PID studies with proto-TORCH testbeam
TORCH meeting

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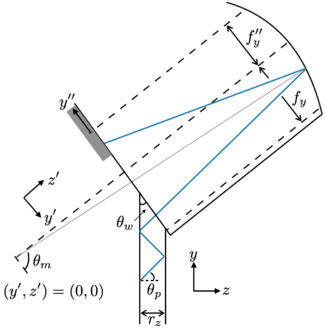
Introduction

- My work so far:
  - Study how photons are propagated through TORCH optics
  - Study analytical photon reconstruction from MCP hits
  - Understand likelihood calculation
- Long term goal:
  - Build on Jenny's testbeam data analysis:
    - Jenny has focused on timing resolution studies
    - I will study PID separation power
  - Prepare for PID study of next testbeam data
- Thanks to:
  - Thomas Blake for providing code
  - Jenny for providing testbeam data

Introduction to reconstruction code

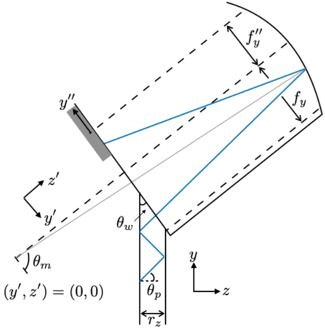
- Forwards propagation:
  1. Trace emitted photon through quartz bar
  2. Reflect in cylindrical mirror
  3. MCP hit!



- Reconstruction and PID algorithm described in LHCb-PUB-2022-007

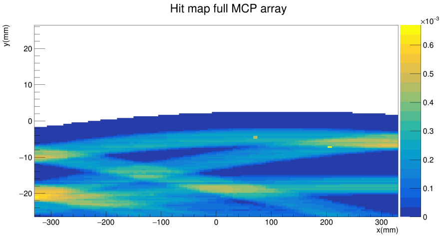
Introduction to reconstruction code

- Reconstruction:
  1. Reconstruct photon direction from vertical MCP pixel position
  2. From photon direction, calculate $\theta_c \rightarrow n_{\text{phase}} \rightarrow n_{\text{group}}$
  3. Reconstruct propagation time!

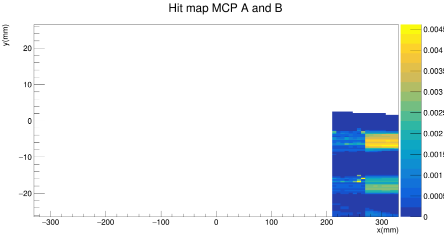


- Reconstruction described in LHCb-PUB-2022-007

Hit maps



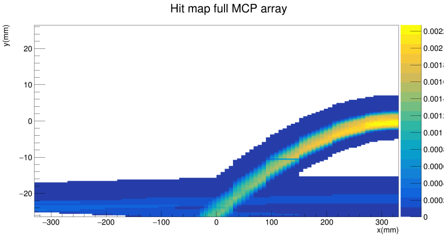
(a) Full MCP array



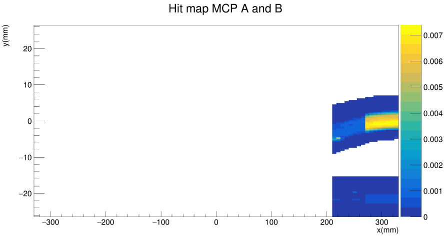
(b) MCP A and B

Figure 1: Track incident 1 m from top

Hit maps



(a) Full MCP array



(b) MCP A and B

Figure 2: Track incident on top right corner (position 1)

Likelihood calculation

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

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

- Transform to detector coordinates (x_d, y_d):

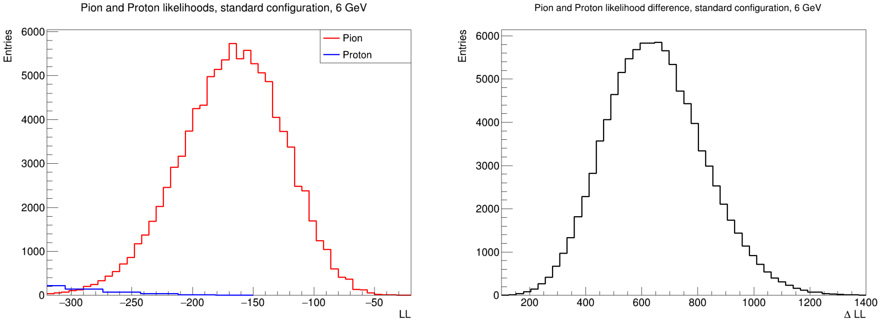
$$P(x_d, y_d, t_d) = P(E_\gamma, \phi_c, t_0)/|J|, \quad |J| = \left|\frac{\partial y_d}{\partial E_\gamma}\frac{\partial x_d}{\partial \phi_c} - \frac{\partial x_d}{\partial E_\gamma}\frac{\partial y_d}{\partial \phi_c}\right|$$

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

Test likelihood calculation

- Does it work?
- Set up single charged track simulation:
  1. Send single particle (pion, kaon, proton) through quartz
  2. Generate Cherenkov photons
  3. Propagate photons to MCPs
  4. Calculate likelihood from photon hits
  5. Start over from step 1
- No background hypothesis
- Turn on pixelisation, charge sharing, clustering

Pion-Proton likelihood simulations

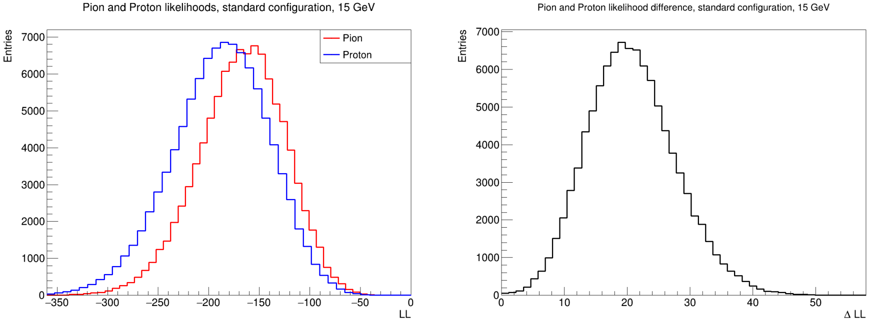


(a) Pion and proton hypotheses

(b) Pion-proton $\Delta\mathrm{LL}$

Figure 3: Log likelihood at 6 GeV

Pion-Proton likelihood simulations

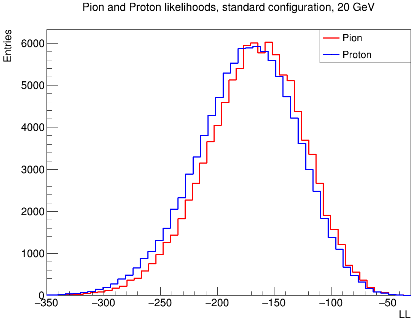


(a) Pion and proton hypotheses

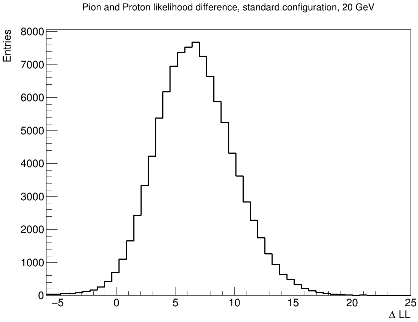
(b) Pion-proton $\Delta\mathrm{LL}$

Figure 4: Log likelihood at 15 GeV

Pion-Proton likelihood simulations



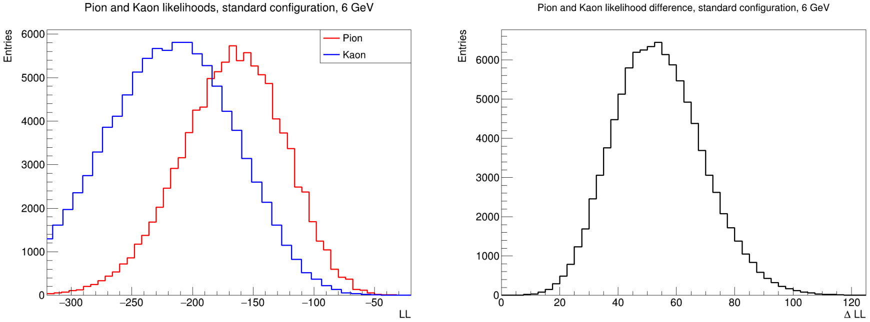
(a) Pion and proton hypotheses



(b) Pion-proton $\Delta \mathrm{LL}$

Figure 5: Log likelihood at 20 GeV

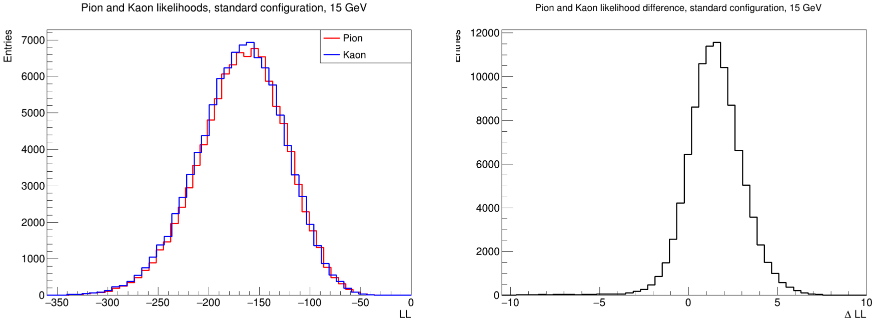
Pion-Kaon likelihood simulations



(a) Pion and kaon hypotheses **(b)** Pion-kaon $\Delta\mathrm{LL}$

Figure 6: Log likelihood at 6 GeV

Pion-Kaon likelihood simulations

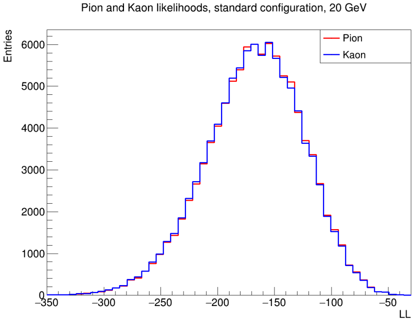


(a) Pion and kaon hypotheses

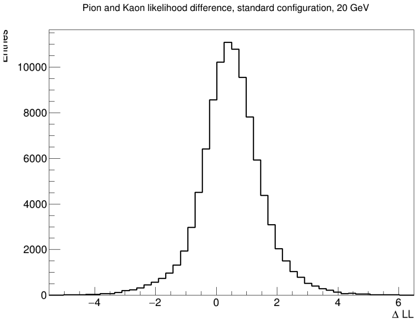
(b) Pion-kaon $\Delta\mathrm{LL}$

Figure 7: Log likelihood at 15 GeV

Pion-Kaon likelihood simulations



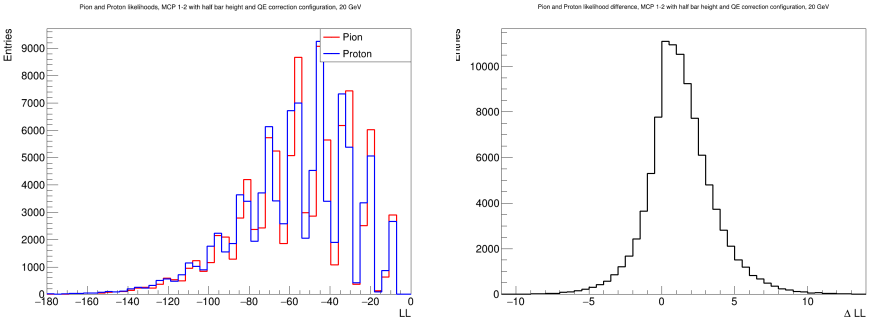
(a) Pion and kaon hypotheses



(b) Pion-kaon $\Delta\mathrm{LL}$

Figure 8: Log likelihood at 20 GeV

Pion-Proton likelihood simulations



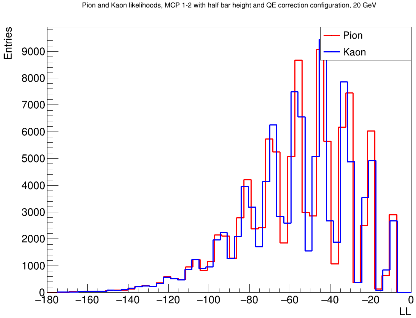
(a) Pion and proton hypotheses

(b) Pion-proton $\Delta \mathrm{LL}$

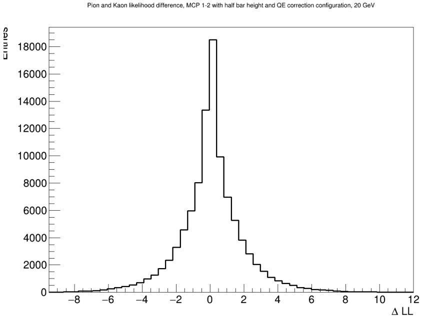
Figure 9: Log likelihood at 20 GeV

Adopt to testbeam setup: MCP A and B
Assume MCP A has QE that is 65% of MCP B

Pion-Kaon likelihood simulations



(a) Pion and kaon hypotheses



(b) Pion-kaon $\Delta\mathrm{LL}$

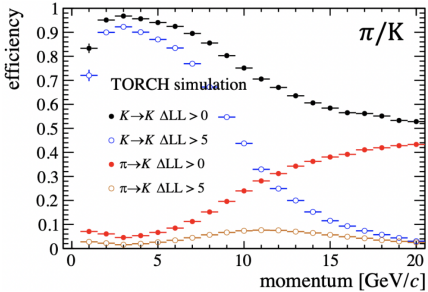
Figure 10: Log likelihood at 20 GeV

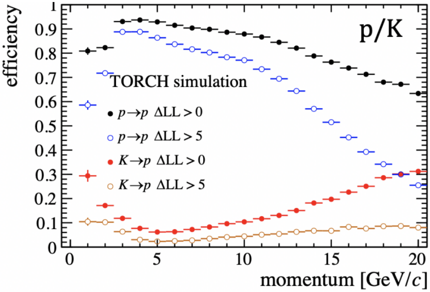
Adopt to testbeam setup: MCP A and B
Assume MCP A has QE that is 65% of MCP B

PID efficiency from FTDR

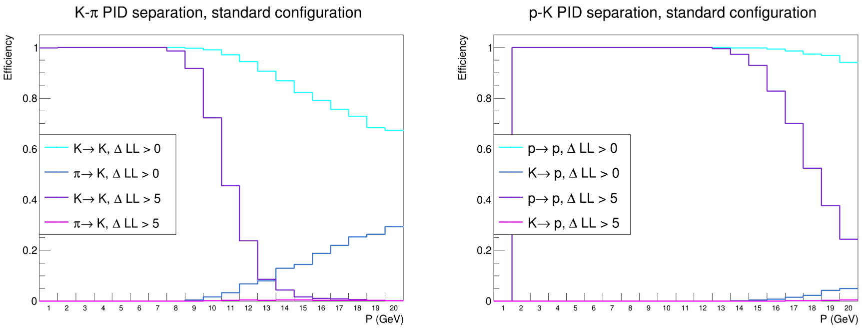
PID efficiency study from FTDR

Aim: Reproduce similar study with testbeam setup





PID efficiency simulation



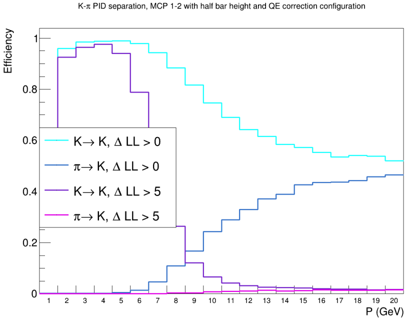
(a) Kaon-pion

(b) Pion-proton

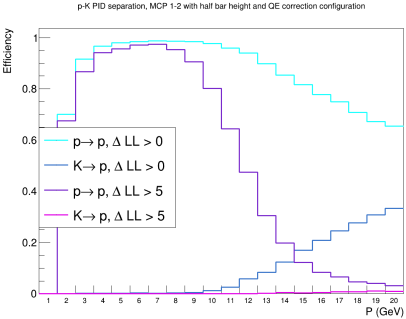
Figure 11: PID efficiency

Full array of MCPs with same QE

PID efficiency simulation



(a) Kaon-pion



(b) Pion-proton

Figure 12: PID efficiency

2 MCPs, one with lower QE

PID study of proto-TORCH testbeam data

Obviously, more messy and challenging:

1. Not many photons $\implies$ Use position 1 only
2. Backgrounds $\implies$ For now, discard events where reconstruction fails
   - Photon hits do not match track sometimes...
3. T2 has an unknown offset $\implies$ Align time distribution from simulation with that in data
   - There is probably a much better way...
4. No T1 $\implies$ Introduce artificial 9500 mm offset to time information

Results from testbeam data

PID cut	$\Delta\mathrm{LL} > 0$	$\Delta\mathrm{LL} > 5$
8 GeV pion simulation	99.0%	97.9%
9 GeV pion simulation	98.9%	96.8%
Proto-TORCH testbeam pions	78.6%	72.9%
8 GeV proton simulation	98.7%	97.4%
9 GeV proton simulation	98.8%	96.5%
Proto-TORCH testbeam protons	66.9%	59.5%

Summary and next steps

- Summary
  1. Likelihood calculation gives consistent results
  2. Single particle simulation shows very good PID separation power
  3. Testbeam data show some PID separation power, but not as good as simulation
- Next steps:
  1. Discuss with Neville!