SiPM news

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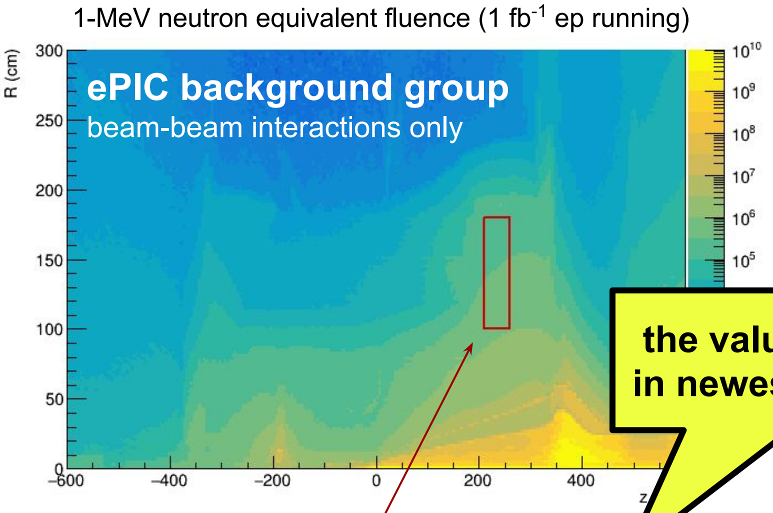
Neutron fluxes at the dRICH photosensor surface



location of dRICH photosensors

mean fluence: 3.9 10^5 neq / cm^2 / fb^{-1}

max fluence: 9.2 10^5 neq / cm^2 / fb^{-1}

the values increased in newest simulations

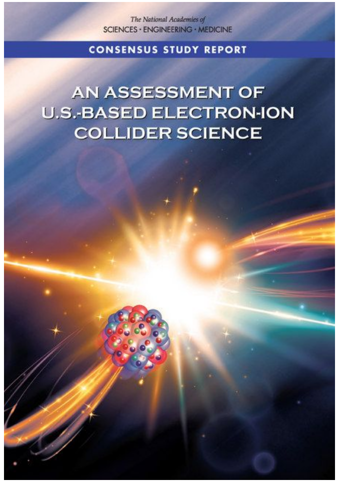
- radiation level is moderate

assume fluence: ~ 10^7neq / cm^2 / fb^{-1}

conservatively assume max fluence and 10x safety factor

Most of the key Physics goals defined by the NAS require an integrated luminosity of 10 fb^{-1} per center of mass energy and polarization setting

The nucleon imaging programme is more ... gry and **requires 100 fb^{-1}** ... **s energy and polarization setting**



in 10-12 years the EIC will accumulate 1000 fb^{-1} integrated $\mathscr{L}$ corresponding to an integrated fluence of ~ 10^{10} n_{eq}/cm^2

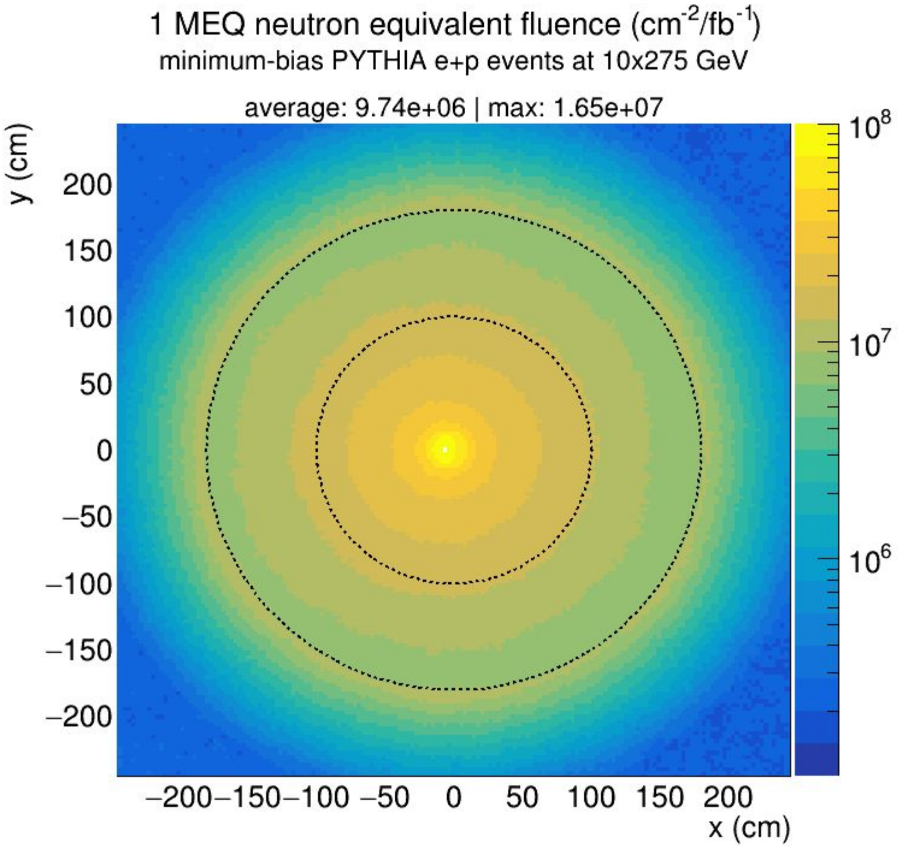
study the SiPM usability for single-photon Cherenkov imaging applications in moderate radiation environment

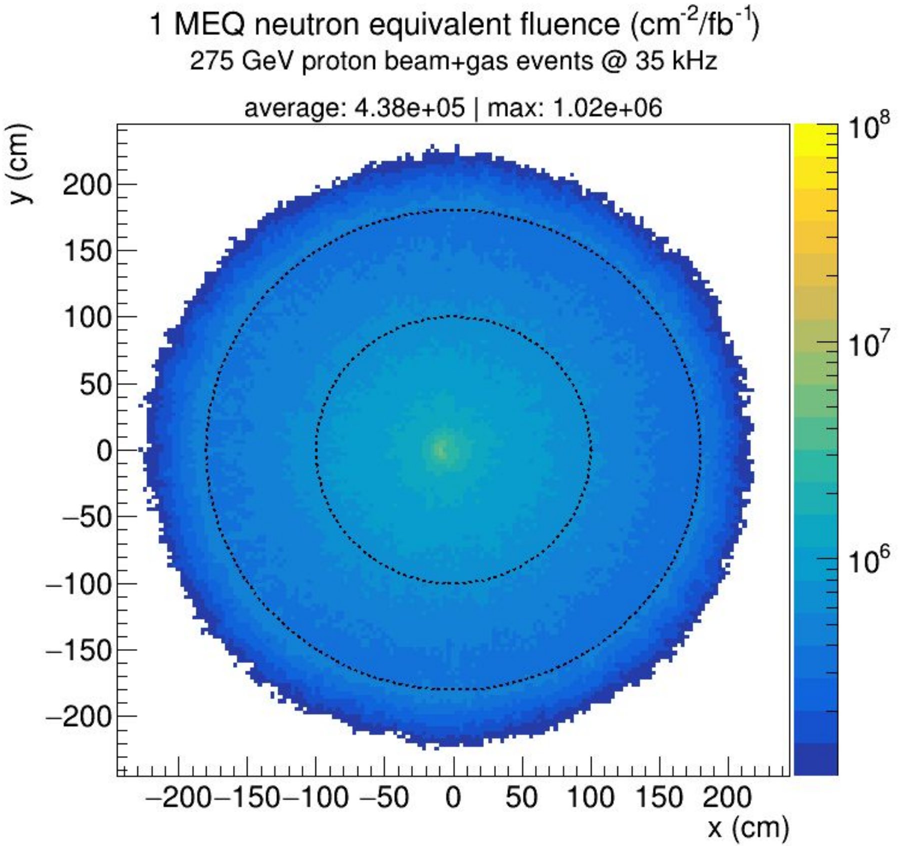
→ radiation damage studied in steps of radiation load

10^9 1-MeV n_{eq}/cm^2	*most of the key physics topics*
10^{10} 1-MeV n_{eq}/cm^2	*should cover most demanding measurements*
10^{11} 1-MeV n_{eq}/cm^2	*might never be reached*

updated radiation simulations

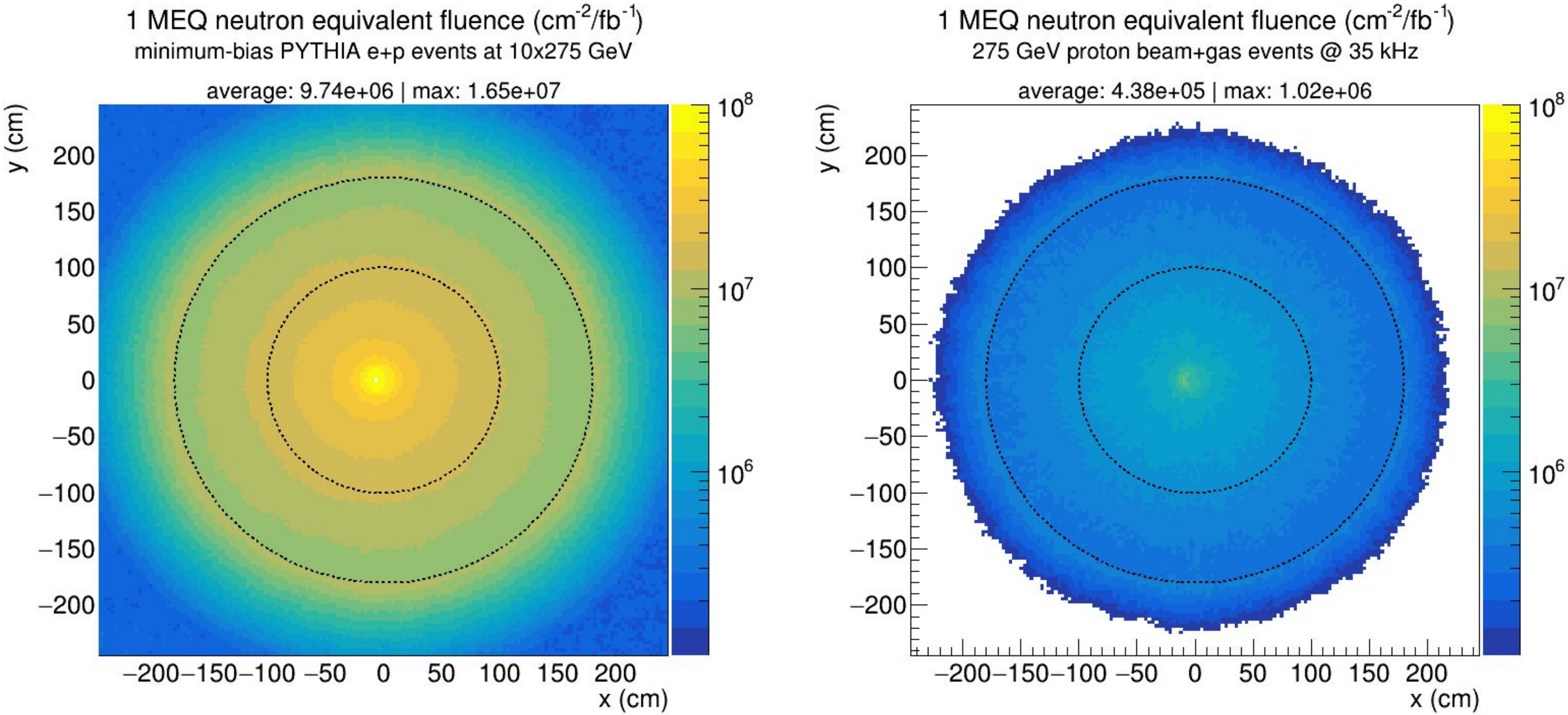
New radiation damage estimates





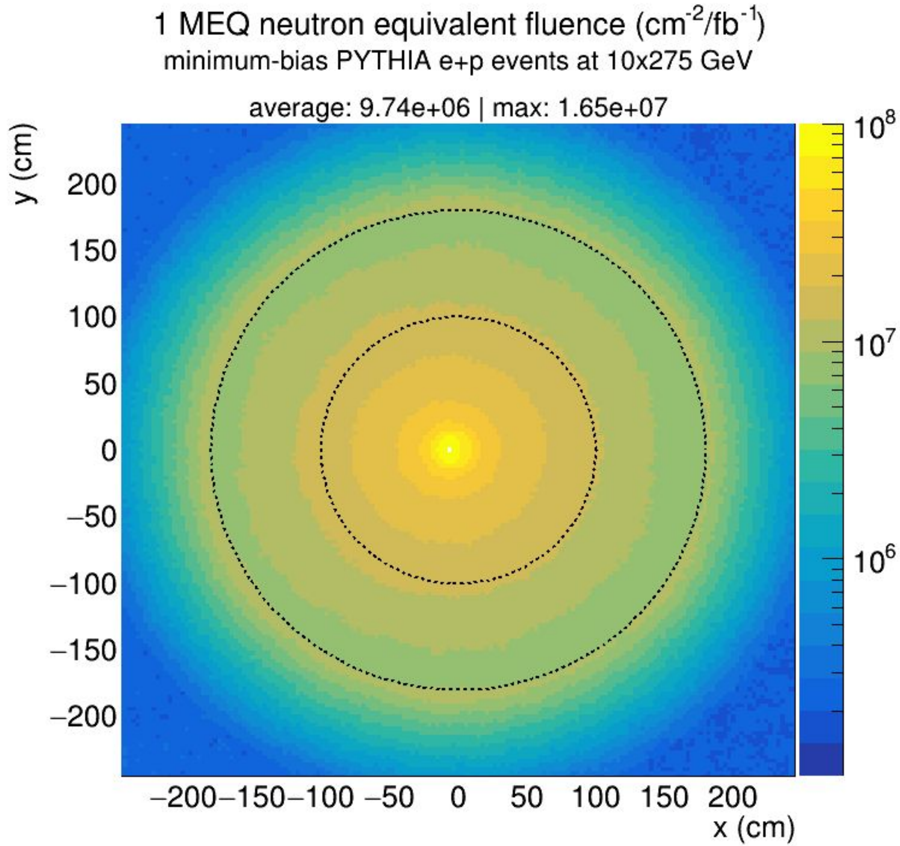
xy projections in 210 < z < 260 cm region, average and max values reported for 100 < R < 180 cm region

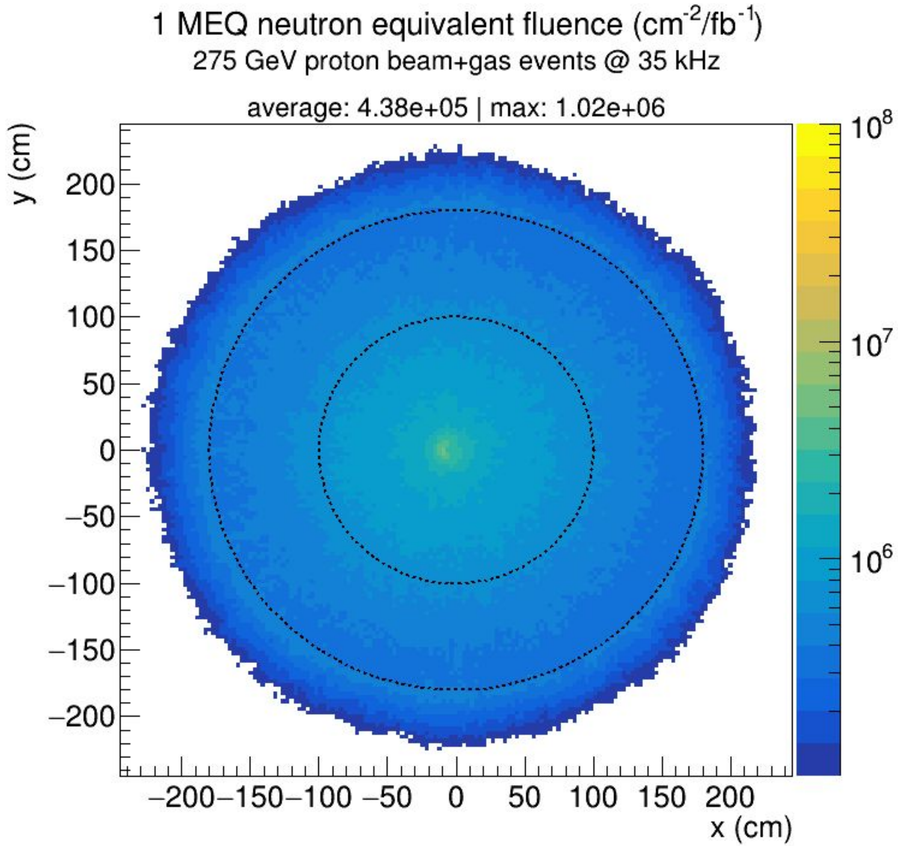
New radiation damage estimates



before: max fluence = 9.2 10^5 neq/fb^{-1} | now: max fluence = 1.75 10^7 neq/fb^{-1} ⇒ new estimates are ~20x larger

New radiation damage estimates

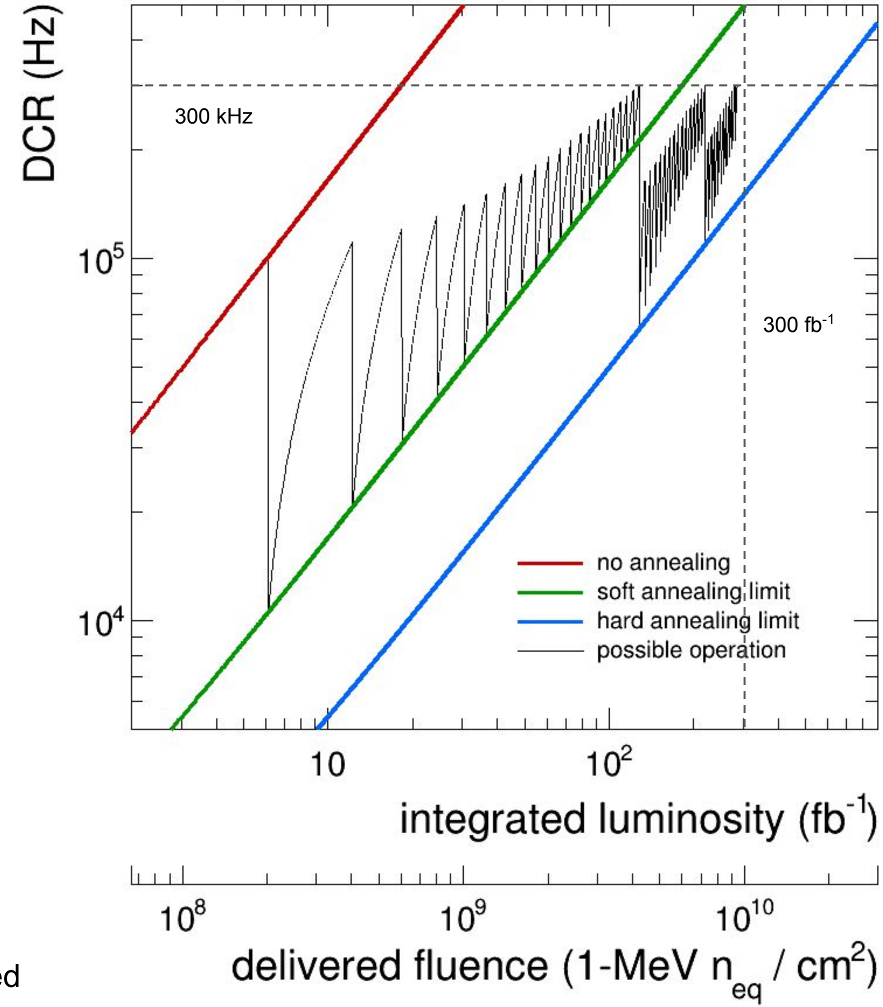




new estimates are ~20x larger, but we had a 10x safety factor ⇒ we got the safety factor eaten and a 2x faster ageing

Updated ageing model

Hamamatsu S13360-3050 @ Vover = 4 V, T = -30 C



model input from R&D measurements (up to 2022)

- DCR increase: 500 kHz/10^9 n_{eq}
- residual DCR (online annealing): 50 kHz/10^9 n_{eq}
- residual DCR (oven annealing): 15 kHz/10^9 n_{eq}

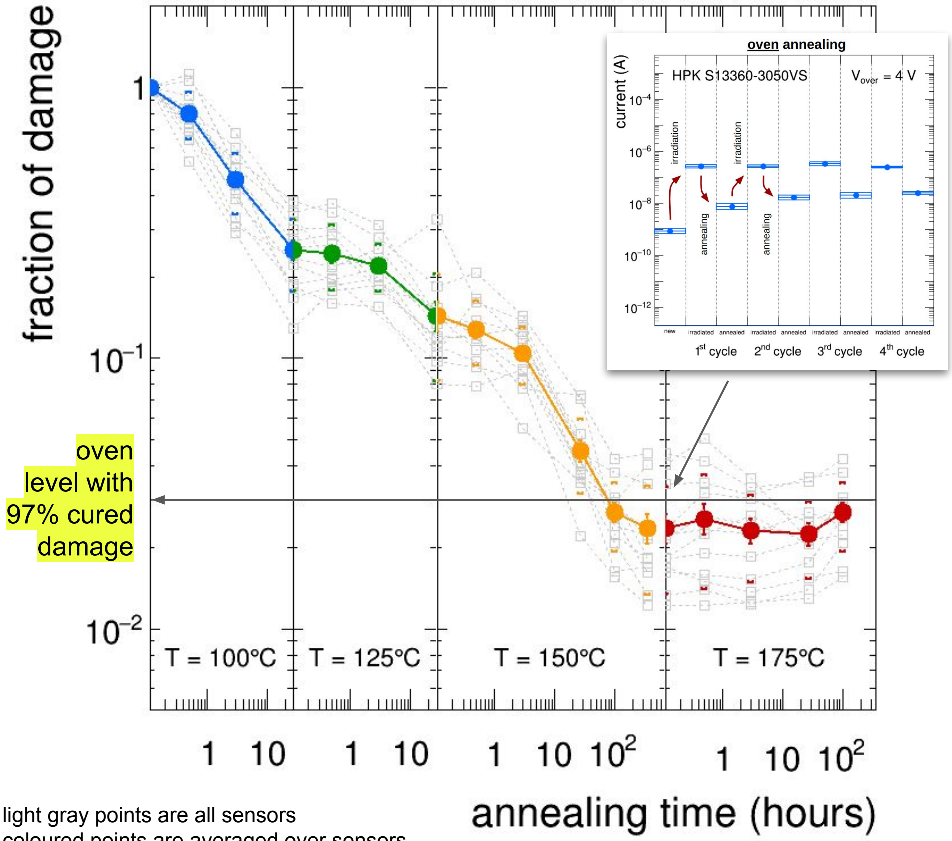
1-MeV neq fluence from background group

- 1.75 10^7 n_{eq} / fb^{-1}
- includes 2x safety factor

all parameters are the same used for the previous model
only neq/fb^{-1} is updated to new estimate, with 2x safety factor
which corresponds to a 4x faster ageing than previously reported

Detailed studies of SiPM online self-annealing

online self-annealing with forward bias



light gray points are all sensors
coloured points are averaged over sensors
coloured brackets is the RMS

test on a large number of proton irradiated sensors how much damage is cured as a function of temperature and time

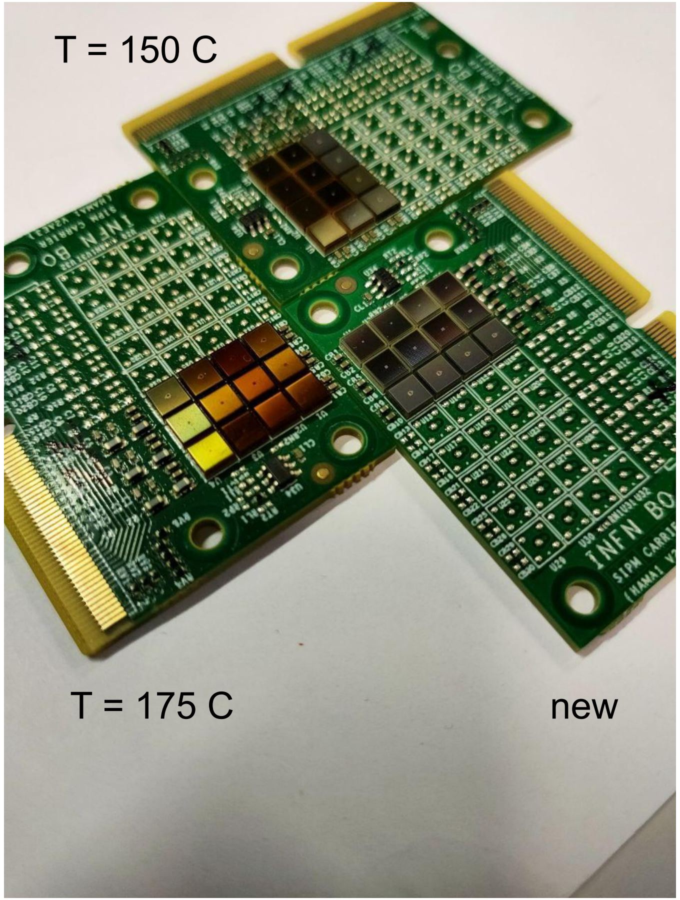
in this study, the same sensors have undergone self-annealing in increasing temperature steps and increasing integrated time steps

- started with T = 100 C annealing
  - performed 4 steps up to 30 hours integrated
- followed by T = 125, 150 and 175 C

fraction of residual damage seems to saturate at 2-3%
after ~ 300 hours at T = 150 C

continuing at higher T = 175 C seems not to cure more than that

Detailed studies of SiPM online self-annealing



but, after many hours of online annealing

we noticed alterations on the SiPM windows
in particular in one board that underwent

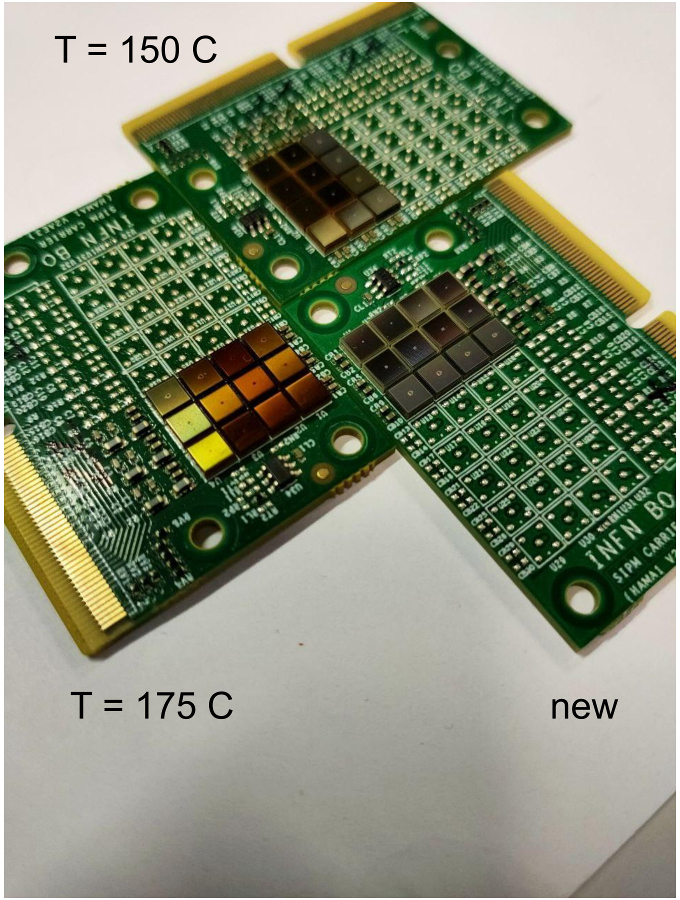
500 hours of online annealing at T = 175 C

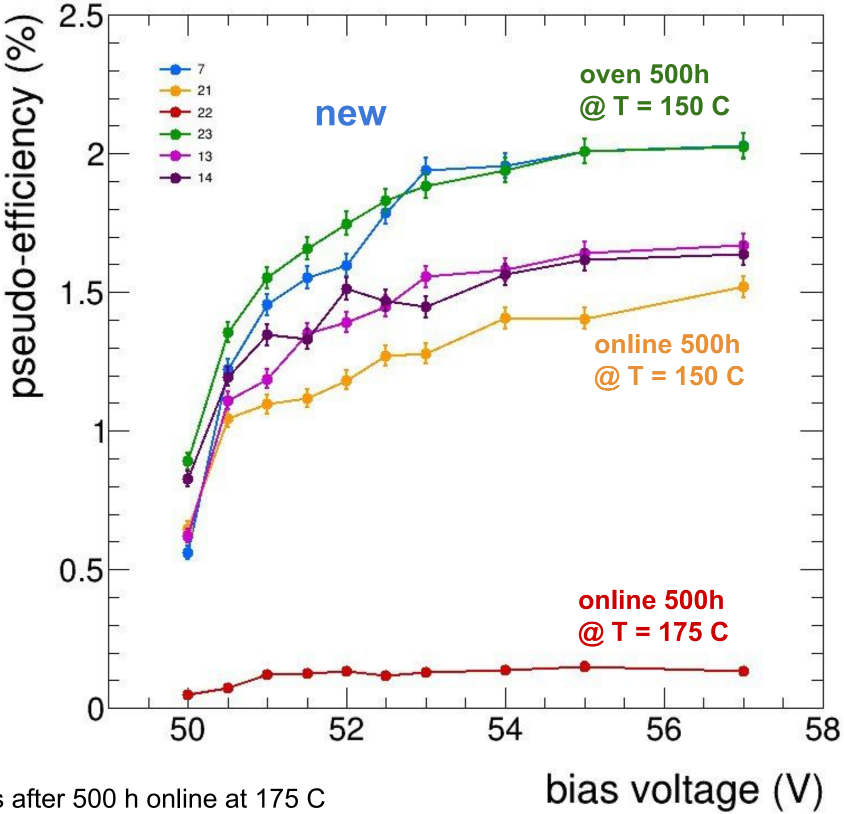
the sensors appear "yellowish" when compared to new

less "yellowish" but still a bit "yellowish" the sensors
in a board that underwent 500 hours at T = 150 C

let's compare them under the laser light

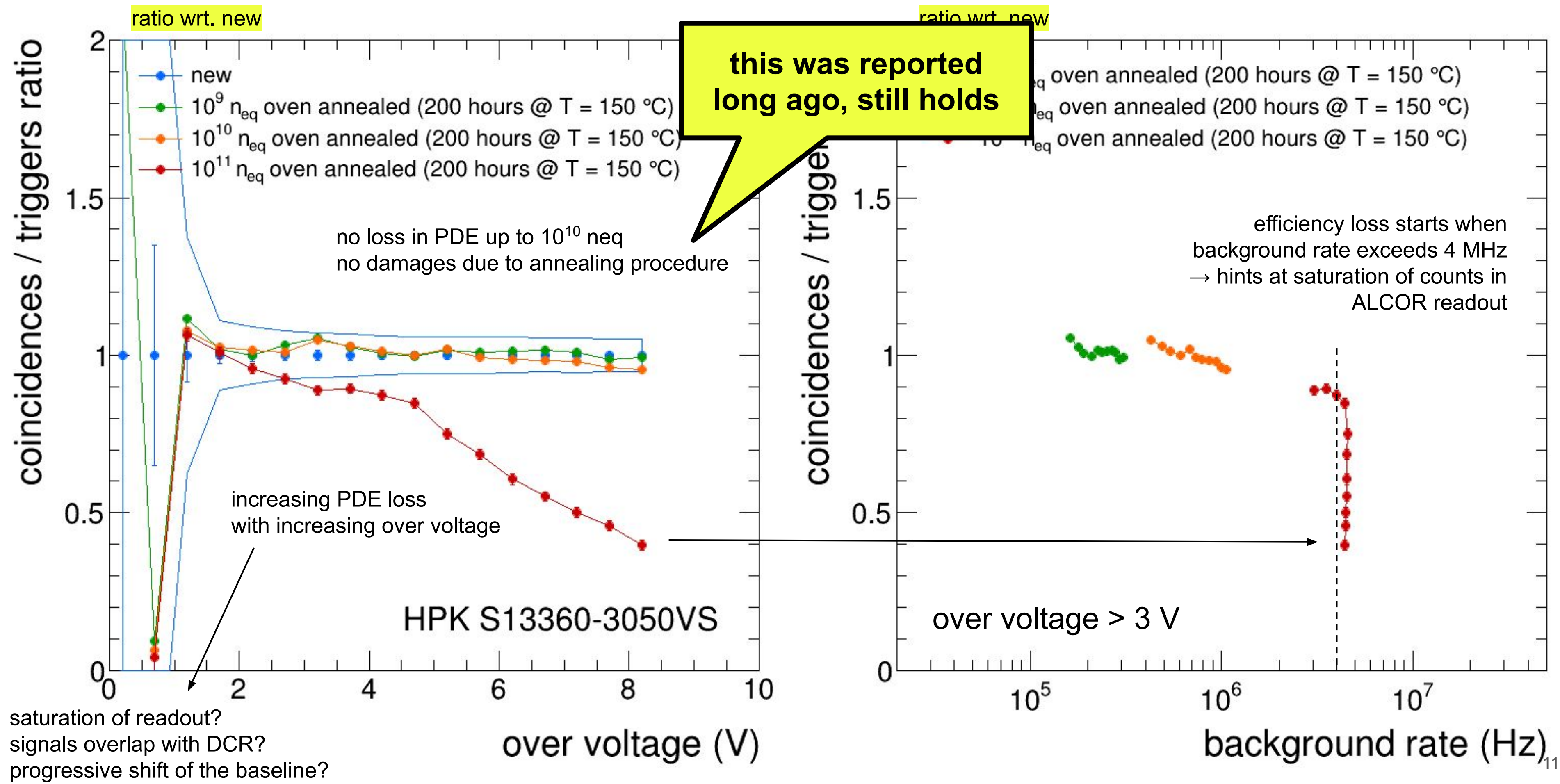
Detailed studies of SiPM online self-annealing





serious efficiency loss after 500 h online at 175 C
25% efficiency loss after 500 h online at 150 C
no efficiency loss after 500 h oven at 150 C
not clear why oven annealing is less critical on window, but in line with previously-reported "no damages due to annealing procedure" for 200 h in oven at T = 150 C

Light response after irradiation and annealing



window damage studies

Detailed studies of SiPM window damage

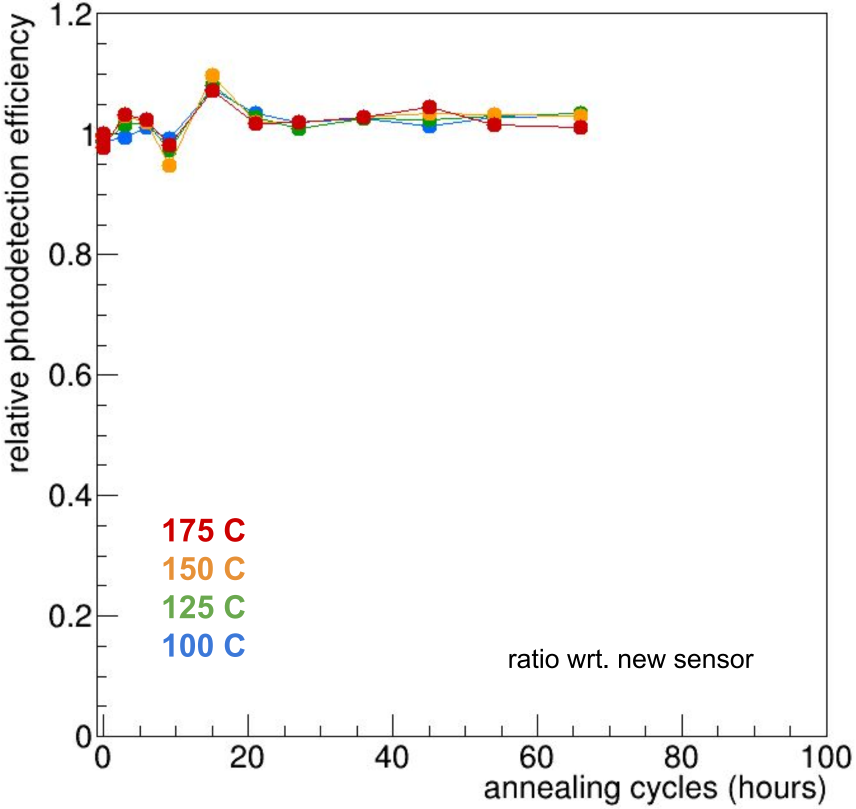
measurements are ongoing
4 SiPM under study
each undergoing online annealing

- at forward bias
- at different temperature
- following the same annealing protocol
- same integrated annealing time and cycles

measurements are performed with the upgraded laser setup (see next slides)

the plot reports the variation of the PDE wrt. the sensors measured before the beginning of the annealing cycles (new)

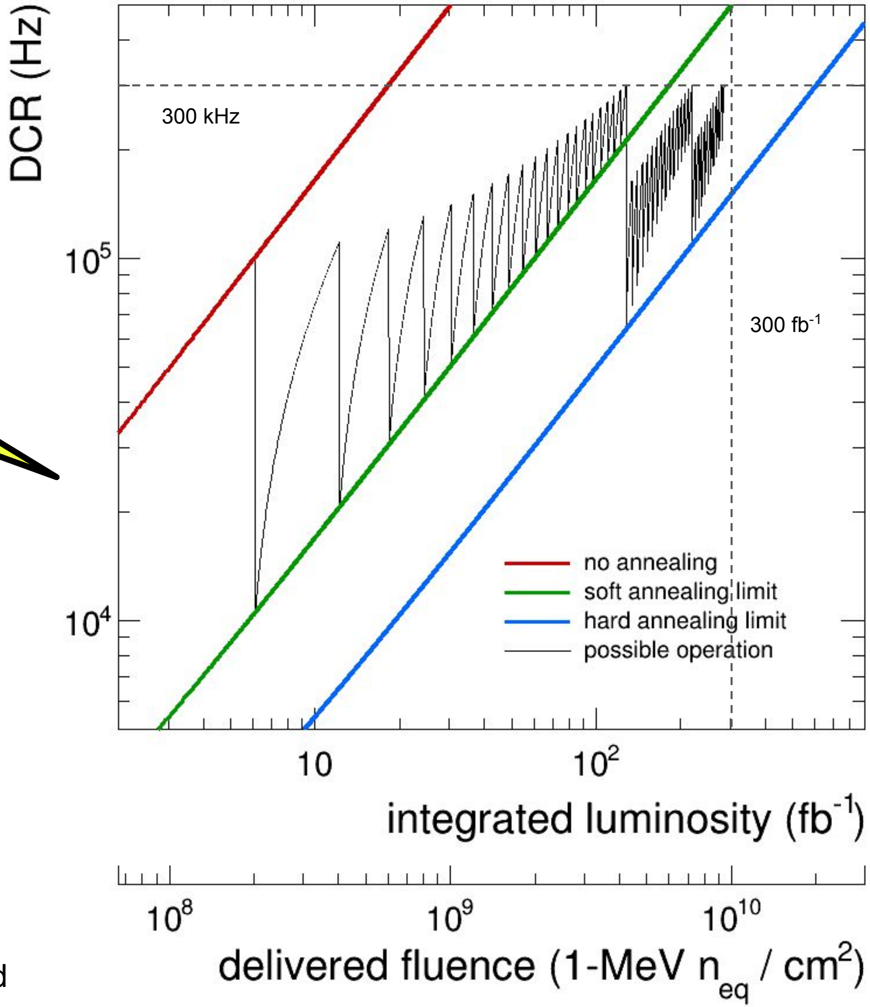
measurements are still ongoing
so far, after 66 hours (66 1-hour cycles)
no observation of efficiency loss at any temperature



Updated ageing model

the "possible operation" scenario shown here has 44 soft-annealing cycles and 3 hard-annealing cycles

Hamamatsu S13360-3050 @ Vover = 4 V, T = -30 C



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1-MeV neq fluence from background group (conservative)

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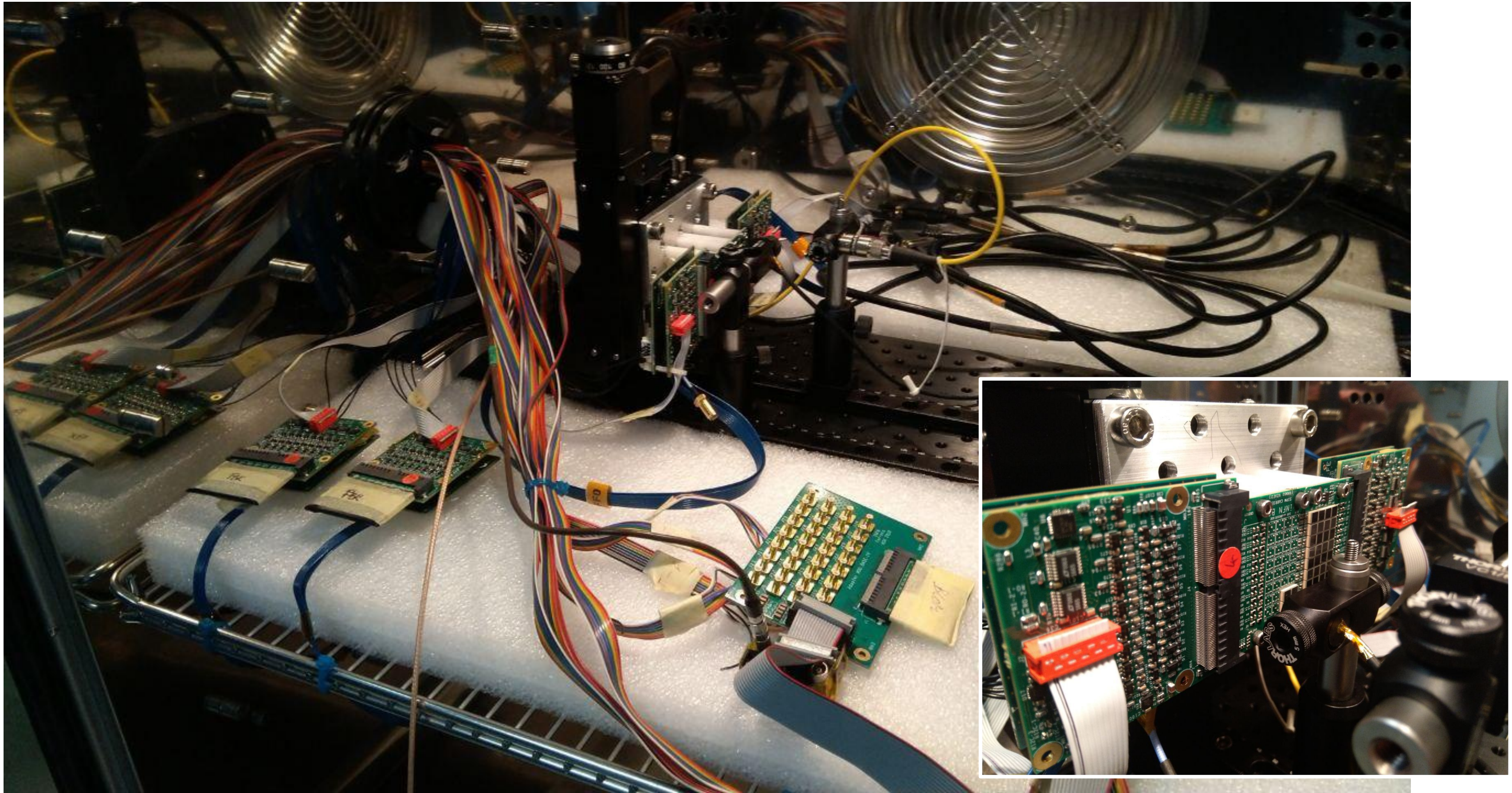
upgraded laser setup

Old moving stage

workhorse! great results, despite limitations: only 2 axes, no low temperature operation, limited 25 mm range



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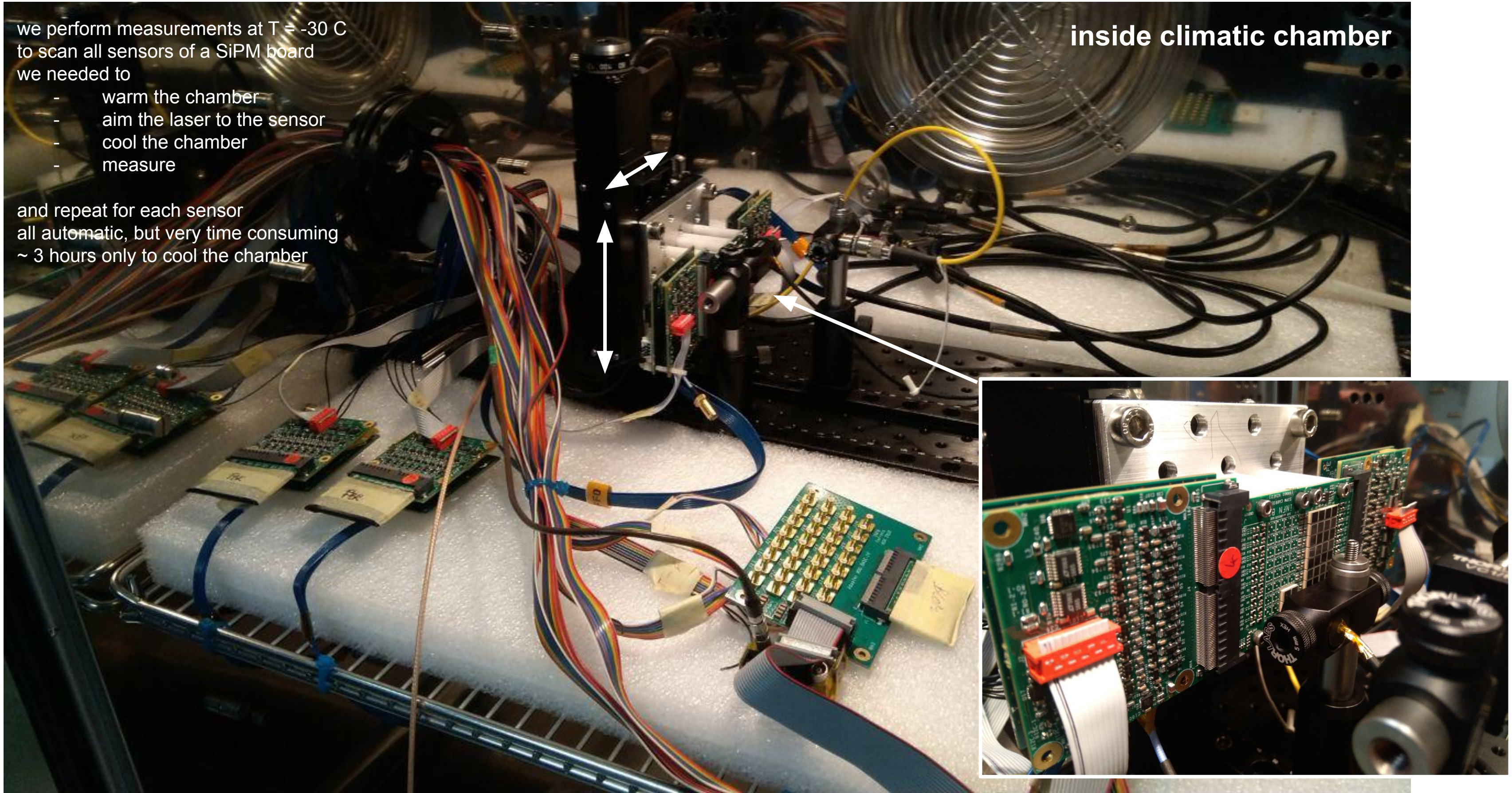
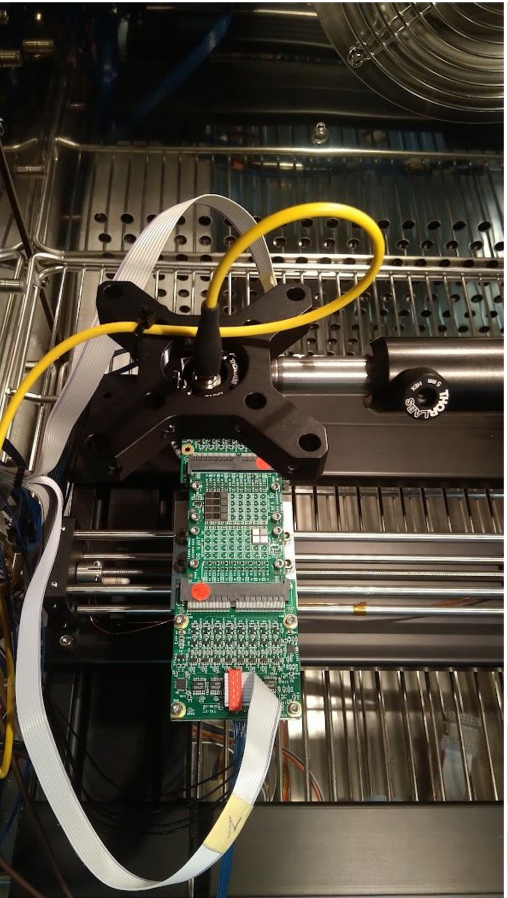
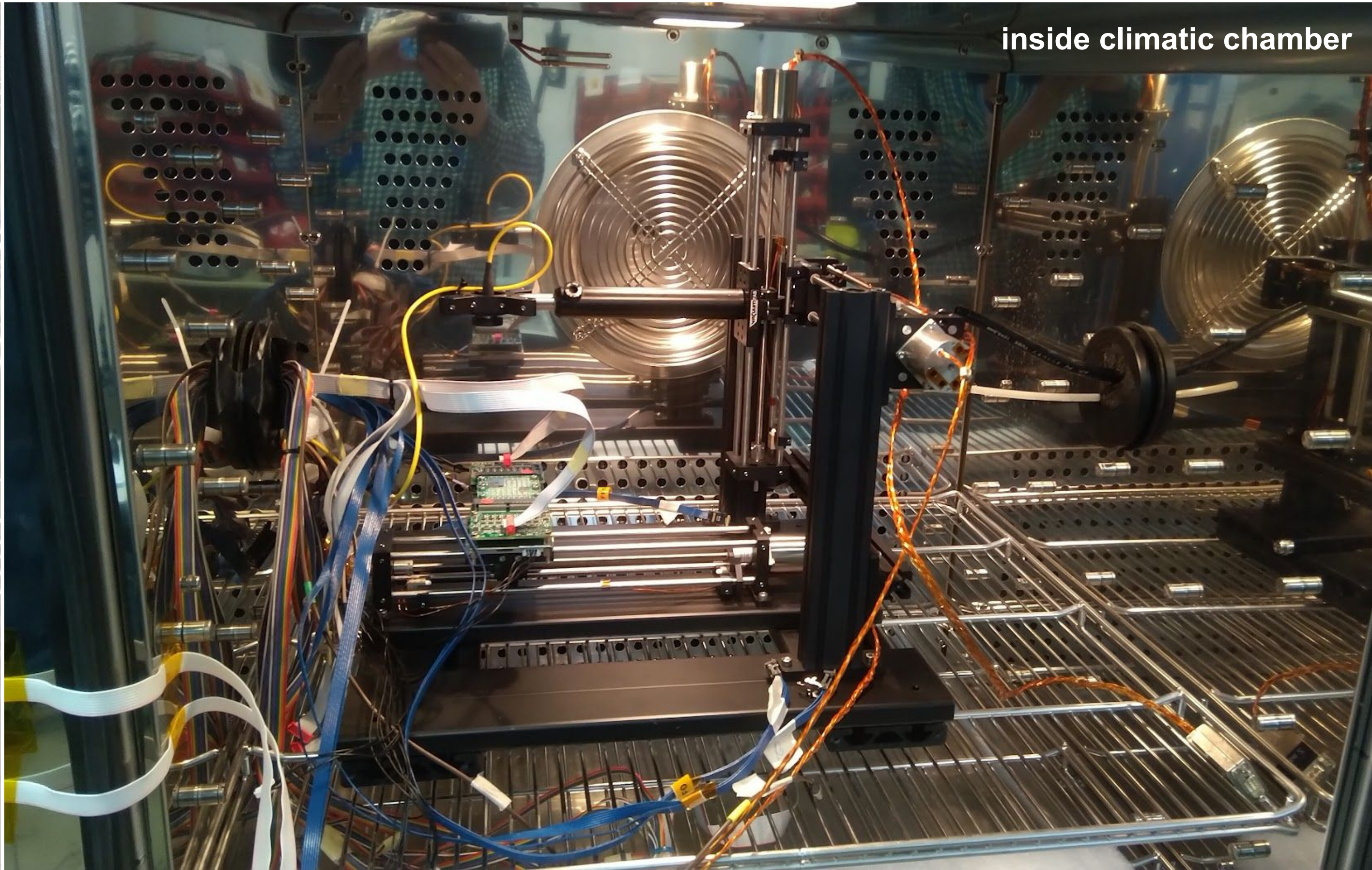


New moving stage

big upgrade! new xyz moving stage can operate at low temperature (down to T = -40 C) within a 200 mm range





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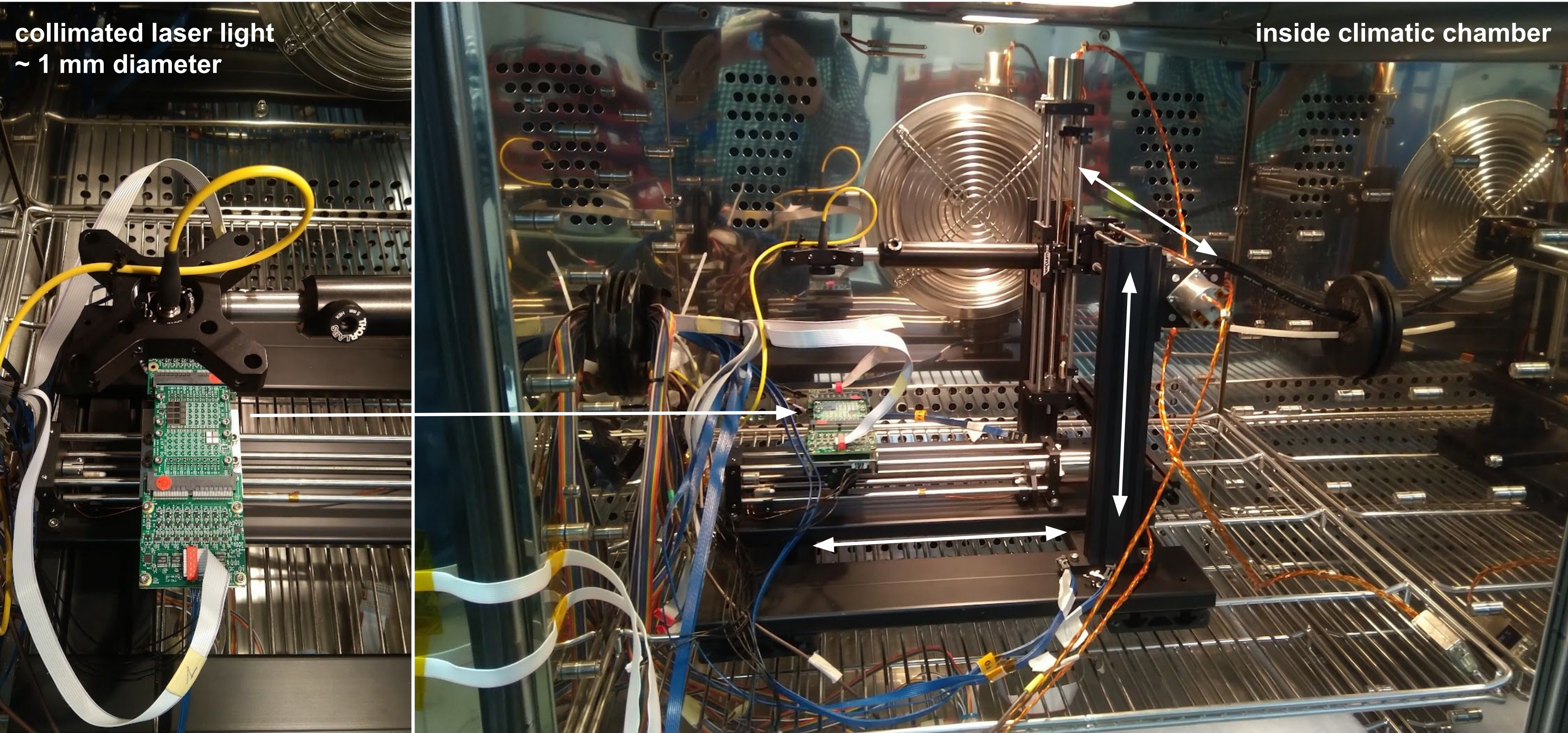
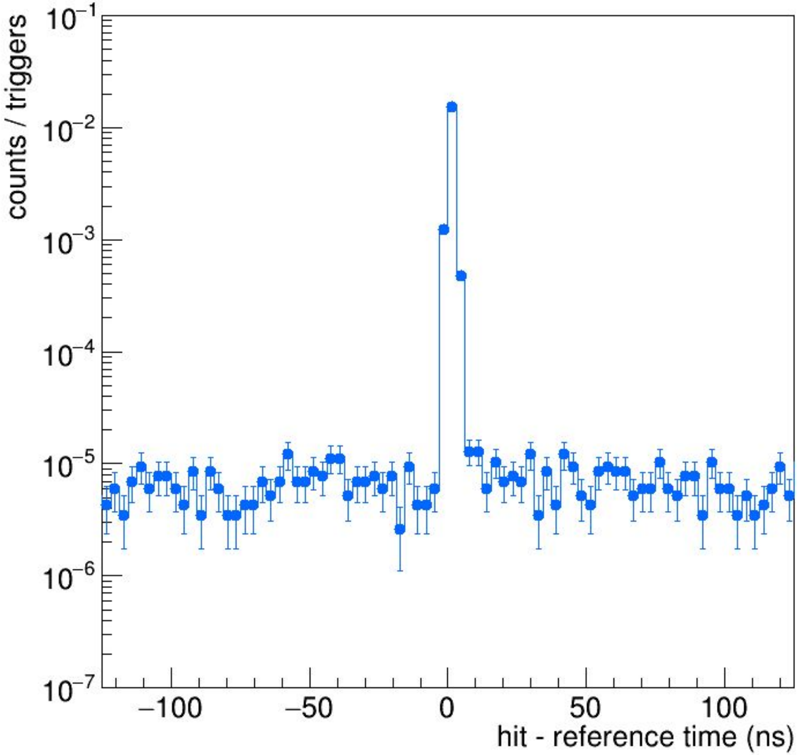
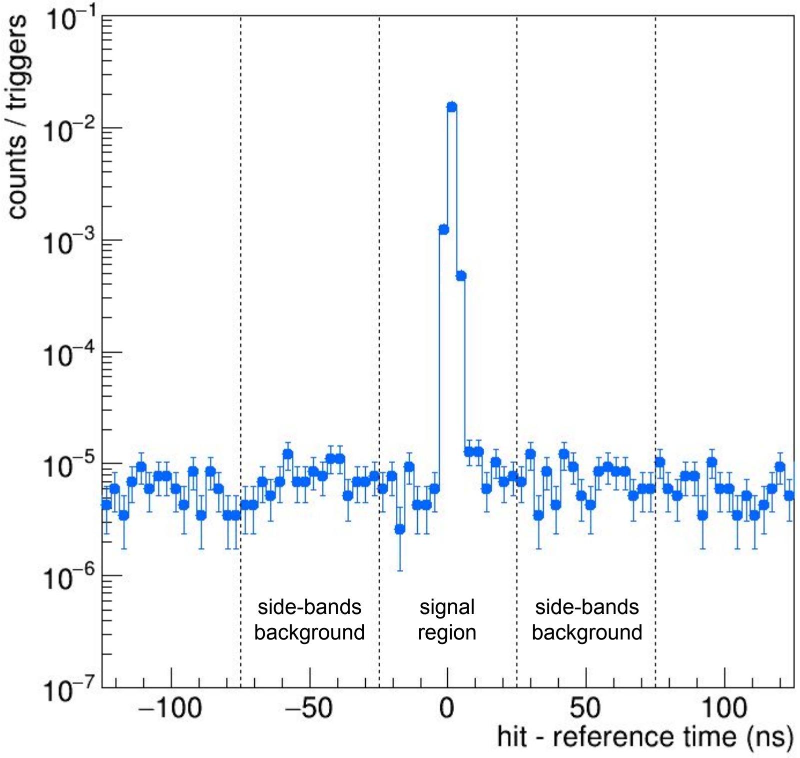


examples of laser operation

Signal extraction



Signal extraction

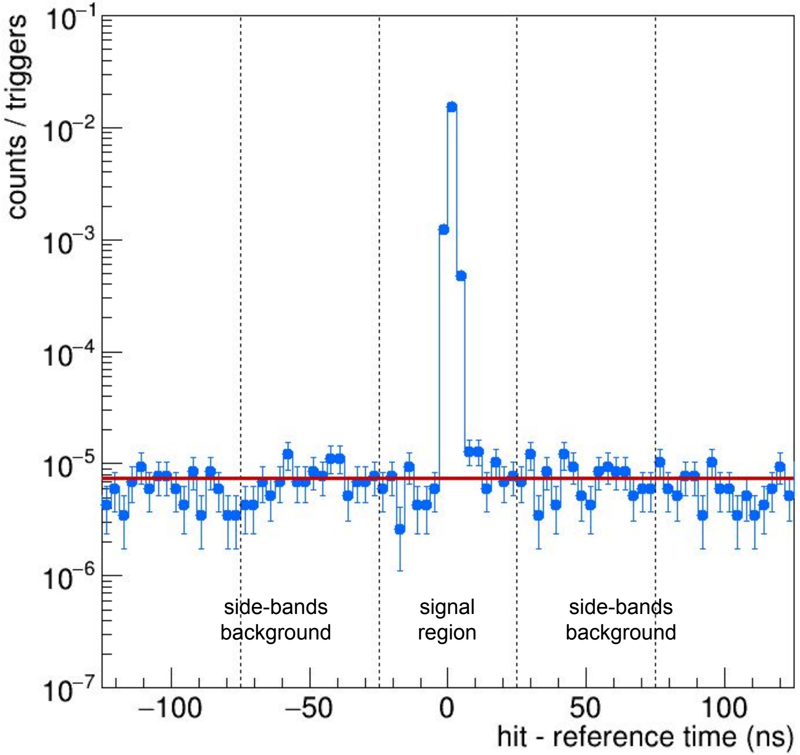


Signal extraction

measured signal coincidences

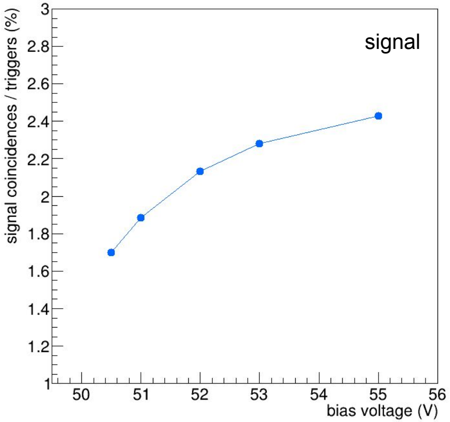
background-subtracted counts / triggers

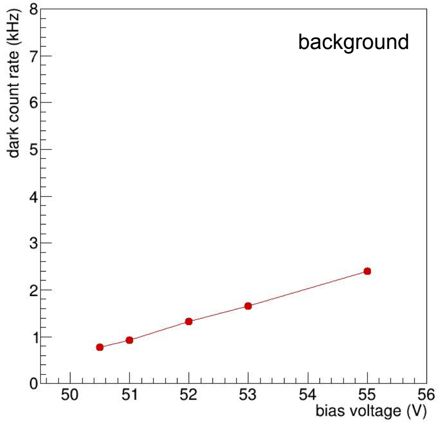
probability to detect light from laser pulse



estimated background within signal region

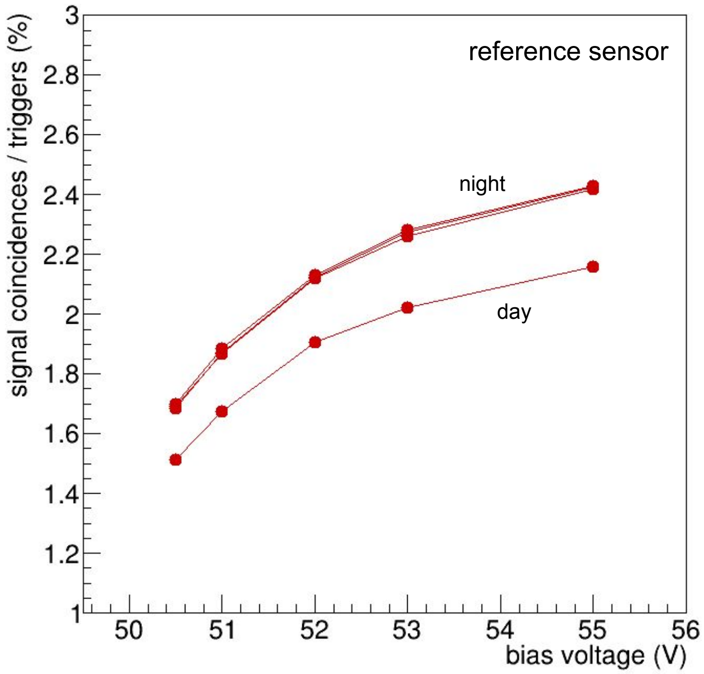
proxy for photodetection efficiency

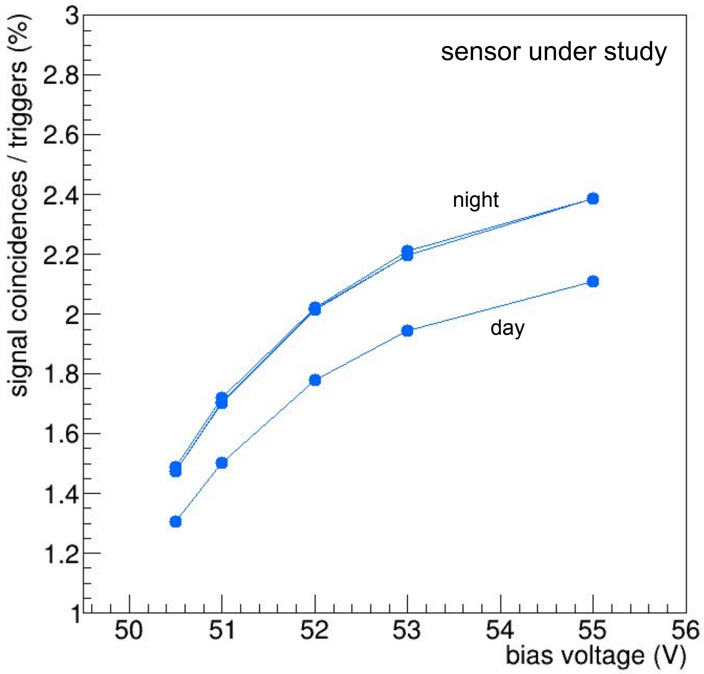




Repeated measurements: signal

several measurements repeated on the same NEW sensor

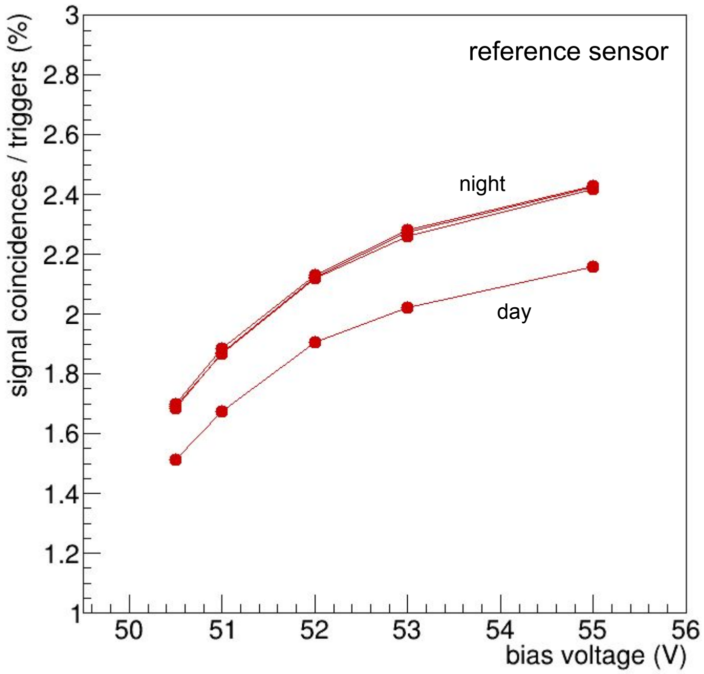


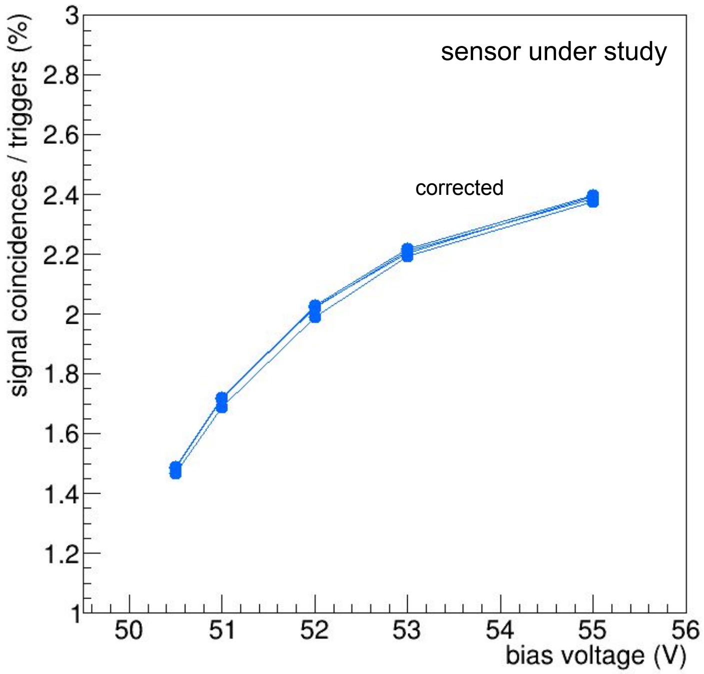


don't know why the signal changes this much, same change in reference and sensor under study
reference sensor measurement to quantify changes in the laser light yield

Repeated measurements: signal

several measurements repeated on the same NEW sensor

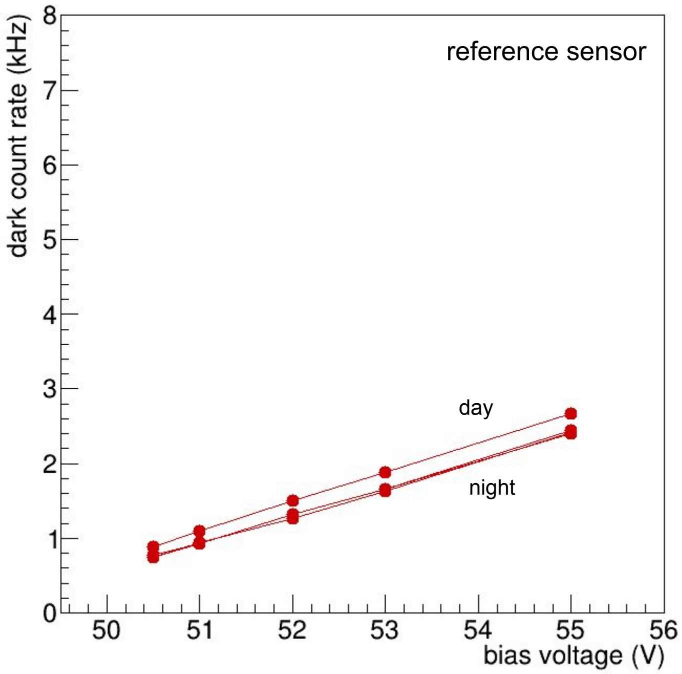


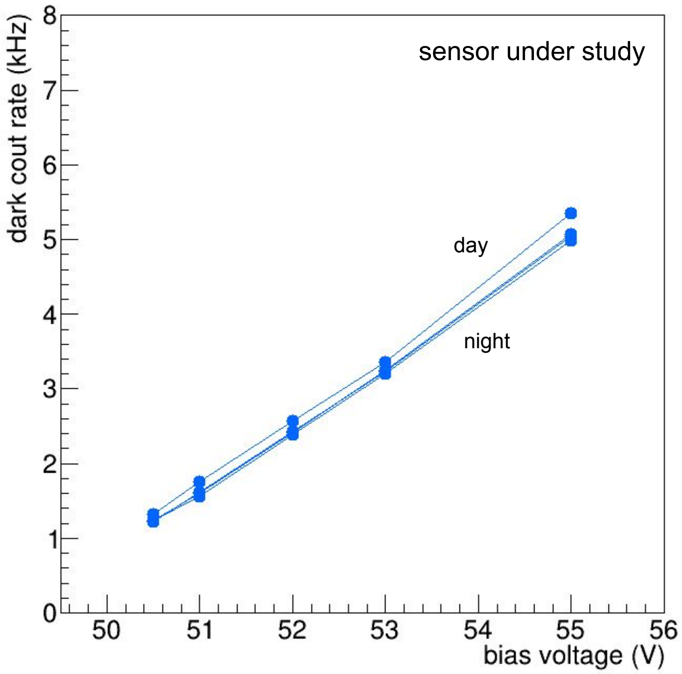


after correction for laser light yield, measurements of sensor under study are compatible

Repeated measurements: background

several measurements repeated on the same NEW sensor

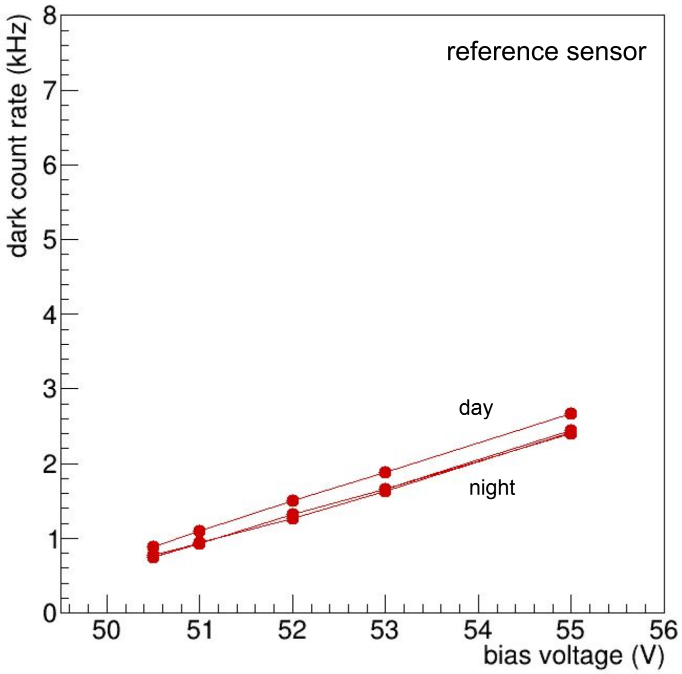


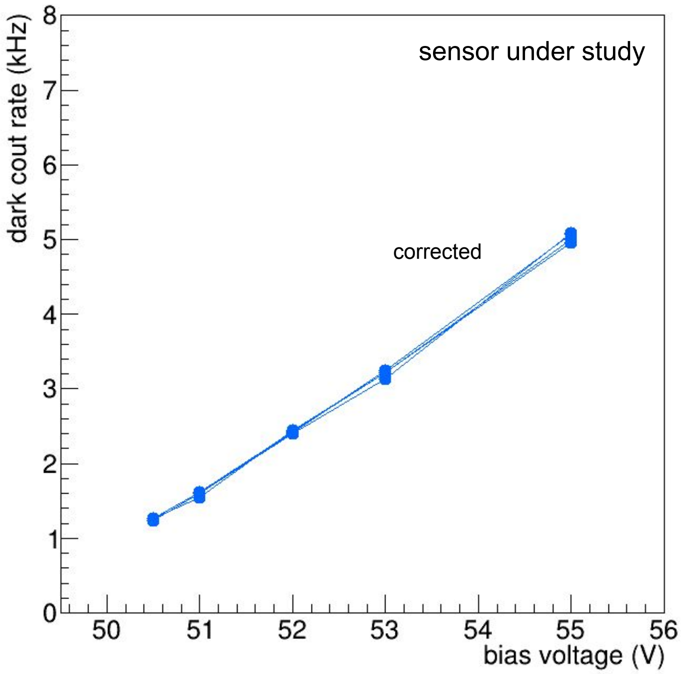


there is likely some background light entering in the dark box
reference sensor measurement to quantify changes in the background light

Repeated measurements: background

several measurements repeated on the same NEW sensor

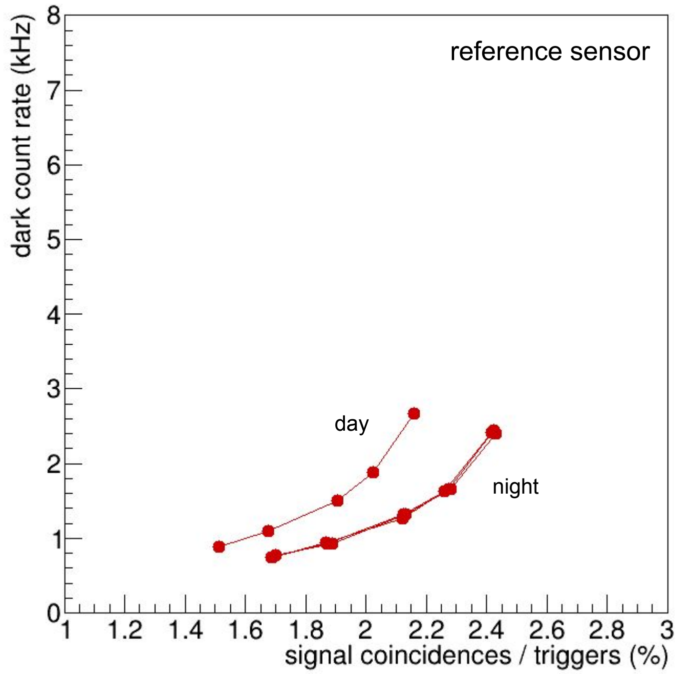


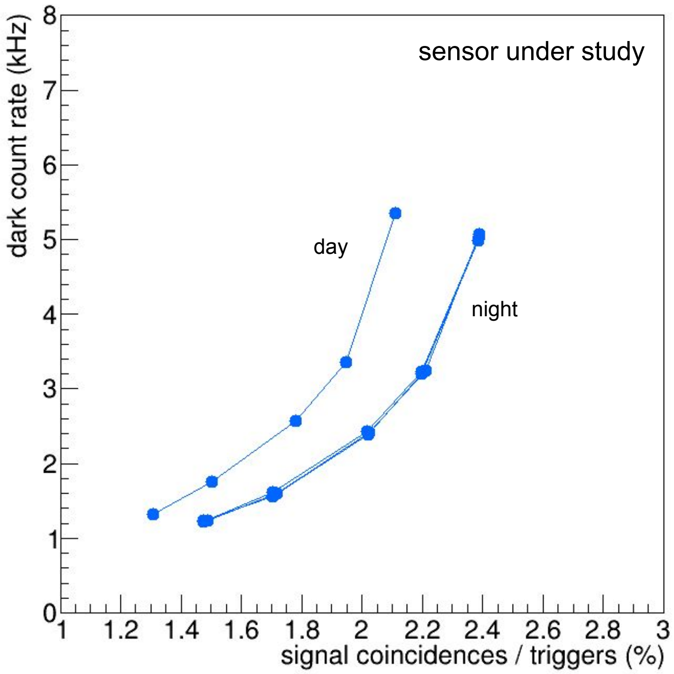


after correction for background light, measurements of sensor under study are compatible

Repeated measurements: signal & background

powerful measurement of the SiPM performance: efficiency vs. dark count rate (or viceversa)

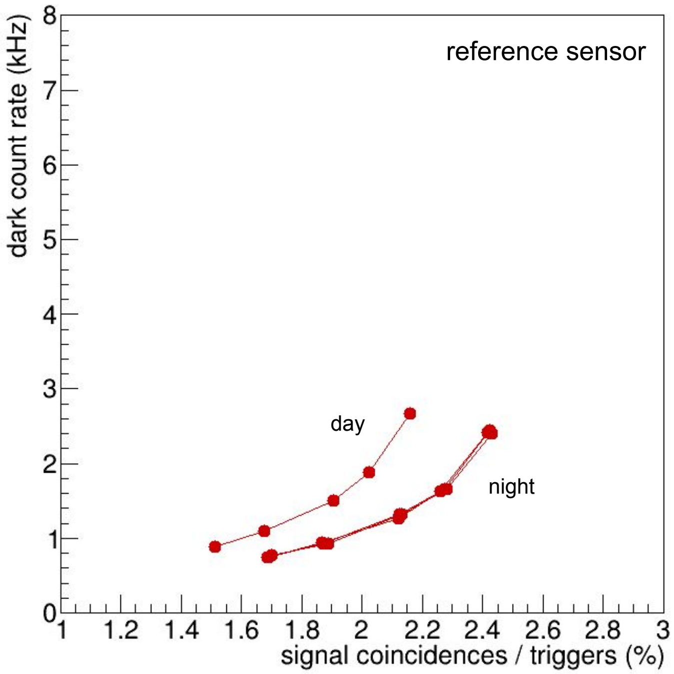


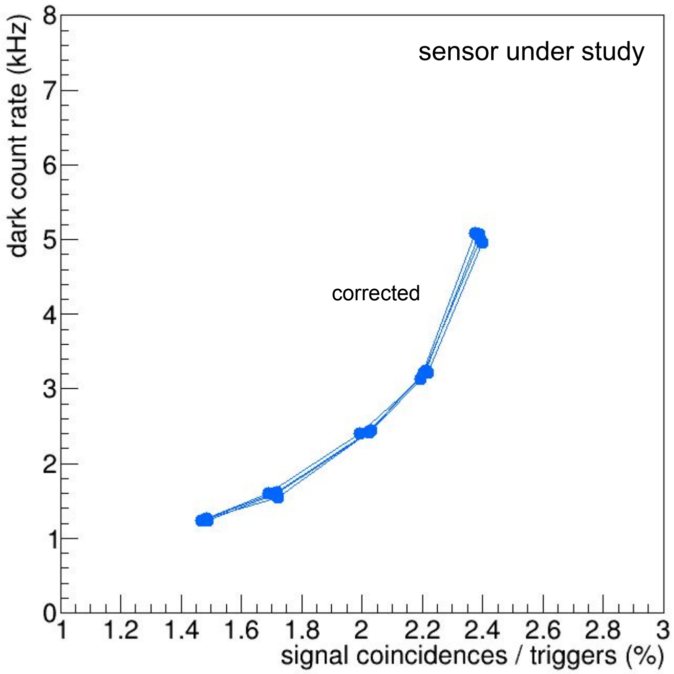


before correction

Repeated measurements: signal & background

powerful measurement of the SiPM performance: efficiency vs. dark count rate (or viceversa)

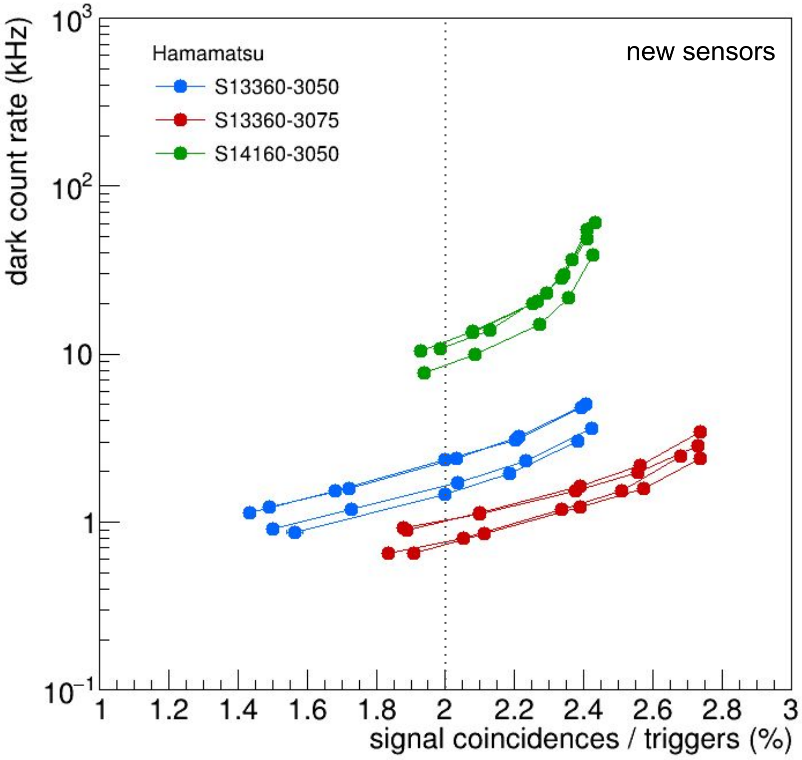




after correction for laser yield and background light, measurements of sensor under study are compatible

Comparison between sensors

3 Hamamatsu sensor types, 4 sensors each measured as NEW



proxy for photodetection efficiency

at the same level of detection efficiency

namely, the probability to detect light from laser pulse

different sensors have different DCR level

<u>best</u>: S13360-3075

most promising sensors, large pitch SPADs (75 μm)

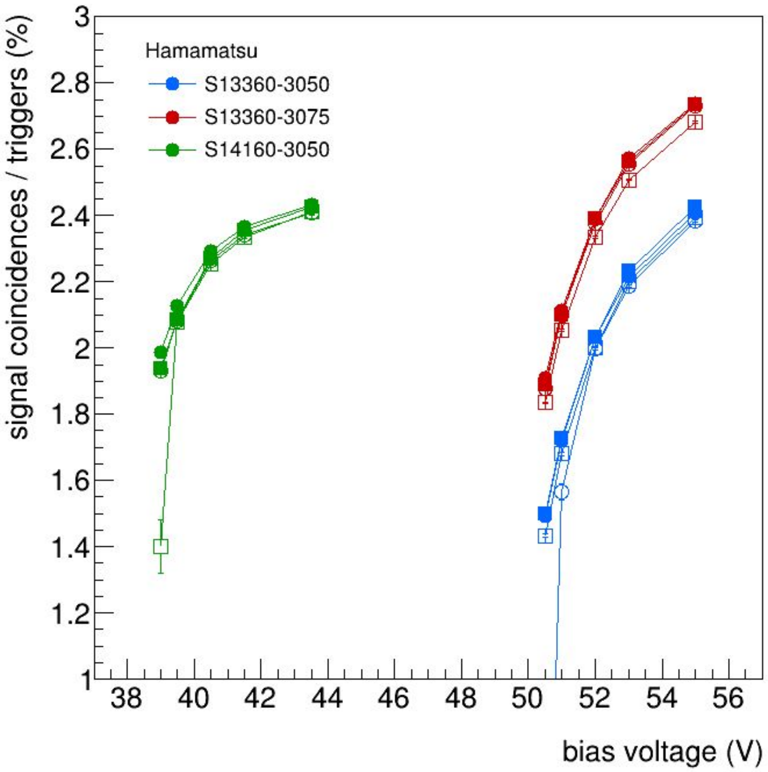
<u>second</u>: S13360-3050

same technology, medium pitch SPADs (50 μm)

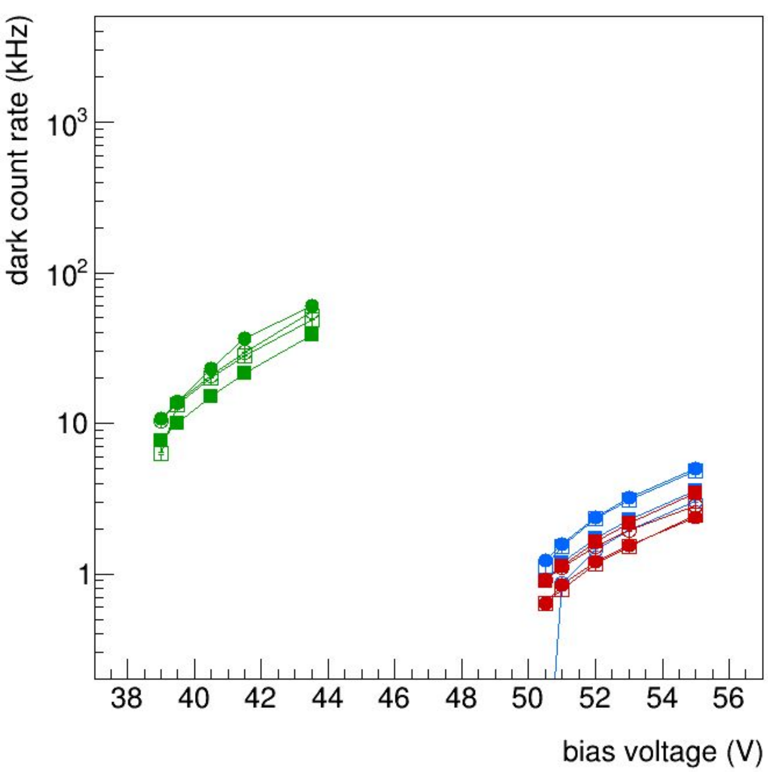
<u>worst</u>: S14160-3050

different technology, medium pitch SPADs (50 μm) what follows is

new boards



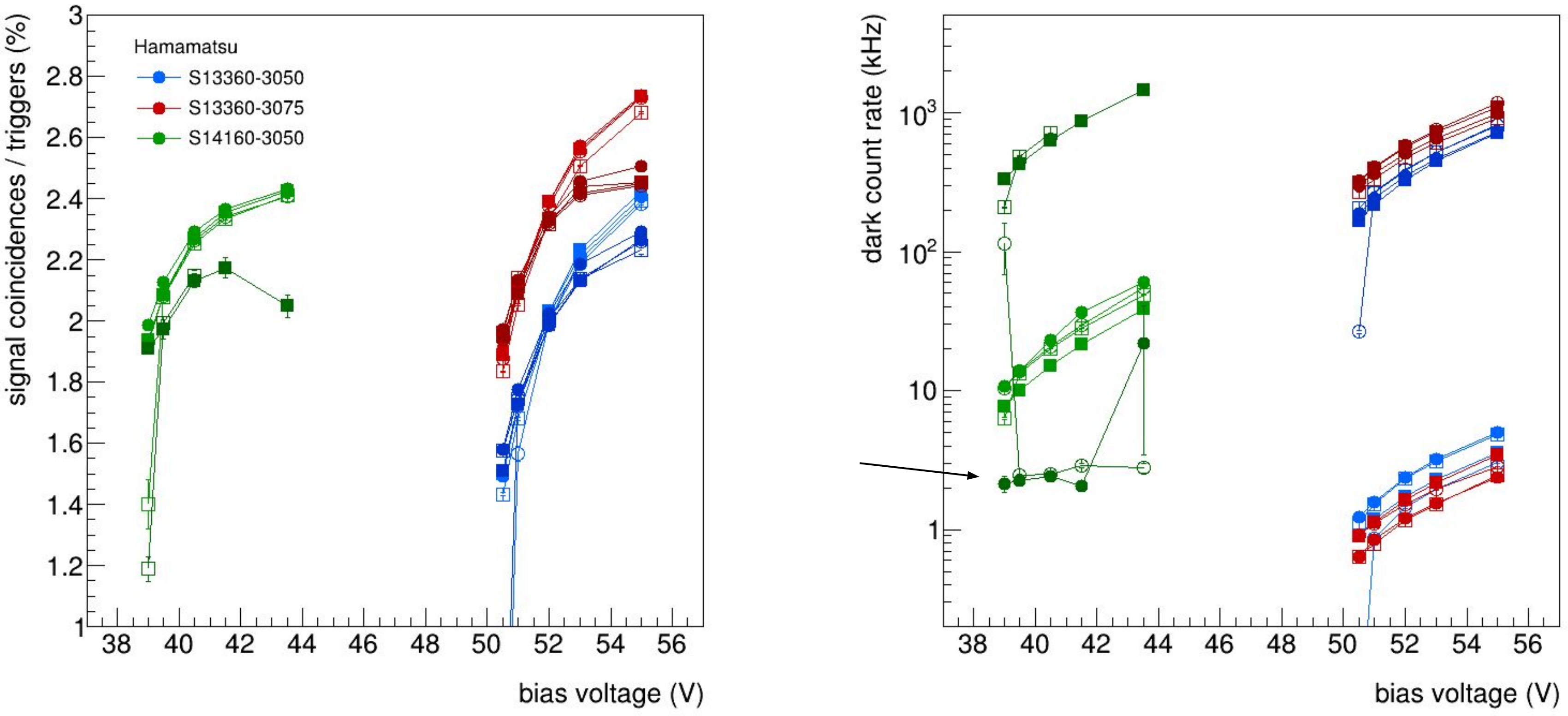
signal coincidences / triggers (%)
Hamamatsu
S13360-3050
S13360-3075
S14160-3050
bias voltage (V)



dark count rate (kHz)
bias voltage (V)

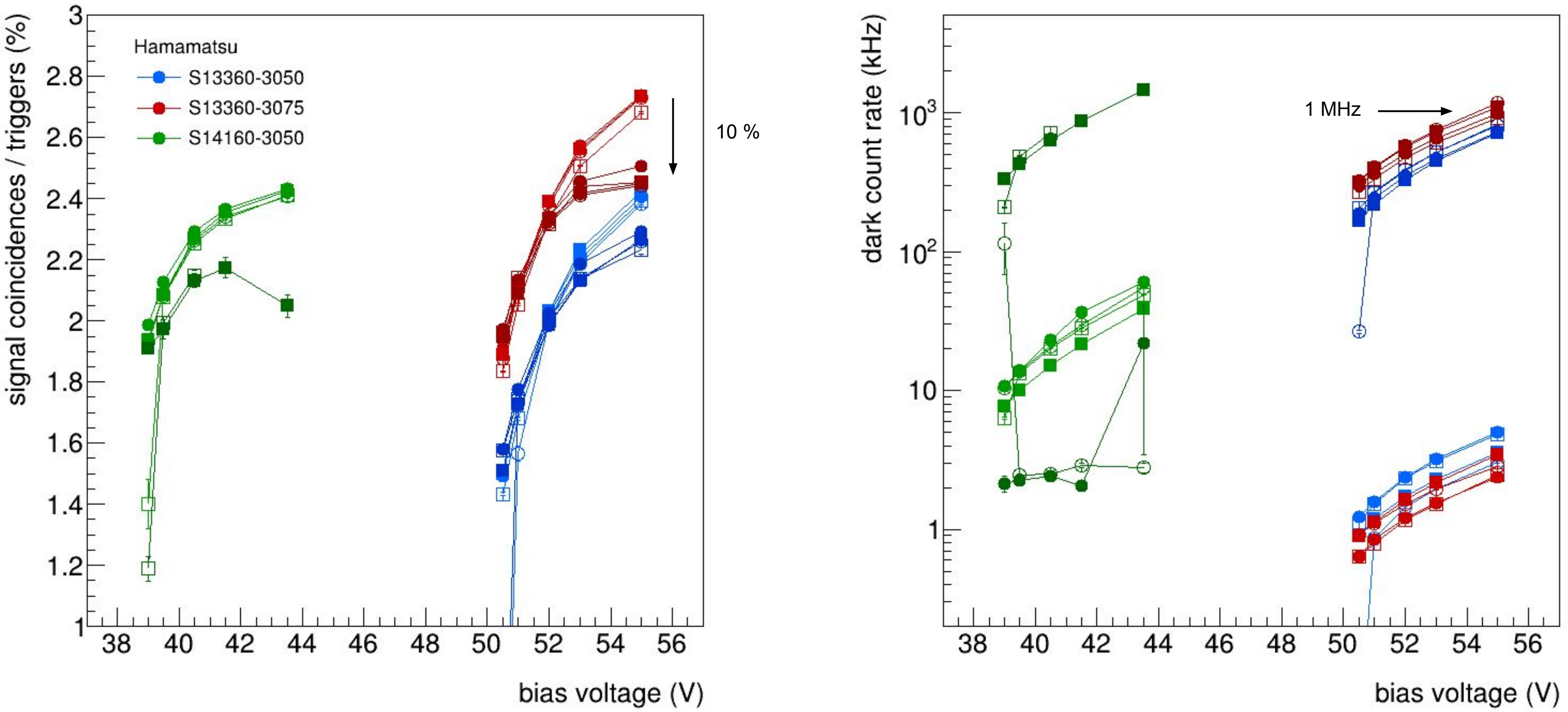
PRELIMINARY

new boards and irradiated boards (10^9 neq)



the Hamamatsu S14160-3050 sensors seem to have more troubles to be reconstructed after irradiation

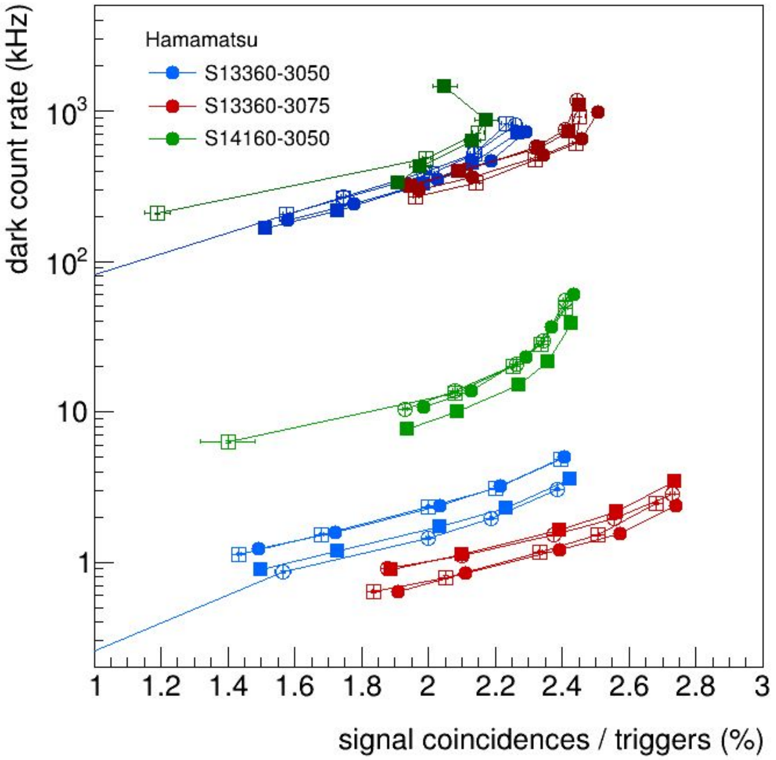
new boards and irradiated boards (10^9 neq)

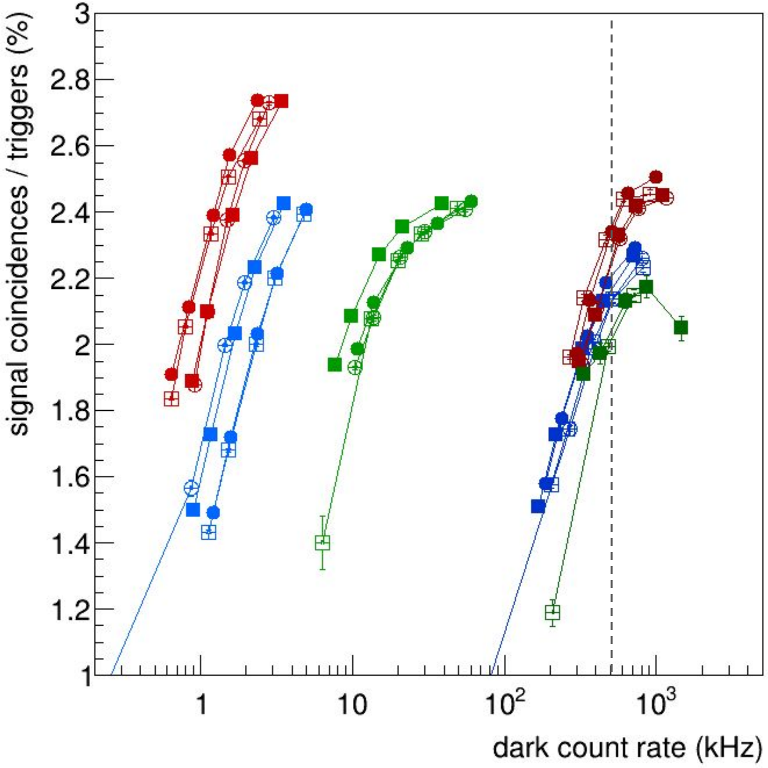


the efficiency loss is likely due to the "after-pulse" suppression algorithm used for analysis
"every signal which is within less than 100 ns wrt. the preceding signal is discarded"
at ~ 1 MHz DCR rate, the probability of having a DCR hit 100 ns before the laser pulse is ~ 10%

new boards and irradiated boards (10^9 neq)

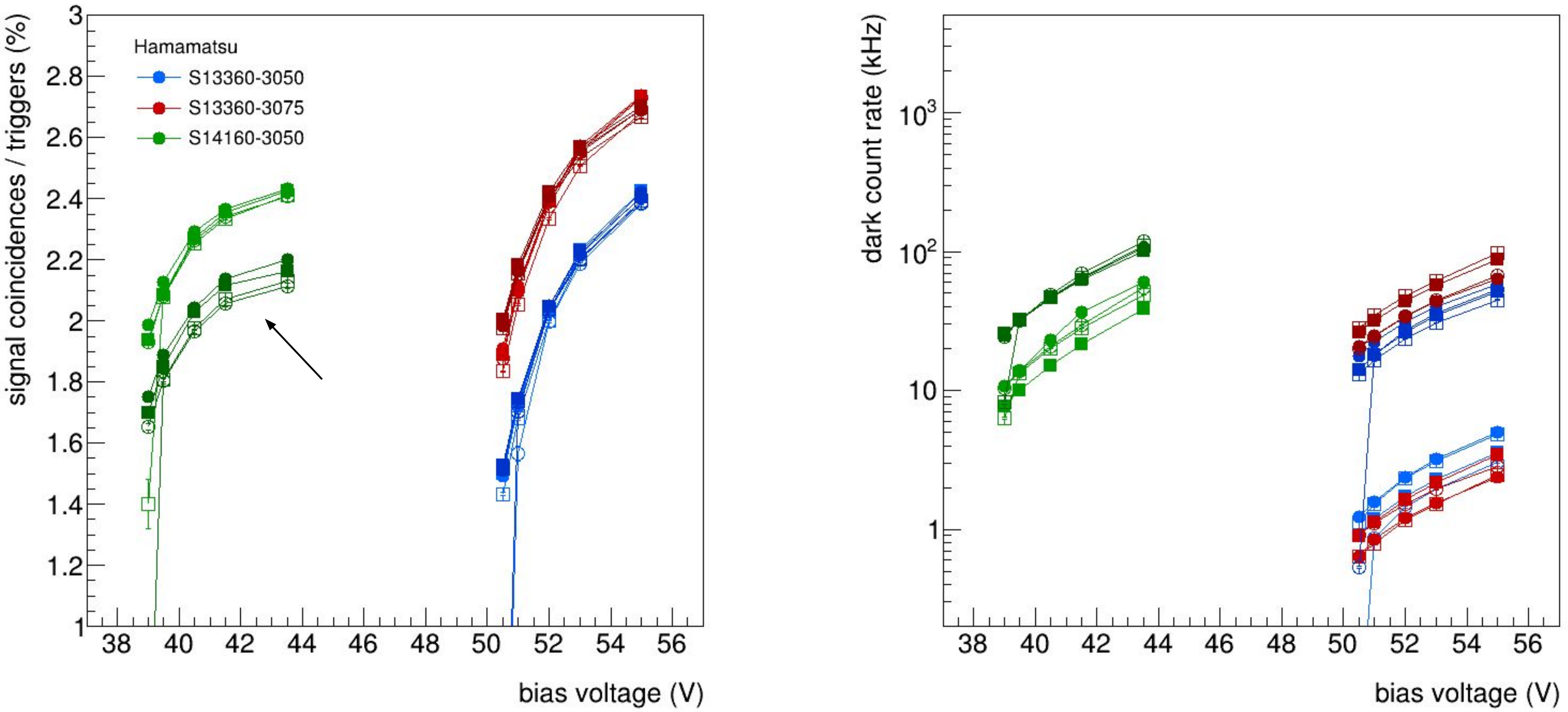
PRELIMINARY





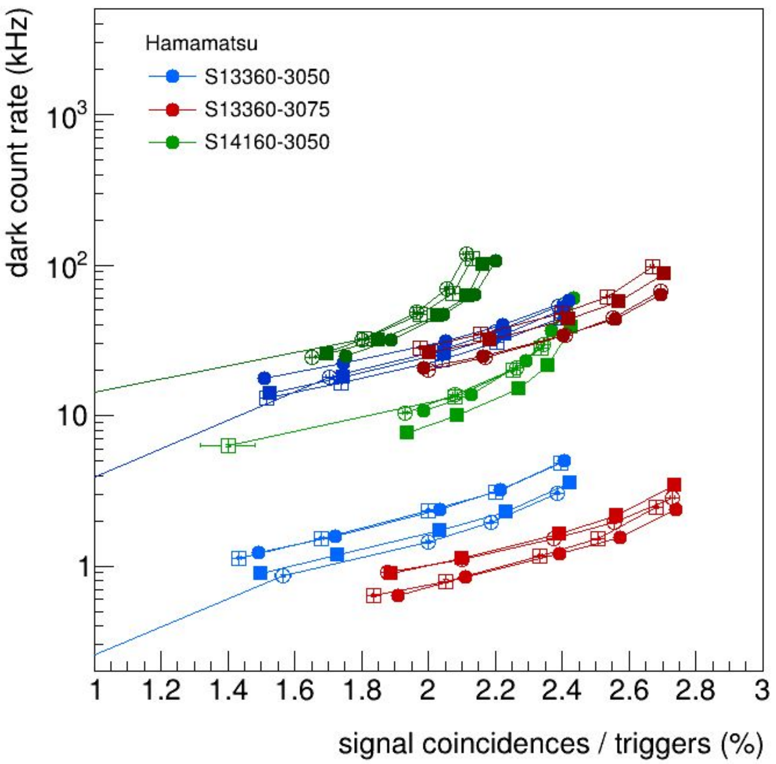
at fixed DCR of 500 kHz after 10^9 neq (without annealing)
the S13360-3075 sensor (75 m SPADs) is more efficient (20% larger PDE)
caveat: new and irradiated are not the same sensors, so the comparison is not fully quantitative

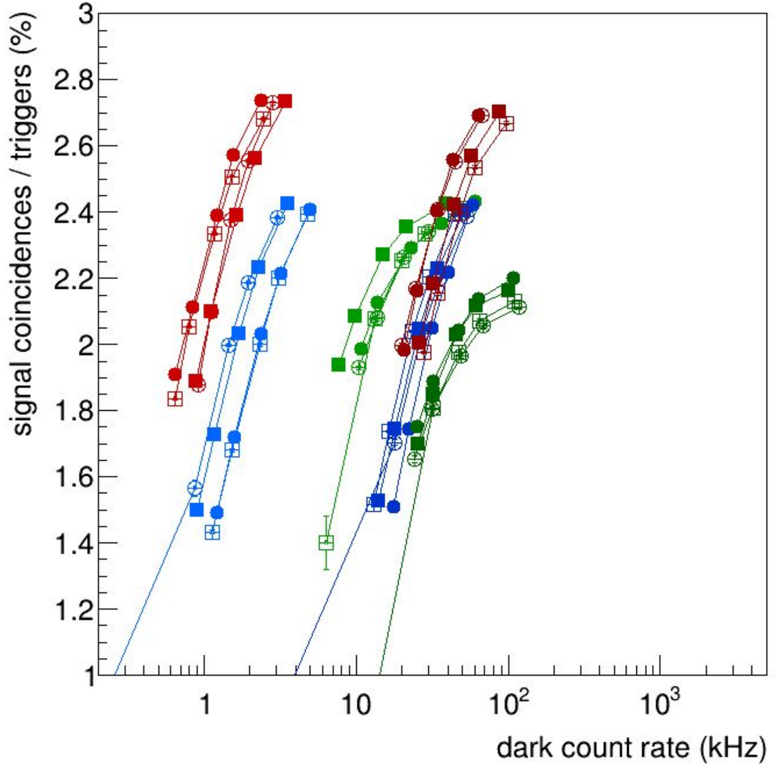
new boards and annealed boards (10^9 neq)



the Hamamatsu S14160-3050 sensors seem to have lower efficiency after irradiation and annealing
in S13360-3050 sensors the efficiency is unaffected, only DCR increases (we know)

new boards and annealed boards (10^9 neq)





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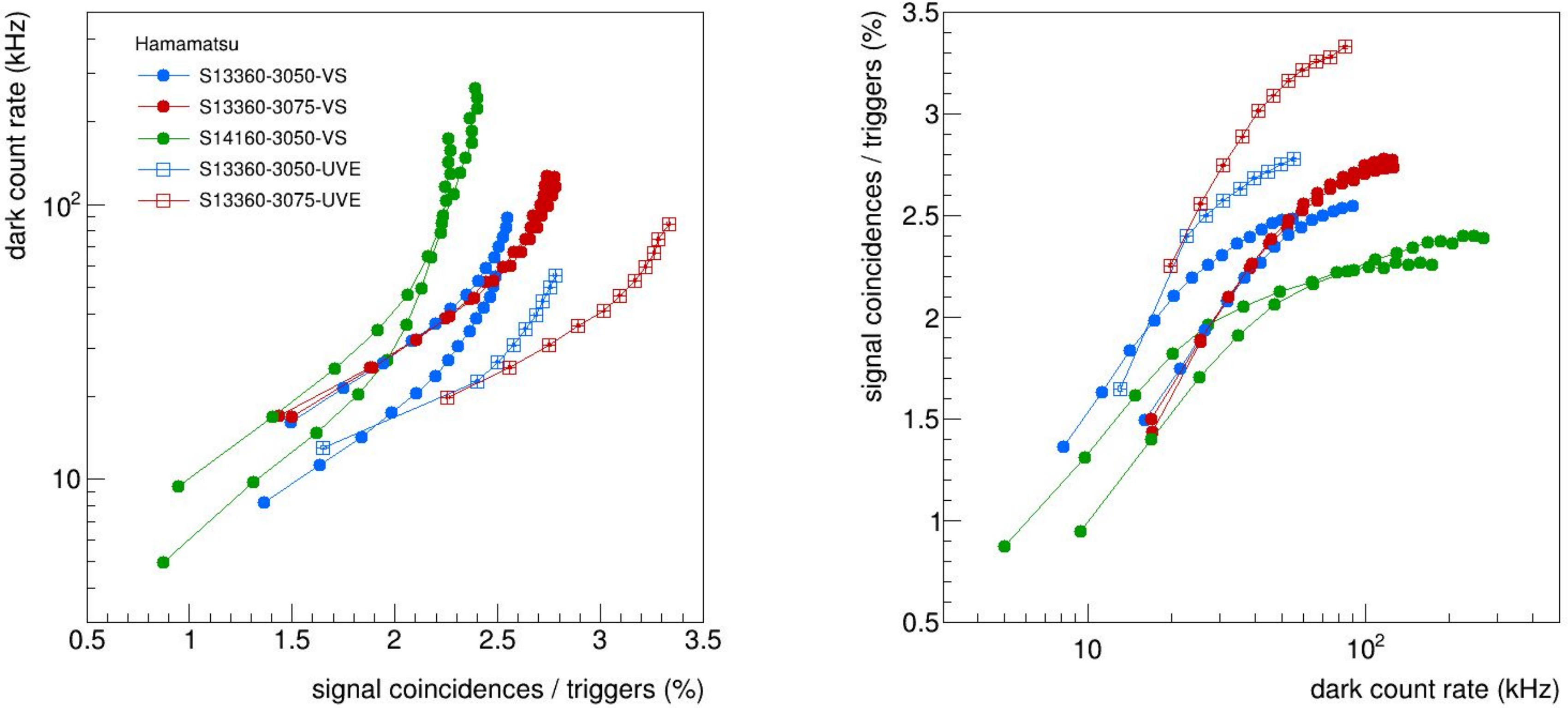
prototype Hamamatsu sensors (10^9 neq after oven annealing)



prototype Hamamatsu UVE sensors have significantly higher efficiency than standard sensors
caveat: we only measure PDE at the fixed laser wavelength of ~400 nm, larger PDE expected because…
prototype sensors have a NUV-enhanced (quartz + special silicone) protective window… might be of our interest to study further