Performance assessment of MCP tubes for the LHCb Upgrade

DT Detectors Physics Meeting

14th June 2011

CERN

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Outline

- Introduction
  - LHCb upgrade. TORCH detector
- Laboratory material
- Picosecond laser tests:
  - Experimental setup
  - Pulse height spectrum – Photoelectrons contribution fit
  - Pulse height spectrum – SPE efficiency estimation
  - Spatial aspects – Intensity scans. Point Spread Function
  - Scans at pixel boundaries – SPE efficiency (segmentation)
  - Time jitter distribution – Distribution fit
  - Time jitter distribution – σ vs μ behavior
  - CFD time walk properties
- Conclusions and plans

Who am I?

- My cities:
  - Barcelona
  - Granada
  - Lausanne
  - Geneva

Sagrada Familia, Barcelona

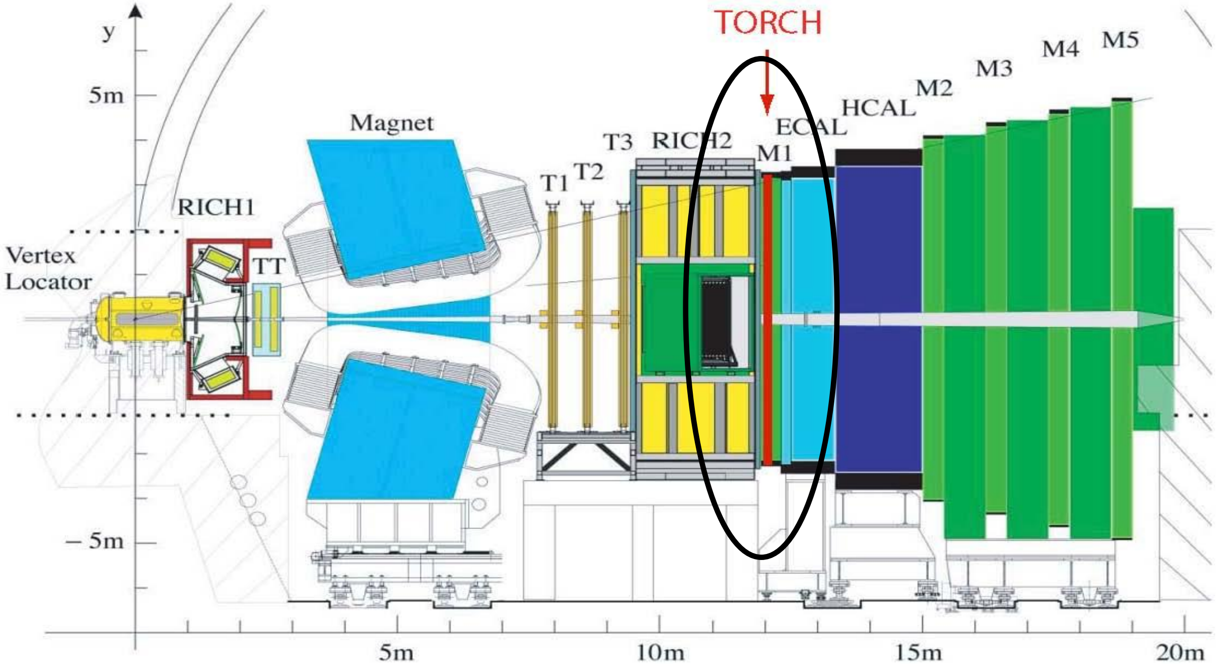
Alhambra, Granada

- Studies:
  - Physics Degree: Universidad de Barcelona, Universidad de Granada.
  - Erasmus: École Polytechnique Fédérale de Lausanne (1 year)
  - Technical student: CERN (8 months)

- Next destination…

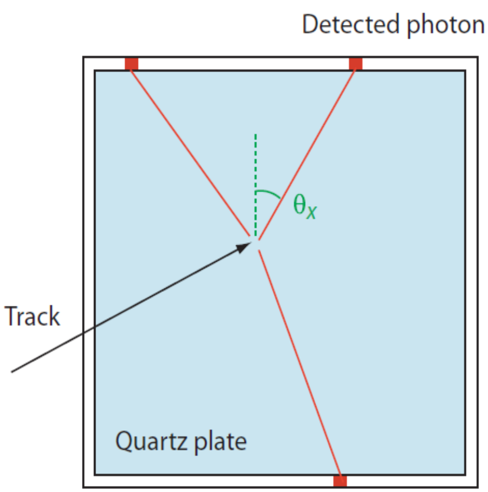
Introduction – LHCb upgrade. TORCH detector

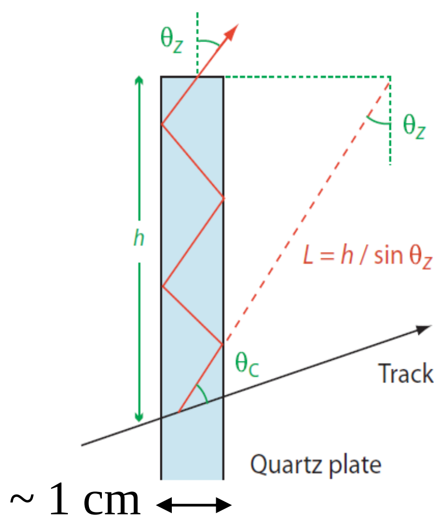
- **TORCH** (Time Of internally Reflected CHerenkov light) particle identification system at low momentum (<10 GeV/c)
- LHCb upgrade framework
- Transverse dimension of plane to be instrumented is ~ 5 × 6 m^2 → **replace Aerogel** at z = 12 m

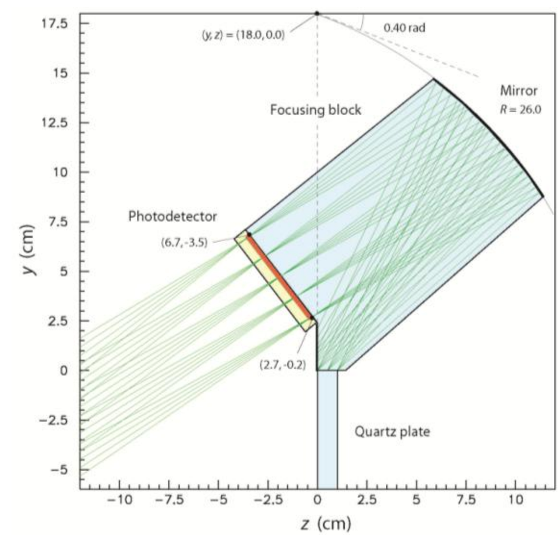


Introduction – LHCb upgrade. TORCH detector

- Cherenkov photons detection from 1 cm-thick quartz plane
- Photons propagate by **total internal reflection** to the edge of the plane and are focused onto an array of micro-channel plate photon detectors, where their arrival would be timed
- Need to measure *angles* of photons, so their **path length can be reconstructed**
- 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

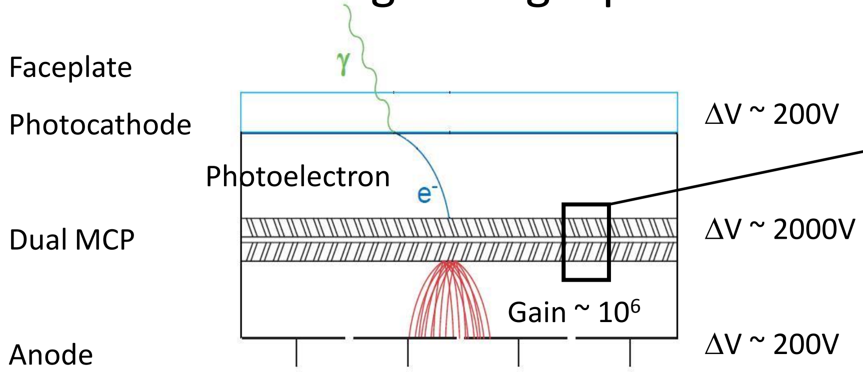


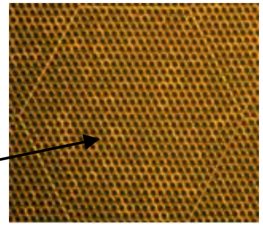


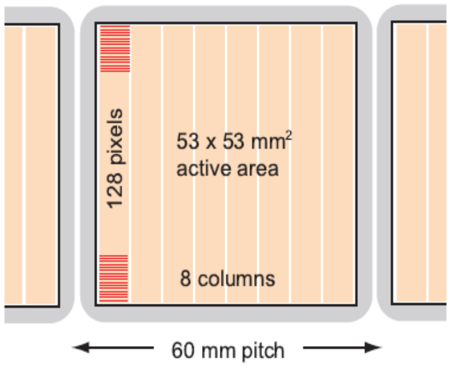


Introduction – LHCb upgrade. TORCH detector

- Requires:
  - Development of photon detectors with **very fine anode segmentation** (8x128 pixels)
  - **Time spread better than 50 ps for single photons**
  - **~ 1 mrad precision** required on the angles in both transverse planes
  - **coarse segmentation** (~ 1cm) is sufficient for the transverse direction (θx)
- 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 $\oplus$ 50 ~ 70 ps**, as required
- Micro-channel plate (MCP) photodetectors are currently the best choice for fast timing of single photons

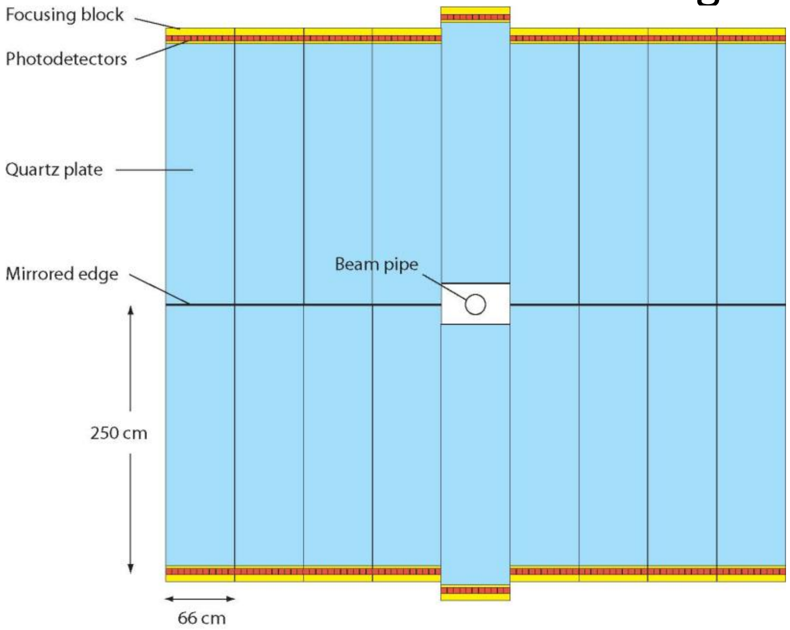


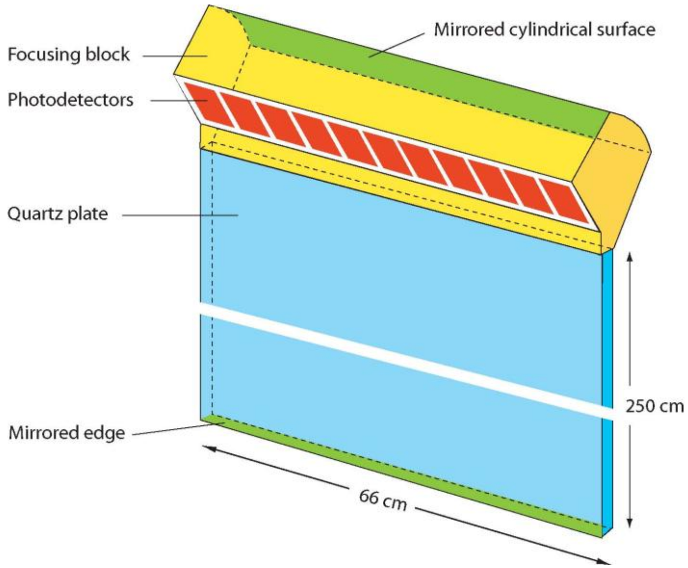




Introduction – LHCb upgrade. TORCH detector

- 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

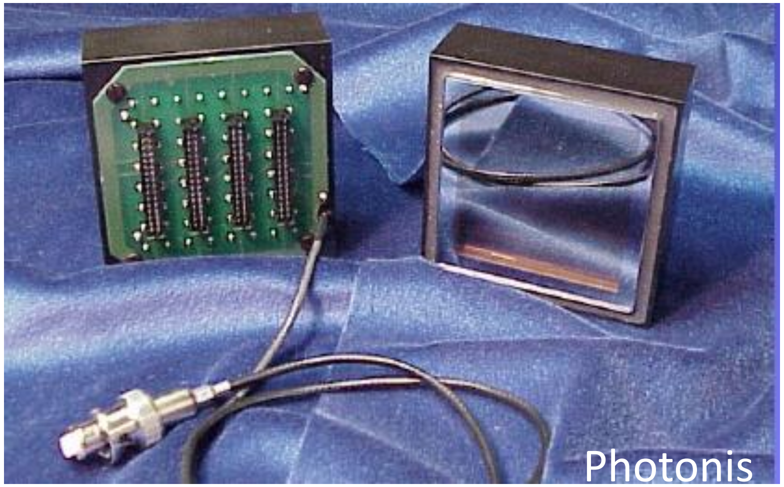
Reflective lower edge

→ **photon detectors only needed on upper edge**

18 × 11 = 198 units

Each with 1024 pads → 200k channels total

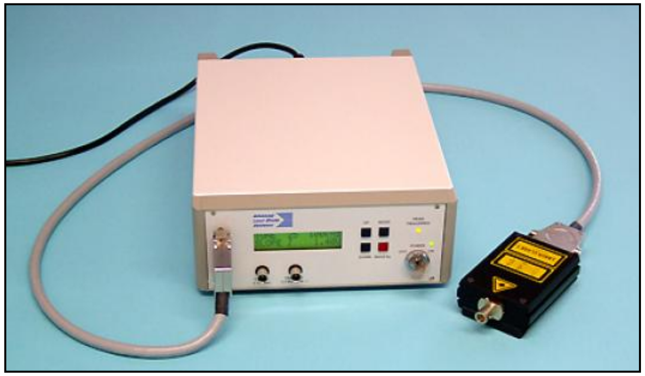
Laboratory material



- Photon detectors:
  - Two 8x8 channels MCP-PMTs (Burle)

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

Laboratory material

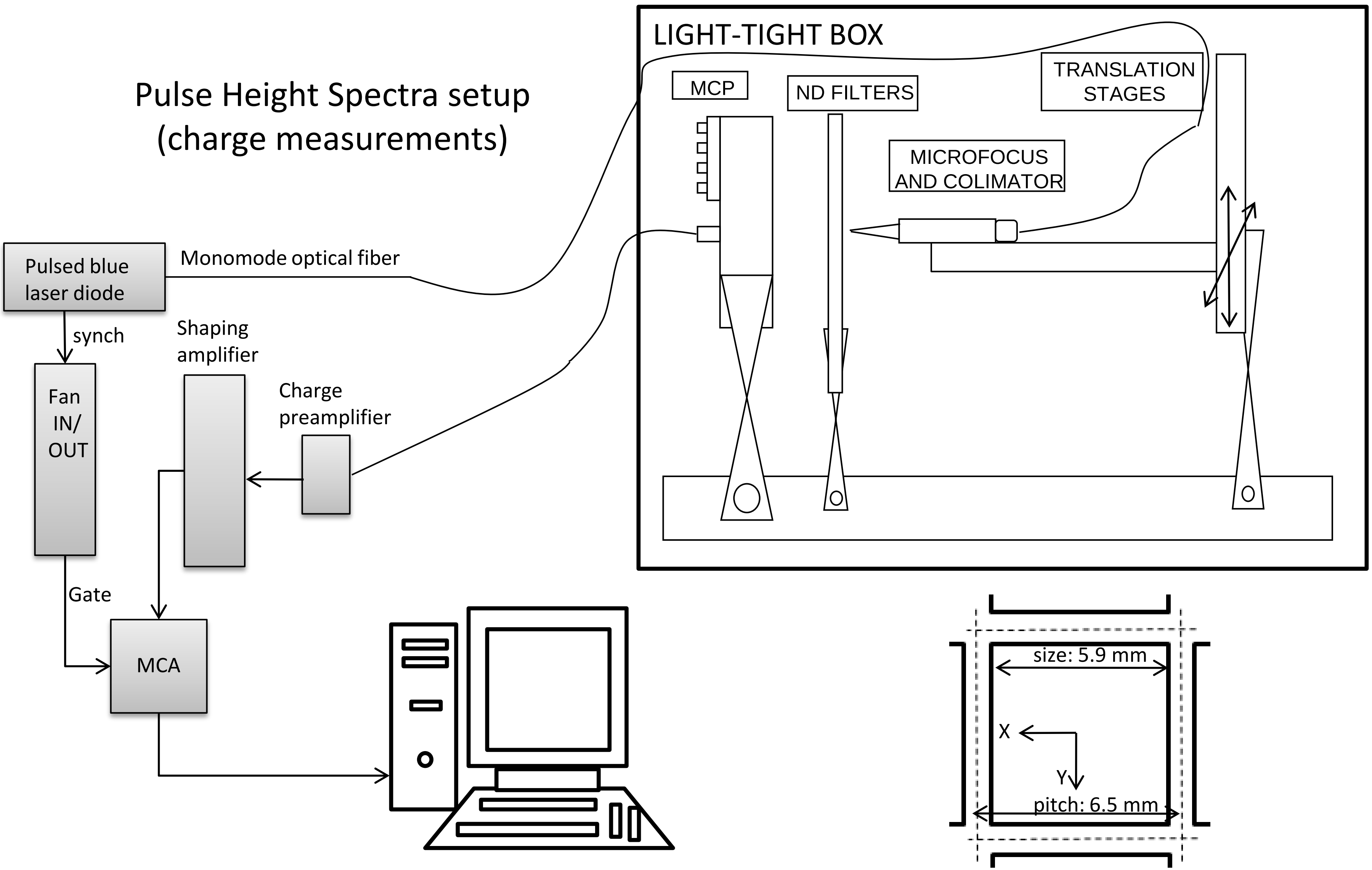


- Pulsed (~20ps) blue (405nm) laser (PiLas)

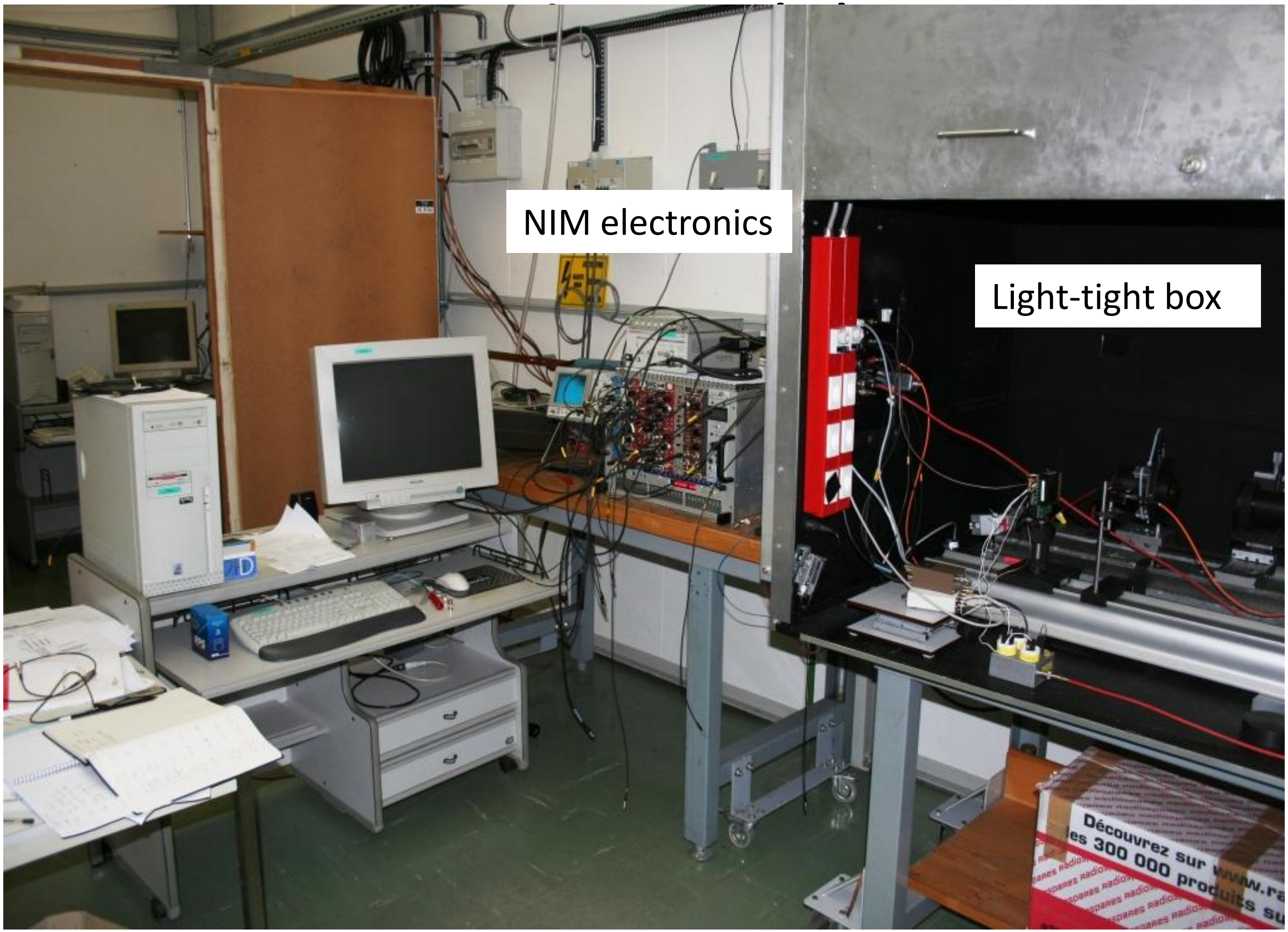
- Readout electronics:
  - Multi-channel analyzers (MCA)
  - Spectroscopy charge preamplifier and shaping amplifiers
  - Standard NIM electronics
  - Fast single-channel NIM electronics (ORTEC)
    - Fast timing amplifier with Constant Fraction Discriminator (CFD)
    - Time-to-Amplitude Converter (TAC)

Blue laser tests – Experimental setup

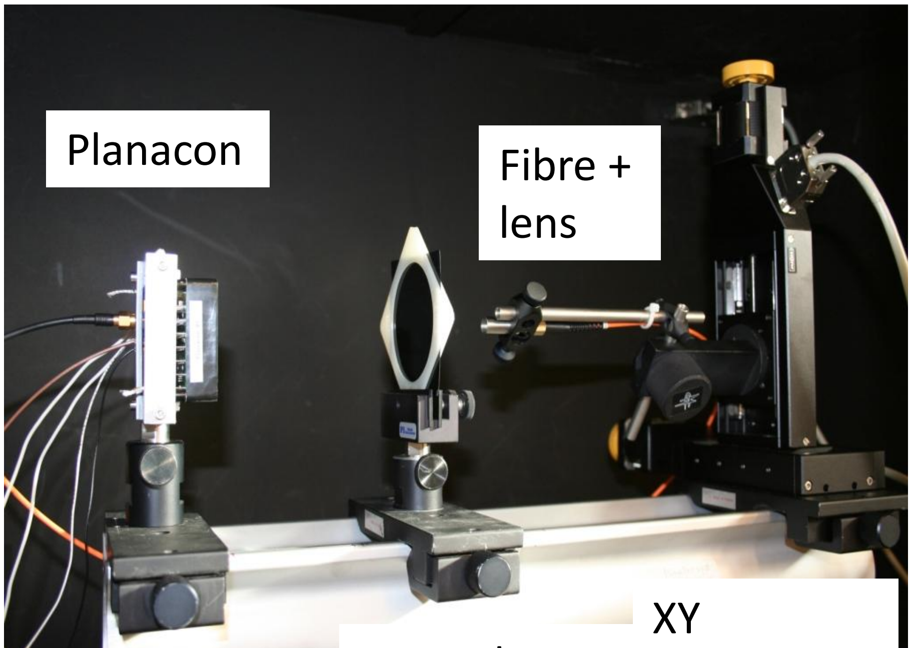
Pulse Height Spectra setup
(charge measurements)

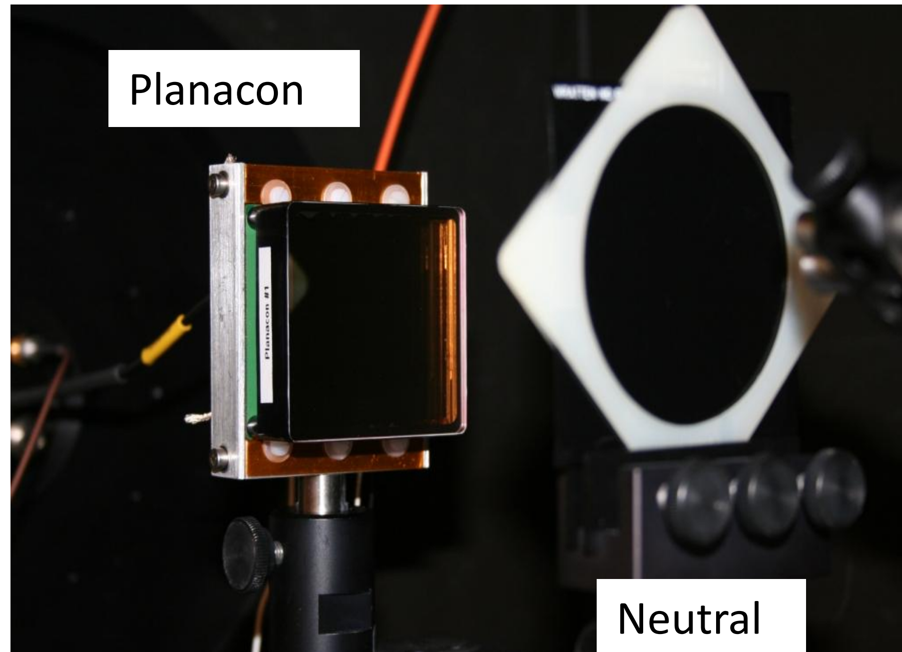


MCP tests – experimental setup



MCP tests – experimental setup photos (2)





Blue laser tests – Pulse height spectrum. Photoelectrons contribution fit

- HV = **-2450V** → bleeder chain 2:10:2 (-350V : -1750V : -350V)
- Gain: **5 10^5**
- **μ ~ 0.51**

- Fitted accordingly to **Poisson distribution**

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

- P(0) as a **gaussian**

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

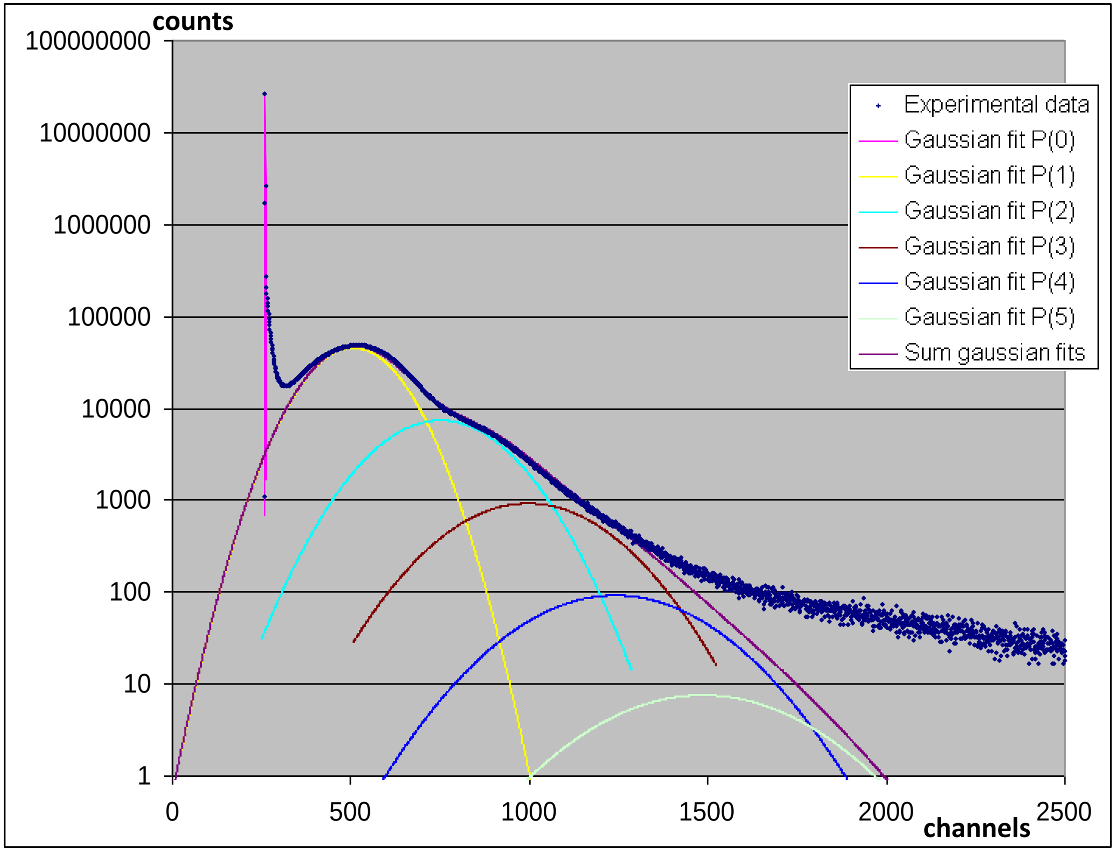
$$P_\mu(0) = e^{-\mu} = \frac{A_0 \sigma_0 \sqrt{2\pi}}{total\,surface}$$

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

Light source fluctuation

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

MCP gain fluctuations



Blue laser tests – Pulse height spectrum. SPE efficiency estimation

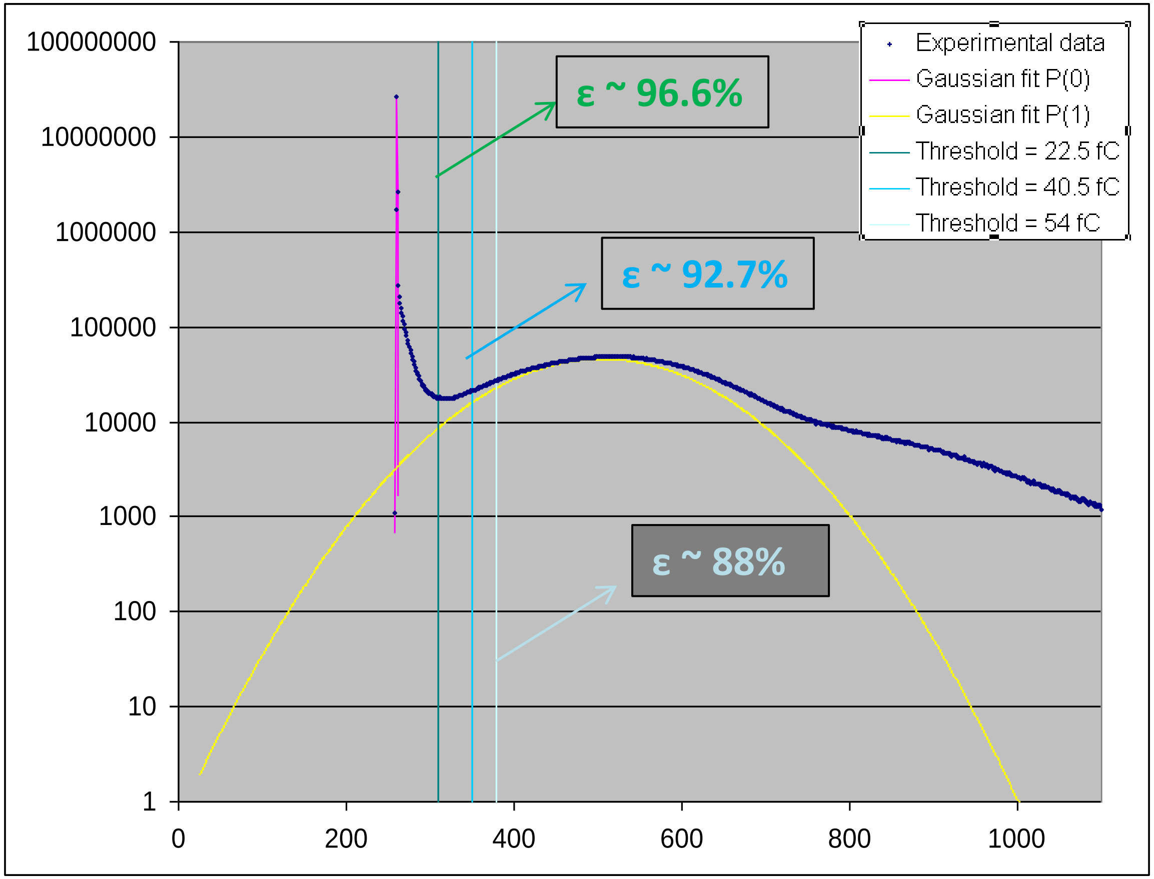
– For **1 photoelectron**: $$P_{\mu}(1) = \frac{\mu}{1!} e^{-\mu} = \frac{A_1 \sigma_1 \sqrt{2\pi}}{total\, surface}$$

$$< Q_{input}(1\ photoelectron) > = 110.81\ fC$$

- Input range 0 → -150 mV (low gain):
  - **3 CFD thresholds**:
    -1.125 mV → Q ~ 22.5 fC
    -2.025 mV → Q ~ 40.5 fC
    -2.7 mV → Q ~ 54 fC

$$100\ fC \Rightarrow 221.1\, channels$$

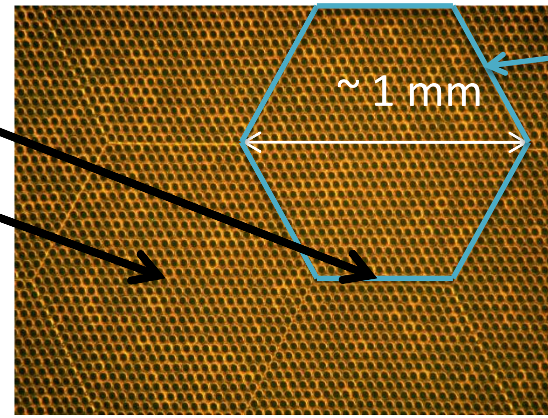
  - **3 PHS thresholds**:
    49.75 channels
    89.55 channels
    119.36 channels

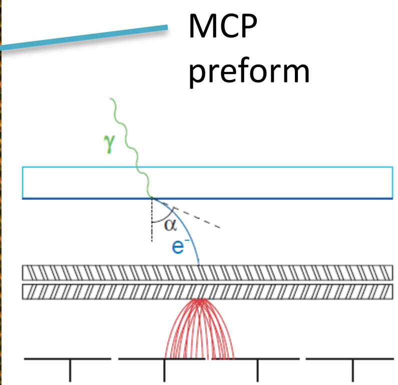


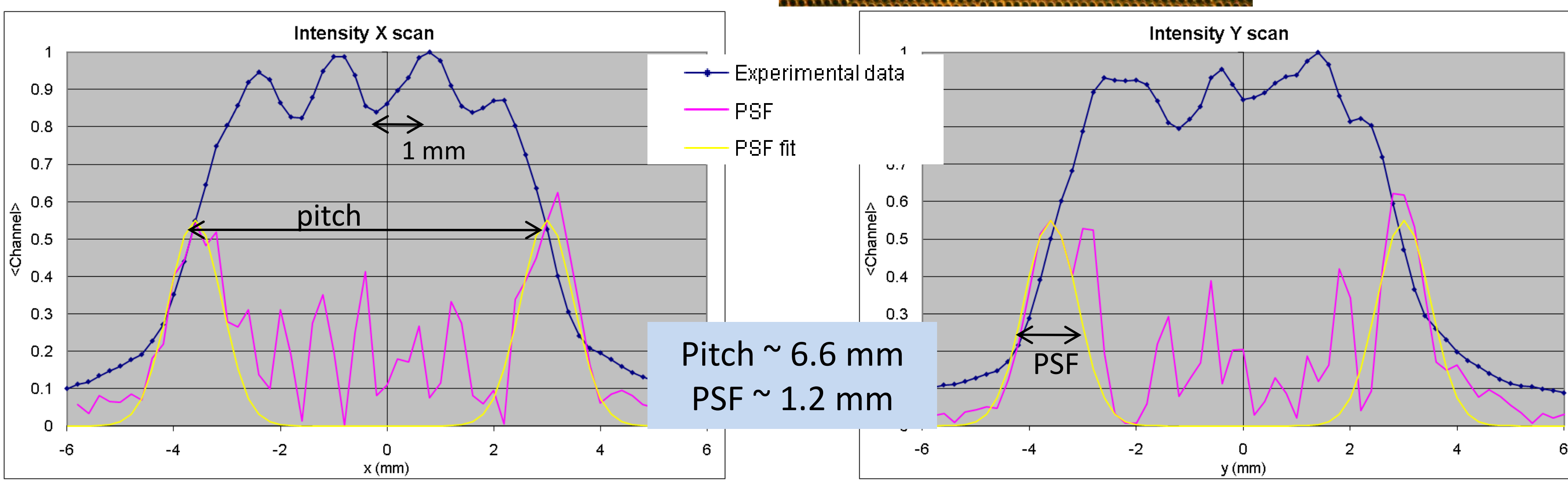
Blue laser tests – Spatial aspects. Intensity scans. Point Spread Function

- 1st hypothesis:
  - Periodic oscillation could be due to the number of affected pores on the second MCP
- 2nd hypothesis:
  - Min. at limit between hexagons
  - Max. at centre of hexagon

Pitch size = 6.5 mm
Required PSF ~ 1 mm

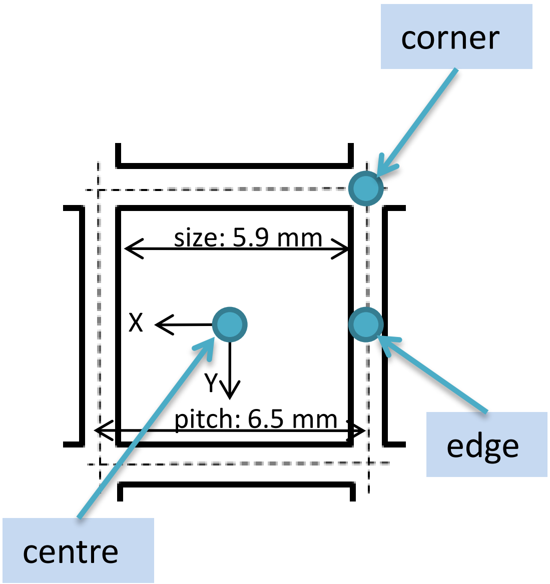






Blue laser tests – Scans at pixel boundaries. SPE efficiency

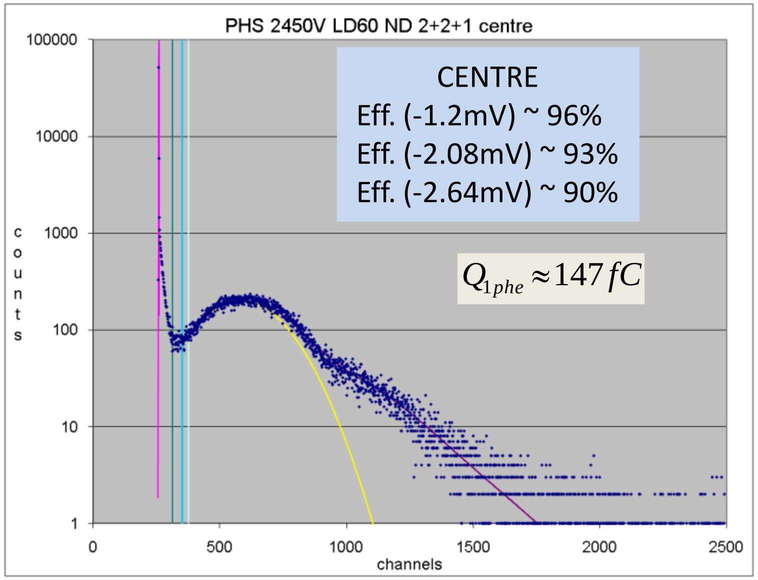
- Scans for different laser alignments on the pixel
- Pulse height measurements:
  - **ND 2+2+1 ➔ μ ~ 0.5 unchanged** (see next slide)
  - Gain ~ 8 10^5 electrons
  - Efficiency estimation
- Time jitter distributions:
  - Timing amplifier input range: 0 → -30 mV
  - CFD threshold: -70 mV → -1.2 mV
  - Time resolution
    - By fitting the leading edge



- Importance on **anode readout segmentation** (8x128 pixels)
- **Don't want to lose on timing performance**

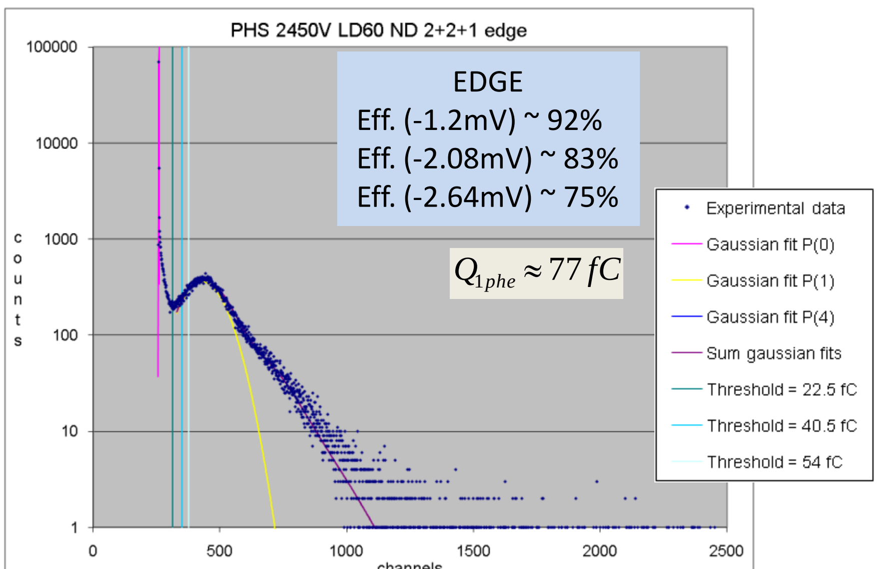
CFD threshold: -70 mV ➔ input threshold: -1.2 mV = 24 fC ➔ PHS threshold: 53 channels
CFD threshold: -120 mV ➔ input threshold: -2.08 mV = 42 fC ➔ PHS threshold: 92 channels
CFD threshold: -160 mV ➔ input threshold: -2.64 mV = 53 fC ➔ PHS threshold: 117 channels

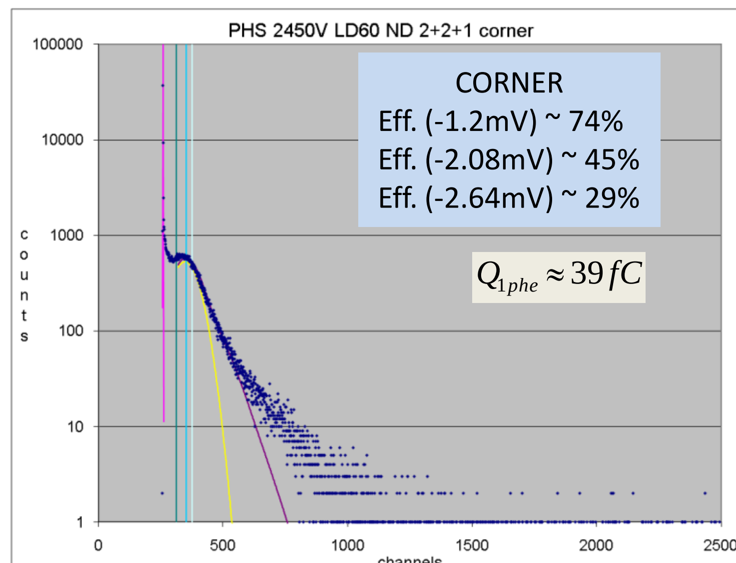
Blue laser tests – Scans at pixel boundaries. SPE efficiency



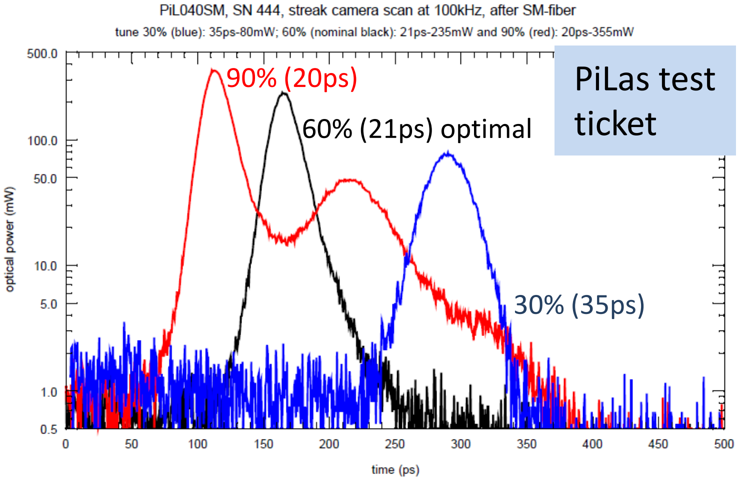
	σt (Y direction)	σt (X direction)
Centre	~ 49 ps	~ 43 ps
Edge	~ 45 ps	~ 51 ps
Corner	~ 50 ps	~ 55 ps

- Depending on how the distribution is fitted (see next slides)





Blue laser tests – Time jitter distribution. Distribution fit



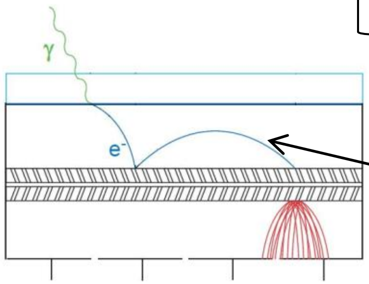
PiLas test ticket

- Shoulder due to a second laser pulse
- 60% TUNE asymmetric pulse shape
- Low statistics **2nd laser pulse**
- Second pulse as we increase LD TUNE
- **2nd relaxation oscillation** clearly seen ~ 150 ± 50 ps → shoulder in measurements

ND 2+2+1 → **μ ~ 0.54**
CFD threshold -60mV → -2.7 mV at input

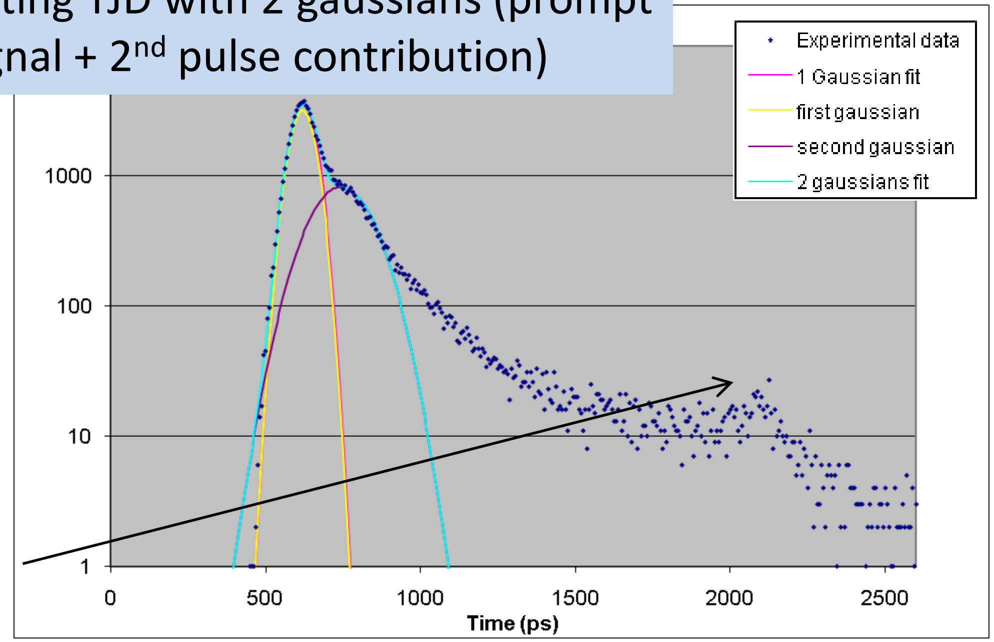
1 gaussian fit → $\sigma \sim 38$ ps

2 gaussians fit → $\sigma_1 \sim 38$ ps, $\sigma_2 \sim 94$ ps



$t_{backscatte} \sim 1.5\,ns$

Fitting TJD with 2 gaussians (prompt signal + 2nd pulse contribution)



Blue laser tests – Time jitter distribution. σ vs μ behavior

- Many contributions to time jitter:

$$\sigma = \sqrt{\sigma^2_{MCP} + \sigma^2_{synch} + \sigma^2_{laser\,pulse} + \sigma^2_{channel} + \sigma^2_{Blue\,light} + \sigma^2_{electronics} + \ldots}$$

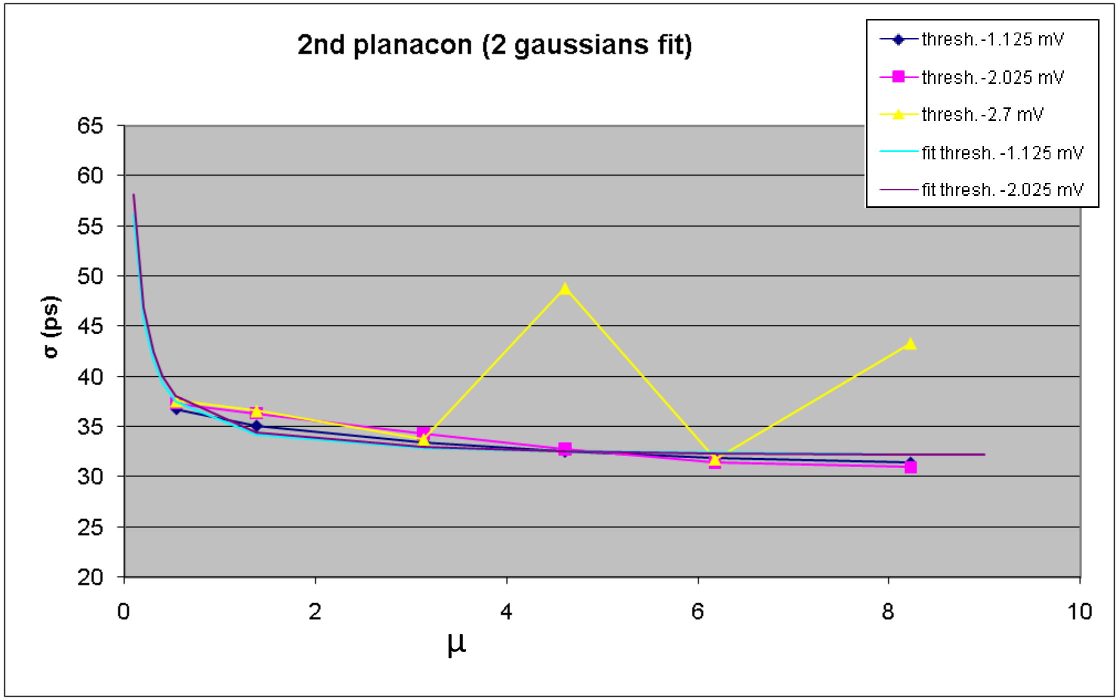
  - **MCP intrinsic time jitter**
  - Laser synchronization pulse (~ 2-3 ps)
  - Optimal laser pulse width (~ 20 ps FWHM)
  - MCA channel resolution (6.25 ps)
  - Blue light (PE emission velocity spectrum)
  - Slope signal (proportional # phe) vs CFD time jitter and residual time walk (signal amplitudes)
  - …

A = σ_{TTS} ~ 15 ps
B~4 → σ_{other} ~ 30 ps

$$\sigma_{fit}(\mu) = \sqrt{\sigma^2_{MCP} + \sigma^2_{other}} = \sigma_{TTS}\sqrt{\frac{1}{\mu} + \frac{\sigma^2_{other}}{\sigma^2_{TTS}}}$$

$$\sigma_{fit}(\mu) = A\sqrt{\frac{1}{\mu} + B}$$

⇒

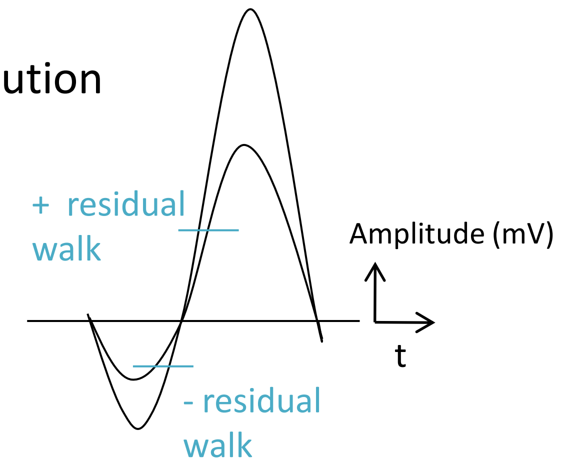


Blue laser tests – CFD time walk properties

- How does CFD work?
  - Based on zero-crossing techniques
- Explain timing performance and see time jitter contribution

CFD
- Large amplitudes:
  +walk → earlier / -walk → later
- Smaller amplitudes:
  +walk → later / -walk → earlier

- SPE zone: very sensitive to time walk



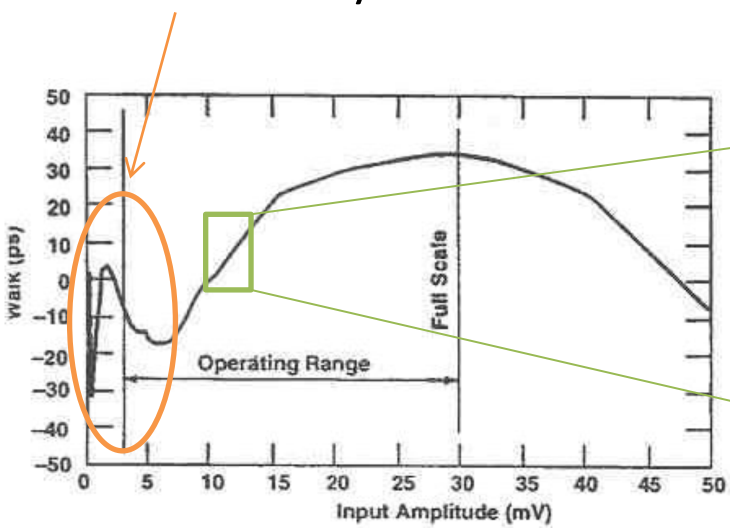
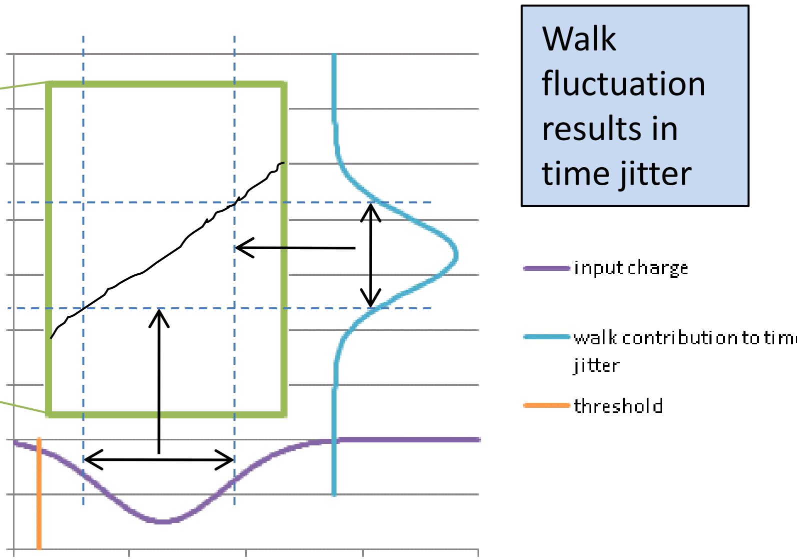
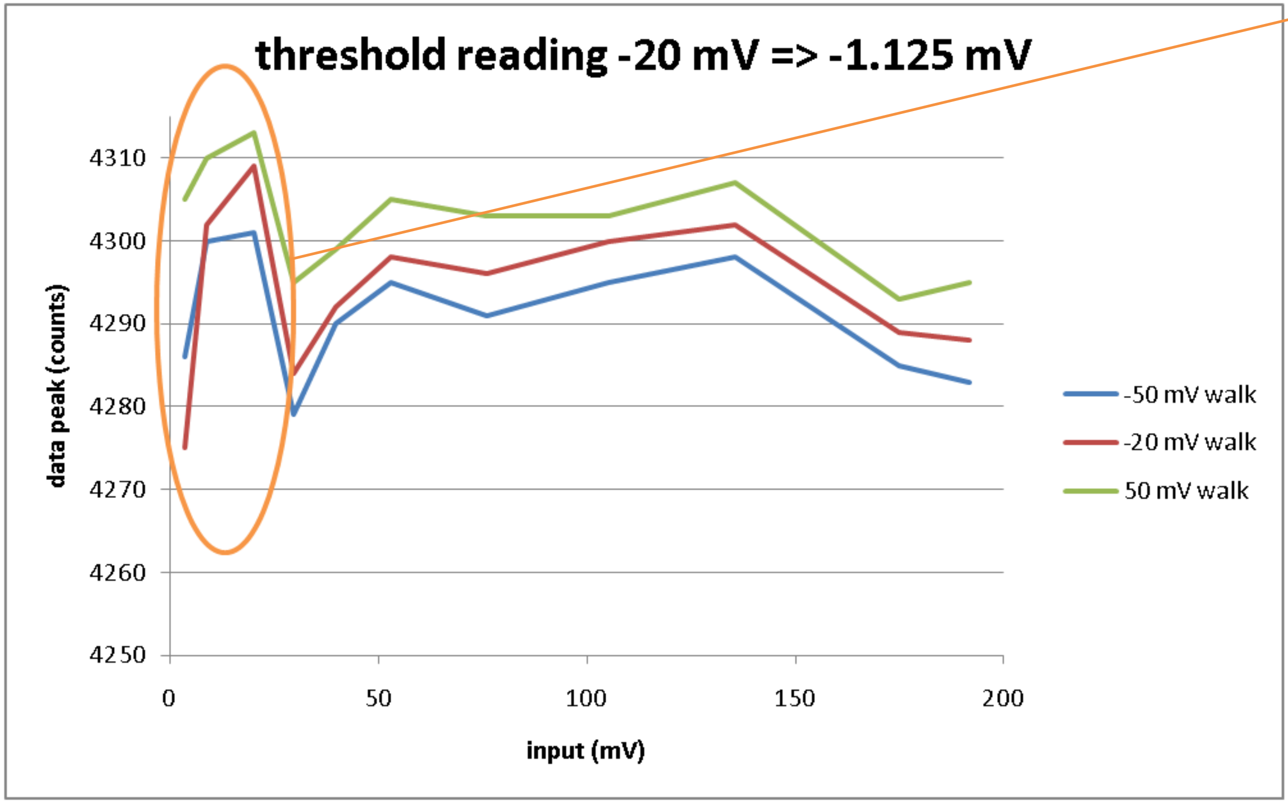


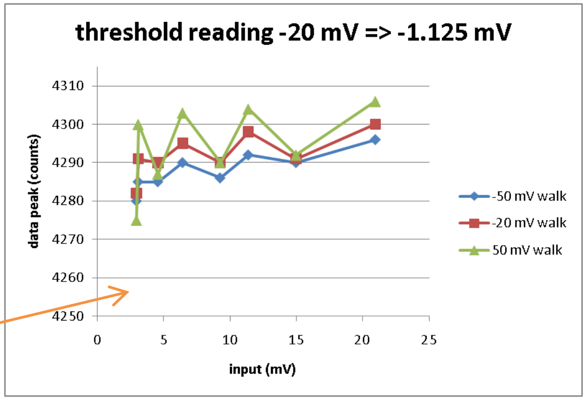
Fig. 1.3. Typical Walk vs. Pulse Amplitude.
Full scale is denoted by the Over Range LED turning on.
Measured with a pulse width of 300 ps FWHM.

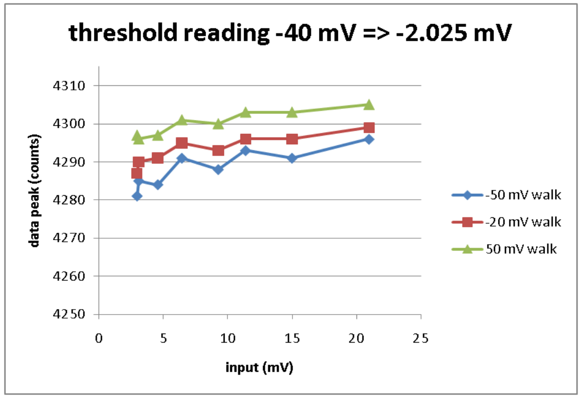


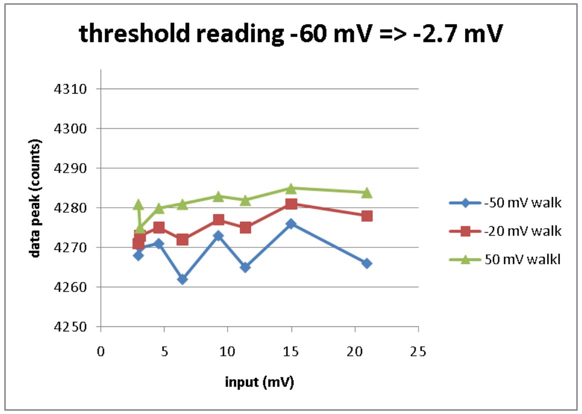
Blue laser tests – CFD time walk properties

– Low gain. Timing amplifier input range (0 → -150 mV)



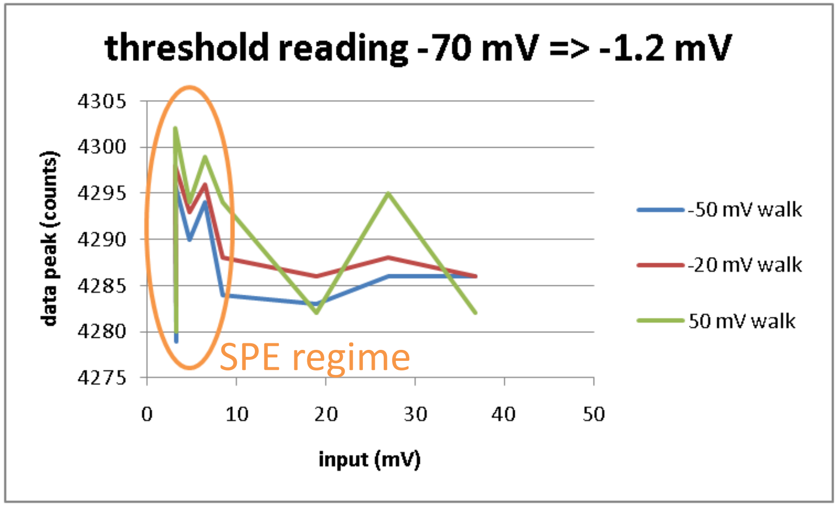


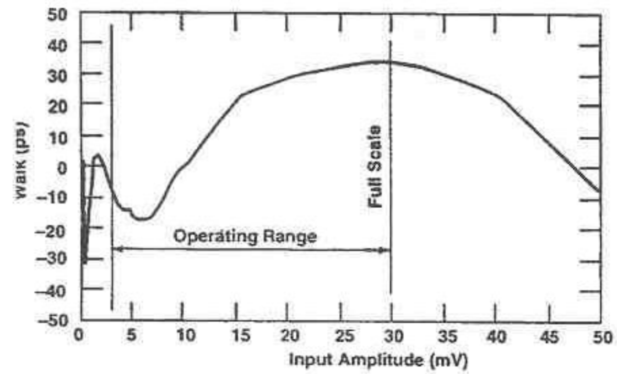




Blue laser tests – CFD time walk properties

– High gain. Timing amplifier input range (0 → -30 mV)





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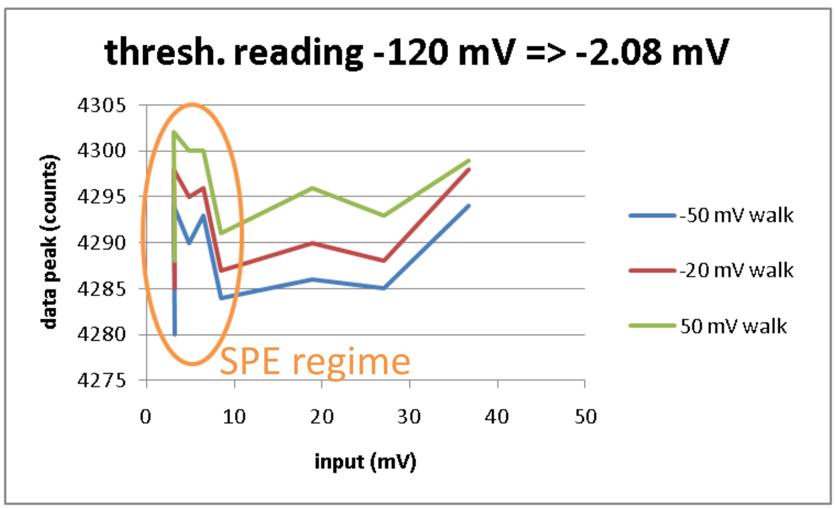

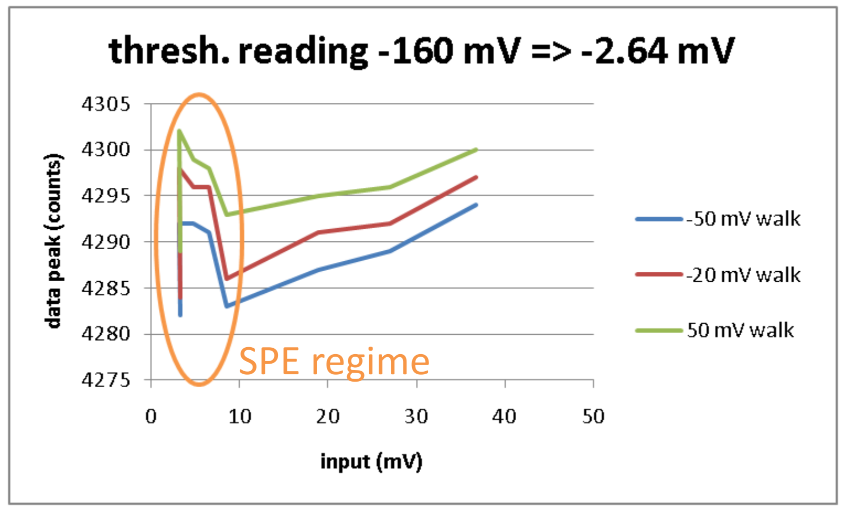

Conclusions and plans

- Lab tests:
  - MCP operating parameters & calibration under control
  - Achieved an excellent timing resolution O(<40 ps) with estimated ε of ~ 90% for single photons on pixel centre.
  - Timing performance similar on pixel boundaries with expected efficiency drop.
  - Better understanding of laser pulse contribution to timing distributions.
  - Detailed studies of residual time walk. Data analysis on-going.

- Poster presentation on NDIP Conference (4-8 July 2011) in Lyon, France