CYGNO PROJECT

E. Baracchini, a,b L. Benussi, S. Bianco, C. Capoccia, M. Caponero, d. G. Cavoto, A. Cortez, a,b I. A. Costa, E. Di Marco, G. D'Imperio, G. Dho, a,b F. Iacoangeli, G. Maccarrone, M. Marafini, A. Mazzitelli, A. Messina, A. Nobrega, A. Orlandi, E. Paoletti, L. Passamonti, F. Petrucci, D. Piccolo, D. Pierluigi, D. Pinci, F. Renga, F. Rosatelli, A. Russo, G. Saviano, and S. Tomassini

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/CF₄ based gas target (atmospheric pressure);
- GEM amplification stage;
- Combined optical readout (CMOS for granularity + PMT for timing);

30-100 m³

PHASES OF PROJECT

PHASE 0: R&D

PHASE 1: ~1M³ DEMOSTRATOR

2018

2019

2020

2021/22

2023

@ ROMA1/LNF

@ LNF

@ LNF/LNGS

LIME

@ LNF/LNGS

Construction

& test

@ LNGS

Installation &

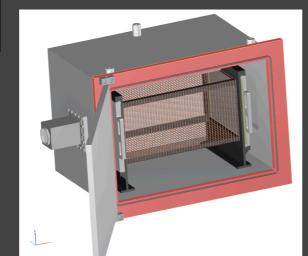
commissioning

ORANGE

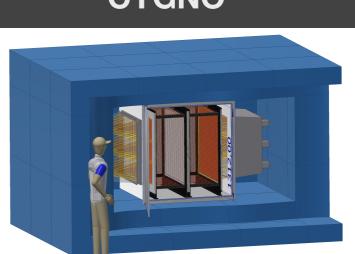


LEMON





CYGNO



- OPT readout
- 1 cm drift
- 0 resolution

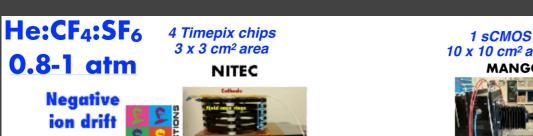
- OPT readout
- 3D printing
- 20 cm drift
- PID
- tracking
- drift resolutions

2017

2018

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

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



50 cm³



reliability

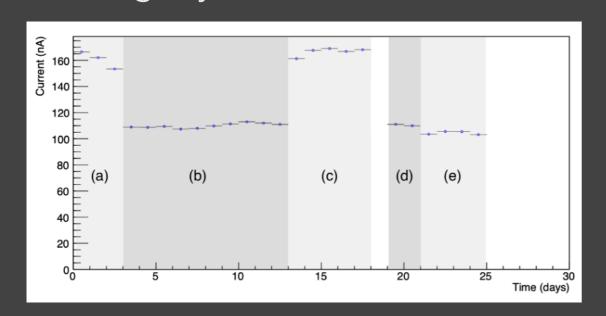
0.8-1 atm

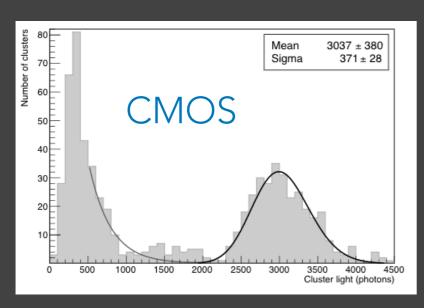
Davide Pinci - The CYGNO Project

WHERE DO WE ARE

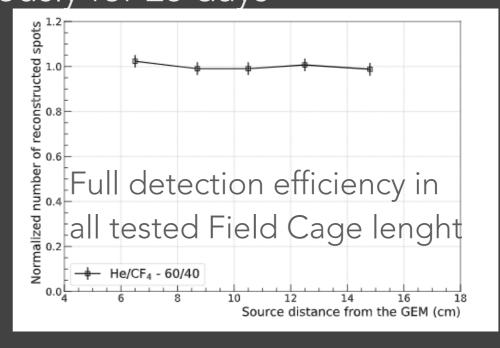
PERFORMANCE WITH 55FE

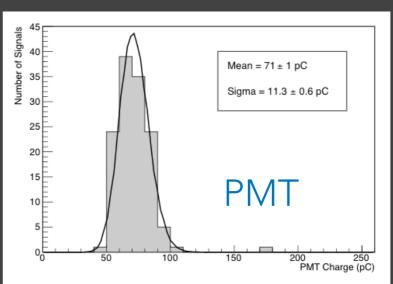
5.9 keV photons from ⁵⁵Fe source were used to test detection efficiency and light yield. Detector run continuously for 25 days





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 ⁵⁵Fe and AmBe sources.

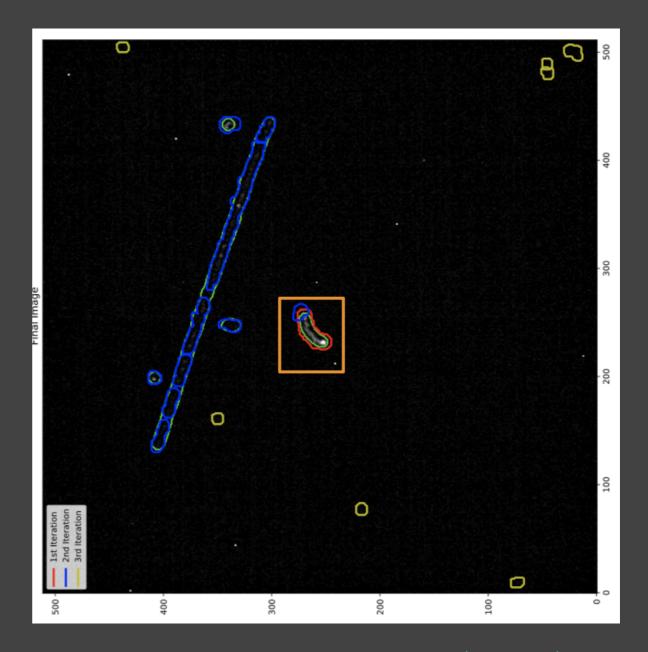
AmBe produces:

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

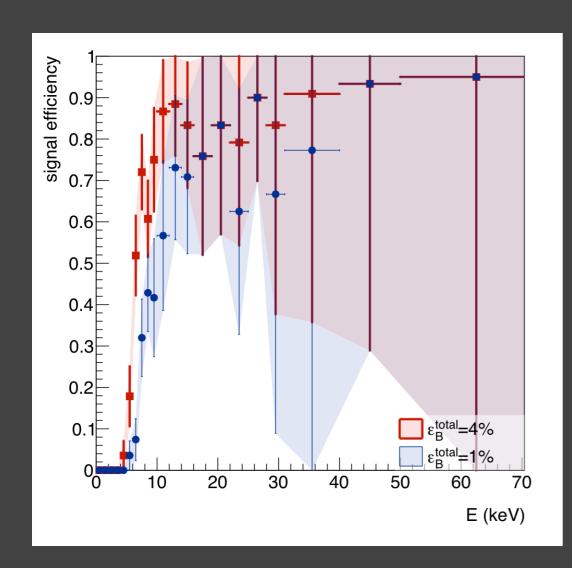
A 5 cm Pb shield was used

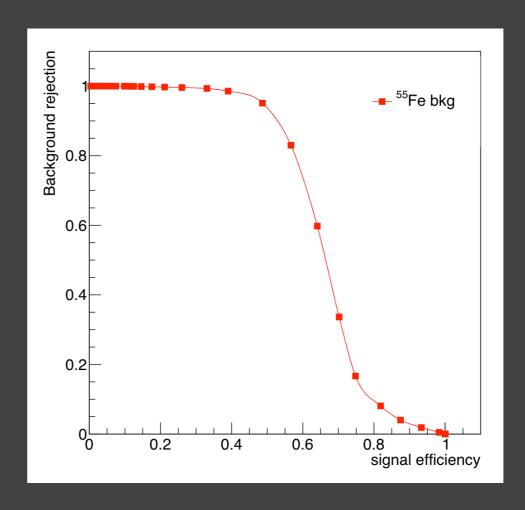
Unfortunately in all cases cosmics and natural radioactivity produce an unknown background that piles-up to signals.

Need to go underground.



SIGNAL EFFICIENCY



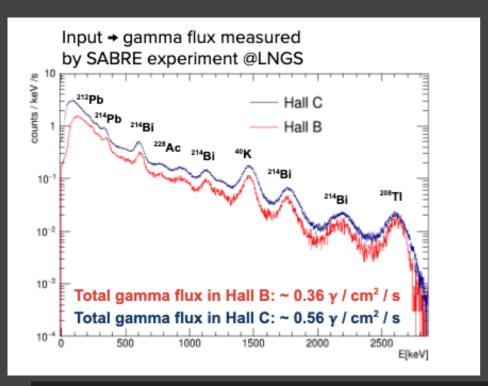


working point	Signa	d effici	ency	Background efficiency				
	$arepsilon_S^{presel}$	$arepsilon_S^\delta$	$arepsilon_S^{total}$	$arepsilon_B^{presel}$	$arepsilon_B^\delta$	$arepsilon_B^{total}$		
$\overline{\mathrm{WP}_{50}}$	0.98	0.51	0.50	0.70	0.050	0.035		
WP_{40}	0.98	0.41	0.40	0.70	0.012	0.008		

A sizeable efficiency in the range 5-10 keV was measured while more than 95% (99%) 55Fe 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

Even with shield, the rate is far beyond the threshold we want to reach (~10^4 cpy from ER)

Cam_noshield_BG

Cam_noshield_BG

Cam_noshield_BG

Cam_noshield_BG

Cam_noshield_BG

Cam_noshield_BG

Th232

Th232

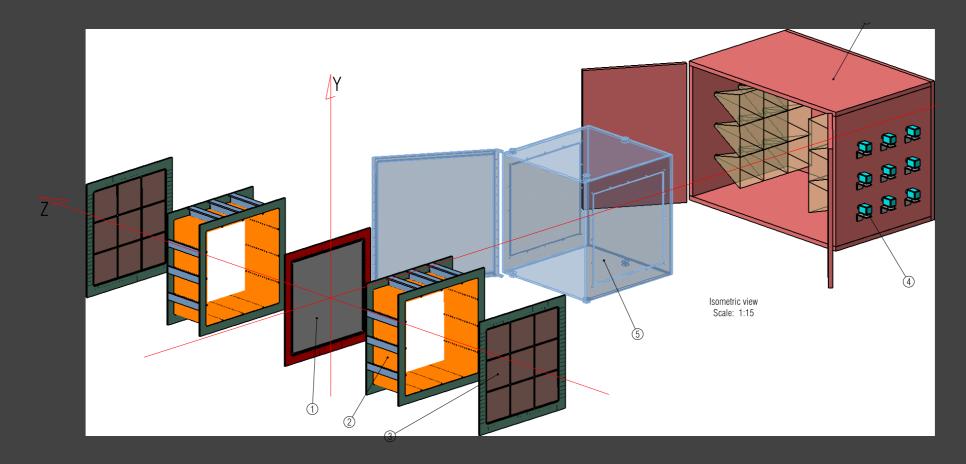
No shield: 2.05 x 10⁷ cpy

Shield: 6.60 x 10⁶ cpy

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

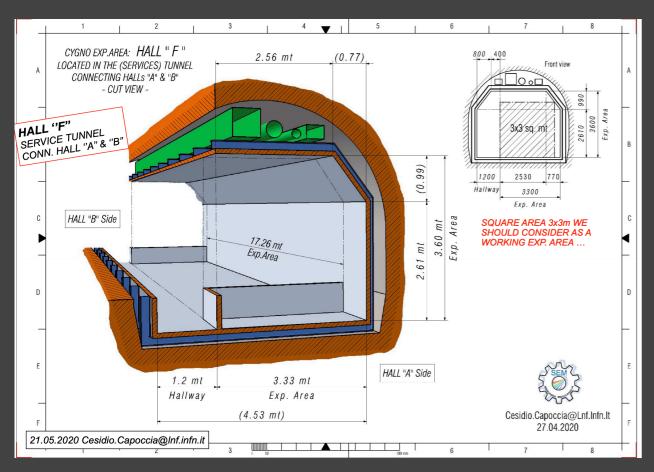


Each side equipped by a 3x3 matrix of LIME-like:

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

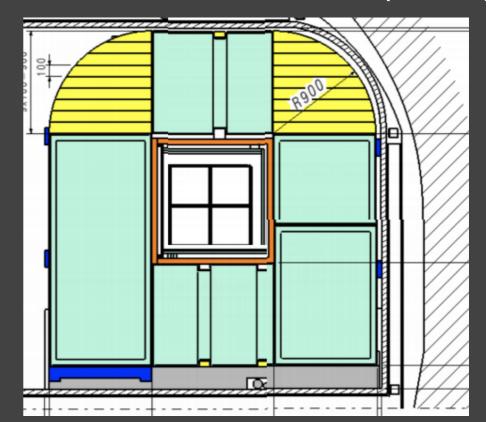
Shielding of 200 cm water and 5 cm copper giving a bkg cpy [1-20] keV of few 10²;

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 m² (I=17 m)

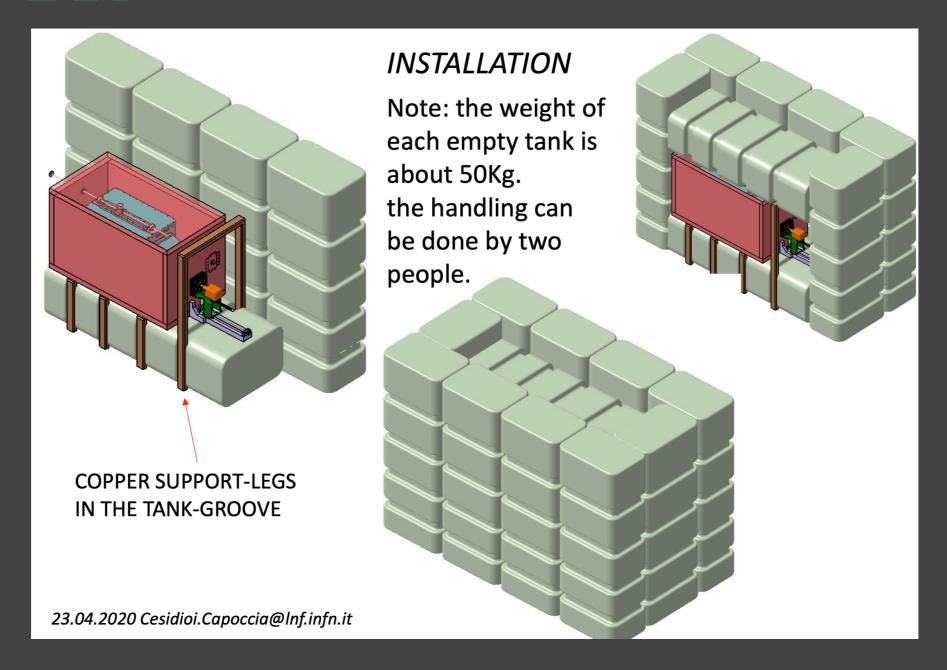


It will be possible to house 0.4 m³ - CYGNO with a 110/10 (water/Cu) shielding scheme;

Background rate of **2x10**4 cpy, will be lower than internal bkg (currently **5x10**5 cpy) and will allow to study it;

With a rejection of 10²-10³ 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

-										
		MC	OLD-TOOLING	DRAW-DOCUM			T. MOULDING	N.TANK	TOTAL	
	VERZELLESI SRL	R	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
0.85	Diff (%)	267%		250%		111%		244%		244%

We are investigating the possibility of building custom tanks

BACKGROUND- OPEN POINTS

¹⁴C contamination in gas can give important bkg. Need to know the origin of C in CF₄.

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;

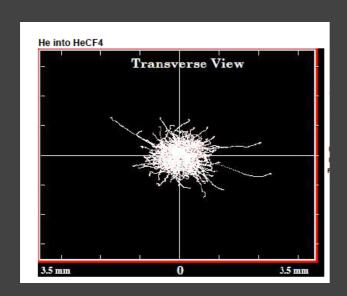
Need to purify and monitor gas mixture.

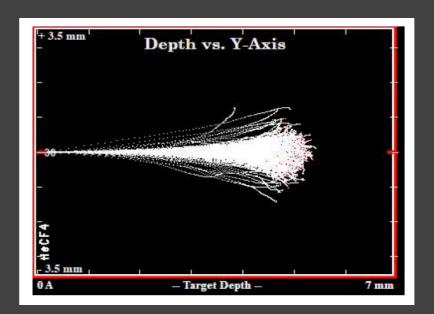
Some study already started about radioactive source to be used. Any advice?

SIGNAL SIMULATION

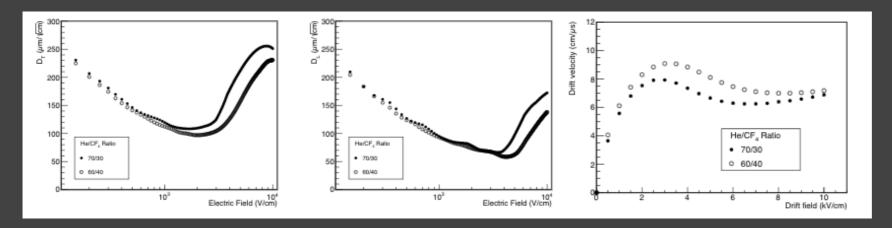
Interactions of recoils in gas simulated: GEANT

for electrons and SRIM for nuclei;





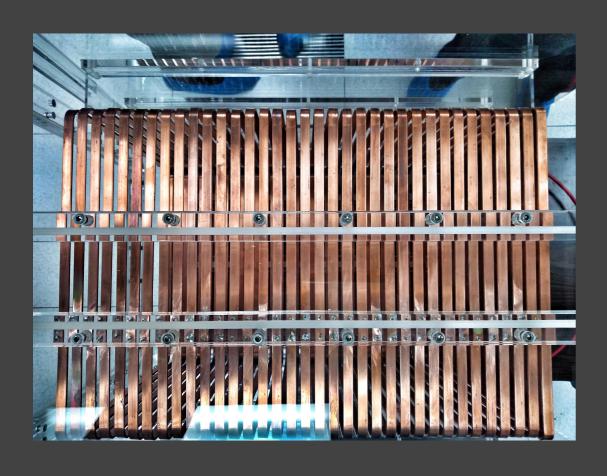
Gas parameters (ionization, diffusion, drift velocity, attachment) simulated with GARFIELD;

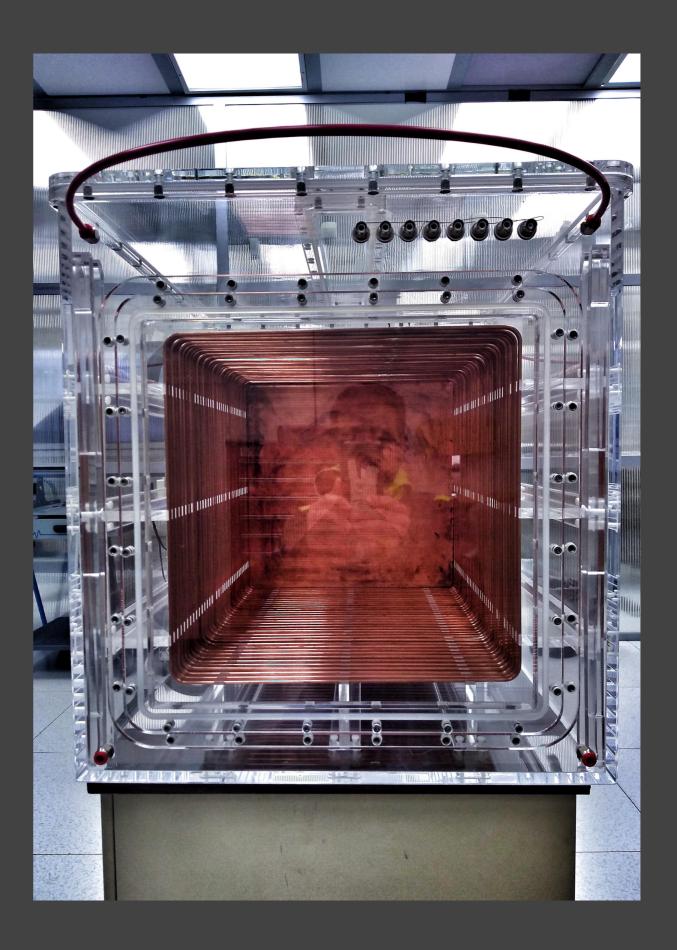


Response and noise behavior of PMT and CMOS simulation on-going

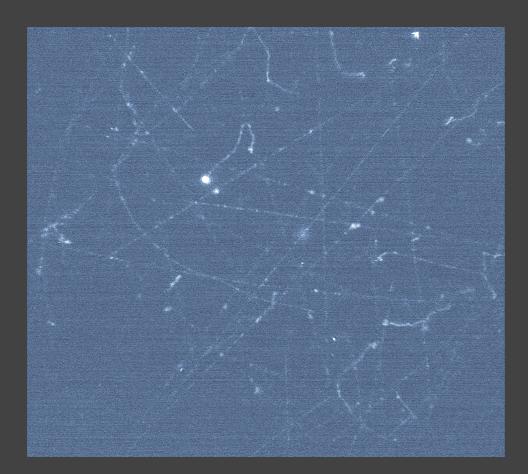
LIME

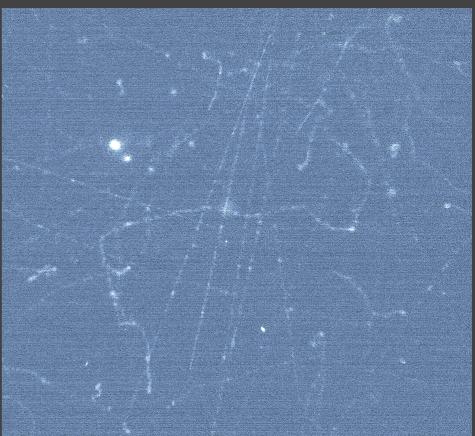
50 litre sensitive volume

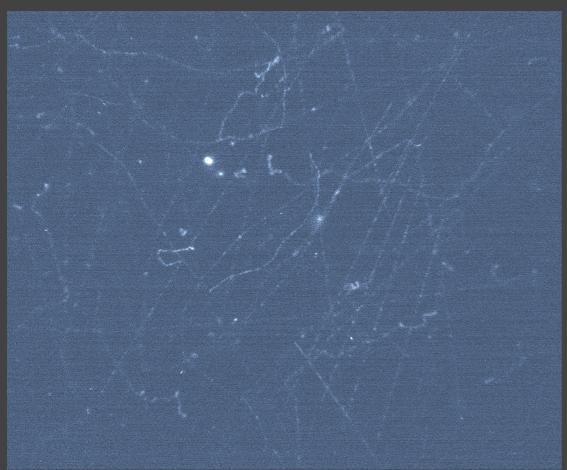


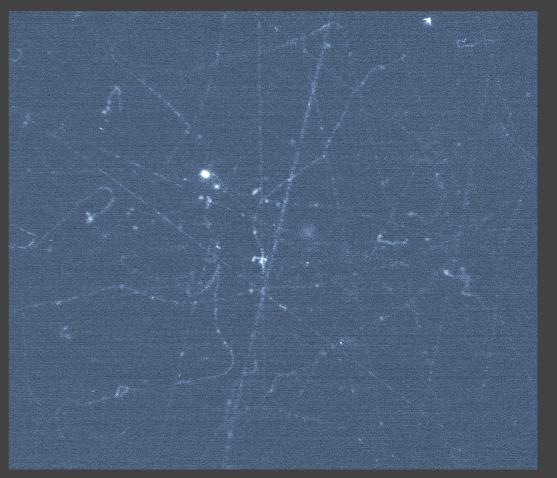


LIME







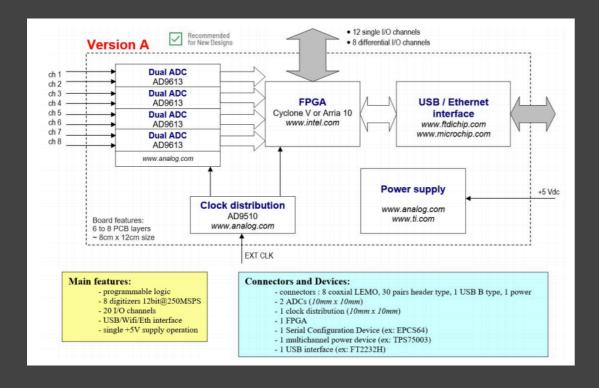


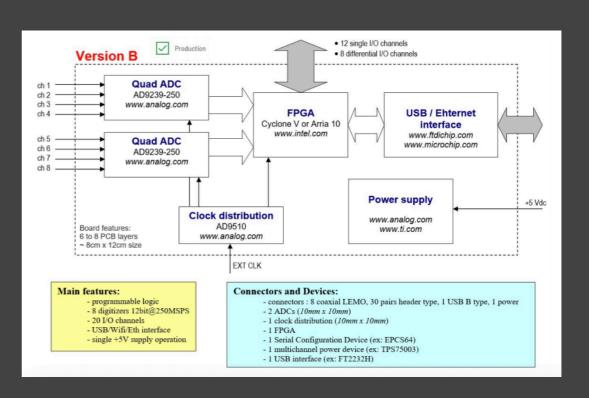
DAQ

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;

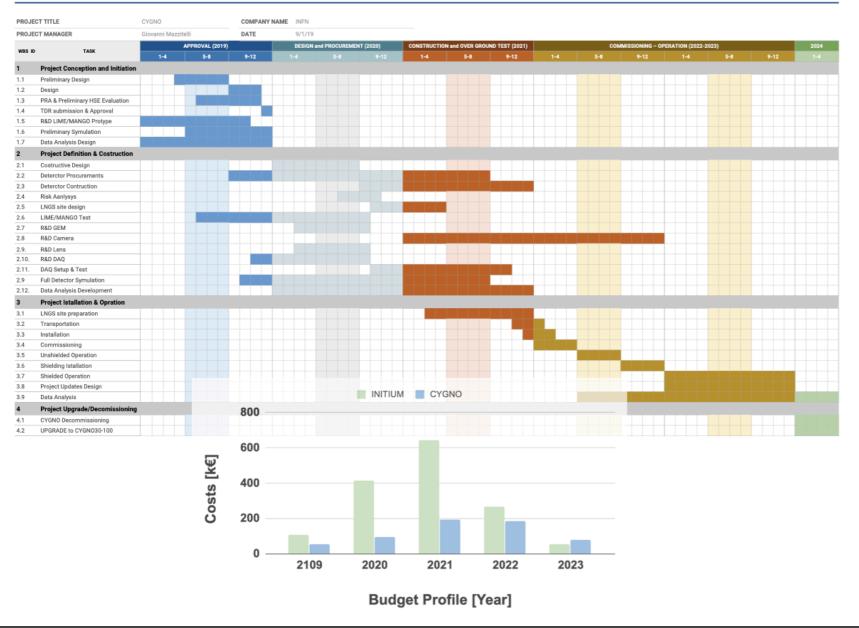
Brazilian group is working on this.

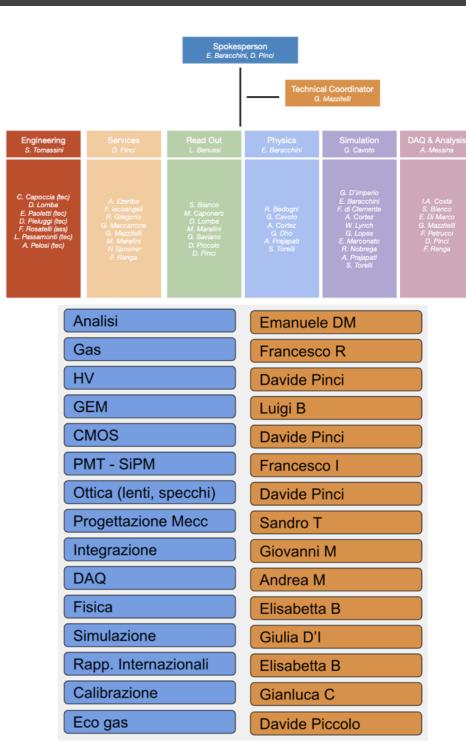




CYGNO Schedule

GANTT





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

2020 PAPERS

Two papers submitted

A GEM-based Optically Readout Time Projection Chamber for charged

Large Time Projection Chambers (IPC) have various applications in high energy physics and nuclear physics. These detectors are among the best in offering good charged particle energy resolution and to allow the identification of the particles' mass. This cut no elicitation of the particles' mass. This cut no elicitation of the particles' mass. This cut no elicitation of the particles' mass. This cut not such as technology for ultra-rare cents searches as the directional search of Dark Matter¹⁻¹ (DM) and the detection of metrics coming from the Sun (SNS) is currently of the CYGNUS international network.

CYGNUS' international network.

A longer term project for tess of my "olume TPC" requires the construction of 1 m" demonstrators. In this pager we describe the performance of a smaller? Times appear we describe the performance of a smaller of times.

In INTRODUCTION

The purpose of the current R&D place is to asses the performance of an Electron SIMCD in Standard on their off of the cuterton SIMCD in Standard on the order of the cuterton SIMCD in Standard on the order of the cuterton SIMCD in Standard on the order of the cuterton SIMCD in Standard on the order of the cuterton SIMCD in Standard on the order of the cuterton SIMCD in Standard on the order of the cuterton SIMCD in Standard on the SIMCD in S

First evidence of luminescence in a He/CF₄ gas mixture induced by non-ionizing electrons

E. Baracchini, 1,2 L. Benussi, 3 S. Bianco, 3 C. Capoccia, 3 M. Caponero, 3,4 G. Cavoto, 5,6 A. Cortez, 1,2 I. A. Costa,5 E. Di Marco,5 G. D'Imperio,5 G. Dho,1,2 F. Iacoangeli,5 G. Maccarrone,3 M. Marafini. 5.7 G. Mazzitelli. 3 A. Messina. 5.6 A. Orlandi. 3 E. Paoletti. 3 L. Passamonti. 3 F. ucci, ^{8,9} D. Piccolo, ³ D. Pierluigi, ³ D. Pinci, ⁵ F. Renga, ⁵ F. Rosatelli, ³ A. Russo, ³ G. Saviano,3,10 and S. Tomassini

"Gran Sasso Science Institute,
L'Aquila, 1-67100, Italy
L'Aquila, 1-67100, Italy
Filituto Nazionale di Fisica Nucleure,
Laboratori Nazionali del Gran Sasso, Assergi, Italy
Filituto Nazionali del Gran Sasso, Assergi, Italy
Filituto Nazionali di Fisica Nucleure
Laboratori Nazionali di Fisica Nucleure
Filituto Nazionale di Fisica Nucleure

Sezione di Roma, I-00185, Italy

Dipartimento di Fisica Sapienza Università di Roma. I-00185. Ital Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi"

Musco Storco deita Fisto a Centro Suña e Ricerche Entroco Ferm.;

Plazza del Viminel I. Roma, I-Old Sk. Italy

**Dpartimento di Matematica e Fisica, Università Roma TRE, Roma, Italy

**Station Nazionale di Fisica Nucleare, Secional Roma TRE, Roma, Italy

**Dipartimento di Ingegneria Chimica, Materiali e Ambiente, Sapienza Università di Roma, Roma, Italy

**Opartimento di Ingegneria Chimica, Materiali e Ambiente, Sapienza Università di Roma, Roma, Italy

Optical readout of Gas Electron Multipliers (GEM) provides very interesting performan and has been proposed for different applications in particle physics. In particular, thanks to its good efficiency in the keV energy range, it is being developed for low-energy and rare event studies, such as Dark Matter search. So far, the optical approach exploits the light produced during the avalanche processes in GFM channels

processes in GEM channels. Further luminescence in the gas can be induced by electrons accelerated by a suitable electric field. The CYGNO collaboration studied this process with a combined use of a triple-GEM structure and a grid in an He/CF $_4$ (60/40) gas mixture at atmospheric pressure. Results reported in this paper allow to conclude that with an electric field of about 11 kV/cm a photon production mean free path of about 1.0 cm was found.

Three papers under internal review

A density-based clustering algorithm for the CYGNO data analysis

E. Baracchini, a,b L. Benussi, c S. Bianco, c C. Capoccia, c M. Caponero, c,d G. Cavoto, c,f A. Maccarone, 'M. Marrain', 'A. C. D'Imperio,' G. Dho,' "F. Iacoangeli,' G. Maccarone, 'M. Marrain', 'A. G. Mazzitelli,' A. Messina, "f. R. A. Nobrega," A. Orlandi, 'E. Paleutti, 'L. Passamonti, 'F. Petrucci, 'd. D. Piccolo, 'D. Piertuigi,' D. Pinci' F. Renga,' F. Rosatelli,' A. Russo,' G. Saviano, 'd and S. Tomassini'

^aGran Sasso Science Institute, L'Aquila, 1-67100, Italy ^bIstituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Gran Sasso, Assergi, Italy

Istituto Nazionale di Fisica Nucleare , Laboratori Nazionali di Frascati, I-00044, Italy dENEA Centro Ricerche Frascati, Frascati, Italy

Istituto Nazionale di Fisica Nucleare, Sezione di Roma, I-00185, Italy

f Dipartimento di Fisica Sapienza Università di Roma, ⁸ Universidade Federal de Juiz de Fora, Juiz de Fora, I

Istituto Nazionale di Fisica Nucleare, Sezione di Rom k Dipartimento di Ingegneria Chimica, Materiali e Am

ABSTRACT: Time Projection Chambers (TPCs) wor photons generated during the GEM electron multiphoto camera. The CYGNO Experiment has rec plod to a low noise and high spatial resolution CMf based on an adapted version of the well-known DBS tion of the CYGNO's DBSCAN-based algorithm w arameters, and a comparison with a widely used a (NNC). The results will show that the adapted vers al detection efficiency and very good energy reso

Stability and detection performance of a GEM-based Optical Readout TPC with He/CF₄ based gas mixtures

E. Baracchini, a,b L. Benussi, c S. Bianco, c C. Capoccia, c M. Caponero, c,d G. Cavoto, e,f A. Cortez, ^{n,b} I. A. Costa, ^c E. Di Marco, ^c G. D'Imperio, ^c G. Do, ^{n,b} F. Iacoangeli, ^c G. Maccarrone, ^c M. Marzifini, ^{ch} G. Mazzifeli, ^{ch} A. Messina, ^{ch} R. A. Nobrega, ^c A. Orlandi, ^c E. Paoletti, ^c L. Passamonti, ^{ch} F. Petruci, ^{ch} D. Pierluigi, ^c D. Pierluigi, ^{ch} D. Pierluigi, ^{ch} F. Renga, ^c F. Rossalelli, ^{ch} A. Russo, ^{ch} G. Saviano, ^{ch} and S. Tomassini ^{ch}

L'Aquila, I-67100, Ital

. Identification of nuclear recoils in a gas TPC with optical readout

6 The advent of a market of high position resolution and single photon light sensors can 7 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 kev issues to understand our Universe aggiungere reference generica su DM Different models predicts the existence of neutral 11 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 $_{\rm 14}$ the Milky Way towards the Cygnus constellation such nuclear recoils would exhibit a s 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 17 (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 20 shape can be located in space adopting a cluster recognition algorithm. Neutron and $_{21}$ γ radiation emitted by radioactive sources are used to set in motion atomic electrons 22 and nuclei respectively in the gas volume. Moreover, natural radiation as cosmic rays 23 is leaving a trail of ionization in the gas. They are all producing different patterns of 24 light emission from the GEMs that can be reconstructed and analyzed. Nuclear recoils 25 can then be efficiently identified down to a few keV kinetic energy. The study of the

26 optical readout of TPC has been recently conducted with several small size prototypes 27 (NITEC [1], ORANGE [2,3], LEMON [4-6]) with various particle sources, in the context 28 of the CYGNO project. In the following, we report the study of nuclear recoils excited by

29 neutron from an AmBe source and electron recoils from a 55Fe source in the gas volume

na, I-00185, Italy

Roma TRE, Roma, Italy Roma TRE, Roma, Italy Ambiente, Sapienza Università di Roma, Roma, Italy

1 in two different proportions (60/40 and 70/30) in me. With electrical configurations providing very efficiency in the whole detector volume was found 0% larger for the 60/40 was found. The electrostatic currents for 25 days. The detector worked in very Anyway, in the presence of less CF4, a larger

The CYGNO Experiment

E. Baracchini, ^{a,b}, R. Bedogni, ^c, F. Bellini, ^{a,i}, L. Benussi, ^c, S. Bianco, ^c, C. Capoccia, ^c, M. Caponero, ^{c,d}, G. Cavoto, ^{c,i}, A. Cortez, ^{a,b}, I. A. Costa, ^a, E. Di Marco, ^c, G. D'Imperio, ^c, G. Dho, ^{b,b}, F. Jacoungeli, ^c, G. Maccarrone, ^{c,i}, M. Marafini, ^{c,i,b}, G. Mazzitelli, ^{c,i,b}, A. Messina, ^{c,i,b}, A. Nobregna, ^{a,i,b}, O'Inadis, ^{c,i,b}, Passamonti, ^{c,i,b}, P. Petrucci, ^{i,j}, D. Piccolo, ^{c,i,b}, D. Pincie, ^{a,i,b}, F. Renga, ^e, F. Rossatelli, ^{c,i,b}, R. Russo, ^{e,i,b}, G. Saviano, ^{c,i,b}, and S. Tomassini^e

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 keV energy range together with a very good particle identification useful to dis-

Preprint submitted to Journal of LATEX Templates

CYGNO paper in preparation. Who wants to contribute and sign?