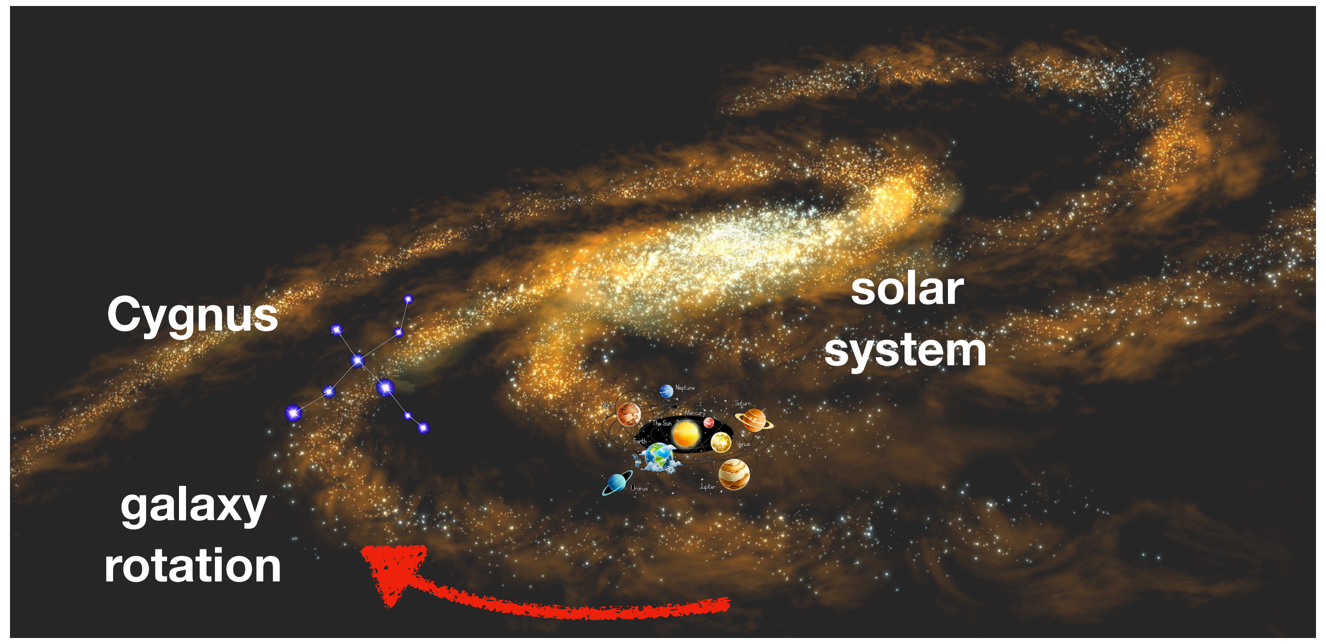
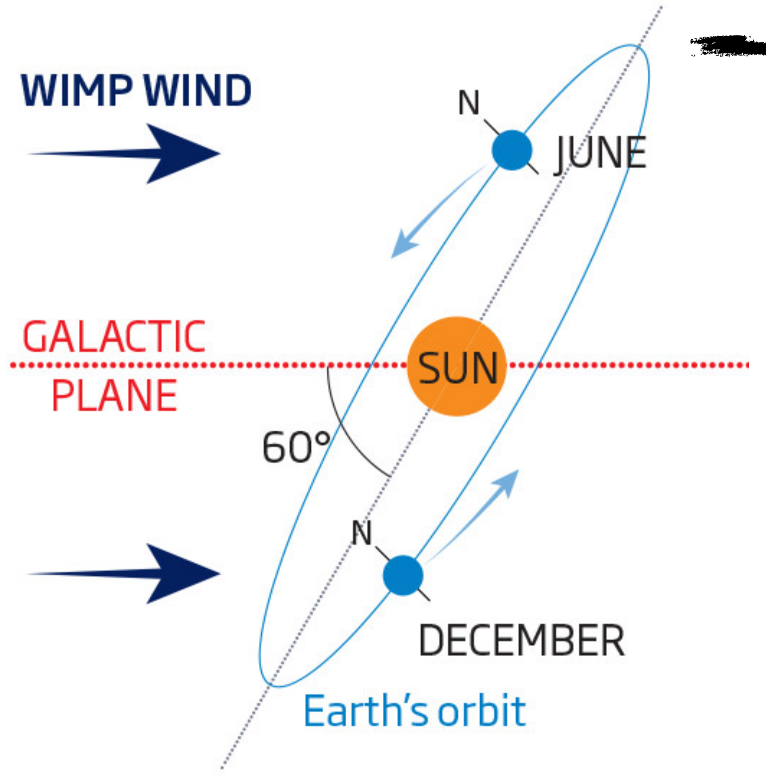
CYGNO/INITIUM project

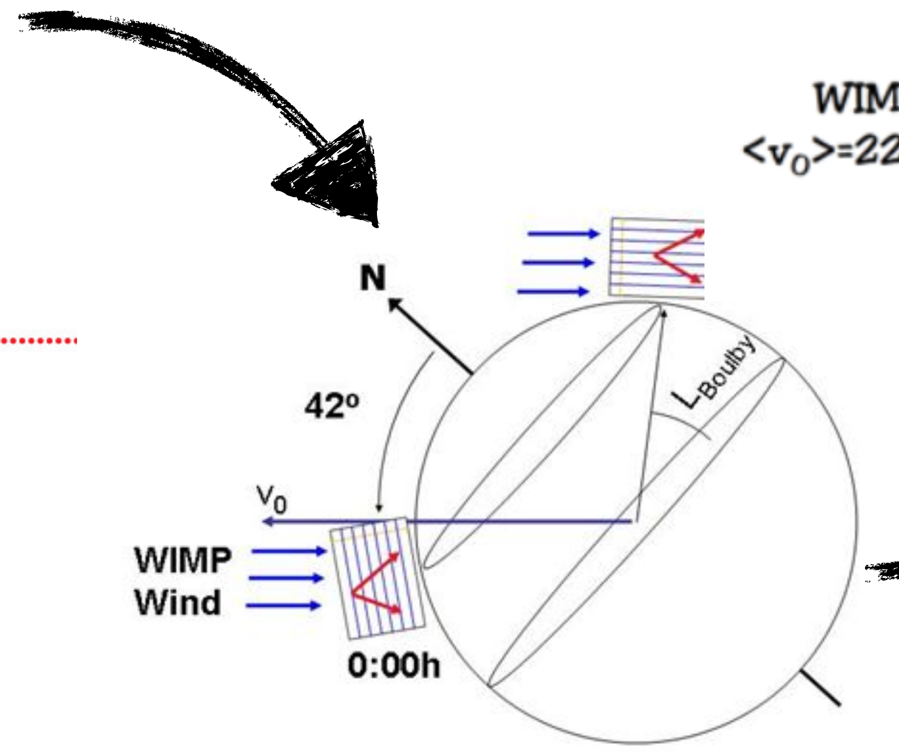
a CYGNus TPC module with Optical readout

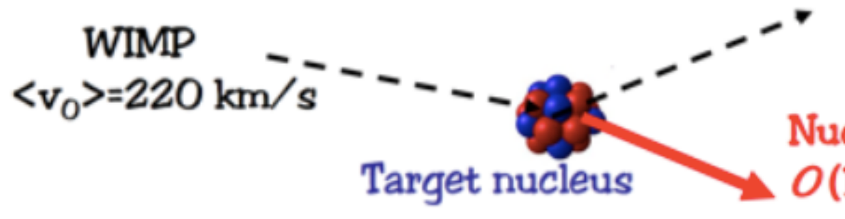
<u>G. Mazzitelli</u>, E. Baracchini, R. Bedogni, F. Bellini, L. Benussi, S. Bianco, L. Bignell, M. Caponero, G. Cavoto, E. Di Marco, C. Eldridge, A. Ezeribe, R. Gargana, T. Gamble, R. Gregorio, G. Lane, D. Loomba, W. Lynch, G. Maccarrone, M. Marafini, A. Messina, A. Mills, K. Miuchi, F. Petrucci, D. Piccolo, D. Pinci, N. Phan[7], F. Renga, G. Saviano, N. Spooner, T. Thorpe, S. Tomassini, S. Vahsen[9]

CYGNUS collaboration objective

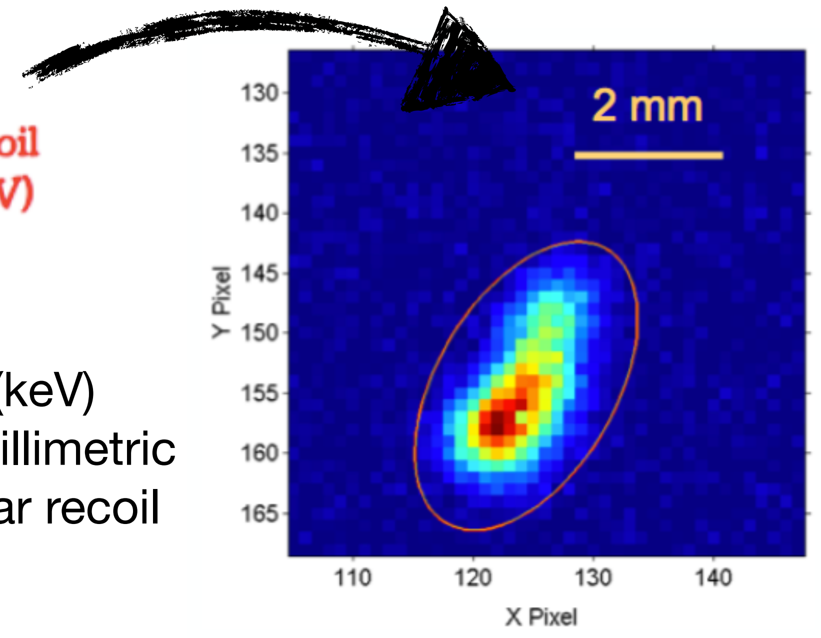


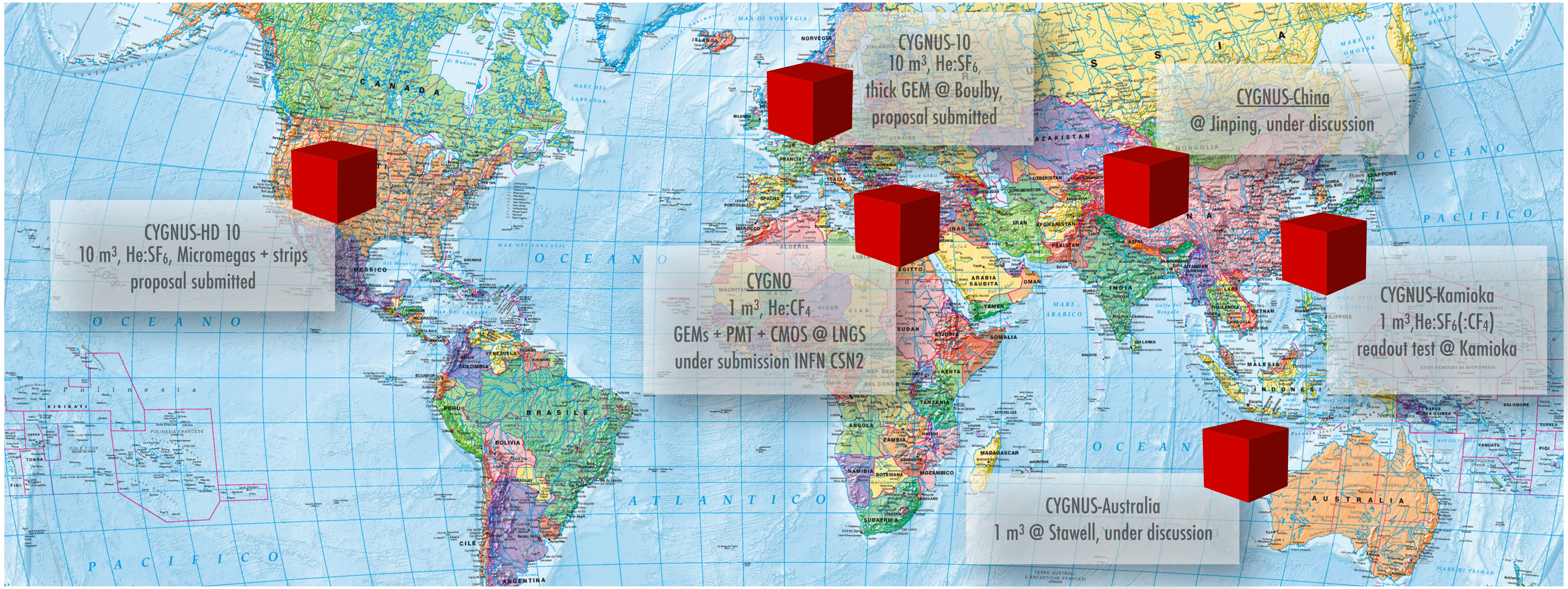






O(keV)
sub-millimetric
nuclear recoil





Galactic Nuclear Recoil Observatory

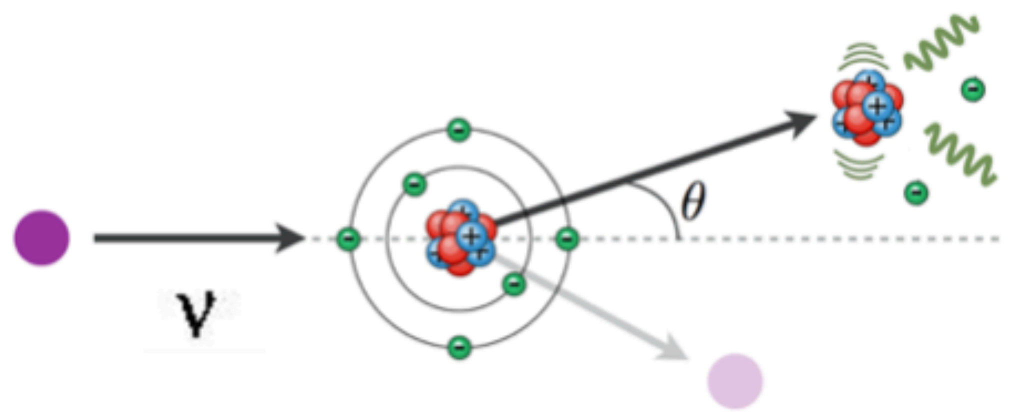
- **Energy threshold 1 keV_NR**
- **Target mass 100-1000 kg (F, He)**
- **Zero neutron background**
  - no steel (vacuum) vessel (acrylic?)
  - ceramics; almost no internal electronics
- **x, y, z fiducialisation and radon rejection**
  - either **negative ion** drift or other technique
  - **material** selection and scrubbing is not enough
- **Gamma discrimination below 10 keV_NR**
- **Directional sensitivity**

Physics motivation

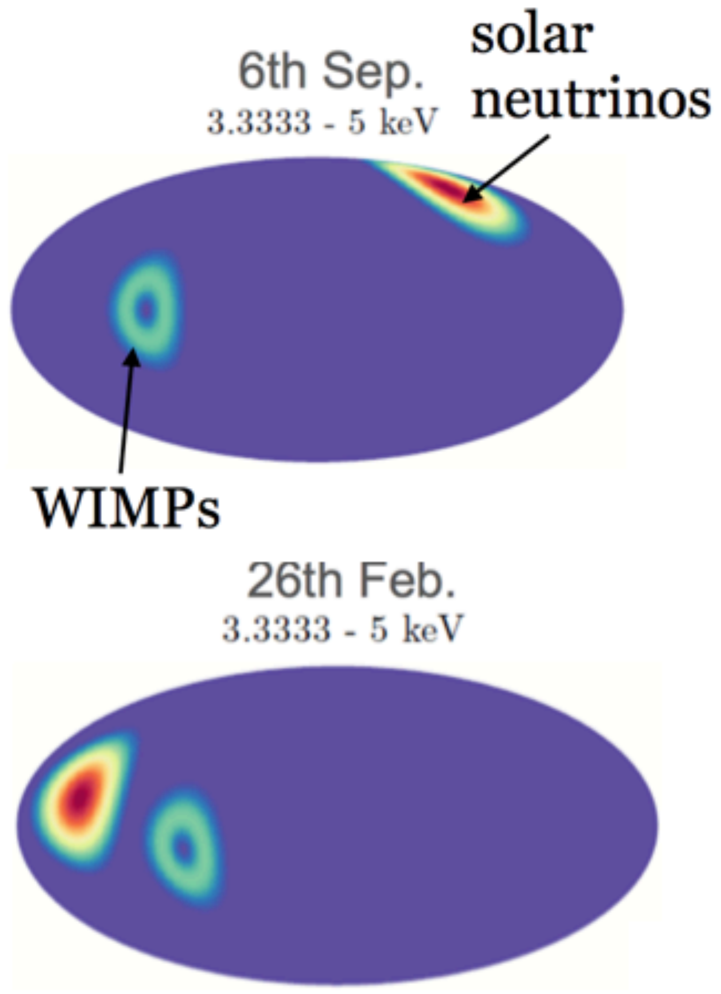
- low energy nuclear recoil O(10 GeV), dark matter
- low energy electrons recoil O(10 keV), light dark matter
- low energy neutrino scattering, solar physics

NOTE: only a directional detector can distinguish from WIMP signal

Coherent Neutrino-Nucleus scattering

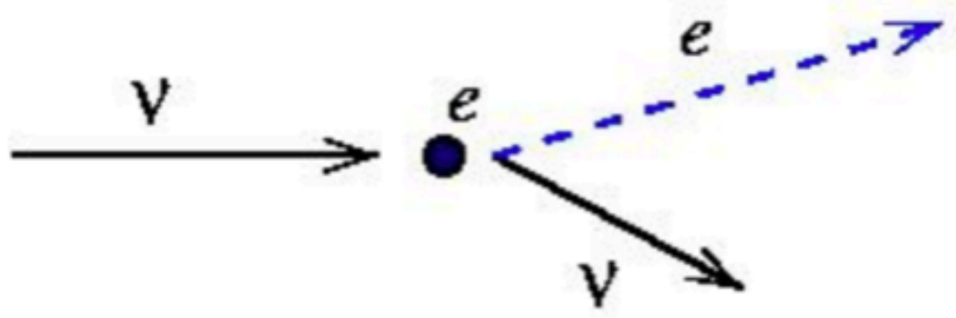


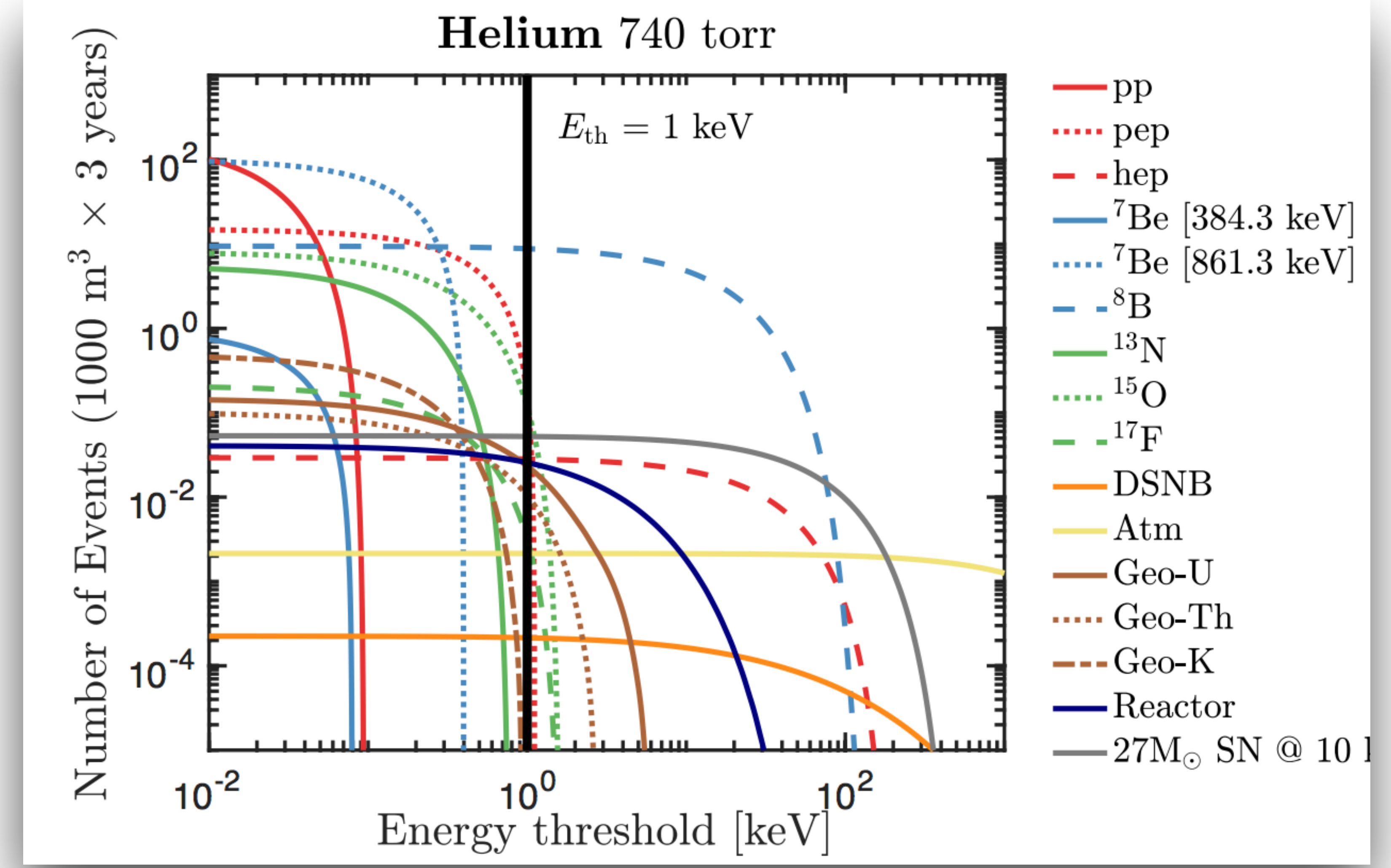
C. O'Hare et al, Phys. Rev. D 92 063518 (2015)



NOTE: only a directional detector can distinguish from ER background

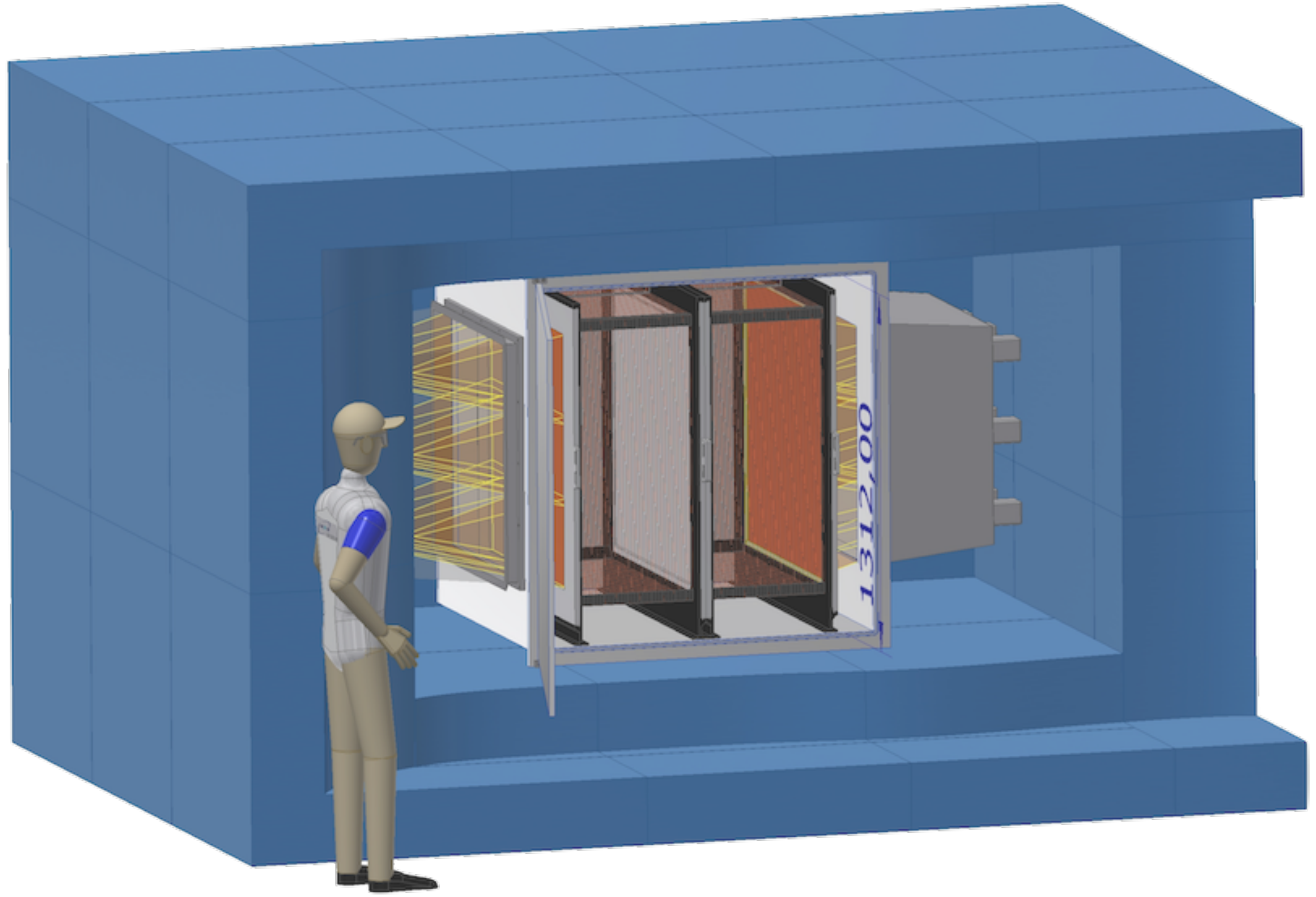
Elastic Neutrino-Electron scattering



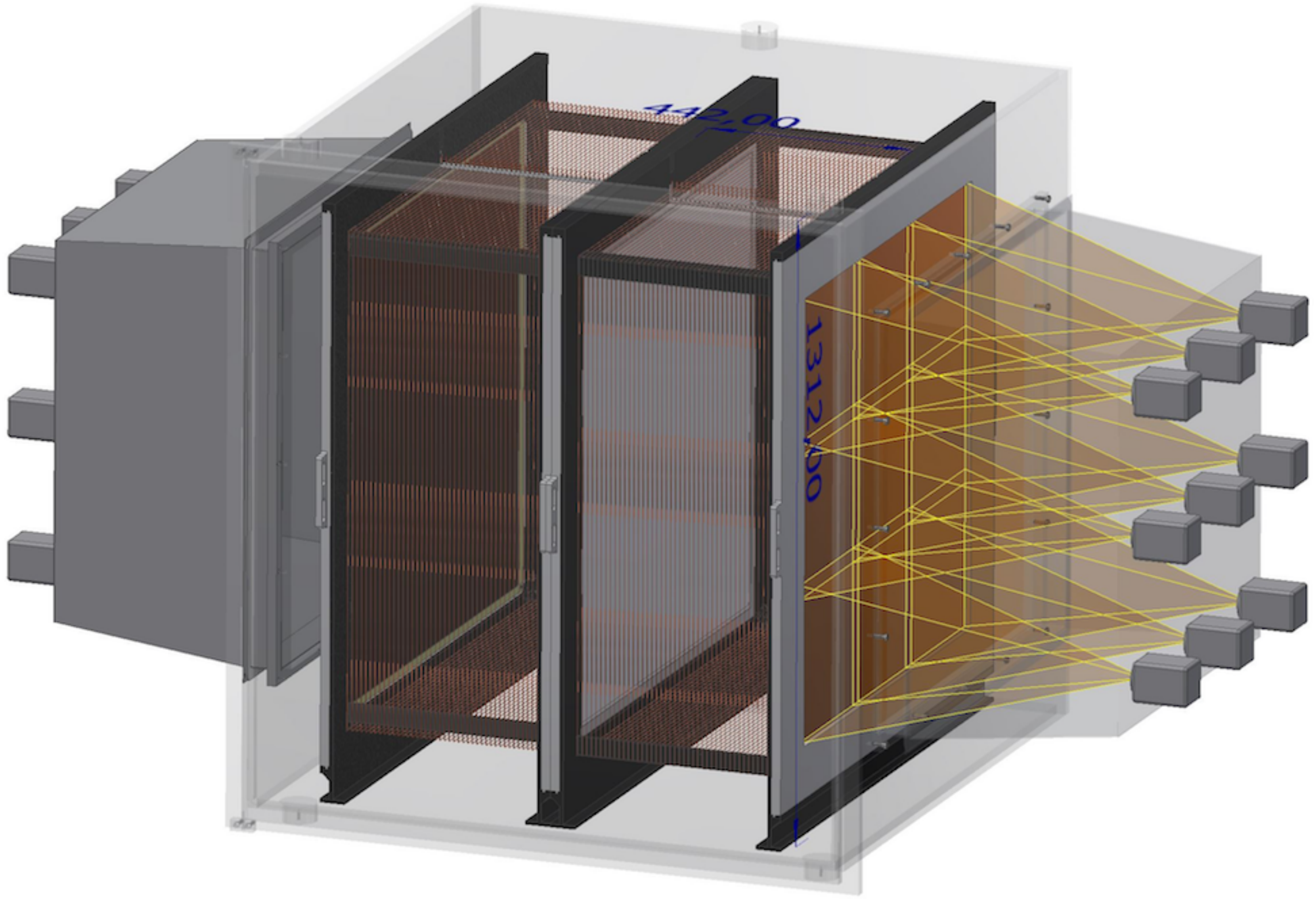


E. Baracchini et al.

The CYGNO/INITIUM project



18 cameras monitoring
330*330 mm each
with **150 mμ** resolution and
a sensitivity of ~ **1 ph / 20 eV** released in gas



CYGNO is a demonstrator exploiting large gas TPC, GEM based charge amplification, hight granularity and sensitivity of optically readout at atmospheric pressure in $HeCF_4$ based gas mixture

INITIUM-ERC is an R&D for testing possibility to improve nuclear recoil threshold and directionality by means of negative ions gas mixture in CYGNO demonstrator

A total of 95 10^6 readout 15 x 15 mm^2 pixels

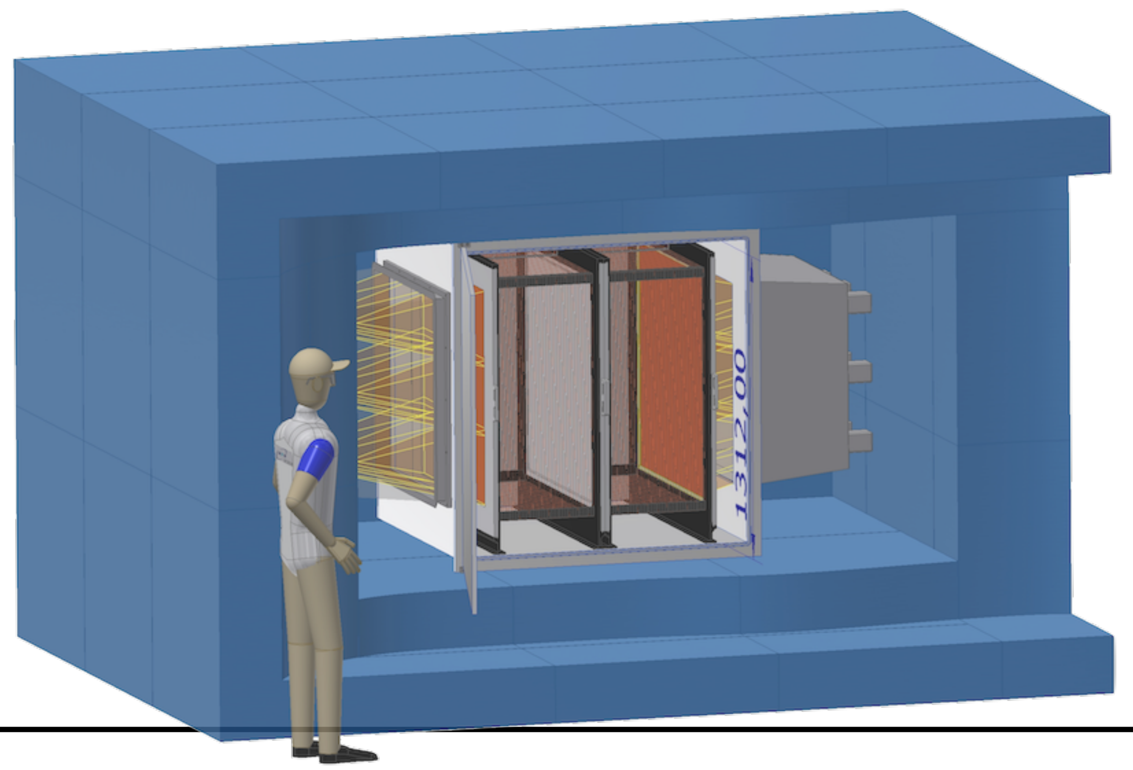
The demonstrator strategy

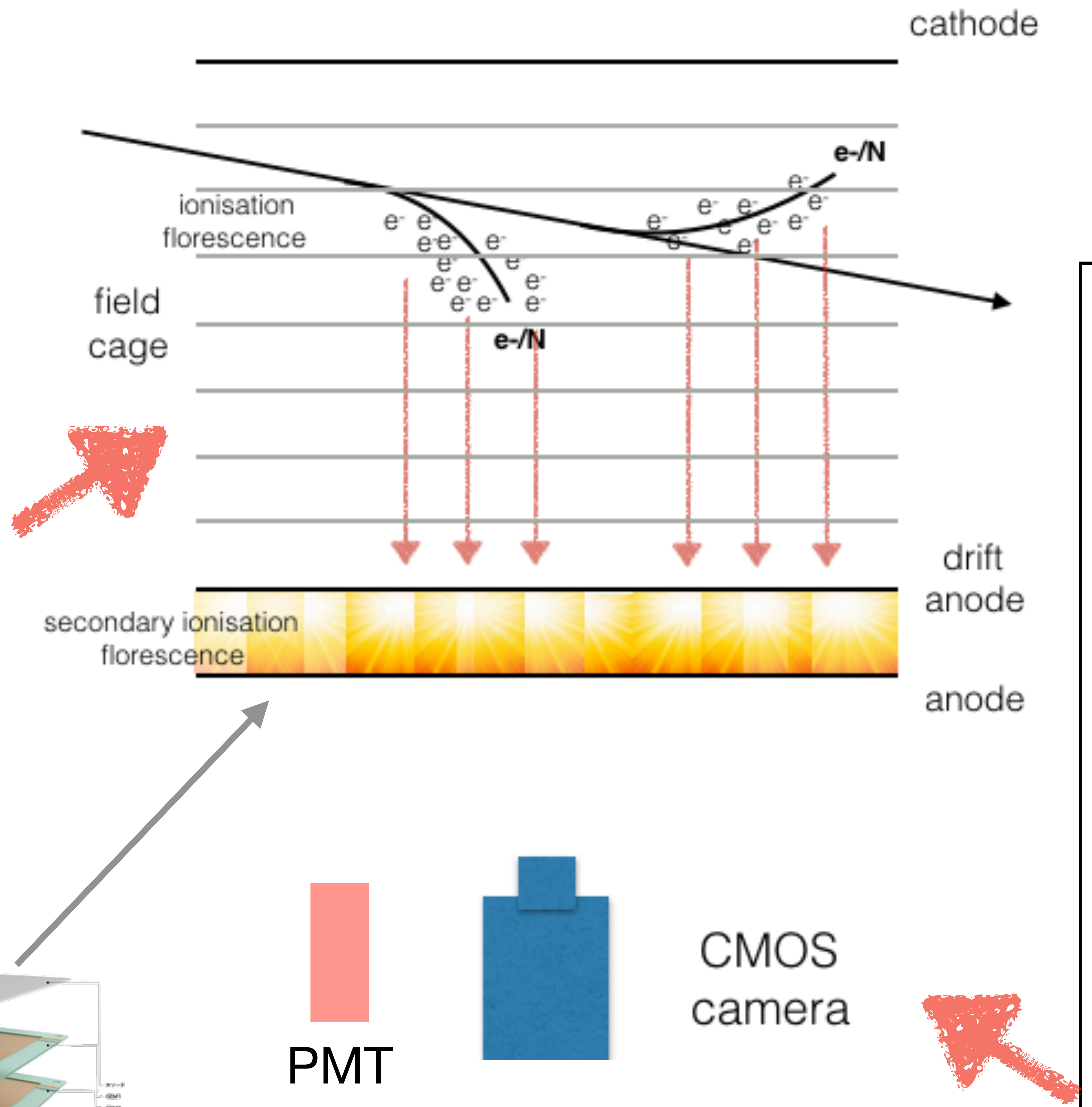
Time Projection Chambers provide:

- **3D** tracking (position and direction);
- total **released energy** measurement;
- **dE/dx** profile (pid, head-tail);
- reduced readout channel number;

gas represents an interesting target:

- nuclei free path can be **long** enough to be reconstructed;
- **low mass** gases allow an efficient momentum transfer from light DM;



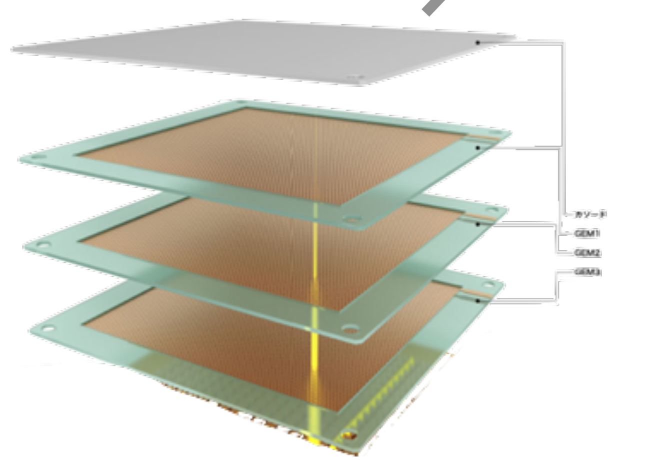


high granularity (CMOS+PMT) optical read out:

- threshold
- discrimination
- directionality;
- x, y, (z) fiducialisation
- electronics decoupling

atmospheric pressure He gas mixture:

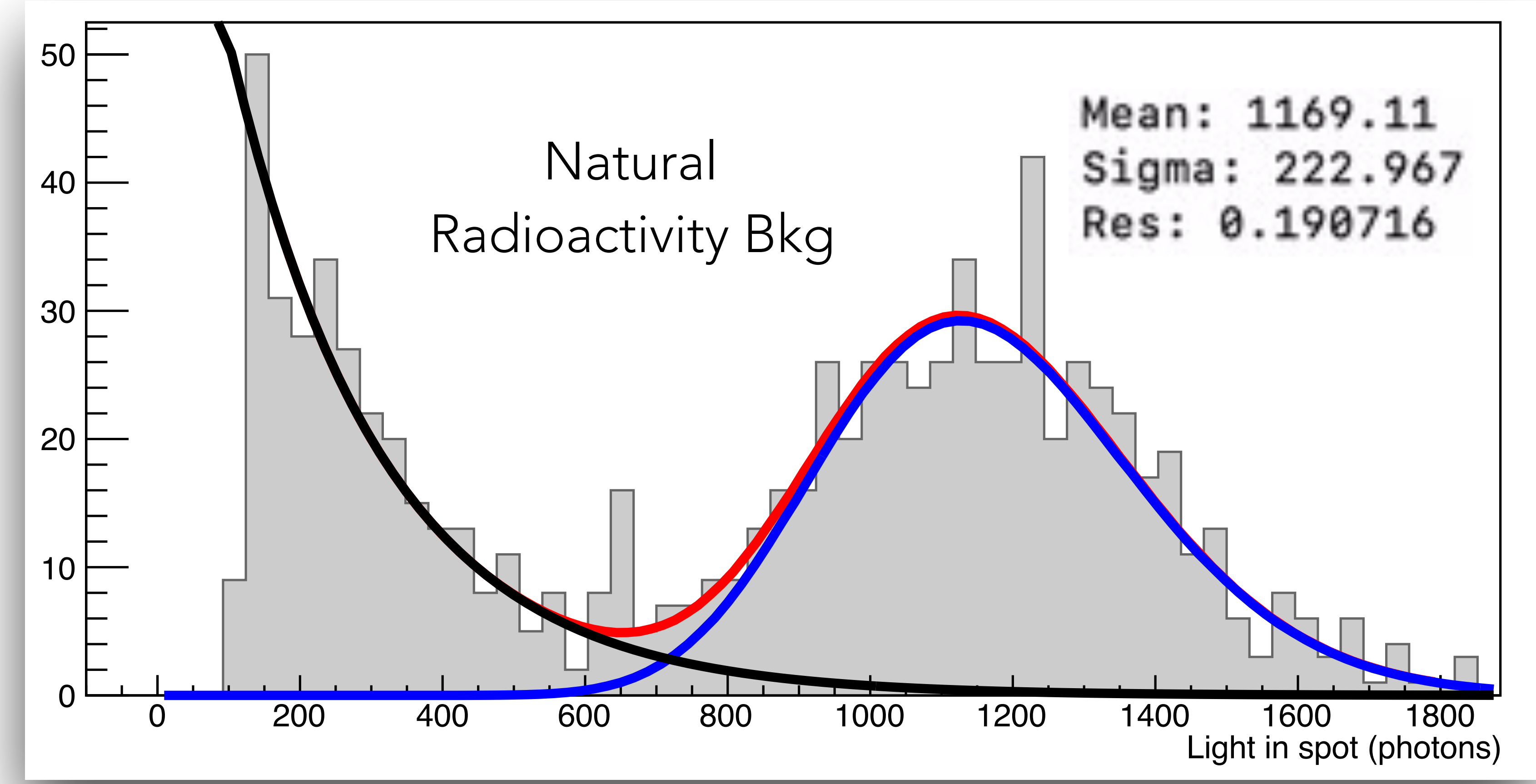
- high target density (low threshold)



multiple GEM structures is used to obtain **gain** and **stable** detectors.

Energy threshold and sensitivity

JINST_024P_0519



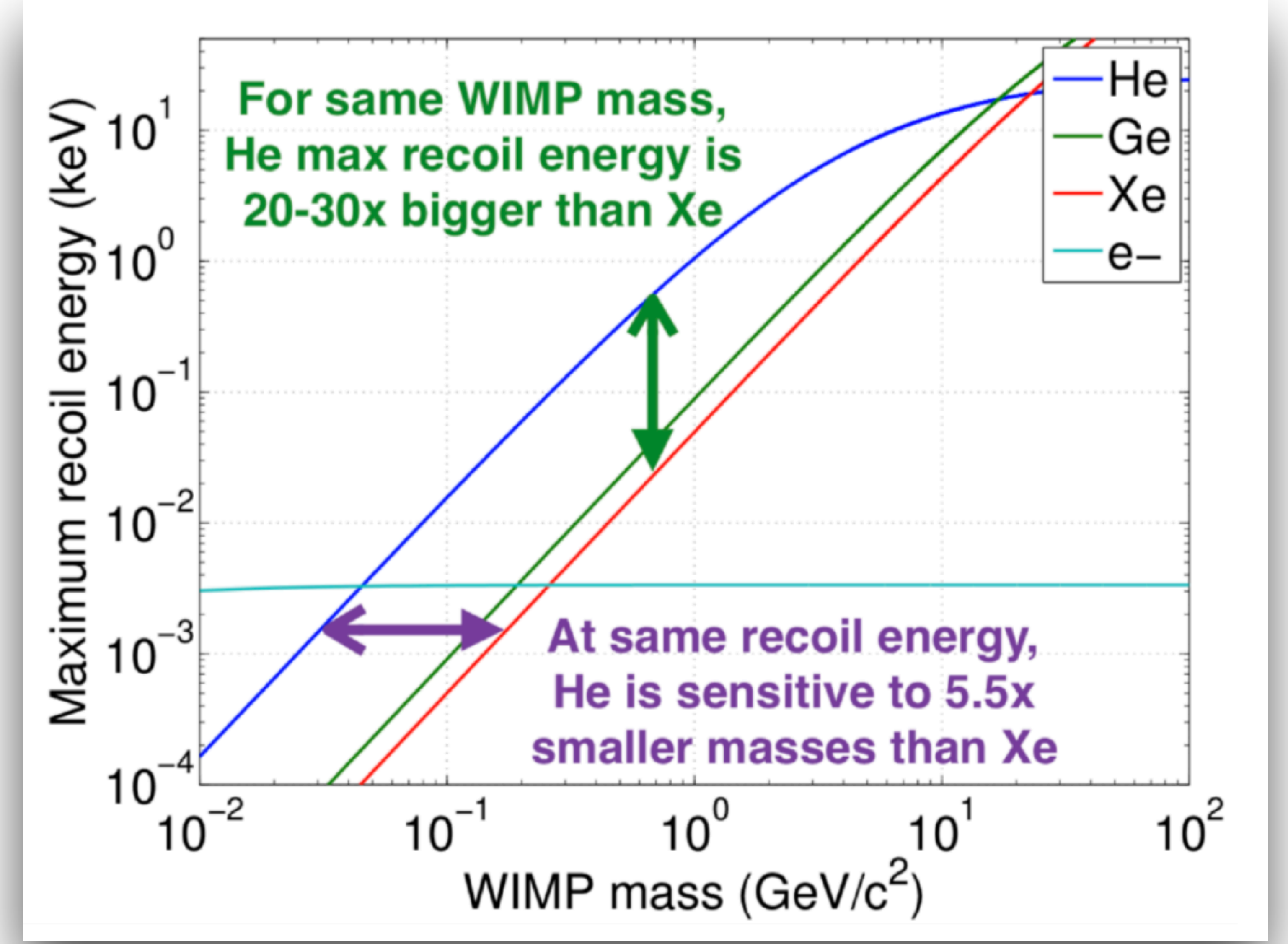
About 1170 photons are detected:
i.e. 1 photon each 5 eV released.

The **operative threshold** value is one of the parameter to evaluate the ultimate sensitivity to WIMPS. Moreover, crucial values is represented by the **mass of the target** nucleus (m_N), given the ratio between the m_N and the m_{WIMP}, the maximum transferred energy fraction is given by:

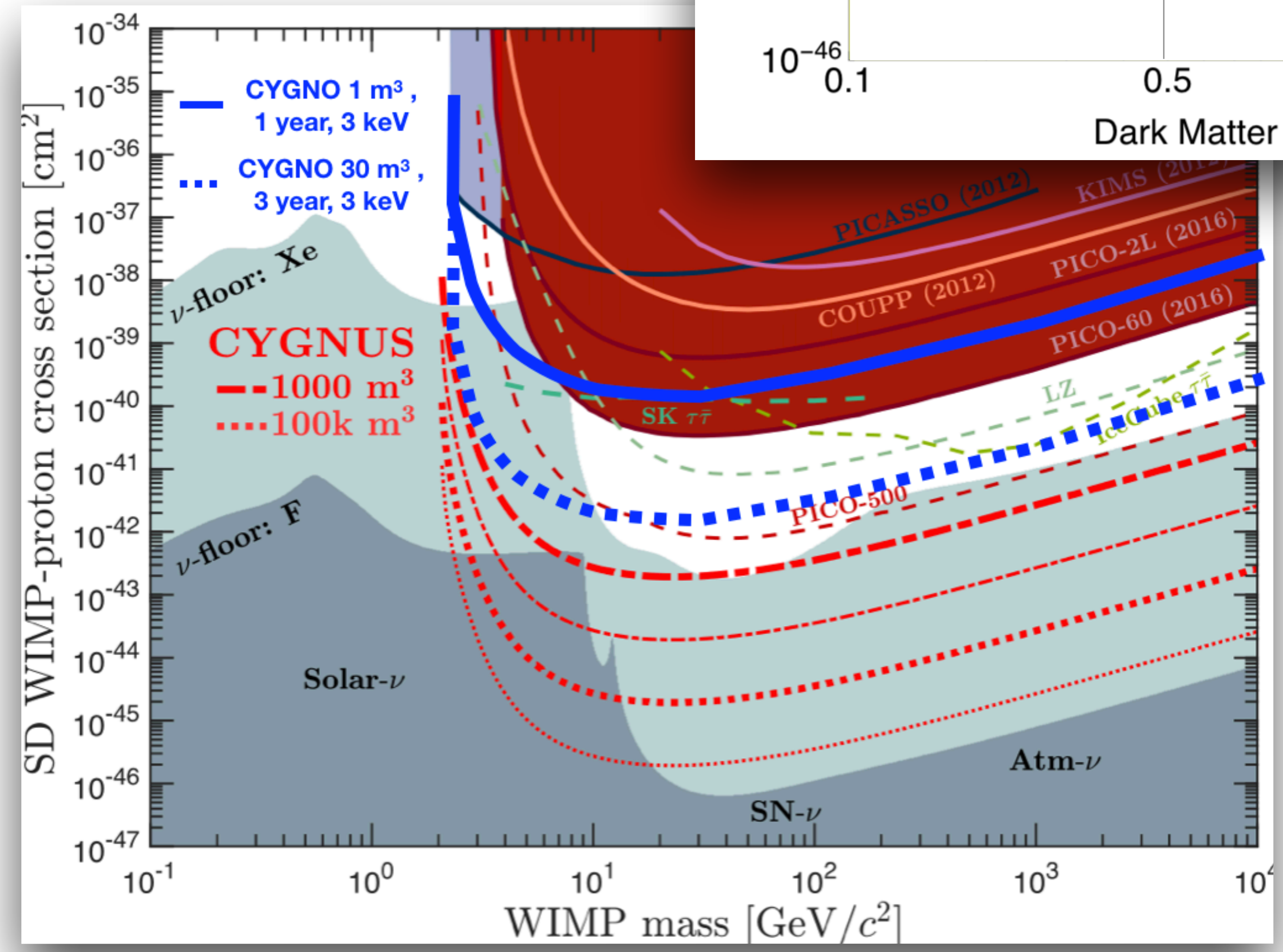
$$\epsilon = \frac{4\rho}{(\rho+1)^2} \quad \text{where} \quad \rho = \frac{m_N}{m_{WIMP}}$$

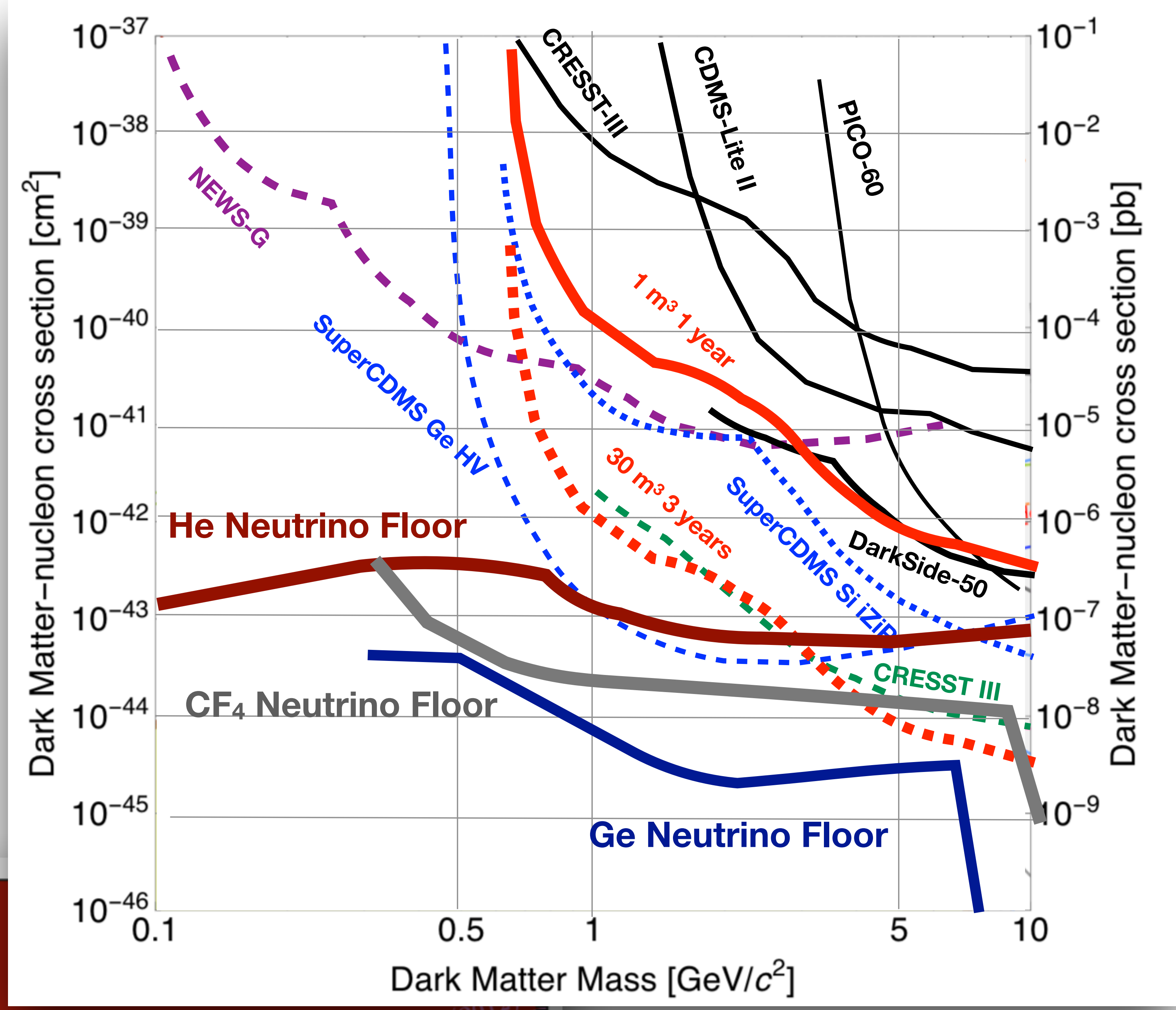
Therefore, a WIMP with a 1 GeV mass, would transfer different energy to different target nuclei:

Target	Max Energy Transf. (keV)
He	1,2
Ar	0,2
Xe	0,06



WIMP energy sensitivity





estimate with zero background

- **Energy threshold 1 keV_NR**
- **Target mass 30-100 kg (F, He)**
- **Zero neutron background**
  - no steel (vacuum) vessel (acrylic?)
  - ceramics; almost no internal electronics
- **x, y, z fiducialisation and radon rejection**
  - either negative ion drift or other technique
  - material selection and scrubbing is not enough
- **Gamma discrimination below 10 keV_NR**
- **Directional sensitivity**

Directionality, head tail & PID

Time Projection Chambers provide:

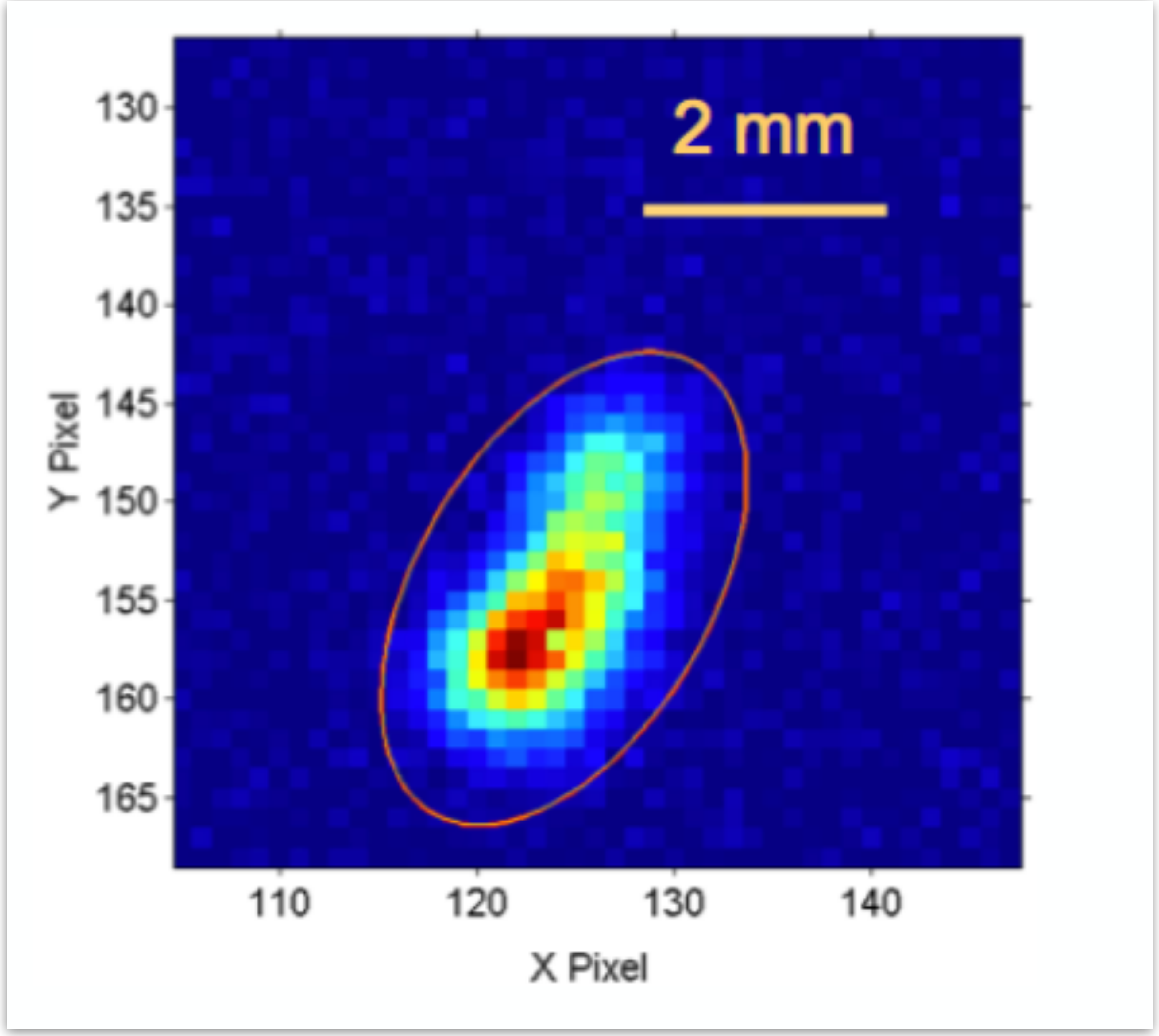
- **3D** tracking (position and direction);
- total **released energy** measurement;
- **dE/dx** profile (pid, head-tail);
- reduced readout channel number;

gas represents an interesting target:

- nuclei free path can be **long** enough to be reconstructed;
- **low mass** gases allow an efficient momentum transfer from light DM;

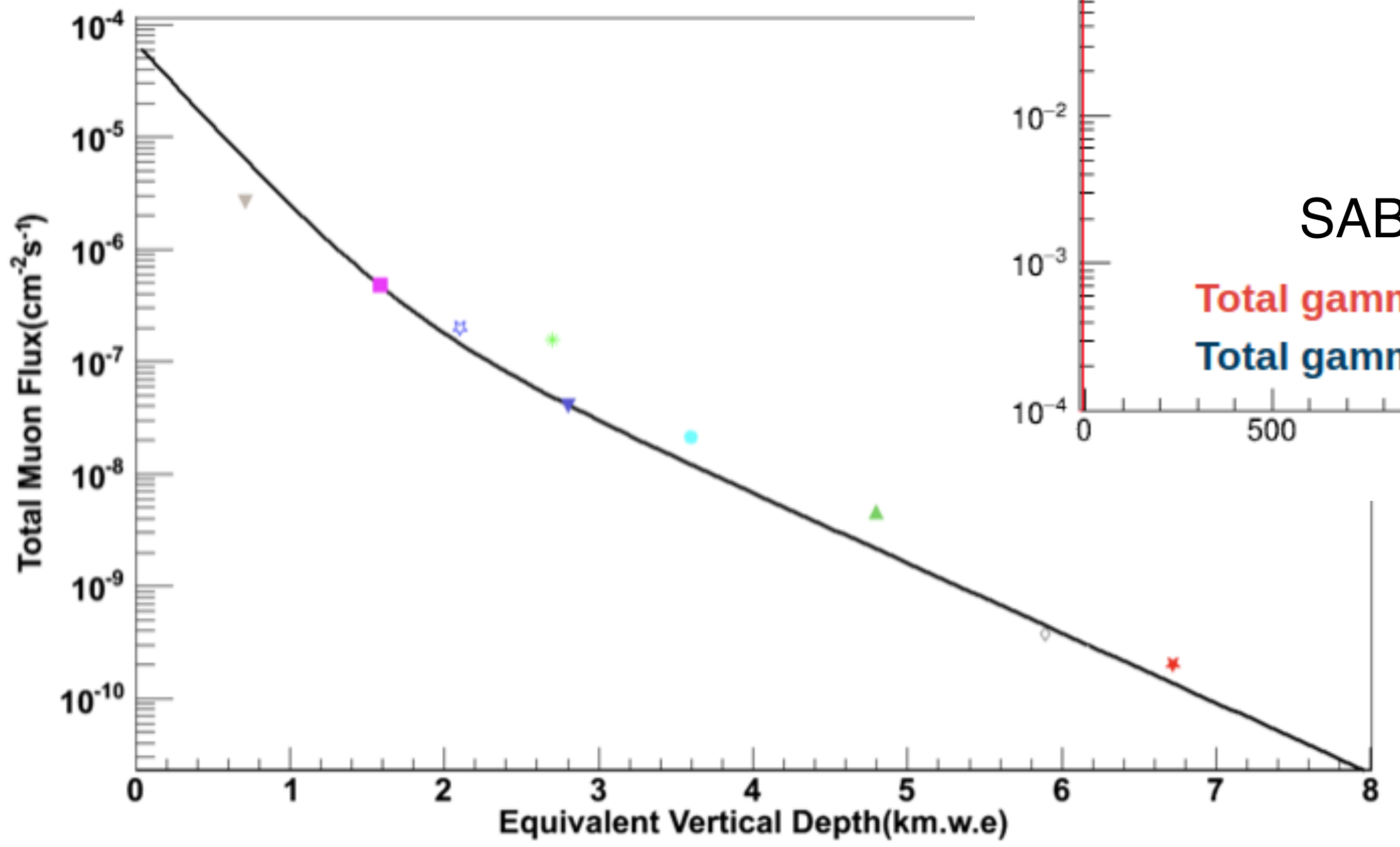
avalanche mechanism allows a **sensitivity to single primary electrons** (i.e. energy release of 30-40 eV);

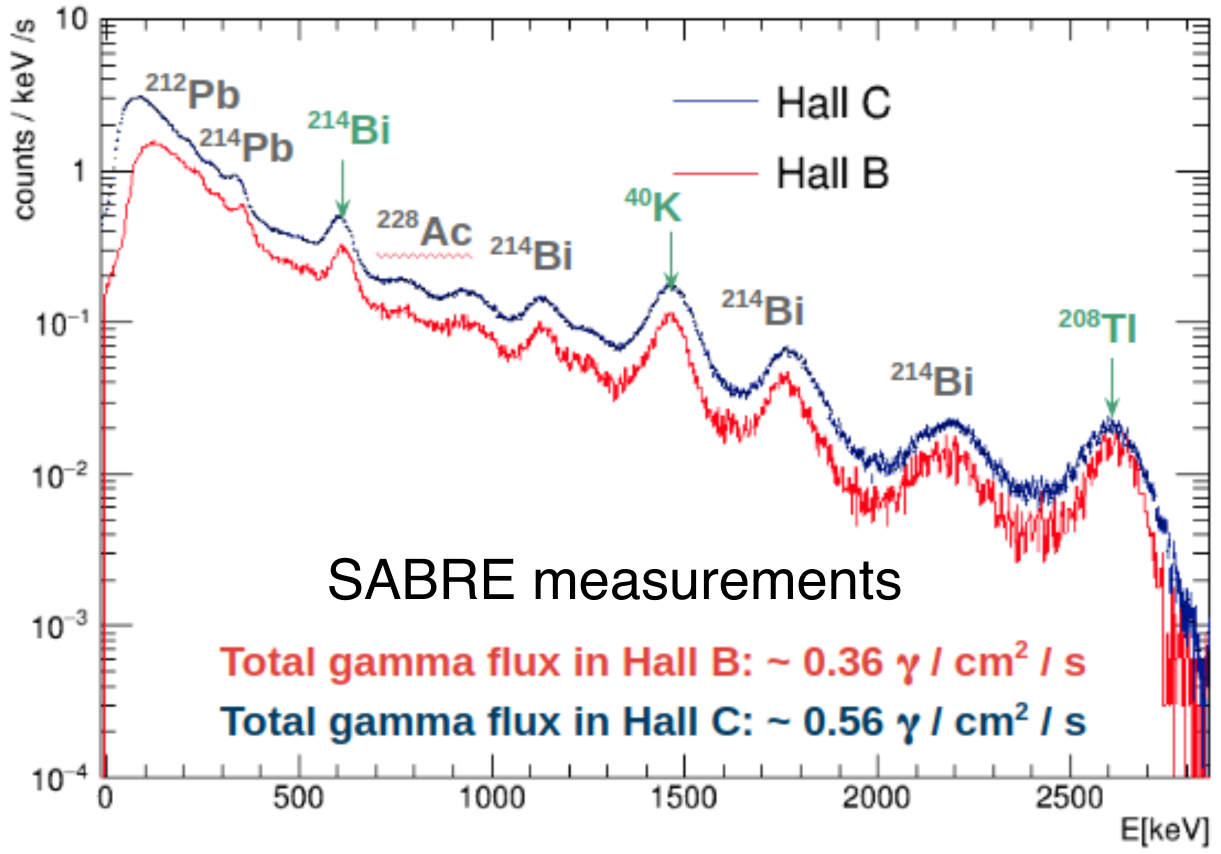
Nuclear recoil in gas



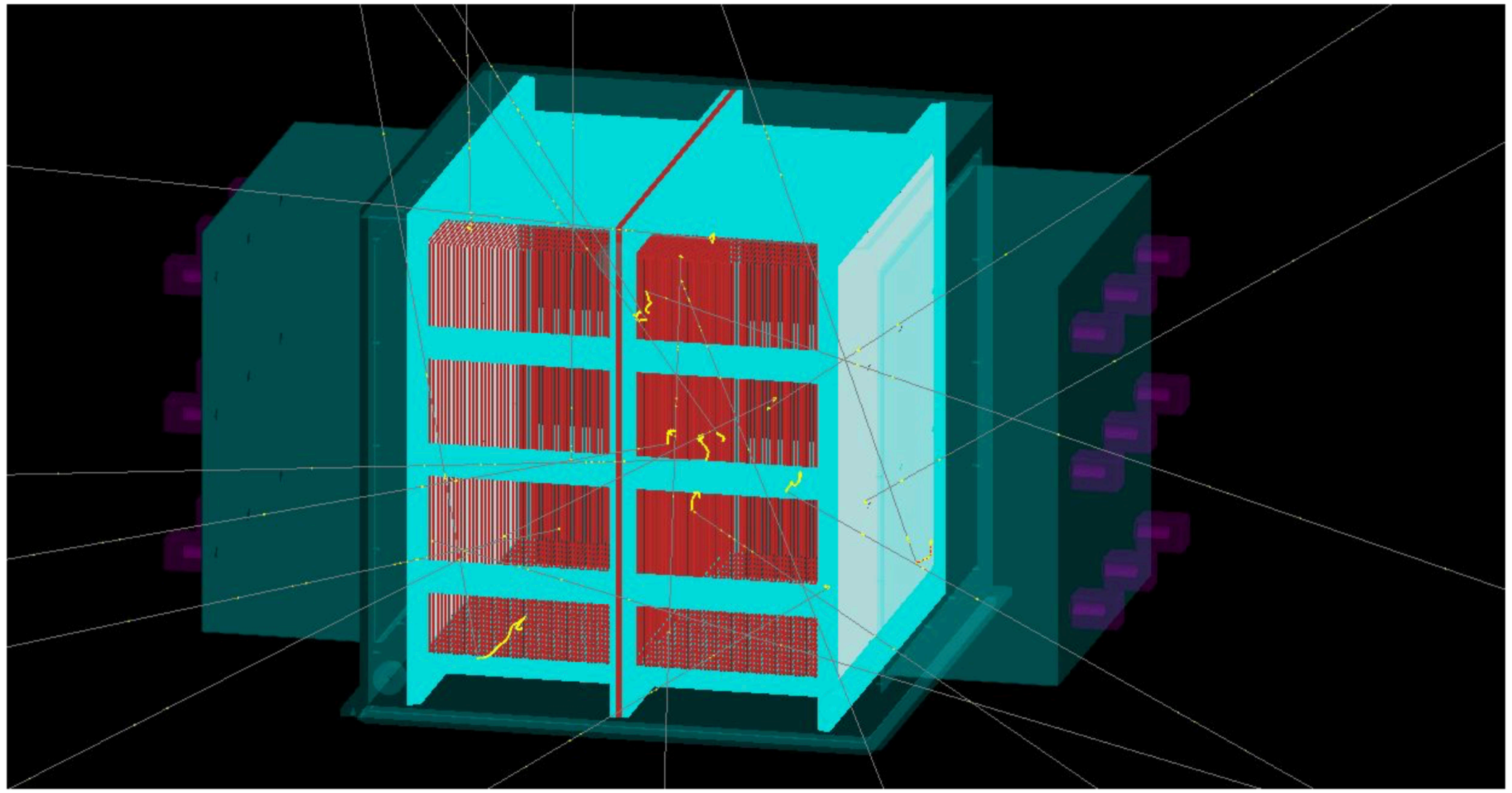
Background & Full Sim

- **internal background**:
  gas radioactivity and materials
  ➡ materials choice and gas purification
- **external background**:
  gamma, neutrons, and comics
  ➡ shielding (water+Cu+Pb?+…)





Example: ^{14}C decays in the gas

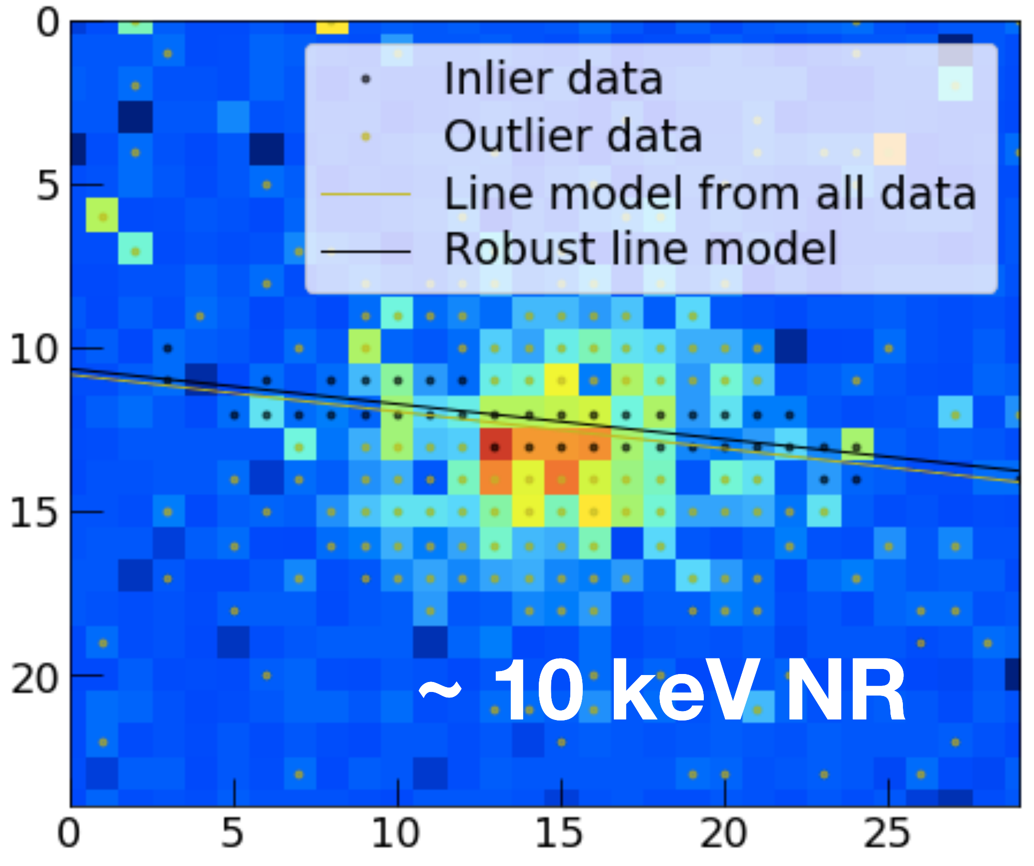


G. Cavoto, F. Bellini, A. Messina, G. D'Imperio

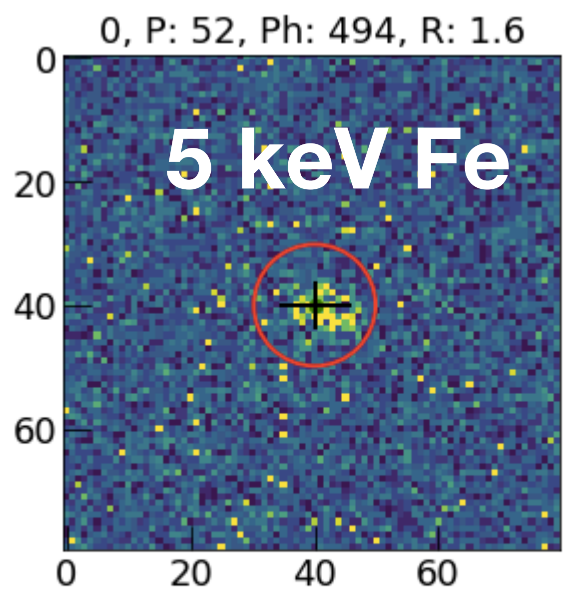
Data analysis

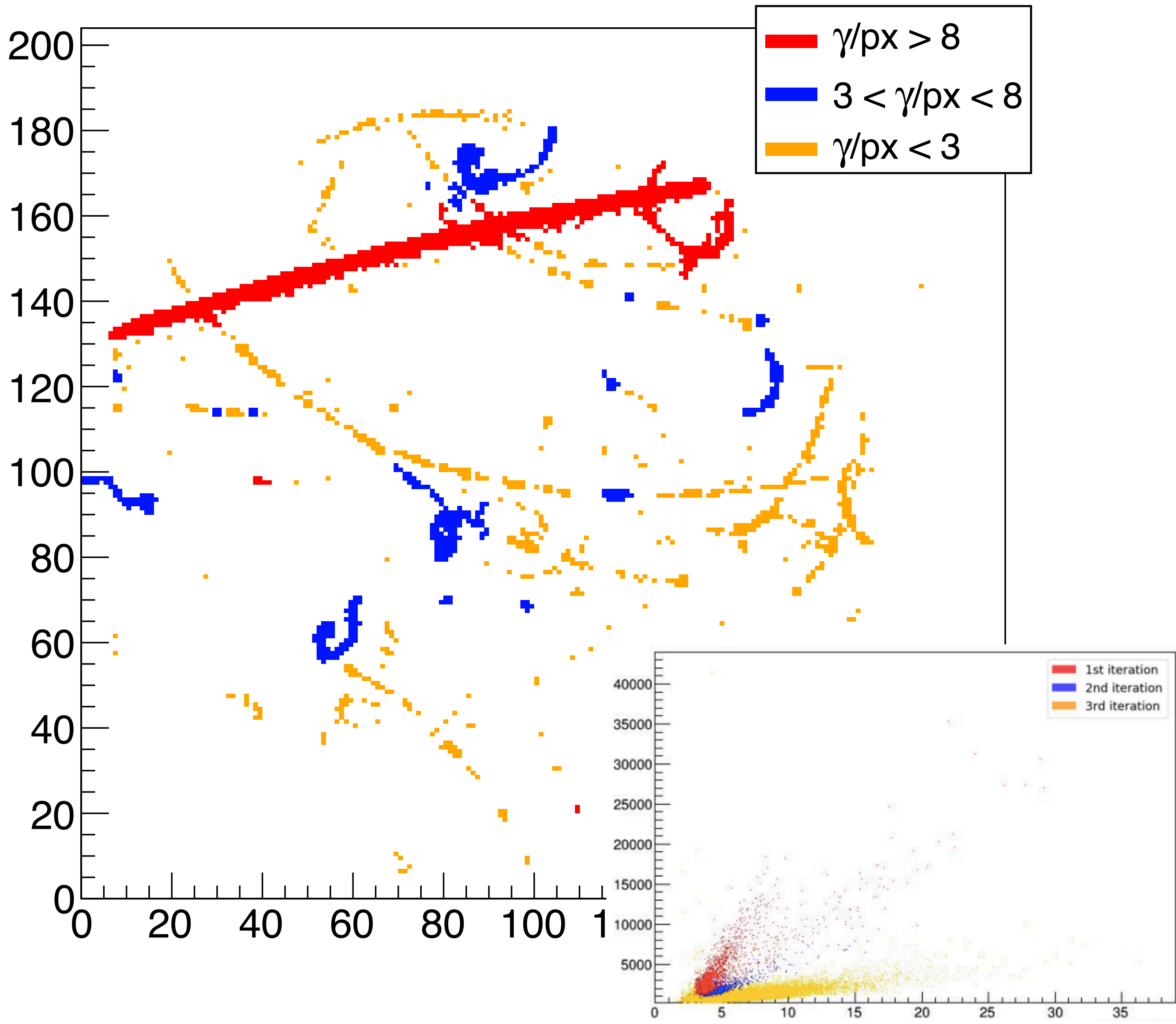
The effective energy threshold is determinate by the ability to identify candidate over background

- Particle Identification (PID)
- directionality & head tail
- topology (sparsity, curly, etc)

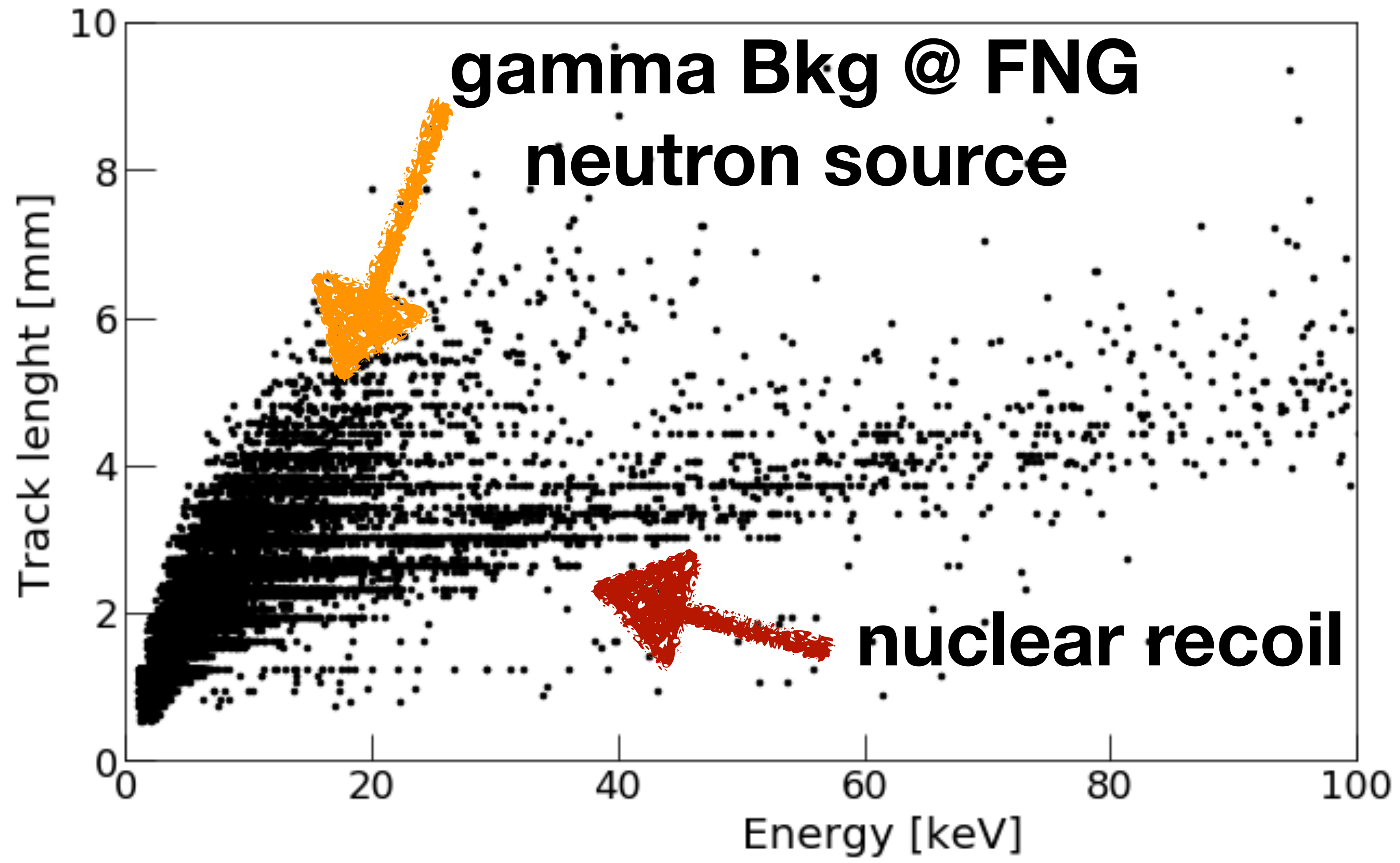


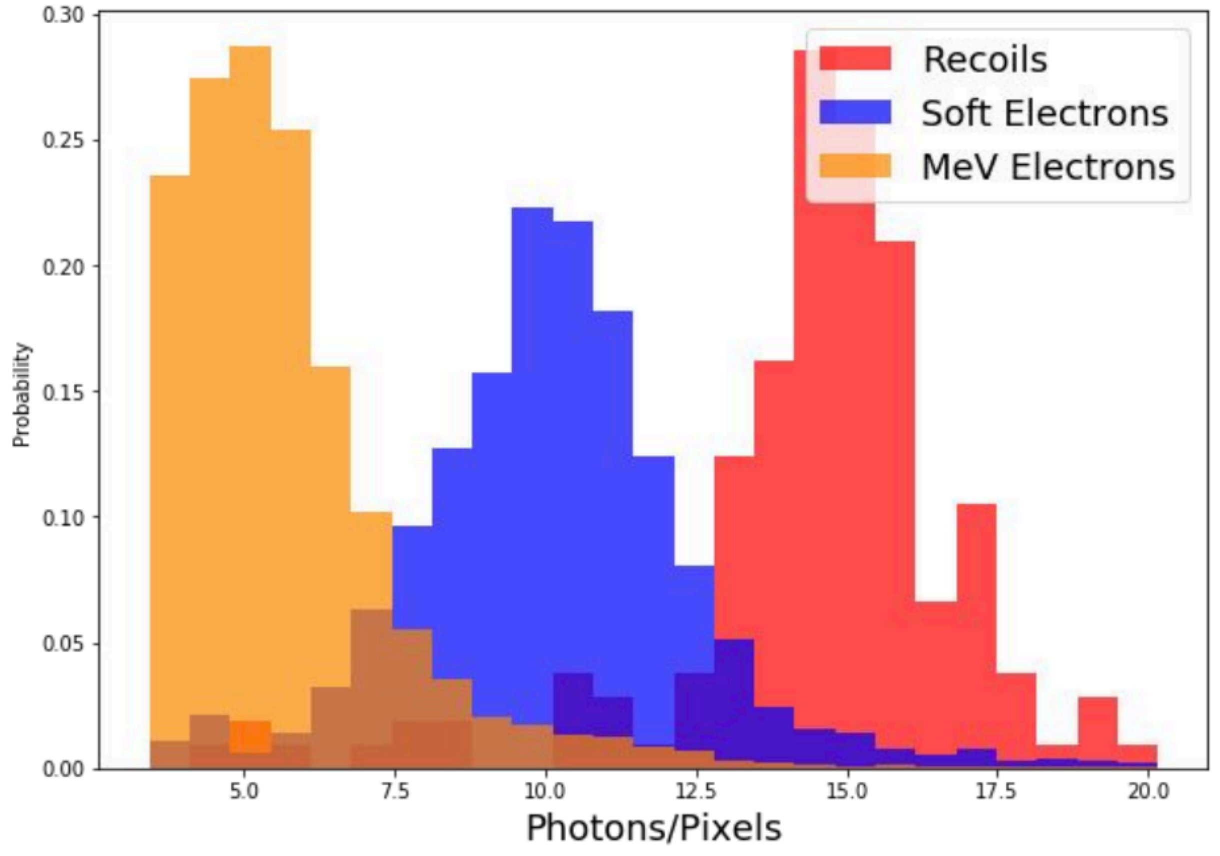
clustering_run831_Nsig_1_Mcut_350_Pcut_0_scale_4_close_2_nccs.txt





Moreover, a throughput of ~GB/s (strongly dependent on underground background condition) is foreseen and a first level real time analysis is need in order downsample data
- front end farm, GPU/FPGI
- machine learning tools

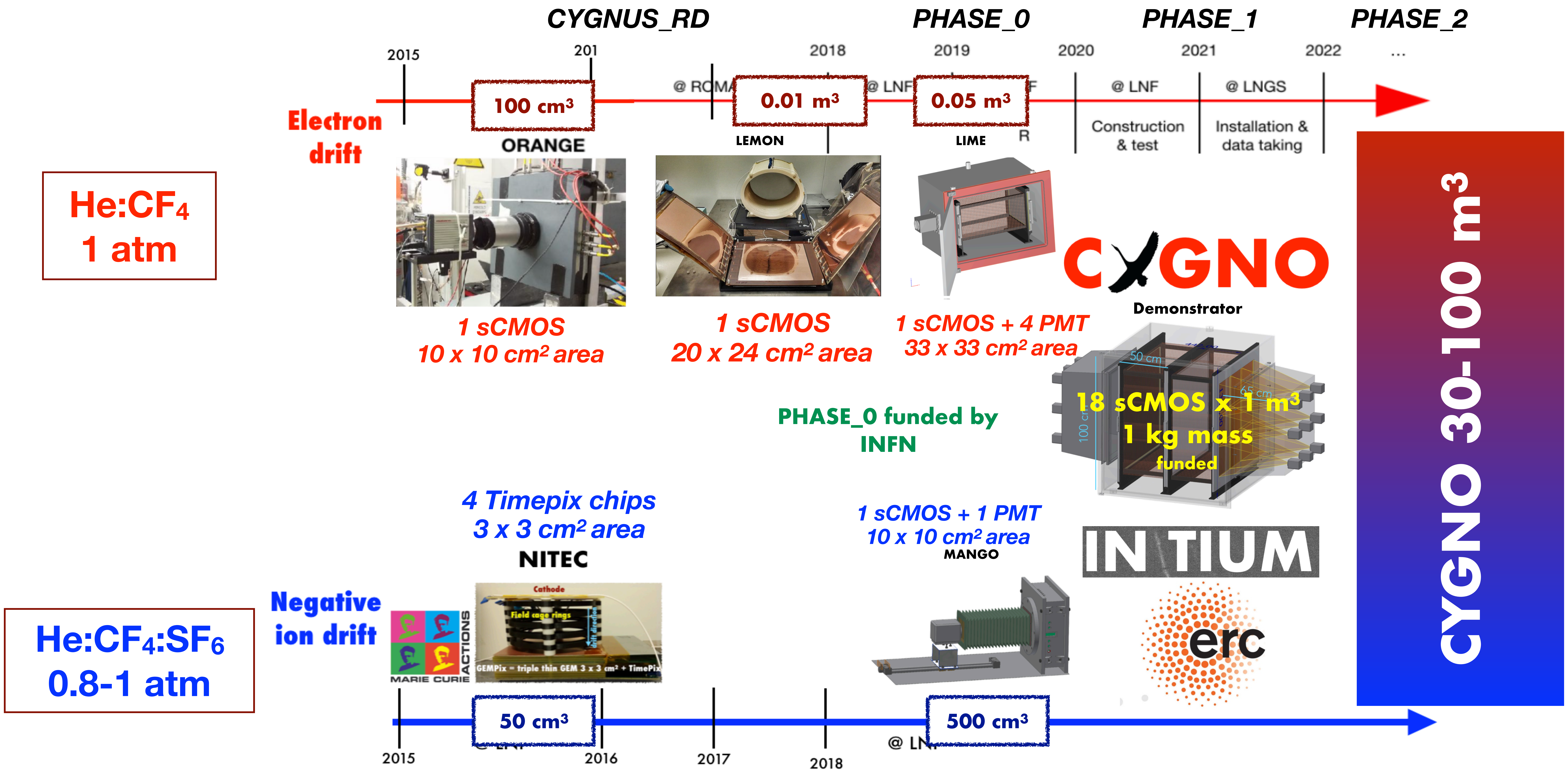




i2DBSCAN classification

I. Abritta Costa, E. Di Marco, A. Messina, G. Mazzitelli, D. Pinci

Roadmap R&D and project Phase



G. Mazzitelli for CYGNO/INITIUM Collaboration

Phase0 - TDR status and working plan

Technical Design Report

Esperimento XXX

In questo documento sono descritte le linee guida principali che necessariamente devono essere presenti nella redazione di un Technical Design Report (TDR).

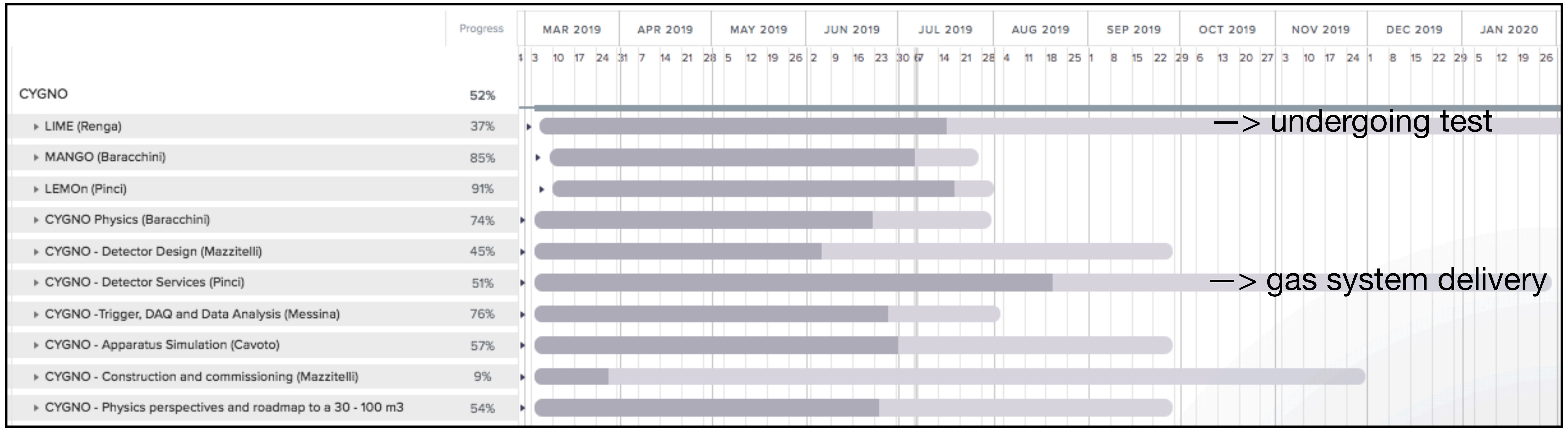
Questo documento è derivato dal template redatto e approvato dal Gruppo di Lavoro "Project Management" dell'Istituto Nazionale di Fisica Nucleare (INFN) ed è declinato tenendo conto delle peculiarità dei Laboratori Nazionali del Gran Sasso (LNGS).

Autore	Verificato da	Approvato da

Summary

- Spokesperson: INITIUM, E. Baracchini (GSSI), CYGNO, D. Pinci (INFN-ROMA1)
- Technical Coordinator: G. Mazzitelli (INFN-LNF)
- Engineering Coordinator: S. Tomassini (INFN-LNF)
- Services Coordinator: D. Pinci (INFN-ROMA1)
- Read Out Coordinator: L. Benussi (INFN-LNF)
- Physics Coordinator: E. Baracchini (INFN-ROMA1)
- Simulation Coordinator: G. Cavoto (INFN-ROMA1)
- DAQ & Analysis Coordinator: A. Messina (INFN-ROMA1)
- Local Responsible: to be define
- Site Manager: to be define
- Funds Responsible: E. Baracchini (GSSI), F. Renga (INFN-ROMA1) , D. Pinci (INFN-ROMA1), G. Mazzitelli (INFN-LNF)
- GLIMO-S&E: to be define

TDR and R&D 2019 GANTT

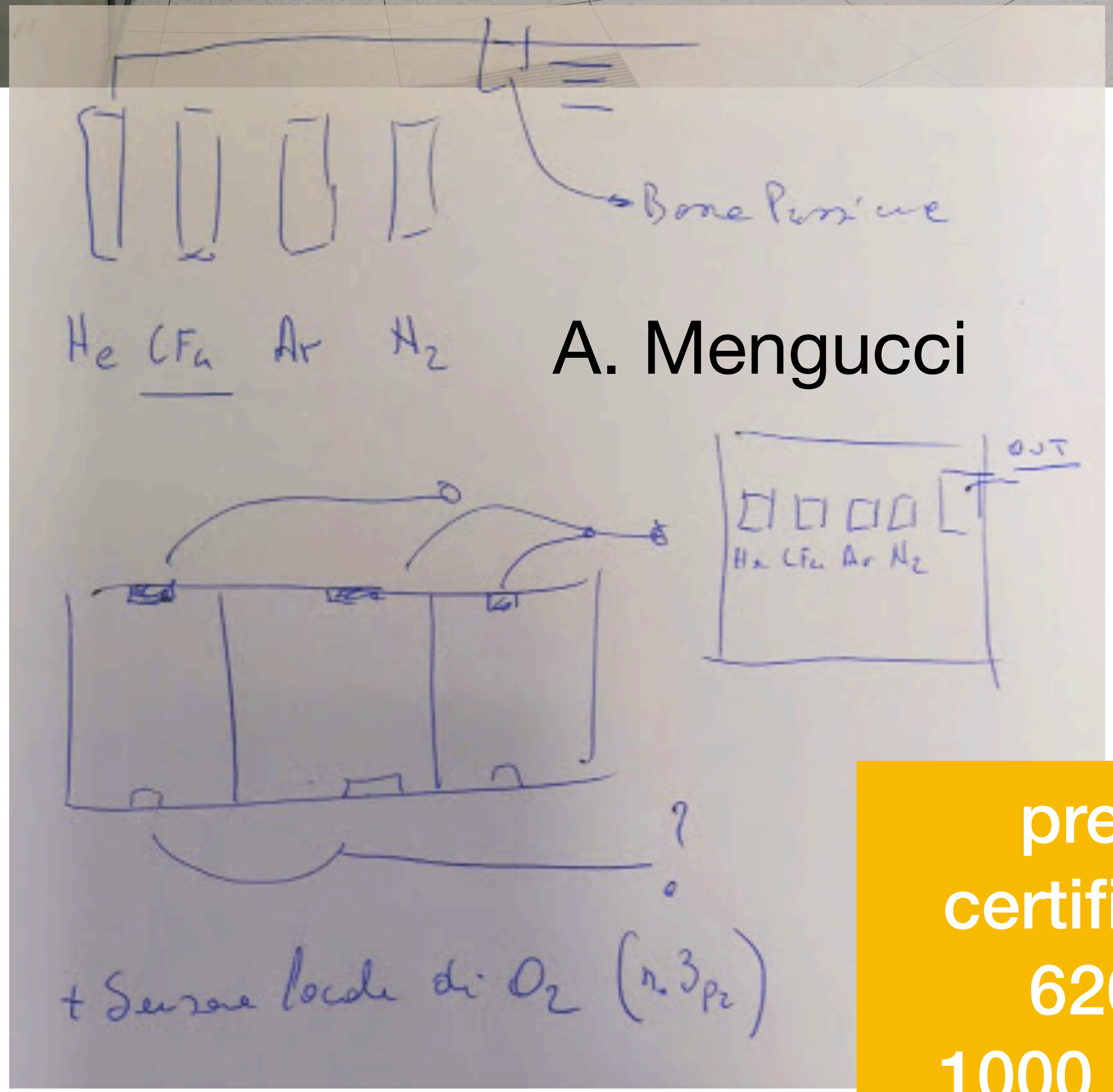


S. Gazzana (management), M. Tobia (sicurezze),
R. Adinolfi (ambiente), DT LNGS

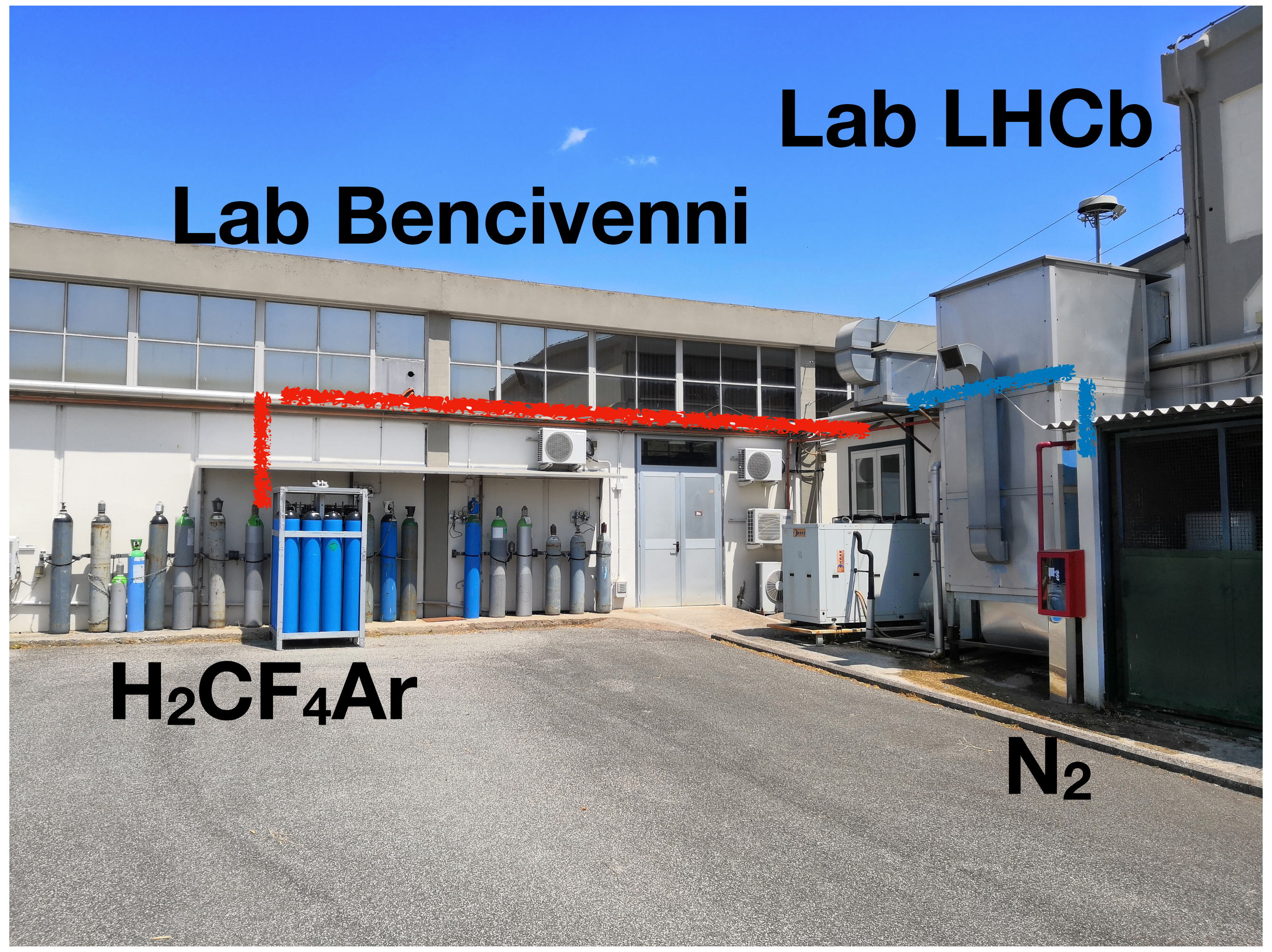
Phase0 LNF infrastructure

Refuse, Reduce, Reuse, Repurpose, Recycle!

many thanks to MU2E group and in particular to E. Paoletti and F. Marino

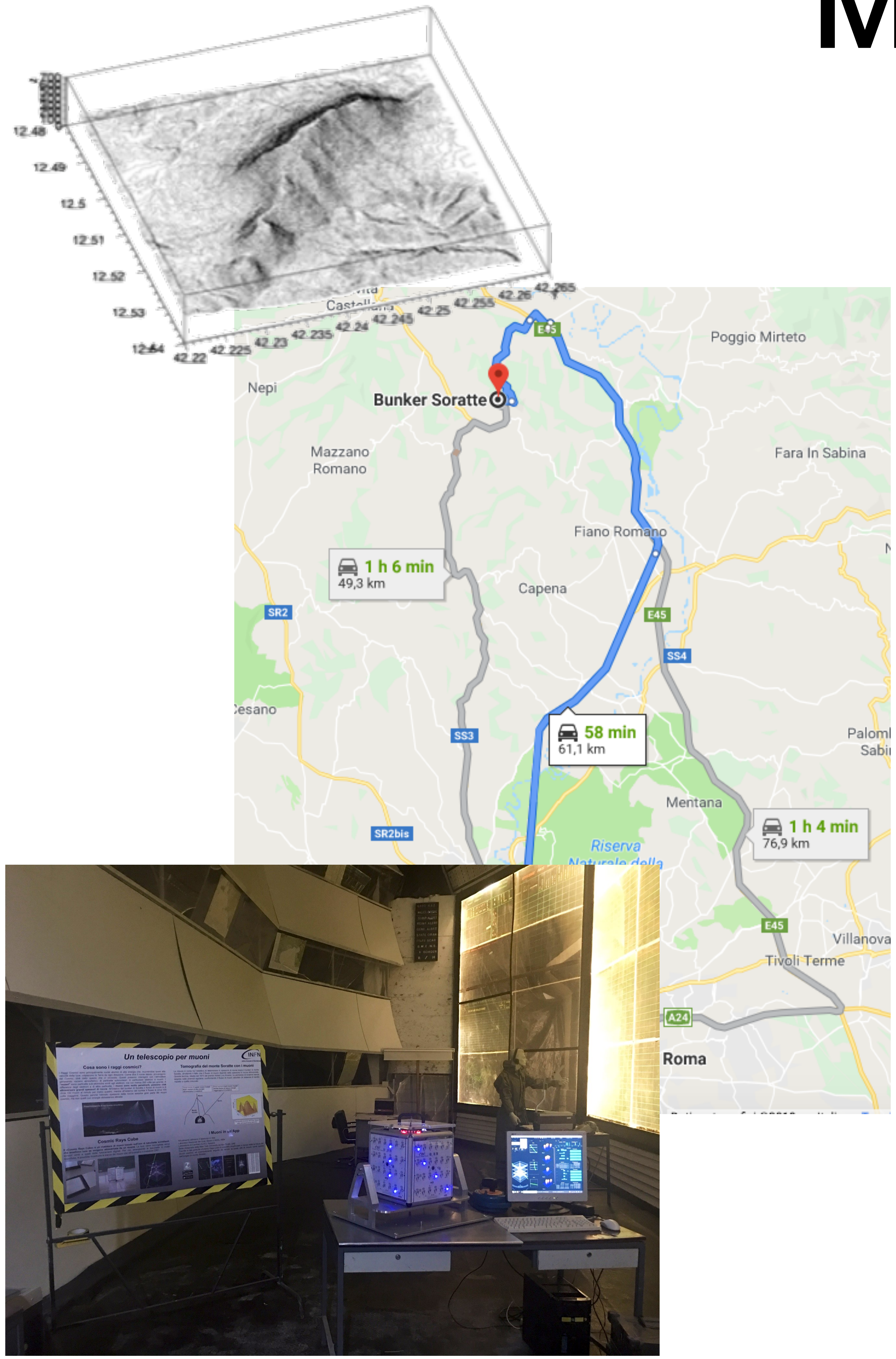


A. Mengucci



preventivo ditta, certificazioni incluse, 6200 euro + IVA
1000 euro monitor O_2

Monte Soratte site



- Under M. Soratte, a dismissed bunker partially used as a museum
- Some free galleries could be used as a site for tests under **reduced radioactivity conditions**:
- 200 - 400 m of rock (limestone) in vertical direction, few 10 m in horizontal direction
- cosmic ray measurements on going (LNGS + C. Gustavino), ~ 1/100 w.r.t. outside

- Identified as a possible site for the PTOLEMY experiment
- There is an interest by the CYGNO/INITIUM group for tests of prototypes
- What about building **a facility for tests under reduced environmental radiation** (cosmics + natural radioactivity)?
- Possible short-term plan:
  - site characterisation (cosmics, gamma, neutrons, radon,…) in collaboration with LNGS and **LNF**
  - evaluation of safety issues
  - evaluation of potential interest of other groups (**multidisciplinary** and **interdisciplinary**)
  - evaluation of possibile **public engagement** impact
- Initial costs could be borne by the PTOLEMY & CYGNO/INITIUM group, then?

Phase0 - The GWP (CF_4, SF_6) gases issue

Tests of **eco-friendly** gas mixtures in GEM based detectors with optical readout (D. Piccolo et al)

The European Community has prohibited the production and use of gas mixtures with Global Warming Power GWP > 150

- This is valid mainly for industrial (refrigerator plants) applications
- Scientific laboratories are excluded today

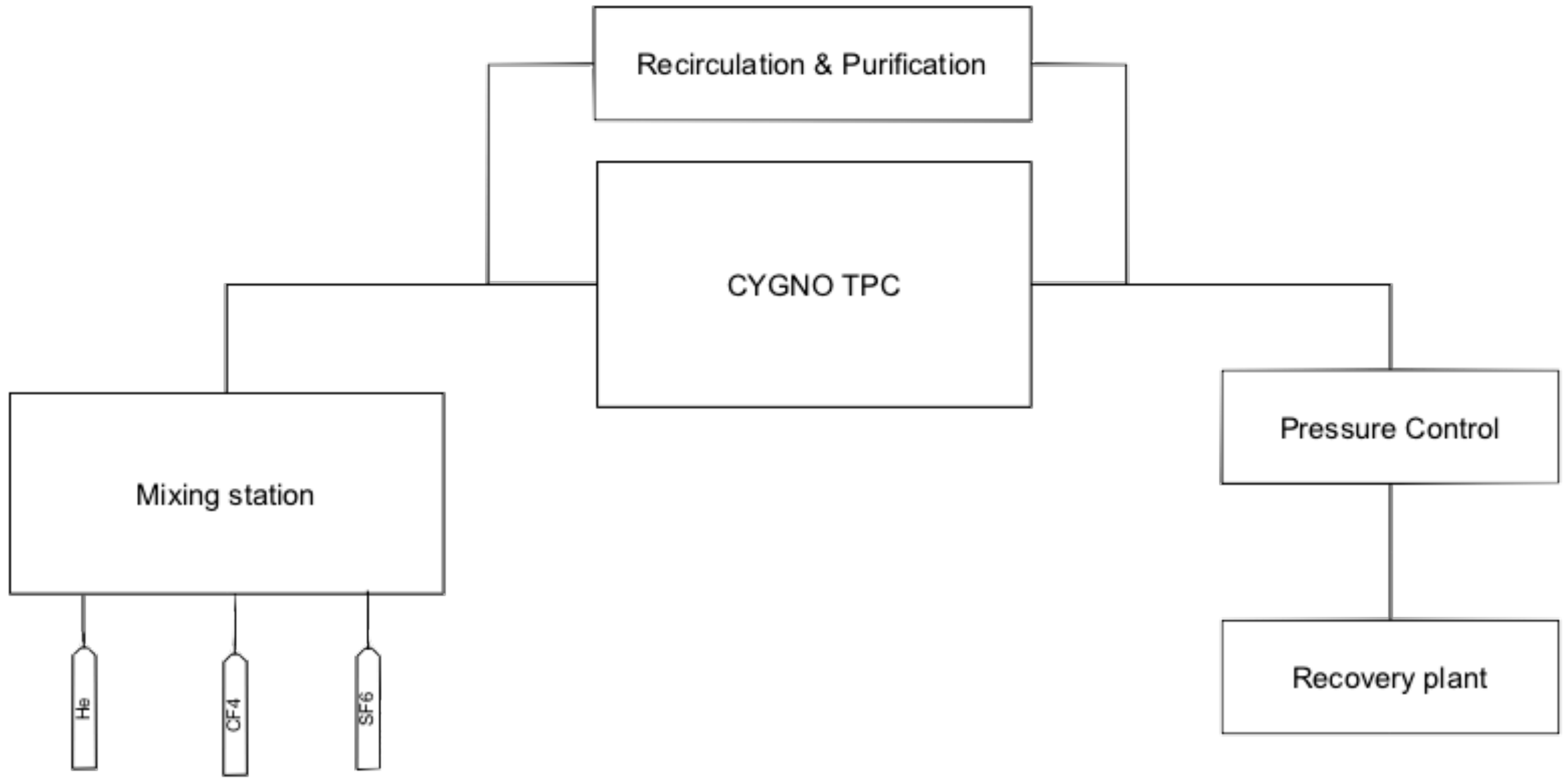
GWP(CO_2) = 1, GWP(CF_4) = 6500; GWP(SF_6)=23,900

Many GEM based applications uses or plan to use tetrafluoromethane (CF_4) in the mixture LHCb, Cygno (He-CF_4) etc.

Although scientific laboratories could still use CF_4 a recovery system is needed to not put CF_4 in the environment, moreover, prices of banned gases could became more expansive in the next years

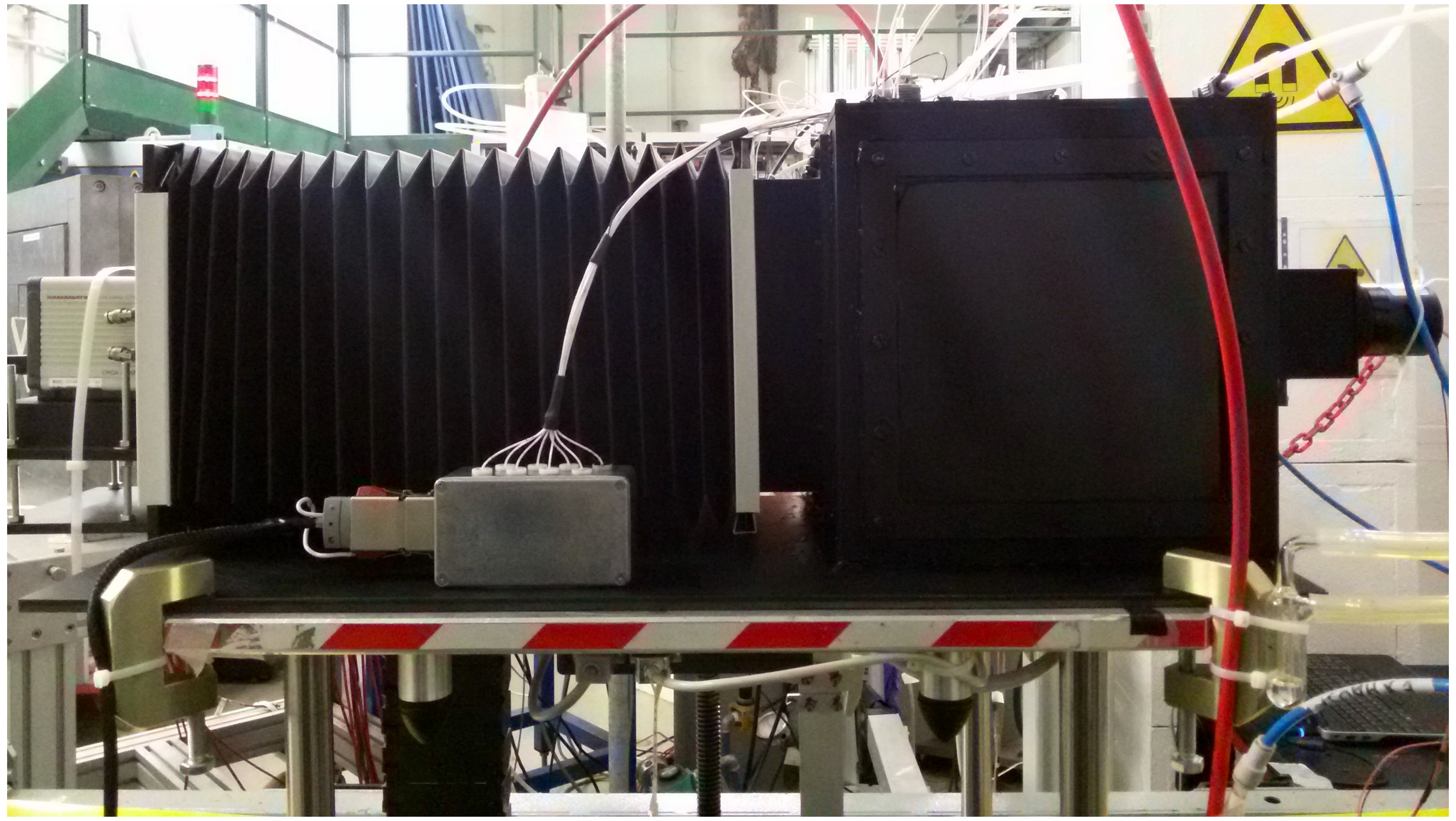
use of HFO to replace CF4 is not straightforward.
10% of HFO reduce light emission ~10

Mix	HV GEM	<Qgem> (pC)	G (10^4)
He-CF4 (60-40)	340	-2.1	8
He-CF4 (60-40)	350	-2.9	10
He-CF4 (70-30)	320	-2.4	8.5
He-CF4 (70-30)	330	-3.2	11
He-CF4-HFO(70-30-10)	360	-1.4	5
He-CF4-HFO(70-30-10)	370	-2.2	7
He-CF4 (80-20)	380	~0.6	~ 1.7



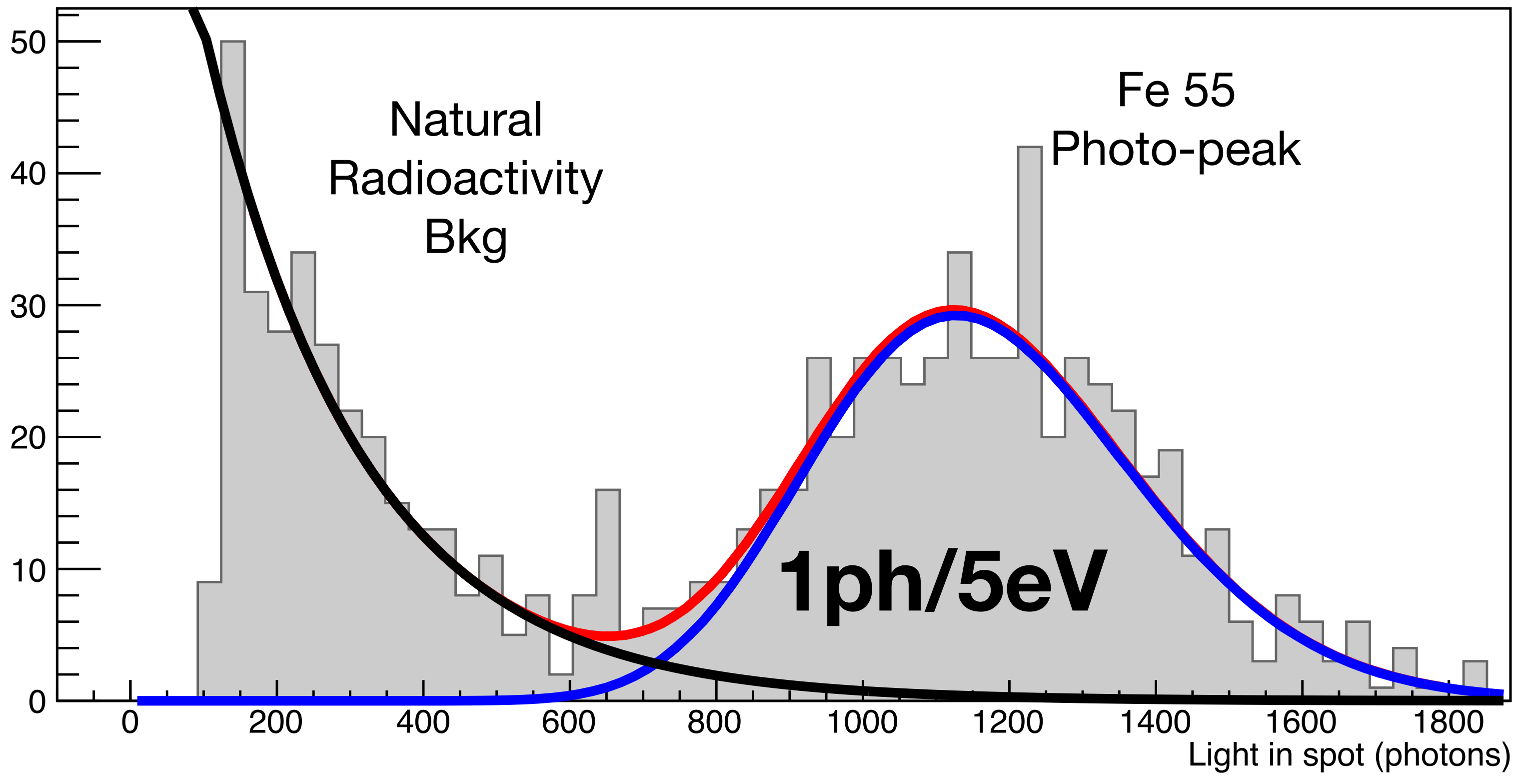
CYGNO gas system (He, CF_4, SF_6) block diagram executive design and construction under evaluation

Phase0 - Prototype



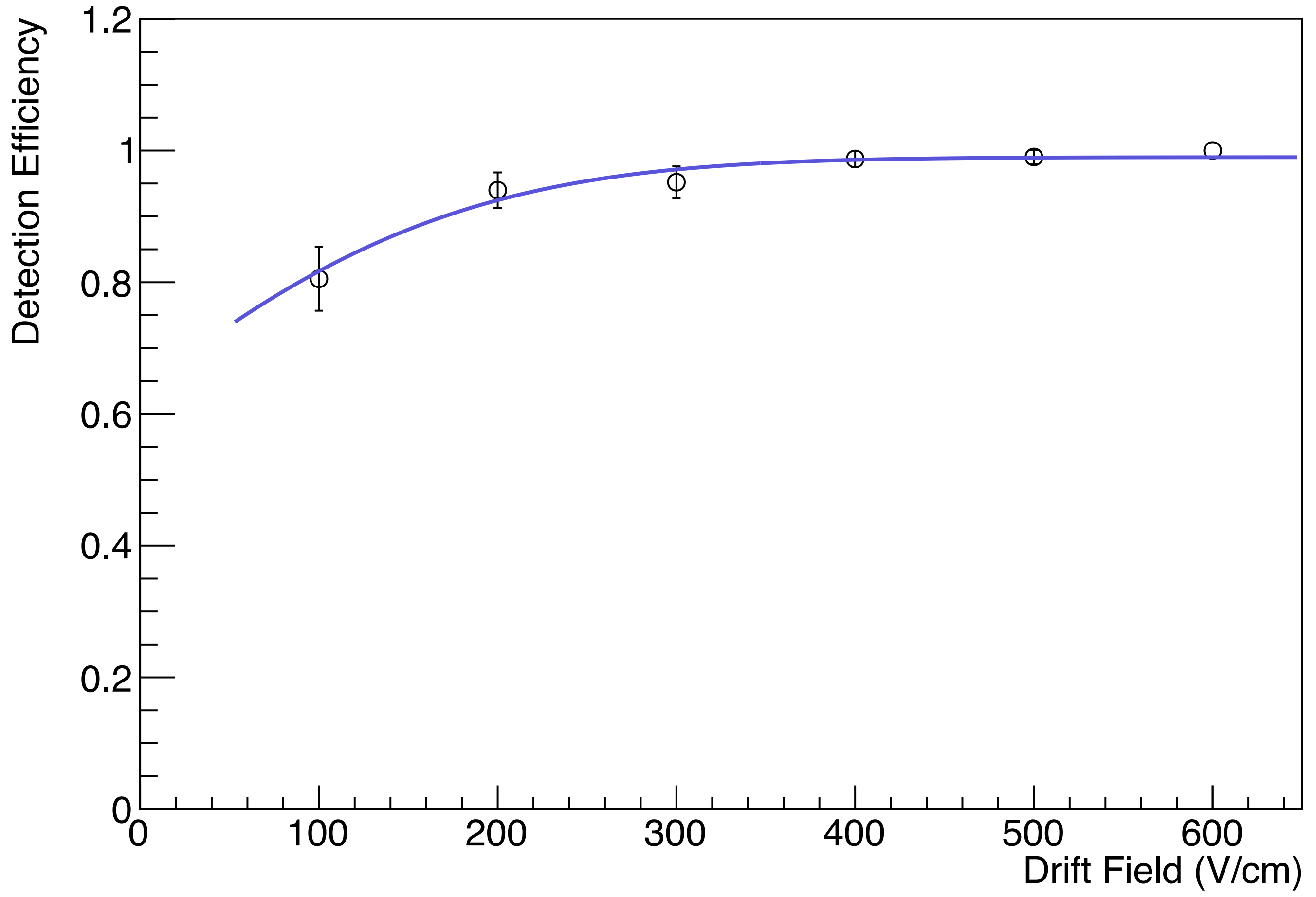
LEMOn: Large Elliptical Module Optically readout

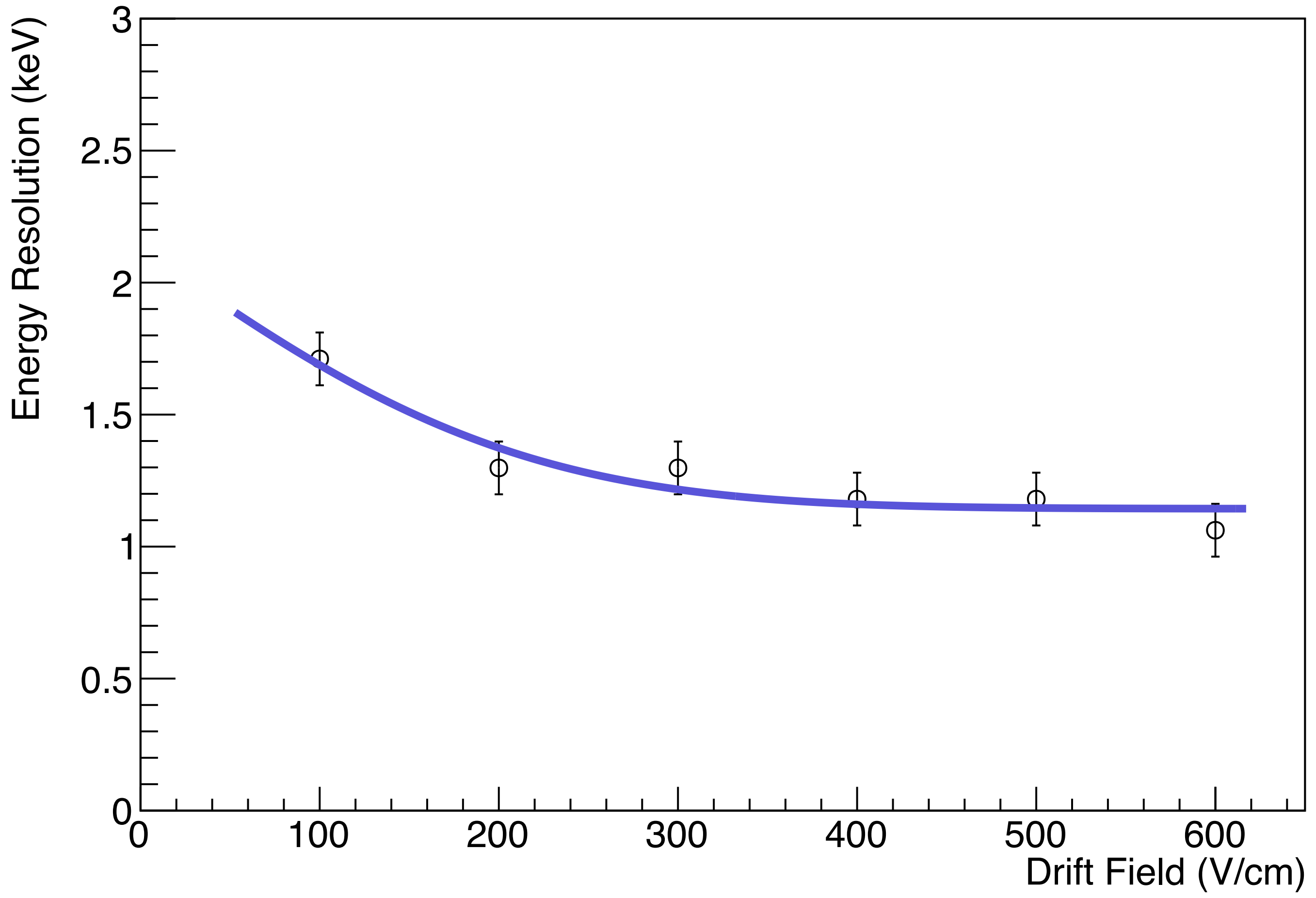
- 7 litre sensitive volume
- 25 cm drift
- 20*24 GEM
- 3D printed
- semi-transparent cathode

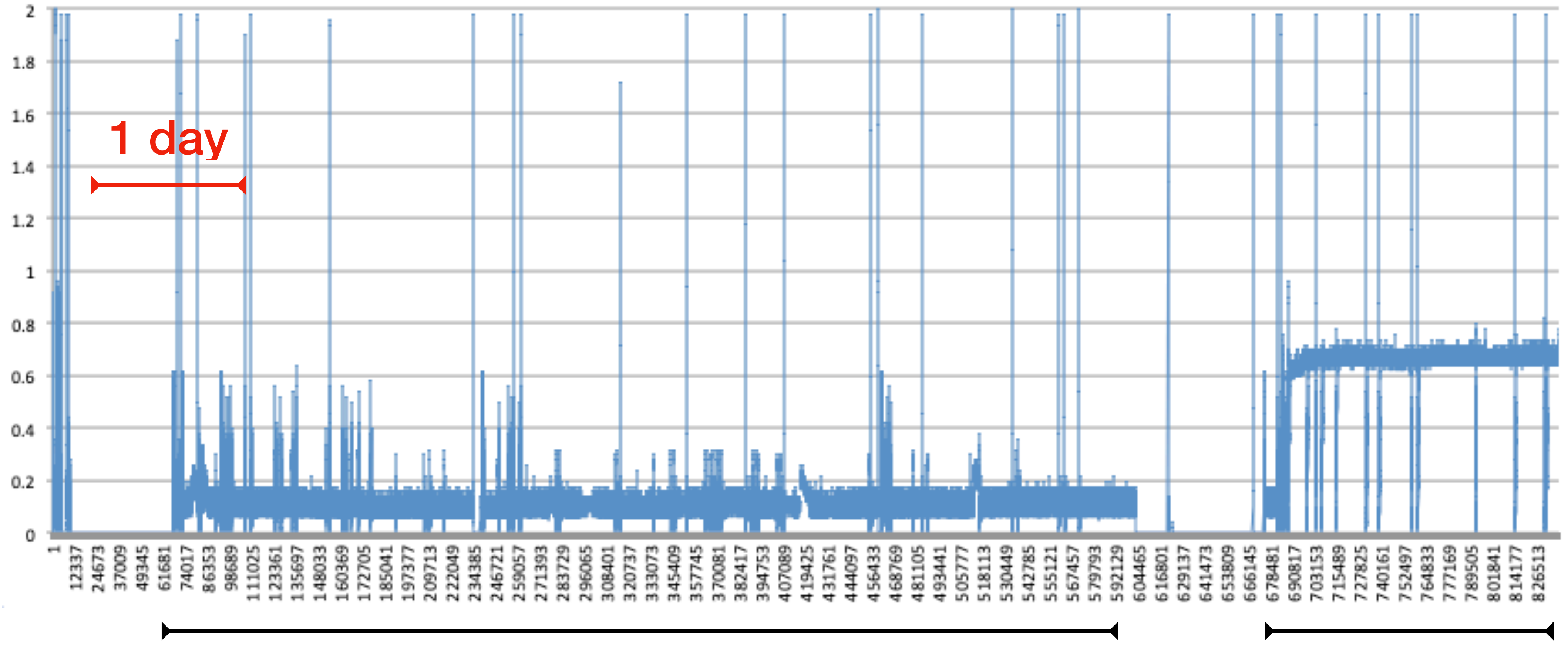


2 keV energy threshold (conservative) with 18% energy resolution @ 5.9 keV for events at <u>20 cm drift distance</u>

JINST_024P_0519



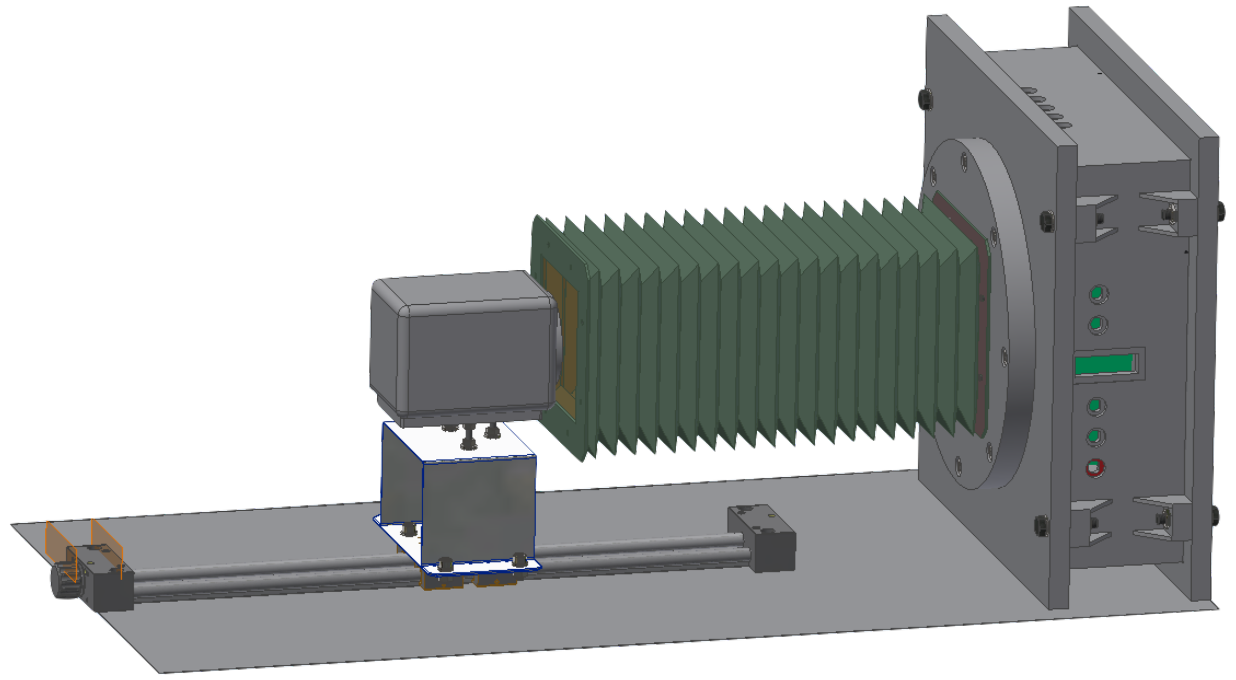




In this period 98.4% nominal conditions

Strong ^{55}Fe

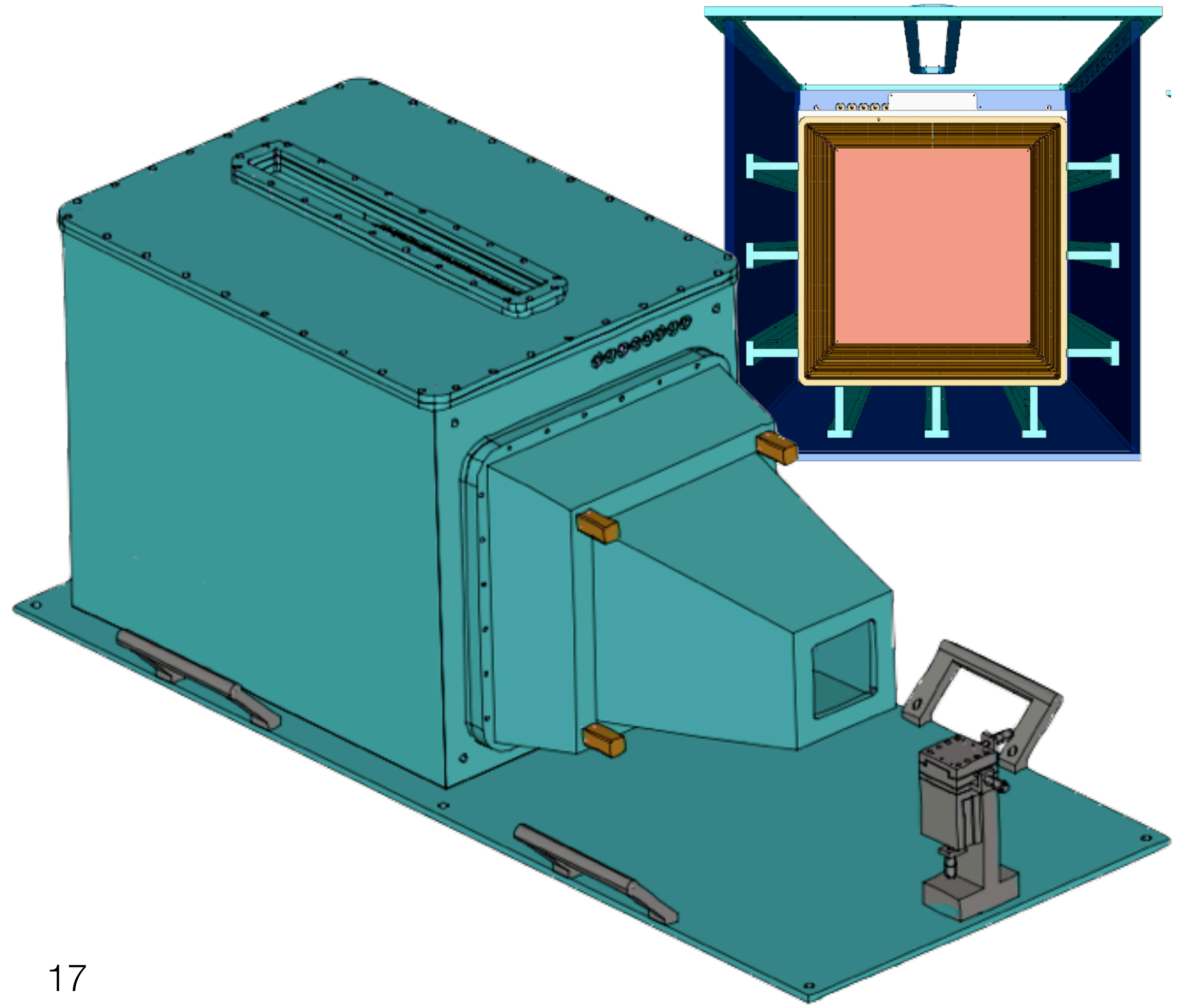
Phase0 - Prototype (con't)

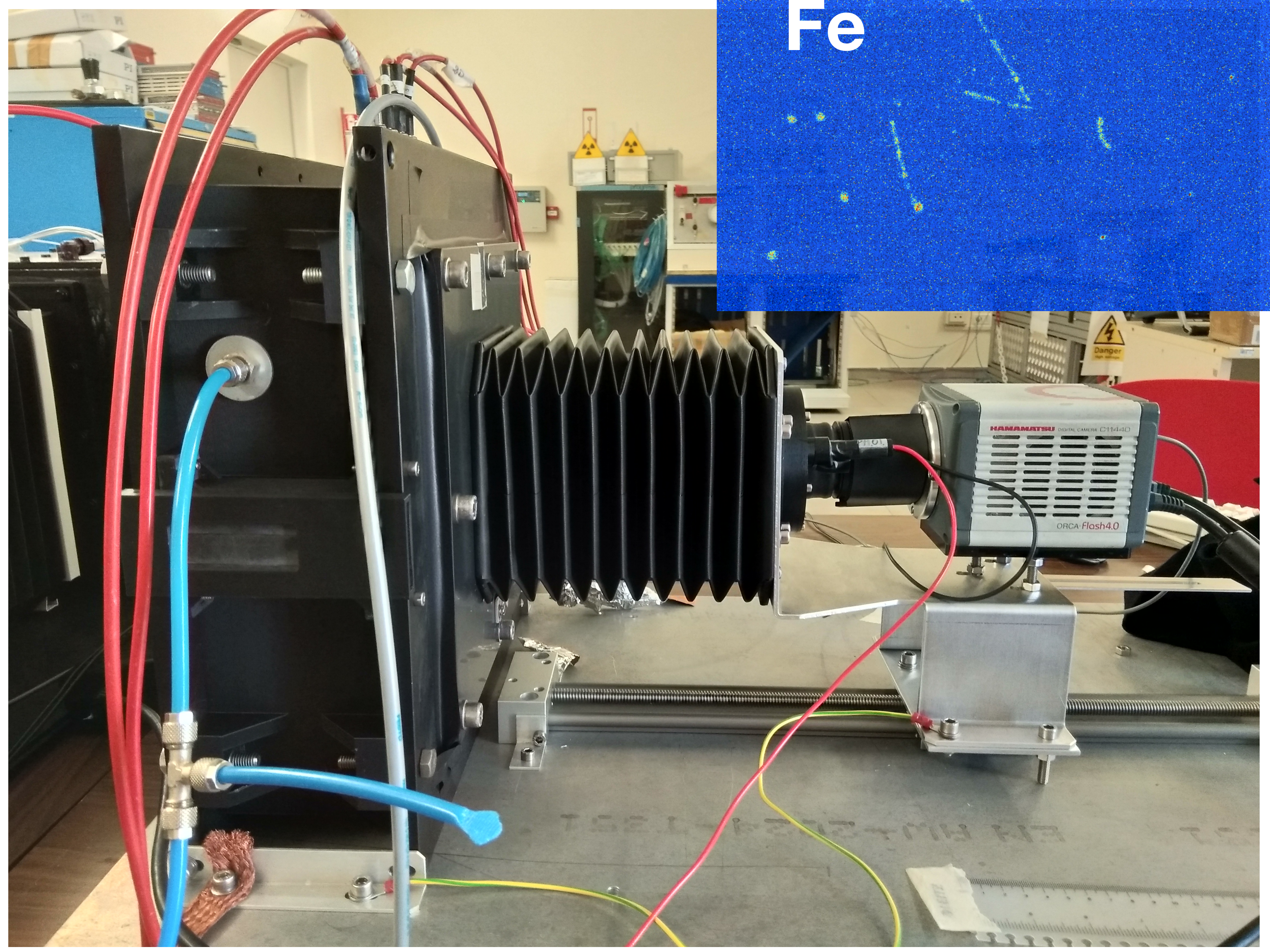


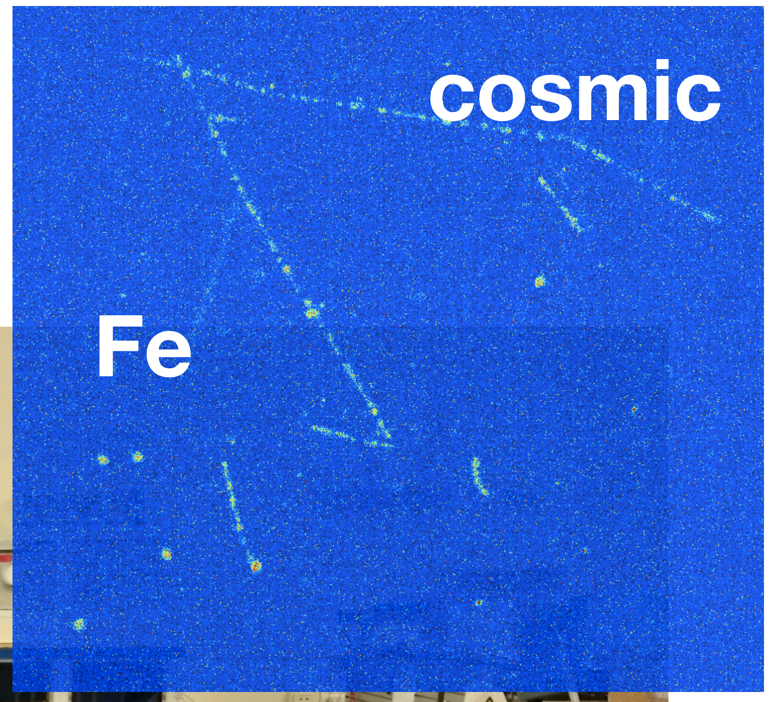
C. Capoccia, A. Pelosi, F. Rosatelli, S. Tomassini

MANGO - Multipurpose Apparatus for Negative ion studies with GEM and Optical readout

- 5 cm drift gap
- THGEM test
- 4 GEM test
- Negative Ion test







LIME: Long Imaging ModulE

- 50 cm long drift gap
- studying materials
- performing a detailed study, minimisation and simulation of **radioactive background;**
- **gas re-circulation and purification.**
- optimisation of **PMT/SiPM** readout and trigger.
- HV Test

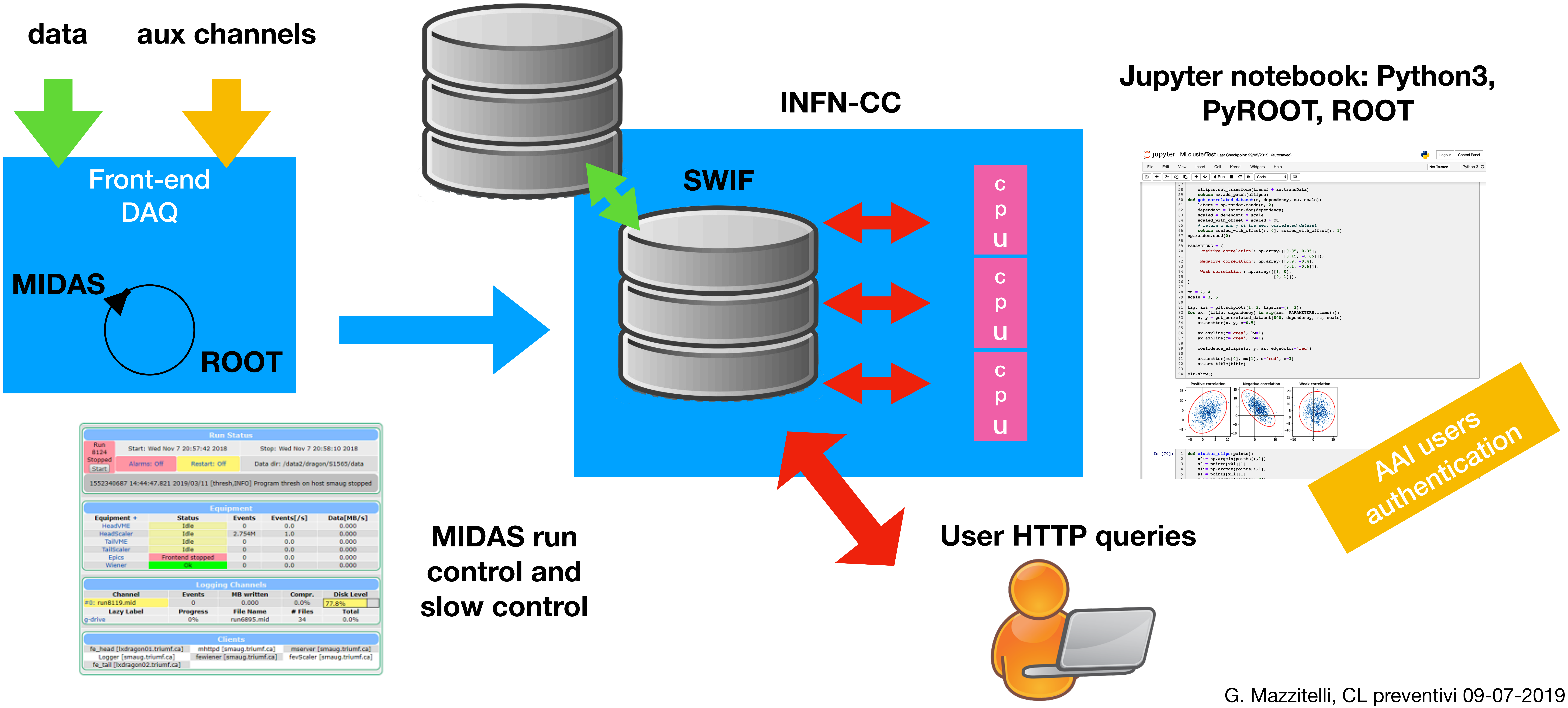
50-liter prototype
the delivery is foreseen for half of July!

Tests expected in fall 2019
@ BTF and the in 2020 at LNGS

A. Orlandi, E. Paoletti, L. Passamonti, D. Pierluigi, A. Russo

INFN-CC @ LNGS-LNF

G. Mazzitelli thanks to the support
of R. Gargana, D. Maselli, S. Stalio



CYGNO/INITIUM @ LNF 2019-2020

CYGNO/INITIUM prevede attività che avranno il loro apice fra il 2020 e il 2021 con la costruzione del rivelatore da istallare presso i LNGS nel 2022. Per il secondo semestre del 2019, oltre alla progettazione del rivelatore principale, si prevede l'assemblaggio dei prototipi LIME e MANGO e la preparazione/realizzazione delle attività di test ai LNGS/Soratte con tali prototipi

Richieste/assegnazioni ultimo CIF

- 5 mu/0.7 FTE servizio Servizio Meccanica DR per la progettazione di CYGNO/INITIUM e supporto all'assemblaggio di LIME/MANGO
- 1 mu servizio SPCM supporto lavorazioni prototipo LIME/MANGO
- 0.25 mu servizio SPCM per la stampa 3D prototipo LIME/MANGO
- 6 mu/0.8 FTE servizio Servizio Costruzione Rivelatori DR supporto al montaggio dei prototipi LIME/MANGO e supporto alle attività di preparazione/realizzazione delle misure presso i LNGS.
- 3 mu Servizio Elettronico e Automazione

Richieste LNF 2010:
Il maggiore impatto sui servizi LNF sarà nella seconda metà del 2020
Servizio Costruzione Rivelatori DR, Servizio Meccanica DR in piena con l'attuale, probabile un maggiore coinvolgimento SEA e SPCM

Richieste CSNII 2020: supporto alle attività di R&D per CYGNO 30-100 e cofinanziamento ad INITIUM per costi di costruzione del detector non rendicontabili

Vai alla sezione: LNF LNGS RM1

SEZIONE	NOME COGNOME	TIPO	CONTRATTO	QUALIFICA	RICERCATORI	TECNOLOGI	TOT. PERS.	FTE	FTE / PERS.
LNF	Bedogni Roberto				x			15	-10
	Benussi Luigi				x			10	
	Bianco Stefano				x			20	
	Maccarrone Giovanni				x			30	+10
	Mazzitelli Giovanni				x			60	+ 40 INITIUM
	Piccolo Davide				x			20	
	Tomassini Sandro					x		10	+ 10 INITIUM
LNF					**1.55 fte** **6 pers.**	**0.1 fte** **1 pers.**	**7**	**2.2**	**0.314**

torna su

Giovanna Saviano + 20
Michele Caponero + 20
Un articolo 15 bandito + 100
Un assegno di ricerca + 100

FTE = 2.45 + 1 + 0.8 + 0.7 —> 4.95 + 1…

Effort Phase1 2020

anagrafica 2019

Vai alla sezione: LNF LNGS RM1

SEZIONE	NOME COGNOME	TIPO	CONTRATTO	QUALIFICA	RICERCATORI	TECNOLOGI	TOT. PERS.	FTE	FTE / PERS.
LNF	Bedogni Roberto				x			15	
	Benussi Luigi				x			10	
	Bianco Stefano				x			20	
	Maccarrone Giovanni				x			30	
	Mazzitelli Giovanni				x			60	+ 40 INITIUM
	Piccolo Davide				x			20	
	Tomassini Sandro					x		10	+ 10 INITIUM
LNF					1.55 fte 6 pers.	0.1 fte 1 pers.	7	1.7	0.236
SEZIONE	NOME COGNOME	TIPO	CONTRATTO	QUALIFICA	RICERCATORI	TECNOLOGI	TOT. PERS.	FTE	FTE / PERS.
LNGS	Baracchini Elisabetta				x			20	+ 80 INITIUM
LNGS					0.2 fte 1 pers.	0 fte pers.	1	0.2	0.200
SEZIONE	NOME COGNOME	TIPO	CONTRATTO	QUALIFICA	RICERCATORI	TECNOLOGI	TOT. PERS.	FTE	FTE / PERS.
RM1	Cavoto Gianluca				x			20	+ 10 INITIUM
	D'Imperio Giulia				x			50	
	Di Marco Emanuele				x			10	+ 10 INITIUM
	Marafini Michela				x			20	
	Messina Andrea				x			30	
	Pinci Davide				x			40	+ 10 INITIUM
	Renga Francesco				x			30	+ 10 INITIUM
RM1					2 fte 7 pers.	0 fte pers.	7	2.0	0.286
TOTALE					3.75 FTE 14 PERS.	0.1 FTE 1 PERS.	15	3.85	0.257

1.7 INITIUM

activity partially founded by European Research Council (ERC) grant agreement No 818744

anagrafica 2020

	Appartenenza	Qualifica	FTE CYGNO	FTE INITIUM
Baracchini E.	GSSI-LNGS	Professore	0,20	0,80
Dho G.	GSSI-LNGS	PhD		1,00
PhD 1	GSSI-LNGS	PhD		1,00
PhD 2	GSSI-LNGS	PhD		1,00
Postdoc	GSSI-LNGS	Postdoc		1,00
Bedogni R.	LNF	Ricercatore	0,05	
Benussi L.	LNF	Ricercatore	0,10	
Bianco S.	LNF	Primo Ricercatore	0,20	
Caponero M.	LNF	Primo Ricercatore	0,20	
Maccarone G.	LNF	Primo Ricercatore	0,40	
Mazzitelli G.	LNF	Primo Ricercatore	0,60	0,40
Piccolo D.	LNF	Primo Ricercatore	0,20	
Saviano G.	LNF	Ricercatore	0,20	
Tomassini S.	LNF	Tecnologo	0,10	0,10
Cavoto G.	Roma1	Ricercatore	0,20	0,10
D'Imperio G.	Roma1	Assegnista	0,50	
Di Marco E.	Roma1	Ricercatore	0,10	0,10
Marafini M.	Roma1	Ricercatore	0,20	
Messina A.	Roma1	Ricercatore	0,30	
Pinci D.	Roma1	Ricercatore	0,40	0,10
Renga F.	Roma1	Ricercatore	0,30	0,10
Iacoangeli F.	Roma1	Tecnologo	0,20	
Petrucci F.	Roma3	Ricercatore	0,20	
Totale			**4,65**	**5,70**

Budget Phase1 2020

Richieste CSNII 2020

RM1	Richieste k€
DAQ (sviluppo schede DAQ)	8
Missioni (LNGS, LNF, CERN, Conferenze)	15
TOTALE	**23**

LNGS	Richieste k€
GAS (LIME test @ LNGS)	3
Meccanica	2
Missioni (LNGS, LNF, CERN, Conferenze)	6
TOTALE	**11**

RM3	Richieste k€
Missioni (LNGS, LNF, Conferenze)	1
TOTALE	**1**

LNF	Richieste k€
PRA, etc	7
Test materiali (GEM a bassa radioattività)	15
Missioni (LNGS, RM1, CERN, Conferenze)	17
GAS (HeCF4, no aresol)	10
TRASPORTI	3
R&D sistema monitoraggio strutturale	5
TOTALE	**57**

Budget INITUM (su 5 anni)

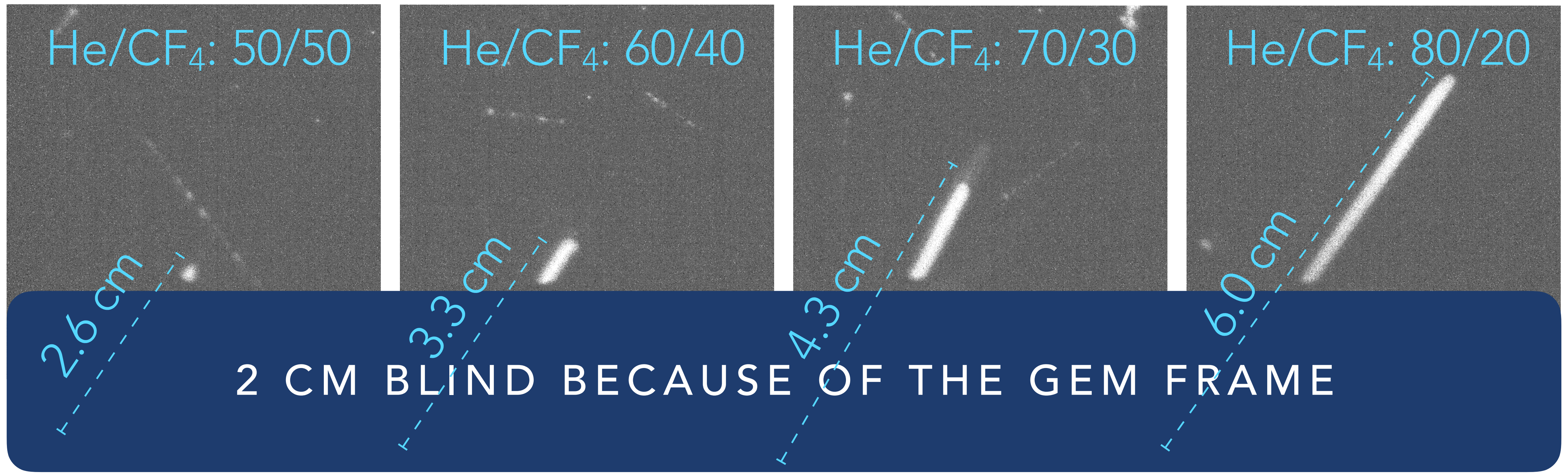
- 700 k€ al netto dell'overhead INFN/RM1
- 200 k€ fondi NRC: personale LNF (1 art15 per 2 anni) + (1 ass ricerca per 2 anni) + 50 k€
- 500 k€ per costruzione apparato
- equivalente budget al GSSI per dottorandi e assegnasti

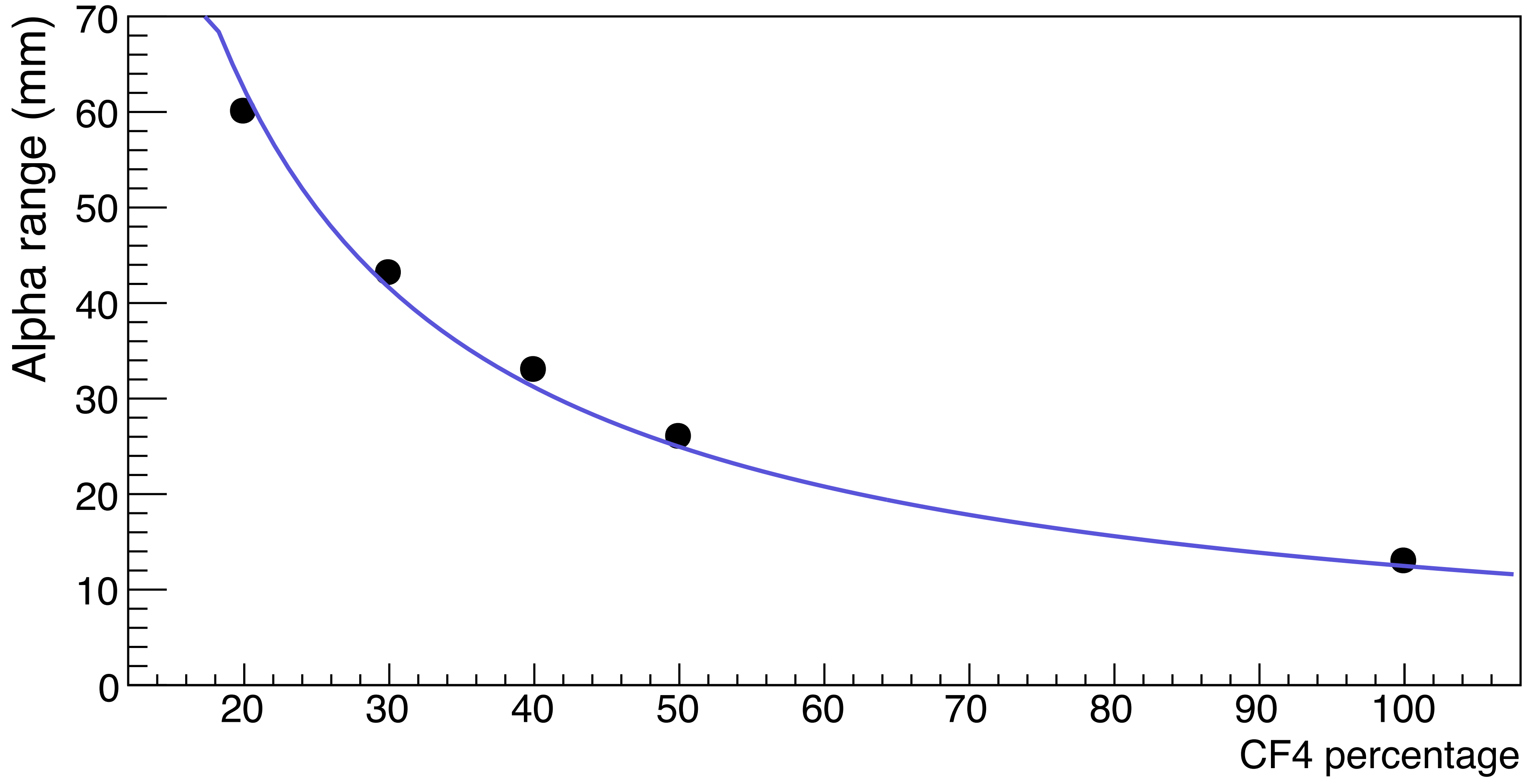
10-12 July @ ROMA

http://www.roma1.infn.it/conference/CYGNUS_2019

Range and recoil energy released

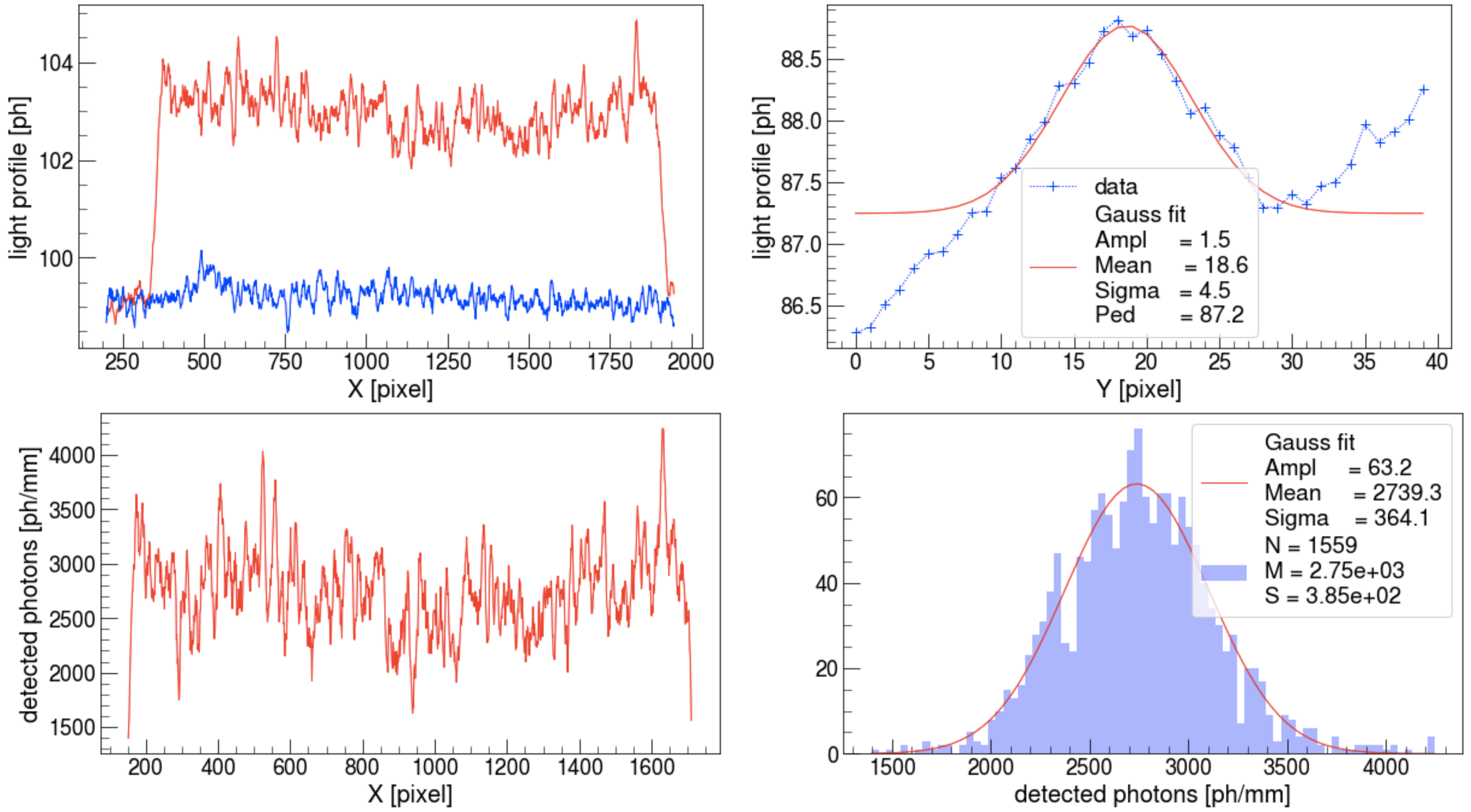
Am alpha source (5.48 MeV);
alpha range in $HeCF_4$



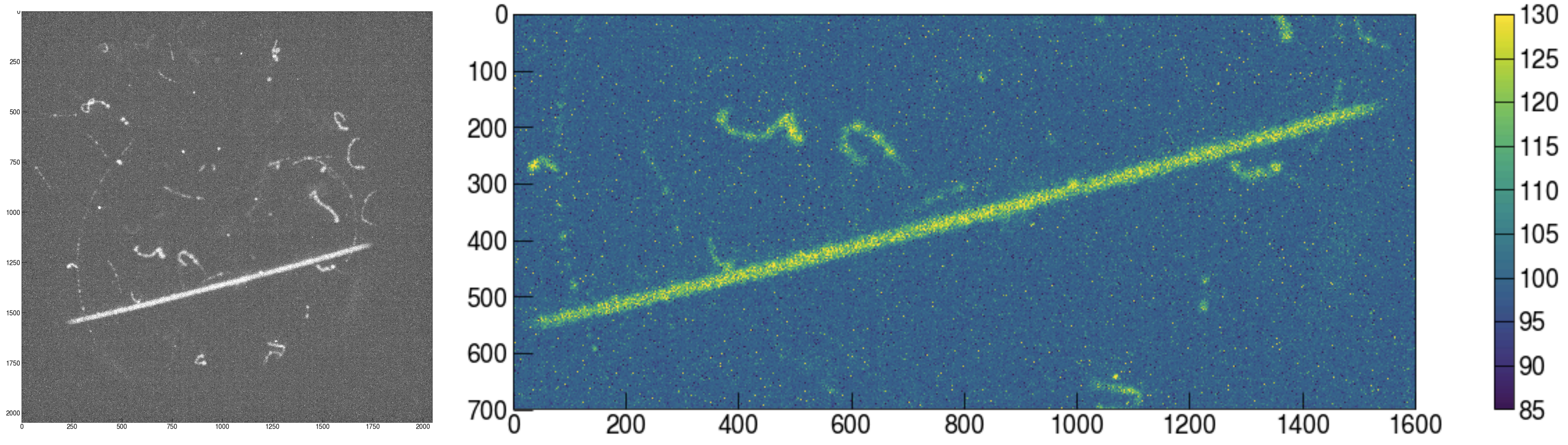


alpha range seems to be "determined" only by CF_4 and to decrease linearly with its amount

AmBe (5-11 MeV) neutron source;
nuclear recoil in $HeCF_4$ / 60:40

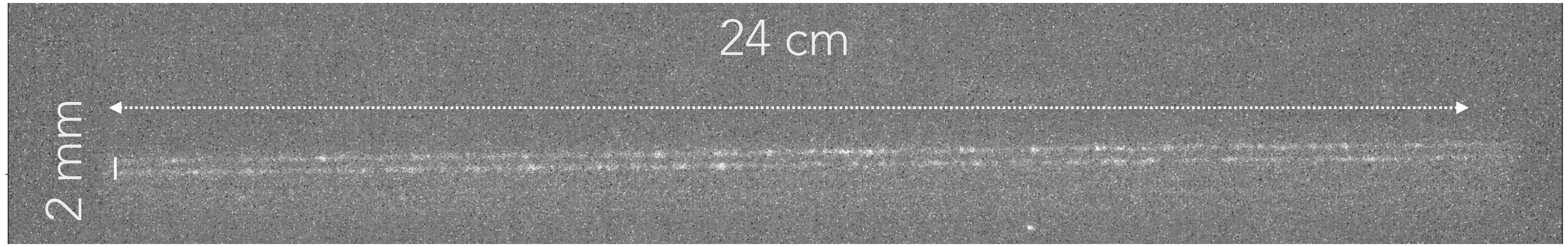


GEM 440/2kV/cm - drift 1kV/cm - 2000 ms

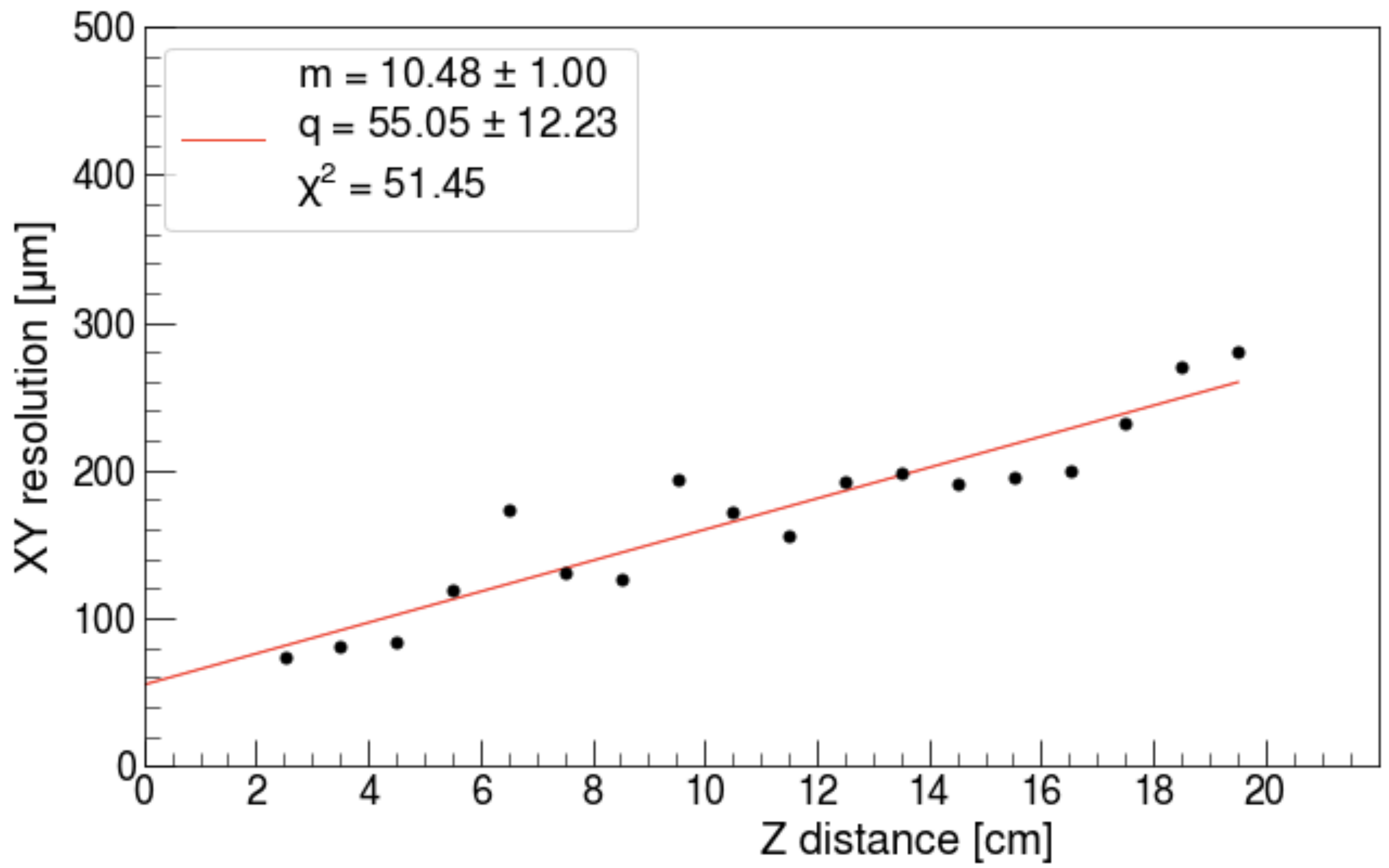


2740 [ph/mm] / 1.5 [ph/eV] —> 1.7 keV/mm (55 μm resolution)

XY and energy resolution

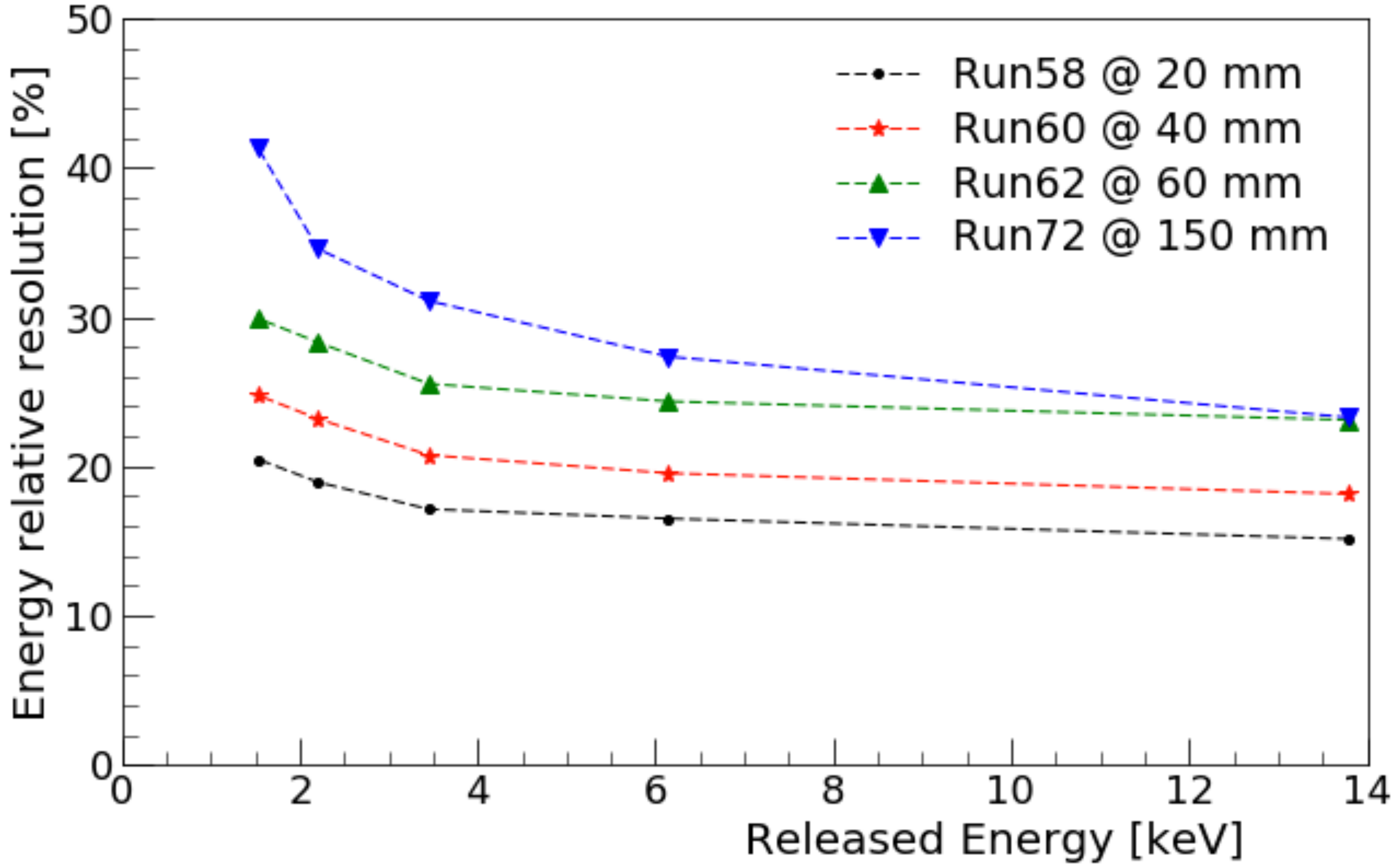


XY resolution vs depths (Z)



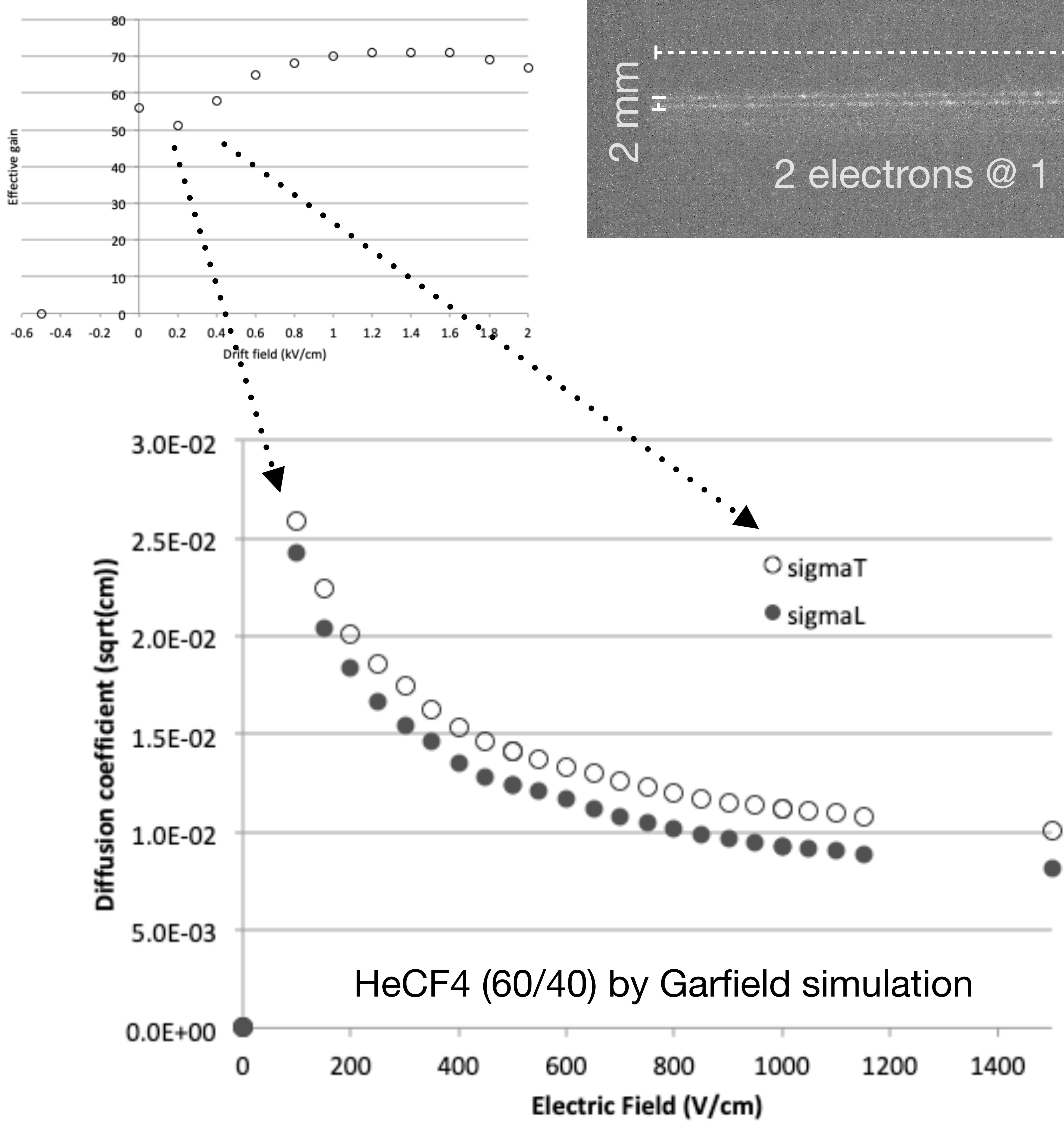
resolution obtained with a drift field to 0.6kV/cm

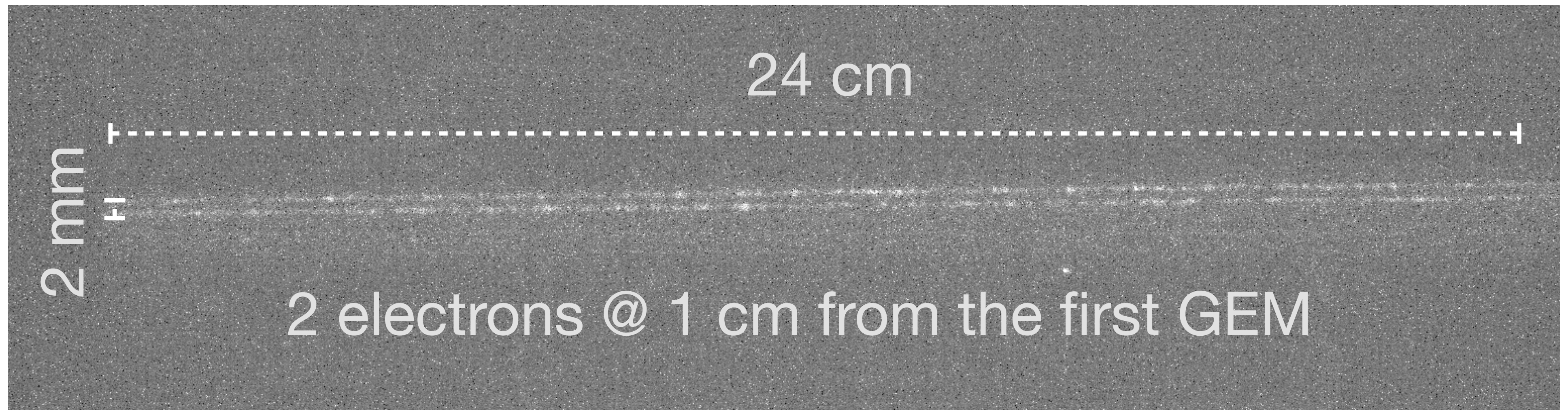
energy resolution @ depths (Z)

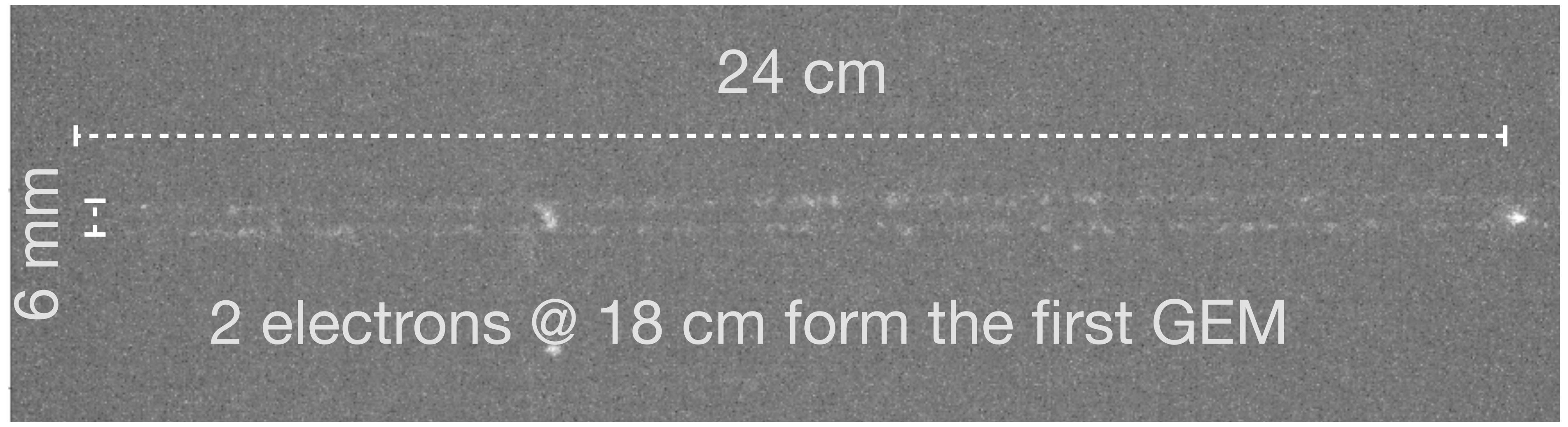


in the few keV region a relative resolution of 20%-30% is achieved

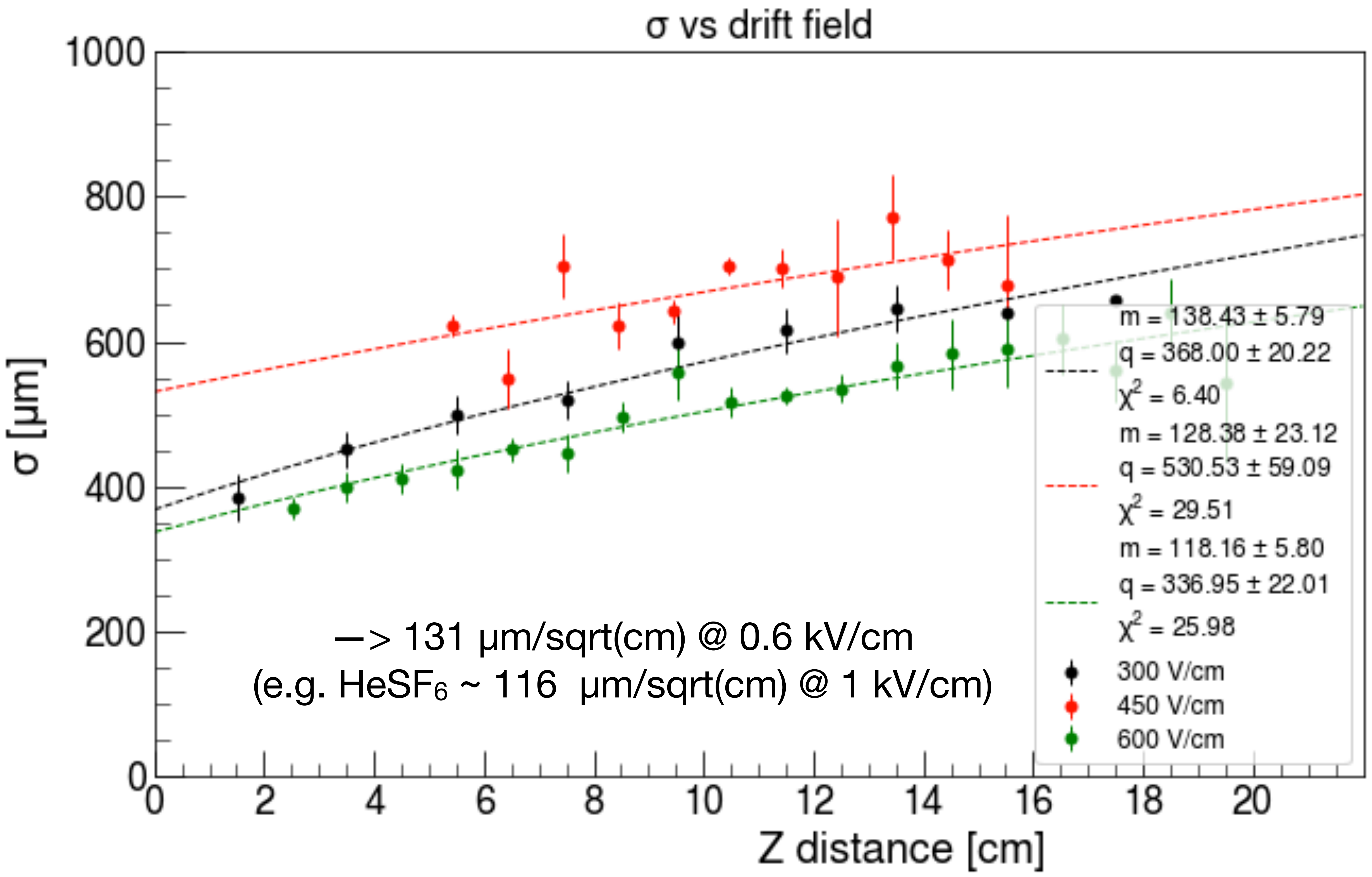
diffusion in $HeCF_4$ for electrons







V_{drift} = 4.36 cm/μs @ 0.6 kV/cm

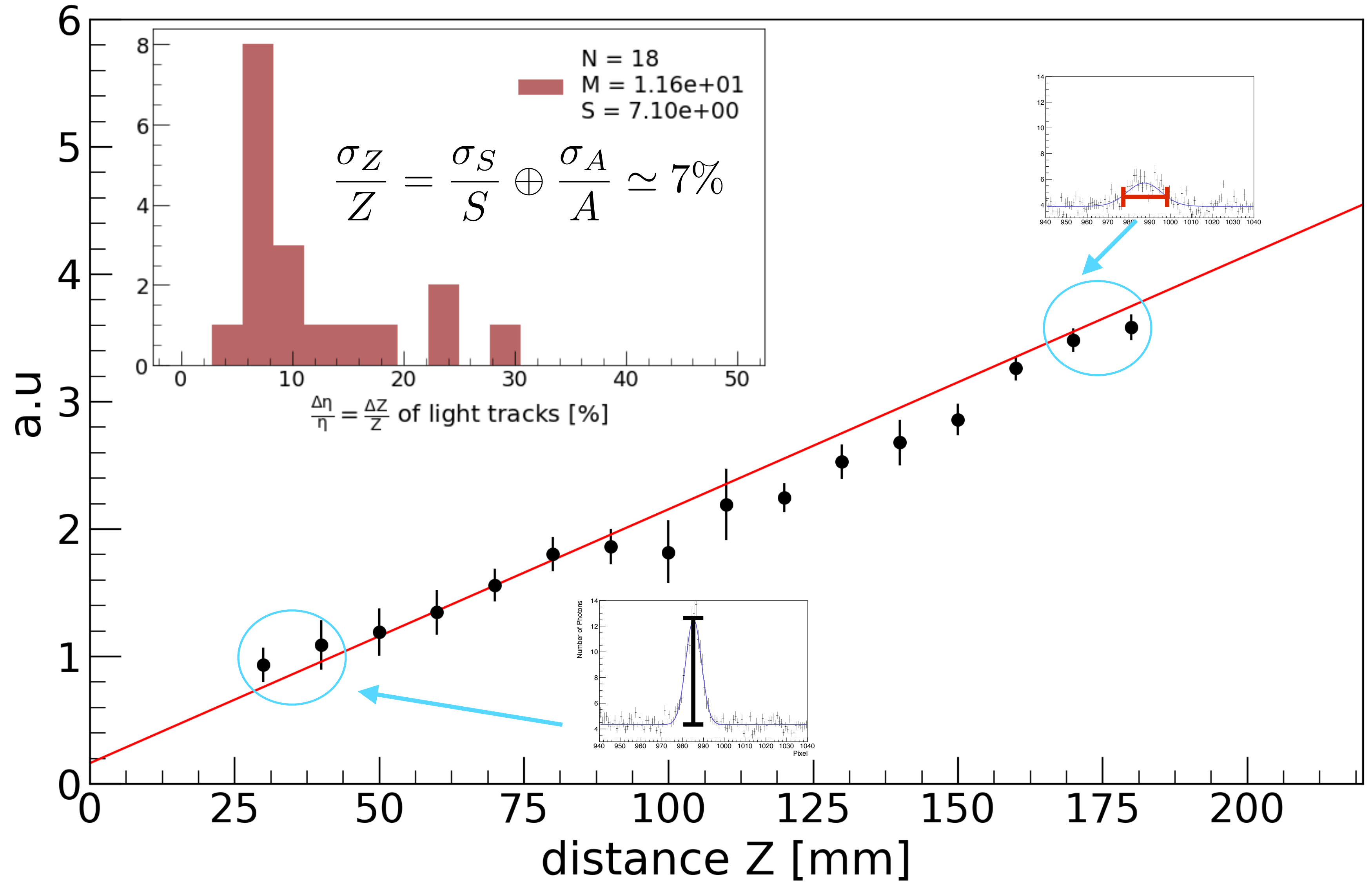


LEMON data @ Frascati BTF

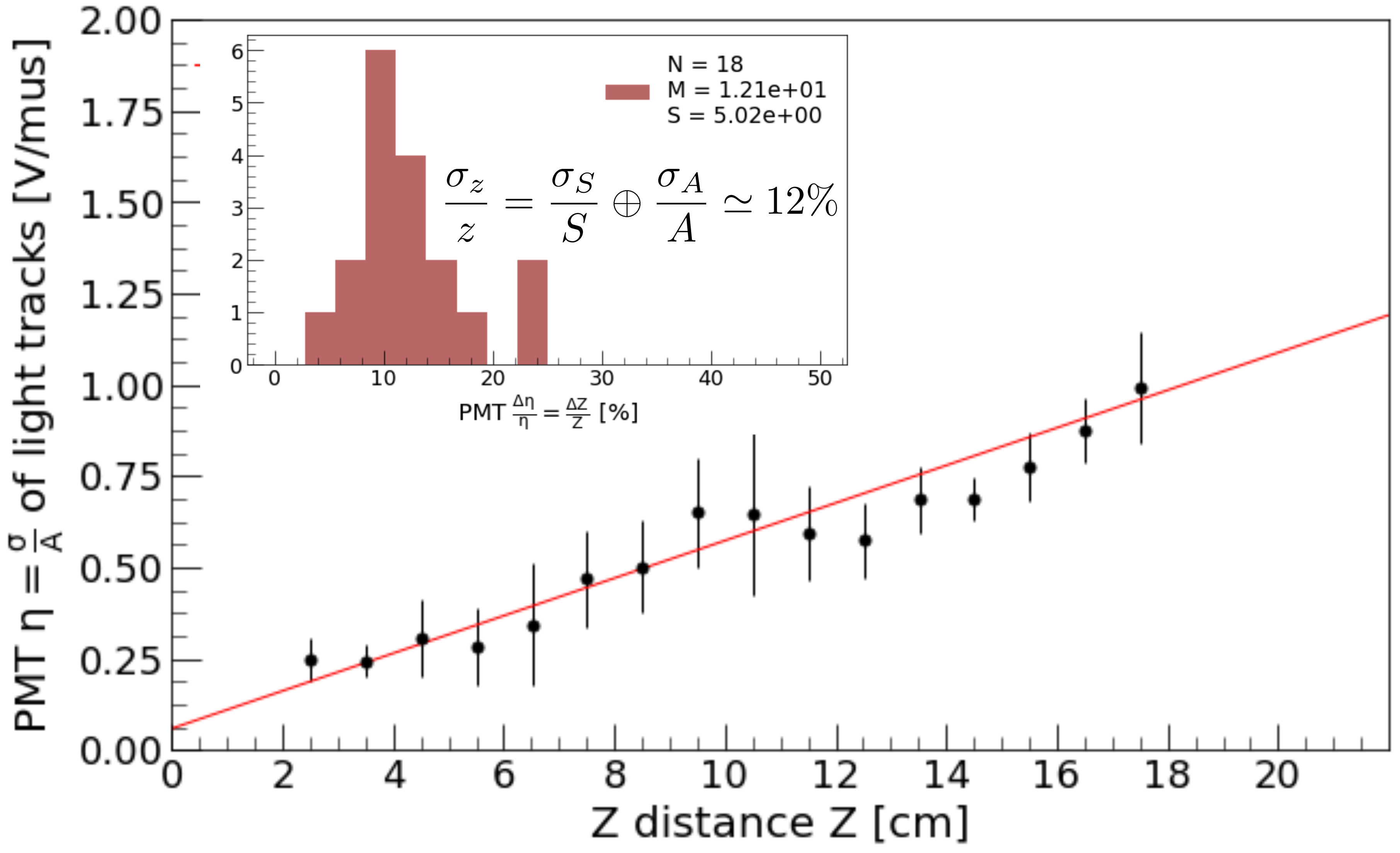
Z resolution in LEMOn

Electron diffusion in the drift gap can be exploited to evaluate the Z of the event. The transverse light profile and the PMT signal waveform are expected to become lower and larger as long as the event is far from the GEM;
Since the amplitude (A) decreases and the width (S) increases with Z, their ratio η = S/A increases (independently from the amount of produced light);

transverse diffusion



longitudinal diffusion



both methods gives 10% precision: σz ~ 2 cm @ 20 cm