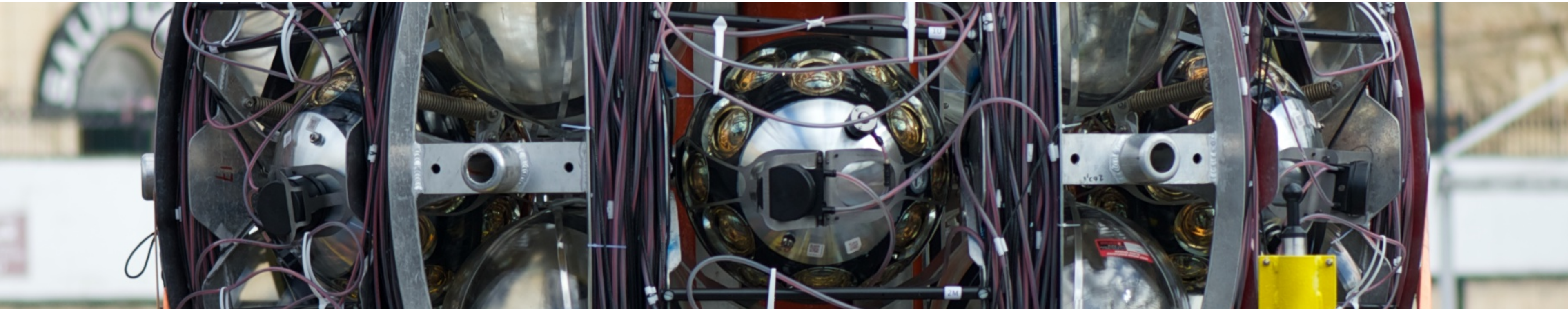
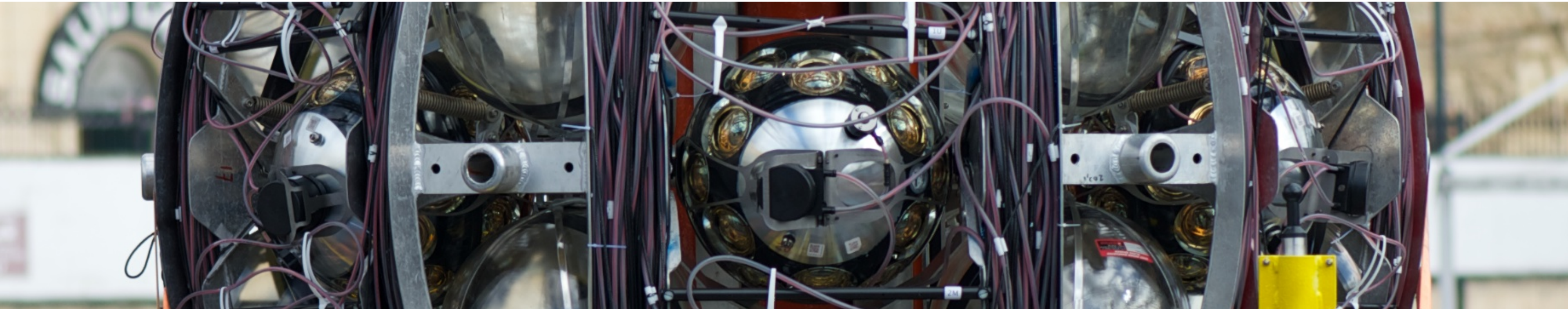
In-Situ Calibration



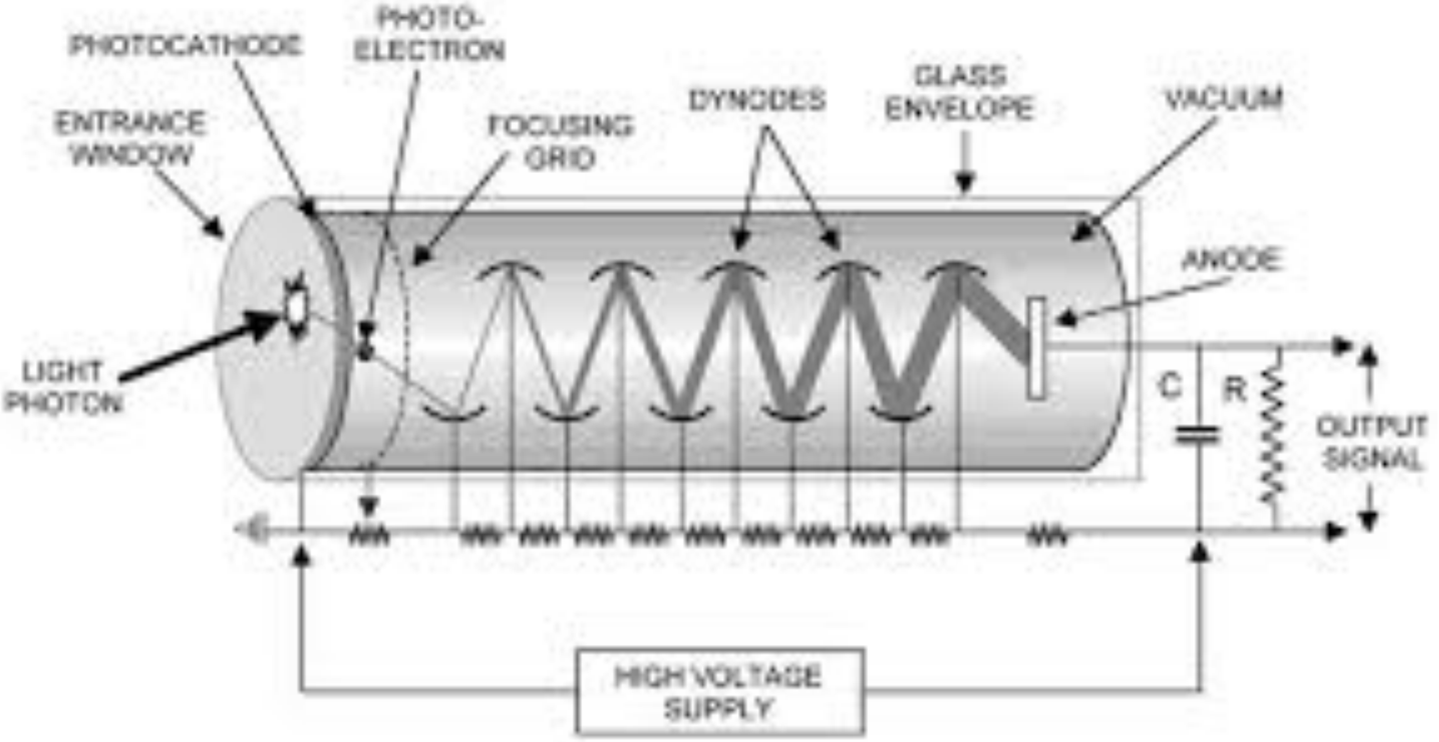
Note for online slides

- Please see the vertcial text on the right of each slide for the script(s) used to produce the plot (and if not in JPP: where to find them)

Part 1: Introduction

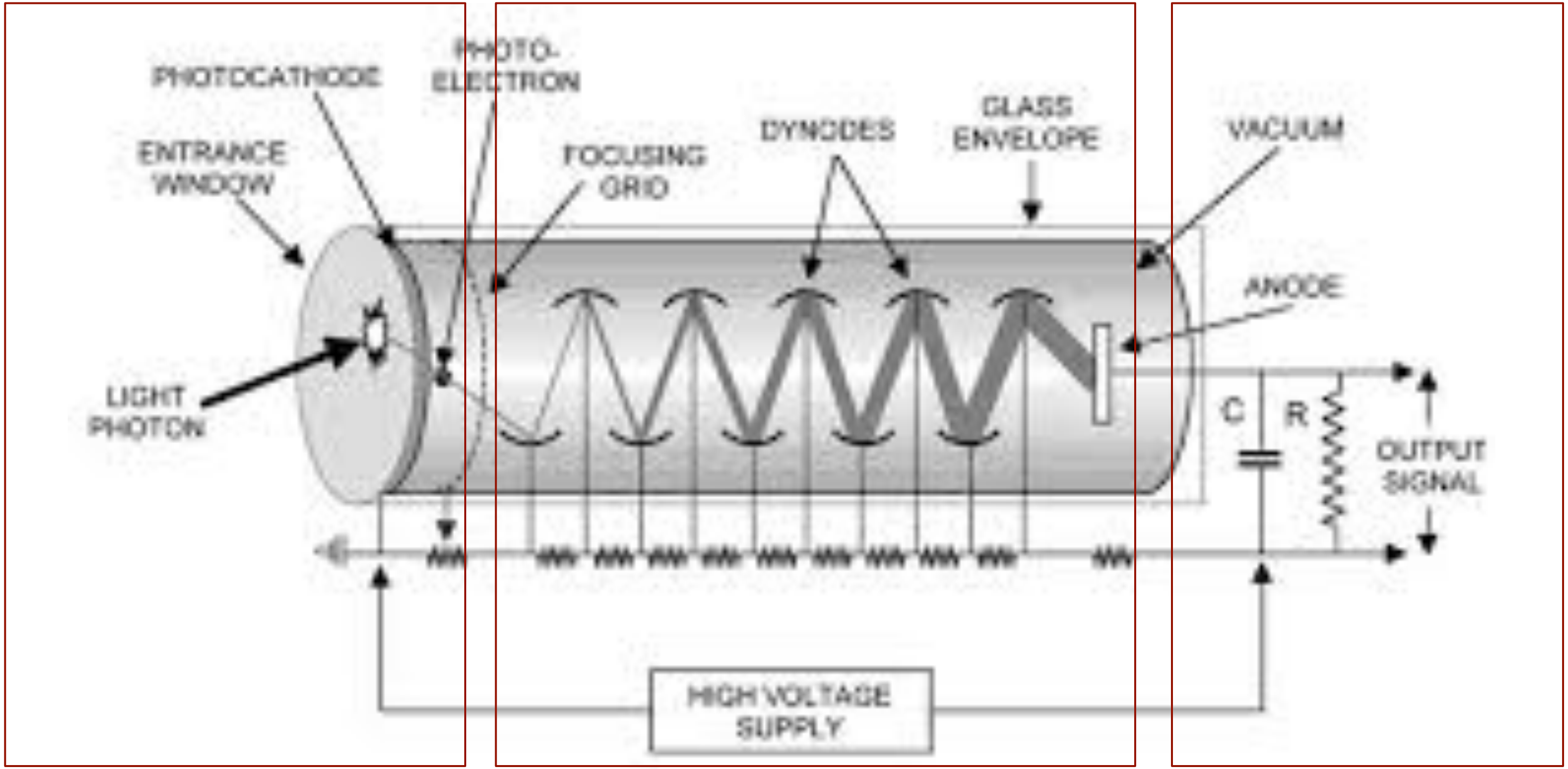


PMTs



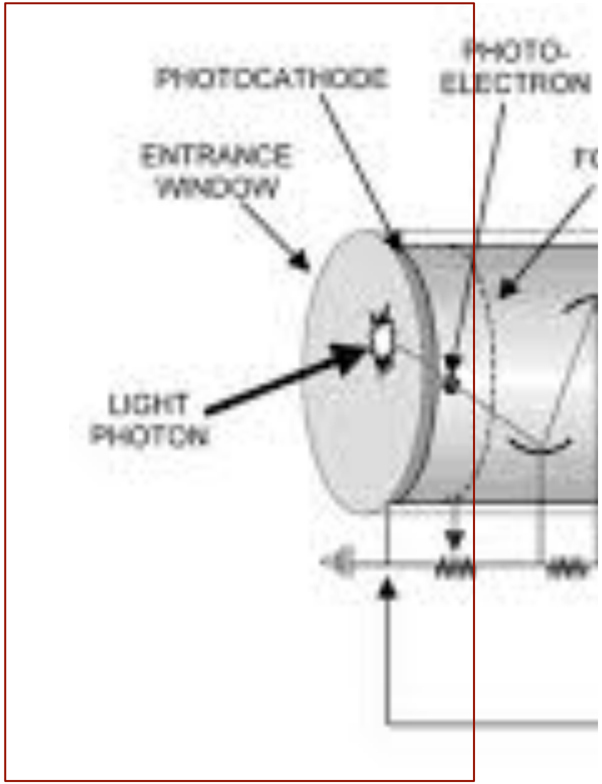
PHOTOCATHODE
PHOTO-
ELECTRON
ENTRANCE
WINDOW
FOCUSING
GRID
DYNODES
GLASS
ENVELOPE
VACUUM
ANODE
LIGHT
PHOTON
C
R
OUTPUT
SIGNAL
HIGH VOLTAGE
SUPPLY

PMTs



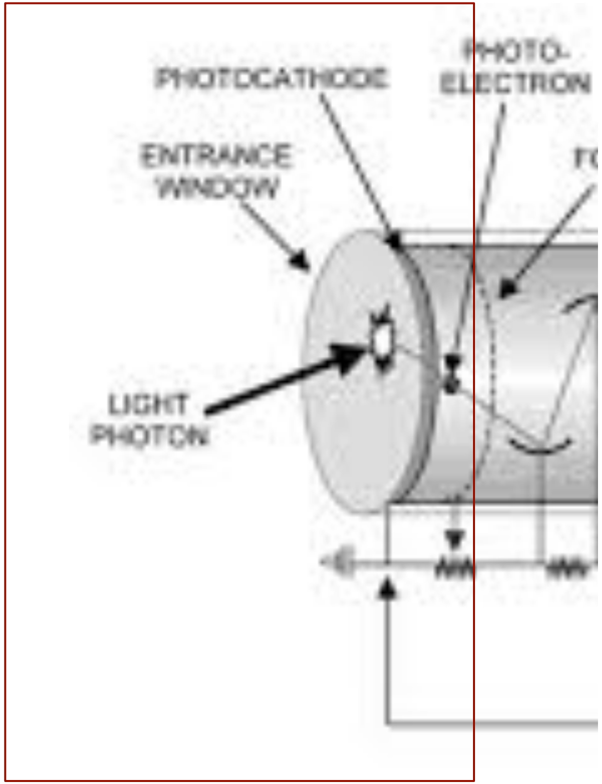
Electron emission Amplification Analogue pulse

PMTs



Electron emission

PMTs

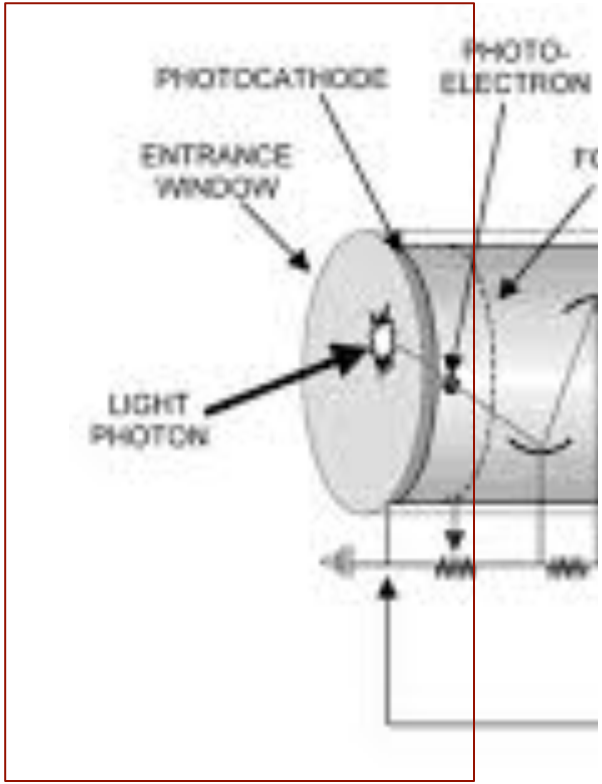


Electron emission

Quantum Efficiency

Probability to emit an electron

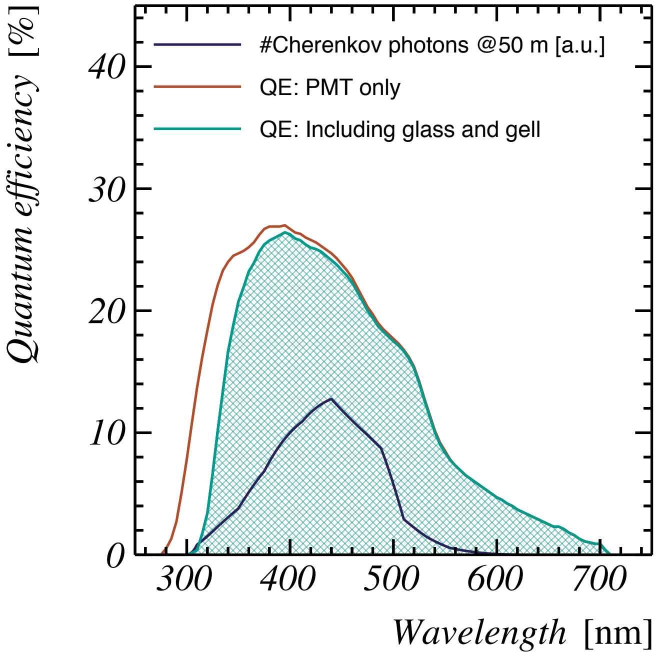
PMTs



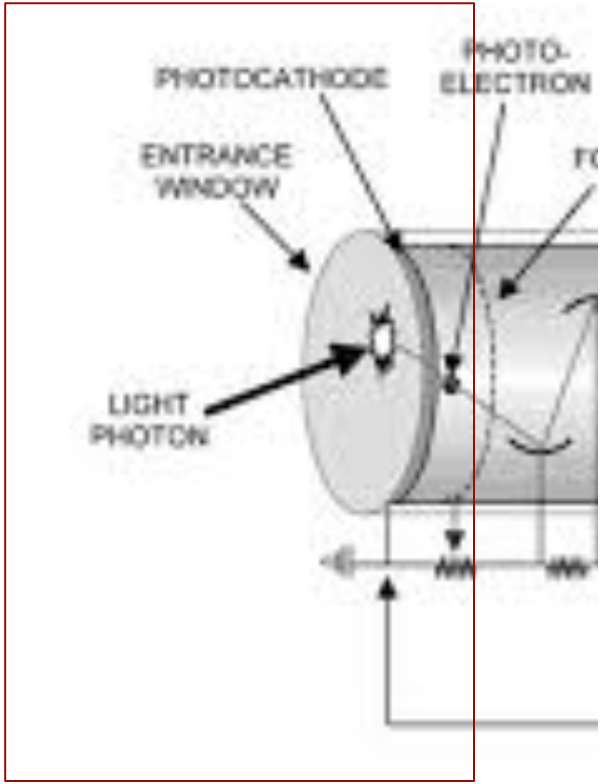
Electron emission

Quantum Efficiency

Probability to emit an electron



PMTs



Electron emission

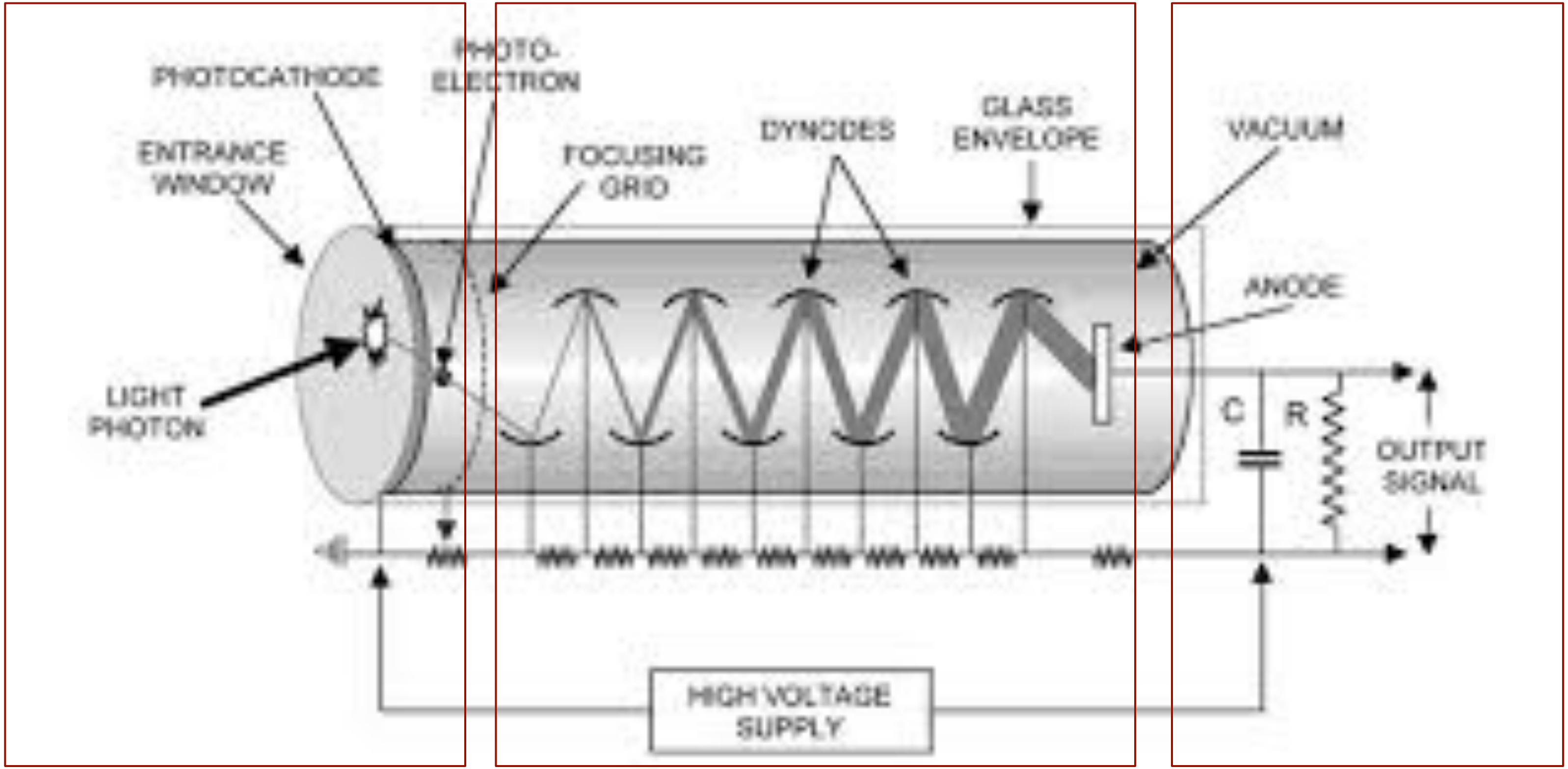
Quantum Efficiency

Probability to emit an electron

Collection Efficiency

Probability to 'catch' the electon

PMTs



Electron emission | Amplification | Analogue pulse

Gain & Gainspread

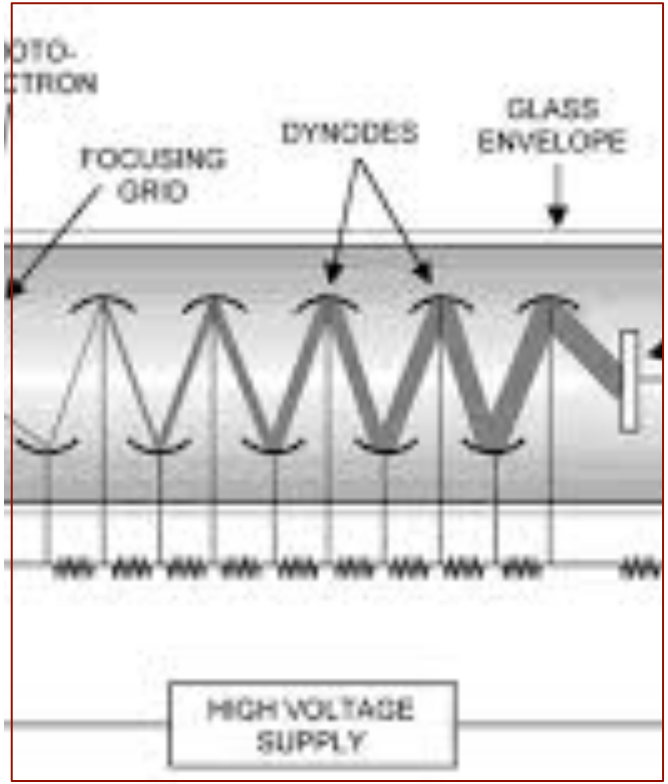
Gain:

#electrons hitting anode given one photoelectron

~3*10^6 in KM3NeT

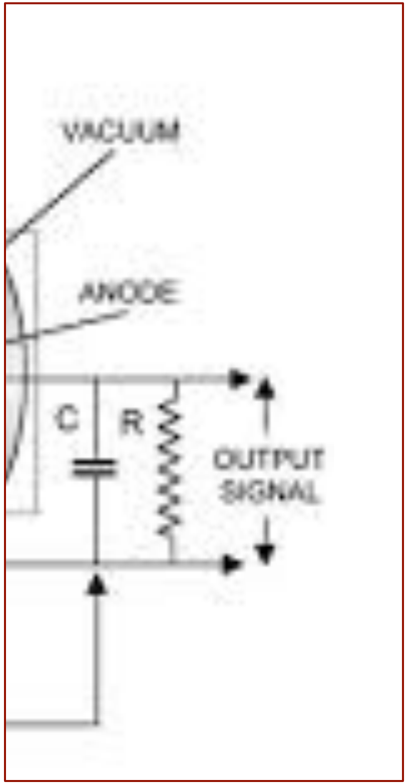
Gainspread:

Statistical fluctuation in #electrons



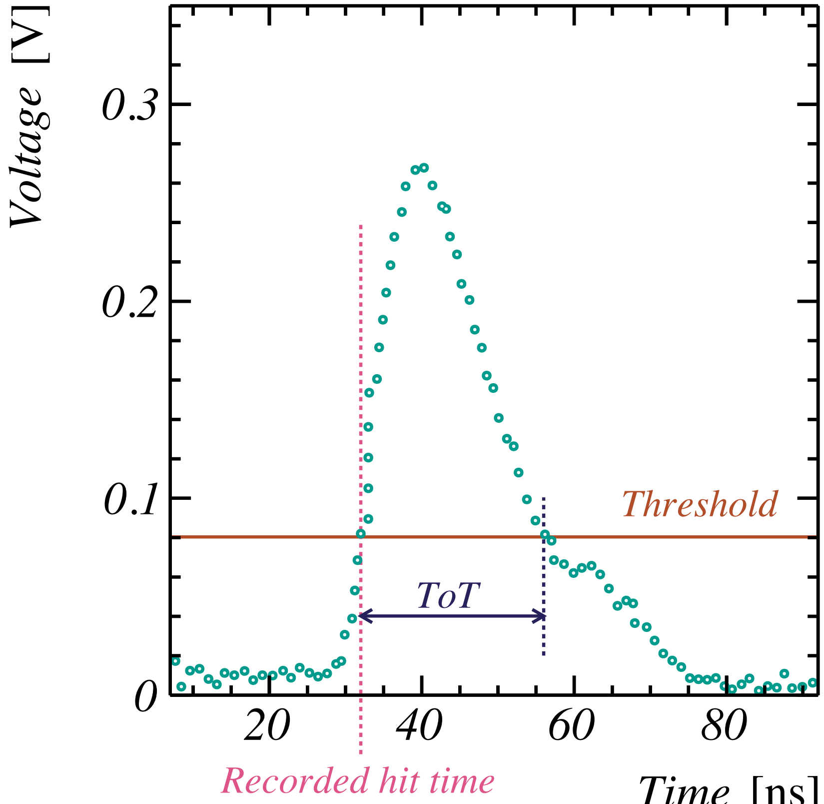
Amplification

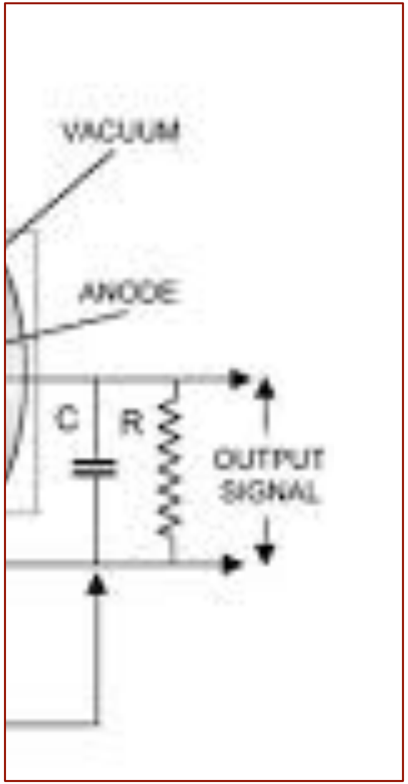
Pulse -> L0 hit



Analogue pulse

Pulse -> L0 hit





Analogue pulse

PMT Parameters

Efficiency-Related

QE shape

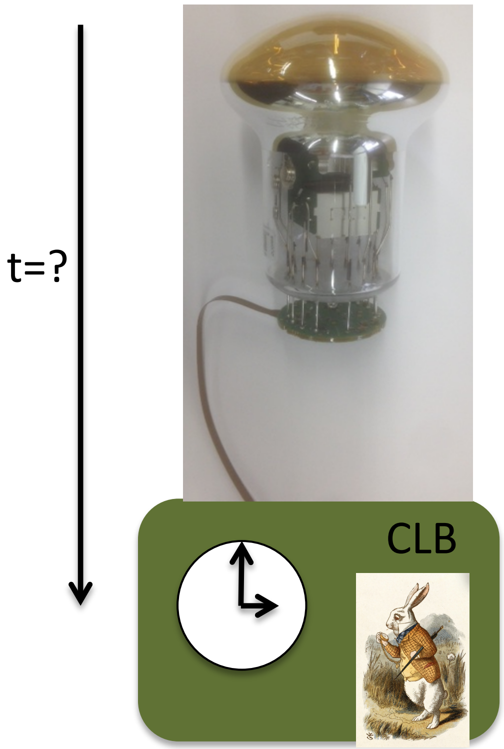
Relative PMT Efficiency

Absolute QE * Collection eff. * …

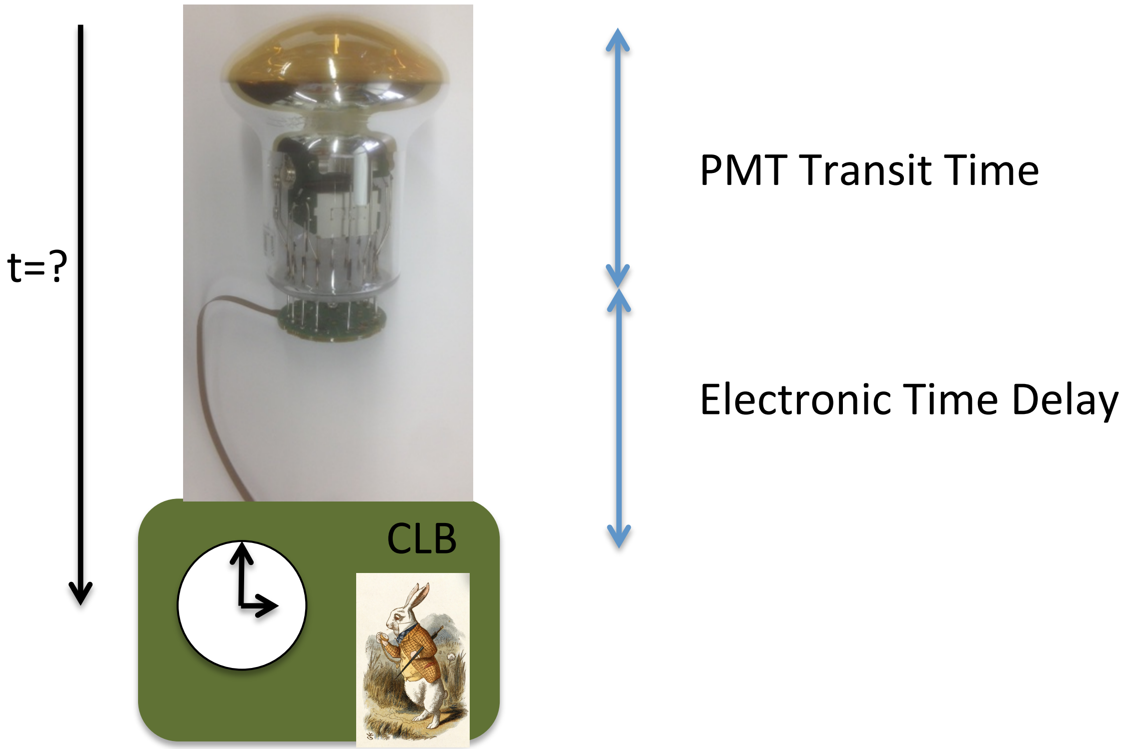
Gain

Gainspread

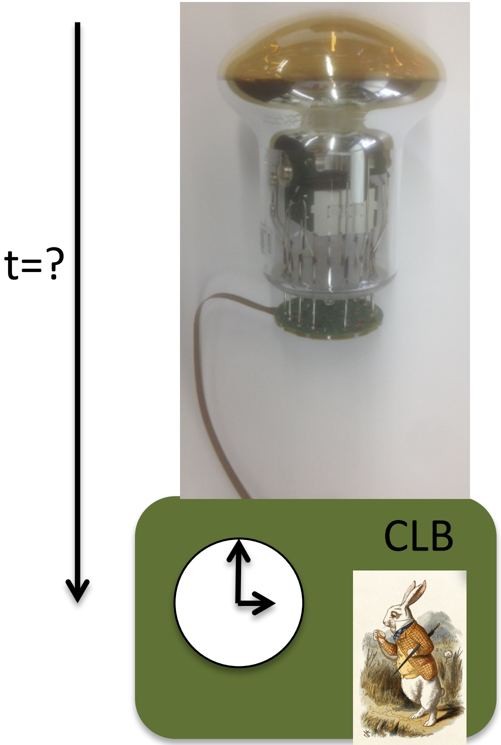
Time-Related Parameters

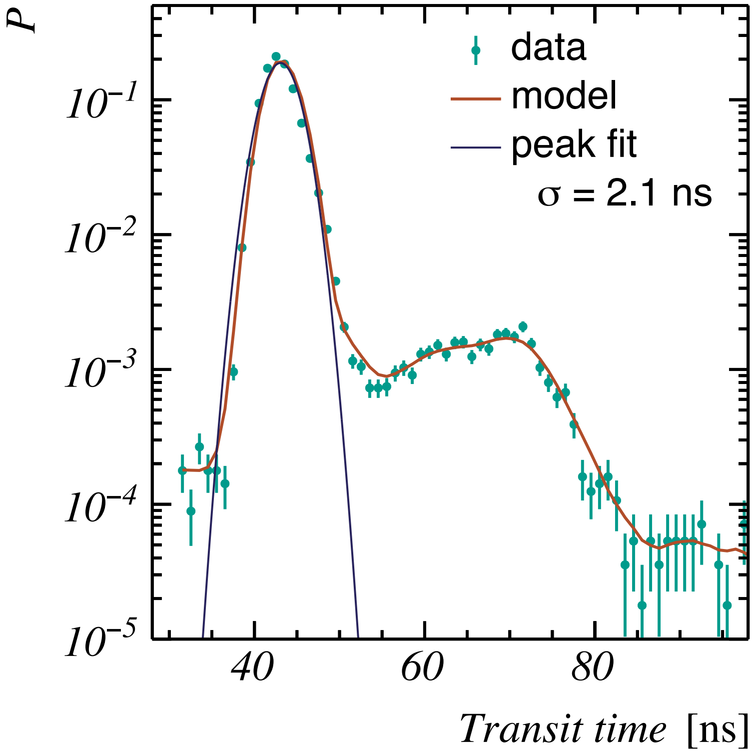


Time-Related Parameters

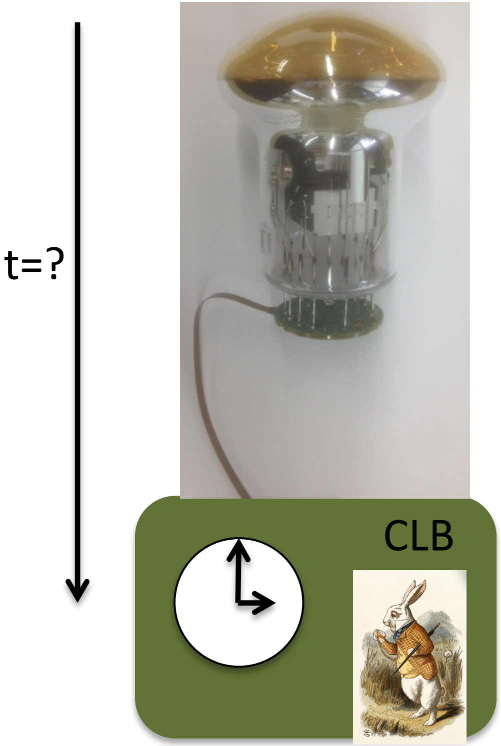


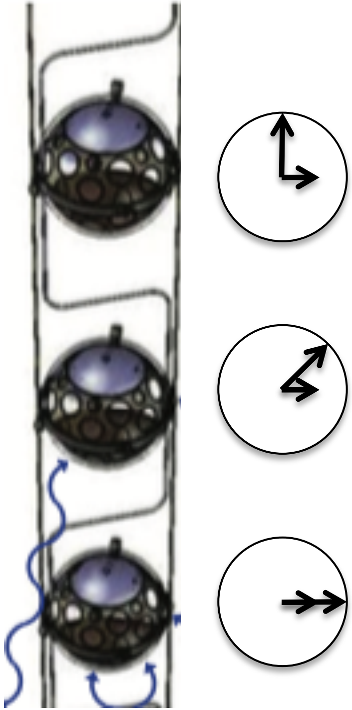
Time-Related Parameters





Time-Related Parameters





PMT Parameters

Efficiency-Related

QE shape

Relative PMT Efficiency

Absolute QE * Collection eff. * …

Gain

Gainspread

Time-Related

Transit time

Transit time spread

Electro-Optical time delays

PMT Parameters

Efficiency-Related

QE shape

Relative PMT Efficiency

Absolute QE * Collection eff. * …

Gain

Gainspread

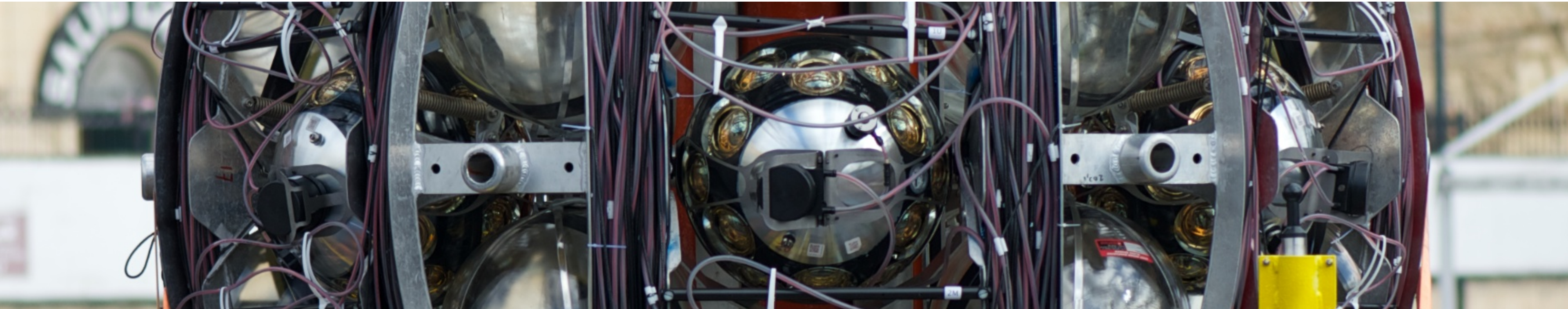
Time-Related

Transit time → PMT Time Offset (detx file)

Transit time spread

Electro-Optical time delays → PMT Time Offset (detx file)

Part 2: In-Situ Calibration



Motivation: Why In-Situ?

115*18*31=64170 PMTs

-> 3.5 years of work (assuming 5min/PMT)

Detector settings and environment change over time

HV settings, temperature, etc.

In-situ calibration allows to monitor+calibrate all PMTs over detector livetime, without the need for special calibration runs (=downtime)

PMT Parameters

Efficiency-Related

Relative PMT Efficiency

Absolute QE * Collection eff. * …

Gain

Gainspread

Time-Related

PMT Time offset

Transit time spread

PMT Parameters

Efficiency-Related

Relative PMT Efficiency

Absolute QE * Collection eff. * …

Gain

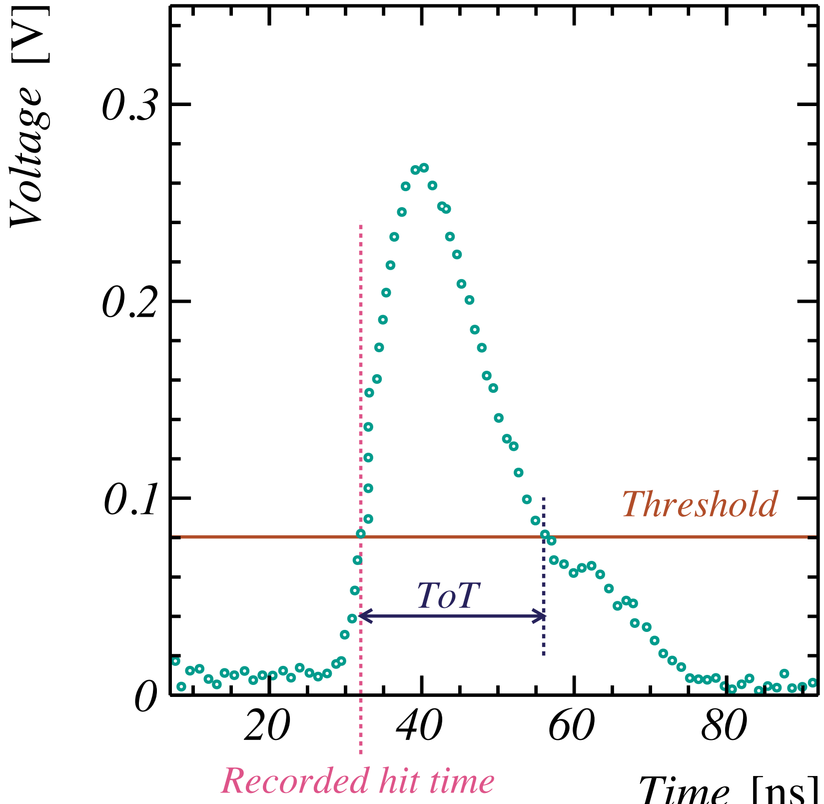
Gainspread

Time-Related

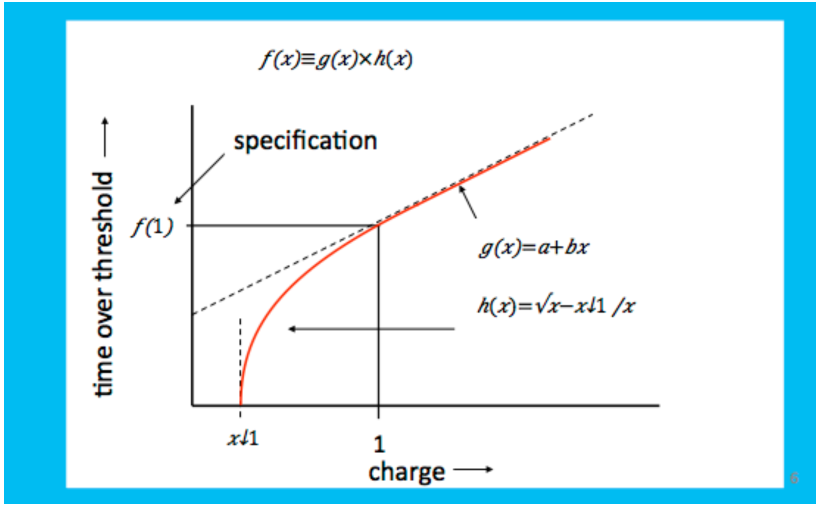
PMT Time offset

Transit time spread

Time-over-Threshold

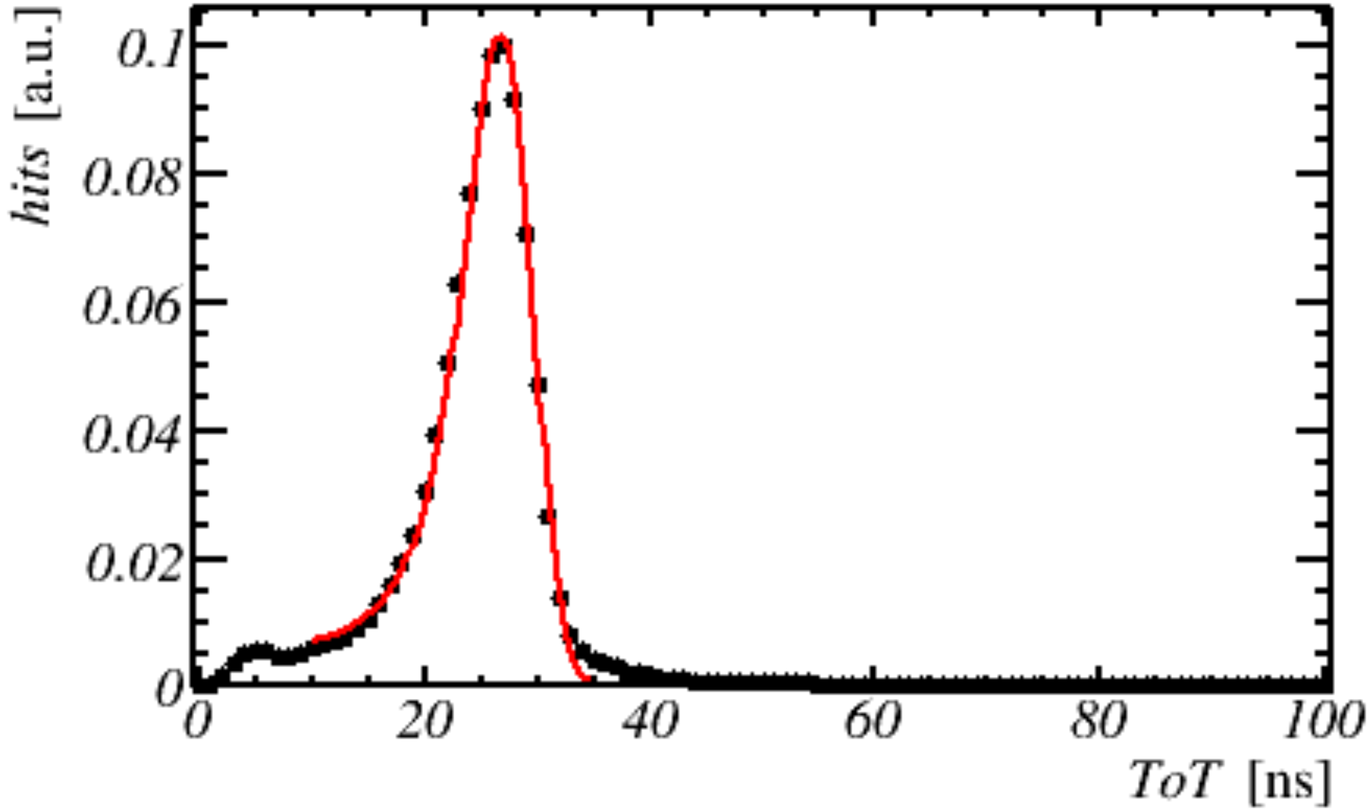


Simple JPP model



https://indico.nikhef.nl/event/717/session/0/contribution/7/material/slides/

ToT distribution

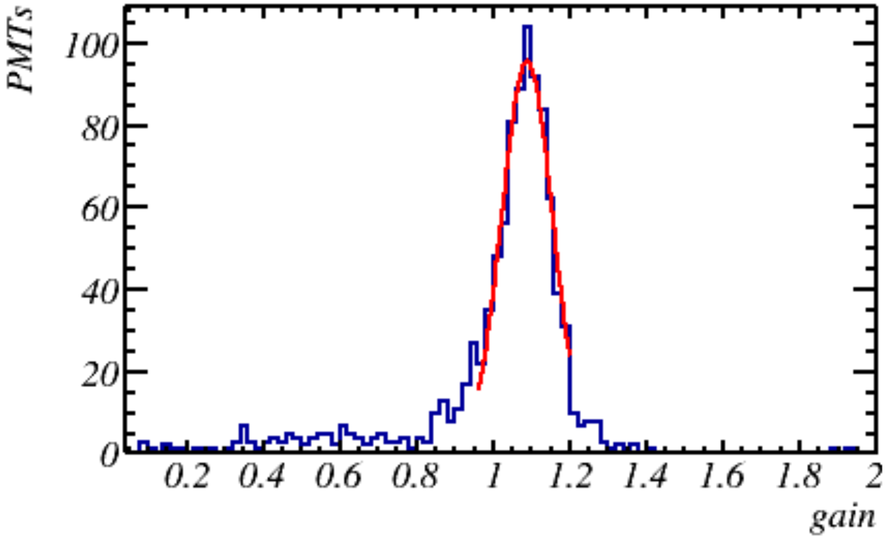


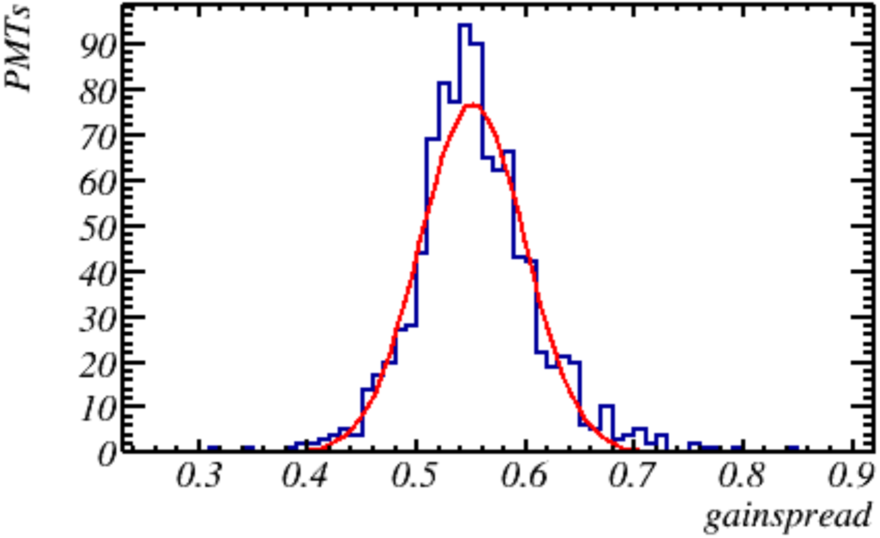
JMonitorToT -a <detfile> -f <datafile> -o monitor.root

JFitToT -a <detfile> -f monitor.root -o fit.root -w -t 15+35 -P <gainfile>

- -w: write the fits to the ouput file
- -t 15+35: ToT-range to fit
- -P: JTE-compatible output txt file with fitted values

ToT -> Gain & Gainspread





https://elog.km3net.de/Analysis/154

PMT Parameters

Efficiency-Related

Relative PMT Efficiency

Absolute QE * Collection eff. * …

Gain (ToT distribution)

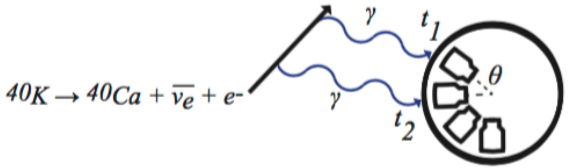
Gainspread (ToT distribution)

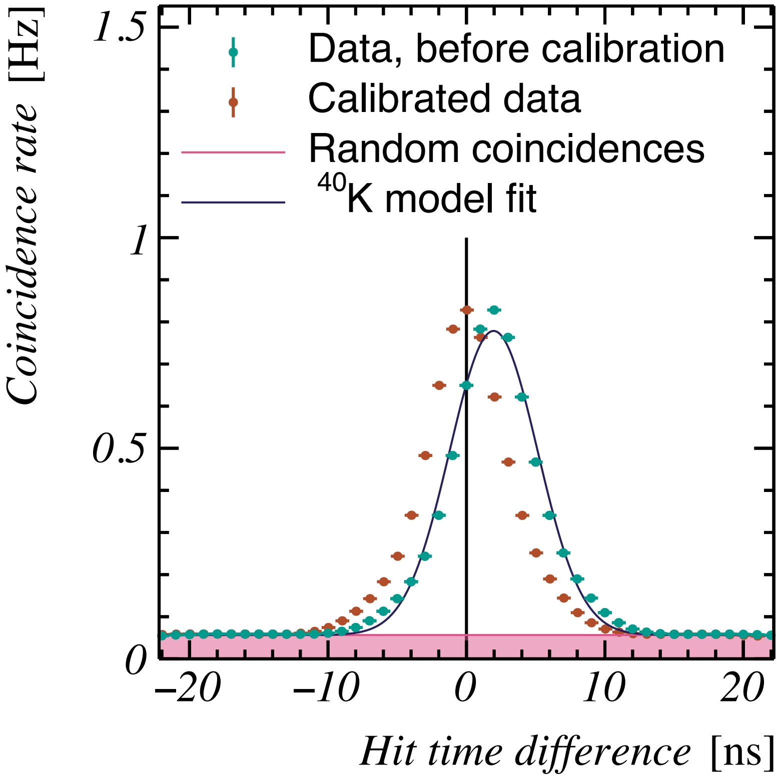
Time-Related

PMT Time offset

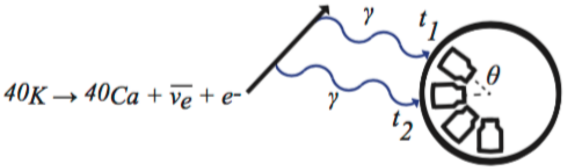
Transit time spread

^{40}K fit method

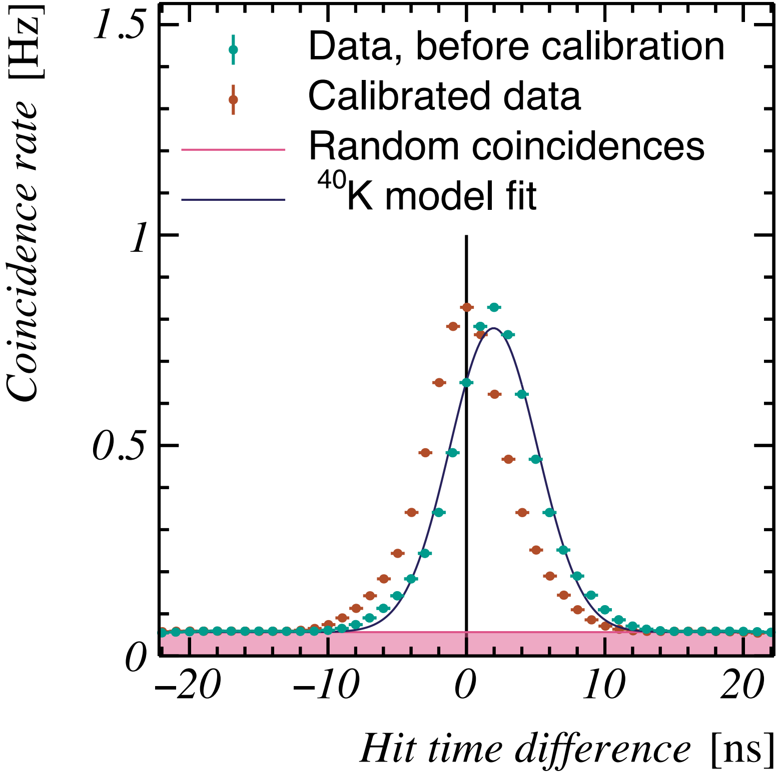




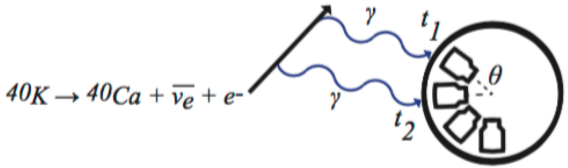
^{40}K fit method



Mean	<> PMT time offsets	*(t0)*
Width	<> PMT transit time spreads	*(TTS)*
Amplitude	<> PMT efficiencies	*(ε)*



^{40}K fit method



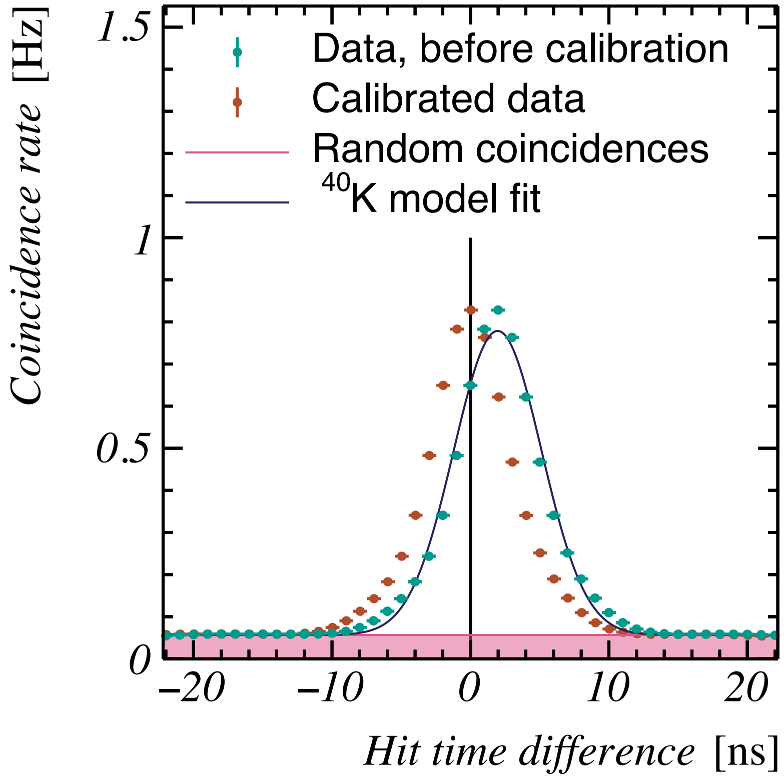
Mean	<> PMT time offsets	*(t0)*
Width	<> PMT transit time spreads	*(TTS)*
Amplitude	<> PMT efficiencies	*(ε)*

$$R_{i,j}(\Delta t) = \frac{A_{i,j}}{\sqrt{2\pi}\sigma_{i,j}} \cdot \exp\left[-\frac{(\Delta t - \mu_{i,j})^2}{2\sigma_{i,j}^2}\right]$$

$$A_{i,j} = \epsilon_i \cdot \epsilon_j \cdot R(\theta_{i,j})$$

$$\mu_{i,j} = t_{0,i} - t_{0,i}$$

$$\sigma_{i,j}^2 = TTS_i^2 + TTS_j^2 + 0.54^2$$



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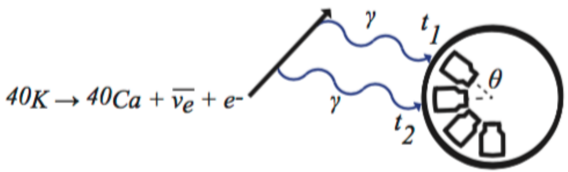

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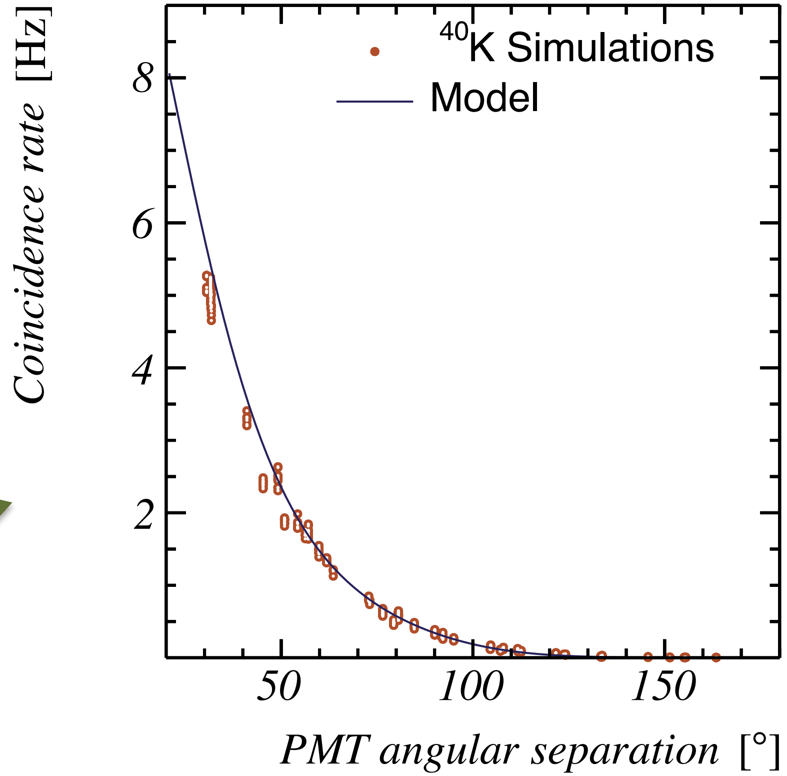
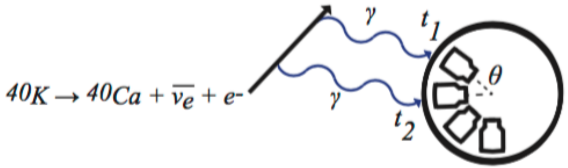


^{40}K fit method



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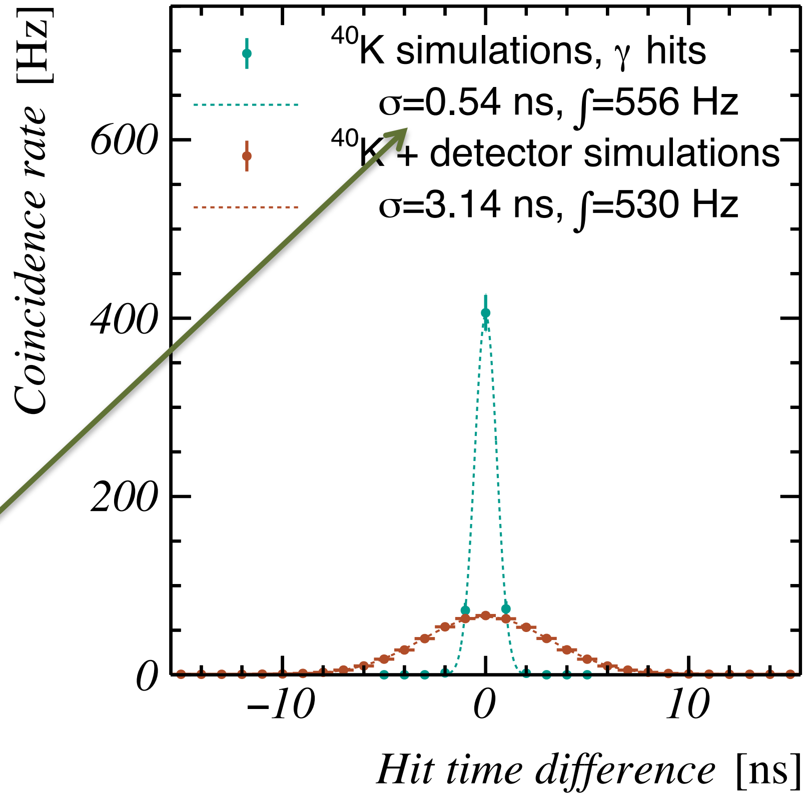
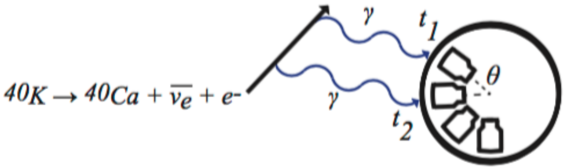


^{40}K fit method



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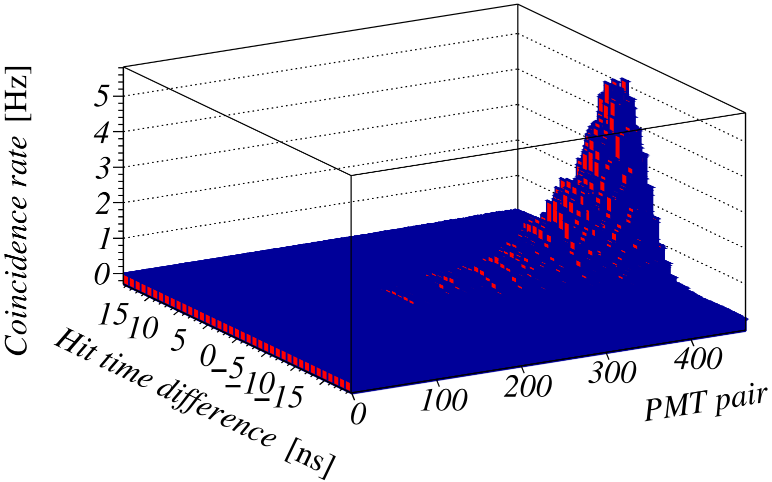
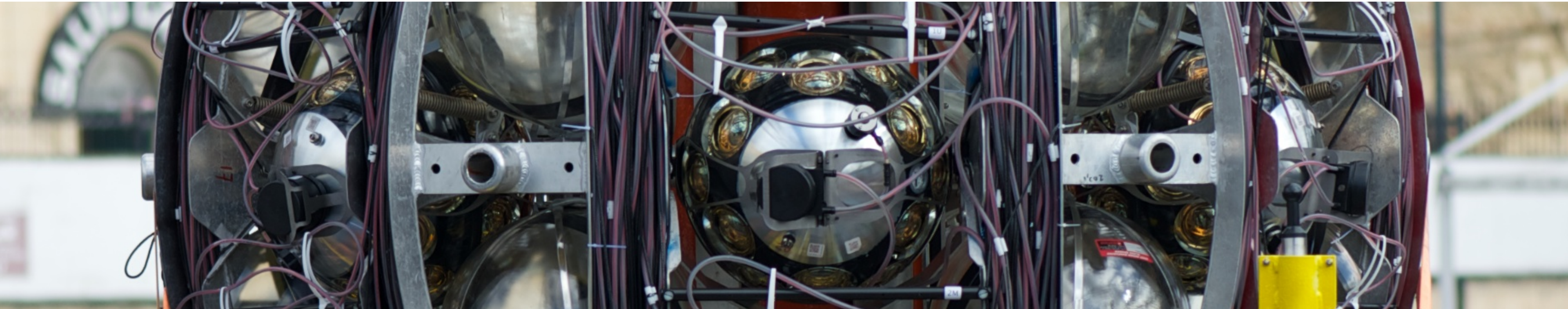
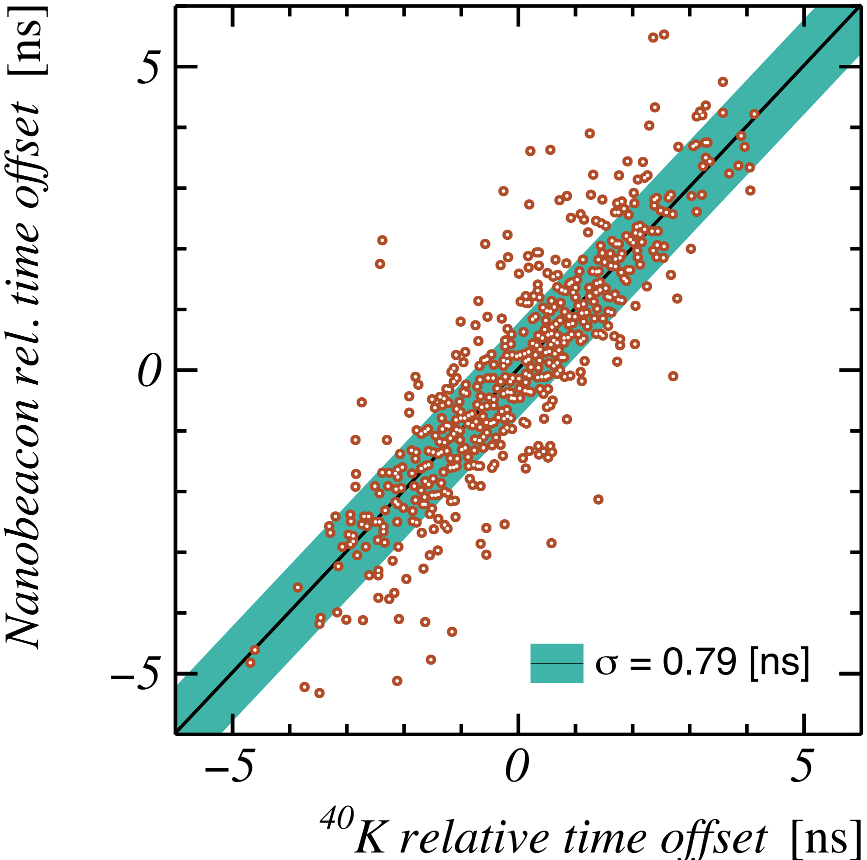


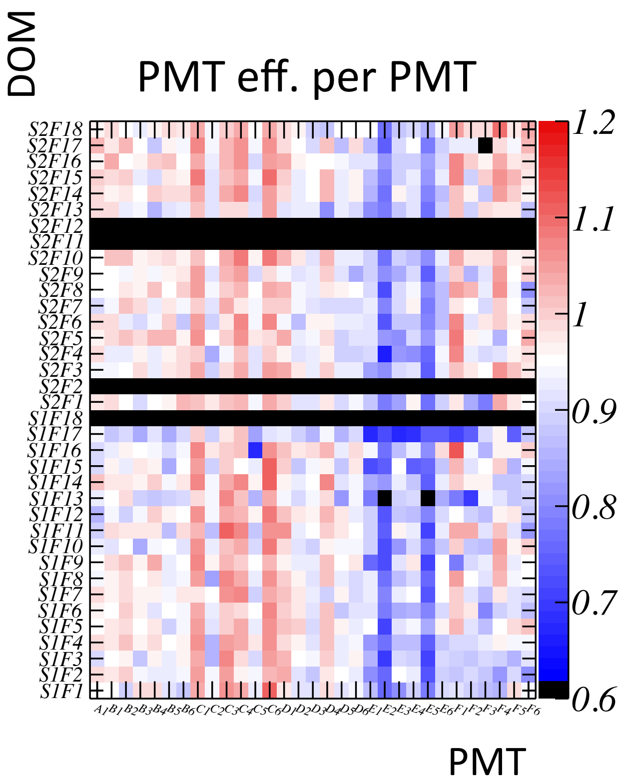
JMonitorK40 -B 20+25 -T 25 -M 2+31 -a <detfile> -f <datafile> -o monitor.root
JFitK40 -F -N -A -a <detfile> -f monitor.root -o fit.root -P <pmtefficienciesfile>

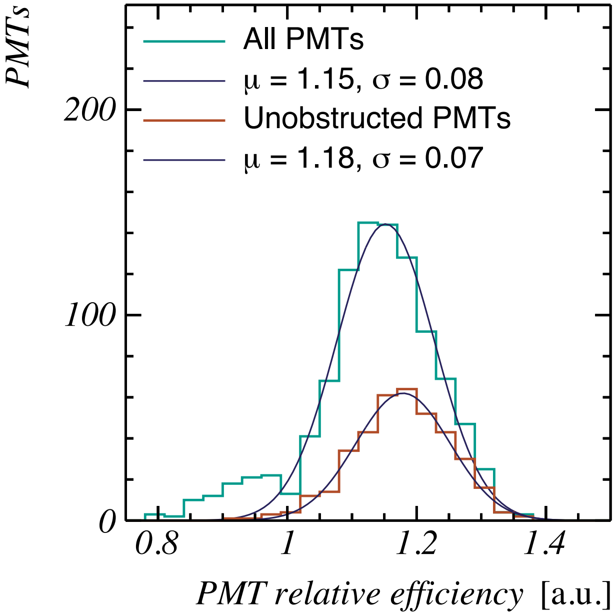


Time Calibration Cross-Check



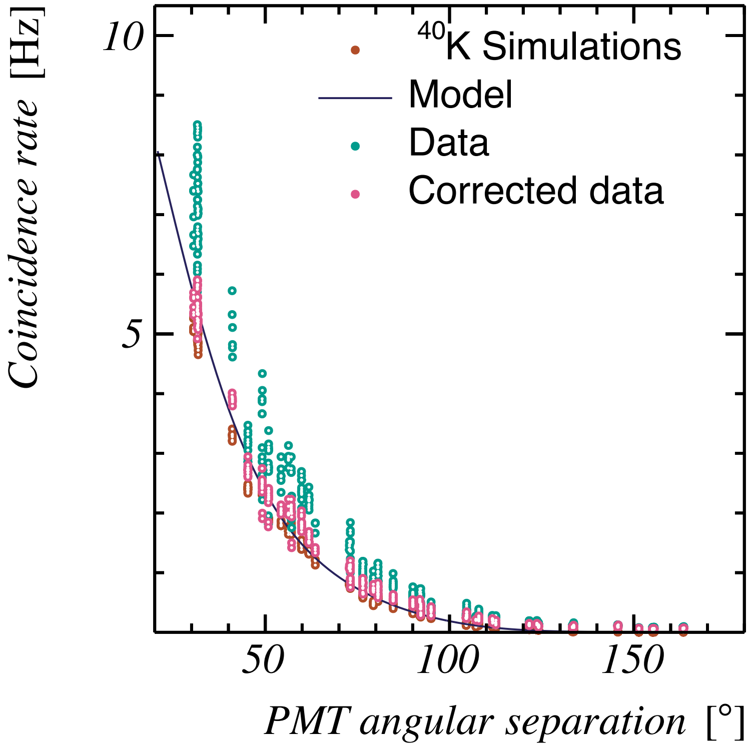
PMT efficiencies <-> superstructure





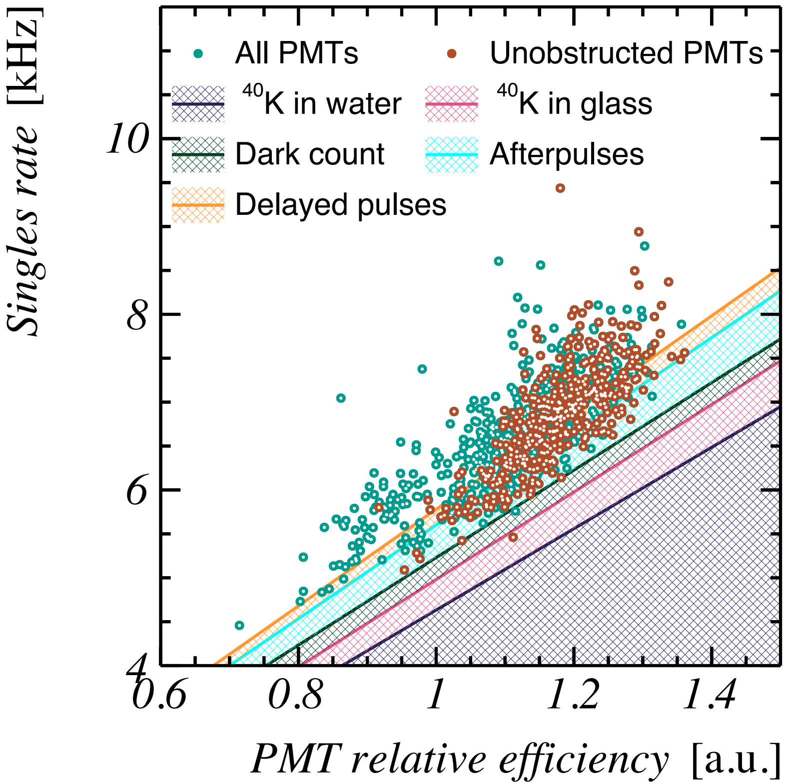
- Calibration precise enough to see collar
- PMT efficiency spread: ~6%

Efficiencies > 1?



Indeed more coincidence light seen than expected

Efficiencies > 1?



PMT Parameters

Efficiency-Related

Relative PMT Efficiency (^{40}K fit)

Absolute QE * Collection eff. * …

Gain (ToT distribution)

Gainspread (ToT distribution)

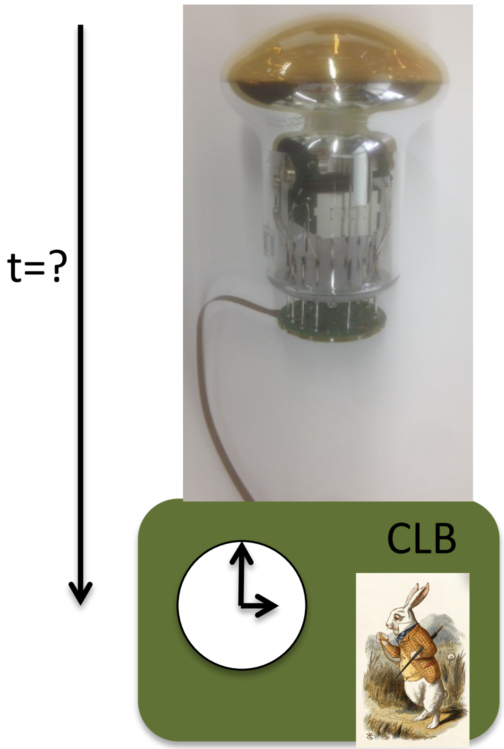
Time-Related

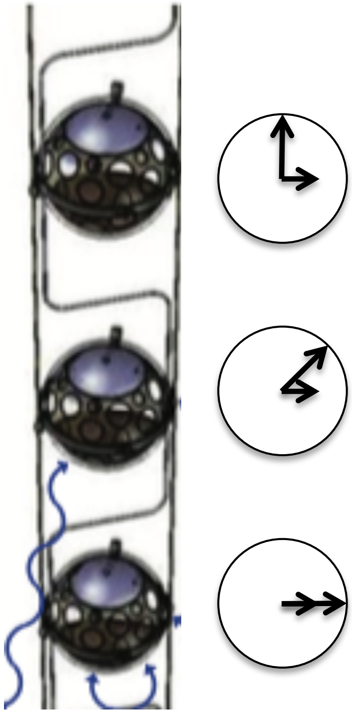
PMT Time offset (^{40}K fit)

Transit time spread (^{40}K fit)

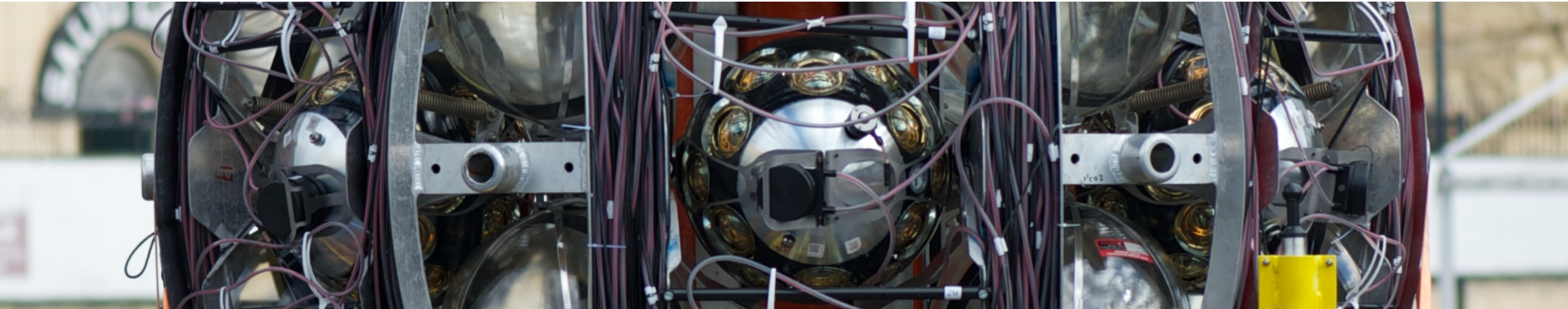
The end of the story?

Time-Related Parameters

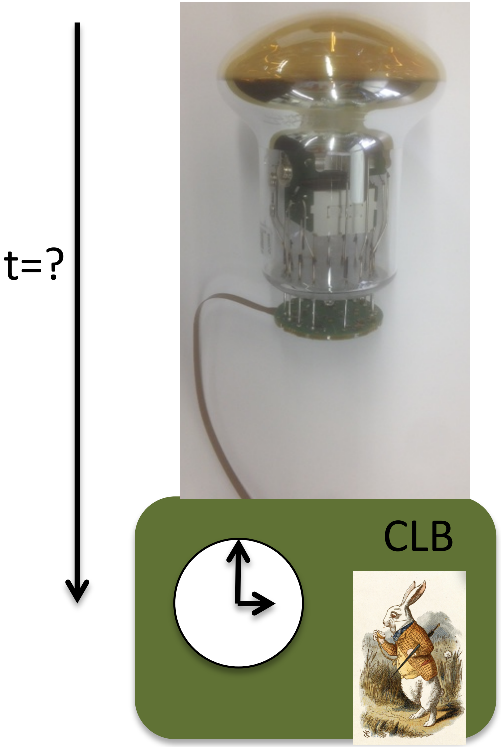


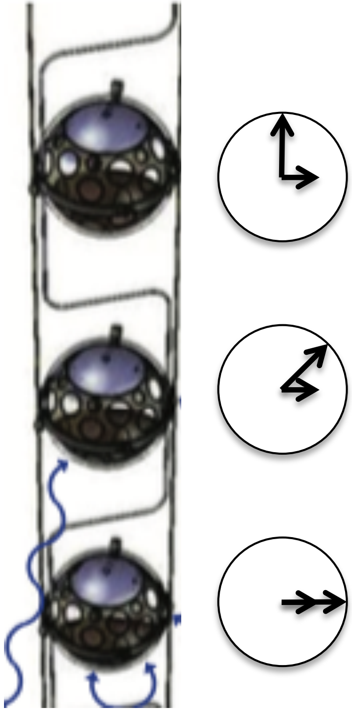


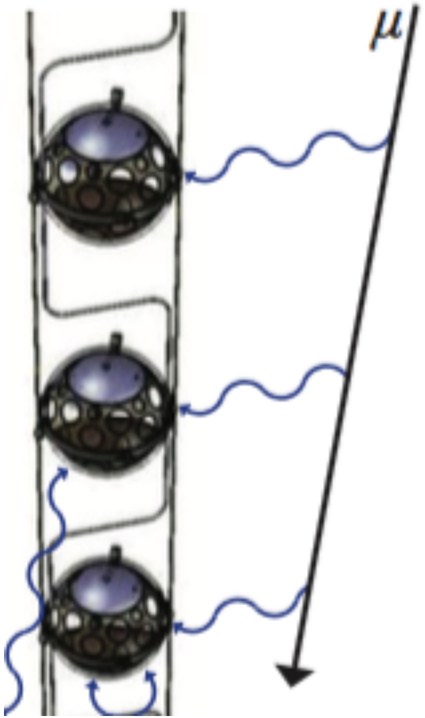
Inter-DOM Time Calibration



Time-Related Parameters





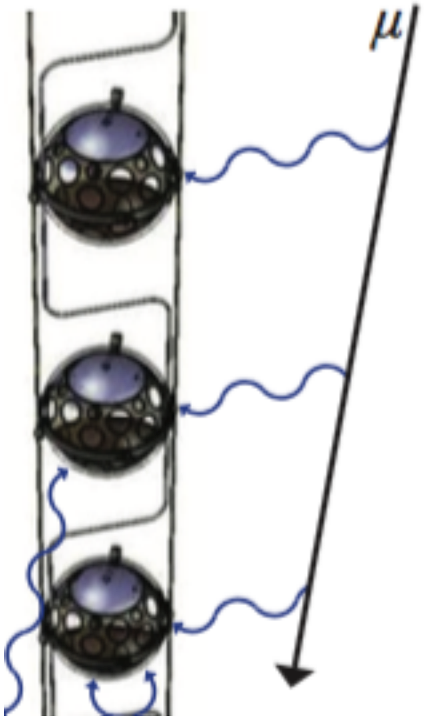


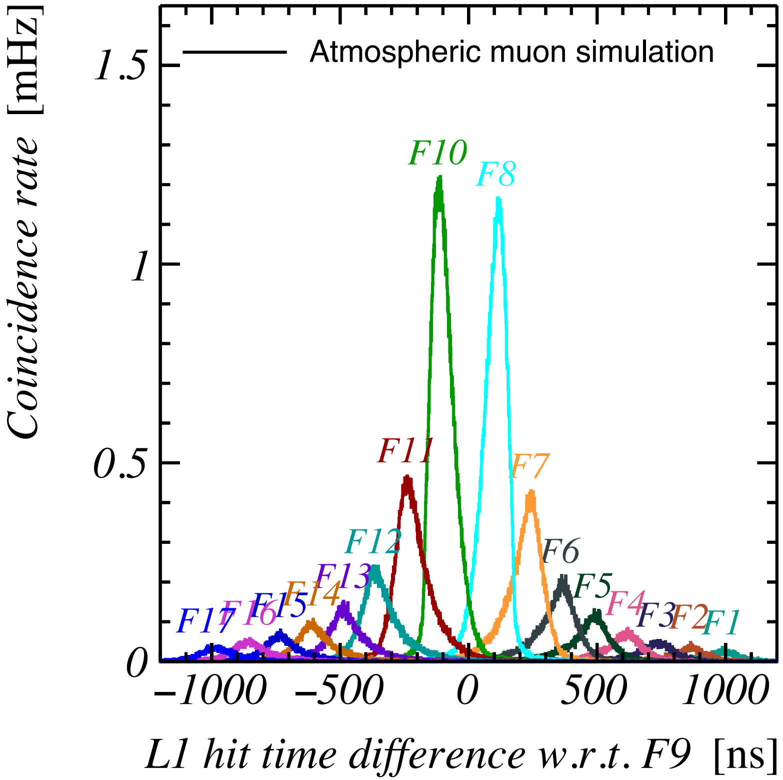
Dark Room laser calibration
- Calibrated laser shoots on one PMT per DOM

LED Nanobeacons
- LED flashers on each DOM

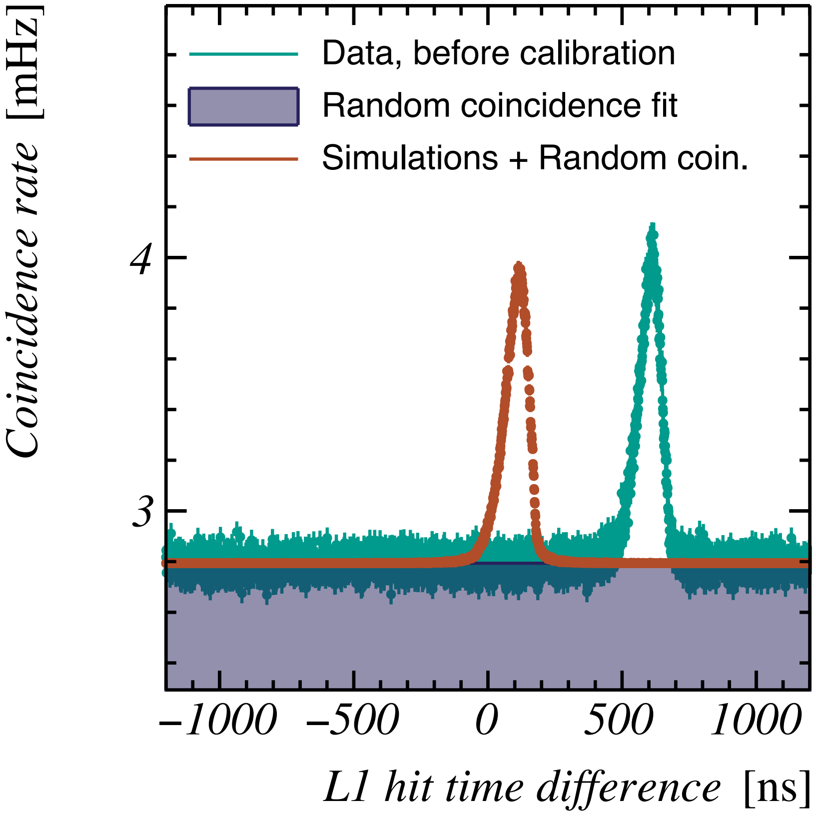
Atmospheric Muons

L1 Hit Time Differences



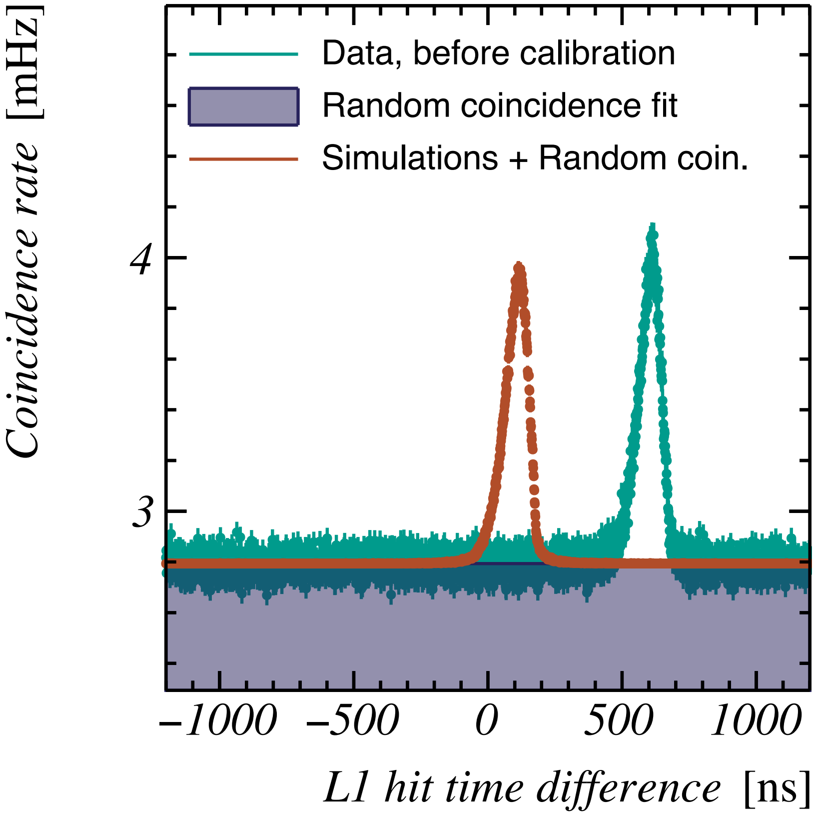


L1 Hit Time Differences



/sps/km3net/users/kmelis/DU_calibration/software/L1dt/
MonitorL1dt –a <detfile> -f <inputfile>

L1 Hit Time Differences



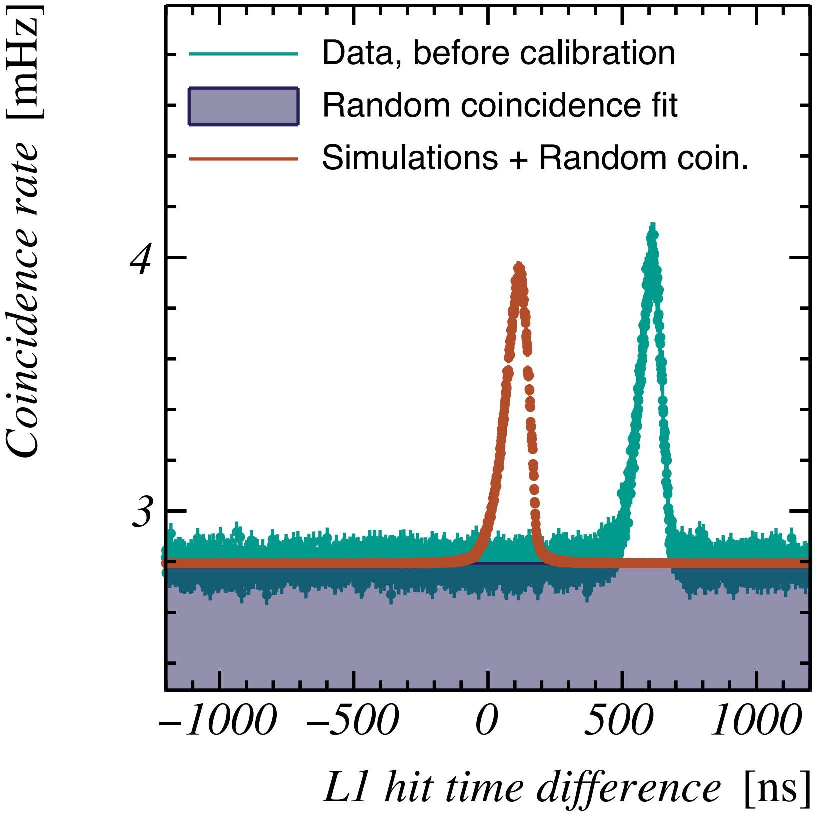
$$Q_{i,j}(\Delta t0_{i,j}) \equiv \prod_{\text{bins } k} \left[\text{Poisson}(d_{k+l} \mid m_k) \right]$$

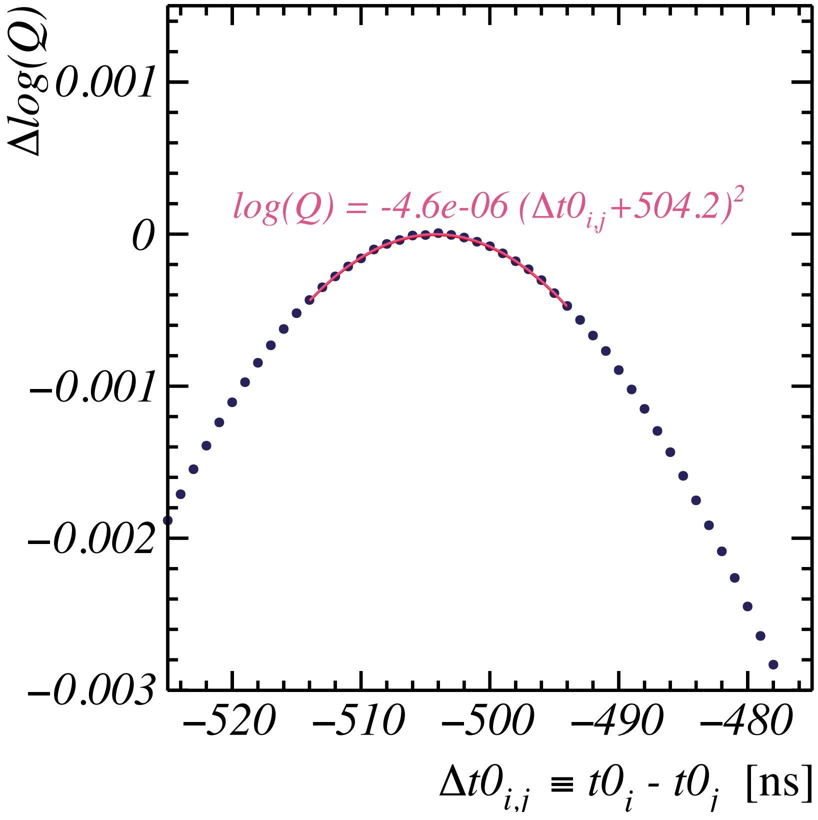
m_k : Expected coincidence rate in bin k

d_{k+l} : Detected rate in bin $k + l$

$$l = \frac{t0_i - t0_j}{\text{binwidth}}$$

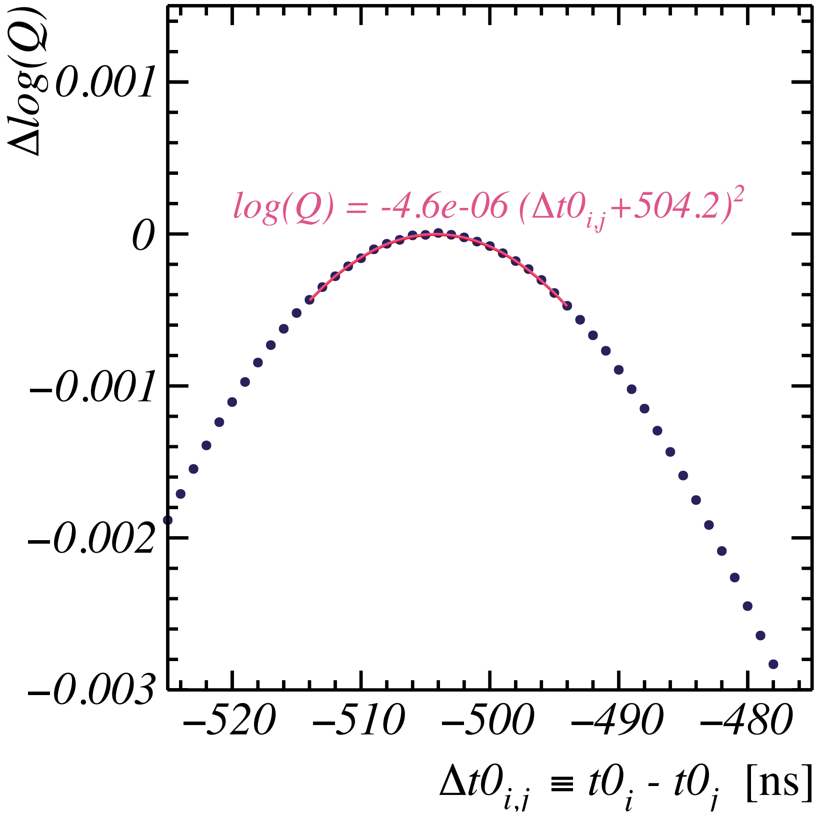
L1 Hit Time Differences





/sps/km3net/users/kmelis/DU_calibration/software/L1dt/
FitL1dtSlices –a <detfile> -f <monitoL1dt file from data> -m <monitoL1dt file from simulations>

Best Fit DOM Time Offsets



Best Fit DOM Time Offsets

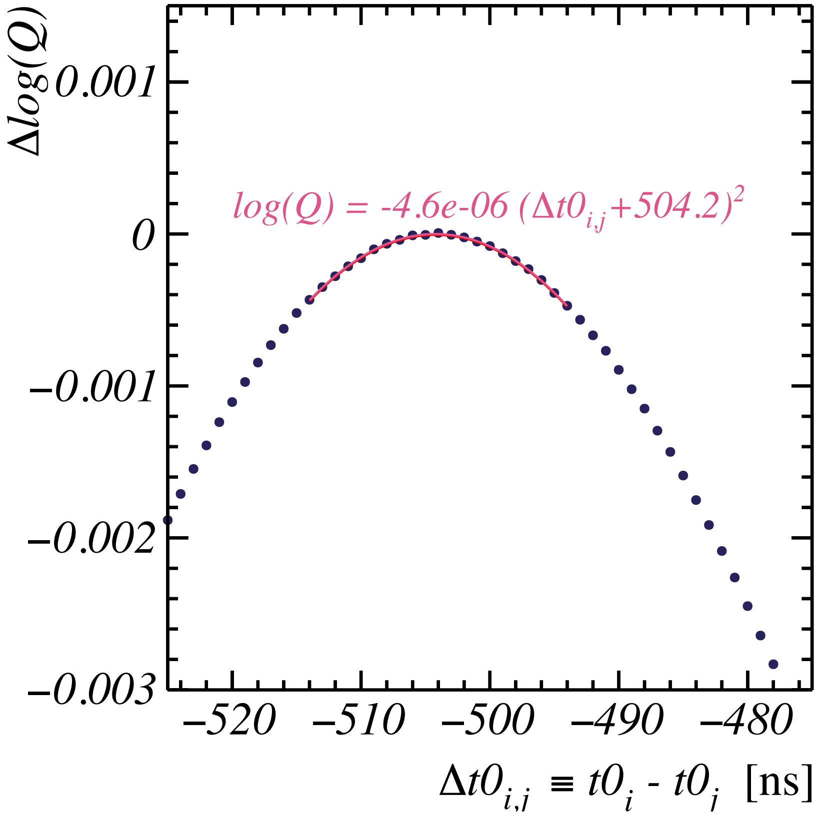
$$0 = \frac{\partial}{\partial t0_k} log\left(\sum_{i,j\neq i}[Q_{i,j}(\Delta t0_{i,j})]\right)$$

$$= \sum_{i,j\neq i}\left[\frac{\partial}{\partial t0_k} log(Q_{i,j}(\Delta t0_{i,j}))\right]$$

$$= \sum_{i,j\neq i}\left[\frac{\partial}{\partial t0_k}\left(A_{i,j}\cdot(\Delta t0_{i,j}-B_{i,j})^2+C_{i,j}\right)\right]$$

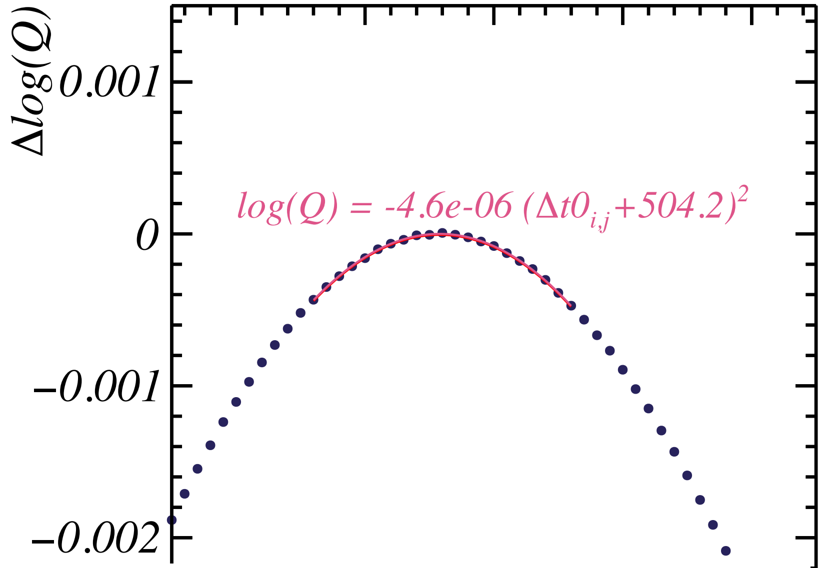
$$= \sum_{j\neq k}[2A_{k,j}\,(t0_k - t0_j - B_{k,j})] + \sum_{i\neq k}[-2A_{i,k}\,(t0_i - t0_k - B_{i,k})]$$

$$= \sum_{i\neq k}[4A_{k,i}\,(t0_k - t0_i - B_{k,i})]$$



L1 Hit Time Differences

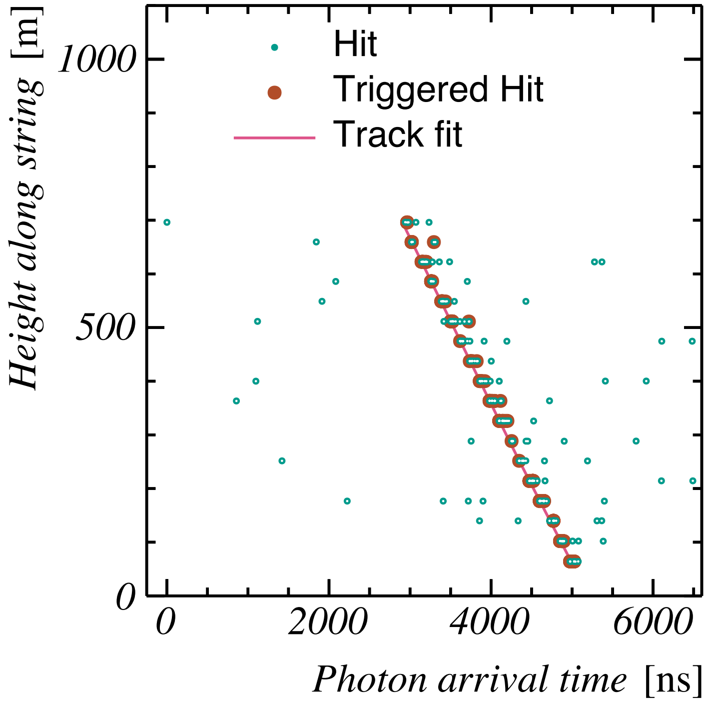
$$0 = \frac{\partial}{\partial t0_k} log\left(\sum_{i,j\neq i}[Q_{i,j}(\Delta t0_{i,j})]\right)$$
$$= \sum_{i,j\neq i}\left[\frac{\partial}{\partial t0_k} log(Q_{i,j}(\Delta t0_{i,j}))\right]$$
$$= \sum_{i,j\neq i}\left[\frac{\partial}{\partial t0_k}(A_{i,j}\cdot(\Delta t0_{i,j}-B_{i,j})^2+C_{i,j})\right]$$
$$= \sum_{j\neq k}[2A_{k,j}(t0_k-t0_j-B_{k,j})]+\sum_{i\neq k}[-2A_{i,k}(t0_i-t0_k-B_{i,k})]$$
$$= \sum_{i\neq k}[4A_{k,i}(t0_k-t0_i-B_{k,i})]$$



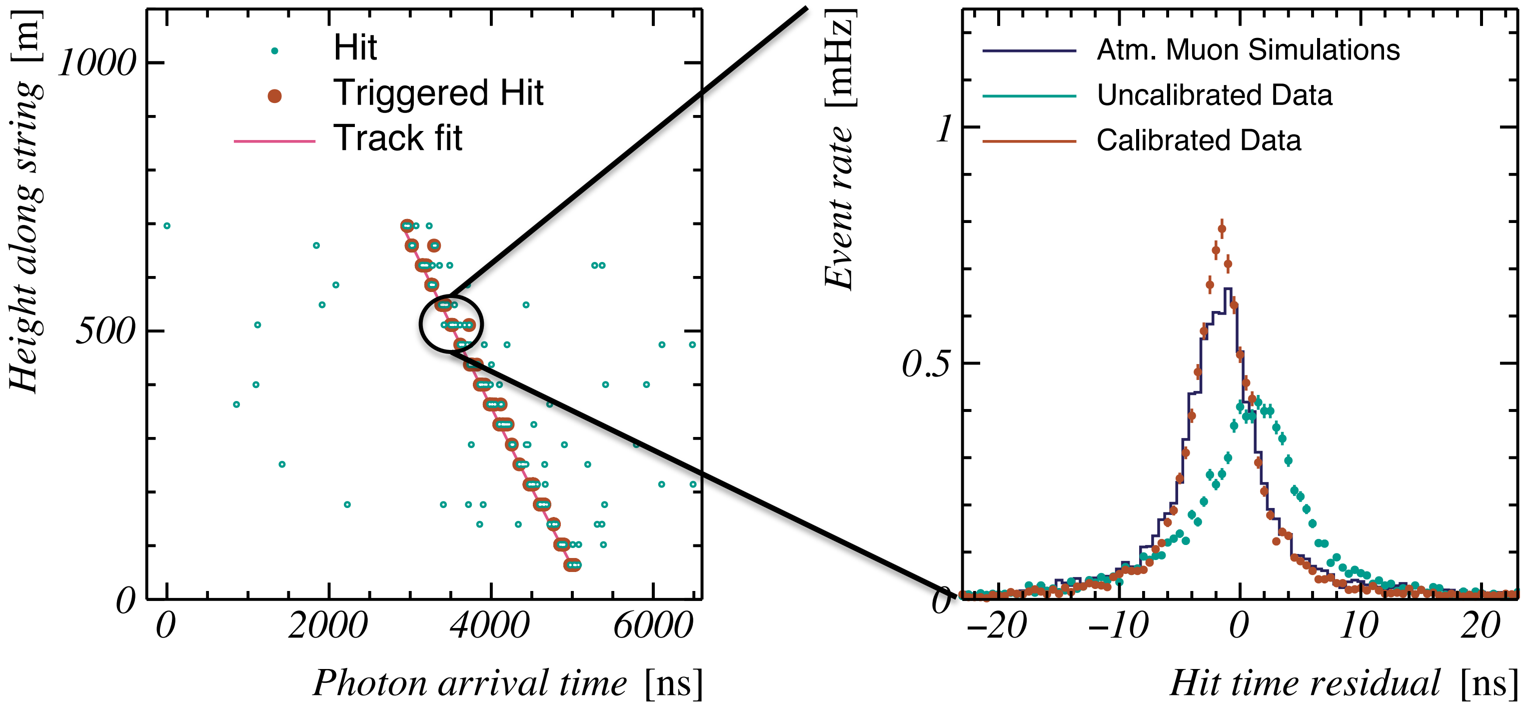
$$\begin{bmatrix}0\\0\\0\\\vdots\end{bmatrix} = 4\cdot\begin{bmatrix}\sum_{i\neq 0}[A_{0,i}] & -A_{0,1} & -A_{0,2} & \cdots\\ -A_{1,0} & \sum_{i\neq 1}[A_{1,i}] & -A_{1,2} & \cdots\\ -A_{2,0} & -A_{2,1} & \sum_{i\neq 2}[A_{2,i}] & \cdots\\ \vdots & \vdots & \vdots & \ddots\end{bmatrix}\cdot\begin{bmatrix}t0_0\\t0_1\\t0_2\\\vdots\end{bmatrix} - 4\cdot\begin{bmatrix}\sum_{i\neq 0}[A_{0,i}\cdot B_{0,i}]\\\sum_{i\neq 1}[A_{1,i}\cdot B_{1,i}]\\\sum_{i\neq 2}[A_{2,i}\cdot B_{2,i}]\\\vdots\end{bmatrix}$$

/sps/km3net/users/kmelis/DU_calibration/software/L1dt/
FitL1dt –a <detfile> -f <fitL1dtslices output file>

2nd Method: Hit Time Residuals

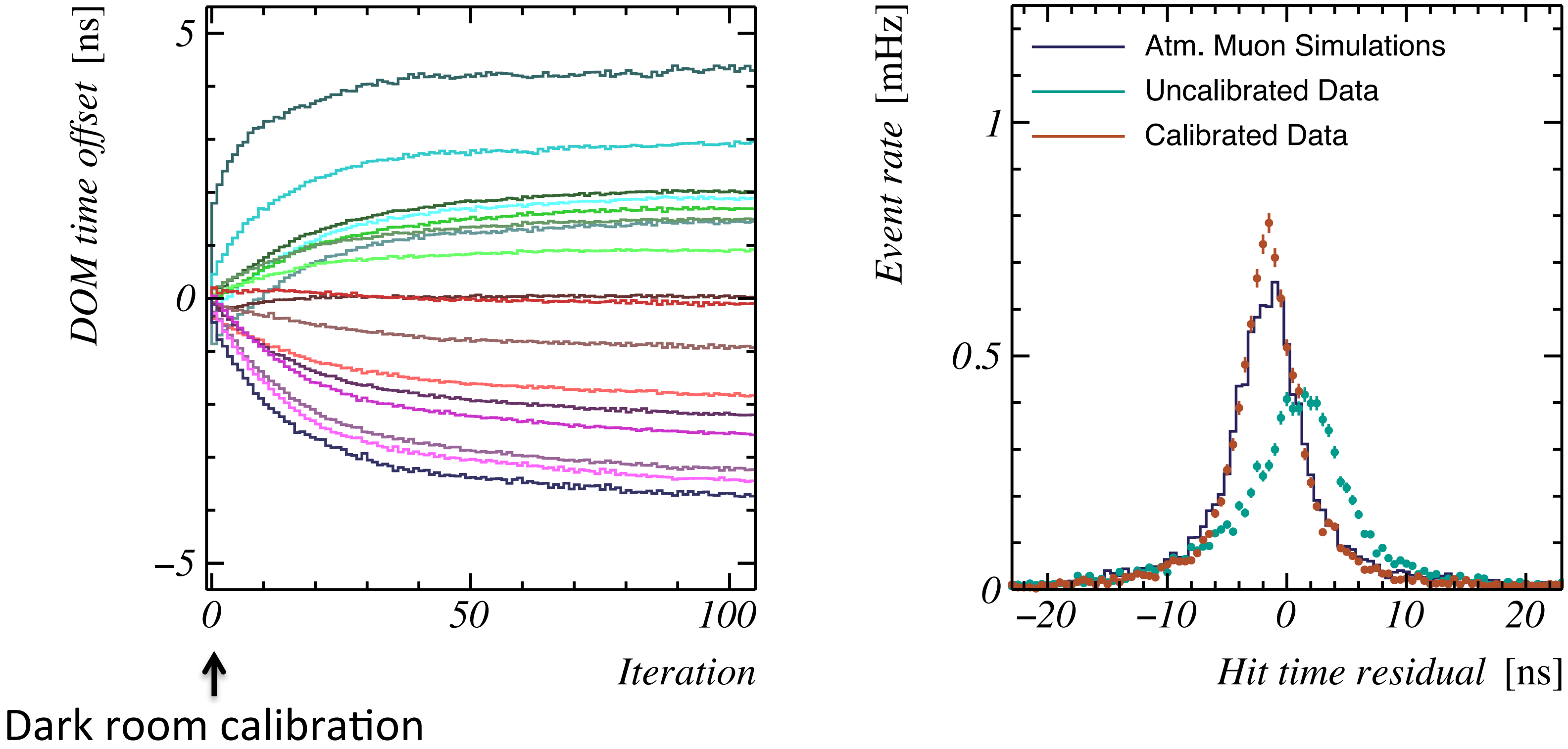


Hit Time Residuals



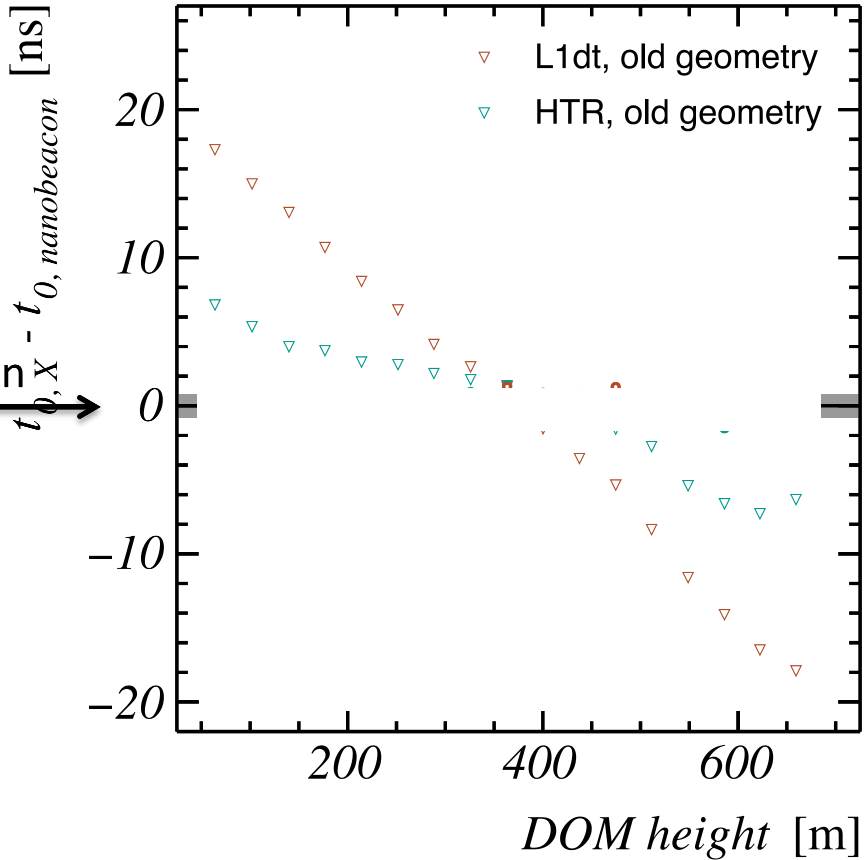
JPreSim_HTR.cc

Hit Time Residuals

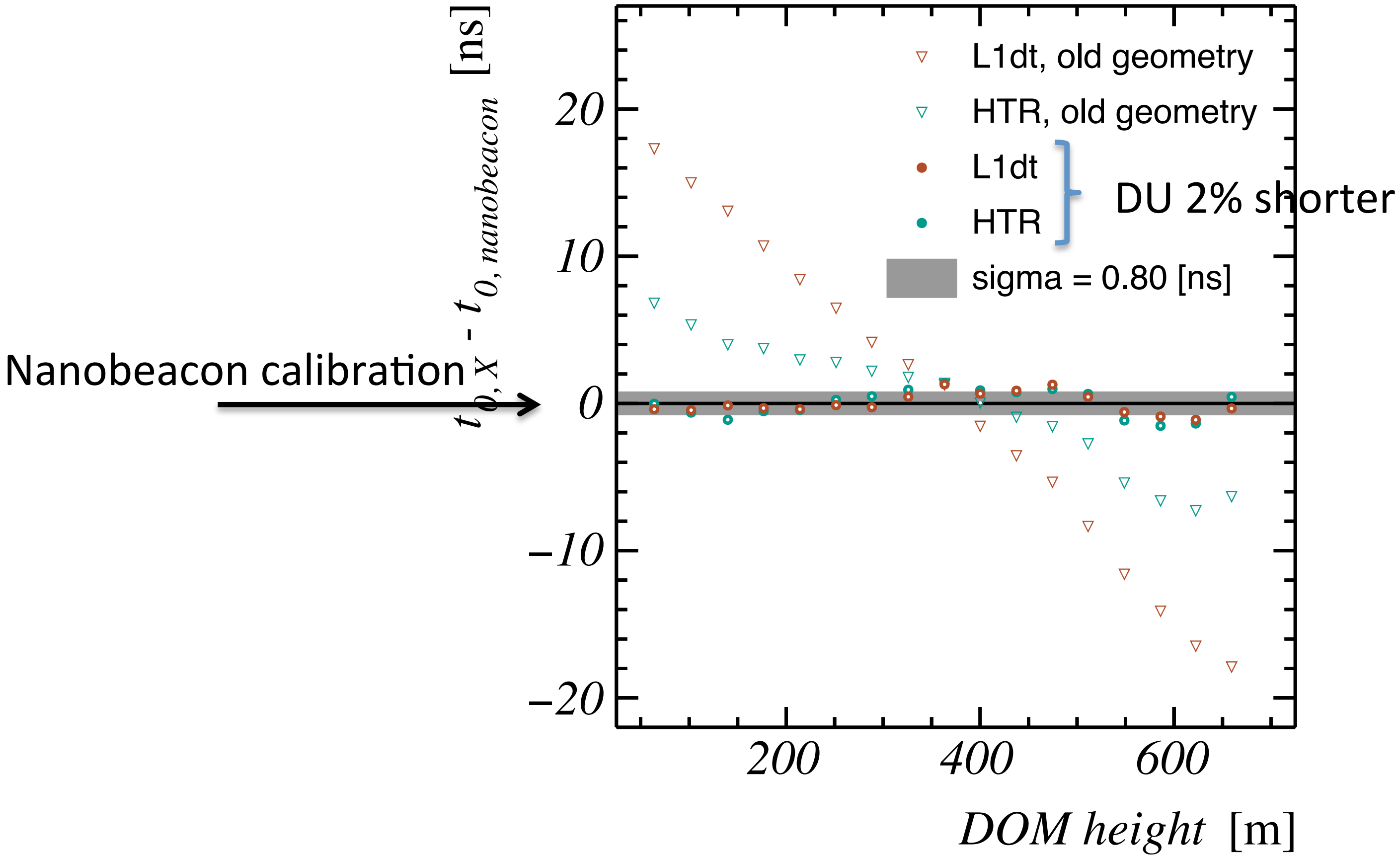


DOM Time Offsets

Nanobeacon calibration



DOM Time Offsets



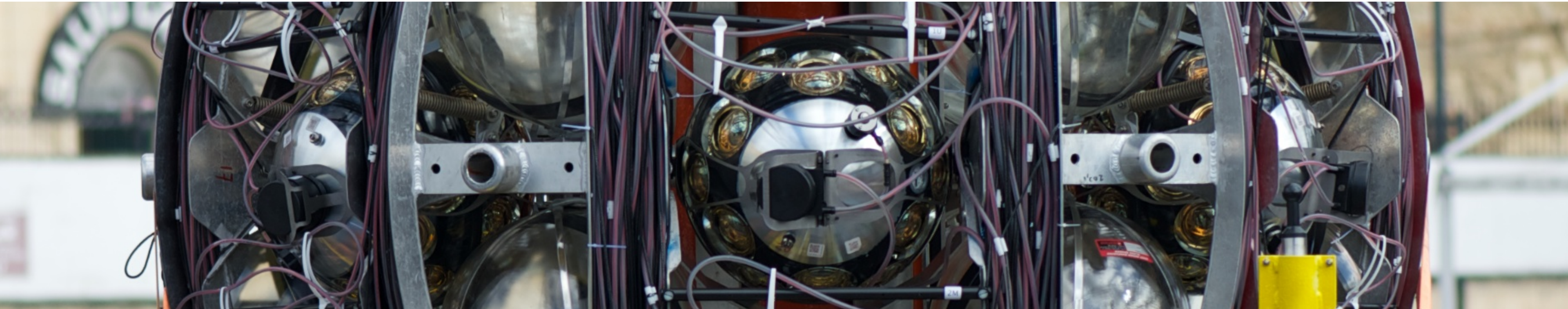
Calibration Overview

Inter-PMT	Inter-DOM
^{40}K Calibration	
(Atmospheric muons)	Atmospheric muons
(Nanobeacons)	Nanobeacons
(Laser Calibration)	Darkroom Laser Calib.
(^{40}K in lab.)	White Rabbit

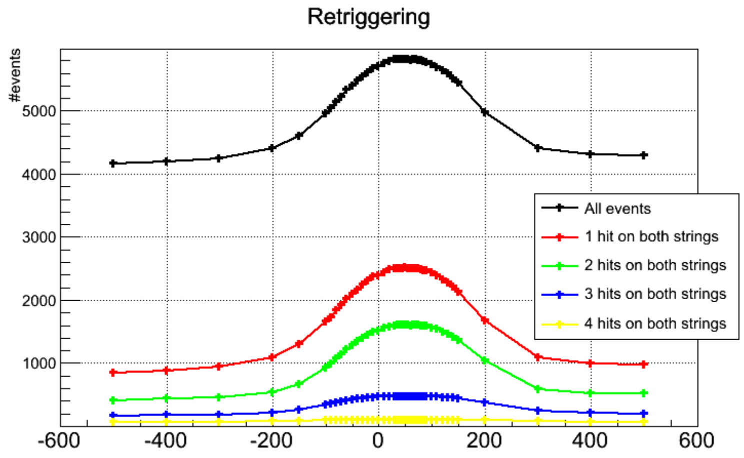
Calibration Overview

Inter-PMT	Inter-DOM	Inter-DU
^{40}K Calibration		
(Atmospheric muons)	Atmospheric muons	Atmospheric muons
(Nanobeacons)	Nanobeacons	Nanobeacons
(Laser Calibration)	Darkroom Laser Calib.	
(^{40}K in lab.)	White Rabbit	White Rabbit

Inter-DU Time Calibration



Trigger Rate Optimization



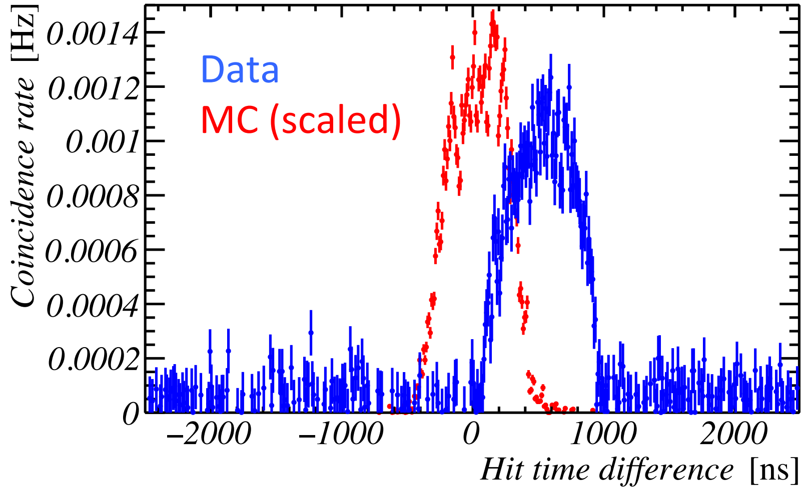
Inter-DU time offset difference – 575 [ns]

- Triggered Event:
  - At least 5 local DOM coincidences complying with track hypothesis
- Optimal DU time offset reflects in high trigger rate
- Best fit inter-DU time offset compatible with other methods (muons and LEDs)

*Work + plots by M. Jongen

Inter-DU Coincident Hits

S1F13 <-> S2F13
Background subtracted



- 18 inter-DU DOM pairs on same floor
  - 18 inter-DU coincidence rate distributions

Best fit inter-DU time offset difference: 524±10 ns

/sps/km3net/users/kmelis/DU_calibration/software/L1dt/
MonitorL1dt –a <detfile> -f <inputfile>

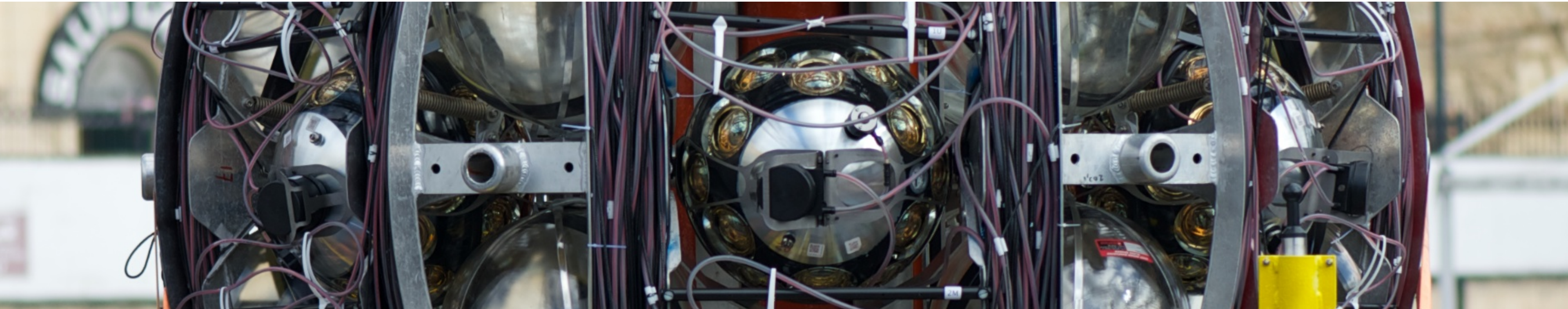
Comparison: Inter-DU

- From white rabbit round trip time: ~529 ns
- From nanobeacon fit: ~509 ns
- From trigger rate optimisation: ~525 ns
- From inter-DU coincidences: ~524 ns

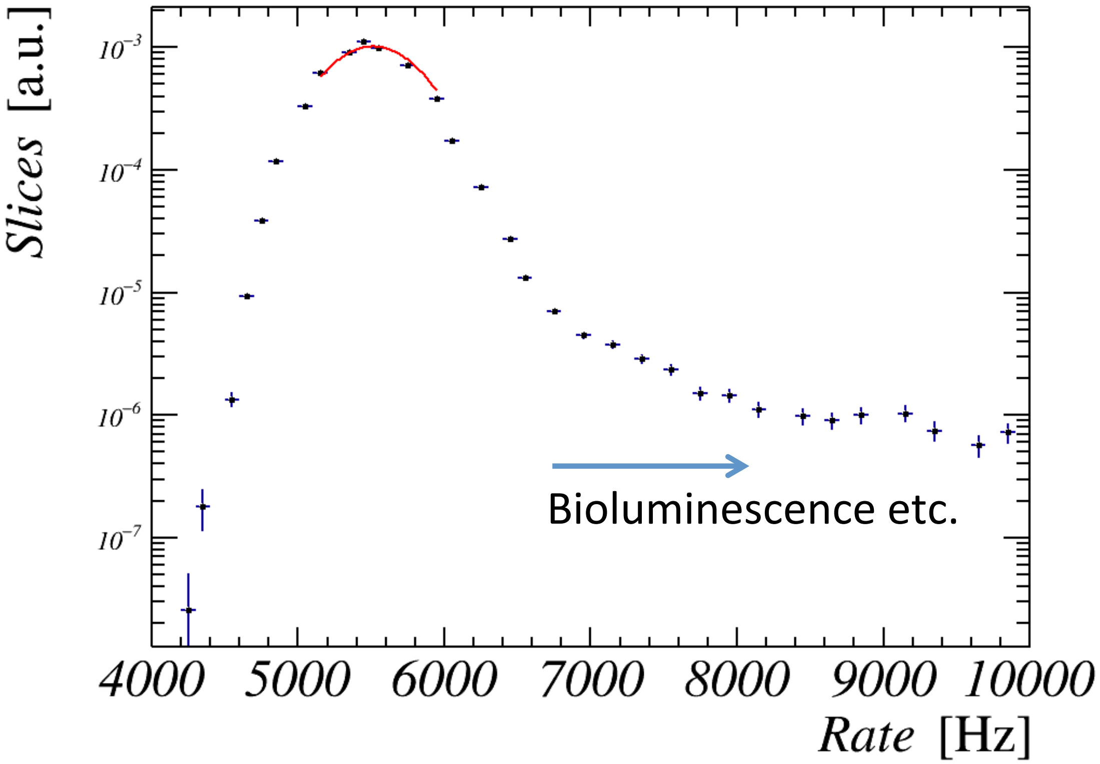
* Nanobeacon fit is sensitive to inter-DU spacing,
16 ns difference corresponds to 3.2 meters difference

Good agreement between methods, given resolution on inter-DU distance (91±2.5 m)

Backup

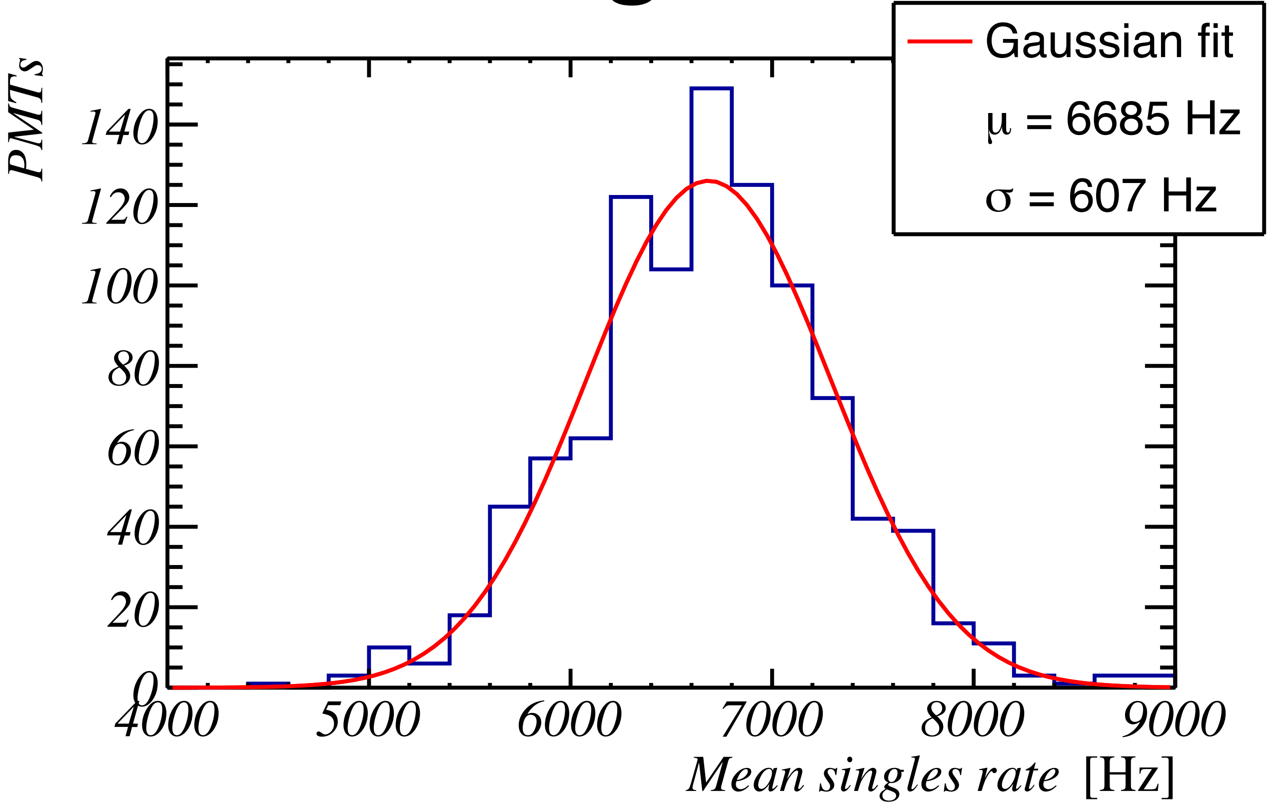


Singles Rates



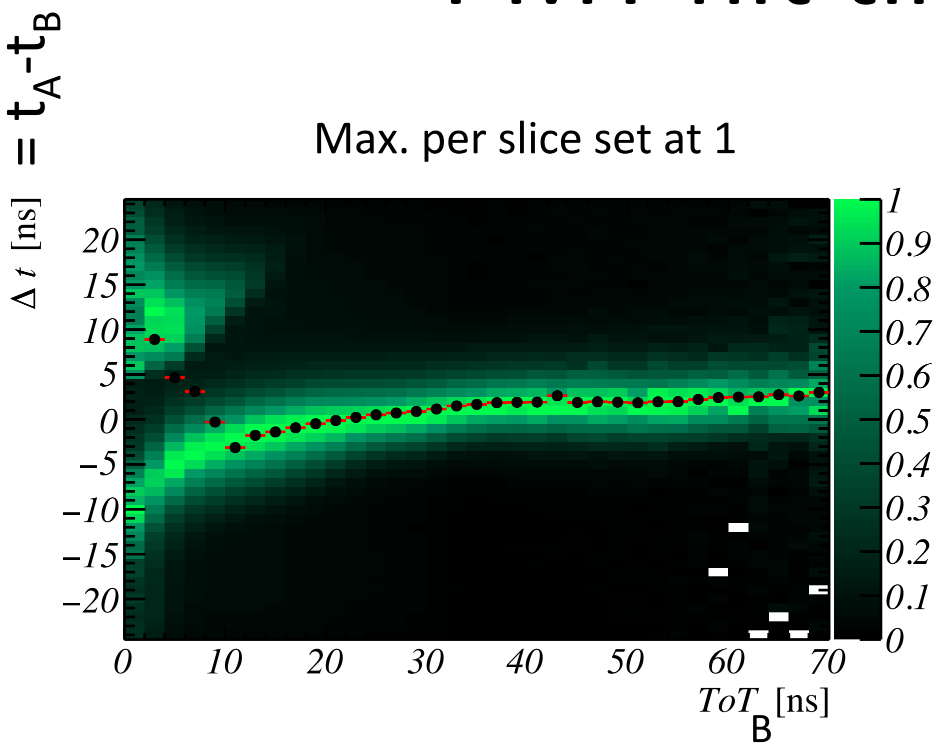
JMonitorSinglesRates -a <detfile> -f <datafile> -o monitor.root
JFitSinglesRates -a <detfile> -f monitor.root -o fit.root -p 0.3
/sps/km3net/users/kmelis/DU_calibration/software/singlesrates/

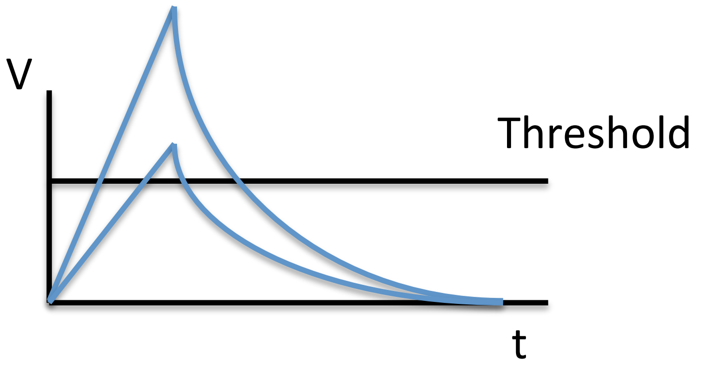
Mean Singles Rates



JPlotPMTSystematics -a ${detfile} -f <globalmon> -o <outputfile> -p "mean 4000.0+9000.0"
/sps/km3net/users/kmelis/Jpp_r10589/software/JCalibrate/

PMT hit time slewing





High ToT -> Earlier hits
- combinatorics (2 photons)
- time-slewing of leading edge

Low ToT -> Later hits
- time slewing of leading edge
- pre-pulses?