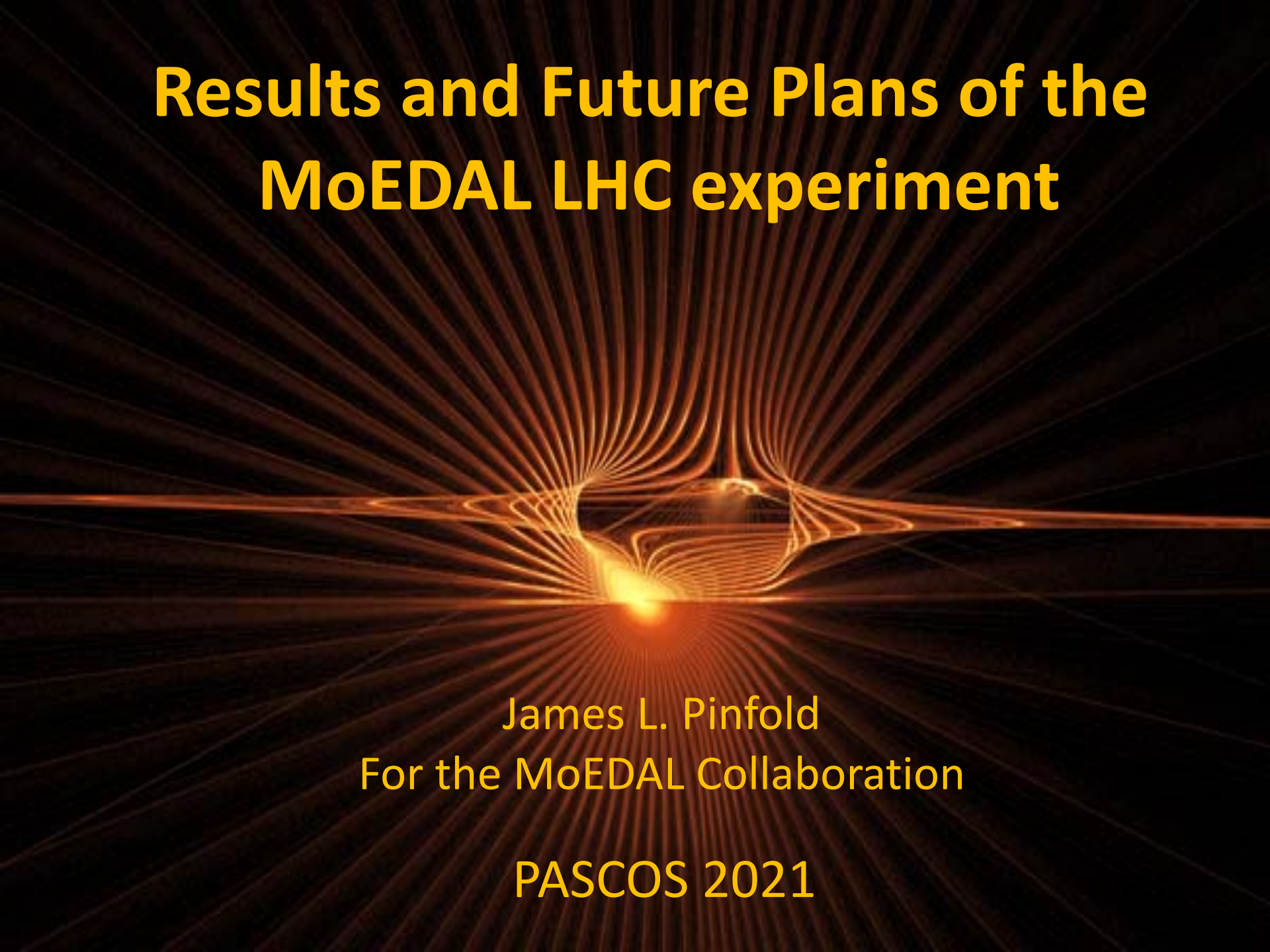
Results and Future Plans of the MoEDAL LHC experiment



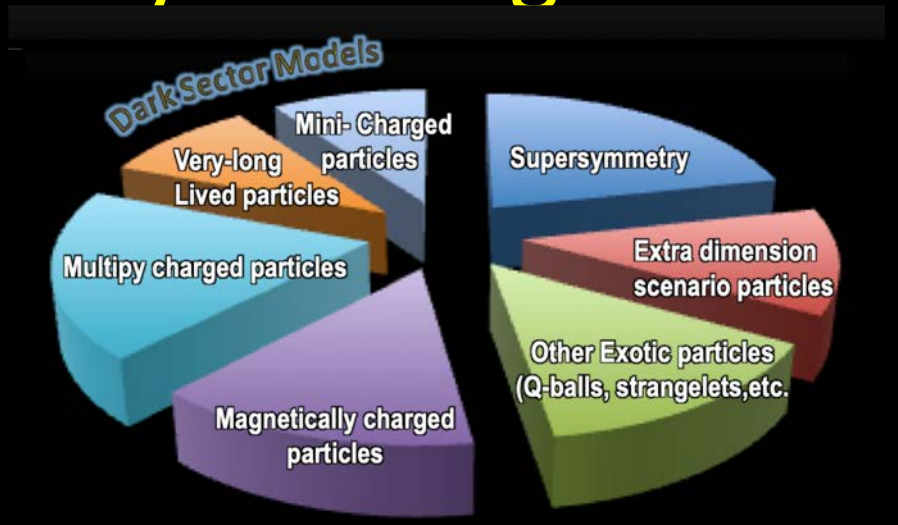
James L. Pinfold
For the MoEDAL Collaboration

PASCOS 2021

The LHC – no new physics yet

MoEDAL-MAPP – Physics Program

- *MoEDAL-MAPP will be sensitive to 3 clear avatars of new physics: HIPs, mQPs and LLPs in a way that is complementary to the general purpose LHC detectors ATLAS & CMS*



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

Very Highly ionizing particles *(≥ 5 times that of a standard relativistic charged particle)*

Feebly Interacting particles *(with tiny SM interactions)*

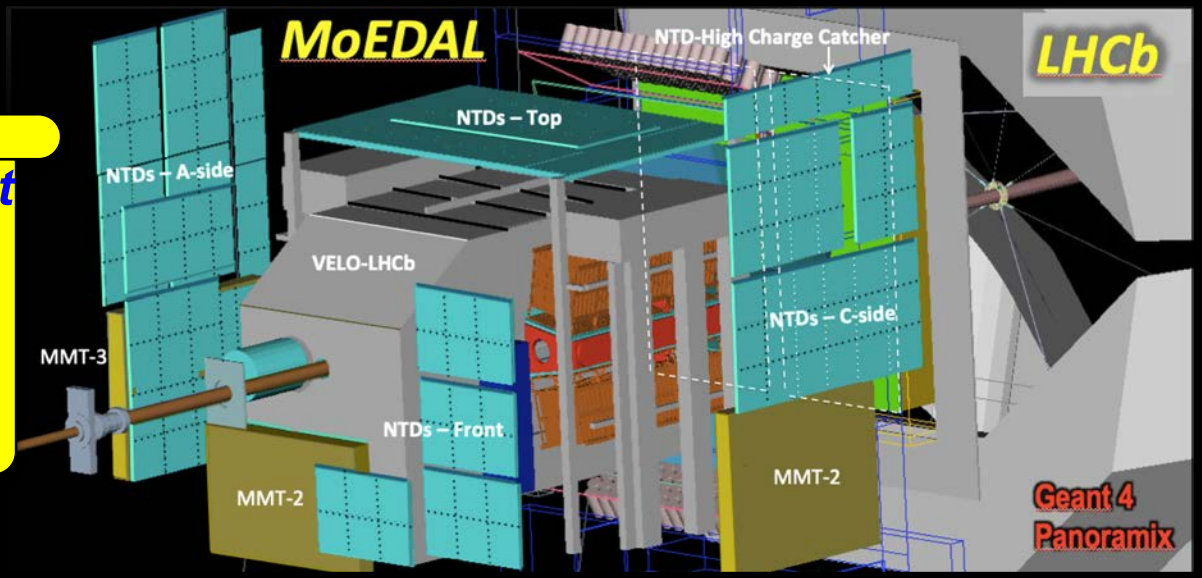
Long lived neutral particles – *($c\tau$ up to ~1km)*

Very long-lived charged particles *(with lifetimes up to ~10 years)*

The MoEDAL Detector at Run-2 and Run-3

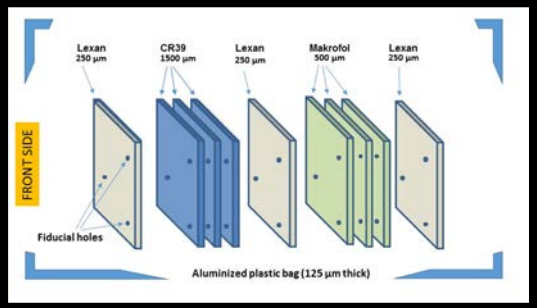
*Started data taking in 2015– **the LHC's first dedicated search experiment***

Permanent Physical record of new physics

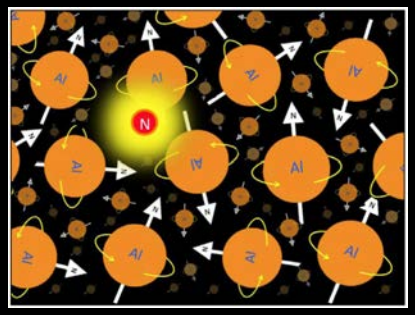


No Standard Model Physics Backgrnds

MoEDAL is made up of 3 detector system designed to search for HIPs.



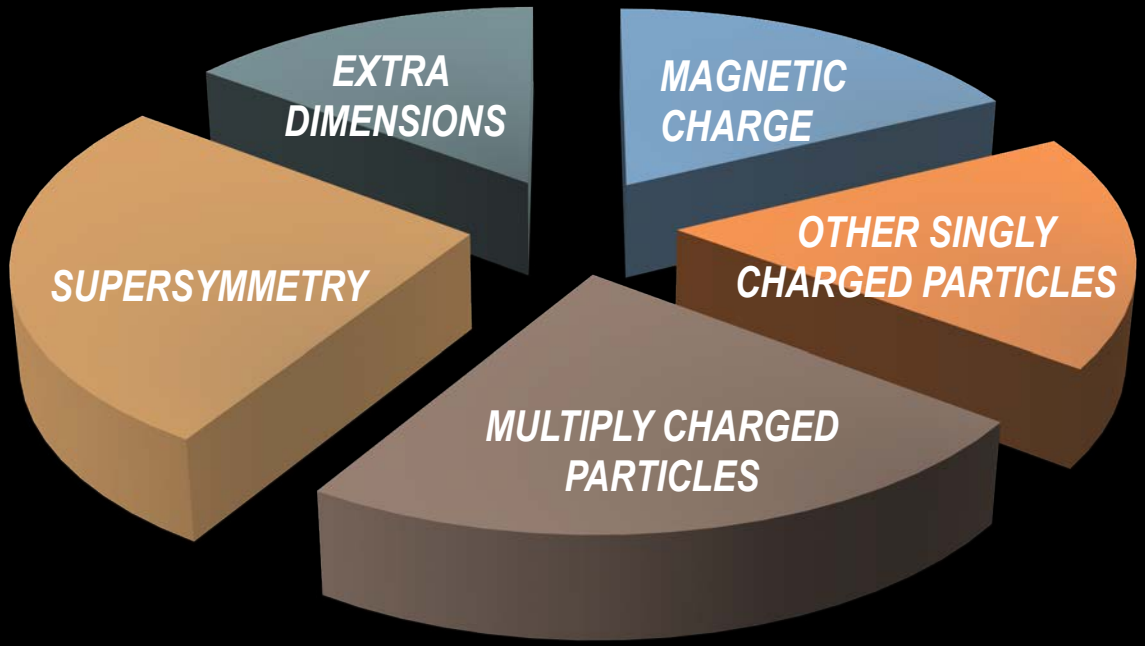
***NUCLEAR TRACK DETECTOR** Plastic array (185 stacks, 12 m^2) – Like a big Camera*



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

***TIMEPIX Array** a digital Camera for real time radiation monitoring*

HIP Physics at the LHC

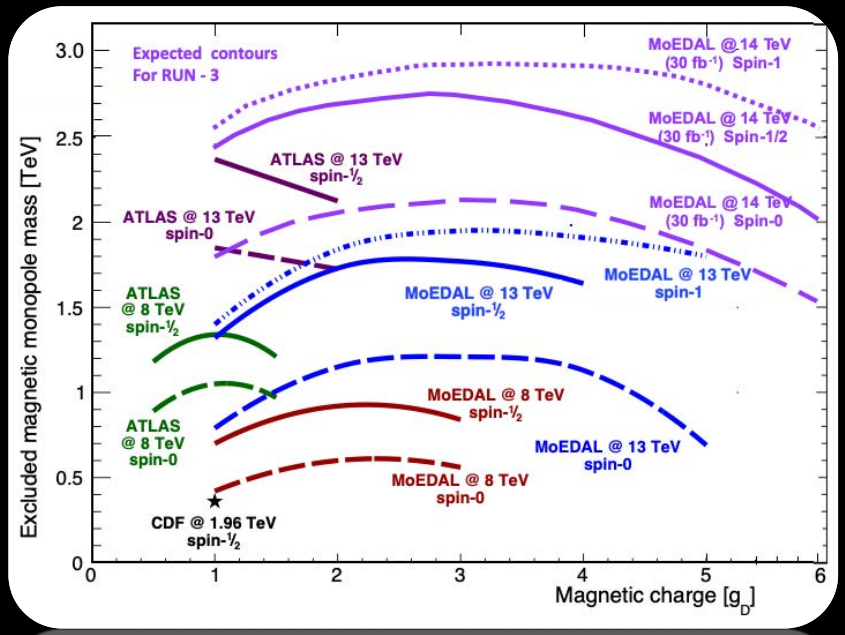


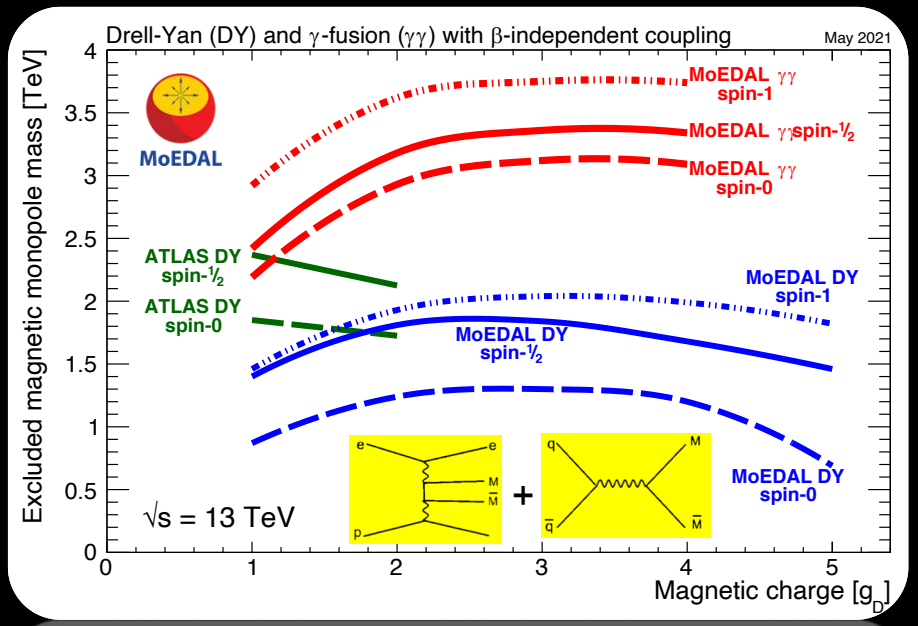
Highly ionizing particles (HIPs)

HIP physics accessible at the LHC summarized in: IJMPA, 2014, Vol. 29, No. 23

- *MAGNETIC CHARGE*
  - *Dyons/Monopoles*
  - *Electroweak Monopoles*
  - *Electroweak strings*
  - *Light t'Hooft-Polyakov monopoles*
  - *D-particles*
- *ELECTRICAL CHARGE*
  - *Q-balls & Strangelets*
  - *SUSY – eg massive sleptons, etc*
  - *Stable microscopic black holes & remnants*
  - *Doubly charged Higgs (LR Sym. Models)*
  - *Multiply charged exotic states, etc*

Mass Limits on Multiply Charged Monopoles

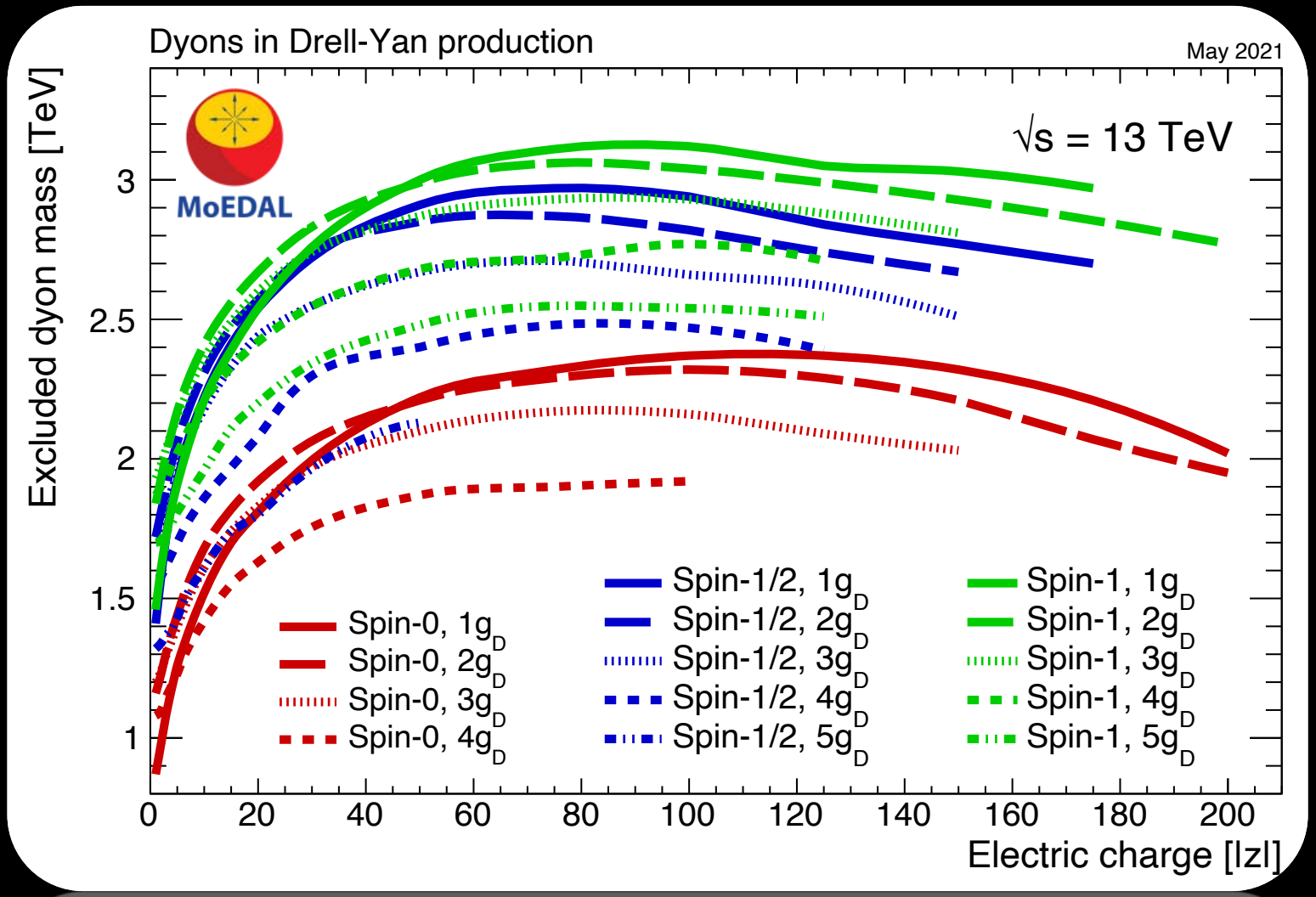




JHEP 1608 (2016) 067 PRL 118 (2017) 061801 Phys.Lett. B782 (2018) 510 PRL 123 (2019) 021802

- *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.*

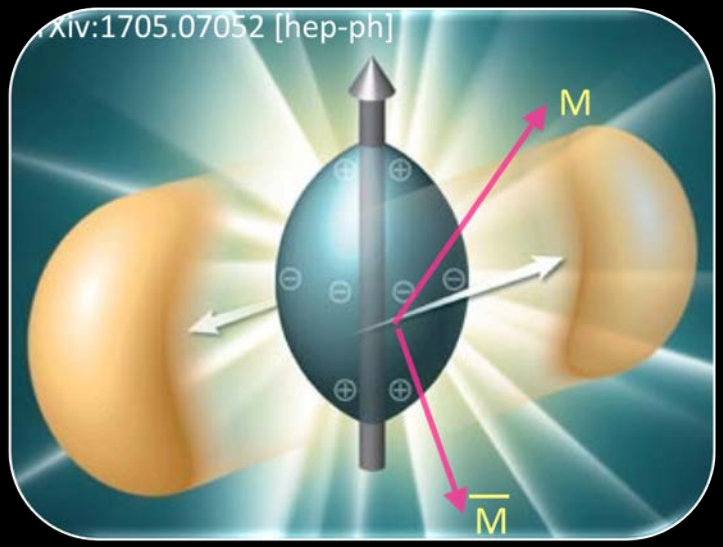
First Direct Search Specifically for a Dyon

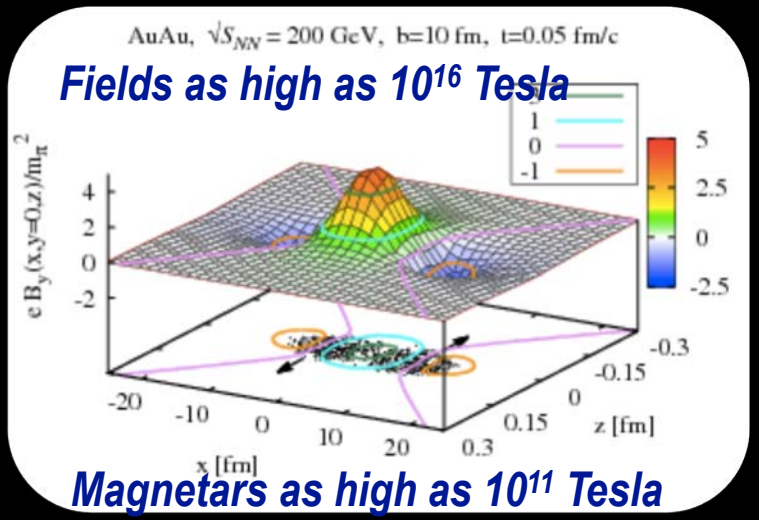


•*Phys.Rev.Lett. 126 (2021) 7, 071801*

Monopoles From Heavy-ion Collisions

via the Schwinger Mechanism (paper near submission)





- *Schwinger mechanism originally described spontaneous creation of $e^{--} - e^{+}$ pairs in presence of an extremely strong electric field.*
- *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 couplings as in DY*

MoEDAL @ Run-3 – Desperately Seeking SUSY

arXiv.org > hep-ph > arXiv:1903.11022

Search... Help | Advance

High Energy Physics - Phenomenology

SUSY discovery prospects with MoEDAL

K. Sakurai, D. Felea, J. Mamuzic, N. E. Mavromatos, V. A. Mitsou, J. L. Pinfold, R. Ruiz de Austri, A. Santra, O. Vives

(Submitted on 26 Mar 2019)

We present a preliminary study on the possibility to search for massive long-lived electrically charged particles at the MoEDAL detector. MoEDAL is sensitive to highly ionising objects such as magnetic monopoles or massive (meta-)stable electrically charged particles and we focus on the latter in this paper. Requirements on triggering or reducing the cosmic-ray and cavern background, applied in the ATLAS and CMS analyses for long-lived particles, are not necessary at MoEDAL, due to its

Eur. Phys. J. C (2020) 80:431
https://doi.org/10.1140/epjc/s10052-020-7994-7

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Prospects for discovering supersymmetric long-lived particles with MoEDAL

D. Felea[1,a], J. Mamuzic[2,b], R. Maselek[3,c], N. E. Mavromatos[4,d], V. A. Mitsou[2,e], J. L. Pinfold[5,f], R. Ruiz de Austri[2,g], K. Sakurai[3,h], A. Santra[2,i], O. Vives[2,6,j]

ICNFP 2017 V.A. Mitsou

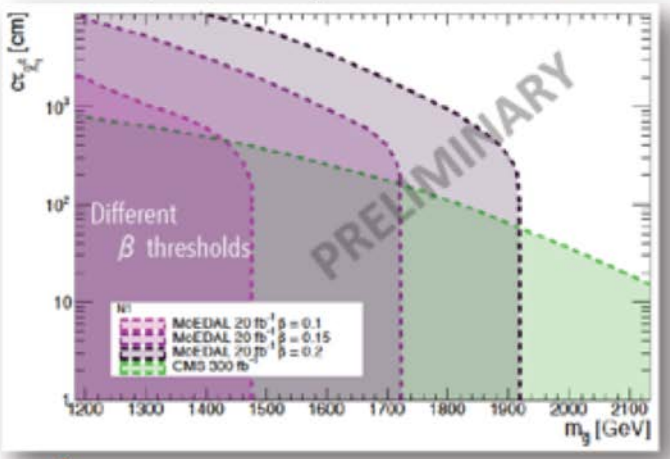
Results for $\tilde{g}\tilde{g}$, $\tilde{g} \to jj\tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to \tau^{\pm}\tilde{\tau}_1$

$\tilde{\chi}_1^0$ long-lived despite large mass split between $\tilde{\chi}_1^0$ and $\tilde{\tau}_1$ ➜ decays in tracker

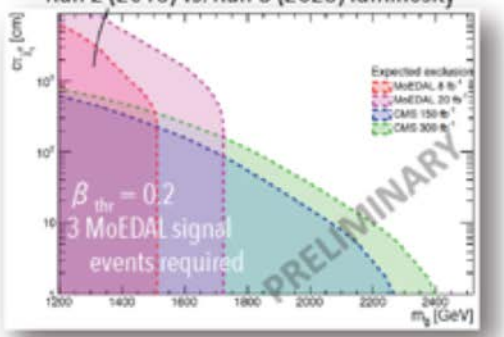
(massive) $\tau^{\pm}$ produces a kink between $\tilde{\chi}_1^0$ and $\tilde{\tau}_1$ tracks ⇒ large impact parameter d_{xy}, d_z

$\tilde{\tau}_1$ metastable, e.g. gravitino LSP ➜ detected by MoEDAL

End-of-run-3 (2023) luminosity



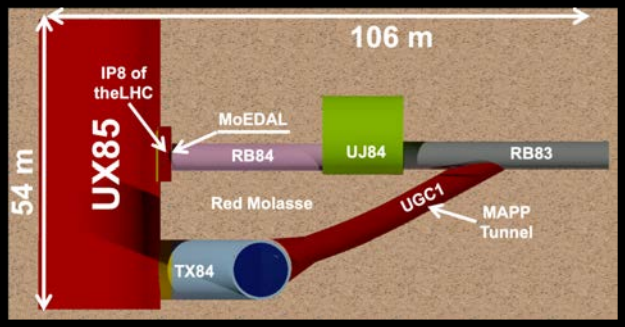
Run 2 (2018) vs. Run-3 (2023) luminosity

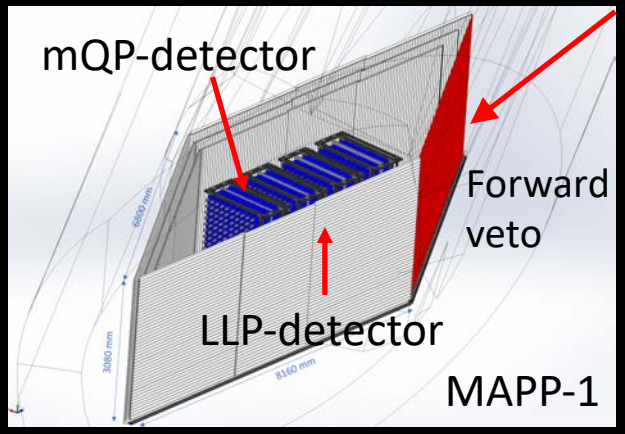


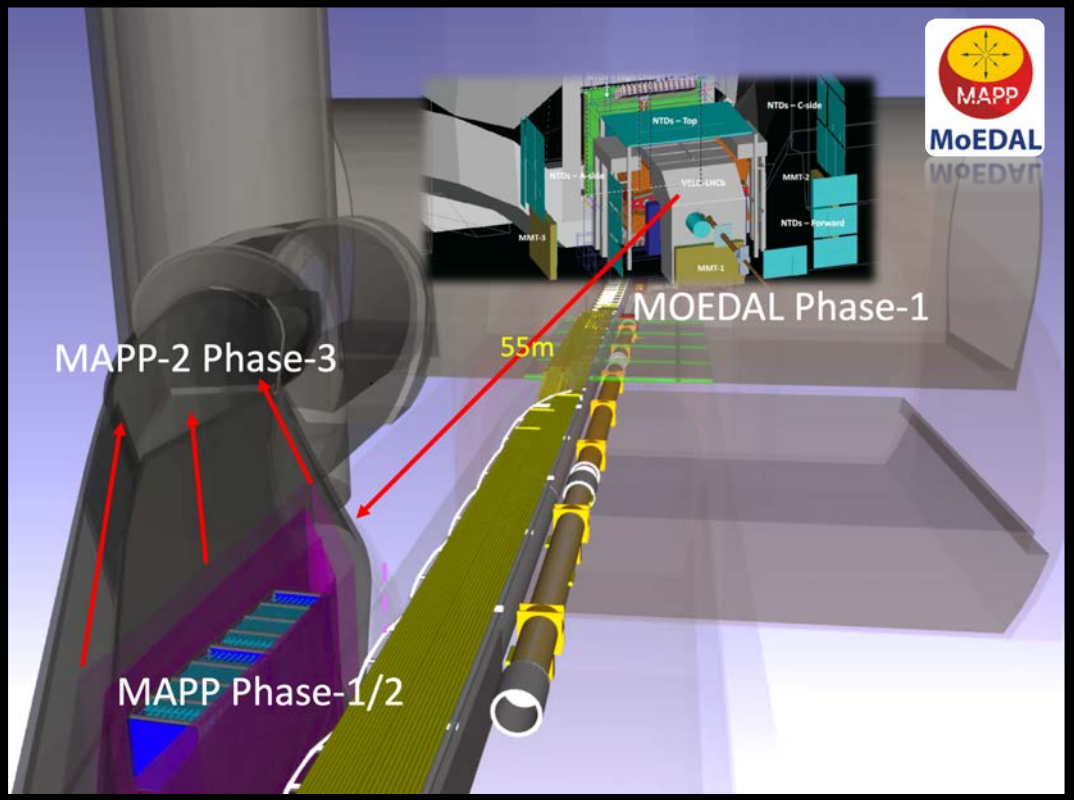
- CMS suffers twice:
  - a) no pixel hit
  - b) too large impact parameters
- MoEDAL can cover long-lifetime region inaccessible by ATLAS/CMS even with a *moderate* NTD performance $z/\beta > 10$

Comparison of CMS exclusion with MoEDAL discovery potential requiring 1 event

The MoEDAL-MAPP Project



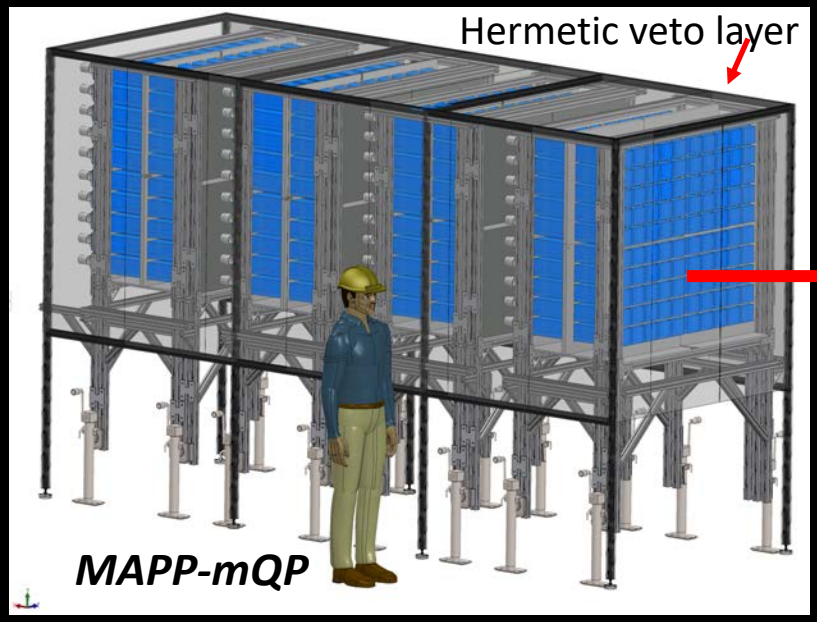


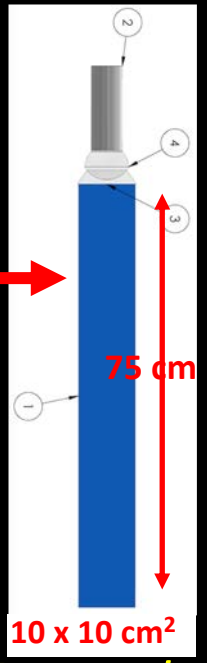


- *Phase-1 of MoEDAL-MAPP for Run-3 (TP submitted):*
  - *Redeploy MoEDAL detector (Spring 2022)*
  - *Deploy MAPP-1 milli-charged particle detector (MAPP-mQP) (Spring 2023)*
- *Phase-2: Deploy MAPP-1 LLP detector (MAPP-LLP) for Run-4*
- *Phase-3 Deploy MAPP-2 extended LLP detector for Run-5*

Phase-1 MAPP-mQP for Run-3 (2023)

Currently under construction

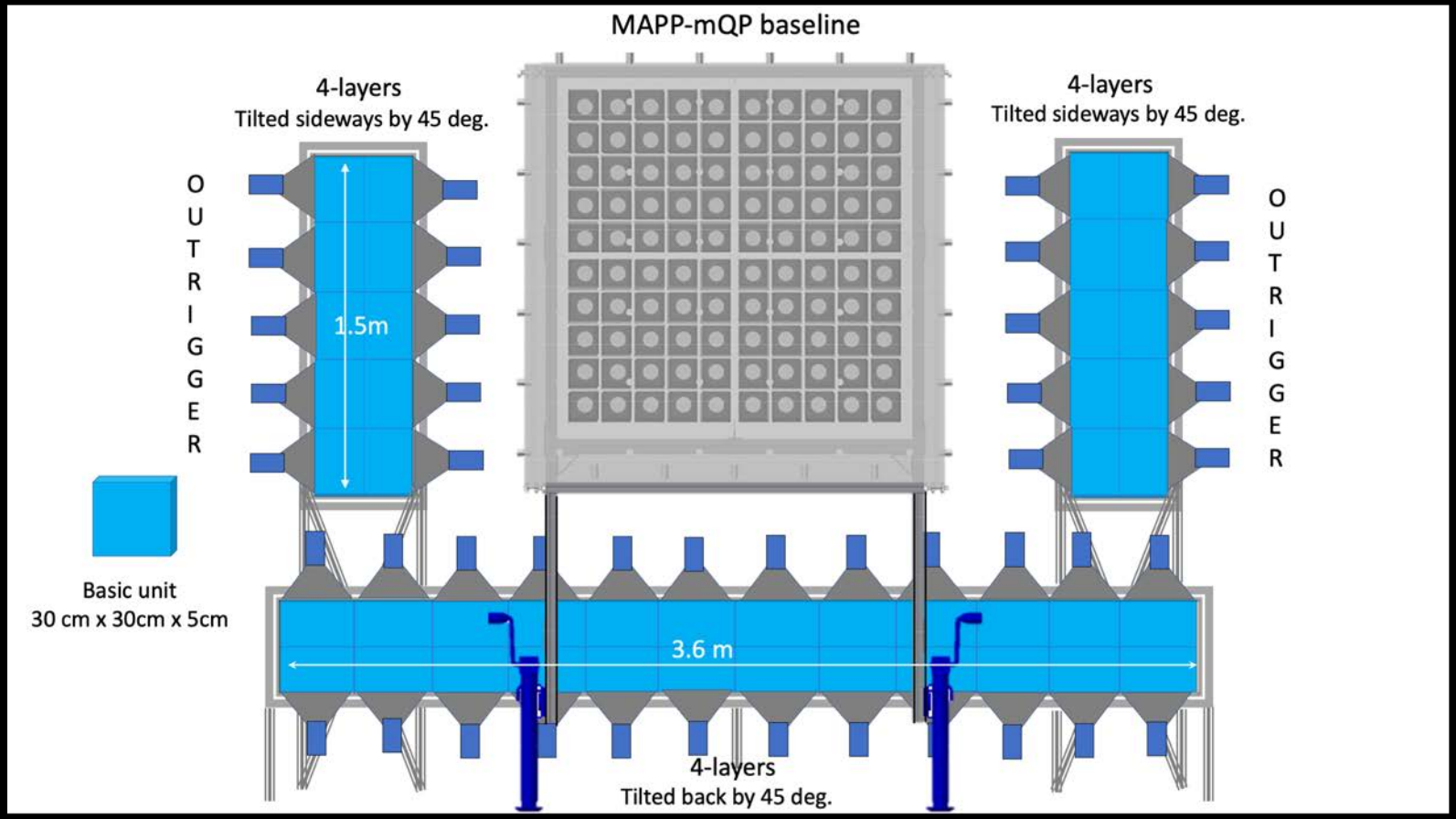




- *For Phase-1 at Run-3 MoEDAL with redeployed to continue the HIP search + the MAPP-mQP detector will be ready to quest for mQPs in 2023.*
  - *Deployed in the UGC1 gallery that is ~level with the floor of the LHC tunnel – thus support structure is ~horizontal - It weighs 4-5 tonnes with size ~1.5 X 2.5 x 4.0m^3*
  - *It is surrounded by a veto layer to help eliminate cosmic ray backgrounds.*
  - *Consists of 400 scint. bars (10x10x75 cm^3) in 4 sections readout by 400 low noise PMTs*
  - *Uses SW (FPGAs) trigger and is readout over the internet. It operates in a standalone mode in the UGC1 cavern*
  - *Calibration using blue LEDs (in each bar) + neutral density filter absolute calibration*

The MAPP-mQP Outrigger for Run-3

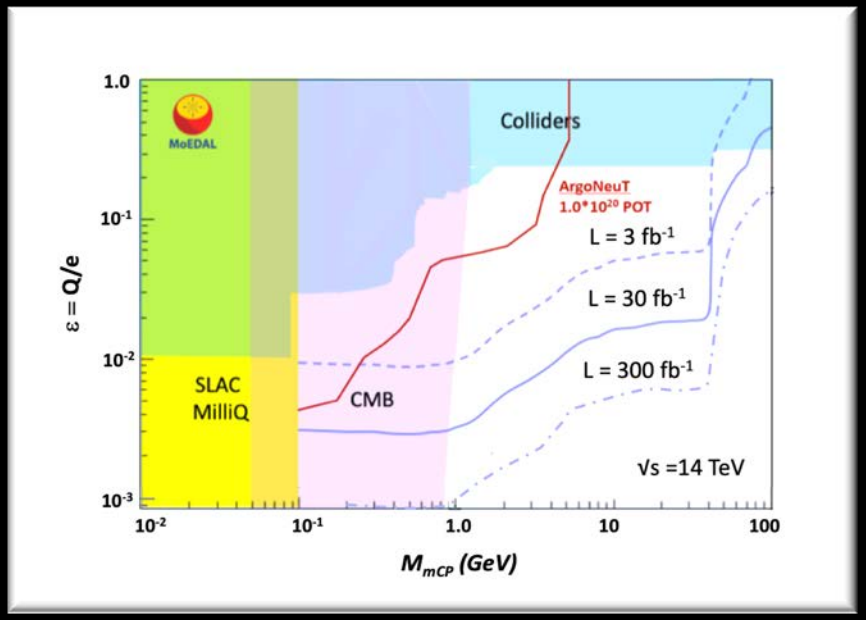
Currently under construction



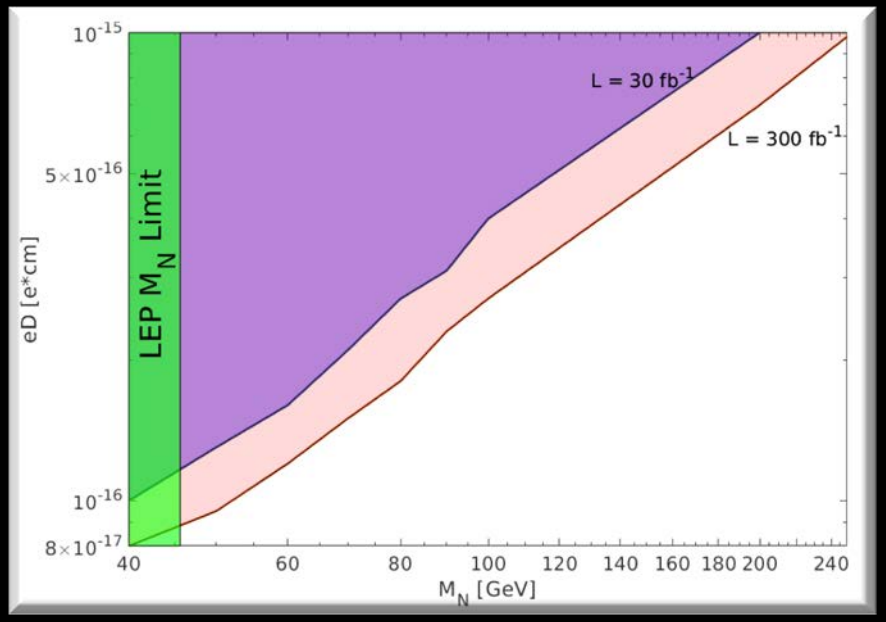
- *Lower sensitivity to smaller fractional charges but much larger area: ~16m deployed in 4 layers*
- *Greater reach at larger fractional charges*

MAPP-mQP – Feebly Interacting Particles

Outrigger NOT taken into account as yet



Dark photon decays to mQPs

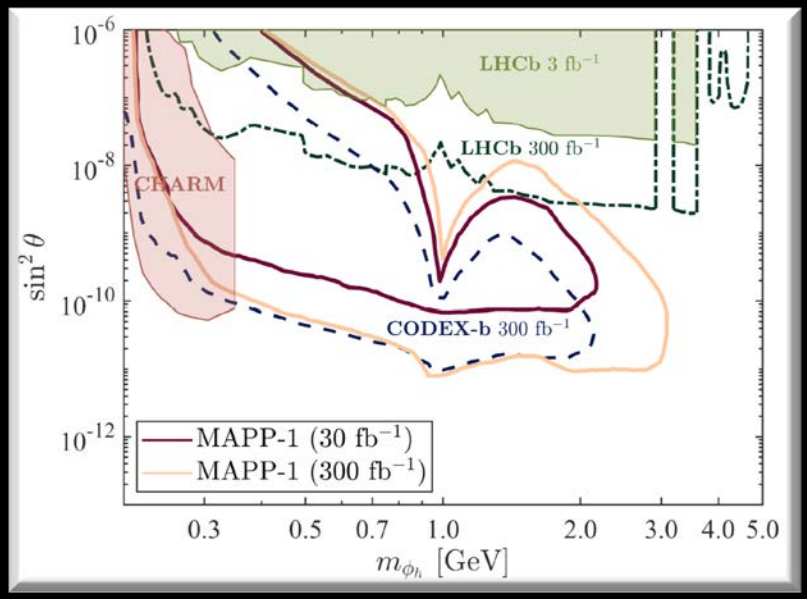


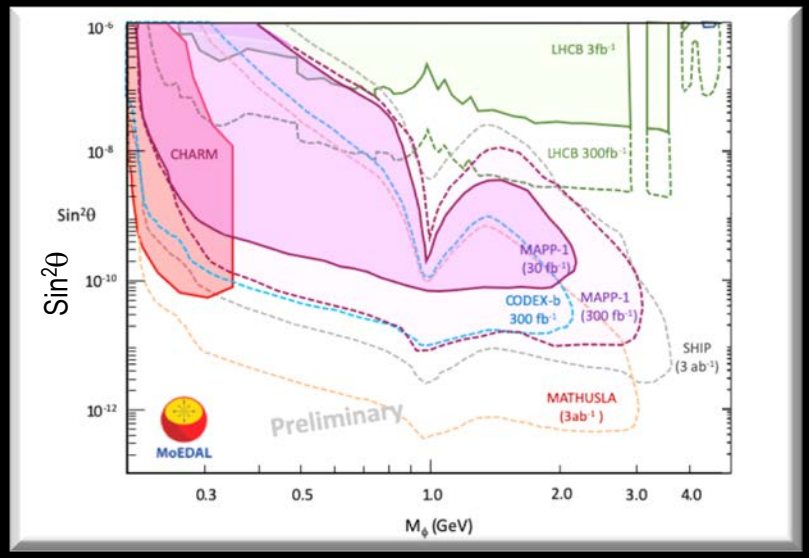
Heavy neutrino with large EDM

- *(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) (assume 100% efficient detector and no background)*
- *(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-1 (LLP): Example Physics Studies

- *Benchmark process:*
  - *Where 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 $\vartheta \ll 1$.*
- *TOP: MAPP-1 each for 30 fb^{-1}/ 300 fb^{-1} compared to CODEX-b*
- *Bottom: Reach for 30 fb^{-1} /300 fb^{-1} compared to SHIP (3ab^{-1}) & MATHUSLA (3ab^{-1})*
  - *Valuable complementarity with MATHUSLA & CODEX-b*

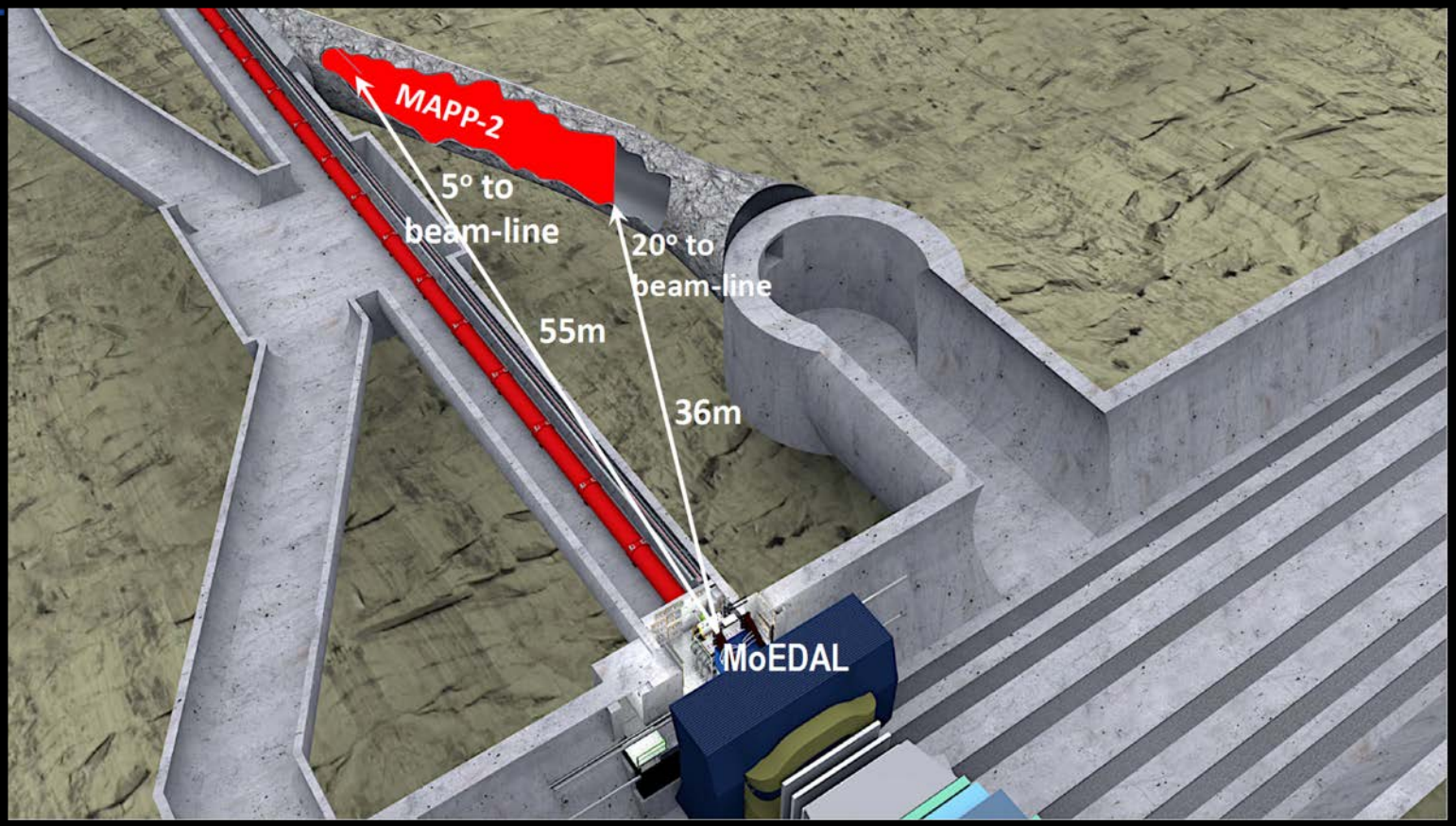




***In these plots CODEX-b, MAPP, MATHUSLA and SHIP, taken to be 100% efficient with no backgrounds*

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

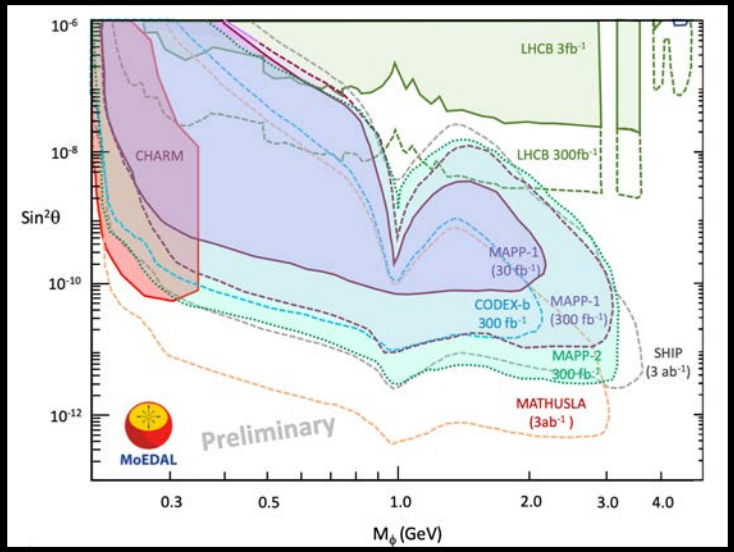
Phase-3: MAPP-2 for HL-LHC



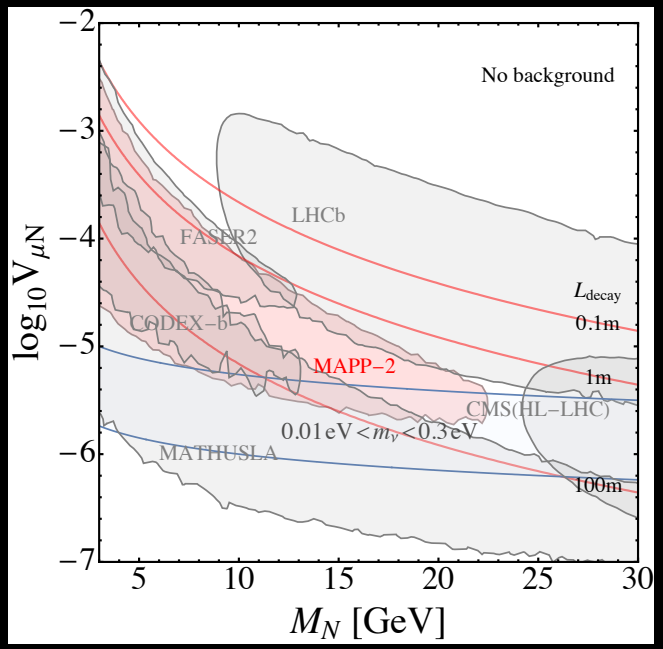
- *MAPP-2 is an extension of MAPP-1 down the UGC1 gallery.*
- *The MAPP-I technology would be used to provide a cost effective approach.*

MAPP-2 (LLP): Example Physics Studies

- *Using the same Higgs mixing portal benchmark we see that MAPP-2 extends MAPP-1's sensitivity so that it is competitive with SHIP's.*



- *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.*



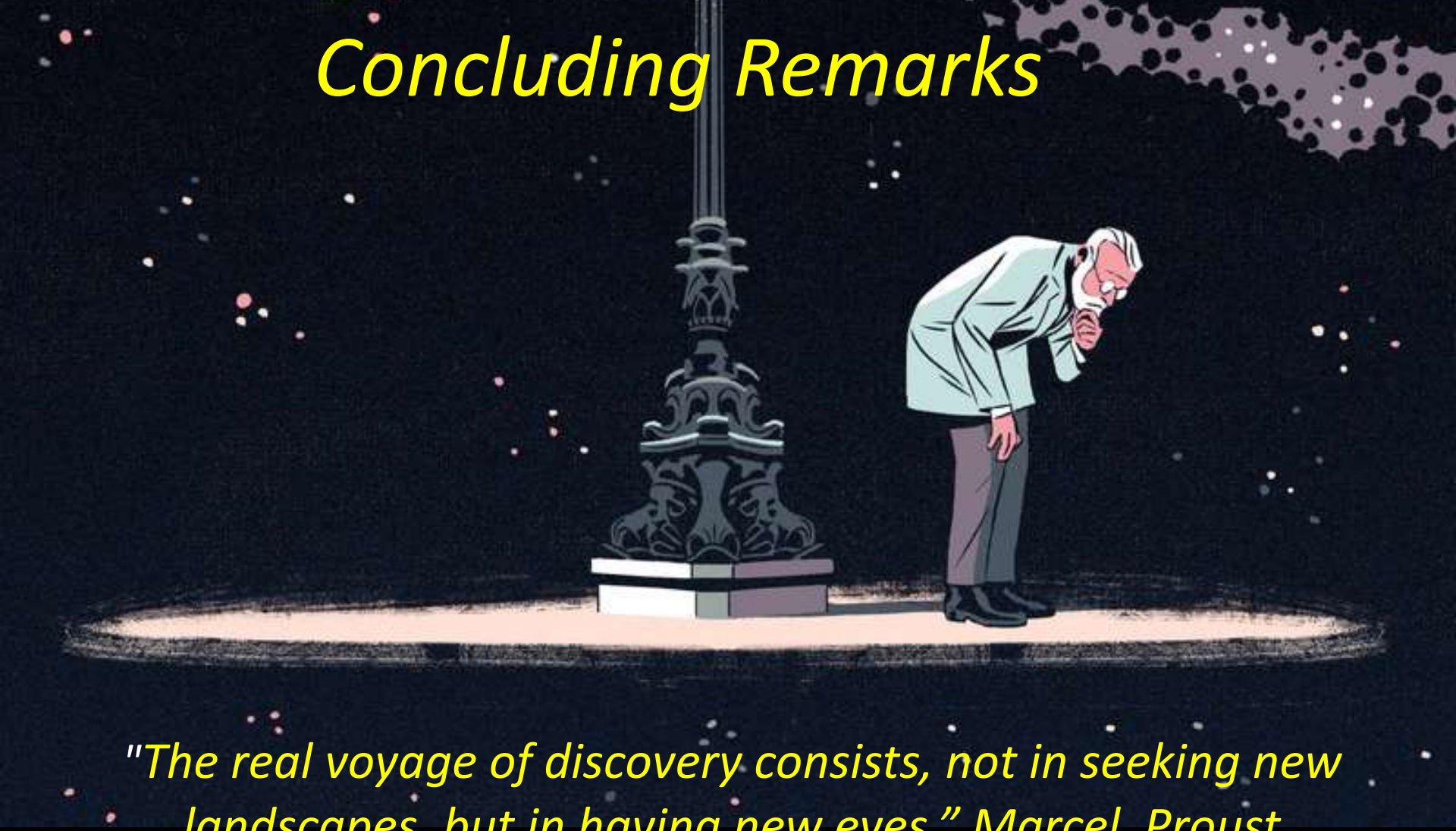
MAPP-2 → 300 fb-1

CODEX-b → 300 fb-1

FASER-2 → 3Ab-1

MATHUSLA →3 Ab-1

Concluding Remarks



"The real voyage of discovery consists, not in seeking new landscapes, but in having new eyes." Marcel Proust

Dedicated search experiments such as MoEDAL-MAPP are the "new eyes" of the LHC