Searching for a Mixed-Phase Milil-Charged Dark Sector at MoEDAL-MAPP

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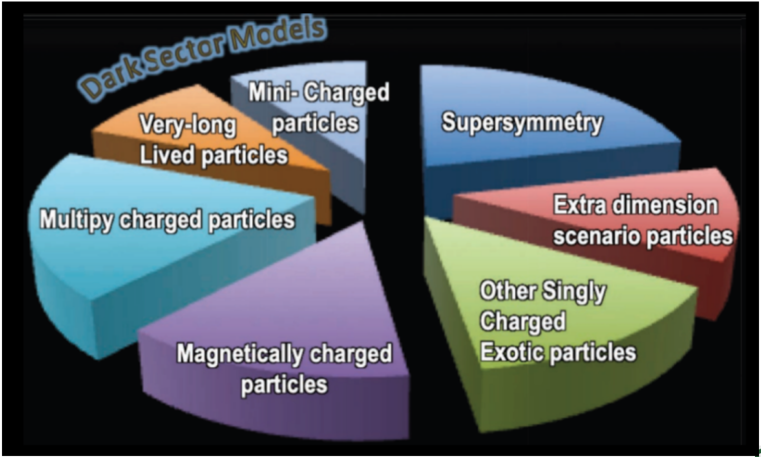
MoEDAL Experiment

MoEDAL stands for **Mo**nopoles and **E**xotics **D**etector **A**t the **L**HC

- MoEDAL is the first dedicated search detector at the LHC.
- One of world's best limits on the existence of singly and multiply charged MMs.
- Carried out first-ever searches for Spin-1 MMs and dyons at colliders, and MMs produced in heavy-ion collisions via Schwinger mechanism.
- Is complementary to General Purpose Detectors such as ATLAS and CMS.

MoEDAL-MAPP Experiment

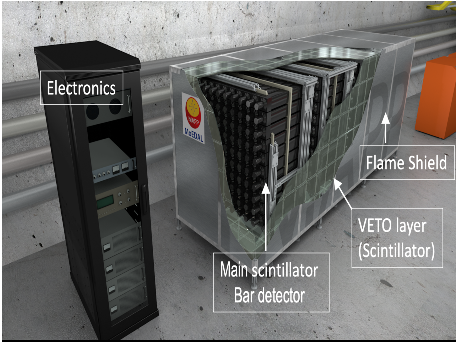


MoEDAL-MAPP

MAPP stands for **M**oEDAL **A**pparatus for **P**enetrating **P**articles

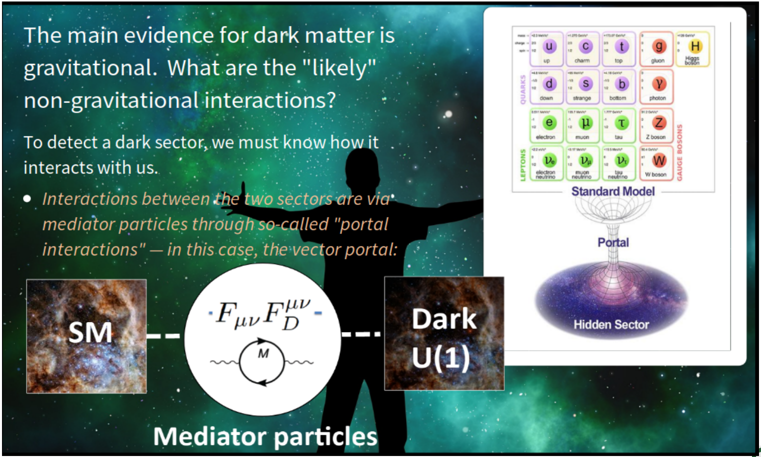
- Designed to search for FIPs: mCPs and heavy neutrinos with an anomalously large EDM.
- Sensitivity to charged and neutral LLPs.
- The main LHC experiments are not optimized for HIPs, FIPs.

MoEDAL-MAPP1



- Located at UA83, about 100m from the LHCb IP at about 7° from the beam axis
- 400 scintillator bars ($10 \times 10 \times 75cm^3$) readout by PMTs
- Each particle going through covers 3m of scintillator

MAPPing the Dark Sector



mCPs - Holdom Phase

- Mini-charged particles (mCPs) are hypothetical non-SM particles that have a fraction of the charge of electron e.
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- A standard mCP model (Holdom Phase) would have a massless $U'(1)$ gauge field: the dark photon, coupling to $B^{\mu\nu}$.
- Have a massive dark fermion ψ_{mCP}, with a mass of m_{mCP} that couples to A'_μ, with a charge of e'
- Would have a kinetic mixing term in the Lagrangian:

$$\mathcal{L}_{mix} = -\frac{\kappa}{2} B_{\mu\nu} A'^{\mu\nu}$$

- Effective Charge: $\kappa e'$

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- This is a more general model, and one can differentiate the mixed phase from the Holdom phase by studying the decay of dark Z to a pair of mCPs in the detector.

Production Mechanism

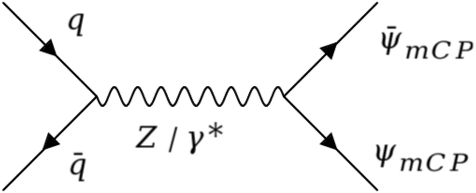

Figure: Drell-Yan Process for the Holdom phase

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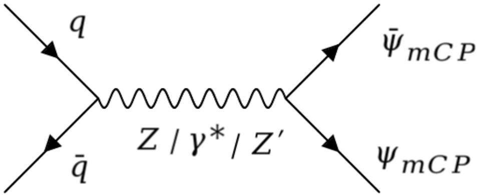

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Holdom vs Mixed Phase

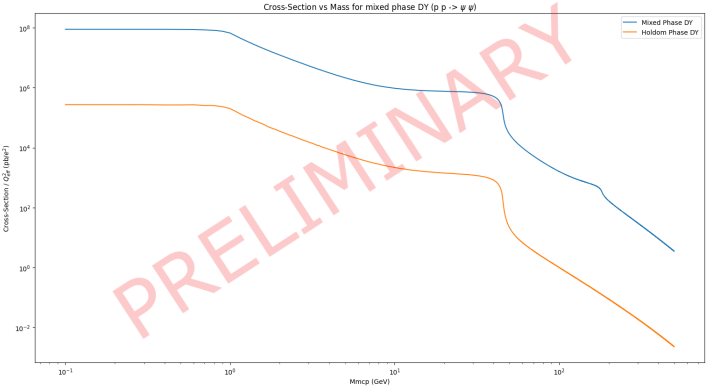

Figure: Cross-Section of Mixed Phase vs Holdom Phase

Preliminary Sensitivity Plot

- To generate a preliminary sensitivity plot of MAPP-1, we use the following formula for the estimated number of signal events:

$$N_{\mathrm{sig}} = N_{\chi} \times A \times P \tag{1}$$

- For a 95% C.L. N_{sig} equates to having 3 hits (Background free) in the detector. $N_{\chi} = \sigma L$, and A is given by:

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With a 25% QE and $N_\gamma \simeq 6.824 \times 10^5$, we get $N_{PE} = 1.706 \times 10^5 Q^2$

Staelens, Michael et. al 10.1007/JHEP04(2024)137.

Sensitivity Plot with Detector Efficiency factored in

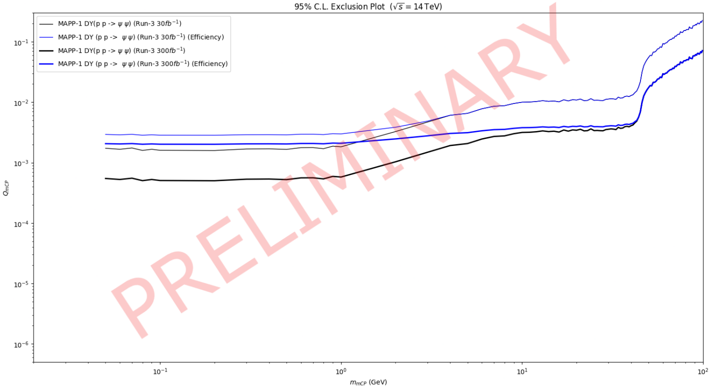
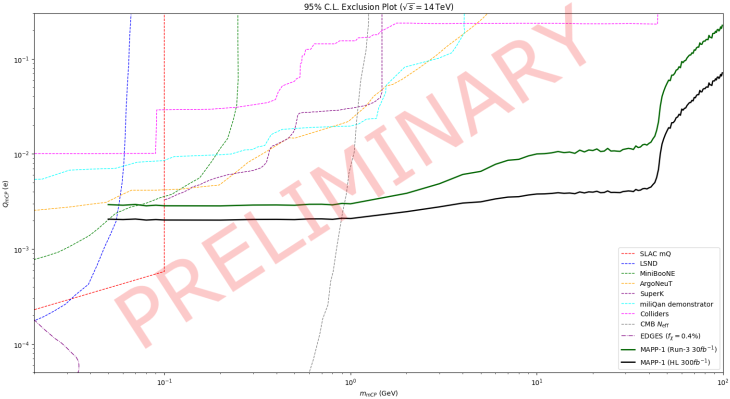


Figure: Sensitivity plot with Detector Efficiency included and without

Sensitivity Plot



Conclusions and Future Work

- Constructed a model of mixed phase mCPs and performed preliminary analysis in the context of MoEDAL-MAPP.
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- Further studies with different masses of the dark Z, as well as the dark Weinberg angles.
- Perform a full detector simulation with GEANT4.

Thank You

References for the Sensitivity Plot:

SLAC mQ (The Millicharged Particle Search) — Phys. Rev. Lett. 81, 1175.

LSND (Liquid Scintillator Neutrino Detector) — Phys. Rev. Lett. 122, 071801. Data from LSND used in their analysis is from Phys. Rev. D 63, 112001.

miniBooNE (Mini Booster Neutrino Experiment) — Phys. Rev. Lett. 122, 071801. Data from miniBooNe used in their analysis is from Phys. Rev. Lett. 121, 221801 and Phys. Rev. Lett. 98, 112004.

Colliders/Accelerators — The collider bounds are combined limits from beam dump experiments and LEP presented in JHEP 2000, 003. There are also two papers that I know of with bounds from CMS (but they only cover $e/3 < Q < e$), so they are cut-off on my versions of the limit plots.

ArgoNeuT (The Argon Neutrino Teststand) — Phys. Rev. Lett. 124, 131801.

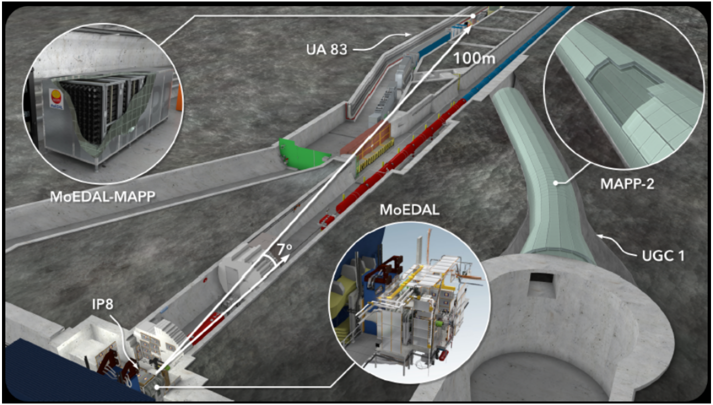
milliQan Demonstrator — Phys. Rev. D 102, 032002.

SuperK — Phys. Rev. D 102, 115032.

CMB N_eff (Indirect) — JHEP 2013, 58; JCAP 2014, 029.

BACKUP

MoEDAL-MAPP



Details into the Detector

- PMT - XP72B22
- QE estimate of 25% is consistent with both the manufacturer specifications and the measurements reported by the JUNO experiment.
- Scintillator bars are wrapped with Tyvek®, and GEANT4 simulations assumed an overall surface reflectivity of 98%, a bulk light attenuation length 2.6 m, and a light output of 10000 photons/MeV.
- Modeled the silicone (refractive index of 1.44) light guide at the end of the scintillator bar.

Background

- Preliminary GEANT4 estimates suggest that collision-related BG rates are of the order of approximately one event per millisecond, a significant portion of which can be vetoed.
- We estimate an approximately dead time of around 50 to 100 ns per 40,000 bunch-crossings.