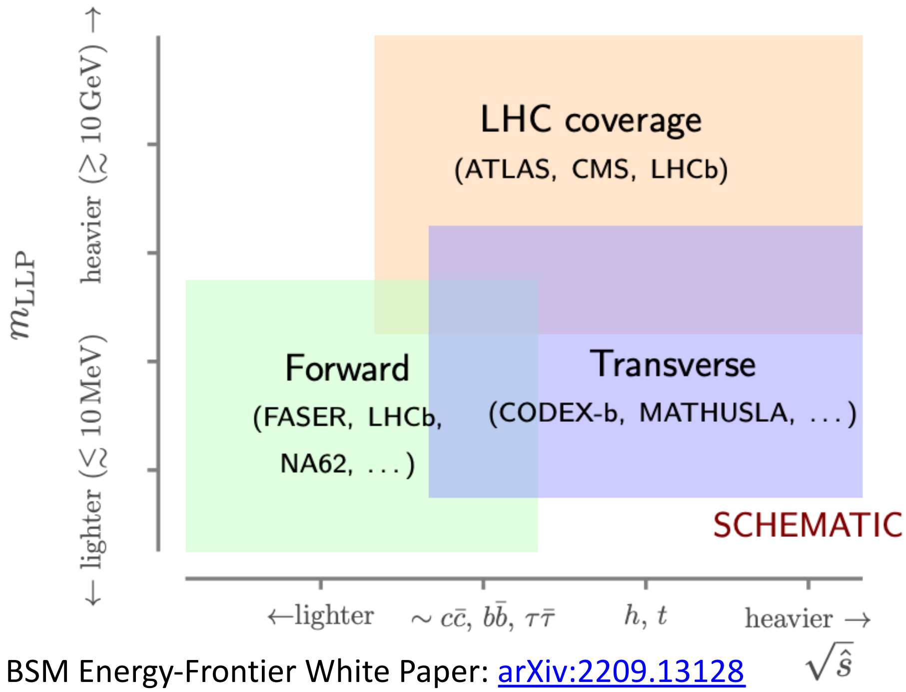
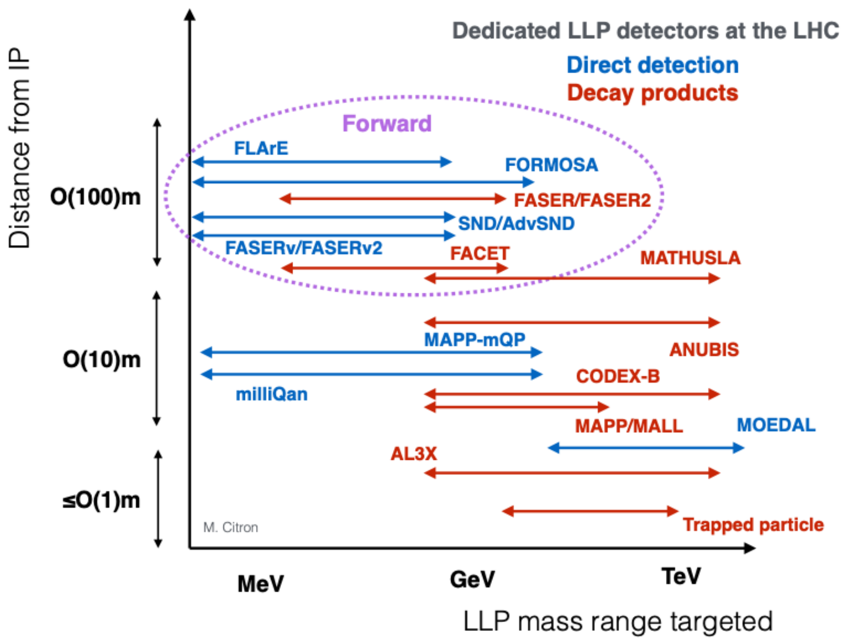


BSM Energy-Frontier White Paper: arXiv:2209.13128



Theory Overview for Small LHC Experiments

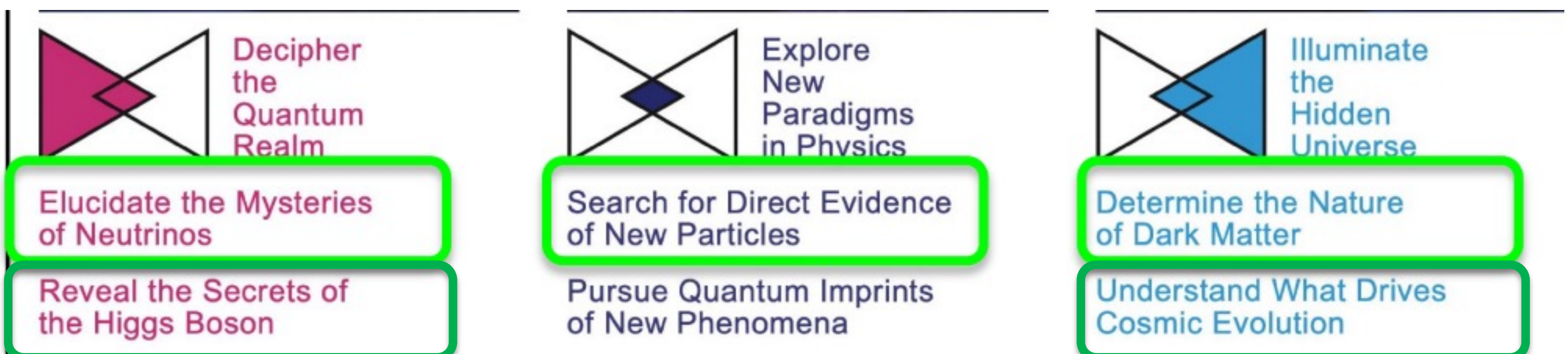
Yu-Dai Tsai

Los Alamos National Laboratory (LANL)

Contact: yt444@cornell.edu

Outline

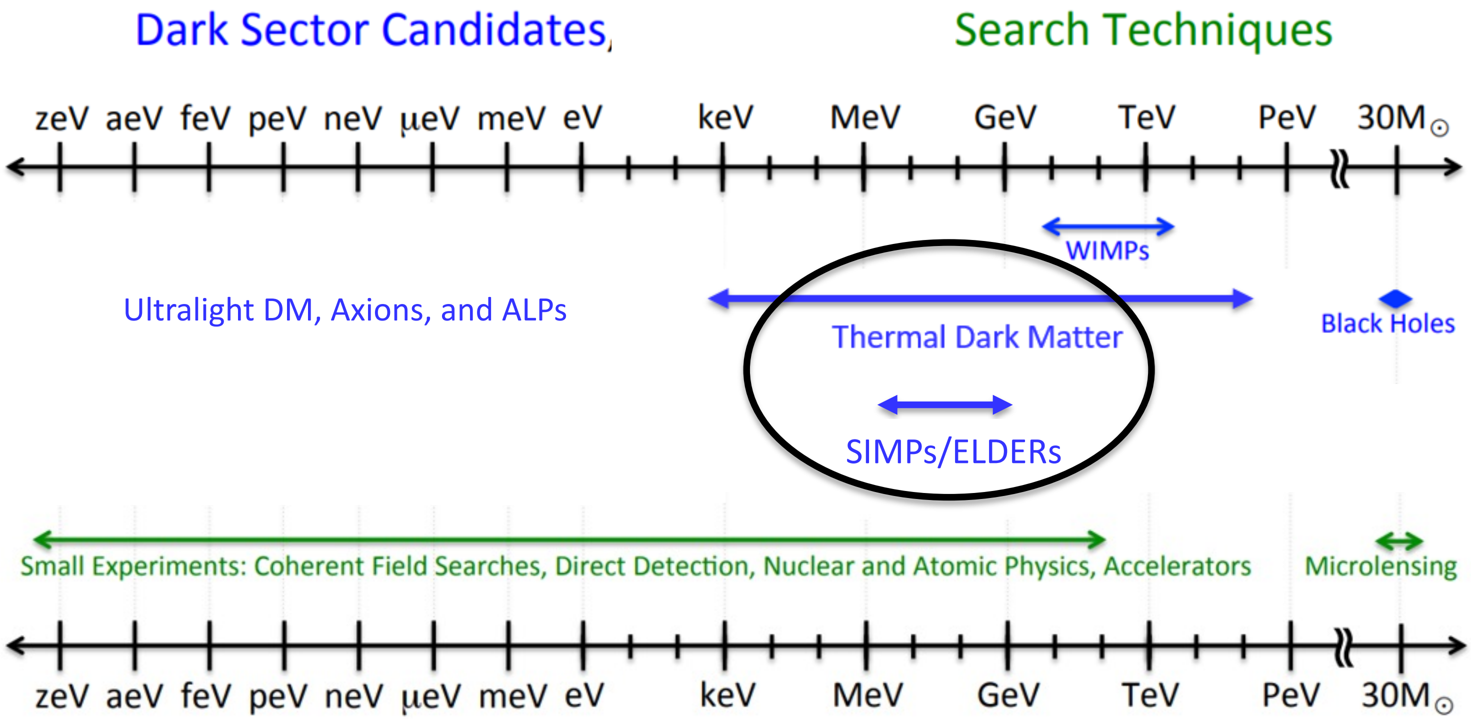
- Theory Motivations
  Examples: **Portals** & **Millicharge** Searches
- Exciting Targets @ Transverse Detectors
- Look Forward for New Physics @ Forward Detectors



P5 Science Drivers

Gan, **Tsai**, [arXiv:2308.07951]

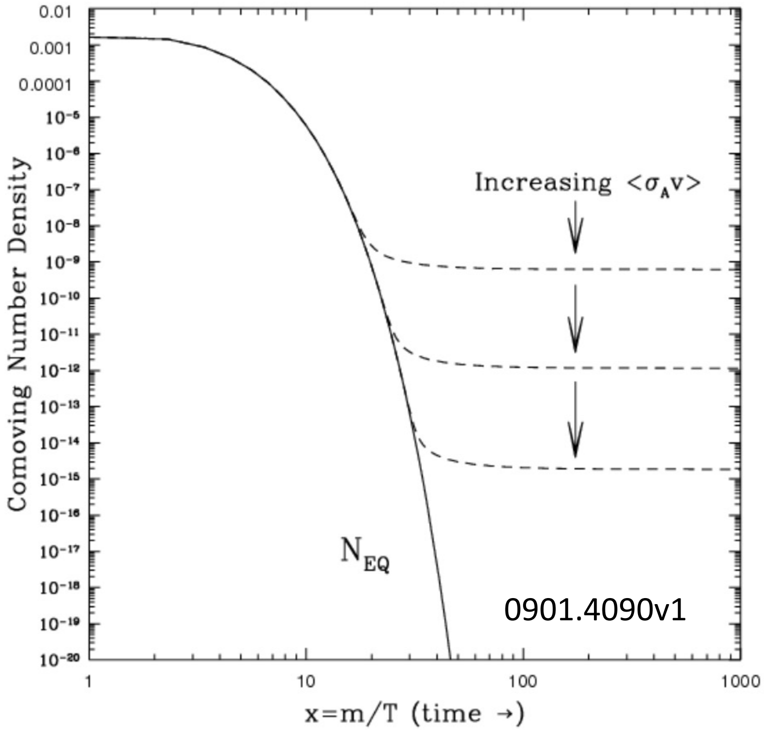
Exploration of Dark Matter & Dark Sector

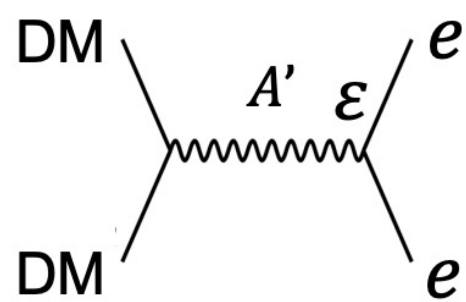


US Cosmic Visions 2017

- **Why MeV to TeV: many exciting anomalies and phenomenology**

Light Thermal DM & The Rise of Dark Sector

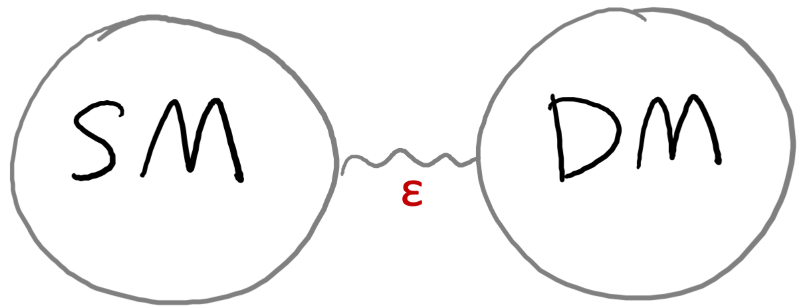




$$<\sigma v> \sim \frac{\varepsilon^2}{m_{A'}^2}$$

- The **Lee-Weinberg bound** (1977'): below $\sim \mathbf{2\ GeV}$,
  DM freeze-out through weak-Interaction (e.g., through Z-boson) would **overclose the Universe**.
- Mediator is needed for a proper freeze-out:
  the rise **of "dark sector" (DM + mediators).**

"Portals" to Dark Matter & New Physics



- **Renormalizable "portal" interactions:**

$$\mathcal{L} \supset \begin{cases} -\dfrac{\epsilon}{2\cos\theta_W} B_{\mu\nu}F'^{\mu\nu}, & \text{vector portal} \\ (\mu\phi + \lambda\phi^2)H^\dagger H, & \text{Higgs portal} \\ y_n LHN, & \text{neutrino portal} \end{cases}$$

- **Millicharge particle (mCP): $U(1)_Y$ hypercharge portal**

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

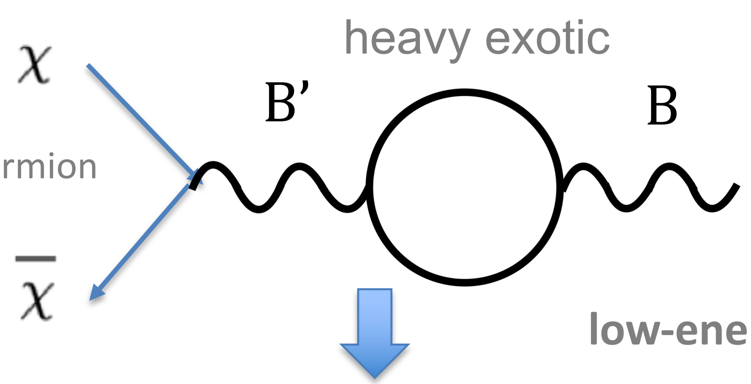
Millicharge Motivations

Millicharged particle (mCP) is a particle χ with {mass, electric charge} = $\{m_\chi, \epsilon e\}$

$\epsilon = Q_x/e$

1. **Is electric charge quantized? To what unit? And why? Long-standing questions.** Inspired **Dirac quantization.**
2. A test of **Grand Unified Theories (GUTs)** & **promising prediction of String theory,** see Wen, Witten, NPB (1985)
3. **Millicharged dark matter (mDM) & implications on CMB absorption spectrum**
4. Can **originate from massless vector-portal theory**, Holdom, PLB (1985)

Massless B' coupled to new dark fermion



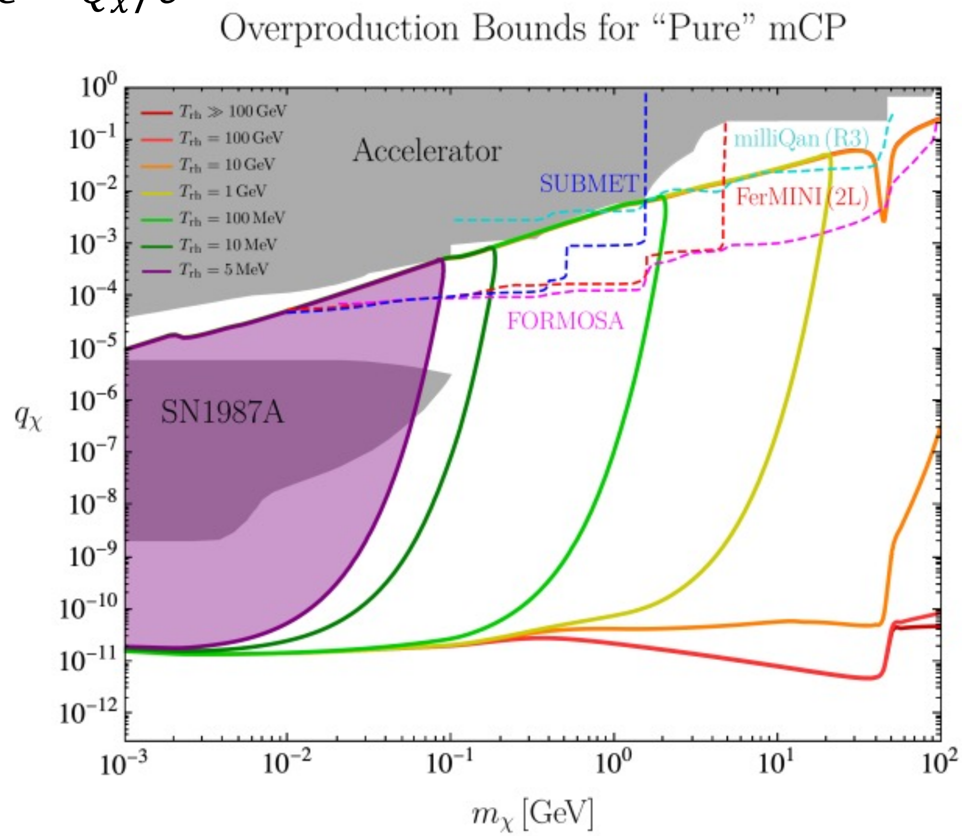
(Standard Model $U(1)_Y$)

low-energy effective interaction

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

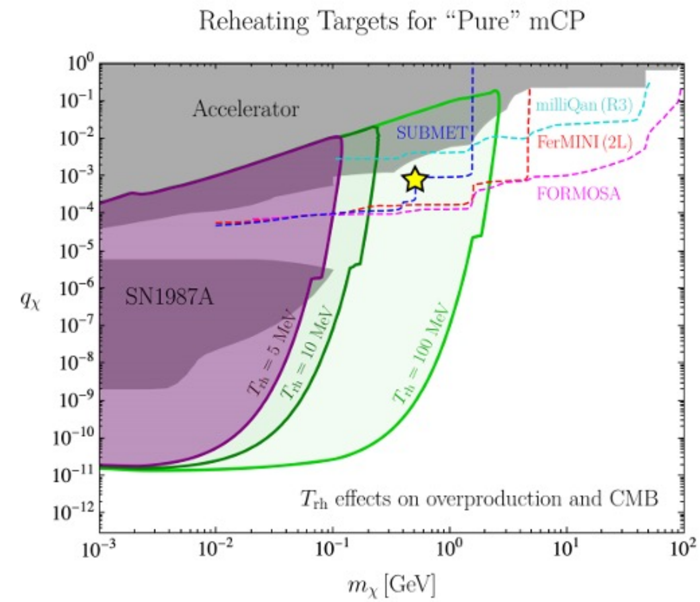
Probing Reheat Cosmology with dedicated mCP searches

$\epsilon = Q_x/e$



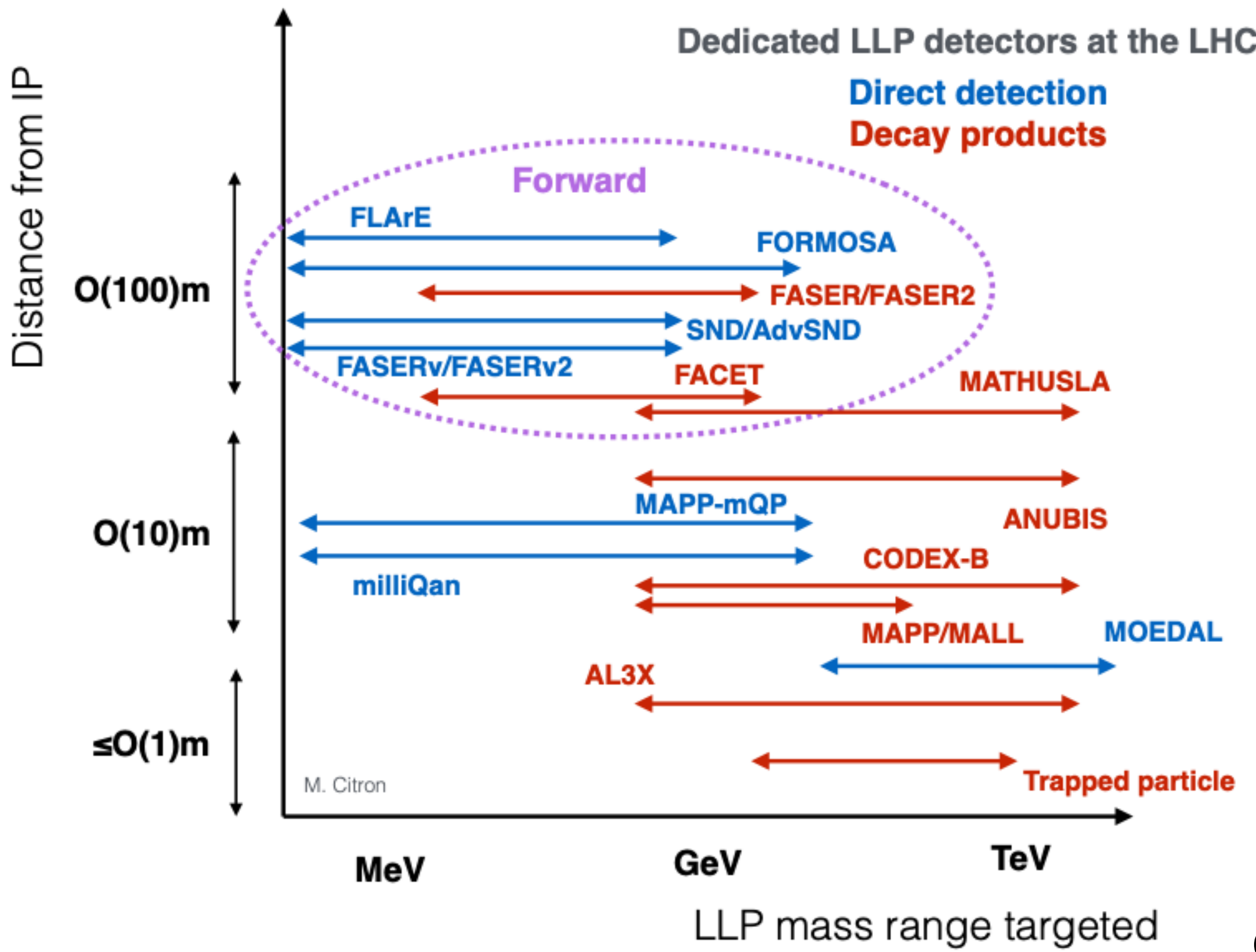
Gan, **Tsai**, 2308.07951

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



- Minimal reheating temperature larger than T_{BBN}
- Our purple bound is covering the SN1987A constraint
- Can use cosmology to distinguish **“pure” mCPs** & **dark photon mCPs**
- Gan, **Tsai**, 2308.07951, can extend to many non-minimal BSM models

List of Detectors

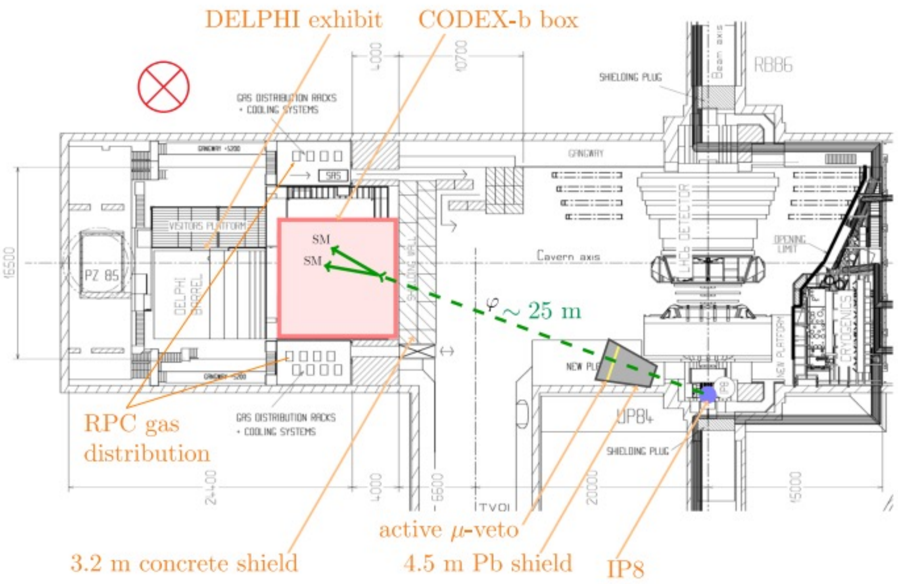


Credit: M. Citron

Transverse Detectors: Decay

up ~10 GeV LLPs with large $c\tau$

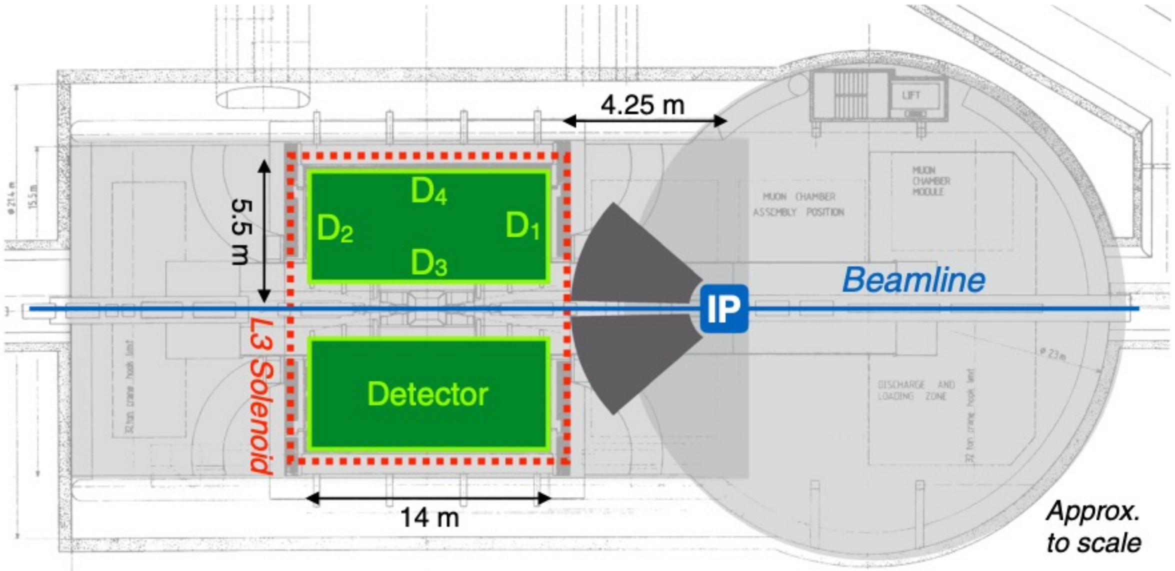
pseudo-rapidity $\eta < 4$, or smaller



CODEX-B

- $\sim (10\ m)^3$ tracker box behind a 3.2 m thick shield placed transverse to **LHCb**, 0.13 < η < 0.54
- See, arXiv:2203.07316

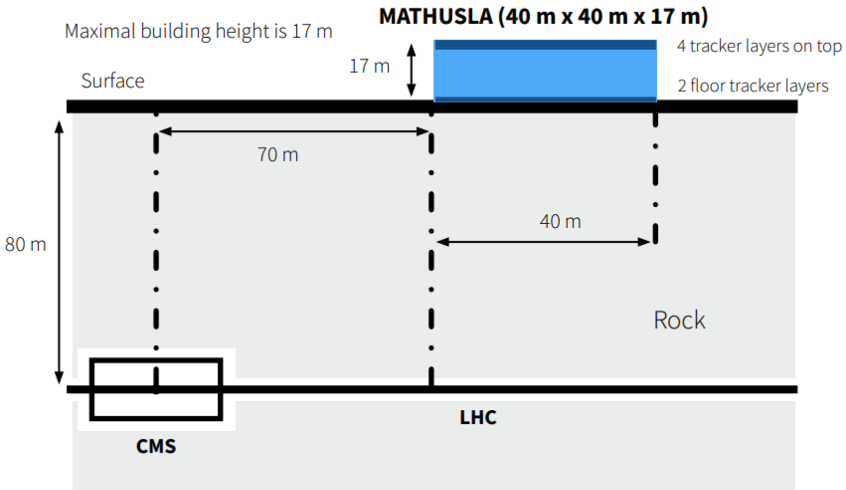
[Slides from B. Dey (ELTE)]()



AL3X

- https://arxiv.org/abs/1810.03636
- Utilizing **ALICE/L3 cavern** after Run 4 of the LHC.
- 0.9 ≤ η ≤ 3.7
- ALICE: Pb-Pb nuclei, centre of mass energy ~ 5.36 TeV.

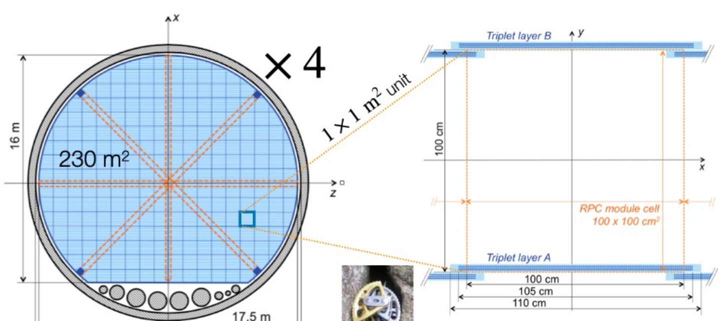
[Slides from B. Nachman]()



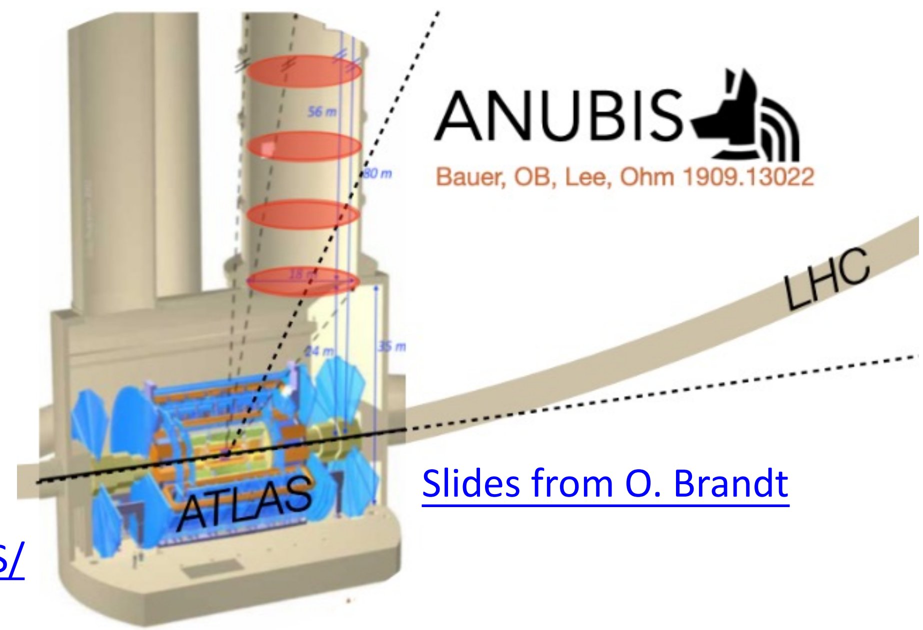
Side view with CMS

MATHUSLA (Updated design)

- From [slides of C. Alpigiani]
- [arXiv:2203.08126] & [arXiv:2308.05860]



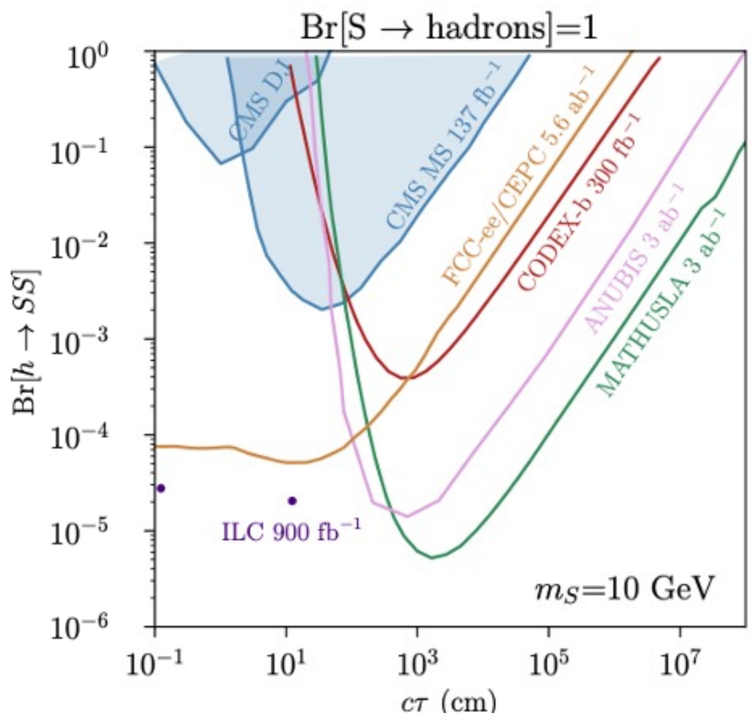
Parameter	Specification
Time resolution	$\delta t \lesssim 0.5$ ns
Angular resolution	$\delta\alpha \lesssim 0.01$ rad
Spatial resolution	$\delta x, \delta z \lesssim 0.5$ cm
Per-layer hit efficiency	$\varepsilon \gtrsim 98\%$

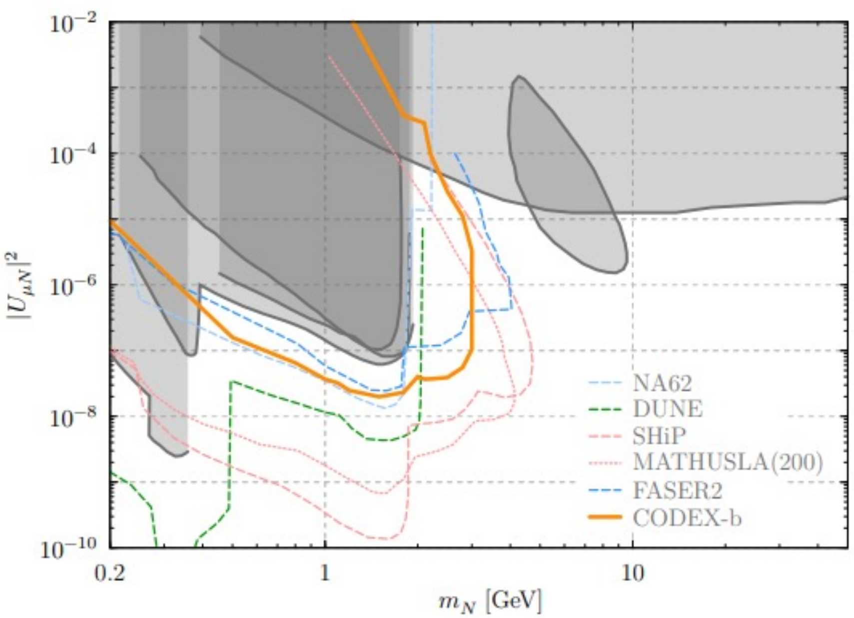


[Slides from O. Brandt]

- [https://twiki.cern.ch/twiki/bin/view/ANUBIS/]

Portals: Higgs Decays & HNLs





- Snowmass Energy Frontier Whitepaper
- **FACET, AL3X, and FASER (lower S mass) can also have sensitivities, e.g.,** arXiv: 2201.00019

- μ-coupled Dirac heavy neutral leptons
- **CODEX-b Col. arXiv:2203.07316**
- **MATHUSLA projections have to be readjusted with the down-scaled design**

Transverse Detectors: “Direct Detection”

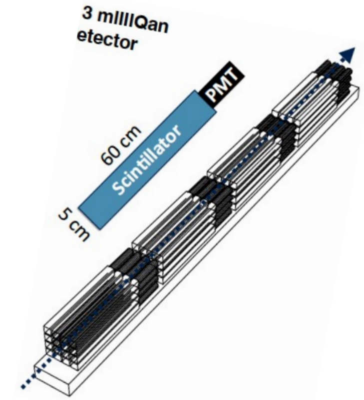
Scintillation & Scattering of Accelerator Produced Particles

Yu-Dai Tsai, UC Irvine, 2024

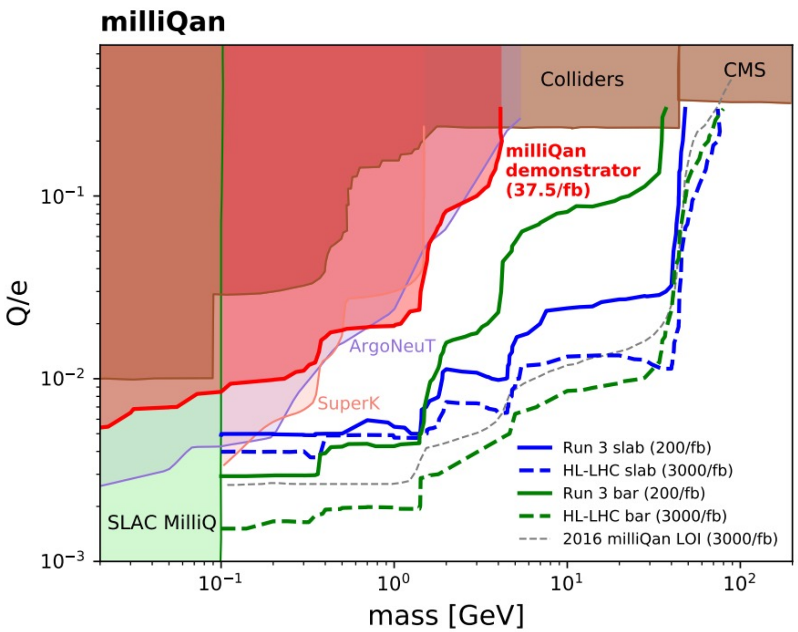
milliQan

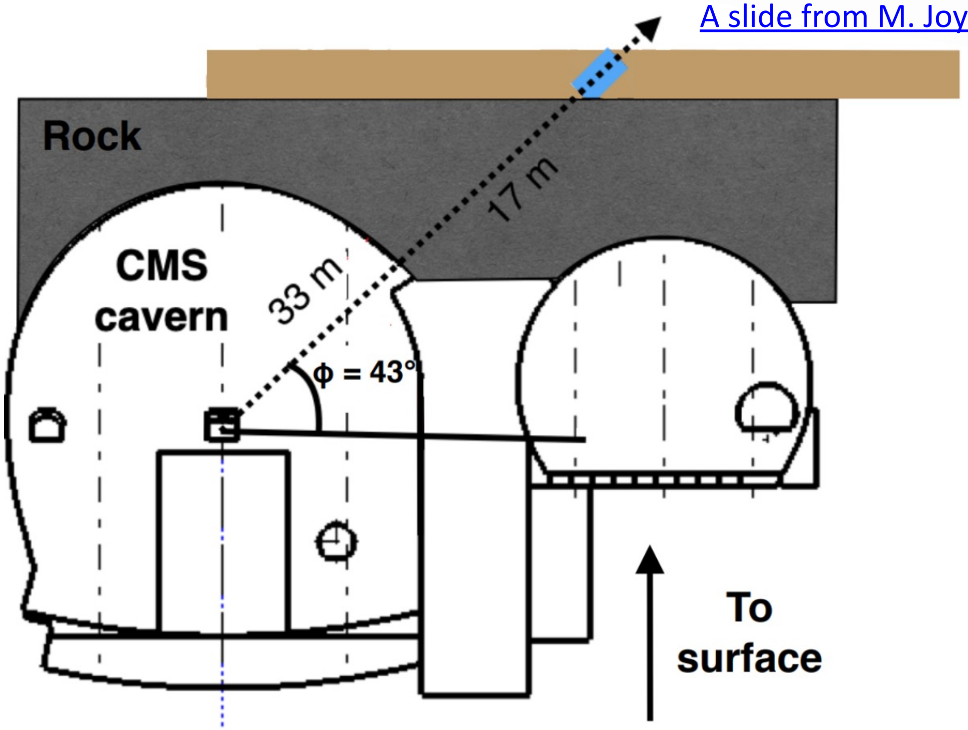
- https://arxiv.org/pdf/2209.03988
- Re-juvenated mCP dedicated searches
- milliQan is fully operating & taking data

- **Run 3 detector**: Array of 64 60 x 5 x 5 cm scintillator bars + PMTs arranged in 4 layers, pointed at IP used to detect small ionization from MCPs



A slide from M. Joyce

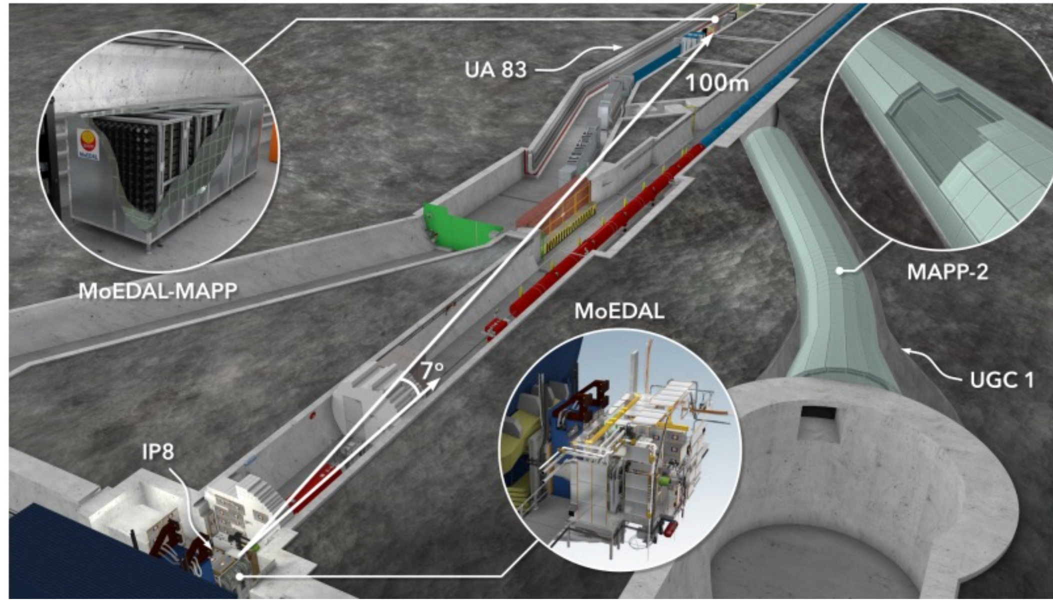


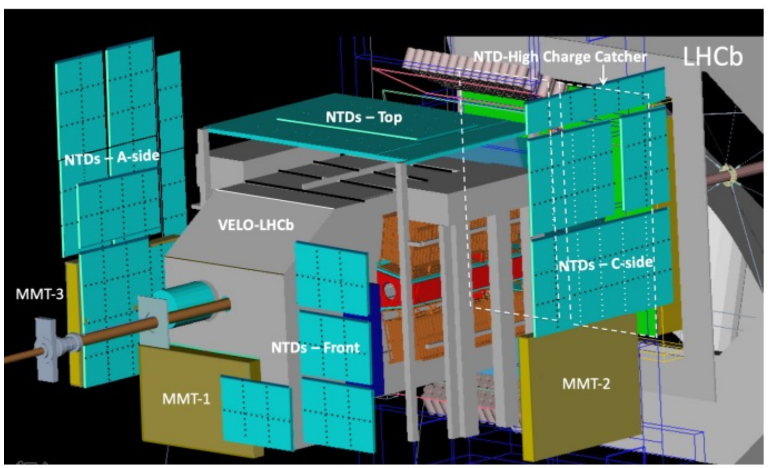


Result from milliQan demonstrator
milliQan Col. arXiv:2104.07151

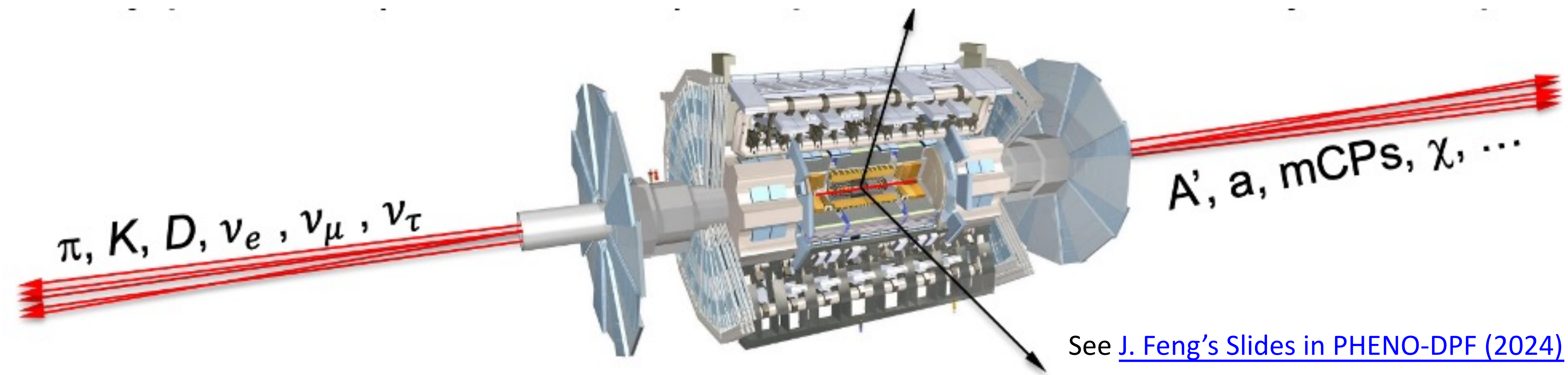
MoEDAL & MoEDAL-MAPP

- MoEDAL-MAPP Collaboration [arXiv:2209.03988](https://arxiv.org/abs/2209.03988) (Snowmass 21)





- **MoEDAL primary targets: magnetic monopole & dyon**
- 155 m^2 of plastic of Nuclear Track Detectors (NTDs): track highly ionizing particles (HIPs) and accurately measure their charge.
- 800 kg of trapping volumes, forming the MMT sub-detector, that can capture HIPs for study in the laboratory.
- **MoEDAL-MAPP is scintillation experiment for mCPs**



See J. Feng's Slides in PHENO-DPF (2024)

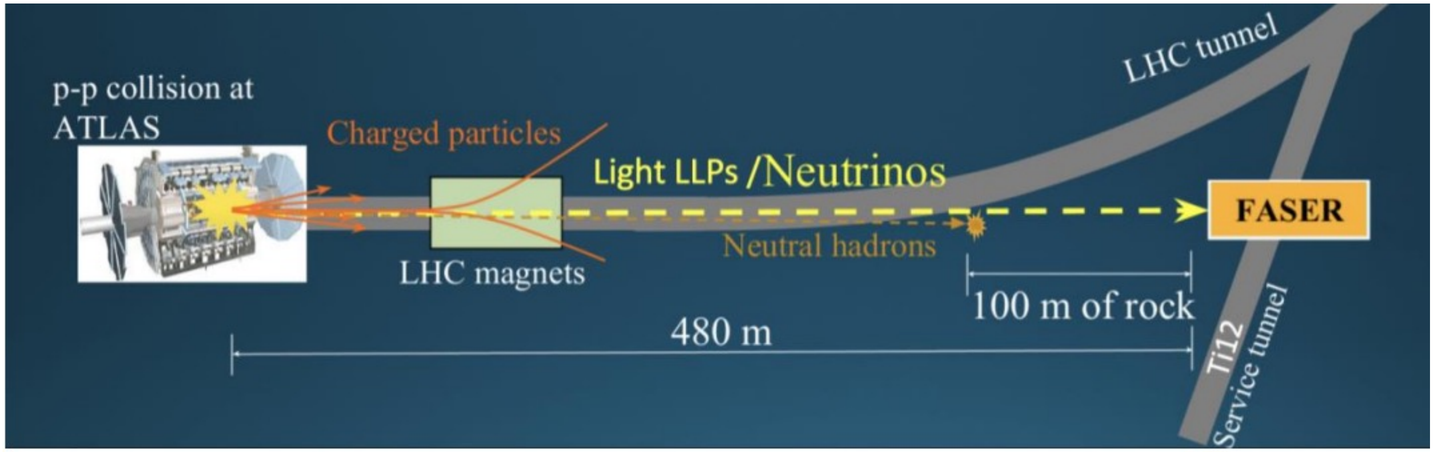
Forward Detectors:

"When high energy meets high intensity" strong meson productions

Yu-Dai Tsai, UC Irvine, 2024

Forward Detectors: Decay

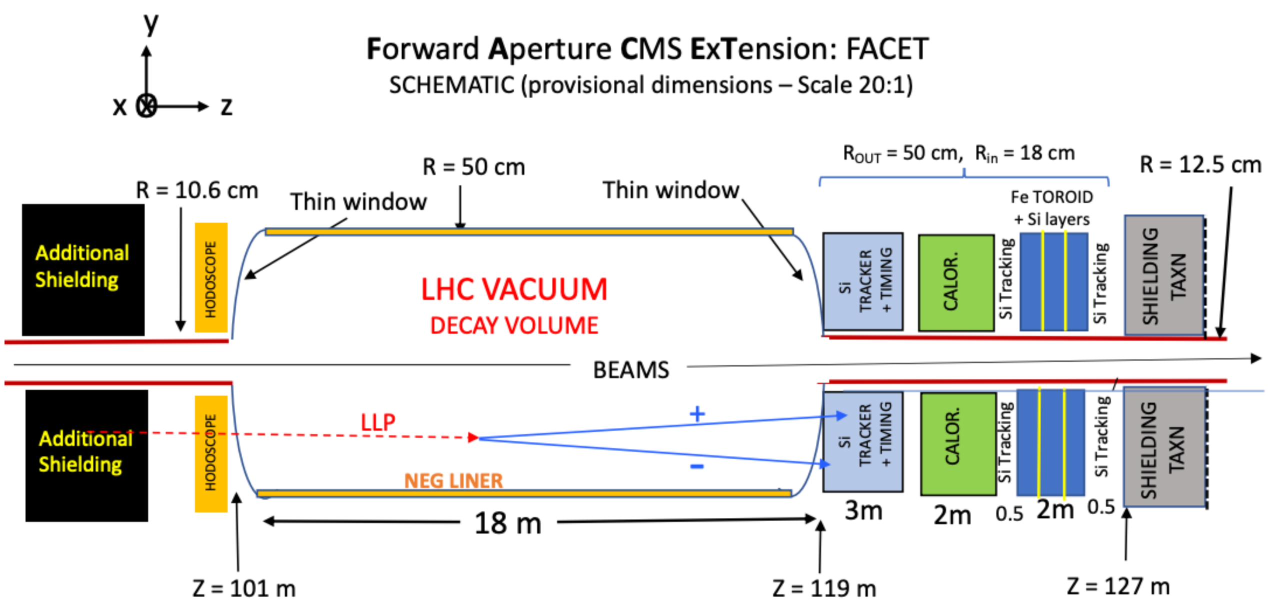
FASER



Website: https://home.cern/science/experiments/faser; Slide from L. Cavanagh

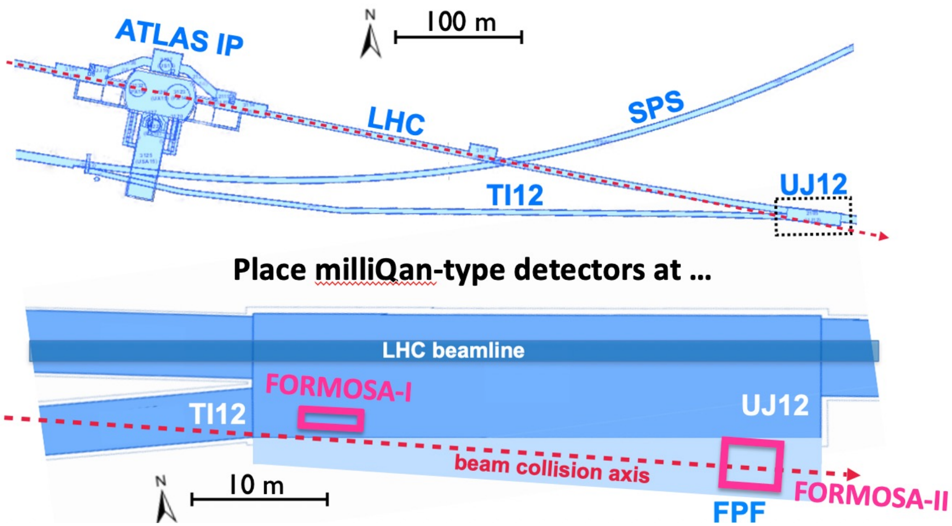
See the next talk for FASER result updates.

FACET



FACET Collaboration: arXiv: 2201.00019

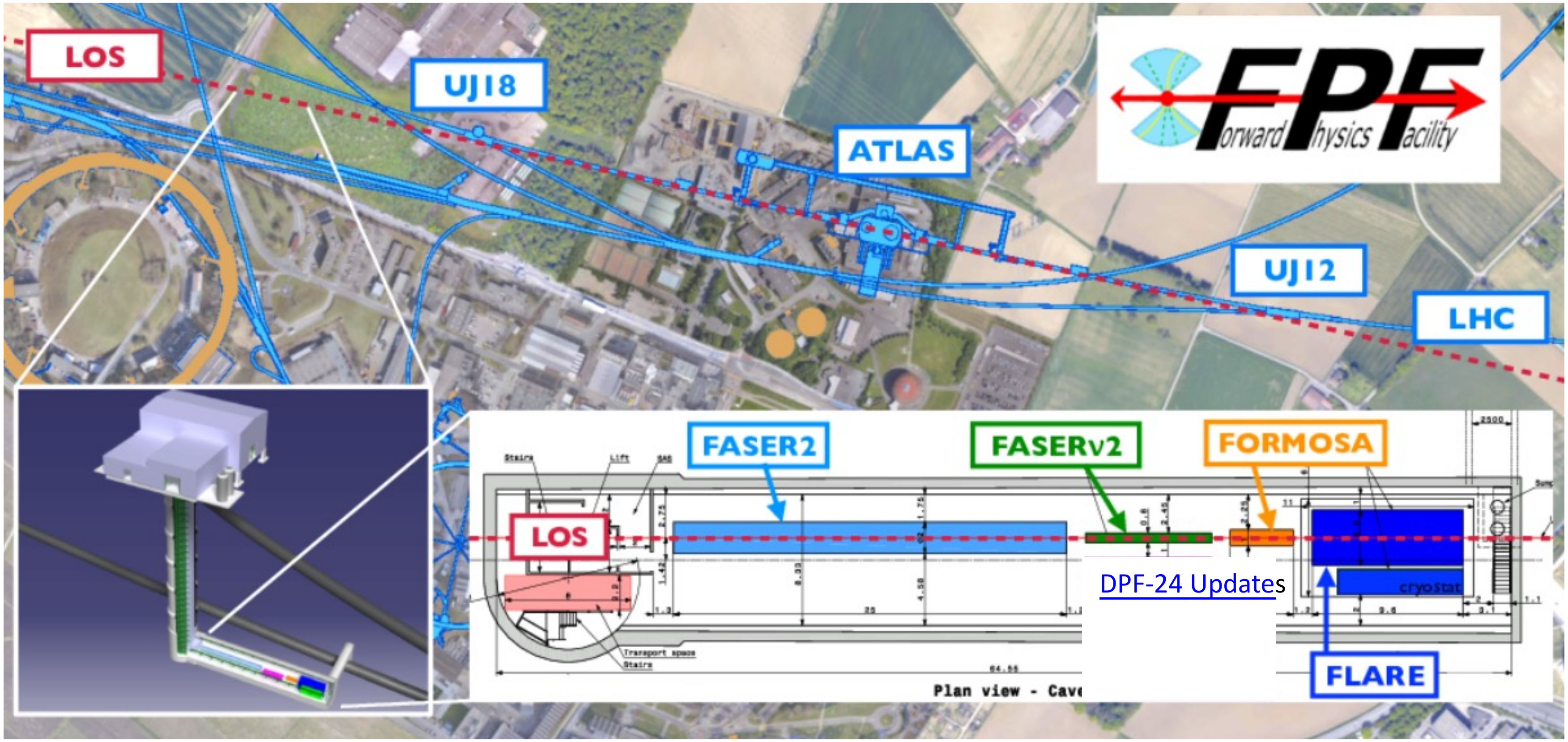
Forward Detectors: Direct Detection through scintillation



- FORMOSA Phase-I installed!

- Foroughi-Abari, Kling, **Tsai**, PRD (2021), arXiv:2010.07941
- The most "beautiful" (in Portuguese) experiment; Ancient name of Taiwan.
- **mCP scintillation experiment is one of the most "agile" setups, can applied to almost all accelerators.**

Forward Physics Facility: Decay + Direct

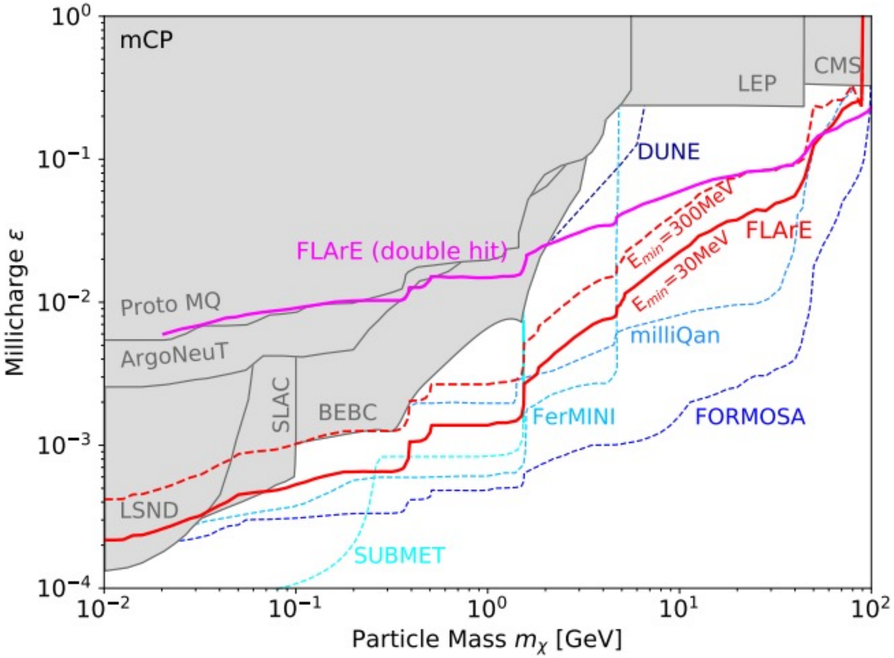


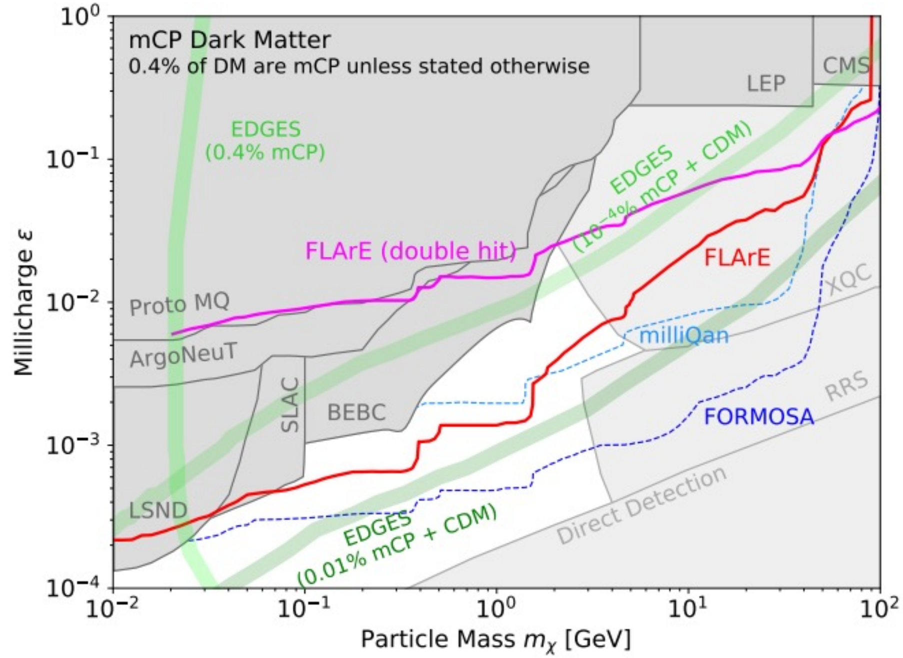
One of the homes to the eminent future of particle physics

- FASER2: magnetized spectrometer for BSM searches
- FASERv2: 10-ton emulsion-based neutrino detector
- FLArE: 10-ton LArTPC neutrino detector
- FORMOSA (Phase-II): scintillator array for BSM searches

Snowmass Whitepaper: arXiv:2203.05090

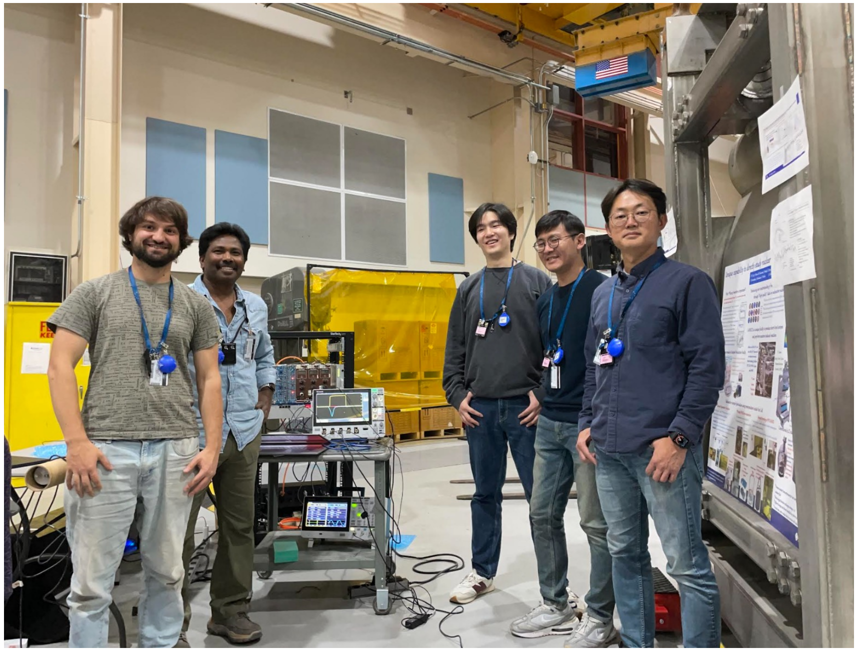
mCP Searches vs mDM Searches





- Kling, Kuo, Trojanowski, **Tsai**, NPB (2023), 2205.09137
- **Two advantages of accelerator searches**

1. Insensitive to assumptions
2. Not stopped in atmosphere or curst



Scintillators tested in LANL

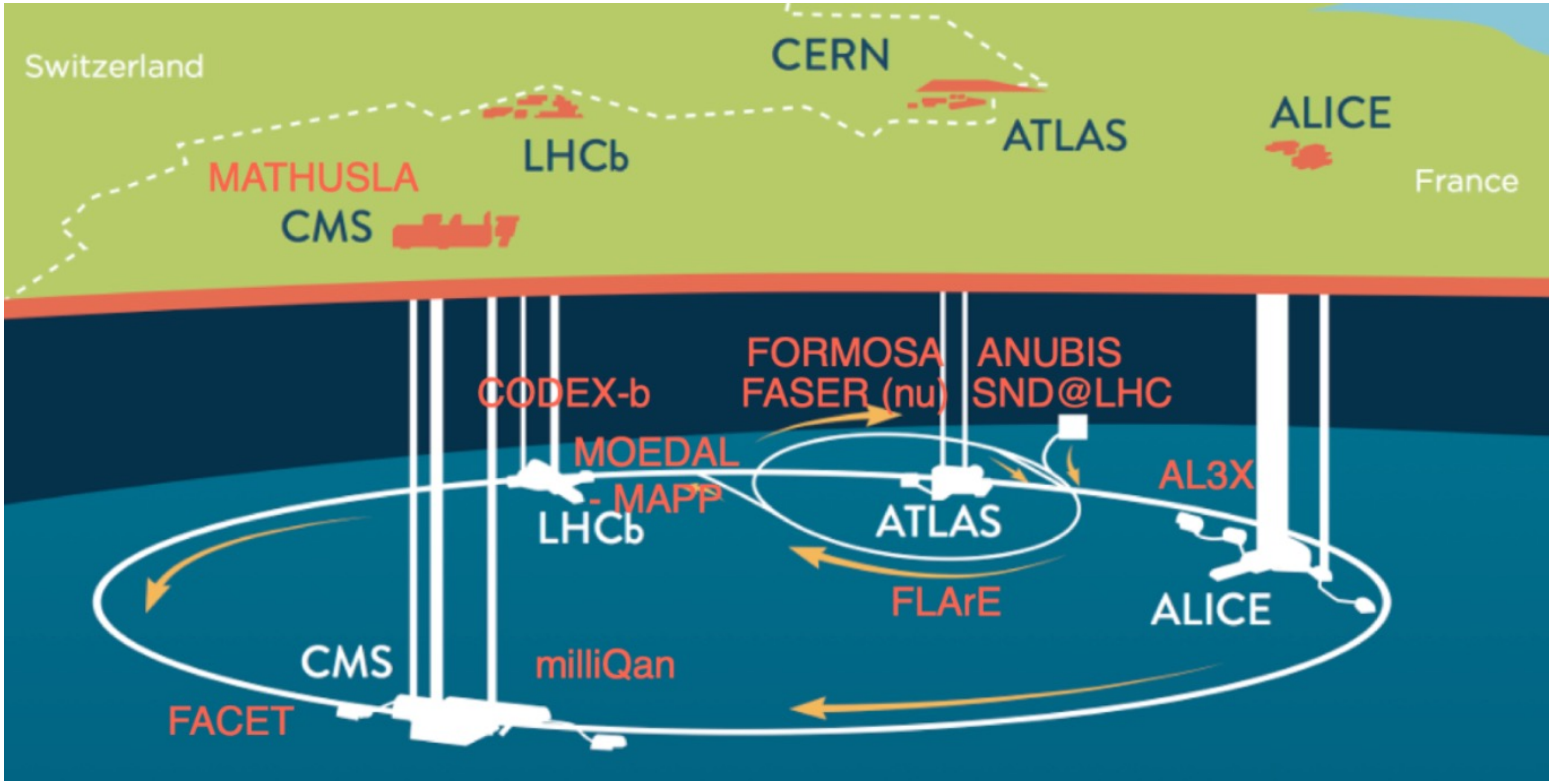
Our experimental team installed FORMOSA-I

Thank you!

Thanks for the invitation and the conference

Please contact me if you think your work should be featured.

Compilation



Credit: Royal Society / Emma Torro Pastor
https://ep-news.web.cern.ch/content/llp11-eleventh-workshop-long-lived-particle-community