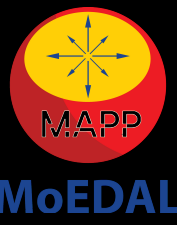


MoEDAL

MoEDAL-MAPP — The Monopole and Exotics Detector at the LHC: Progress, Plans & Prospects

Michael Staelens (staelens@ualberta.ca), Ph.D.
Department of Physics, University of Alberta

On Behalf of the MoEDAL Collaboration

IPP 50th Anniversary Symposium — Saturday, May 28, 2022

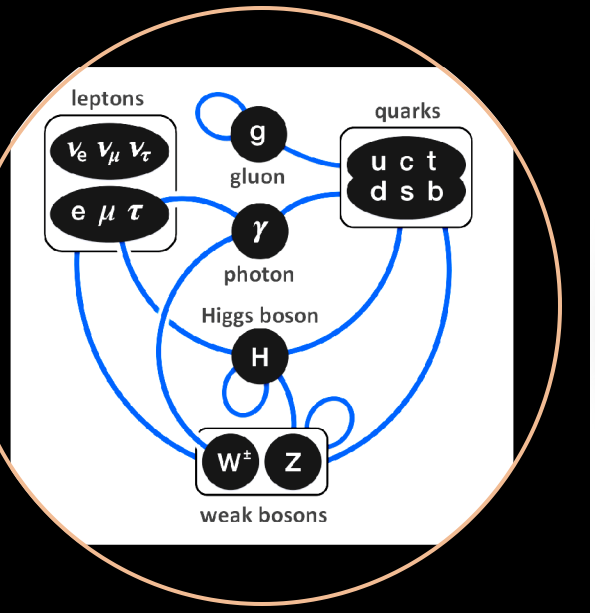
1

Dedicated Detectors at Accelerators/Colliders

The Origins of MoEDAL

New Physics Remains Unseen at the LHC

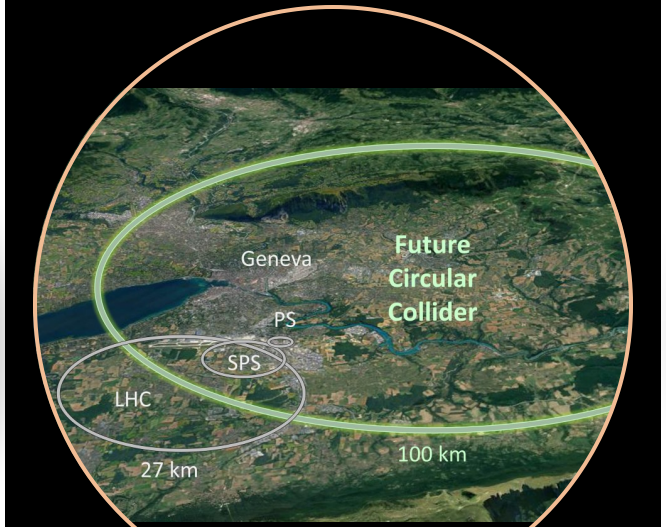
What are the possibilities?



The Standard Model is it

There is no new physics

New physics exists but a mass scale we can't ever reach



New physics exists but we can only see something at a future collider

e.g., the FCC

$$\sigma << 1\,\text{ab}$$

The physics exists at our mass scale but has an extremely small cross-section

...or, perhaps new physics is right under our noses — but we can't see it with our existing "standard" detectors

Dedicated Search Experiments at Colliders

MoEDAL was part of the 1st notice of intent (NOI) for dedicated detectors, which proposed searches for highly ionizing & long-lived particles at the LHC

MoEDAL is the First Dedicated LHC Search Experiment

ELSEVIER

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

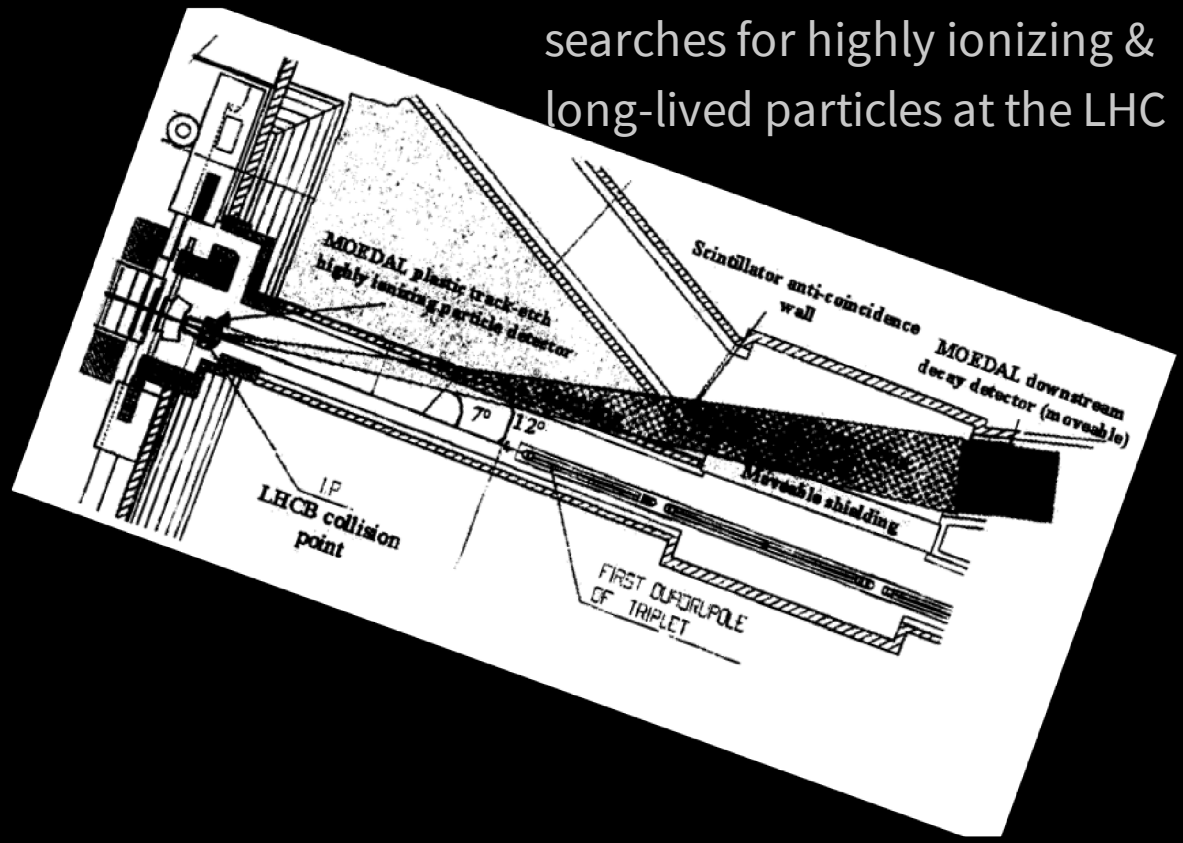
NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

www.elsevier.nl/locate/npe

Searching for Exotic Particles at the LHC with Dedicated Detectors.

J. L. Pinfold, [a*]

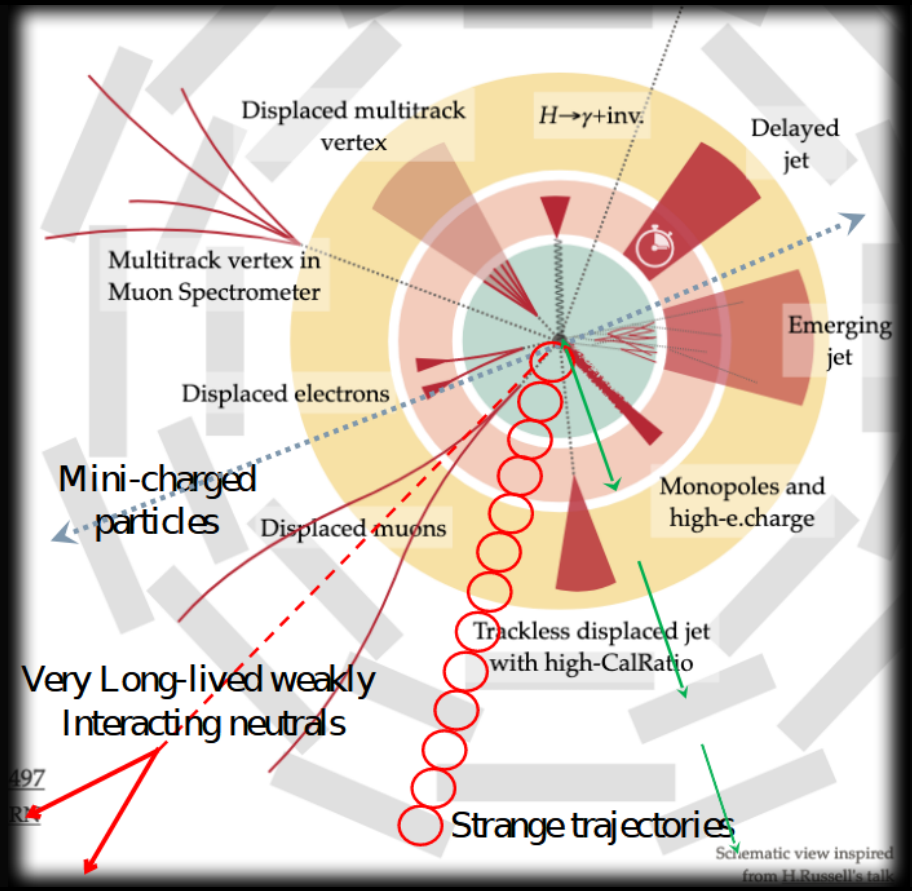
[a]Centre for Subatomic Research, University of Alberta,
Edmonton, Alberta T6G 2N4,Canada



- *Dedicated experiments concentrate on an explicit experimental signature of new physics (e.g., anomalously ionizing particles)*
- *They provide a complementary physics reach to the main collider detectors*

  Typically stand alone, smaller, and lower cost w/ small teams

The Unconventional Signs of New Physics for which ATLAS & CMS are not Optimized



2

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)

MoEDAL Today

MoEDAL-MAPP Collaboration 26 Institutes

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

United Kingdom

Imperial College London

King's College London

Queen Mary University

Track Analysis Systems Ltd.

IRIS Canterbury

Europe

Technical University of Athens

University of Bologna

INFN Bologna

CERN, Switzerland

Czech Technical University (IEAP)

University of Helsinki

Institute of Space Science (ISS) Romania

University of Valencia (IFIC)

Vaasa Universities

India

University of Calcutta

National Institute of Technology, Kurukshetra

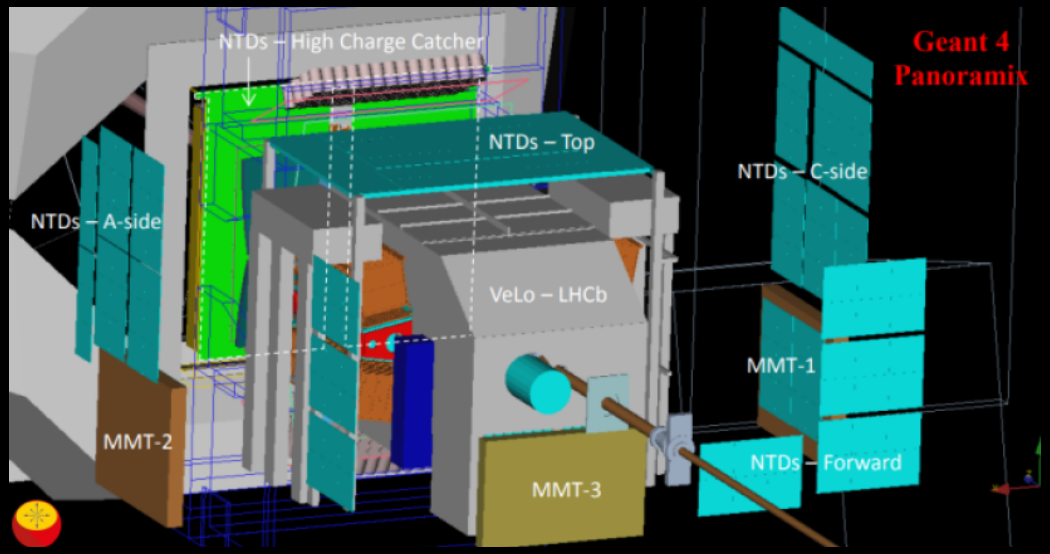
Korea

Center for Quantum Spacetime, Seoul

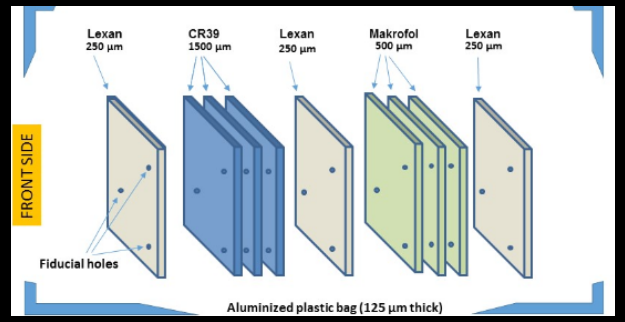
The MoEDAL Detector

Started data taking in 2015 — the LHC's first dedicated search experiment designed to search for HIPs

Permanent physical record of new physics!

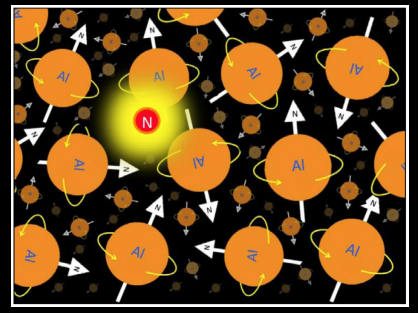


No Standard Model physics BGs!



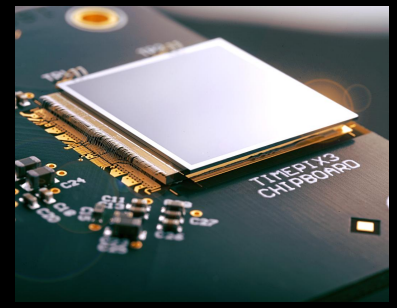
Nuclear Track Detector (NTD)

Plastic array (185 stacks, 12 sq. m)



Trapping Detector Array (MMT)

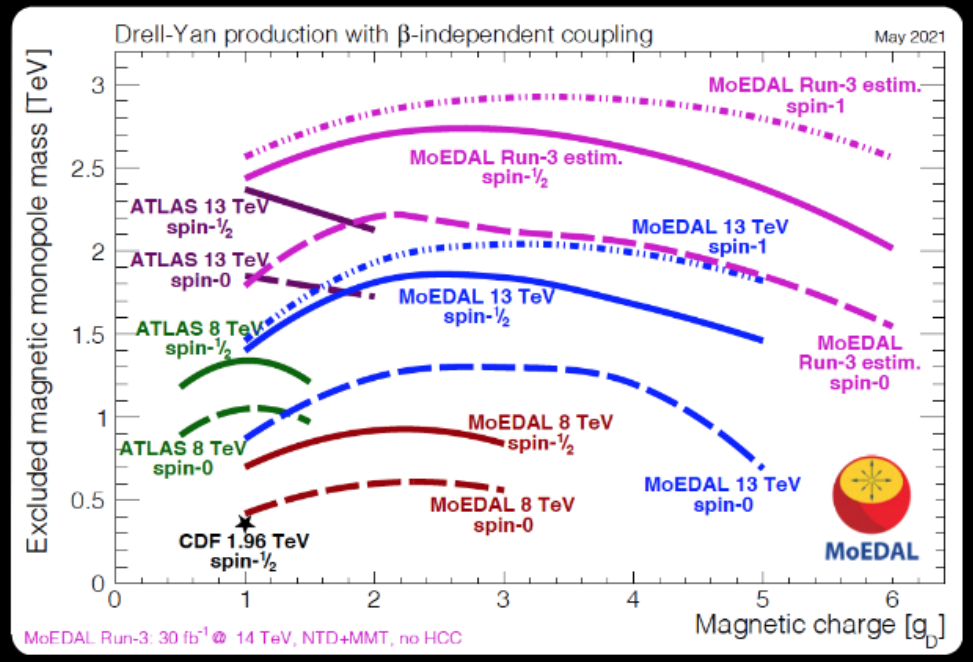
A tonne of Al to trap HIPs for analysis

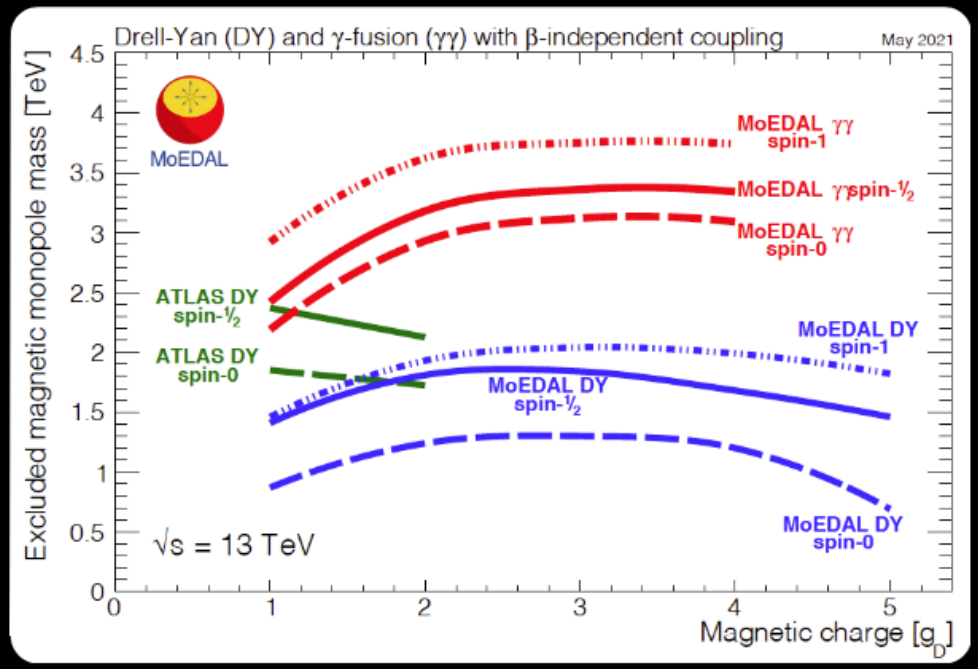


TIMEPIX Array

A digital camera for live rad. monitoring

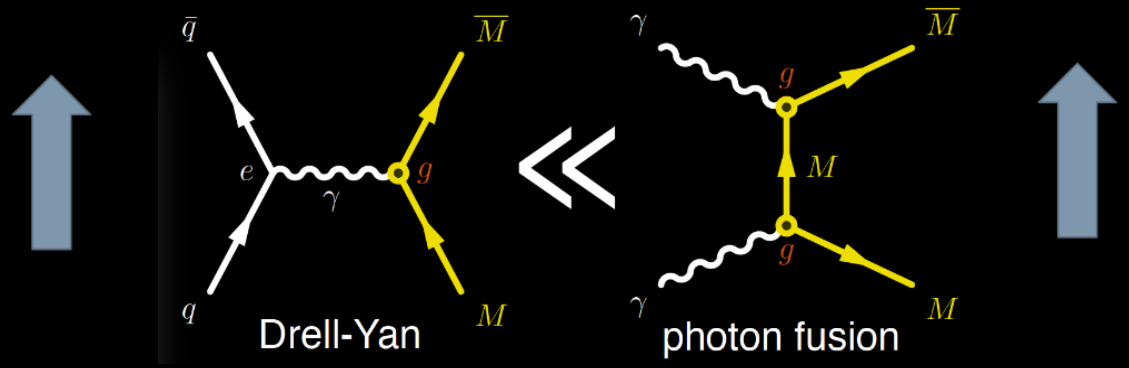
MoEDAL's Magnetic Monopole Searches





J. High Energy Phys. **2016**, 67 (2016); *Phys. Rev. Lett.* **118**, 061801 (2017); *Phys. Lett. B* **782**, 510–516 (2018); *Phys. Rev. Lett.* **123**, 021802 (2019); *Phys. Rev. Lett.* **126**, 071801 (2021);

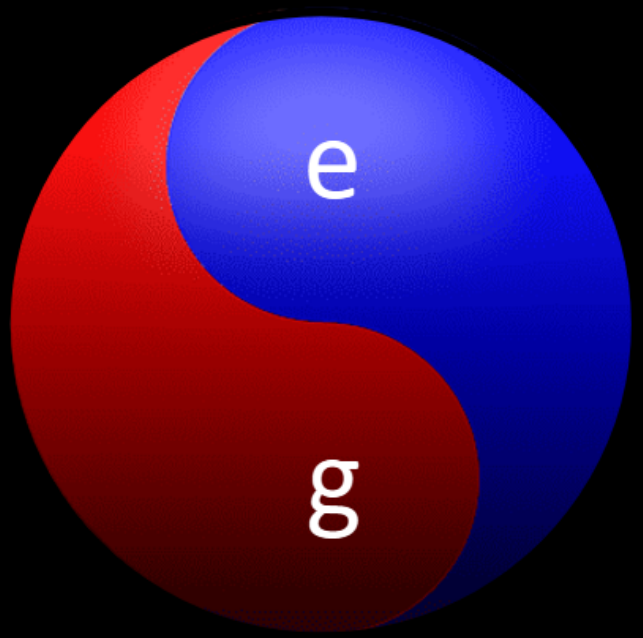
Phys. Rev. Lett. **123**, 021802 (2019); *Eur. Phys. J. C* **78**, 966 (2018)



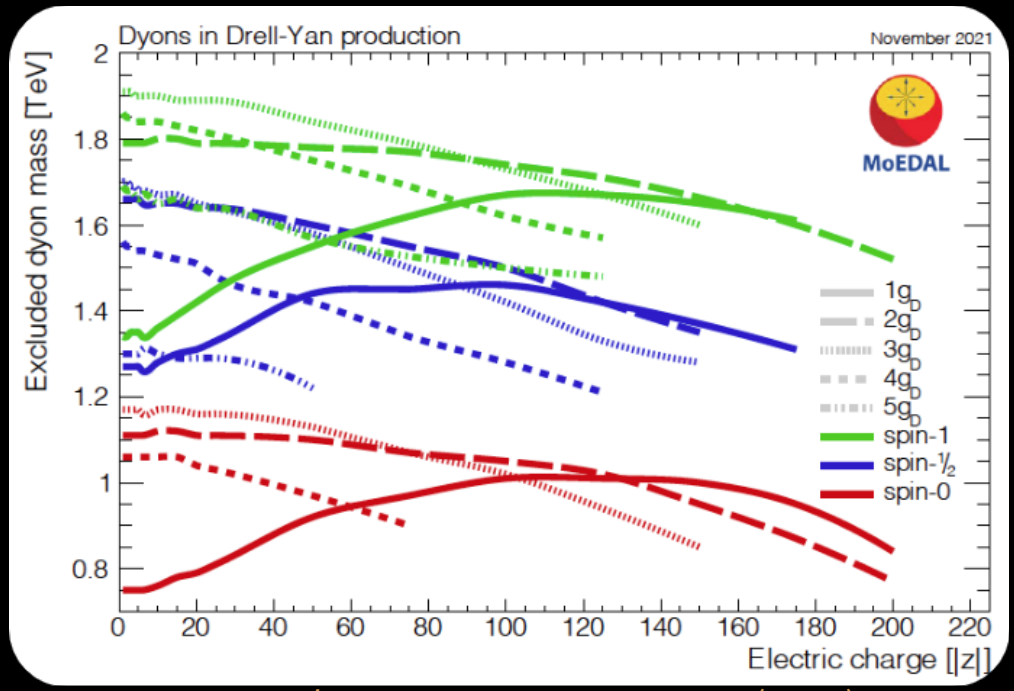
First search for spin-1 MMs!

The Search for Schwinger's Dyon

The **first ever** explicit accelerator search for a dyon!



A dyon has both electric and magnetic charge

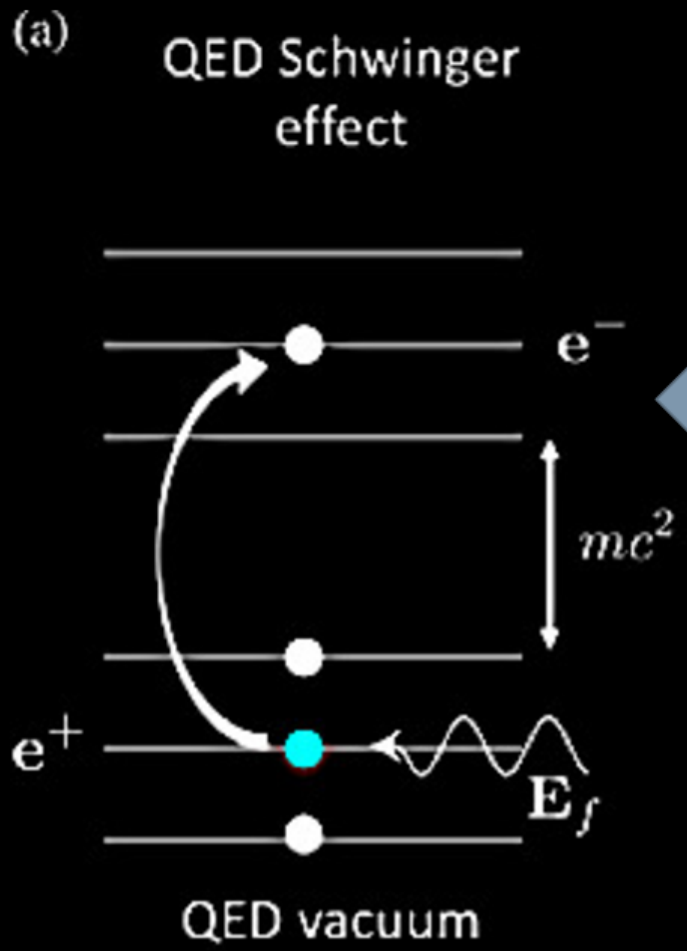


Phys. Rev. Lett. **162**, 071801 (2021)

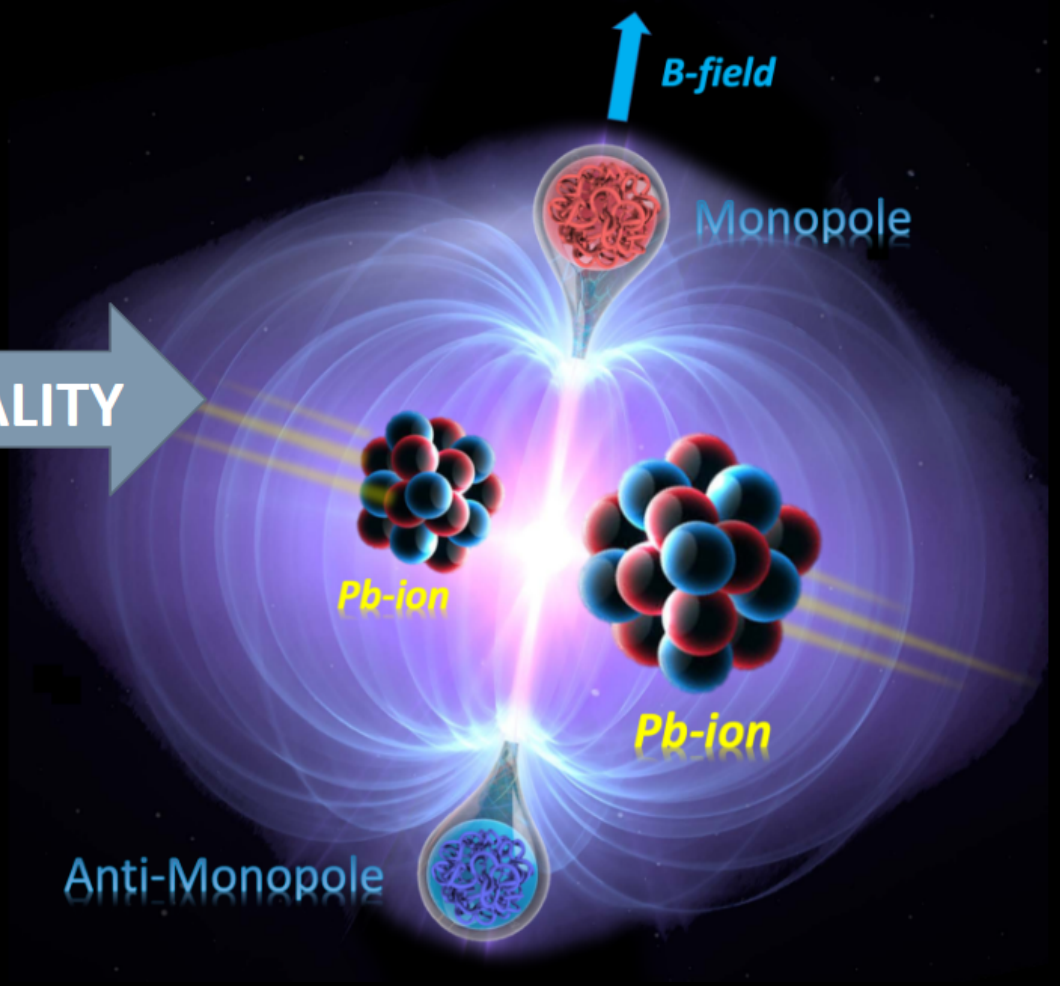
- *Spin-dependent mass limits were set for dyons w/ up to 5 Dirac magnetic charges and electric charges as large as 200e.*

  Search was exclusively based on analyses of the MoEDAL MMT exposed to pp collisions at Run-2 (13 TeV, 6.46 fb-1)

Monopole Production via the Schwinger Mechanism



DUALITY



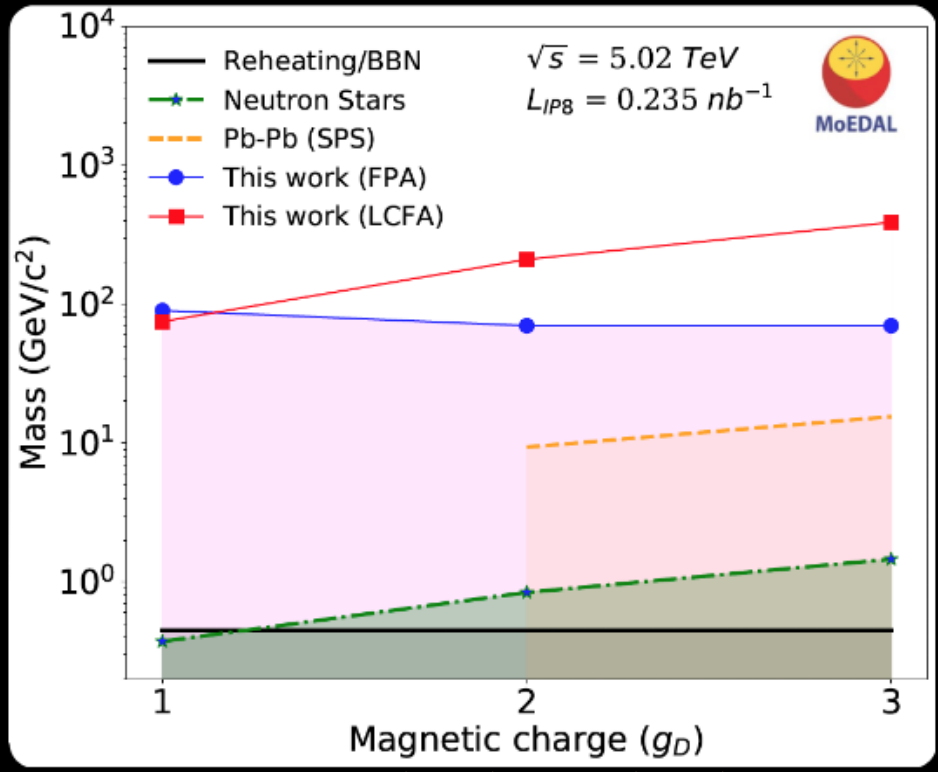
Results for Schwinger Production of MMs

Two approximations to the calculation of the overall MM production cross-section are used:

- *Free-particle approximation (FPA) — spacetime dependence of EM field of the heavy ions is treated exactly, but MM self-interactions are neglected*
- *Locally-constant field approximation (LCFA) — spacetime dependence of EM field is neglected, but MM self-interactions are treated exactly*

Limits on monopoles of 1–3 Dirac magnetic charges and masses up to 75 GeV

Advantageous over DY & γγ-fusion as the x/s calculation doesn't suffer from non perturbative nature of coupling and finite-sized MMs are not exponentially suppressed



Nature **602**(7895), 63–67 (2022)

Probably the first time that finite sized monopoles would have been detectable!

Other MoEDAL Searches

Searches for Electrically Charged HIPs:

- *Sleptons — Eur. Phys. J. C* **80**, 431 (2020)
- *Doubly-charged particles — Eur. Phys. J. C* **80**, 572 (2020)
- *Multiply-charged particles (2–4e) — Eur. Phys. J. C* **81**, 697 (2021)

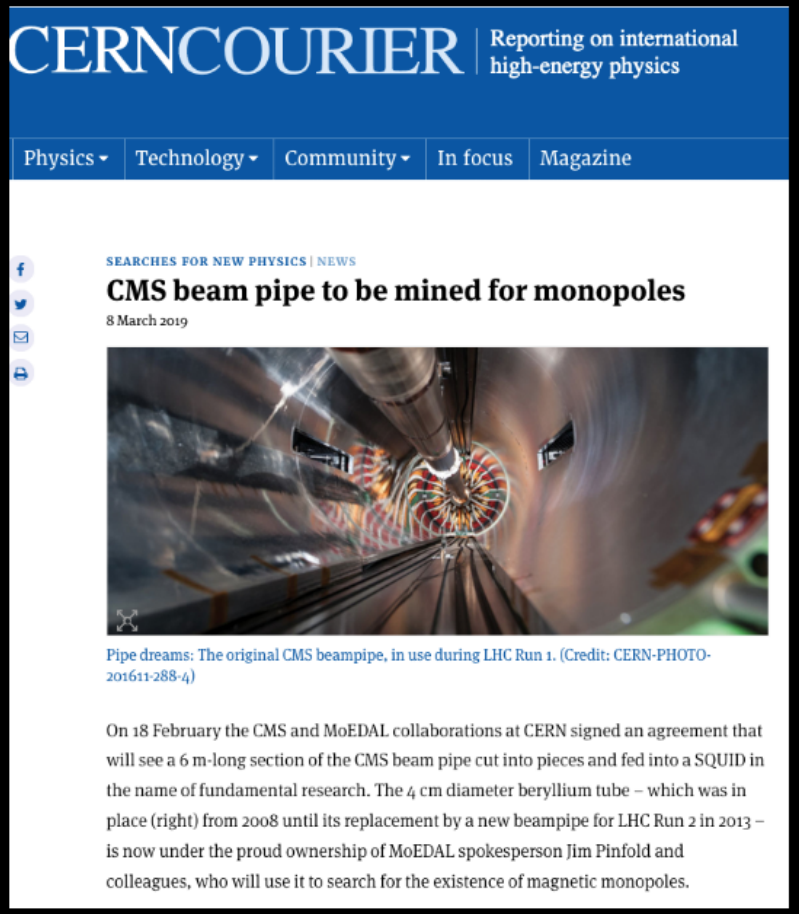
Searches for Highly-Electrically Charged Objects (HECOs):

- *MoEDAL NTDs exposed to pp collisions at Run-1 — Submitted to EPJC, currently in review (arXiv:2112.05806)*
- *Spin-dependent limits were set on DY pair-produced HECOs for electric charges of 15e–175e and masses from 110–1020 GeV*

HECO limits are the strongest to date!

- *Run-2 NTD analysis (currently underway!)*

A search for MMs trapped in the Run-1 CMS beampipe is also currently underway!



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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.

3

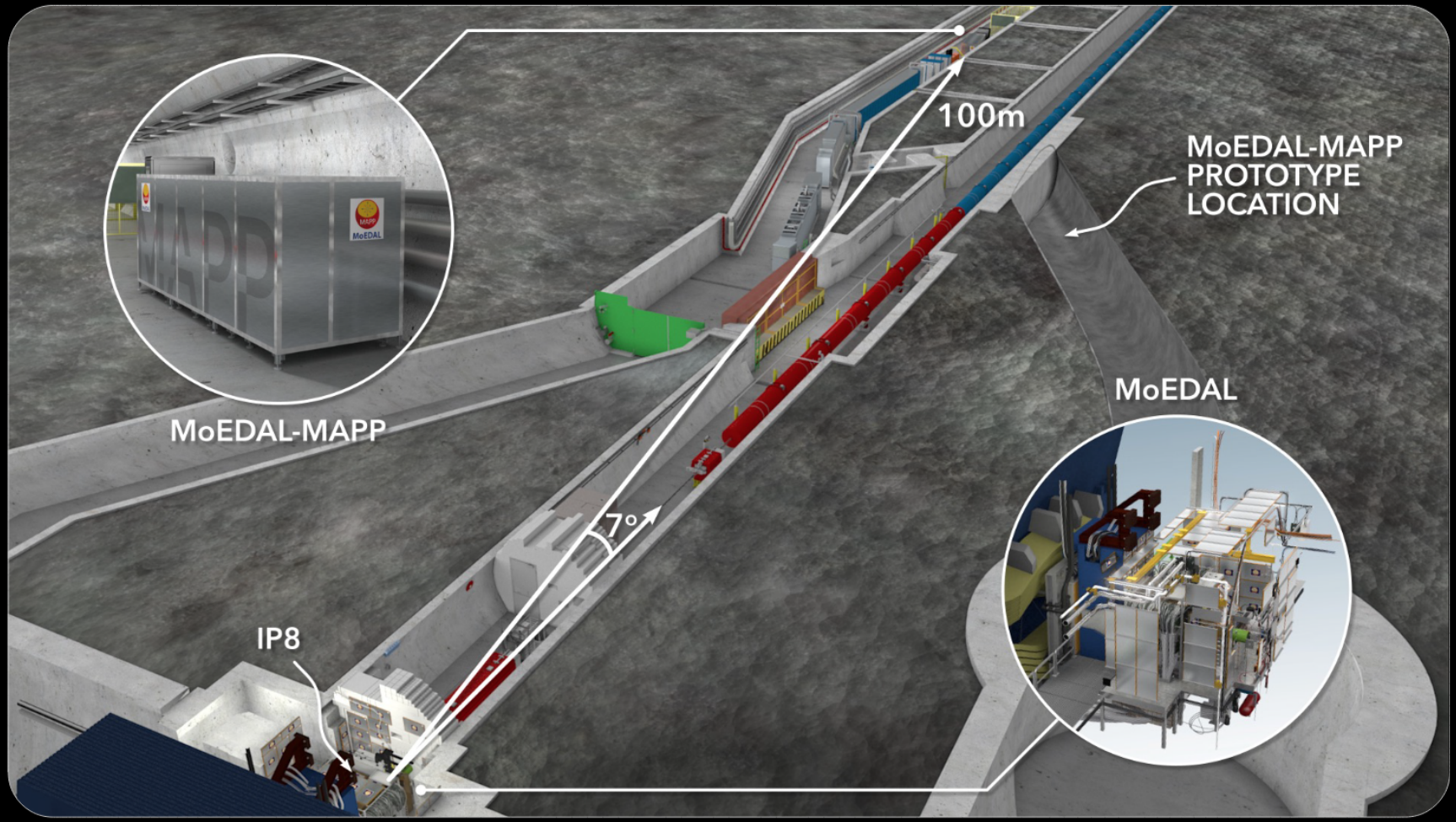
Phase-I: MoEDAL-MAPP (MoEDAL's Apparatus for Penetrating Particles)

Approved Dec. 2021 by the CERN Research Board! (CERN-LHCC-2021-024, LHCC-P-022)

Run-3 Plans & Prospects

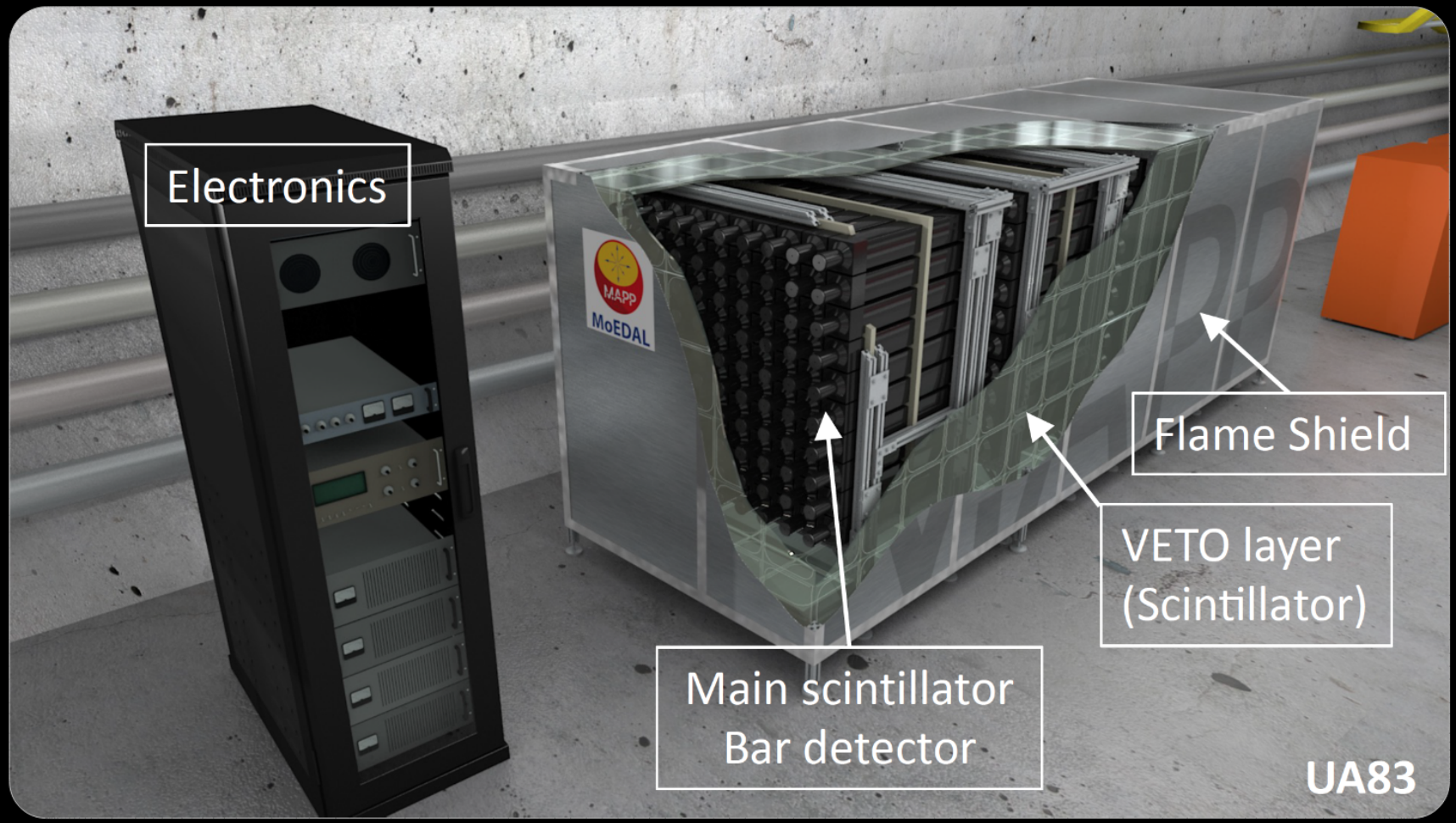
MoEDAL & MAPP Phase-I

Expanding the Physics Reach of MoEDAL Beyond HIPs to Include Feebly-Interacting Particles (FIPs)



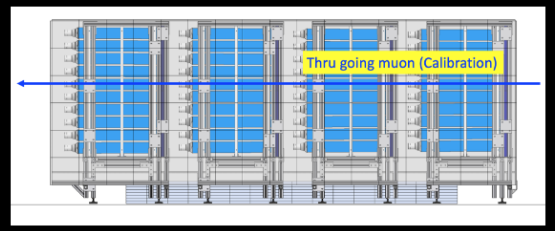
The Phase-I MAPP Detector

400 scintillator bars (10 x 10 x 75 cm) in 4 sections readout by coincidental PMTs protected by a hermetic VETO system

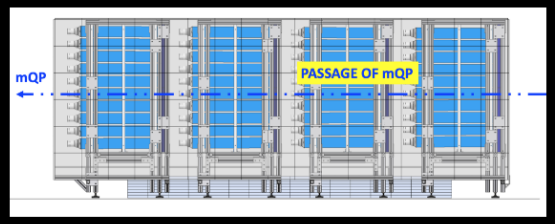


Installation of MAPP Phase-I in UA83

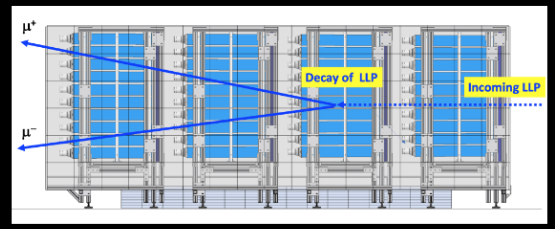
MAPP — Modes of Detection



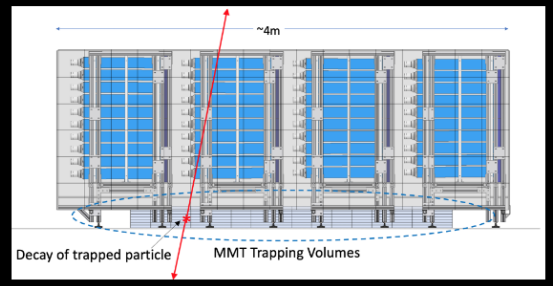
Muons from IP (Calibration)



Millicharged particle detection



Neutral LLP Detection



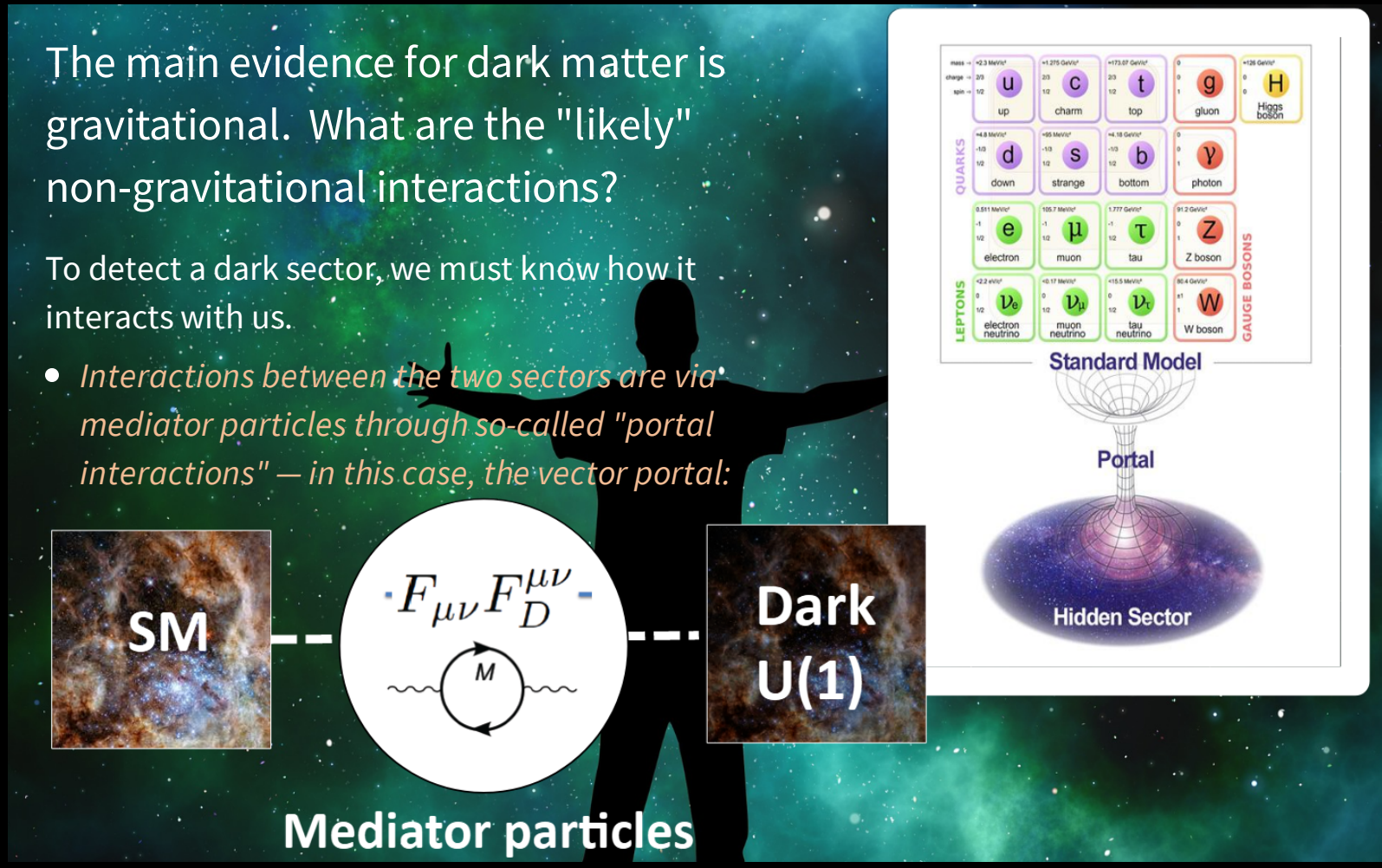
Charged LLP Detection
(In conjunction with MoEDAL)

MAPPing the Dark Sector

The main evidence for dark matter is gravitational. What are the "likely" non-gravitational interactions?

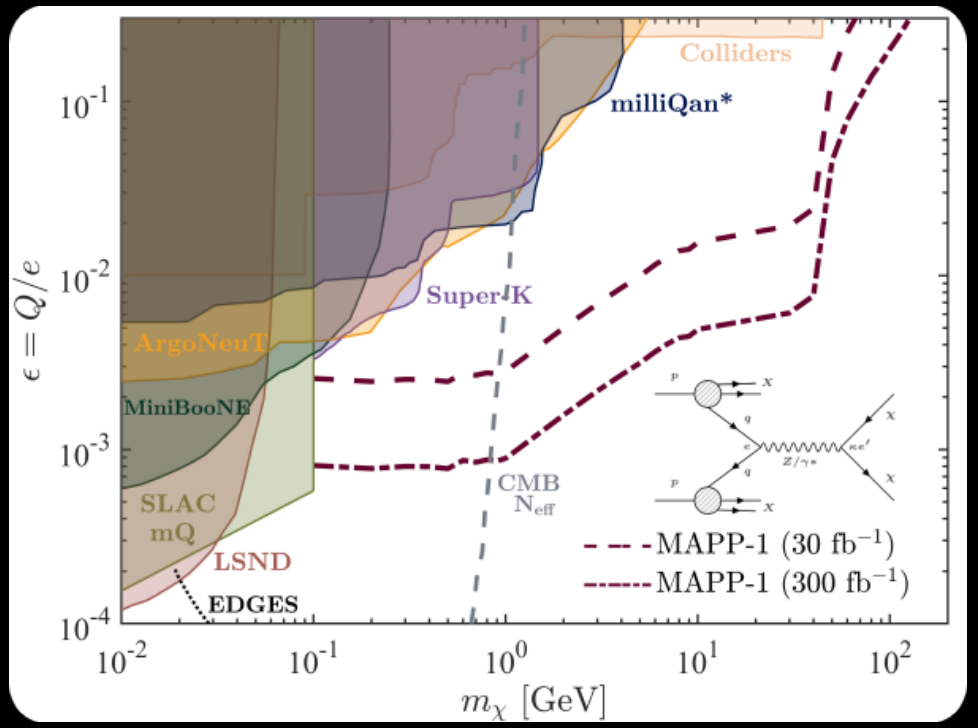
To detect a dark sector, we must know how it interacts with us.

- *Interactions between the two sectors are via mediator particles through so-called "portal interactions" — in this case, the vector portal:*



The Physics Program of MAPP-1 (A Couple Examples)

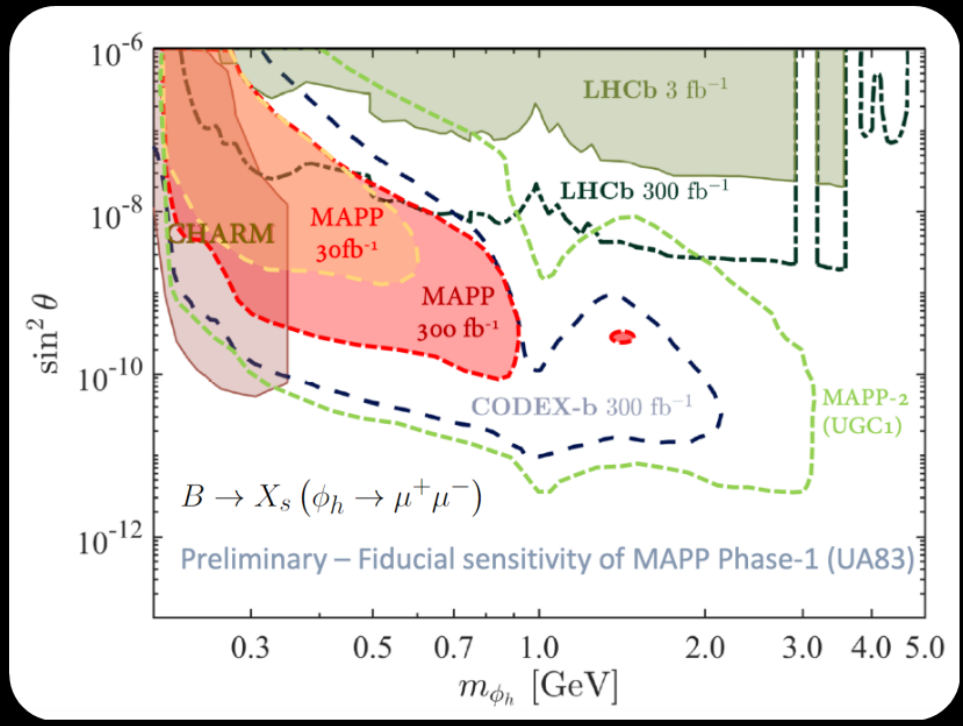
95% C.L. for DY pair-produced mCPs in 14 TeV *pp* collisions



Minicharged Particles (mCPs)

Phys. Lett. B **166**(2), 196–198 (1986); *Phys. Lett. B* **746**, 117–120 (2015)

95% C.L. for a light CP-even dark scalar produced via rare B decays



Long-Lived Dark Higgs Bosons (Scalar Portal)

Phys. Rev. Lett. **115**, 161802 (2015); *Phys. Rev. D* **95**, 071101 (2017); *Phys. Rev. D* **97**, 015023 (2018); *Phys. Rev. D* **99**, 015018 (2019)

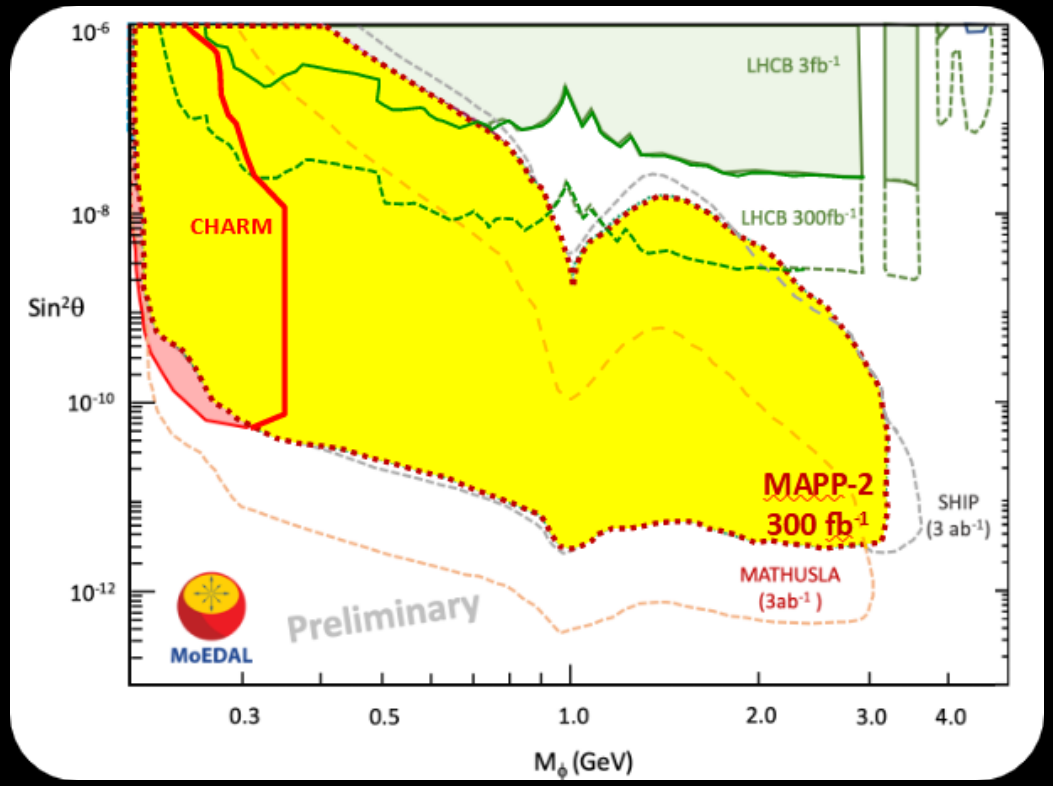
4

The Future of the MoEDAL-MAPP Experiment

The HL-LHC & Beyond

The Physics Program of MAPP-2 (A Couple Examples)

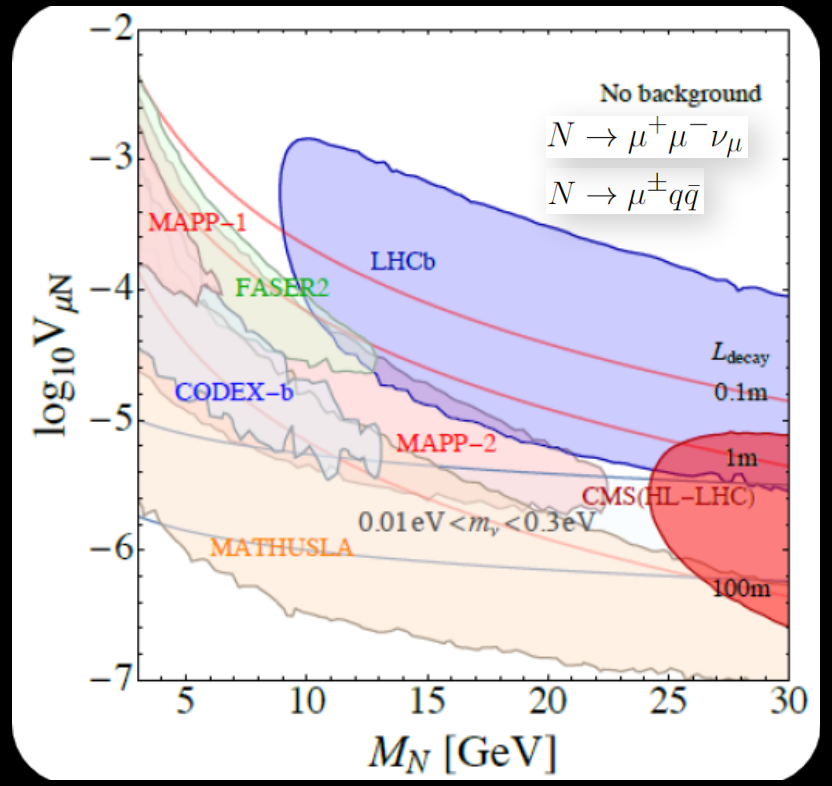
Results based on 14 TeV *pp* collisions



Long-Lived Dark Higgs Bosons (Scalar Portal)

Phys. Rev. Lett. **115**, 161802 (2015); *Phys. Rev. D* **95**, 071101 (2017); *Phys. Rev. D* **99**, 015018 (2019)

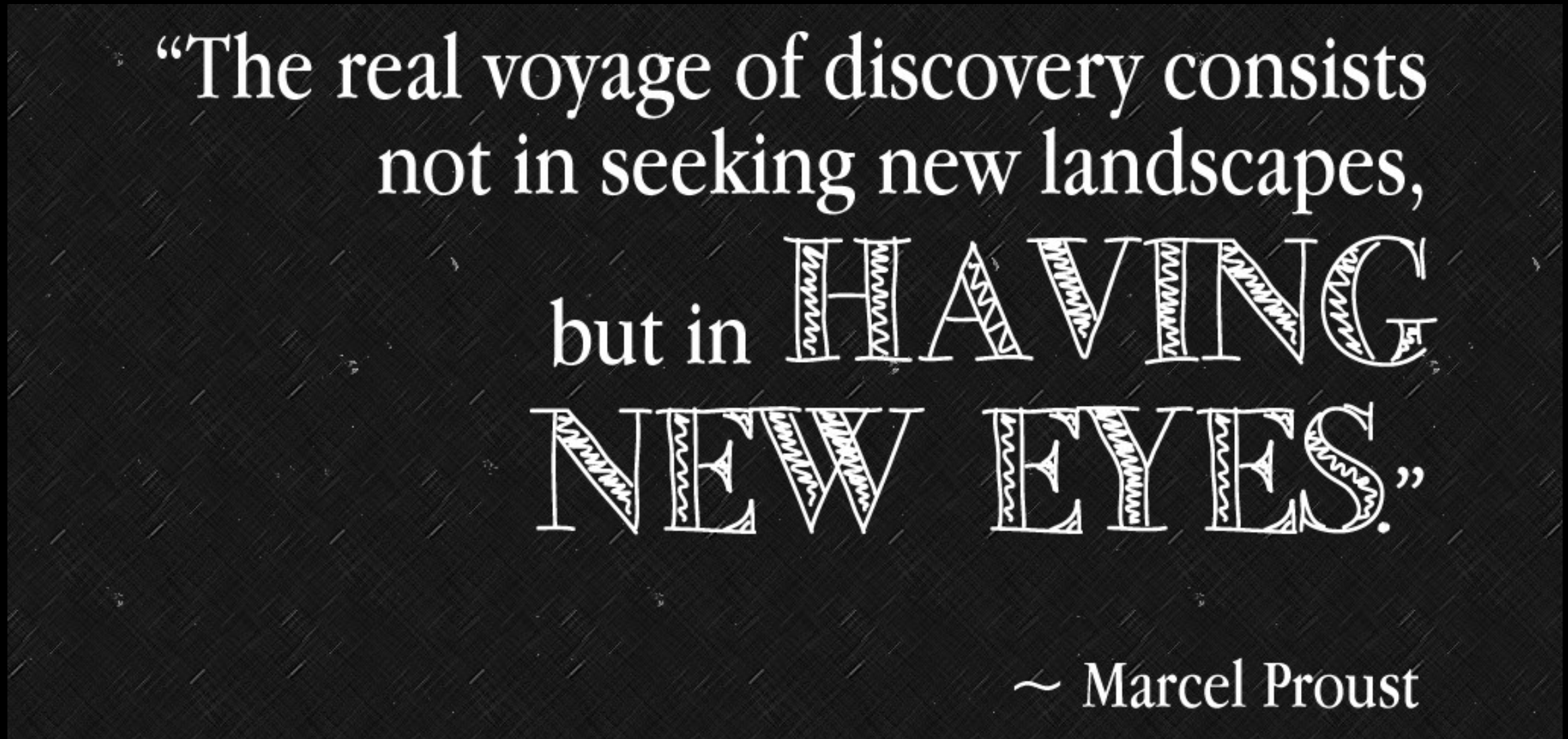
Pair production of right-handed neutrinos (HNLs) from the decay of an additional neutral Z0 boson in the gauged U(1) ***B-L*** model



Long-Lived Heavy Neutral Lepton (Neutrino Portal)

Phys Rev. D **100**, 035005 (2019); *J. High Energy Phys.* **2018**, 181 (2018). MAPP-1 → 30 fb-1; MAPP-2, CODEX-b & LHCb → 300 fb-1; FASER2, CMS & MATHUSLA → 3 ab-1

Concluding Remarks



Thank you!

Questions?