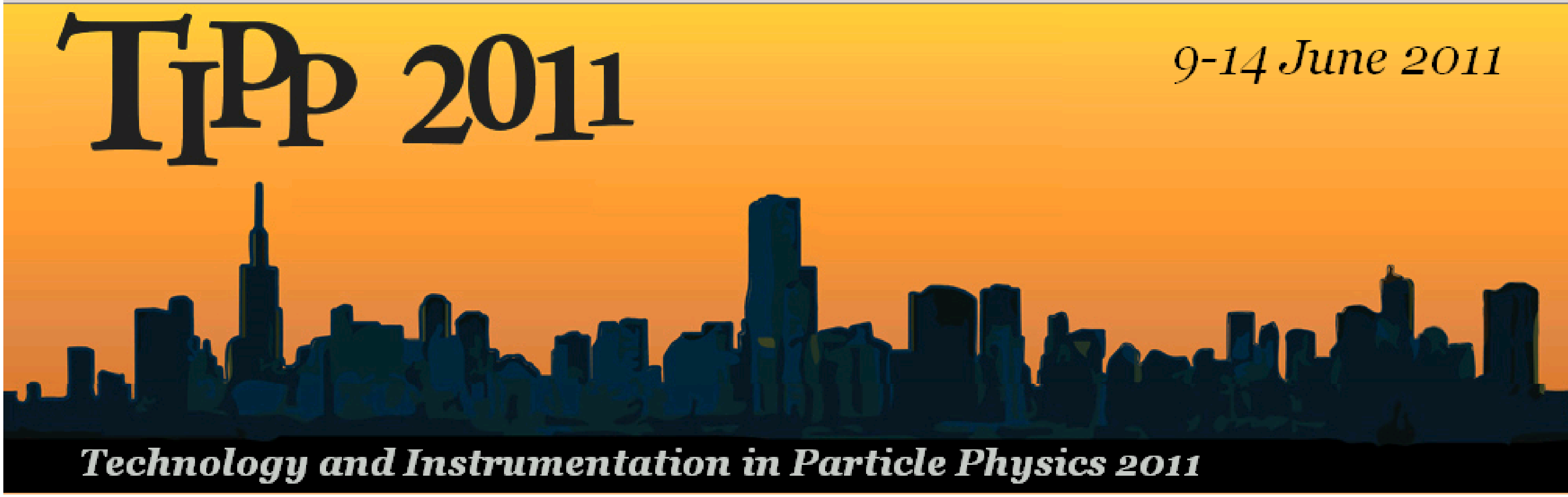


TORCH: A large-area detector for precision time-of-flight measurements at LHCb

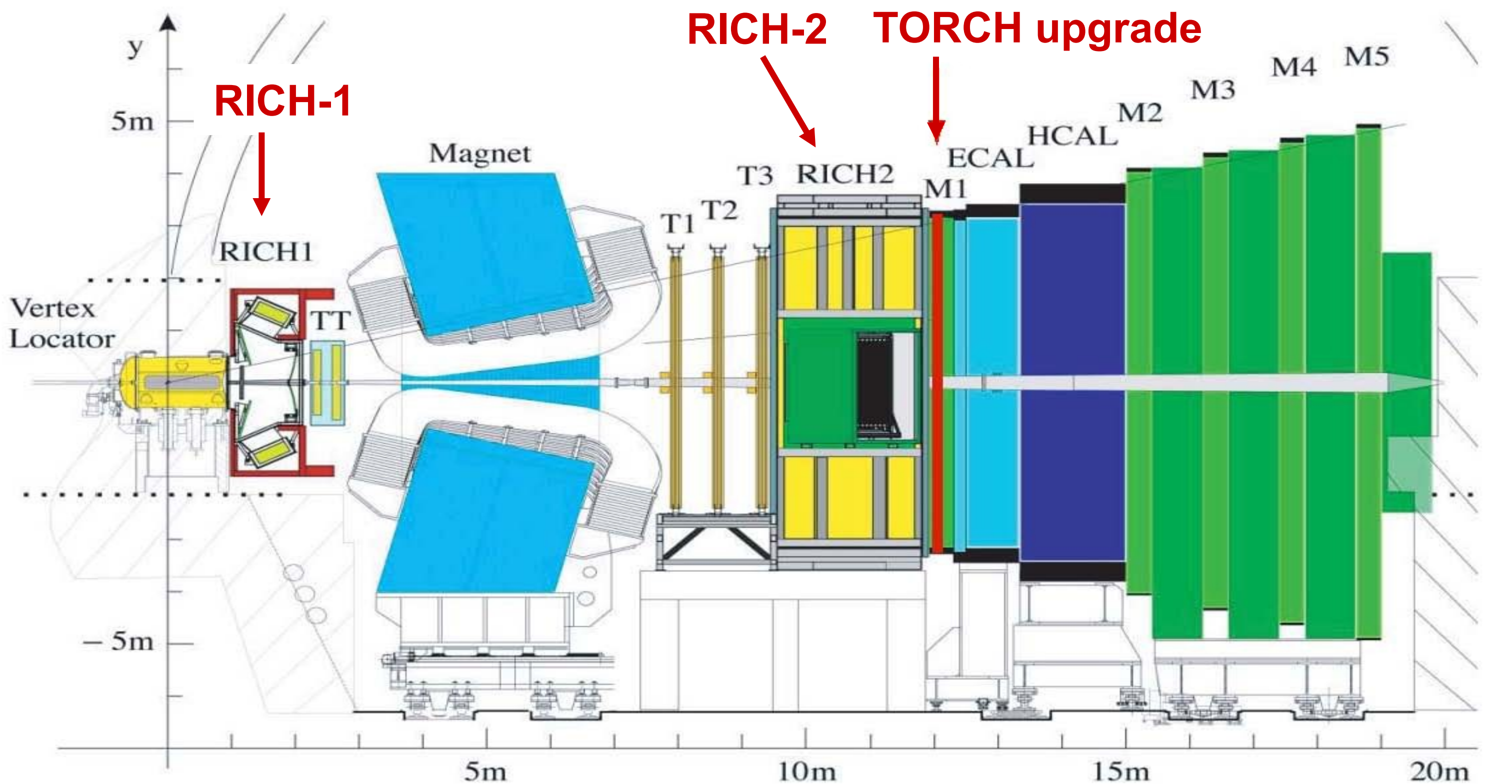
Neville Harnew
University of Oxford
ON BEHALF OF THE LHCb RICH/TORCH COLLABORATION

Outline

- The LHCb upgrade
- TORCH concept & principles
- R&D $\rightarrow$ commercial MCPs & customized readout electronics
- Conclusions and future

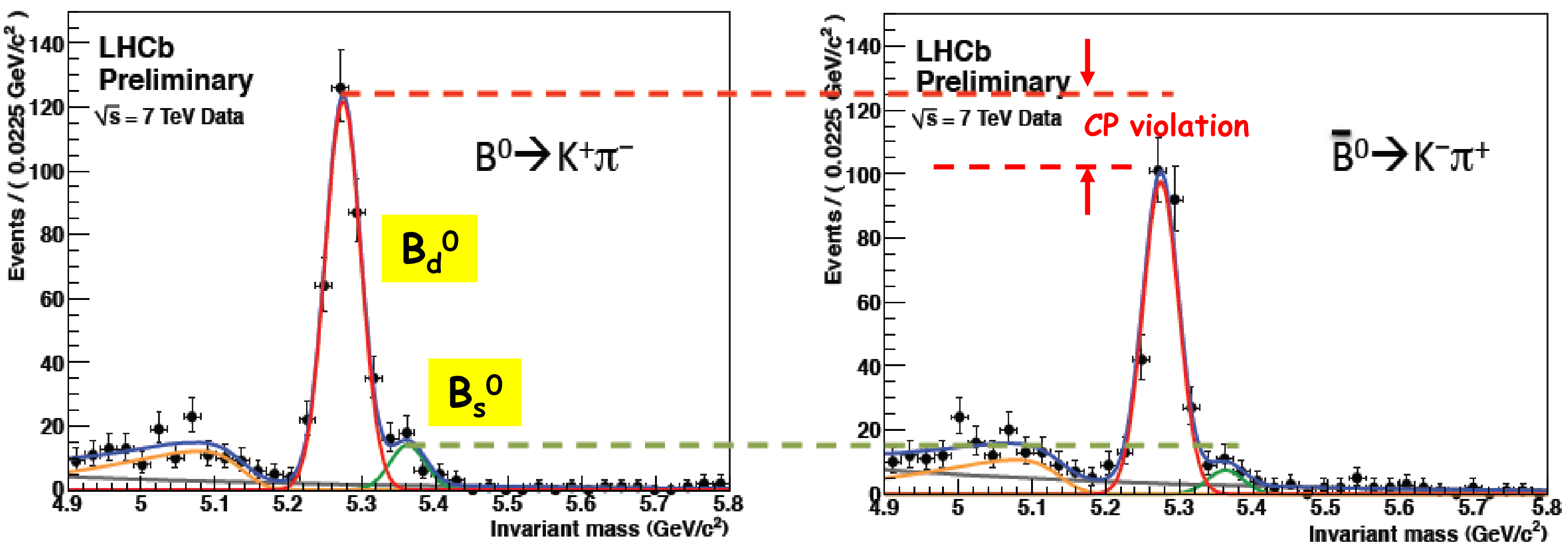
The LHCb Experiment

- LHCb is an experiment to the search for new physics in CP violation and rare decays of heavy flavours
- Optimized for the strongly forward peaked heavy quark production at the LHC
- Covers only ~4% of solid angle but captures ~40% of heavy-quark production cross section



The need for good PID : 2010 data

- Example of direct *CP* violation measurement (> 3σ) observation
- Separate samples into B^0 and $\bar{B}^0$ using particle identification from RICH



Upgraded LHCb experiment & PID

- Plan to upgrade in 2017/18: LHCb will increase data by an order of magnitude (from 5 $fb^{-1} \rightarrow$ 50 fb^{-1})
- Major trigger upgrade necessary for higher luminosity → read out *complete* experiment at 40 MHz to CPU farm (software trigger)
- Current PID is provided by 2 RICH detectors, 3 radiators : aerogel, C_4F_{10}, CF_4 → RICH system will be retained but with photodetectors replaced
- Aerogel is less effective at high lumi due to its low photon yield & high occupancy. Propose to replace the aerogel with time-of-flight based detector (TORCH)

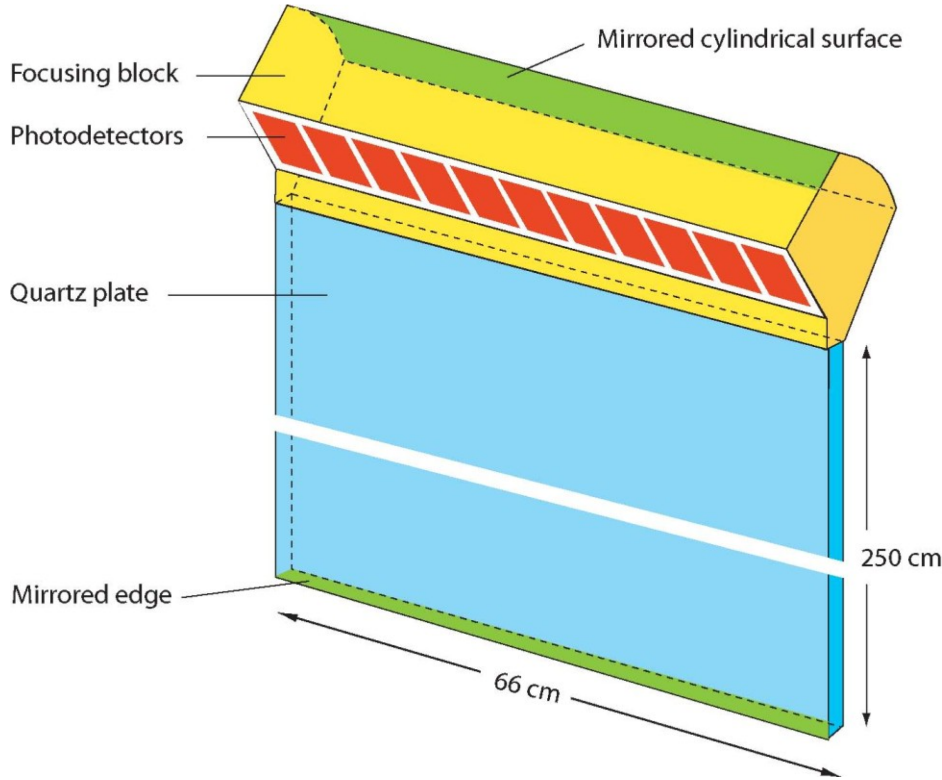
TORCH concepts & principles (1)

- TORCH (Time Of internally Reflected CHerenkov light)

- TORCH will provide positive identification of kaons up to p ~ 10 GeV/c, i.e. below the K threshold in the C_4F_{10} gas of RICH-1

- ΔTOF (π-K) = 35 ps at 10 GeV over ~10 m flight path → aim for ~15 ps resolution per track

- Cherenkov light production is prompt → use quartz as source of fast signal



- Cherenkov photons travel to the end of the bar by total internal reflection → time their arrival

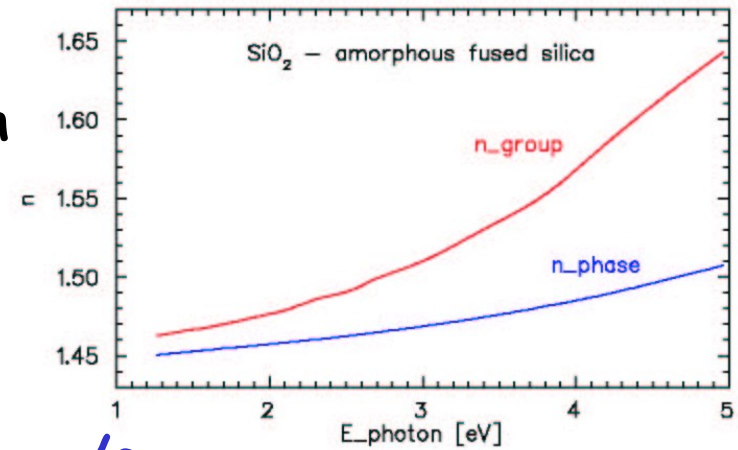
TORCH concepts & principles (2)

- For fast timing measurement, need to correct for the chromatic dispersion of quartz : refractive index given by

$$n_{group} = n_{phase} - \lambda \, (dn_{phase}/d\lambda)$$

  - Photons emitted with Cherenkov angle $\cos\theta_C = 1/\beta\, n_{phase}$
  - Photons with different λ emitted with different $\cos\theta_C$

- Measure Cherenkov emission angle at the top of the bar → reconstruct path length of photon through quartz

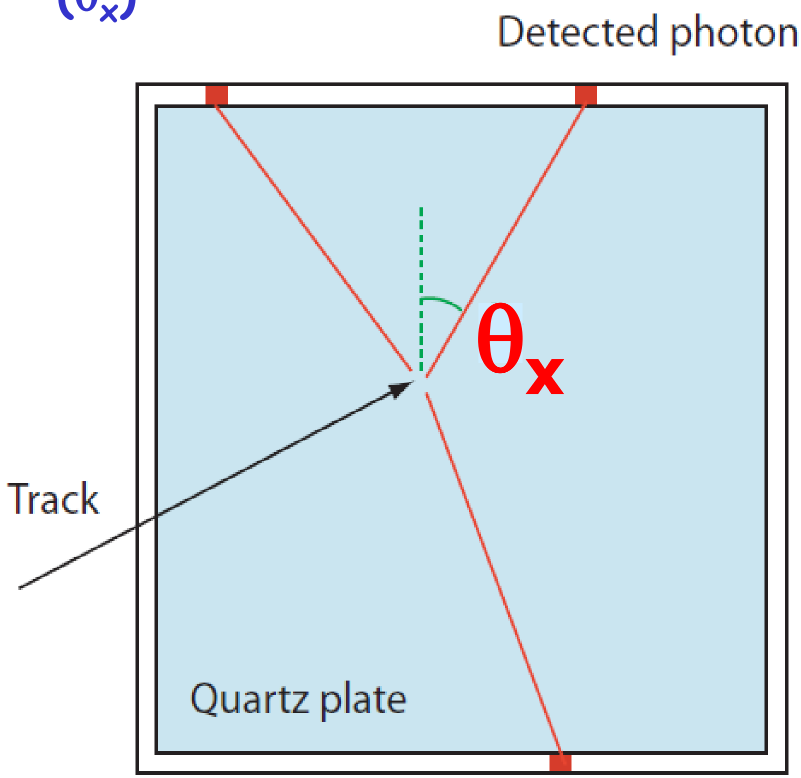


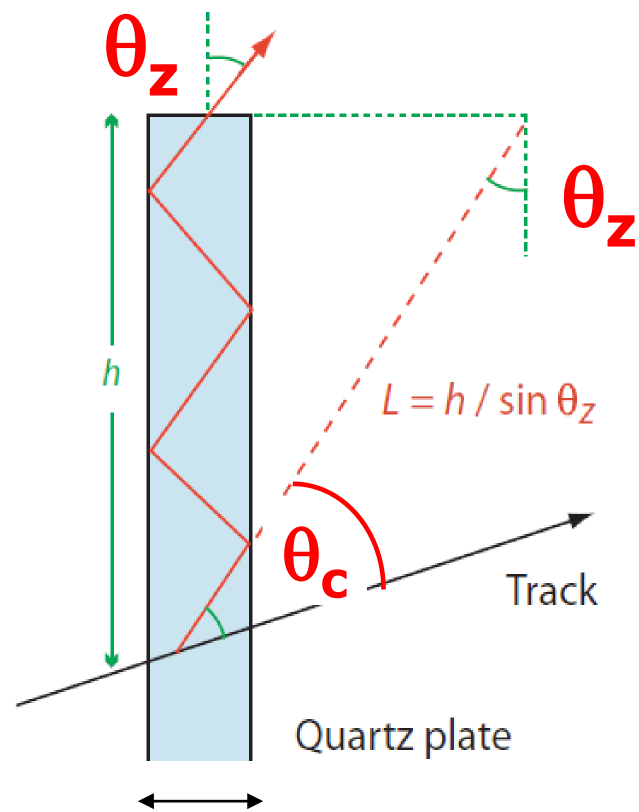
- The wavelength of the photon can be determined by this construction
  → Measure arrival time: $(t - t_0) = L\, n_{group}/c$

- 1 cm thickness of quartz produces ~ 50 detected photons/track (assuming a reasonable quantum efficiency of the photon detector)
  → ~ 70 ps resolution required per detected photon

Angular measurement

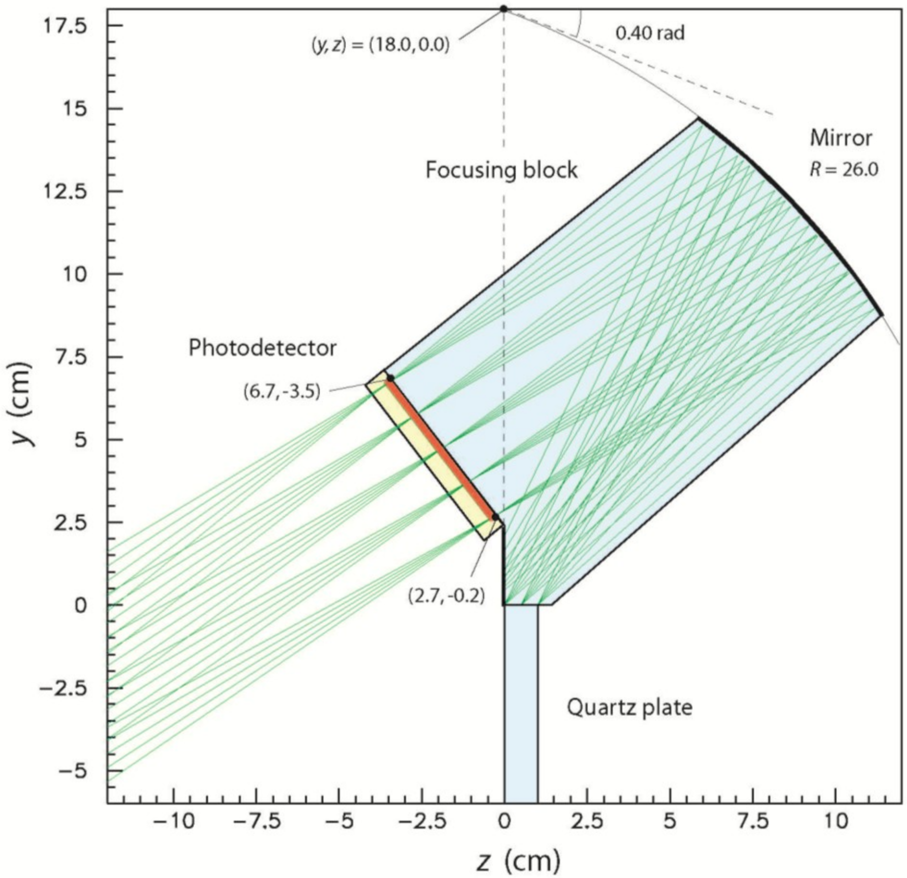
- Need to measure *angles* of photons, so their path length can be reconstructed (see also Dr. J.Schwiening – PANDA, Dr. K.Nishimura - Belle II ToP, this session)
  - ~ 1 mrad precision required on the angles in both planes
  - Coarse segmentation (~1cm) sufficient for the transverse direction (θ_x)





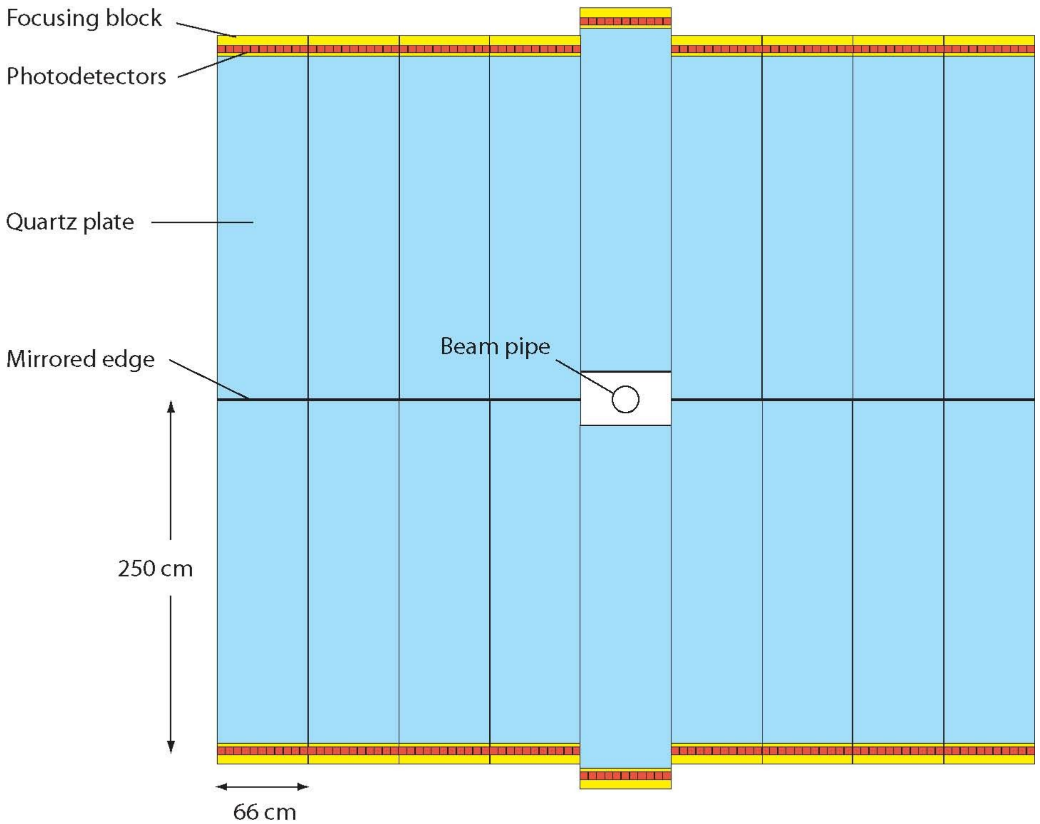
Focusing system

- To measure the angle in the longitudinal direction (θ_z)
  - Use a focusing block
  - Measure the position of photon on the photodetector plane
- Linear array of photon detectors - dimensions match the Planacon MCP from Photonis



TORCH modular design

- Dimension of quartz plane is ~ 5 × 6 m^2 (at z = 10 m)
- Unrealistic to cover with a single quartz plate → evolve to modular layout



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

- MCP photon detectors on upper edge

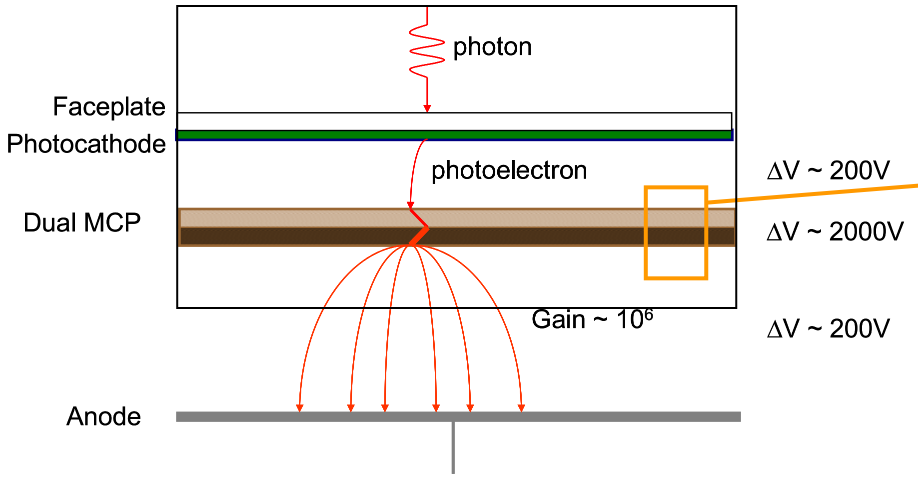
  18 × 11 = 198 units

  Each with 1024 pads

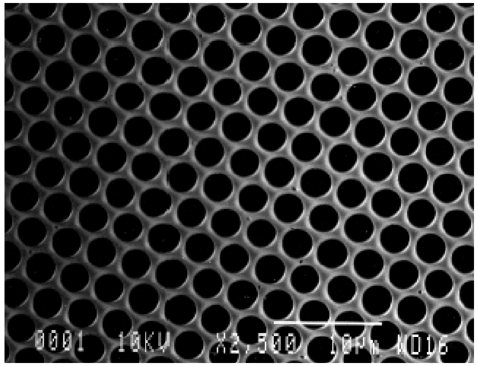
  → 200k channels total

Photon detection

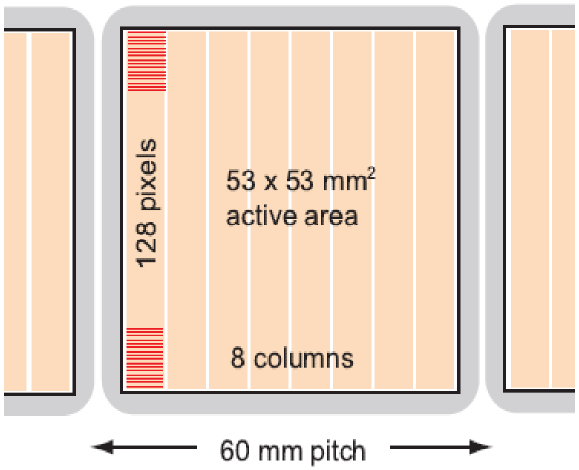
- Micro-channel plate (MCP) - Planacon XP85022 comes close to matching requirements. Currently available with 32 × 32 anode pads.
- Test result from K. Inami et al [RICH2010]: $\sigma(t)$ = 34.2 ± 0.4 ps



e.g. ~10 μm pores



- Anode pad structure can in principle be customed:
  We require a layout of 8 × 128
  → in discussion with manufacturers (Photek, UK).

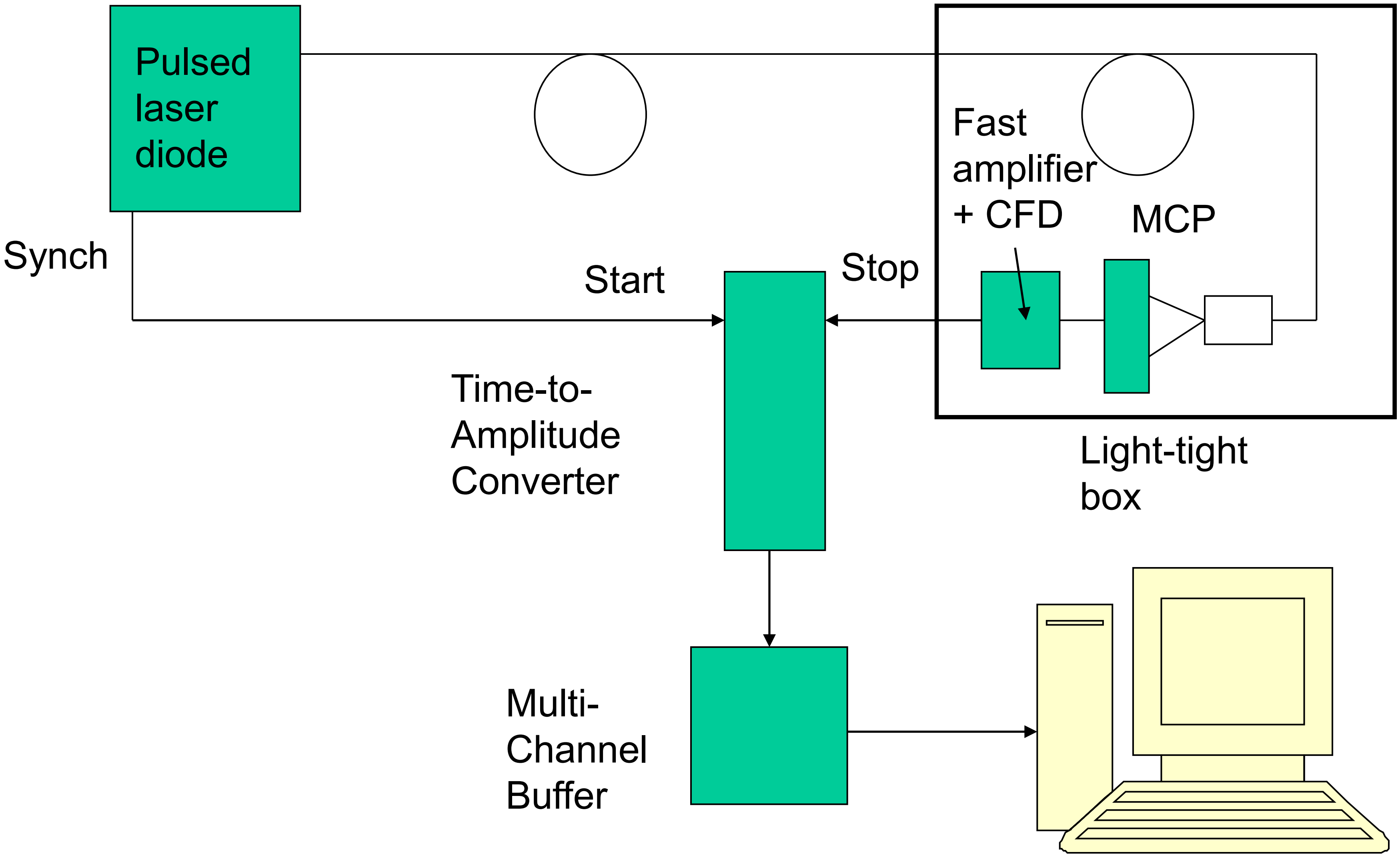


- Lifetime of MCP is an issue

TORCH R&D: in progress

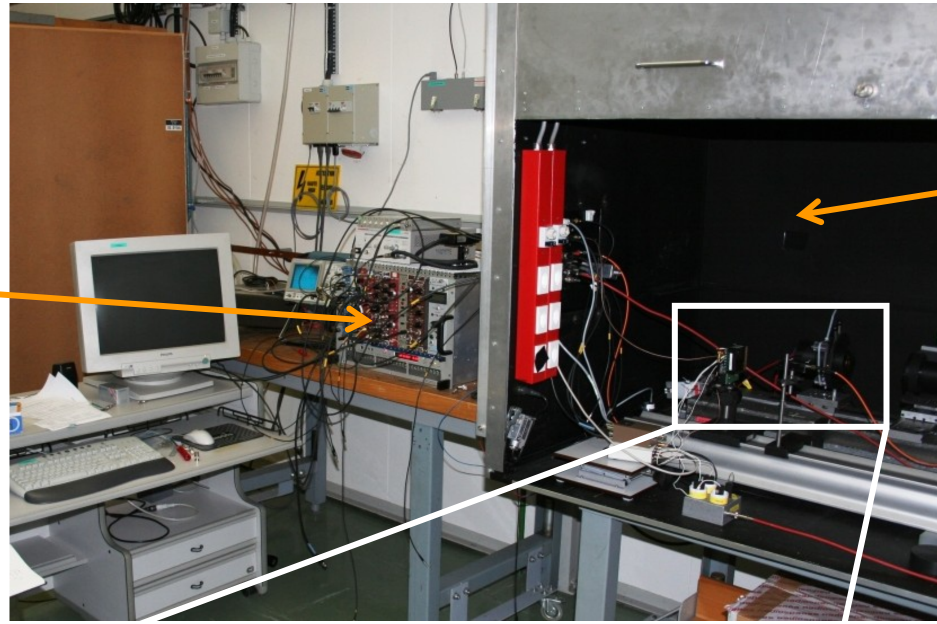
- Photon detectors: evaluate performance of existing MCP devices : 8×8-channel MCPs (Burle Planacons)
  - single photoelectron response, efficiency and time jitter
  - design and development of suitable anode pad structure
- Develop readout electronics
  - speed - 40 MHz rate, resolution, cross-talk
- Simulation
  - detailed simulation of TORCH
  - tagging performance
- Letter of Intent submitted to the CERN LHCC
  [CERN/LHCC 2011-001]

MCP tests – time resolution experimental setup



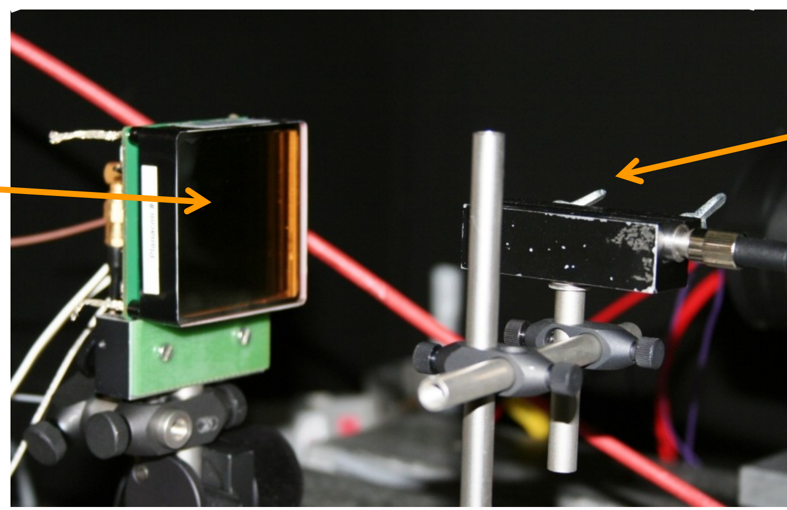
MCP tests – experimental setup

Single channel NIM electronics



Dark box

Planacon MCP



Laser light source

Planacon 8x8 : pulse height spectrum – fit

- Run at gain ~ 5×10^5 e^-
- Blue laser, μ~0.51
- Fit according to Poisson distribution

$$P_\mu(N) = \mu^N \frac{e^{-\mu}}{N!}$$

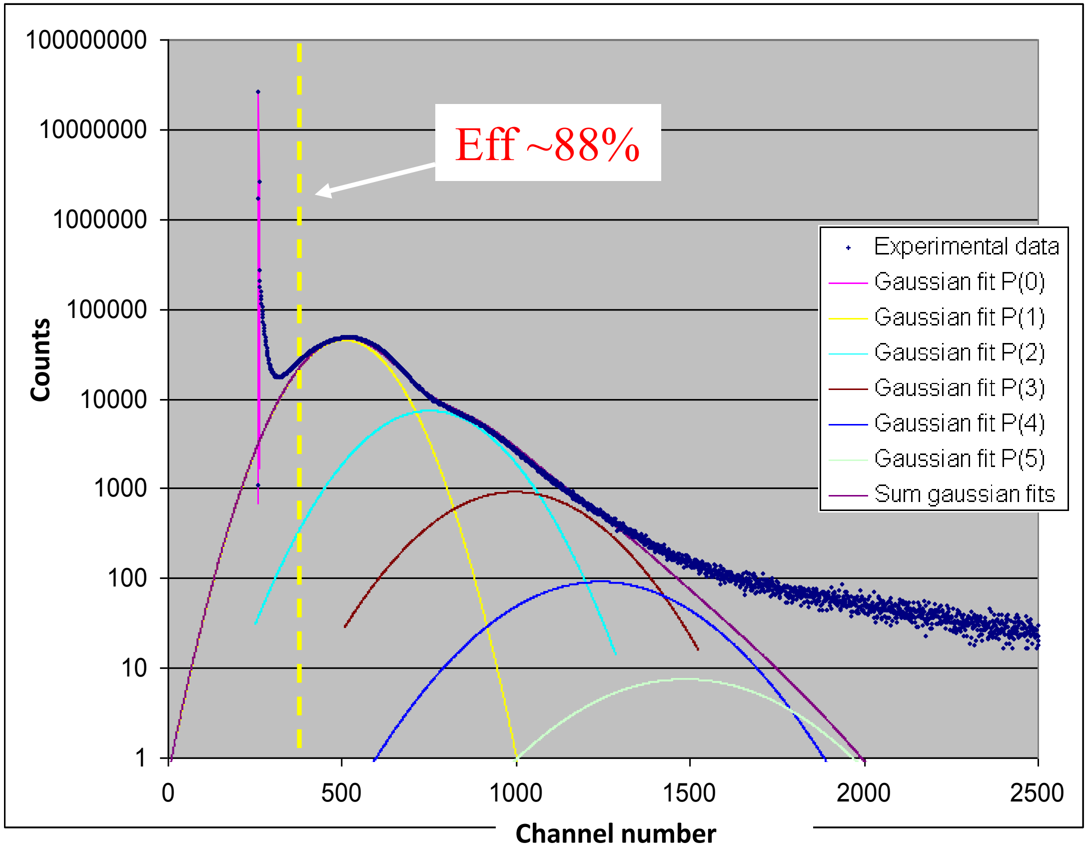
$$P_\mu(0) = e^{-\mu} = \frac{A_0\sigma_0\sqrt{2\pi}}{total\ \ surface}$$

- Gaussian pedestal P(0) and resolution functions

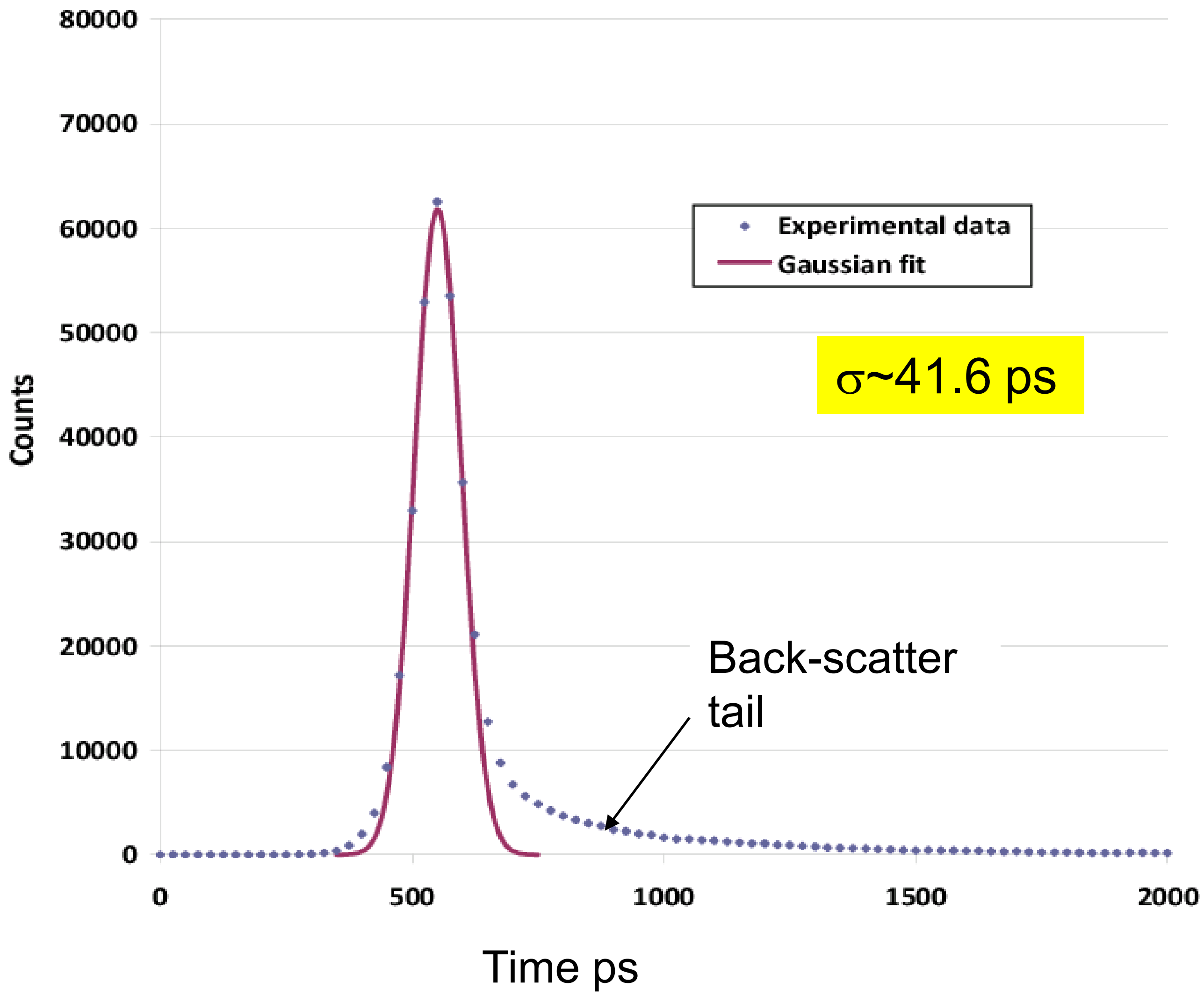
$$y = A_0 e^{-\frac{1}{2}\left(\frac{x-x_0}{\sigma_0}\right)^2}$$

$$P_\mu(N) = \frac{\mu^N}{N!}e^{-\mu} = \frac{A_N\sigma_N\sqrt{2\pi}}{total\ \ surface}$$

$$\sigma_N = \sqrt{N}\sigma_1$$

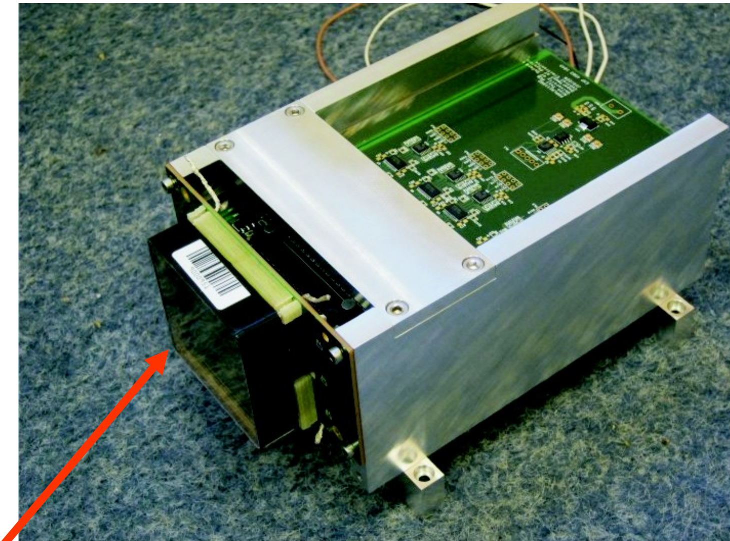


Planacon 8x8 : time resolution distribution



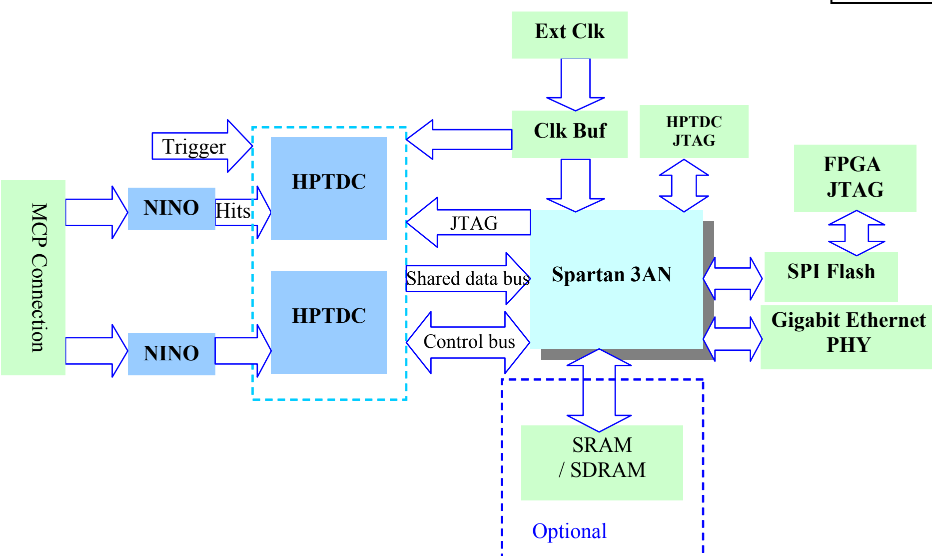
Readout electronics

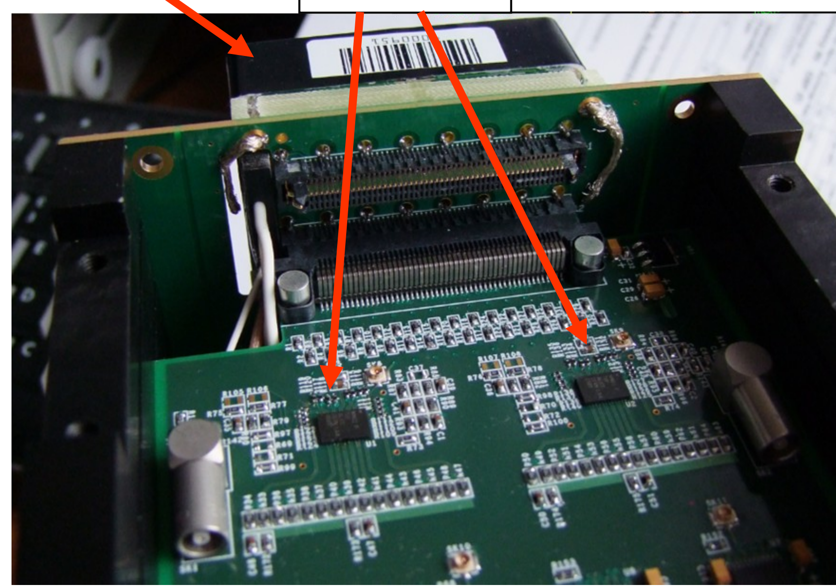
- Starting with 8-channel NINO chips and HPTDC (high resolution mode), developed for the ALICE TOF
- Jitter measured to be 14-20 ps RMS
- Test-beam studies foreseen for later this year



Planacon

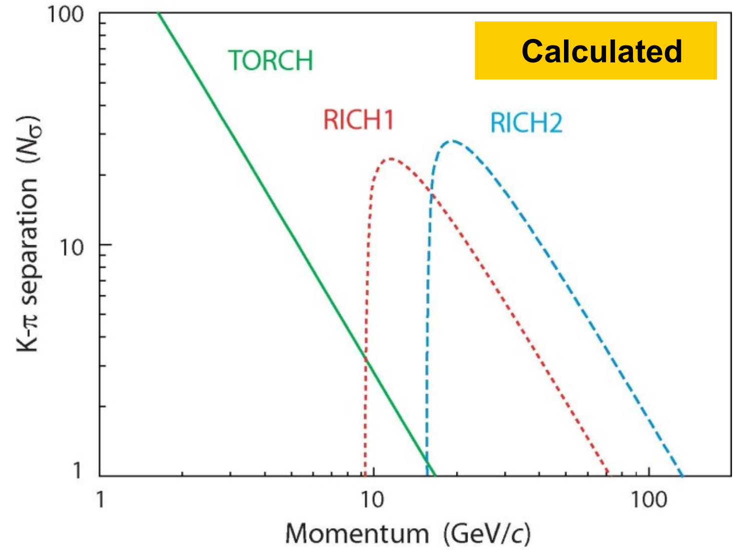
2 NINO chips

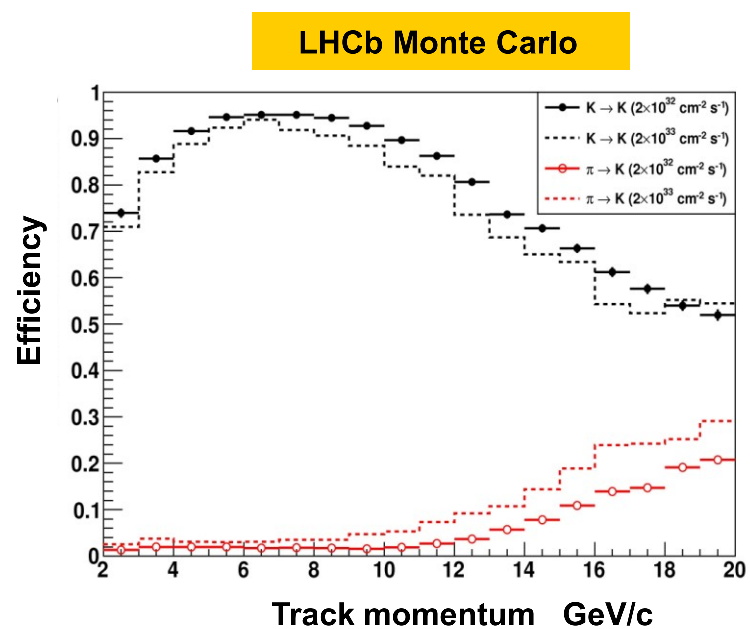




TORCH expected performance

- Simple simulation of the TORCH detector & interfaced to a full simulation of LHCb, plus pattern recognition
- Obtain a start time t_0 from the other tracks in the event originating from the primary vertex
- The intrinsic arrival time resolution per p.e. is 50 ps giving a total resolution per detected p.e. of 40 ps [MCP] ⊕ 50 ps [intrinsic] ≈ 70 ps, as required
- Excellent particle ID performance achieved, up to and beyond 10 GeV/c (with some discrimination up to 20 GeV/c)





Conclusions & future plans

- TORCH is a novel detector concept proposed for the upgrade of LHCb.

- Given a per-photon resolution of 70 ps, excellent K-π separation can be achieved up to 10 GeV/c and beyond (with TOF resolution of ~15 ps per track)

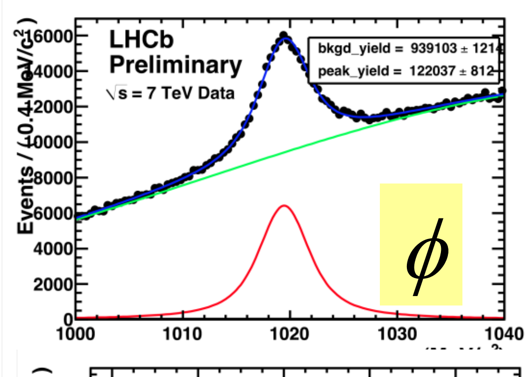
- R&D is in progress, starting with the photodetector and readout electronics

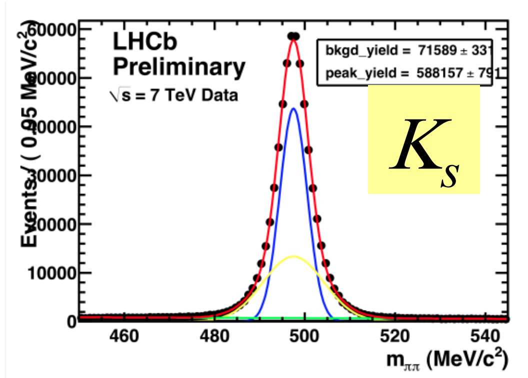
- Impact of the TORCH is under study with detailed simulation

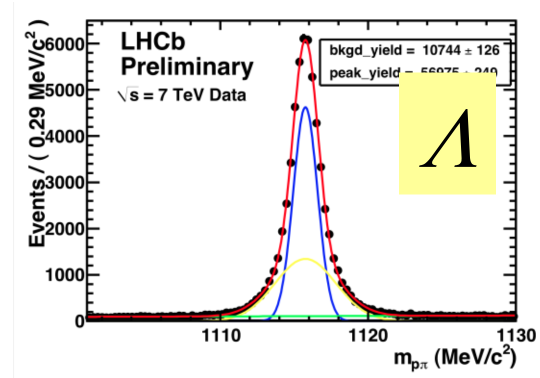
- Letter of Intent for the LHCb upgrade already submitted; Technical Design Report in ~2 years' time.

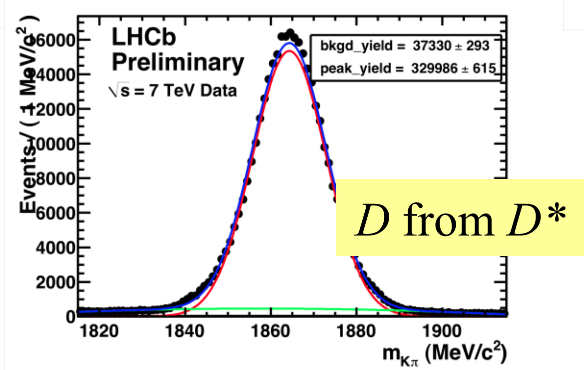
Spare slides from here on

PID calibration samples

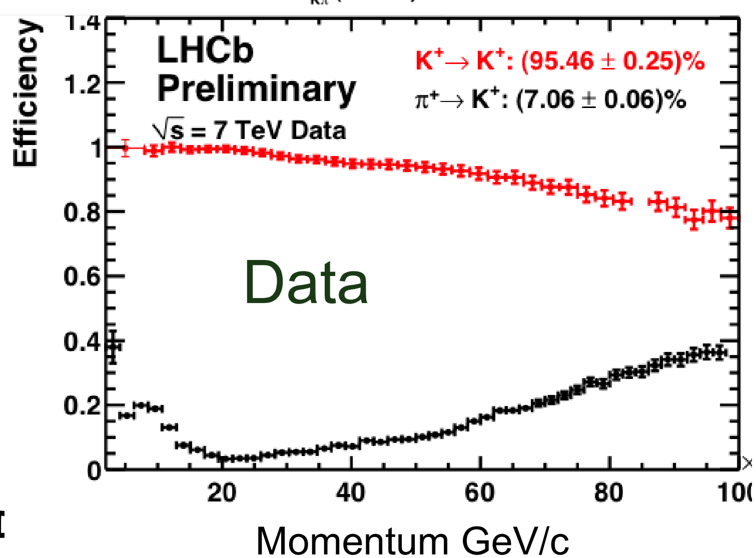


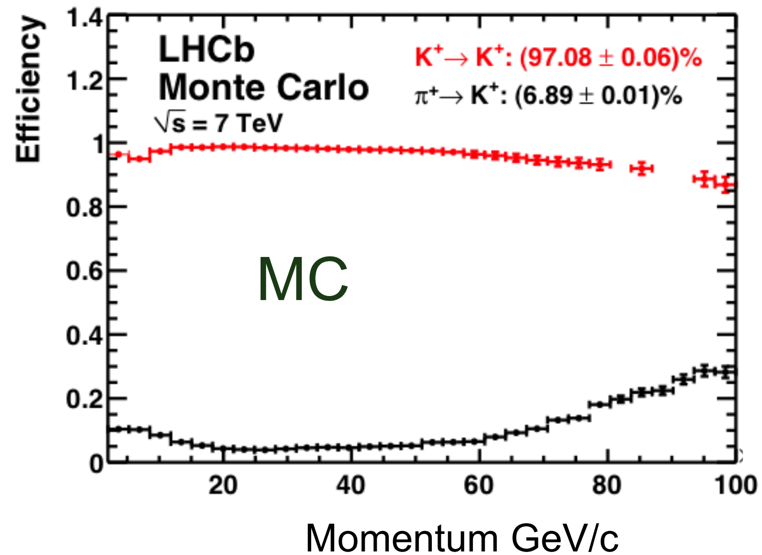




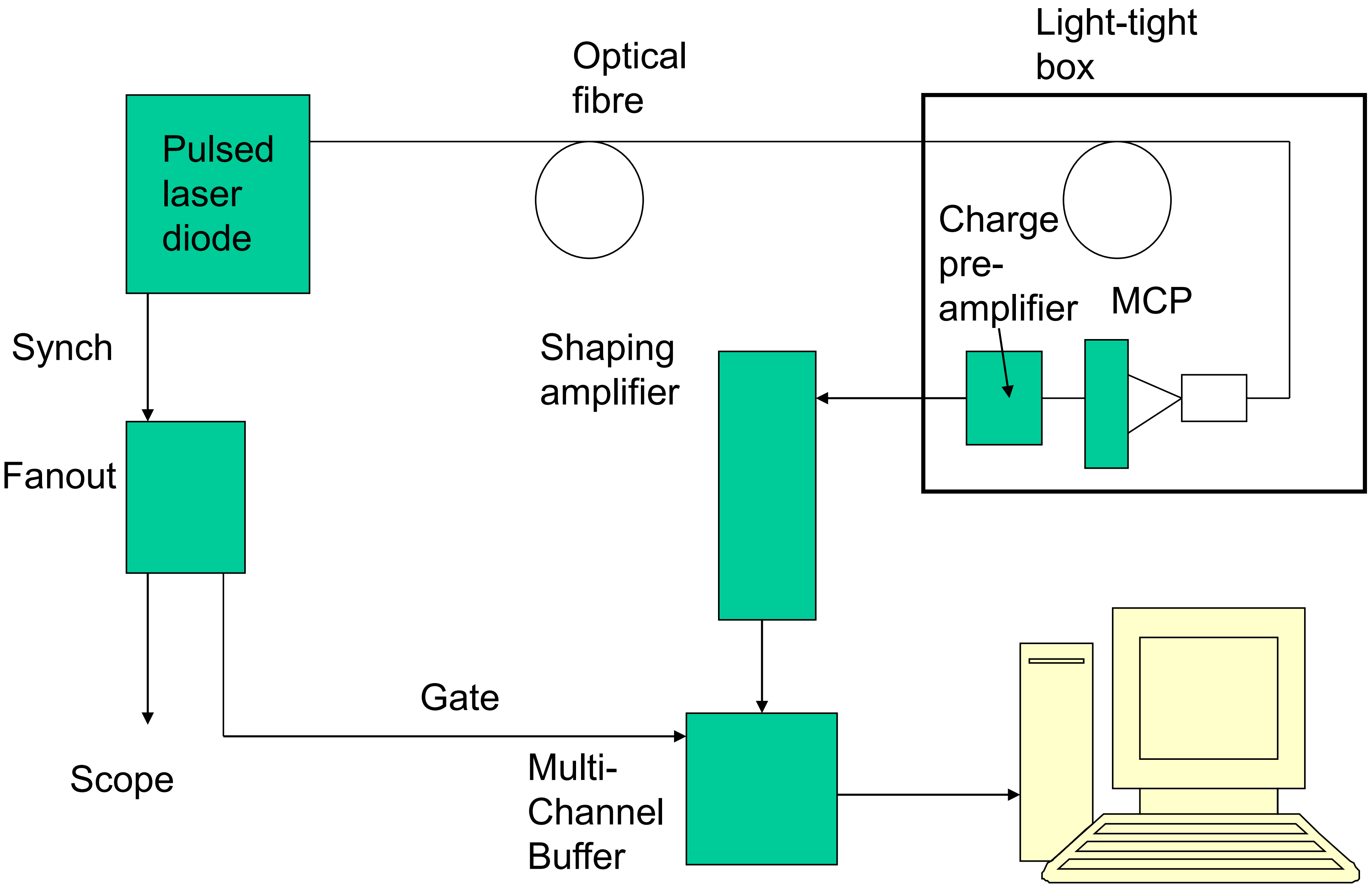


- Samples allow PID calibrations in efficiency and purity to be evaluated with data



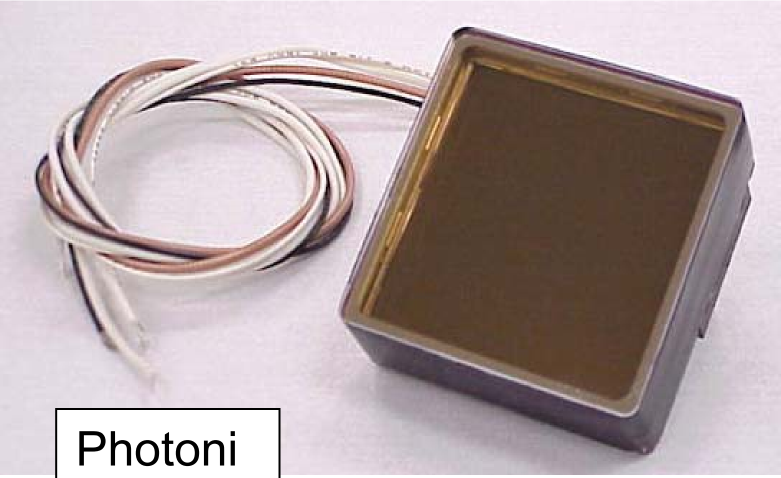


MCP tests – pulse height experimental setup

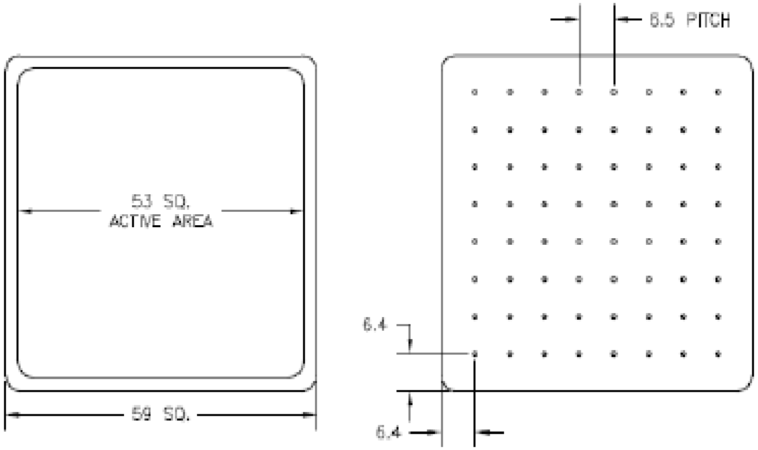


Specifications of 8×8-channel MCPs

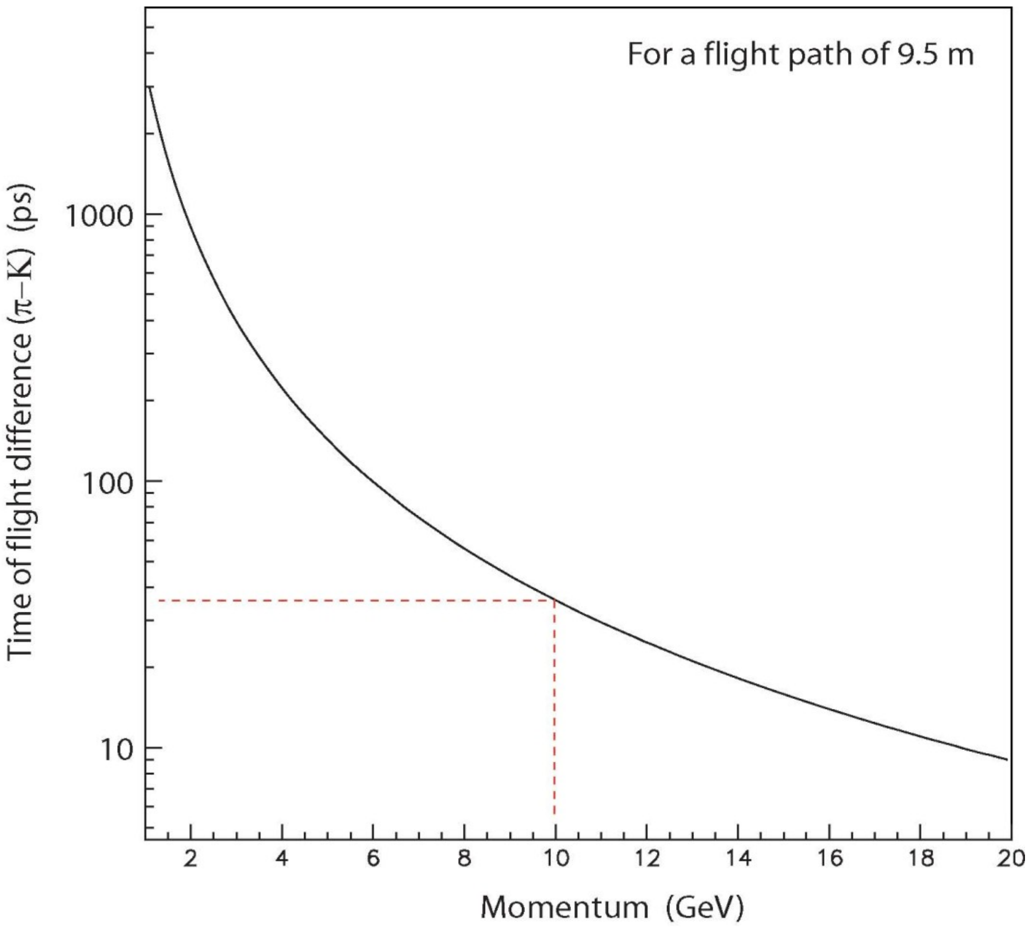
- **XP85012/A1**
  - MCP-PMT planacon
  - 8x8 array, 5.9/6.5mm size/pitch
  - 25um pore diameter, chevron type (2), 55% open-area ratio
  - MCP gain up to 10^6
  - Large gaps:
    - PC-MCPin: ~4mm
    - MCPout-anode: ~4mm
  - 53mmx53mm active area, 59mmx59mm total area -> 80% coverage ratio
  - Total input active surface ratio ≤44%
  - bialkali photocathode
  - rise time 600ps, pulse width 1.8ns



Photonis-Burle

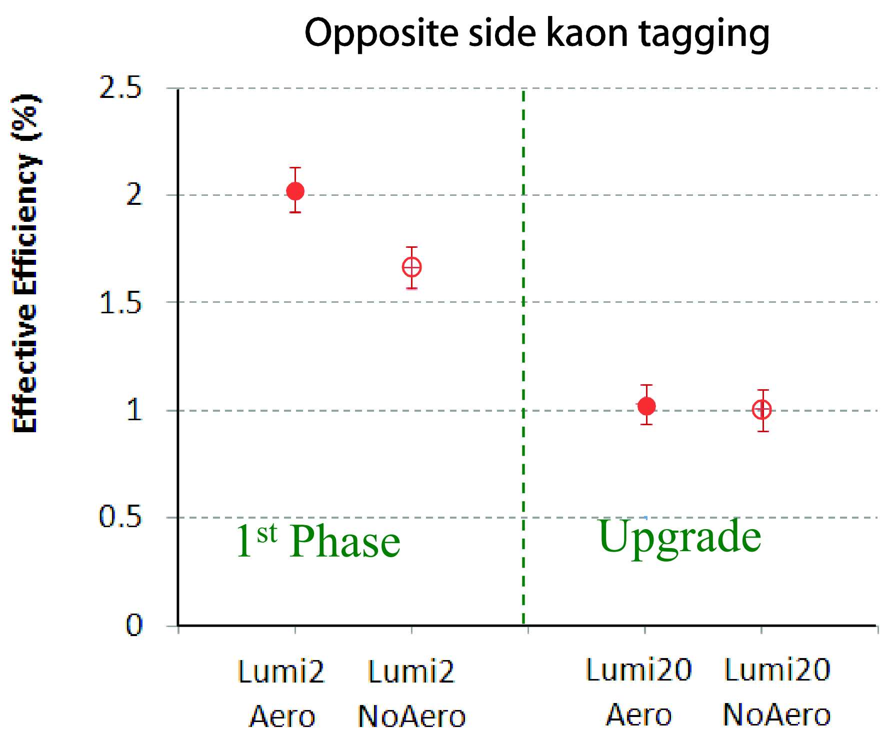


TOF over 9.5m flight distance



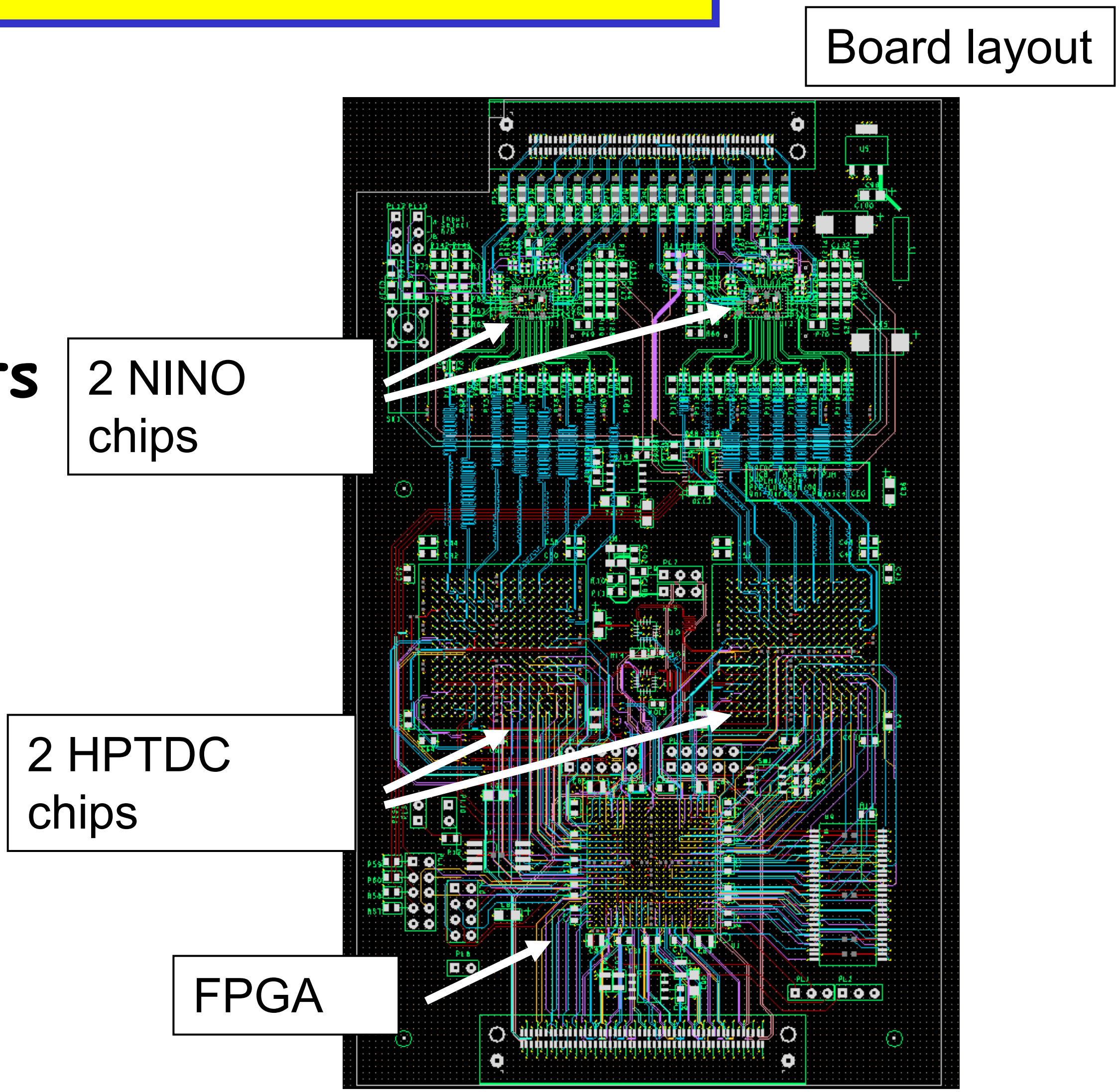
Aerogel & high lumi running

- Flavour tagging (distinguishing B from $\bar{B}$) is one of the primary requirements for low-momentum particle ID in LHCb (2-10 GeV) currently provided by aerogel

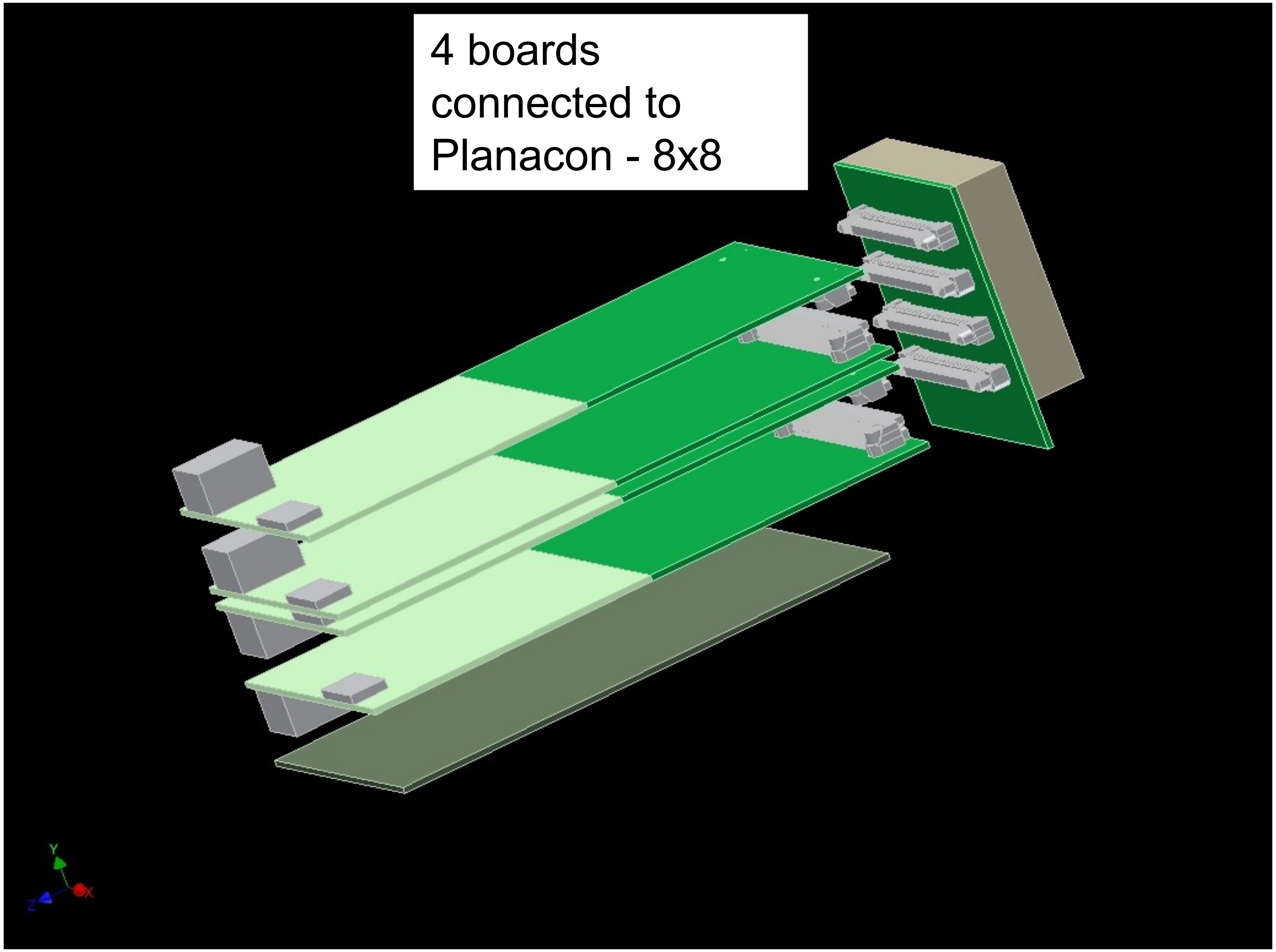


HPTDC-NINO Board status

- **Layout completed, under final review**
- **Sourcing components for 14 boards**



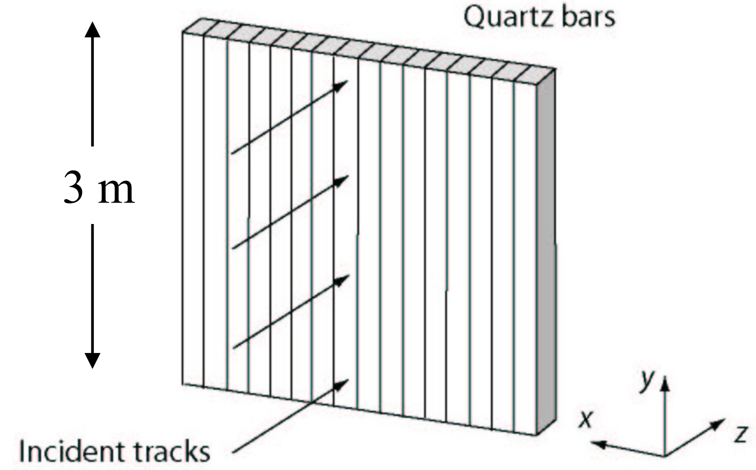
Readout electronics - general assembly drawing



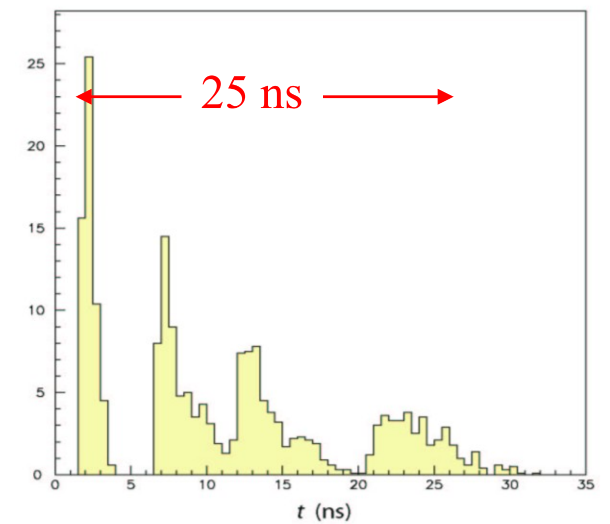
Spread of arrival times

- 1 cm thickness of quartz is enough to produce ~ 50 detected photons/track (assuming a reasonable quantum efficiency of the photon detector)

  → ~ 70 ps resolution required per detected photon
- However, spread of arrival times is *much* greater than this, due to different paths taken by photons in the bar

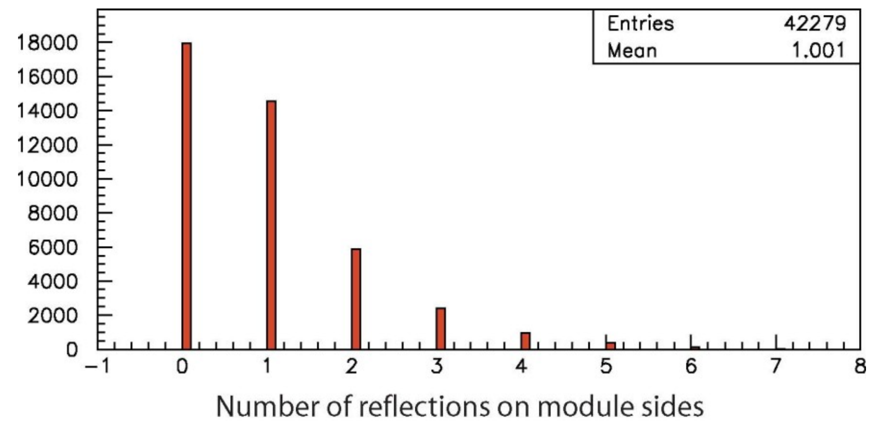


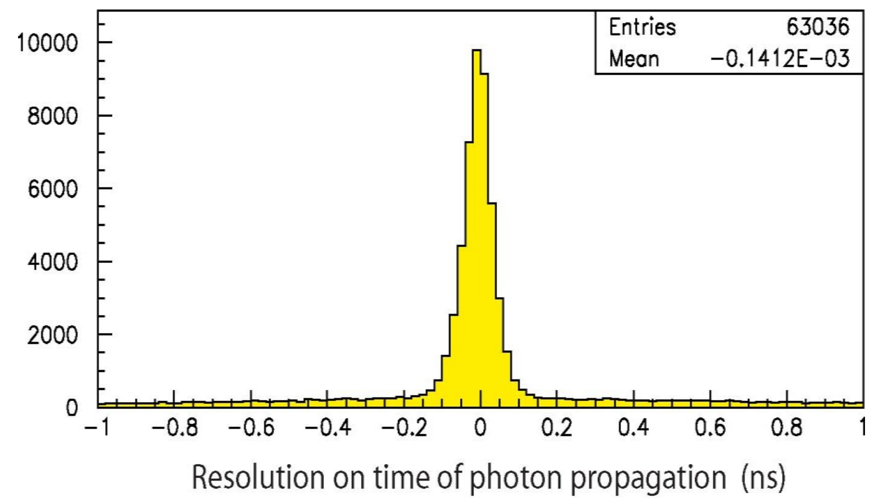
Photon arrival time



Effect of edges

- Reflection off the *faces* of plate is not a problem, as the photon angle in that direction (θ_z) is measured via the focusing system
- In the other coordinate (x) position is measured rather than angle
  → reflection off the *sides* of the plate gives ambiguities in the reconstructed photon path
- Only keep those solutions that give a physical Cherenkov angle
  → only ~ 2 ambiguities on average
- Effect of the remaining ambiguities is simply to add a ~ flat background to reconstructed time distribution





Pattern recognition

- **Event display illustrated for photons from 3 different tracks hitting plane**