# Thresholds and rates in backward EMC due to SiPM radiation damage

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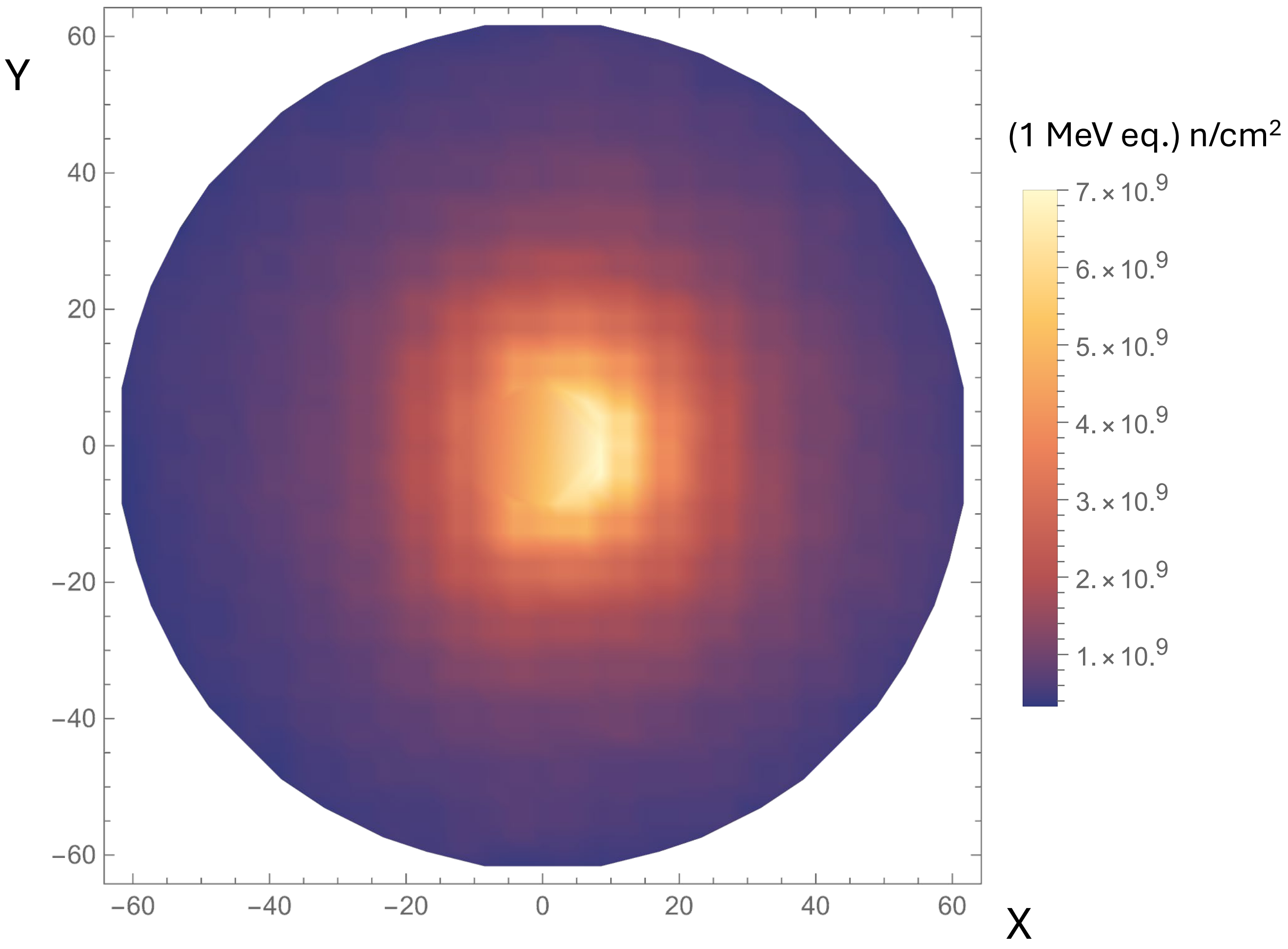
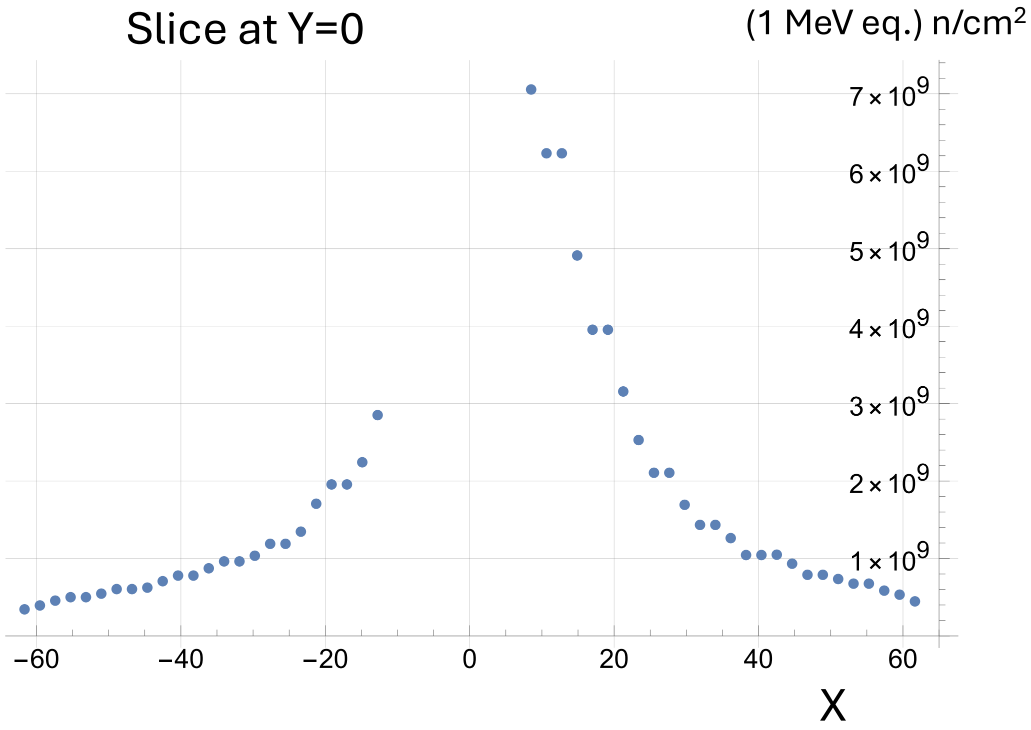
8/13/2025 ePIC Calo. meeting

# Lifetime neutron fluence at EEECAL SiPM's

(data provided by Carlos)

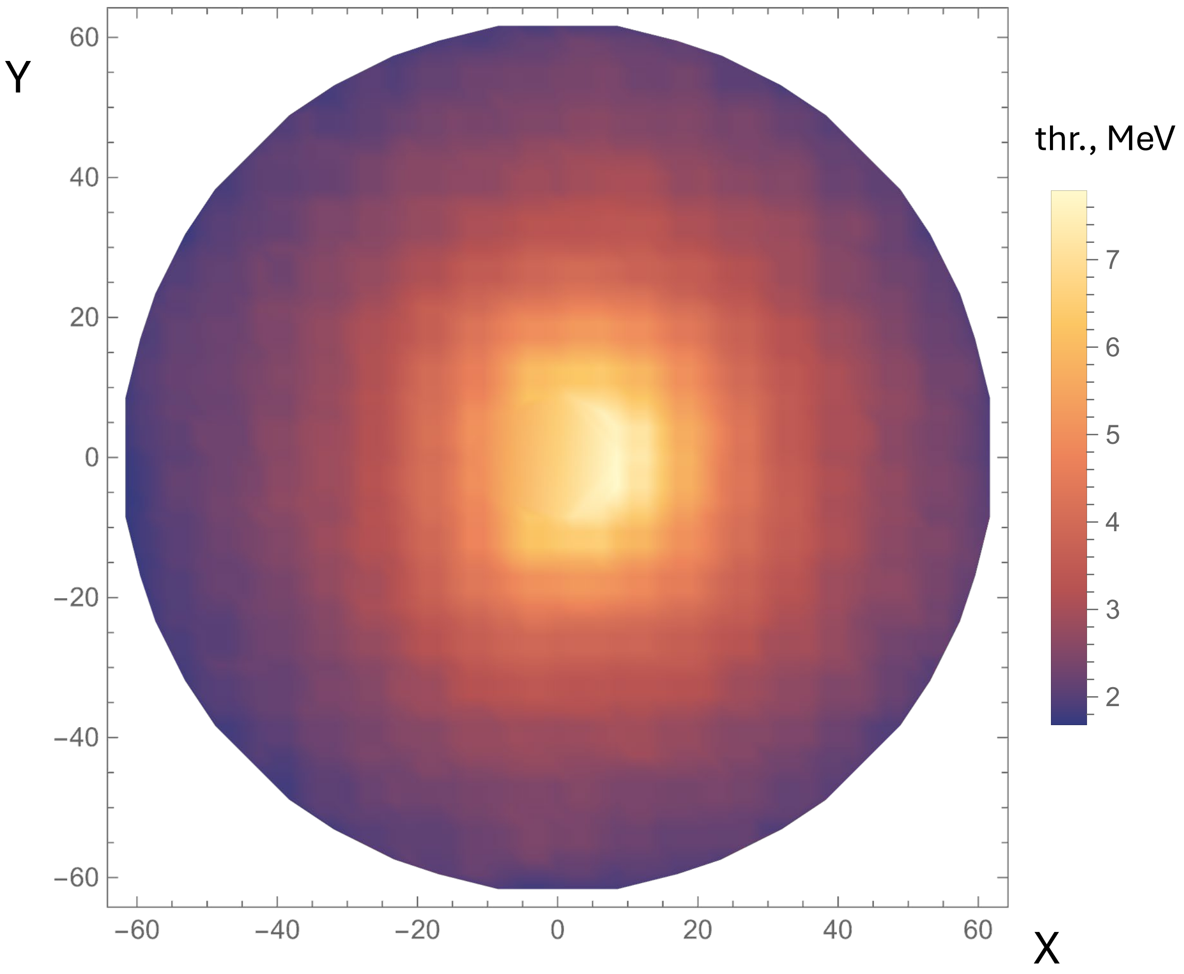


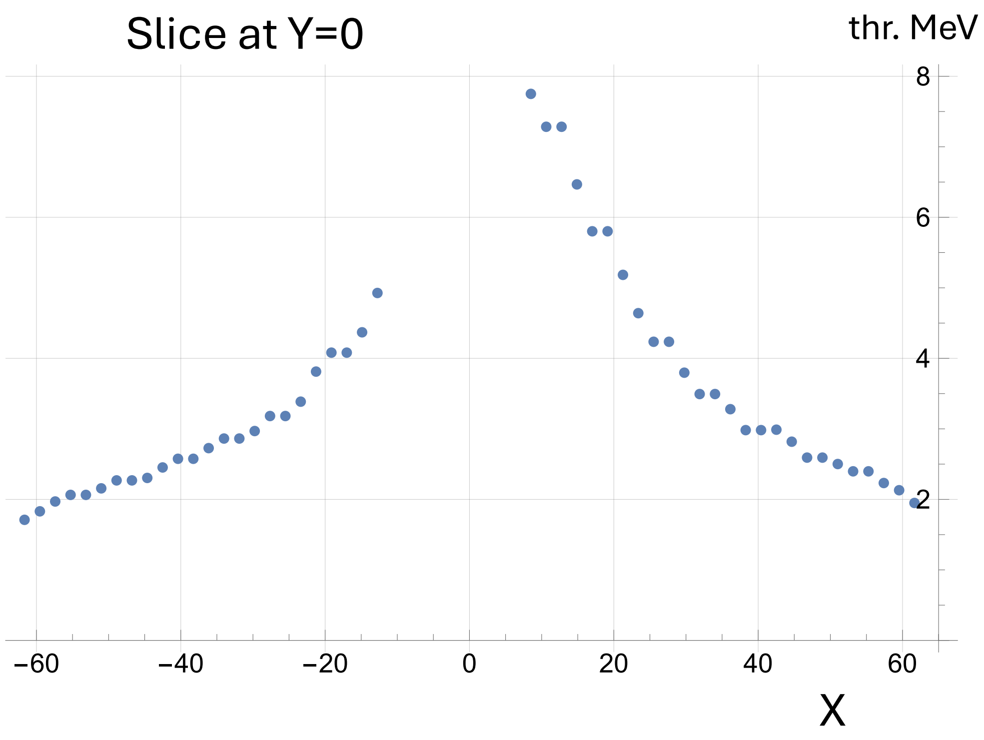




Plot is interpolated somewhat from datapoints, I'm sorry but can't make a better plot at the moment

Threshold for 50 kHz noise rate in "discrete" readout
(with LY = 7.23 pix/MeV)

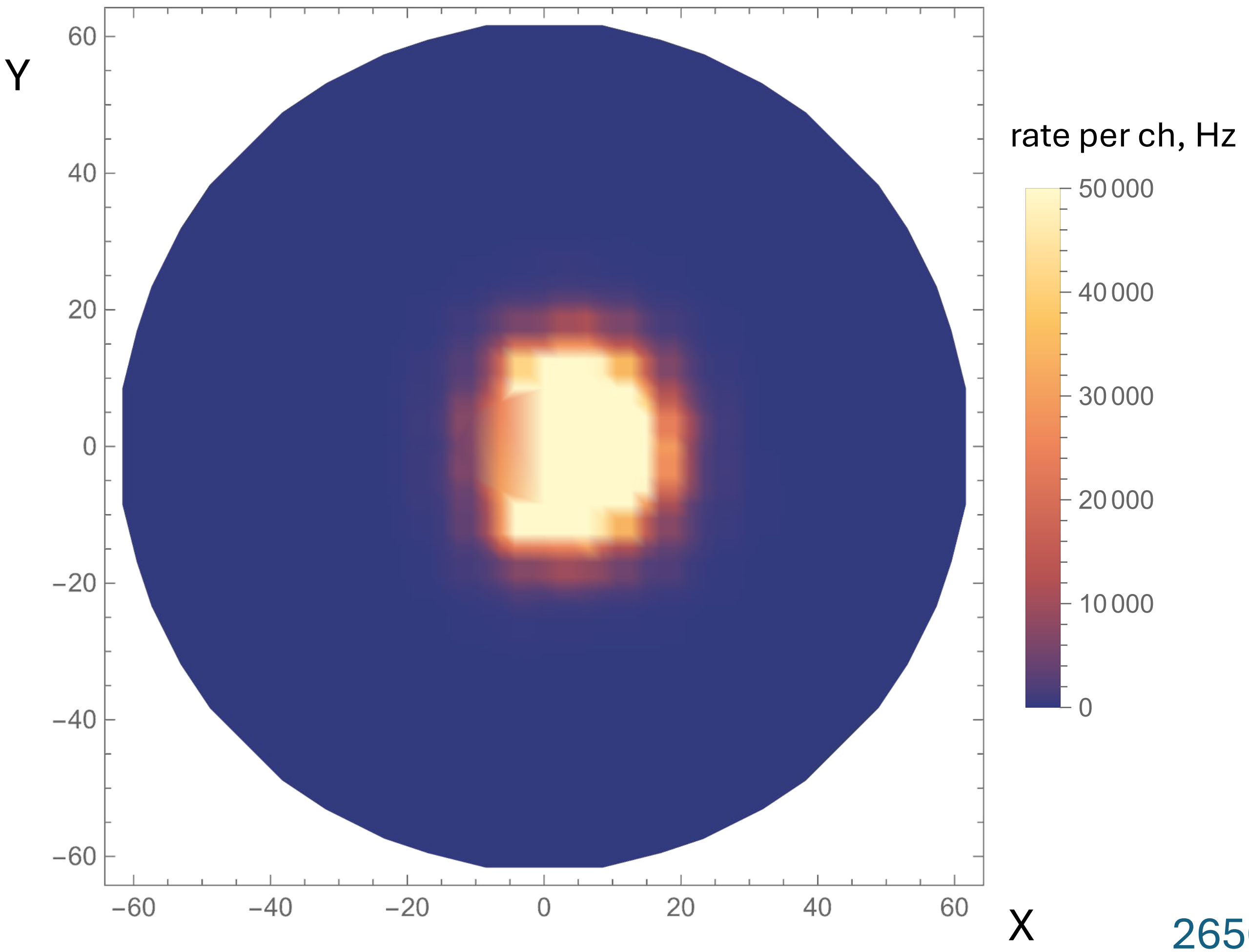
(I'm not accounting here for rate budget taken up with real hits. Obviously this is not fully realistic yet...)

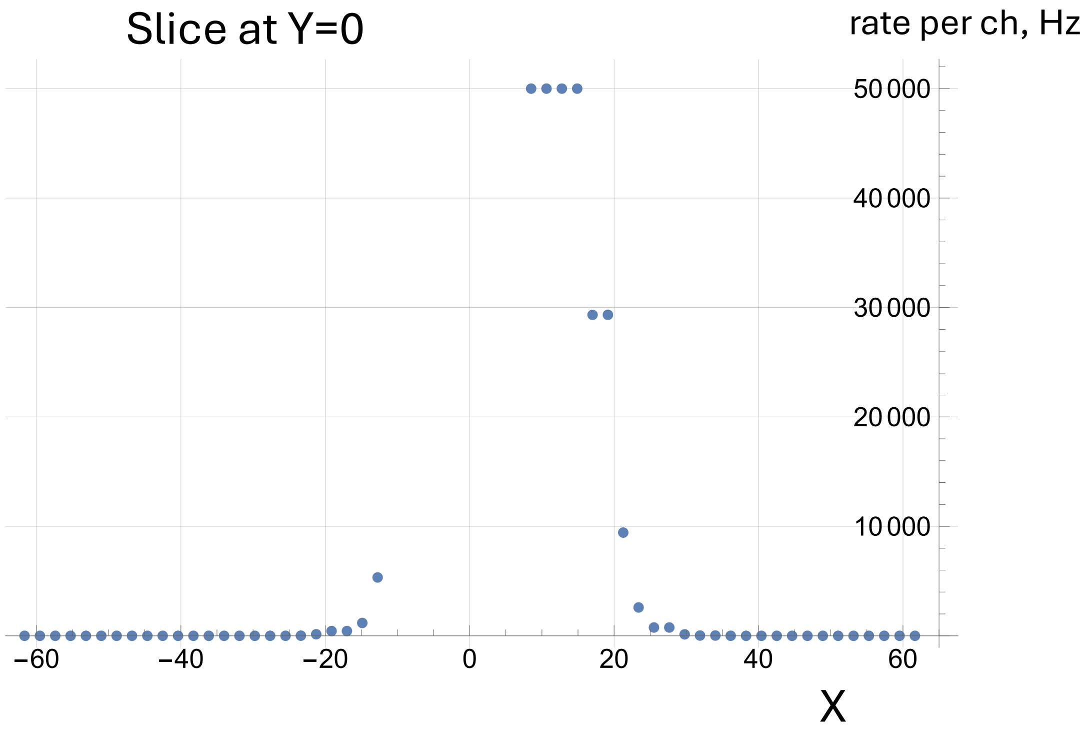



Looks acceptable!

Noise rates for 6.2 MeV threshold where possible and otherwise higher threshold for <50 kHz channel, in “discrete” readout
(with LY = 7.23 pix/MeV)

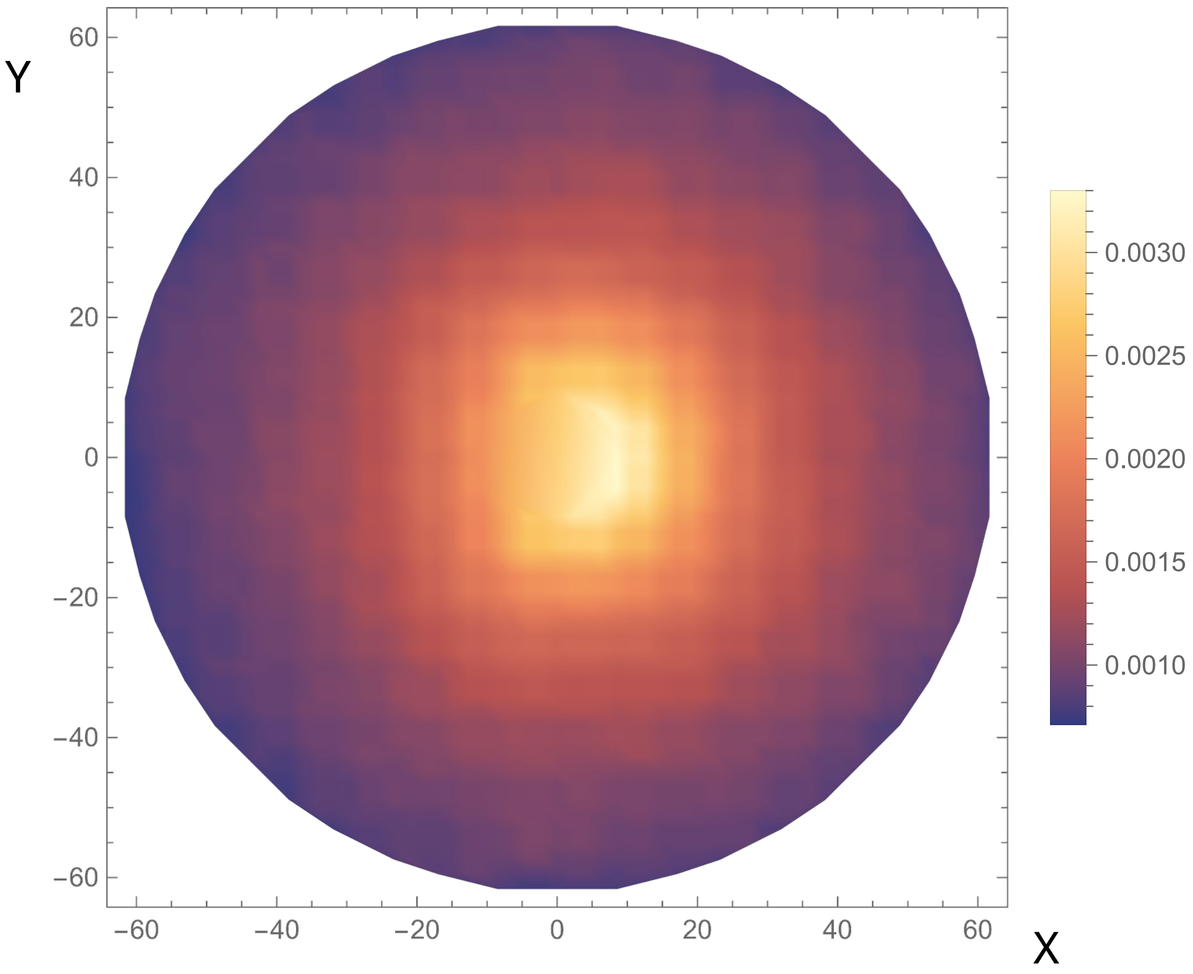


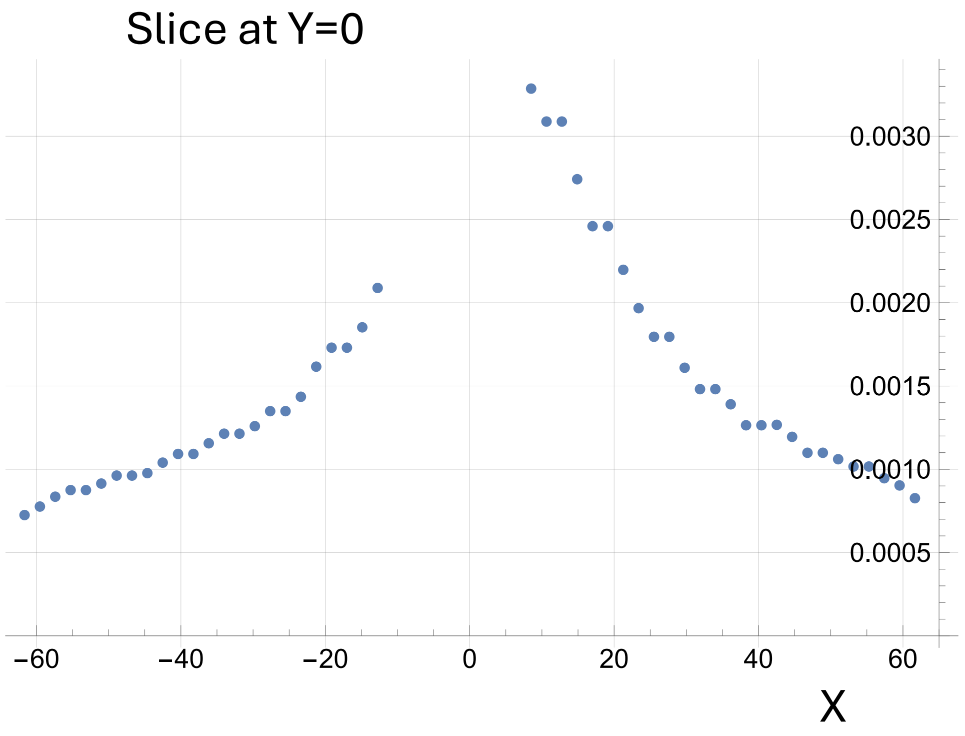




2656 towers total [which is not *exactly* the real design…]
66 towers have raised thresholds
total noise hit rate for all channels together 5.99 MHz

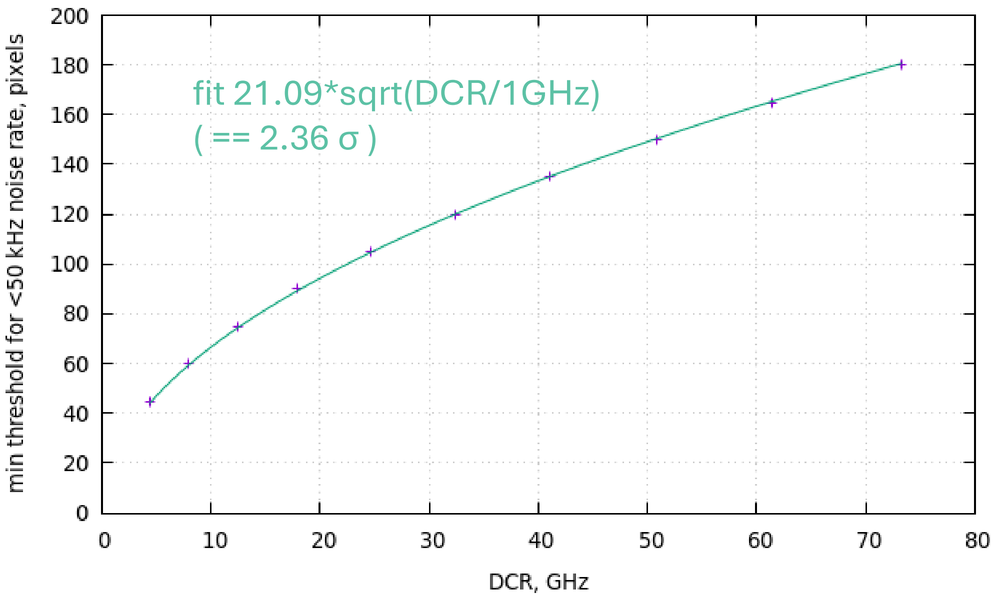
(~137 MB/s)

the 1/E term in energy resolution (in “discrete” readout) – just considering a single tower here → not the physics resolution
(with LY = 7.23 pix/MeV)

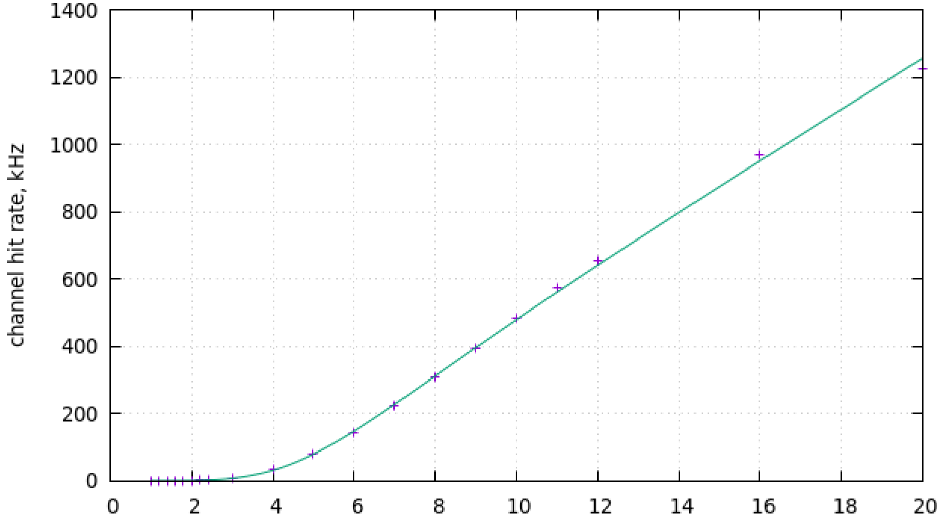


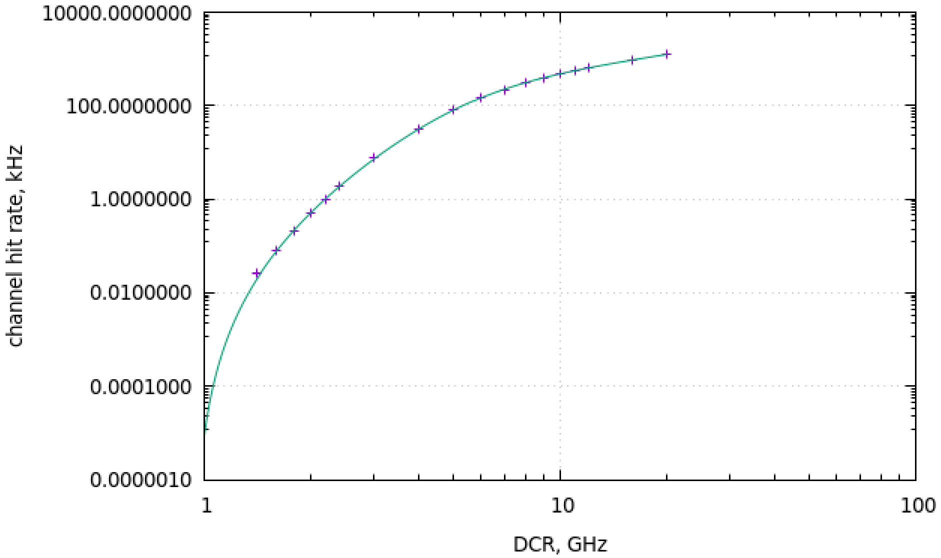



## BACKUP – above was based on 7/30/2025 presentation for FEMC (**the following slides**)




THRESHOLD = 45 pixels



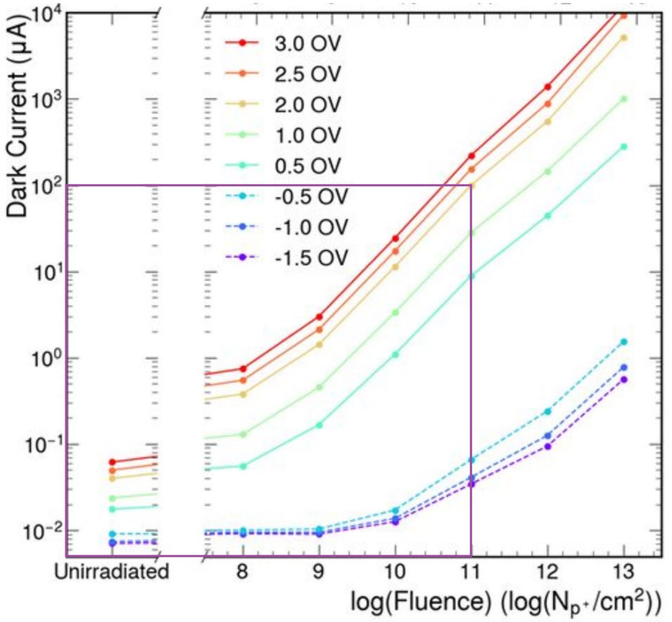

ad hoc fit
f(x)=(x>x0?(x-x0)**p/(a+b*(x-x0)**q):0)
a = 2.52816
b = 0.0197875
p = 4.06173
q = 2.96498
x0 = 0.928984

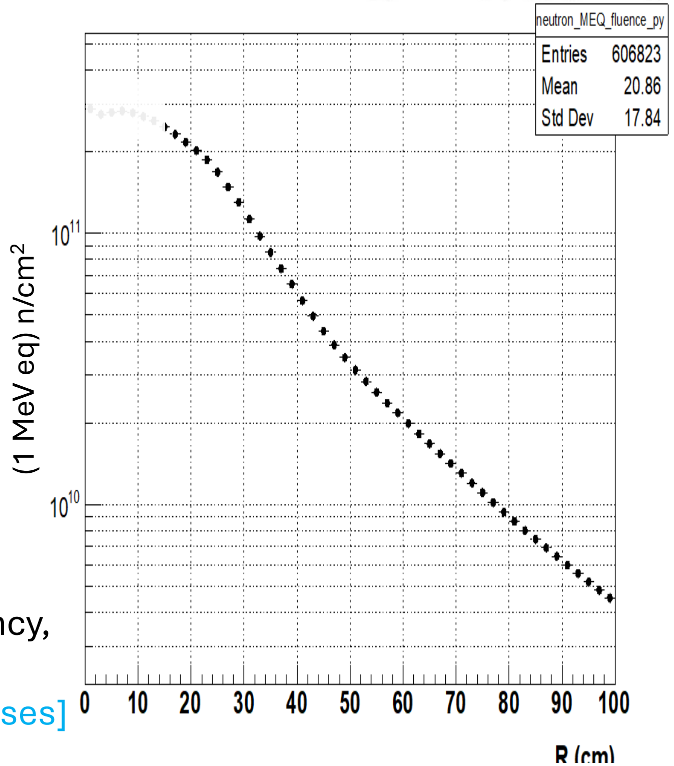
7/30/2025

# DCR estimation for FEMC

- assume (likely) overvoltage 2.0 V
- → gain 1.6E5 per datasheet
- From Miguel's presentation, dark current at $V_{OV}$=2.0 V **for 3×3 mm² SiPM** is **100 uA per 1E11 (64 MeV) p/cm²**
- → **3.9 GHz per 1E11 p/cm²**
- Adjust to 1 MeV eq. neutrons → **2.6 GHz per 1E11 n/cm²**
- That is for rapid damaging, allow for (RT) annealing (following Fig. 5.2 in Moll's thesis, see backup slide)
- → Factor of 0.33 for 3 years at RT relative to 1 hour. 3 years is *my WAG* of a timescale on which to get "a large portion" of total damage, 1 hour is *my WAG* of timescale relevant to the SiPM irradiation tests at UC Davis and the analysis of that.
  - → **0.86 GHz per 1E11 n/cm²**
- Adjust for area (4× 6×6 mm²) → **14 GHz per 1E11 n/cm²**
- Projected fluence (for 100 $fb^{-1}$) is **1E11 for R>32 cm, up to 2E11 innermost**
  - Side remark: 28 GHz is 720 µA, ~29 mW

I think, >>100 uA points in the I-V curves would need temperature compensation to be accurate. Was not done?



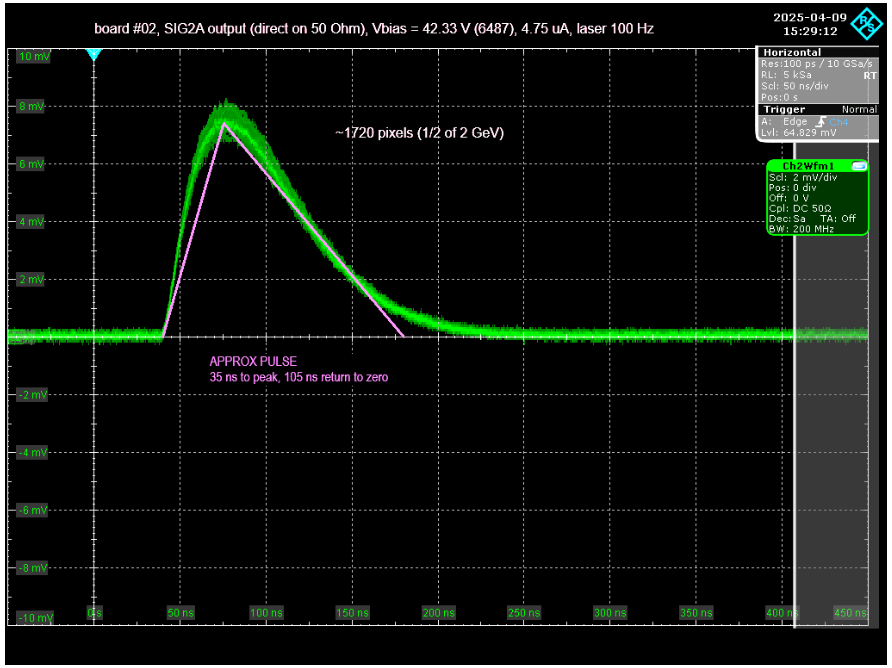



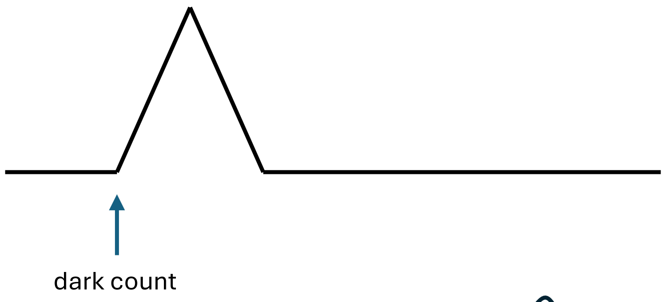

Integrated neutron fluence ePIC 10x275 top luminosity, 6 month running at 100 % efficiency, SiPM located at Z =3408 from IP

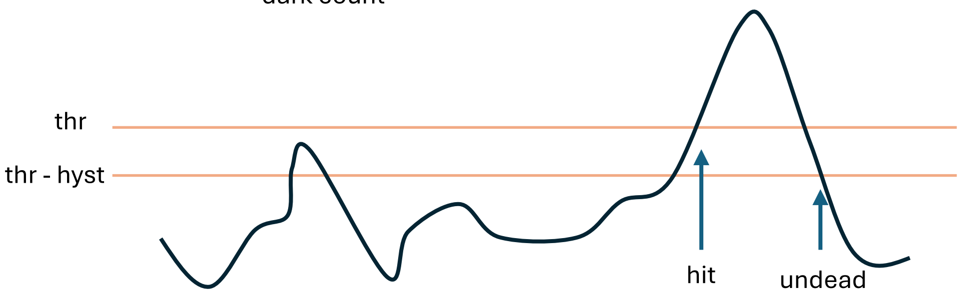
O.T. [Lifetime fluence for design purposes]

# A simple simulation for “hits” detected due to dark counts (for “discrete” readout)

- Generate dark counts at a given Poisson rate
- Make a “waveform” pulse starting at each dark count time
    - For now, a simple-minded triangular pulse, with 80 ns peaking time (somewhat realistic)
- Sum all those pulses
- Sample at 98.5 MHz / 2 (the planned ADC sample rate)
- ~~Digitize to 14-bit~~ (NOT IMPLEMENTED YET)
- Discriminate when there is a hit or not
    - “Plan A”: Single waveform sample > threshold
    - Require single waveform sample < threshold-hysteresis to re-arm for next hit
    - Channel is dead when hit until re-armed
- (A range of waveform points is then read and processed around each discriminated hit, but that isn’t important at the moment and isn’t simulated.)
    - However, readout/processing imposes a limit ~50 kHz on the hit rate we can allow. (Can be improved a little, probably, but this is current specification.)

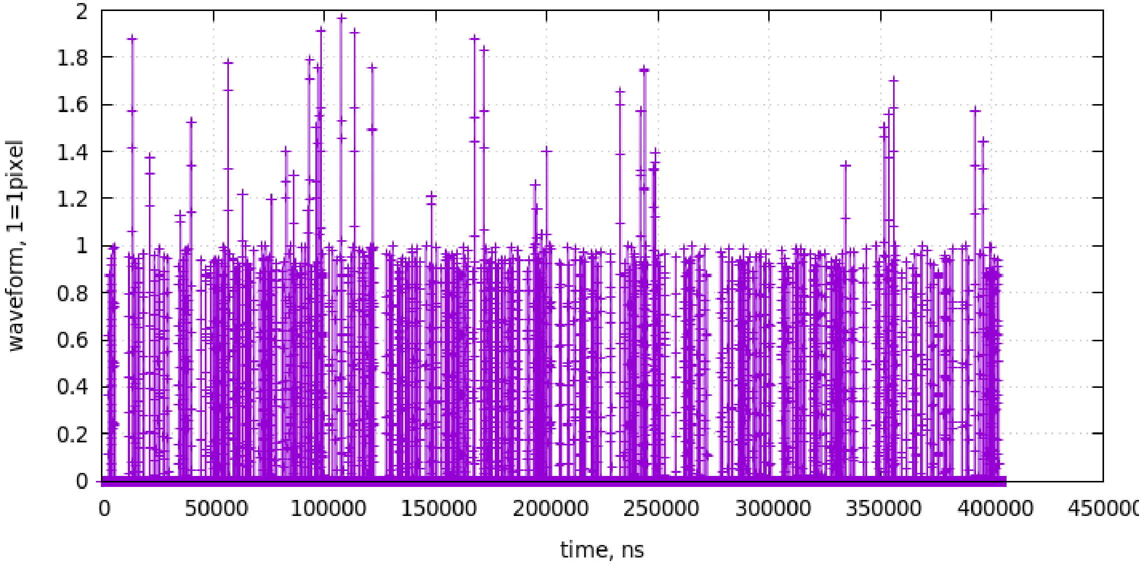


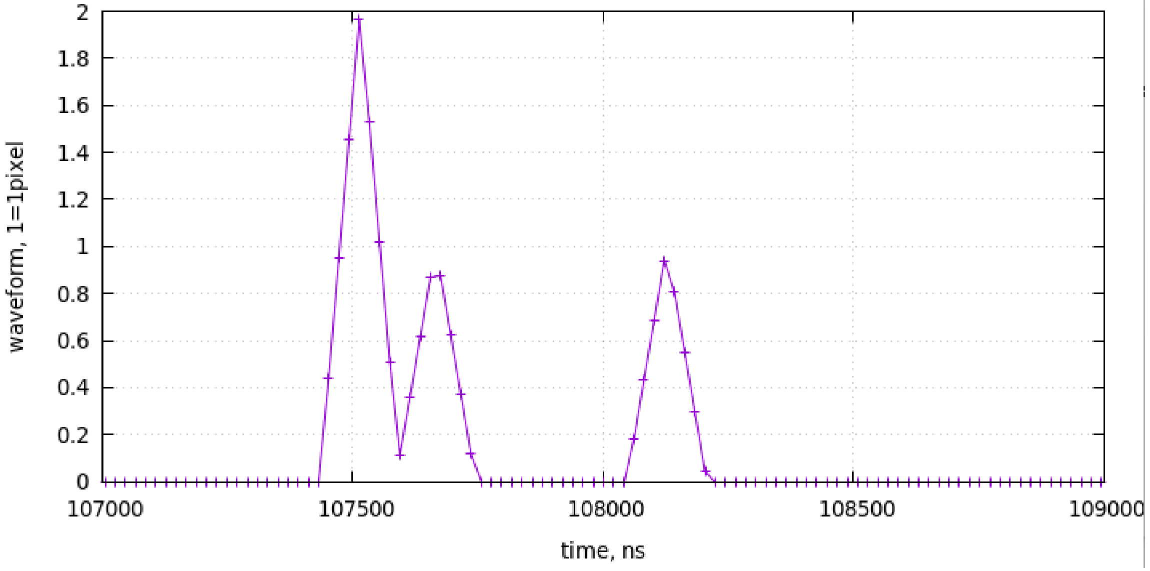



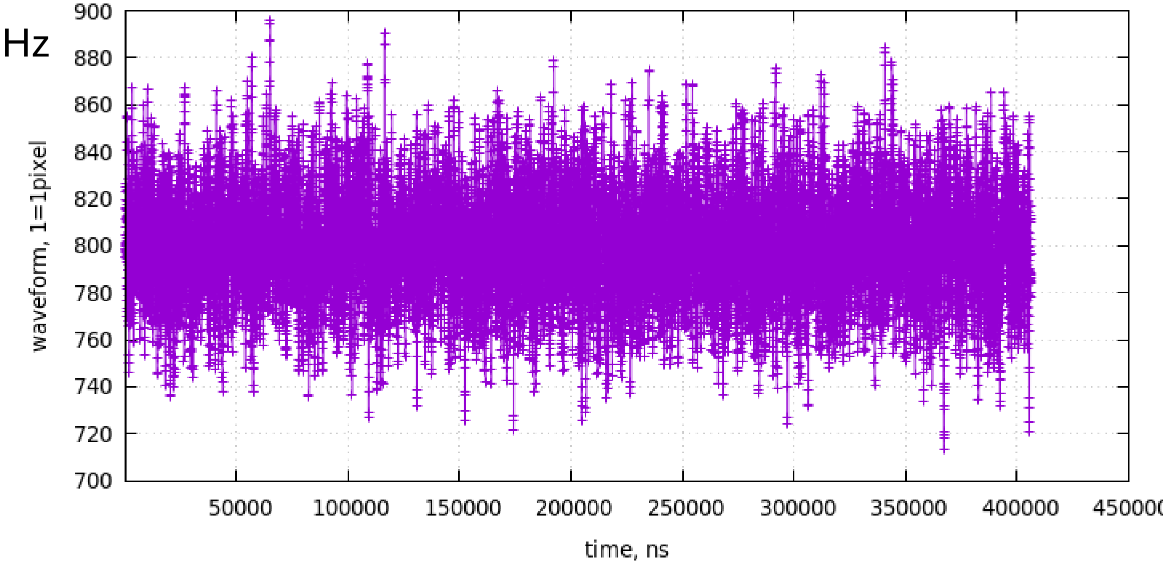
# Waveform examples

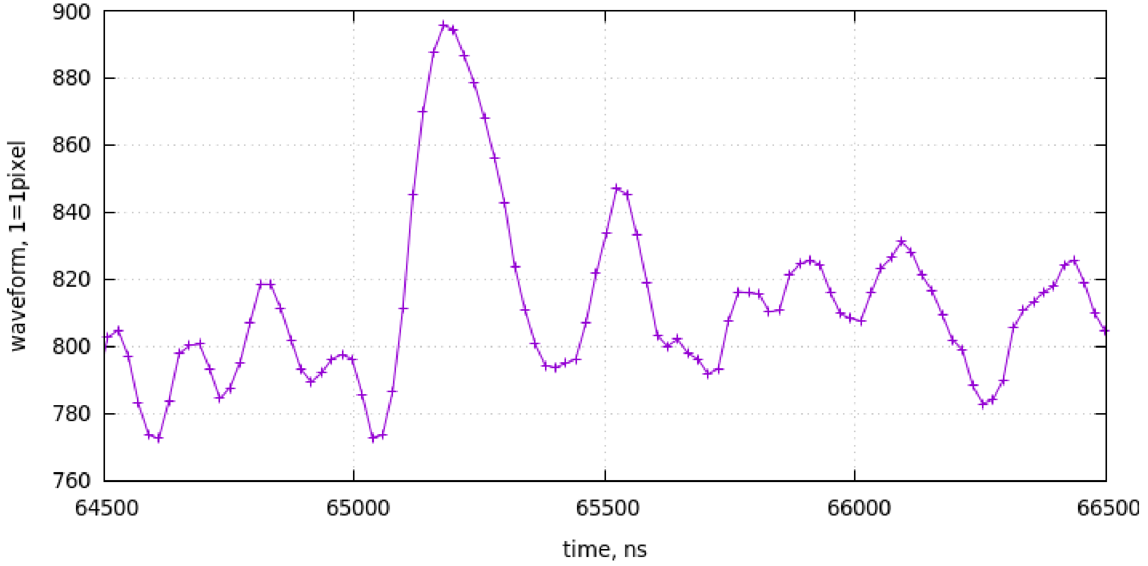
DCR=1MHz




DCR=10GHz



# Results – hit rates and deadtime

triangular pulse model, peaking time 80 ns

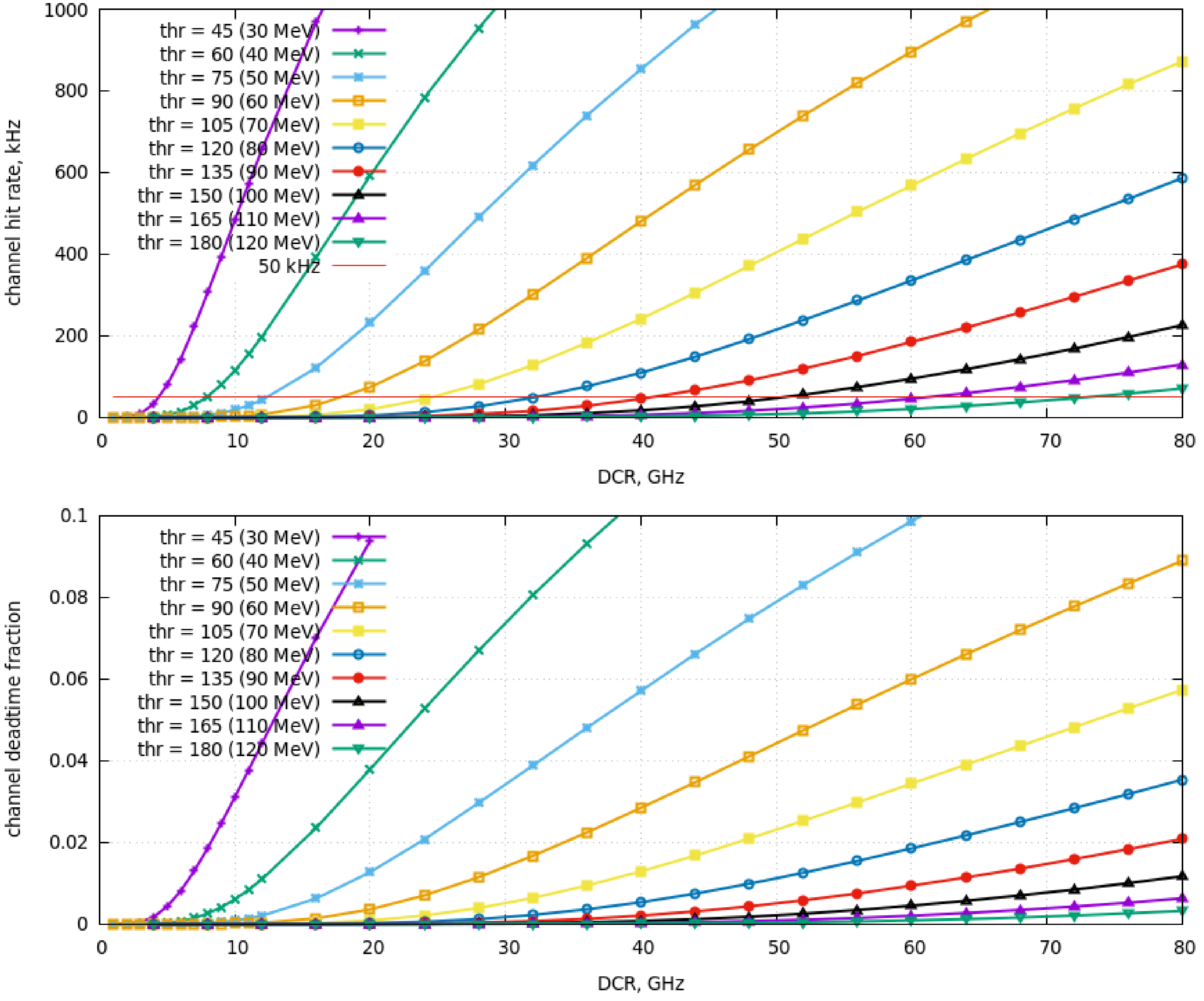
various thresholds, w/ hysteresis=5 (pixels)

ADC sampling rate 98.5 MHz / 2

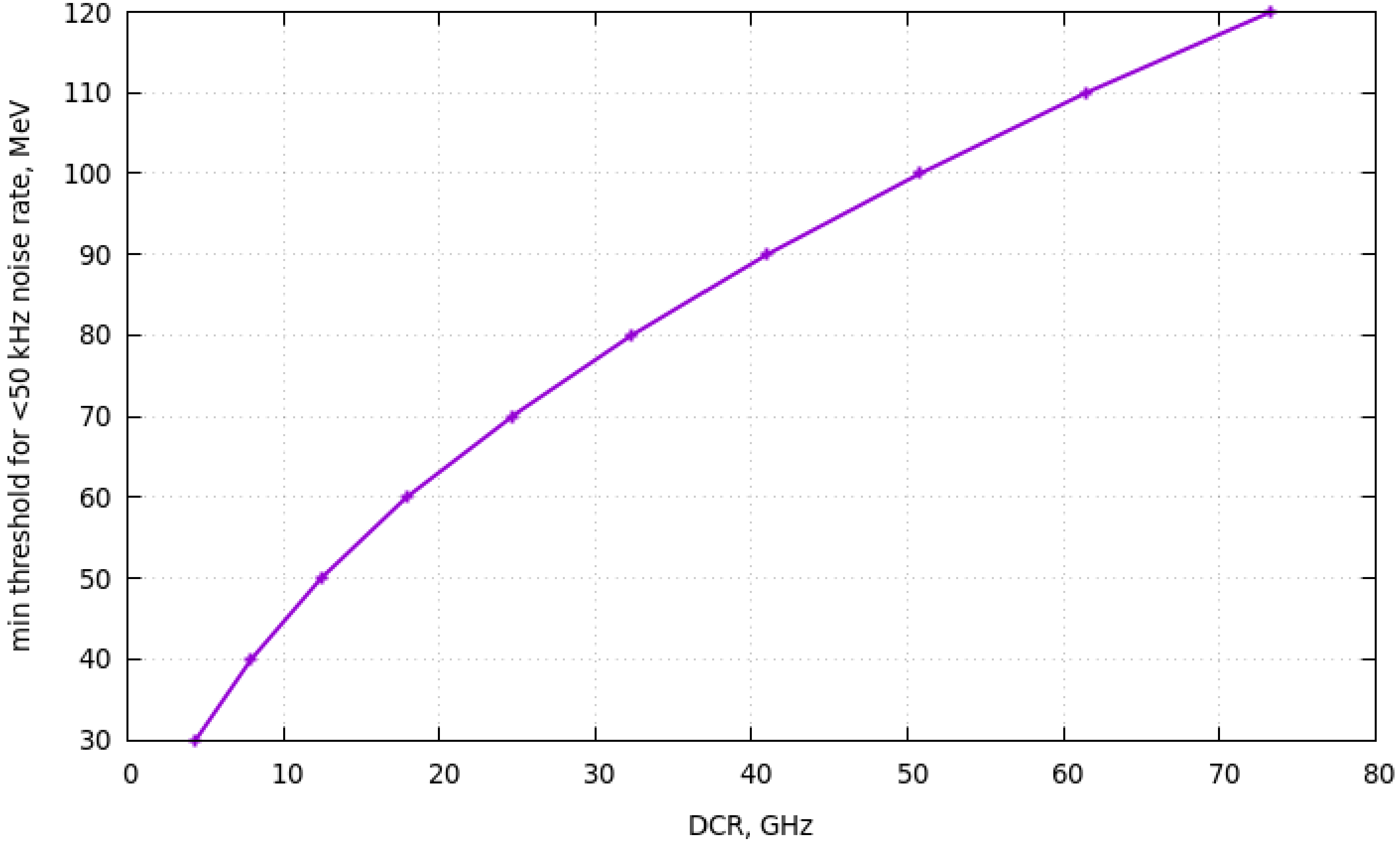
NO DIGITIZATION, just sampling

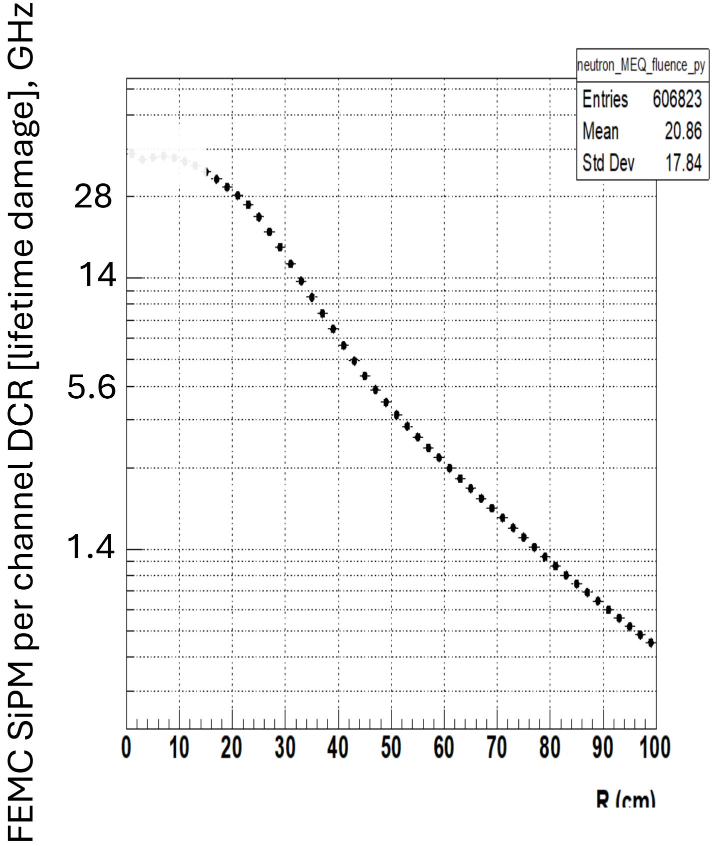
0.15 s simulation time

Assumed FEMC LY 1.5 pix/MeV (just to convert thresholds to MeV)



Required threshold vs. DCR
(Linearly interpolated from data set plotted on previous page)



# Conclusions

- Projected threshold for 50 kHz noise hit rates
  - 30 MeV ok for R> ~48 cm
  - 40 MeV at ~42 cm
  - Up to a peak about 75 MeV at innermost towers
- Channel deadtime <1% whenever hit rate < ~200 kHz

To-do

- More realistic pulse shape – should only make a slight impact
- Digitization – probably no impact really
- Extract fit for allowable threshold as a function of DCR
  - → feed in to data rate simulation for whole detector
- How much of hit rate budget needed for real hits, needs study

Remarks on hardware rate limits

- On latest estimations the full raw data format should work up to 65 kHz
- With feature extraction on FEB, we might be able to work up to 190 kHz

# BACKUP – annealing factor

**Radiation Damage in Silicon Particle Detectors**

– microscopic defects and macroscopic properties –
Dissertation
zur Erlangung des Doktorgrades
des Fachbereichs Physik
der Universität Hamburg

I assume that the UCR analysis results in dark current for irradiation on a time scale of roughly 1 hour, not in dark current for instantaneous irradiation.

Then the annealing factor we want to apply is that from 1 hour to, say, 3 years (arguably).

Drops from 7.5 to 2.5 ($\times10^{-17}$ A/cm) on the plot here

→ SiPM DCR will similarly drop by factor of 0.33

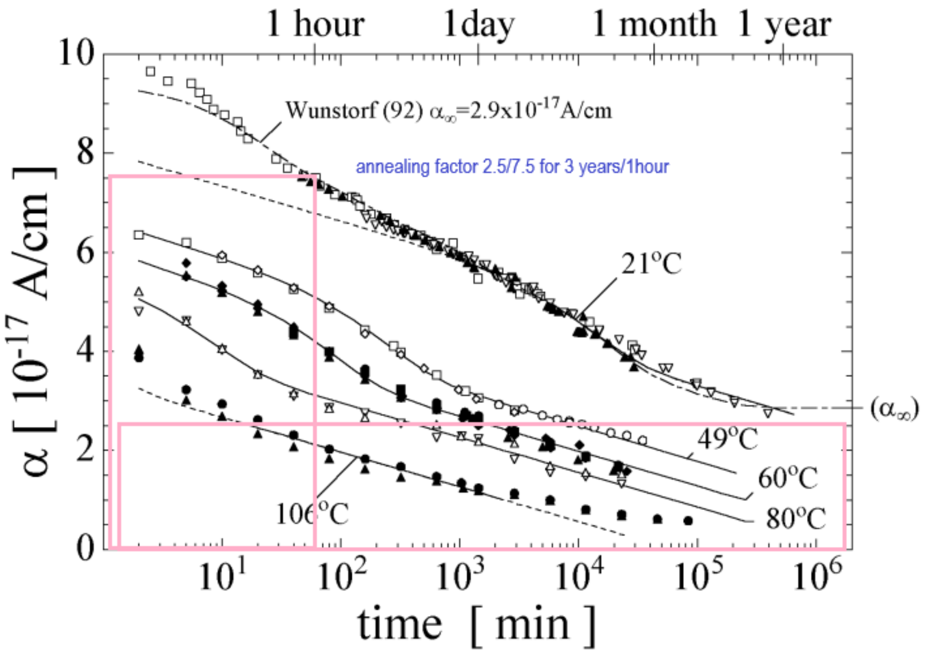



Figure 5.2: Current related damage rate $\alpha$ as function of cumulated annealing time at different temperatures. For each temperature at least one type inverted and one not type inverted sample has been used. The dashed–dotted line represents a simulation according to Eq. 5.3 with parameters as given in Tab. 5.1 and $\alpha_\infty$ as displayed in the figure. The solid lines