I. Time Resolution of a MCP-PMT and
II. Test Infrastructure in the Solid State Detector Lab

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22.02.2017
RD51 Precise Timing Workshop, CERN

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The RD51 PICOSEC collaboration

Fast Timing for High-Rate Environments: A Micromegas Solution

Institutes:

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- **CERN**:
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- **Princeton University**:
  S. White, K.T. McDonald, Changguo Lu
- **University of Thessaloniki**:
  S. Tzamarias
- **University of Science and Technology of China**:
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Contributing from the RD50 collaboration:

- **CERN**:
  M. Centis Vignali, M. Moll, and the SSD lab group (EP-DT-DD)

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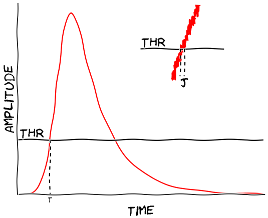
I. Time Resolution of a MCP-PMT

Timing

$$\Delta t = t_2 - t_1 \qquad \sigma^2_{\Delta t} = \sigma^2_{t_1} + \sigma^2_{t_2} \qquad \sigma^2_t = \sigma^2_J + \sigma^2_{TW} + \dots$$

Jitter



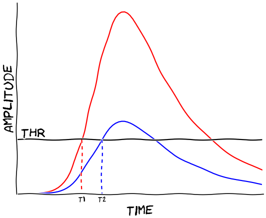
The noise influences the time at which the threshold is crossed

$$\sigma_J = \sigma_n / \frac{dV}{dt}$$

Countermeasures:

- Reduce rise time
- Improve noise figure

Time walk



Variations in the amplitude influence the time at which the threshold is crossed

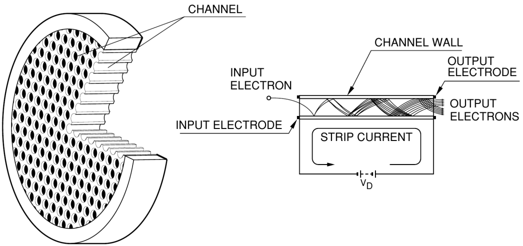
Countermeasures:

- Algorithm e.g. CFD

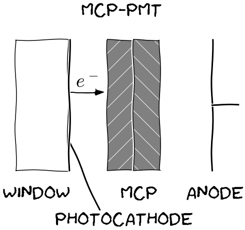
MCP-PMT

Microchannel plate photomultipliers

- MPC as amplification structure
- Million of microglass tubes fused in parallel
- $1 - 3$ plates in one PMT
- Channel diameter 6-20 μm
- $V_{bias} \approx 3000\,\text{V}$
- Gain $10^4 - 10^6$

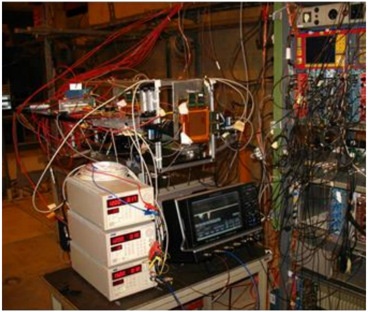


Hamamatsu PMT handbook, chapter 10



Beam Test

- Performed by the PICOSEC group of the RD51 collaboration
- CERN SPS
- Fall 2016
- Several timing detectors
- Gas detectors
- Silicon detectors
- MCP-PMT used as time reference



Analysis of a special run to characterize the timing reference

Beam Test Setup

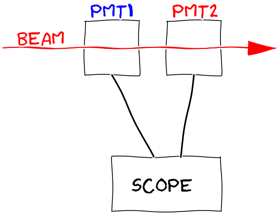
- 150 GeV/c muons
- 2 MCP-PMTs (Č light)
- Scope readout
- Trigger on PMT2 (50 mV thr)

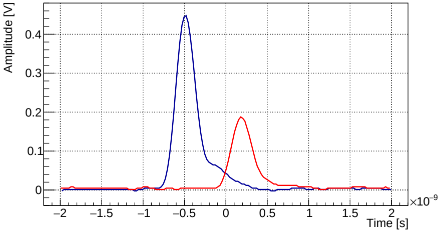
MCP-PMTs

- Hamamatsu R3809U-50/52
- 3.2 mm quartz window
- 11 mm diameter photocathode
- Bias 2.8 kV
- Gain $\approx 8 \cdot 10^4$

Scope

- 2.5 GHz bandwidth
- 8 bit (LSB 3.5 mV)
- 40 GSa/s (25 ps sampling)

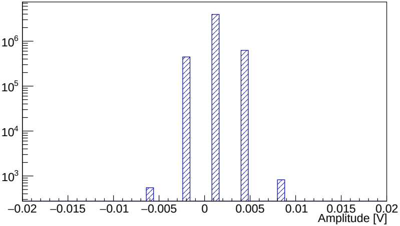


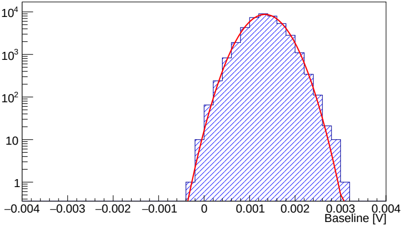


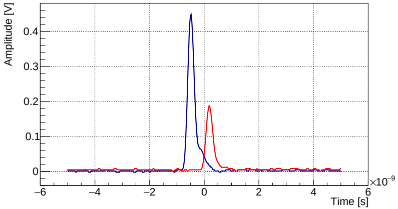
Thanks to Stefano Mazzoni for lending one of the MCP-PMT

Noise and Baseline

Noise	Baseline
Distr of all points with time < -2 ns	Mean (evt by evt) of all points with time < -2 ns
$\approx$ 1.6 mV for both PMTs	
PMT1	PMT1



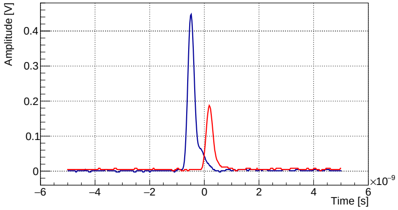




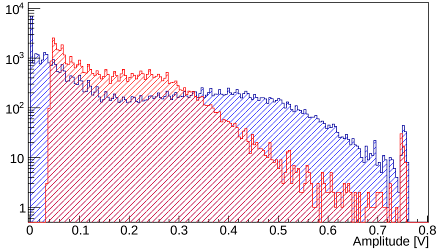
Event Selection

From run using a 5×5 mm^2 trigger scintillator:

- **Max ampli 1 > 200 mV**
- **Max ampli 2 > 120 mV**
- Max using parabolic interpolation
- Max measured from baseline



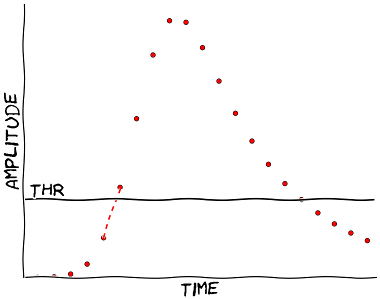
Max ampli distribution
PMT1, PMT2



Components:

- Poisson distribution of number of photoelectrons
- Partial collection of Č light

Data Interpolation

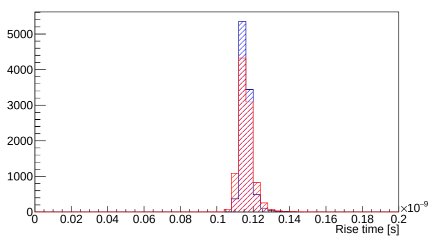


- Signal sampled every 25 ps
- Linear interpolation of 2 points to determine crossing time

Rise Time 20% 80%

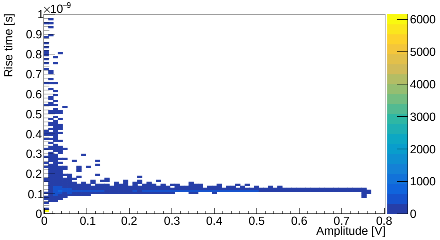
Average rise time 116 ps

PMT1, PMT2

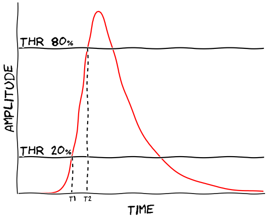


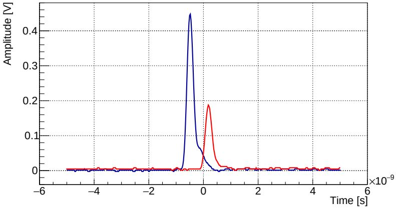
Same rise time for both PMTs

Correlation rise time amplitude PMT1 (no amplitude cuts)



Rise time independent of amplitude

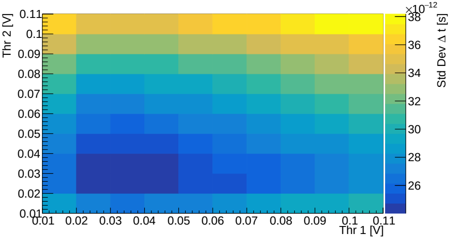




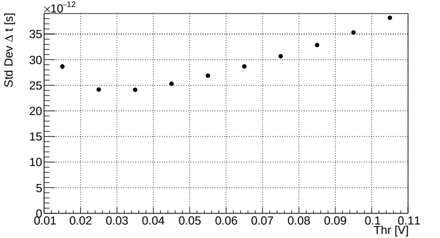
Timing using Leading Edge Discriminator

Resolution $\rightarrow$ std dev of $\Delta t = t_2 - t_1$

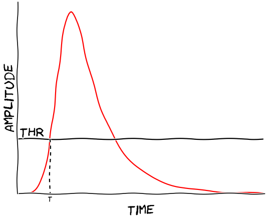
Resolution map



Diagonal of the 2d plot

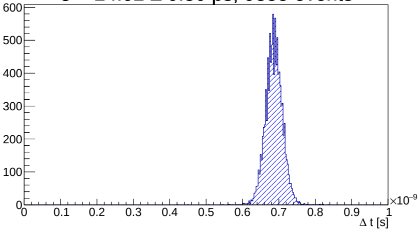


- Max ampli at least 5% higher than thr



Δt distribution, thr = 30 mV

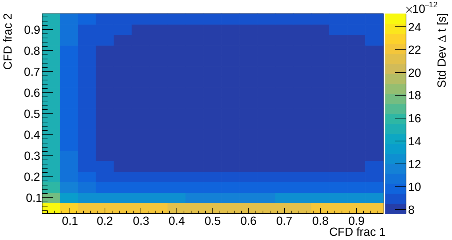
σ = 24.02 $\pm$ 0.30 ps, 9855 events



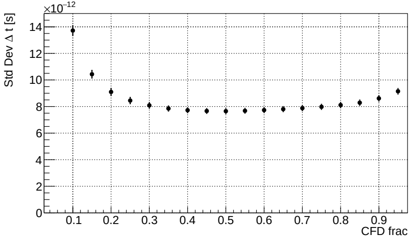
Timing using Constant Fraction Discriminator

Resolution $\rightarrow$ std dev of $\Delta t = t_2 - t_1$

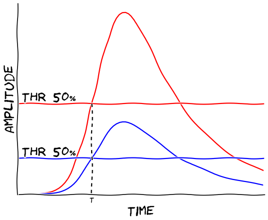
Resolution map



Diagonal of the 2d plot

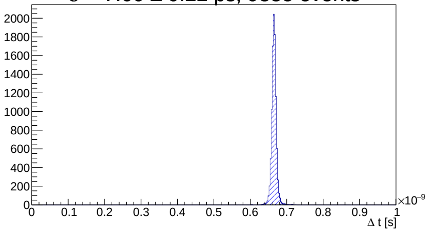


- Reduction of time walk



Δt distribution, CF = 0.45

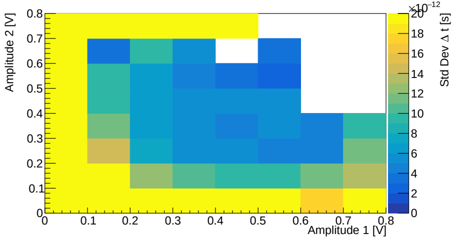
σ = 7.66 ± 0.22 ps, 9855 events



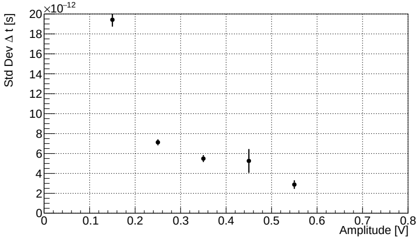
Timing as a Function of Amplitude

Resolution $\rightarrow$ std dev of $\Delta t = t_2 - t_1$

Resolution map



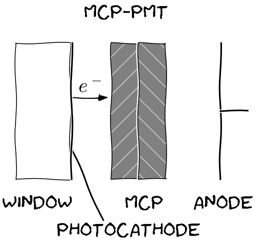
Diagonal of the 2d plot



- CFD with CF = 0.45
- No amplitude cuts
- “Holes” due to low statistics

- The resolution improves with amplitude

Transit Time Spread for MCP-PMT



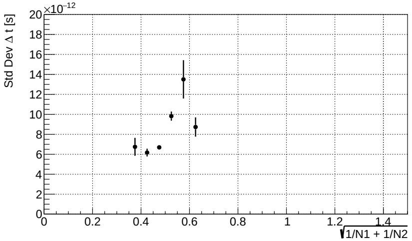
Variations in the time it takes for an electron to move from the photocathode to the MCP

$$\sigma_{TTS} \propto TTS/\sqrt{N}$$

$N \rightarrow$ number of photoelectrons

$$\Rightarrow \sigma_{\Delta t}^{TTS} \propto \sqrt{\frac{1}{N_1} + \frac{1}{N_2}}$$

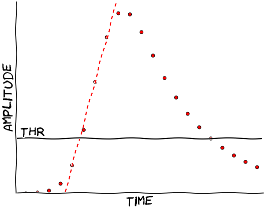
Conversion coeff to number of photons from a different run



- Outliers probably due to low statistics

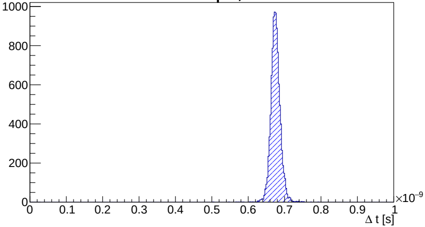
Leading Edge Interpolation

Linear interpolation of points between 20% and 80% of ampli



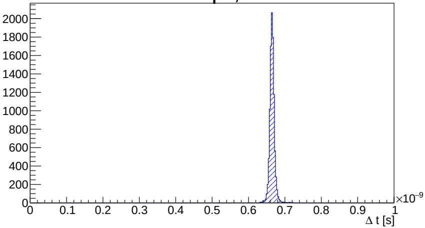
LED thr = 30 mV

σ = 13.61 ± 0.21 ps, 9855 events



CFD CF = 0.45

σ = 7.78 ± 0.22 ps, 9855 events



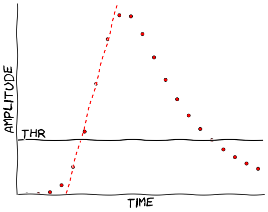
Std dev 2 pt interpolation: 24.0 ps

Std dev 2 pt interpolation: 7.7 ps

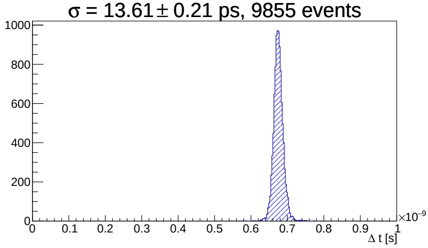
LED more affected than CFD due to different thr

Leading Edge Interpolation

Linear interpolation of points between 20% and 80% of ampli

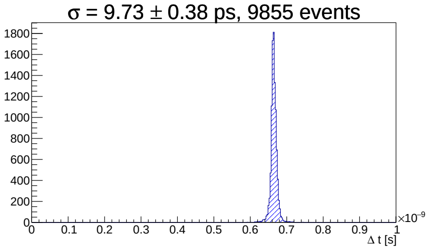


LED thr = 30 mV



Std dev 2 pt interpolation: 24.0 ps

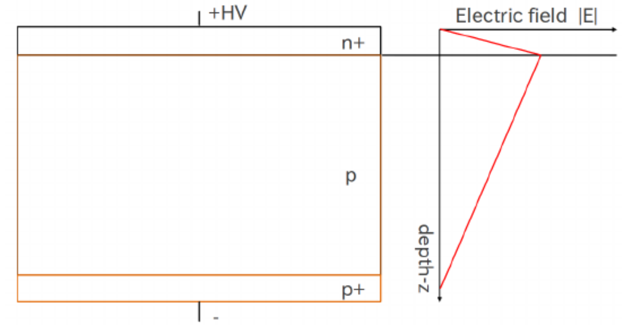
Extrapolation to 0 of interpolation



Improvement wrt LED due to partial time walk correction

II. Test Infrastructure in the Solid State Detector Lab

Silicon Detectors



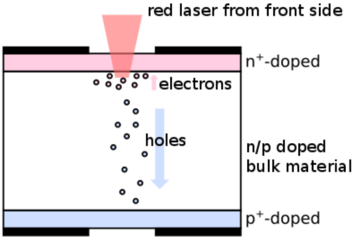
- Solid state ionization detector
- Mono-crystalline Si
- Rectifying junction in reverse bias
- Mean ionization energy: 3.6 eV/eh
- Typical thickness, 300 μm typical
- Signal $\approx$ 24000 e^- in 300 μm
- Fast signals, O(10 ns)

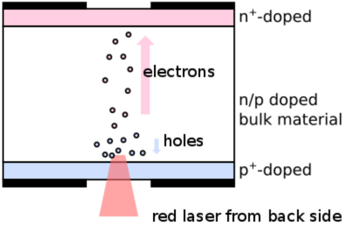
Transient Current Technique (TCT)

Measure $i(t)$ to investigate sensor's electric field and charge collection

$$i_{ind} = n \cdot q_0 \cdot v \cdot E_W = \frac{n q_0 \mu E}{d} \qquad E_W = 1/d \qquad v = \mu \cdot E$$

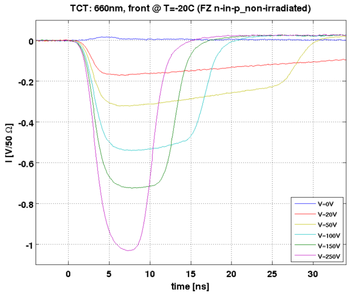
- Produce eh pairs using a pulsed laser
- Red laser $\rightarrow$ short absorption depth (few μm)
  $\rightarrow$ one type of charge carriers drifts
- Infrared laser $\rightarrow$ long absorption depth ($\approx$mm)
  $\rightarrow$ similar to charged particle signal
- Read out the signal using an oscilloscope



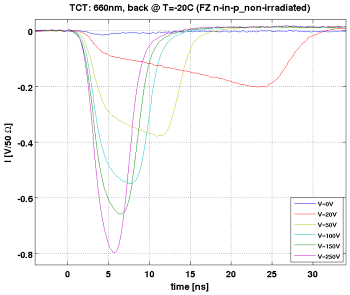


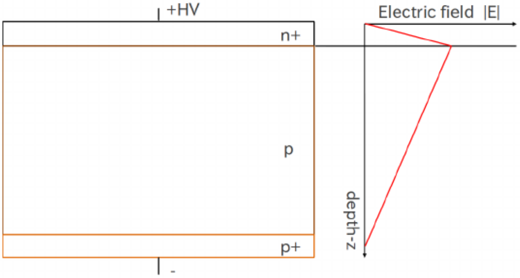
TCT Example (Non-irradiated Diode)

Holes drift (red top)

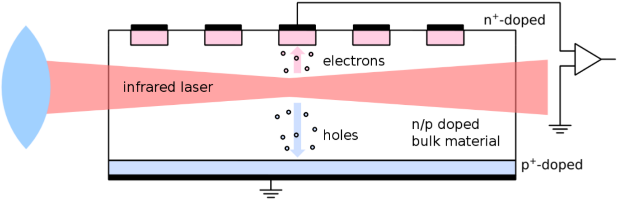


Electrons drift (red bottom)



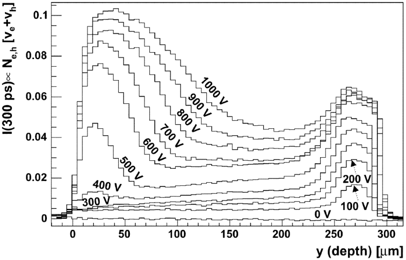


Edge TCT



- In irradiated sensors trapping of e/h reduces the signal during drift $\rightarrow$ less signal to study the E field
- Edge illumination
- Use the first part of the $i(t)$ pulse to extract information
- Scan the sensor thickness by moving the laser spot

Drift velocity profile for an irradiated detector ($\Phi_{eq} = 5 \cdot 10^{15}\,\mathrm{cm}^{-2}$)

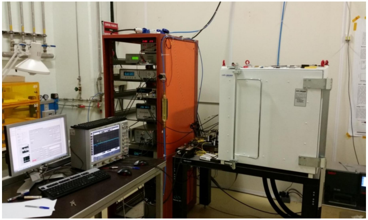


From: Investigation of Irradiated Silicon Detectors by

Edge-TCT, G. Kramberger et al., IEEE 2010

TCT setup

- Red (600 nm) and infrared (1064 nm) laser
- 200 ps pulse
- Laser focus $\approx 10\,\mu$m
- Front, back, and edge illumination
- Current amplifier
- 2.5 GHz, 20 GSa/s oscilloscope
- Reference diodes to monitor laser intensity
- Temperature control
- Translation stages



TCT setup

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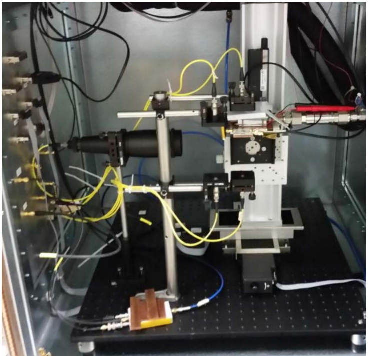
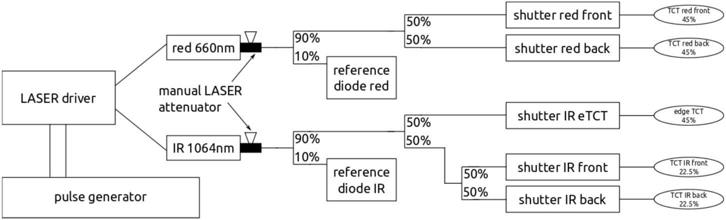
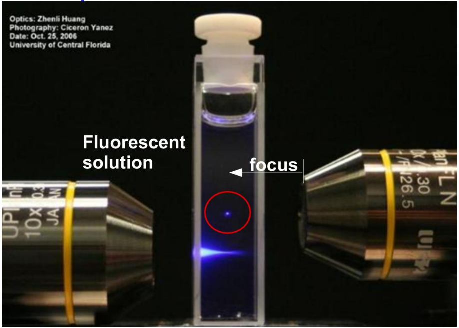


TCT for Timing



- Use signal from reference diodes as time reference
- Alternatively, use second detector for reference
- To be tested in the next weeks

Two Photon Absorption TCT



- Point-like charge carrier generation
- 3D sensor scan
- Use wavelength for which Si is transparent
- e/h pair generation through virtual states
- Photons densly packed in space and time
- High intensity femtosecond laser
- Measurement performed at the SGIKER laser facility in Bilbao
- Application ongoing to acquire components for one setup

Summary SSD Lab Test Infrastructure

- Current infrastructure used to characterize irradiated and non-irradiated Si detectors
- Several parameters investigated
- No time to show all the setups
- Extension to timing measurement in the next months
- Lab setups constantly maintained and upgraded

Summary MCP-PMT Timing

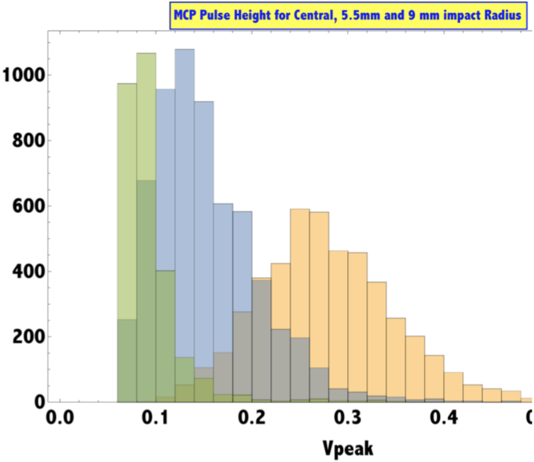
- Implemented different timing algorithms to estimate the timing resolution of the 2 MCP-PMT system
- The result depends on the used algorithm
- The best resolution is obtained using a CFD
- The results are similar to the ones of Inami et al. NIM A560 303-308 (2006)

	Resolution [ps]		Single PMT resolution [ps]	
Algorithm	2 pt inter	Leading edge inter	2 pt inter	Leading edge inter
LED thr = 30 mV	24.0	13.6	17.0	9.6
CFD CF = 0.45	7.7	7.8	5.4	5.5
Extr 0	-	9.7	-	6.9

The resolution of a single MCP-PMT is obtained by dividing the result by $\sqrt{2}$

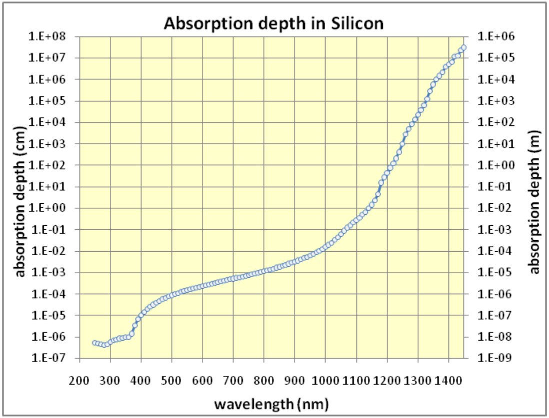
Backup Material

Max Ampli vs Radius



- From different run
- Using tracking information

Absorption Depth in Si



From: http://www.pveducation.org/pvcdrom/materials/optical-properties-of-silicon

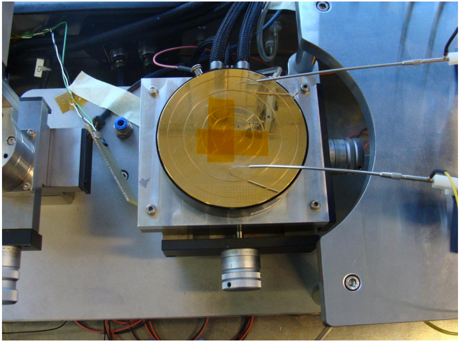
IV/CV

Current-Voltage

- Dark current
- Noise
- Power consumption

Capacitance-Voltage

- Capacitance
- Depletion voltage
- Doping



Setup

- Temperature controlled chuck
- Probe needles
- Voltage source
- Ammeter
- LCR meter