Neue Ansätze bei der Strahlteilchenidentifikation im COMPASS Experiment

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21. März 2012
Outline

The COMPASS Experiment

Beam Particle Identification

New: Particle Identification using Likelihoods

Performance of the New Method
The COMPASS Experiment

- **Common Muon and Proton Apparatus for Structure and Spectroscopy**
- Located at SPS at CERN
The COMPASS Experiment

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2.4% $K^-$
97% $\pi^-$
190 GeV/c
The COMPASS Experiment

- **COmmon Muon and Proton Apparatus for Structure and Spectroscopy**
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![Diagram of COMPASS Experiment](image)

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- 97% \(\pi^-\)
- 190 GeV/c
The COMPASS Experiment

- **COmmon Muon and Proton Apparatus for Structure and Spectroscopy**
- Located at SPS at CERN

![Diagram showing the COMPASS Experiment setup]

- **Target**
- **CEDARs**

- 2.4% $K^-$
- 97% $\pi^-$
- 190 GeV/c
The COMPASS Experiment

- **COmmon Muon and Proton Apparatus for Structure and Spectroscopy**
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- **2.4% K^-**
- **97% π^-**
- **190 GeV/c**

**CEDARs**

**Large Angle Spectrometer**

**Target**

**RICH**
The COMPASS Experiment

- **COmmom Muon and Proton Apparatus for Structure and Spectroscopy**
- Located at SPS at CERN

- **2.4% $K^-$**
- **97% $\pi^-$**
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**Diagram:**
- CEDARs
- Large Angle Spectrometer
- Small Angle Spectrometer
- Target
- RICH
Example: $K\pi\pi$ analysis

Analysis of diffractive dissociation of $K^-$ into $K^-\pi^+\pi^-$ on a liquid hydrogen target at the COMPASS spectrometer, PhD Thesis P. Jasinski (JGU Mainz)

![Graph 1](image1)

![Graph 2](image2)
Example: $K\pi\pi$ analysis

Analysis of diffractive dissociation of $K^-$ into $K^-\pi^+\pi^-$ on a liquid hydrogen target at the COMPASS spectrometer, PhD Thesis P. Jasinski (JGU Mainz)

Only 40% of the beam kaons used for analysis
Bad efficiency of particle identification in the CEDARs
How does a CEDAR work?

- CEDAR = ČErenkov Differential counters with Acromatic Ring focus
- Fast charged particles emit Čerenkov light with angle \( \cos(\theta) = \frac{1}{n\beta} \)
How does a CEDAR work?

- Čerenkov light detected with 8 PMTs
- Particle identification using multiplicities, e.g. 6 of 8 PMTs
Influence of Beam Divergence

- Kaon ring leaves acceptance, pion ring enters

⇒ Multiplicity method does not work for divergent beams
Influence of Beam Divergence

- Kaon ring leaves acceptance, pion ring enters

⇒ Multiplicity method does not work for divergent beams

Goal

Find a better method to take divergence into account
General Idea

- Look at PMT response for Kaon and Pion separately
- Take beam divergence into account
- Identify beam particles using likelihoods
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- Look at PMT response for Kaon and Pion separately
- Take beam divergence into account
- Identify beam particles using likelihoods

5 steps to take

1. Measure beam divergence
2. Create a pure Kaonsample and a pure Pionsample
3. Determine probabilities to have hits in PMTs for Pion and Kaon
4. Calculate likelihoods from probabilities
5. Use likelihoods to identify particles
Step 1: Measure beam divergence

- Measure beam position in front of \((x_1, y_1)\) and behind \((x_2, y_2)\) CEDARs
- Calculate relative displacement \(\Delta_x = \frac{x_2 - x_1}{1283.4\, \text{cm}}\)
- Divergence \(\theta_x = \arctan(\Delta_x) \approx \Delta_x\)
Step 2: Create a pure Kaonsample and a pure Pionsample

Create a Kaonsample and a Pionsample

- **Kaonsample**
  - Use free Kaon decay $K^- \rightarrow \pi^- \pi^- \pi^+$
    - 3 outgoing particles with correct charged
    - Primary vertex outside of the target
    - Cut on transverse momentum and Kaon mass

- **Pionsample**
  - Use diffractive production $\pi^- p \rightarrow \pi^- \pi^- \pi^+ p$
    - 3 outgoing particles with correct charge
    - Primary vertex inside the target
    - Small angle to beam direction

*In addition:* Produce a Beamsample without any filtering for testing the method
### Step 3: Determine probabilities to have hits in PMTs for $\pi$ and $K$

**Example:** Probability that a particle with divergence $\theta_x, \theta_y$ that produces a signal in PMT $i$ is a Kaon

→ Use Bayes’ Theorem:

$$P_{\theta_x, \theta_y}^i (\text{Kaon}|\text{Signal}) = \frac{P_{\theta_x, \theta_y}^i (\text{Signal}|\text{Kaon}) \cdot P_{\theta_x, \theta_y}(\text{Kaon})}{P_{\theta_x, \theta_y}(\text{Signal})}$$

Here:

- $P_{\theta_x, \theta_y}^i (\text{Signal}|\text{Kaon})$: Probability that Kaon at $\theta_x$, $\theta_y$ produces signal in PMT $i$  
  ($\rightarrow$ Kaonsample)
- $P_{\theta_x, \theta_y}(\text{Kaon})$: Probability that Kaon has divergence $\theta_x$ and $\theta_y$  
  ($\rightarrow$ Kaonsample)
- $P_{\theta_x, \theta_y}^i (\text{Signal})$: Probability that signal in PMT $i$ is produced at $\theta_x$, $\theta_y$  
  ($\rightarrow$ Beamsample)
Step 3 continued

Pions and Kaons have the same divergence distribution:

\[ P_{\theta_x, \theta_y}(\text{Kaon}) = P_{\theta_x, \theta_y}(\text{Pion}) = P_{\theta_x, \theta_y}(\text{Beam}) \]

\[ \Rightarrow P^i_{\theta_x, \theta_y}(\text{Kaon} | \text{Signal}) \text{ and } P^i_{\theta_x, \theta_y}(\text{Pion} | \text{Signal}) \text{ have same normalization} \]

factor \( \frac{P_{\theta_x, \theta_y}(\text{Beam})}{P^i_{\theta_x, \theta_y}(\text{Signal})} \), thus

\[ P^i_{\theta_x, \theta_y}(\text{Kaon} | \text{Signal}) \propto P^i_{\theta_x, \theta_y}(\text{Signal} | \text{Kaon}) \]

\[ P^i_{\theta_x, \theta_y}(\text{Pion} | \text{Signal}) \propto P^i_{\theta_x, \theta_y}(\text{Signal} | \text{Pion}) \]

Also calculate

\[ P^i_{\theta_x, \theta_y}(\text{Kaon} | \overline{\text{Signal}}) \text{ and } P^i_{\theta_x, \theta_y}(\text{Pion} | \overline{\text{Signal}}) \]
\( P_{xy}^i(\text{Signal}|\text{Pion}) \propto P_{xy}^i(\text{Pion}|\text{Signal}) \)

\( P_{xy}^i(\text{Signal}|\text{Kaon}) \propto P_{xy}^i(\text{Kaon}|\text{Signal}) \)

Preliminary
Step 4: Calculate likelihoods from probabilities

To obtain the log likelihood just add logarithms of probabilities

\[
\log L(Kaon) = \sum_{i=1}^{8} \log P_{\theta_x, \theta_y}^{i}(\text{Kaon}|\text{Signal}) \cdot \eta^i + \sum_{i=1}^{8} \log P_{\theta_x, \theta_y}^{i}(\text{Kaon}|\overline{\text{Signal}}) \cdot (1 - \eta^i)
\]

Where:

\[
\eta^i = \begin{cases} 
1 & \text{Signal in PMT } i \\
0 & \text{no Signal in PMT } i 
\end{cases}
\]
Comparison of Likelihoods CEDAR 2

log \( L(K) \)

log \( L(\pi) \)
Comparison of Likelihoods CEDAR 2

\[ \log L(K) \]

\[ \log L(\pi) \]
Step 5: Use likelihoods to identify particles

- Compare log likelihoods to get an ID for each CEDAR:
  - \( \log L^K > \log L^\pi + A \Rightarrow \text{PID } K \)
  - \( \log L^\pi > \log L^K + B \Rightarrow \text{PID } \pi \)
  - else no PID given

- Tune \( A \) and \( B \) due to efficiency/purity.
**Step 5: Use likelihoods to identify particles**

- Compare log likelihoods to get an ID for each CEDAR:
  - $\log L^K > \log L^\pi + A$ \(\Rightarrow\) PID $K$
  - $\log L^\pi > \log L^K + B$ \(\Rightarrow\) PID $\pi$
  - else no PID given

- Tune $A$ and $B$ due to efficiency/purity.

- Combine CEDARs afterwards with OR combination

\[
\begin{array}{ccc}
  C_2 & \backslash & C_1 \\
  \hline
  ? & ? & \pi & K \\
  \pi & \pi & \pi & ? \\
  K & K & ? & K \\
\end{array}
\]
Particle Identification in the Beamsample

Bayesian Method with OR combination and $A = 0.1$:

- 22.8% no ID
  - 21% too large divergence
  - 1.8% no decision
- 75.7% Pions
- 1.6% Kaons
Particle Identification in the Beamsample

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→ 65% of beam kaons
### Performance of the New Method

#### Comparison with Majority Method

The table below compares the performance of the new method with the majority method for different types of particles.

<table>
<thead>
<tr>
<th>Method</th>
<th>π</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Majority</td>
<td>62300</td>
<td>45</td>
</tr>
<tr>
<td>Bayes</td>
<td>18892</td>
<td>110</td>
</tr>
<tr>
<td>no ID</td>
<td>599</td>
<td>777</td>
</tr>
</tbody>
</table>

- Most of majority Kaons reproduced as Kaons (771 of 932).
- 514 additional Kaons from majority Pions.
- Additional Kaons have large divergence.

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Comparison with Majority Method

- Most of majority Kaons reproduced as Kaons (771 of 932)

Comparison between different Methods

- Bayes
- K
- 599
- 777
- π
- 62300
- 45
- no ID
- π
- 18892
- 110
- K

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Summary

- COMPASS hadron beam consists of 97% Pions and 2.4% Kaons
- Pions and Kaons have to be identified for analyses
- Majority method identifies 40% of the Kaons
  - Problems with divergent beams
- Likelihood method improves identification for divergent beams
  - Identifies 65% of the Kaons
BACKUP
Comparison of Likelihoods CEDAR 2
\[ P_{xy}^{i}(\text{Signal}|\text{Pion}) \propto P_{xy}^{i}(\text{Pion}|\text{Signal}) \]
\[ P_{xy}^{i} (\text{Signal}|\text{Kaon}) \propto P_{xy}^{i} (\text{Kaon}|\text{Signal}) \]
A-Dependence of Kaon Identification

\[ \log L^K > \log L^\pi + A \Rightarrow PID \ K \]

Number of reconstructed Kaons
PMT correlation between CEDAR 1 and CEDAR 2

- Beamsample
- Look at “matrix” PMT_{ij}
- Clear correlation visible
PMT efficiencies

- Take Kaonsample
- Choose Events with $\theta_x, \theta_y < 30 \mu rad$
- All 8 PMTs in both CEDARs expected to have a signal
- PMT$_{ij}$ should be uniform