# Snowmass 2021 - EF9/10+

THE OHIO STATE UNIVERSITY

## Scintillator Array Probes of the Dark Sector

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*The Ohio State University*

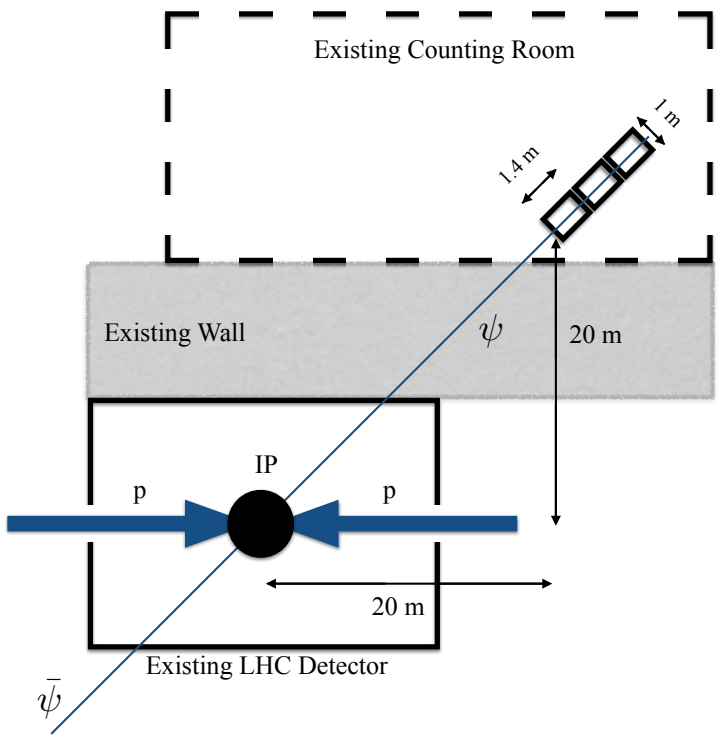
# Who? Why?

- I am giving this talk on behalf of several people who have submitted similar EOIs and who have self-organized into a group that is planning to submit an LOI to write a whitepaper. Currently we are:
  - *Chris Hill, Brian Francis (OSU)*
  - *Albert De Roeck (CERN)*
  - *Andy Haas (NYU)*
  - *David Stuart, Matthew Citron (UCSB)*
  - *Yu-Dai Tsai (FNAL)*
  - *Jae Hyeok Yoo (Korea U.)*
    - **We are all involved in one or more "scintillator array" experiments**
    - **In short, for Snowmass we intend to produce an updated, consistent (apples-to-apples) comparison of these experiments to each other (and other exp. where relevant/possible)**
      - *This talk similar to one Matthew gave in previous EF session,*

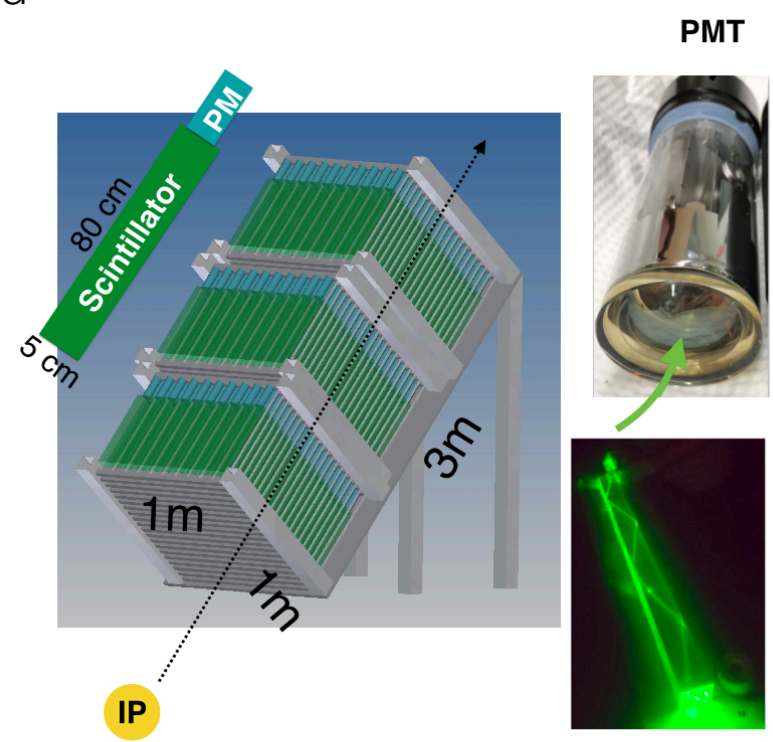
Others are welcome to join!

# What?

- By scintillator array experiments, we mean something like that which Andy and I advocated in *Phys.Lett.B* 746 (2015) 117-120
  - *Dark sector probe using distinctive signature*
    - ***"millicharged" particles***

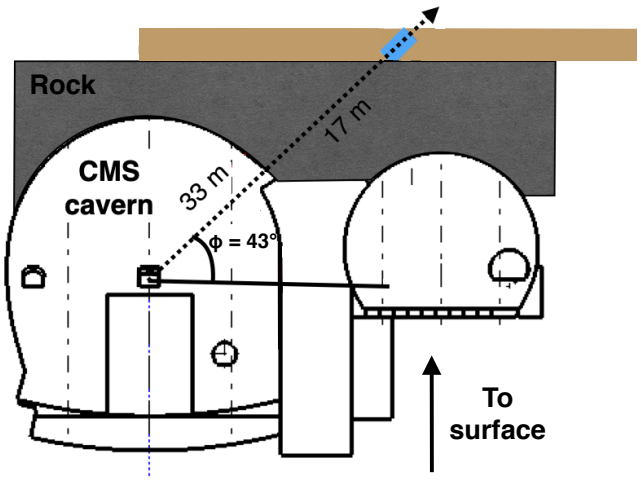


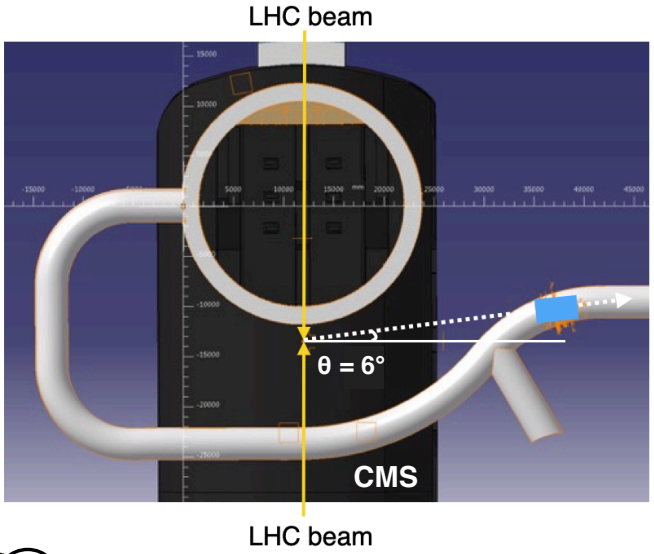

- Inexpensive dedicated detector
- With Q down to ~$10^{-3}$e, dE/dx is $10^{-6}$ MIP -> need long, sensitive, active length to see signal, $\mathcal{O}(1)$ PE.
- ~1 m x 1 m x 3 m scintillator + PMT array, pointing back to IP, in well shielded area near CMS/ATLAS
- With triple coincidence, thought expected dominant random background would be controlled



# What? (cont.)

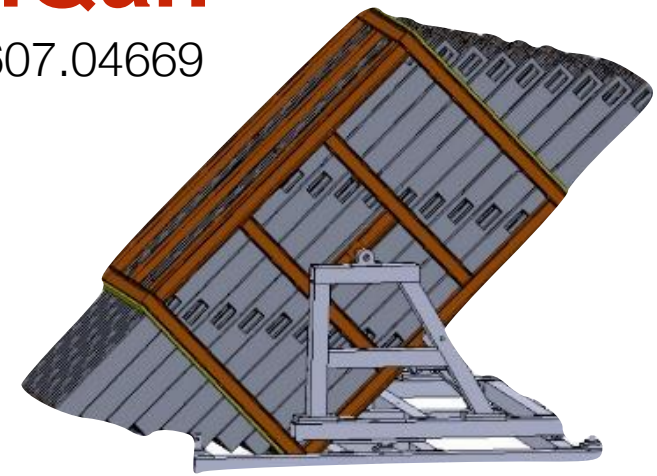
- This paper soon led to the formulation of the **millliQan collaboration**, with proposed detector sited at P5 (near CMS)

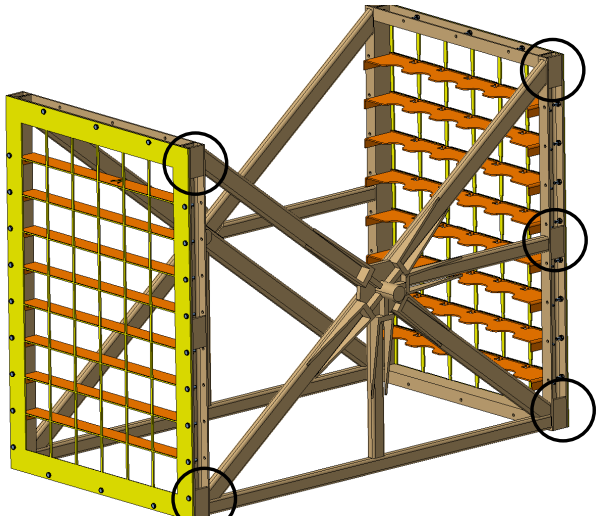


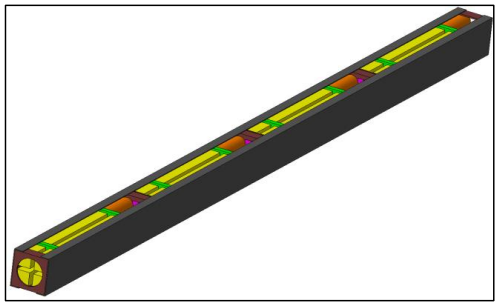




**milliQan**

arXiv:1607.04669



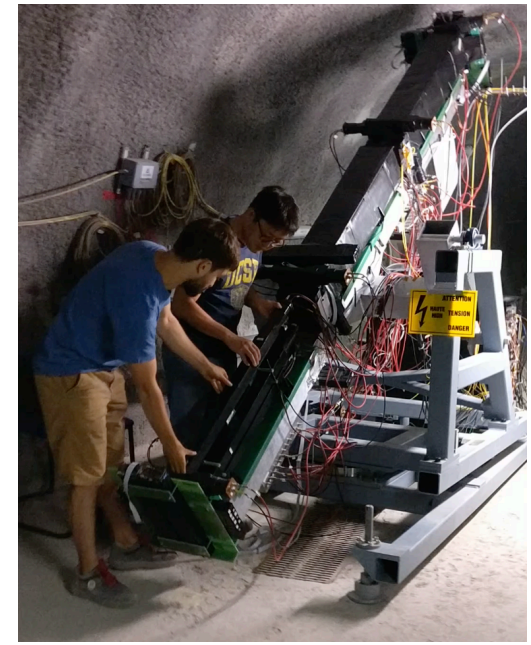


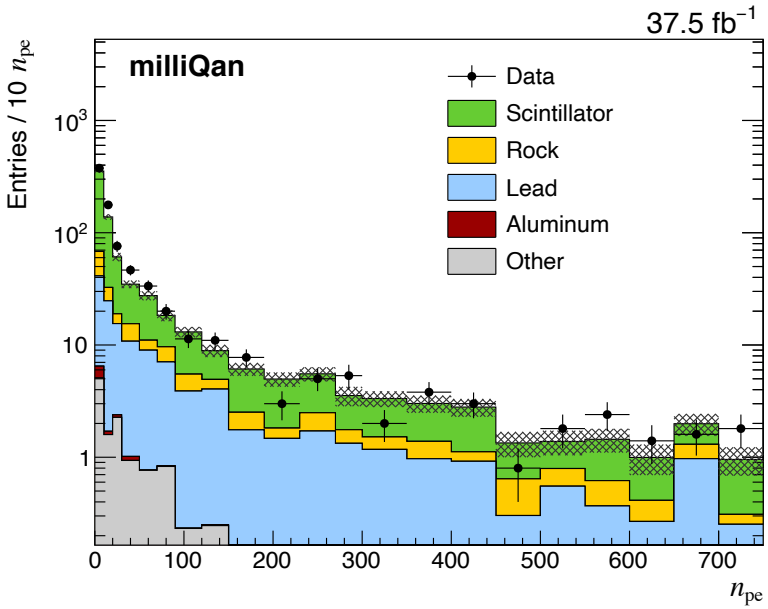


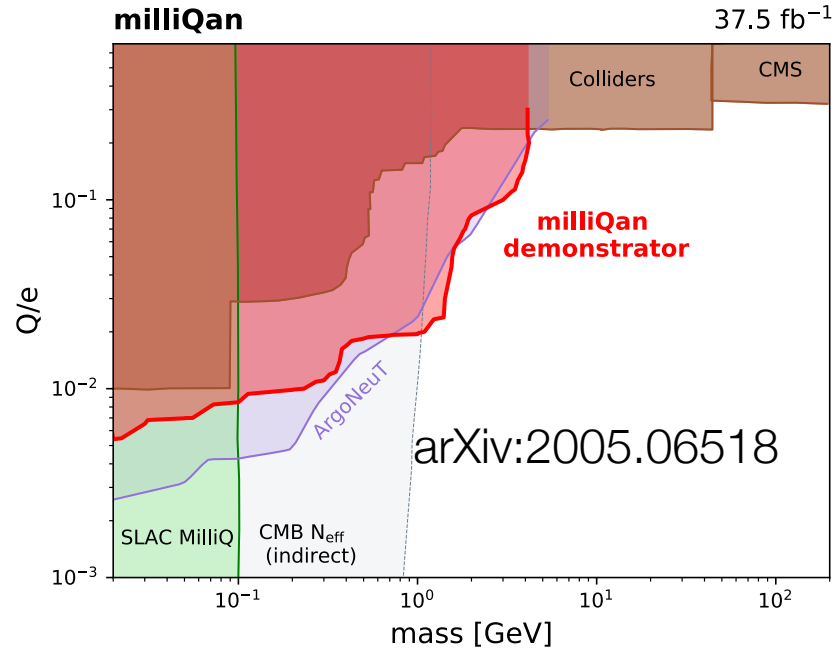
- *Experimental design at an **advanced stage** of experimental design (validated. full simulation, in-situ experience with alignment, calibrations, backgrounds, fully engineered mechanics/electronics) … **only need $***

# Physics obtained from 1% milliQan demonstrator!

- One reason at advanced stage is we built, installed, and operated a 1% prototype
- "Physics" run in 2018, collecting ~35/fb, 2000h of data
  - *Operational experience (triggering/DAQ/DQM)*
  - *Used for range of studies to prove feasibility of full detector: alignment, calibrations, background measurements*
    - **e.g. modified full milliQan design to have 4-fold coincidence**
  - *Fully simulated in GEANT4 (validated with data)*
    - **Able to produce competitive limits with only 1%**





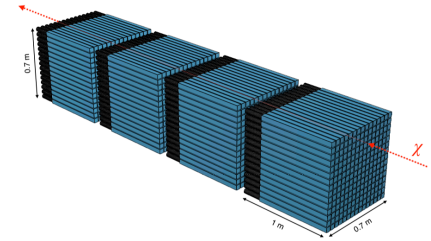



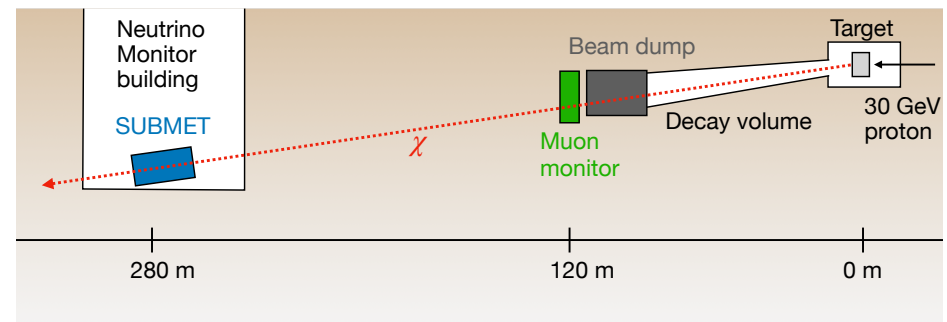
# New milliQan-like proposals

- Success of this simple scintillator approach has (more recently) led to proposals to install milliQan-like detectors at other accelerator complexes
  - *FerMINI at FNAL*
  - *SUBMET at J-PARC*

## SUBMET

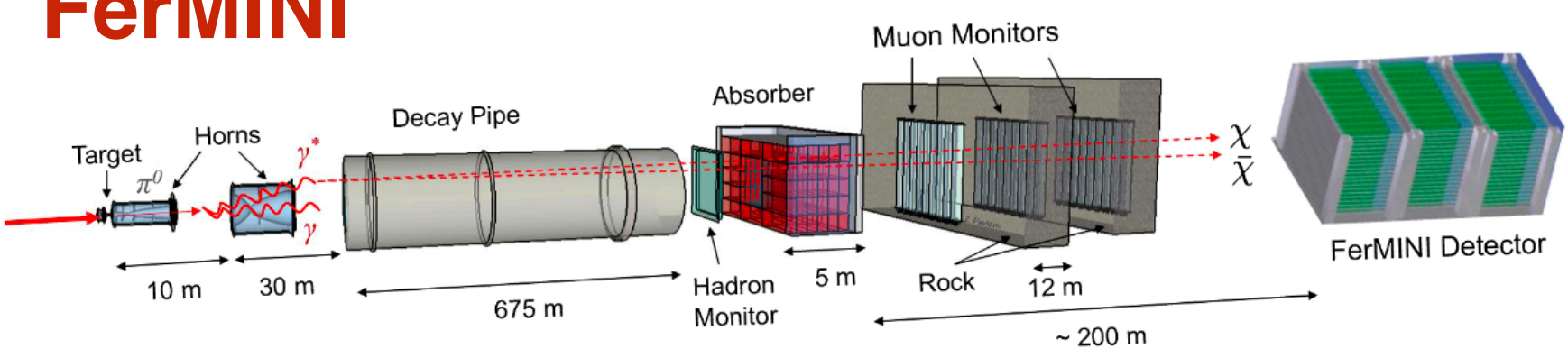
arXiv:2007.06329






**J-PARC** with sensitivity for m < ~1.5 GeV

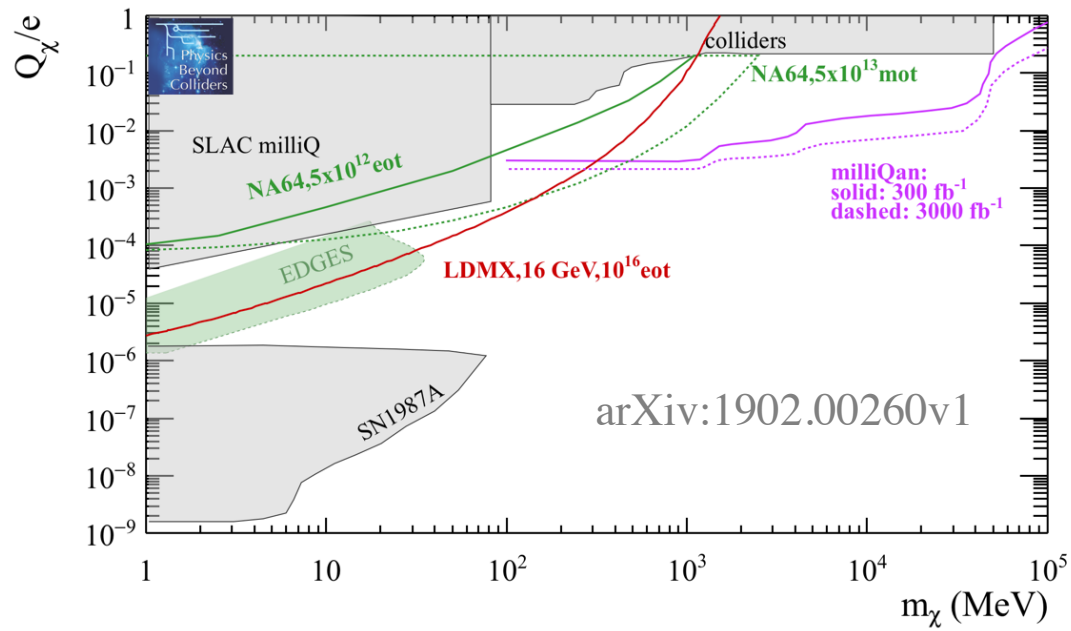
## FerMINI

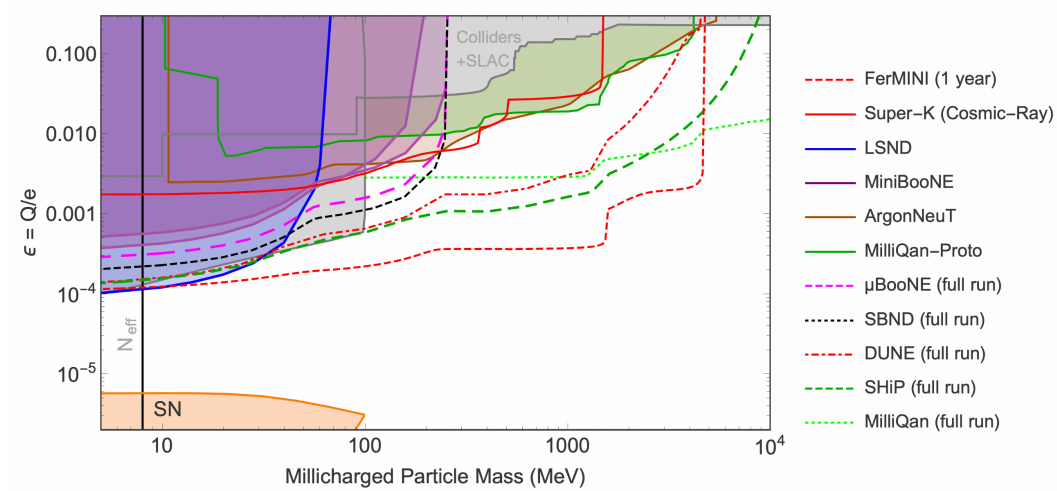



**Fermilab** with sensitivity for m < ~5 GeV

# Snowmass Plans

- Pick up where CERN PBC report (and others) have left off
- Use data and/or lessons learned from demonstrator to update sensitivity projections with “realism” for scintillation based detectors at range of facilities: LHC, J-PARC, FERMILAB
  - *Characterization/ understanding of backgrounds (and how to reject them)*
  - *Guide design of future detectors based on experience*
  - *Add other experiments where relevant? If more expert collaborators join us …*

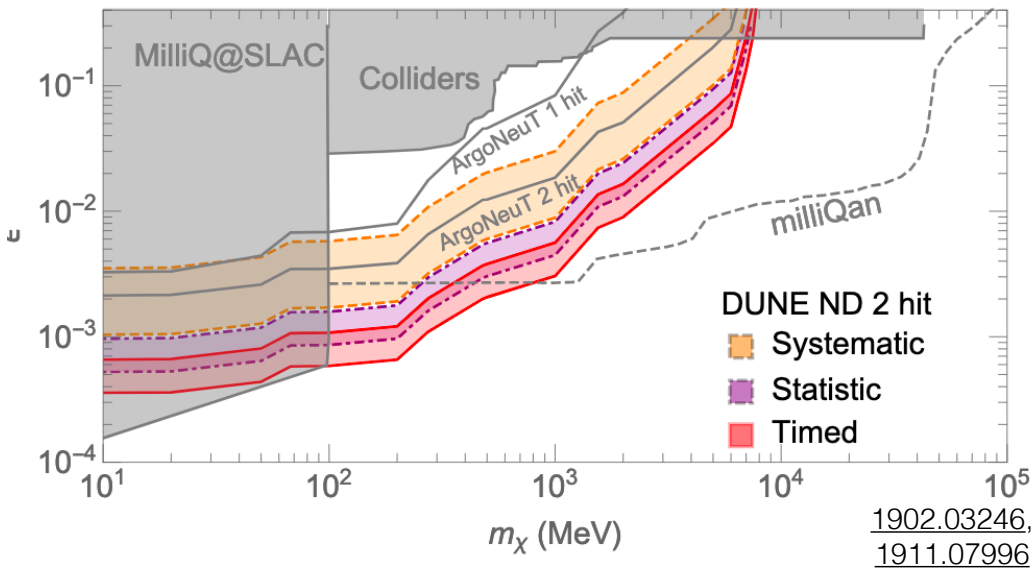



Yu-Dai Tsai

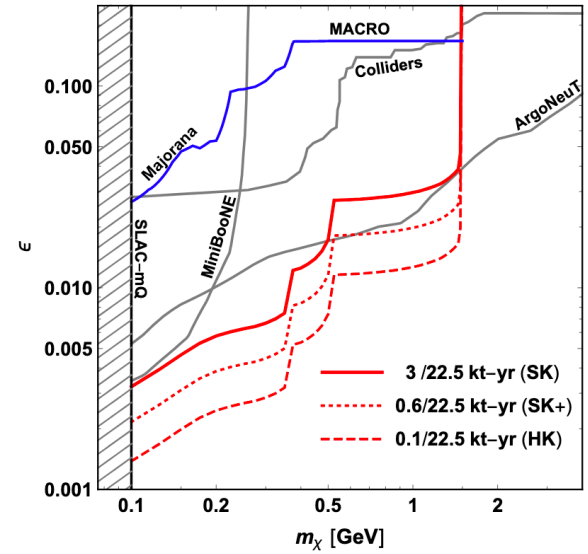
# Additional Material

# Searching for millicharged particles with other experiments




1902.03246, 1911.07996

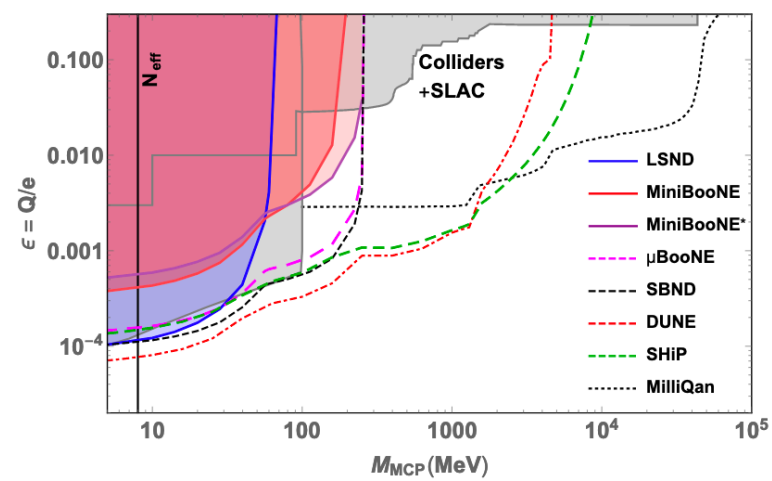
**Detection with LarTPC**




**Production in cosmic ray showers**

2002.11732

- Neutrino detectors provide sensitivity to millicharged particles through hard (> MeV recoil) electron scattering
- Many recent results!
- Would be interested in collaborating to expand scope of project: **full consideration of all complementary methods to search for mCPs**!




1806.03310

**Fixed source neutrino experiments**

# Why milli-charged?

$$\mathscr{L} = \mathscr{L}_{SM} - \frac{1}{4}B'_{\mu\nu}B'^{\mu\nu} - \frac{\kappa}{2}B'_{\mu\nu}B^{\mu\nu}$$

kinetic mixing


**SM**

**dark sector**

massless U'(1) boson in the dark sector

'dark EM'

$\kappa \sim 10^{-3} - 10^{-2}$

(naturally $\sim \alpha/\pi$)

Kinetic mixing with a new massless 'dark' boson **can provide link between SM and a hidden/dark sector**

# Why milli-charged?

Now add fermion charged under new U'(1):

$$\mathscr{L} = \mathscr{L}_{SM} - \frac{1}{4}B'_{\mu\nu}B'^{\mu\nu} - \frac{\kappa}{2}B'_{\mu\nu}B^{\mu\nu} + i\overline{\psi}(\not{\partial} + ie'\not{B}' + iM_{mCP})\psi$$

Standard trick - redefine gauge field B': $B' \rightarrow B' + \kappa B$

$$\mathscr{L} = \mathscr{L}_{SM} - \frac{1}{4}B'_{\mu\nu}B'^{\mu\nu} + i\overline{\psi}(\not{\partial} + \underbrace{i\kappa e'\not{B}} + ie'\not{B}' + iM_{mCP})\psi$$

new fermion has small EM charge**: milli-charged particle**