ToT/NPE calibration of the KM3NeT PMT/Base pair

Jonas Reubelt*, Johannes Schumann
On behalf of the KM3NeT collaboration

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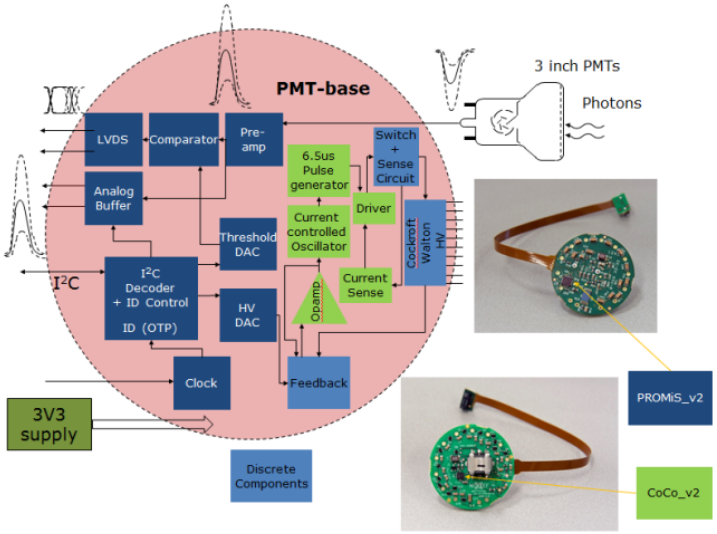
ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

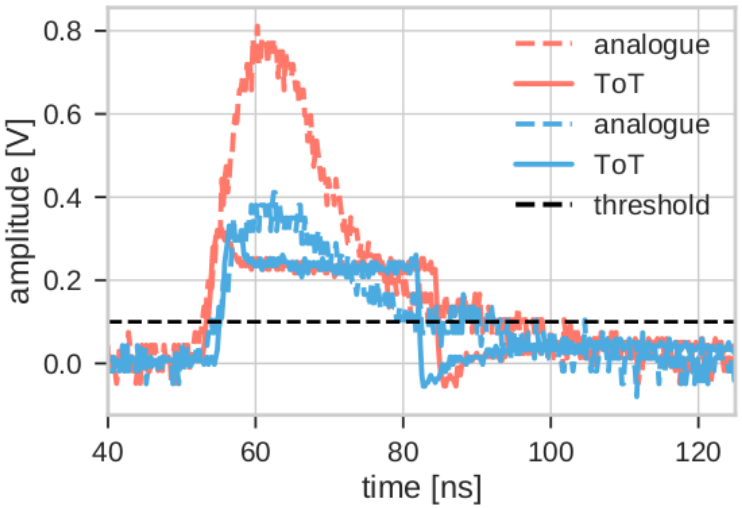
FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG

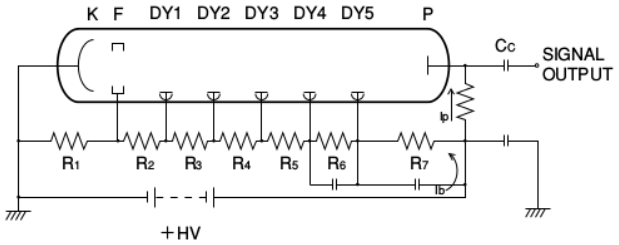
Outline

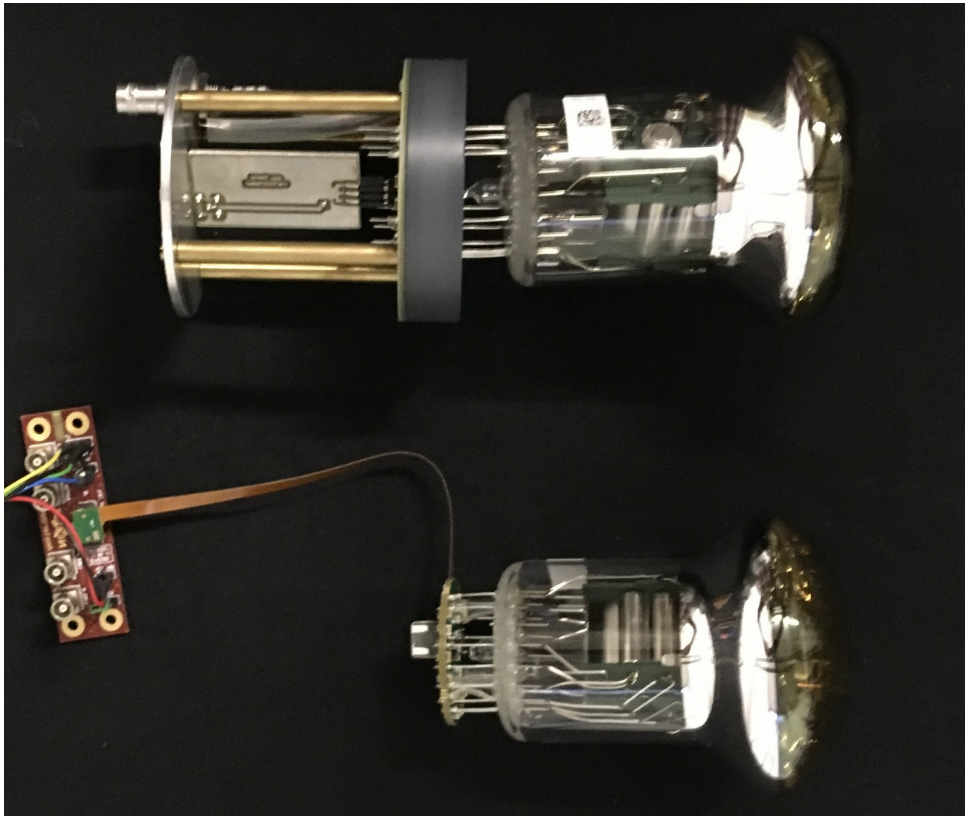
- Determination of the measured number of photoelectrons (NPE) with a passive base
- Time-over-threshold (ToT) measurement with the KM3NeT active base
- ToT/gain calibration via variation of the PMT high voltage
- ToT/NPE calibration via light source intensity variation

PMT and Base









PMT: Hamamatsu R12199

Why do we need a ToT/NPE calibration?

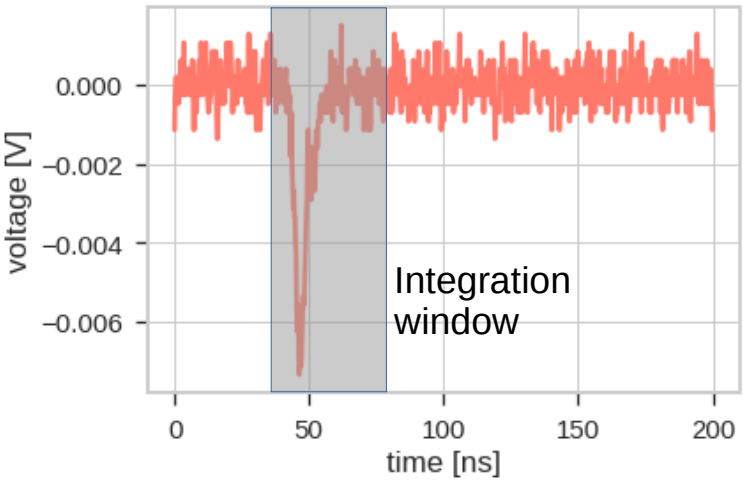
- Event reconstruction relies on the measured intensity of the involved DOMs/PMTs
- Information about the charge or number of photoelectrons of the hits on the PMTs is essential
- But: KM3NeT hit only consists of time, time-over-threshold and PMT ID
- ToT/NPE calibration gives a handle on the intensity of a hit when only ToT is measured

How do we measure PMT signals?

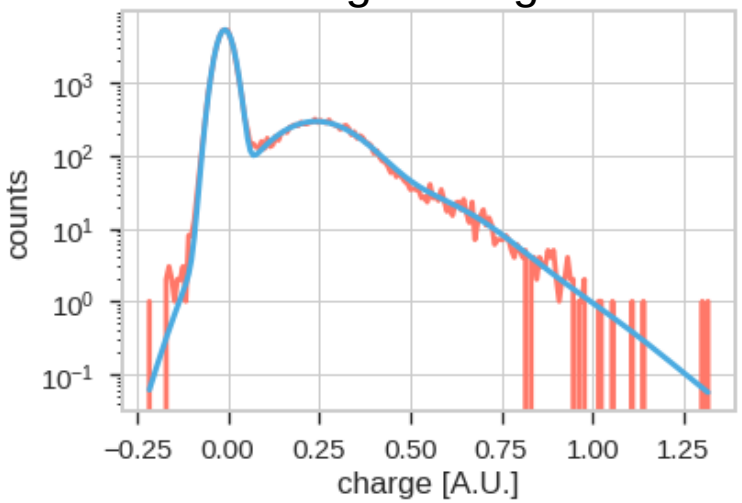
- Measurement in dark room or dark box
- LED/laser as pulsed light source
- Waveform measurement at oscilloscope
- Trigger at oscilloscope on LED/laser
- Acquire 50k waveforms
- Analyse data afterwards

Passive Base – Charge Distribution

waveform



charge histogram



- Integrate all waveforms => charge
- Fill charge values in histogram
- Fit PMT response function:

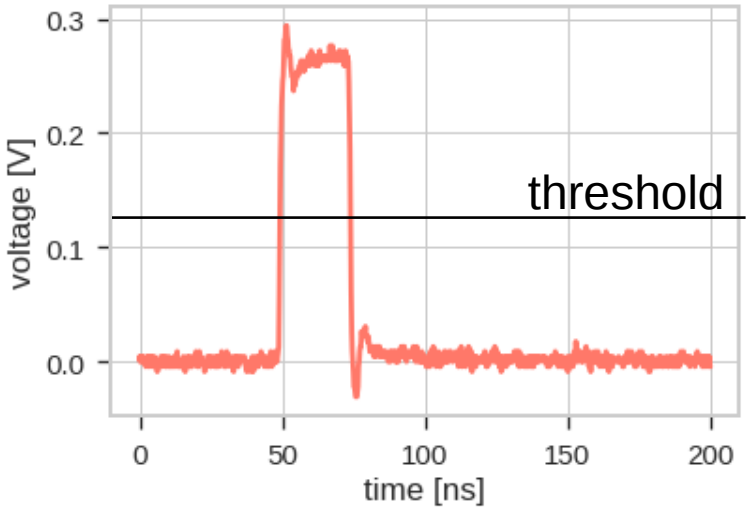
$$PRF(x) = \sum_{n=0}^{\infty} \frac{\mu^n \cdot e^{-\mu}}{n!} \cdot \frac{1}{\sigma\sqrt{2\pi n}} \exp\left(-\frac{(x-nQ)^2}{2n\sigma^2}\right)$$

Poisson Gaussian

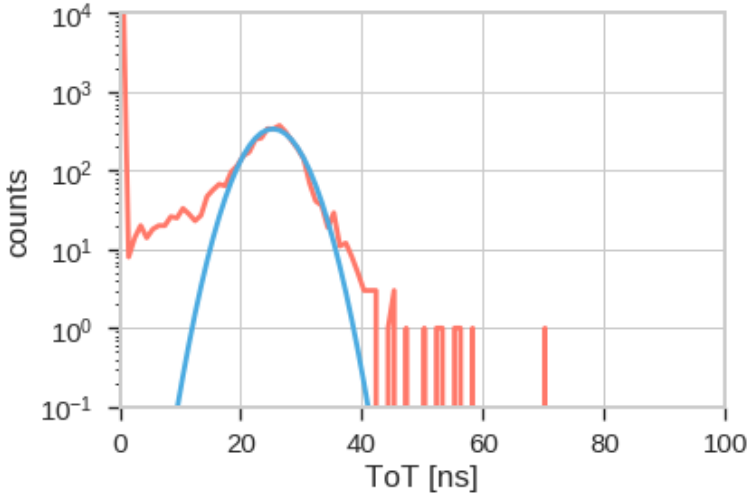
Fit parameters: μ (mean number of photoelectrons)
Q (single photoelectron charge), measure of gain
σ (sigma of single photoelectron peak)

Active Base – ToT Distribution

waveform



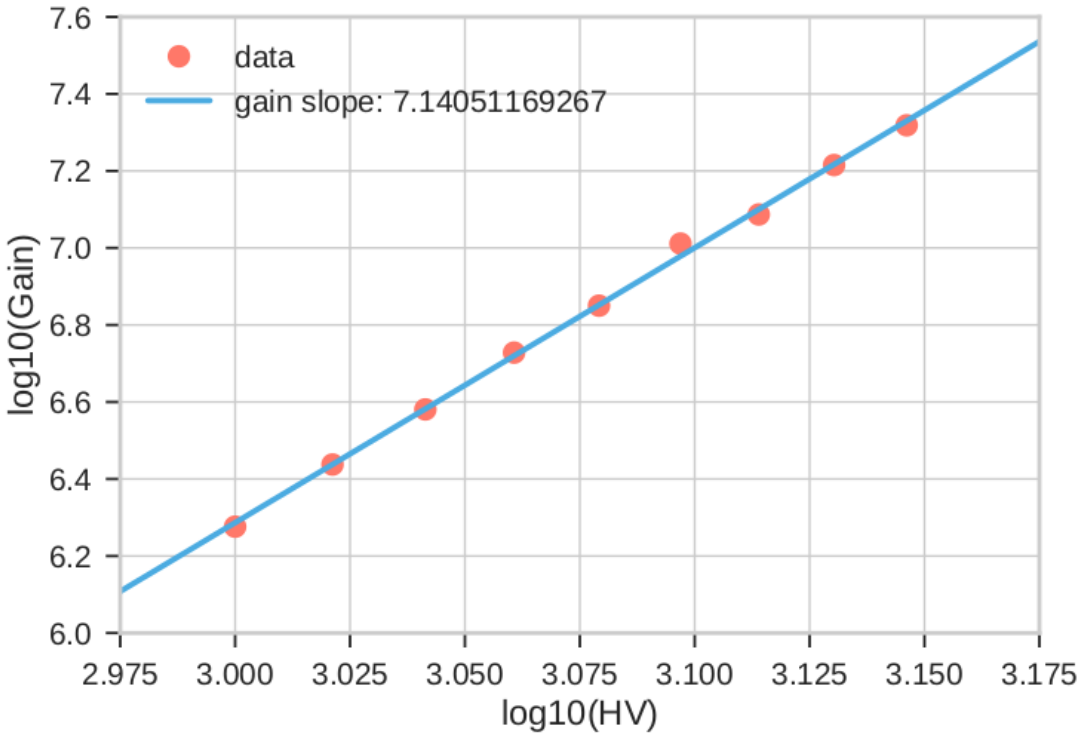
ToT histogram



- Measure ToT of all waveforms
- Fill ToT values in histogram
- Fit simple Gaussian
- Take mean value as ToT measure

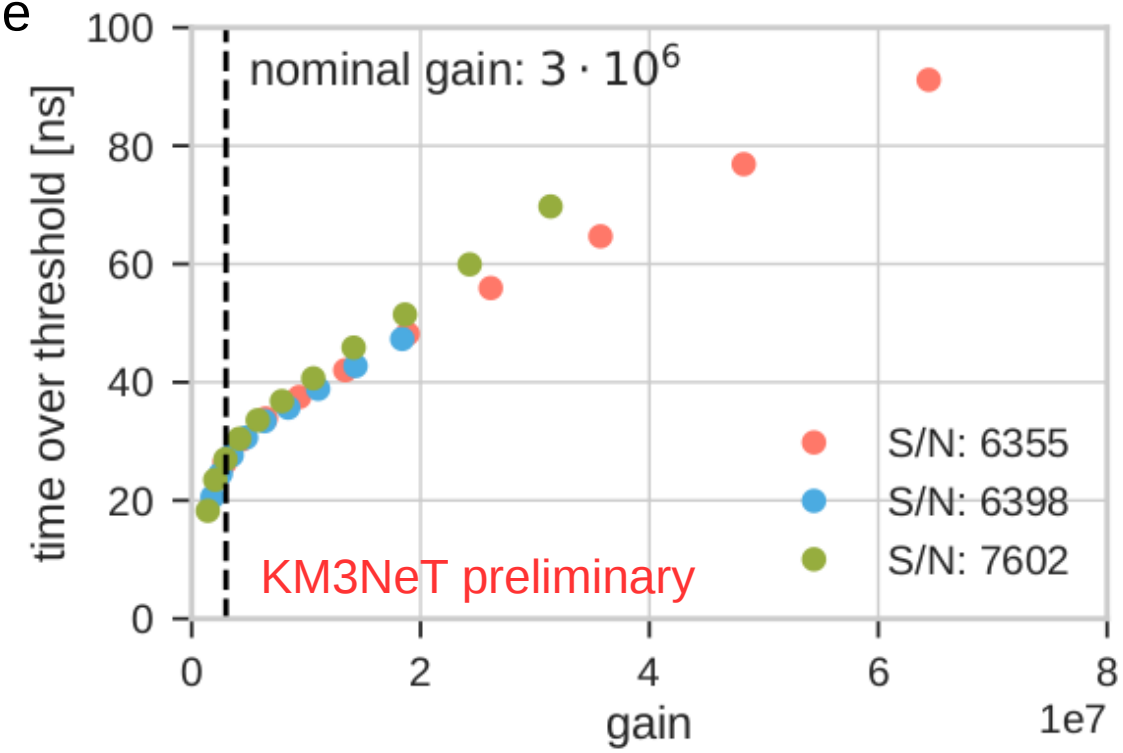
How can we calibrate ToT vs. gain?

- Use pre-calibrated PMT with known gain slope



ToT vs. Gain

- Measure ToTs at different HVs/gains in single photoelectron regime



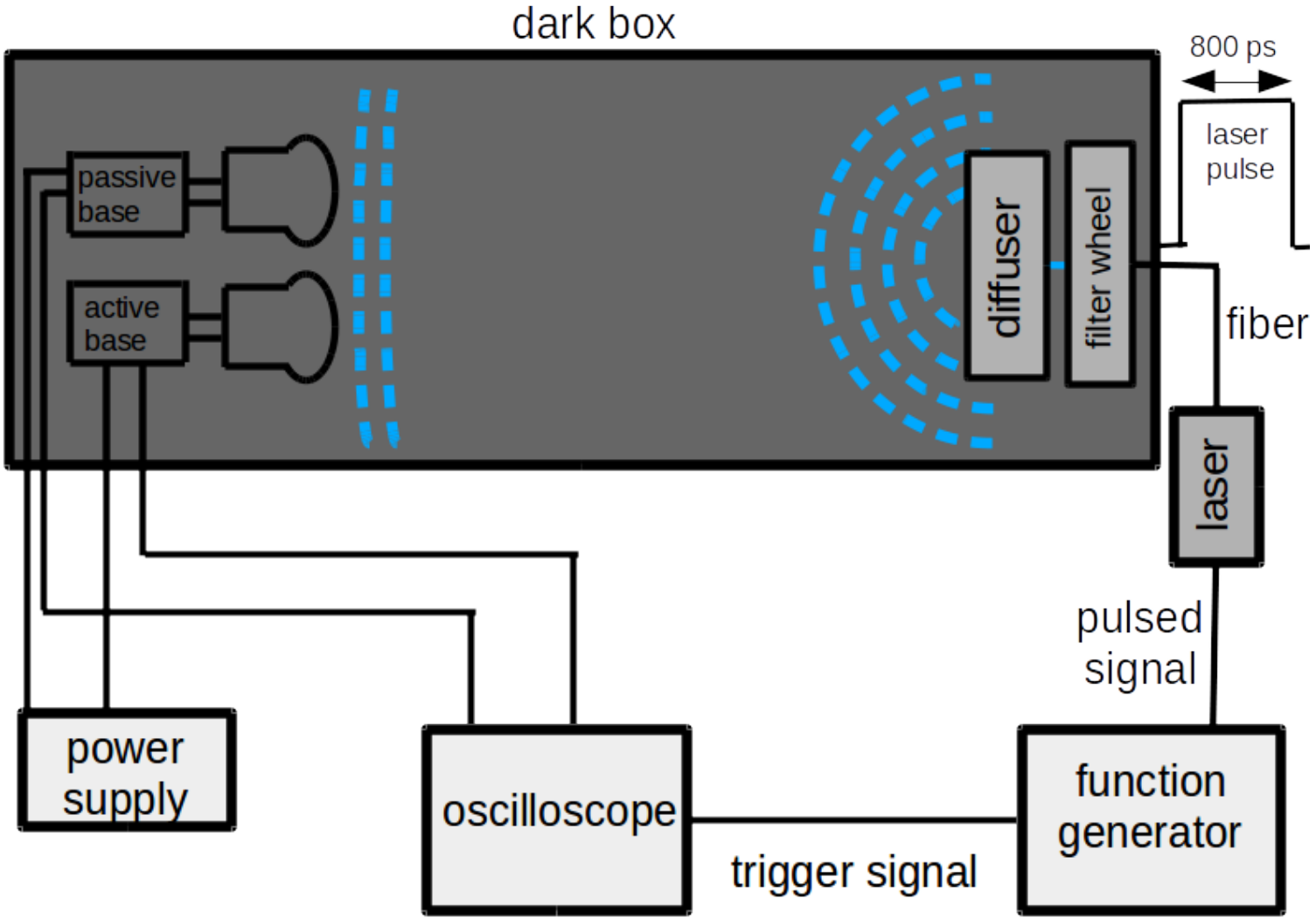
- Limited measurement range up to roughly 20 photoelectrons due to max HV
  => go for increased number of photoelectrons

Measurement with high intensities

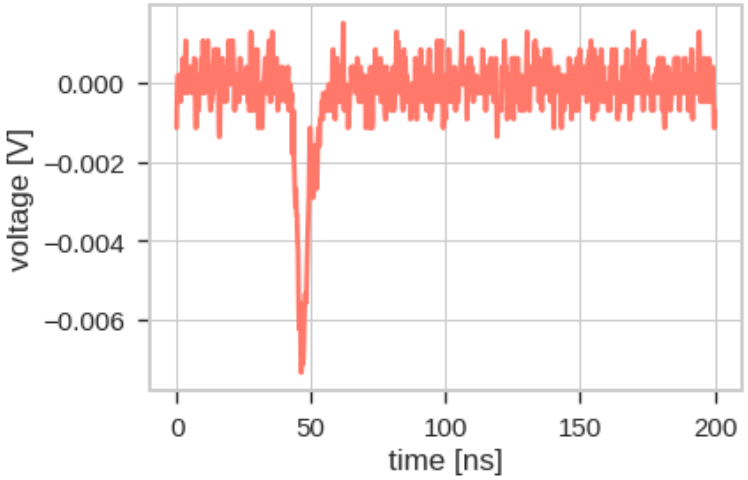
- Use pulsed laser as light source
- Use two PMTs, one with active, one with passive base
- Measure ToT and mean number of photoelectrons with different PMTs
- Correct for different intensities at PMTs

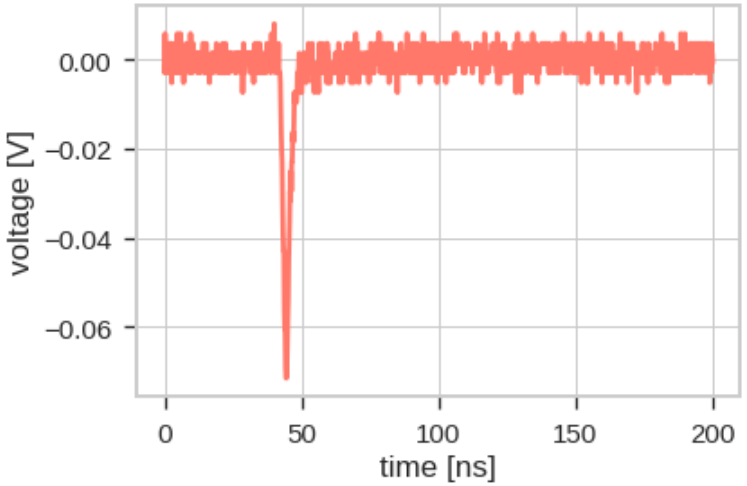
  => ToT/NPE calibration

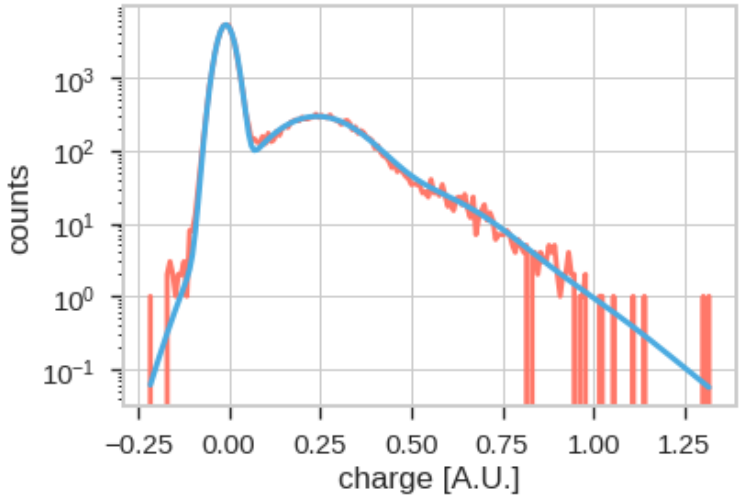
Setup

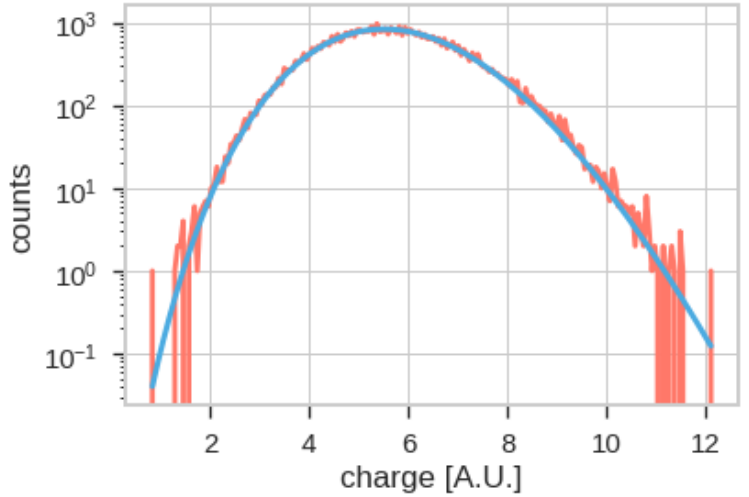

dark box
800 ps
laser pulse
passive base
active base
diffuser
filter wheel
fiber
laser
pulsed signal
power supply
oscilloscope
trigger signal
function generator

Passive Base – Signals and Charge

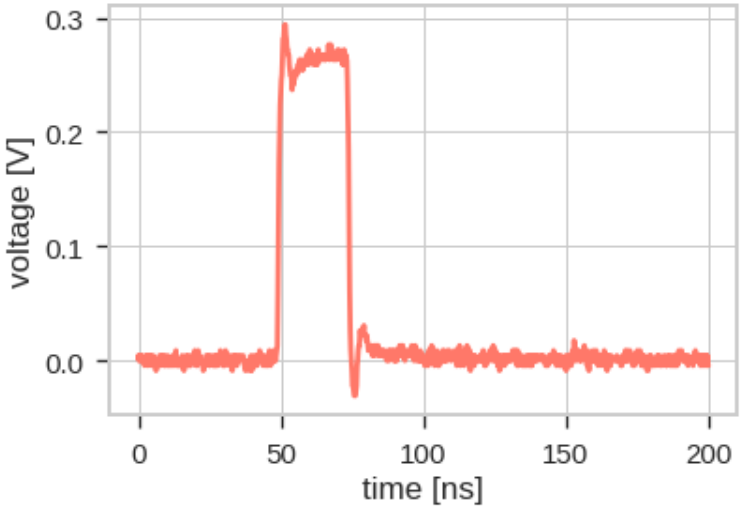


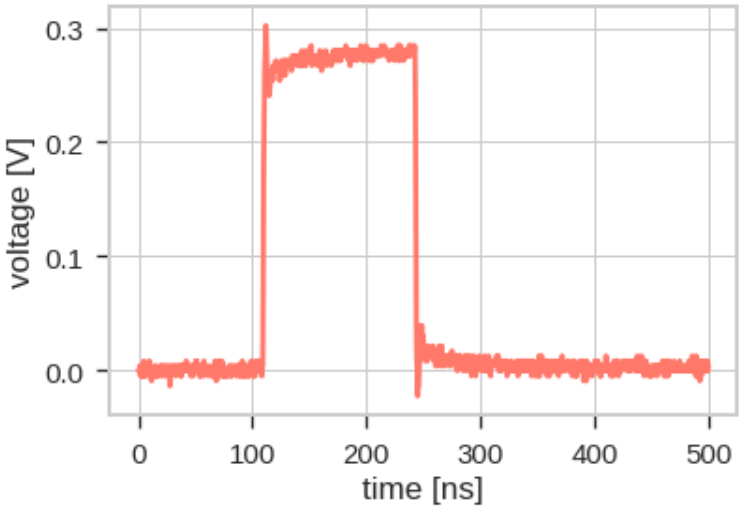


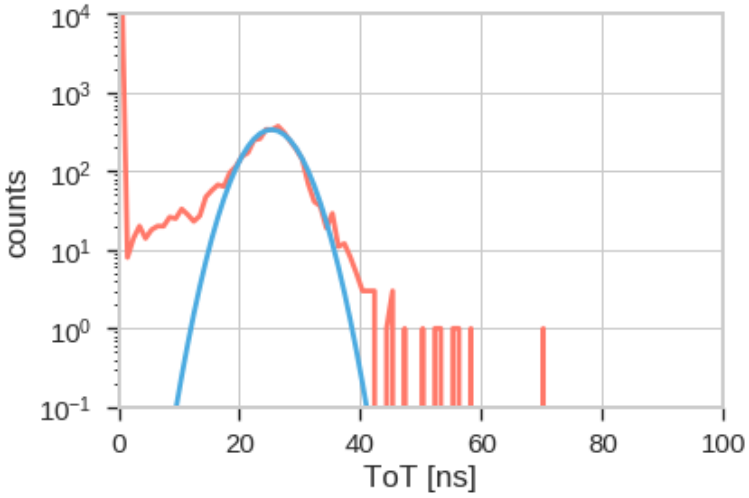


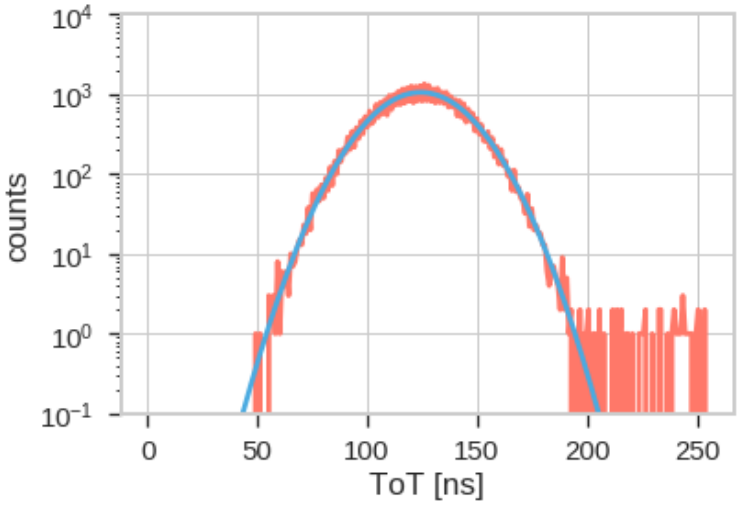


Active Base – Signals and ToT

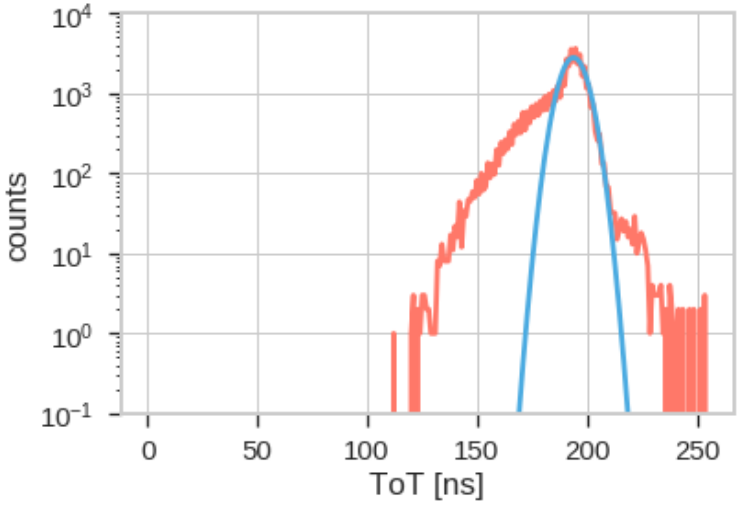


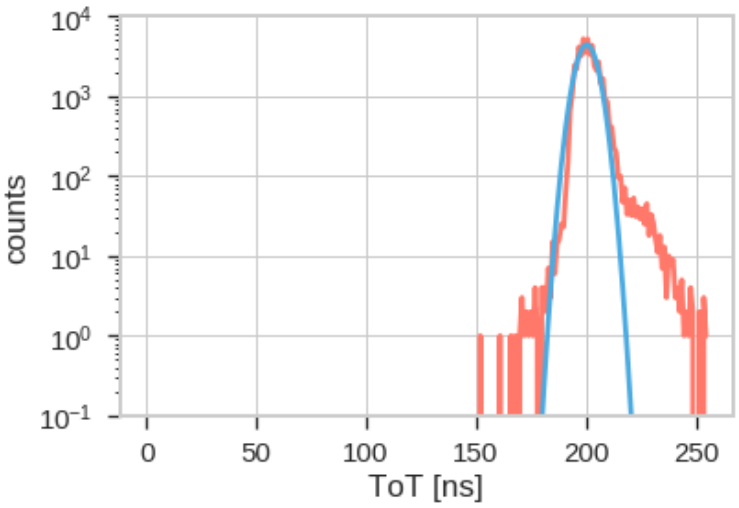


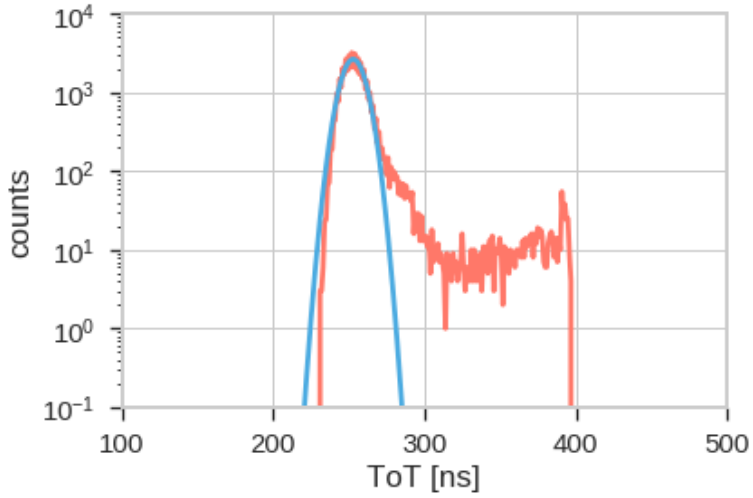


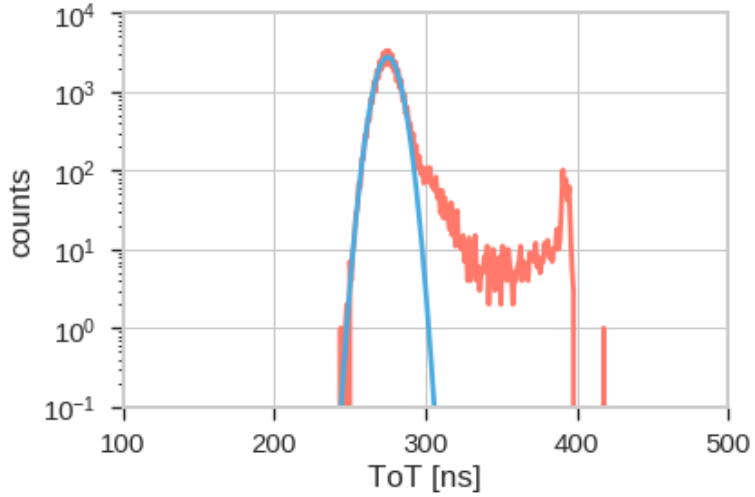


Active Base – Large ToT Signals









Intensity comparison

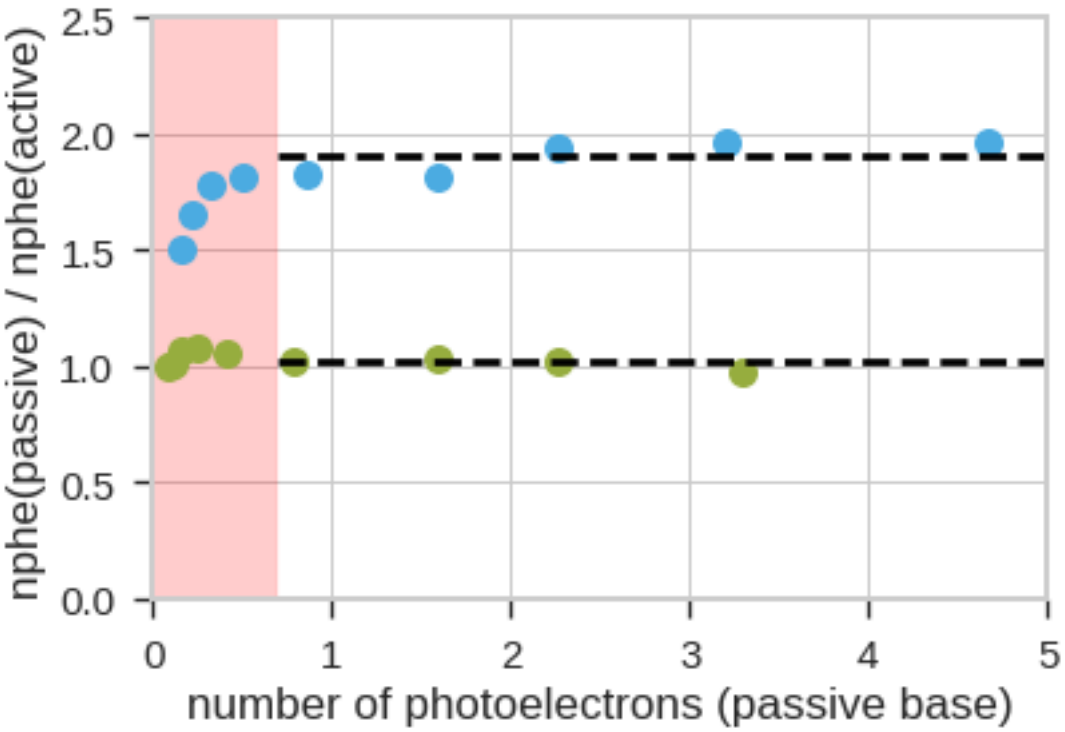
- Light intensity at both PMTs can be different
- Comparison of mean number of photoelectrons (μ) for small intensities
- For passive base: μ from PRF fit
- For active base from Poisson distribution:

$$P(\mu, n) = \frac{\mu^n \cdot e^{-\mu}}{n!}$$

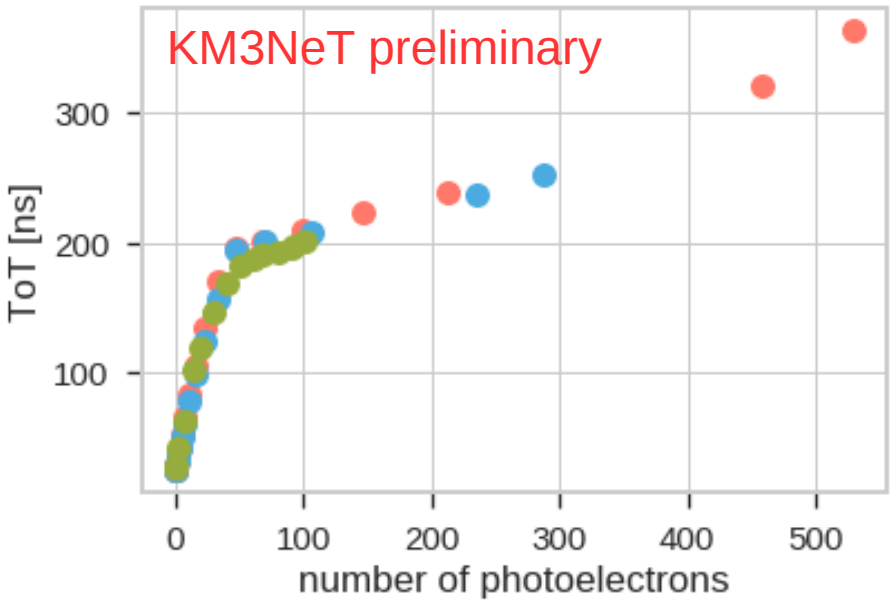
Via probability of zero-event P(0)

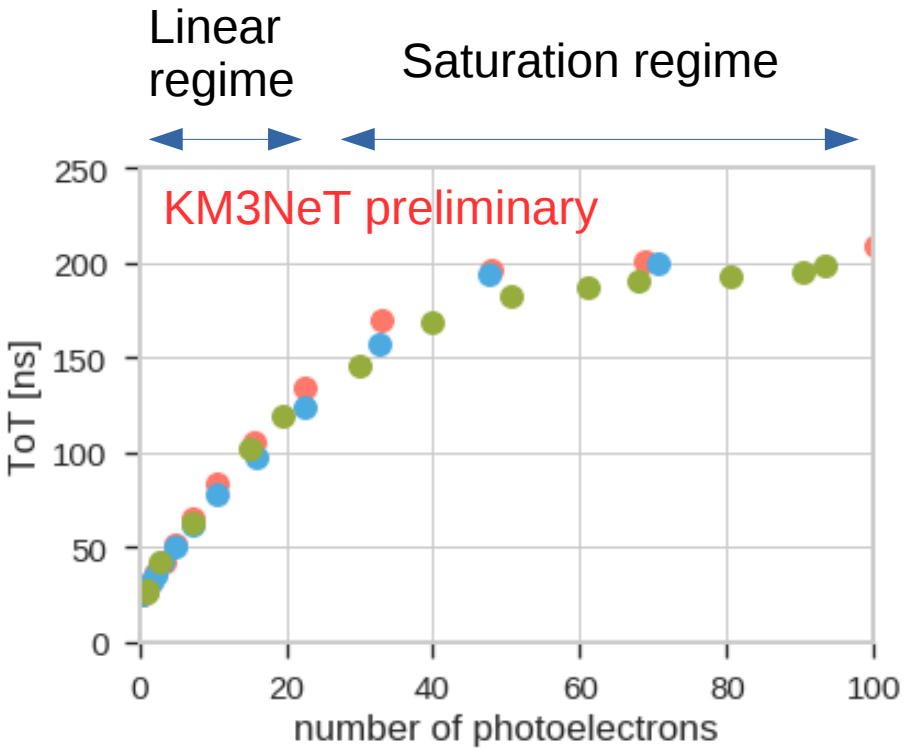
$$P(\mu, 0) = \frac{\mu^0 \cdot e^{-\mu}}{0!}$$

$$\Rightarrow \mu = -ln(P(\mu, 0)) = -ln(\frac{N_0}{N_{all}})$$



ToT vs. NPE


KM3NeT preliminary
ToT [ns]
300
200
100
0
100
200
300
400
500
number of photoelectrons


Linear regime
Saturation regime
KM3NeT preliminary
ToT [ns]
250
200
150
100
50
0
0
20
40
60
80
100
number of photoelectrons

Summary

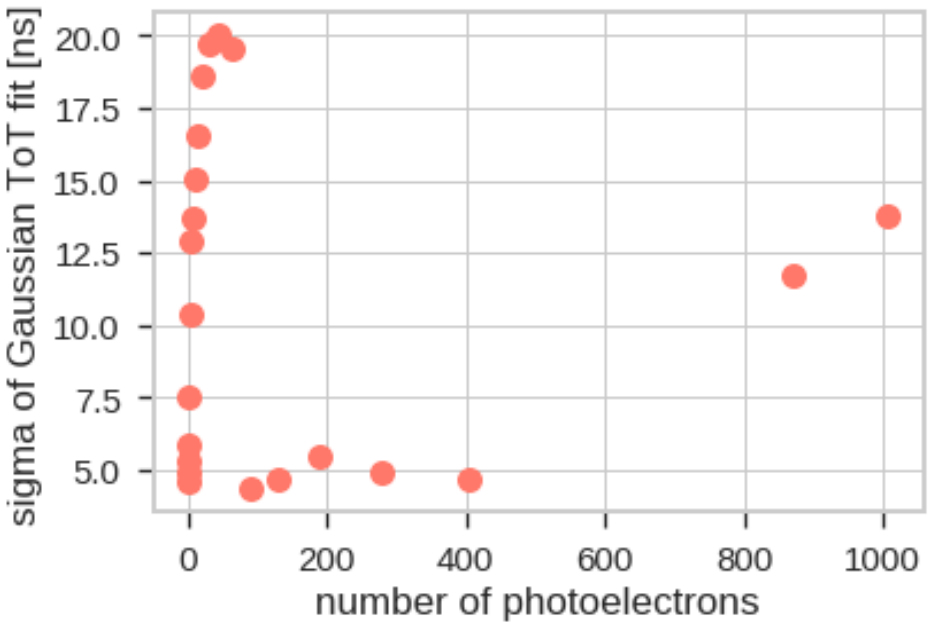
- In KM3NeT, each PMT hit comprises photon arrival time and time-over-threshold (ToT) value
- A successful method for calibration of ToT vs. number of photoelectrons (NPEs) has been presented
- ToT/NPE calibration yields comparable results for different PMT-base pairs
- Relation between ToT and NPE well defined in the measured intensity range

Outlook

- Measurement will be extended to even higher intensities (~1000 photoelectrons)
- Measurement of at least 5-10 more PMT-base pairs for comparison

Backup

Gaussian sigma of ToT distributions



Different analogue buffer signals