The MoEDAL-MAPP LHC Experiment - Searching for Anomalously Ionizing and Long Lived Avatars of New Physics

Snowmass Joint BSM session

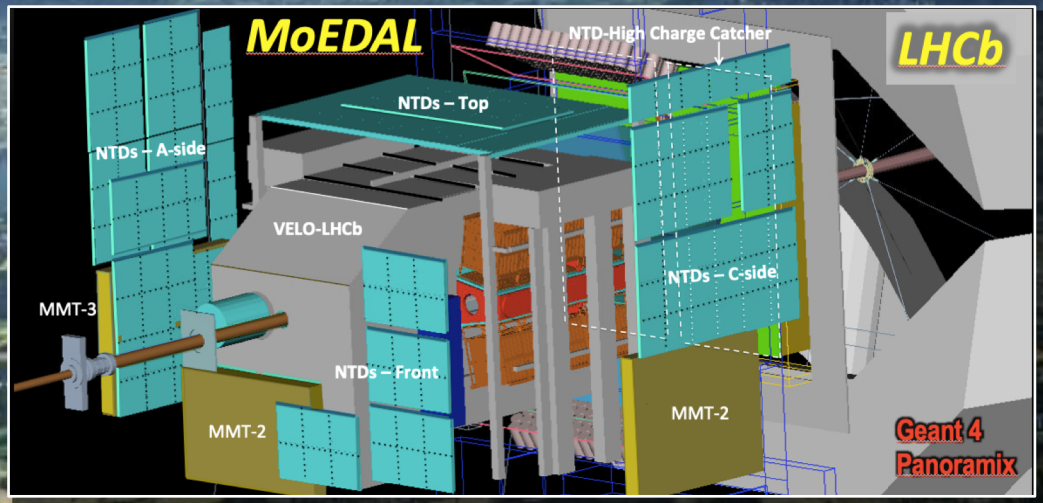
Tuesday, July 7th 2020

James Pinfold for the MoEDAL Collaboration

An overview of the Run-2 MoEDAL Detector.

Started data taking in2015 – the LHC's first dedicated search experiment

Permanent Physical record of new physics



No Standard Model Physics Backgrnds

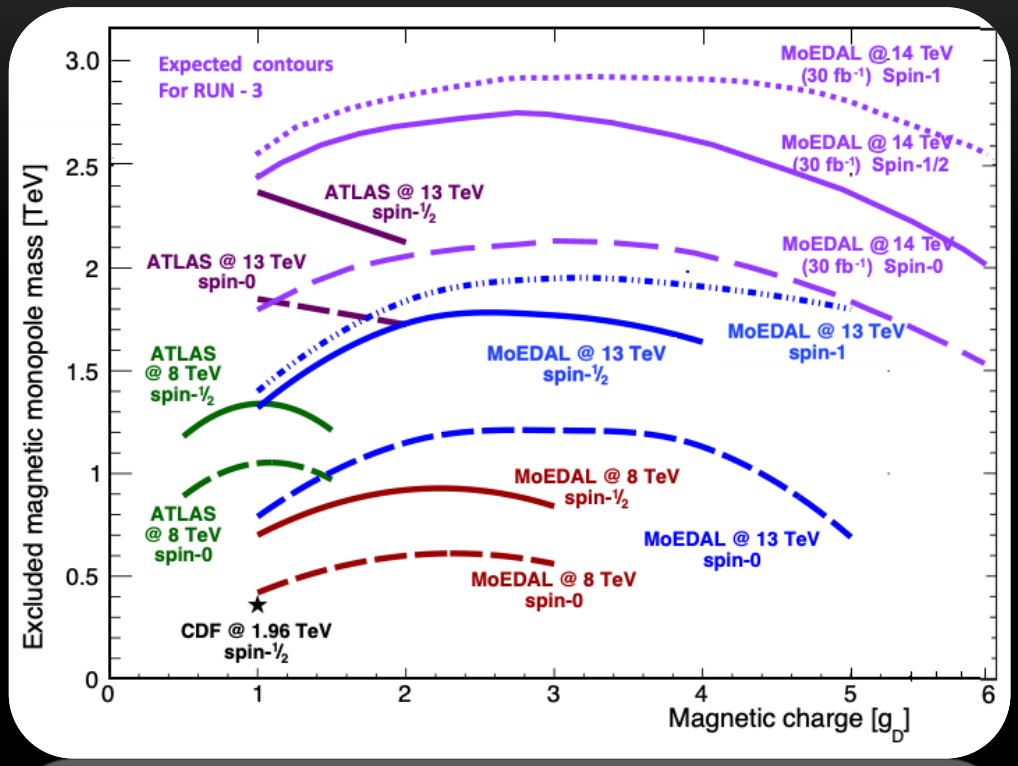
MoEDAL is largely passive made up of three detector system.

NUCLEAR TRACK DETECTOR Plastic array (~200 sqm) – Like a Giant Camera

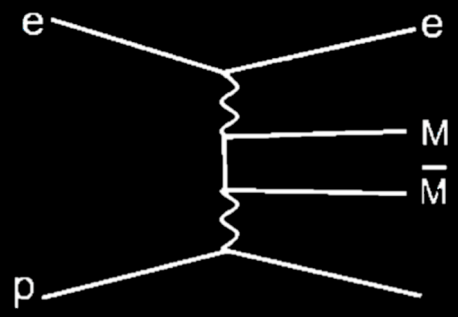
TRAPPING DETECTOR ARRAY A tonne of Al to trap Highly Ionizing Particles for analysis

TIMEPIX Array a digital Camera for real time radiation monitoring

Mass Limits on Multiply Charge Monopoles



Drell Yan mechanism

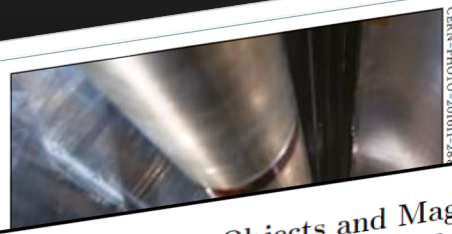


Photon fusion

JHEP 1608 (2016) 067 PRL 118 (2017) 061801 Phys.Lett. B782 (2018) 510 PRL 123 (2019) 021802

- *So far MoEDAL has placed the world's best published direct limits on:*
  - *Multiply charged magnetic monopoles*
  - *Spin-1 monopoles*
  - *DY + Photon fusion production of monopoles*
  - *Dyons – electrically and magnetically charged particles.*

Other Run-2 Papers in the Pipeline



MONOPOLES

CMS beam pipe to be mined for monopoles

On 18 Feb
collaborat
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beampipe

Pipe dreams
The original CMS beampipe, in use during LHC Run 1.

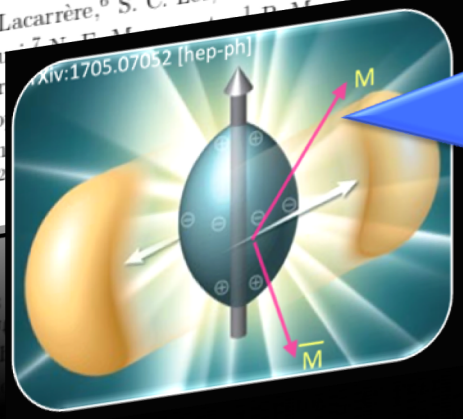
CERN-PHOTO-201611-28

Search for High Electrically Charge Objects and Magnetic Monopoles in 8 TeV pp Collisions at the LHC Using the Full MoEDAL Detector

B. Acharya,[1,*] J. Alexandre,[1] S. Baines,[1] P. Benes,[2] B. Bergmann,[2] J. Bernabéu,[3] A. Bevan,[4] H. Branzas,[5] M. Campbell,[6] S. Cecchini,[7] Y. M. Cho,[8,†] M. de Montigny,[9] A. De Roeck,[6] J. R. Ellis,[1,10,‡] M. El Sawy,[6,§] M. Fairbairn,[1] D. Felea,[5] M. Frank,[11] J. Hays,[4] A. M. Hirt,[12] J. Janecek,[2] D.-W. Kim,[13] A. Korzeney,[14]
D. H. Laca
N. E. M
I. Ostrov
M. Pozzato,
S. Sarkar,[1]
M. Tenti,

The search for Dyons with the full MoEDAL trapping detector in 13 TeV pp collisions

B. Acharya,[1,*] J. Alexandre,[1] P. Benes,[2] B. Bergmann,[2] J. Bernabéu,[3] A. Bevan,[4] H. Branzas,[5] M. Campbell,[6] S. Cecchini,[7] Y. M. Cho,[8,†] M. de Montigny,[9] A. De Roeck,[6] J. R. Ellis,[1,10,‡] M. El Sawy,[6,§] M. Fairbairn,[1] D. Felea,[5] M. Frank,[11] J. Hays,[4] A. M. Hirt,[12] J. Janecek,[2] M. Kalliokoski,[13] D.-W. Kim,[14] A. Korzenev,[15] D. H. Lacarrère,[6] S. C. Lee,[14] C. Leroy,[16] G. Levi,[17] A. Lionti,[15] J. Mamuzic,[3] A. Maulik,[7,9] A. Margiotta,[17]
N. Mau
I. Ostr
V. Po
A. San
M. Suk,

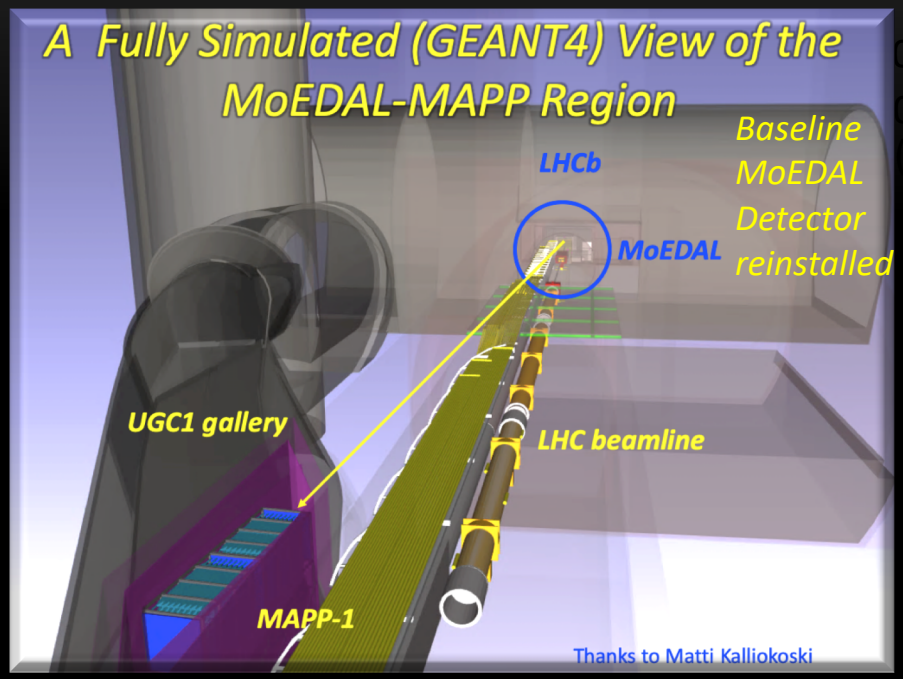


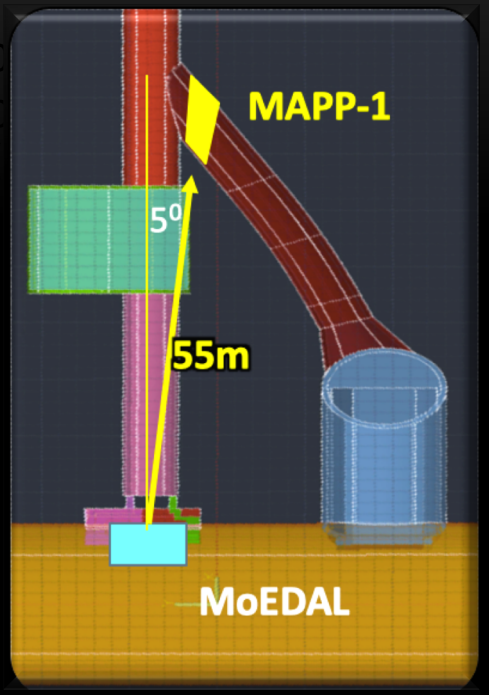
Search for Monopole Pair Production in Heavy-Ion Collisions at the LHC

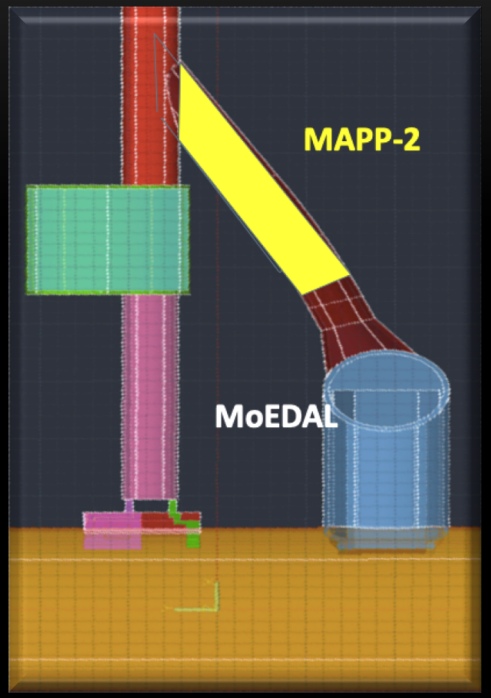
First use of the intense magnetic fields generated in heavy-ion collisions?

arXiv:1705.07052 [hep-ph]

Run-3: The MoEDAL-MAPP Detector

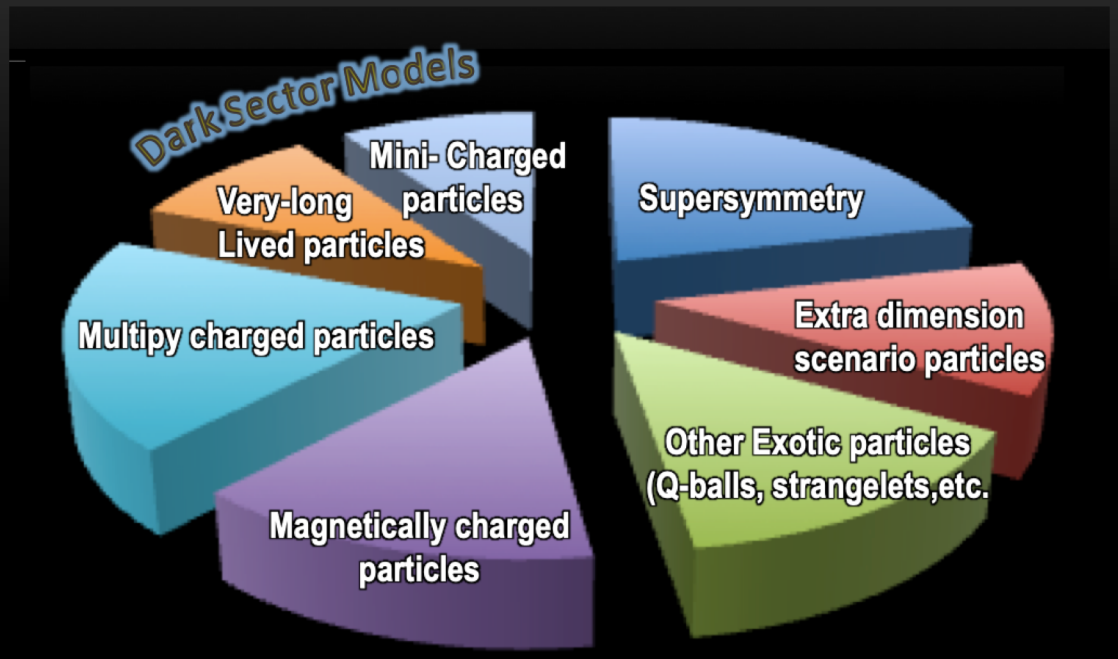






- *Run-3 MoEDAL-MAPP detector consists of 3 basic subdetectors:*
  - *The reinstalled baseline MoEDAL detector(Phase-1 2021)*
  - *The core mini-charged particle (mQP) detector MAPP-mQP (Phase-1 2021)*
  - *The LLP detector – MAPP-LLP –installed in 2022 (MAPP-1) and 2025 (MAPP-2)*

Run-3 MoEDAL-MAPP – Physics Program



IJMPA, September 2014, Vol. 29, No. 23

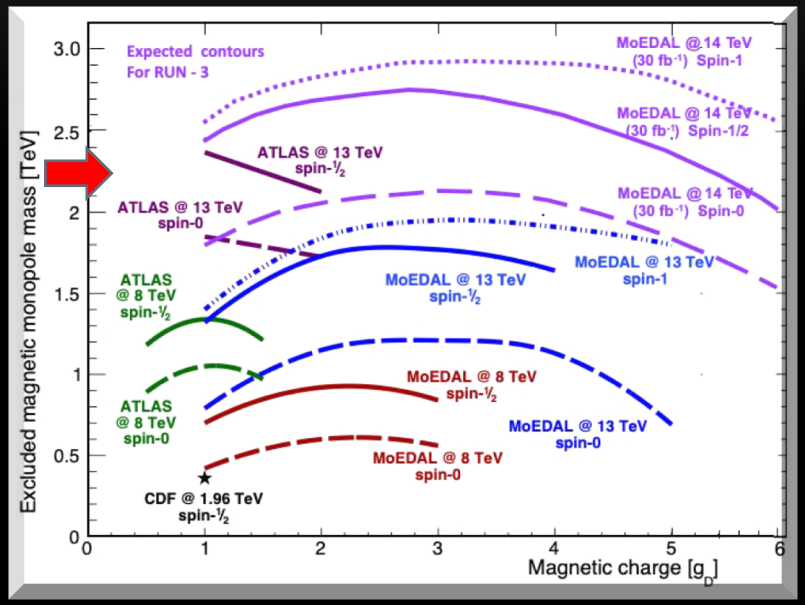
Highly ionizing particles (HIPs)

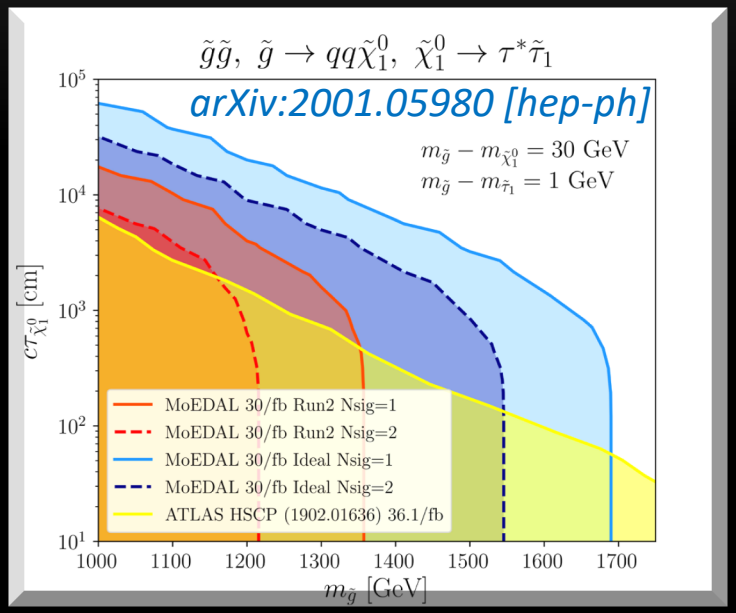
Long-Lived Particles (LLPs)

Mini-charged particles (mCPs)

- *With MAPP the MoEDAL Experiment will be sensitive to 3 clear avatars of new physics: HIPs, mQPs and LLPs.*
- *MAPP allows us expand the physics reach of our existing program to include dark sector models, hidden valley models, etc.*

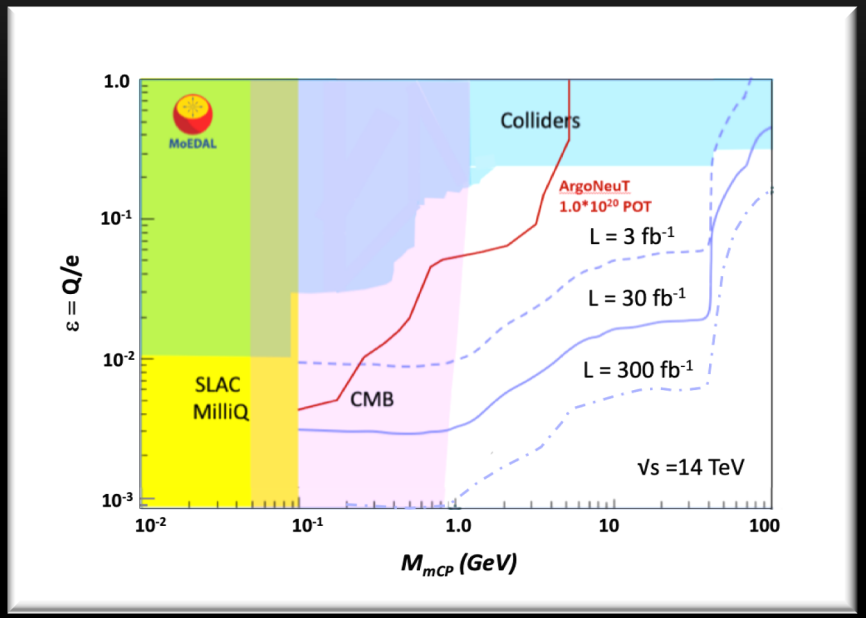
Physics Goals with the Baseline MoEDAL Detector at Run-3



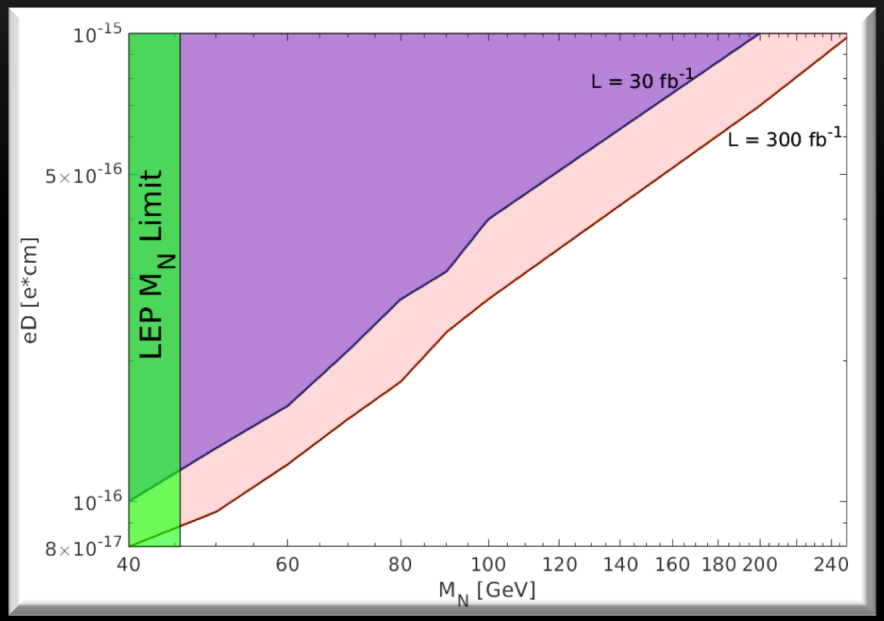


- *Pursue the hunt for magnetic charge using NTD & MMT detectors (see above left) to higher energy (14 TeV) and luminosity.*
- *Search for massive electrically charged objects with low threshold NTD detectors (CR39) from a number of new physics scenarios*
  - *EG complementary sensitivity to long-lived massive SUSY particles (see above right)*

MAPP-mQP – Feebly Interacting Particles



Dark photon decays to mQPs



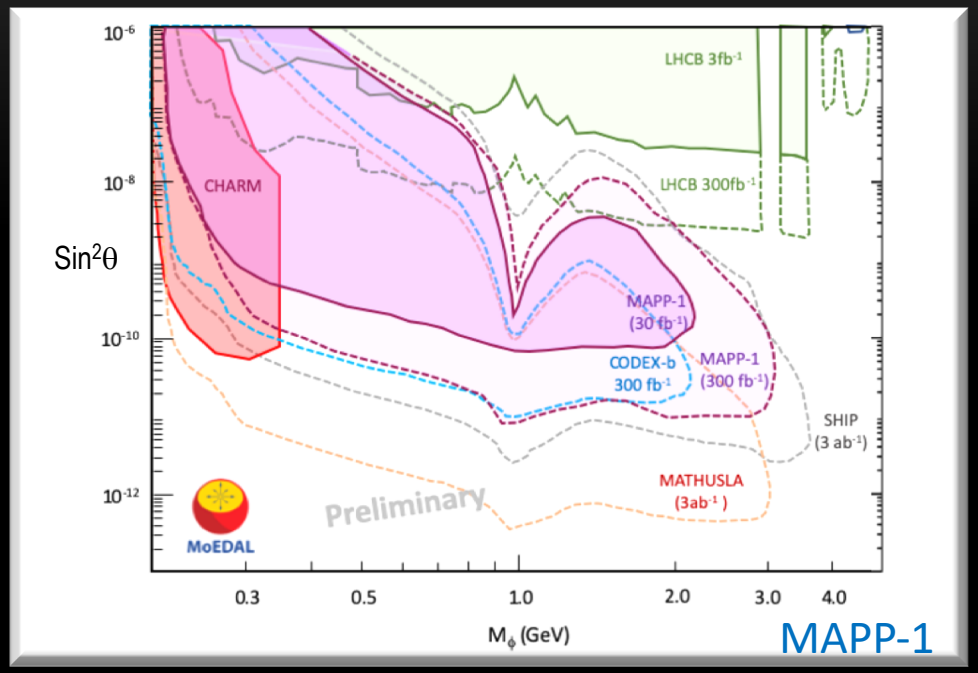
Heavy neutrino with large EDM

- *(LEFT) Limits that can be placed in Run-3 for the decay of a dark photon to mQP pairs (Phys. Lett. B746 (2015) 117-120)*
- *(RIGHT) Limits that MAPP can place of heavy neutrino production with large EDM at Run-3 and HL-LHC at IP8 (Phys. Lett. B802 (2020) 135204).*

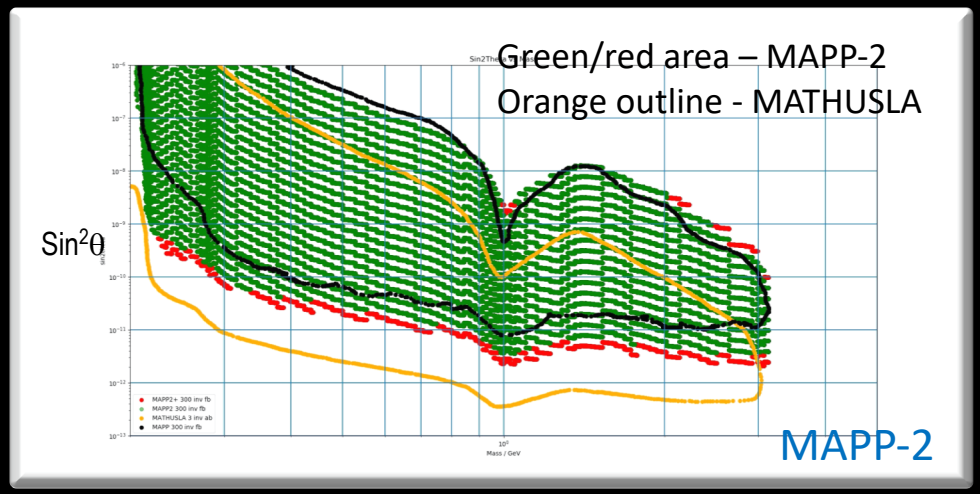
MAPP-LLP – Example Physics Studies

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

- *TOP: Reach for 30 fb^{-1}/300 fb^{-1} for the scenario 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 $\vartheta \ll 1$.*
- *Bottom: Reach for 300 fb-1 with MAPP-2.*
  - *Valuable complementarity with MATHUSLA*
  - *Covers almost the same exclusion region as SHIP*

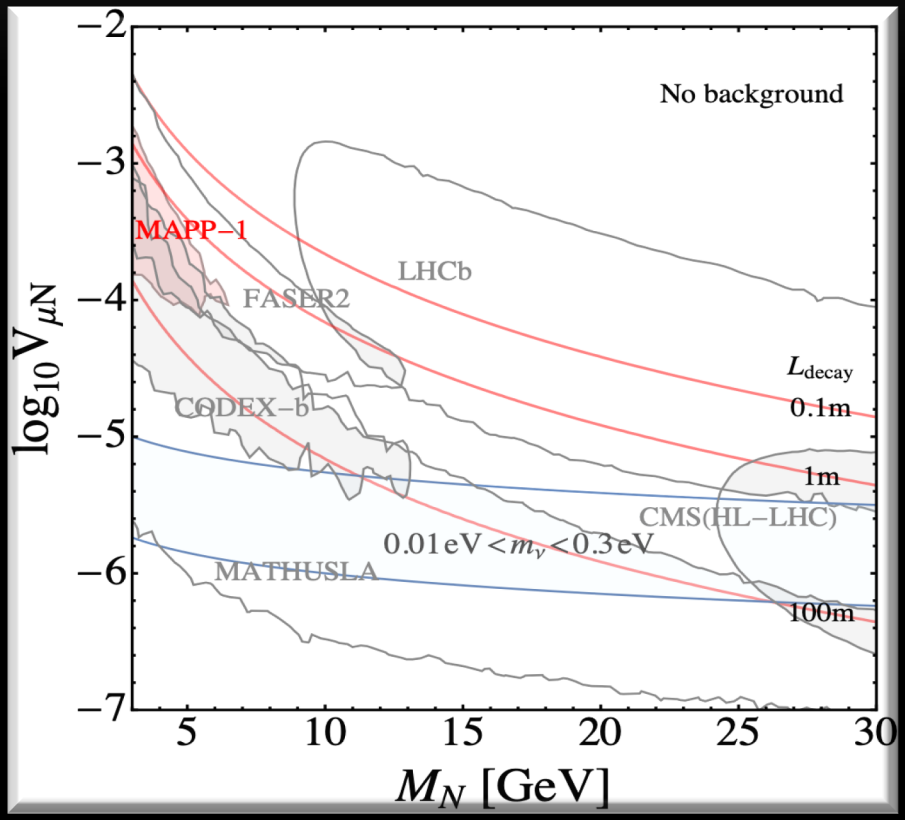


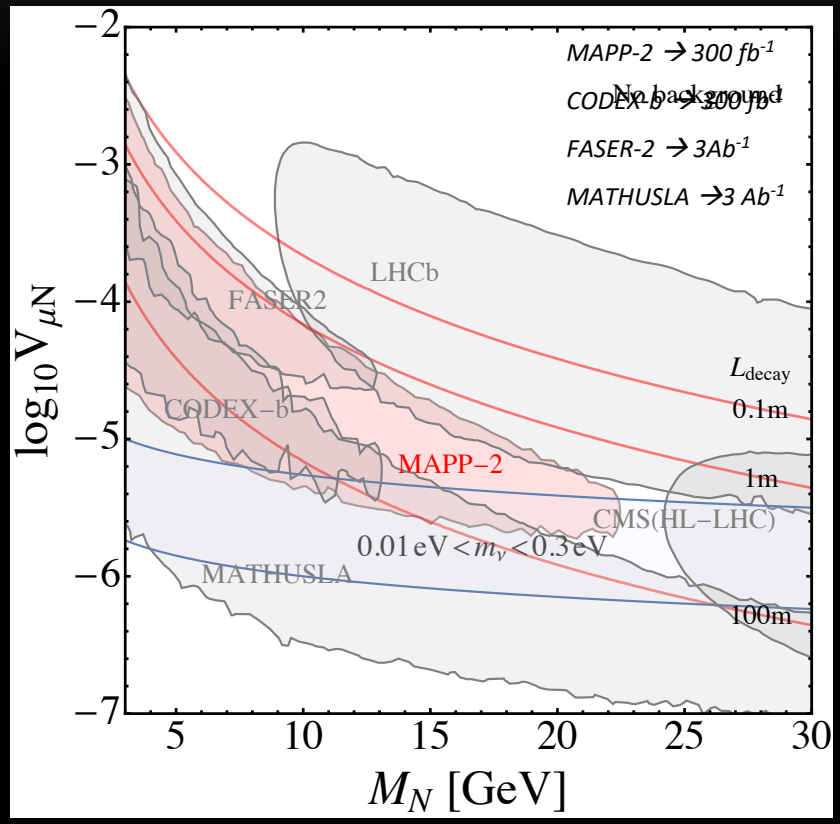
MAPP-1



MAPP-2

Heavy Neutrino Production at the Lifetime Frontier

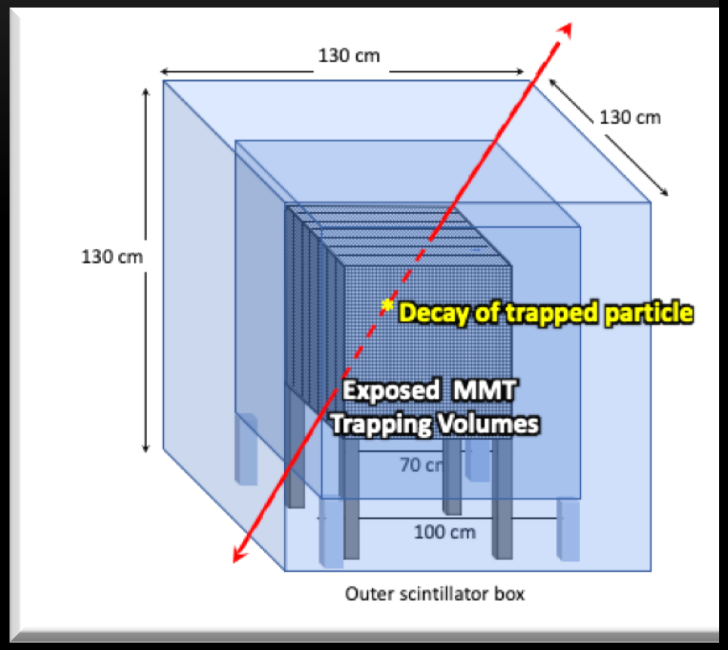


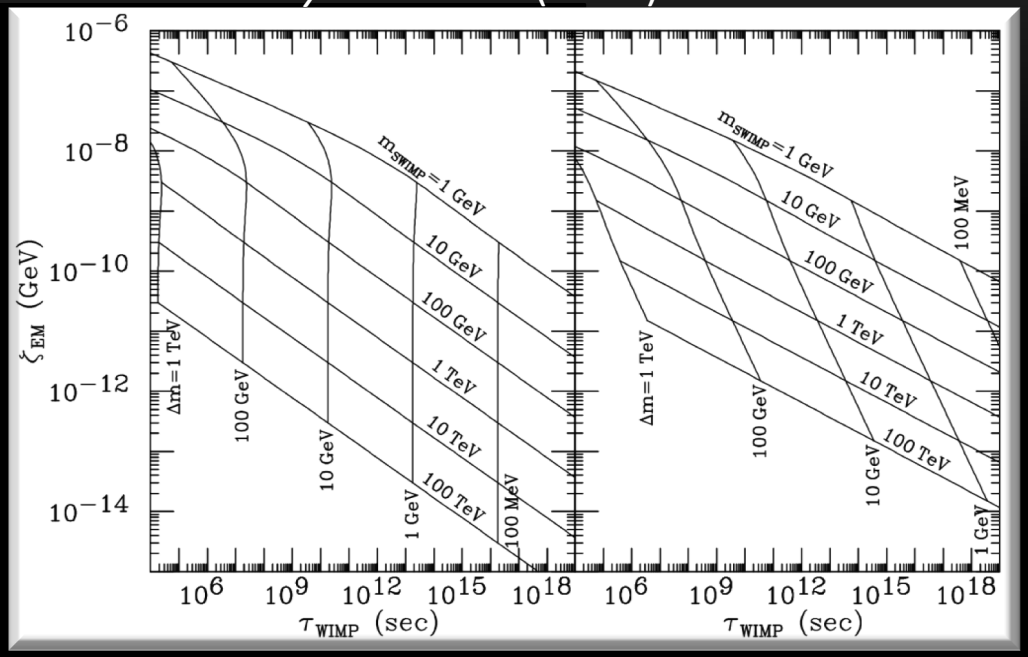


- *Pair production of right-handed neutrinos from the decay of an additional neutral **Z^0** boson in the gauged **B-L** model – Phys. Rev. D100 (2019), 035005.*

The MoEDAL-MALL Detector

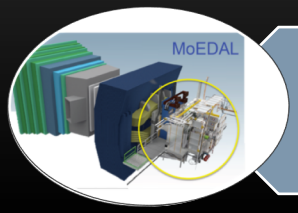
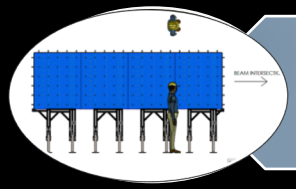
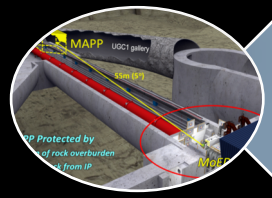
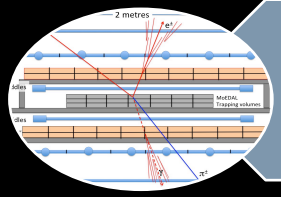
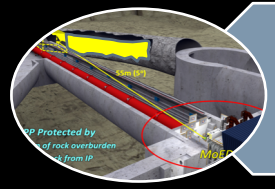
Phys.Rev.D 68 (2003) 063504





- *After exposure MoEDAL trapping volumes will be monitored in the UGC1 gallery for the decays of trapped ultra long-lived particles using the MALL (MoEDAL Apparatus for ultra Long Lived particles) detector*
  - *The massive SuperWIMP particles are naturally bequeathed the desired relic density from the late decays of metastable WIMPs. For example a charged slepton NSLP in this scenario the lifetime of a 150 GeV stau decaying to a 100 GeV gravitino is about 10^9 s or around 10 years*

MoEDAL-MAPP: Run-3 and Beyond

	Highly Ionizing Particles *(HIPs)*	Weakly Ionizing Particles *(mQPs)*	Long-lived Particles *(LLPs)*	APPROVED	START
 **MoEDAL**	✓	✗	✗	**TDR Phase-1**	**≥ 2015**
 **MAPP-mQP**	✗	✓	✗	**TDR Phase-1**	**≥ 2021**
 **MAPP-1**	✗	✗	✓ *LLP-neutral*	**TDR Phase-2**	**≥ 2022**
 **MALL**	✗	✗	✓ *LLP-charged*	**TDR Phase-2**	**≥ 2022**
 **MAPP-2**	✗	✗	✓ *LLP-neutral*	**TDR Phase-3**	**≥ 2025**
OVERALL	✓	✓	✓		

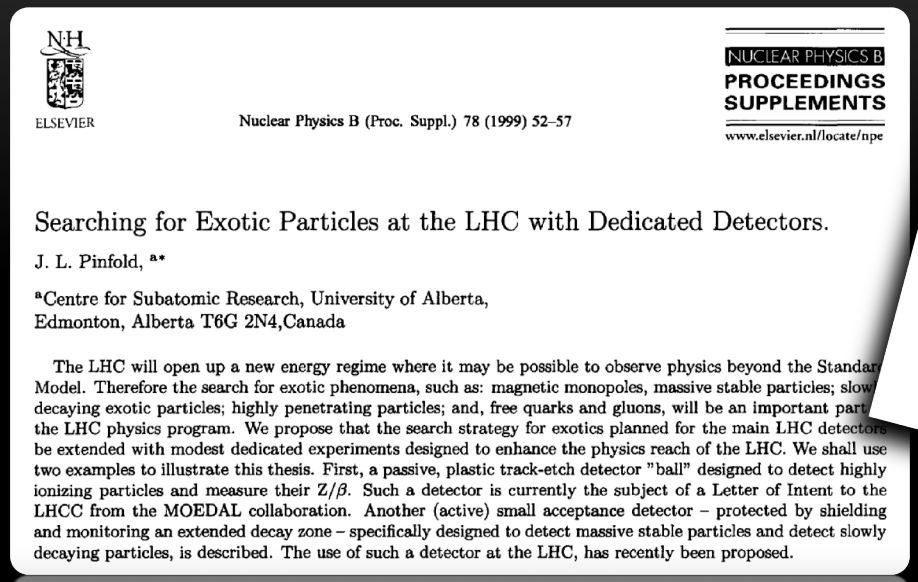
ADDITIONAL SLIDES

The MoEDAL Experiment

(Now 70 physicists Contributing)

The LHC's First Dedicated Search Experiment

Dedicated Search Experiments at Colliders



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

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Searching for Exotic Particles at the LHC with Dedicated Detectors.

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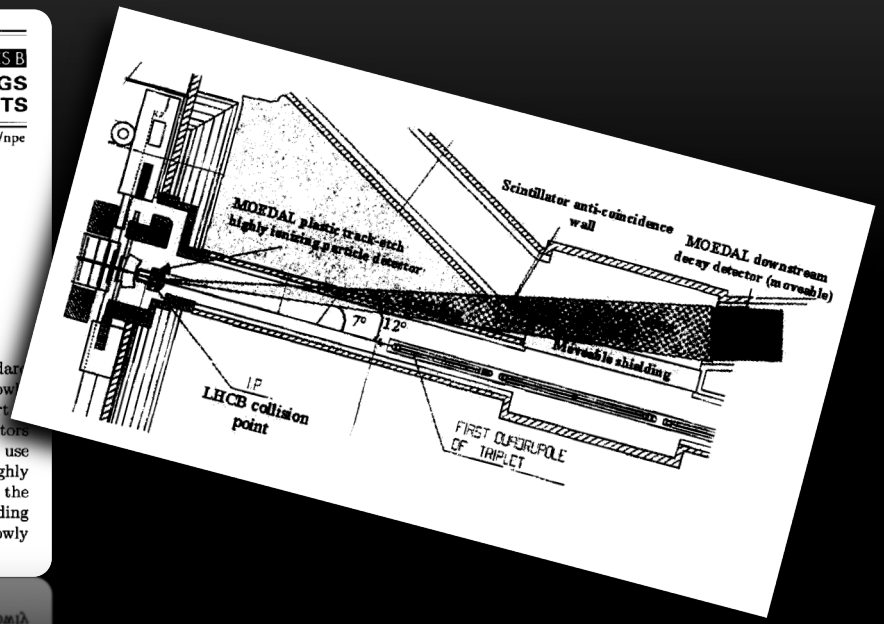
Edmonton, Alberta T6G 2N4,Canada

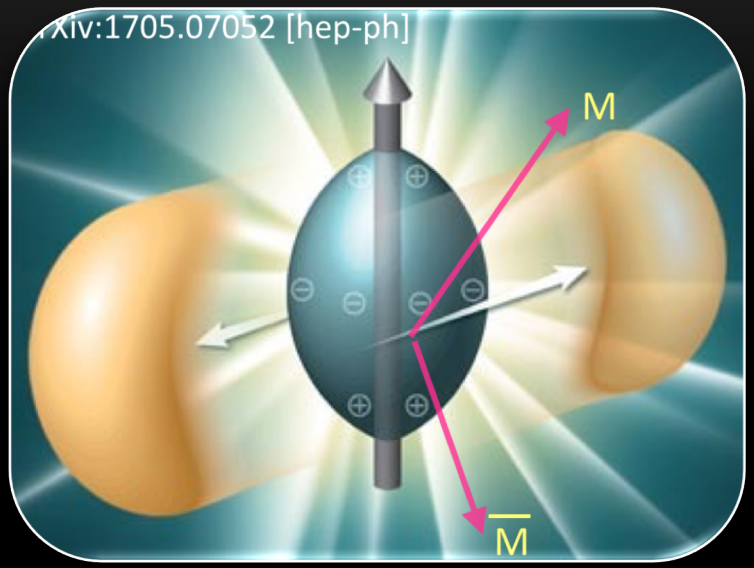
The LHC will open up a new energy regime where it may be possible to observe physics beyond the Standar Model. Therefore the search for exotic phenomena, such as: magnetic monopoles, massive stable particles; slow decaying exotic particles; highly penetrating particles; and, free quarks and gluons, will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

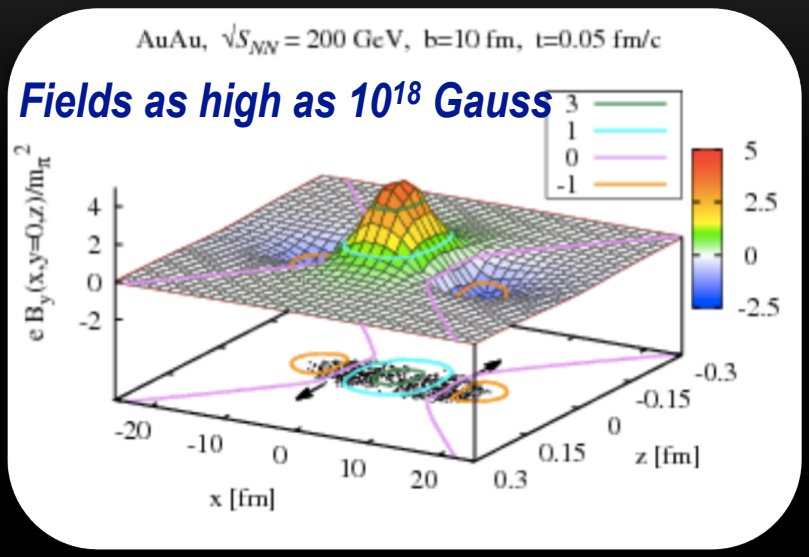


- *What are dedicated search experiments at the LHC?*
  - *They concentrate on some particular clear experimental signature of new physics eg long-lived particles or anomalously ionizing particles*
  - *Their physics reach is complementary to the main collider detectors – extending the LHC's discovery horizon*
  - *They are usually stand alone, smaller & needs-be lower cost with small teams*
- *MoEDAL is the 1st dedicated LHC search experiment - proposing in 1999 the search for highly ionizing & long-lived particles at the LHC*

Monopoles From Heavy-ion Collisions

via the Thermal Schwinger Mechanism





- *Probability of producing a monopole pair* $\sigma_{MM} = \sigma_{Inl} V_{ST} \Gamma_T$ *(where* V_{st} *is the space-time volume of the field,* Γ_T *is the rate/unit volume &* σ_{inl} *is the inelastic nuclear cross-section)*
- *Important benefits:*
  - *No exponential suppression for finite sized monopoles*
  - *X-sec calculation does not suffer from non-perturbative nature of coupling as in DY production*
- *Expect a MoEDAL result on this topic by Winter 2020.*