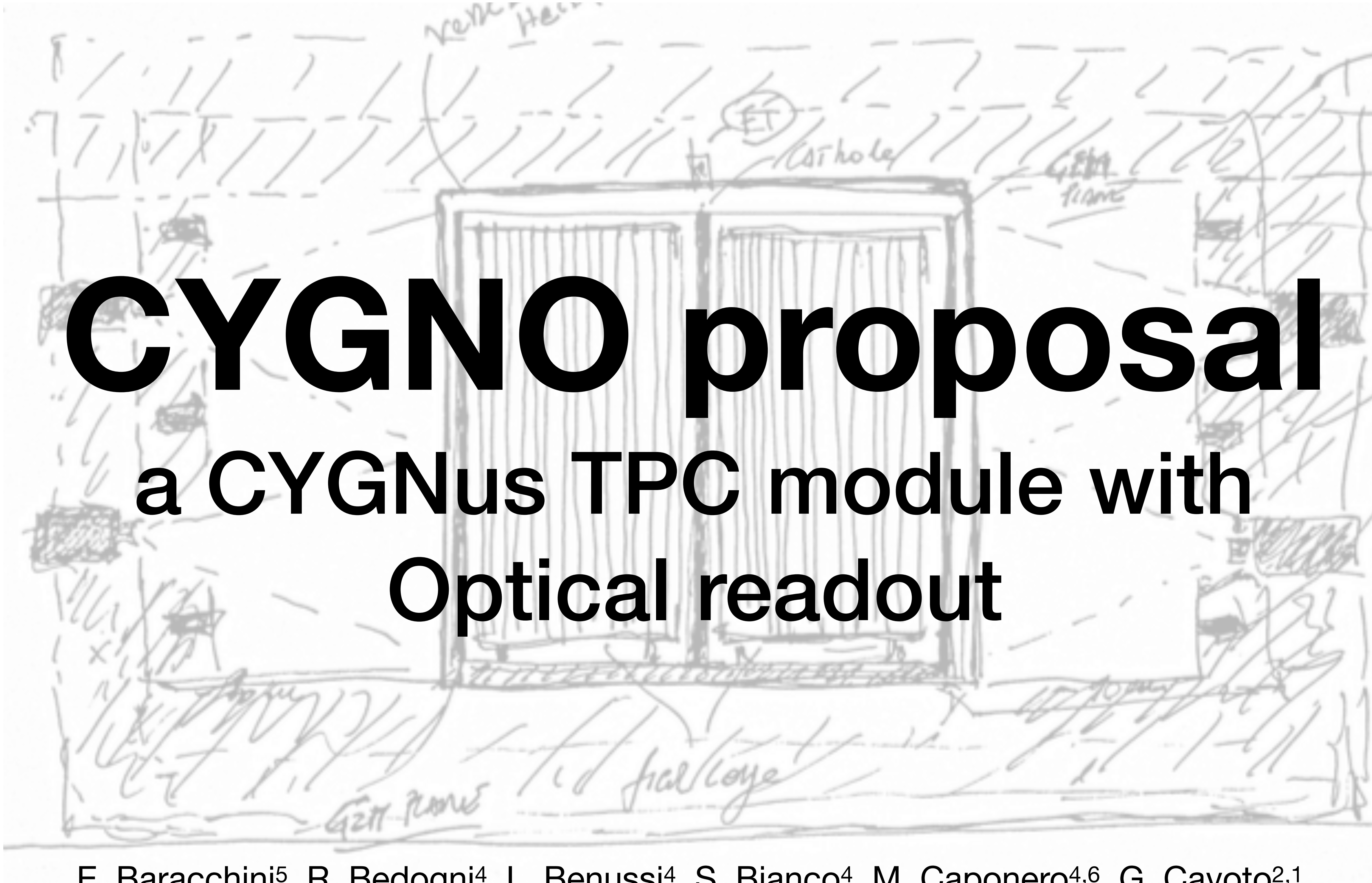


CYGNO proposal

a CYGNus TPC module with Optical readout

E. Baracchini[5], R. Bedogni[4], L. Benussi[4], S. Bianco[4], M. Caponero[4,6], G. Cavoto[2,1], E. Di Marco[1], M. Marafini[3,1], G Mazzitelli[4], A. Messina[2,1], D. Pinci[1], D. Piccolo[4] F Renga[1], G. Saviano[4,2], S. Tomassini[4], C. Voena[1]

[1]INFN Sezione di Roma
[2]Dipartimento di Fisica della Sapienza Università di Roma
[3]Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi
[4]INFN Laboratori Nazionali di Frascati
[5]Gran Sasso Scientific Institute, L'aquila
[6]ENEA Frascati

INFN LNF
Istituto Nazionale di Fisica Nucleare

CENTRO FERMI

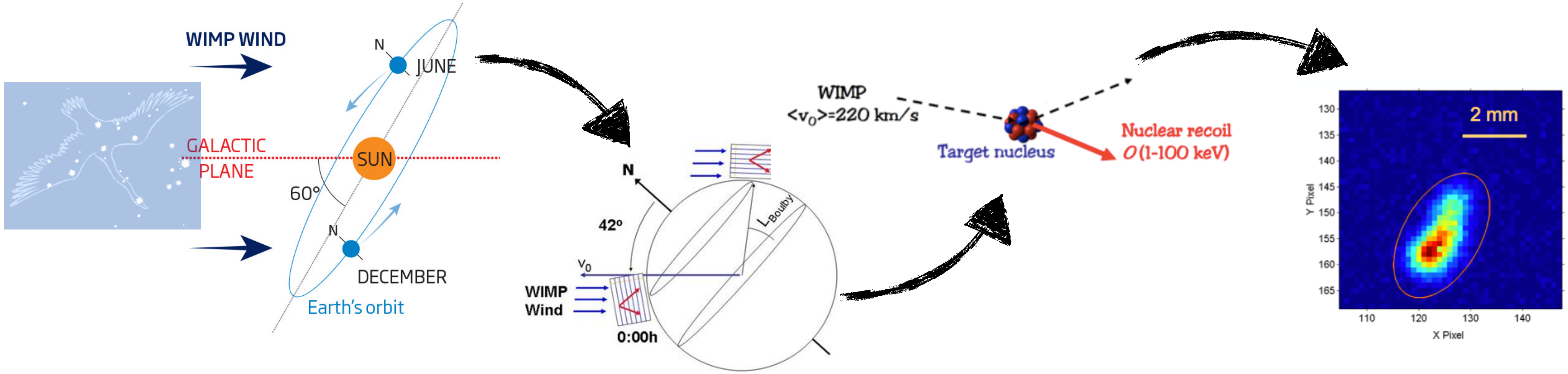
GSSI

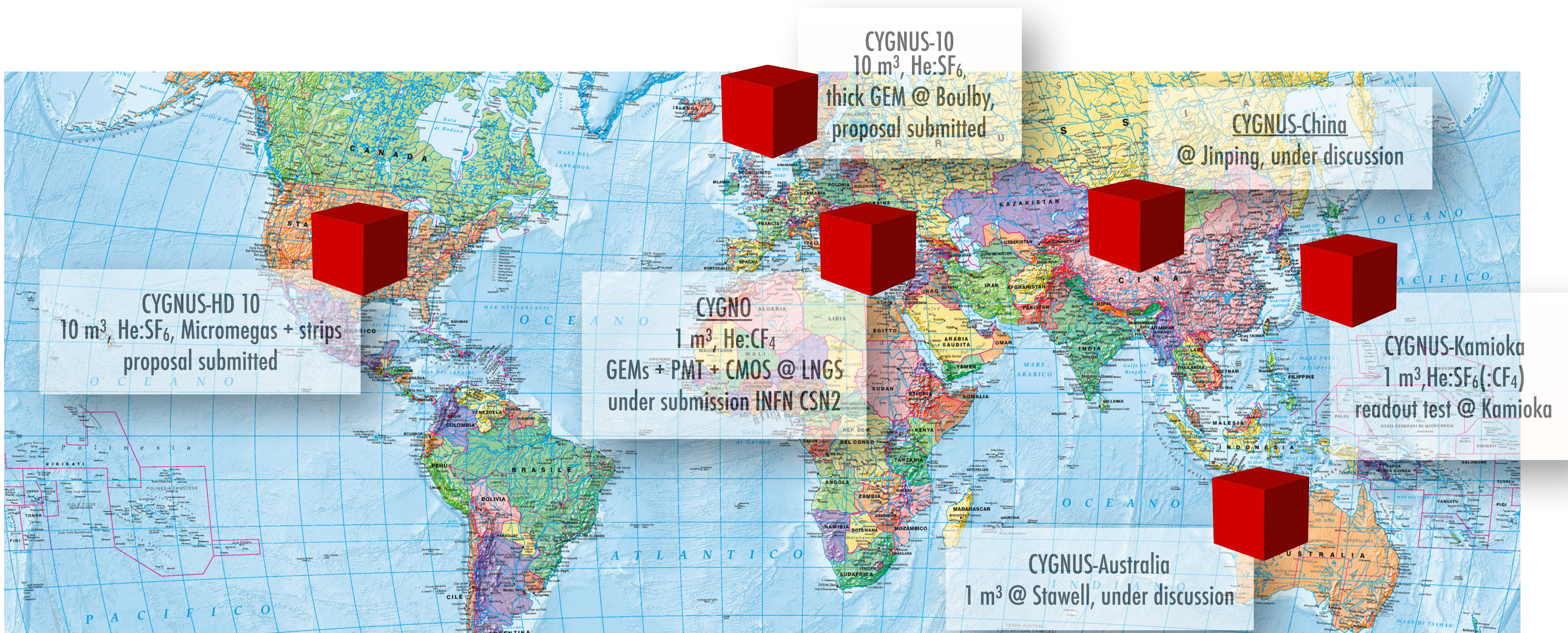
CYGNUS collaboration

Galactic Nuclear Recoil Observatory
identify with **directional** sensitivity clear **dark matter** candidate
and **coherent neutrino** scattering from the Sun and other sources

1. to establish the **science** case for CYGNUS, working with external experts as required
2. to establish the **feasibility** and **technology** choices for CYGNUS, coordinating R&D activities, resources and **joint publications** as necessary
3. to form an Institute **Board** including remit to prepare an organisational structure in readiness for launch of the collaboration
4. to write an **experiment LOI** as basis for formation of the collaboration based on (1-3)
5. to launch and follow the **international collaboration**

CYGNUS collaboration objective



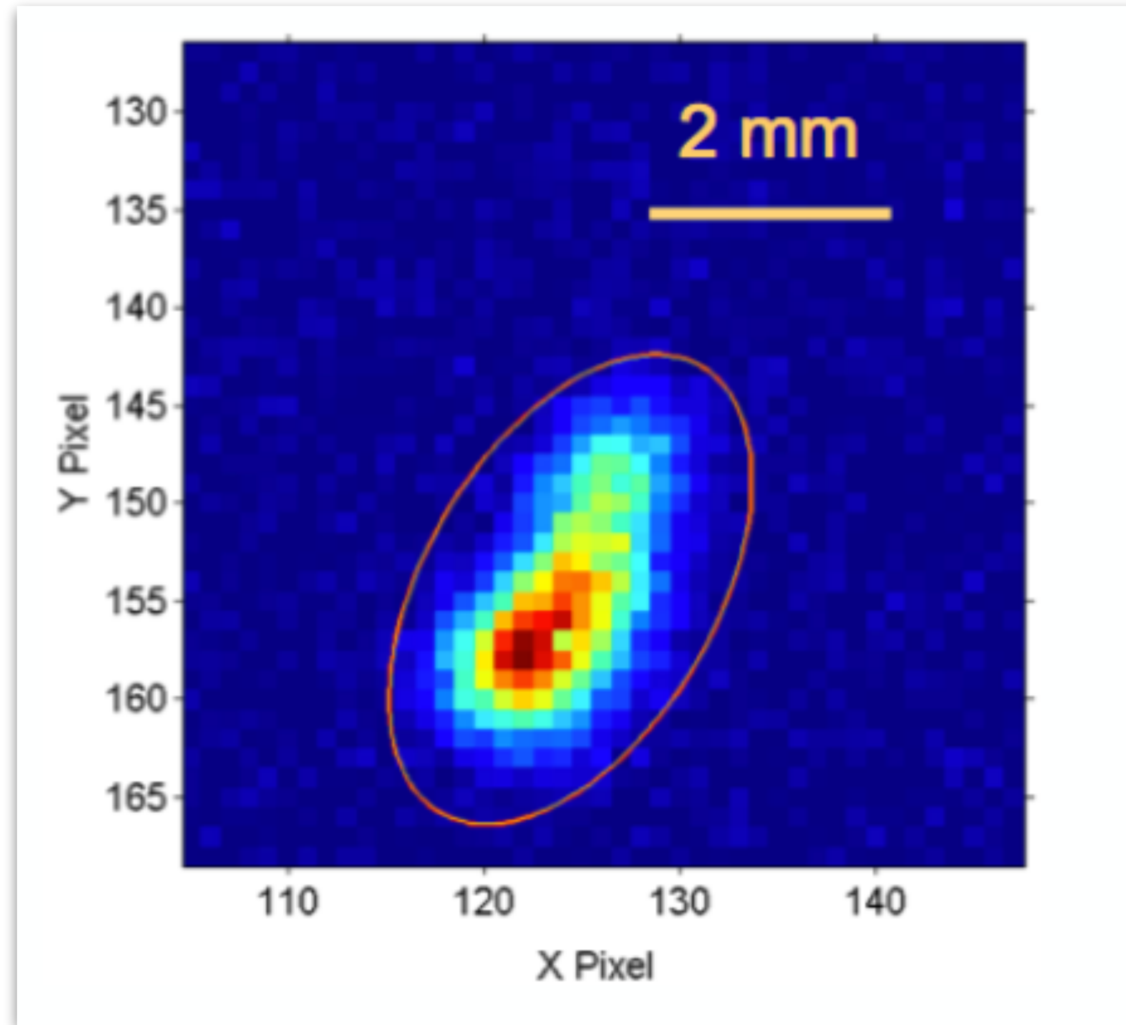


Why TPC?

Time Projection Chambers provide:

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

Nuclear recoil in gas

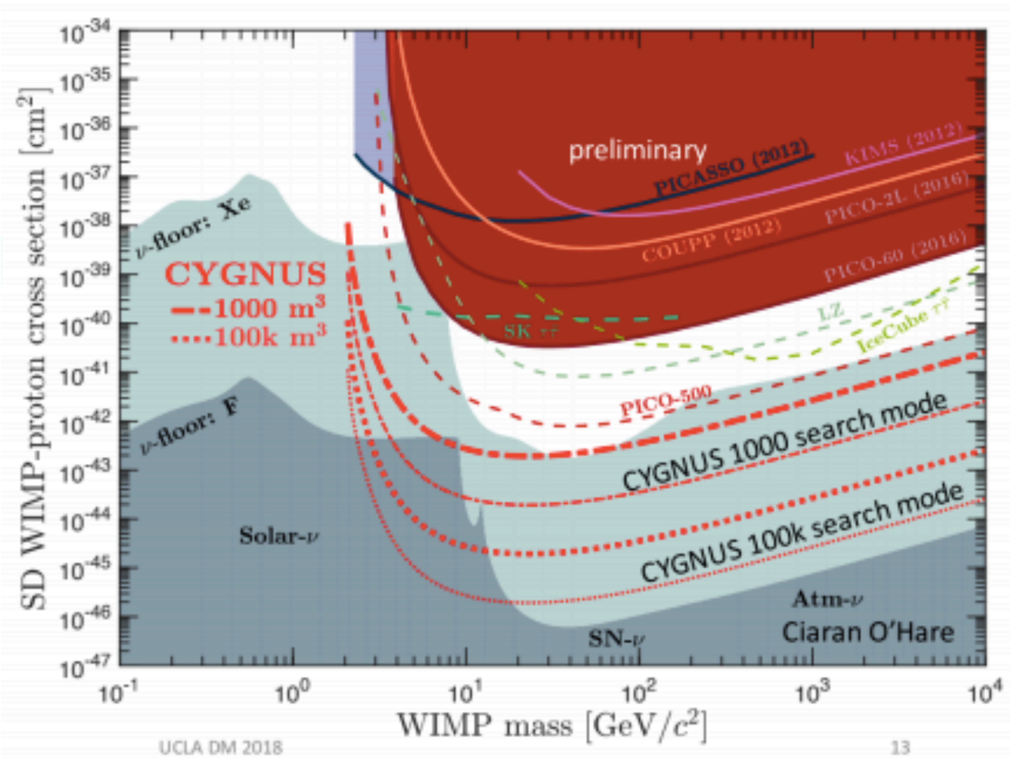


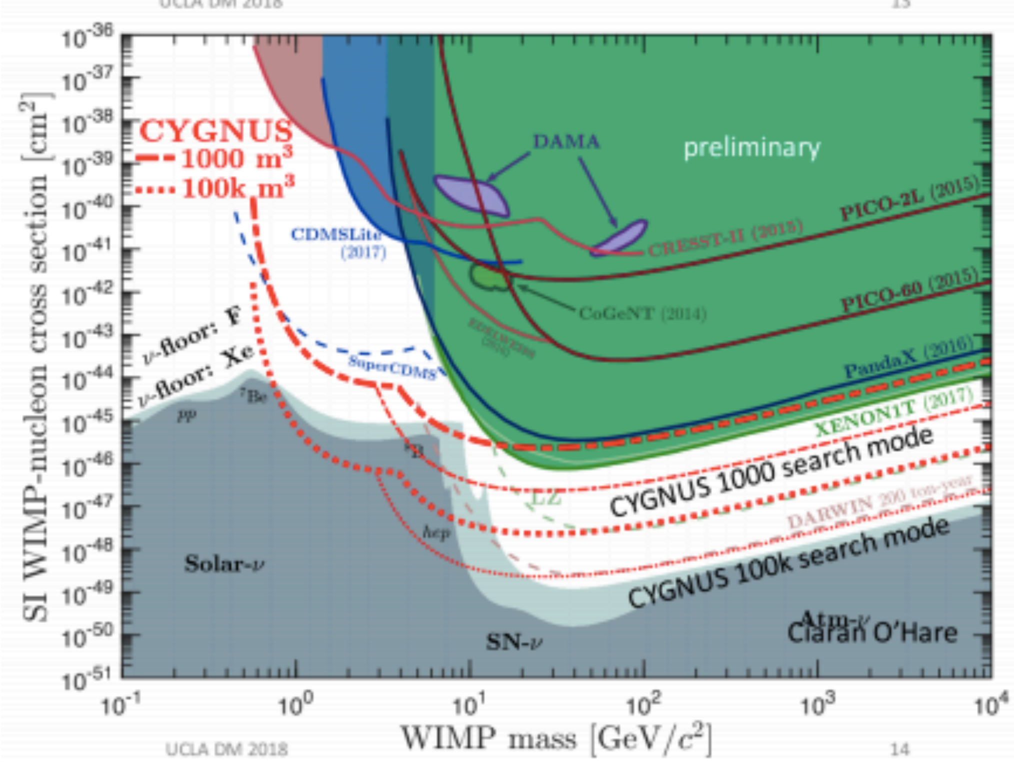
gas represents an interesting target:

- 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);

The CYGNUS TPC challenging to goal

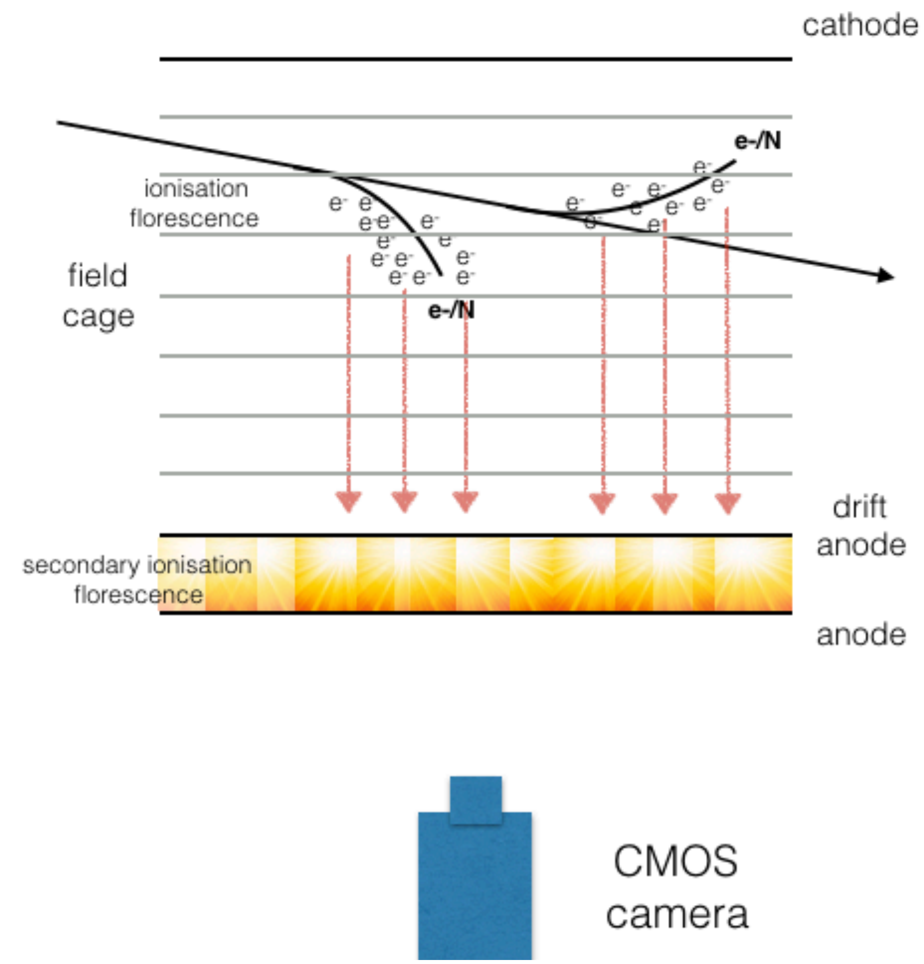




- **Energy threshold 1 keVee**
- **Target mass 100-1000 kg (F, He)**
- **Zero neutron background**
  - no steel (vacuum) vessel (acrylic?)
  - ceramics; almost no internal electronics
- **x, y, z fiducialisation and radon rejection**
  - either negative ion drift or other technique
  - material selection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

The CYGNO demonstrator strategy and objectives

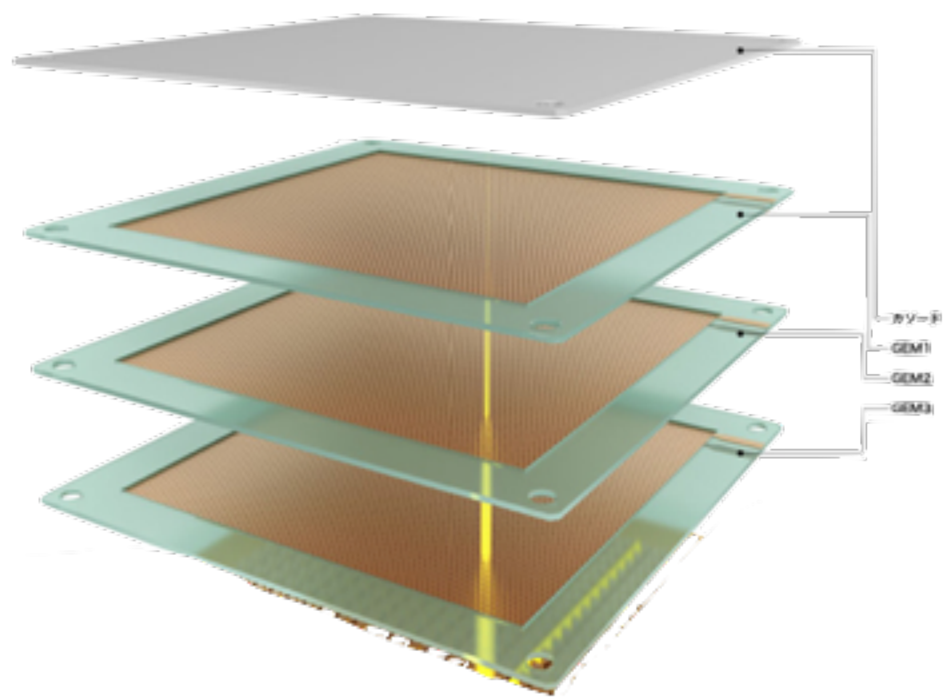
- **high granularity (CMOS+PMT) optical read out:**
  - threshold
  - discrimination
  - directionality;
  - x, y, (z) fiducialisation
  - electronics decoupling

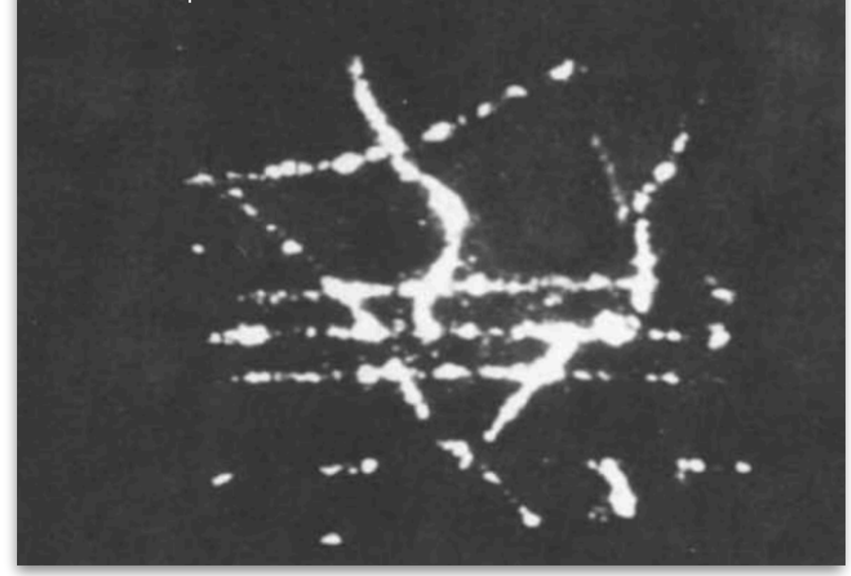


- **atmospheric pressure He gas mixture:**
  - high target density (low threshold)
- **objectives:**
  - demonstrating the validity of technology
  - understanding noise
  - participating to a new international rising community for sub GeV DM candidate measurement
  - performing neutron LNGS flux measurements and contribute to directional dark matter upper limit measurements with a different systematics

Optical Read Out

Multiple GEM structures can be used to share the gain and make more stable detectors.





G. Charpak at al., NIM A258 (1987) 177

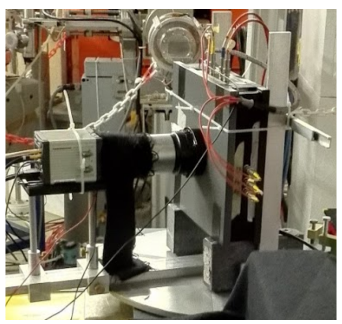
During the multiplication process, photons are produced along with electrons by the gas through atomic and molecular de-excitation;

- optical sensors are able to provide high granularities along with very low noise level and high sensitivity;
- optical coupling allows to keep sensor out of the sensitive volume (no interference with HV operation and lower gas contamination);
- suitable lens allow to acquire large surfaces with small sensors;

CYGNO Roadmap @ LNGS

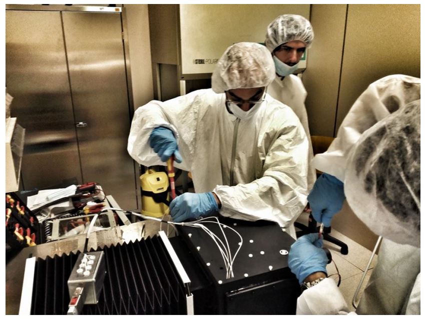
2018	2019	2020	2021	2022	…
@ ROMA1/LNF	@ LNF	@ LNF	@ LNF	@ LNGS	
		TDR	Construction & test	Installation & data taking	

ORANGE



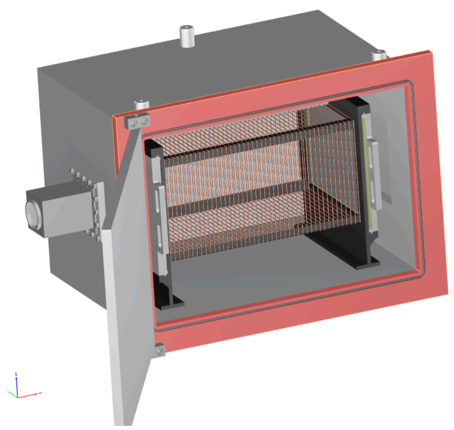
- OPT readout
- 1 cm drift
- 0 resolution

LEMON



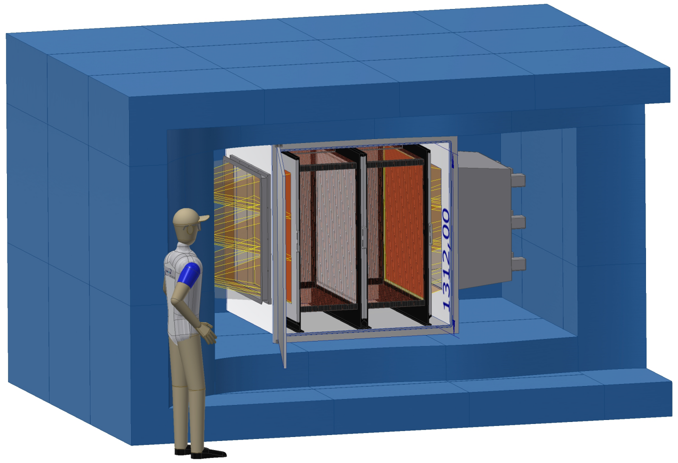
- OPT readout
- 3D printing
- 20 cm drift
- PID
- tracking
- drift resolutions

LIME



- ...
- 50 cm drift
- drift scaling
- materials test
- gas

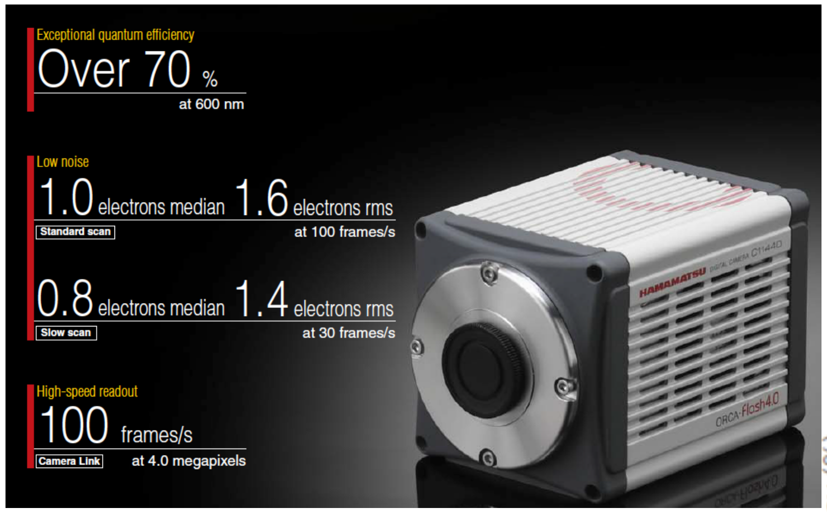
CYGNO "demonstrator"



- ...
- background
- materials test
- gas purification
- shielding
- stability
- scalability
- reliability

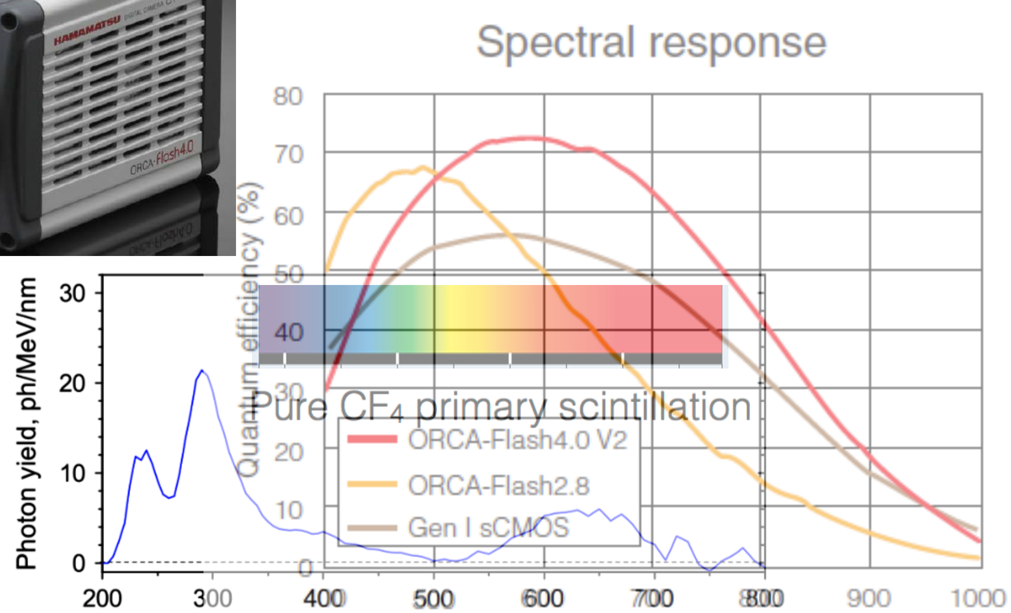
CYGNUS 100-1000 m^3

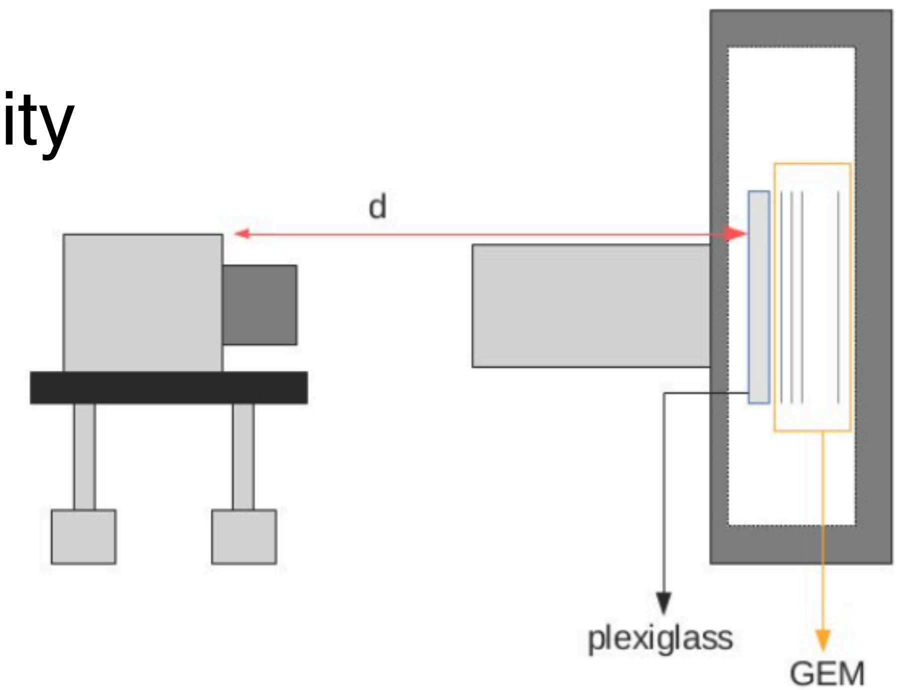
ORAnGE prototype



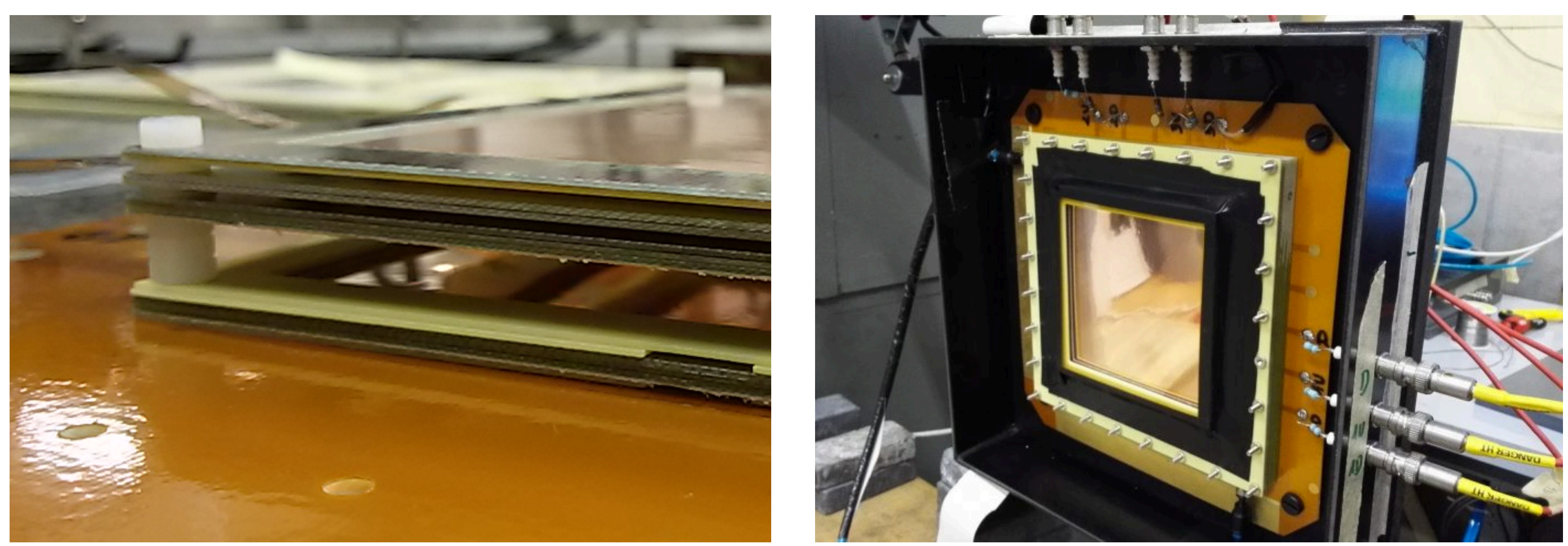
CMOS: low noise; high granularity and sensitivity

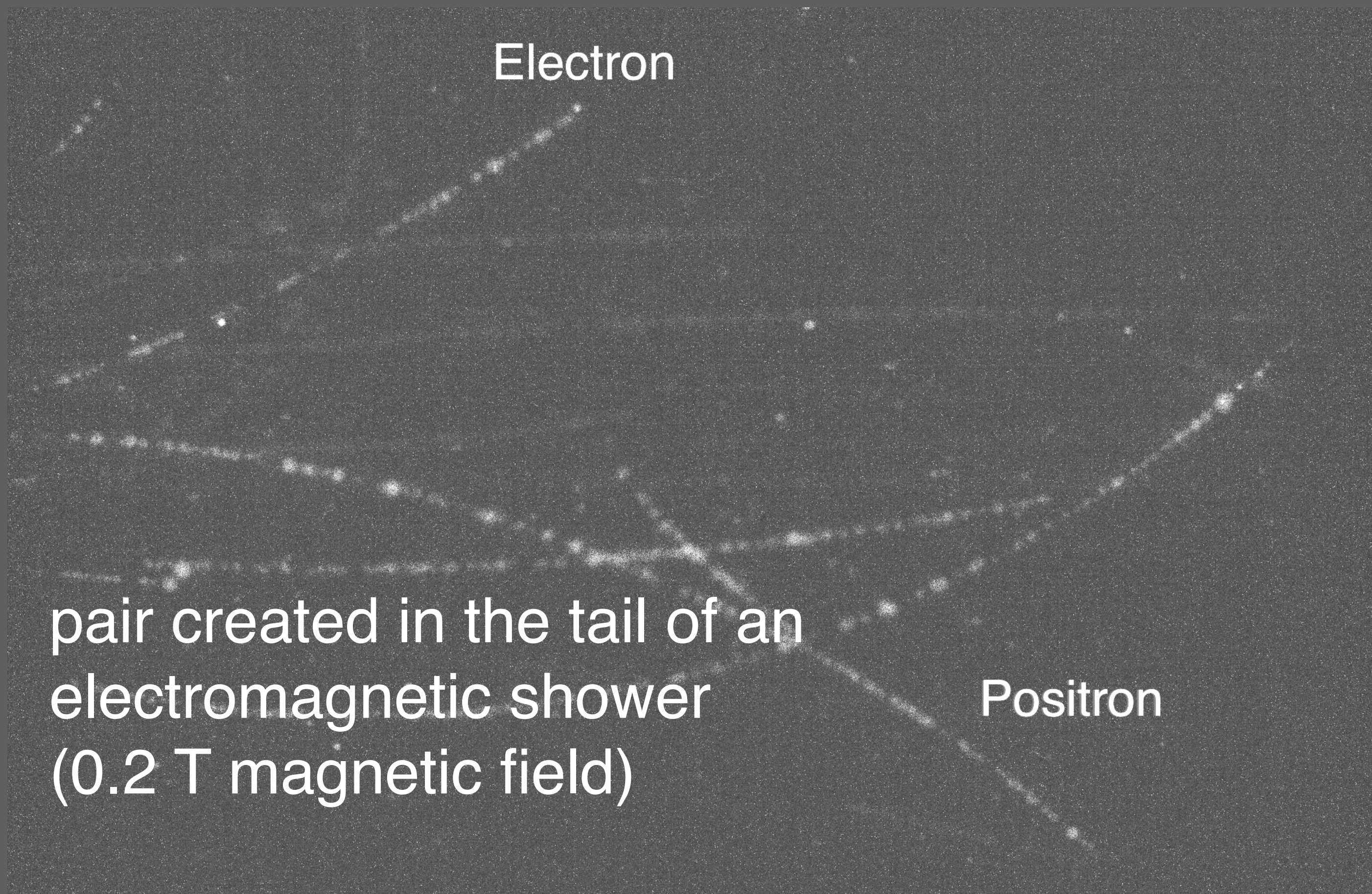
He/CF_4 (60/40) mixture





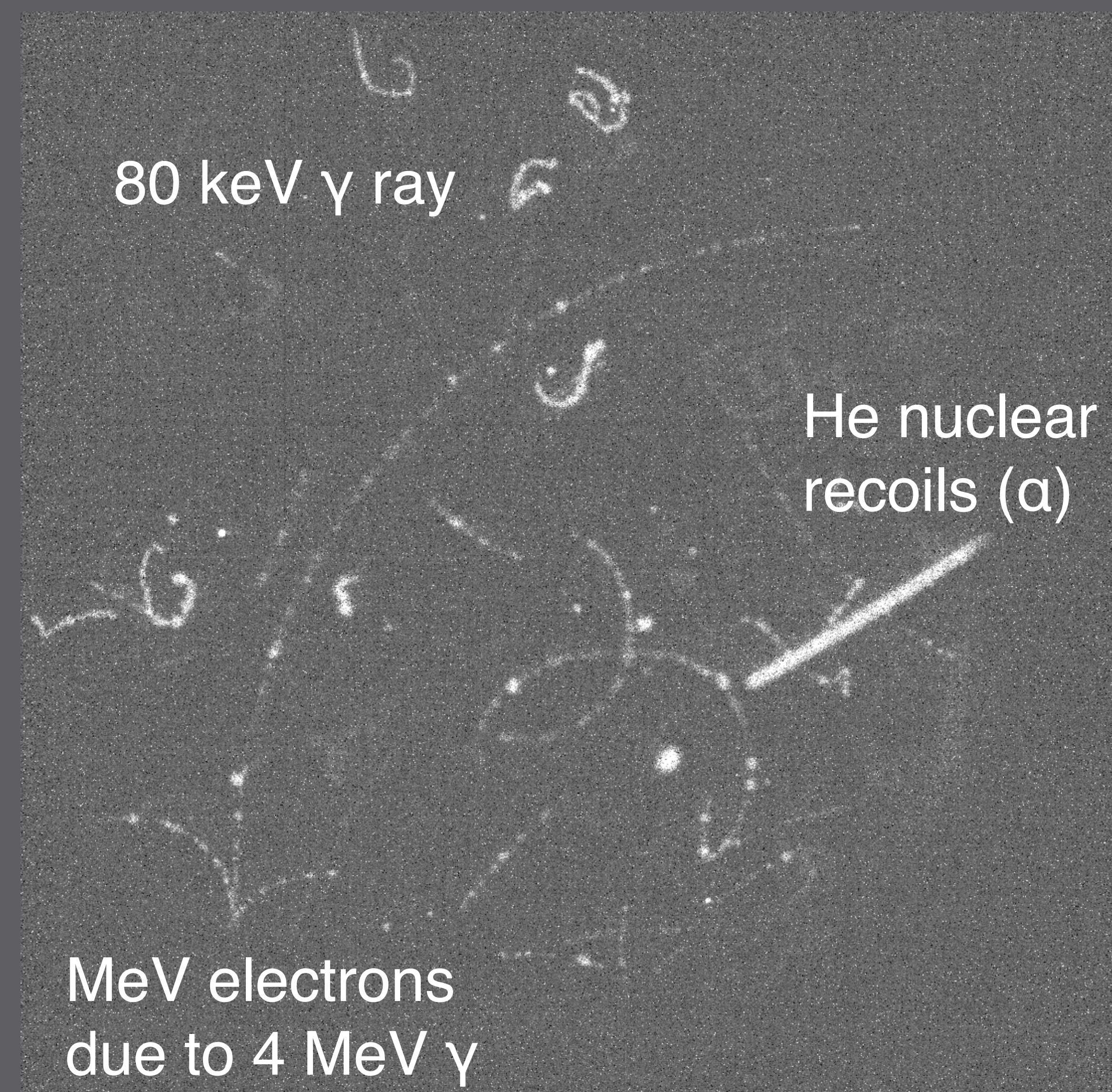
Triple GEM structure ($10x10\ cm^2$) with 1 cm sensitive gap.

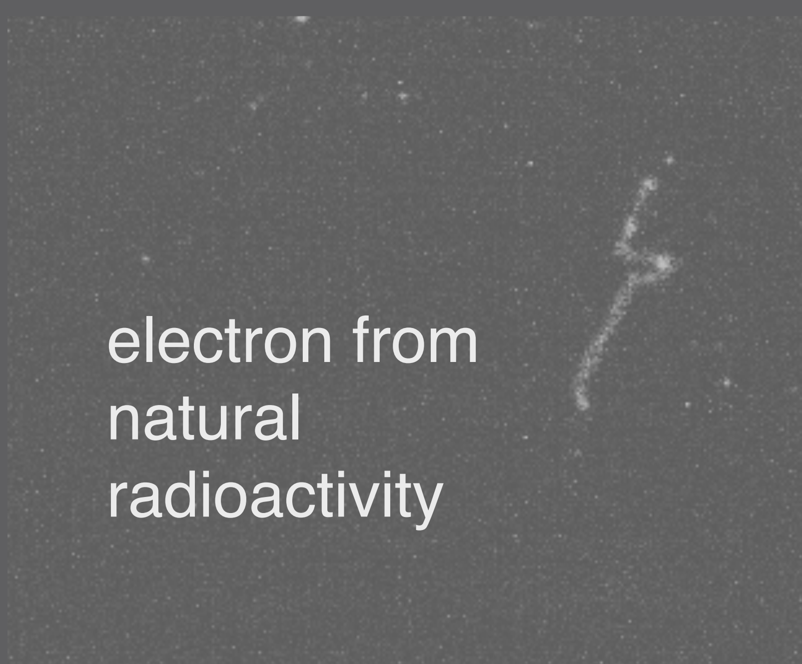




(thanks to BTF)

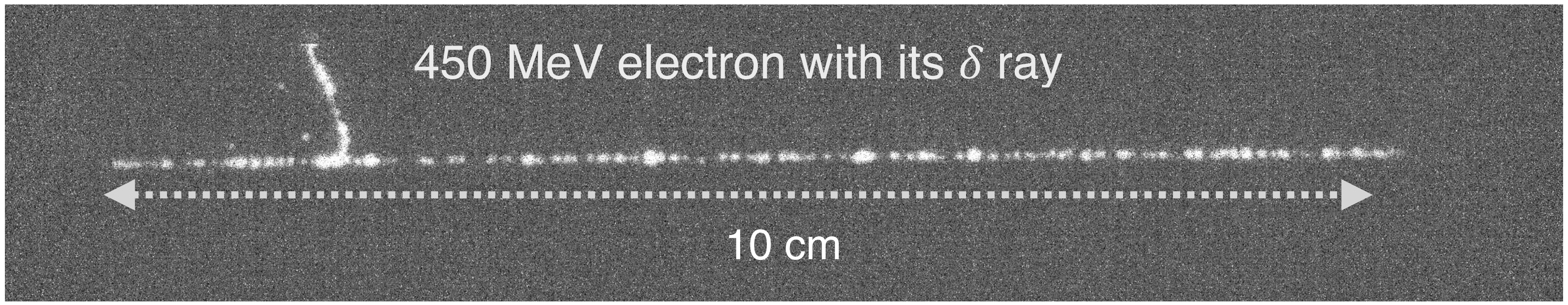
AmBe Neutron source
(thanks to FISMEL)

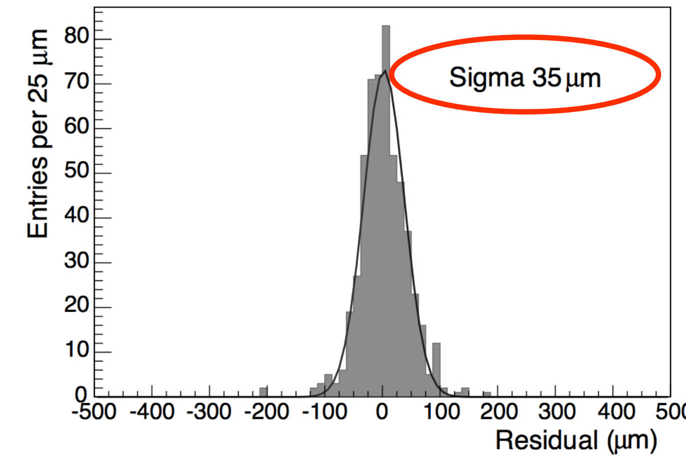




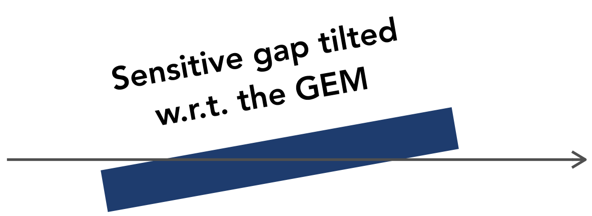
(thanks to
nature…)

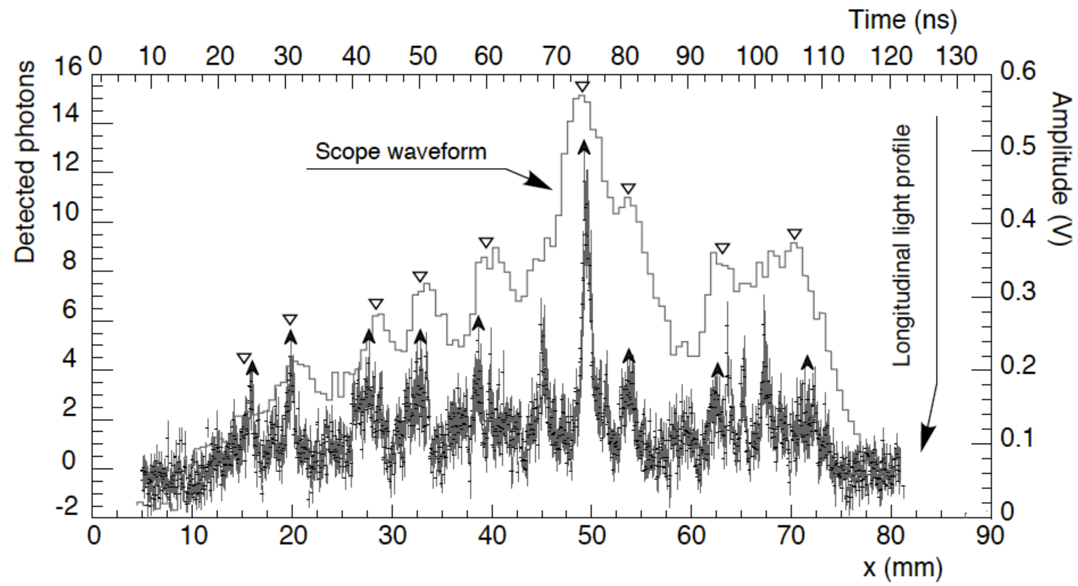
ORAnGE performances

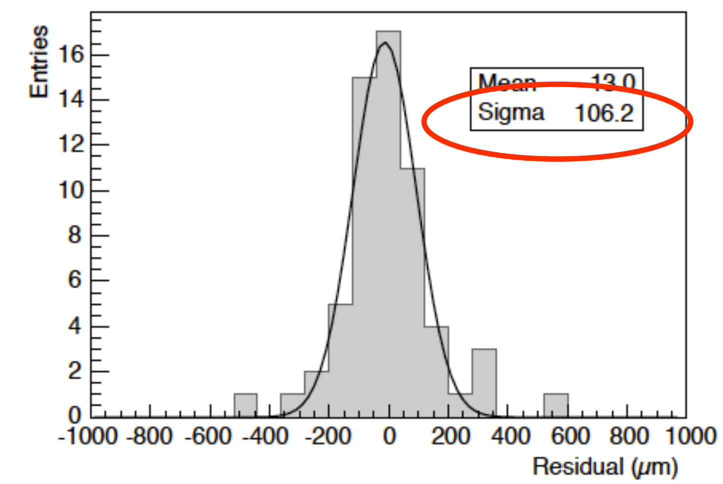


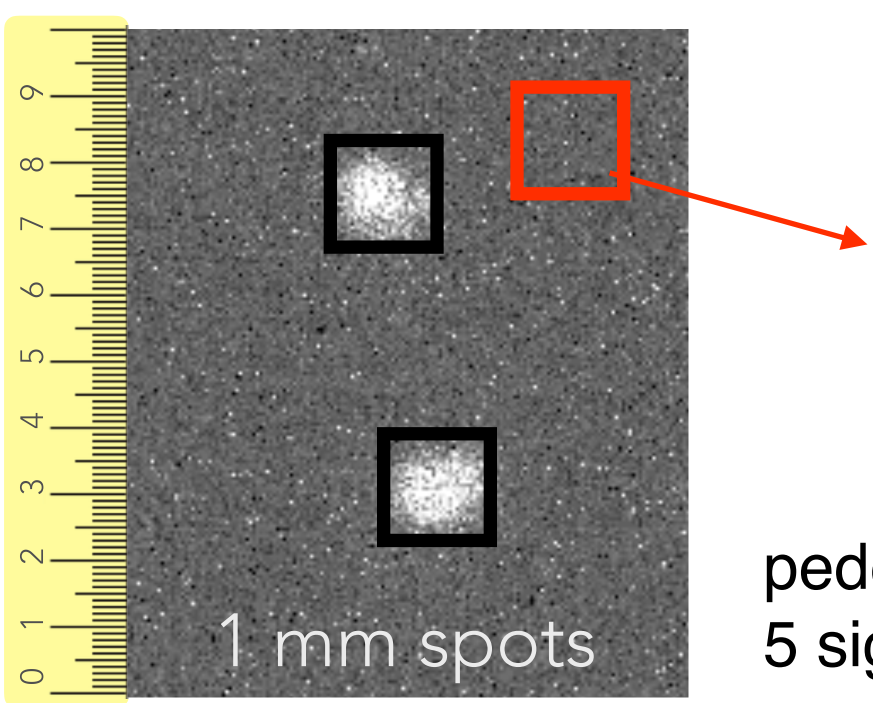


combined OPT readout PMT+CMOS

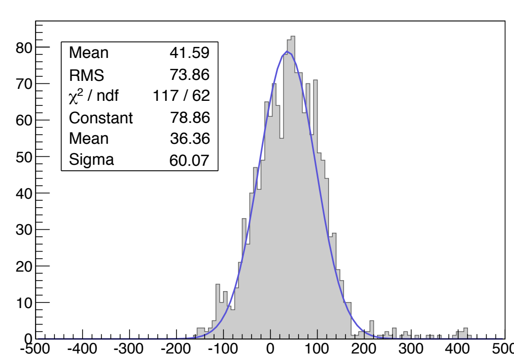


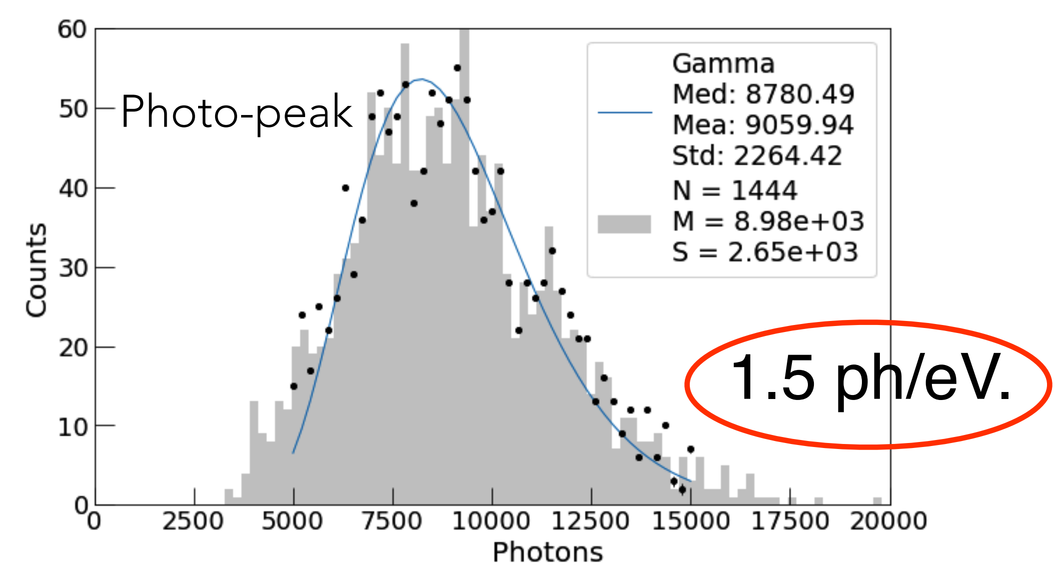






5.9 keV ^{55}Fe





pedestal jitter of 60 photons

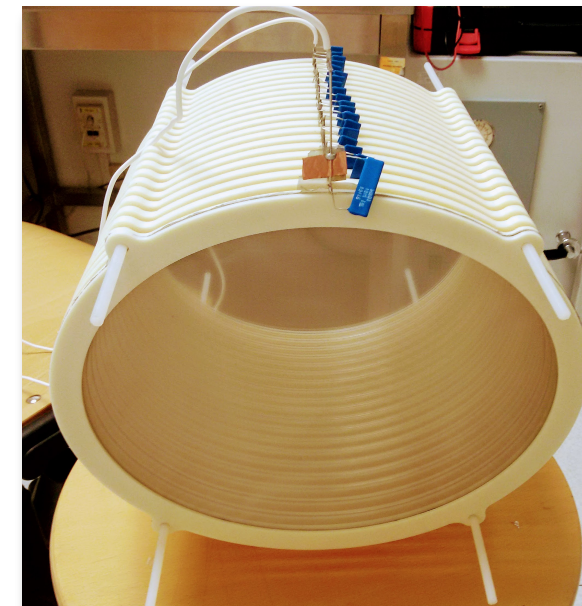
5 sigma threshold would be: 300 ph/(1.5 ph/eV) = 200 eV.

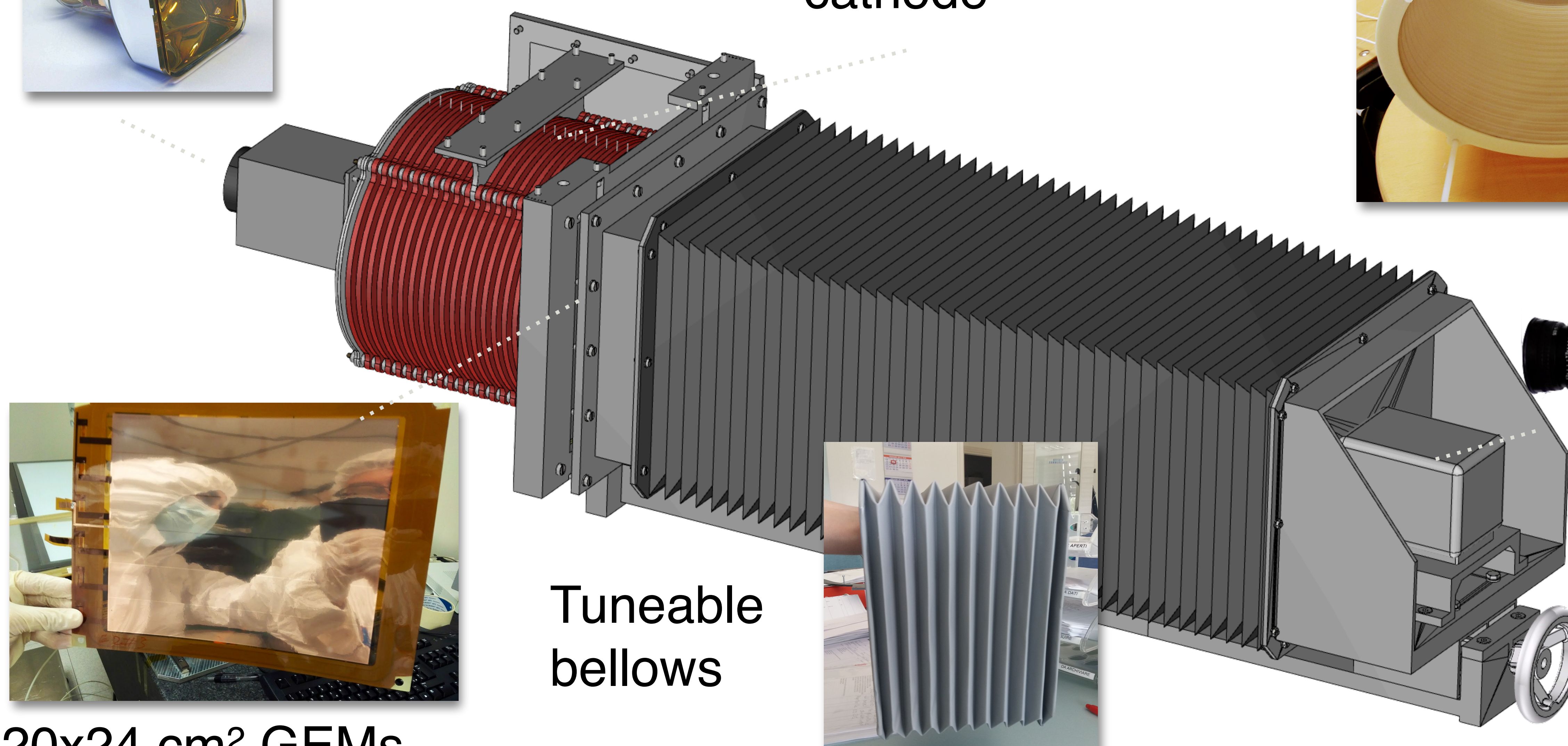
LEMOn prototype

A new prototype with 7 litre sensitive volume (LEMOn: Large Elliptical Module Optically readout) was built in 2017 tested on electron beam in July.

7x7 cm^2 PMT

Elliptical field cage with semi-transparent cathode

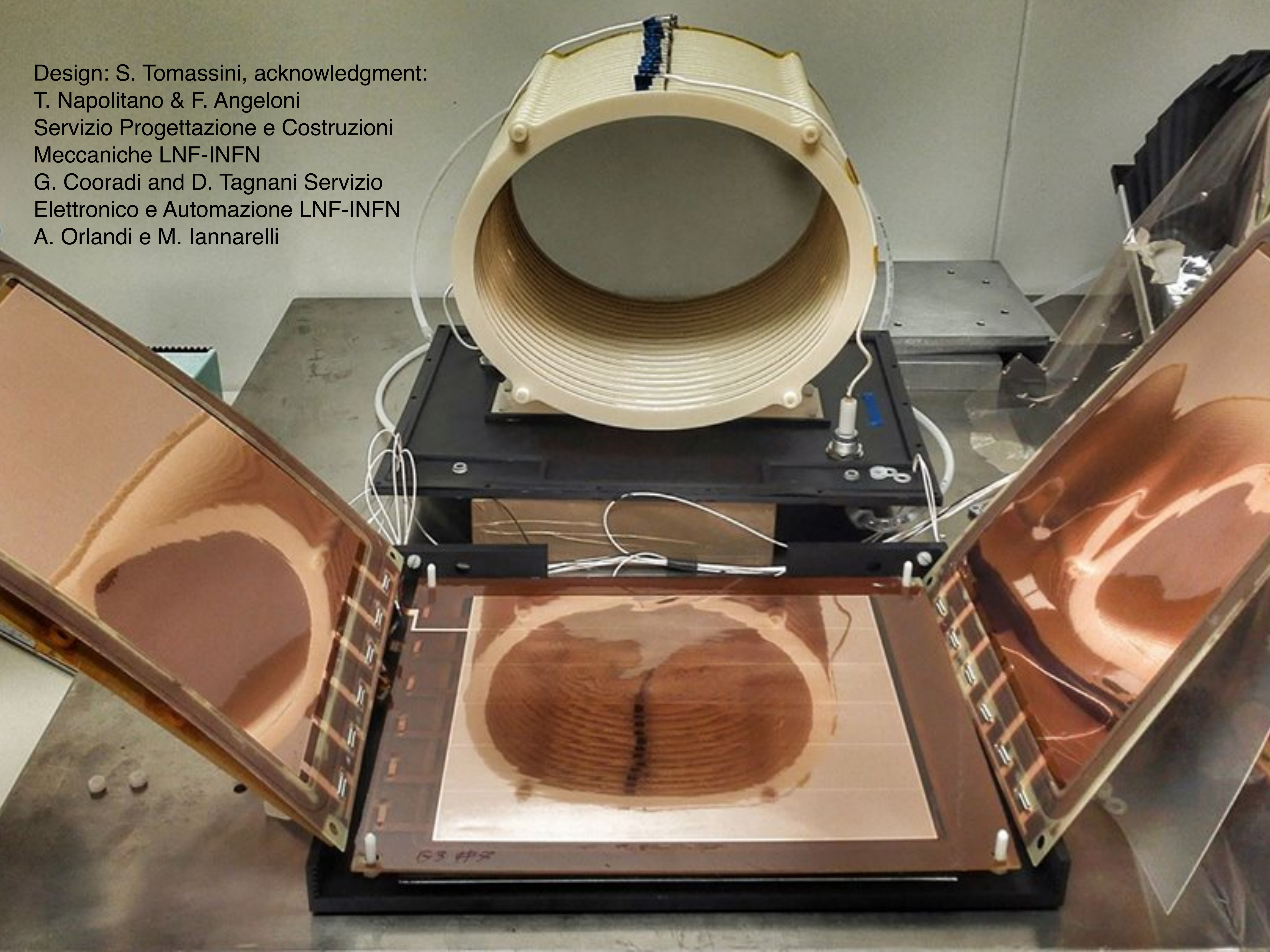




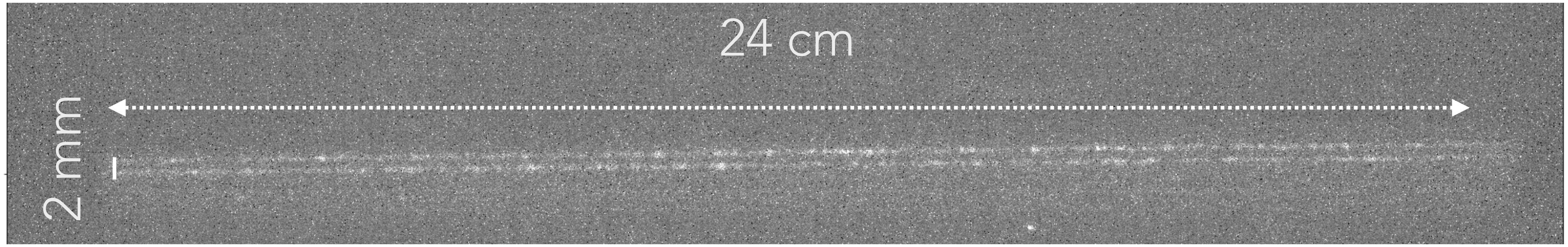
CMOS camera

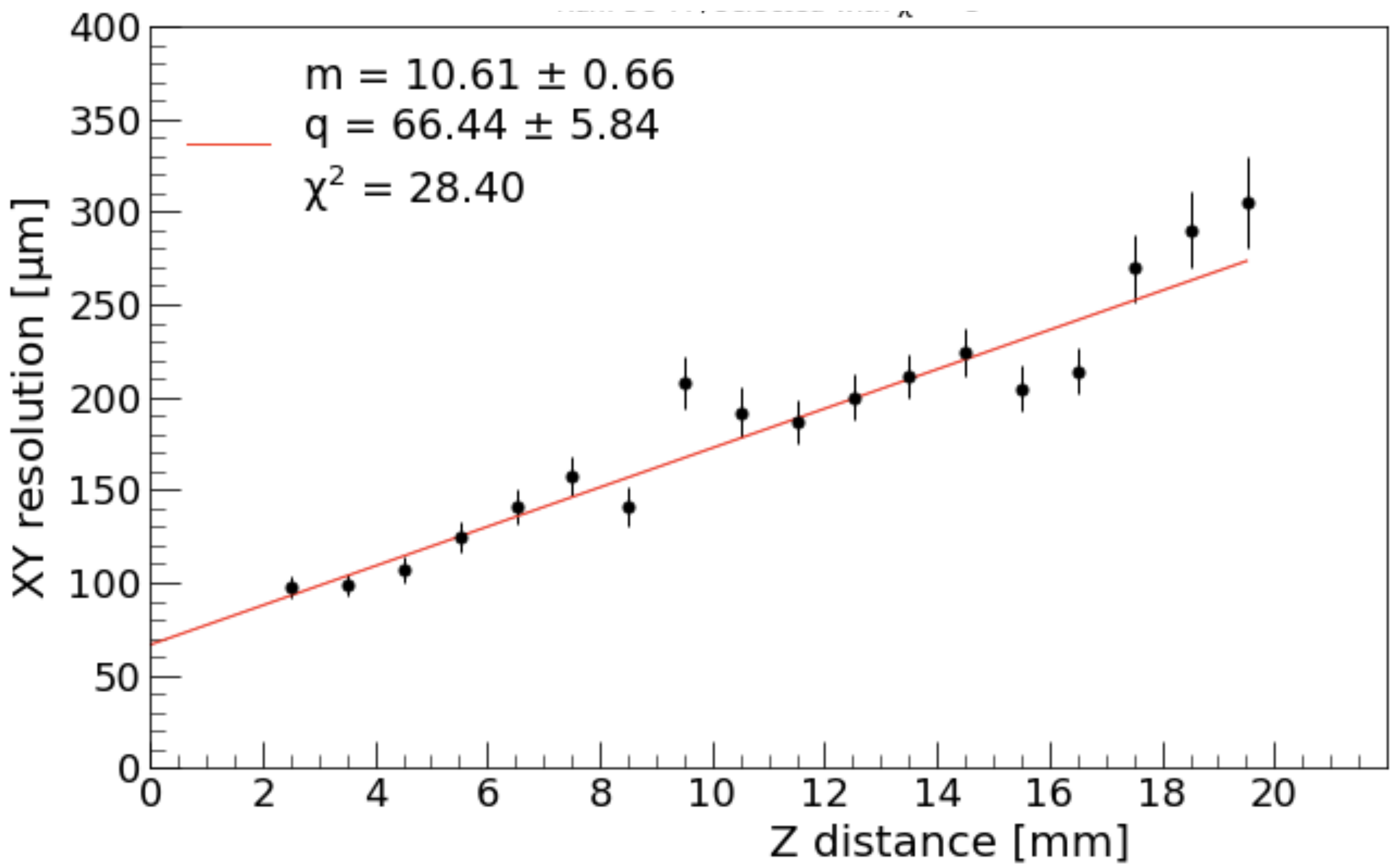
Tuneable bellows

20x24 cm^2 GEMs

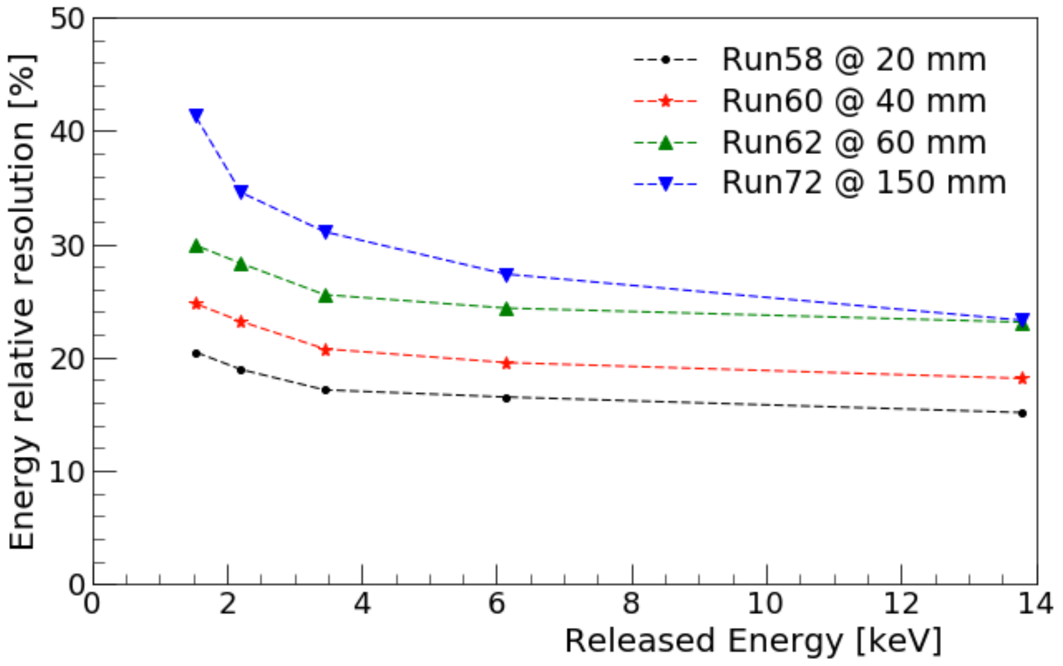

Design: S. Tomassini, acknowledgment:
T. Napolitano & F. Angeloni
Servizio Progettazione e Costruzioni
Meccaniche LNF-INFN
G. Cooradi and D. Tagnani Servizio
Elettronico e Automazione LNF-INFN
A. Orlandi e M. Iannarelli

XY and Energy resolution in LEMOn





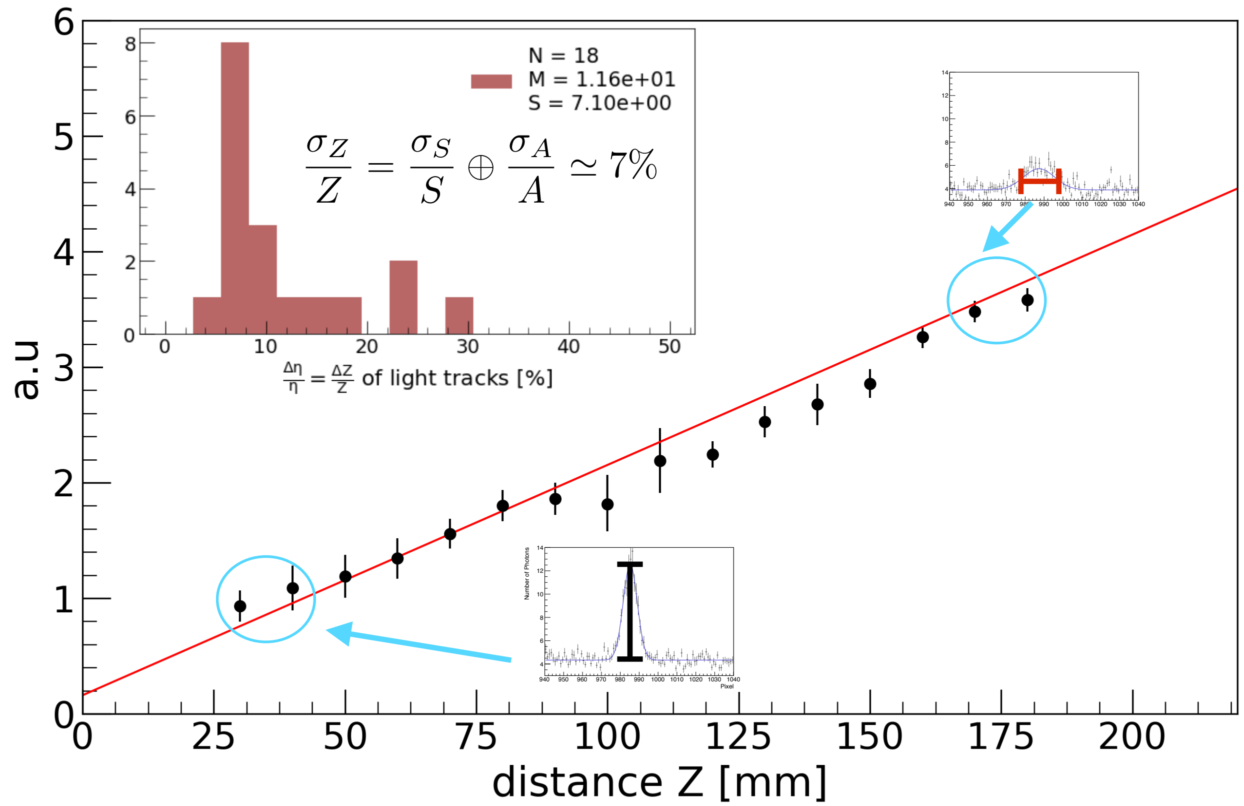
energy resolution @ depths (Z)

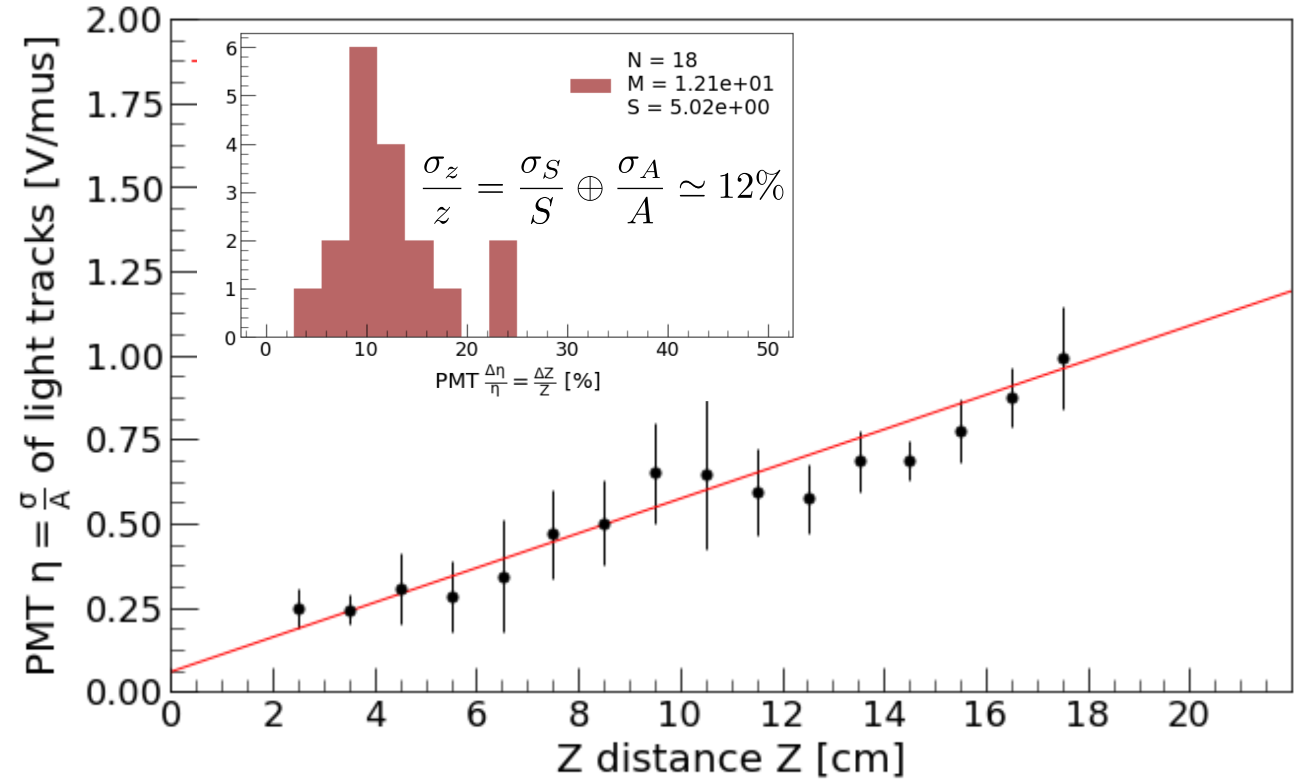


in the few keV region a relative resolution of 20%-30% is achieved

Z resolution in LEMOn

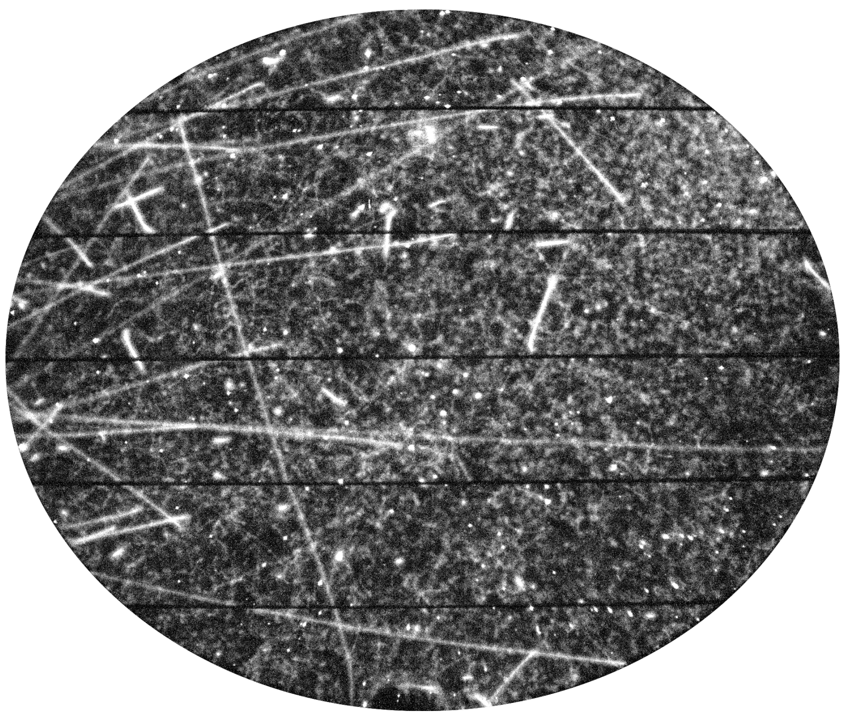
Electron diffusion in the drift gap can be exploited to evaluate the Z of the event. The transverse light profile and the PMT signal waveform are expected to become lower and larger as long as the event is far from the GEM;
Since the amplitude (A) decreases and the width (S) increases with Z, their ratio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

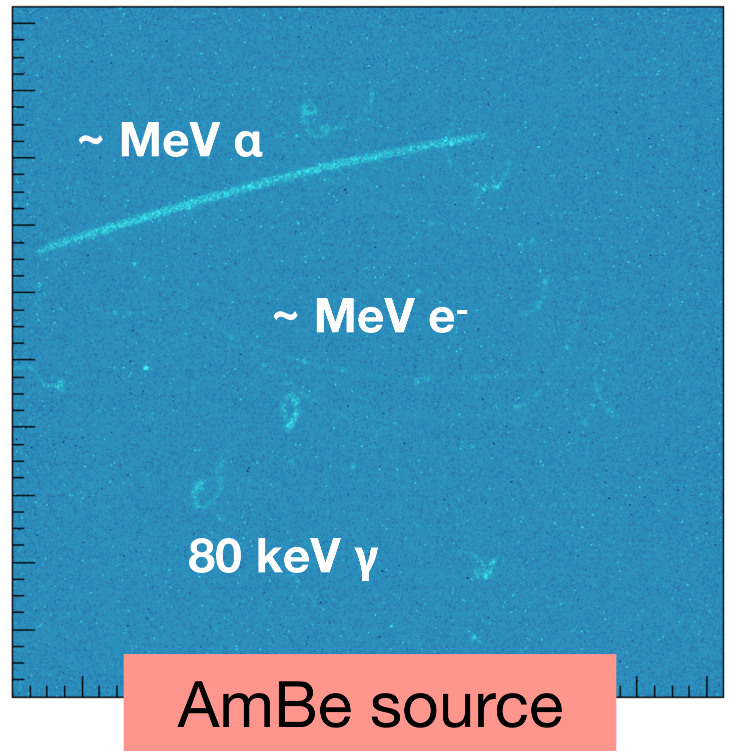


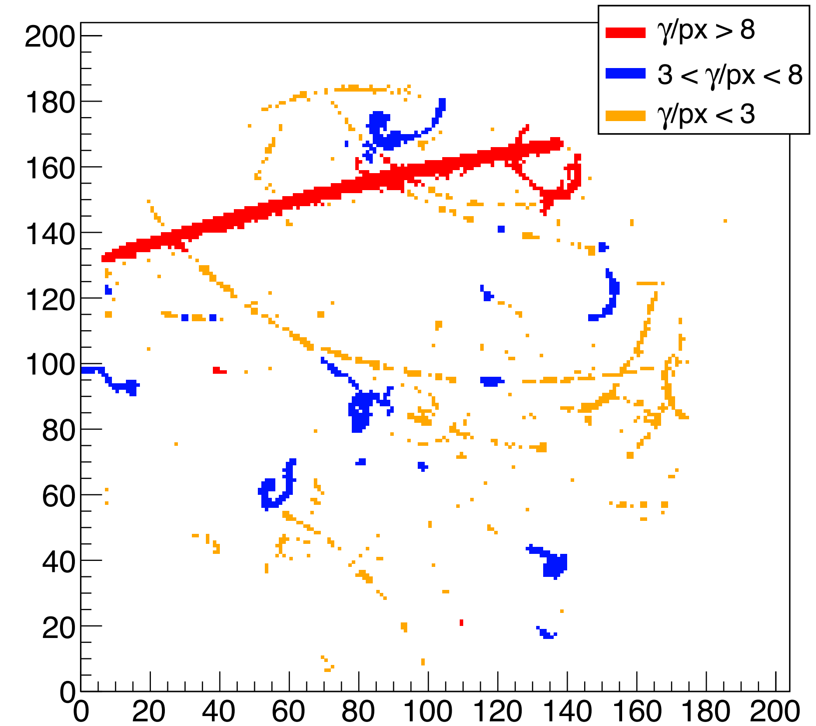


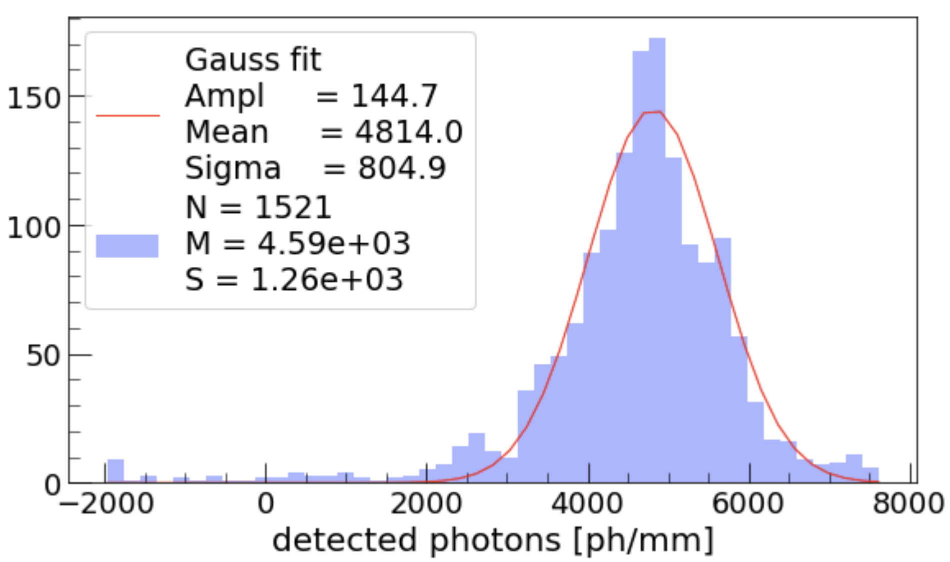
both methods gives 10% precision: σz ~ 2 cm @ 20 cm

PID performances

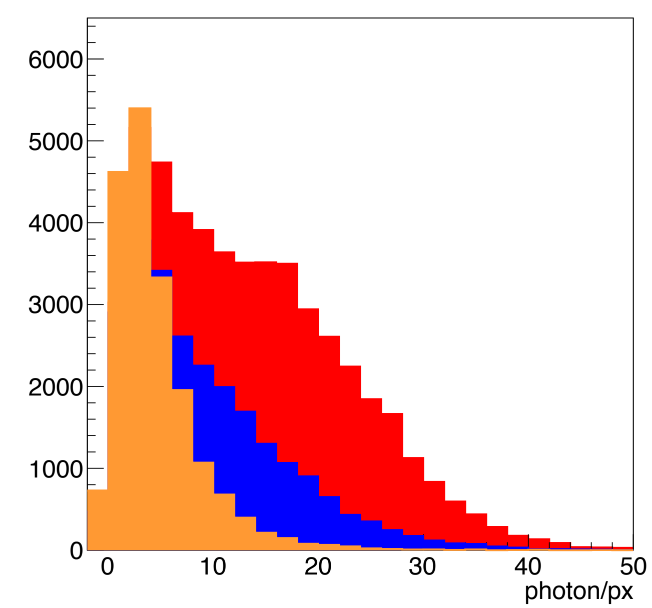








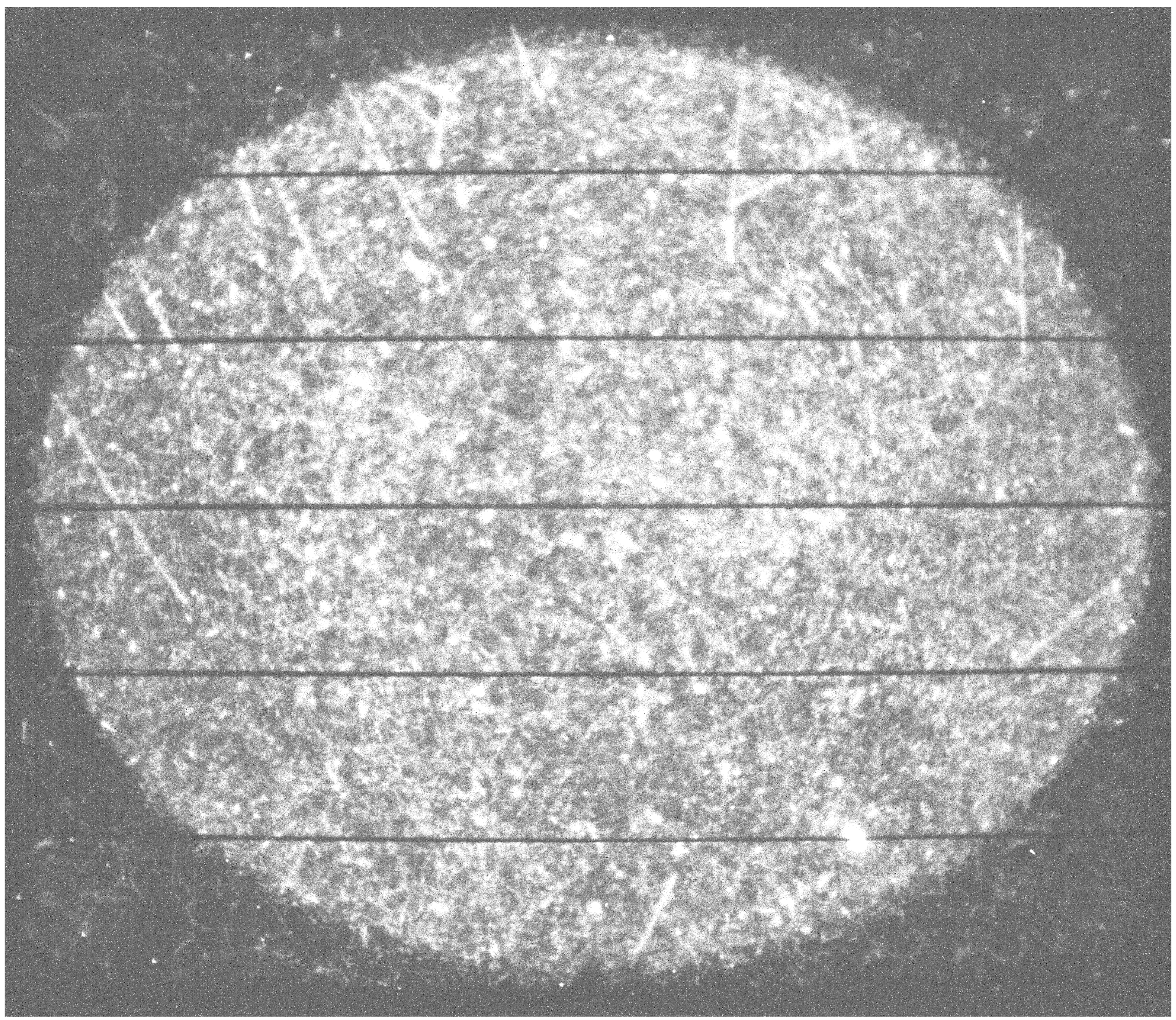
4000 ph/mm
(~ 4 times mips)



Thanks to the collaboration of R. Gargana (LNF), S Stanlio (LNGS), G. Donvito (BA) and Calcolo-LNF we are starting to exploit the **INFN Corporative Cloud (INFN-CC)** as back-end for data storage and front-end for analysis recurses; part of the challenging work cold be done a DAQ board, see next LNF-SEA study and design…

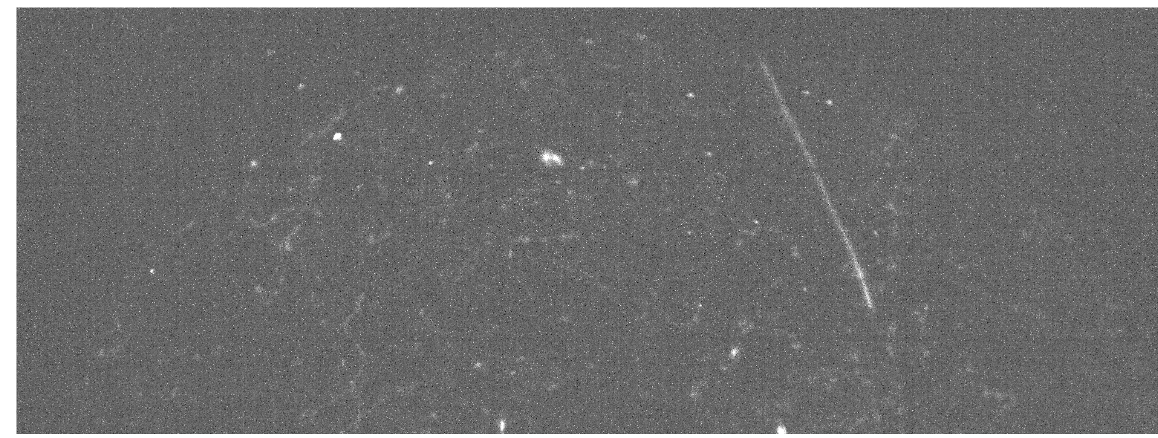
LEMOn @ ENEA FNG

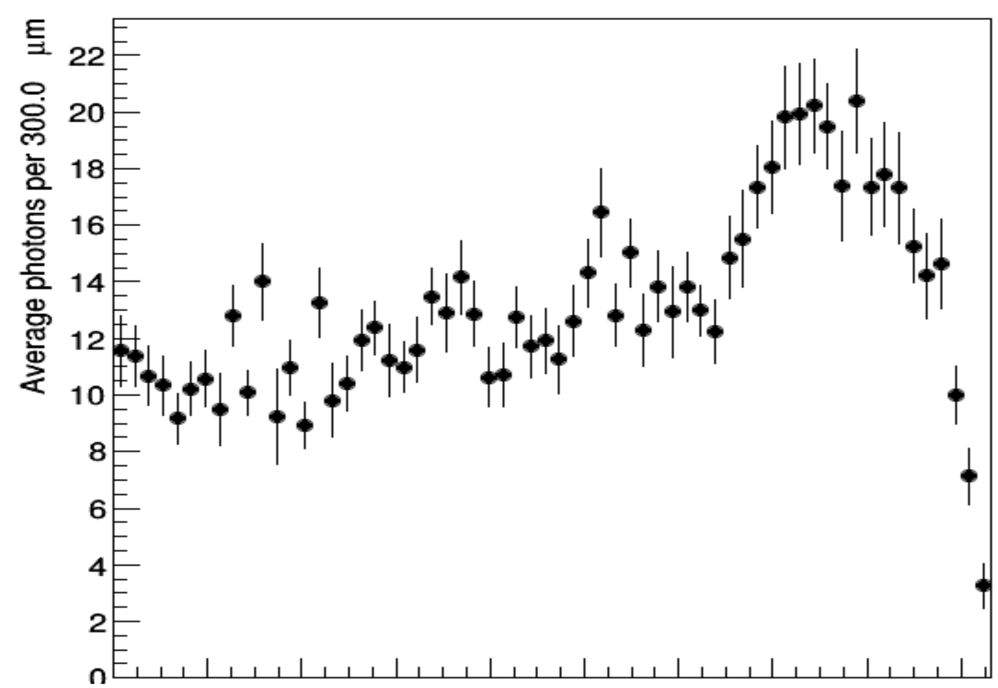
5s exposure @ 2.45 MeV neutrons
Frascati Neutron Generator



test beam 18-20 June 2018
(tanks to FNG)

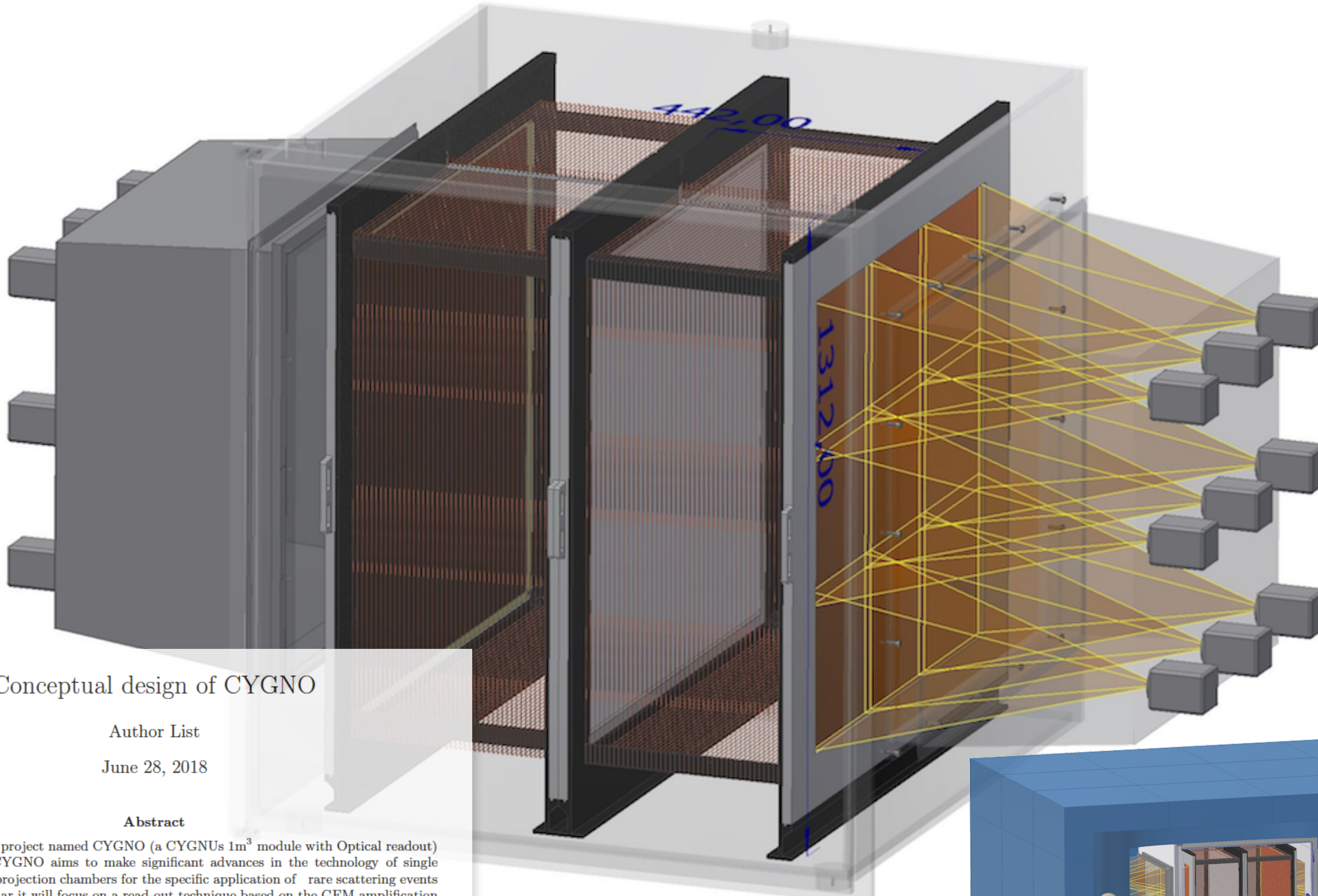
0.1s exposure @ 2.45 MeV neutrons
Frascati Neutron Generator





Longitudinal light profile shows
a typical Bragg peak shape

CYGNO Detector



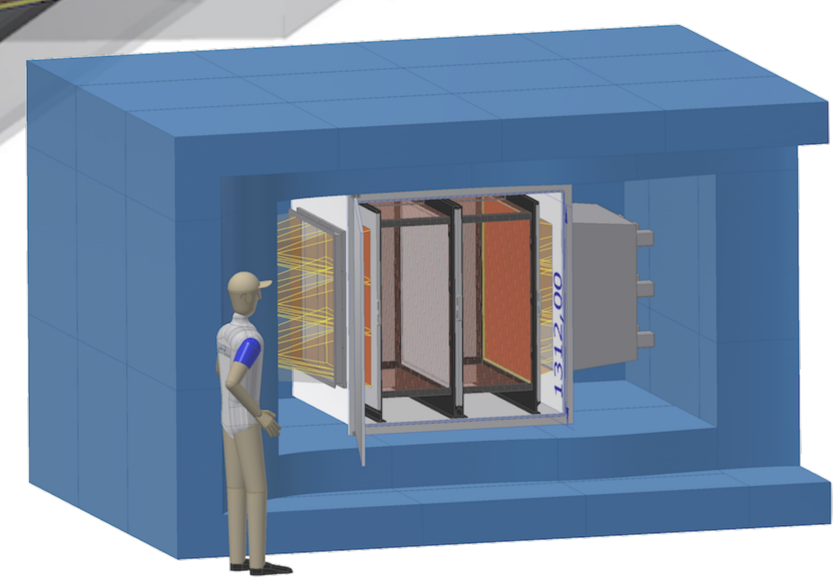
Conceptual design of CYGNO

Author List

June 28, 2018

Abstract

The design of the project named CYGNO (a CYGNUs 1m^3 module with Optical readout) is described here. CYGNO aims to make significant advances in the technology of single phase gas-only time projection chambers for the specific application of rare scattering events detection. In particular it will focus on a read-out technique based on the GEM amplification of the ionization and on the visible light collection with a sub-mm position resolution sCMOS camera. This type of readout - in conjunction with a fast light detection - will allow to reconstruct 3D images of the recoiling particles, offering new ways to distinguish the electron and nuclear recoils. The final goal is to deliver a high resolution 1 cubic meter detector for underground neutron flux measurements that - with proper shielding and accurate choice of the materials - can be a prototype for a dark matter (DM) detector. The recoil direction resolution is also being investigated as a further tool to reject background in the detection of Galactic DM particles. This project is part of the world-wide effort of the CYGNUS collaboration to define an optimal DM detection scheme sensitive to DM direction, towards a one-ton gas TPC nuclear recoils observatory.



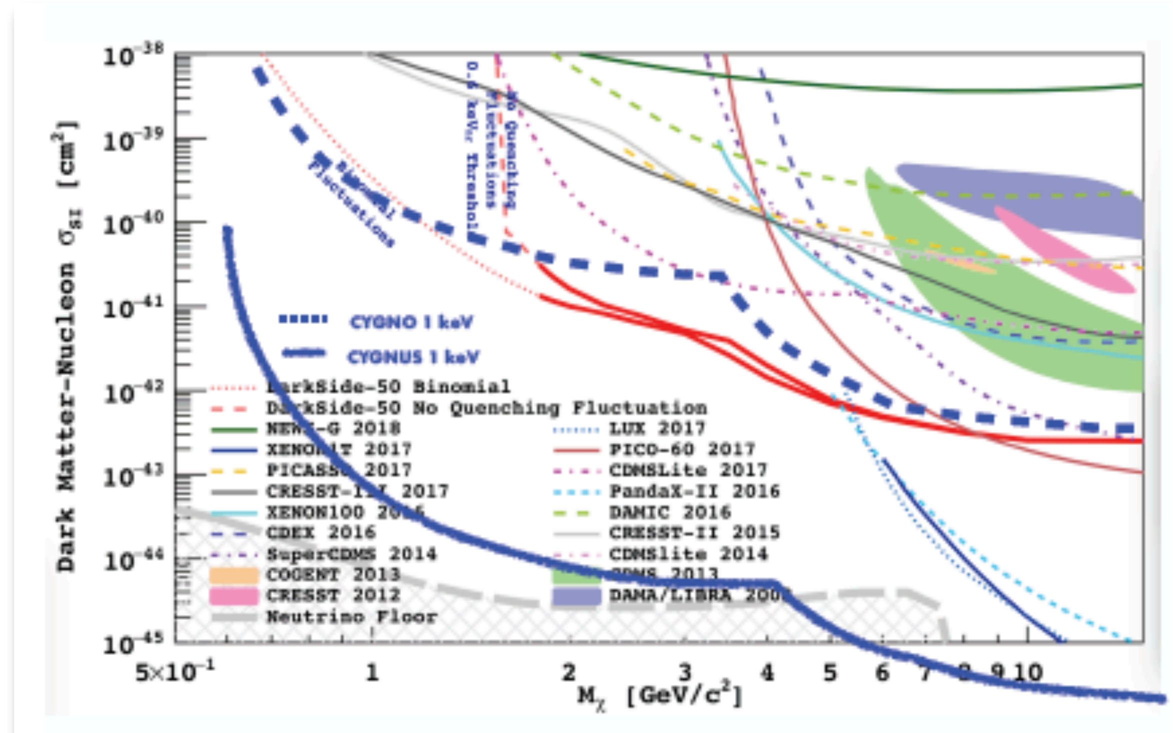
CYGNO Physics

a 1.6kg-1m³ of HeCF4 with a threshold of few 1keVe could exploit some interesting area in sub GeV DM search, but before that, CYGNO have to dimostrate with an emerging technology a full compression of: **background; materials; gas purification; stability; scalability and reliability**

E interval (eV)	Thermal Neutron Flux (10^{-6}cm^{-2}s^{-1}) Ref. [21]	Ref. [22]	Ref. [23]	Ref. [24]
0 - 0.05	5.3 ± 0.9	1.08 ± 0.02 (1.07 ± 0.05)	0.54 ± 0.13	0.32 ± 0.09
0.05 - 1000		1.84 ± 0.20 (1.99 ± 0.05)		

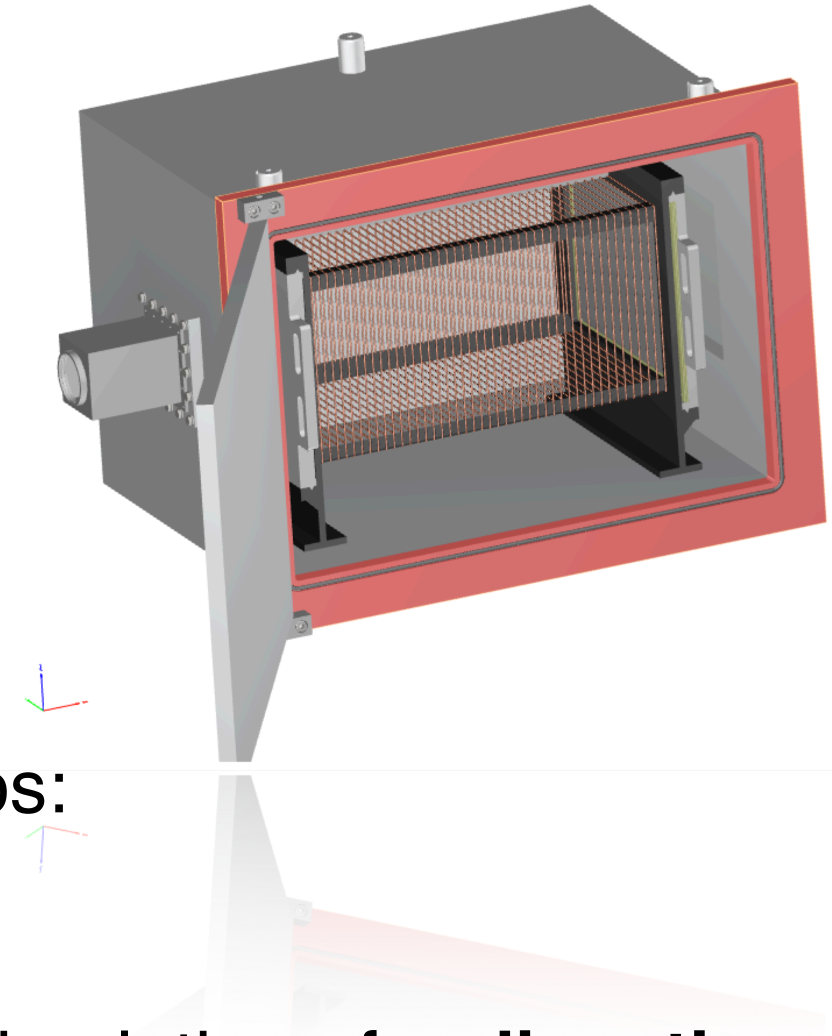
Table 2: Thermal and epithermal (top) and fast (bottom) neutron flux measurements at the Gran Sasso laboratory reported by different authors. In analyzing their experimental data with Monte Carlo simulations, Belli et al. [22] have used two different hypothetical spectra: flat, and flat plus a Watt fission spectrum. This leads to the upper and lower data sets shown for ref.[22] respectively.

E interval (MeV)	Fast Neutron Flux (10^{-6}cm^{-2}s^{-1}) Ref. [25]	Ref. [26]	Ref. [22]	Ref. [21]	Ref. [27]	Ref. [28]
0.1 – 1			0.54±0.01			
1 – 2.5		0.14±0.12	(0.53±0.08)			
2.5 – 3		0.13±0.04	0.27±0.14			
3 – 5			(0.18±0.04)			2.56±0.27
5 – 10		0.15±0.04	0.05±0.01			
			(0.04±0.01)	3.0±0.8	0.09±0.06	
10 – 15	0.78±0.3	$(0.4 \pm 0.4) \cdot 10^{-3}$	$(0.6 \pm 0.2) \cdot 10^{-3}$			
			$((0.7 \pm 0.2) \cdot 10^{-3})$			
15 – 25			$(0.5 \pm 0.3) \cdot 10^{-6}$			
			$((0.1 \pm 0.3) \cdot 10^{-6})$			



on the other hand CYGNO can provide a low noise **seasonal measurement of the neutron flux** intensity and spectrum at LNGS, presently highly desirable in order to check the current results and to **reduce the experimental errors.**

LIME



In the second half of 2018 we will build a new Long Imaging ModulE (LIME, 50 cm long drift gap, 25 litre sensitive volume) paying particular attention to the **material choice.**

The project in CSN2 is subdivided in two steps:

- 2019 will be devoted to
  - the conclusion of the R&D:
    - detailed study, minimisation and simulation of **radioactive background**;
    - **gas circulation and purification**.
    - **optimisation of PMT/SiPM readout and trigger**.
  - the drafting of a TDR describing final setup and performance;

- 2020/2022: realisation of CYGNO, according to the R&D results.

CYGNUS-RD in CNS5

Richieste per il laboratorio a breve termine ovvero attività già finanziata da CNS5

- 2 mu servizio Servizio Meccanica DR per la progettazione e supporto alla realizzazione di LIME
- 4 mu servizio SPCM per la realizzazione di LIME
- 0.5 mu servizio SPCM per la stampa 3D di alcuni pezzi di LIME
- 1 mu servizio Servizio Meccanica DR supporto al montaggio di LIME
- accesso alla camera pulita ex lhcb e supporto di un tecnico per la sua gestione e mantenimento (1mu)
- 4 mu SEA per lo studio e design di una scheda per l'acquisizione dei segnali analogici e digitali dell'esperimento CYGNUS-RD

ma **NON nelle priorità attuali dell'ultimo CIF-LNF**. Cercheremo quindi di fare quanto possibile per realizzarle esternamente, e comunque parte della richieste per il 2019.

INFN - FTE

Table 4: People involved in project.

Name.	Institution	Role	FTE
INFN - LNGS			
E. Baracchini	GSSI	Assistant Prof.	80%
INFN - Roma1			
A. Messina	Sapienza Univ	Researcher	30%
G. Cavoto	Sapienza Univ	Assoc. Prof.	30%
E. Di Marco	INFN-Roma11	Researcher	20%
M. Marafini	Centro Fermi	Researcher	20%
D. Pinci	INFN-Roma11	Researcher	50%
F. Renga	INFN-Roma11	Researcher	30%
C. Voena	INFN-Roma11	Researcher	20%
INFN - LNF			
R. Bedogni	INFN-LNF	Researcher	20%
E. Benussi	INFN-LNF	Researcher	10%
S. Bianco	INFN-LNF	Senior Researcher	20%
G. Mazzitelli	INFN-LNF	Senior Researcher	80%
D. Piccolo	INFN-LNF	Senior Researcher	20%
S. Tomassini	INFN-LNF	Engineer	30%

	FTE	PERS	FTE/P
LNGS	0,8	1	0,80
RM1	2,0	7	0,28
LNF	1.8	6	0,30
TOT	4,6	14	0,33

Colleagues from Cygnus Collaboration agreed to being involved in the project, a WP and Task distribution is under definition: C. Mancini, F. Petrucci, G. Saviano, M. Caponero, N. Spooner (materials budget), T. Thorpe, S. Vahsen (simulation), K. Miuchi (gas purification), D Dwyer, W. Lynch, A. Ezeribe, T. Baroncelli, L. Bignell, G. Lane, D.Loomba, Chung-Lin Shan, R. Gargana, S Stanlio, G. Donvito….

COSTI & Richieste ai LNF

Grazie al recentissimo ingresso di molti colleghi stranieri della collaborazione CYGNUS nel progetto CYGNO stiamo ancora lavorando alla divisione dei compiti e l'ottimizzazione dei costi anche in base al supporto che può venire dai collaboratori nazionali ed internazionali.

costi indicativi 2019

	LNF	RM1	LNGS
HV		15	
Mechanics	10		
TDAQ	10		
Gas (Bottles)	5	5	
Gas (System)		20	
Travel	5	5	3
Tot	30	45	3

item	unit cost (k€)	q.ty	total (k€)
Flash 4.0	7.5	18	140
Lens	1.5	18	25
GEM	1.0	60	60
PMT	1.0	18	18
Vessel&FT	30.0	1	30
FC&Windows	1.0	2	2
Shielding	10.0	1	10
Veto System	10.0	1	10
HV System	50.0	1	50
Gas System	80.0	1	80
DAQ System	50.0	1	50
Gas	20.0	1	20
Consumable	20.0	-	20
Total			515

i maggiori contributi per servizi dei LNF sono attesi nel 2019 nella progettazione (meccanica ed elettronica) e nel supporto meccanico alla realizzazione dei prototipi (LIME e DAQ); nel 2020 per la realizzazione meccanica ed elettronica (CYGNO e DAQ); nel 2021 supporto alla istallazione (CYGNO); >= 2021 supporto alla manutenzione…