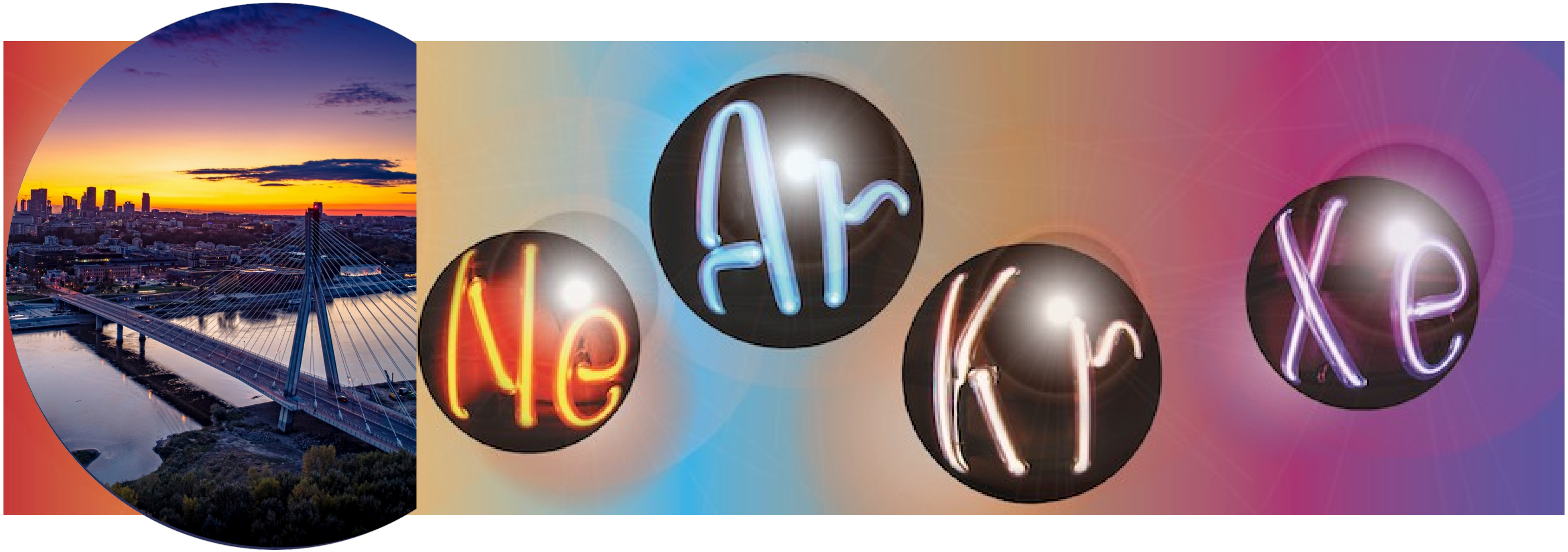
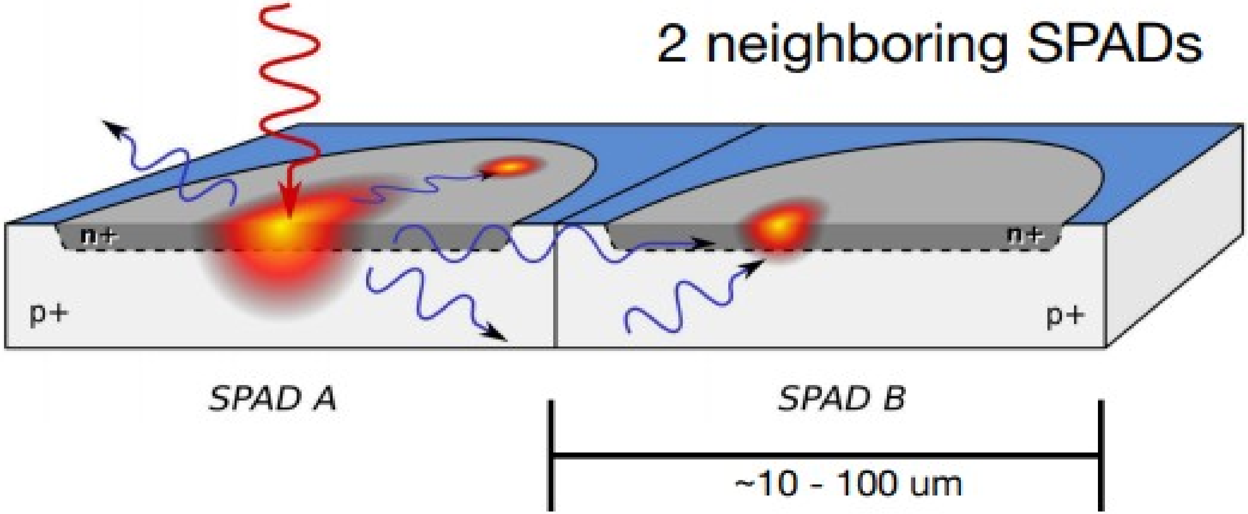


Correlated noises for NUV-HD-Cryo SiPMs

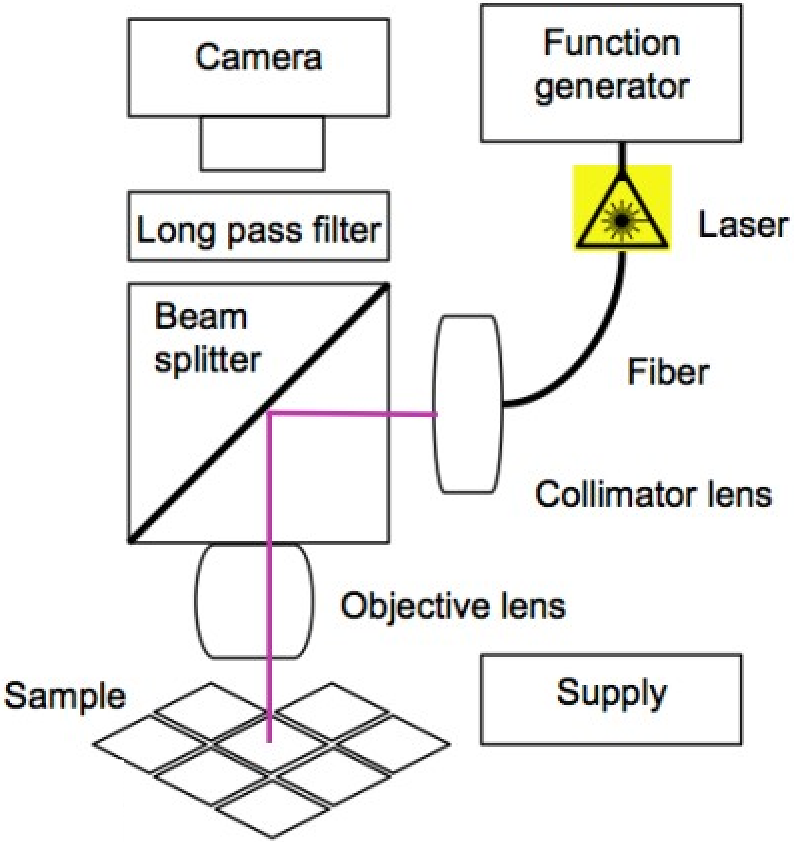
Alessandro Razeto – LNGS

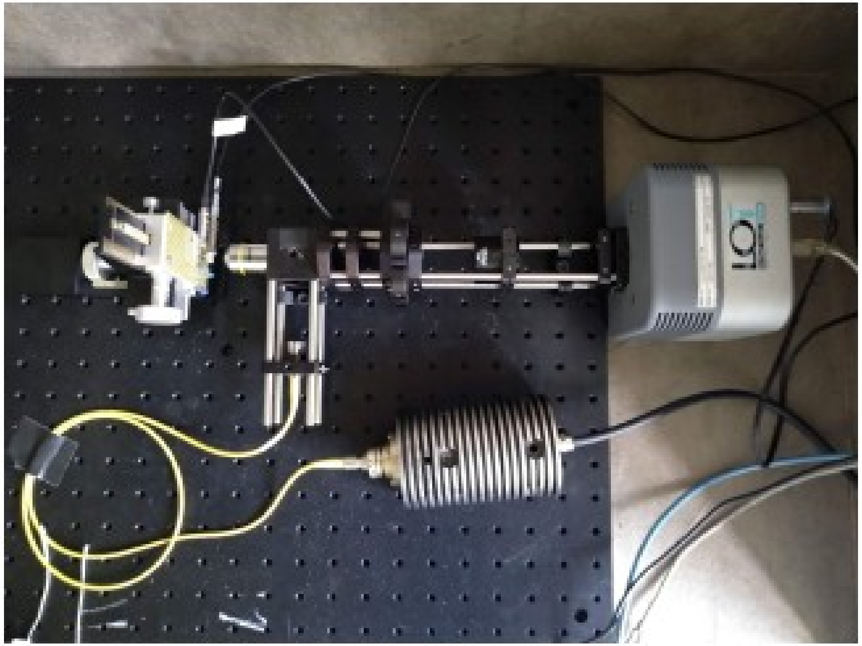
LIDINE 2022 - 22/09/2022 University of Warsaw

Optical Cross-Talk



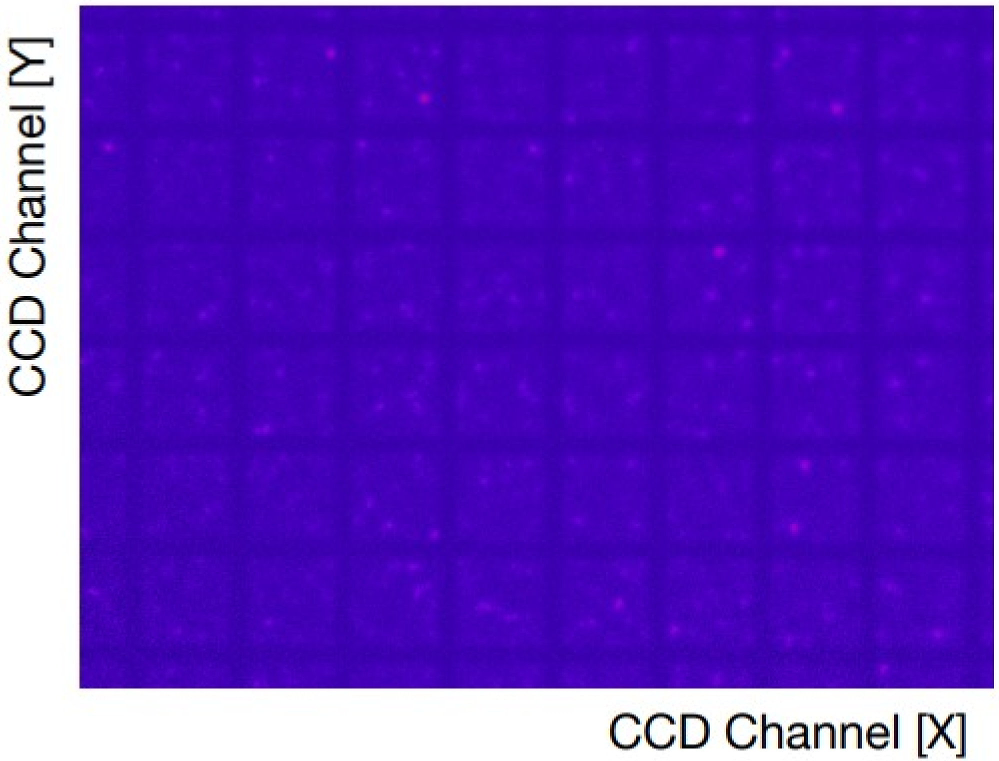
- Biased silicon junctions emits light (Newman 1955)
- In SiPMs 1 photon every 106 e- (Mirzoyan 2009)
  - Emission is peaked at longer wavelengths
- Photon emission is the origin of cross-talk
  - Between SPADS or between SiPMs

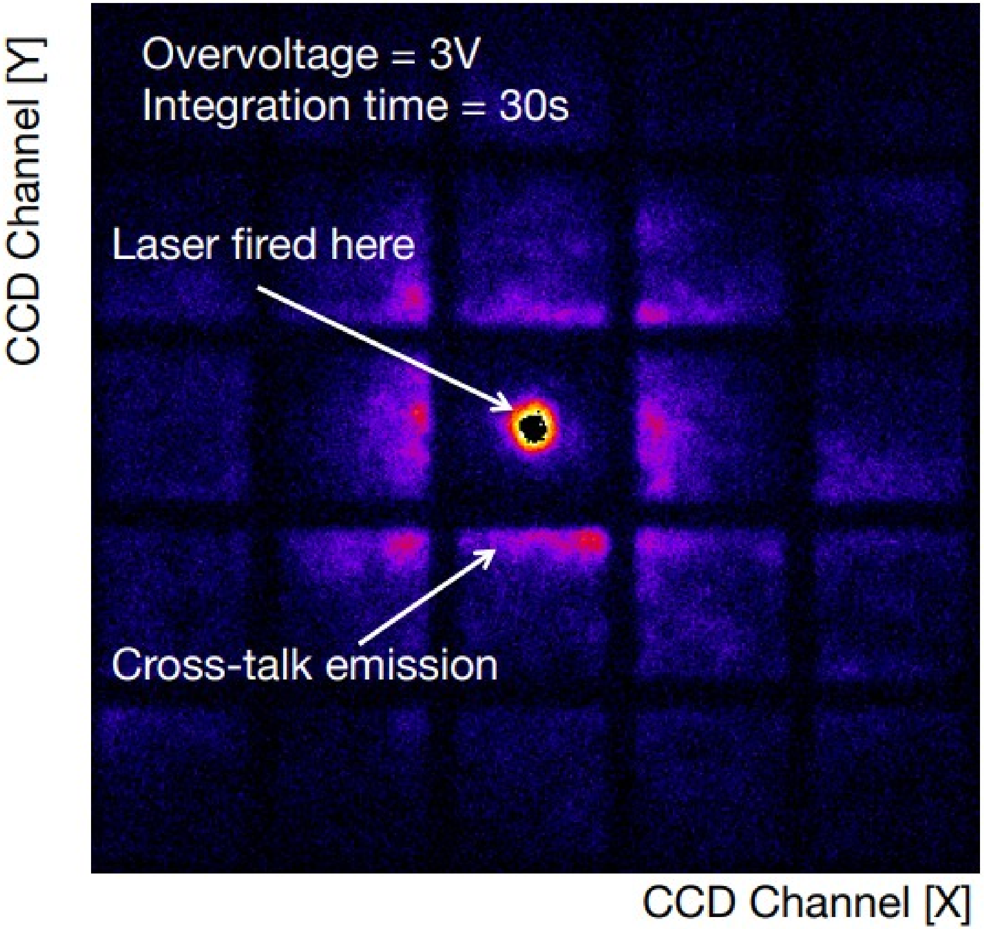




PD18 – Workshop on PhotoDetectors
D. Strom - Max Planck Institute
https://l.infn.it/strom

Light Emission Microscopy

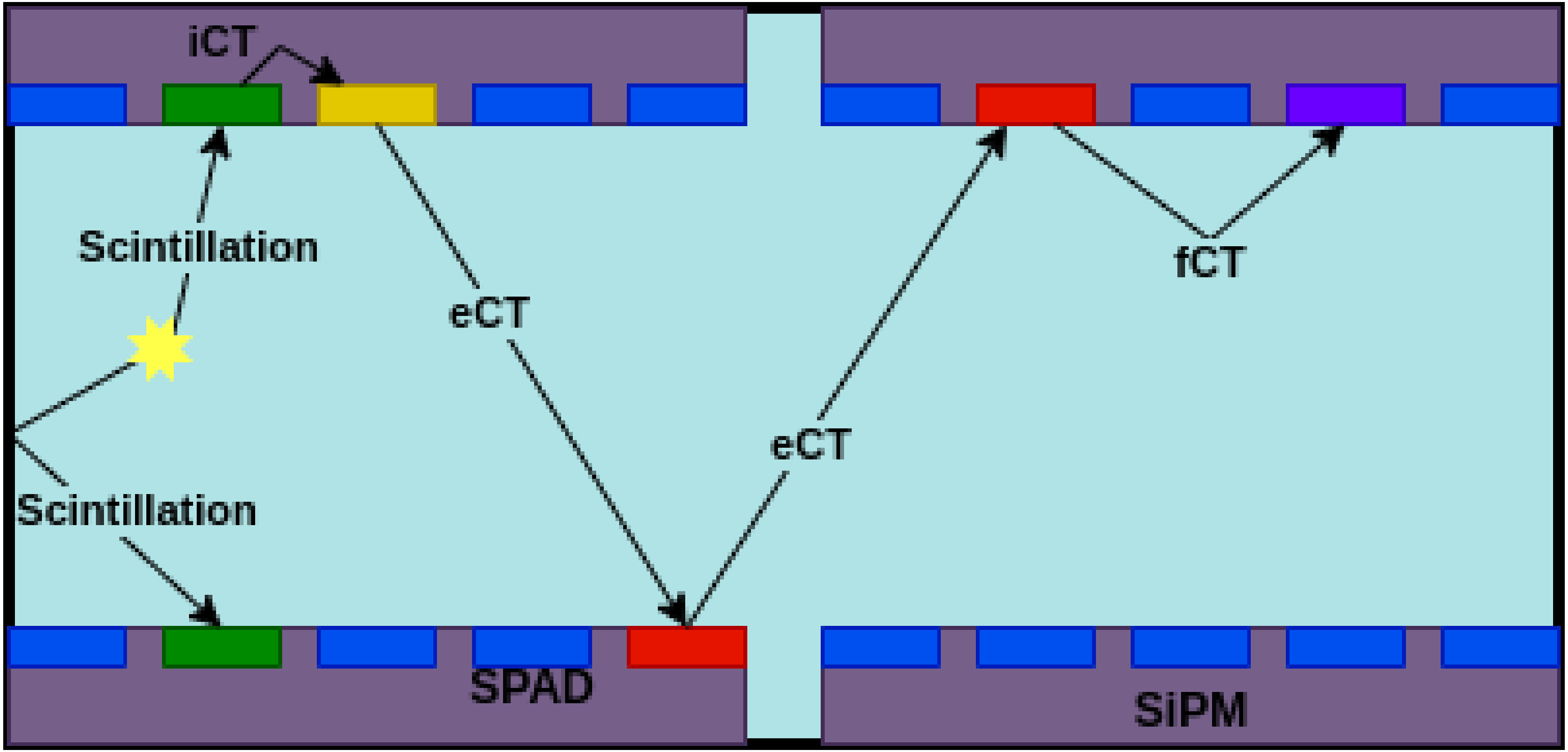




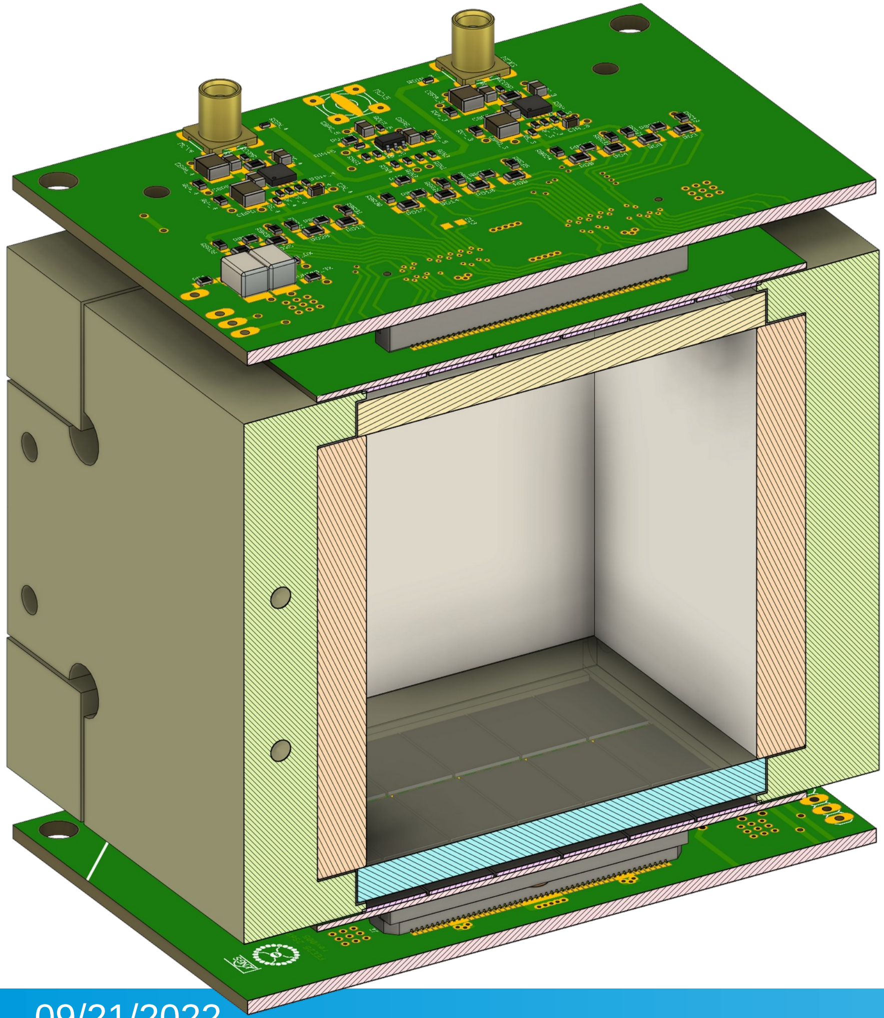
Hamamatsu LCT4

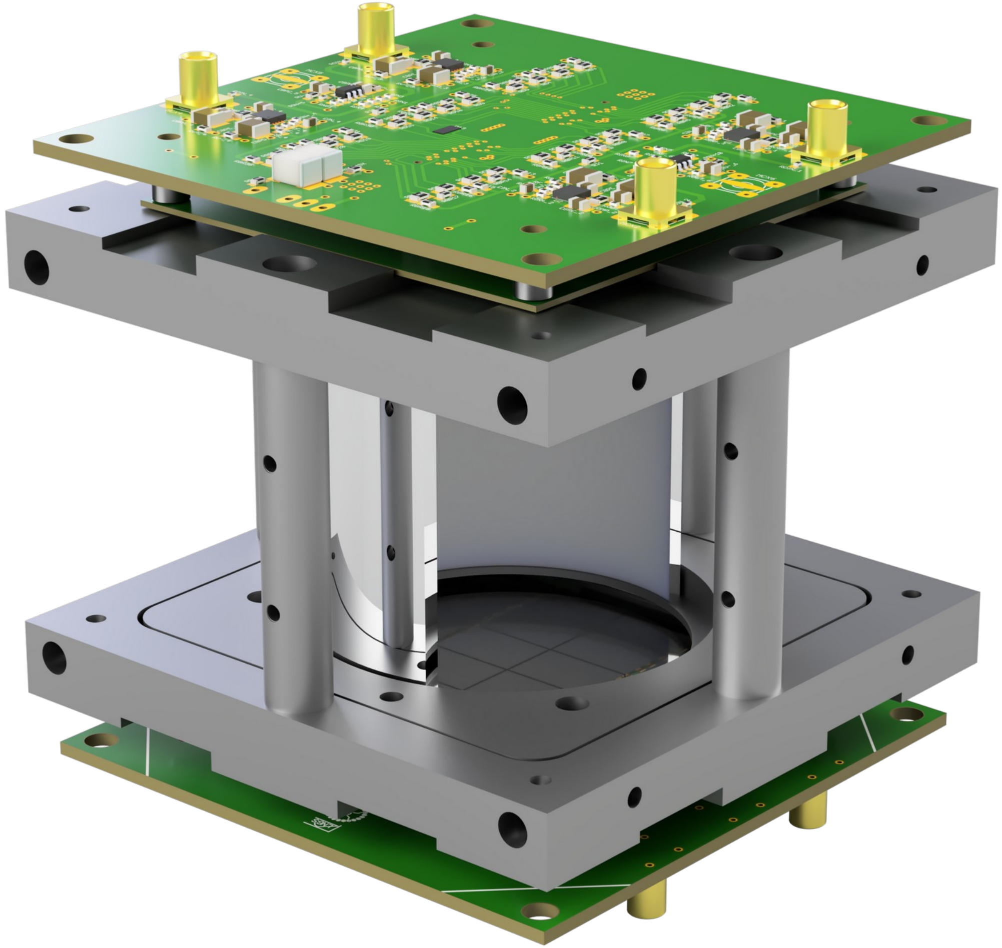
Cell size = 100 x 100 um2

Breakdown voltage = 51.89V

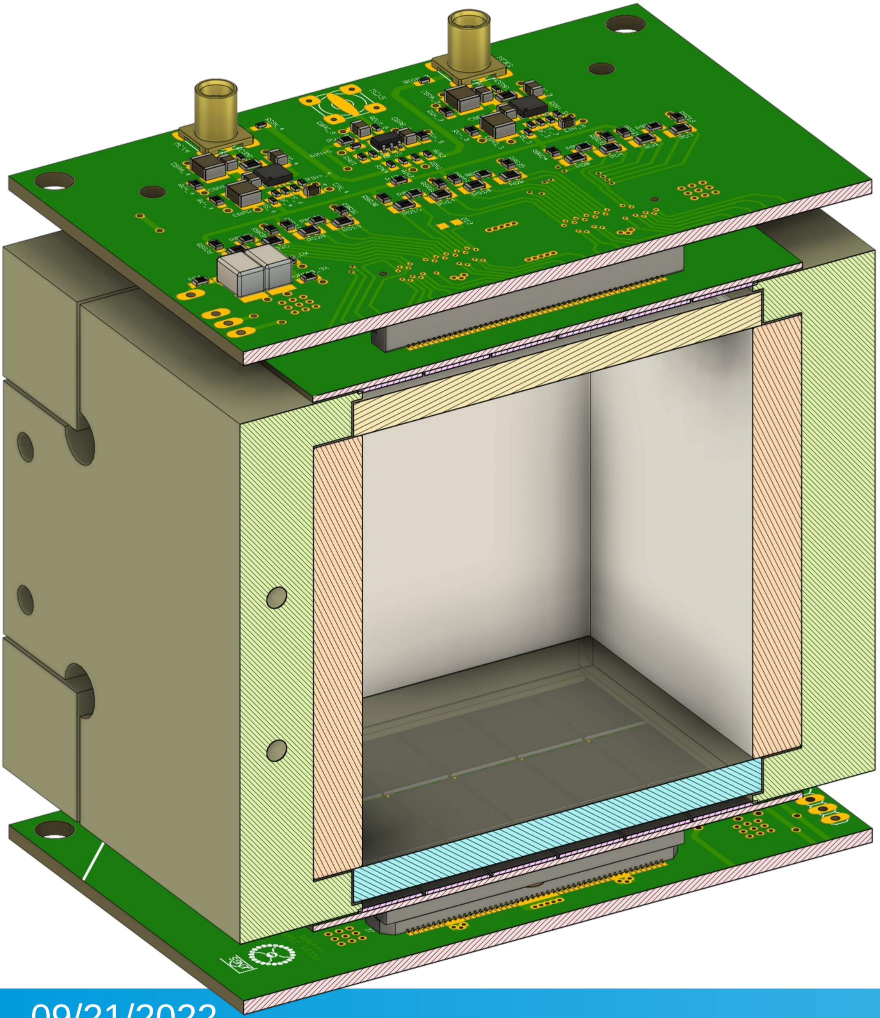


iCT
Scintillation
eCT
eCT
fCT
Scintillation
SPAD
SiPM

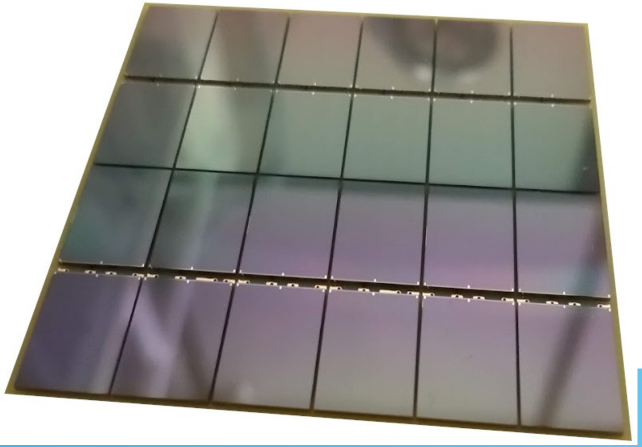




LAr chambers



- 5 x 5 x 5.1 cm^3 chamber
  - Lined with 3M reflective foil
  - Top & bottom window in fused silica
    - Collection efficiency ~ 85%
- Internal surfaces TPB evaporated
- Top & bottom 5x5 cm2 SiPM tiles
  - 88% SiPM coverage

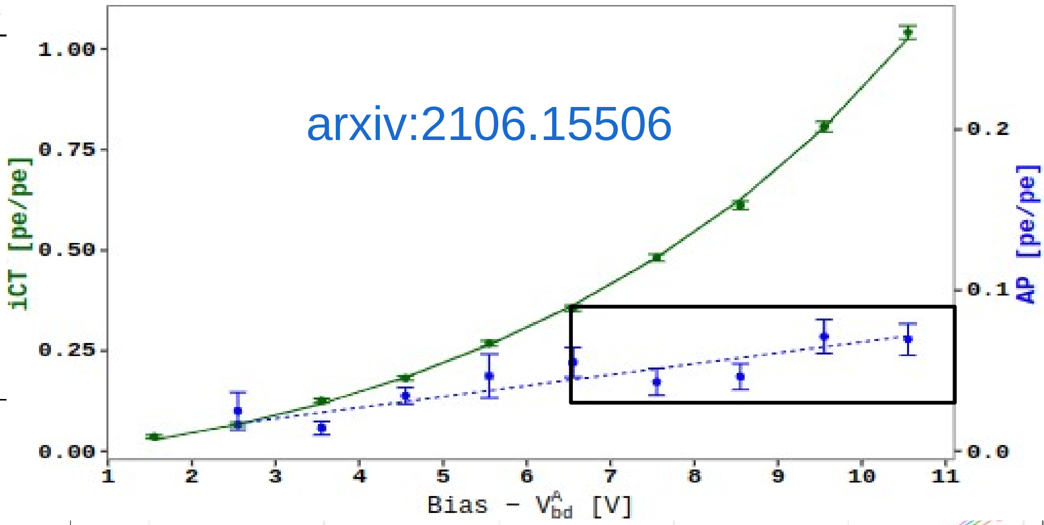


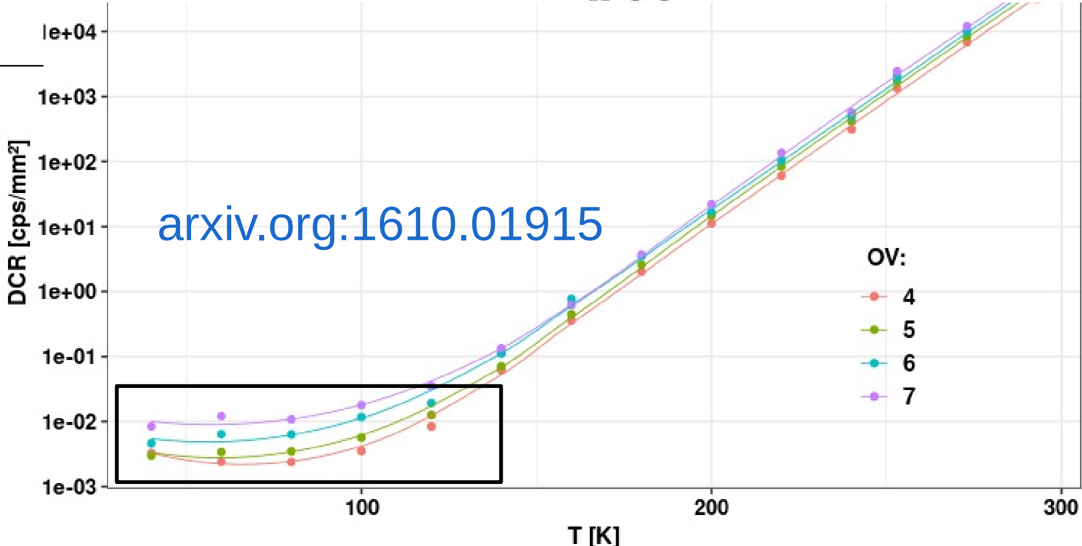
NUV-HD-Cryo

Group	Parameter at 77 K	NUV-HD-Cryo
SiPM	SiPM Size	$7.9 \times 11.7\,\mathrm{mm}^2$
	Cell Unit Size (S_c)	30 µm
	Cell Capacitance (C_d)	65 fF
	Number of cells (N_c)	100 k
	Quenching Resistance (R_q)	(3.0 ± 0.3) MΩ
	Breakdown Voltage (V_{bd})	(27.5 ± 0.3) V
	Maximum Over-voltage (OV_{MAX})	9 V
	Primary Recharge Time ($R_q \times C_d$)	180 ns
4s6p Tile	Aggregated Recharge Time (τ^+)	350 ns
	Current Peak ($I_p = \frac{1}{4}\, C_d \,/\, \tau$)	50 nA/OV
	Input noise density at 1 MHz	$9\,\mathrm{pA}/\sqrt{\mathrm{Hz}}$
	SNR with Matched Filter	>3.8/OV

arxiv:2201.04615

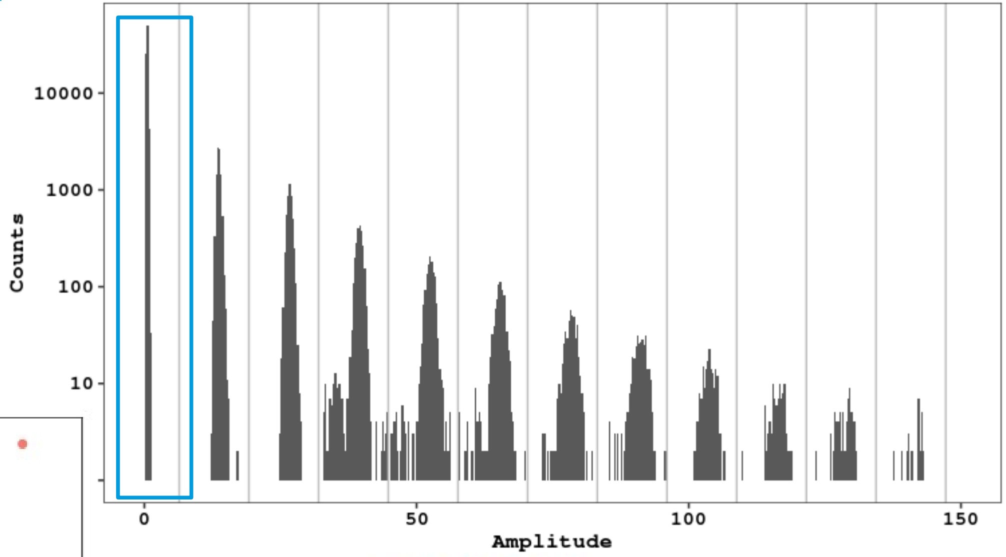
- Design in FBK
- Production in LFoundry





Internal cross-talk

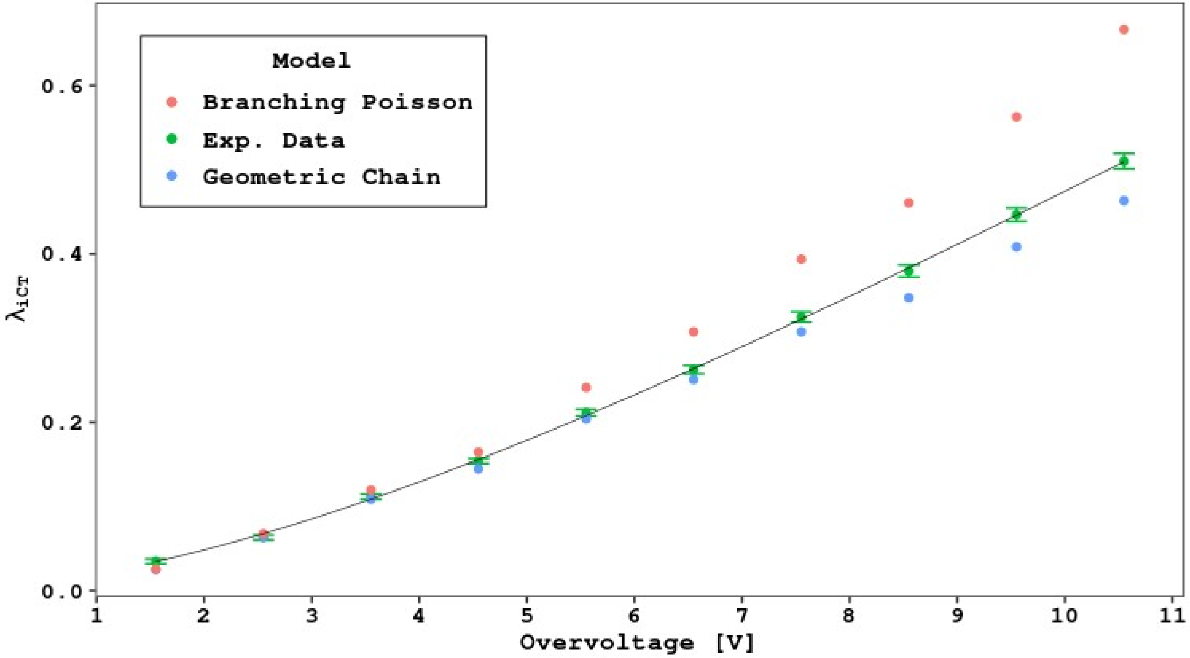
- 1 cm^2 NUV-HD-Cryo
- Measured in LN2
  - With laser
  - With high resolution pre-amplifier



$$\lambda_{iCT}^{OV} = 1 + \frac{ln(\mathcal{R}_0^{OV})}{\langle n \rangle}$$

$$\mathcal{R}_0 = e^{-\mu_{laser}}$$

$$\langle n \rangle = \frac{\mu_{laser}}{1 - \lambda_{ict}}$$



Internal cross-talk

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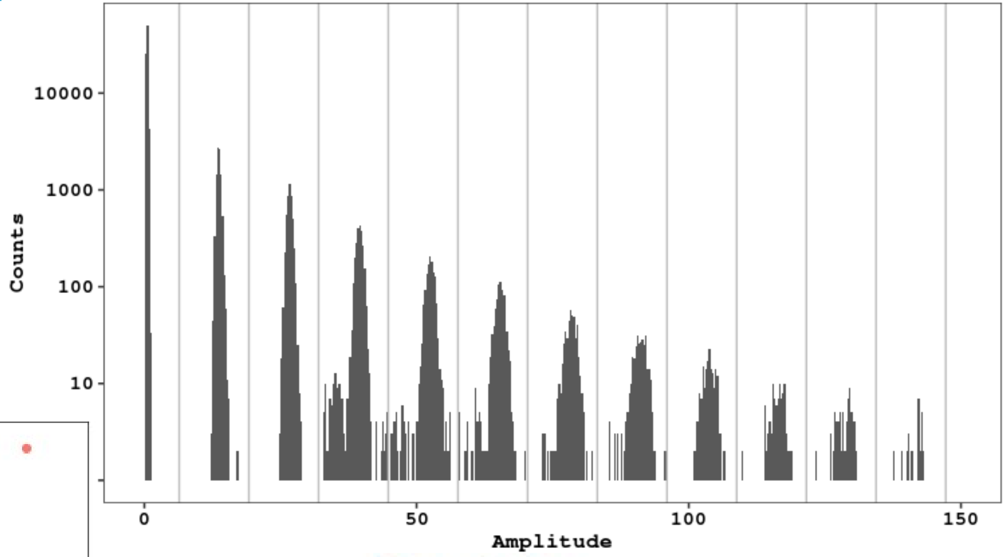
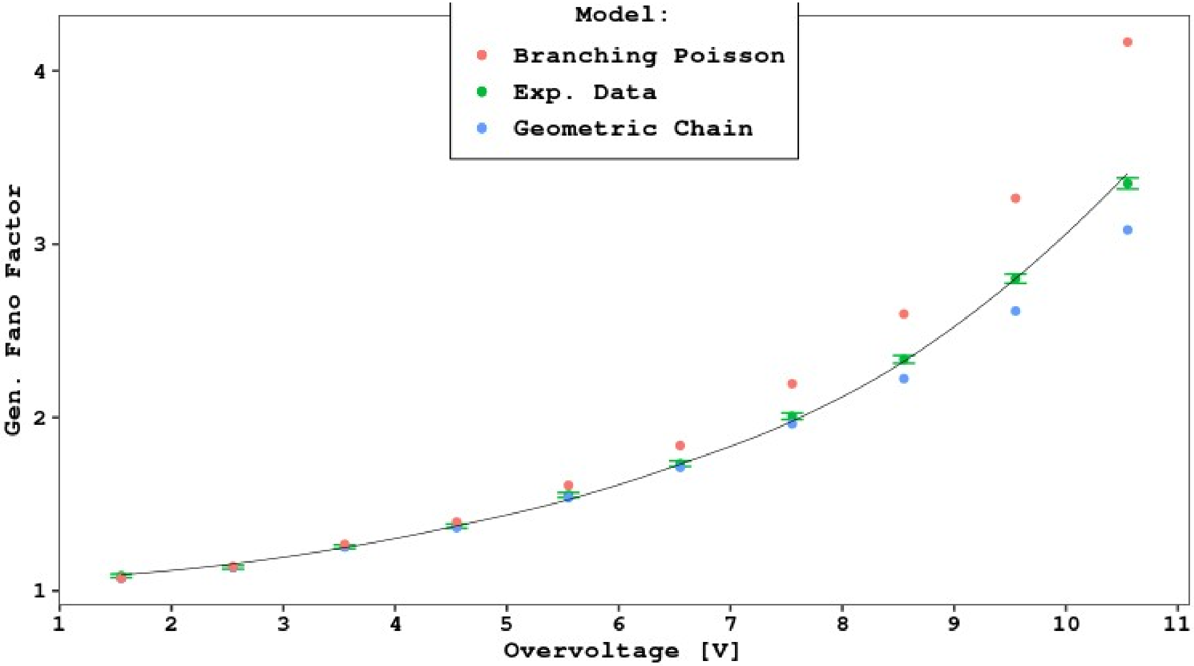


$$\mathcal{F}_{\mathrm{iCT}}^{\mathrm{OV}} = \frac{\mathrm{Var}[n]}{\langle n \rangle}$$

$$\lambda_{\mathrm{iCT}}(V) = \xi_{\mathrm{iCT}} \cdot (V - V_{bd}^{C}) \cdot P_T^h(V - V_{bd}^{A})$$

$$\mathcal{F}_{\mathrm{iCT}}(V) = \delta \cdot (1 - \lambda_{\mathrm{iCT}}(V))^{\alpha}$$

$$P_T^h(\Delta V) = 1 - e^{\frac{\Delta V}{-V_h}}$$

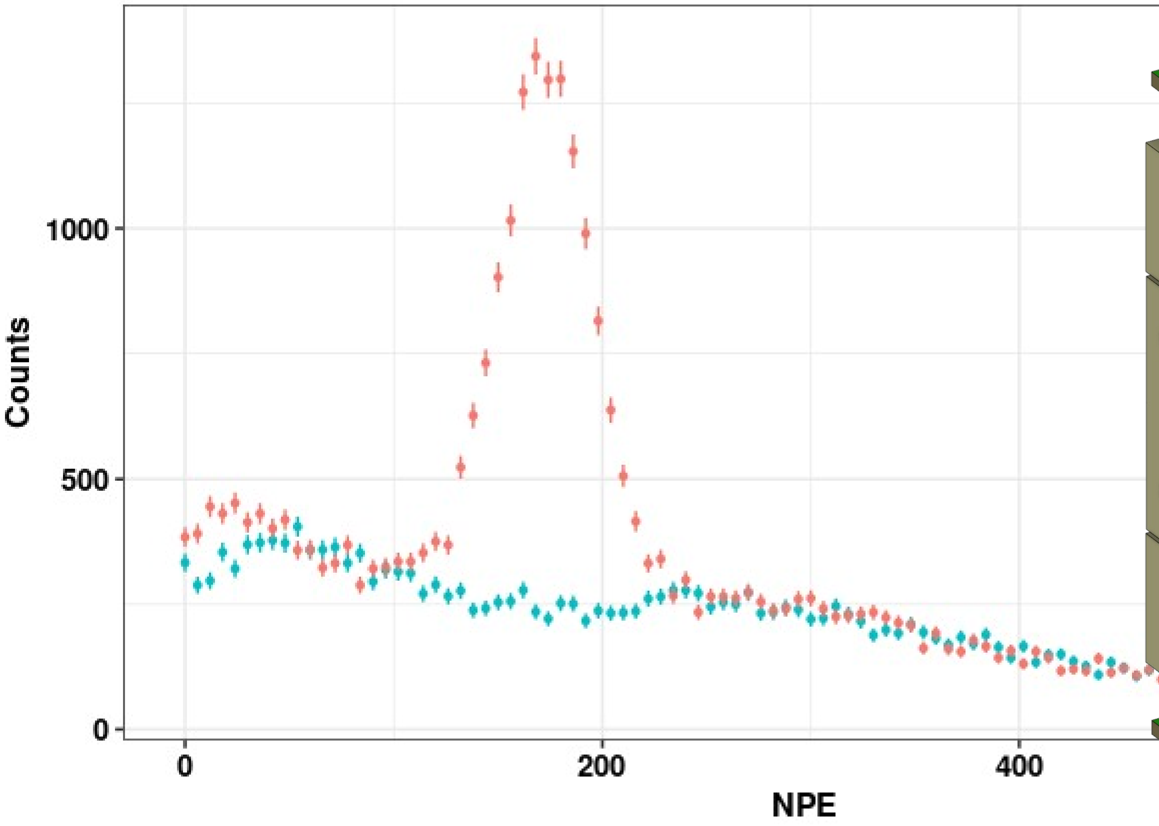


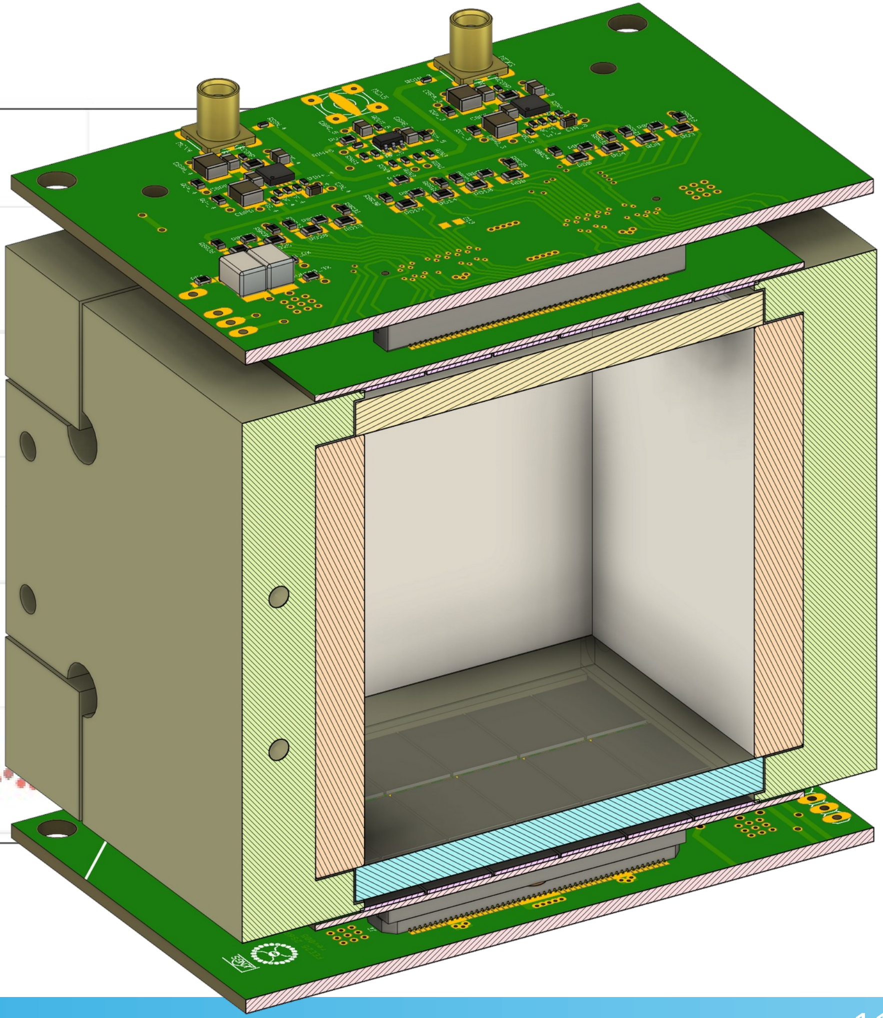
V_h = (5.4 ± 0.3) V and ξ_{iCT} = (53 ± 1)/kV

α = −1.68 ± 0.01 and δ = 1.031 ± 0.008

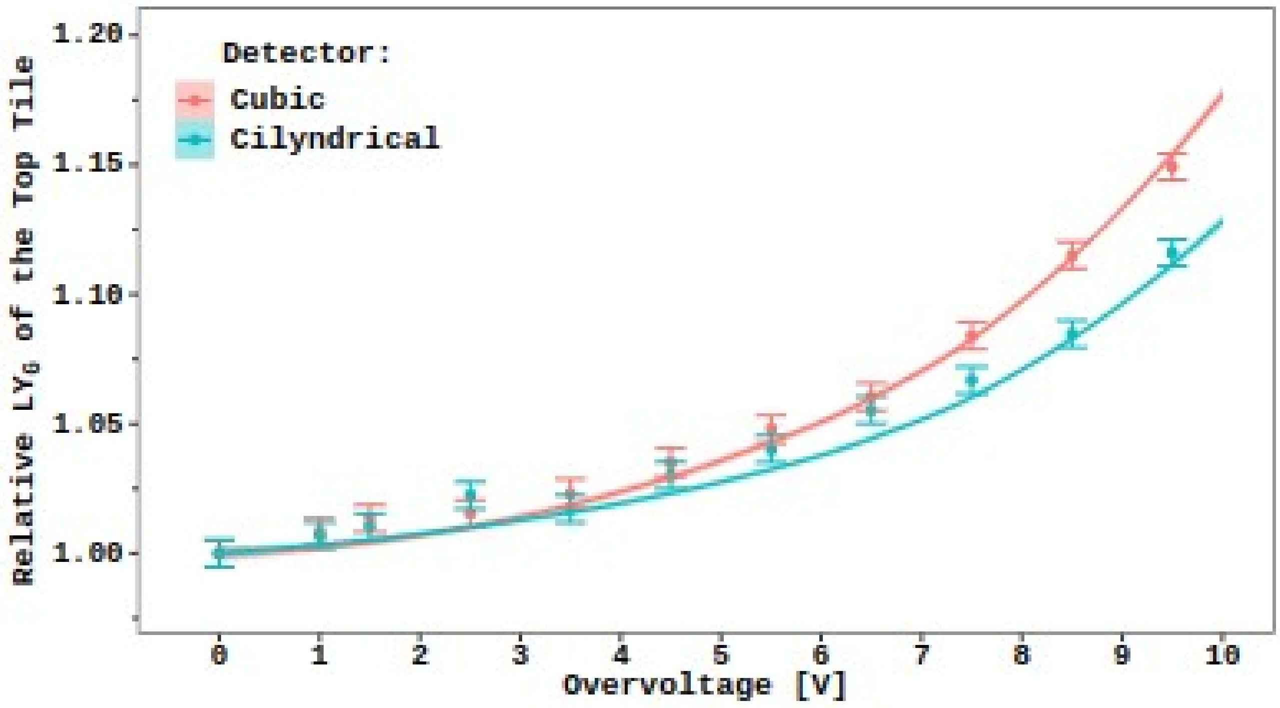
Light yield

^{241}Am and ^{83m}Kr sources

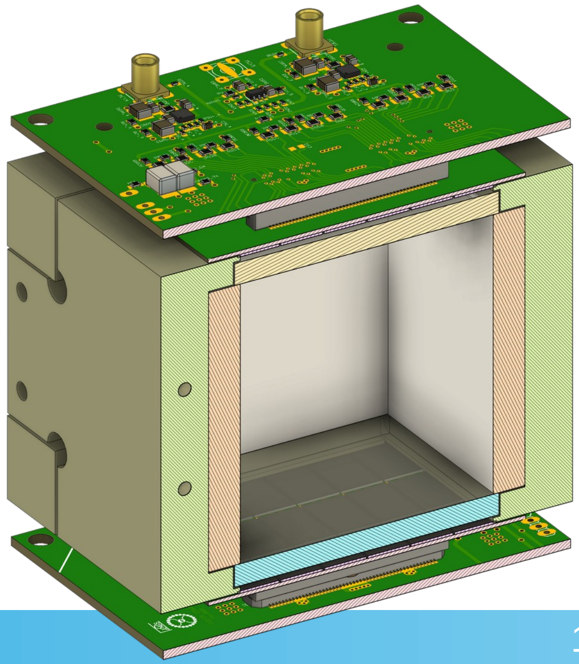




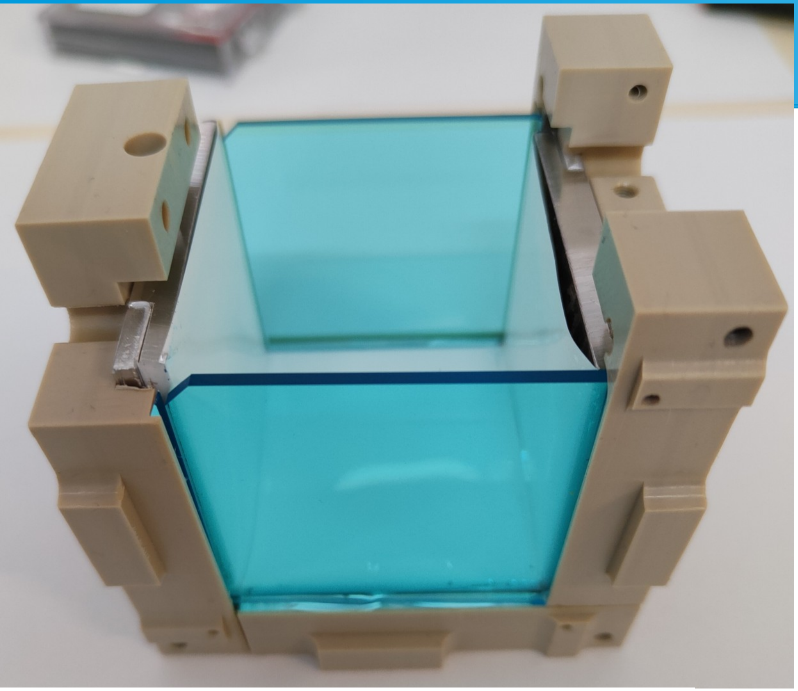
Asymmetric setup

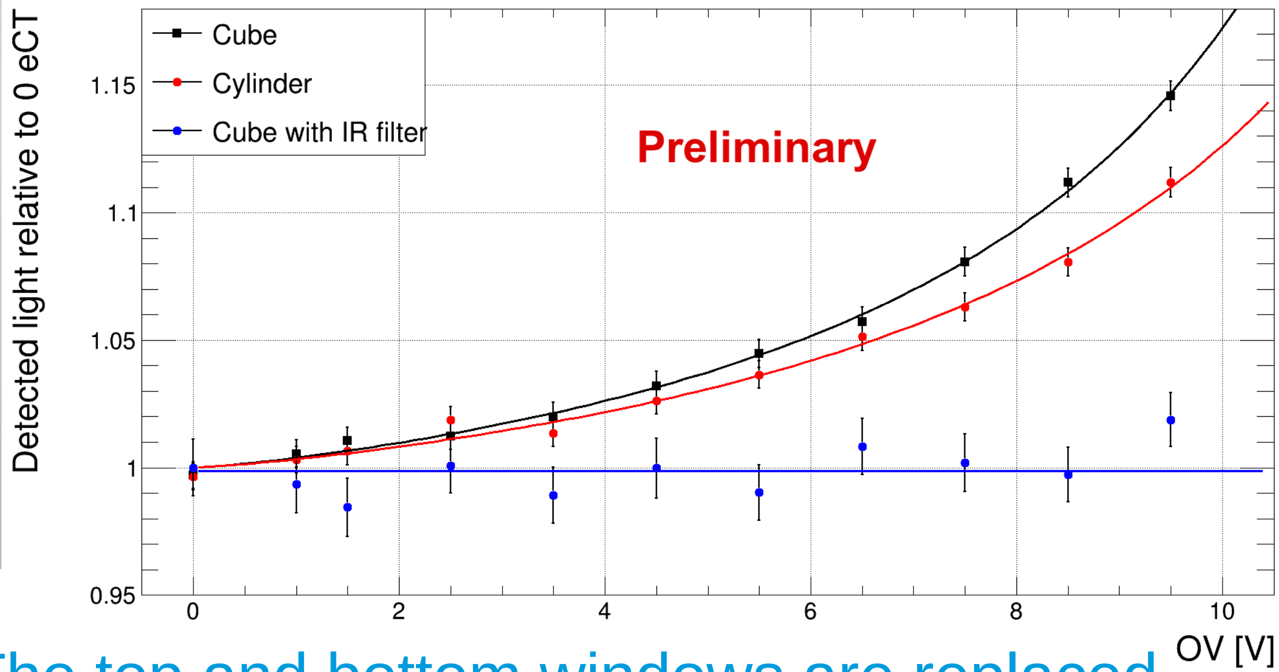


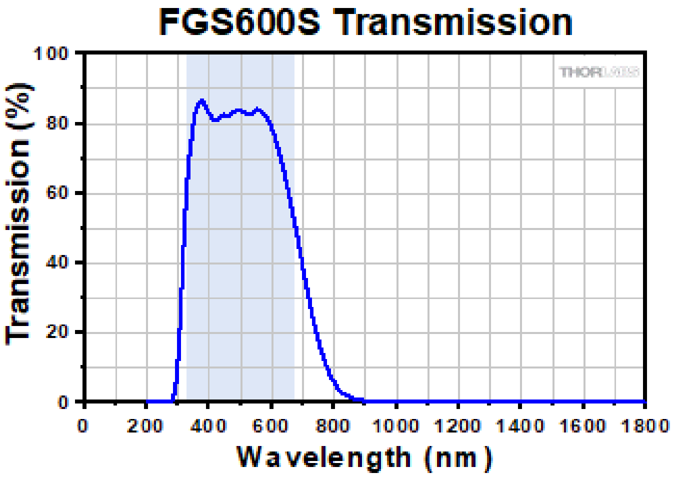
- Relative LY of TOP tile
  - Top tile at 8.5 OV
  - Bottom tile [0, 9.5] OV
- We expect a flat line



Is really eCT?

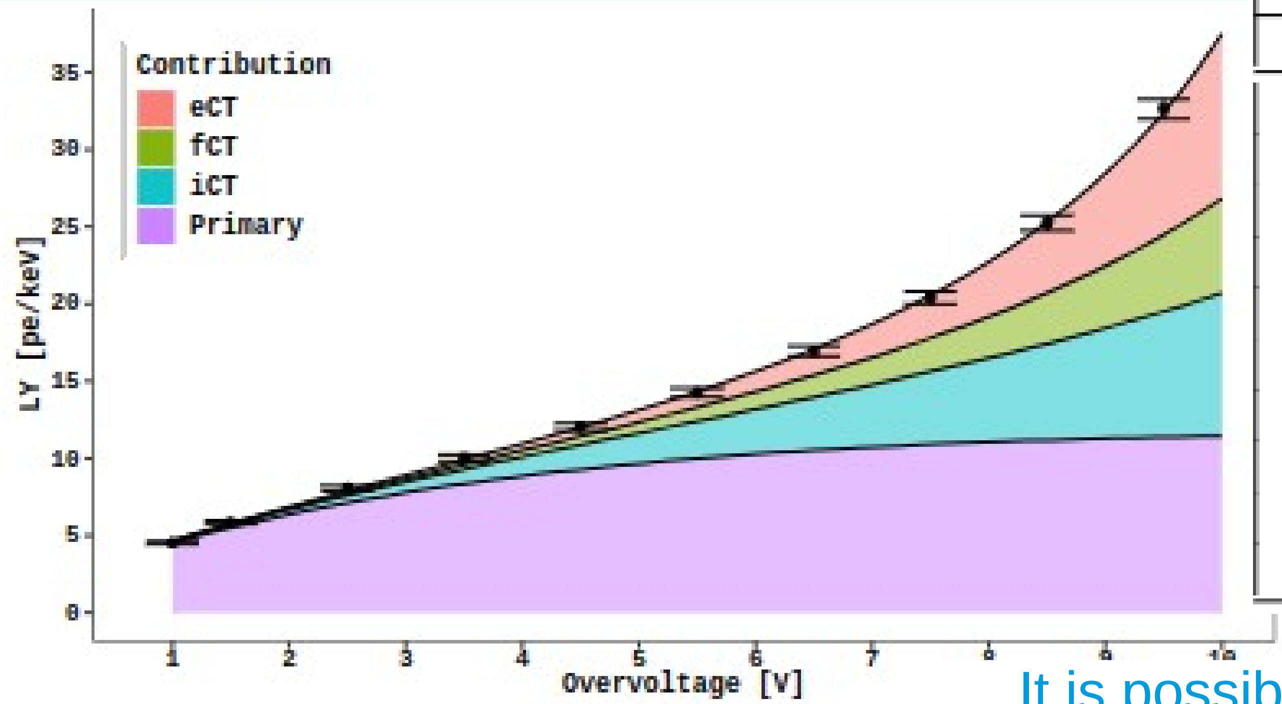






- The top and bottom windows are replaced with optical filters
  - Optical cross-talk is peaked in RED & IR
- We get the flat line → eCT evidence

Symmetric setup



Bias	Asymmetric	
Algorithm	tMC	
$\bar{n}^{\rm pe}$	13.0 ± 0.5	12.1 ± 0.3
ζ	0.34 ± 0.05	0.34 ± 0.10
V_h	5.4	5.4
V_e	1.0 ± 0.1	1.0 ± 0.1
$\xi_{\rm iCT}$	53	53
$\xi_{\rm fCT}$	15 ± 1	15
$\xi_{\rm eCT}$	7 ± 1	7 ± 1
α		
δ^*		
$\chi^2/n.d.f.$	4 / 5	3 / 6

$$P_{\rm PDE}(V) = \zeta \cdot P_T^e(V - V_{bd}^A) + (1-\zeta) \cdot P_T^h(V - V_{bd}^A)$$

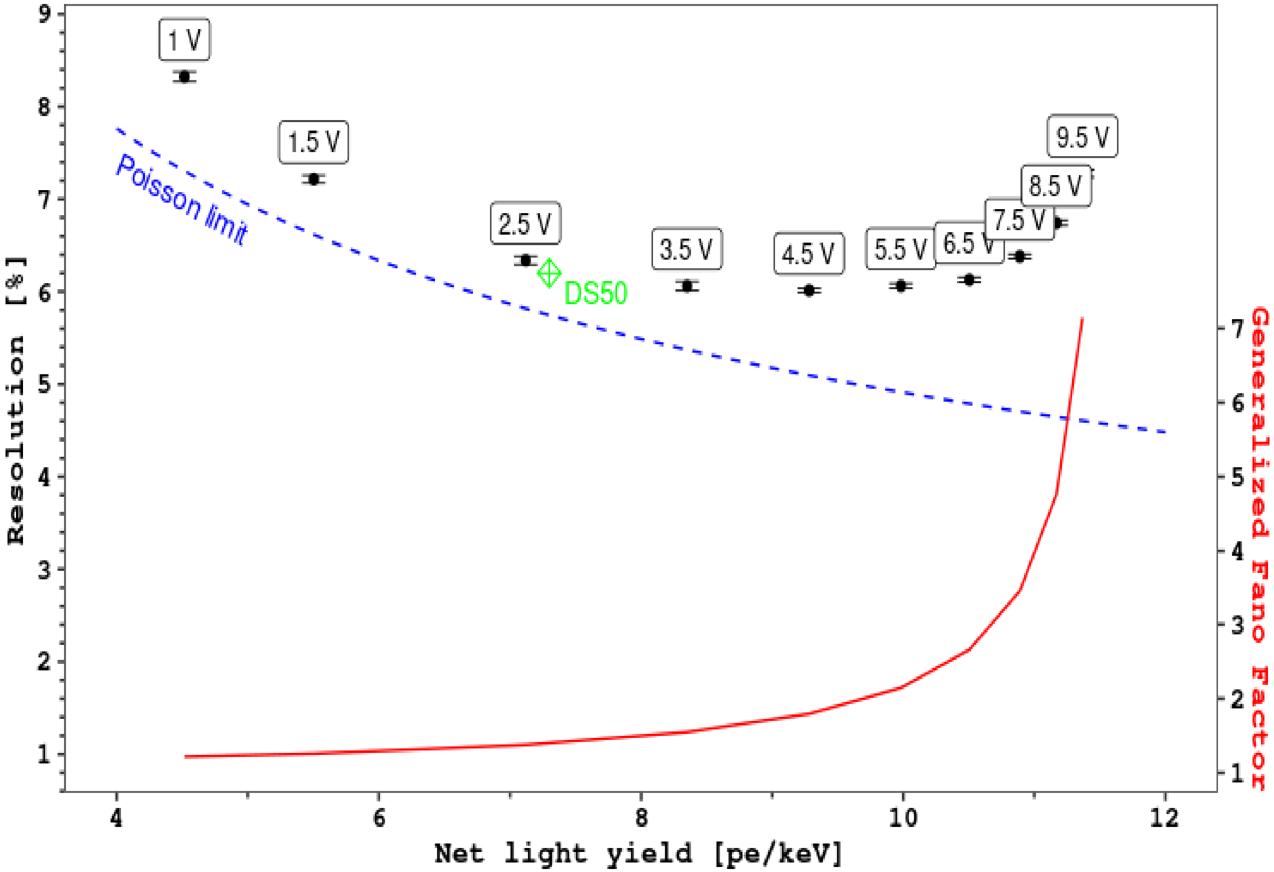
$$\lambda_{\rm xCT}(V_S, V_T) = \xi_x \cdot (V_S - V_{bd}^C) \cdot P_T^h(V_T - V_{bd}^A)$$

$$\mathrm{LY}_G(V) = \frac{\bar{n}^{\rm pe} \cdot P_{\rm PDE}(V)}{1 - (\lambda_{\rm iCT}(V) + \lambda_{\rm fCT}(V) + \lambda_{\rm eCT}(V))}$$

It is possible to model the gross LY

- Triggering probabilities for h^+ & e^-
- Photon interaction probability
- Optical cross-talk
- Net asymptotic LY

Resolution

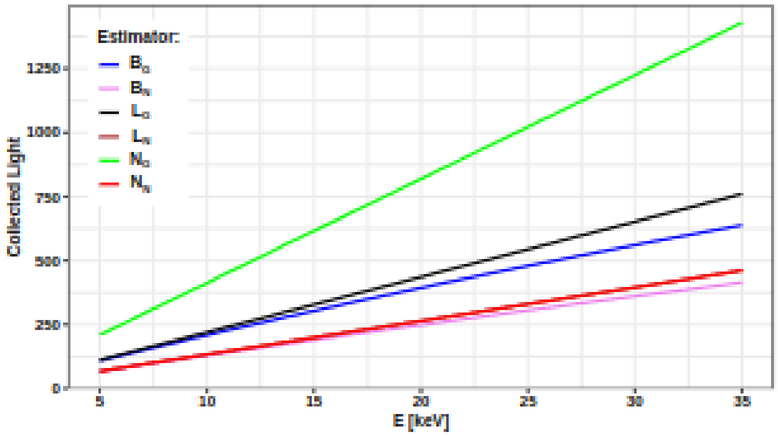


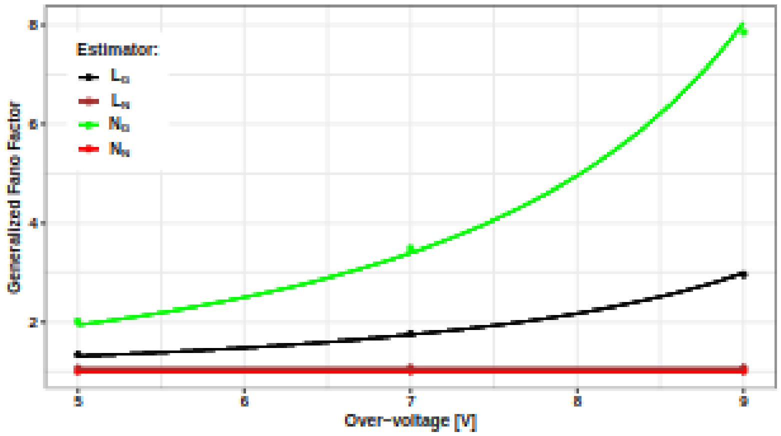
- Correlated noise photons
  - At 9.5 OV 23 over 12
  - Worser resolution
    - Fluctuation of oCT pe
- Fano factor explodes above 4-5 OV

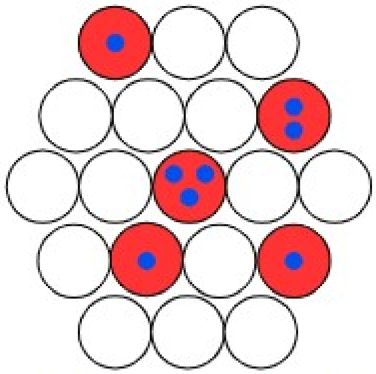
On larger detectors?

- Simulated a TPC with ~2000 10x10 cm^2 SiPM tiles
- With an exposure of 200 t y
- Using a toy Monte Carlo that includes only the SiPM oCT models
  - Optics and disuniformities are not simulated
  - 3 10^{10} e^- events simulated

arxiv:2209.09224



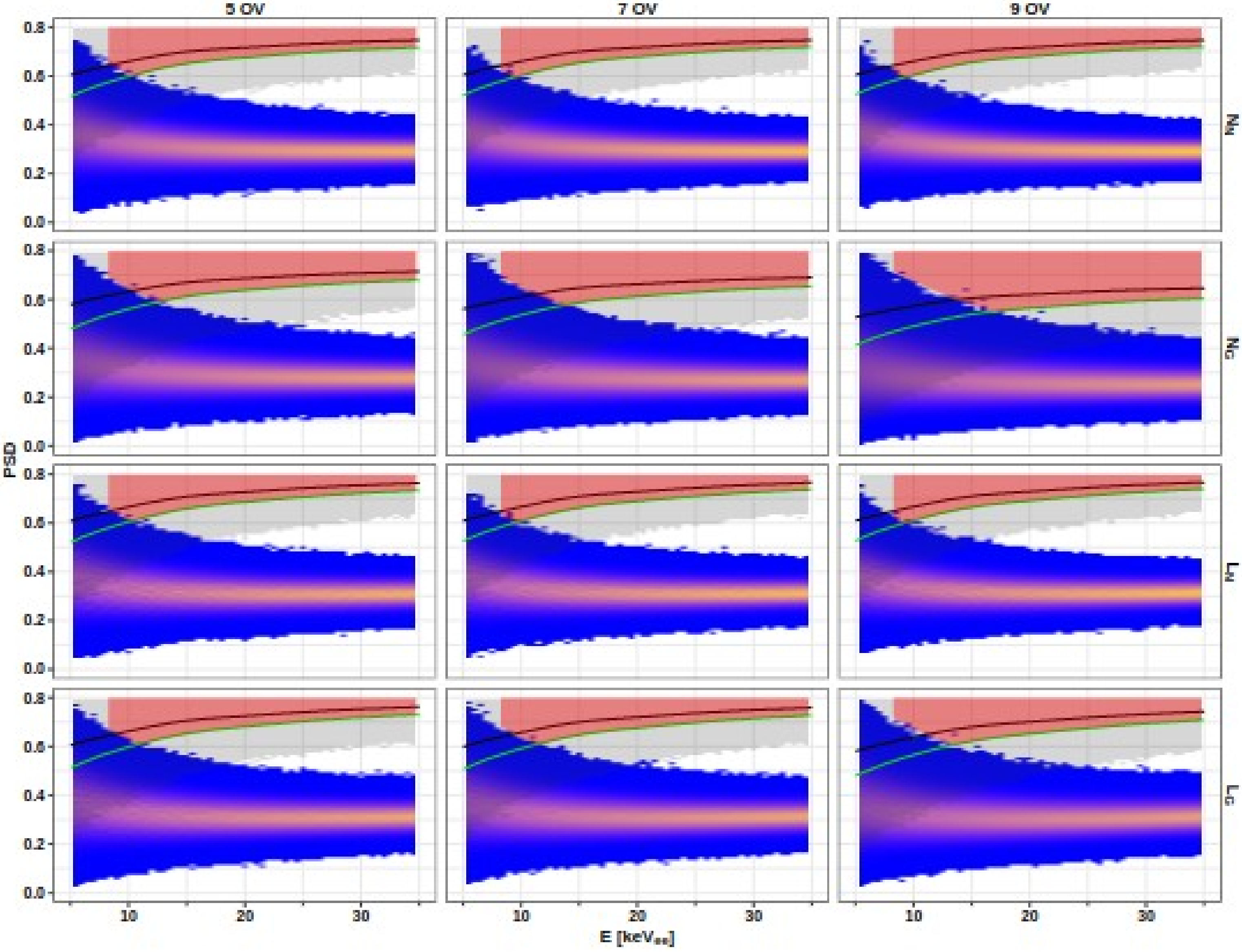




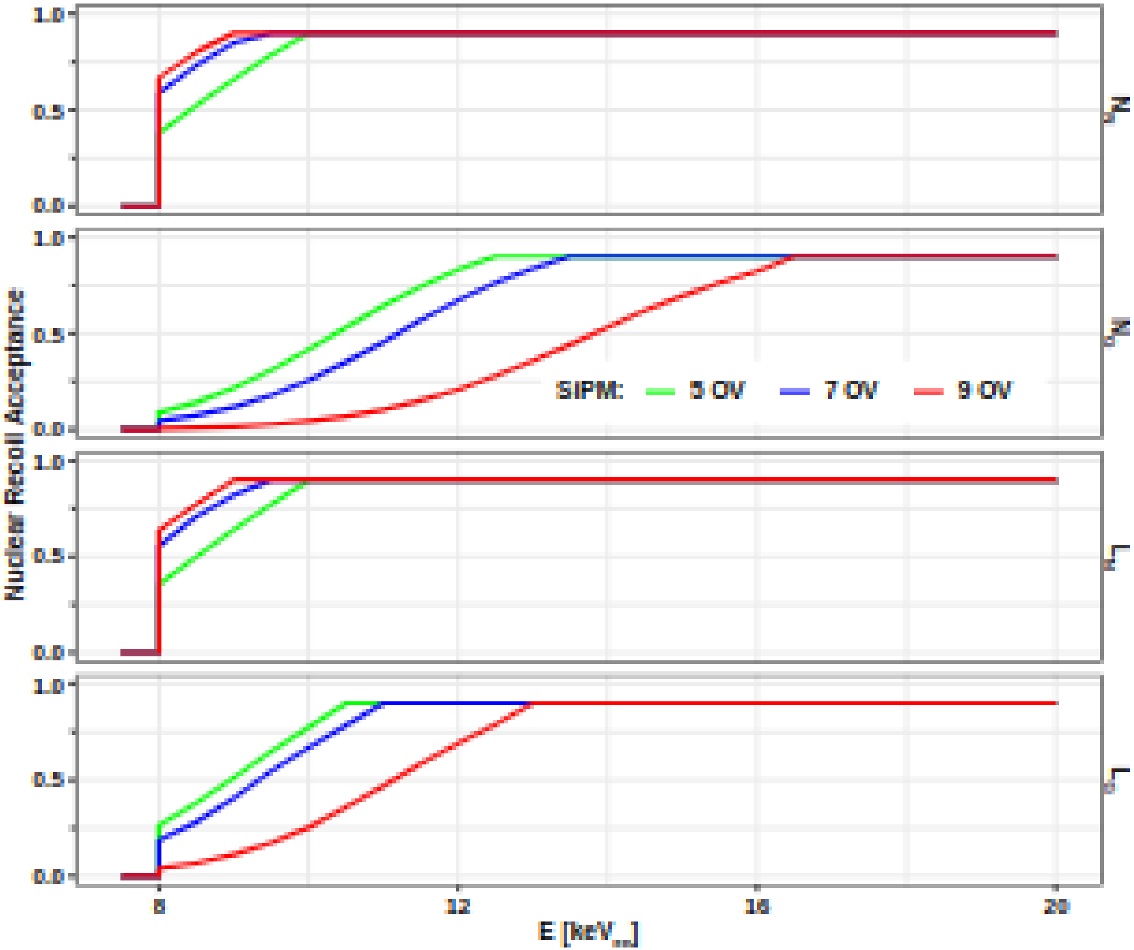
$$L_N = -N_{\mathrm{pd}} \ln\left(1 - \frac{B_N}{N_{\mathrm{pd}}}\right)$$

PSD

- $3\ 10^{10}$ e^- blue-gold
- 10^6 n grey
  - Black = 50%
  - Green = 90%
- Acceptance in red
  - 10 events

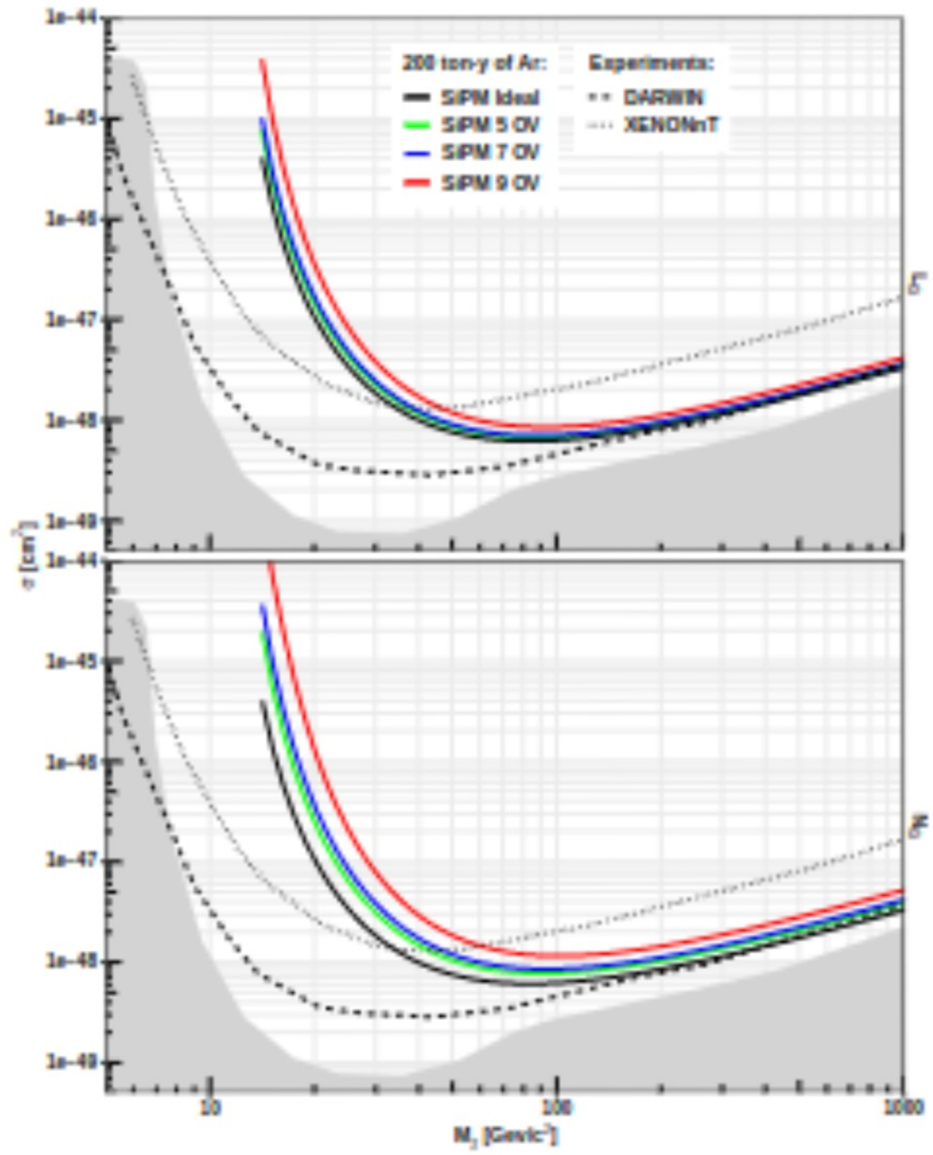


Acceptance regions



- 10 e^- in 3 10^{10} events
  - Leakage 0.1 in 200 t y
    - 10 e- in the acceptance
  - Using Uar (1400 depletion)

- Binomial energy estimators much better
  - ICT is not accounted



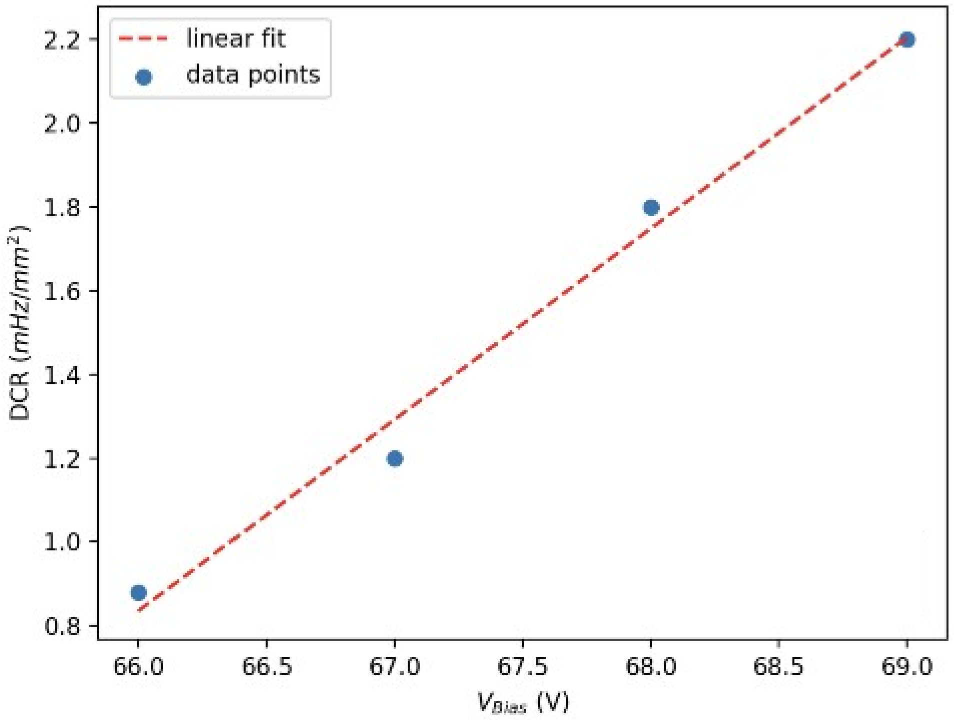
Projected sensitivity

- A note of caution
  - Only oCT and AP are simulated
    - Real experiments would include more disuiniformities
  - The projected sensitivity is over-estimated by a factor 2
- An opportune analysis algorithm can mitigate the iCT contribution
  - That is dominant
  - But eCT remains
  - And asymmetric events will be a problem

Conclusions

- The eCT in SiPM is a real effect
  - With possible large effects on experiments
    - A case of a Ar-based experiment was shown
  - It is important to account eCT in reflective chambers

- Solutions are available to reduce it
  - Analysis
  - Fully opaque tranches
    - FBK achieved few % of iCT with metal filled tranches
  - Optical filters to absorb long wavelengths


linear fit
data points
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
DCR (mHz/mm²)
66.0
66.5
67.0
67.5
68.0
68.5
69.0
V_Bias (V)