Electronics, Triggering and Gd monitoring check

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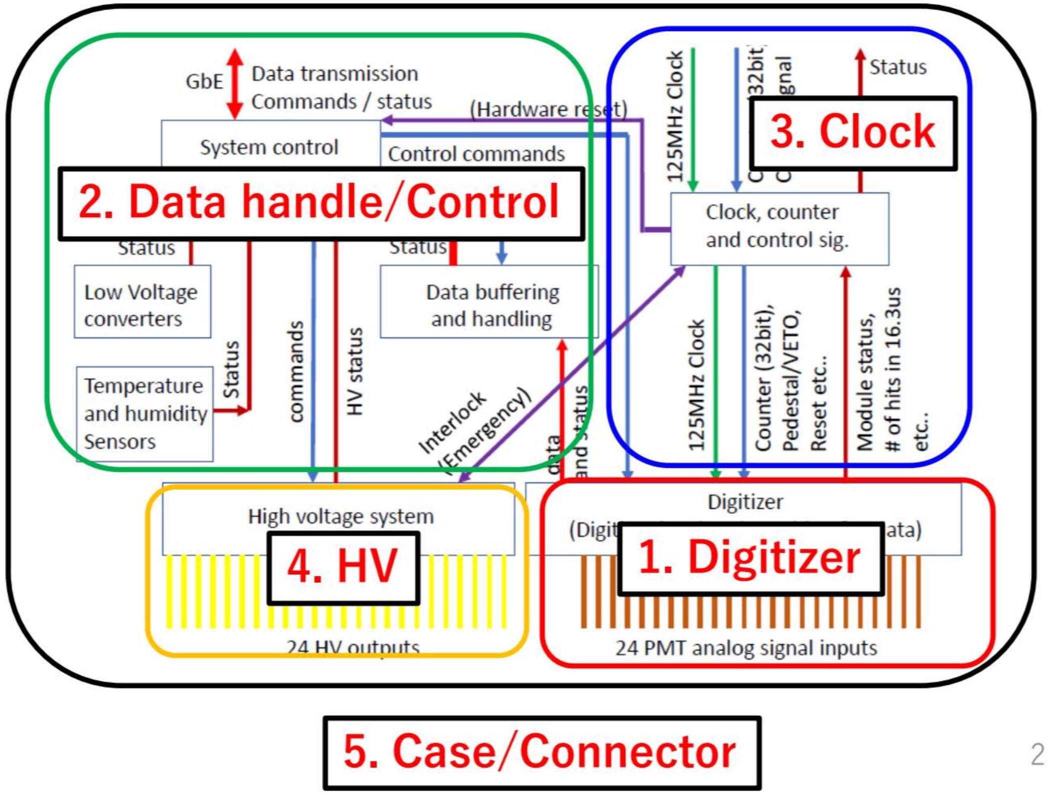
Electronics Proposals

There are 3 proposals for the Hyper-K front end digitisation electronics:

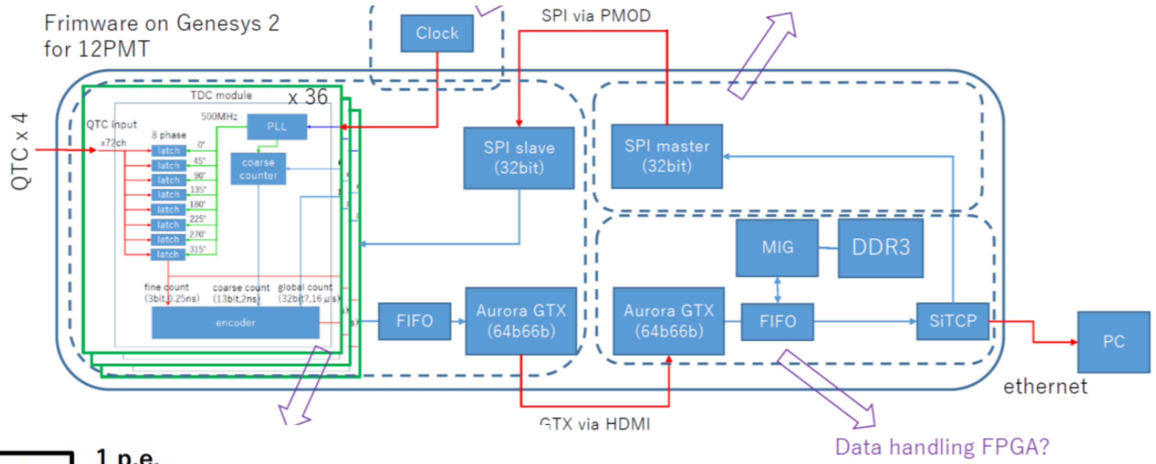


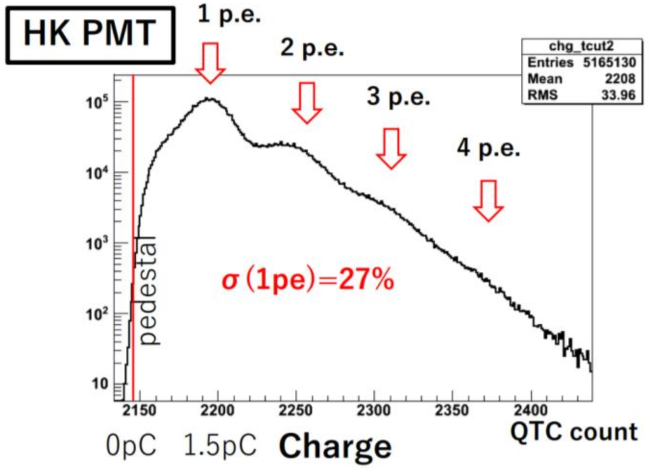
Electronics Proposals

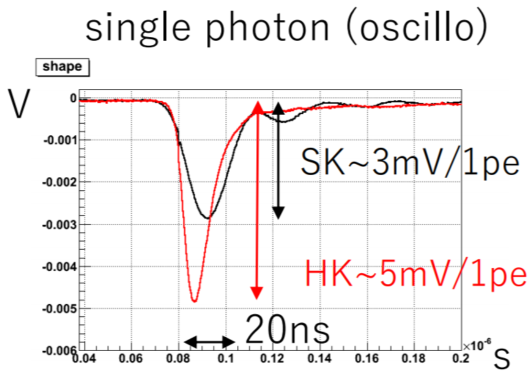
There are 3 proposals for the Hyper-K front end digitisation electronics:

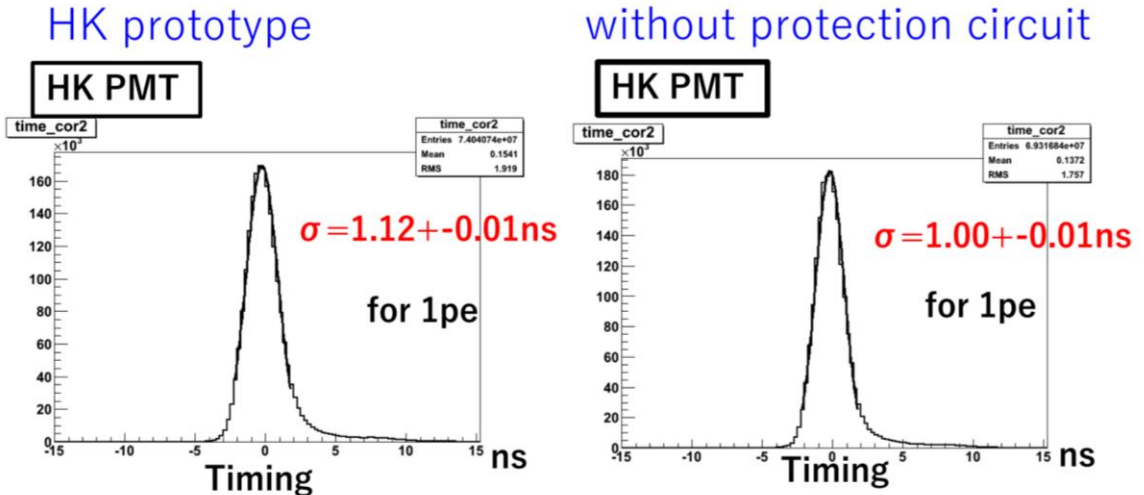
1. Analogue QTC ASIC with FPGA based TDC

- ✓ PMT gain set ~ 1.5pC/1pe
- ✓ Threshold ~ -0.6mV (~0.1pe)
- ✓ excellent resolution of HK PMT
- ✓ consistent with QBEE



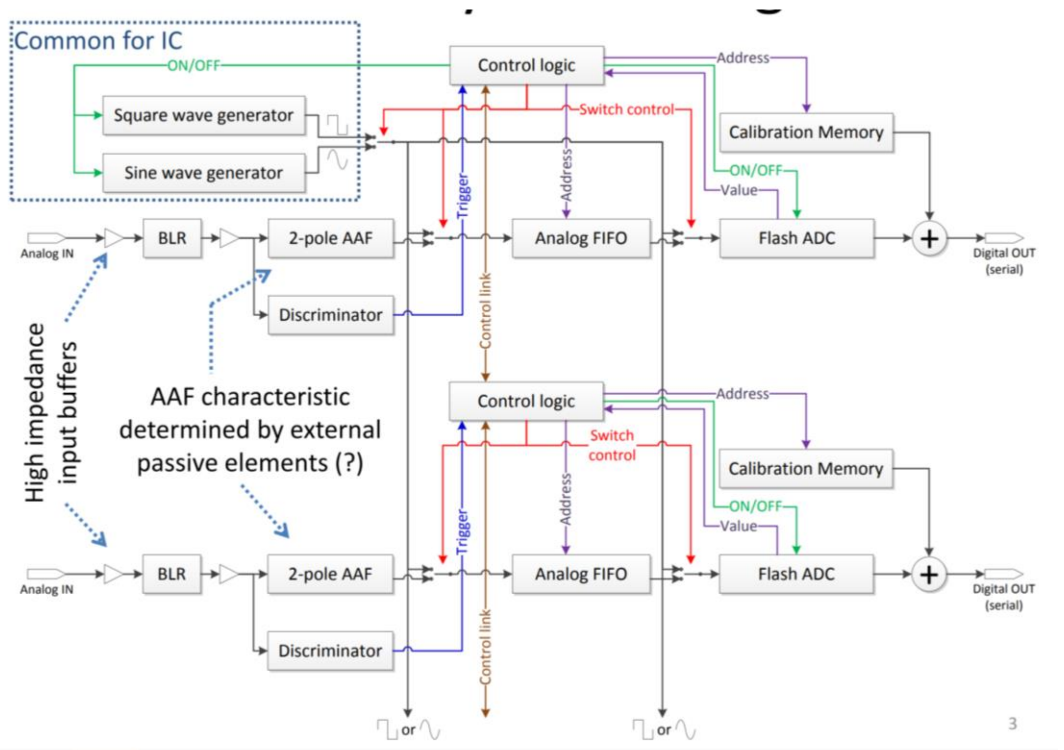




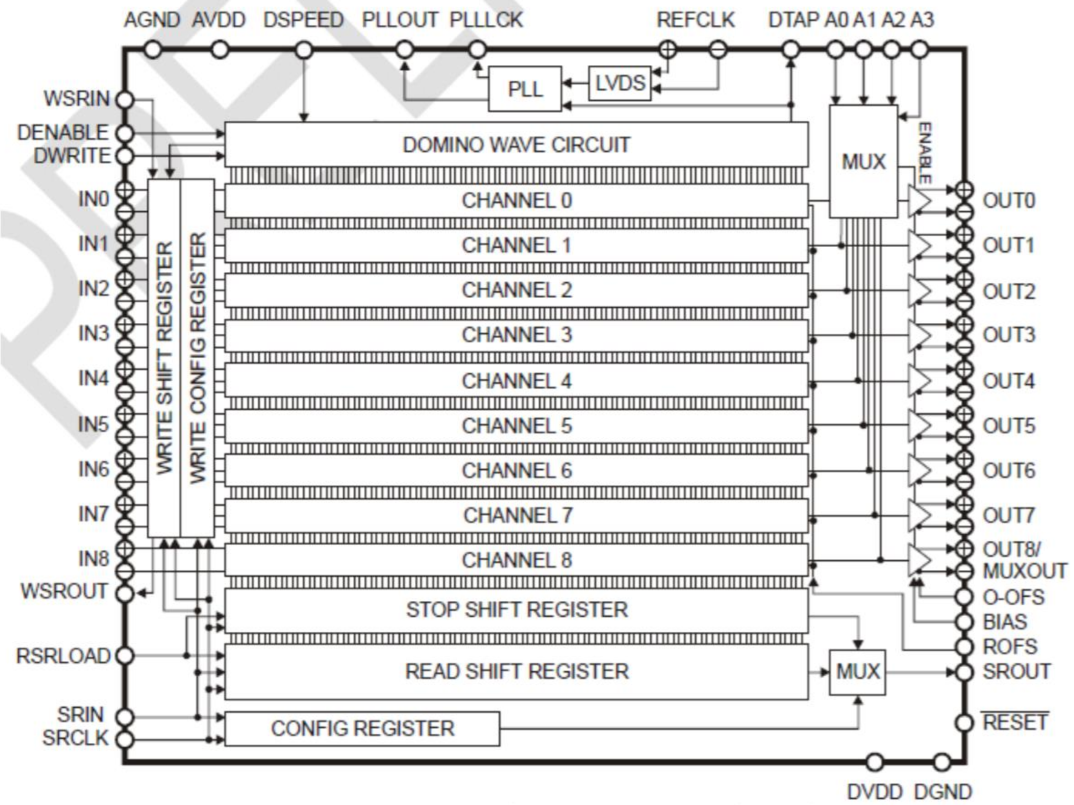


2. Flash ADC Waveform digitisation

- Provide Flash-ADC type of readout at minimum power
- Keep FADC in low-power state most of the time
  - Wake-up only on incoming pulse
  - Run as long as necessary
  - Go to sleep again after no more pulses
  - FADC optimized for fast wake-up time
- Use analog memory (circular buffer, FIFO-type) to store the pulse until FADC is ready to accept signal
- Equal sampling speed of FIFO and FADC
- Need self-triggering for FADC wake-up
- Built-in calibration circuitry to account for leakage currents of analog FIFO and FADC non-linearity
- Possibility to couple channels for low-gain/high-gain configuration



3. DRS switched capacitor array

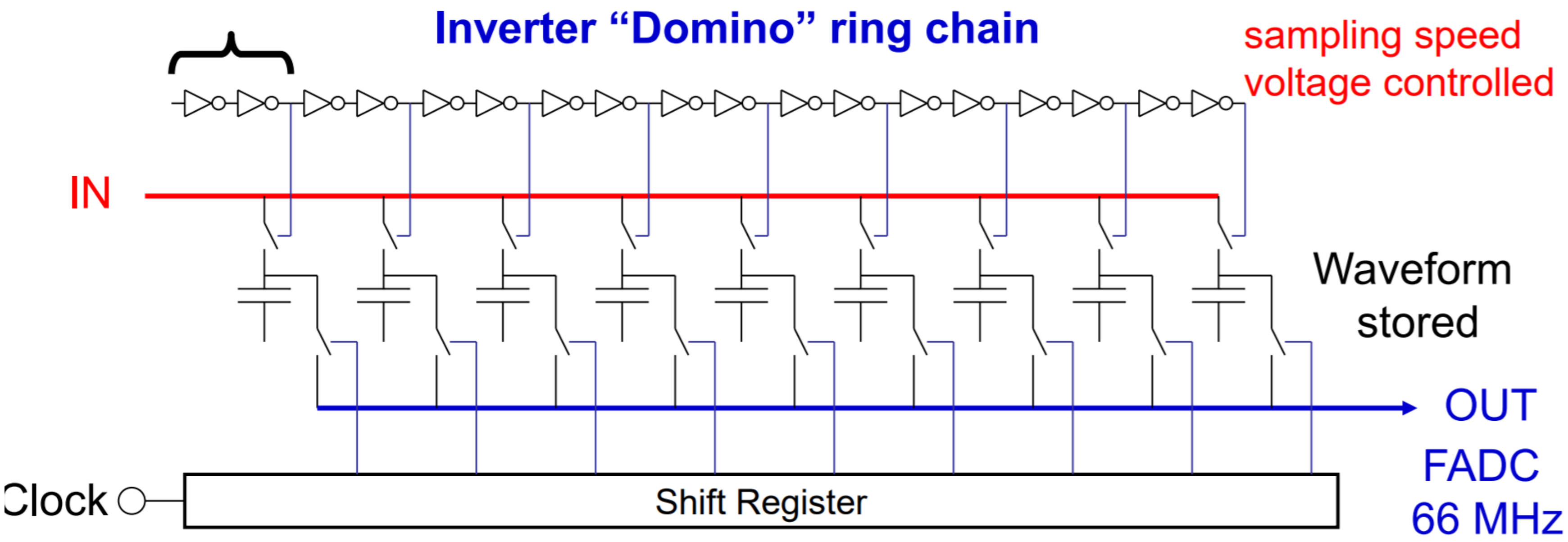


ASIC with 8 switched capacitor arrays (1024 caps / ch.)
- up to 5 GHz sampling speed (controlled by an internal digital delay line)
- 11.5 bit resolution
- various operation modes

note: not the only capacitor array on the market, but I'm in Switzerland …
different arrays have different merits …

3. DRS switched capacitor array

5 GHz – 0.8 GHz: 0.2 – 1.25 ns sampling → 200 to 1250 ns deep buffer



it works like a time stretcher, but w/ no deterioration of signal / loss of information:

sampling ~ GHz range

digitization ~ 50 MHz range

☺ low power !

☹ one single array cannot sample during readout

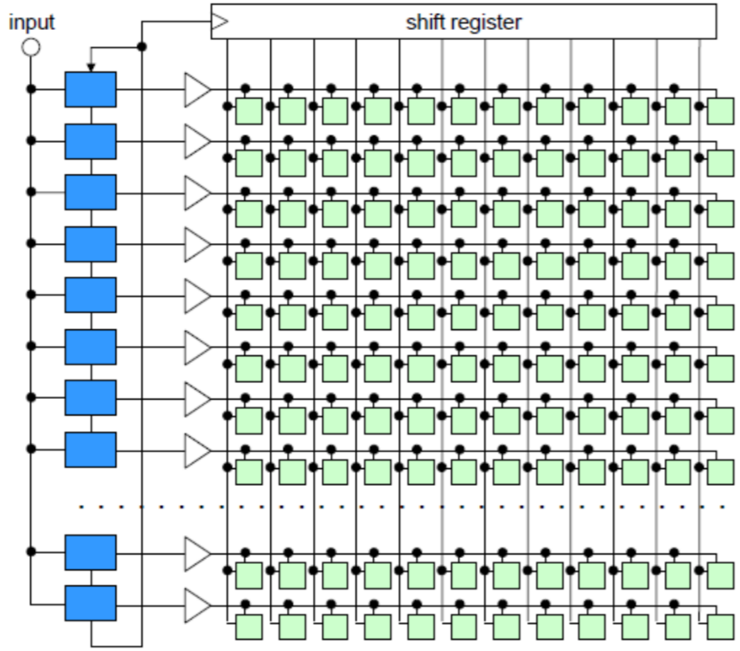
→ deadtime (can be made as short as 15 μs)!

but one array on the DRS chip can be "digitized" while the other is sampling

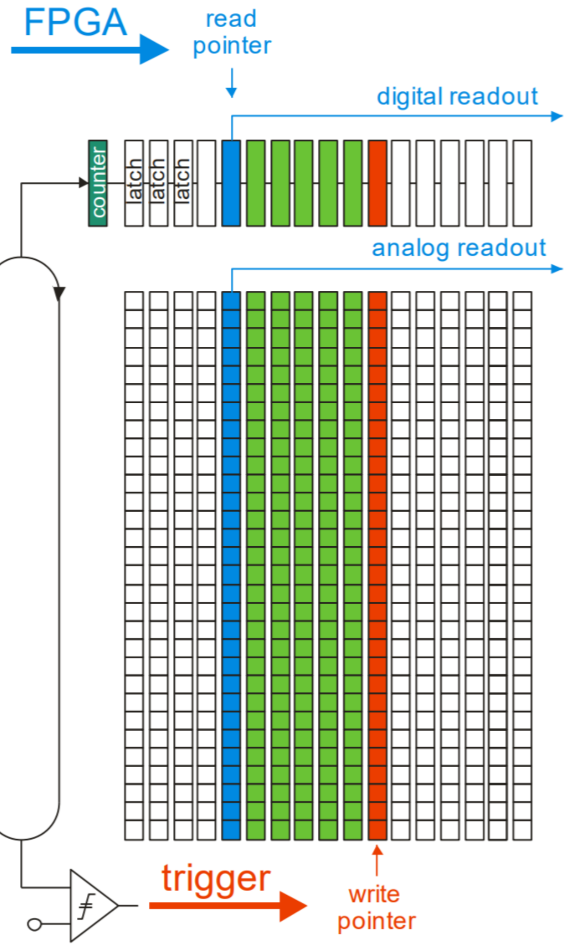
☺ virtually deadtime less solution

3. DRS switched capacitor array

The DRS5 Digitizer



fast sampling storage of segments



100 ps sample time. 3.1 ns hold time

2-5 times better timing resolution

data driven readout

(almost) dead-time-less waveform digitizing

(can sustain rates in excess of 2 MHz)

Trigger Algorithm Development

- 1. n hits trigger
- 2. Test-vertices algorithm
- 3. Cone finder
- 4. Radioactivity tagging by charge
- 5. Convolutional neural network
- 6. Supernova Trigger

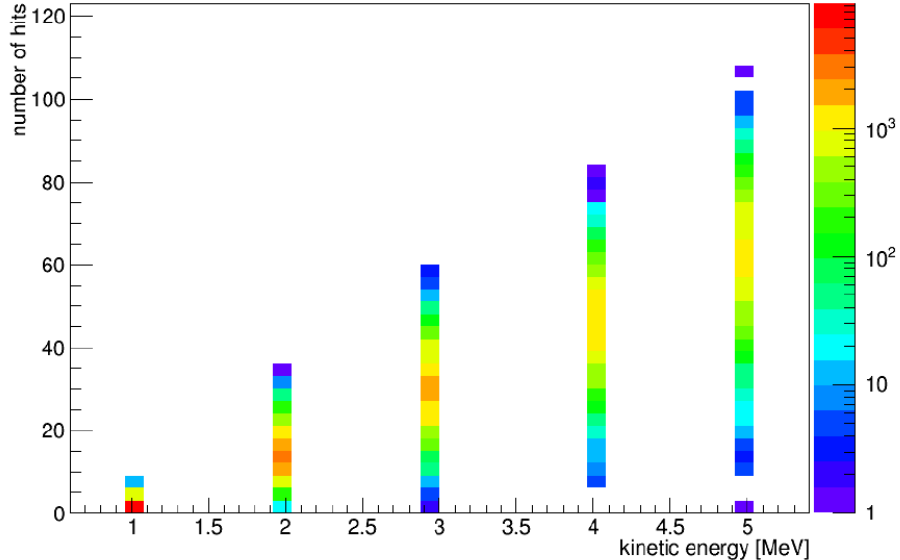
n Hits

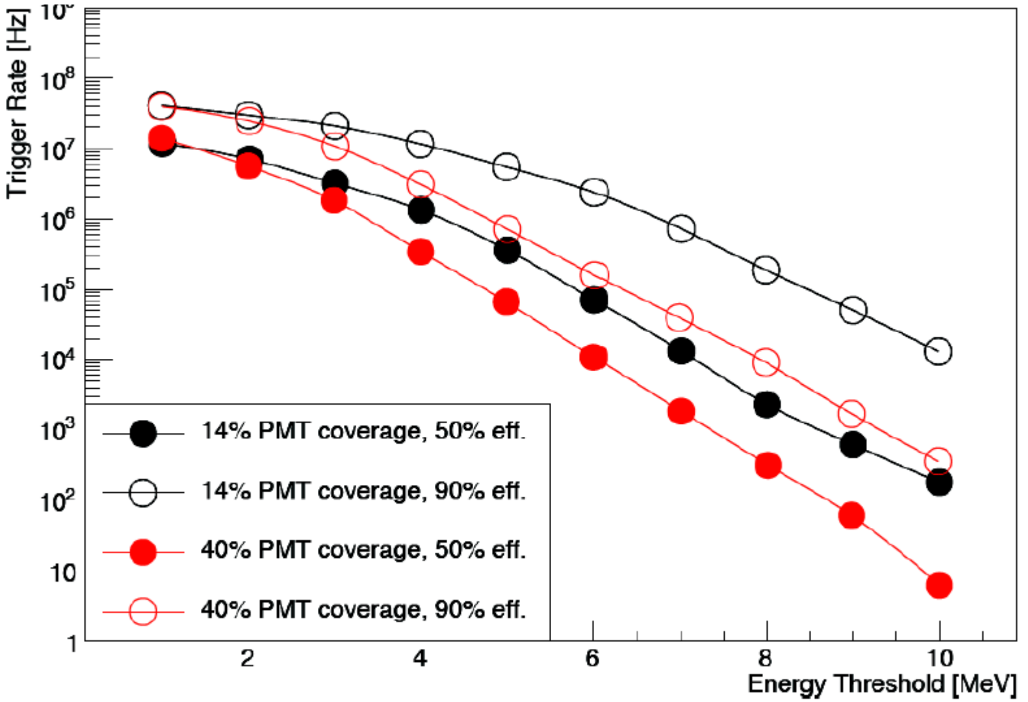
- trigger if (nhits in sliding window) > (threshold)

	SK	HK 14%	HK 40%
light transit time (ns)	200	400	400
n PMT's	11146	14728	44028
dark noise rate (kHz/PMT)	4.2	8.4	8.4
dark noise hits in transit time	9	49	148

- expect 150 ± 12 background hits
- a 600 MeV beam muon generates 3000 hits
- trivial to trigger on beam + atmospheric events

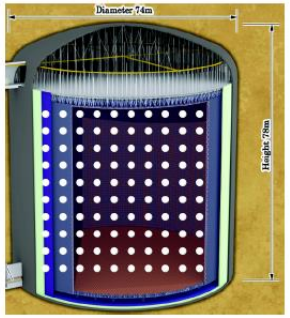
kinetic energy [MeV]	1	2	3	4	5
number of hits	1.7 ± 0.8	14 ± 5	30 ± 7	46 ± 9	61 ± 11

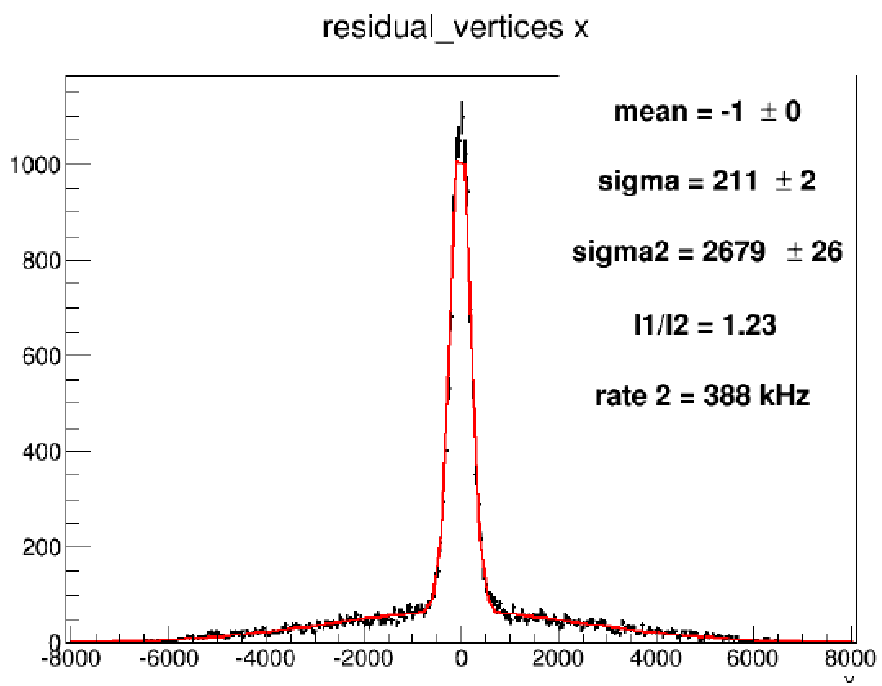




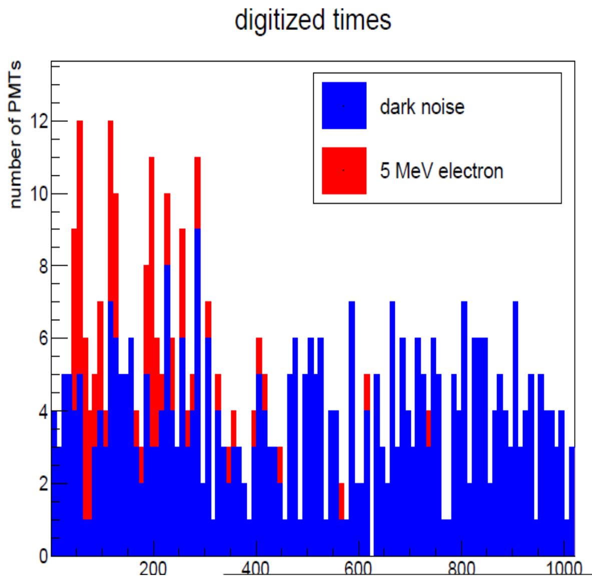
Test-vertices Trigger

- Čerenkov photons reach the PMTs at many different times
- the low-energy signal, diluted in time, is hidden by dark noise
- grid of test vertices ($\Delta L = 5$ m)
-
  - find the Cerenkov vertex
  - subtract time of flight
  - shrink time window (400 ns to 20 ns)
  - kill dark noise

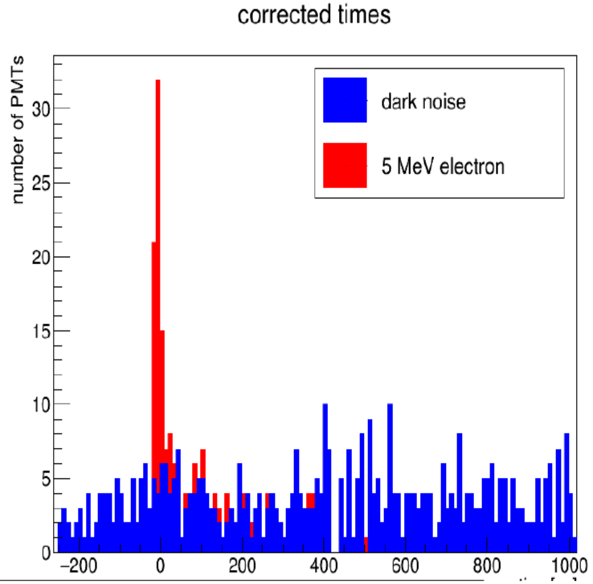


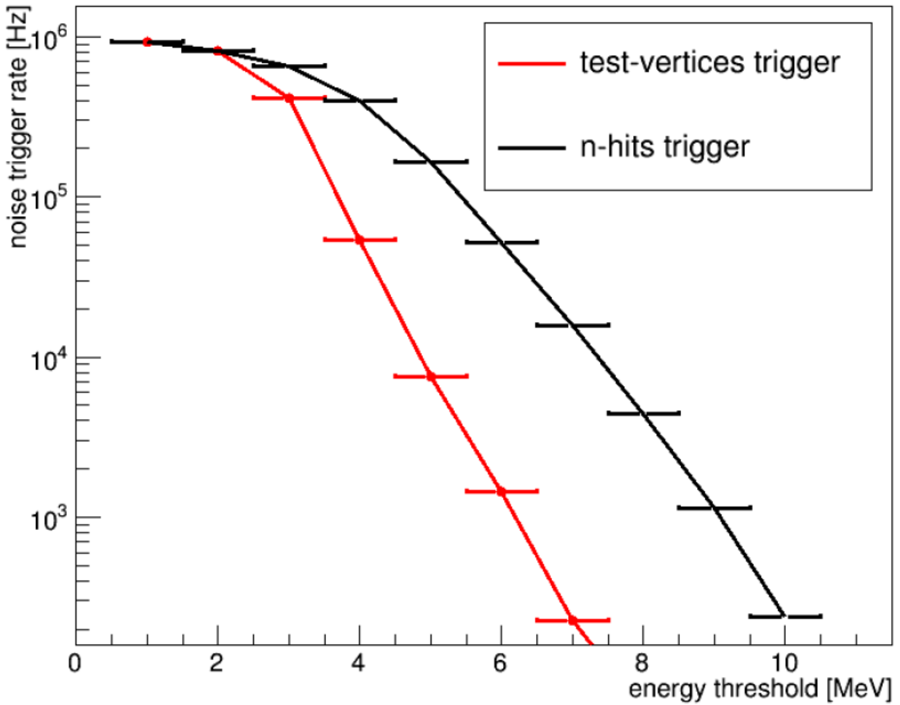


raw time (5 MeV e^-):

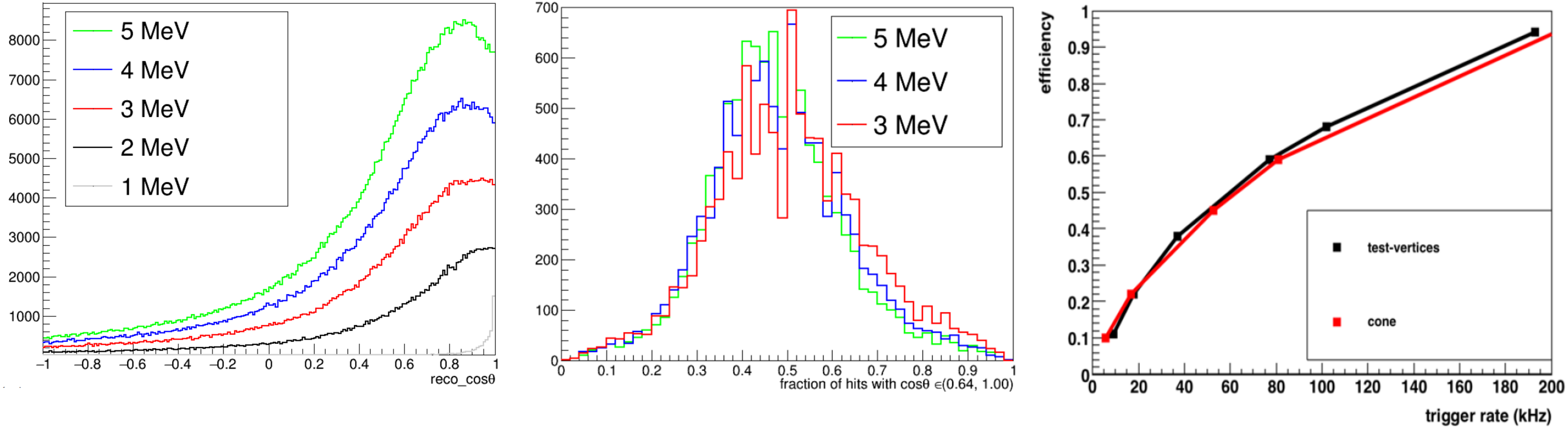


after reconstructed TOF correction:





Cone Finder



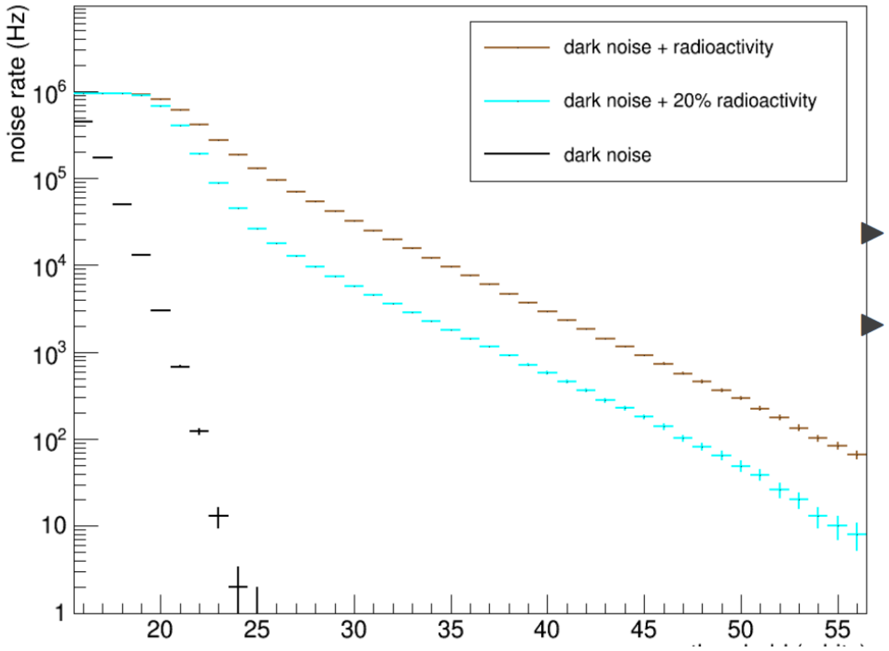
- Performance at 3 MeV:

electron hits	$0.51 \times 30 = 15.3$
dark noise hits	$\frac{1.00-0.64}{2} \times 10 = 1.8$
S / N	$3 \rightarrow 8.5$

Wall Vert Trigger

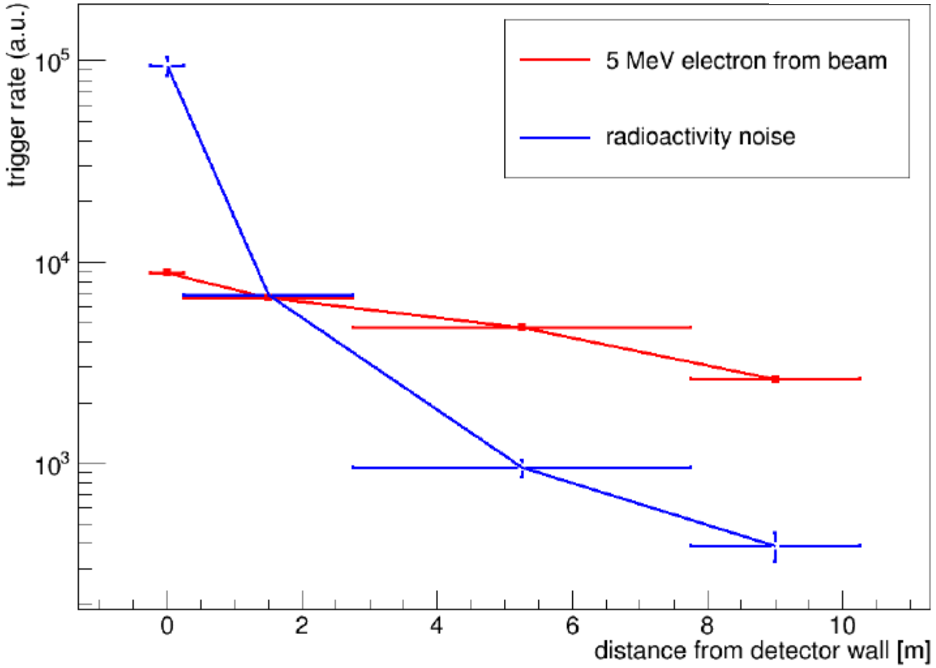
- Radioactivity dominates around 3 MeV

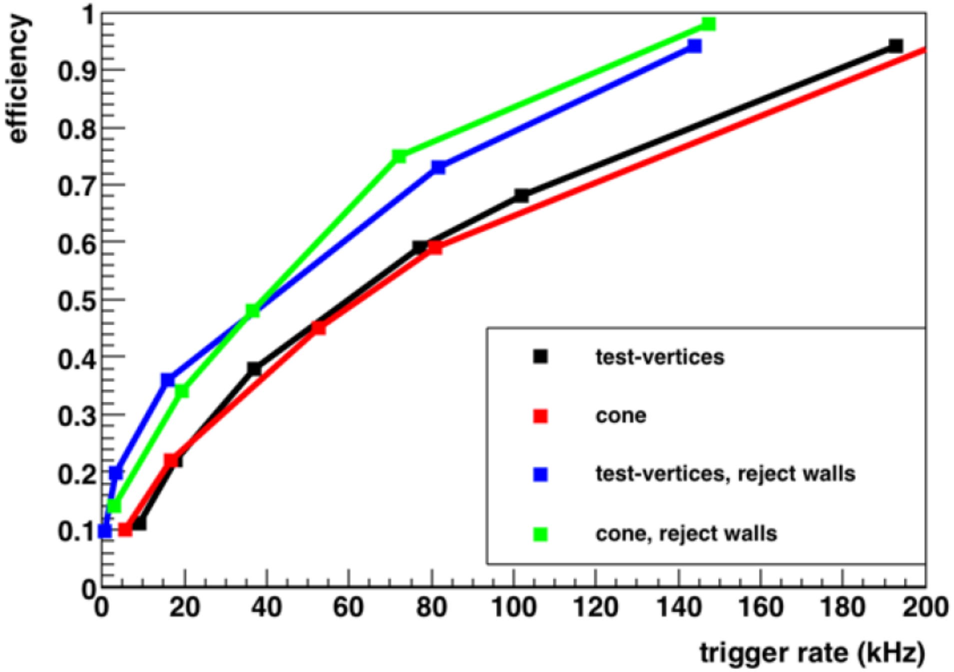
performance using test-vertices trigger:



- around 3 MeV (threshold = 23), we are completely dominated by radioactivity
- this conclusion heavily depends on radioactivity levels, which are not well known

40% coverage, 5 MeV electron

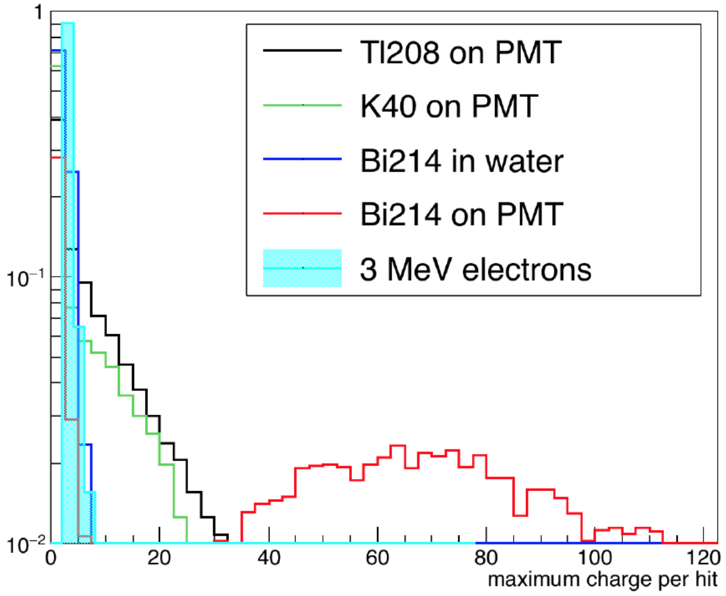


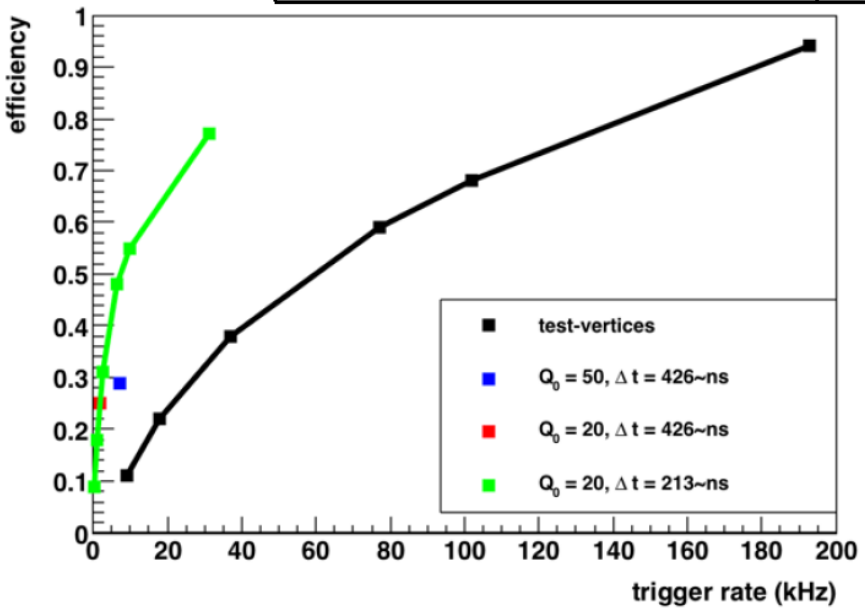


5 M from wall

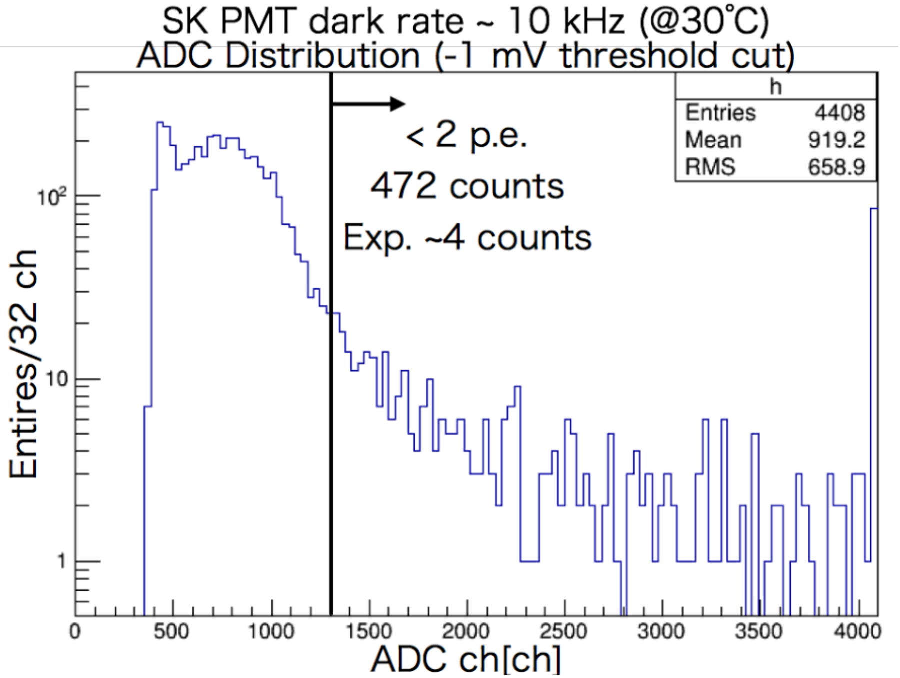
Charge Trigger

	3 MeV electron + dark noise	radioactivity + dark noise
test-vertices	efficiency 38%	rate 37 kHz
$Q_0 = 50, \Delta t = 426$ ns	efficiency 29%	rate 7 kHz
$Q_0 = 20, \Delta t = 426$ ns	efficiency 25%	rate 2 kHz
$Q_0 = 20, \Delta t = 213$ ns	efficiency 31%	rate 2.5 kHz



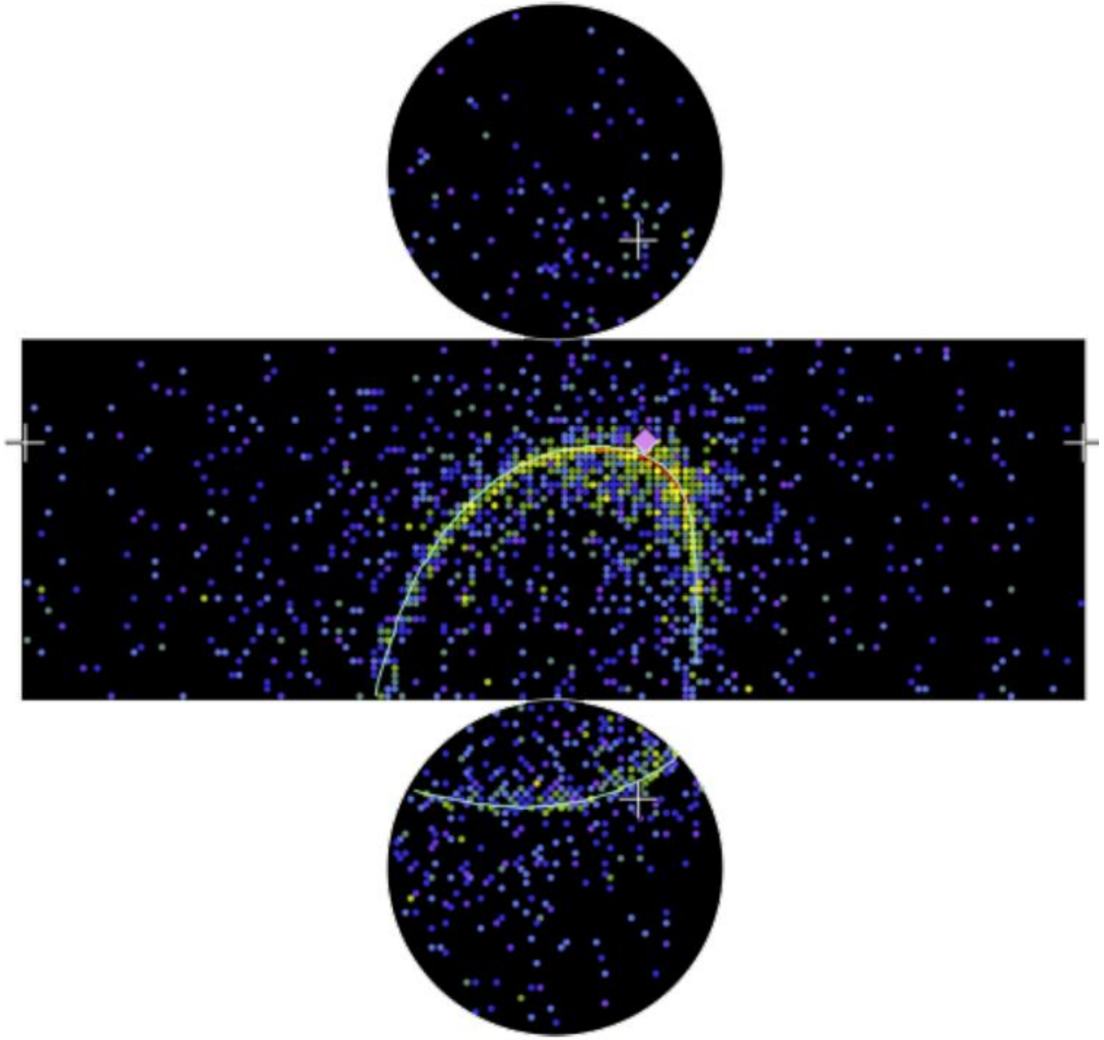


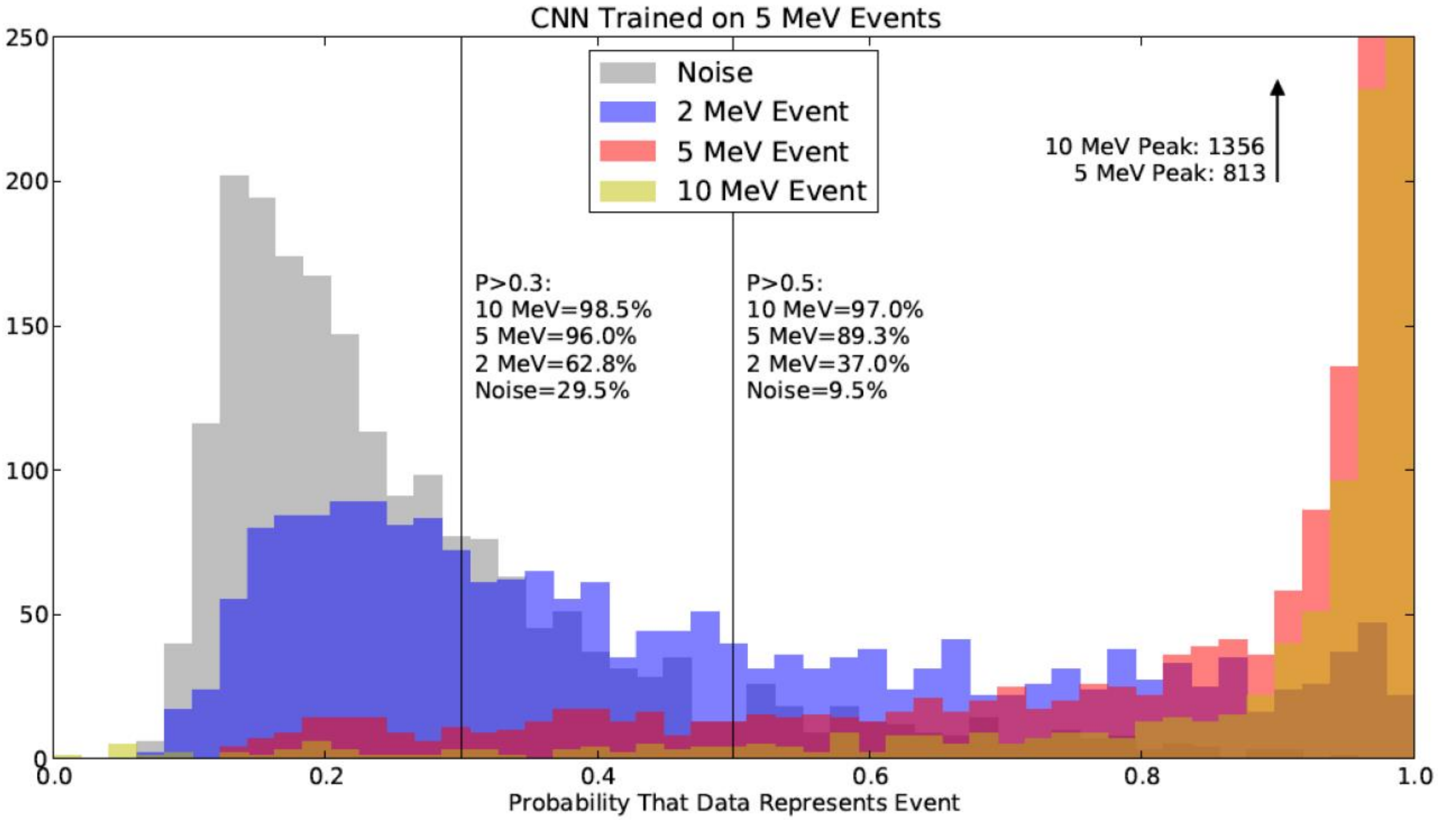
- A β^- decay in the PMT glass makes a faint cone and **one** hit with a large multi PE pulse (WCSim)



- data taken in SK tank
- above 2 pe, expect 4 counts from accidental coincidence rate (we know coincident light background using up to 100 pe's)
- there is a large excess (472 counts)

CNN Trigger





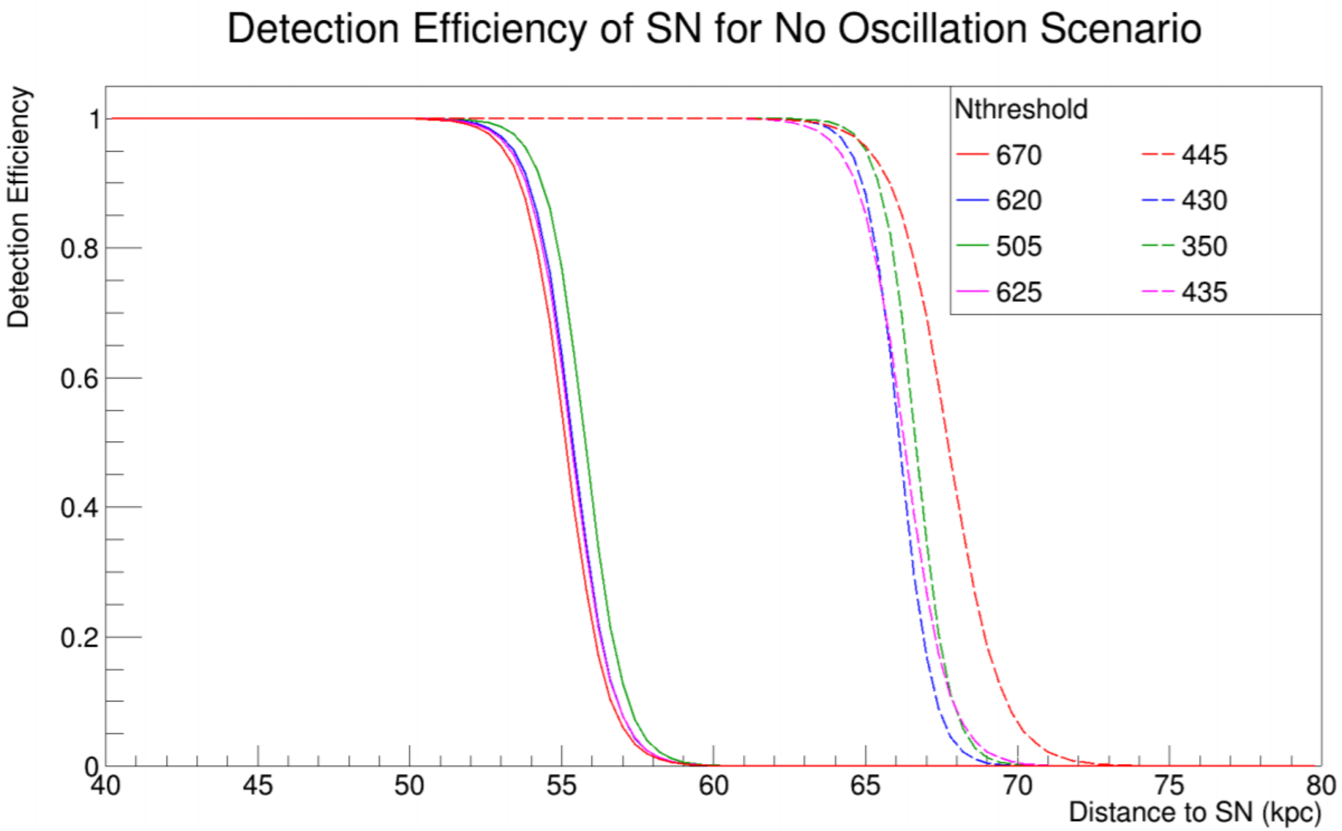
- 89.3% efficiency at 5 MeV
- 9.5% dark noise acceptance

SK SN monitoring method

- N_{cluster}, number of events (excluding cosmic rays and their decay electrons) in the fiducial volume with $E > 7\,\text{MeV}$ in a $20\,\text{s}$ window is calculated
- A variable D is computed for each $20\,\text{s}$ window to determine whether events originated from a point, line, plane or volume ($D = 0, 1, 2,$ or 3 respectively)

- Golden warning: $N_{\text{cluster}} \geq 60$ && $D = 3$
  - Experts called and decision expected in less than 1 hour
  - SK are 100% efficient up to LMC (50 kpc) with golden warning
- Normal warning: $60 \geq N_{\text{cluster}} \geq 25$ && $D = 3$
  - Experts emailed
- Silent warning: $N_{\text{cluster}} \geq 10$ in $10\,\text{s}$
  - Super-K experts only emailed

N_{cluster} thresholds

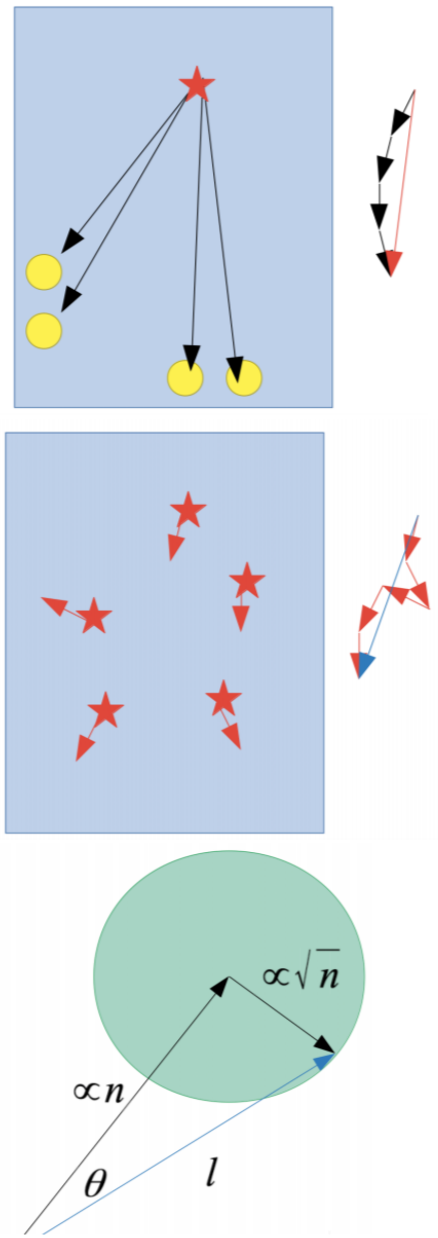


E_{true} cut
N_{hits} cut on 40k 20" PMTs
N_{hits} cut on 30k 20" & 7.7k mPMTs separately
N_{hits} cut on 30k 20" & 7.7k mPMTs combined

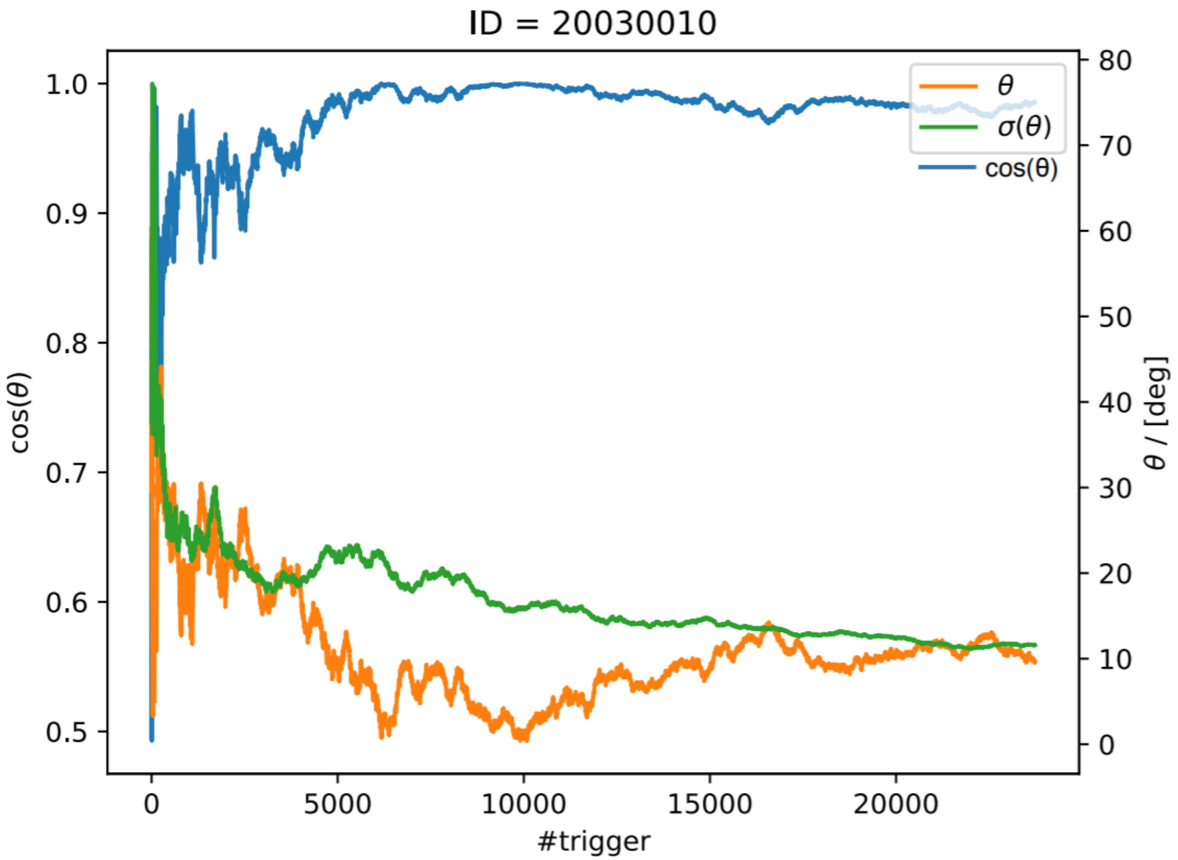
- 100% efficient out to SMC (60 kpc) with $N_{\text{cluster}} \gtrsim 430$
  - Recall: SK 100% efficient at LMC (50 kpc) with $N_{\text{cluster}} \geq 60$

SN direction reconstruction

- Get single trigger direction
  - Get vertex position (from e.g. test vertices)
  - Sum normalised direction vector of all associated hits
  - Normalise
  - Fast
- Add all trigger directions
  - Uncertainty assumes random walk of trigger directions
  - $\sigma(\theta) = \arcsin\left(a\sqrt{n}/l\right)$
    - ★ Calculations suggest $a \approx 0.87$ for 68% C.L.
    - ★ Note: plots in this talk use $a = 1$ corresponding to $\sim$80% C.L.



SN direction reconstruction: single SN @ 10 kpc



- Using Nakazato model with $M = 20\,M_{\odot}$, $t_{\mathrm{revive}} = 300\,\mathrm{msec}$ and $Z = 0.02$ with no oscillations in z-direction
- The more events, the better the direction resolution
  - But by $\mathcal{O}(1000)$ events the improvement is limited

Gadolinium Absorbance Detector (GAD)

- GAD is a device being developed in the UK for automated continuous monitoring of Gd concentration.

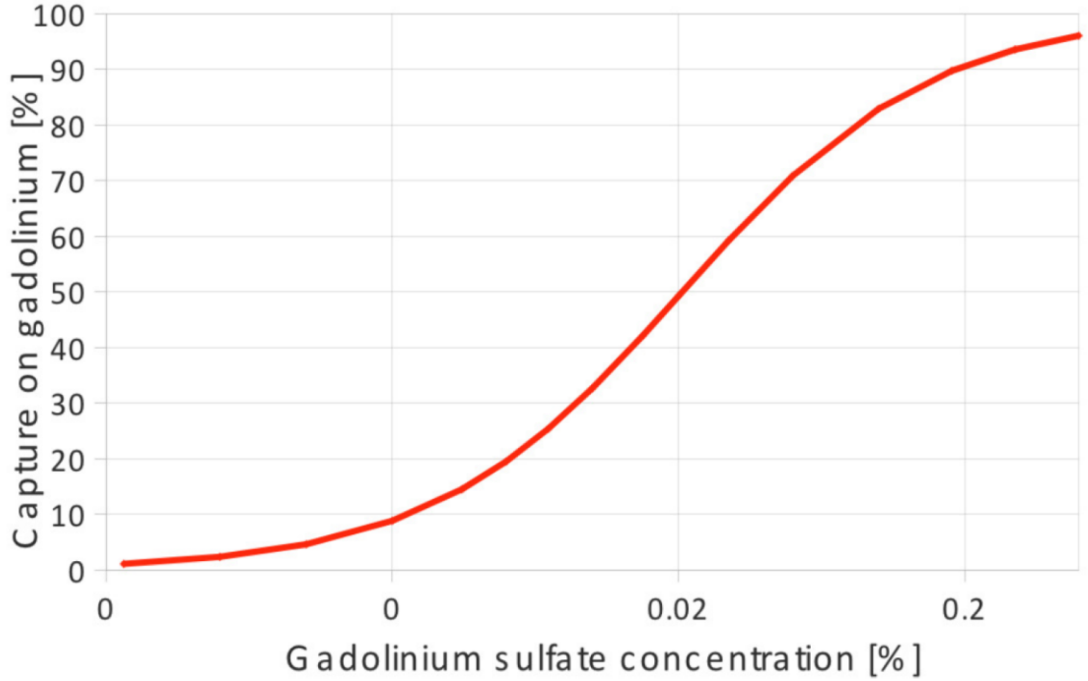
- Its currently in development for EGADS, Super-Kamiokande Gd upgrade and for the IWCD and has interests from other Gd detectors

- Current Gd measurement techniques require manual water sampling one monthly basis that is taken off site and passed through a mass spectrometer (slow, infrequent & labour intensive)

- Mass spec has **3.5%** on a concentration determination

Measuring Gd Concentration $Gd_2(SO_4)_3$%

The concentration of Gd affects the **efficiency** and **timing** of neutron captures. It can change inside the tank with **temperature** and **flow**.



T. Mori, PhD Thesis, The University of Okayama, 2015

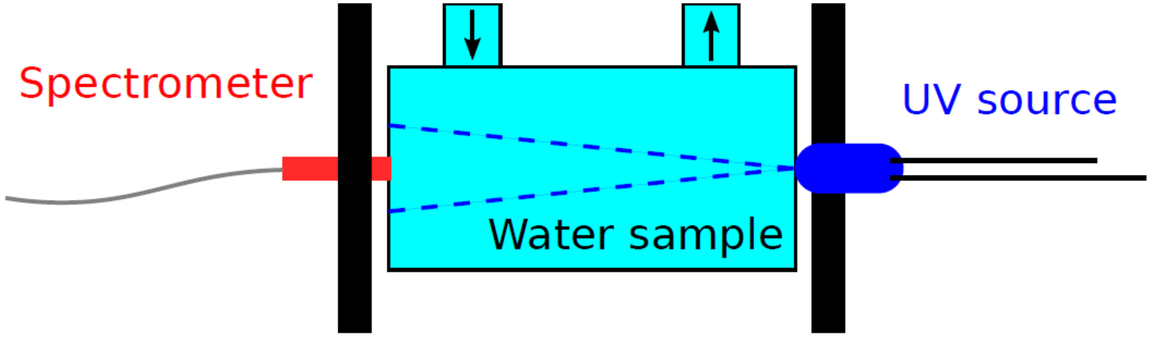
- It is therefore important to track the concentration of Gd over time to know capture efficiency to a high accuracy (~1%)
- Would also be useful to measure the spatial distribution of Gd

Measurement Technique

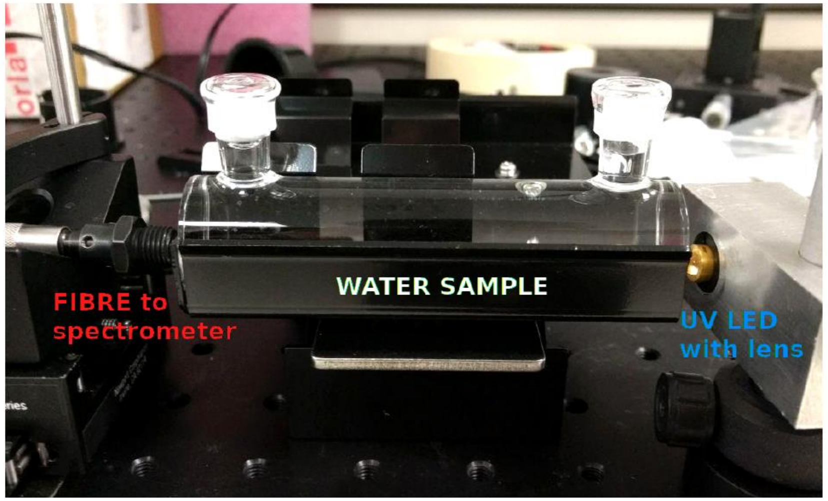
- Gd has strong **absorption lines** near 275 nm.
- Measure the absorbance $\mathcal{A}$.
- It is directly **proportional** to Gd[%].

$$\mathcal{A} = \log_{10}\left(\frac{I_0}{I_{Gd}}\right)$$

I_0 is the reference, I_{Gd} is the Gd-loaded sample.



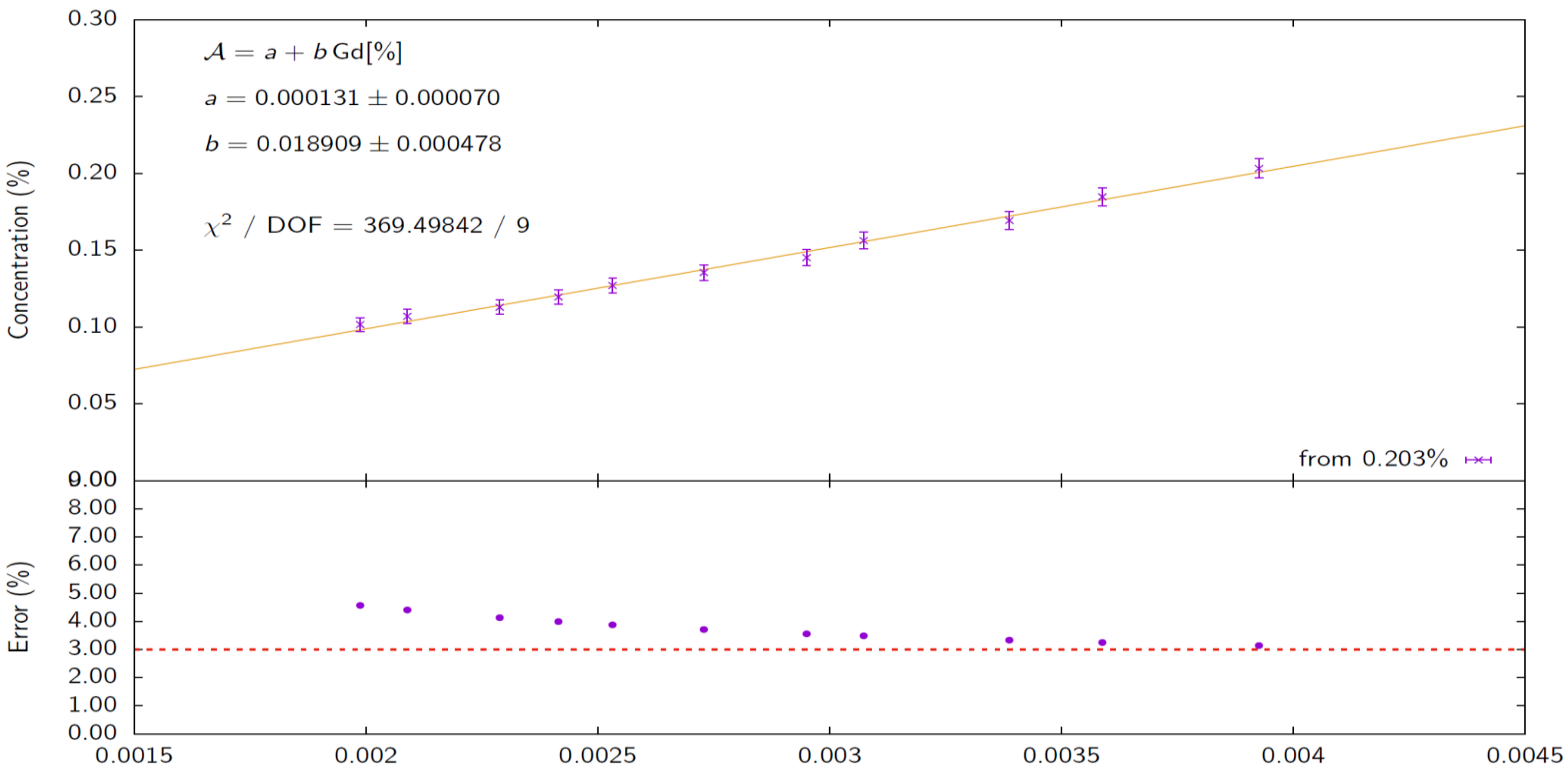
Early prototype

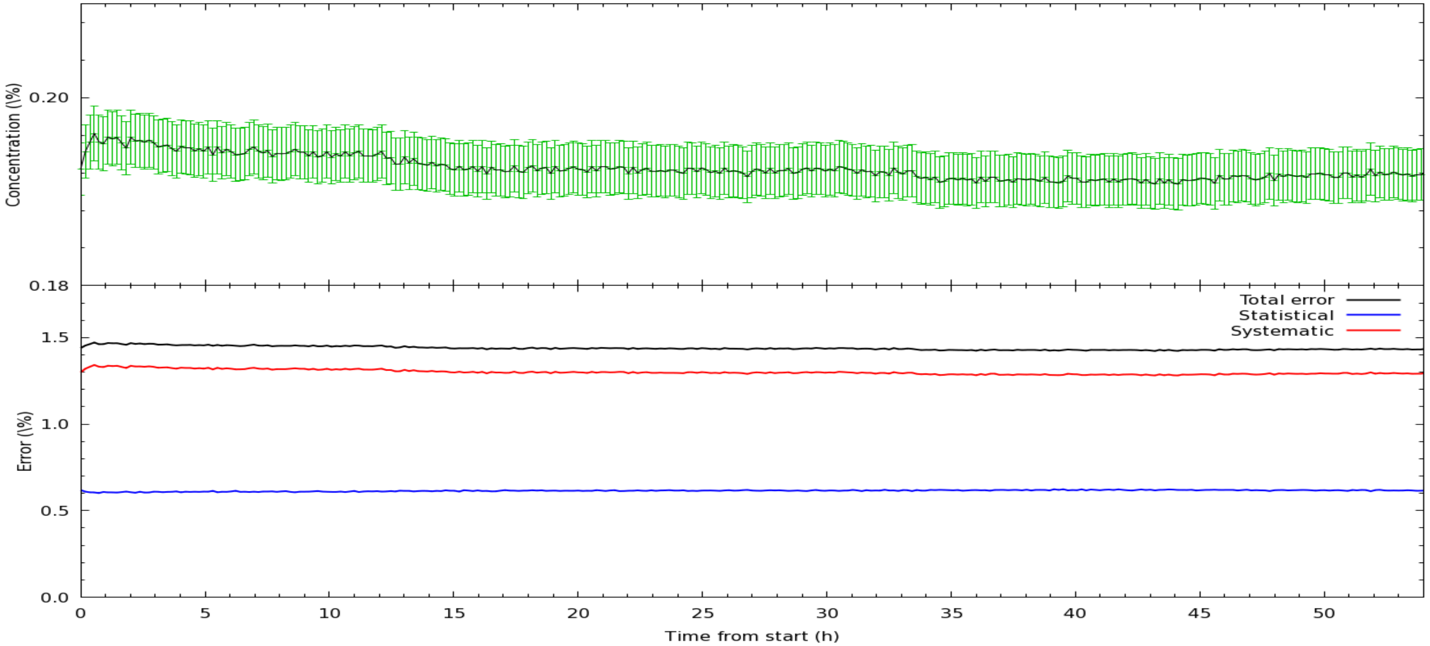


We could determine the **Gd concentration** by measuring the **absorption**

Results

- First prototype was built to monitor 0.2% $Gd_2S_3O_{12}$ concertation using a differential background independent method





- Able to achieve <**3%** error on concentration at 0.2% $Gd_2S_3O_{12}$ loading

- Stable automated operation with regular measurements using **ToolDAQ** DAQ framework

Neutron capture efficiency

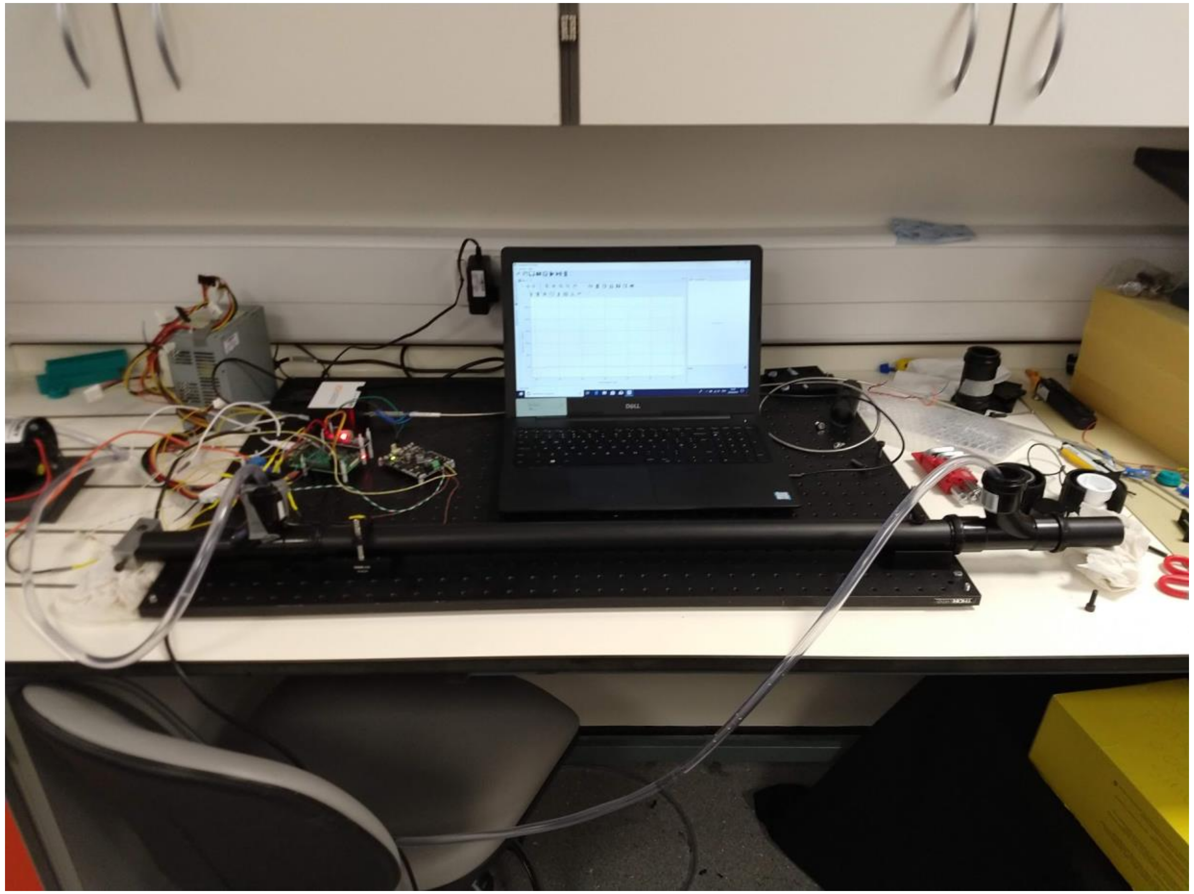
- In terms of **capture efficiency**, for 0.2%: $Gd_2S_3O_{12}$ Concentration
  - 3% $Gd_2S_3O_{12}$ Conc. error $\Longrightarrow$ 0.90 ± 0.01 (1.1%) Efficiency error
  - 1% $Gd_2S_3O_{12}$ Conc. error $\Longrightarrow$ 0.900 ± 0.005 (0.5%) Efficiency error

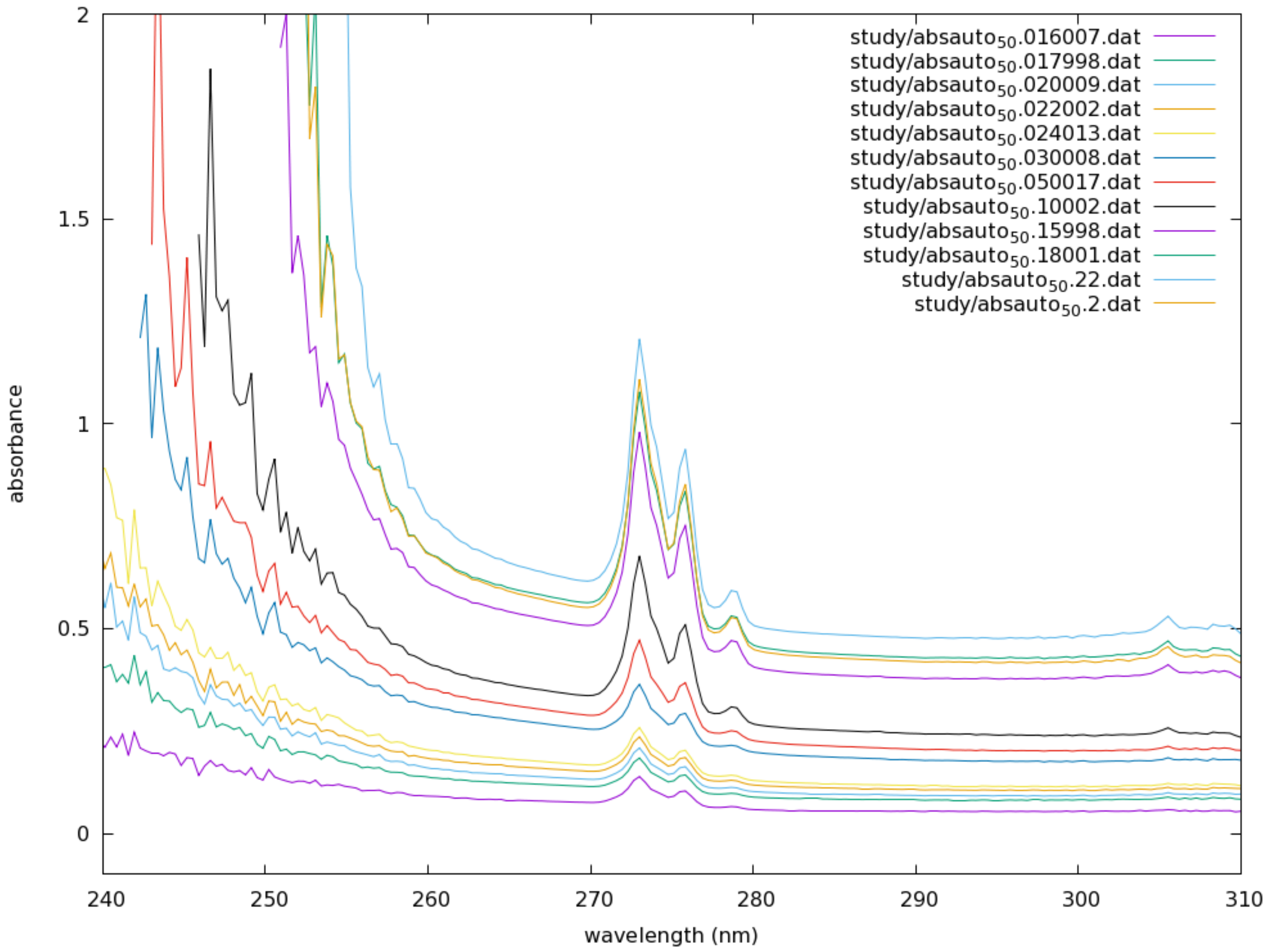
So we can measure neutron capture efficiency to **~1%**

- A fully automated standalone prototype has been produced for **0.2%** $Gd_2S_3O_{12}$ concentration (full loading), with built in electronics, pumps and DAQ software.

- Testing has begun on V2.0 at order of magnitude less concentration **(0.02% $Gd_2S_3O_{12}$ initial loading)**

GAD V2.0 Prototype





Results

- ~1% error at 0.02% $Gd_2S_3O_{12}$ concentration
- ~1% error at 0.2% $Gd_2S_3O_{12}$ concentration
- V1.0 had 3% error at 0.2% $Gd_2S_3O_{12}$ concentration
- For full version we expect improvements to these numbers