

CYGNO/INITIUM - Annual Report

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CYGNO collaboration: INFN (LNF, RM1, RM3),
La Sapienza Dip di Fisica and Dip di Ing. Chimica,
Università di Roma Tre, GSSI, Centro Fermi
University of Sheffield (GB), University of Coimbra (PT)
and University of UFJF and CBPF (BR)

The CYGNO experiment ¹⁾ is validating the Montecarlo simulation with a set of scientific runs collected with LIME prototype installed at LNGS. The schedule for 2023 was to acquire data in different background/shielding configurations (no shielding, 4cm of Cu, 10cm of Cu, 10cm + 50cm of water), to start the design of the final detector, CYGNO04, and the executive design/procurement of infrastructure to host the experiment in 2025 at the Hall F of LNGS. Moreover, Frascati is in charge of the R&D tests on a prototype for CYGNO04 and of the computing infrastructure. Since October 2023 Frascati is also in charge of the Analysis and Reconstruction of the experiment.

In the following a brief report of tasks under the responsibility of LNF in the CYGNO collaboration developed in 2023.

1 Design, construction and test of R&D prototypes and CYGNO04 detector

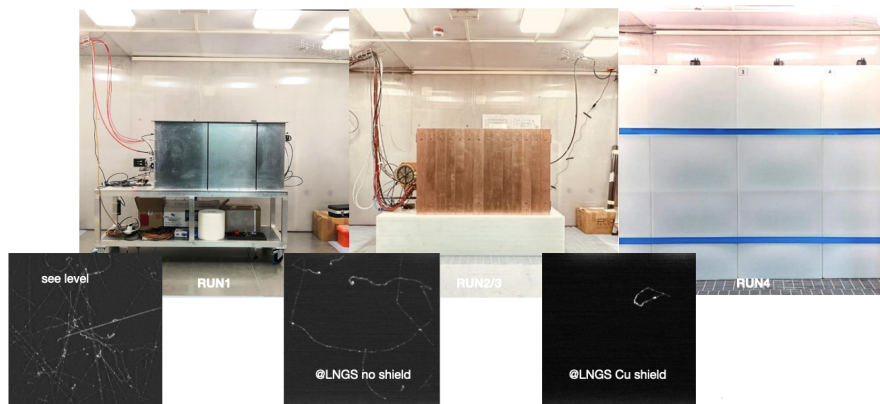


Figure 1: From left to right: LIME within the mere Faraday cage, copper shielding, water shielding and the background observed attenuation in the camera acquired pictures;

The LNF group is in charge of the design, installation and test of all the prototypes/detector of the CYGNO project. During 2023 this has included the tests with the GIN prototype, devoted

to test electro-mechanics components for CYGNO04 detectors, and the installation of shielding (fig. 1) for LIME detector at the LNGS, aimed to validate Montecarlo simulation and long term detector performances.

This directly implies that all the LNGS infrastructure facility needed has to be taken care of: electronics and control room equipment, gas systems, auxiliary sensors, cooling, purification filters, etc ^{9, 10}).

In the meantime, LNF are hosting at building 28/48 by means of the GIN prototype, the development and tests of trigger and DAQ, readout electronics, gas mixture characterization, etc. In particular LNF are responsible of the developing, assembling and testing of the low radioactivity large GEM (800*500 mm) needed for CYGNO04 and of the validation of the low radioactive filed cage made of flexible PCB and cathode of the CYGNO TPC.

Moreover, a strong effort has been put in the design of the of CYGNO04 detector, that required a redaction of a Technical Design Report (TDR) ¹¹) submitted to LNGS SCICOM and CSN2 committee for final space allocation, economical sustainability and scientific validation. The TDR was approved in September 2022 and the installation and commissioning of the CYGNO04 detector is foreseen in 2025 in the Hall F at the LNGS. The TDR required the design of the new service infrastructure in Hall F, today an empty small gallery with only concrete floor, and to study safety and environmental interference for the CYGNO04 installation. Thus, it has required a Preliminary Risk and Environmental Evaluation (PRA/PEA) and a VINCA followed by the approval of Regione Abuzzo, arrived in fall 2023. The executive design of the technical room, hosting electronics, computing and auxiliary system and of the control room has been realized and the tender started in December 2023.

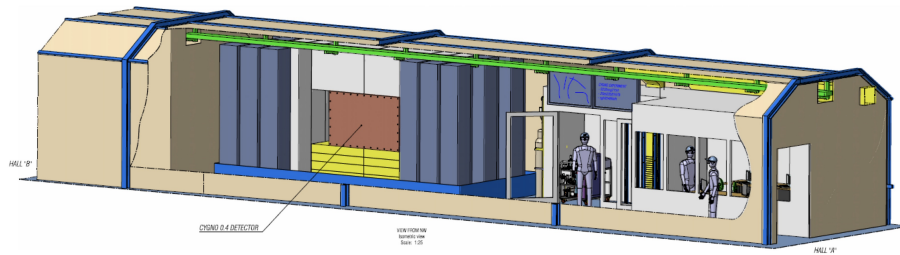


Figure 2: *design of CYGNO04 in Hall F at LNGS*

In parallel, the Frascati group is also in charge of the support (design and technical implementation) of the tests performed overground at LNGS (at the Hall di Montaggio - HdM), where the optical readout technique has been applied, in the framework of the INITIUM ERC, to gas mixtures which included small amount of SF6 to exploit negative ion drift operation which lead to interesting and promising results.

Regular weekly meeting are organized every Monday at 9.00 am. Reports and useful documentation at link: <https://github.com/CYGNUS-RD/WIKI-documentation/wiki/Integration>

2 Data Analysis

Since October 2023 the LNF are in charge of data analysis coordination of the CYGNO experiment. The organization of the principal and long term goals of the collaboration have been thought upon and divided among the man-power available in the different CYGNO groups. Tasks span from the analysis of the underground data of the LIME prototype, to machine learning techniques applied to signal-background discrimination, to studies on the stability of the detector and more others. Weekly meetings are organized every Thursday.

Together with the analysis coordination, the LNF are in charge of the maintenance and development of the main reconstruction algorithm used to analyse the raw data of the experiment. Continuous checks on performance, bug fixes and performance improvements have been undertaken with the goal of restructuring and improving the algorithm to match the large data output of the CYGNO04 future detector.

3 Design and development of the computing infrastructure

The LNF are responsible to design and implement the experiment computing model and infrastructure.

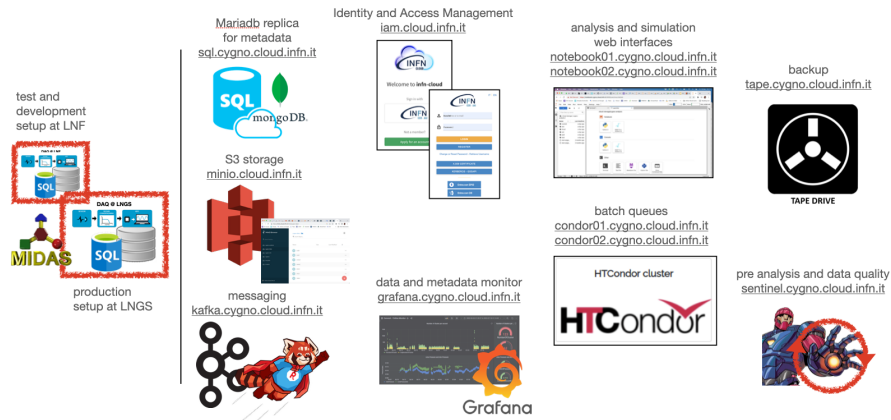


Figure 3: *Services part of the CYGNO Computing model, developed in the INFN cloud infrastructure.*

The computing model (CM) for CYGNO, which is the benchmark and beta-tester for all small/medium experiments in the astroparticle physics community supported by the PNRR Spoke2, has been defined. The software architecture has been designed and is hosted on the INFN cloud infrastructure. The INFN cloud is providing the Virtual Machines (VM) where services, by means of a set of docker containers, are developed and operating. The CM design foresees a set of services for data streaming, data management, data visualization, data analysis and simulation.

In order to achieve this objectives, DAQ, by means of MIDAS environments, is providing the following services under test and characterization:

- an identity management interface, based on the INFN one, providing the correct access to

the services;

- SQL/noSQL db for data (slow control) and metadata historization;
- a kafka server for data online streaming, and pre-analysis;
- a grafana server for data and metadata visualization and remote monitoring;
- jupyterlab servers for data analysis and simulation interfaced with the experiment along with HTCondor queues
- a HTCondor on demand, deployed on kubernetes clusters, running a worker node with the optimized docker image for the experiment.
- online data reconstruction and pre-analysis services producing DST and metadata to monitor data quality and detector performance.
- a data management services ensuring data replication and archiving on tape

The CYGNO Computing Model was presented in May at CHEP23. The proceedings are under publication.

and more...

The Frascati group also hosted in 2023 a student for 8 month, a DOE fellow, one fellow CSN2-INFN and three students of the La Sapienza Phys Lab II course.

Group organization, codes developed, computing infrastructure details, documentation, cads etc are available at the link:

<https://github.com/CYGNUS-RD/WIKI-documentation/wiki/Integration>

4 List of Conference Talks by LNF Authors in Year 2023

1. G. Mazzitelli et al. Data handling of CYGNO experiment using INFN-Cloud solution, under publication in proceedings of CHEP23, 8-12 May 2023, Norfolk, VA, US.
2. G. Mazzitelli - Channeling Primer - Open Issues in Astroparticle Experimental Physics, 9th International Conference "Charged & Neutral Particles Channeling Phenomena", 4-9 Jun 2023, Riccione, IT.
3. G. Mazzitelli - Dark matter and neutrino study with CYGNO: Computing model and data handling, SOSC 2023 Fifth International School on Open Science Cloud, 23-27 Oct 2023, INFN Perugia, IT
4. G. Mazzitelli - Towards CYGNO04, 8th CYGNUS Workshop on Directional Recoil Detection, 11-15 Dec 2023 School of Physics, Sidney, AU
5. G. Dho - Diving into the neutrino fog with optical TPC, at 11th Symposium on Large TPCs for low-energy rare event detection, Paris, France, 11 - 13 December 2023

List of Publications signed by LNF Authors in Year 2023

1. F. D. Amaro, E. Baracchini, L. Benussi, S. Bianco, C. Capocchia, M. Caponero, D. S. Cardoso, G. Cavoto, A. Cortez and I. A. Costa, *et al.* “The CYGNO Experiment,” *Instruments* **6** (2022) no.1, 6 doi:10.3390/instruments6010006 [arXiv:2202.05480 [physics.ins-det]].
2. A. Messina *et al.* [CYGNO], “The CYGNO project for directional Dark Matter searches,” *PoS TAUP2023* (2024), 020 doi:10.22323/1.441.0020
3. F. D. Amaro *et al.* [CYGNO], “The CYGNO experiment: a directional Dark Matter detector with optical readout,” *JINST* **18** (2023) no.09, C09010 doi:10.1088/1748-0221/18/09/C09010
4. B. D. Almeida, F. D. Amaro, R. Antonietti, E. Baracchini, L. Benussi, S. Bianco, F. Borra, C. Capocchia, M. Caponero and D. S. Cardoso, *et al.* “Noise assessment of CMOS active pixel sensors for the CYGNO Experiment,” *Measur. Sci. Tech.* **34** (2023) no.12, 125145 doi:10.1088/1361-6501/acf7e1
5. F. D. Amaro, R. Antonietti, E. Baracchini, L. Benussi, S. Bianco, F. Borra, C. Capocchia, M. Caponero, D. S. Cardoso and G. Cavoto, *et al.* “Directional iDBSCAN to detect cosmic-ray tracks for the CYGNO experiment,” *Measur. Sci. Tech.* **34** (2023) no.12, 125024 doi:10.1088/1361-6501/acf402
6. F. D. Amaro, E. Baracchini, L. Benussi, S. Bianco, C. Capocchia, M. Caponero, D. S. Cardoso, G. Cavoto, A. Cortez and I. A. Costa, *et al.* “The CYGNO/INITIUM experiment,” *SciPost Phys. Proc.* **12** (2023), 019 doi:10.21468/SciPostPhysProc.12.019
7. F. D. Amaro, E. Baracchini, L. Benussi, S. Bianco, C. Capocchia, M. Caponero, D. S. Cardoso, G. Cavoto, A. Cortez and I. A. Costa, *et al.* “The CYGNO experiment, a directional detector for direct Dark Matter searches,” *Nucl. Instrum. Meth. A* **1054** (2023), 168325 doi:10.1016/j.nima.2023.168325 [arXiv:2306.04568 [physics.ins-det]].
8. F. D. Amaro *et al.* [CYGNO], “A 50 l Cygno prototype overground characterization,” *Eur. Phys. J. C* **83** (2023) no.10, 946 doi:10.1140/epjc/s10052-023-11988-9 [arXiv:2305.06168 [hep-ex]].
9. F. D. Amaro, E. Baracchini, L. Benussi, S. Bianco, C. Capocchia, M. Caponero, D. S. Cardoso, G. Cavoto, A. Cortez and I. A. Costa, *et al.* “LIME — A gas TPC prototype for directional Dark Matter search for the CYGNO experiment,” *Nucl. Instrum. Meth. A* **1051** (2023), 168207 doi:10.1016/j.nima.2023.168207 [arXiv:2306.16856 [physics.ins-det]].
10. G. Mazzitelli, F. A. Domingues, E. Baracchini, L. Benussi, S. Bianco, C. Capocchia, M. Caponero, D. S. Cardoso, G. Cavoto and A. Cortez, *et al.* “50 litres TPC with sCMOS-based optical readout for the CYGNO project,” *Nucl. Instrum. Meth. A* **1045** (2023), 167584 doi:10.1016/j.nima.2022.167584
11. G. Mazzitelli et al, Technical Design Report - TDR CYGNO-04/INITIUM (2022) Technical note - INFN-23-06-LNF doi:10.15161/oar.it/76967