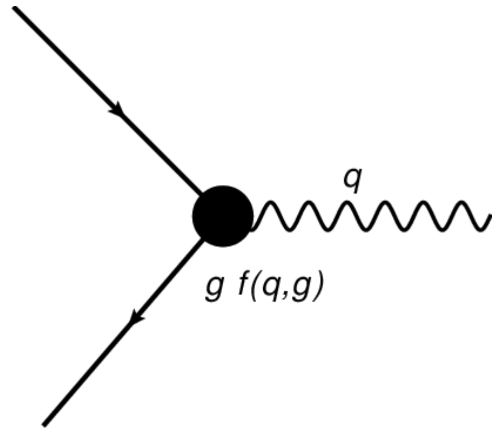
First search for magnetic monopoles through the Schwinger mechanism

Vasiliki A. Mitsou

for the MoEDAL Collaboration

Magnetic monopoles in a nutshell

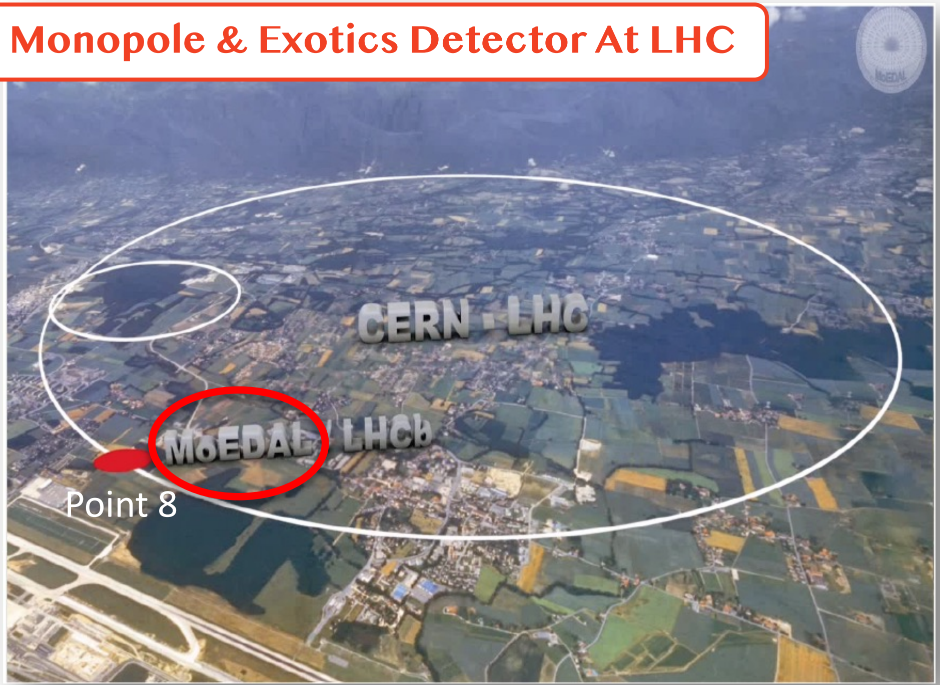


- Why? Because they symmetrise Maxwell's equations
  - electric ↔ magnetic charge duality
- Single magnetic charge (Dirac charge): $g_D = 68.5e$
  - higher charges are integer multiples of Dirac charge: $g = ng_D$, $n = 1, 2, \ldots$
  - if carries electric charge as well, is called **Dyon**
- Photon-monopole coupling constant
  - large: $g/\hbar c \sim 20$ (precise value depends on units)
- Dirac monopole is a *point-like* particle; GUT monopoles are *extended* objects
  - production of composite monopoles exponentially suppressed by $e^{-4/\alpha}$
- Monopole spin is not determined by theory → free parameter
- Monopole mass not theoretically fixed → free parameter

For a review on monopole theory and searches:
Mavromatos & VAM, Int.J.Mod.Phys.A 35 (2020) 2030012

MoEDAL Collaboration

Monopole & Exotics Detector At LHC



~70 physicists from 21 institutions

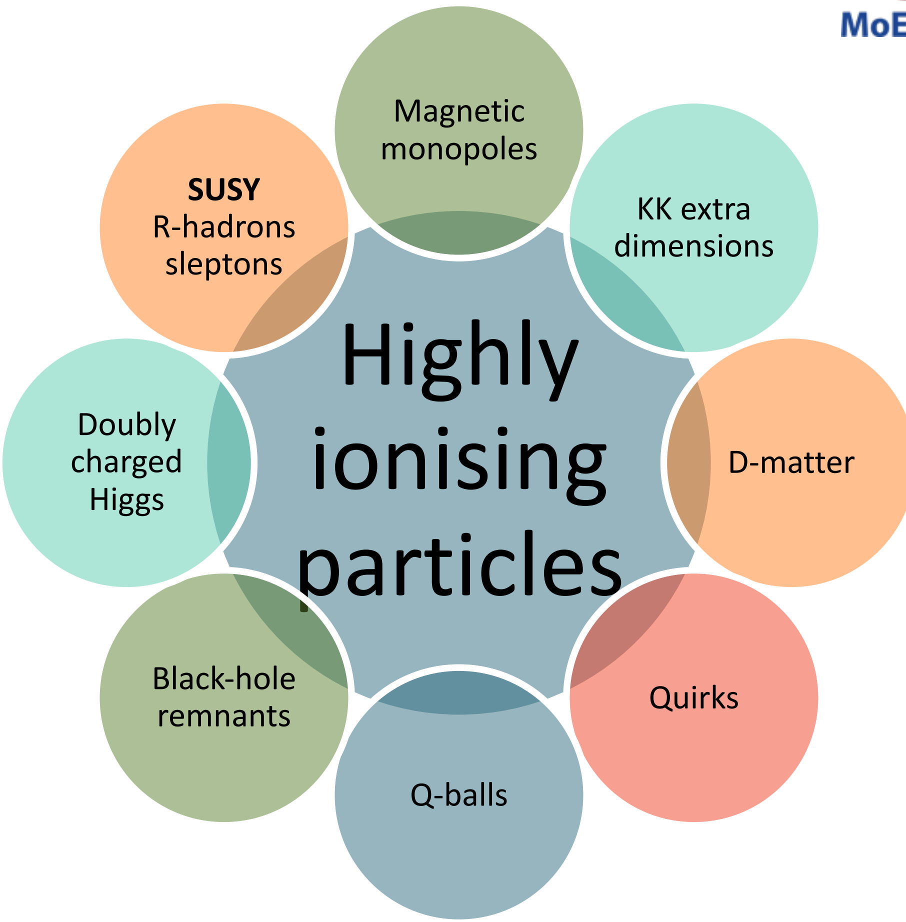
UNIVERSITY OF ALABAMA
UNIVERSITY OF ALBERTA
INFN & UNIVERSITY OF BOLOGNA
UNIVERSITY OF BRITISH COLUMBIA
UNIVERSITÉ DE GENÈVE
UNIVERSITY OF HELSINKI
UNIVERSITY OF MONTREAL
CERN
CONCORDIA UNIVERSITY
IMPERIAL COLLEGE LONDON
KING'S COLLEGE LONDON
NATIONAL INSTITUTE OF TECHNOLOGY, KURUKSETRA
TECHNICAL UNIVERSITY IN PRAGUE
QUEEN MARY UNIVERSITY OF LONDON
INSTITUTE OF SPACE SCIENCE, ROMANIA
INSTITUTE FOR RESEARCH IN SCHOOLS, CANTERBURY
CENTER FOR QUANTUM SPACETIME, SEOUL
TUFT'S UNIVERSITY
VAASA UNIVERSITIES
IFIC VALENCIA
UNIVERSITY OF VIRGINIA

MoEDAL

LHC's first dedicated *search* experiment
(approved 2010)

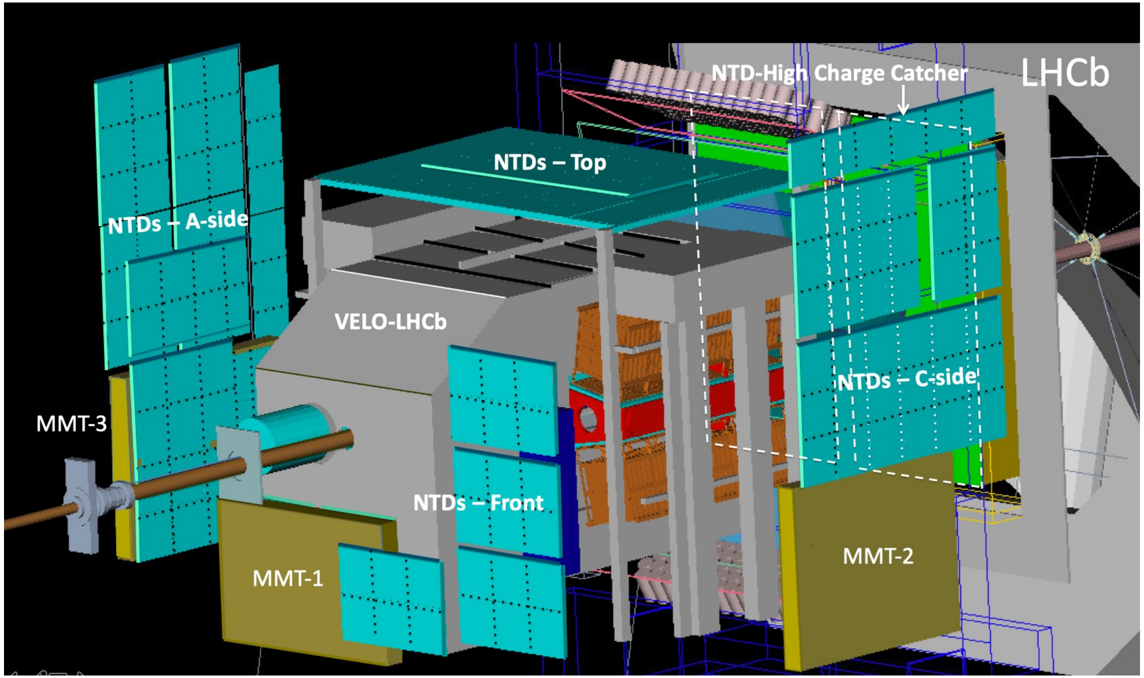
MoEDAL physics goals

- MoEDAL has pioneered the search for **long-lived particles**
  - complementary to ATLAS, CMS and LHCb
- MoEDAL is optimised for the detection of (meta)stable **highly ionising** particles
  - → high charges (**high z**)
    ⇒ electric and/or magnetic charges
  - → slow moving (**low β**)
    ⇒ massive



MoEDAL physics program
[Int. J. Mod. Phys. A29 (2014) 1430050]

Baseline MoEDAL detector



- Mostly **passive detectors**; no trigger; no readout
- Permanent physical record of new physics
- No Standard Model physics backgrounds

THREE DETECTOR TECHNOLOGIES

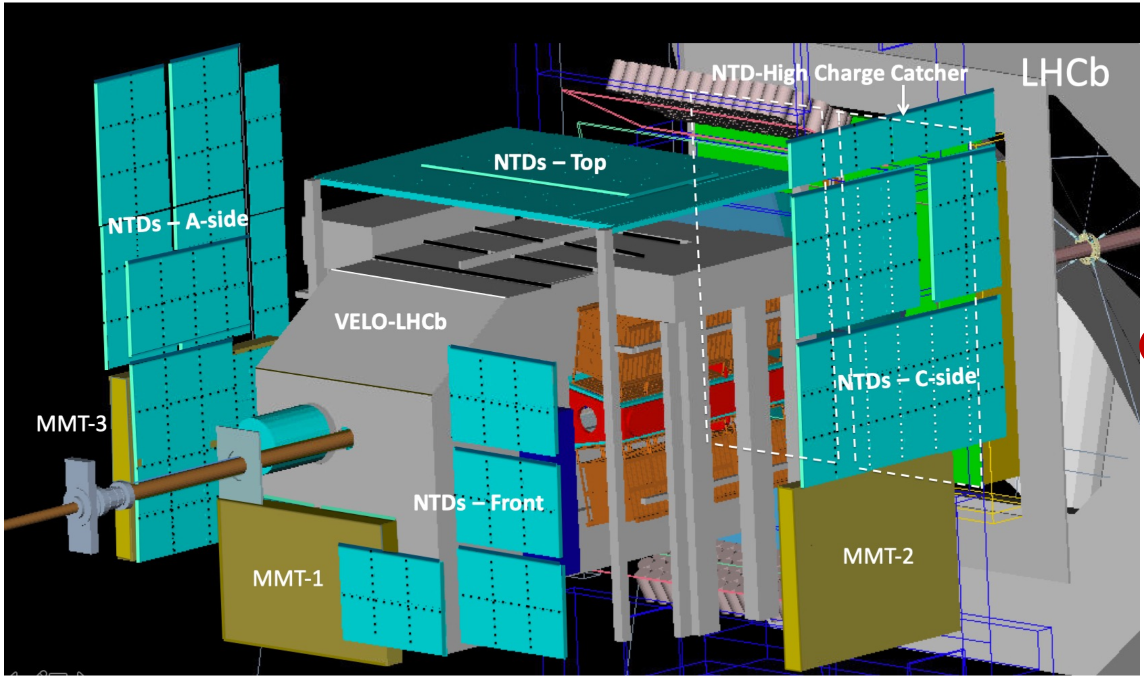
① Nuclear Track Detectors

② Monopole Trapping detector (**MMT**) – aluminum bars

③ **TimePix** radiation background monitor

Baseline MoEDAL detector

MoEDAL



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THREE DETECTOR TECHNOLOGIES

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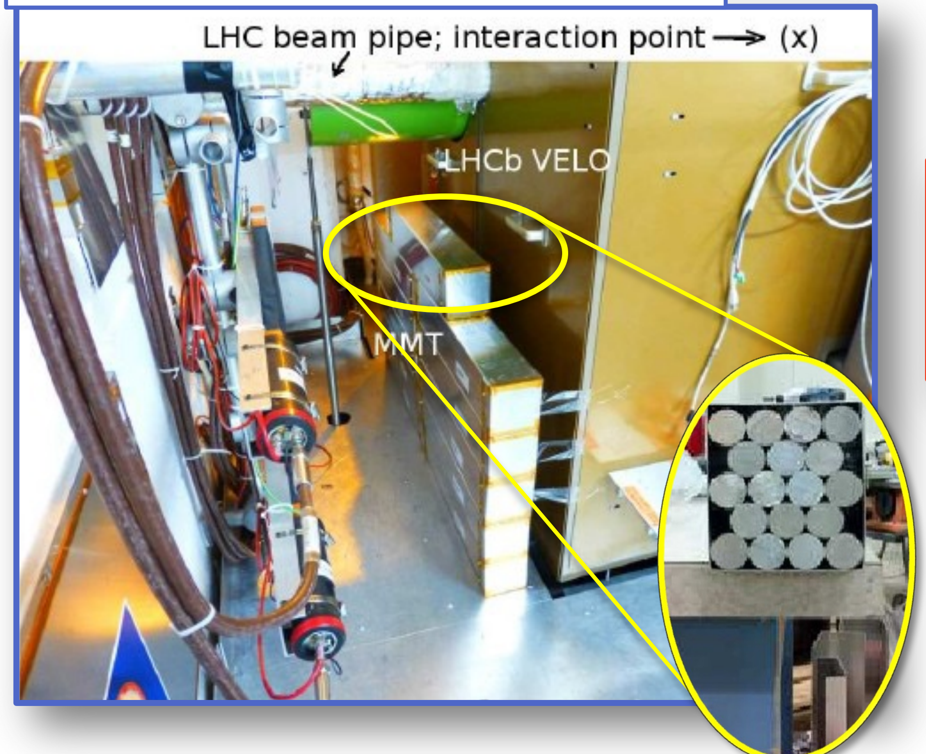
② Monopole Trapping detector (**MMT**) – aluminum bars

③ **TimePix** radiation background monitor

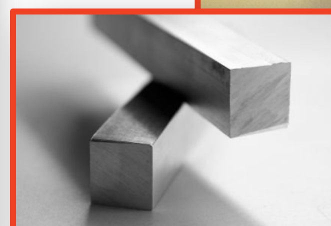
MMTs deployment

MoEDAL

2012
11 boxes each containing 18 Al rods of 60 cm length and 2.54 cm diameter (**160 kg**)

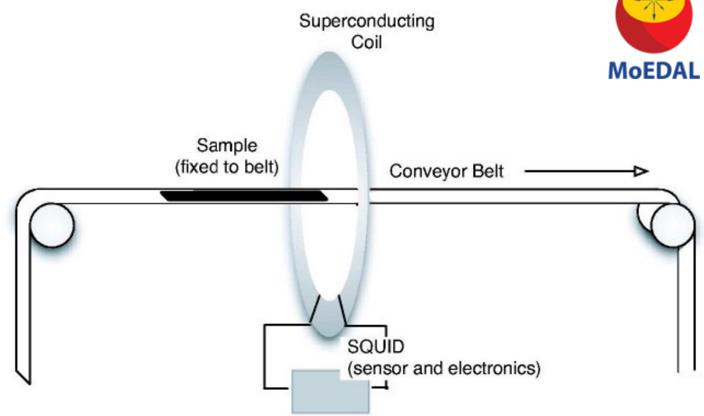


2015-2018
- Installed in forward region under beam pipe & in **sides A & C**
- Approximately **800 kg** of aluminium
- Total 2400 aluminum bars

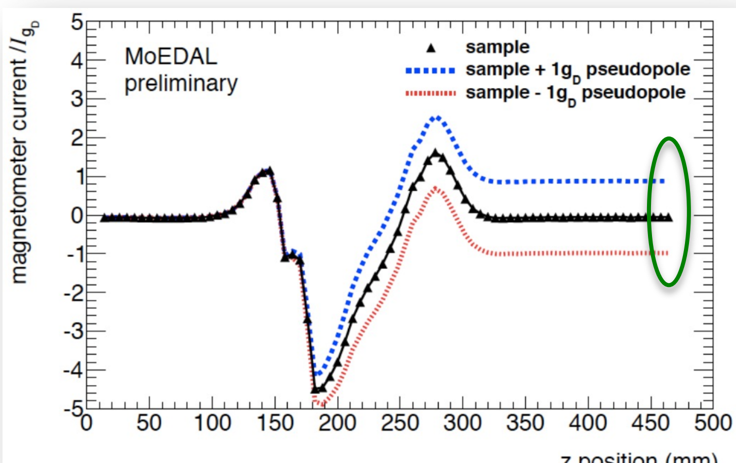


MMT scanning

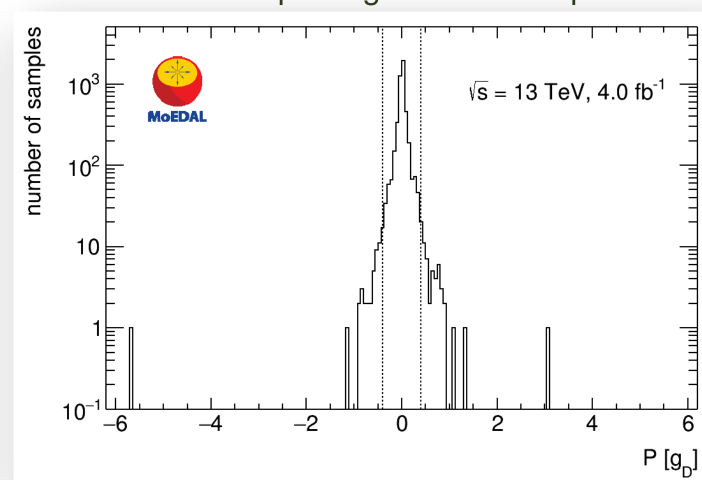
- Monopoles can bind to nuclei and get trapped
- MMTs analysed in superconducting quantum interference device (SQUID) at ETH Zurich
- **Persistent current:** difference between resulting current after and before
- Outliers are **scanned several times** further



SQUID analysis – Persistent current after first two passages for all samples



Calibration: Typical sample & pseudo-monopole curves



MoEDAL, PRL 123 (2019) 021802

Monopole results

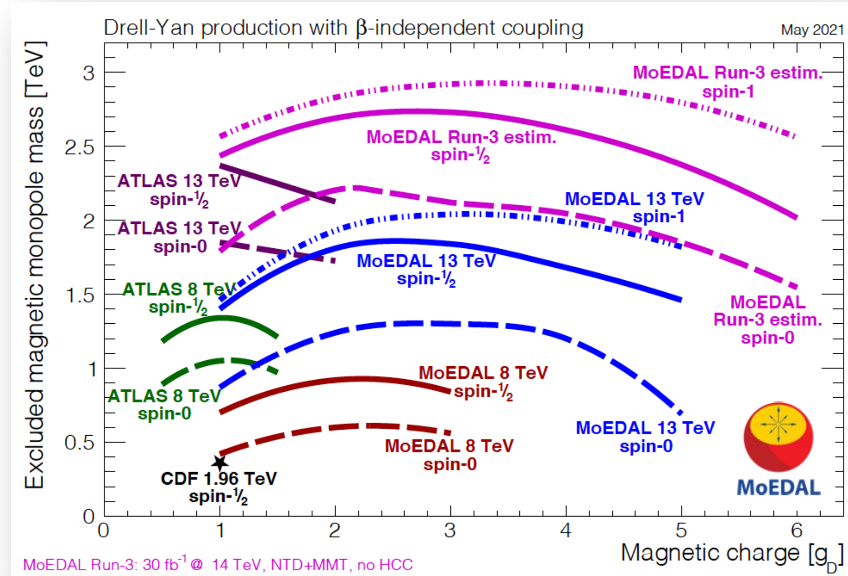
MoEDAL

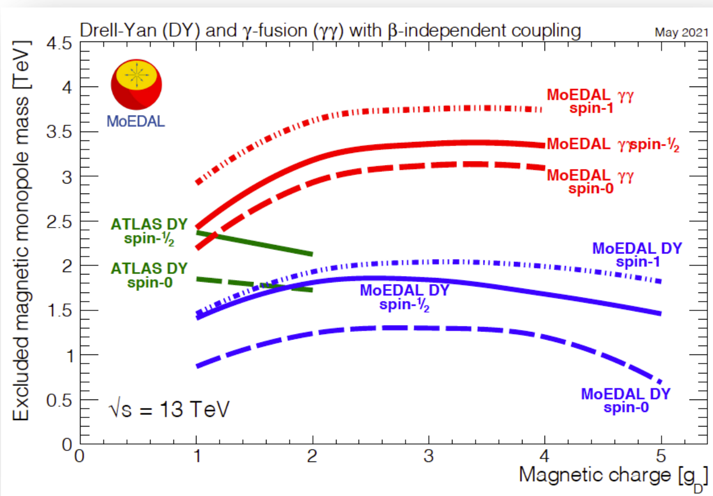
- 2016 – **First results @ 8 TeV** ☛ *CERN Press Release*
  JHEP 1608 (2016) 067 [arXiv:1604.06645]
- 2017 – **First results @ 13 TeV** Phys.Rev.Lett. 118 (2017) 061801 [arXiv:1611.06817]
- 2018 – **MMT results** Phys.Lett.B 782 (2018) 510–516 [arXiv:1712.09849]
  - **spin-1 monopoles ← FIRST in colliders**
  - β-dependent coupling
- 2019 – **MMT results** Phys.Rev.Lett. 123 (2019) 021802 [arXiv:1903.08491]
  - **photon fusion** interpretation **← FIRST at LHC**
- 2020 – **MMT search for Dyons ← FIRST in colliders**
  Phys.Rev.Lett. 126 (2021) 071801 [arXiv:2002.00861]

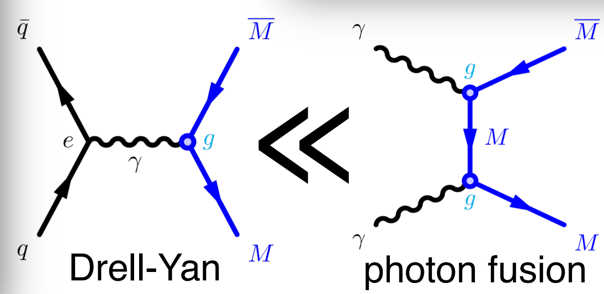
- 2021 – **Schwinger thermal production ← FIRST**
  Nature 602 (2022) 7895, 63 [arXiv:2106.11933]
- 2021 – **NTD & MMT combination ← FIRST NTD analysis** arXiv:2112.05806
  - First limits in highly electrically charged objects

Magnetic monopole limits

- Novelties in monopole models: β-dependent coupling, spin-1 monopoles, γγ fusion
- MoEDAL set world-best collider limits for **|g| > 2 g_D**
- Overall, MoEDAL achieved extended reach by **combining Drell-Yan and γ-fusion mechanisms**







MoEDAL, JHEP 1608 (2016) 067, PRL 118 (2017) 061801, PLB 782 (2018) 510, PRL 123 (2019) 021802, PRL 126 (2021) 071801

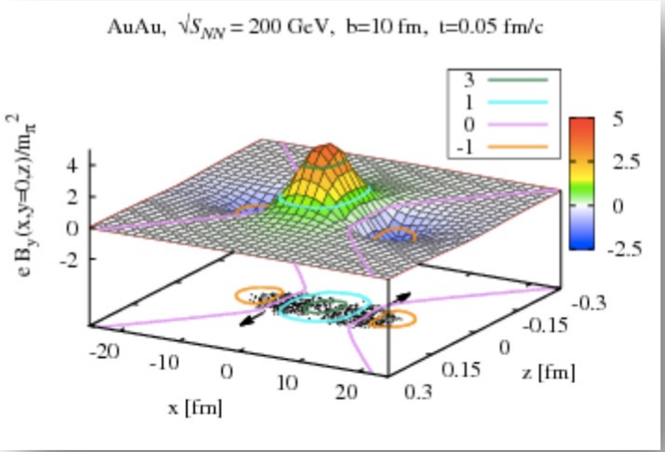
See also, Baines, Mavromatos, VAM, Pinfold, Santra, Eur.Phys.J.C 78 (2018) 966

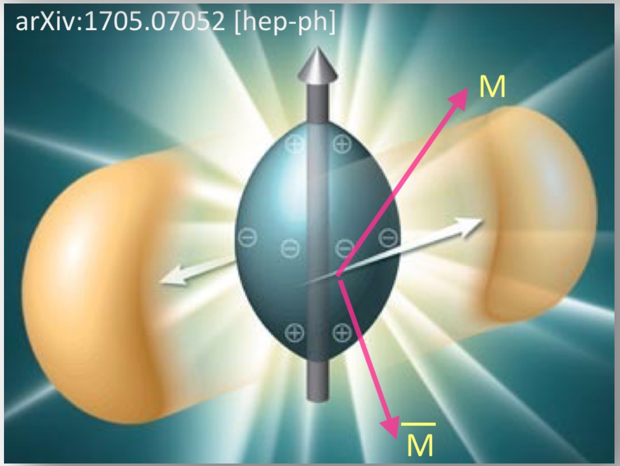
Mass limits extracted with Feynman-*like* diagrams that **ignore non-perturbativity of large monopole-photon coupling**

Monopoles via thermal Schwinger mechanism

- Schwinger mechanism originally described spontaneous creation of e^+e^- pairs in presence of an extremely strong **electric field**
- Same mechanism can work for **monopole pairs** in the presence of strong ***magnetic* fields**
- Advantages over DY & γγ-fusion production
  - cross-section calculation using semiclassical techniques
    ⇒ does not suffer from non-perturbative nature of coupling
  - no exponential suppression $e^{-4/\alpha}$ for finite-sized monopoles

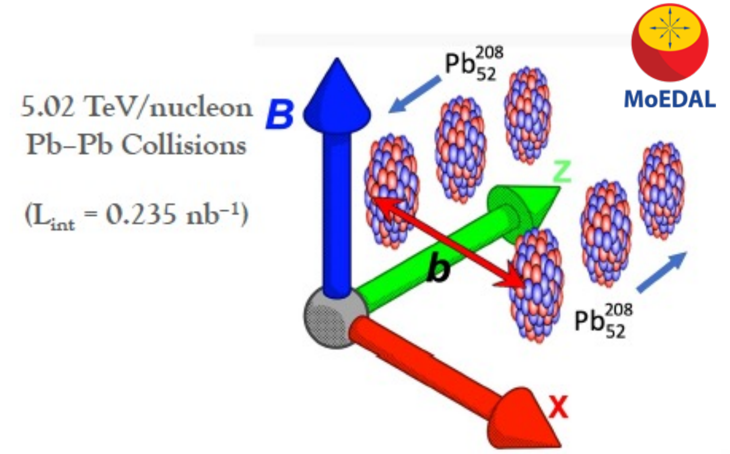
Gould, Ho, Rajantie, PRD 100, 015041 (2019), PRD 104, 015033 (2021)
Ho & Rajantie, PRD 101, 055003 (2020), PRD 103 (2021) 11, 115033

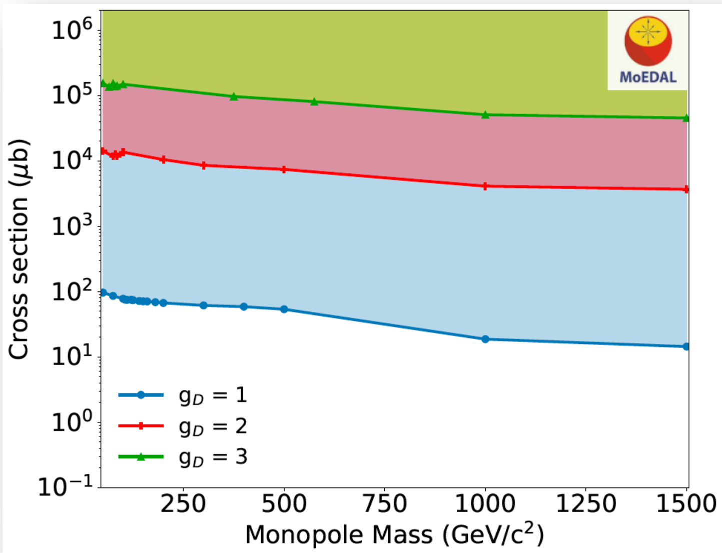




Schwinger production results

- Exposure of MMTs in 0.235 nb^{-1} of Pb-Pb heavy-ion collisions at 5.02 TeV per nucleon
  - peak magnetic field strength $B \approx 10^{16}$ T
  - four orders of magnitude greater than strongest known astrophysical magnetic fields: the surfaces of Magnetars
- MMT scanning in SQUID showed no monopole in exposed samples
- Kinematics of produced monopoles assumes *free-particle approximation* (see next slide)
- Cross-section limits set for magnetic charge of up to **3 g_D**

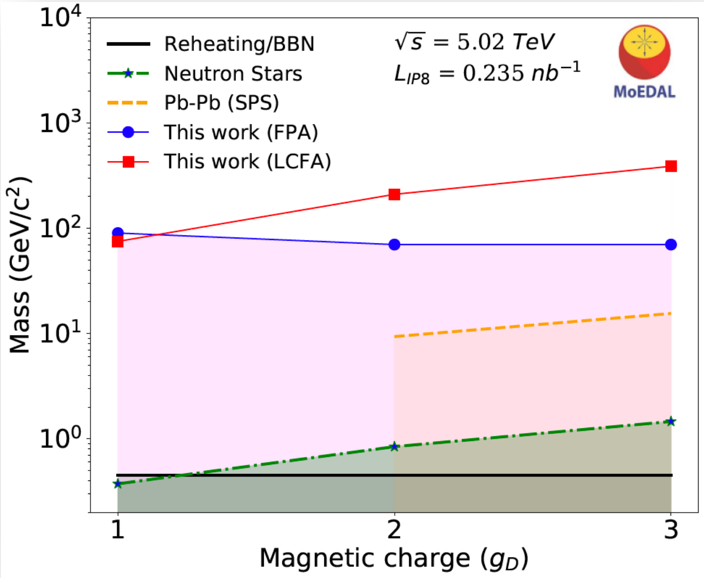




MoEDAL, Nature 602 (2022) 7895, 63-67

Schwinger production results – mass limits

- Two approximations to the calculation of the overall MM production cross-section
  - **FPA** (free-particle approximation): spacetime dependence of EM field of the heavy ions is treated exactly, but MM self-interactions are neglected
    - MM self-interactions enhance expected cross sections
  - **LCFA** (locally constant field approximation): spacetime dependence of EM field is neglected, but MM self-interactions are treated exactly
    - spacetime dependence of EM field enhances expected cross sections
- Complementary approaches with uncorrelated uncertainties leading to conservative results



Monopole mass reach appears to be 20–30 times lower than current bounds from ATLAS and MoEDAL, however, this cross-section calculation is theoretically sound

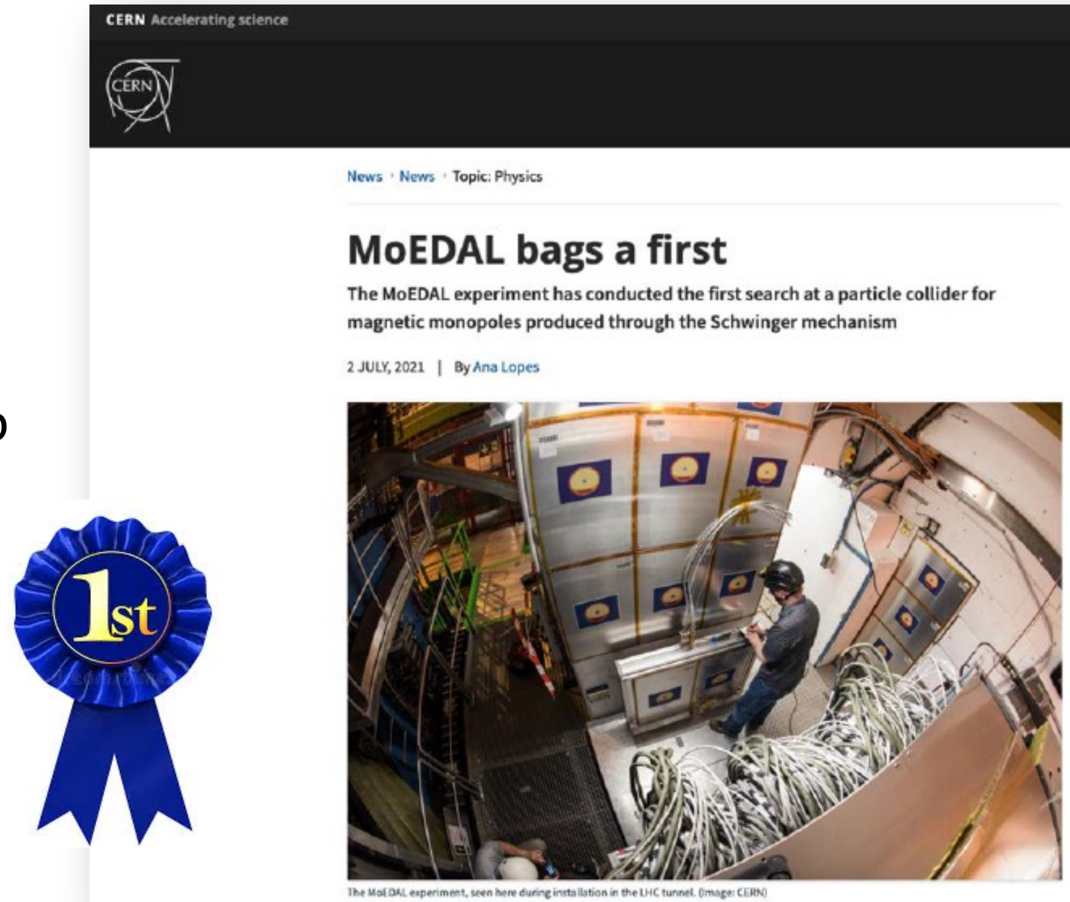
Limits on monopoles of 1 – 3 g_D and masses up to 75 GeV

MoEDAL, Nature 602 (2022) 7895, 63-67

Schwinger production results

MoEDAL

- <u>First</u> limits from collider experiment based on **non-perturbative** calculation of monopole production cross section
- <u>First</u> direct search sensitive to **non point-like** monopoles



Schwinger production: Nature 602 (2022) 7895, 63

Article | Published: 02 February 2022

Search for magnetic monopoles produced via the Schwinger mechanism

B. Acharya, J. Alexandre, … O. Vives + Show authors

Nature **602**, 63–67 (2022) | Cite this article

nature

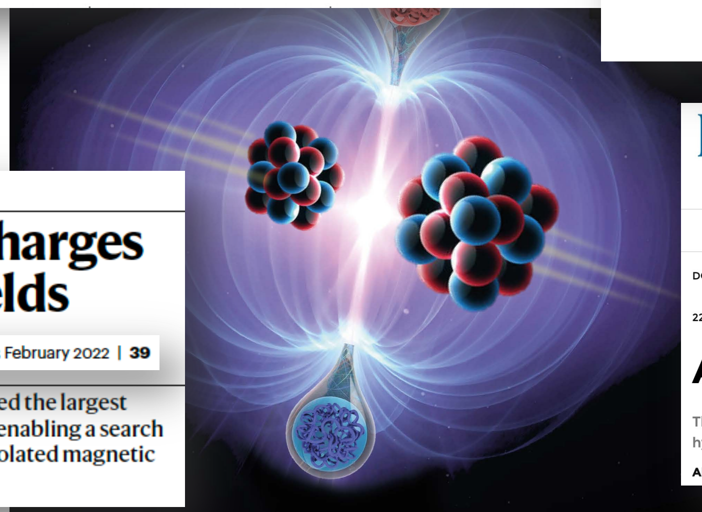
RESEARCH HIGHLIGHTS

Iulia Georgescu

Nature Reviews Physics | https://doi.org/10.1038/s42254-022-00428-4 | Published online 2 February 2022

PARTICLE PHYSICS

Searches for magnetic monopoles



Particle physics

Single magnetic charges in the largest of fields

Nature | Vol 602 | 3 February 2022 | 39

Sonia Kabana

Collisions between lead ions have produced the largest measured magnetic field in the Universe, enabling a search for elusive exotic particles that carry an isolated magnetic charge. See p.63

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DOI:10.1063/PT.6.1.20220222a

22 Feb 2022 in Research & Technology

A new search for magnetic monopoles

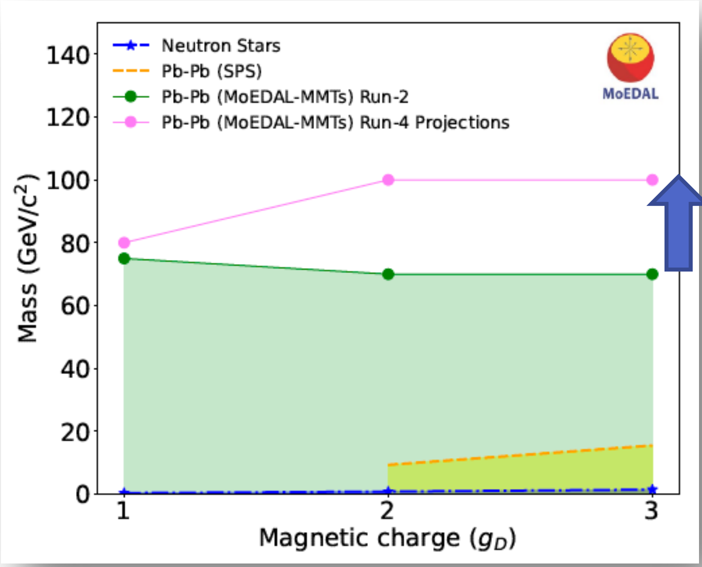
The latest results from CERN's Large Hadron Collider have established a lower mass limit for the still elusive hypothesized particle.

Alex Lopatka

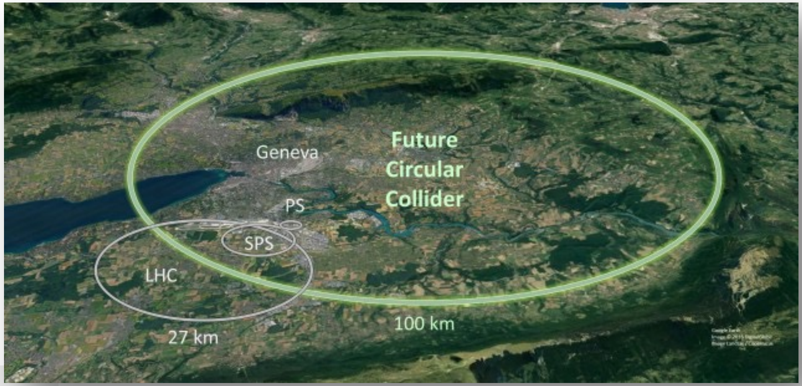
Future analyses and prospects

MoEDAL

- Analysis of full NTD data from Run-2 heavy-ion collisions
- HL-LHC projection for MoEDAL's MMTs
    - Conservative theoretical assumptions
    - Nuclear track detectors not included in projection
    - Assuming 2.5 nb^{-1} Pb-Pb collisions at $\sqrt{s_{NN}} = 5.52$ TeV



~20 GeV increase in sensitivity in HL-LHC heavy-ion run



For FCC : $\sqrt{s_{NN}} \sim 40$ TeV
$\Rightarrow M \gtrsim 600$ GeV

Opportunities for new physics searches with heavy ions at colliders, Snowmass 2021 white paper, arXiv:2203.05939

Theoretical improvements in semiclassical and fully classical approaches

Conclusions

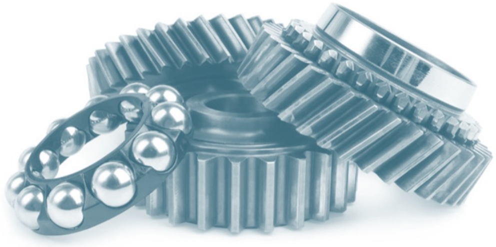
- MoEDAL pioneered searches for long-lived particles at the LHC
  - sole contender in **high magnetic charges**
  - sole **dyon** search in accelerator experiment
  - entered the arena of searches ***electrically* charged particles**
- First search for monopoles produced via the **Schwinger mechanism**
  - evades non-perturbativity of monopole-photon coupling
  - sensitive to finite-size monopoles
- Stay tuned for upcoming results!

MoEDAL

More info in: VAM, CERN EP Seminar, March 22nd, 2022

Thank you for your attention!

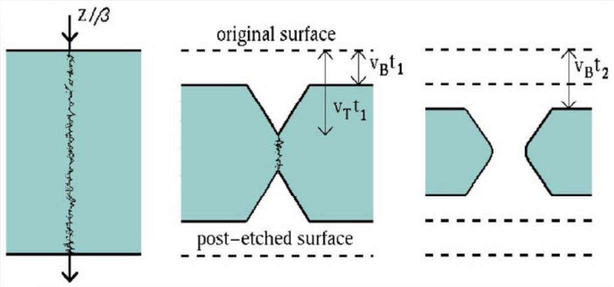
Spares

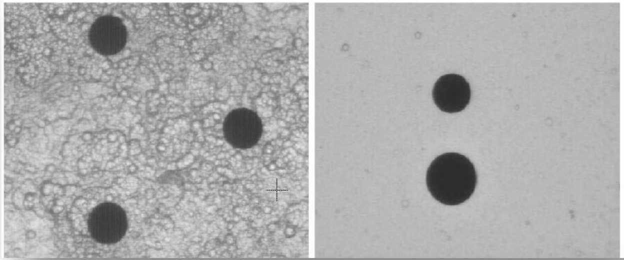


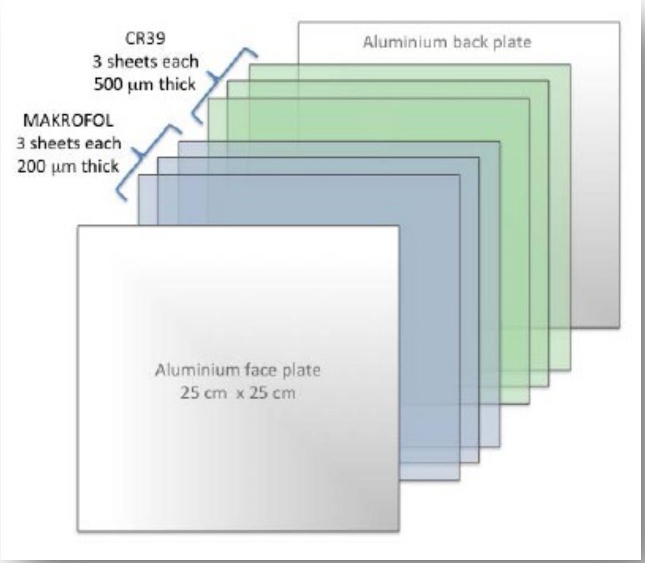
1 Nuclear Track Detectors (NTDs)

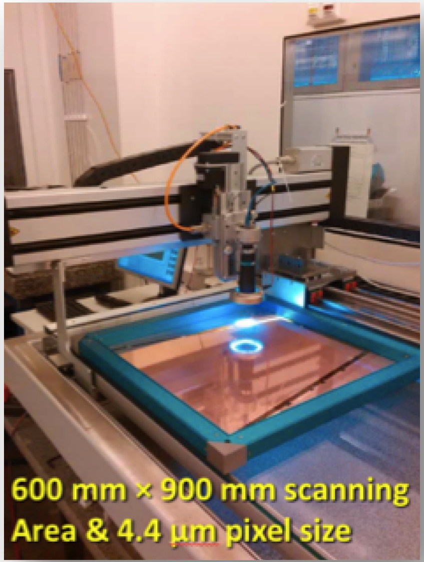
MoEDAL

- Passage of a highly ionising particle through the plastic NTD marked by an *invisible* damage zone (**"latent track"**) along the trajectory
- Damage zone revealed as a **cone-shaped etch-pit** when the plastic sheet is **chemically etched**
- Plastic sheets are later **scanned** to detect etch-pits

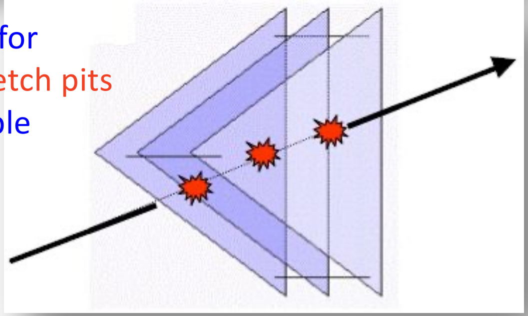








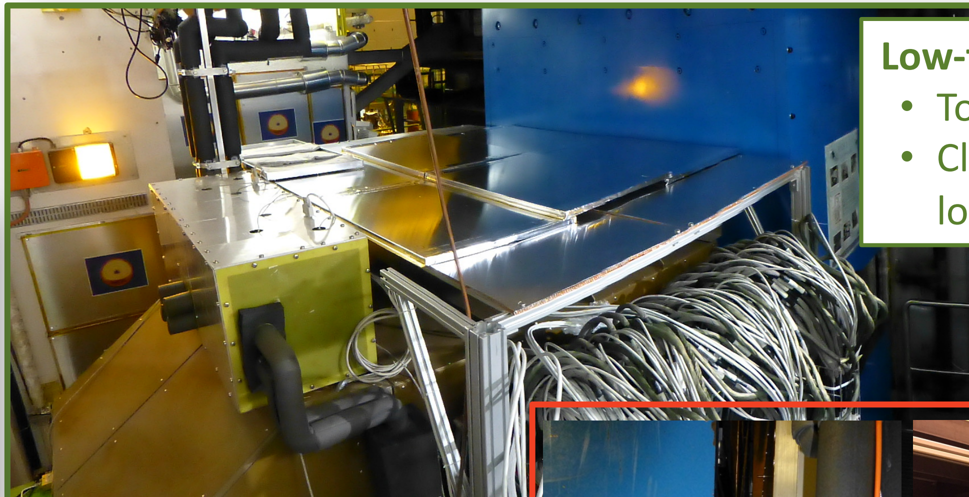
Looking for aligned etch pits in multiple sheets



1 Run-2 NTD deployment

MoEDAL

Low-threshold NTD
NTDs sheets kept in boxes mounted onto cavern walls

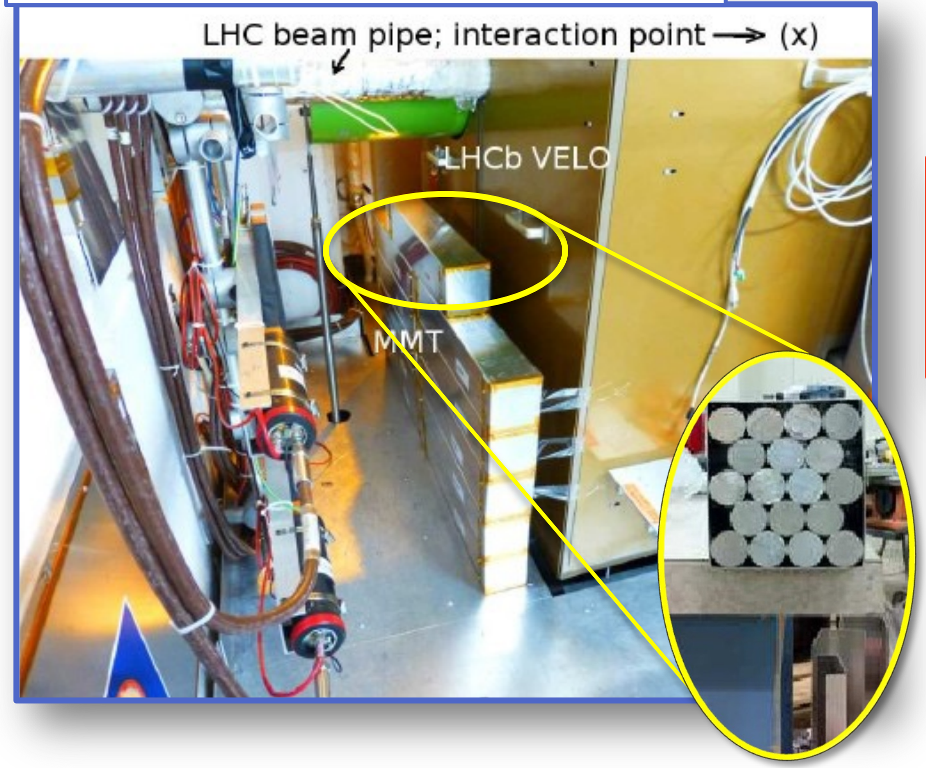


Low-threshold NTD
- Top of VELO cover
- Closest possible location to IP

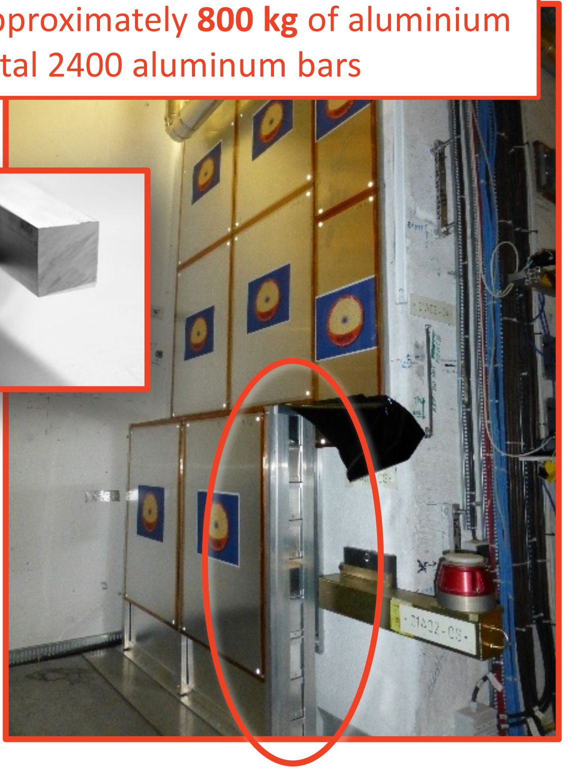
HCC-NTD
Installed in LHCb acceptance between RICH1 and Trigger Tracker

MMT deployment

2012
11 boxes each containing 18 Al rods of 60 cm length and 2.54 cm diameter (**160 kg**)



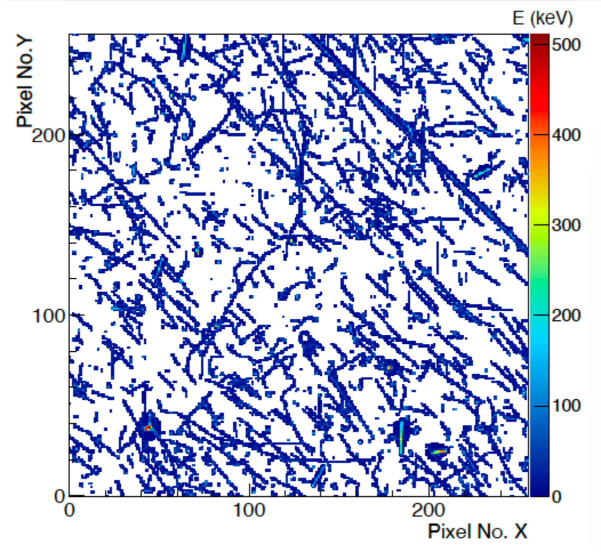
2015-2018
- Installed in forward region under beam pipe & in **sides A & C**
- Approximately **800 kg** of aluminium
- Total 2400 aluminum bars



3 TimePix radiation monitor

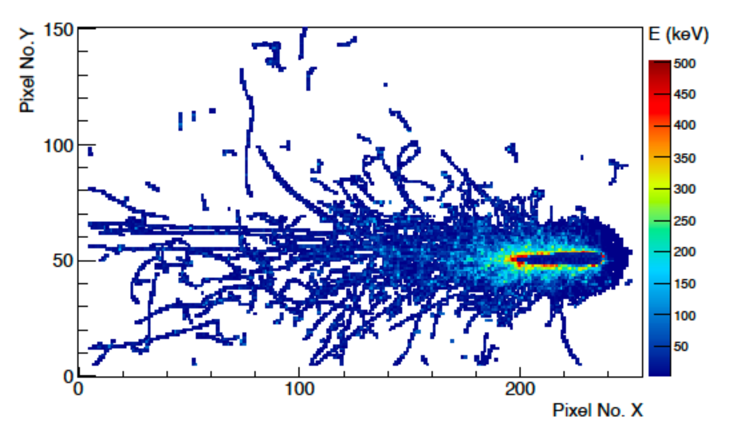
- Timepix chips used to measure online the radiation field and monitor spallation product background
- Essentially act as little electronic "bubble-chambers"
- The only active element in MoEDAL

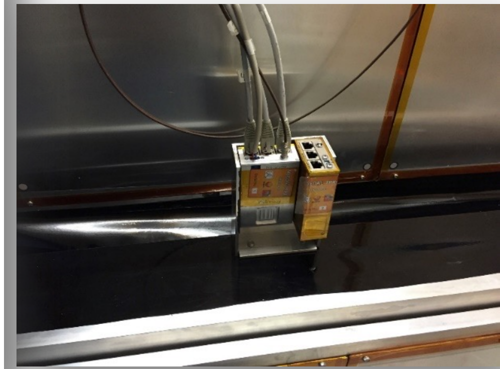
- 256×256 pixel with 55 μm pitch
- Time-of-interaction precision 1.56 ns
- 3D track reconstruction
- Energy deposition measured via time-over-threshold
- Particle ID through *dE/dx*



Tracks accumulated during 1s in MoEDAL during Pb-Pb run

330 GeV Pb-ion measured at the SPS



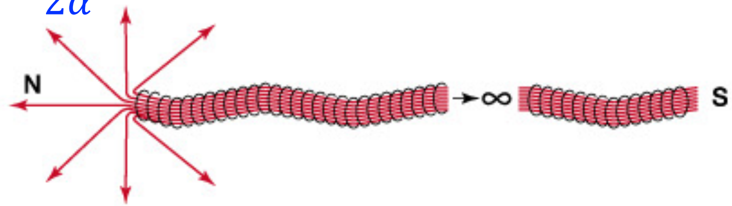


MoEDAL, PoS ICHEP2020 (2021) 720

Magnetic monopoles

Laws	Without monopoles	With magnetic monopoles
Gauss's law	$\nabla \cdot \mathbf{E} = 4\pi\rho_e$	$\nabla \cdot \mathbf{E} = 4\pi\rho_e$
Gauss's law for magnetism	$\nabla \cdot \mathbf{B} = 0$	$\nabla \cdot \mathbf{B} = 4\pi\rho_m$
Faraday's law	$-\nabla\times\mathbf{E} = \frac{\partial\mathbf{B}}{\partial t}$	$-\nabla\times\mathbf{E} = \frac{\partial\mathbf{B}}{\partial t} + 4\pi\mathbf{J}_m$
Ampère's law	$\nabla\times\mathbf{B} = \frac{\partial\mathbf{E}}{\partial t} + 4\pi\mathbf{J}_e$	$\nabla\times\mathbf{B} = \frac{\partial\mathbf{E}}{\partial t} + 4\pi\mathbf{J}_e$

- Symmetrise Maxwell's equations
  - electric ↔ magnetic charge duality
- **Paul Dirac** in 1931 hypothesised that the magnetic monopole exists
  - monopole is the end of an infinitely long and infinitely thin solenoid *(Dirac's string)*
  - Dirac's quantisation condition: $ge = n\left(\frac{\hbar c}{2}\right)$ OR $g = \frac{n}{2\alpha}e = ng_D = n(68.5e)$
- In 1974 **'t Hooft and Polyakov** found that GUTs predict monopoles as topological solitons
  - produced in early Universe with mass $10^{17} - 10^{18}$ GeV



- **Yongmin Cho & D. Maison** proposed in 1986 the **Electroweak monopole**
  - non-trivial hybrid between (Abelian) Dirac and (non-Abelian) 't Hooft-Polyakov monopoles
  - magnetic charge $2g_D$
  - mass between 4 to 7 TeV ➪ **detectable at LHC!**

Monopole results

MoEDAL

- 2016 – **First results @ 8 TeV** ☛ *CERN Press Release*
  JHEP 1608 (2016) 067 [arXiv:1604.06645]
- 2017 – **First results @ 13 TeV** Phys.Rev.Lett. 118 (2017) 061801 [arXiv:1611.06817]
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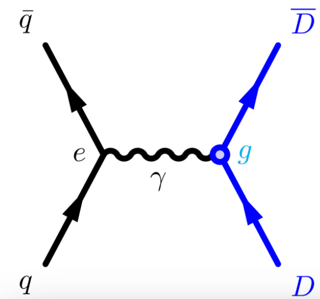
- 2021 – **NTD & MMT combination ← FIRST NTD analysis** arXiv:2112.05806
  - First limits in highly electrically charged objects

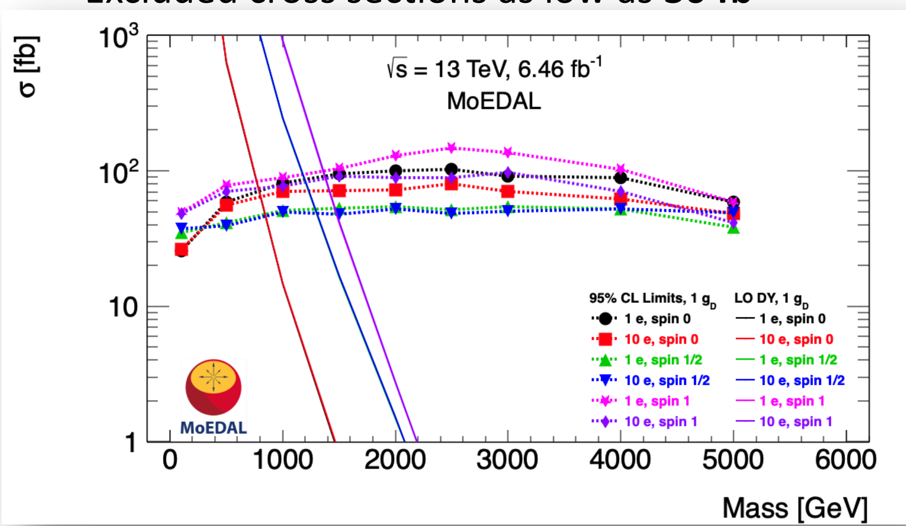
Search for dyons

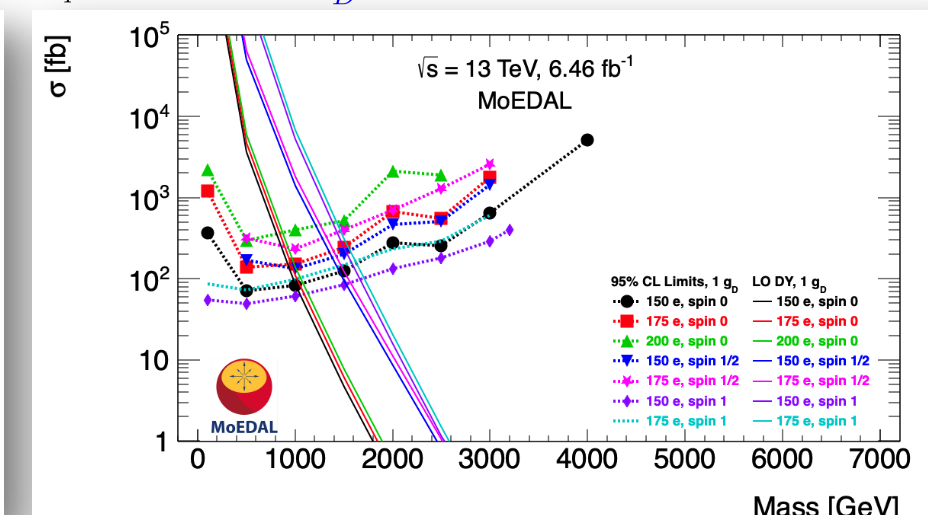
First explicit accelerator search for direct dyon production!

- Dyons possess both electric and magnetic charge
- MMT scanning searching for captured dyons
  - 6.46 fb^{-1} of 13 TeV *pp* collisions during 2015-2018
- Analysis considered
  - dyons of spin 0, ½, 1
  - Drell-Yan production
- Excluded cross sections as low as **30 fb**



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

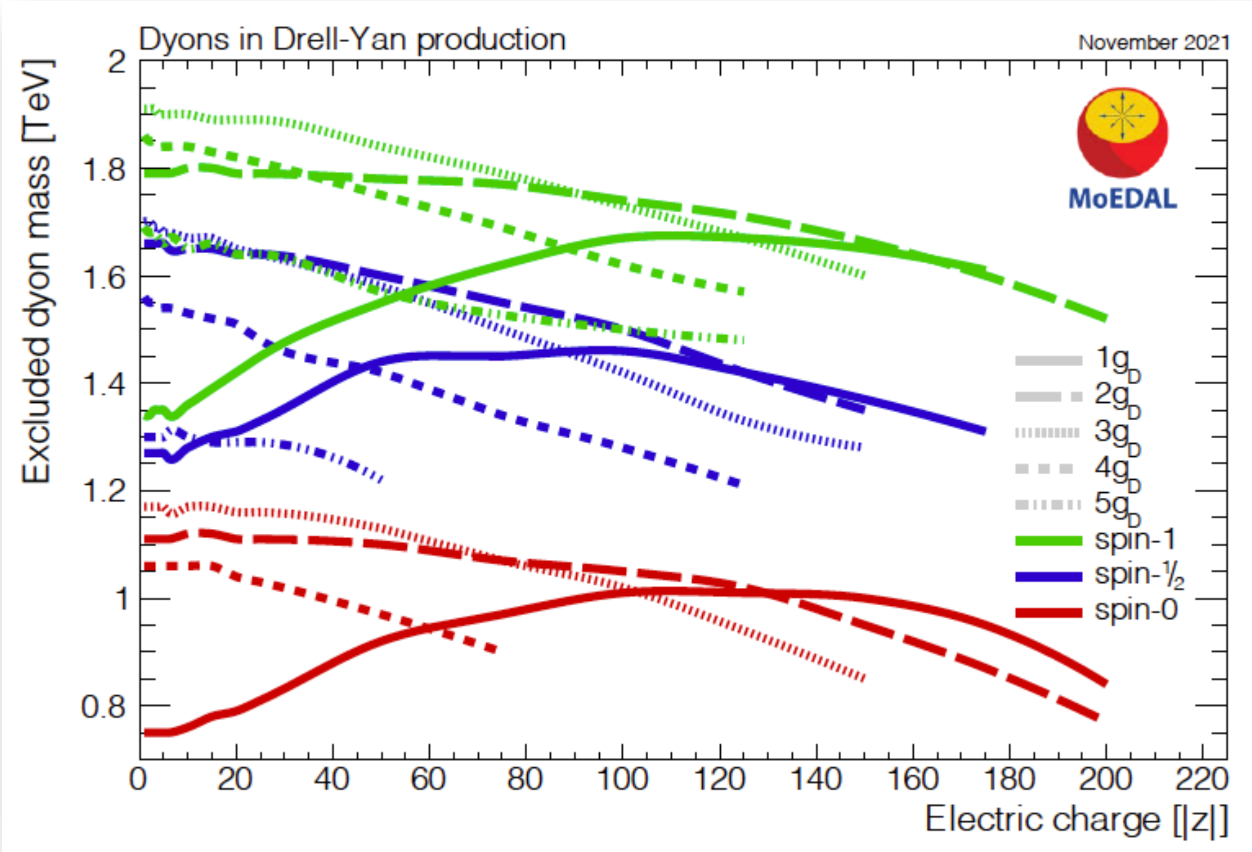




Search for dyons – results

MoEDAL

- Mass limits **750-1910 GeV** were set for dyons with
  - up to 5 Dirac magnetic charges (**5g$_D$**)
  - electric charge ***1e – 200e***
- Previous searches for highly ionising particles would, in principle, also have sensitivity to dyons
  - caution on behaviour under magnetic field

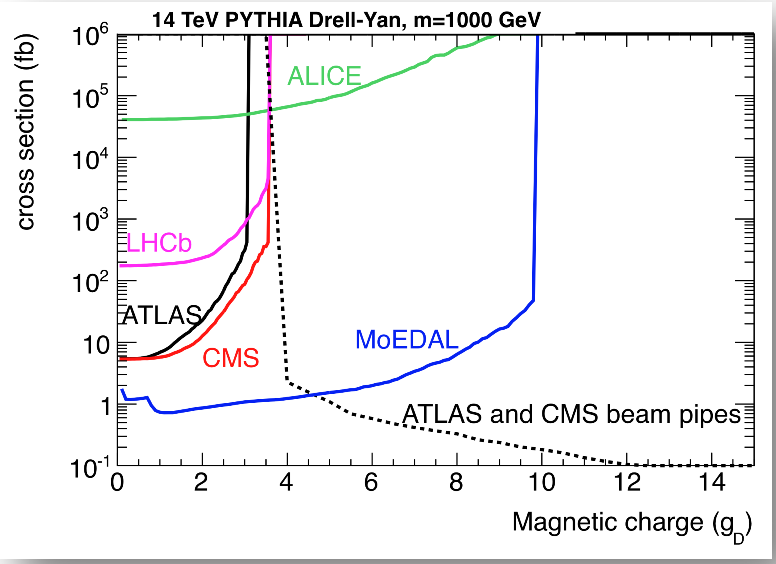


MoEDAL, Phys.Rev.Lett. 126 (2021) 071801

CMS beam pipe

Beam pipe
- most directly exposed piece of material
- covers **very high magnetic charges**

- **1990's:** materials from CDF, D0 (Tevatron) and H1 (HERA) subject to SQUID scans for trapped monopoles
- **2012:** first pieces of CMS beam pipe tested [EPJC72 (2012) 2212]; far from collision point
- **Feb 2019:** CMS officially transfers ownership of the Run-1 CMS beam pipe to MoEDAL



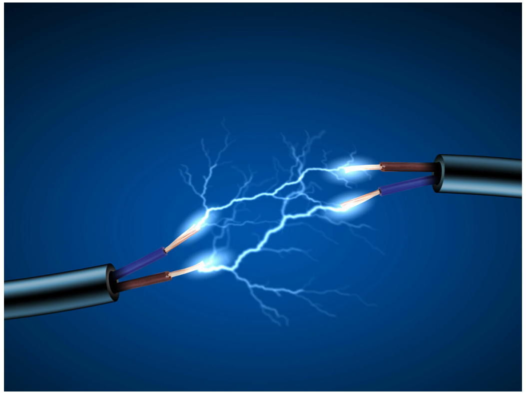
De Roeck et al, EPJC72 (2012) 1985

CERN Courier, Mar-Apr 2019

Beam pipe scanned with SQUID at ETH Zurich
Interpretation in progress

Electrically charged particles

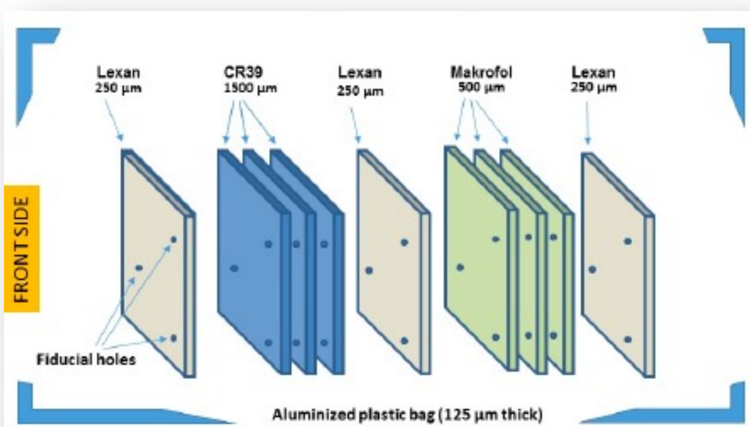
- Run 1 results on HECOs (and monopoles)
- Prospects for low charges ($1e - 4e$)

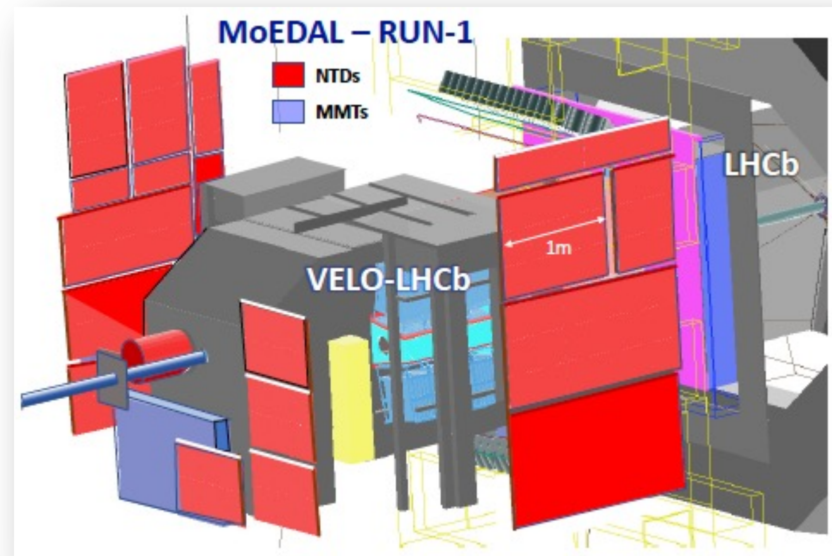


NTD+MMT search for HECOs and monopoles

- Highly Electrically Charged Objects (HECOs): finite-sized objects (Q-balls), condensed states (strangelets), microscopic black holes (through their remnants)
- MoEDAL exposed in 2.2 fb^{-1} of *pp* collisions at 8 TeV (Run 1)
- Prototype NTD array of 125 × 25 cm × 25 cm stacks (7.8 m^2)
  - three layers of 1.5 mm thick CR39® polymer → low threshold Z/β ~ 5 ⇒ time intensive analysis
  - three layers of Makrofol DE® 0.5 mm thick ☚ **used in analysis (less "visual noise"); threshold Z/β ~ 50**
  - three layers of Lexan® and 0.25 mm thick
    - protective layers only

MoEDAL, arXiv:2112.05806

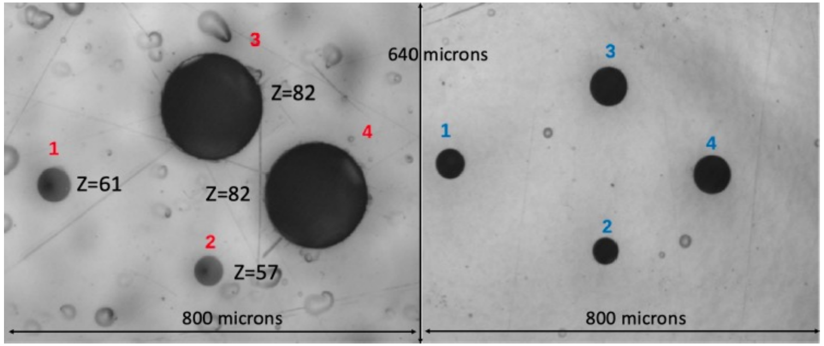


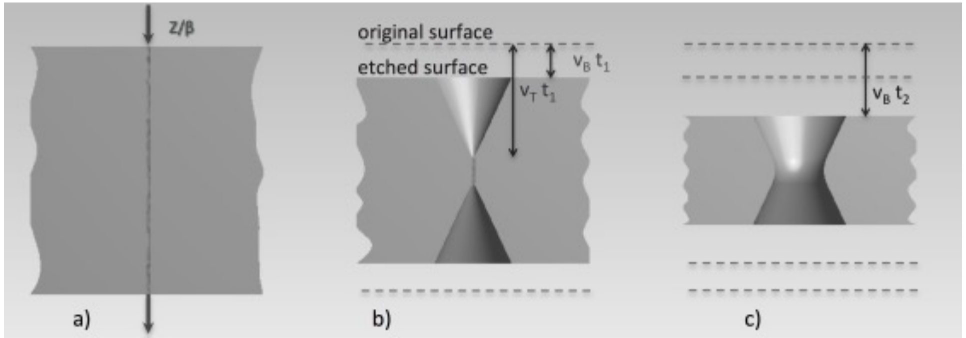


NTD analysis

- Calibration with 158 A GeV Pb^{82+} and 13 A GeV Xe^{54+} ion beams at the CERN SPS, University of Montreal & University of Alabama
- Scanning efficiency for detection above threshold is **>99%**
- Detectors were etched in 6N KOH+20% ethyl alcohol at 50°C for 10 hours in INFN Bologna
- After etching, the size of the etch pits was measured with an automatic scanning system providing the cone base area and the coordinates of the centre of the etch pits

Strong etching *Soft etching*

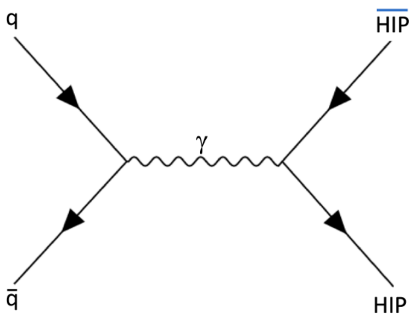


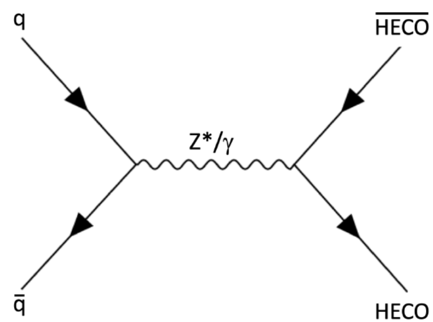


No candidates were found in the stacks examined

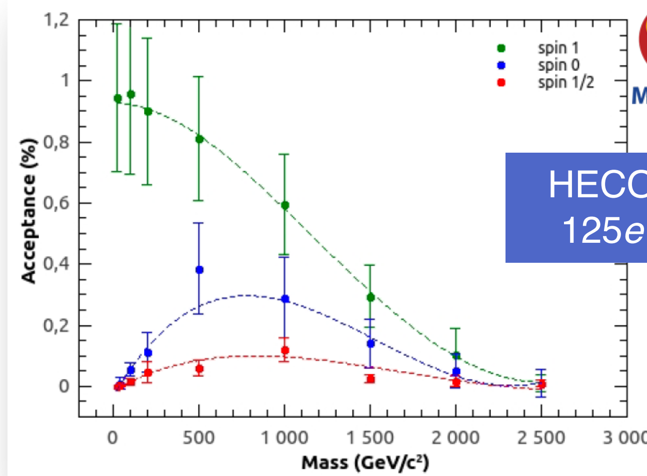
MoEDAL, arXiv:2112.05806

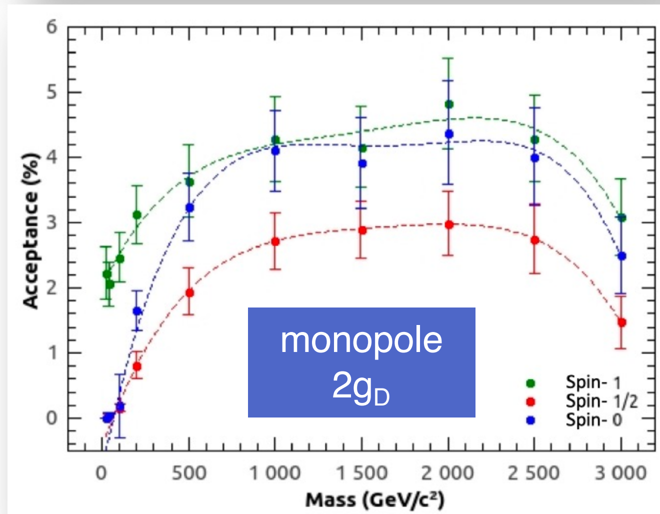
NTD+MMT acceptance





- For HECOs
  - Z* exchange is also taken into account for fermions [Song & Taylor, J.Phys.G 49 (2022) 4, 045002]
  - non-perturbativity of large coupling can be tackled by appropriate **resummation** *(in progress)*
- Acceptance determined by an interplay of
  - geometrical disposition of NTD modules and MMT detectors
  - energy loss in the detectors
  - particle mass
  - spin-dependent kinematics of the interaction products





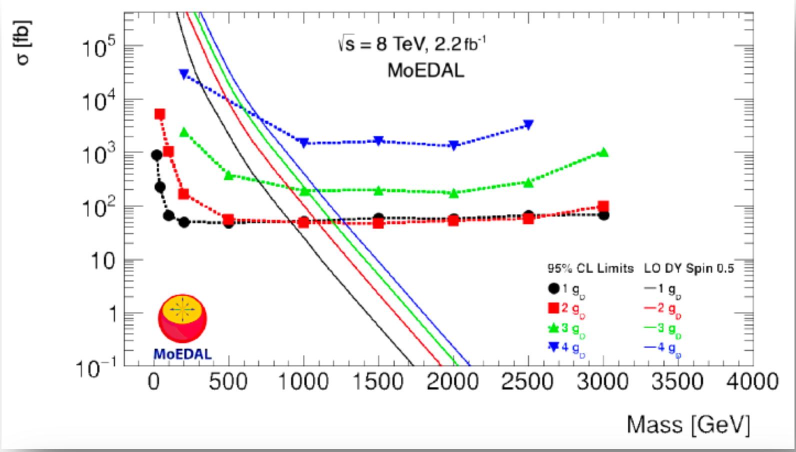
MoEDAL, arXiv:2112.05806

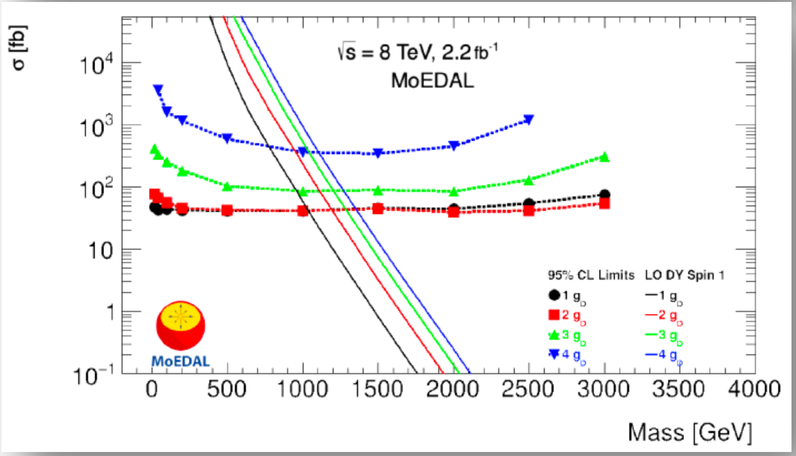
NTD+MMT results – monopoles

- Limits on DY production of magnetic monopole pairs with cross-section in the range of **~40 fb – 5 pb** were set for magnetic charges up to **4g_D** and mass as high as **1.2 TeV**
- Monopole limits not competitive with recent Run-2 collider limits due to
  - limited acceptance of MMT and NTD Run-1 prototype detectors compared to Run-2
  - smaller √s, hence DY cross-section at Run-1
  - lower integrated luminosity of Run-1 compared to Run-2

	Magnetic charge (g_D) 1	2	3	4
Spin	95% CL mass limits [GeV/c^2]			
0	590	740	710	520
1/2	910	1090	1020	700
1	1030	1190	1190	1110

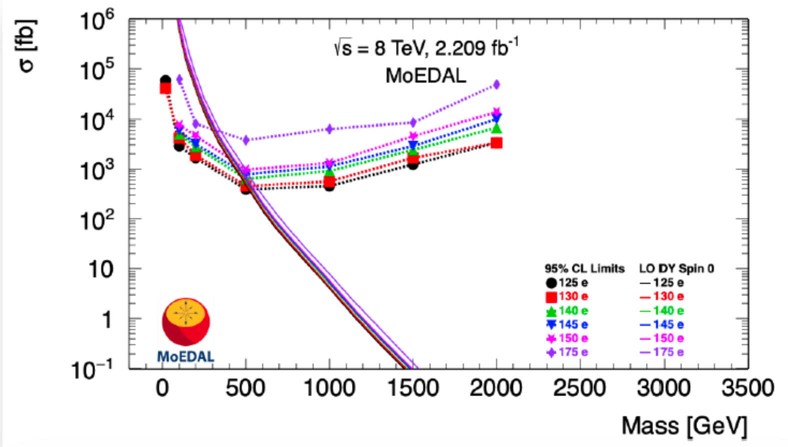
MoEDAL, arXiv:2112.05806

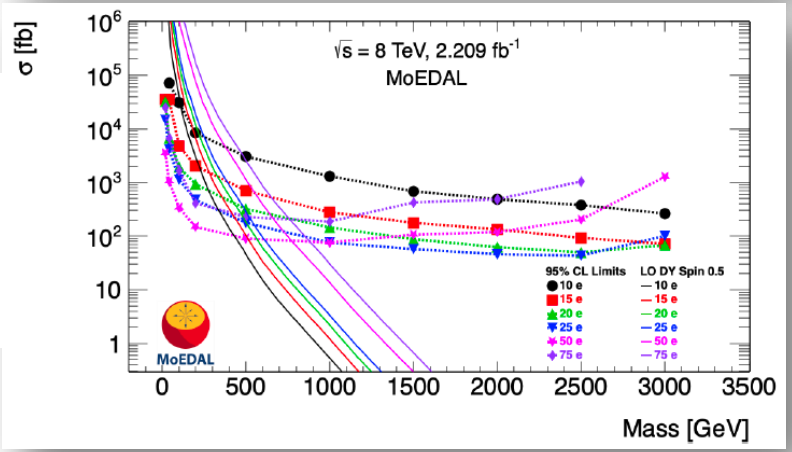




NTD+MMT results – HECOs

- Limits set on the DY production of HECO pairs with cross-sections from **~ 30 – 70 pb**, for electric charges in the range **15e – 175e** and masses from **110 – 1020 GeV**
- **HECOs limits are the strongest to date**, in terms of charge, at any collider experiment
  - ATLAS has set limits on HECOs of **20*e* – 100*e*** [PRL 124, 031802 (2020)]



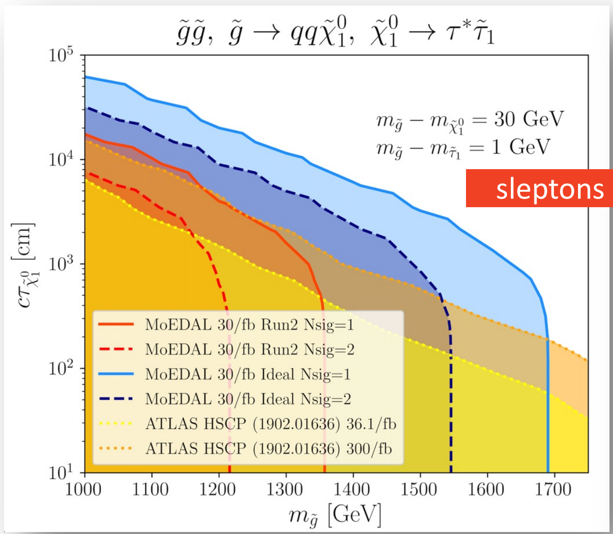


	Electric charge (e)											
	15	20	25	50	75	100	125	130	140	145	150	175
Spin	95% CL mass limits [GeV/c^2]											
0	110	190	310	580	580	560	510	510	490	470	460	380
1/2 (γ-exchange)	310	440	560	800	780	730	650	640	600	590	550	-
1/2 (γ/Z^*-exchange)	300	430	560	780	750	710	650	640	590	-	-	-
1	400	570	740	1010	1020	1000	970	950	930	921	900	850

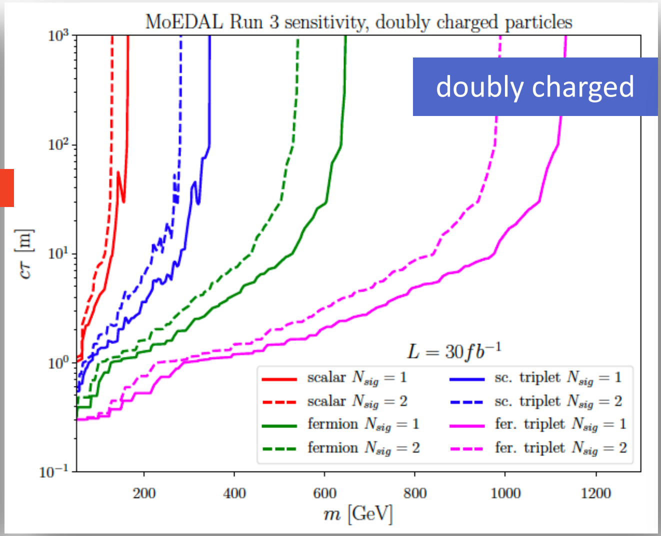
MoEDAL, arXiv:2112.05806

Prospects for electrically charged particles

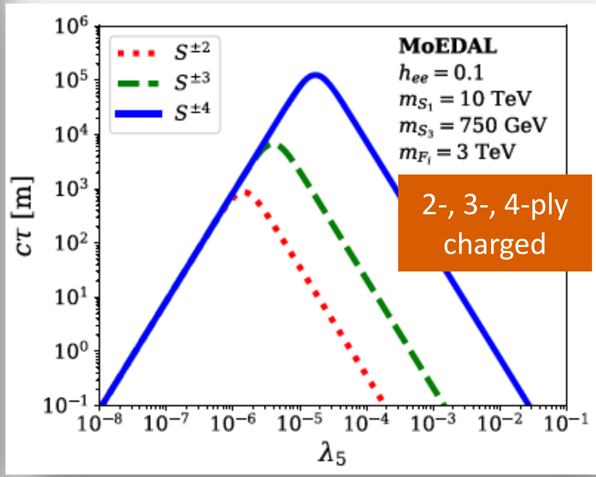
- If sufficiently slow moving, even *singly* or *multiply ($\lesssim$ 10)* charged particles may leave a track in NTDs
- Supersymmetry offers such long-lived states: **sleptons, R-hardons, charginos**
- Multiply charged scalars or fermions are predicted in Higgs bosons and in several models of ν masses



Felea et al, EPJC 80 (2020) 431



Acharya et al, EPJC 80 (2020) 572



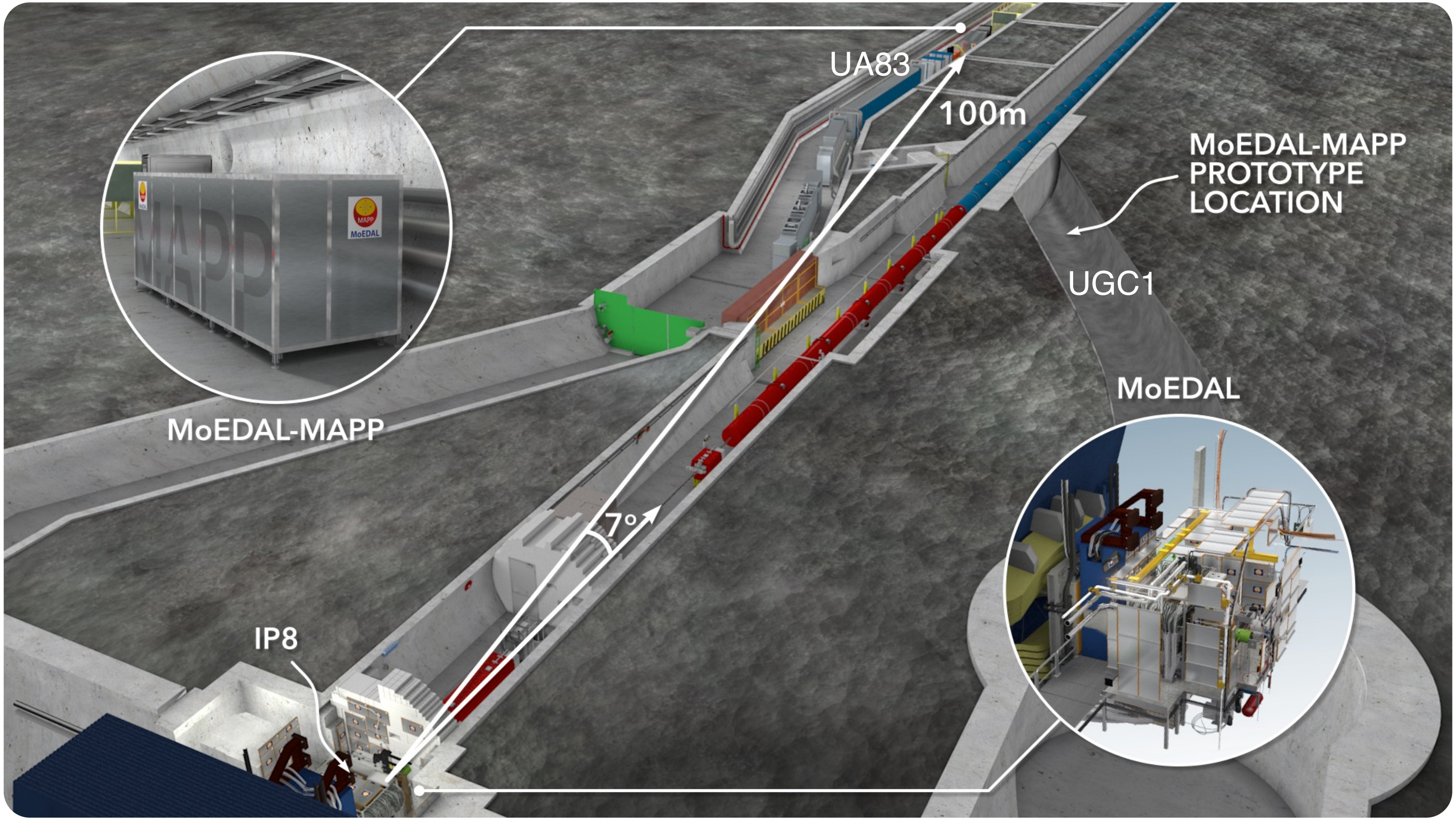
Hirsch et al, EPJC 81 (2021) 697

MoEDAL-MAPP

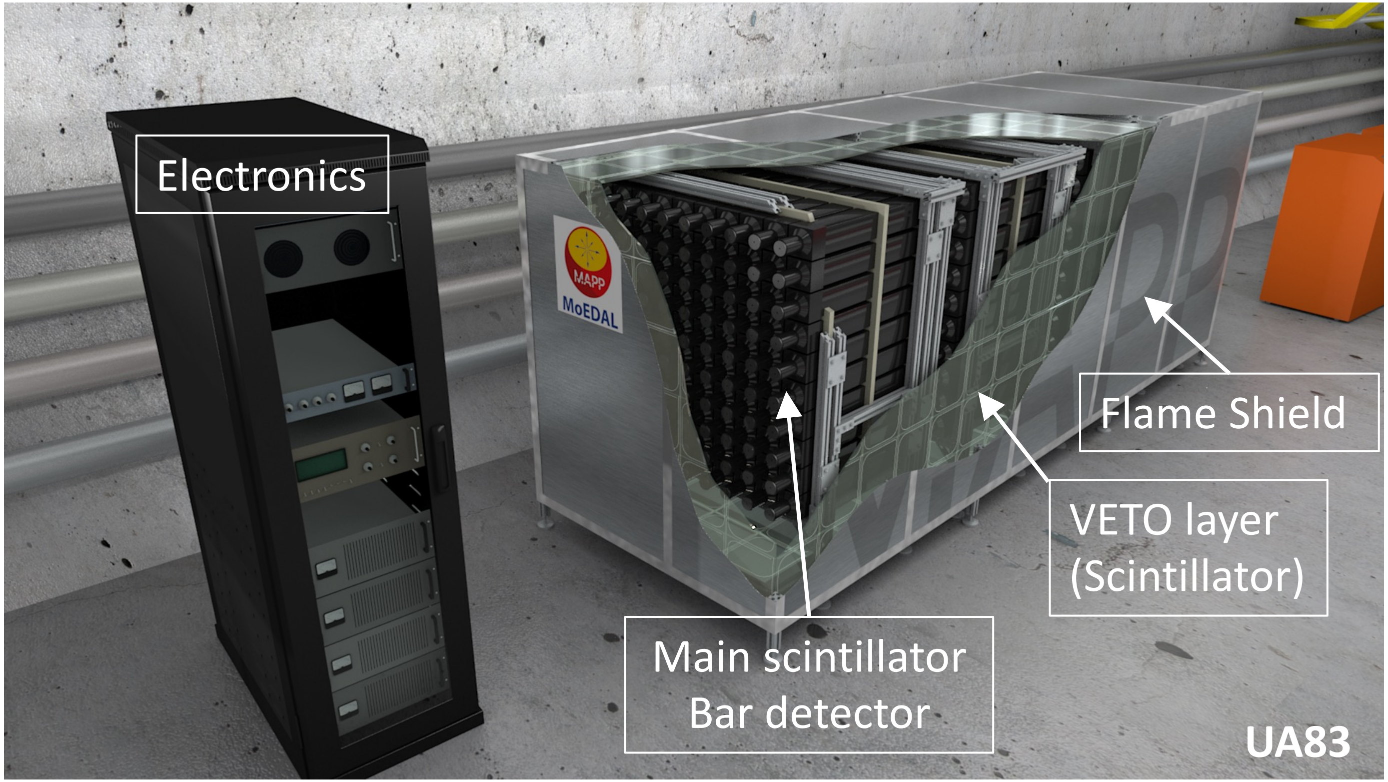
- MoEDAL baseline detectors
  - **redeployment for Run-3** pending LHCb green light
  - plans to operate during HL-LHC
- **MAPP** can further explore the *low ionisation* regime
  - **millicharged** particles
  - neutral long-lived particles giving rise to **displaced vertices** → dark sectors, neutrino portals, SUSY, ...
- MAPP installation plan
  - Phase-1 approved by CERN Research Board on Dec 1st 2021
  - Phase-1 (**MAPP-mQP**) installation for **Run-3** in UA83 is underway; start taking data in 2023 to probe millicharged particles
  - Phase-2 **HL-LHC**: Reinstall Phase-1 in UA83 and add **MAPP-LLP** in UGC1 to expand the physics reach to neutral long-lived particles

MoEDAL-MAPP flythrough:
http://www.physixel.com/JLP_MAPP/MAPP_FlyOver1.mp4

MAPP location



MAPP-mQP Phase-1 detector concept



- 400 scintillator bars (10×10×75 cm^3) in 4 sections readout by PMTs
- Protected by a hermetic VETO counter system

MAPP-mQP Phase-1 installation

complete section

MAPP – MoEDAL Apparatus for Penetrating Particles

MAPP
MoEDAL

Consists of two subdetectors:

- core millicharged particle detector **MAPP-mQP**
  - particles with charges ≪ ***1e*** leaving a trace of low ionisation
- very long-lived weakly interacting neutral particle detector **MAPP-LLP**

- At forward region w.r.t. beam axis
- Protected by ~100 m of rock overburden

Prototype mQP installed in 2017 in UGC1 gallery

- 3×3 bars (~30×30 cm)
- ~10% of full detector

MAPP Phases

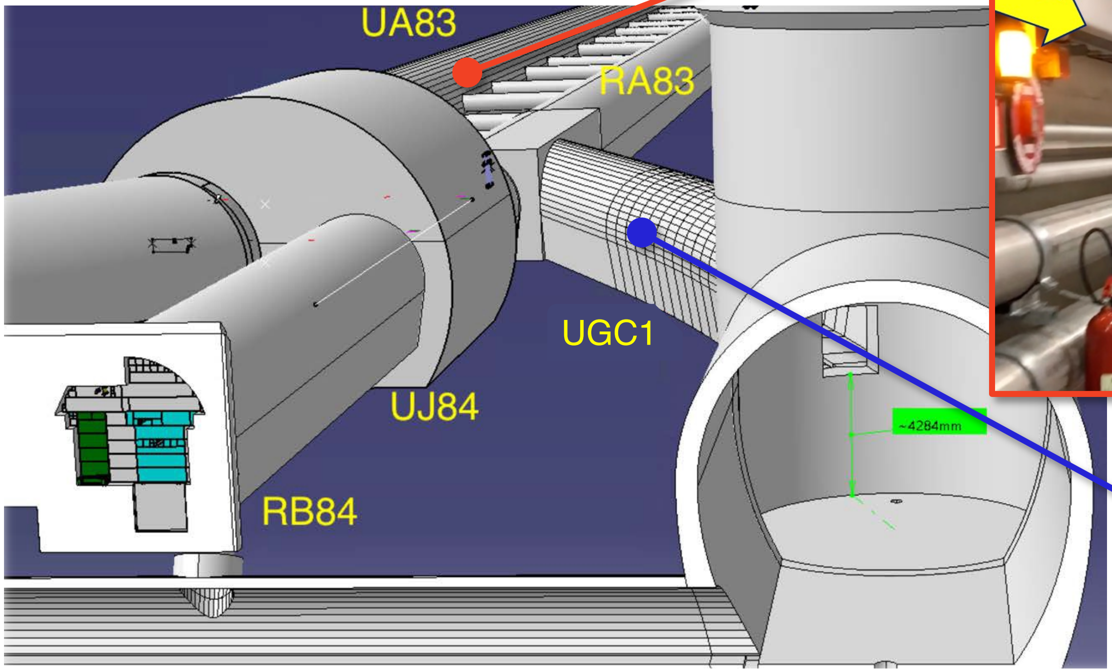
- Phase-1: mQP → Run-3 Approved by CERN Research Board on Dec 1st 2021
- Phase-2: mQP + LLP → HL-LHC

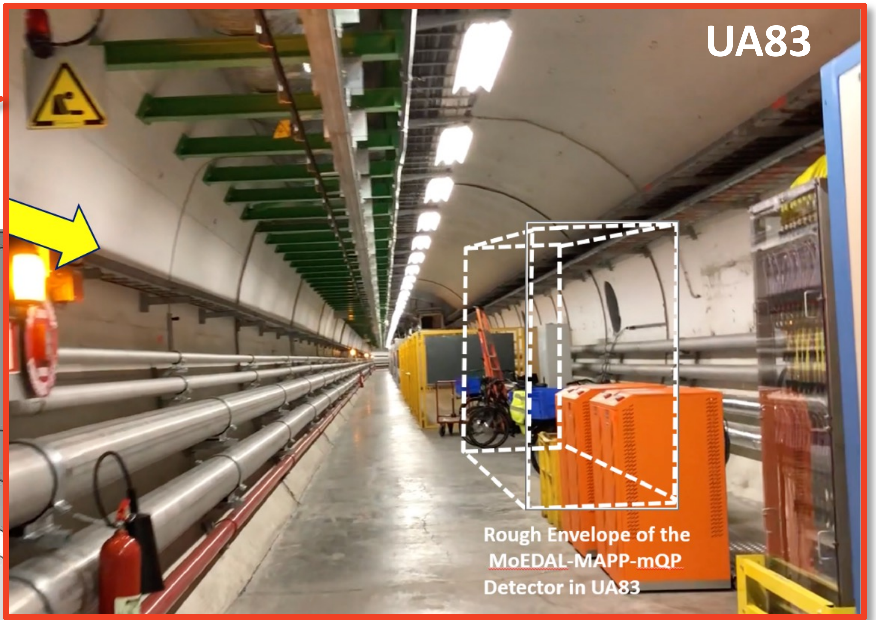
Pinfold, Phil.Trans.Roy.Soc.Lond.A 377 (2019) 20190382

MAPP locations

UA83

- mQP location
- 100 m from IP8 at 6.5° to the beam
- Easily accessible gallery, already fitted out
- Access independent from LHCb



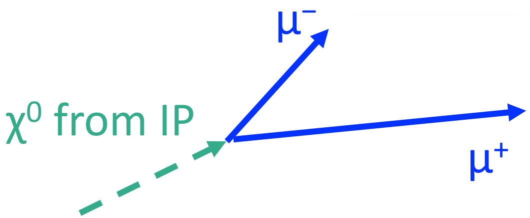


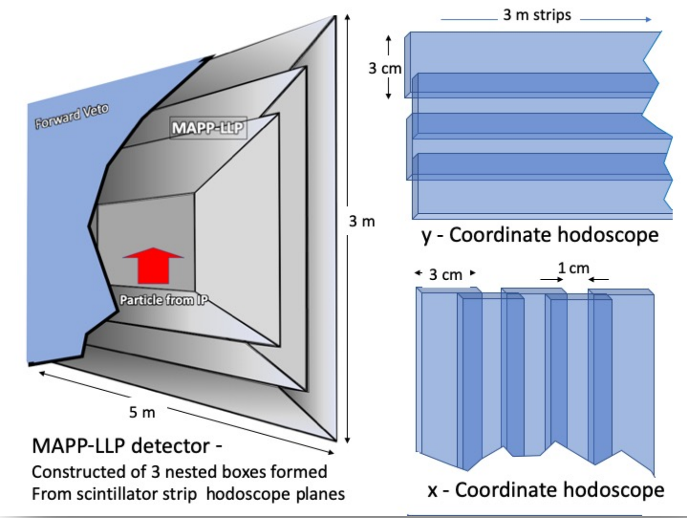
- mQP 2017 prototype location
- Extensive engineering required
- To be ready for MAPP LLP during HL-LHC

UGC1

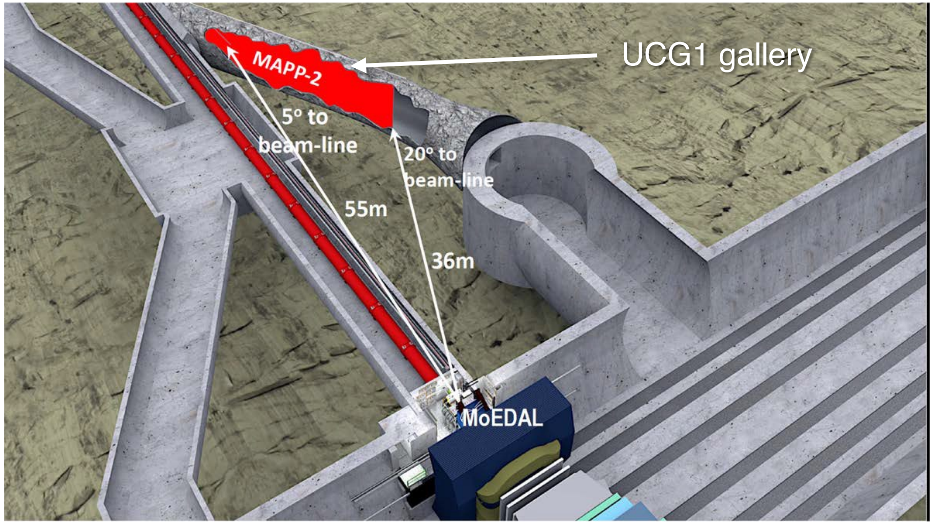
MAPP Phase 2 includes LLP detector

- "Box-within-a-box" structure to detect charged tracks from neutral-particle decays
- Scintillator strips in *x-y* configuration readout by SiPMs
  - resolutions ~1cm × 1cm on each hit
  - 500 ps or better timing resolution
- To be installed during LHC Long Shutdown 3 and run in HL-LHC



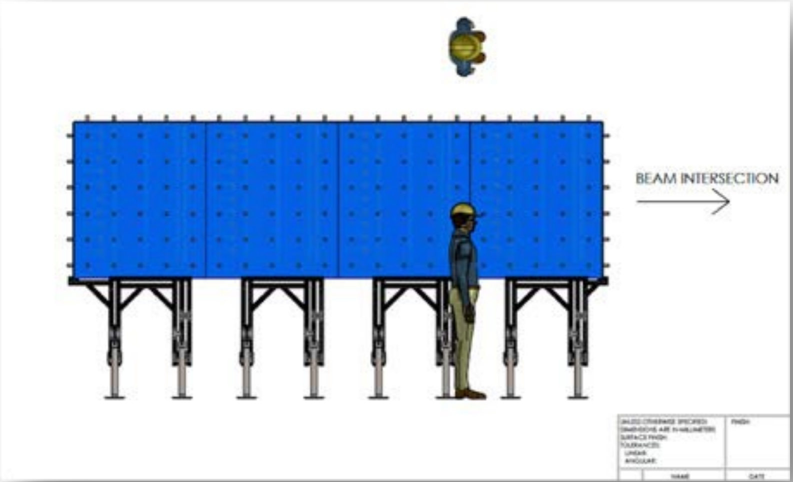


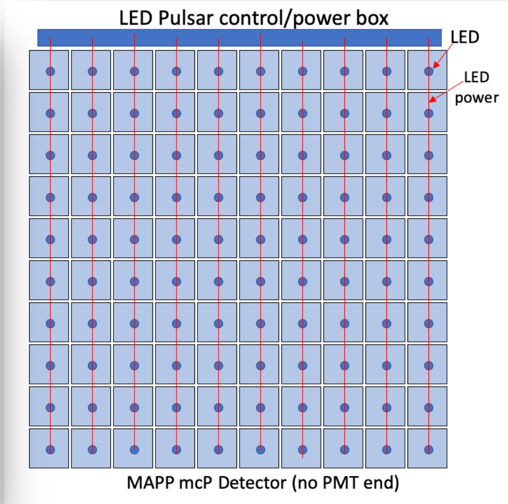
MAPP-LLP detector -
Constructed of 3 nested boxes formed
From scintillator strip hodoscope planes



The MAPP-mQP detector

- Central milli-charged (mCP) detection sections
- Forward veto from SM particles coming from IP8
- 100 × (10 cm × 10 cm × 75 cm) scintillator bars in 4 lengths, 2 lengths/section readout by 4 low noise 3.1” PMTs in coincidence
- No background from dark counts and radiogenic backgrounds

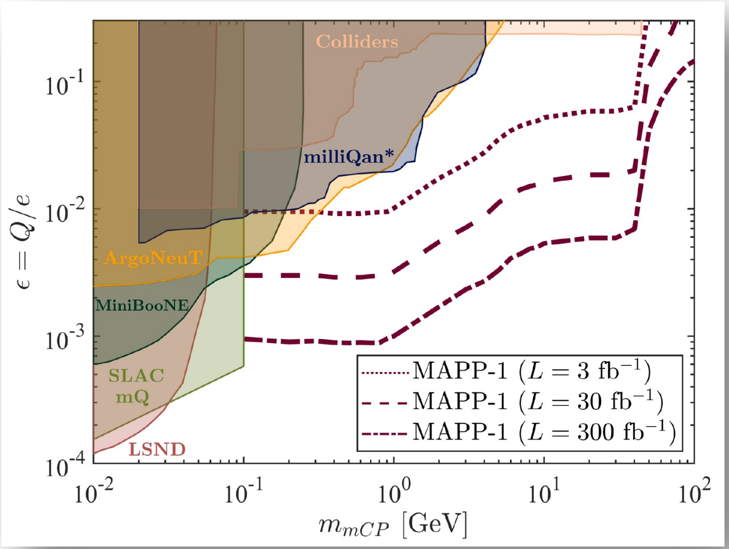




Calibration by pulsed blue LEDs + neutral density filter

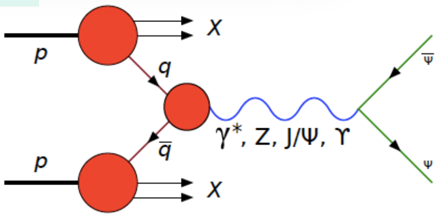
mQP & millicharged particles (mCPs)

Dark photon decays to mCPs

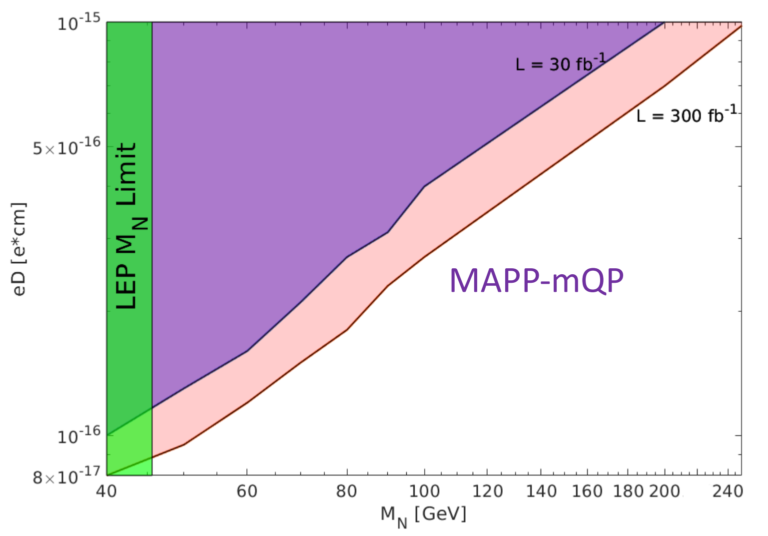


M. Staelens, PhD thesis, U. Alberta

Run-3 sensitivity for dark-photon decays to mCP dark fermions ψ



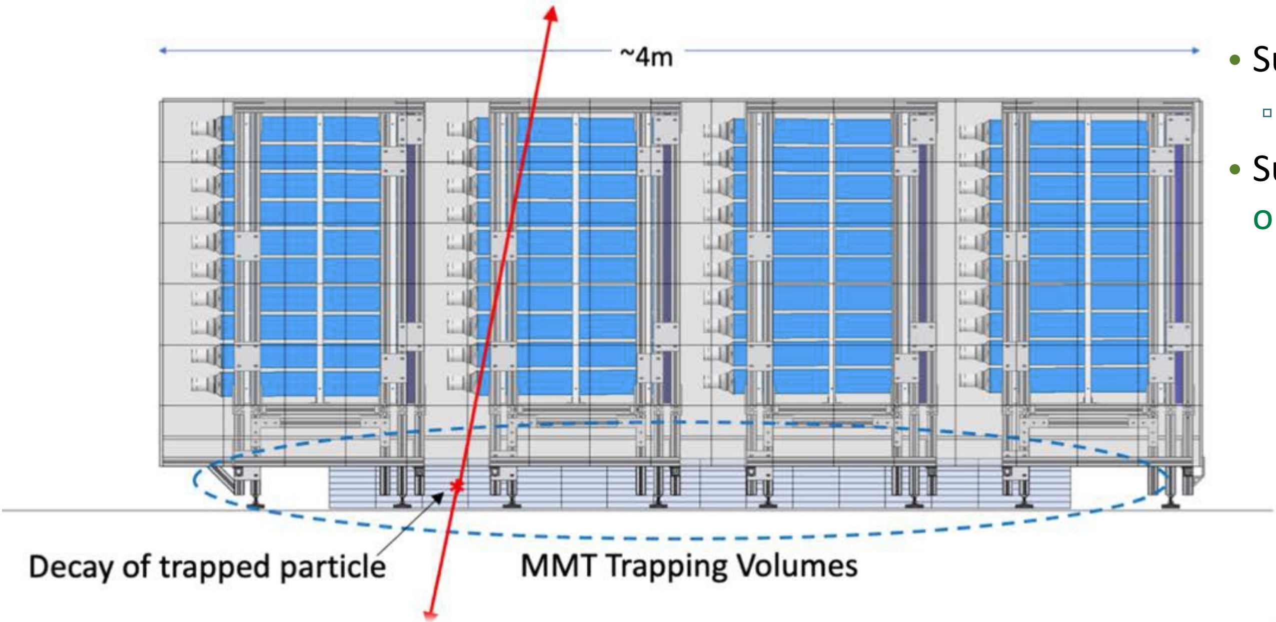
Heavy neutrino with large EDM



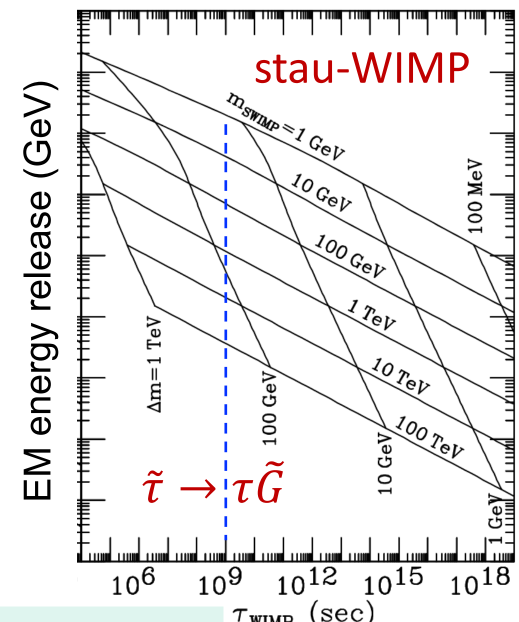
Frank et al, Phys.Lett.B 802 (2020) 135204

Limits that MAPP can place on heavy neutrino production with large EDM at Run-3 and HL-LHC at IP8

Extremely Long-Lived Charged Particles with MAPP-mQP



- SuperWIMP model for cold dark matter
  - WIMP → SM + SWIMP
- SuperWIMP particles may explain the observed lithium under-abundance

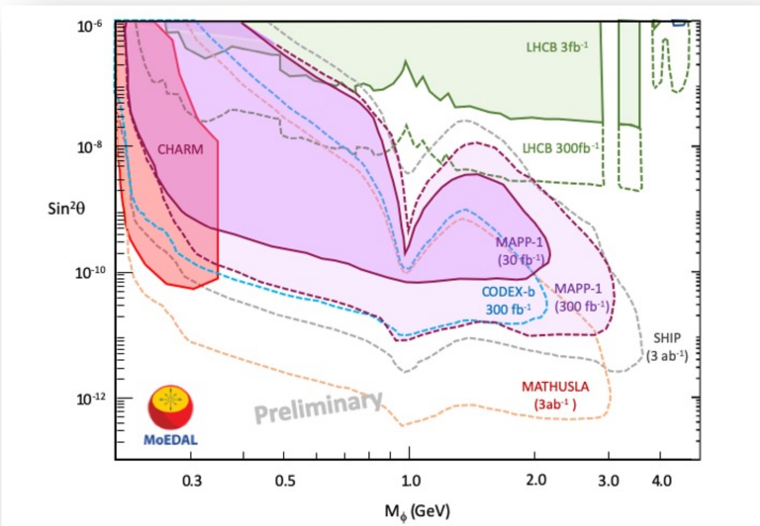


- MAPP-mQP can be used to monitor MoEDAL's exposed trapping detector for the decays of electrically charged trapped particles
  - exposed trapping volumes moved directly underground to UA83
  - lifetimes longer than 10 years can be probed

Feng, Rajaraman, Takayama, Phys. Rev. D 68, 063504 (2003)

MAPP-LLP – dark matter & supersymmetry

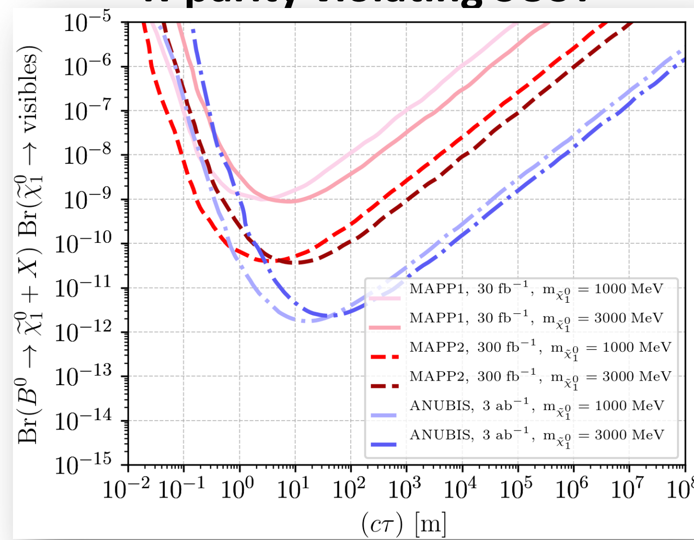
Dark Higgs scenario



Reach for 30 fb^{-1}/300 fb^{-1} for a scenario where a dark Higgs ϕ mixes with SM H^0 (mixing angle $\theta \ll 1$), leading to exotic $B \to X_s\phi$ decays with $\phi \to \ell^+\ell^-$

adopted from Phys.Rev.D 97 (2018) 015023

R-parity violating SUSY



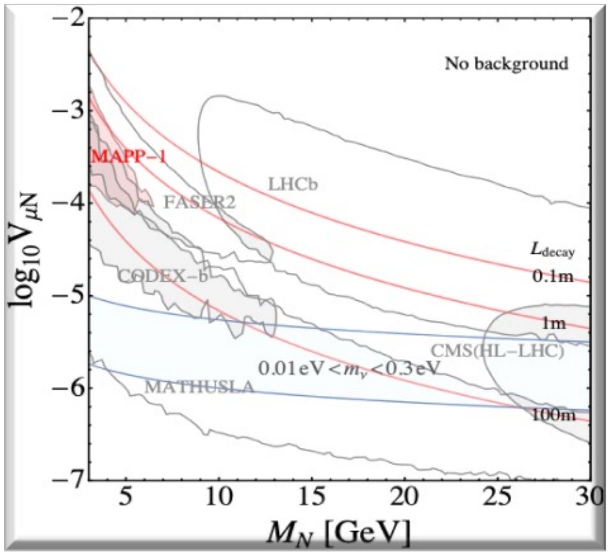
Dreiner, Günther, Wang, Phys.Rev.D 103 (2021) 075013

λ'_P for production	λ'_{131}
λ'_D for decay	λ'_{112}
Produced meson(s)	B^0, $\bar{B}^0$
Visible final state(s)	$K^\pm + e^\mp$, $K^{*\pm} + e^\mp$
Invisible final state(s) via λ'_P	None
Invisible final state(s) via λ'_D	$(K_L^0, K_S^0, K^*) + (\nu_e, \bar{\nu}_e)$

RPV couplings

MAPP-LLP – extended neutrino models

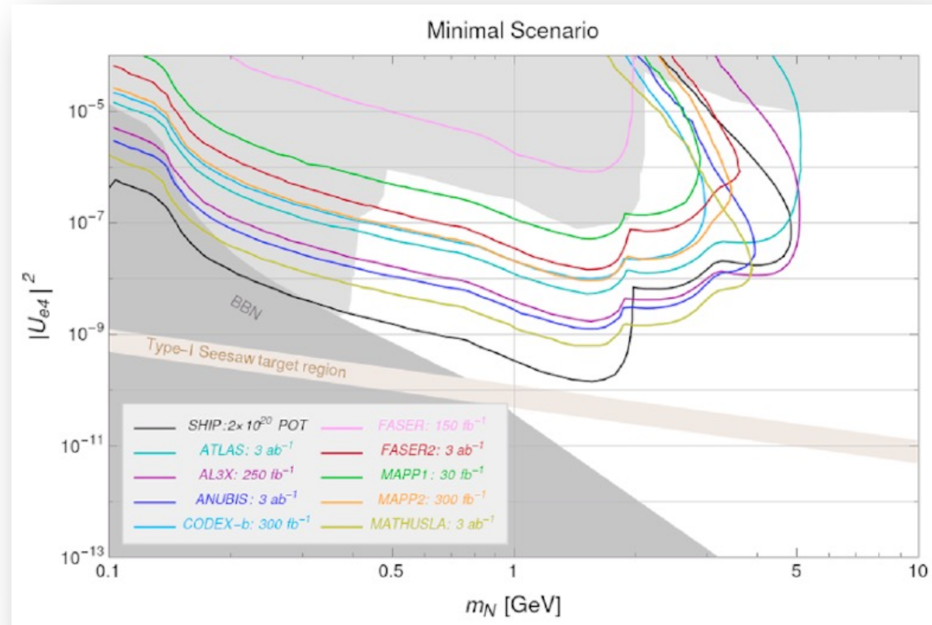
Heavy neutrino via Z’ production



Pair production of RH neutrinos from the decay of an additional neutral Z′ boson in the gauged B-L model – Run-3 (30 fb^{-1})

adopted from
Phys.Rev.D 100 (2019) 035005

Sterile neutrinos



Minimal scenario: interactions are purely mediated by W- and Z-bosons via active-sterile neutrino mixing

De Vries, Dreiner, Günther, Wang, Zhou, JHEP 03 (2021) 148