CYGNO PROJECT

E. Baracchini,[a,b] L. Benussi,[c] S. Bianco,[c] C. Capoccia,[c] M. Caponero,[c,d] G. Cavoto,[e,f] A. Cortez,[a,b] I. A. Costa,[g] E. Di Marco,[e] G. D'Imperio,[e] G. Dho,[a,b] F. Iacoangeli,[e] G. Maccarrone,[c] M. Marafini,[e,h] G. Mazzitelli,[c] A. Messina,[e,f] R. A. Nobrega,[g] A. Orlandi,[c] E. Paoletti,[c] L. Passamonti,[c] F. Petrucci,[i,j] D. Piccolo,[c] D. Pierluigi,[c] D. Pinci,[e,1] F. Renga,[e] F. Rosatelli,[c] A. Russo,[c] G. Saviano,[c,k] and S. Tomassini[c]

CYGNO PROJECT

The aim of CYGNO project is the development and realisation of a GEM-based Optically Readout Time Projection Chamber for the study of rare events with energy releases in the range 1-100 keV.

Expected performance is:

- High detection efficiency down to 1 keV;
- Directionality at 10 keV;
- Background rejection below 10 keV;

Main ideas of the technology are:

- He/CF_4 based gas target (atmospheric pressure);
- GEM amplification stage;
- Combined optical readout (CMOS for granularity + PMT for timing);

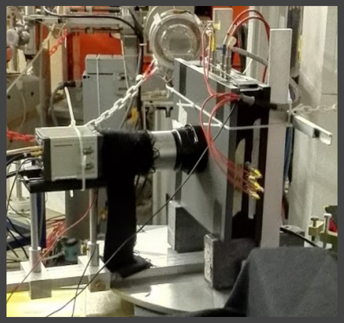
PHASES OF PROJECT

PHASE 0: R&D

PHASE 1: ~1M³ DEMOSTRATOR

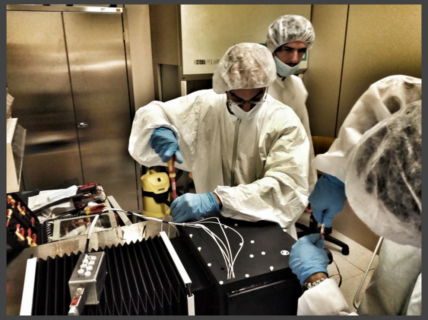
2018	2019	2020	2021/22	2023 ...
@ ROMA1/LNF	@ LNF	@ LNF/LNGS	@ LNF/LNGS	@ LNGS

ORANGE



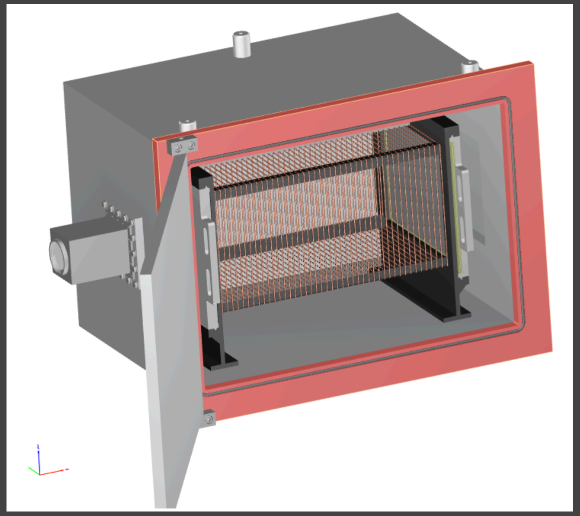
- OPT readout
- 1 cm drift
- 0 resolution

LEMON



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

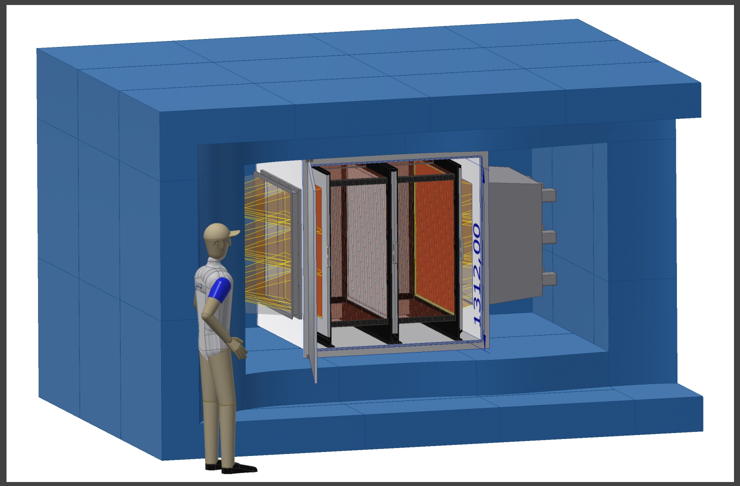
LIME



- 50 cm drift
- materials test
- underground tests
- shielding

Construction & test

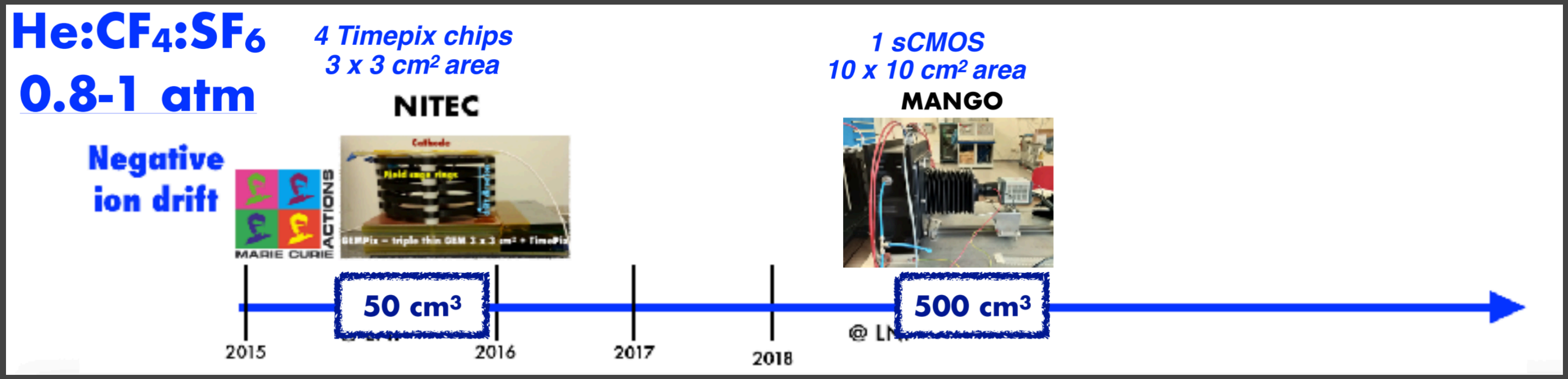
CYGNO



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

Installation & commissioning

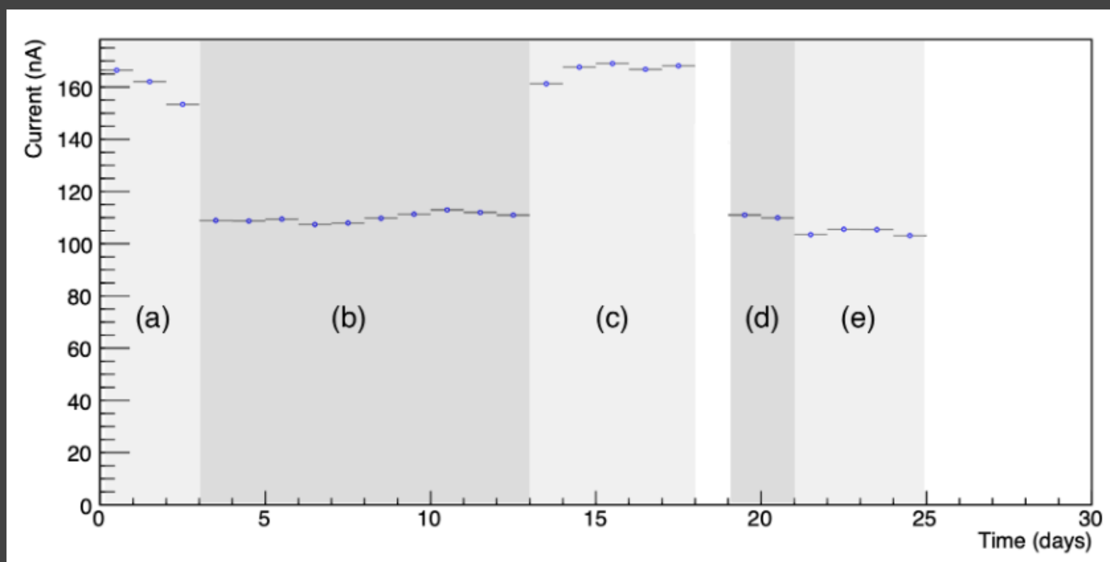
CYGNUS 30-100 m³

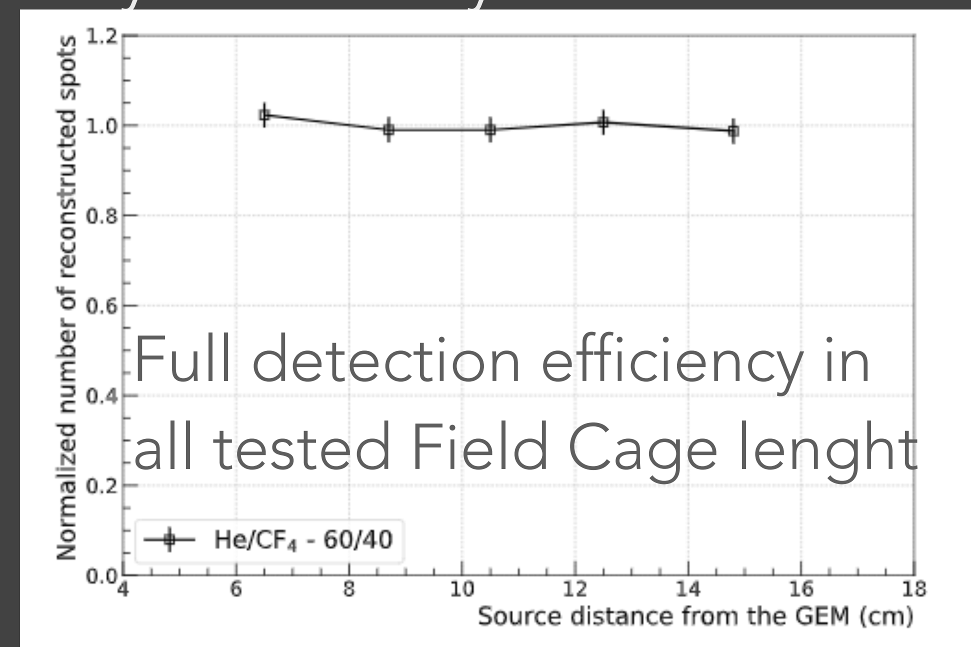


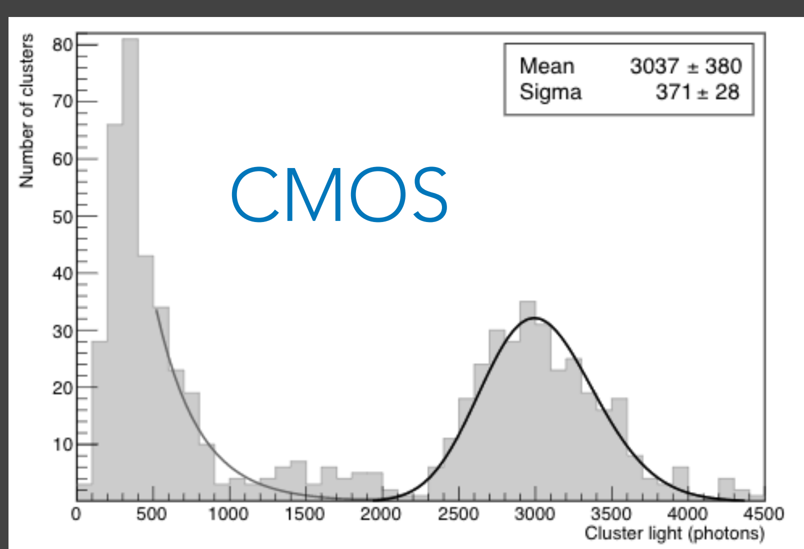
WHERE DO WE ARE

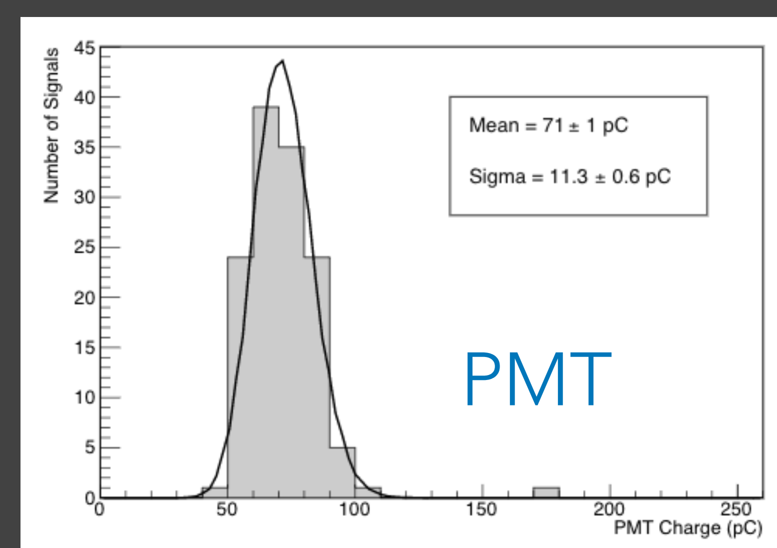
PERFORMANCE WITH ^{55}FE

5.9 keV photons from ^{55}Fe source were used to test detection efficiency and light yield. Detector run continuously for 25 days









500 photons collected per keV
Energy resolution of 15%

Similar resolution with PMT

BACKGROUND REJECTION

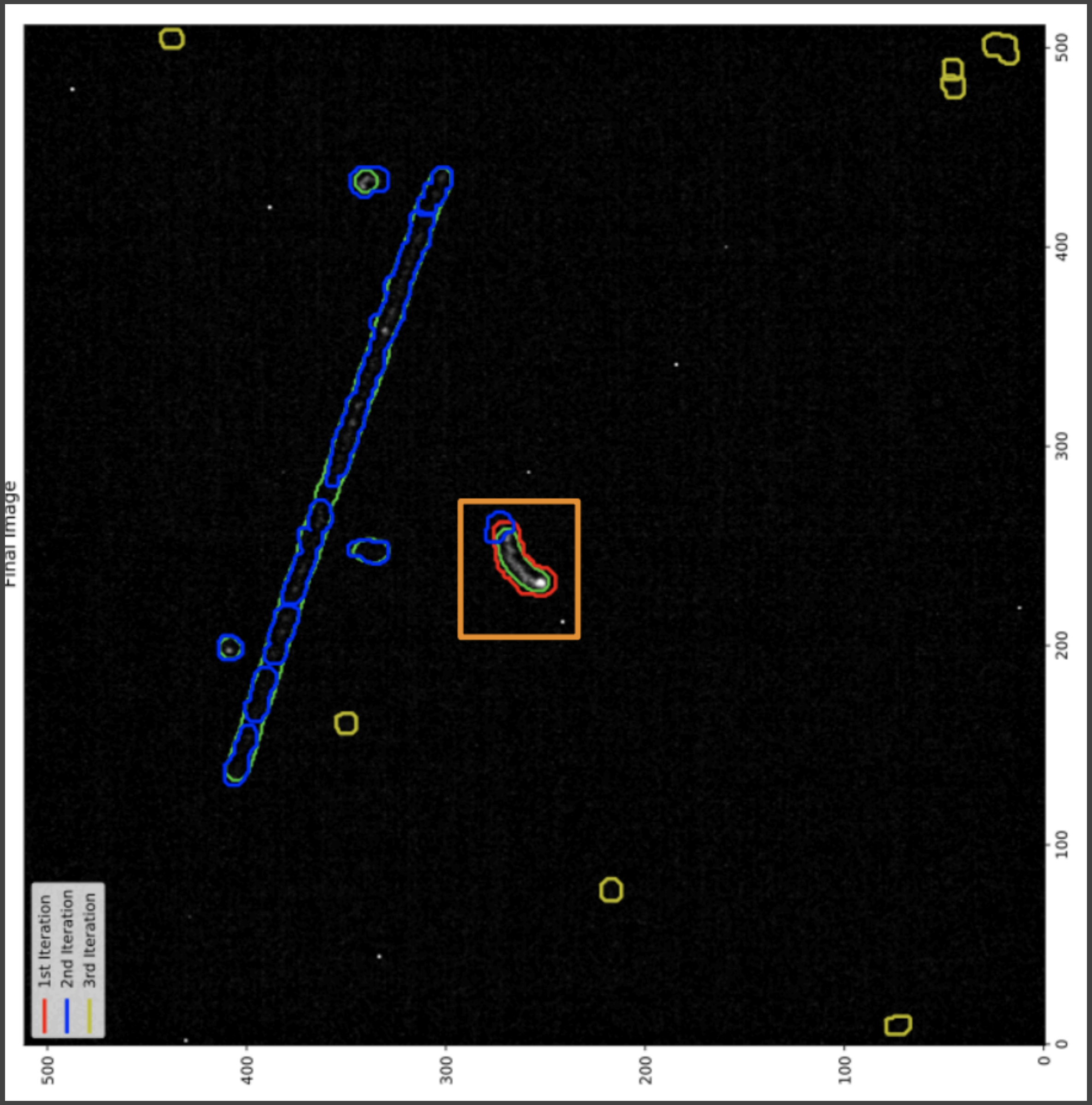
To evaluate the background (electron recoils) rejection capability and the signal (nuclear recoils) efficiency, we tested LEMON (a 7 litre prototype) with ^{55}Fe and AmBe sources.

AmBe produces:

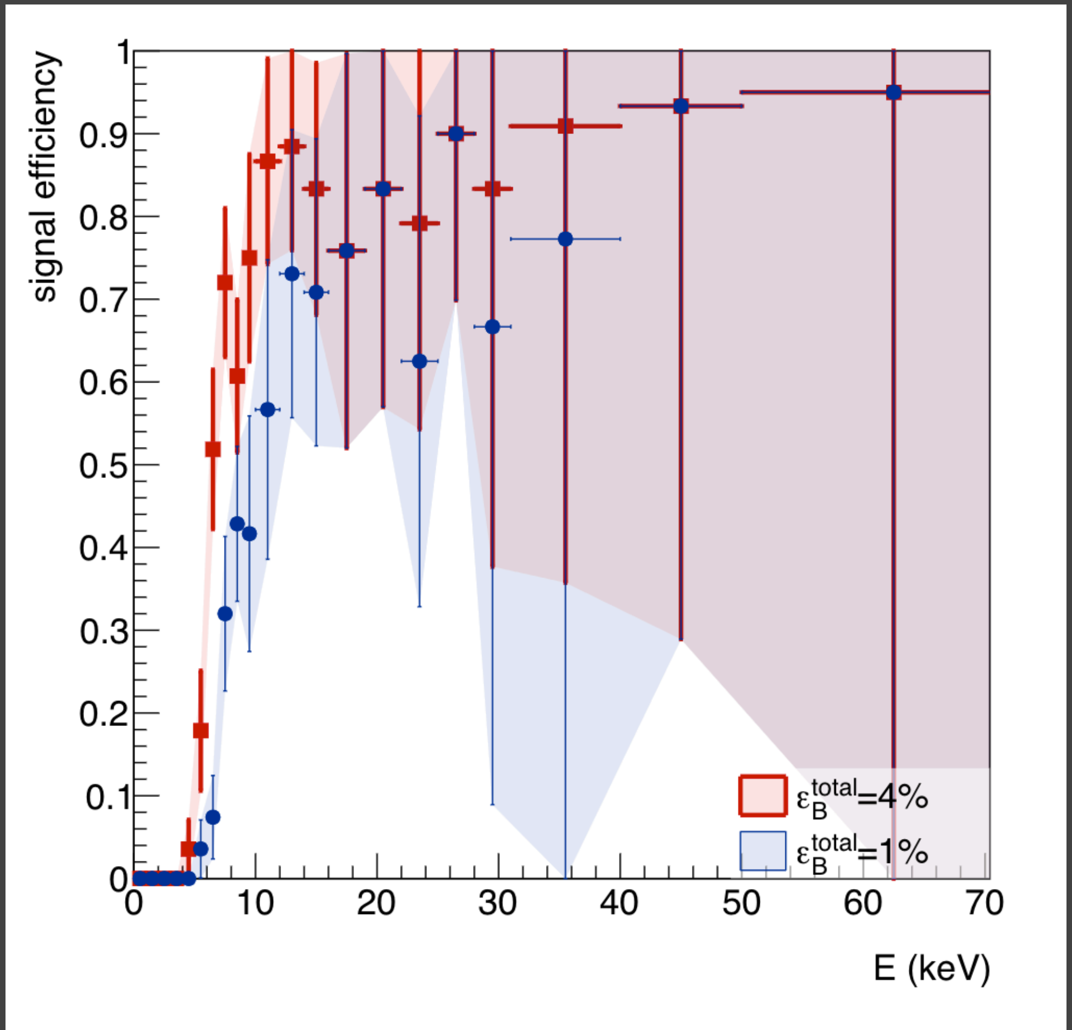
- 59 keV photons;
- 4 MeV photons;
- 1-10 MeV neutrons;

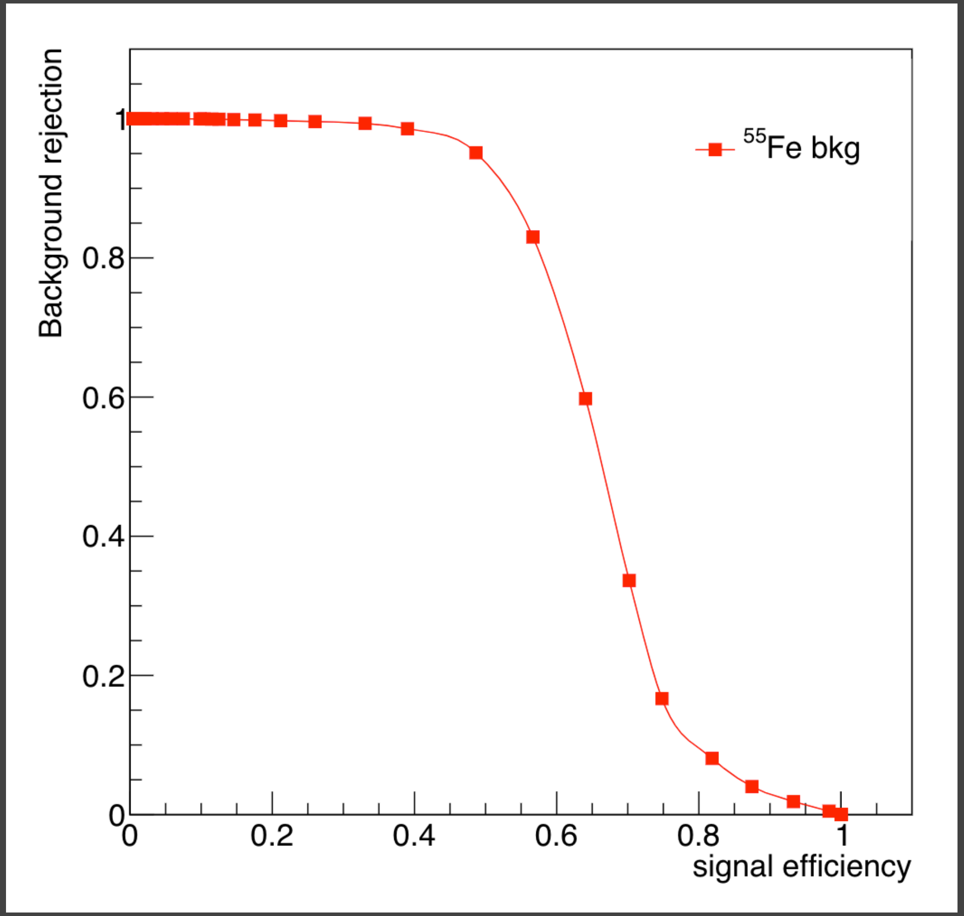
A 5 cm Pb shield was used

Unfortunately in all cases cosmics and natural radioactivity produce an unknown background that piles-up to signals.
Need to go underground.



SIGNAL EFFICIENCY





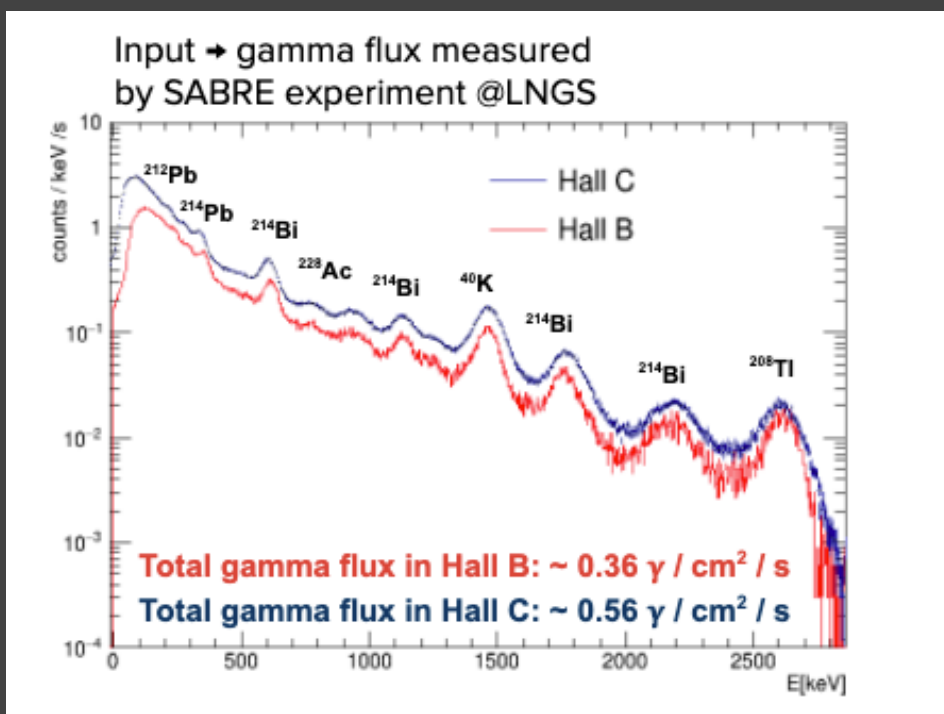
working point	Signal efficiency			Background efficiency		
	ε_S^{presel}	ε_S^{δ}	ε_S^{total}	ε_B^{presel}	ε_B^{δ}	ε_B^{total}
WP_{50}	0.98	0.51	0.50	0.70	0.050	0.035
WP_{40}	0.98	0.41	0.40	0.70	0.012	0.008

A sizeable efficiency in the range 5-10 keV was measured while more than 95% (99%) ^{55}Fe photons were rejected

BACKGROUND SIMULATION

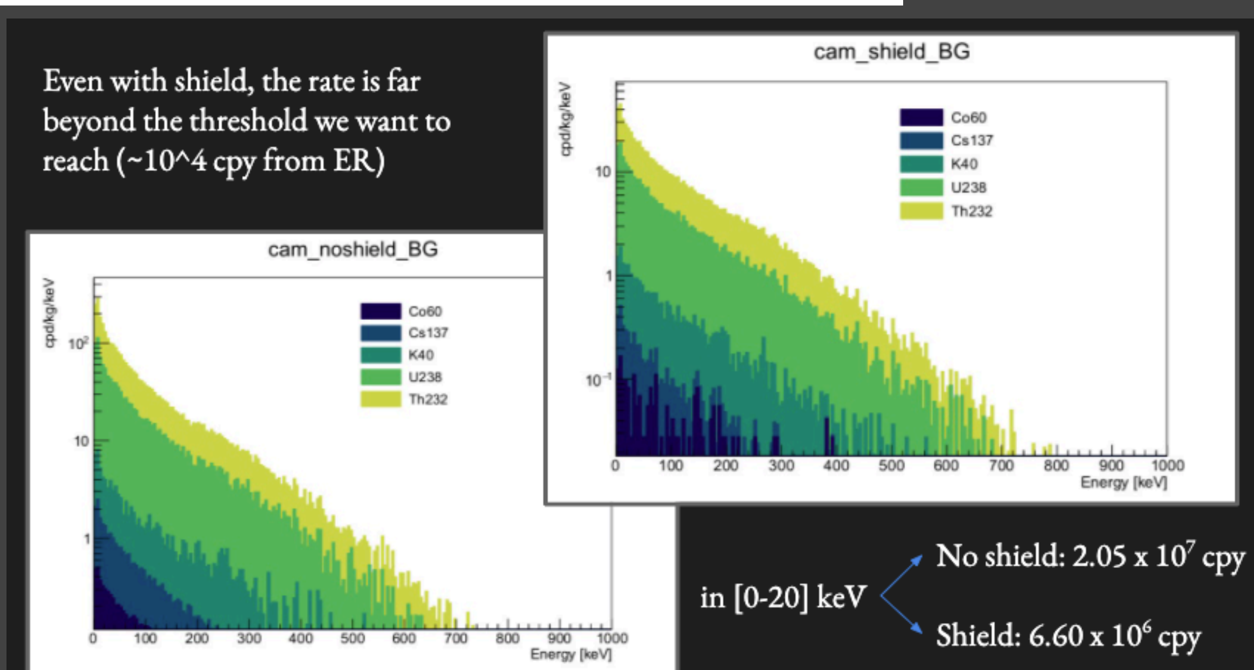
Full Detector simulation in GEANT4

Gamma and neutron background due to internal radioactivity simulated



Measured radioactivity of GEM and different Cameras

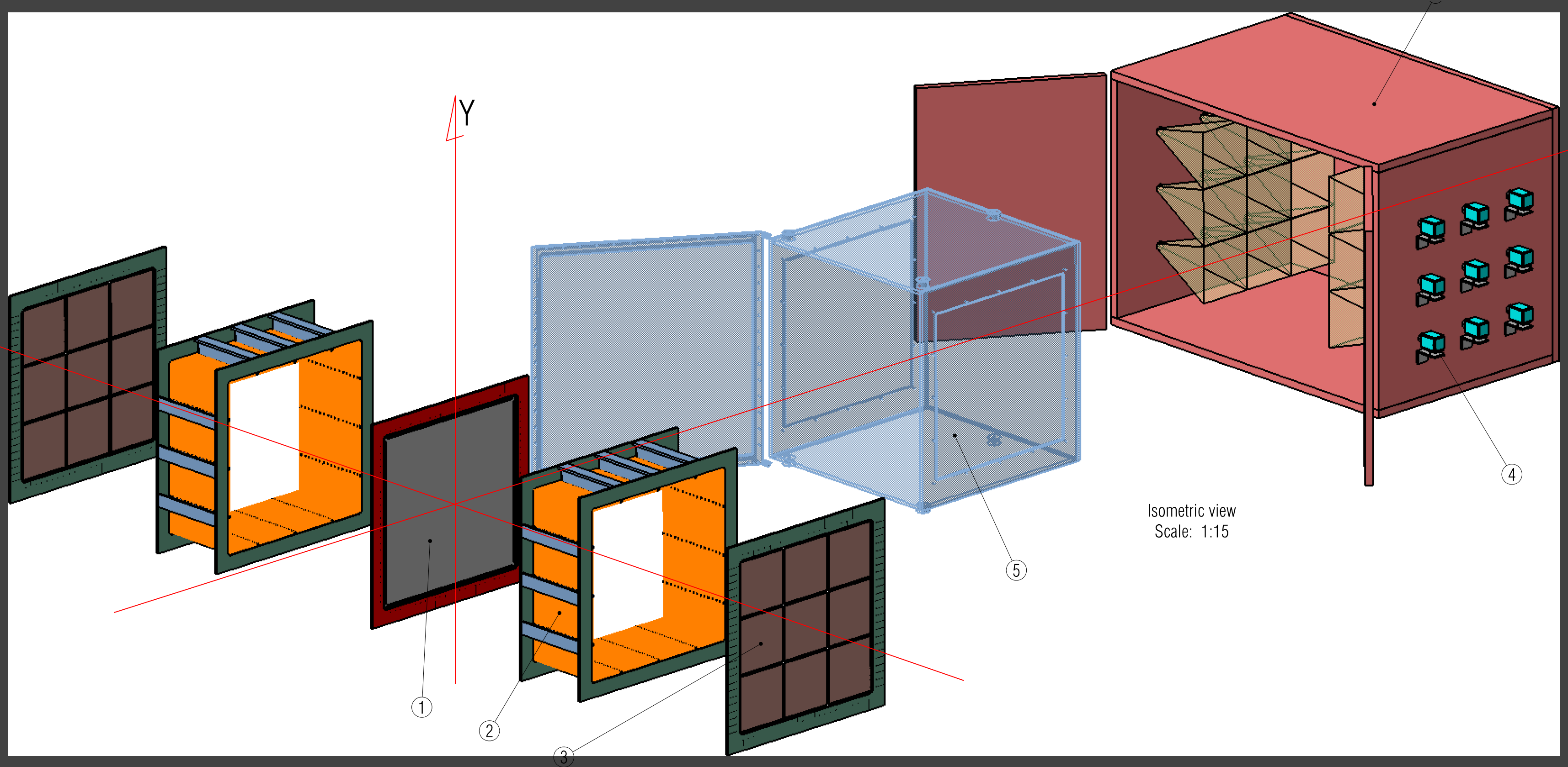
Camera	Sensitivity (eV/count)	Resolution (%)	Noise (eV)	^{228}Ra (Bq)	^{228}Th (Bq)	^{226}Ra (Bq)	^{234}Pa (Bq)	^{40}K (Bq)	Total activity
Hamamatsu ORCA FLASH 4.0	2.96	15.2	4.6	2.1	2.1	1.9	7.0	1.9	15.0
ORCA FLASH sensor	2.6	15.2	8	1.0	1.0	1.1	1.1	4.3	8.5
Photometrics Prime BSI Mode 1	3.3	19.0	9.7	-	-	-	-	-	tbm
Photometrics Prime BSI Mode 2	1.12	16.4	4.5	-	-	-	-	-	tbm
Photometrics BSI Express Mode 2	0.84	13.4	3.0	1.3	1.8	1.0	6.0	3.6	13.7
Hamamatsu Fusion Closer (LEMON)	0.65	17.5	1.58	-	-	-	-	-	tbm
Hamamatsu Fusion Farther (LIME)	0.85	16.4	2.06	-	-	-	-	-	tbm
Thorlab Quantalux	tbm	tbm	tbm	0.3	0.6	0.2	3.0	1.2	5.3



Included in GEANT4, resulted dominant with respect to external shielded

CYGNO BASELINE DESIGN

1 m^3 of He/CF_4 60/40 (1.6 kg) at atmospheric pressure subdivided in two 50 cm long parts by the cathode with a drift field of about 1 kV/cm

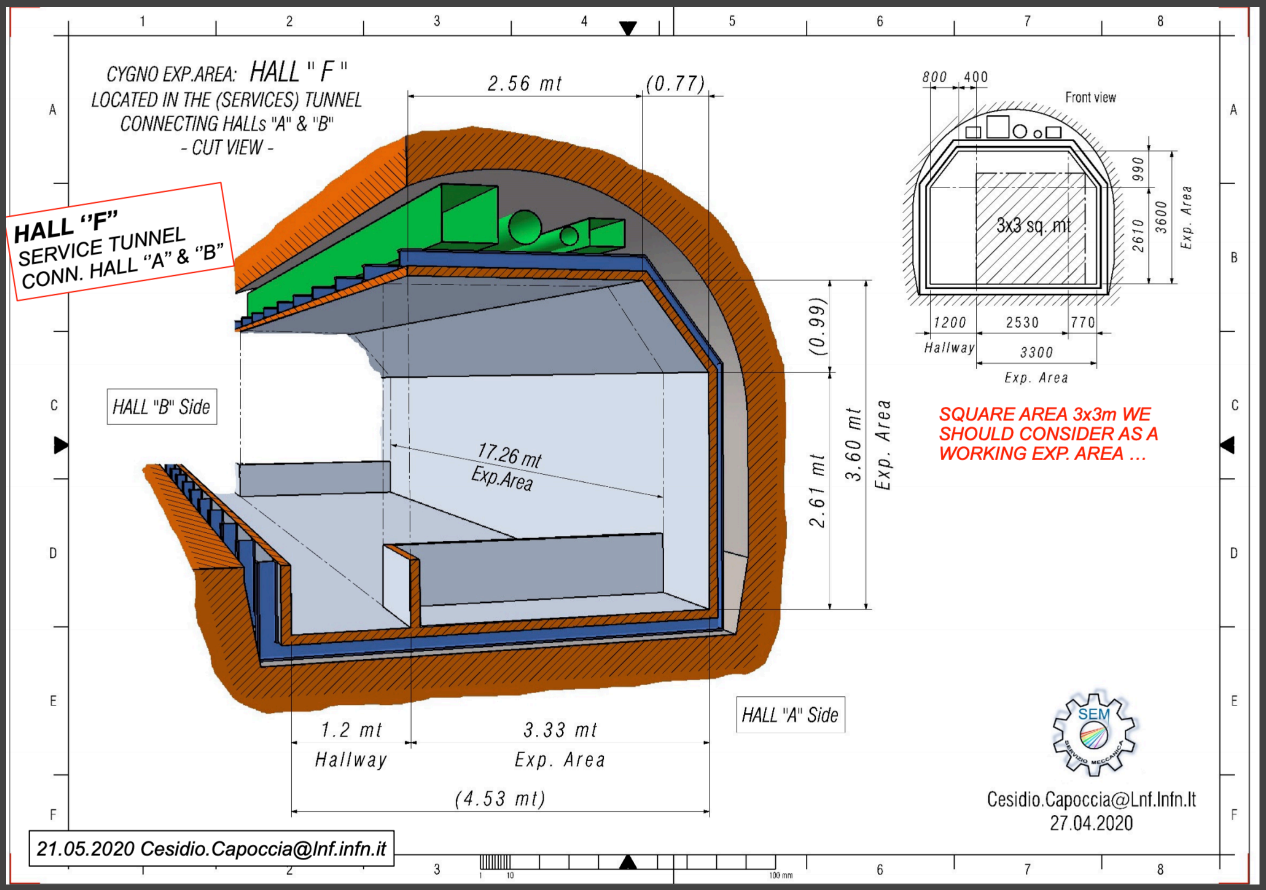


Each side equipped by a 3x3 matrix of LIME-like:

- sCMOS sensor 65 cm away;
- Fast light detector (PMT or SiPM).

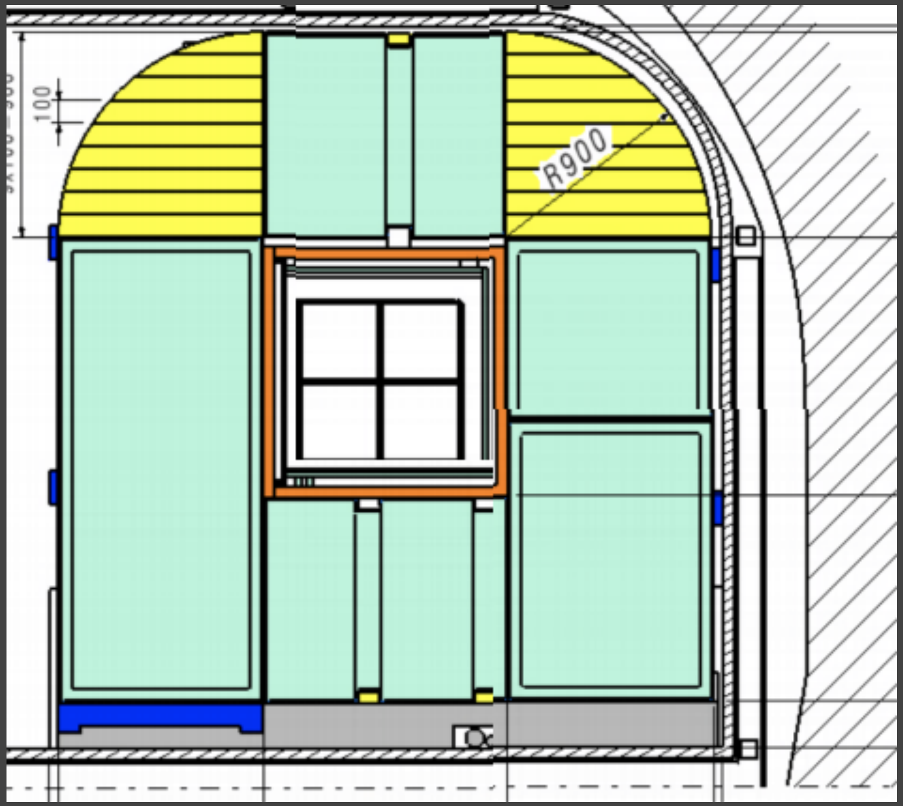
Shielding of 200 cm water and 5 cm copper giving a bkg cpy [1-20] keV of few 10^2;

HALL-F: CYGNO IN THE BOTTLE



A possible room for CYGNO is in Hall-F (tunnel connecting A and B halls);

Available cross section is 3x3 m^2 (l=17 m)

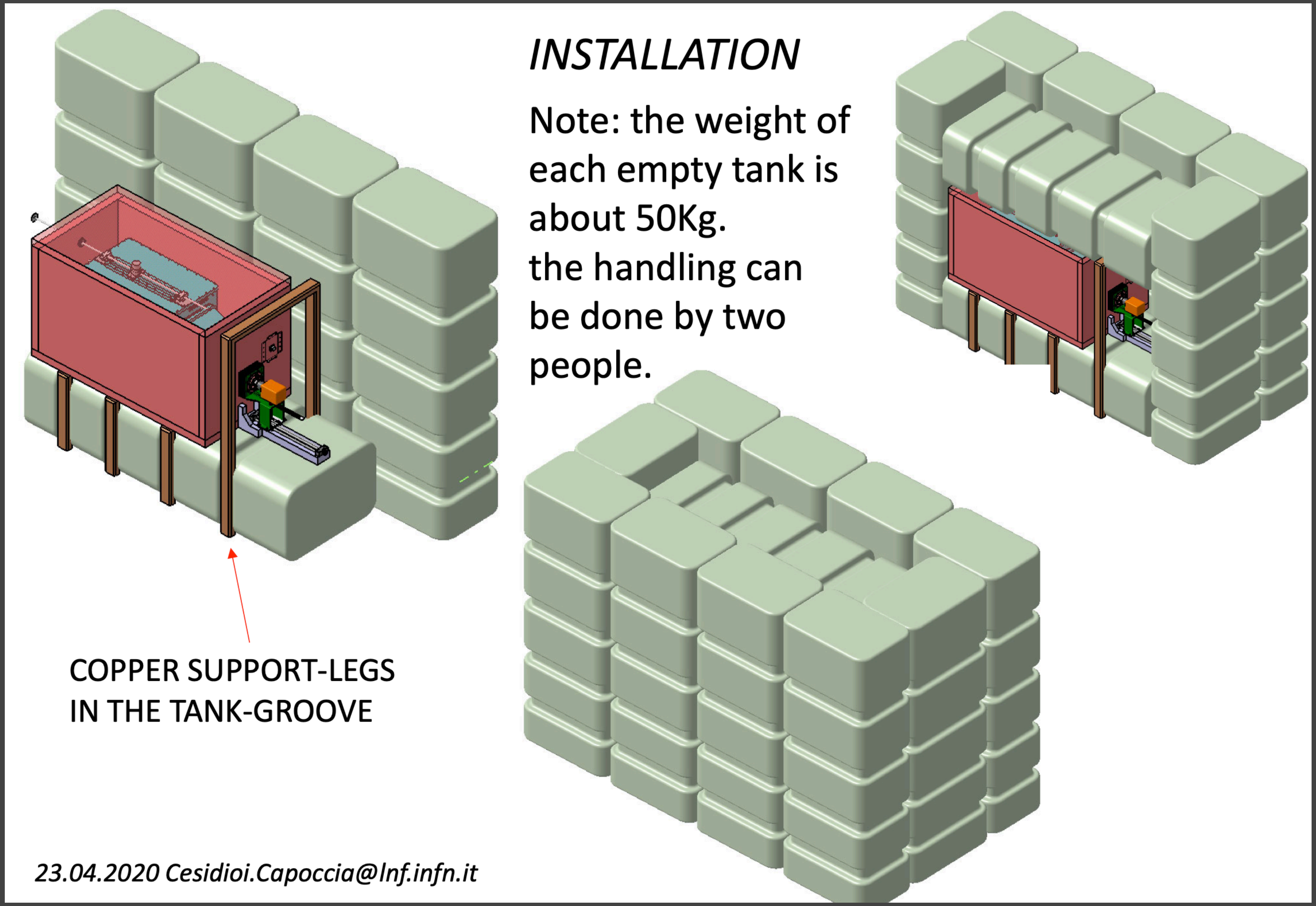


It will be possible to house 0.4 m^3 - CYGNO with a 110/10 (water/Cu) shielding scheme;

Background rate of **2×10^4** cpy, will be lower than internal bkg (currently **5×10^5** cpy) and will allow to study it;

With a rejection of **10^2-10^3** these numbers will result in an avoidable bkg of few **tens** of events/year **external** and few **hundreds** of events/year **internal;**

SHIELD



PRODUCTION COSTS

	MOLD-TOOLING	DRAW-DOCUM	ROT. MOULDING	N.TANK	TOTAL
VERZELLESI SRL	Refused to carry out an evaluation due to the low quantity				
TELCOM SPA	€ 42,500.00	€ 3,000.00	€ 260.00	12	€ 48,620.00
MOULDING SERV. SRL	€ 15,900.00	€ 1,200.00	€ 235.00	12	€ 19,920.00
Diff (%)	267%	250%	111%		244%

We are investigating the possibility of building custom tanks

BACKGROUND- OPEN POINTS

^{14}C contamination in gas can give important bkg. Need to know the origin of C in CF_4.

Copper and plexiglass can be produced with low-radioactivity content. Need to get in contact with producers, develop special procedures, measure quality of materials.

Need to study a low radioactive GEM production;

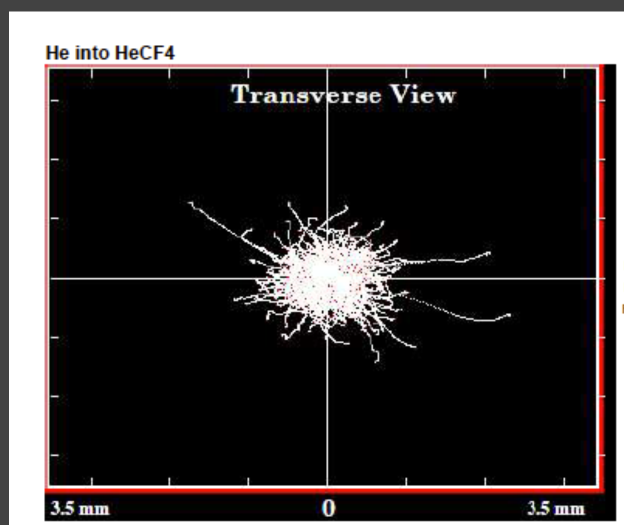
Need to find low radioactive CMOS sensors;

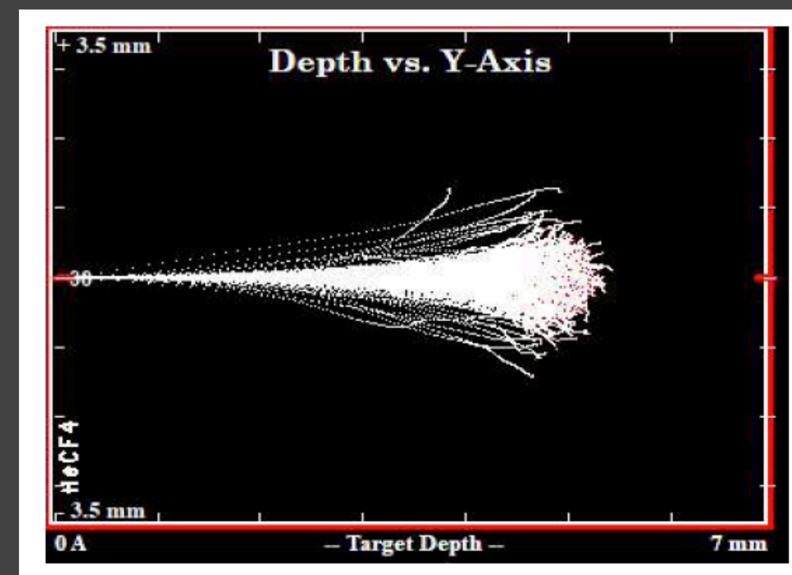
Need to purify and monitor gas mixture.

Some study already started about radioactive source to be used. Any advice?

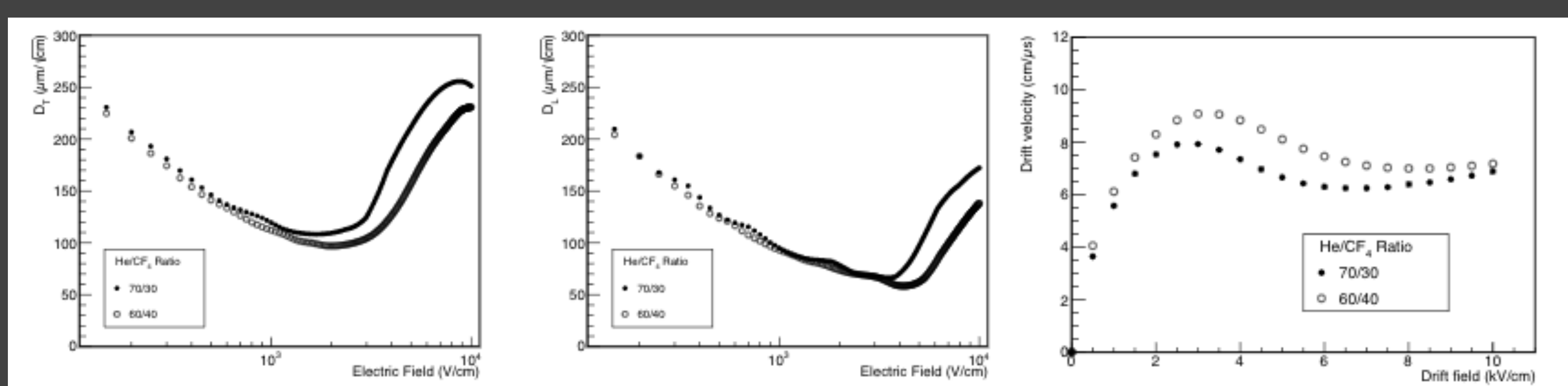
SIGNAL SIMULATION

Interactions of recoils in gas simulated: GEANT for electrons and SRIM for nuclei;





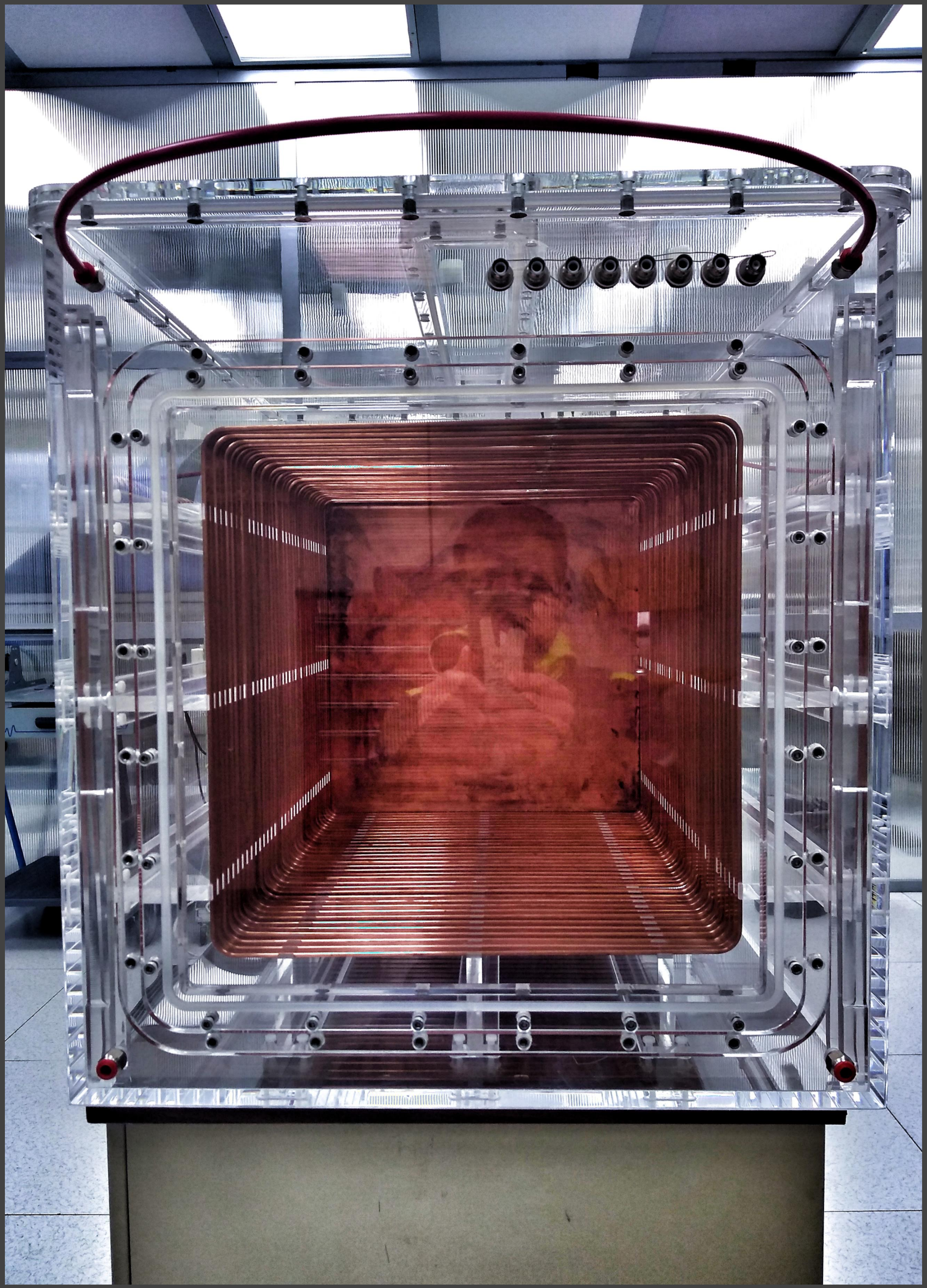
Gas parameters (ionization, diffusion, drift velocity, attachment) simulated with GARFIELD;



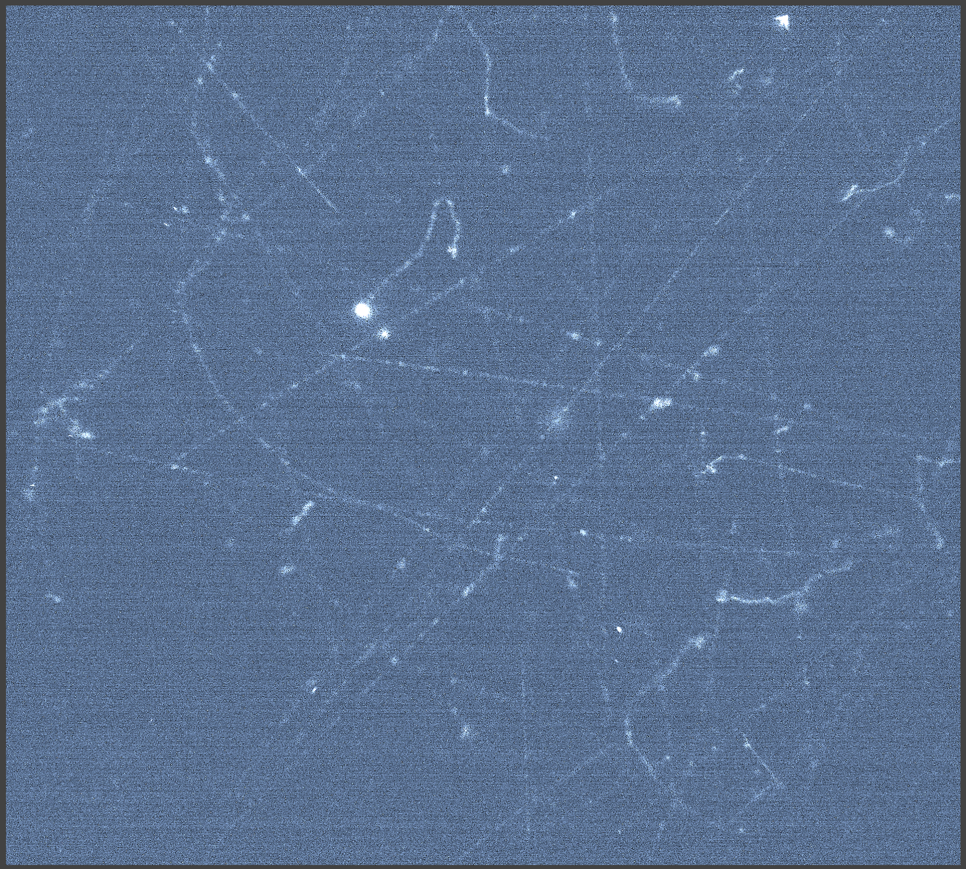
Response and noise behavior of PMT and CMOS simulation on-going

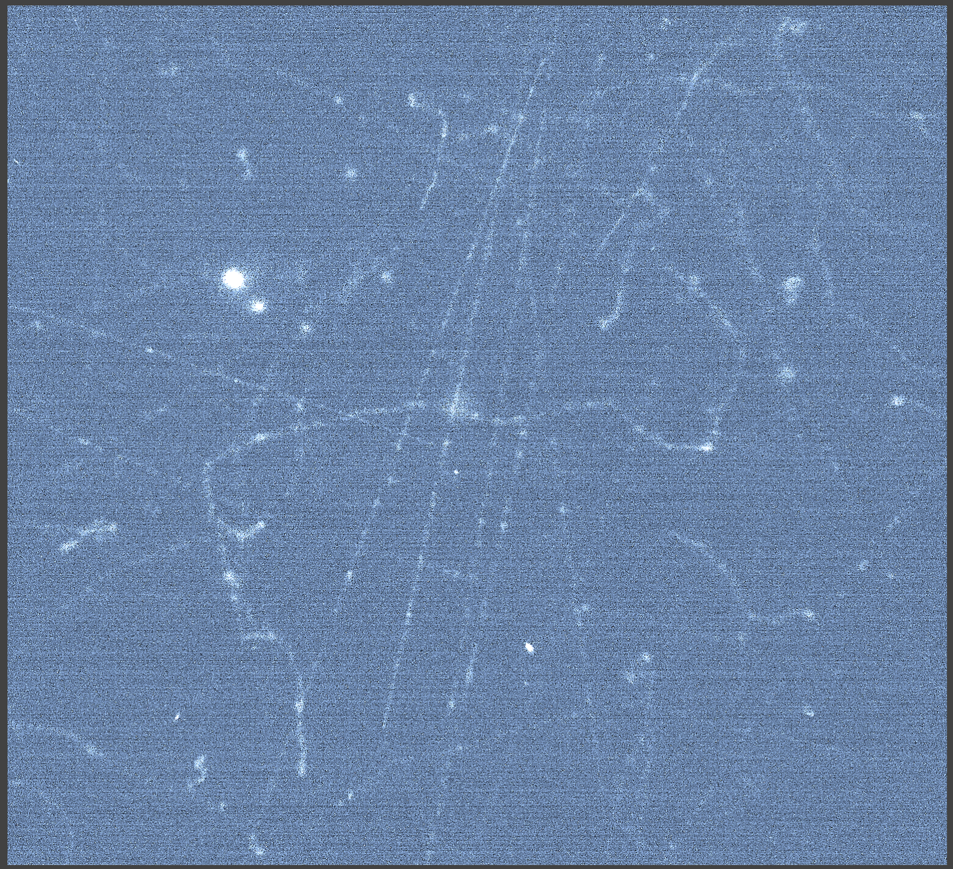
LIME

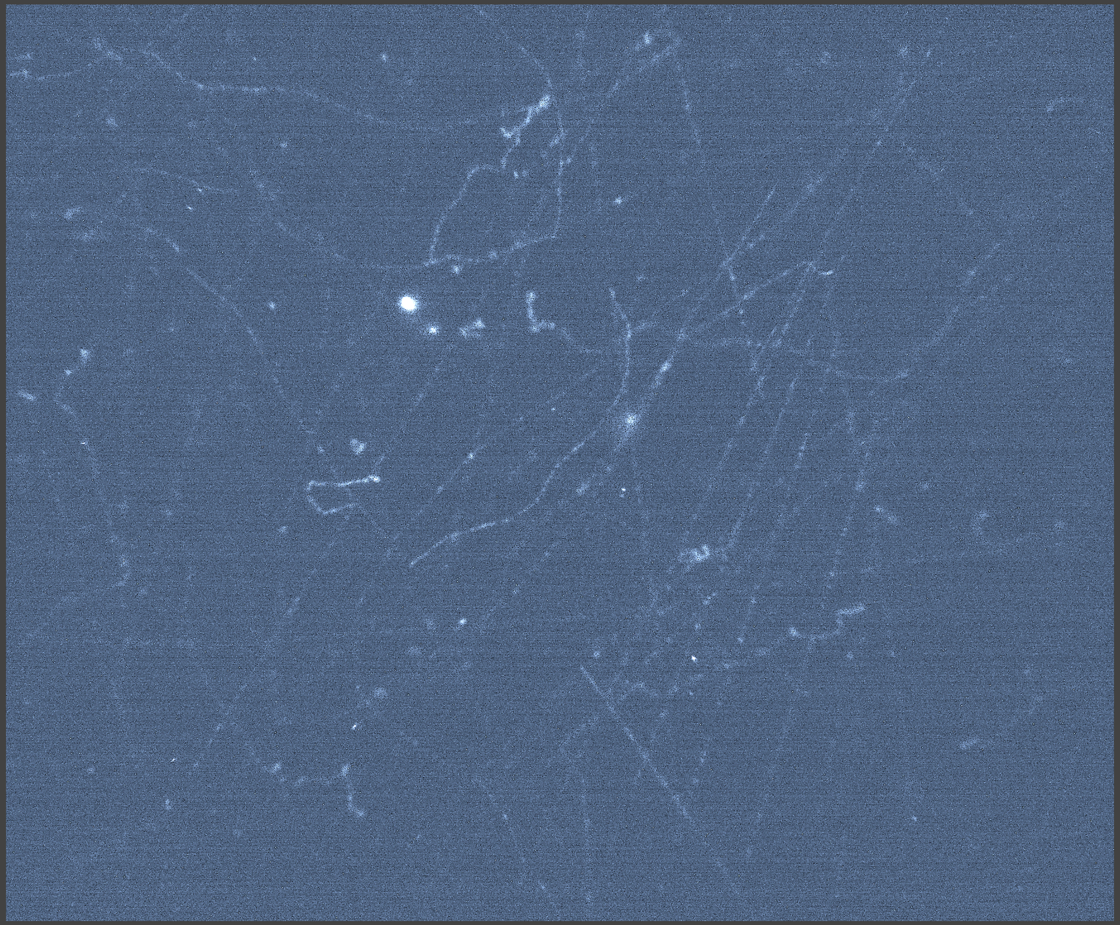
50 litre sensitive volume

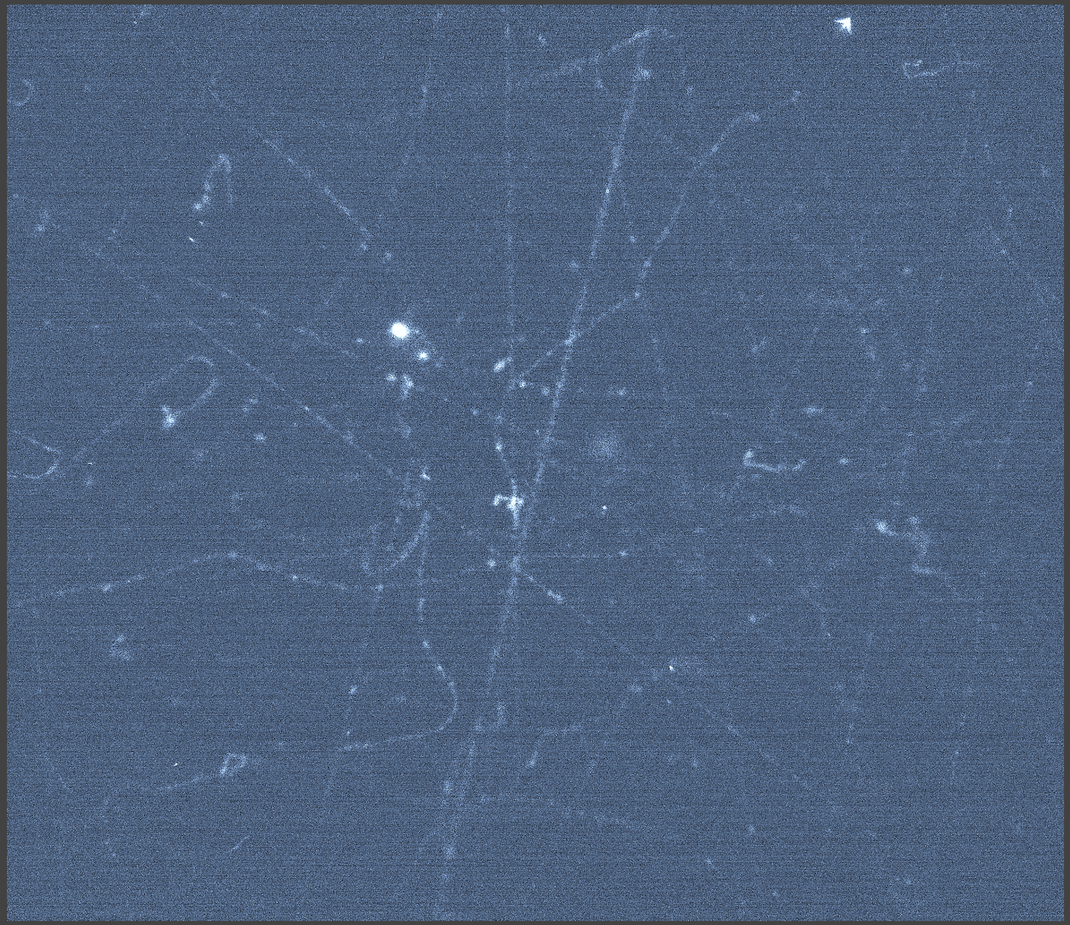


LIME







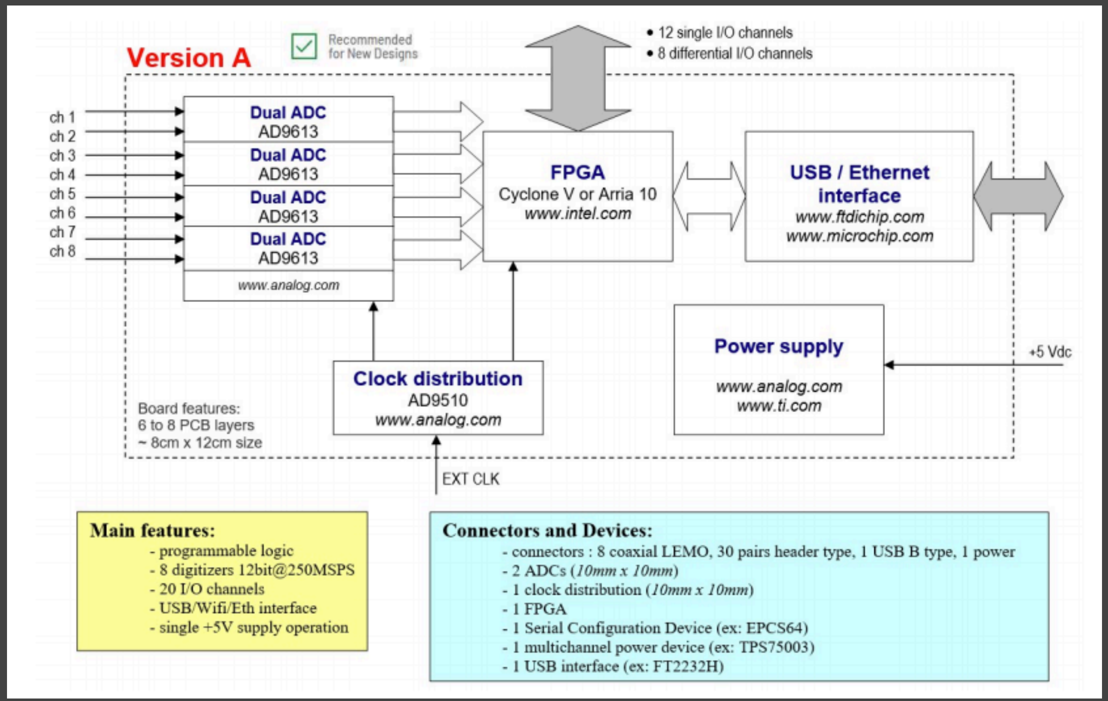


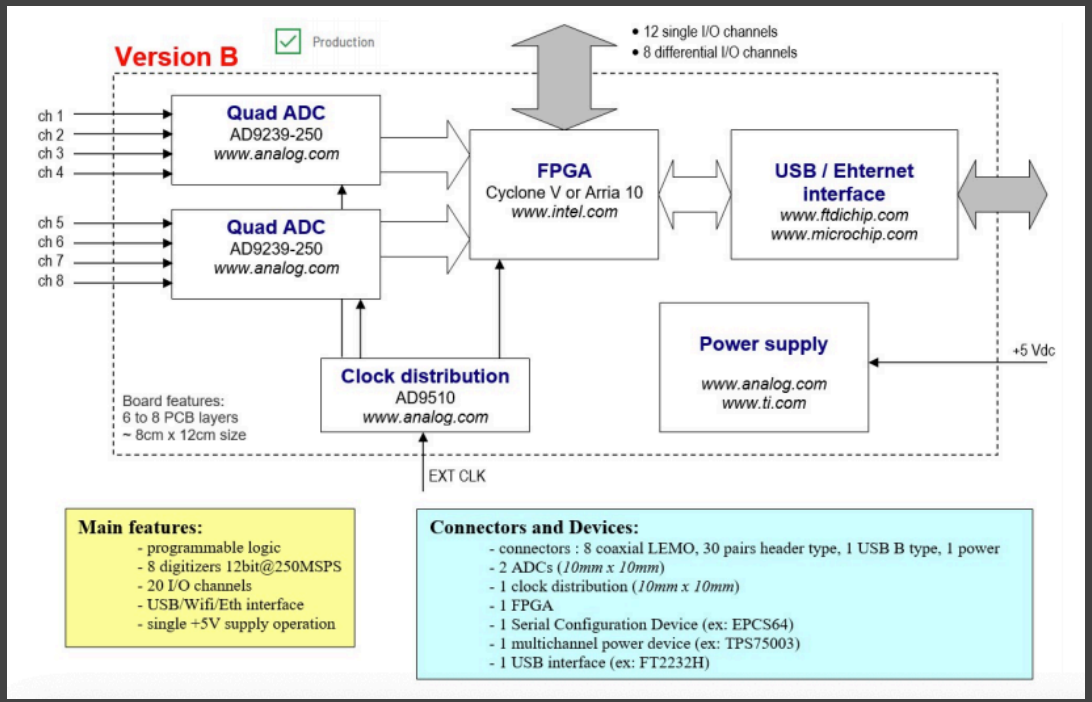
DAQ

Data acquired so far with a DAQ prototype able to synchronise CMOS and PMT;

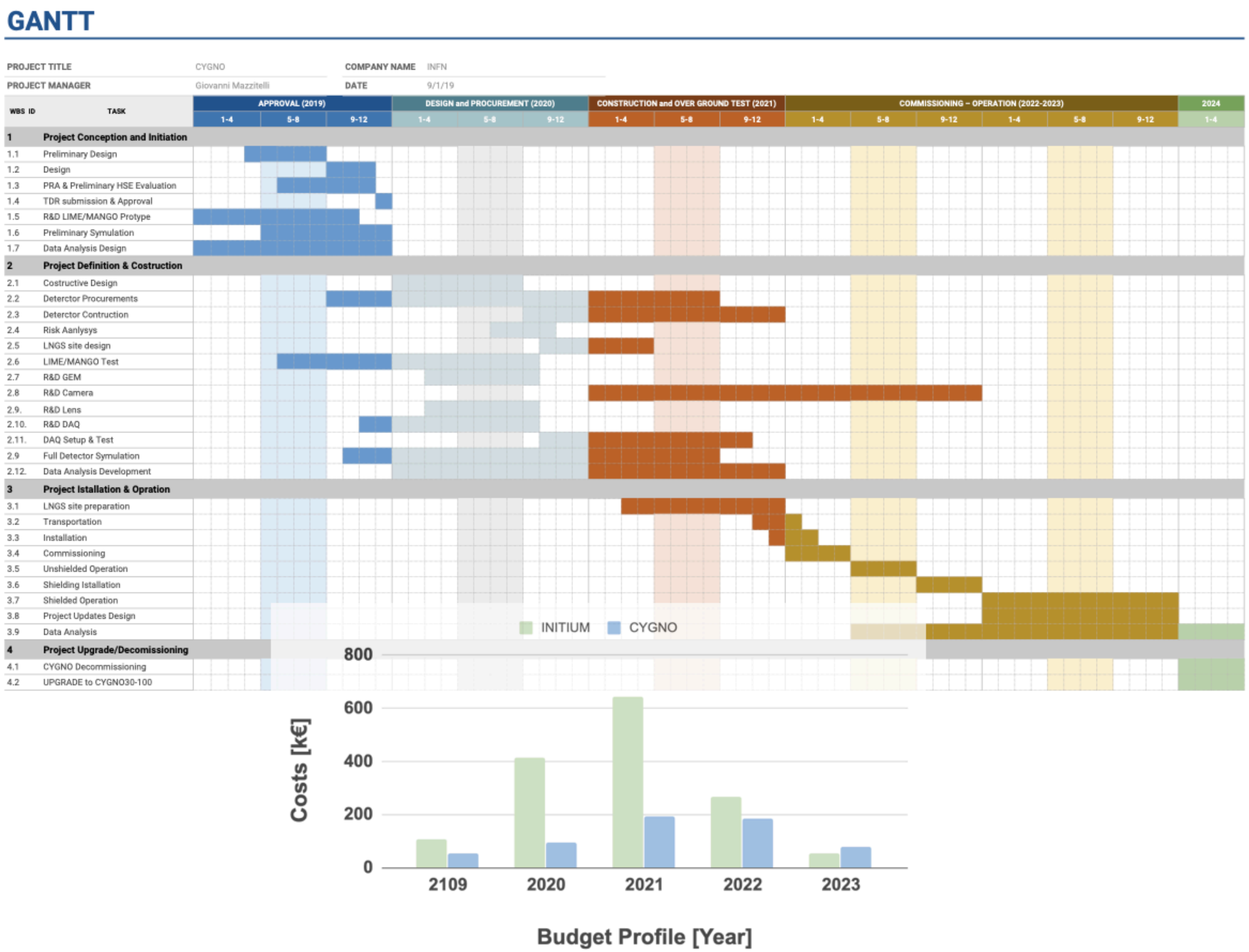
Need to design and assemble a reliable DAQ system, running underground for several CMOS and PMT;

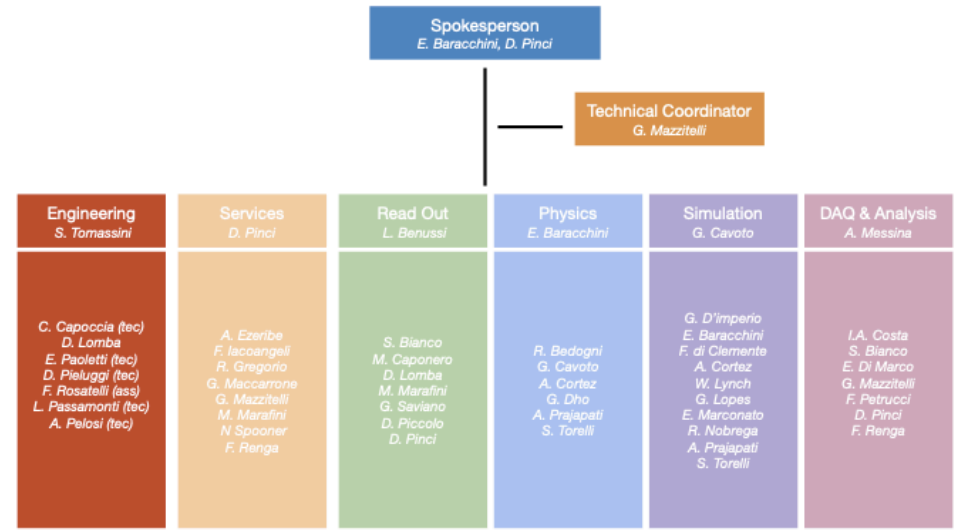
Brazilian group is working on this.





CYGNO Schedule





Analisi	Emanuele DM
Gas	Francesco R
HV	Davide Pinci
GEM	Luigi B
CMOS	Davide Pinci
PMT - SiPM	Francesco I
Ottica (lenti, specchi)	Davide Pinci
Progettazione Mecc	Sandro T
Integrazione	Giovanni M
DAQ	Andrea M
Fisica	Elisabetta B
Simulazione	Giulia D'I
Rapp. Internazionali	Elisabetta B
Calibrazione	Gianluca C
Eco gas	Davide Piccolo

G. Mazzitelli-LNF-INFN, UFJF, Oct. 2019

2020 PAPERS

Two papers submitted

A GEM-based Optically Readout Time Projection Chamber for charged particle tracking

Prepared for submission to JINST

First evidence of luminescence in a He/CF_4 gas mixture induced by non-ionizing electrons

Three papers under internal review

Prepared for submission to JINST

A density-based clustering algorithm for the CYGNO data analysis

Prepared for submission to JINST

Stability and detection performance of a GEM-based Optical Readout TPC with He/CF_4 based gas mixtures

Identification of nuclear recoils in a gas TPC with optical readout

May 2020

Abstract.

1. Introduction

The advent of a market of high position resolution and single photon light sensors can open new opportunity to investigate ultra-low rate phenomena as Dark Matter (DM) particle scattering on nuclei in a gaseous target.

The nature of DM is still one of the key issues to understand our Universe. aggiungere reference generica su DM Different models predicts the existence of neutral particles with a mass of GeV or higher that would fill our Galaxy. They could interact with the nuclei present in ordinary matter producing highly ionizing nuclear recoils but with a kinetic energy as small as few keV. Moreover, given the motion of the Sun in the Milky Way towards the Cygnus constellation such nuclear recoils would exhibit a dipole angular distribution in a terrestrial detector. In this paper we describe the use of a scientific CMOS camera to capture the light emitted by Gas Electron Multipliers (GEMs) in a Time Projection Chamber (TPC) device. The GEMs are located in the TPC gas volume at the anode position and are used to convert the ionization produced in the gas by the nuclear recoils into flashes of visible light. The flash of light and its shape can be located in space adopting a cluster recognition algorithm. Neutron and γ radiation emitted by radioactive sources are used to set in motion atomic electrons and nuclei respectively in the gas volume. Moreover, natural radiation as cosmic rays is leaving a trail of ionization in the gas. They are all producing different patterns of light emission from the GEMs that can be reconstructed and analyzed. Nuclear recoils can then be efficiently identified down to a few keV kinetic energy. The study of the optical readout of TPC has been recently conducted with several small size prototypes (NITEC [1], ORANGE [2,3], LEMON [4–6]) with various particle sources, in the context of the CYGNO project. In the following, we report the study of nuclear recoils excited by neutron from an AmBe source and electron recoils from a ^{55}Fe source in the gas volume of the LEMON prototype.

The CYGNO Experiment

Abstract

CYGNO (a CYGNUs module with Optical readout) is an experiment that aims at searching Dark Matter in the low mass region, exploiting very promising performance of the Optical Readout approach of multiple-GEM structures for large volume TPC. This experiment is part the CYGNUS proto-collaboration which aims at constructing a network of underground observatories for directional Dark Matter search. The combined use of high-granularity sCMOS and fast sensors to read out the light allows the reconstruction of the 3D direction of the tracks, offering good energy resolution and very high sensitivity in the keV energy range together with a very good particle identification useful to dis-

Preprint submitted to Journal of LaTeX Templates — June 8, 2020

CYGNO paper in preparation.

Who wants to contribute and sign?