LHCb PID system & TORCH detector

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On behalf of the LHCb collaboration

CEPC: Flavour Physics
Symposium on New Physics and Related Detection Techniques
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The LHCb experiment

- The Large Hadron Collider is the largest producer in the world of b-hadrons
  - These are great for studying as they have $O(10^4)$ different decays that each give information
  - About 10^{12} b-hadrons per year
  - LHC Run 3 that just started will increase this rate by a factor 5

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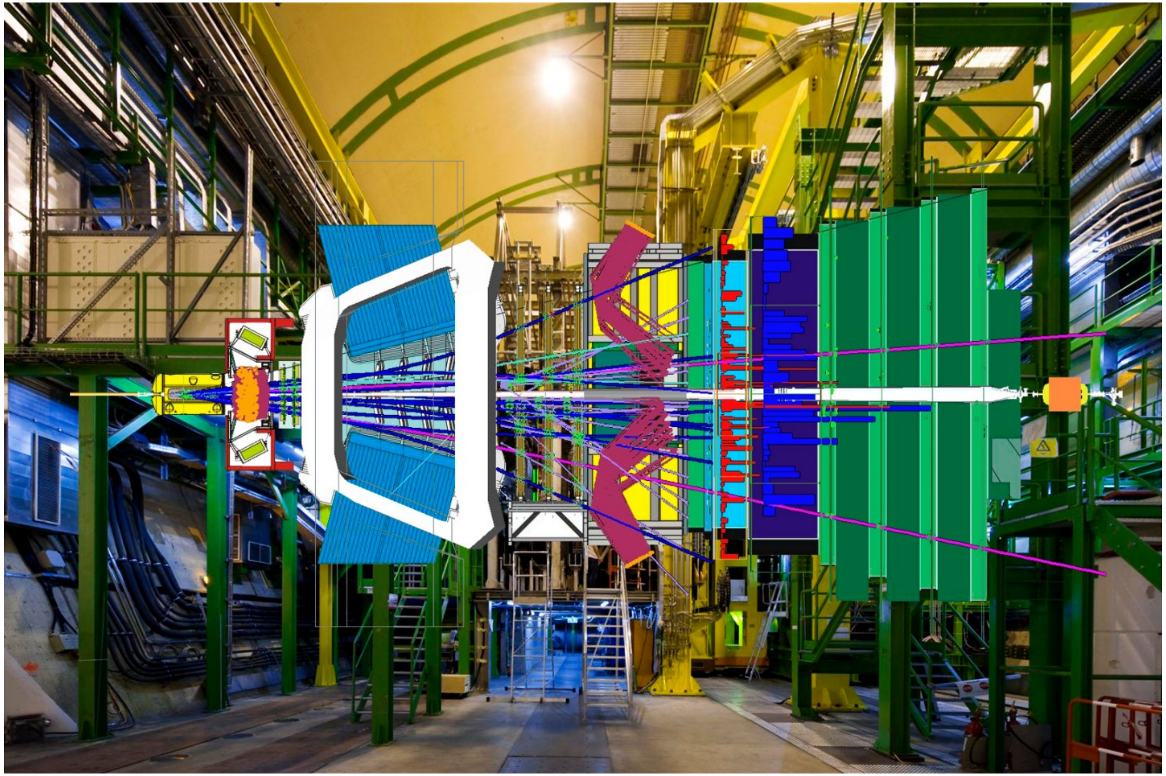


Why add hadronic PID

- While some flavour physics can be done without hadronic particle identification, it is severely curtailed
  - Time dependent CP violation depends on flavour tagging
  - Any decay with broad resonances like $K^* \to K\pi$ suffers from reflections without it
  - Essential to reduce background in partially reconstructed final states like $\Lambda_b \to p\mu\nu$
  - Different decays, with different physics like $B \to D\pi$ and $B \to DK$ turn indistinguishable at high B momentum without PID

Kinematics at LHCb

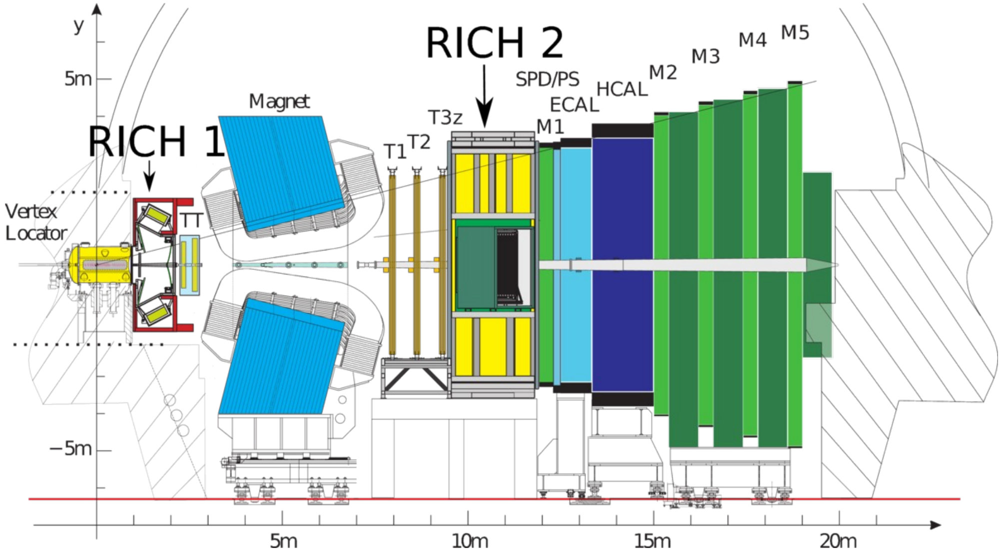
- In pp collisions, the typical p_T of a b hadron is a few GeV ($m_b/2$)
  - In a forward experiment like LHCb (10 mrad < θ < 250 mrad), this leads to b hadrons with high momentum
  - Typical range is $10 < p < 200$ GeV
- Daughters of the b hadron decays will have momentum $2 < p < 150$ GeV
  - Huge range represents a large challenge for a particle identification system

Instrumentation outside acceptance

- As a forward experiment LHCb has a layout that is in between a central collider experiment and a fixed target experiment
  - Underground location and geometry of collider enforces a fixed total length
  - The fixed forward acceptance allows for support structures, photon detectors, electronics, cooling etc. to be placed outside the acceptance

The run 1+2+3 PID system.

- The hadronic PID for the original LHCb detector (runs 1+2) and for the Upgrade I detector (run 3) is based on two RICH detectors



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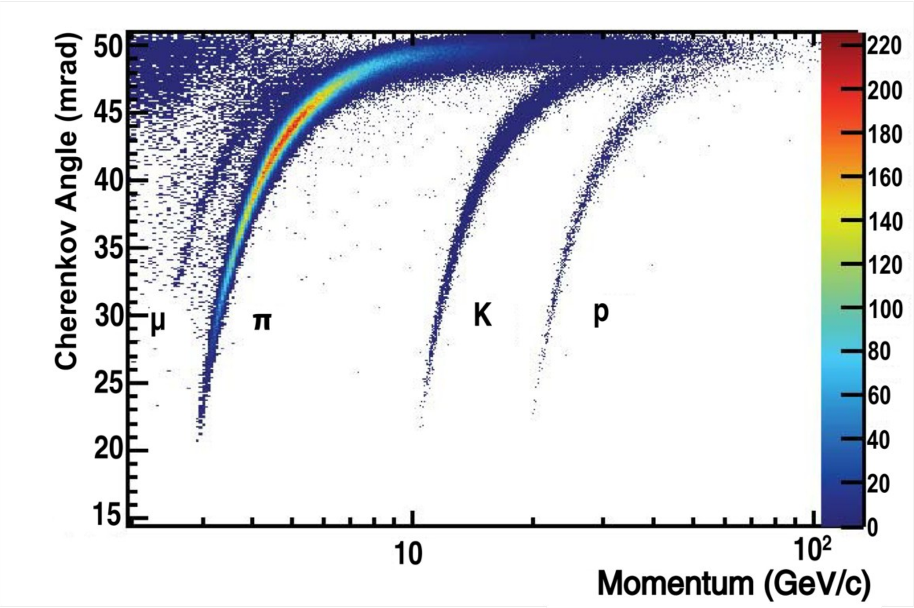
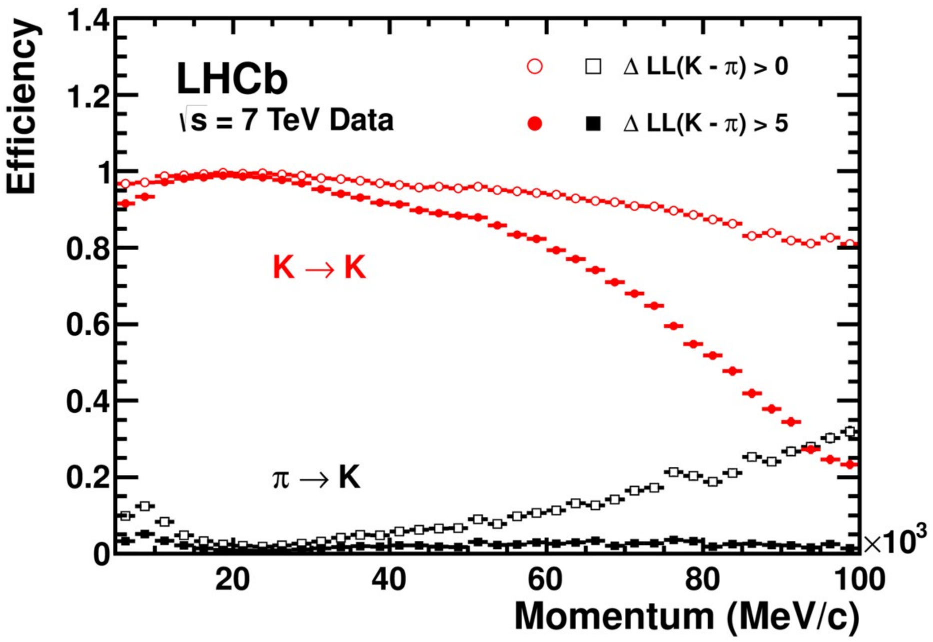
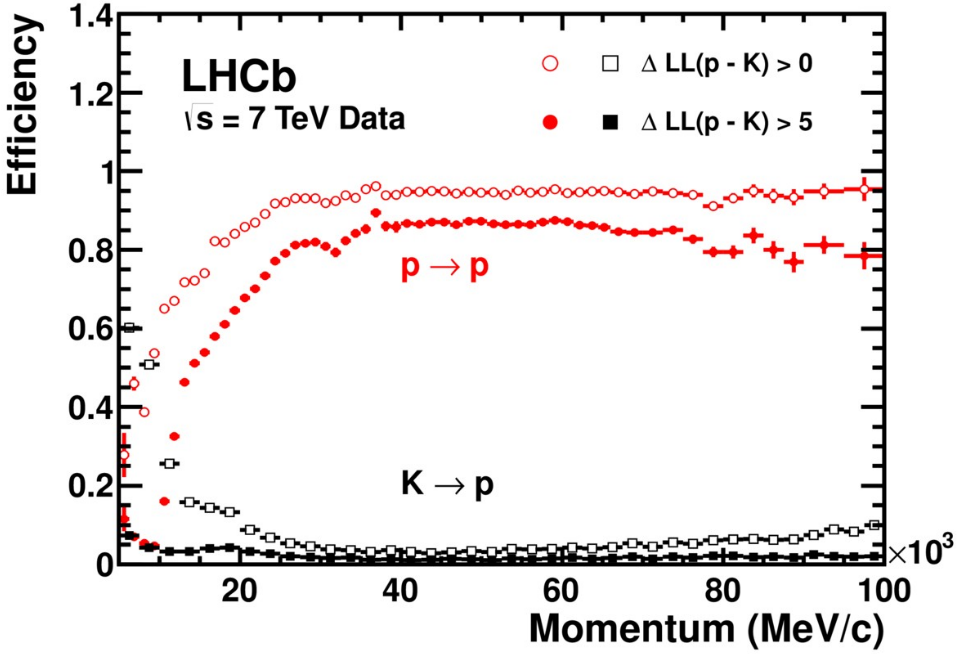


Performance observed

- Separation between kaons and pions great above 7 GeV
- Proton – kaon separation suffers below 25 GeV

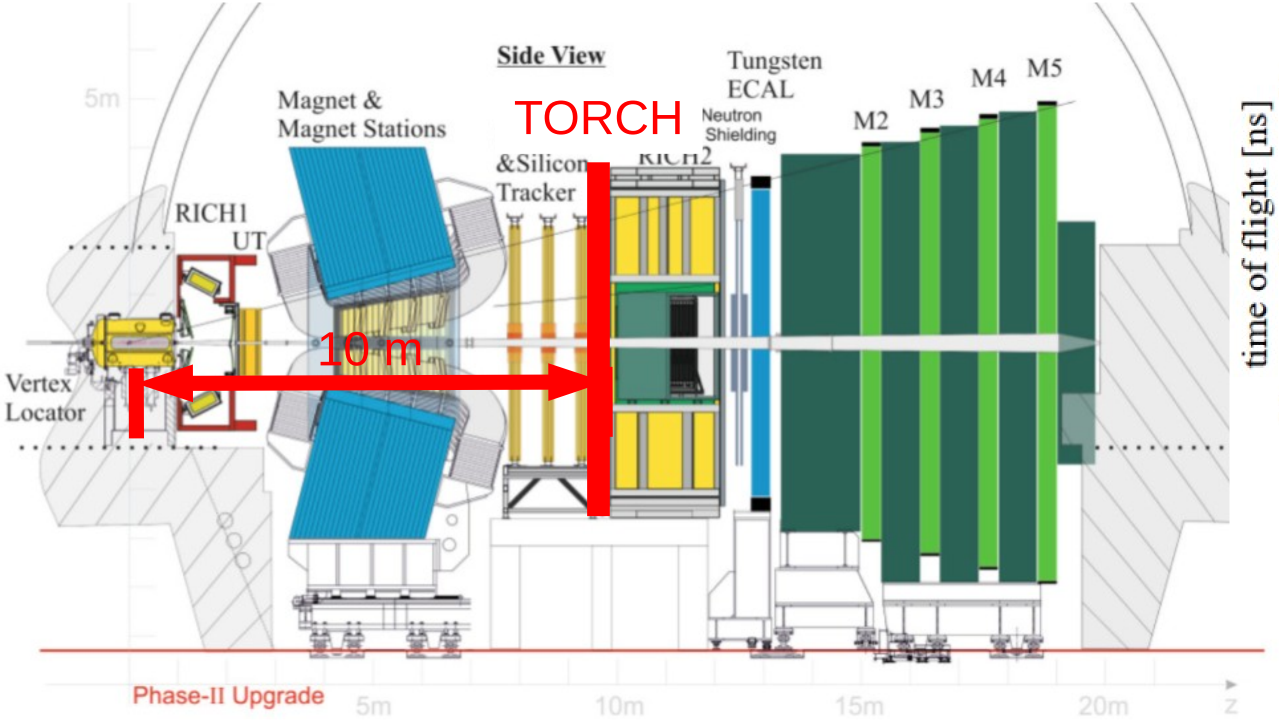
Eur. Phys. J. C 73 (2013) 2431

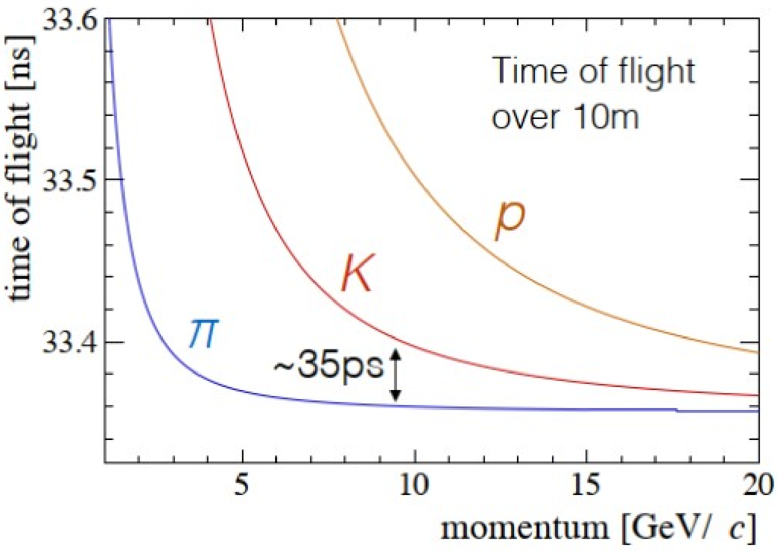




The TORCH concept

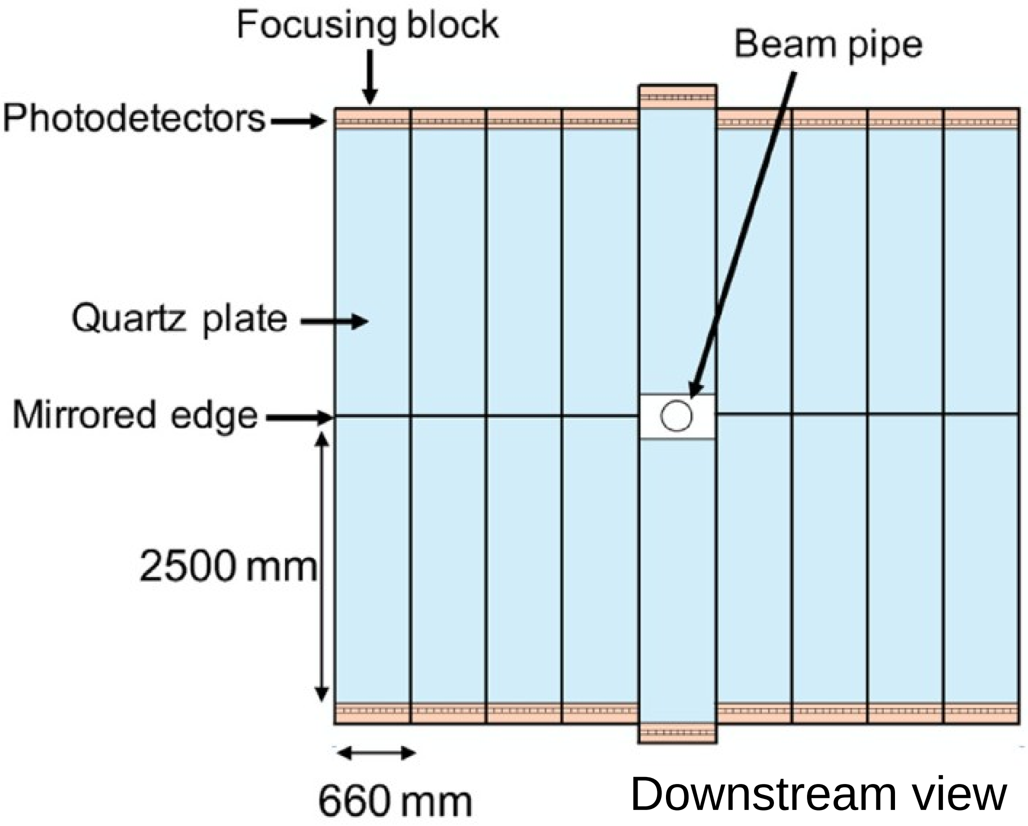
- A Time-of-Flight system becomes attractive at low momentum





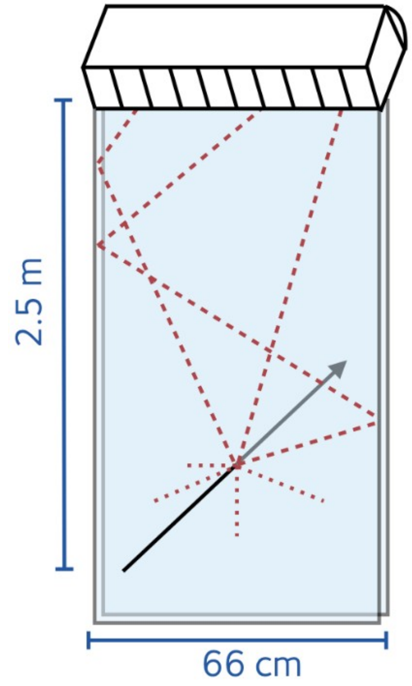
The TORCH concept

- Measure the arrival time from tracks using Cherenkov photons in quartz



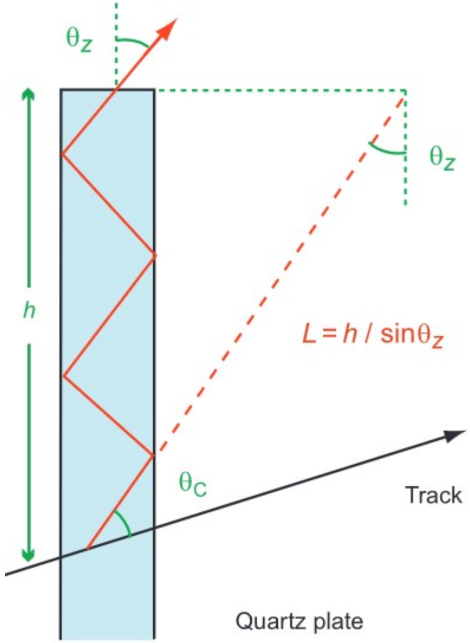
The TORCH concept

- Light propagated to electronics outside acceptance



Downstream view

NIM-A 639 (2011) 173



Side view
Photon propagation

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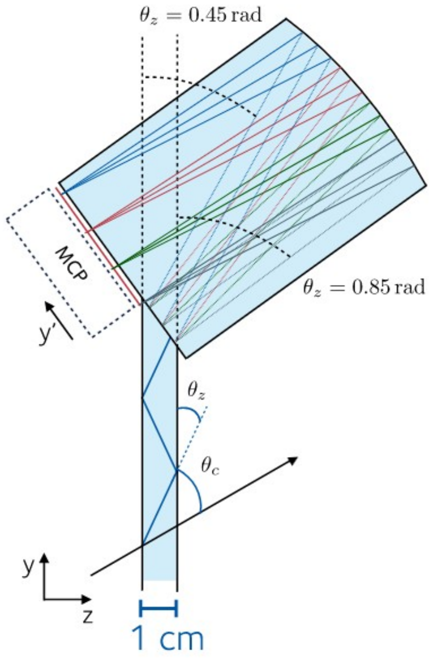
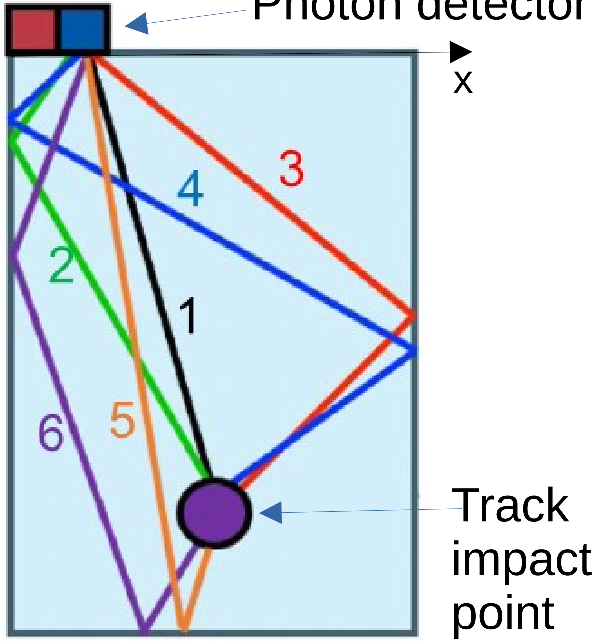


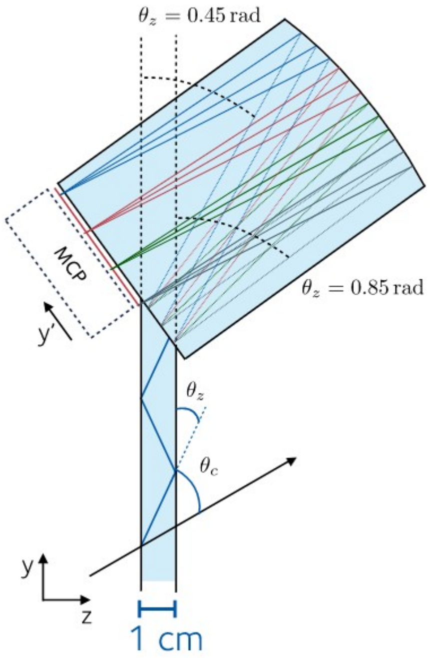
Side view
Focusing

The TORCH concept

- Photons from track are measured in 3D (x,y,t)



Downstream view



Side view
Focusing

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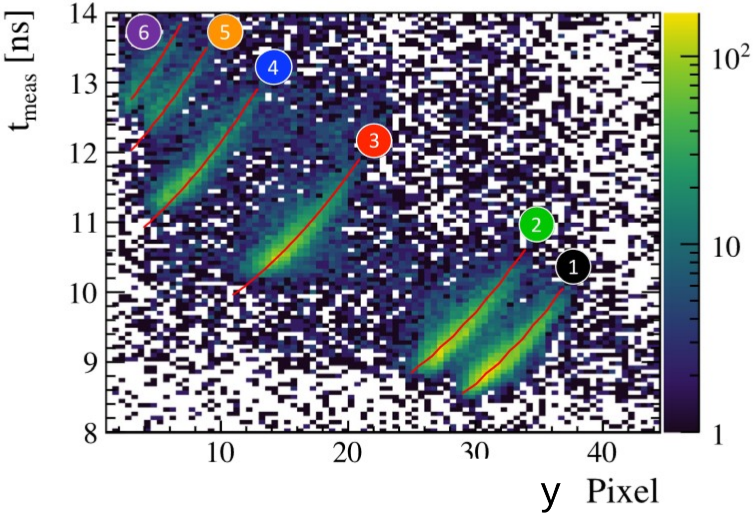

The y measurement corrects for the chromatic dispersion

TORCH design requirements

- Around 10ps time resolution per track is required
  - With around 30 photons, this translates into a requirement of around 70ps resolution per photon
  - This includes effects from pixel resolution, electronics, flatness of quartz, photon detectors, …
- Radiation hard photon detectors
- Readout every 25 ns
- Low channel count to keep costs down

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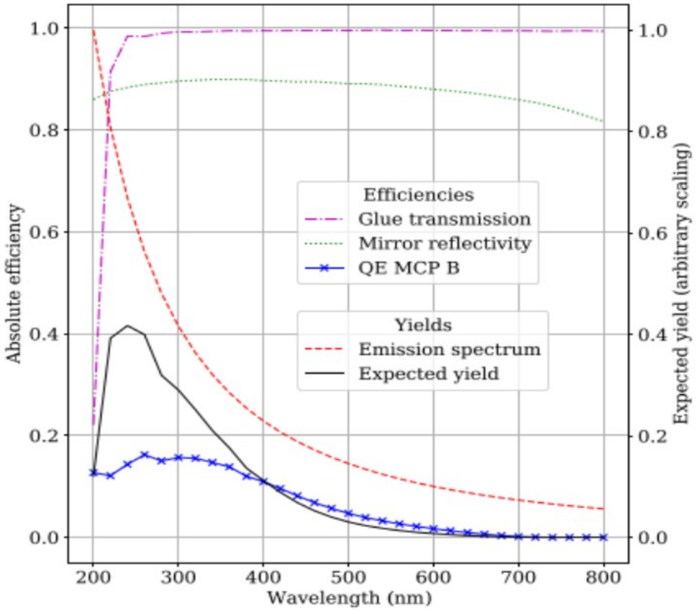
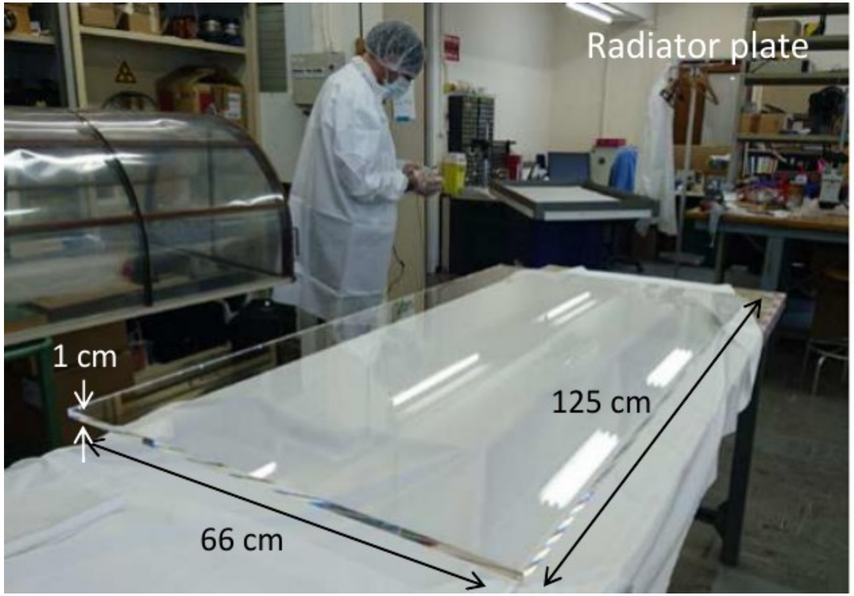
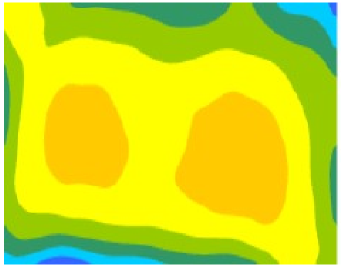
Optical system

- A half length prototype was made
  - Focusing block glued to radiator with Pactan 8030





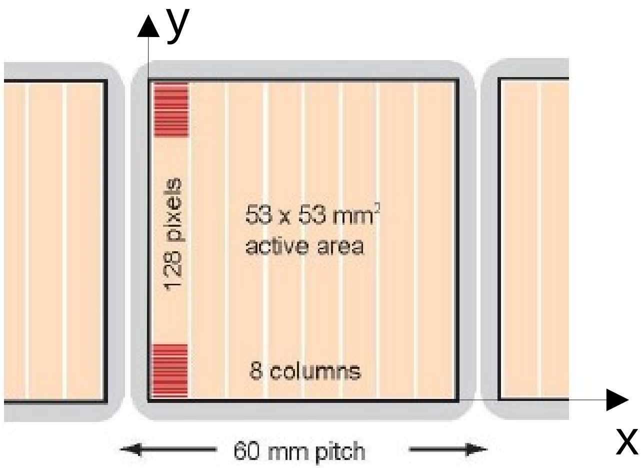
Fused silica



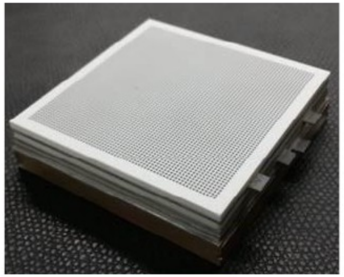
1 µm contours of surface flatness

Photon detectors

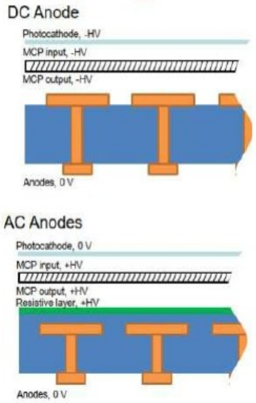
- Microchannel plate (MCP) PMT from Photek*
- 64x64 pads in 60x60 mm^2 configuration
- Channels can be bonded in x-direction to get balance between occupancy and cost of readout electronics



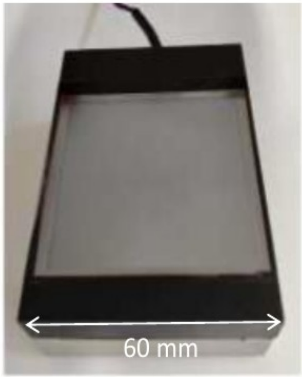
64 x 64 pads on anode



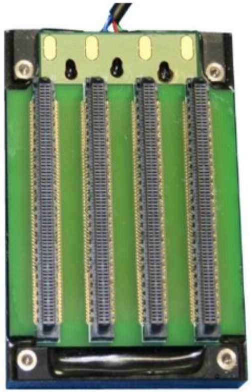
JINST 10 (2015) C05003



Front of potted MCP



Rear of MCP with PCB



*via ERC-funded R&D programme with TORCH

Photon detectors

- From measurements in the lab we see the following characteristics

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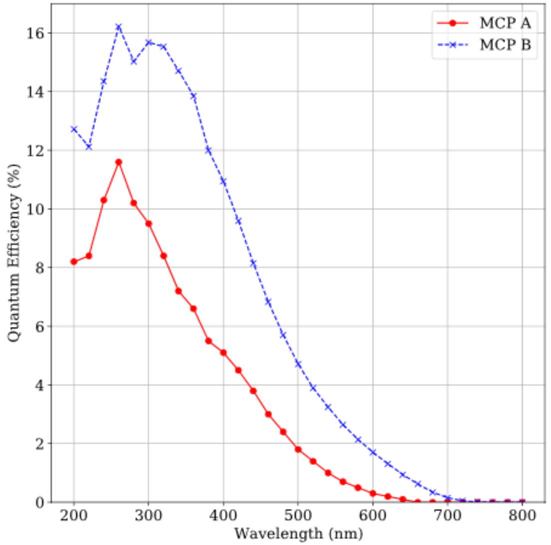
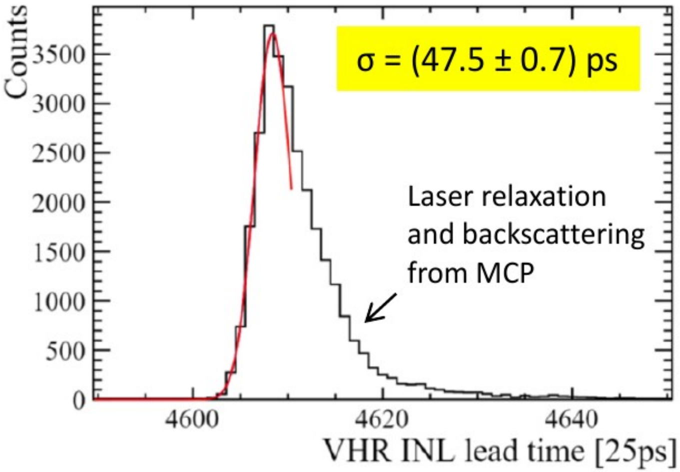
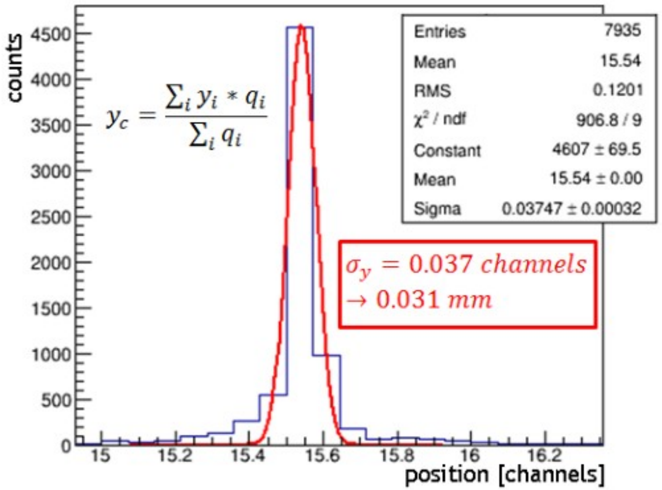
JINST 11 (2016) C05022



Quantum Efficiency



Time resolution

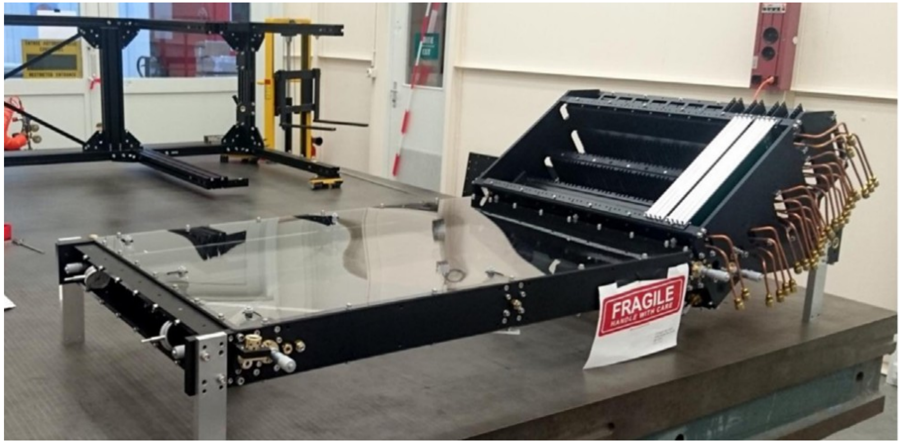


Spatial resolution

In TORCH design corresponds to 0.3 mrad

Testbeam

- Mixed p/π beam of 3-10 GeV from CERN PS used
- Tests in 2018, 2020 and 2022



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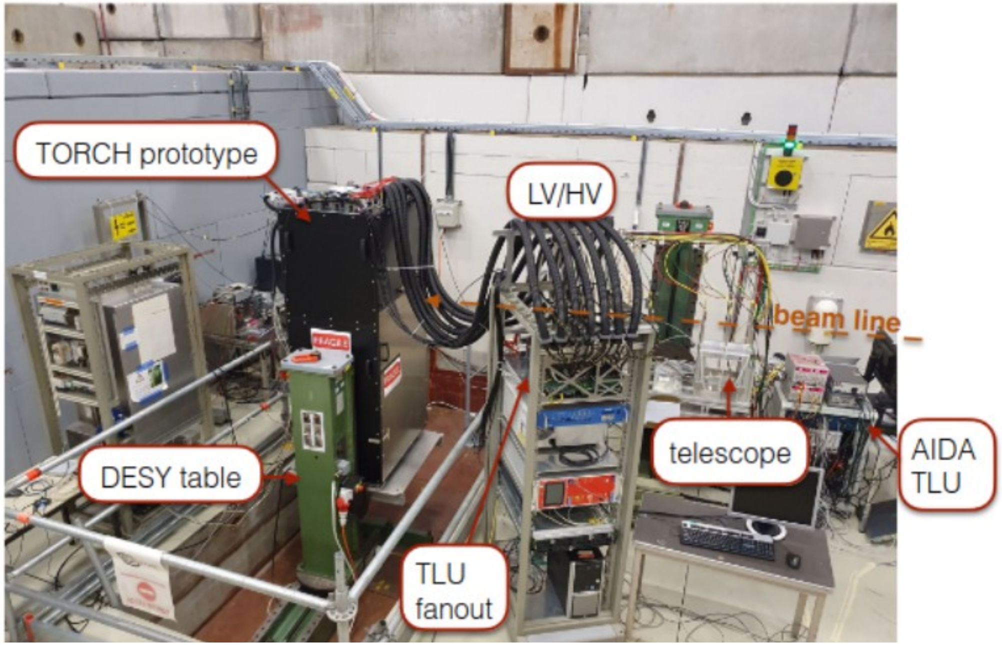

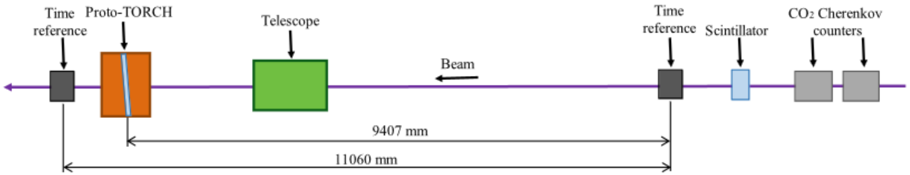

Testbeam results

- The single photon resolution was investigated in the testbeam
  - Contributions from propagation, spatial resolution, MCP and electronics
  - Approaching the 70ps requirement

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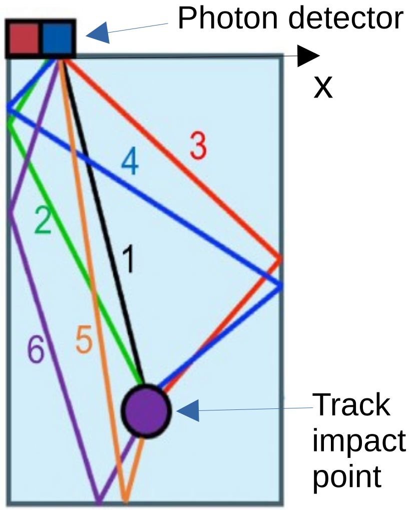

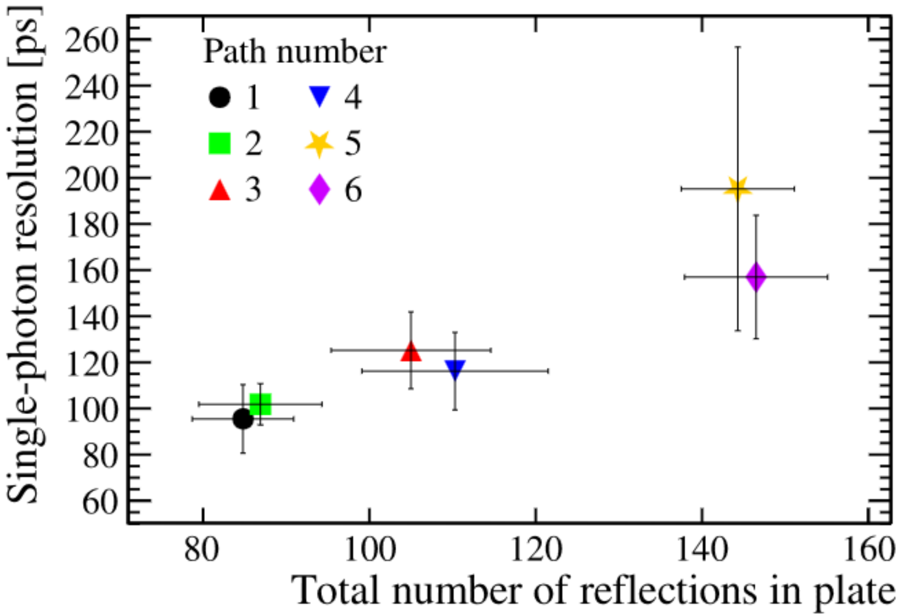

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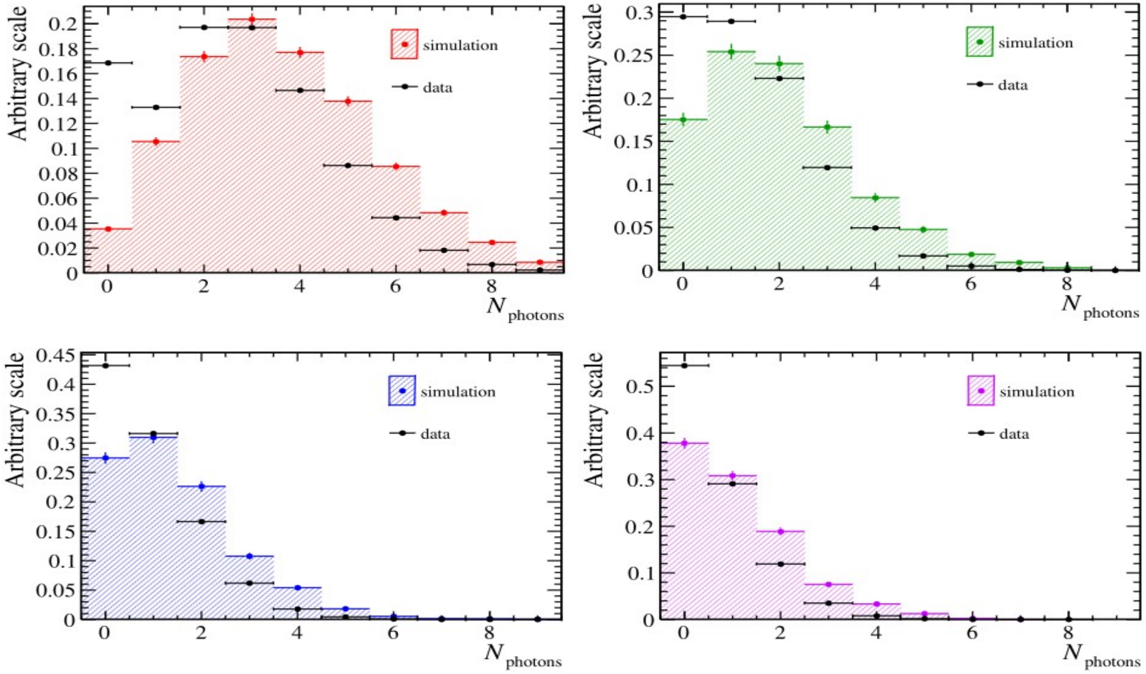
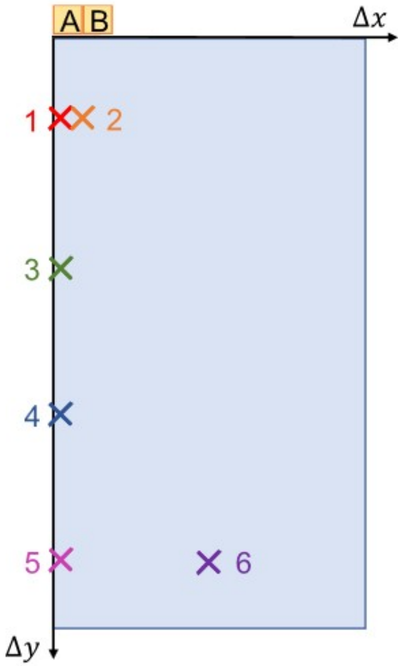
Testbeam results

- Photon yield is above 80% of expectation from simulation

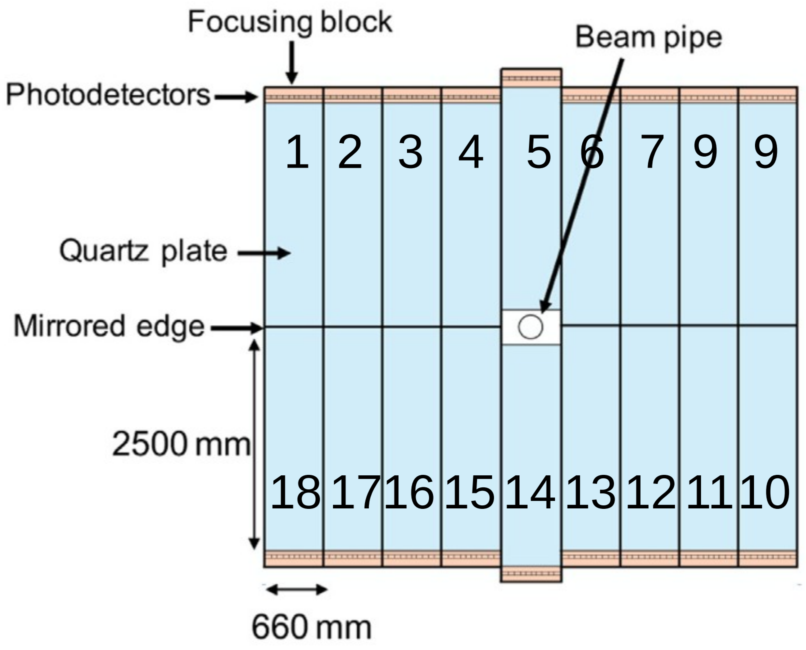


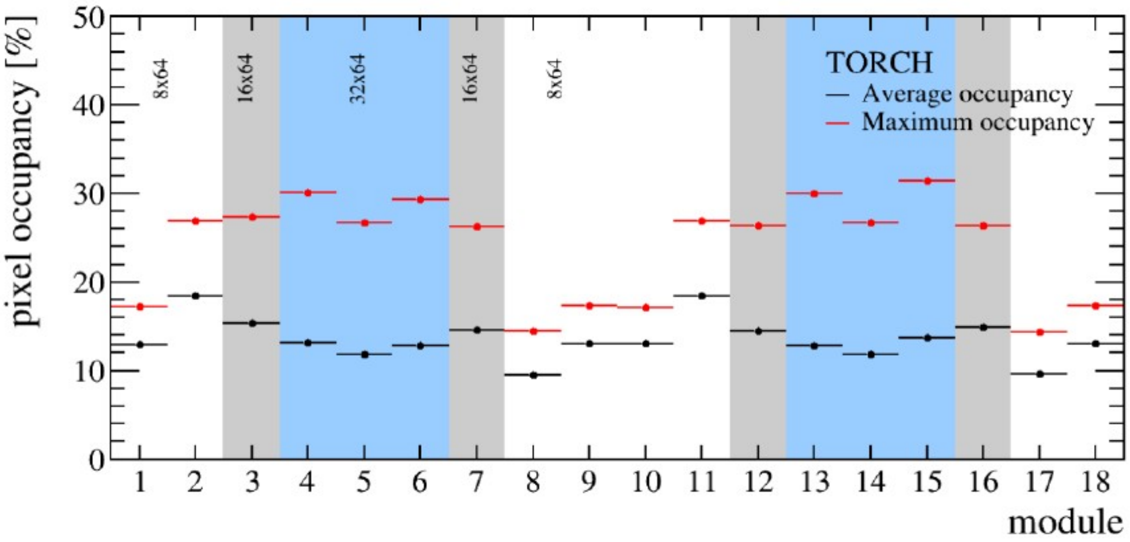
Zero yield measurements caused by accidental triggers and the too high thresholds in prototype electronics



Occupancy in TORCH

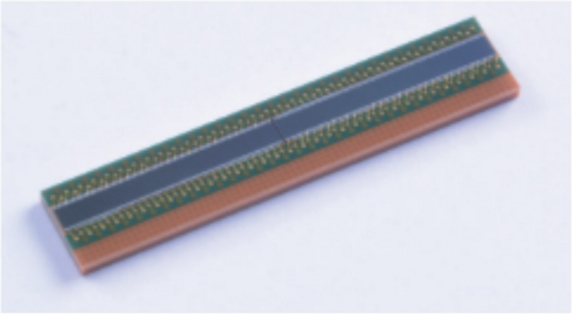
- Regions closest to the centre axis will face a very high occupancy
- Bonding fewer channels together can lower it, but still high





Occupancy in TORCH

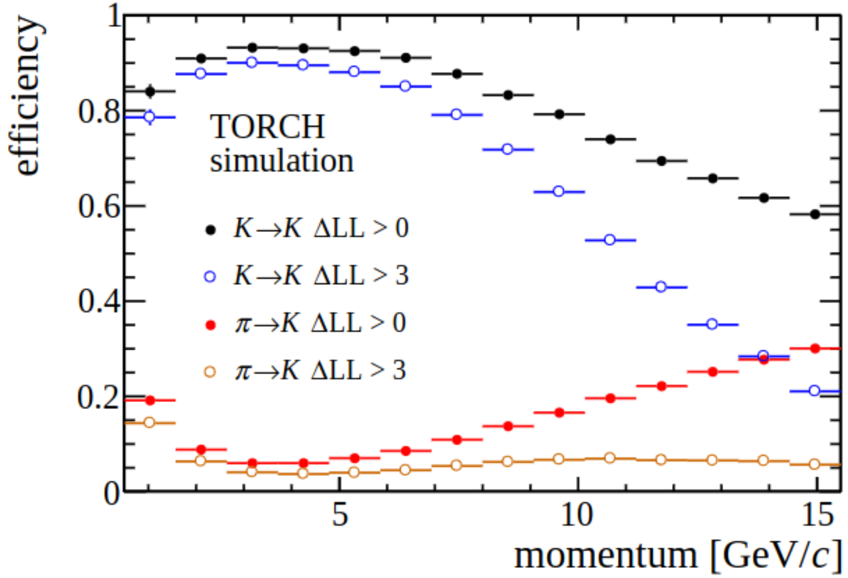
- Further developments ongoing with Photek to develop a MCP with more channels and reduced cluster sizes to reduce occupancy
- Ongoing considerations about equipping part of the detector with solid state photon detectors (SiPM, MPPC, …)
- Existing MCCP experience within LHCb from their use in the scintillating fibre tracker

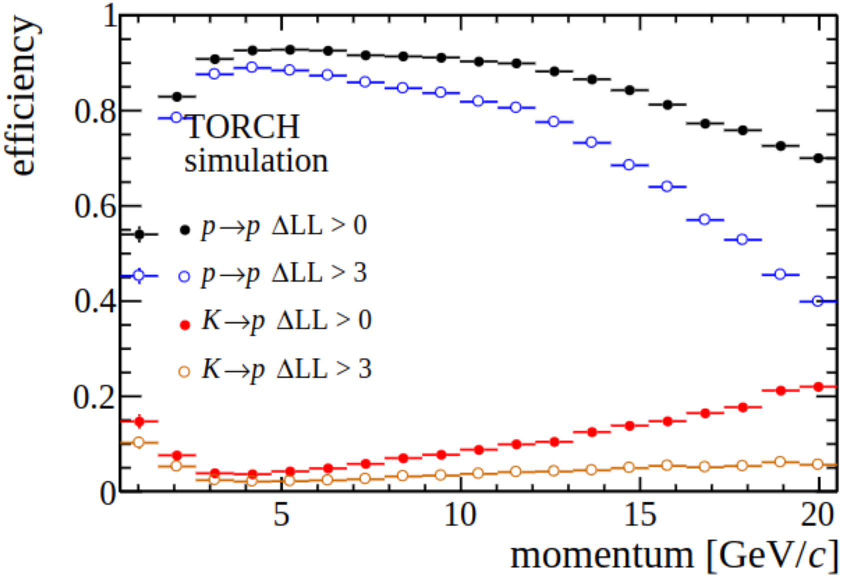


Hamamatsu S13552
Pitch 1.6 x 0.23 mm^2
Used in LHCb SciFi

Simulated TORCH performance

- With design specifications and at Upgrade II luminosity, excellent hadron ID down to 1 GeV





Conclusions

- The TORCH detector will add hadron identification at low momentum to LHCb Upgrade II
- In conjunction with upgraded RICH detectors this will provide hadron identification across full momentum range for pp collisions
- Beam tests and their ongoing analysis has demonstrated feasibility of concept
- An ambitious R&D programme is required to enable installation in a decade from now
- Will be part of the new DRD4 collaboration on photon detectors and PID