Studies of LIME performance

Data sets

In 2021 we collected a huge amount of data with LIME (almost 2500 runs):

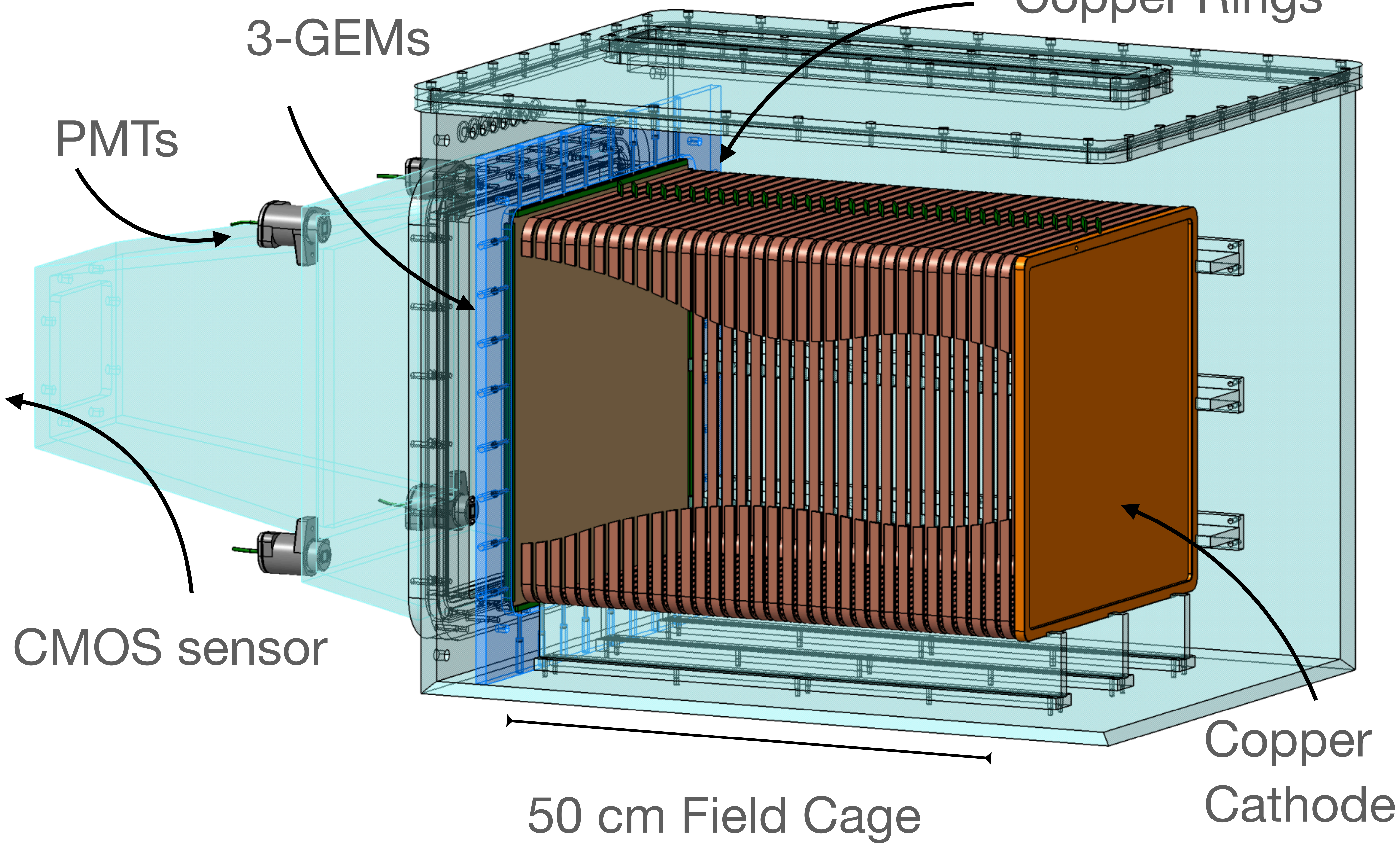
- ^{55}Fe;
- multi-energy source;
- cosmic and natural radioactivity;
- studies with PMTs and some with SiPMs;
- studies of different cameras;
- long term stability studies;

Some of them were analysed, others are under studies, others have to be looked;

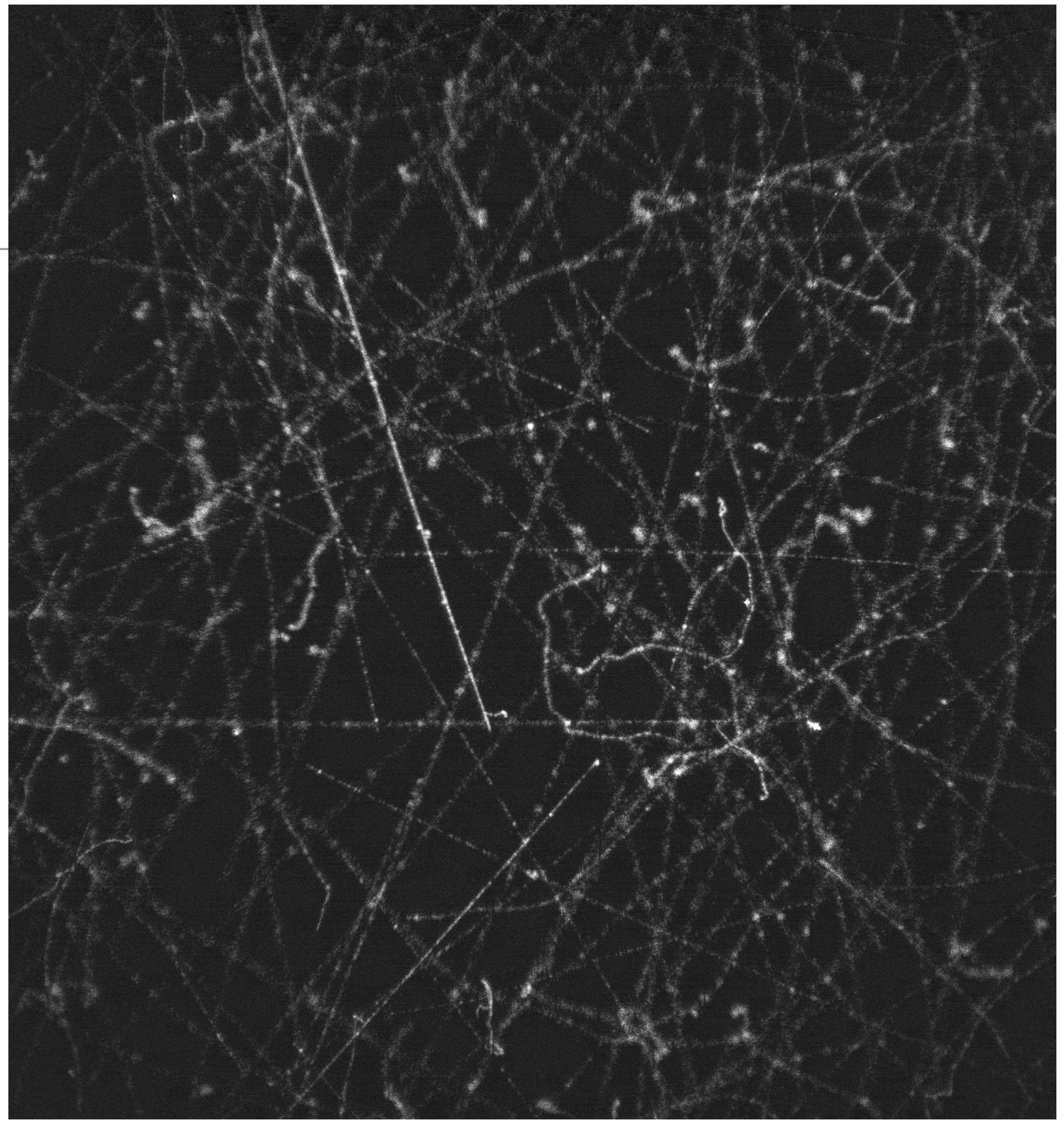
In this presentation, I'll display part of the main results obtained so far and underline what it still needed. Other ones will be presented by Rita and Emanuele;

We should proceed with the missing analyses and collect all of them in a LIME_at_LNF paper;

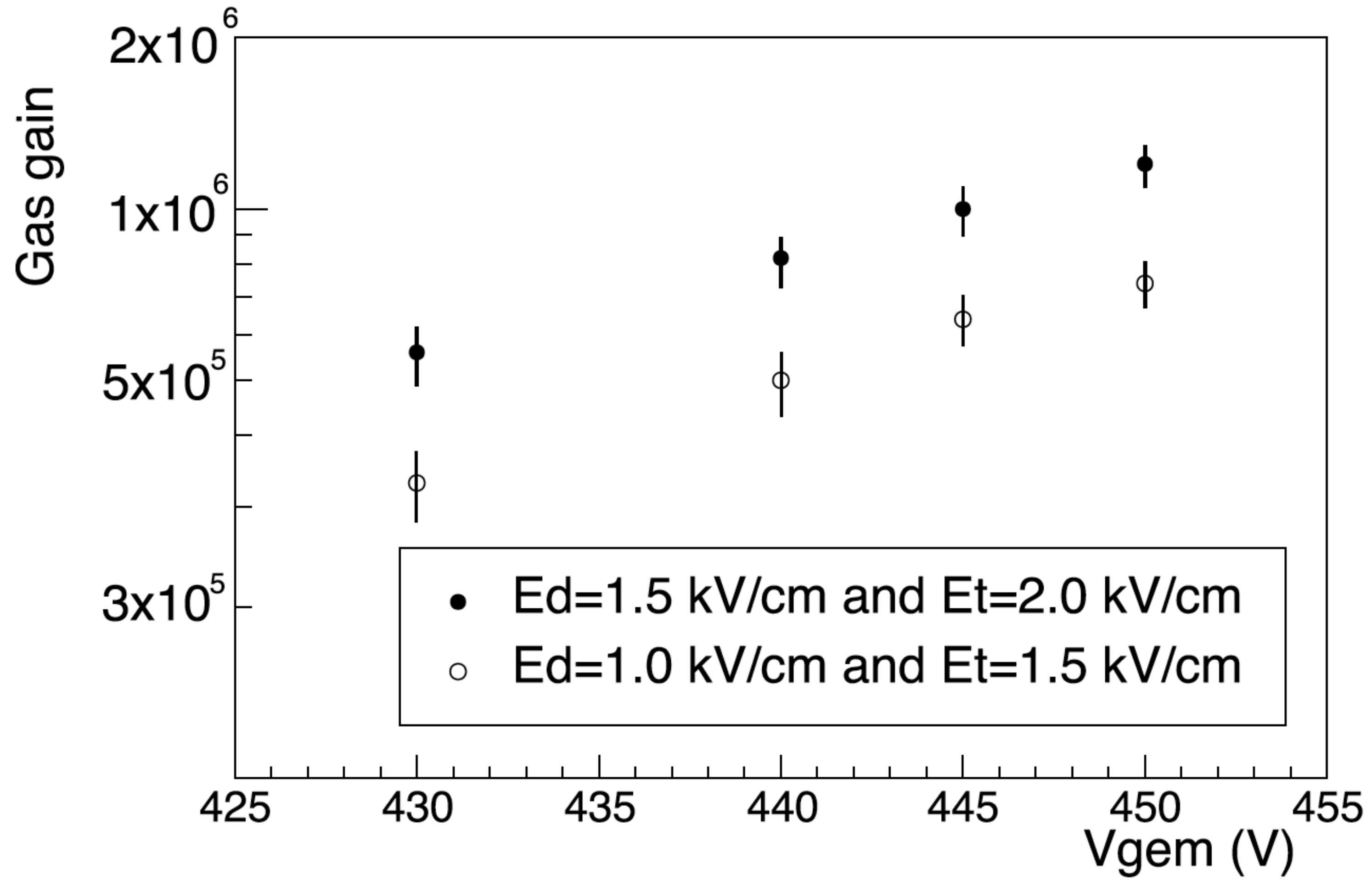
The Long Imaging ModulE LIME prototype



Same readout granularity and drift length of the demonstrator



He/CF_4 (60/40) gas mixture

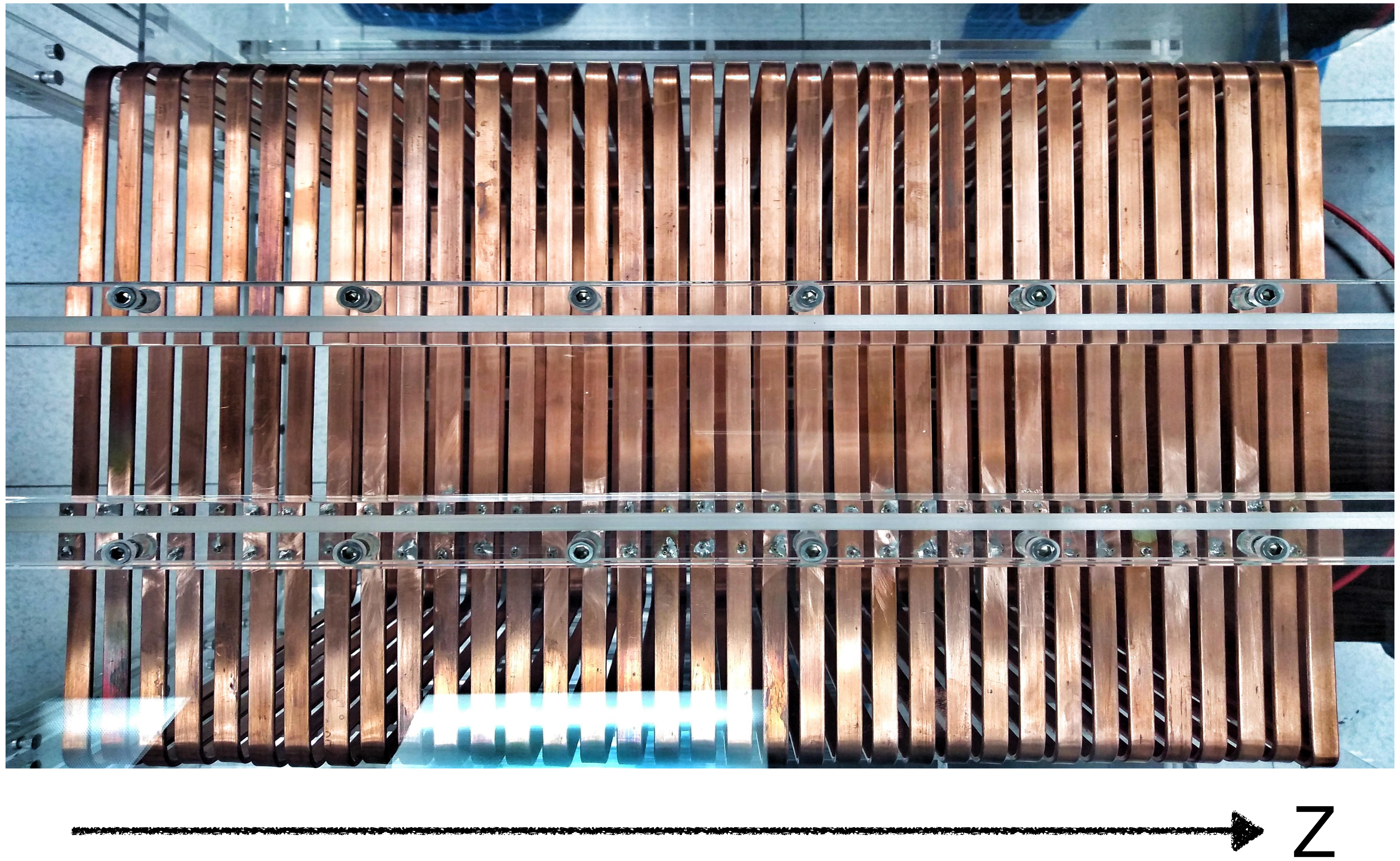


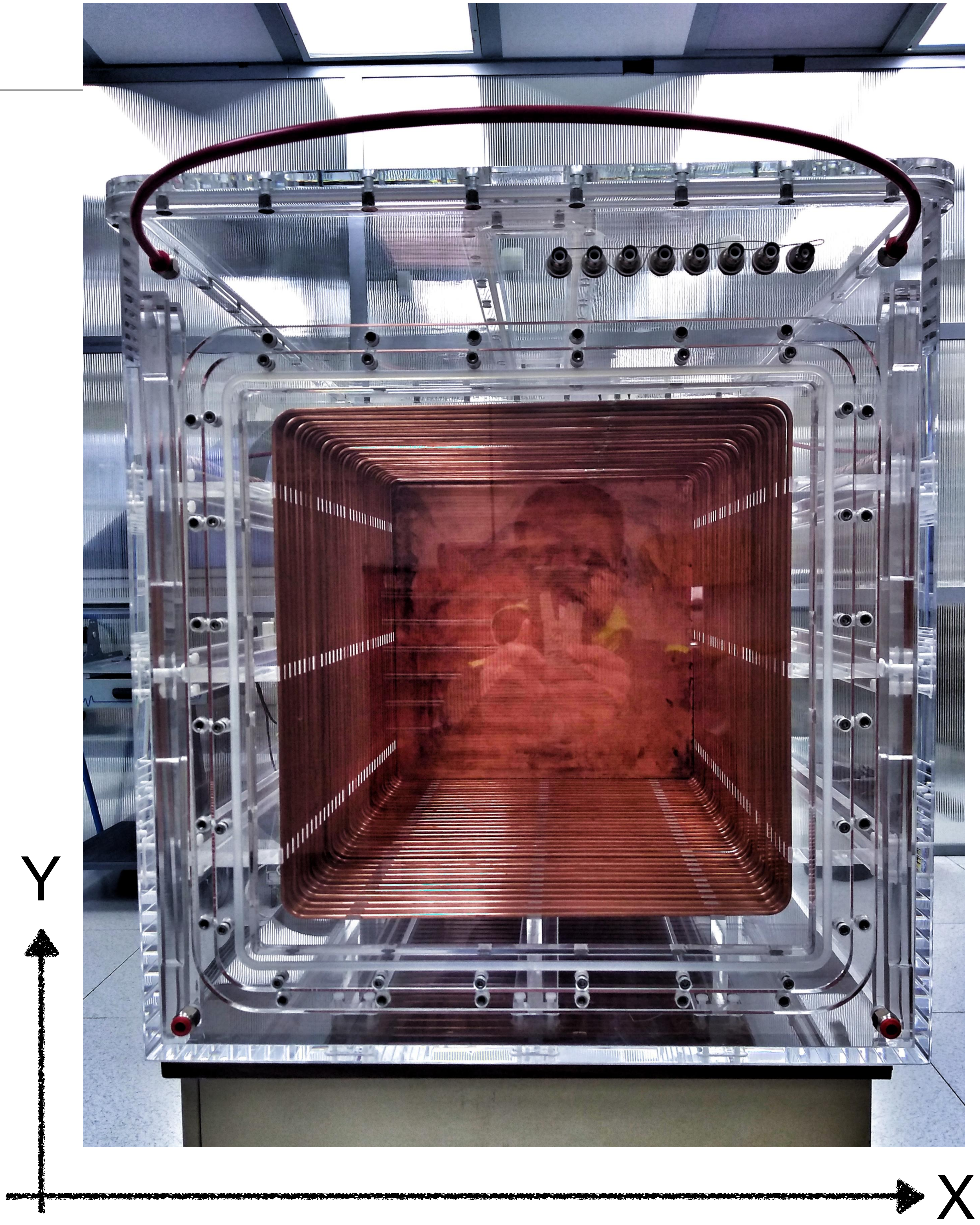
usually operated with a gain of 10^6

LIME: Large Imaging module

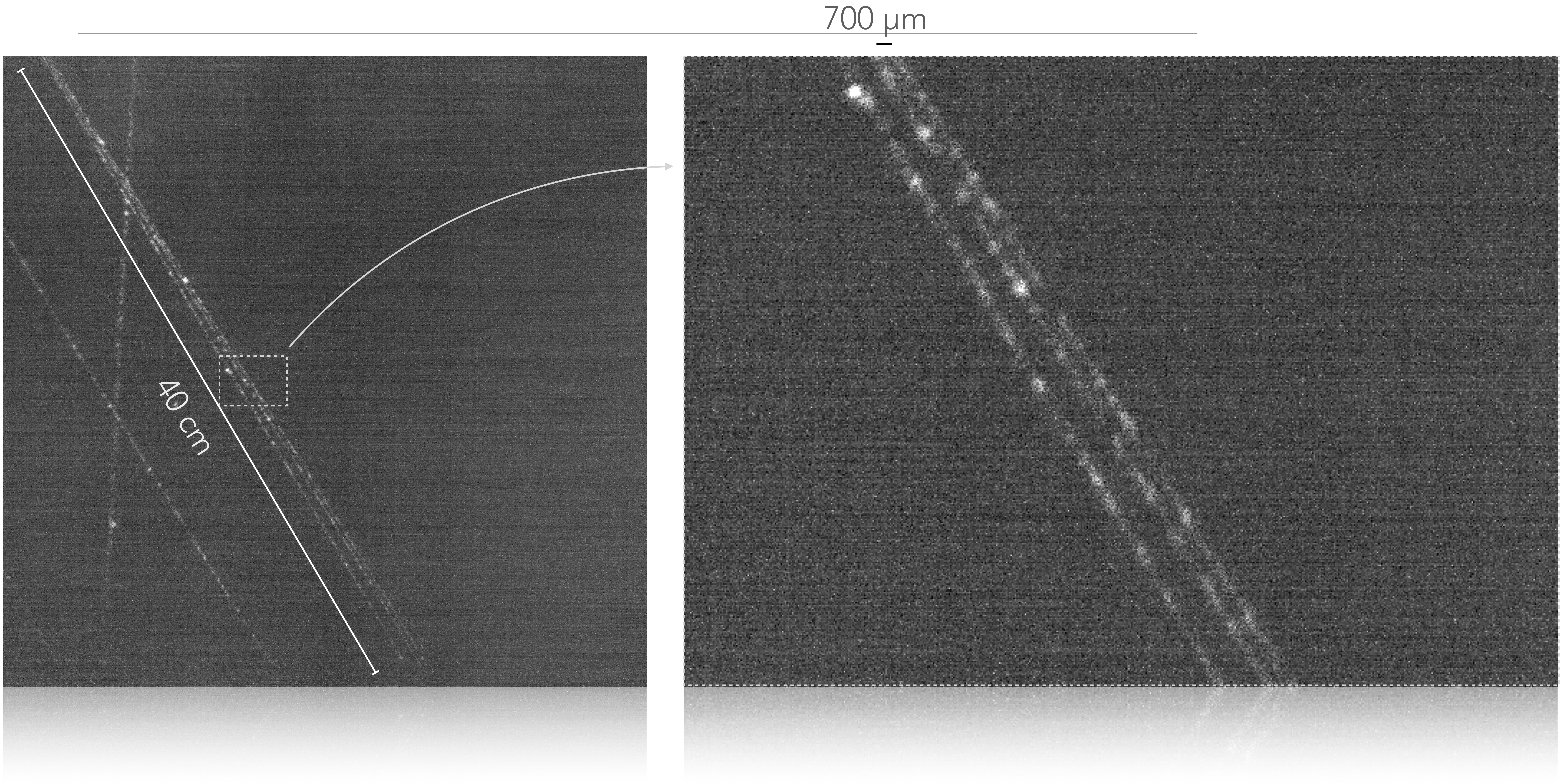
50 litres sensitive volume:

- 33 x 33 ~ 1000 cm^2 GEM surface;
- 50 cm drift path;





Optically readout TPC



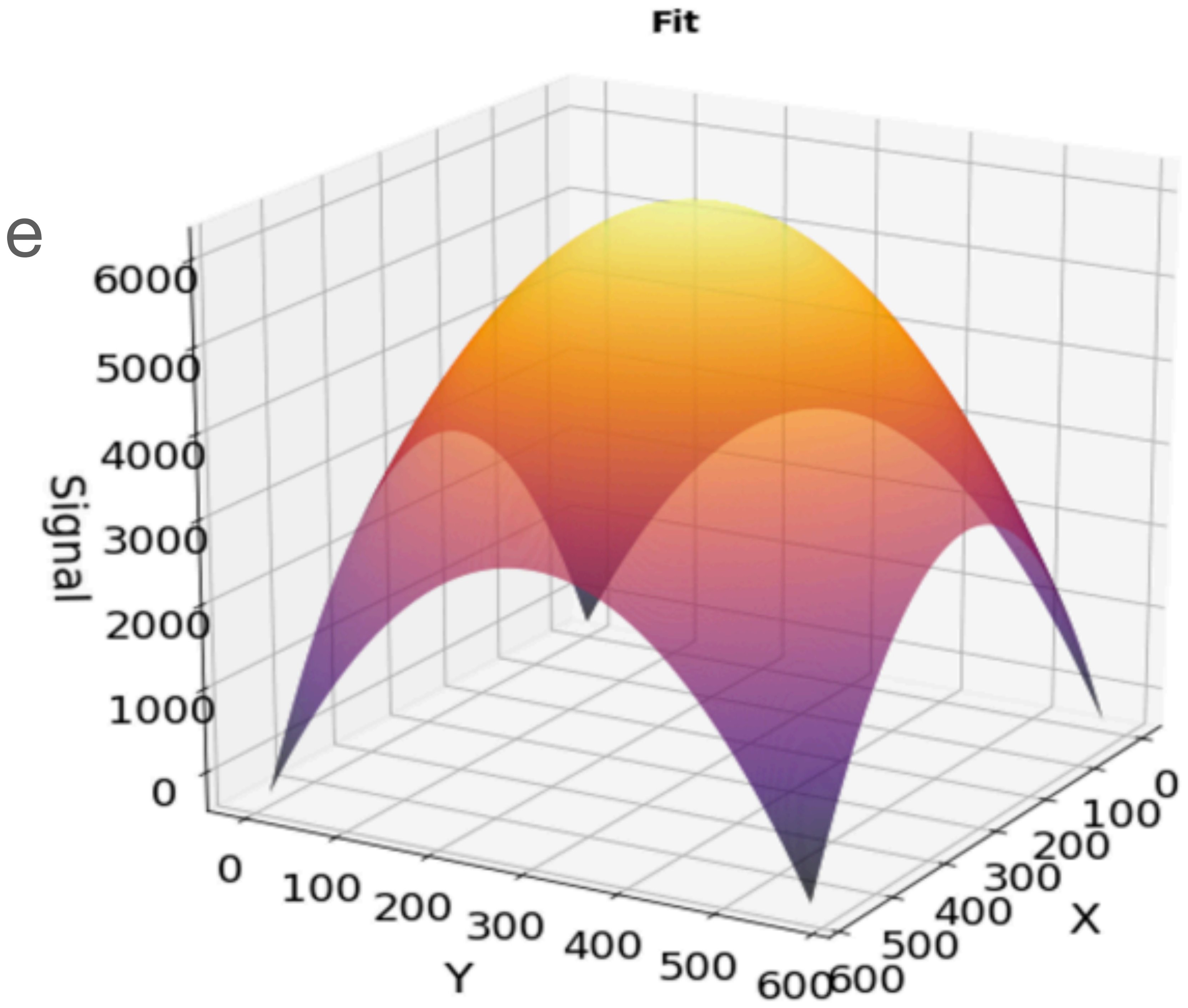
The optical vignetting and other XY dis-uniformities

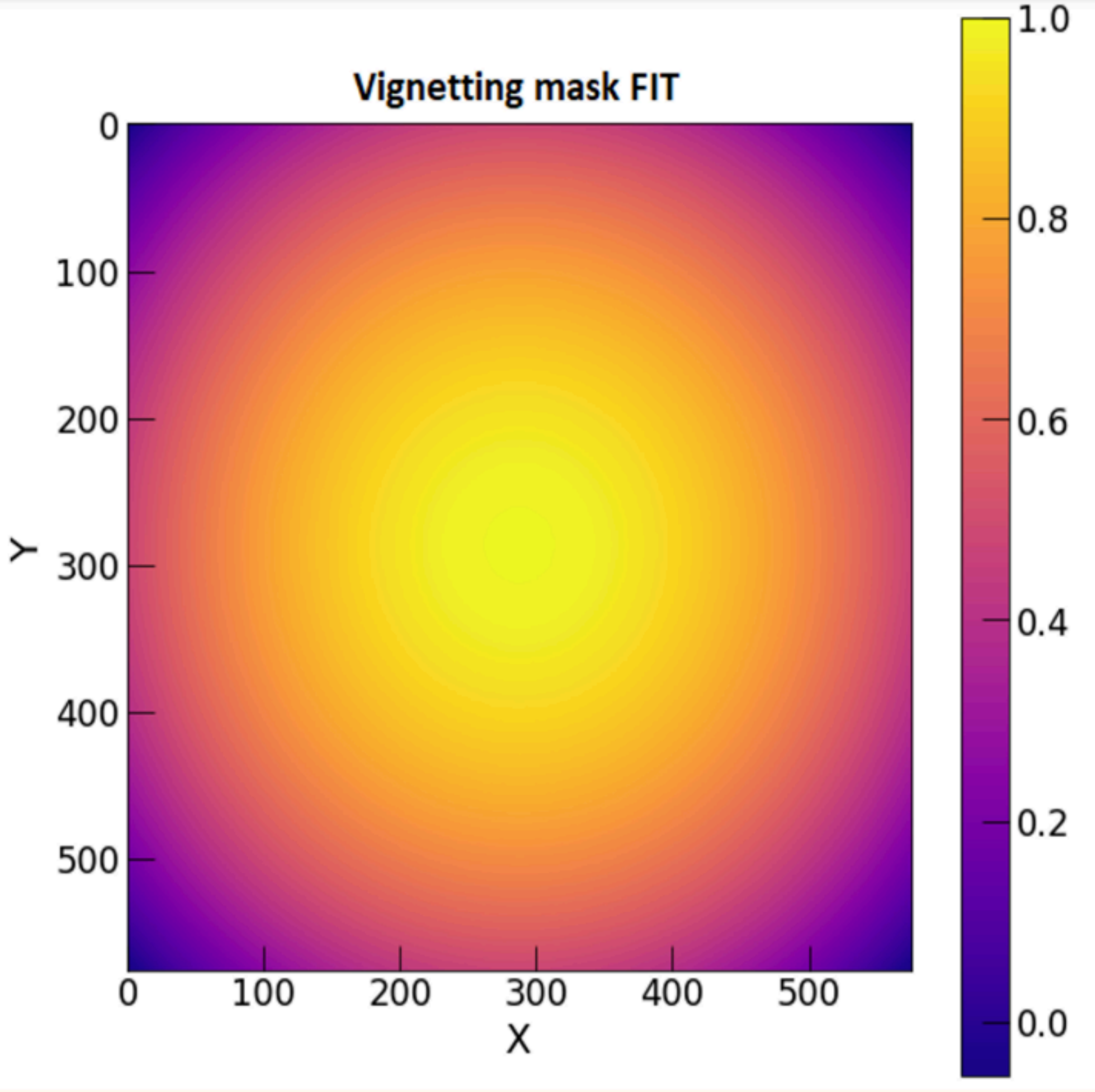
The optical system introduces several effects in the acquired images;

The most relevant from the quantitative point of view is the “vignetting”, i.e. a light collection decrease as a function of the distance from the lens centre;

A “correction map” was produced by starting from the acquisition of a “white wall’

This allows to study possible other dis-uniformities in the LIME response on the XY plane

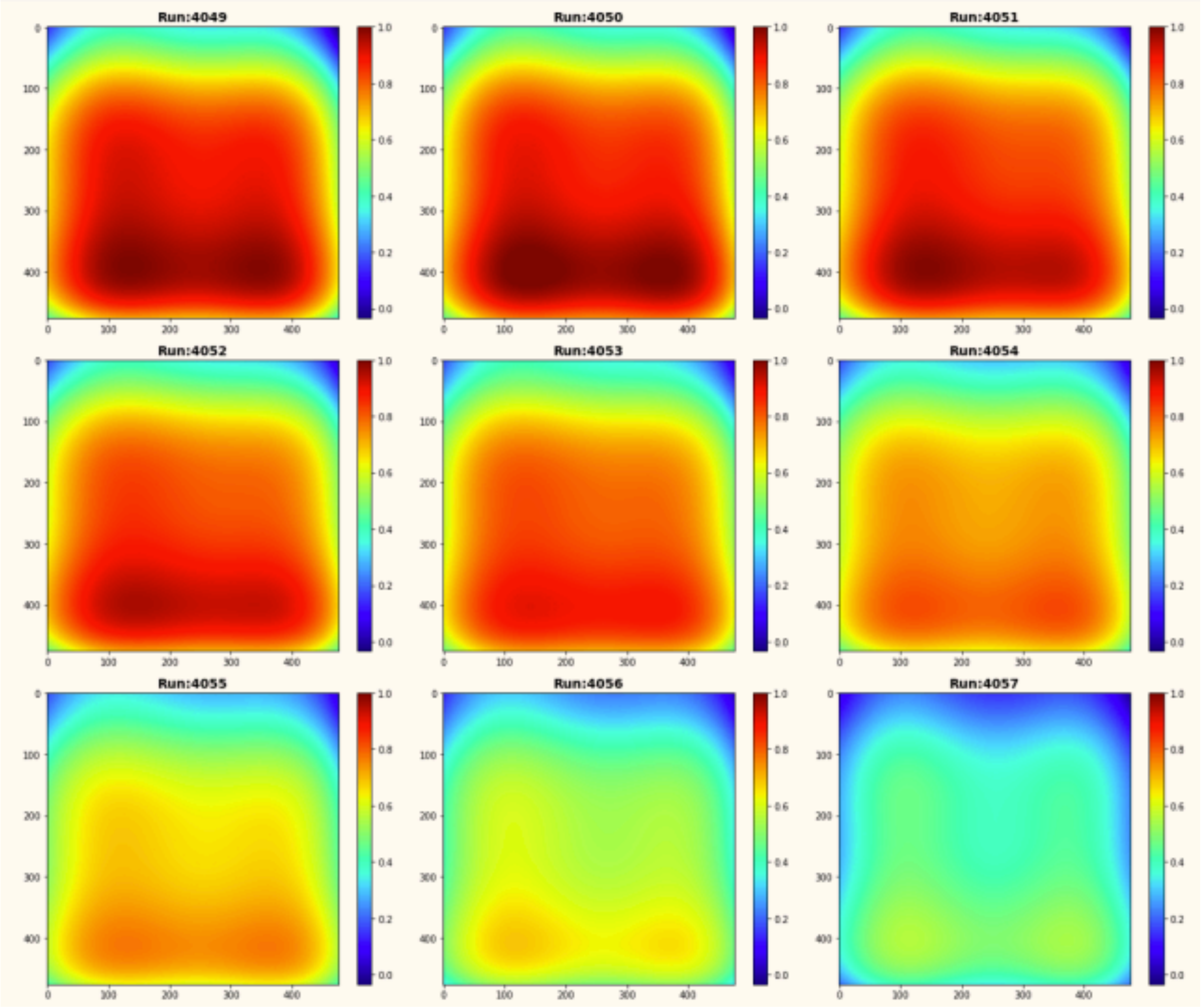




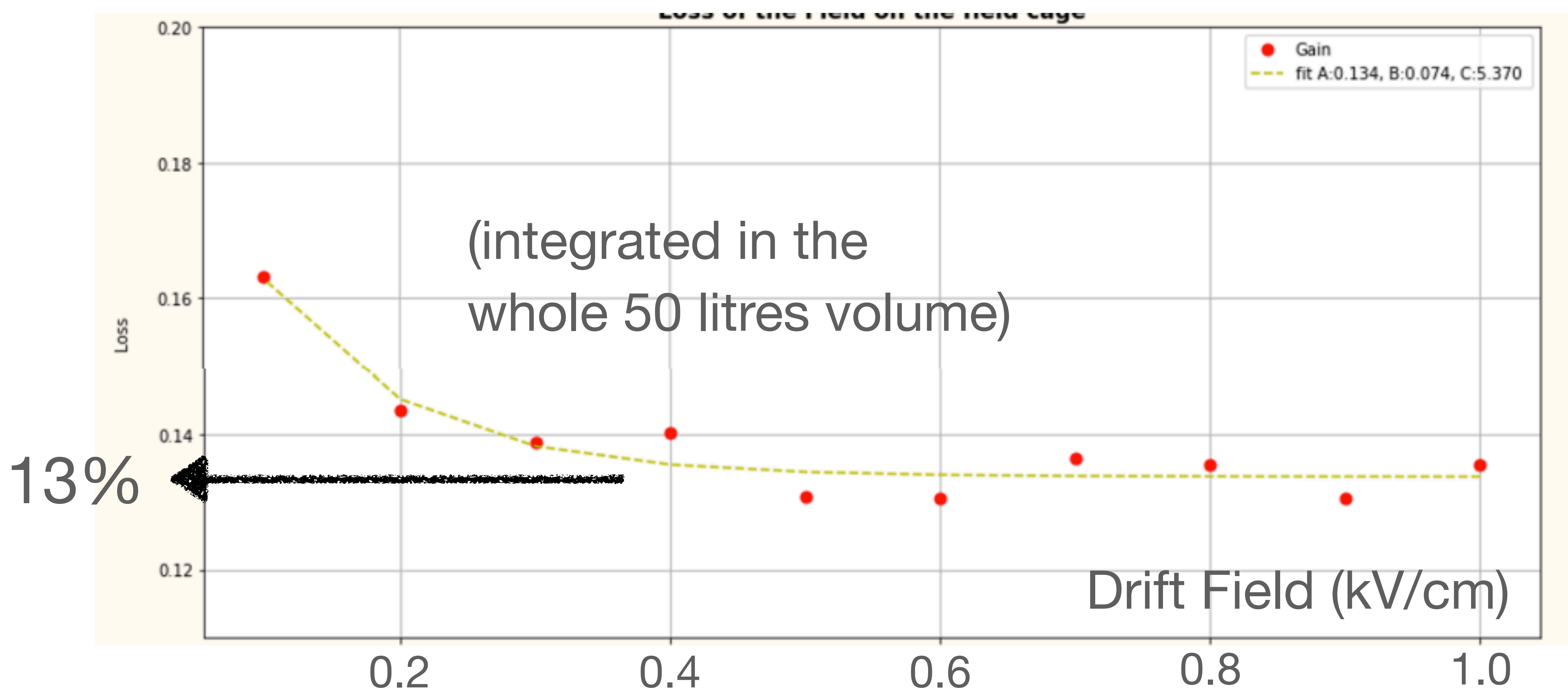
The optical vignetting and other XY dis-uniformities

A first study was performed by undergraduate students:

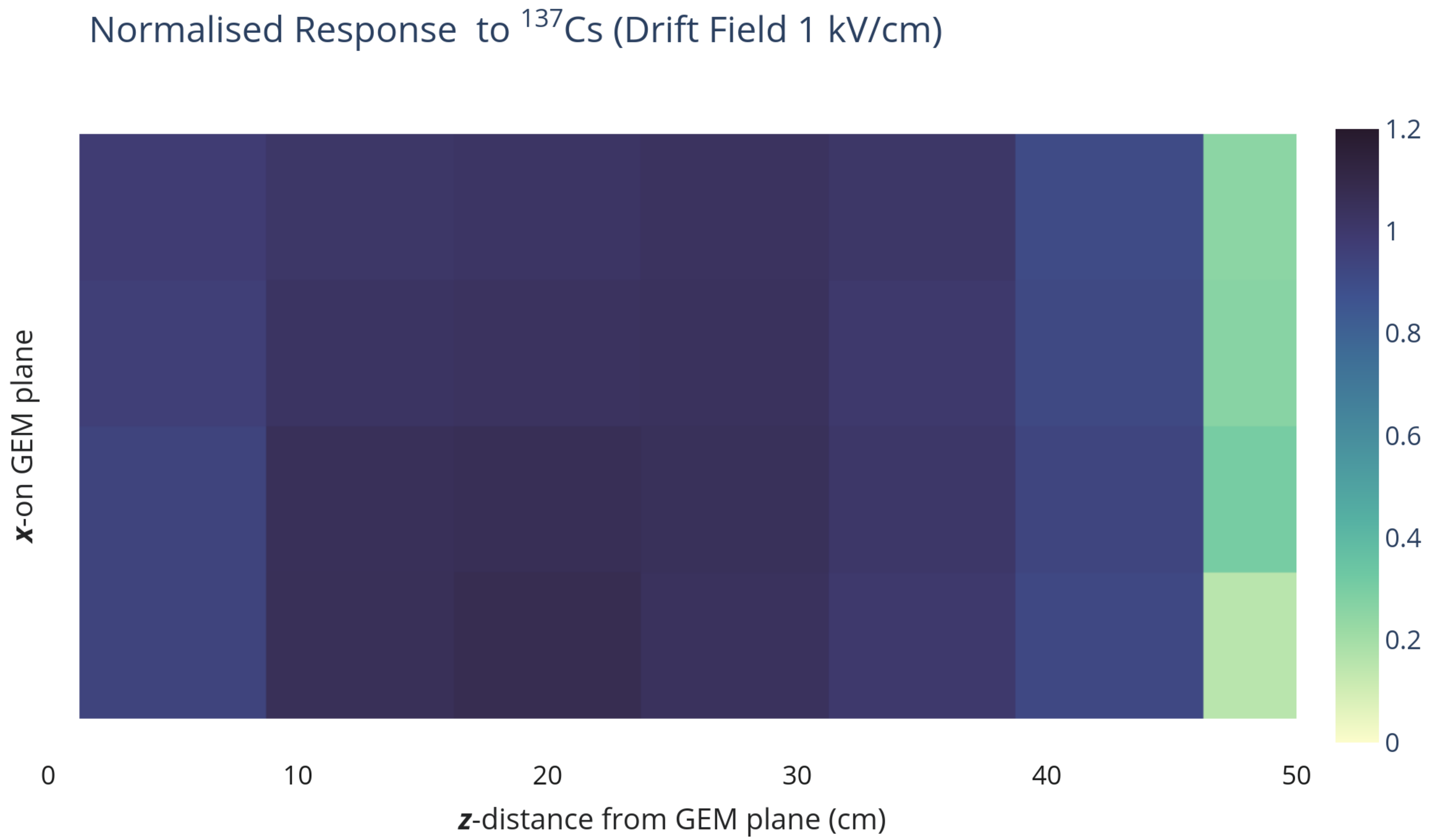
The response to an uniform signal (natural background) was studied as a function of the Drift Field value.



Once the pure optical effect was corrected, the RMS of the distribution provided a good evaluation of other contributions (electric field, gas, mis-alignment, GEM gain)



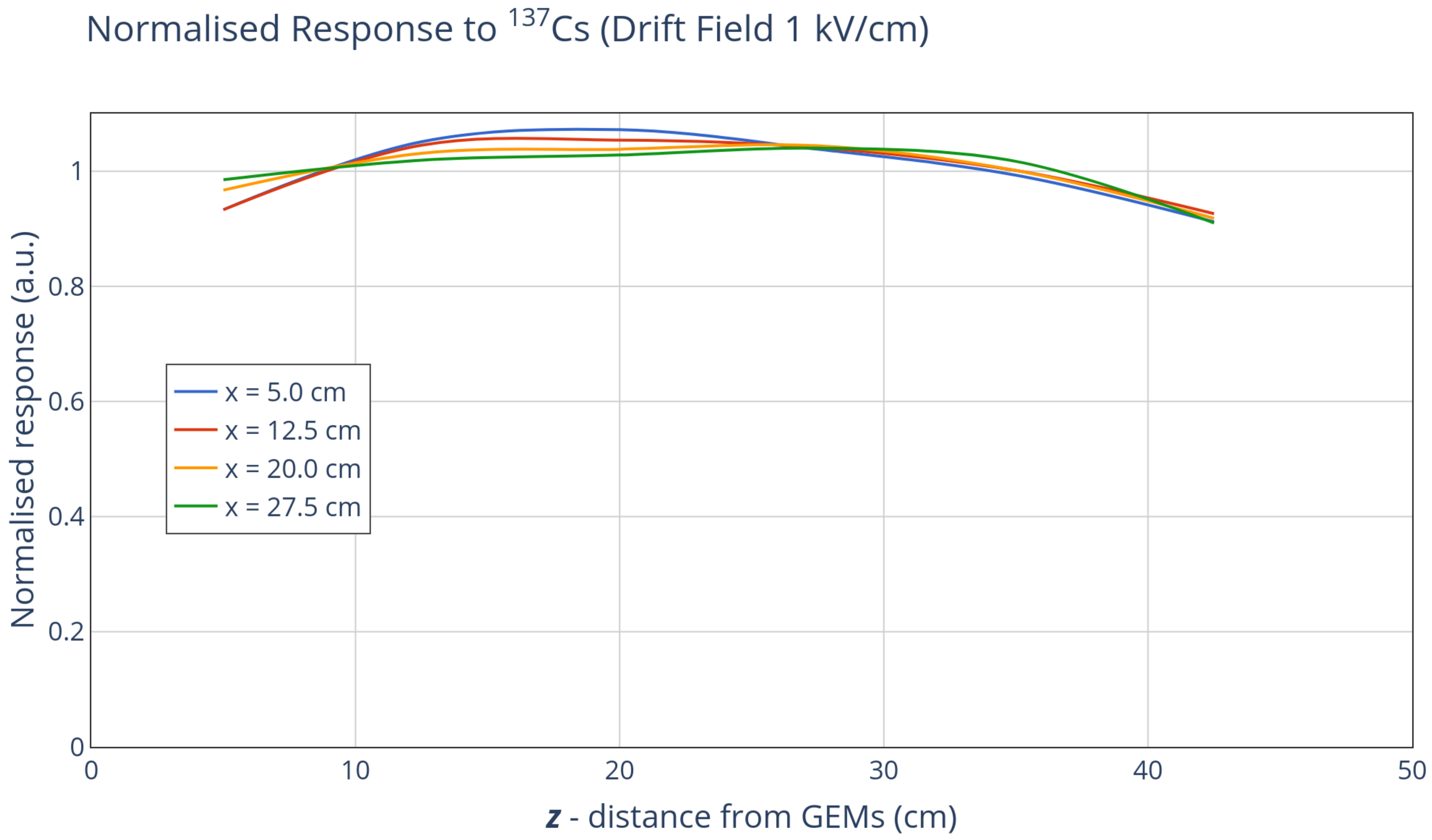
XZ dis-uniformities



By means of a ^{137}Cs source emitting 660 keV penetrating photons, it was possible to check the response on a XZ grid. Caveat:

No vignetting correction performed (to be done);

High energy electrons are not expected to provide saturation;



Data taken and analysed by Alex and Rita;

From the different (normalised) Z-profiles, a very low dependence of the response on the depth was found: below 6% in the whole tested X;

^{55}Fe studies

The 5.9 keV produced by an 55Fe iron source, produce spot like signals similar to the one expected by NR induced by WIMP scattering;

The response of LIME to them were extensively studied;

Average spot shapes show an evident dependence on the distance from the GEM:

- Profile is larger because of the electron diffusion in gas;
- Profile amplitude and total integral increase because of the gain “saturation”;

^{55}Fe studies - light yield in *z*-scans

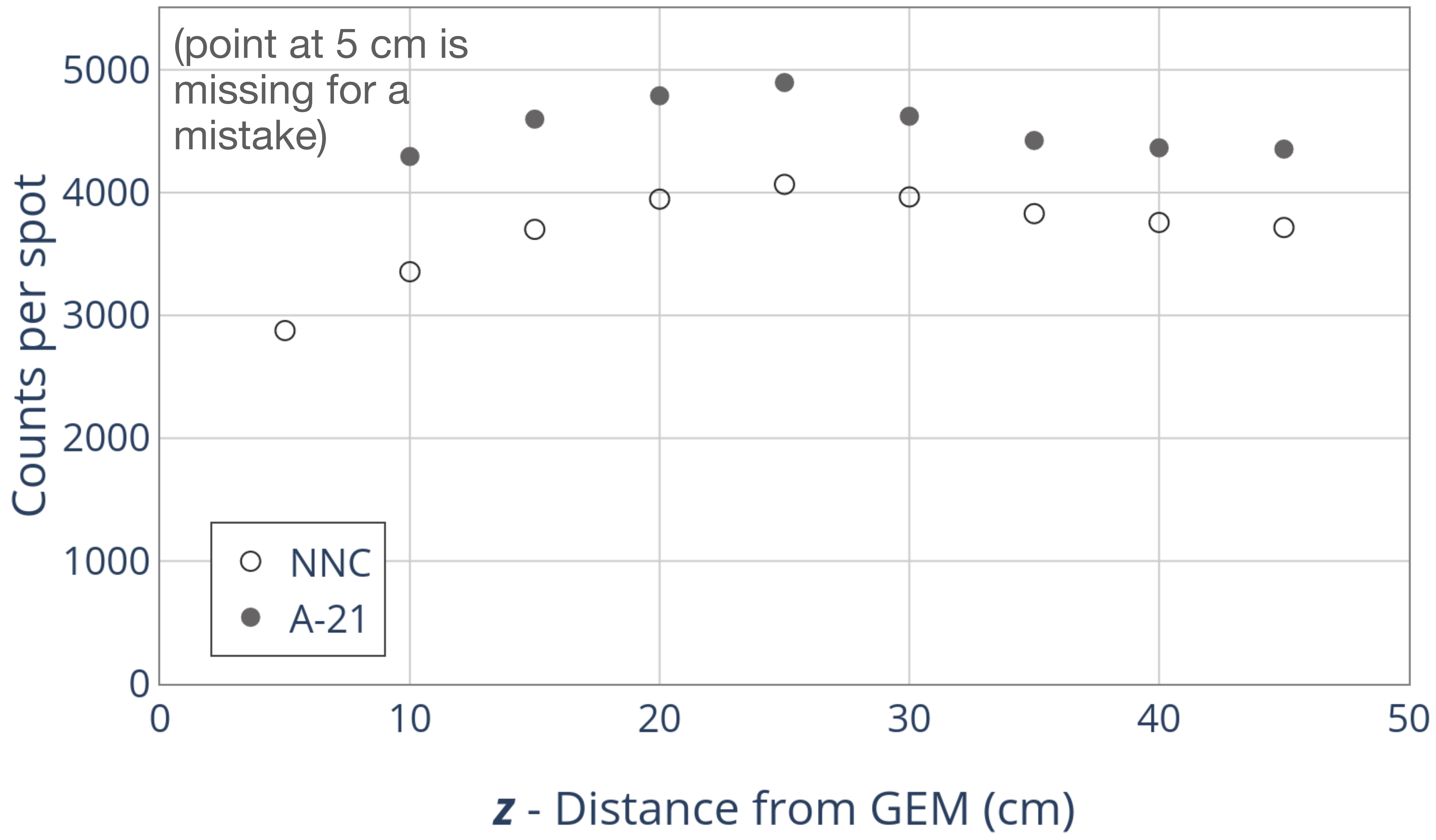
Data analysis was performed in two different ways, to cross check the results:

- a Near Neighbour Clustering (NNC) algorithm by Donatella;
- the Autumn-21 (A-21) version of Emanuele's code by Giulia;

Light collected per spot as a function of the distance from the GEM have very similar behaviours:

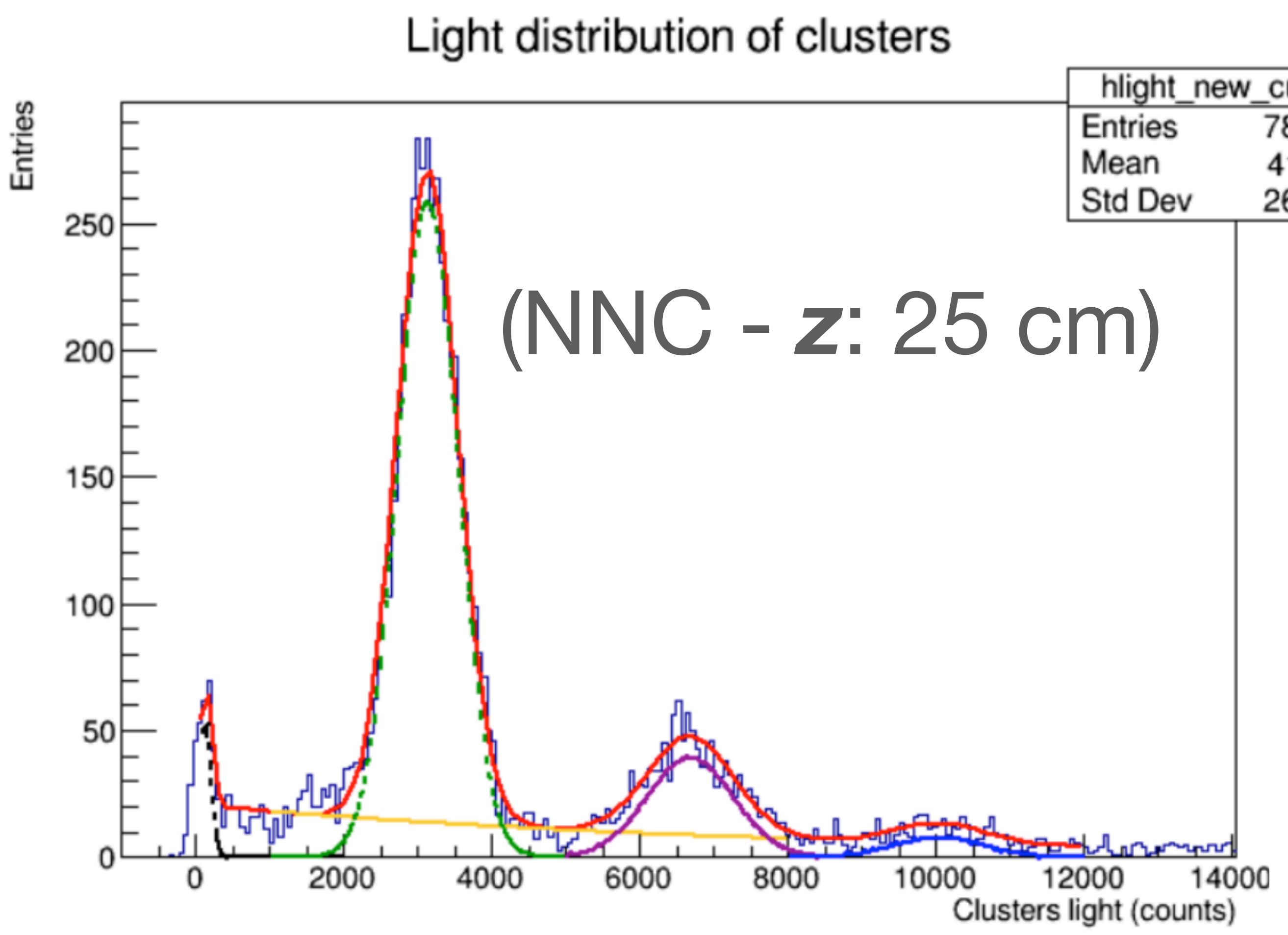
- first increase due to mitigation of saturation because of the diffusion;
- then decrease due to electron absorption in gas;

Still some absolute difference probably due to a different pedestal subtraction. To be investigated;

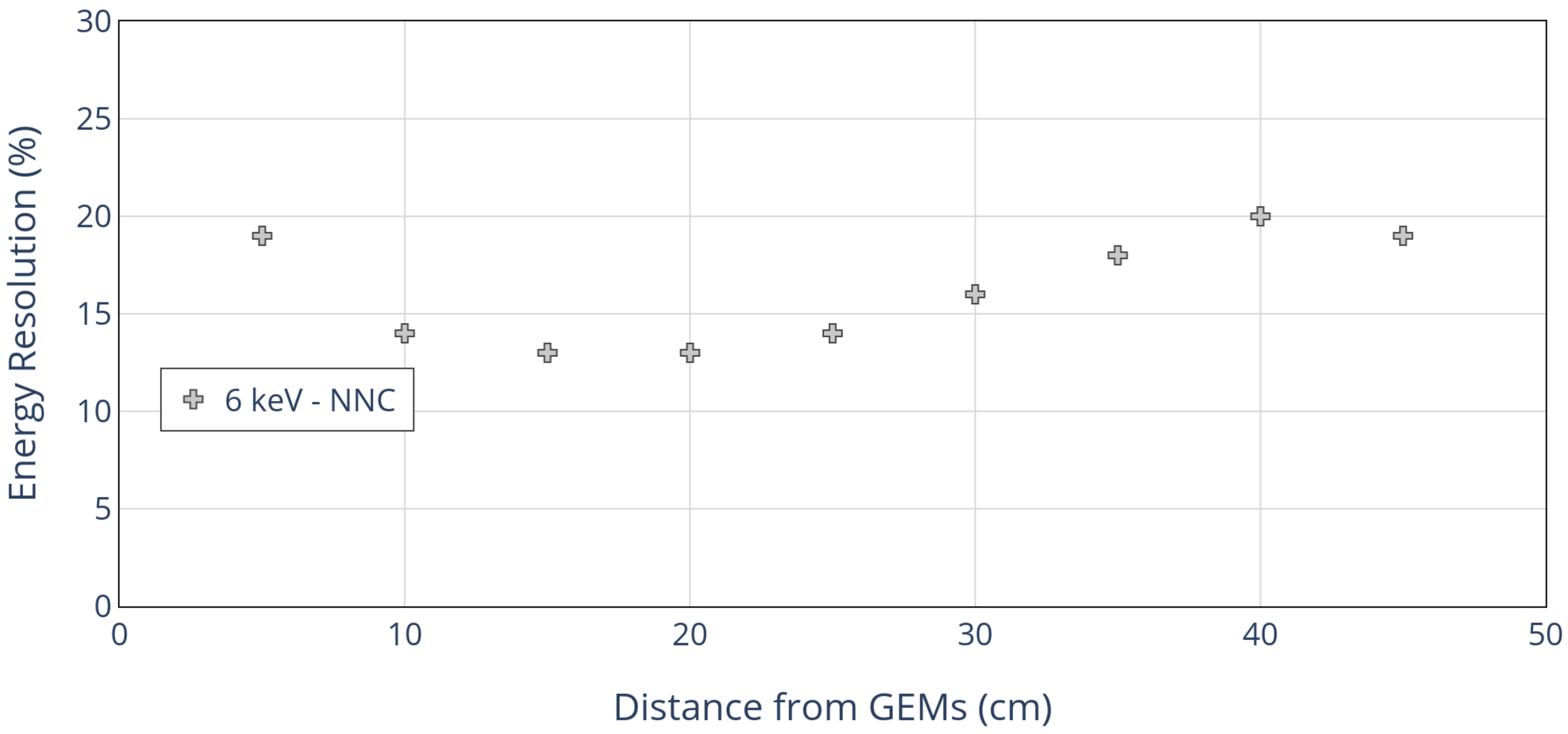


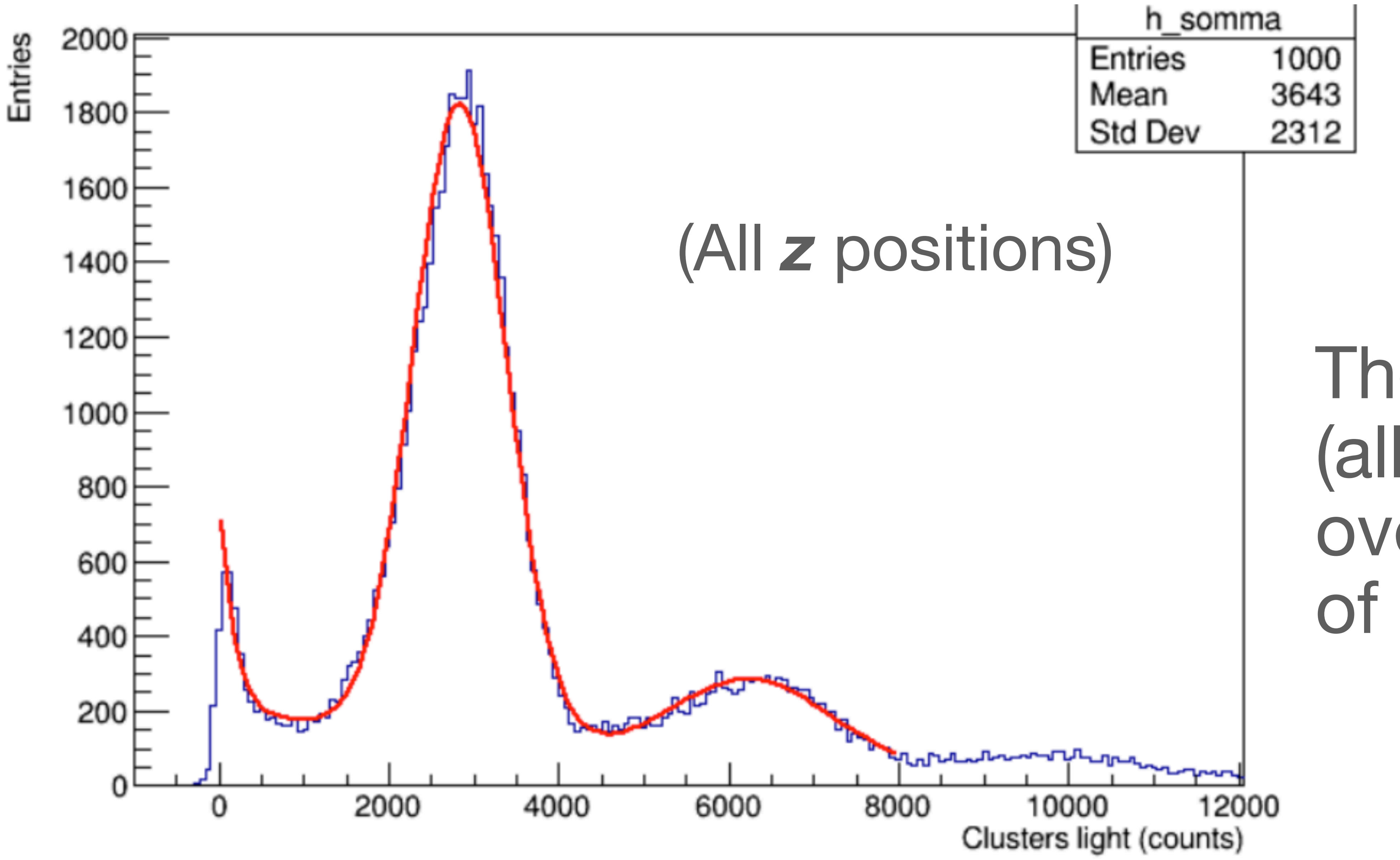
^{55}Fe studies - energy spectra

At fixed ***z*** positions, an Energy resolution between 13% and 20% was found;



Second and third peaks due to not-resolved spots

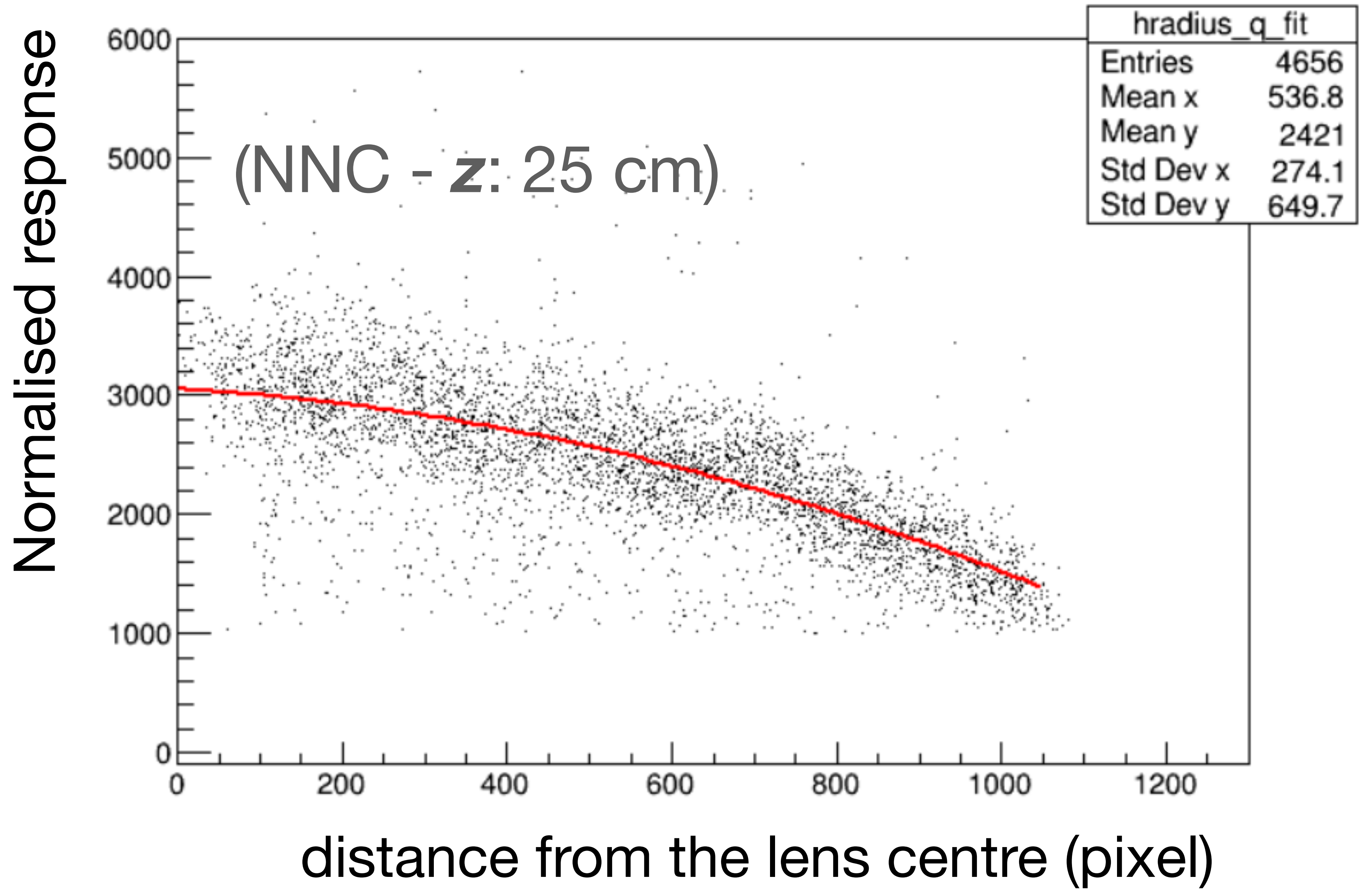


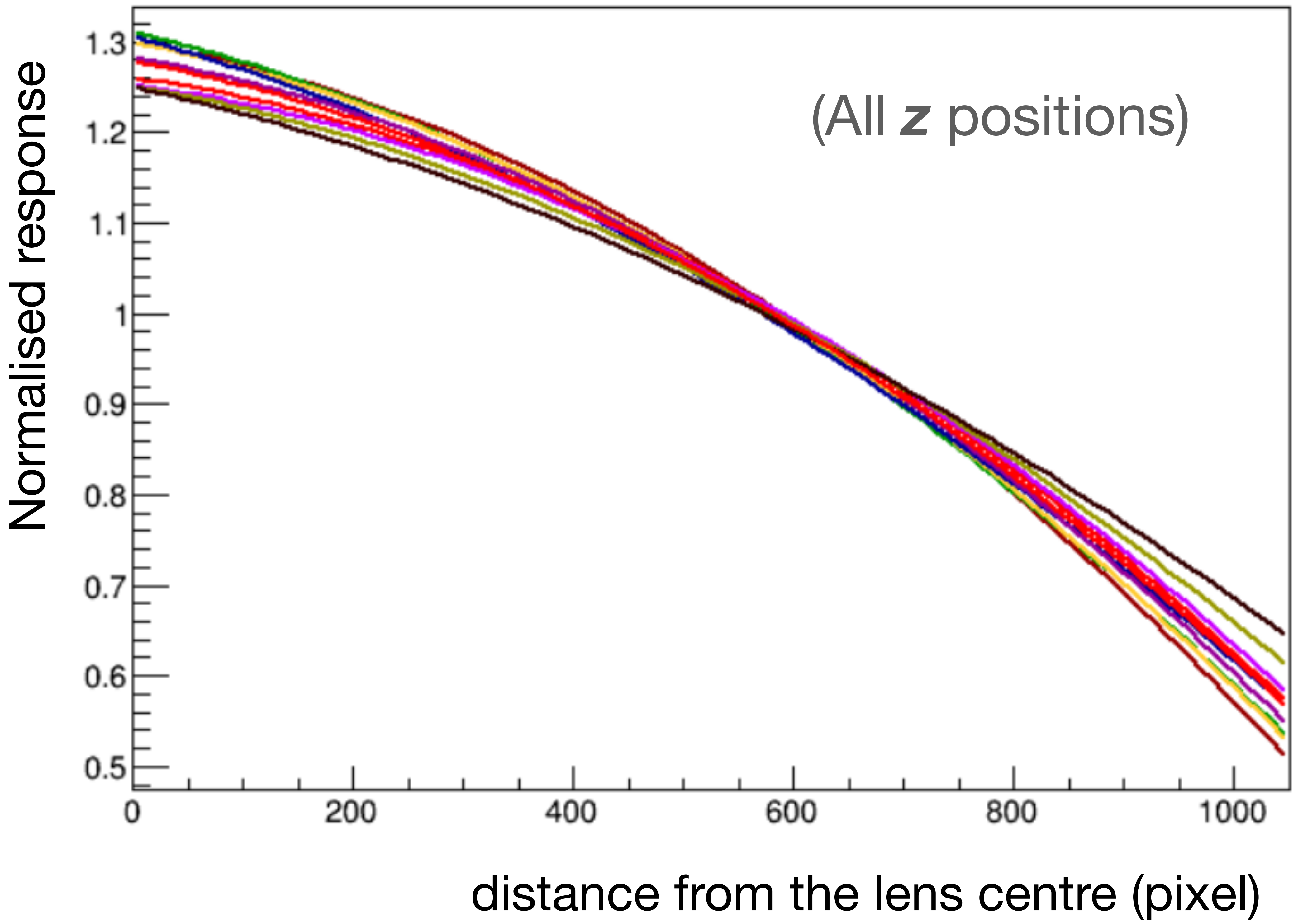


The cumulative spectrum (all ***z*** positions), shows an overall Energy resolution of 19% was found;

^{55}Fe studies - light yield in ***z***-scans

The profiles of the dependence of LIME response as a function of the distance from the lens centre was studied by placing the source to highlight any possible dependence of ***xy*** dis-uniformities on ***z***



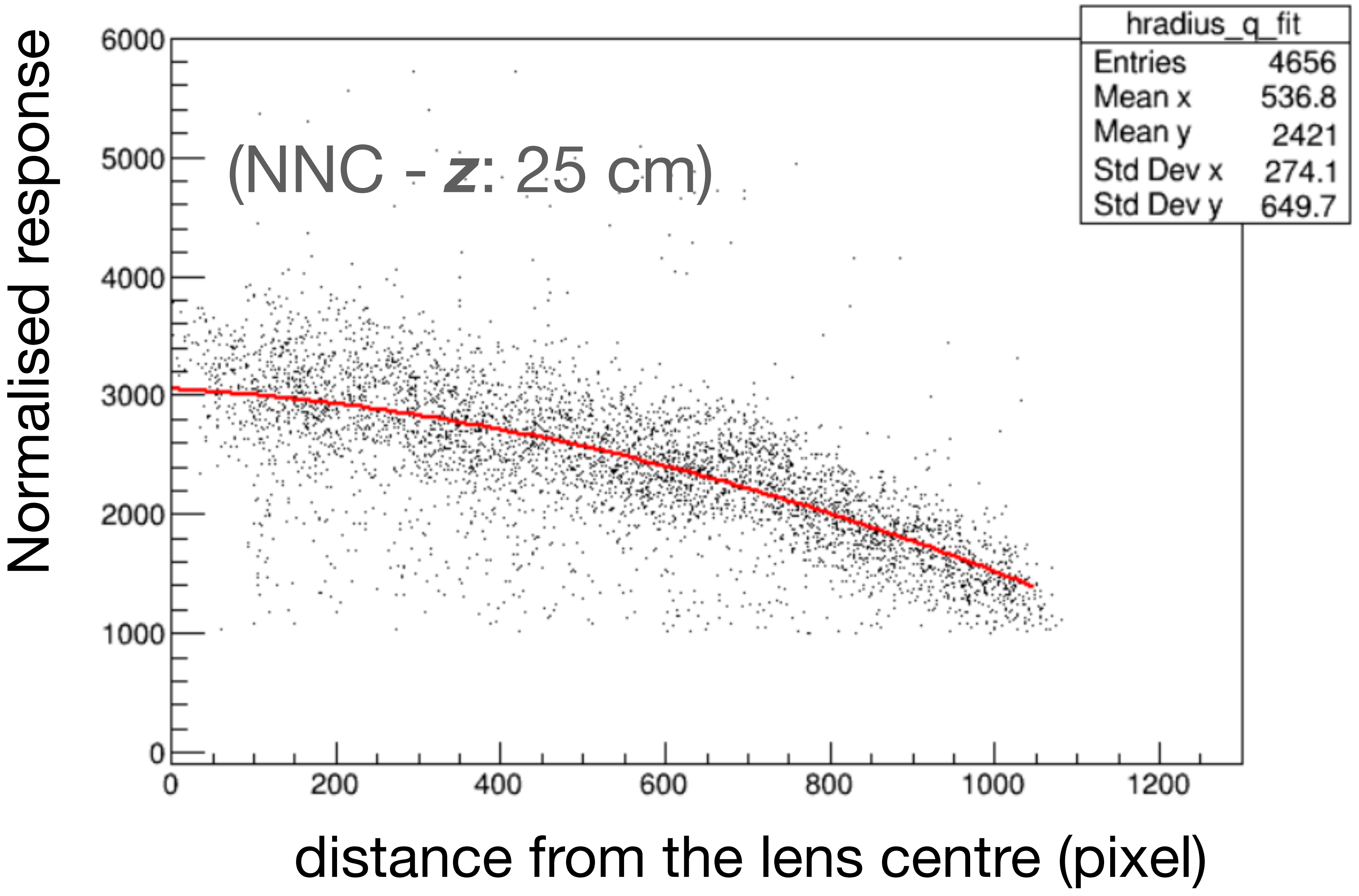


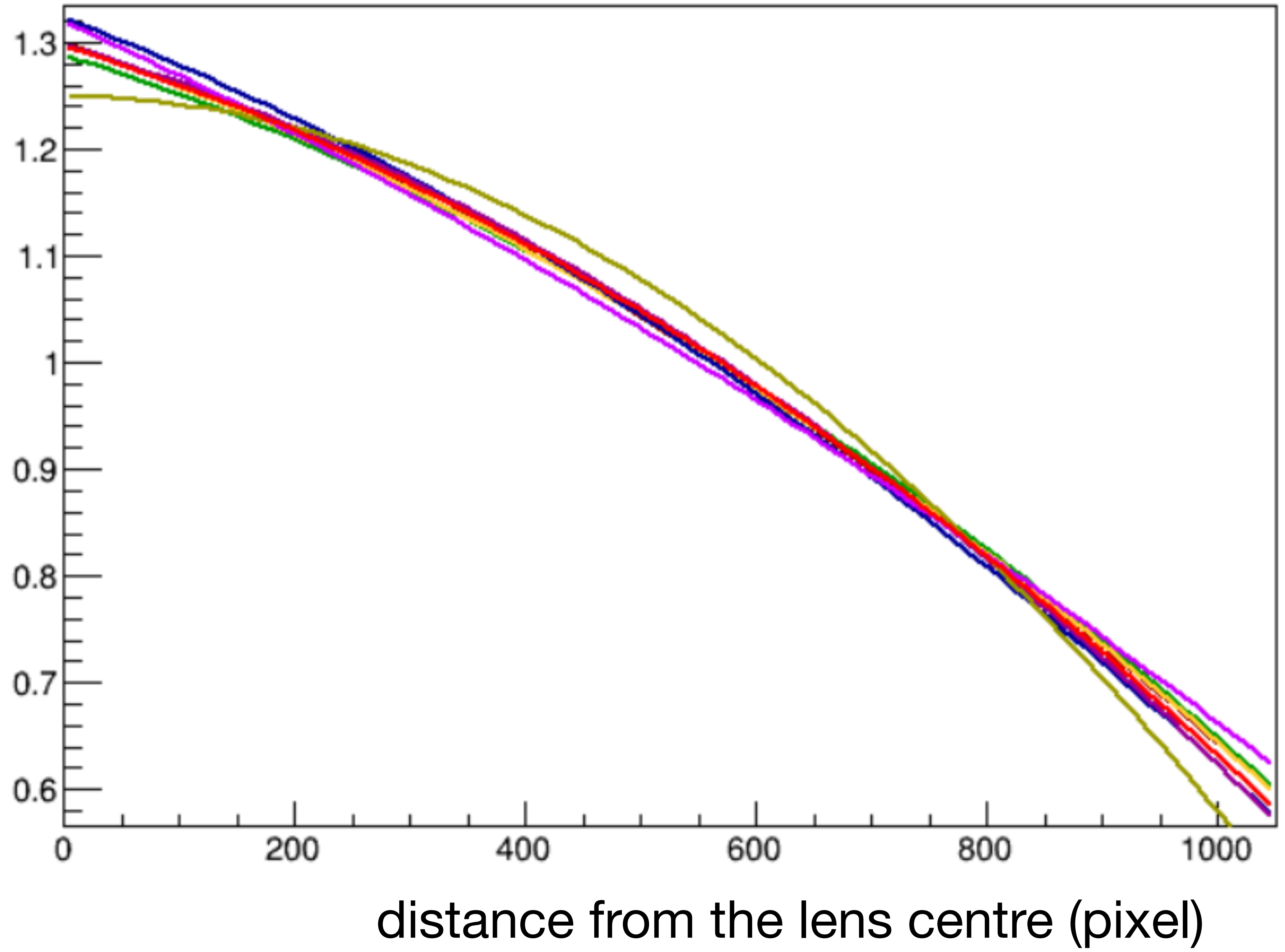
Once normalised, behaviors are very similar. An overall RMS of 2% was evaluated, confirming the good response stability ***z***;

A comparison with pure optical correction no yet done. To be done;

^{55}Fe studies - light yield in V_{GEM1}-scans

The profiles of the dependence of LIME response as a function of the distance from the lens centre was studied by placing the source to highlight any possible dependence of ***xy*** dis-uniformities on V_{GEM1}





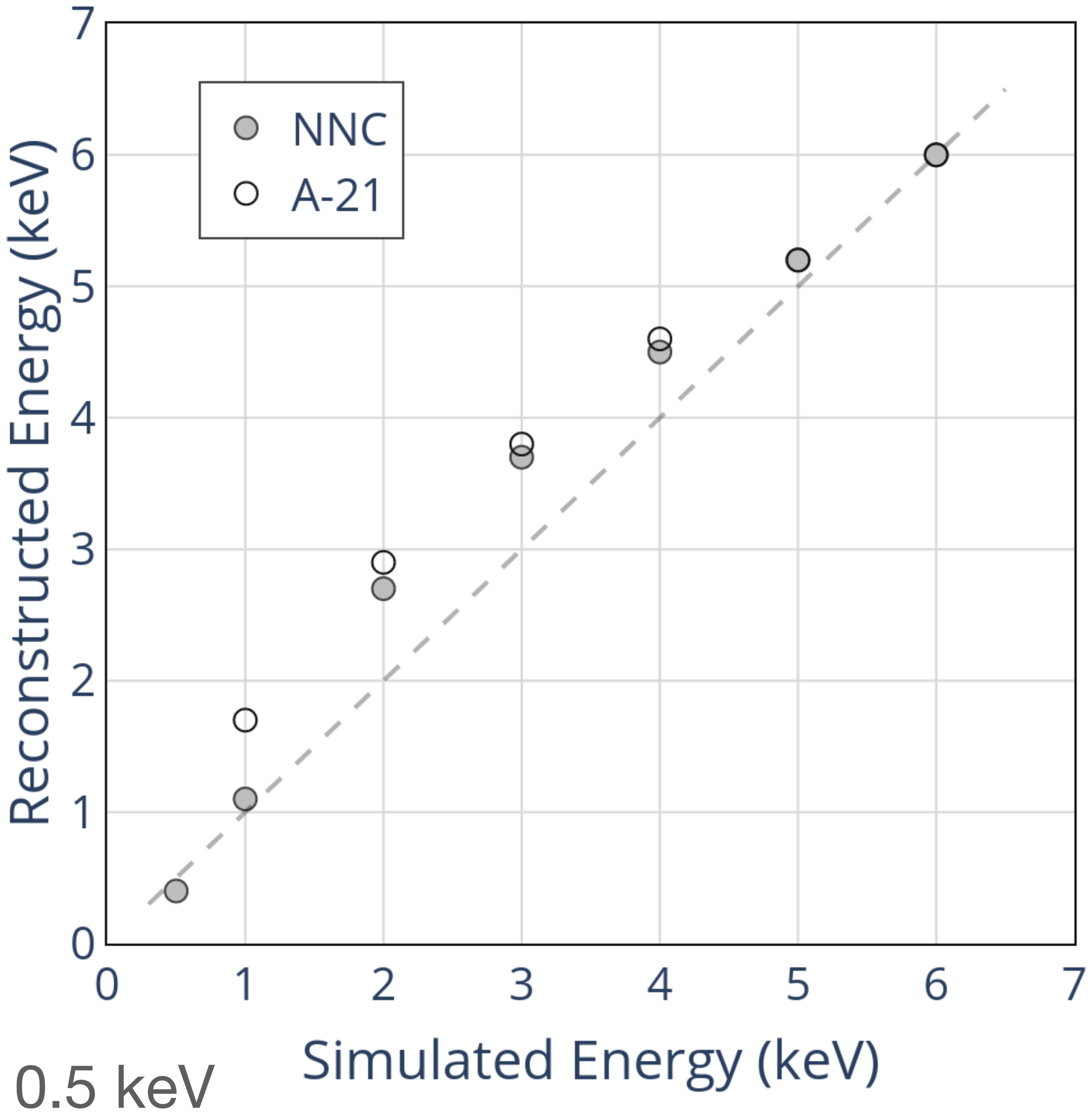
Once normalised, also in this case, behaviors are very similar with an overall RMS of 2%;

Effect doesn’t seem to be related to GEM gain;

^{55}Fe studies - light yield

To simulate energy releases below the 6 keV provided by the ^{55}Fe source, the response was studied while decreasing the voltage on the first GEM (V_{GEM1})

V_{GEM1}	Energy (keV)
440	6
431	5
420	4
406	3
386	2
350	1
320	0.5



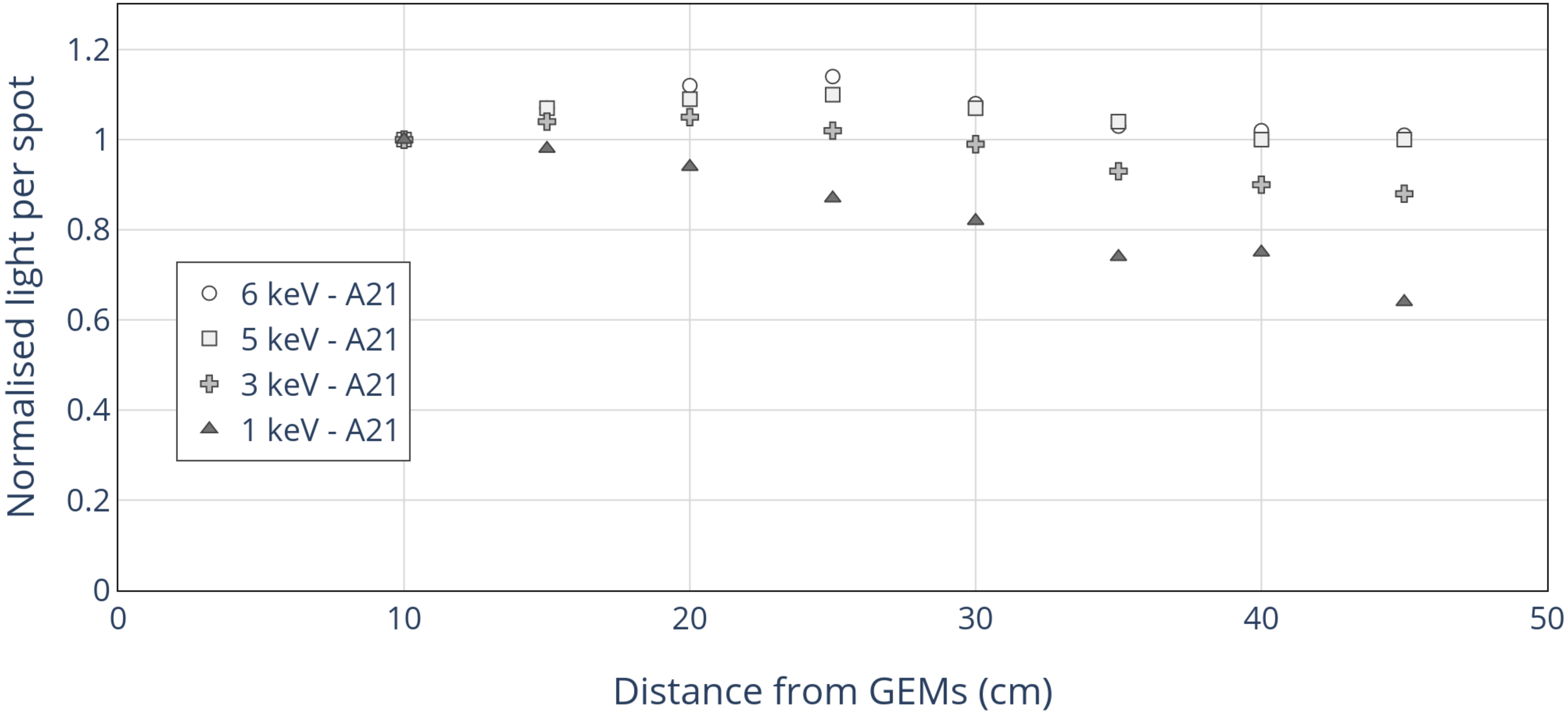
A-21: point at 0.5 keV is missing for a mistake

Even if the NNC algorithm reconstructs last two points very close to the ideal behavior, in both cases the simulated energies seems to be far from perfect.

^{55}Fe studies - light yield

A first effect is that, for lower charges, the “saturation” effect decreases and almost disappears;

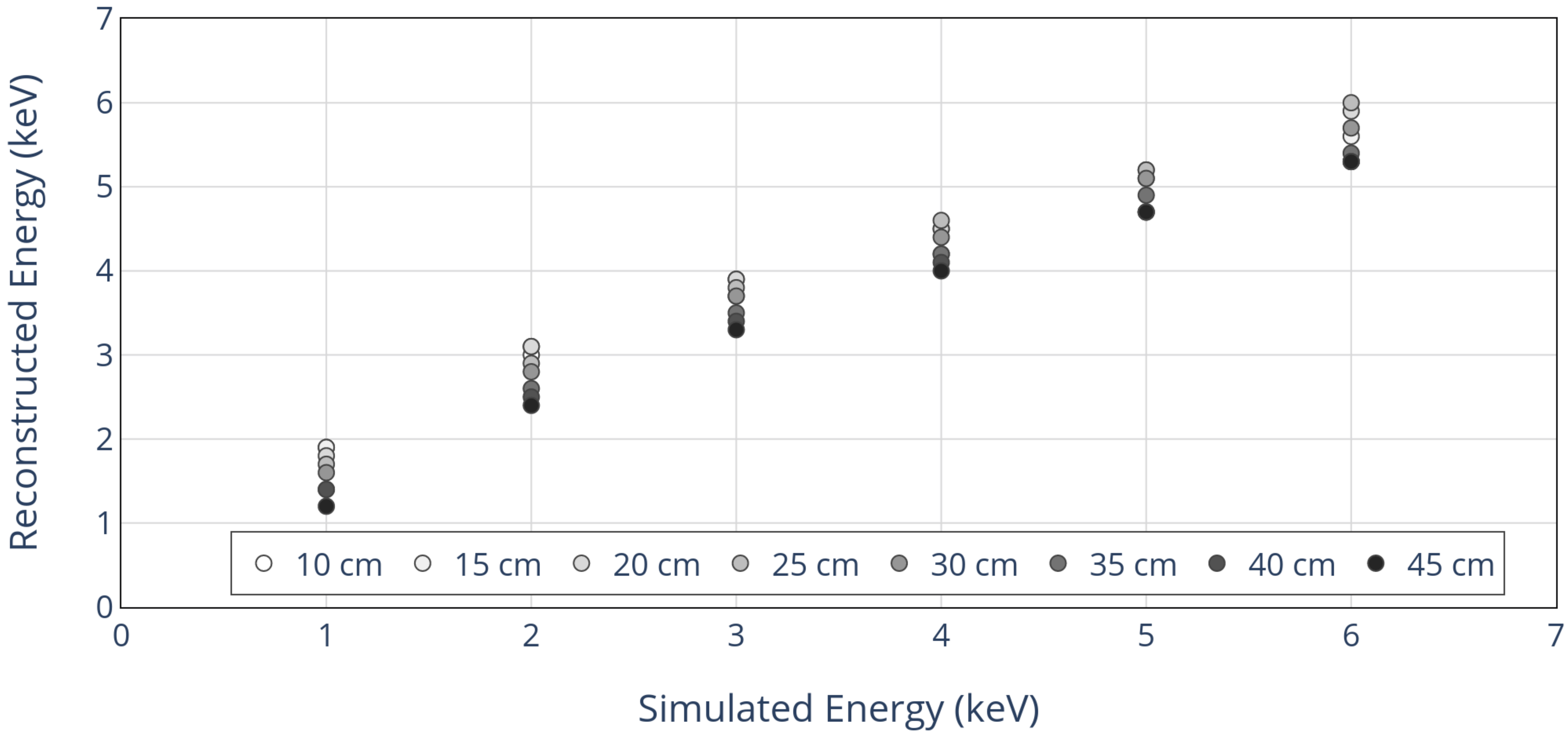
V_{GEM1}	Energy (keV)
440	6
431	5
420	4
406	3
386	2
350	1



^{55}Fe studies - light yield

An annoying secondary effect of the different "saturation" is that calibration depends on the position

V_{GEM1}	Energy (keV)
440	6
431	5
420	4
406	3
386	2
350	1

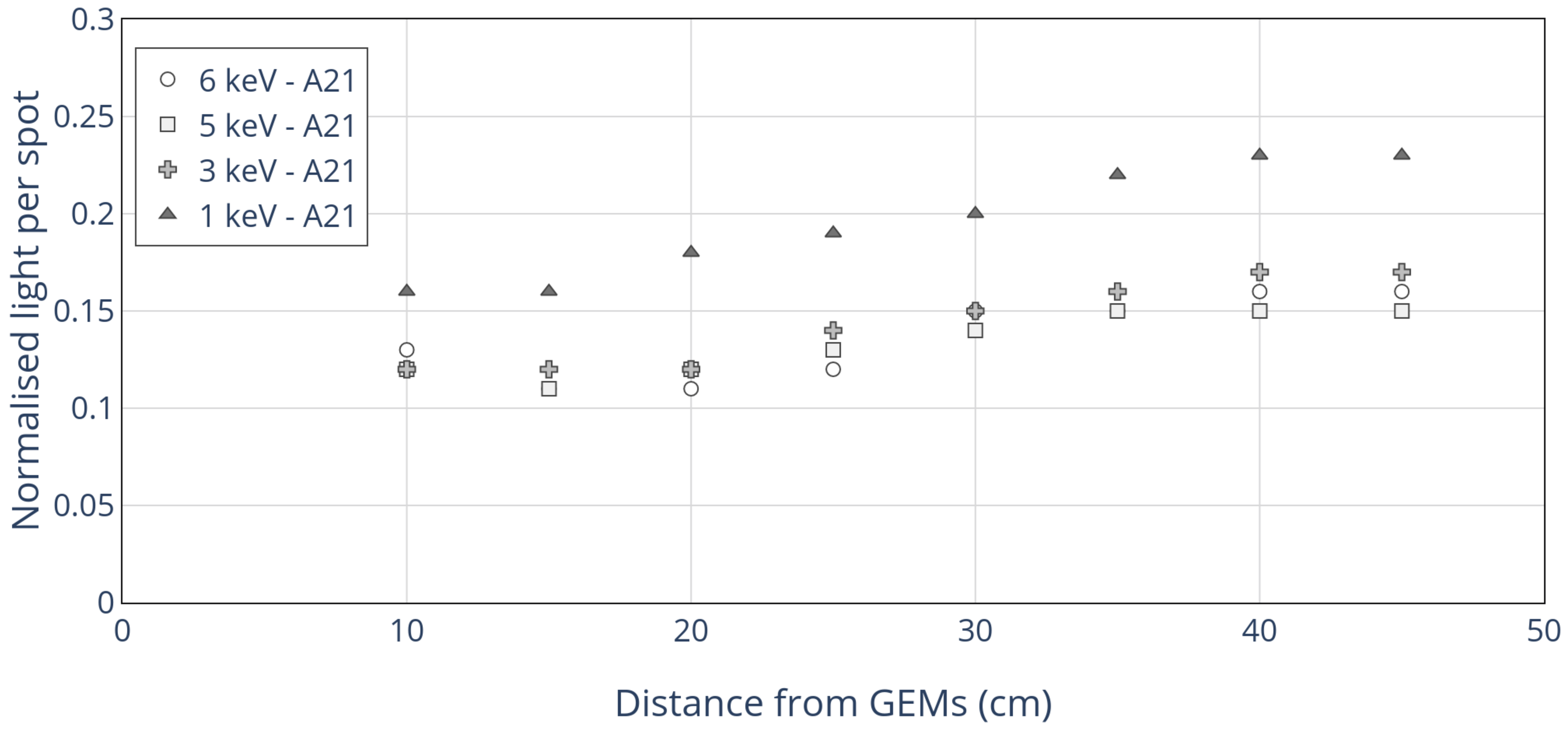


The same amount of charge, released at different ***z,*** produces different amount of light

^{55}Fe studies - light yield resolution

At different ***z***, the resolution was evaluated for the different "simulated energies"

V_{GEM1}	Energy (keV)
440	6
431	5
420	4
406	3
386	2
350	1

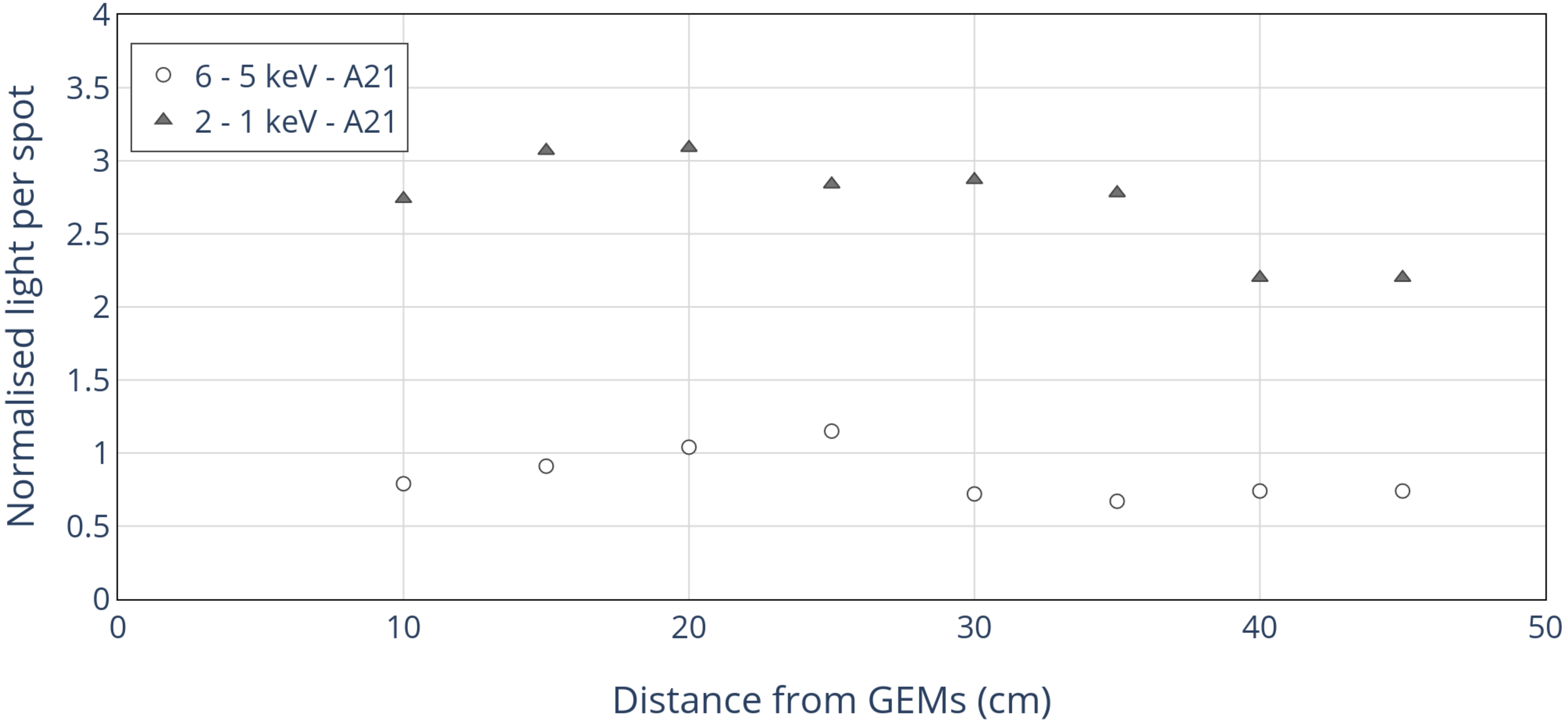


Even for the "1 keV" a resolution between 15% and 25% was found.

^{55}Fe studies - resolving power

At different ***z,*** the resolving power between two energies $\Delta\mu/\sigma$ was evaluated

V_{GEM1}	Energy (keV)
440	6
431	5
420	4
406	3
386	2
350	1



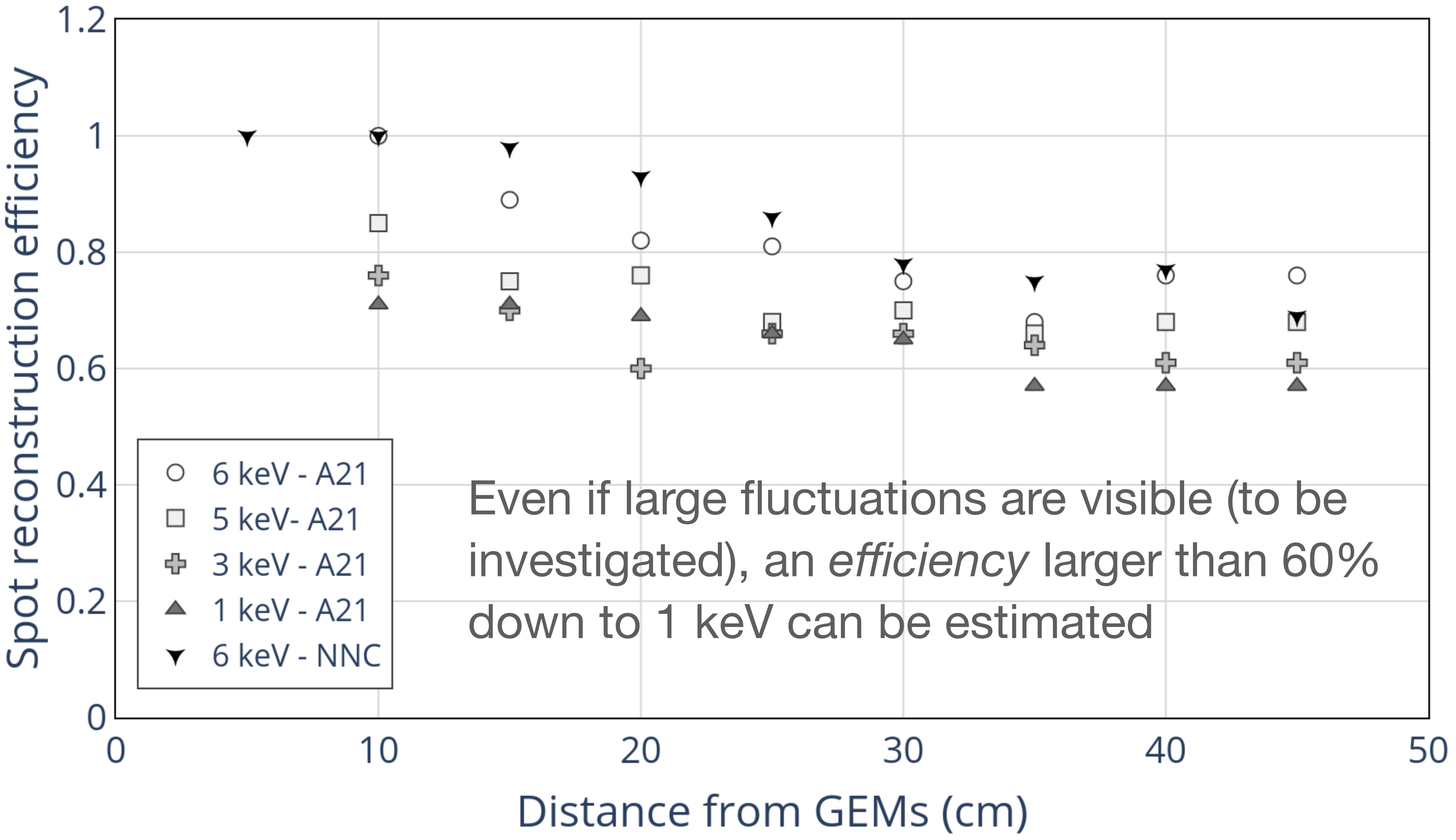
An average separation of more than 2σ was found for the “1 keV” data.

^{55}Fe studies - detection efficiency

The number of reconstructed spots per run was studied to evaluate the detection efficiency;

The ratio to the maximum number reconstructed spots (10 cm - V_{GEM1}=440 V) is shown in the plot;

V_{GEM1}	Energy (keV)
440	6
431	5
420	4
406	3
386	2
350	1

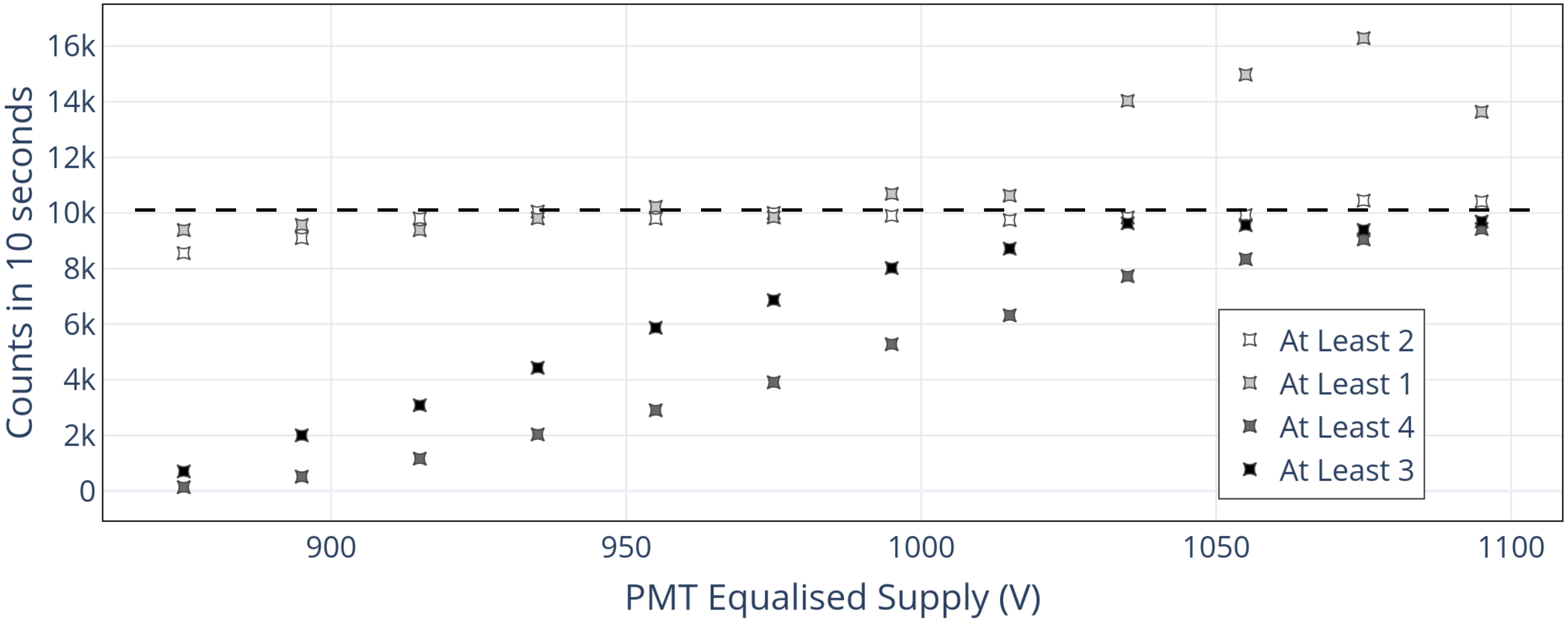


Even if large fluctuations are visible (to be investigated), an *efficiency* larger than 60% down to 1 keV can be estimated

PMT-Trigger

The responses of the 4 PMTs were studied and equalised by Chiara;

With the help of GSSI team, the rate of different trigger schemes were studied;



Accidental rate was:

“At Least 1”: 10 Hz;

“At Least 2”: 1 Hz;

“At Least 4”: 0.1 Hz;

“At Least 1” is too prone to noise at high HV values;

“At Least 4” requires high HV values to be efficient;

Anyway, all schemes seem to stabilise at the same level around 1 kHz;

We’ll tune the scheme (and thresholds) once LIME is underground;

Activities: R&D

CAMERA Background reduction

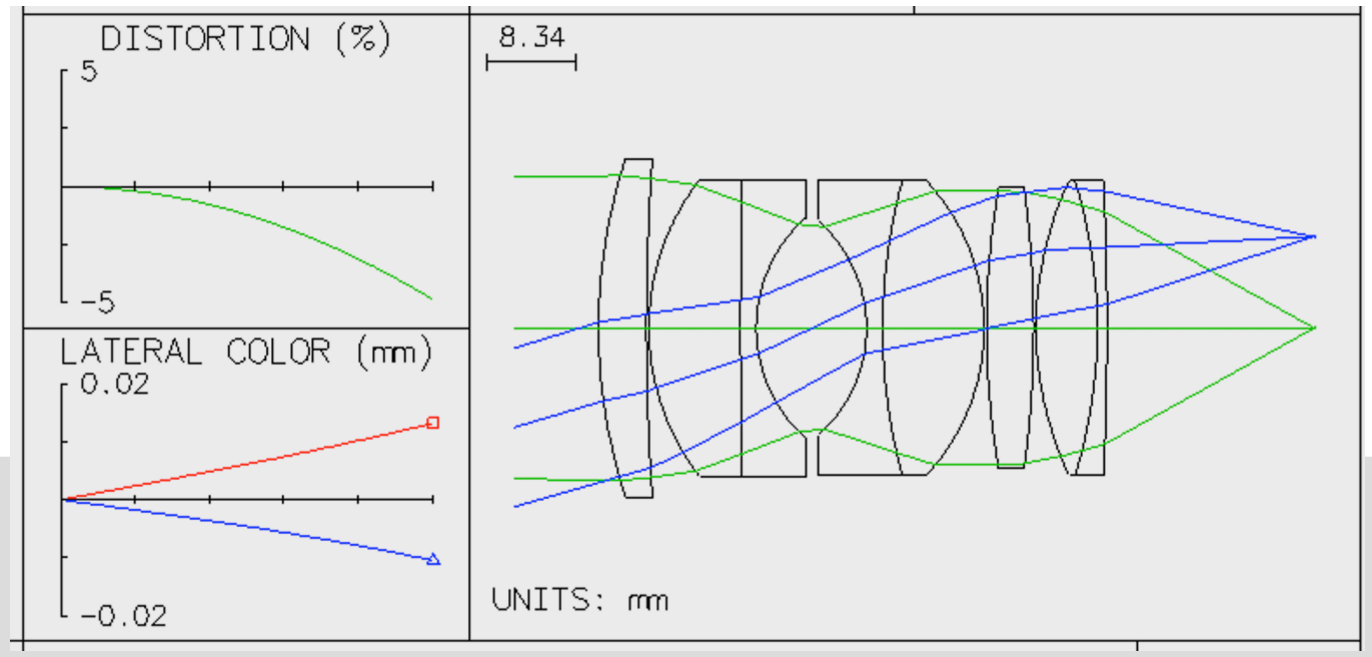
description	piece	Ra228 from Th232 [Bq]	Th228 from Th232 [Bq]	Ra226 from U238 [Bq]	Th234 from U238 [Bq]	Pa234m from U238 [Bq]	K40 [Bq]	U235 [Bq]	Cs 137 [Bq]
CMOS sensor	1	0.0052	0.0053	0.0068	0.011	0.007	3.5	0.00091	0.00042
sensor frame	1	0.113	0.111	0.08	0.29	0.14	0.08	0.006	0.00086
sensor frame holder	1	0.007	0.016	0.0046	0.5	0.26	0.08	0.015	0.001
peltier cooler	1	0.00036	0.00024	0.00017	0.012	0.021	0.0026	0.0002	0.000054
electronic board	1	0.208	0.202	0.187	0.16	0.25	0.24	0.009	0.002
electronic board	1	0.248	0.229	0.335	0.12	0.2	0.19	0.0075	0.0025
electronic board	1	0.0679	0.0639	0.0552	0.053	0.1	0.053	0.0017	0.00047
electronic board	1	0.104	0.1	0.072	0.12	0.266	0.07	0.002	0.0011
cooling fan	1	0.07	0.0687	0.0558	0.1	0.2	1.4	0.0013	0.0011
metal supports	1	0.0012	0.0007	0.00031	0.024	0.036	0.0052	0.00074	0.0004
plastic support	1	0.0048	0.002	0.0024	0.08	0.16	0.1	0.004	0.00085
metal support	1	0.01	0.0067	0.003	0.8	1.1	0.015	0.039	0.0015
plastic objective support	1	0.006	0.0073	0.003	1.6	1.2	0.02	0.052	0.00093
camera case	1	0.0028	0.013	0.001	0.24	0.2	0.01	0.008	0.00031
camera objective case	1	0.0025	0.028	0.001	0.36	0.33	0.012	0.013	0.00029
sensor plastic frame	1	0.0004	0.00025	0.00011	0.0011	0.0081	0.0025	0.0004	0.00008
glass window	1	0.00033	0.00022	0.0002	0.0023	0.0016	0.006	0.0002	0.00024
plastic o-ring	1	0.001	0.001	0.00043	0.027	0.06	0.0032	0.001	0.00013
plastic o-rings	1	0.0011	0.00041	0.00049	0.0059	0.02	0.0043	0.00027	0.00009
Total		0.85359	0.85572	0.80851	4.5063	4.5597	5.7938	0.16222	0.014324

Different **cameras** were **measured** (Thanks to M. Laubenstein)

We had separate meetings with **Hamamatsu** and **Teledyne-Photometrics** both expressed interest in **investigating the possibility of reducing** as much as possible the **radio-activity**;

Lens background reduction

We studied low radioactive **fused silica** to produce fixed focus **lenses** (thanks to Ioan Dafinei)

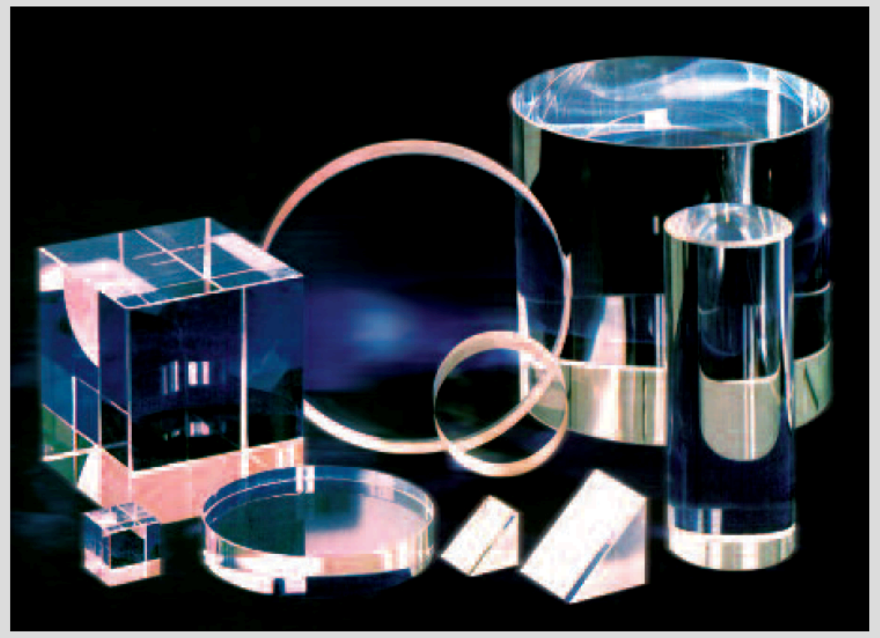


Heraeus

Spectrosil® synthetic fused silica is manufactured using a patented, environmentally friendly process resulting in a glass of exceptional purity and excellent visual quality. It is a very homogeneous synthetic fused silica glass for deep UV optical applications.

Spectrosil® is chlorine-free resulting in outstanding laser damage resistance due to the reduced tendency to form E' centres.

Spectrosil® 2000 is free of bubbles and inclusions and due to its ultra-high purity, has exceptional optical transmission in the deep ultraviolet and visible, with a useful range from below 180 nm through to 2000 nm.



LOBRE SRL

Ottica ed apparecchi ottici speciali,
Obiettivi per proiezione,Microproiettori,
Lenti di ingrandimento,Specchi,Prismi,
Mirini fotografici,filtri di luce,Cannocchiali Lettori

LABORATORIO OTTICO BRESCIANO / BREVETTI ING. S.MARCUCCI

Sede certificata di Carpenedolo

Intestato a
INFN
ROMA

IT - ITALIA

Documento	Numero	Data	Pagina
OFFERTA CLIENTI	114	02/04/2021	1

Mail	Referente	Fax
info@lobre.it		

Con la presente per sottoporVi la nostra migliore offerta , come segue:

Cod.Articolo	Descrizione	UM	Quantità	Prezzo[cad]	Consegna
	STUDIO DI FATTIBILITA' PER UN OTTICA PER CYGNO	n.	1,00	5.000,00	
	STUDIO DI PROGETTAZIONE PER UN OTTICA PER CYGNO	n.	1,00	15.000,00	
	TEMPI DI CONSEGNA : 45/60GG PER LA FATTIBILITA'				
	TEMPI DI CONSEGNA : 60/90GG PER LA PROGETTAZIONE				
	PAGAMENTO DA CONCORDARE				

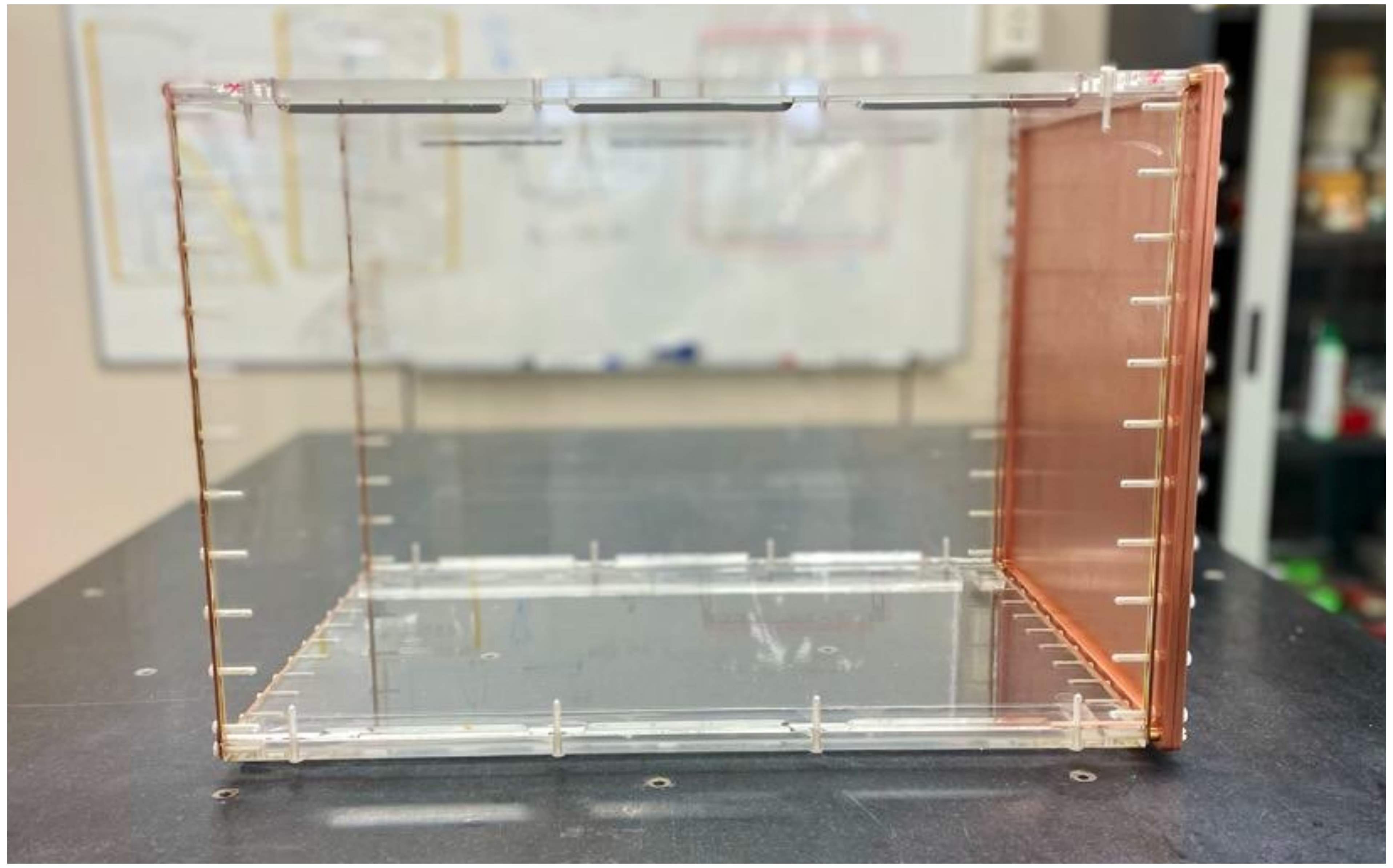
```
sample:        Heraeus Spectrosil disks, 298.8 g, CYGNUS
number:        4
live time:     2034019 s
detector:      GeMPI4

radionuclide concentrations:

Th-232:
Ra-228:        < 62 microBq/disk
Th-228:        < 24 microBq/disk

U-238:
Ra-226         < 48 microBq/disk
Th-234         < 0.86 mBq/disk
Pa-234m        < 1.0 mBq/disk

U-235:         < 30 microBq/disk

K-40:          (0.6 +- 0.3) mBq/disk

Cs-137:        < 8.3 microBq/disk

upper limits with k=1.645,
uncertainties are given with k=1 (approx. 68% CL);

Ra-228 from Ac-228;
Th-228 from Pb-212 & Bi-212 & Tl-208;
Ra-226 from Pb-214 & Bi-214;
U-235 from U-235 & Ra-226/Pb-214/Bi-214
```

Feasibility study started in 2021:

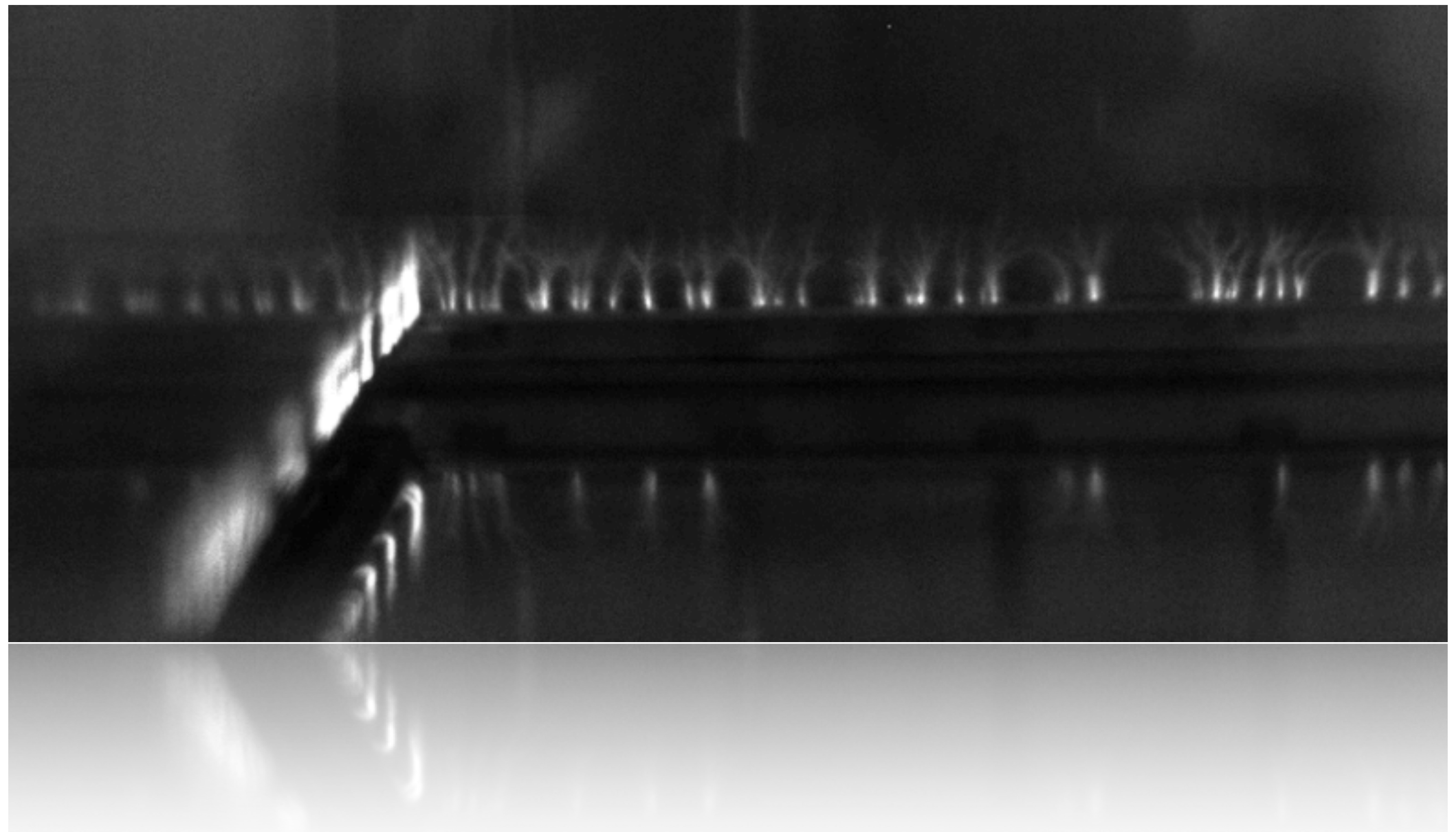
- one single crystal won't work;
- investigating the CaF_2 option;

R&D: Resistive foil Field cage

We tested a **transparent plastic resistive foil** (R=30 GΩ/□) as possible solution to provide the **drift field**.

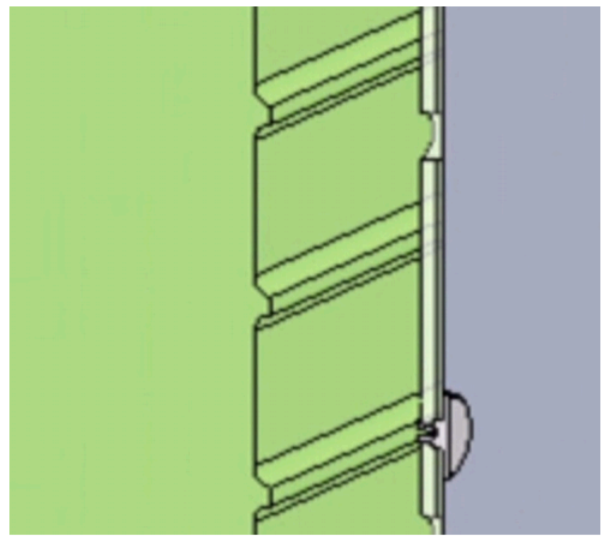


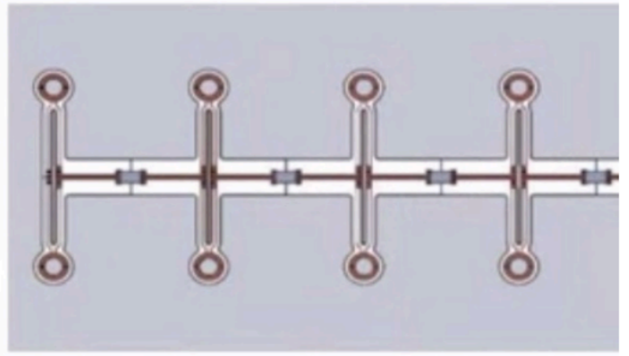
Very good preliminary results with cosmics and ^{55}Fe, indicating an **excellent uniformity** of the electric field



Unfortunately, after a week of operation, **small discharges** appeared all around the copper-plastic interface.

DARKSIDE: for **"copperless" FC**: we could shape the acrylic box and paint it with clevios





They can indicate low radioactive resistors

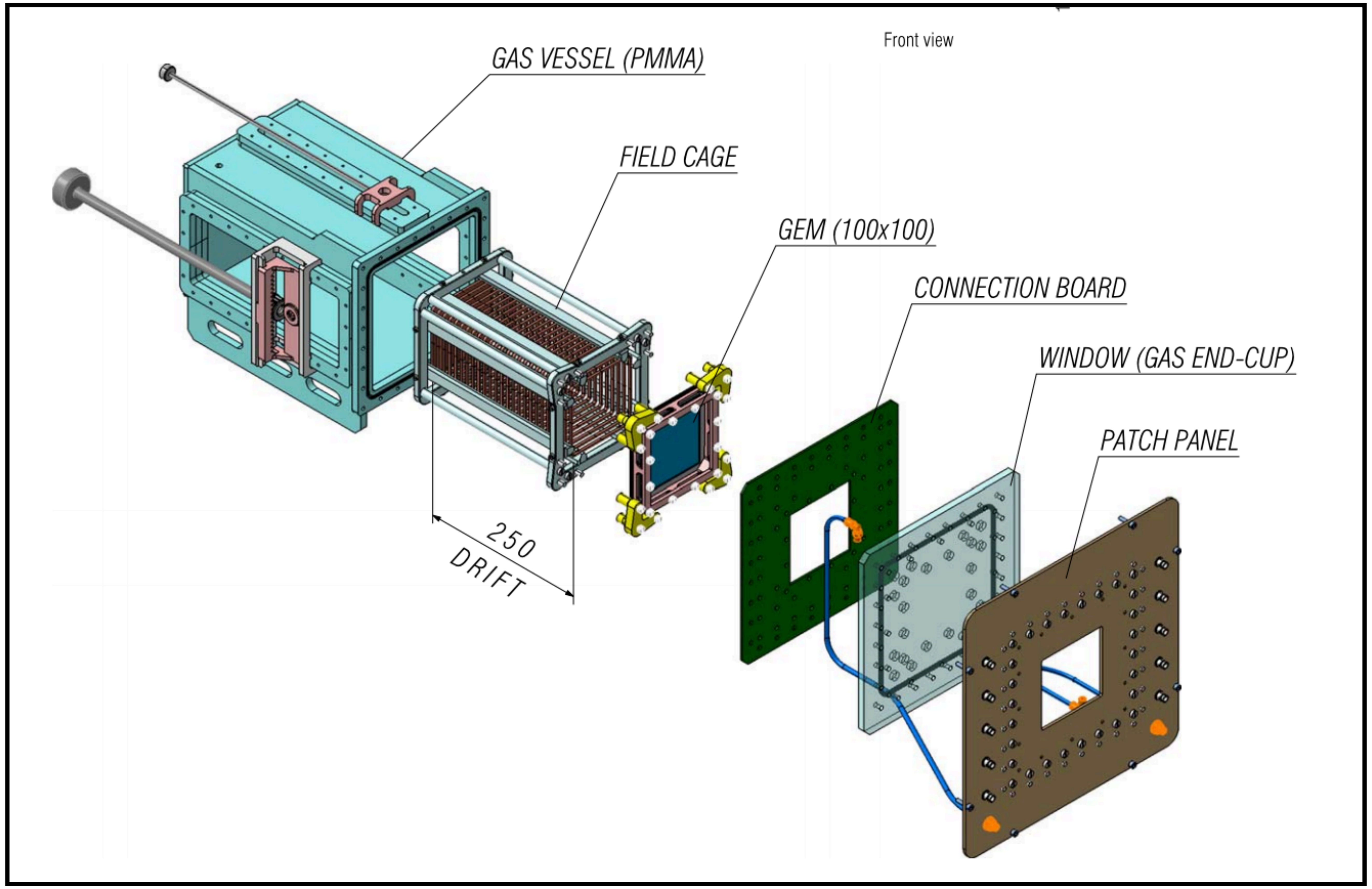
We had a couple of meetings with DarkSide colleagues to investigate the possibility of using the "clevios" solution

R&D: activities for 2022

Even if main focus will be on LIME operation, R&D activities are foreseen for testing new solution for **Field Cage** (Dark Side like)**, gas mixtures, electroluminescence**;

We need to discontinue to use LEMON and to assemble a new prototype for R&D (Gas Imaging New Prototype, **GIN**):

- **25 cm** drift length;
- standard **10x10 cm² GEM**, more easy and cheap to purchase;
- **flexible to modify** and adapt to different tests;



Conclusion

LIME was deeply characterised in the last months;

Data analysed so far, show that it is in a good shape even at low charges (about 1 keV):

- high detection efficiency;
- good energy resolution;
- good resolving power;

Response disuniformities are anyway evident:

- up to 40% along ***z***: can we reconstruct the position and correct it?;
- less than 15% on the ***xy*** plane: optical mis-alignment? drift field? gas?

Conclude the analysis work (PMT!), collect and compare all results to better understand the detector performance;

A paper will help…