TORCH Detector Studies

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Introduction

- Aim to provide proof of concept for the TORCH detector

- Targeting three areas:

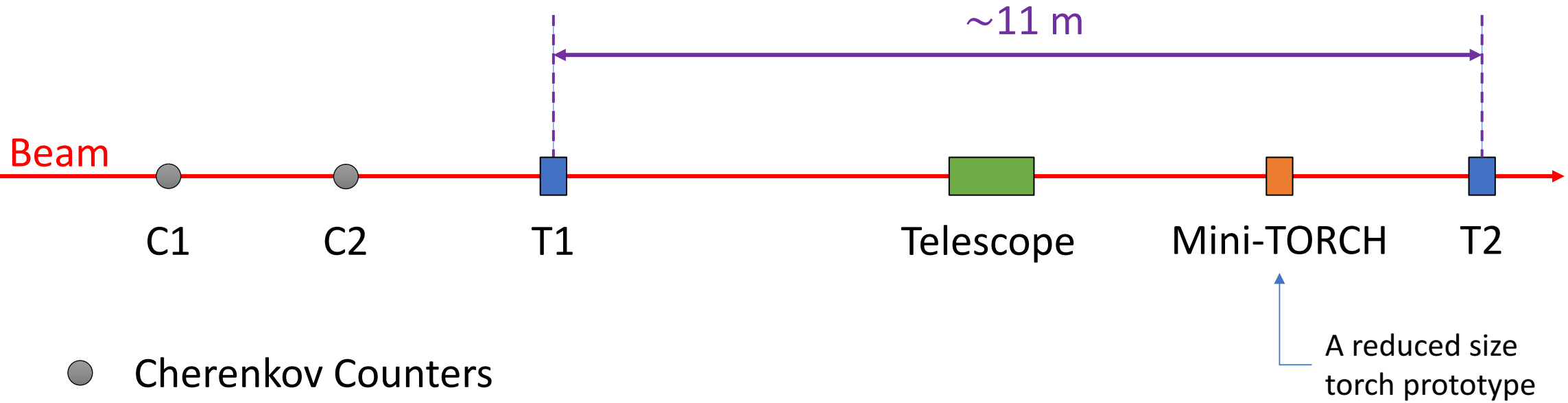
Individual Photon Timing Resolution

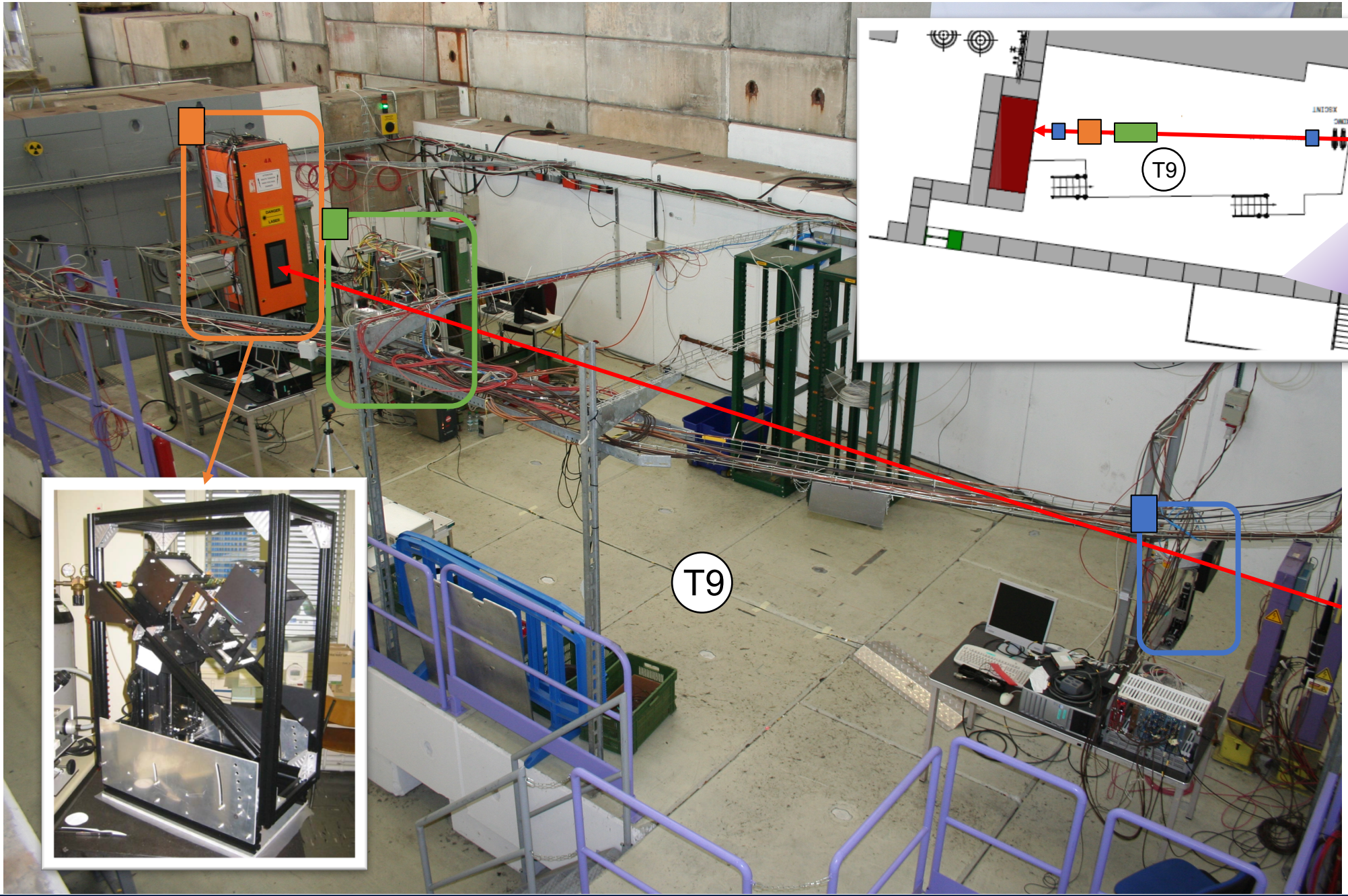
Photon Counting Efficiency

PID Performance

Testing TORCH - Testbeam Setup

- Testbeam carried out in the East Area T9 facility at CERN in Nov 2017





Mini-TORCH

Beam Telescope

Cherenkov Counters

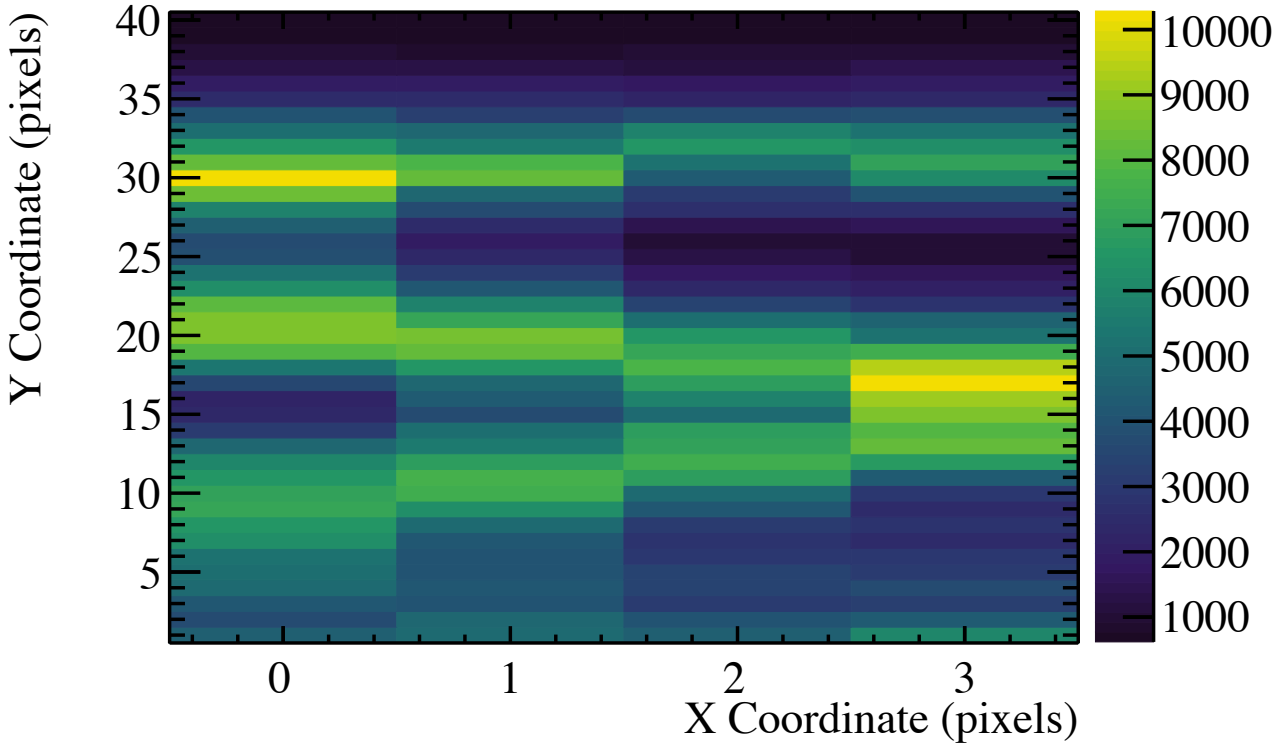
Timing Stations

Beam

Camera's View

Testing TORCH - Initial look at data

Hitmap of clustered testbeam data



- Electron shower from single photon falls across multiple pixels

➢ Hits are clustered using both positional and time information

- Time measured using NINO/HPTDC electronics

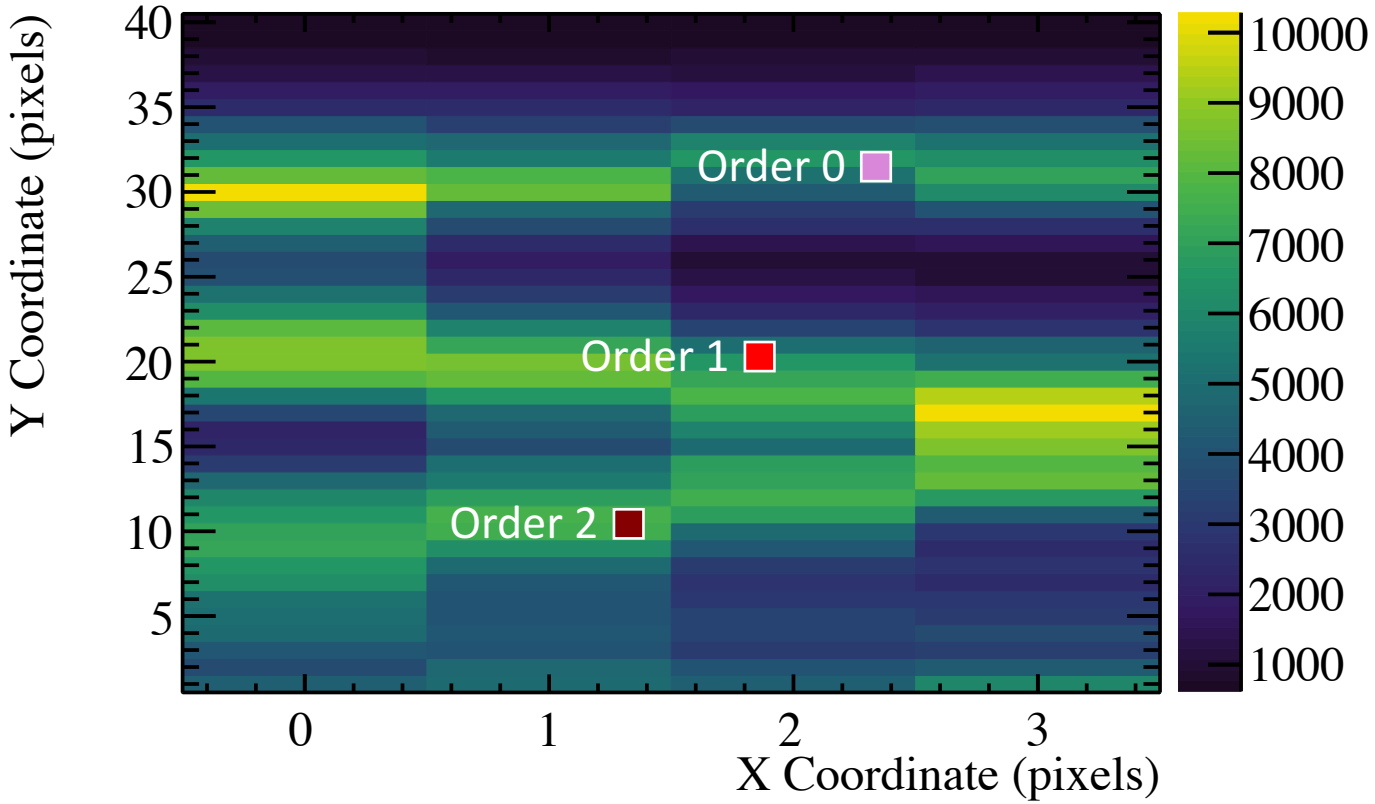
Time Resolution

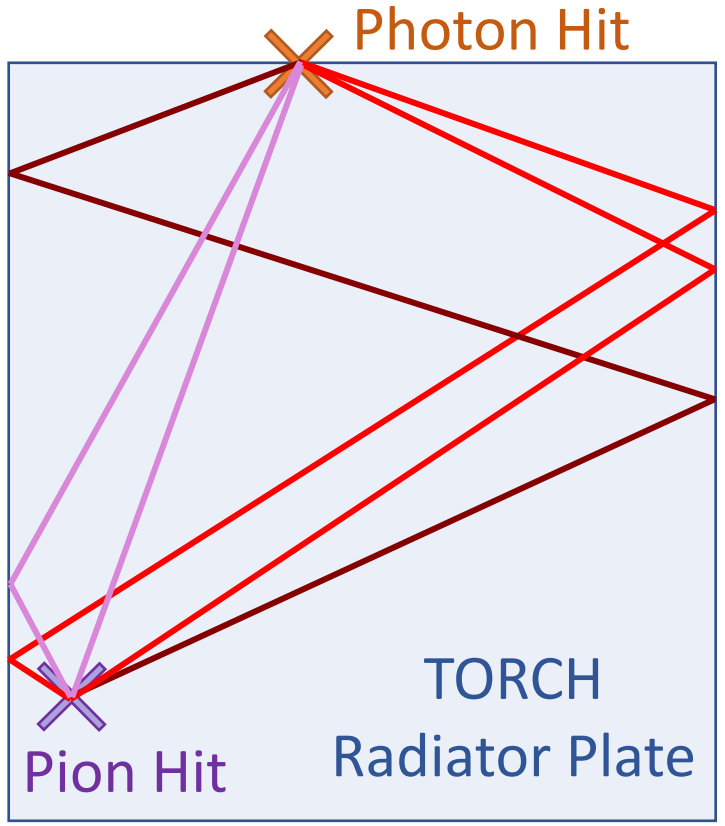
- Aim to measure the individual photon timing resolution of TORCH

➢ Determined by comparing the detected time in TORCH to that expected from reconstruction

- Need a method to cleanly separate orders of reflection

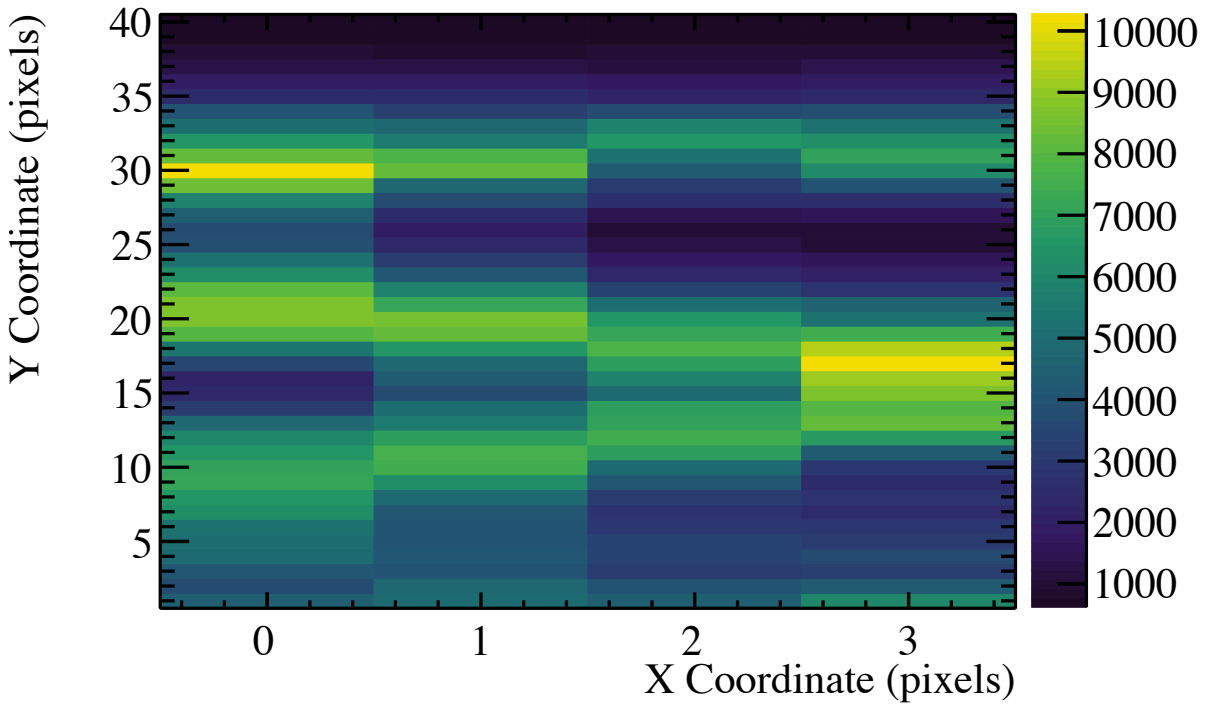
Time Resolution – Separating Reflections



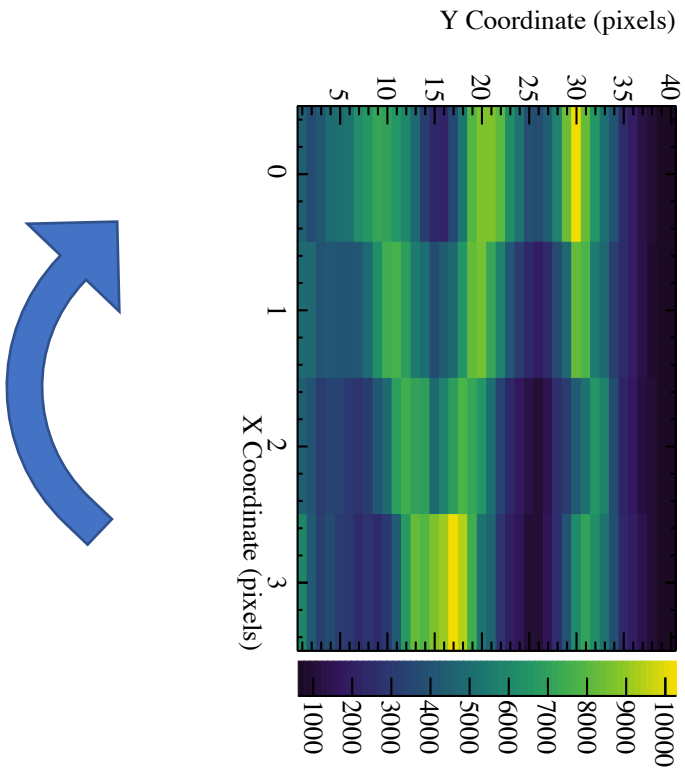


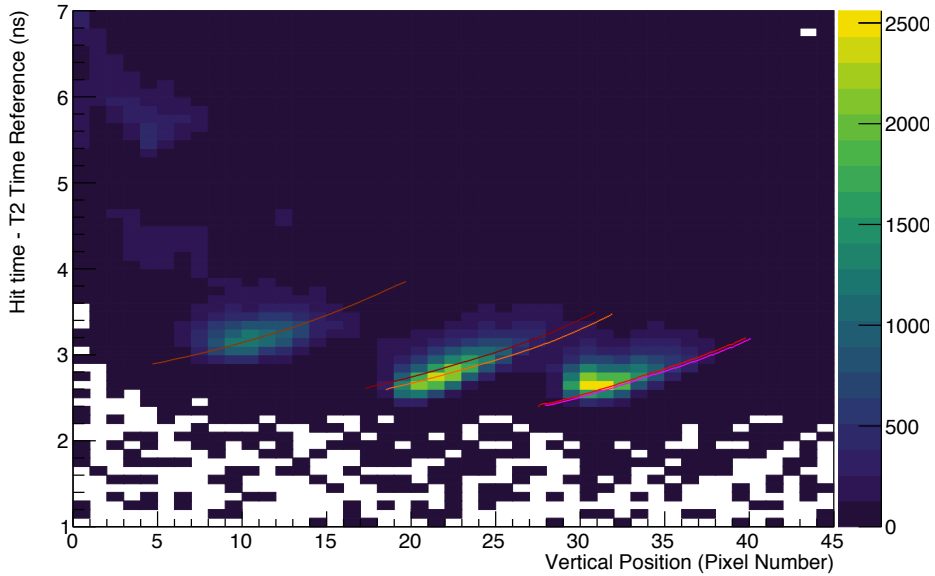
Beam striking radiator close to the edge results in superimposed patterns

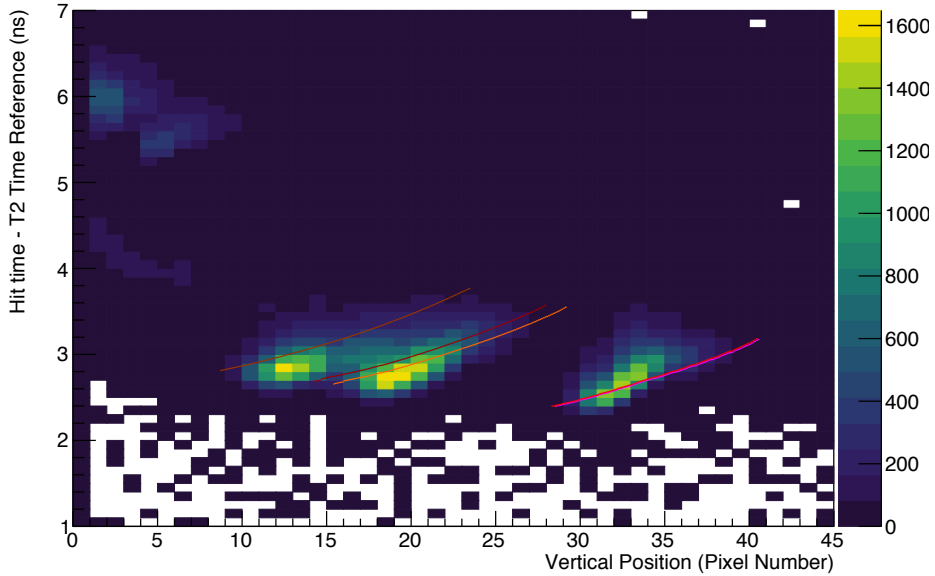
Time Resolution – Separating Reflections



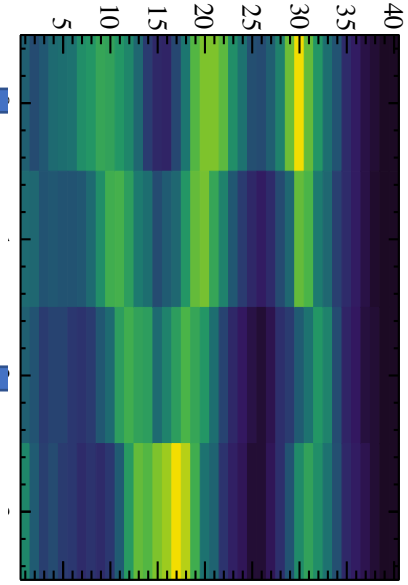
Time Resolution – Separating Reflections



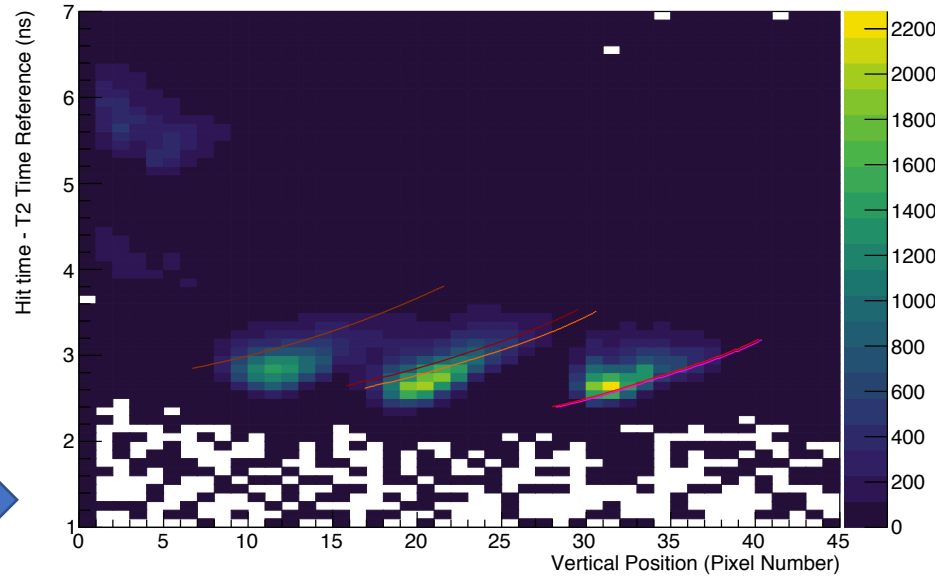


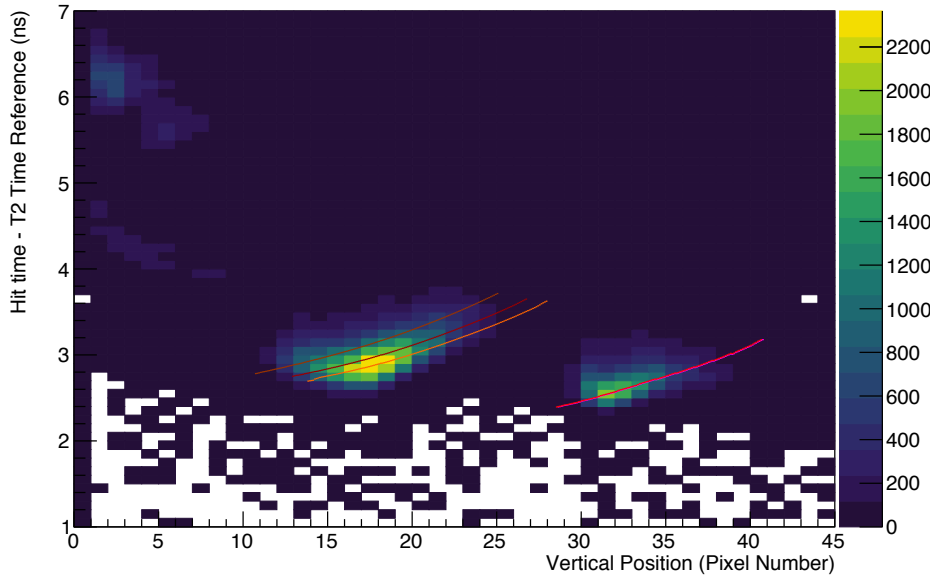


Project hitmap y-axis in time

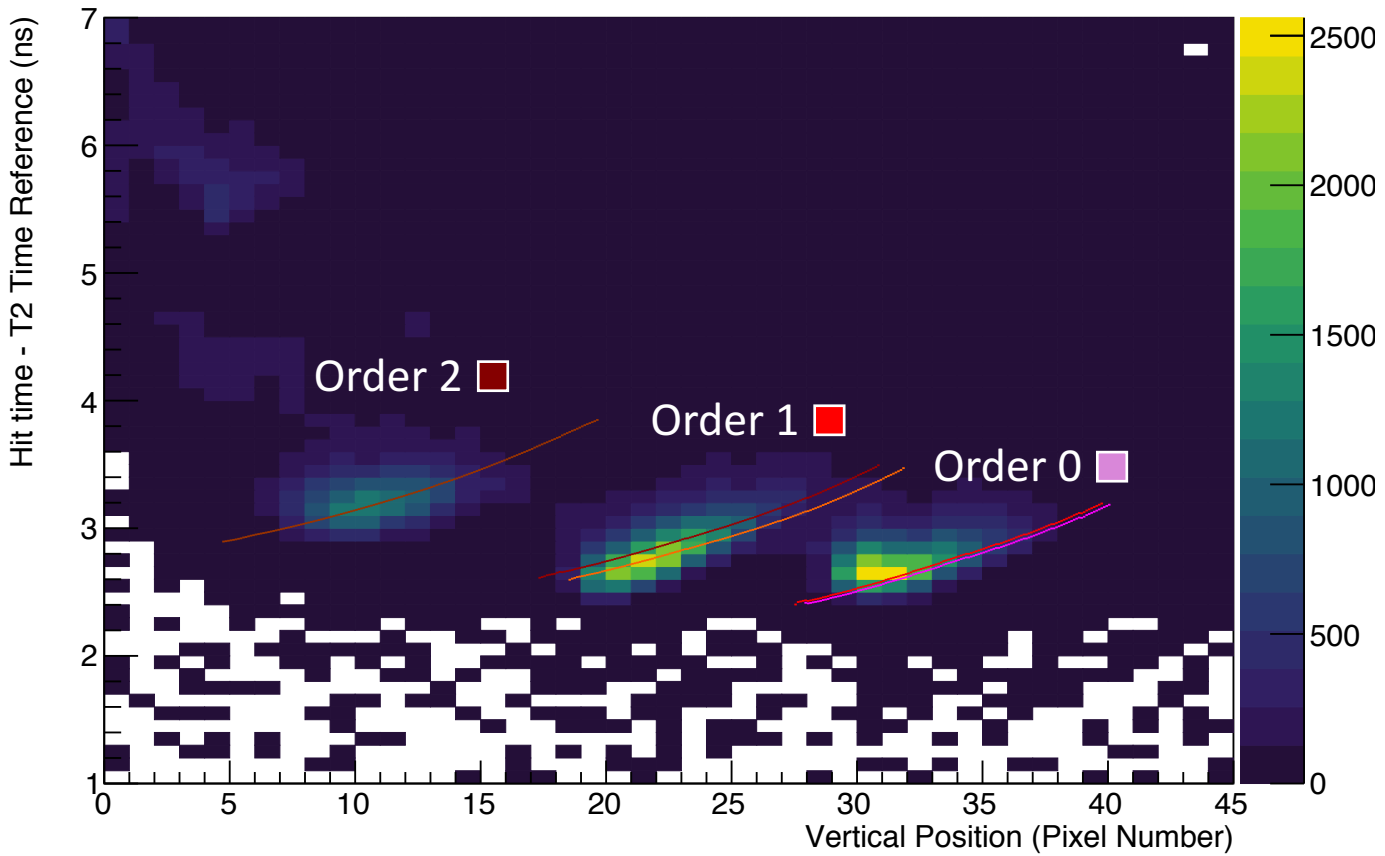


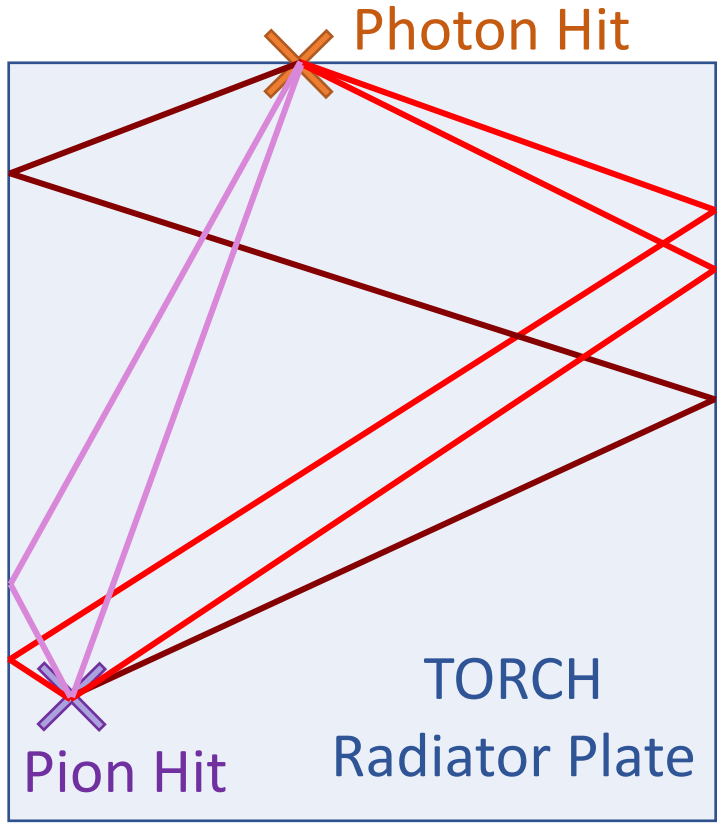
Overlaid lines show predictions from reconstruction





Time Resolution – Separating Reflections





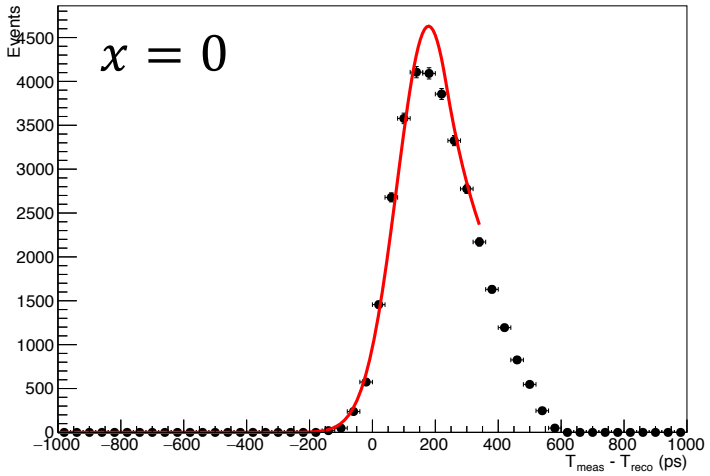
Beam striking radiator close to the edge results in superposed patterns

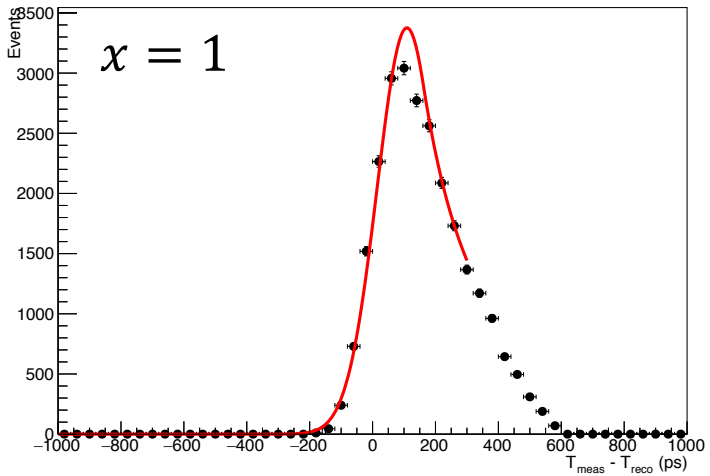
Time Resolution – Preliminary Measurement

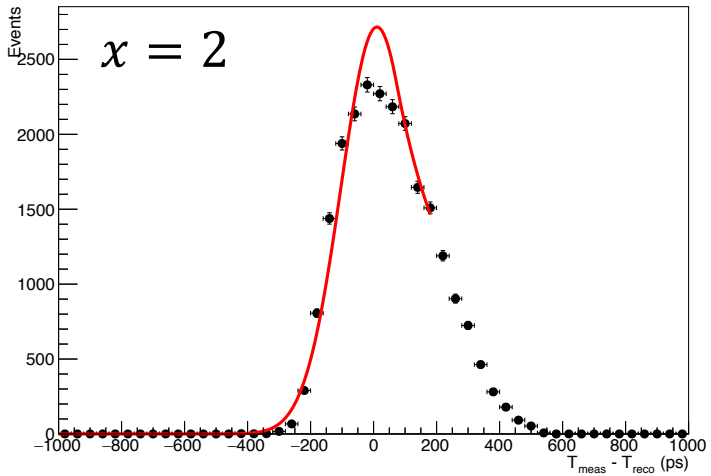
- Fit residuals with Crystal-Ball function to find resolution

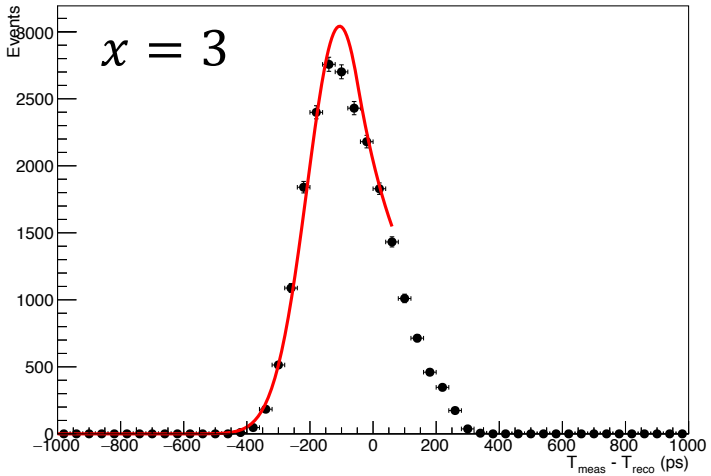
x	σ (ps)	Resolution* (ps)
0	100.9 ± 0.8	91 ± 4
1	95 ± 1	84 ± 4
2	114 ± 1	105 ± 3
3	103 ± 1	93 ± 4

* Final resolution has time reference resolution of 44 ± 9 ps subtracted









Time Resolution – Future Improvements

- For $K - \pi$ separation up to $10\ \mathrm{GeV/c}$ at 3σ in LHCb, aim for $70\ \mathrm{ps}$ timing resolution

- Analysis is ongoing - several improvements yet to come:

➢ Additional corrections for readout electronics effects (inc. time walk)

➢ Beam telescope integration

➢ Improved alignment from data

Photon Counting

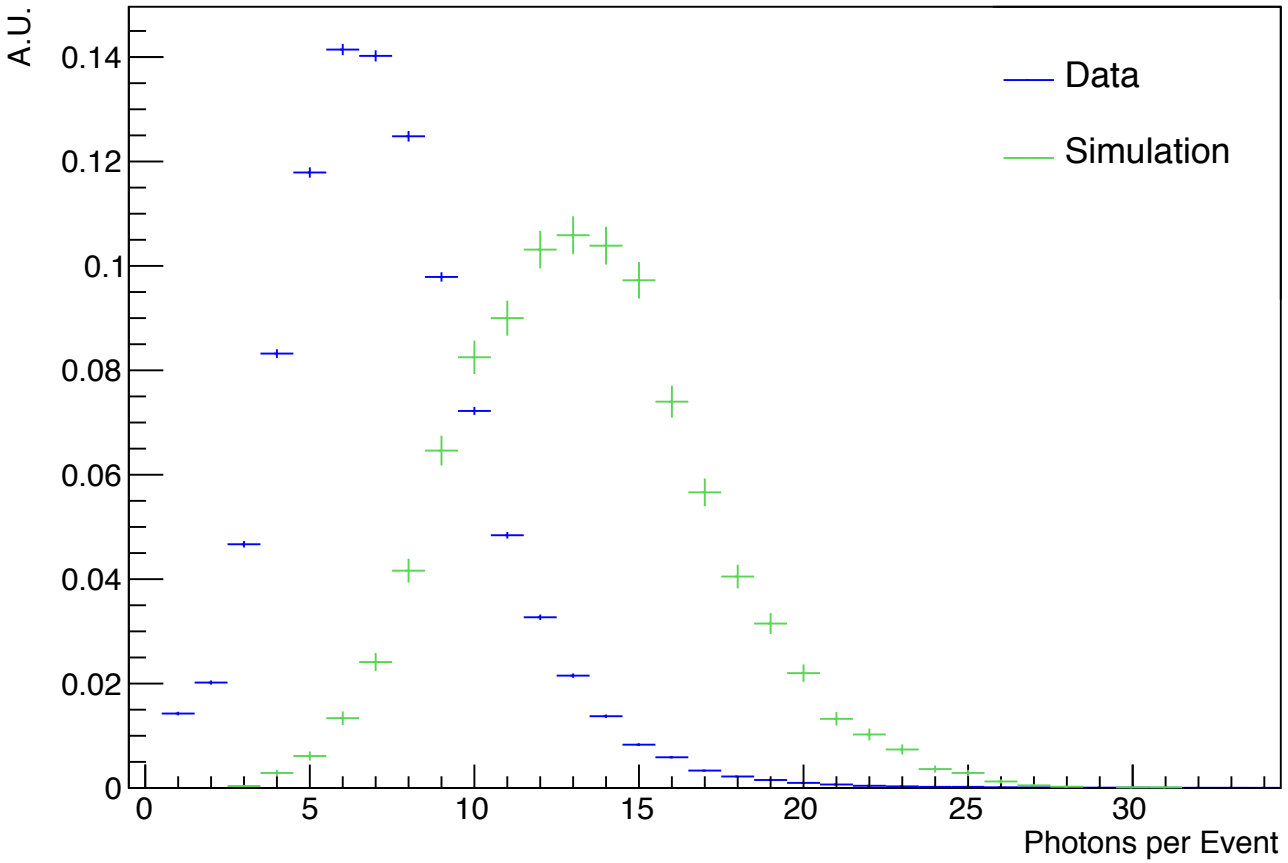
- Aim to test the photon detection efficiency of TORCH
  - ➢ Measure the number of detected photons per event
  - ➢ Compare to simulation

- Use a stand-alone Geant4 simulation to model optical effects
  - ➢ Surface Roughness, Rayleigh Scattering…
- Apply detector effects post-Geant4
  - ➢ Quantum Efficiency, Collection Efficiency, Glue Absorption…
- Note: Clustering not yet included in simulation

Photon Counting - Very Preliminary

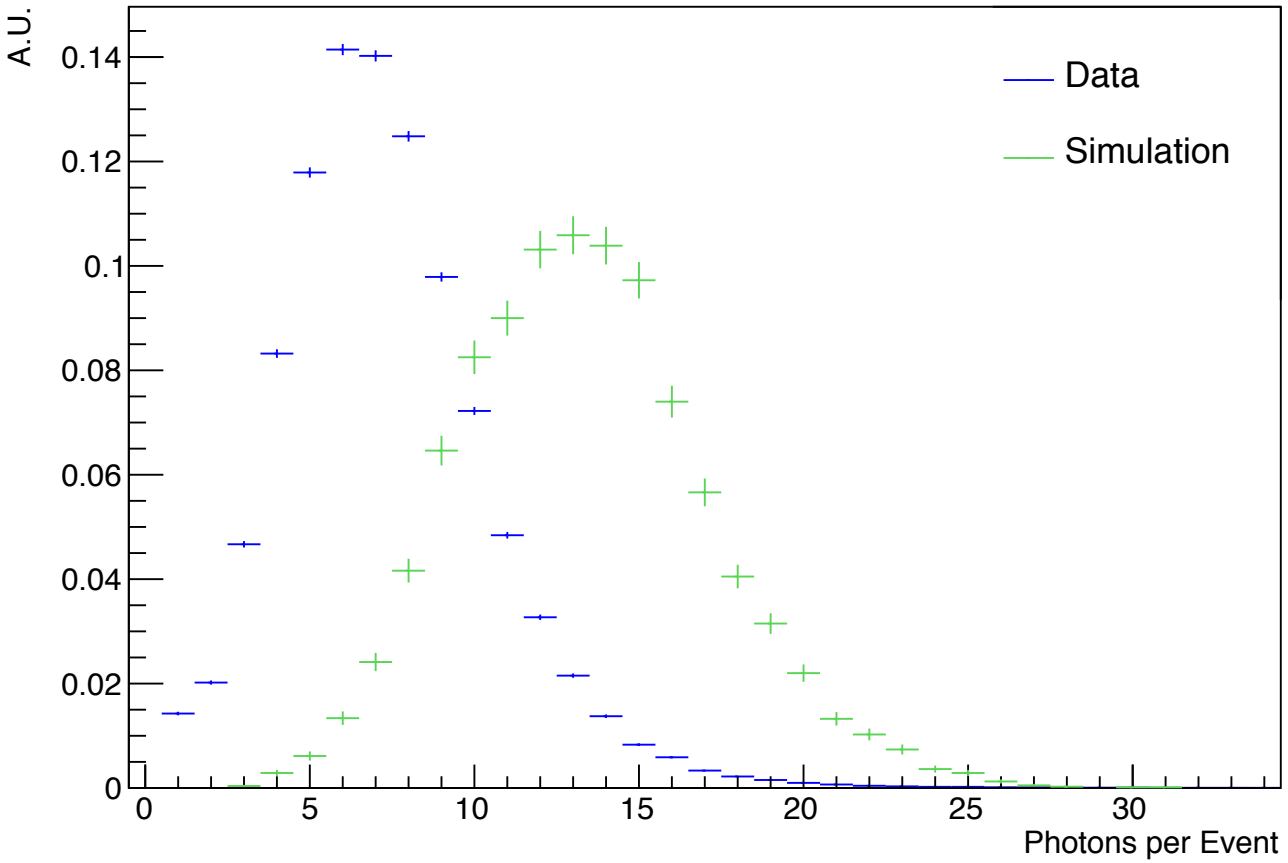
- Number of photons from data is commensurate for final TORCH detector

➢ Testbeam with full-scale module needed to confirm the efficiency is sufficient



Photon Counting - Very Preliminary

- Simulation efficiency is double that from data - still some factors to be taken into account:
  - ➢ Clustering Efficiency
  - ➢ Efficiency from NINO thresholds
  - ➢ Merging of photon clusters in data

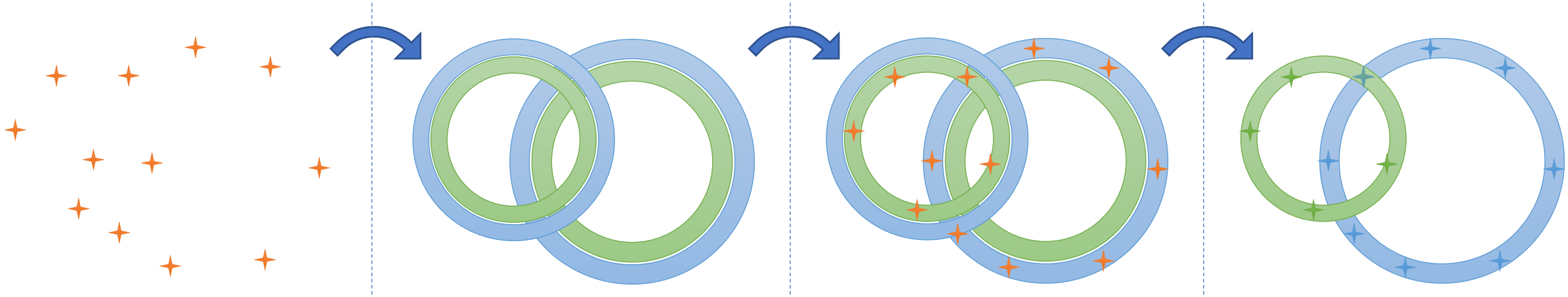


PID Performance

- Measured using stand-alone Geant4 simulation of a full module

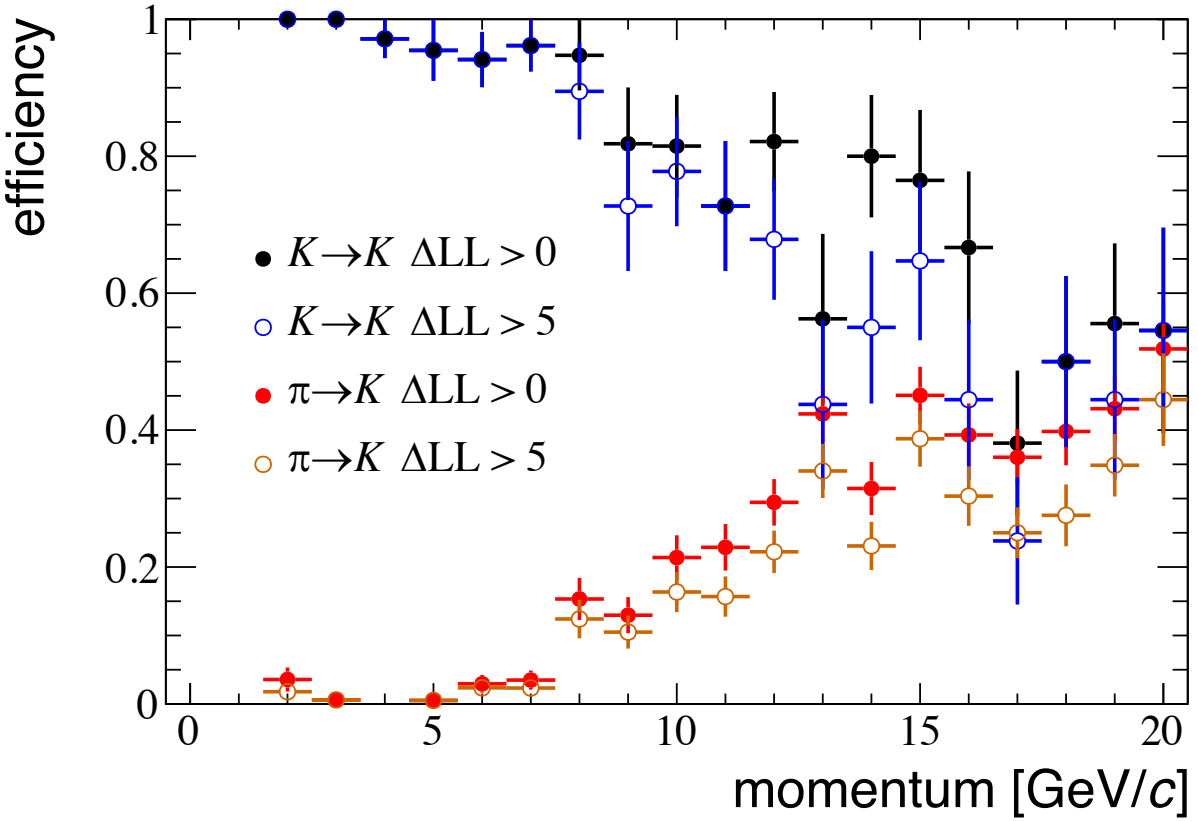
➢ Use full LHCb simulation as input to model TORCH in LHCb

- Pattern recognition algorithm based on the RICH algorithm



PID Performance – Preliminary Results

- TORCH shows good separation in the $2 - 10$ GeV/c region
- Previously observed tail-off at low momentum now solved
- Looking at ways to improve performance for $8 - 10$ GeV/c



Inclusive B Events, $\mathcal{L} = 2{\times}10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Conclusions

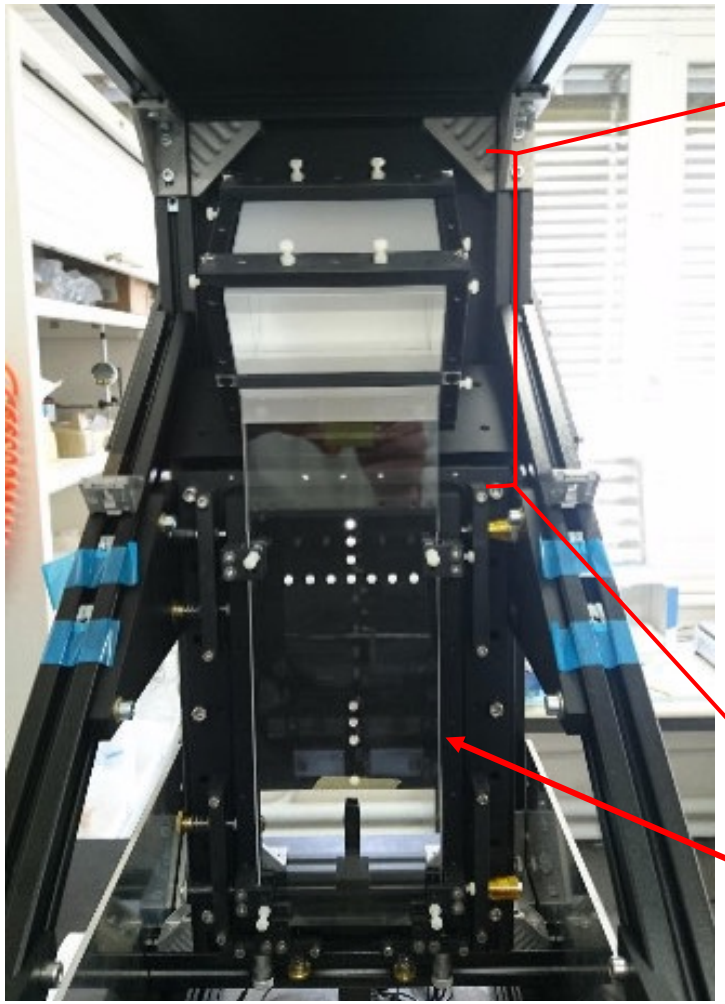
- Photon Time Resolution is approaching the desired $70\ \mathrm{ps}$
- ➢ With planned analysis improvements, expect we can reach this

- Photon Counting shows some disagreement with simulation, but is compatible with the final system

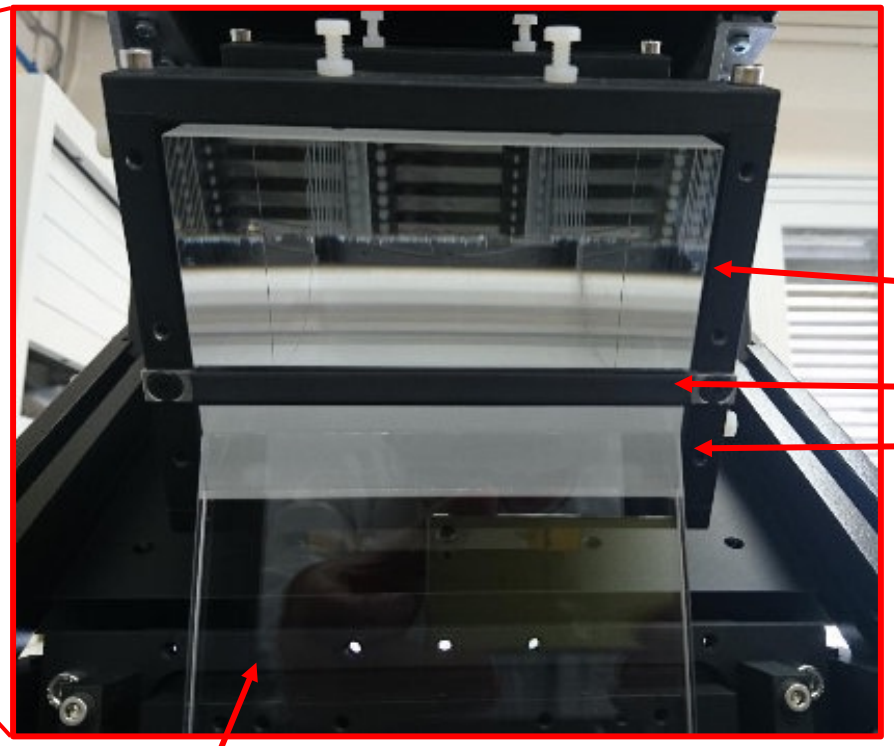
- PID algorithm shows good performance in the region of interest, and improvements to the algorithm are underway

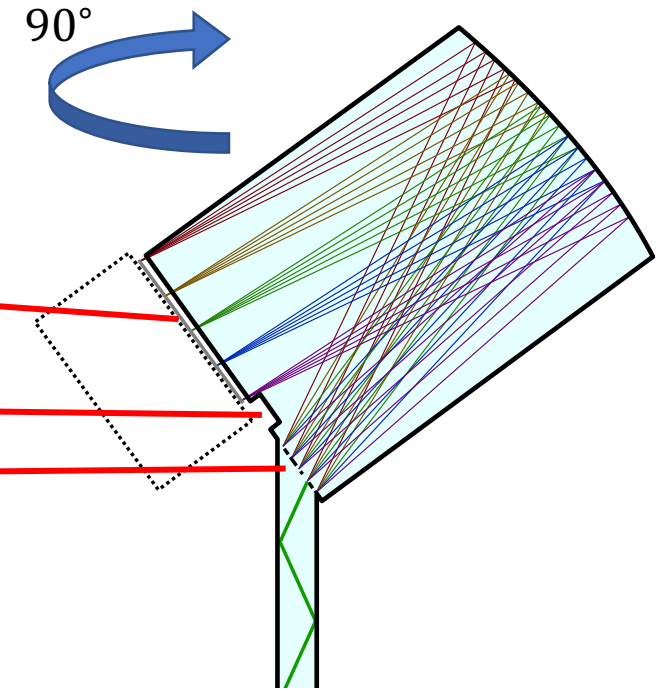
Back-up

The Testbeam Setup – Mini-TORCH



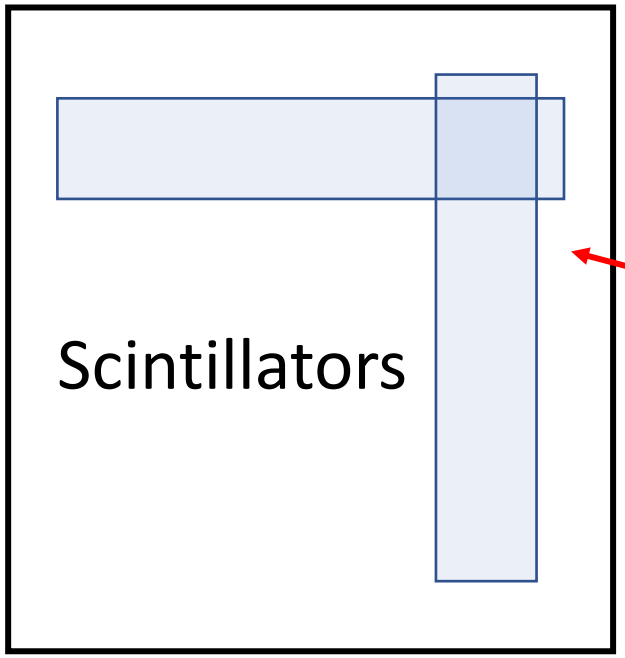
Focusing Optics

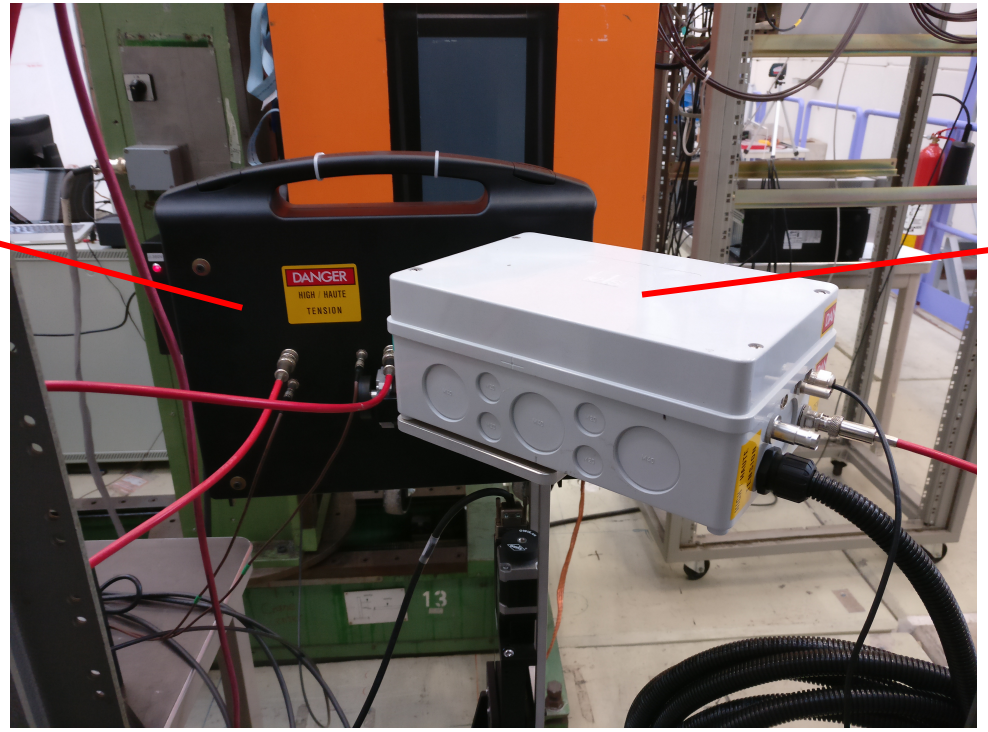




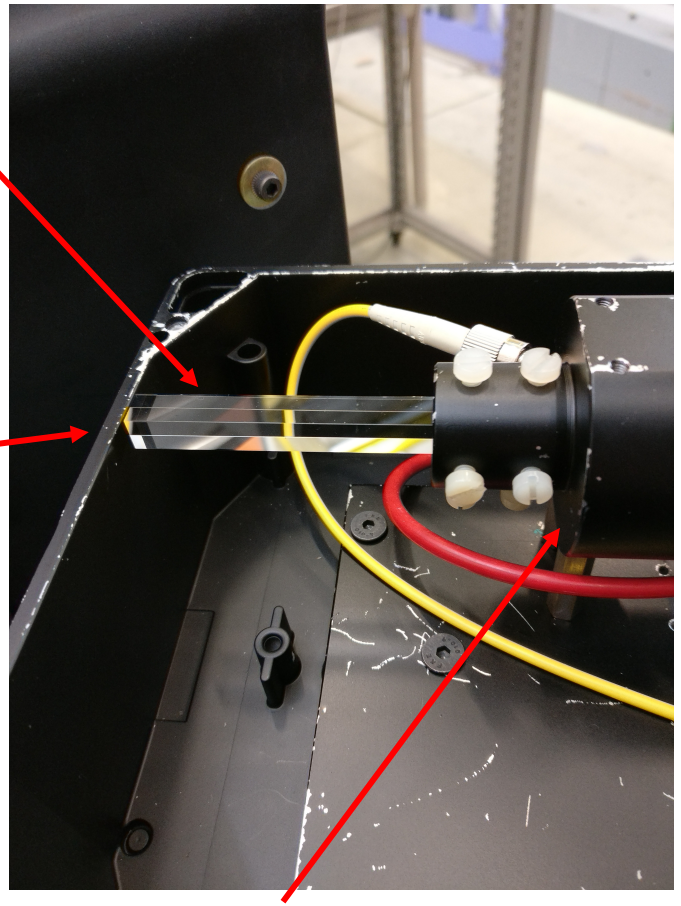
Radiator Plate

The Testbeam Setup – Timing Stations



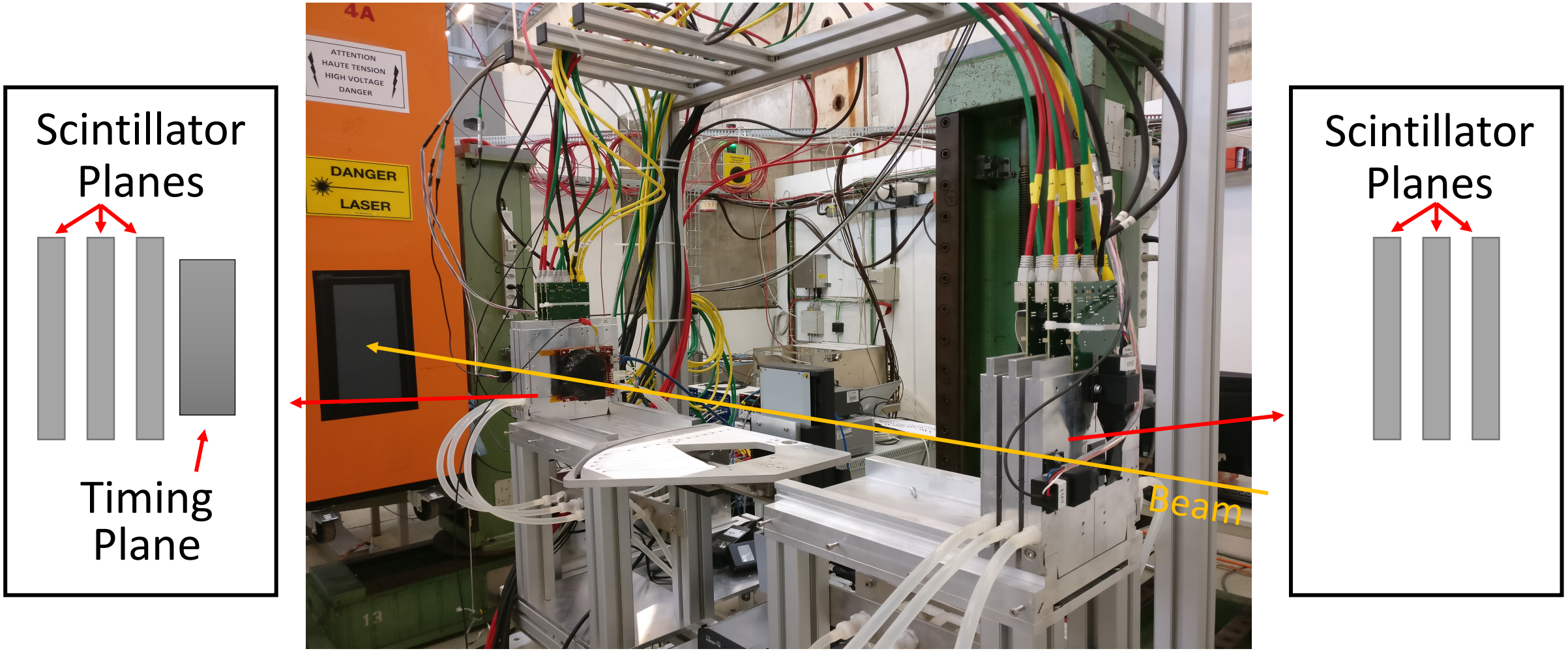


Borosilicate
"Timing Finger"



MCP-PMT

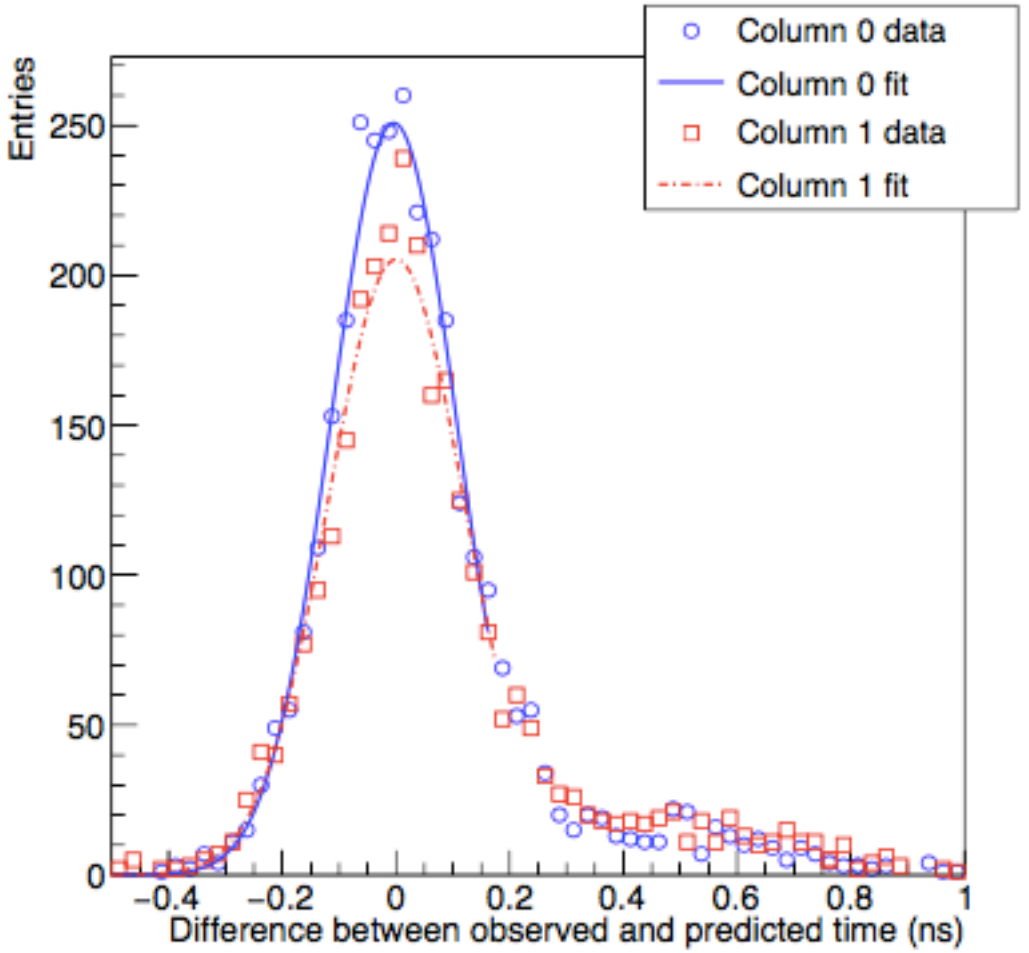
The Testbeam Setup – Beam Telescope



Previous Time Resolution Results

- Previous analysis of 2016 testbeam data gave time resolutions of $(83 - 115) \pm 6$ ps

➢ Figure on right shows example fit to timing residuals



Time walk Correction

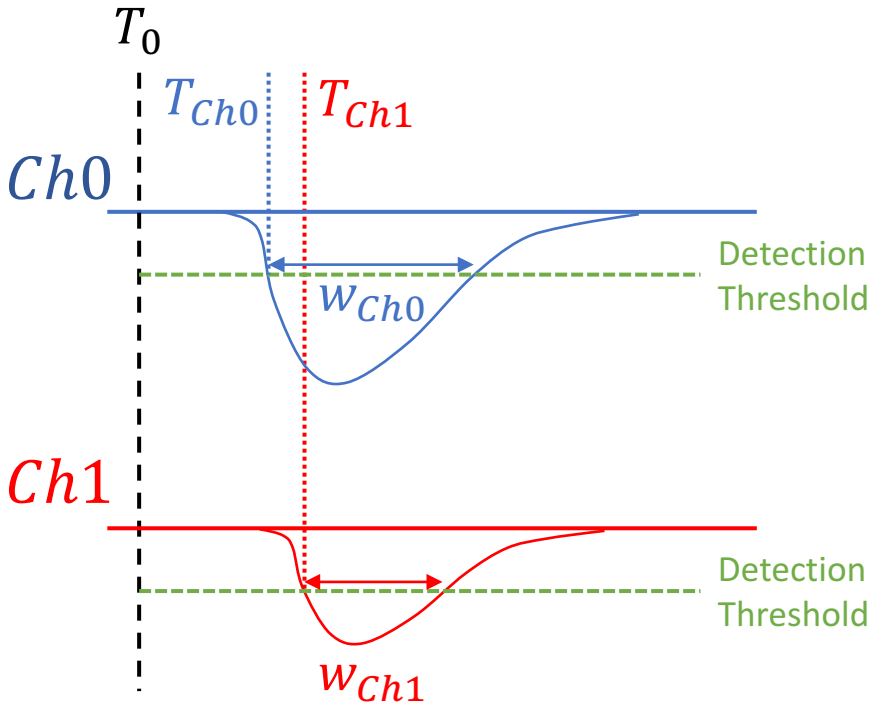
- Hits in TORCH are grouped into clusters

➢ 1 cluster = 1 incident photon

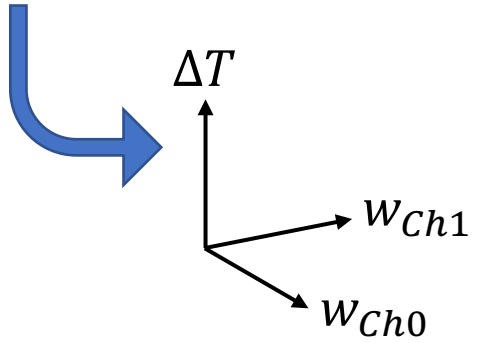
- Hits in a cluster should be simultaneous

➢ Time walk correction adjusts the relative time of all hit in a cluster to make this true

- Data driven approach utilises correlation between hit width (w_x) and leading edge time (T_x) to perform the correction



$$T_{Ch0} - T_{Ch1} = \Delta T(w_{Ch0}, w_{Ch1})$$



Fit to get time walk correction