Testing PMT properties with nanosecond interval between photons for KM3NeT

Master thesis presentation

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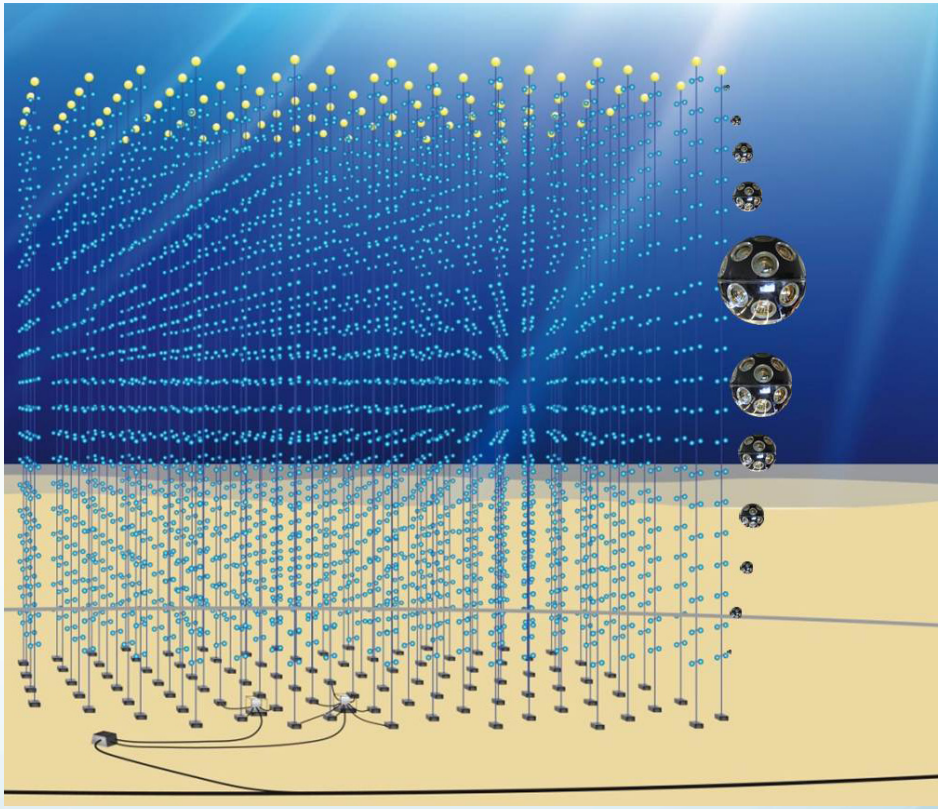
KM3NeT

- KM3NeT
  - Large volume deep sea neutrino telescope
- Neutrinos
  - 3 flavours
  - Only weak interaction
    - Very small interaction cross-section
    - Hard to detect
  - Mass hierarchy problem

plaatje

KM3NeT

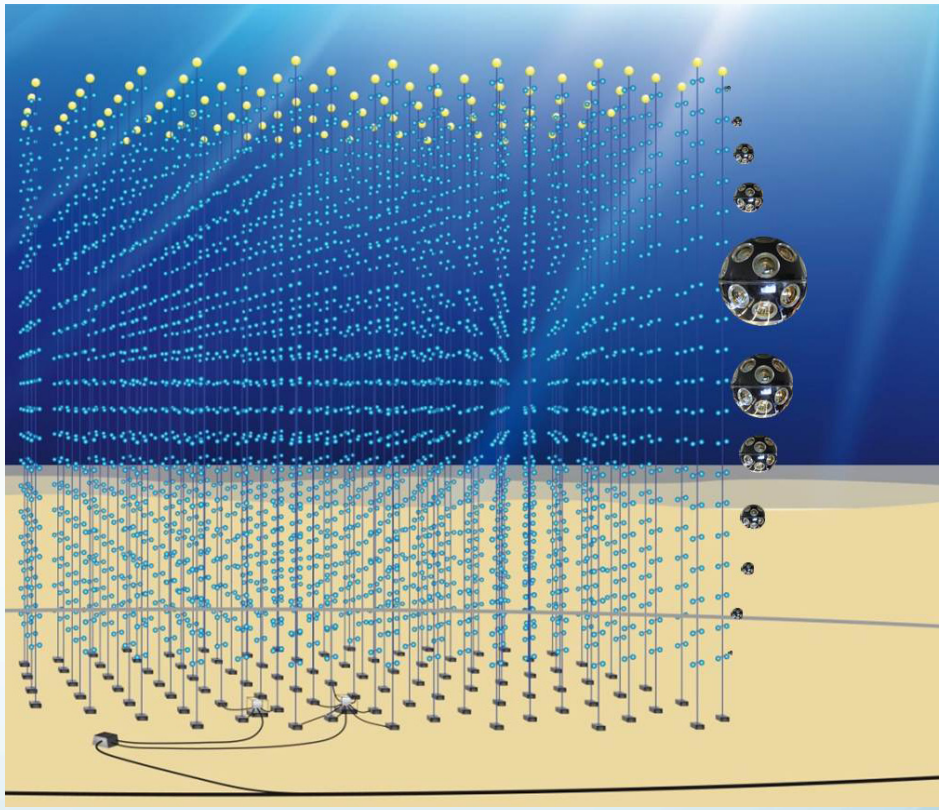
- Objectives:
  - Measure cosmic neutrinos and find their sources *
  - Determine mass hierarchy by measuring neutrino oscillations
- Cubic kilometer effective volume
  - Small neutrino interaction cross-section
  - Sea floor → 3000 meters deep
  - String 700 meters high
  - 18 Digital optical modules (DOMs) per string
  - ~80 meters between strings
  - 115 strings in a detection block



* Icecube reported high energy cosmic neutrino flux (2015)

KM3NeT

- Cubic kilometer effective volume
  - Small neutrino interaction cross-section
  - Sea floor → 3000 meters deep
  - 80 meters between strings
  - String 700 meters high
  - 115 strings in a detection block
  - 18 Digital optical modules (DOMs) per string
- Cosmic neutrinos (ARCA)
  - Cosmic neutrino flux measured by Icecube
  - Searching for neutrino sources
- Atmospheric neutrinos (ORCA)
  - Oscillation probabilities
  - Mass hierarchy problem



KM3NeT

- DOM
  - 17 inch glass sphere
  - 31 PMTs
  - Central logic board
  - Optical communication with the shore

KM3NeT

- Detecting neutrinos
  - Neutrino interacts
  - Carged particles created
    - Cherenkov Radiation
  - Light reaches the DOM
  - PMTs in the DOM detect the light and convert into a electrical signal
  - CLB processes the signal and sends it to shore

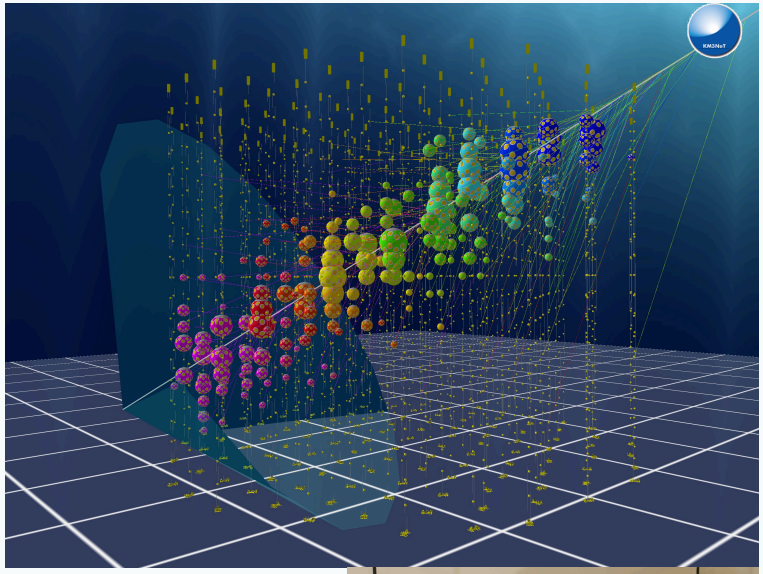
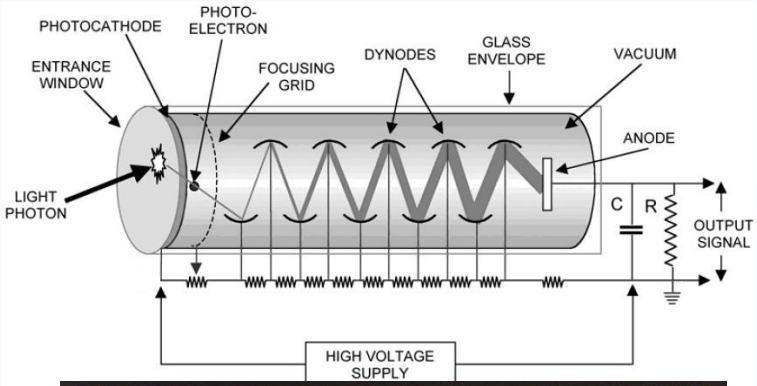
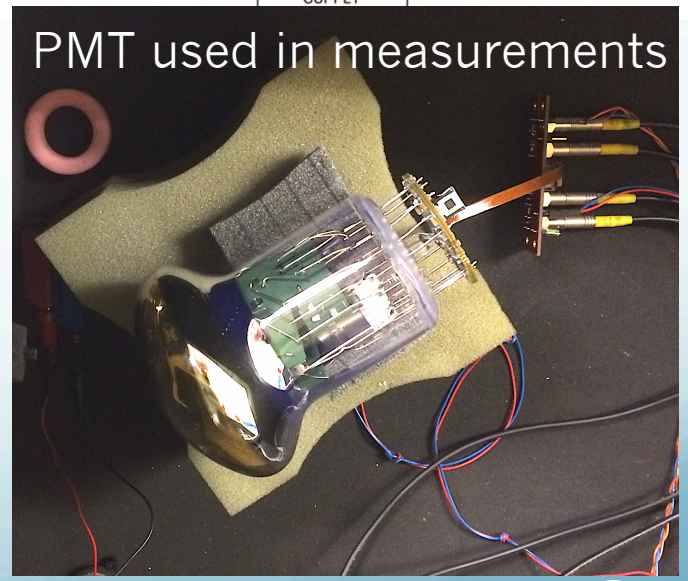


Photo multiplier tube

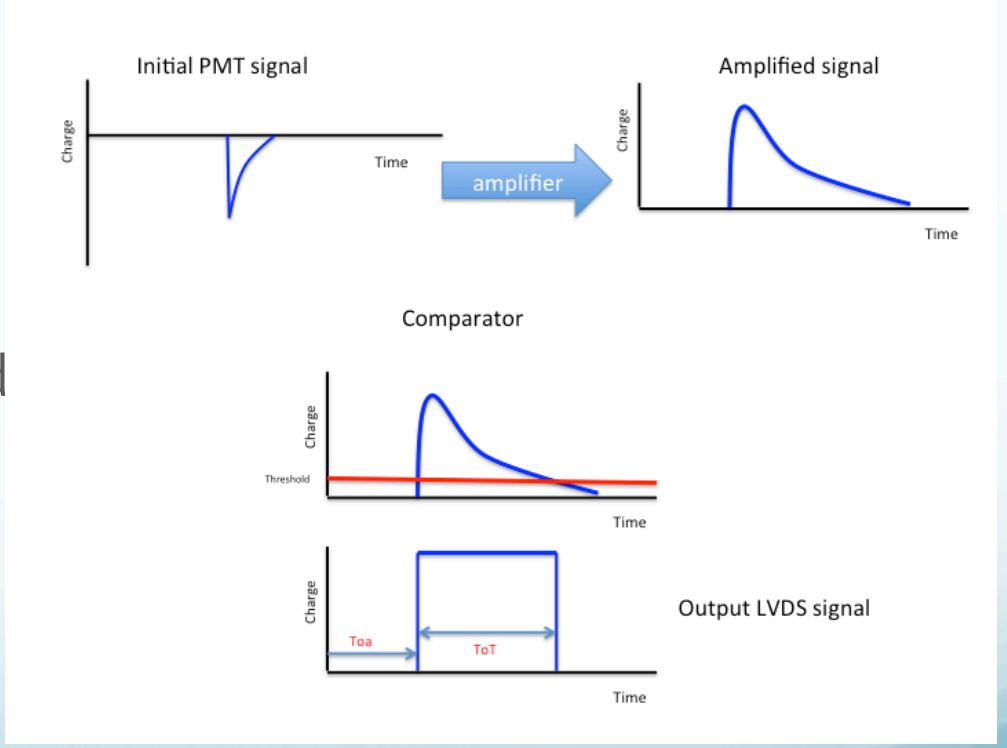
- Photo cathode
- Dynodes
  - High voltage
  - Gain
- Hamamatsu PMT
- Connected to the base





PMT Base

- Converts analog PMT signal
- Amplifier
- Comparator
- High or low singal
  - Time over Threshold
- LVDS out

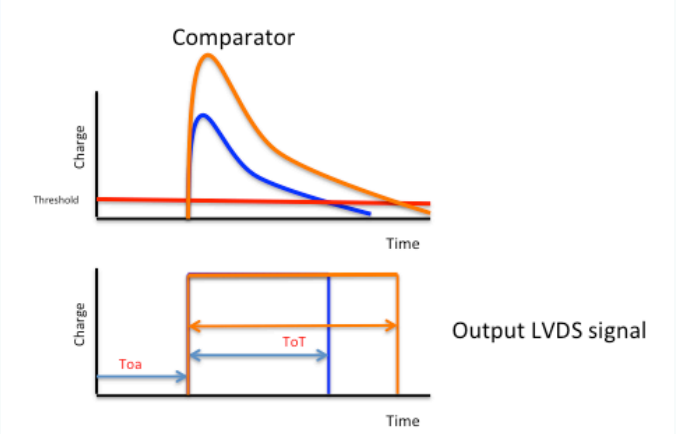


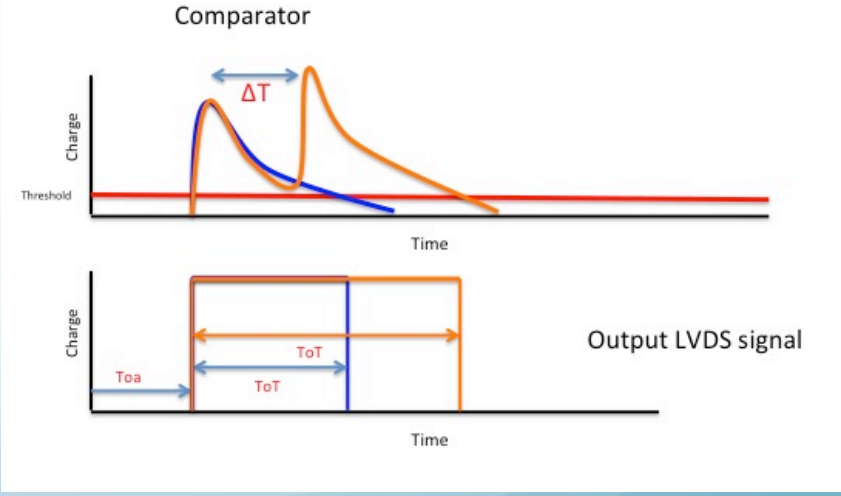
Project

- Testing detailed time properties of the PMT used in KM3NeT
- Motivation
  - Event reconstruction can be improved by:
    - Actual number of incoming photons
    - Detailed time structure
  - Why is it not used yet?
    - Non trivial relation between the photon flux and ToT

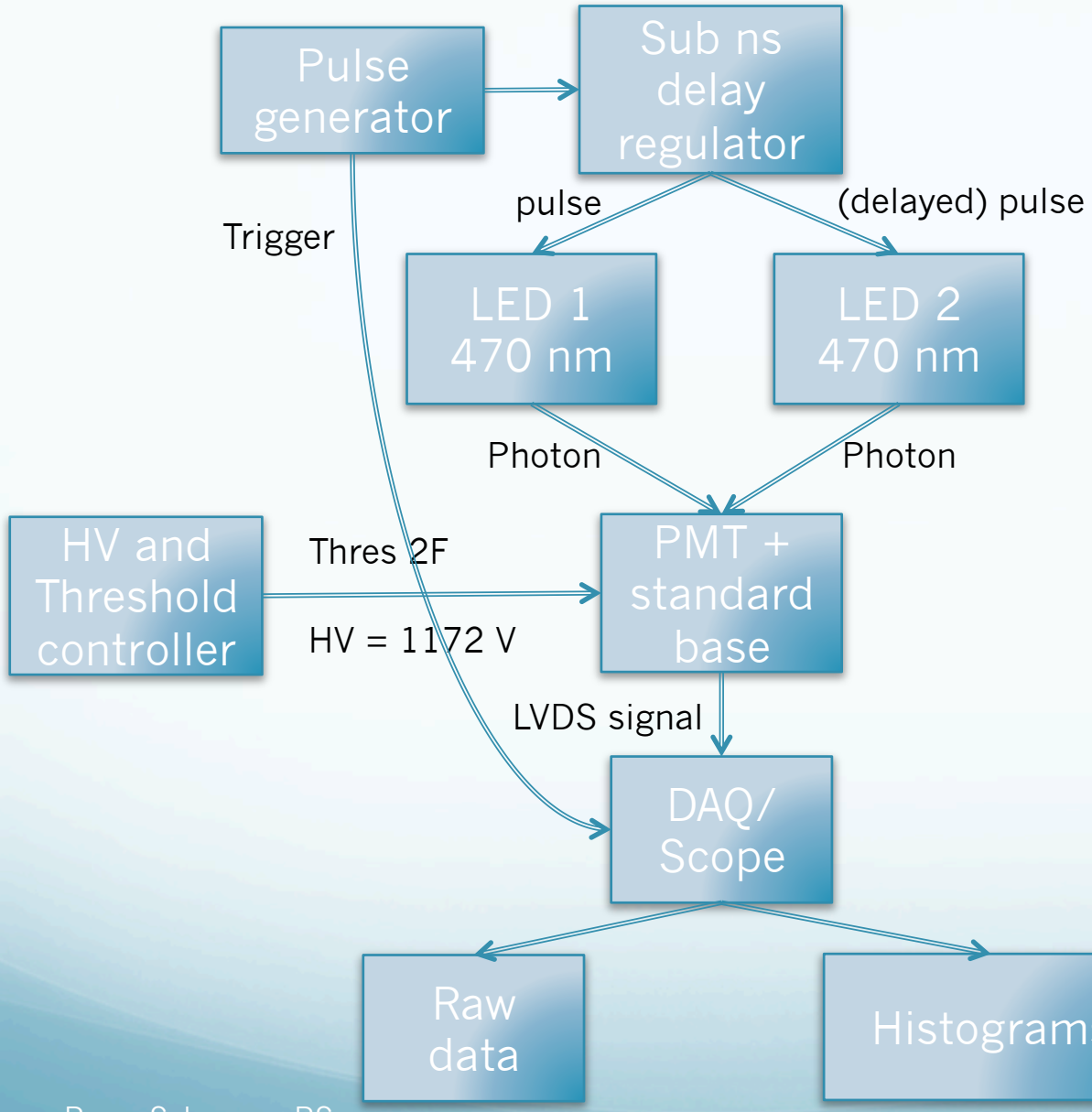
Project

- Photonflux vs ToT relation
  - Single photon
  - Multiple photons
- Detailed time structure of incoming photons
  - Delayed photons
  - Pre and afterpulses
- Threshold scan
  - Threshold and gain spread important in simulations
  - Threshold is 0.3 p.e.



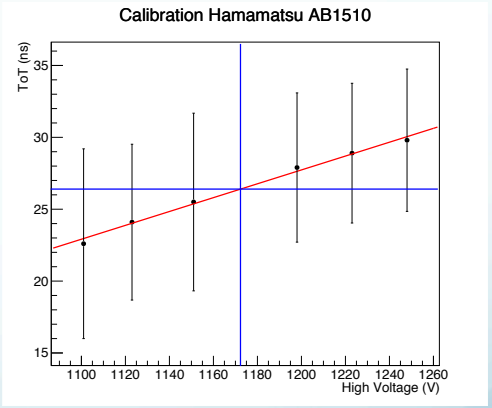


Setup



Scope specs:
Waverunner HRO 66 ZI
600 Mhz 12-bit Oscilloscope
2GS/s

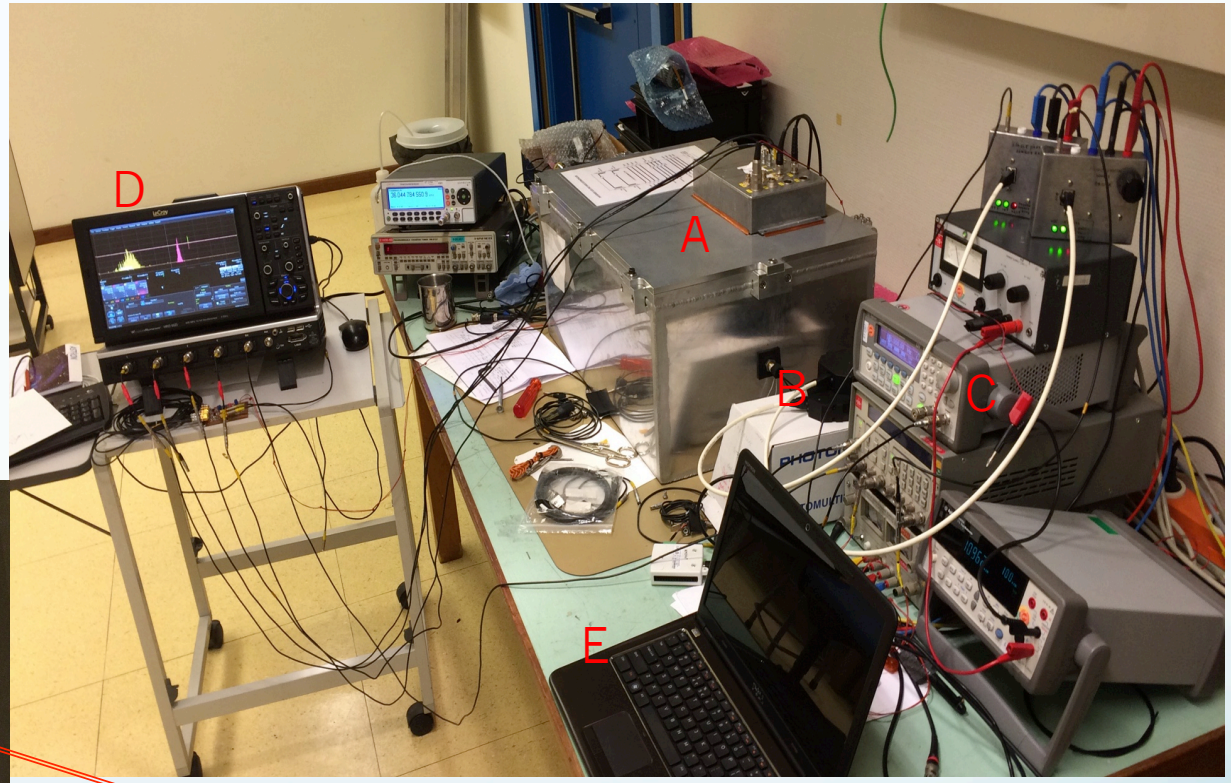
HV calibration to a ToT of 26.4 ns equal to 3 *10^6 gain.

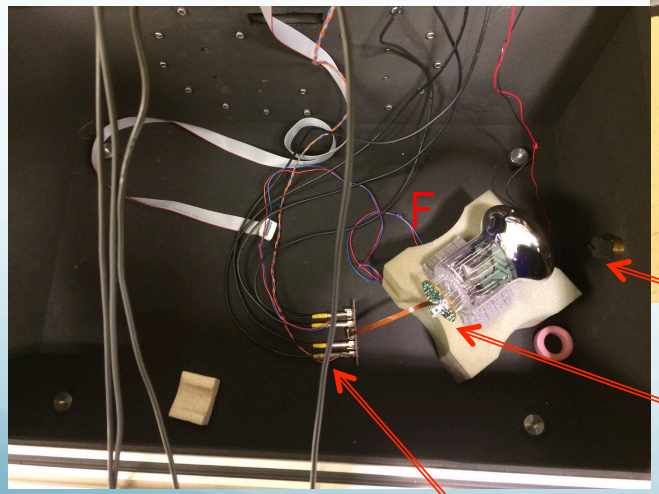


- ToT distributions
- Toa distributions

Setup

A. Black box
B. Photon sources
C. Pulse generator
D. DAQ
E. Controller
F. Hamamatsu PMT



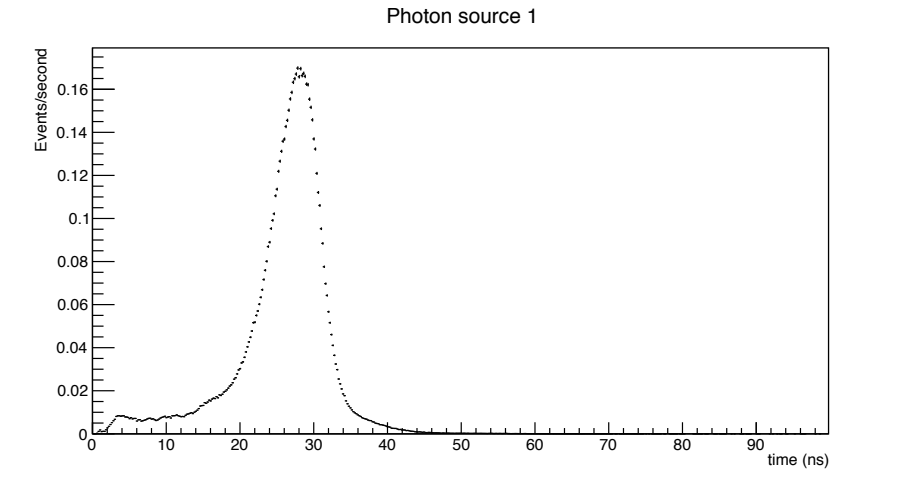


Photons, fiber ends

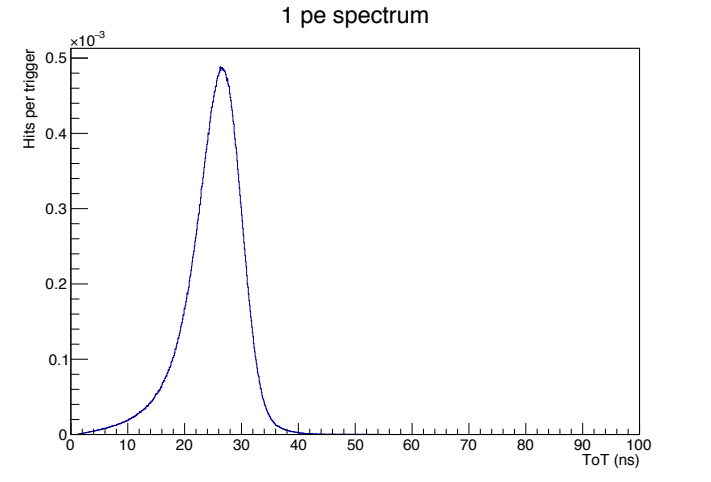
Base

LVDS out, connected with PMT connector

1 photon ToT distribution



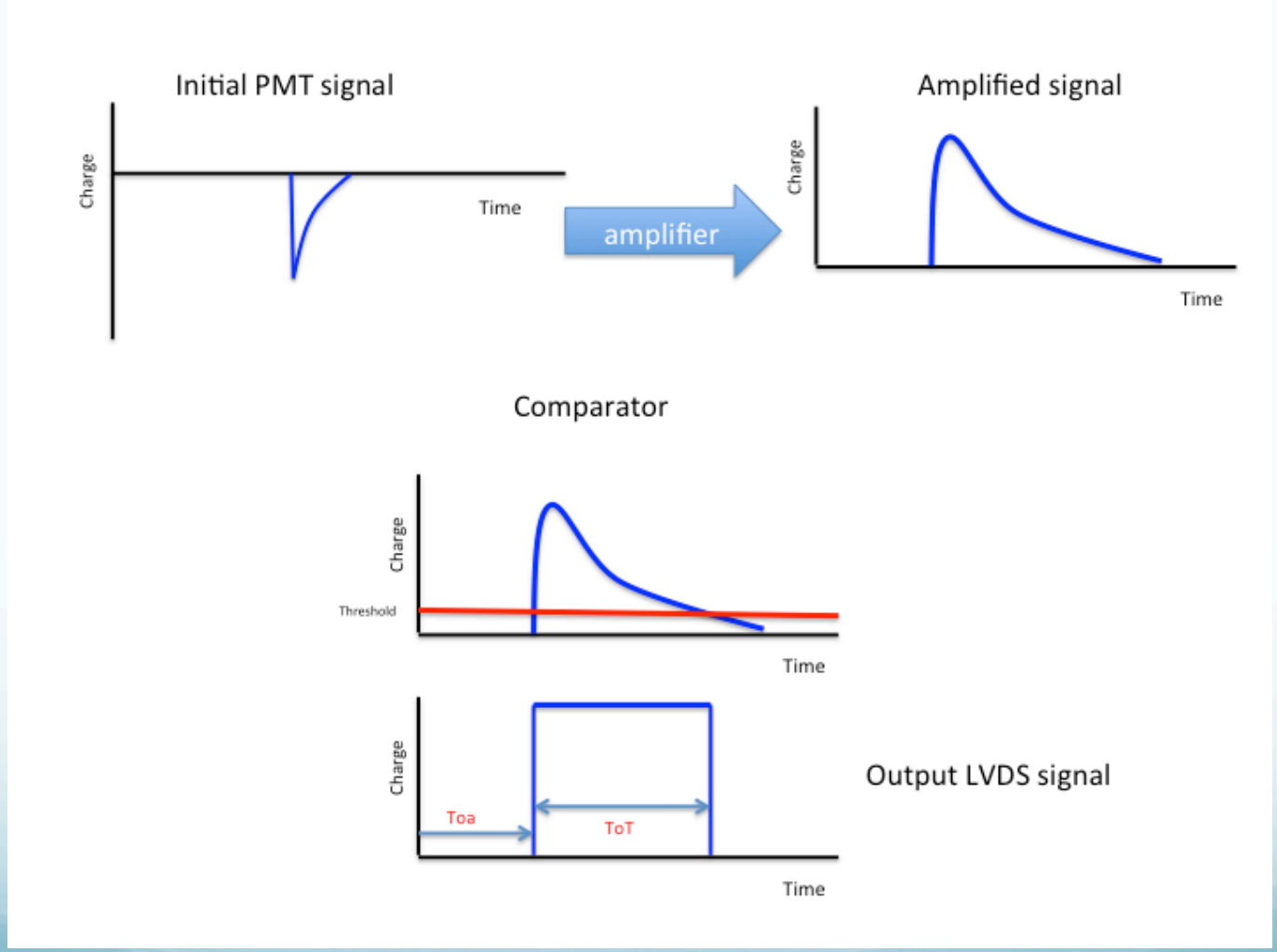
Measurement of the 1 photo electron peak



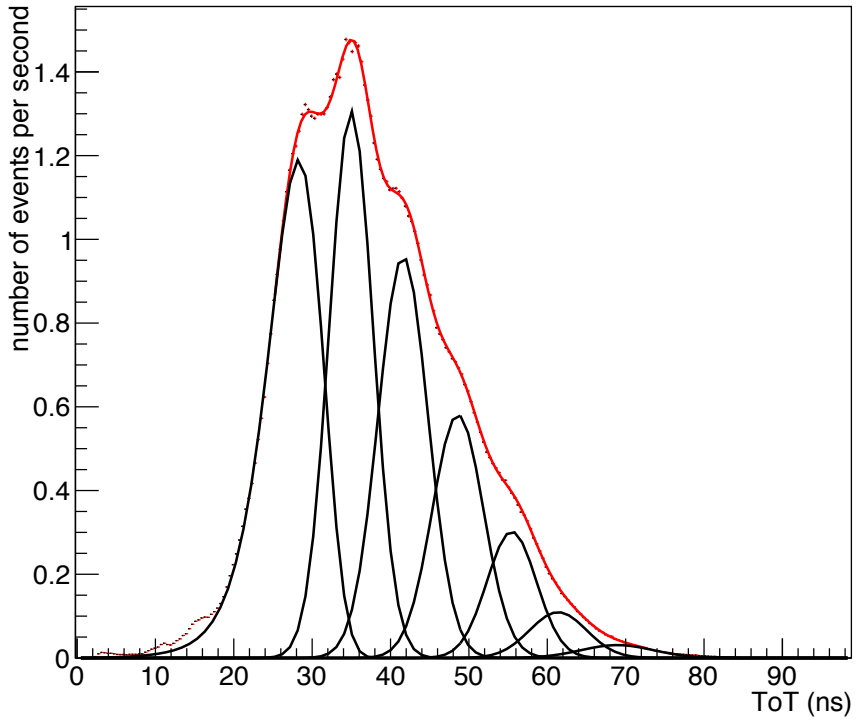
Simulation of the 1 pe peak

- Peak of 1pe peak at 27.10 ± 0.09 ns
- Difference with calibration due to fit model
- Fit in a larger range leads to deviation
- Simulation corresponds with measurement
- 1 pe peak is not Gaussian distributed

Multiple photon distribution

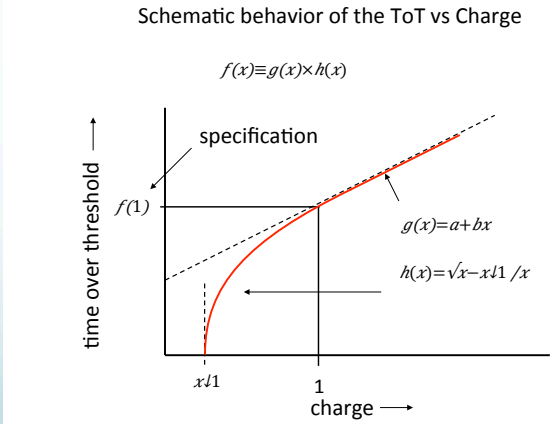


Multiple photon distribution



1 pe peak fitted with transformation Model, due to the linear behavior of the model the 2 pe peak and higher are Gaussian distributed.

- Correlation between the number of photons and ToT
- Poisson constraint on the heights of underlying distributions

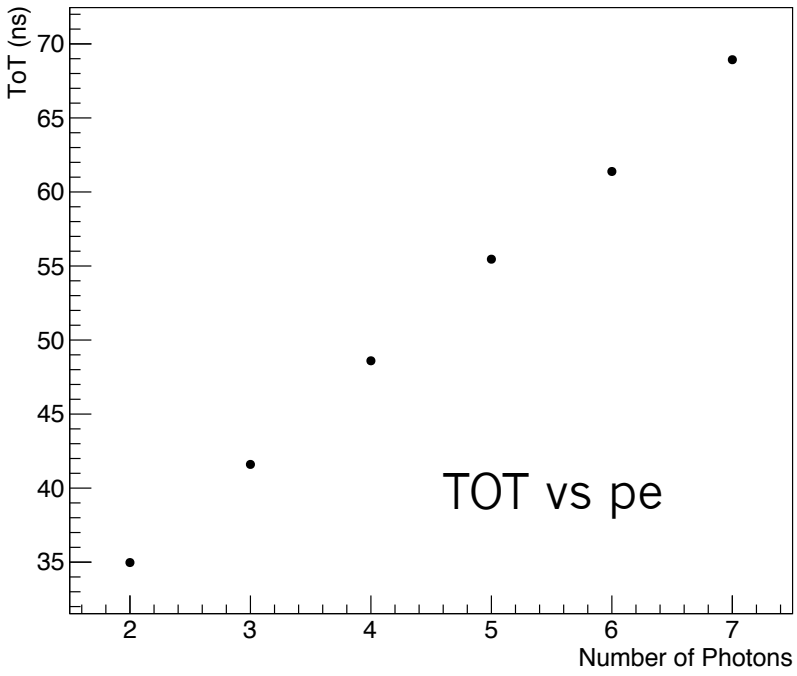


Fit function used:

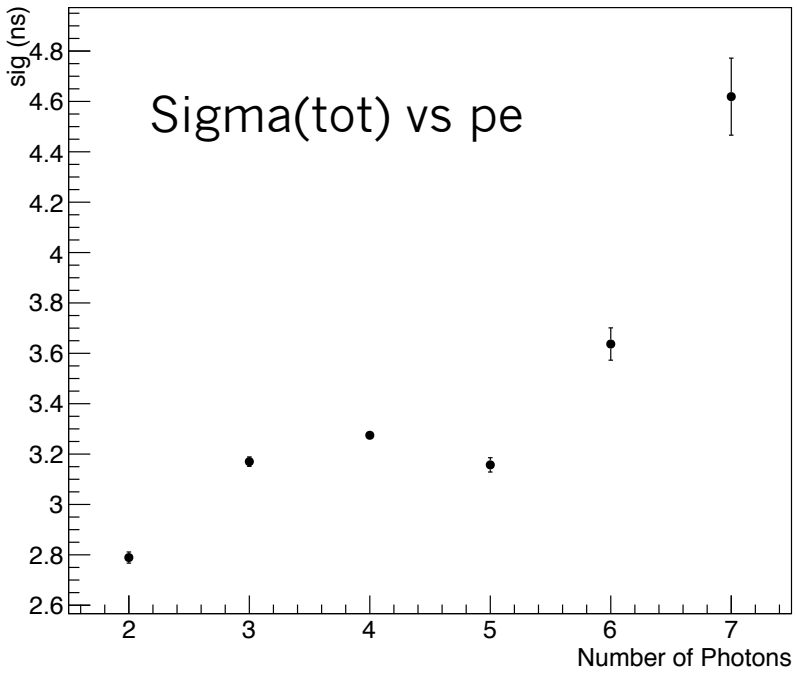
$$F(ToT) = const1 \cdot e^{-0.5\left(\frac{(x-\mu)}{\sigma}\right)^2} \cdot \frac{dQ(tot)}{dtot} + const2 \cdot \sum_{n=2}^{n=7} Pois(\lambda, N) \cdot e^{-0.5\left(\frac{(x-\mu_N)}{\sigma_N}\right)^2}$$

Multiple photon distribution

Distributions of the ToT of peaks



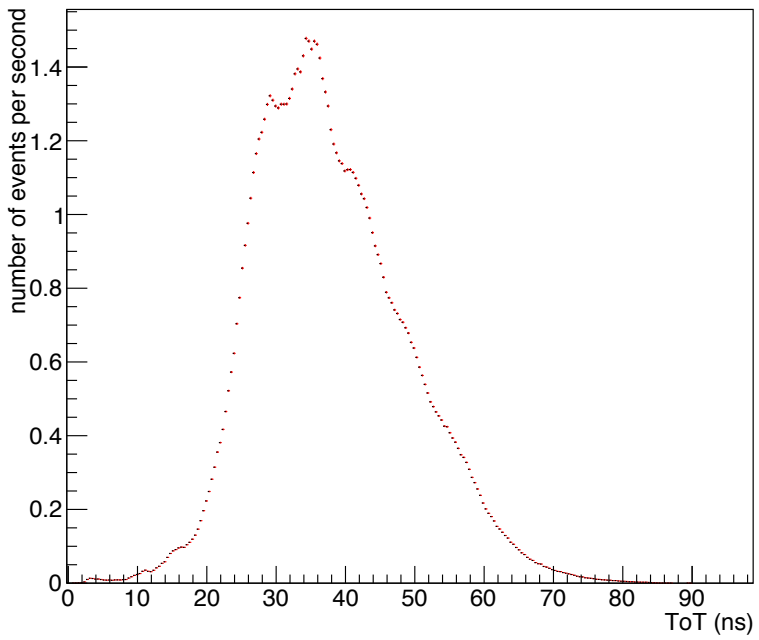
Distributions of the widths of the peaks

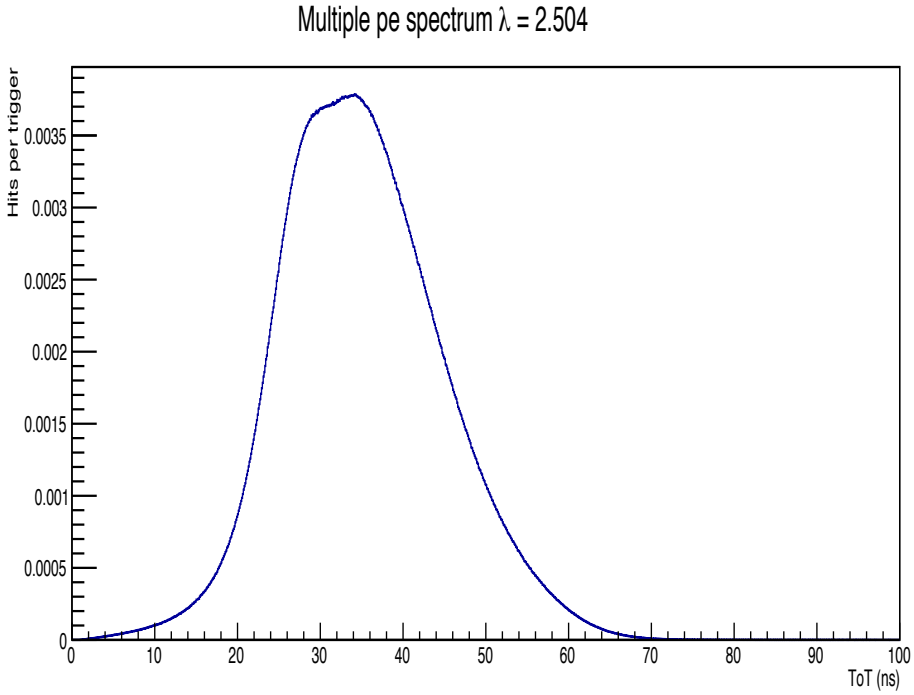


Linear behavior in the ToT of the pe

Irregular behavior in the sigma's
Further studies needed

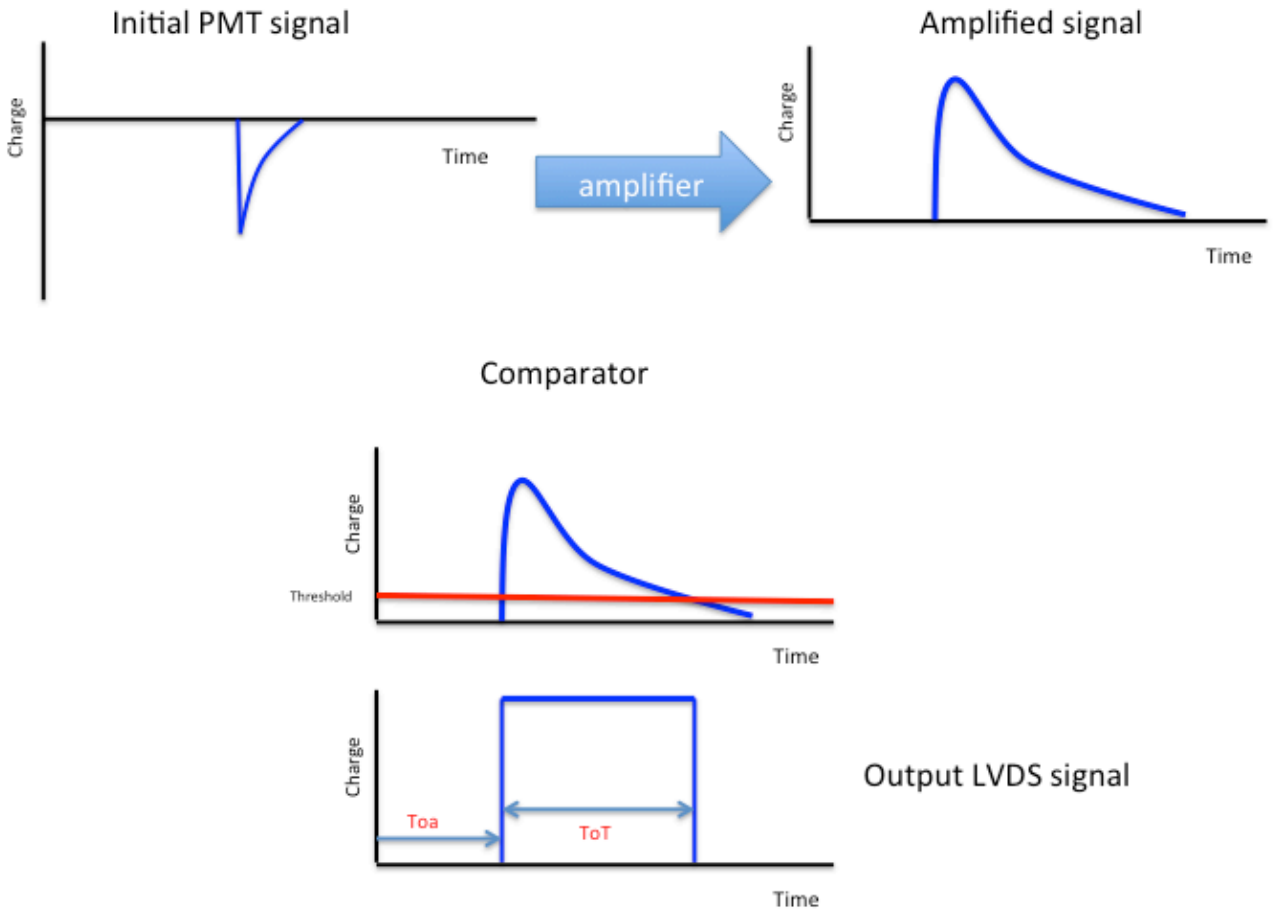
Multiple photon distribution





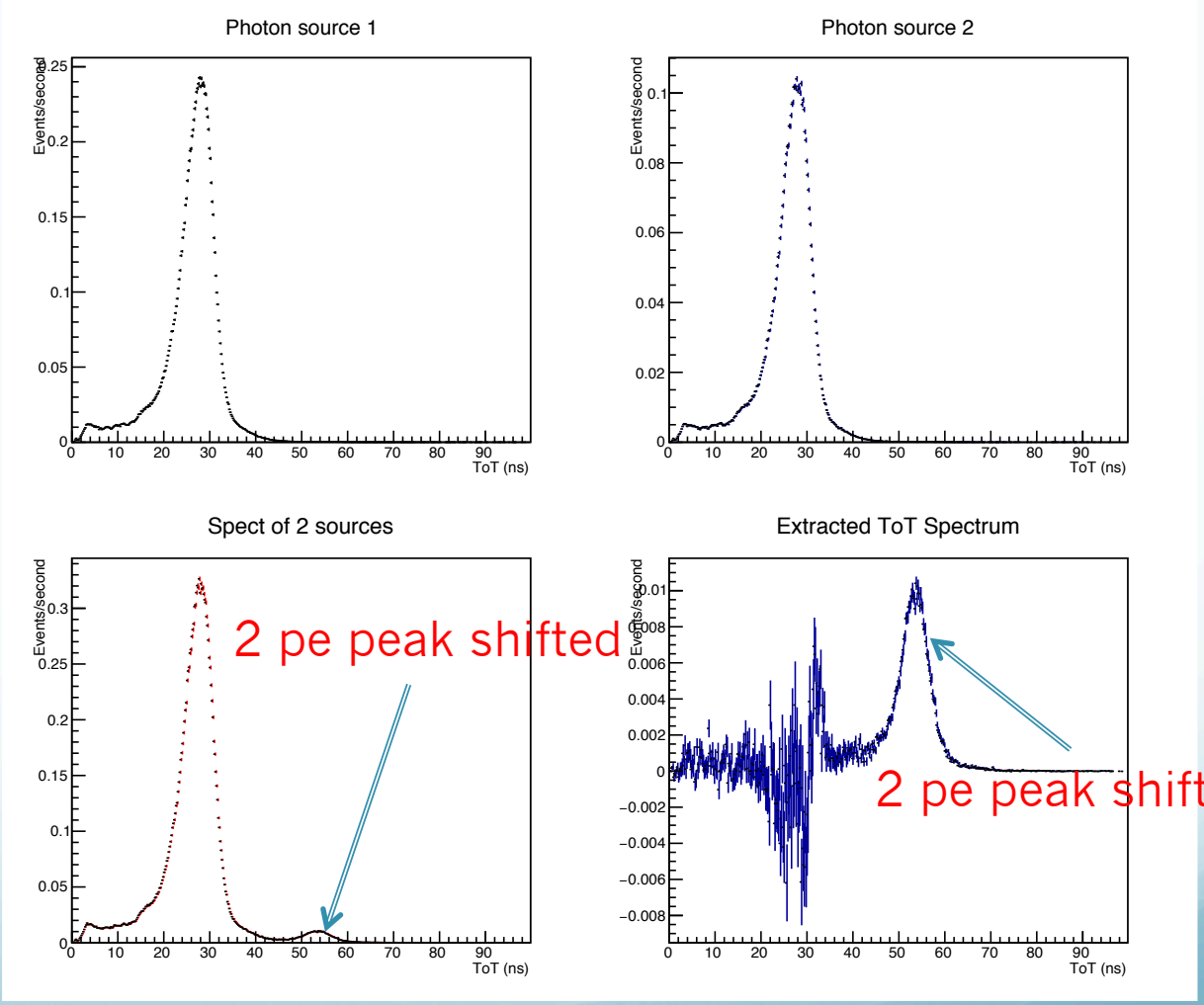
Measurement compared to Simulation. Both the same source intensity.
Simulation breaks down in the higher pe range.
$\lambda = 2.50397$ pe per hit

Δ T between photons



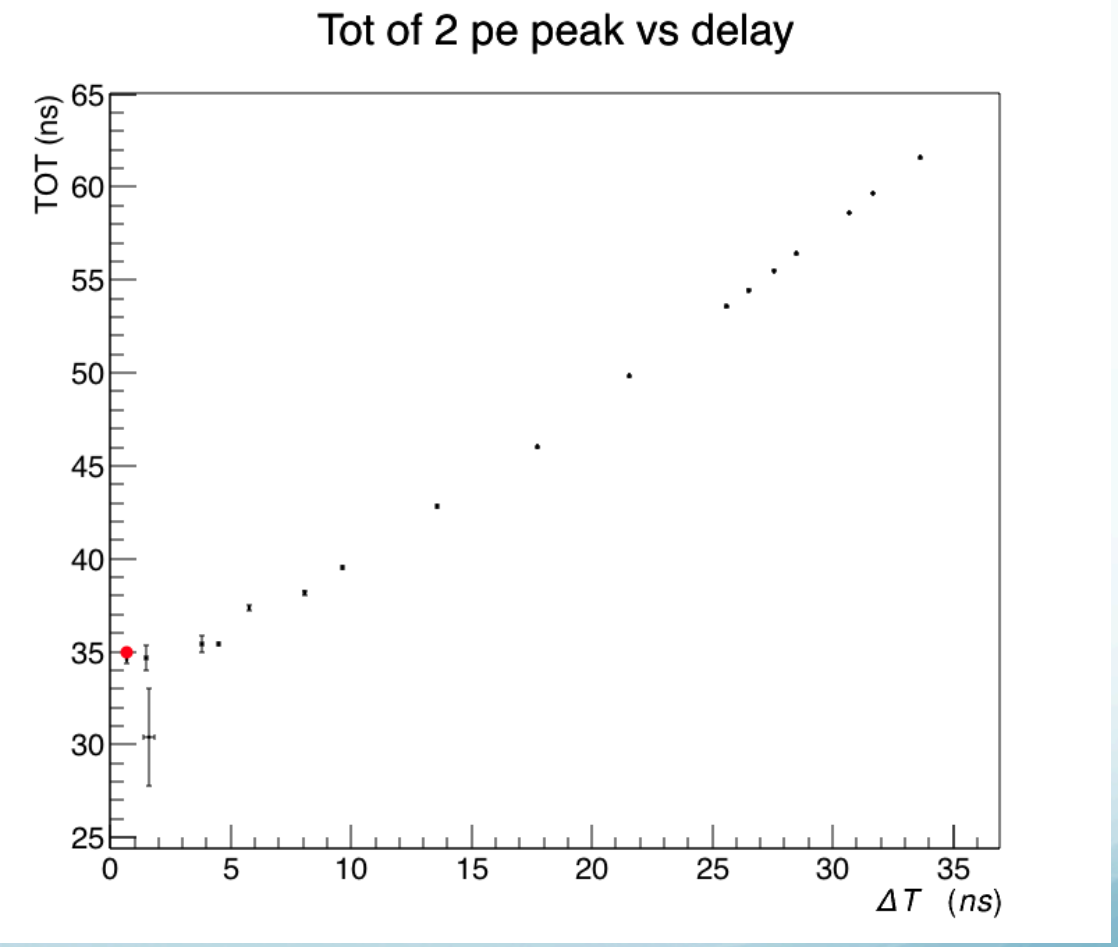
Δ T between photons

- Controllable delay between incoming photons
- Subtraction method used
  - Poisson normalized distributions
- 2 pe peak position determined



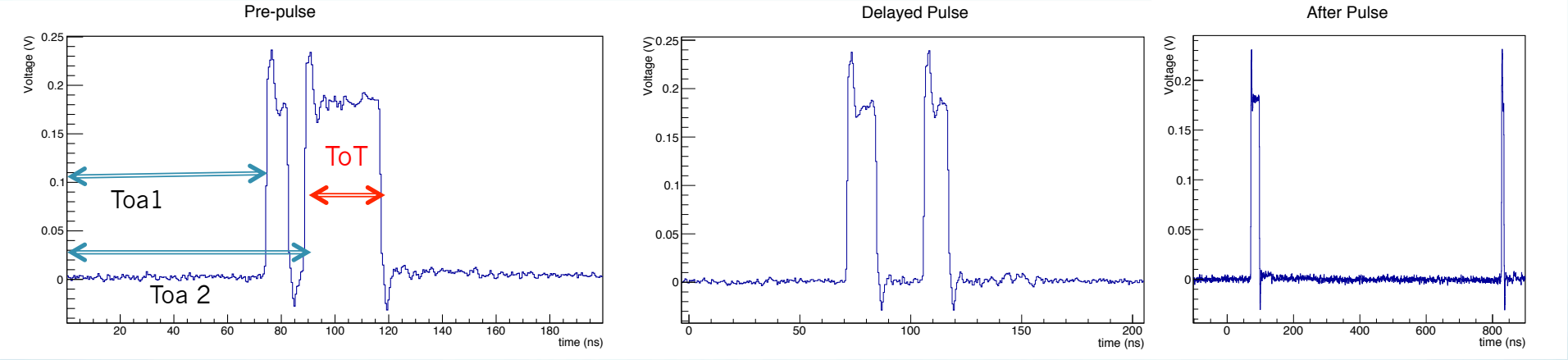
Δ T between photons

- Slewing in the beginning
  - Expected from TTS effects
- Linearity on the right side
- Red dot from multiple photon measurement



Transit time and ToT

- LVDS signal directly measured
- Insight into multiple effects in the PMT
  - More then only ToT response



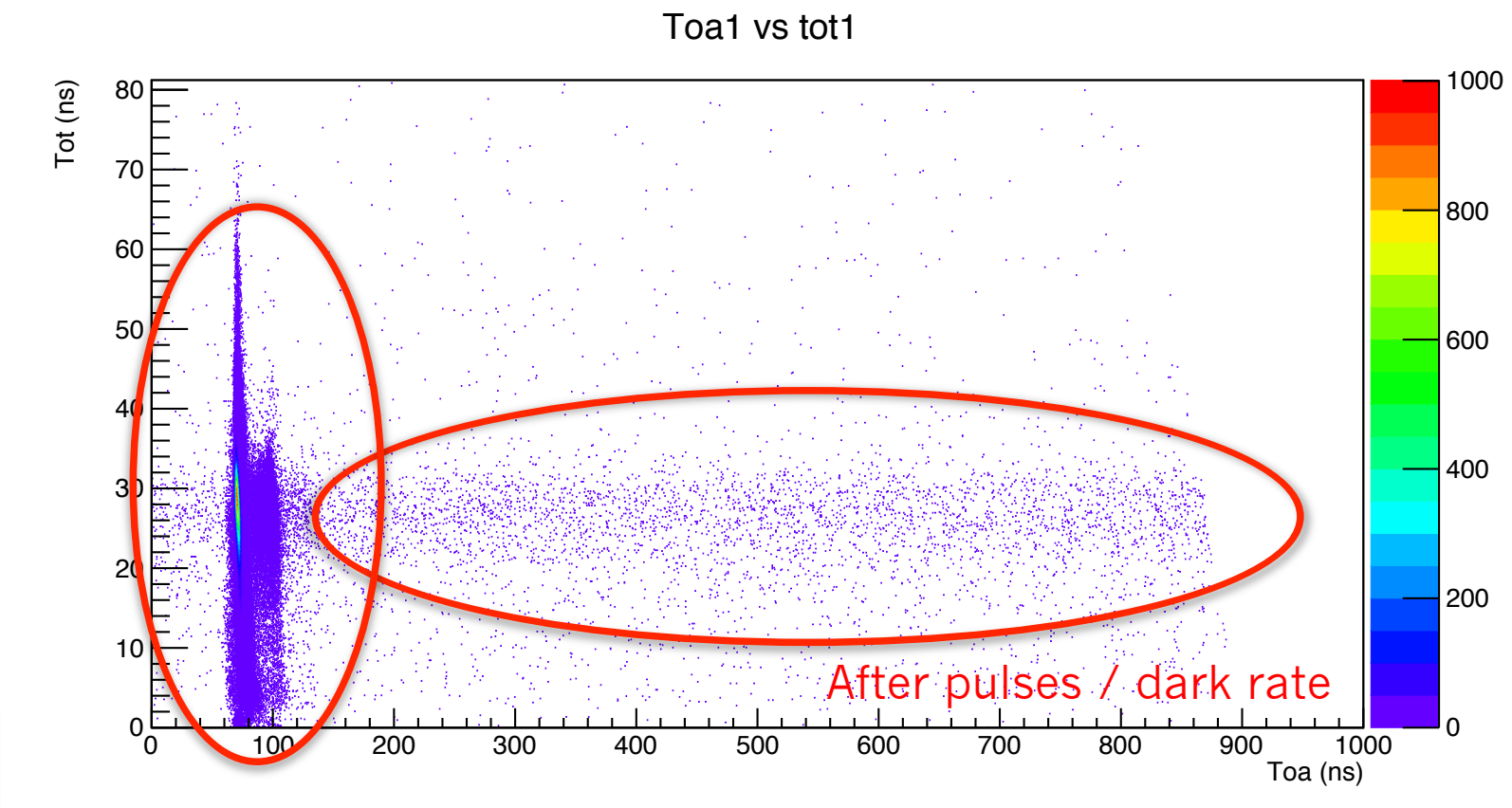
Pre pulse

Delayed pulse

After pulse

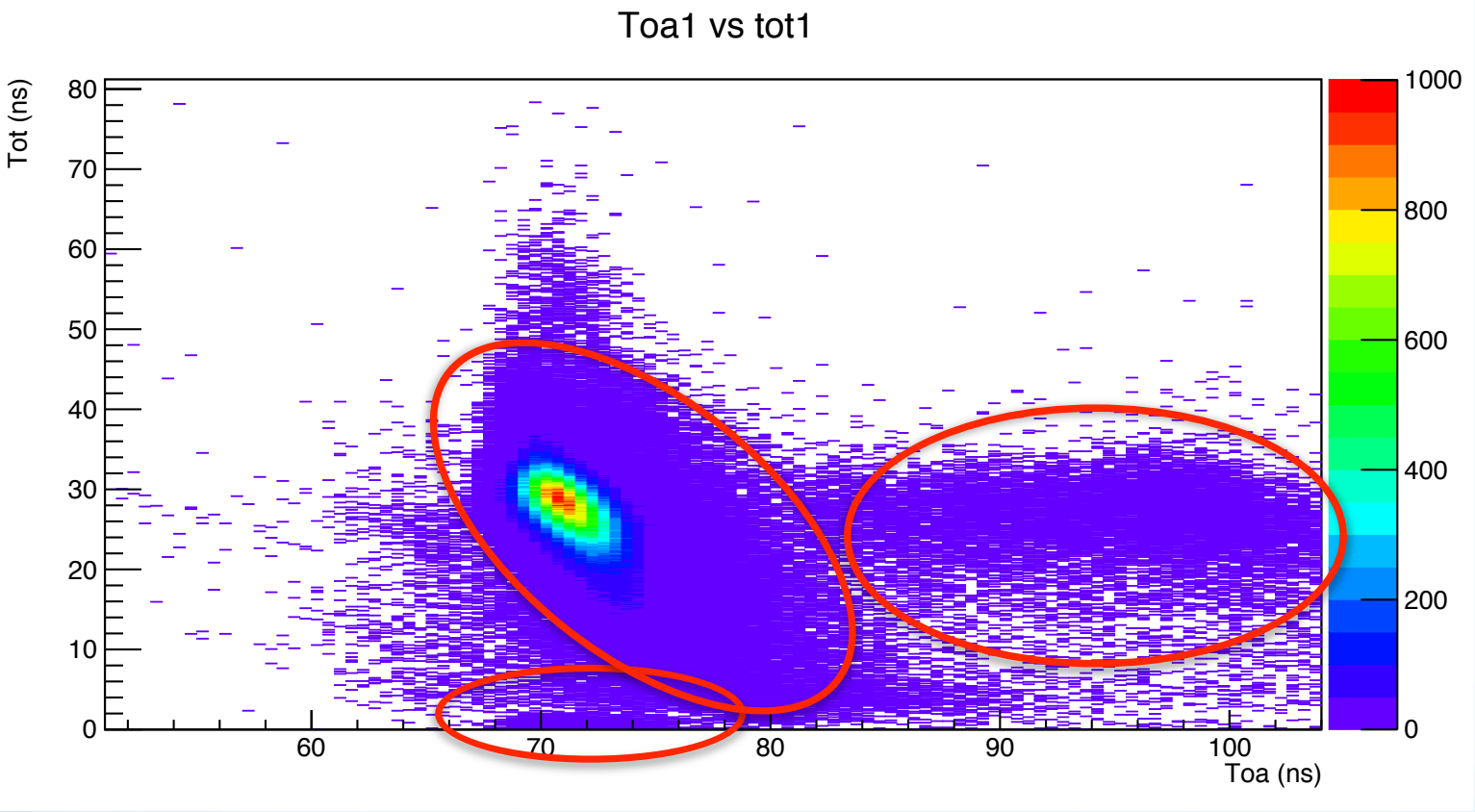
ToT1 = ToT of all first pulses
ToT2 = ToT of second pulses

Transit time and ToT



After pulses / dark rate randomly distributed in the toa plane.

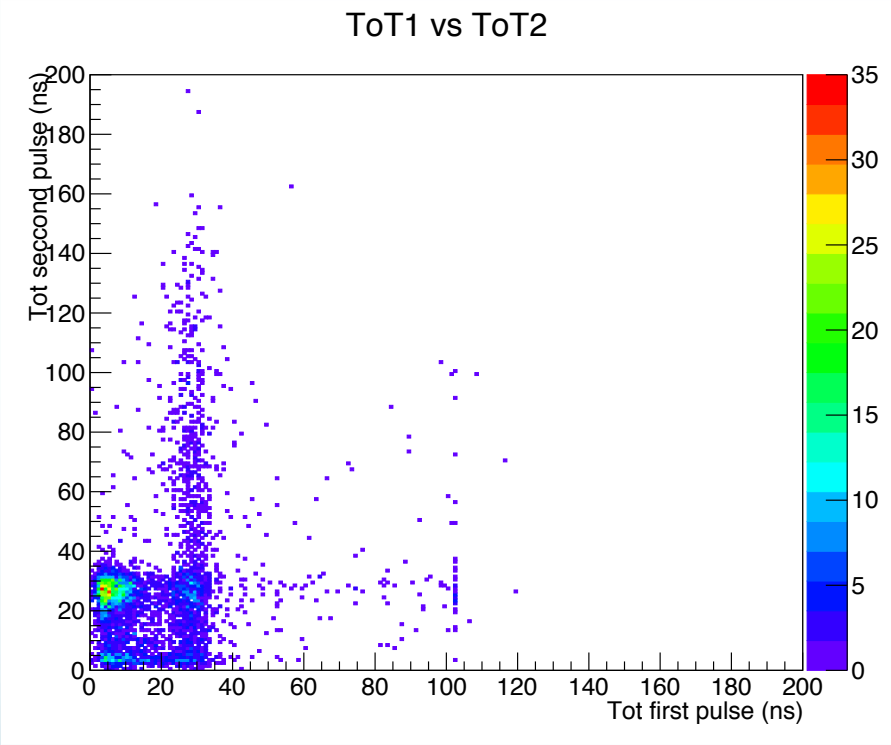
Transit time vs ToT

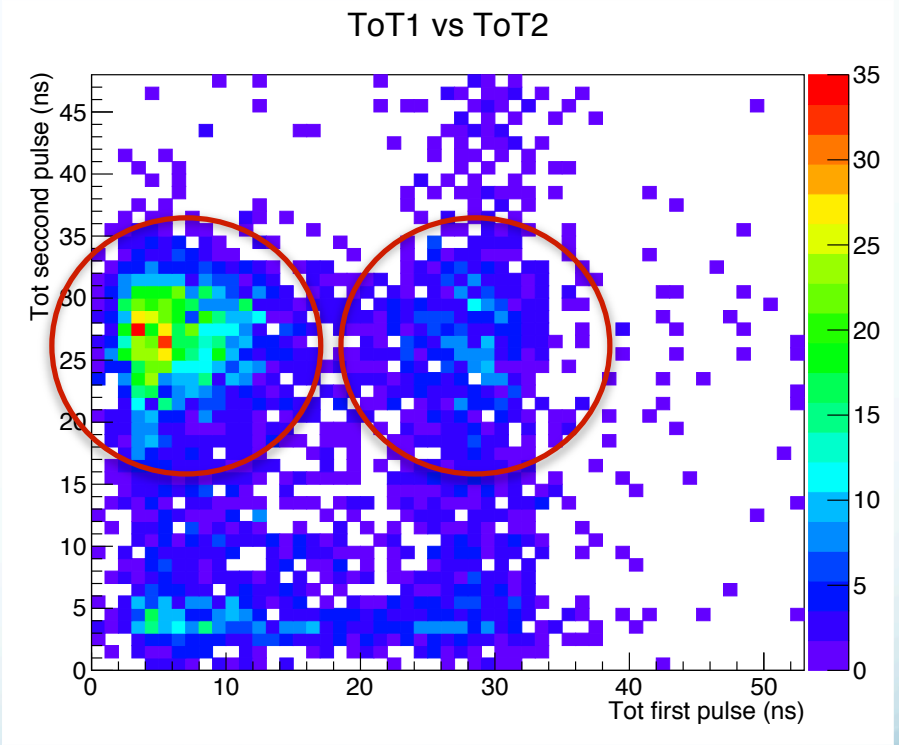


- Normal 1 pe pulses, pre pulses and after pulses / dark rate
- Same effect seen in situ
- Further studies needed

Similar in situ data see elog: http://elog.km3net.de/Analysis/186

ToT1 vs ToT2



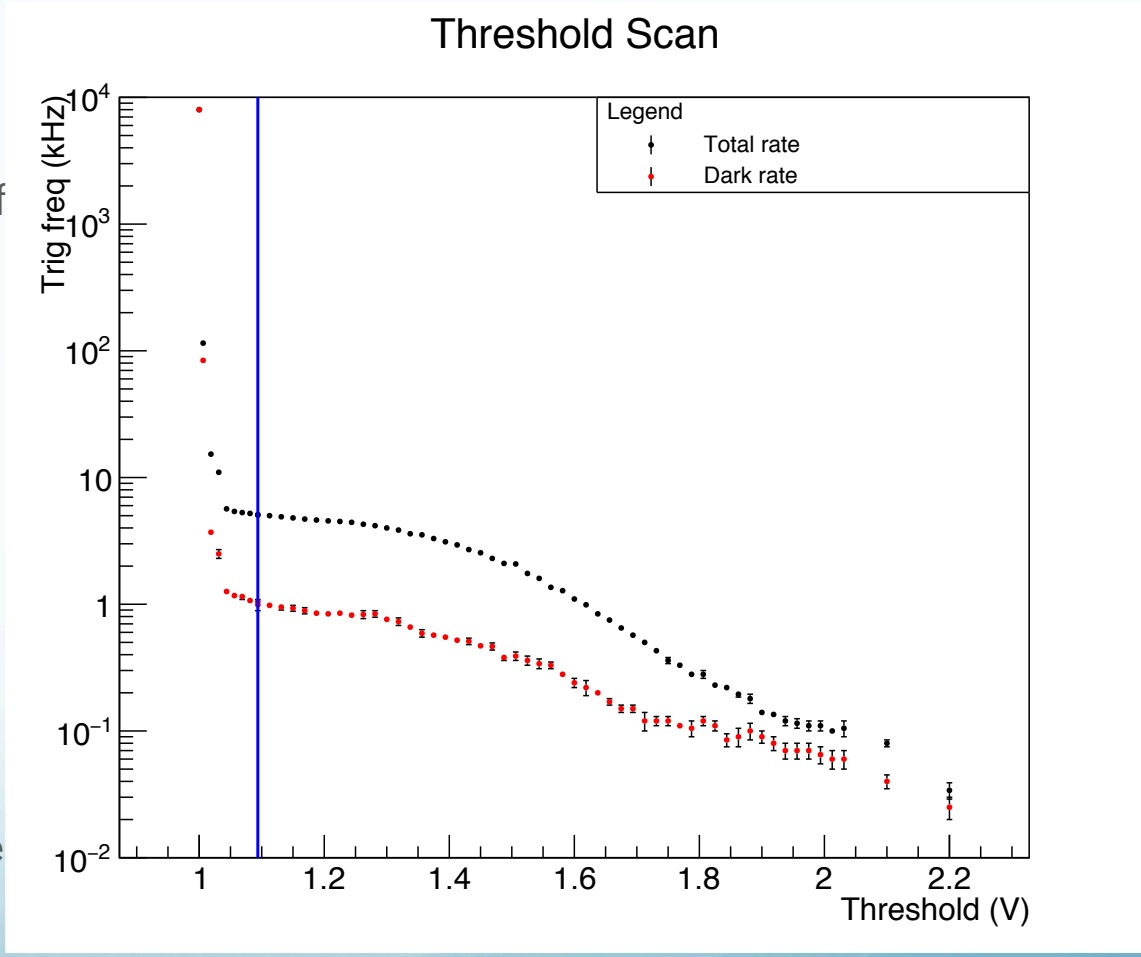


2 populations of pulses.

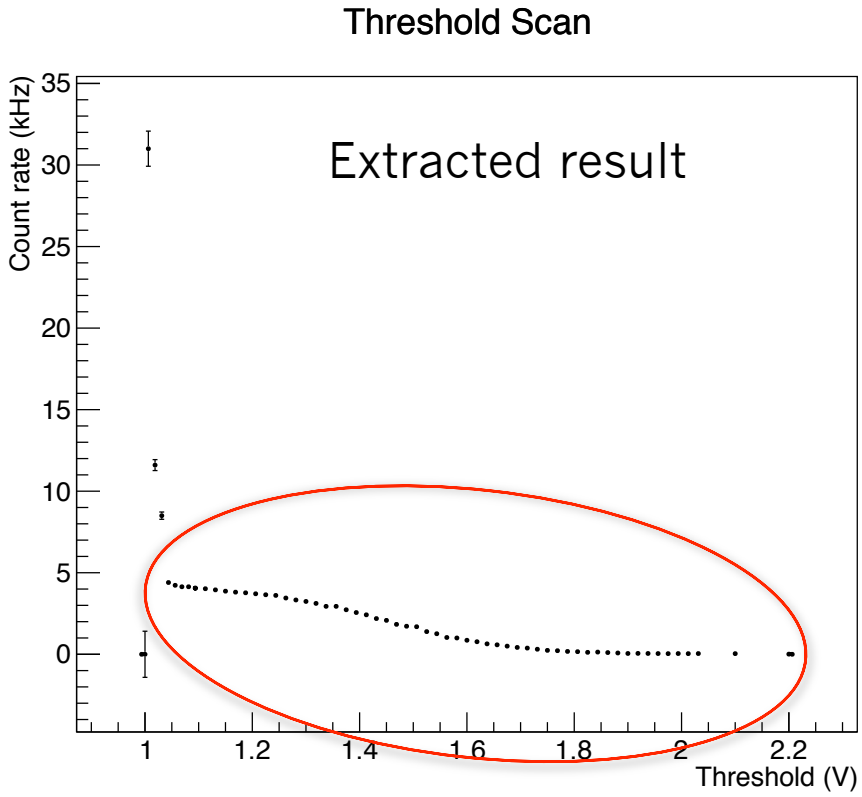
0.92% of the total hits have two hits in one trigger

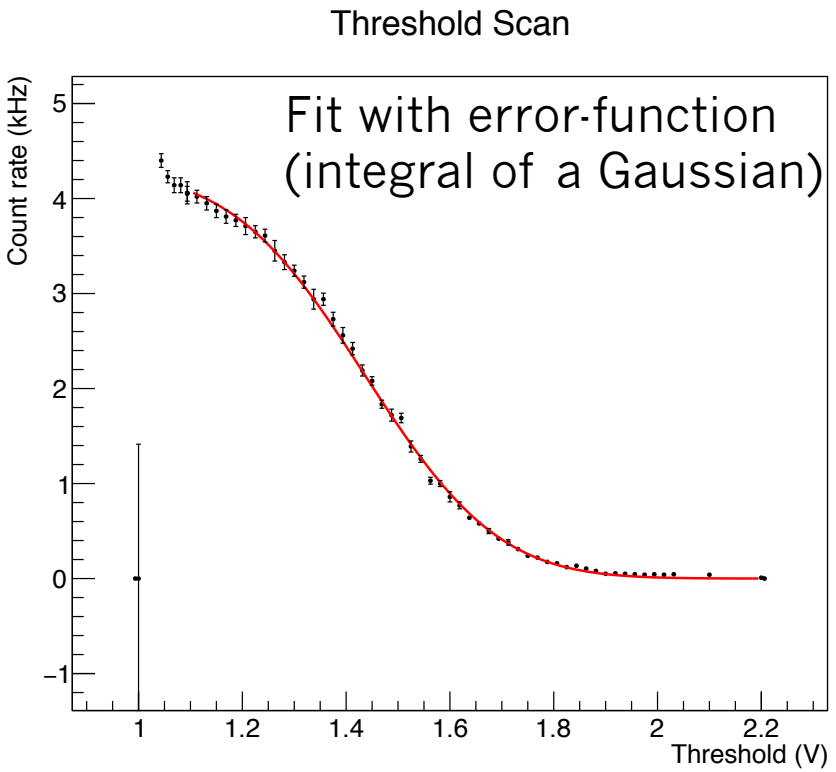
Threshold Scan

- Determine shape of 1 pe peak
  - Identify the current threshold with respect to the amount of pe
  - Width of the 1 pe peak
  - Mean of the 1 pe peak
- Threshold Scan is
  - Set fixed HV at calibrated level
  - Set different thresholds
  - Take count rate
    - Dark rate
    - Photon source + Dark rate



Threshold scan





μ = 1.43674 ± 0.003 V

σ = 0.202 ± 0.002 V = 0.462 ± 0.002 pe

Default threshold at 1.09375 V = 0.2147 ± 0.003 pe

Base line at 1 V

Conclusion and Outlook

- Input from measurements improved simulation model
  - The threshold parameter in the model is adjusted
- First time measured the mean ToT position of the 2 till 7 photon peaks
- Future studies could be:
  - Improve the model further
  - Understand the linear relation between ToT and Toa
  - Doing a threshold scan with multiple PMTs
  - Delayed photons with a higher intensity per source

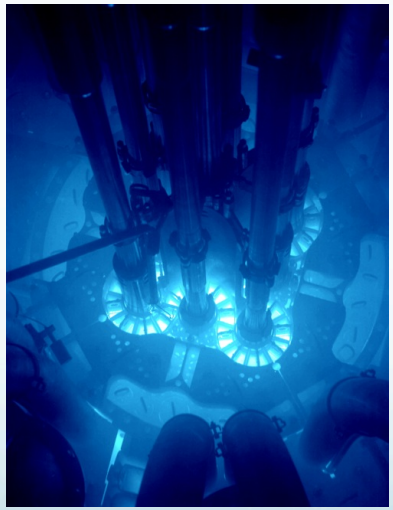
Conclusion and Outlook

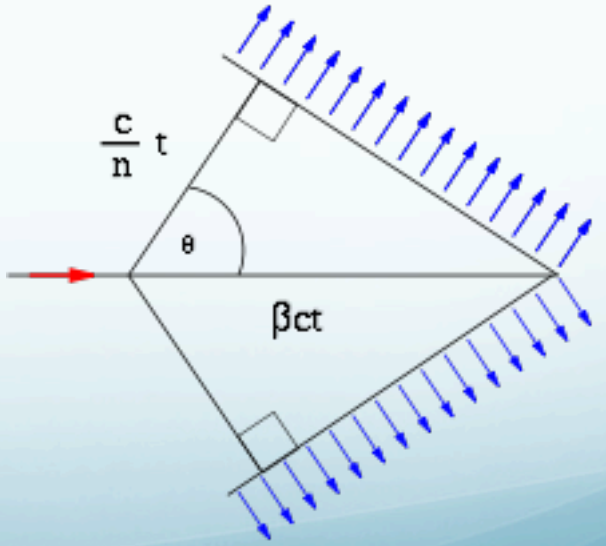
- Better model needed for multiple incoming photons
  - Single photon well described
- Threshold scan:
  - Threshold value is: 1.09375 V = 0.2147 ± 0.003 pe
  - Gain spread (σ) is: 0.202 V = 0.462 ± 0.002 pe
- ToT of 2 pe peak behaves linear with the delay
- Further studies needed in the Toa vs ToT relation

Back up

Cherenkov radiation

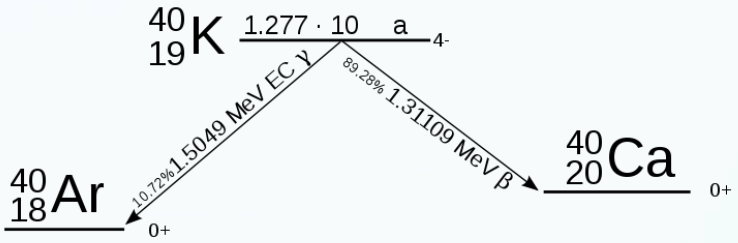
- Relativistic charged particle
  - Faster speed than the speed of light in medium
- Emitted under constant angle: $\cos(\theta) = \frac{1}{n\beta}$





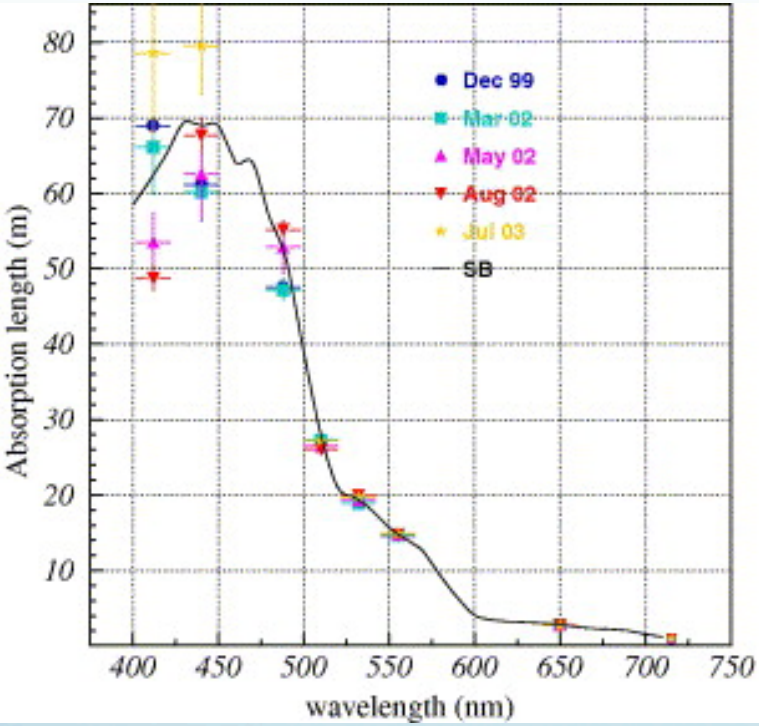
Background effects

- Bioluminescence
- ^{40}K decay
  - Cherenkov electron
- Cosmic muons
  - High energy
  - Path length order of kms



Absorption length water

Between 400 and 500 nm the longest



Relation between ToT and Charge

$f(x) \equiv g(x) \times h(x)$

Model currently used in the PMT response simulations
(extracted from slide by Maarten de Jong)