The MoEDAL- MAPP Experiment – Extending the Physics Reach of the LHC

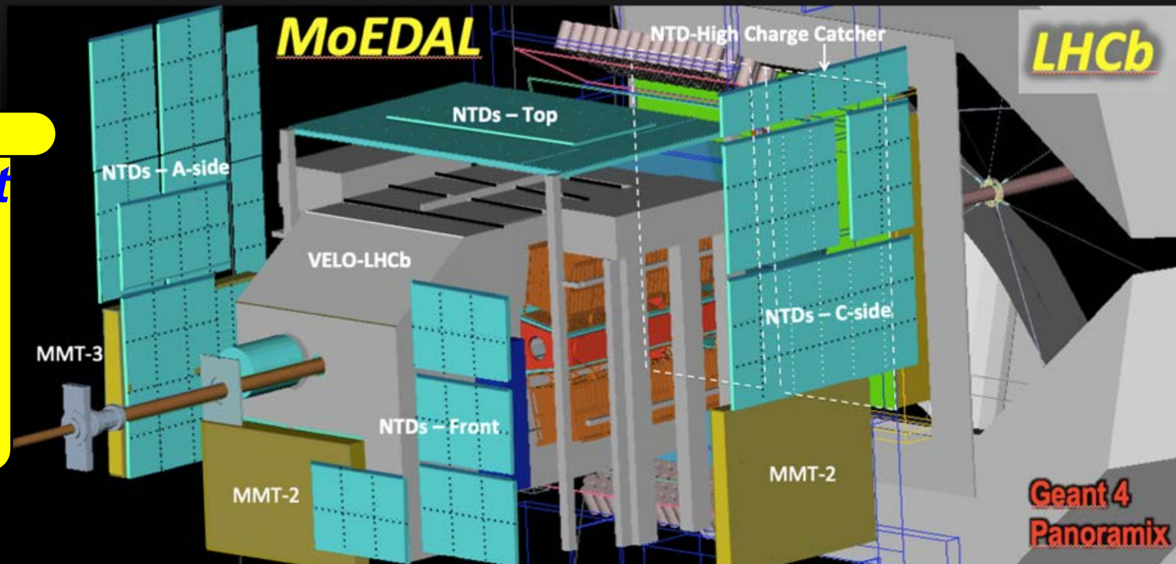
MG16 5-10 JULY 2021
SIXTEENTH MARCEL GROSSMANN MEETING

James L. Pinfold for the MoEDAL Collaboration

The MoEDAL Detector at Run-2 and Run-3

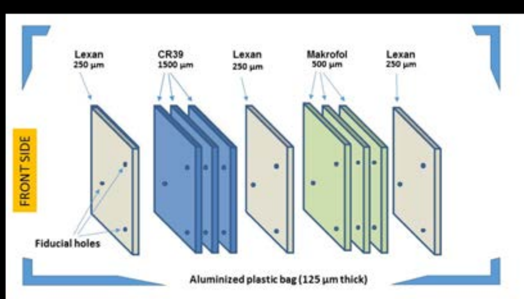
*Started data taking in 2015– **the LHC's first dedicated search experiment***

Permanent Physical record of new physics

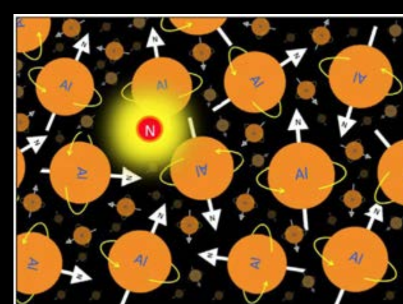


No Standard Model Physics Backgrnds

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



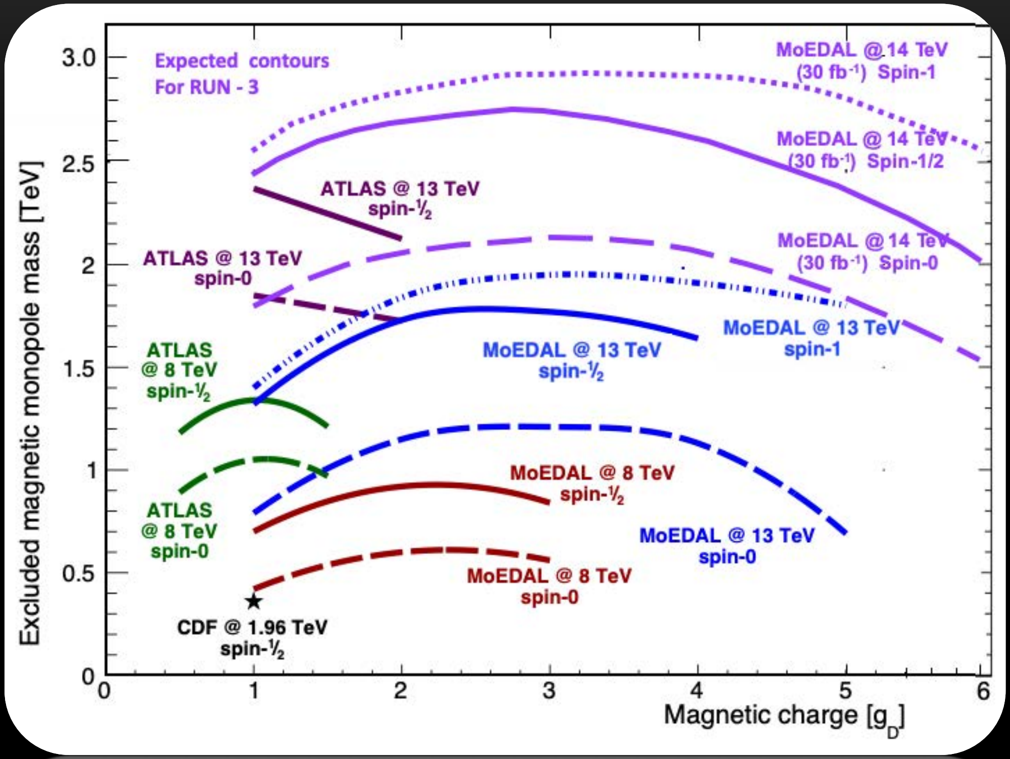
NUCLEAR TRACK DETECTOR
Plastic array (185 stacks, 12 m²) – Like a big Camera



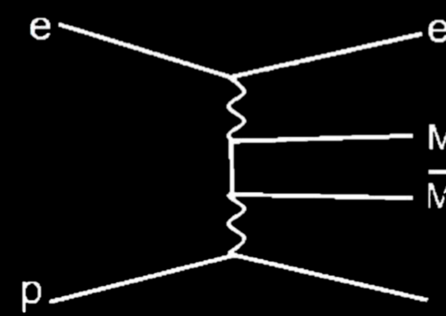
TRAPPING DETECTOR ARRAY
A tonne of Al to trap Highly Ionizing Particles for analysis

TIMEPIX Array a digital Camera for real time radiation monitoring

Mass Limits on Multiply Charged Monopoles



Drell Yan mechanism

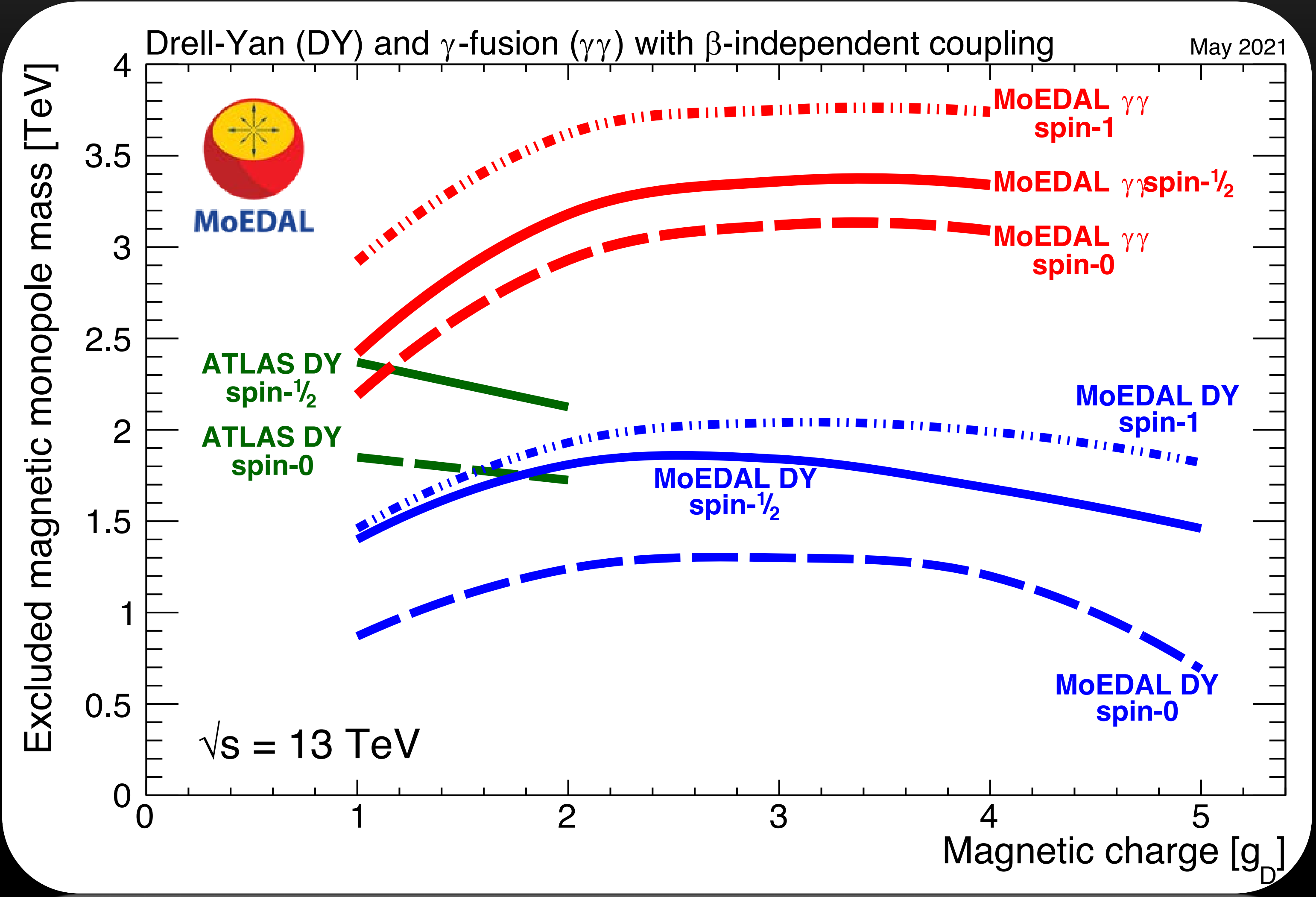


Photon fusion

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

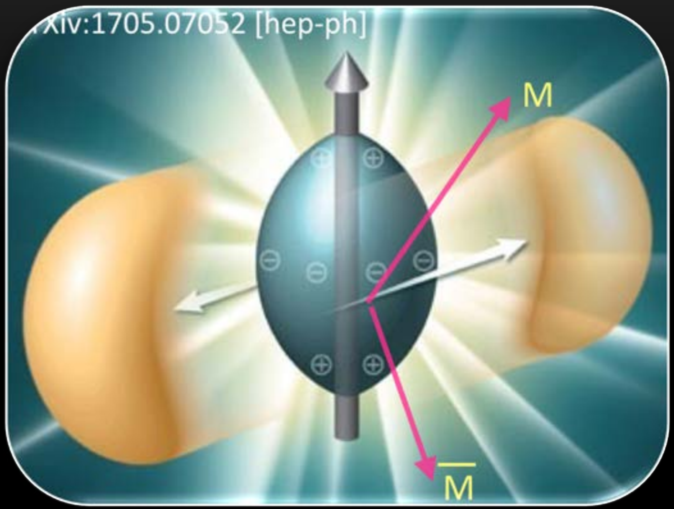
- *So far MoEDAL has placed the world's best published direct limits on:*
  - *Multiply charged magnetic monopoles*
  - *Spin-1 monopoles*
  - *DY + Photon fusion production of monopoles*
  - *Dyons – electrically and magnetically charged particles.*

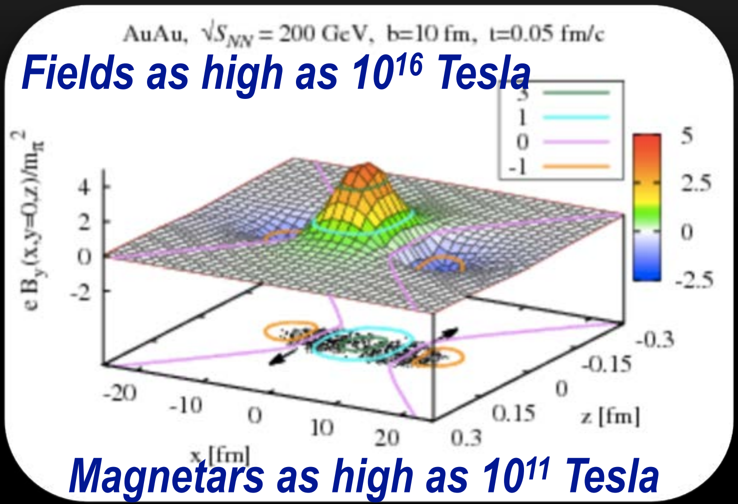
Mass Limits for DY & $\gamma\gamma$ Combined



(ATLAS has only reported DY results to date).

Monopoles From Heavy-ion Collisions
via the Schwinger Mechanism





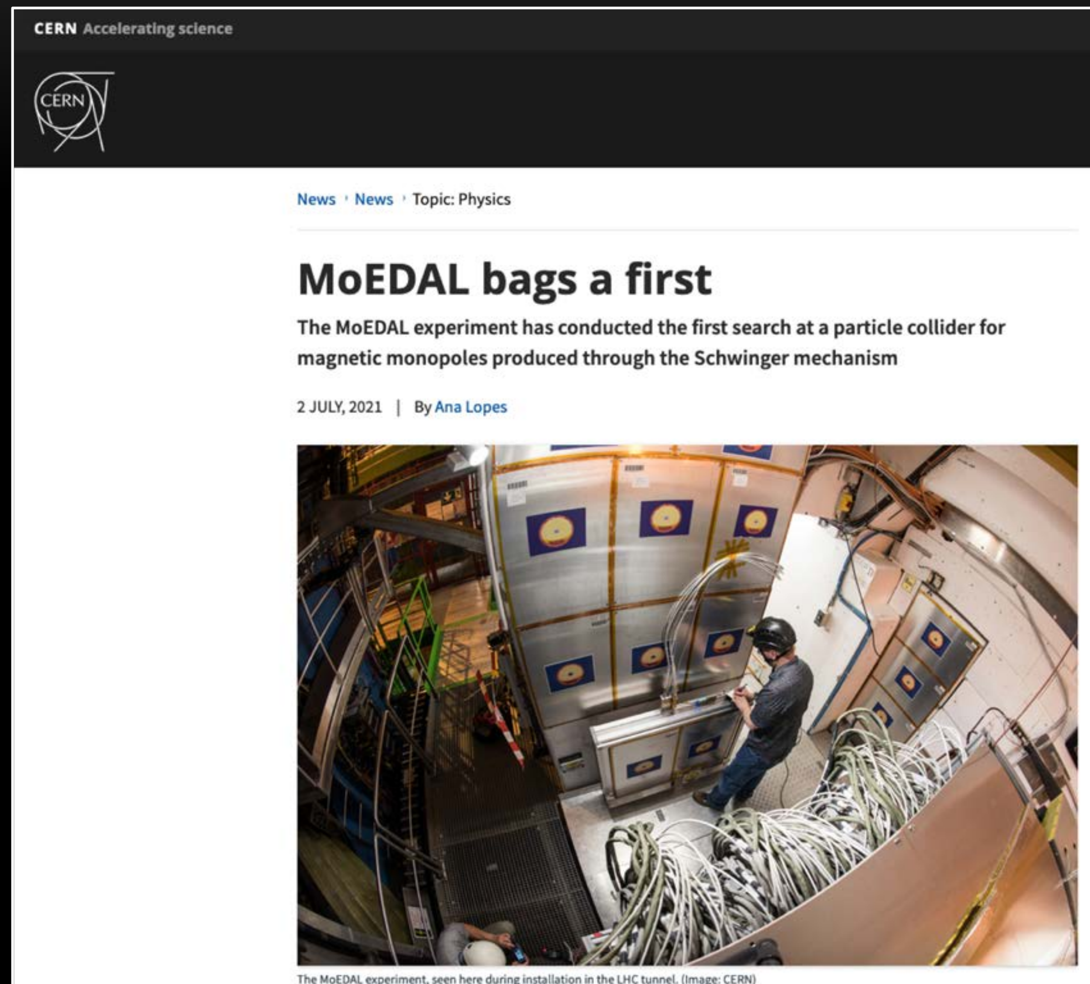
arXiv:2106.11933v1 [hep-ex] 22 Jun 2021

- *Here we look for monopole-pair production in the unprecedented magnetic fields produced in heavy-ion (Pb-Pb) collisions at the LHC*
  - *Schwinger mechanism originally described spontaneous creation of $e^{-} - e^{+}$ pairs in presence of an extremely strong electric field.*
  - *X-sec calculation does not suffer from non-perturbative couplings as in DY*
- *MMs with Dirac charges $1g_D \leq g \leq 3g$ and masses up to 75 GeV/c^2 were excluded providing the 1st mass limit for direct production of finite-size MMs*

The Search for the Dyon

MoEDAL

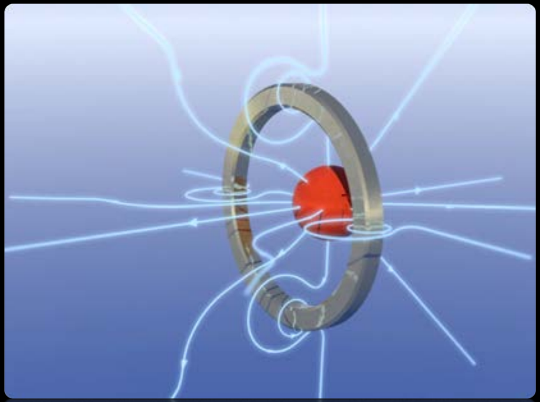
- *MoEDAL just completed the first direct search for Schwinger's Dyon – a particle with electric and magnetic charge*
- *We exclude dyons with:*
  - *A magnetic charge ranging up to $5g_D$ and an electric charge up to 200 times the fundamental electric charge for mass limits in the range 750–1910 GeV*
  - *And also monopoles with magnetic charge up to and including $5g_D$ with mass limits in the range 850 – 2040 GeV.*



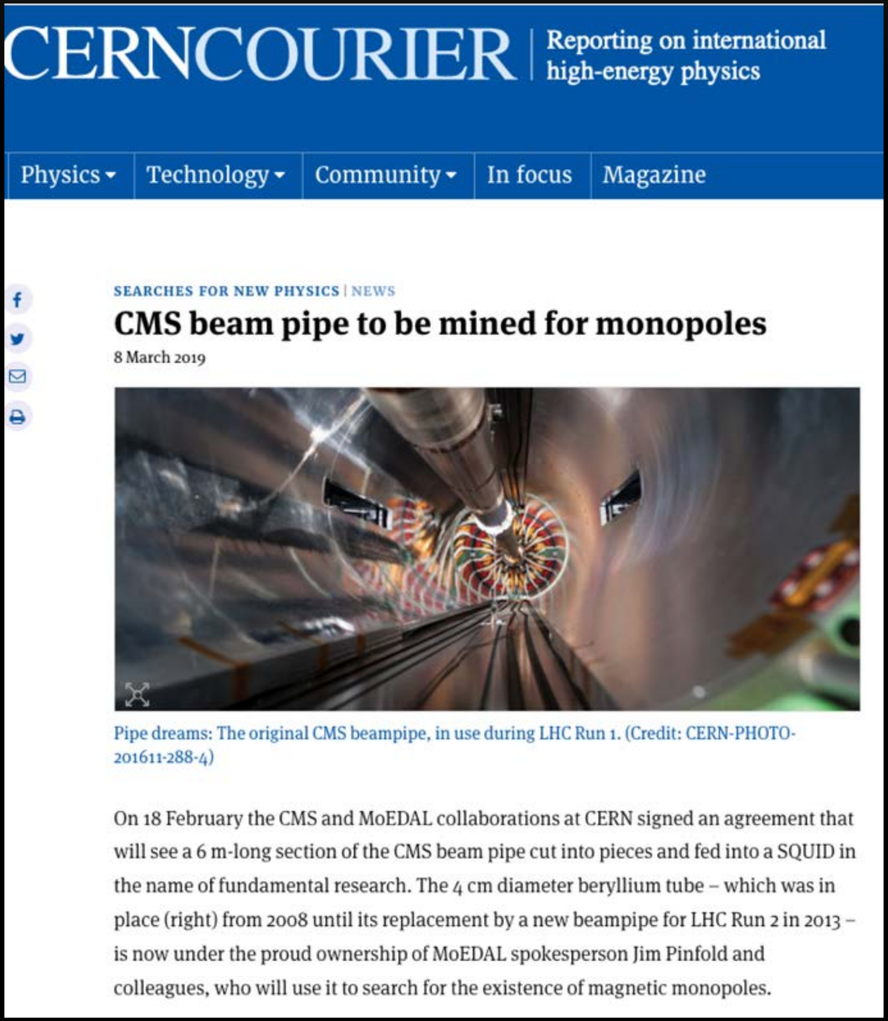
Phys. Rev. Lett. 126 (2021) 7, 071801

MoEDAL's Search for Monopoles Trapped in CMS Beampipe

- *MoEDAL searched for highly charge magnetic monopoles trapped in the Run1 CMS beampipe*
- *We used the MoEDAL's SQUID detector based at ETH Zurich*



- *No evidence was seen for trapped magnetic charge*
- *Publication in preparation*



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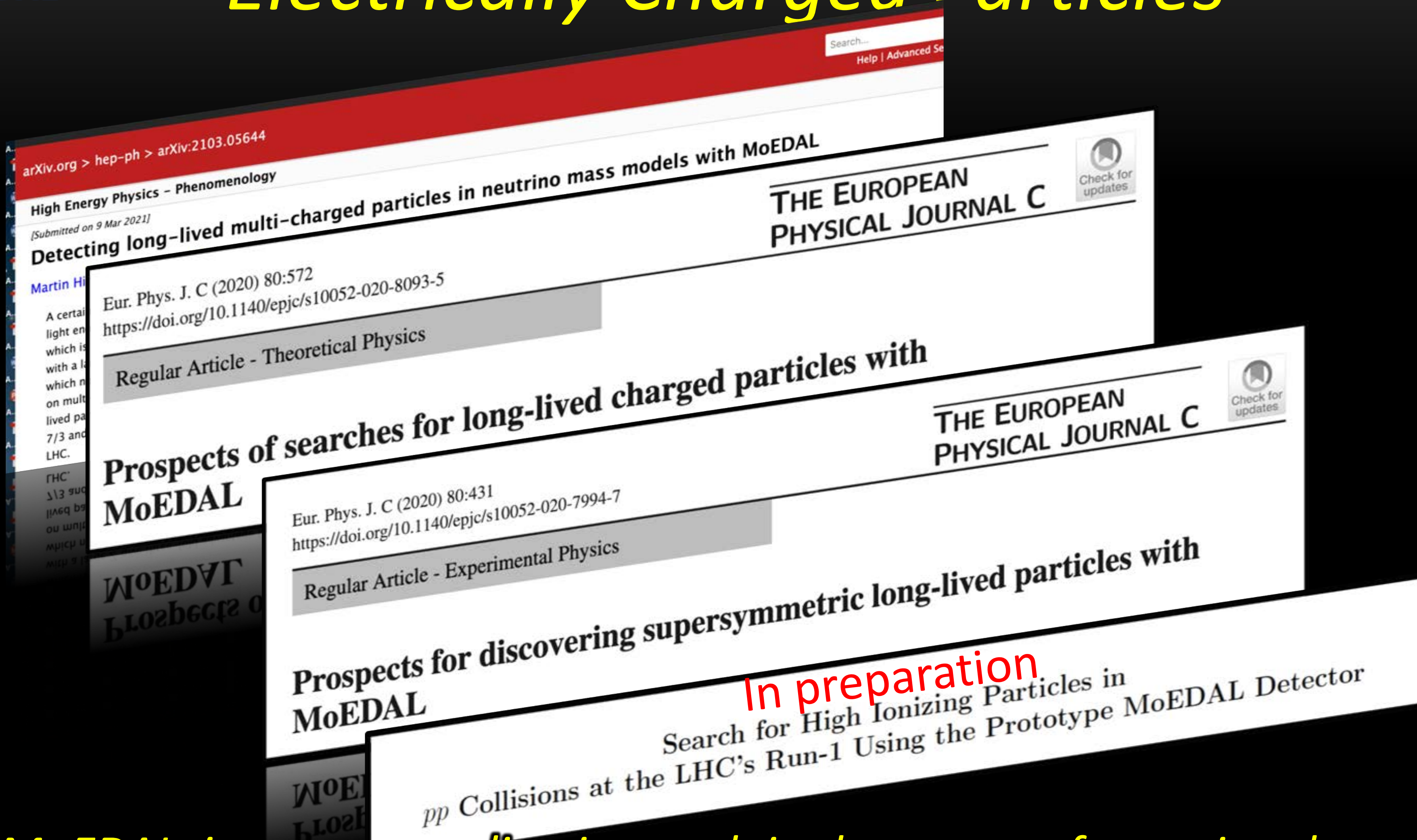
CMS beam pipe to be mined for monopoles

8 March 2019

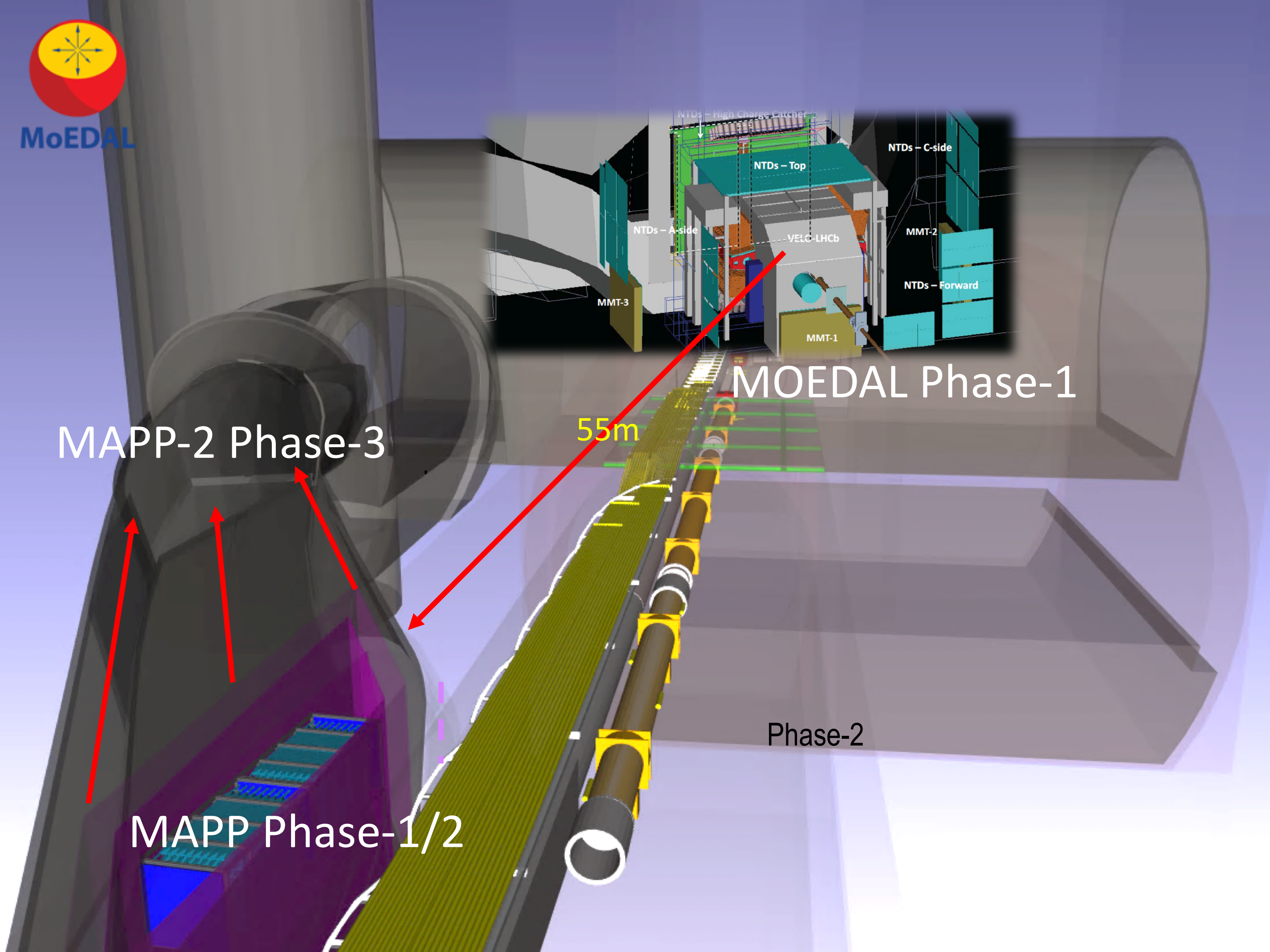
Pipe dreams: The original CMS beampipe, in use during LHC Run 1. (Credit: CERN-PHOTO-201611-288-4)

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.

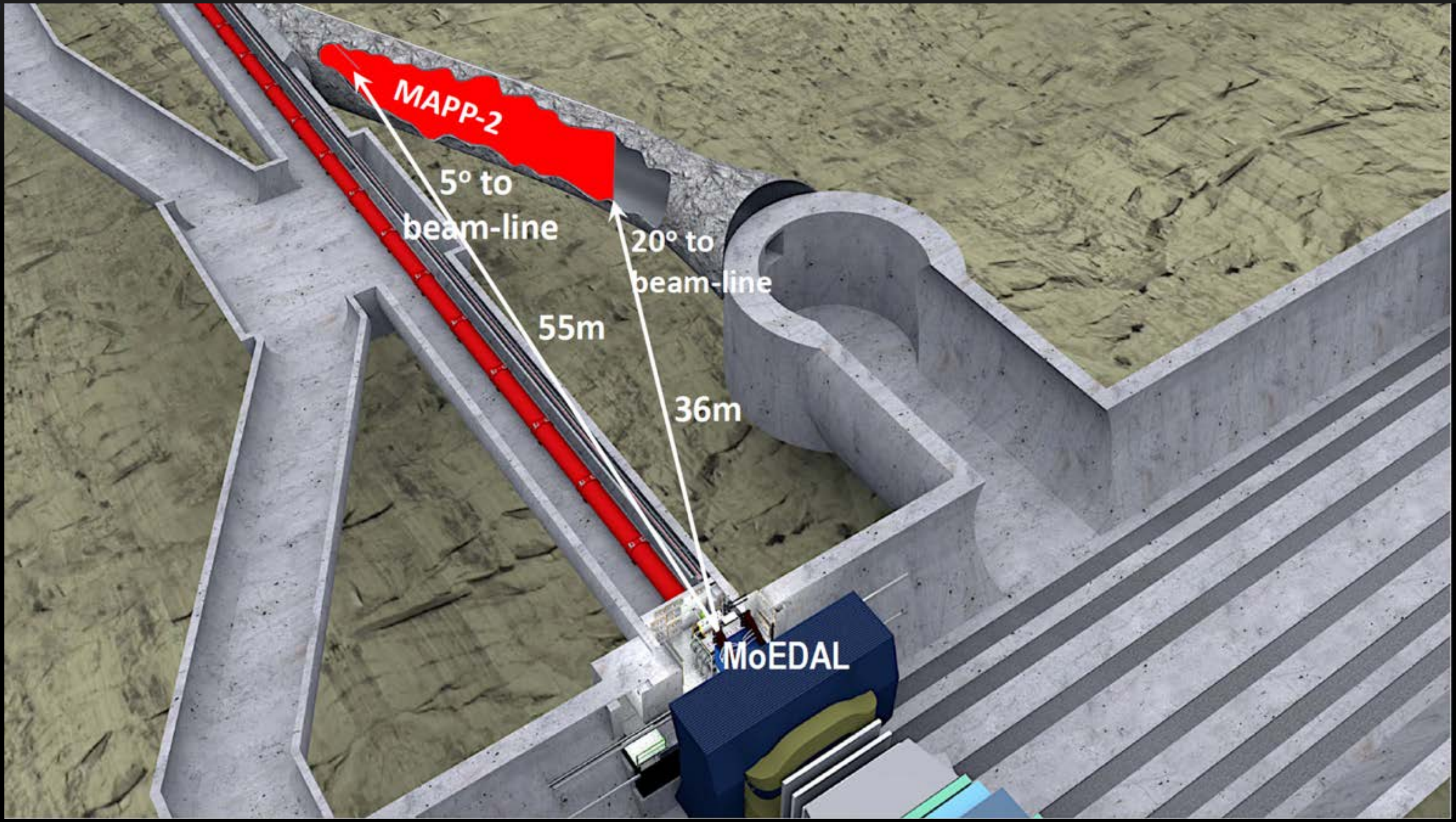
MoEDAL Searches for Massive Electrically Charged Particles



- *MoEDAL is now expanding its reach in the arena of massive slow moving and long-lived electrically charged particles*


MoEDAL
NTDs – High Charge Catcher
NTDs – Top
NTDs – C-side
NTDs – A-side
VELO-LHCb
MMT-2
NTDs – Forward
MMT-3
MMT-1
MOEDAL Phase-1
55m
MAPP-2 Phase-3
Phase-2
MAPP Phase-1/2

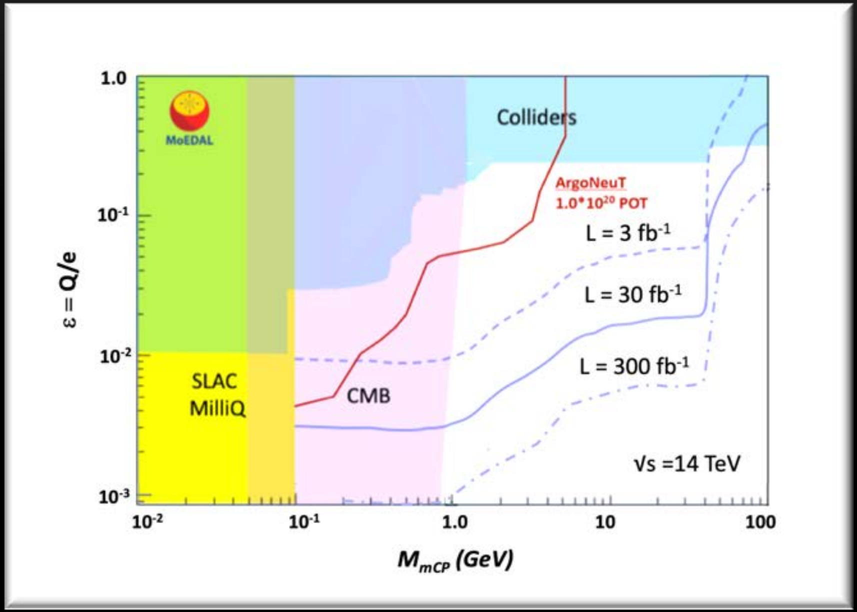
Phase-3: MAPP-2 for HL-LHC



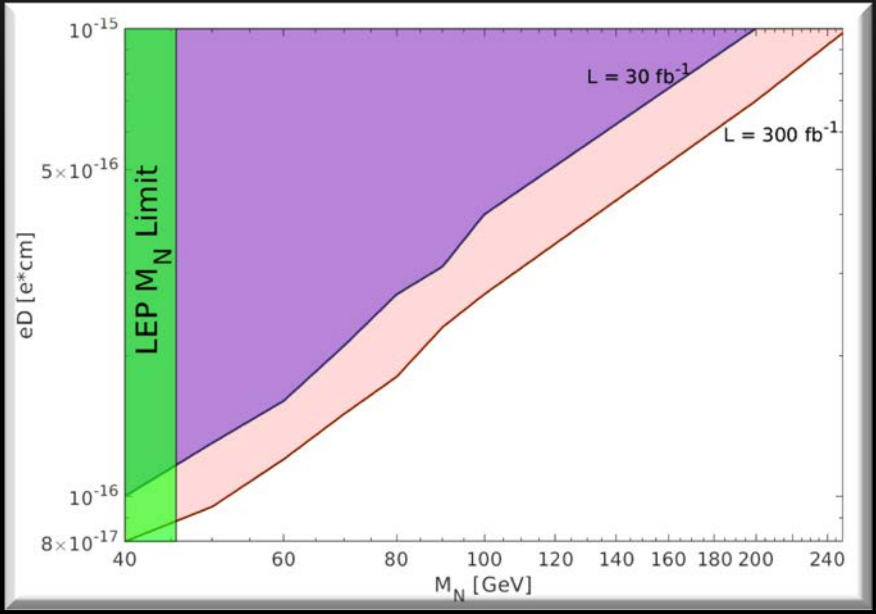
- *MAPP-2 is an extension of MAPP-1 down the UGC1 gallery.*
- *The MAPP-I technology would be used to provide a cost effective approach.*

MAPP-mQP – Feebly Interacting Particles

Outrigger NOT taken into account as yet



Dark photon decays to mQPs

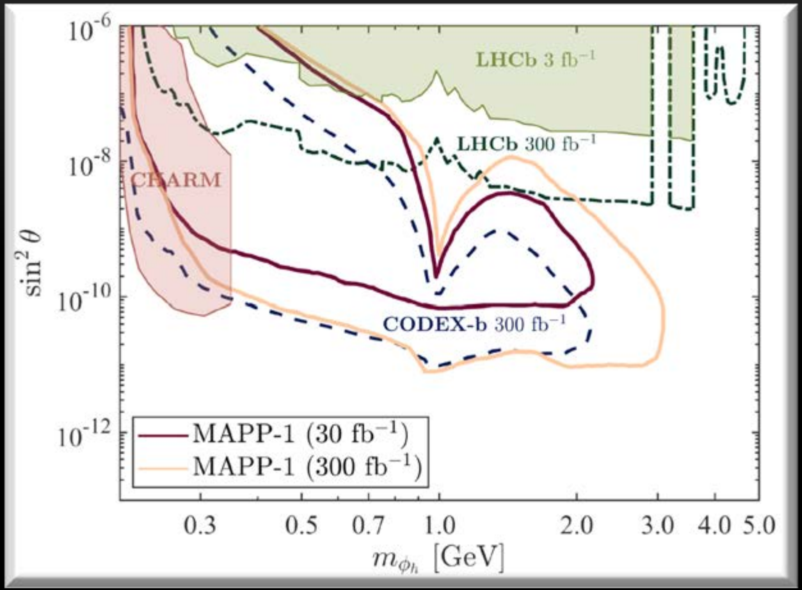


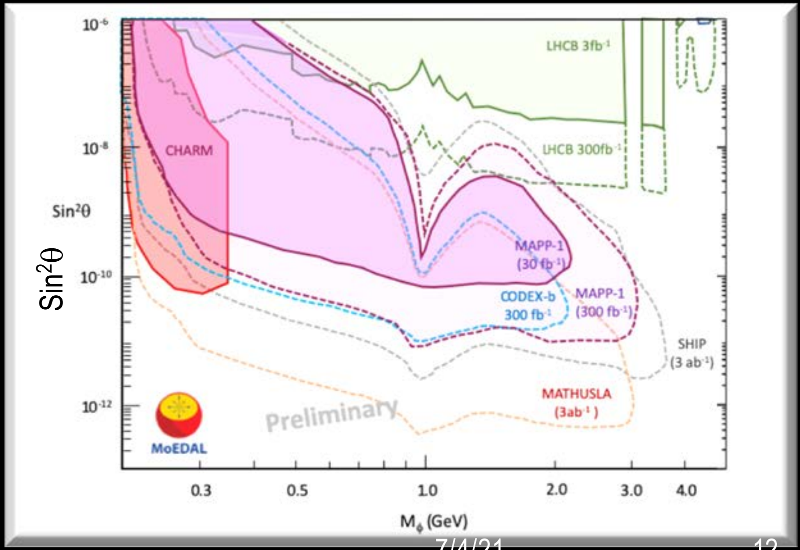
Heavy neutrino with large EDM

- *(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)*
- *(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*

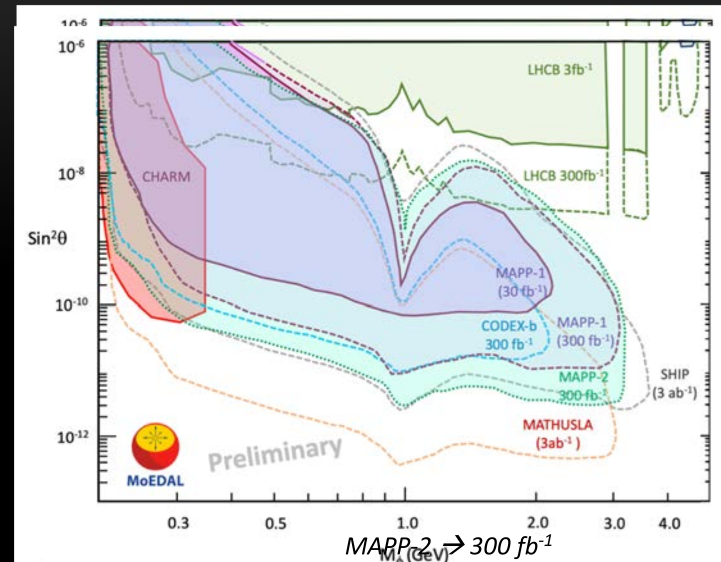




See Phys. Rev. D97 (1) (2018) 15023 for CODEX-b results.

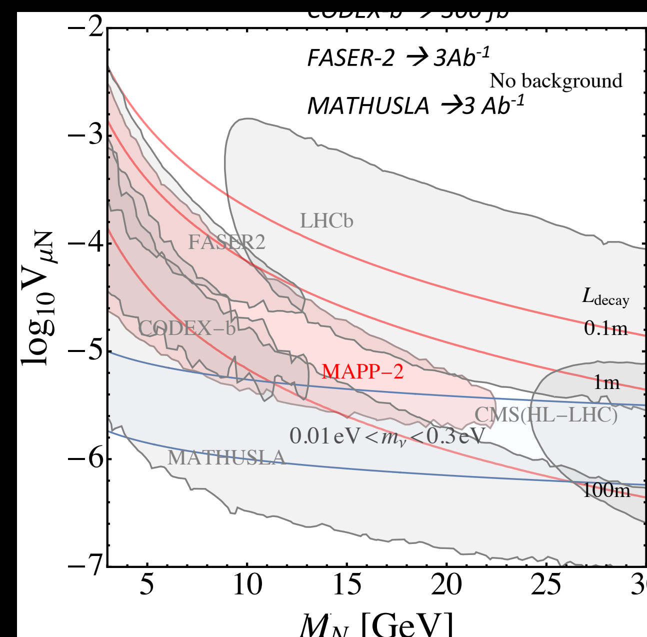
MAPP-2 (LLP): Example Physics Studies

- *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.*

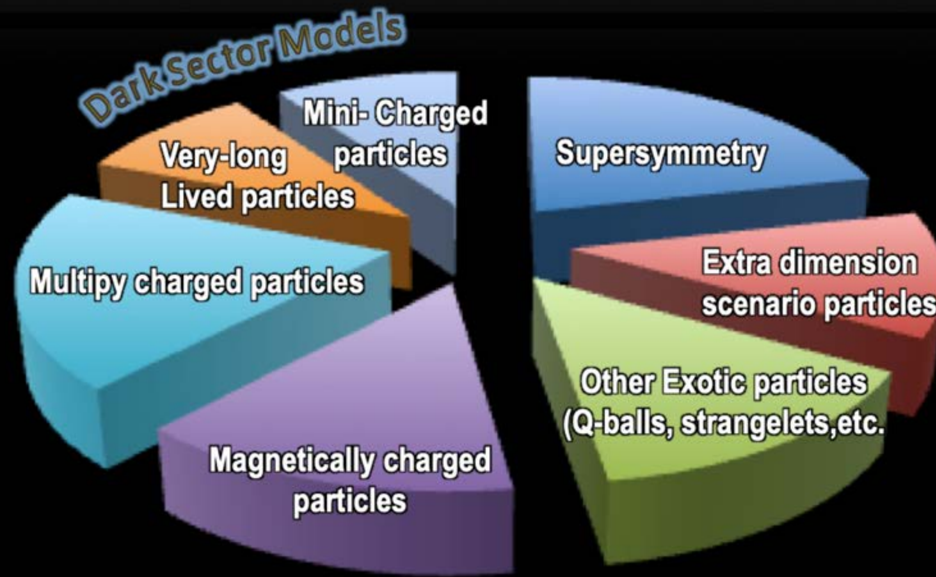


- *Pair production of right-handed neutrinos from the decay of an additional neutral* ***Z***^{0} *boson in the gauged* ***B-L*** *model – Phys. Rev. D100 (2019), 035005.*

MAPP-2 → 300 fb^{-1}
CODEX-b → 300 fb^{-1}
FASER-2 → 3Ab^{-1}
MATHUSLA → 3 Ab^{-1}



Conclusion Dark Matter Scenarios



- *With MAPP the MoEDAL Experiment will be sensitive to 3 clear avatars of new physics: HIPs, mQPs and LLPs.*
- *The MoEDAL- MAPP physics program covers numerous exotic dark matter scenarios in a complementary way to the four main LHC experiments*

Highly ionizing particles (HIPs)

Long-Lived Particles (LLPs)

Mini-charged particles (mQPs)

EXTRA SLIDES

MoEDAL-MAPP Expt Approval for Run-3

MoEDAL -MAPP Phase-1 Technical Design Report

Version 1.1

B. Acharya,[1,2] J. Alexandre,[1] P. Benes,[3] B. Bergmann,[3] J. Bernabéu,[4] A. Bevan,[5] H. Branzas,[6] P. Burian,[3] M. Campbell,[7] M. Campbell,[7] S Cecchini,[8] Y. M. Cho,[28], M. de Montigny,[9] A. de Roeck,[7] J. R. Ellis,[1,10] M. El Sawy,[7] M. Fairbairn,[1] D. Felea,[6] M. Frank,[11] J. Hays,[5] A. M. Hirt,[29] J. Janecek,[3] M. Kalliokoski,[18] D-W Kim,[13] A. Korzenev,[15] D. Lacarèrre,[7] S. C. Lee,[13] C. Leroy,[16] G. Levi,[8] A. Lionti,[15] A. S. Lobos, [9] J. Mamuzik,[4] A. Maulik,[8,9] A. Margiotta,[17] N. Mauri,[8] N. E. Mavromatos, [1] P. Mermod,[15] M. Mieskolainen,[18] L. Millward,[5] V. A. Mitsou,[4] R. Oravo,[18] I. Ostrovskiy,[19] P.-P. Ouimet,[9] J. Papavassilou,[4] B. Parker,[20] L. Patrizii,[8] G. E. Păvălaş,[6] J. L. Pinfold,[9,*] L. A. Popa,[6] V. Popa,[6] M. Pozzato,[8] S. Pospisil,[3] A. Rajantie,[21] R. Ruiz de Austi,[4] Z. Sahnoun,[8,22] M. Sakellariadou,[1] A. Santra,[4] S. Sarkar,[1] G. Semenoff,[23] A. Shaa,[24] G.Sirri,[8] K. Sliwa,[25] R. Soluk,[9] M. Spurio,[8] M. Staelens,[9] M. Suk,[4] M. Tenti,[27] V. Togo,[8] J. A. Tuszynski,[9], A. Upreti,[19] V. Vento,[3] O.Vives,[4] A.Wall,[19]

MoEDAL

MoEDAL Run-3 Technical Design Report

Version 1.1

March 2021

B. Acharya,[1,2] J. Alexandre,[1] P. Benes,[3] B. Bergmann,[3] J. Bernabéu,[4] A. Bevan,[5] H. Branzas,[6] P. Burian,[3] M. Campbell,[7] M. Campbell,[7] S Cecchini,[8] Y. M. Cho,[28], M. de Montigny,[9] A. de Roeck,[7] J. R. Ellis,[1,10] M. El Sawy,[7] M. Fairbairn,[1] D. Felea,[6] M. Frank,[11] J. Hays,[5] A. M. Hirt,[29] P.Q. Hung,[30] J. Janecek,[3] M. Kalliokoski,[18] D-W Kim,[13] A. Korzenev,[15] D. Lacarèrre,[7] S. C. Lee,[13] C. Leroy,[16] G. Levi,[8] A. Lionti,[15] A. S. Lobos, [9] J. Mamuzik,[4] A. Maulik,[8,9] A. Margiotta,[17] N. Mauri,[8] N. E. Mavromatos, [1] P. Mermod,[15] M. Mieskolainen,[18] L. Millward,[5] V. A. Mitsou,[4] G Moss,[31] R. Oravo,[18] I. Ostrovskiy,[19] P.-P. Ouimet,[9] J. Papavassilou,[4] B. Parker,[20] L. Patrizii,[8] G. E. Păvălaş,[6] J. L. Pinfold,[9,*] L. A. Popa,[6] V. Popa,[6] M. Pozzato,[8] S. Pospisil,[3] A. Rajantie,[21] R. Ruiz de Austi,[4] Z. Sahnoun,[8,22] M. Sakellariadou,[1] A. Santra,[4] S. Sarkar,[1] G. Semenoff,[23] A. Shaa,[24] G.Sirri,[8] K. Sliwa,[25] R. Soluk,[9] M. Spurio,[8] M. Staelens,[9] M. Suk,[3] M. Tenti,[27] V. Togo,[8] J. A. Tuszynski,[9], A. Upreti,[19] V. Vento,[3] O.Vives,[4] A.Wall,[19]

On track for full approval in 2021 to ***start data taking in 2022***

MAPP

MAPP Phase-1 Technical Design Report

Version 1.0

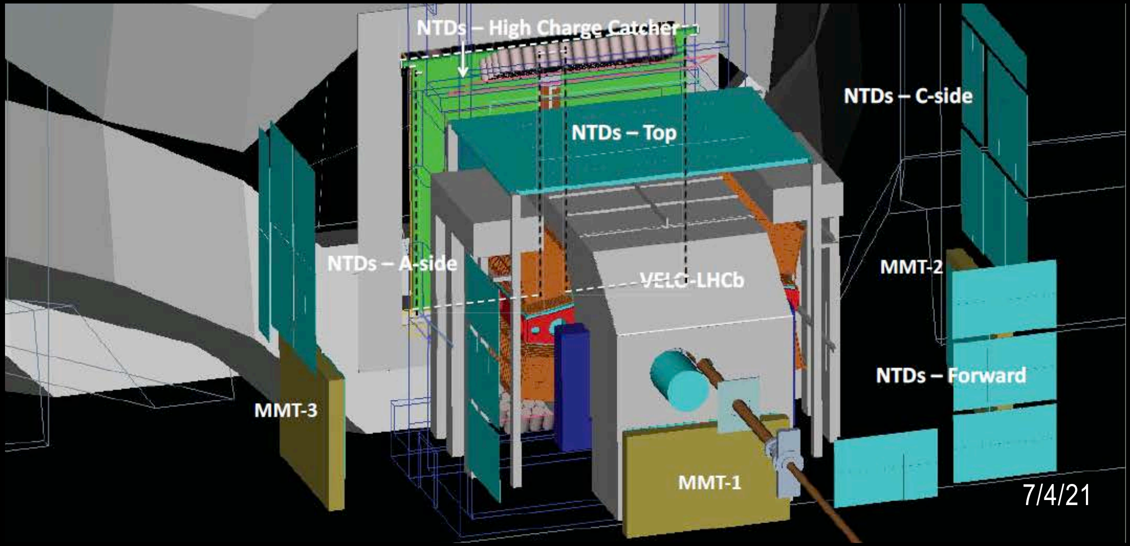
B. Acharya,[1,2] J. Alexandre,[1] P. Benes,[3] B. Bergmann,[3] J. Bernabéu,[4] A. Bevan,[5] H. Branzas,[6] P. Burian,[3] M. Campbell,[7] M. Campbell,[7] S Cecchini,[8] Y. M. Cho,[28], M. de Montigny,[9] A. de Roeck,[7] J. R. Ellis,[1,10] M. El Sawy,[7] M. Fairbairn,[1] D. Felea,[6] M. Frank,[11] J. Hays,[5] A. M. Hirt,[29] P.Q. Hung,[30] J. Janecek,[3] M. Kalliokoski,[18] D-W Kim,[13] A. Korzenev,[15] D. Lacarèrre,[7] S. C. Lee,[13] C. Leroy,[16] G. Levi,[8] A. Lionti,[15] A. S. Lobos, [9] J. Mamuzik,[4] A. Maulik,[8,9] A. Margiotta,[17] N. Mauri,[8] N. E. Mavromatos, [1] P. Mermod,[15] M. Mieskolainen,[18] L. Millward,[5] V. A. Mitsou,[4] R. Oravo,[18] I. Ostrovskiy,[19] P.-P. Ouimet,[9] J. Papavassilou,[4] B. Parker,[20] L. Patrizii,[8] G. E. Păvălaş,[6] J. L. Pinfold,[9,*] L. A. Popa,[6] V. Popa,[6] M. Pozzato,[8] S. Pospisil,[3] A. Rajantie,[21] R. Ruiz de Austi,[4] Z. Sahnoun,[8,22] M. Sakellariadou,[1] A. Santra,[4] S. Sarkar,[1] G. Semenoff,[23] A. Shaa,[24] G.Sirri,[8] K. Sliwa,[25] R. Soluk,[9] M. Spurio,[8] M. Staelens,[9] M. Suk,[4] M. Tenti,[27] V. Togo,[8] J. A. Tuszynski,[9], A. Upreti,[19] V. Vento,[3] O.Vives,[4] A.Wall,[19]

UGC1 gallery must be upgraded to house MAPP in 2021/22

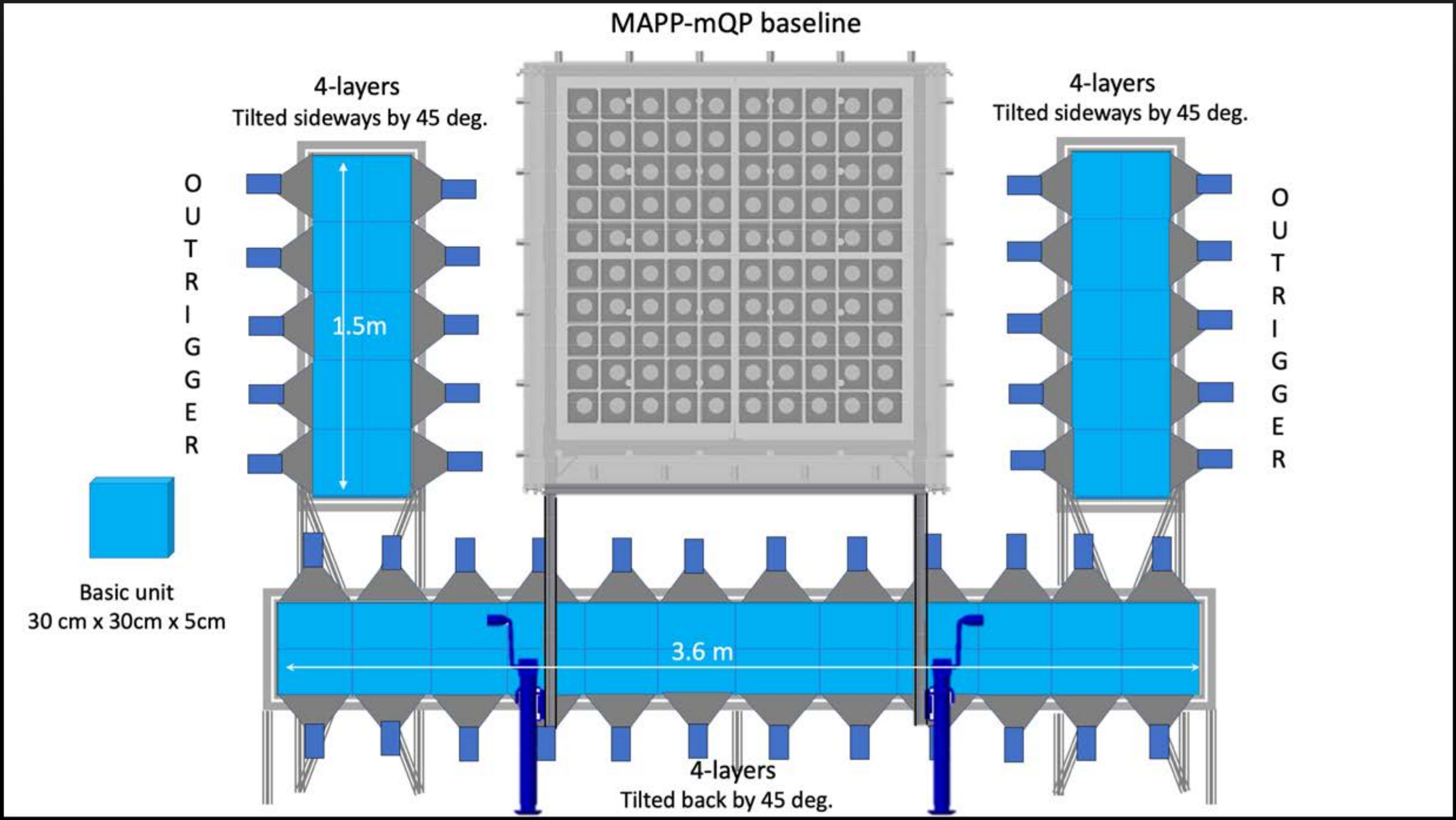
Envisage approval in 2022 and the ***start of data taking in 2023***

Phase 1a: MoEDAL for Run-3

- *Very similar to the Run-2 detector** deployed from 2015-2018*
  - *Running to benefit for higher E_{cm} and factor of 5 higher luminosity in Run-3*
- *There continue to be 4 independent subdetectors:*
  - *Nuclear Track Detectors (NTDs) consisting of stacks of plastic*
  - *Magnetic Monopole Trappers (MMTs) composed of aluminum bars*
  - *TimePix3 devices which are active silicon particle detectors*
  - *High Charge Catcher (HCC) a thin low mass NTD (if agreed by LHCb)*

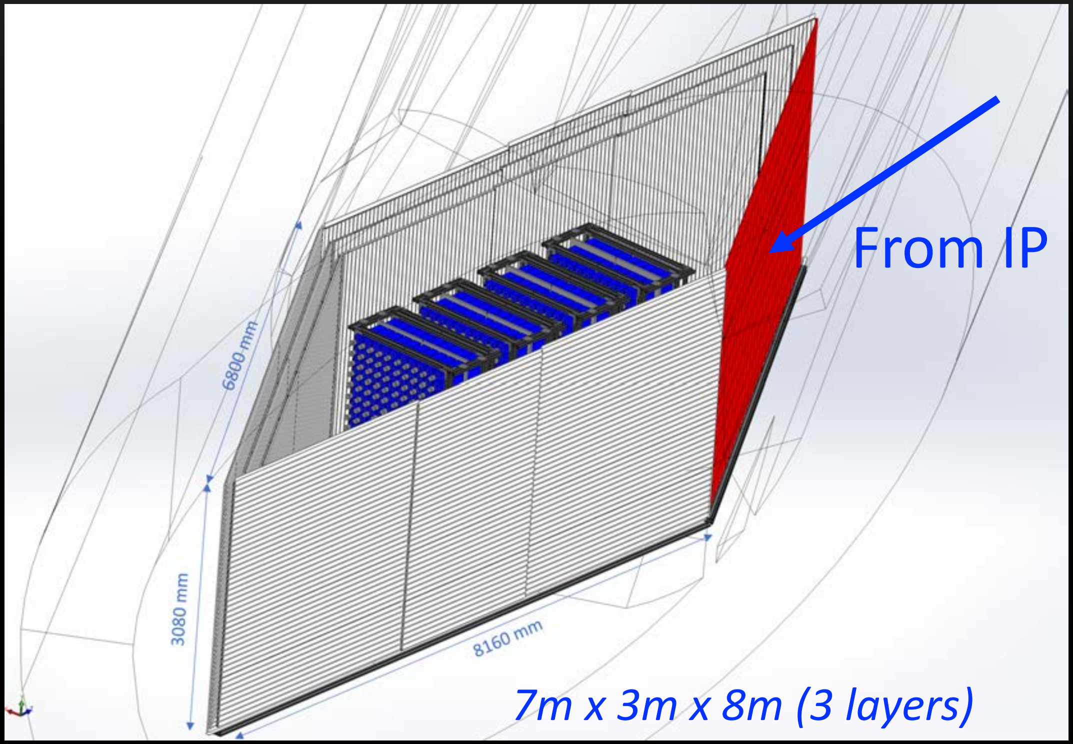


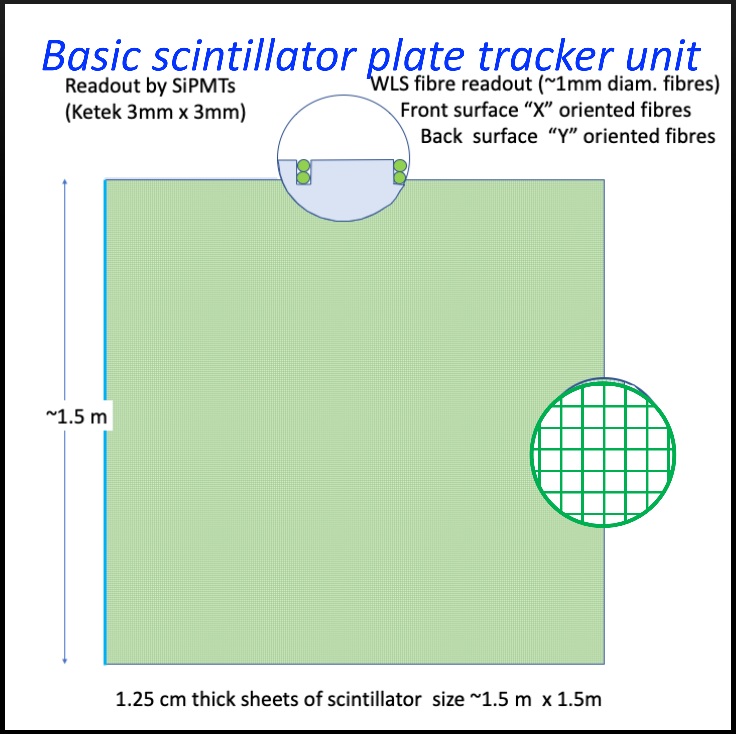
The MAPP-mQP Outrigger (in plan)



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

Phase-2: MAPP-1 (mQP+LLP) for Run-3





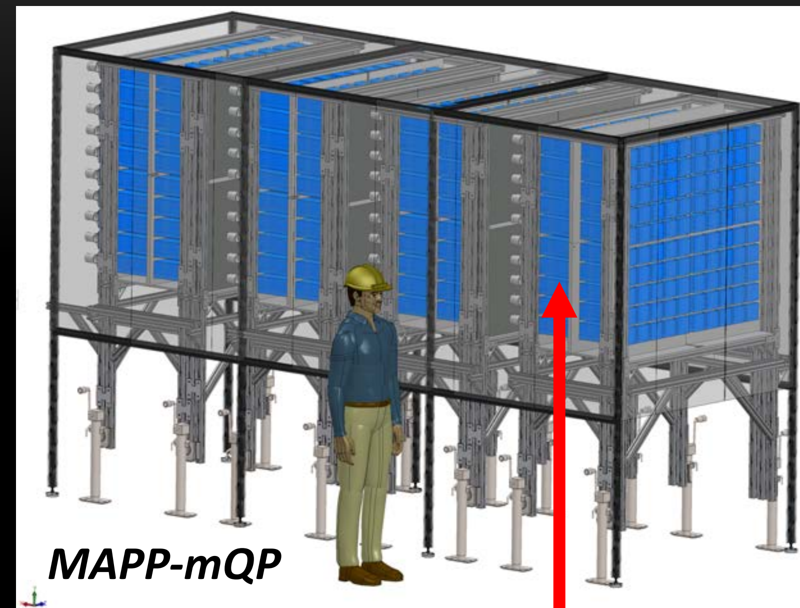
When Phase-2 is installed (2022/23) we will be able to search for

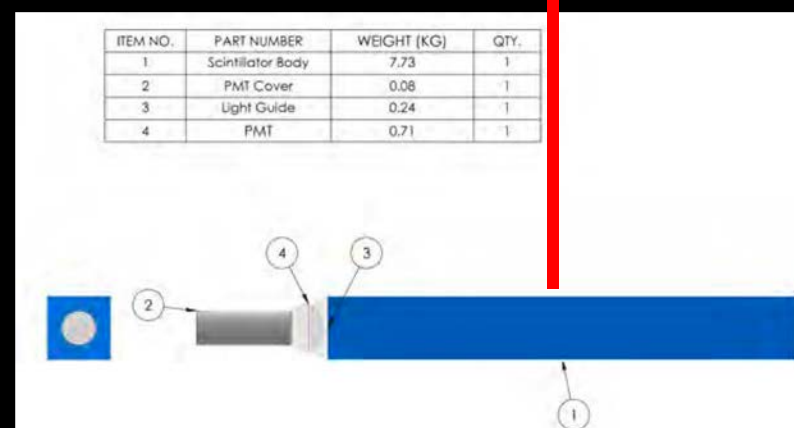
HIPs

mCPs

LLPs

Phase-1b MAPP-mQP for Run-3





ITEM NO.	PART NUMBER	WEIGHT (KG)	QTY.
1	Scintillator Body	7.73	1
2	PMT Cover	0.08	1
3	Light Guide	0.24	1
4	PMT	0.71	1

Scintillator bar basic unit

- *Weight 4-5 tonnes, size ~1.5 X 2.5 x 4.0m^3*
- *400 scintillator bars (10 x 10 x 75 cm^3) in 4 sections readout by 400 low noise PMTs*
- *Scintillator based doesn't require gas or HV (CW bases)*
- *Uses SW (FPGAs) trigger and is readout over the internet*
- *Operates in a standalone mode in the UGC1 cavern*