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

RESULTS & FUTURE PLANS

James L. Pinfold
University of Alberta
For the MoEDAL-MAPP Colaboration

ICHEP 2022

MoEDAL-MAPP Collaboration

70 physicists at 26 Institutes

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

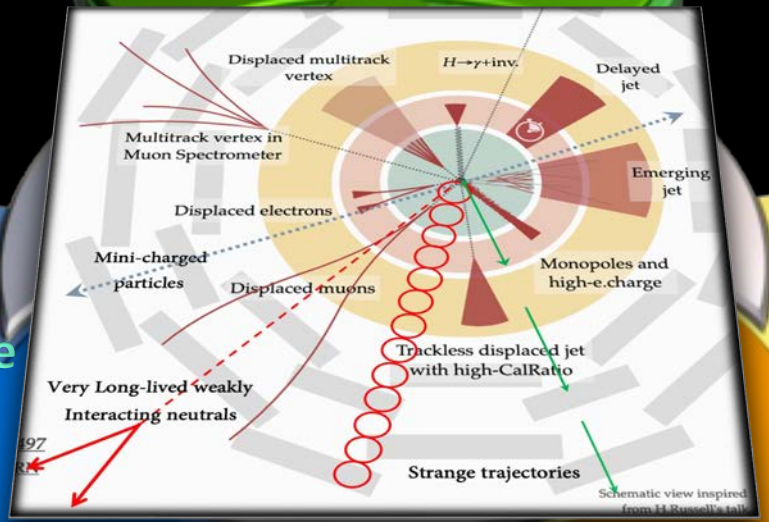
Avatars of New Physics.....

MoEDAL

Long-lived Particles (LLPs)

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

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



Magnetic charge
-dE/dx ∝ g^2
g =n68.5e

Electric charge
-dE/dx ∝ z^2/β^2
Z ≥1 β < 1

Highly-ionizing particles (HIPs)

Electric charge
-dE/dx ∝ Z^2/β^2
Z(<<1) β(~1)

Feebly interacting particles (FIPs)

.....for which ATLAS & CMS are not optimized

MoEDAL-MAPP Physics Program

MoEDAL

HIPs

Magnetic monopoles
KK extra dimensions
D-matter
Quirks
Q-balls
Black-hole remnants
Doubly charged Higgs
SUSY R-hadrons sleptons

MAPP-1&2

FIPs

Hidden Sector Millicharged particles
FCHAMPS
D-Brane insp. SU(3)C X SU(3)L X SU(3)R - Models
Free Quarks
Magnons
Dark Monopoles
Strongly Interacting Ultralight Millicharged Particles (STUMPS)
Superstring models

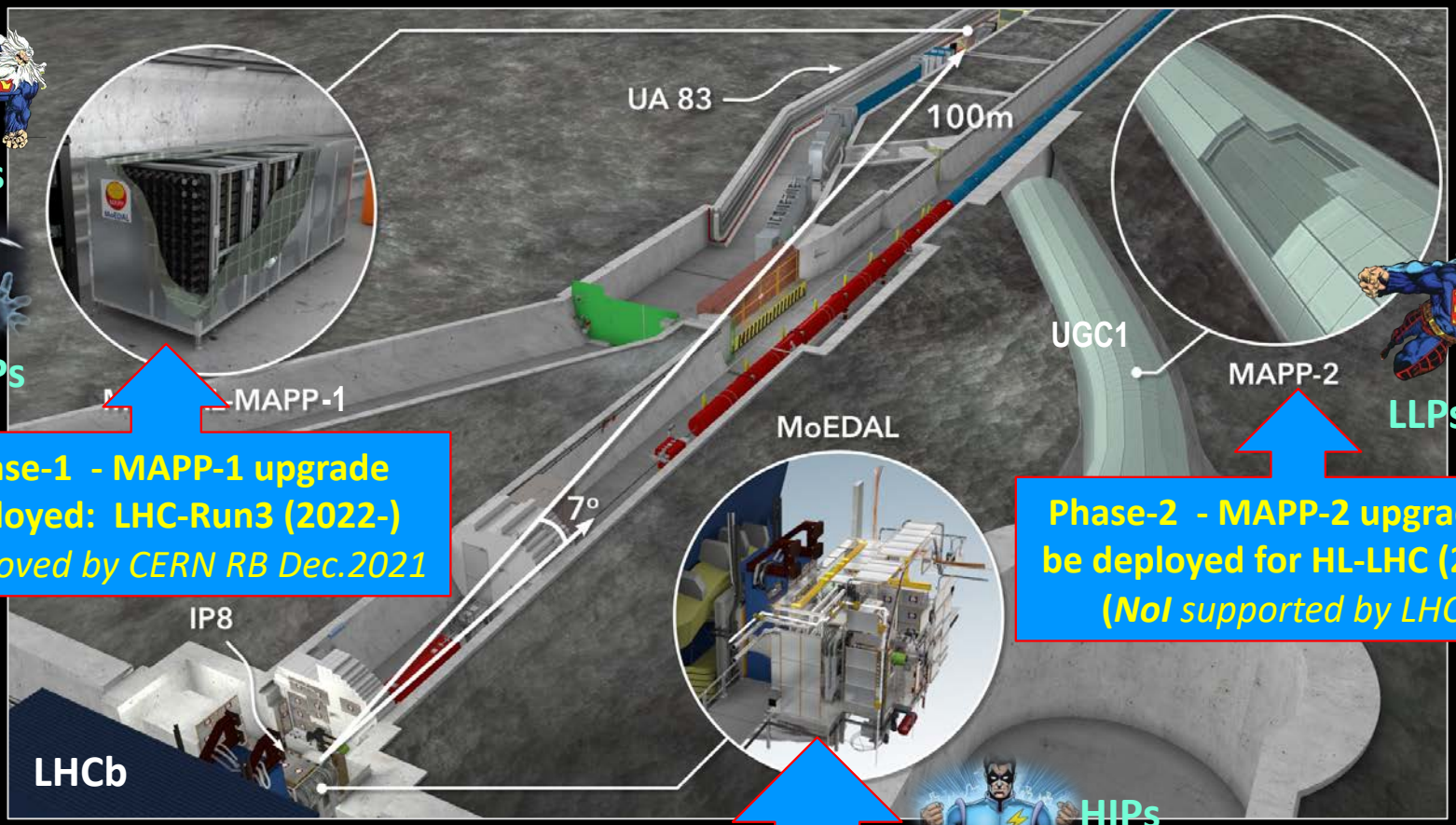
MoEDAL

MAPP-1

LLPs

Hidden Valley Models
Dark Sector Models
ALPs
Heavy Neutral Leptons
Neutrino Mass Models
Mirror-matter models
SUSY GMSB models
SUSY RPV models

MoEDAL-MAPP a >20 Year Project



Phase-1 - MAPP-1 upgrade deployed: LHC-Run3 (2022-)
(Approved by CERN RB Dec.2021

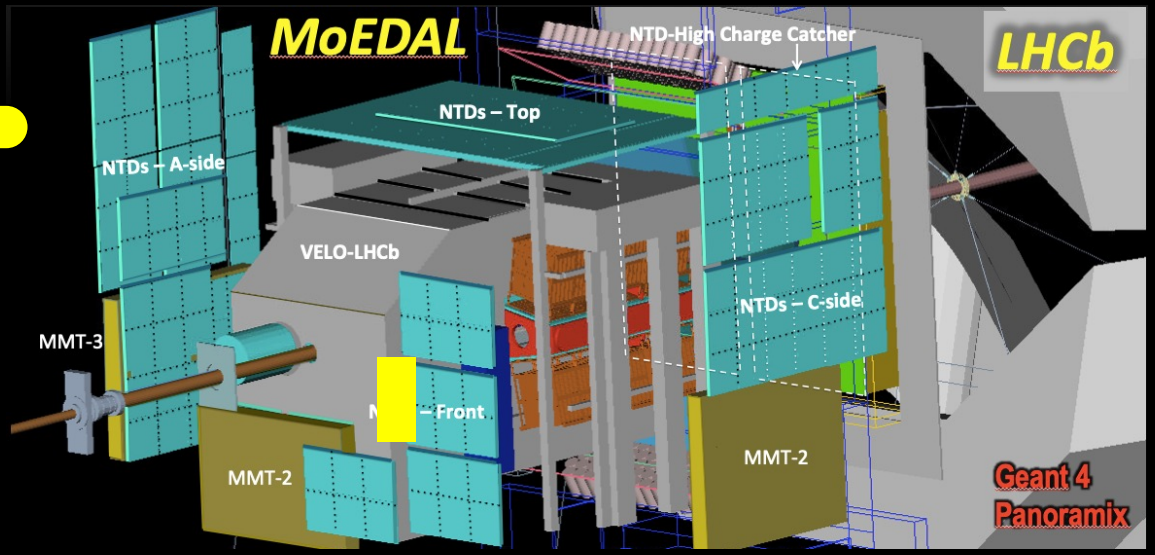
Phase-2 - MAPP-2 upgrade to be deployed for HL-LHC (2027-)
*(**NoI** supported by LHCC)*

Phase-0 - MoEDAL Detector deployed for LHC-Run-1& 2 (2010 - 18) and Run-3 (2022 -)
(Approved by CERN RB in 2010 & reapproved for LHC's Run-3 in Dec. 2021

The MoEDAL Detector at Run-2&3

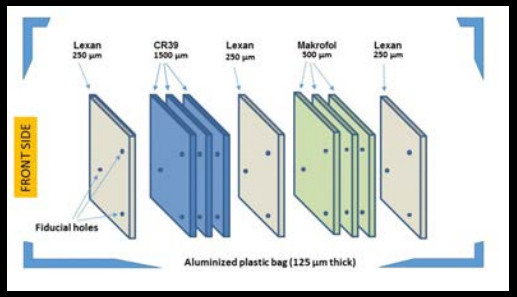
MoEDAL

Permanent Physical record of new physics

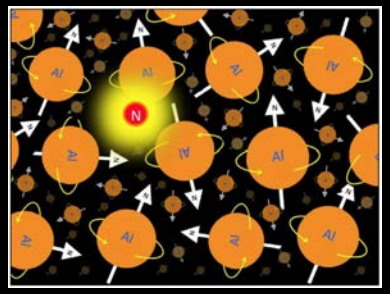


No Standard Model physics backgrounds

Passive detectors - No Trigger Requirements



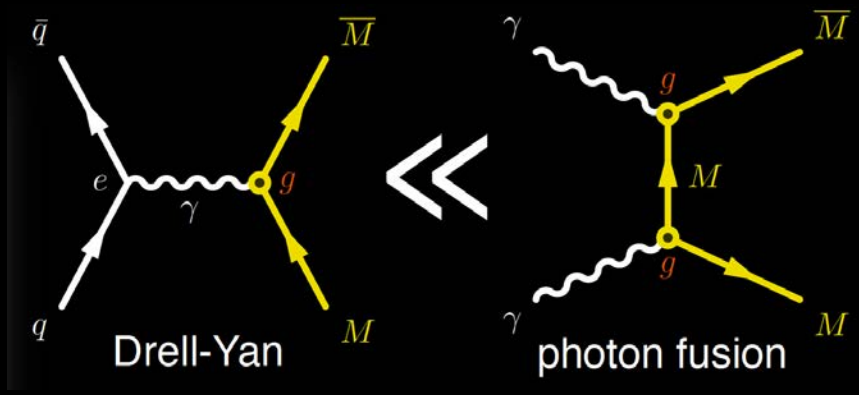
NUCLEAR TRACK DETECTOR Plastic array (186 stacks, 12 m^2) – Like a big Camera

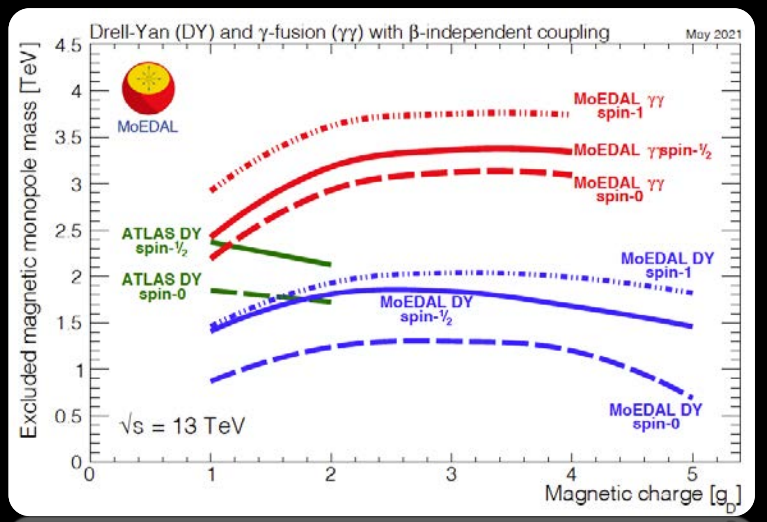


TRAPPING DETECTOR ARRAY A tonne of Al to trap Highly Ionizing Particles for analysis

TIMEPIX Array a digital Camera for real time radiation monitoring

MoEDAL's Monopole Searches

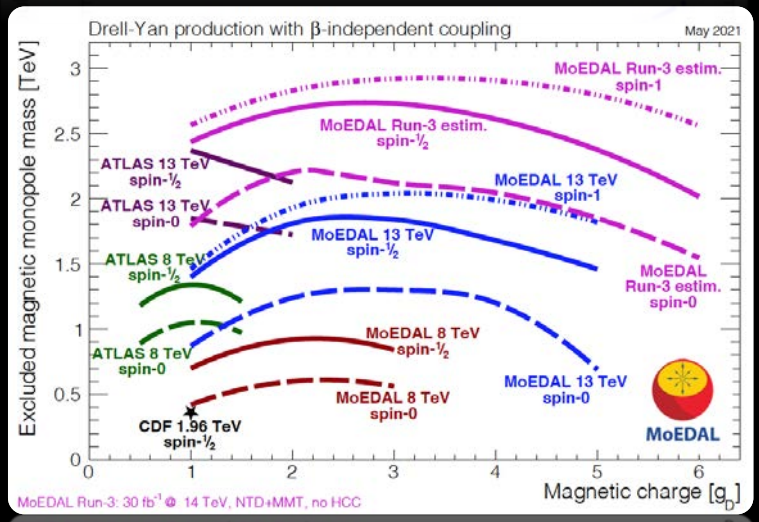




JHEP 1608 (2016) 067, PRL 118 (2017) 061801, PLB 782 (2018) 510, PRL 123 (2019) 021802, PRL 126 (2021) 071801

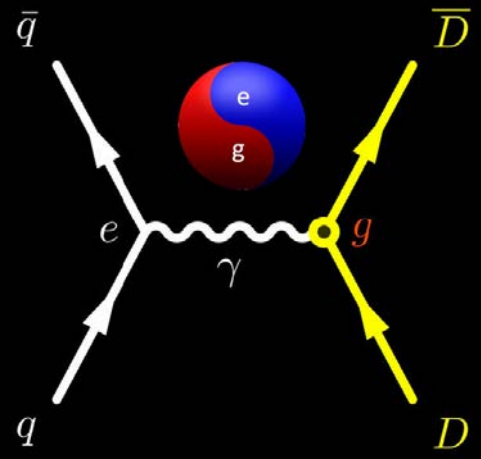
- *Unique features of MoEDAL's Search for Monopoles at the LHC*
  - *We consider β-dep./indep. couplings*
  - *Spin-1 monopoles*
  - *γγ fusion*
- *More results from Run-3 & HL-LHC*

MoEDAL has set the world's best monopole mass limits



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

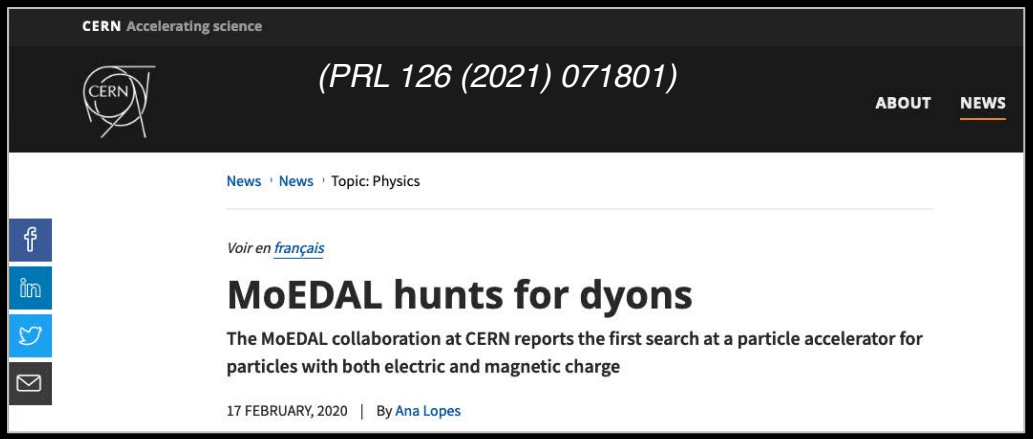
First Direct Search for the Dyon

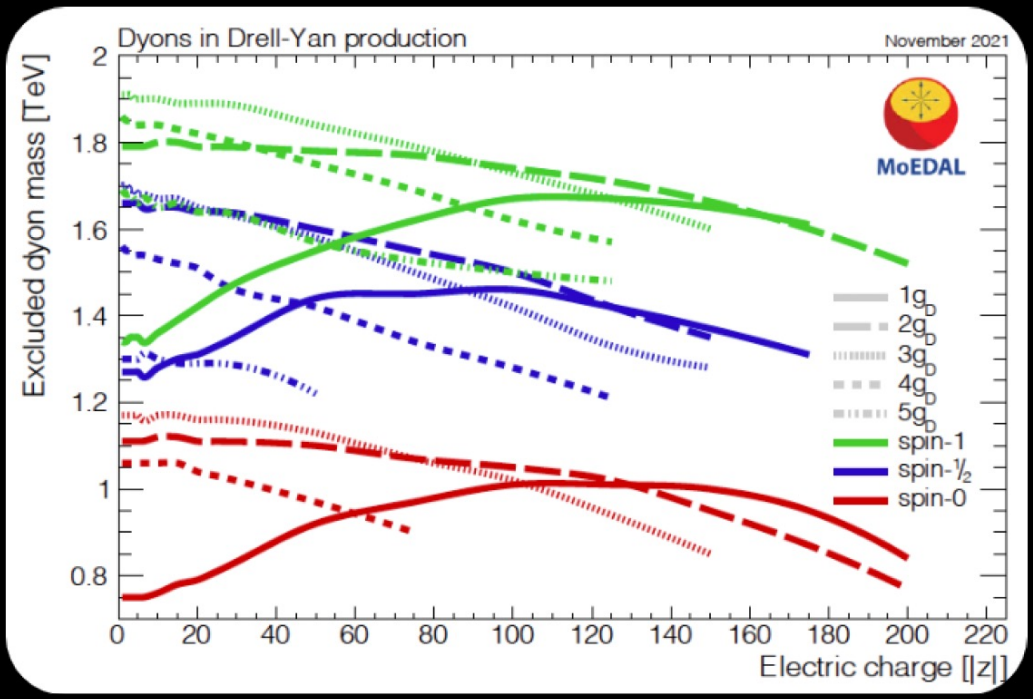


Predicted by Schwinger in 1969 a dyon has electric &magnetic charge

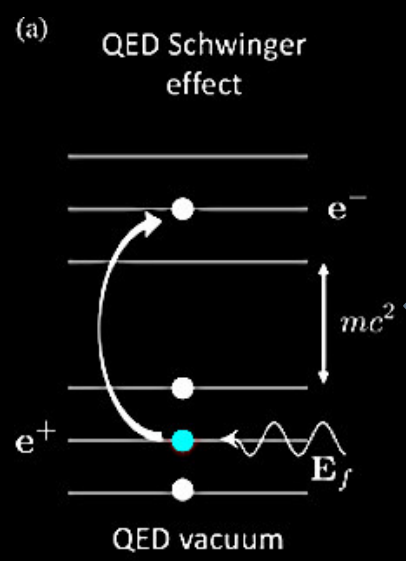
- *Mass limits 750-1910 GeV were set for dyons with ≤5g_D & electric charge ≤ 200e*

First ever explicit search for a dyon

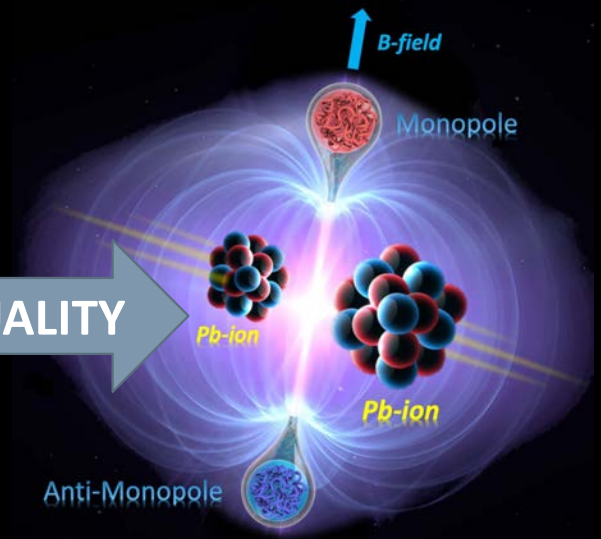


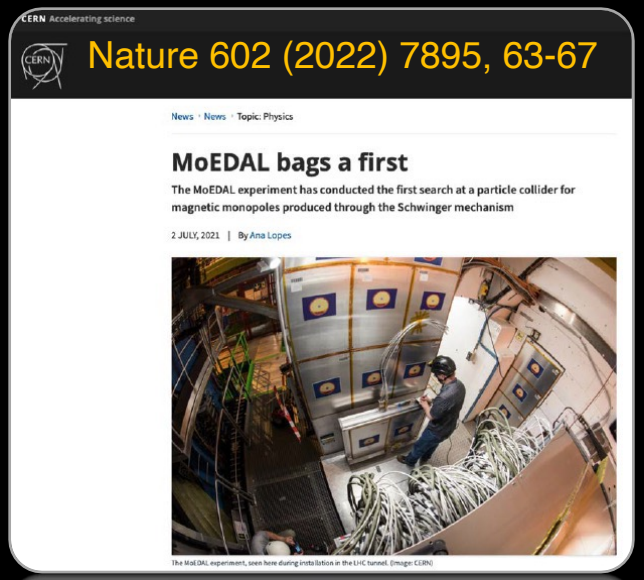


Schwinger Production of Monopole Pairs



DUALITY





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

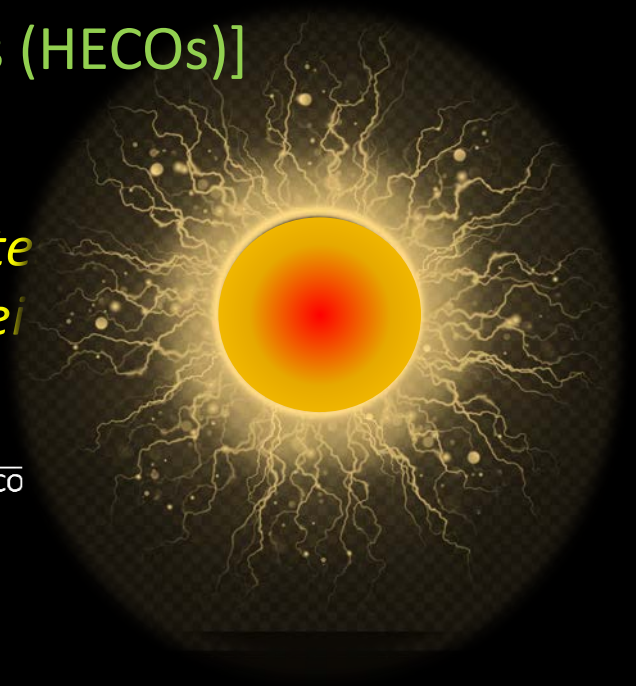
Pair production of monopole-antimonopole pairs in a very strong magnetic field created in ultraperipheral "collisions" of Pb-ions at the LHC can be as much as 10^{16}T.

- ***Limits on Schwinger monopoles of 1 – 3 g_D and masses up to 75 GeV***
- *Advantages of Schwinger monopole production:*
  - *X-section calculation does not suffer from perturbative nature of coupling;*
  - *No exponential suppression for finite-sized monopoles.*

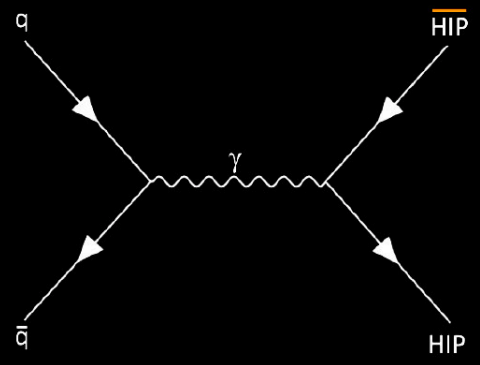
1st time finite sized monopoles detectable?

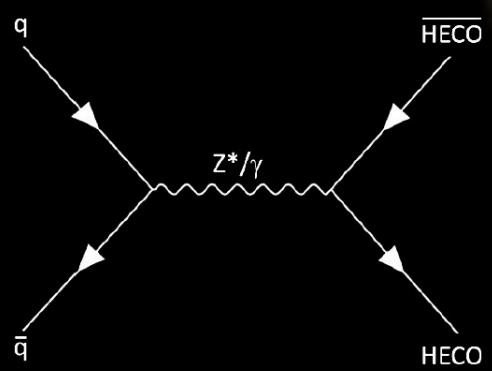
Searching for HECOs

[Highly Electrically Charged Objects (HECOs)]



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





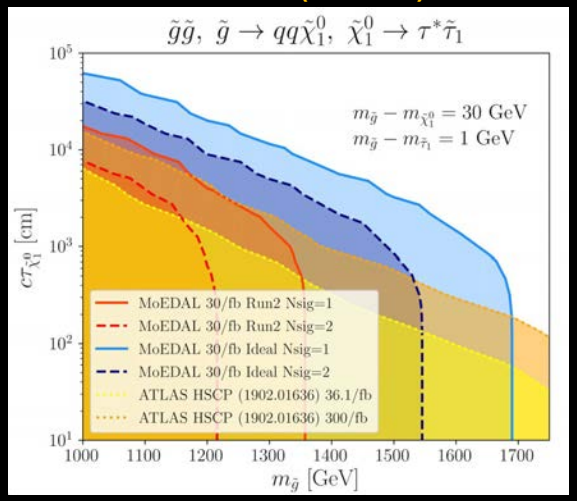
- *Run-1 limits set on the DY production of HECO pairs with cross-sections from ~ 30 – 70 pb, for electric charges in the range 15e – 175e and masses from 110 – 1020 GeV*

World's best charge limits on HECOs

To be publication by EPJ-C (arXiv:2112.05806)

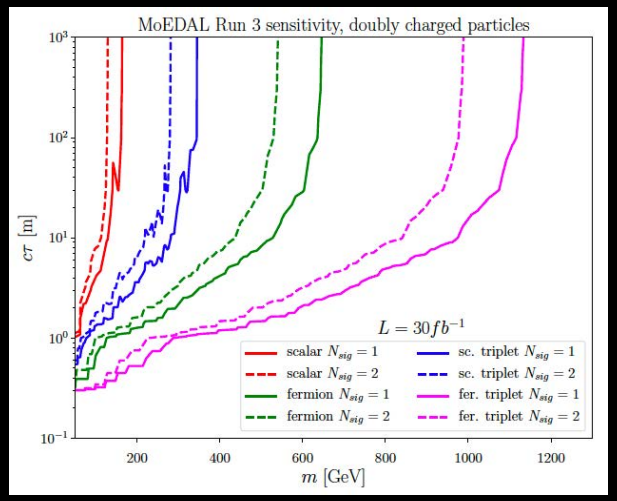
Searching for Electrically Charged HIPs

EPJC 80 (2020) 431



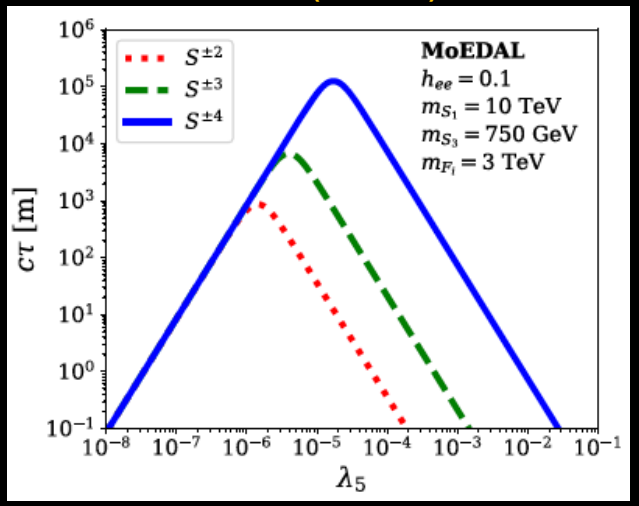
SLEPTONS

EPJC 80 (2020) 572



DOUBLY CHARGED

EPJC 81 (2021) 697



2,3 and 4 CHARGED

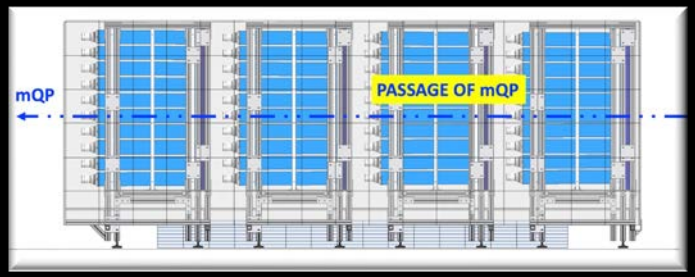
- *If sufficiently slow moving, even singly or multiply ($\lesssim 10$) charged particles may leave a track in NTDs*
- *Supersymmetry offers such long-lived states: sleptons, R-hadrons, charginos*
- *Multiply charged scalars or fermions are, for example, predicted in several neutrino mass models.*

The Phase-1 MAPP Detector

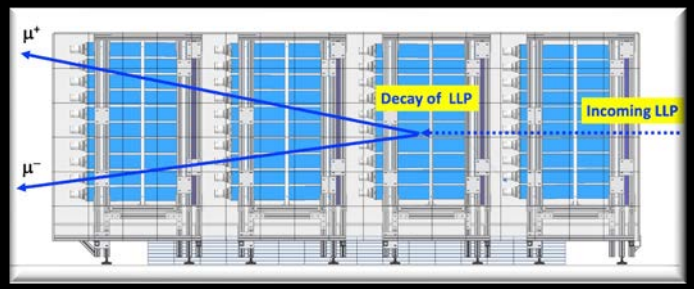
- *400 scintillator bars (10 x 10 x 75 cm^3) in 4 sections readout by PMTs - Protected by a hermetic VETO counter system*
- *Each through-going particle sees 3m of scintillator readout by a coincidence of 4 low noise PMTs*

MAPP – Modes of Detection

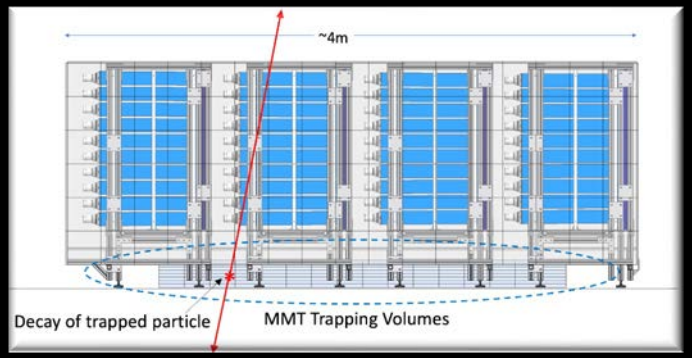
Muons from IP (Calibration)



Millicharged particle detection



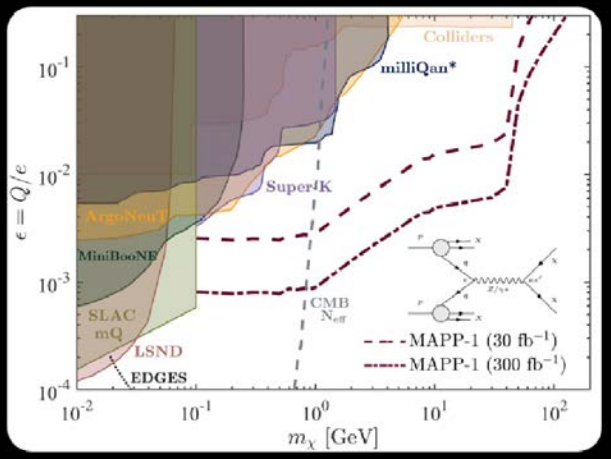
Neutral LLP Detection



Charged LLP Detection
(In conjunction with MoEDAL)

Physics Program – Examples

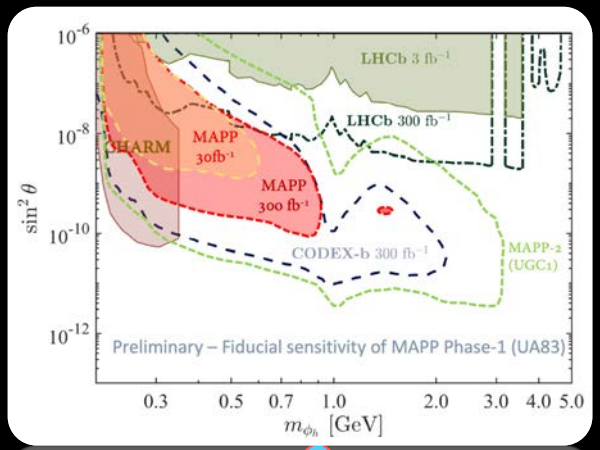
mQPs



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)

Neutral LLPs

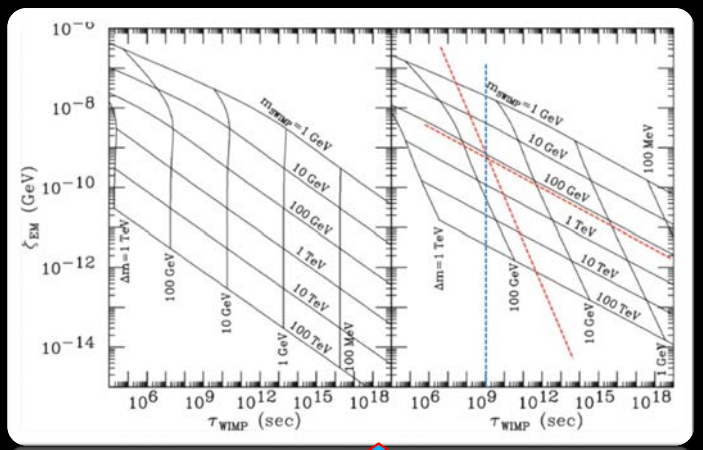


arXiv:2110.09392v1 [hep-ph] Oct 2021

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) & $\phi_h \rightarrow \mu^+\mu^-$

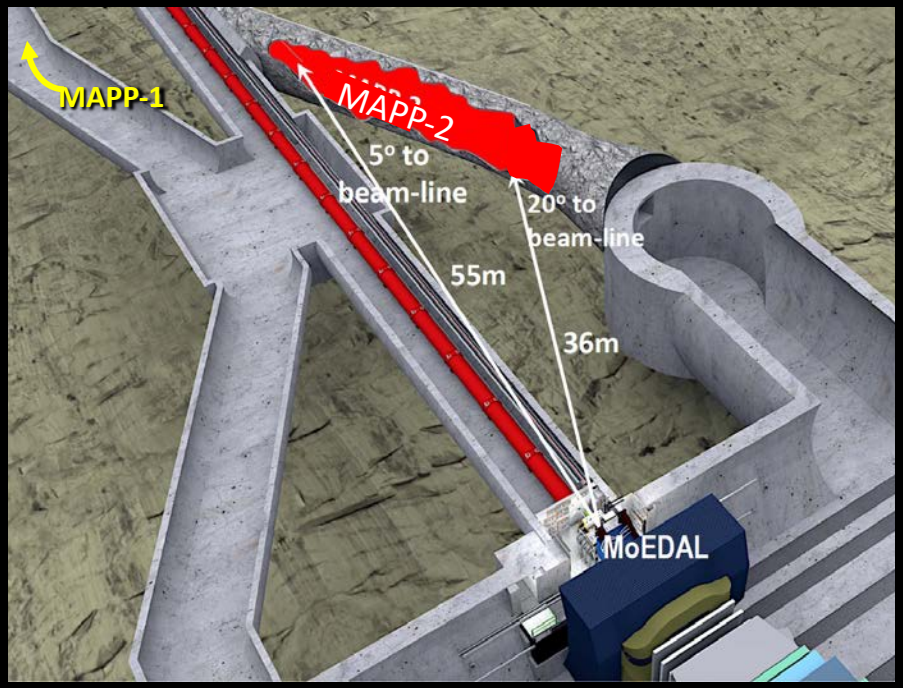
Charged LLPs

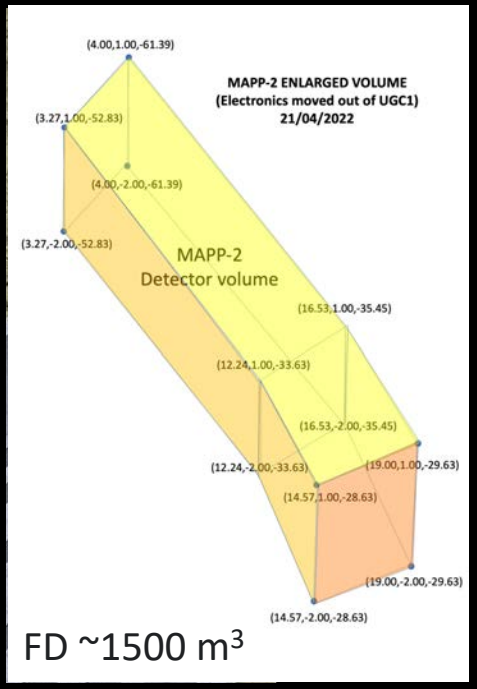


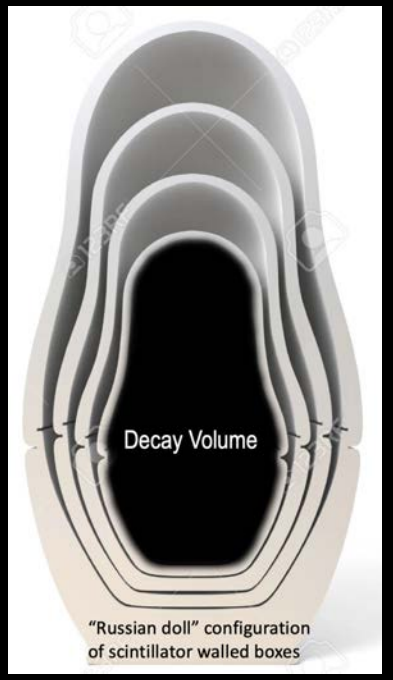
J. L. Feng, A. Rajaram Phys. Rev. D 68, 063504 (2003).

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

Phase-2: MAPP-2 for HL-LHC



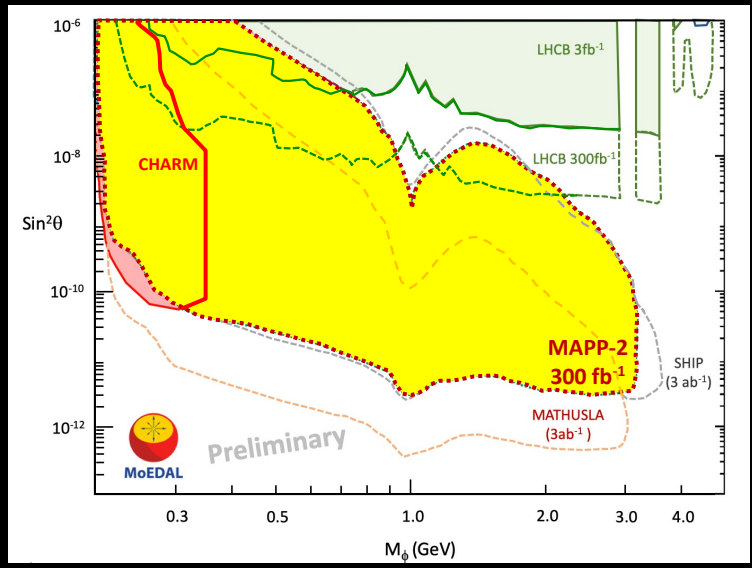




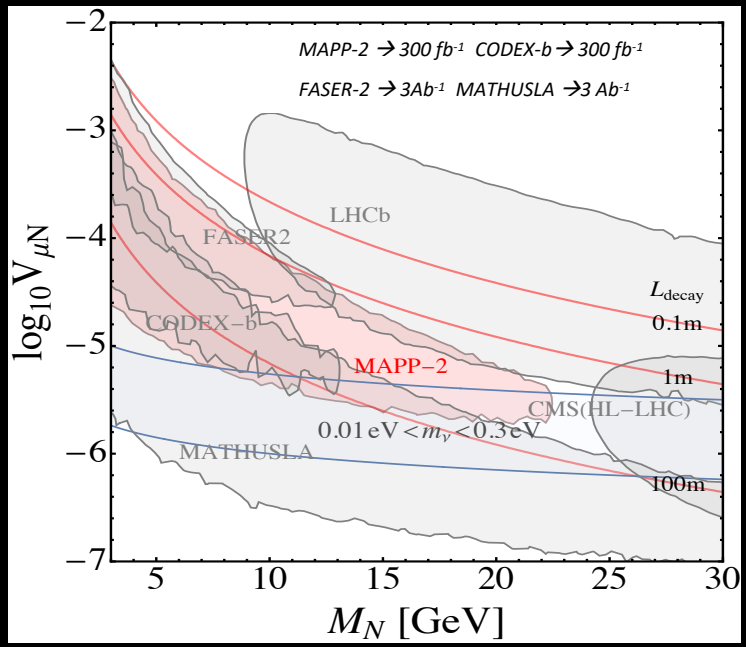
- *The UGC1 gallery would be prepared during LS3 prior to HL-LHC*
- *The MAPP-2 detector extends down the length of the UGC1 gallery*
- *The tracking detectors would form 3 or 4 hermetic containers - one within the other – lining the walls of UGC1*
  - *Detector technology large tiles with x-y WLS fibre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

MAPP-2 (LLP): Example Physics Studies

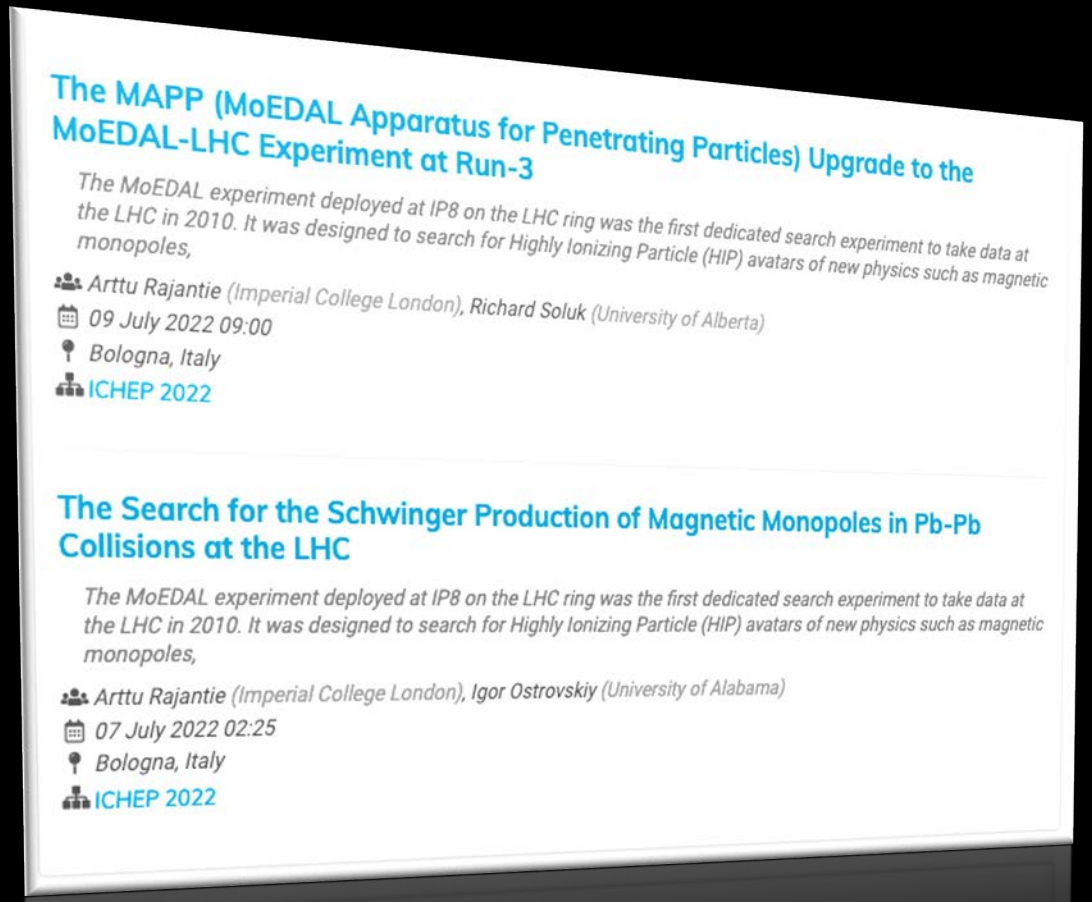
- *Benchmark process:*
  - *Where the Higgs mixing portal admits inclusive B → $X_s\phi$ decays, where φ is a light CP-even scalar that mixes with the Higgs, with mixing angle $\vartheta \ll 1$.*
- *TOP: MAPP-2 each for 300 fb^{-1} compared to CODEX-b, SHIP, MATHUSLA.*
- *Bottom: Pair production of right-handed 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*
  - *Full Monte-Carlo simulation now available and being studied*



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



Other MoEDAL-MAPP Talks At ICHEP 2022



The MAPP (MoEDAL Apparatus for Penetrating Particles) Upgrade to the MoEDAL-LHC Experiment at Run-3

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,

Arttu Rajantie (Imperial College London), Richard Soluk (University of Alberta)
09 July 2022 09:00
Bologna, Italy
ICHEP 2022

The Search for the Schwinger Production of Magnetic Monopoles in Pb-Pb Collisions at the LHC

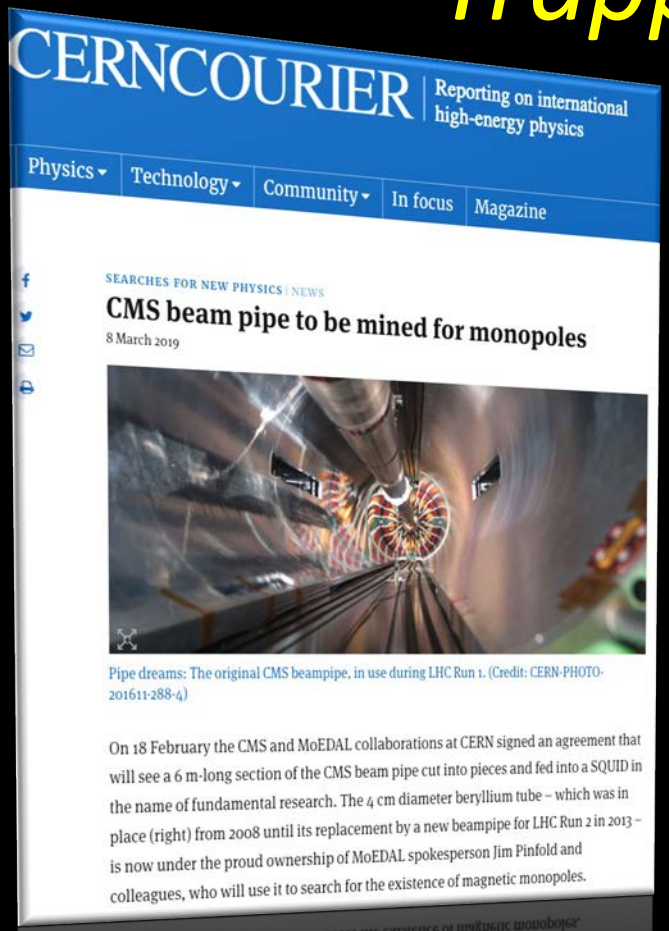
The MoEDAL experiment deployed at IP8 on the LHC ring was the first dedicated search experiment to take data at the LHC in 2010. It was designed to search for Highly Ionizing Particle (HIP) avatars of new physics such as magnetic monopoles,

Arttu Rajantie (Imperial College London), Igor Ostrovskiy (University of Alabama)
07 July 2022 02:25
Bologna, Italy
ICHEP 2022

Grazie per l'attenzione

EXTRA SLIDES

MoEDAL's Search for Monopoles Trapped in CMS Beampipe



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CMS beam pipe to be mined for monopoles

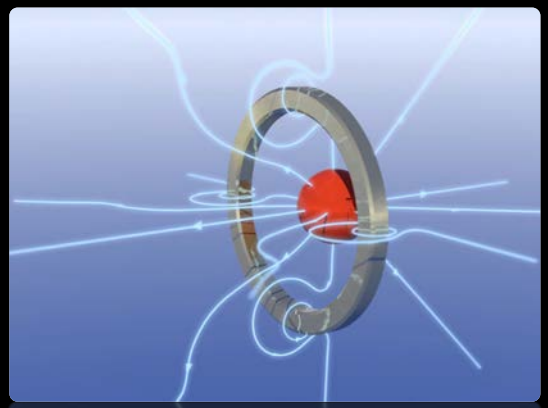
8 March 2019

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*