TORCH test beam analysis and developments in MCP-PMTs and electronics

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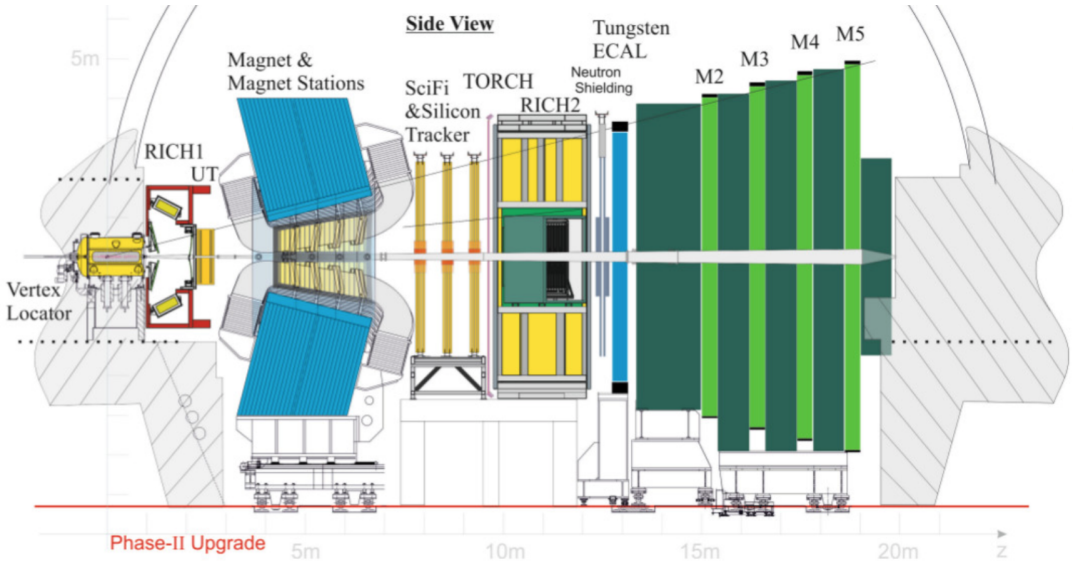
LHCb-UK annual meeting, RAL

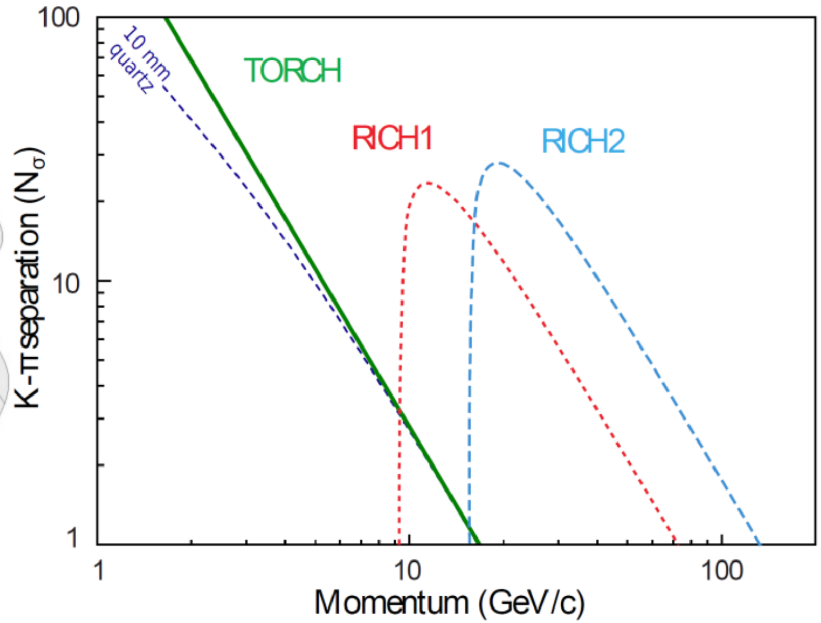
8th-10th January 2024

Introduction to TORCH

TORCH: Time Of internally Reflected CHerenkov light

- Particle identification at LHCb at low momentum (2-20 GeV)
- Ensure full coverage of LHCb's flavour physics programme
  1. Boost signal efficiencies and suppress mis-ID backgrounds
  2. Improve flavour tagging efficiency by 25-50%

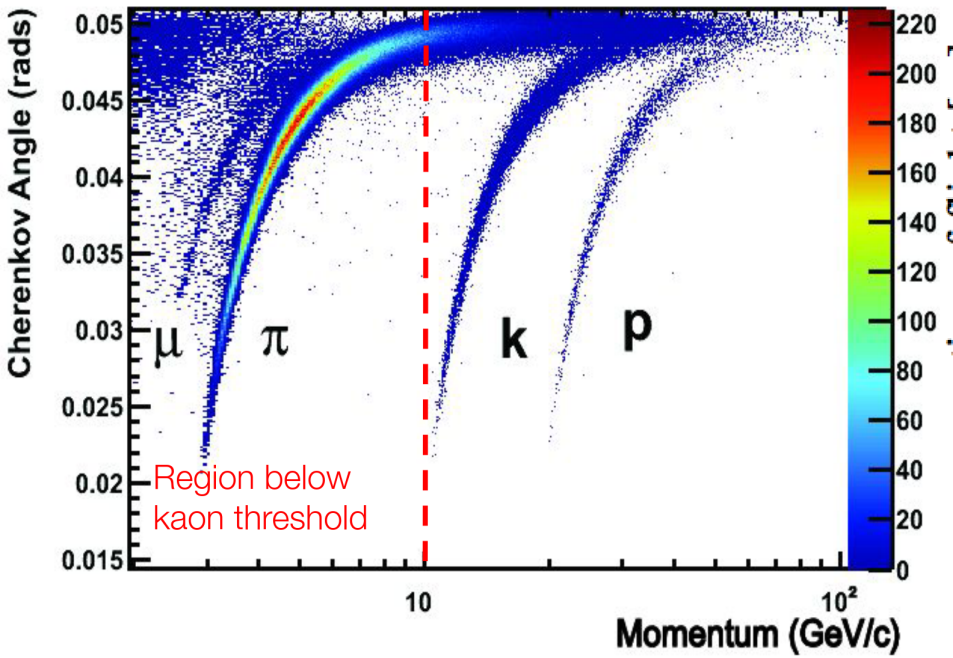


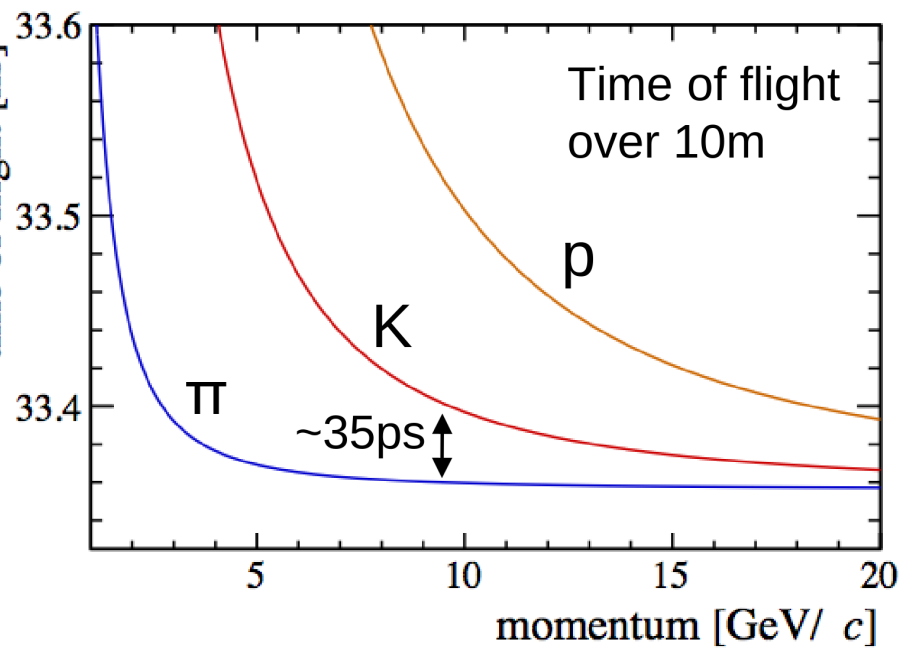


Introduction to TORCH

PID with Time-of-Flight, combined with Cherenkov information

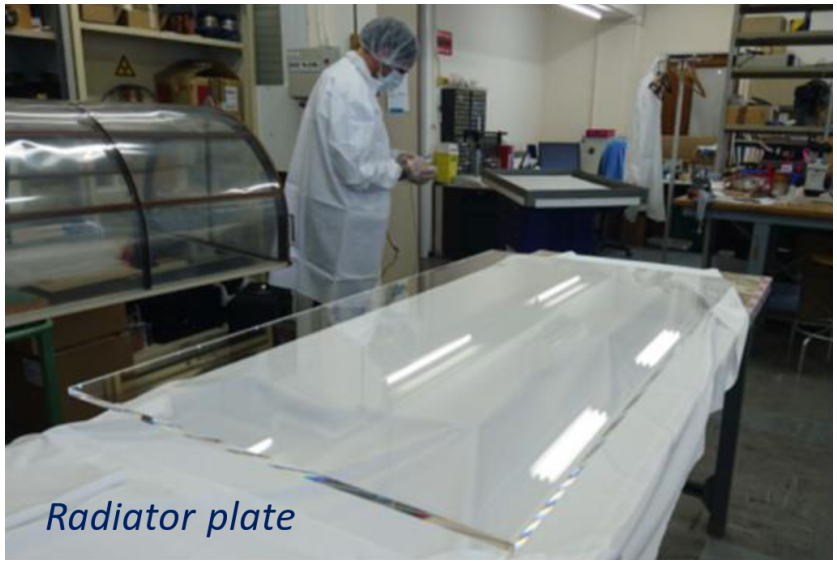
- Cover physics region inaccessible to RICH
- π-K ToF difference over 10 m $\implies$ Aim for 10-15 ps resolution
- Single-photon precision of 70 ps with $\sim$ 30 detected photons

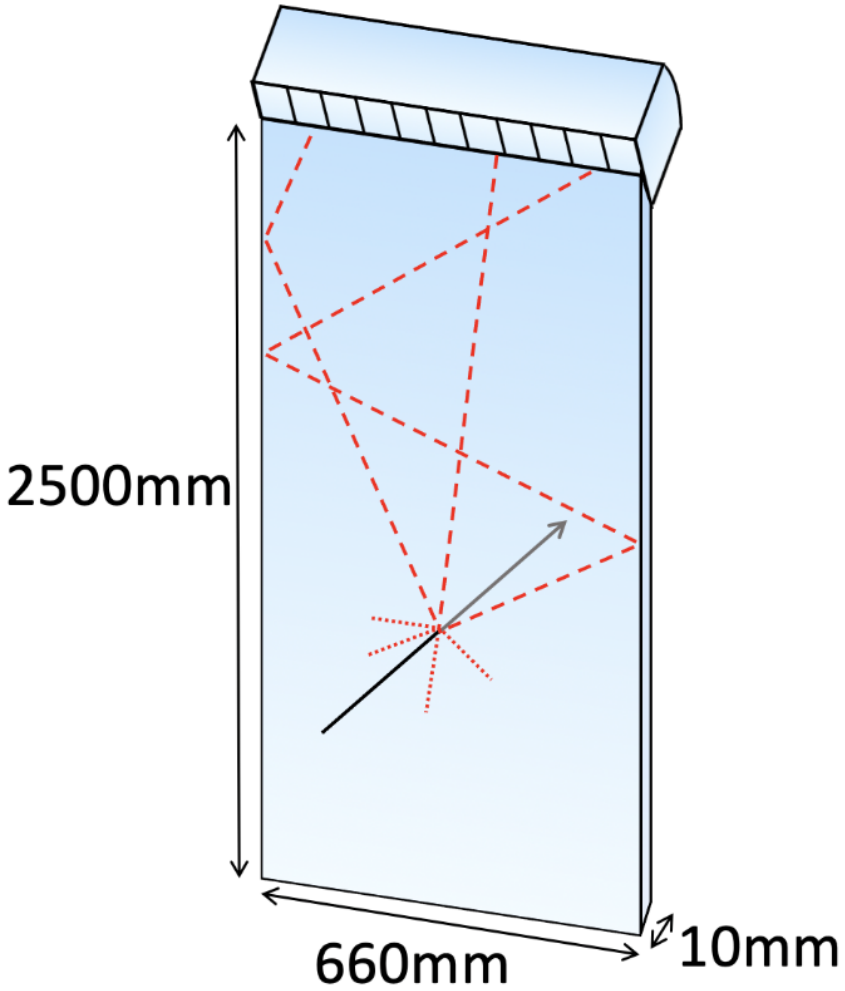




TORCH working principle

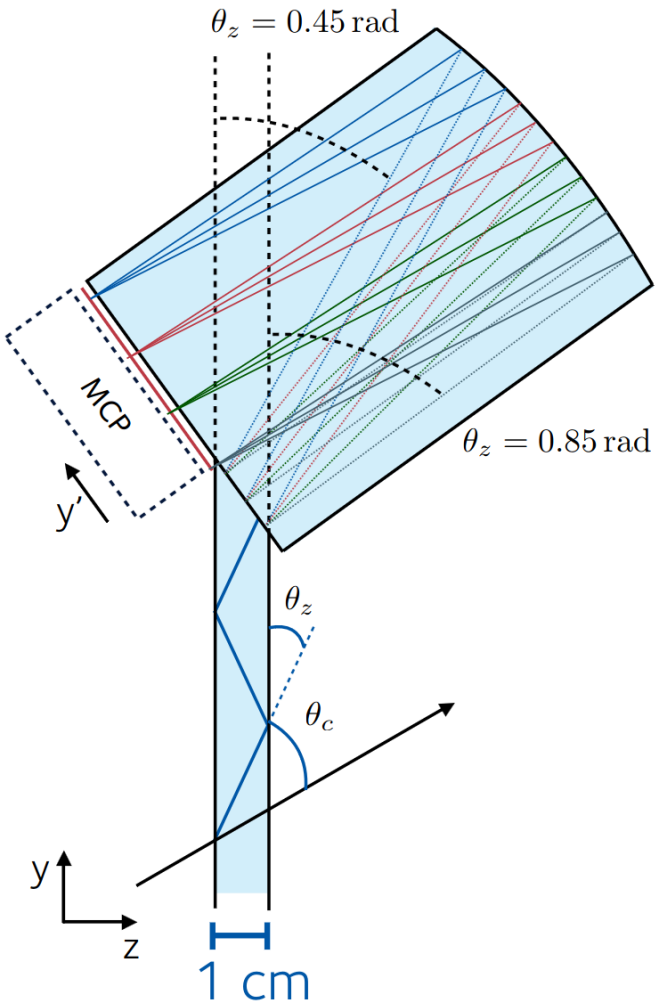
1. Charged particle enter quartz
2. Cherenkov photons emitted
3. Photons undergo internal reflection until they reach the top of the plate





TORCH working principle

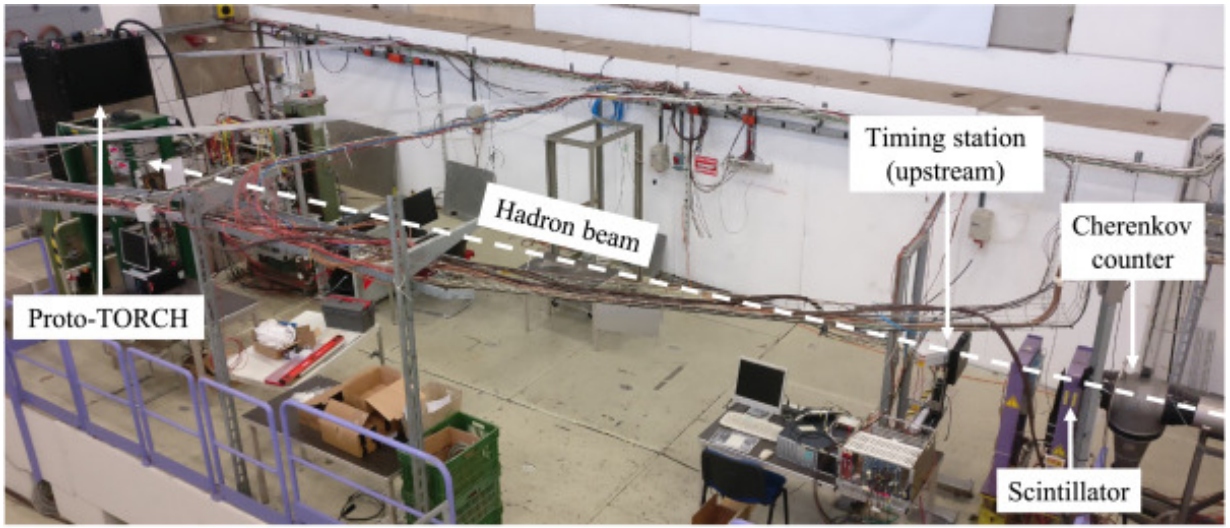
1. Focus photons with cylindrical mirrror
2. Image consists of hyperbolic "bands"
   - Compare with circular rings in RICH
3. Correct for chromatic dispersion using the Cherenkov angle obtained from y'



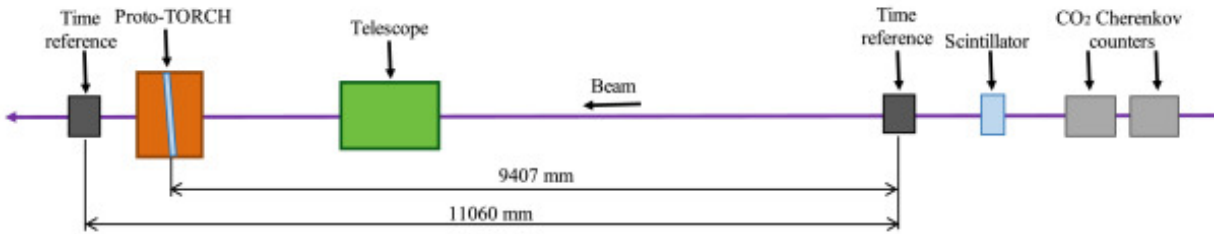
2018 test beam analysis

2018 test beam analysis paper published earlier this year

- 8 GeV beam of pions and protons from the CERN T9 beamline
- Single-photon resolution down to 70 ps achieved



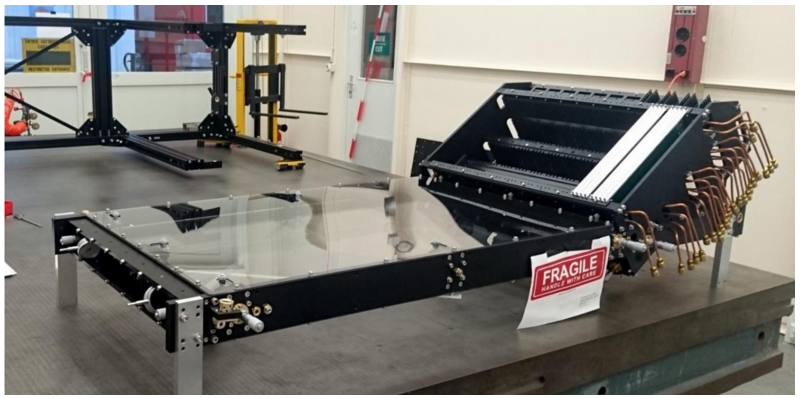
(a)



(b)

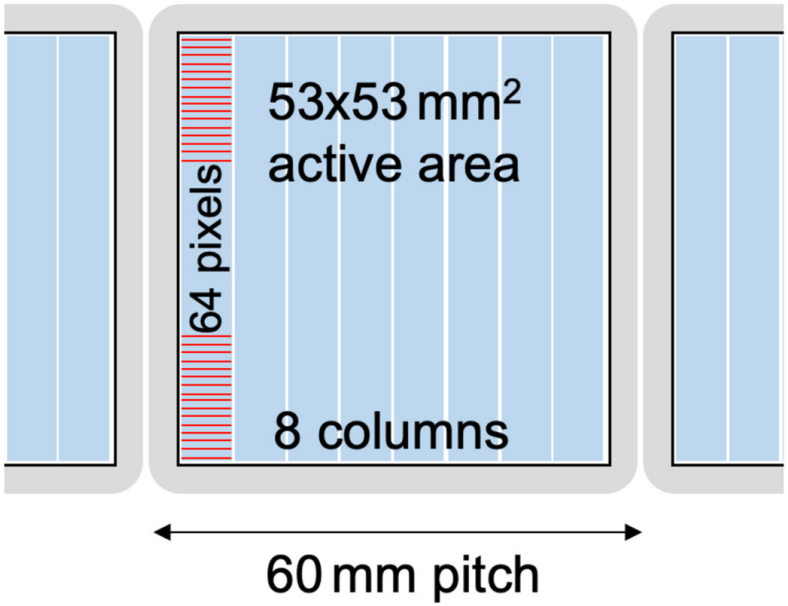
2018 test beam analysis

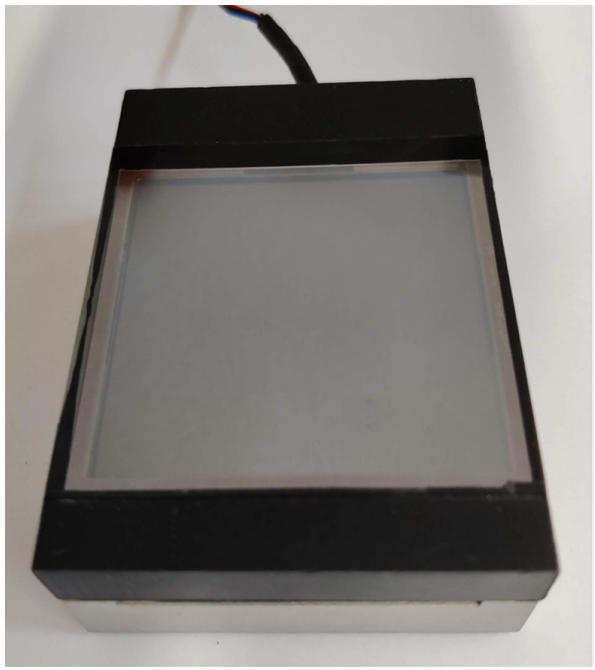
- Prototype of TORCH
- Full width, half height
- Nikon glass with polished surfaces

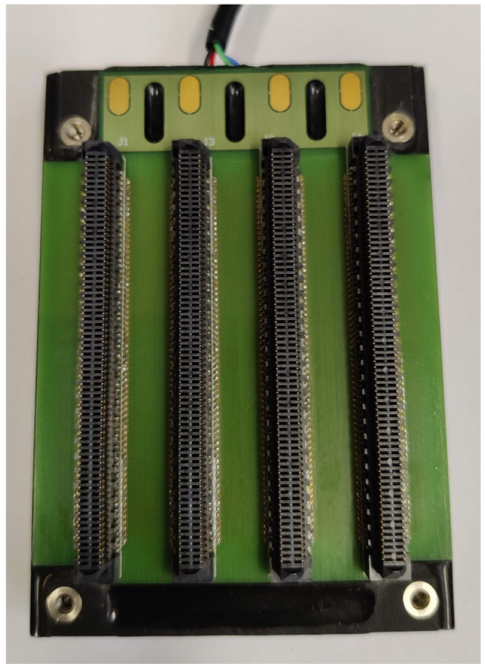


2018 test beam analysis

- Photon detector: MicroChannel Plate PhotoMultiplier Tube
- $53 \times 53\text{mm}^2$ active area
- 8 columns, each with 64 pixels
- Effectively 128 pixels with charge sharing







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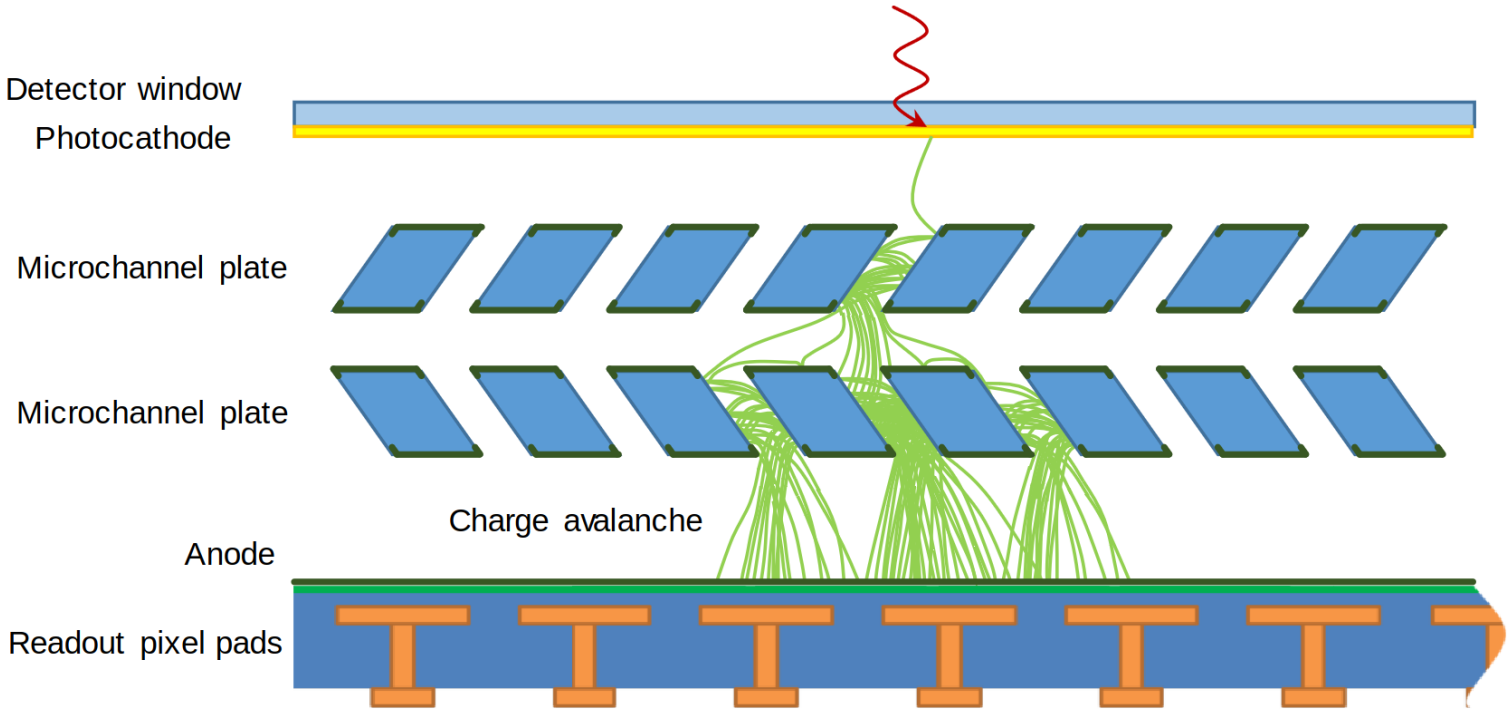
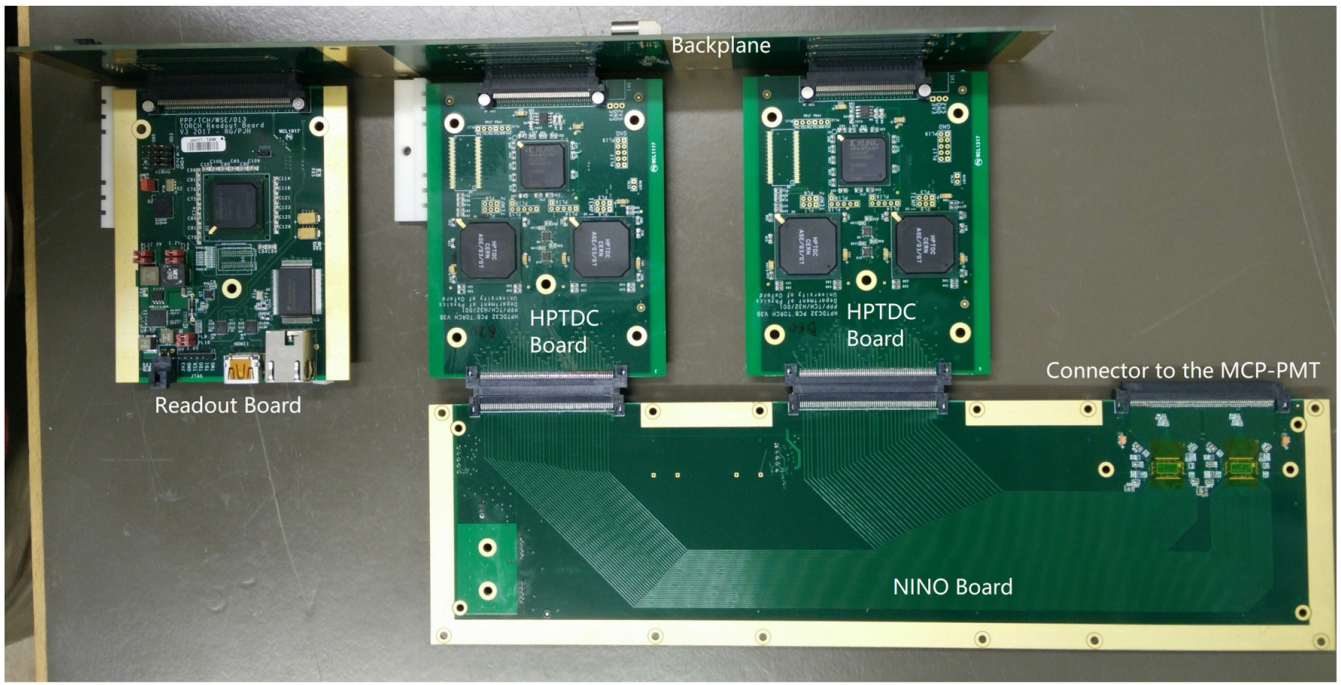


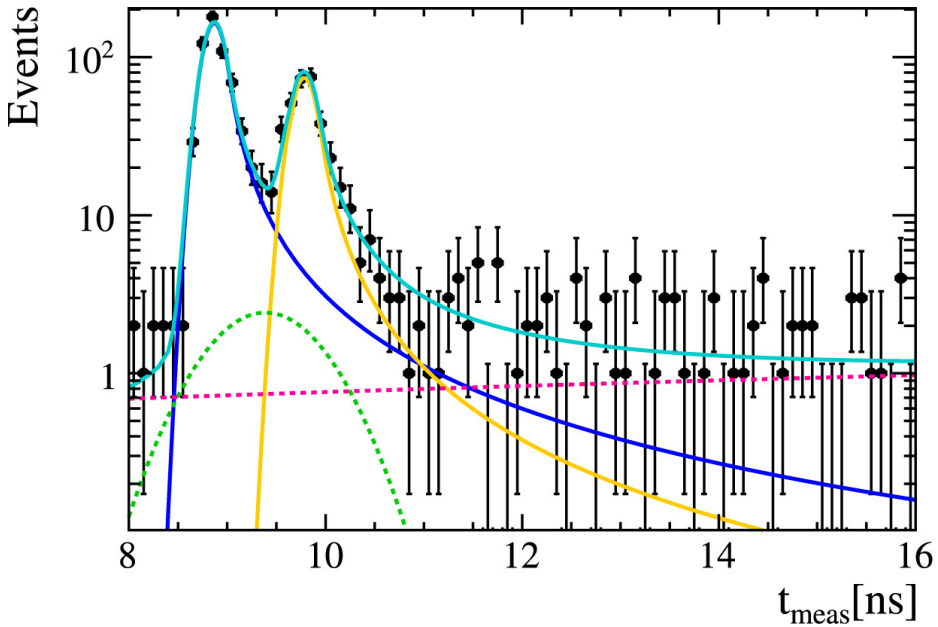
2018 test beam analysis

- NINO: Amplifier and discriminator
- High Performance Time to Digital Converter: 100 ps bins
- Legacy electronics that will be replaced, more on this later!

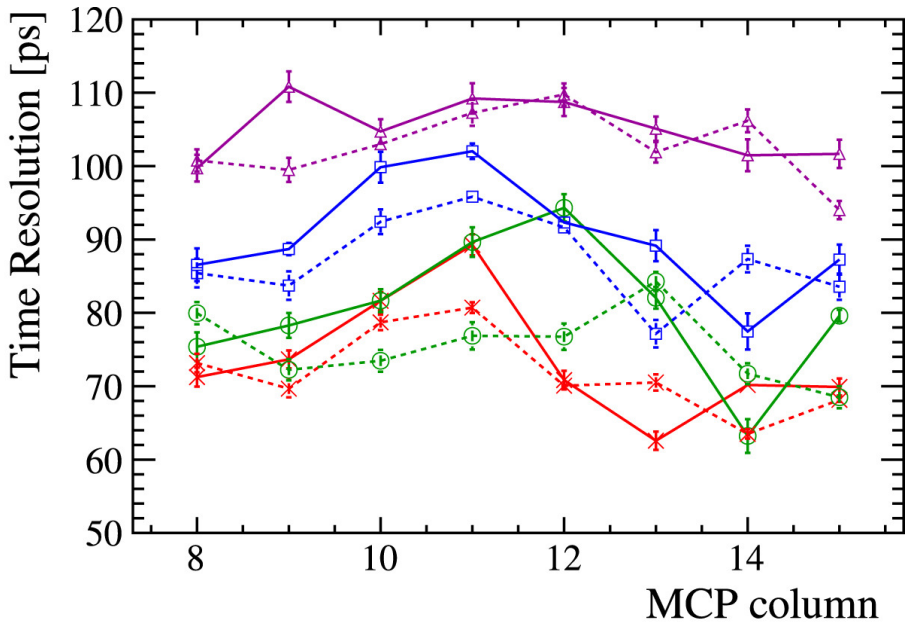


2018 test beam analysis

- Time resolution down to 70 ps
- Worse resolution for tracks entering at the bottom
  - Uncertainty in chromatic dispersion scales with photon path length
  - Improvements expected with further electronics calibrations



(a)

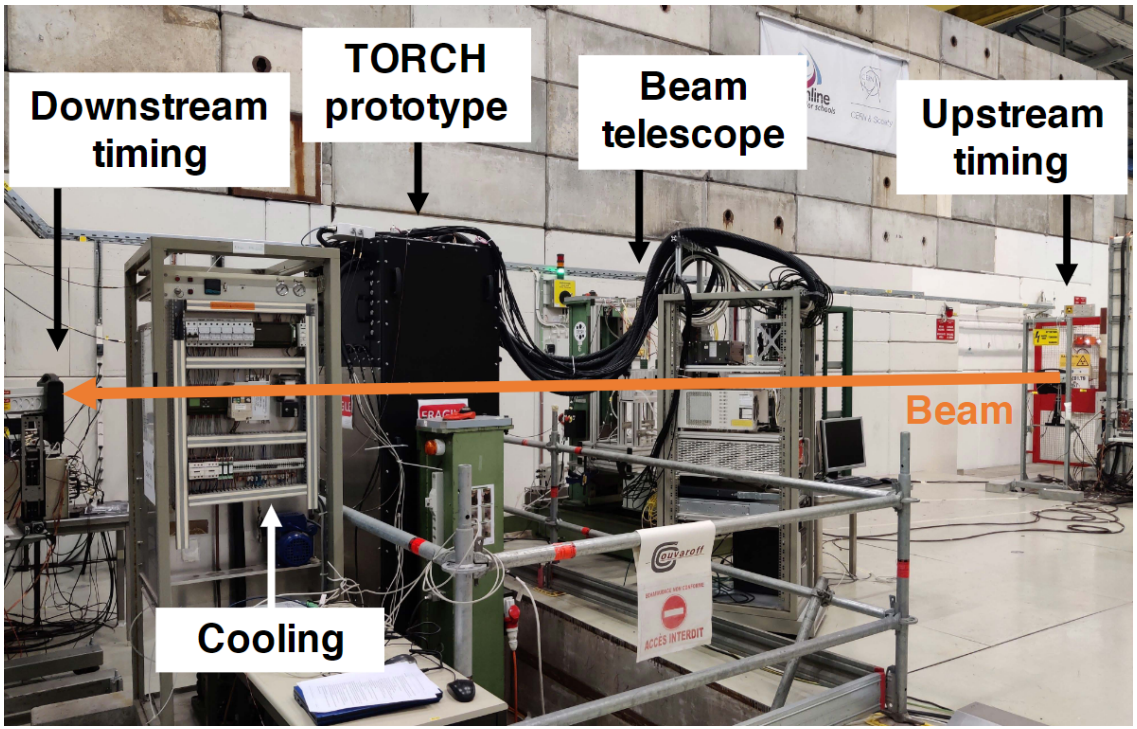


(b)

2022 test beam analysis

Back to T9, with several new goals:

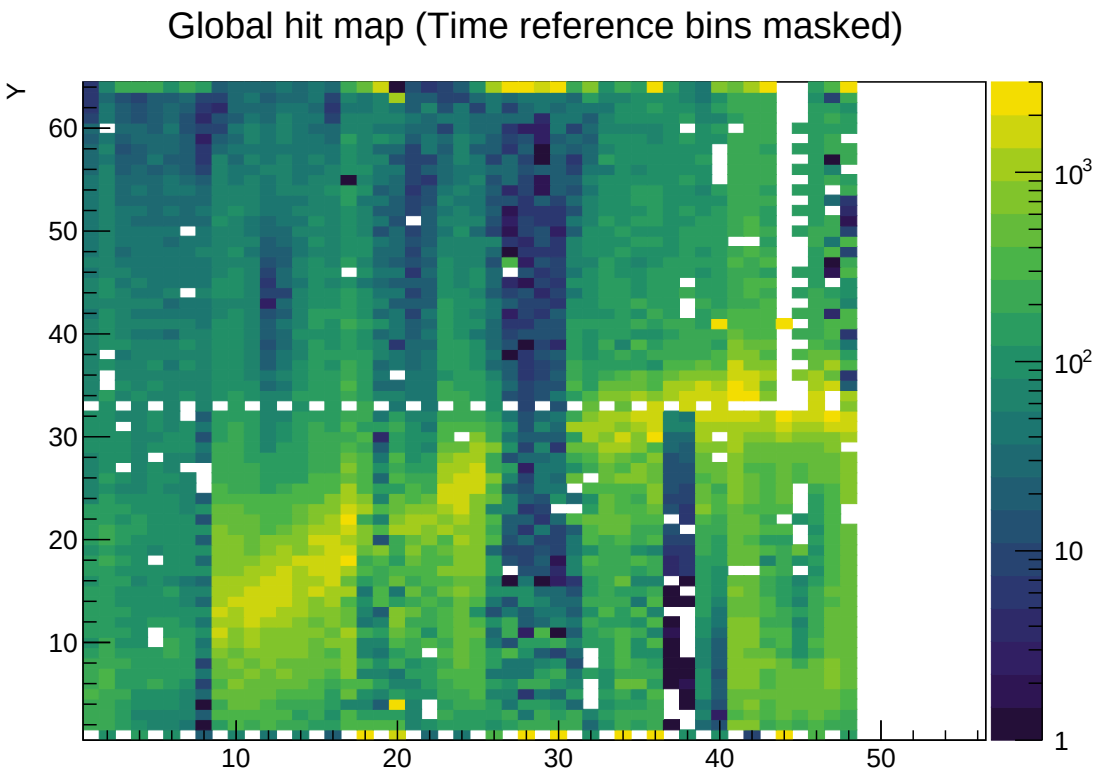
1. Additional, fully instrumented, MCP-PMT tubes (7 in total)
2. Wide range of beam momenta (3, 5, 8, 10 GeV and higher)
3. First demonstration of PID separation in TORCH



2022 test beam analysis

Global hit map looks very encouraging!

1. Hit pattern seen across 6 MCP-PMT tubes
2. Minimal degradation of original MCP A and B
3. Proper time reference channel present in (almost) all columns

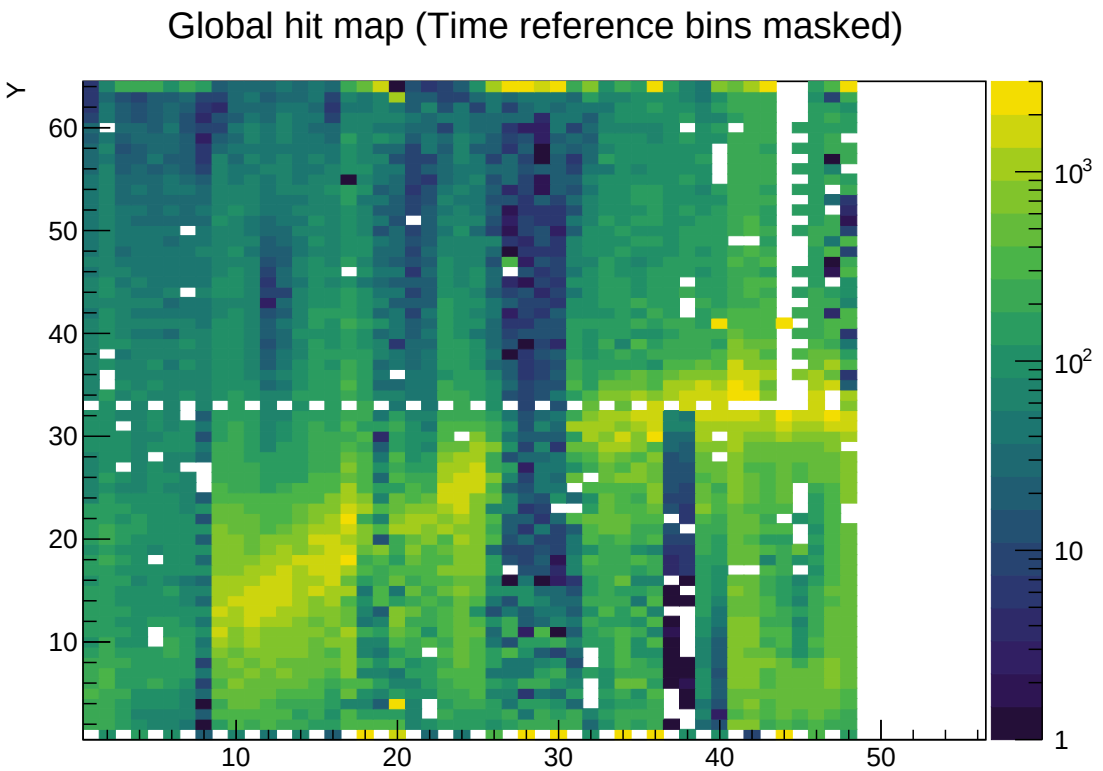


2022 test beam analysis

Additional MCP tubes work well, but focus on MCP A and B for now

1. Electronics of new MCPs need to be understood better
   - Improve stability and reliability
   - NINO thresholds need to be optimised

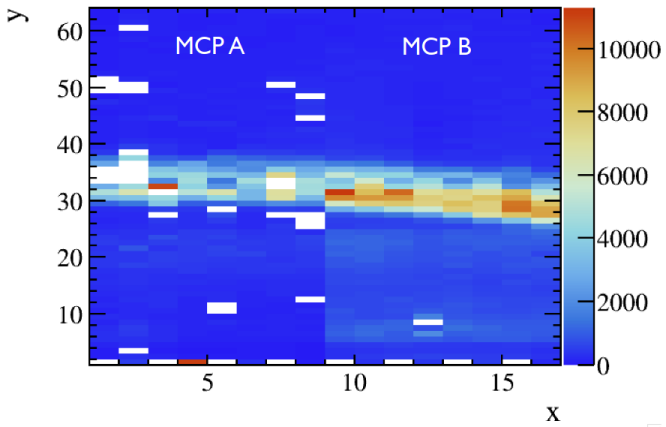
2. Some non-uniformity in QE and gain seen in MCP C, D and F



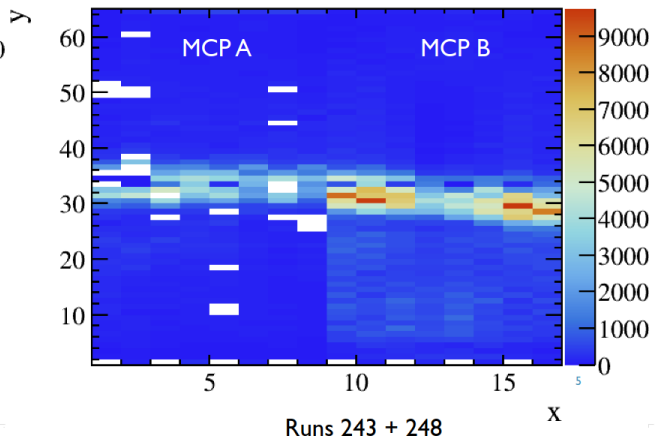
2022 test beam analysis

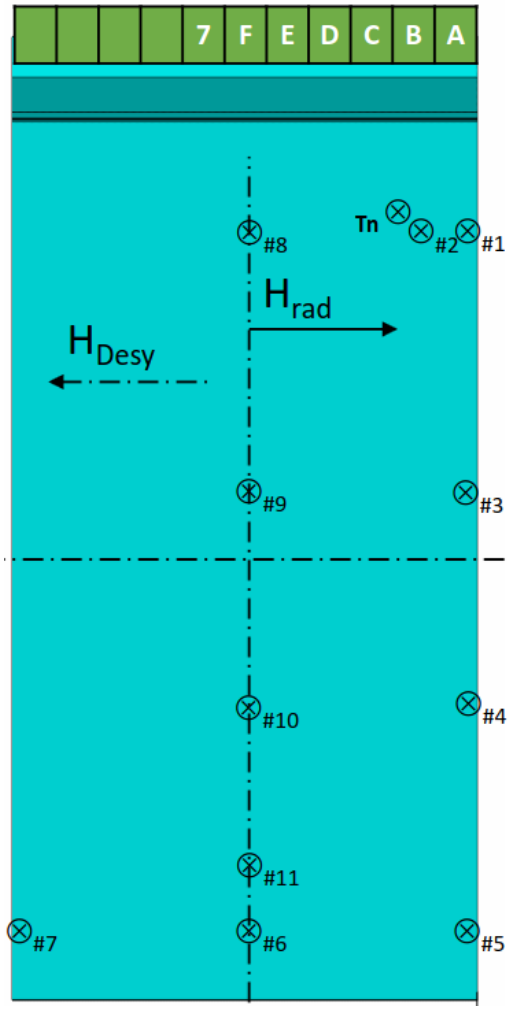
- Study positions 1, 8, 9, 10, 11, 12
- Below: Comparison of position 1 between 2018 and 2022 data $\Longrightarrow$ Perfect agreement!

2018



2022

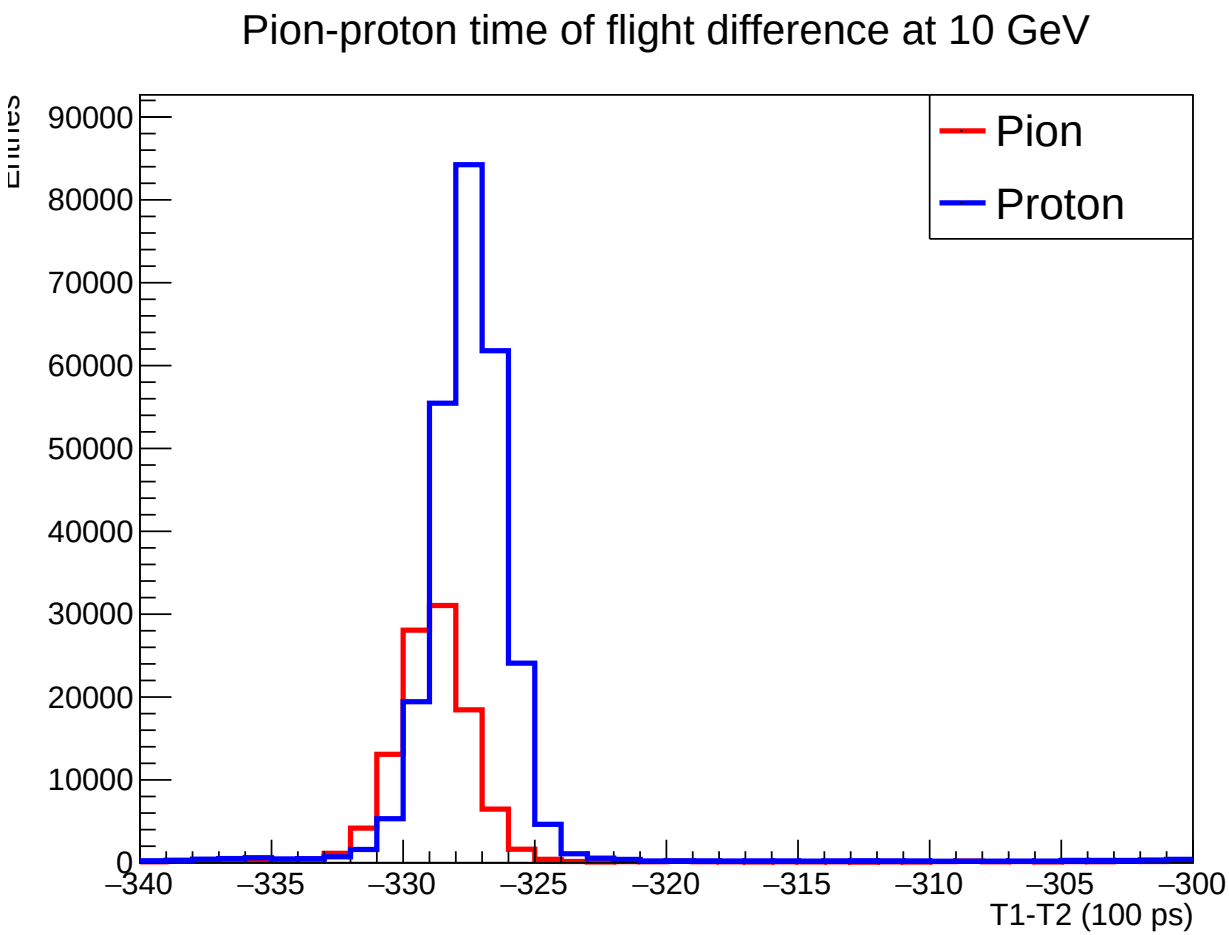




- This talk: Preliminary results from position 8
  - Never studied before!

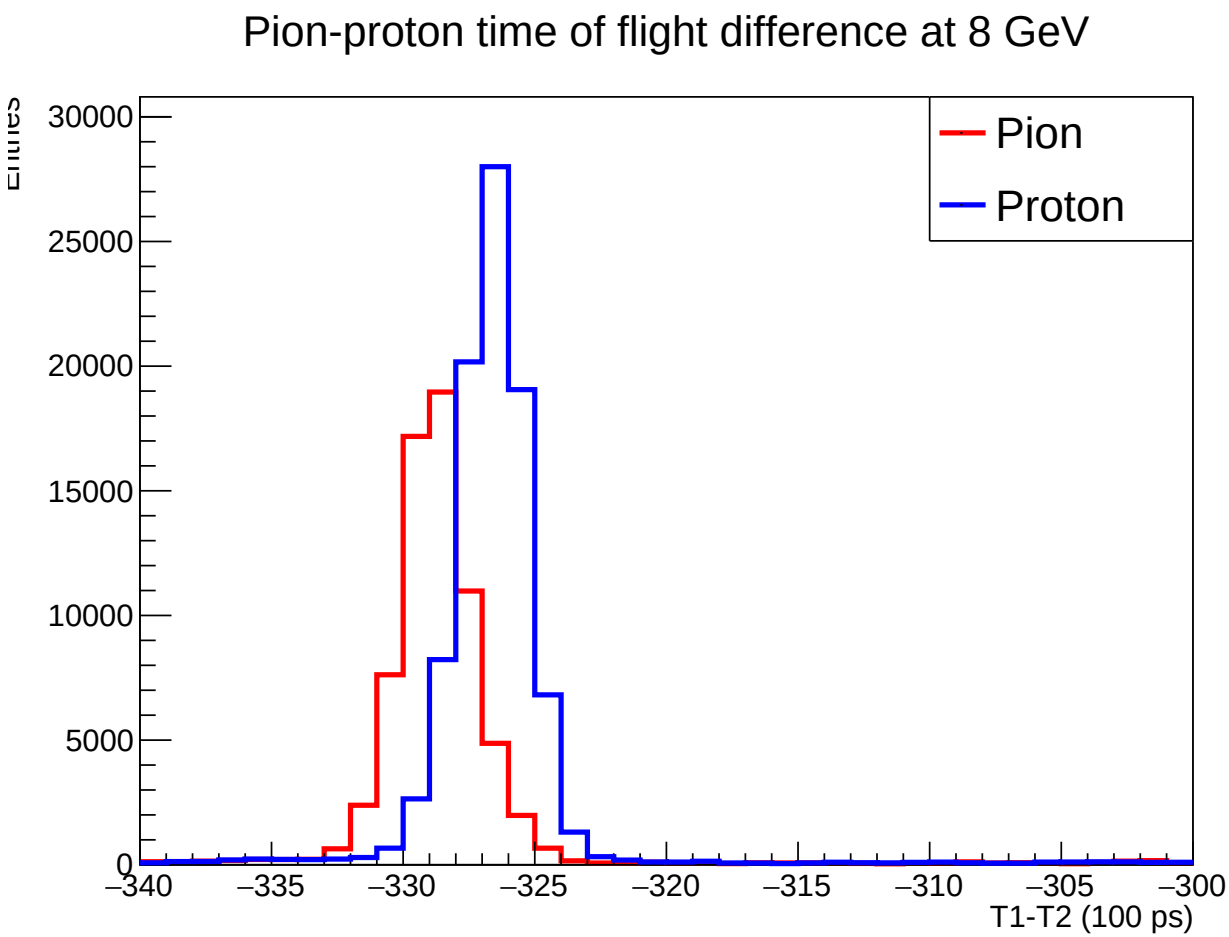
2022 test beam analysis

Check time of flight between time references
Expected time difference at 10 GeV: 0.15 ns



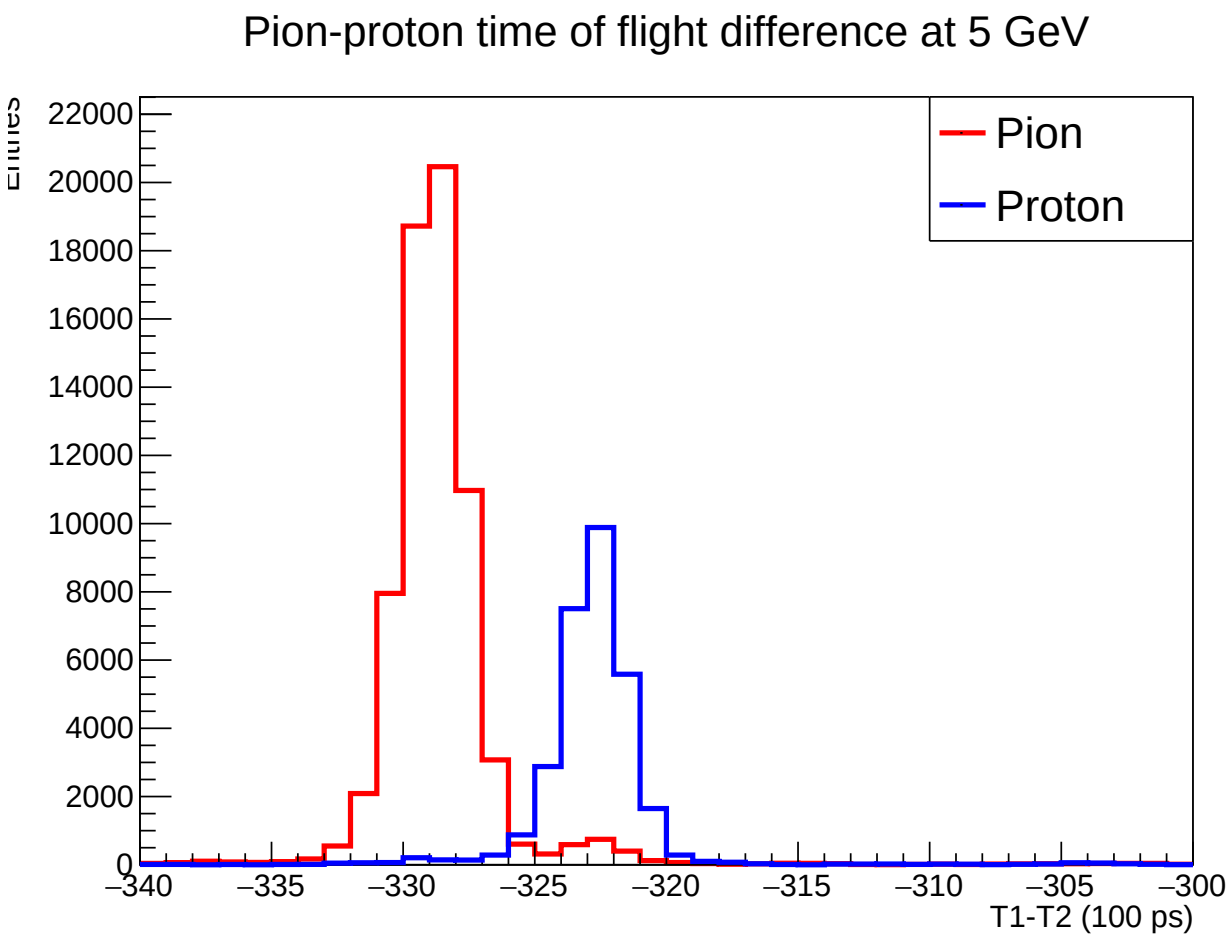
2022 test beam analysis

Check time of flight between time references
Expected time difference at 8 GeV: 0.23 ns



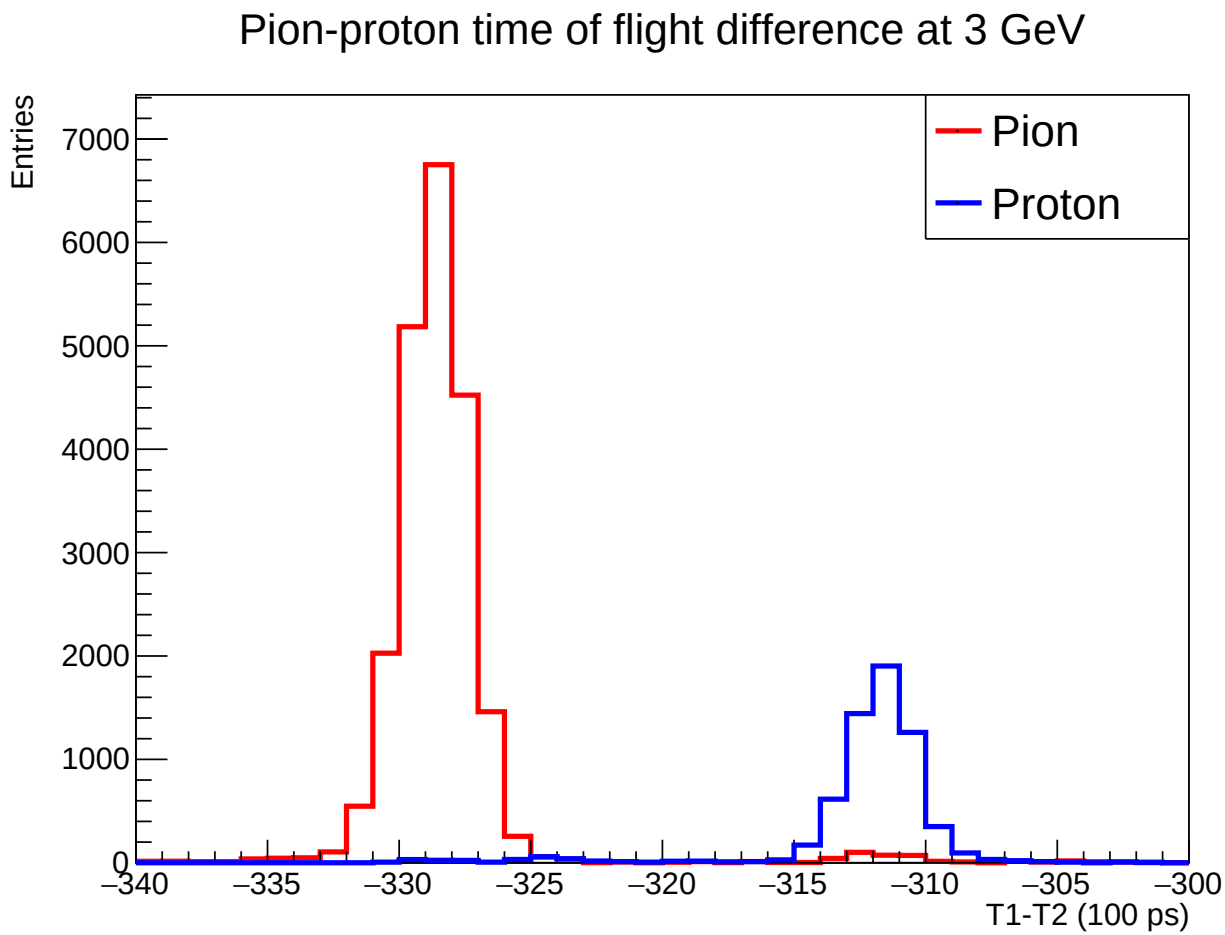
2022 test beam analysis

Check time of flight between time references
Expected time difference at 5 GeV: 0.59 ns



2022 test beam analysis

Check time of flight between time references
Expected time difference at 3 GeV: 1.6 ns



Summary and future prospects

Summary:

1. Test beam analysis progressing well, with promising results
   - Hit patterns well understood
   - More detailed analysis of time information ongoing

2. We have aquired new electronics and new MCP-PMTs
   - Lab testing ongoing
   - New electronics will replace legacy NINOs and HPTDCs
   - New MCP-MPTs have higher spatial resolution

Summary and future prospects

Future prospects:

1. Finalise test beam analysis
   - Calibrations
   - Photon counting
   - Time resolution
   - PID performance

2. New test beam is planned for early 2025
   - Demonstration of full height quartz plate TORCH and mechanics

Thanks for your attention!