MoEDAL-MAPP Weekly Meets

Oct 15 2020

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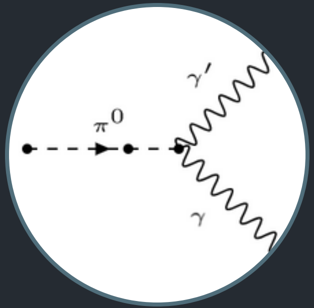
Overview



The Physics Case of the MAPP Detector

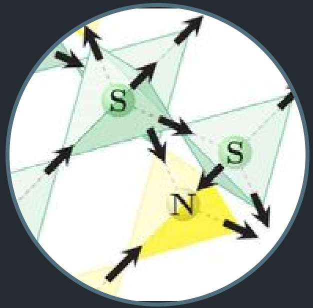
Updates on LLP Models:

Dark Photons --> 95% CL Curve complete

ALPs - In progress

2 EPJ papers in progress..

GEANT4 mCP Simulations in development..



Emergent Monopoles

Modeling Emergent Monopole Excitations in spin ice.

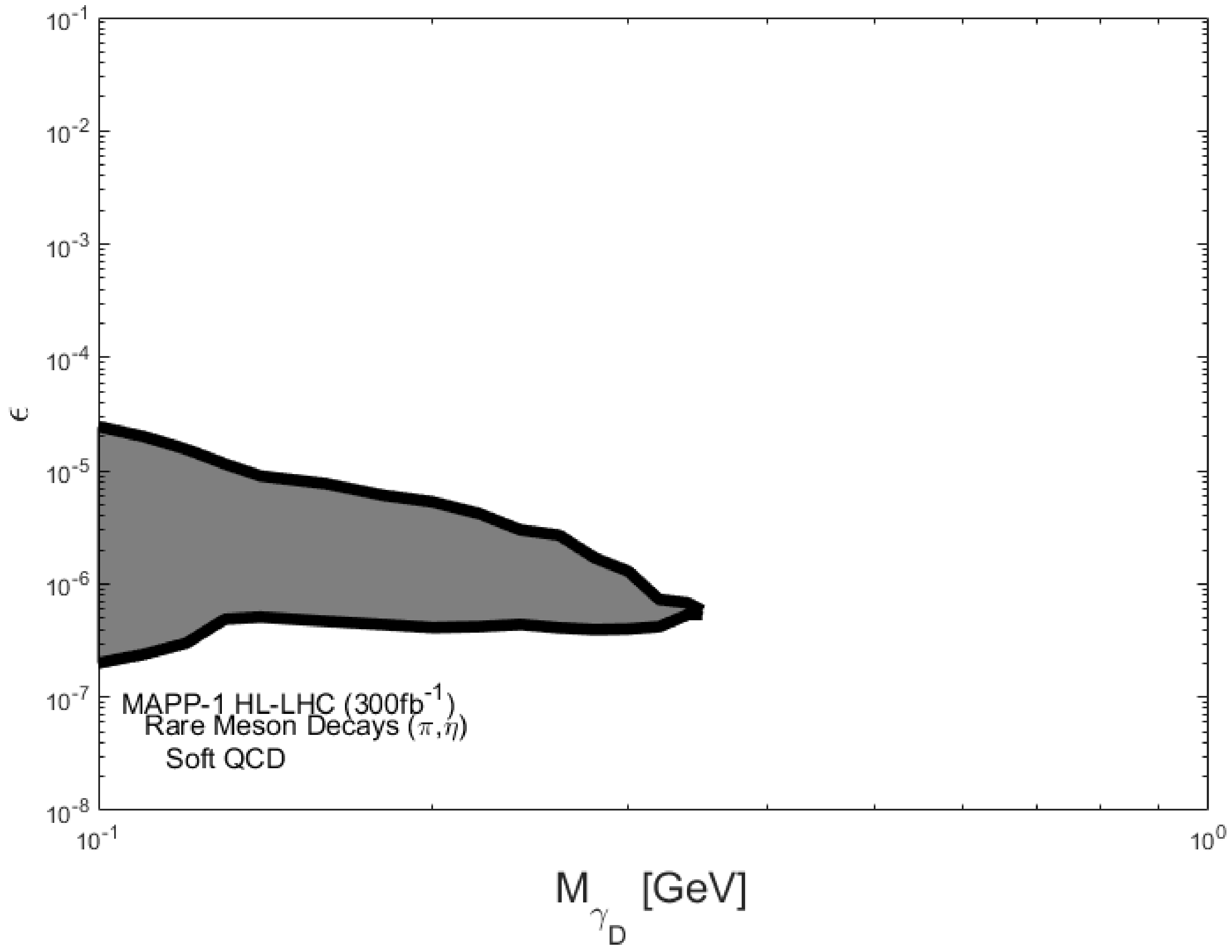
Calculation Part 1: 2nd Quantized Hamiltonian

Calculation Part 2: H in k-space

Calculation Part 3: EOM(s) Derived

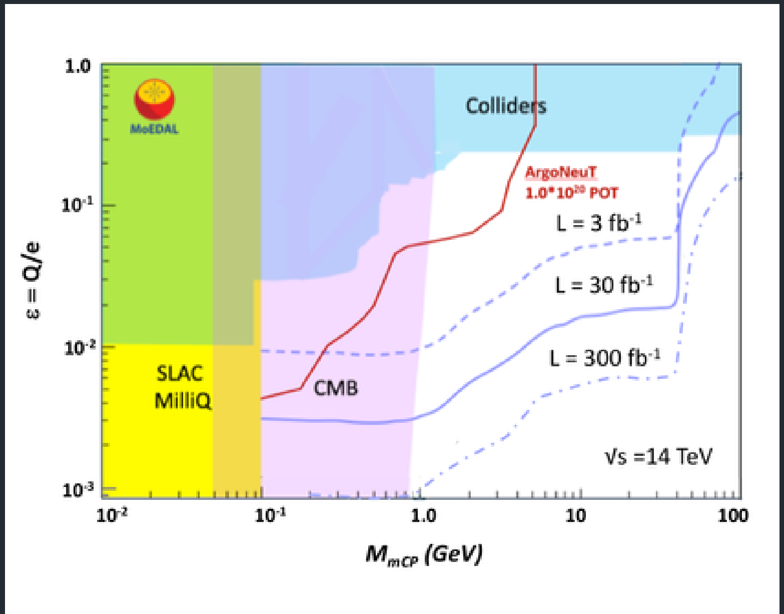
Physics Performance of the MoEDAL-MAPP Detector

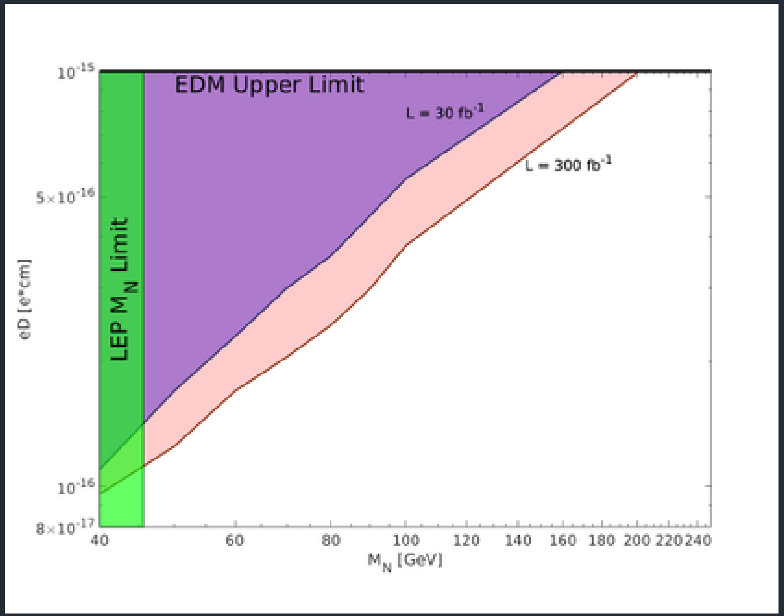
Meson Results Updated

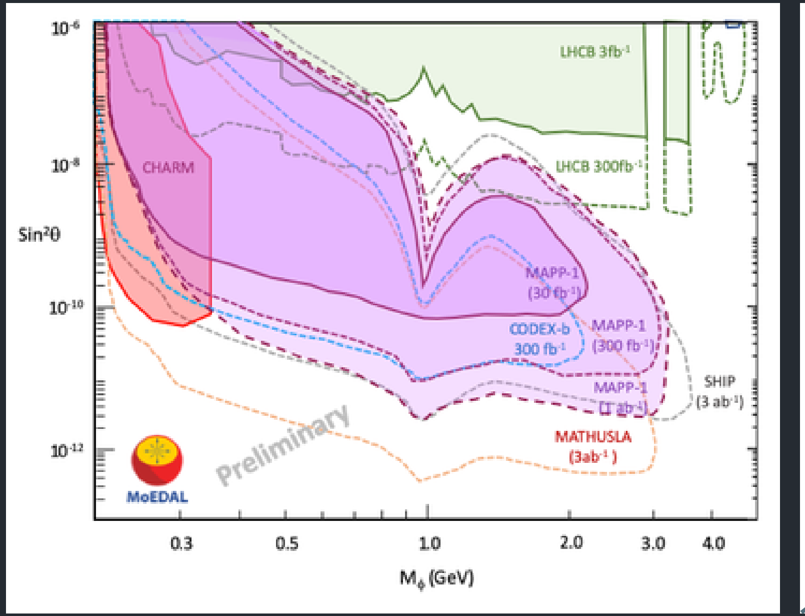


10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
ϵ
MAPP-1 HL-LHC (300fb^{-1})
Rare Meson Decays (π,η)
Soft QCD
10^{-1}
10^{0}
M_{γ_D} [GeV]

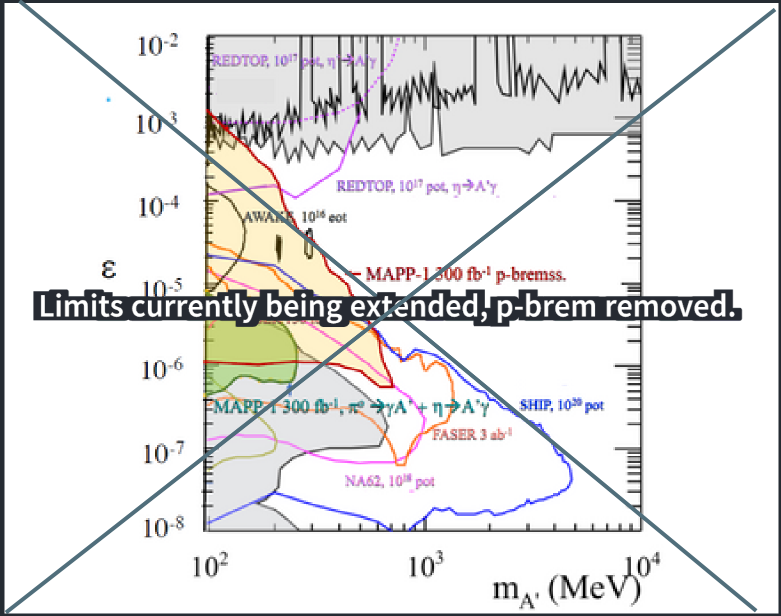
MAPP-1.. Results So Far



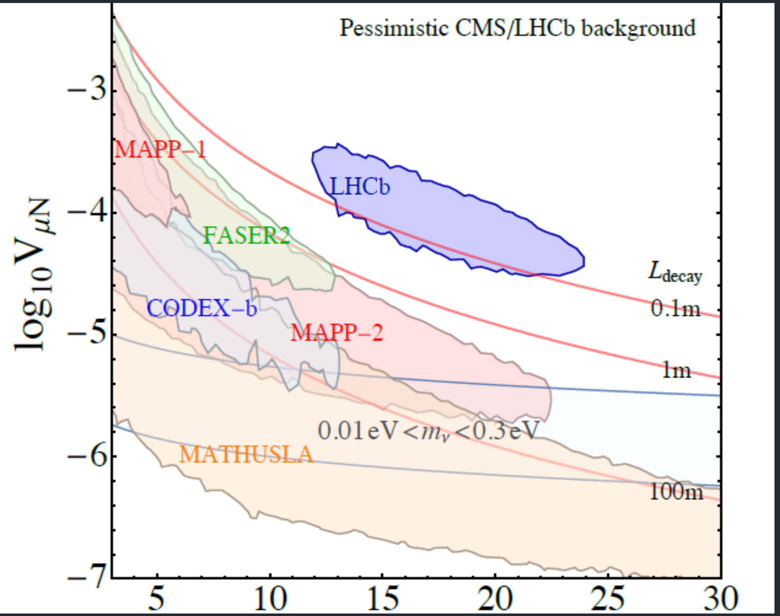




MAPP-2 Dark Higgs Limits for HL-LHC also done & FCC (Coming)



Limits currently being extended, p-brem removed.



External Study1

Emergent Monopoles

The Method of Coherent Structures (MCS)

Applied to a system aimed to be a first approximation at a spin-ice. (A Frustrated system)

$$H = J_1 \sum_{i=1}^{N} (\boldsymbol{S}_{1,i} \cdot \boldsymbol{S}_{1,i+1} + \boldsymbol{S}_{2,i} \cdot \boldsymbol{S}_{2,i+1} + \boldsymbol{S}_{3,i} \cdot \boldsymbol{S}_{3,i+1}) + J_2 \sum_{i=1}^{N} (\boldsymbol{S}_{1,i} \cdot \boldsymbol{S}_{2,i} + \boldsymbol{S}_{2,i} \cdot \boldsymbol{S}_{3,i})$$

- **The MCS begins with a generic spin Hamiltonian. We take 3 coupled 1-d lattices w/ NN interactions and couplings J1, J2.**

$$H = J_1 \sum_{\alpha=1}^{3} \sum_{i=1}^{N} \boldsymbol{S}_{\alpha,i} \cdot \boldsymbol{S}_{\alpha,i+1} + J_2 \sum_{\alpha=1}^{2} \sum_{i=1}^{N} \boldsymbol{S}_{\alpha,i} \cdot \boldsymbol{S}_{\alpha+1,i}$$

- **In order to obtain a QFT description, we begin by second-quantizing this Hamiltonian (which is standard procedure in the MCS)**

2nd Quantized Hamiltonian

Expanded up to order a1^2 (six-legged terms)

$$
\begin{aligned}
H = J_1 \sum_{\alpha=1}^{3} \sum_{i=1}^{N} S^2 - S(b^\dagger_{\alpha,i} b_{\alpha,i} + b^\dagger_{\alpha,i+1} b_{\alpha,i+1} - b^\dagger_{\alpha,i} b_{\alpha,i+1} - b^\dagger_{\alpha,i+1} b_{\alpha,i}) + b^\dagger_{\alpha,i} b_{\alpha,i} b^\dagger_{\alpha,i+1} b_{\alpha,i+1} \\
+ S a_1 (b^\dagger_{\alpha,i} b^\dagger_{\alpha,i+1} b_{\alpha,i+1} b_{\alpha,i+1} + b^\dagger_{\alpha,i+1} b^\dagger_{\alpha,i+1} b_{\alpha,i+1} b_{\alpha,i} + b^\dagger_{\alpha,i} b^\dagger_{\alpha,i} b_{\alpha,i} b_{\alpha,i+1} + b^\dagger_{\alpha,i+1} b^\dagger_{\alpha,i} b_{\alpha,i} b_{\alpha,i}) \\
+ S a_1^2 (b^\dagger_{\alpha,i} b^\dagger_{\alpha,i} b_{\alpha,i} b^\dagger_{\alpha,i+1} b_{\alpha,i+1} b_{\alpha,i+1} + b^\dagger_{\alpha,i+1} b^\dagger_{\alpha,i+1} b_{\alpha,i+1} b^\dagger_{\alpha,i} b_{\alpha,i} b_{\alpha,i}) \\
+ J_2 \sum_{\alpha=1}^{2} \sum_{i=1}^{N} S^2 - S(b^\dagger_{\alpha,i} b_{\alpha,i} + b^\dagger_{\alpha+1,i} b_{\alpha+1,i} - b^\dagger_{\alpha,i} b_{\alpha+1,i} - b^\dagger_{\alpha+1,i} b_{\alpha,i}) + b^\dagger_{\alpha,i} b_{\alpha,i} b^\dagger_{\alpha+1,i} b_{\alpha+1,i} \\
+ S a_1 (b^\dagger_{\alpha,i} b^\dagger_{\alpha+1,i} b_{\alpha+1,i} b_{\alpha+1,i} + b^\dagger_{\alpha+1,i} b^\dagger_{\alpha+1,i} b_{\alpha+1,i} b_{\alpha,i} + b^\dagger_{\alpha,i} b^\dagger_{\alpha,i} b_{\alpha,i} b_{\alpha+1,i} + b^\dagger_{\alpha+1,i} b^\dagger_{\alpha,i} b_{\alpha,i} b_{\alpha,i}) \\
+ S a_1^2 (b^\dagger_{\alpha,i} b^\dagger_{\alpha,i} b_{\alpha,i} b^\dagger_{\alpha+1,i} b_{\alpha+1,i} b_{\alpha+1,i} + b^\dagger_{\alpha+1,i} b^\dagger_{\alpha+1,i} b_{\alpha+1,i} b^\dagger_{\alpha,i} b_{\alpha,i} b_{\alpha,i}) \quad (8)
\end{aligned}
$$

- **Use operators defined by the Holstein-Primakov transformation.**
- **Taylor expand to first order.**

2nd Quantized Hamiltonian in Reciprocal Space

Removing site-dependence

$$
\begin{aligned}
H = \sum_{\alpha=1}^{3} \Bigg\{ & S^2 N J_1 + 2 S J_1 \sum_{k=1}^{N} (\cos\phi_k - 1)\, b^\dagger_{\alpha,k} b_{\alpha,k} \\
& + \frac{J_1}{N} \sum_{k_1 k_2 k_3 k_4} \{\cos(\phi_{k_1} - \phi_{k_4}) + 2 S a_1 [\cos(\phi_{k_2} - \phi_{k_3} - \phi_{k_4}) + \cos(\phi_{k_1} + \phi_{k_2} - \phi_{k_3})]\} \\
& \times \Delta(\phi_{k_1} + \phi_{k_2} - \phi_{k_3} - \phi_{k_4}) b^\dagger_{\alpha,k_1} b^\dagger_{\alpha,k_2} b_{\alpha,k_3} b_{\alpha,k_4}
\end{aligned}
$$

- **Apply Fourier Transforms to the creation/annihilation operators.**
- **Simplify..**

  On a periodic lattice there a some sums here that simplify to N (number of lattice sites/particles).

$$
H = \sum_{\alpha=1}^{3} \left\{ S^2 N J_1 + \sum_k \omega_k b^\dagger_{\alpha,k} b_{\alpha,k} + \frac{1}{N} \sum_{k,l,m} \Omega_{klm} b^\dagger_{\alpha,k} b^\dagger_{\alpha,l} b_{\alpha,m} b_{\alpha,k+l-m} \right\}
$$

2nd Quantized Hamiltonian in Reciprocal Space

Removing site-dependence

$$i\hbar\partial_t b_\eta = -[H, b_\eta]_-$$

$$\psi_\alpha(\vec{r},t) = N^{-1/2}\sum_k b_{\alpha,k}(t)exp(-i\vec{k}\cdot\vec{r})$$

$$i\hbar\partial_t\psi_\alpha = \sum_{\alpha=1}^{3}\{\hat{\mu}_0\psi_\alpha + i\hat{\mu}_1\nabla\psi_\alpha + \hat{\mu}_2\nabla^2\psi_\alpha + \hat{\mu}_3\psi_\alpha^\dagger\psi_\alpha\psi_\alpha\} + \sum_{\alpha=1}^{2} J_2 S\,(\psi_\alpha - \psi_{\alpha+1})$$

NLS Form

- **Apply Heisenberg's eqn for a particular operator**
- **Define a quantum field**
- **Multiply both sides by summed exponential over the particular quantum numbers * N^{-1/2}, replace operators & coefficients w/ fields**

There are some subtleties left out here

Overall Plan Ahead

- Thesis Writing (Chapter 1, 5 are just over 50% done)

  Outstanding research items (MAPP) --> ALP limit curve (for both MAPP-mCP & MAPP-LLP as the fiducial volume), this be running next week. Also hopefully, a working method for calculating the fiducial efficiencies (currently going through Ameir's latest presentation & calculations on this.)

  Outstanding research items (Emergent-MM) --> Solution(s) to simplified EOMs + Discussion (dynamics, nature of soln, etc.)

Overall Plan Ahead

- **Thesis Writing**

  Outstanding research items (MAPP) --> ALP limit curve (for both MAPP-mCP & MAPP-LLP as the fiducial volume), and hopefully, a working method for calculating the fiducial efficiencies.

  Outstanding research items (Emergent-MM) --> Solution(s) to simplified EOMs + Discussion (dynamics, nature of soln, etc.)

- **Future Items**

  ALPs via the Primakoff Process v1 - MAPP + TAXN-like scenario as a first look

  ALPs via the Primakoff Process v2 - Proper Simulation w/ Pythia (+GEANT?)

  mCP vs. Heavy nu Ionizations in 3m of plastic Scintillator, a first look w/ GEANT4.

Questions?