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UNIVERSITY OF MINNESOTA

UCSB UNIVERSITY OF CALIFORNIA SANTA BARBARA

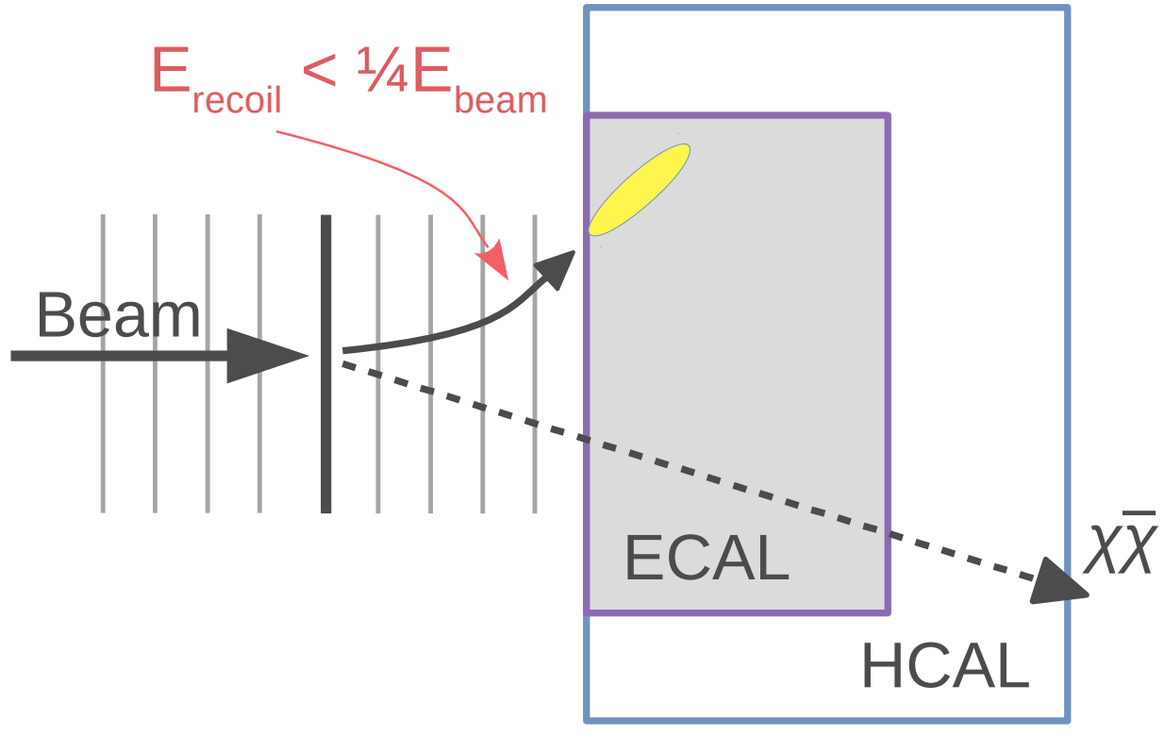
Carnegie Mellon University

LDMX

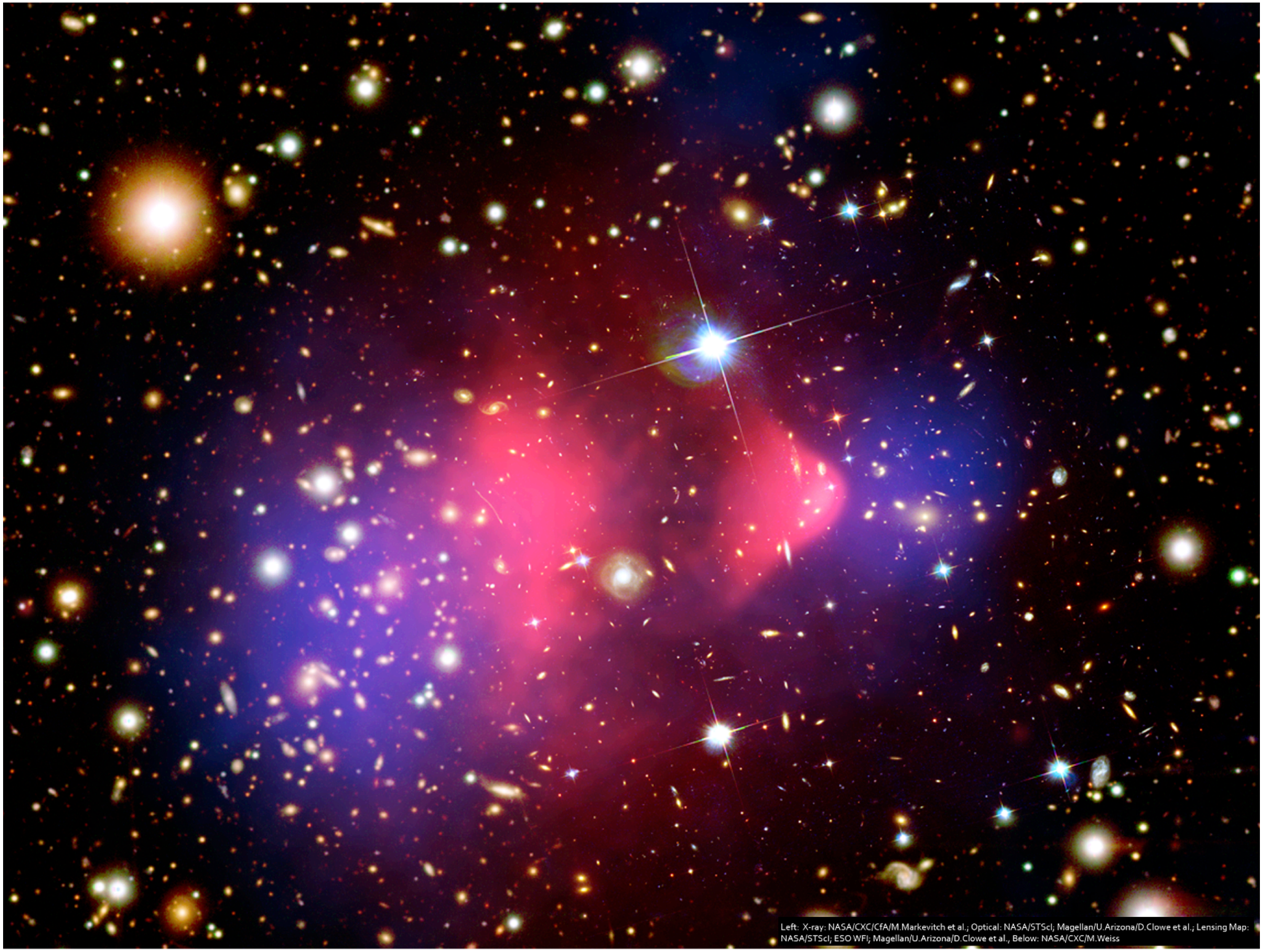
The Light Dark Matter Experiment

Christian Herwig (Fermilab)
for the LDMX Collaboration

PIC // October 12, 2023



Dark Matter: the question of our time



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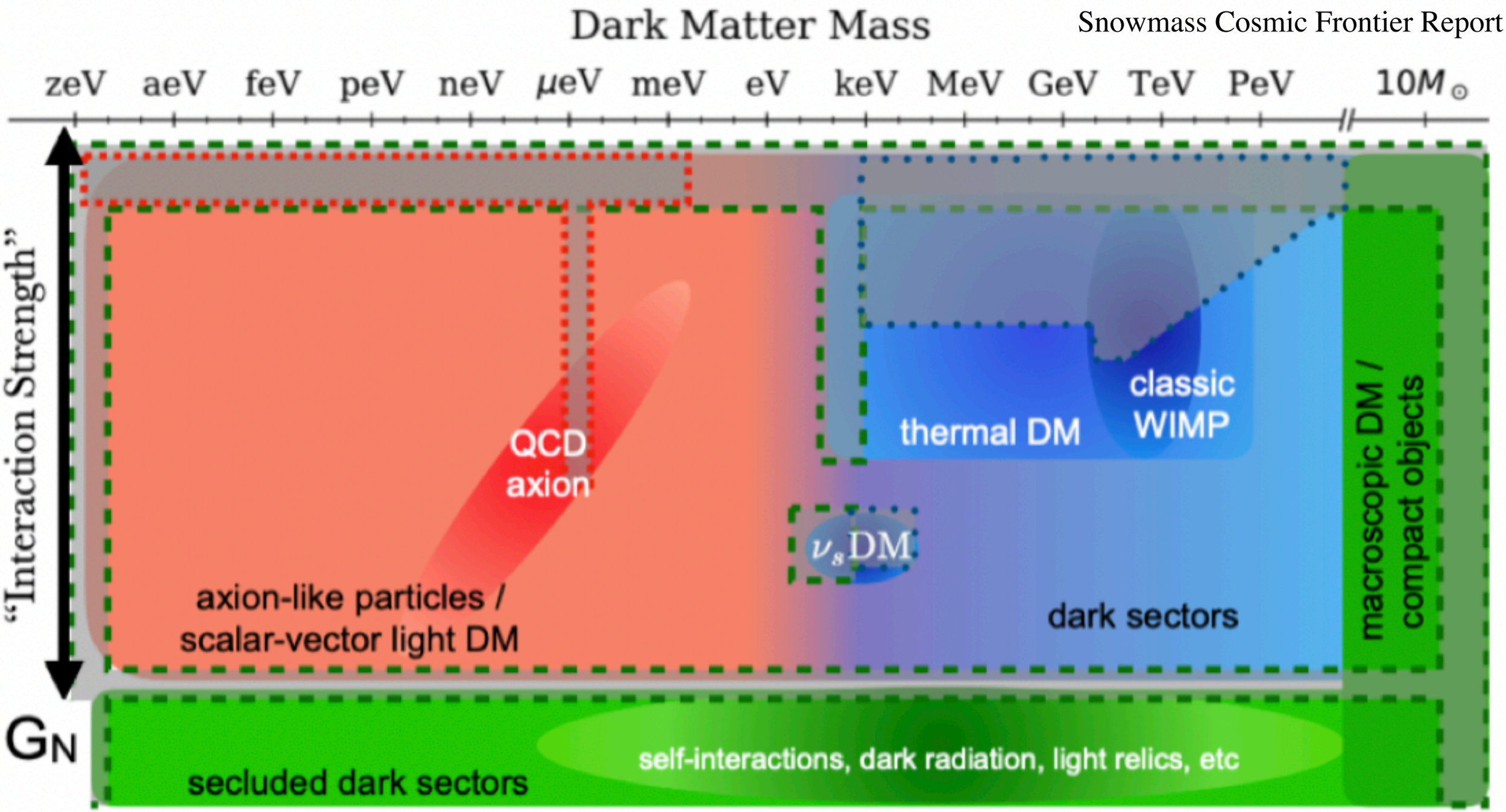
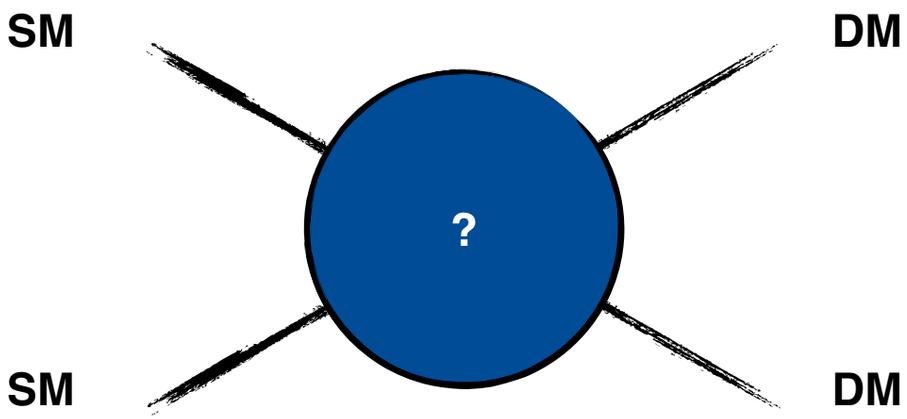


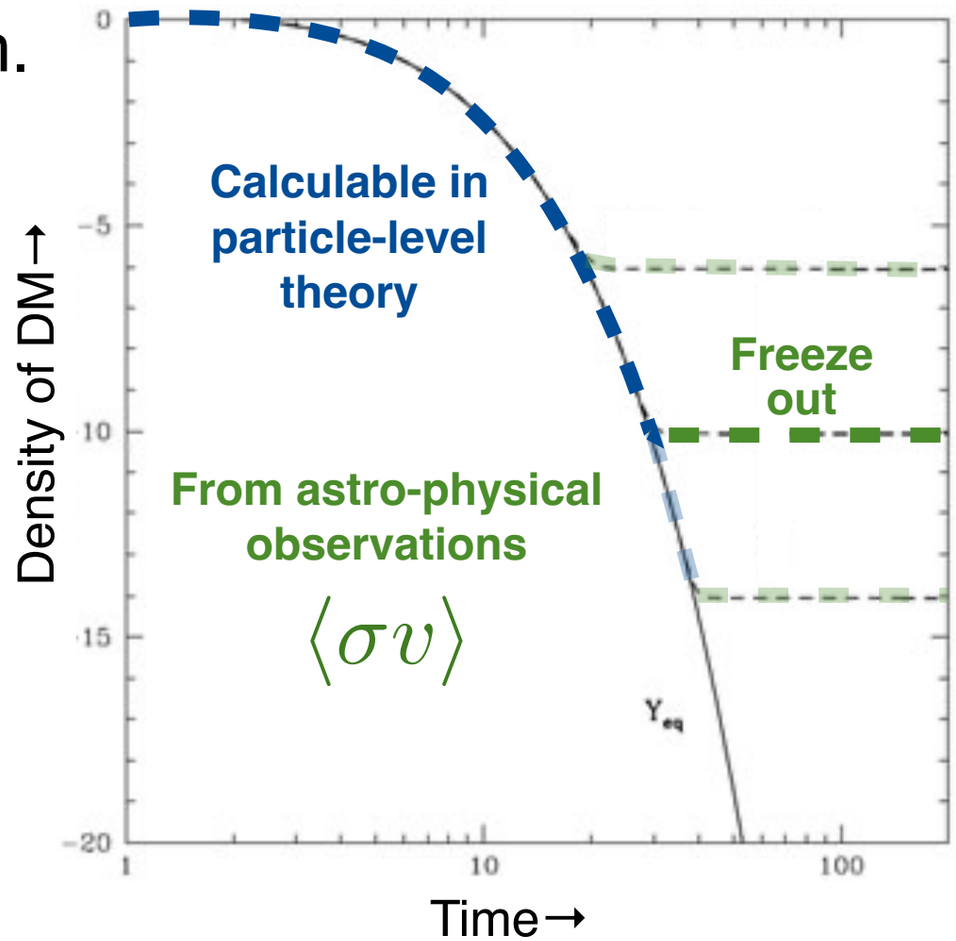
Snowmass Cosmic Frontier Report

"Delve Deep, Search Wide!"

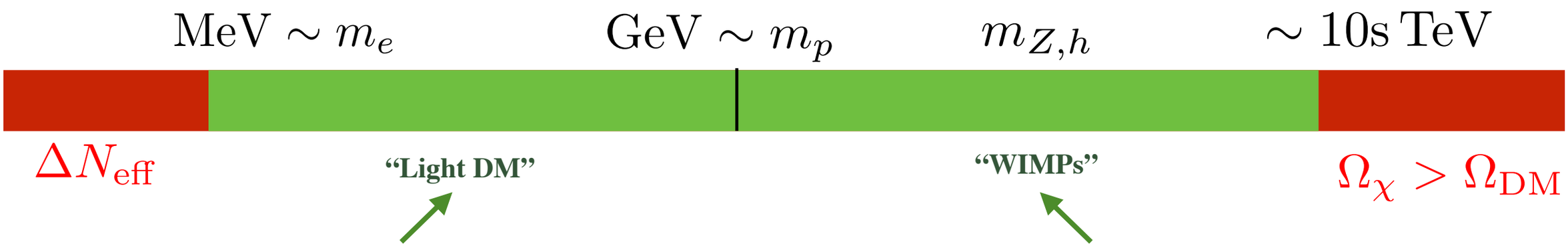
Thermal dark matter

DM and SM were initially in chemical equilibrium.





Compare interaction rate to Hubble expansion.



Light DM implies feeble coupling to the SM

"Heavy" case: classic WIMP

Thermal dark matter

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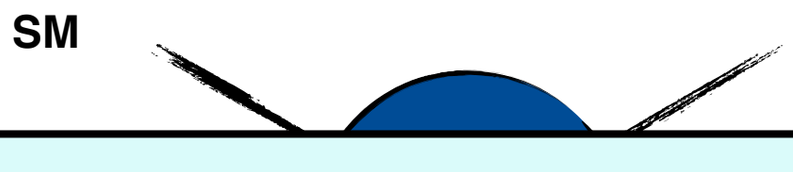
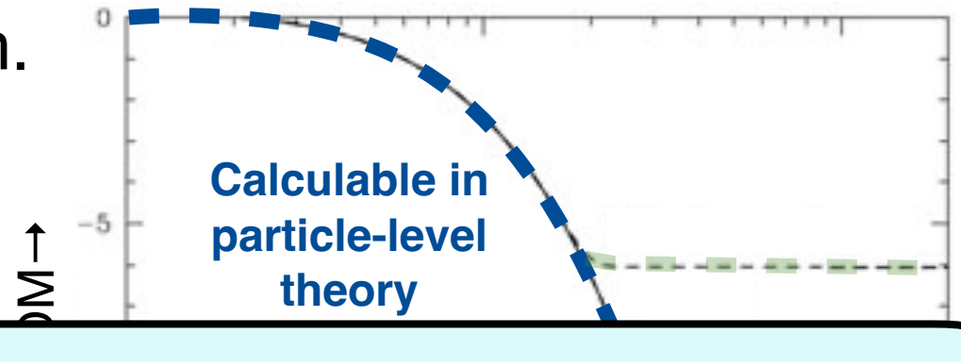


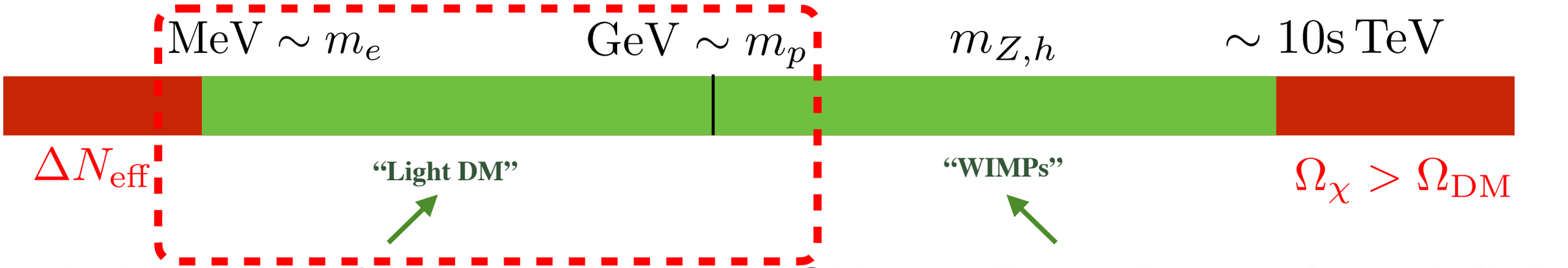


Focus for today: **Light Dark Matter**

Mass range means a *broad set of experimental tools* may be relevant.

Implies DM is a SM singlet → new "mediator" / gauge force.

Potential connections to other SM puzzles?



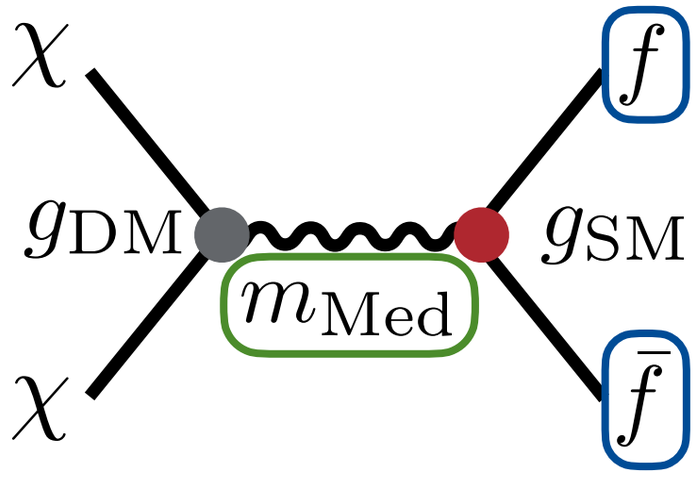
Light DM implies feeble coupling to the SM

"Heavy" case: classic WIMP

DM with accelerators

Precisely-controlled experimental setup:

- Beam particle species (p, e, μ, ν,…)
- DM/mediator masses (beam energy, q^2)
- Interaction strengths (search strategy, lumi)



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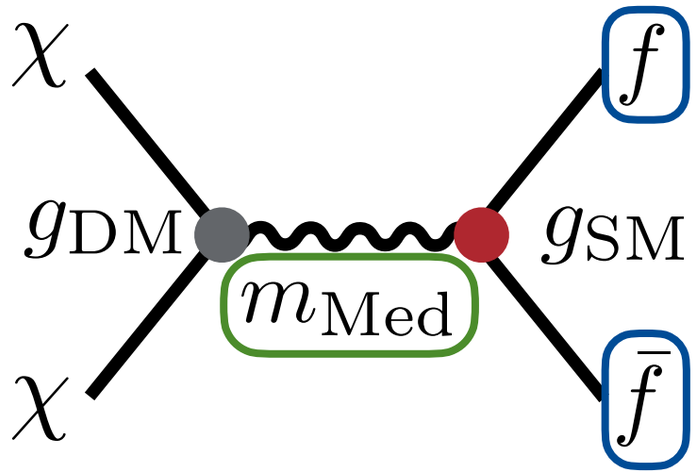
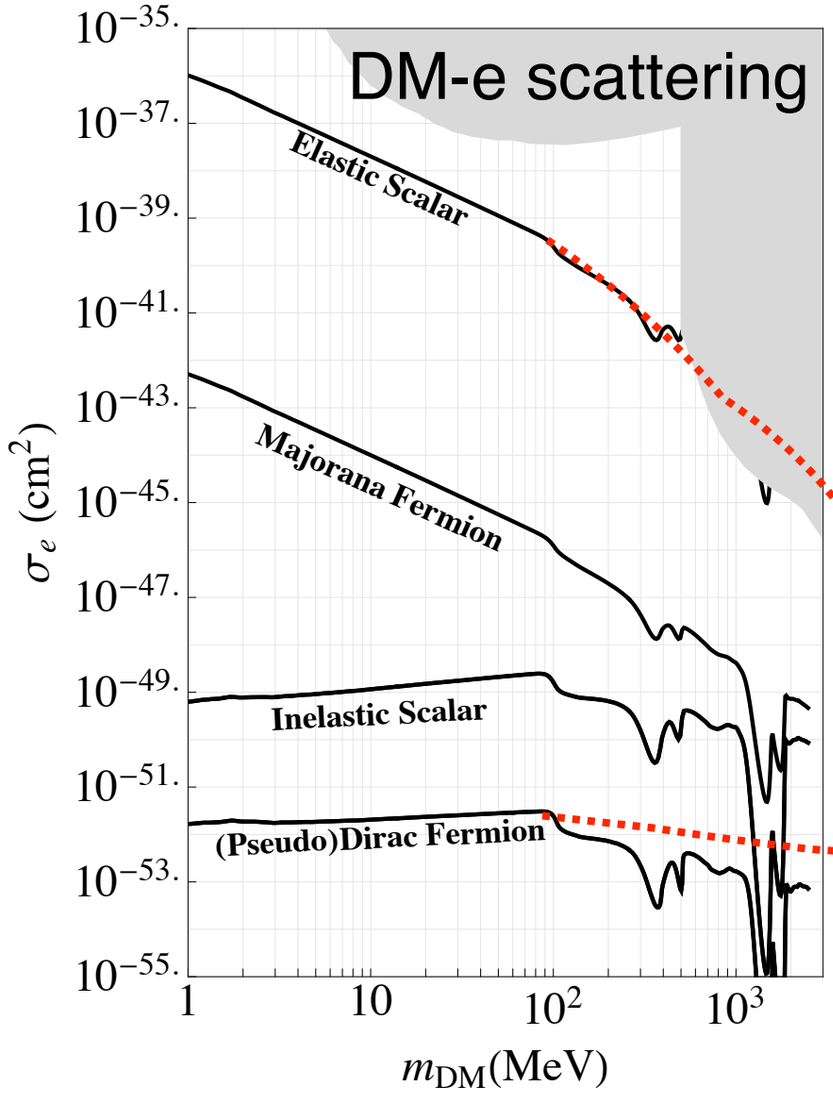
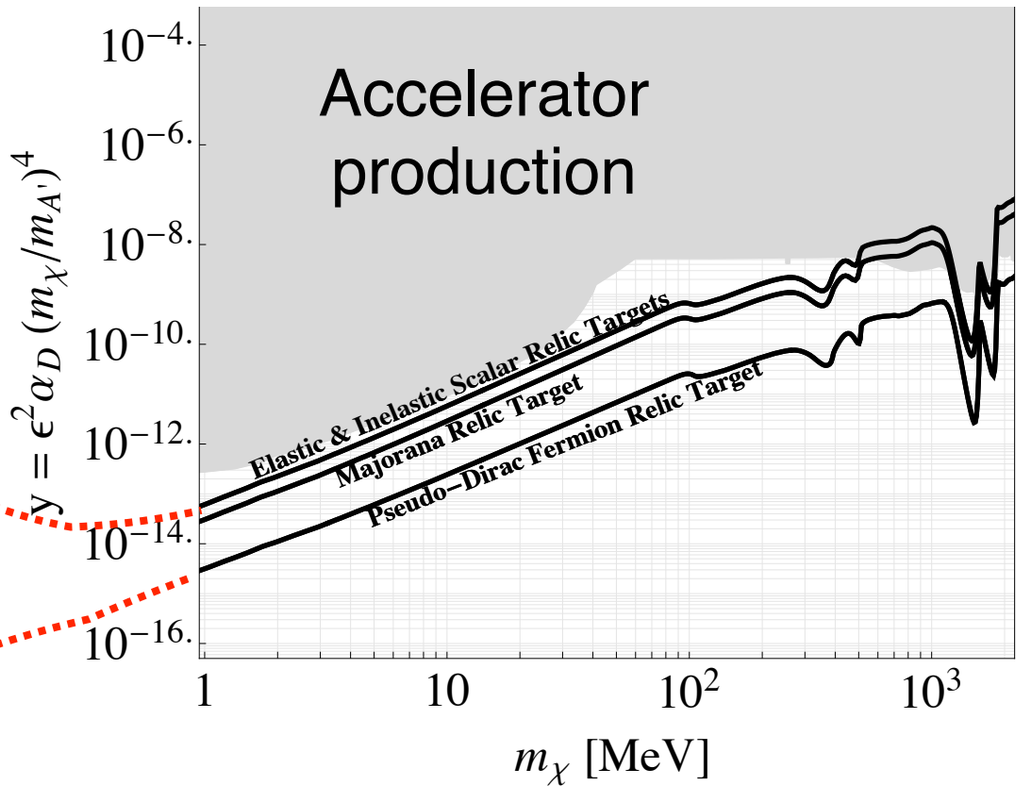
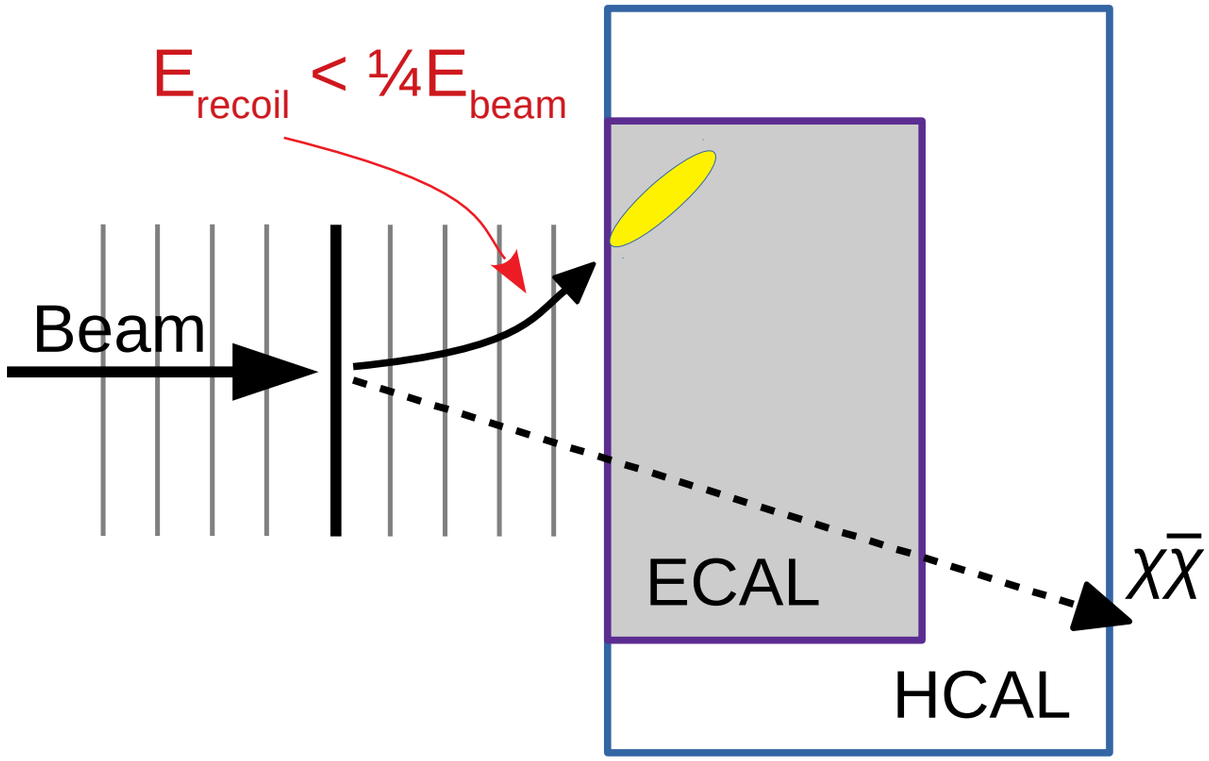


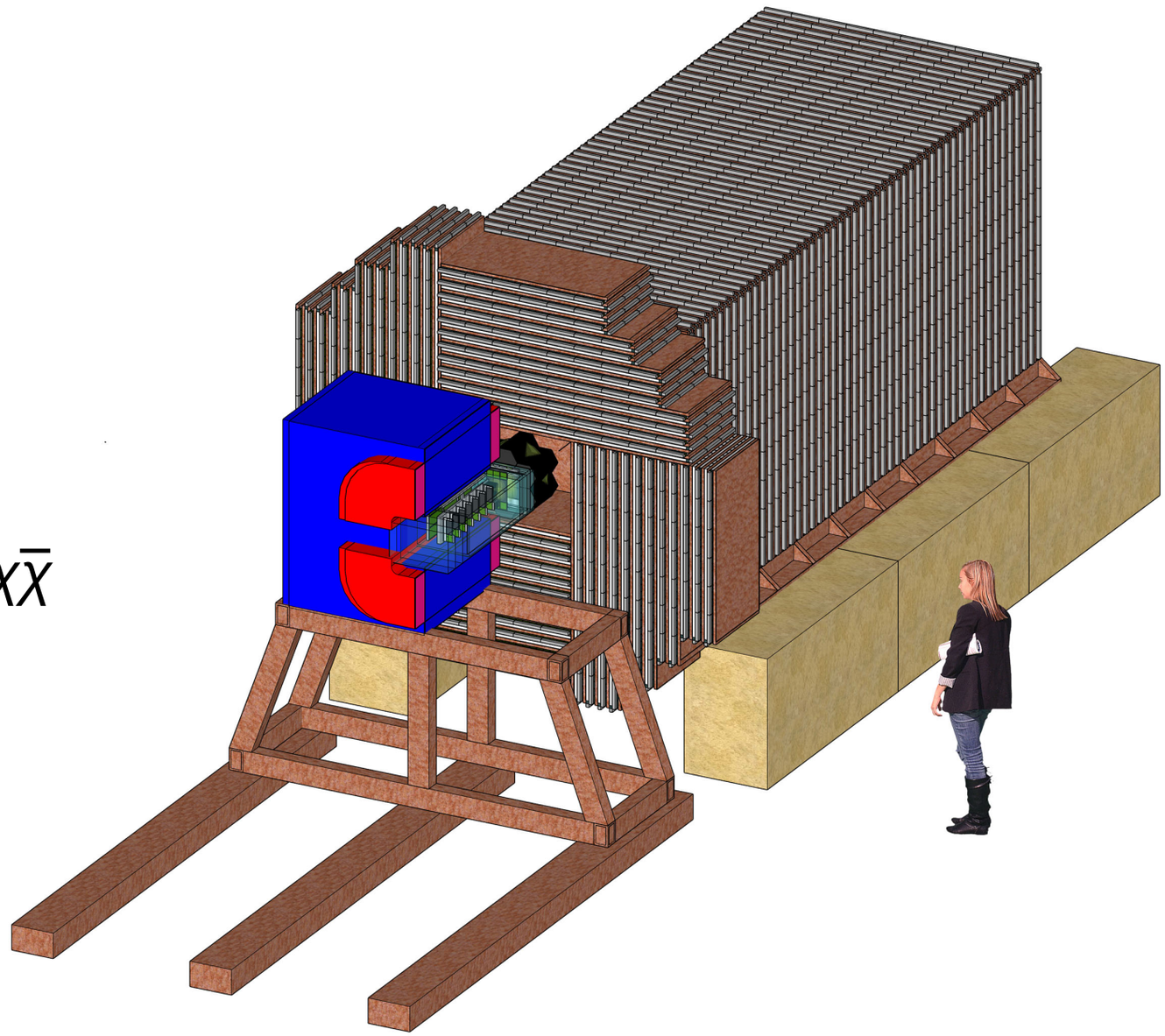




The Light Dark Matter eXperiment

Proposed search for Light DM with a fixed-target electron beam setup.





Key requirements:

Precise beam (high rate, low current)

Hermetic detector (background veto)

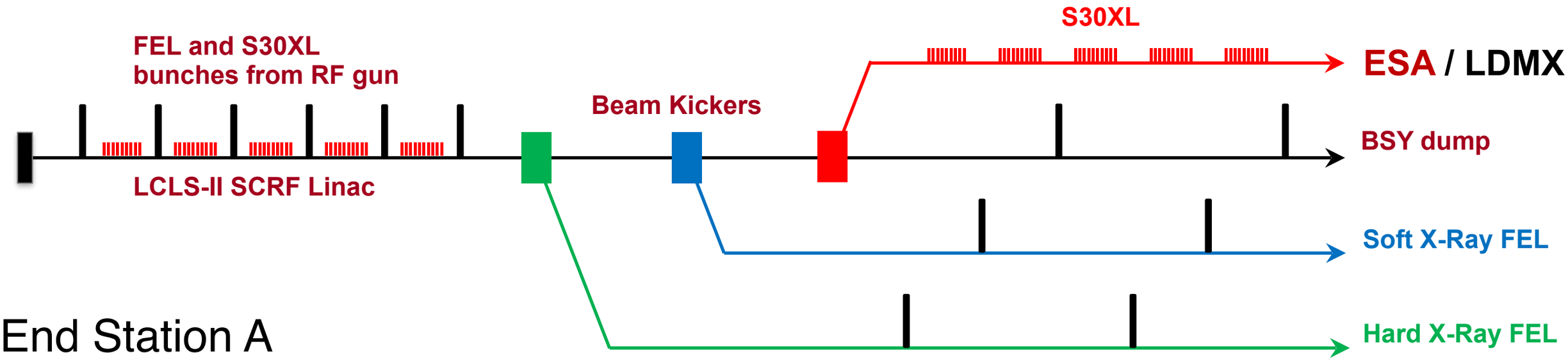
Fast electronics (E_{miss} trigger)

Experiment whitepaper
arXiv:1808.05219 [hep-ex]

High-precision electron source

LCLS-II SRF (SLAC) will provide electrons to End Station A delivering ~27 ns bunches w/ $\langle n_e \rangle \sim 1$, via parasitic dark current between FEL pulses.

→ Upgrade planned from 4→8 GeV



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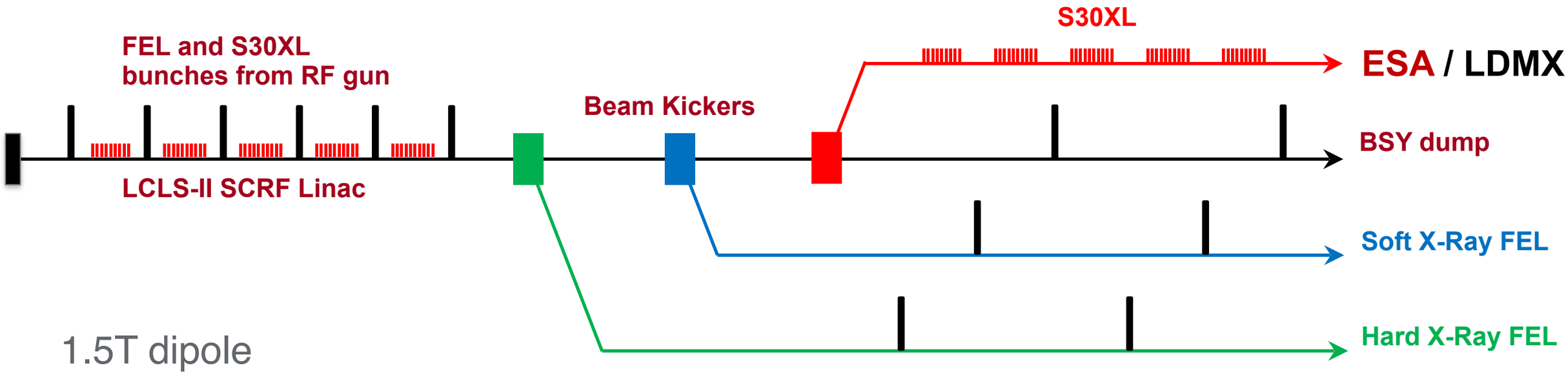
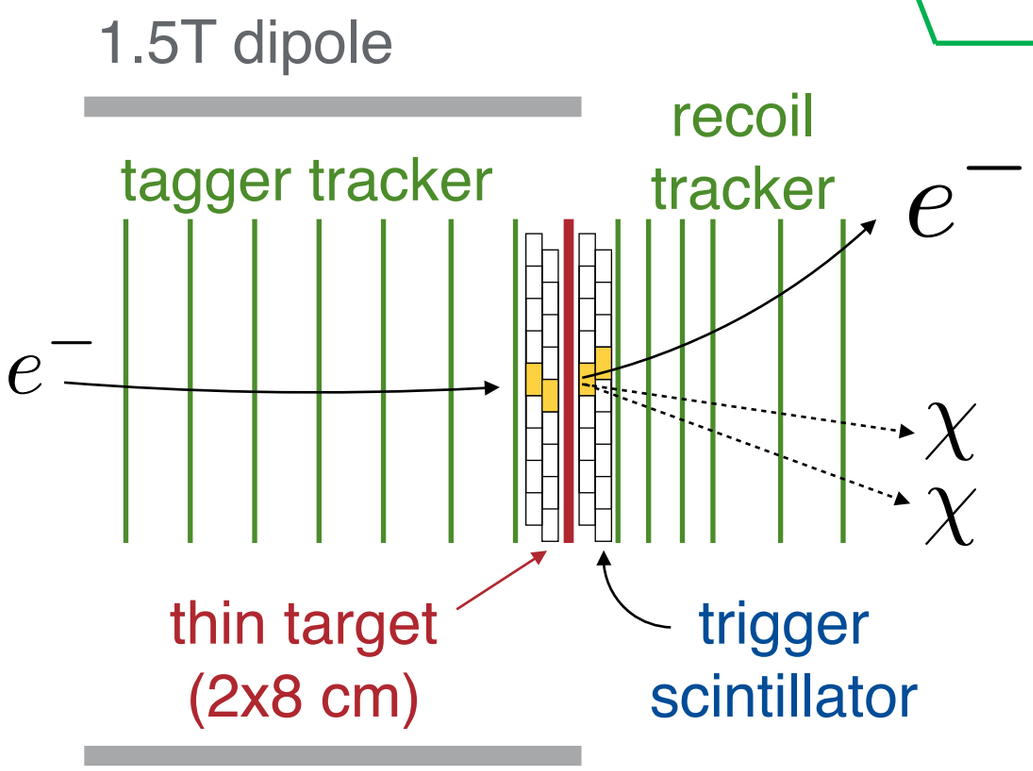




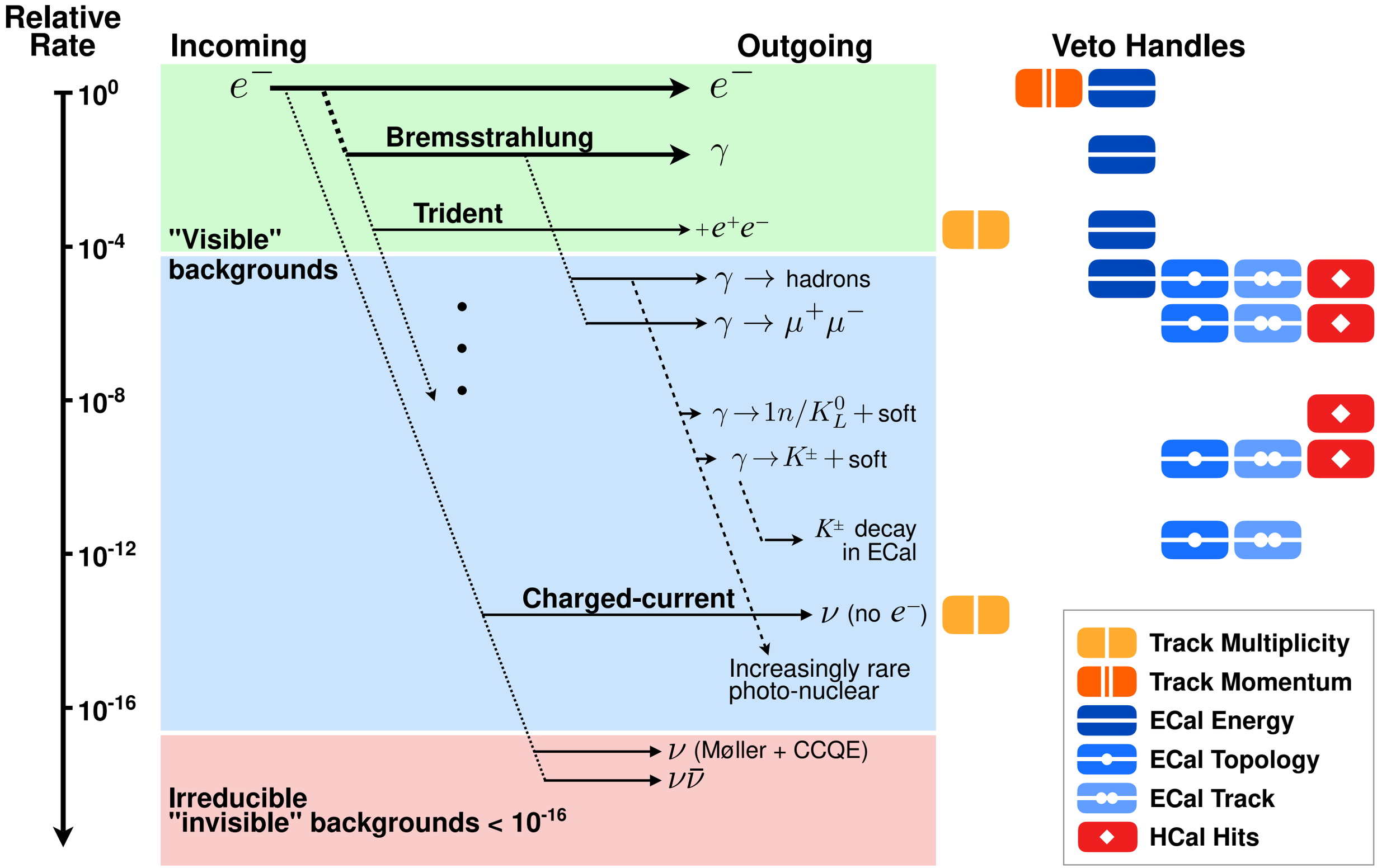
Tracking system measures $p_T(e^-)$ in B field.

e^- interacts in thin ($0.1X_0$) W/Al target.

Segmented scintillator tags filled bunches.

1 year (10^7 s) of beam: 4e14 EOT
Ultimate target ~ 1e16 EOT

SM Background rejection



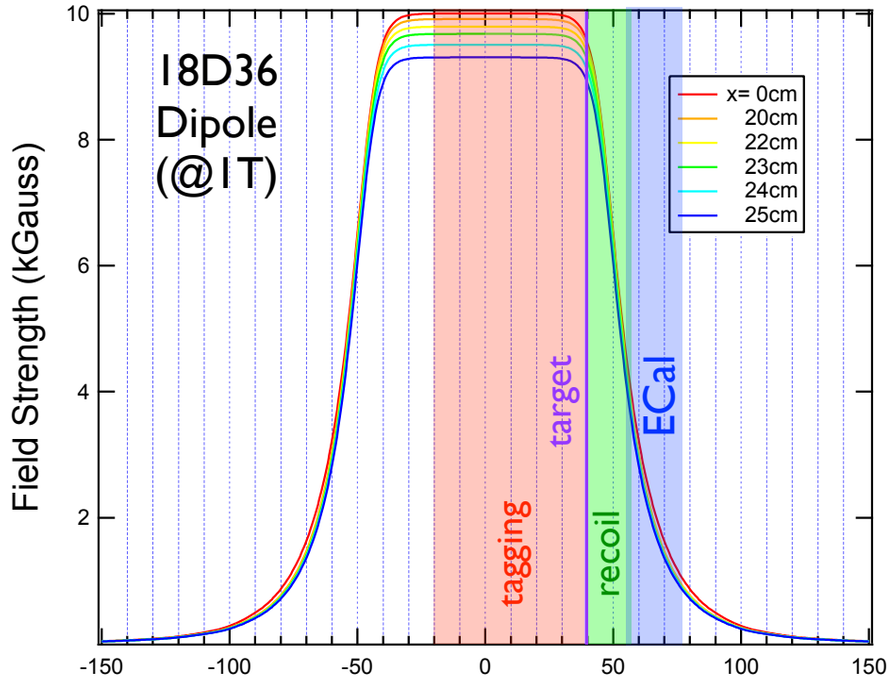
Magnet and trackers

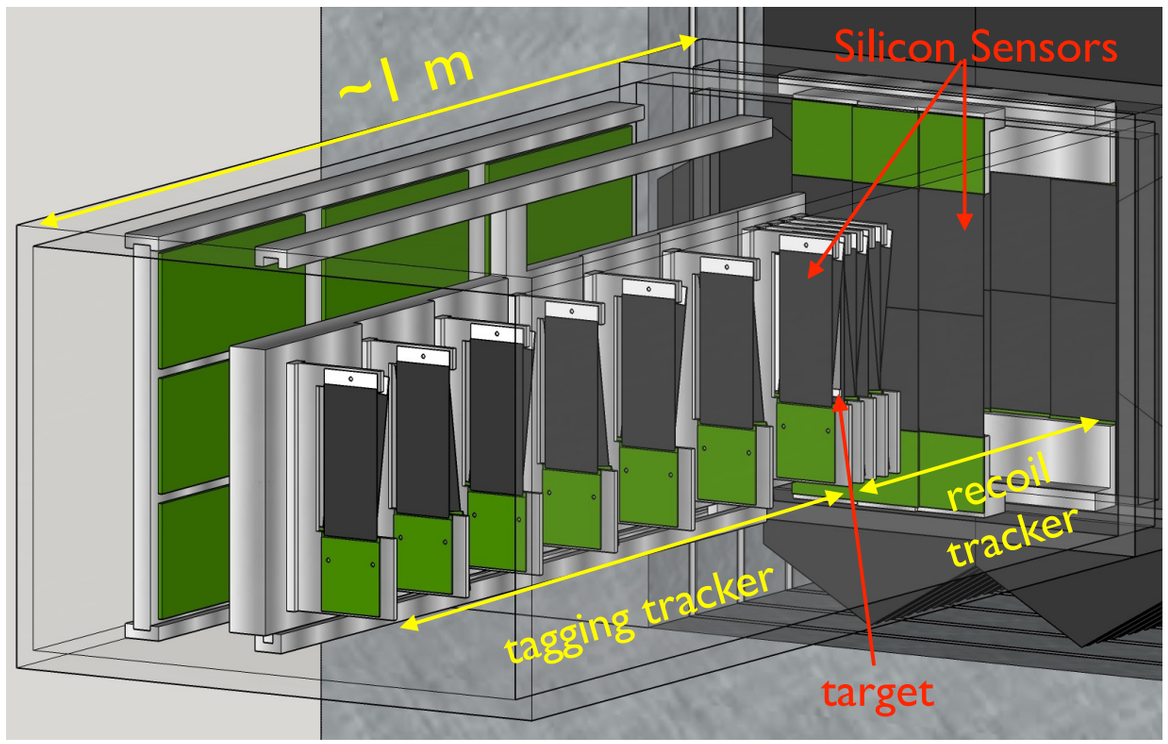
Refurbished dipole.

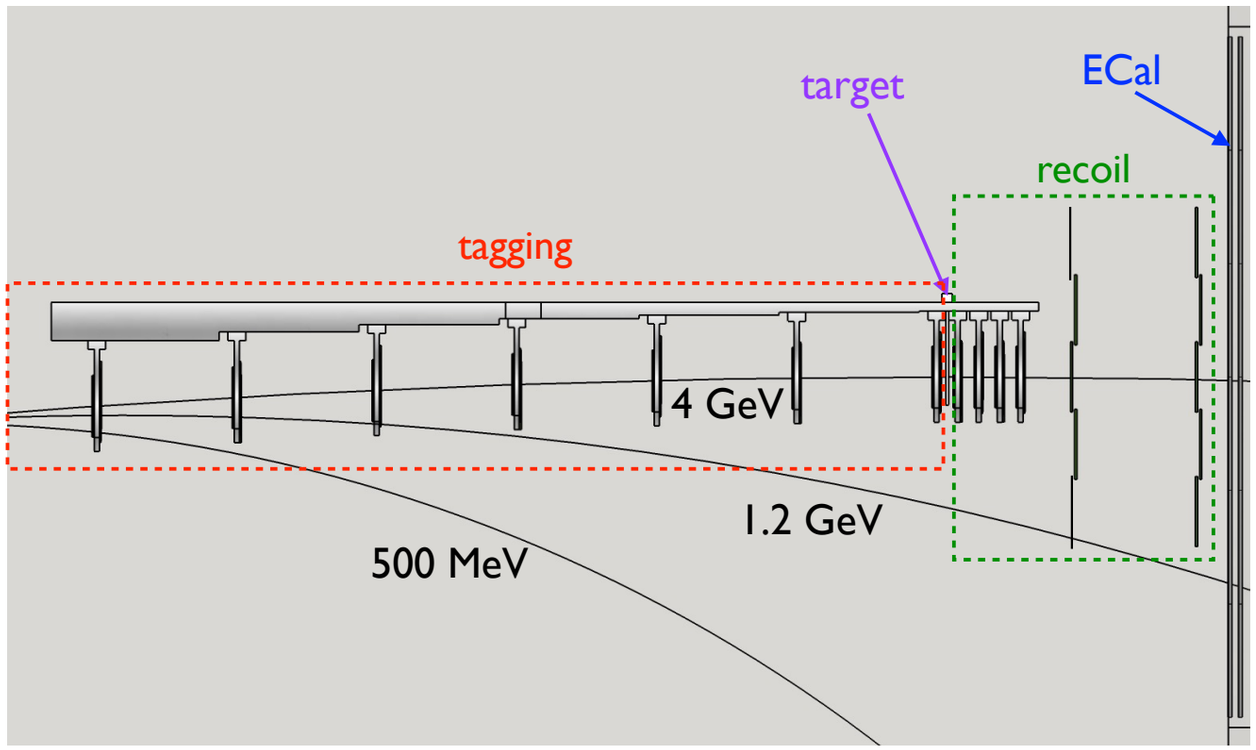
Tracker modules based on HPS/CMS.

Tagger: robust p_{in}.

Recoil: aims for max acceptance.







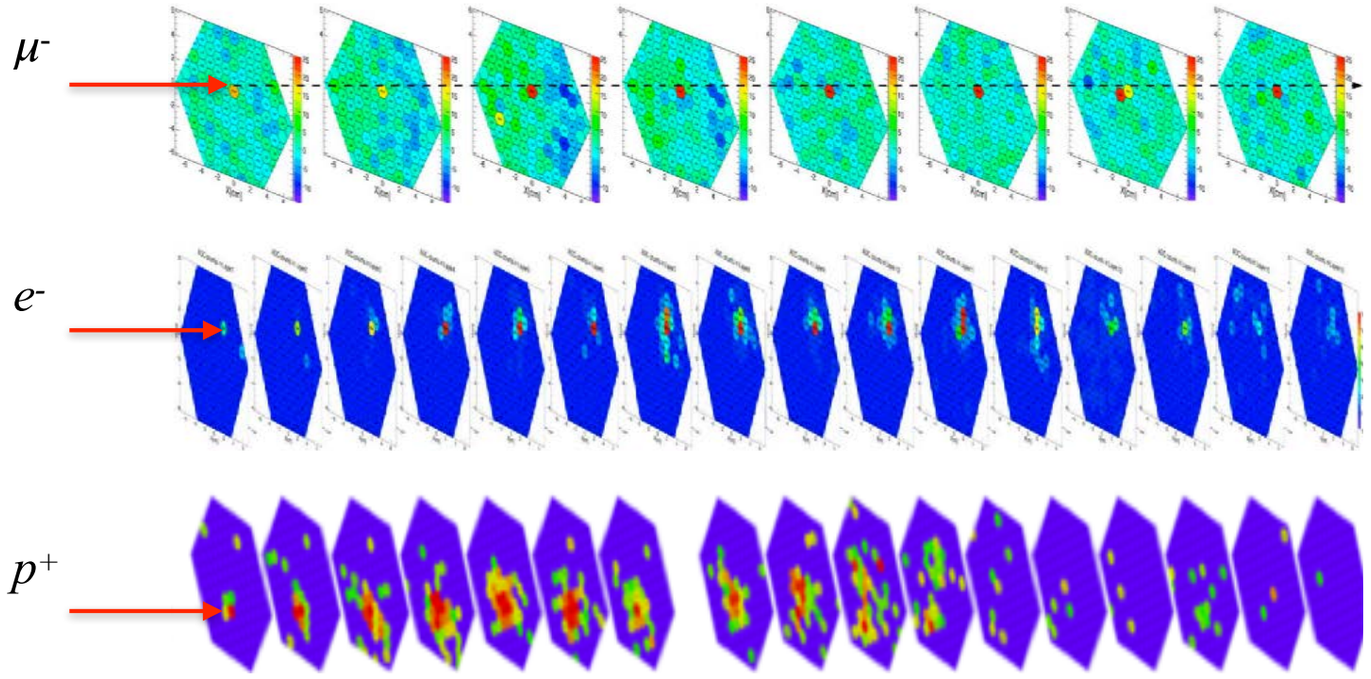
Electromagnetic calorimeter

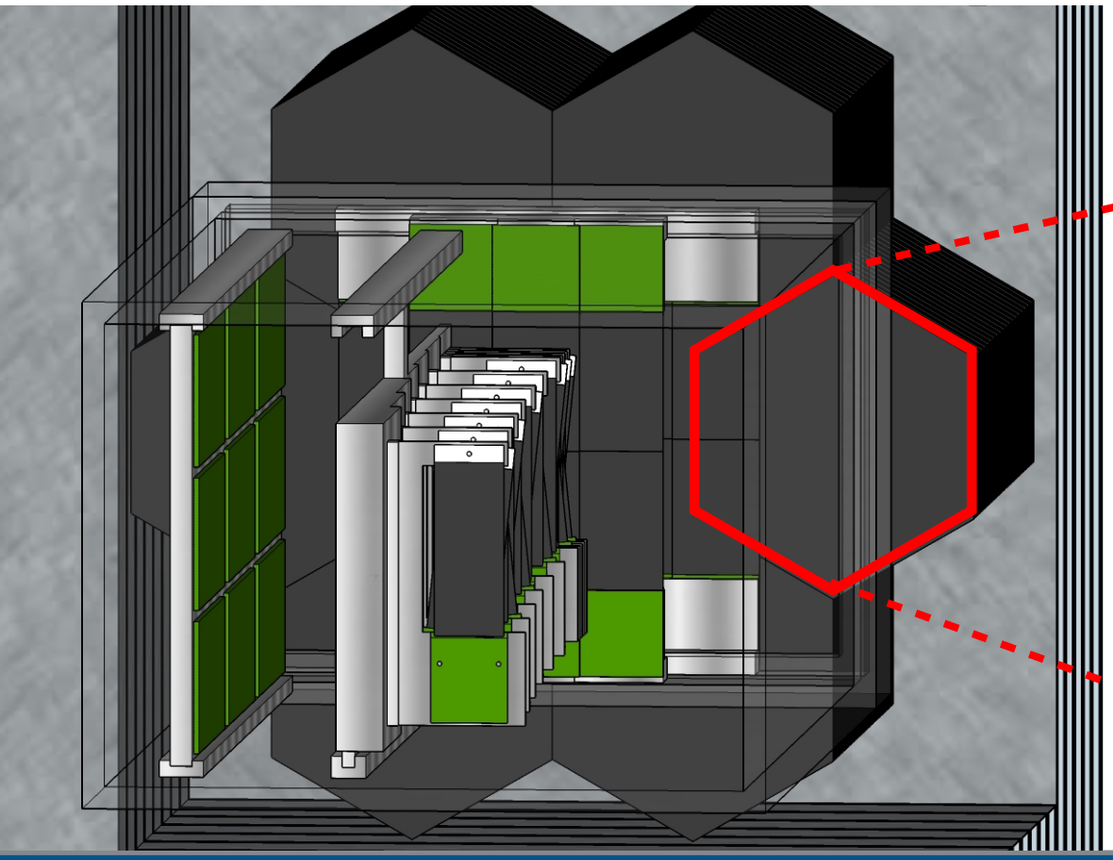
Based on the CMS high-granularity endcap calorimeter.

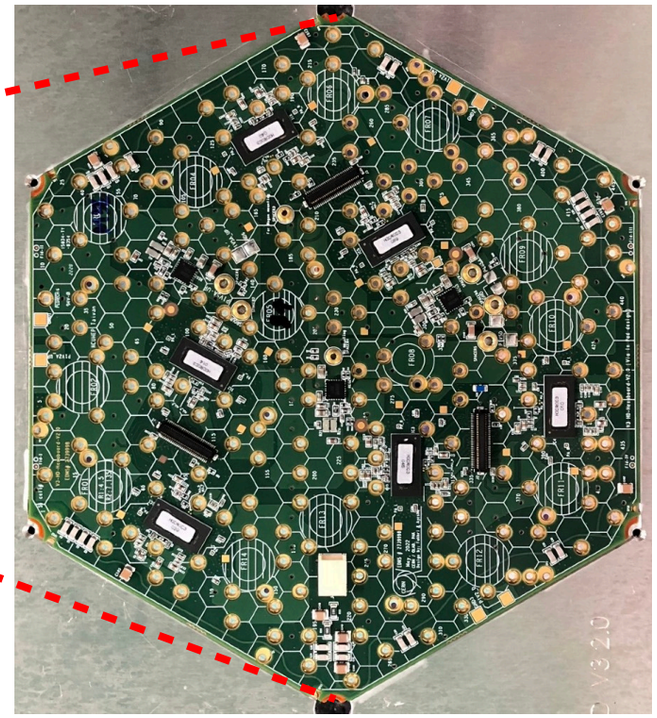
Effectively a beam dump: must be highly radiation-tolerant!

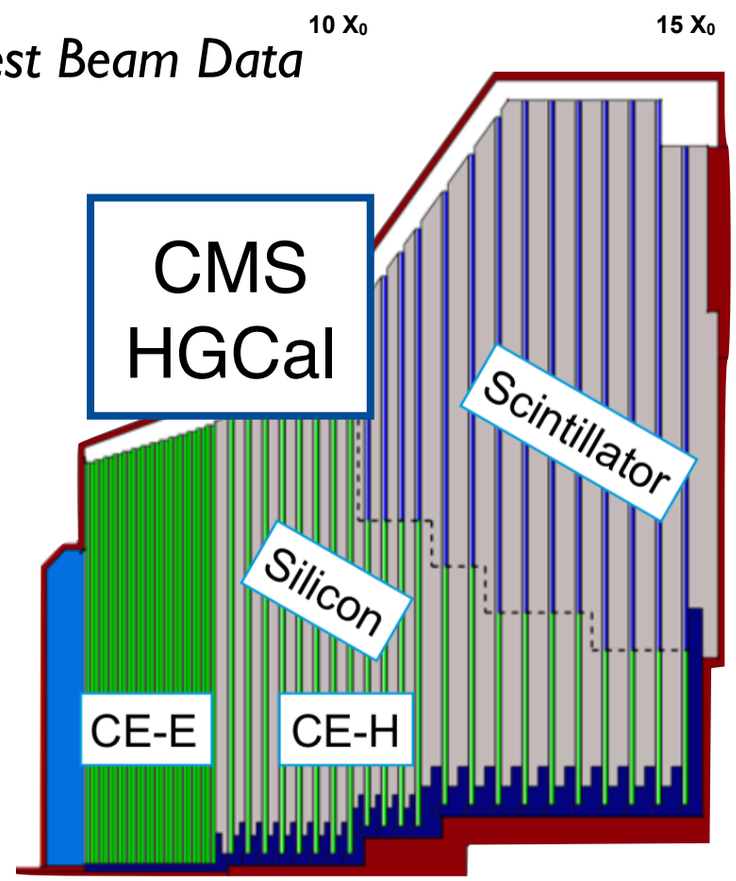
34 Si/W layers (40 X_0)

432 sensor pads / hex module









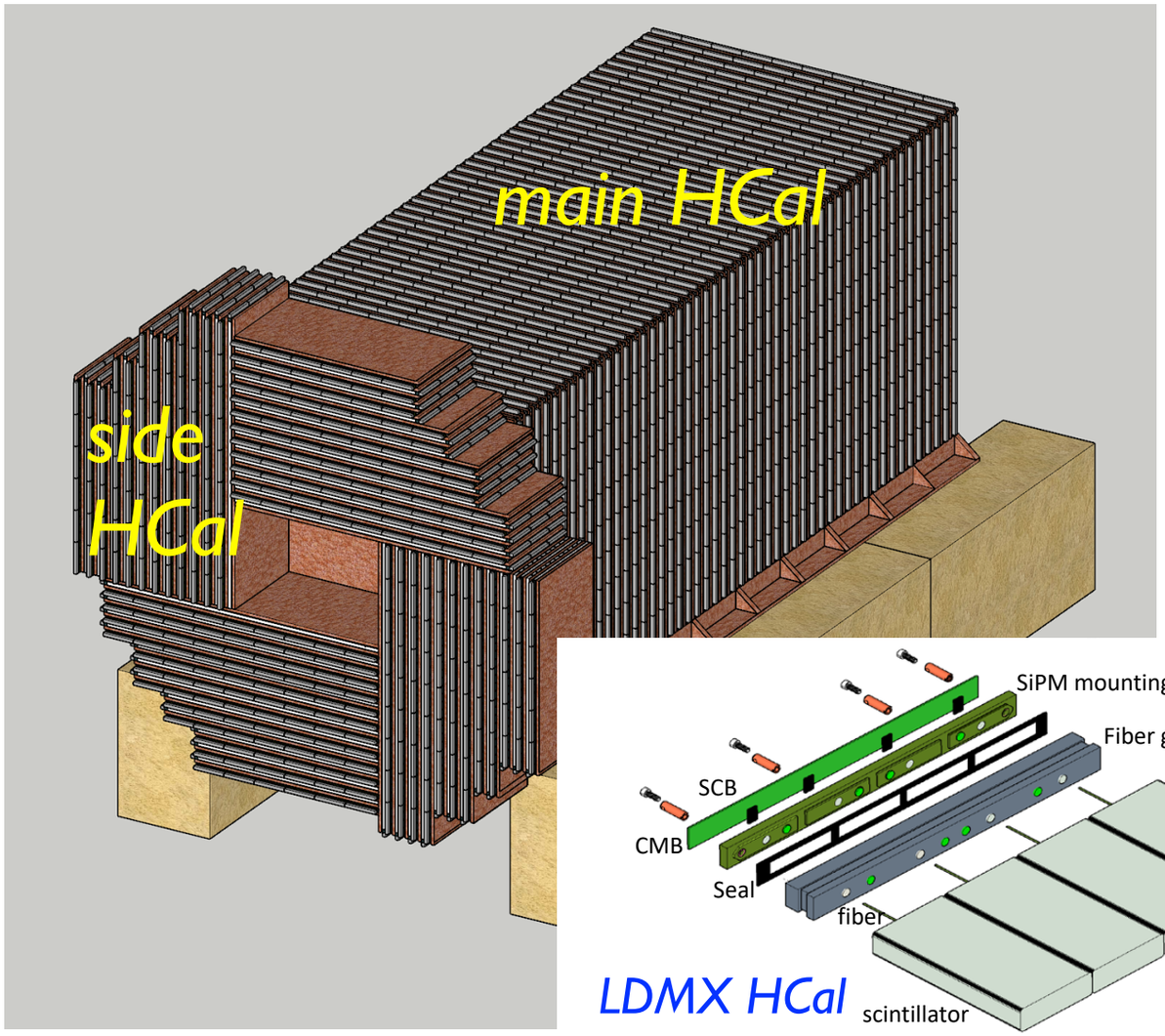
Hadronic calorimeter

Based on Mu2e cosmic veto technology.

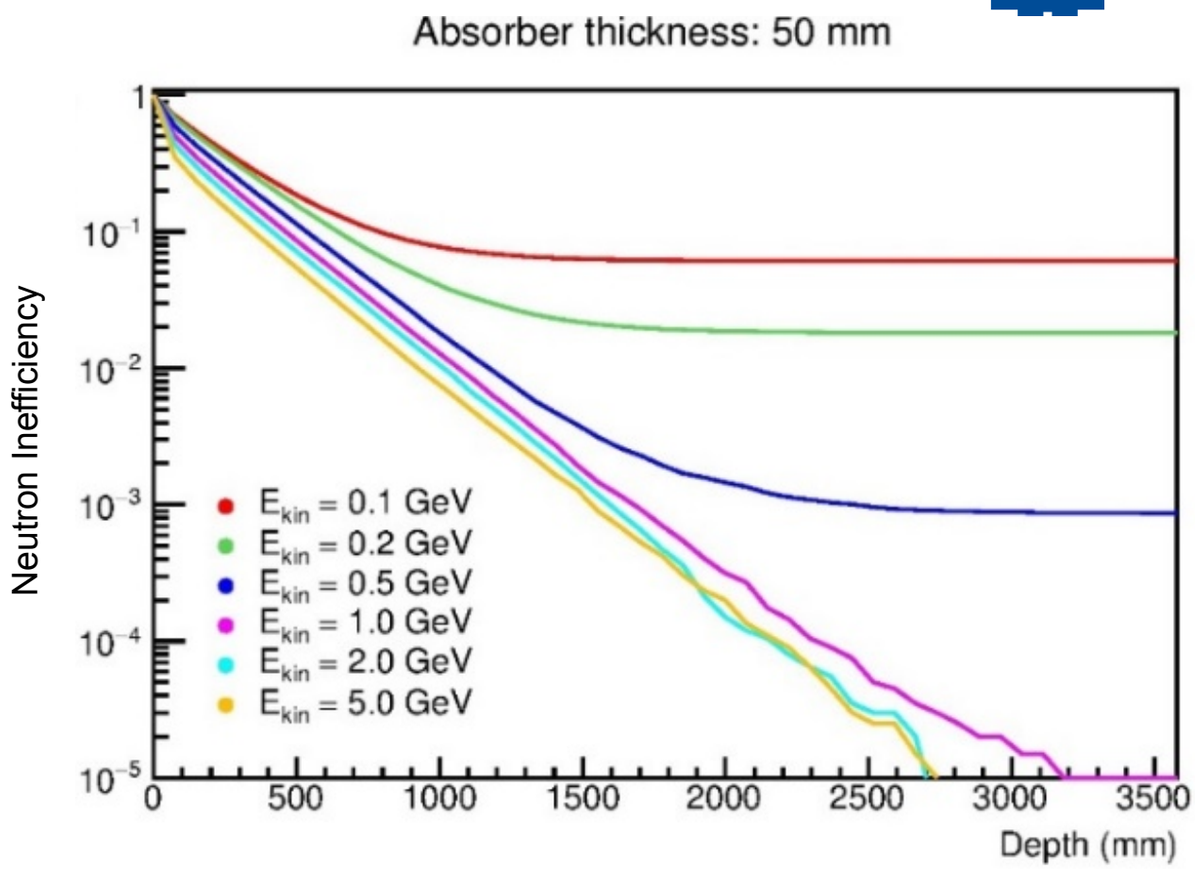
2x2m steel / scintillating bars (17λ)

Main HCal: veto hard neutrons, K_L.

Side HCal for wide-angle emissions.



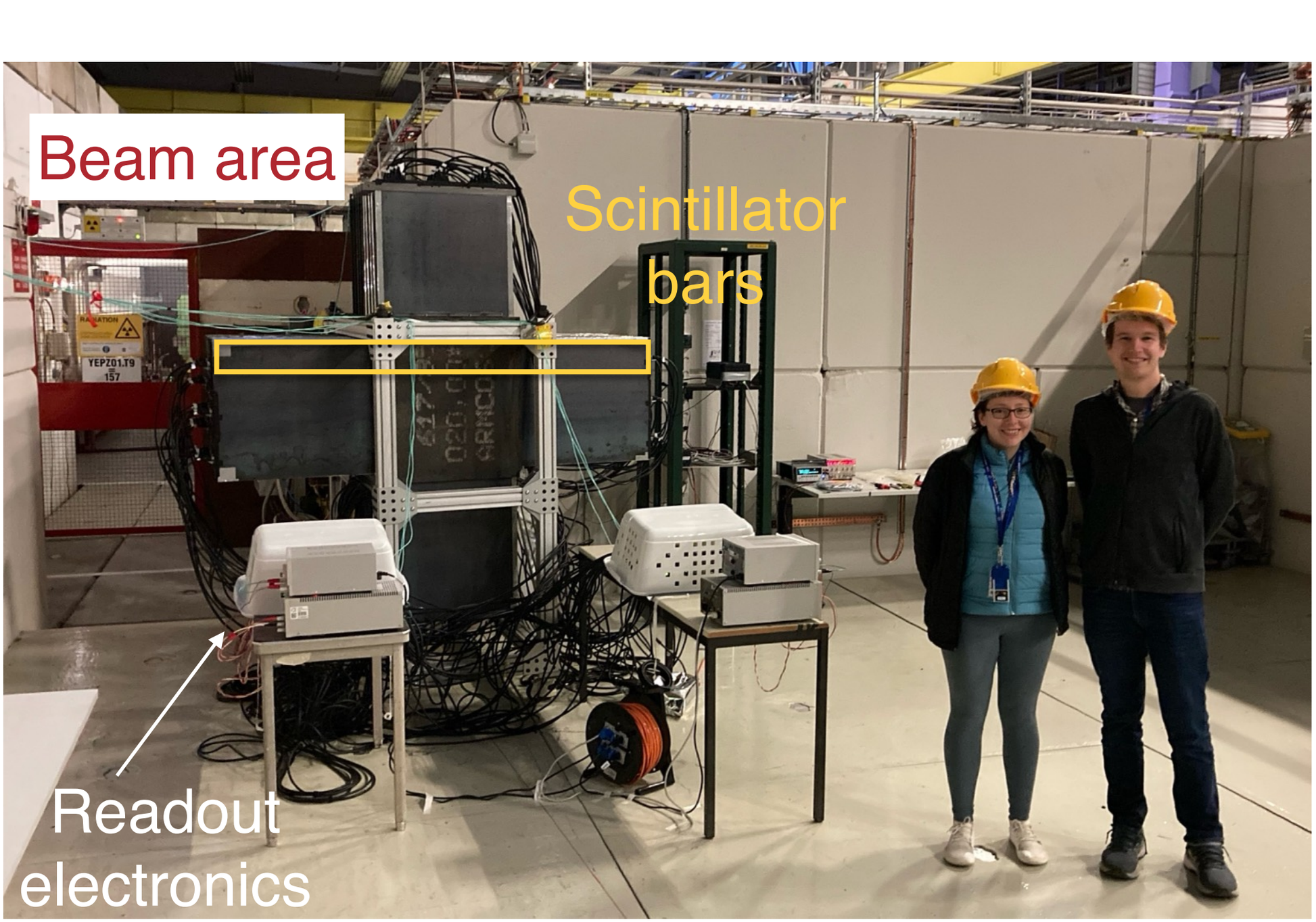
LDMX HCal

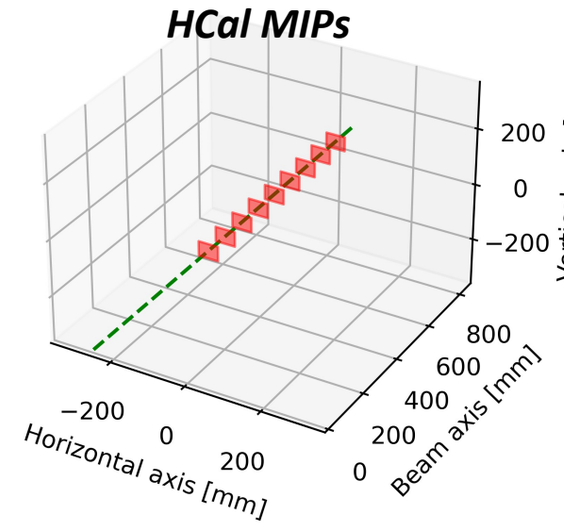


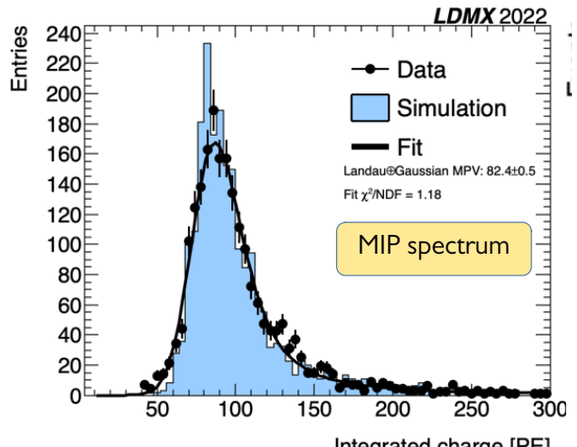
Scintillator extruder facility @ FNAL

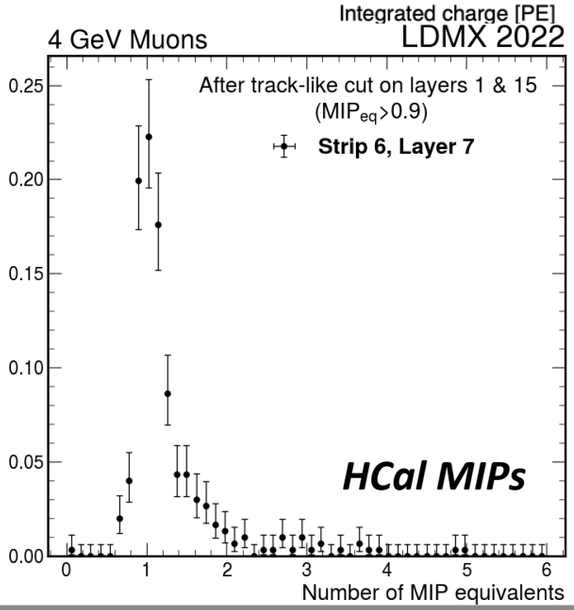
Beam test for HCal, TS prototypes

Partial HCal (20 layers of 4/6 bars) and Trigger Scintillator sent to CERN for several weeks in 2022 (data with e, π, μ).





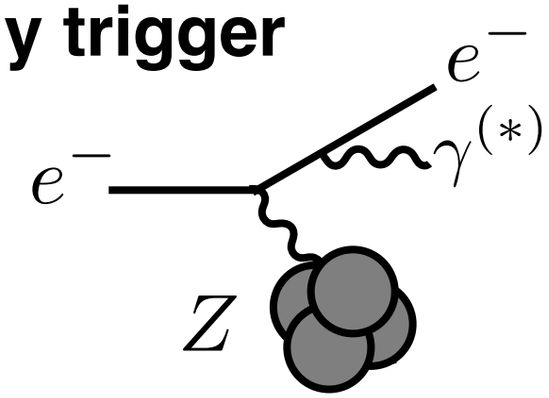


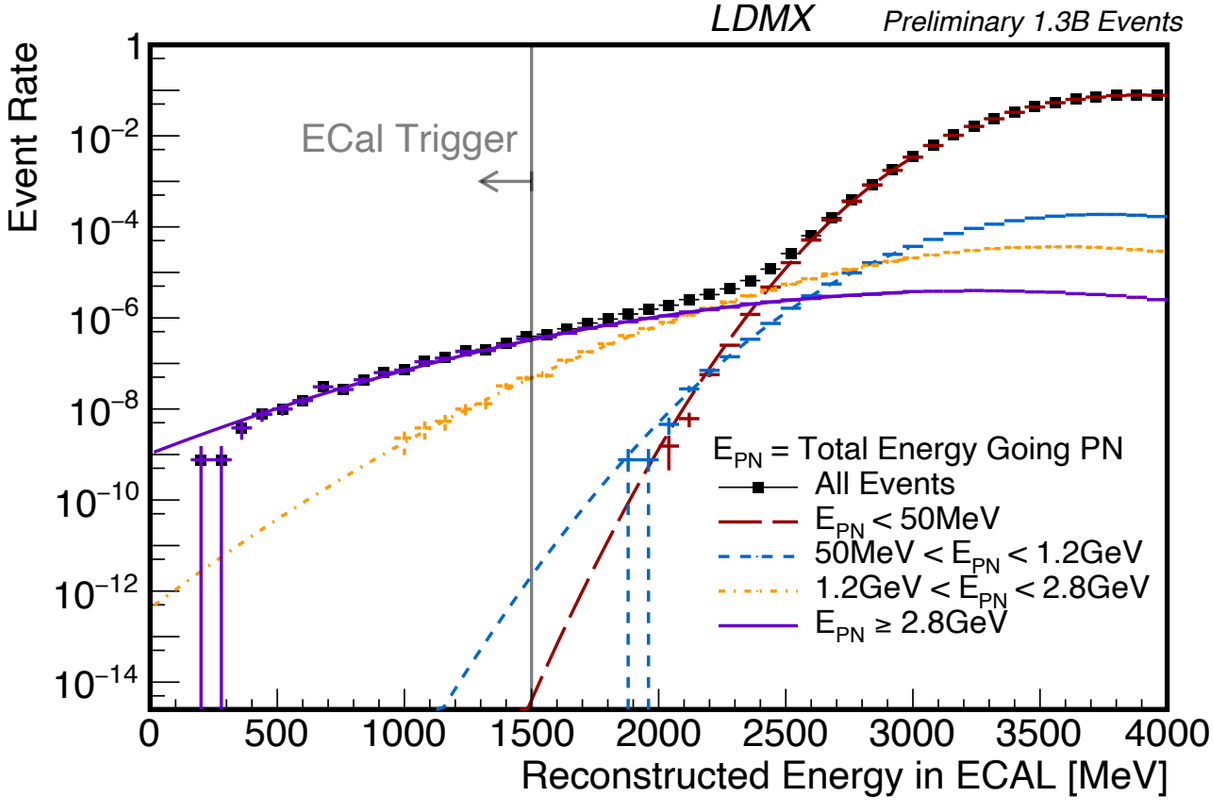


Background elimination strategy (4 GeV)

1. Missing energy trigger

(majority of events are γ-nuclear)





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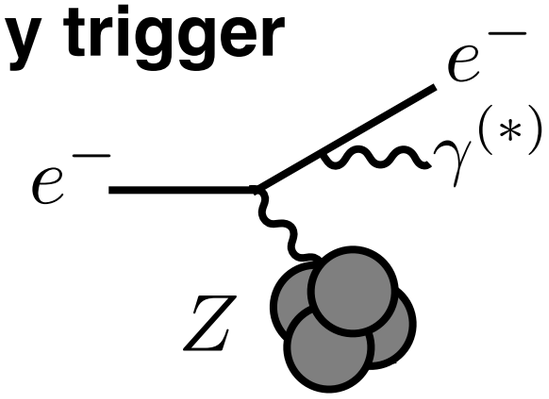

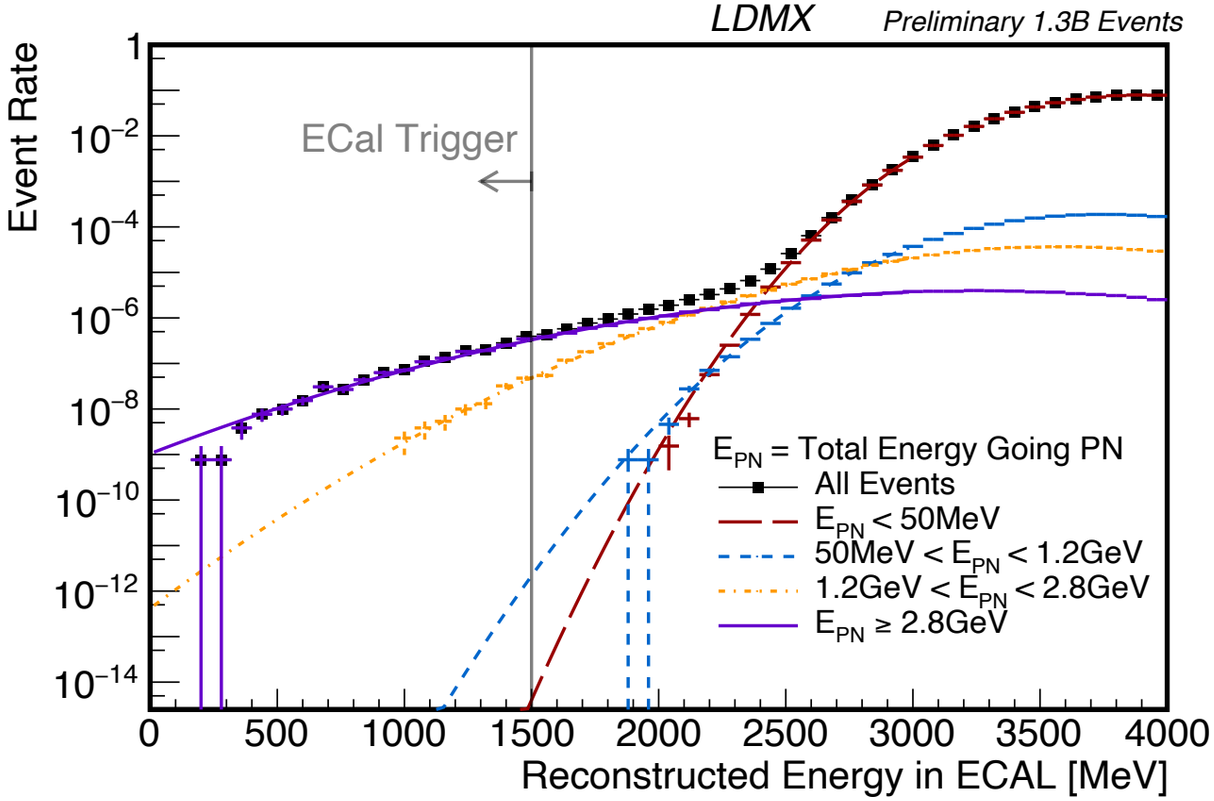

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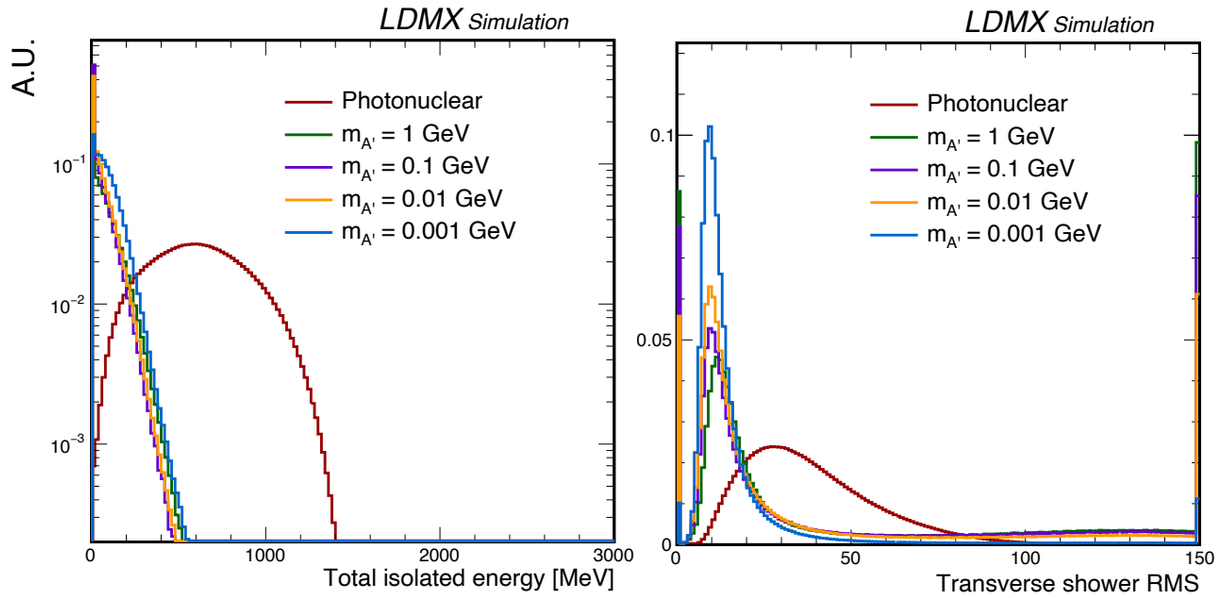
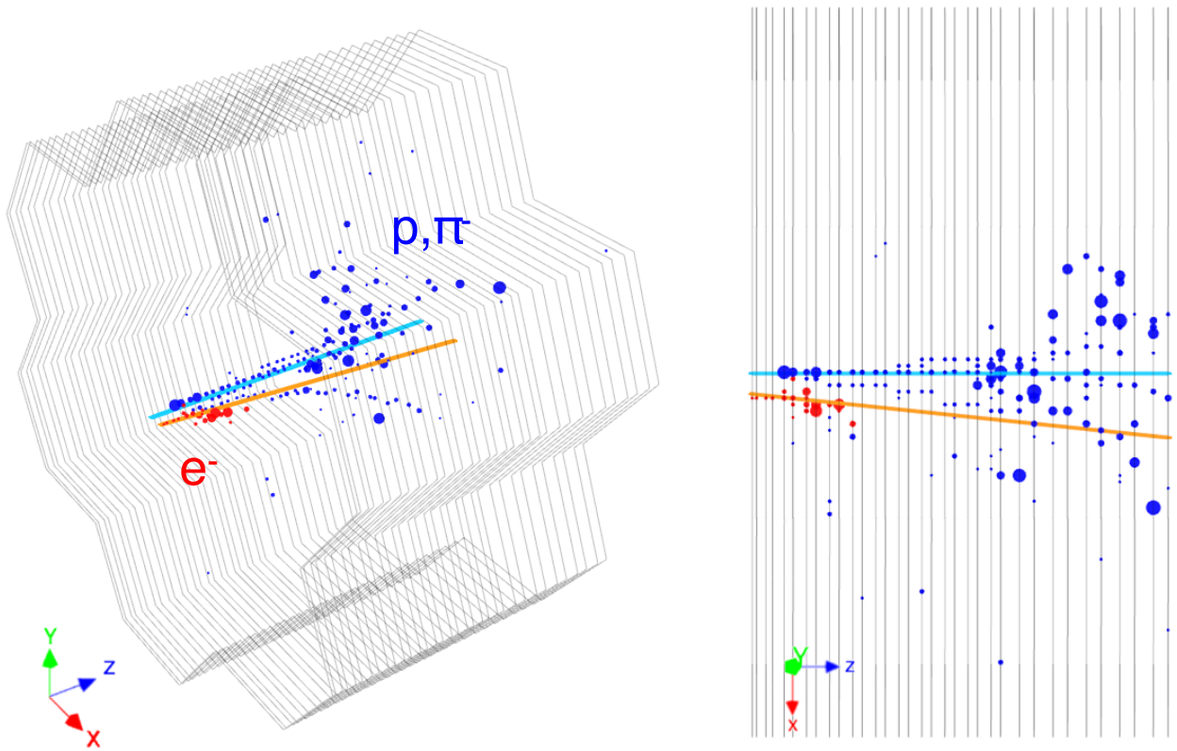


2. ECal shower discriminants → BDT



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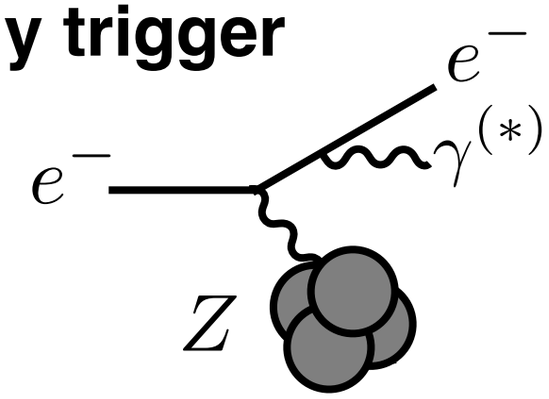

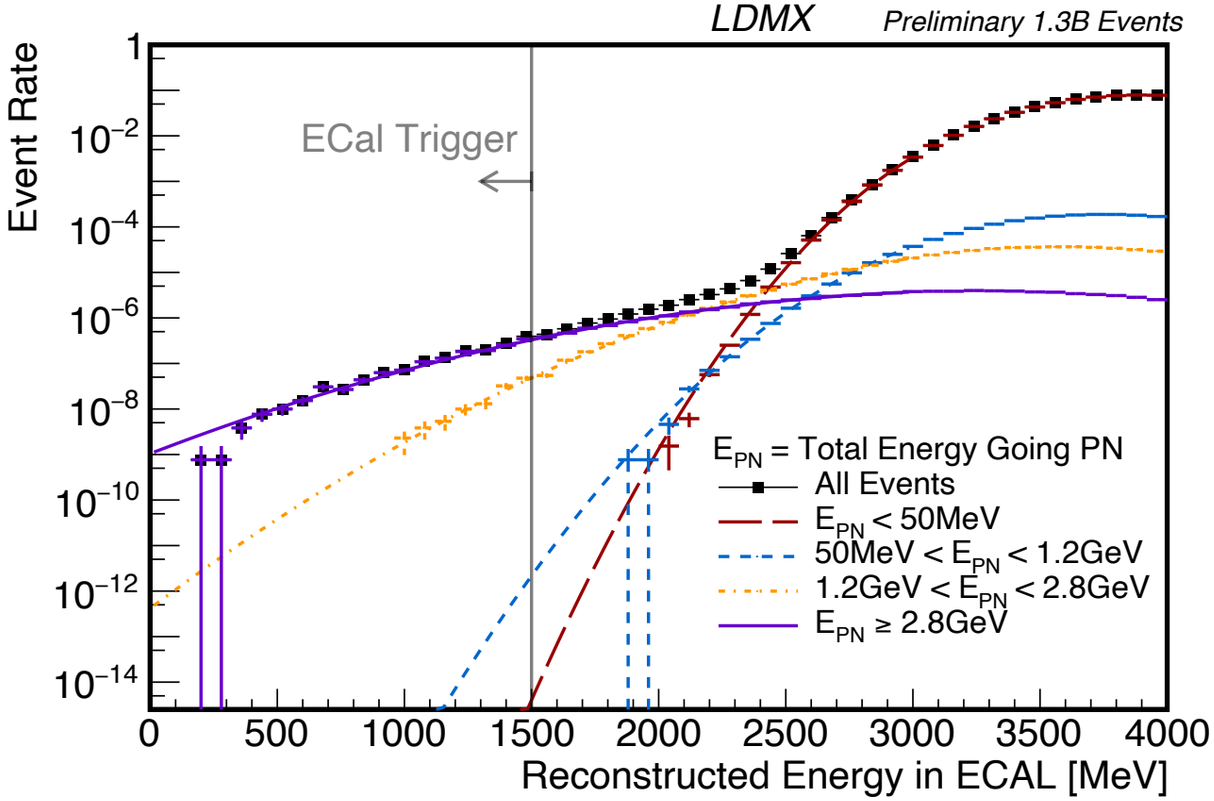

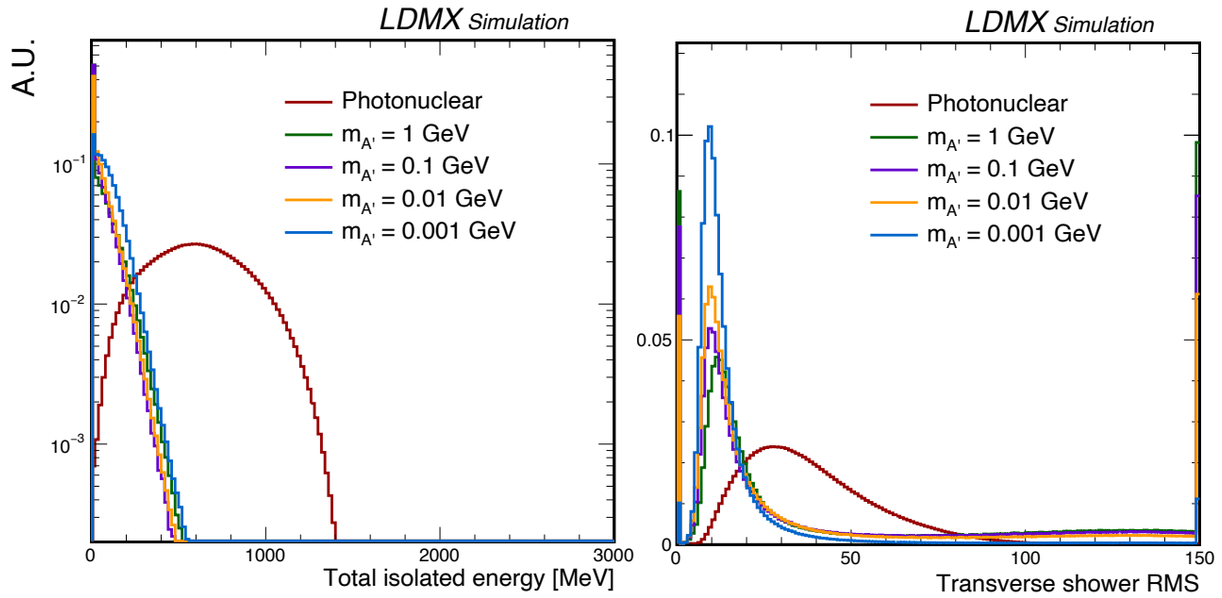

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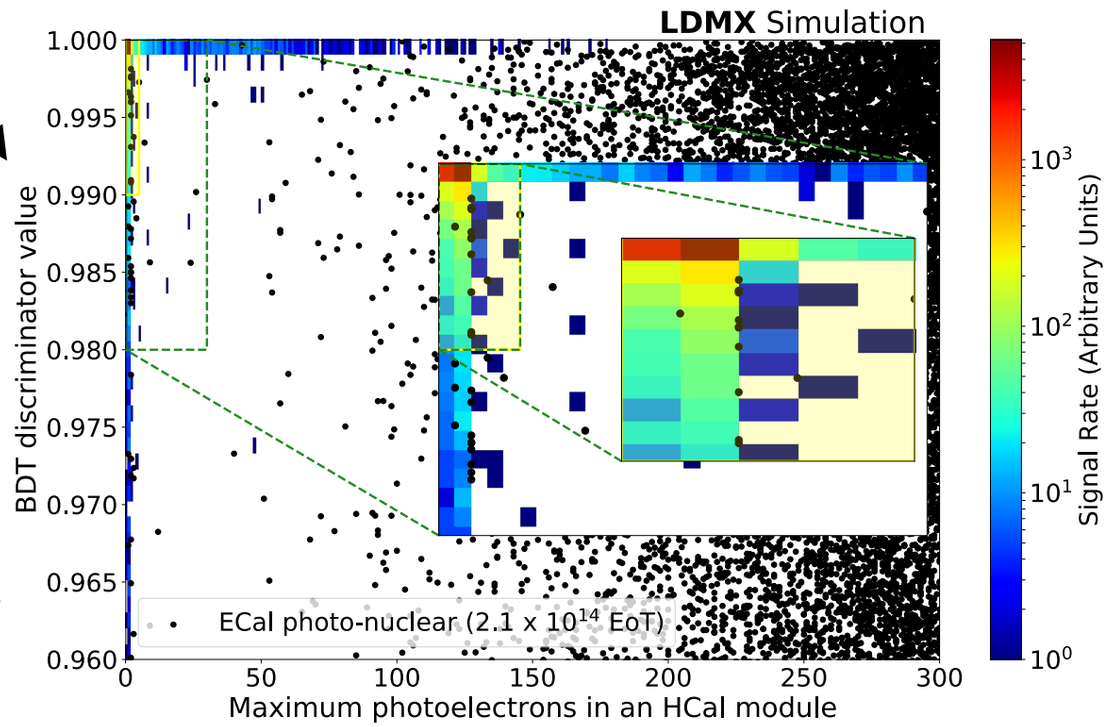

3. Veto HCal activity + extra tracks →

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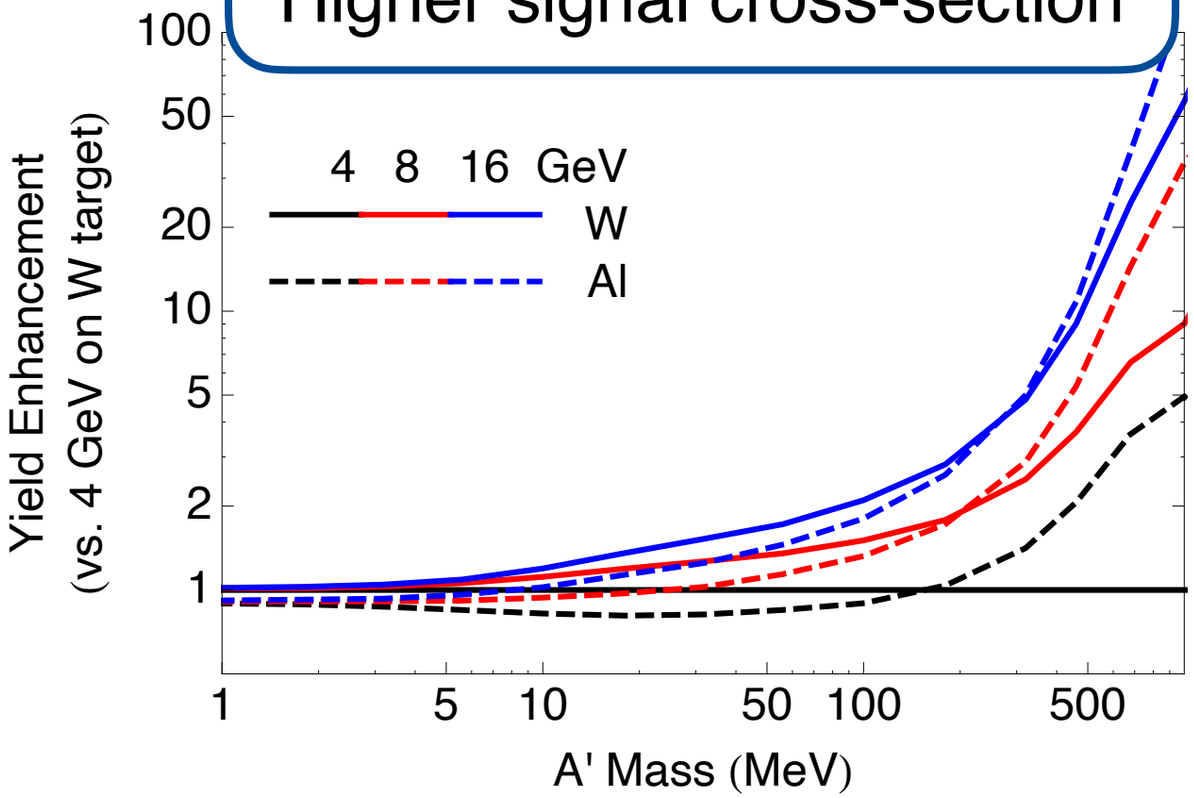
Background-rejection with 8 GeV beam

Majority of LDMX data will likely be taken with an 8 GeV beam.

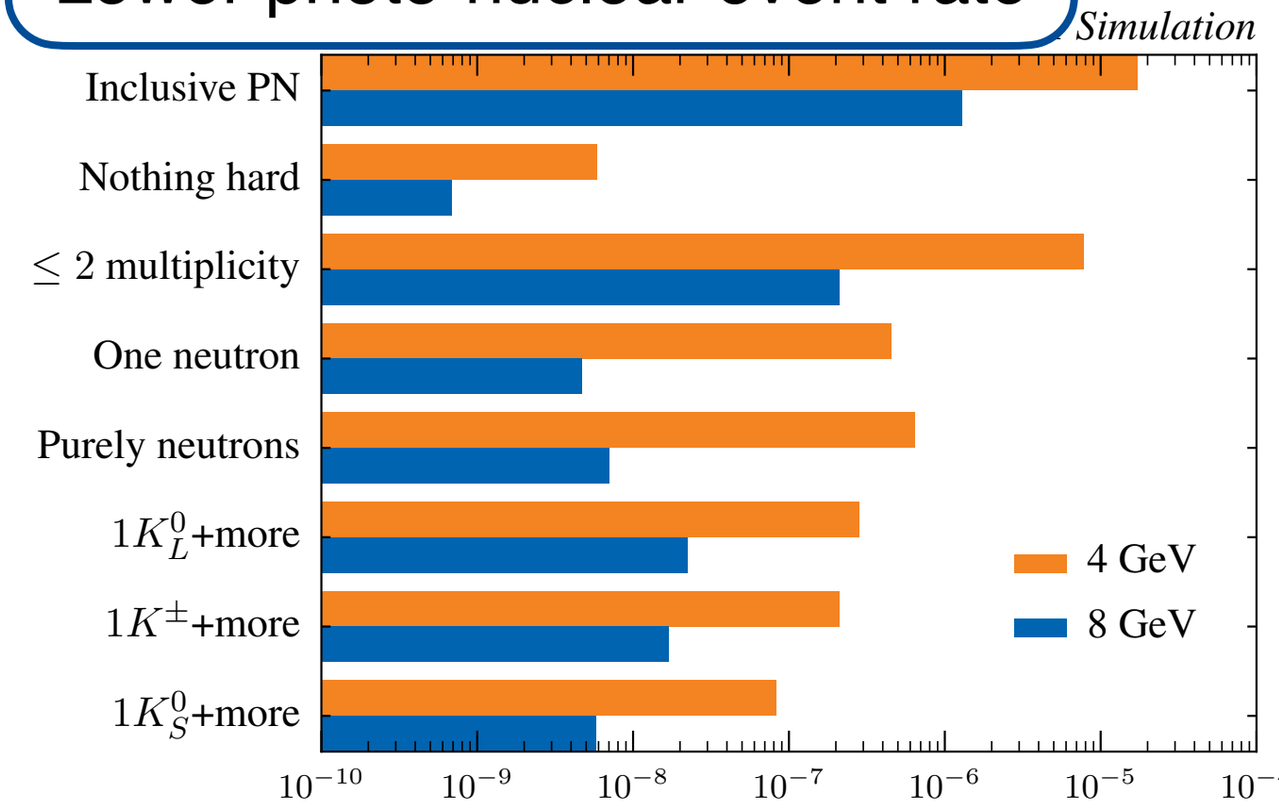
Several advantages over 4 GeV.

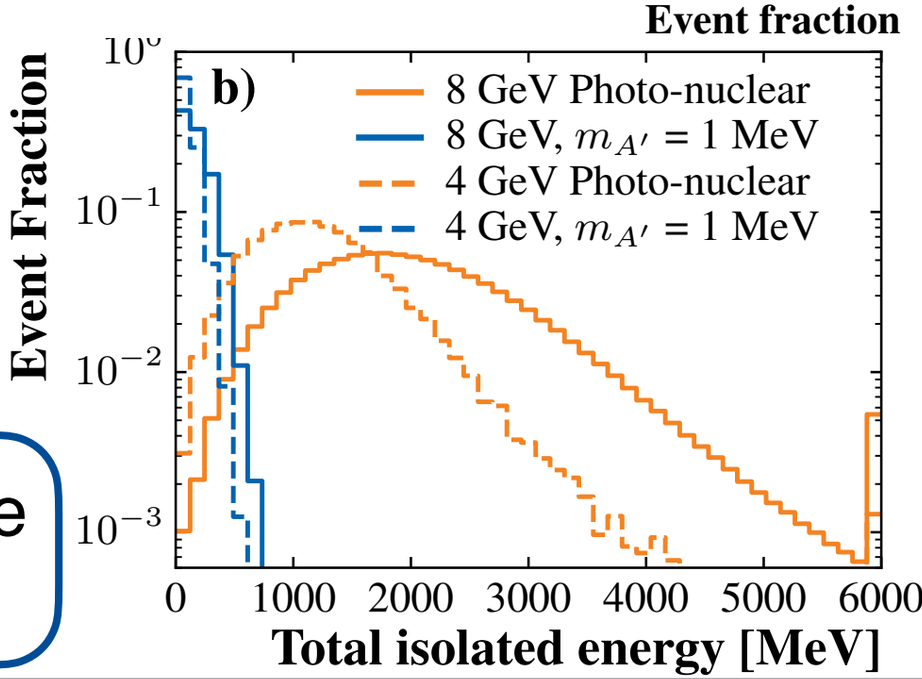
Higher signal cross-section



hep-ex:2308.15173

Lower photo-nuclear event rate



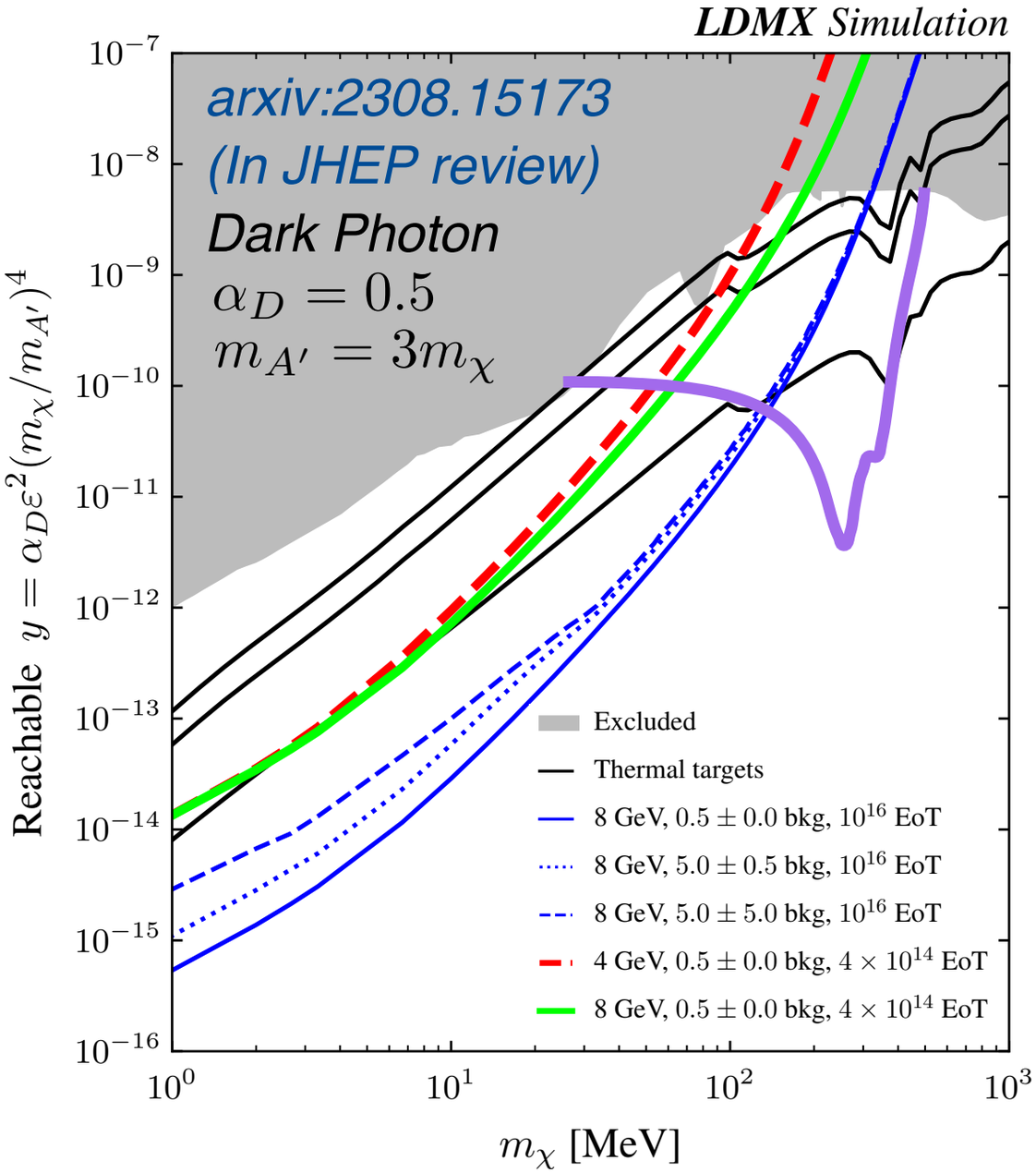


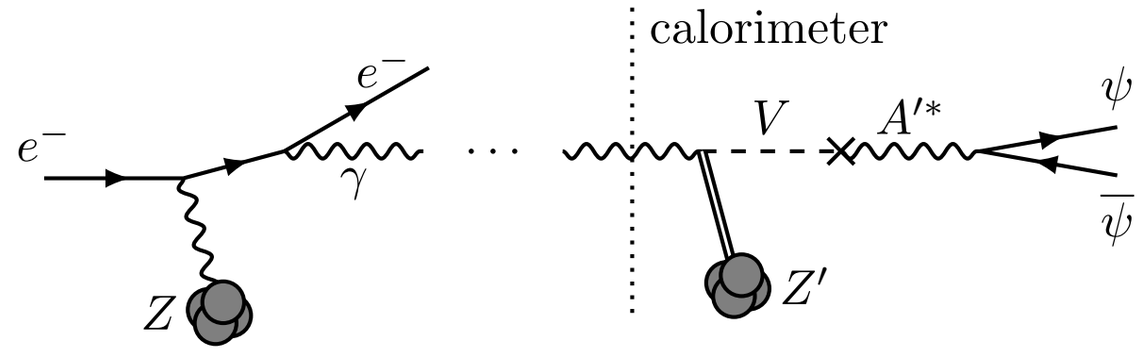
Example ECal BDT input.

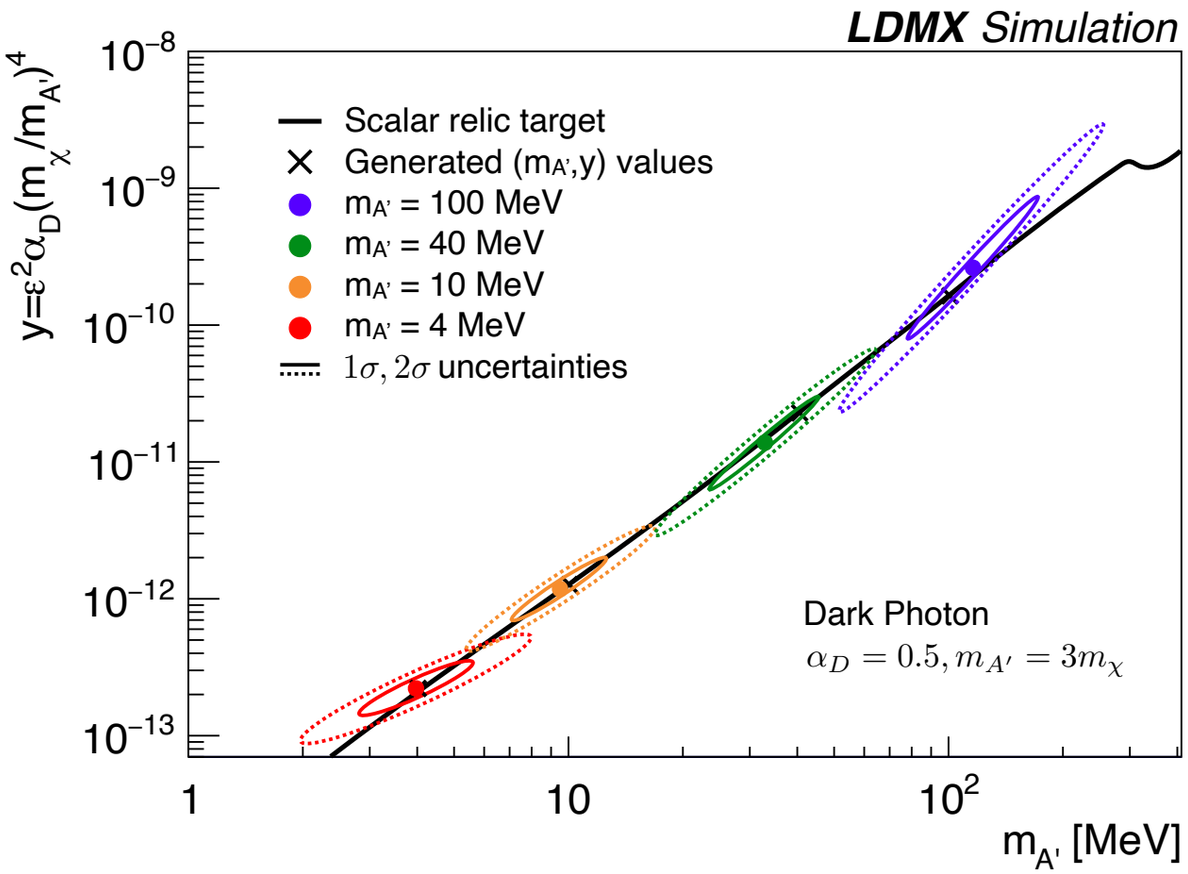
Remaining photo-nuclear events have higher energy, multiplicity

Projected search sensitivity

Sensitive to Dark Bremsstrahlung and invisible meson decay channels.







Background-free (4e14 EoT, Geant4)

Can characterize a potential signal!

Beyond the dark photon

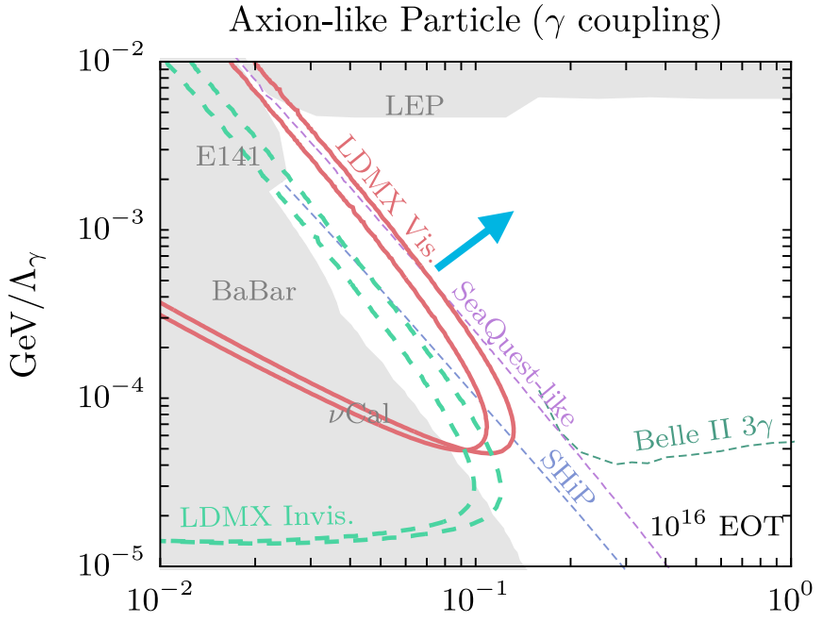
LDMX is sensitive to a broad set of DM models

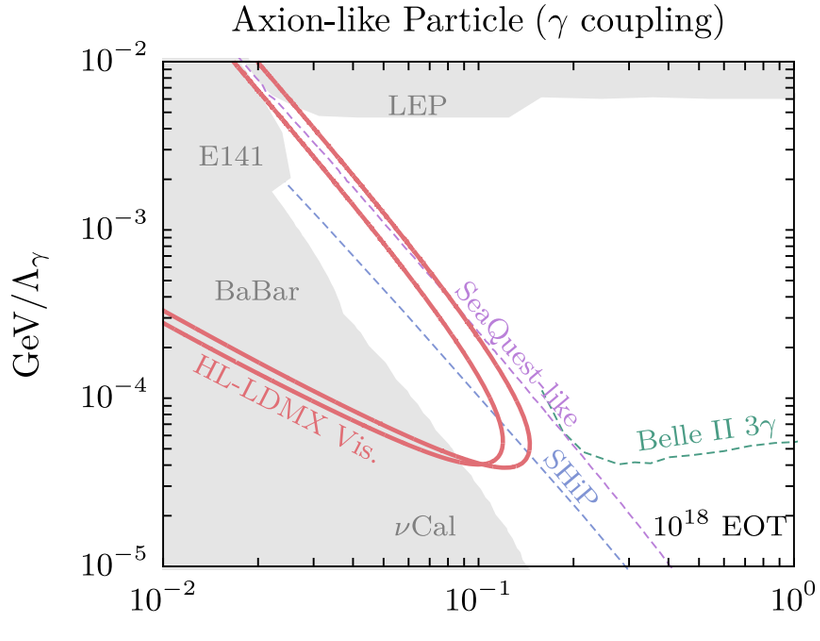
- Millicharge particles
- Inelastic DM
- SIMPs (semi-vis.)
- Freeze-in DM
- Spin-1 DM
- …

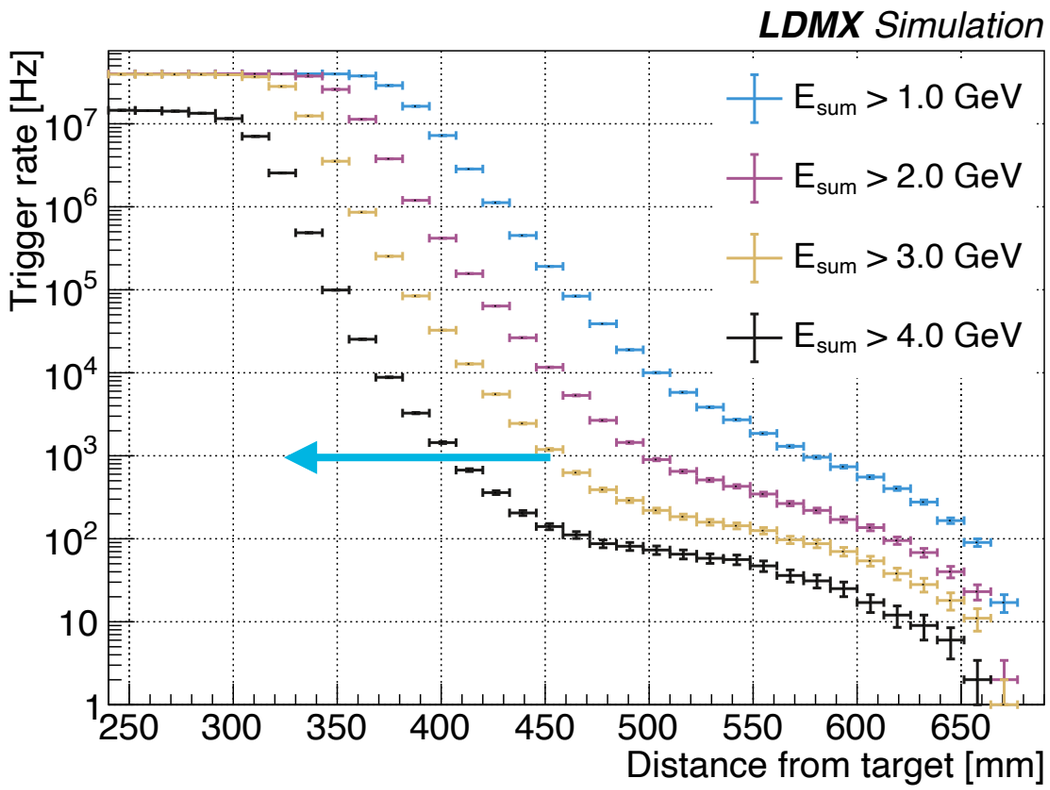
Visible signatures too

- ‘Minimal Dark Photon’
- Axion-like particle

Berlin, Blinov, Krnjaic, Schuster, Toro
Phys. Rev. D 99, 075001 (2019)
Catena, Gray
hep-ph:2307.02207

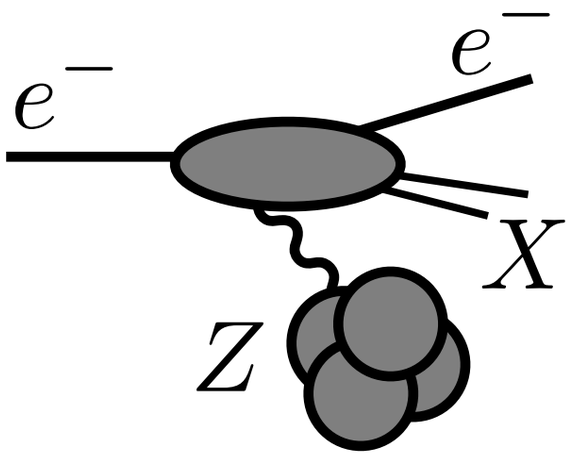




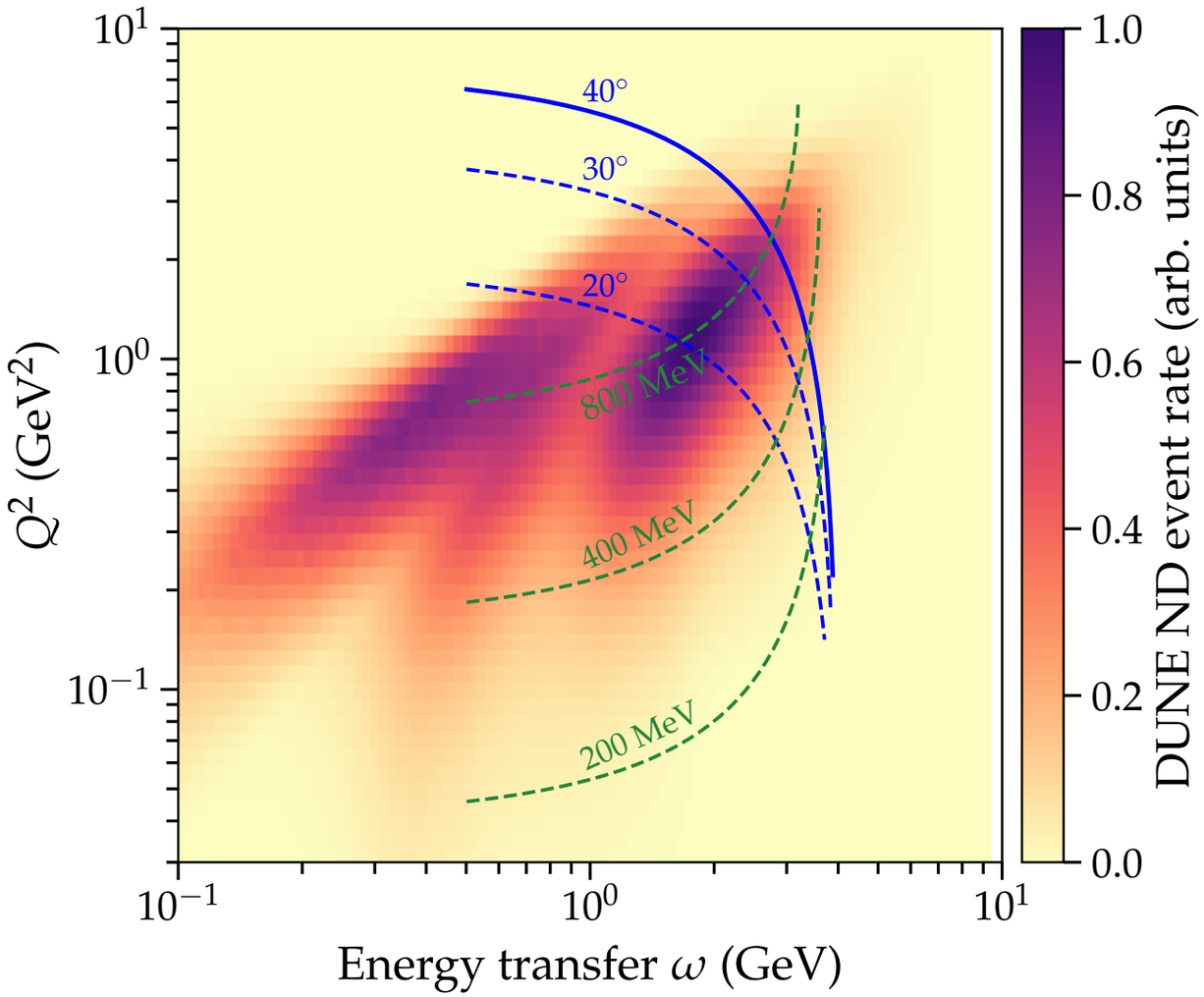


Developing new trigger algorithms for long-lived signatures.

Broader physics impact: eN scattering

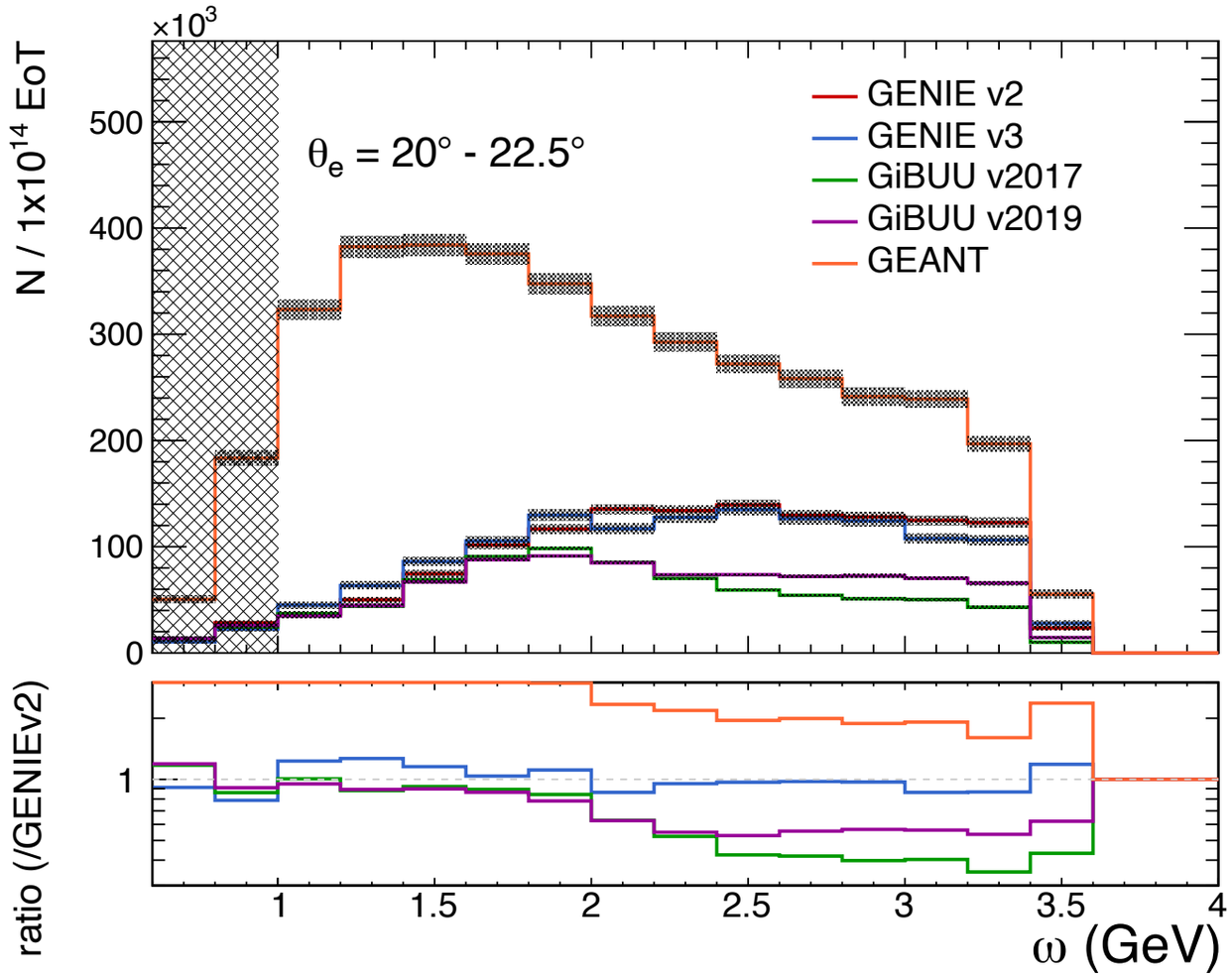


Electron-nucleon scattering



Signature: high-p_T electron + X

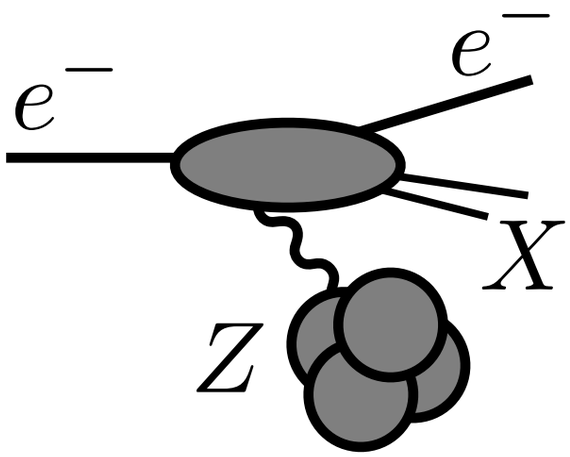
No missing momentum!



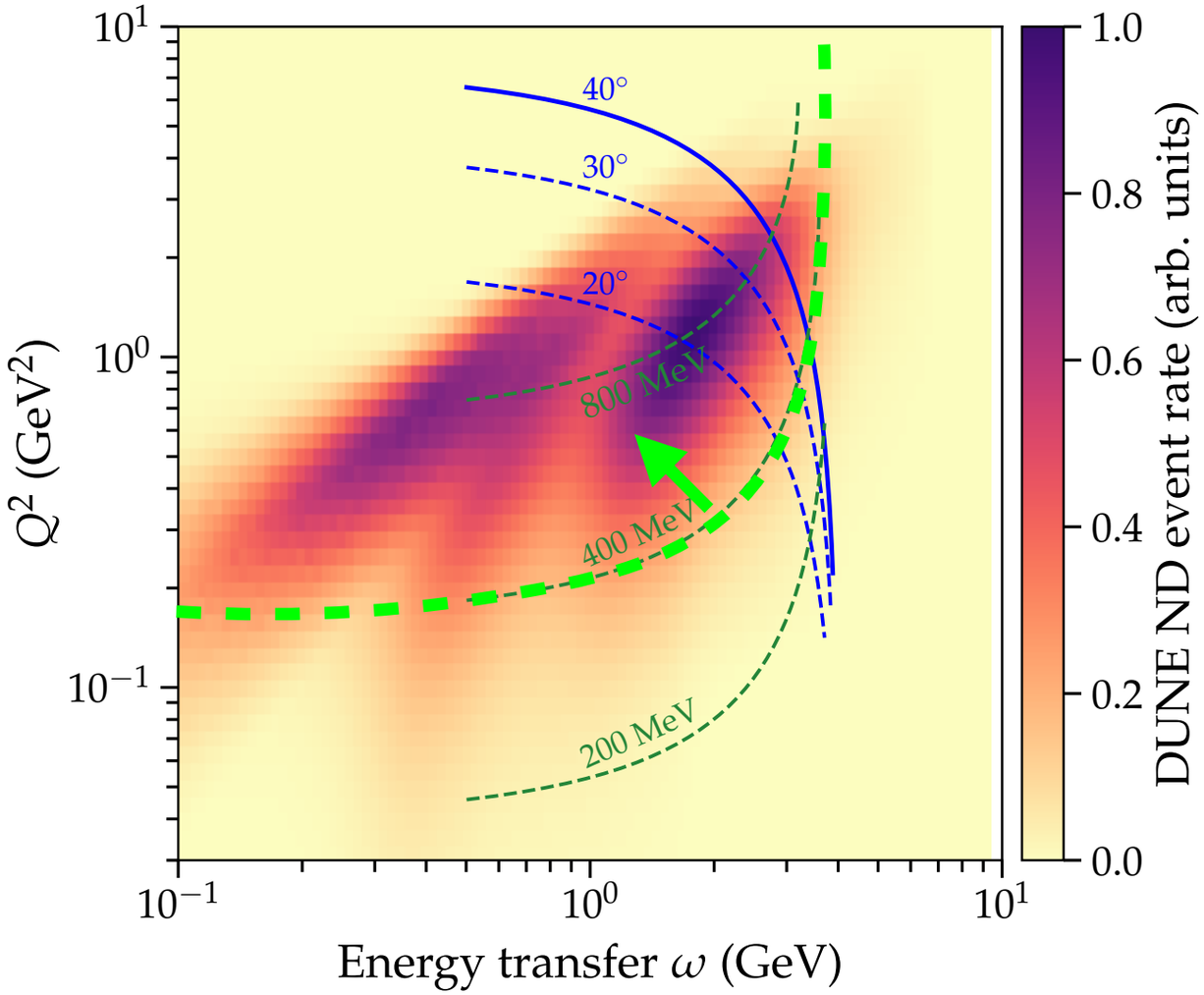
Theory predictions vary widely
→ constrain w/ LDMX data!

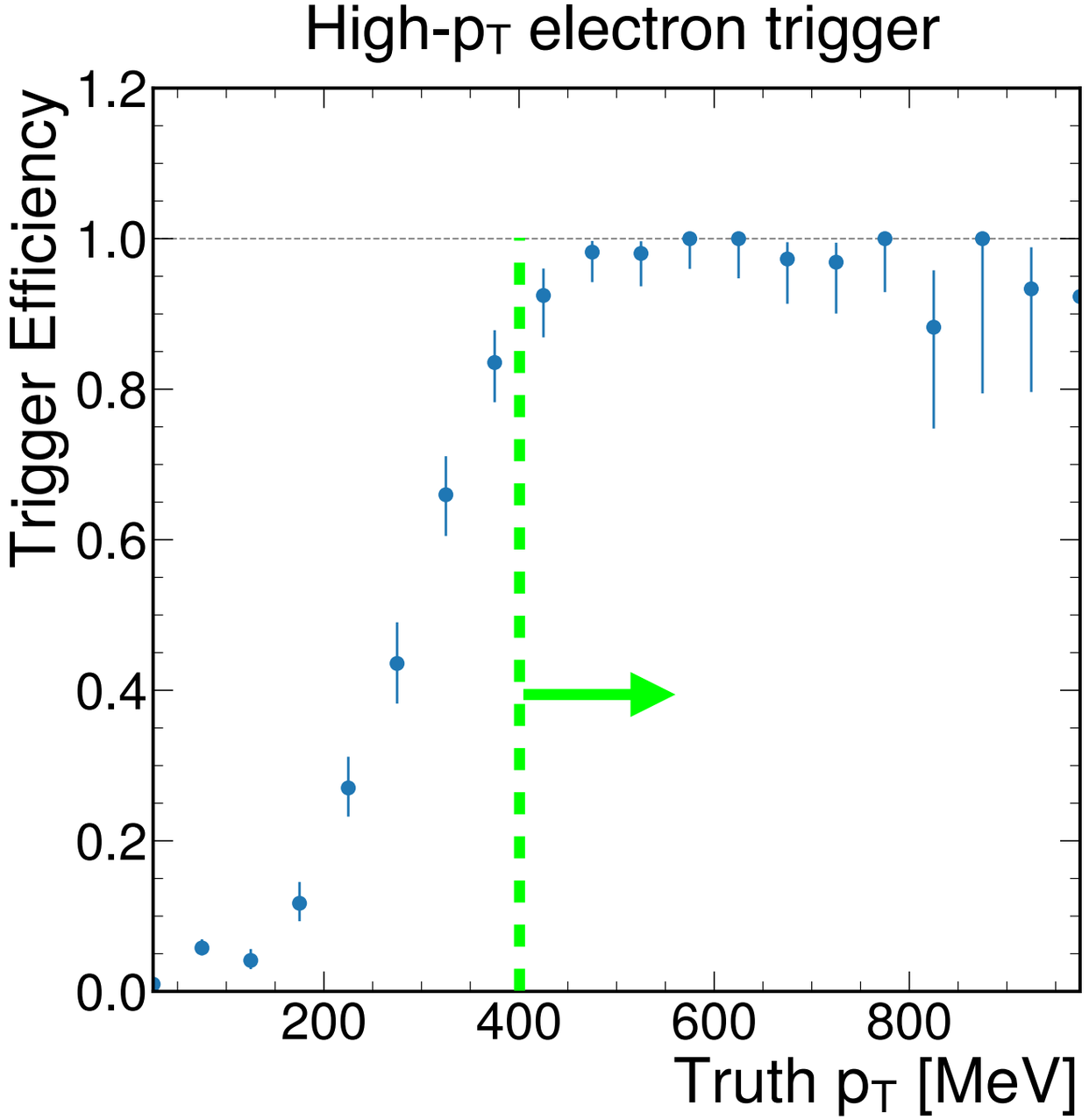
Ankowski, Friedland, Li, Moreno, Schuster, Toro, Tran
Phys. Rev. D 101, 053004 (2020)

Broader physics impact: eN scattering



Electron-nucleon scattering





Conclusions

Thermal dark matter motivates a broad search program for $m_e < m_{DM} < m_p$.
The missing momentum technique is a powerful accelerator probe.

LDMX will explore vast new territory, *reaching thermal relic targets across most of the MeV-GeV mass range* and testing models beyond dark photon.

Will also provide new tests of *lepton-nucleon interaction* models for DUNE.

Aim for a broad physics program, on short time scale! Eager to start soon!

LDMX Collaboration Meeting, SLAC 2022