DIRC 2011
International Workshop on Fast Cherenkov Detectors
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R & D status for the LHCb TORCH project

Thierry Gys on behalf of the LHCb-RICH group

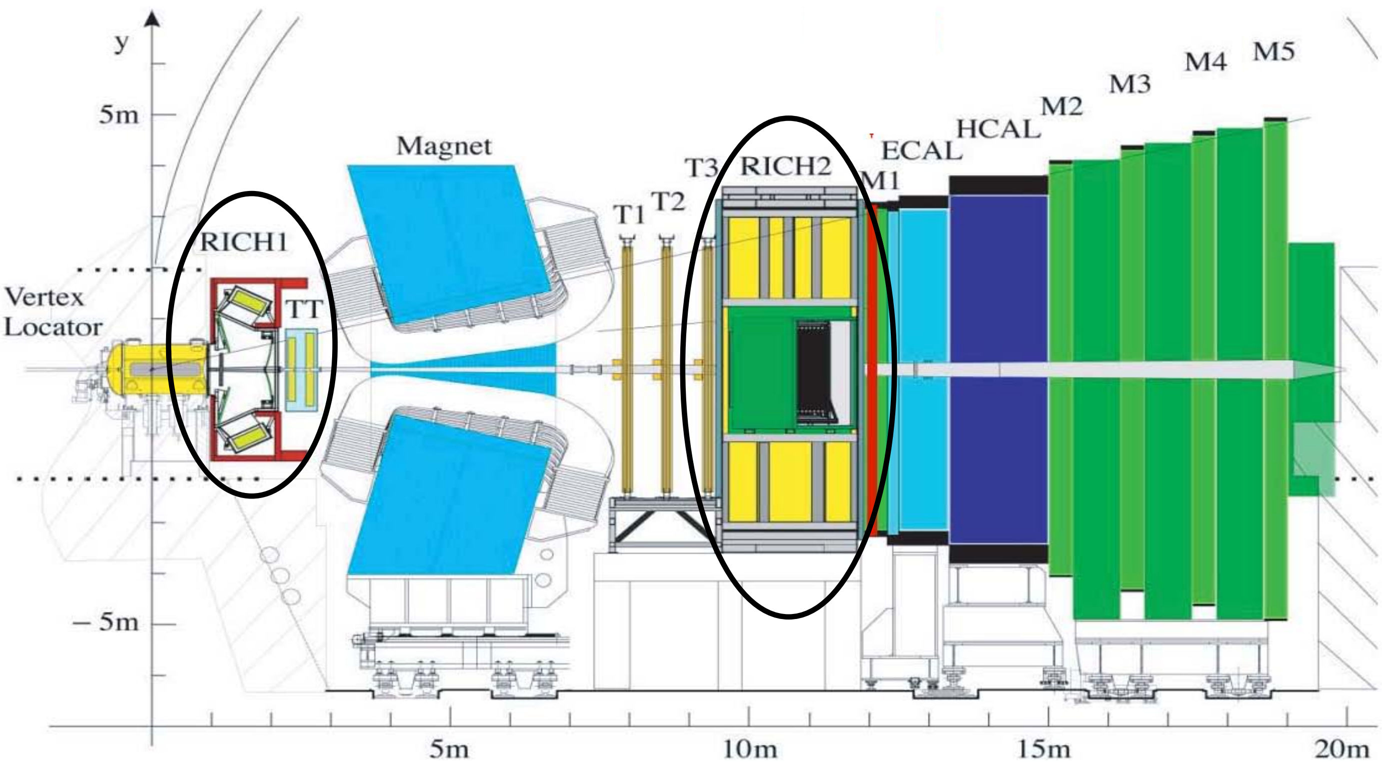
Talk layout

- LHCb upgrade
- TORCH concept
- Specifications and tests of commercial MCPs
- Readout electronics status
- Conclusions and perspectives

  - Material for this talk from: L. Castillo-García, M. Charles, J. Fopma, R. Forty, R. Gao, T. Gys

LHCb

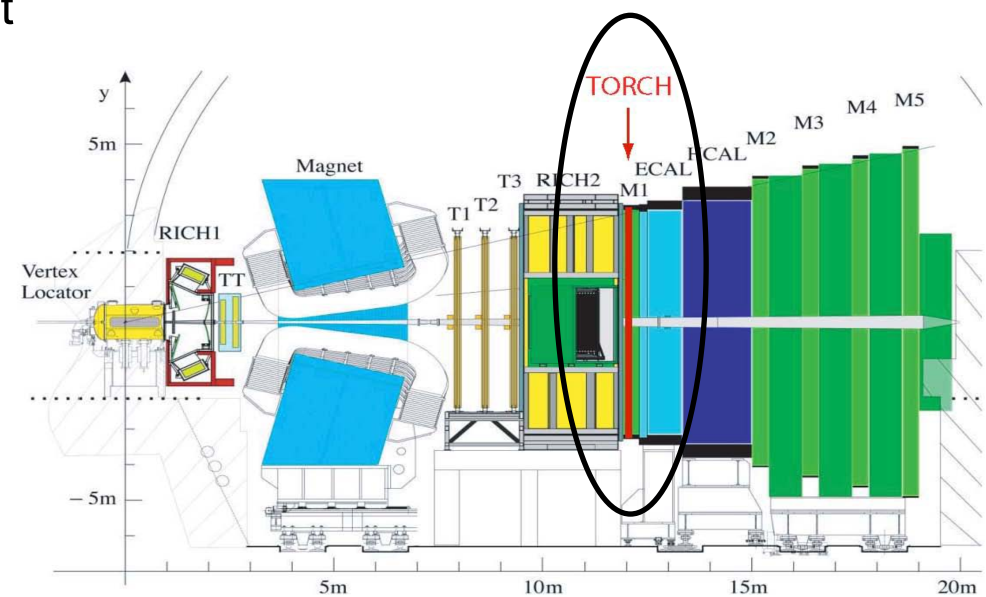
- LHCb is one of the four major experiments at the LHC, dedicated to the search for new physics in CP violation and rare decays of heavy flavours
- It is a forward spectrometer (10–300 mrad) operating in pp collider mode Particle identification is provided by two RICH detectors currently equipped with three radiators: silica aerogel, C_4F_{10} and CF_4 gases



Current LHCb performance and low-momentum PID at high luminosity

- LHCb detector is performing superbly: clean b-hadron signals accumulating rapidly
- Low-momentum particle ID in LHCb (2–10 GeV) is currently provided by aerogel
- Monte Carlo studies of high-luminosity (2×10^{33} cm^2 s^{-1}) running indicate that aerogel will be less effective, due to its low photon yield (< 10 detected photons/saturated track) and the high-occupancy environment

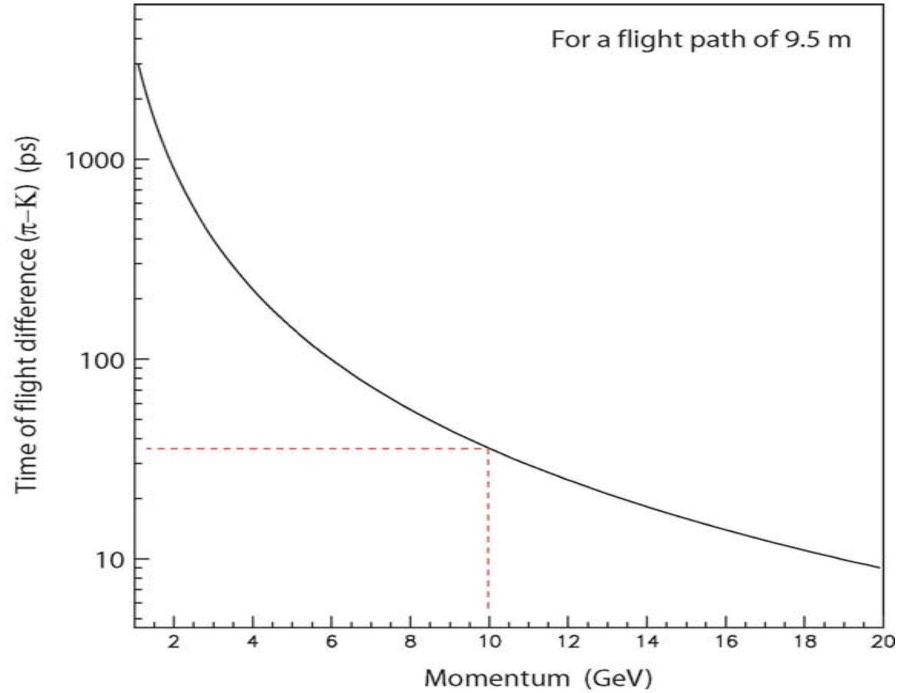
- Aim for installation of upgrade in 2017, during a planned long LHC shutdown
- Main focus is on trigger, which must be upgraded to handle higher luminosity
- Current bottleneck is at the hardware level that reduces 40 MHz bunch crossing rate to 1 MHz for readout into HLT
  - → read out complete experiment at 40 MHz into the CPU farm, fully-software trigger
- RICH system will be kept for PID with photodetectors replaced
- Propose to replace the aerogel with time-of-flight based detector
- First muon station will be removed → space available for new device



- TORCH (Time Of internally Reflected CHerenkov light) is a possible solution for low-momentum particle ID
- Closely related to the TOP concept of Belle II (see related talks in this workshop)

- Want positive identification of kaons in region below their threshold for producing light in the C_4F_{10} gas of RICH-1, i.e. $p < 10$ GeV

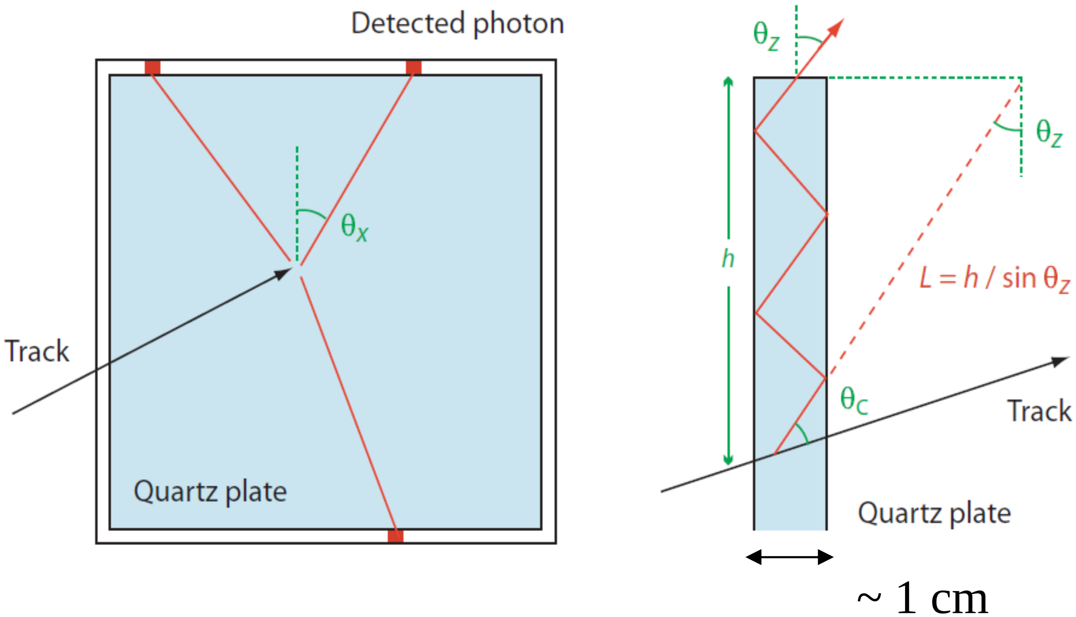
  ΔTOF (π-K) = 35 ps at 10 GeV
  over a distance of ~ 10 m
  → aim for 15 ps resolution per track



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

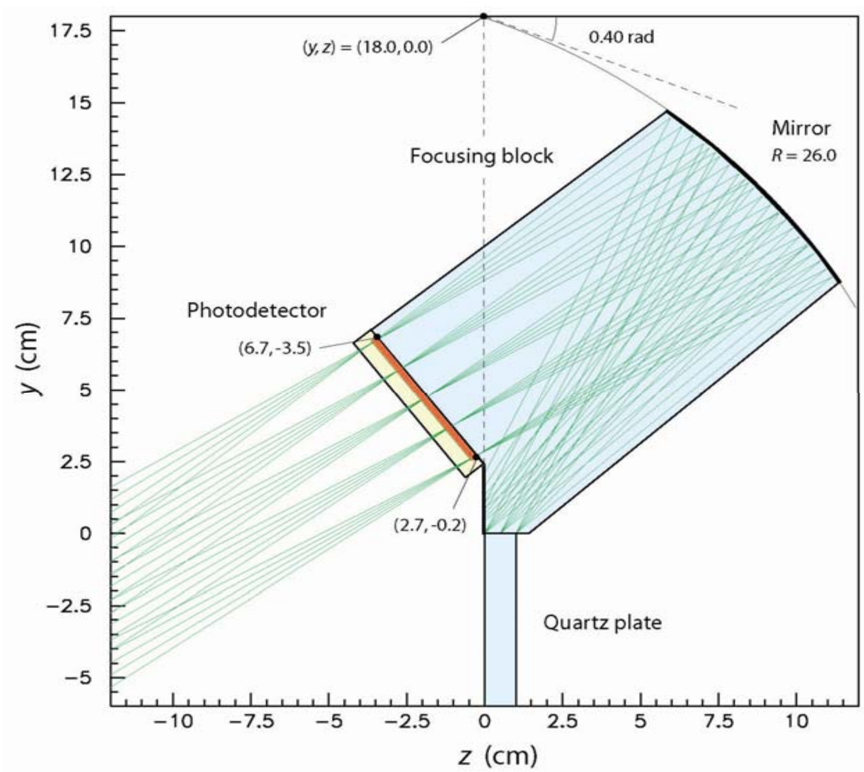
Planar detector

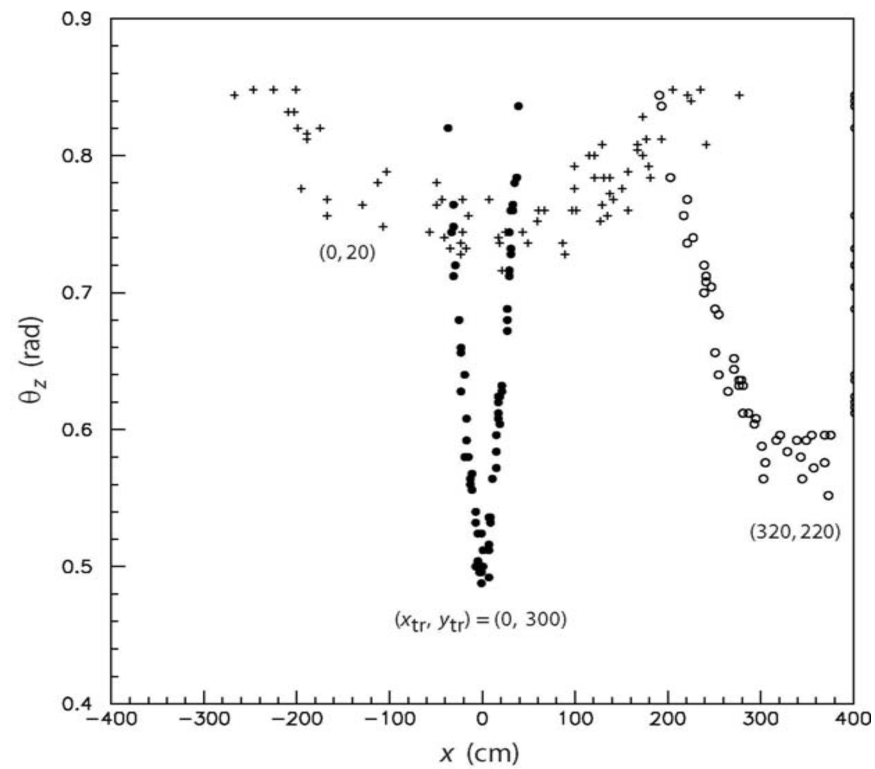
- Cherenkov photons produced in the quartz transported to the end of the bar by total internal reflection, where their arrival would be timed
  - 70 ps overall resolution required per detected photon
- Need to measure *angles* of photons, so their path length can be reconstructed
  - ~ 1 mrad precision required on the angles in both transverse planes
- Borrow idea from the end-cap DIRC of PANDA*: use a plane of quartz
  - → coarse segmentation (~1cm) is sufficient for the transverse direction (θx)
- * see related talks in this workshop



50 detected Cherenkov photons per track

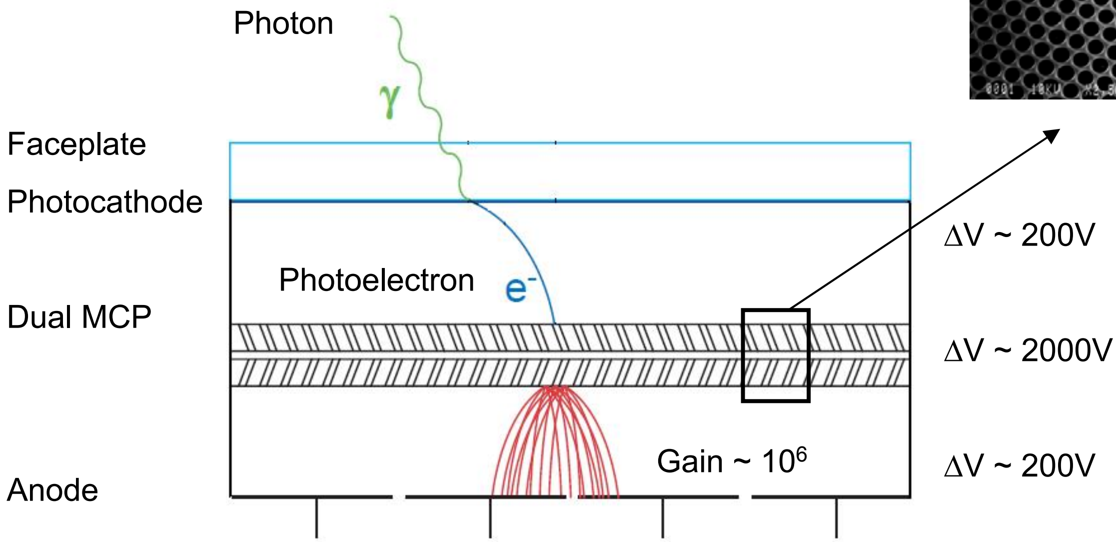
- To measure the angle in the longitudinal direction (θz) we use a focusing block, to convert angle of the photon into position on the photodetector
- Event display illustrated for photons from 3 different tracks hitting plane

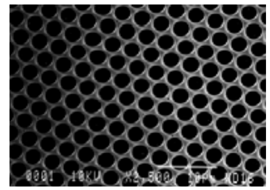


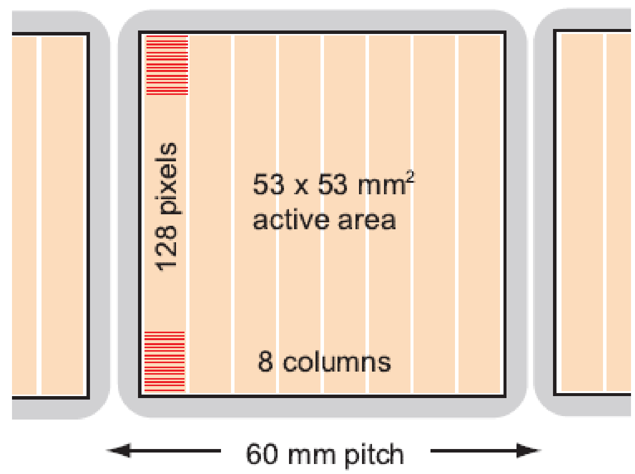


Photon detection

- Micro-channel plate (MCP) photodetectors are currently the best choice for fast timing of single photons

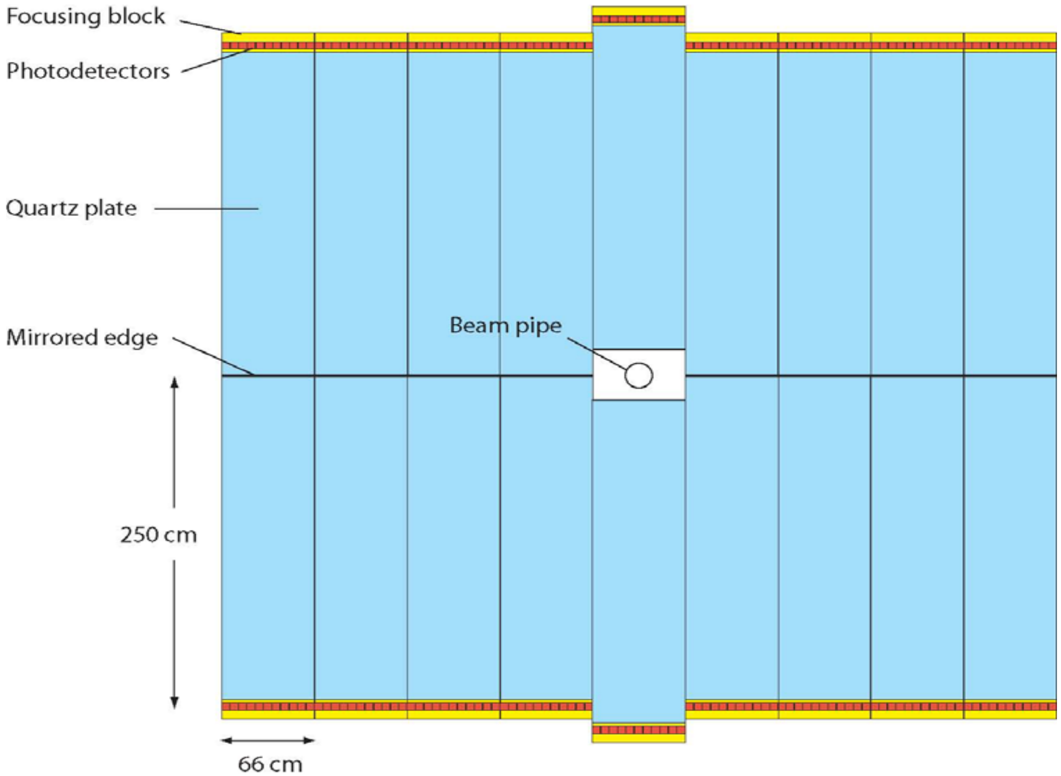






- Anode pad structure can in principle be adjusted according to need
  - Smearing of photon propagation time due to photodetector granularity ~40 ps
  - Assuming an intrinsic arrival time measurement resolution per p.e. of 50 ps the total resolution per detected p.e. is 40 ⊕ 50 ~ 70 ps, as required

- For the application in LHCb, transverse dimension of plane to be instrumented 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

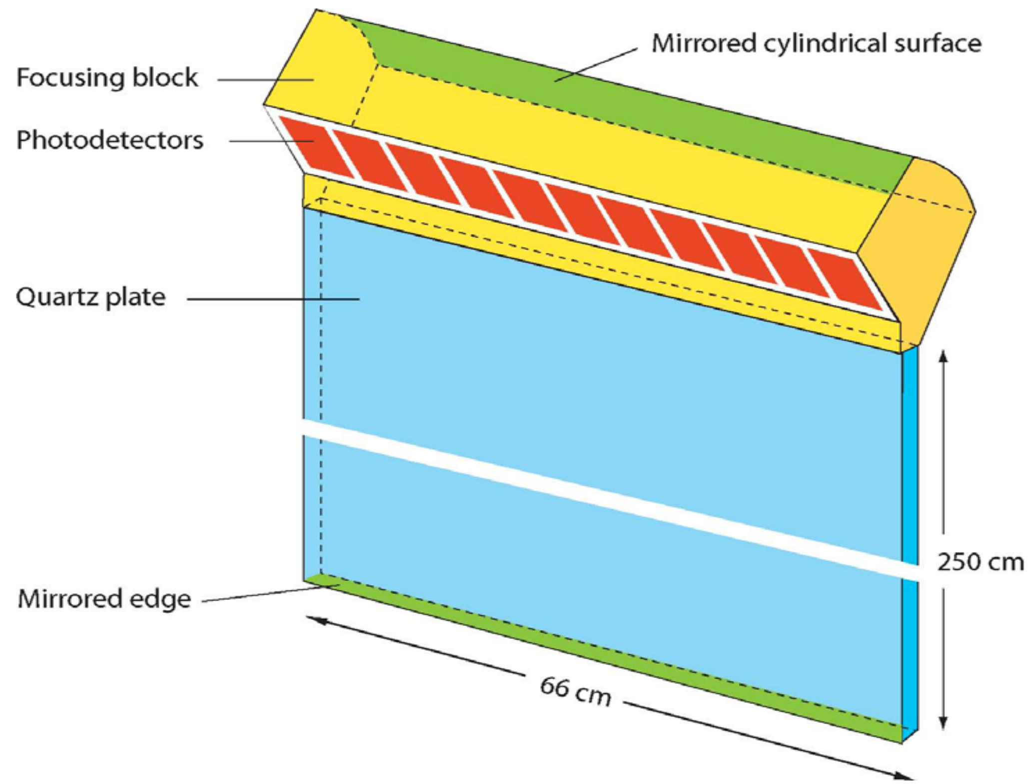
Reflective lower edge
→ photon detectors only needed on upper edge

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

- reflection off the sides of the plate gives ambiguities in the reconstructed photon path

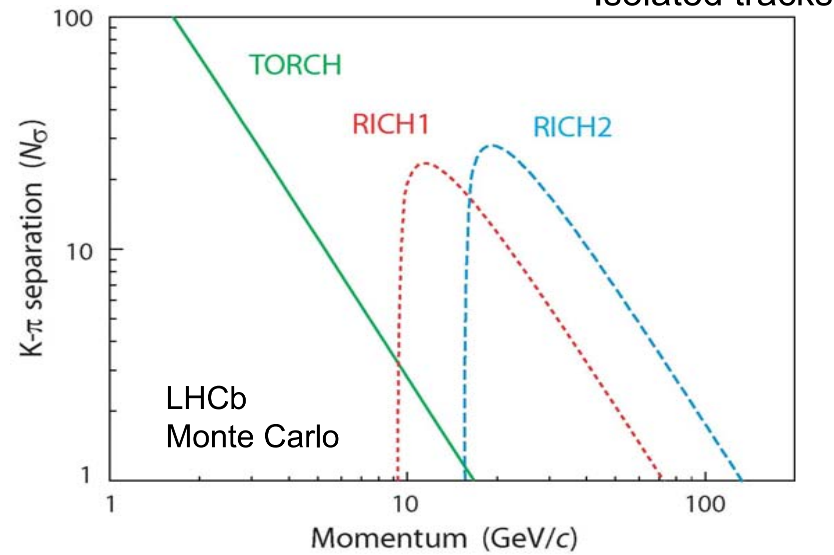
TORCH module

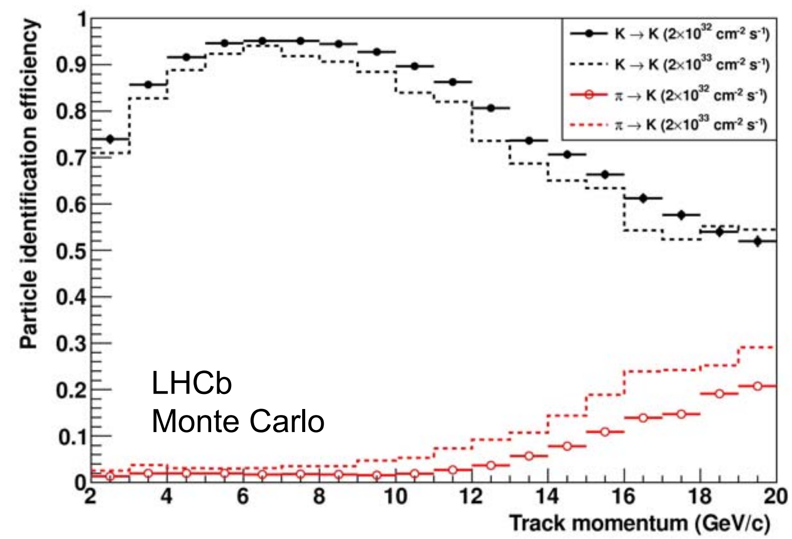
- Focusing block in quartz or plastic (should match refractive index)
- Cylindrical mirror
- Linear array of photon detectors
- Dimensions have been chosen to correspond to the Planacon MCP from Photonis
- Plate thickness (~ 1 cm) to be optimized once photoelectron yield known



- Full algorithm has been studied, including pattern recognition, using a simple simulation of the TORCH detector, interfaced to the full simulation of LHCb
- For particle ID, need to correct for the strong chromatic dispersion of quartz Achieved by measuring the photon angles, and knowing path of track through quartz
  - determine Cherenkov emission angle
    $\cos\theta_C = 1/\beta\, n_{phase}$
    $t - t_0 = L\, n_{group}/c$
- Effectively the wavelength of the photon is determined by this construction
- Excellent particle ID performance achieved, up to 10 GeV as required

Isolated tracks





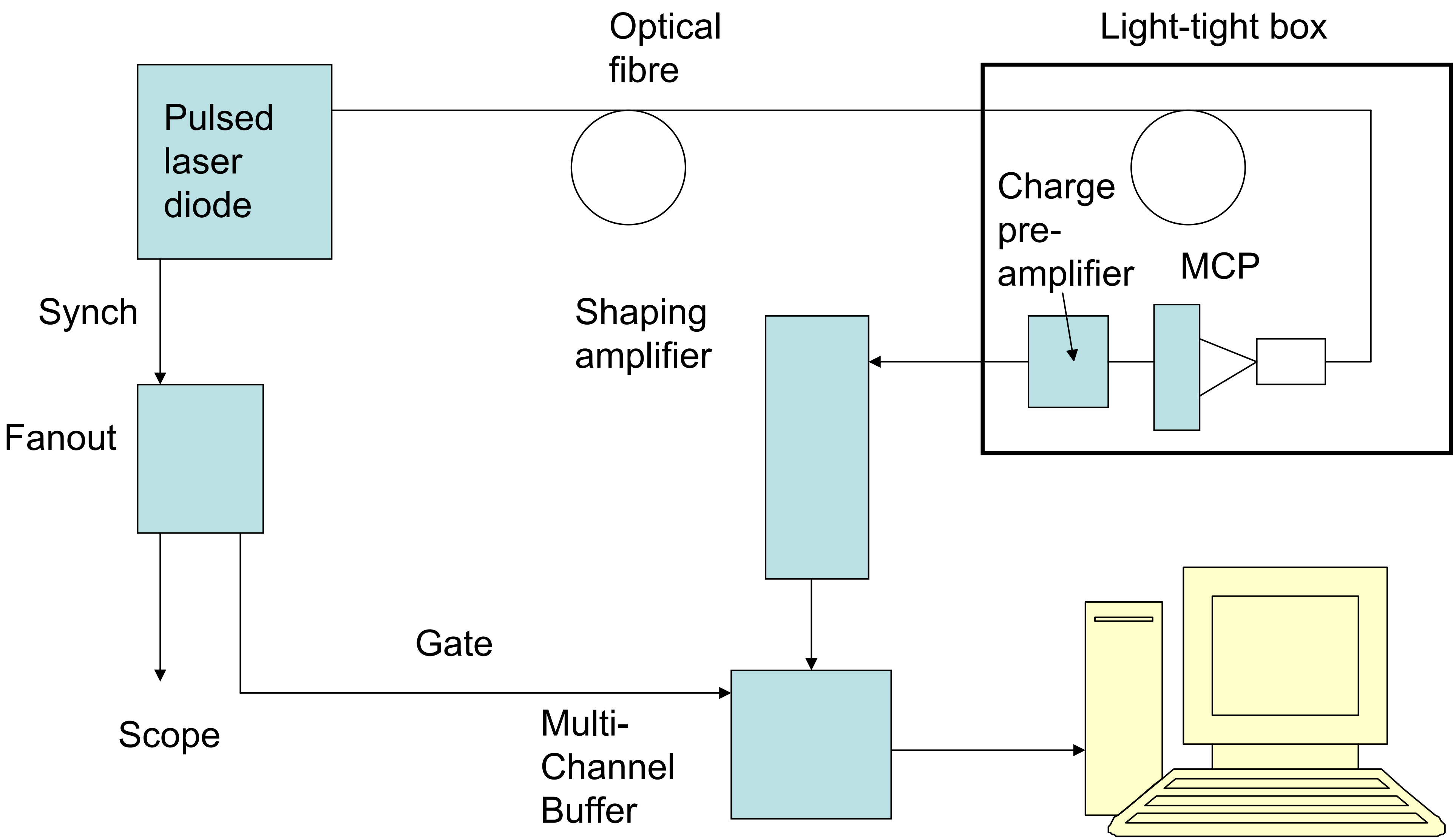
- R&D has been launched on the following aspects:
  - Photodetectors
    - performance of existing MCP devices;
    - emphasis on single photoelectron response, efficiency and time jitter
    - design and development of suitable anode pad structure
    - gain aspects vs lifetime
    - cost
  - Readout electronics
    - speed - 40 MHz rate - clocking - synchronisation between boards/modules
    - gain - noise - cross-talk
  - Quartz radiator
    - polishing: required quality for total internal reflection
    - cost
  - Simulation
    - detailed simulation of TORCH
    - tagging performance in upgrade

- First results included in Letter of Intent for the upgrade submitted to LHCC

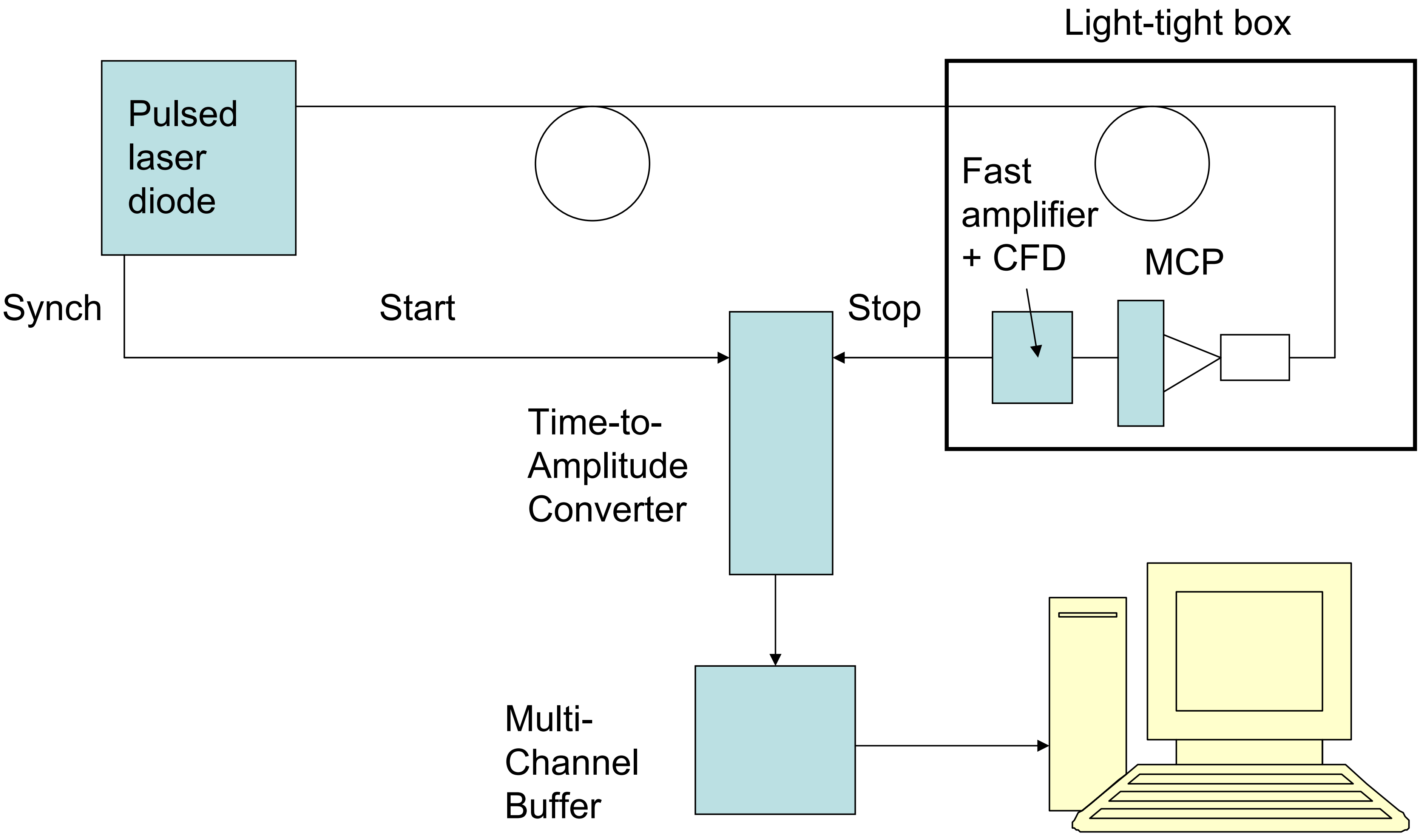
- Laboratory material
  - Multi-channel buffers (MCB)
  - Pulsed (~100ps) red (630nm) laser (Hamamatsu)
  - Pulsed (~20ps) blue (405nm) laser (PiLas)
  - Spectroscopy charge preamplifiers and shaping amplifiers
  - Fast single-channel NIM electronics (ORTEC)
    - Fast amplifier and Constant Fraction Discriminator (CFD)
    - Time-to-Amplitude Converter (TAC)
  - Fast clock generator (Stanford)
  - Standard NIM electronics

- Photodetectors
  - Two 8×8-channel MCPs (Burle Planacons)
  - Two single-channel MCPs (Photonis-NL)
  - Possible loan of other single-channel MCPs (PMT210 from Photek)

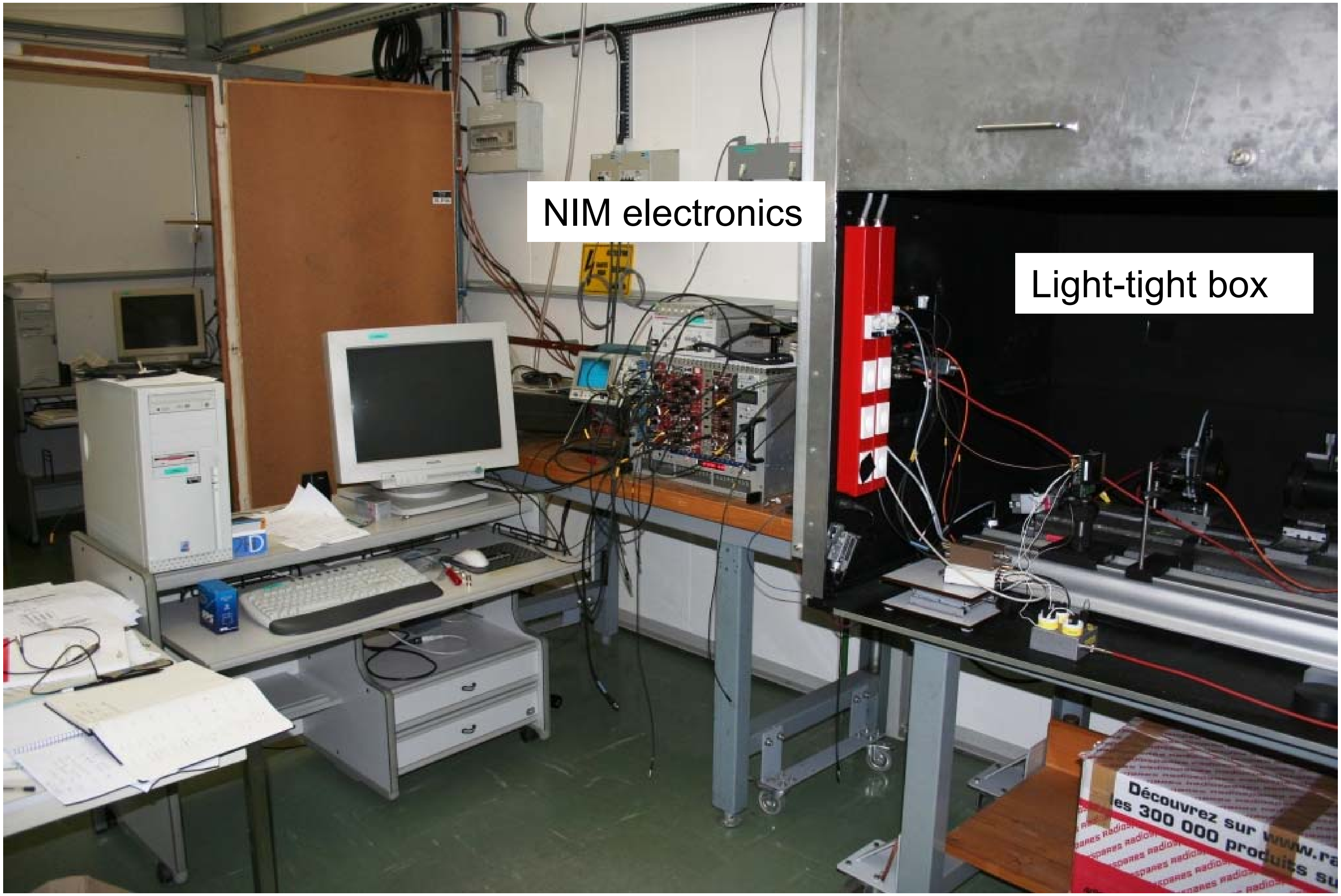
MCP tests – pulse height experimental setup



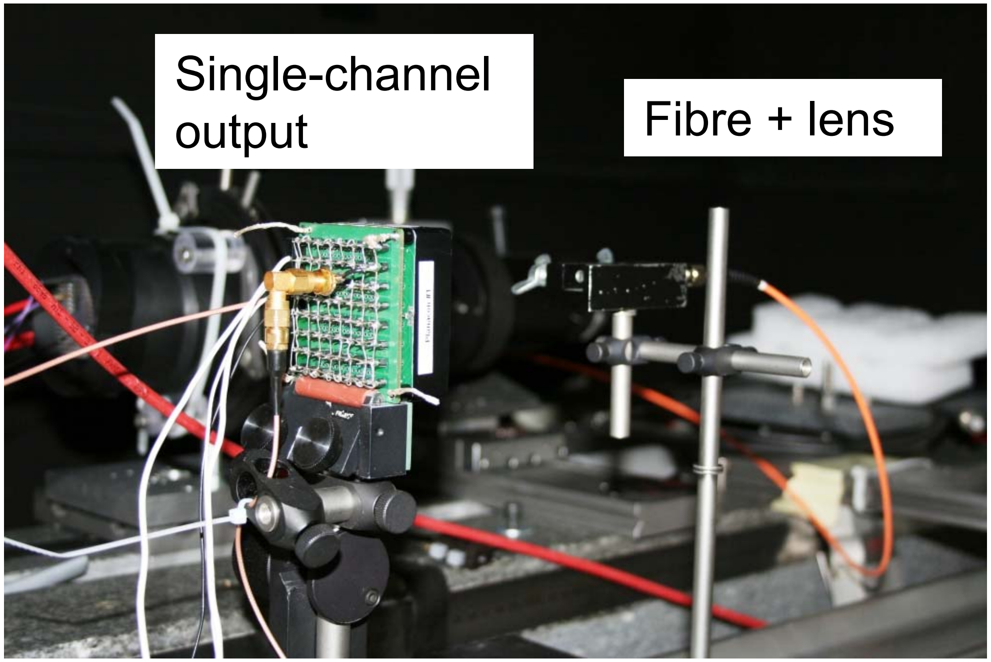
MCP tests – time jitter experimental setup

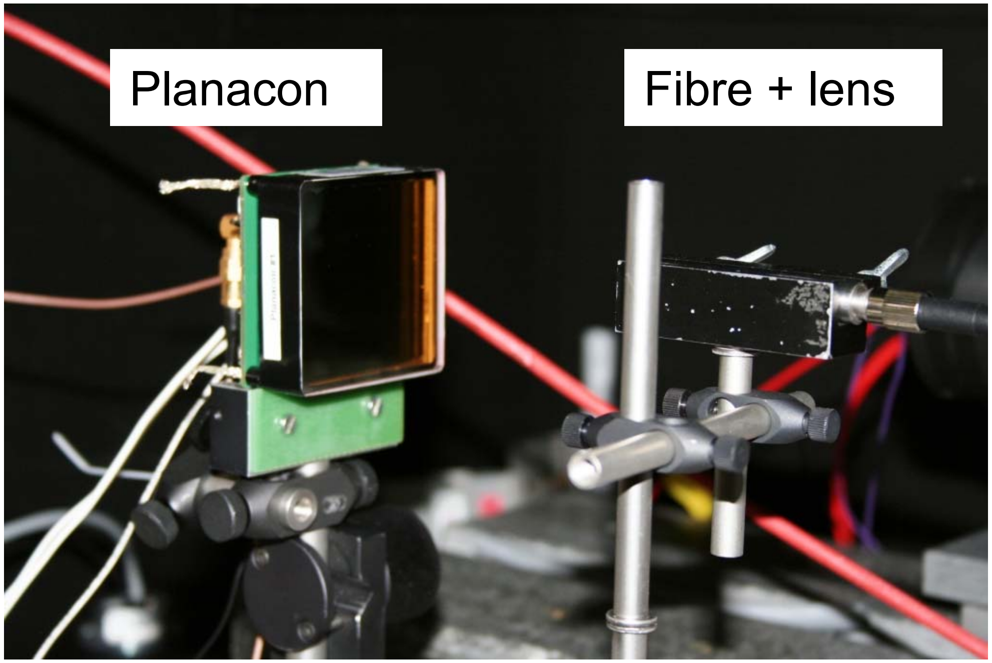


MCP tests – experimental setup photos (1)

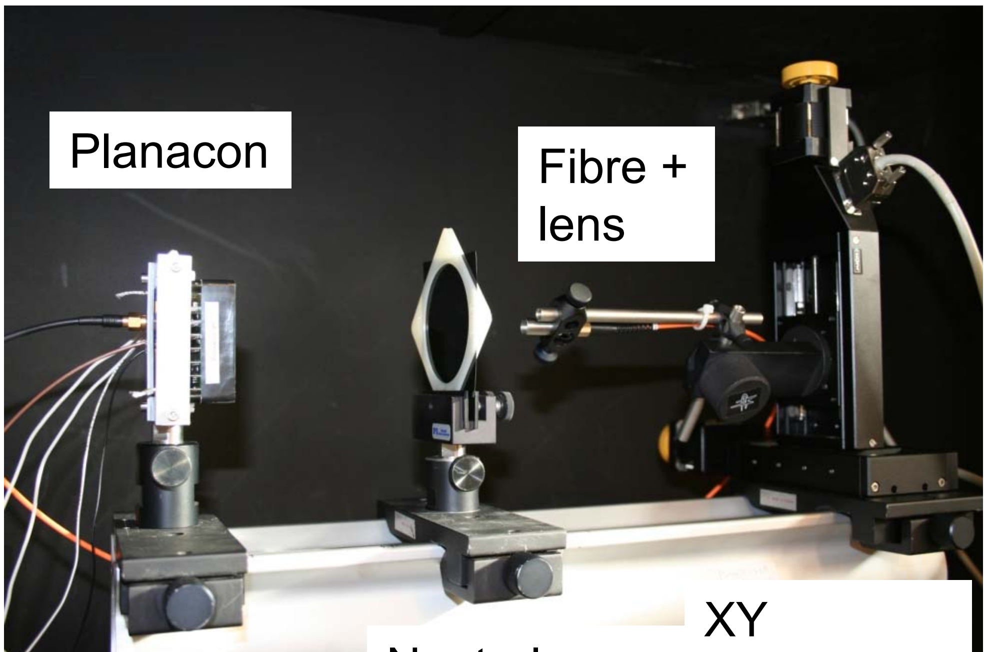


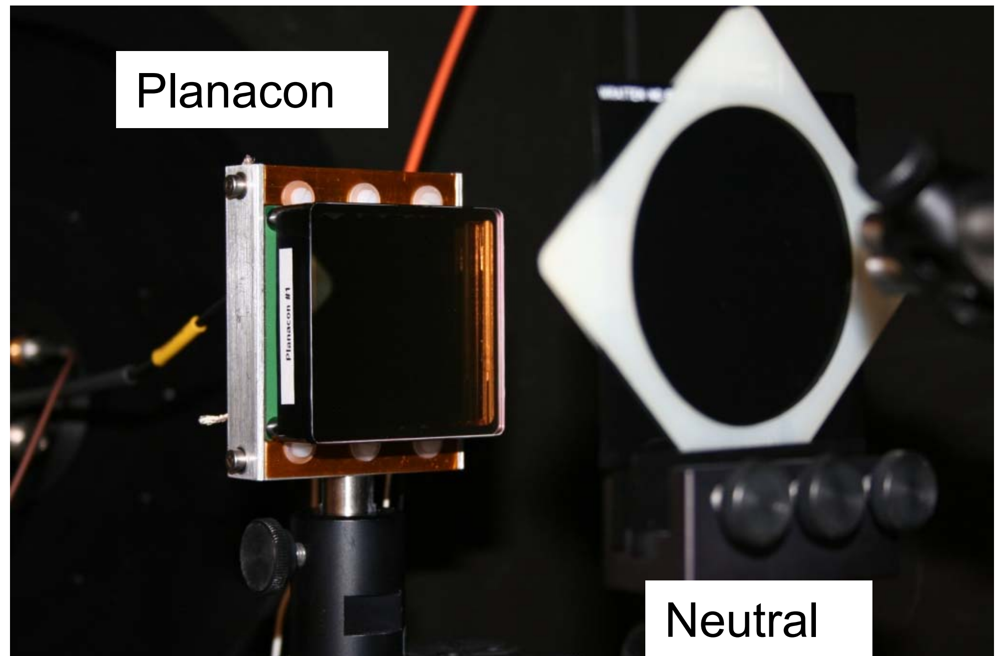
MCP tests – experimental setup photos (2)





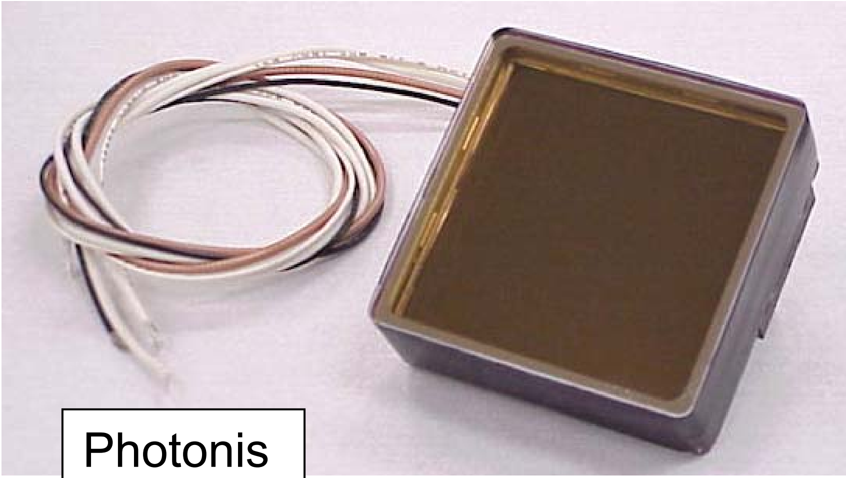
MCP tests – experimental setup photos (3)



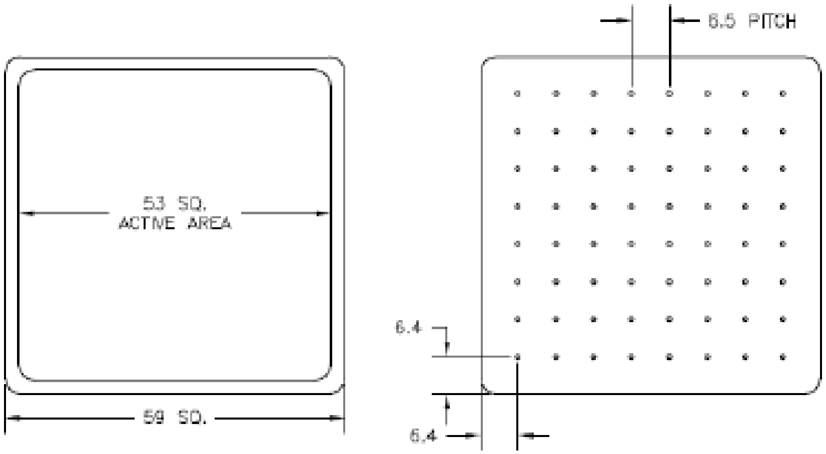


Specifications of 8×8-channel MCPs

- 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
  - status:
    - 2 units delivered and under test at CERN
    - 1 “reject” unit at Oxford



Photonis -Burle



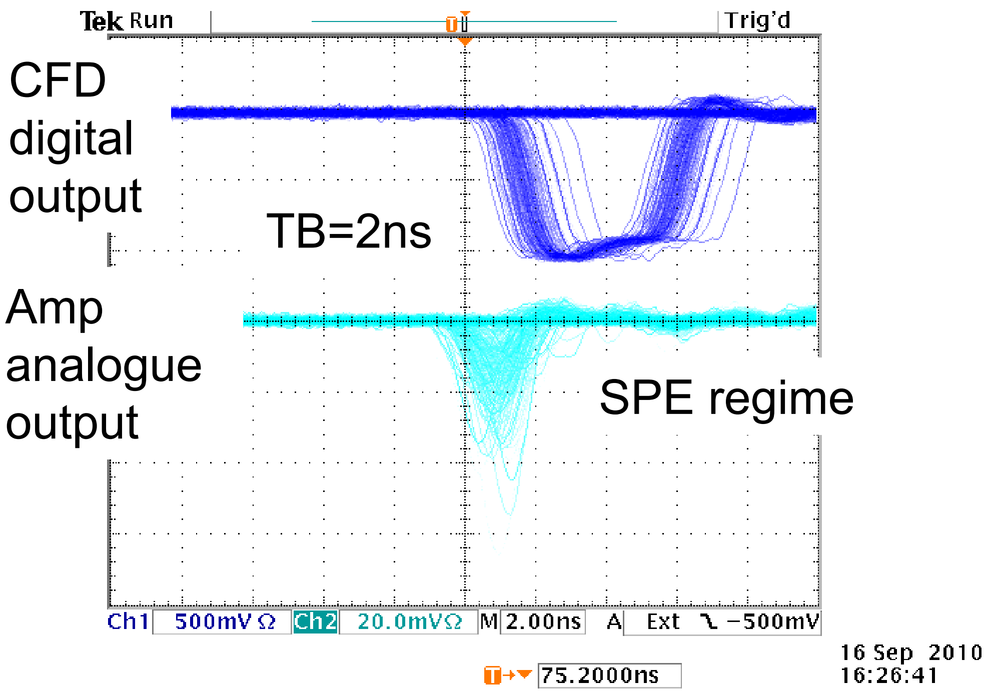
Planacons: time jitter signal shape

- MCP operating point
  - HV 2100V
  - LD intensity “low” – SPE regime

- CFD
  - Amp jitter ~ 20ps
  - Amp slewing ≤ ±40ps

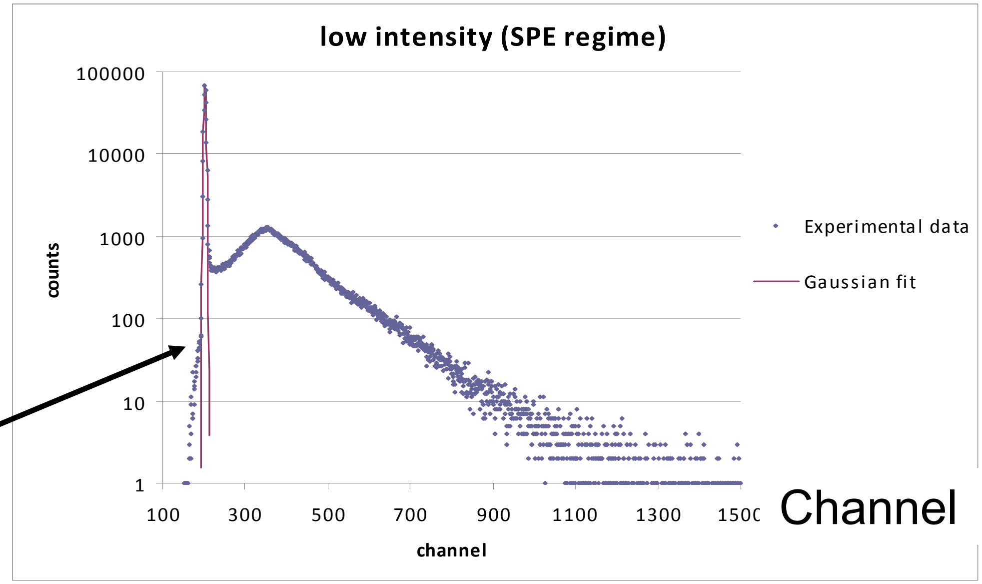
- TAC + MCB
  - TAC range 50ns
  - jitter 0.01% full range + 5ps
  - MCA resolution 25ps/channel

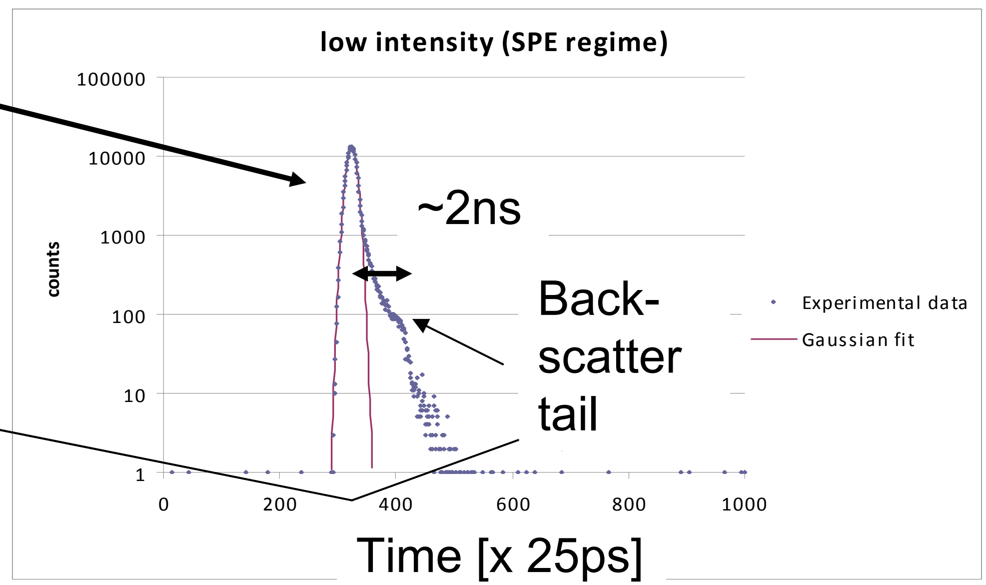
- Other contributions to time jitter
  - LD 100ps/20ps FWHM
  - SYNCH ~ 20ps/2ps
  - Various *standard* NIM electronics modules ...

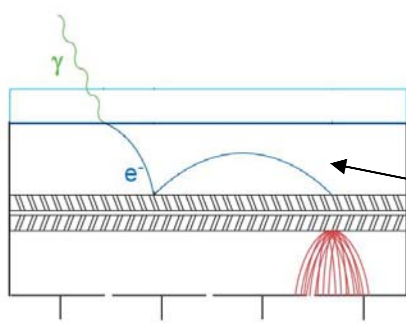


Planacons: pulsed red laser tests

- Operating conditions: HV=-2100V
- MCB:
  - 25ps resolution
  - 2048 channels
- Bleeder chain: 1:10:1 (175V – 1750V – 175V)
- Gain: 4 10^5 e-
- μ ~ 0.48 estimated from P(0)
- σ ~ 205 ps
- Notes:
  - non-optimal setup and operating parameters
  - red laser SYNCH time jitter ~20ps







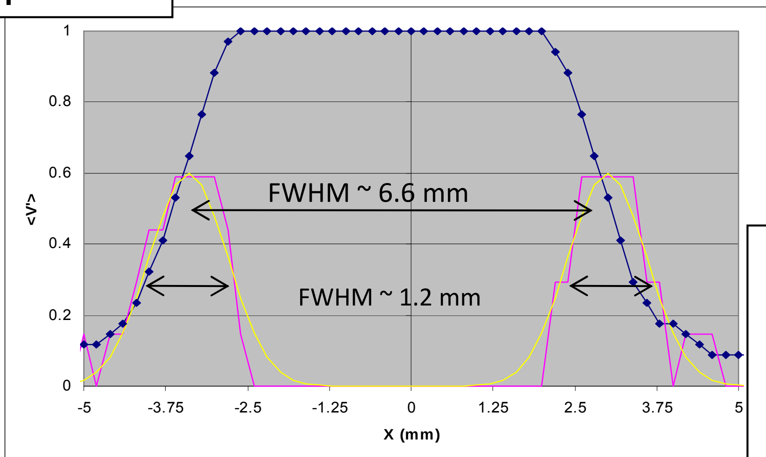
Planacons: spatial scans – charge sharing - Point Spread Function

Pitch = 6.5mm

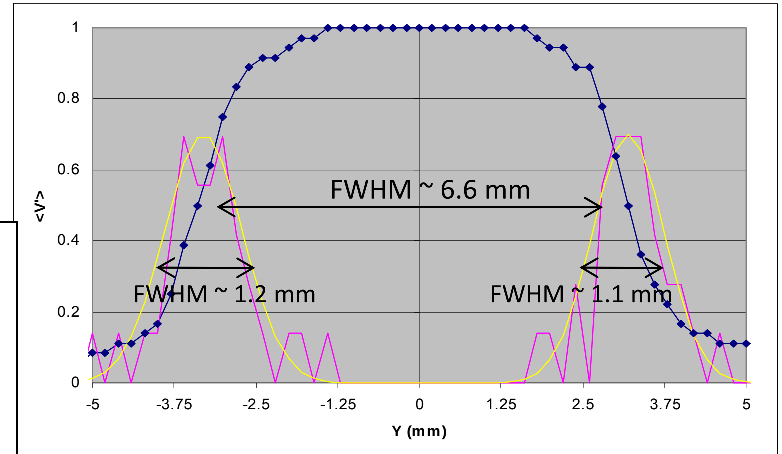
HV=-2450V
Gain ~ 5 10^5 e-

Improved bleeder chain values 2:10:2
(350V – 1750V – 350V)

Scope



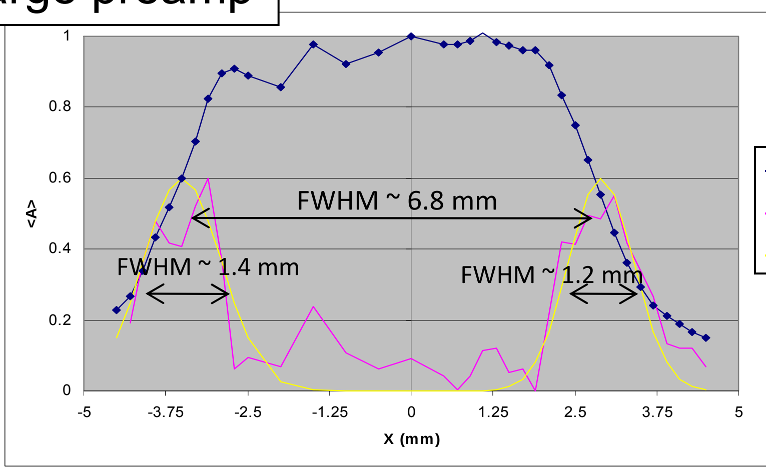
μ ~7.63
ND 2+2



PSF ~1mm

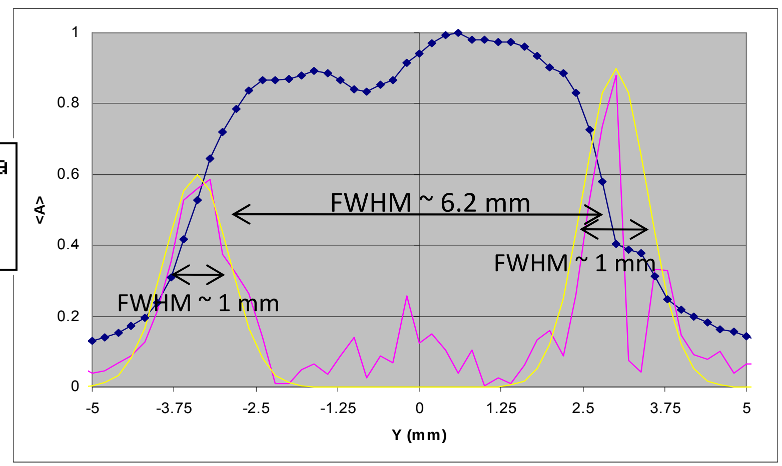
(~ TORCH required granularity)

Charge preamp



Experimental data
PSF
PSF Gaussian fit

μ ~ 0.48
ND 2+2+1



Planacons: pulse height spectrum (blue laser) – fit

- HV=-2450V
- Gain: 5 10^5 e-
- μ~0.51
- Fit according to Poisson distribution

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

- Pedestal P(0)

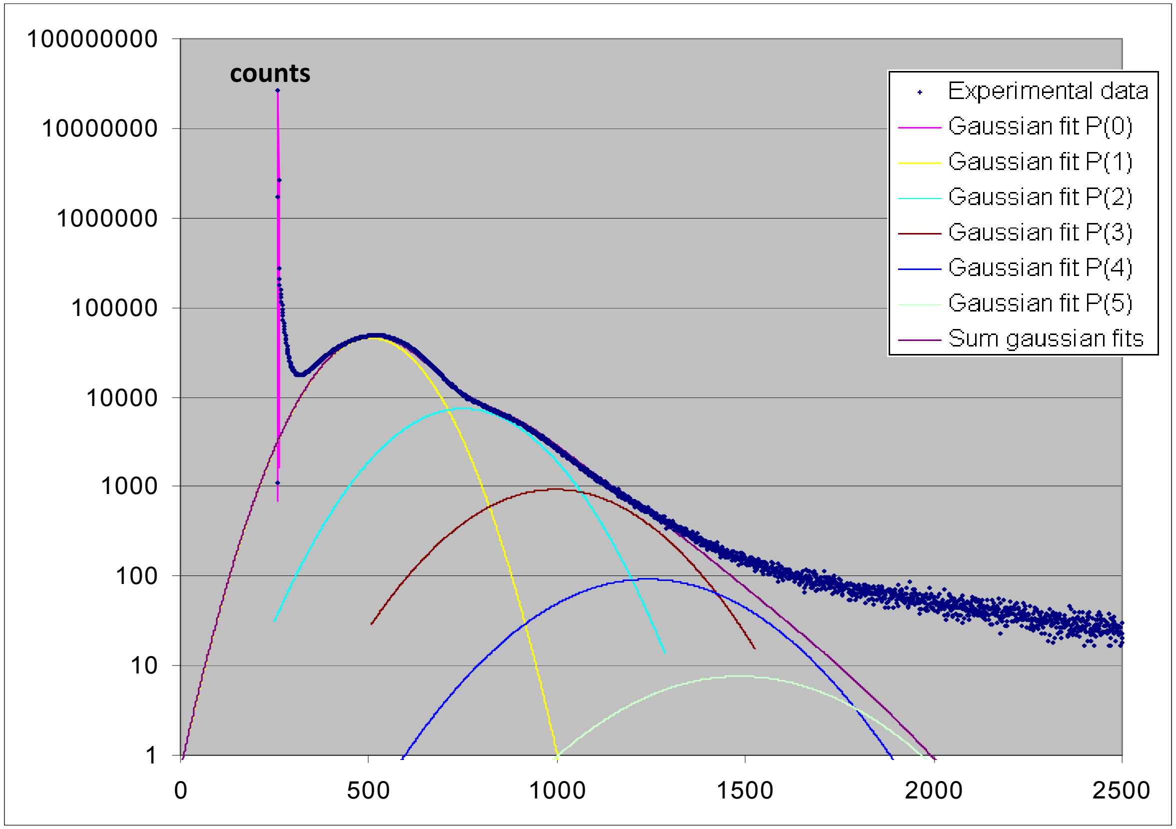
$$P_\mu(0) = e^{-\mu} = \frac{A_0\sigma_0\sqrt{2\pi}}{total\ \ surface}$$

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

- Photoelectron peaks P(N)

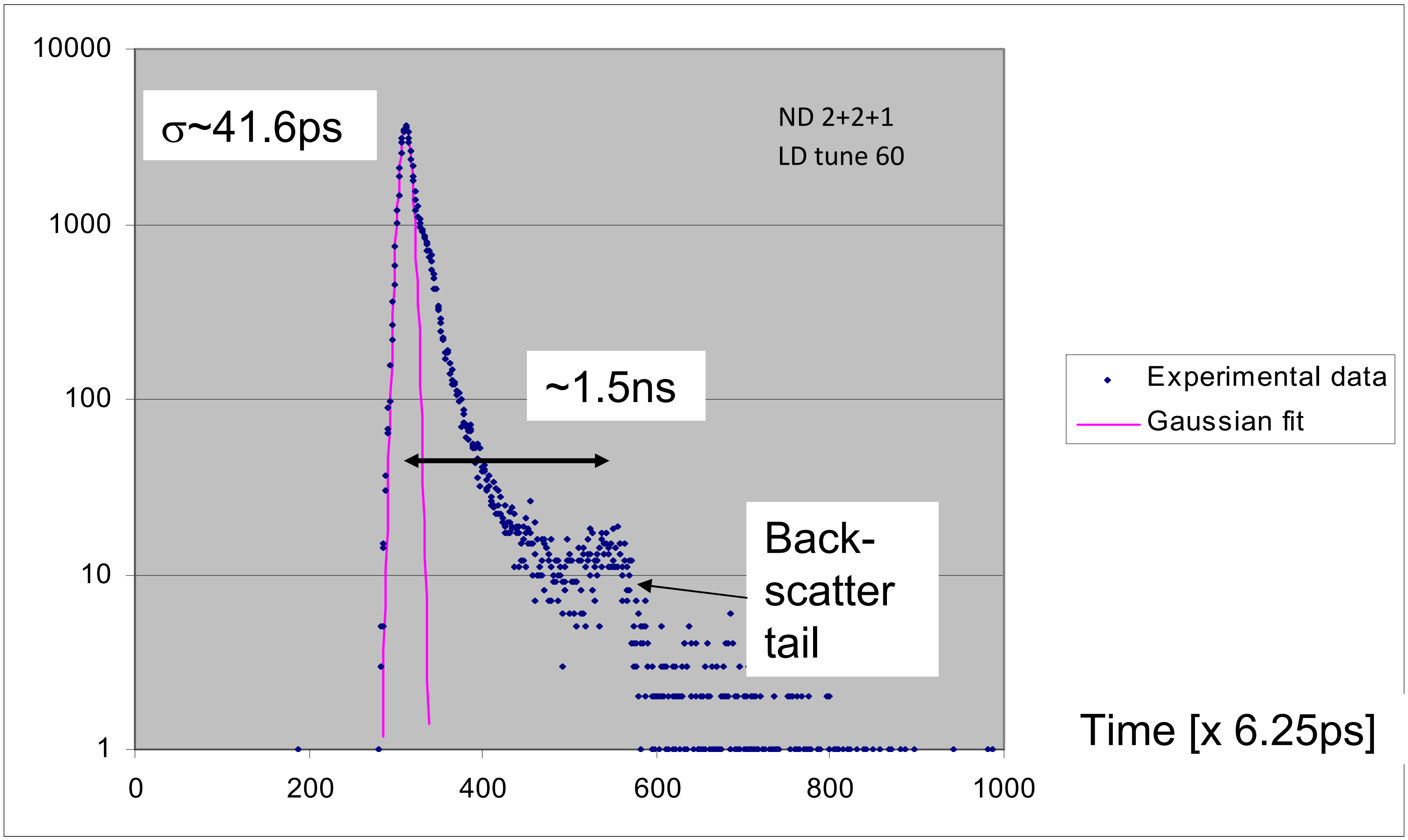
$$P_\mu(N) = \frac{\mu^N}{N!}e^{-\mu} = \frac{A_N\sigma_N\sqrt{2\pi}}{total\ \ surface}$$

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

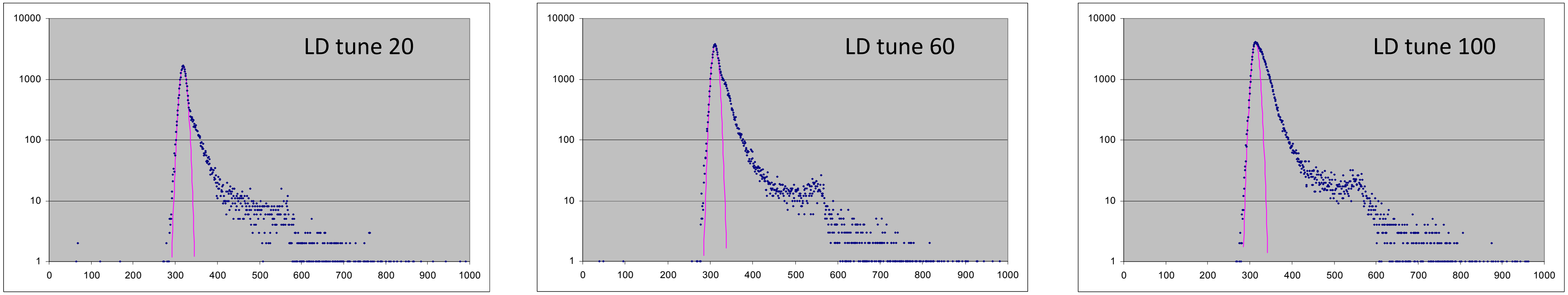


Planacons: time jitter distribution (blue laser)

- Varying LD tune setting and ND fixed
- Fitting leading edge of peak (see next slide)

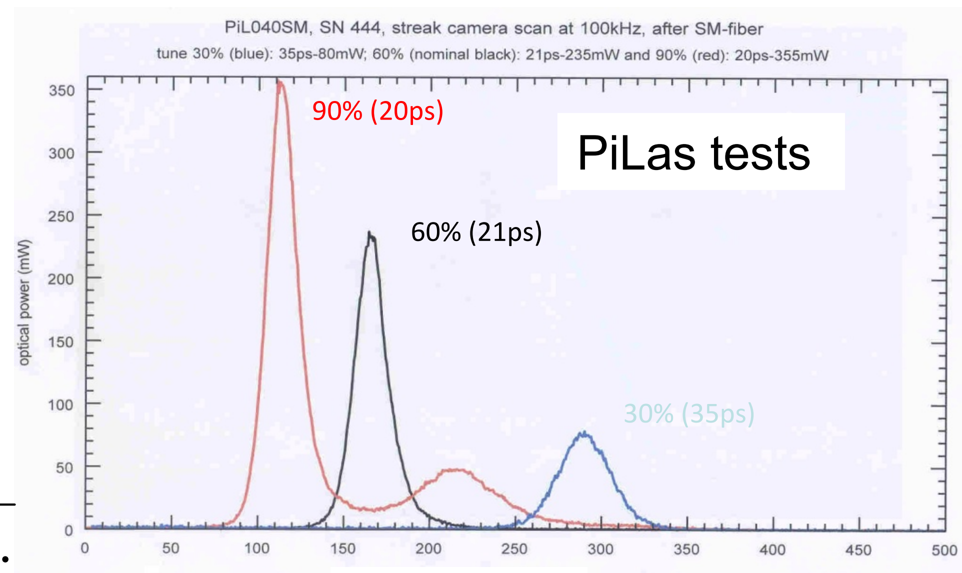


Planacons: time jitter distribution (blue laser) – σ vs laser tune setting



Time [x 6.25ps]

- Contributions to time jitter:
  - MCP (photon energy, backscattering, intrinsic MCP jitter)
  - Laser pulse width (tune setting)
  - Synchronization pulse
  - Residual TDC time walk
  - Channel resolution
  - (signal amplitudes)
  - …

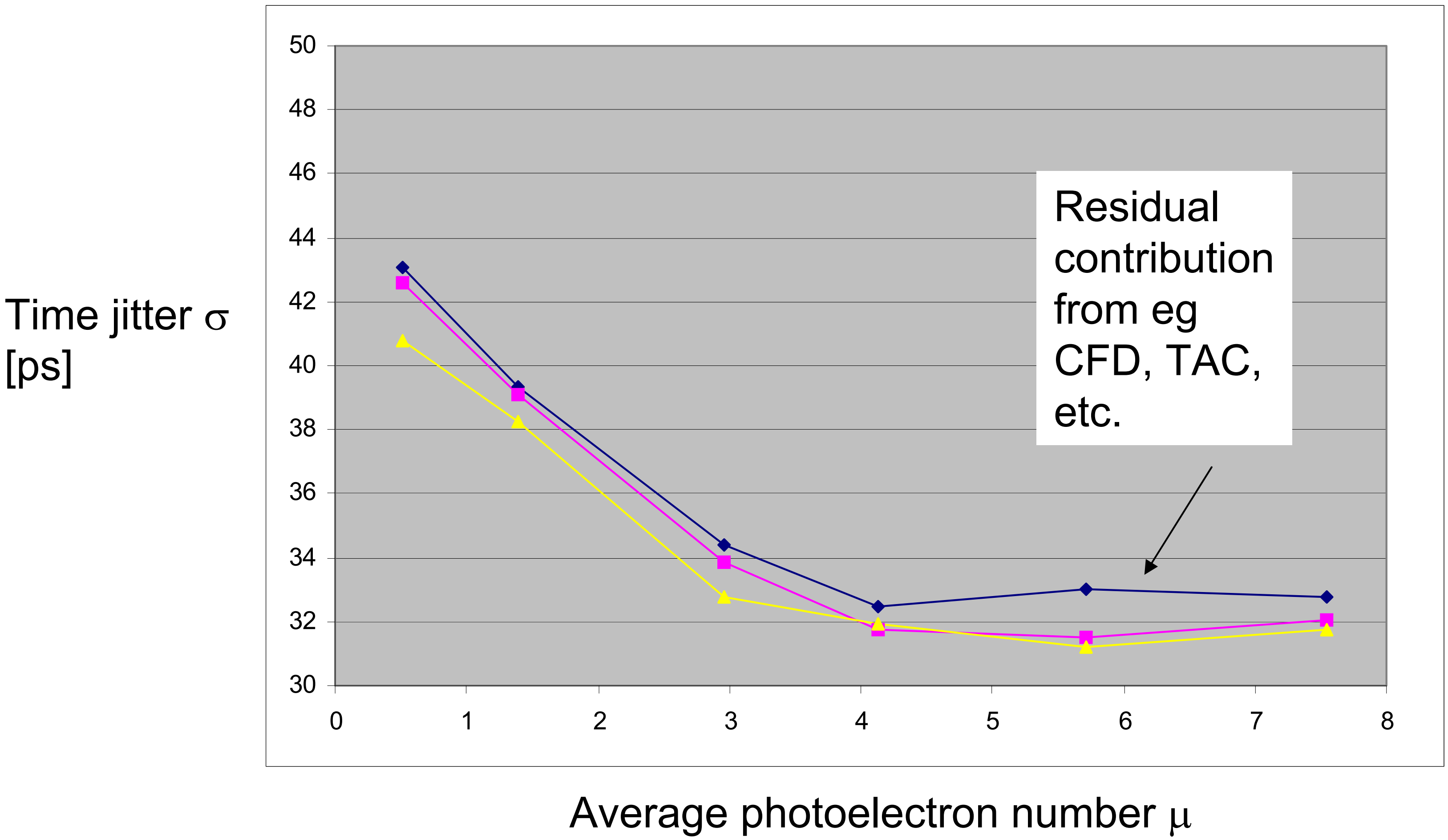


Time [ps]

$$\sigma = \sqrt{\sigma_{MCP}^{2} + \sigma_{pulse}^{2} + \sigma_{synch}^{2} + \sigma_{CFD}^{2} + \sigma_{TAC}^{2} + \ldots}$$

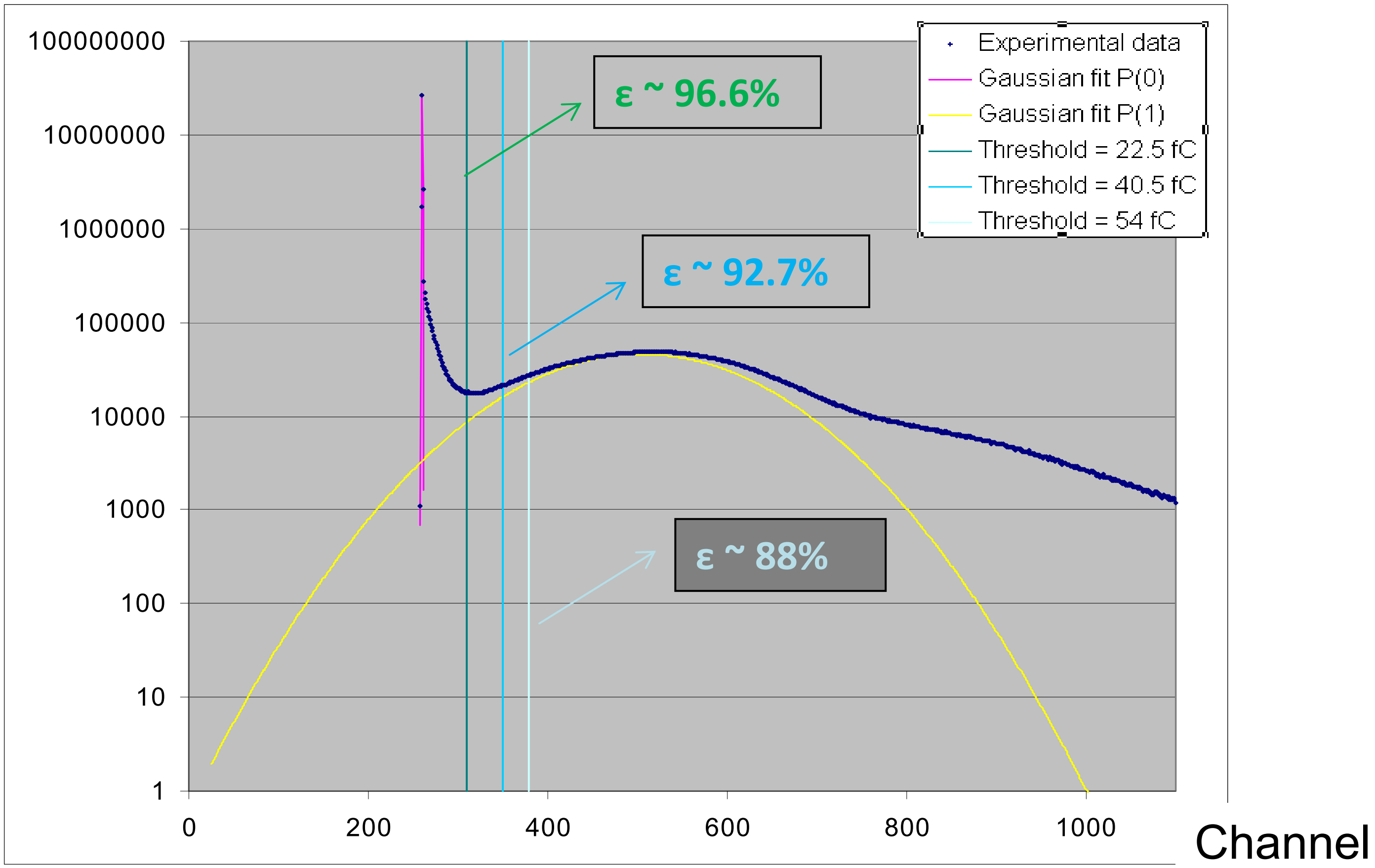
Planacons: time jitter distribution (blue laser) – σ vs μ

- Expected behaviour with:
  - optimal LD tune setting (60%)
  - varying ND filters



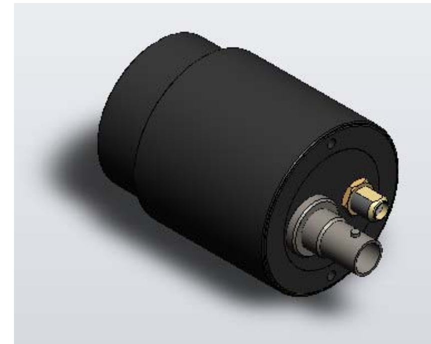
Planacons: pulse height spectrum (blue laser) – single PE efficiency

- Q for one photoelectron ~ 6.9 10^5 e-
- Convert CFD threshold in charge
- Consider only 1^{st} photoelectron peak



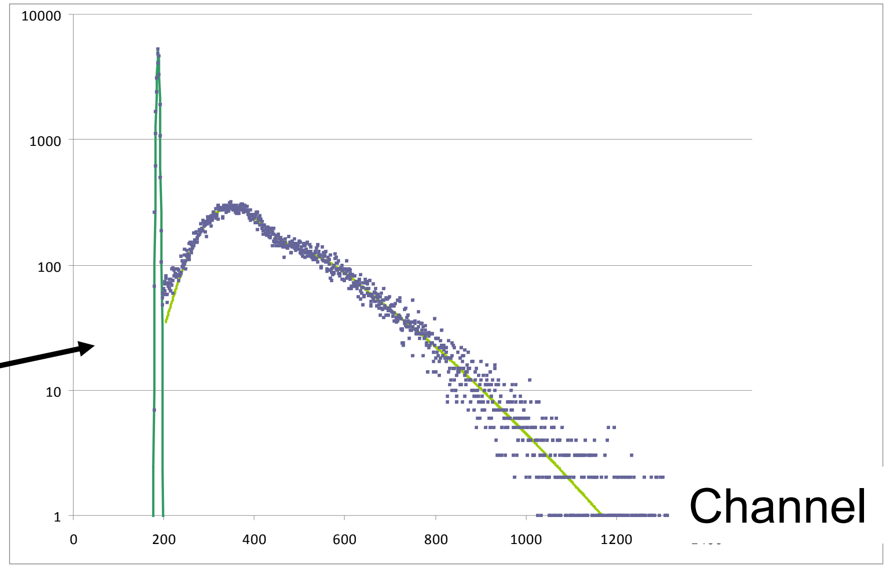
Specifications of single-channel circular MCPs - reference tubes

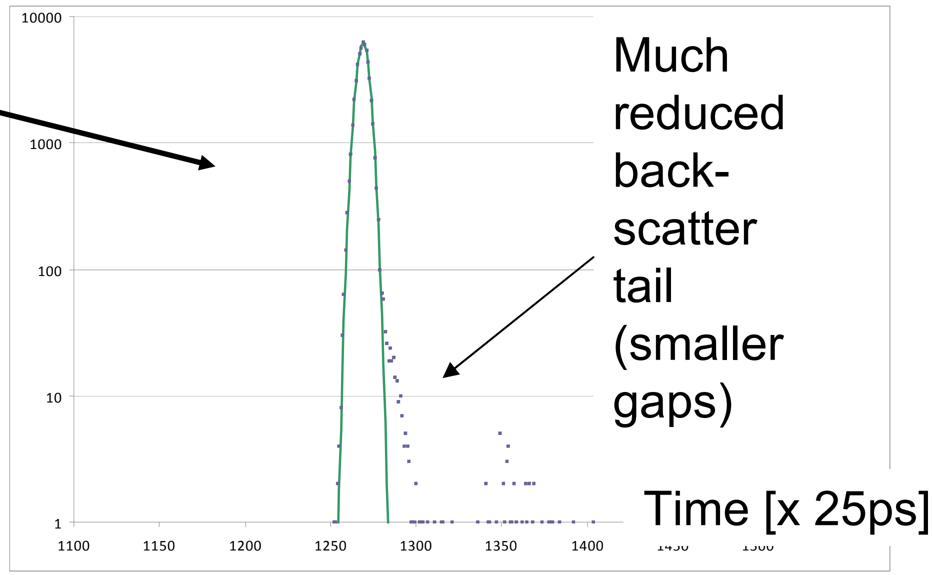
- PP0365G "preliminary"
  - MCP-PMT tube
  - single channel (SMA connector)
  - 6um pore diameter, chevron type (2), ~55% open-area ratio
  - low MCP gain typ. <10^5
  - Small gaps:
    - PC-MCPin: 120μm
    - MCPout-anode:1mm
  - S20 photocathode on quartz
  - 18mm active ∅
  - 6pF anode capacitance
  - rise/fall time 200ps "target"
  - bleeder chain 1-10-2
  - status:
    - 2 units delivered and under tests at CERN

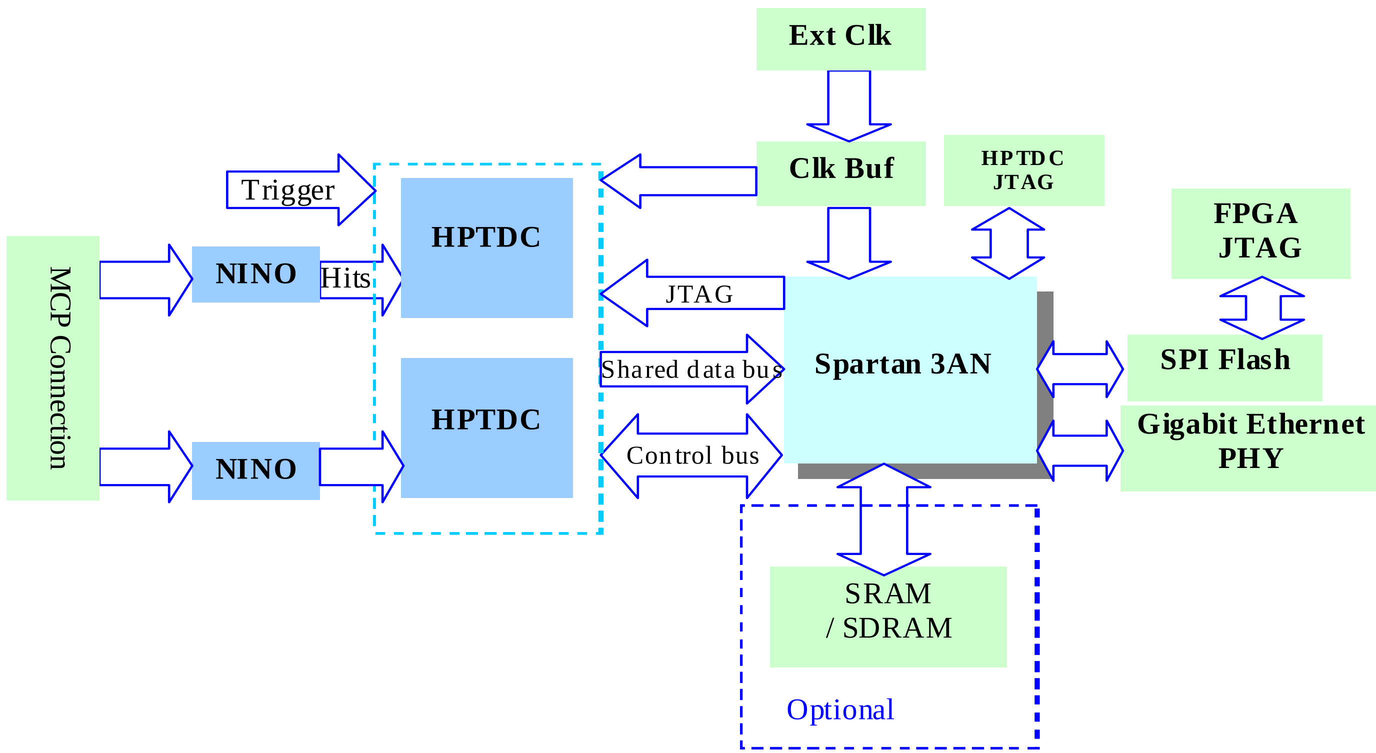
Photonis -NL

- Operating conditions: HV=-2340V
- MCB:
  - 25ps resolution
  - 2048 channels
- Bleeder chain: 1:10:2
  (180V – 1800V – 360V)
- Gain: 1.3 10^5
- μ ~ 1.2 estimated from P(0) and full fit
- σ ~ 87 ps
- Notes:
  - red laser pulse FWHM ~100ps
  - red laser SYNCH time jitter ~20ps

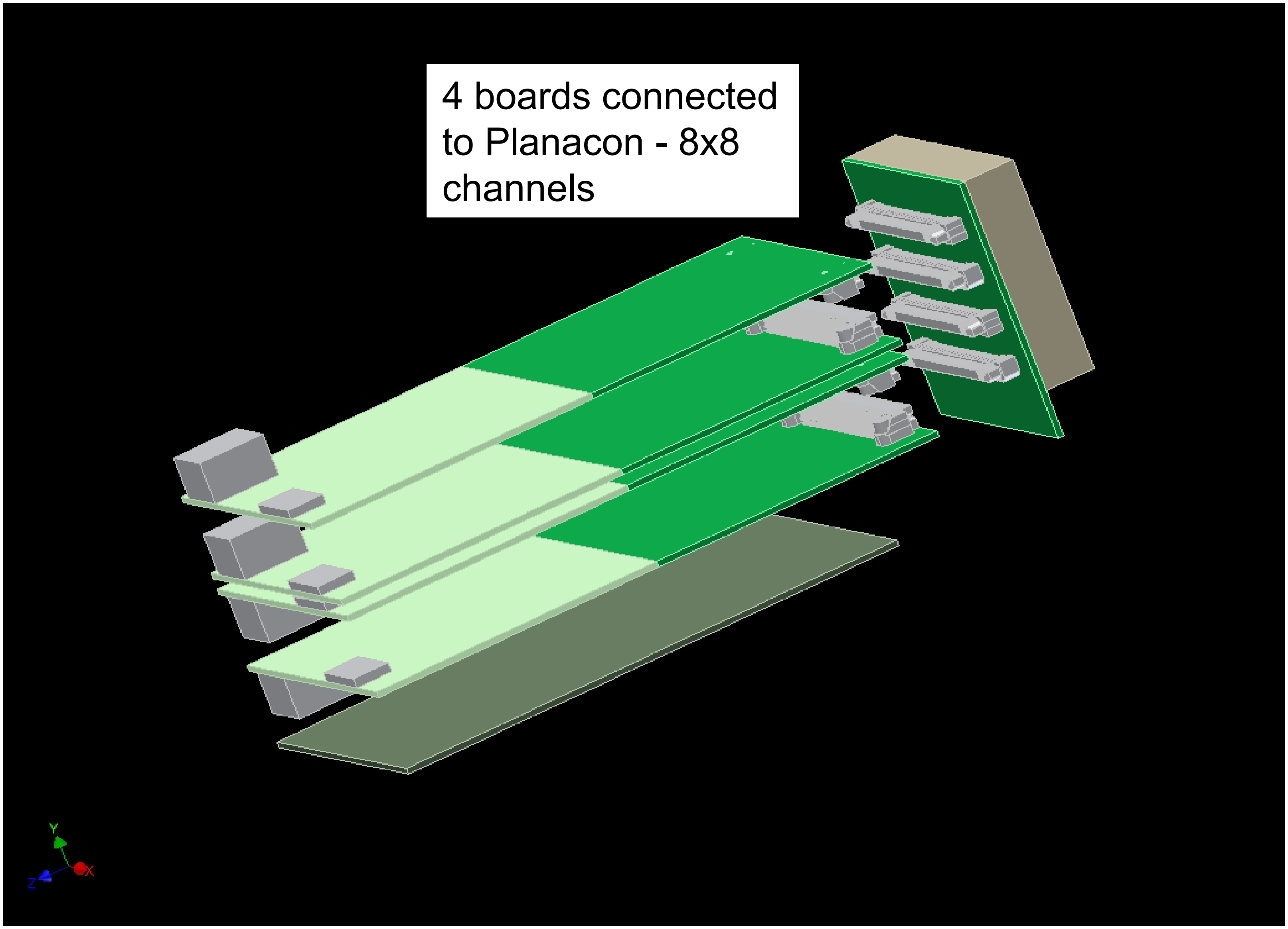




- Under development
- Starting with 8-channel NINO chips and HPTDC (high resolution mode), developed for the ALICE TOF
- Test-beam studies foreseen for this year



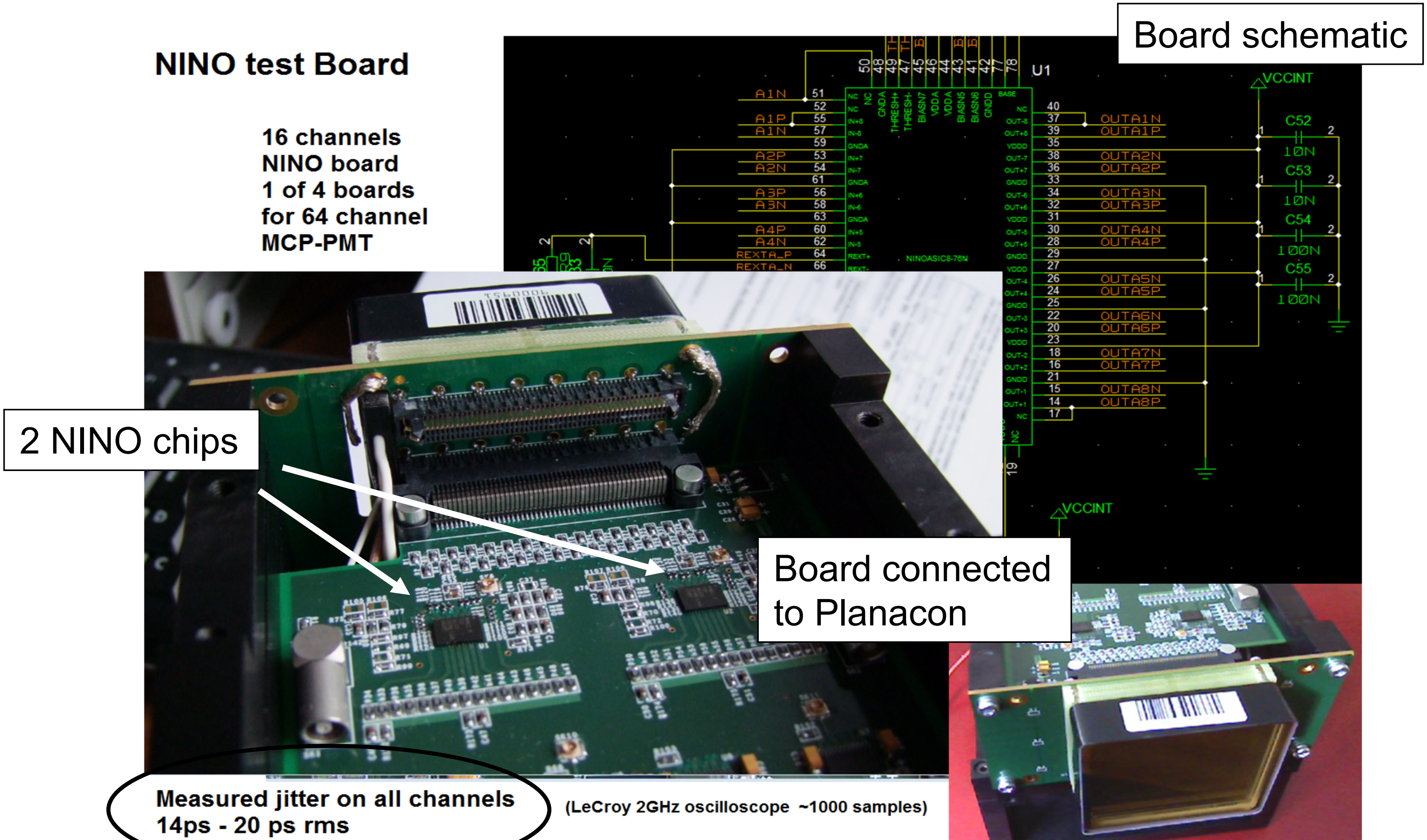
Readout electronics - general assembly drawing



NINO Board status and tests

NINO test Board

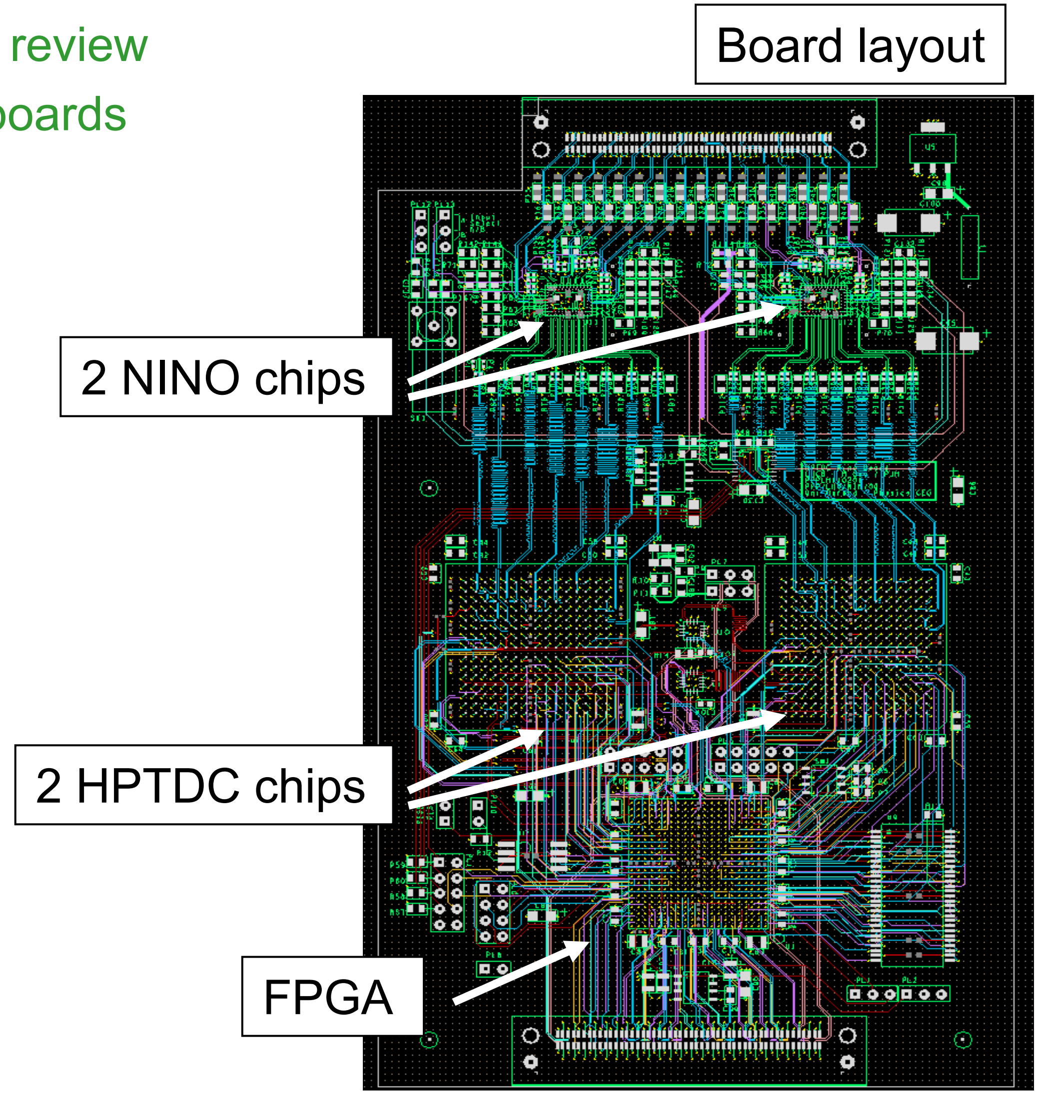
16 channels NINO board
1 of 4 boards for 64 channel MCP-PMT



Measured jitter on all channels 14ps - 20 ps rms

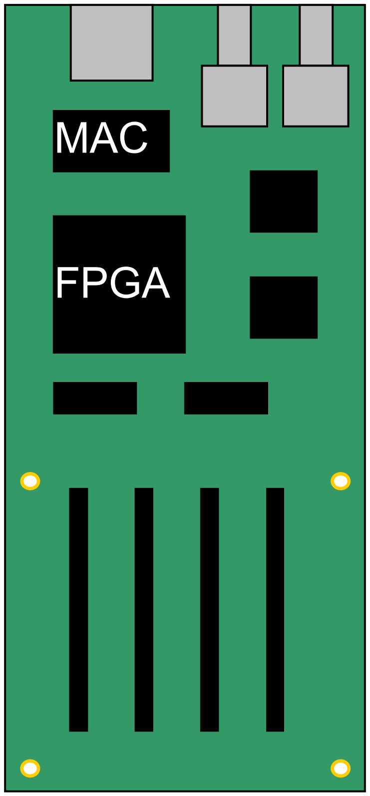
(LeCroy 2GHz oscilloscope ~1000 samples)

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



Interface / clock board

- Readout 4 HPTDC-NINO Boards
- FPGA for data formating, ethernet MAC driving the PHY chip
- Clock and trigger fanout
- Schematic stage



Readout electronics: overall status

- NINO Board under testing
- NINO-HPTDC Board layout finished
- Ethernet readout interface: schematics design
- Light-tight box assembled

Top: feed-through panel

B. left: front panel

B. right: light-tight box body with translation stage

Conclusions and perspectives

- TORCH is a novel detector concept proposed for the upgrade of LHCb It is intended to complement the high-momentum particle ID provided by the RICH system - aimed at providing excellent K-π separation up to 10 GeV
- R&D is in progress, starting with the photodetector and readout electronics
  - MCP operating parameters & calibration under control
  - timing resolution O(40 ps) achieved with single-channel electronics with estimated ε of O(90%) for single photoelectrons - fine-tuning of electronics settings on-going
  - First readout electronics boards under electrical tests - tests with real Planacon imminent - other boards at various developments stages
- Prototyping of quartz plates and focussing optics to follow
- Aim at testing basic performance in test beam this year
- Impact of the TORCH on tagging performance in the upgraded experiment is under study with detailed simulation
- Letter of Intent for the LHCb upgrade has been submitted

SPARE SLIDES

CFD timing properties

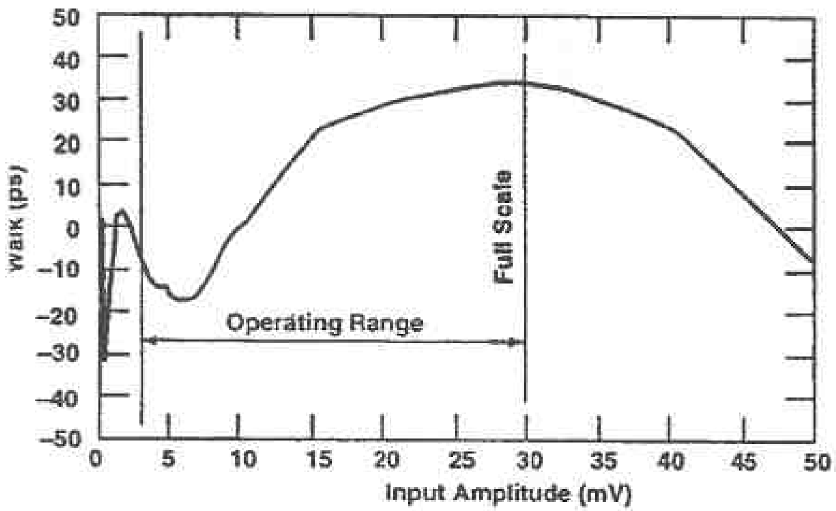


Fig. 1.3. Typical Walk vs. Pulse Amplitude.
Full scale is denoted by the Over Range LED turning on. Measured with a pulse width of 300 ps FWHM.

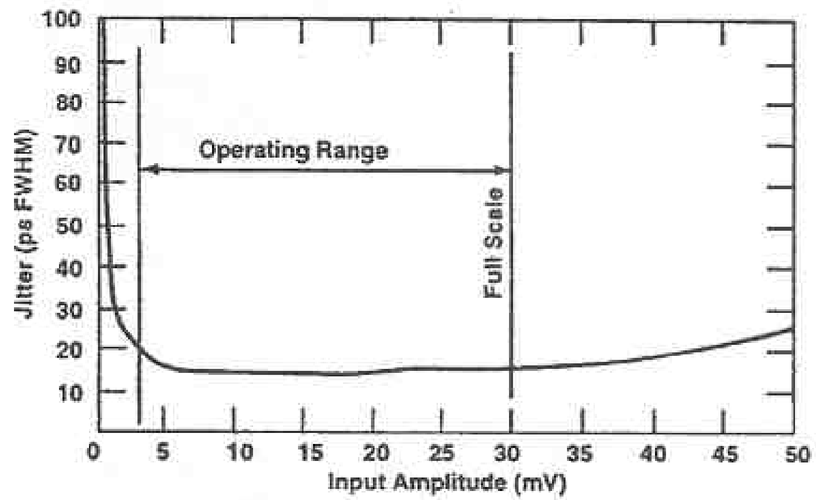
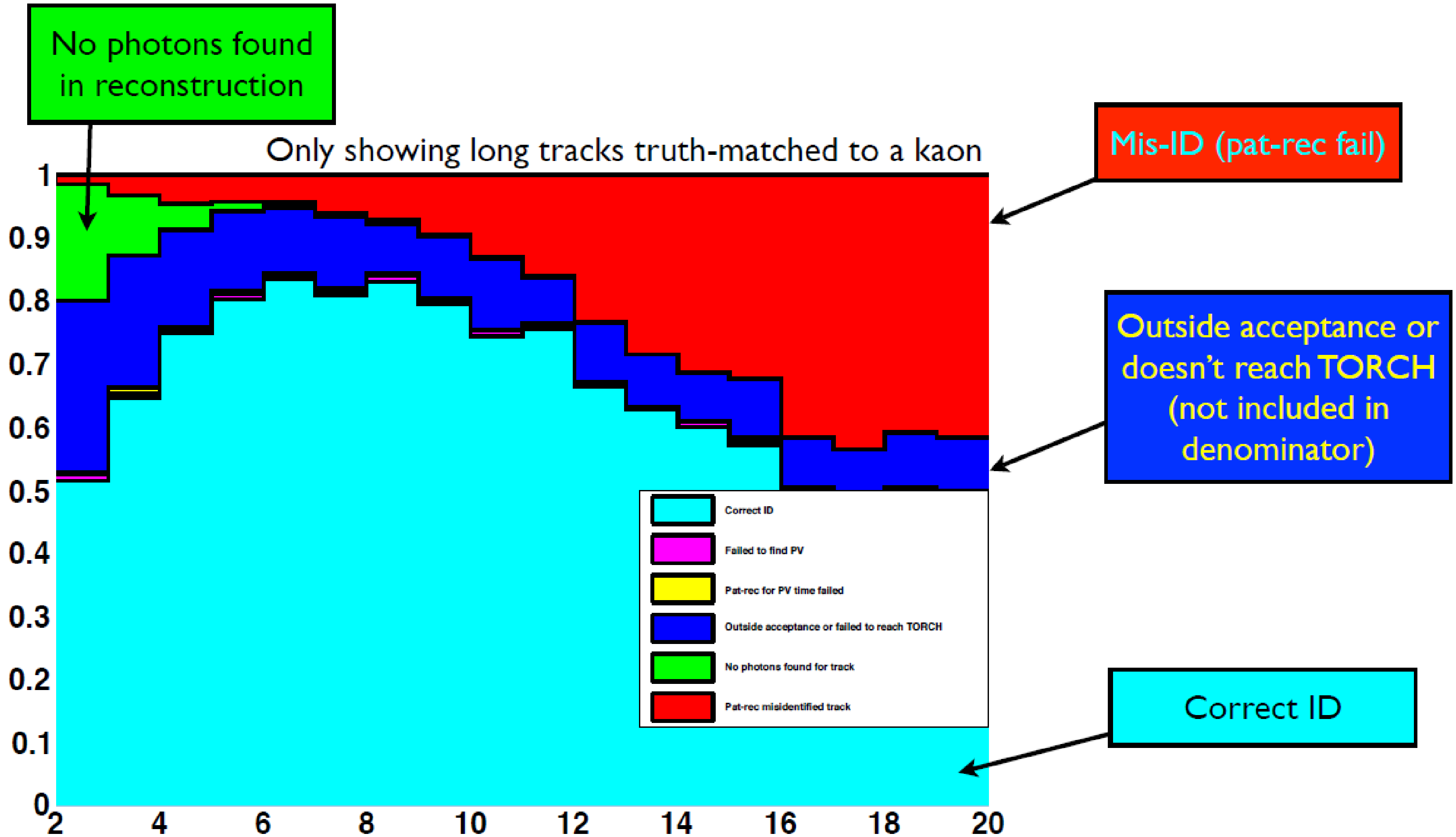


Fig. 1.4. Timing Jitter vs. Pulse Amplitude.
Measured with the system in Fig. 1 by replacing the detectors with a pulser having a pulse width of 300 ps FWHM. Full scale is denoted by the Over Range LED turning on.

Where tracks are lost



Showing for kaons in MUL 1.0 at Lumi20

- Get the software into SVN
- Known missing things that could be implemented in the current framework
  - switch to updated/modular design
  - Add tail to time resolution to mimic photoelectron backscattering
- Known missing things that need full GEANT simulation:
  - Multiple scattering (smears track angle; not negligible)
  - Non-toy track timing/propagation through B-field