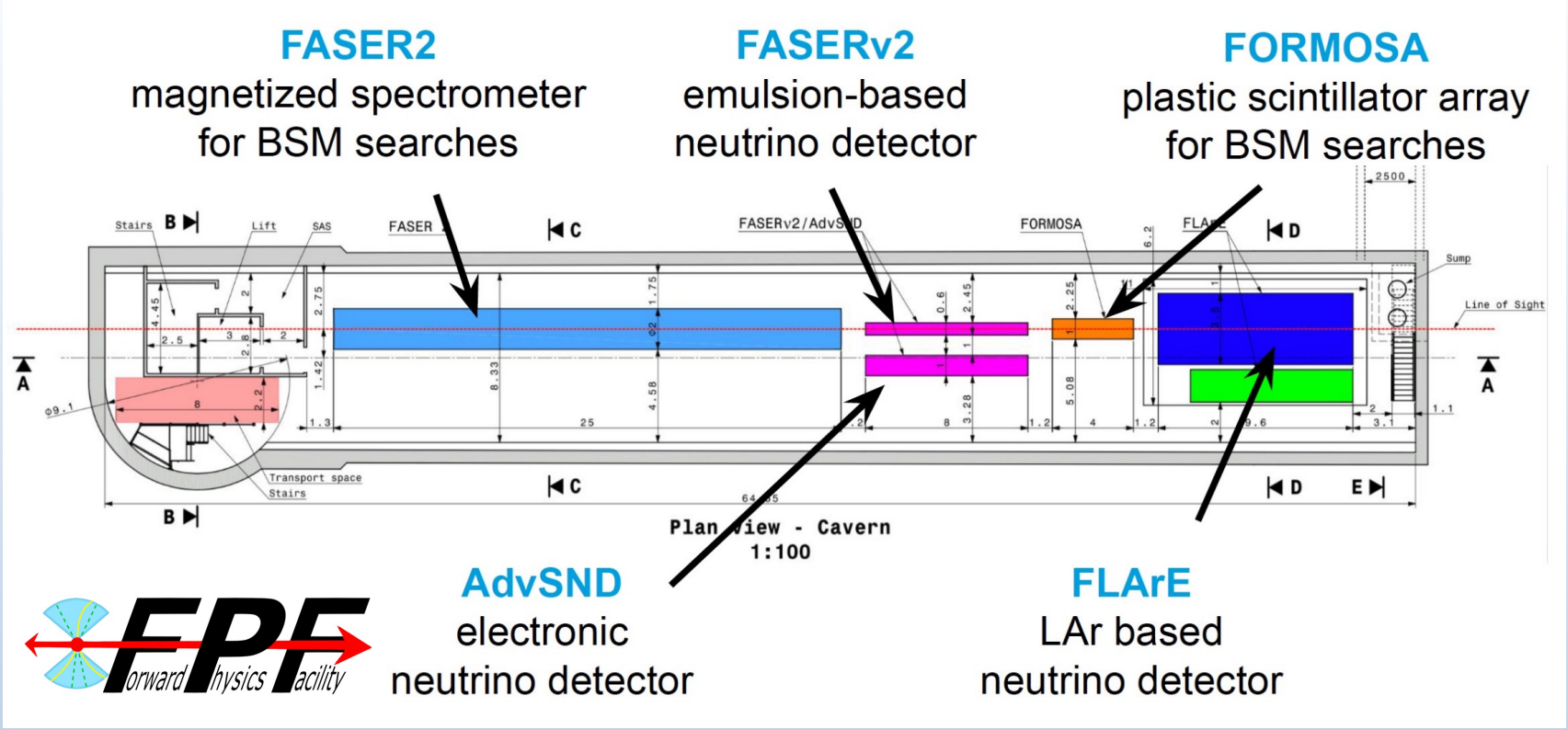

Strong & Robust Searches for Millicharged Particles (mCP) with LHC FPF & FORMOSA

Yu-Dai Tsai, **University of California, Irvine**

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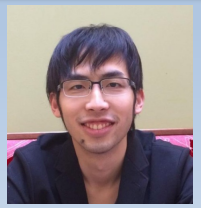
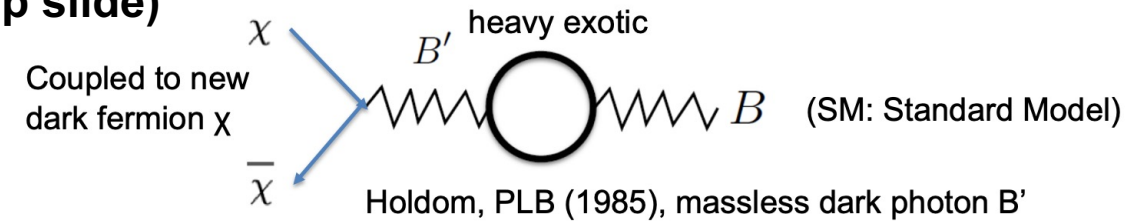


Theoretical Motivations

Paul Dirac

- **Is electric charge quantized and why?** A long-standing question!
- Motivates **Dirac quantization, Grand Unified Theories (GUTs)**
- **Fractionally charged particles (not confined) is predicted by some Superstring theories**: Wen, Witten, NPB (1985)
- Link to **string compactification, quantum gravity, and reheating in Cosmology,** Shiu, Soler, Ye, PRL (2013), Gan, Shiu, **Tsai**, in progress
- **Conservatively, testing if e/3 is the minimal charge**
- Simply a search for particles with **{mass, electric charge}** = $\{m_\chi, \epsilon e\}$, $\epsilon = Q_x/e$
- **Massless dark photon yields millicharged particles; dark matter implication (backup slide)**



Millicharged Particles (mCP) is an important benchmark model

Snowmass RF06 Classification; **PBC** Benchmark

Benchmarks in Final State x Portal Organization

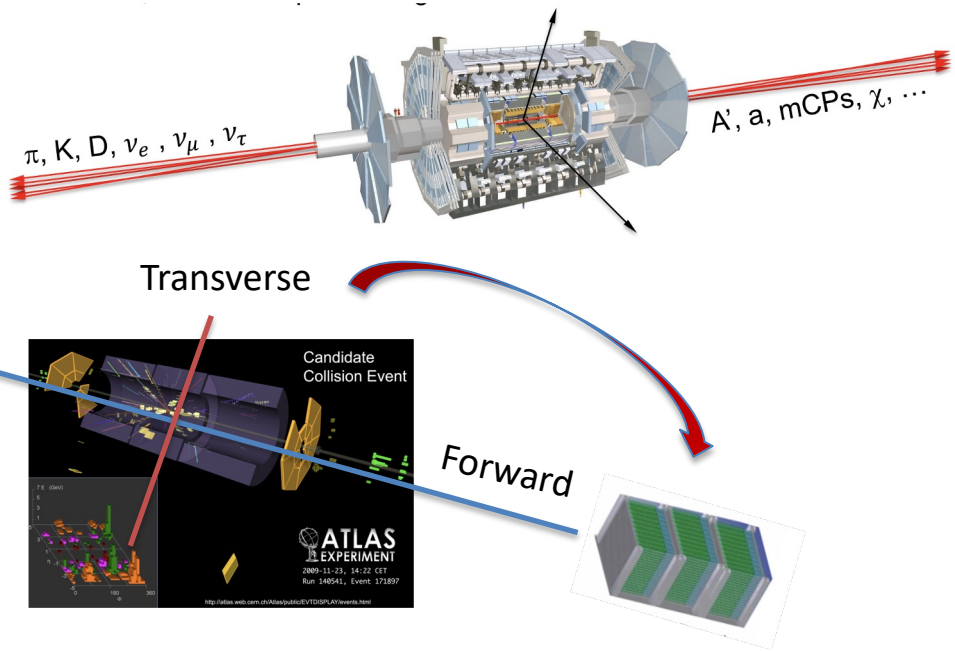
	DM Production	Mediator Decay Via Portal	Structure of Dark Sector
Vector	m_χ vs. y $[m_{A'}/m_\chi=3, \alpha_D=.5]$ **$m_{A'}$ vs. y** [α_D=0.5, 3 m_χ values] m_χ vs.α_D $[m_{A'}/m_\chi=3, y=y_{fo}]$ m_χ vs. m_A [α_D=0.5, $y=y_{fo}$] *Millicharge m vs. q*	$m_{A'}$ vs. ϵ [decay-mode agnostic] ***$m_{A'}$ vs. ϵ [decays]***	**iDM m_χ vs. y** [$m_{A'}/m_\chi=3, \alpha_D=.5$] (anom connection) **SIMP-motivated cascades [slices TBD]** $U(1)_{B-L\,/\,\mu-\tau\,/\,B-3\tau}$ (DM or SM decays)
Scalar	m_χ vs. sinθ [λ=0, fix m_S/m_χ, g_D] (thermal target excluded 1512.04119, should still include) Note secluded DM relevance of S→SM of mediator searches	*m_S vs. sinθ* [λ=0] *m_S vs. sinθ* [λ=s.t. Br(H→ss ~10^{-2})]?	Dark Higgssstrahlung (w/vector) scalar SIMP models Leptophilic/leptophobic dark Higgs
Neutrino	e/μ/τ a la1709.07001	*m_N vs. U_e* *m_N vs. U_μ* *m_N vs. U_τ* Think more about reasonable flavor structures	Sterile neutrinos with new forces
ALP	m_χ vs. fq/l [λ=0, fix m_a/m_χ, g_D] (thermal target excluded) What about f_γ, f_G?	*m_a vs. f_γ* *m_a vs. f_G* *m_a vs. $f_q=f_l$* *m_a vs. f_w*	FV axion couplings

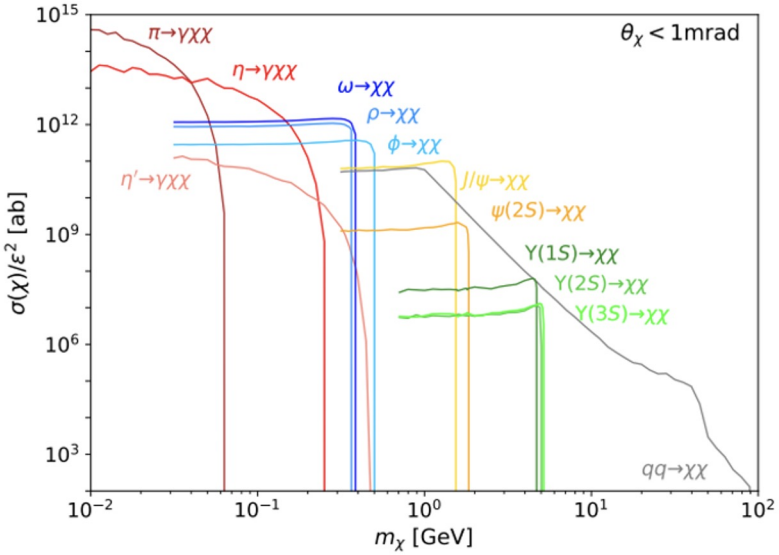
Bold = BRN benchmark, *italic=PBC benchmark.* others are new suggestions. Underline=CV benchmarks that were not used in BRN

PBC: The Physics Beyond Colliders initiative at CERN

FORMOSA: A “New” Way to Study mCP

FORward MicrOcharge SeArch (FORMOSA),
Foroughi-Abari, Kling, **Tsai**, *PRD (2021)*, 2010.07941





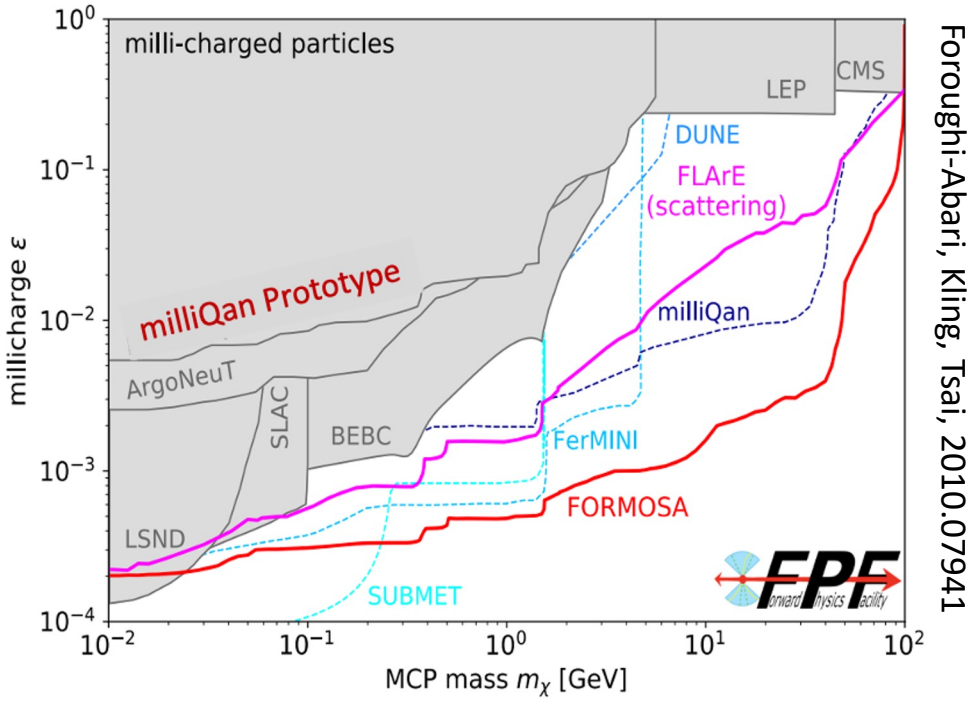
$$\mathcal{L}_{\mathrm{MCP}} = i\bar{\chi}(\partial\!\!\!/ - i\epsilon' e A\!\!\!/ + M_{\mathrm{MCP}})\chi$$

- milliQan Col., PRD (2021), Haas at al, PLB (2015)
- milliQan detector: **long scintillator bars to detector small ionization from mCP**
- milliQan run with great success in the transverse region of CMS

- FORMOSA (2010.07941)
- The flux increases by $\sim 10^3$ to 10^4 from the **transverse** to the **forward region**
- This increases the sensitivity of $\epsilon = Q_x/e$ by roughly 1 order of magnitude.

Projection and Timelines

- **milliQan prototype** ran successfully and **has set new limits**
- **Full milliQan operating now (’22 - ’26)**
- **FORMOSA prototype installation** (end of 2023)
- New scintillator study & R&D ongoing;
- Collaborating with **Matthew Citron (UC Davis)** to design and install prototype to reach even better sensitivity
- **FPF/Full FORMOSA construction** (~ 2029)



Foroughi-Abari, Kling, Tsai, 2010.07941

Solid/colored: FPF experiments

Dotted/dashed: other near-future experiments

Thank you!

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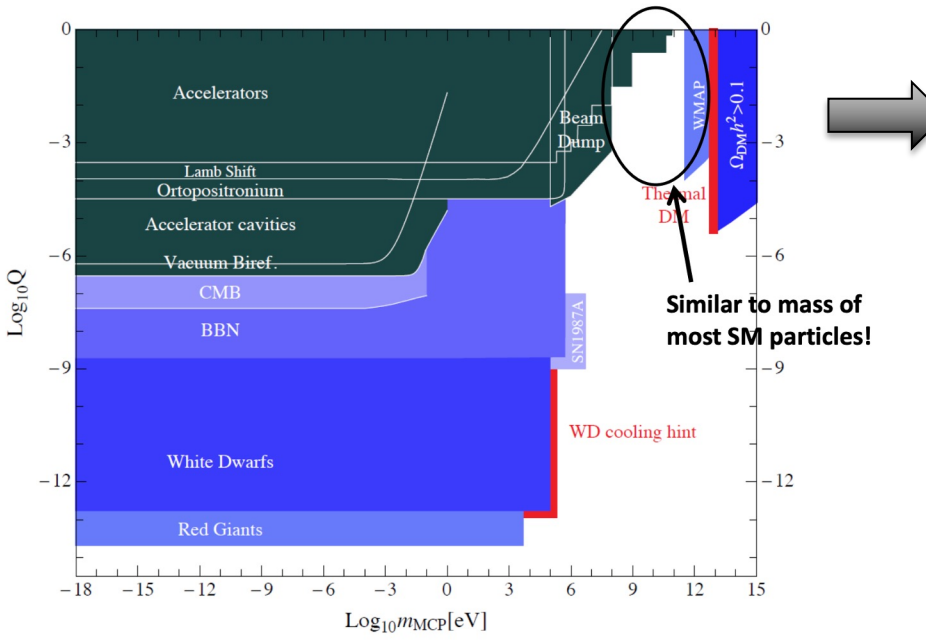
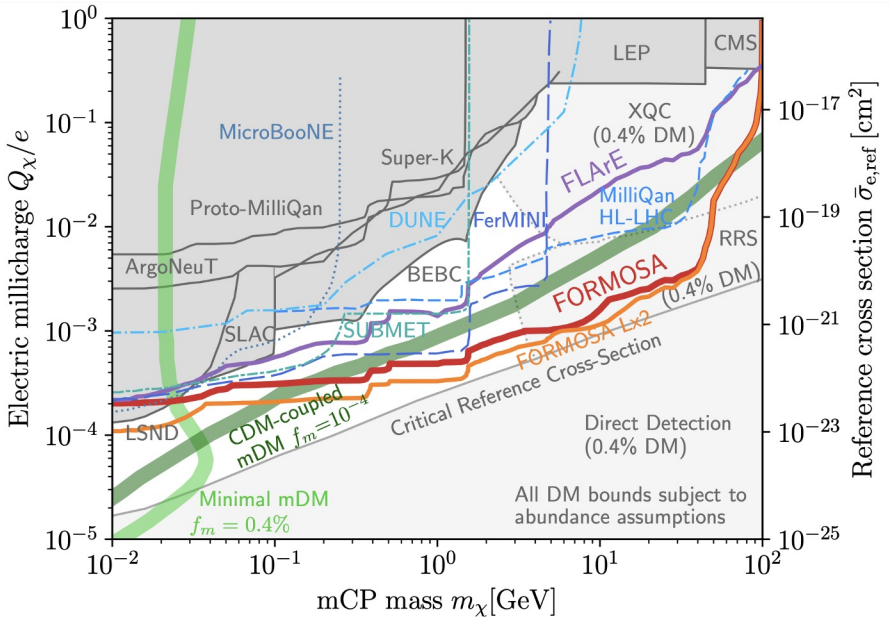
Tremendous Progress in Millicharge Studies: Both mCP and Millicharge Dark Matter





Andy Haas, Fermilab, 2017

- Both **experimental** & **theoretical** advances
- Led by **milliQan**, followed by neutrino experiments, **FerMINI, SUBMET, FORMOSA, FLArE, etc**

Yu-Dai Tsai, UC Irvine, 2023
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