Neue Ansätze bei der Strahlteilchenidentifikation im COMPASS Experiment

Tobias Weisrock

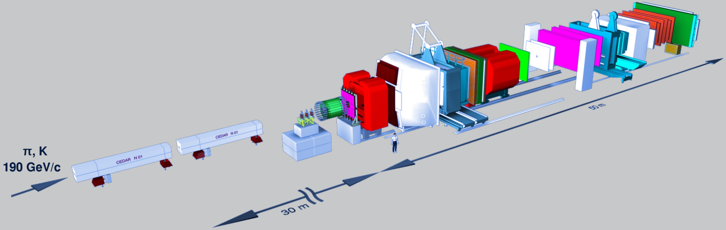
Graduate School Symmetry Breaking
Johannes Gutenberg-Universität Mainz

DPG-Frühjahrstagung Mainz
21. März 2012

Outline

The COMPASS Experiment

- **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
- Located at SPS at CERN



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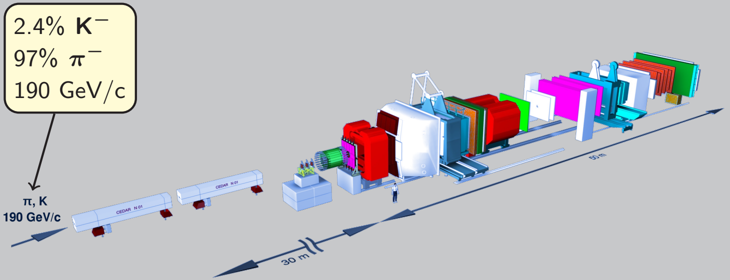

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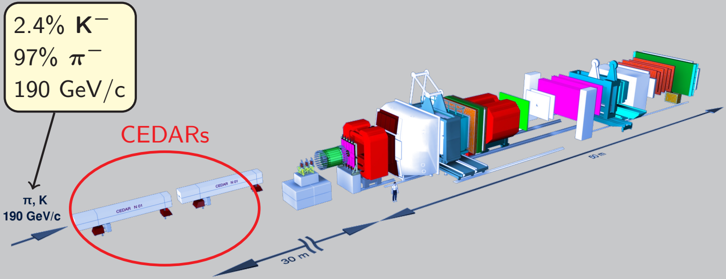

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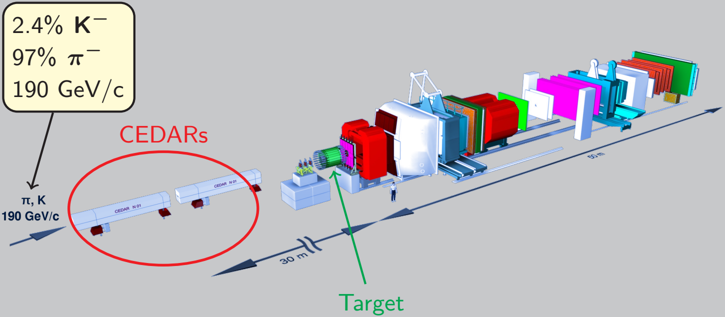

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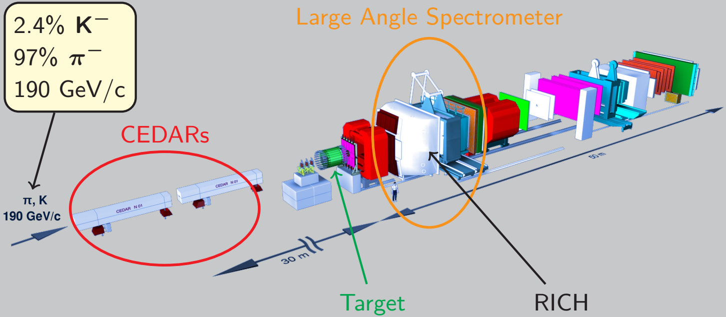

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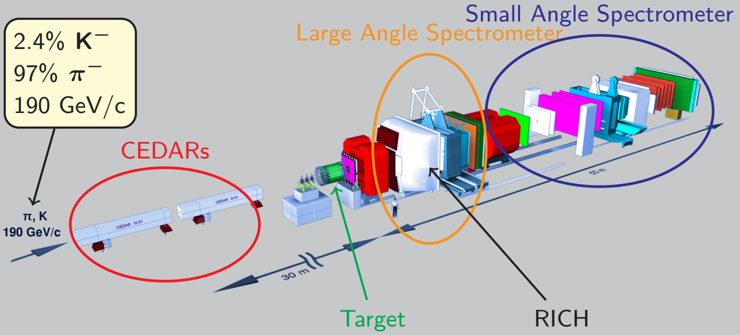
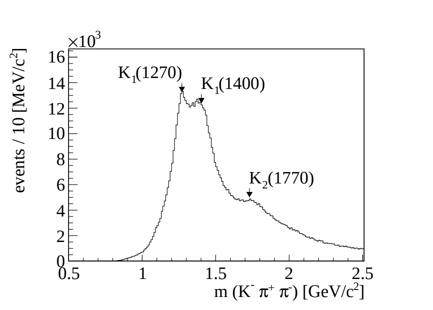
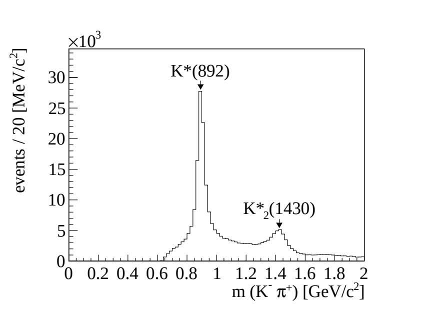


Example: $\mathbf{K}\pi\pi$ analysis

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





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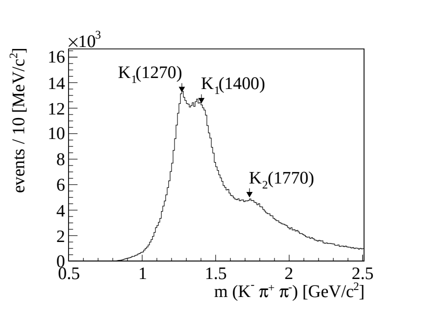
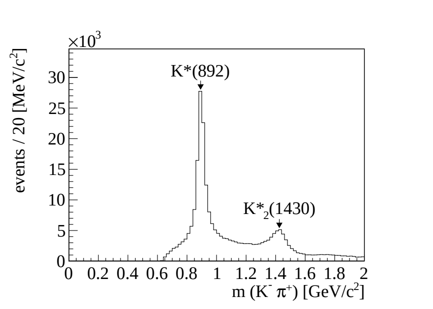


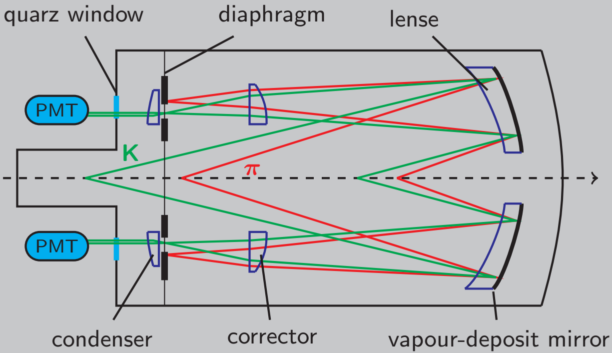


Only 40% of the beam kaons used for analysis

Bad efficiency of particle identification in the CEDARs

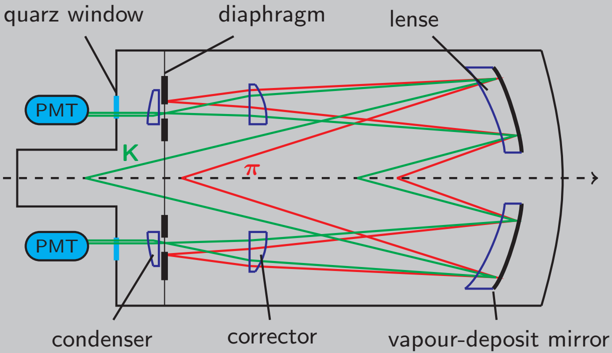
How does a CEDAR work?

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



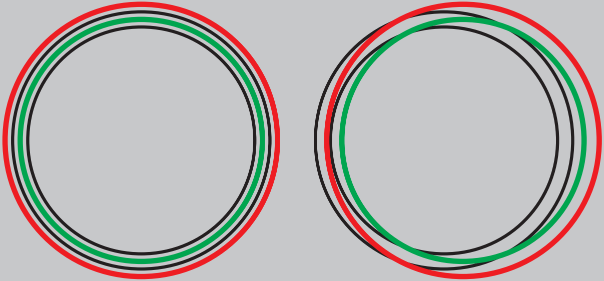
How does a CEDAR work?

- 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

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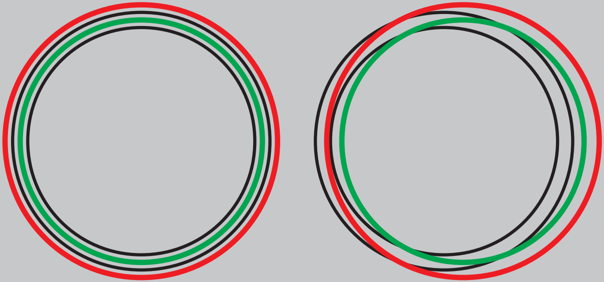

$\Rightarrow$ Multiplicity method does not work for divergent beams

Goal

Find a better method to take divergence into account

General Idea

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

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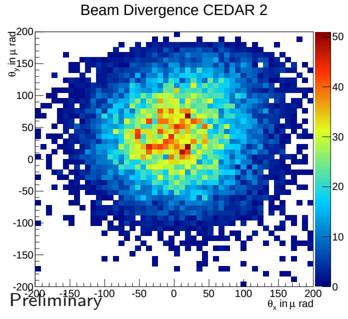
- Take beam divergence into account
- Identify beam particles using likelihoods

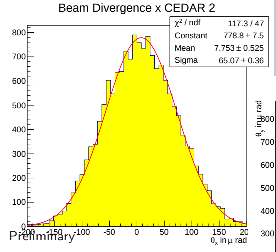
5 steps to take

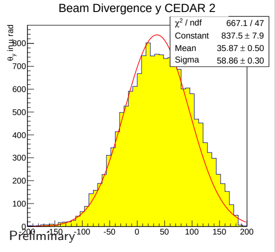
1. Measure beam divergence
2. Create a pure Kaonsample and a pure Pionsample
3. Determine probabilities to have hits in PMTs for Pion and Kaon
4. Calculate likelihoods from probabilities
5. Use likelihoods to identify particles

Step 1: Measure beam divergence

- Measure beam position in front of $(\mathbf{x_1}, \mathbf{y_1})$ and behind $(\mathbf{x_2}, \mathbf{y_2})$ CEDARs
- Calculate relative displacement $\boldsymbol{\Delta}_\mathbf{x} = \frac{\mathbf{x_2} - \mathbf{x_1}}{\mathbf{1283{,}4\,cm}}$
- Divergence $\boldsymbol{\theta_x} = \mathbf{arctan}(\boldsymbol{\Delta}_\mathbf{x}) \approx \boldsymbol{\Delta}_\mathbf{x}$







Step 2: Create a pure Kaonsample and a pure Pionsample

Create a Kaonsample and a Pionsample

- Kaonsample

→ Use free Kaon decay $\mathbf{K}^- \rightarrow \pi^-\pi^-\pi^+$

  - 3 outgoing particles with correct charged
  - Primary vertex outside of the target
  - Cut on transverse momentum and Kaon mass

- Pionsample

→ Use diffractive production $\pi^-\mathbf{p} \rightarrow \pi^-\pi^-\pi^+\mathbf{p}$

  - 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 π and $\mathbf{K}$

Example: Probability that a particle with divergence θ_x, θ_y that produces a signal in PMT **i** is a Kaon

→ Use Bayes' Theorem:

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

Here:

$\mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Signal}\|\text{Kaon})$:	Probability that Kaon at θ_x, θ_y produces signal in PMT **i**	(→ Kaonsample)
$\mathbf{P}_{\theta_x,\theta_y}(\text{Kaon})$:	Probability that Kaon has divergence θ_x and θ_y	(→ Kaonsample)
$\mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Signal})$:	Probability that signal in PMT **i** ist produced at θ_x, θ_y	(→ Beamsample)

Step 3 continued

Pions and Kaons have the same divergence distribution:

$$\mathbf{P}_{\theta_x,\theta_y}(\text{Kaon}) = \mathbf{P}_{\theta_x,\theta_y}(\text{Pion}) = \mathbf{P}_{\theta_x,\theta_y}(\text{Beam})$$

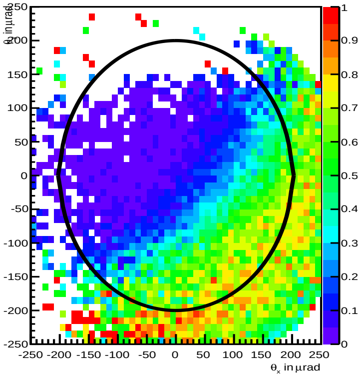
$\Rightarrow \mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Kaon}|\text{Signal})$ and $\mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Pion}|\text{Signal})$ have same normalization factor $\frac{\mathbf{P}_{\theta_x,\theta_y}(\text{Beam})}{\mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Signal})}$, thus

$$\mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Kaon}|\text{Signal}) \propto \mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Signal}|\text{Kaon})$$
$$\mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Pion}|\text{Signal}) \propto \mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Signal}|\text{Pion})$$

Also calculate

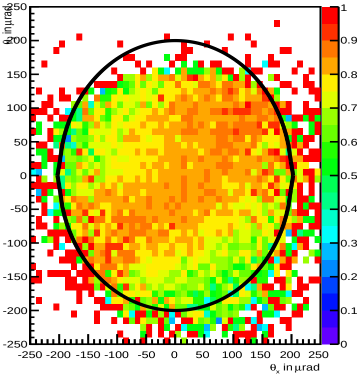
$$\mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Kaon}|\overline{\text{Signal}}) \text{ and } \mathbf{P}^{\mathbf{i}}_{\theta_x,\theta_y}(\text{Pion}|\overline{\text{Signal}})$$

$P^i_{xy}(\text{Signal}|\text{Pion}) \propto P^i_{xy}(\text{Pion}|\text{Signal})$



Preliminary

$P^i_{xy}(\text{Signal}|\text{Kaon}) \propto P^i_{xy}(\text{Kaon}|\text{Signal})$



Preliminary

Step 4: Calculate likelihoods from probabilities

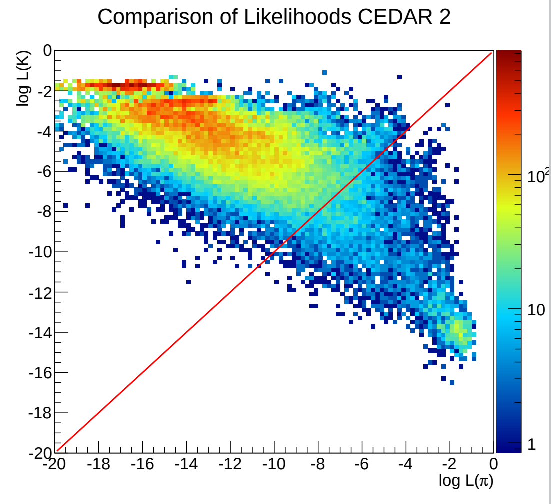
To obtain the log likelihood just add logarithms of probabilities

$$\mathbf{log\,L(\text{Kaon})} = \sum_{i=1}^{8} \mathbf{log\,P}^{i}_{\theta_x,\theta_y}(\text{Kaon}|\text{Signal}) \cdot \eta^{i} + \sum_{i=1}^{8} \mathbf{log\,P}^{i}_{\theta_x,\theta_y}(\text{Kaon}|\overline{\text{Signal}}) \cdot (1 - \eta^{i})$$

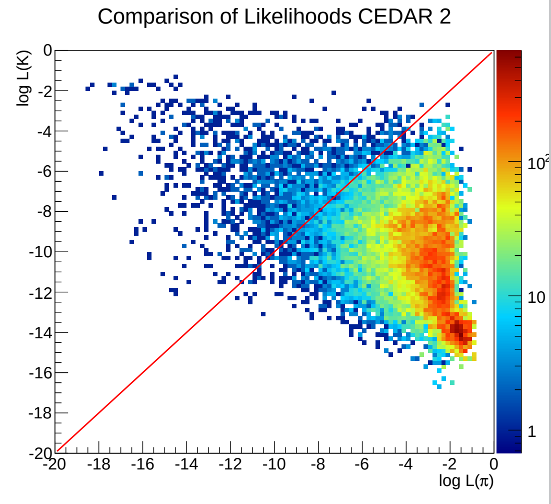
Where:

$$\eta^{i} = \begin{cases} 1 & \text{Signal in PMT i} \\ 0 & \text{no Signal in PMT i} \end{cases}$$

Kaonsample


Comparison of Likelihoods CEDAR 2
log L(K)
log L(π)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
10²
10
1

Pionsample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log L(π)
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1

Step 5: Use likelihoods to identify particles

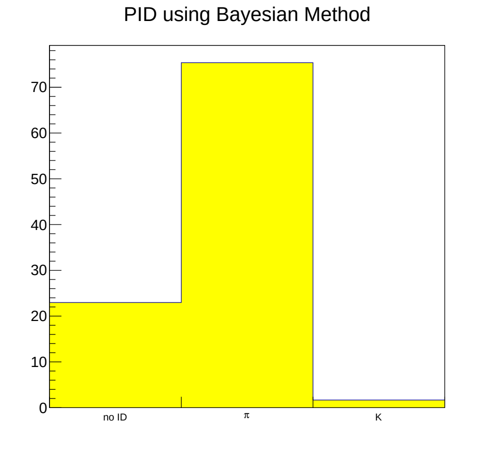
- Compare log likelihoods to get an ID for each CEDAR:
  - $\mathbf{\log L^{K} > \log L^{\pi} + A}$ ⇒ PID **K**
  - $\mathbf{\log L^{\pi} > \log L^{K} + B}$ ⇒ PID $\boldsymbol{\pi}$
  - else no PID given
- Tune **A** and **B** due to efficiency/purity.

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 π
  - else no PID given
- Tune **A** and **B** due to efficiency/purity.
- Combine CEDARs afterwards with OR combination

C2 \ C1	?	π	**K**
?	?	π	**K**
π	π	π	?
K	**K**	?	**K**

Particle Identification in the Beamsample



Bayesian Method with OR combination and $\mathbf{A = 0.1}$:

- 22.8% no ID
  - 21% too large divergence
  - 1.8% no decision
- 75.7% Pions
- 1.6% Kaons

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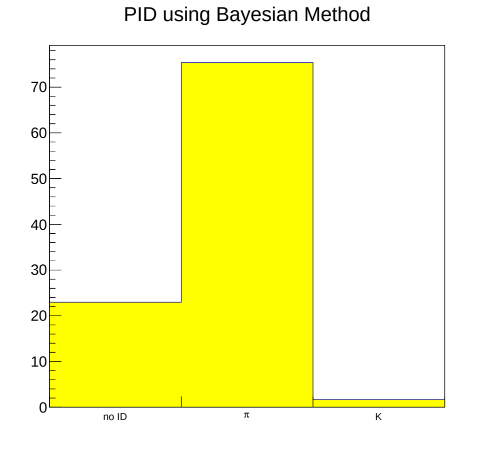

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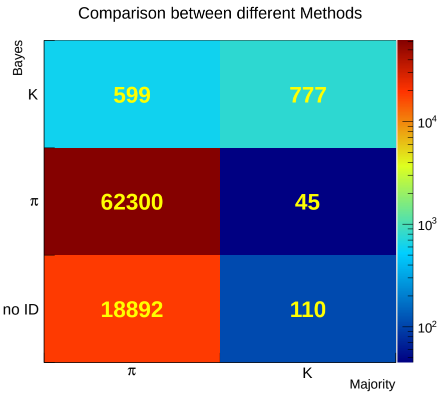
→ 65% of beam kaons

Comparison with Majority Method



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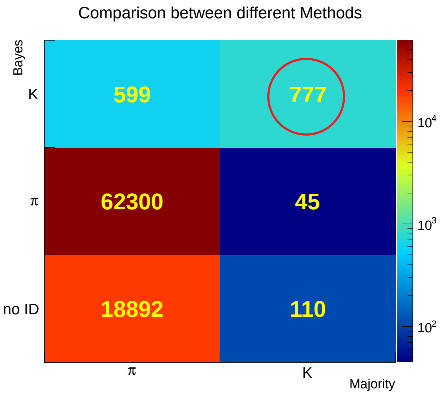

- Most of majority Kaons reproduced as Kaons (771 of 932)

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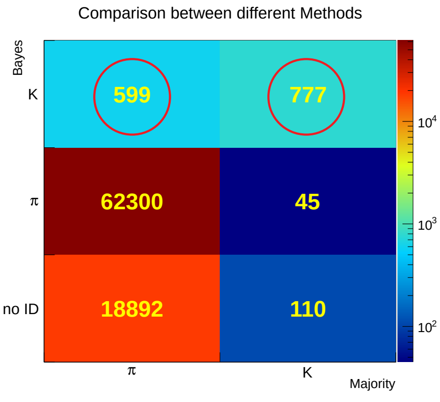

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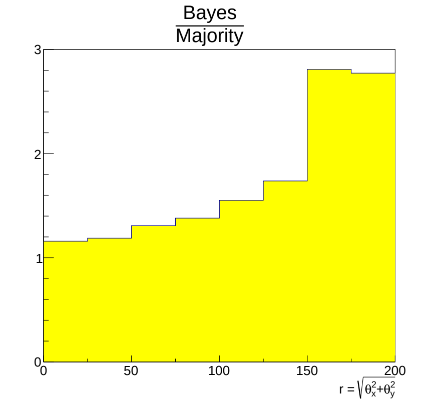


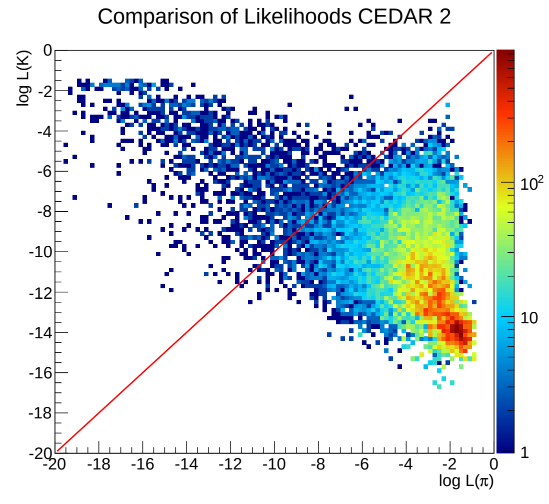
- Most of majority Kaons reproduced as Kaons (771 of 932)
- 514 additional Kaons from majority Pions
- Additional Kaons have large divergence

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

Beamsample



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0
log L(π)
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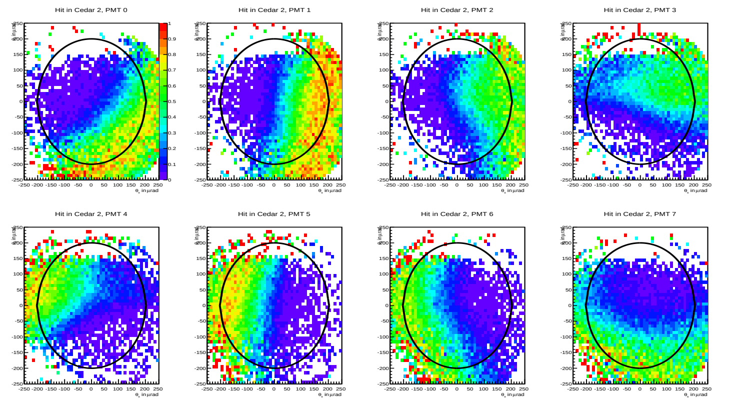
10^2

$P^i_{xy}(\text{Signal}|\text{Pion}) \propto P^i_{xy}(\text{Pion}|\text{Signal})$



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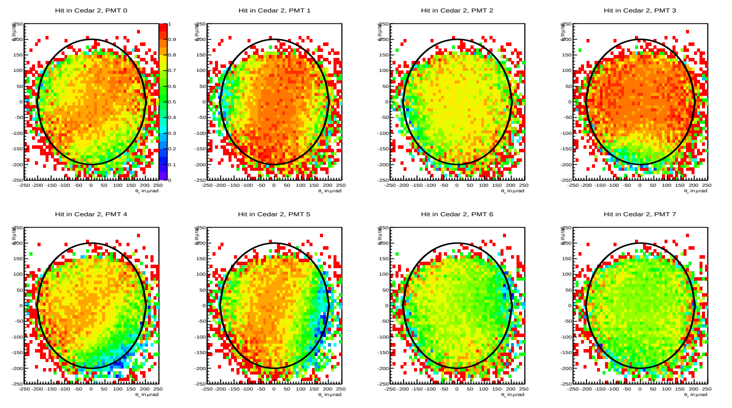
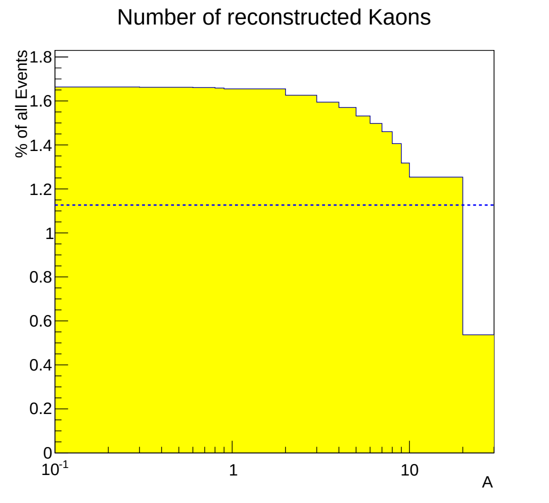


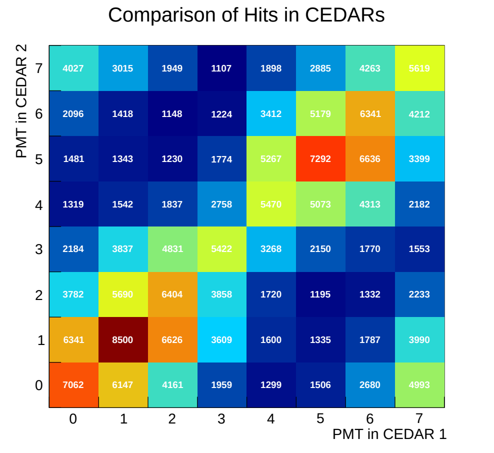
A-Dependence of Kaon Identification

$$\log L^K > \log L^\pi + A \Rightarrow \text{PID } K$$



PMT correlation between CEDAR 1 and CEDAR 2

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



PMT efficiencies

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