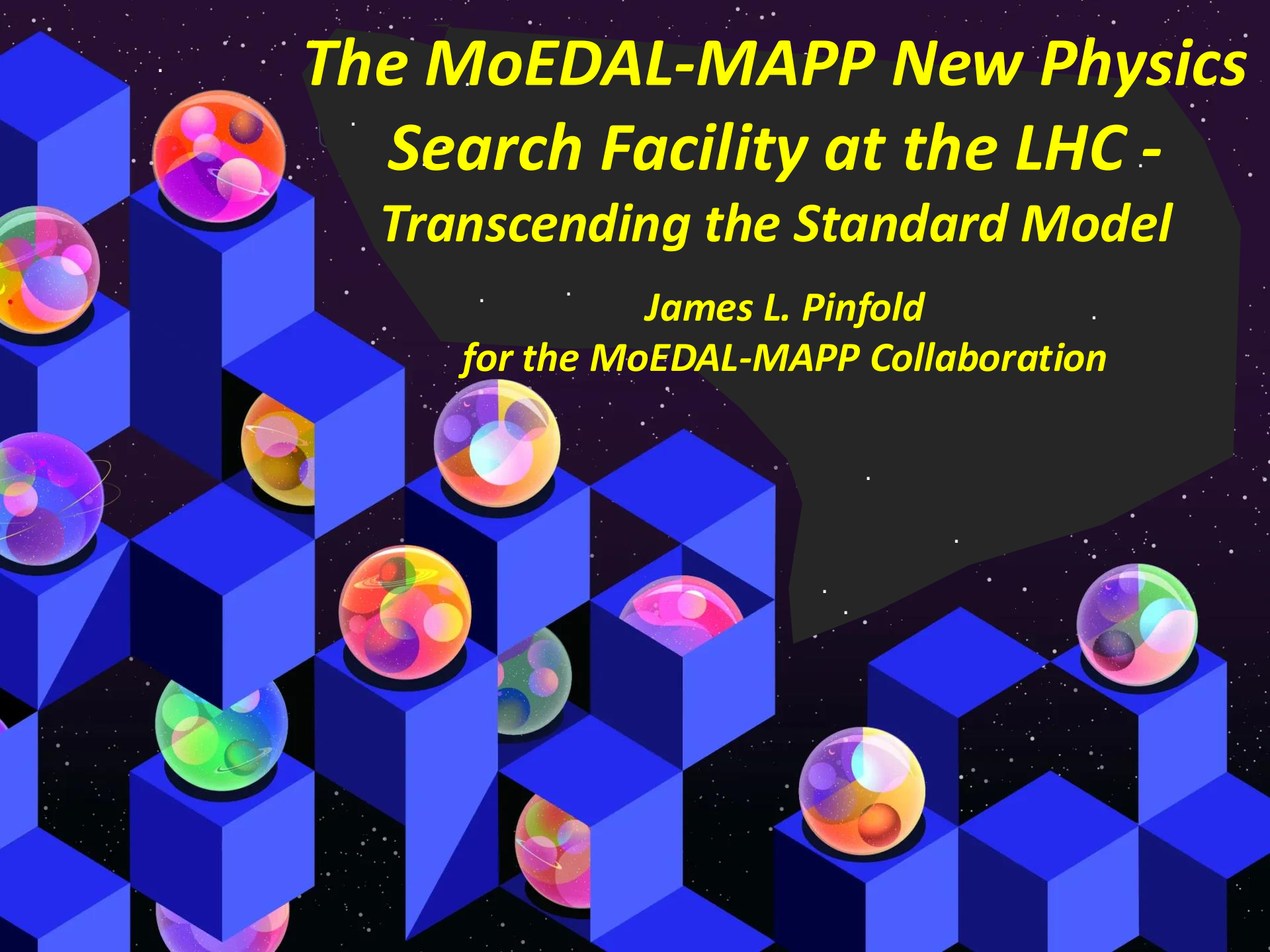


The MoEDAL-MAPP New Physics Search Facility at the LHC - Transcending the Standard Model

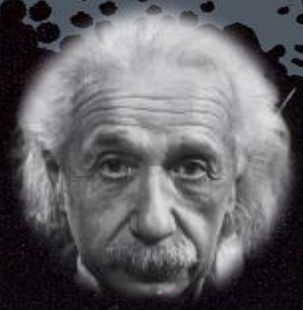
James L. Pinfold
for the MoEDAL-MAPP Collaboration

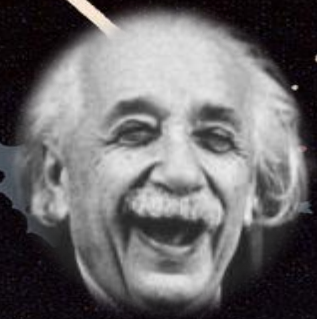
Why No New Physics Yet at the LHC?

MAPP

MoEDAL

Another answer





- *The Standard Model is it - there is no New Physics*
- *The mass scale of the new physics is beyond the LHC's reach*

- ***The mass scale is within LHC's reach, but the New Physics is not well illuminated!***

Dedicated Search, or "Agile," Detectors at the LHC – a New Light

The beginning.....

ELSEVIER

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

NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

www.elsevier.nl/locate/npe

Searching for Exotic Particles at the LHC with Dedicated Detectors.

J. L. Pinfold, [a*]

[a]Centre for Subatomic Research, University of Alberta,
Edmonton, Alberta T6G 2N4,Canada

The LHC will open up a new energy regime where it may be possible to observe physics beyond the Standard Model. Therefore the search for exotic phenomena, such as: magnetic monopoles, massive stable particles; slowly decaying exotic particles; highly penetrating particles; and, free quarks and gluons, will be an important part of 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.

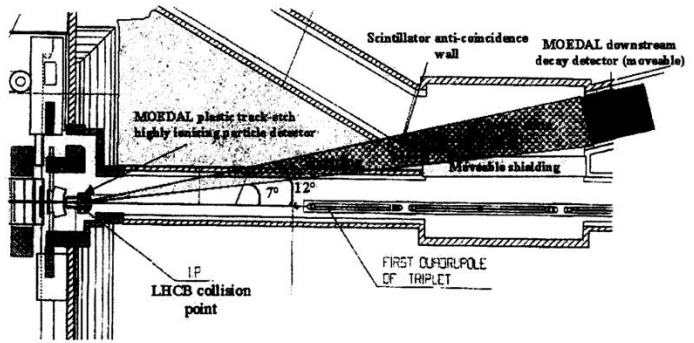


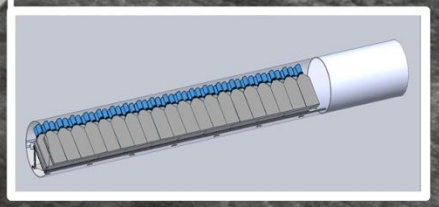
Figure 1. A schematic view of a detector for heavy stable and quasi-stable exotic particles. The detector is deployed in this case in the region UJ84 behind a minimum of 16m of rock/concrete shielding with a decay zone of similar length. The MOEDAL passive detector for highly ionizing particles is also shown deployed around the LHCB vertex chamber.

MoEDAL was the first such experiment, approved by CERN in 2010

MoEDAL-MAPP a >24 Year Project

MAPP-1

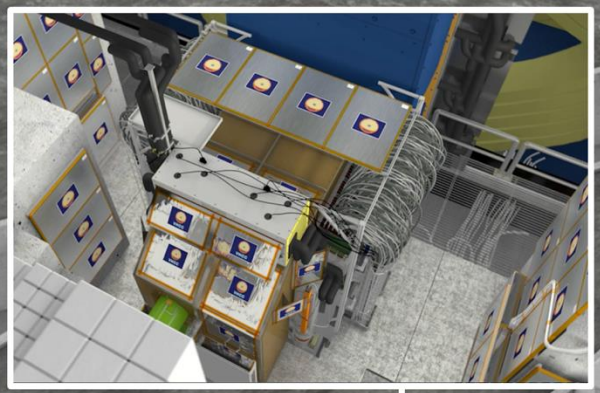
UA83 Tunnel



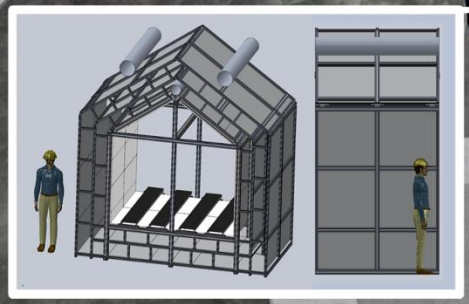
MAPP-1 Outrigger

LHC – Beam-line

UGC1 Gallery



MoEDAL



MAPP-2 "House"

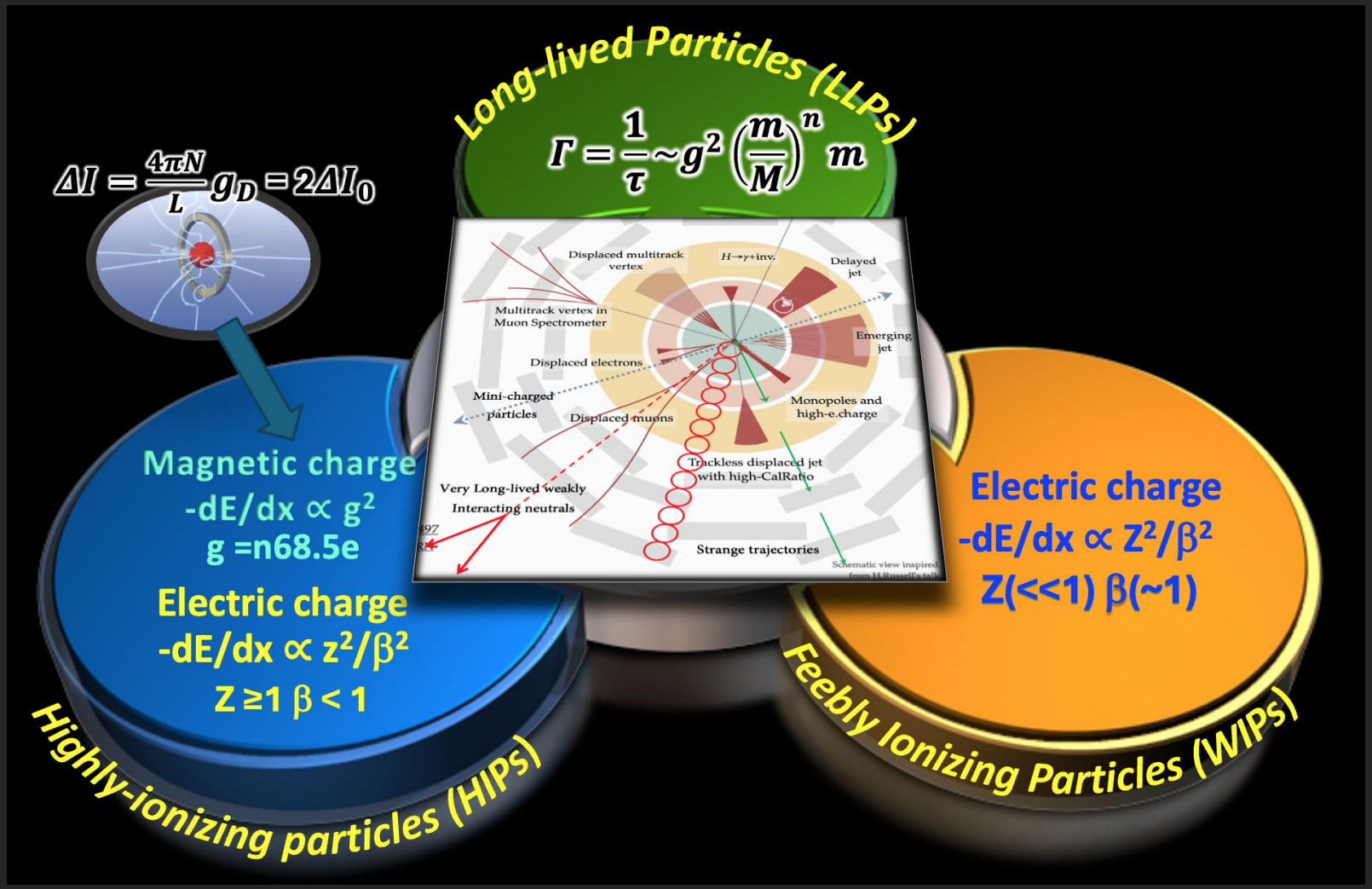
MAPP-2

LHCb at IP8

MoEDAL-MAPP DETECTOR FACILITY
(100m undergound on the LHC ring)

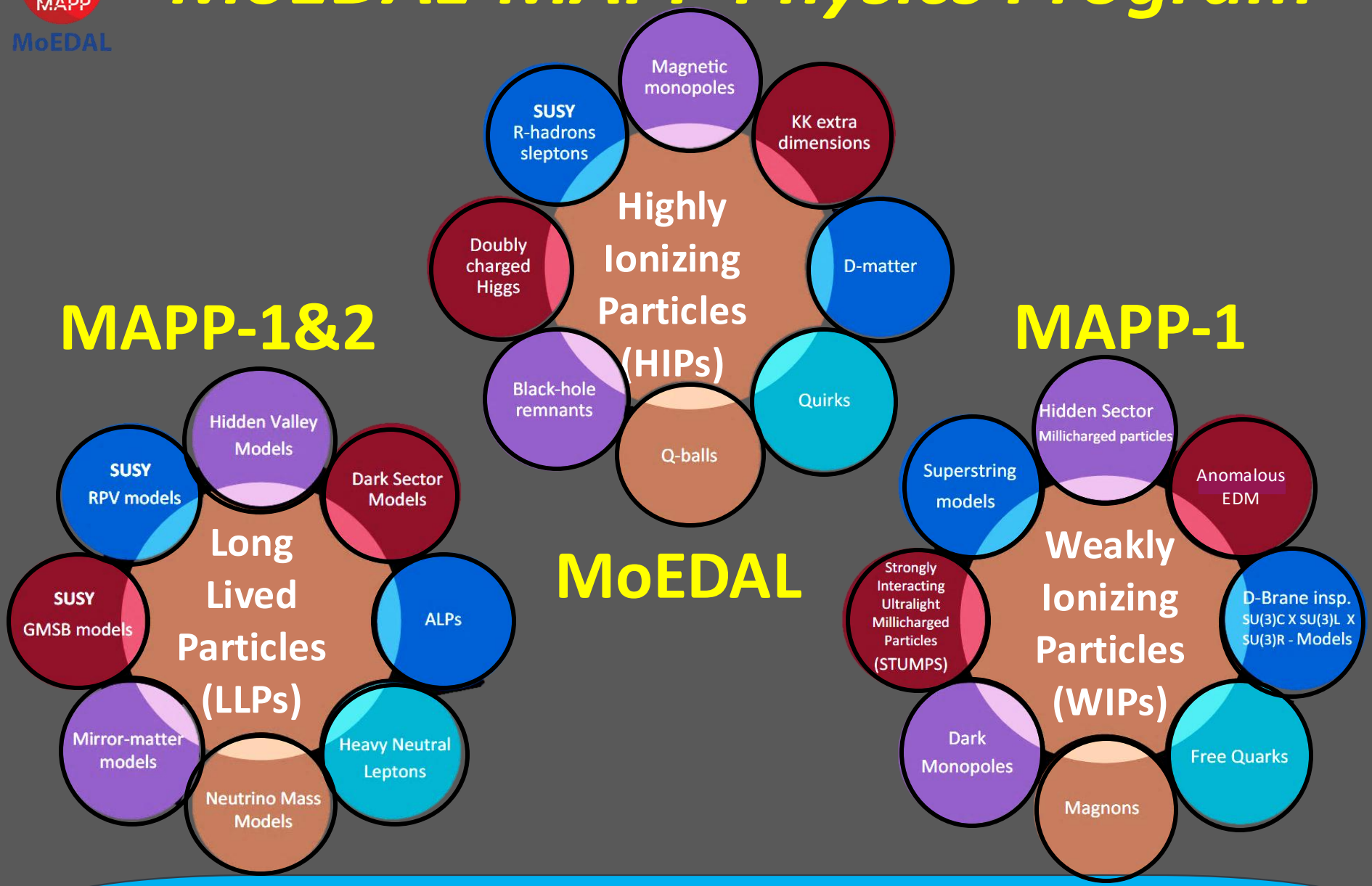
MoEDAL-MAPP Search for New Physics.

MoEDAL-MAPP is optimized to detect these avatars of New Physics



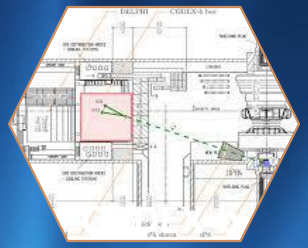
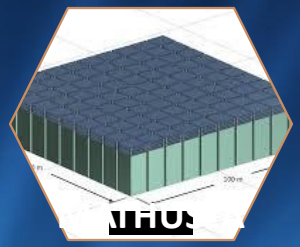
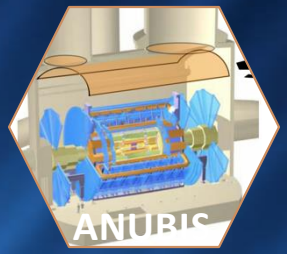
ATLAS and CMS are not optimized to detect HIPs, WIPs and LLPs.

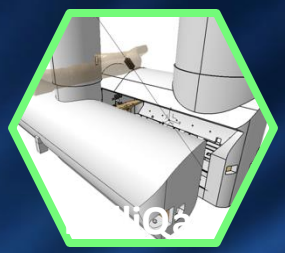
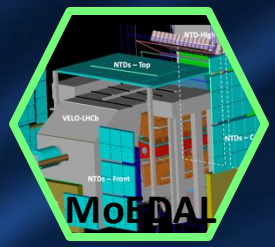
MoEDAL-MAPP Physics Program

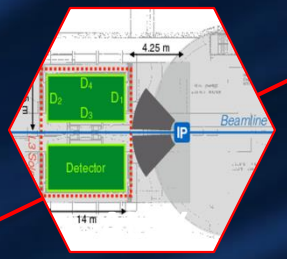


Most of the above scenarios contain Dark Matter candidates

The Caste of "Agile" Detectors Today



η=0

η=0.5

η=1

η=1.5

η=2

η=2.5

η=3

η=4

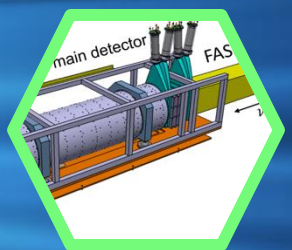
Transverse
$0 < \eta < 1.5$

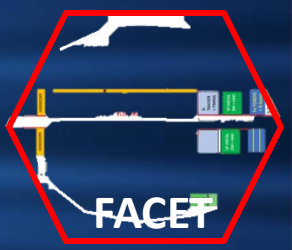
Intermediate
$1.5 < \eta < 4$

Forward
$\eta > 4$

FPF Forward Physics Facility

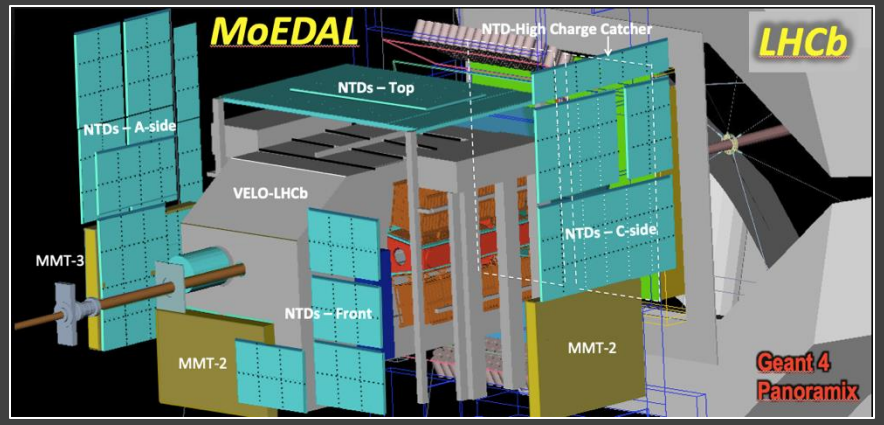
FASER- 2, FASERnu2, advSND, FORMOSA, FLARE



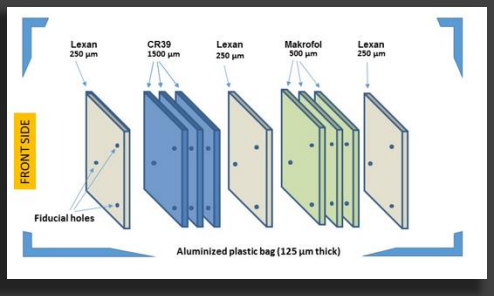


The Phase-0 MoEDAL Detector

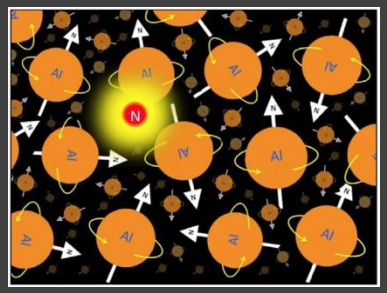
LHC's 1st dedicated search expt. –upgraded for Run-3 with higher eff. & lower thresholds



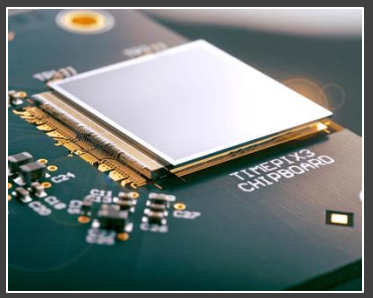
Searching for HIP avatars of new physics



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 BACKGROUNDS** **PERMANENT RECORD**

MoEDAL's Remote Detector Facilities

NTD Processing - INFN Bologna

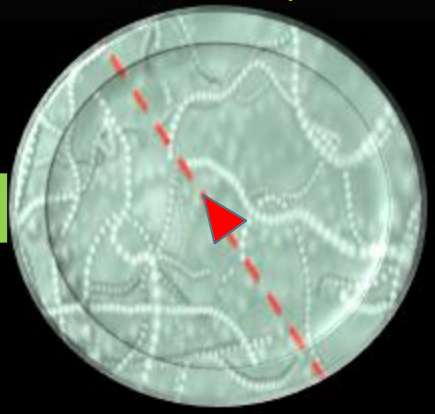
MMT Scanning- ETH Zurich

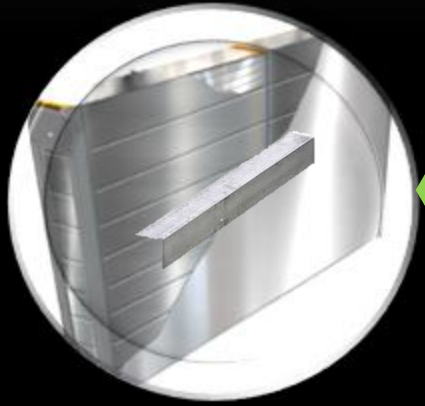
Etching in hot sodium Hydroxide reveals damage

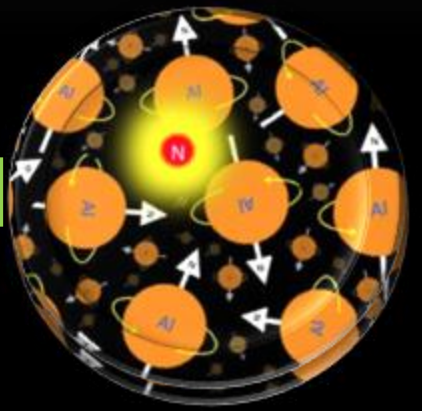
HIP causes damage Zone In NTD plastic

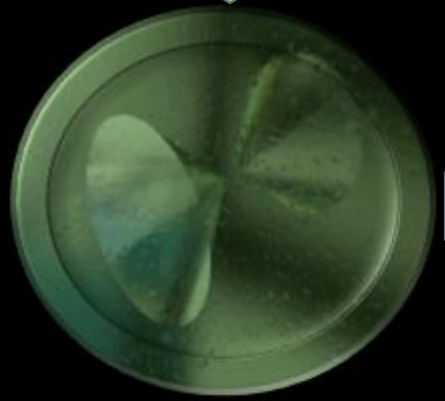
Trapping volumes are Removed for scanning

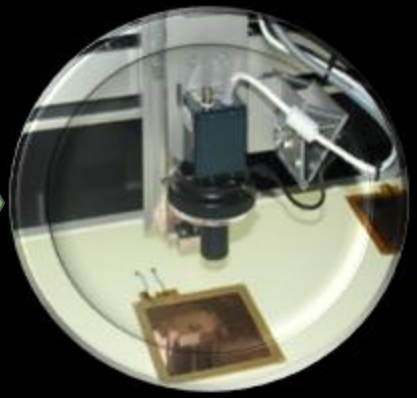
Monopole is trapped











Etch pits reveal path and charge of HIP

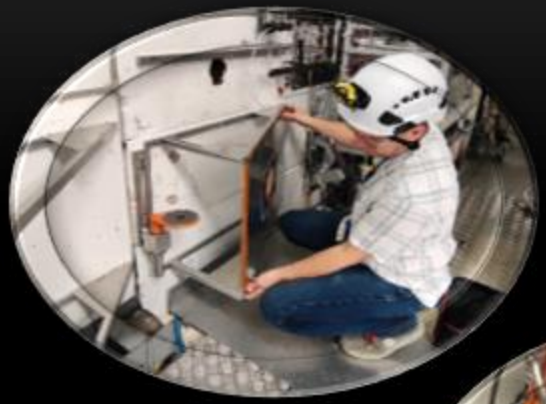
Etch pits measured by optical microscope

Trapping volumes are Passed through a SQUID

Monopoles cause a stable current in the SQUID

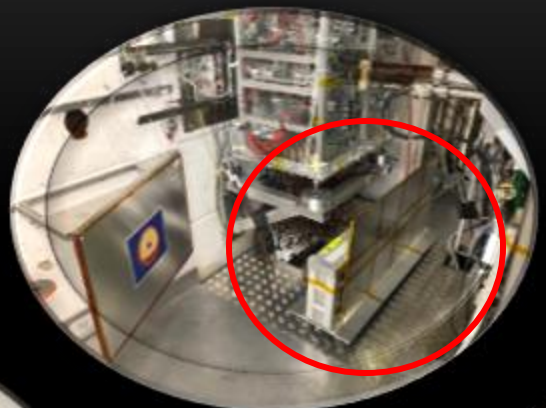
Upgraded MoEDAL Installed for Run-3

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

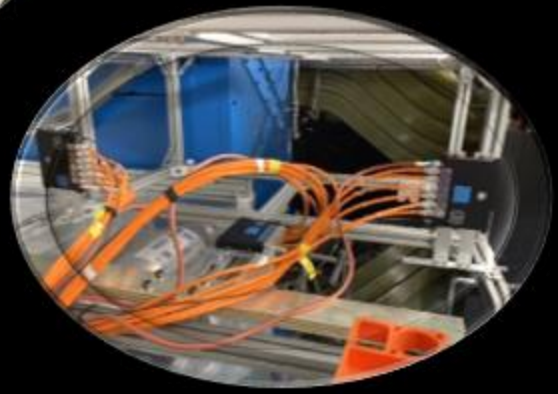


NTD Stacks Point to IP

VELO-TOP NTD array installed



Forward MMT box reconfigured



TimePix3 Chips connected to LHC clock

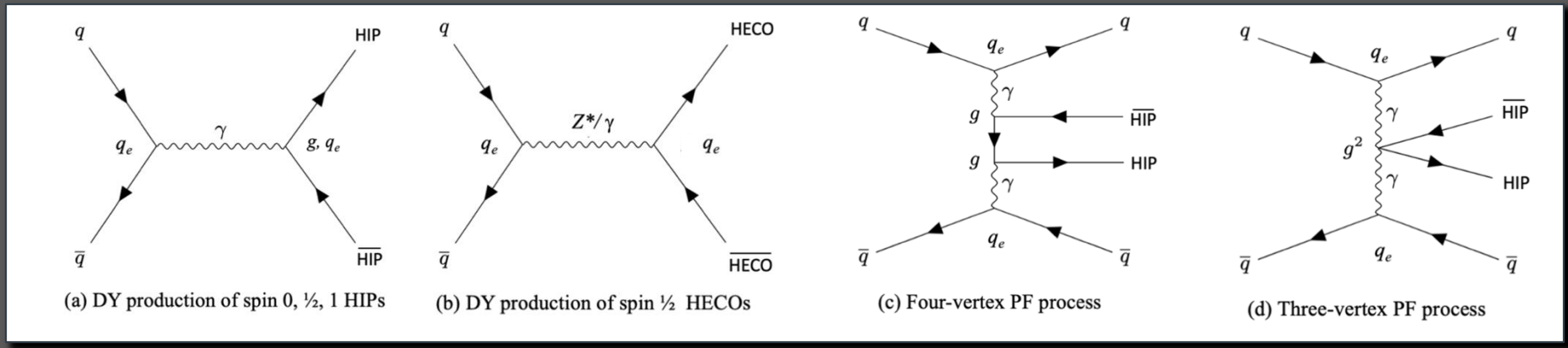
The Search for Highly ionizing particles (HIPs) continues with:

5 x Higher Instantaneous Luminosity at IP8

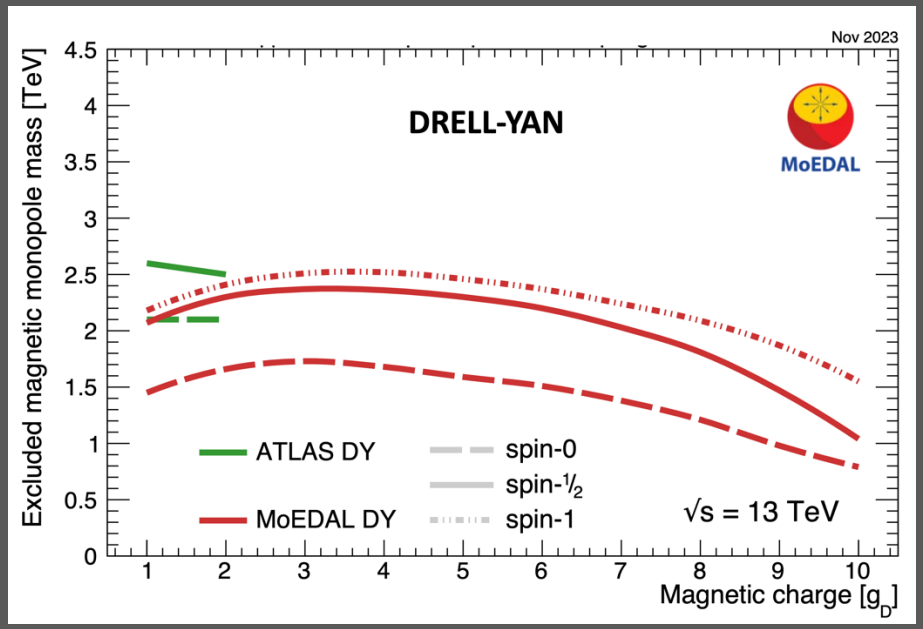
a) Improved Detector Efficiency
b) X10 lower threshold

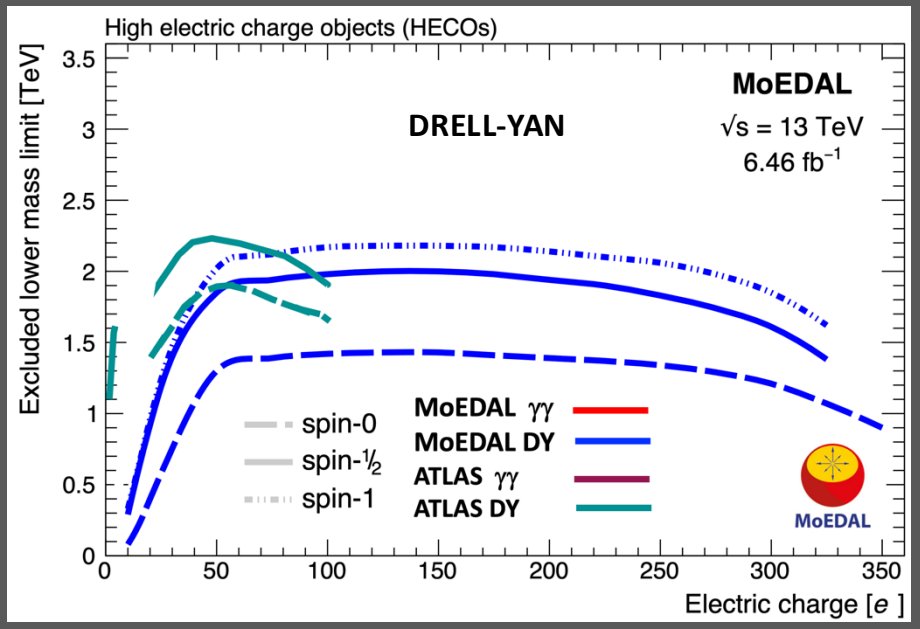
Slightly higher Centre-of-mass Energy

Results from HIP Search - DY production



(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



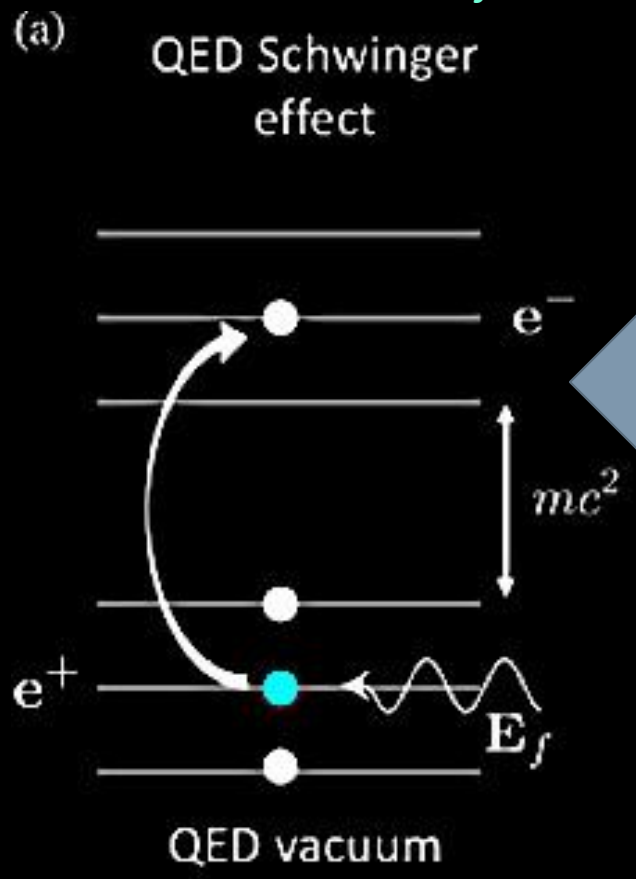


MAGNETIC MONOPOLES (MMs) **HIGHLY ELECTRICALLY CHARGED OBJECTS**

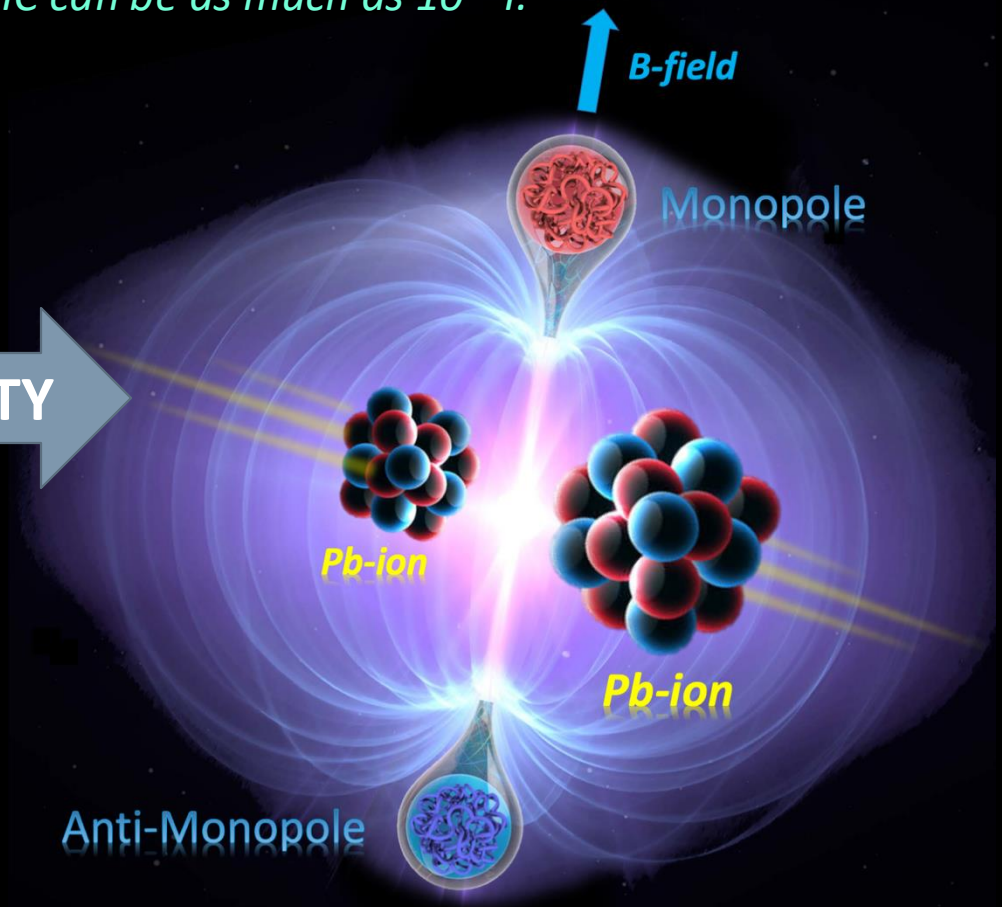
•MoEDAL e-Print: 2311.06509 [hep-ex]….to be published in PRL

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

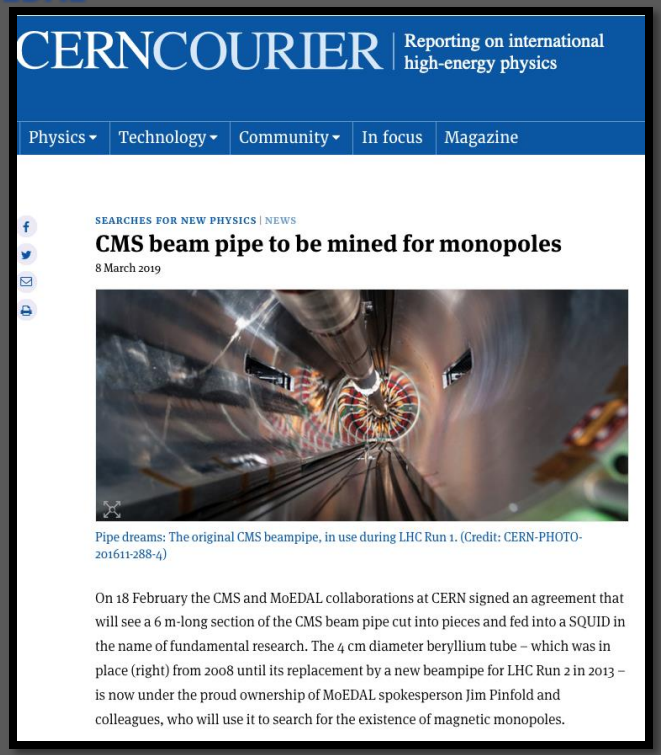


Pair production of electron-positron pairs in a very strong electric field

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

James Pinfold

1st Search Sensitive to Composite MMs?



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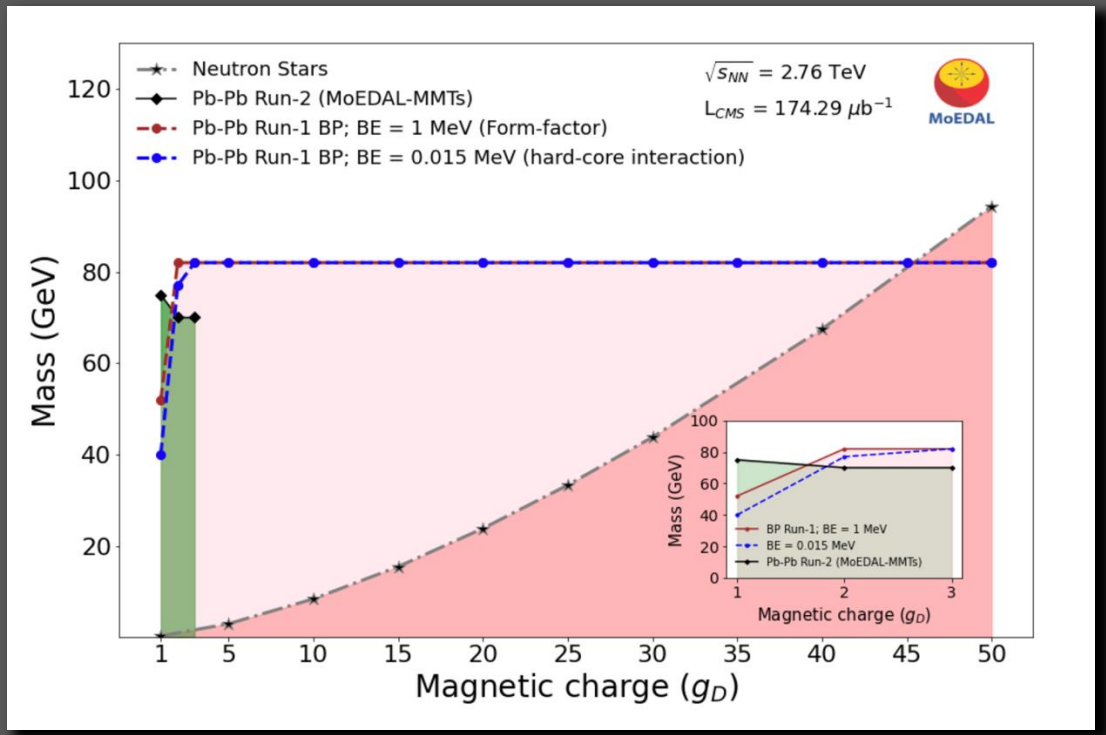
SEARCHES FOR NEW PHYSICS | NEWS

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.



- *The CMS Beampipe was scanned by the MoEDAL experiment using a SQUID magnetometer to search for trapped MMs.*
  - *Limits produced via the Schwinger production are theoretically valid – limits from DY and $\gamma\gamma$ are not due to perturbation theory busting coupling of MMs to photons.*
  - *The Schwinger production of composite MMs is NOT exponentially suppressed by a factor of $e^{-O(500)}$ as is MM production using DY or $\gamma\gamma$ production modes.*

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

1st Search Sensitive to Composite MMs?

MoEDAL

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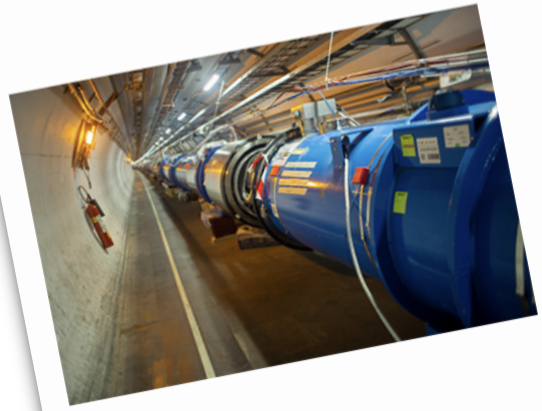
SEARCHES FOR NEW PHYSICS

CMS ha

120 Neutron Star

EDITORS' SUGGESTION

MoEDAL Search in the CMS Beam Pipe for Magnetic Monopoles Produced via the Schwinger Effect



A search for the magnetic monopoles that carry 2 to 45 Dirac units of magnetic charge that could have been produced by heavy-ion collisions places world-leading limits on the monopole masses.

B. Acharya et al.

Phys. Rev. Lett. **133**, 071803 (2024)

- *Th*
  - *ma*
    - *production are theoretically valid – limits from DY*
    - *to perturbation theory busting coupling of MMs to photons.*
    - *The Schwinger production of composite MMs is NOT exponentially suppressed by a factor of $e^{-O(500)}$ as is MM production using DY or $\gamma\gamma$ production modes.*

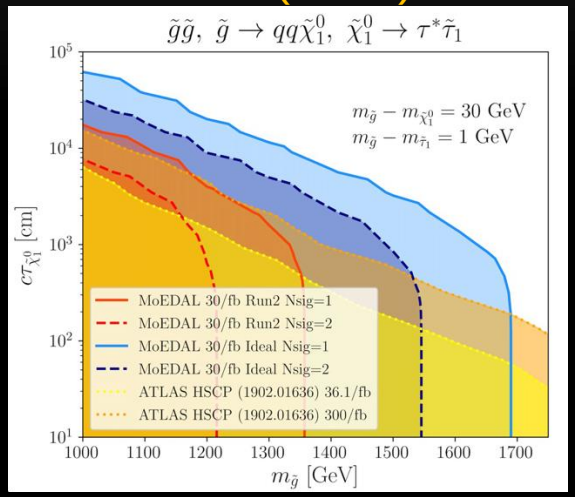
Nature 602 (2022) 7895, 63-67 (Run-1)

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

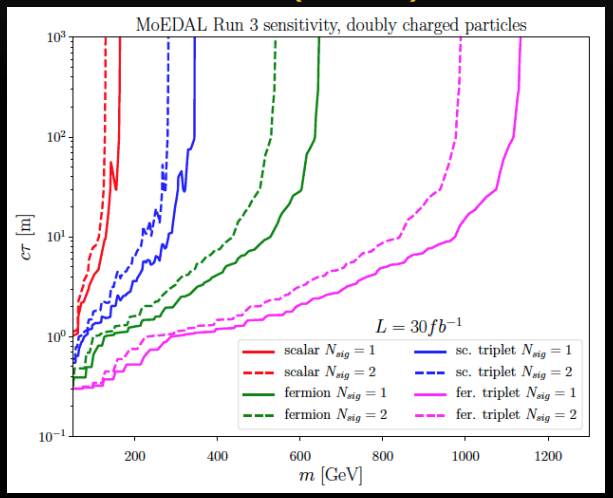
EPJC 80 (2020) 431



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

SLEPTONS

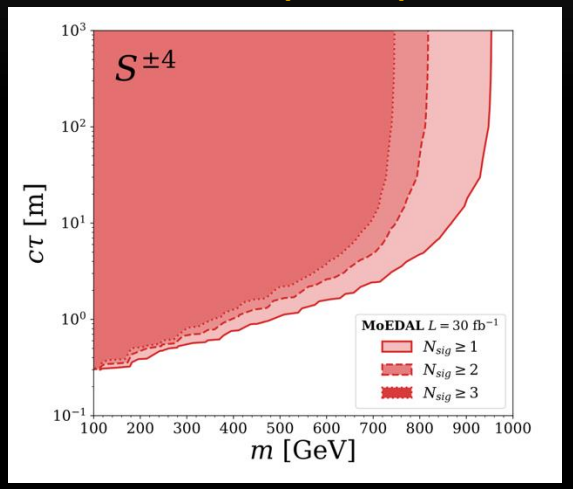
EPJC 80 (2020) 572



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

DOUBLY CHARGED

EPJC 81 (2021) 697



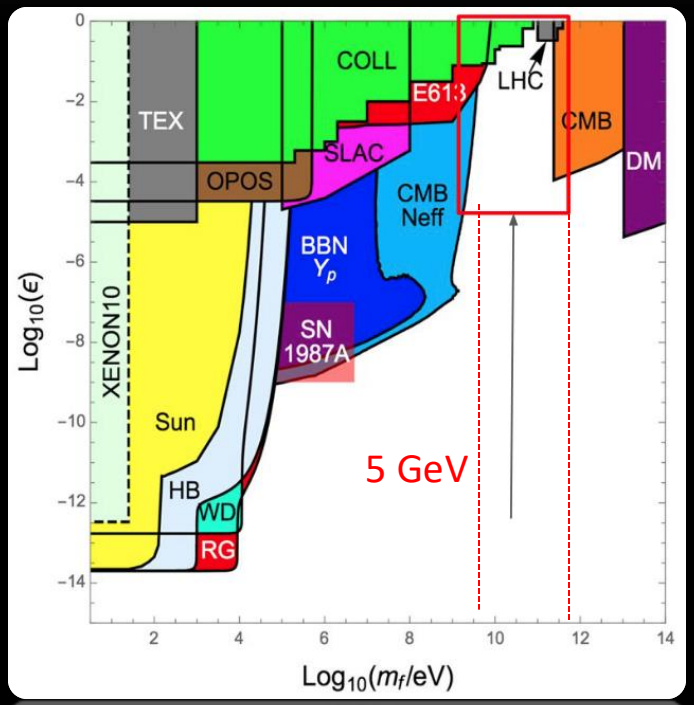
In this class of neutrino mass models, the SM is extended with two scalar fields, and 3 pairs of vector-like fermions.

2,3 and 4 CHARGED

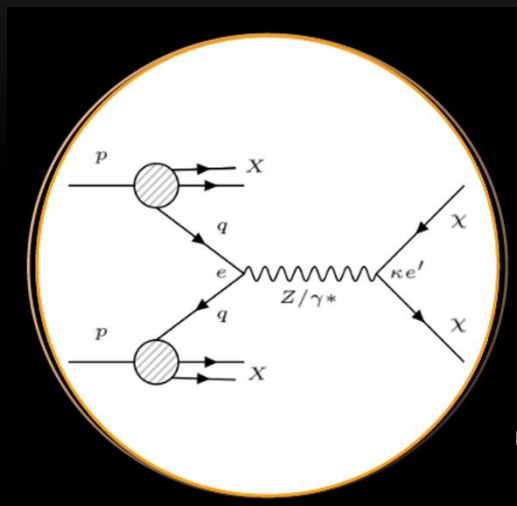
- *If sufficiently slow moving, even singly or multiply ($\lesssim 10e$) charged particles may leave a track in NTDs*
- *Supersymmetry offers such long-lived states: sleptons, R-hadrons, charginos*
- *Multiply charged scalars or fermions are, for example, predicted in several neutrino mass models.*

Production of Milli-charged at Colliders

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

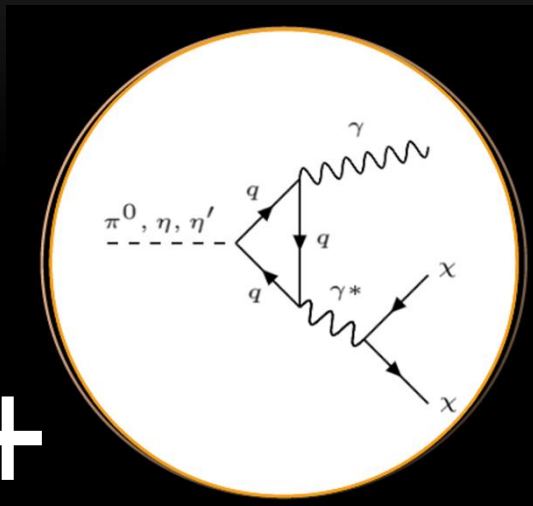


The Sweet Spot
arXiv:1511.01122

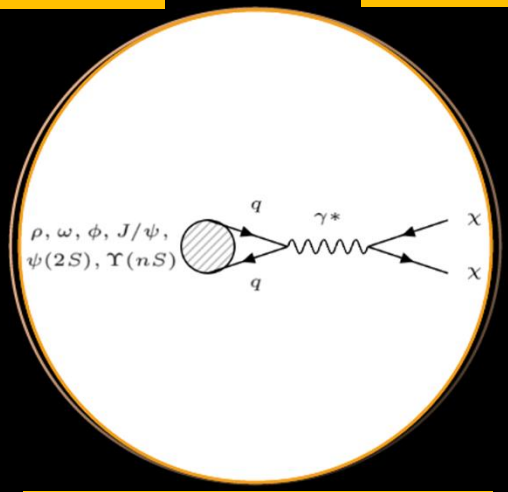


DRELL-YAN

+

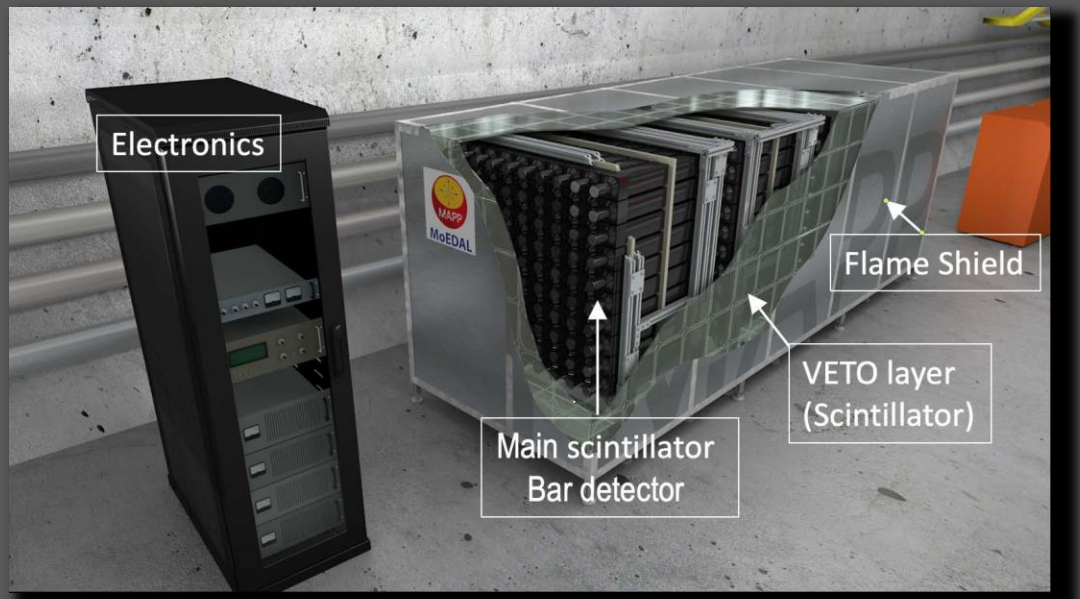


DALITZ DECAYS



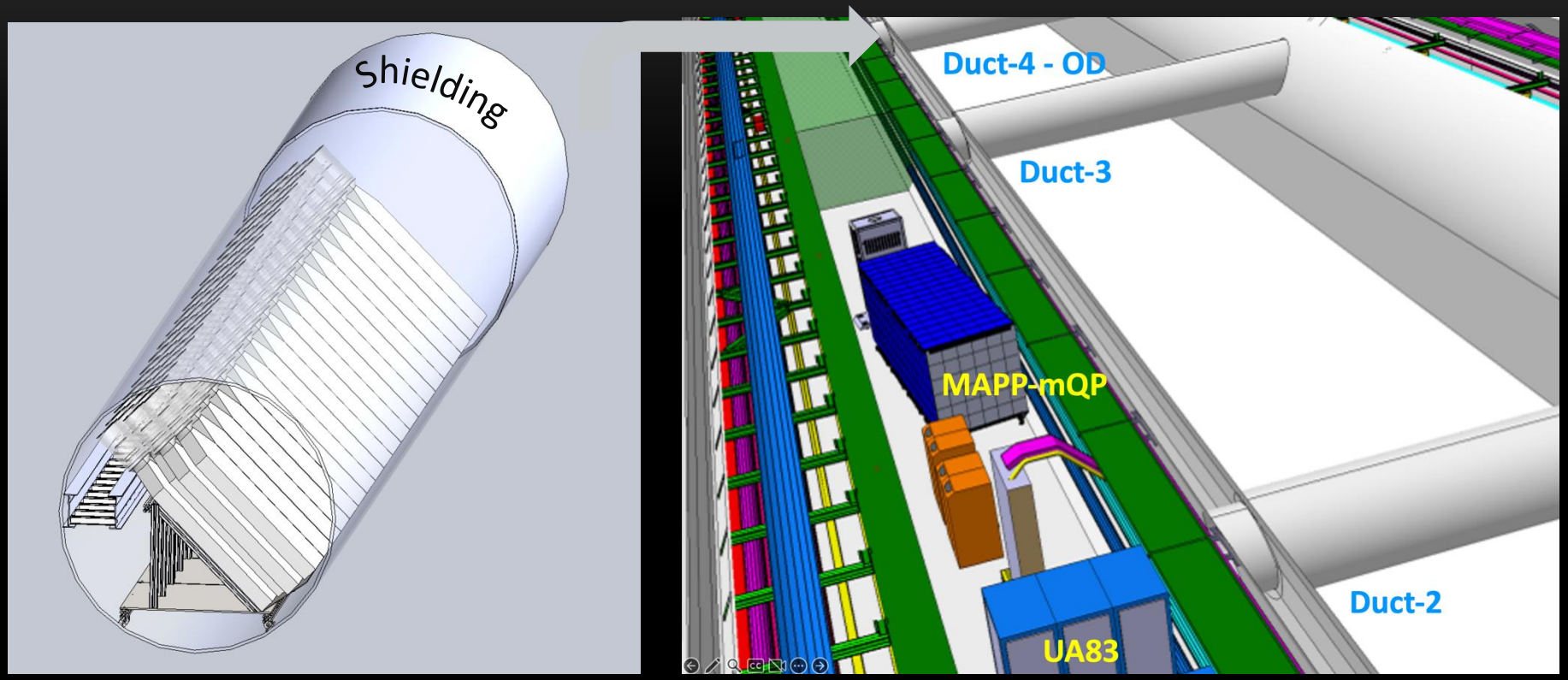
DIRECT DECAYS

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

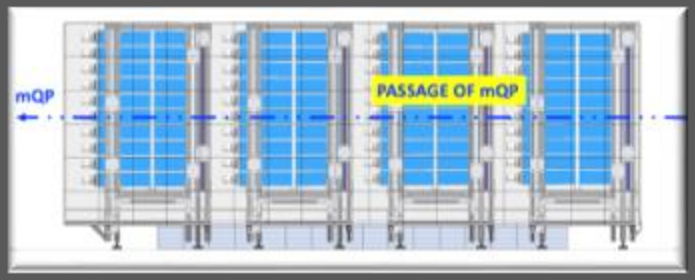
The MAPP-1 Outrigger



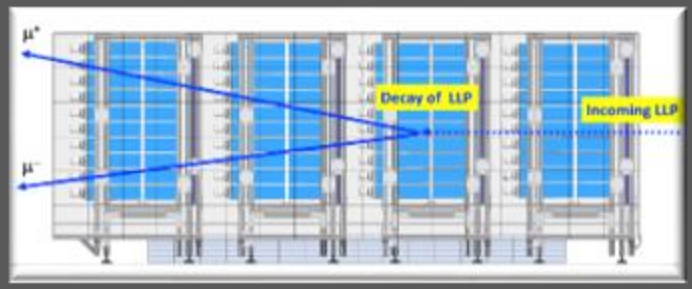
- *OUTRIGGER- A proposed extension of the MAPP bar detector to improve the overall reach for higher mass mCPs (above a few GeV)*
- *4 scintillator planes (each comprised of 20 60 cm x 30 cm x 5 cm sub-planes angled at 45 degrees) readout by coincident PMTs – an effective area of ~2.6m^2*

MAPP – Modes of Detection

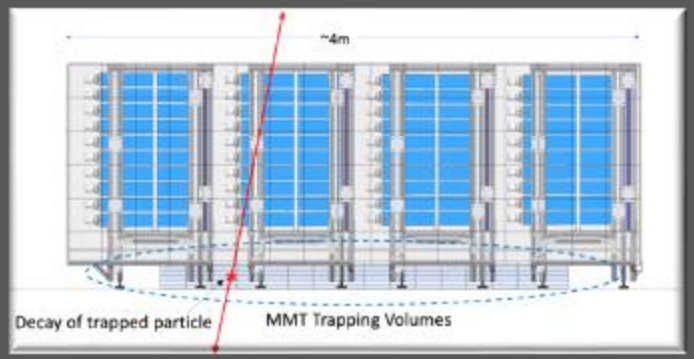
Muons from IP (Calibration)



Millicharged particle detection



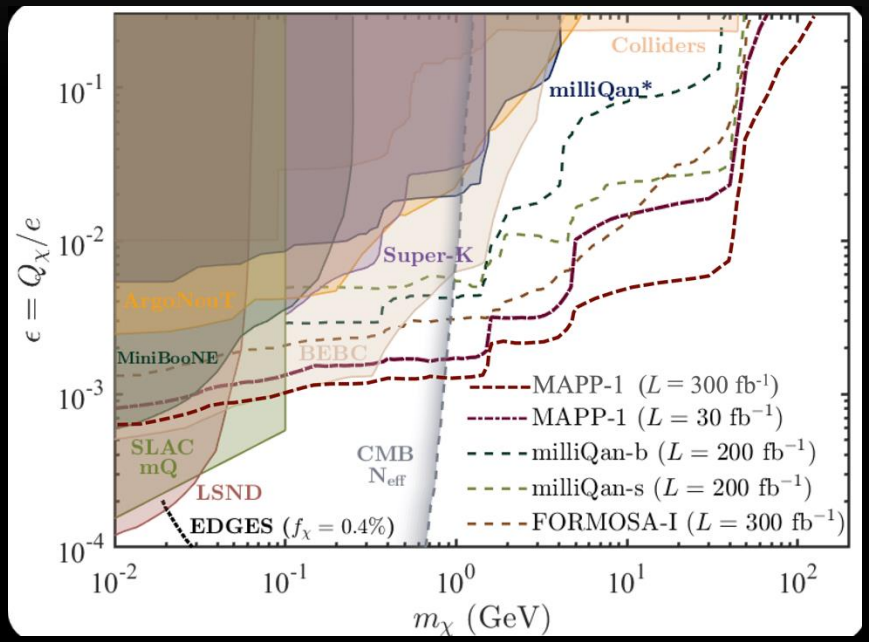
Neutral LLP Detection

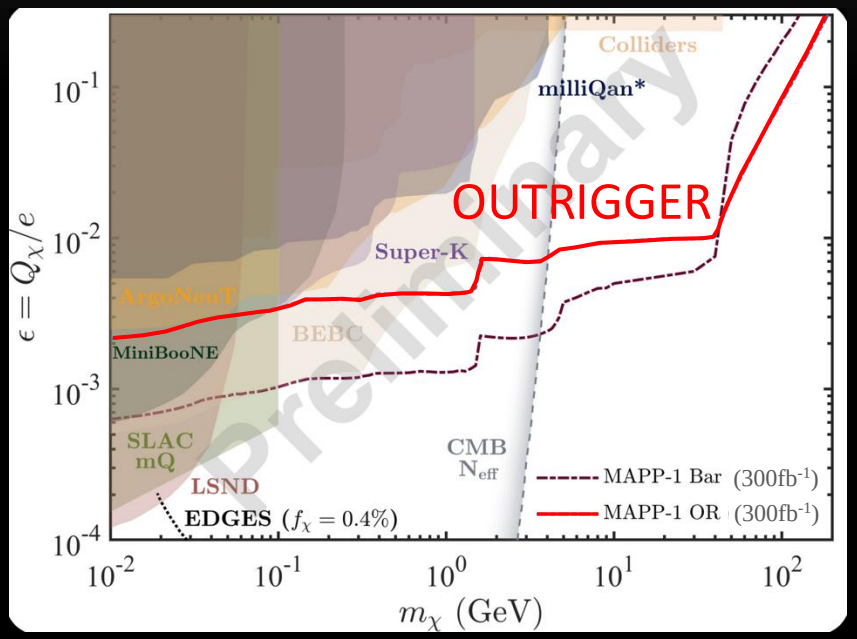


Charged LLP Detection
(In conjunction with MoEDAL)

MAPP-1 Sensitivity to Millicharged Matter

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

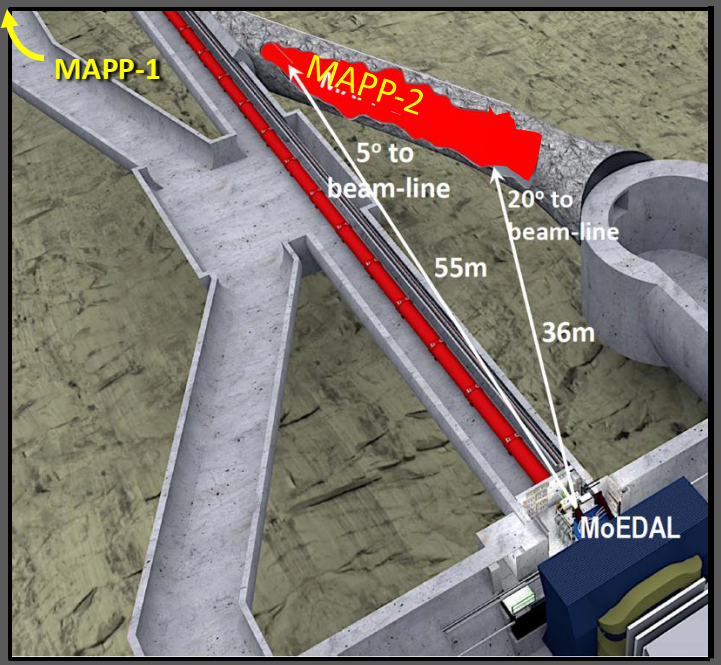


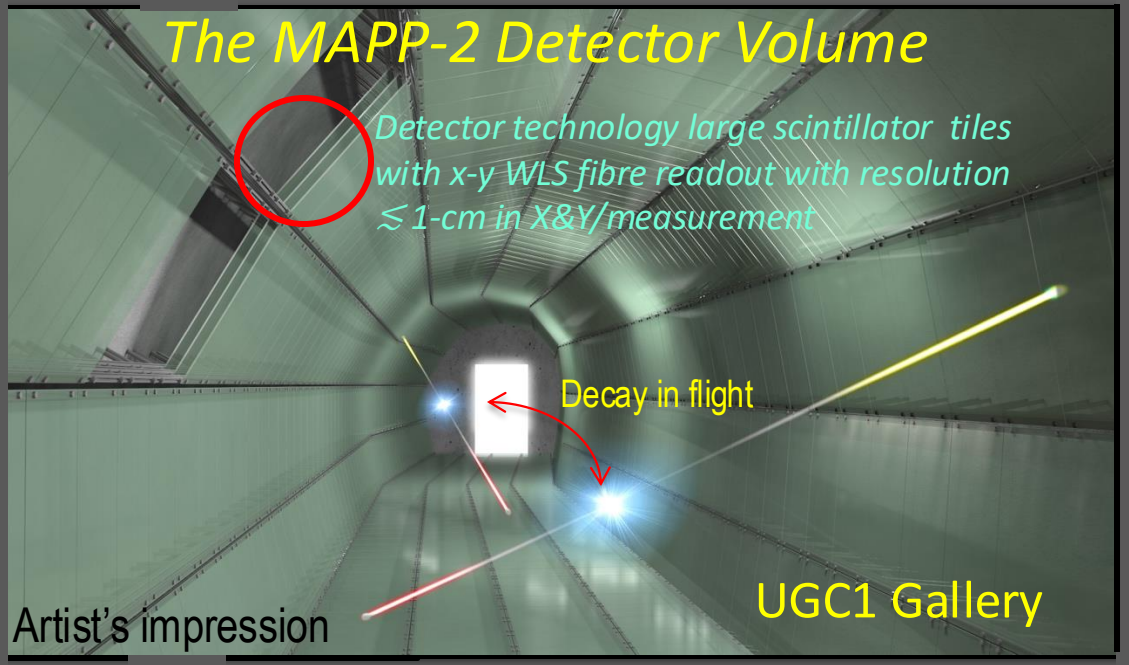


- *The 95% CL exclusion Limits for MAPP-1 for **mCPs produced by DY** mech. + direct decays of heavy quarkonia, light vector mesons, and single Dalitz decays of PS mesons.*
  - *Signal efficiency estimates included*
- *The OUTRIGGER improve the mass reach 130 GeV → 200 GeV*

The Future

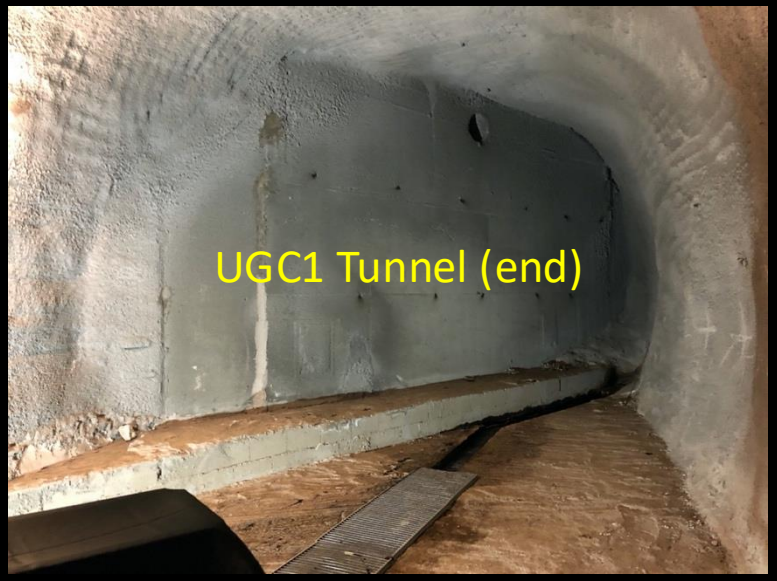
Phase-2 → MAPP-2 for HL-LHC





- *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 would form 3 or 4 hermetic containers - one within the other – lining the walls of UGC1*
- *MAPP-2 ~1200 m^3 of instrumented decay volume – estimated cost < 3M CHF*
- *Designed to detect Long-Lived particle decays to **charged particle & photons***

UGC1 Refurbishment

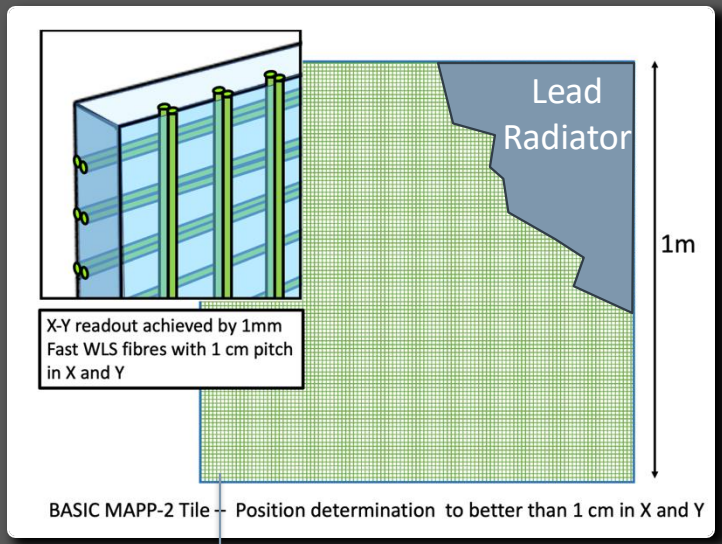


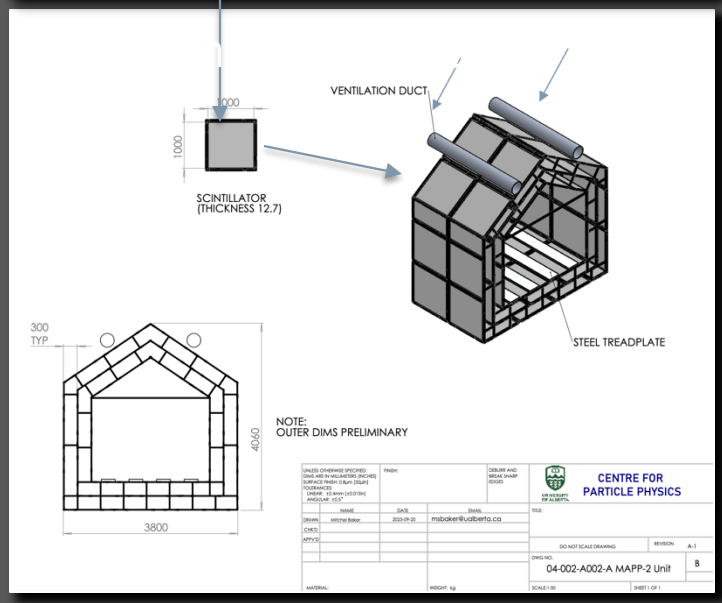
Safety Requirement	Cost	Cost + Contingency
Fire Detection	21,000 CHF	23,100 CHF (10 %)
Emergency Red phone	11,200 CHF	11,760 CHF (5 %)
Electrical Safety	48,200 CHF	53,000 (10 %)
Civil Engineering	151,000 CHF	166,100 CHF (10 %)
HVAC	45,000 CHF	54,000 CHF (20%)
Access and work at height at UGC1	10,000 CHF	11,000 CHF (10 %)
Radiation Protection Patrol & Access System Requirement	45,000 CHF 4,500 CHF	49,500 CHF (10 %) Patrol System 4,725 CHF (5 %) Sector door
TOTAL	335,900 CHF	373,185 CHF

Safety assessment CERN EDMS #2487833

- *Civil work ~$0.4 million*
- *MAPP-2 Detector cost ~$2-3 million*
- *Funding requested for work in 2026 awarded in 2025 (if successful)*
- *TP under construction (NoI given)*

Design of MAPP-2 Detector





STRUCTURE FREE DECAY ZONE

PHOTONS

Threshold sensitivity - few hundred MeV

UGC1

CHARGED

Position sensitivity

σ_x, σ_y and σ_z ~3mms

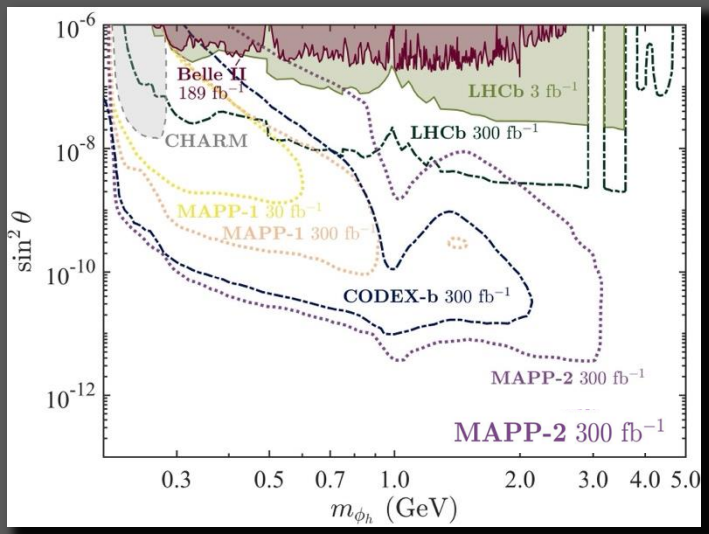
Vertex resolution

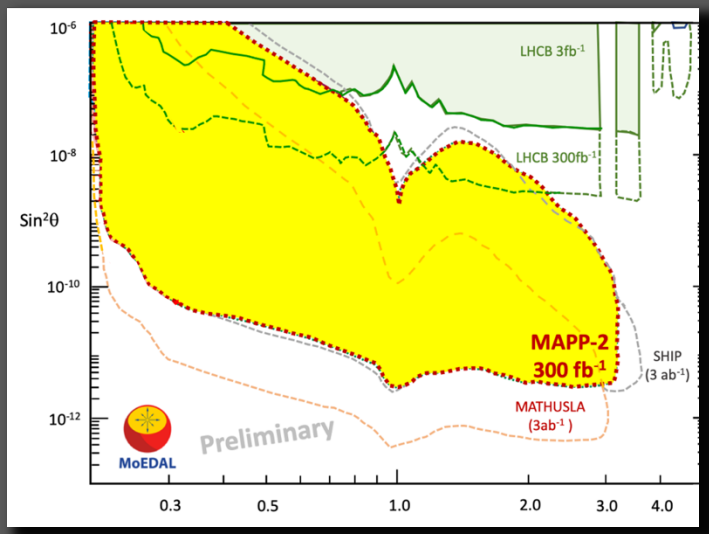
σ_x, σ_y and σ_z ofo 1cm

Two hit resolution ~ 2cm

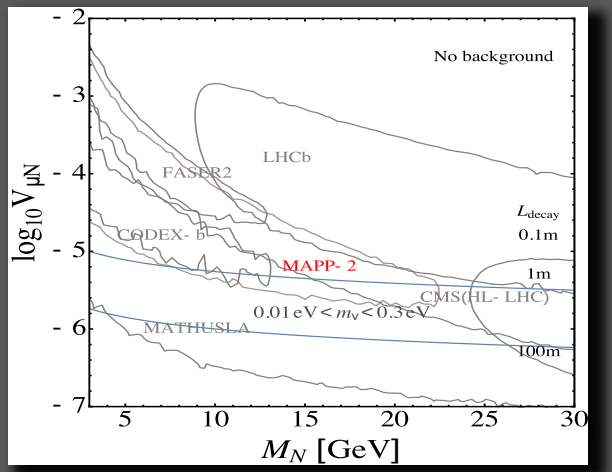
- *MAPP-2 Detector technology similar to that used for muon tomography*

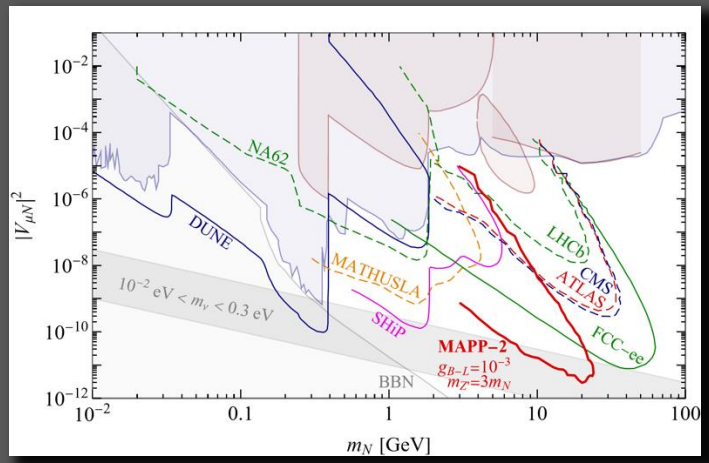
MAPP-2 – Sensitivity Benchmarks





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 ϑ ≪ 1. See PRD97 (1) (2018) 15023.



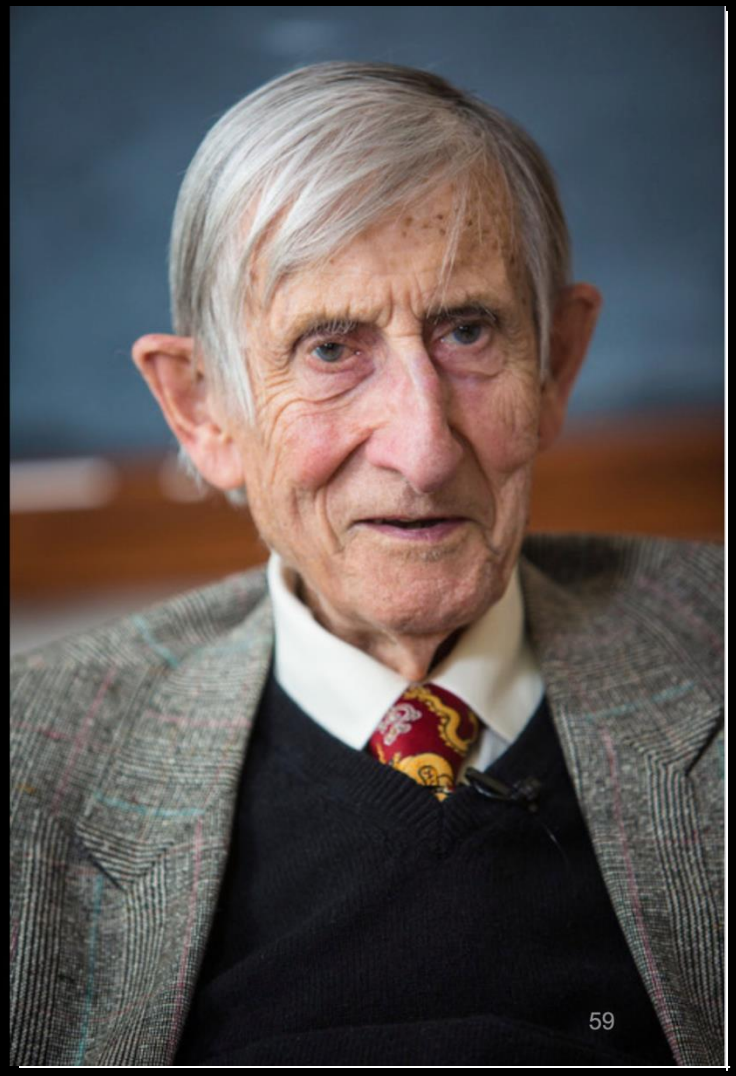


*Pair production of right-handed neutrinos from the decay of an additional neutral **Z^0** boson in the gauged **B-L** model – Phys. Rev. D100 (2019), 035005.*

Final Words

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

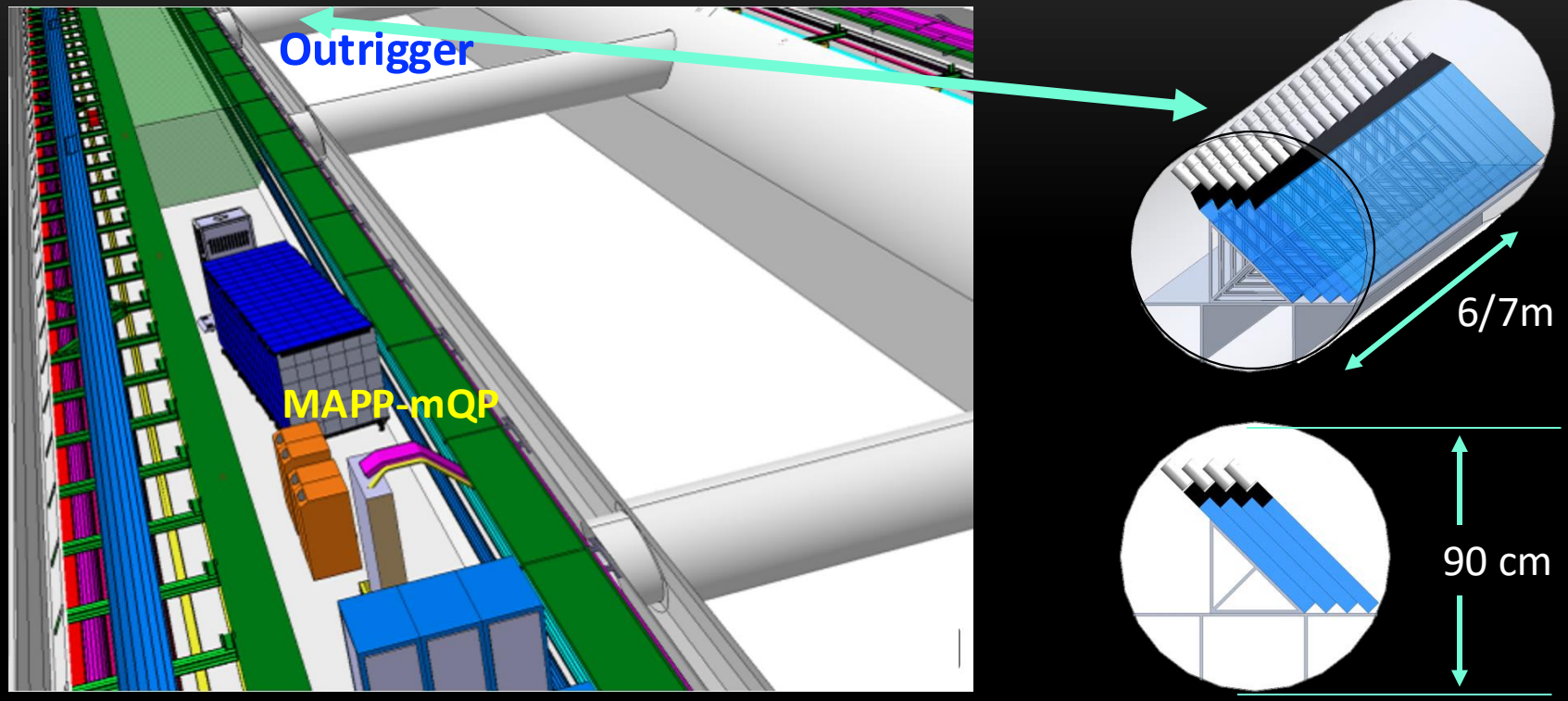
- Freeman Dyson



- ***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***

SUPPLEMENTAL SLIDES

The MAPP Outrigger Detector Upgrade



- *The outrigger detector for the MAPP-mQP is designed to improve its sensitivity at larger masses and millicharged.*
  - *Phase-1 (for 2024) - The basic unit of the outrigger is a 60 cm x 30 cm x 5 cm plate readout by a PMT on a light guide. These basic units are combined in 4 layer, 6/7m long, ~80 detector array that fill the ducts joining UA83 and the beam-line tunnel*
  - *Phase-2 (for 2025) – The Outrigger detector will be doubled in size using two additional ducts*

EXTRA SLIDES

MoEDAL-MAPP 22 Institutes

75 Physicists & Engineers

UNITED KINGDOM
Imperial College London.
Kings College London.
Queen Mary University.
Track Analysis Systems Ltd. (Assoc.)

EUROPE
Technical University of Athens (Assoc.)
University of Bologna & INFN Bologna.
Czech Tech. University.
University of Helsinki.
Institute of Space Sciences Romania.
University of Valencia (IFIC).
University of Warsaw (Assoc.)

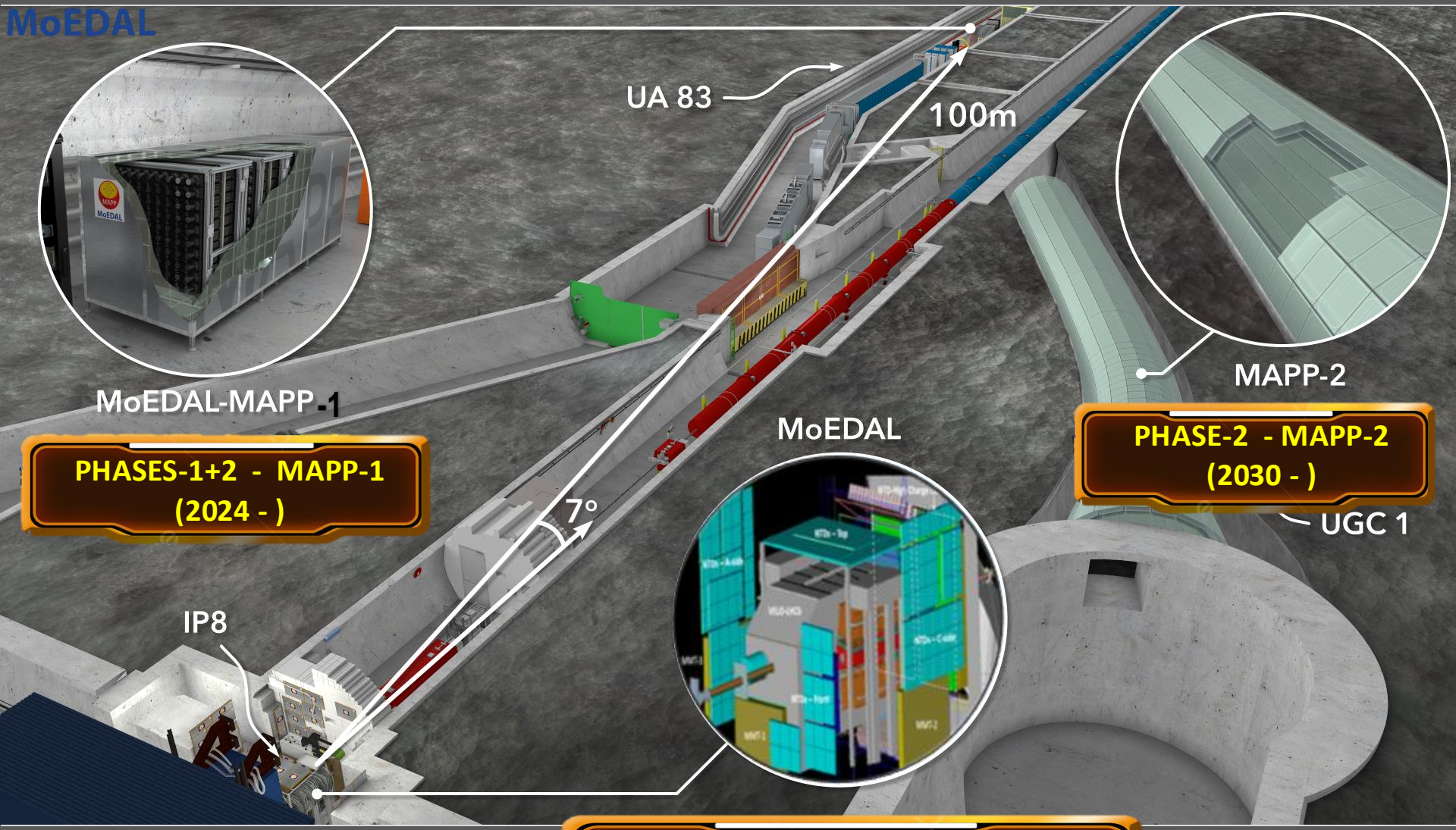
NORTH AMERICA
University of Alabama.
University of Alberta.
University of British Columbia.
Concordia University.
University of Montreal.
University of Regina.
Tuft's University.
University of Virginia.

MOROCCO
Oujda University

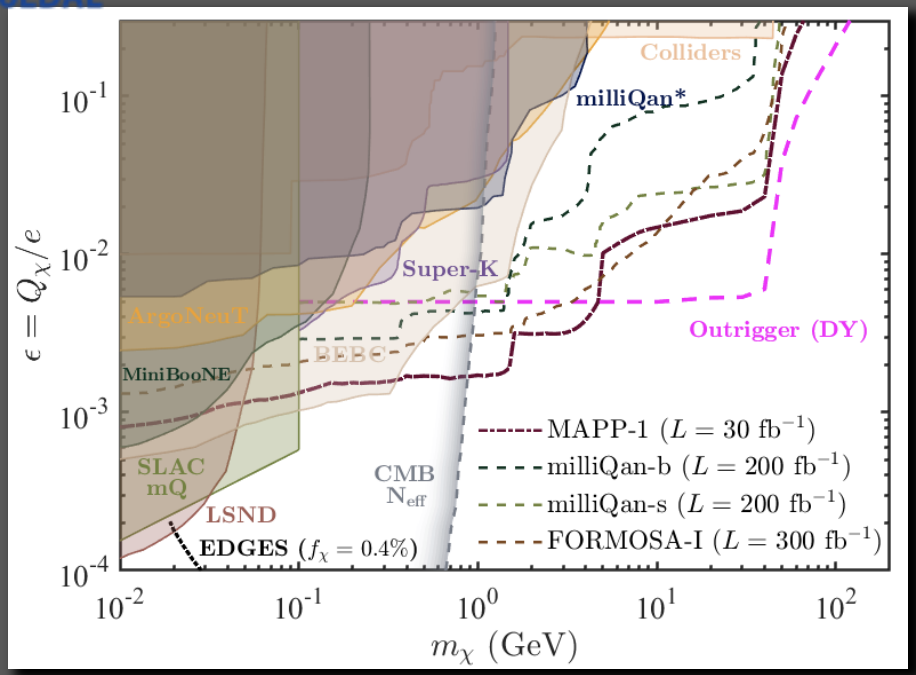
INDIA
University of Calcutta.
National Institute of Technology, Kuruksetra (Assoc.)

KOREA
Centre for Quantum Spacetime, Seoul.

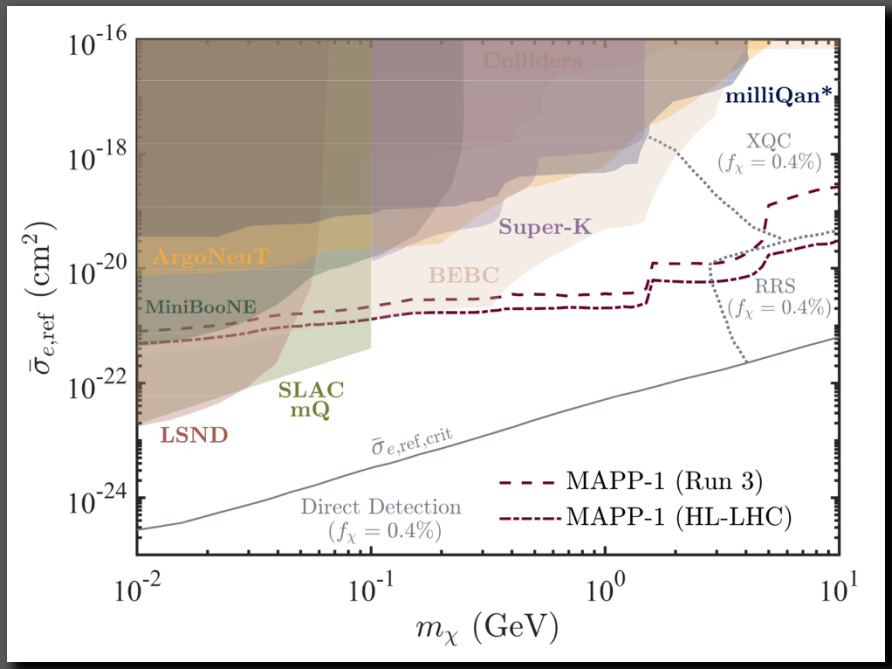
MoEDAL-MAPP a >24 Year Project



Millicharged Particles & Dark Matter



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:



The sensitivity of MAPP-1 to mCP **strongly interacting dark matter** at the LHC's Run3 and the HL-LHC established at the 95% confidence level. (XQC - X-ray quantum calorimetry (XQC) rocket experiment; RRS, balloon-based experiment conducted by Rich et al.

- *A DM candidate is mCP strongly interacting DM (mC-SIDM)*
  - *There is a $\sigma_{critical}$ above which these particles range out before reaching UG DM det.*
  - *A small mCP subcomponent of DM , $f_\chi \leq 0.4\%$, remains consistent with CMB data*
- *Assuming 0.4% mC-SIDM, MAPP-1's exclusion of a significant part of the mC-SIDM window is shown on the RH plot.*