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# The MoEDAL-MAPP Experiment - The Continuation of the LHC's 1st Dedicated Search Experiment

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The MoEDAL experiment deployed at IP8 on the LHC ring was the first dedicated search experiment to take data at the LHC in 2010. It was designed to search for Highly Ionizing Particle (HIP) avatars of new physics such as magnetic monopoles, dyons, Q-balls, multiply charged particles, massive slowly moving charged particles and long-lived massive charged SUSY particles. We shall report on our search at LHC's Run-2 for Magnetic monopoles and dyons produced in p-p and photon-fusion. We will also provide our most recent result in this arena: the search for magnetic monopoles via the Schwinger Mechanism in Pb-Pb collisions; and, the search for Highly Electrically Charged Objects (HECOS). The MoEDAL detector will be reinstalled for LHC's Run-3 to continue the search for electrically and magnetically charged HIPs. As part of this effort we will initiate the search for massive very long-lived charged particles as well as multiply charged particles with charge less that ten times the electron charge. An upgrade to MoEDAL, the MoEDAL Apparatus for Penetrating Particles (MAPP), approved by CERN's Research Board is now the LHC's newest detector. The MAPP detector, positioned in UA83, expands the physics reach of MoEDAL to include sensitivity to feebly-charged particles with charge, or effective charge, as low as $\sim 10^{-3}$ e (where e is the electron charge). Also, the MAPP detector in conjunction with MoEDAL's trapping detector gives us a unique sensitivity to extremely long-lived charged particles. MAPP also has some sensitivity to long-lived neutral particles. Additionally, we will very briefly report on the plans for the MAPP-2 upgrade to the MoEDAL-MAPP experiment for the High Luminosity LHC (HL-LHC). We envisage that this detector will be deployed in the UGC1 gallery near to IP8. This phase of the experiment is designed to maximize MoEDAL-MAPP's sensitivity to very long-lived neutral messengers of physics Beyond the Standard Model (BSM).

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## 1. Introduction

The pioneering MoEDAL-MAPP Experiment, the LHC's first dedicated search experiment, is engaged in a 26-year endeavour that is divided into three phases, as shown in Figure 1. Phase-0 started in 2011with the installation of the MoEDAL detector for LHC's Run-1 and ran to the end of Run-2, in 2018. This Phase was committed to the search for Highly Ionizing Particle (HIP) avatars of new physics, such as the Magnetic Monopole.

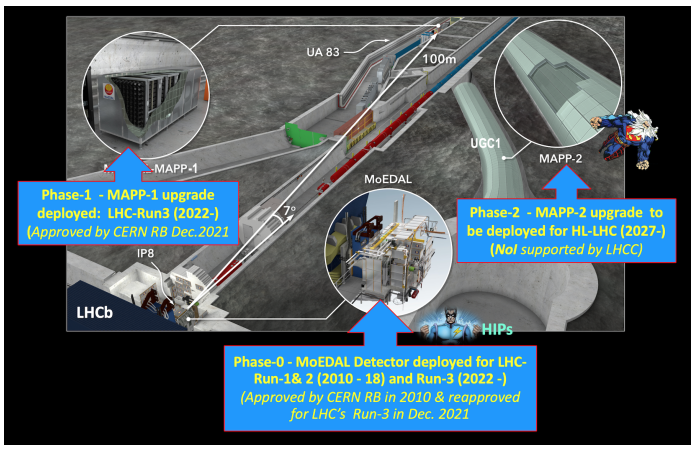


**Figure 1:** The three Phases of the MoEDAL-MAPP project

The largely passive MoEDAL detector, deployed at Point 8 on the LHC ring (IP8), has a dual nature. First, it acts like a giant camera, comprised of Nuclear Track Detectors (NTDs - read offline by ultra-fast scanning microscopes - sensitive only to new physics. Second, it is uniquely capable of capturing with trapping detectors (MMTs) the particle messengers of physics Beyond the Standard Model (BSM), for further study. MoEDAL's radiation environment is monitored by an array of state-of-the-art real-time TimePix (TPX) pixel detectors.

Phase-1 started with the redeployment of an improved MoEDAL detector and the deployment of the new MAPP-1 (MoEDAL Apparatus for Penetrating Particles) detector in the UA83 tunnel some 100m for IP8, that started in 2022. In this phase the discovery horizon of MoEDAL-MAPP was broadened to include Feebly Interacting Particles (FIPs) such as milli-charged particles (mCPs), as well as Long-Lived Particles (LLPs).

The MAPP-2 detector will be installed in the UGC1 gallery between roughly 25m to 55m from IP8, for Phase-2 of the MoEDAL-MAPP project which covers High luminosity LHC (HL-LHC) running, that nominally starts in 2029. MoEDAL and MAPP-1 will also be installed for HL-LHC data taking. The MAPP-2 detector is designed to radically enhance MoEDAL-MAPP's physics reach in the search for neutral LLPs.

MoEDAL-MAPP ground breaking physics program [1–3] defines over forty scenarios with potentially revolutionary insights into foundational questions, involving: magnetic charge; topological objects such as the electroweak monopole; the generation of mass; a 4th generation; heavy neutrinos; extra dimensions; new symmetries such as supersymmetry; and, dark matter.

## 2. MoEDAL Run-1/2 Results on the Search for HIPs,

The physics program of Phase-0 MoEDAL detector is designed to search for HIP messengers of new physics. To date, MoEDAL has placed the world's best limits on the existence of singly and multiply charged Magnetic Monopoles (MMs) [4–8] and Highly Electrically Charged Objects (HECOs) [9]. It has also carried out the first ever searches for, 1) Spin-1 MMs [7]; 2) dyons [10], particles with electric and magnetic charge; and, 3) MMs produced in heavy-ion collisions via the



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Schwinger Mechanism [11, 12]. Additionally, it has published the LHC's only search for MM production via photon fusion [8]. The latest limits from MoEDAL compared to those from ATLAS are shown in Figure 2.

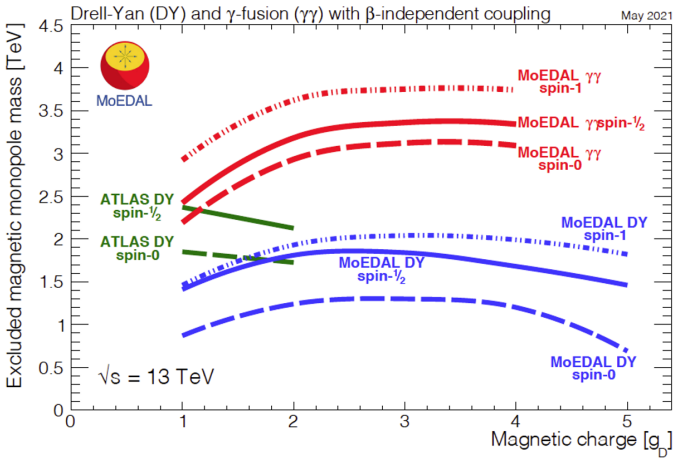


**Figure 2:** Recent mass limits from DY and photon-photon production of MM pairs in MoEDAL compared to the latest ATLAS limits.

## 3. MoEDAL-MAPP at Run-3

We are currently in Phase-1 which encompasses LHC's Run-3. In this phase the updated MoEDAL detector and the new MAPP detector were installed to enhance MpEDAL's physics reach to incorporate sensitivity to FIPs, such as mCPs, with additional sensitivity to both charged and neutral LLPs.

The MoEDAL detector will take data in Run-3 with: improved detector efficiency; ten times lower charge threshold $50e \rightarrow 5e$, where $e$ is the unit electric charge; 5 times greater instantaneous luminosity; and, the higher collision energy of 14 TeV. The continuing analysis of MoEDAL's Run-2 and Run-3 data promises other pioneering results. For example, the extension in a complimentary and competitive way of the LHC search for massive singly and/or multiply electrically charged long-lived particles (LLPs) with a number of scenarios including supersymmetry L-R symmetry and neutrino mass models [13–15].

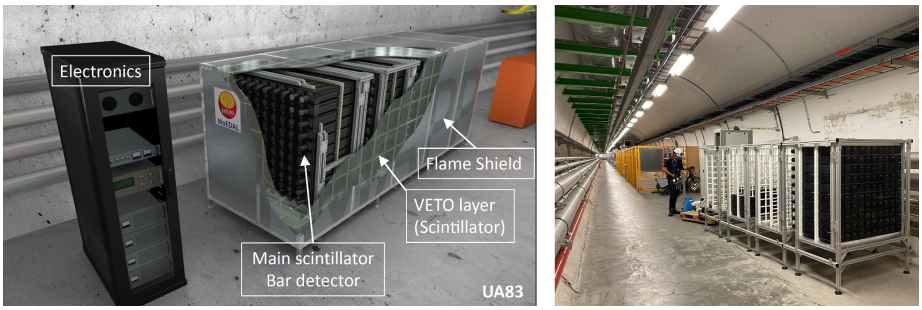


**Figure 3:** (Left) The MAPP-1 detector; (Right) The installation of MAPP-1 in the UA83.

The new MAPP detector is a state-of the art scintillator detector designed to search for Feebly Interacting Particles (FIPs), such as Milli-Charged Particles (mCPs), with charge as small as of the order of thousandth the electron charge. MAPP also has sensitivity to charged and neutral LLPs. The MAPP detectors represents a "Phase-1" addition to the MoEDAL program for Run-3. A 3D



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computer model of the MAPP-1 detector - deployed in the UA83 tunnel situated 110m underground and 100m from IP8 at an angle of 7 deg. to the beam - is shown in Figure 3. Unlike MoEDAL, MAPP is an active detector with electronic-readout and a software/firmware trigger.

As an example of the sensitivity of the MAPP-1 for mCPs detector we consider here a class of Feebly Interacting Particles (FIPs) that has a milli-charge (mCP) as small as $10^{-3}e$, or lower. A common scenario is from a Dark Sector model where one considers a mCP coupled through a very light kinetically mixed dark photon [16, 17]. The response of the MAPP detector to such a scenario, assuming 100% detector efficiency, is shown in Figure 4.

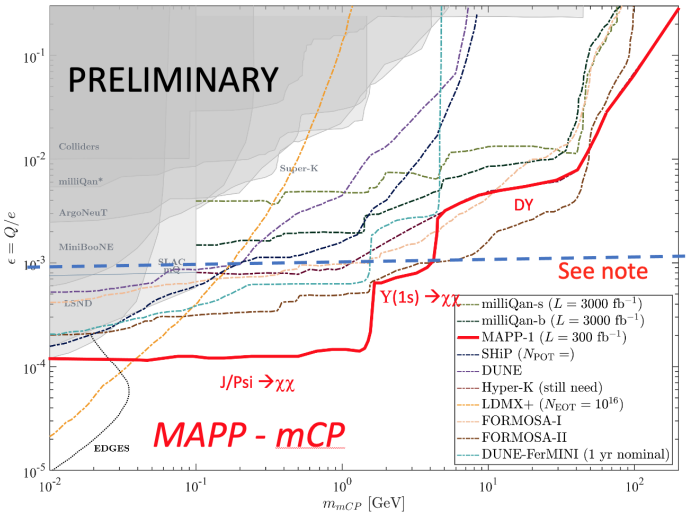


**Figure 4:** Direct bounds from accelerator based searches and indirect bounds from the effective number of neutrinos from Planck are shown. The projected sensitivity for mCPs, for models with a massless dark photon are presented for milliQan (for the slab (s) and bar (b) detectors) and for the MAPP-1 mCP detector (for the Bar (B) and Outrigger (O) detectors) at Run-3. The existing bounds given here are cited in Ref. [18]. The green dashed line shows the naive limit on experimental sensitivity assuming that the only energy loss photons derive from ionization of a very relativistic particle.

## 4. MoEDAL-MAPP at Run-4 and Beyond,

The LHC Committee has endorsed the full MoEDAL-MAPP program LoI that includes a new "Phase-2" MoEDAL detector, MAPP-2, together with the MoEDAL and MAPP-1 detectors, for High Luminosity LHC (HL-LHC) running that nominally starts in 2029 (Run-4). We have already begun designing the MAPP-2 detector and planning Phase-2 of our program. MAPP-2 will greatly enhance the ability of MoEDAL-MAPP to search for neutral LLPs in a competitive and complementary way, due to its substantially larger fiducial volume, increased by a factor a few hundred compared to MAPP-1.

The MAPP-2 detector, deployed for the HL-LHC will greatly enhance the fiducial volume used to detect the decays of LLPs compared to the MAPP-1 detector, now being deployed for Run-3, by a factor of a few hundred times. The fiducial volume of MAPP-2, defined by the UGC1 gallery, is shown in Figure 5.

To illustrate the physics-reach of the Phase-2 MAPP detector for LLPs dark Higgs bosons we again used the well-studied benchmark involving the decay of dark Higgs bosons [19]. The sensitivity of the MAPP-2 detector, assuming 100% efficiency, to this scenario is shown in Figure 6 (Left). Considering another example, the response of the MAPP-2 detector to a heavy neutral lepton produced within the framework a a gauged B-L model [24] is shown in Figure 6 (Right).

The cost effective and well understood scintillator technology planned for MAPP-2 provides a highly competitive and/or complementary solution to the detection of LLP-decays when matched



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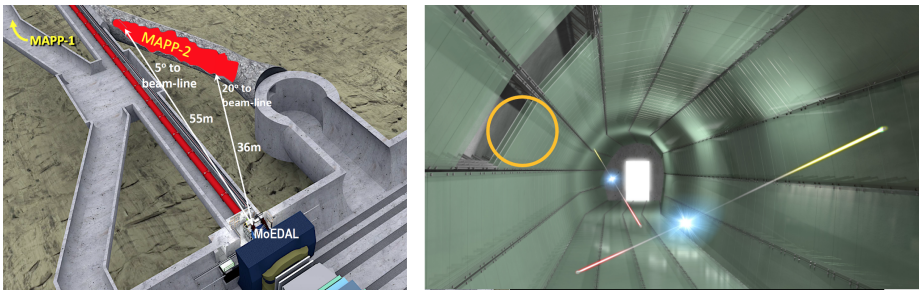


**Figure 5:** (Left) The disposition of the MAPP-2 detector in the UGC1 gallery. (Right) A 3D depiction of part of the MAPP-2 detector fiducial volume in the UGC1 gallery lined with 3 layers of large scintillator tiles with fine grain (1 cm pitch) WLS fibre readout in X-Y .

against other more expensive experiments such as CODEXb [19], SHIP [20] and MATHUSLA [21, 22] that are planned for the HL-LHC.

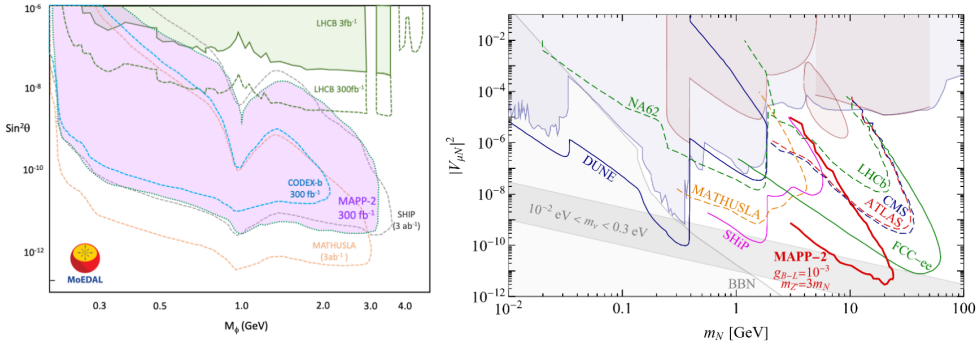


**Figure 6:** (Left) MAPP-2 reach for B $\rightarrow \chi_s \phi$ in the $\sin^2_\theta$ - $M\phi$ plane where 100% detector/tracking efficiency is assumed. (Right) Current constraints (shaded regions) and future sensitivity on the active-sterile neutrino mixing strength $V^2_{\mu N}$ as a function of the sterile neutrino mass $m_N$. Here, the sterile neutrinos only couple through the mixing and they are produced via SM neutral or charged current [23]. In the case of the MAPP-2 result right handed neutrino production takes place within the framework of the B-L model [24]

## 5. Concluding Remarks

The MoEDAL experiment is the LHC's first dedicated search experiment designed to seek messengers of new physics in a complementary way to the general purpose detectors: ATLAS and CMS, thus expanding the discovery horizon of the LHC. In 2021, the MoEDAL experiment became the MoEDAL-MAPP experiment with the addition of the MAPP-1 detector, deployed in UA83, and the reinstallation of an improved MoEDAL detector, for MoEDAL-MAPP data taking at Run-3. The physics capability of the MoEDAL experiment - built to search for HIP avatars of new physics - has been extended with the addition of the MAPP detector to include a competitive sensitivity to FIPs and LLPs. We will deploy the MAPP-2 detector in the Long Shutdown (LS3) preceding Run-4 of the HL-LHC, in order to drastically improve MoEDAL-MAPP's response to LLPs.

## References

[1] J. L. Pinfold, "Technical Design Report of the MoEDAL Experiment", MoEDAL Collaboration Jun 8, 2009. 76 pp. CERN-LHCC-2009-006, MoEDAL-TDR-001.
[2] B. Acharya et al., "The Physics Programme Of The MoEDAL Experiment At The LHC," MoEDAL Collaboration, Int. J. Mod. Phys. A29 (2014) 1430050.



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[3] J. L. Pinfold for the MoEDAL Collaboration, "MoEDAL-MAPP - an LHC Dedicated Search Facility," 2022 Snowmass Summer Study, ePrint: 2209.03988 [hep-ph].
[4] B. Acharya et al., MoEDAL Collaboration,"Search for magnetic monopoles with the MoEDAL forward trapping detector in 2.11 fb?1 of 13 TeV proton-proton collisions at the LHC," Phys. Lett. B782 (2018) 510-516.
[5] B. Acharya et al., MoEDAL Collab., "Search for Magnetic Monopoles with the MoEDAL Prototype Trapping Detector in 8 TeV p-p Collisions at the LHC", JHEP 1608 (2016) 067.
[6] B. Acharya et al., MoEDAL Collaboration, "Search for Magnetic Monopoles with the MoEDAL Forward Trapping Detector in 13 TeV Proton-Proton Collisions at the LHC," Phys. Rev. Lett. 118 (2017) no.6, 061801.
[7] J. Ellis, N. E. Mavromatos, T. You, Phys. Lett. B756 (2016) 29-35; S. Baines, N.E. Mavromatos, V.A. Mitsou, J.L. Pinfold, A. Santra, "Monopole production via photon fusion and Drell-Yan processes: MadGraph implementation and perturbativity via velocity-dependent coupling and magnetic moment as novel features". Eur.Phys.J. C78 (2018) no.11, 966.
[8] B. Acharya et al., MoEDAL Collaboration, "Magnetic Monopole Search with the Full MoEDAL Trapping Detector in 13 TeV pp Collisions Interpreted in Photon-Fusion and Drell-Yan Production," Phys. Rev. Lett. 123 (2019) no.2, 021802.
[9] B. Acharya et al., MoEDAL Collaboration, "Search for highly-ionizing particles in pp collisions at the LHC's Run-1 using the prototype MoEDAL detector," Eur.Phys.J.C 82 (2022) 8, 694, e-Print:2112.05806 [hep-ex].
[10] B. Acharya et al., MoEDAL Collaboration "First Search for Dyons with the Full MoEDAL Trapping Detector in 13 TeV pp Collisions," Phys. Rev. Lett. 126 (2021) 7, 071801.
[11] B. Acharya et al., MMoEDAL Collaboration. "Search for magnetic monopoles produced via the Schwinger mechanism," Nature 602 (2022) 7895, 63-67, e-Print: 2106.11933 [hep-ex].
[12] O. Gould, D L.-J Ho, A Rajantie, "Towards Schwinger production of magnetic monopoles in heavy-ion collisions," Phys. Rev. D100 (2019) no.1, 015041.
[13] B. S Acharya, A de Roeck, J. Ellis, D. K. Gosh, R. Maselek, G. Panizzo, J. L. Pinfold, K. Sakurai, A. Shaa, A. Wall, "Prospects of searches for long-lived Supersymmetric charged particles with MoEDAL," Eur.Phys.J.C 80 (2020) 6, 572, e-Print 2004.11305 [hep-ph].
[14] K. Sakurai, D. Felea, J. Mamuzic, N.E. Mavromatos , V.A. Mitsou, J.L. Pinfold, R. Ruiz de Austri, A. Santra, O. Vives, "SUSY discovery prospects with MoEDAL", e-Print: arXiv:1903.11022 [hep-ph]. 10 citations.
[15] M. Hirsch, R. Mase?ek, K. Sakurai, "Detecting long-lived multi-charged particles in neutrino mass models with MoEDAL," Eur.Phys.J.C 81 (2021) 8, e-Print, 2103.05644 [hep-ph].
[16] B. Holdom,"Two U(1)'s and charge shifts," Phys. Lett. B166, p196-198 (1986).
[17] A. Haas, C. S. Hill, E. Izaguirre and I Yavin, "Looking for milli-charged particles with a new experiment at the LHC," Phys. Lett. B746, p117-120 (2015).
[18] M. Staelens, "Physics From Beyond the Standard Model: Exotic Matter Searches at the LHC with the MoEDAL-MAPP Experiment," Thesis, Doctor of Philosophy, https://doi.org/10.7939/r3-g8yh-hv16 (2021).
[19] V. V. Gligorov, "Searching for Long Lived Particles: A Compact Detector for Exotics at LHCb,"Physical Review D97 (2018) 015023.
[20] G. Lanfranchi (SHiP Collaboration), "Sensitivity of the SHiP experiment to a light scalar particle mixing with the Higgs," https://cds.cern.ch/ record/2243034.
[21] G. Marsell et al., MATHUSLA Collaboration, "Ultra-long-lived Particle Searches with MATHUSLA," Nucl. Instrum. Meth. A936 (2019) 507-508.
[22] J. A. Evans, "Detecting Hidden Particles with MATHUSLA," arXiv:1708.08503 (2017).
[23] https://www.hep.ucl.ac.uk/ pbolton/
[24] F. Deppisch, S. Kulkarni and W. Liu, " Sterile Neutrinos at MAPP in the B-L Model," to be published in EPJ-ST.



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