening $B_W$

Durham two-jet flip parameter $y_{23}^D \equiv y_3$

(One-hemisphere variables)
Fits of event shape distributions: Thrust

\[
\frac{1}{\sigma_0} \frac{d\sigma}{dy}(s, y) = \left( \frac{\alpha_s(\mu^2)}{2\pi} \right) \frac{d\bar{A}}{dy} + \left( \frac{\alpha_s(\mu^2)}{2\pi} \right)^2 \frac{d\bar{B}}{dy} + \left( \frac{\alpha_s(\mu^2)}{2\pi} \right)^3 \frac{d\bar{C}}{dy} + \text{normalisation} + \text{scale dependence}
\]

JADE: NNLO+NLLA (prelim.)

ALEPH: NNLO

(Hadron level with statistical errors)

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\( \alpha_s, \chi^2/d.o.f. \) vs. \( x_\mu \)

**JADE (prelim.)**

- \( \alpha_s(m_Z) \)
- \( \chi^2 \)
- \( x_\mu \equiv \mu_R/\sqrt{s} \)

**ALEPH**

- Using thrust at LEP1

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$\alpha_s(M_{Z0})$ results

JADE (prelim.)

Results from $1-T$, $M_H$, $B_T$, $B_W$, $C$, $y_{23}^D$, $M_H$, and combination.

$\pm 0.0036$  $\pm 0.0086$  $\pm 0.0029$  (Theoretical errors)

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Running $\alpha_s(\sqrt{s} = E_{cm})$ results

**JADE NNLO (prelim.)**

$\alpha_s(m_Z) = 0.1210 \pm 0.0061$

**ALEPH NNLO**

$\alpha_s(E_{cm})$

$\chi^2/\text{dof} = 13.4/7$

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Moments of the distribution of event shape variables

\[ \langle y^n \rangle = \frac{1}{\sigma_{\text{tot.}}} \int y^n \frac{d\sigma}{dy} dy , \]

Higher moments probe the multi-jet region.

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Perturbative moment fits

\[ \langle y^n \rangle, y = 1 - T, C, B_T, B_W, y_{23}^D, M_H; n = 1...5 \].

Hadronisation correction by Monte Carlo models

NLO prediction:

\[ \langle y^n \rangle = A_n \alpha_s(s) + B_n \alpha_s^2(s) \]

(Parton level with statistical, experimental systematic errors)

All fits \( \chi^2 / \text{d.o.f.} \approx 1...10 \).
Perturbative moment fits

\[ \langle y^n \rangle, \quad y = 1 - T, \quad C, \quad B_T, \quad B_W, \quad y_{23}^D, \quad M_H; \quad n = 1...5. \]

Hadronisation correction by Monte Carlo models

NLO prediction: \[ \langle y^n \rangle = A_n \alpha_s(s) + B_n \alpha_s^2(s) \]

\[ \langle C_1 \rangle_{\text{part}} \]

\[ \langle C_2 \rangle_{\text{part}} \]

\[ \langle C_3 \rangle_{\text{part}} \]

\[ \langle C_4 \rangle_{\text{part}} \]

\[ \langle C_5 \rangle_{\text{part}} \]

\[ \langle B_1 \rangle_{\text{part}} \]: JADE/OPAL incompatible

\[ \langle B_2 \rangle_{\text{part}} \]

\[ \langle B_3 \rangle_{\text{part}} \]

\[ \langle B_4 \rangle_{\text{part}} \]

\[ \langle B_5 \rangle_{\text{part}} \]

\[ \chi^2/\text{d.o.f.} \approx 1...10. \]

Parton level with statistical, experimental systematic errors

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Measurement of event shapes and \( \alpha_s \) in \( e^+e^- \) annihilation

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Incompleteness of the one-hemisphere observables in NLO

Large regions of unphysically negative cross section lead to “unphysically low” $O(\alpha_s^2)$-coefficients, especially for moments of low order.
Fit results: $\alpha_s(M_{Z0})$

Predictions: $K = B_n/A_n$

Significant rise of $\alpha_s(M_{Z0})$ with order $n$ for two-hemisphere observables

Combination of results from predictions with $NLO < 0.5 \cdot LO$:

$$\alpha_s(M_{Z0}) = 0.1262 \pm 0.0006 (\text{stat.}) \pm 0.0010 (\text{exp.}) \pm 0.0007 (\text{had.}) \pm 0.0064 (\text{theo.})$$

$$= 0.1262 \pm 0.0065 \, \text{(tot.)}$$

consistent with the world average.
Non perturbative QCD: Dispersive model (Dokshitzer et al.)

Shift of the differential distribution
\[
\frac{d\sigma}{dy} = \frac{d\sigma_{pt.}}{dy} (y - a_y \cdot \mathcal{P}),
\]
observable dependent \(a_y\), observable independent power correction \(\mathcal{P}(\alpha_0)\).

\[\frac{d\sigma}{dy} (y - a_y \cdot \mathcal{P}),\]

\(\alpha_s(M_{Z0}) = 0.1174 \pm 0.0050 \text{(tot.)},\)
\(\alpha_0(\mu_I) = 0.484 \pm 0.053 \text{(tot.)}.\)
**Conclusion**

- NNLO, NNLO+NLLA fits of event shape distributions measured by JADE and ALEPH:
  - reduced scale uncertainty
  - reduced scatter for different variables
  - $\alpha_s(M_{Z^0}) = 0.1240 \pm 0.0033$; precision of 3\% by ALEPH.

- Moments (and variance) of event shape distributions measured by JADE and OPAL:
  - Perturbative NLO prediction adequate for some moments
  - Incomplete perturbative description shows up in non perturbative models
  - Passing from first to higher moments: Perturbative and non perturbative problems

**Outlook**

- Better resummation
- NNLO predictions of moments awaited
- Qualitative explanations?