Dark states with electromagnetic form factors at FLArE

Jui-Lin Kuo

UC Irvine

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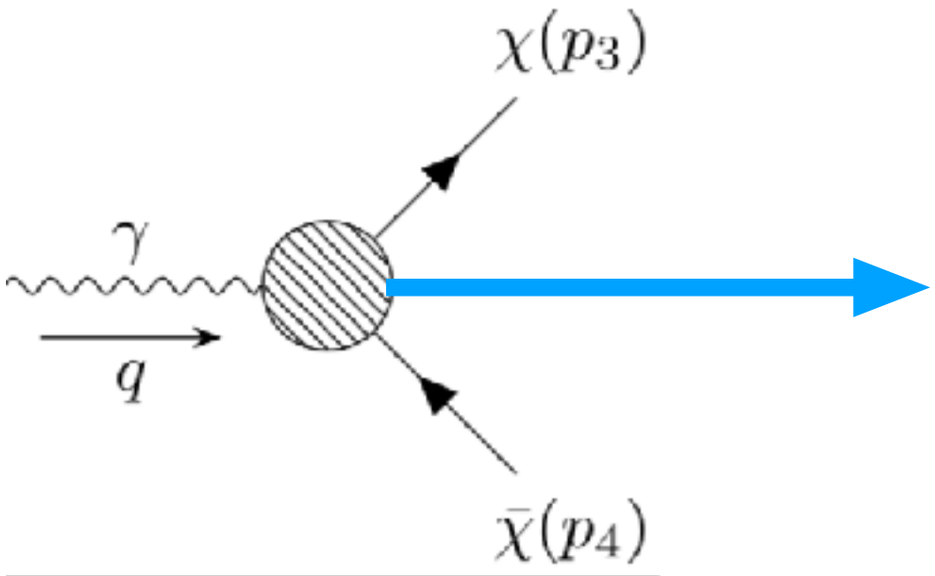
“Photon” portal

- How dark is the dark sector?
- Mediator between dark sector and SM sector: SM photon
- Dark sector particles are electromagnetic neutral
- Talk to photons with higher-dimensional operators



Electromagnetic form factors

Dark States with EM Interactions

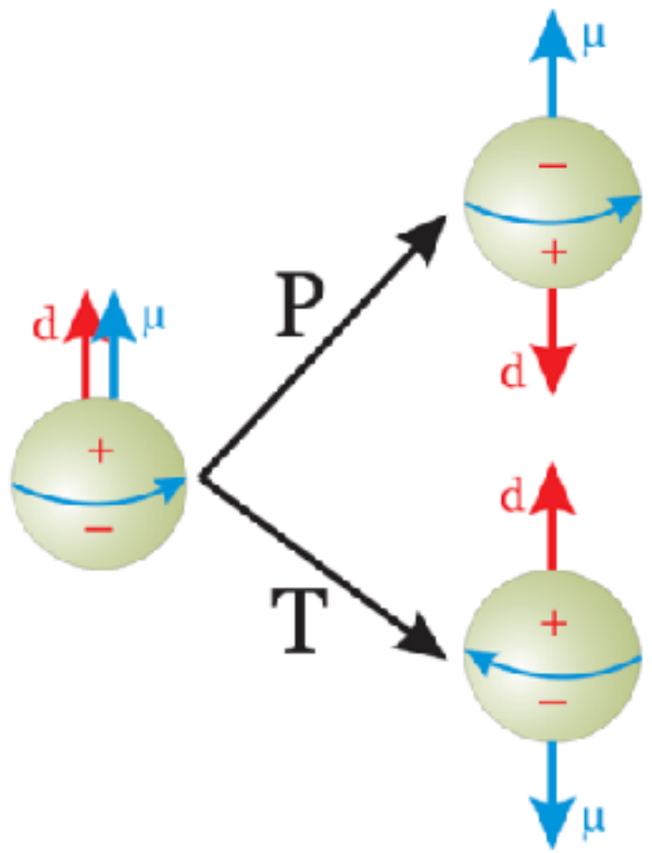
- magnetic/electric dipole moment

$$H_{\mathrm{MDM}} = -\mu_\chi(\vec{B}\cdot\vec{\sigma}_\chi)$$

P, T even

$$H_{\mathrm{EDM}} = -d_\chi(\vec{E}\cdot\vec{\sigma}_\chi)$$

P, T odd: CP violating



Credit: https://www.physics.uoguelph.ca/radon-electric-dipole-moment

Dark States with EM Interactions

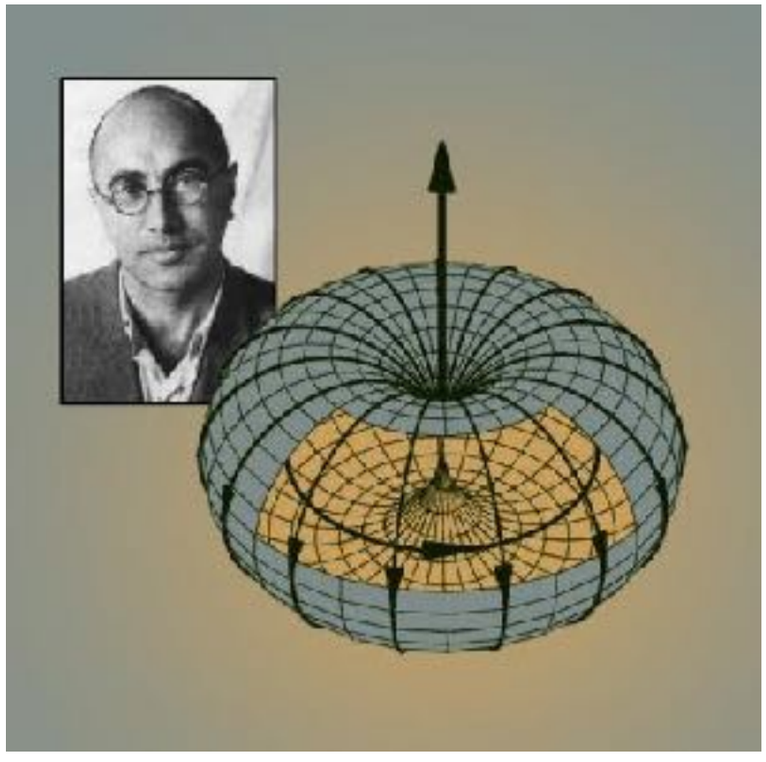
- anapole moment and charge radius

$$H_{\mathrm{AM}} = -a_\chi(\vec{J}\cdot\vec{\sigma}_\chi)$$ **(Zel'dovich 1954)**

P odd but CP even

$$H_{\mathrm{CR}} = -b_\chi(\vec{\nabla}\cdot\vec{E})$$

P, T even



Credit: Lawrence Berkeley National Laboratory

Effective Operators

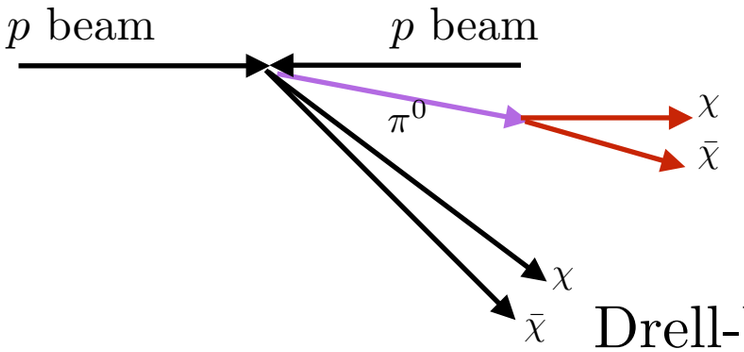
millicharge (ϵQ):	$\epsilon e\, \bar{\chi}\gamma^{\mu}\chi A_{\mu}$,	Dimension-4
magnetic dipole (MDM):	$\frac{1}{2}\mu_{\chi}\, \bar{\chi}\sigma^{\mu\nu}\chi F_{\mu\nu}$,	Dimension-5
electric dipole (EDM):	$\frac{i}{2}d_{\chi}\, \bar{\chi}\sigma^{\mu\nu}\gamma^{5}\chi F_{\mu\nu}$,	Dimension-5
anapole moment (AM):	$a_{\chi}\, \bar{\chi}\gamma^{\mu}\gamma^{5}\chi\partial^{\nu}F_{\mu\nu}$,	Dimension-6
charge radius (CR):	$b_{\chi}\, \bar{\chi}\gamma^{\mu}\chi\partial^{\nu}F_{\mu\nu}$.	Dimension-6

- Possible UV completion: compositeness, new charged particles in loop at high scale
- We focus on dim-5 and dim-6 operators and assume UV scale is much higher than the CM energy of LHC

Existing constraints

- Stellar energy loss **Chu, JLK, Pradler, Semmelrock 2019 (PRD)**
- Electron-beam facilities **Chu, Pradler, Semmelrock 2019 (PRD)**
- Proton-beam facilities **Chu, JLK, Pradler 2020 (PRD)**
- Missing-E search at ee colliders **Chu, Pradler, Semmelrock 2019 (PRD)**
- FLArE: forward and energetic flux of dark states from the IP

Production channels



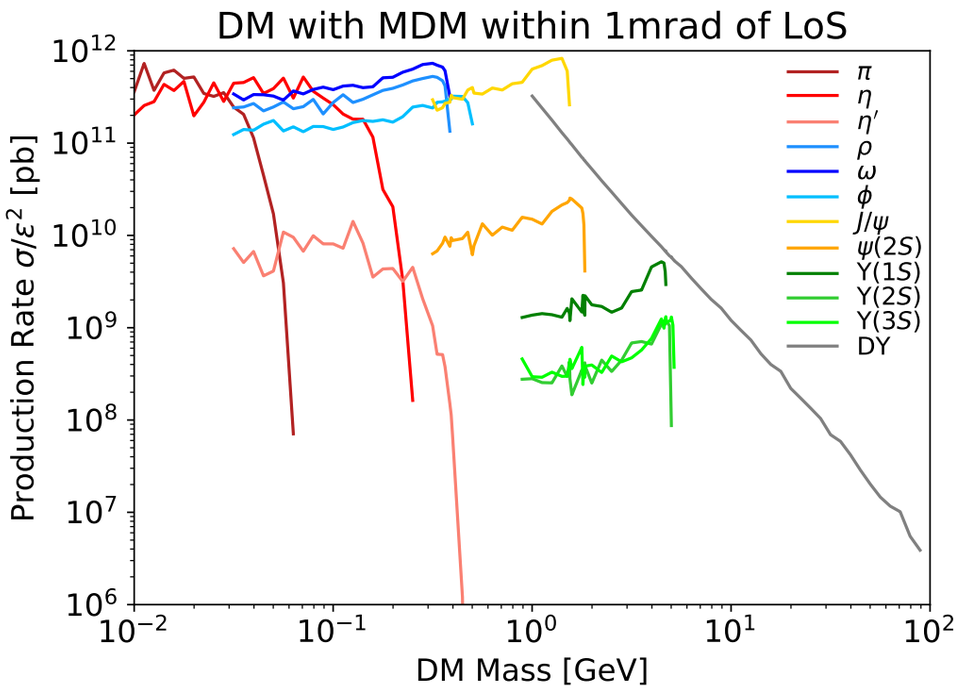
Meson decay: $pp \to \text{scalar meson} \to \gamma\chi\bar{\chi}$

$pp \to \text{vector meson} \to \chi\bar{\chi}$

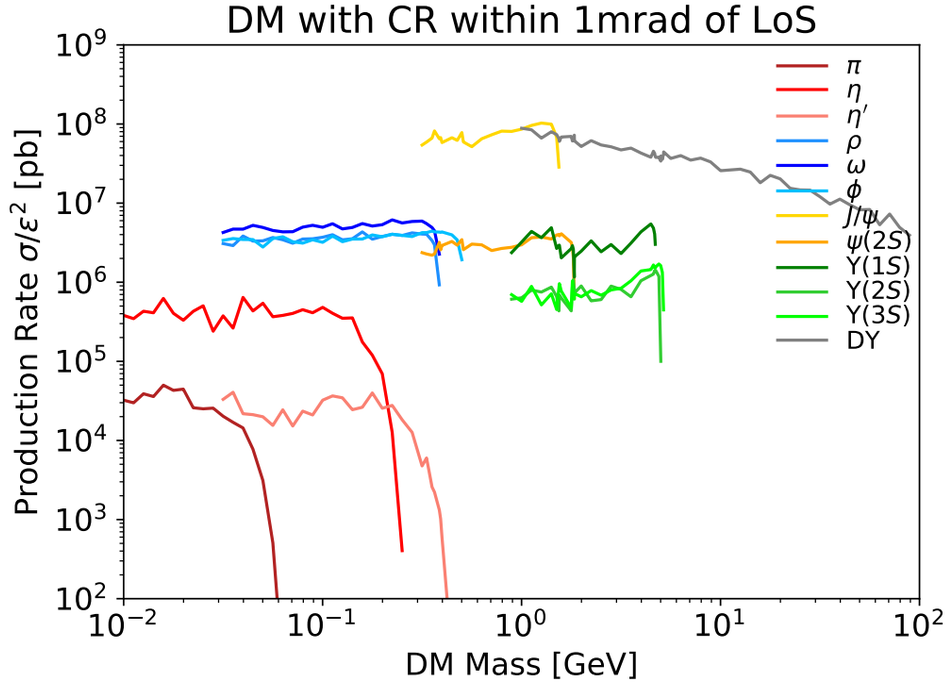
Drell-Yan process: $q\bar{q} \to \chi\bar{\chi}$

- Note: mass/energy-dependence of production rate, e.g., $\text{BR}_{M\to\chi\bar{\chi}} \propto M^2$ (dim-5), M^4 (dim-6)

dim-5: MDM/EDM

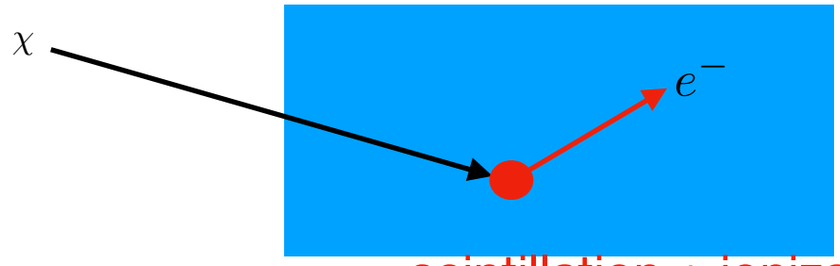


dim-6: AM/CR



Preliminary result by Felix Kling, JLK, Sebastian Trojanowski and Yu-Dai Tsai

Electron recoil signal



scintillation + ionization electron

- Differential cross section

event rate less IR-biased

$$\frac{d\sigma_{\chi e}^{\text{dim-4}}}{dE_R} \simeq \frac{2\pi\alpha^2\epsilon^2}{E_R^2 m_e}\,, \qquad \frac{d\sigma_{\chi e}^{\text{dim-5}}}{dE_R} \simeq \frac{\alpha\mu_\chi^2}{E_R}\,, \qquad \frac{d\sigma_{\chi e}^{\text{dim-6}}}{dE_R} \simeq 2\alpha b_\chi^2 m_e$$

$$N_{\text{event}} = n_e L_{\text{det}} \int dE_R\, \epsilon(E_R) \int dE_\chi \int d\cos\theta_\chi\, \frac{d^2 N_\chi}{dE_\chi d\cos\theta_\chi} \frac{d\sigma_{\chi e}}{dE_R}$$

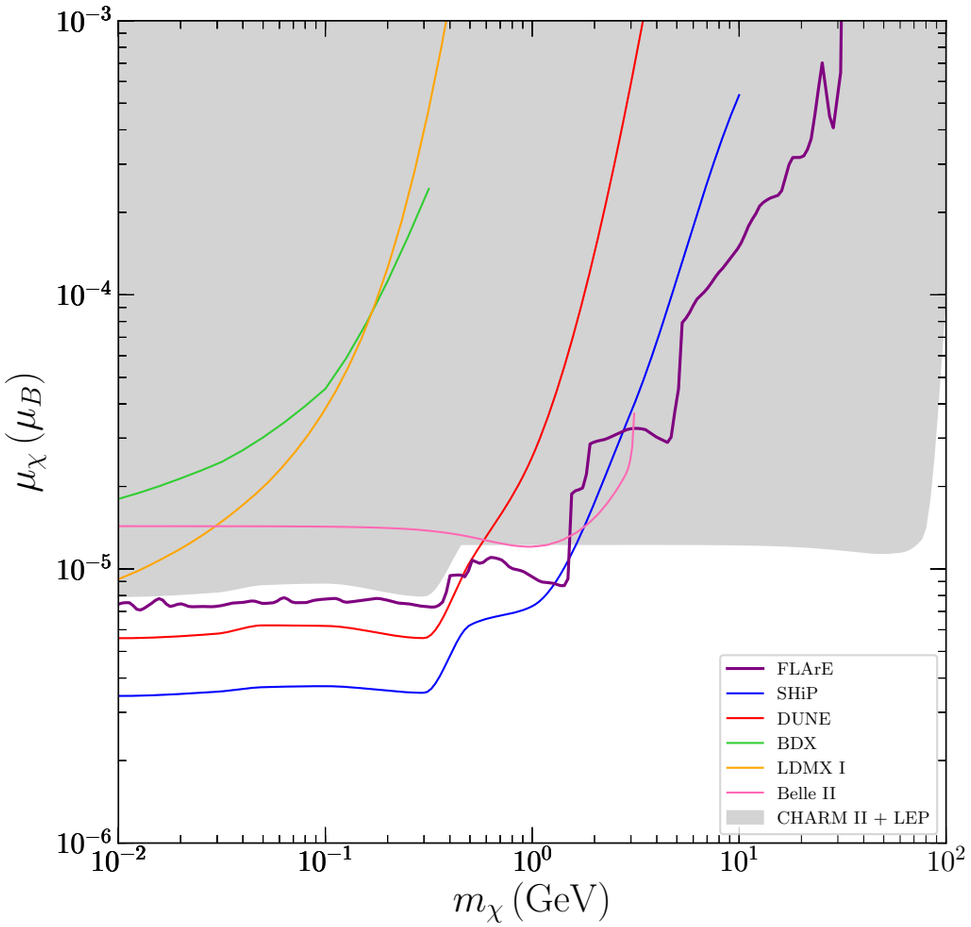
- Background: neutrinos

Recoil energy cut: $30\,\text{MeV} \leq E_R \leq 3\,\text{GeV}$

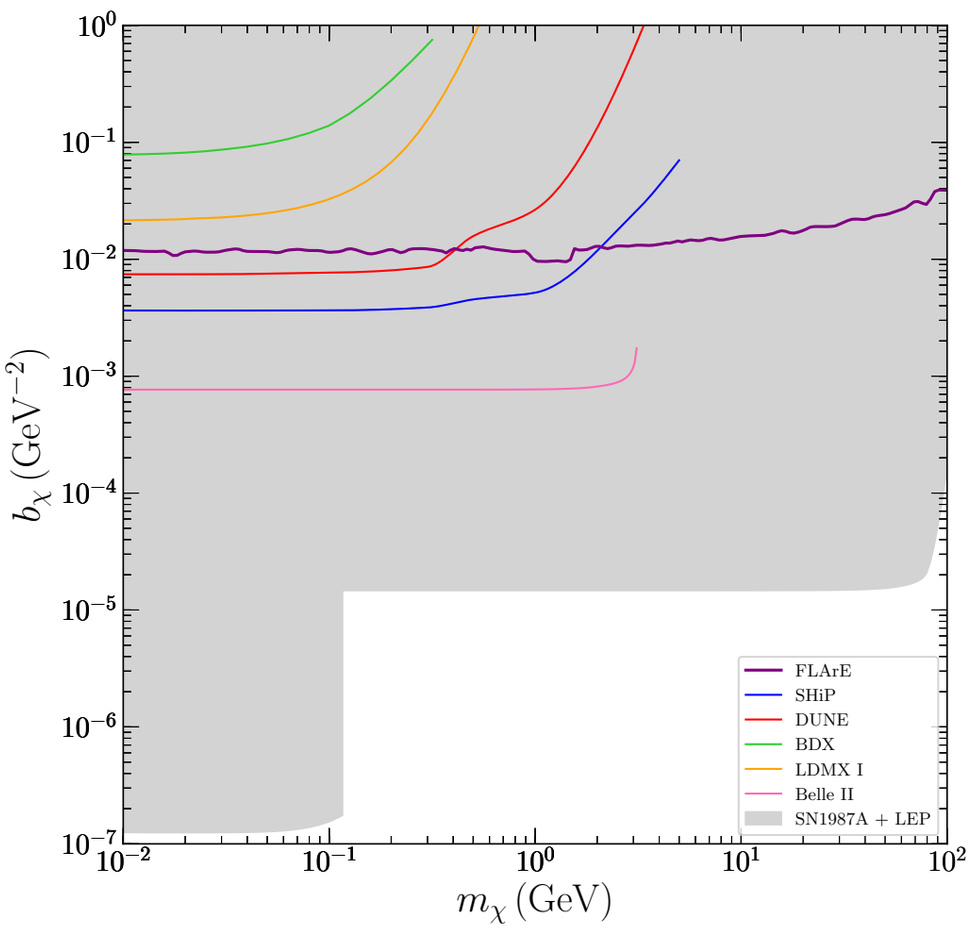
Relaxing the energy cut does not improve the sensitivity much

Projected sensitivity of FLArE

dim-5: MDM/EDM



dim-6: AM/CR



- Current leading constraints: proton-beam exp. and LEP missing-E for dim-5, and SN1987A and LEP missing-E for dim-6
- FLArE improves sensitivity on dim-5 for sub-GeV mass range and competes with other proposed exp.

Preliminary result by Felix Kling, JLK, Sebastian Trojanowski and Yu-Dai Tsai

Short summary

- Dark states coupled to photon can be probed at FPF

- Dark states are produced by meson decay and Drell-Yan processes, and detected via electron-recoil

- For sub-GeV mass range, FLArE can improve current sensitivity on dim-5 operators and compete with other proposed experiments