The MoEDAL-MAPP Experiment – the LHC's First Dedicated Search Exp.

RESULTS & FUTURE PLANS

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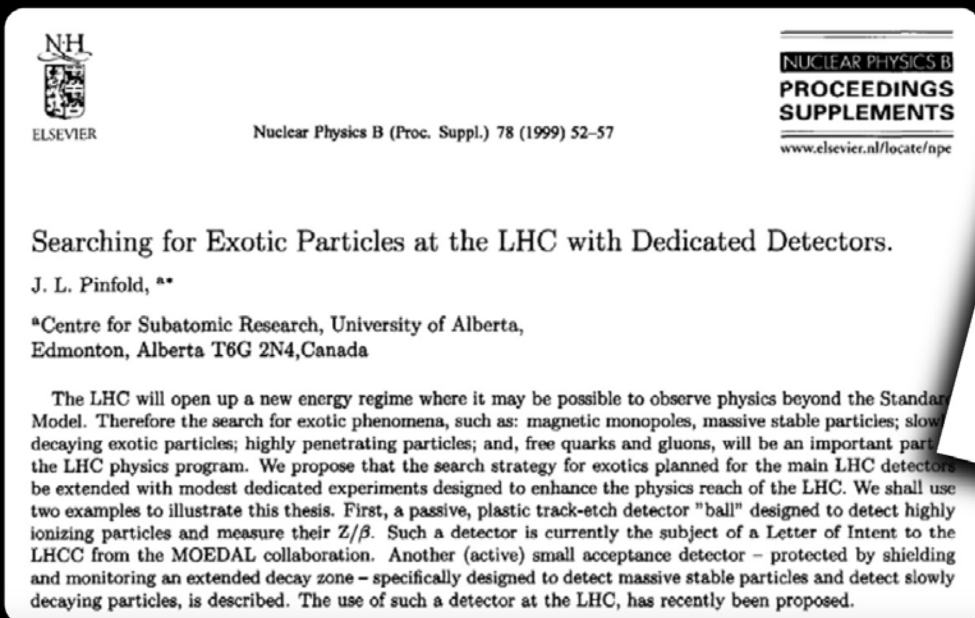
University of Alberta

2022 CAP CONGRESS

The MoEDAL Philosophy

MoEDAL the Dedicated Search Experiment at the LHC



NUCLEAR PHYSICS B
PROCEEDINGS SUPPLEMENTS
www.elsevier.nl/locate/npe

ELSEVIER

Nuclear Physics B (Proc. Suppl.) 78 (1999) 52–57

Searching for Exotic Particles at the LHC with Dedicated Detectors.

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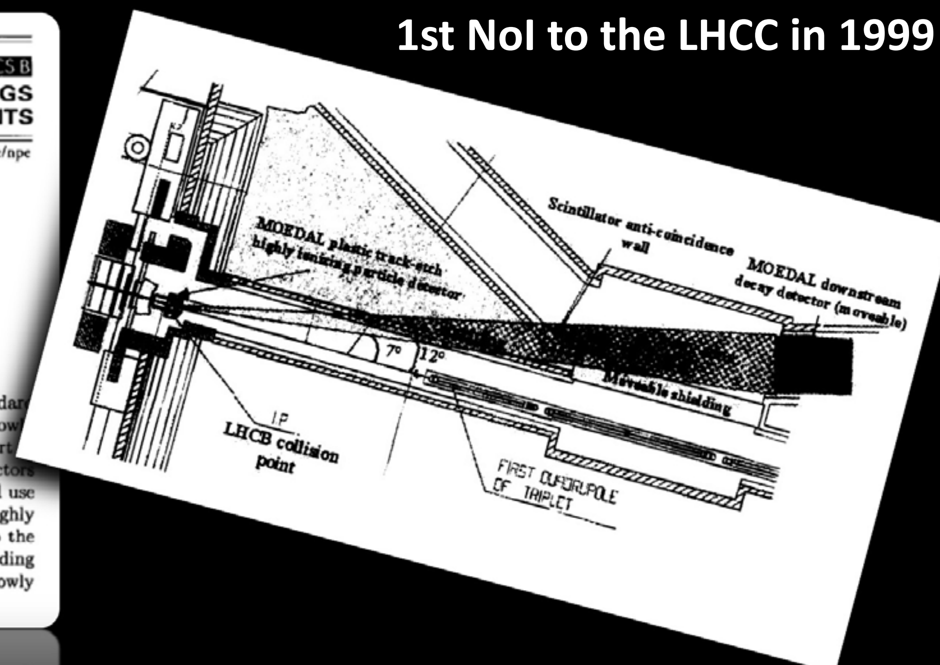
The LHC will open up a new energy regime where it may be possible to observe physics beyond the Standar Model. Therefore the search for exotic phenomena, such as: magnetic monopoles, massive stable particles; slow decaying exotic particles; highly penetrating particles; and, free quarks and gluons, will be an important part the LHC physics program. We propose that the search strategy for exotics planned for the main LHC detectors be extended with modest dedicated experiments designed to enhance the physics reach of the LHC. We shall use two examples to illustrate this thesis. First, a passive, plastic track-etch detector "ball" designed to detect highly ionizing particles and measure their Z/β. Such a detector is currently the subject of a Letter of Intent to the LHCC from the MOEDAL collaboration. Another (active) small acceptance detector – protected by shielding and monitoring an extended decay zone – specifically designed to detect massive stable particles and detect slowly decaying particles, is described. The use of such a detector at the LHC, has recently been proposed.

1st NoI to the LHCC in 1999



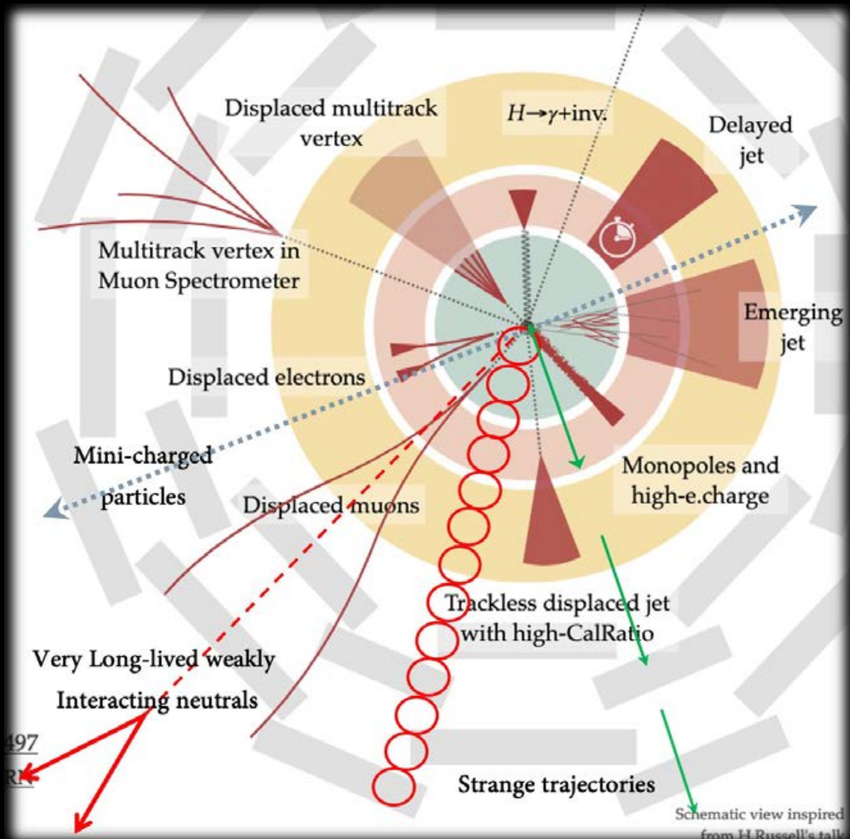
Dedicated Search Experiments:

- *They concentrate on some particular clear experimental signature of new physics*
- *Their physics reach is complementary to the main detectors*
- *They are usually stand alone, smaller & needs-be lower cost with small teams (<100)*


MAPP
MoEDAL
Where is the New Physics?
New Physics
The Standard Model

MAPP
MoEDAL

The Unconventional Signs of New Physics
(for which ATLAS & CMS are not optimized)



Conventional collider detectors are not optimized for certain signatures of new physics

Mass
< ~ 0.1 eV

Mass
> ~180 GeV/c^2

Lifetime (cτ)
> ~10m

Fractional charge

Charge > 1 or Magnetic charge

CLEAR ATTRIBUTES OF NEW PHYSICS

MAPP
MoEDAL

Avatars of New Physics

$$\Delta I = \frac{4\pi N}{L} g_D = 2\Delta I_0$$

Long-lived particles

$$\Gamma = \frac{1}{\tau} \sim g^2 \left(\frac{m}{M}\right)^n m$$

Avatars of New Physics

Magnetic charge
$-dE/dx \propto g^2$
g =n68.5e

Electric charge
$-dE/dx \propto z^2/\beta^2$
$Z \geq 1$ $\beta < 1$

Electric charge
$-dE/dx \propto Z^2/\beta^2$
$Z(<<1)$ $\beta(\sim 1)$

Highly-ionizing particles

milli-charged particles

The MoEDAL Experiment Today

The Monopole and Exotics Detector at the LHC (MoEDAL) Experiment

Approved by the CERN Research Board in 2010! (CERN-LHCC-2009-006, MoEDAL-TDR-001)

The Updated MoEDAL detector was reapproved by the LHCC for LHC's Run-3 in 2021

MoEDAL-MAPP Collaboration
26 Institutes

MAPP
MoEDAL

UNITED KINGDOM
Imperial College London
Kings College London
Queen Mary University
Track Analysis Systems Ltd
IRIS Canterbury

KOREA
Centre for Quantum Spacetime, Seoul

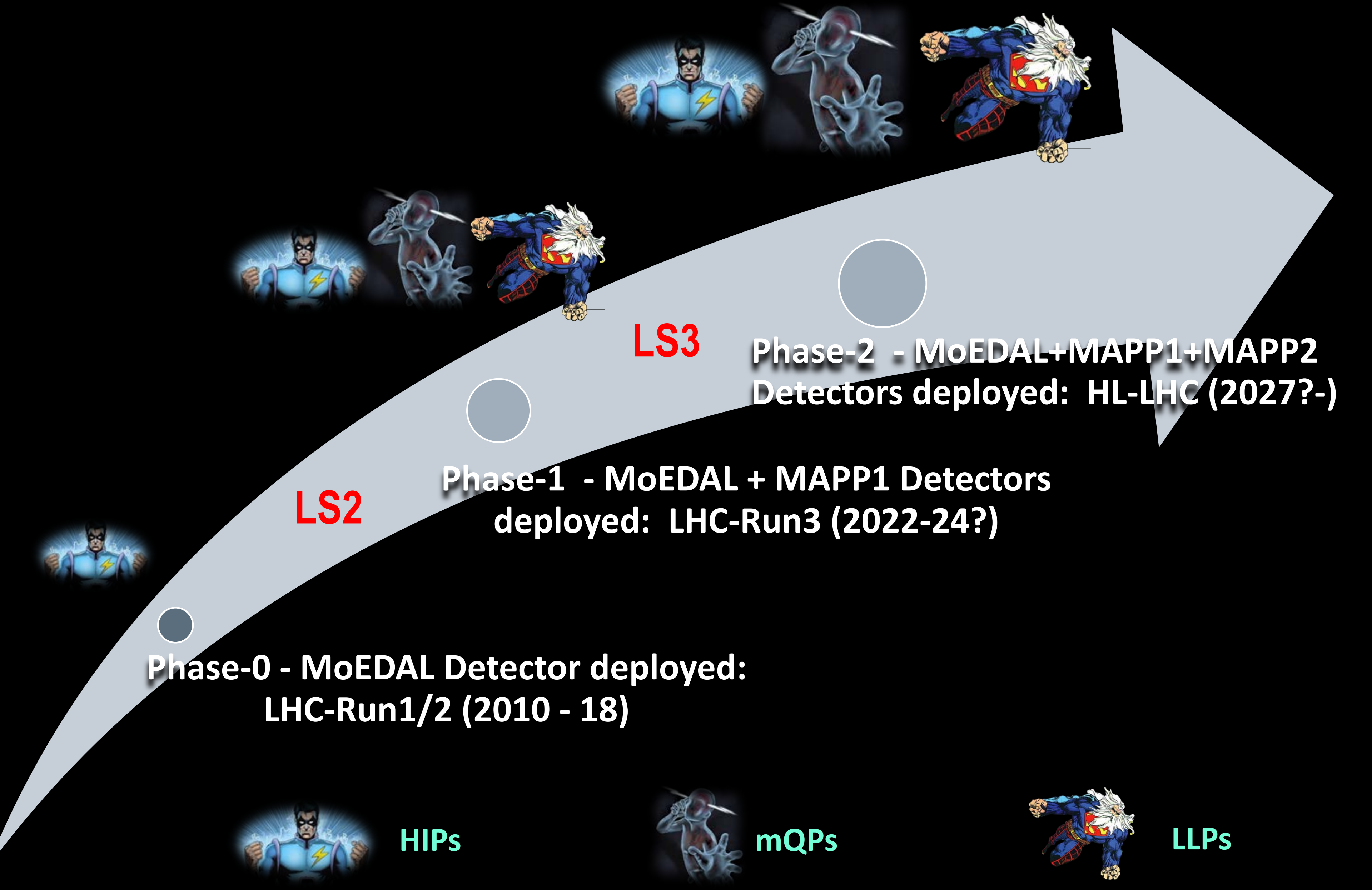
NORTH AMERICA
University of Alabama
University of Alberta
University of British Columbia
Concordia University
University of Montreal
University of Regina
Tuft's University
University of Virginia

EUROPE
Technical University of Athens
University of Bologna & INFN Bologna
CERN, Switzerland
Czech Technical University (IEAP)
University of Helsinki
Institute of Space Sciences Romania
University of Valencia (IFIC)
Vaasa Universities

INDIA
University of Calcutta
National Institute of Technology, Kuruksetra

MoEDAL was approved by the CERN Research Board in\ 2010

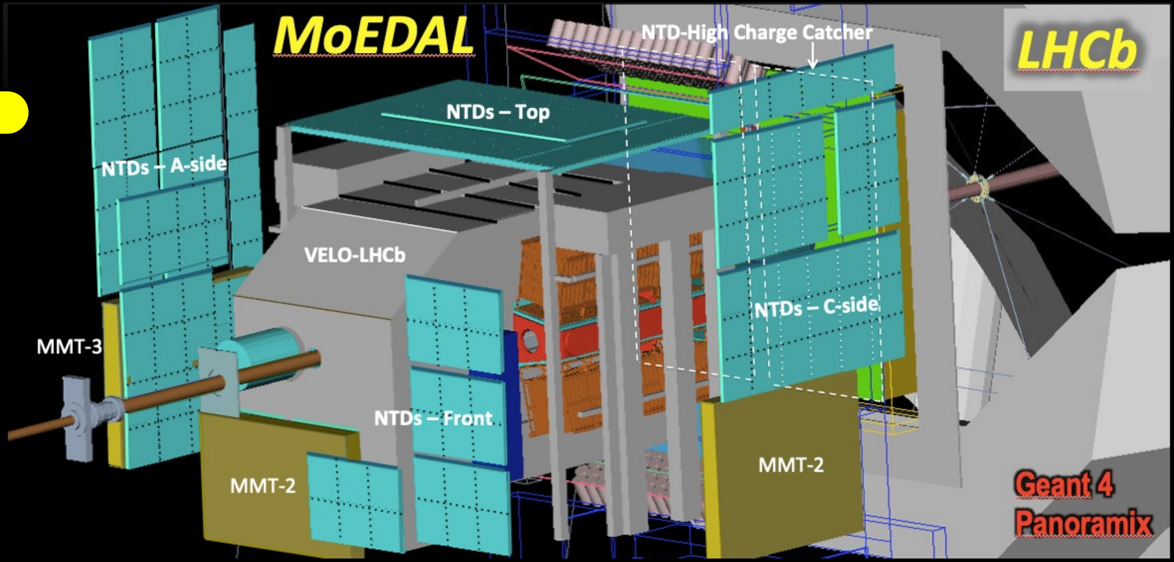
The MoEDAL-MAPP 20 Year Project



The MoEDAL Detector at Run-2 and Run-3

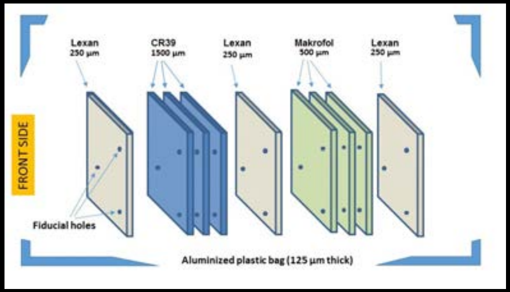
Started data taking in 2015– the LHC's first dedicated search experiment

Permanent Physical record of new physics

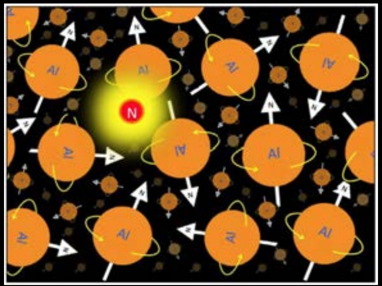


No Standard Model physics backgrounds

MoEDAL is made up of 3 detector system designed to search for HIPs.



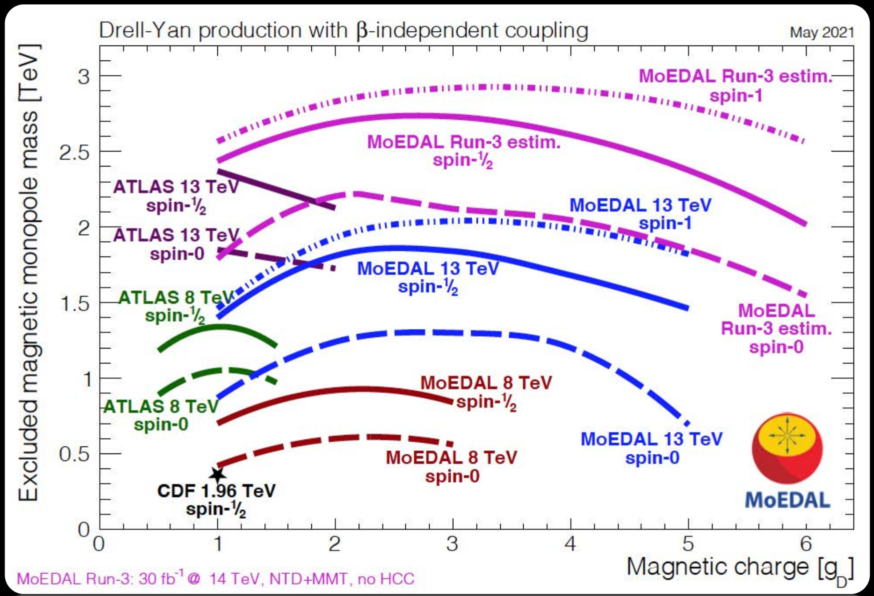
NUCLEAR TRACK DETECTOR Plastic array (185 stacks, 12 m^2) – Like a big Camera



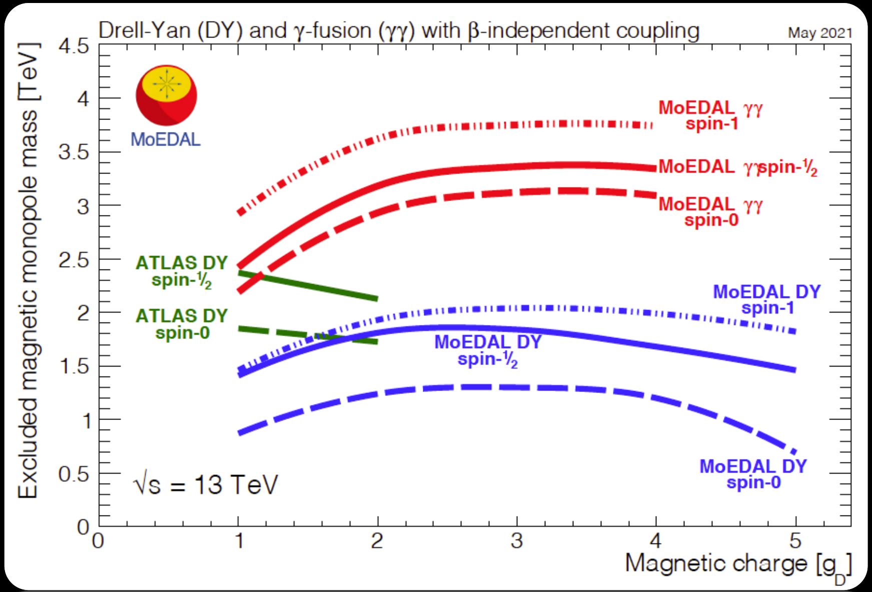
TRAPPING DETECTOR ARRAY A tonne of Al to trap Highly Ionizing Particles for analysis

TIMEPIX Array a digital Camera for real time radiation monitoring

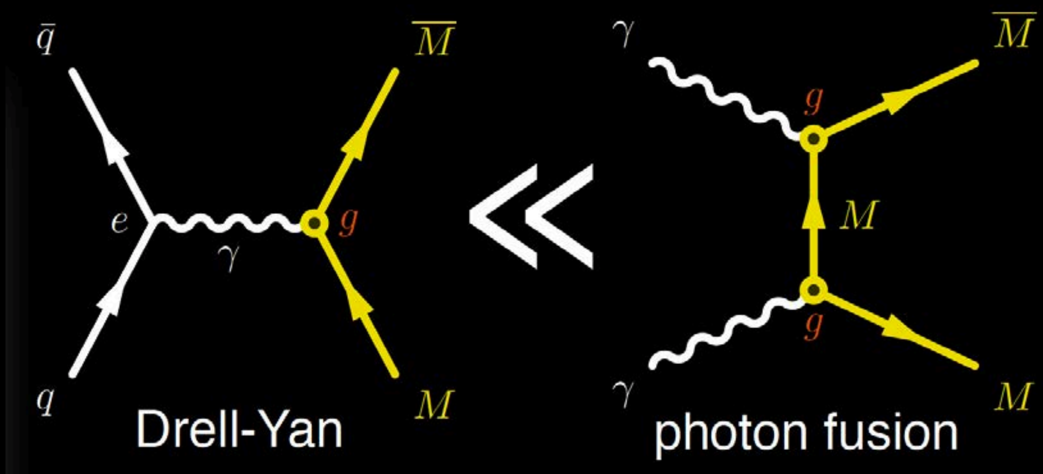
MoEDAL's Monopole Searches



JHEP 1608 (2016) 067, PRL 118 (2017) 061801, PLB 782 (2018) 510, PRL 123 (2019) 021802, PRL 126 (2021) 071801



MoEDAL, Phys.Rev.Lett. 123 (2019) 021802. Eur.Phys.J.C 78 (2018) 966

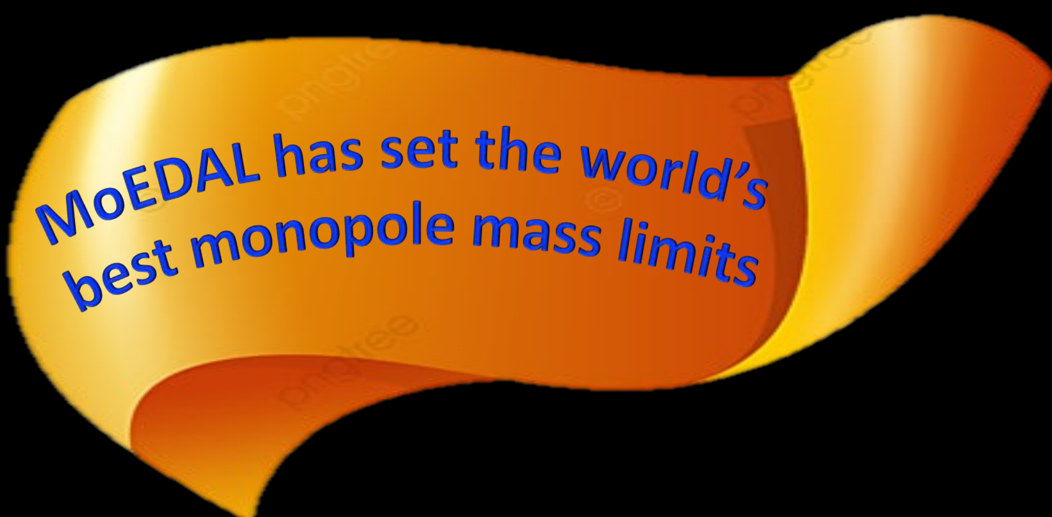


MoEDAL's Monopole Limits

MoEDAL

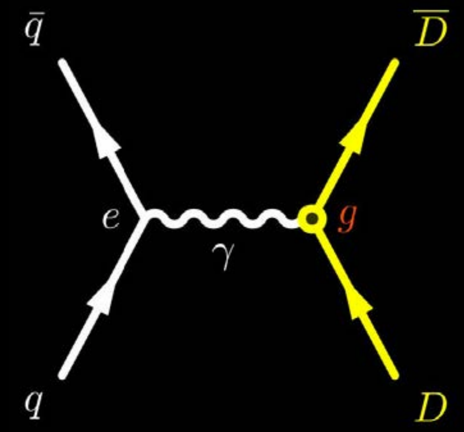
- *Unique features of MoEDAL's Search for Monopoles at the LHC*
  - *We consider β-dependent/independent couplings*
  - *Spin-1 monopoles*
  - *γγ fusion*
- *More results coming from Run-3 & HL-LHC*

Mass limits extracted that ignore non-perturbativity of large monopole-photon coupling. They serve as benchmarks to Facilitate comparisons.

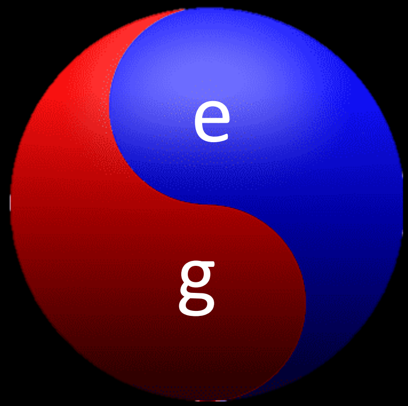


Monopole production is exponentially suppressed if the Monopole has finite size. This implies monopole searches are for point-like monopoles only

The Search for Schwinger's Dyon



Drell-yan production of a dyon

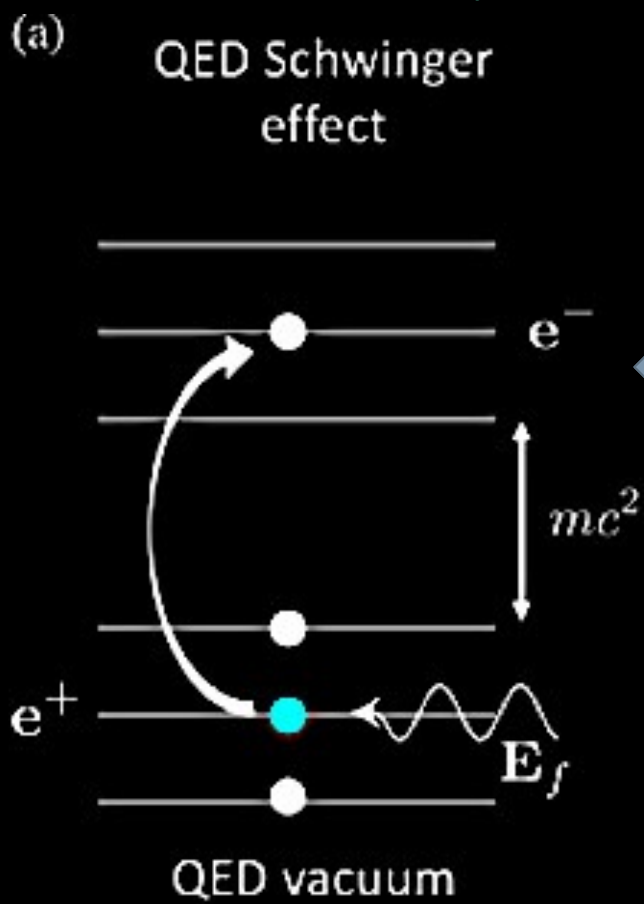


A dyon has electric and magnetic charge

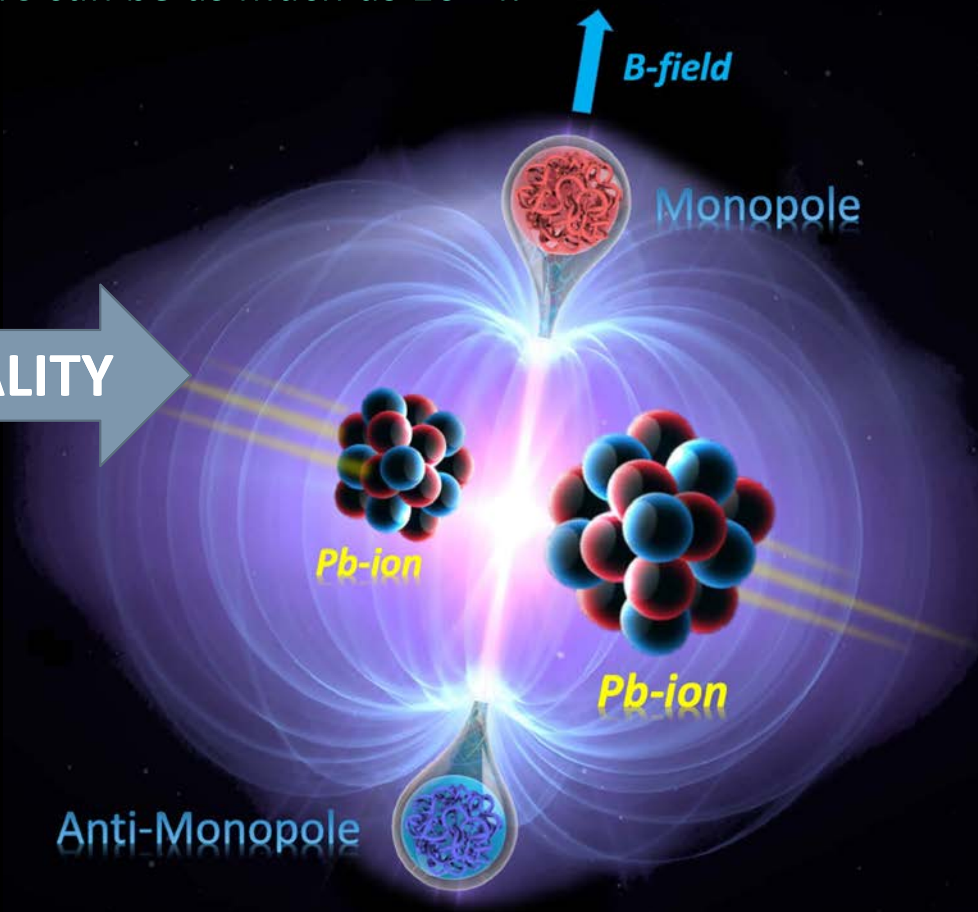
- *Mass limits 750-1910 GeV were set for dyons with up to 5g_D and electric charge 1e – 200e* (PRL 126 (2021) 071801)

Monopole Production Via the Schwinger Mechanism

The field created in ultraperipheral "collisions" of Pb-ions at the LHC can be as much as 10^{16}T.



DUALITY



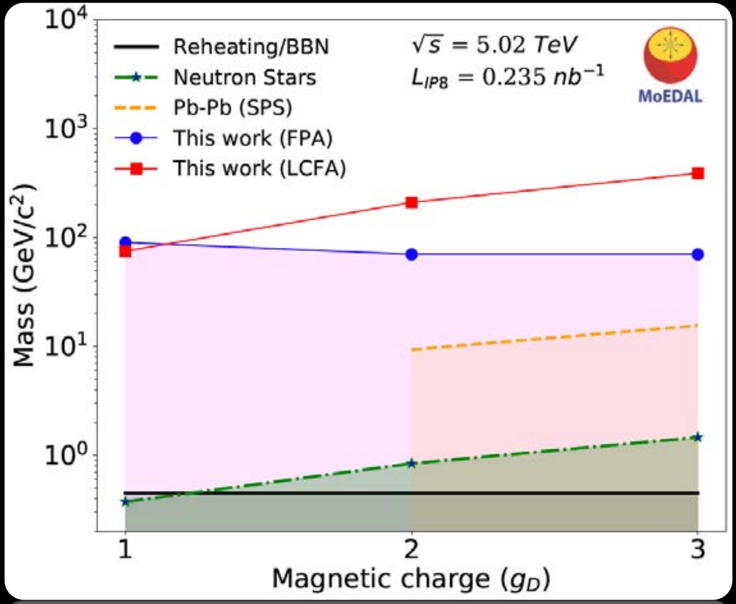
Pair production of electron-positron pairs in a very strong electric field

Pair production of monopole-antimonopole pairs in a very strong magnetic field

James Pinfold

Schwinger Production Results

- *Two approximations to the calculation of the overall MM production X-section*
  - *FPA (free-particle approximation): spacetime dependence of EM field of the heavy ions is treated exactly, but MM self-interactions are neglected MM*
  - *LCFA (locally constant field approximation): spacetime dependence of EM field is neglected, but MM self interactions are treated exactly*
- *Limits on monopoles of 1 – 3 g_D and masses up to 75 GeV*



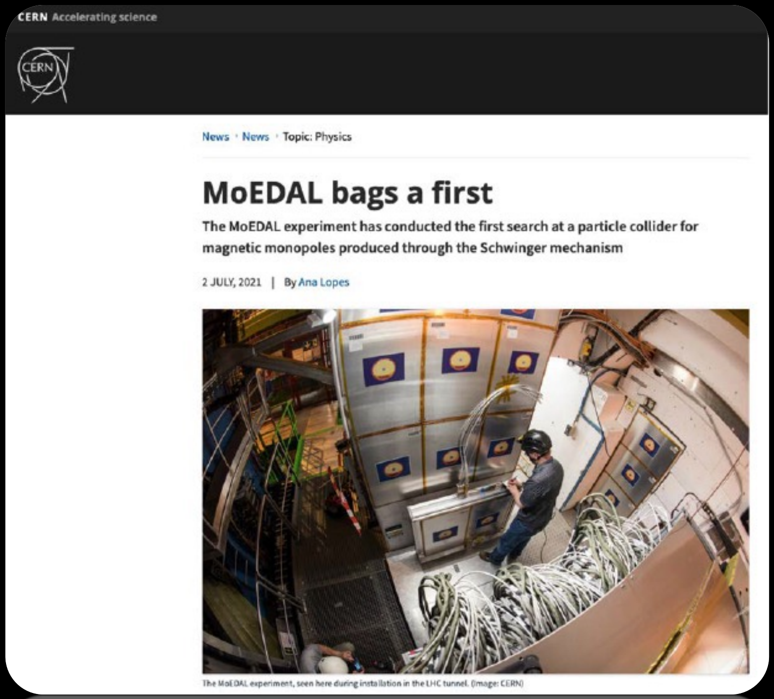
Nature 602 (2022) 7895, 63-67

First ever search for Schwinger Produced monopoles

The Importance of Schwinger Production

- *Advantages over DY & γγ-fusion monopole production:*
  - *Cross-section calculation does not suffer from non perturbative nature of coupling*
  - *No exponential suppression for finite-sized monopoles*
- *This is probably the first time that finite sized monopoles would have been detectable.*

Gould, Ho, Rajantie, PRD 100, 015041 (2019), PRD 104, 015033 (2021) Ho & Rajantie, PRD 101, 055003 (2020), PRD 103 (2021) 11, 115033


CERN Accelerating science

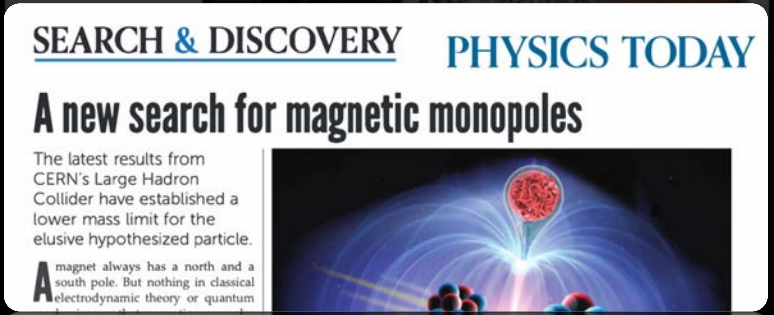
News · News · Topic: Physics

MoEDAL bags a first

The MoEDAL experiment has conducted the first search at a particle collider for magnetic monopoles produced through the Schwinger mechanism

2 JULY, 2021 | By Ana Lopes

The MoEDAL experiment, seen here during installation in the LHC tunnel. (Image: CERN)

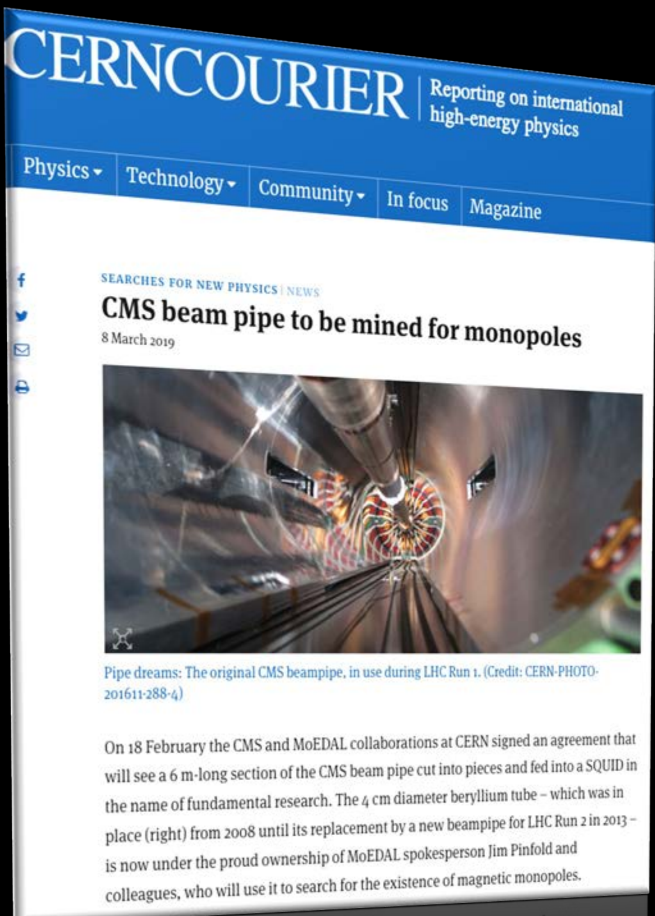

SEARCH & DISCOVERY PHYSICS TODAY

A new search for magnetic monopoles

The latest results from CERN's Large Hadron Collider have established a lower mass limit for the elusive hypothesized particle.

A magnet always has a north and a south pole. But nothing in classical electrodynamic theory or quantum

MoEDAL's Search for Monopoles Trapped in CMS Beampipe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SEARCHES FOR NEW PHYSICS | NEWS

CMS beam pipe to be mined for monopoles

8 March 2019

Pipe dreams: The original CMS beampipe, in use during LHC Run 1. (Credit: CERN-PHOTO-201611-288-4)

On 18 February the CMS and MoEDAL collaborations at CERN signed an agreement that will see a 6 m-long section of the CMS beam pipe cut into pieces and fed into a SQUID in the name of fundamental research. The 4 cm diameter beryllium tube – which was in place (right) from 2008 until its replacement by a new beampipe for LHC Run 2 in 2013 – is now under the proud ownership of MoEDAL spokesperson Jim Pinfold and colleagues, who will use it to search for the existence of magnetic monopoles.

On Feb 2019: CMS officially transferred ownership of Run-1 CMS beampipe to MoEDAL

- *MoEDAL searched for highly charged (up to 12 g_d) magnetic monopoles trapped in the Run1 CMS beampipe*
  - *Also useful in the search for Schwinger produced monopoles.*
- *We used the MoEDAL's SQUID detector based at ETH Zurich*

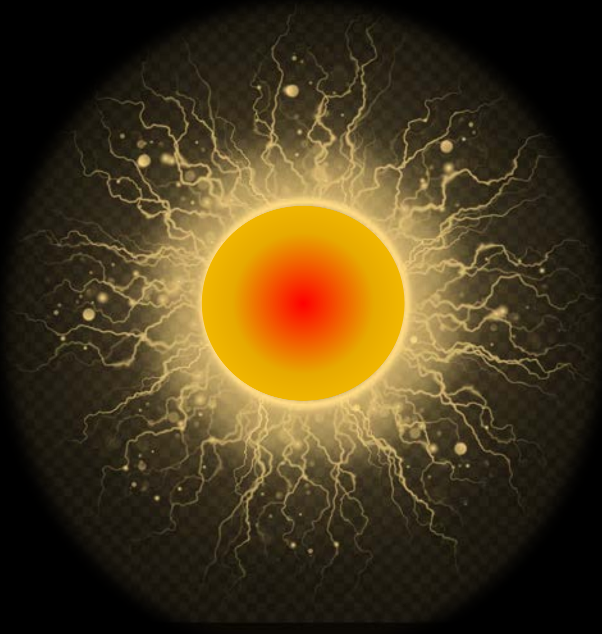
Signal for a monopole is a continuing current in the SQUID after the monopole has passed through

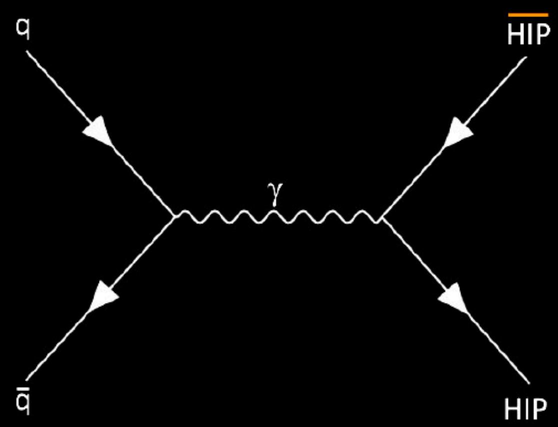
- *Analysis of the beampipe is underway*

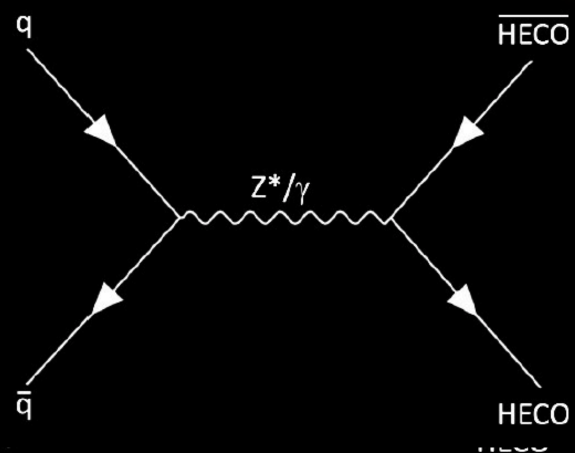
Searching for HECOs

[Highly Electrically Charged Objects (HECOs)]

- *Highly Electrically Charged Objects (HECOs, Q > ~5e): finite-sized objects (Q-balls), condensed states (strangelets), microscopic black holes (through their remnants),etc.*







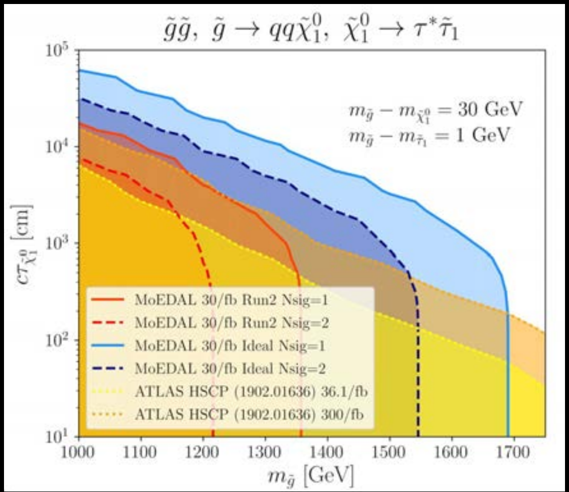
MoEDAL's First HECO Search Results

- *Run-1 limits set on the DY production of HECO pairs with cross-sections from ~ 30 – 70 pb, for electric charges in the range 15e – 175e and masses from 110 – 1020 GeV*
  - *HECOs limits are the strongest to date, in terms of charge, at any collider experiment (ATLAS limits on HECOs of 20–100e [PRL 124, 031802 (2020)])*
  - *Results accepted for publication by EPJ-C (arXiv:2112.05806)*
  - *Run-2 results in preparation promise much better limits on HECOs and Monopoles (HIPs)*

World's best charge limits on HECOs

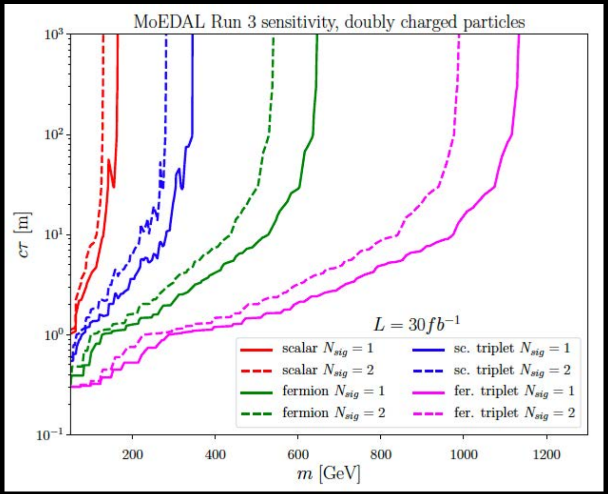
Searching for Electrically Charged HIPs

EPJC 80 (2020) 431



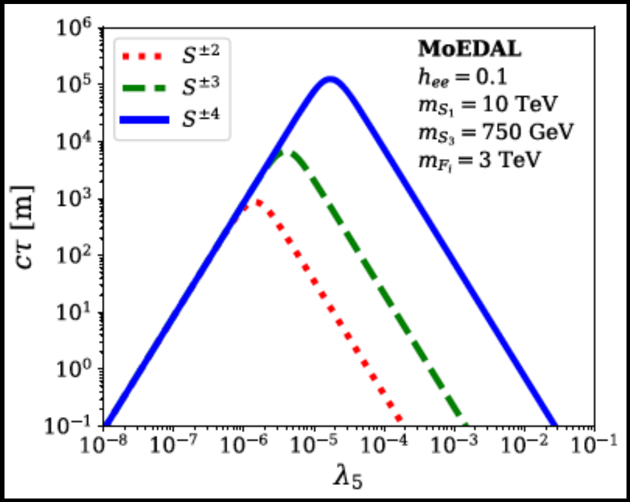
SLEPTONS

EPJC 80 (2020) 572



DOUBLY CHARGED

EPJC 81 (2021) 697



2,3 and 4 CHARGED

- *If sufficiently slow moving, even singly or multiply ($\lesssim 10$) charged particles may leave a track in NTDs*
- *Supersymmetry offers such long-lived states: sleptons, R-hadrons, charginos*
- *Multiply charged scalars or fermions are, for example, predicted in several neutrino mass models.*

MoEDAL

3

The MoEDAL Apparatus for Penetrating Particles (MAPP) Phase-1

Approved by the CERN Research Board in December 2021

For LHC's Run-3

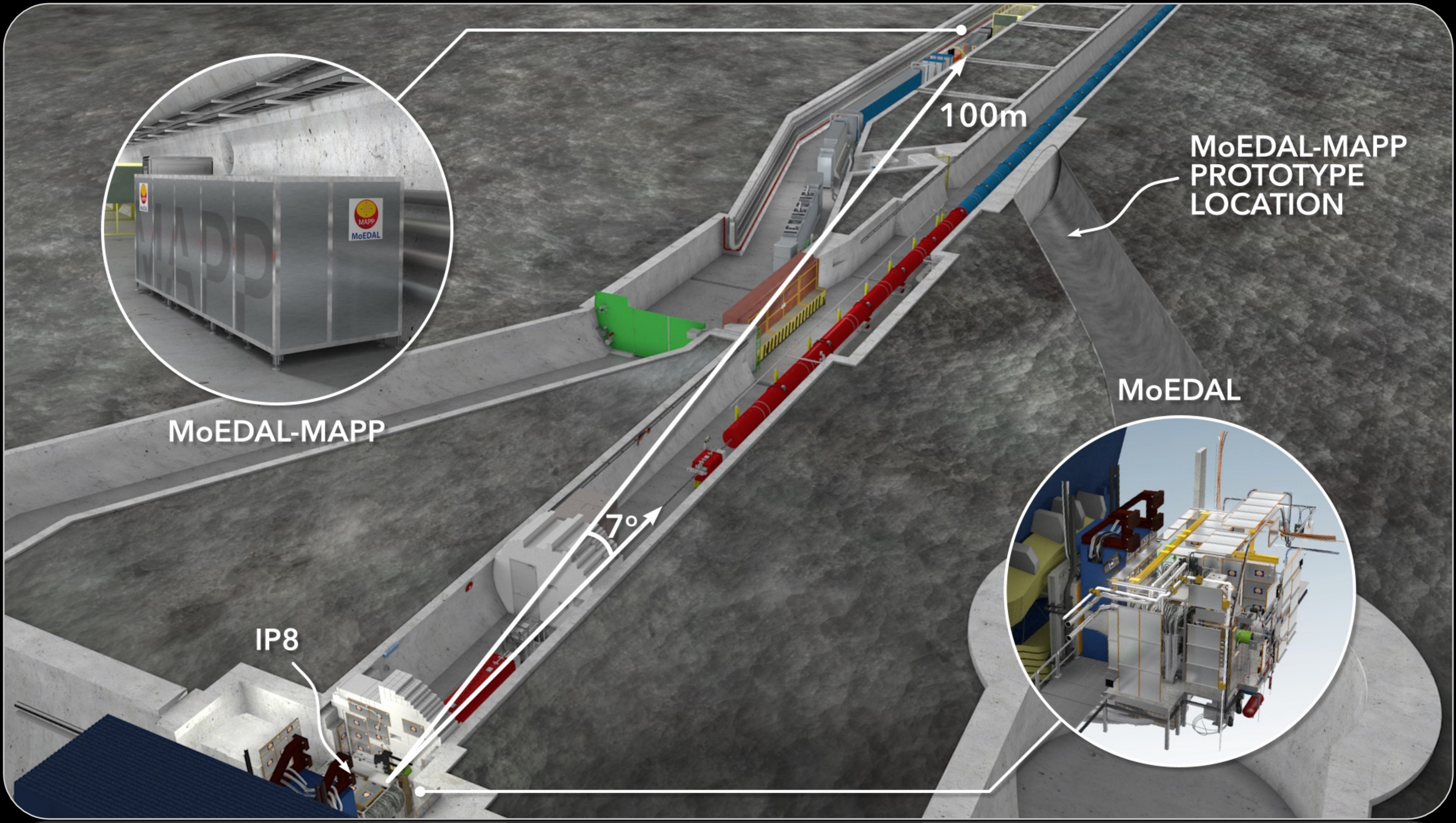
Rationale

Extend sensitivity of MoEDAL to include sensitivity to:

a) Highly Ionizing Particles
b) Milli-charged particles
c) Long-lived neutral particles
d) Very long-lived charged particles

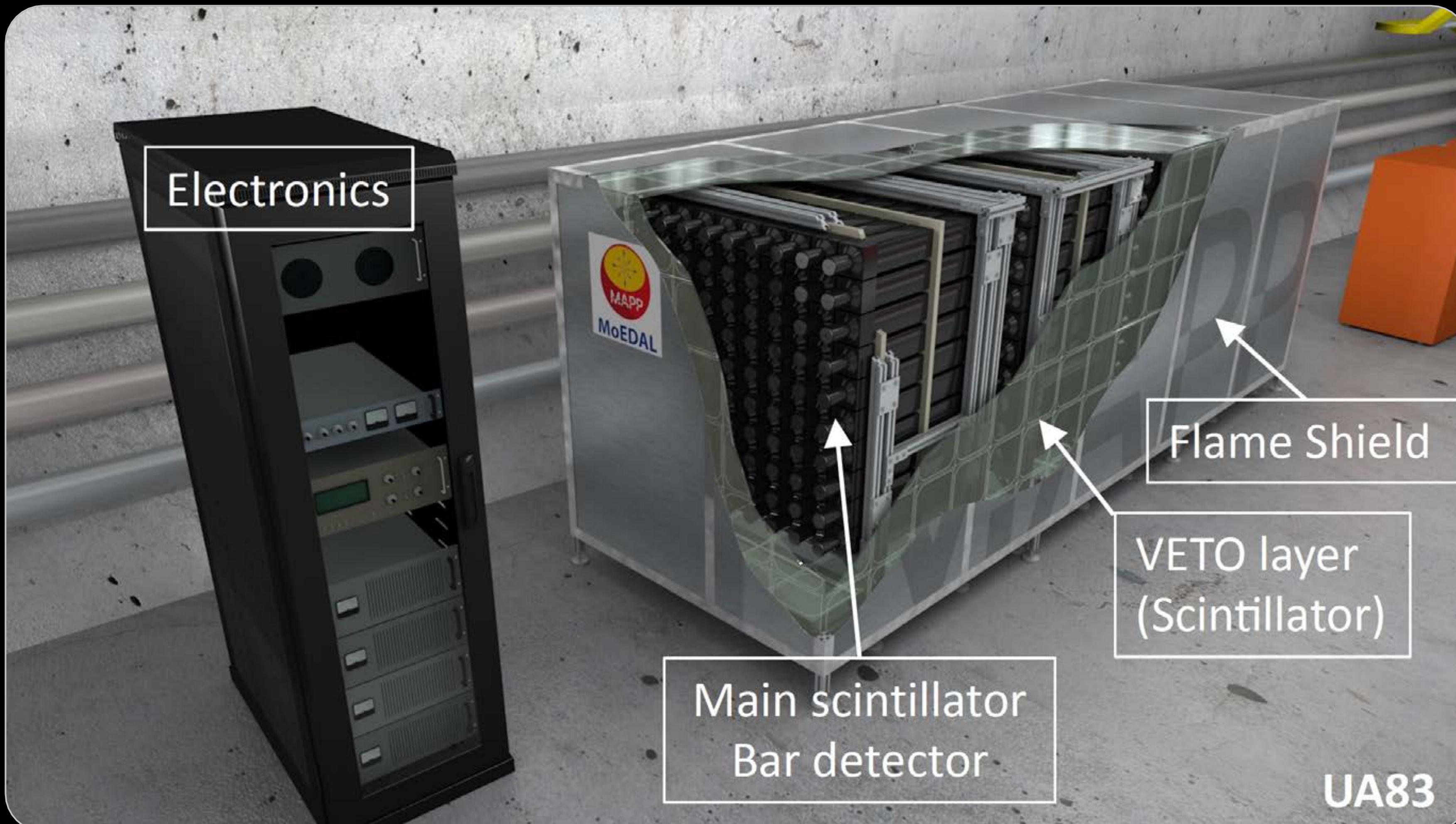
MoEDAL and MAPP Phase-1

The MoEDAL Apparatus for Penetrating Particles (MAPP) Upgrade



Expanding the Physics Reach of MoEDAL from HIPs to include FIPS

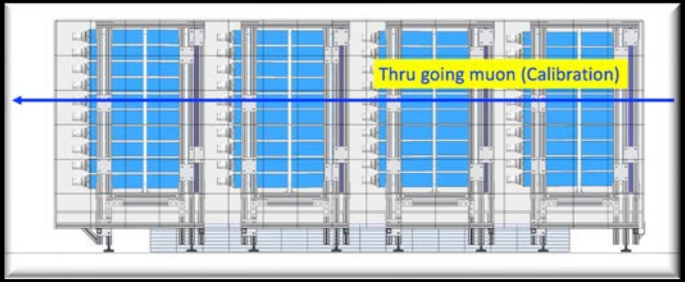
The Phase-1 MAPP Detector



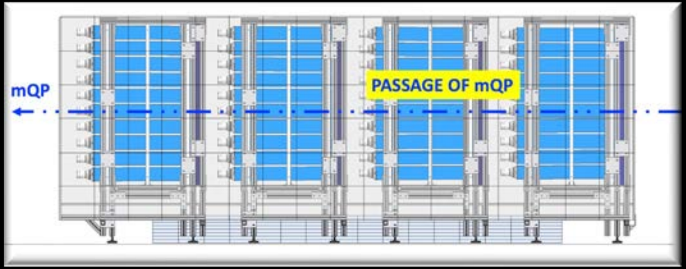
400 scintillator bars (10 x 10 x 75 cm^3) in 4 sections readout by PMTs - Protected by a hermetic VETO counter system

MAPP Phase-1 Installation in UA83

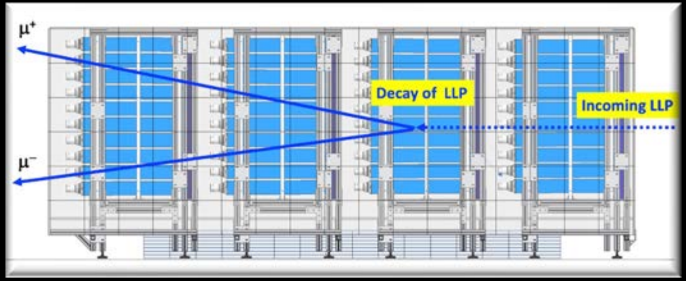
MAPP – Modes of Detection



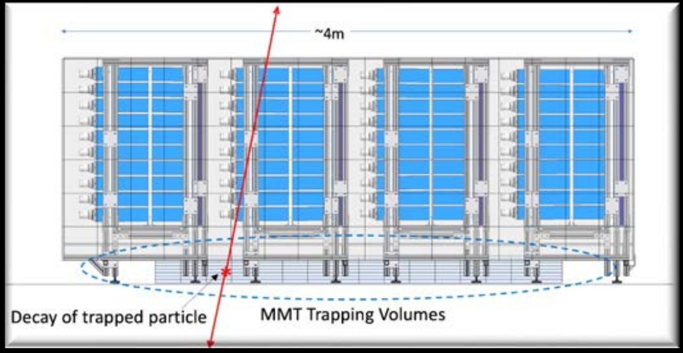
Muons from IP (Calibration)



Millicharged particle detection



Neutral LLP Detection



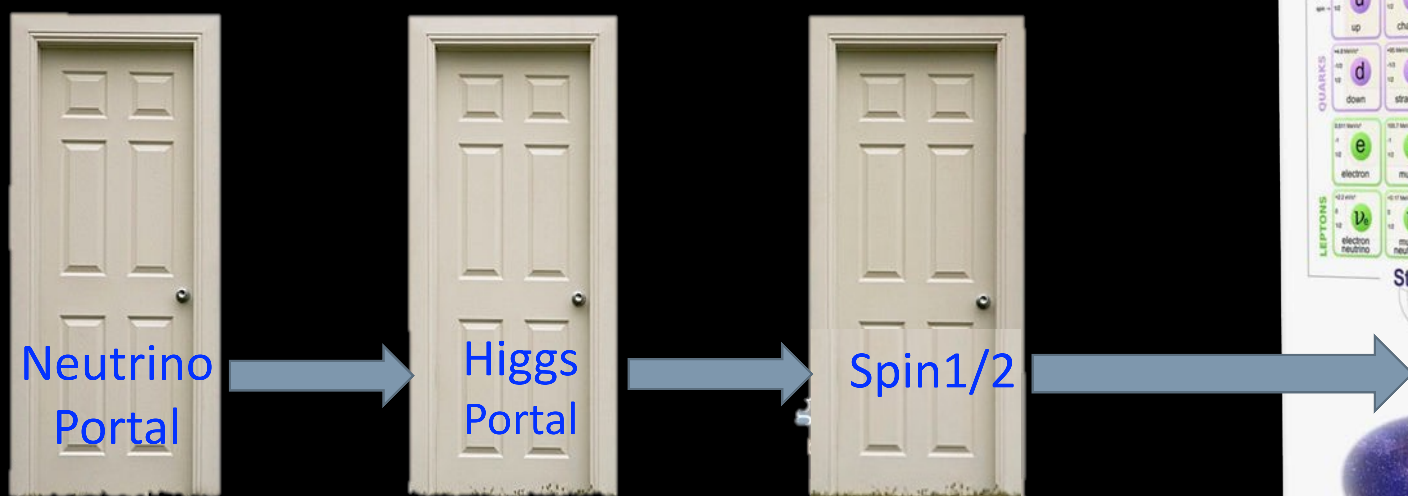
Charged LLP Detection
(In conjunction with MoEDAL)

MAPPing the Dark Sectors

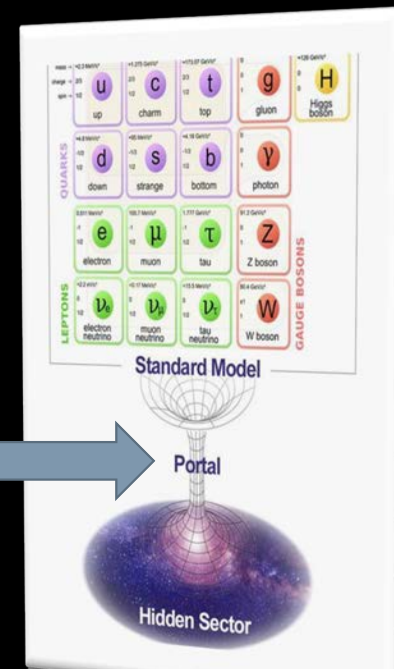
MAPP MoEDAL

Main evidence so far for dark matter is gravitational. What are the " likely" non-gravitational interactions? Dark Sector theory attempts to answer this question

Dark Sector Portals



$hL\psi_D$ $h^{\dagger}h\phi_D^{\dagger}\phi_D$ $F_{\mu\nu}F^{\mu\nu}$

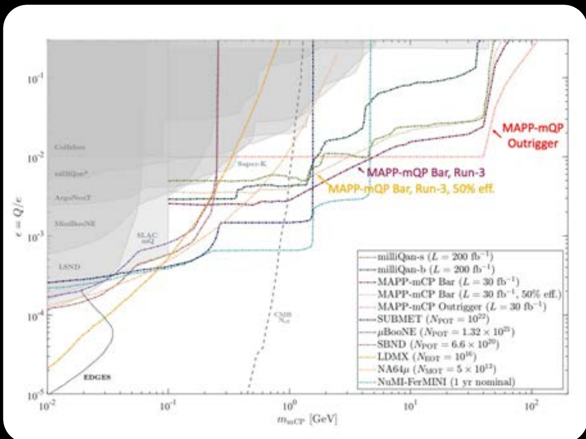


- ***VECTOR PORTAL* – Dark Photon, couples to SM fermions with suppressed couplings proportional to charge $\varepsilon.q_f$**
- ***HIGGS PORTAL* – Dark Higgs Boson, Couples to Standard Model fermions with couplings proportional to mass: $\sin\theta.m_f$**
- ***NEUTRINO PORTAL* – Sterile Neutrino, mixes with SM nu's with suppressed mixing $\sin\theta$**
- ***MESSENGER PARTICLES*** - *Interactions between the two sectors are via mediator particles*

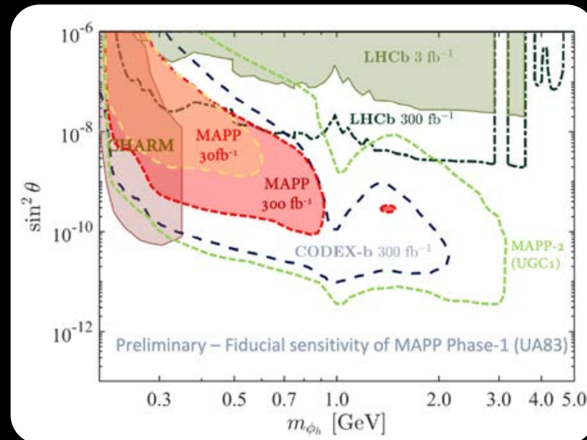
Physics Program – Examples

MoEDAL

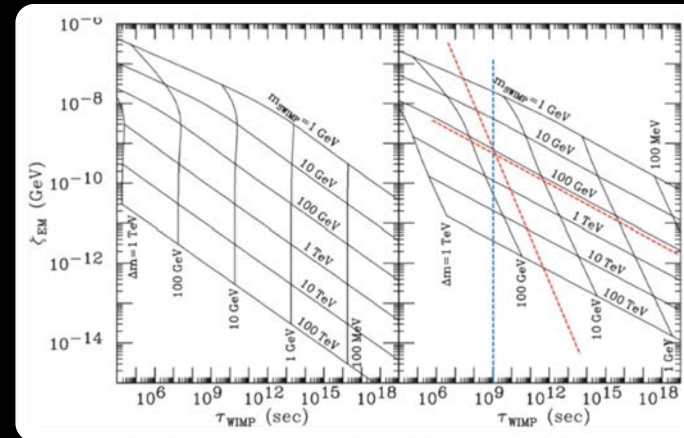
mQPs



Neutral LLPs



Charged LLPs



Phys.Lett.B746,117 2015.

Run-3 sensitivity for the decay of a dark photon to mQP pairs (assume 100% efficient detector and no background)

arXiv:2110.09392v1 [hep-ph] Oct 2021

Phys. Rev. D, 97:015023, Jan. 2018.

This benchmark involves the decay of dark Higgs where the dark Higgs mixing portal allows the exotic inclusive B decays, $B \rightarrow X_s \phi_h$, (ϕ_h is a light CP–even scalar that mixes with the SM Higgs) & $\phi_h \rightarrow \mu^+\mu^-$

J. L. Feng, A. Rajaram Phys. Rev. D 68, 063504 (2003).

CDM made of super WIMPs, that inherit the desired relic density from late decays of metastable WIMPs. Predicted values of WIMP lifetime and EM energy release shown above

MoEDAL

4

High Luminosity LHC

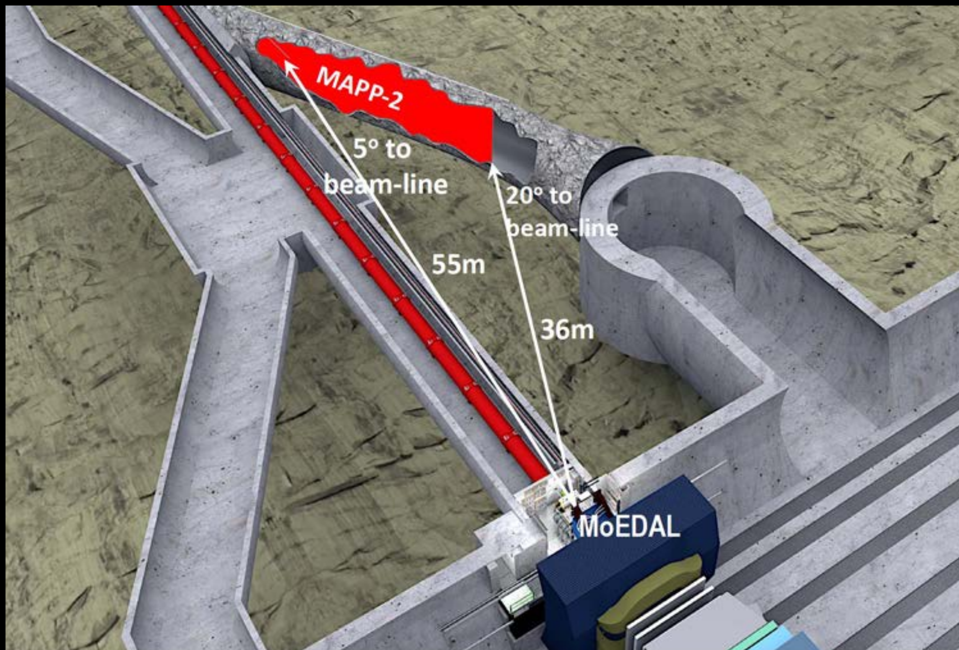
MAPP Phase-2

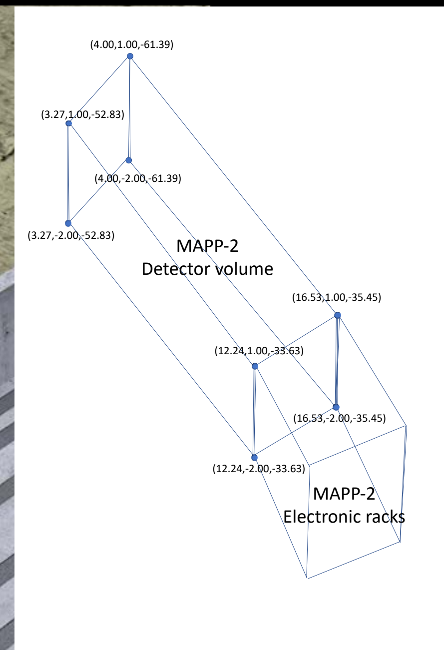
Rationale

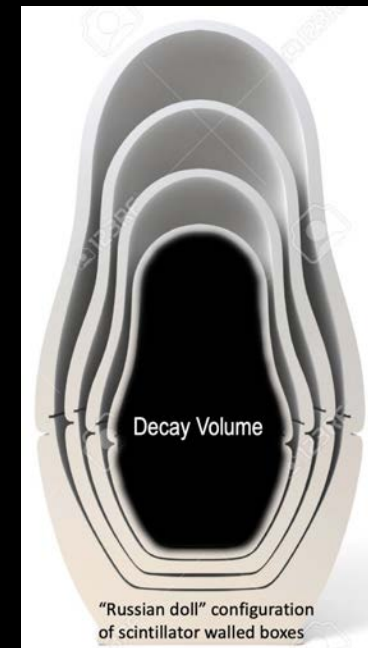
SEARCH FOR HIPs, mQPs, LLPs TO HIGH LUMINOSITY

Build the MAPP-2 detector in the UGC1 gallery to greatly Increase the fiducial volume For the search for LLPs.

Phase-2: MAPP-2 for HL-LHC



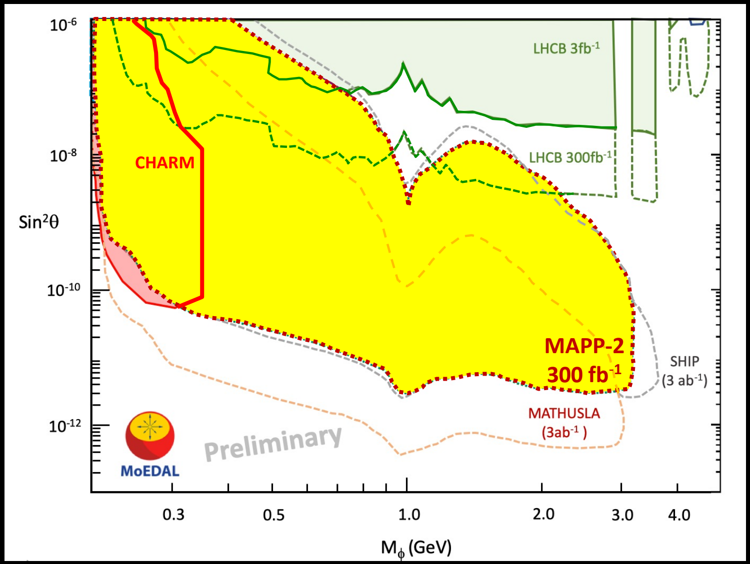




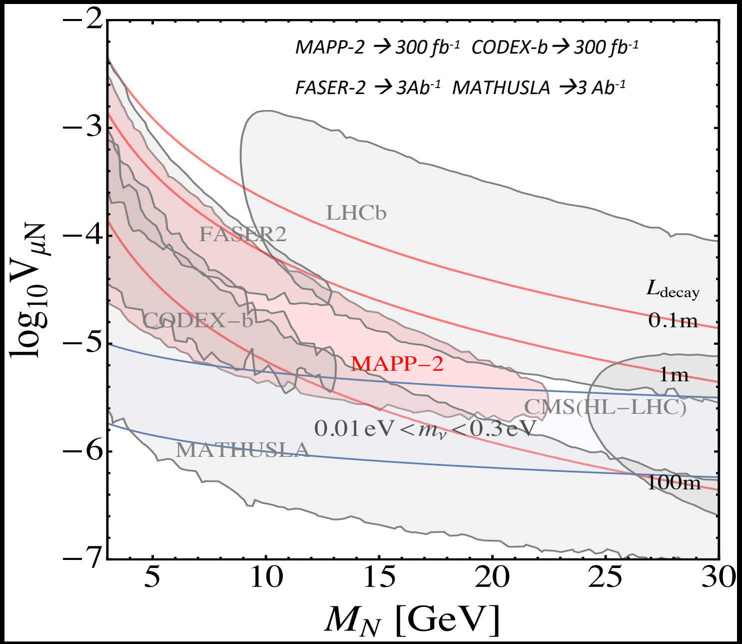
- *The UGC1 gallery would be prepared during LS3 prior to HL-LHC*
- *The MAPP-2 detector extends down the length of the UGC1 gallery*
- *The tracking detectors would form 3 or 4 hermetic containers - one within the other – lining the walls of UGC1*
  - *Detector technology large tiles with x-y WLS fibre readout with resolution $\lesssim$ 1cm/measurement*

MAPP-2 (LLP): Example Physics Studies

- *Benchmark process:*
  - *Where the Higgs mixing portal admits inclusive $B \rightarrow X_s \phi$ decays, where φ is a light CP-even scalar that mixes with the Higgs, with mixing angle $\vartheta \ll 1$.*
- *TOP: MAPP-2 each for 300 fb^{-1} compared to CODEX-b, SHIP, MATHUSLA.*
- *Bottom: Pair production of right-handed neutrinos from the decay of an additional neutral **Z^0** boson in the gauged **B-L** model – Phys. Rev. D100 (2019), 035005.*
  - *No backgrounds/efficiencies are included*



See Phys. Rev. D97 (1) (2018) 15023 for CODEX-b results.



Concluding Remarks