SiPM readout of Xenoscope

XeSAT 2022

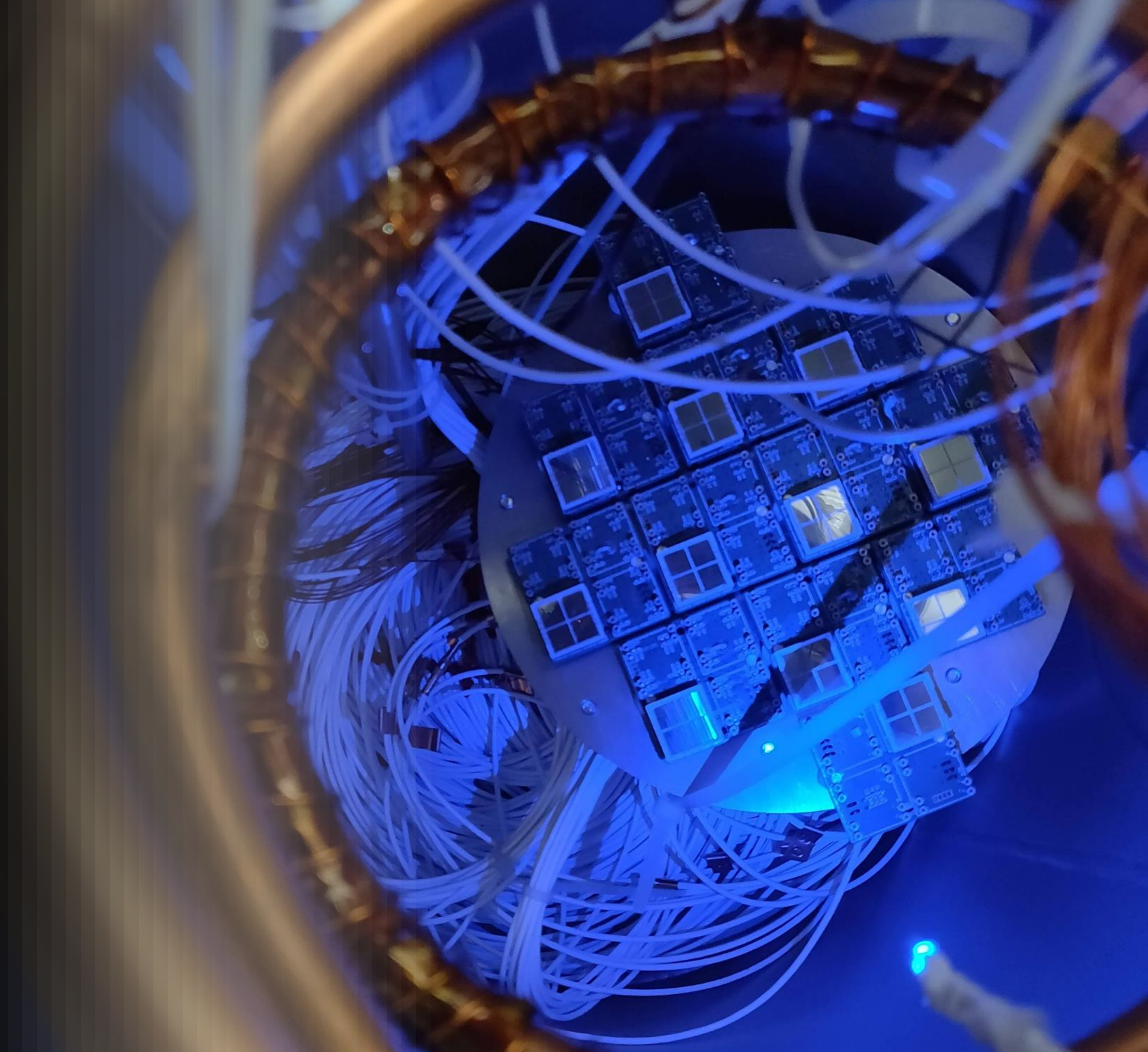
University of Coimbra

Ricardo Peres

24/05/2022

DARWIN

Universität Zürich UZH



Xenoscope - a full-scale vertical DARWIN demonstrator

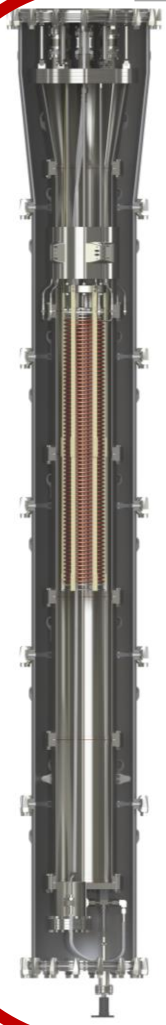
University of Zurich[UZH]

erc European Research Council

DARWIN

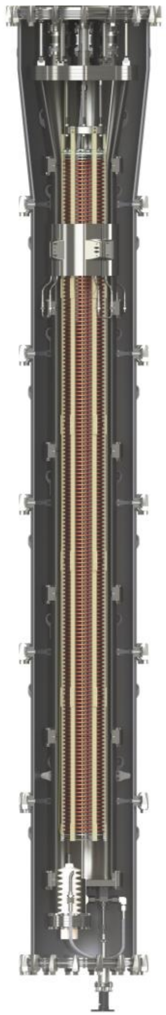
52.5 cm Purity Monitor

- 52.5 cm single phase PM
- Signal from Xe flash-lamp shining on a photocathode
- Direct charge readout from electrodes



1 m TPC

- 1 m dual-phase time projection chamber
- Electron signal from the photocathode
- Proportional scintillation light readout with a SiPM tiled array



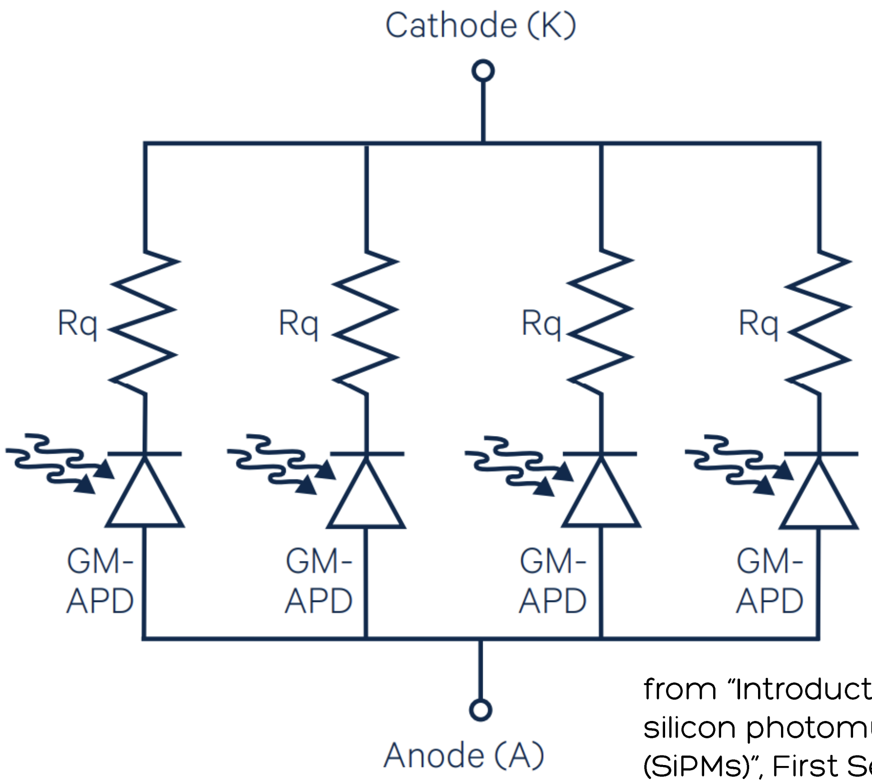
2.6 m TPC

- Final drift length goal.
- Electron signal from photocathode and possibly internal and external sources

See Prof. Baudis' talk from earlier today

Light detection with SiPMs

- Avalanche Photo Diodes (APDs) with a doped PN junction in a silicon wafer
- Each APD is set in Geiger-mode and proportionality achieved by the number of triggered cells
- In recent years VUV sensitive SiPMs were made accessible in large form factors

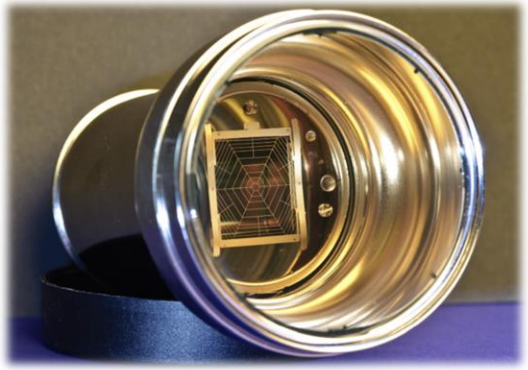


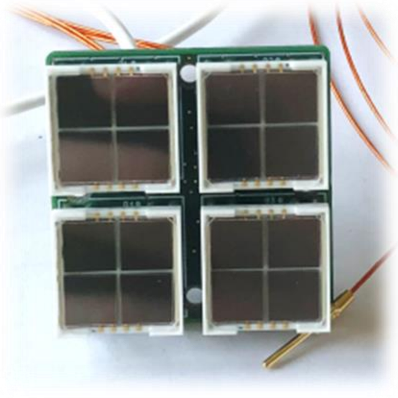
from "Introduction to silicon photomultipliers (SiPMs)", First Sensor

Light detection with SiPMs

- Are SiPMs the photosensors of the next generation LXe DM experiment?

	PMTs	SiPMs
Bias voltage	1-2 kV	~50 V
QE @175 nm	~35%	~30%
SPE	30%	4-6%
DCR	0.01 Hz/mm^2	O(1) Hz/mm^2
Radioactivity	Higher per area	Lower per area (excluding readout)





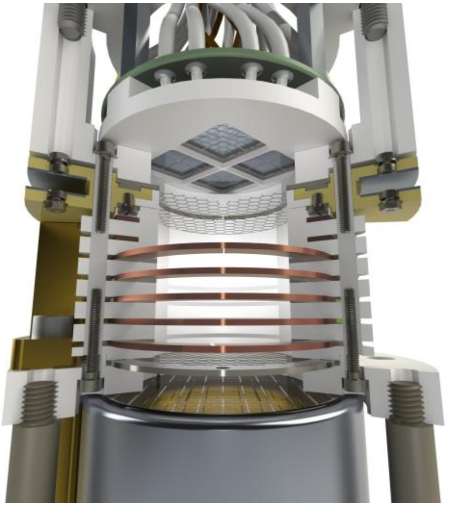
SiPMs in a dual-phase LXe TPC - Xurich II

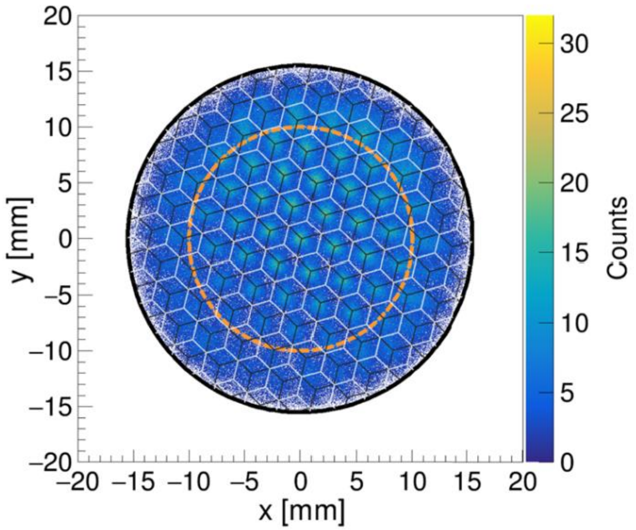
- LXe dual-phase TPC with 31 mm x 31 mm (diameter x height)
- Operated with a 2" PMT on the bottom, 16 VUV MPPCs on the top.
- Position reconstruction (center-of-gravity) with ~1.5 mm resolution
- Detector calibrated with ^{83m}Kr and ^{37}Ar

(https://doi.org/10.1140/epjc/s10052-020-8031-6)

- New measurement of W-value in Lxe

(https://doi.org/10.1140/epjc/s10052-021-09834-x)

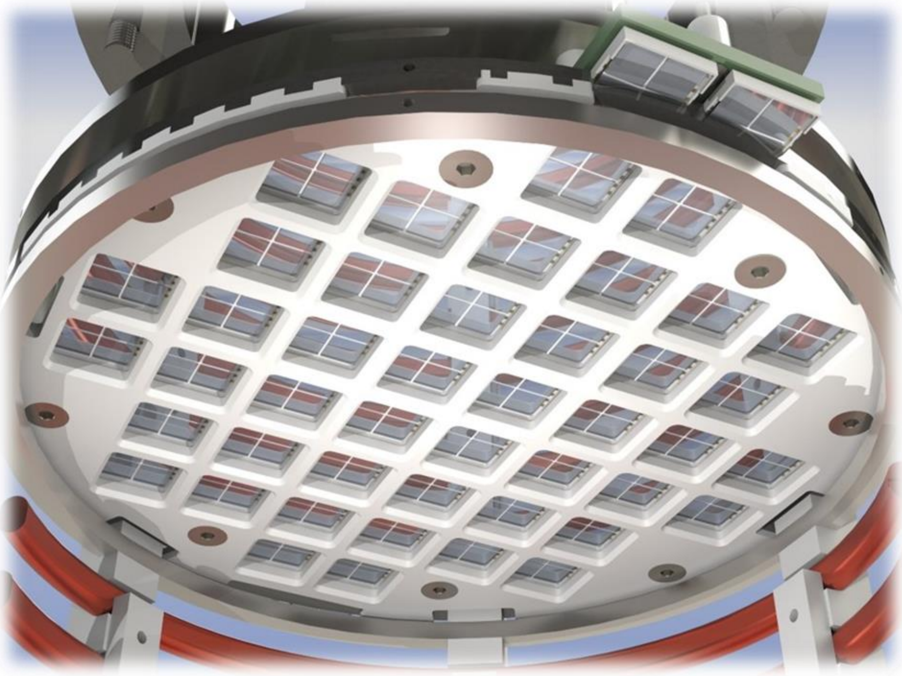




See K. Thieme's talk (Thu. 14h)

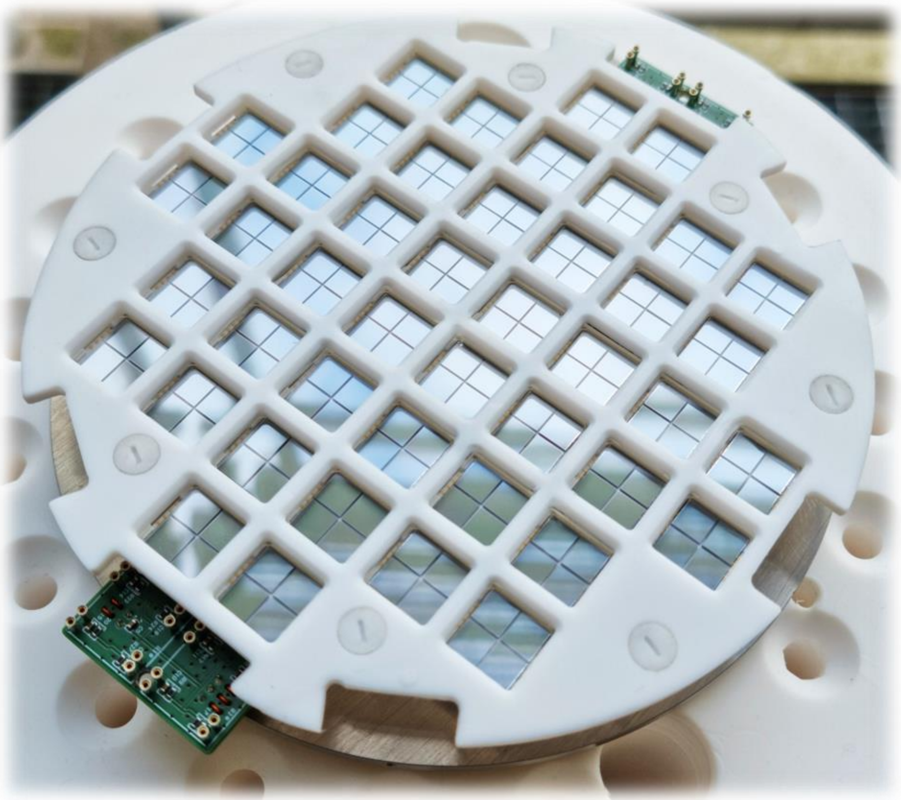
The Top Array of Xenoscope

- Dimensions:
  - Back plate: ø160 mm
  - TPC/active area: ø150 mm
- Testing SiPMs on a large-scale dual-phase LXe TPC
- Detect proportional scintillation light signal from drifted electrons:
  - Xe lamp on photocathode
  - Muons with coincidence trigger
- Total of 48 12x12 mm^2 VUV4 MMPCs from Hamamatsu
  - 192 6x6 mm^2 SiPMs
  - ~2.76 x 10^6 APD cells



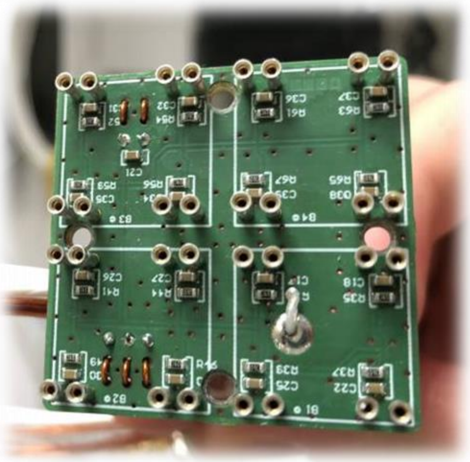
The Top Array of Xenoscope

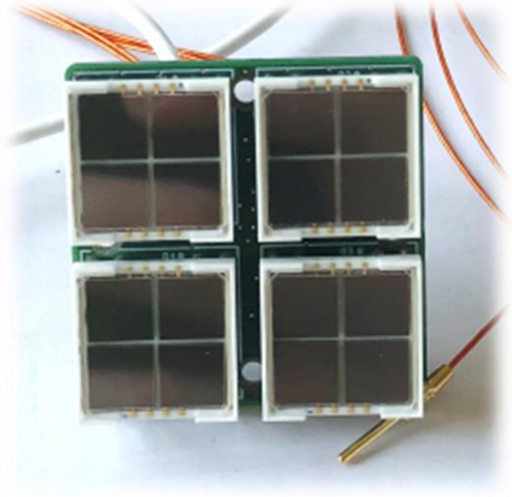
- Dimensions:
  - Back plate: ⌀160 mm
  - TPC/active area: ⌀150 mm
- Testing SiPMs on a large-scale dual-phase LXe TPC
- Detect proportional scintillation light signal from drifted electrons:
  - Xe lamp on photocathode
  - Muons with coincidence trigger
- Total of 48 12x12 mm^2 VUV4 MMPCs from Hamamatsu
  - 192 6x6 mm^2 SiPMs
  - ~ 2.76 x 10^6 APD cells

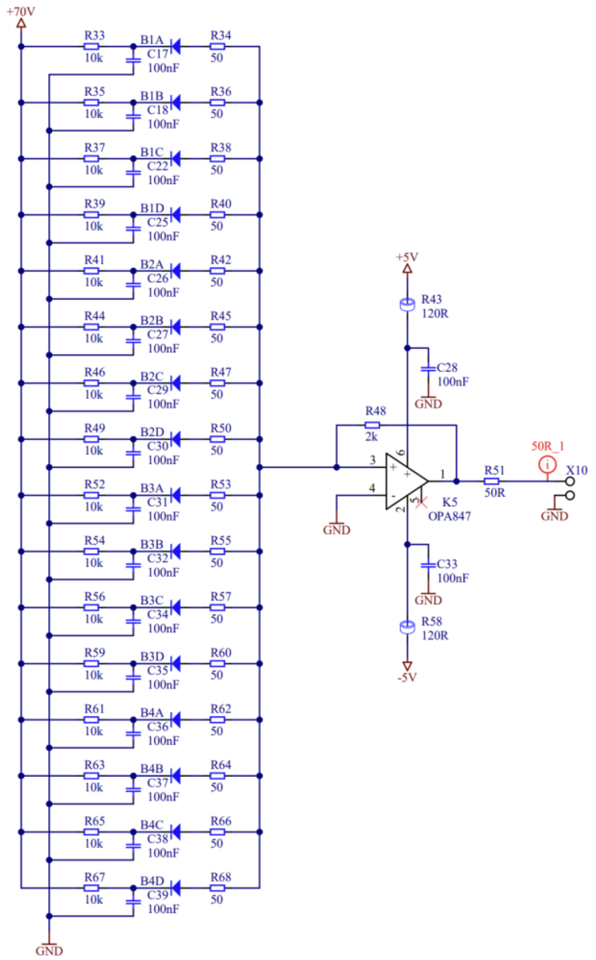


Hamamatsu VUV4 12x12 mm^2 MPPC

- Latest generation of VUV SiPMs from Hamamatsu
- 50-µm pitch cells
- Tiled array with 4 12x12 mm^2 MPPCs
- Summed readout (parallel) with a x20 pre-amplifier
- Known gain of each sensor allows gain-matching within tiles

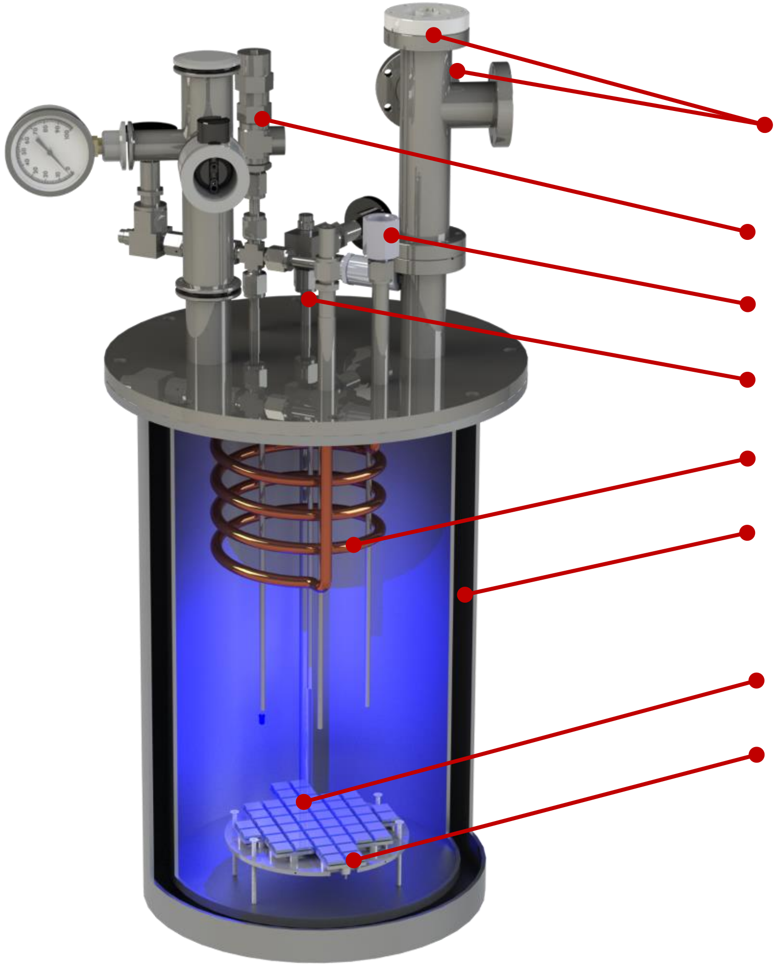






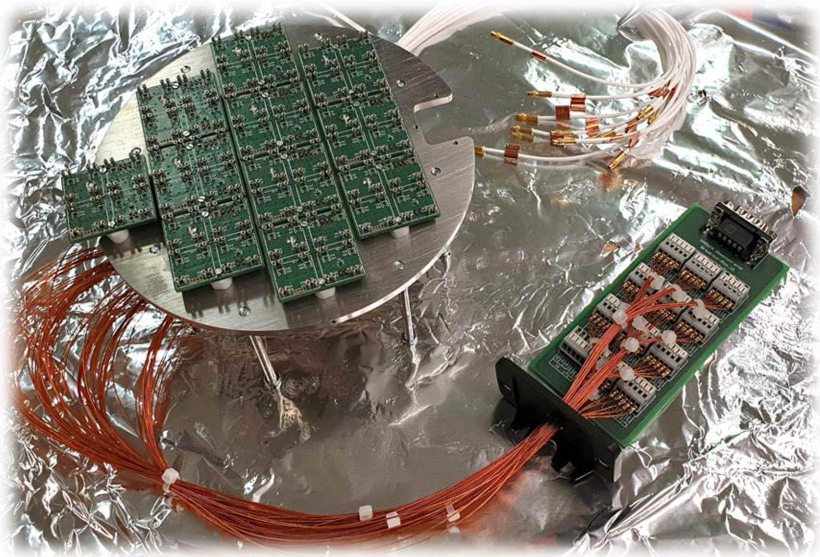
Liquid Argon Setup - LArS

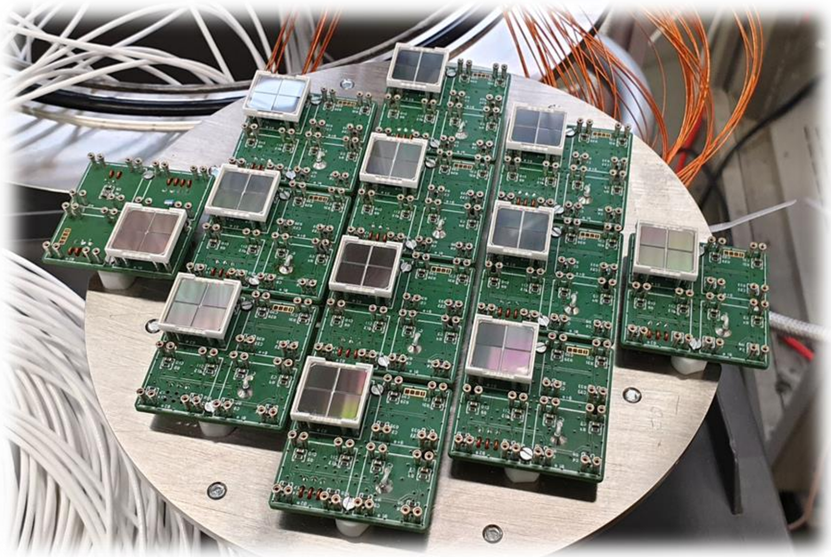
- LN_2 boil-off cooling
- Cryostat filled with GN_2 or GHe.
- Pressure: 1.9 bar
- Tests between 170 K and 200 K
- Temperature stability: < 0.5 K
- Temperature sensor soldered to one PCB



Liquid Argon Setup - LArS

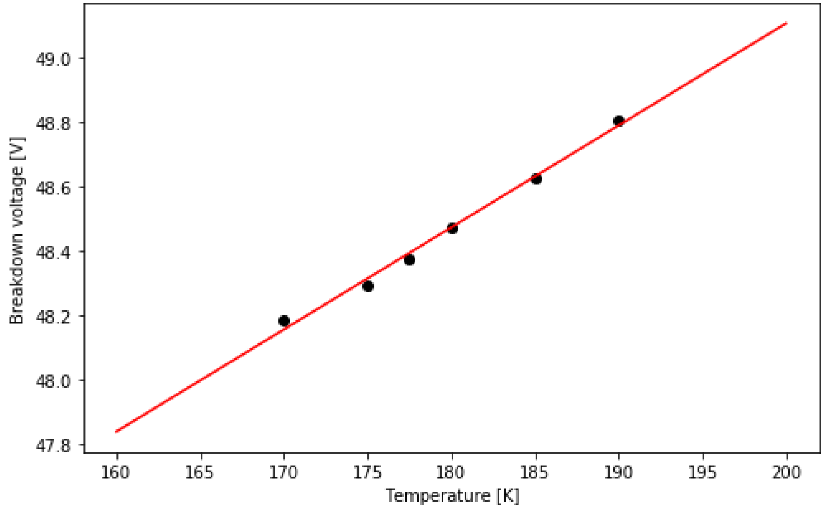
University of Zurich[UZH]
erc European Research Council
DARWIN

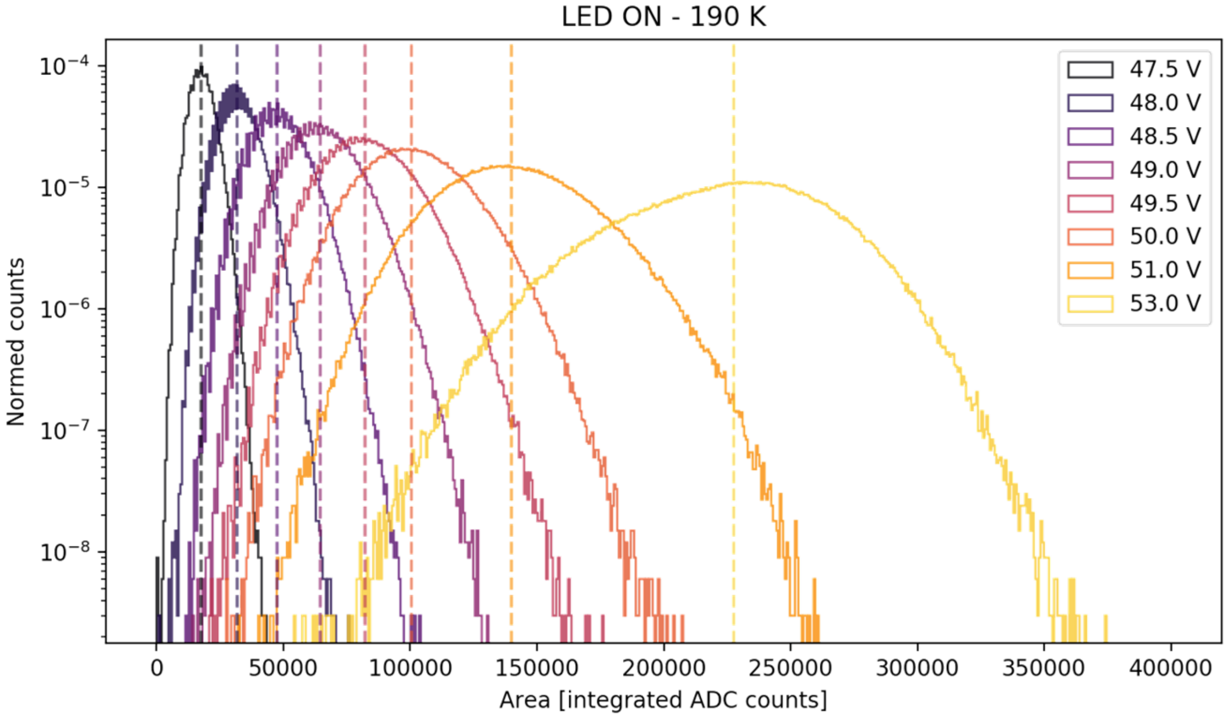




SiPM characterization - breakdown voltage

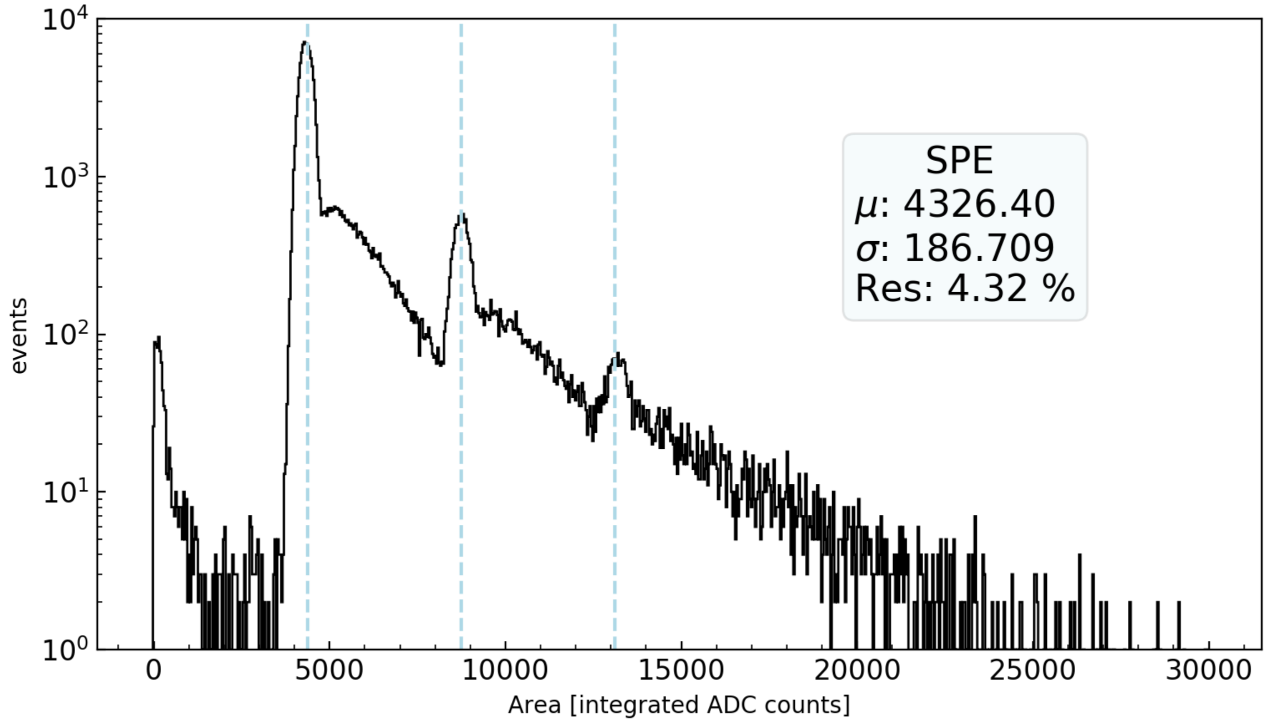
- Measurements at different temperatures in GN_2
- In-situ LED at constant luminosity
- Measured: 48.2-49.0 V





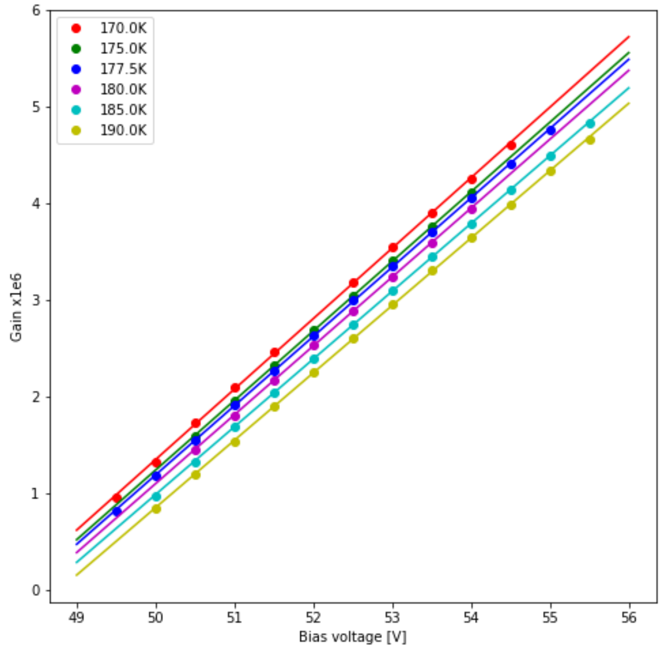
SiPM characterization - gain and SPEres

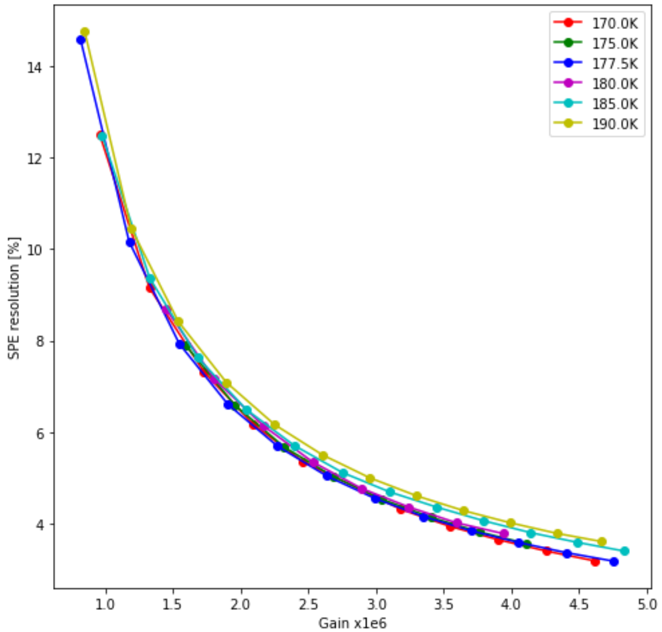
- Measurements at different temperatures in GN_2
- Fit of 1 pe peak in dark count dataset
- Presence of "shoulders" in photoelectron peaks (as seen in G. Gallina et al. (nEXO collaboration), Nucl.Instrum.Meth.A 940, 2019)
- Measured gain: O(10^6)
- Measured SPE resolution: 4% at ~$4x10^6$ gain



SiPM characterization - gain and SPEres

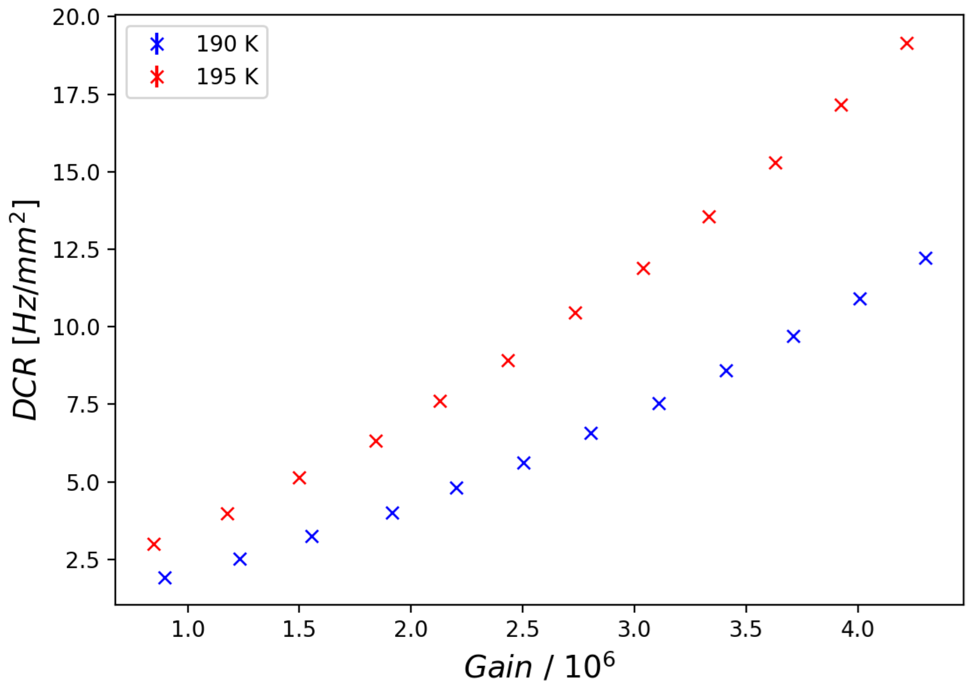
- Measurements at different temperatures in GN_2
- Fit of 1 pe peak in dark count dataset
- Presence of "shoulders" in photoelectron peaks (as seen in G. Gallina et al. (nEXO collaboration), Nucl.Instrum.Meth.A 940, 2019)
- Measured gain: $O(10^6)$
- Measured SPE resolution: 4% at $\sim 4\times10^6$ gain

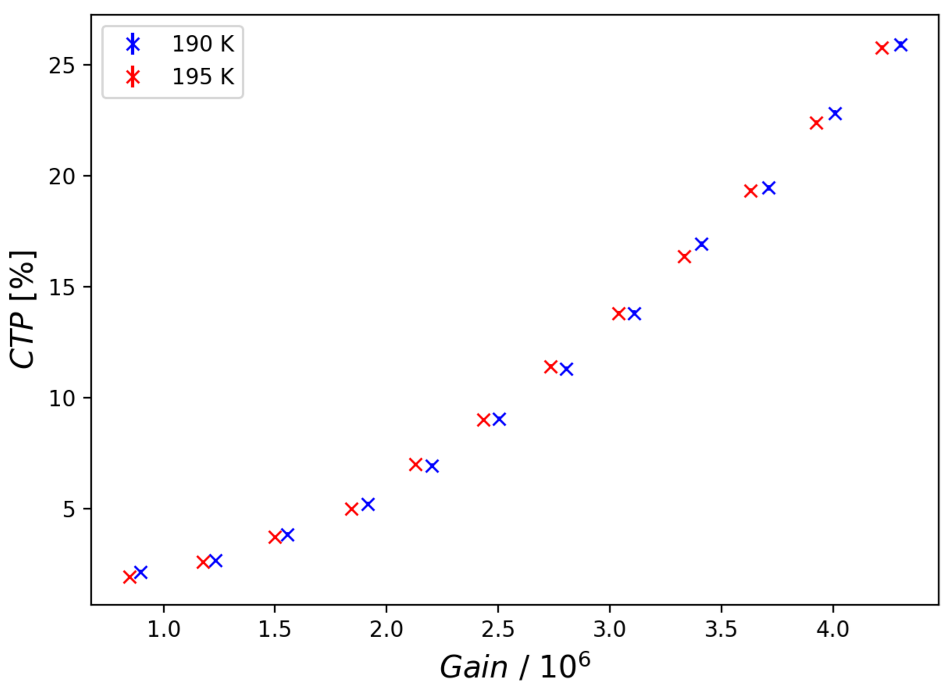




SiPM characterization - DCR

- Measured DCR: O(1) Hz/mm^2 at GXe temperature up to 2x10^6 gain
- Low cross talk probability: 2-5 % up to 2x10^6 gain





Electron diffusion simulation

- The overall effect is a combination of two independent random-walks with distinct diffusion constants, D_L and D_T.
- In the parallel direction, usually z, the field gives an extra component $v_d t$.

$$n(\vec{x},t) = \frac{N}{4\pi D_T t\sqrt{4\pi D_L t}} \exp\left[\frac{-\left(x^2+y^2\right)}{4D_T t}\right] \times \exp\left[\frac{-\left(z-v_d t\right)^2}{4D_L t}\right]$$

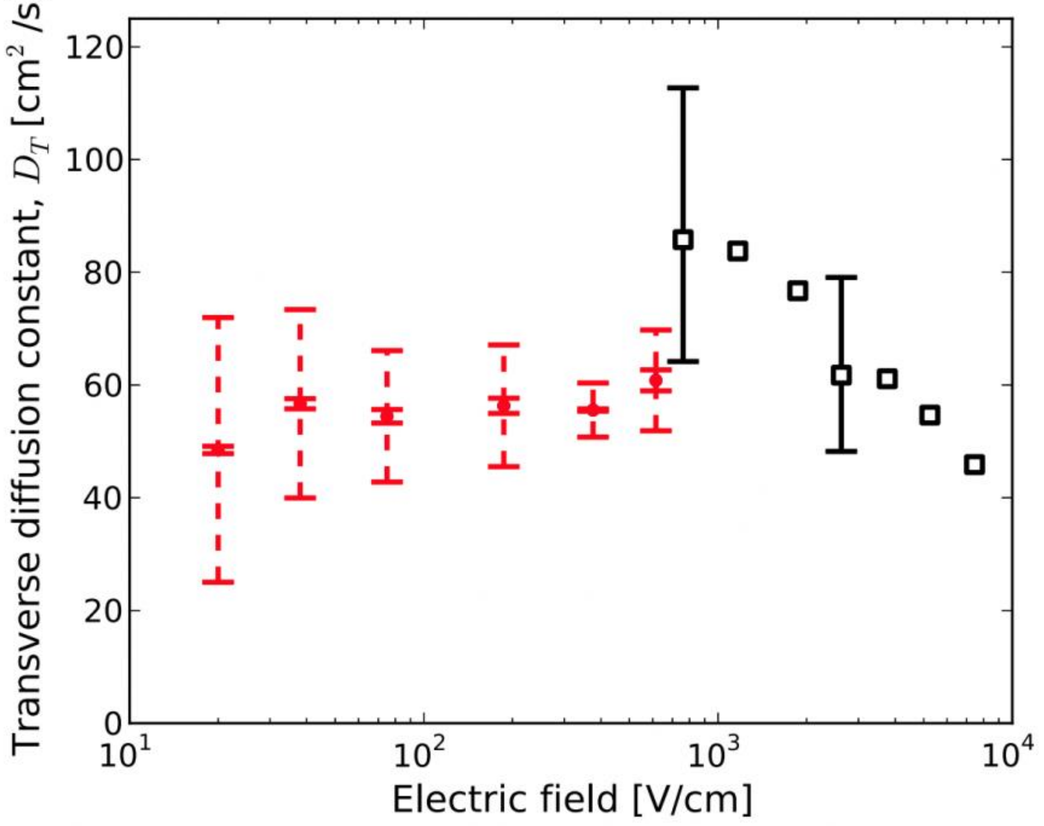
- The variance of the gaussian distributions is given by the diffusion constants such that:

$$\sigma^2 = 2D_{T/L}t$$

Transverse diffusion measurements

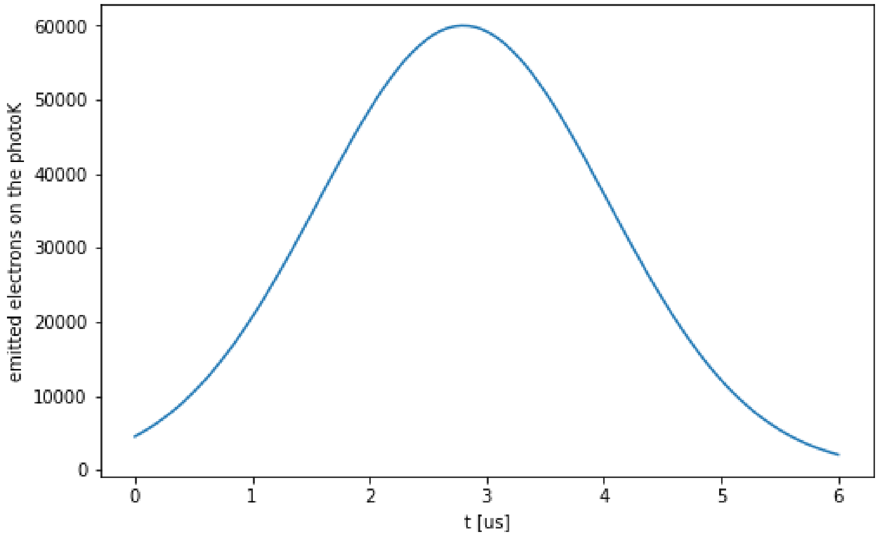
- Few and contradicting results in current literature.
- Requires fine position reconstruction
- Improved fit by deep characterization of the detector response
- Accentuated in longer drift times

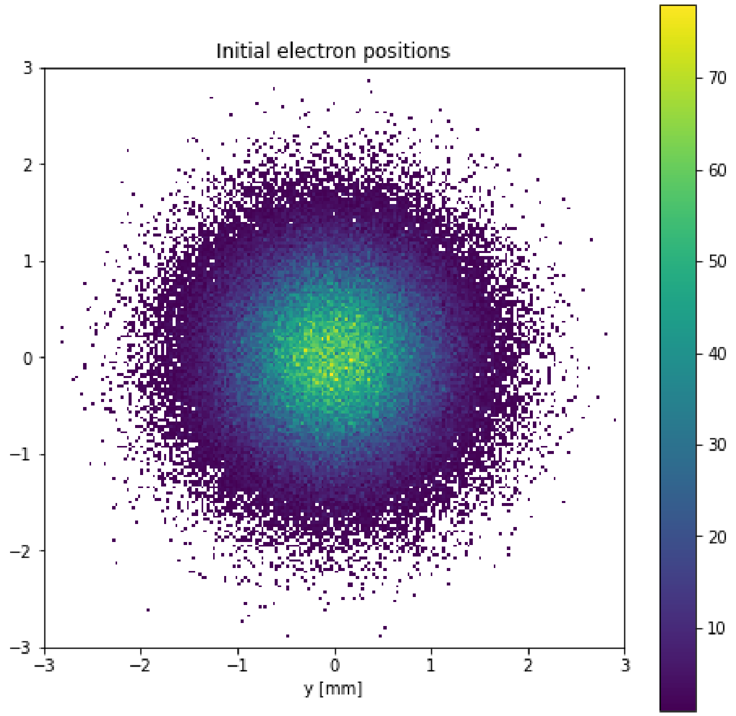
from J. B. Albert et al. (EXO-200 Collaboration), Phys. Rev. C 95, 2017



Xe lamp pulse (work of Y. Biondi)

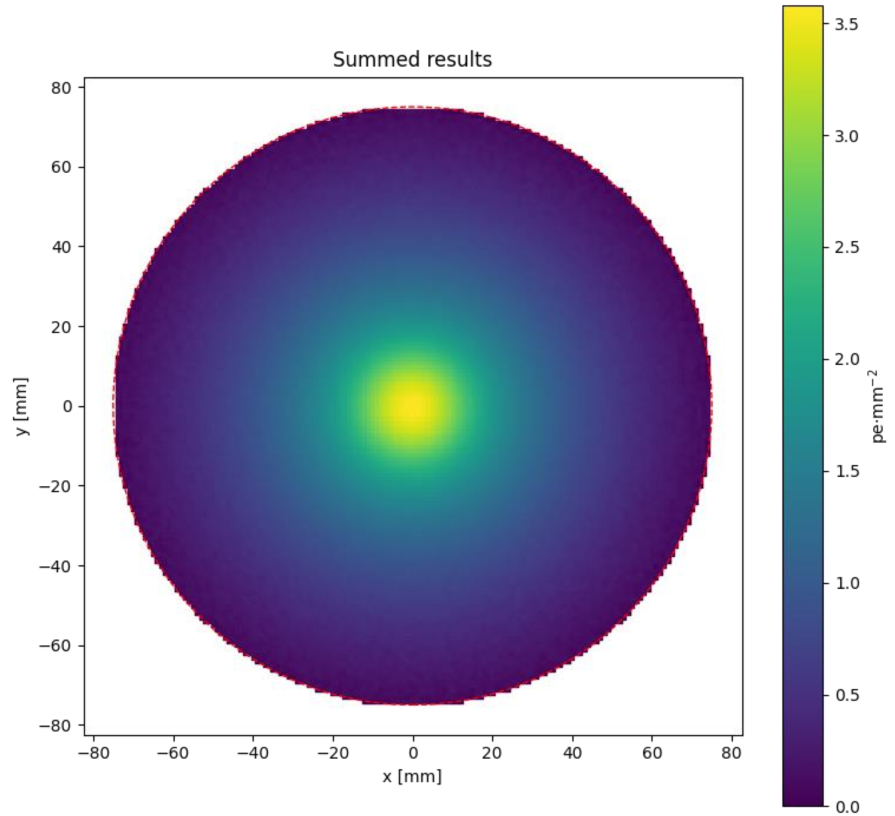
- Gaussian pulse with FWHM=2,9 us
- Numerical aperture: 0.22
- Distance from Photocathode: 2mm
- Gaussian distribution of produced electrons*





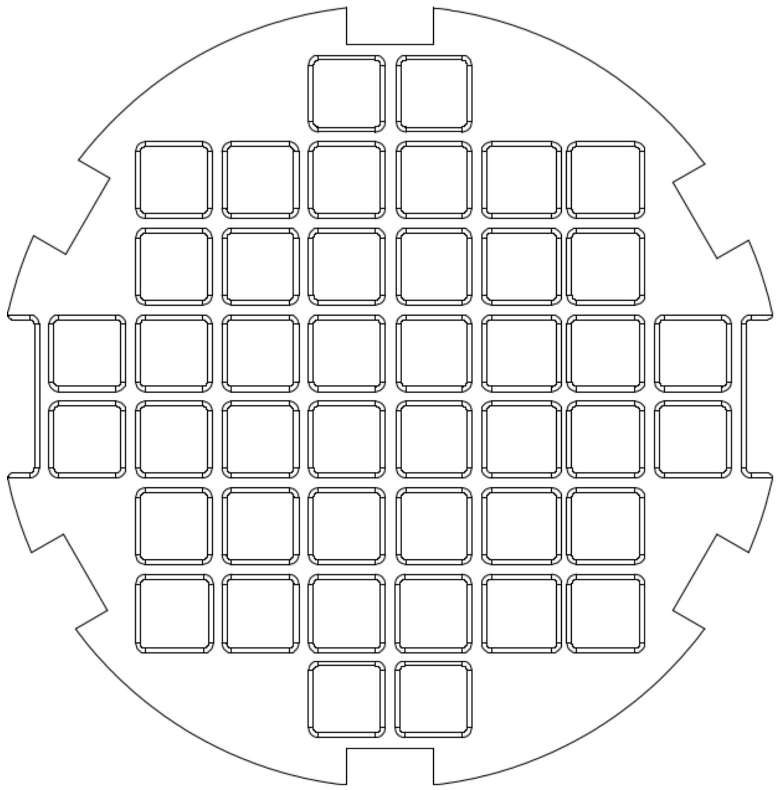
Drift, diffusion and electron extraction

- Drift and diffuse the electron cloud over through the TPC volume.
  - 90% within a 15 mm radius
- Adjusted for electron lifetime and extraction efficiency.
- Binned toy-MC light patterns on the top array area.
- Final light distribution as the sum of each electron light pattern



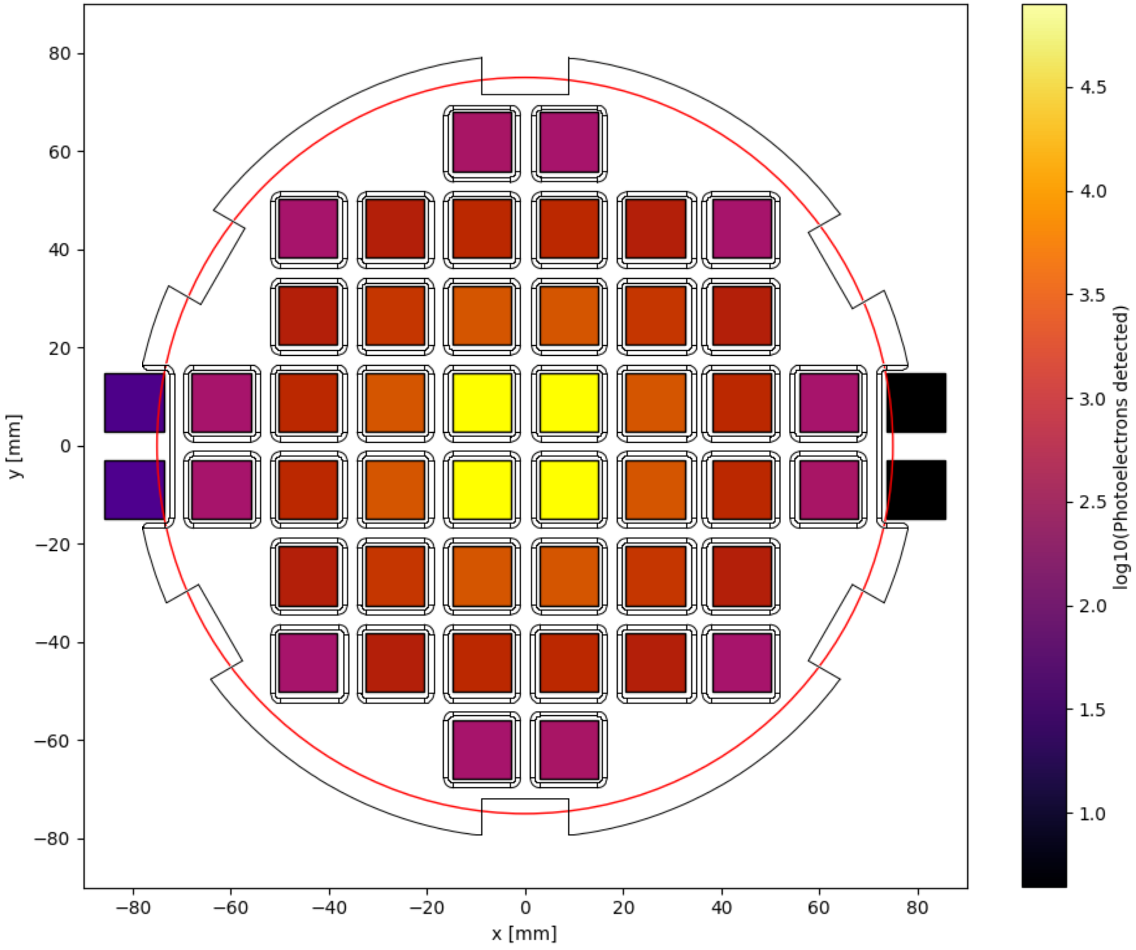
Signal on the Top Array

- Actual top array is finitely tilled:
  - 12 tiles of 4 12x12 SiPMs
- Direct measurement of diffusion
- Simulated response of SiPM array can be used as a template for diffusion constant fit
- Inform next design choices and physics reach



Signal on the Top Array

- Actual top array is finitely tilled:
  - 12 tiles of 4 12x12 SiPMs
- Direct measurement of diffusion
- Simulated response of SiPM array can be used as a template for diffusion constant fit
- Inform next design choices and physics reach



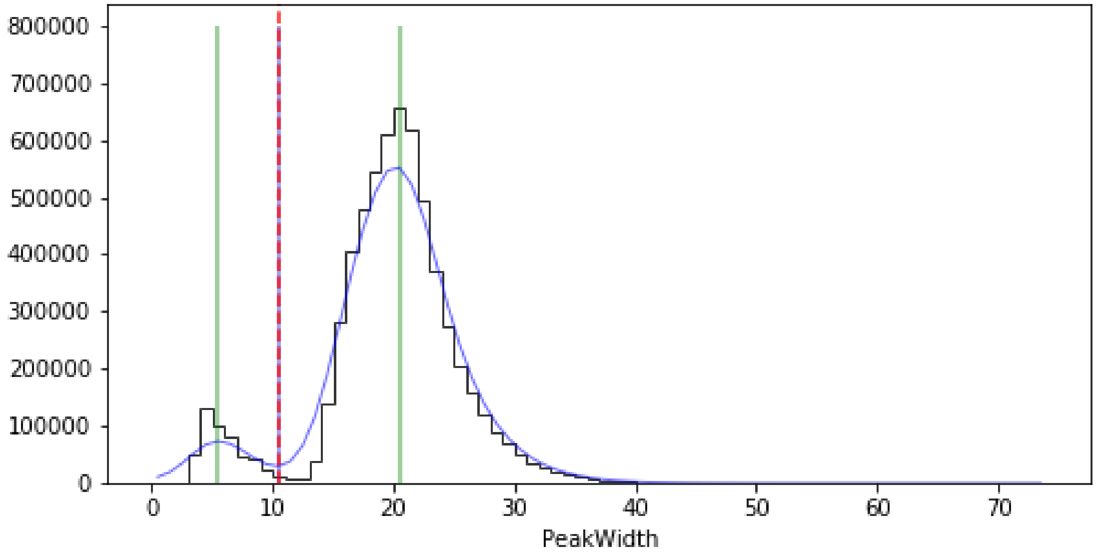
Outlook

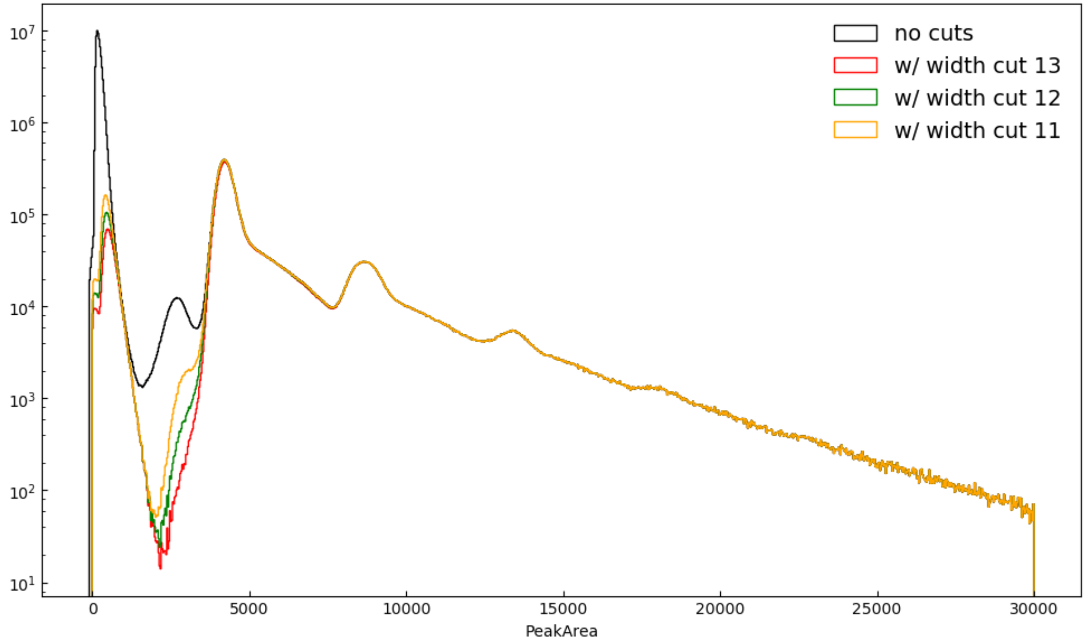
- Xenoscope will feature an array of VUV SiPMs in its next run (starting this summer/autumn!)
- All the sensors are being characterized to detect outliers and allow gain-matching
  - Breakdown voltage, gain, SPE resolution, DCR and CTP
  - At LXe and expected GXe temperature (170 K to 200 K)
- Equipped with light readout, Xenoscope will be able to measure the electron longitudinal and transversal diffusion constants in LXe

Thank you!

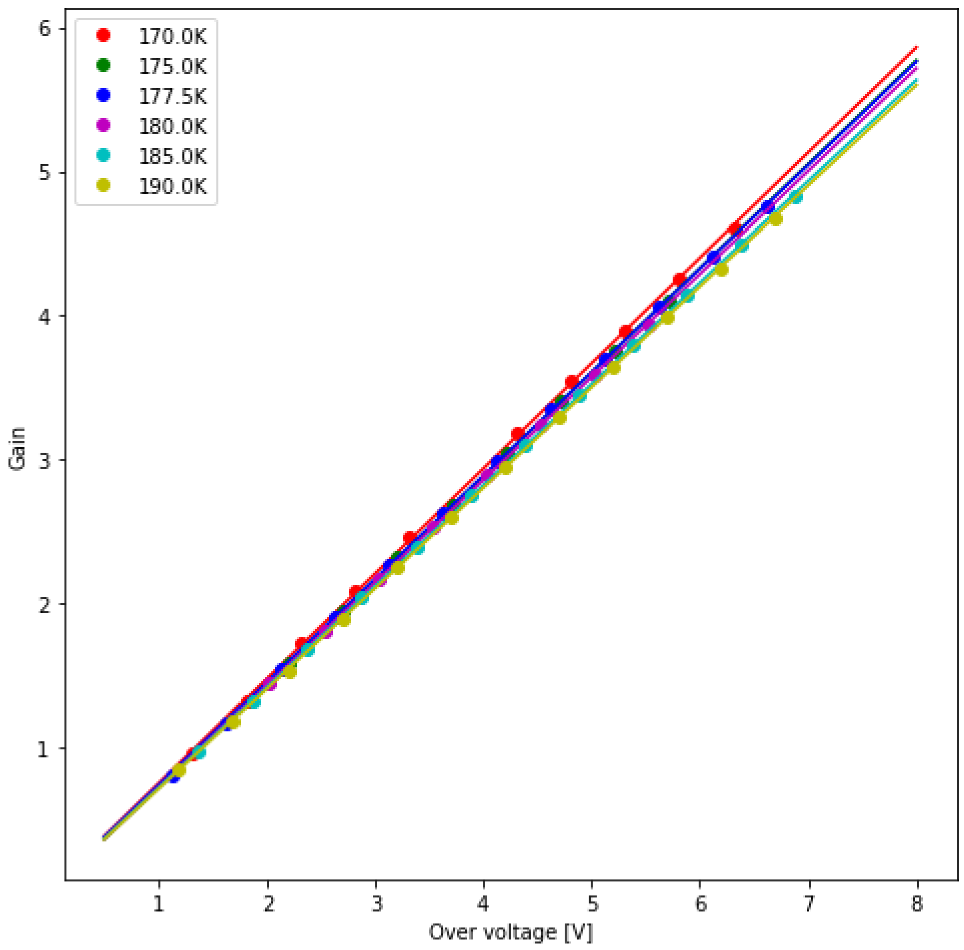
Backup Slides

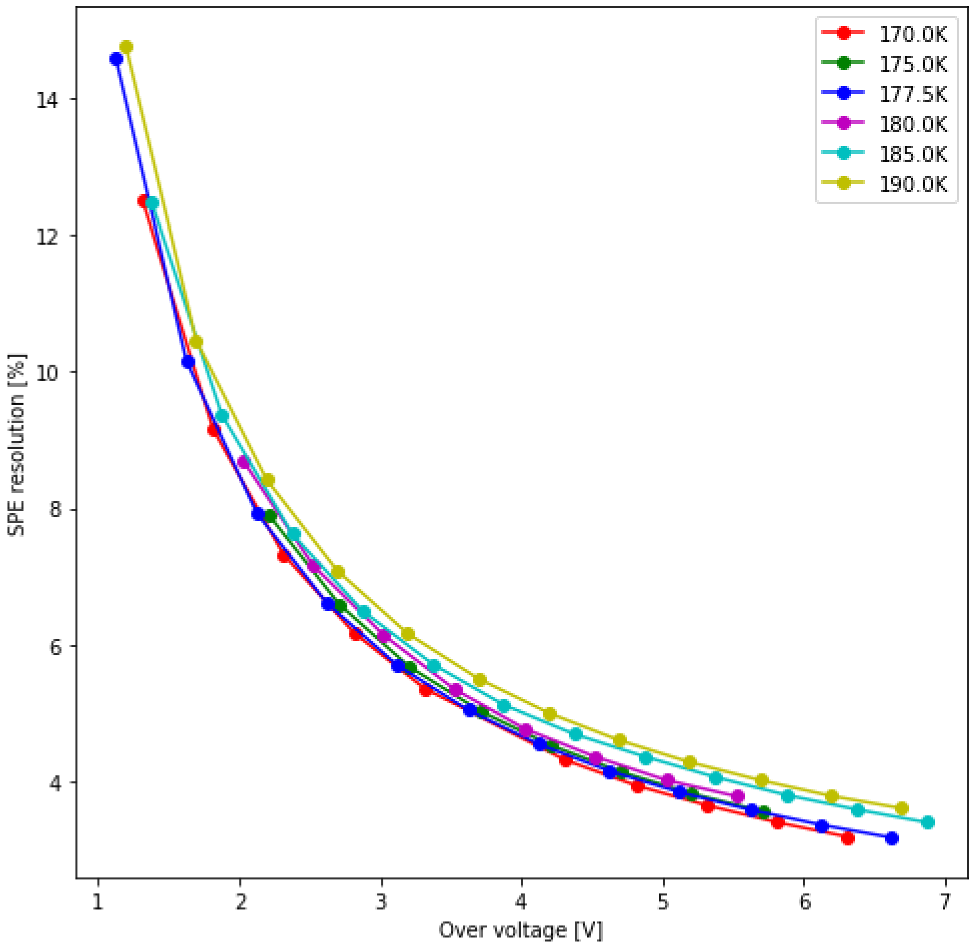
Event selection



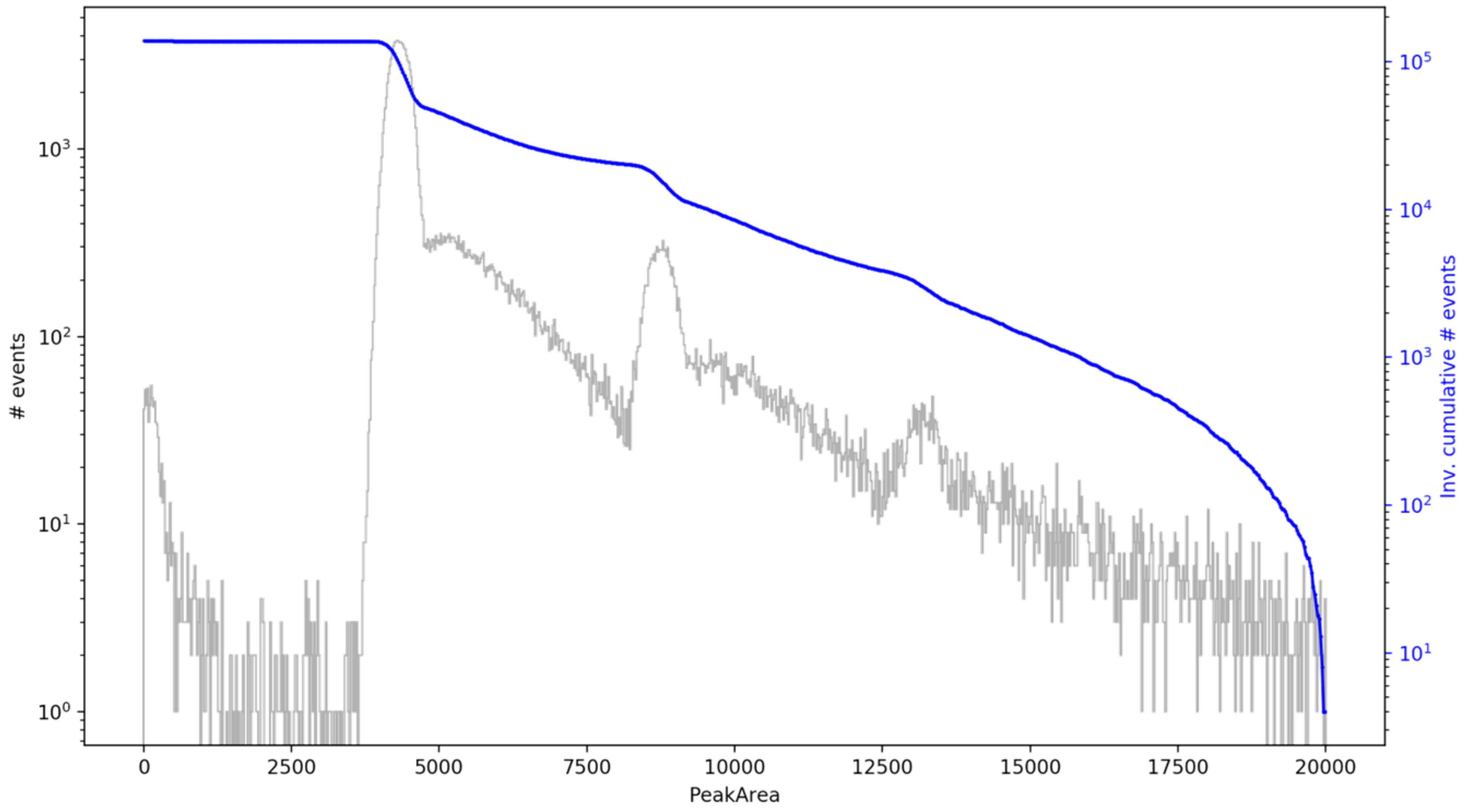


Gain and SPE - alternative plots

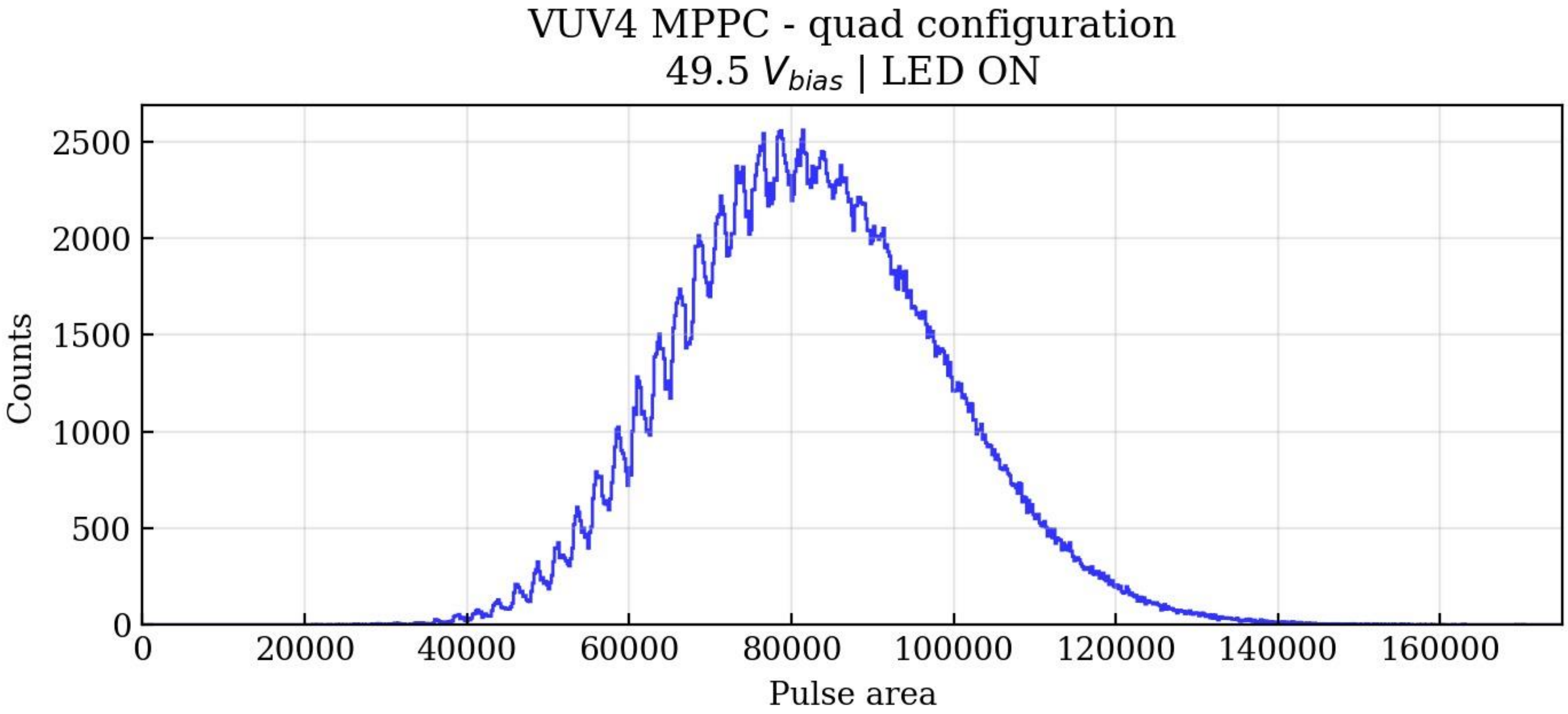




DCR vs threshold



Lots of PEs



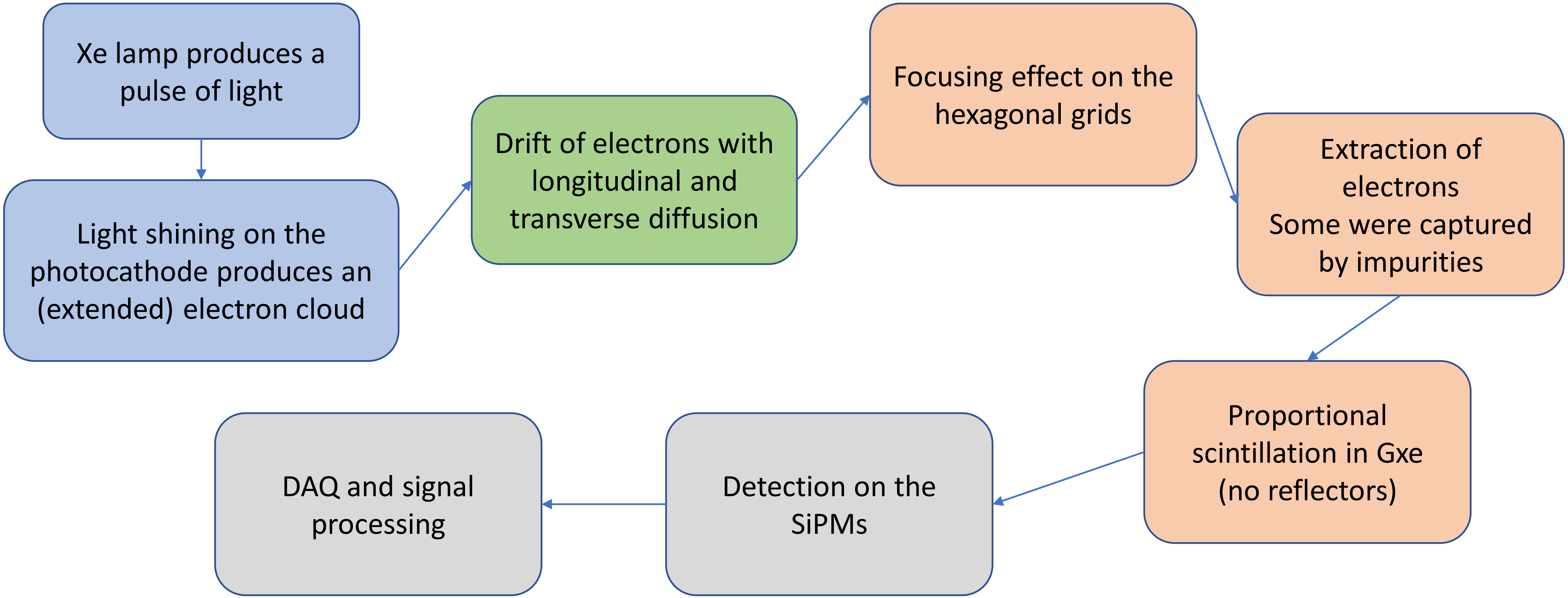
VUV4 MPPC - quad configuration
49.5 V_{bias} | LED ON
Counts
0
500
1000
1500
2000
2500
0
20000
40000
60000
80000
100000
120000
140000
160000
Pulse area

Simulating a light signal from a diffused electron cloud

University of Zurich[UZH]

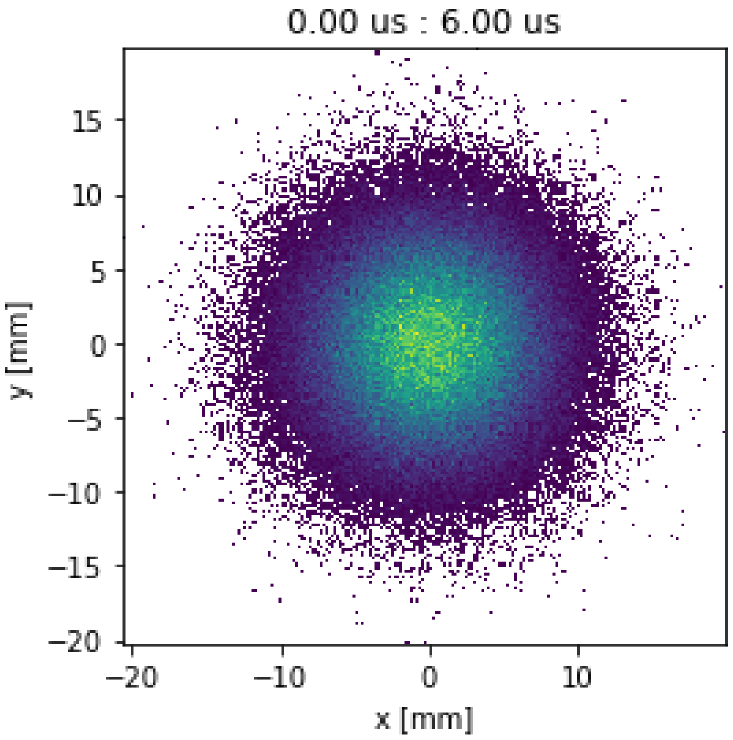
erc European Research Council

DARWIN



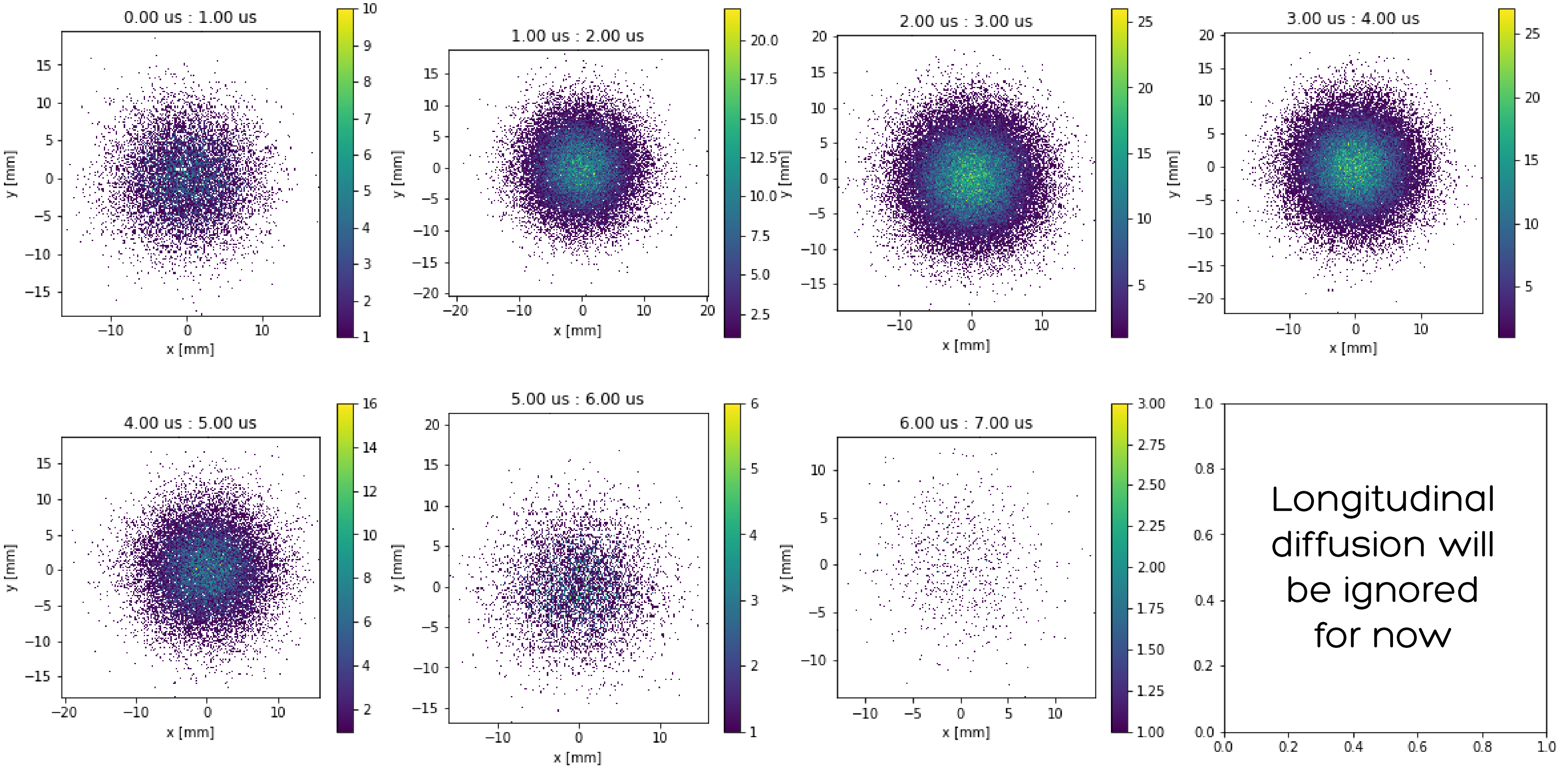
Drift and diffuse

- Propagate the electrons given a certain time step.
- Gaussian random-walk + drift velocity
- Stop when electrons reach the length of the TPC



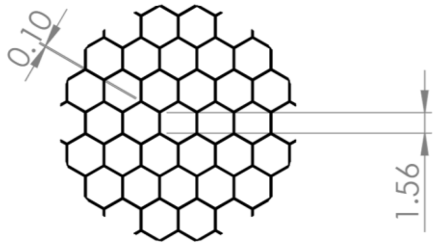
Drift and diffuse

Electron positions after drift

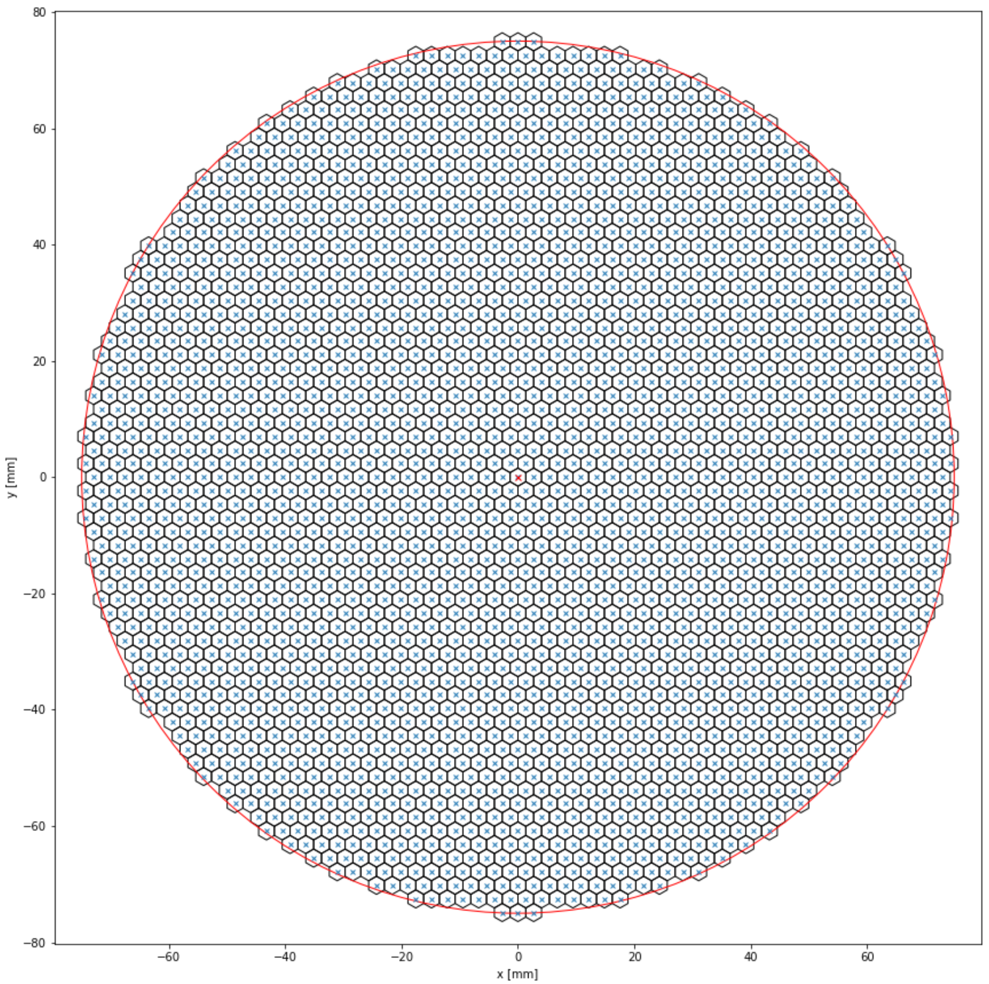


Focusing effect on hex mesh

- If you need hexagonal meshes take a look at hexalattice.
- Radius: 150 mm
- Hex side: 1.56 mm
- Hex center radius: 2.70 mm

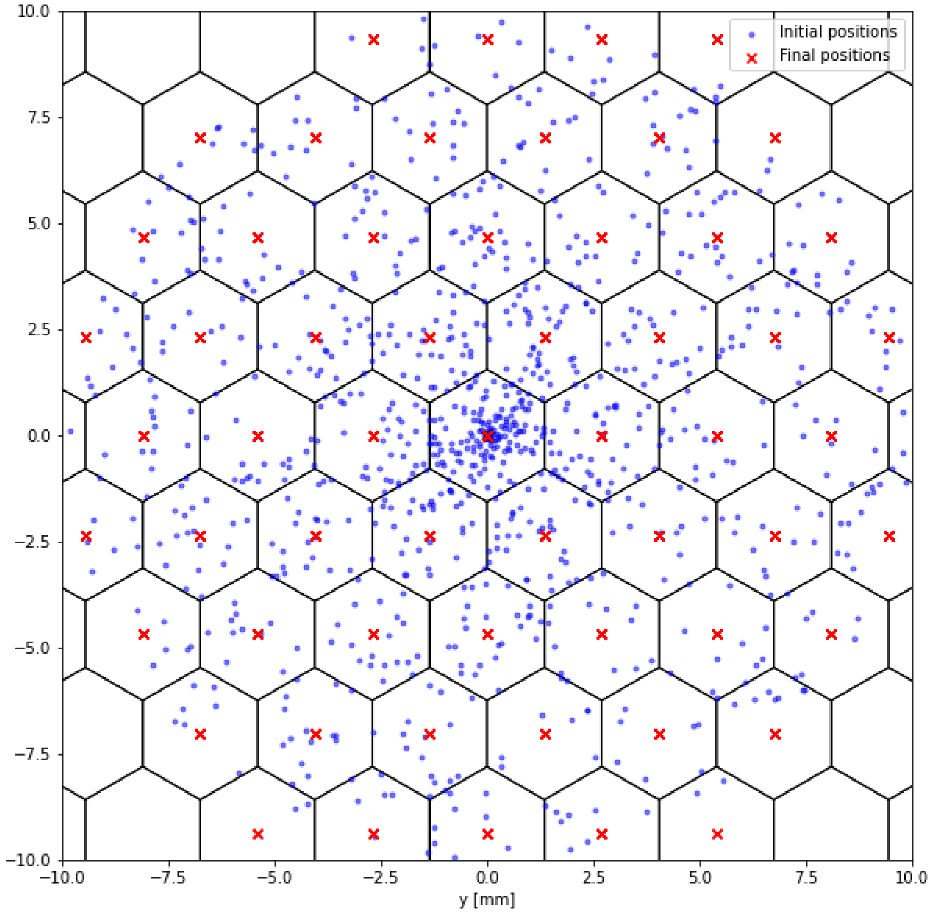


DETAIL A
SCALE 2 : 1

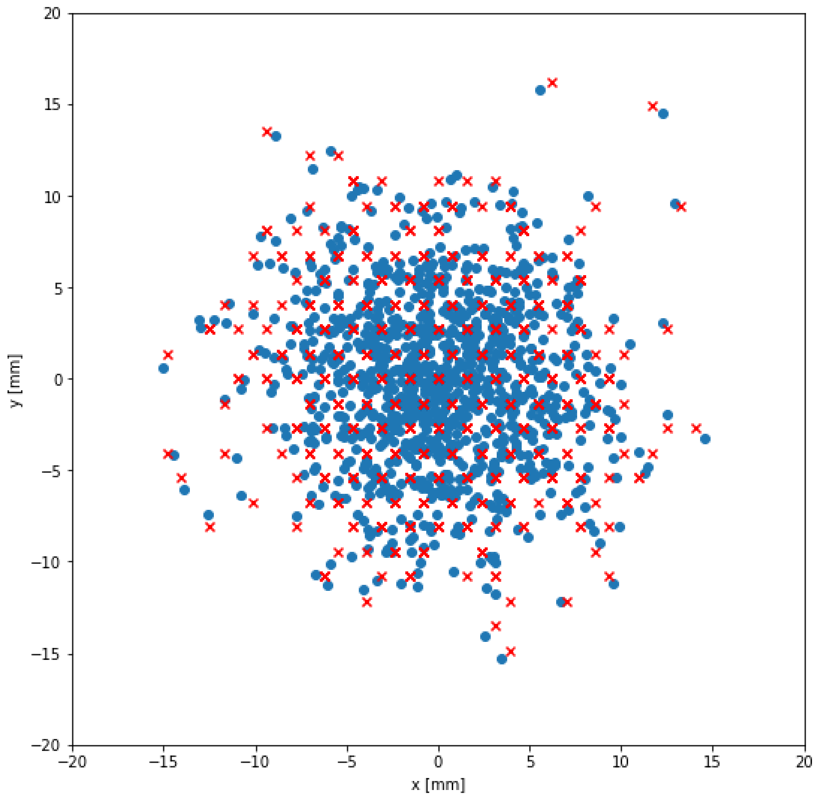


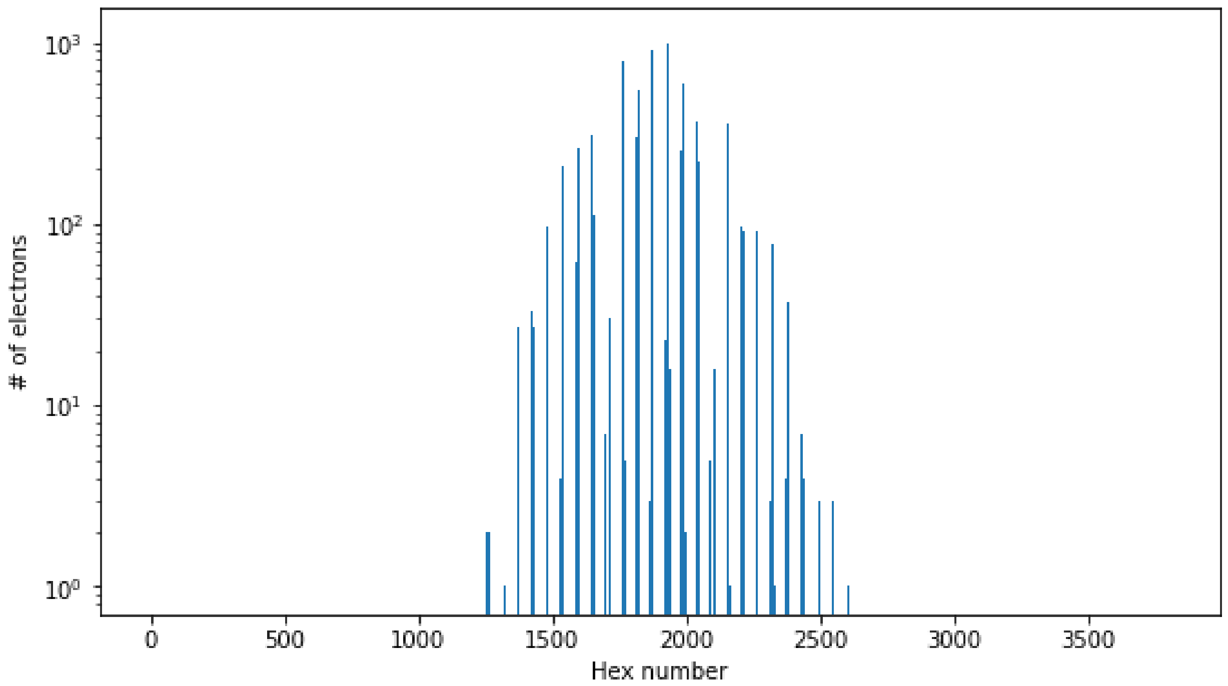
Focusing effect on hex mesh

- Focusing effect simplified: all the electrons converge to their closest hex center.
- Count how many electrons are in each.
- Apply extraction efficiency (99%)
- Apply e-lifetime (2000 us)



Focusing effect on hex mesh





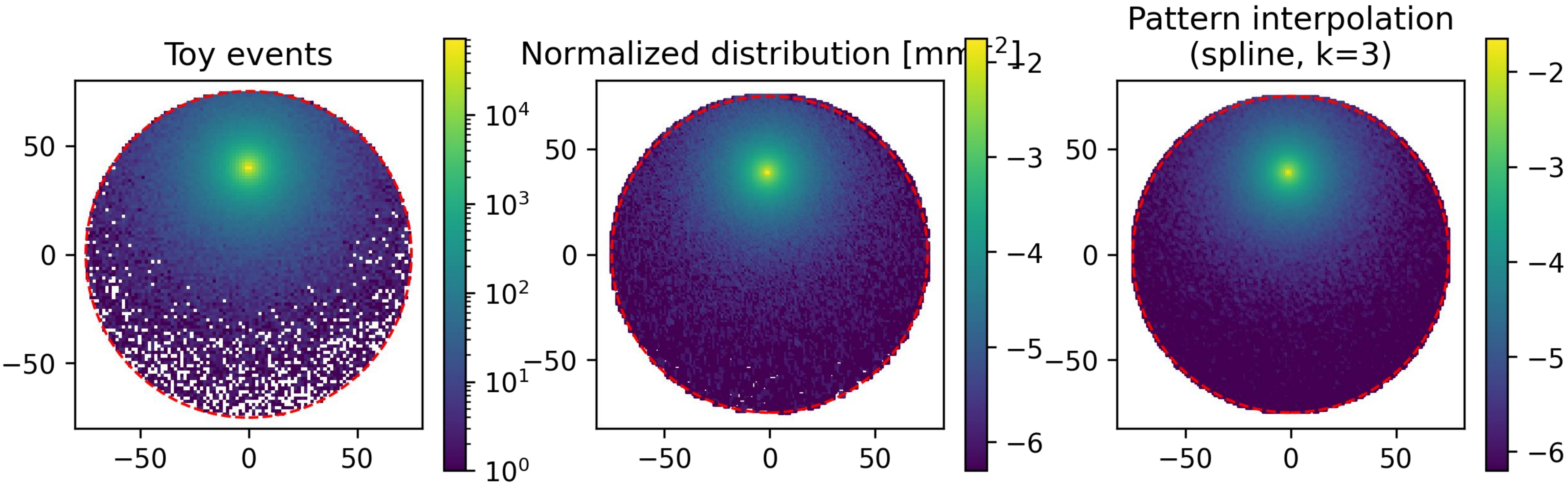
From electrons to detected photoelectrons

- What to take into account:
  - Proportional scintillation: ("over")simplified by using a single-electron gain (28.57 pe/e- from Xurich II)
  - LCE maps, or what's the chance that a photon from a certain hex center hits a certain (x,y) on the top array?

- LCE maps:
  - Toy-MC in half a sphere (1e6-1e8)
  - Select hits on the Top Array
  - Discretize into bins (2dhist), normalize and define interpolative function (spline)
  - Repeat for each hex center
  - The number of photon/pe for a given area is then $\sum^{n_{hex}} \int LCE_i(x,y)dxdy$

$$\begin{cases} x' = x_0 + (z' - z_0)\cos\varphi\tan\theta \\ y' = y_0 + (z' - z_0)\,sin\,\varphi\tan\theta \end{cases}$$

From electrons to detected photoelectrons



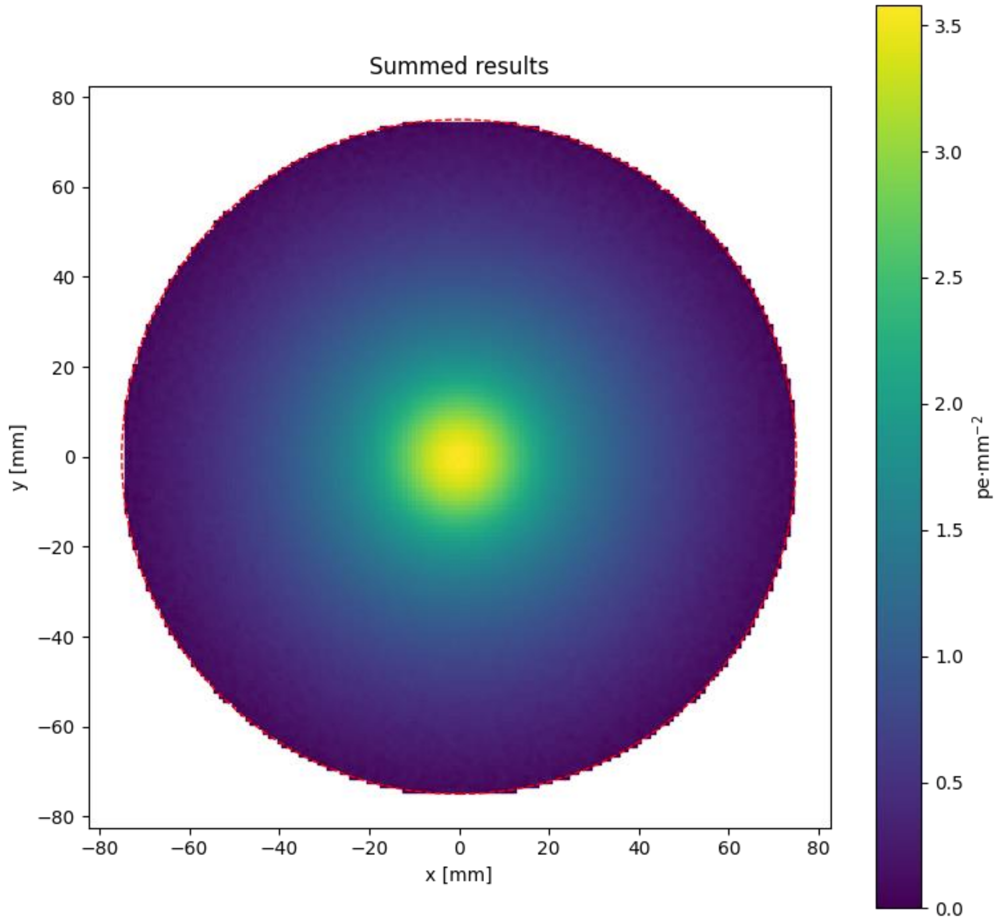
From electrons to detected photoelectrons

- All 3808 hex centers' LCEs were computed (~30 min)
- Say a number between 0 and 3807 :)

Add all the patterns

- Add all the patterns from all the (non-empty) hex centers
- Recheck normalization
- Get your final pattern

- No grid survives on this size and gas gap?



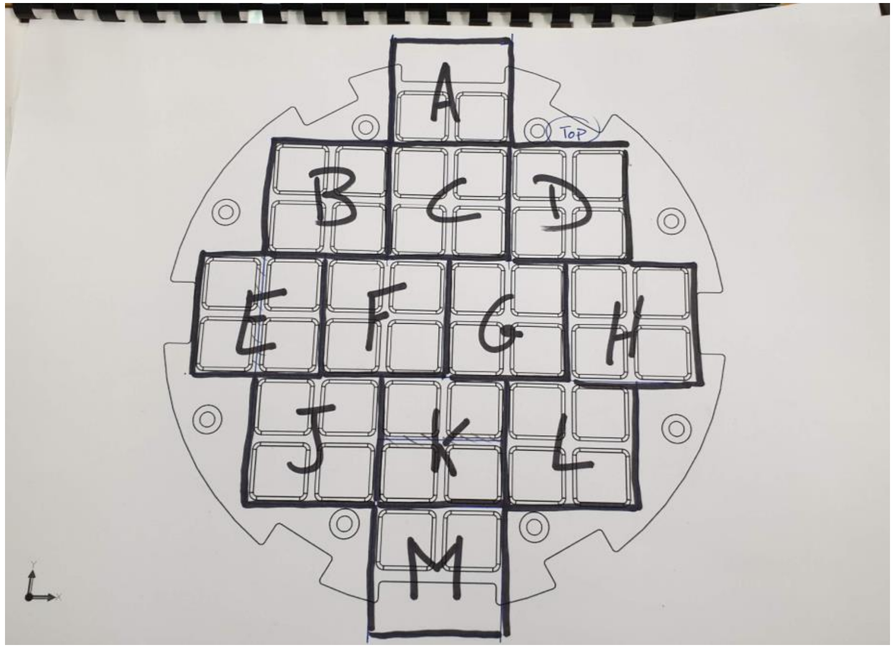
Read on the actual Top Array

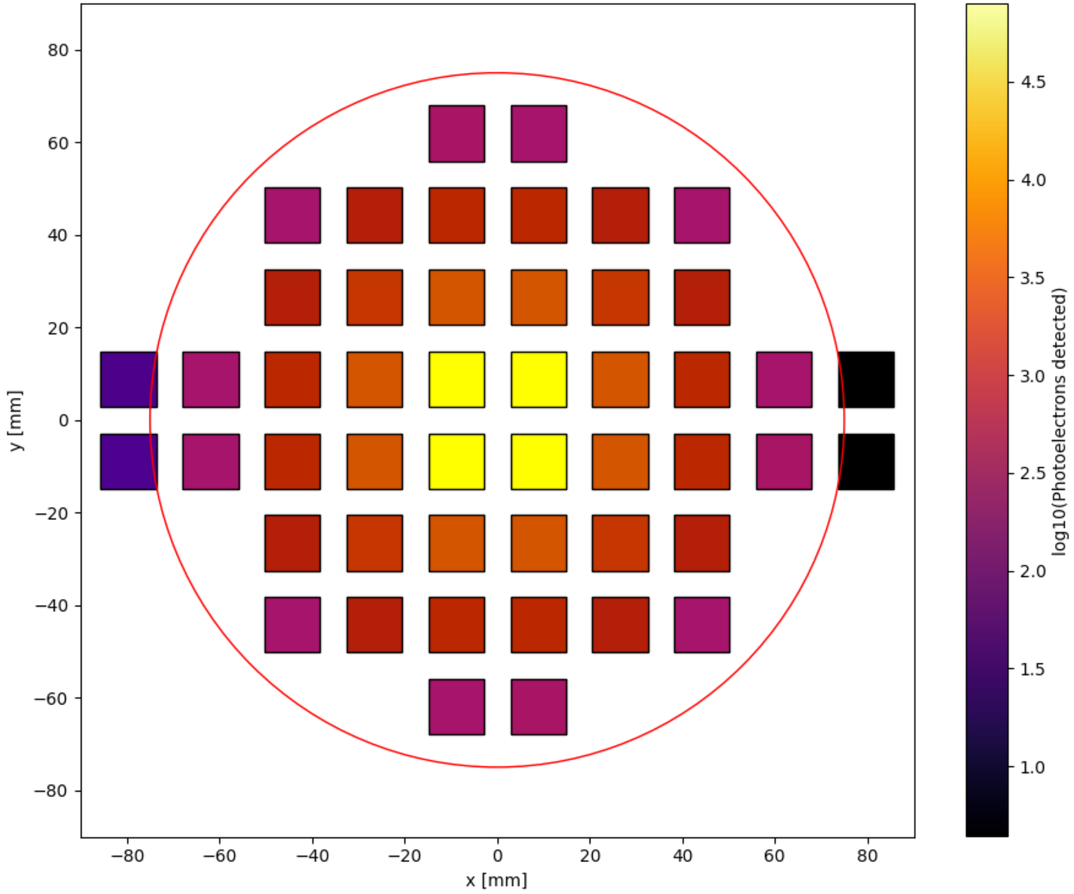
- 12 tiles
- 12*4 = 48 12x12mm2 VUV4 MPPCs
- 12*4*4 = 192 6x6mm2 VUV4 MPPCs

- What kind of patterns do we expect from such an ensemble?
- Should any adjustments still be done?

Read on the actual Top Array

- Take the summed pattern and integrate





Alternative configurations