TORCH, a novel time-of-flight detector for LHCb upgrade II

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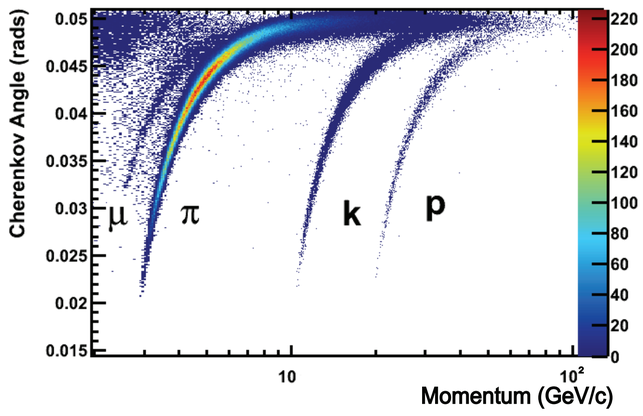
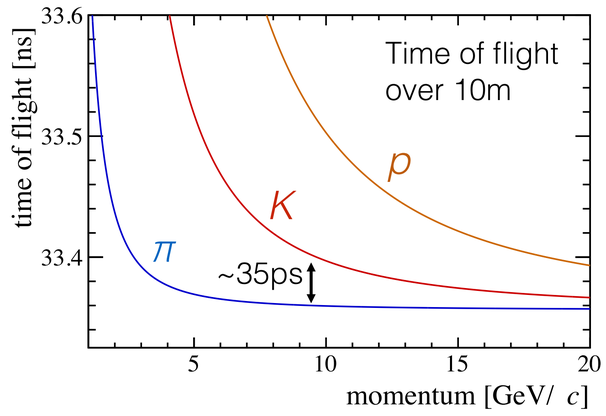
Motivation

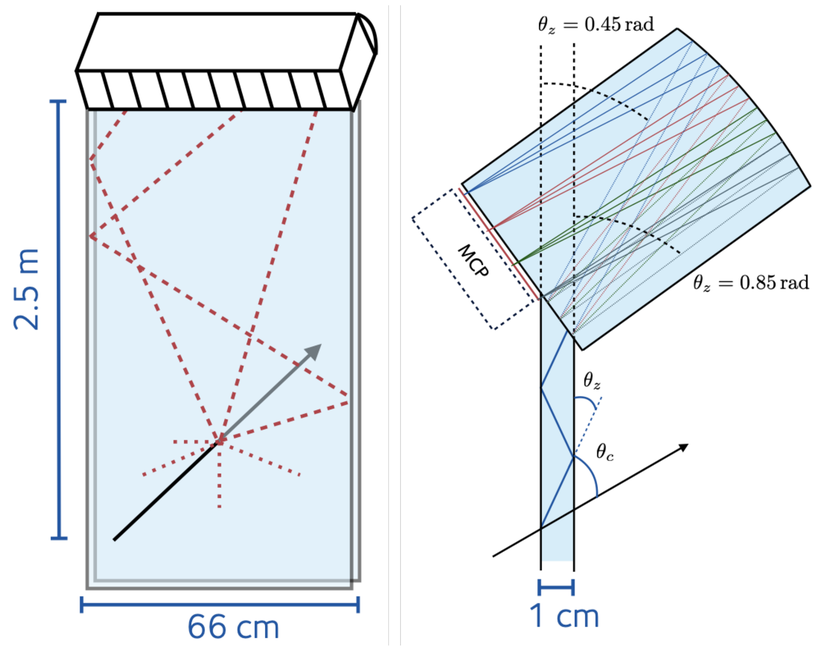
- Physics programme at LHCb relies on good PID, currently provided by 2 RICH detectors
- At low momentum both kaon and proton are below Cherenkov light emission threshold [1]
- Idea is to add large area time-of-flight detector to provide PID below 15 GeV/c
- For K–π separation over 10 m, need a per-track resolution of 10–15 ps





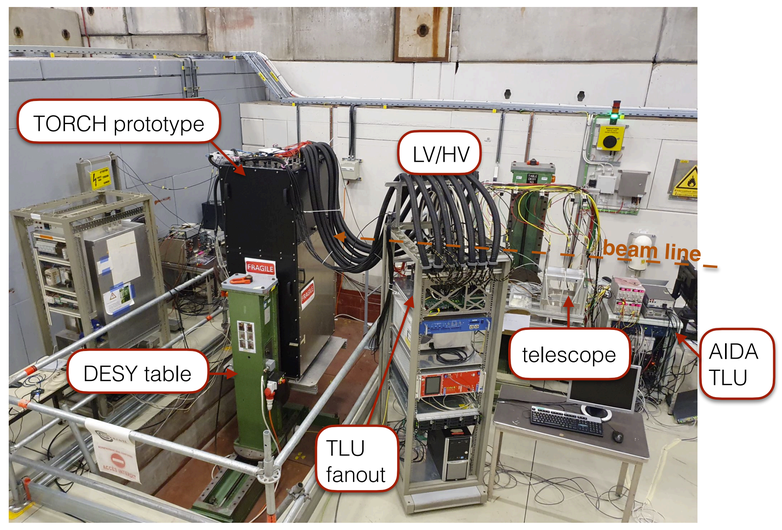
1) TORCH principle [2]

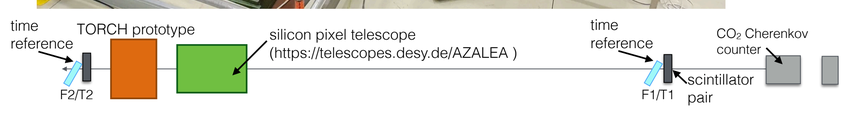
- Exploits prompt production of Cherenkov light in quartz bars
- Cherenkov photons travel to detector plane via total internal reflection
- Photons detected with MCP-PMTs developed by Photek Ltd.
- Expect 20-30 photons detected per track
- 15 ps per track resolution ⇒ single photon resolution of 70 ps



2) Beam test

- Half-height module with space for 11 MCP-PMTs
- CERN PS T9 beamline provides p and π with about 3–15 GeV/c momentum
- Time reference, threshold Cherenkov counter, beam telescope and trigger scintillators to define beam and start time



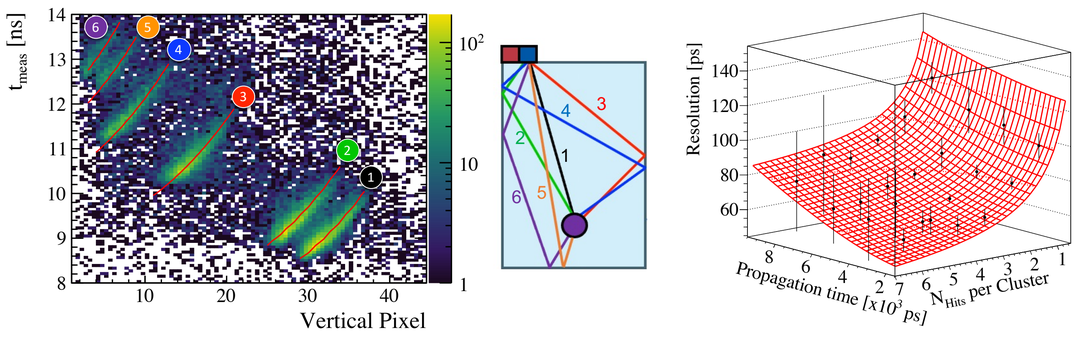


3) Results from 2018 campaign [3]

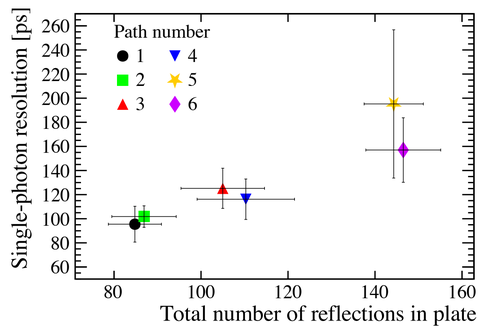
- Prototype equipped with 2 MCP-PMTs
- Main aim to demonstrate single photon time resolution
- Measurement at several radiator entry positions
- Time resolution depends on cluster size and photon pathlength

$$\sigma^2_{\text{TORCH}} = \sigma^2_{\text{MCP}} + \sigma^2_{\text{prop}}(t) + \sigma^2_{\text{RO}}(N_{\text{hits}})$$

	Measurement [ps]		Target [ps]
	Pions	Protons	
$\sigma_{\text{prop}} \times 10^3/t_p$	8.3 ± 0.7	7.6 ± 0.5	3.75 ± 0.8
σ_{MCP}	34.5 ± 8.6	31.0 ± 7.6	33
$\sigma_{\text{RO}} \times \sqrt{N_{\text{Hits}}}$	96.2 ± 6.7	95.0 ± 6.0	60

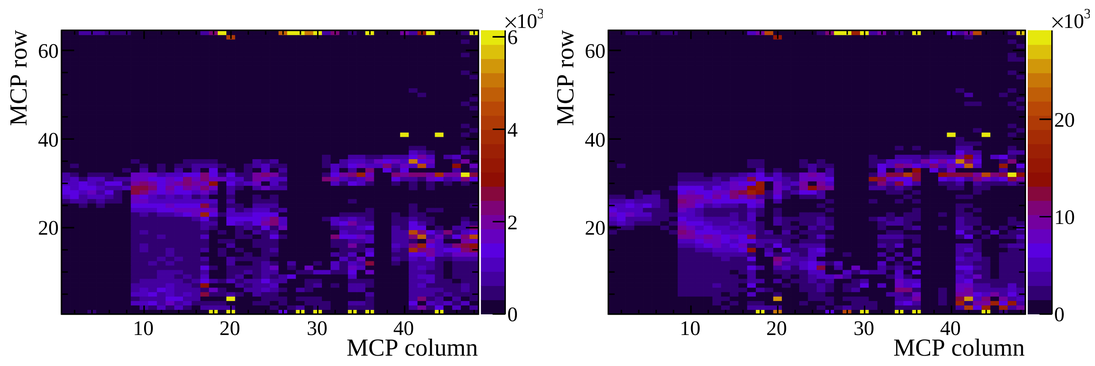


- Time resolution approaches design
- Expected path dependence seen
- Number of clusters seen in reasonable agreement with expectation
- Limited by electronics calibration



4) Beam test campaign 2022

- Six MCP-PMTs compared to two in previous beam tests
- Improved DAQ to cope with more data
- Better synchronisation between various subsystems
  - Telescope reconstruction fully working and events synchronised to Torch data
  - For the first time we have per-track information for TORCH data analysis



- Small improvements in time resolution on two MCP-PMTs used before
- Working on calibrations and detailed understanding of additional MCP-PMTs
- Data at several energies with momentum of 3, 5, 8 and 10 GeV/c
- Aim to demonstrate PID

References

(1) M. Adinolfi et al., *Eur. Phys. J. C*, 2013, **73**, 2431.

(2) M. Charles and R. Forty, *Nucl. Instrum. Meth. A*, 2011, **639**, 173–176.

(3) S. Bhasin et al., *Nucl. Instrum. Meth. A*, 2023, **1050**, 168181.