The TORCH R&D Project Status and Perspectives

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University of Bristol
CERN
University of Oxford
erc
European Research Council
Established by the European Commission

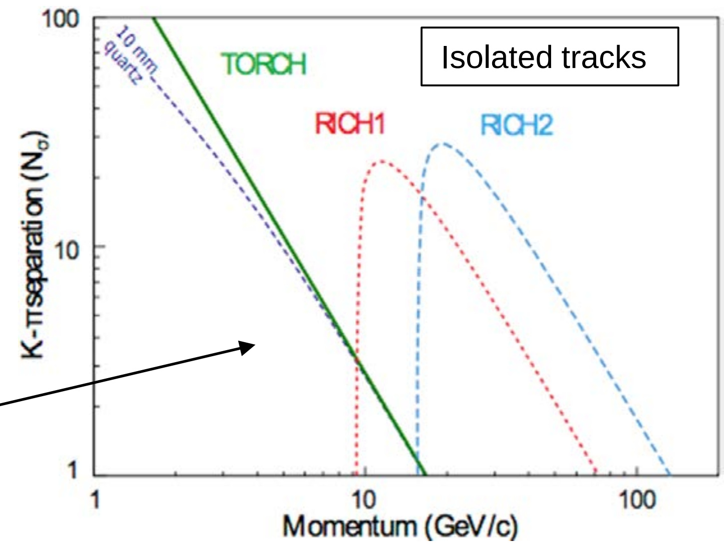
Talk layout

- TORCH – basic principles and requirements
- Micro-channel plate developments
- Test beam results
- Conclusions and perspectives

TORCH – basic principles and requirements

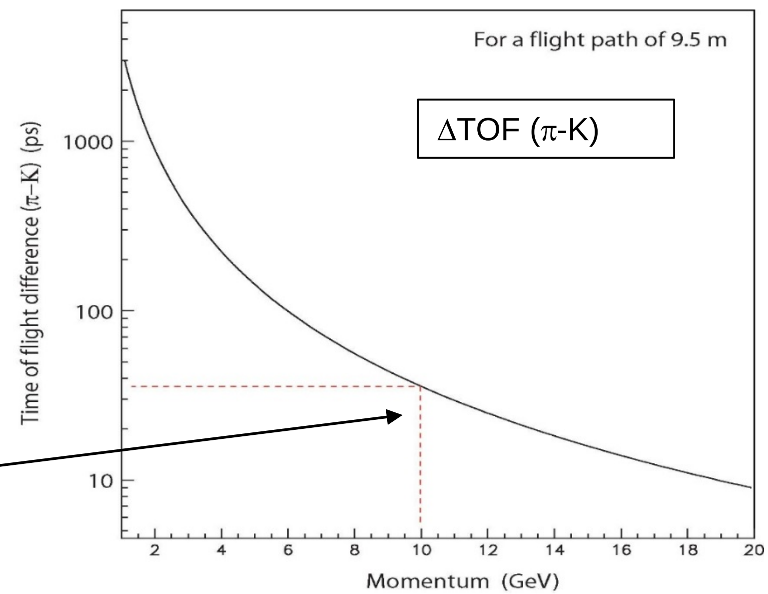
TORCH motivation

- TORCH* (Time Of internally Reflected CHerenkov light) is a proposed solution for low-momentum particle ID
  - Closely related to iTOP of Belle II and DIRCs of PANDA (see related contributions in this Conference)



- Want to complement in LHCb existing PID capabilities provided by 2 gaseous RICH detectors
  - Positive identification of kaons in region below their threshold for producing light in the C_4F_{10} gas of LHCb RICH1, i.e. p < 10 GeV

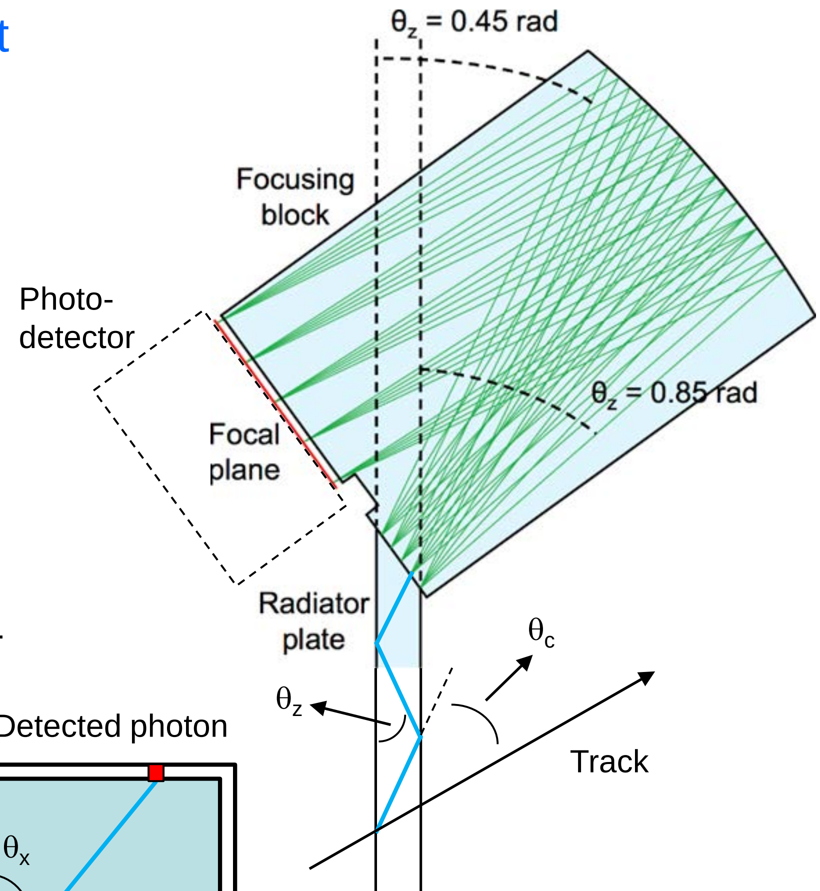
- TORCH to measure the particle time-of-flight
  - ΔTOF (π-K) = 37.5 ps at 10 GeV over a distance of ~ 10 m
    → aim for ~15 ps resolution per track

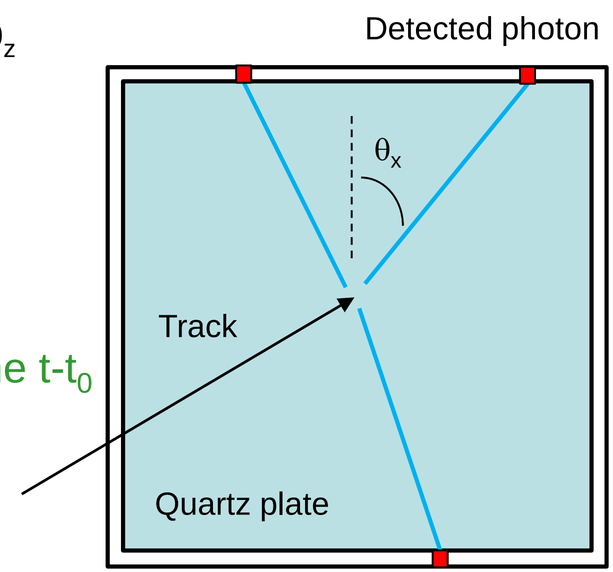


* M. J. Charles, R. Forty, *NIMA 639 (2011) 173-176*

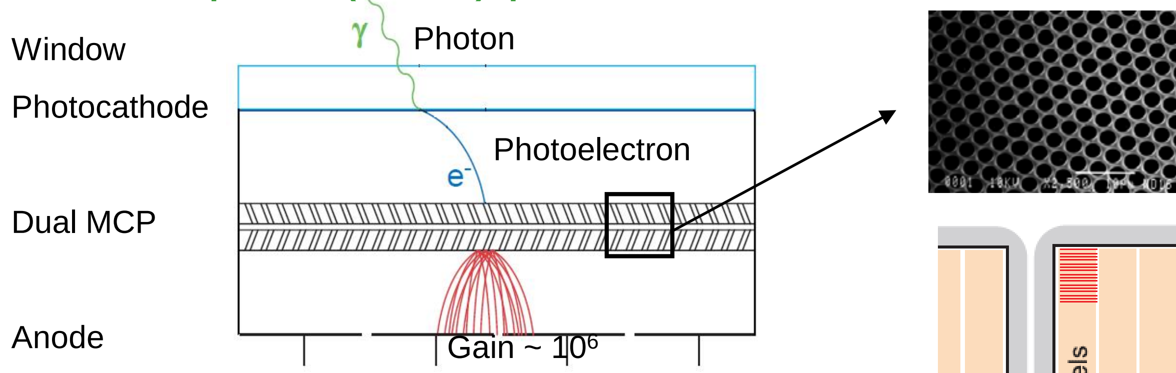
TORCH concept

- Cherenkov (Č) photons produced in quartz propagate to the periphery by total internal reflection
- Measure photon arrival time t
- Measure angles θ_x, θ_y to reconstruct photon trajectory and path length L
  - 1 mrad angular precision required
  - Coarse photo-detector segmentation (6.4mm) for θ_x
  - Focussing block converts θ_z in precise position on photo-detector
  - Fine segmentation (0.4mm)) for θ_z
- Infer Č angle θ_c and correct for chromatic effects
  - $\cos \theta_c = 1 / (\beta \times n_{phase})$
- Determine photon propagation time $t - t_0$
  - $t - t_0 = (L \times n_{group}) / c$
- Combine all photon times

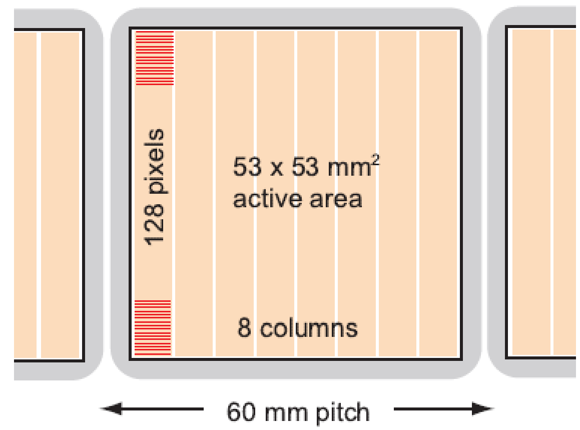




- Use micro-channel plate (MCP) photo-detectors for fast timing of single photons

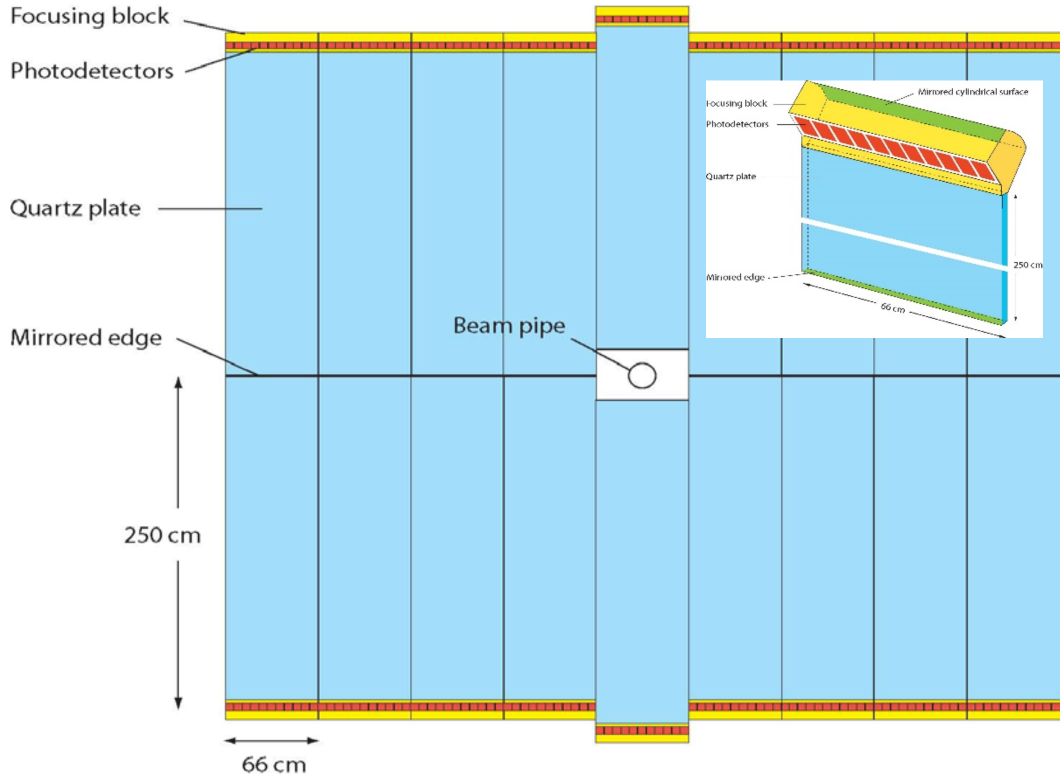


- Anode pad structure adjusted to TORCH needs
  - 128×8 pads each 0.4mm×6.4mm in size
  - Smearing of photon propagation time estimate due to photodetector granularity ~50 ps
  - Assuming an intrinsic arrival time measurement resolution per p.e. of 50 ps the total resolution per detected p.e. is 50 ⊕ 50 ~ 70 ps, as required for 30 detected photons



- Readout electronics
  - Based on NINO and HPTDC ASICs originally developed by ALICE

- For the application in LHCb, transverse dimension of plane to be instrumented is ~ 5 × 6 m^2 (at z = 10 m)
- Realistic layout is with quartz modules



18 identical modules
each 250 × 66 × 1 cm^3
→ ~ 300 litres of quartz in total

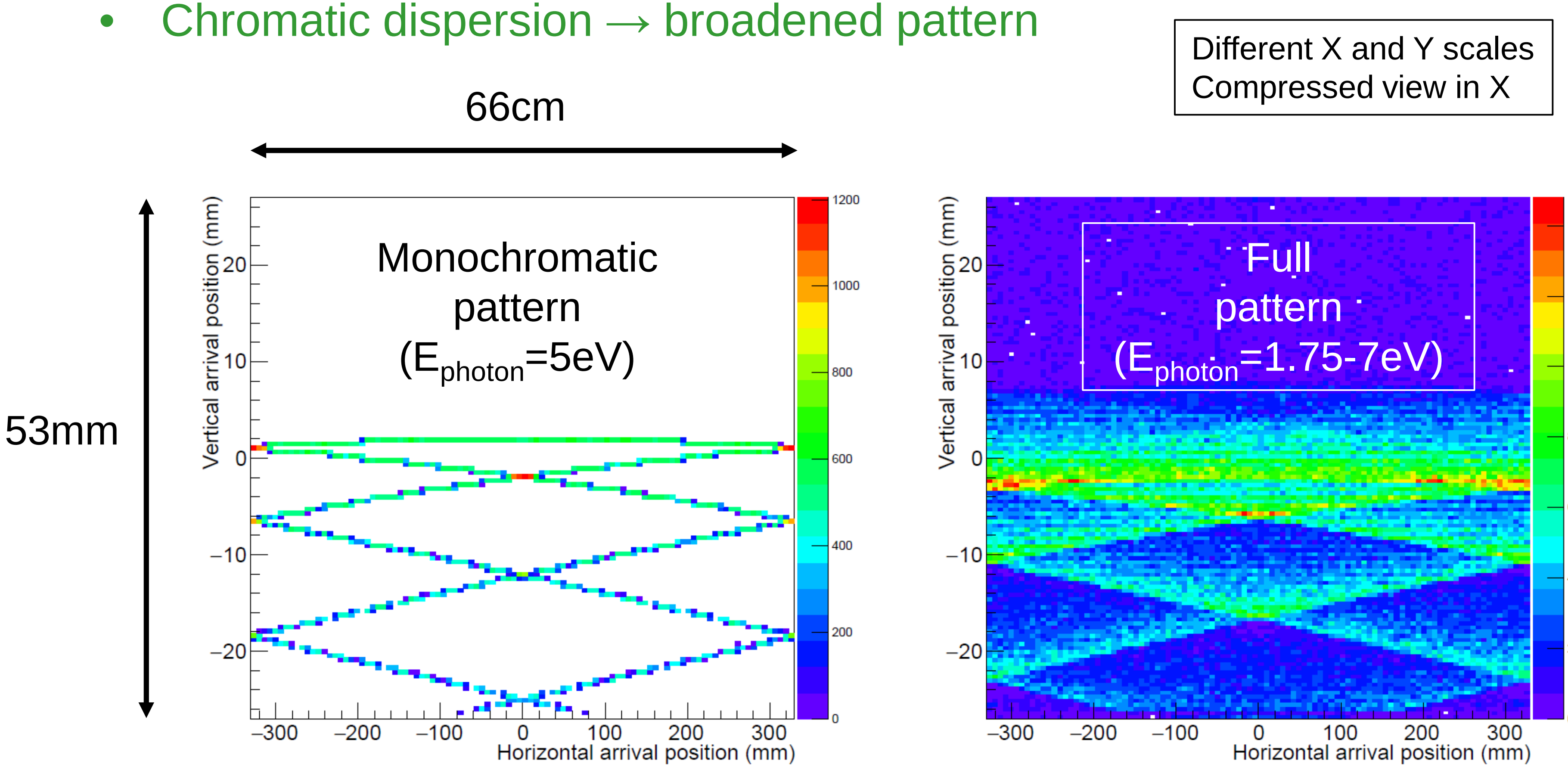
Reflective lower edge
→ photon detectors only needed on upper edge

18 × 11 = 198 units
Each with 1024 pads
→ 200k channels total

- Reflections off the sides of the quartz module give ambiguities in the reconstructed photon path

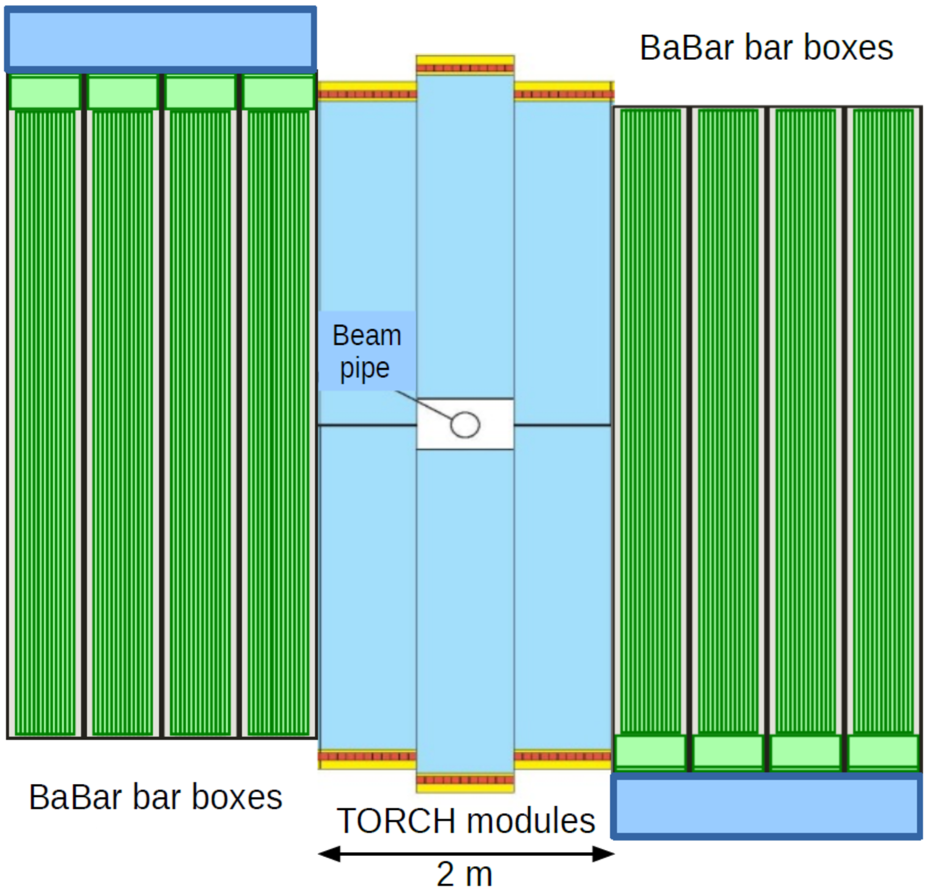
Cherenkov photon pattern on detector

- Cherenkov cone mapped onto a hyperbolic pattern
- Reflections off module edges → folded pattern
- Chromatic dispersion → broadened pattern



TORCH *hybrid* modular design

- TORCH modules at periphery replaced by BaBar bar boxes
- See dedicated poster by K. Föhl at this Conference



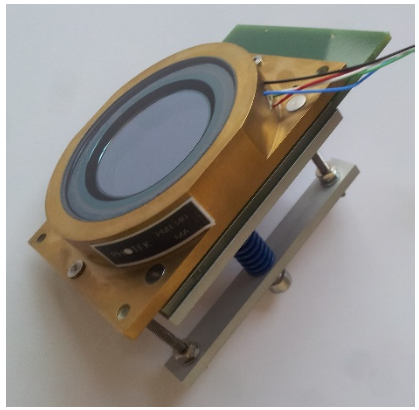
Micro-channel plate developments

MCP developments with industrial partner Photek Ltd.

- 3-phase development programme
  - See also dedicated talk of J. Milnes (Photek Ltd.) at this Conference

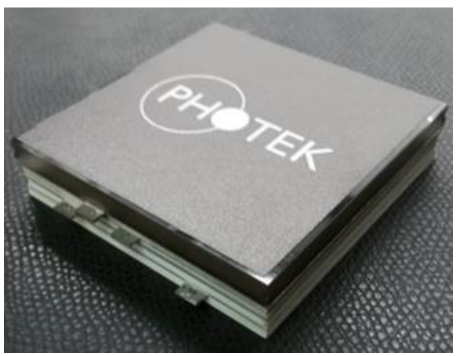
- Phase I
  - MCP tubes with extended lifetime
    - Circular prototypes
    - 25mm active diameter
    - Single channel

- Phase II
  - MCP tubes with required granularity
    - Circular prototypes
    - 40mm active diameter
    - Quarter-size anode
      - 32×4 pixels (0.8mm×6.4mm pixel size) – channel count halved
      - Charge sharing used to achieve required resolution



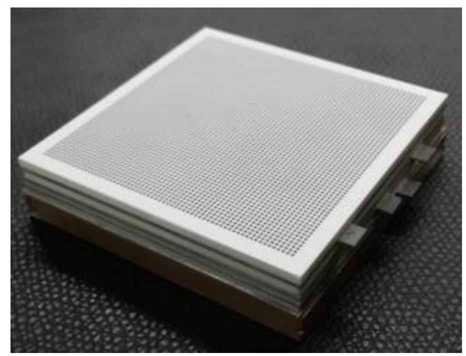
MCP developments (2)

- Phase III
  - MCP tubes with extended lifetime and required granularity
    - 2”×2” square prototypes
  - Full-size anode
    - 64×8 pixels (0.8mm×6.4mm pixel size) – channel count halved
    - Charge sharing used to achieve required resolution
  - Prototypes close to completion, to be delivered in fall

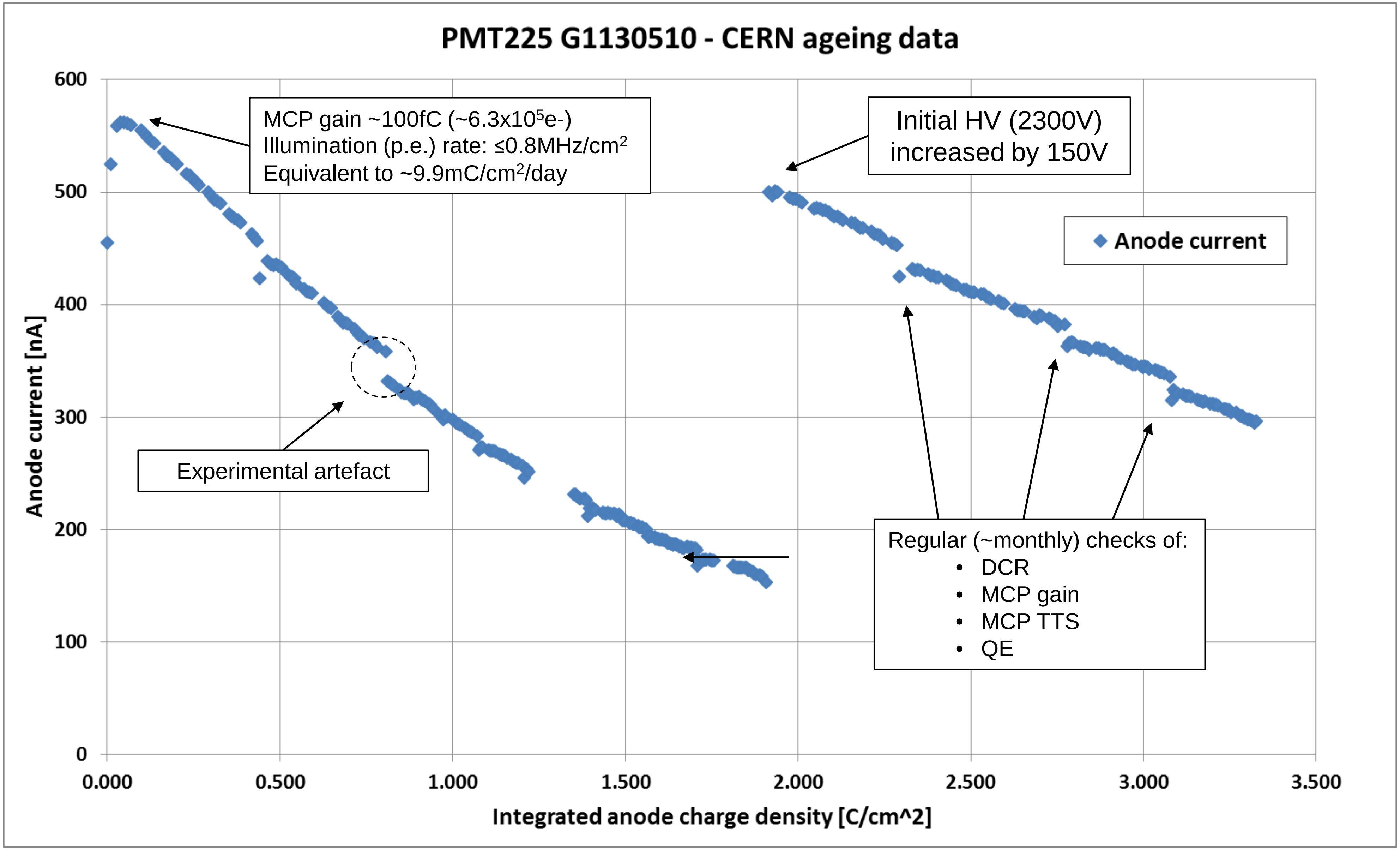


Front view

Rear view

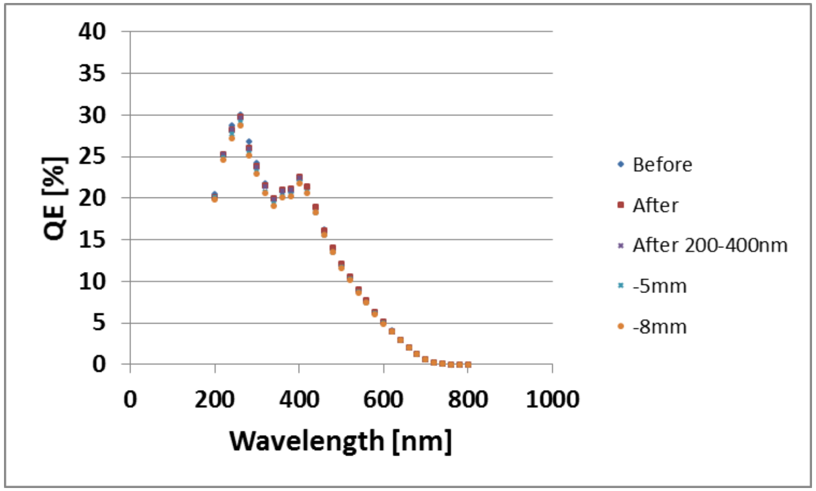


Phase-I tube anode current trend vs integrated anode charge density

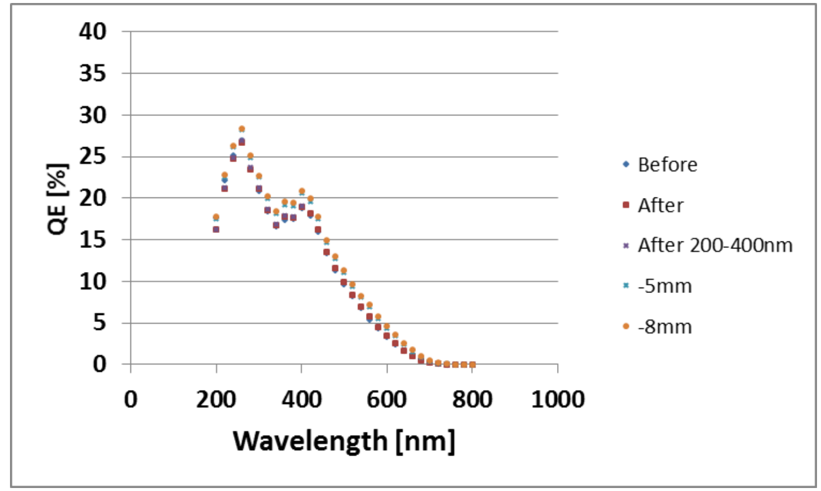


QE and (gain vs anode current) monitoring

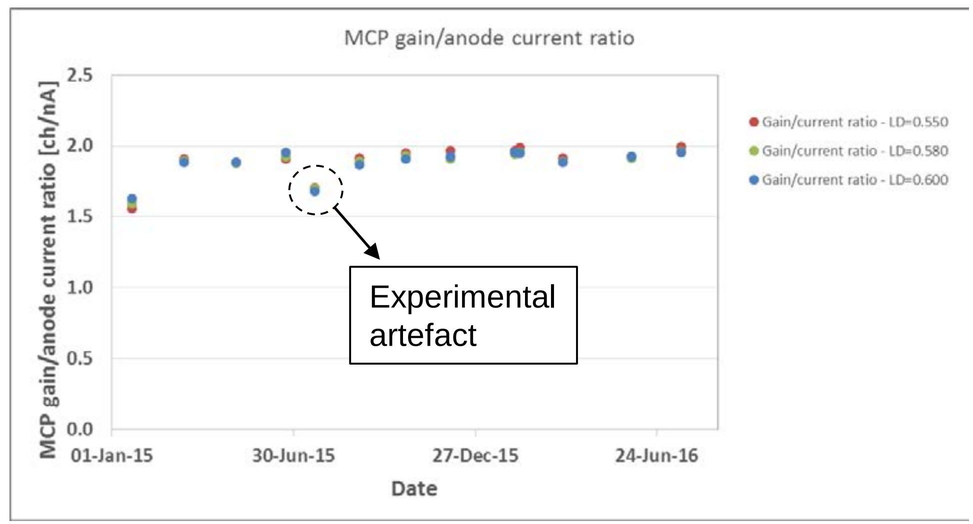
Prior to ageing



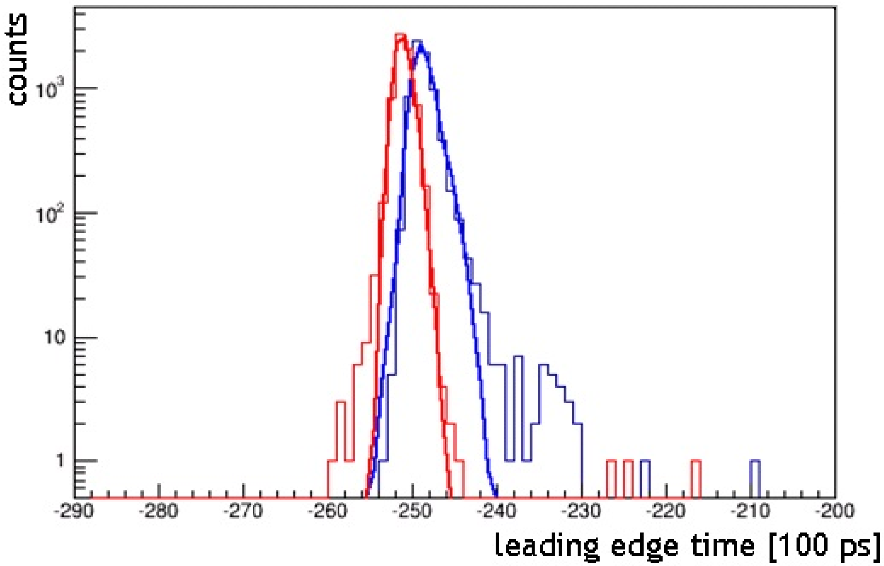
After 3.09 C/cm^2



(MCP gain/anode current) ratio



Phase-II tubes with required granularity – laboratory test results



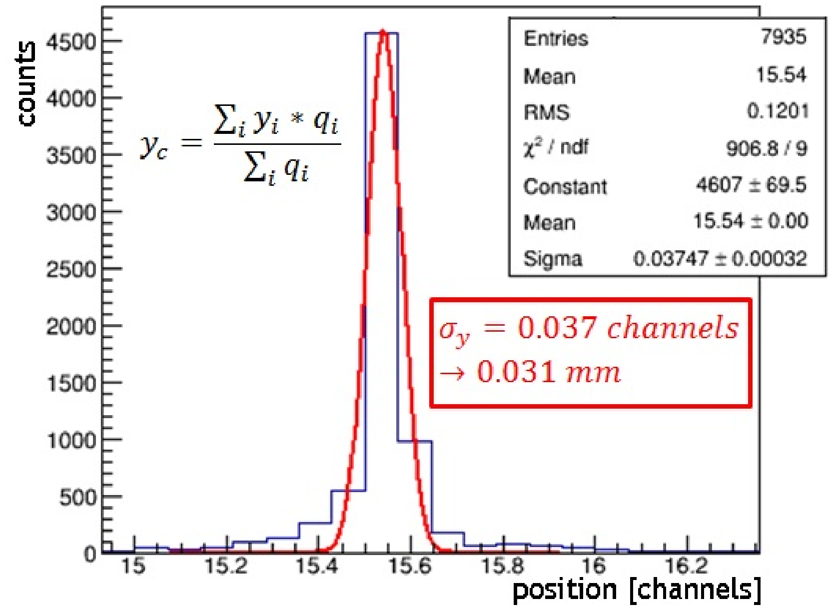
Pixel time resolution

- Raw data (blue): 100ps
- After correction (red): 80ps

- Note: 100ps HPTDC time bin

Pixel cluster spatial resolution

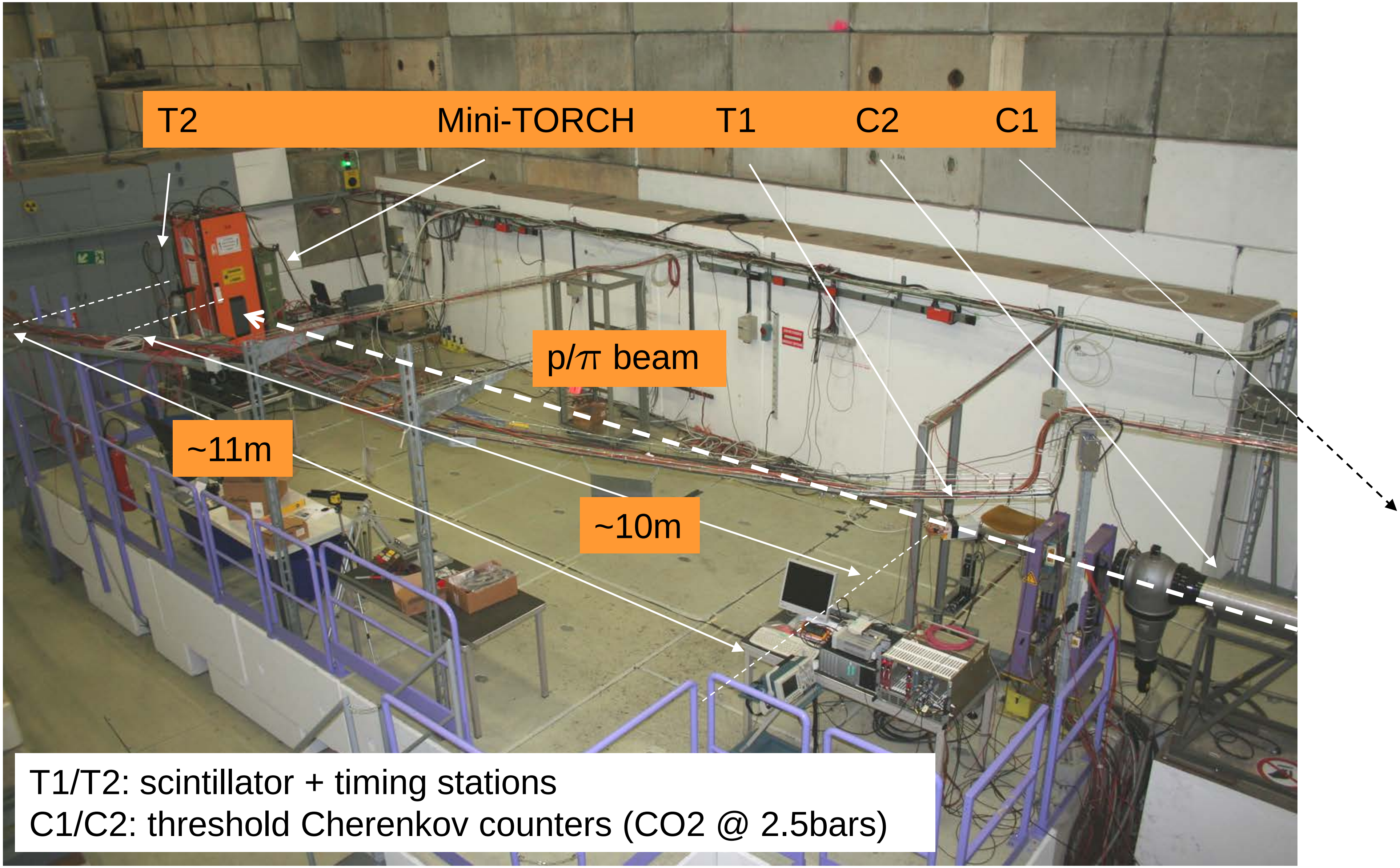
- Cluster size: 3-4 pixels
- After full time-over-threshold to charge calibration of all pixels in cluster: $\sigma_y \approx 0.03$mm



L. Castillo García et al, *JINST 11 C05022 (2016)*

Test beam results

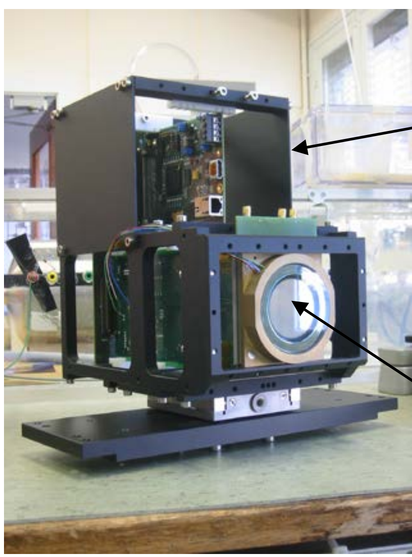
TORCH beam test infrastructure in PS/T9

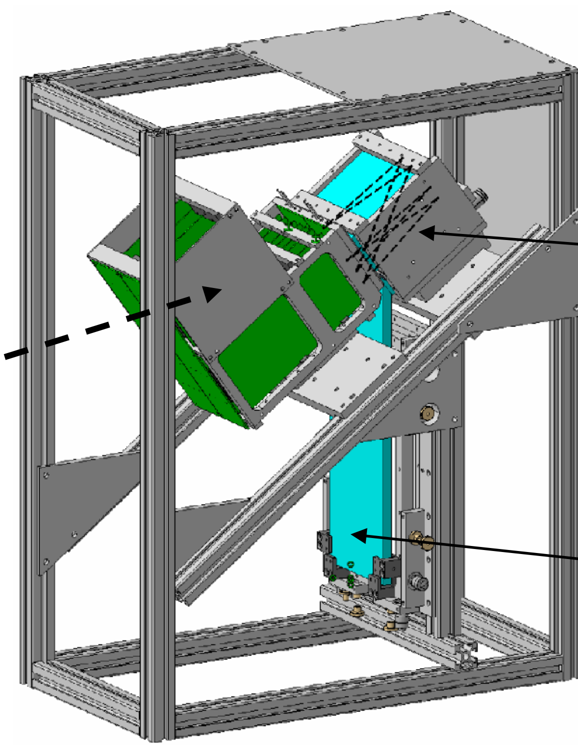


T1/T2: scintillator + timing stations
C1/C2: threshold Cherenkov counters (CO_2 @ 2.5bars)

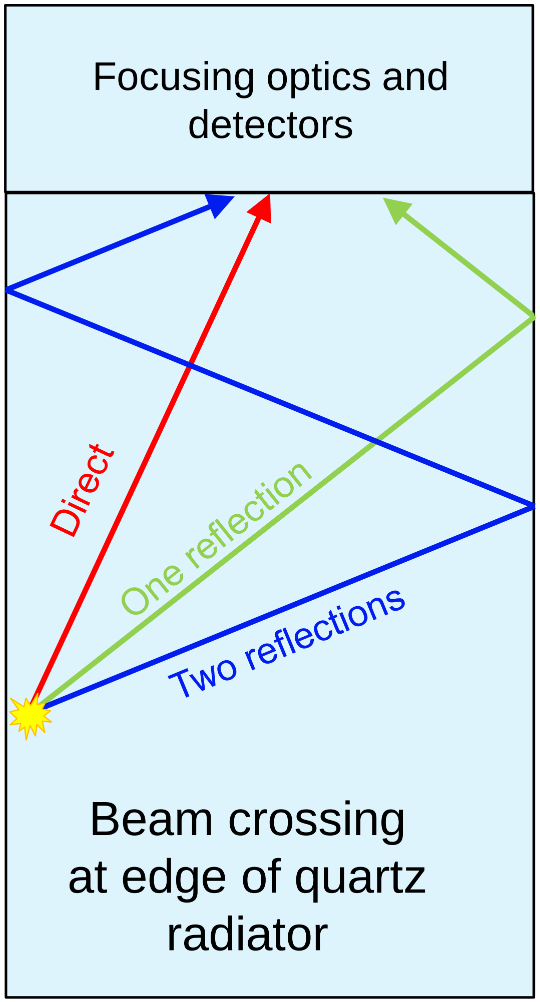
TORCH beam test infrastructure - details

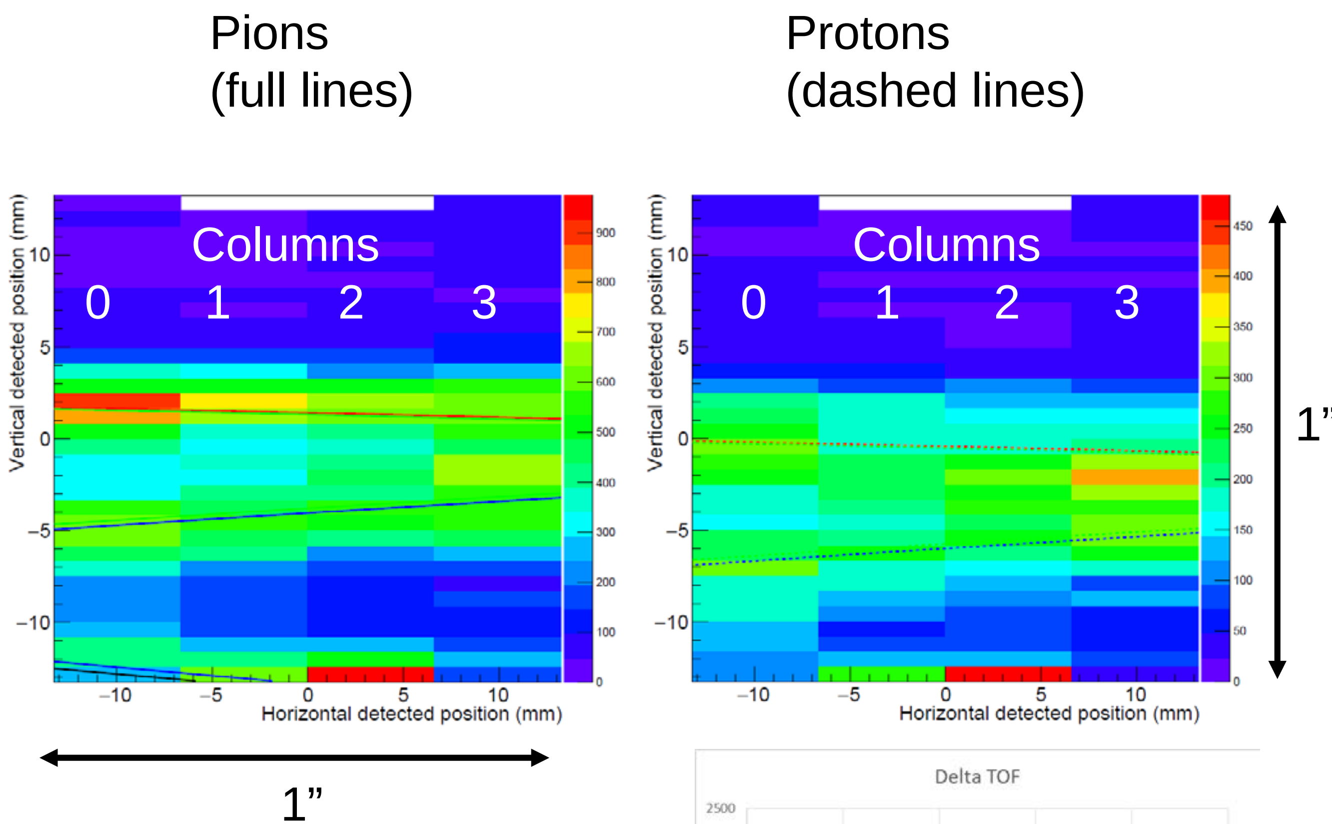
- "Mini-TORCH" prototype
  - Quartz radiator plate 35×12×1cm^3
  - Quartz focusing block 12cm width
  - Prototype Phase-II Photek MCP-PMT
  - Readout electronics
    - 32-channel NINOs
    - HPTDC operated @ 100ps time bins





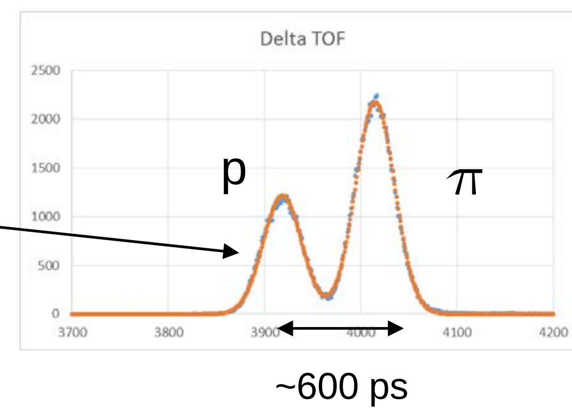
Cluster maps @ 5GeV/c





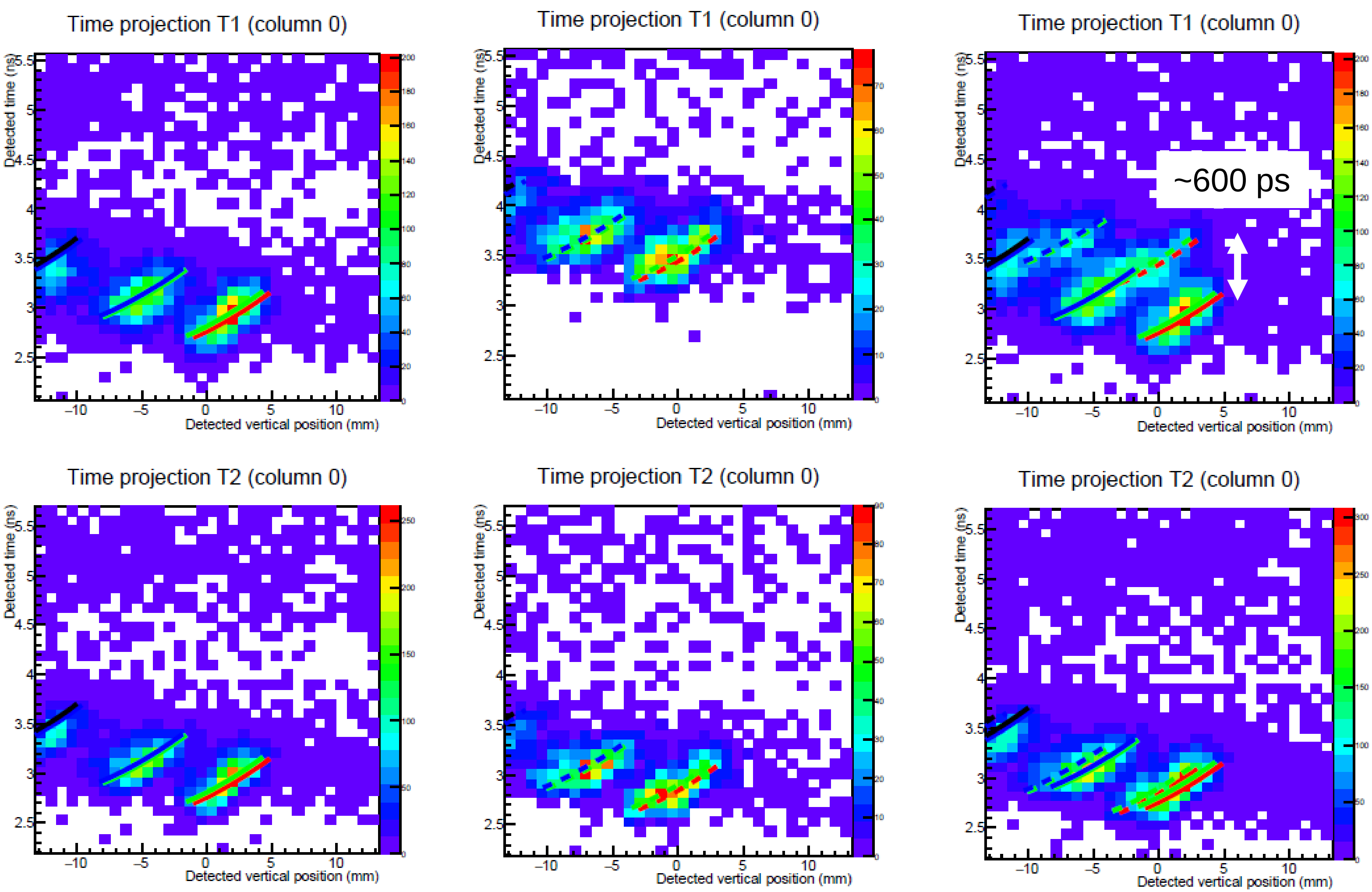
Particle selection using:

- T1/T2 time references
- C1/C2 signals



Time projections for column 0

Pions | Protons | All



Flight path 10m

T1 reference

Flight path 1m

T2 reference

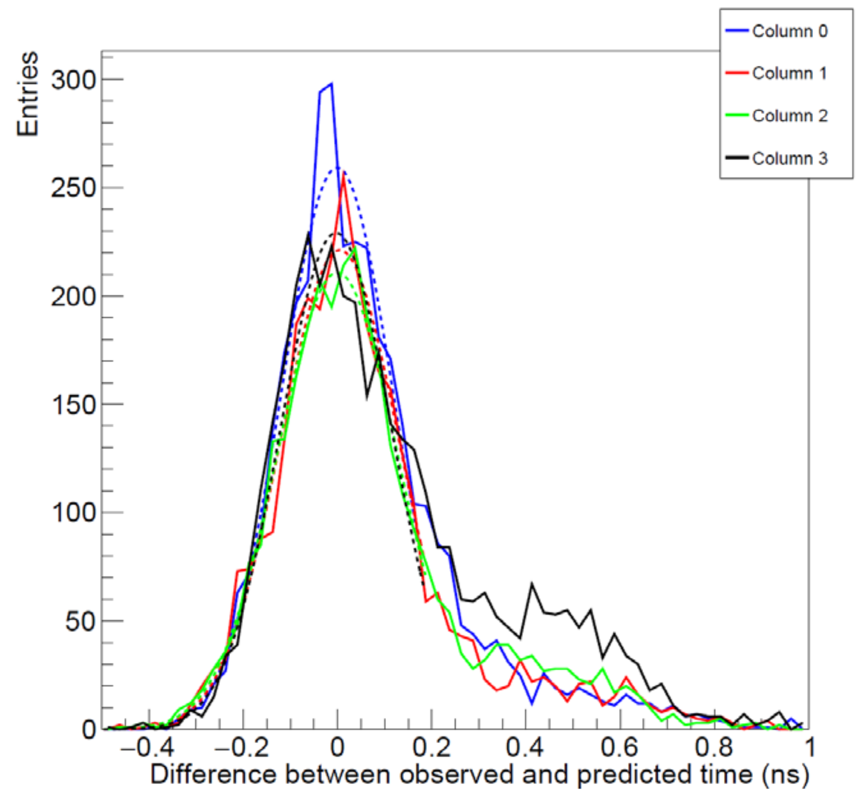
Time resolutions

- Predicted photon arrival time
  - Full reconstruction based on:
    - Track position
    - Particle momentum
    - Particle type
- Time resolution estimates
  - Gaussian fit of main peak

Col. #	Mean [ps]	Sigma [ps]
0	-0.6	117.2
1	4.7	124.9
2	-0.3	126.9
3	-3.0	117.7

  - Notes:
    - 100ps HPTDC time bin
    - No tracking (defined by scintillators)

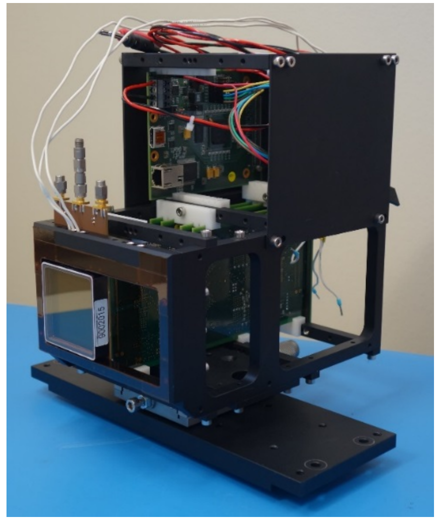
Pions
1m flight path
T2 reference



Observed – predicted time [ns]

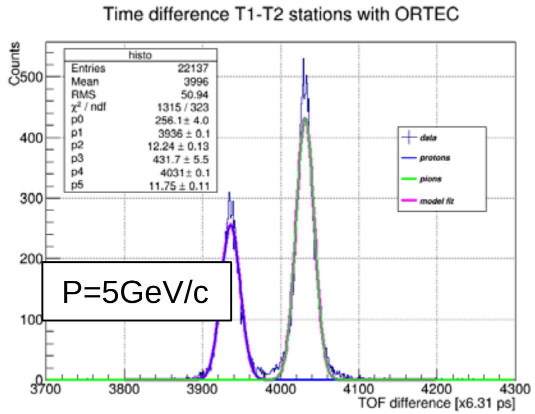
Conclusions and perspectives (1)

- Quartz for full demonstrator module
  - Radiator plate 125×66×1cm^3
  - Single-piece focusing block 66cm width
  - Price enquiry completed
  - Order is imminent



- New iteration of R/O electronics
  - New FE boards with 4 NINO32 chips each
  - HPTDC boards
  - Readout boards
  - Synchronization and data management

- On-going PS beam tests
  - Fully instrumented 32×32 Planacon
  - Compatible with final Phase-III MCP prototypes



Conclusions and perspectives (2)

- TORCH R&D showed excellent progress

- Results on required specifications very satisfactory
  - Ageing
  - Spatial resolution using charge sharing technique
  - Time resolution using dedicated readout electronics

- Results from beam tests confirm laboratory investigations
  - Clear TORCH patterns
  - Clear time projections
  - Per-photon time resolutions reach 115ps, approaching target

The TORCH Collaboration

- European Research Council Support
  - The support of the European Research Council in funding this work is gratefully acknowledged:
  - ERC-2011-AdG, 291175-TORCH (http://cordis.europa.eu/projects/rcn/103813_en.html)

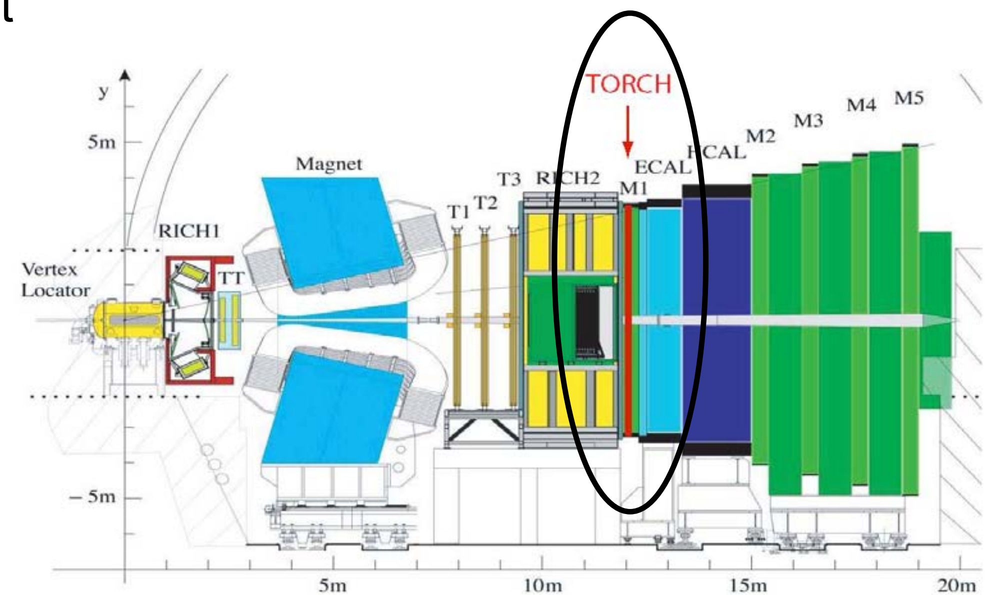
- Collaborating institutes
  - University of Bristol
  - CERN
  - University of Oxford

- Industrial Partner
  - Photek Ltd.

Spare slides

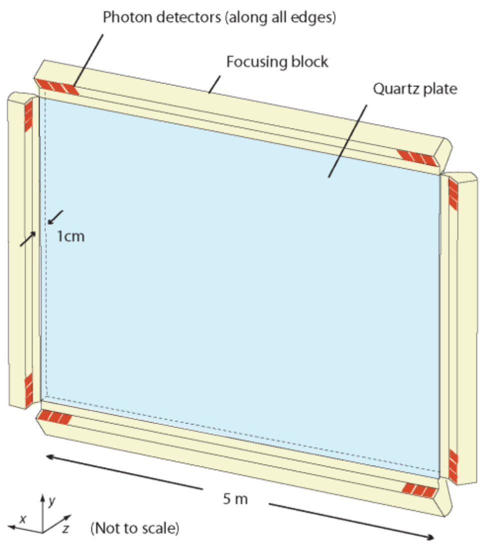
LHCb upgrade plan

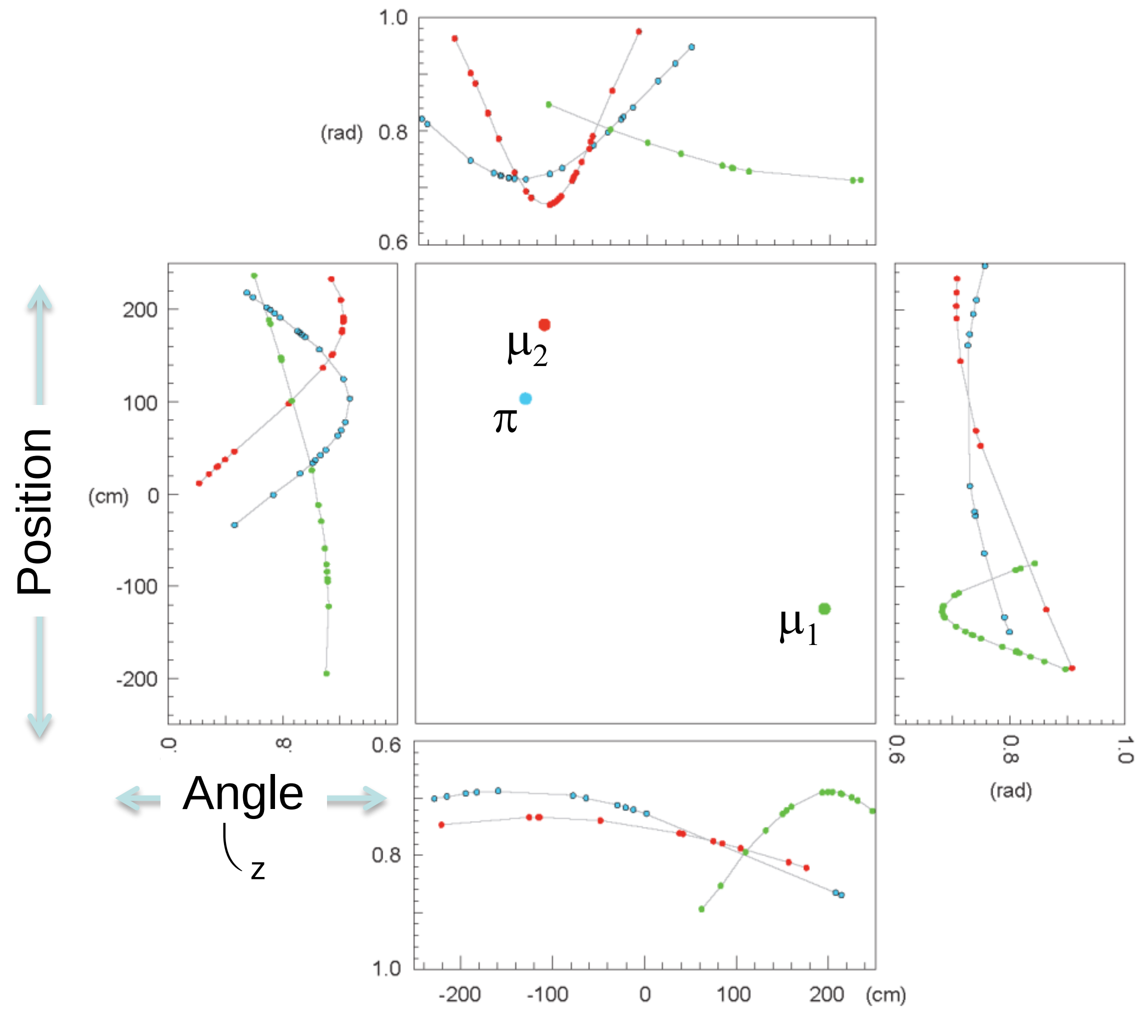
- Aim for installation of upgrade in 2019, during a planned long LHC shutdown (LS2)
- Main focus is on trigger, which must be upgraded to handle higher luminosity
- Current bottleneck is at the hardware level that reduces 40 MHz bunch crossing rate to 1 MHz for readout into HLT
  - → read out complete experiment at 40 MHz into the CPU farm, fully-software trigger
- RICH system will be kept for PID with photodetectors replaced
- Propose to perform low-p PID with time-of-flight based detector
- First muon station will be removed → space available for new device



Low Multiplicity Event

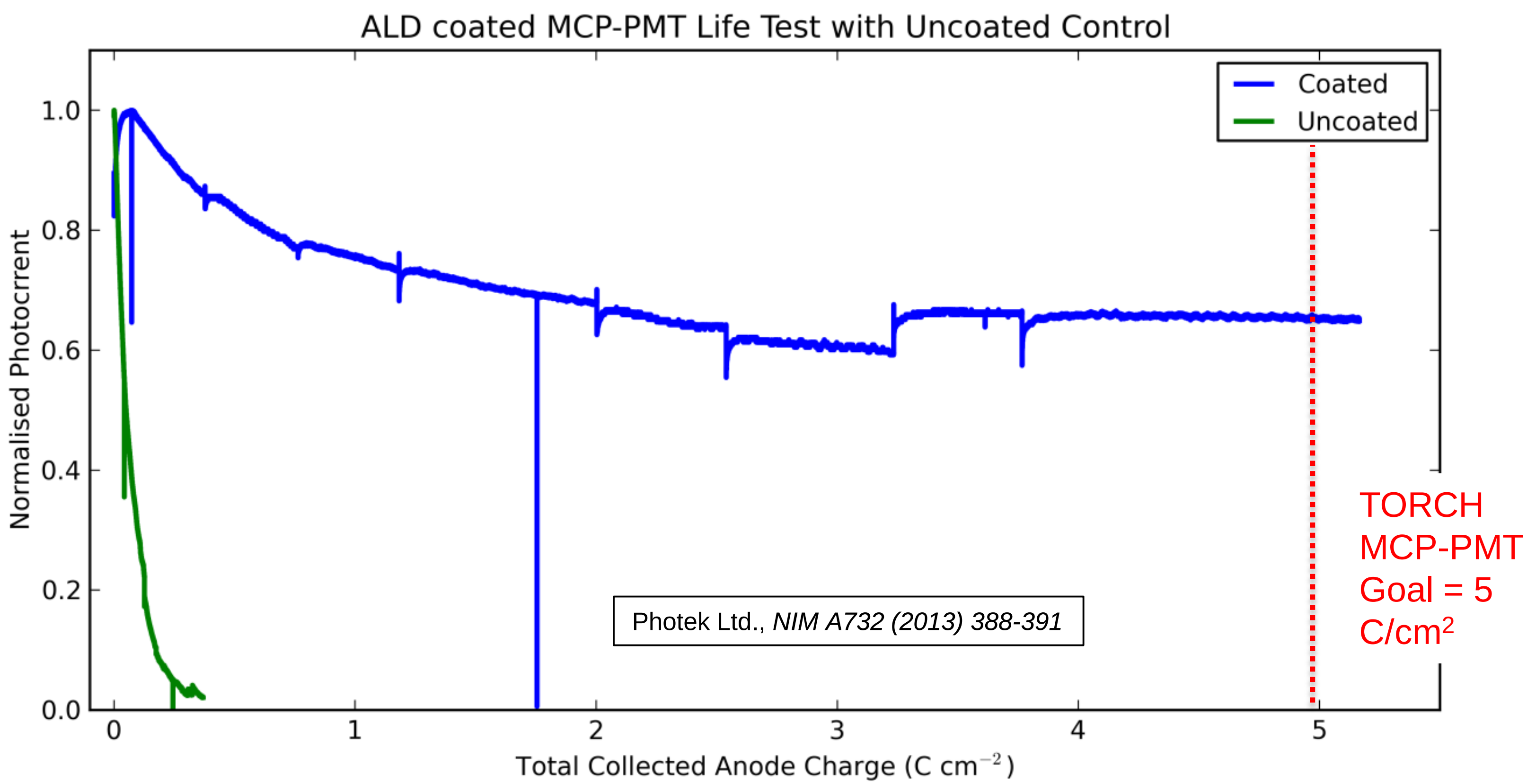
- Focusing blocks map angle θ_z onto position
- No chromatic dispersion
- Photons colour-coded to match their parent track





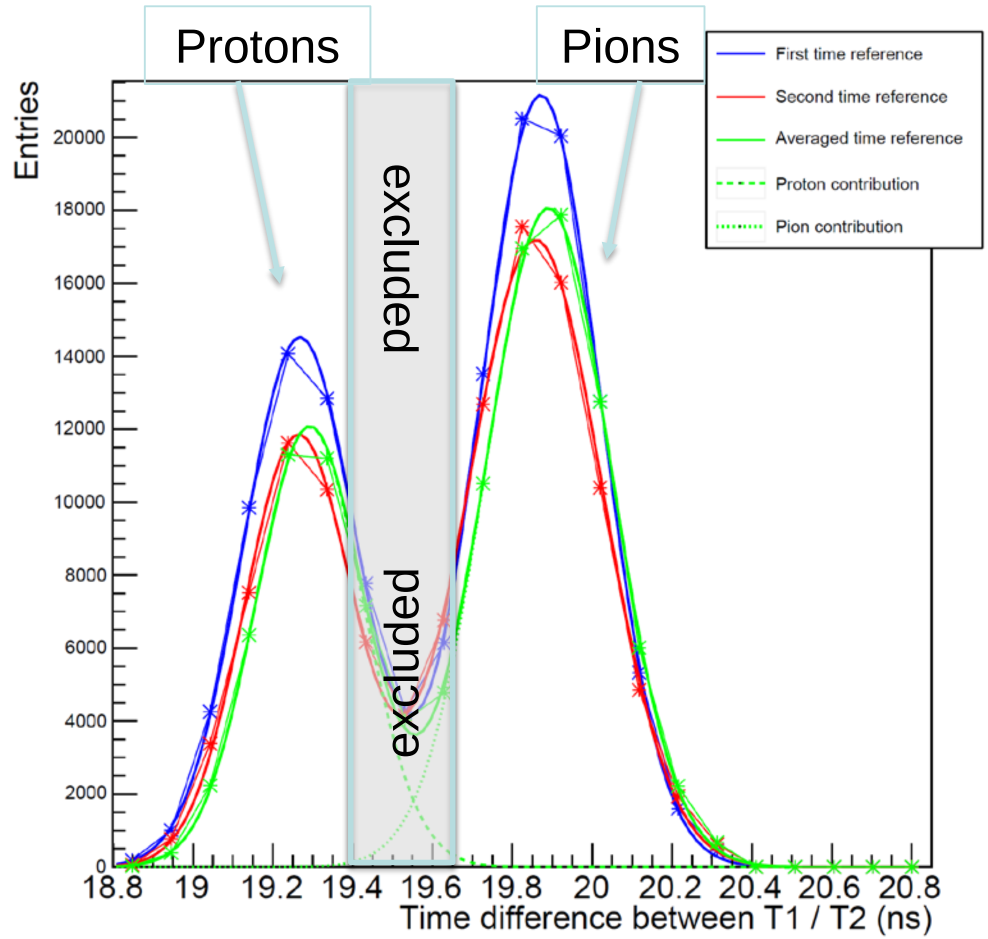
Ageing tests from Photek

- Using ALD to increase lifetime



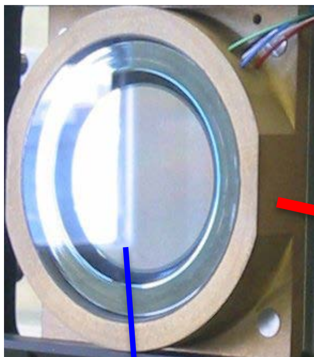
Beam tests – selection of proton/π samples

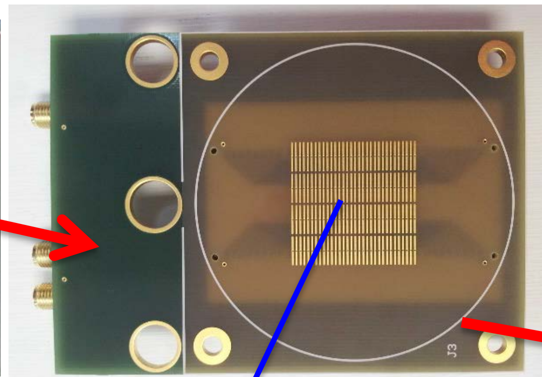
- p = 5 GeV/c
- Select protons/π
  - TOF (and cable delay) between T1, T2
- Proton peak
  - TOF < 19.40ns
  - Retains 79%
  - Contamination <0.2%
- Pion peak
  - TOF > 19.65ns
  - Retains 93.7%
  - Contamination <0.2%

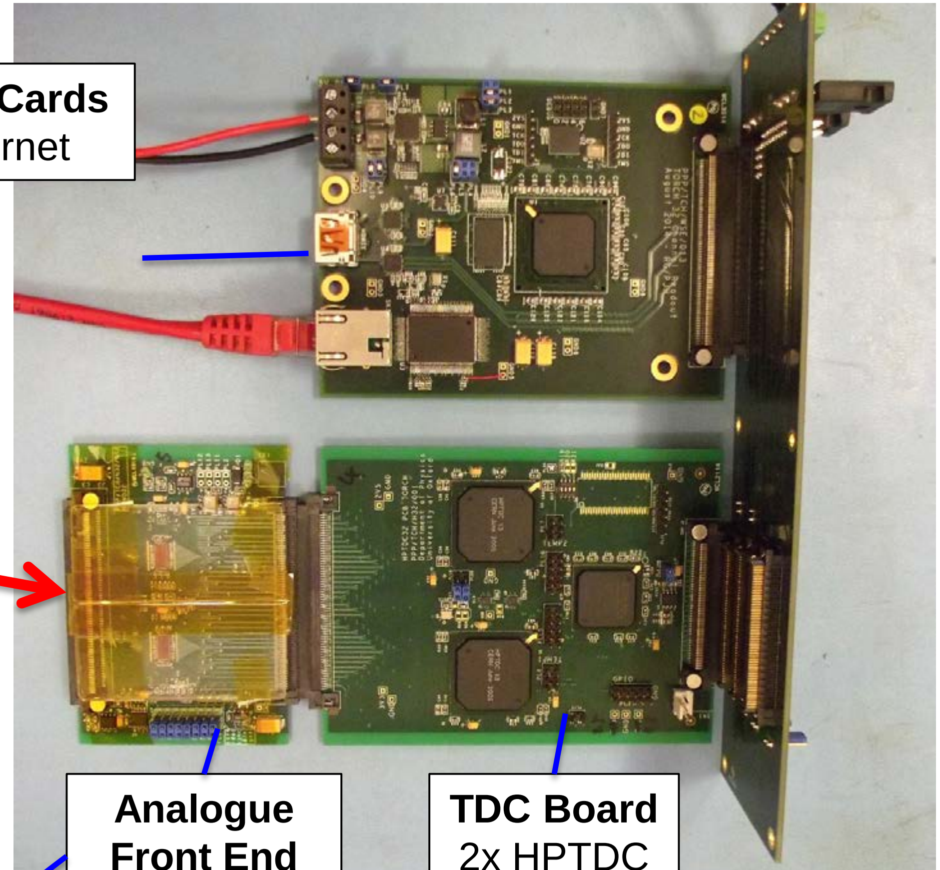


High-density custom readout electronics

Readout for 4 Front-End Cards
Readout by Gigabit Ethernet







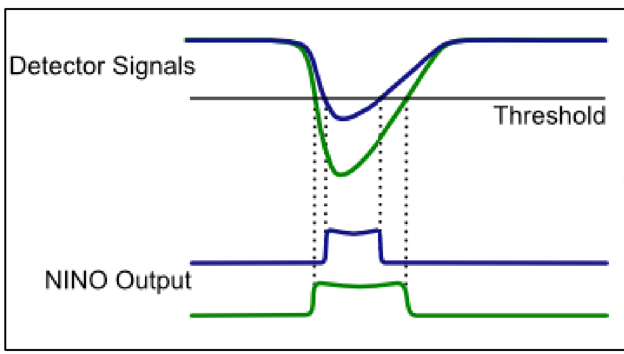
Phase-II prototype

Pickup-pads

Analogue Front End
2x NINO32

TDC Board
2x HPTDC

Measure charge, correct time- walk with ToT



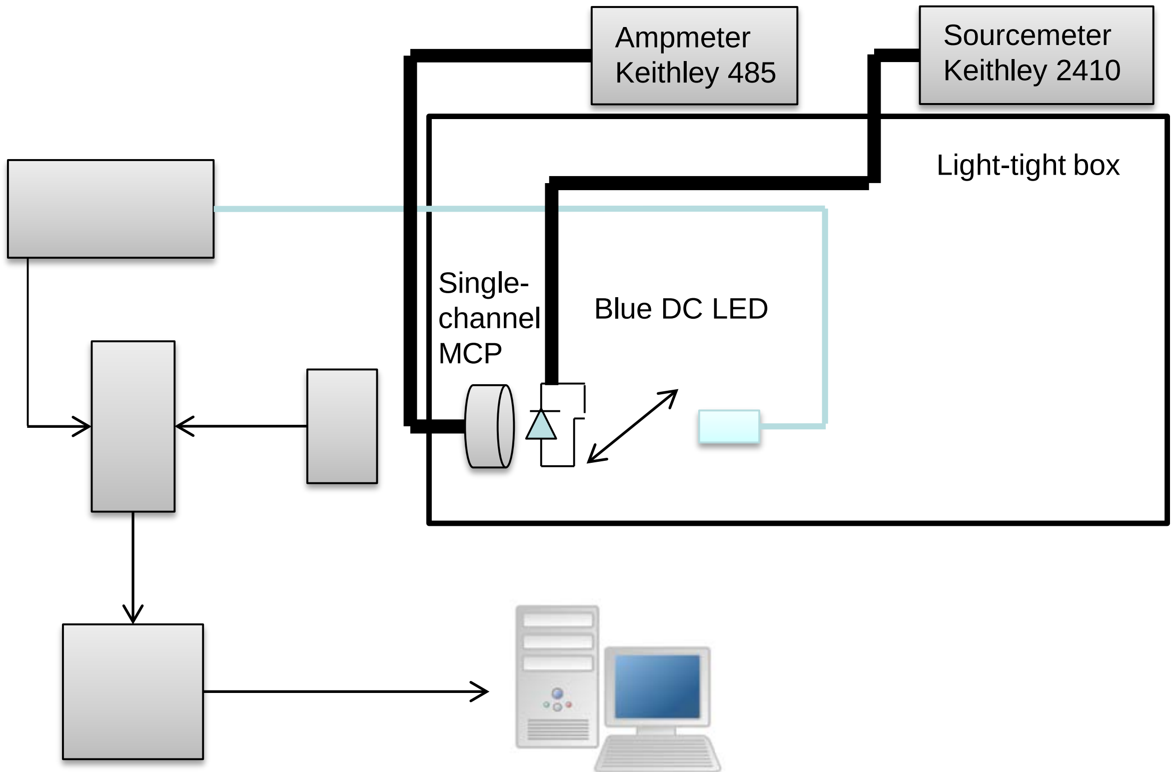
Ageing test with tube G1130510 – experimental conditions

- Initial ageing test parameters
  - MCP HV: -2300V
  - Use Photek bleeder chain specific to that tube
  - Initial MCP gain measured with pulsed laser and calibrated to be ~100fC (~6.3×10^5e-)
  - Stabilized blue (428nm) DC LED
    - Low illumination setting: 10pW
    - Corresponding *calculated* anode current: ~ 430nA (photoelectron rate of ≤0.8MHz/cm^2) assuming all light reaches MCP
  - Anode current increasing from ~400nA to ~560nA over a few days
  - After settling, anode *initial* current is measured to be ~562nA equivalent to ~9.9mC/cm^2/day assuming a uniform light distribution
- New ageing test parameters
  - As of 8 Feb. 2016, HV increased by 150V to reach MCP anode current of ~500nA

Monitoring conditions

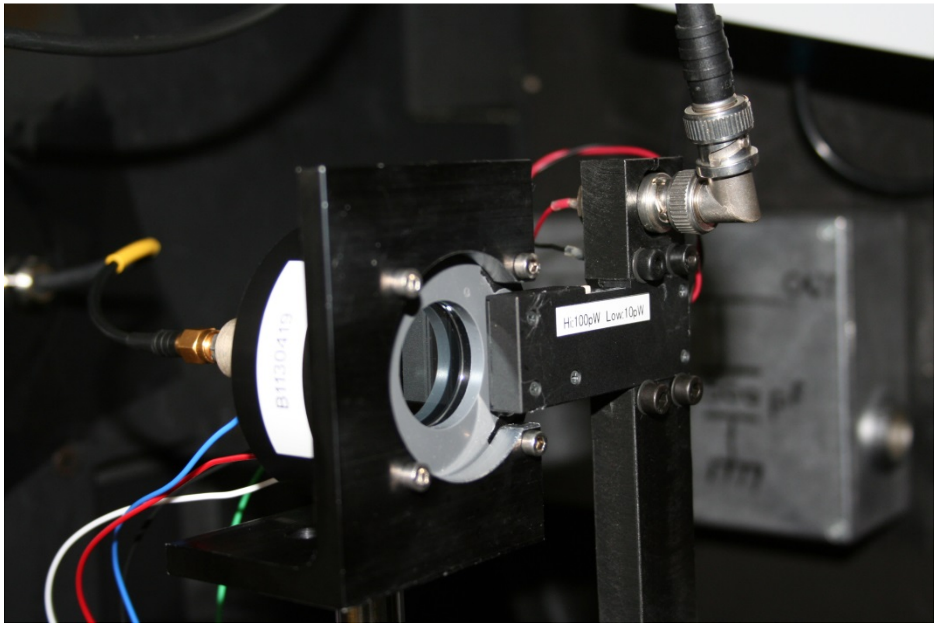
- Monitoring of anode current with ampmeter Keithley model 485
- Monitoring of blue DC LED supply current (light intensity is stabilized) with source-meter Keithley model 2410
- Regular check of:
  - MCP DCR
  - MCP gain
  - MCP TTS
  - MCP QE

Ageing test setup – high illumination configuration

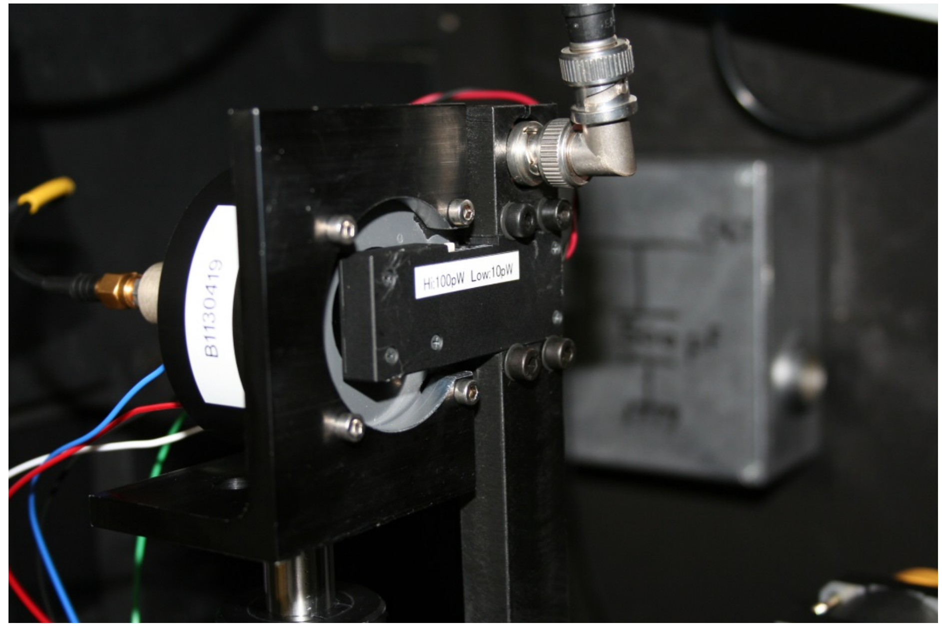


Stabilized blue LED - photos

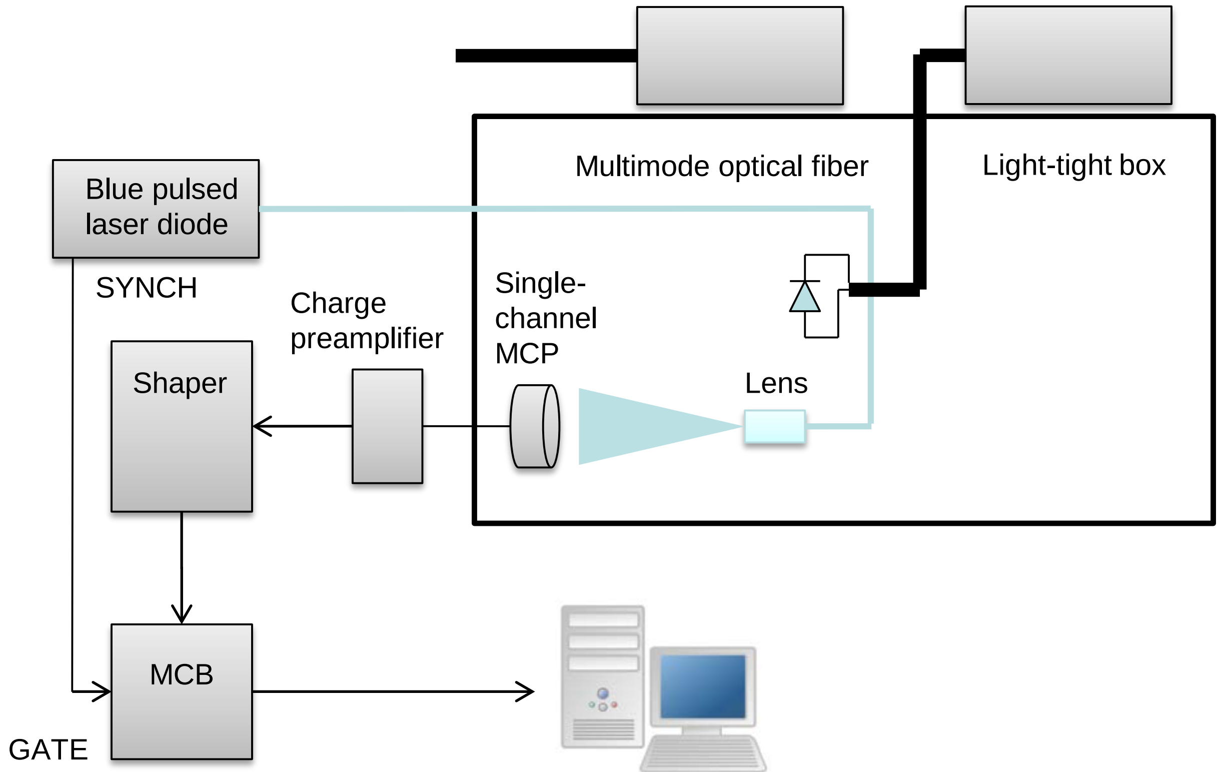
LED in “parking” position
Gain and TTS measurements



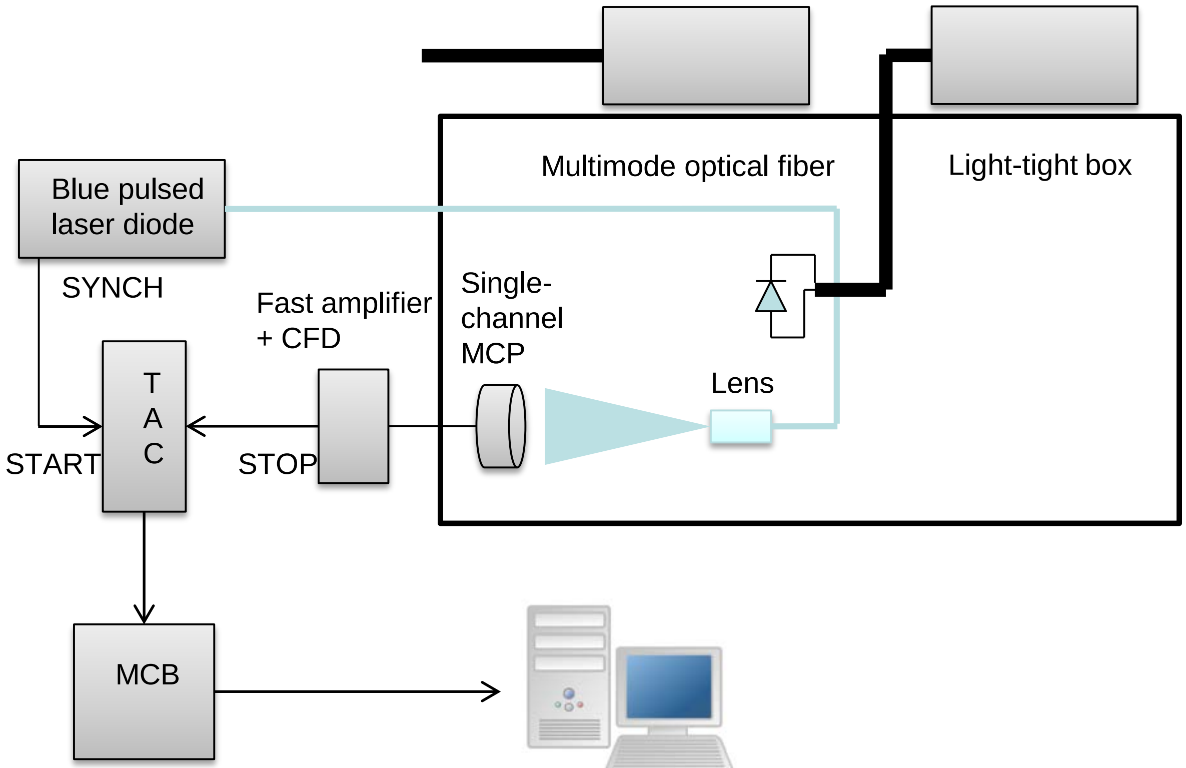
LED in “illumination” position
For accelerated ageing tests



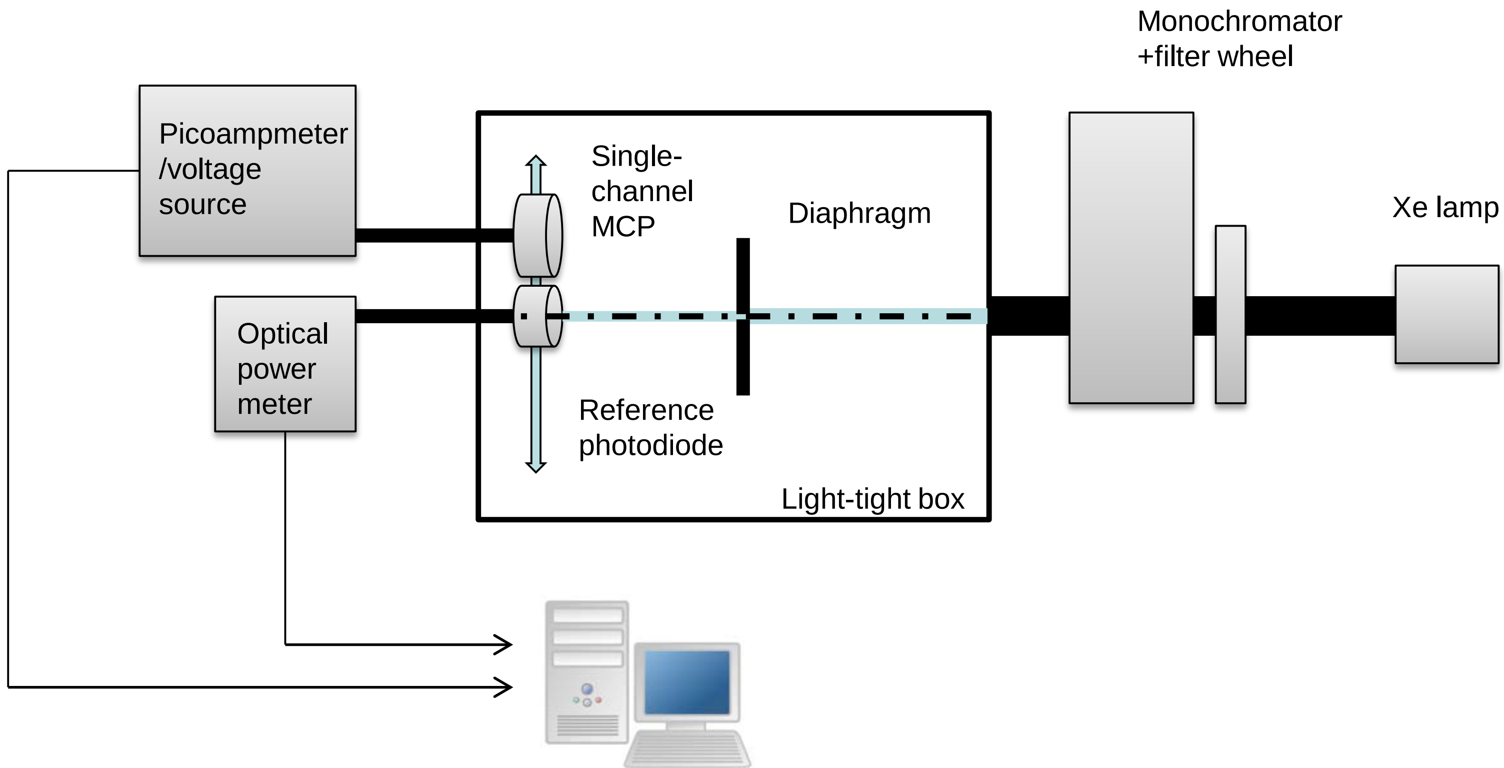
Ageing test setup – gain monitoring measurements



Ageing test setup – timing monitoring measurements



QE setup


Monochromator
+filter wheel
Picoampmeter
/voltage
source
Single-
channel
MCP
Diaphragm
Xe lamp
Optical
power
meter
Reference
photodiode
Light-tight box

Conclusions and perspectives (3)

- TORCH module installation in LHCb
  - Outside the LHCb acceptance

- TORCH for timing high-energy photons
  - Pile-up mitigation for high-luminosity LHC
  - High-precision timing to assign high-energy photons to their primary vertex in multi-vertex events
  - Place thin (Pb) converter in front of TORCH
  - Appropriate calorimeter granularity to provide the required angular precision for TORCH reconstruction