TORCH:
a new concept for PID

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TORCH (Time Of internally Reflected CHerenkov light) is a detector concept intended for fast timing of charged particles over large areas

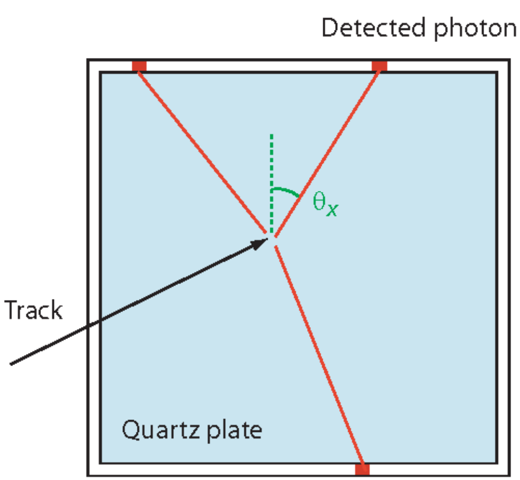
Currently an R&D project, under study for a Phase-2 upgrade of LHCb
Potentially interesting for use in a future FCC-ee detector?

1. TORCH principle
2. R&D project
3. Application in FCC-ee?

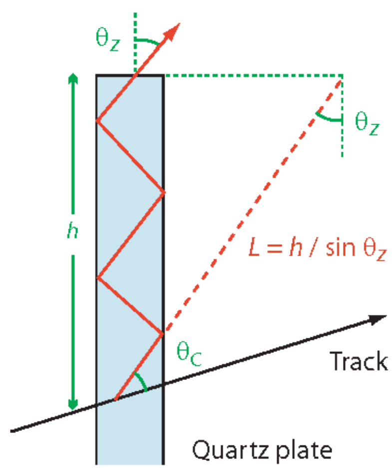
FCC-ee detector brainstorming meeting, 4 July 2016

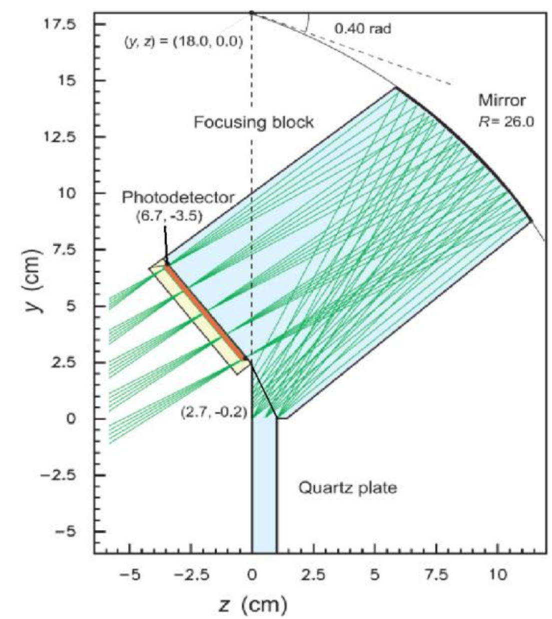
1. TORCH principle

- DIRC-style detector concept, with a ~1 cm thick quartz radiator plate: Cherenkov light produced in the plate propagates to the edge by TIR and is focused via a cylindrical lens onto fast photon detectors
- Reconstruction of the Cherenkov angle at emission allows the propagation time in the radiator plate to be corrected for dispersion
- Requires precise track information (~ 1 mrad) to achieve timing resolution of ~ 70 ps/photon → 15 ps/track by combining ~ 30 detected p.e./track



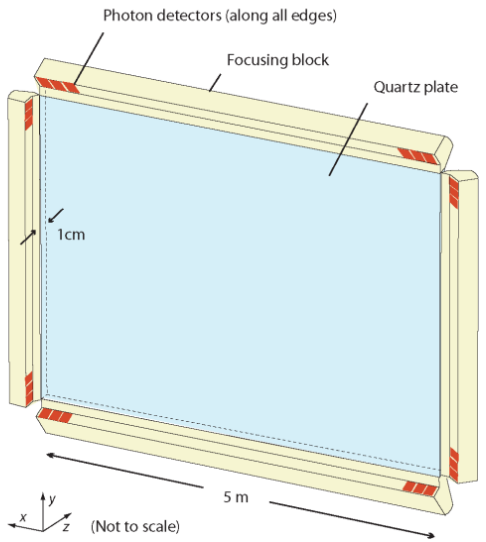
(schematic)

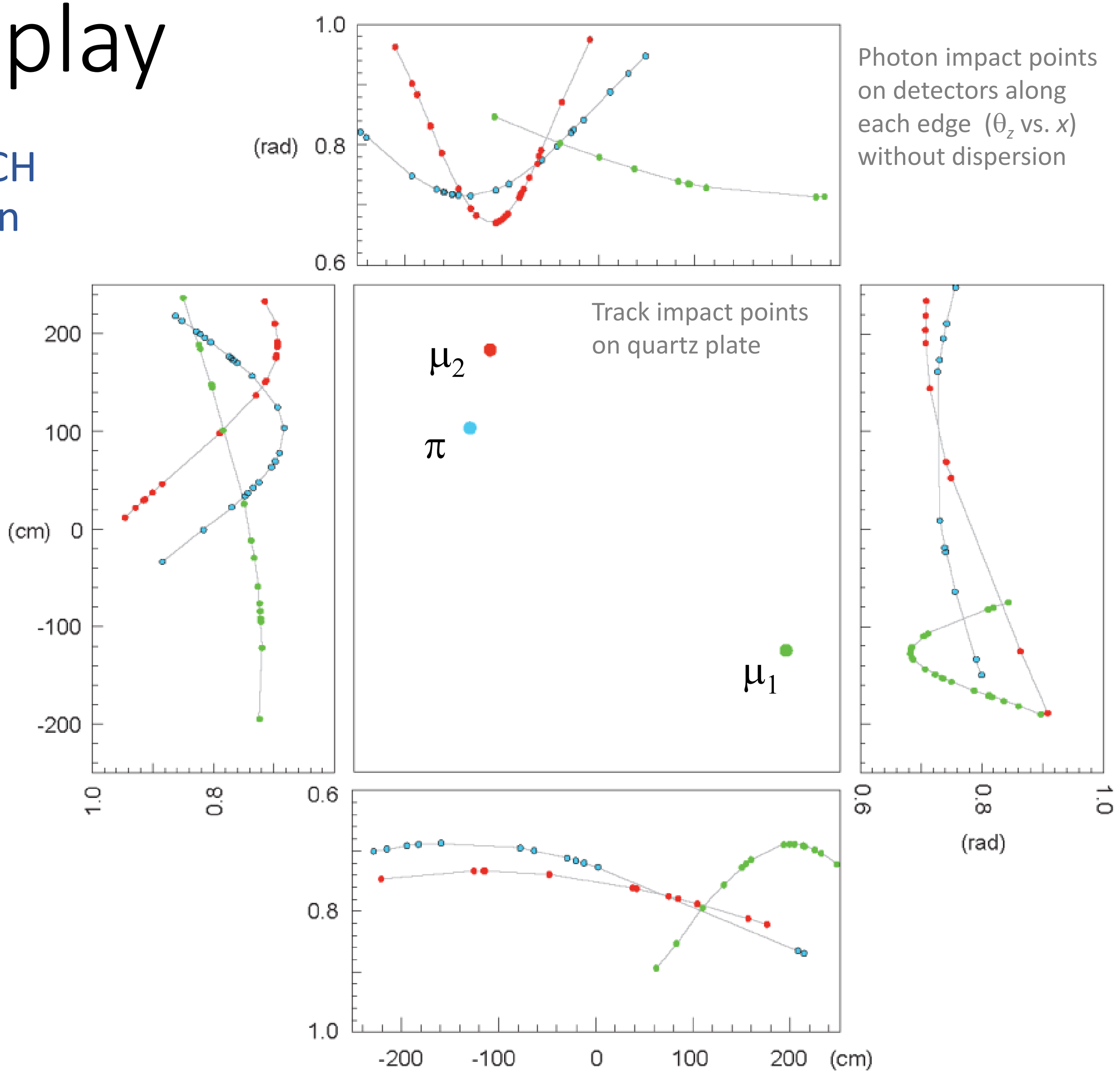




Event display

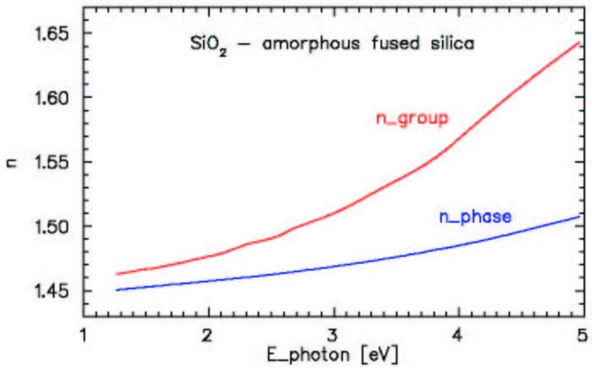
- Typical event in TORCH detector in simulation of sterile neutrinos (low multiplicity)
- Photons colour-coded to match their parent track



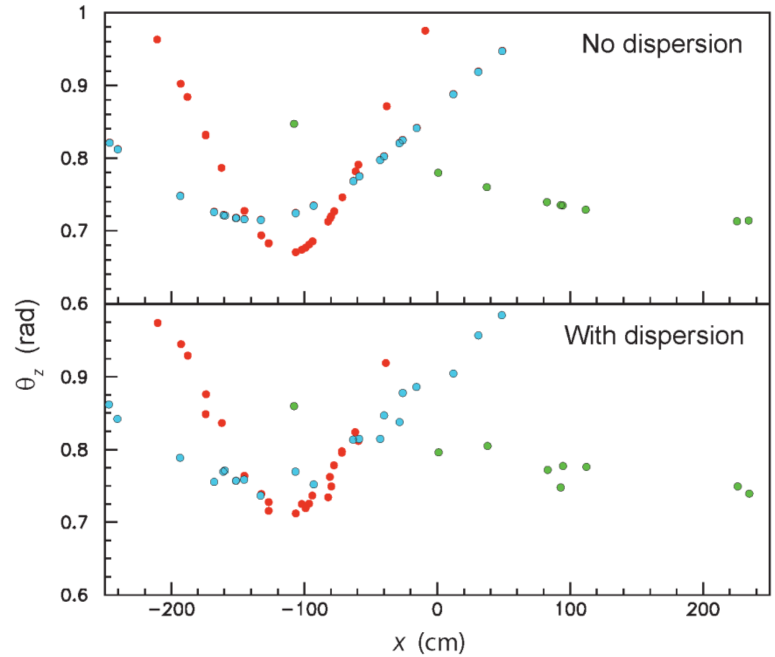


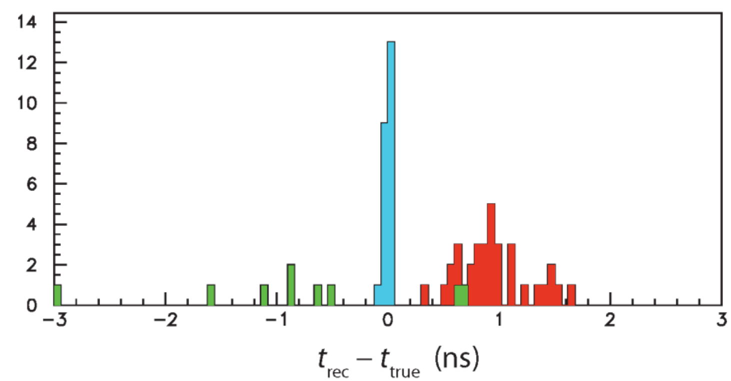
Reconstruction

Refractive index vs. E_{γ}



- Smearing from dispersion in quartz:
- Use timing information as well as spatial information from detector to separate signals from each track
- Calculate time of propagation of all photons relative to the blue track (π)
- Hits from that track peak at true time
  Hits from other tracks spread out
  (but peak in time distribution when it is calculated relative to *that* track)

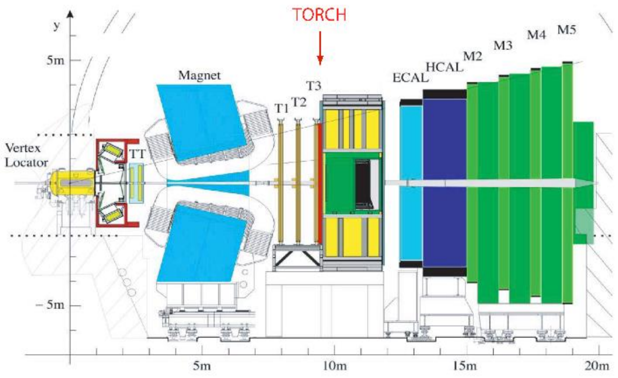


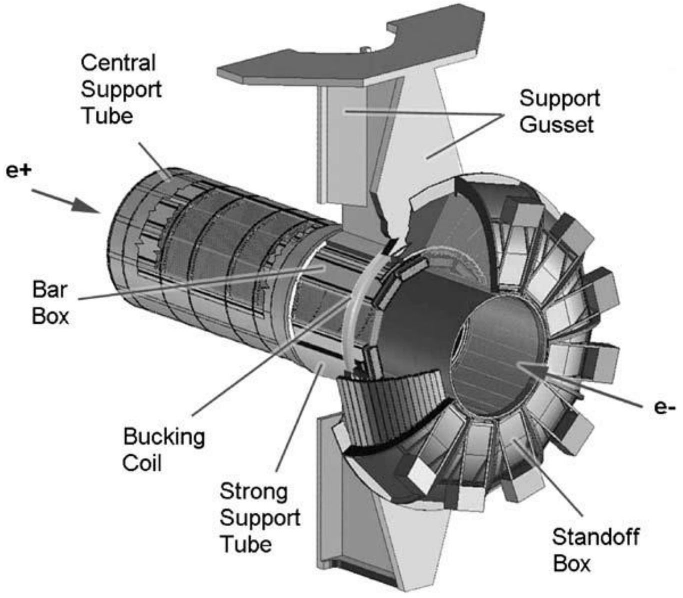


TORCH in LHCb

- Conceived for low-momentum PID in LHCb to replace aerogel radiator of RICH system that cannot handle expected increase in occupancy
- Nominal position of TORCH chosen to be as close as possible to tracker and to reduce area to be covered (~ 30 m^2)
- Original DIRC of BaBar required large standoff volume for readout, and achieved K/π separation up to ~ 3.5 GeV (based on Cherenkov *angle*, not timing)
- BELLE-II iTOP "time-of-propagation" detector adds timing but limited focussing→ 4–5 GeV?
- TORCH uses measured Cherenkov angle to *correct* timing, aiming for "ultimate" resolution Over 10 m TOF should provide > 3σ K/π separation up to 10 GeV

LHCb

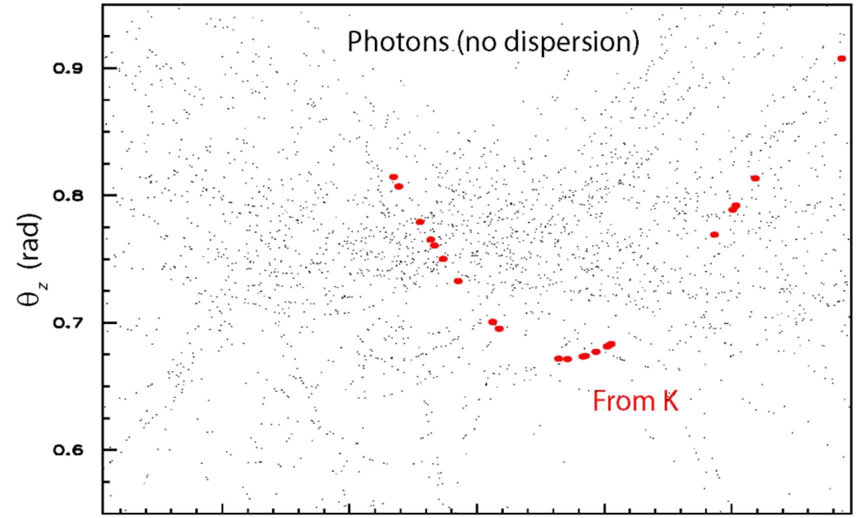


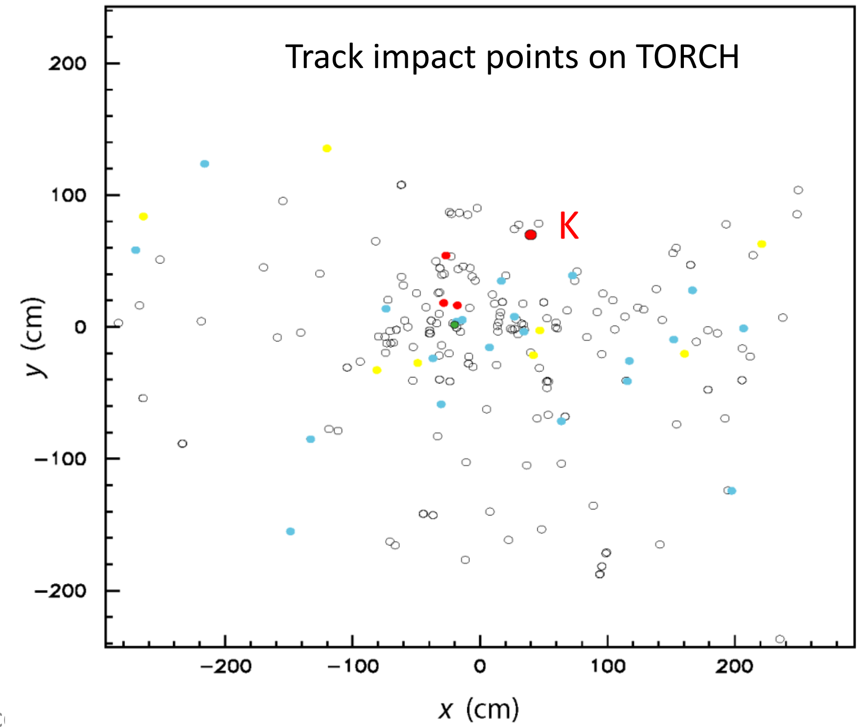


BaBar DIRC

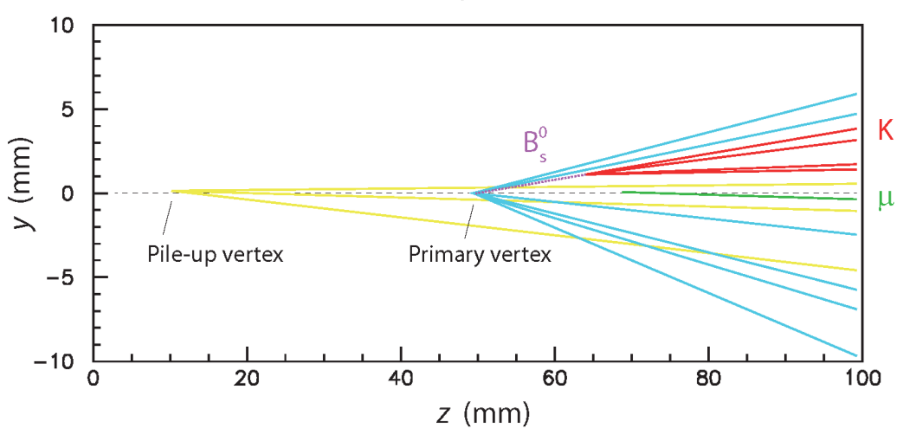
LHCb event

- Typical LHCb event, at luminosity of 10^{33} $cm^{-2}s^{-1}$ (only photons reaching the upper edge shown)
- High multiplicity! >100 tracks/event
- Tracks from vertex region colour-coded according to the vertex they come from (rest are secondaries)
- "Start time" from primary tracks



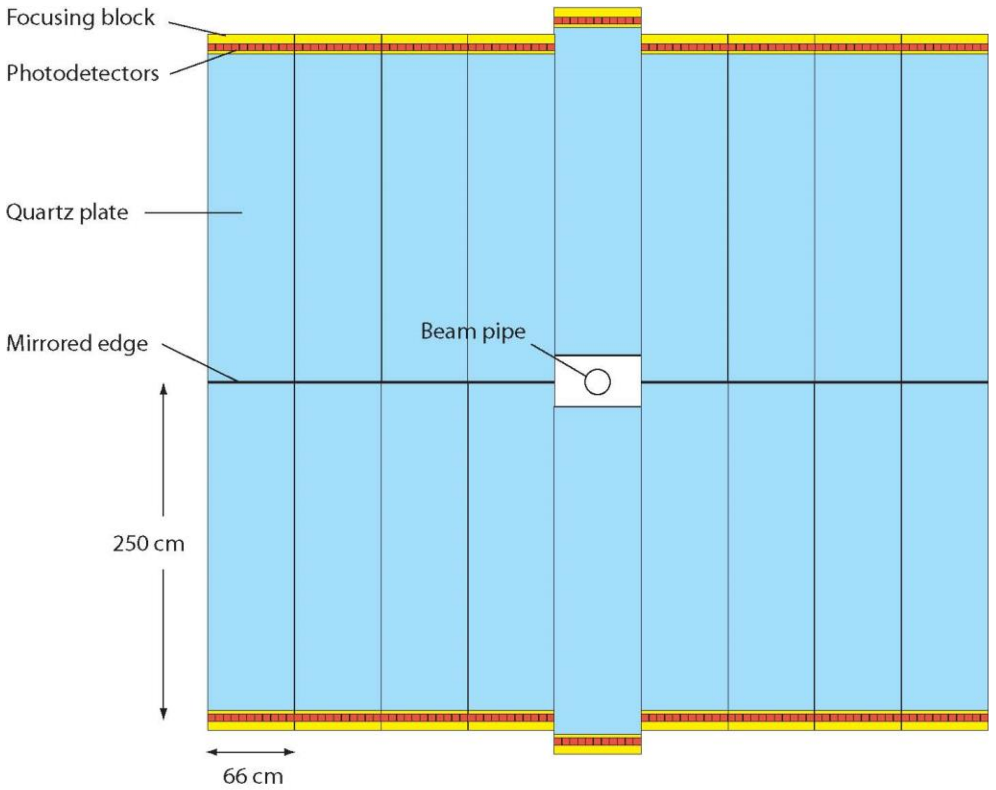


Zoom on vertex region



Modular design

- For the application in LHCb, transverse dimension of plane to be instrumented is ~ $5 \times 6\ m^2$ (at z = 9.5 m) + central hole for beam pipe
- Unrealistic to cover with a single quartz plate → developed modular layout:

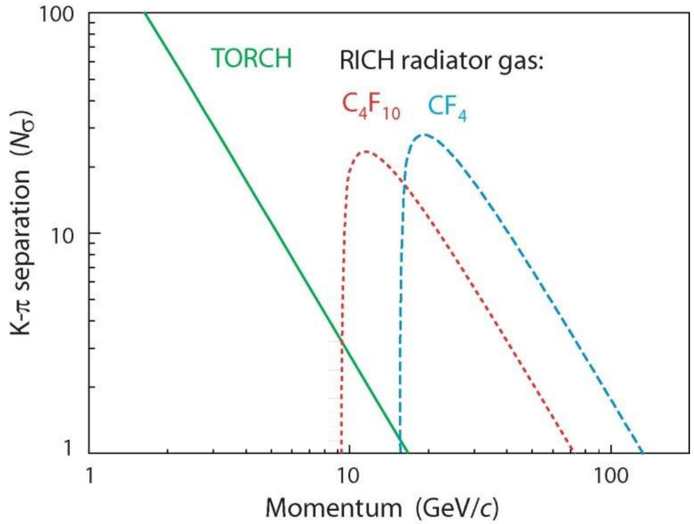


- 18 identical modules each $250 \times 66 \times 1\ cm^3$ → ~ 300 litres of quartz in total (less than BaBar)
- Reflective lower edge → photon detectors only needed on upper edge

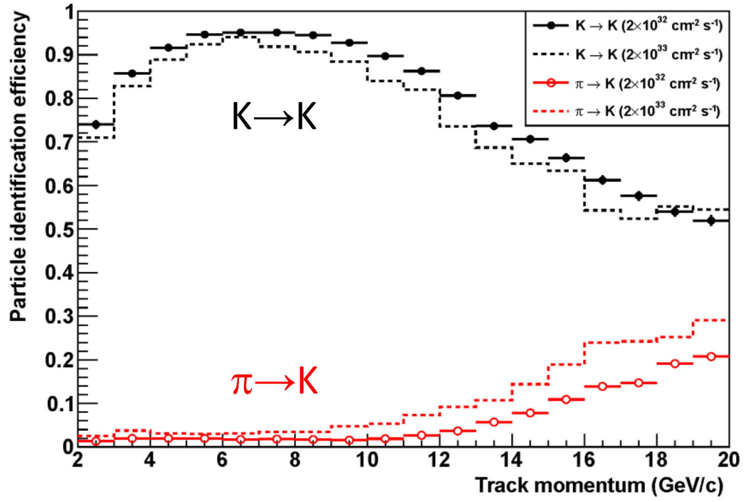
18×11 = 198 detectors
Each with 1024 pixels
→ 200k channels total

Performance

Isolated tracks (TOF only)



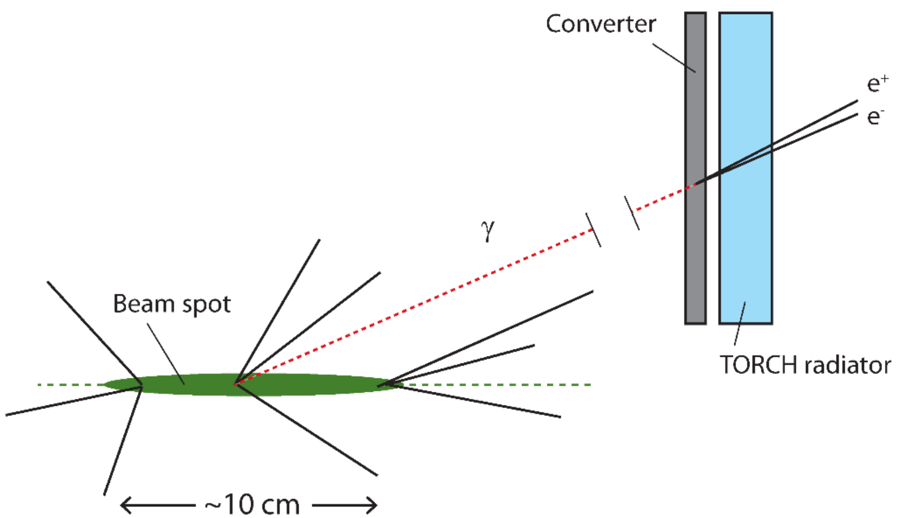
LHCb simulation: efficiency vs. *p*



- Expected performance for low-momentum particle ID from full simulation: good, and robust to increasing luminosity (shown dashed)
- Study shown was made at the time of the LHCb upgrade LoI, for a single plate design, should be updated with the modular layout

Use for timing photons?

- Discussion has also started for using TORCH for generalized timing, to help resolve pileup at high lumi (similar use of timing discussed in ATLAS/CMS)
- Since TORCH detects Cherenkov light from charged particles, detection of photons requires conversion to e^+e^- → make it part of the pre-shower?
- Assume layer of converter material $O(1\ X_0)$ placed in front of TORCH
  - Too thin and efficiency of conversion will be low
  - Too thick, and shower will develop, degrading angular precision
    Even if only single pair produced, tracks will undergo multiple scattering

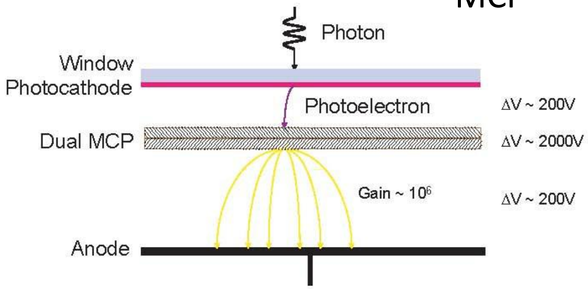


First studies indicate that PID performance degrades quickly due to multiple scattering, so will be difficult to optimize system for *both* photon timing and PID

2. R&D project

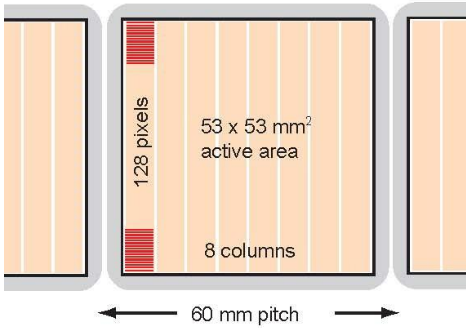
- Fast photon detectors required, ~ 50 ps for single photons: use microchannel plate PMTs
- Fine spatial granularity needed (~ 0.4 mm) in one dimension (due to focusing) + long lifetime (> 5 C/cm^2) + large active area
- Not available on commercially-available tubes, nearest is Planacon from Photonis (32x32 ch):
- R&D project set up to develop suitable photodetector, funded by the ERC: collaboration between CERN, Oxford, Bristol and UCL, with industrial partner Photek (UK) Runs for another year (Brexit permitting)
- Granularity and lifetime (using ALD coating) achieved in round tubes, final phase under way for square tubes with large active area

MCP



Planacon

TORCH pixellization

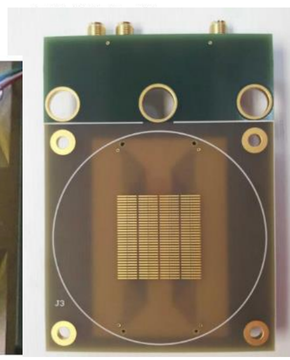


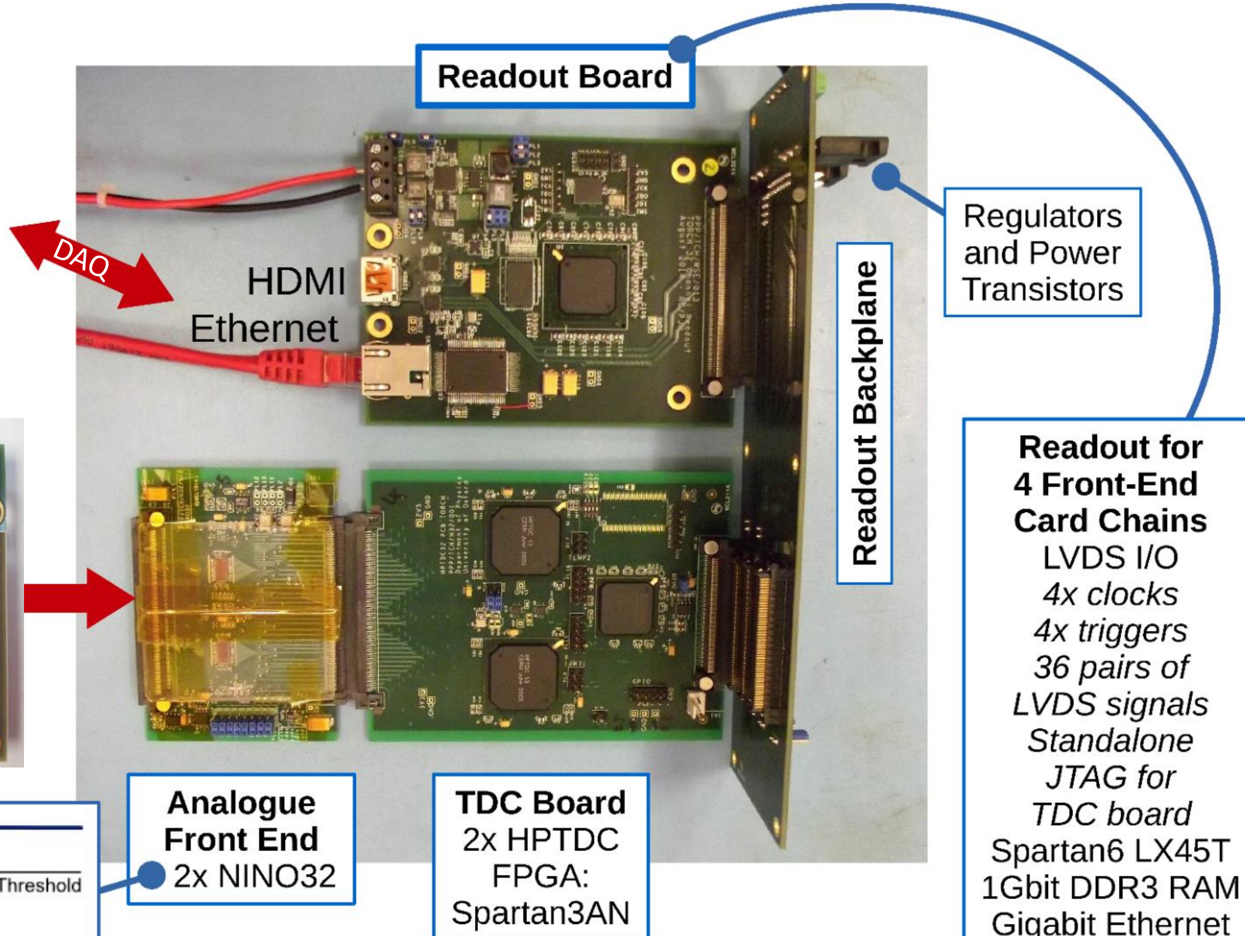
Custom electronics

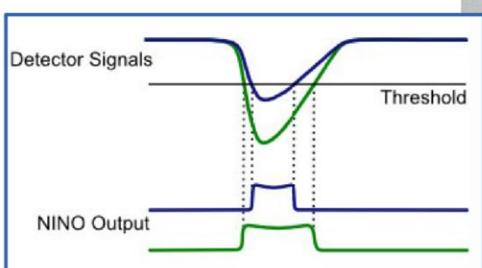
- Full readout for prototype tubes developed based on 32 ch NINO (ALICE) and HPTDC chips

Photek MCP

Anode pads



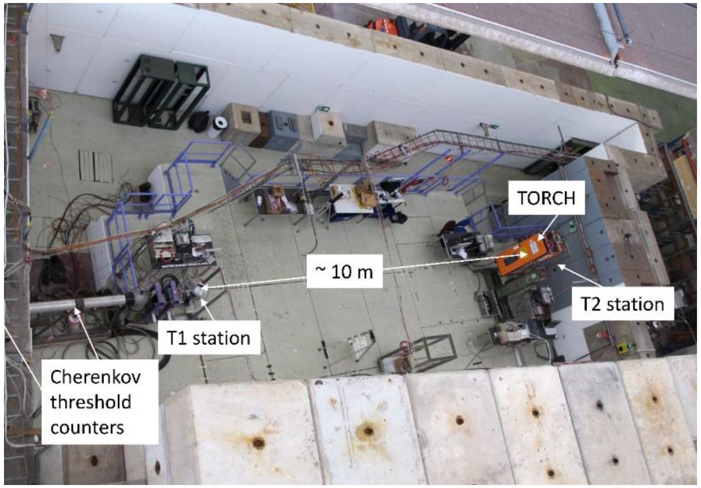




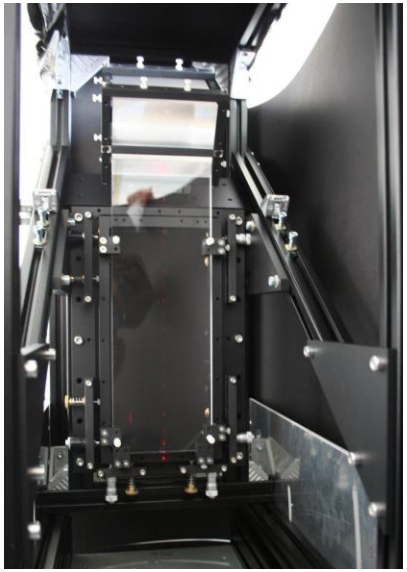
Time-over-threshold used for charge estimate → reduce number of pixels in fine direction (to 64)

Testbeam studies

- Small prototype TORCH module constructed
  35 x 12 x 1cm^3 radiator plate
- Coupled to focusing block and MCP with readout electronics + timing stations
- Data taken successfully in PS T9 beam
  ~ 100 ps resolution/p.e. achieved so far

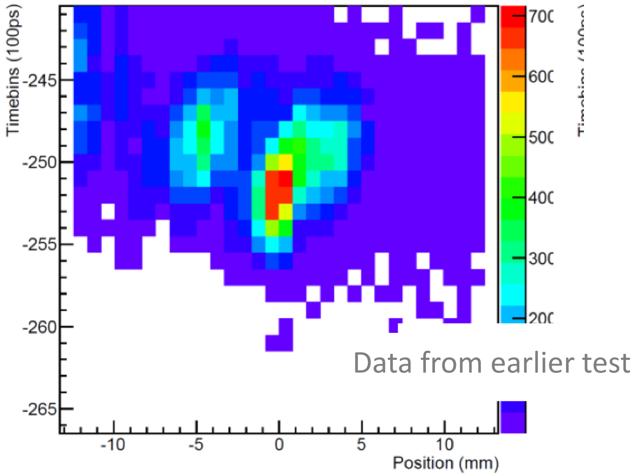


TORCH prototype



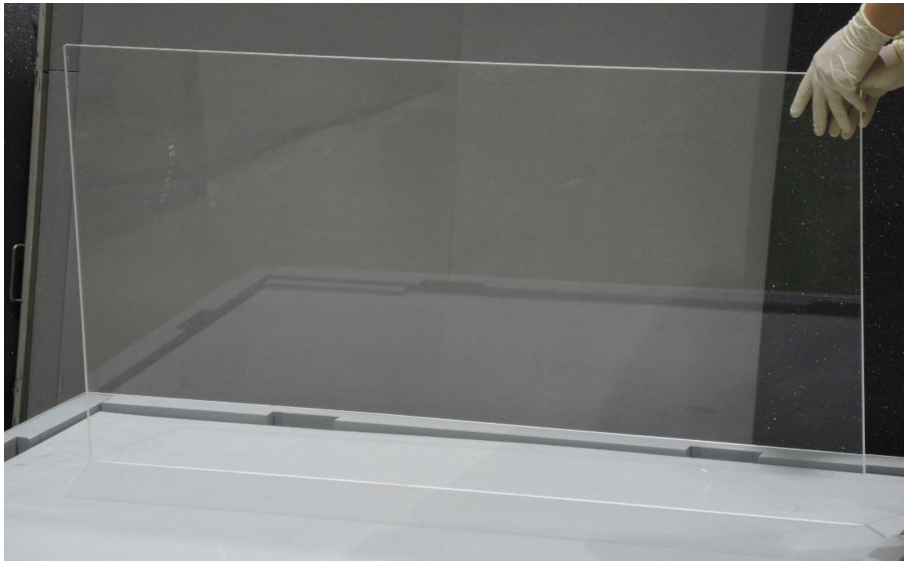
MCP + readout

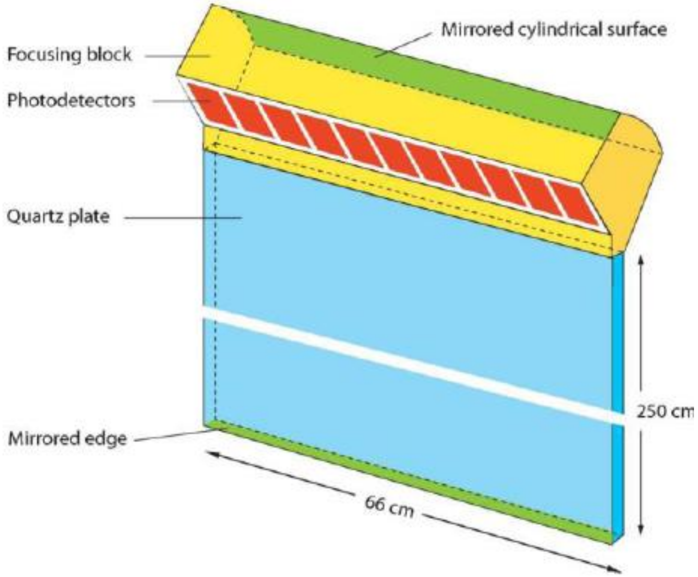
Data analysis in progress



Full-scale prototype

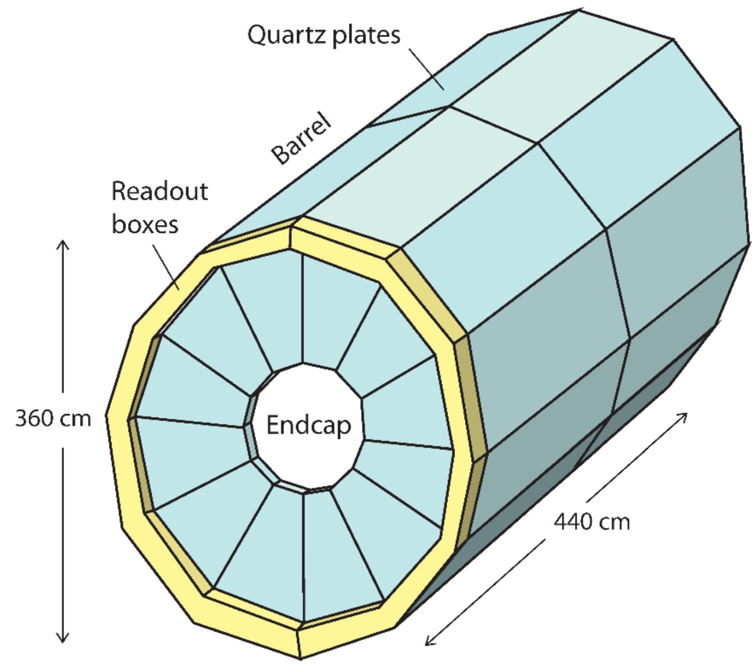
- Final goal of the ERC-funded R&D project is to prototype a TORCH module which accommodates 10 MCP-PMTs of 128 × 8 effective granularity
- R&D is on track to produce suitable MCP-PMTs (64 x 8, with charge sharing)
- Size of the quartz plate for the final prototype will be 66 × 125 × 1 cm^3
- Test for radiator plate of full-scale prototype module in progress in industry (although order not yet sent…)





3. Application in FCC-ee?

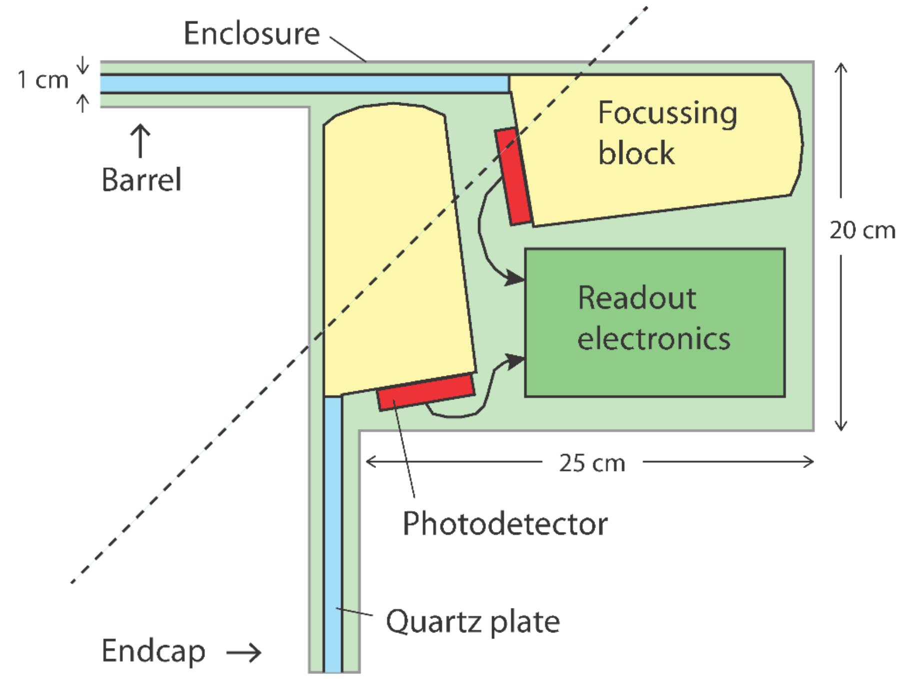
- *In the spirit of brainstorming…* Not aware of current design for a detector at FCC-ee, so assume something ALEPH-like (can be easily scaled for other designs)
- Correct place for TORCH is just after tracking volume, *R* ~ 180 cm i.e. between TPC and ECAL
- Adapt to barrel geometry following 12-fold symmetry
  Endcap modules (if required) could be optically coupled to each other



- Some space required for focussing, photodetectors, electronics
  → place in overlap region ("readout boxes") – *much* smaller than BaBar!
- 24 barrel modules 96 x 220 cm^2 = 50 m^2
  12 modules for each endcap ~ 10 m^2 (i.e. total area ~ 2x LHCb design)

Readout box

- Possible layout illustrated, to give idea of what would be required
- Focussing scheme can be adapted according to constraints (here arranged to lie on one side of modules only)
- Assuming 6 x 6 cm^2 photo-detectors along edge of module → 16 tubes per module
- 48 modules → 768 tubes in total
  512 channels each (using charge sharing)
  → 400 k total — i.e. not outrageous



- Practical details would need to be optimized: separate barrel/endcap? full coverage of overlap? material budget from readout box, etc.
  (for LHCb the readout box can be arranged to be outside the acceptance)

Performance considerations

- Time-of-flight from IP to quartz plate smaller in this layout than in LHCb (distance 2–3 m instead of 10 m) However, time-of-propagation of the Cherenkov photons in quartz is similar (distance 2–3 m)
- Total timing difference of K/π is sum of the two (they add constructively) so overall performance should be somewhat degraded, but still good — simulation would be required, to be quantitative
- What momentum range for PID is needed for the flavour physics? On the Z, b fragmentation ~ 0.7 → p_b ~ 30 GeV, typical b decay has 5 charged and 5 neutral daughters → $p_{daughter}$ ~ 3 GeV on average (?)
- Occupancy will be much lower than in LHCb; is planned luminosity high enough that general timing would be useful for pile-up suppression?
- Note that MCP-PMTs are insensitive to magnetic field
- Material budget: 1 cm quartz = 8% X_0 (plus support/enclosure)

Conclusions

- TORCH is a novel detector concept designed to provide exquisite timing over large areas, pushing the limits of the DIRC technique
- Aiming to provide K/π separation up to > 10 GeV in LHCb environment
  Possible use for generalized timing of charged + neutrals under study
- R&D project progressing well, to develop the photodetectors required and a full-scale prototype module on the timescale of next year
- TORCH technique may be interesting for application in an FCC-ee detector: it has been developed to tolerate LHC-levels of radiation and occupancy, compact for integration in experiment + affordable for large area coverage
  Cost of prototype module ~ 400 kCHF split between optics + photodetectors
  Hope for economy of scale → 200 kCHF/module for final detector (?)
  i.e. overall scale would be *O*(10 MCHF)
- Estimating the performance at FCC-ee would require a simulation study, and the physics requirements should be well defined