Detecting Velocity Dependent Milli-Magnetic Dark Abelian Monopoles at the LHC

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Outline of this Presentation

- Brief Introduction to MoEDAL-MAPP
- Dark Sector Models and Kinetic Mixing
- Kinetic Mixing and Milli-Magnetic Charges
- A New Approach: The Baines *et al* Effective Theory
- Future Work

Introducing MoEDAL-MAPP

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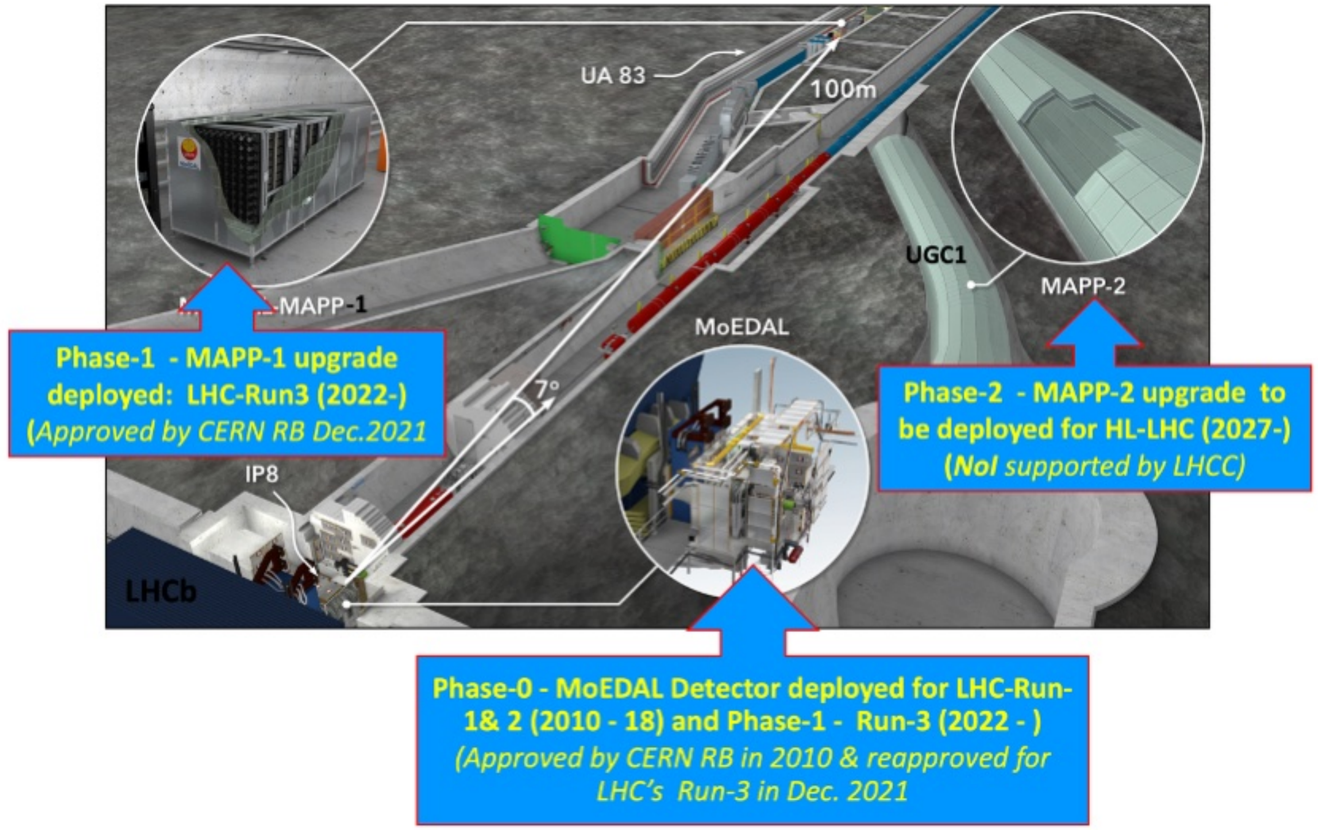
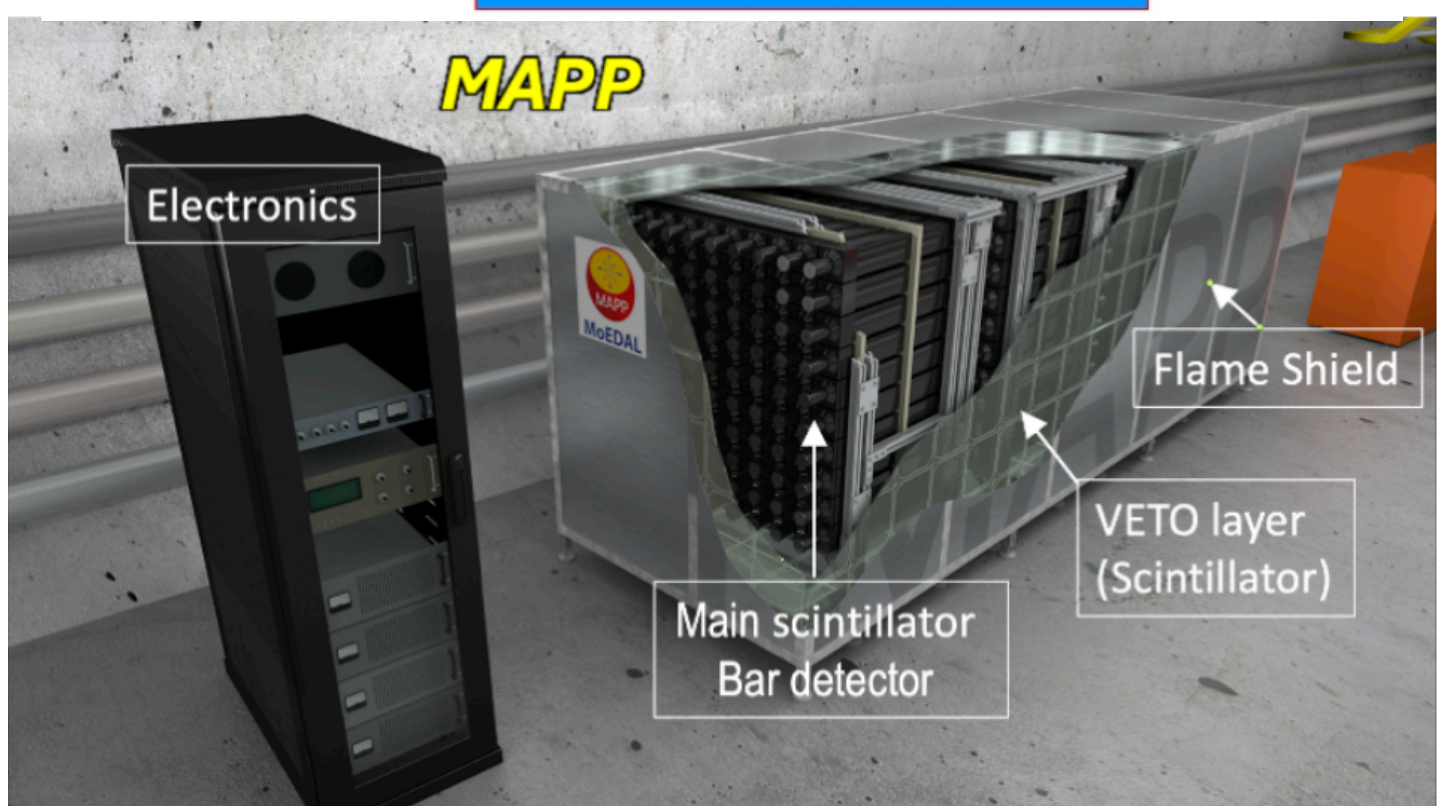




Why Dark Sector Models?

- Dark sector models are theoretically well motivated by:
    - Naturalness (Ex: Craig and Howe, JHEP 1403 (2014) 140.)
    - Thermal dark matter (Ex: Pospelov, Ritz and Voloshin, Phys. Lett. B662 (2008) 53-61)
    - Electroweak baryogenesis (Morrissey and Ramsey-Musolf, New J.Phys. 14 (2012) 125003.)
- They also represent a generic expectation for physics beyond the SM. (Strassler and Zurek, Phys. Lett. B651 (2007) 374-379)

Kinetic Mixing and Maxwell's Equations (after field redefinition)

$A \to A + \epsilon A_D :$

$$\partial_\mu F^{\mu\nu} = eJ^\mu$$

$$\partial_\mu F_D^{\mu\nu} = \epsilon e J^\mu + e_D J_D^\mu + m_D^2 A_D^\nu$$

$$\partial_\mu \tilde{F}^{\mu\nu} = -\epsilon g_D K_D^\mu$$

$$\partial_\mu \tilde{F}_D^{\mu\nu} = g_D K_D^\mu$$

A. Hook and J. Huang, ”Bounding millimagnetically charged particles with magnetars”, Phys. Rev. **D 96** (2017) 055010

Milli-Magnetically Charged Particles

Hook and Huang (Phys. Rev. D 96 (2017) 055010) show that:

$$\mathcal{L}_{\rm mMC} = i\overline{\psi}_D \left(\not{\partial} + ig\not{\tilde{A}}_D + iM_{\rm DM} \right) \psi_D - \frac{1}{4} A_{D\mu\nu} A_D^{\mu\nu} - \frac{\epsilon}{2} A_{D\mu\nu} B^{\mu\nu} + \cdots$$

Becomes

$$\mathcal{L}_{\rm mMC} = i\overline{\psi}_D \left(\not{\partial} + ig\not{\tilde{A}}_D - i\epsilon g \not{\tilde{B}} + iM_{\rm DM} \right) \psi_D - \frac{1}{4} A_{D\mu\nu} A_D^{\mu\nu} + \cdots$$

Under the field redefinition:

$$\tilde{A}_D \rightarrow \tilde{A}_D - \epsilon \tilde{B}$$

Hook and Huang also point out that:

- mMCP are confined objects:

  At close distances (like quarks) they look like point sources.

  At longer distances, the gauge fields arrange themselves to form strings between monopoles and anti-monopoles.

  The mass of the dark photon sets the scale for where this transition happens.

- mMCP only behave like magnetically charged objects for distances $\geq \frac{1}{m_{\mathrm{D}}}$

The Baines *et al* Effective Theory

Baines *et al* introduced an effective theory for monopoles with a velocity dependent charge.

$$\mathscr{L} = -\frac{1}{4}A_{\mu\nu}A^{\mu\nu} + i\bar{\psi}(\not{\partial} - ig_{\beta}\not{A} - m)\psi - \frac{i}{4}g_{\beta}\kappa A_{\mu\nu}\psi[\gamma^{\mu},\gamma^{\nu}]\bar{\psi}$$

$$g^2(\beta) = g^2\beta^{2\delta} \quad \delta = 0, 1$$

We propose to model dark monopoles using a version of this effective theory coupled to the standard model via kinetic mixing:

$$\mathscr{L}_{A,A_D} = \mathscr{L}_{SM} - \frac{\epsilon^2}{4}A^{D}_{\mu\nu}A^{\mu\nu}_{D} + i\bar{\psi}_D(\not{\partial} - ig^{D}_{\beta}\not{A}_D - i\epsilon g^{D}_{\beta}\not{A} - m_D)\psi_D$$
$$-\frac{i}{4}g^{D}_{\beta}\kappa_D A^{D}_{\mu\nu}i\bar{\psi}_D[\gamma^{\mu},\gamma^{\nu}]\psi_D + \frac{i\epsilon}{4}g^{D}_{\beta}\kappa_D A_{\mu\nu}i\bar{\psi}_D[\gamma^{\mu},\gamma^{\nu}]\psi_D$$

Baines, S., Mavromatos, N. E., Mitsou, V. A., Pinfold, J. L., & Santra, A. (2018). Monopole production via photon fusion and Drell–Yan Processes: MadGraph implementation and perturbativity via velocity-dependent coupling and magnetic moment as novel features. *The European Physical Journal C*, *78*(11). https://doi.org/10.1140/epjc/s10052-018-6440-6

The analytic form of the fermionic cross section is:

The only significant difference from Baines *et al* is the factor of ϵ^2 for Drell-Yan

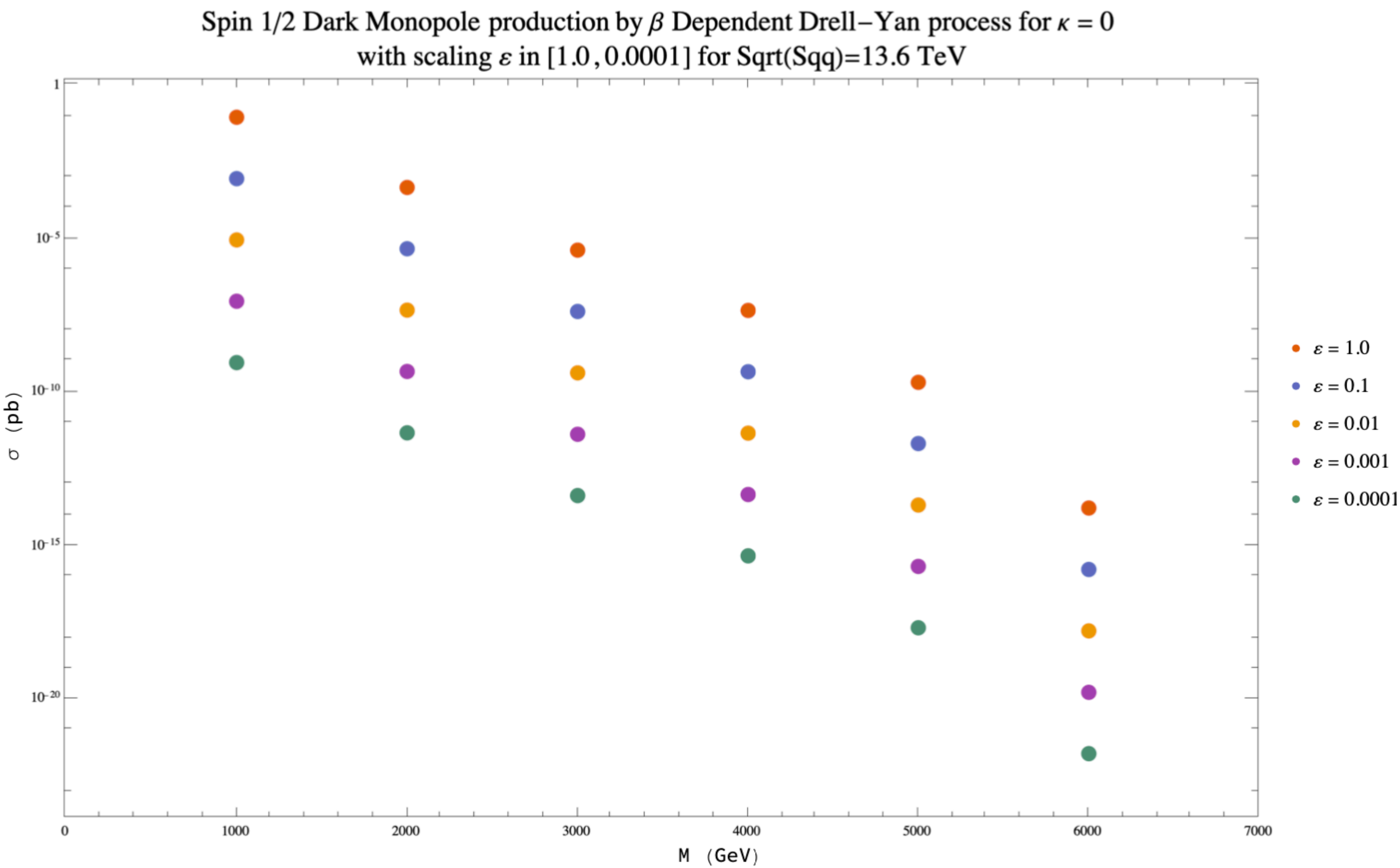
$$\sigma = \frac{10\pi\epsilon^2\beta\alpha_{\mathrm{e}}\alpha_{\mathrm{g}}(\beta)}{27 s_{\mathrm{qq}}}\left(3-\beta^2-(2\beta^2-3)\kappa^2 s_{\mathrm{qq}}+6\kappa\sqrt{s_{\mathrm{qq}}-\beta^2 s_{\mathrm{qq}}}\right)$$

Similarly, the difference from Baines *et al* is the factor of ϵ^4 for photon-fusion

Baines, Mavromatos, Mitsou, Pinfold & Santra, Eur. Phys. J. C (2018) 78:966

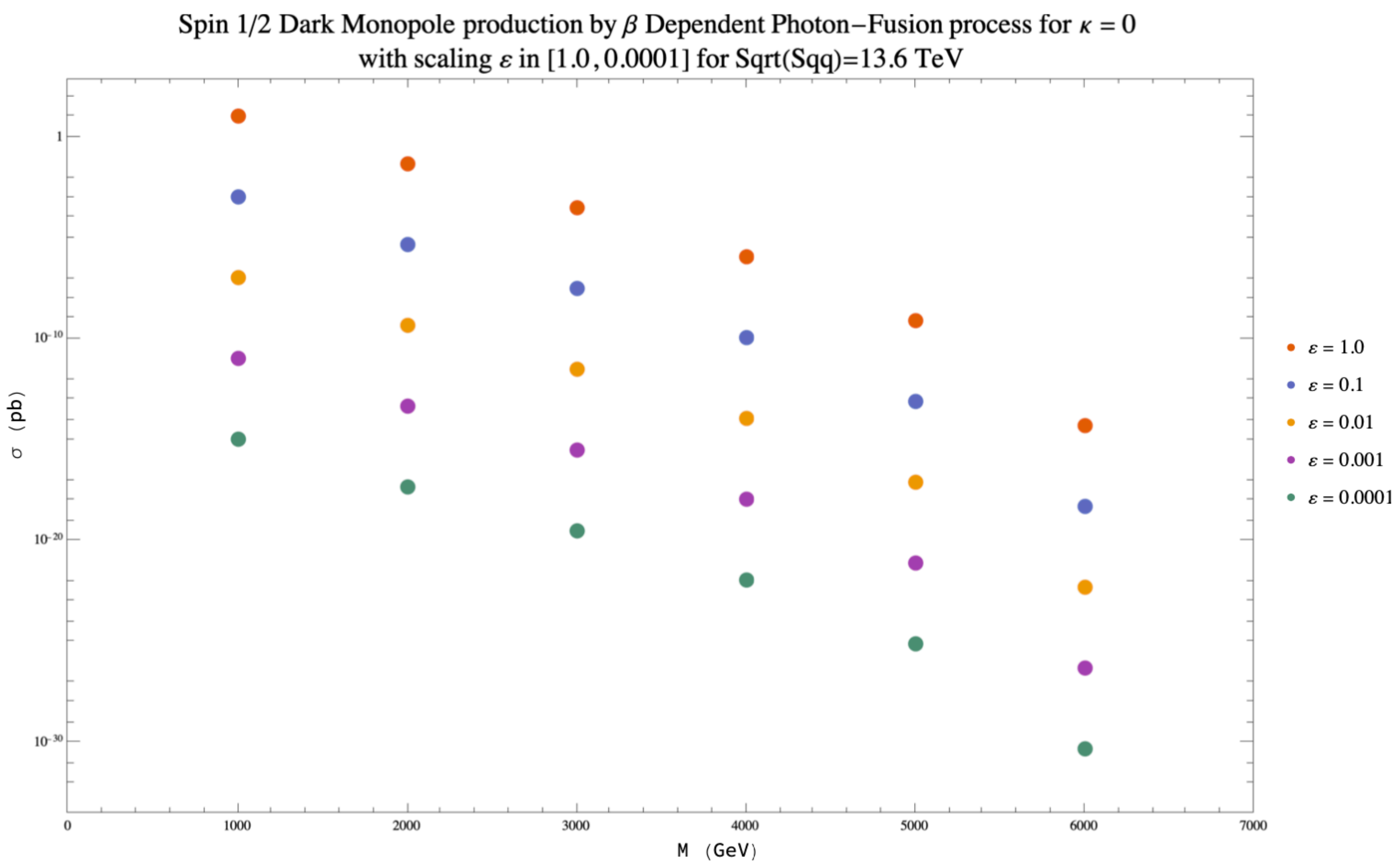
MadGraph results for Drell-Yan Monopole Production Mechanism at LHC scale

β Dependent Case



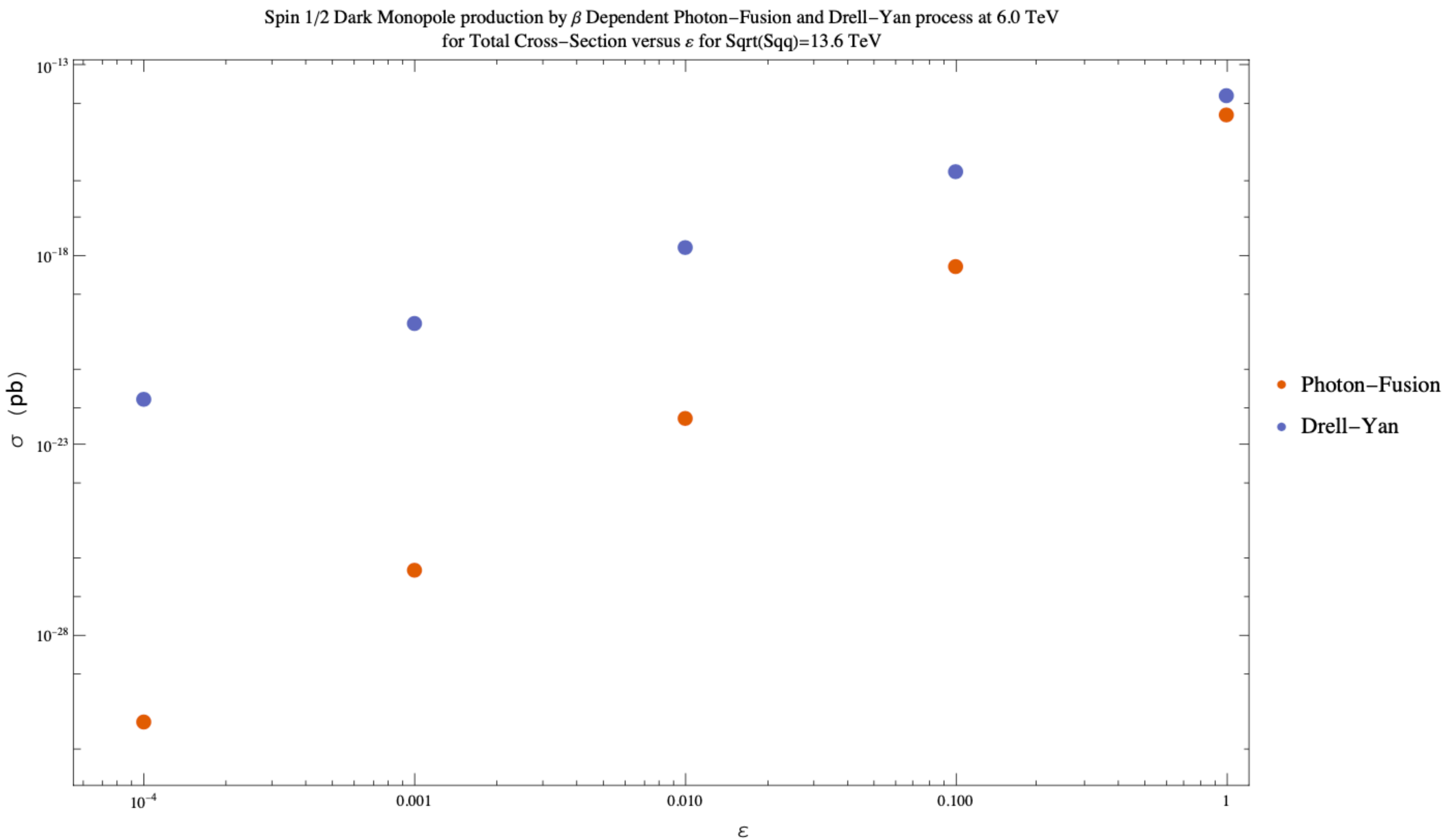
MadGraph results for Photon-Fusion Monopole Production Mechanism at LHC scale

β Dependent Case



MadGraph results comparison of both mechanisms for various values of ε

β Dependent Case



Future Work

- Look at cosmological implications to determine allowable range of the parameters in the theory (self-interaction, etc)
- Modify physics list in Geant4 to simulate energy loss for dark monopoles with velocity dependent charge for interaction with MAPP detector
- Investigate phenomenology of these dark sector objects at MAPP

Thank you very much.

MadGraph results for both mechanisms with proton beam comparison plot

β Dependent Case