Missing momentum for dark matter and beyond

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for the LDMX collaboration and the M^3 concept

Rare Processes and Precision Frontier Townhall Meeting
October 2, 2020

Outline

- Dark Matter and Missing Momentum

- **LDMX Snowmass status and plans**
  - Dark matter LoI
  - Electron-scattering LoI
    (includes neutrino community members)

- **M3 Snowmass status and plans**
  - M3 LoI

What is the physics / motivation for your LOIs?

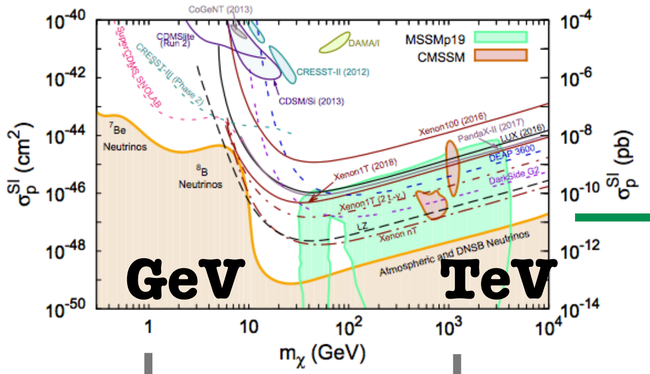
What will you work on between now and Snowmass, and what is your schedule for developing a contributed paper?

What common data sets, joint efforts, etc. do you need?

What would you like to come out of the Snowmass process?

An evolution of the community...
Dark Sectors, 2016
Cosmic Visions, 2017
Dark Matter New Initiatives, 2018
CERN Physics beyond colliders, 2019

Thermal, but not WIMP



CDM bound ← BBN bound ← ~100 TeV, Violate unitarity →

keV | MeV | GeV | TeV

DIRECT DETECTION

COLLIDER

LHC: DIJETS, MONOJETS, SUSY, ETC.

B-FACTORIES

WHAT ABOUT THIS REGION?

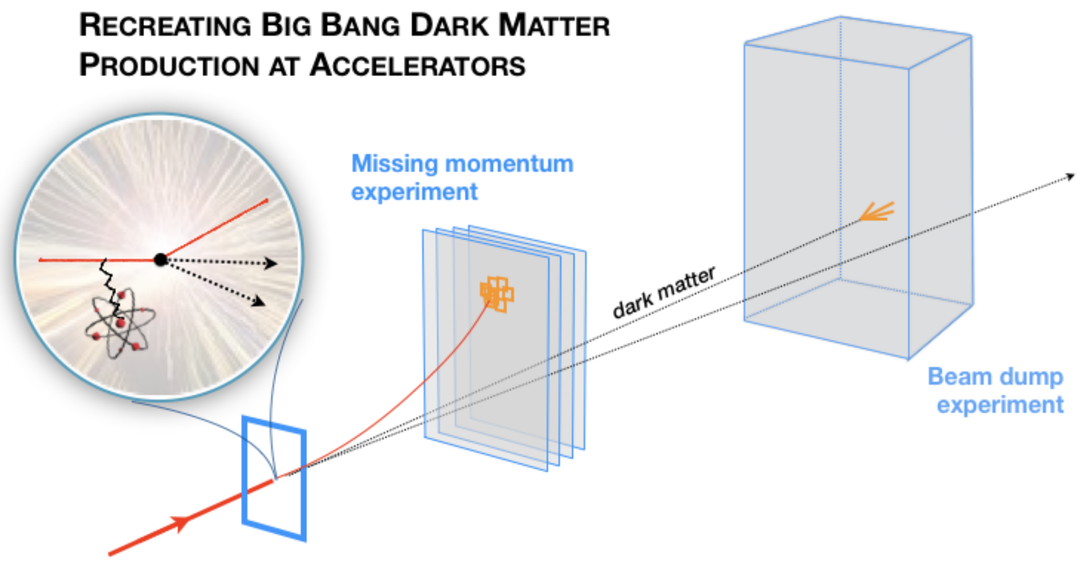
Lee-Weinberg bound,
light DM requires light mediators
→ Dark Sectors

NORMAL MATTER LIVES HERE. WHY NOT DM?

+ Curious results…
muon g-2, proton radius puzzle, KTEV excess, astrophysical inconsistencies

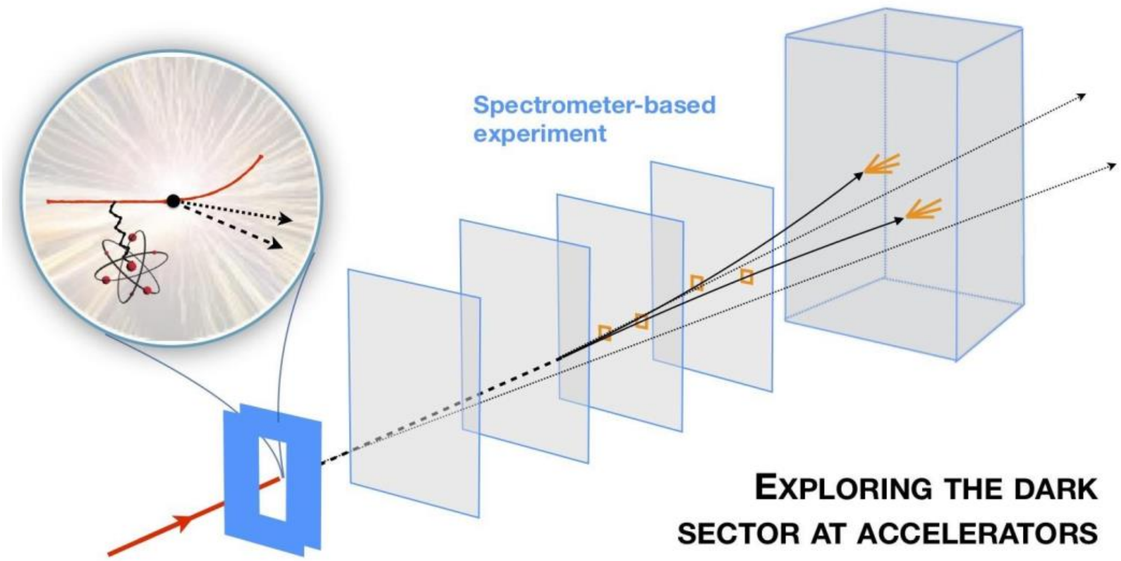
Dark matter and dark sectors

Dark Matter New Initiatives

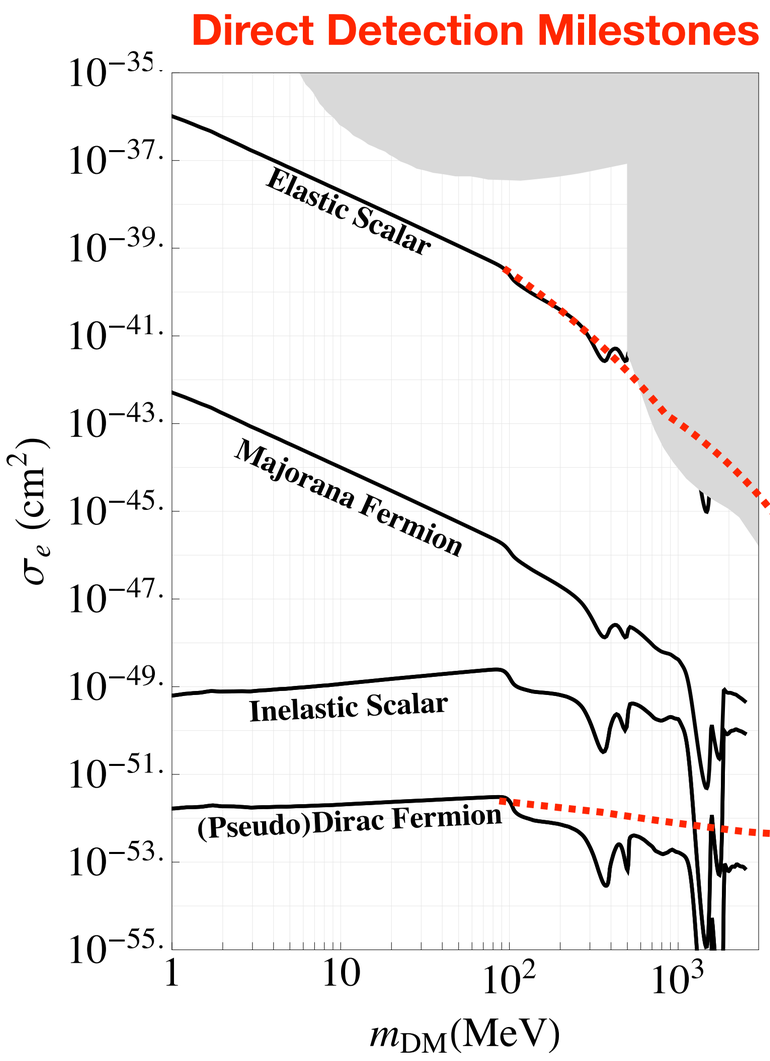


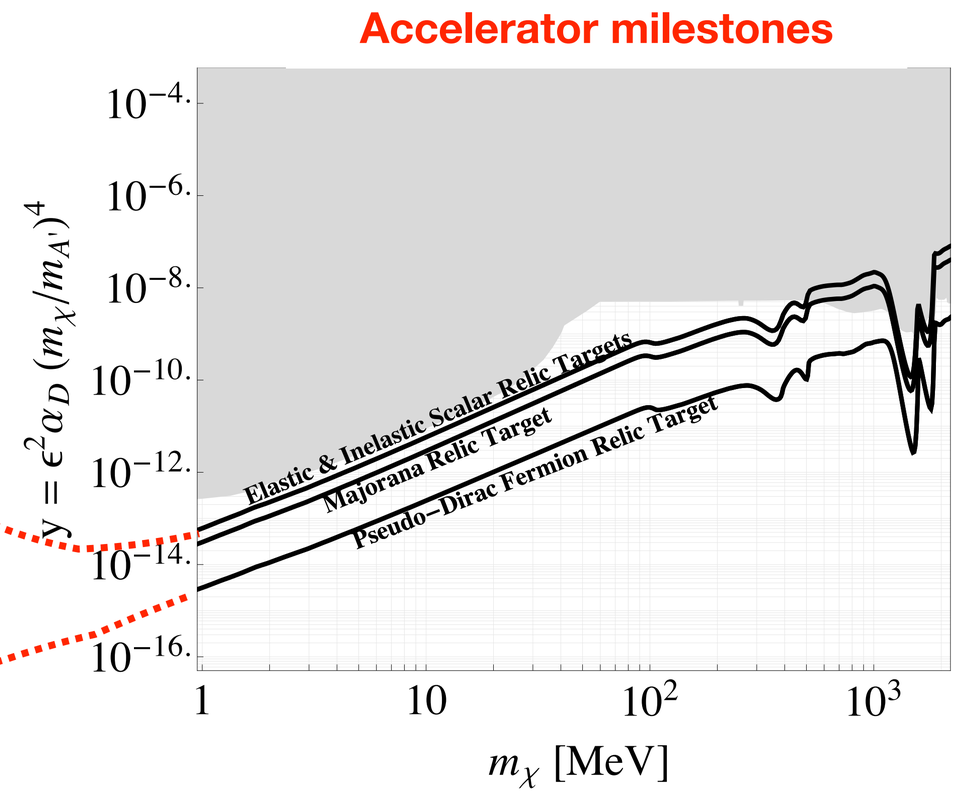
Thrust 2 (near and long term): Explore the structure of the dark sector by producing and detecting unstable dark particles.

Thrust 1 (near term): Through 10- to 1000-fold improvements in sensitivity over current searches, use particle beams to explore interaction strengths singled out by thermal dark matter across the electron-to-proton mass range.



Why accelerators?

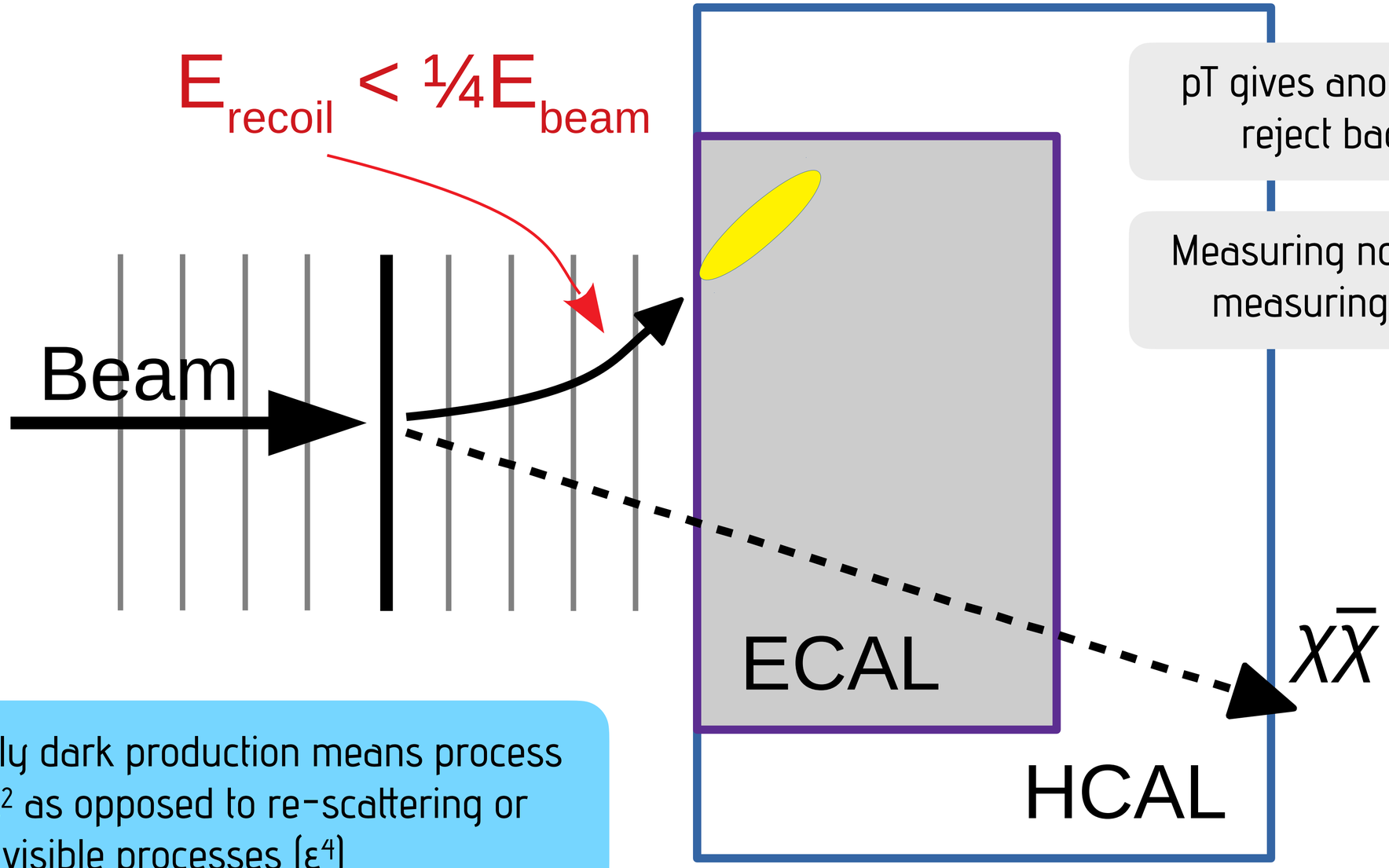




10-1000x improvements
Model parameter choices "blur" these milestones (shown in BRN report) but the idea remains

Relativistic production of DM is less sensitive to loop- and velocity-suppressed couplings

Why missing momentum



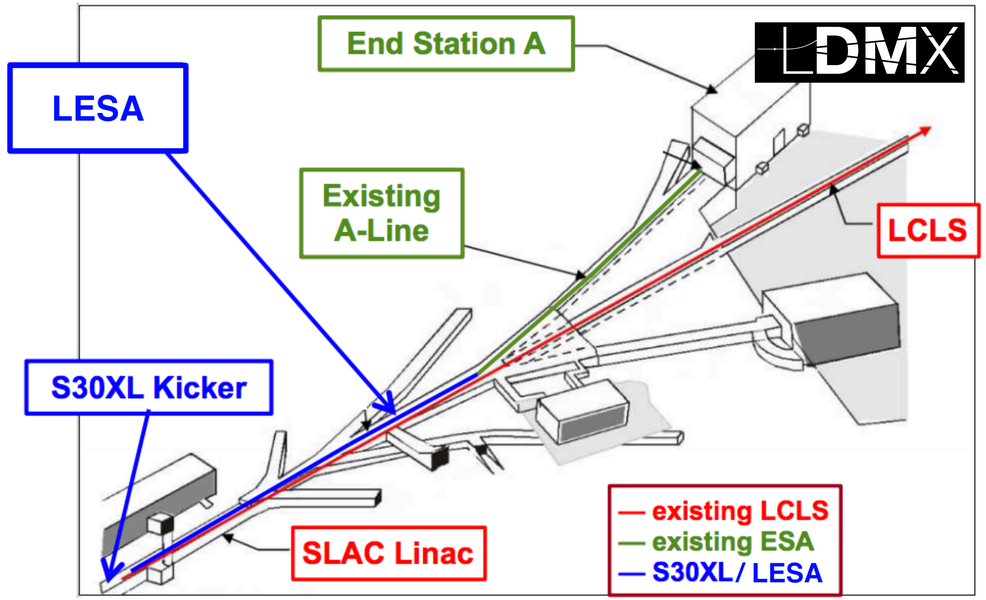
pT gives another handle to reject backgrounds

Measuring nothing requires measuring everything!

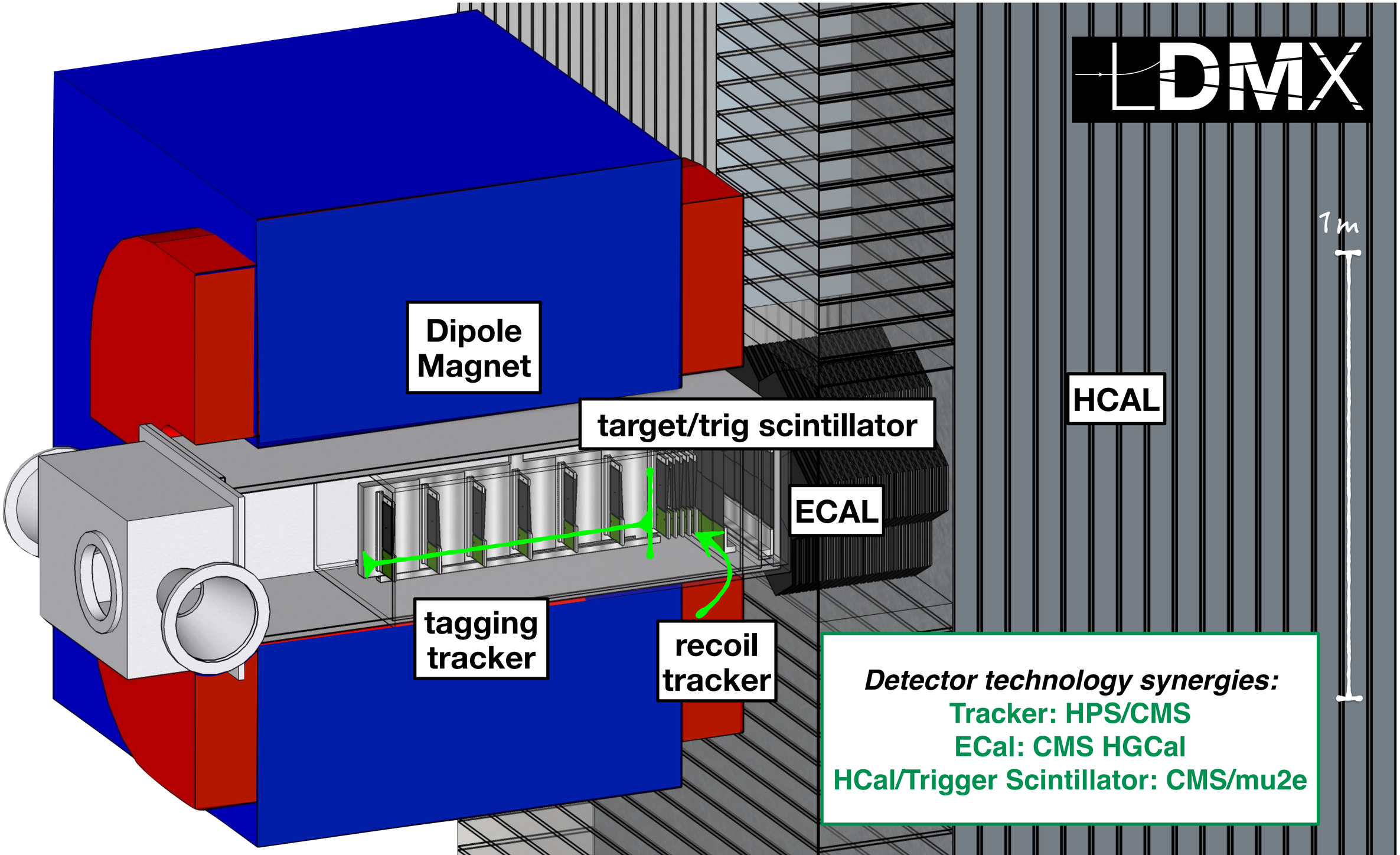
Requiring only dark production means process scales as ε^2 as opposed to re-scattering or visible processes (ε^4)

The Light Dark Matter eXperiment

- **Electron missing momentum experiment 4/8 GeV**
- Primary physics goal: definitively explore thermal dark matter milestones
- Based at LCLS-II @ SLAC; new beamline under development
- Received DMNI R&D funding - currently working on meeting R&D milestones



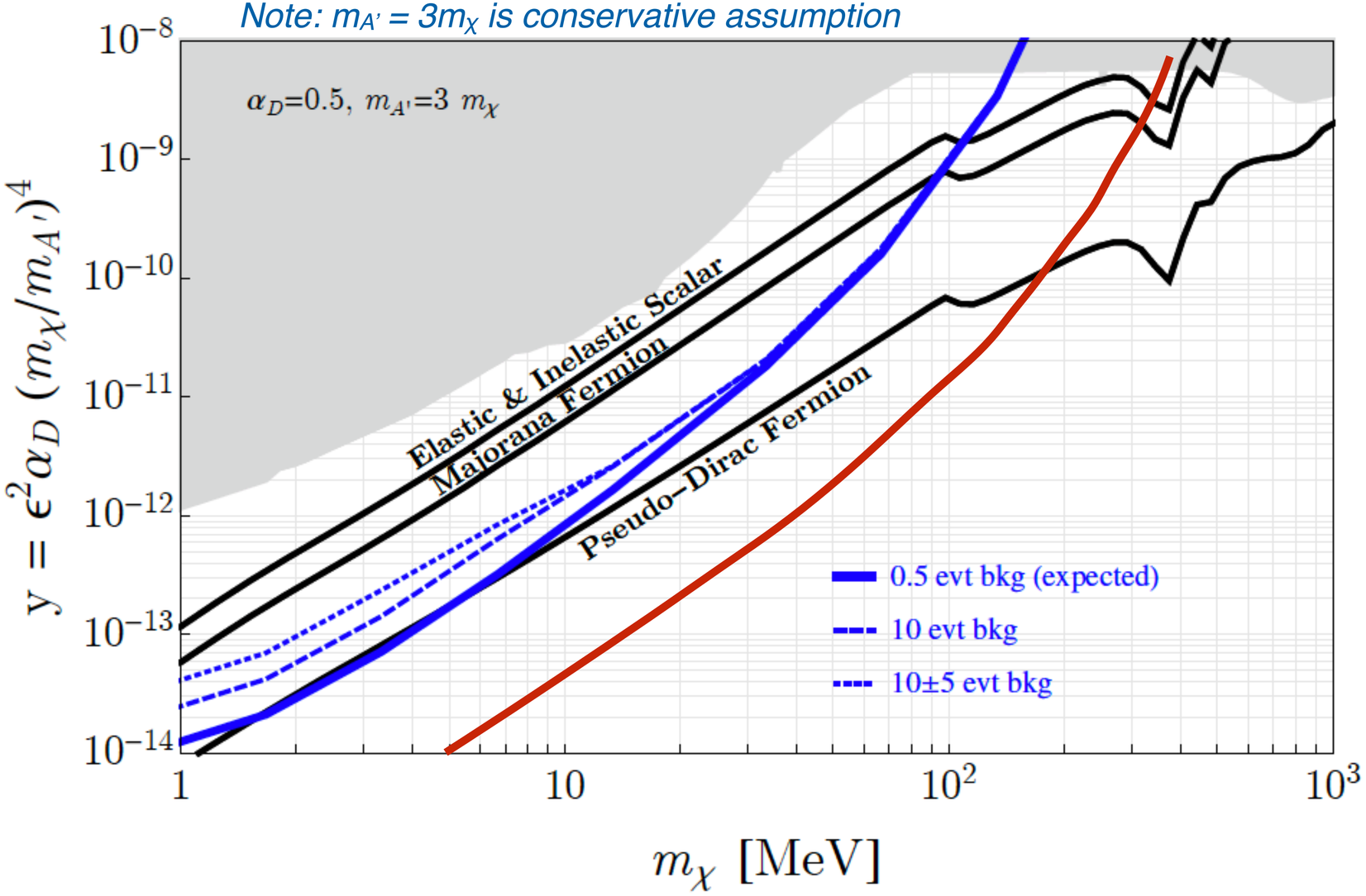
Caltech Fermilab Lunds Universitet University of Minnesota UCSB University of California Santa Barbara SLAC National Accelerator Laboratory Stanford University Texas Tech University University of Virginia



Detector technology synergies:
Tracker: HPS/CMS
ECal: CMS HGCal
HCal/Trigger Scintillator: CMS/mu2e

Projected sensitivity

Note: $m_{A'} = 3m_\chi$ is conservative assumption



4×10^{14} EoT @ 4 GeV

1×10^{16} EoT @ 8 GeV

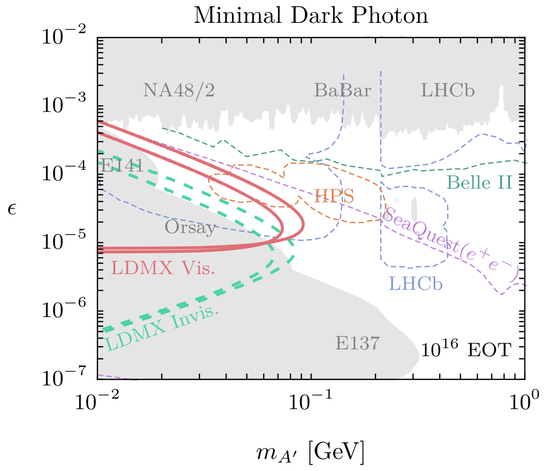
LDMX plans for Snowmass

- **Continue detector design and development** in preparation for construction
  - Meet FY21 milestones for tracker, trigger scintillator, ECal, HCal, and TDAQ, computing infrastructure
  - Continue to improve simulation and reconstruction performance
  - On-going physics studies for 2-electron performance, 8 GeV studies, dark matter production in the ECal, wide-angle background studies

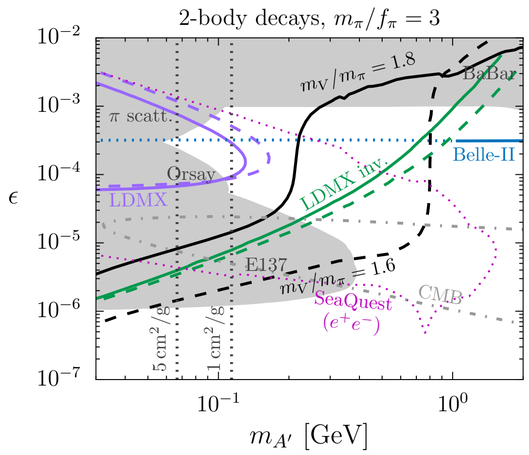
- **Build up broader physics case** for additional dark sector searches and synergy with DUNE physics program through measurements of electron-nucleon scattering processes

LDMX plans for Snowmass

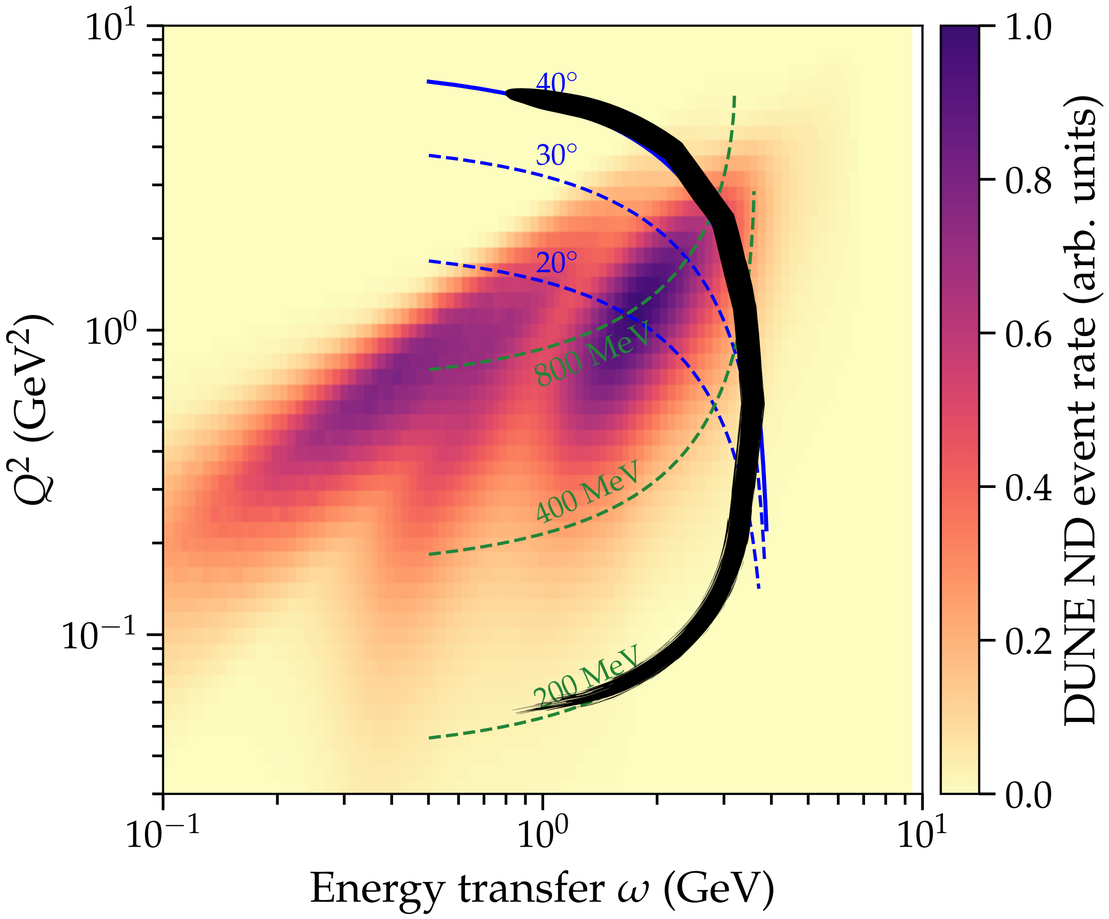
Dark Photon



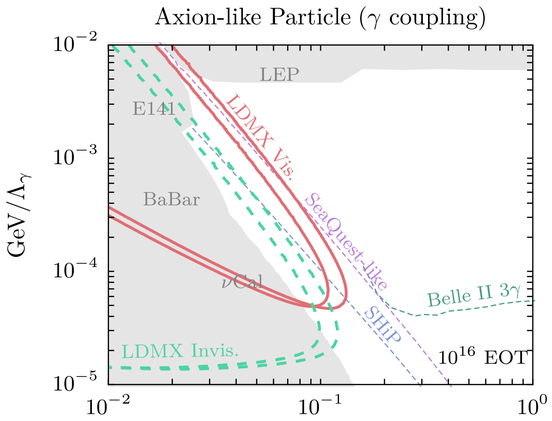
SIMPs



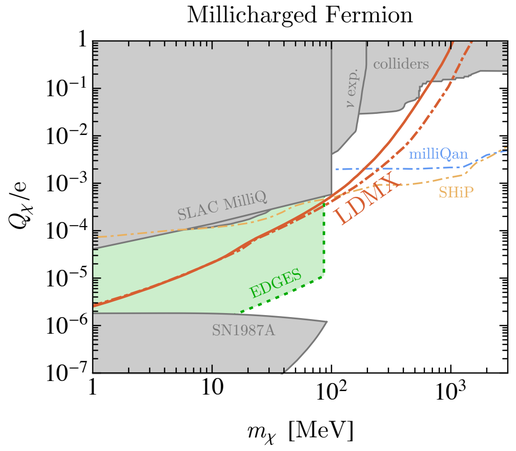
Electron-nucleon scattering



ALPs



Millicharged



LDMX Snowmass process goals

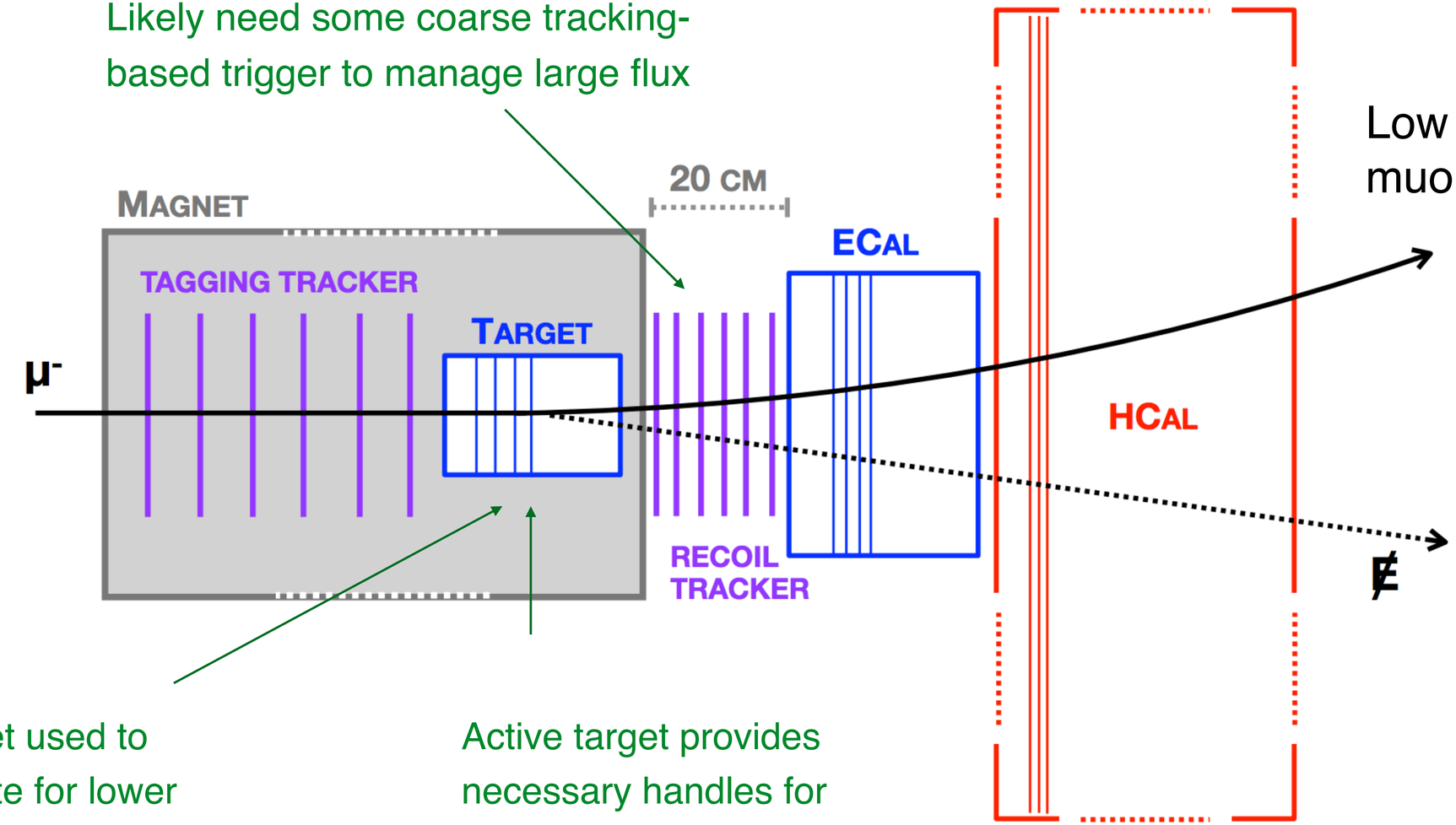
- Raise community awareness in **LDMX** as powerful probe of sub-GeV dark matter and thermal relic benchmark models
  - Develop community narrative for accelerator-based sub-GeV dark matter and dark sector research program building from BRN report paradigm
- Mature LDMX design and experimental readiness for primary dark matter missing momentum analysis
- Explore broader LDMX physics program for visible dark sector signatures and complementarity with DUNE via electron-nucleon scattering measurements

Kahn, Krjnaic, Tran, Whitbeck
https://arxiv.org/abs/1804.03144

M^3

Likely need some coarse tracking-based trigger to manage large flux

Single muon into M^3



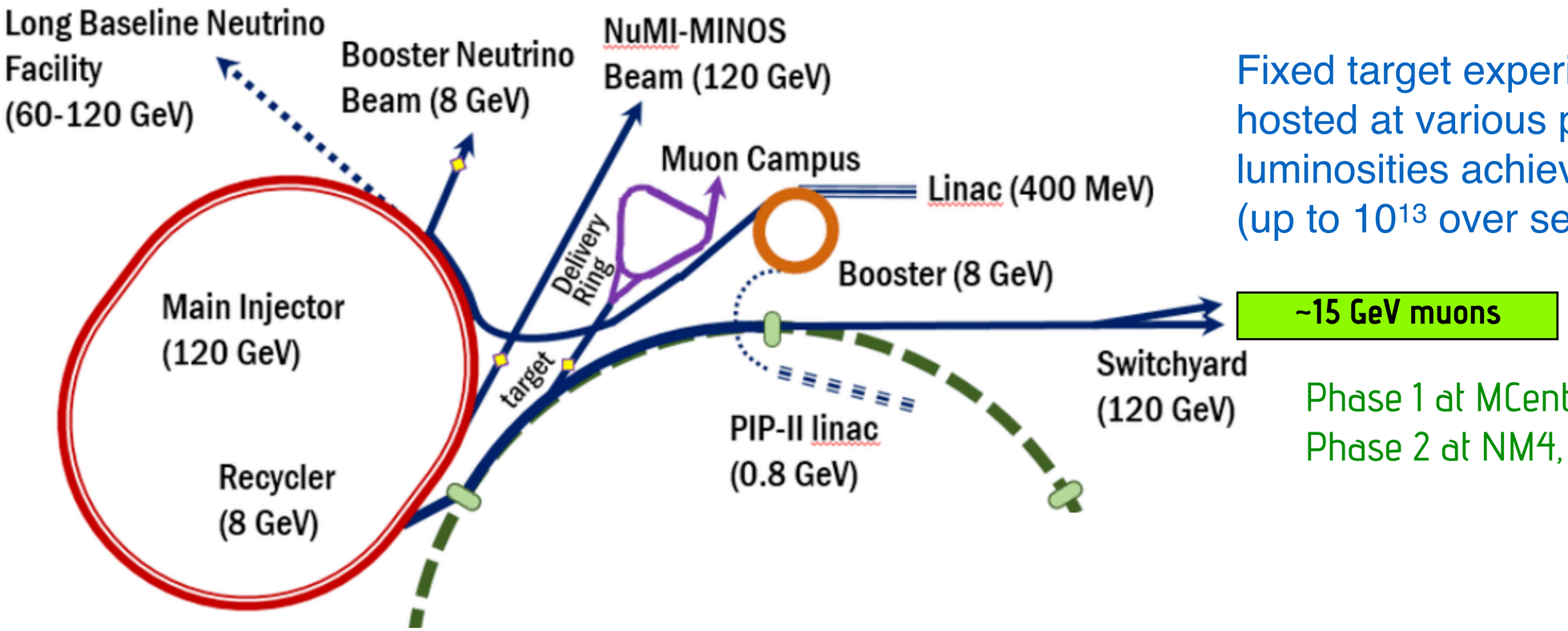
Low E, high p_T muon out

Thick target used to compensate for lower beam current as compared electron fixed target facilities

Active target provides necessary handles for identify backgrounds produced in target

Muon facilities at FNAL

Facilities exist that can be used immediately with minimal modifications to achieve world-leading sensitivity



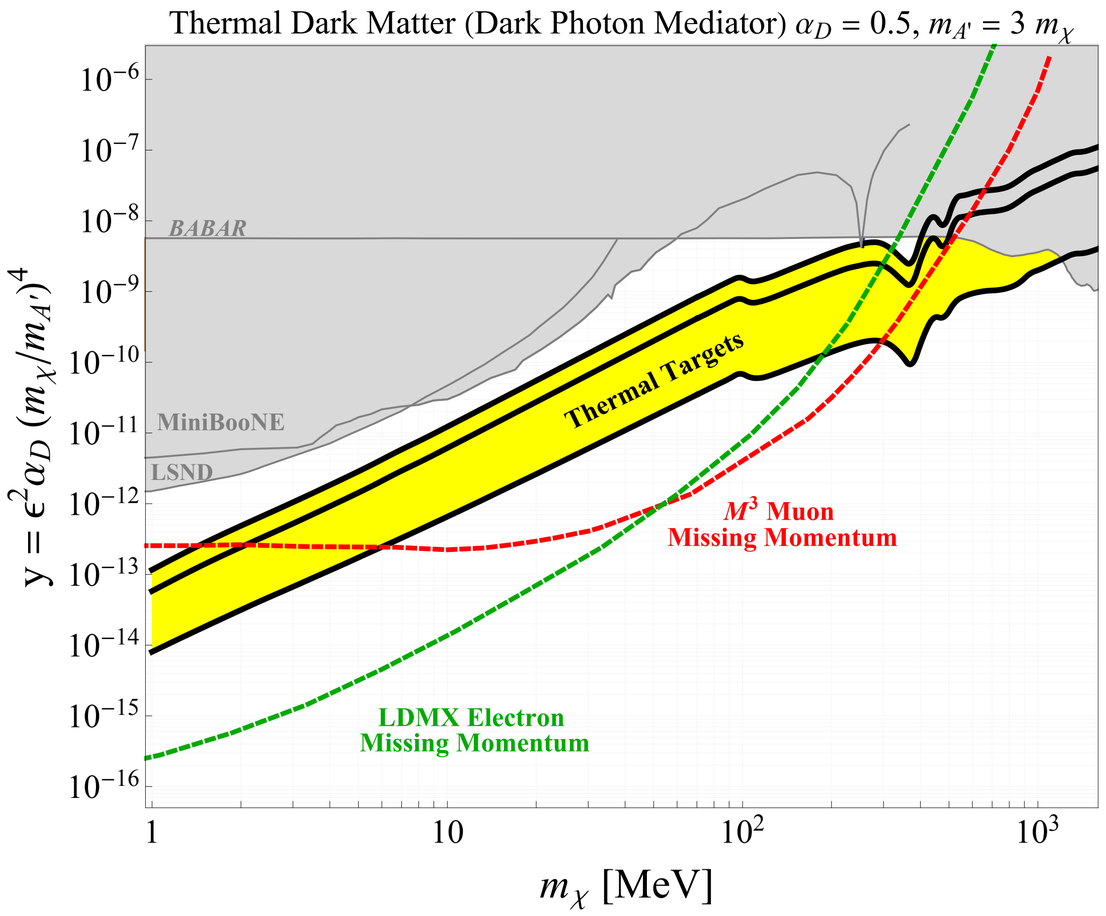
Fixed target experiments can be hosted at various points with varying luminosities achievable (up to 10^{13} over several years)

Phase 1 at MCenter, 10^{10} MoT
Phase 2 at NM4, 10^{13} MoT

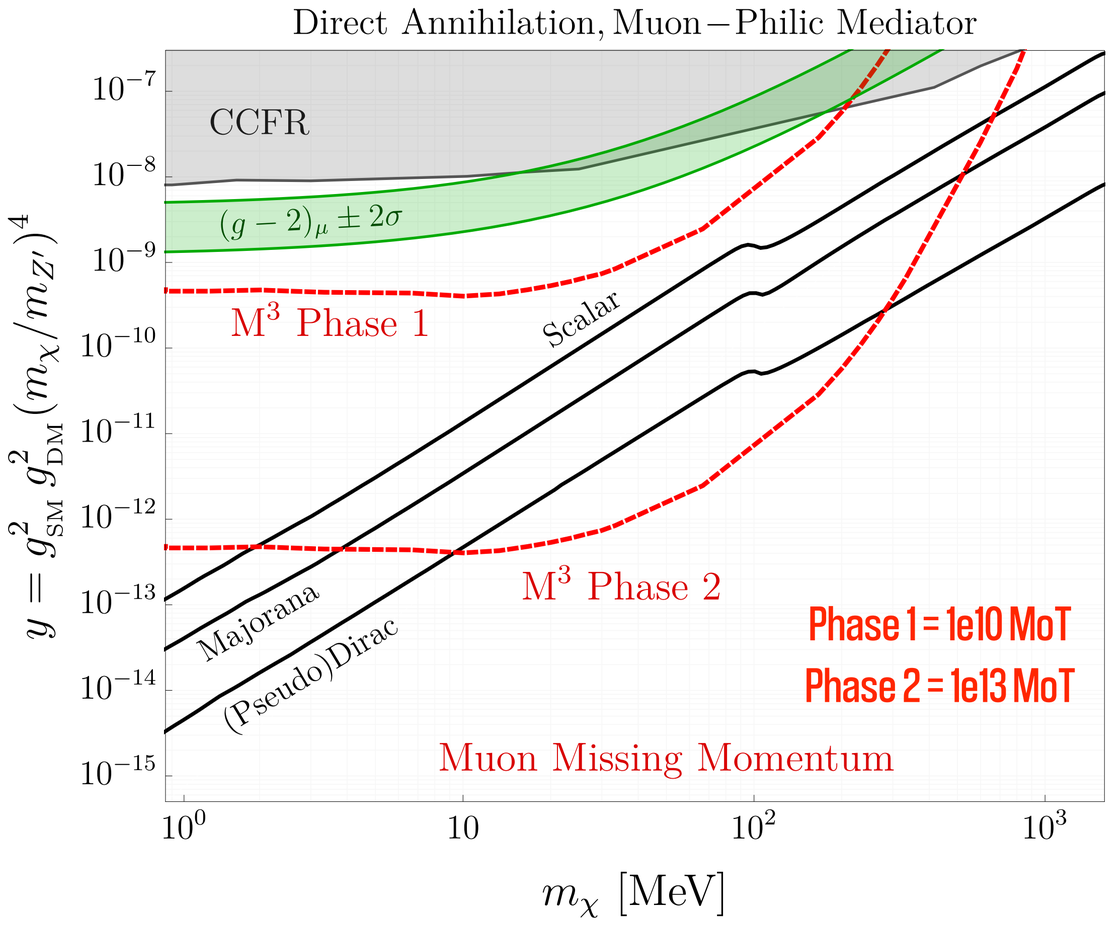
***Similar experiment prosed as an extension to NA64 using CERN's secondary muon beams with higher energy muons — lower energies allow for a more compact design*

M³ sensitivity

Provides competitive (better at high mass) sensitivity to generic thermal relic DM scenarios



Can test the remainder of the $(g-2)_\mu$ parameter space by covering connections to invisible signatures & is uniquely sensitive to muon-philic DM thermal relic models



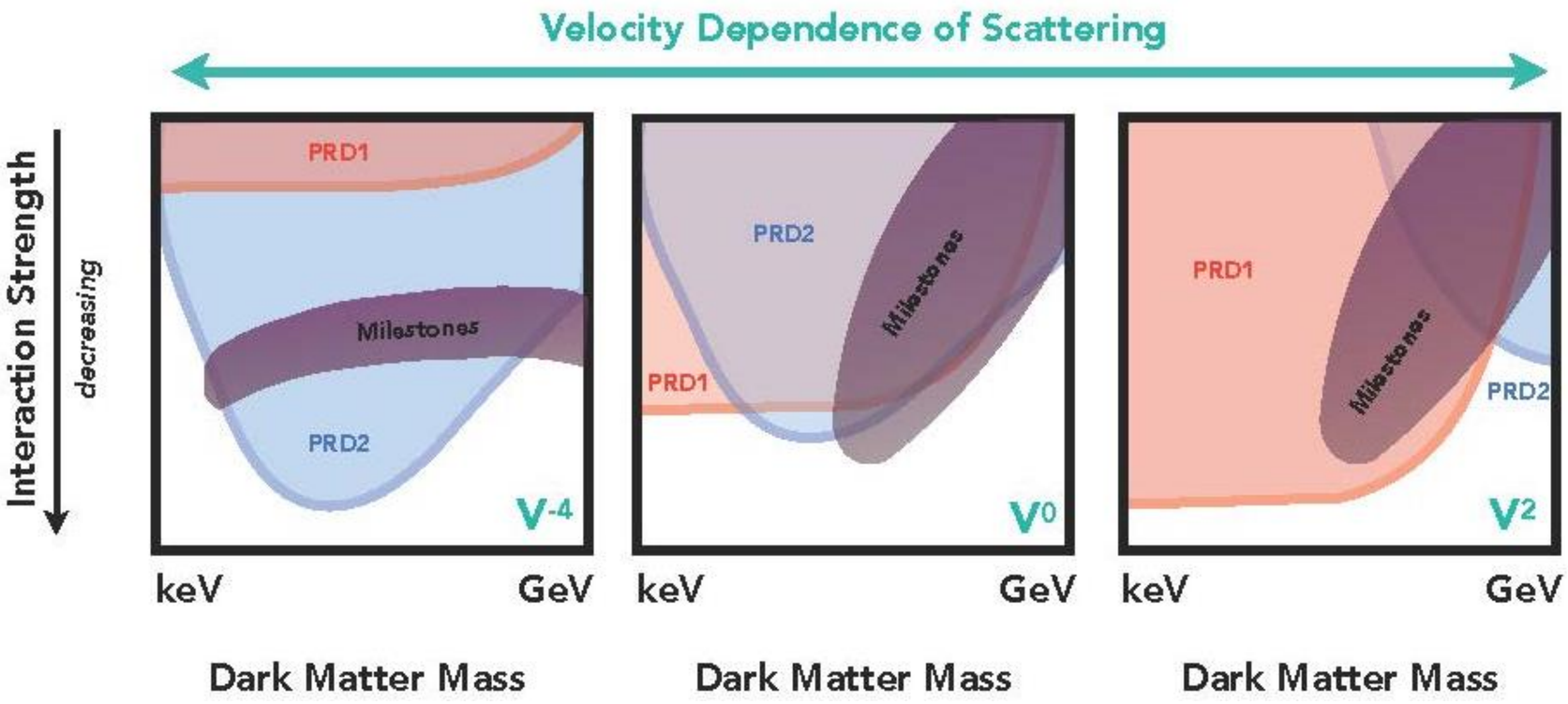
M^3 Snowmass process goals

- Raise community awareness in **M^3** as a unique probe of light new physics related to potentially confirmed g-2 anomaly

- Raise community awareness in **M^3** as potentially powerful probe of sub-GeV dark matter and thermal relic benchmark models
  - Complementary to electron beams for generic light DM benchmark models and as a unique probe of muon-phillic (e.g. $L_{\mu-\tau}$) DM benchmark models

- Develop a first baseline detector concept and simulation;
- Further refine accelerator requirements with Fermilab accelerator complex

Accelerators & Complementarity



PRD1 = accelerator-based
PRD2 = direct detection

- Thermal relic sub-GeV dark matter compelling
- Accelerators important complementarity with direct detection
- New opportunities for to search for dark sectors