Jet and hadron production in photon-photon interactions at L3

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- $e^+e^- \rightarrow e^+e^- \text{ hadrons event selection}$
- Inclusive $\pi^0$ production
- Inclusive $h^\pm$ production
- Jet cross-sections
- Conclusions
Event selection $e^+e^- \to e^+e^- \text{ hadrons}$

- $E_{tot} \leq 40\% \sqrt{s}$
- $\# \text{ particles} \geq 6$
- Anti-tag:
  - reject if $E_{Lumi} > 30$ GeV
- $W_{vis}^2 = (\sum_i E_i)^2 - (\sum_i \vec{p}_i)^2$
  - $W_{vis} < W_{\gamma\gamma}$
  - $W_{vis} > 5$ GeV

![Graph showing event selection criteria](image-url)
$e^+e^- \rightarrow e^+e^- \text{hadrons}$

- $\langle \sqrt{s} \rangle = 194 \text{ GeV}$
  - $L = 414 \text{pb}^{-1}$
  - $\Rightarrow \sim 2 \text{ million events}$

- Main backgr. (1 – 15%):
  - $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$
  - $e^+e^- \rightarrow \text{hadrons}$

- Monte Carlo:
  - PYTHIA 5.722, PHOJET 1.05c

- Phase space defined by MC:
  - $W^2_{\gamma\gamma} < 5 \text{ GeV}$, $Q^2 < 8 \text{ GeV}^2$
Inclusive single hadron production

$\pi^0$ and $K_S^0$ published in PLB524 (2001)\textsuperscript{44}.
$\pi^\pm$ and $K^\pm$ published in PLB554 (2003)\textsuperscript{105}.

$\pi^0$ and $K_S^0$ reconstruction

![Graphs showing inclusive single hadron production results for $\gamma\gamma$ and $\pi^+\pi^-$ combinations with different $pt$ and $|\eta|$ ranges.](image-url)
\( \pi^0 : \) Comparison with NLO QCD

- Measurements exceed QCD predictions \((\text{B.A.Kniehl})\) at high \(p_t\)
- No anomaly in \(\eta\) distribution
$h^\pm$ selection

- **Track selection:**
  \[ p_t > 400 \text{ MeV}, \quad \text{DCA} < 4 \text{ mm}, \]
  \[ > 80\% \text{ expected hits}. \]

- \[ |\eta| < 1 \]

- \[ \sigma_{p_t}/p_t \simeq (0.015 \text{ GeV}^{-1}) \ p_t \]

- **Efficiency ~ 60 – 80\%**

- **Systematics:**
  - MC models: 5-25\%
  - Selection efficiency: 10-1\%
  - Background subtraction: 0.1-5\%
π± and K±

Separation by Monte Carlo ratios (JETSET 7.409).

✦ Good agreement with π0 and Ks0 data
Comparison with OPAL


\[ < \sqrt{s} > \approx 165 \text{ GeV}, \ | \eta | < 1.5 \]
Fits to the data

- For \( p_t < 1.5 \) GeV

  Exponential \( A e^{-p_t/\langle p_t \rangle} \)
  \( \langle p_t \rangle \approx 230 \) MeV for \( \pi^\pm, \pi^0 \)
  \( \approx 300 \) MeV for \( K^\pm, K_S^0 \)
  \( \Rightarrow \) Soft interactions

- For \( p_t > 1.5 \) GeV

  power law \( A p_t^{-B} \)
  \( 1.5 \leq p_t < 5. \) GeV \( B = 4.2 \pm 0.2 \)
  \( \chi^2/d.o.f. = 4.7/2 \)
  \( 5.0 \leq p_t < 20. \) GeV \( B = 2.6 \pm 0.3 \)
  \( \chi^2/d.o.f. = 0.7/2 \)
  \( \Rightarrow \) Direct and resolved (QCD)
Diagrams contributing to $\gamma\gamma$ interactions

Monte Carlo models: VDM, LO QCD (DGLAP), pdf in the photon

SOFT:

HARD:

Direct

Single Resolved

Double Resolved

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Jet and hadron production (page 10)

Frascati 8/4/2003
Measurements exceed QCD predictions (B.A. Kniehl) at high $p_t$

The data are largely beyond the direct contribution
Comparison with Monte Carlo

- PHOJET is too low (similar to NLO calculations)
- PYTHIA has changed! Becomes consistent with PHOJET
Compare Pythia versions

✦ Striking difference, pointing to QCD diagrams!

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Jet analysis

- Generated jets: $\gamma, \pi^\pm, p, n, k^\pm$
- Reconstructed jets: tracks $0.4 \leq p_t \leq 100\text{GeV}$
  e.m. clusters $E > 0.1\text{GeV}$
- Kinematical range:
  $p_t > 3\text{GeV}$ \quad | \eta | < 1
- Algorithms
  **DURHAM**:
  \[ y_{ij} = 2 \min(E_i^2, E_j^2) \left(1 - \cos \theta_{ij}\right)/E_{vis}^2 \]
  $y_{cut} = 0.1$
  **KTCLUS**:
  \[ d_{ij} = \min(p_{ti}^2, p_{tj}^2) \left( (\eta_i - \eta_j)^2 + (\Phi_i - \Phi_j)^2 \right)/D^2 \]
  $D = 1$
**Durham Jet definition**

\[ y_{\text{cut}} = 0.1 \] maximise 2-jet events

\[ \text{Number of jets with } p_t > 3 \text{GeV and } |\eta| < 1 \sim \text{independent of } y_{\text{cut}} \]
Particles inside a jet

- Less particles in KTCLUS jets
- Durham is used at LEP for $e^+e^-$, spherical configurations
- KTCLUS is used in cylindrical configurations and NLO theory

Jets

Durham

KTCLUS

Systematics due to Monte Carlo model: 5-60 %

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Jets: Comparison with OPAL

Using KTCLUS algorithm

\[ \frac{d\sigma}{dE_t} [\text{pb} / \text{GeV}] \]

\[ < \sqrt{s} > \simeq 133 \text{ GeV}, \ W_{\gamma\gamma} > 3 \text{ GeV} \]

K. Ackerstaff et al.
Jets: Fits and NLO calculations

Using KTCLUS algorithm

NLO QCD : S. Frixione and L. Bertora

Again an excess at high pt! For \(2 \rightarrow 2\) process \(B=3\)
Conclusions

Unexpected deviations from theoretical predictions are observed:

- $\sigma(\gamma\gamma \rightarrow \text{hadrons})$
- $d\sigma/dp_t$ of $\pi^0$ and $\pi^\pm$ for $p_t > 5\text{GeV}$
- $d\sigma/dp_t$ of inclusive jet production for $p_t > 20\text{GeV}$
- $\sigma(\gamma\gamma \rightarrow b\bar{b})$

Two questions arise:

Are these phenomena correlated?
Which is their origin?