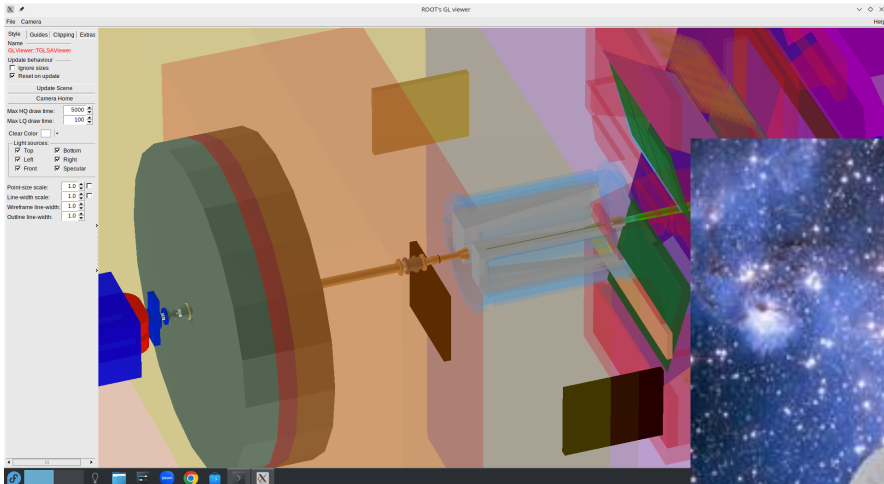
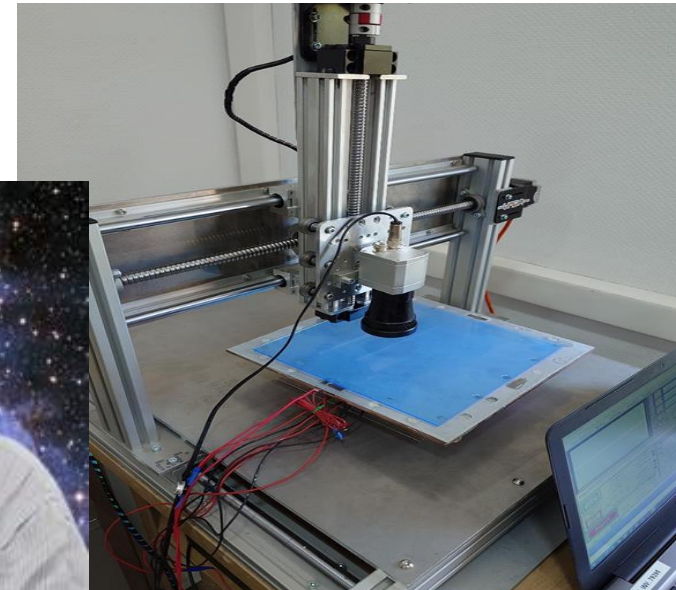
RoMOEDAL status report

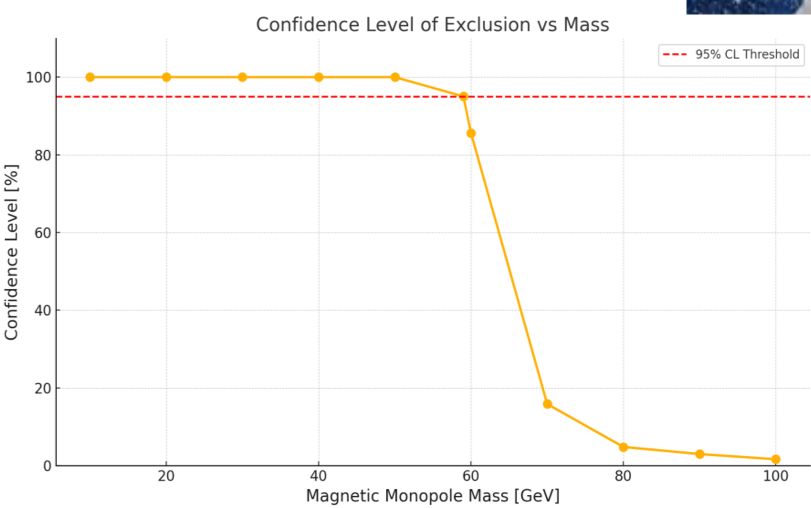
Daniel Felea, for the RoMOEDAL team



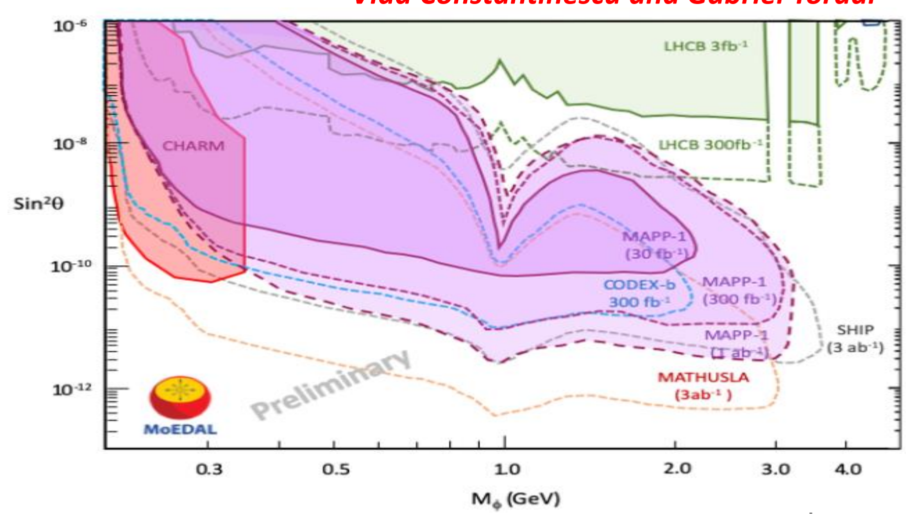
Picture by ***Daniel Felea***



Vlad Constantinescu and Gabriel Tordai



Picture by ***Horea Branzaş***



Picture by ***Lucia Popa***

ISAB – CERN-RO meeting, November 28, 2025

Monopole and Exotics Detection at LHC

MoEDAL

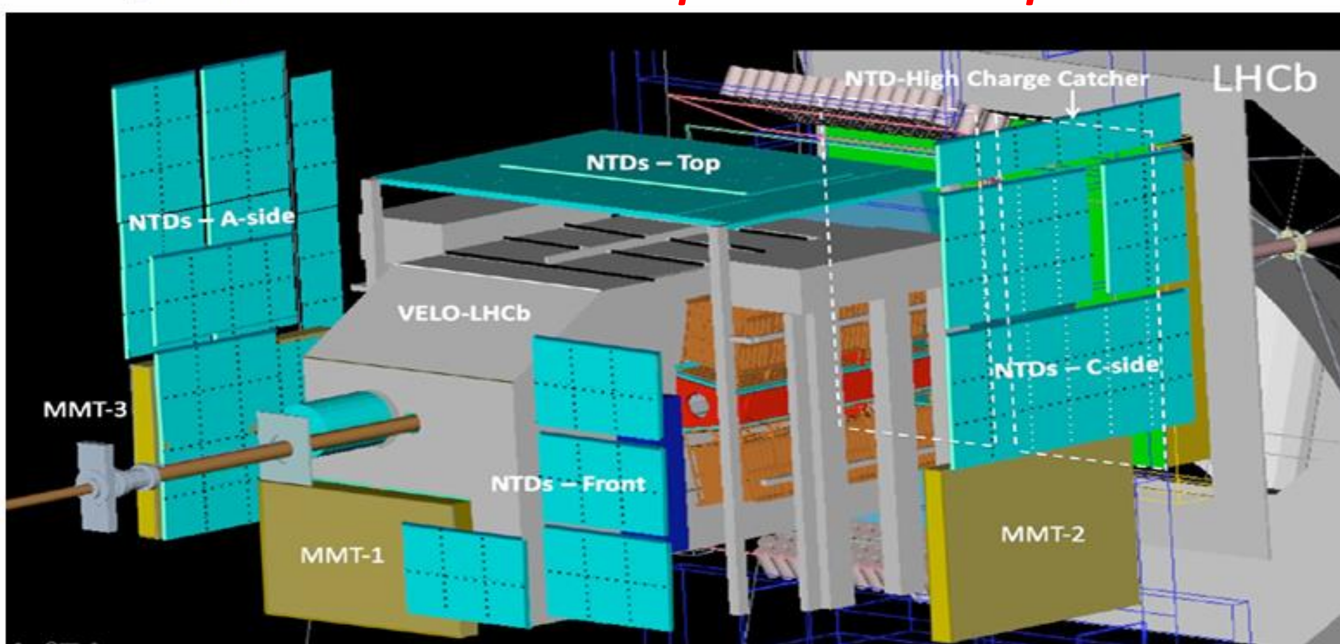
MoEDAL

MoEDAL shares intersection point 8 on the LHC ring with LHCb

1) The main NTD array (low and high threshold, Z/β: CR39 and MAKROFOL)
2) The Very High Charge Catcher NTD array
3) The Monopole Trapping Detector (scanned at the ETH Zurich SQUID)
4) The TimePix radiation background monitor

$$g/e \approx 68.5$$

Run 2 experimental setup



MoEDAL Apparatus for Penetrating Particles (MAPP)

MoEDAL

At the theoretical level, we assess the detectability of different Beyond Standard Model (BSM) scenarios with the MAPP-1 detector.

universe

MDPI

Lucia Aurelia Popa

Article

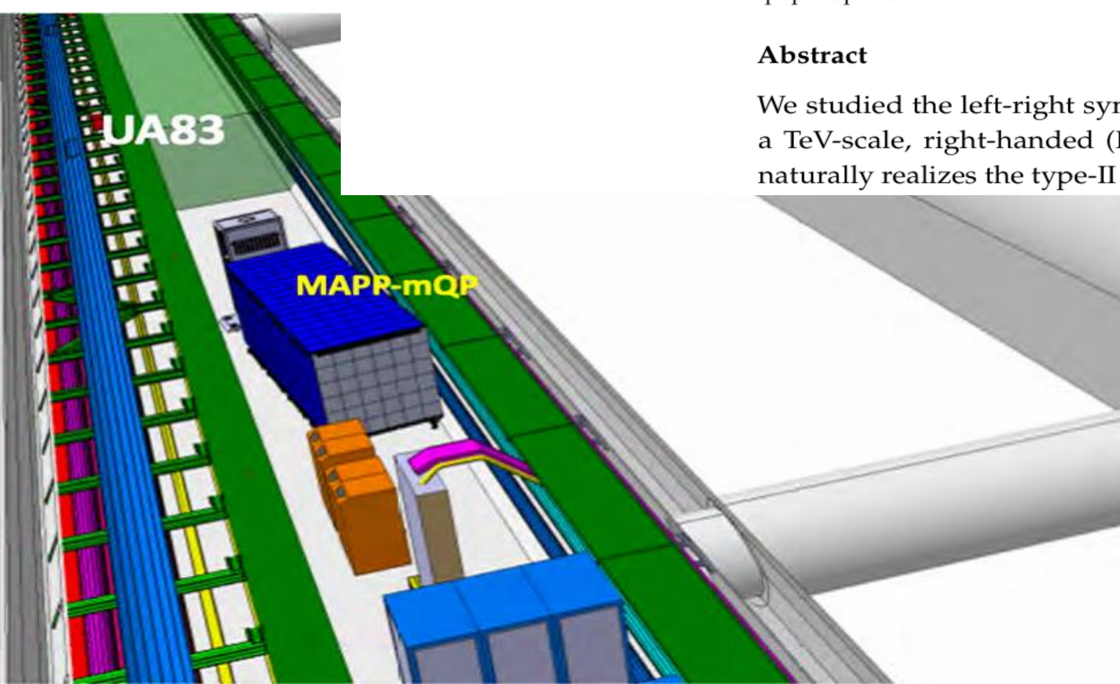
Gravitational Wave Signatures of Warm Dark Matter in the Gauge Extensions of the Standard Model

Lucia A. Popa

Institute of Space Sciences (ISS/INFLPR Subsidiary), Atomiştilor 409, RO-077125 Magurele, Ilfov, Romania; lpopa@spacescience.ro

Abstract

We studied the left-right symmetric extension of the standard model (LRSM), featuring a TeV-scale, right-handed (RH) gauge boson W_R and three RH neutrinos. This setup naturally realizes the type-II seesaw mechanism for active neutrino masses. We identified



Academic Editor: Kazuharu Bamba

Received: 28 August 2025

Revised: 6 October 2025

Accepted: 10 October 2025

Published: 15 October 2025

Citation: Popa, L.A. Gravitational Wave Signatures of Warm Dark Matter in the Gauge Extensions of the Standard Model. *Universe* **2025**, *11*, 343. https://doi.org/10.3390/universe11100343

MoEDAL Apparatus for Penetrating Particles (MAPP)

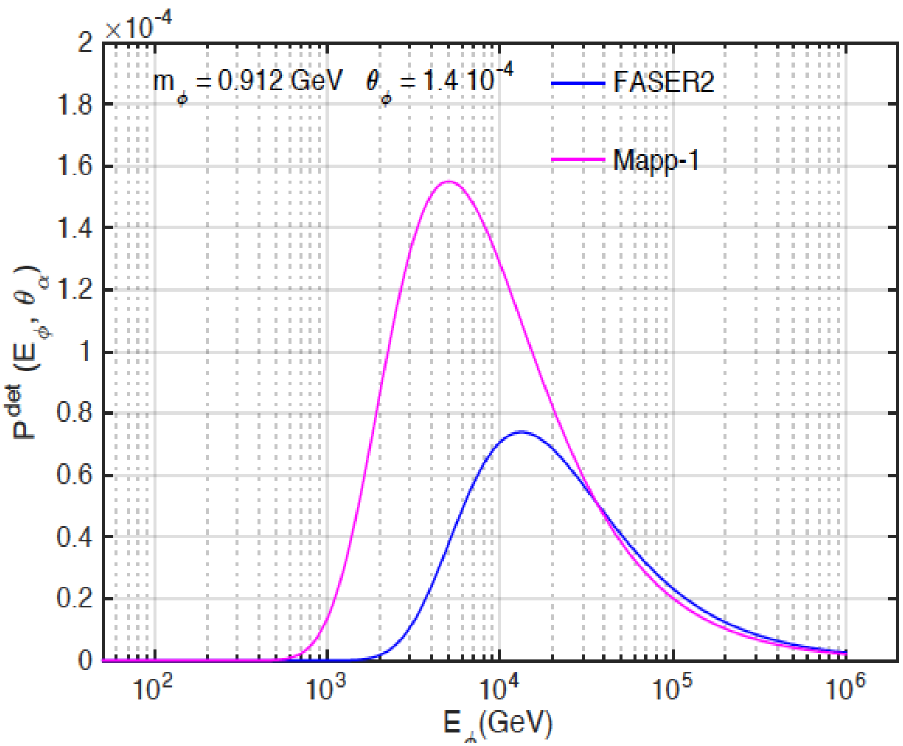
Lucia Aurelia Popa

Dark Higgs inflaton decay probability inside MAPP-1

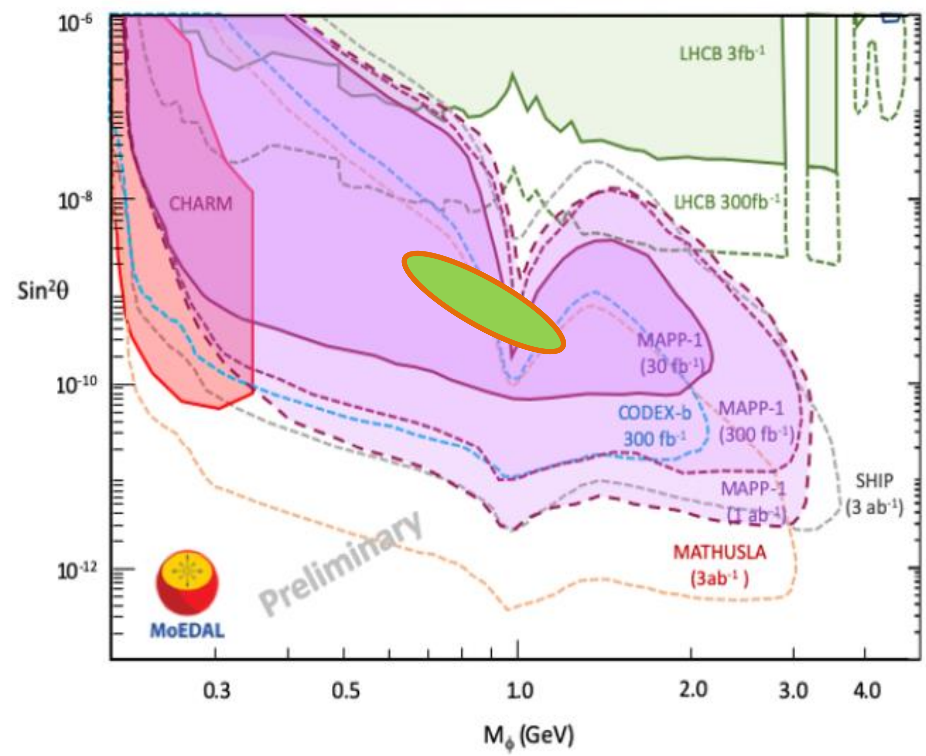
$$\mathcal{P}^{det}(E_\phi, \theta_\alpha) = \left(e^{-L_{min}/d} - e^{-L_{max}/d}\right)\Theta(R, \tan(\theta_\alpha)L_{max})$$

$\mathcal{L}_{min}$=100 m $\quad \Delta = 3m \quad H = 1m \qquad \tan(\theta_\alpha) = \frac{R}{\mathcal{L}_{min}+\Delta}$

R= $\frac{H}{\sqrt{\pi}}$



MAPP-1 reach for Dark Higgs inflaton



This example presents the resulting exclusion limits in the mass–mixing angle sensitivity plane for an inflationary model, in which the inflaton undergoes decay within MAPP-1.

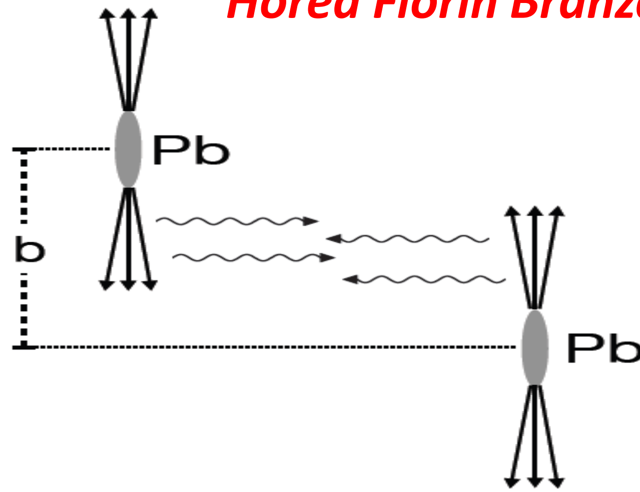
The calculation incorporates the full detector geometry as well as the inflaton decay probability and kinematic acceptance.

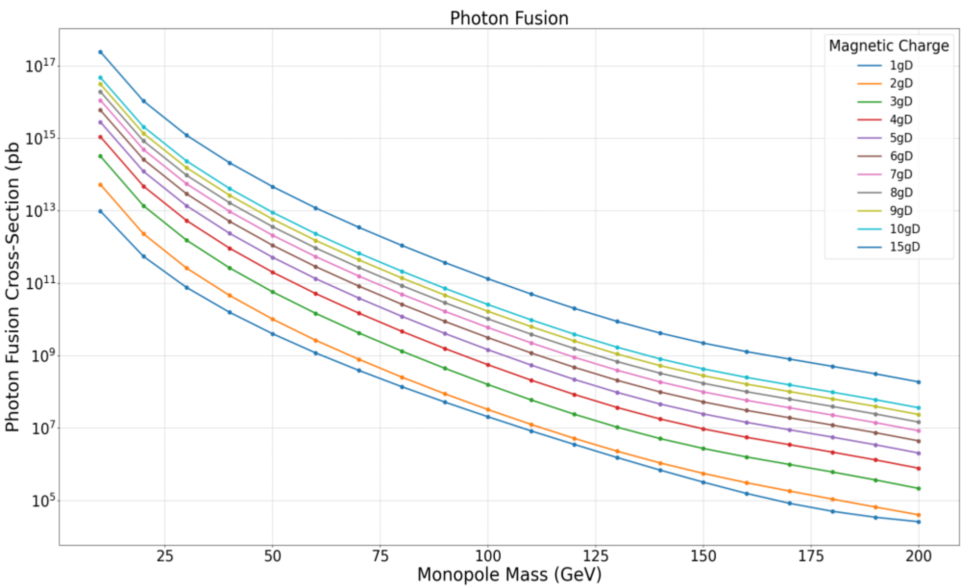
Gamma – Gamma UPC in MadGraph5

The code includes:

- *Photon number density via Weizsäcker-Williams EPA*
- *Full implementation of the Bessel Functions*
- *Integration of the impact parameter from b_{min} to b_{max}*

Horea Florin Brânzaş





- ***Strong electromagnetic fields from ultrarelativistic high-charge ions (e.g. Pb^{208})***
- ***Monopole pair production via photon fusion***
- ***$b_{min} = 2R$, where $R = 1.2 * A^{1/3} = 7.1$ Fm (radius of Pb^{208})***

$$f_\gamma(x) = \frac{Z^2 \alpha}{\pi} \frac{1}{x} [2x_i K_0(x_i) K_1(x_i) - x_i^2 (K_1^2(x_i) - K_0^2(x_i))]$$

The photon spectrum scales as Z^2, thus enhancing the cross section in heavy-ion collisions by Z^4 as compared to photon fusion in proton-proton collisions.

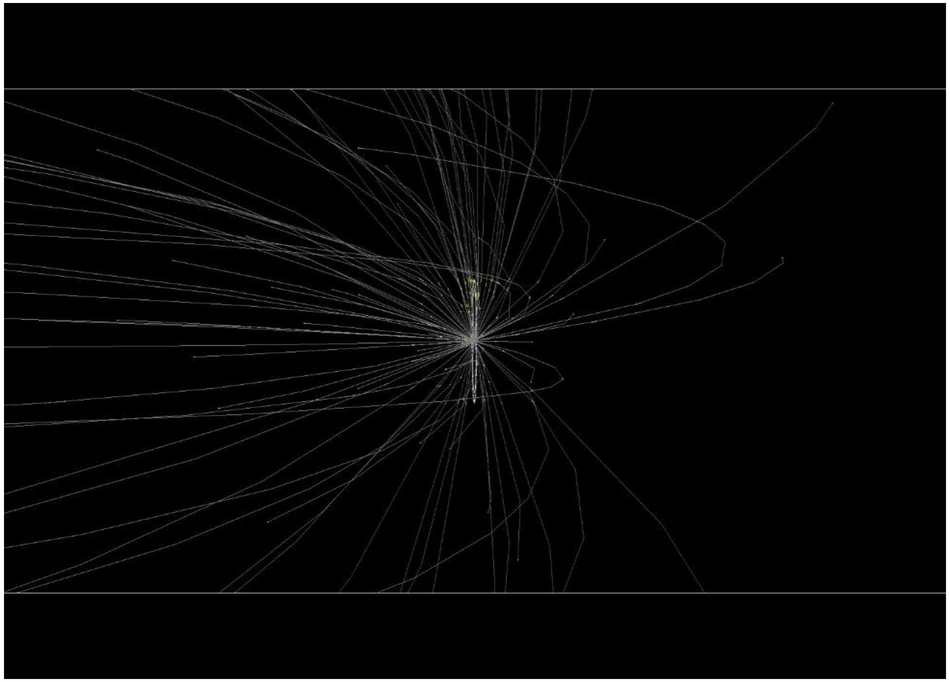
J. D. Jackson, Classical electrodynamics; 2^{nd} ed. (Wiley, New York, NY, 1975) p. 727.

TRAPPING CONDITIONS IN GEANT4

Horea Florin Brânzaş

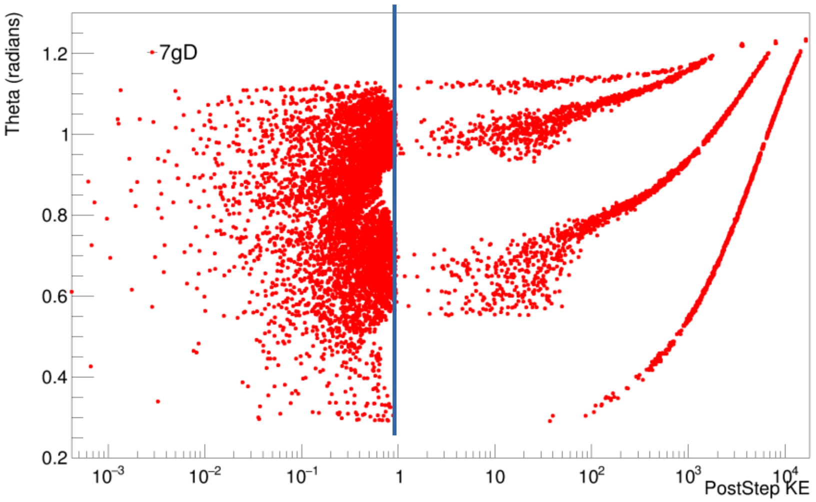
- Monopoles which are initially traveling in the opposite direction to the field, slow down and get turned towards the field direction, entering the beam-pipe material (Beryllium).

- In this instant of turning, the monopole's kinetic energy (in some cases) drops below the threshold energy required for capture by the atomic lattice.



Curved trajectory of the magnetic monopole due to the strong CMS field (3.8 T)

- *We are only interested in the post-step Kinetic Energy, that is of the order of or less than the threshold we set on the binding energy with Beryllium.*
- *We can ignore the values of the turning Kinetic Energy of magnetic monopoles higher than the binding energy threshold in Beryllium (1 MeV).*



RESULTS – PREPARING FOR SUBMISSION

Horea Florin Brânzaş

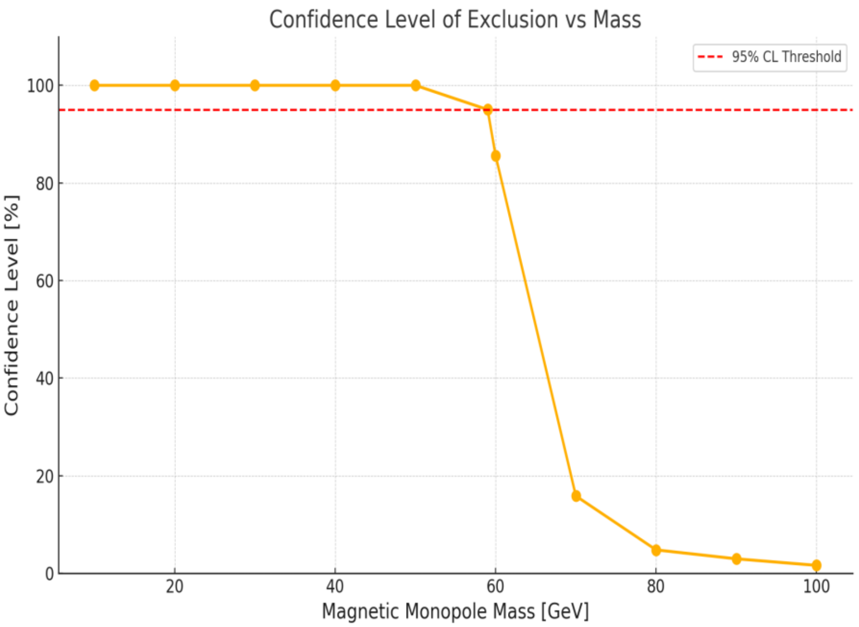
$$BP\ trapping\ efficiency = \frac{\text{No of MMs with KE < threshold and position within the beam pipe volume}}{No\ of\ simulated\ MMs}$$

$$\boldsymbol{Rexp} = \boldsymbol{CMS\ luminosity}\ (184.07\ \mu b^{-1}) \times \boldsymbol{BP\ efficiency} \times \text{Photon Fusion cross section}$$

- In the Photon Fusion MM analysis, we calculate the expected number of MMs trapped in BP based on the cross section, luminosity and efficiency

- *Mass limits obtained for Spin 0 monopoles up to 4 gD.*
- *Mass limits obtained for Spin ½ monopoles up to 8 gD.*

A resummation scheme will be applied in this case; The analysis is in an advanced stage of completion.



1gD (Dirac charge) mass limits at 95% C.L.
Masses excluded up to 59GeV

AUTOMATED THERMAL SCANNING

MoEDAL

Vlad Popa, Vlad Constantinescu, Horea Brânzaş, Gavrila Tordai, Daniel Felea

INSTITUTE OF SPACE SCIENCE INFLPR SUBSIDIARY

In order to automate the scanning process, we developed an experimental setup that allows precise, computer-controlled movement of a thermal camera.

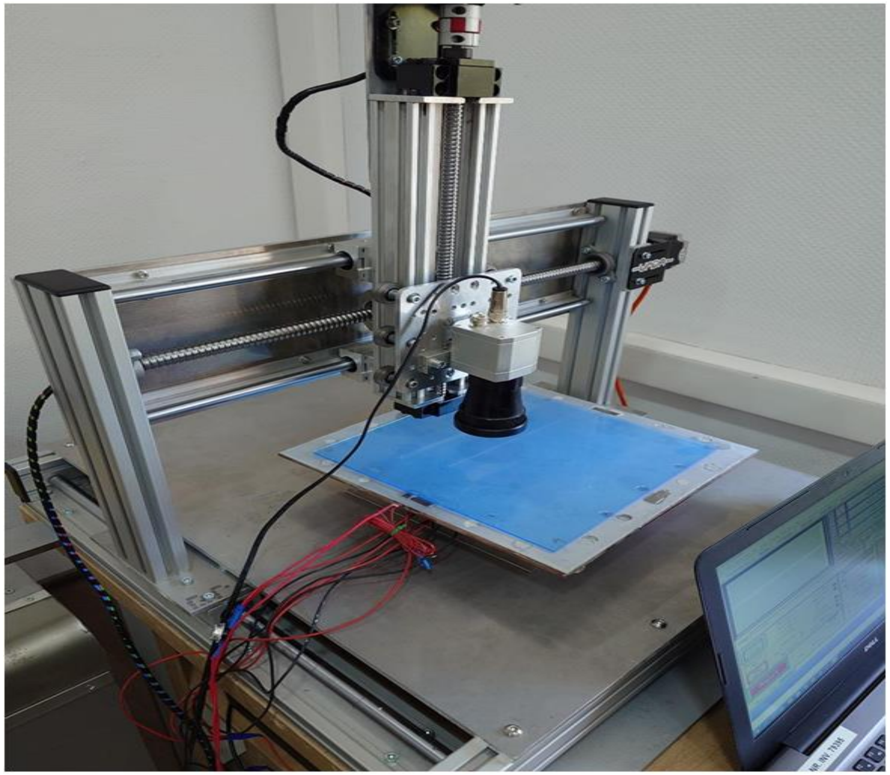


Figure 1: Experimental setup

- ***The camera model is Optris PI 450 fitted with MO44 microscope optics.***
- ***The camera has a resolution of 382x288 pixels and the microscope optics allows the imaging of an area of about 20x16mm.***
- ***The focus distance is around 100 mm and the minimum spot size of the setup is 42 µm, according to the camera datasheet.***
- ***The geometry of an etched-pit produced by a Pb ion, showing the diameter to be around 76 µm.***

AUTOMATED THERMAL SCANNING

MoEDAL Vlad Popa, Vlad Constantinescu, Horea Brânzaş, Gavrila Tordai, Daniel Felea

In order to automate the scanning process, we developed an experimental setup that allows precise, computer-controlled movement of a thermal camera.

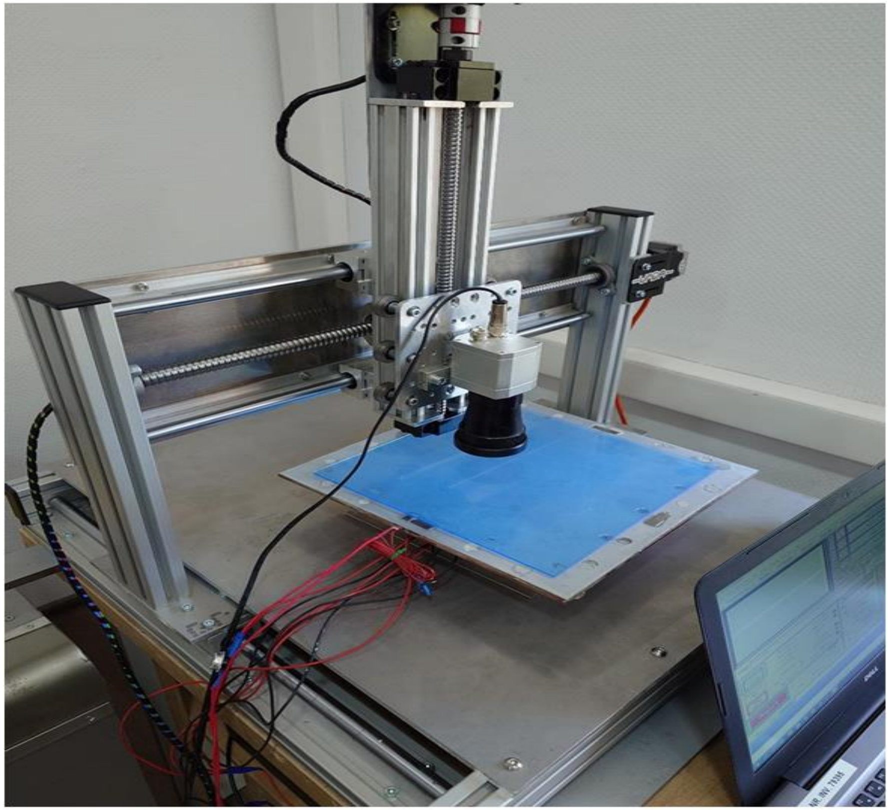
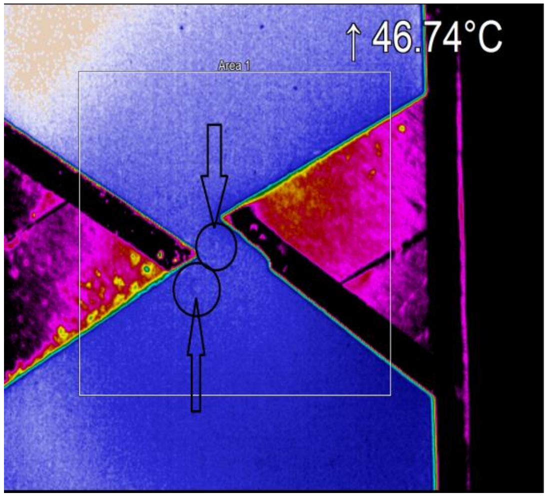


Figure 1: Experimental setup

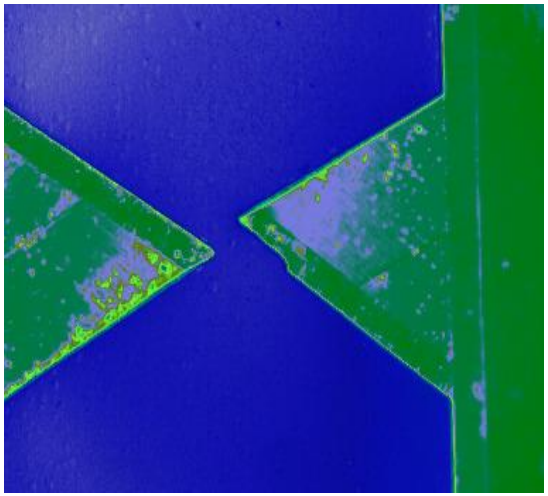
- *The setup allows the movement of the camera on all 3 axes, using computer-controlled stepper motors, one for each axis.*
- *The NTD plate is mounted on a temperature-controlled aluminium bed that can be heated using a heating element embedded in a heating pad or cooled via Peltier elements. The heating element can be controlled from the computer by a relay placed in the control box of the installation.*

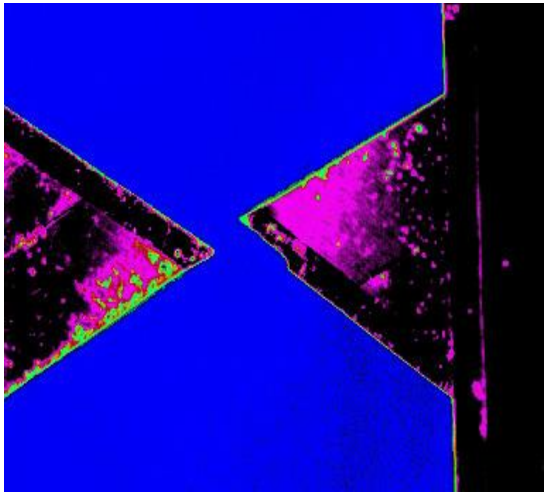
AUTOMATED THERMAL SCANNING

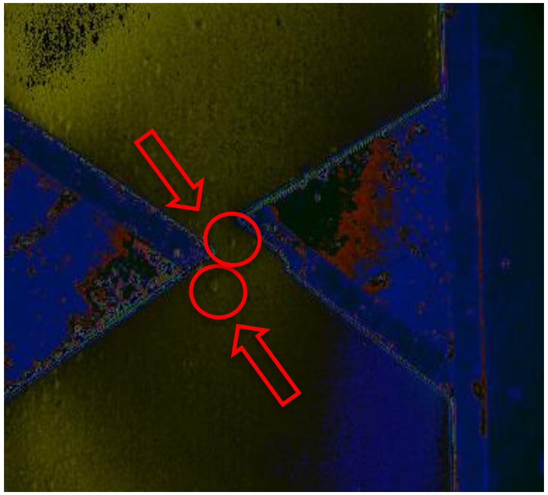
MoEDAL Vlad Popa, Vlad Constantinescu, Horea Brânzaş, Gavrila Tordai, Daniel Felea



Thermal view of an NTD plate (camera software)


Mean of the image series


Median of the image series


RMS of the image series

- ***During our investigations of the plates, we noticed that watching a live, changing thermal image, better enhances the view of the defect.***
- ***We further tested the acquisition of more thermal images of the same area and using them to generate a better image, trying to reduce the noise and offering a better view of the defect.***
- ***For this aim, we manually captured a series of ten images from the camera software and using software from the ImageMagick software package, we computed the mean, median and Root Mean Square (RMS) of the series.***
- ***The plate was heated to around 60°C.***
- ***The figures present a single sample out of the ten images captured and the resulting image of the computations applied on the image series.***

RESULTS – PAPER SUBMITTED to EPJ-ST

Automated thermal scanning installation of Nuclear Track Detector plates- Design and preliminary results

Authors: Constantinescu, Vlad[1] (ORCID: 0000-0002-6340-7567); Brânzaș, Horea[1] (ORCID: 0000-0002-0914-5172); Daniel, Felea[1] (ORCID: 0000-0002-3734-9439); Tordai, Gavrilă[1]

Affiliation: 1 – Institute of Space Science, Romania

Contact email: vlad@spacescience.ro

Currently under Review

Abstract: In this paper, we explore the use of an automated thermal scanning facility aimed at searching for anomalies in Nuclear Track Detectors (NTDs). Our system uses a thermal camera mounted on a CNC (Computer Numerical Control) platform to scan the entire surface of the plates under different thermal conditions. Our setup allows the control of the plate temperature and the movement of the camera on 3 axes. We have developed a custom software that allows the control of the camera movement, heating the pad supporting the NTD plate and acquiring images from the thermal camera. We show images captured using both, our custom software and the camera software, presenting a sequence of images taken with our custom software, aimed at covering the entire surface of the plate and another sequence taken over time on the same spot, to enhance the image quality. We also show preliminary processing of the images and discuss the results.

AUTOMATED THERMAL SCANNING

MoEDAL Vlad Popa, Vlad Constantinescu, Horea Brânzaş, Gavrila Tordai, Daniel Felea

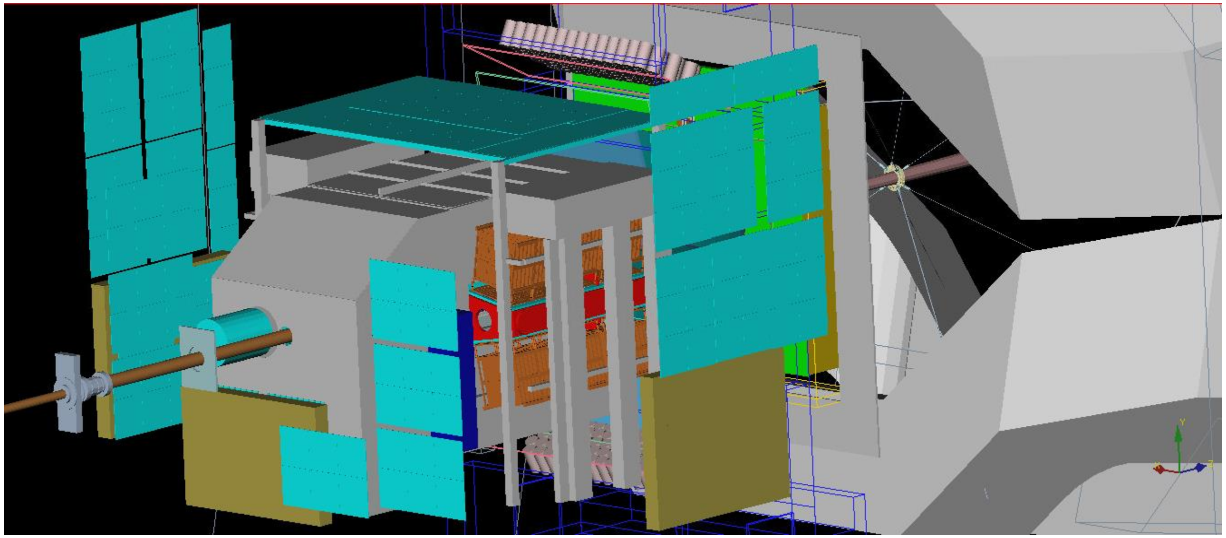
PLANS FOR THE FUTURE

- ✓ *In our study we have shown promising results for using the developed thermal scanning setup when searching for irregularities in NTD plates.*
- ✓ *In the future, we plan to further enhance our software to allow assemble the individual thermal pictures in a single one that shows the entire NTD plate.*
- ✓ *Following our investigations with processing a series of images of the same area, we plan to further extend this work and include the option to capture and process series of images in our custom camera software.*
- ✓ *We also plan a more detailed evaluation of the available focus assessment algorithms in order to choose the one that is the most suitable for our application, allowing for consistent focus evaluation.*
- ✓ *Looking at possible technical enhancements of our setup, the current thermal camera will be soon upgraded to a newer, higher resolution model.*

Fulfilment of the responsibilities specific to the Software Coordinator of the MoEDAL Collaboration and VO administrator of vo.moedal.org

- ***Daniel Felea*** – assigned as **VO admin of vo.moedal.org** (*since the 16th February 2017*), and elected by the MoEDAL Collaboration Board as **MoEDAL Software Coordinator** (*beginning with the 19th October 2018*), having specific activities and responsibilities, in accordance with MoEDAL By-Laws :

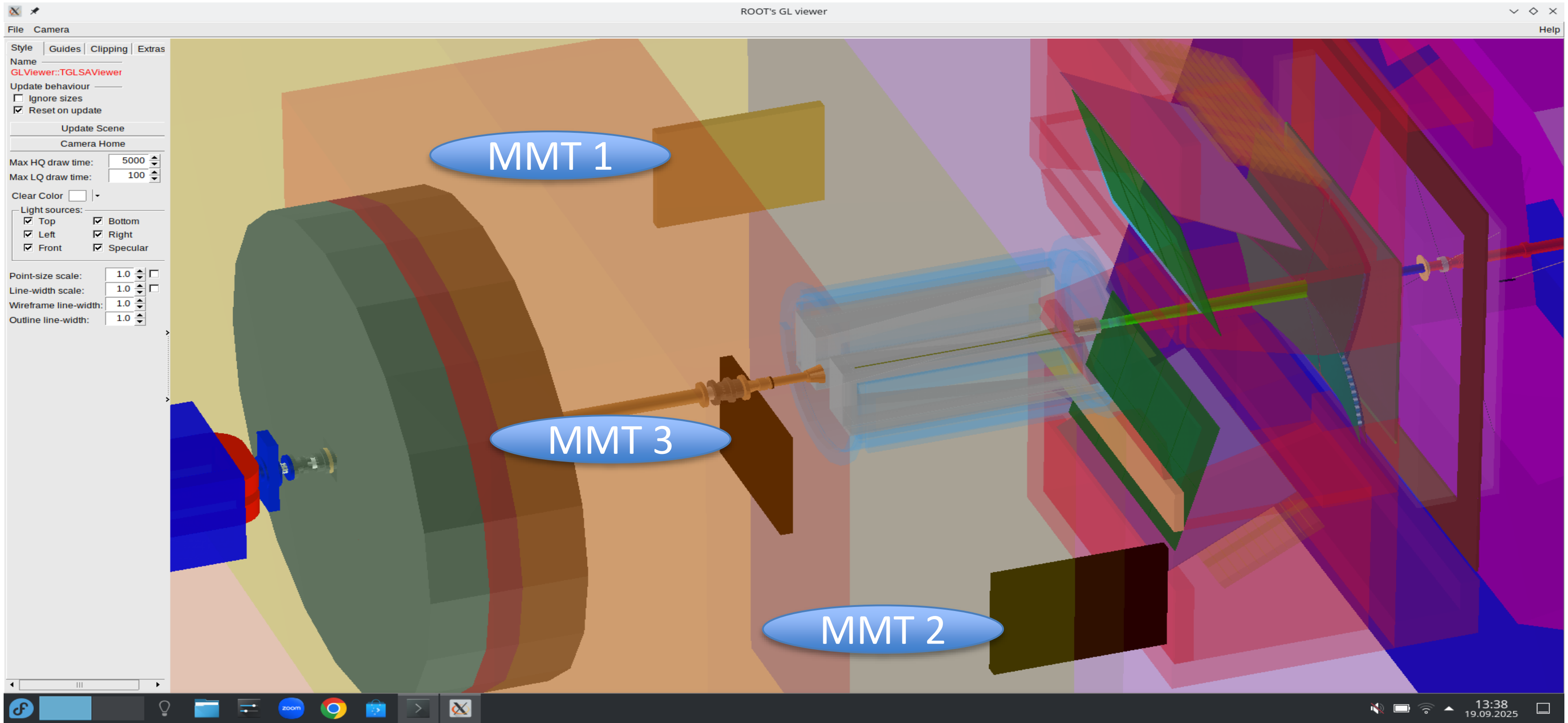
1. *To organize and chair regular software meetings;*
2. *To liaise with the Analysis Coordinator and the Spokesperson to ensure that MoEDAL users have access to the software tools and computing resources they need;*
3. *To maintain fully functional and up-to-date versions of the required software libraries;*
4. *To provide the software tools to access computing resources necessary for analysis and simulations; this includes maintaining software functionality (Ganga, DIRAC) necessary to simulations in VO MoEDAL GRID;*
5. *To provide up-to-date user guides and TWiki pages to the software and also to the computing resources.*



Fulfilment of the responsibilities specific to the Software Coordinator of the MoEDAL Collaboration and VO administrator of vo.moedal.org

- ***Daniel Felea* – *MoEDAL software integration in the LHCb repository, preparing the software for Run3 analyses*.**

Beside regular software activities carried out throughout 2025, a special emphasis was on adapting the MoEDAL geometries to a further integration in a CMake compiled Gauss distribution, thus paving the way for Run3 analyses.



PAPERS PUBLISHED and SUBMITTED in 2025

1. „Search for Highly Ionizing Particles in pp Collisions at the LHC's Run-2 Using the Full MoEDAL Detector"; MoEDAL Collaboration (B. Acharya, ...*Horea Florin Brânzaş*, ...*Daniel Felea*, ...*Gabriela Emilia Păvălaş*, ... *Lucia Aurelia Popa*, *Vlad Popa*, … et al.); Physical Review Letters; Vol. 134 (Issue 7); Article Number 071802; pp. 1-8; 2025.

2. „Gravitational Wave Signatures of Warm Dark Matter in the Gauge Extensions of the Standard Model"; *Lucia Aurelia Popa*; Universe; 11 (10), 343; pp. 1-17; 2025.

3. „Automated thermal scanning installation of Nuclear Track Detector plates – Design and preliminary results"; *Vlad Ion Constantinescu*, *Horea Florin Brânzaş*, *Daniel Felea*, *Gavrilă Tordai*; recently submitted and currently refereed.

TALKS of GROUP MEMBERS over the last year - I

1. “Discussion on Software and Simulation Organisation”; *Daniel Felea* and Matti Kalliokoski; The 22nd MoEDAL Collaboration Meeting; CERN, Geneva, Switzerland, 5-7 December 2024.
2. “Remembering Vlad Popa”; *Daniel Felea*; The 22nd MoEDAL Collaboration Meeting; CERN, Geneva, Switzerland, 5-7 December 2024.
3. “Report of the Software Coordinator”; *Daniel Felea*; The 23rd MoEDAL Collaboration Meeting; Helsinki, Finland, 16-18 June 2025.
4. “Magnetic Monopoles production in Pb-Pb collisions”; *Horea Florin Brânzaş*; The 23rd MoEDAL Collaboration Meeting; Helsinki, Finland, 16-18 June 2025.
5. “Automated thermal scanning installation of Nuclear Track Detector plates design and preliminary result”; *Vlad Ion Constantinescu*, *Daniel Felea*, *Horea Florin Brânzaş*, *Gavrilă Tordai*; The 23rd MoEDAL Collaboration Meeting; Helsinki, Finland, 16-18 June 2025.
6. “Magnetic Monopoles production in Pb-Pb collisions”; *Horea Florin Brânzaş*; MoEDAL Software and Analysis Meeting; CERN, Geneva, 07 March 2025.

TALKS of GROUP MEMBERS over the last year - II

7. "Magnetic Monopoles production in Pb-Pb collisions"; *Horea Florin Brânzaş*; MoEDAL Software and Analysis Meeting; CERN, Geneva, 04 April 2025.
8. "Magnetic Monopoles production in Pb-Pb collisions"; *Horea Florin Brânzaş*; MoEDAL Software and Analysis Meeting; CERN, Geneva, 16 May 2025.
9. "Magnetic Monopoles production in Pb-Pb collisions"; *Horea Florin Brânzaş*; MoEDAL Software and Analysis Meeting; CERN, Geneva, 25 July 2025.
10. "Magnetic Monopoles production in Pb-Pb collisions"; *Horea Florin Brânzaş*; MoEDAL Software and Analysis Meeting; CERN, Geneva, 05 September 2025.
11. "MoEDAL Software Updates"; *Daniel Felea*; MoEDAL Software and Analysis Meeting; CERN, Geneva, 03 October 2025.
12. "MoEDAL Software Updates"; *Daniel Felea*; MoEDAL Software and Analysis Meeting; CERN, Geneva, 17 October 2025.
13. "Magnetic Monopoles production in Pb-Pb collisions"; *Horea Florin Brânzaş*; MoEDAL Software and Analysis Meeting; CERN, Geneva, 31 October 2025.

ACCOMPLISHMENTS over the last year (2025)

Our group has successfully continued its current participation in the Software and Analysis group.

In 2025, we have been contributing to the MoEDAL physics analyses by :

- ***MoEDAL software integration in the LHCb repository, preparing the software for Run3 analyses (Daniel Felea).***

- ***The study concerning the Dark Higgs indirect detection with MAPP has been pursued, starting from the existing astrophysical and cosmological data. A second paper was already published in the ”Universe” Open Access journal (Lucia Aurelia Popa).***

- ***The search in the CMS Berillium beam pipe acceptance for magnetic monopoles produced through the ”Photon Fusion” channel in ultraperipheral Pb-Pb collisions has significantly progressed. A paper is currently prepared to be submitted in the immediate future (Horea Florin Brânzaș).***

- ***The automated thermal scanning test unit has been upgraded, by adding an auto-focus system, and various focus estimator algorithms have been investigated. One paper was recently submitted to a special issue of EPJ-ST (Vlad Ion Constantinescu, Horea Florin Brânzaș, Daniel Felea, and Gavrilă Tordai).***

Thank you for your attention !