Recent Results & Future Plans of the MoEDAL Experiment

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Overview

MoEDAL (Monopole & Exotics Detector @ LHC) Summary & Updates

MoEDAL's Latest Results @ 13 TeV

Upgrading MoEDAL into a multi-purpose detector

MAPP (MoEDAL's Apparatus for Penetrating Particles)

mIPs @ MoEDAL

Sensitivity of MAPP to Milli-Charged Particles in Dark QED

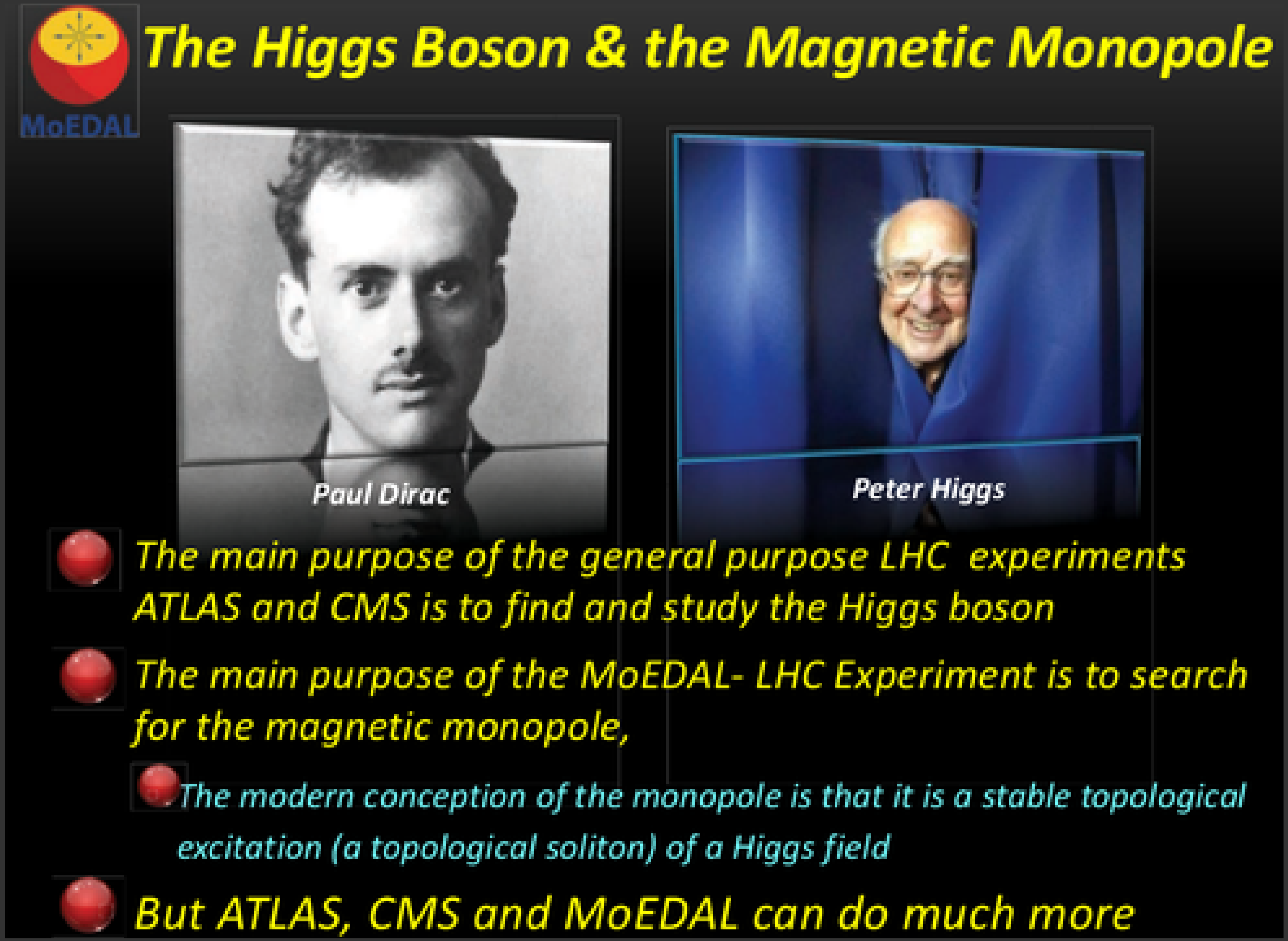
LLPs @ MoEDAL

Sensitivity of MAPP to a Long-Lived New Light Scalar (mixed w/ SM Higgs)

The MoEDAL Experiment

(Now 70 physicists Contributing)

- *MoEDAL has taken data in p-p collisions at 8 TeV and 13 TeV Collision Energy as well as in heavy-ion collisions*

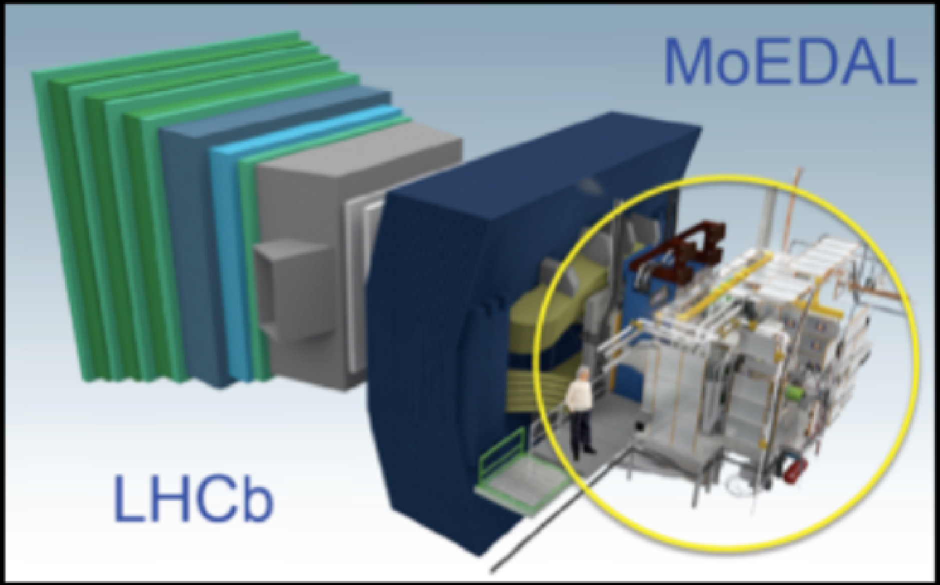


Recent calculations predict a MM mass on the order of *a few TeV!*

(c.f. “The Price of an EW Monopole”, J. Ellis, N. Mavromatos, T. Yu)

The MoEDAL Detector in a Nutshell

Permanent Physical record of new physics



No Standard Model Physics Backgrnds

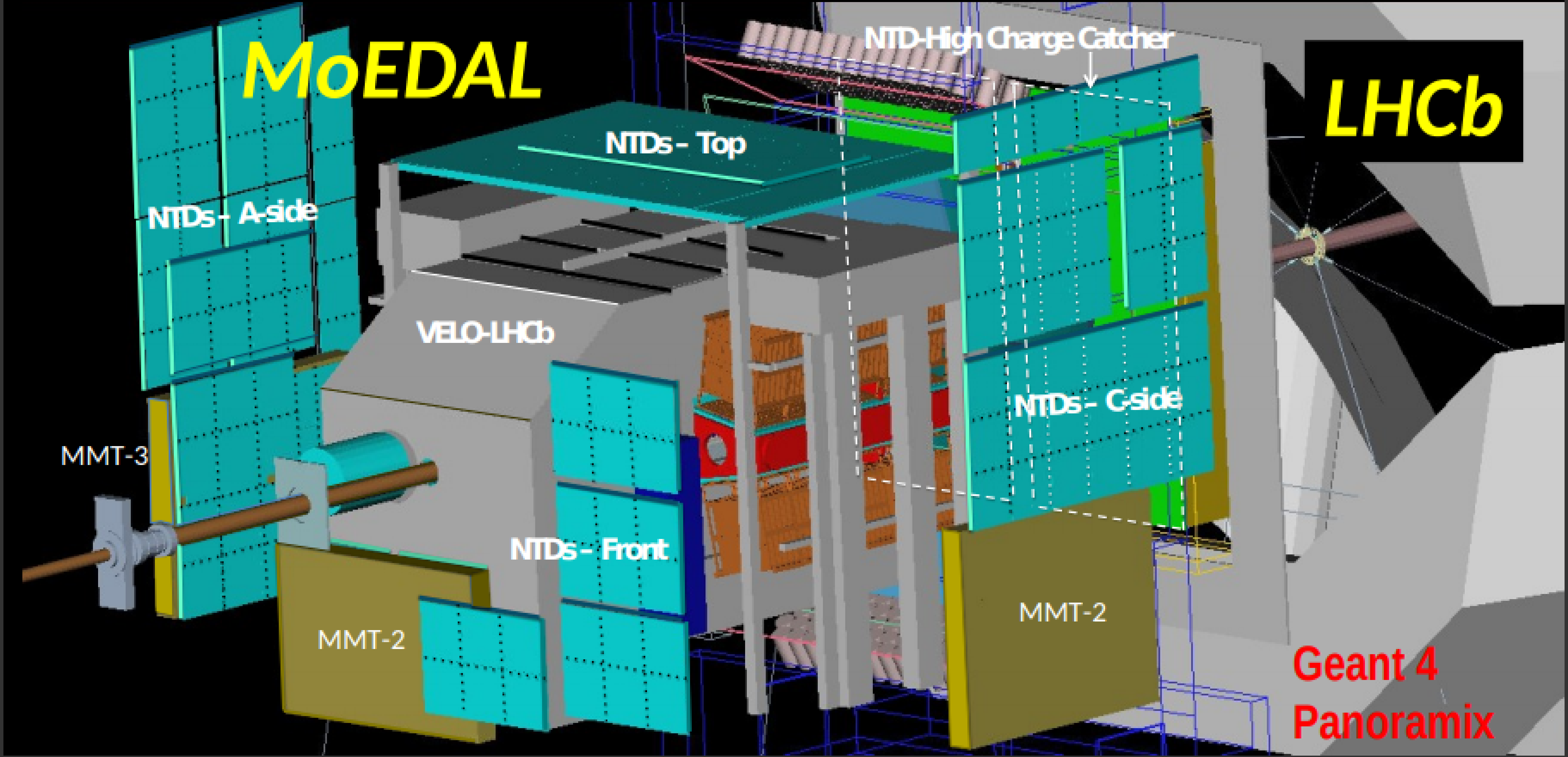
MoEDAL is largely passive and made up of three detector systems

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

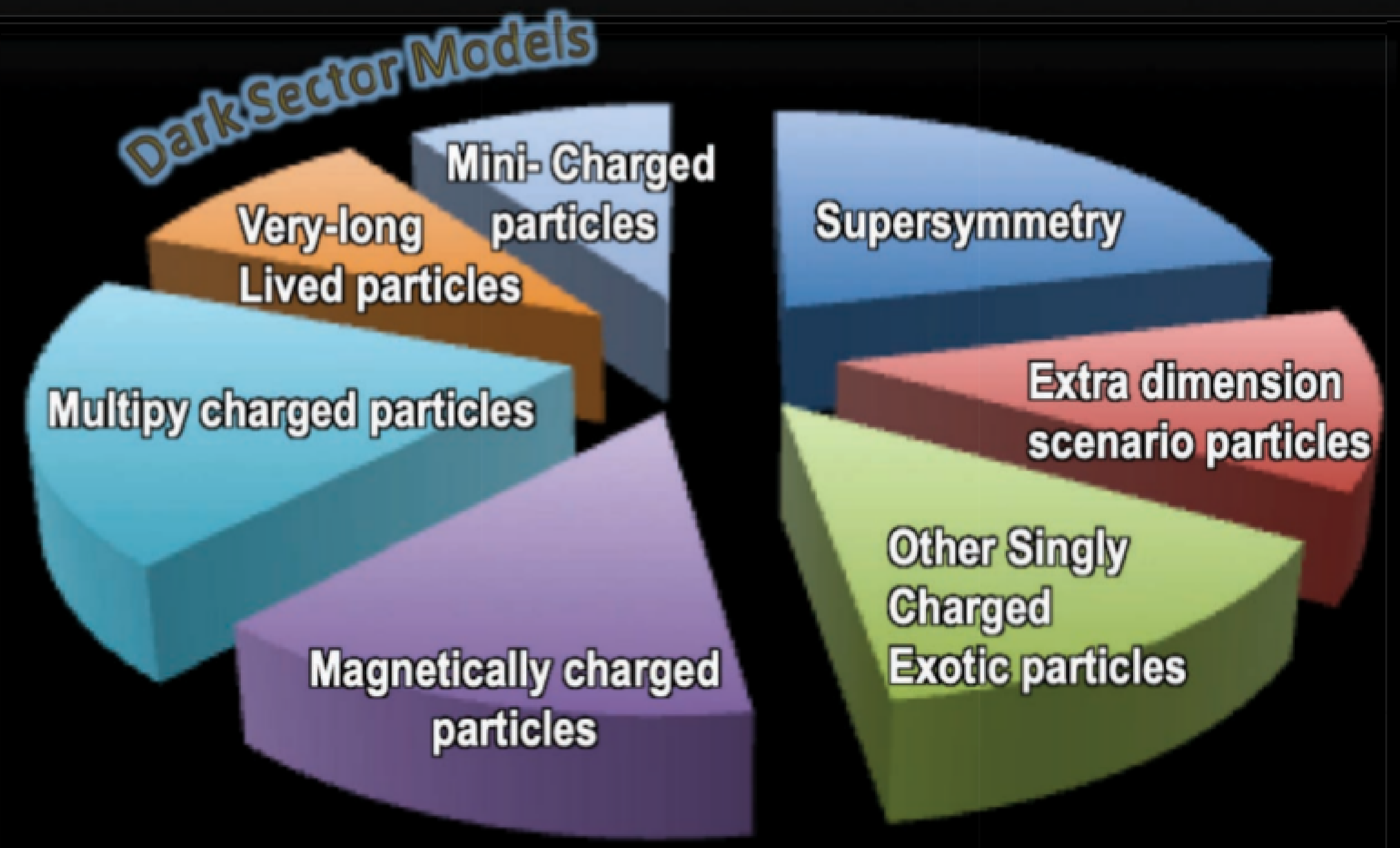
TIMEPIX Array a digital Camera for real time radiation monitoring

The MoEDAL Detector Today



MoEDAL Physics Program

Sensitive to over 40 new physics scenarios



International Journal of Modern Physics A, September 2014, Vol. 29, No. 23

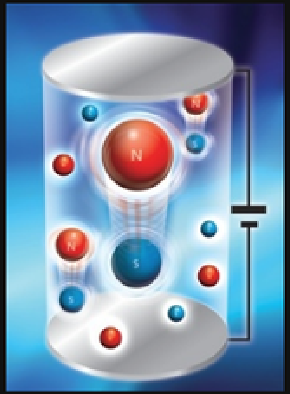
LCN Researchers Create Capacitor Effect for Magnetricity

Researchers at the LCN have created a purely magnetic version of one of the basic effects of electronics - the storage and release of charge in a capacitor. This follows their demonstration last year of the existence of a magnetic equivalent of electricity: so-called "magnetricity".

The new research, published this week in the journal Nature Physics, describes how long lived currents of magnetic charges or "monopoles" may be created in spin ice, the special material that hosts magnetricity. The application of a magnetic field to spin ice charges up the material just like the application of an electric field charges up a capacitor. The subsequent release of the magnetic field causes magnetic currents to flow for several minutes, during which time the current can be measured and characterised in detail.

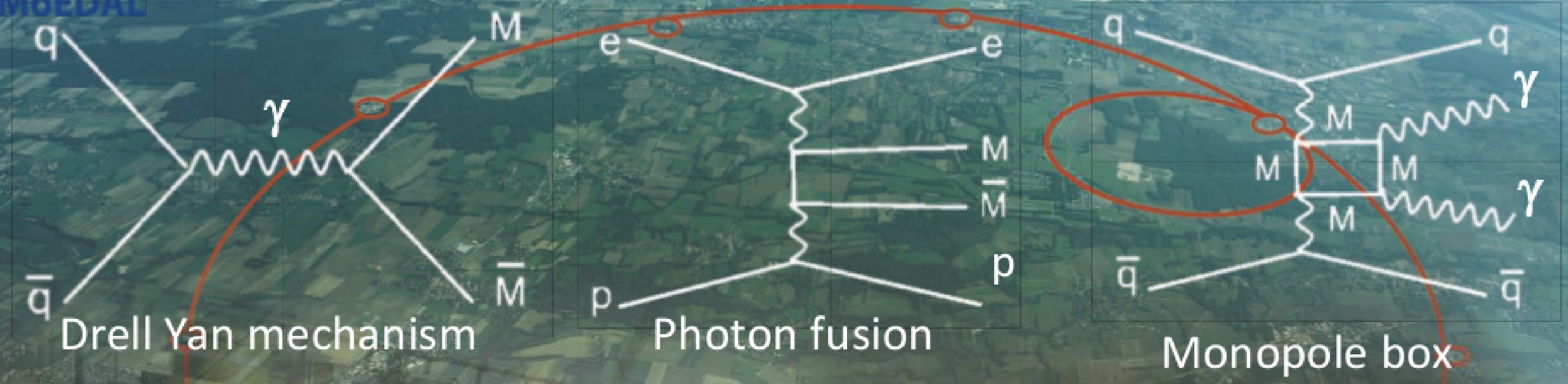
Prof. Steve Bramwell of the LCN collaborated with Dr. Sean Giblin from the ISIS neutron and muon facility, Prof. Ian Terry from Durham University and Prof. Peter Holdsworth from the Ecole Normale Supéieure (ENS) in Lyon, France. They used a sensitive measuring device called a magnetometer to observe and record the magnetic currents in a single spin ice crystal specially prepared by Dr. D. Prabhakaran (Oxford). The researchers then analysed these measurements to prove that the magnetic currents flow in exactly the same way as do electric currents in an electolyte, the material that carries electrical current within a battery.

"These measurements establish how magnetricity works at the atomic level" says Prof. Bramwell, " - we now know how fast the magnetic monopoles move and how they combine to create a magnetic current. Technological applications of magnetricity remain a long way off, but to create a capacitor effect is a prerequisite for any kind of future magnetronics - the magnetic version of electronics."

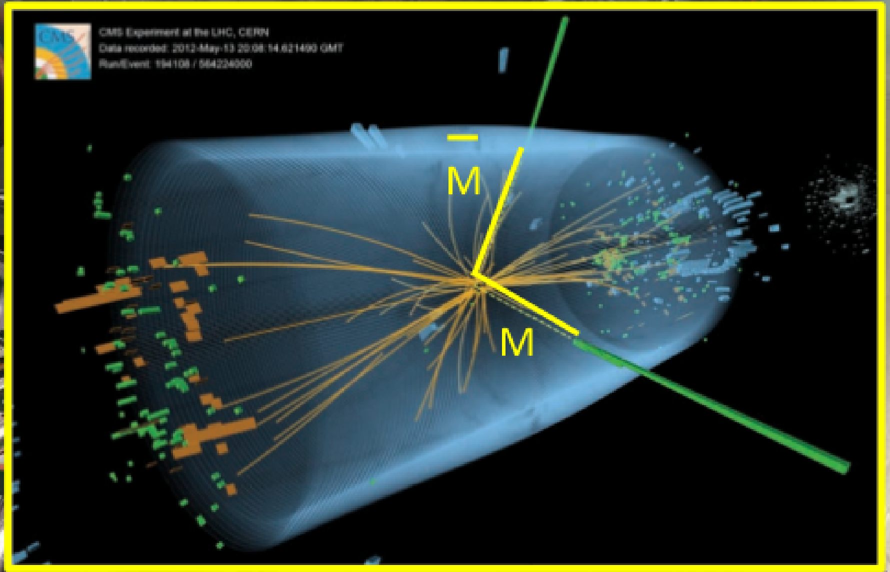


Capacitor effect for magnetic monopoles in spin ice. The application of a magnetic potential adds new magnetic monopoles to a crystal of spin ice which then spring apart and store magnetricity.

Accelerator Searches for Monopoles

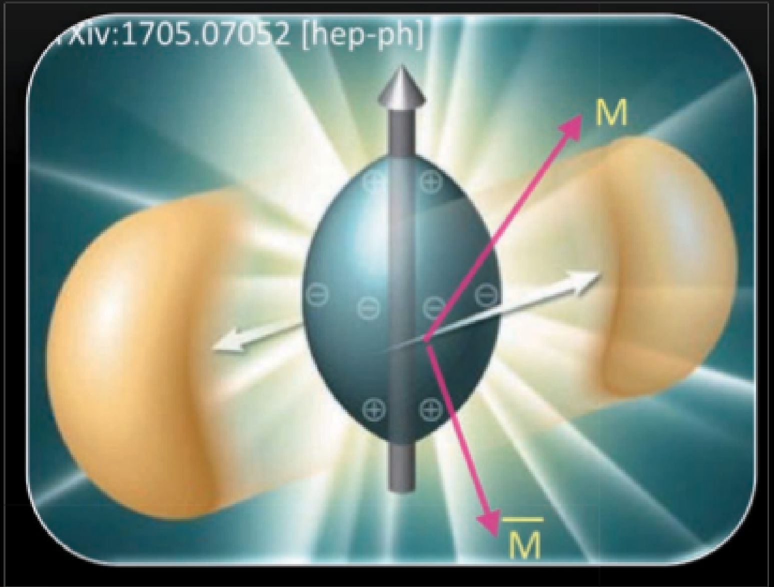


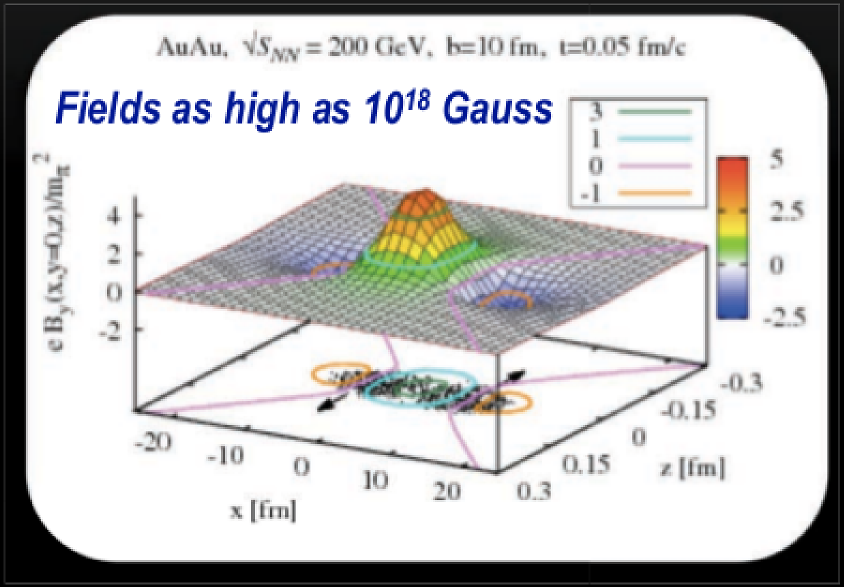
- *Monopole pairs can be directly produced in particle interactions at accelerator experiments*
- *Detection mechanisms, :*
  - *a) High Ionization*
  - *b) Anomalous trajectory*
  - *c) Magnetic induction*



Monopole From Heavy-ion Collisions

via the Thermal Schwinger Mechanism

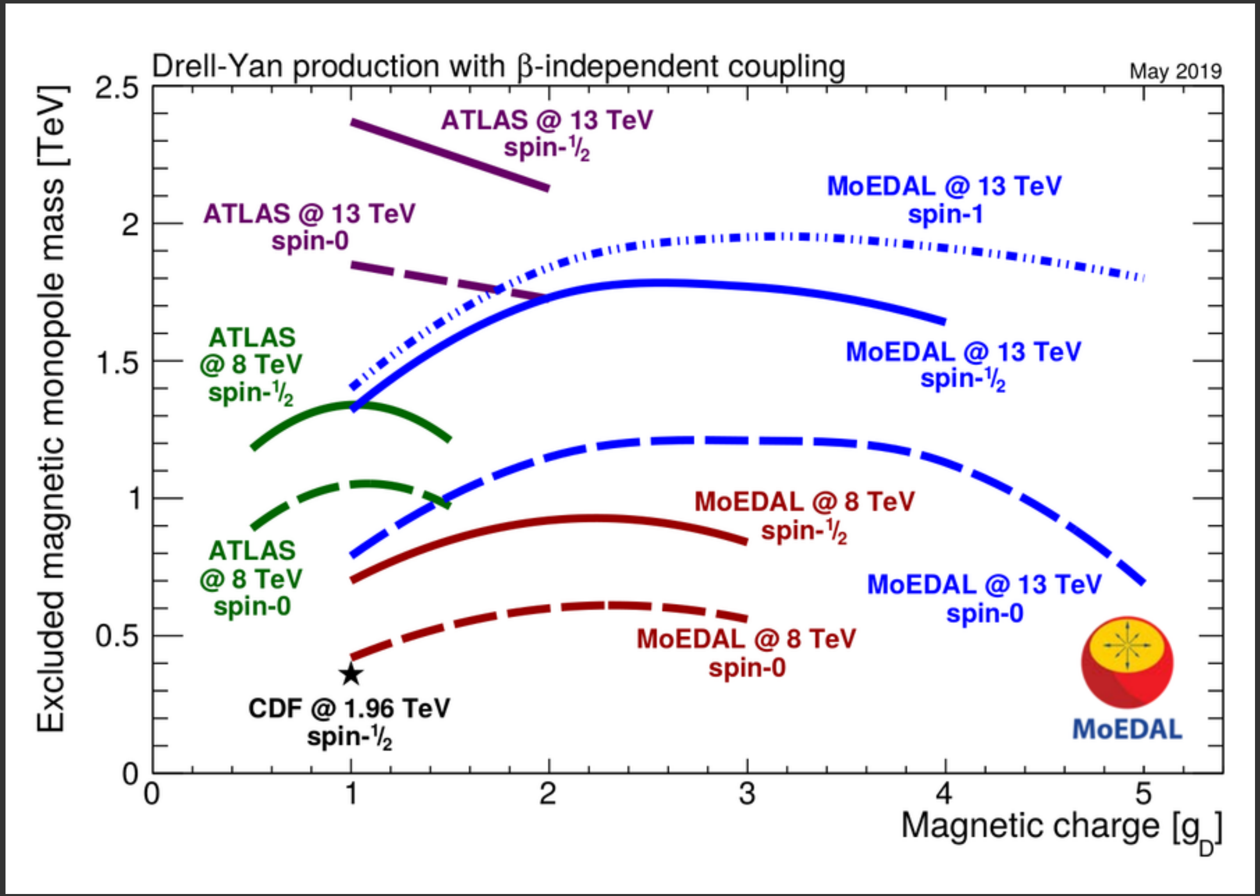


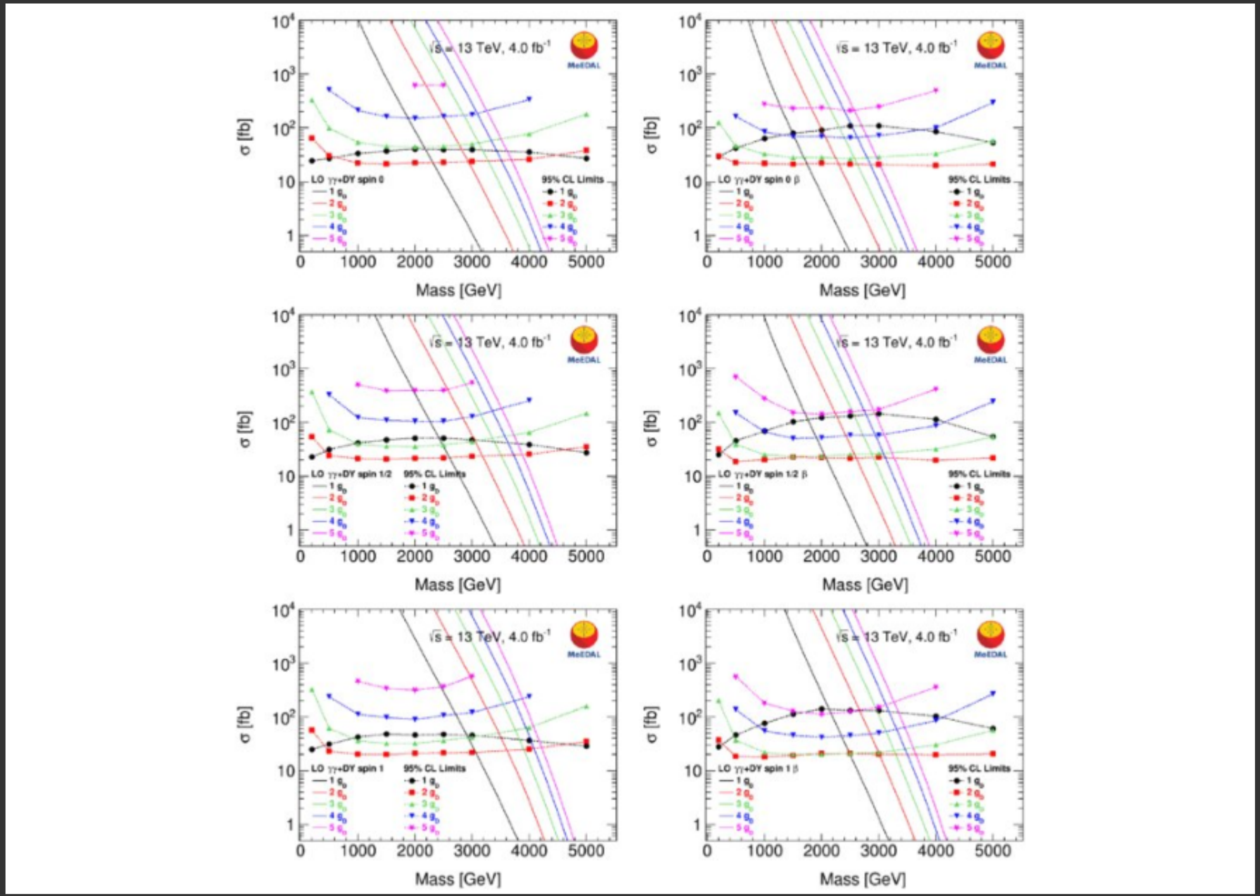


- *Probability of producing a monopole pair $\sigma_{MM} = \sigma_{Inl} V_{ST} \Gamma_T$ (where V_{st} is the space-time volume of the field, Γ_T is the rate/unit volume & σ_{inl} is the inelastic nuclear cross-section)*
- *Important benefits:*
  - *No exponential suppression for finite sized monopoles*
  - *Cross-section calculation does not suffer from non-perturbative nature of coupling as in Drell-Yan production*

MoEDAL's Latest Limits on MM Production @ LHC

Published in PRL July 2019. Including Photon-Photon Fusion for the 1st time @ the LHC.





Spin-1 MM considered for the 1st time @ LHC which corresponds to Lee-Yang Field Theory (Monopole obeys a gauged KG eqn.)

More MoEDAL Results Coming!

- Acquired + Scanned Old CMS Beam Pipe (6m Be pipe cut up & passed through the SQUID @ ETH Zurich)

  No Trapped Monopoles!

- Search for HECOs (Highly Electrically Charged Objects)

  Using the NTD + Run 2 Data

- Search for Schwinger's Dyon (For the first time @ LHC)

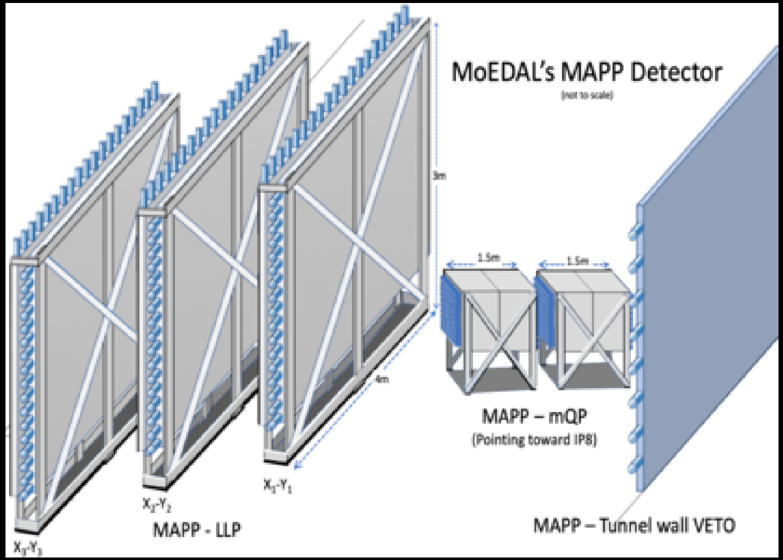
  Using MMT + Run 2 Data

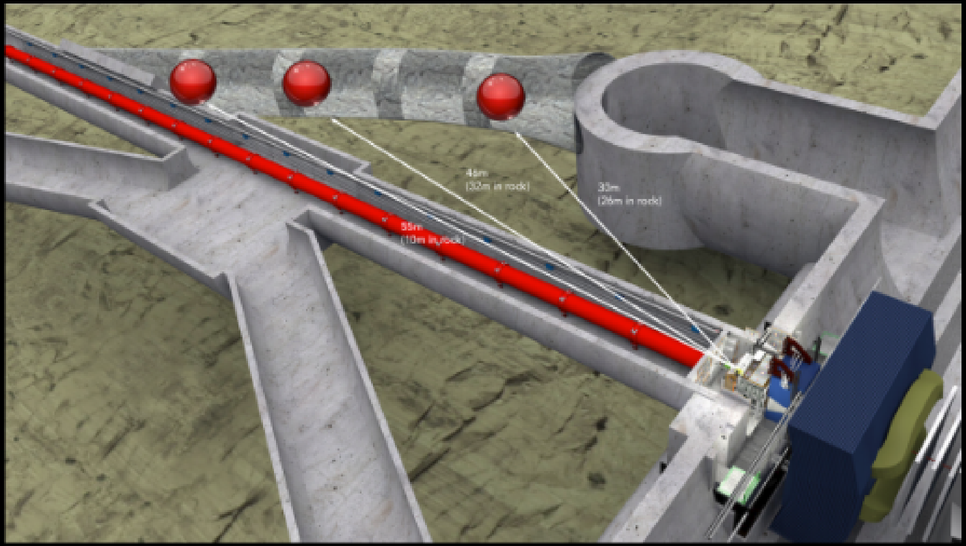
- MoEDAL still looks deeply for SUSY signatures as well

  Still no smoking gun

Upgrading MoEDAL:
The MAPP Detector

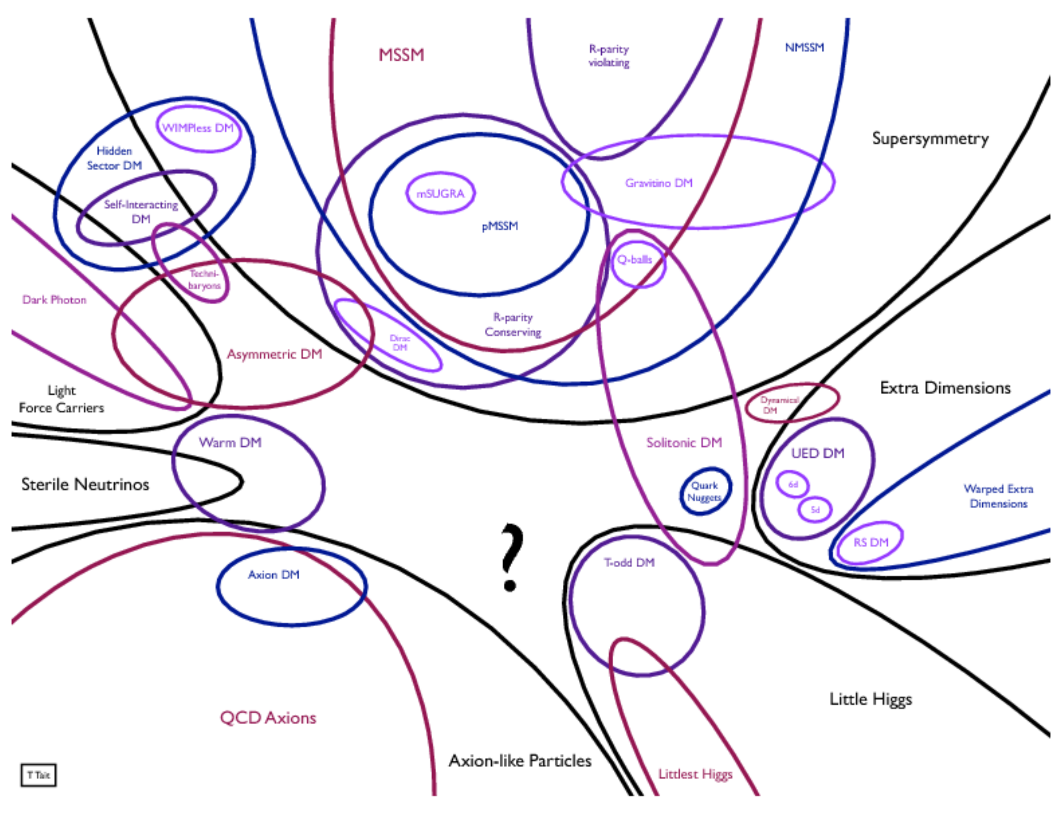
MAPP – MoEDAL Apparatus for Penetrating Particles

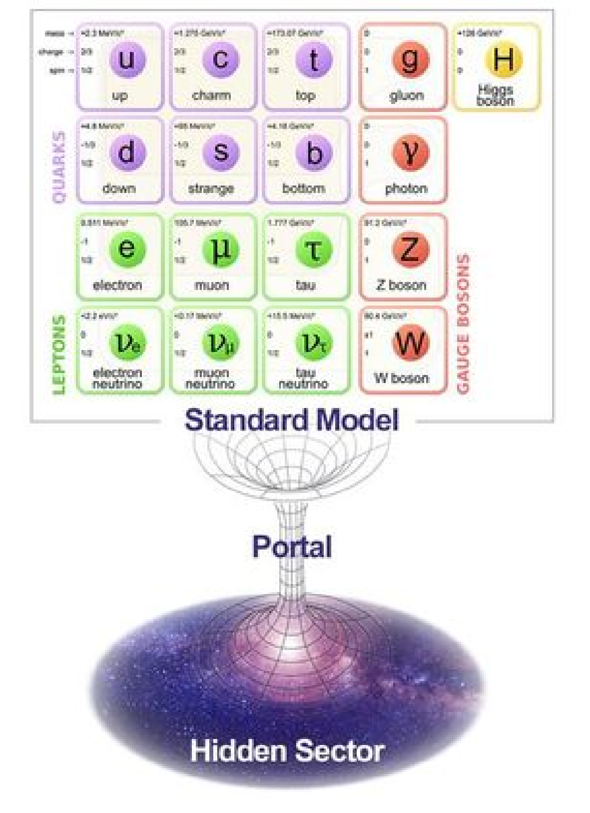




- *MAPP (MoEDAL Apparatus for Penetrating Particles) has 3 motivations:*
  - *To search for "millicharged " particles with charge <<1e*
  - *To search for new neutral particles with very long lifetimes*
  - *To search for anomalously penetrating particles*
- *Detector is protected from SM backgrounds by 20m-30m of rock/concrete and can be moved from 5° to 25° to the beam*
- *Plan for deployment at LHC-RUN3 (2021)*

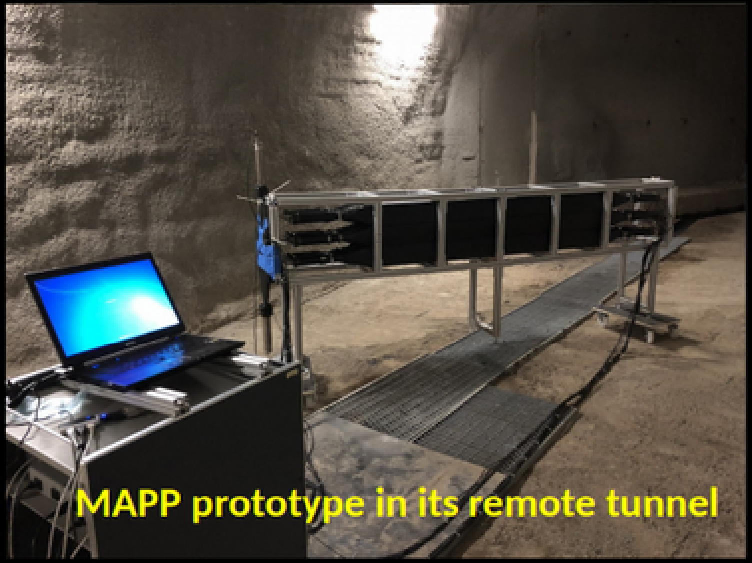
Motivation: DM & Hidden Sectors

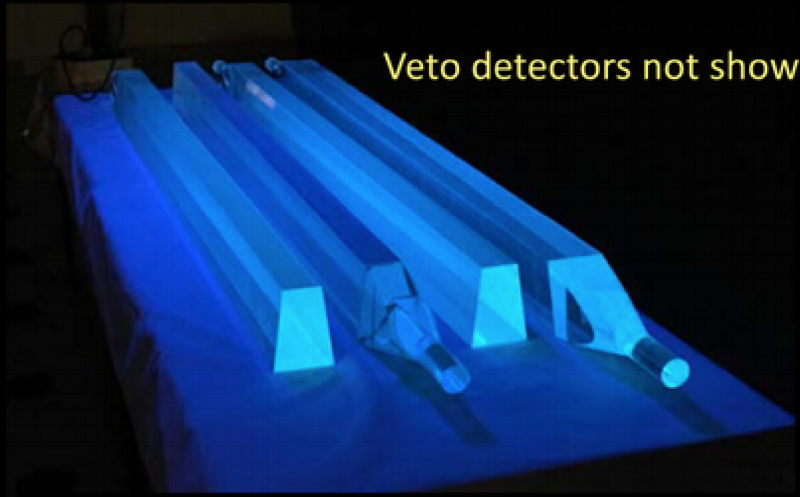




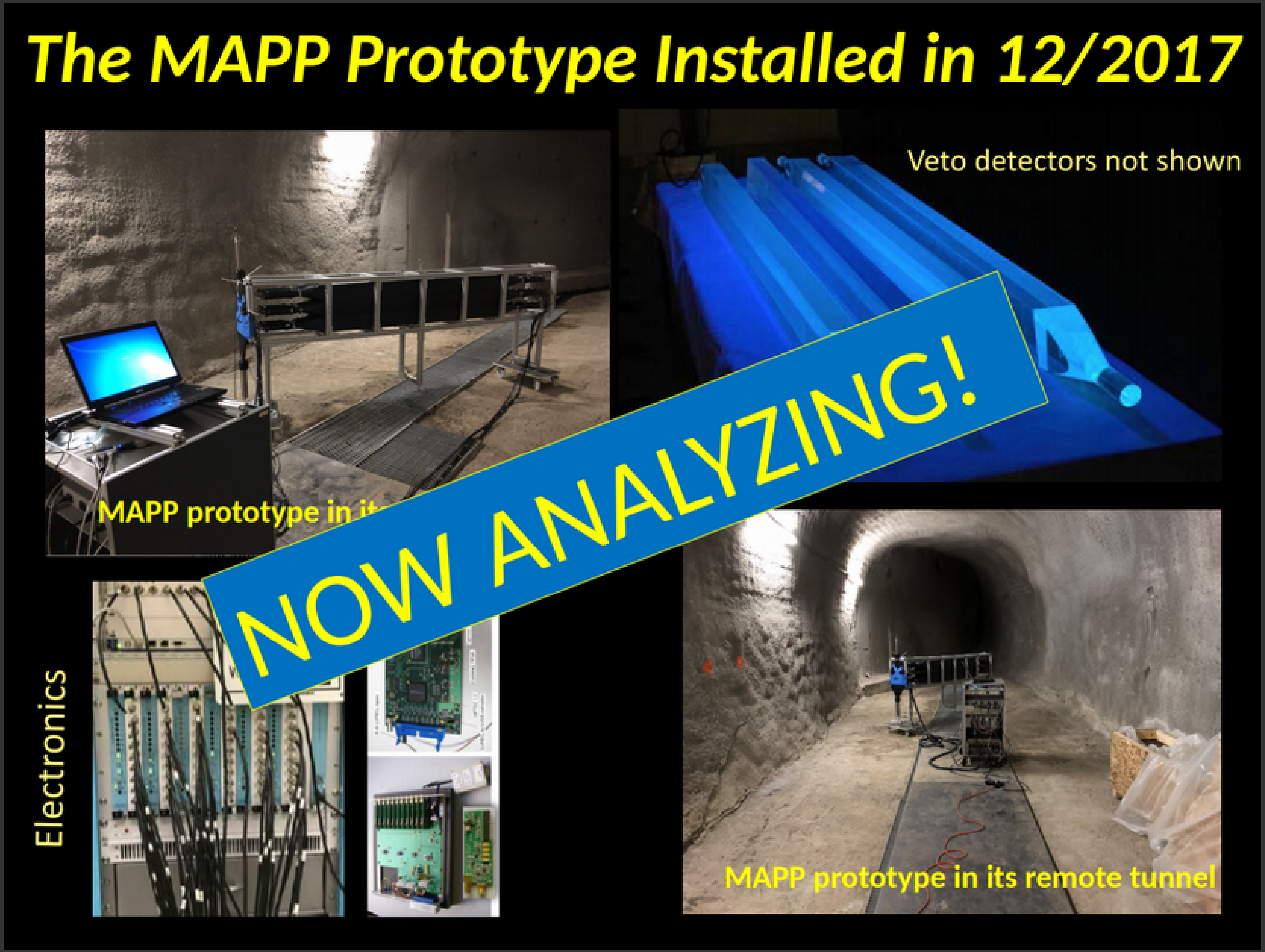
- Vector-Like Portal
  $\epsilon_Y A^{\mu\nu} A'_{\mu\nu}$
- Higgs/Scalar Portal
  $\epsilon_h |h^2||\phi^2|$
- Neutrino Portal
  $\epsilon_\nu L h \psi$

The MAPP Prototype Installed in 12/2017





Electronics



The MAPP Prototype Installed in 12/2017
Veto detectors not shown
MAPP prototype in it
NOW ANALYZING!
Electronics
MAPP prototype in its remote tunnel

MAPP
Physics Performance

MAPP: Physics Processes

- *Explore BSM scenarios from various theories, which have signatures that MAPP could be sensitive to*
- *Use Feynrules + Mathematica to create Madgraph models*
- *Validate models using the literature, analytic calculations, and numerical calculations.*
- *Generate Monte-Carlo events w/ MG5*
- *Write, test, and run simulations of MAPP to get detector acceptance.*
- *Establish MAPP's sensitivity to each of these processes.*

Mini-Charged Particles (mCP) in Dark QED

Dark QED scenario Introduce an extra U(1) gauge field,

A' that mixes with the SM U(1) gauge group. Reformulate this such that the new Dirac fermion ψ couples to the U(1) hypercharge gauge field.

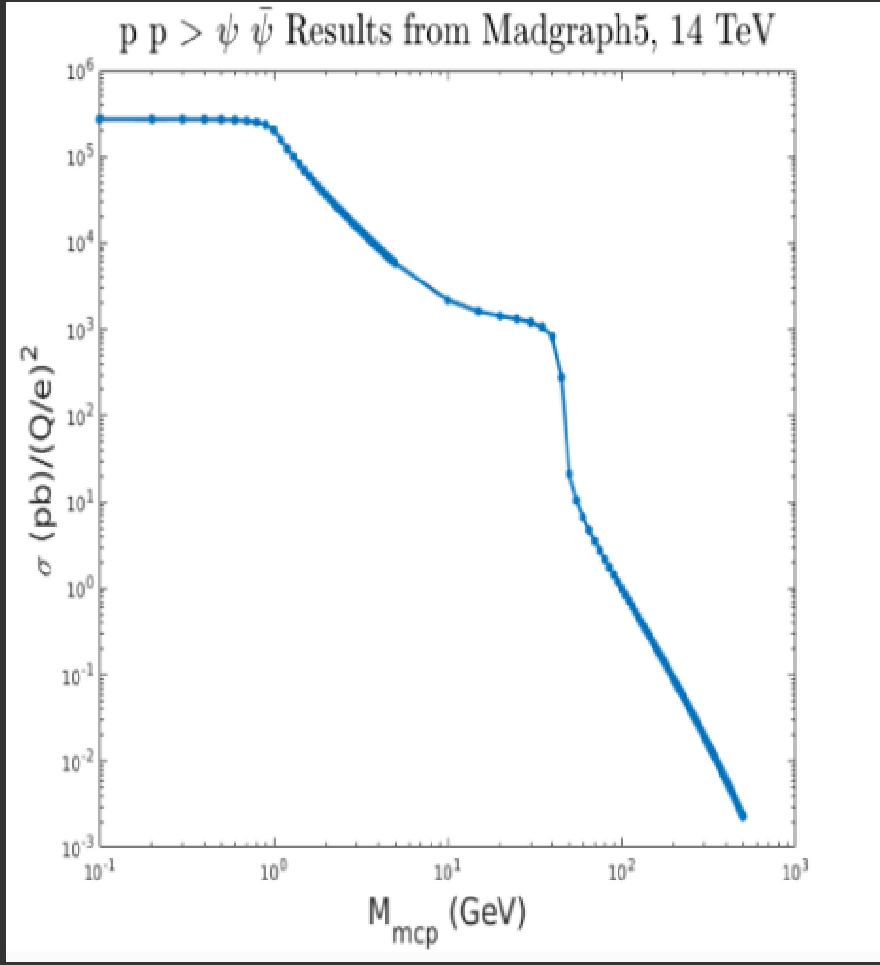
$$\mathscr{L} = \mathscr{L}_{SM} - \frac{1}{4} A'_{\mu\nu} A'^{\mu\nu} + i\bar{\psi}(\not{\partial} + ie'\not{A}' - i\kappa e'\not{B} + iM_{mcp})\psi$$

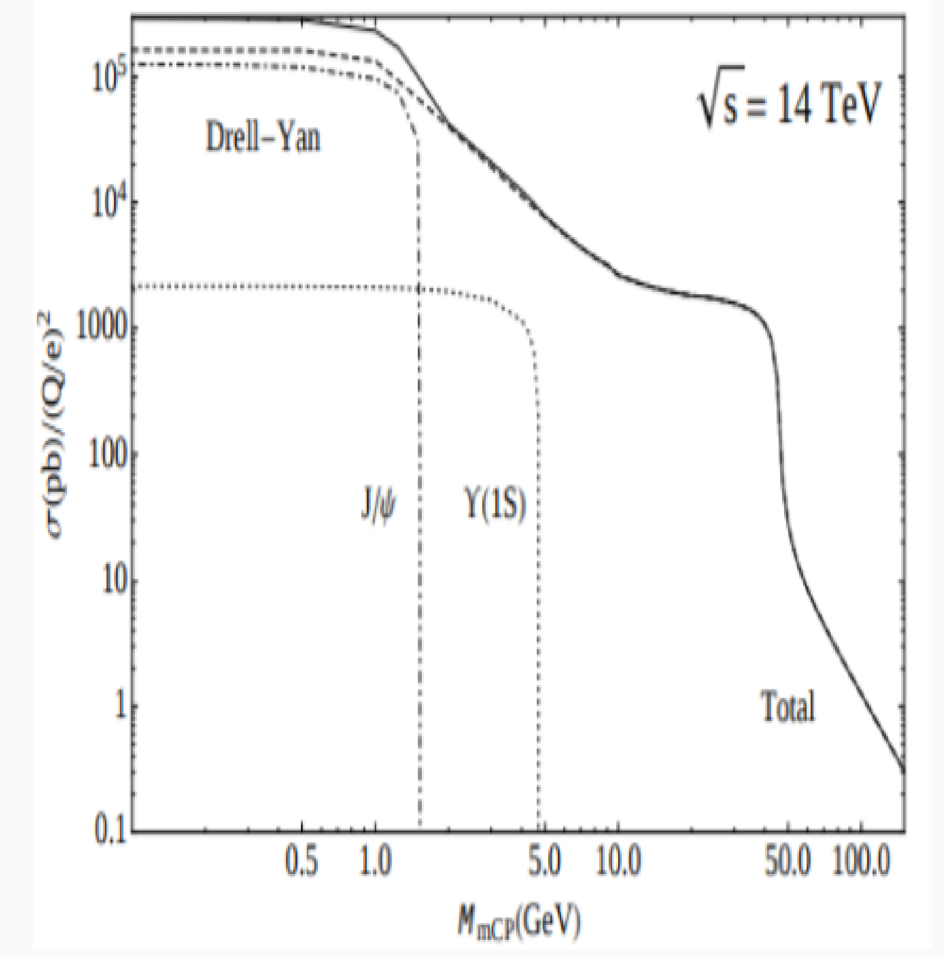
ψ acts a field with a charge of $\kappa e' = \dfrac{e\epsilon}{\cos\theta_W}$

Phys. Lett. B 166, 196 (1986)

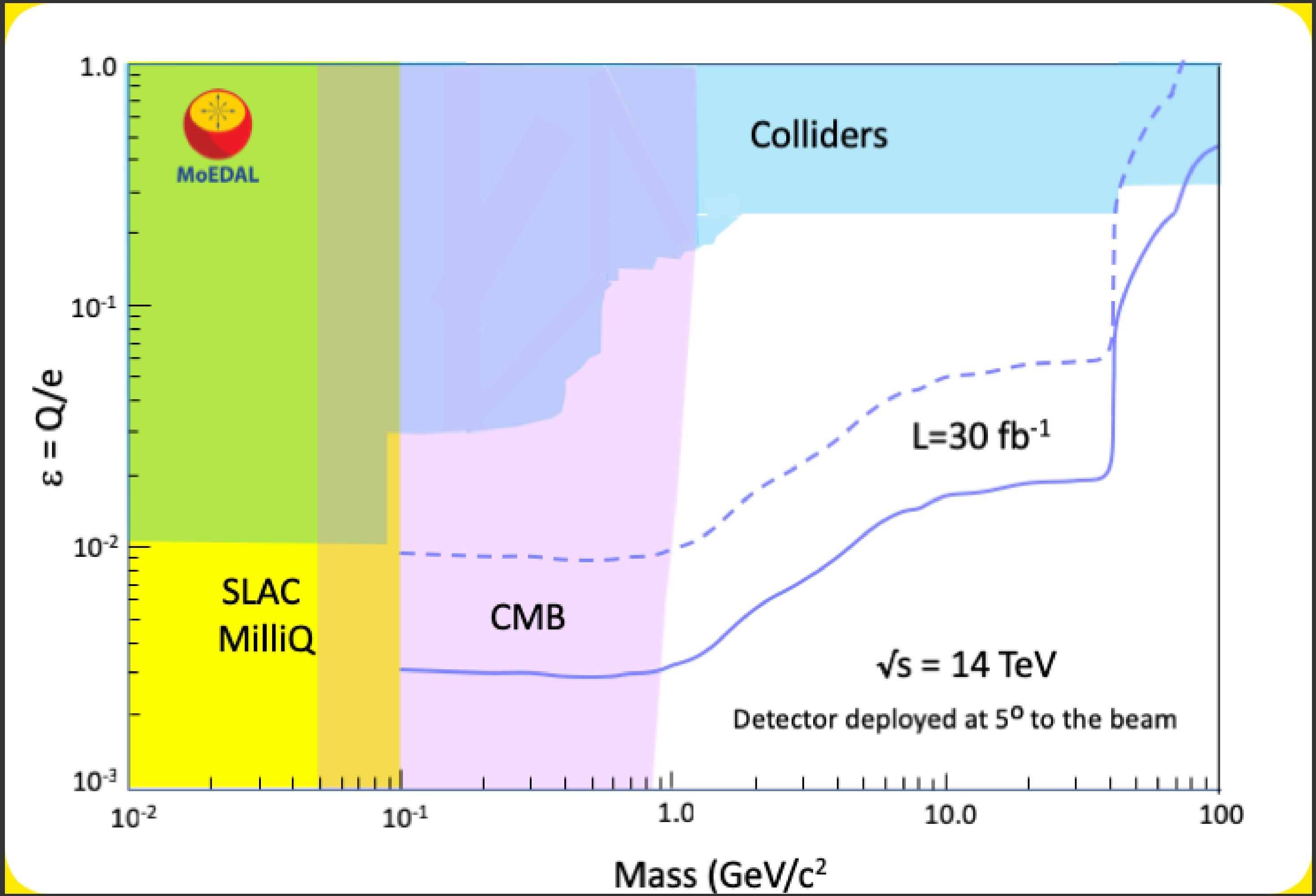
MG5 Cross-Section Results

Drell-Yan Pair Produced mCP





Sensitivity of MAPP to mCP



Long-Lived New Light Scalar (Dark Higgs)

Here the portal between the dark sector and SM is given by a new scalar particle S, coupled to the SM Higgs. A possible Lagrangian including this new dark Higgs is given by:

$$\mathscr{L} = \mathscr{L}_{SM} + \mathscr{L}_{DS} + \mu^2 S^2 - \frac{1}{4}\lambda_S S^4 - \epsilon_H S^2 |H|^2$$

Mixing occurs between SM Higgs and dark scalar via S^4 term. The resulting physical fields are the SM Higgs and a scalar particle ϕ, the dark Higgs.

Arxiv: 1811.12522

Long-Lived Dark Higgs

This coupling between the SM Higgs and dark Higgs induces new Yukawa-like couplings between SM fermions and the dark Higgs. Can write this effective Lagrangian as

$$\mathscr{L}_{eff} = -m_\phi^2\phi^2 - \sin\theta\frac{m_f}{v}\phi\bar{f}f - \lambda v h\phi\phi + \ldots$$

We look at dark Higgs production in rare B decays:

$B \to k\ \phi$

The signal in MAPP is a charged lepton from dark Higgs decay, $\phi \to$l+l-, hitting at least 2 consecutive planes.

Arxiv: 1811.12522

MAPP Fiducial Acceptance of Dark Higgs

100000 Events Generated in Pythia8, with MAPP's fiducial region being ~ 10m x 5m x 3m

Decay Length (m)	MAPP Decays	MAPP Fiducial
10	54	0.00054
20	42	0.00042
30	37	0.00037
40	25	0.00025
50	22	0.00022
60	22	0.00022
70	19	0.00019
80	13	0.00013
90	10	0.0001
100	9	0.00009

95% C.L. Plots have been generated, but are still being cross-checked by Codex-b!

Conclusions & Future Directions

- MAPP is sensitive to mCP between 0.1-100 GeV and down to ~e/500.
- MAPP is competitive and complementary to similar experiments, with a maximum fiducial acceptance (for a LL new light scalar) on the order of a few times 10^-4.
- MoEDAL's HECO and Dyon analyses are still underway + CMS beam pipe scanned.
- Currently establishing MAPP's Sensitivity to other LLP models.
- Full Analysis & Simulation of the Background @ MAPP is a WIP

Thank you!

APS | DIVISION OF PARTICLES & FIELDS