MoEDAL is a passive detector sensitive to new physics only.

It can track (with a permanent record) and trap highly ionizing avatars of new physics such as magnetic monopoles.

MoEDAL’s (proposed) Apparatus for Penetrating Particles (MAPP) will extend our reach to milli-charged particles & long-lived neutrals.
MoEDAL’s Avatars of New Physics

**Avatar** [av-uh-tahr]: An incarnation, embodiment, or manifestation of a person or idea:

- **Very Highly ionizing particles** (≥ 5 times that of a standard relativistic charged particle)
- **Fractionally charged particles** (with charge down to ~1/mille of the electron’s charge)
- **Long lived neutral particles** – (ofto ct ~10)
- **Very long-lived charged particles** (with lifetimes up to ~10 years)
MoEDAL is Sensitive to Many Other New Physics Scenarios

Sensitive to over 40 new physics scenarios

- Supersymmetry
- Extra dimension scenario particles
- Singly Charged Exotic particles
- Magnetically charged particles
- Doubly charged particles
- Milli-Charged particles
- Very-long Lived particles

Acceptance for at least one monopole from monopole pair production to hit the Nuclear Track Detectors (NTDs) ~70% (120 m² of plastic)
The Signal in the Nuclear Track Detectors (NTDs)

Largest NTD array (120m²) ever deployed at an accelerator

- NTD stacks consist of CR39 (Thr. 5 mip) & Makrofol (Thr. 50 mip)
- Damage revealed by controlled etching - etch pits are formed
- Charge resolution is ~1/0.1|e|, where |e| is the electron charge
- Precision of each etch pit measurement ~20-50 microns

NTDs are calibrated at heavy-ion beams at NSRL & NA61
The Principle of the Magnetic Monopole Trappers (MMTs)

Highly ionizing particles lose energy quickly, slow down, stop and are captured in the MMTs.
The Signal from the Magnetic Monopole Trappers (MMTs)

**The Signal**

SQUID coil current is a constant amount after the passage of a monopole.

**The Zurich DC-SQUID magnetometer**

- The MMT can identify magnetic charge.
- The MMT can also trap new massive electrically charged particles.
First ever search for dyons at an acc.

1st ever search for monopole production via γ-fusion at the LHC

First ever limits on a spin-1 monopole
So far MoEDAL has placed the world's best limits on the direct search for magnetic charge (rather than its high ionizing signature)
Other MoEDAL & Related Pubs Since LHCP 2019

Published in PLB
- Searching for heavy neutrinos with the MoEDAL-MAPP detector at the LHC

Published in Eur Phys. J C
- Prospects for discovering SUSY long-lived particles with MoEDAL

Submitted to Eur Phys. J C
- Prospects of searches for long-lived charged particles with MoEDAL

Paper under preparation
- The Search for Highly Electrically Charged Particles at the LHC

Analysis Underway
- The search for highly charge monopole trapped in the CMS beampipe
MoEDAL Results in the Pipeline

Search for Monopole Pair Production via the Schwinger Mechanism using HI Collisions at the LHC
First use of the intense magnetic fields generated in heavy-ion collisions?
arXiv:1705.07052 [hep-ph]

Search for Long-lived Massive Charged Particles at the LHC
Explore SUSY scenarios where we are competitive with other LHC Expts?

Search with Full MoEDAL Detector for Highly Ionizing Particles at 13 TeV
Use the full complement of MoEDAL trapping detectors and NTDs at Run-2
Continue with MoEDAL baseline detector & program to higher energy ($E_{cm}=14$ TeV) and luminosity ($lumi$ – up by 5x at IP8)

Letter of Intent (LOI) endorsed by LHCC; TDR in progress

- Only minor changes to the detector planned
- May need to redesign/relocate HCC to accommodate redesign of LHCb’s TT (UT)
- Major improvements to our NTD system is on track for Run-3, they are:
  - New large-bed computer controlled optical scanning microscopes
  - New deep learning SW developed by our Machine Learning group for automated scanning in the presence of large beam induced backgrounds
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)
MoEDAL’s MAPP Upgrade for Run-3

MAPP (to be installed for Run-3 of the LHC) has 2 motivations

- To search for particles with charges $<< 1e$ (ATLAS & CMS limited to searches with particles of charge around $e \geq 1/3$) with MAPP-mQP
- To search for new weakly interacting neutrals with very long lifetimes with MAPP-LLP.
A small prototype of the MAPP-mQP detector deployed in Dec. 2017

- It consists of 9 x (10cm x 10cm) scintillator bars of length 1.2m complete with readout system
- Studies of this system informed the final design of the MAPP-mQP detector.
MAPP Detector:
- Protected from cosmics by 100m of rock overburden + active veto system
- Protected by 25-26m of rock/concrete (~65 Nuclear Interaction Lengths + forward veto from SM particles from IP8)

MAPP-MQP Detector:
- 100 x (10cm x 10cm x 75cm) scintillator bars in 4 lengths, readout by 4 low noise 3.1” PMTs, in coincidence + hermetic veto detector system

MAPP-LLP Detector
- Fine grained scintillator hodoscope planes with 1cm X/Y resolution readout by SiPMs and picoTDC chips with timing resolution ~500 ps
LEFT: DY production of mQPs in a Dark-EM scenario

RIGHT: The reach for heavy neutrino EDM detection at MoEDAL’s MAPP detector at 14 TeV, with 3 or more events observed at 95% C.L., and 30 fb$^{-1}$ and 300 fb$^{-1}$ of integrated luminosity.
LEFT: Pair production of RH neutrinos from the decay of an additional neutral $Z^0$ boson in the gauged B-L model – for LHC Run 3 (30fb$^{-1}$) (from private communications with F. Deppisch)

RIGHT: Inclusive $B \rightarrow X_s \phi$ decays, where $\phi$ is a light CP-even long-lived scalar (Higgs portal Dark Sector)
We are planning for the HL-LHC run (300 fb⁻¹) to install the MAPP-2 detector.

Here the existing MAPP-LLP detector is extended along the UGC1 gallery as shown above..
LEFT: Reach for 300 fb\(^{-1}\) for the scenario where the Higgs mixing portal admits inclusive \(B \rightarrow X_s \phi\) decays, where \(\phi\) is a light CP-even scalar that mixes with the Higgs, with mixing angle \(\theta \ll 1\).

RIGHT: Pair production of RH neutrinos from the decay of an additional neutral \(Z^0\) boson in the gauged B-L model – for HL-LHC (300fb\(^{-1}\)) (from private communications with F. Deppisch)
Summary

• Analysis of Run-2 data still underway

• MoEDAL has an Exciting Run-3 Program planned that would significantly expand its physics reach.

• Program Planning Underway:
  – Redeploy MoEDAL Baseline Detector for Run-3
  – Install MAPP detector:
    • MAPP-mQP aiming to installed in Winter 2020/21 for Run-3 – Phase 1
    • MAPP1-LLP aiming to stage installation in first two years of Run-3 – Phase 2
    • MAPP2-LLP aiming to stage installation in Long Shutdown 3 – Phase 3
  – MAPP-LLP detector planned for installation after MAPP-mQP

• Discussion document issued: “MoEDAL Request to Take Data at Run-3”.
  – Discussions with LHCb & LHC machine/safety to start forthwith

• LOI endorsed by LHCC & TDR in preparation
EXTRA SLIDES
**MoEDAL in Run 2**

**During RUN-2**

- The MoEDAL detector operated with 100% efficiency during RUN-2
- MoEDAL collected a total of 6.73/fb of a requested 10/fb
NTD Calibration Campaigns in 2018

**AT NSRL**
- BNL NASA Space Radiation Laboratory (NSRL)
- Performed run on Nov 22 2017 (with Igor Ostrovskiy)
- Four different ions used
  - O (z=8), Si (z=14), Fe (z=26) at 1000 MeV/n
  - Kr (z=36) at 400 MeV/n
- Two additional angles used for Fe, one stack each at 15° and 30° from normal
- 12 stacks of plastic exposed
  - A mix of CR39 types used for O, Si and Fe
  - CR39 and Makrofol exposed to Kr
- Stacks now in Bologna not yet etched

**AT NA61**
- Samples were irradiated at NA61
- 17 of 50 stacks of plastic exposed
- 150 GeV/n Pb beam
- Beam spot small so plastic remotely moved in x and y during the spill gate to expose the entire surface
- Assortment of CR39 and Makrofol
- Plastic at Bologna

O, Si, Fe at 1 GeV/N, Kr at 0.4 GeV/N, 150 GeV/N Pb beam

Data used to calibrate NTD plastic and also as training data for MoEDAL’s Deep Machine Learning Group
The construction of the MAPP-mQP and forward veto wall is underway at the UofA.

- We are looking at installation in the Fall->Winter of 2020/21.
- The MAPP-LLP detector will be deployed in the Winter of 2021/22 and 2022/23.
After exposure MoEDAL trapping volumes will be monitored in the UGC1 gallery, for the decays of trapped extremely long-lived particles using the MALL scintillator-based detector.

Lifetimes as long as ~10 years can be probed.

The planned detector has a low threshold (eg ~1 GeV muons) and is sensitive to electrons, muons, hadrons and photons.
A) MAPP-mQP

B) MAPP-LLP

C) MALL

A. DY production of mQPs in a Dark-EM scenario

B. Inclusive $B \rightarrow X_s \phi$ decays, where $\phi$ is a light CP-even long-lived scalar (Higgs portal Dark Sector)

C. Superwimp model for CDM – Eg the lifetime of a 150 GeV stau $\rightarrow$ 100 GeV gravitino is about $10^9$ s