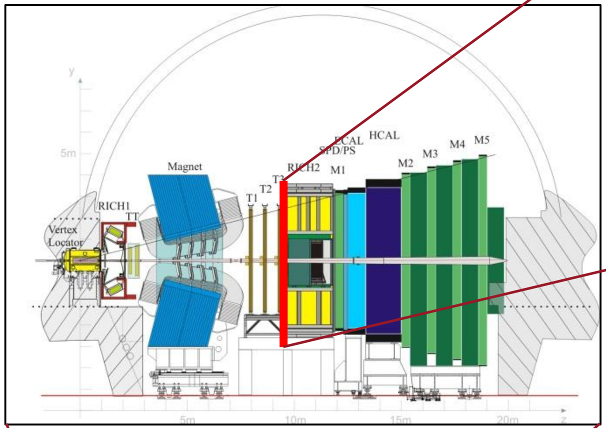
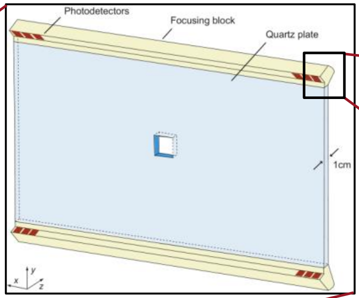
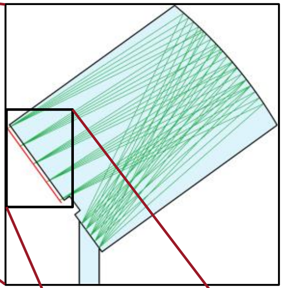
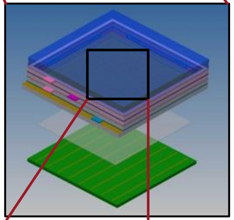
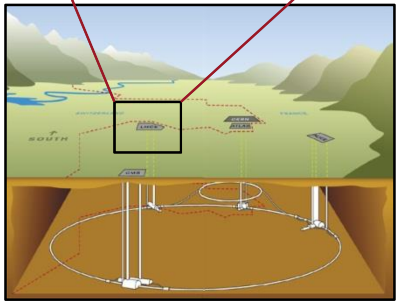


# First results from a prototype TORCH detector

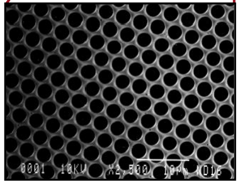




*A Cherenkov based*
*Time of Flight detector*

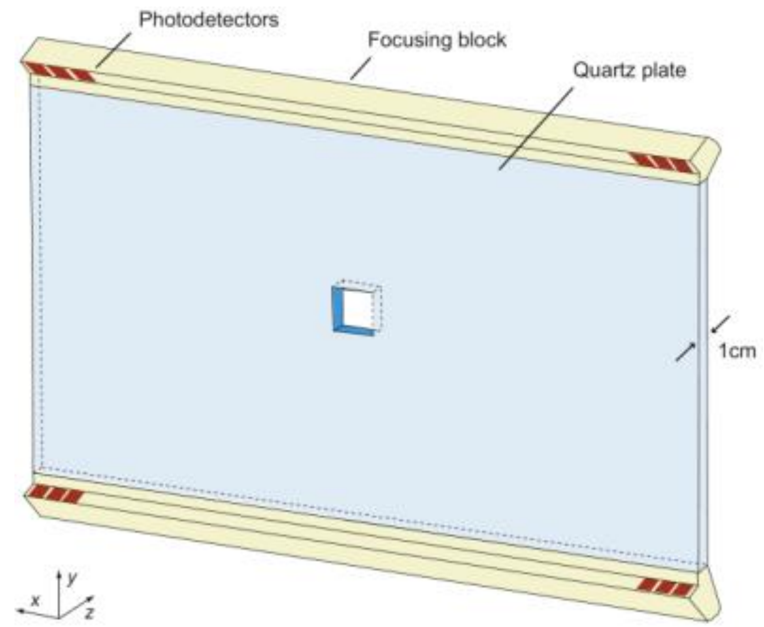

Maarten van Dijk
On behalf of the TORCH collaboration

(CERN, University of Oxford, University of Bristol)

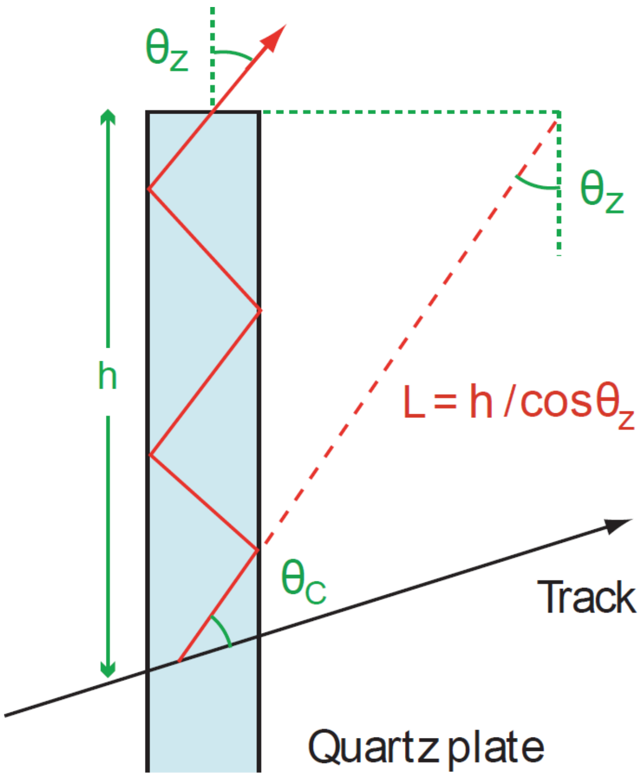
# TORCH – introduction

- The TORCH (Time Of internally Reflected CHerenkov light) detector is an R&D project to develop a large-area time-of-flight system.
- Combines individual photon time information with DIRC-style reconstruction
- ERC-funded project
- Main aims
  - Develop detectors and readout
  - Build and operate prototype



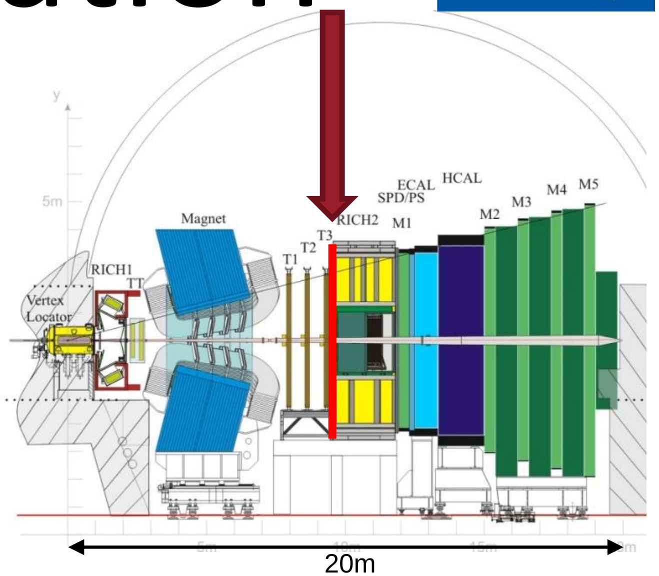
# TORCH

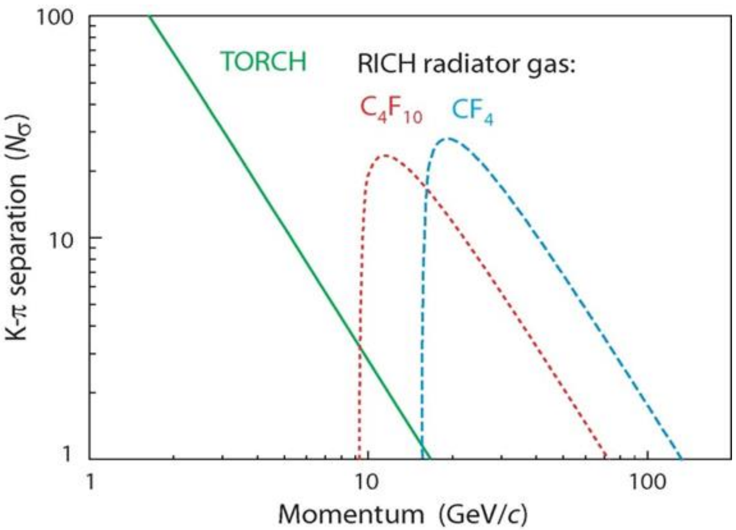
- Basic principle: Measure time of flight, momentum is known – so mass can be derived
- Reconstruct time-of-propagation of individual photons, and combine time information
- Goal is to provide 3σ K-π separation for momentum range 2-10 GeV/c
  - Requires ~15 ps time resolution per track
  - ~30 photons observed per track
  - Required single photon resolution: 70 ps



# TORCH - Application

- TORCH is in the process of getting benchmarked for application in LHCb
- Particle identification is crucial for LHCb physics
- Particularly useful for flavour tagging
- Proposed location of TORCH: in front of RICH2
- Precise tracking of particle available – necessary for reconstruction
- Area ~5x6 $m^2$



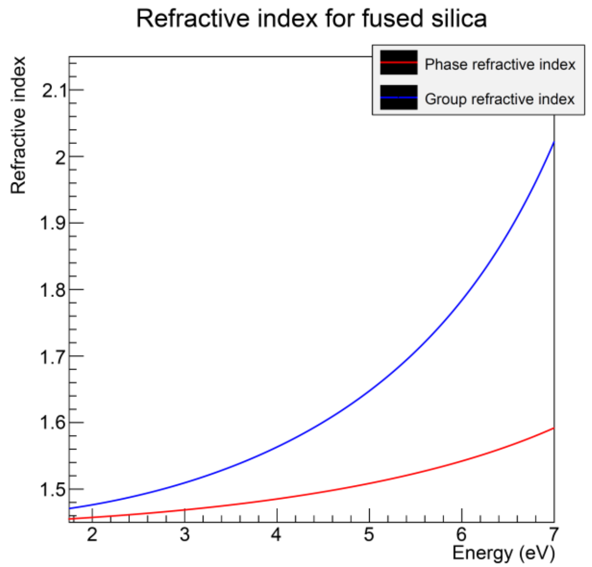



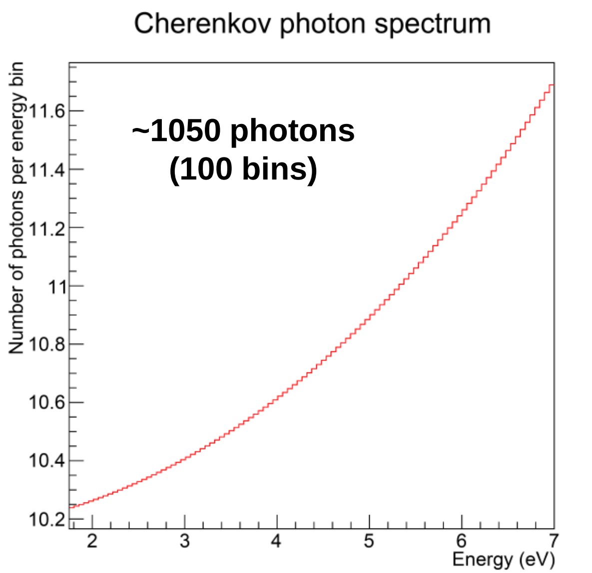
# Cherenkov light

- Photon angle relative to track determined by refractive index

$$\cos\theta_c = \frac{1}{\beta\, n_{phase}}$$

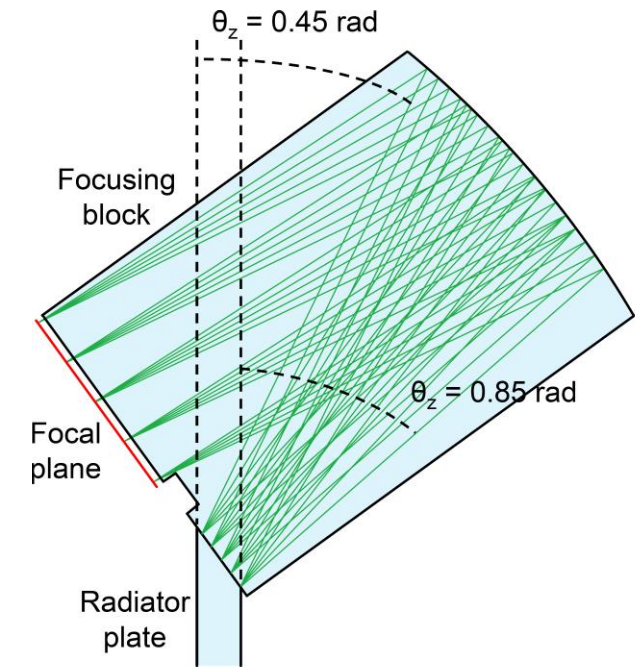
- Quartz has fairly wide range of refractive index
- Leads to large amount of chromatic dispersion
- ~1050 photons generated per charged particle (1.75-7eV)

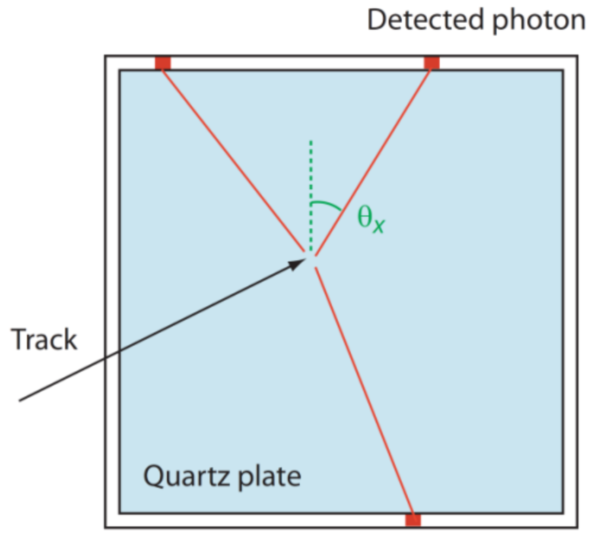


# TORCH optics

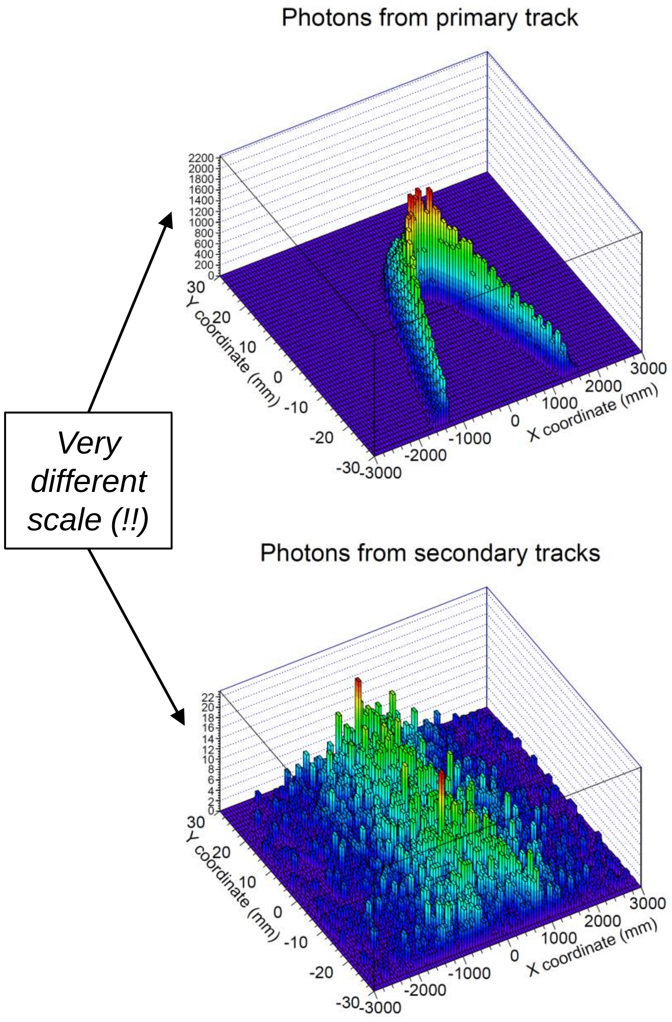
- Focusing block projects photons onto detector plane
- Allows for direct measurement of photon angle $\theta_z$
- Mapping of distance through focusing block calibrated using Geant4 simulation
- Horizontal position on detector combined with tracking info allows for measurement of second angle $\theta_x$



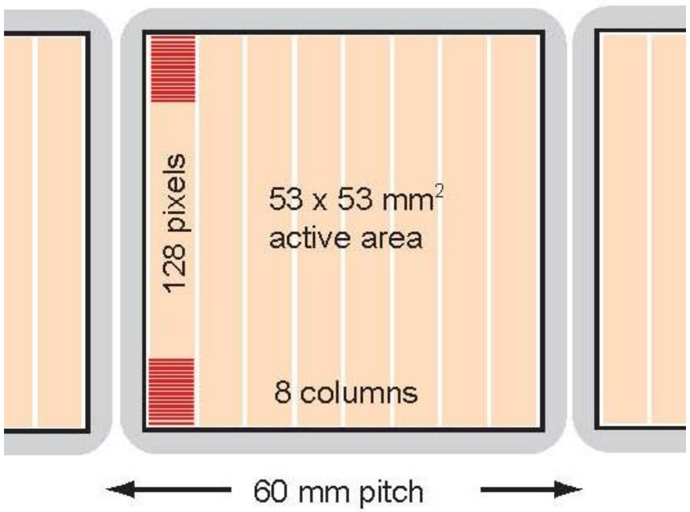
# Timing reconstruction

- Simulation of TORCH run in Geant4
- Some pollution already shows up
- Associate photons to tracks
- Reconstruct full photon path
- Correct for chromatic dispersion
- Limits on time resolution
  - Size of pixels of detector
  - Intrinsic time resolution of MCP
  - Time resolution in electronics



# Photon Detectors for TORCH

- MCP-PMT detectors
- Leading detector for time-resolved photon counting
  - Transit time spread down to ~20-30ps



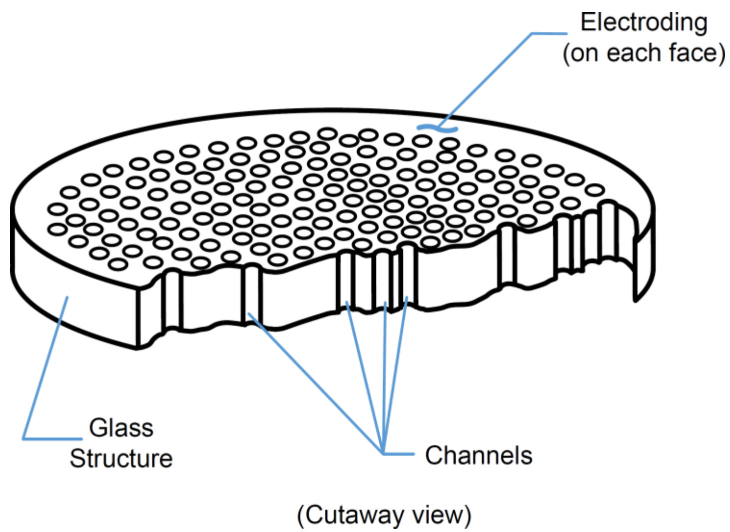
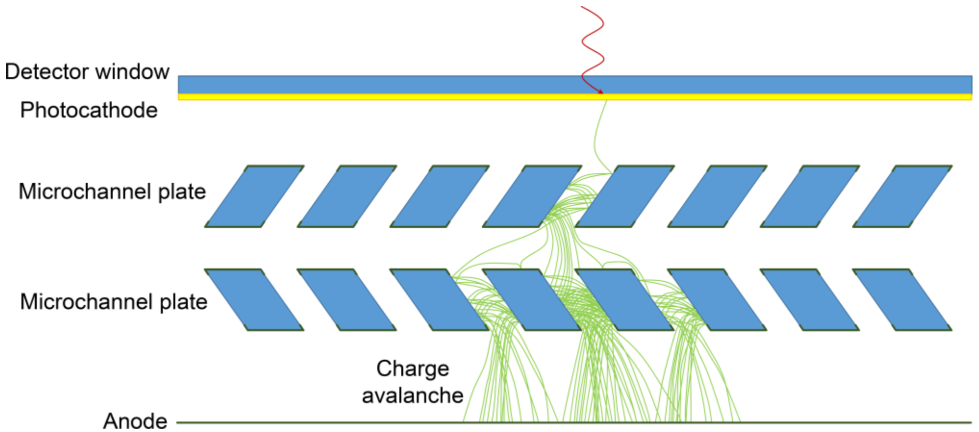
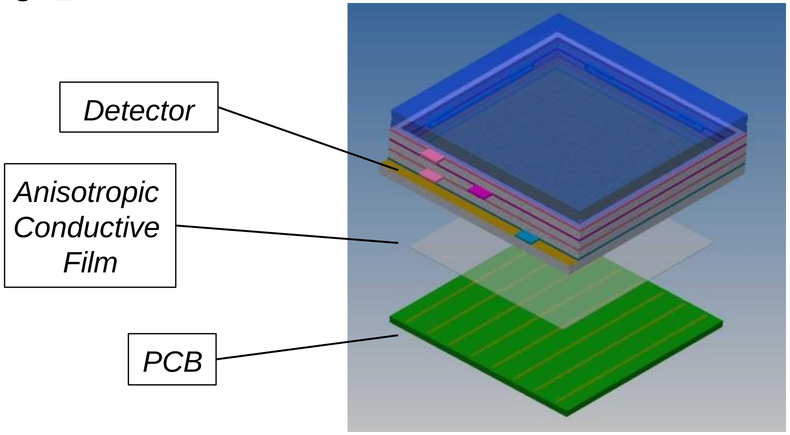




*Figure reproduced from J.L. Wiza, NIMA **162** no. 13 (1979) 587-601*

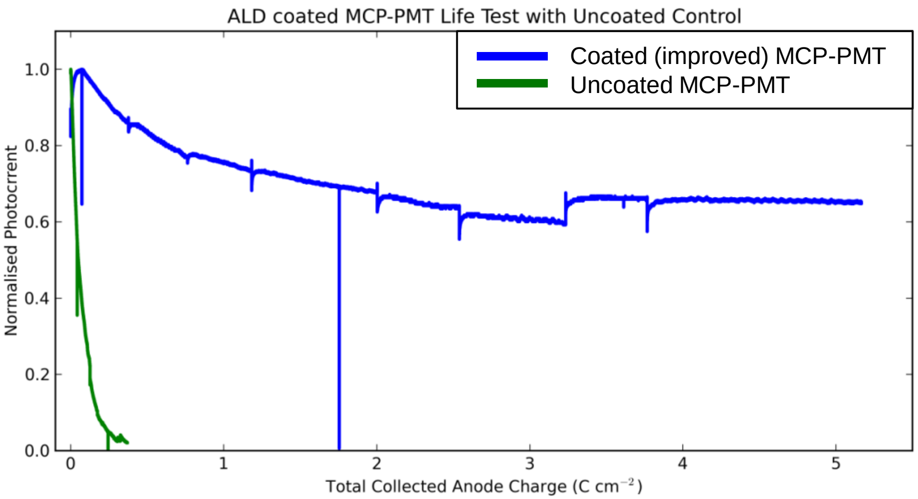


# Detector R&D

- Experimental program at Photek
  - Phase 1 – Long life demonstrator
  - Phase 2 – High granularity multi-anode demonstrator
  - Phase 3 – Square tube with required granularity and lifetime
- Technical aims
  - Lifetime of $5C/cm^2$ accumulated anode charge or better
  - Multi-anode readout of 8x128 pixels
  - Close packing on two opposing sides, fill factor >88%
- Development progressing well
  - Delivery of Phase 2 tubes completed
- See talk of Tom Conneely
  - June 9, 15:10-15:40

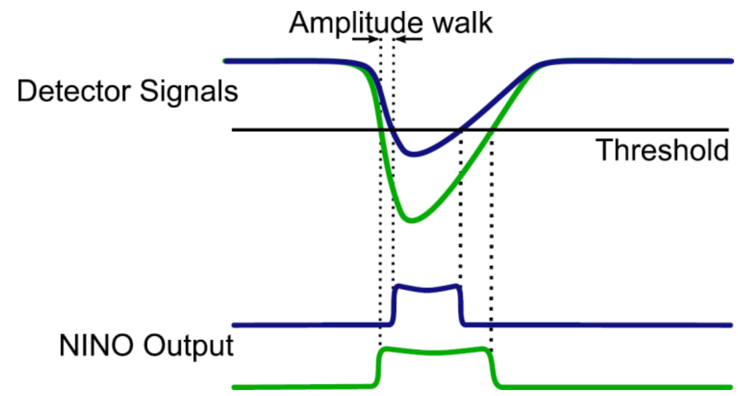


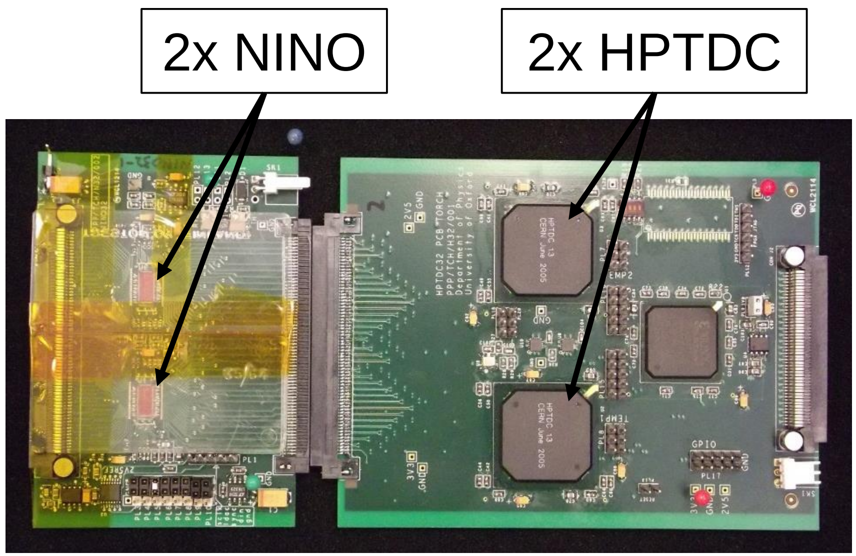

*Schematic of detector layout.*



# Electronics and readout

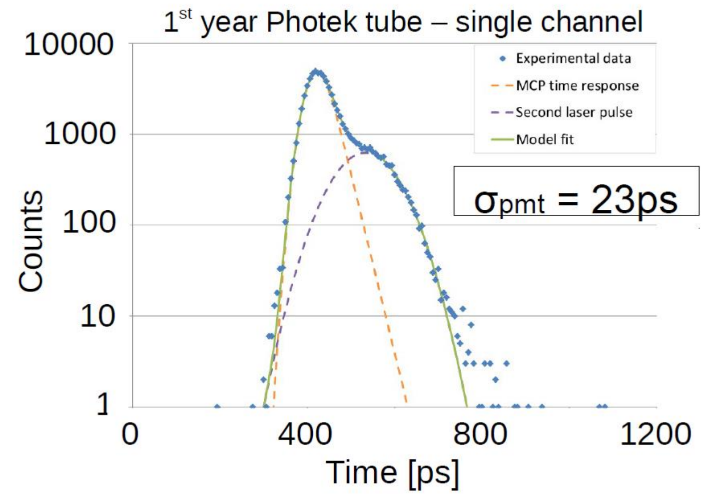
- Signals of MCP-PMT are read out with a combination of two ASIC chips – NINO and HPTDC
- NINO originally developed for use with HPTDC for ALICE ToF detector
- NINO turns "raw" signal into LVDS signal representative for time-over-threshold
- HPTDC times leading and falling edge of NINO signal
- See talk of Tom Conneely
  - June 9, 15:10-15:40



# MCP timing resolution

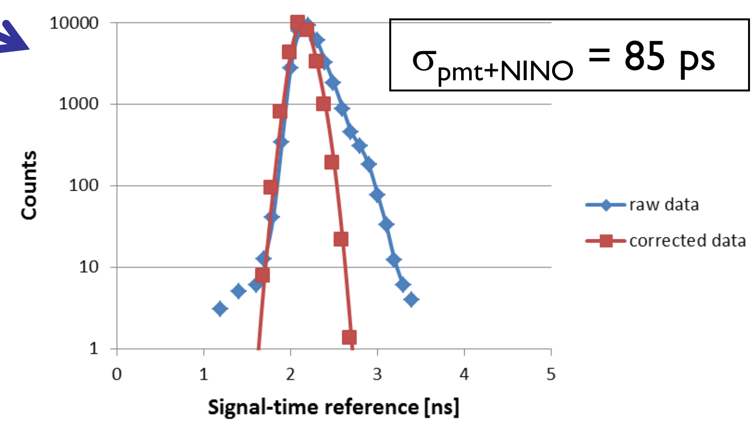
- Phase 1 Photek tubes timing resolution
  - Fast laser
  - Commercial electronics




- Phase 2 Photek tube timing resolution
  - Fast laser
  - Customised NINO-32 and HPTDC electronics
  - HPTDC time binning set to 100 ps

PRELIMINARY

Photek Phase 2 tube: NINO electronics




- Correction made
  - Integral non-linearity (INL) of the HPTDC
  - Time-walk effects from the time-over-threshold (TOT) information from the NINO

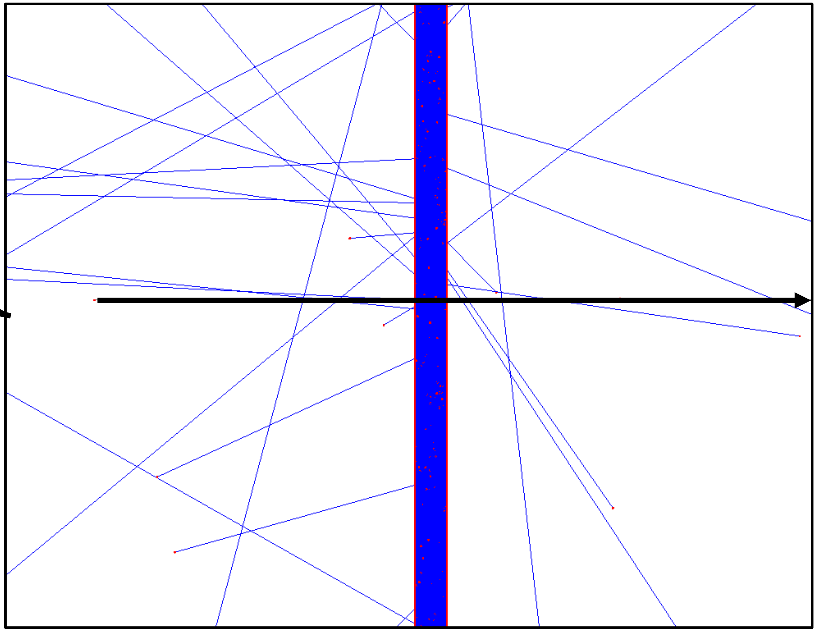
- All timing properties measured at an MCP gain of 1 x $10^6$



M.VanDijk@bristol.ac.uk

# Information loss

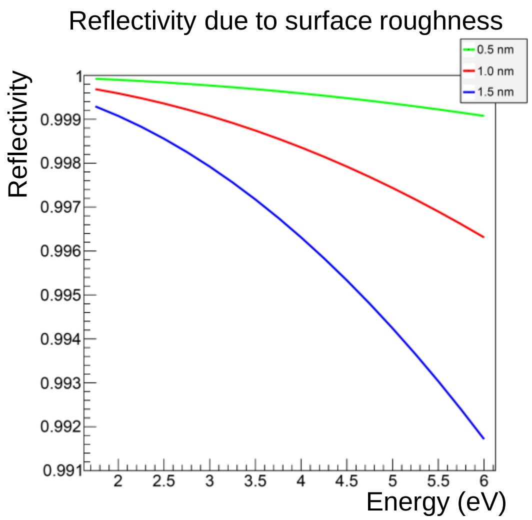
- Two types of information loss present in TORCH
- Both impact time resolution – will be assessed in beamtest
- Loss of photons (quantitative)
  - Absorption
    - Mirrored surface on focusing block
    - Optical bonding
  - Surface roughness of quartz
  - Rayleigh scattering
  - Quantum efficiency
  - Collection efficiency
- Loss of resolution (qualitative)
  - Pixel size
  - Time resolution
  - Reconstruction efficiency
  - Discrimination in electronics



(Geant) Example of impact of surface roughness and Rayleigh scattering

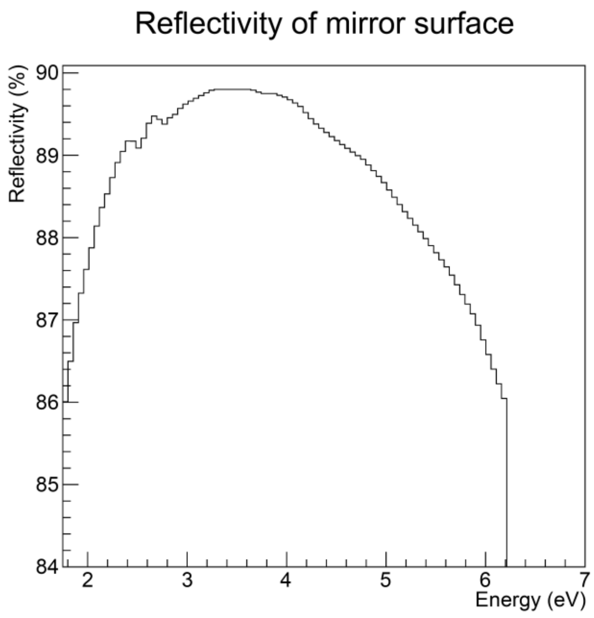
# Quartz for testbeam

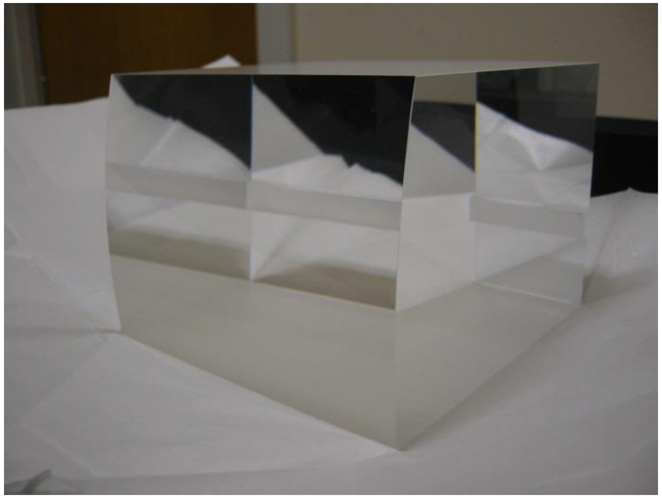
- Full TORCH module
  - $(660 \times 2500 \times 10) mm^3$
- Prototype is scaled down version
  - $(350 \times 120 \times 10) mm^3$
- Highly polished for very good reflectivity
  - Surface roughness ~10 Å (1nm)
- In this prototype: Typically tens of reflections



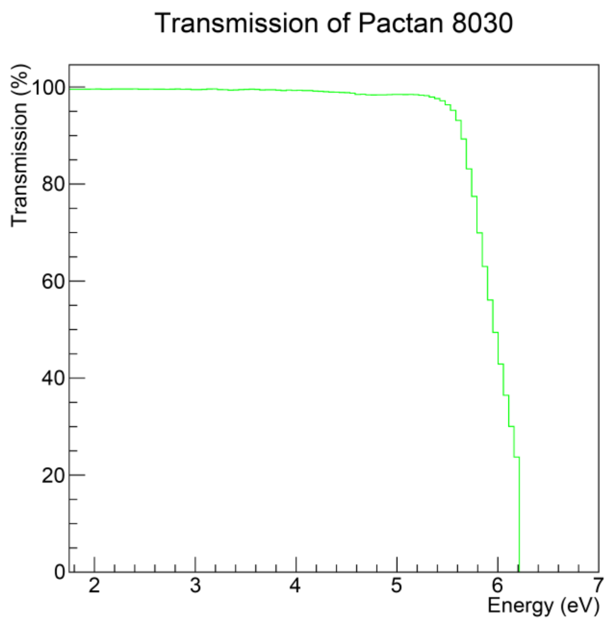

# Focusing block

- Same width (120mm) to match size of plate
- Cylindrical surface coated with aluminium
  - Reflectivity over photon energy range 86-90%
- Expected loss ~10-15%



# Optical coupling

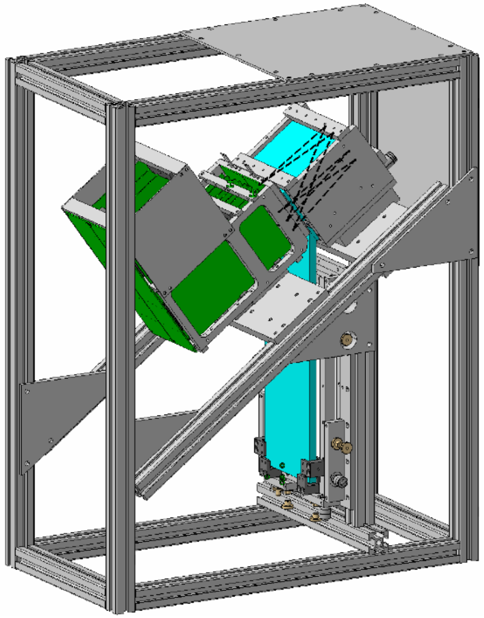


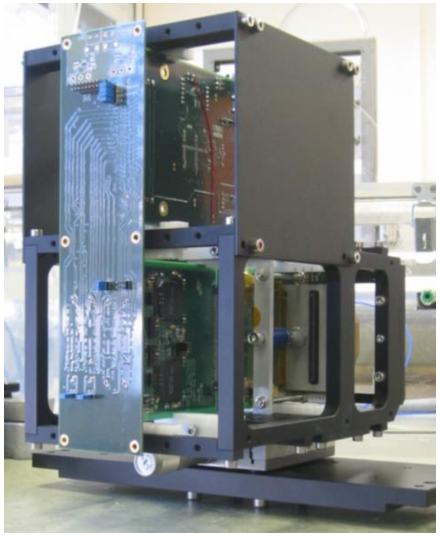

- Interface between plate and focusing block needs optical coupling
- Bonded together using silicone rubber (PACTAN 8030)
- Transmission measured to verify performance

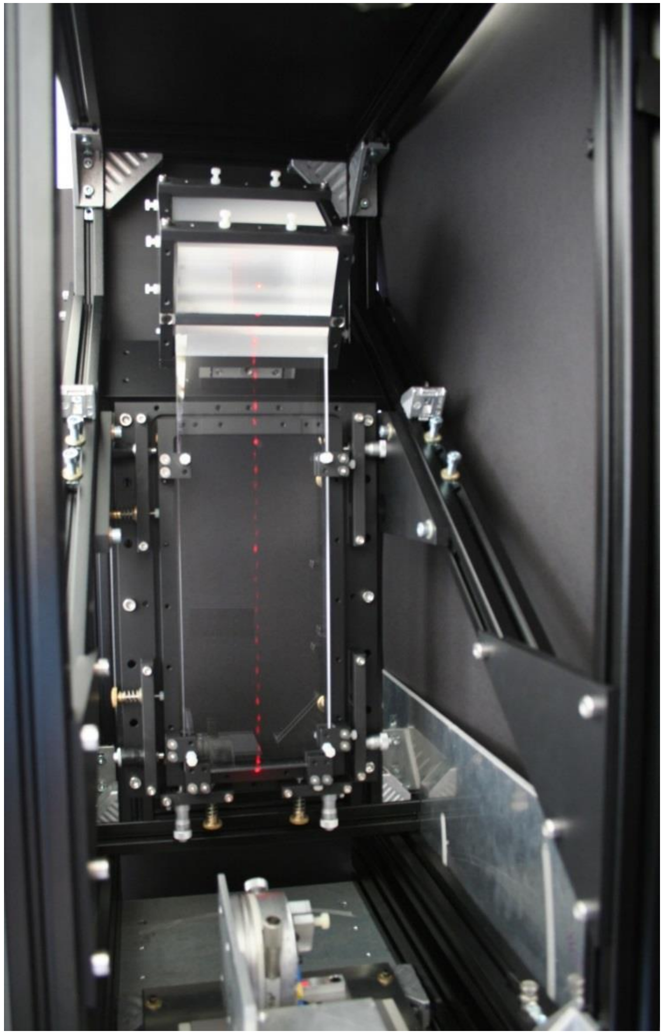

M.VanDijk@bristol.ac.uk

# The TORCH prototype

- Quartz mounted in light tight box
- Testing optics with laser injected from bottom
- Detector will be mounted on exit surface of focusing block

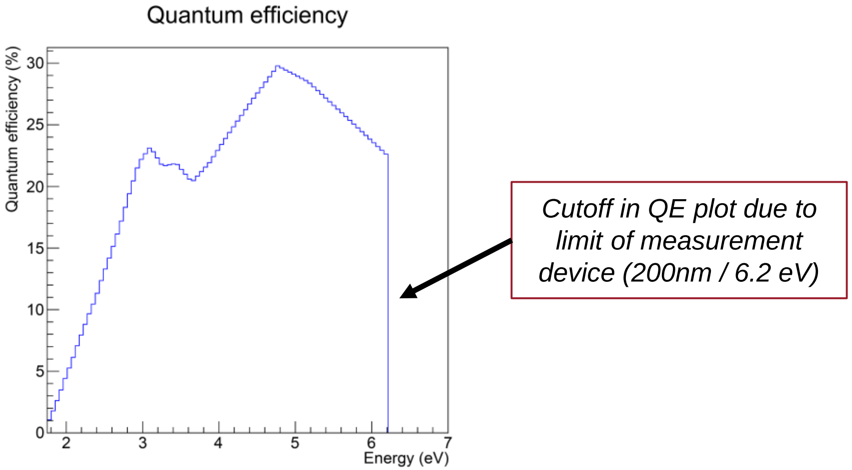


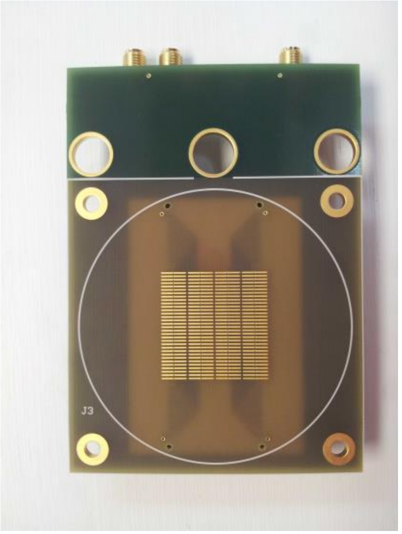


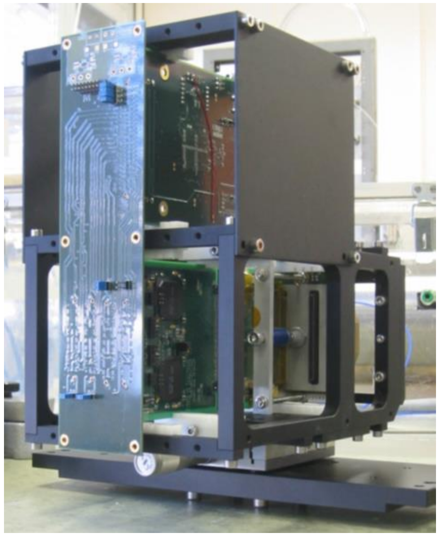


# Detectors for testbeam

- Single MCP-PMT detector from Photek used
- Tube from Phase 2 of the development program
- 4x32 pixels on 26.5x26.5mm
- QE measured on representative tube (Phase 1)
- Two columns of pixels out of four instrumented with electronics



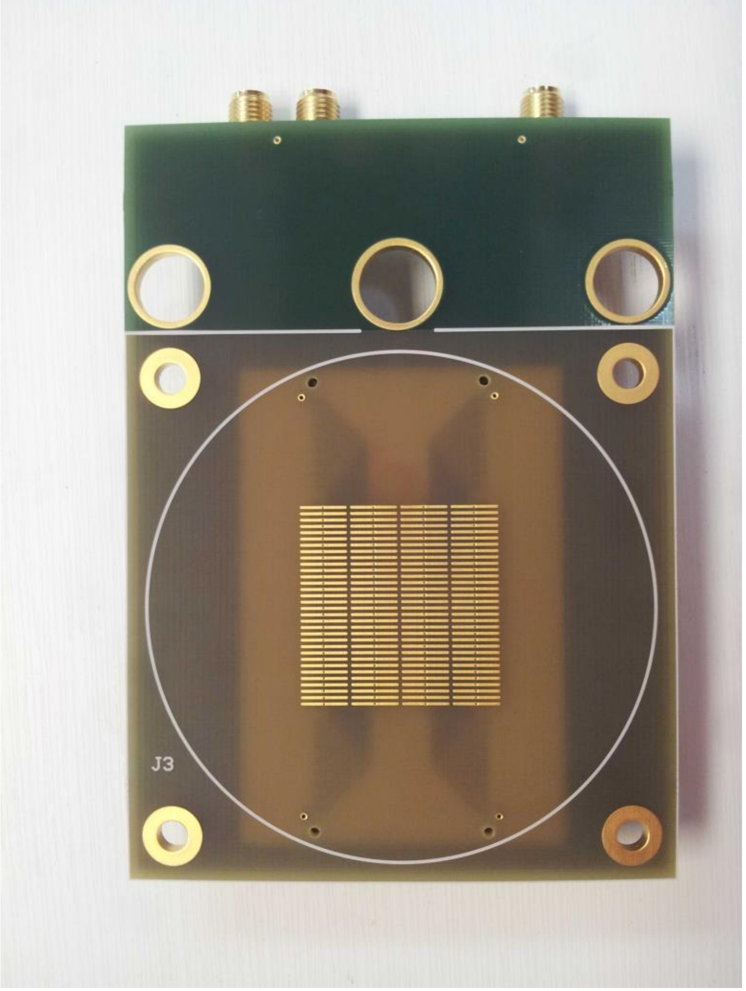



# Charge sharing

- Charge avalanche intentionally made bigger than (vertical) pixel size

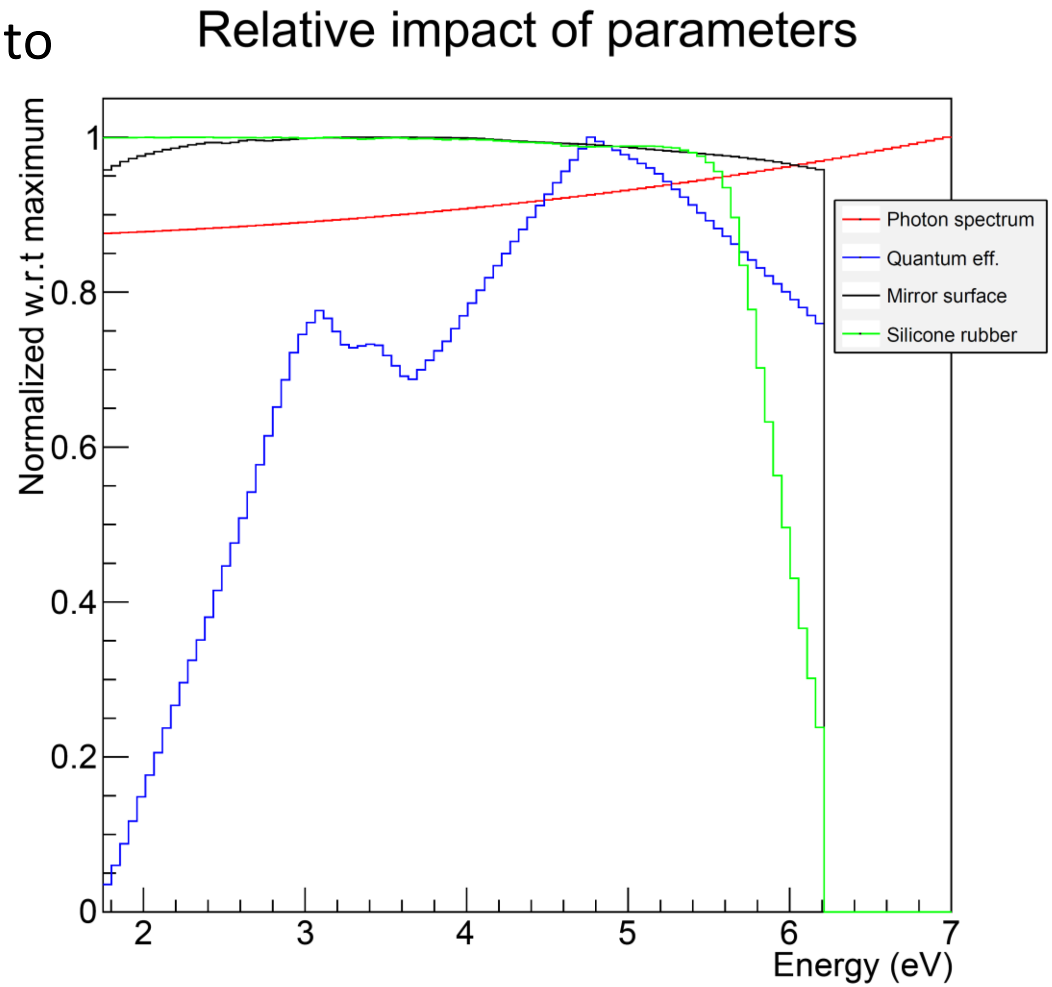
- Benefits
  - Higher position resolution
  - Better time resolution (per photon)
  - Lower channel count

- Drawbacks
  - Occupancy
  - Lifetime of detector



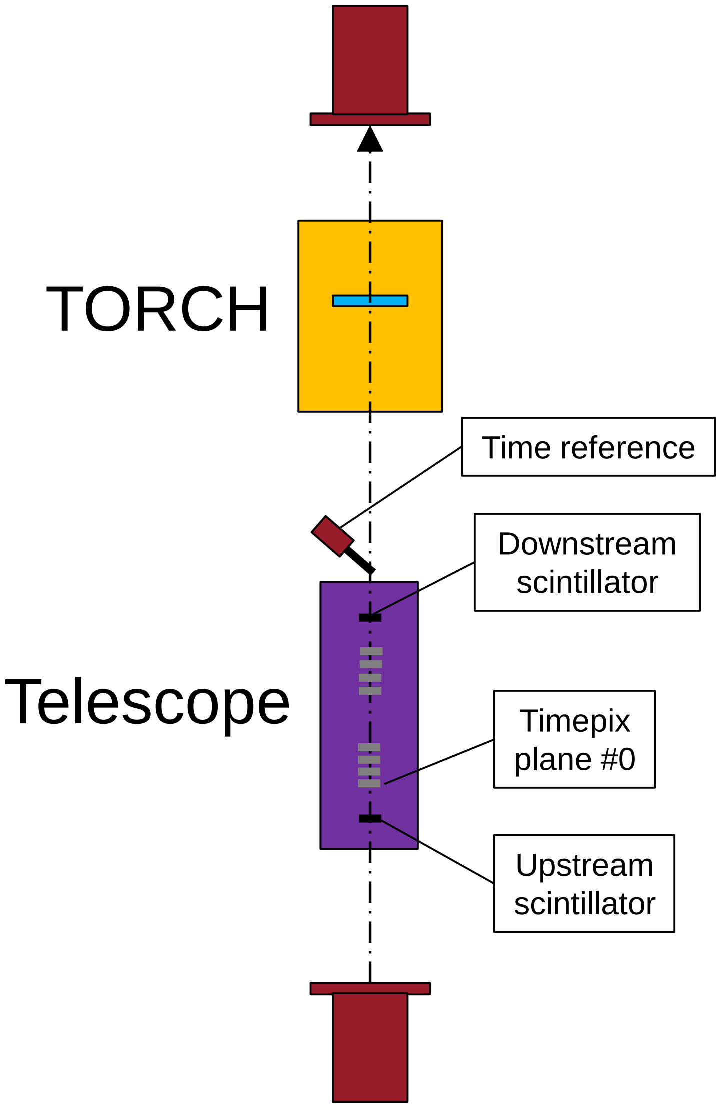
# Impact comparison

- Various factors fold together to limit performance in photon loss
- Photon energy dependent factors shown in diagram
  - Cherenkov spectrum
  - Quantum efficiency
  - Reflectivity of mirror surface
  - Optical bonding
- Limiting factors
  - Low energy: QE
  - High energy: Absorption in bonding



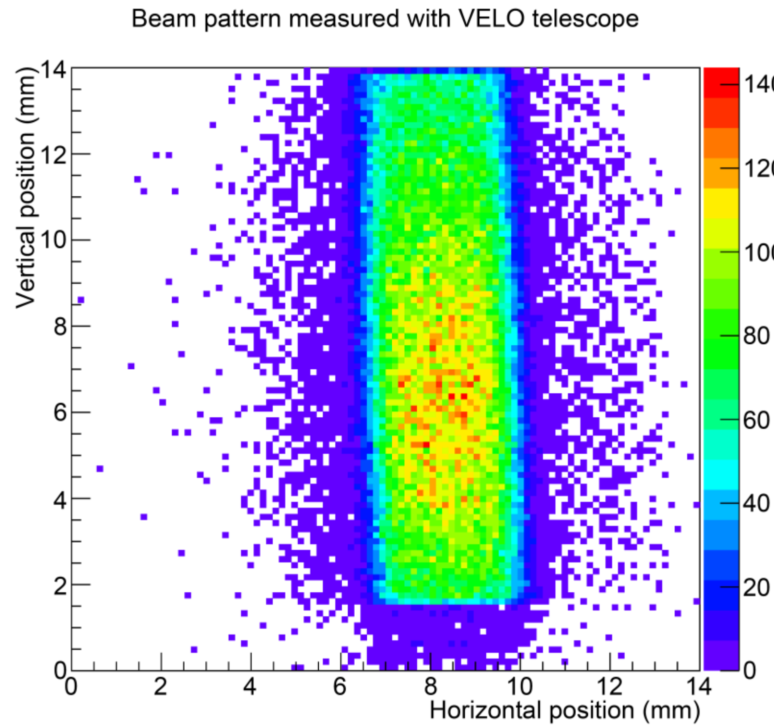
# Testbeam

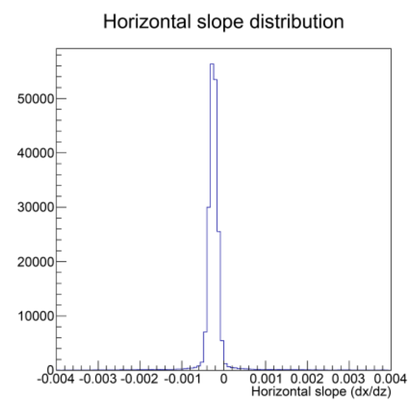
- Testbeam run at CERN at the SPS (H8)
- (Positive) charged hadrons at 180 GeV/c
  - β=1
  - Particle species become indistinguishable
- Scintillators used as trigger
- Tracking taken from VELO telescope
  - Eight consecutive planes of Timepix3 chips
  - 256x256 pixels on 14x14mm
  - High precision tracking, but "low" time resolution
- Timing reference taken from borosilicate finger and inserted into electronics

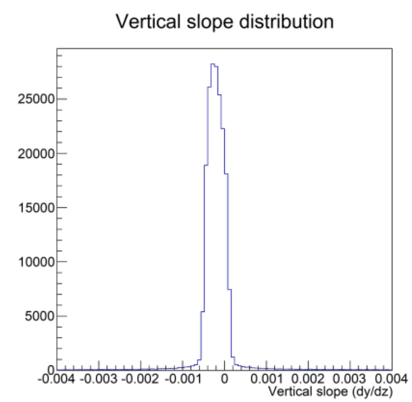


# SPS beam

- Beam profile measured from telescope data
- Large in vertical direction but small in horizontal
- Very low divergence
  - $-2.5 \pm 1.0 * 10^{-4}$ horizontal (-0.25 mrad)
  - $-2.0 \pm 1.7 * 10^{-4}$ vertical (-0.20 mrad)
- Typical for full testbeam program

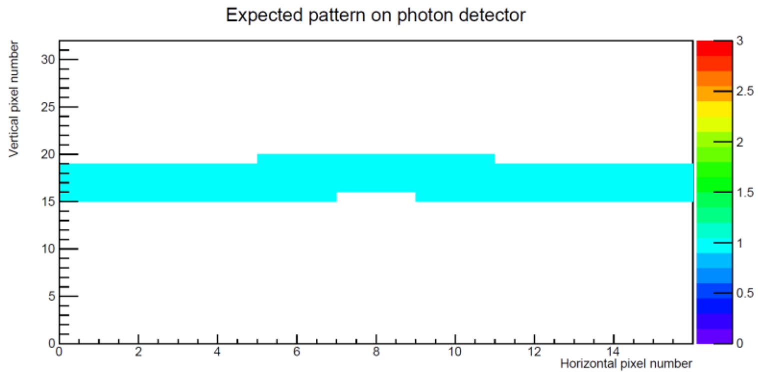


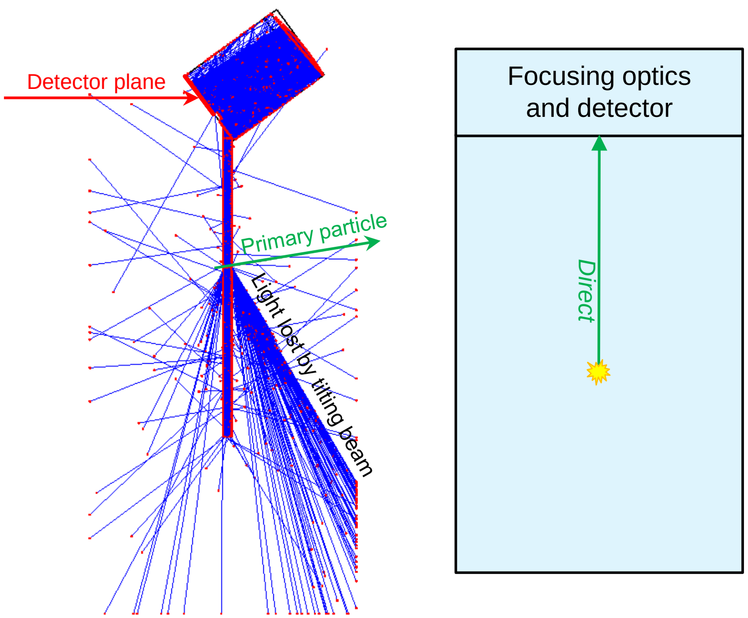



# Selecting beam parameters

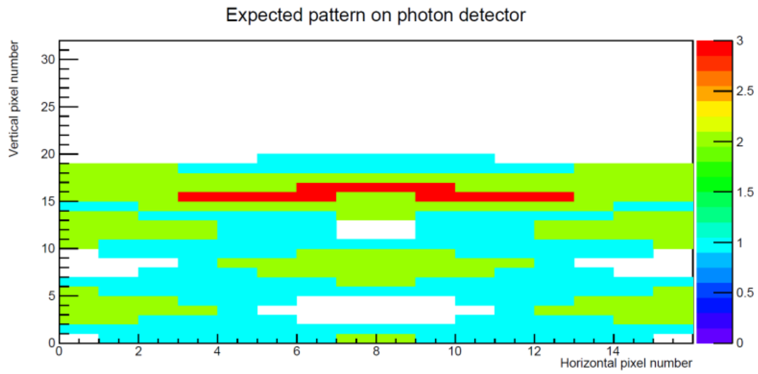
- TORCH can be tilted to select beam configuration
- Light can take many paths to detector (direct path shown)
- Reflections off the side of the radiator plate dominate since Cherenkov cone is isotropic in one angle
- Tilting the beam “filters out” downward light from Cherenkov cone – TIR condition is not met

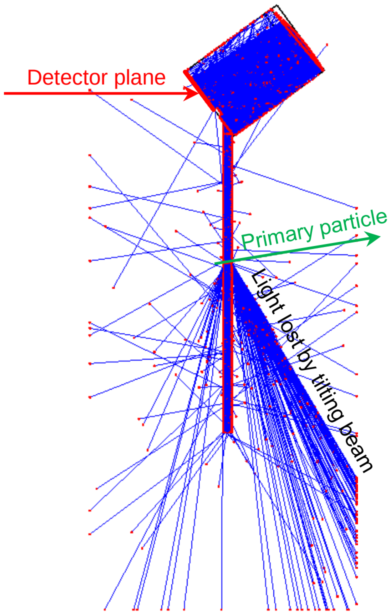


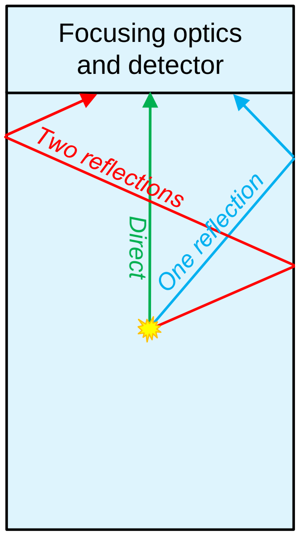



# Selecting beam parameters

- Light can take many paths to detector (all paths shown)
- Simulation set up to help select optimal testbeam parameters
- Reflections off the side of the radiator plate dominate since Cherenkov cone is isotropic in one angle
- Tilting the beam "filters out" downward light from Cherenkov cone – TIR condition is not met

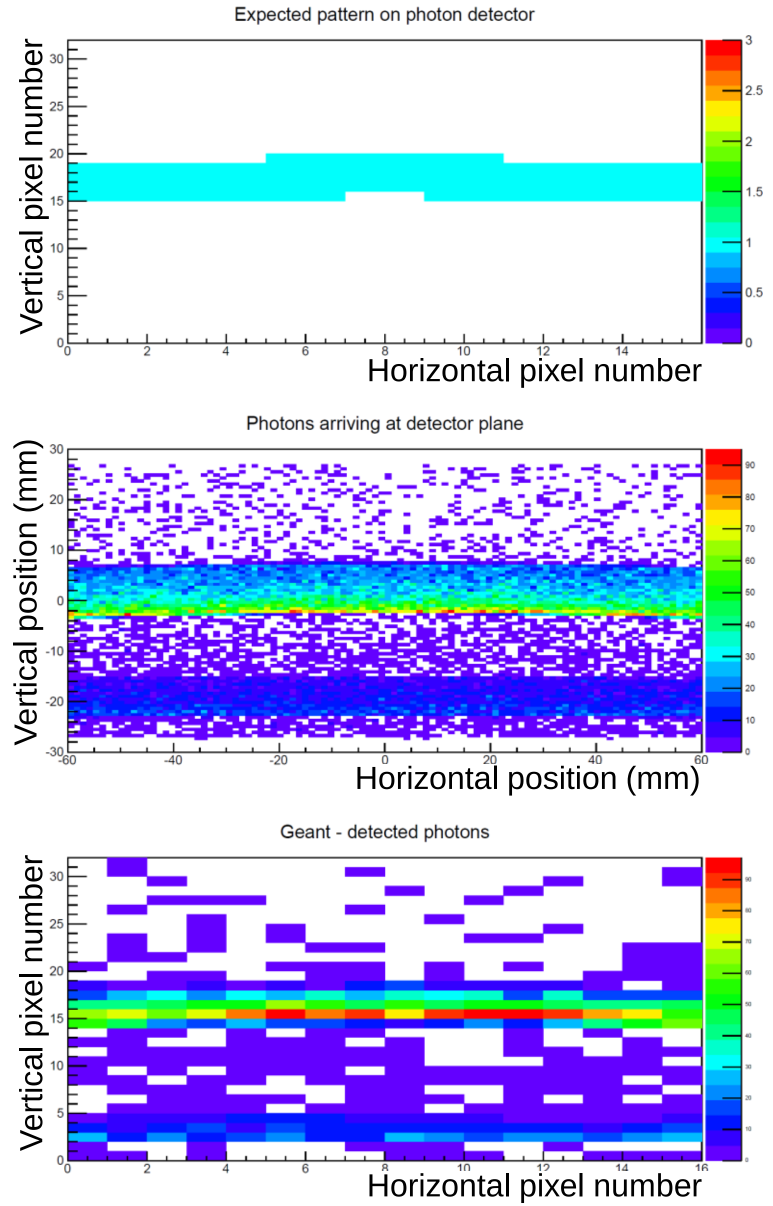


# Patterns

- Simulation run in Geant 4
  (just direct photons shown)
- Many effects accounted for in simulation
  - Quantum efficiency of detector
  - Scattering from surface roughness effects
  - Rayleigh scattering
  - Absorption by glue
  - Imperfect reflection of mirror surface in focusing block



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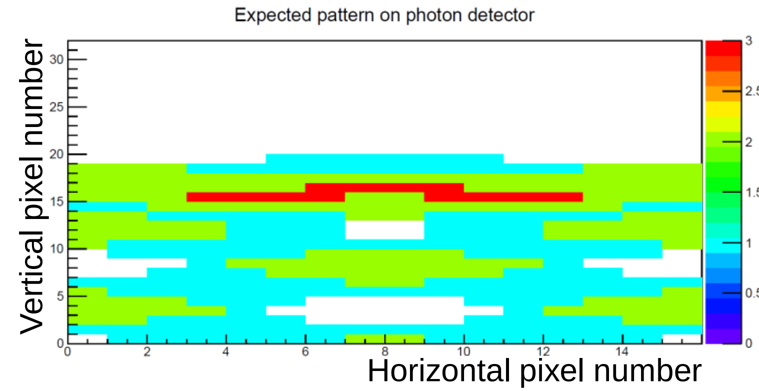
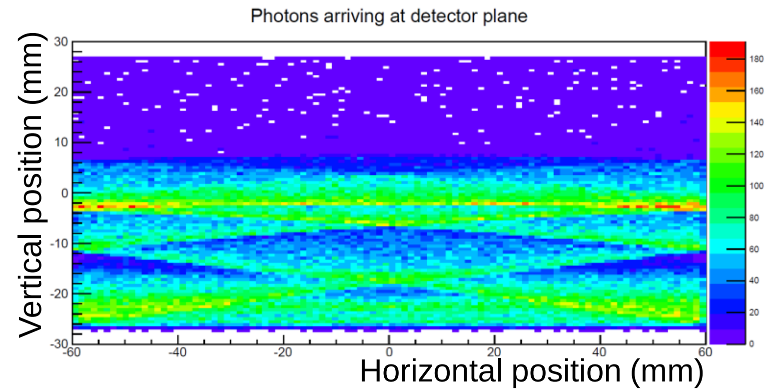
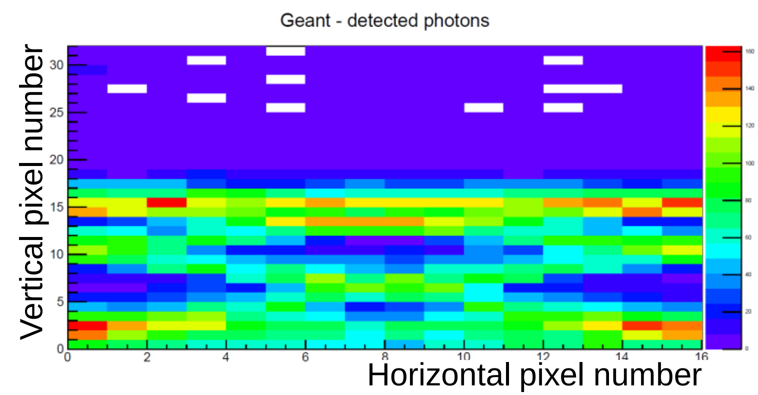
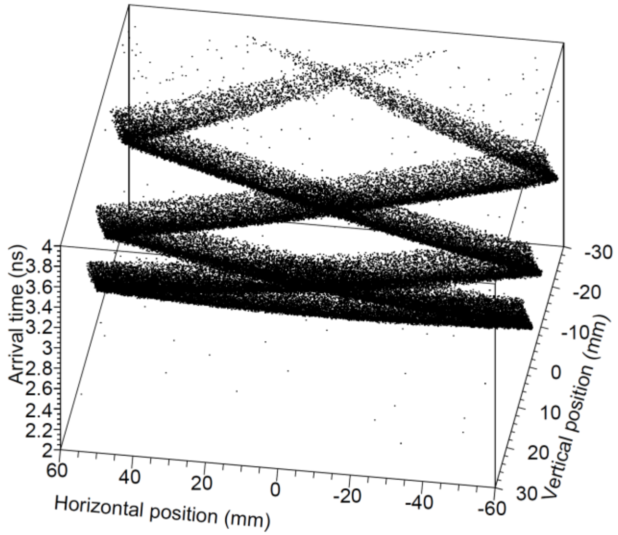


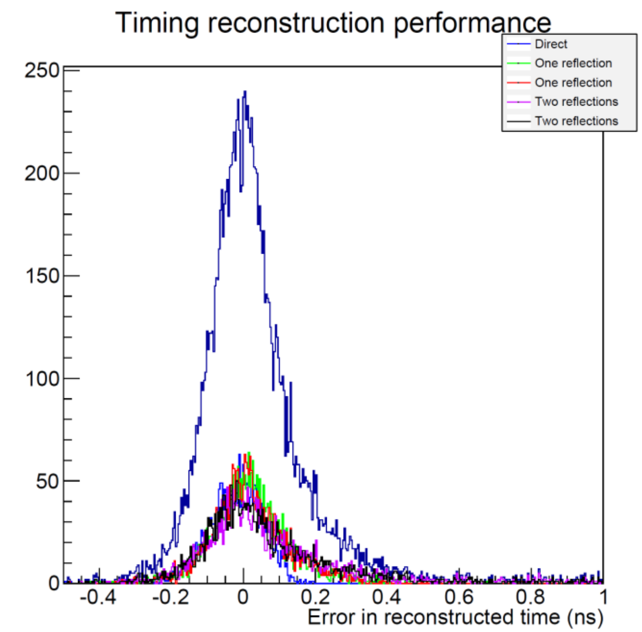



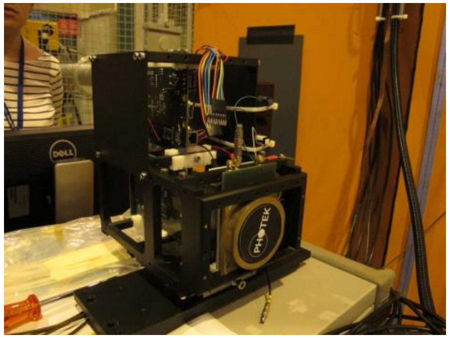
# Timing precision

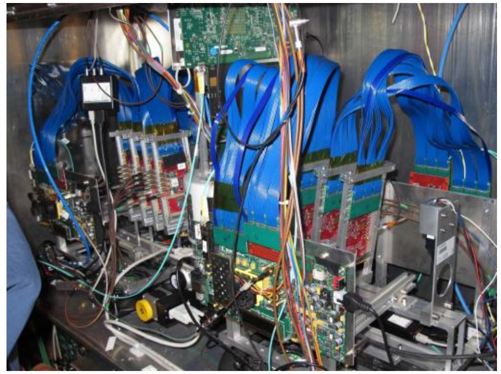
- Performance of testbeam setup dependent on reconstruction
- Chromatic dispersion correction applied
- Algorithm performing well
- Detector performance dominates
  - Taken from lab measurements on different MCP-PMT and electronics
  - Single photon resolution *after reconstruction* ~90ps sigma

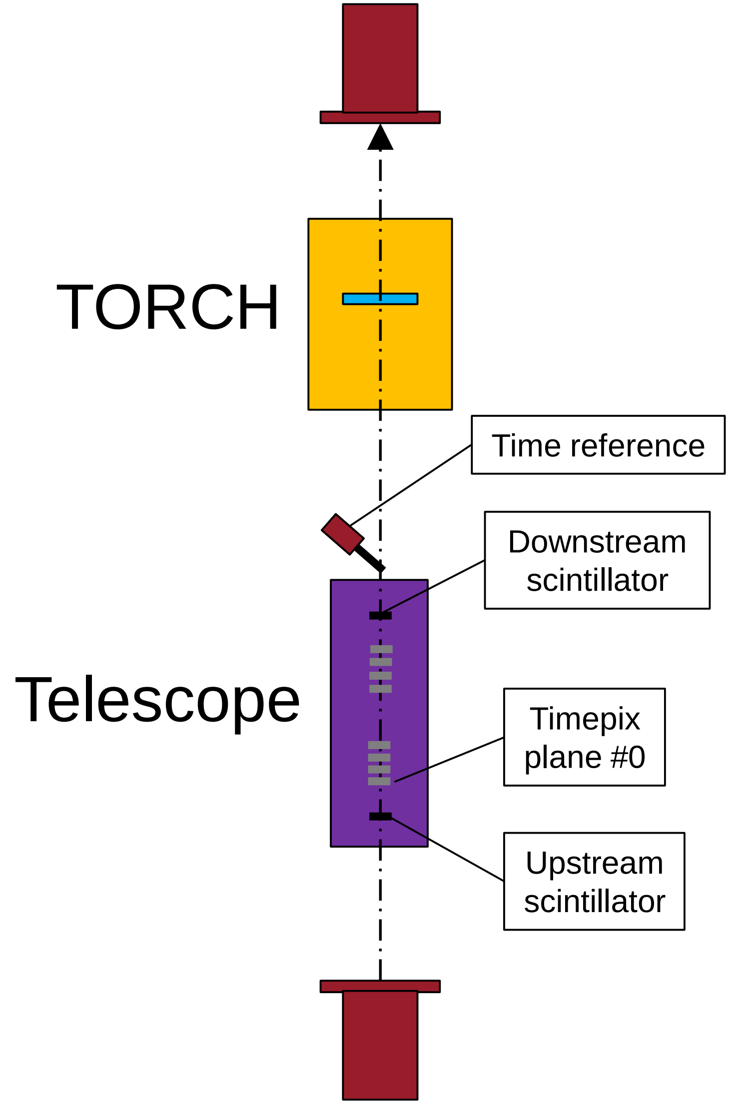


# SPS beamtest

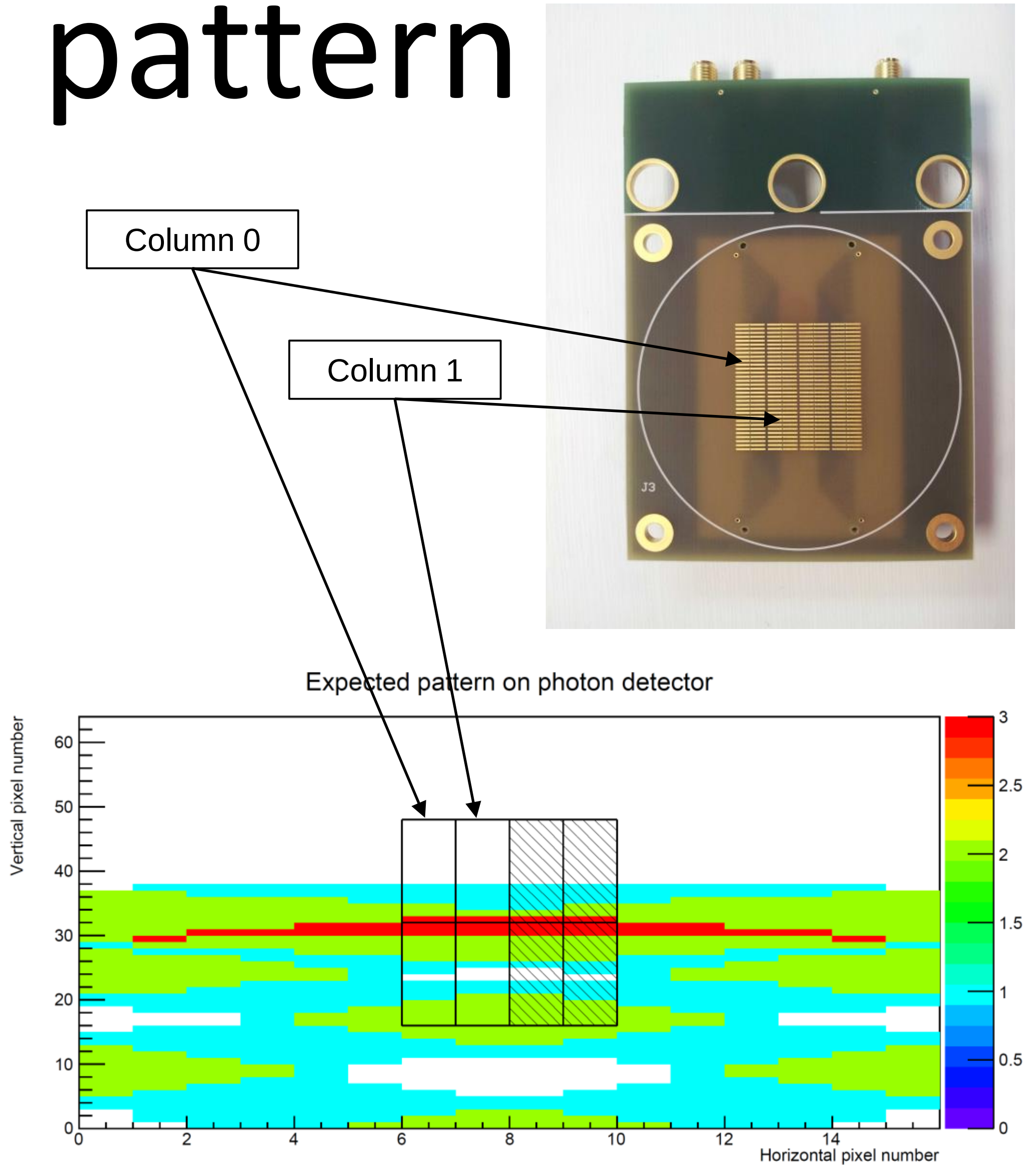




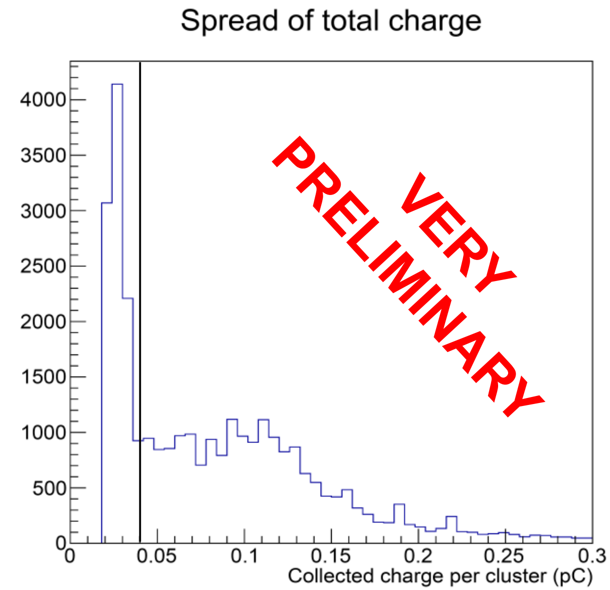
# Expected pattern

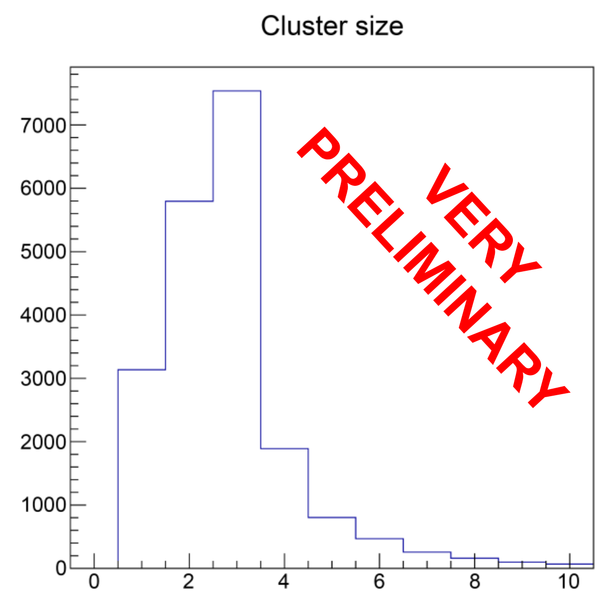
- Tilt chosen for the radiator is 5 degrees
- Main part of pattern covers center of detector
- Direct and first order reflections visible
- Some parts of second order reflection will show



# Results

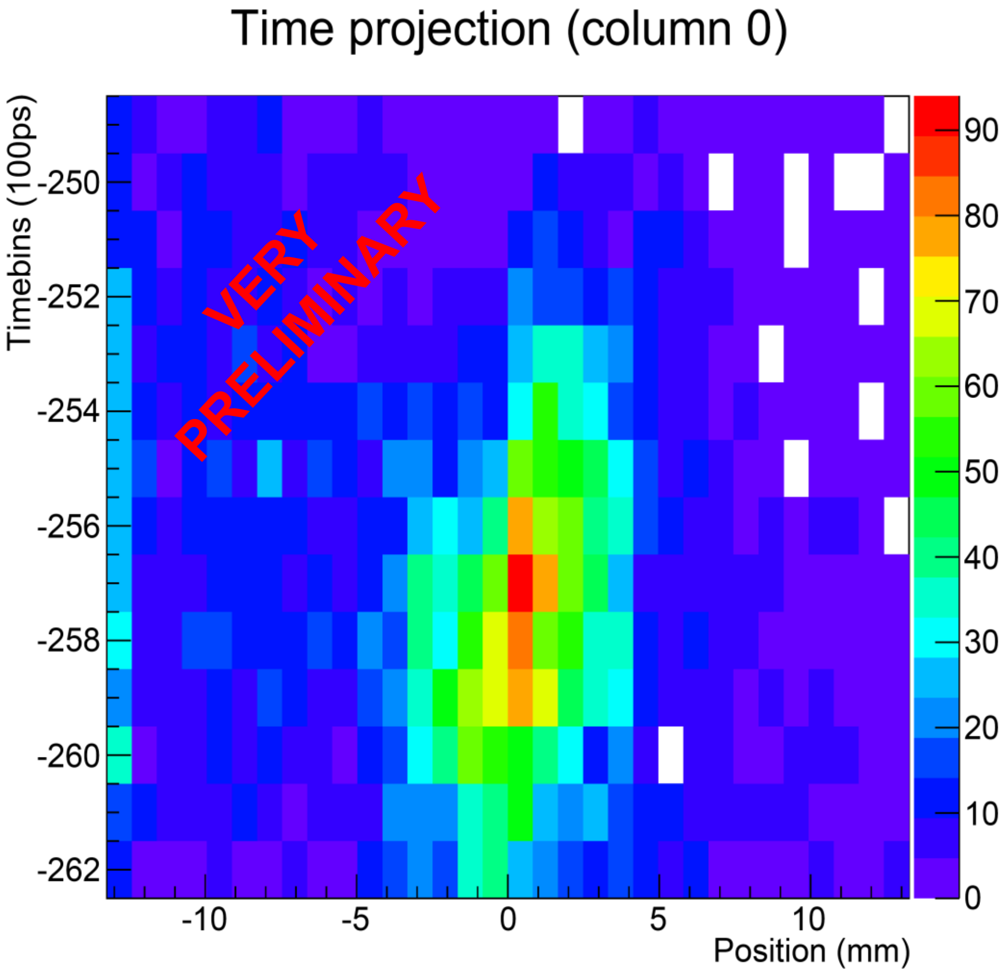
- Hits are clustered and charge sharing applied
- Based on charge distribution, a cut is made at 0.04 pC (cut out pedestal)
- Cut mainly removes single hit clusters
- Several calibrations pending
  - Timewalk correction
  - Width to charge conversion



# Results

- Photon pattern shows up in expected position
- Pending further calibrations
- Further data analysis in progress….



# Conclusions

- TORCH is an R&D project aiming to provide large-area Cherenkov based particle identification in the 2-10 GeV/c region
  - Key focus is on detector development and prototyping

- Testbeam at SPS area at CERN has been completed
  - Small TORCH module
  - 180 GeV/c, tracking from VELO telescope

- Data analysis still in progress, more results will soon be forthcoming

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