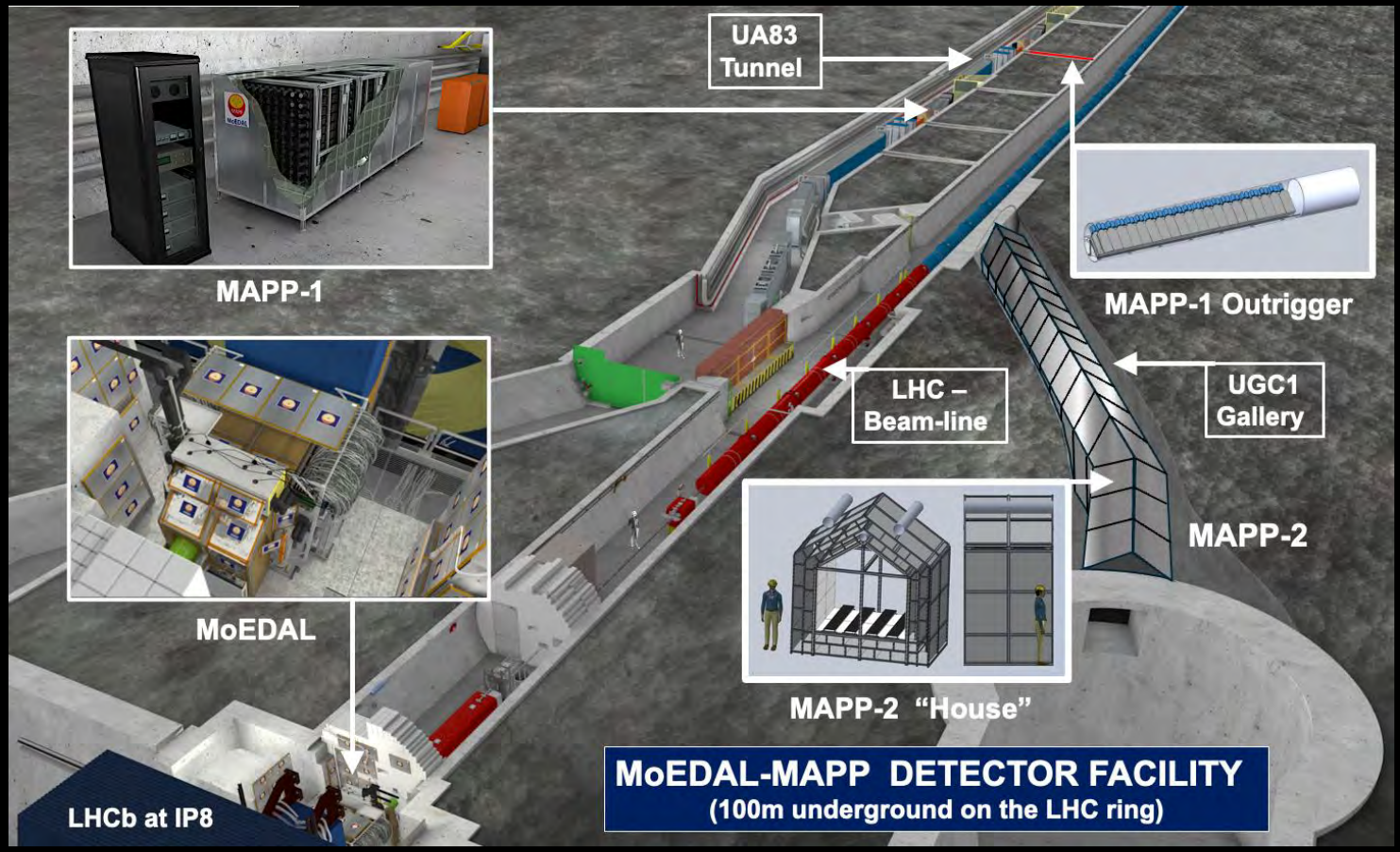

The MoEDAL-MAPP Facility at the LHC
(Expanding the Physics Reach of the LHC)
ERC-HEP Meeting in Marseille 2025
James Pinfold,
for the MoEDAL-MAPP Collaboration
IS NEAR

The MoEDAL-MAPP Facility at the LHC

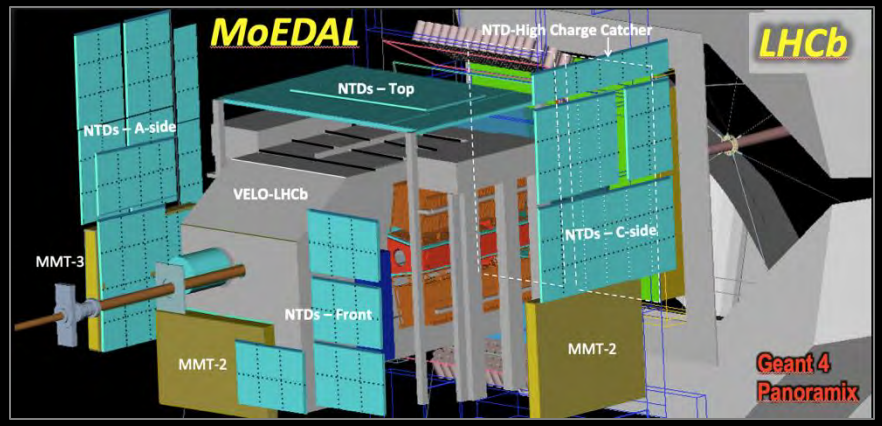
Sensitive to new physics that challenging or impossible for ATLAS & CMS to observe



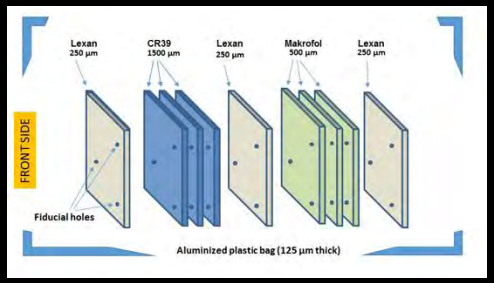
- ***MoEDAL (2010 -)*** *Highly Ionizing Particles (HIPs): Monopoles, dyons, Q-balls, BH-remnants, etc*
- ***MAPP-1 (2021 -) + Outrigger (2025?-)*** *Weakly Ionizing Particles (WIPs): Millicharged particles, Anomalous EDM, etc. + some sensitivity to neutral Long-Lived Particles (LLPs)*
- ***MAPP-2 (2026?)*** *Long-Lived Particles (LLPs): Dark scalars, sterile neutrinos, neutralinos, ALPs,etc*

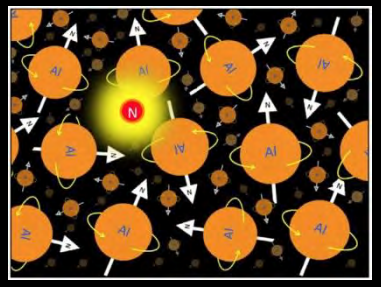
MoEDAL - LHC's 1st Dedicated Search Expt.

Upgraded for Run-3 with much higher eff. & a factor 10 lower charge thresholds



Searching for Highly Ionizing Particle (HIP) avatars of new physics





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

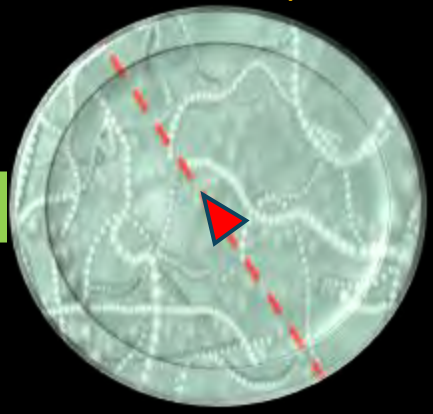
NO TRIGGER	NO SM BACK-GROUNDS	PERMANENT RECORD	PRECISION TRACKING (NTDs)	DIRECTLY DETECTS MAGNETIC CHARGE

MoEDAL's Remote Detector Facilities

NTD Processing - INFN Bologna

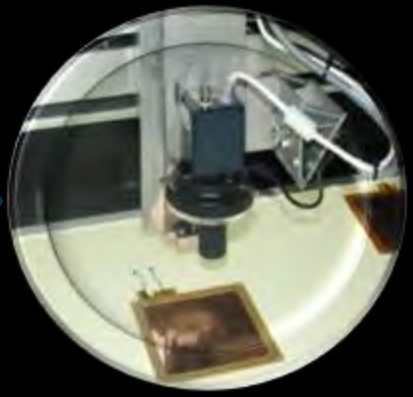
Etching in hot sodium Hrdroxide reveals damage

HIP causes damage Zone In NTD plastic



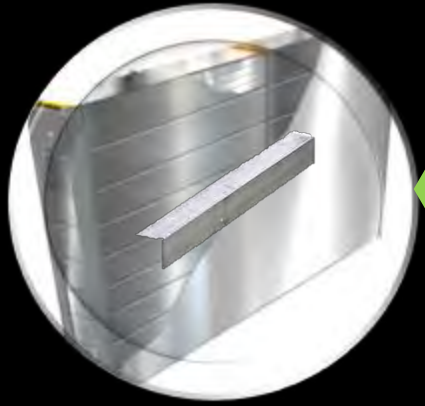
Etch pits reveal path and charge of HIP

Etch pits measured by optical microscope

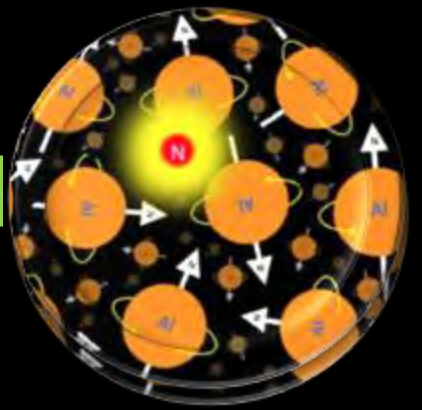


MMT Scanning- ETH Zurich

Trapping volumes are Removed for scanning



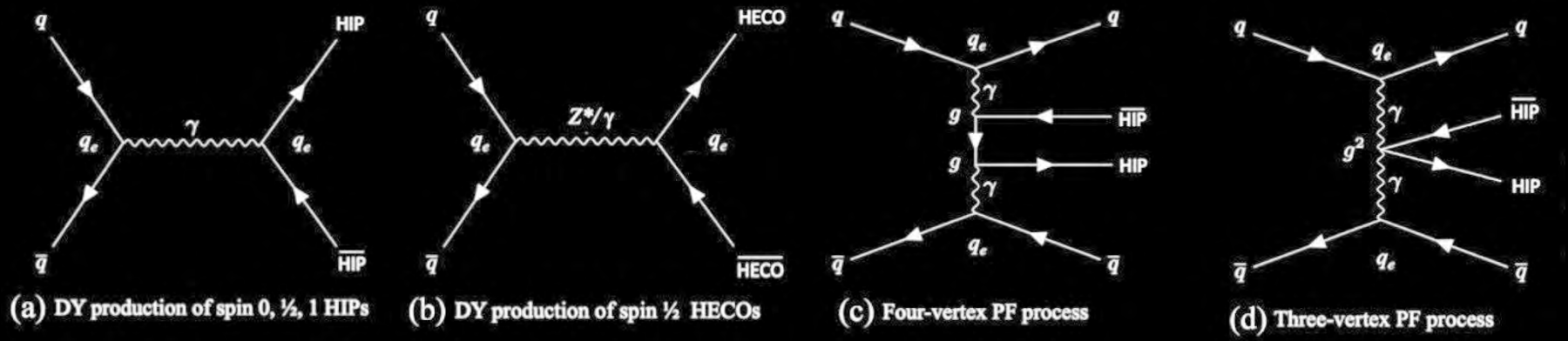
Monopole is trapped



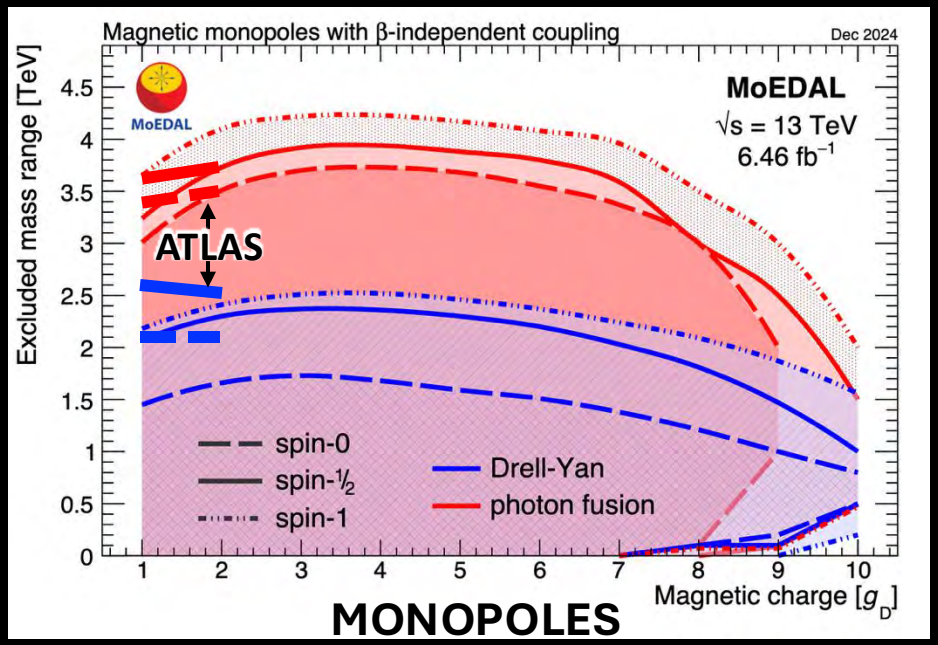
Trapping volumes are Passed through a SQUID

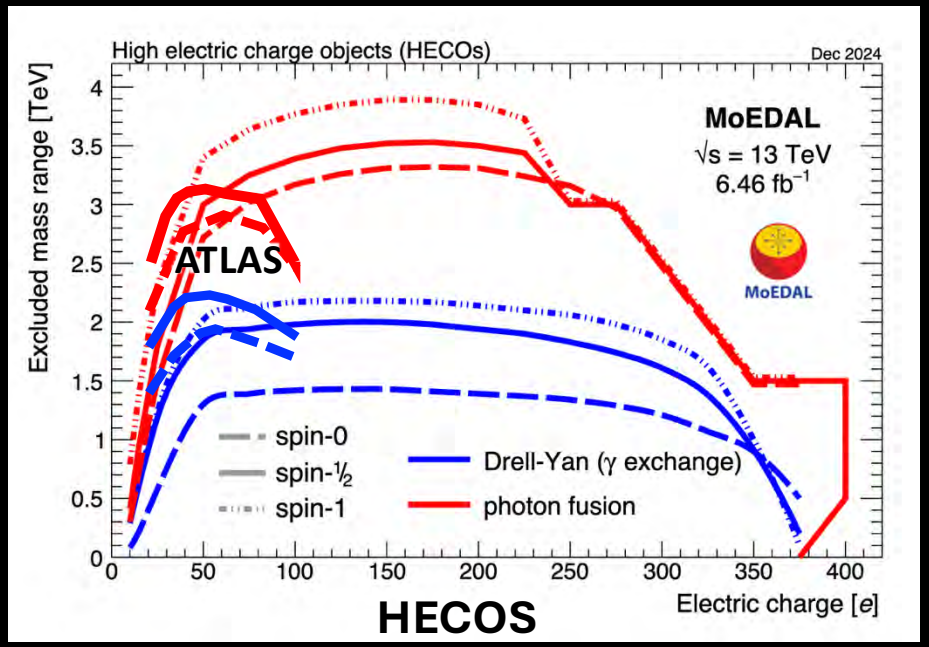
Monopoles cause a stable current in the SQUID

Latest MoEDAL Results on HIPs



(a) DY production of spin 0, ½, 1 HIPs (b) DY production of spin ½ HECOs (c) Four-vertex PF process (d) Three-vertex PF process





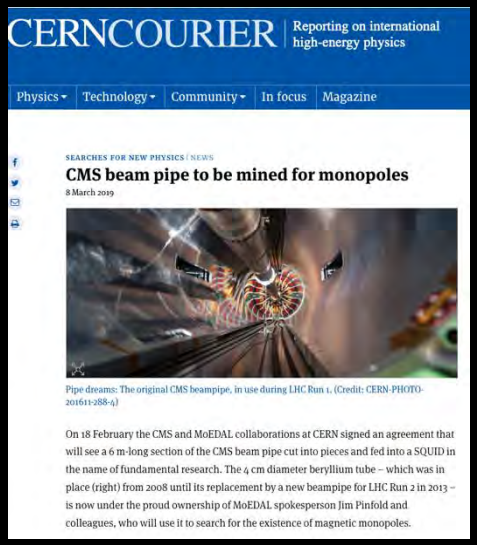
MoEDAL – world's best MM mass limits for $g_d > 1$

MoEDAL – world's best MM mass limits for $Q \geq 70e$

MoEDAL: PRL 134 7 071802 (2025)

ATLAS: JHEP 11 2023 112

Schwinger Production of Monopole Pairs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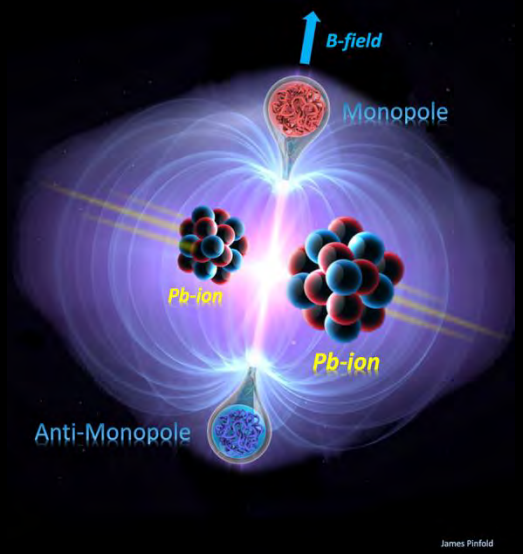
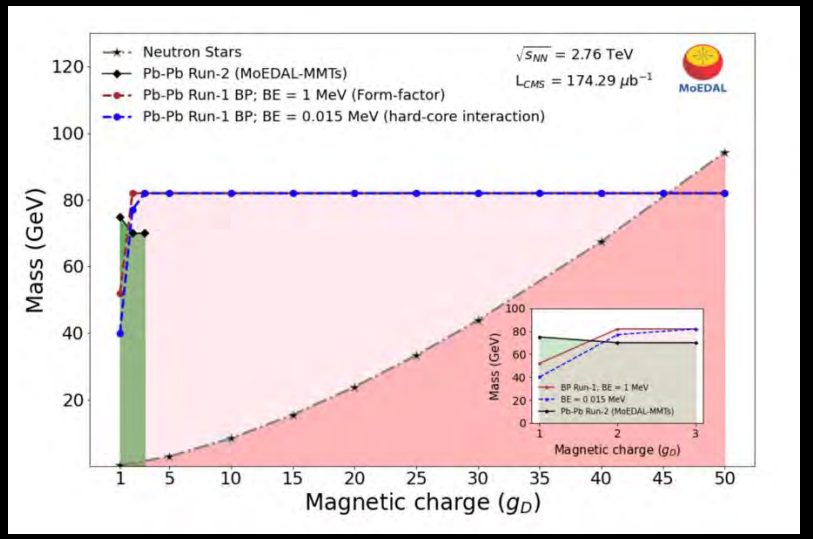
CMS beam pipe to be mined for monopoles

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.





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 80 GeV***
- *Advantages of Schwinger monopole production:*
  - *X-section calculation does not suffer from non -perturbative nature of coupling;*
  - *No exponential suppression for finite-sized monopoles.*

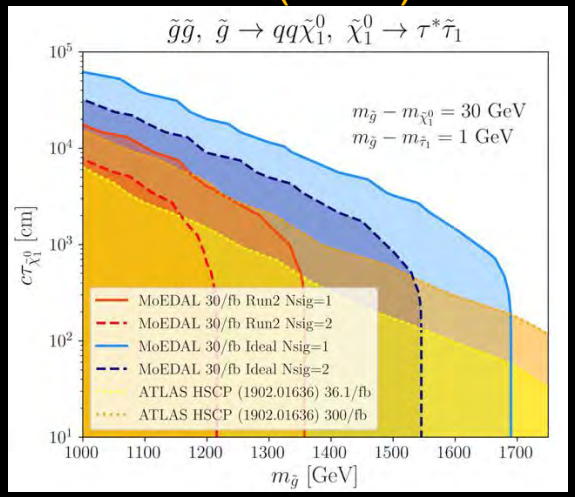
1st time non-pointlike monopoles detectable?

Nature 602 (2022) 7895, 63-67 (Run-1) Phys. Rev. Lett. 133, 071803 – Published 15 August 2024

Searching for Long-Lived HIPS

Due to the absence of trigger, timing & SM backgrounds, MoEDAL can relax selection requirements + increase sensitivity to charged, SUSY LLPs

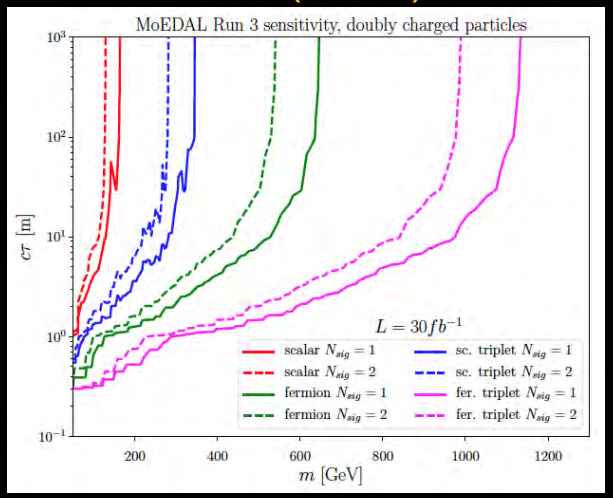
EPJC 80 (2020) 431



MoEDAL can cover the long-lifetime region at Run-2/3 for gluinos, stops, sleptons & charginos

SLEPTONS

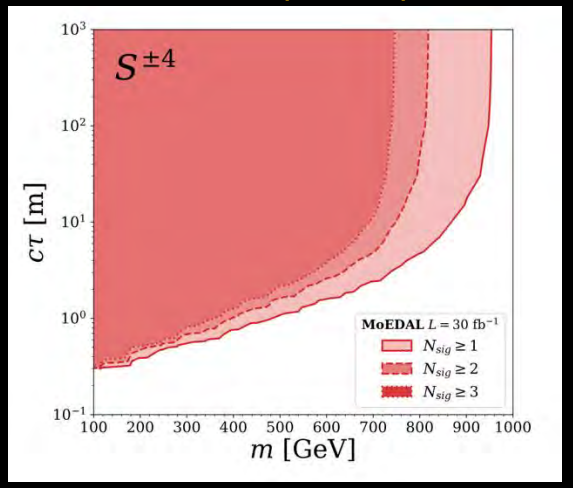
EPJC 80 (2020) 572



Authors added doubly charged scalars & fermions in various SU(2)L rep's, to the SM particle content .

DOUBLY CHARGED

EPJC 81 (2021) 697



In this class of neutrino mass models, the SM is extended with two scalar fields, and 3 pairs of vector-like fermions.

2,3 and 4 CHARGED

- *If sufficiently slow moving, even singly or multiply ($\lesssim 10e$) 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.*

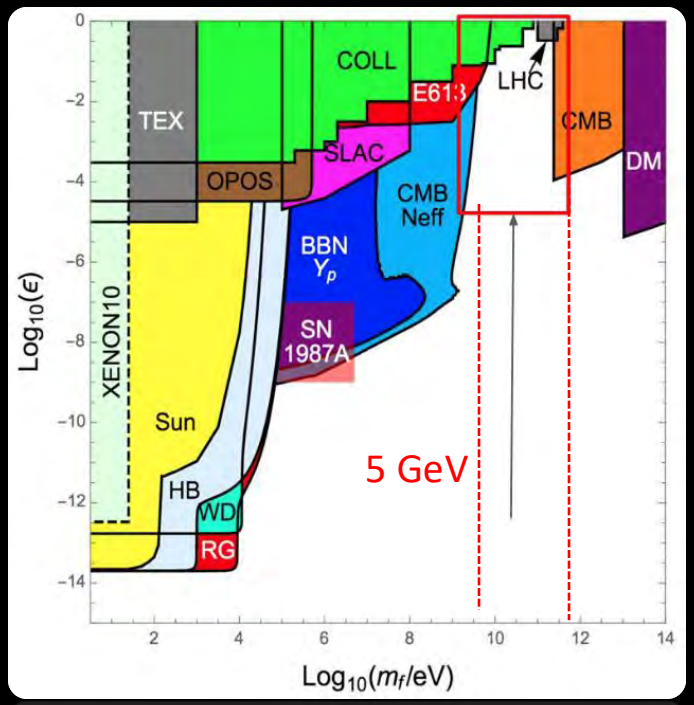
MoEDAL – HIP Innovations

By MoEDAL Theory Board (Chaired by John Ellis) & MoEDAL Experimentalists

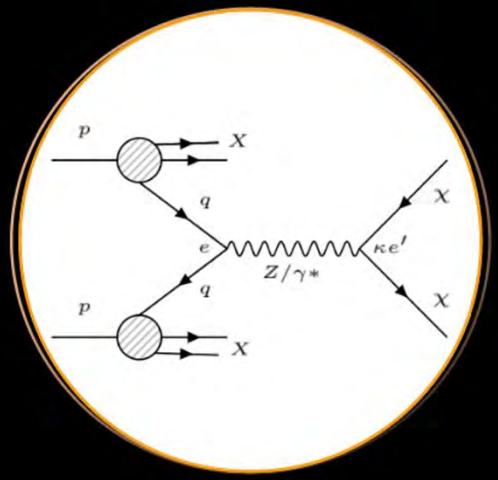
- *MoEDAL constantly innovates, pushing the theory of HIPs as much as the experiment.*
- *Here are some innovations by the MoEDAL-MAPp's experimentalists and theoreticians that are first ever or at least first at the LHC*
  - *Development of the theory of the EW Monopole for LHC physics*
  - *MM β-dependent couplings*
  - *$\gamma\gamma$ - fusion production of HIPs*
  - *p-p cross-sections for Spin-1 HIPs*
  - *Phenomenological treatment of Schwinger production of MMs in p-p collisions*
    - *First ever search at a collider for non-pointlike monopoles.*
  - *Resummation techniques applied to HIPs*

Production of Milli-charged at Colliders

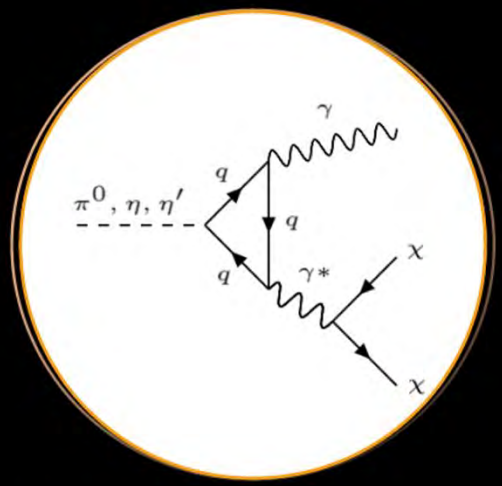
mCPs arise naturally from the dark sector via the Vector Portal/Dark Photon



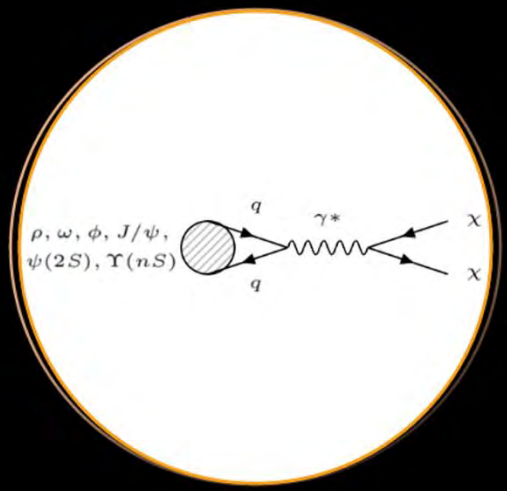
The Sweet Spot
arXiv:1511.01122



Via the Drell-Yan process

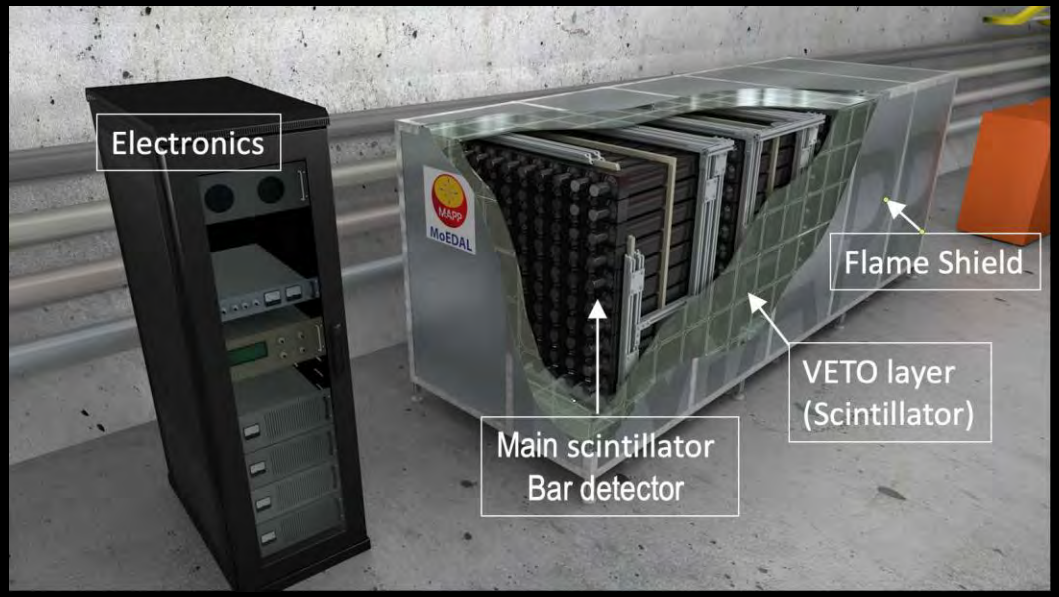


Via Dalitz decays of pseudoscalar mesons



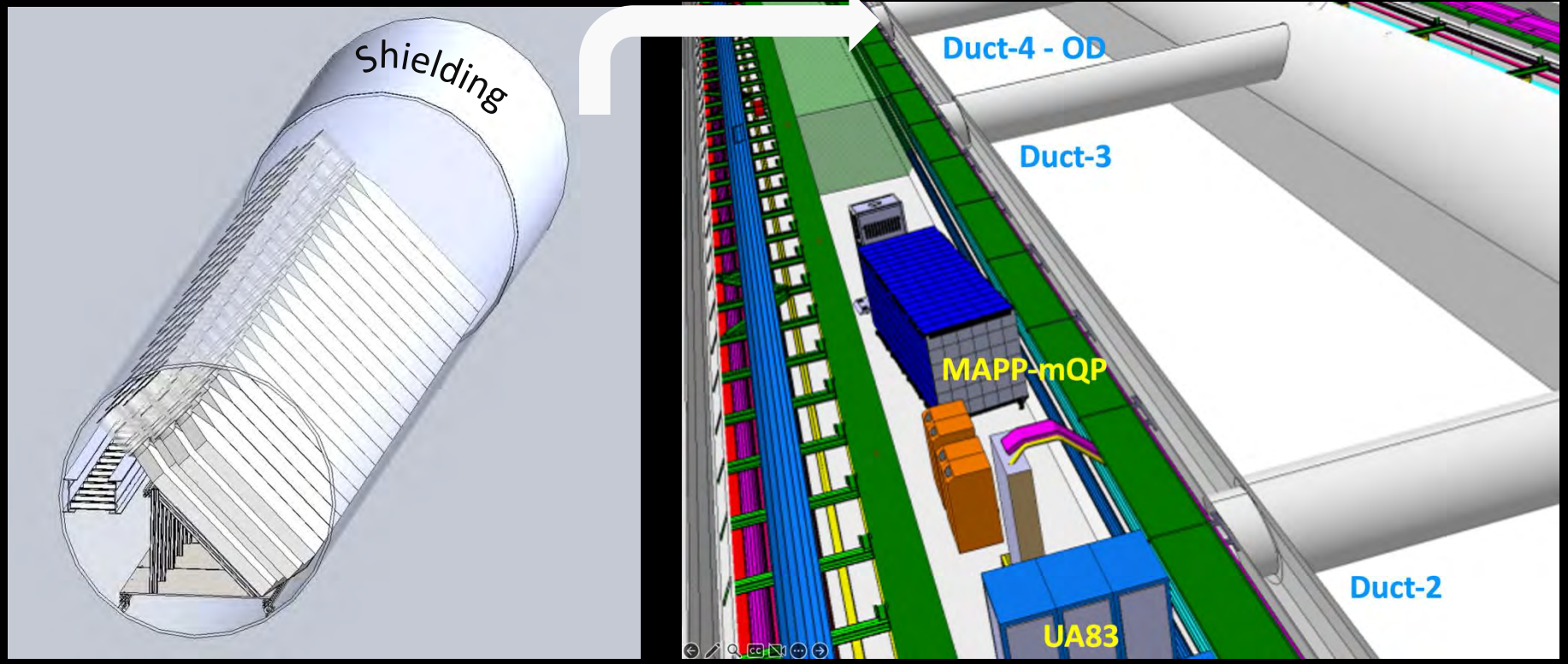
Via direct decays of vector mesons

MoEDAL's MAPP-1 Detector @ UA83



- *400 scintillator bars (10 x 10 x 75 cm^3) in 4 sections readout by 3" PMTs - Protected by a hermetic VETO counter system*
- *MAPP is sensitive to:*
  - *Milli-charged ($10^{-3}c$) particles*
  - *Long-lived neutral particles*
  - *Charged particles (using MoEDAL's MMTs)*
- *Latest paper: "Searching for minicharged particles at the energy frontier with the MoEDAL-MAPP experiment at the LHC", JHEP* 04 (2024) 137

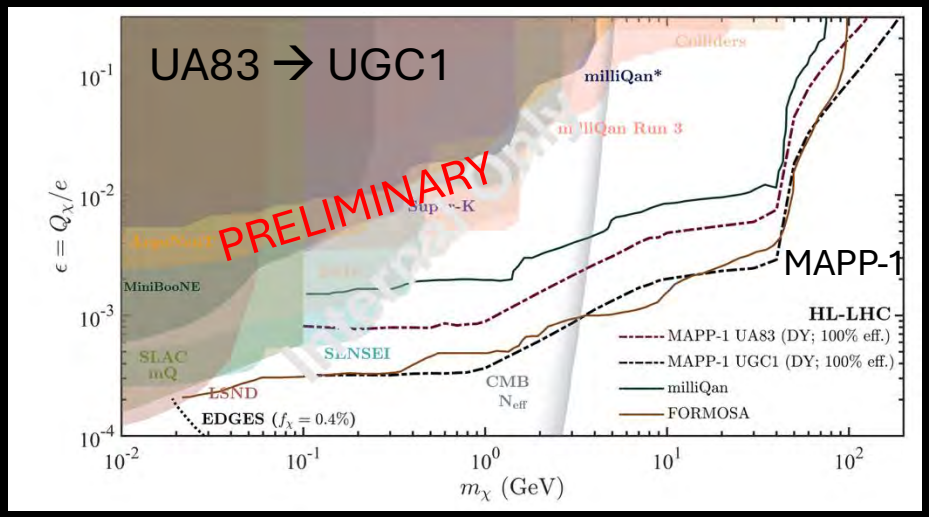
The MAPP-1 Outrigger

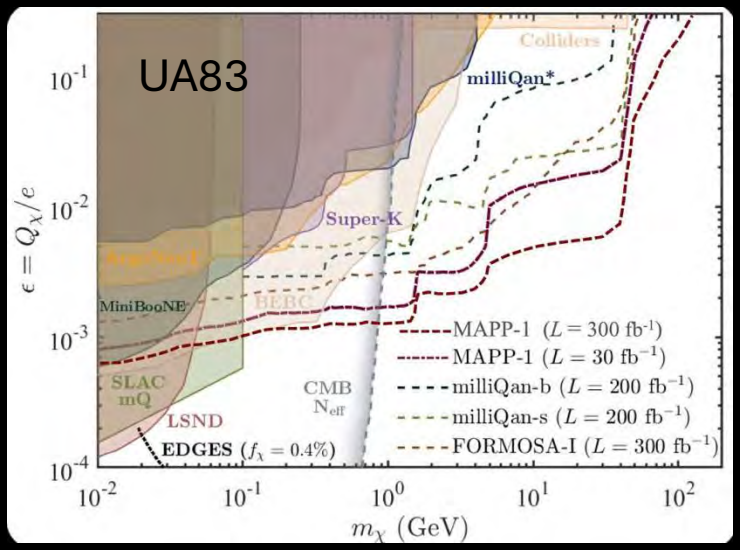


- *OUTRIGGER- An extension of the MAPP bar detector to improve the overall reach for higher mass mCPs (above a few GeV)*
- *4 scintillator planes (each comprised of 20 60 cm x 30 cm x 5 cm sub-planes angled at 45 degrees) readout by coincident PMTs – an effective area of ~2.6m^2*
- *We expect to install this for HL-LHC running.*

MAPP-1 Sensitivity to Millicharged Matter

milliQan results—Phys. Rev. D 104, 032002 (2021); FORMOSA results—Phys. Rev. D 104, 035014 (2021)

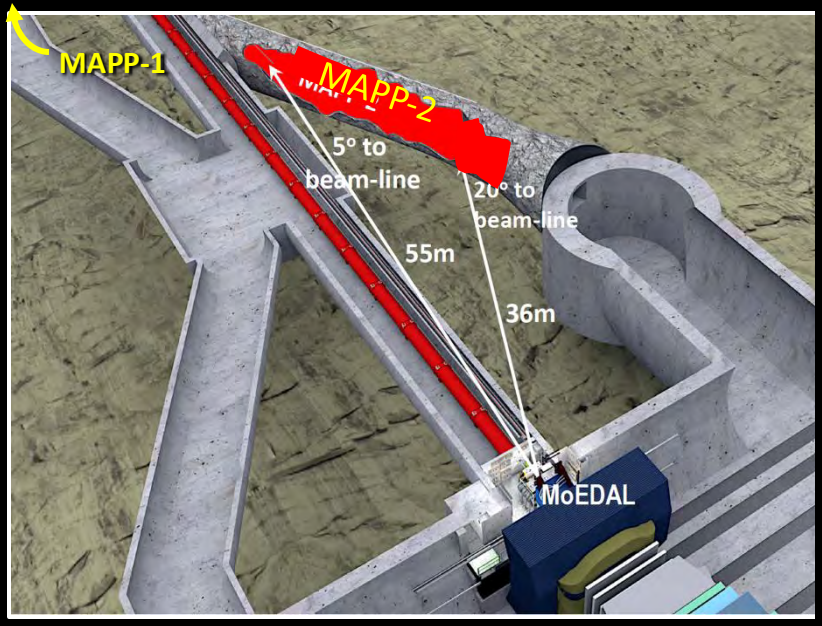


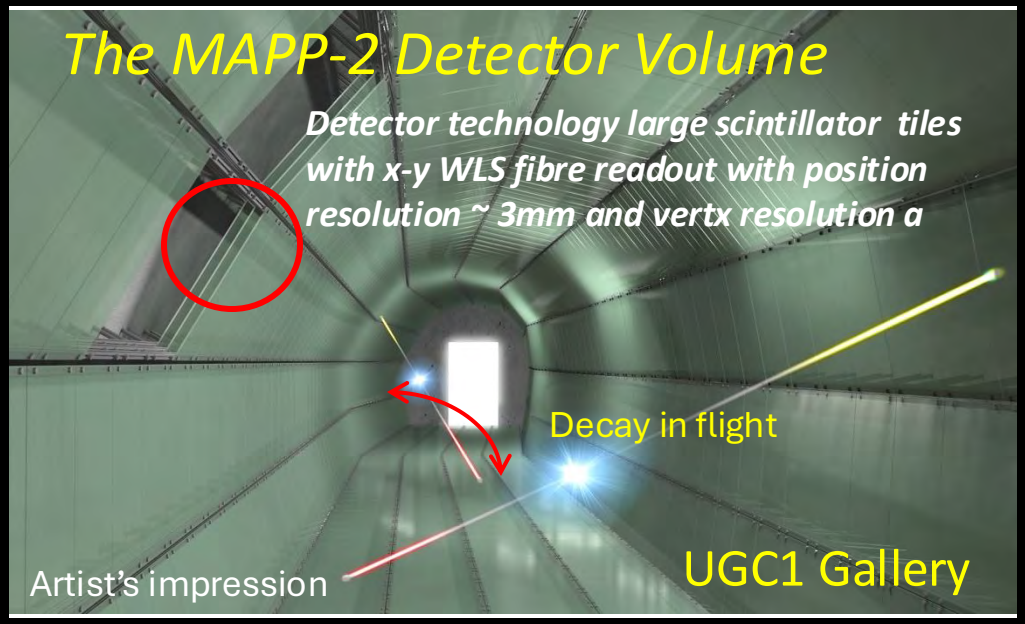


- *The 95% CL exclusion Limits for MAPP-1 for **mCPs produced by DY** mech. + direct decays of heavy quarkonia, light vector mesons, and single Dalitz decays of PS mesons.*
  - *Signal efficiency estimates included*
- *The move to UGC1 (the initial choice for MAPP-1) improves things immensely especially – still need to add in mesons and efficiencies*

The Future – Detecting LLPs

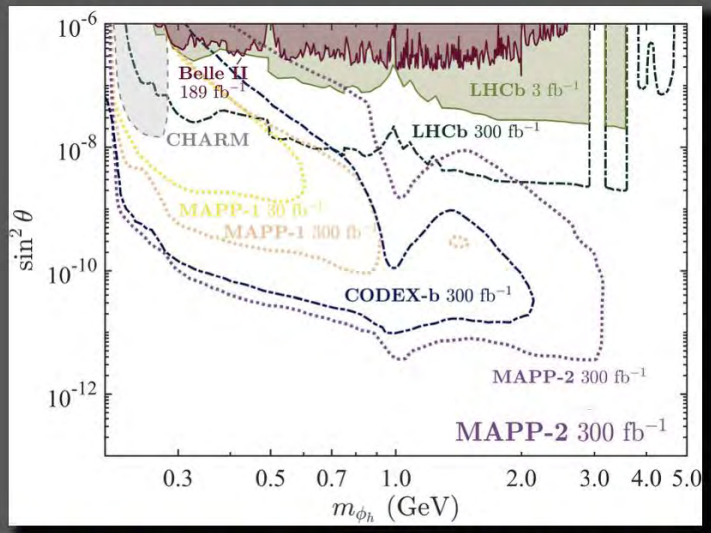
Phase-2 → MAPP-2 for HL-LHC

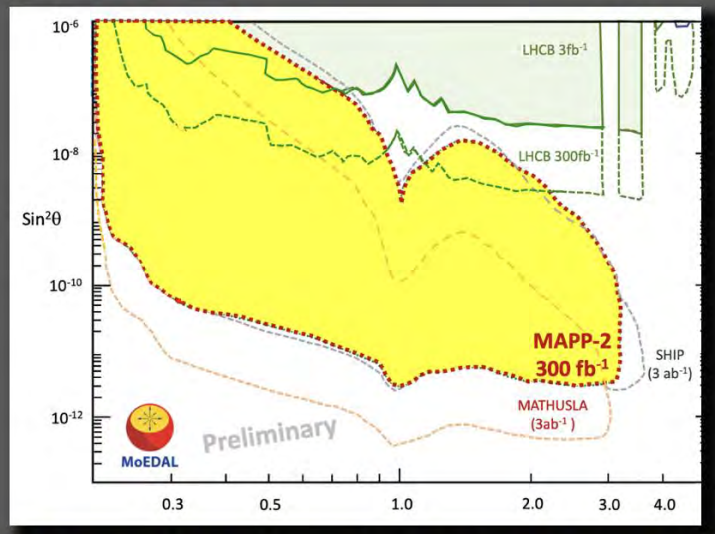




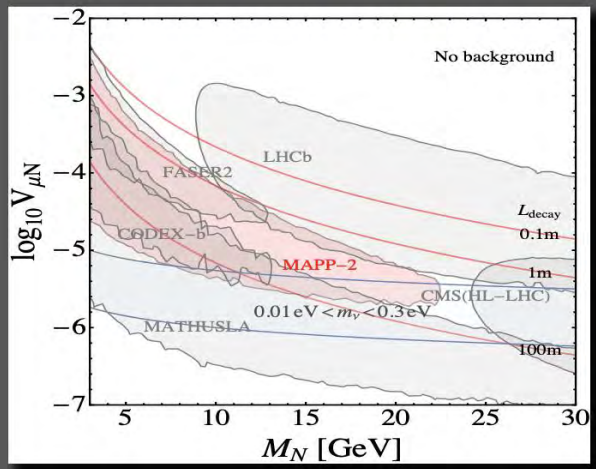
- *The MAPP-2 detector would fill the UGC1 gallery adjacent to LHCb*
  - *The UGC1 gallery would be prepared during LS3 prior to HL-LHC*
  - *The tracking detectors form 3 hermetic scintillator containers - one within the other lining the walls of UGC1 – creating a completely open decay volume*
- *MAPP-2 ~1200 m^3 of instrumented decay volume – est. cost ~ 10 M CHF*
  - *Non-gaseous detector technology gives rise to large cost savings*
  - *Detect Long-Lived particle decays to **charged particle & photons***

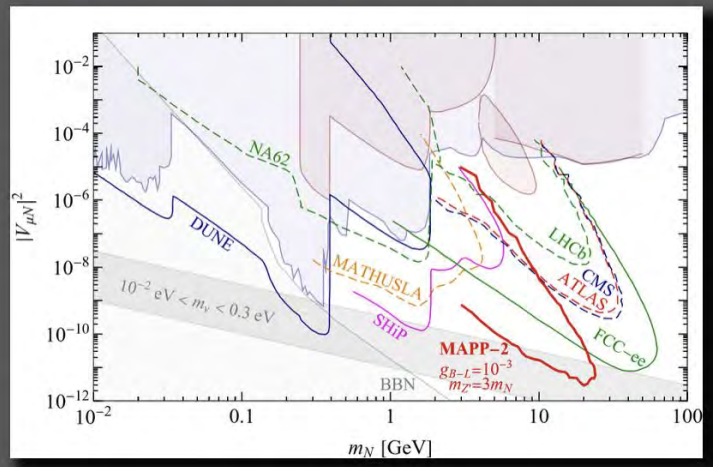
MAPP-2 – Sensitivity Benchmarks





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 $\vartheta \ll 1$. See PRD97 (1) (2018) 15023.





*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.*

Final Words

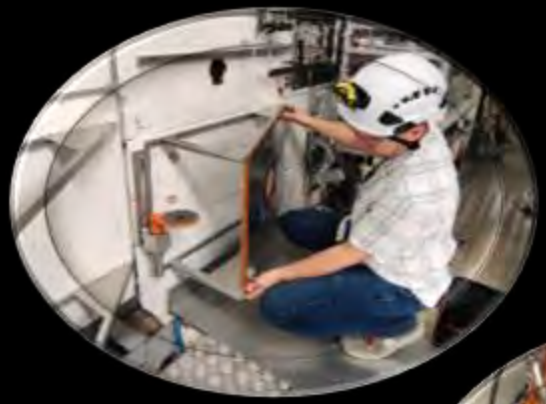
"New directions in science are launched by new tools much more often than by new concepts." Freeman Dyson

- ***MoEDAL-MAPP pioneered the use of Dedicated Search Detectors at the LHC. These detectors are the new tools now being used to reveal physics beyond the SM at the LHC and beyond***
- ***WE ALWAYS NEED NEW COLLABORATORS – IF YOU ARE INTERESTED, PLEASE contact jpinfold@ualberta.ca***

EXTRA SLIDES

Upgraded MoEDAL Installed for Run-3

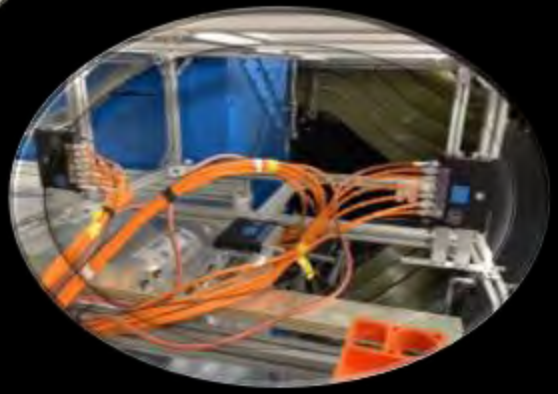
Upgrades to the Run-2 MoEDAL Detector, for Run-3 – completed in March 2023



NTD Stacks Point to IP

VELO-TOP NTD array installed

Forward MMT box reconfigured



TimePix3 Chips connected to LHC clock

The Search for Highly ionizing particles (HIPs) continues with:

5 x Higher Instantaneous Luminosity at IP8

a) Improved Detector Efficiency
b) X10 lower threshold

Slightly higher Centre-of-mass Energy