PID studies with proto-TORCH testbeam update
TORCH meeting

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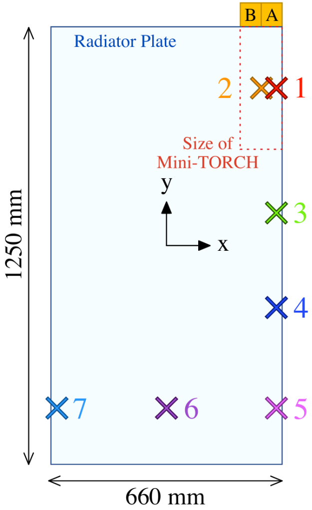
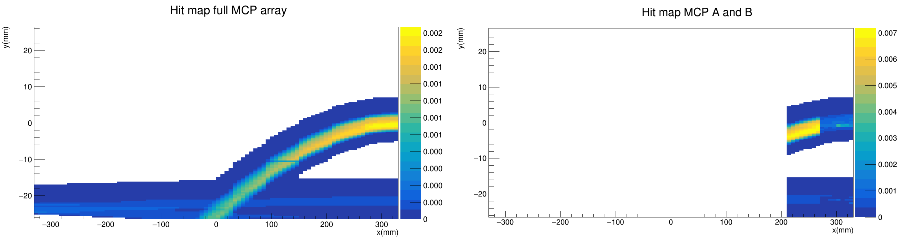
Introduction

- What I presented last time:
  - Study of likelihood calculation with particle gun simulations
  - Initial studies of reconstruction and PID separation power in proto-TORCH testbeam data
  - Need a better understanding of discrepancies between simulation and data
- Today's presentation: Quick progress update
- Long term goal:
  - Prepare for PID study of next testbeam data

Beam position



Have only studied position 1 so far



(a) Full MCP array, nominal QE

(b) MCP (reduced QE) A and B

Figure 1: Track incident on top right corner (position 1)

For now I will only study MCP-B

Likelihood calculation

- Probability of photon hit with energy E_γ, azimuthal angle ϕ_c, time t_0:

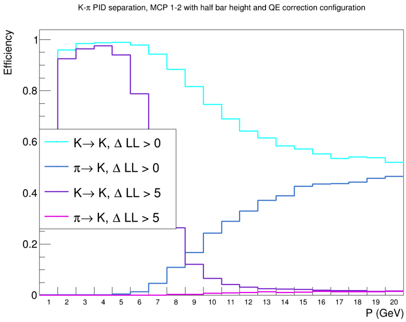
$$\begin{aligned} P(E_\gamma, \phi_c, z, t_0) =& P(\phi_c)P(z)P(t_0)P(E_\gamma)\Theta(E_\gamma, \phi_c, z) \\ =& \frac{1}{2\pi}\frac{1}{r_z}P(E_\gamma)P(t_0)\Theta(E_\gamma, \phi_c, z) \end{aligned}$$

- Transform to detector coordinates (x_d, y_d):

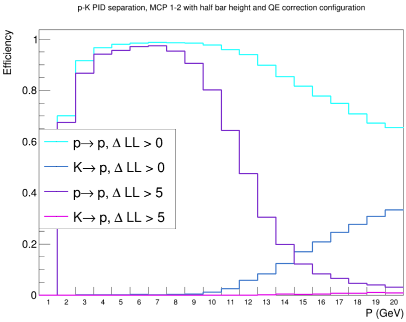
$$P(x_d, y_d, t_d) = P(E_\gamma, \phi_c, t_0)/|J|, \quad |J| = \left|\frac{\partial y_d}{\partial E_\gamma}\frac{\partial x_d}{\partial \phi_c} - \frac{\partial x_d}{\partial E_\gamma}\frac{\partial y_d}{\partial \phi_c}\right|$$

- $P(t_0)$: Gaussian PDF with $\sim 70\,\mathrm{ps}$ time resolution
- $P(E_\gamma)$: Frank-Tamm formula
- PID algorithm described in LHCb-PUB-2022-007

PID efficiency simulation



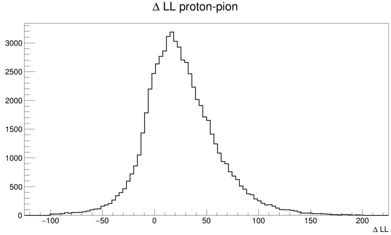
(a) Kaon-pion



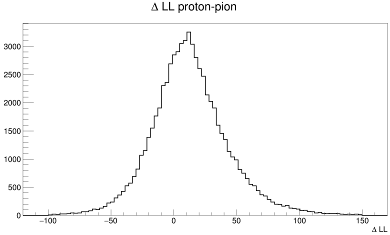
(b) Kaon-proton

Figure 2: PID efficiency

Likelihood in proto-TORCH testbeam data



(a) Pion sample



(b) Proton sample

Figure 3: $\Delta\mathrm{LL}$ of testbeam data

Results “out of the box” at 8 GeV:
Pion efficiency: 78.6%
Proton efficiency: 66.9%

Why was the proton PID performance much worse?

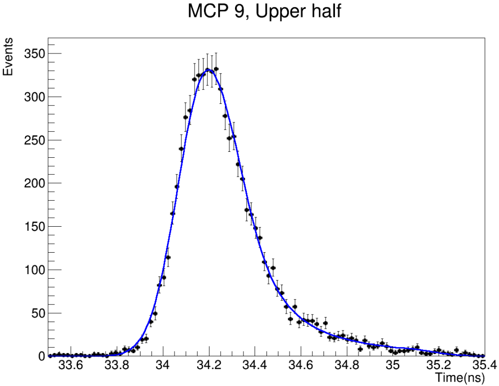
- Main issue: Calibration between MCP columns
  - Solution: Need to time align each MCP column in data with simulation
- Additionally: Need to account for travel time difference from TORCH to T2
- After accounting for these effects, the proton PID efficiency improved:
  - Pion efficiency: 82.7%
  - Proton efficiency: 79.0%

Why is the performance in simulation so good?

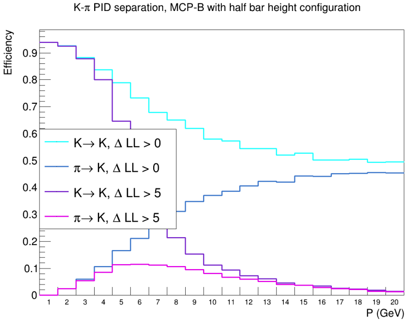
- A few small effects that should be accounted for:
  - Time resolution is simulation is too good (55 ps)
  - Each MCP column can have a different time resolution
  - Solution: Convolve time distribution from simulation with Gaussian and fit to testbeam data
- A very large effect that must be accounted for:
  - Backscattering results in a very large tail in the testbeam time distribution
  - Strategy: Convolve time distribution with a Crystal Ball instead of Gaussian

Why is the performance in simulation so good?

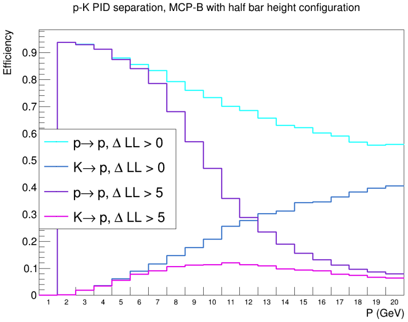
- In summary:
  1. Separate all MCP columns in data and simulation
  2. Convolve time distribution in simulation with Crystal Ball
  3. Fit each MCP column in data separately
  4. Use Crystal Ball position for time calibration, width for resolution effects and tails for backscattering effects



PID efficiency simulation



(a) Kaon-pion



(b) Kaon-proton

Figure 4: PID efficiency

PID efficiency in testbeam

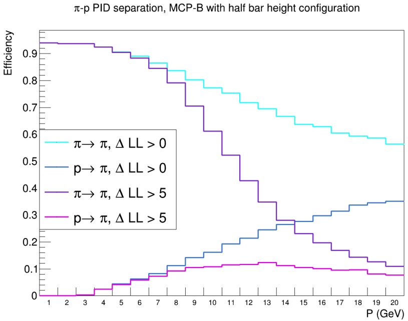
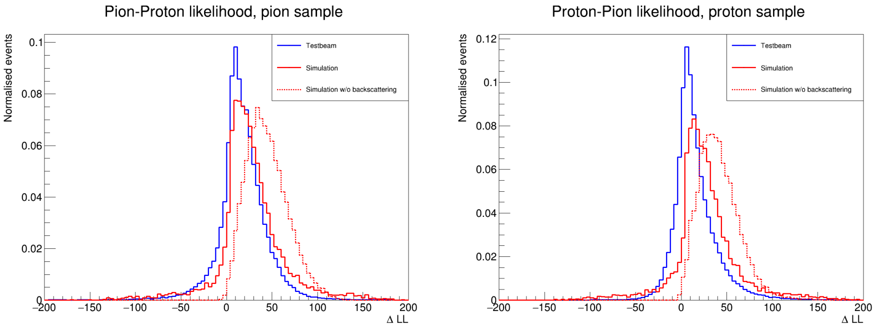


Figure 5: Pion-proton PID efficiency

Sample	Testbeam data	Simulation	Without backscattering
Pion sample	82.7%	85.5%	99.0%
Proton sample	79.0%	84.6%	98.7%

Likelihod distributions in testbeam and simulation



(a) Pion sample

(b) Proton sample

Figure 6: Likelihood distributions

Not perfect agreement, but much better now

Summary

- Discrepancies between PID efficiencies in data and simulation previously
- Two main effects:
  1. Time calibration of individual MCP columns
  2. Backscattering results in large tail in time distribution
- Smear simulation with Crystal Ball shape
- Agreement much better now!

Thank you for listening!