Measurements of two-particle correlations in $e^+e^-$ collisions at 91 GeV with ALEPH archived data

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Introduction

- Origin of ridge in small systems still uncertain
  - Initial state effect (CGC)
  - Flowing mini Quark Gluon Plasma
  - MPIs
  - “Escape” mechanism
- Complications from complexity of hadronic events
  - Hadron structure
  - Gluon ISR
  - Beam remnants
Introduction

- Origin of ridge in small systems still uncertain
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  - “Escape” mechanism
- Complications from complexity of hadronic events
  - Hadron structure
  - Gluon ISR
  - Beam remnants
- $e^+e^-$ allows us to study high-multiplicity events with well-defined initial-conditions
The ALEPH Detector

- **Hadron Calorimeter**
- **Electromagnetic Calorimeter**
- **Superconducting Magnet (1.5T)**
- **Muon Chamber**
- **Time Projection Chamber**
- **Inner Tracking Chamber**

- LEP1 $e^+e^-$ data at Z pole (91 GeV)
- Data archived as list of energy-flow objects
- Charged particle multiplicities up to 50
  - $p_T > 0.2$ GeV and $|\eta| < 1.74$
- Calorimeters used for event shape variables

![Graph](image)
Thrust Axis definition

Thrust axis:
- Maximizes momentum projection
- Proxy for outgoing quarks from Z decay
- Can we reproduce old ALEPH measurement?
Unfolded Thrust Distribution

- Able to reproduce existing measurements with archived data!
- Most events are dijet-like
- But what about high-multiplicity events?
High Multiplicity $e^+e^-\text{ Event (1)}$

**ALEPH Archived Data**

Azimuthal View
Anti-$k_T$ $R=0.8$ E Scheme Jet
Thrust Axis
Tracks in Leading Jet
Tracks in Subleading Jet
Tracks in Third Jet
Tracks in Fourth Jet
Other Tracks

39 tracks
$T = 0.98$
High Multiplicity $e^+e^-\text{Event (2)}$

**ALEPH Archived Data**

- Azimuthal View
- Anti-$k_T$ $R=0.8$ E Scheme Jet
- Thrust Axis
- Tracks in Leading Jet
- Tracks in Subleading Jet
- Tracks in Third Jet
- Tracks in Fourth Jet
- Other Tracks

44 tracks
$T = 0.57$
Beam-axis coordinates

- First repeat analysis done in pp, pA, AA collisions
Beam-axis coordinates

- First repeat analysis done in pp, pA, AA collisions
- Define $\eta$, $\phi$ with respect to the beam pipe
Beam-axis coordinates

- First repeat analysis done in pp, pA, AA collisions
- Define $\eta, \phi$ with respect to the beam pipe

- Look for near-side ridge in two-particle correlation
  - Large $\Delta \eta$, small $\Delta \phi$
  - Sensitive to expansion of 'mini-QGP' perpendicular to beam axis
Beam-axis two-particle correlation

Low Multiplicity

PYTHIA6 $e^+e^- \rightarrow$ hadrons, $\sqrt{s} = 91$GeV

$5 \leq N^\text{Offline}_{\text{Trk}} < 10$, $|\cos(\theta_{\text{lab}})| < 0.94$

$0.2 \text{ GeV} < p_T^{\text{lab}}$

Clear jet peak at $(\Delta\eta, \Delta\phi) = (0,0)$

High Multiplicity

PYTHIA6 $e^+e^- \rightarrow$ hadrons, $\sqrt{s} = 91$GeV

$N^\text{Offline}_{\text{Trk}} \geq 35$, $|\cos(\theta_{\text{lab}})| < 0.94$

$0.2 \text{ GeV} < p_T^{\text{lab}}$

Clear jet peak at $(\Delta\eta, \Delta\phi) = (0,0)$
Beam-axis two-particle correlation

- **Low Multiplicity**
  - $\sqrt{s} = 91 \text{ GeV}$
  - $5 \leq N_{\text{trk}}^{\text{Offline}} < 10$
  - $|\cos(\theta_{\text{lab}})| < 0.94$
  - $0.2 \text{ GeV} < p_T^{\text{lab}}$

- **High Multiplicity**
  - $N_{\text{trk}}^{\text{Offline}} \geq 35$
  - $|\cos(\theta_{\text{lab}})| < 0.94$
  - $0.2 \text{ GeV} < p_T^{\text{lab}}$

- **Clear jet peak at** $(\Delta \eta, \Delta \phi) = (0,0)$
- **No clear near-side ridge**
Low Multiplicity

- Project $1.6<|\Delta \eta|<3.2$ into a 1D plot
- Fit data from $0<|\Delta \phi|<\pi/2$ with Fourier series
- Subtract off the 'zero yield at minimum' (ZYAM)
Projection

Low Multiplicity

PYTHIA6 $e^+e^- \rightarrow$ hadrons, $\sqrt{s} = 91$ GeV

$5 \leq N_{\text{Offline}}^{\text{Trik}} < 10$, $|\cos(\theta_{\text{lab}})| < 0.94$

$0.2$ GeV < $p_T^{\text{lab}}$

Beam coordinates

- Very similar to archived PYTHIA 6.1 predictions
Going to higher multiplicities...

- No ridge observed!
- Agreement with PYTHIA6 is excellent for 10-20 multiplicity bin
- Some discrepancy at large $\Delta \phi$
Setting a limit

- Vary data within uncertainties to create pseudodata sets
- Repeat fit + ZYAM, integrate any near-side yield
- Majority of trials have no associated yield
Setting a limit

- Vary data within uncertainties to create pseudodata sets
- Repeat fit + ZYAM, integrate any near-side yield
- Majority of trials have no associated yield
- Find value that contains 95% of our trials
Setting a limit

- Vary data within uncertainties to create pseudodata sets
- Repeat fit + ZYAM, integrate any near-side yield
- Majority of trials have no associated yield
- Find value that contains 95% of our trials
- Stringent limit for beam-axis analysis
Thrust-axis coordinates

• Maybe beam coordinates are not the best for e^+e^-
Thrust-axis coordinates

- Maybe beam coordinates are not the best for $e^+e^-$
- Align our coordinates with thrust axis
- Follows direction of color string connecting outgoing quarks
Thrust-axis coordinates

- Maybe beam coordinates are not the best for $e^+e^-$
  - Align our coordinates with thrust axis
  - Follows direction of color string connecting outgoing quarks

- Sensitive to final-state radiation
- Fragmentation patterns of quarks
- Thrust (coordinates) vary on event-by-event basis!

\[ e^+ \quad \text{Thrust Axis} \quad \hat{\eta} \quad e^- \]
Correlation with thrust axis

- Correlation function shape qualitatively similar between pp and $e^+e^-$
- Many caveats, but interesting to think about mapping:
  - pp beam axis to $e^+e^-$ thrust axis
  - pp forward production to $e^+e^-$ dijet constituents
Correlation with thrust axis

- Narrower away-side peak in high-multiplicity events
- Toy-event studies indicate this could be due to increased multi-jet events
• Projection into $\Delta \phi$ + ZYAM shows data in agreement with PYTHIA 6
• Small hint of near-side ridge, but sensitive to details of thrust reconstruction
  • ZYAM with fit + yield extraction still ongoing
Thrust axis projection $N_{\text{trk}} > 35$

- Projection into $\Delta \phi$ + ZYAM shows data in agreement with PYTHIA 6
- Small hint of near-side ridge, but sensitive to details of thrust reconstruction
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Summary

- First two-particle correlation analysis in $e^+e^-$ collisions performed in bins of multiplicity up to ~50

- Beam coordinates:
  - No significant ridge signal observed and confidence limits reported

- Thrust coordinates:
  - No significant difference observed between LEP1 data and PYTHIA6
  - Associated yield calculation still ongoing

- No evidence for a final-state effect causing near-side ridge in the multiplicity ranges probed
  - Important reference for pp, pA, AA collisions

- Data preservation projects are valuable for future scientific collaboration and investigation
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Multiplicity comparison

e^+e^- \rightarrow \text{hadrons, } \sqrt{s} = 91 \text{ GeV}

- ALEPH Archived Data
- Archived PYTHIA 6.1 MC
Thrust vs multiplicity

\[ \frac{1}{\sigma} \frac{d\sigma}{dT} \]

- Inclusive \( N_{\text{Trk}}^{\text{Offline}} \)
- \( 5 \leq N_{\text{Trk}}^{\text{Offline}} < 10 \)
- \( 10 \leq N_{\text{Trk}}^{\text{Offline}} < 20 \)
- \( 20 \leq N_{\text{Trk}}^{\text{Offline}} < 30 \)
- \( N_{\text{Trk}}^{\text{Offline}} \geq 30 \)
- \( N_{\text{Trk}}^{\text{Offline}} \geq 35 \)

\( e^+e^- \rightarrow \text{hadrons}, \sqrt{s} = 91 \text{ GeV} \)
- ALEPH Archived Data
- Archived PYTHIA 6.1 MC

Thrust
Pseudodata sets

ALEPH Archived Data
Beam coordinates
5 \leq N_{\text{irr}} < 10

ALEPH Archived Data
Beam coordinates
10 \leq N_{\text{irr}} < 20

\(e^+e^- \rightarrow \text{hadrons, } \sqrt{s}=91 \text{ GeV}\)
Pseudodata sets

$e^+e^- \rightarrow$ hadrons, $\sqrt{s}=91$ GeV

**ALEPH Archived Data**

Beam coordinates

$20 \leq N_{\text{trk}} < 30$

$30 \leq N_{\text{trk}}$
Beam axis correlation functions

\[ \frac{d^2N}{d\eta d\phi} \]

PYTHIA6 \( e^+ e^- \to \) hadrons, \( \sqrt{s} = 91 \text{GeV} \)

10 \( \leq N_{\text{trk}}^{\text{offline}} < 20 \), \( |\cos(\theta_{\text{lab}})| < 0.94 \)

0.2 GeV < \( p_T^{\text{lab}} \)

Beam coordinates