MoEDAL-MAPP Results & Upgrades

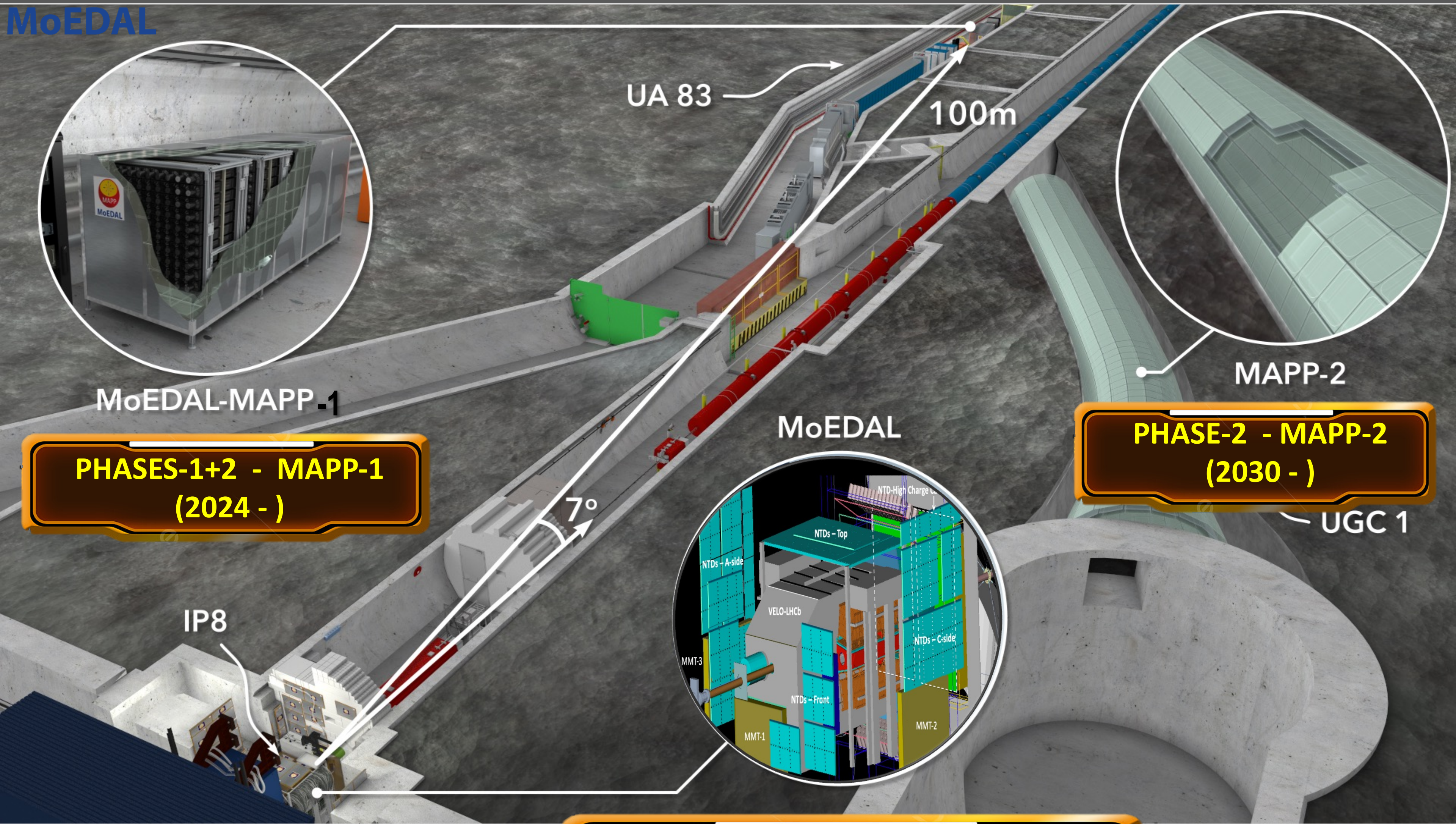
News from the LHC's Discovery Frontier

LLP 2024 Tokyo

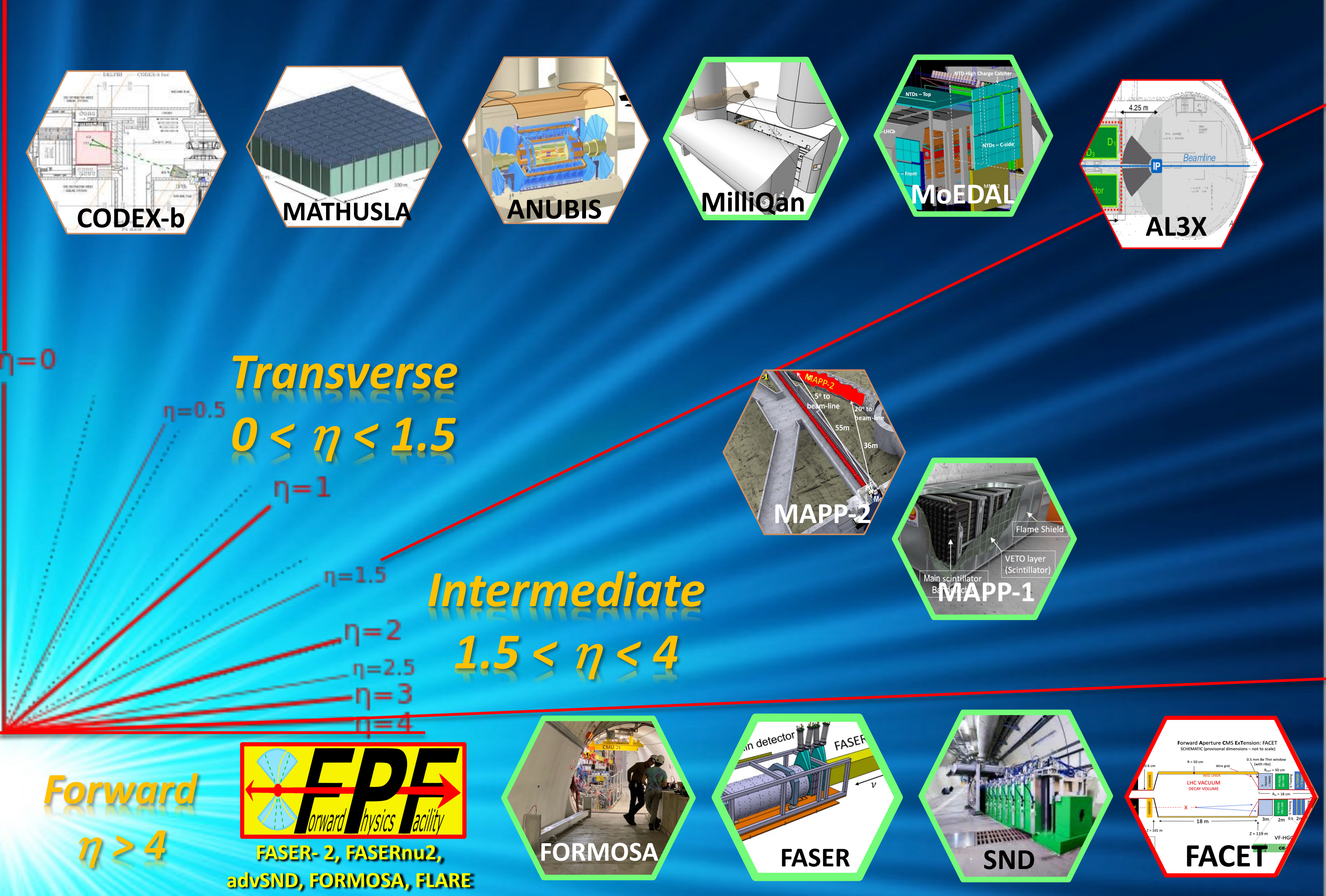
James L. Pinfold

(for the MoEDAL-MAPP Collab.

MoEDAL-MAPP a > 24 Year Project

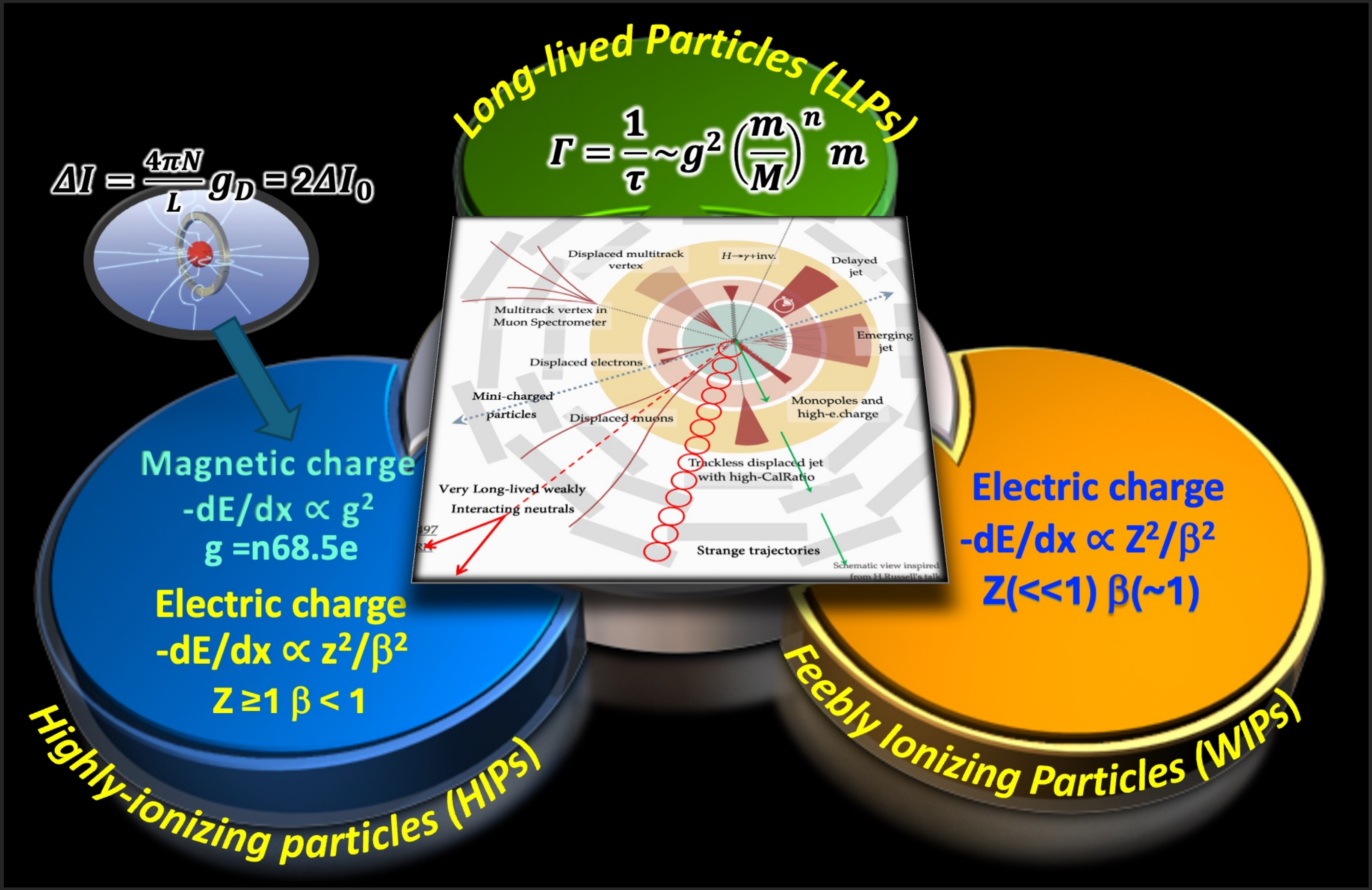


The Cast of Detectors



MoEDAL-MAPP Search for New Physics…

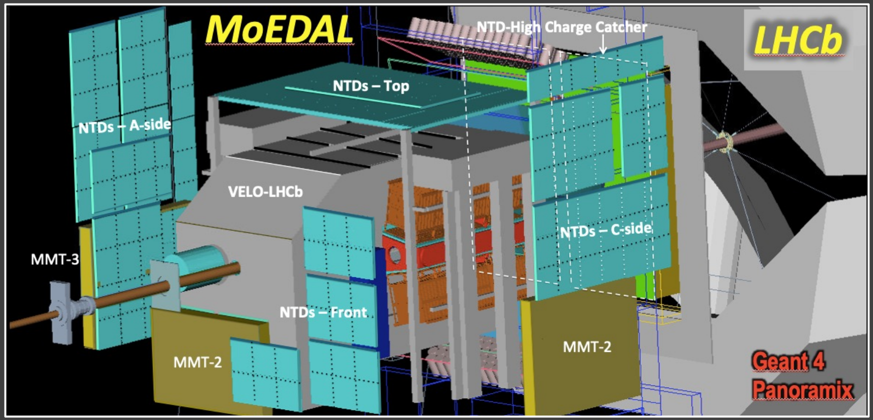
MoEDAL-MAPP is optimized to detect these avatars of New Physics



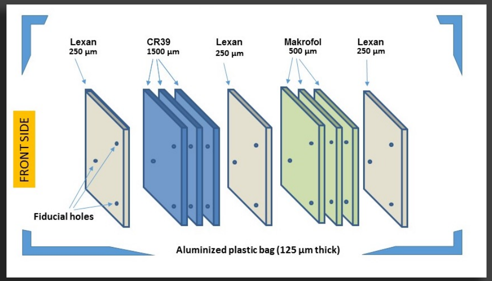
ATLAS and CMS are not optimized to detect HIPs, WIPs and LLPs.

The Phase-0 MoEDAL Detector

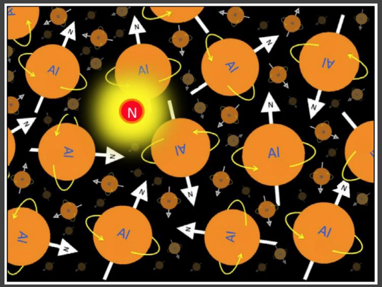
LHC's 1st dedicated search expt. –upgraded for Run-3 with higher eff. & lower thresholds



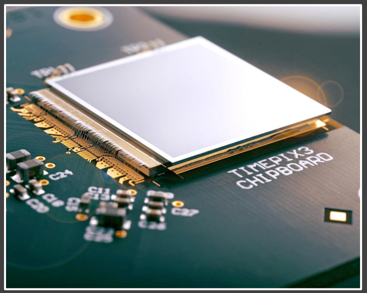
Searching for HIP avatars of new physics



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



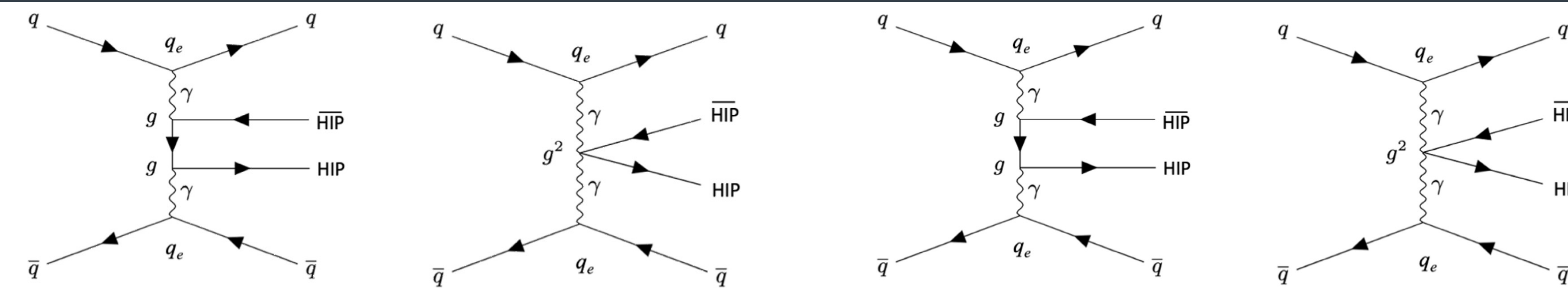
TRAPPING DETECTOR ARRAY A tonne of Al to trap Highly Ionizing Particles for analysis



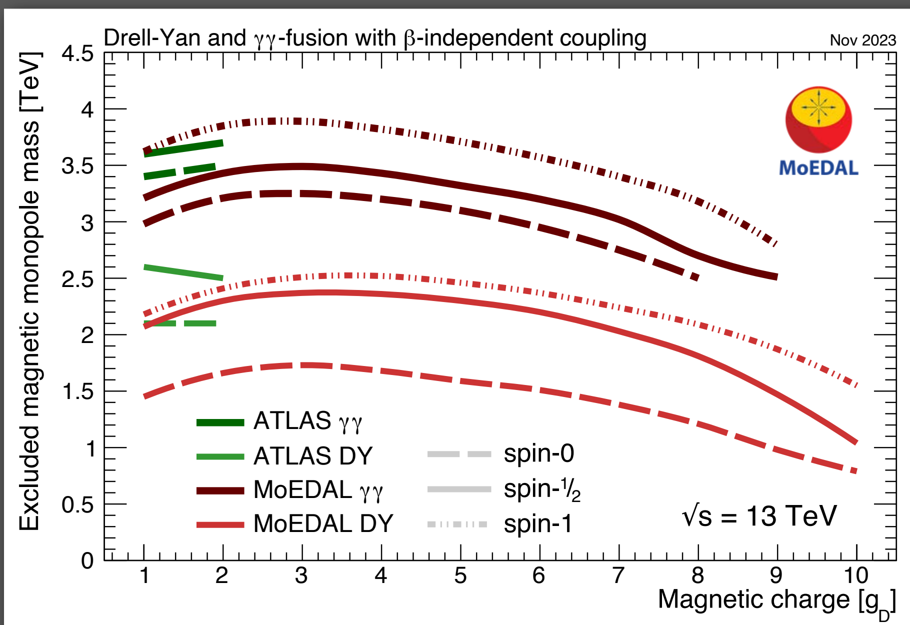
TIMEPIX Array a digital Camera for real time radiation monitoring

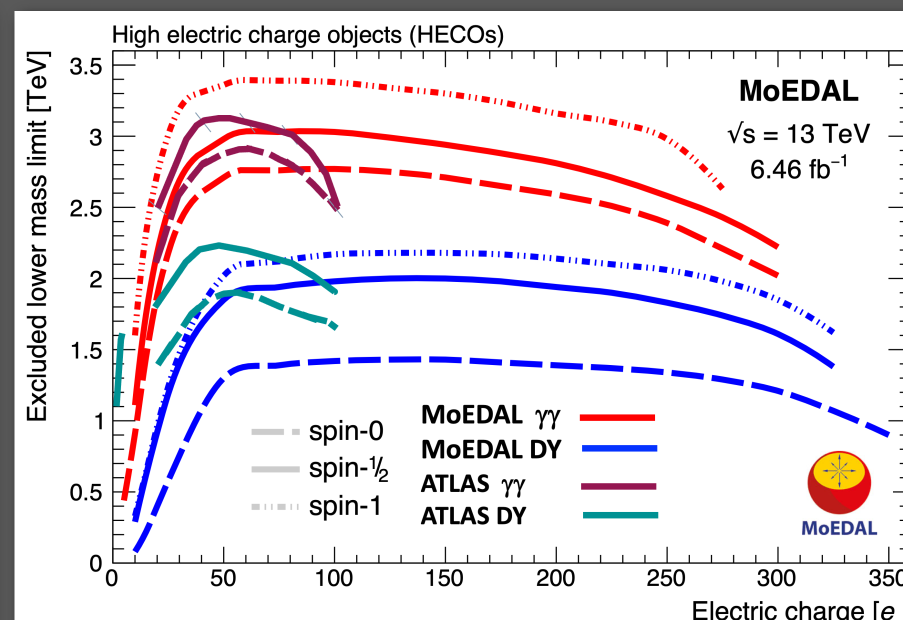
NO TRIGGER | **NO SM BACKGROUNDS** | **PERMANENT RECORD**

Recent Results from HIP Search



(c) Four-vertex PF process (d) Three-vertex PF process (c) Four-vertex PF process (d) Three-vertex PF process



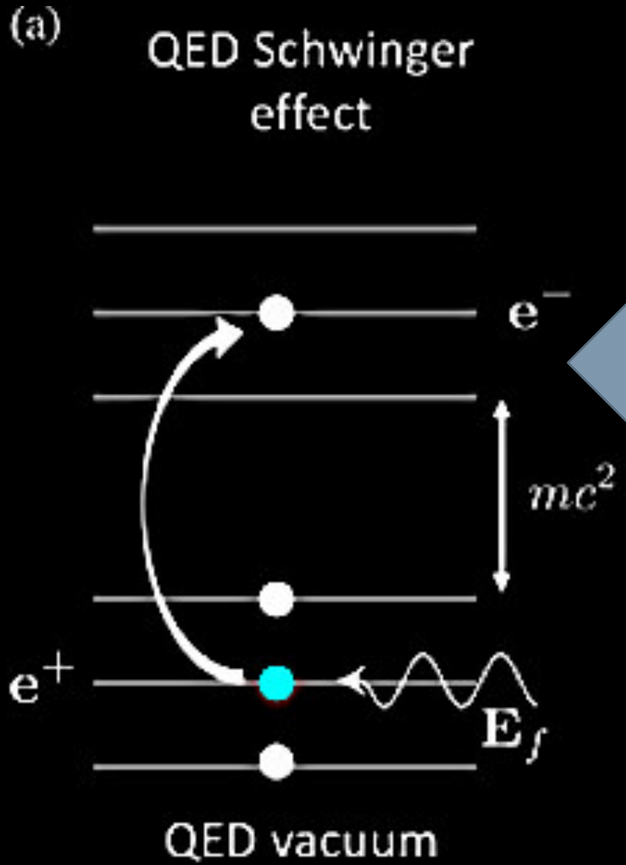


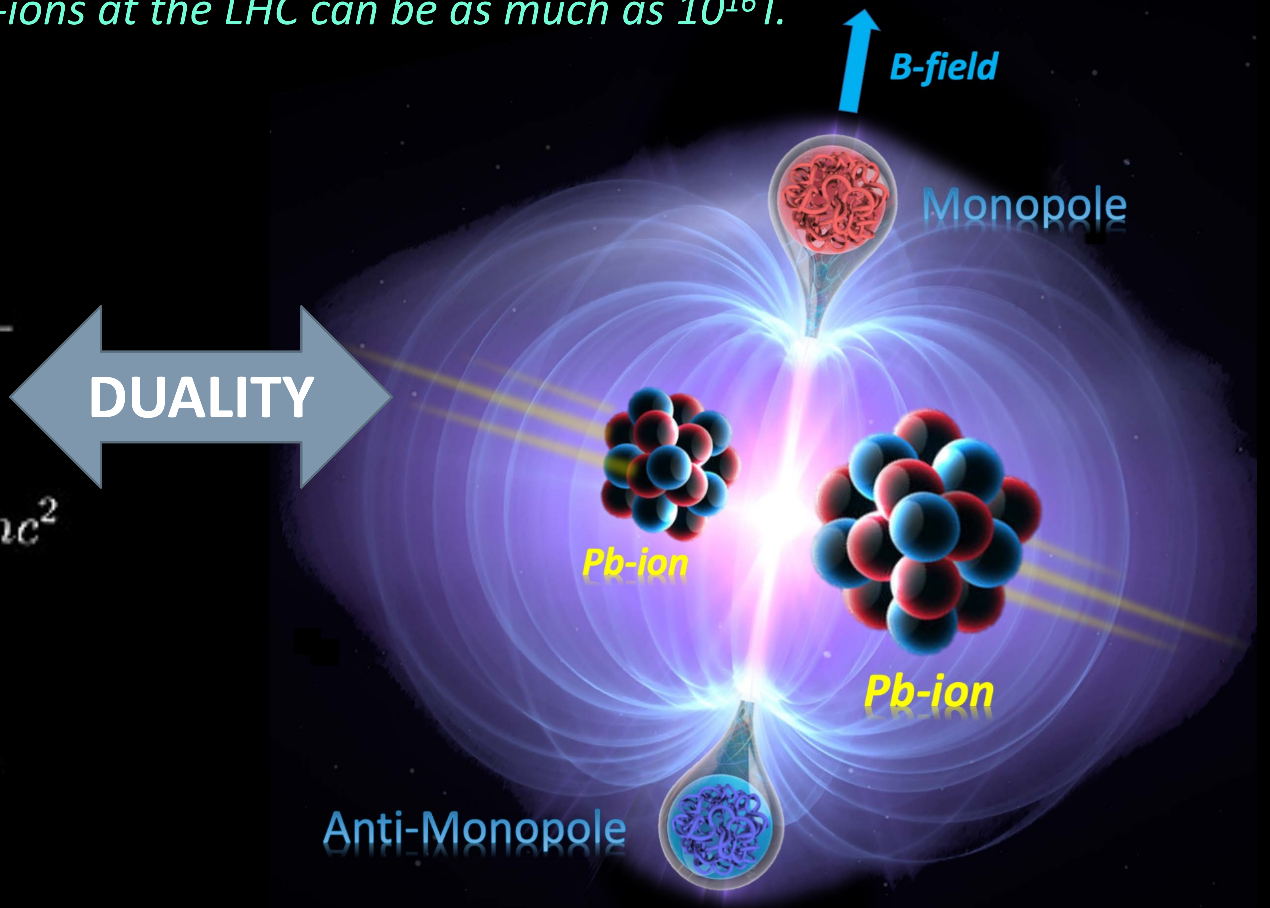
MAGNETIC MONOPOLES (MMs) **HIGHLY ELECTRICALLY CHARGED OBJECTS**

• 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.





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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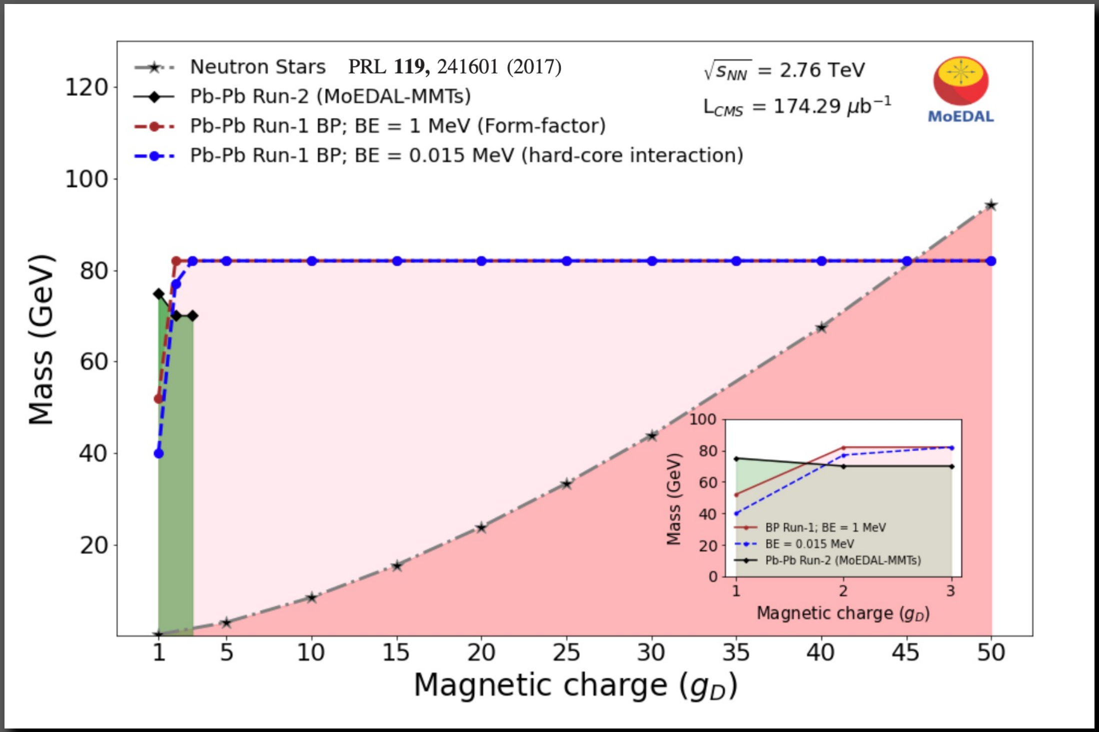
CMS beam pipe to be mined for monopoles

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.*

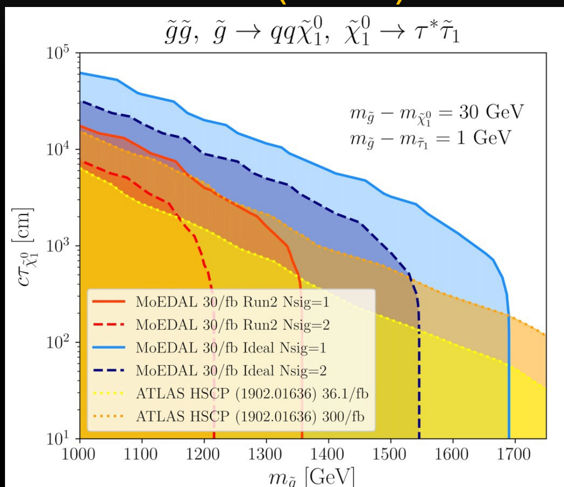
Nature 602 (2022) 7895, 63-67 (Run-1) **arXiv:2402.15682v1, 24 Feb 2024 to be published in PRL**

Searching for Long-Lived HIPS

MAPP MoEDAL

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

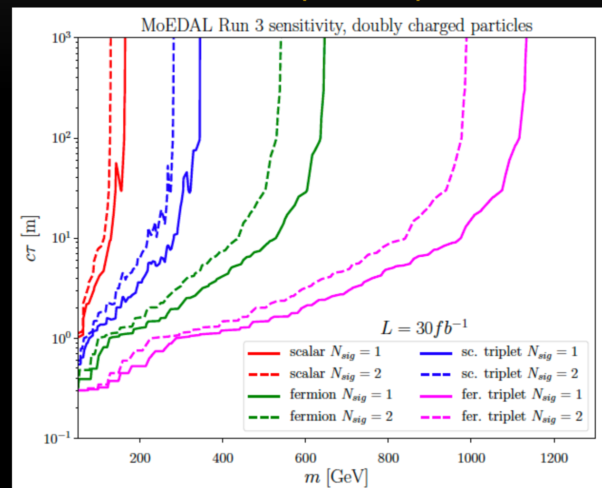
EPJC 80 (2020) 431



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

SLEPTONS

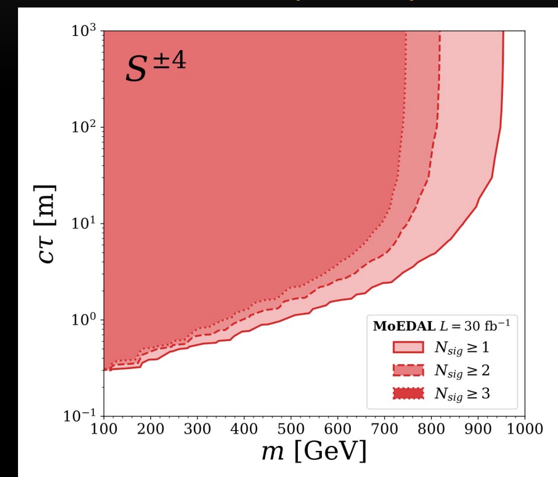
EPJC 80 (2020) 572



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

DOUBLY CHARGED

EPJC 81 (2021) 697

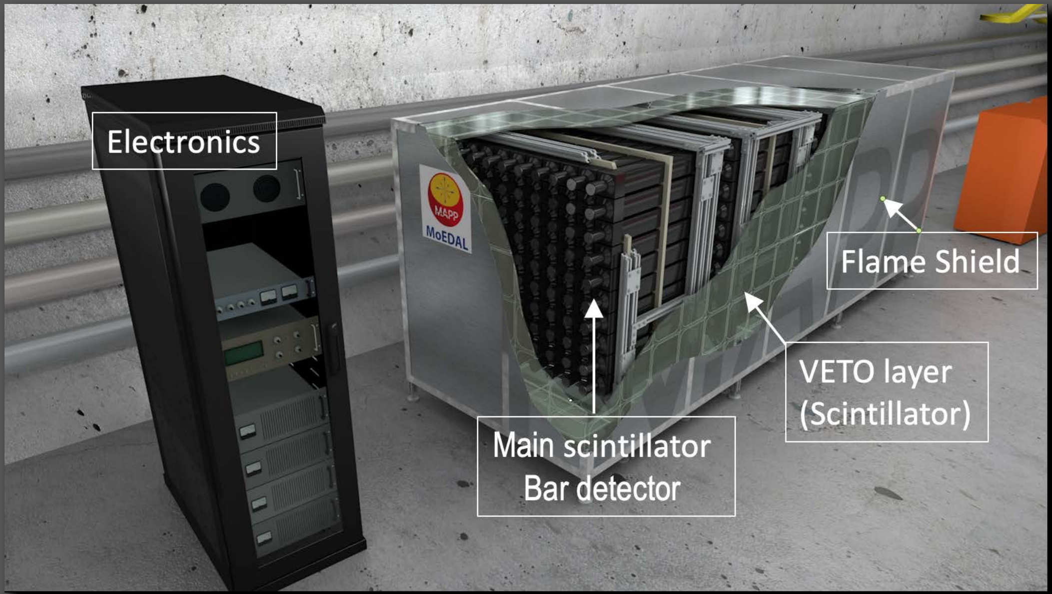


In this class of neutrino mass models, the SM is extended with two scalar fields, and 3 pairs of vector-like fermions.

2,3 and 4 CHARGED

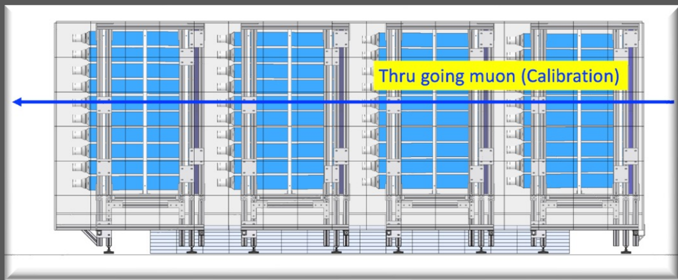
- *If sufficiently slow moving, even singly or multiply ($\lesssim$ 10e) charged particles may leave a track in NTDs*
- *Supersymmetry offers such long-lived states: sleptons, R-hadrons, charginos*
- *Multiply charged scalars or fermions are, for example, predicted in several neutrino mass models.*

MoEDAL's MAPP-1 Detector @ UA83

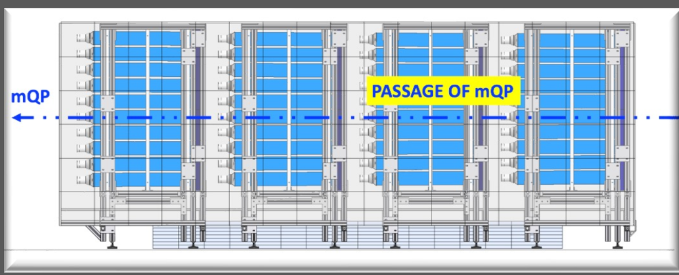


- *400 scintillator bars (10 x 10 x 75 cm^3) in 4 sections readout by 3" PMTs - Protected by a hermetic VETO counter system*
- *MAPP is sensitive to:*
  - *Milli-charged (10^{-3}c) particles*
  - *Long-lived neutral particles*
  - *Charged particles (using MoEDAl's MMTs)*
- *Latest paper: "Searching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

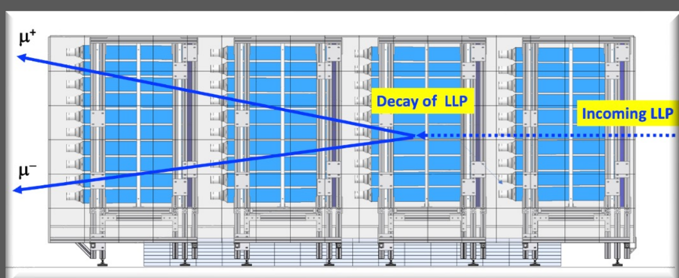
MAPP – Modes of Detection



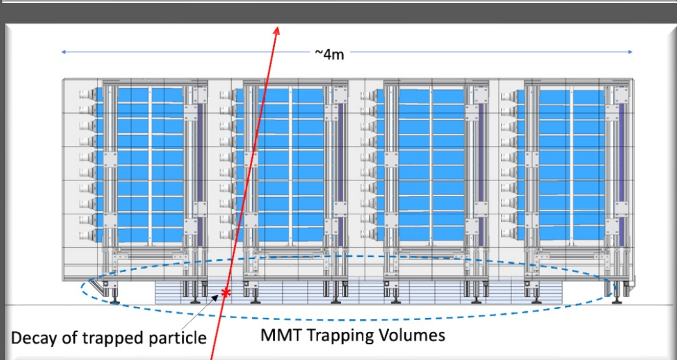
Muons from IP (Calibration)



Millicharged particle detection

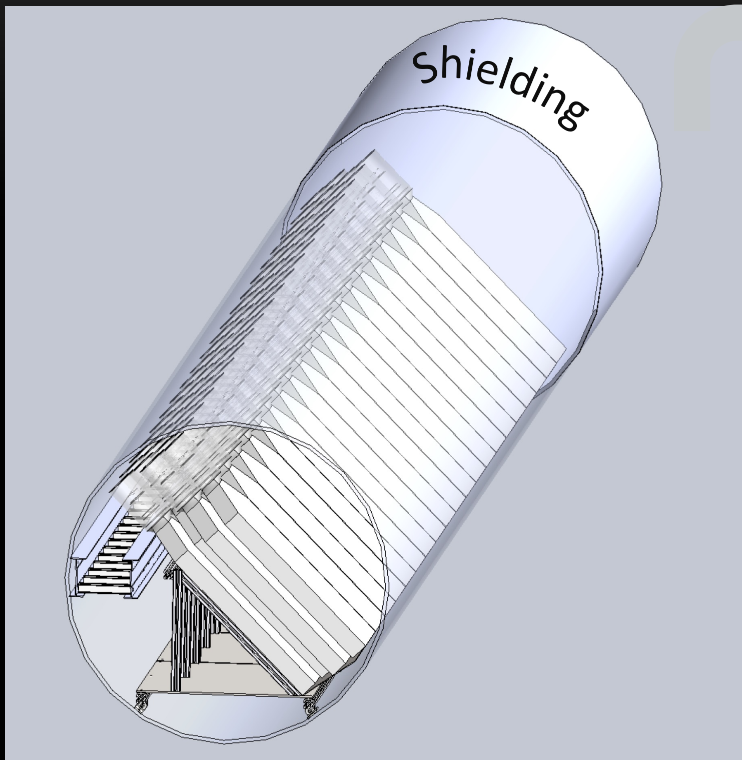


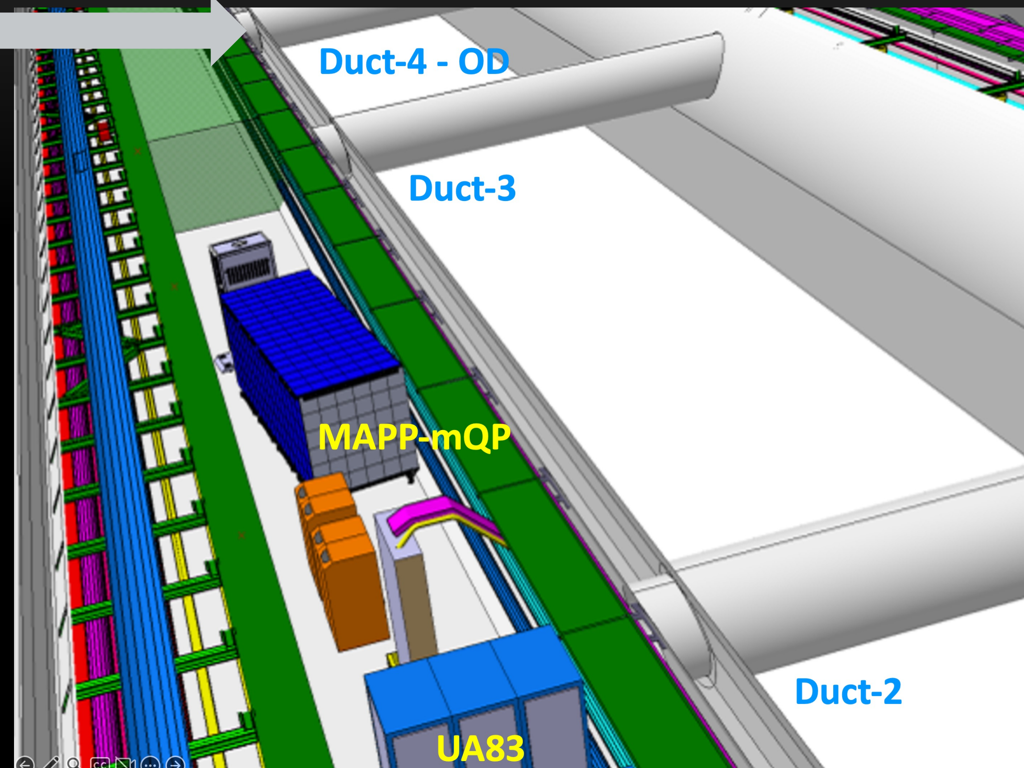
Neutral LLP Detection



Charged LLP Detection
(In conjunction with MoEDAL)

The MAPP-1 Outrigger

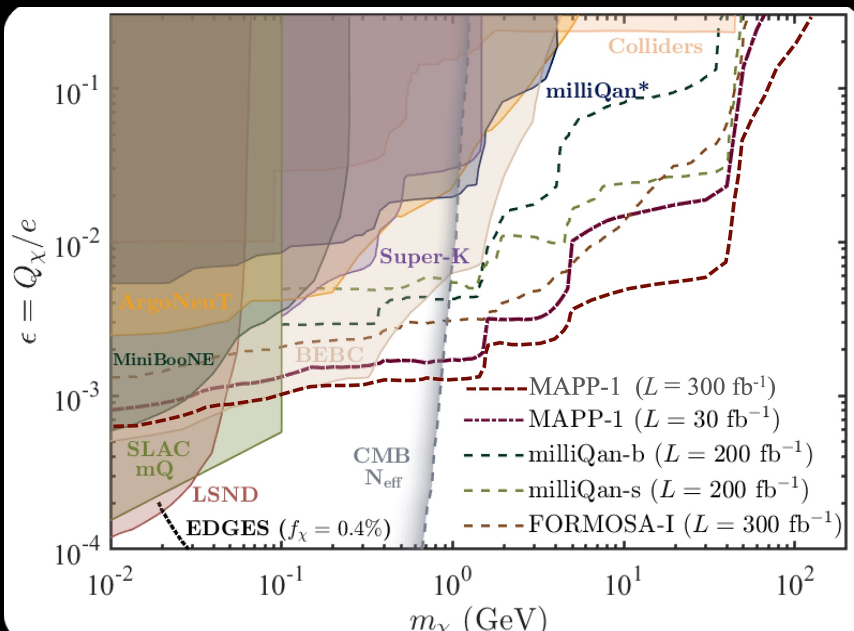


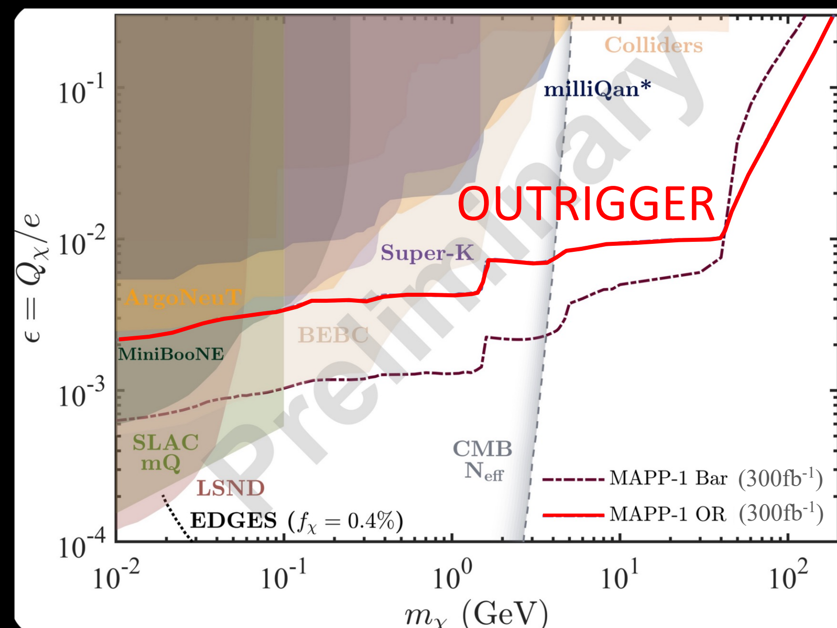


- *OUTRIGGER- A proposed extension of the MAPP bar detector to improve the overall reach for higher mass mCPs (above a few GeV)*
- *4 scintillator planes (each comprised of 20 60 cm x 30 cm x 5 cm sub-planes angled at 45 degrees) readout by coincident PMTs – an effective area of ~2.6m^2*

MAPP-1 Sensitivity to Millicharged Matter

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

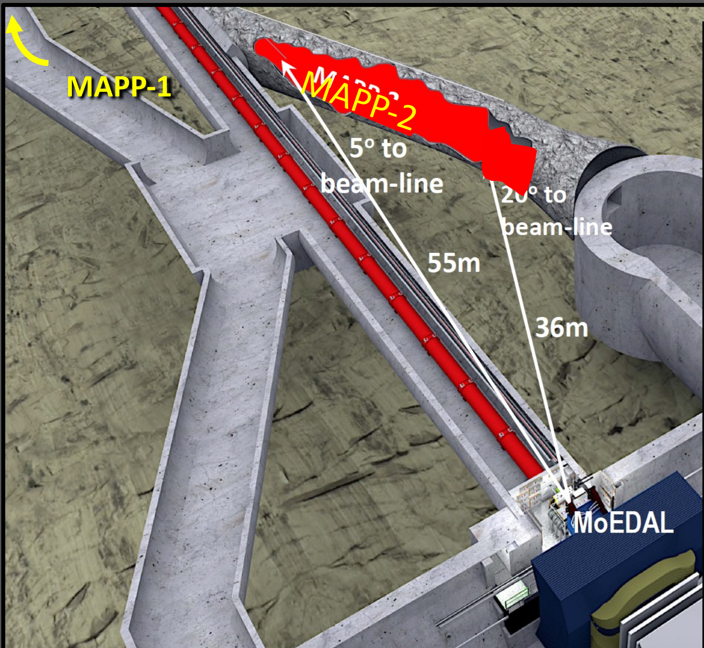


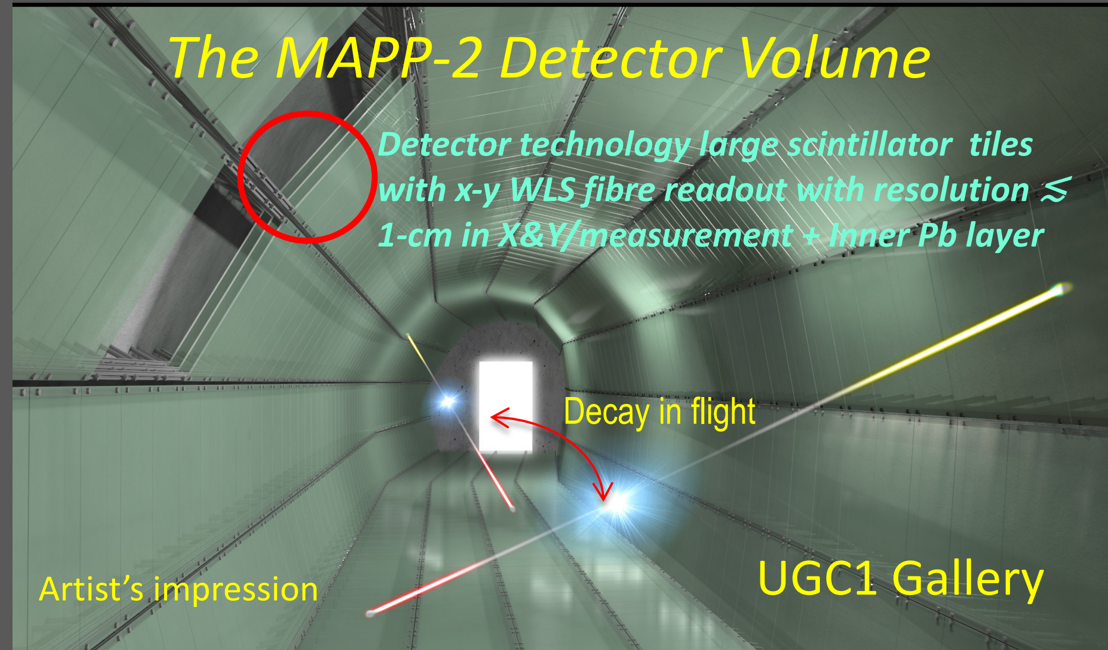


- *The 95% CL exclusion Limits for MAPP-1 for* ***mCPs produced by DY*** *mech. + direct decays of heavy quarkonia, light vector mesons, and single Dalitz decays of PS mesons.*
  - *Signal efficiency estimates included*
- *The OUTRIGGER improve the mass reach 130 GeV → 200 GeV*

The Future

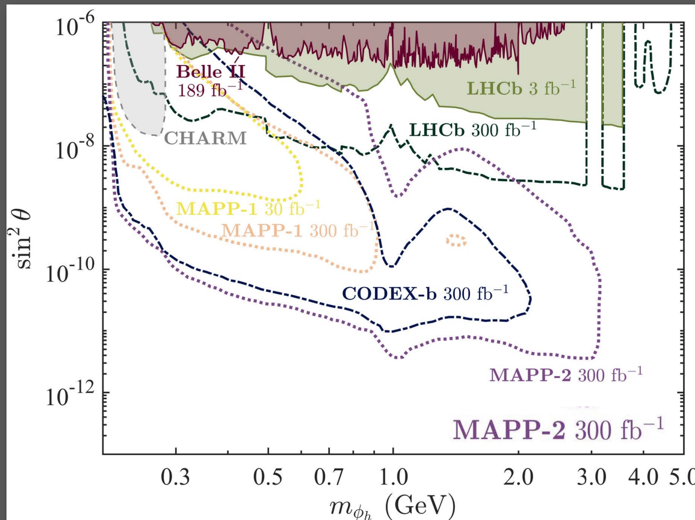
Phase-2 → MAPP-2 for HL-LHC

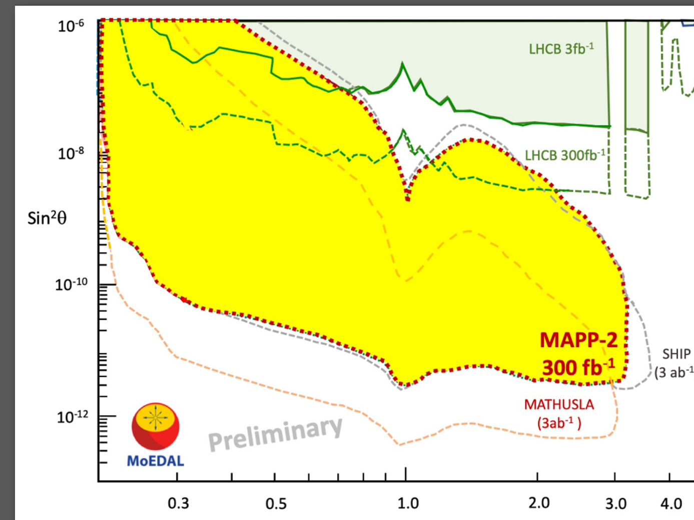




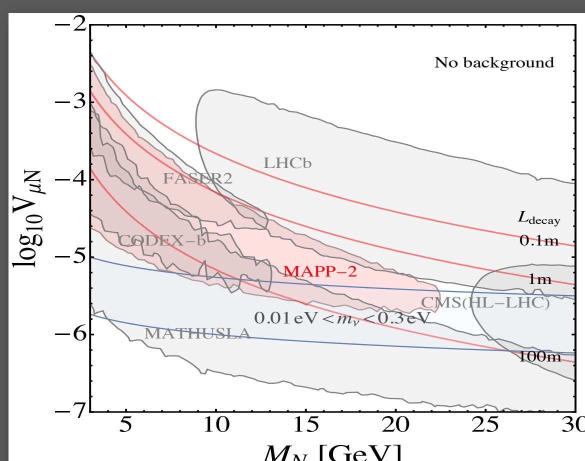
- *The MAPP-2 detector would fill the UGC1 gallery adjacent to LHCb*
  - *The UGC1 gallery would be prepared during LS3 prior to HL-LHC*
  - *The scintillator tracking detectors form 3 or 4 containers - one within the other*
- *The open geometry is chosen to allow max. possible sensitivity to photons*
- *Roughly 1.2K m^3 of Pb-lined instrumented decay volume – est. cost < 3M CHF*
- *Designed to detect Long-Lived particle decays to **charged particle & photons***

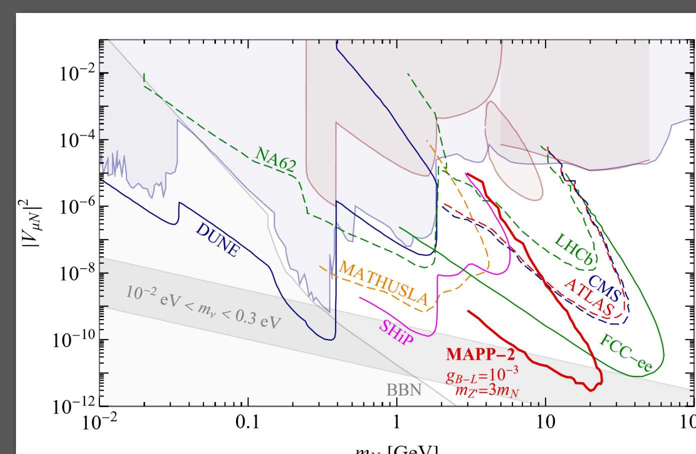
MAPP-2 – Sensitivity Benchmarks





The Higgs mixing portal admits inclusive $B \to X_s\phi$ 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.



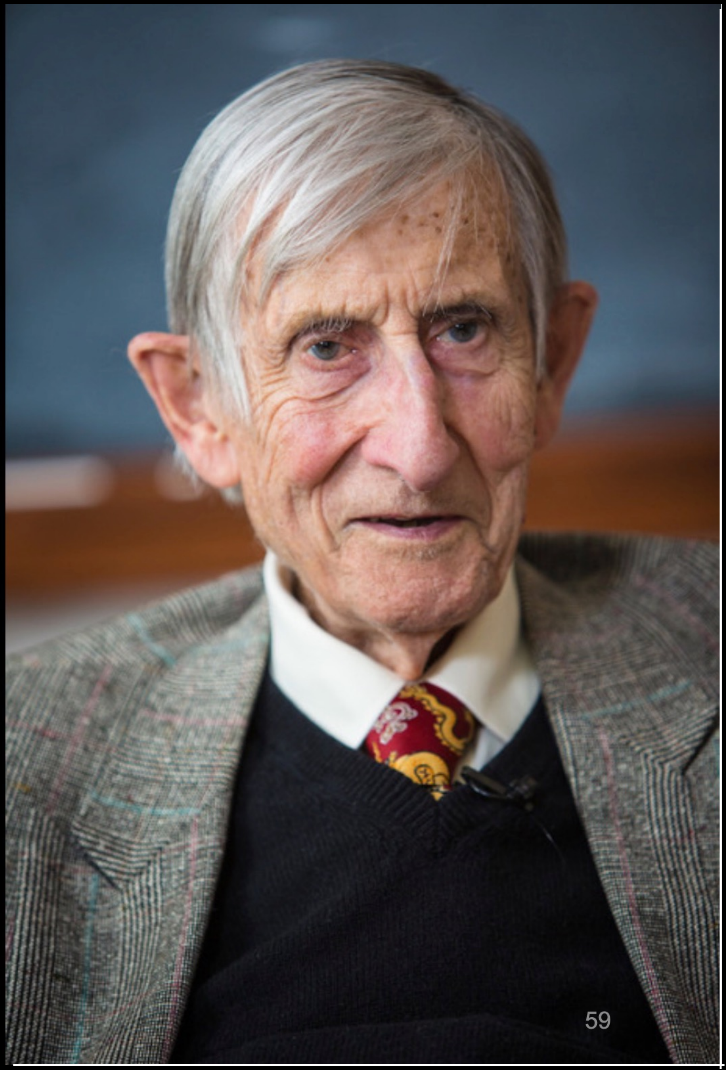


*Pair production of right-handed neutrinos from the decay of an additional neutral **Z^0** boson in the gauged **B-L** model – Phys. Rev. D100 (2019), 035005.*

Final Words

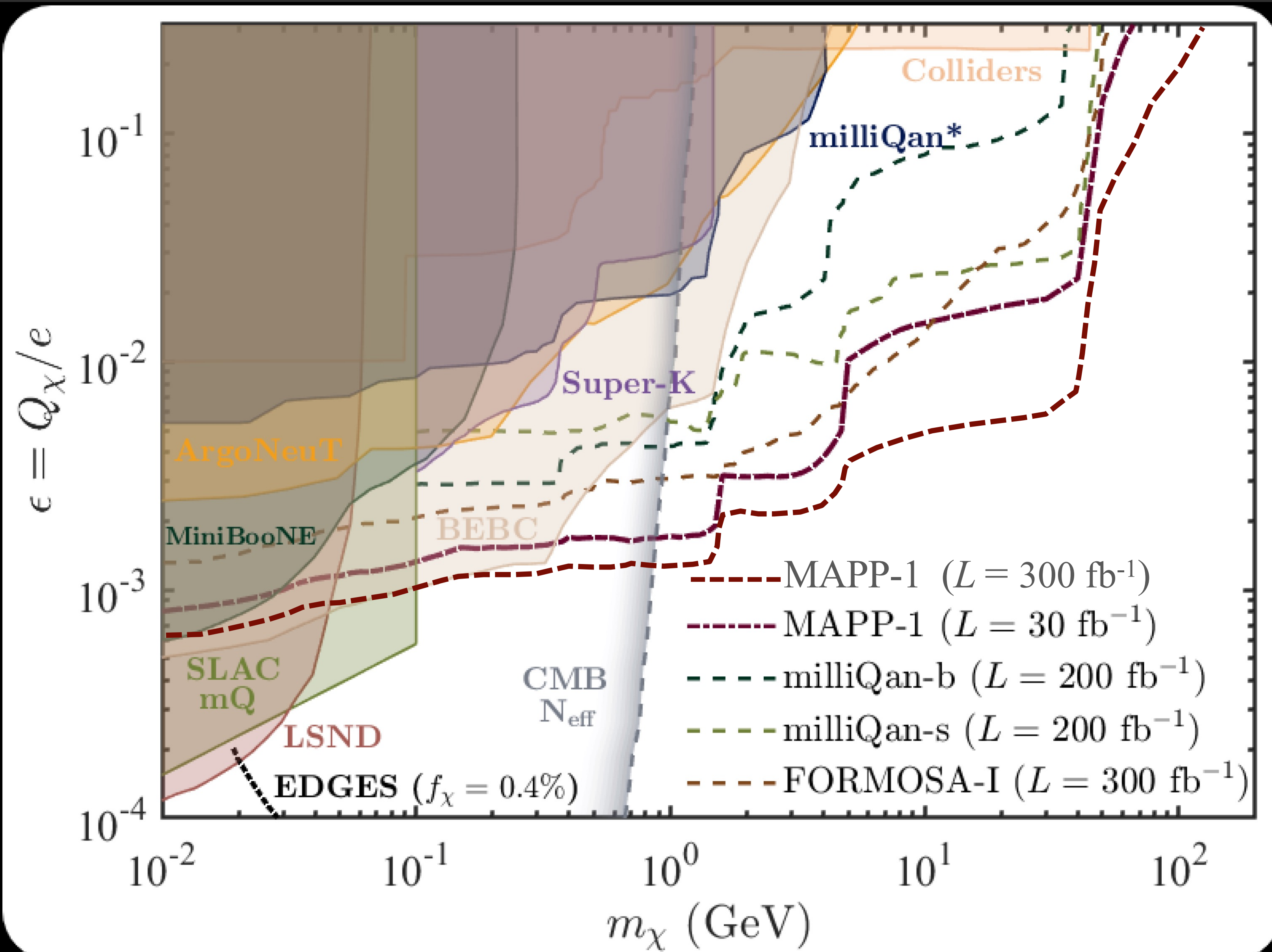
"New directions in science are launched by new tools much more often than by new concepts."

- Freeman Dyson



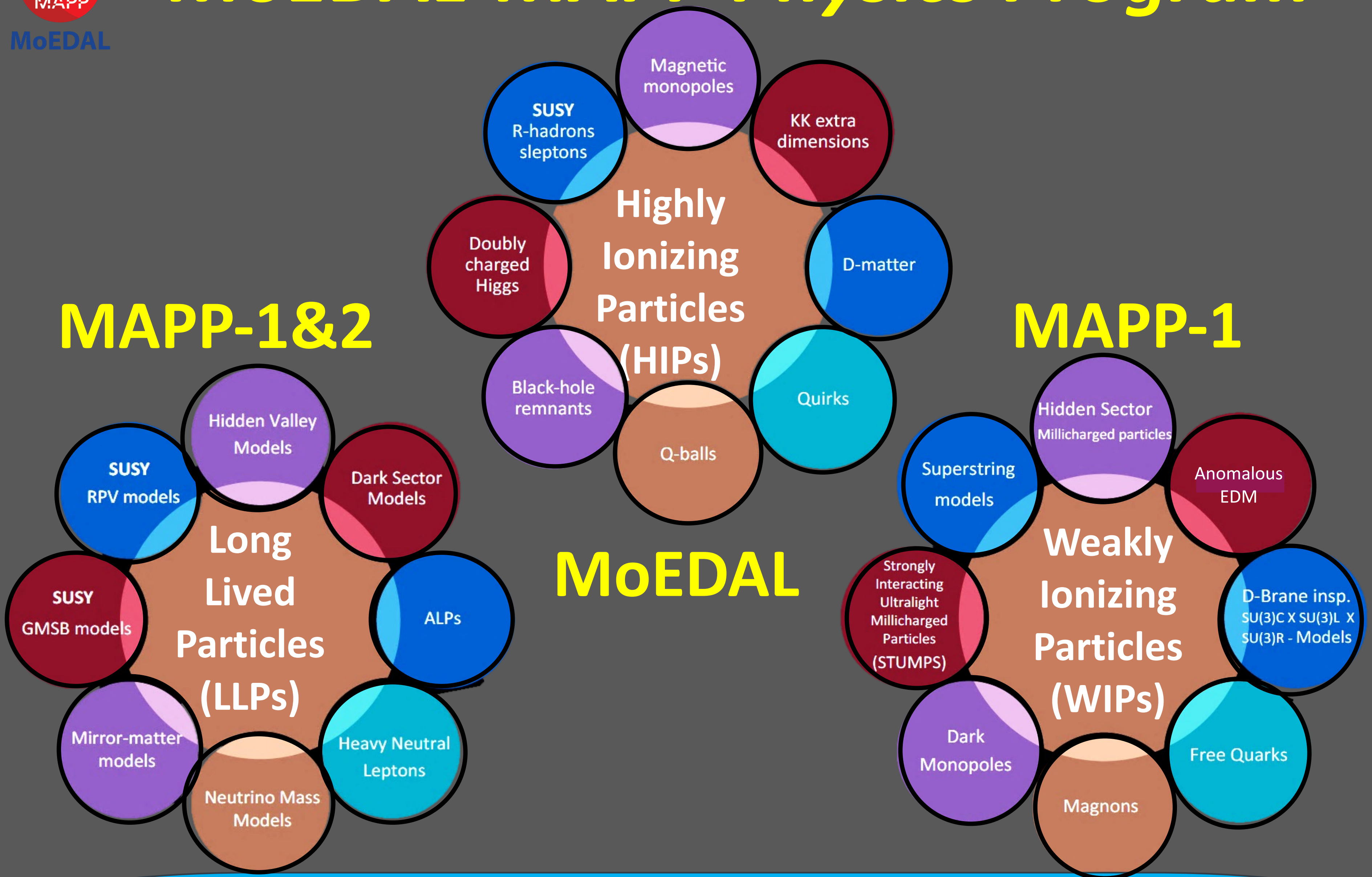
- ***MoEDAL pioneered the use of Dedicated Search Detectors at the LHC. These detectors are the new tools now being used to search for new physics at the LHC and beyond***

SUPPLEMENTAL SLIDES



Colliders
milliQan*
Super-K
ArgoNeuT
MiniBooNE
BEBC
SLAC
mQ
LSND
EDGES ($f_\chi = 0.4\%$)
CMB
N_{eff}
MAPP-1 ($L = 300$ fb^{-1})
MAPP-1 ($L = 30$ fb^{-1})
milliQan-b ($L = 200$ fb^{-1})
milliQan-s ($L = 200$ fb^{-1})
FORMOSA-I ($L = 300$ fb^{-1})
$\epsilon = Q_\chi / e$
m_χ (GeV)

MoEDAL-MAPP Physics Program



Most of the above scenarios contain Dark Matter candidates

MoEDAL-MAPP 22 Institutes

75 Physicists & Engineers

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

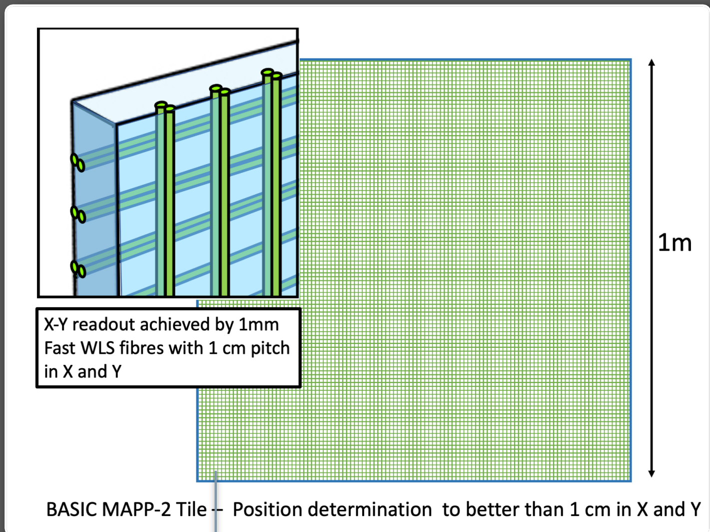
NORTH AMERICA
University of Alabama.
University of Alberta.
University of British Columbia.
Concordia University.
University of Montreal.
University of Regina.
Tuft's University.
University of Virginia.

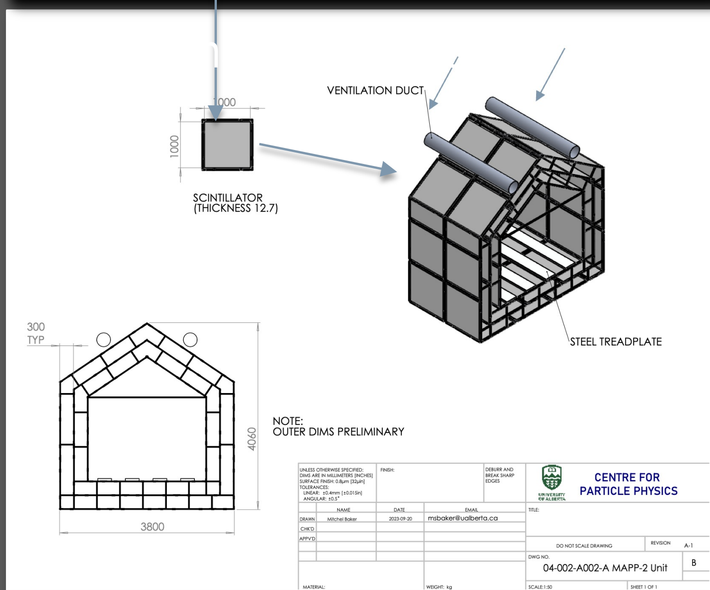
EUROPE
Technical University of Athens.
University of Bologna & INFN Bologna.
Czech Tech. University.
University of Helsinki.
Institute of Space Sciences Romania.
University of Valencia (IFIC).
University of Warsaw (Assoc.)

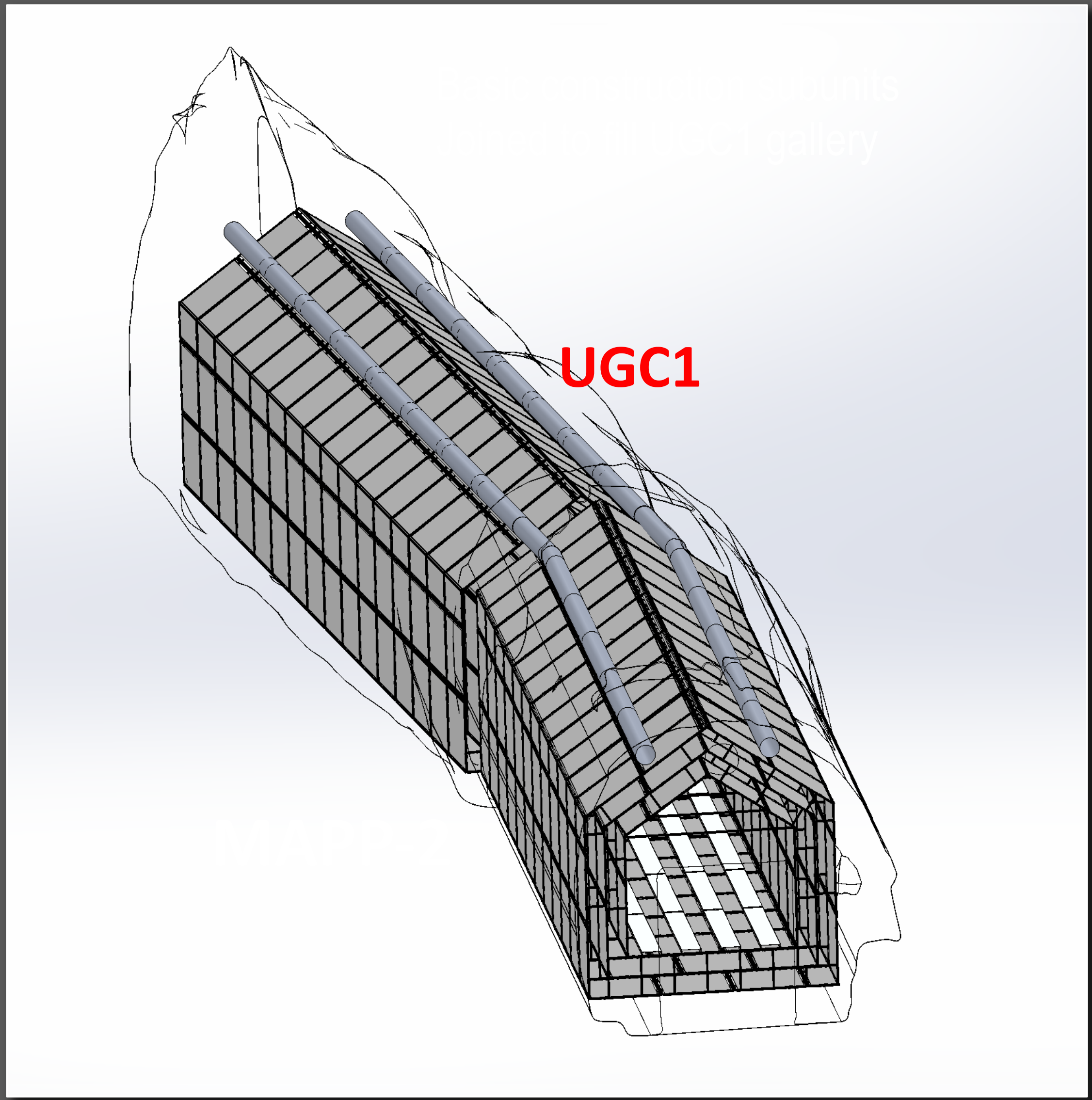
KOREA
Centre for Quantum Spacetime, Seoul.

INDIA
University of Calcutta.
National Institute of Technology, Kuruksetra Iassoc.)

Design of MAPP-2 Detector







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