The Light Dark Matter eXperiment

https://arxiv.org/abs/1808.05219 https://arxiv.org/pdf/1912.05535.pdf

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

and some other fun ideas with lepton fixed target collisions

https://arxiv.org/pdf/1912.06140.pdf https://arxiv.org/pdf/1804.03144.pdf

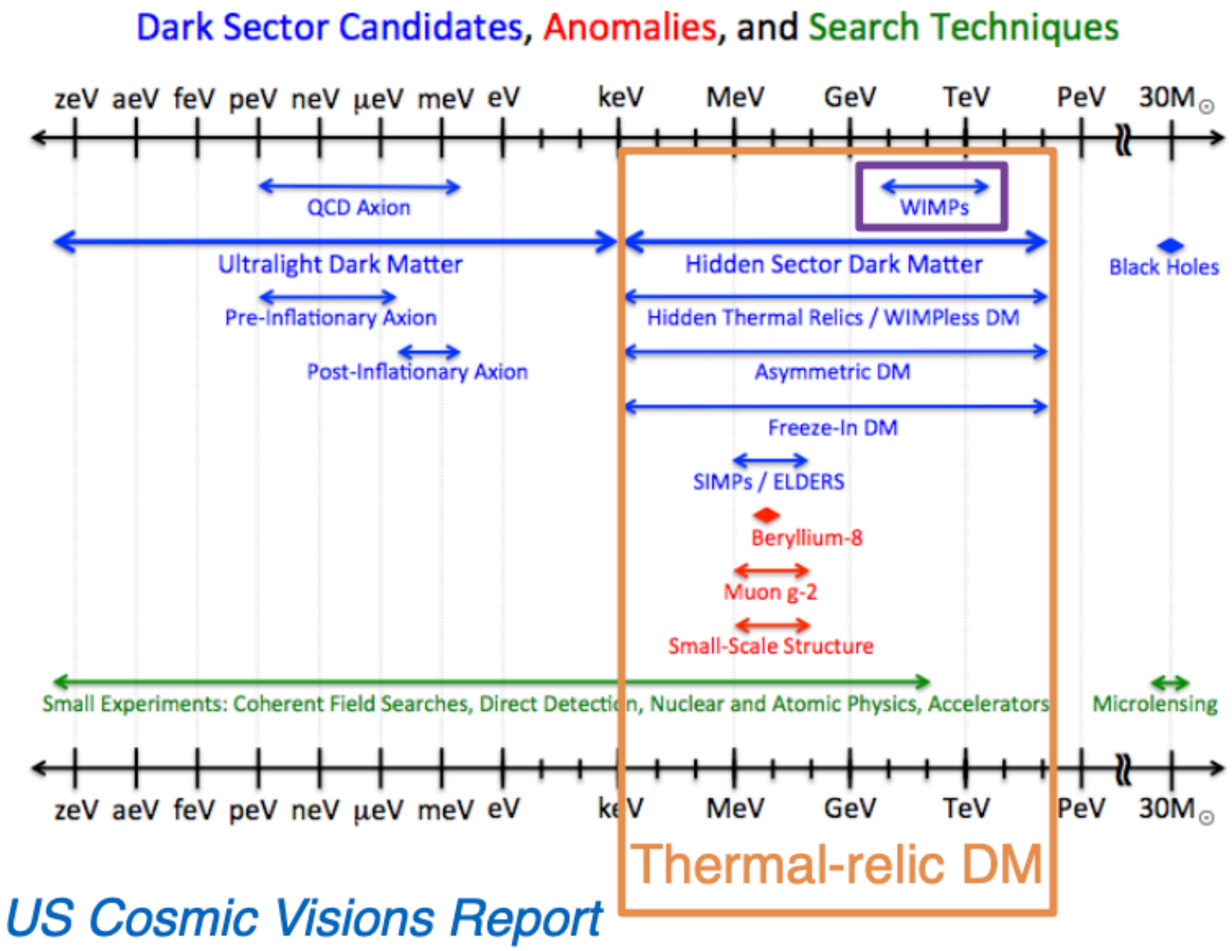
Andrew Whitbeck, Texas Tech University

Seminar @ INFN Laboratori Nazionali di Frascati

April 8, 2021

Dark matter: a thermal-relic?

- A compelling and predictive explanation for the presence of a relic abundance of DM
- Much of the experimental effort has targeted WIMPs
- How do we build a comprehensive program to test the thermal-relic paradigm?
  - A focus of several *community driven workshop* to broaden DM program



US Cosmic Visions Report

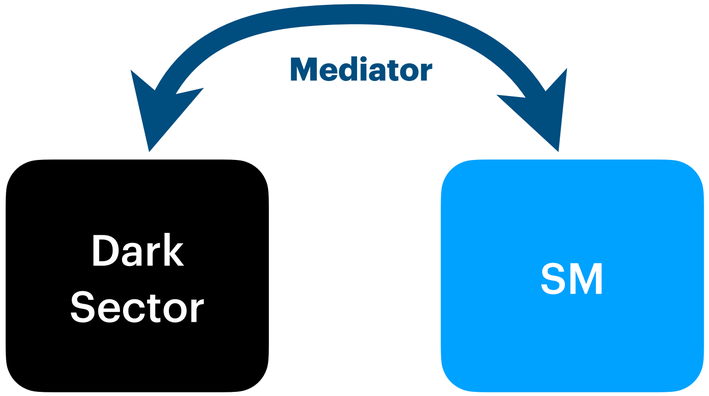
Light dark matter phenomenology

Light dark matter parameter space is a natural evolution of WIMP search program

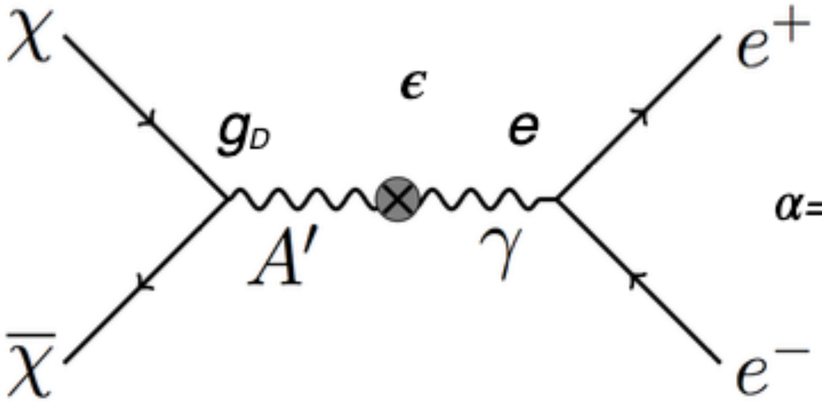
Requires new light mediators:

simple, predictive model: vector mediator which mixes with photon

Electrons play a central role in dark matter & light mediator searches

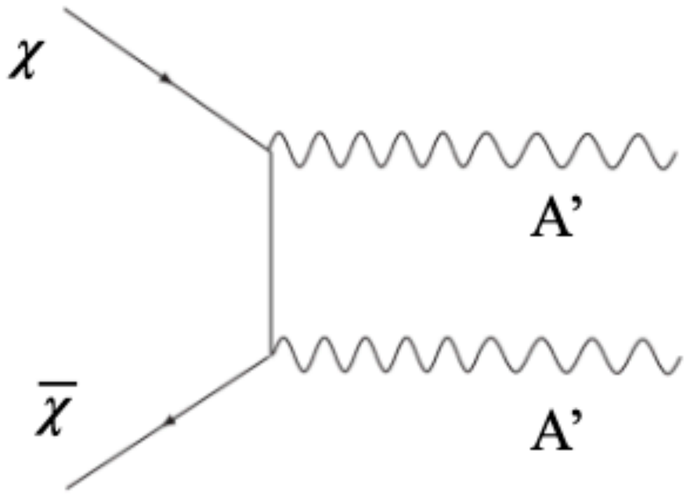


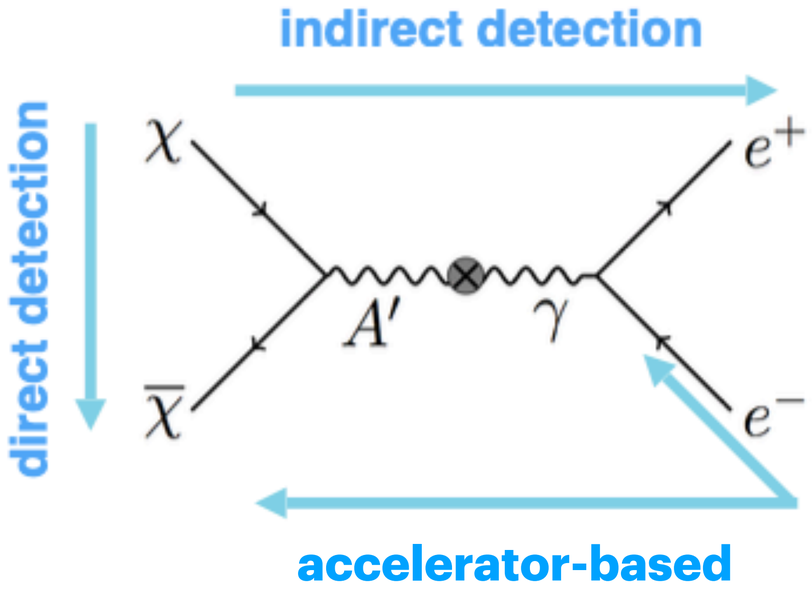
$\alpha_D = g_D^2/4\pi$

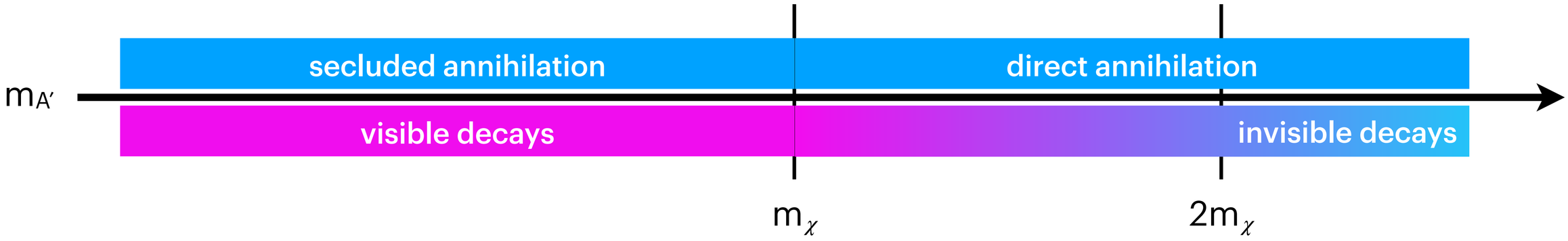


$\alpha = e^2/4\pi$

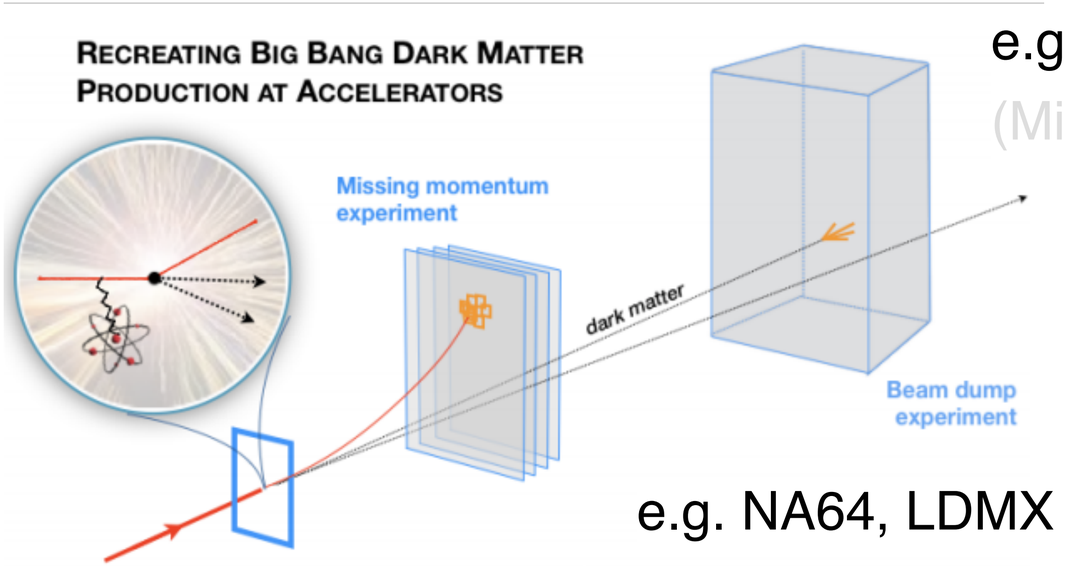
Light dark matter phenomenology





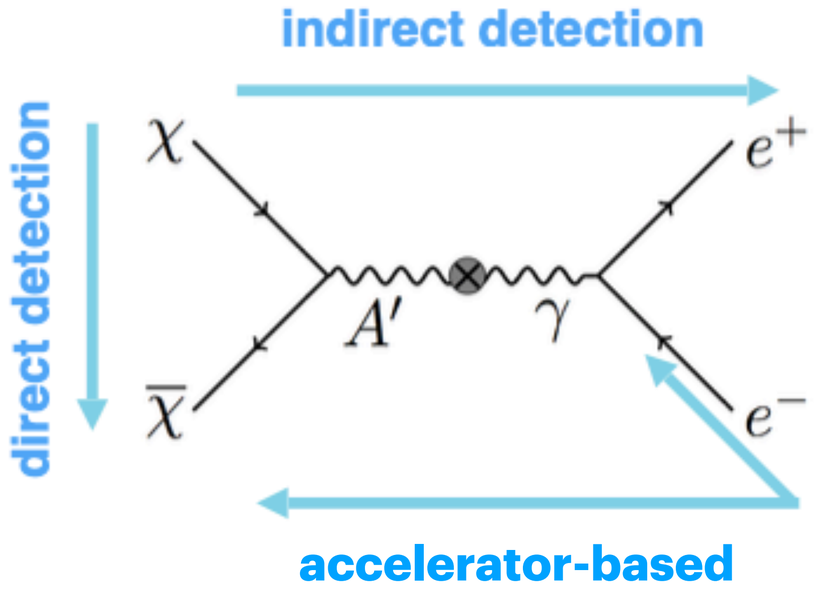


Experimental tools

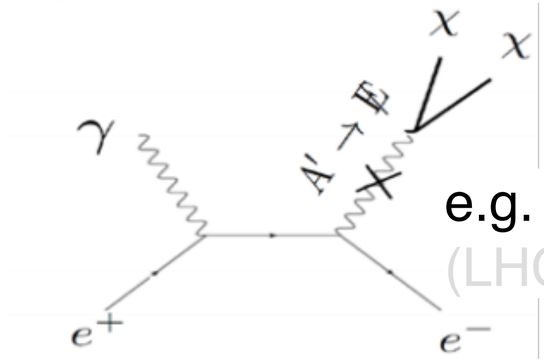


e.g. BDX

(MiniBoone)

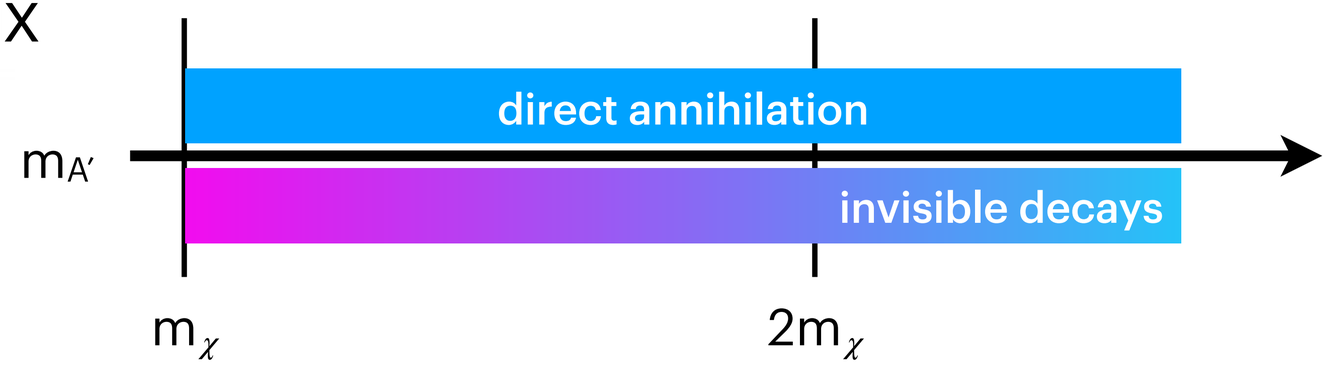


e.g. NA64, LDMX



e.g. Belle II, PADME

(LHC)

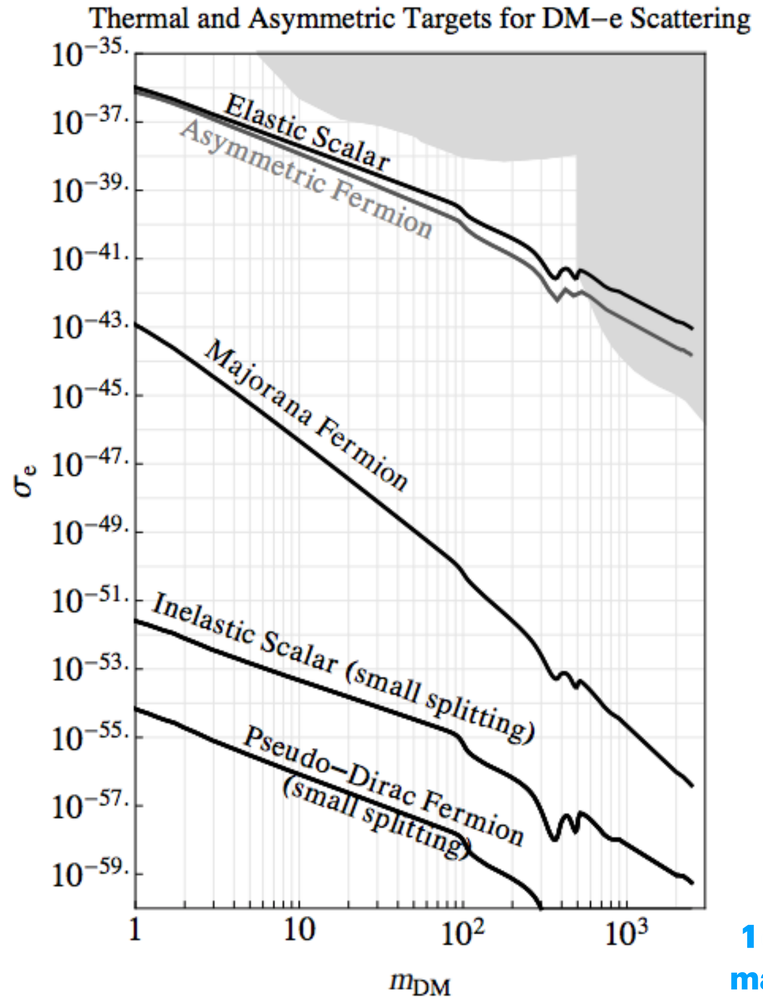


e.g. of proton coupling analogs

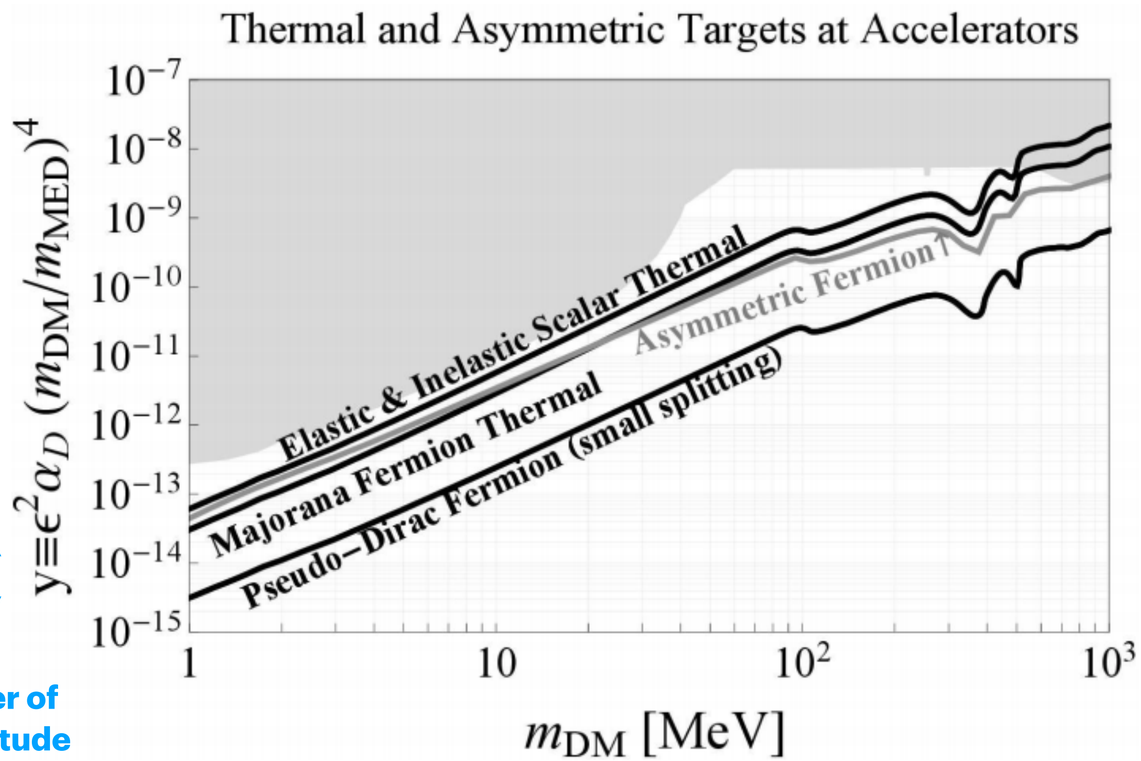
Thermal relic targets

The connection with cosmology gives a target (lower bound) for the coupling strength consistent with the measured thermal relic abundance

9 orders of magnitude



accelerator-based experiments are largely insensitive to the Lorentz structure of DM-SM interactions



1 order of magnitude

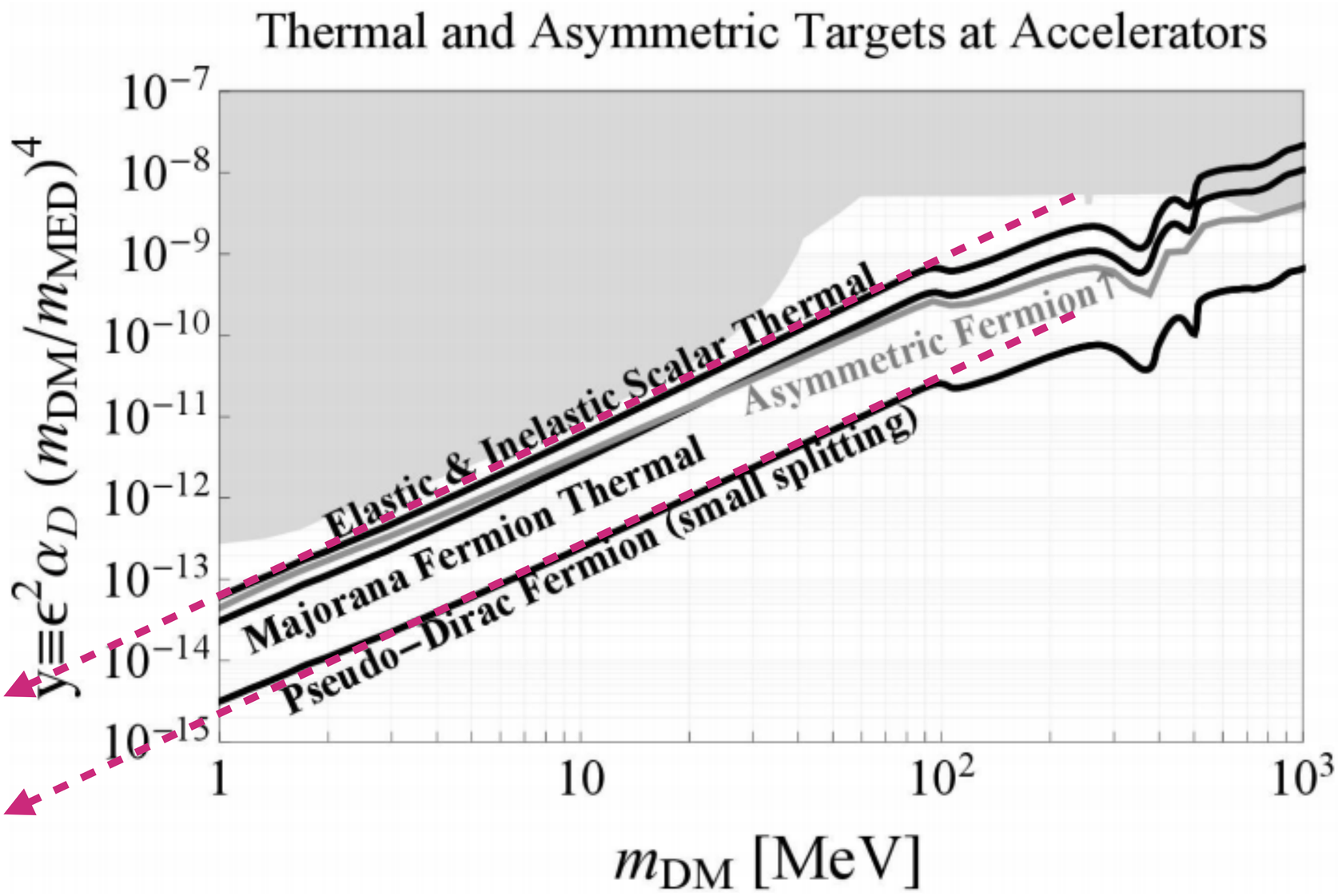
Production rates

$$N \sim N_e \mathcal{C} T \epsilon^2 \frac{m_e^2}{m_{A'}^2},$$

C ~ 5

T = 0.1

$m_{DM}/m_{A'}$ = 1/3



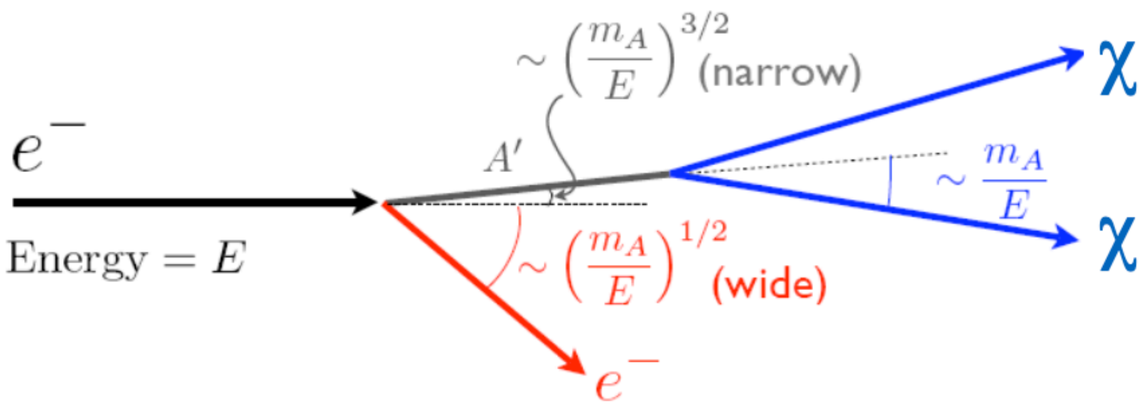
N_{prod}/N_e ~2×10^{-13}

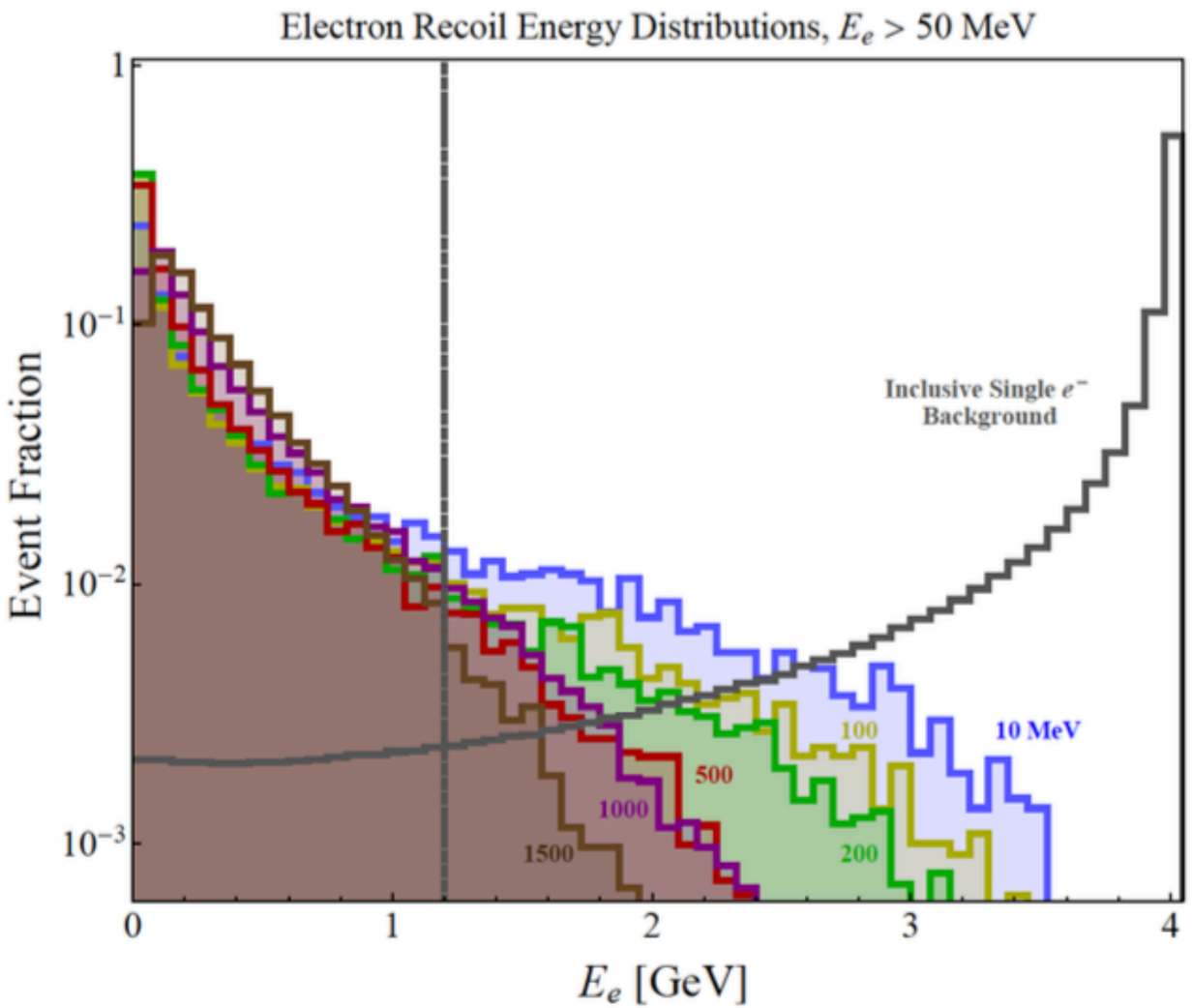
N_{prod}/N_e ~6×10^{-15}

Signal kinematics

recoil energy

A' carries away mostly of the beam energy and converts it to invisible particles



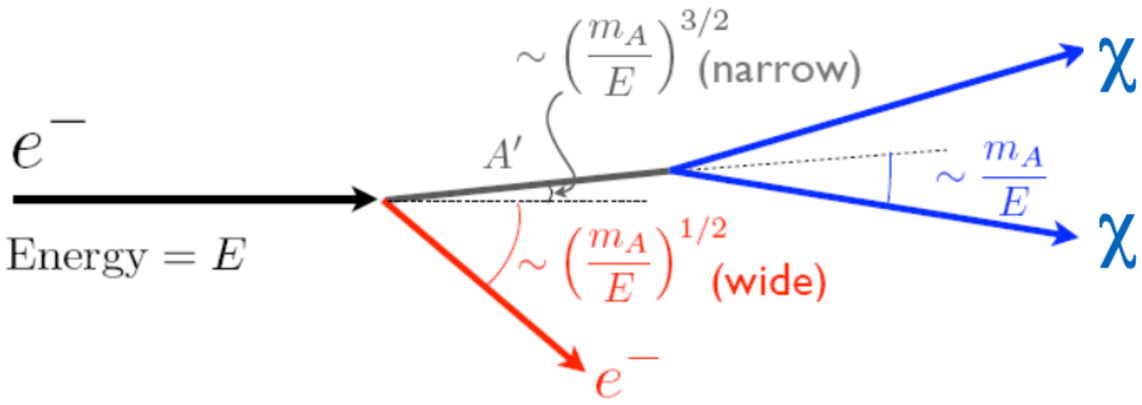


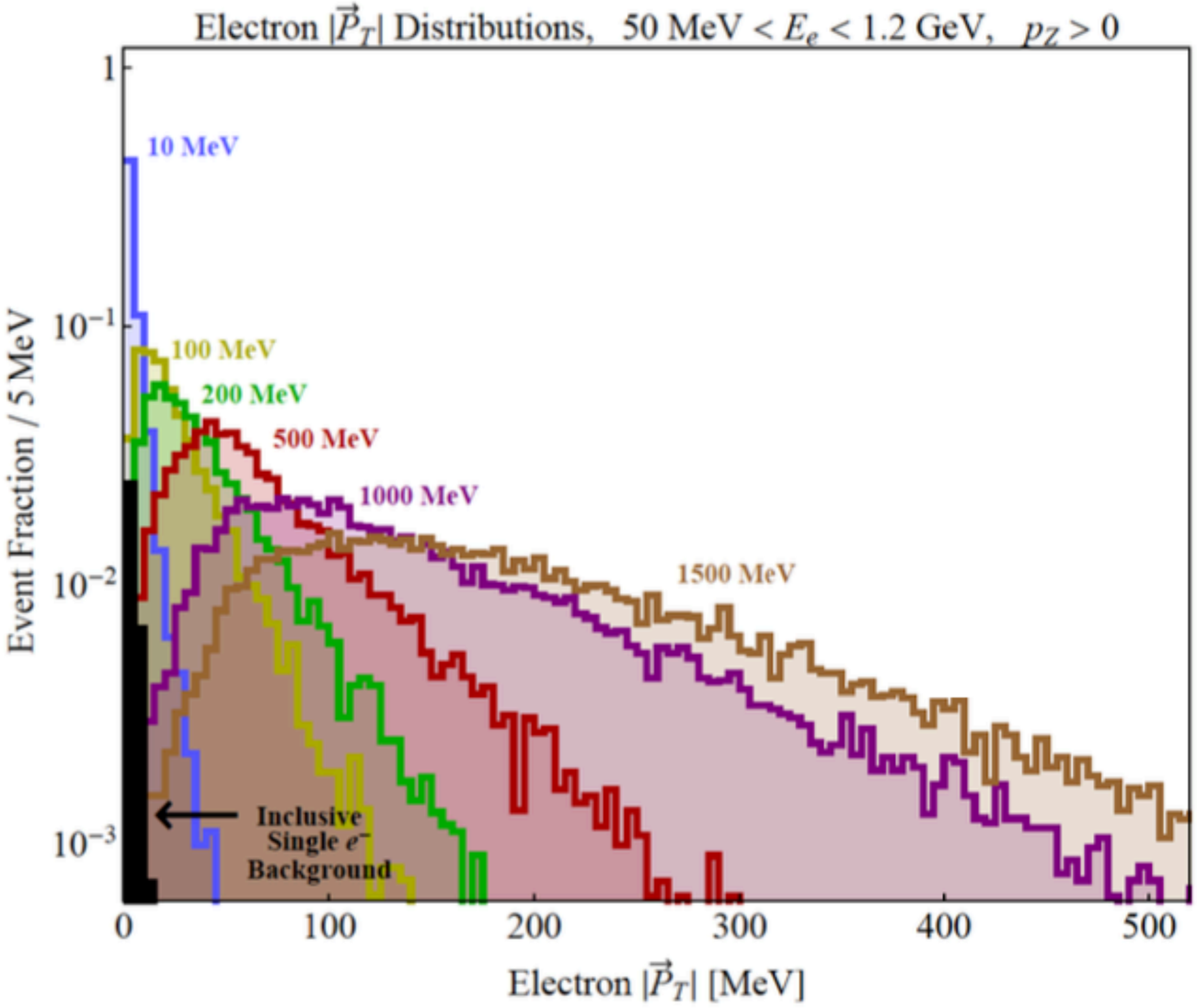
Signal kinematics

recoil p_T

Recoil electron p_T spectrum of signal depends on $m_{A'}$ and is an important experimental handle

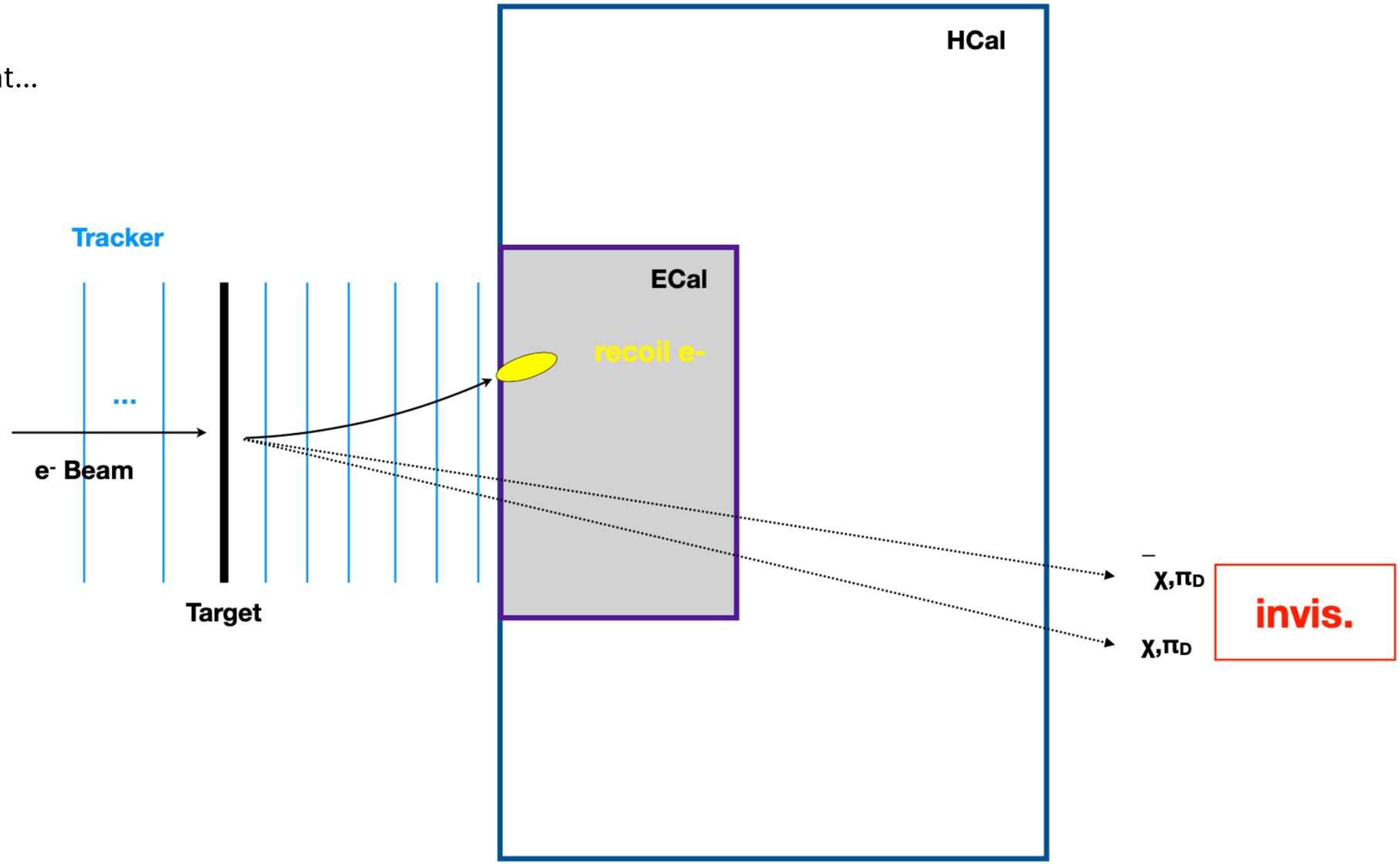
both for background discrimination
and signal characterization





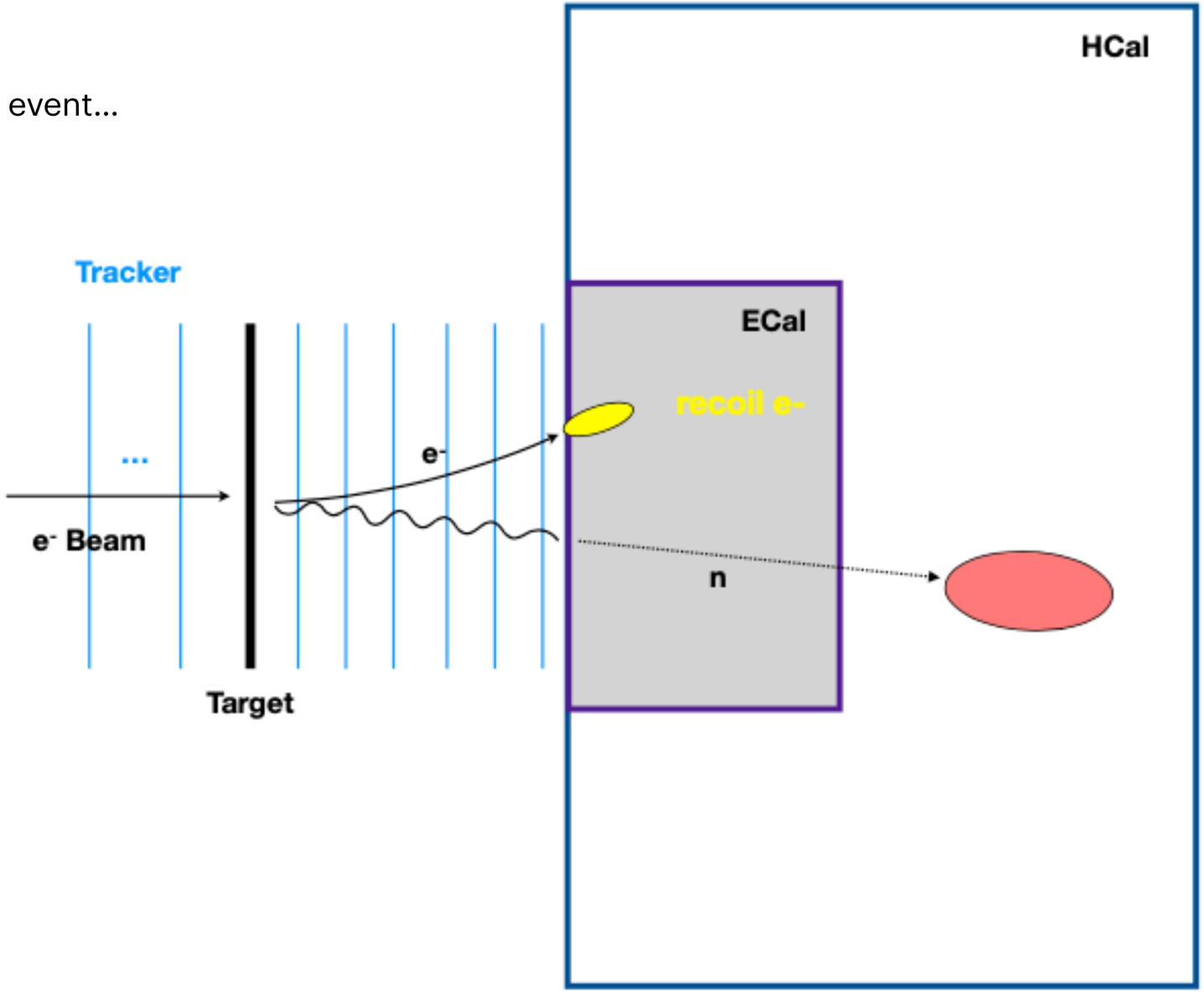
LDMX concept

Idealized signal event...

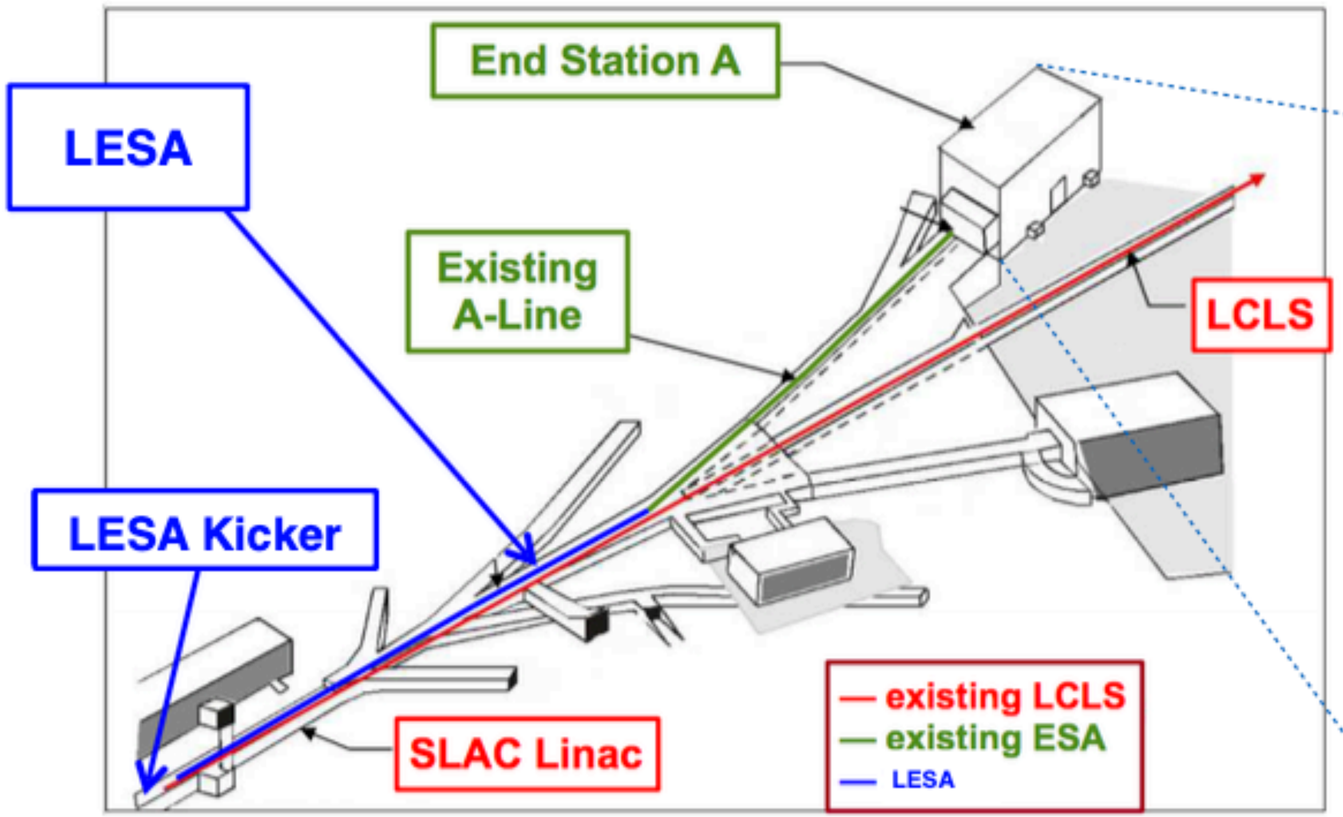


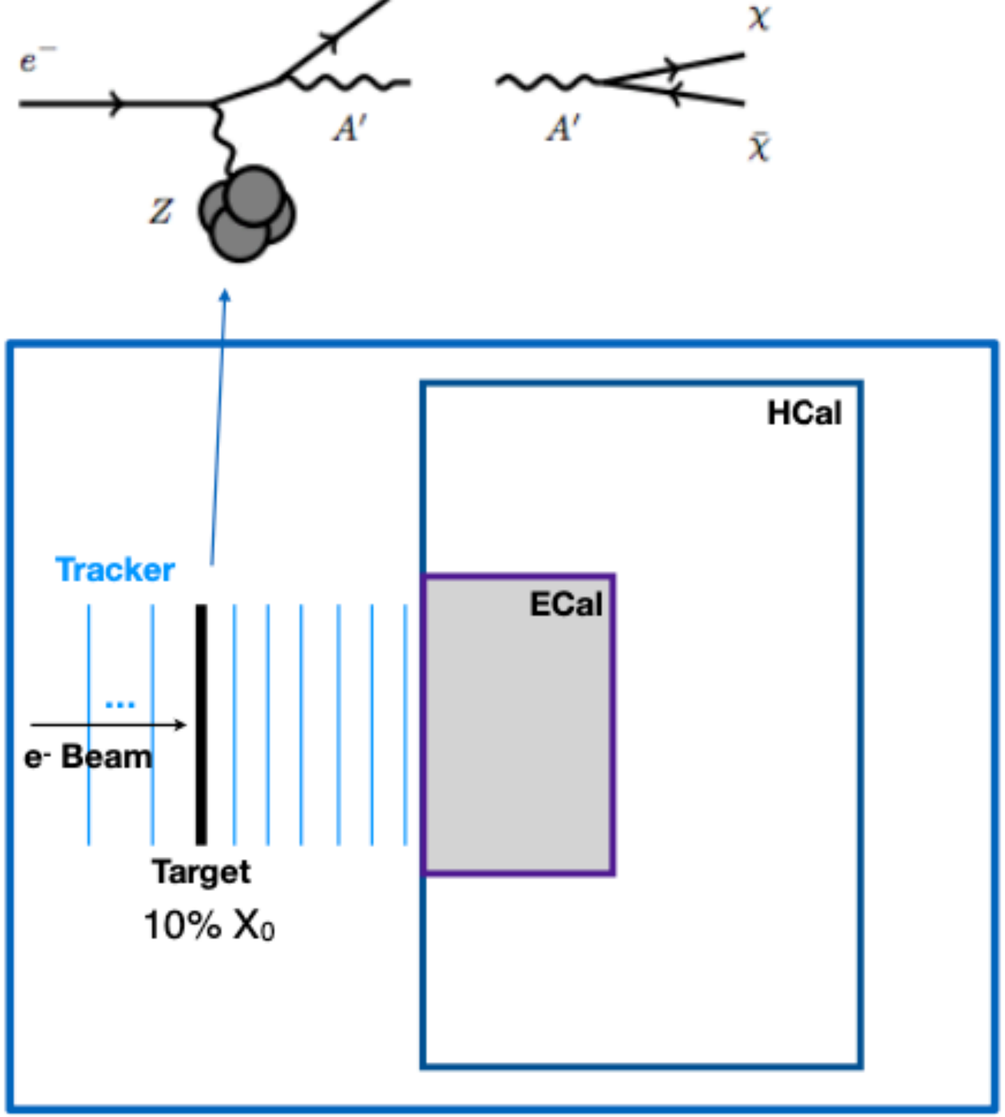
LDMX concept

Idealized background event...



The beam

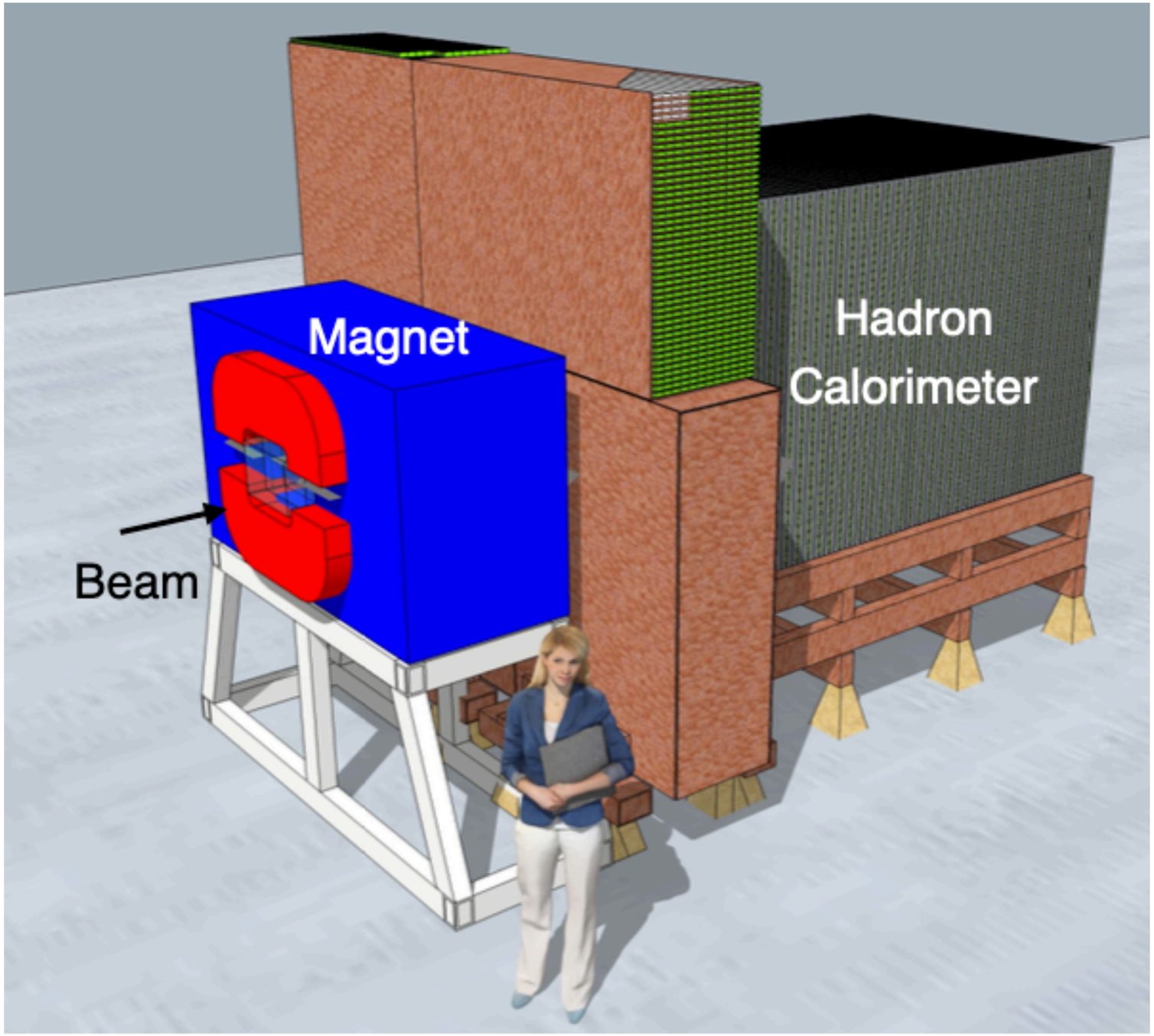


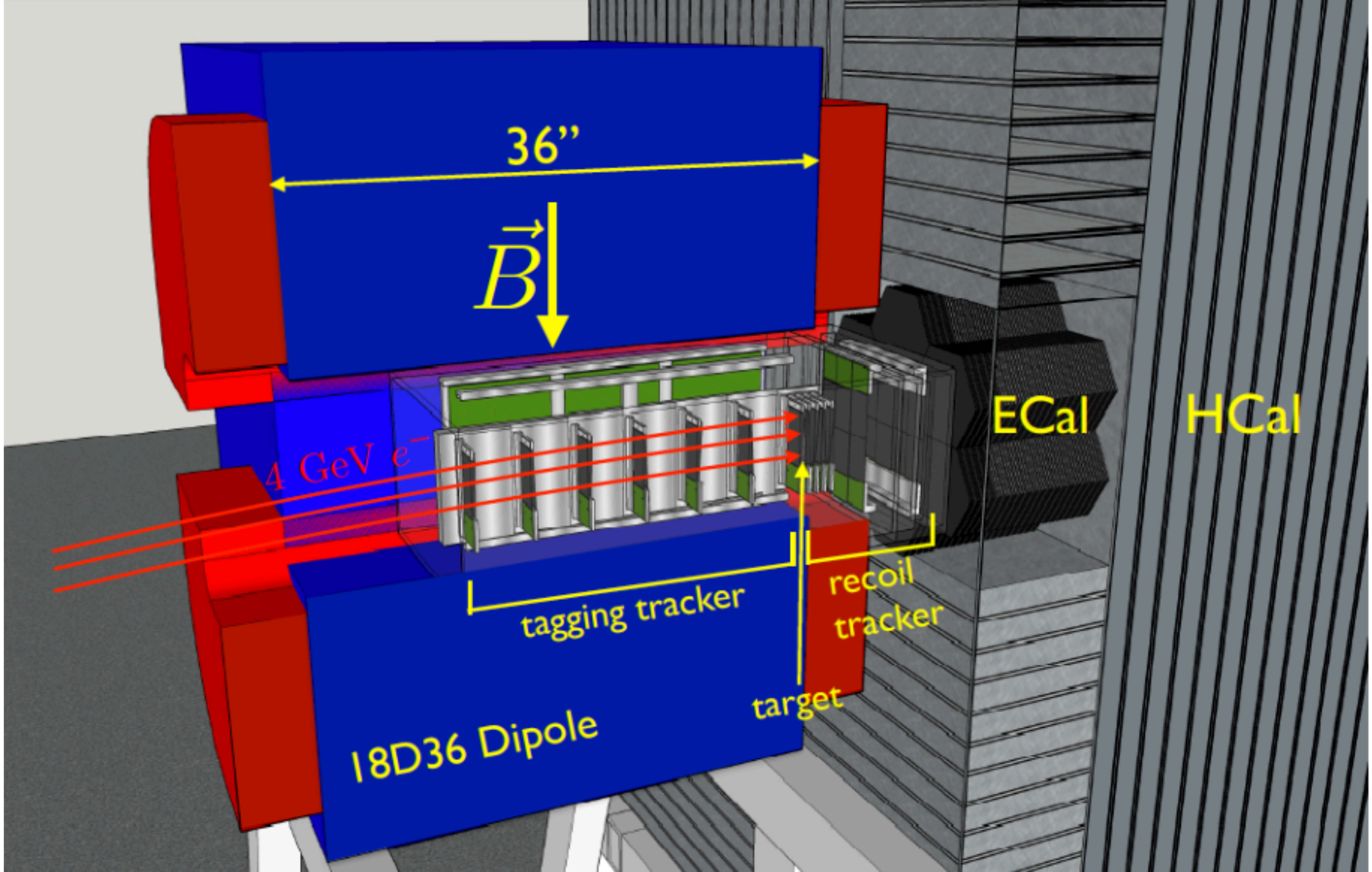


- Beam transfer line under development now
- Will deliver 4 GeV beam initially (~2023) with an eventual upgrade to 8 GeV (~2027)
- Maximum rep. rate of 186 MHz
- LDMX will initially utilize dark current and eventually install a dedicated laser injection system for 186/5 MHz rep. rate
- LESA is expected to initial be able to deliver 10^{15} e^- / year

See also: https://arxiv.org/pdf/1801.07867.pdf Snowmass 2021 LOI

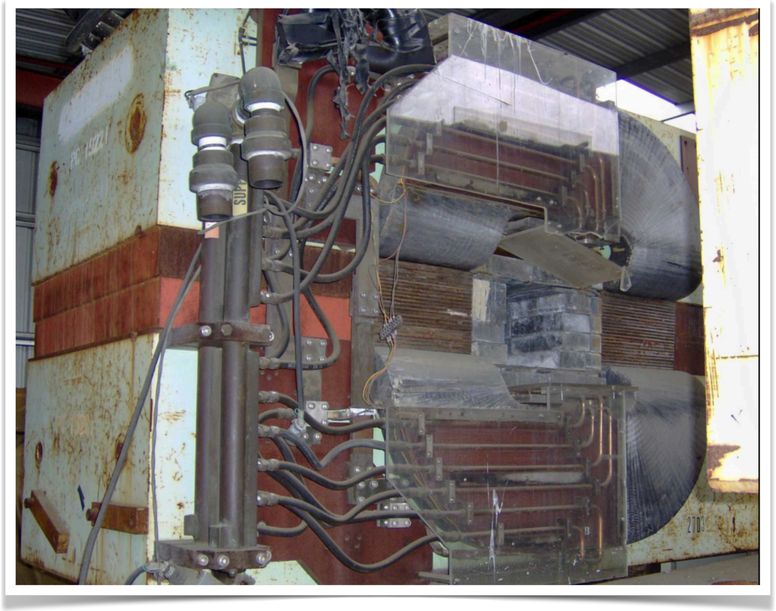
Detector:
Broad strokes



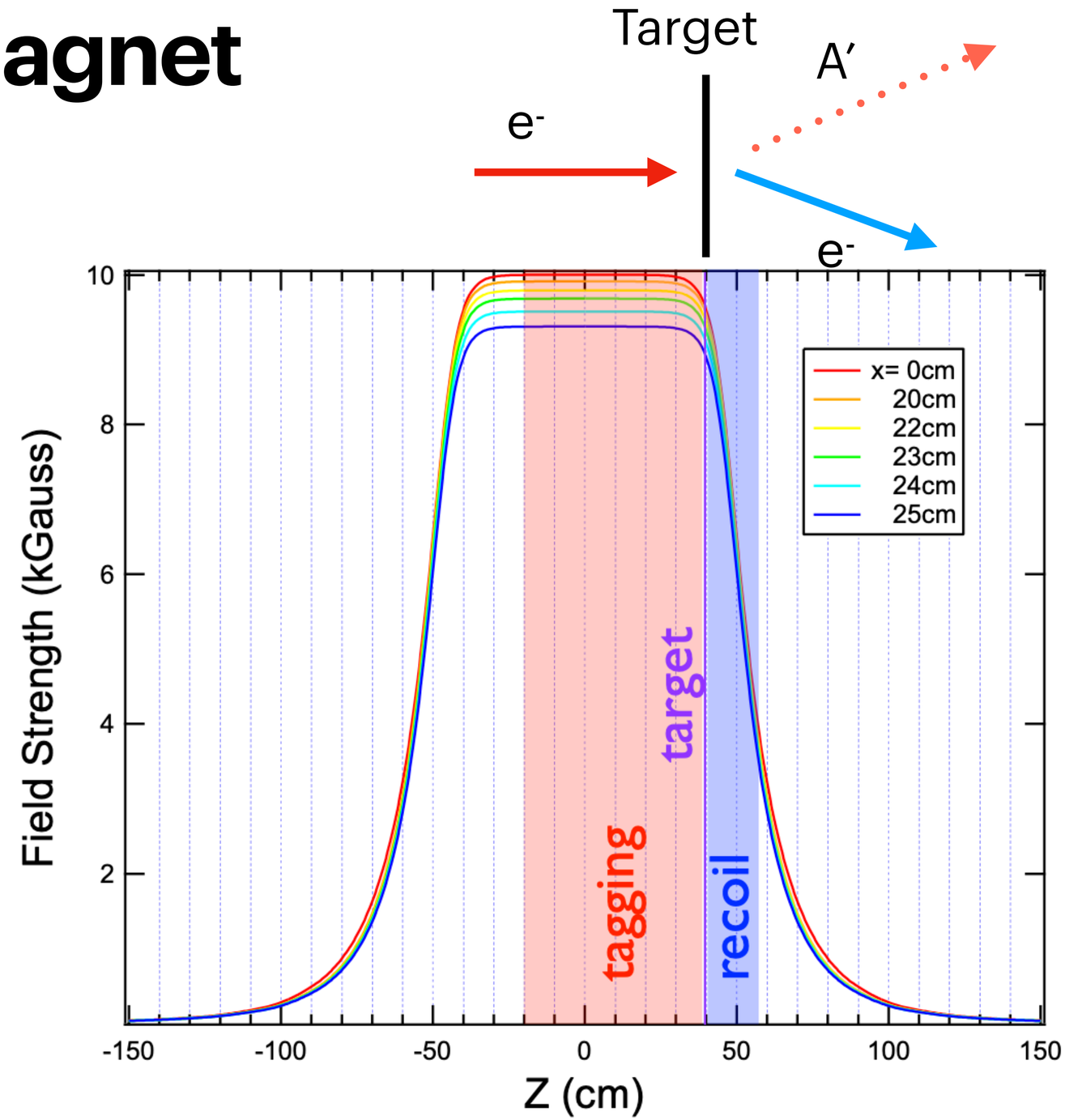

36”
$\vec{B}$
4 GeV e^-
ECal
HCal
tagging tracker
recoil tracker
target
18D36 Dipole

Magnet

- 1T B-field with detectors operating in the bore and the fridge field

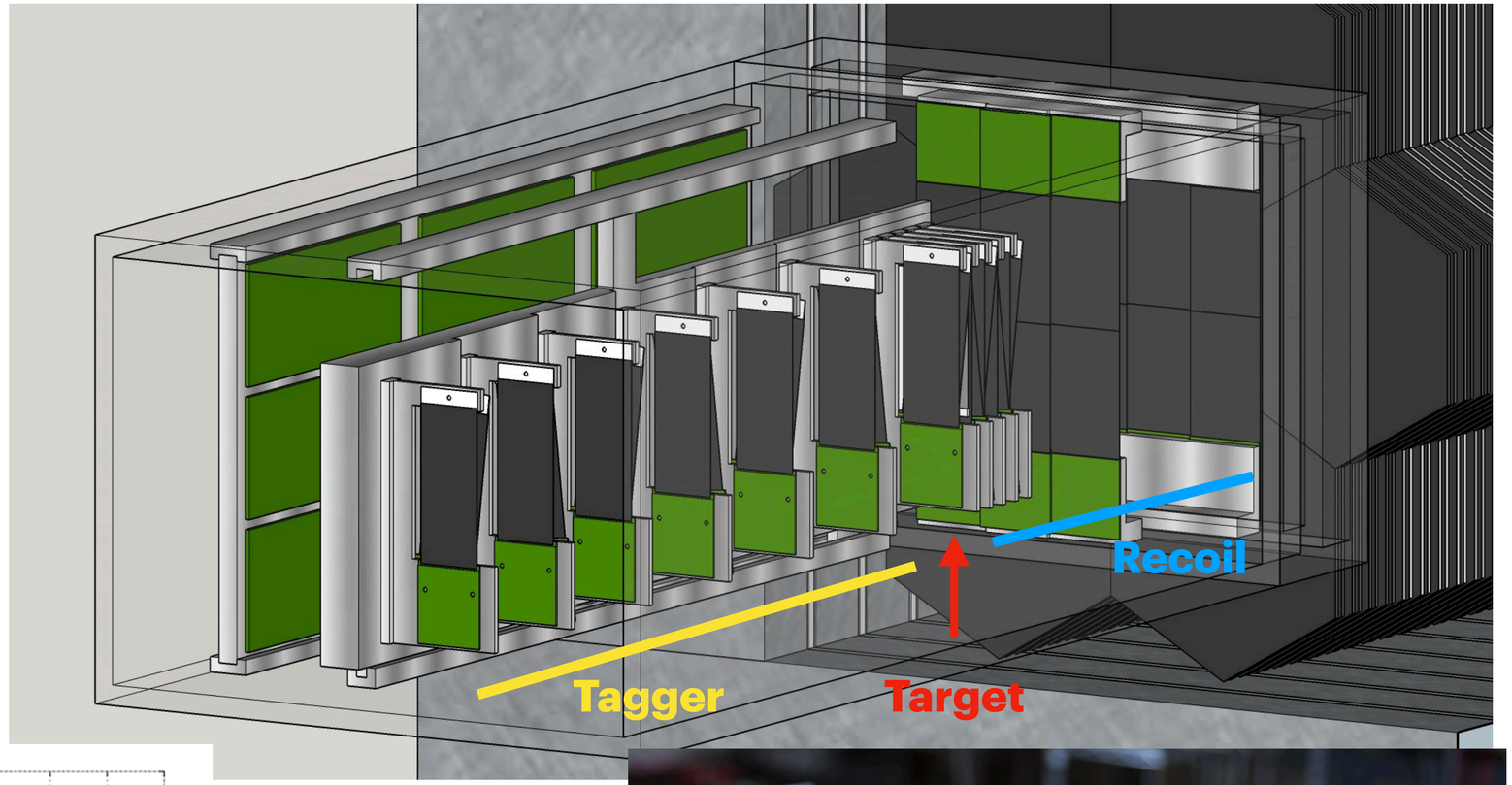


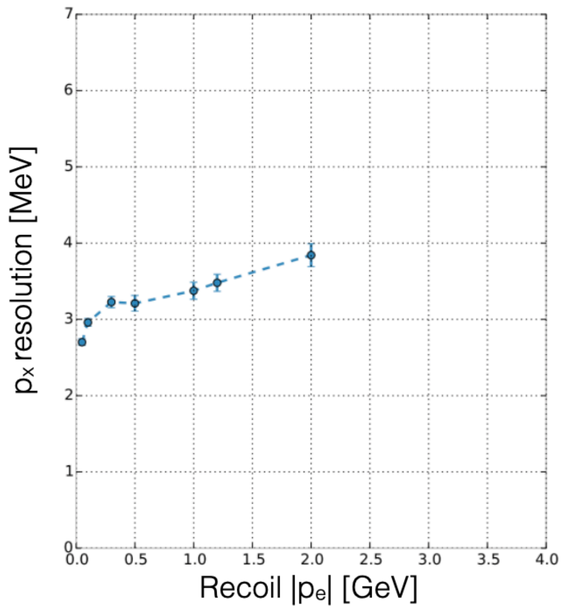
18D36 Dipole magnet @ SLAC

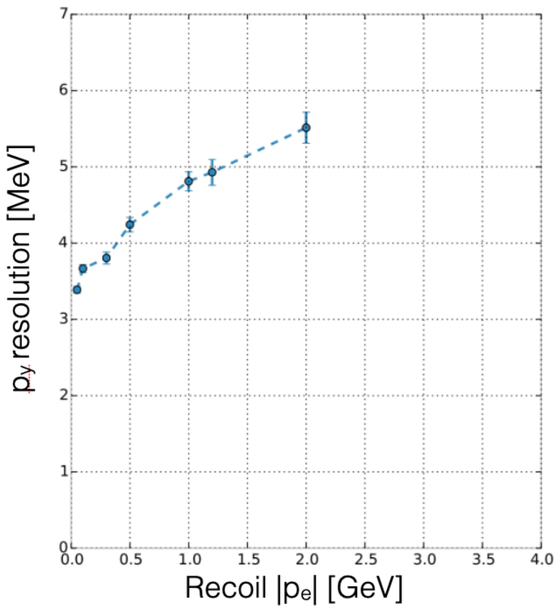


Silicon trackers

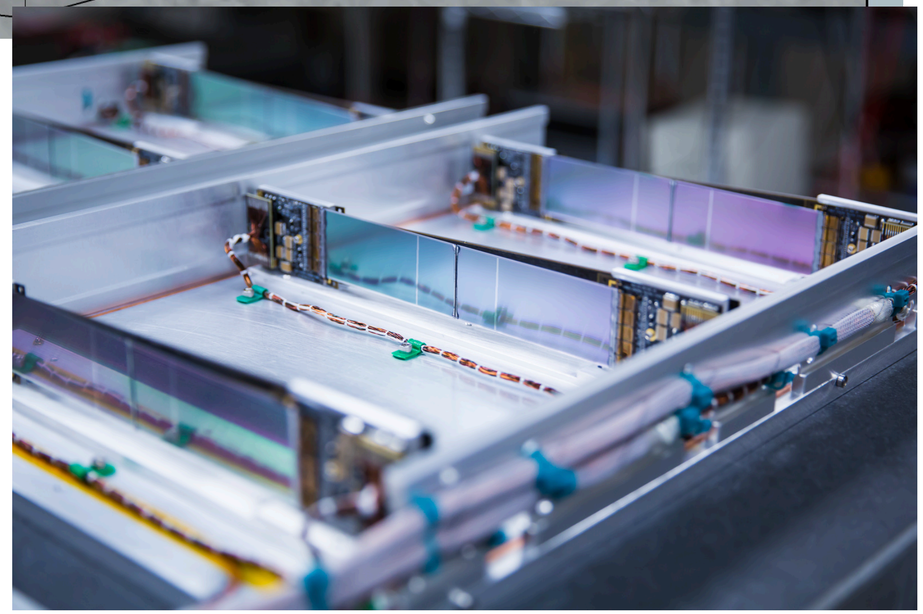
- 7 layers to identify off-energy & off-angle electrons (tagger)
- 6 layers to measure recoiling electron momentum (recoil)







Tracker based off of the HPS vertex detector "powered" by APV25 chip



Missing energy trigger

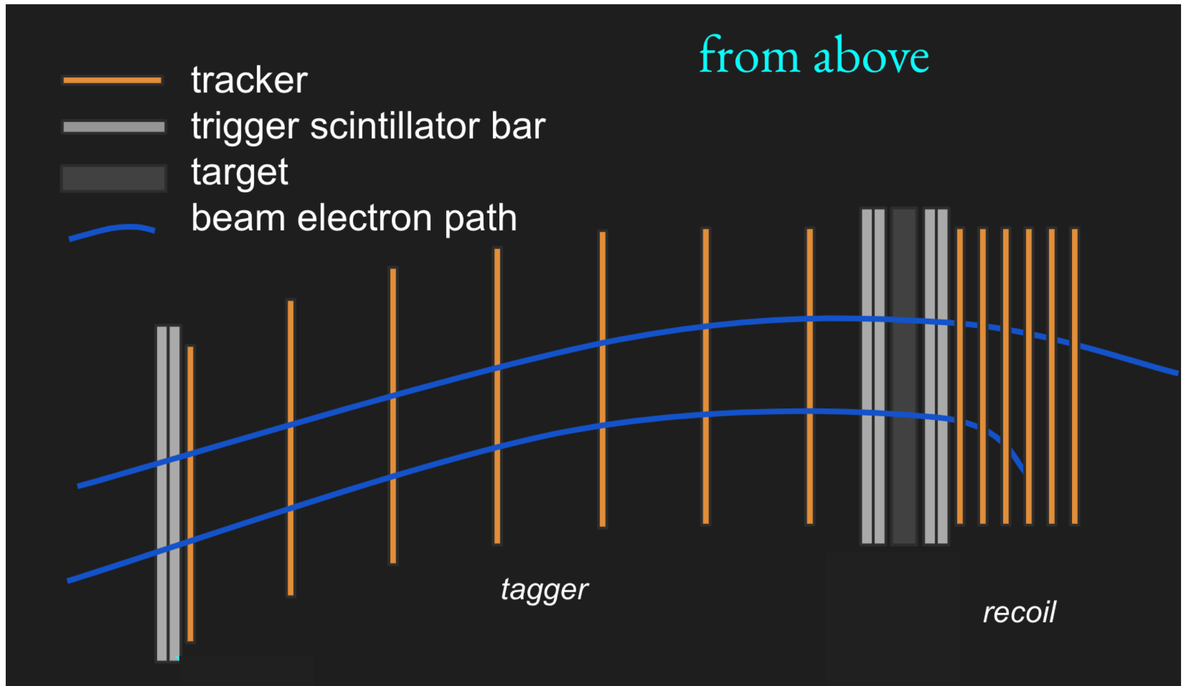
- Missing energy will be computed as: $E_{miss} = n_e E_{beam} - E_{EM}$

  E_{EM}: energy constructed by electromagnetic calorimeter

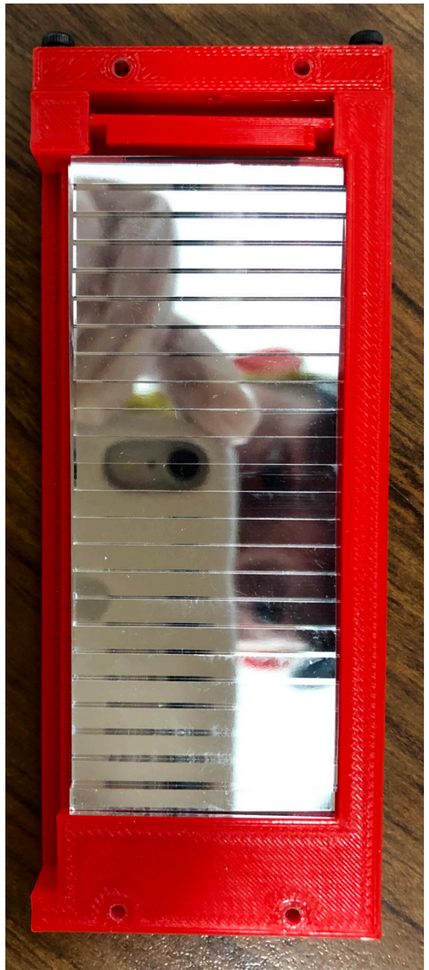
  E_{beam}: Nominal energy of beam electrons

  n_e: number of beam electrons in time sample

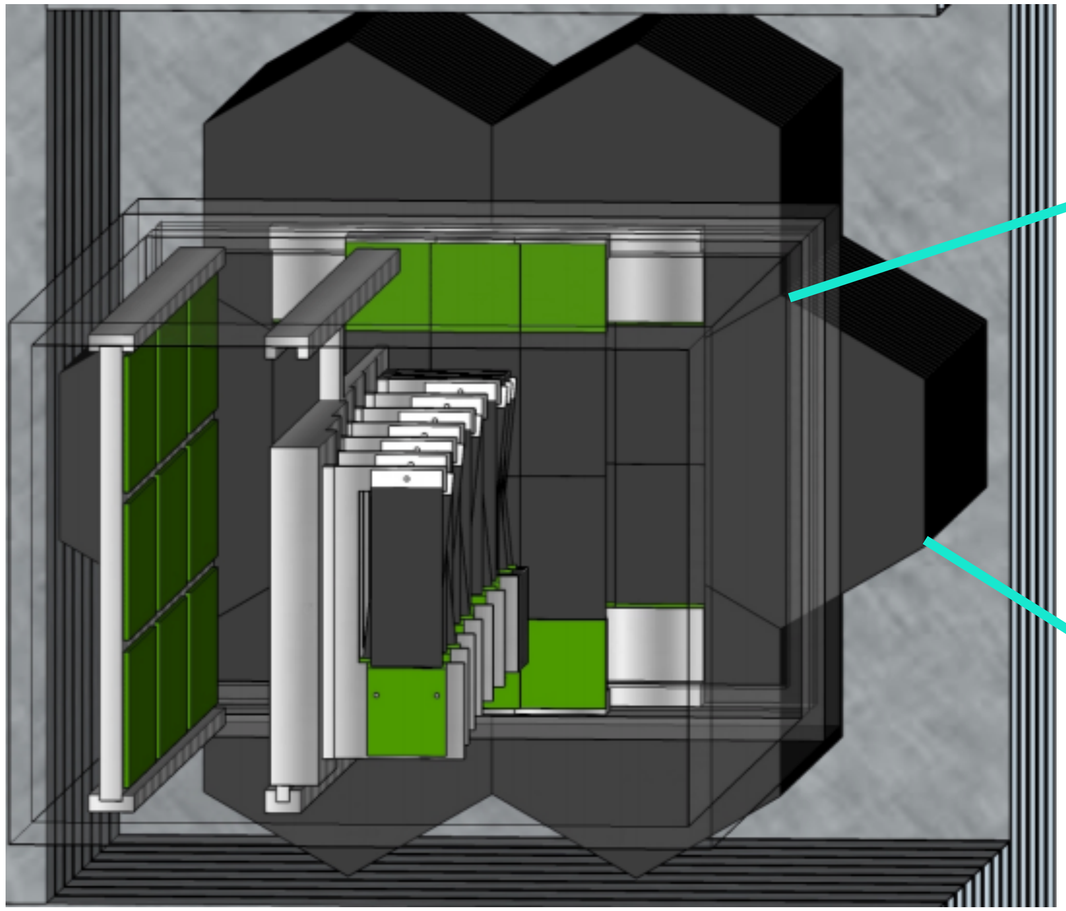
- Beam will vary in a poisson-like distribution
  - Will rely on a fast scintillator-based detectors to count beam electrons

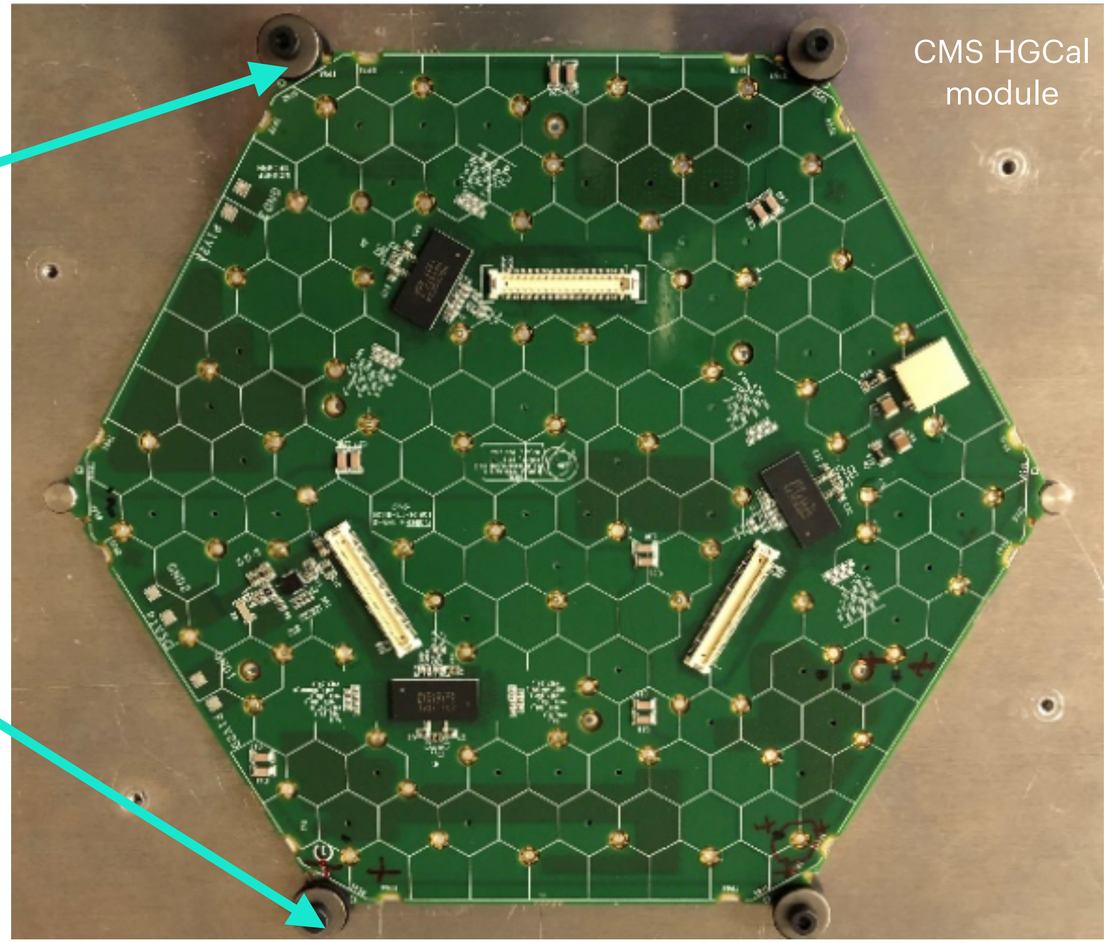


Front view



Electromagnetic calorimeter





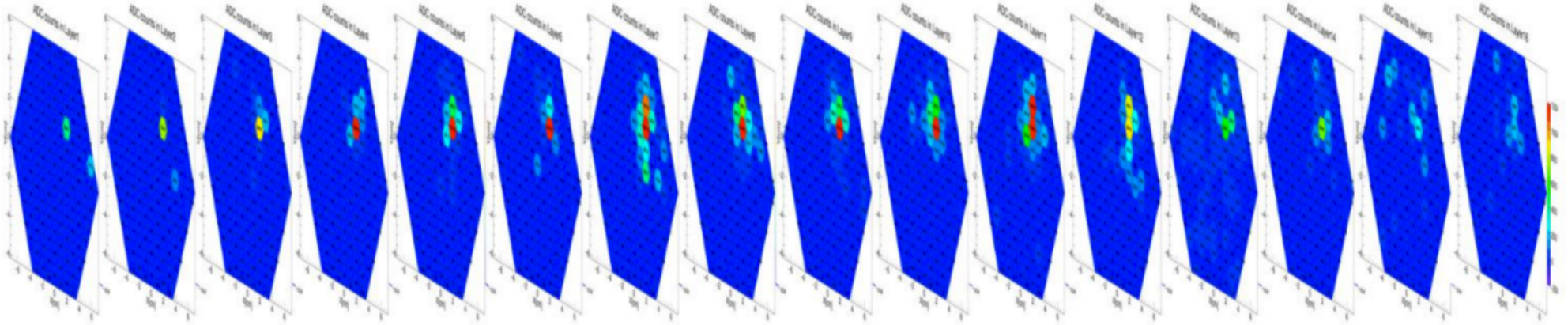
Silicon-tungsten sampling calorimeter
highly granular in the transverse & longitudinal direction
Good energy resolution
Single MIP sensitivity
~40 X_0

CMS test beam performance

e^-

32 GeV

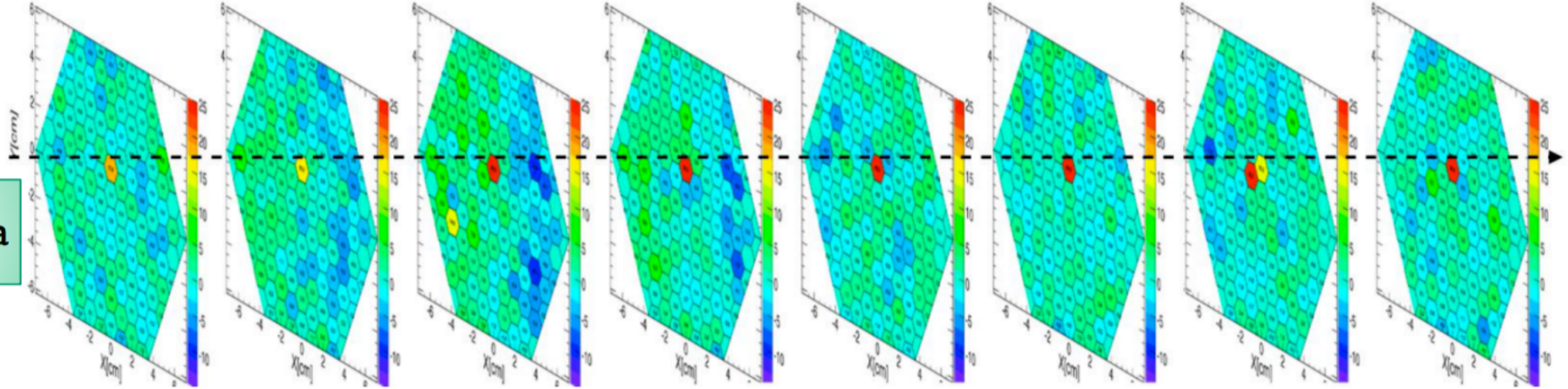
FNAL TB Data



$0.6X_0$ $2.8X_0$ $5.1X_0$ $10.1X_0$ $15.3X_0$

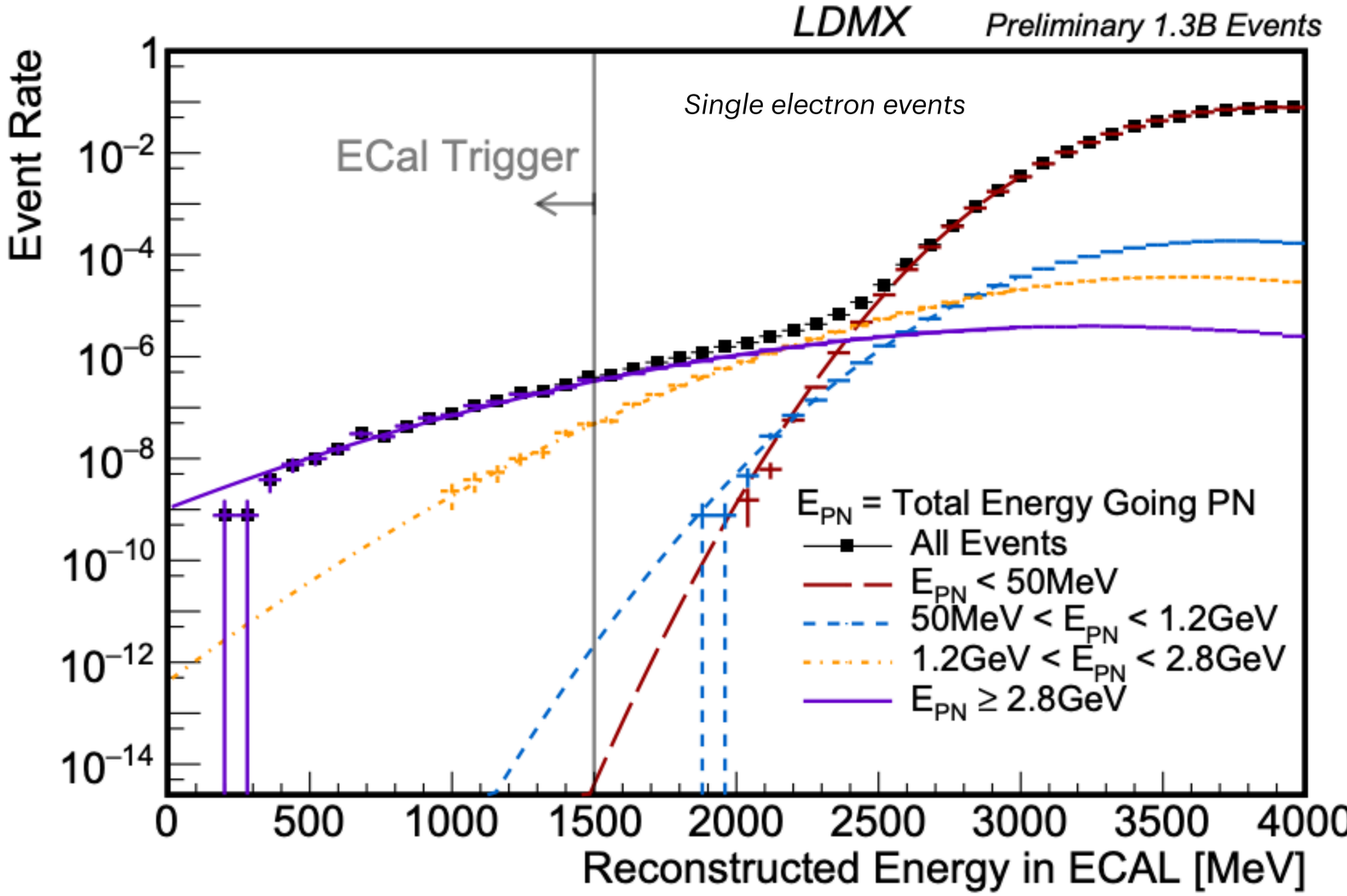
μ^-

CERN TB Data

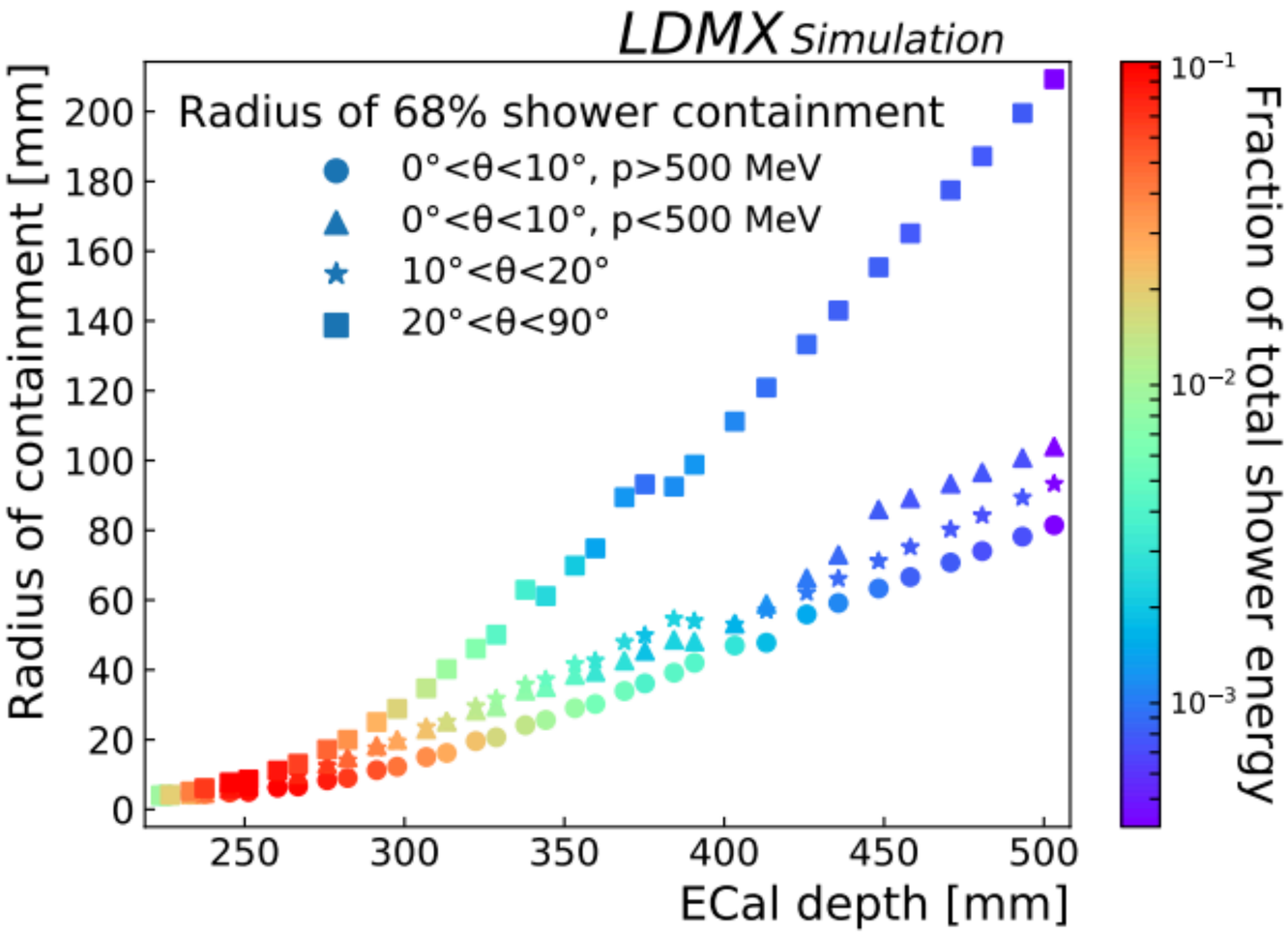


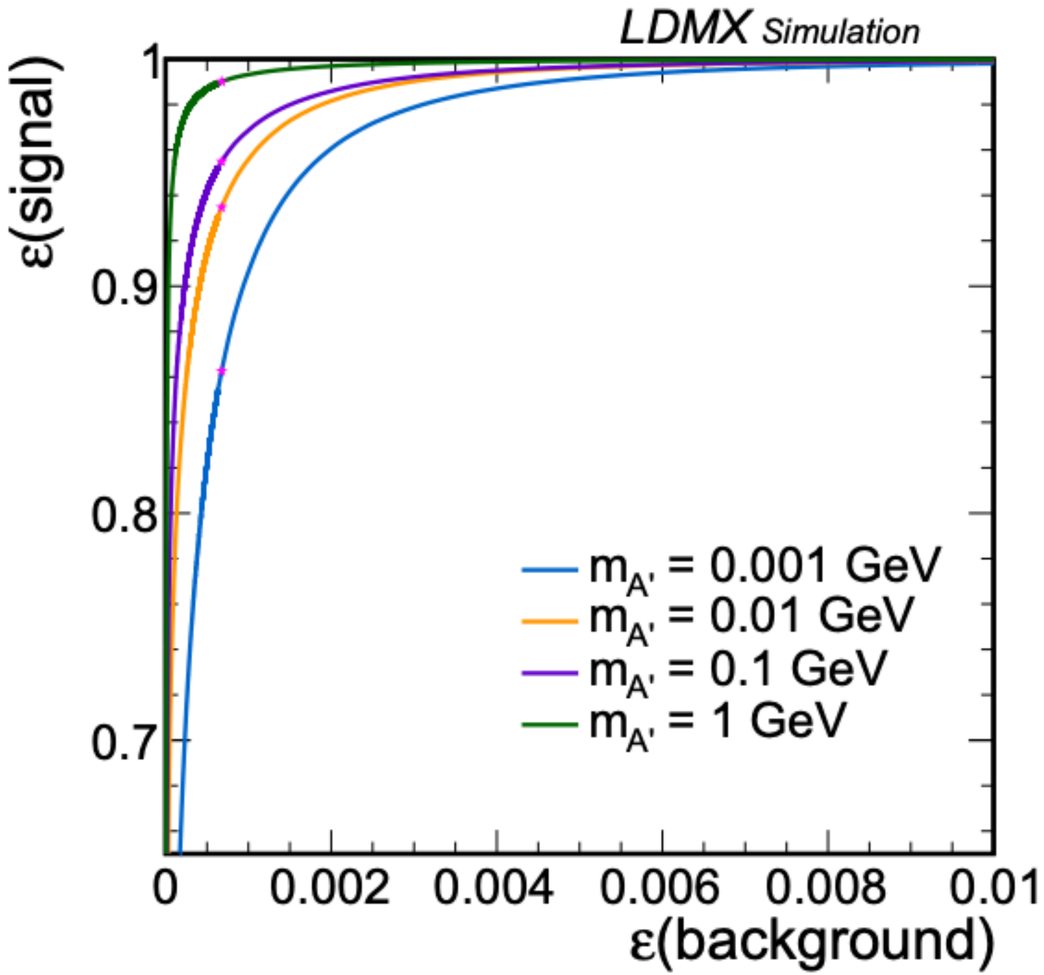
EM energy reconstruction

- ECal does well at removing the tails of “pure” EM showers
- More is needed to identify more insidious backgrounds from photo-nuclear reactions



Pattern recognition

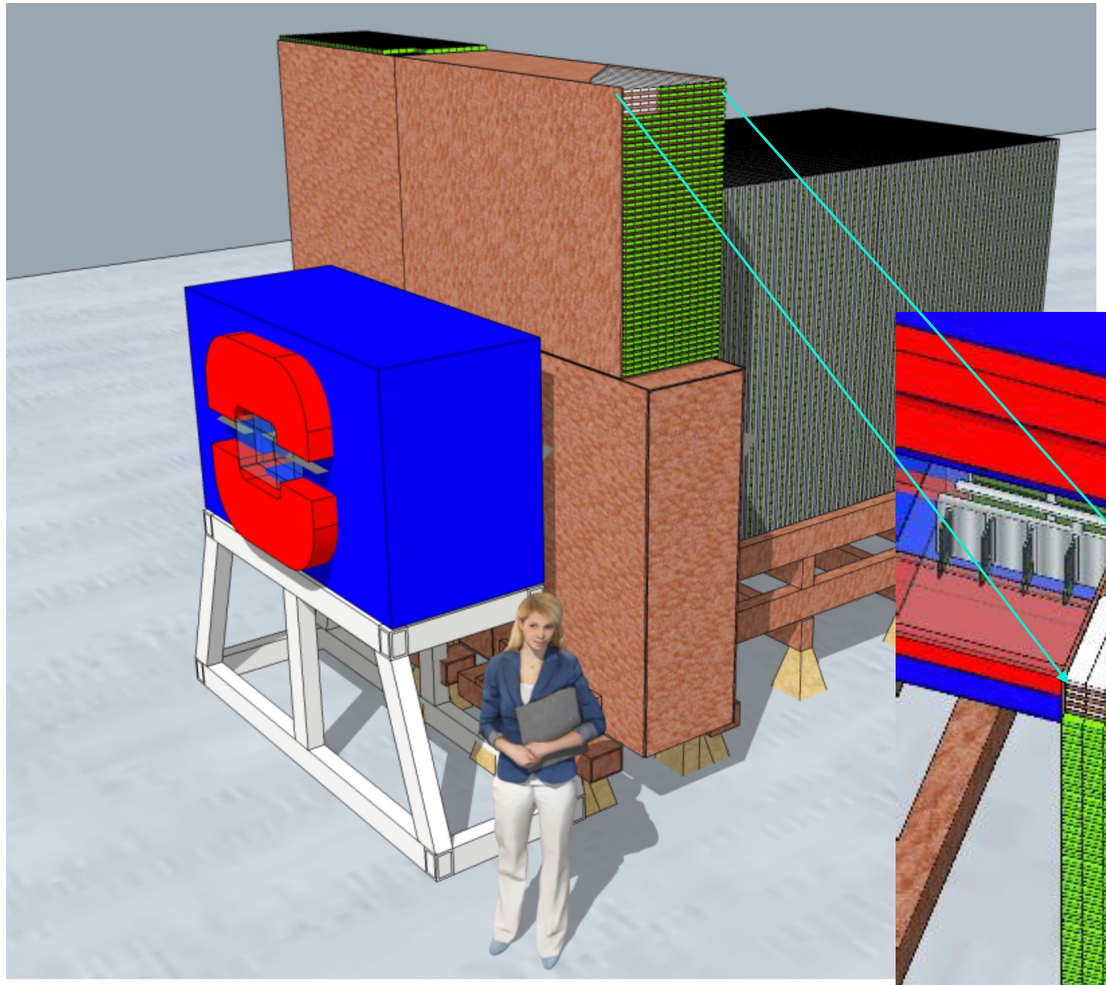


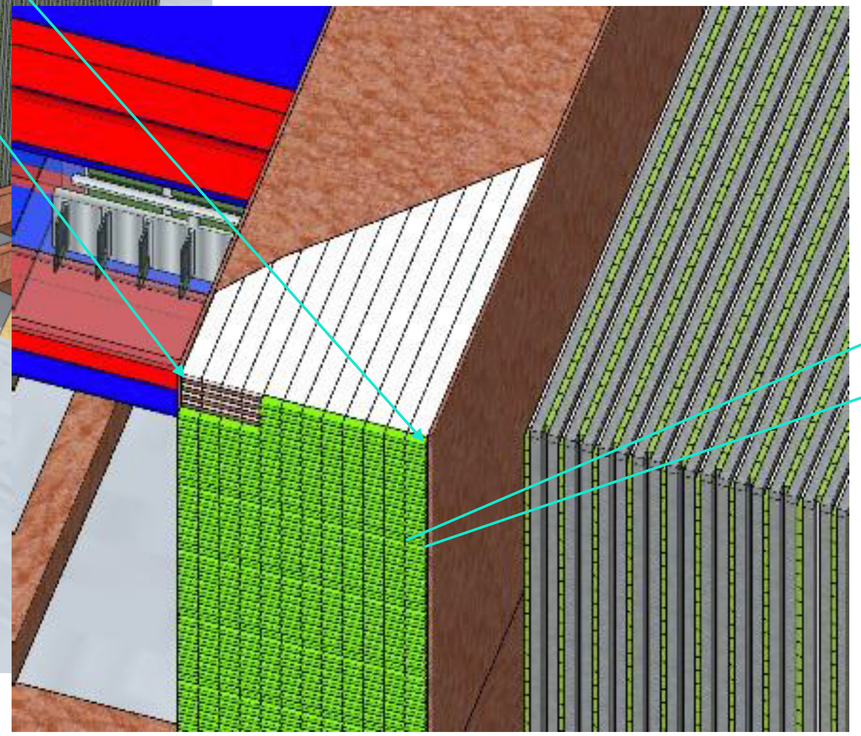


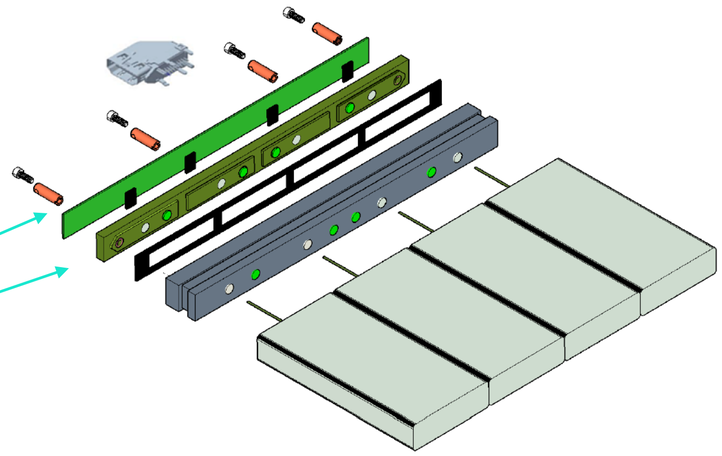
Hadronic calorimeter

Steel/plastic sampling calorimeter

- read out with wavelength shifting fibers & SiPMs
- encloses ECal as much as possible to detect:
  - wide-angle bremsstrahlung
  - hadrons from PN events



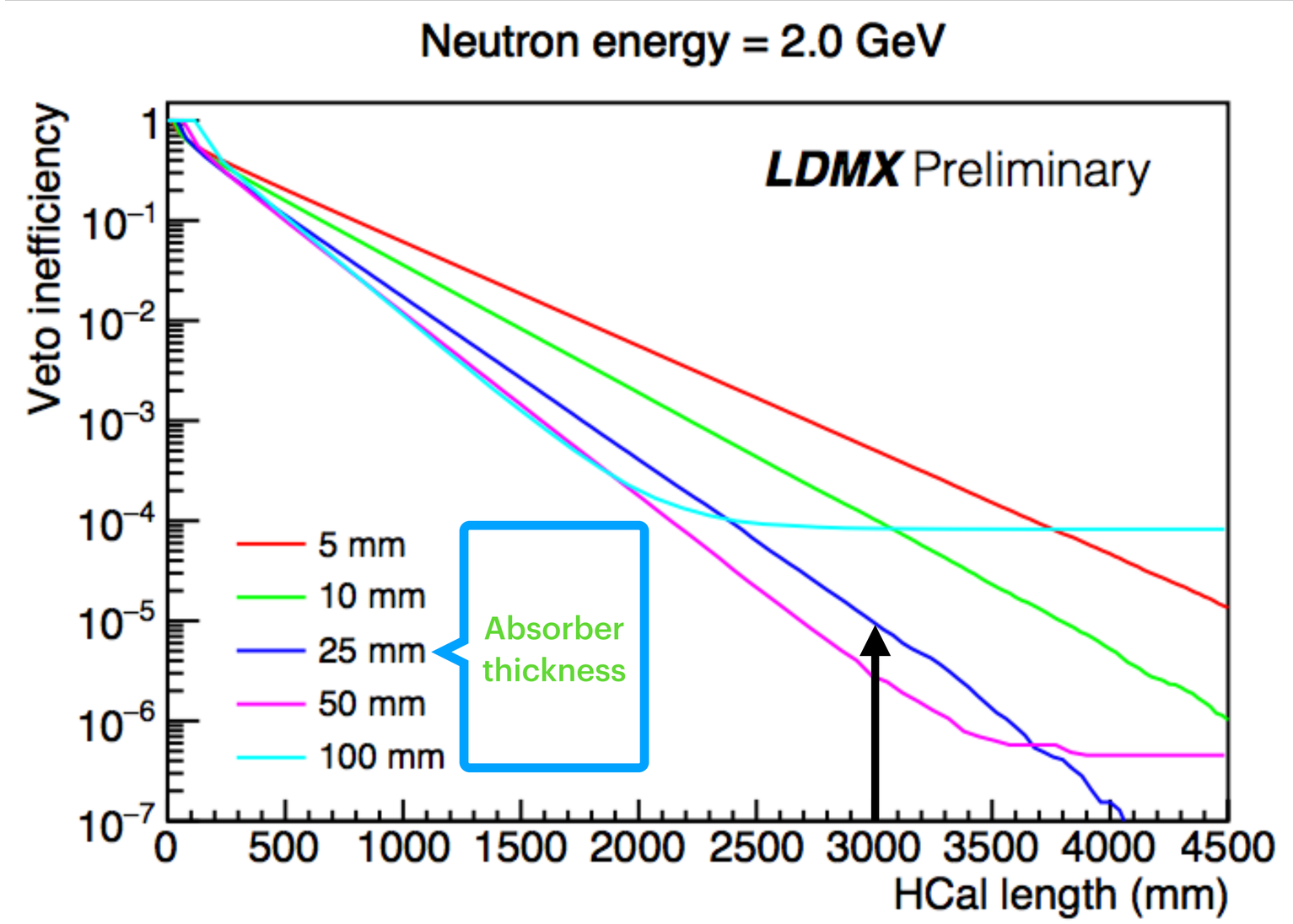




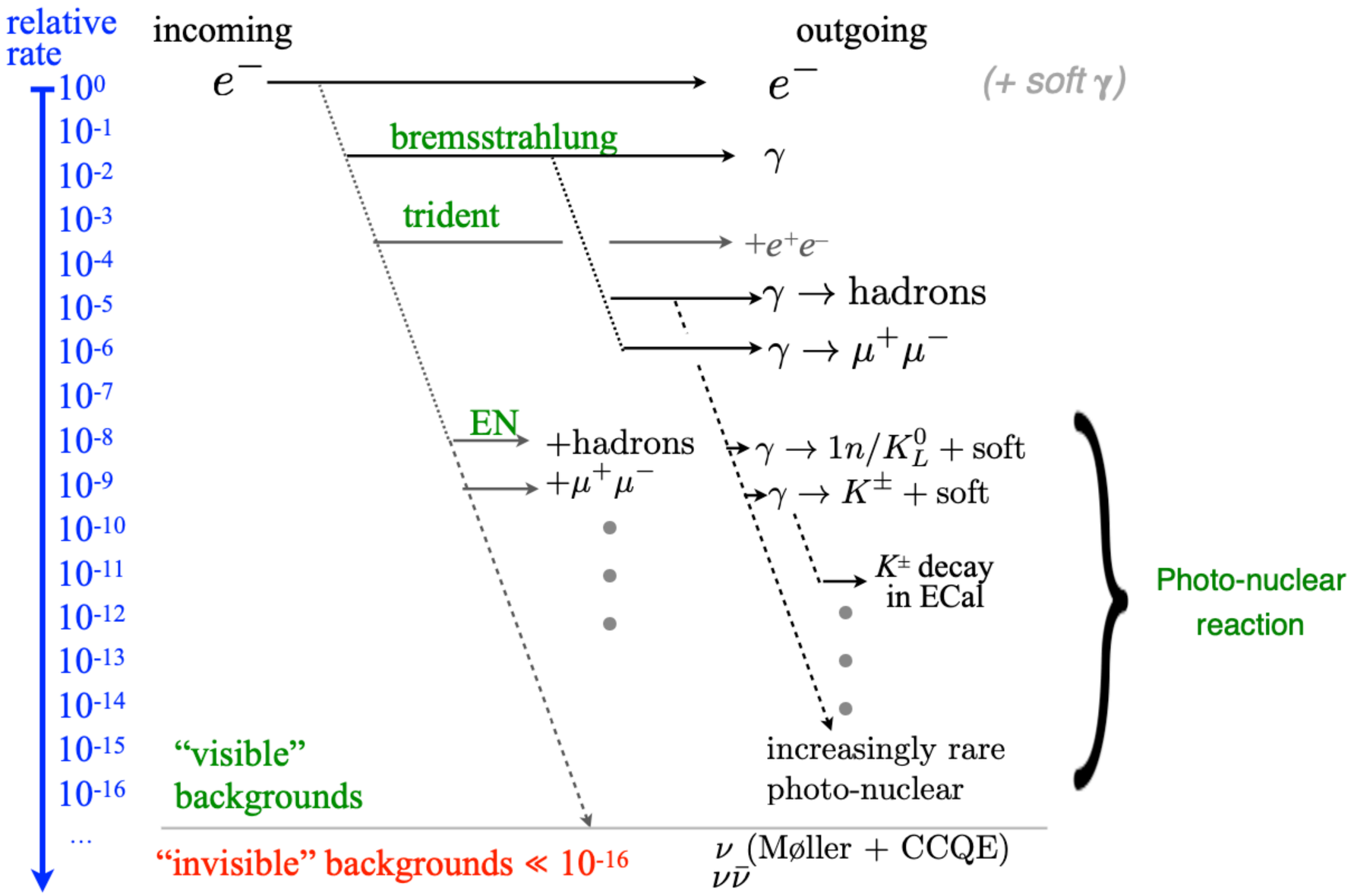
Based of of the Mu2e Cosmic Ray Veto

Hadron calorimeter veto

- MIP response in scintillator is ~80 PEs
- We veto events in which the maximum amplitude in any bar is >5 PEs
- Neutron veto performance drives to depth of the calorimeter



Backgrounds



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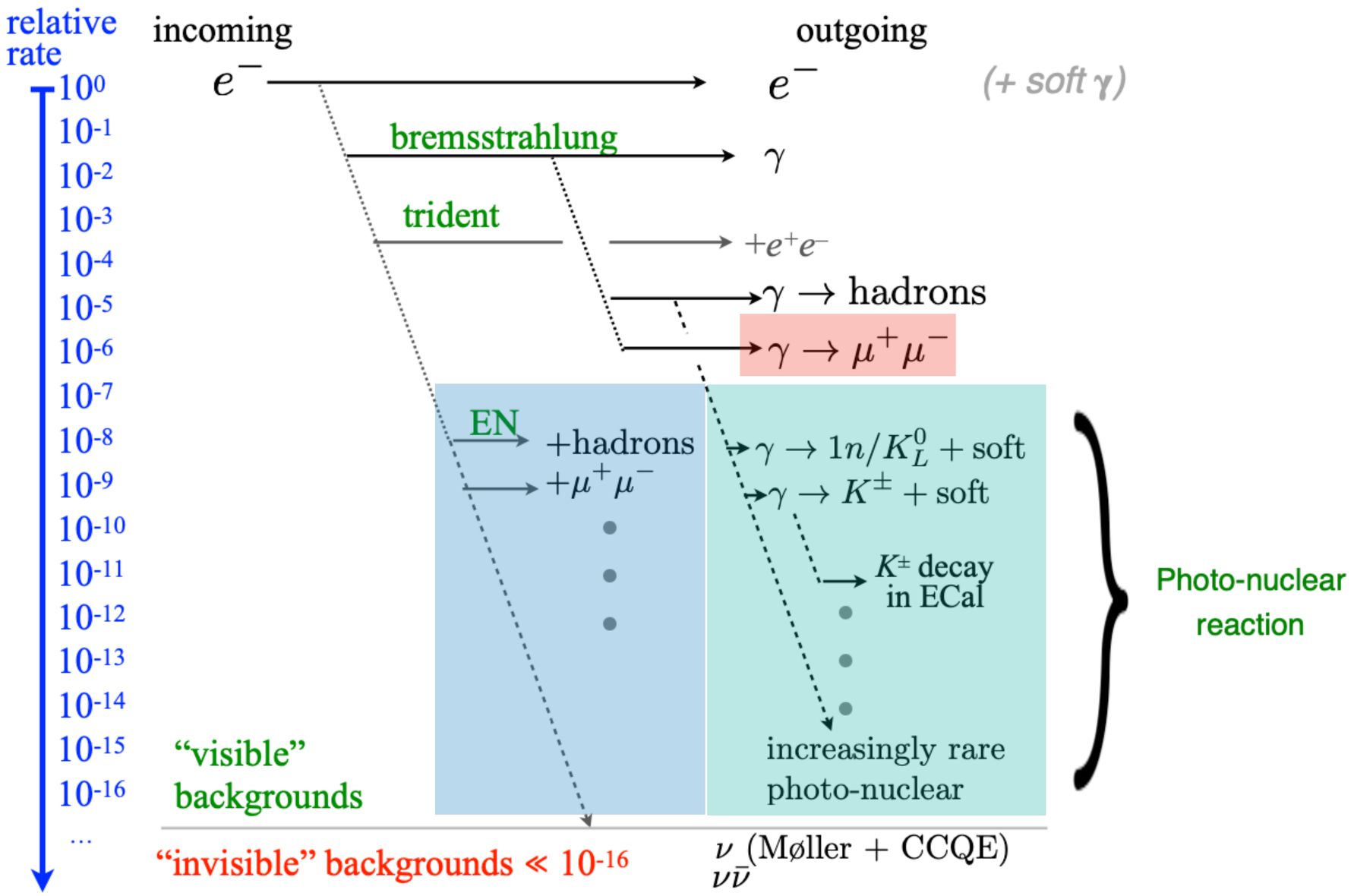
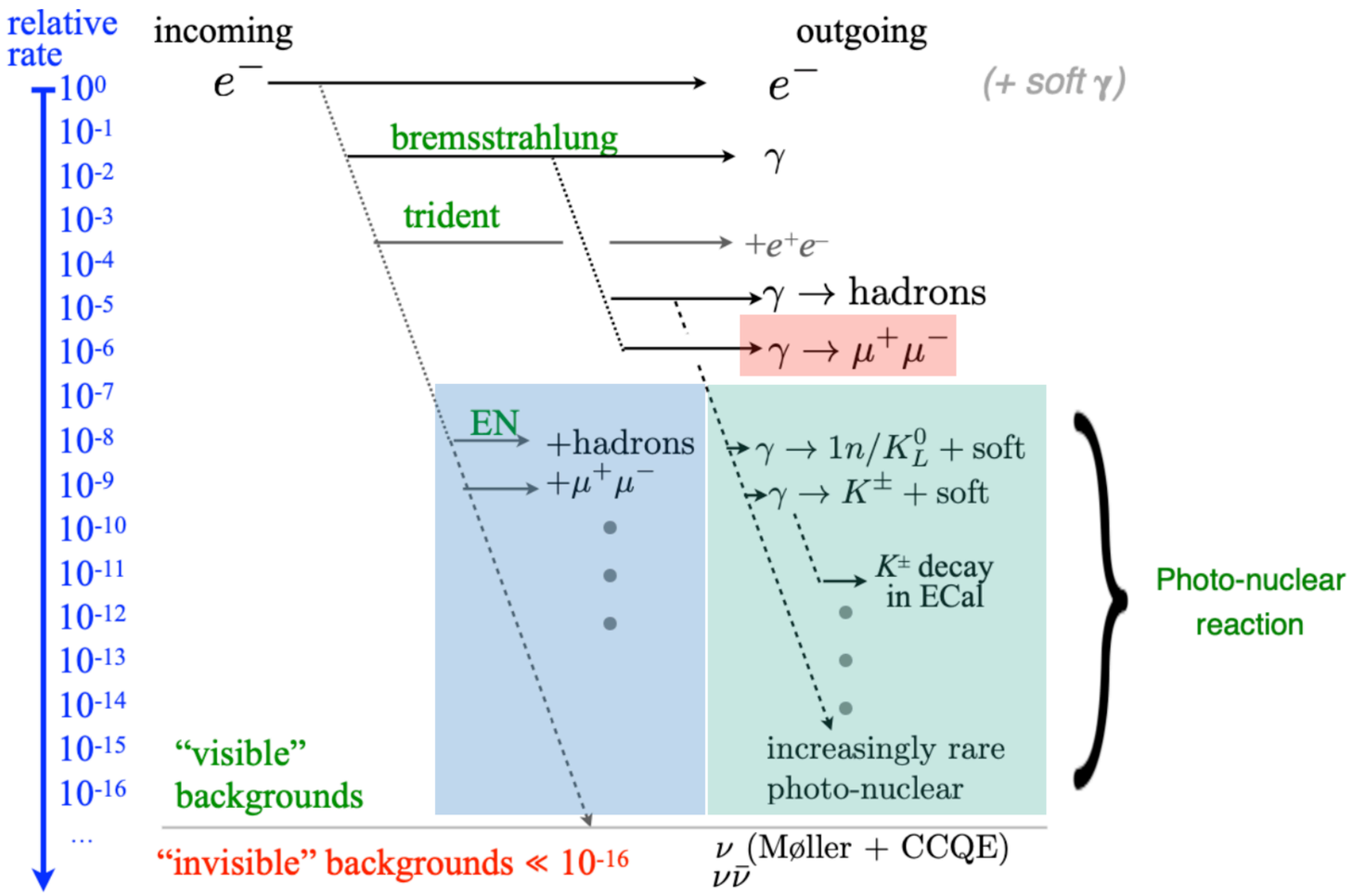
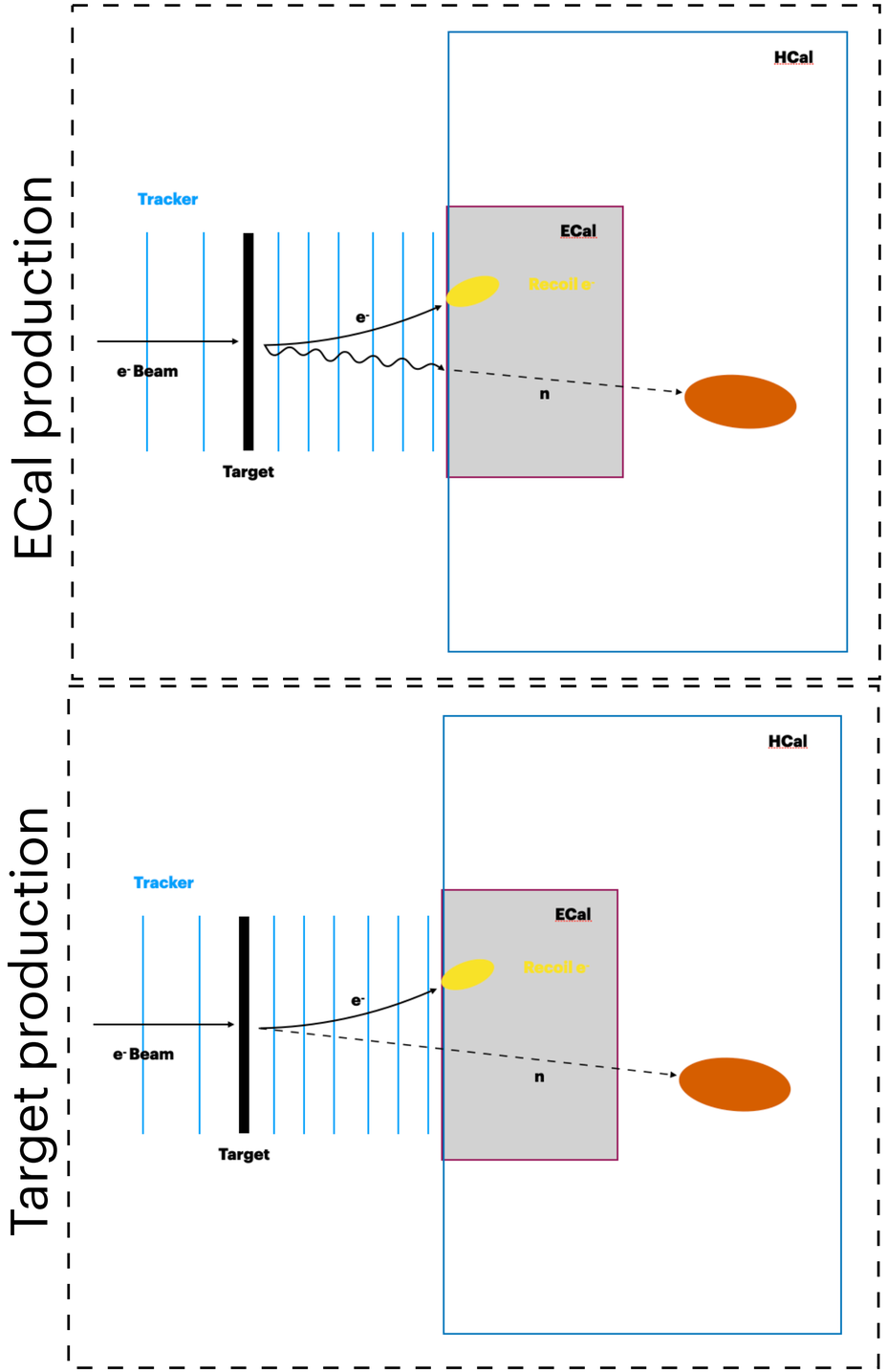
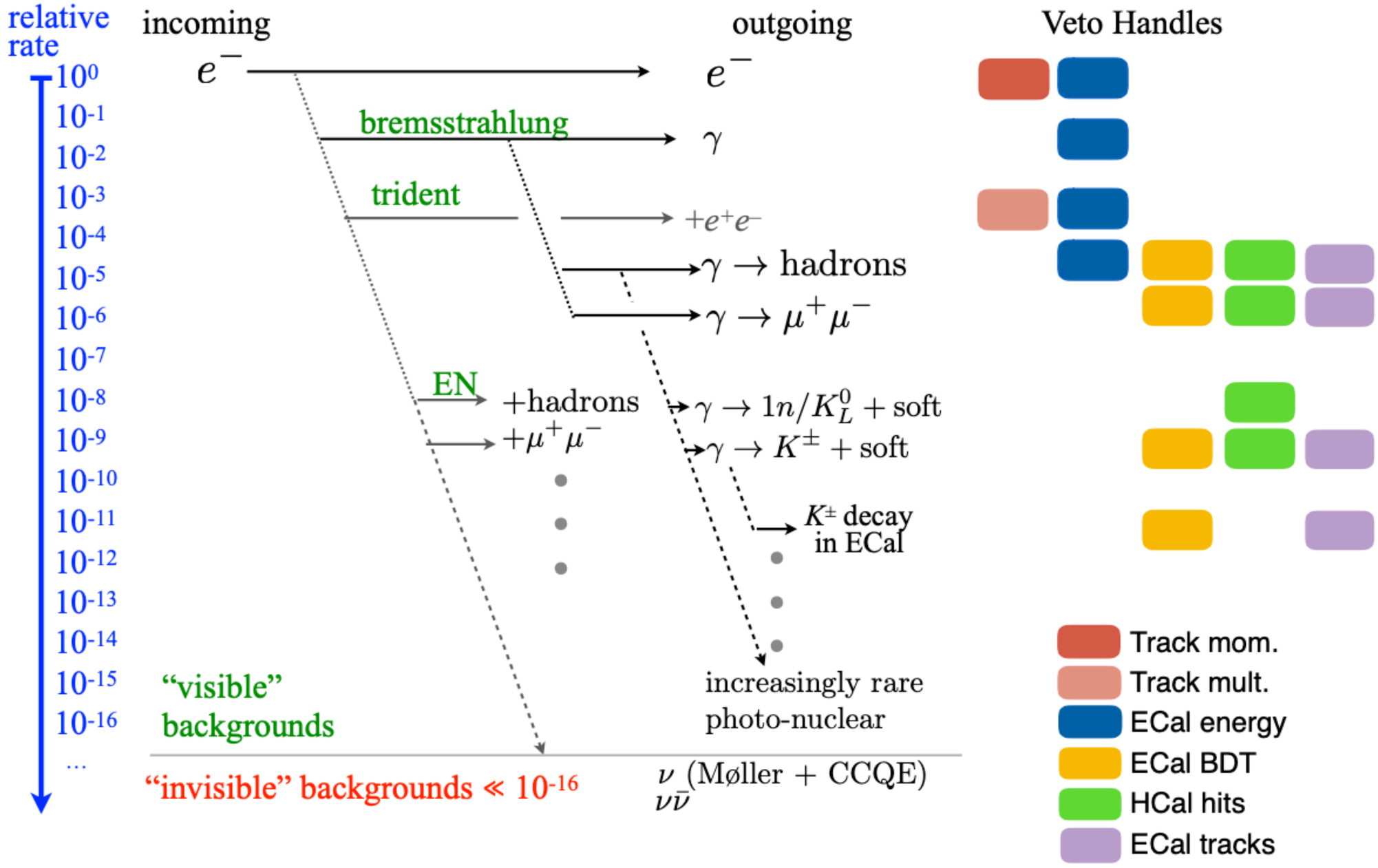


Backgrounds

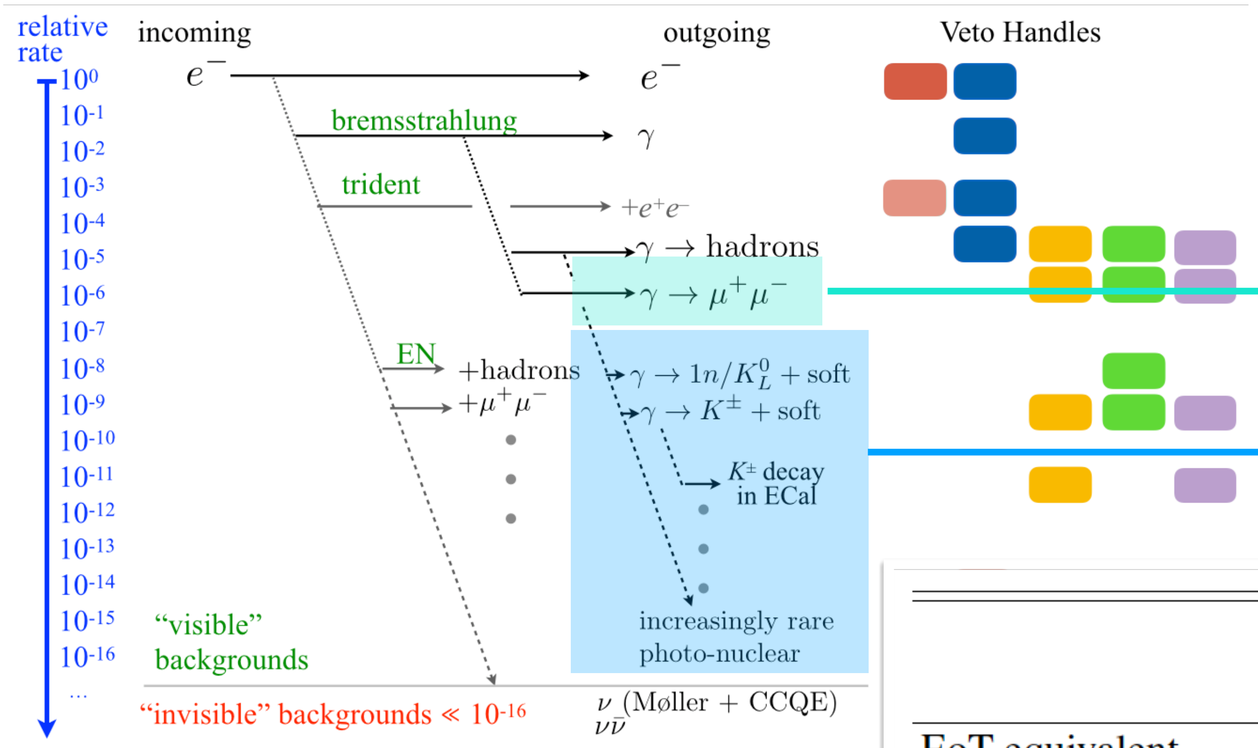




Background redux



PN background rejection



Recent work exploring high-statistics MC samples & background veto performance: *https://arxiv.org/abs/1912.05535*

	Photo-nuclear		Muon conversion	
	Target-area	ECal	Target-area	ECal
EoT equivalent	4×10^{14}	2.1×10^{14}	8.2×10^{14}	2.4×10^{15}
Total events simulated	8.8×10^{11}	4.65×10^{11}	6.27×10^{8}	8×10^{10}
Trigger, ECal total energy < 1.5 GeV	1×10^{8}	2.63×10^{8}	1.6×10^{7}	1.6×10^{8}
Single track with $p < 1.2$ GeV	2×10^{7}	2.34×10^{8}	3.1×10^{4}	1.5×10^{8}
ECal BDT (> 0.99)	9.4×10^{5}	1.32×10^{5}	< 1	< 1
HCal max PE < 5	< 1	10	< 1	< 1
ECal MIP tracks = 0	< 1	< 1	< 1	< 1

Integrated background veto performance

]

PN background rejection

Integrated background veto performance

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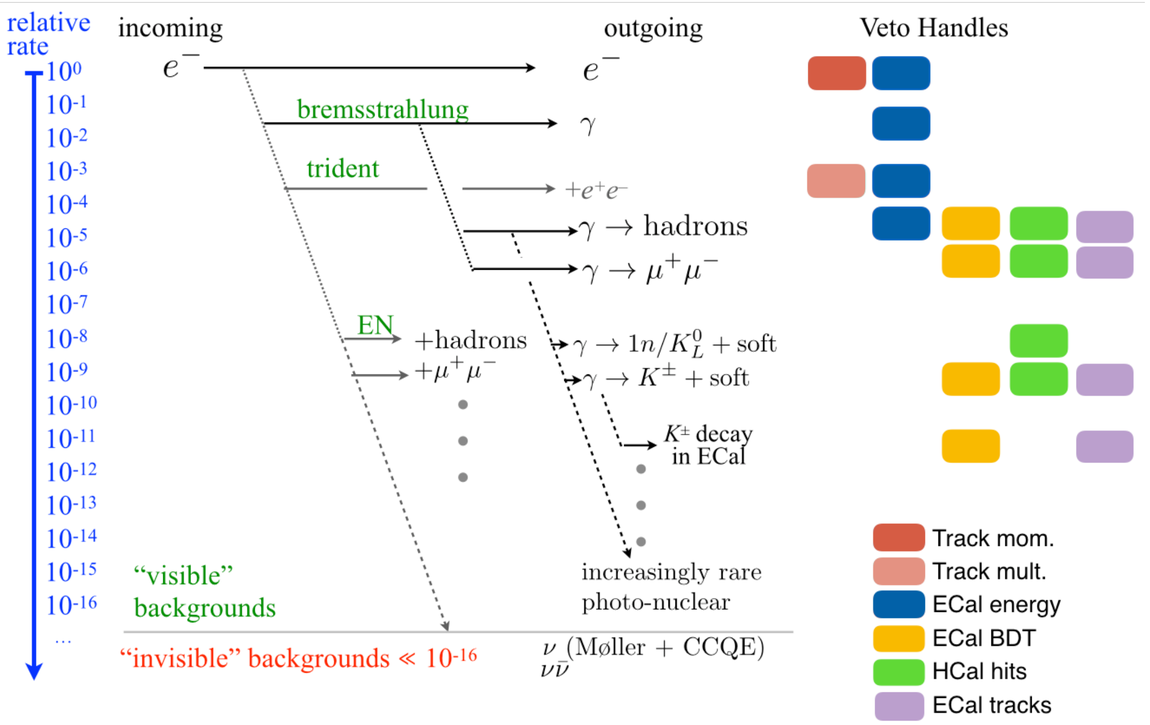
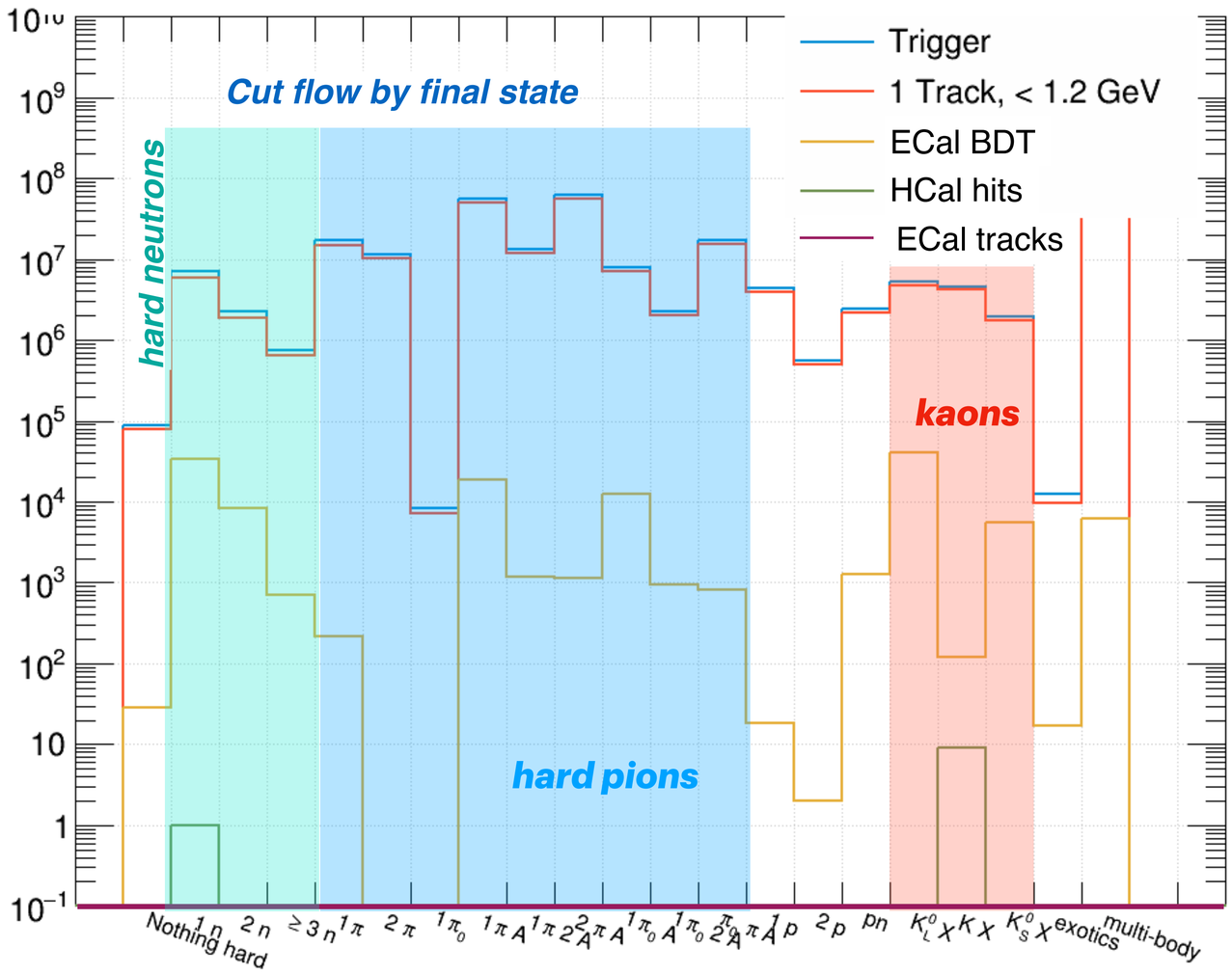
HCal max PE < 5	< 1	10	< 1	< 1
ECal MIP tracks = 0	< 1	< 1	< 1	< 1



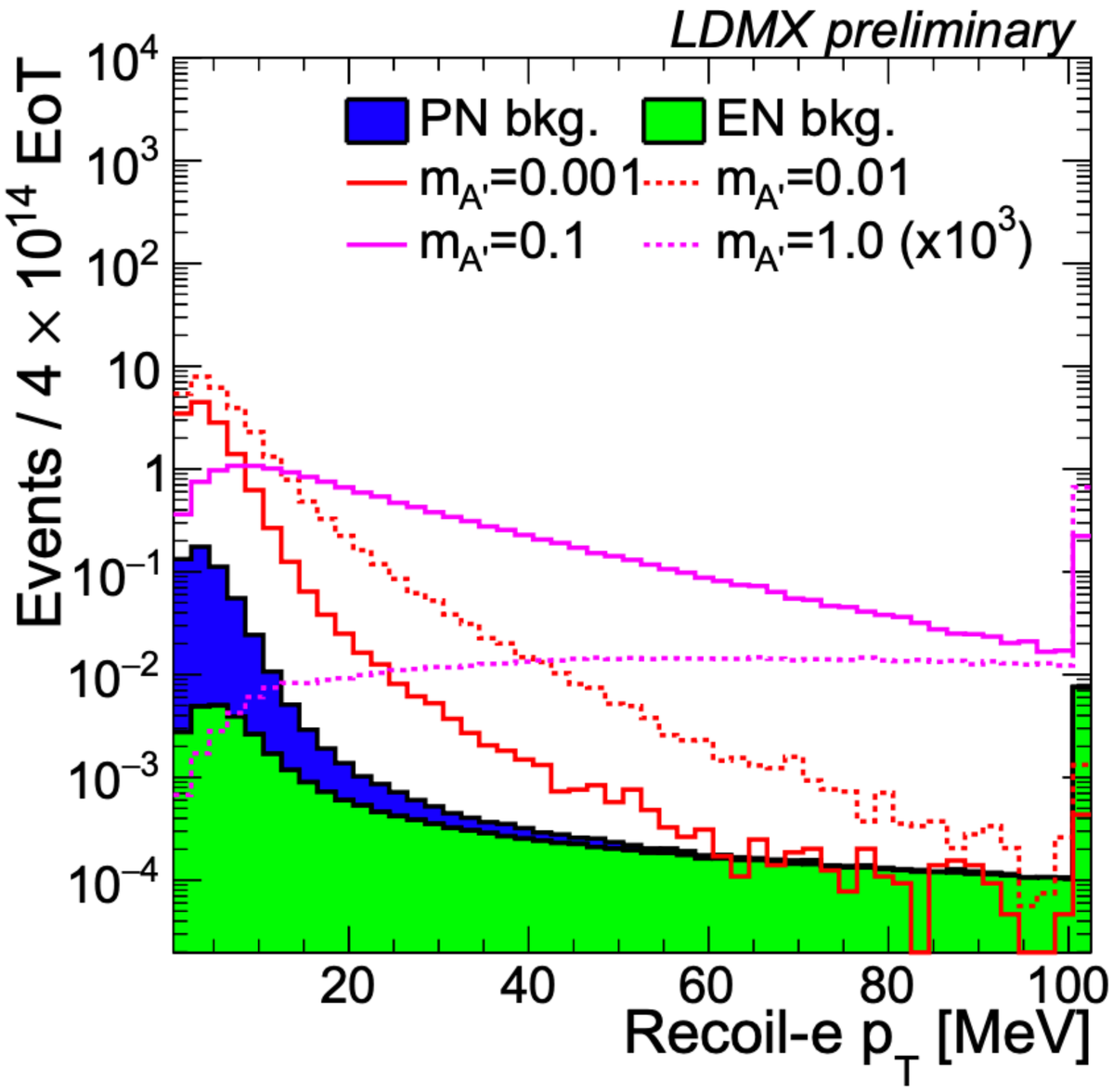


No events remain after all vetoes

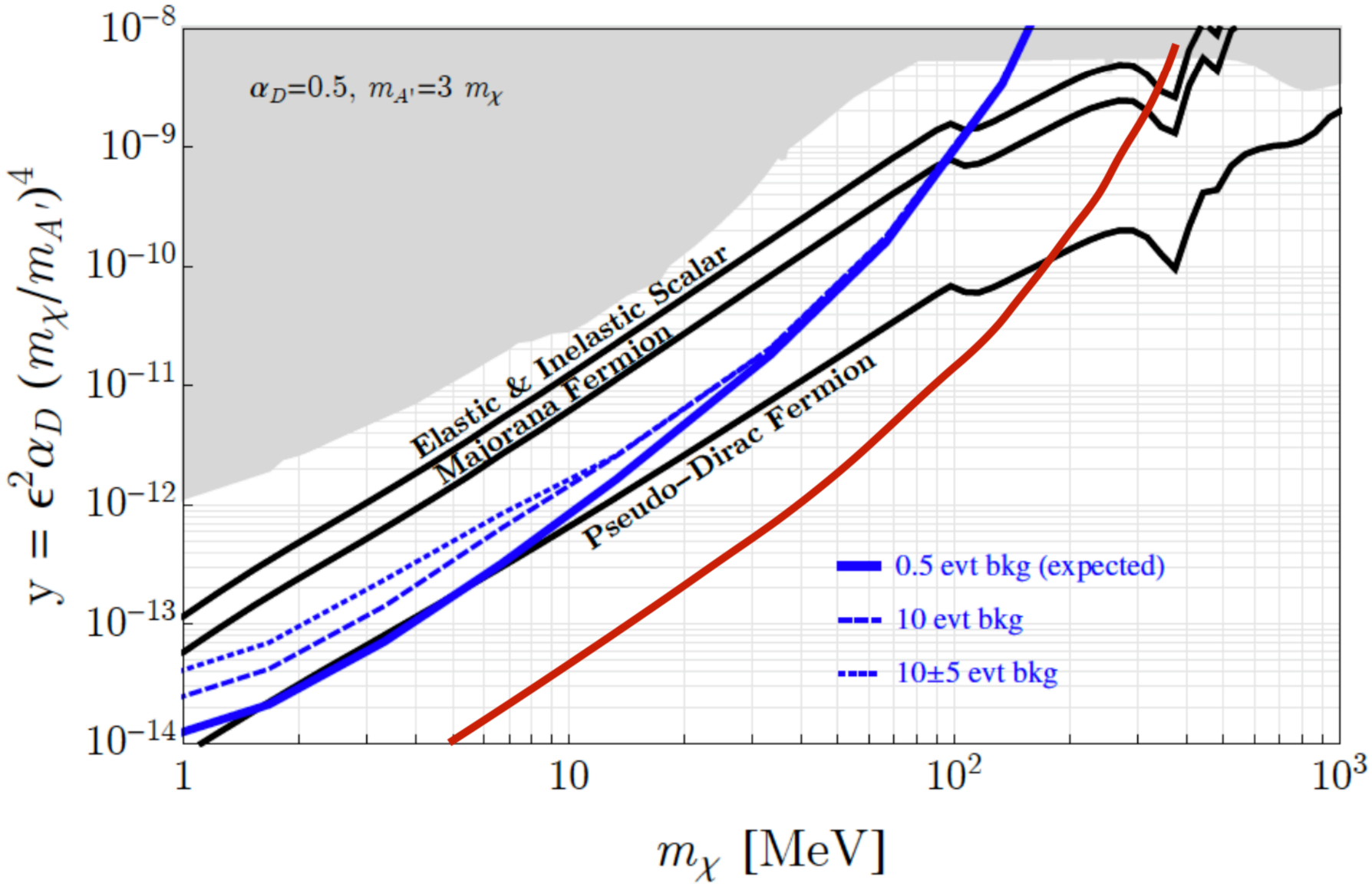
signal efficiencies range from 30-50%

Transverse momentum

- In case we find some events survive our selections, the recoiling electron's p_T is a powerful tool for further reducing backgrounds or characterizing a signal



Projected sensitivity



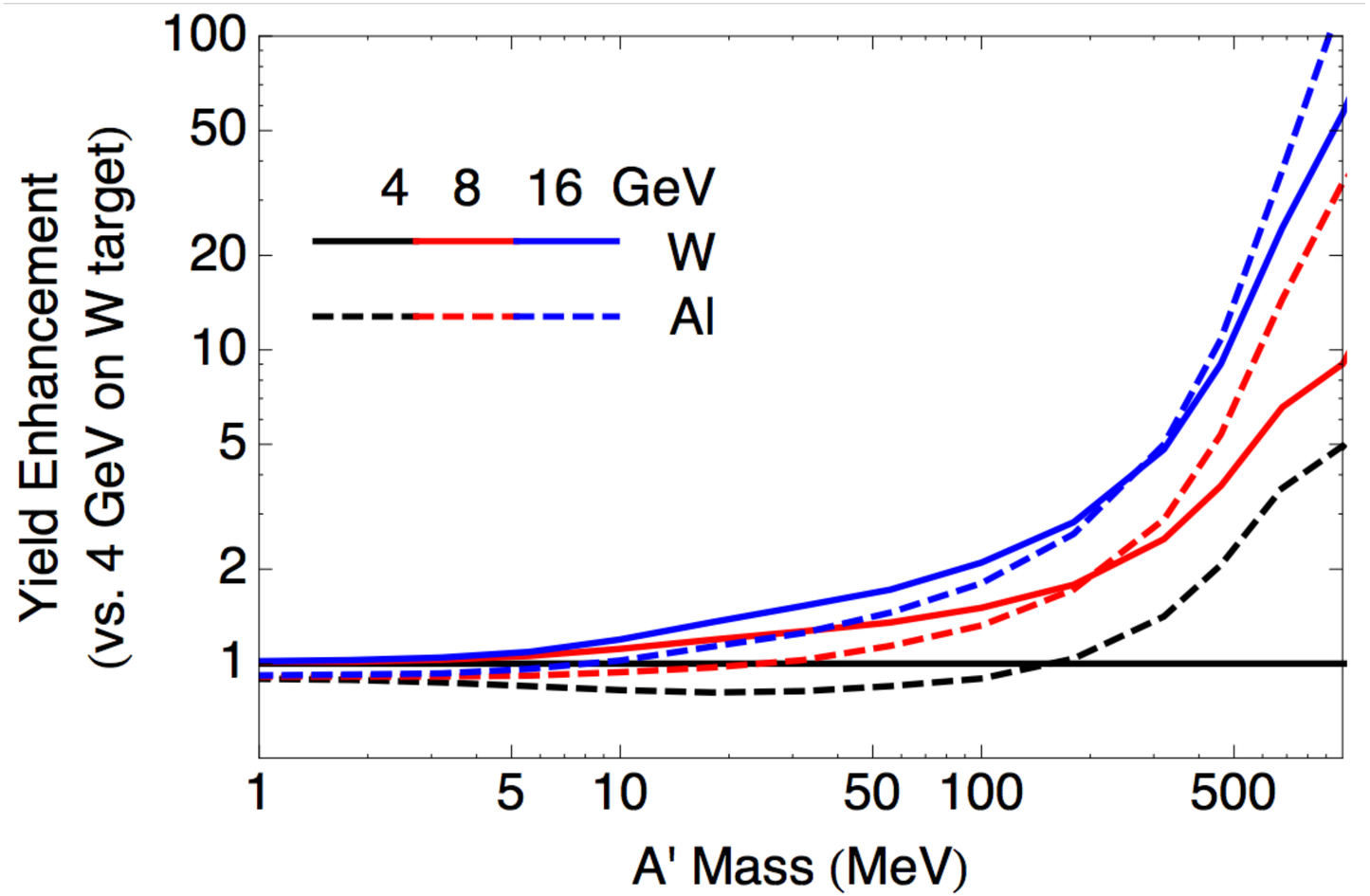
4×10^{14} EoT @ 4 GeV

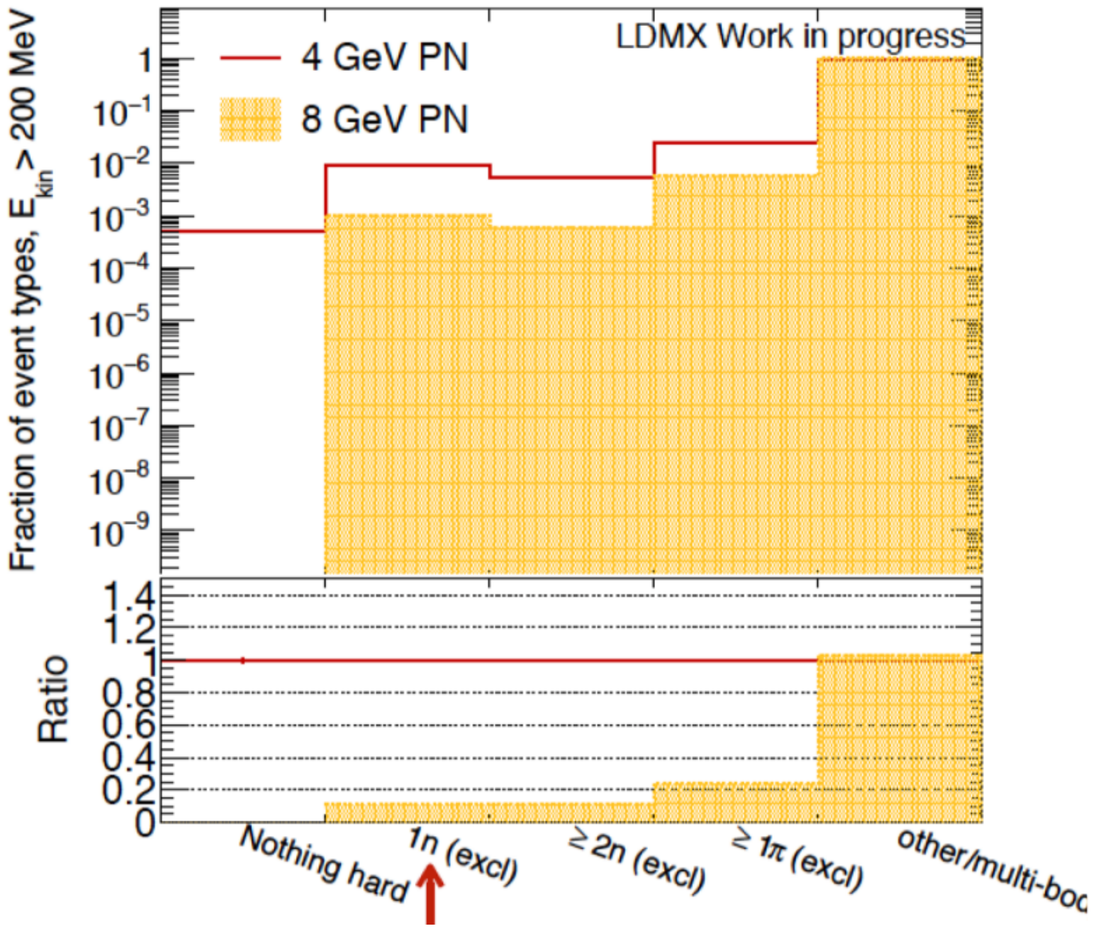
1×10^{16} EoT @ 8 GeV

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

New ideas and recent highlights

- Optimizing sensitivity to high-mass mediators
  - Higher beam energies helps with signal production & bkg rejection



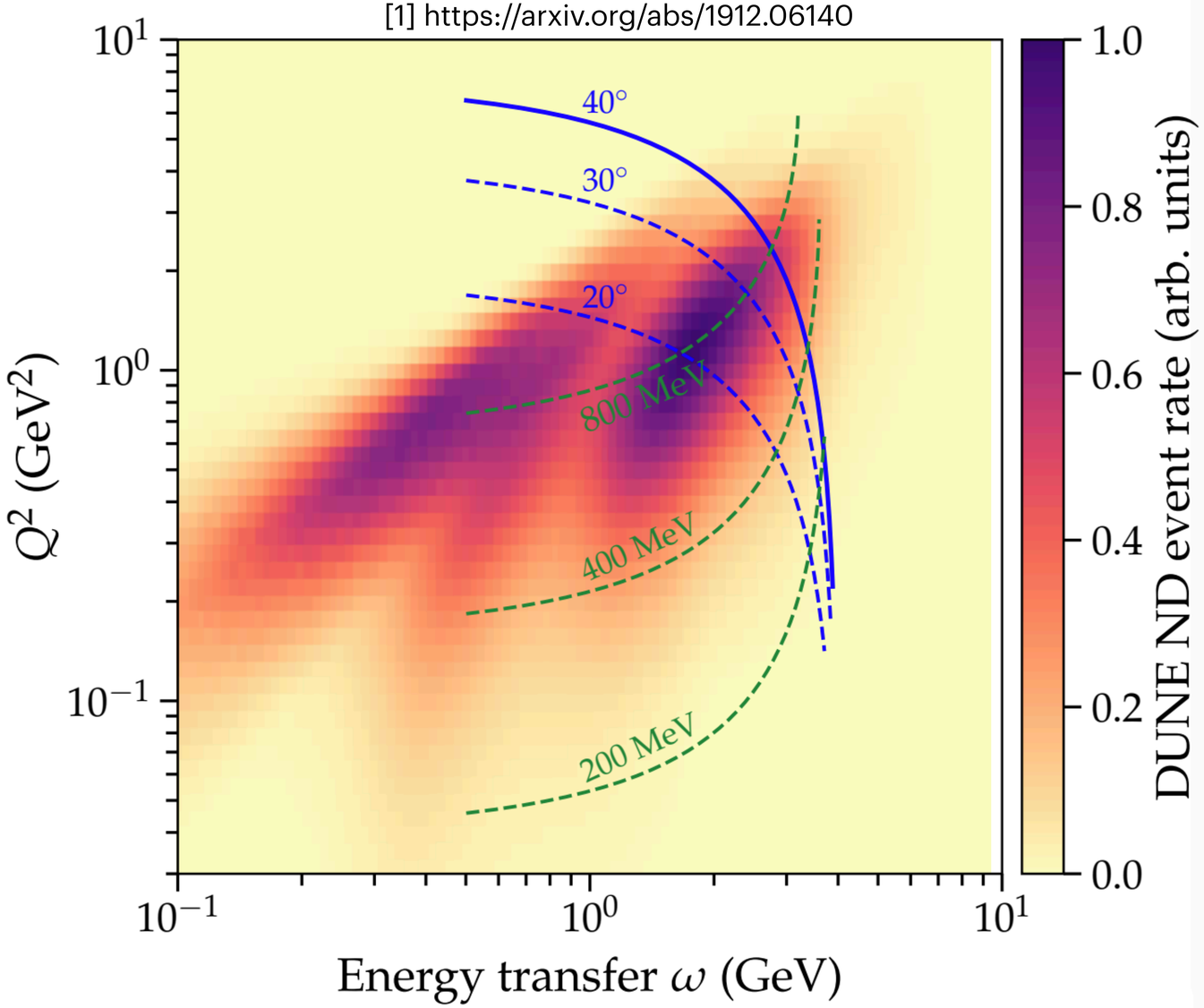


electron-nucleon cross sections

- Kinematics of LDMX overlaps with expected kinematics of DUNE

- Measuring e+N->e+X would allow generators that are developed to "model neutrino-nucleus and electron-nucleus interactions using common physics frameworks" [1]

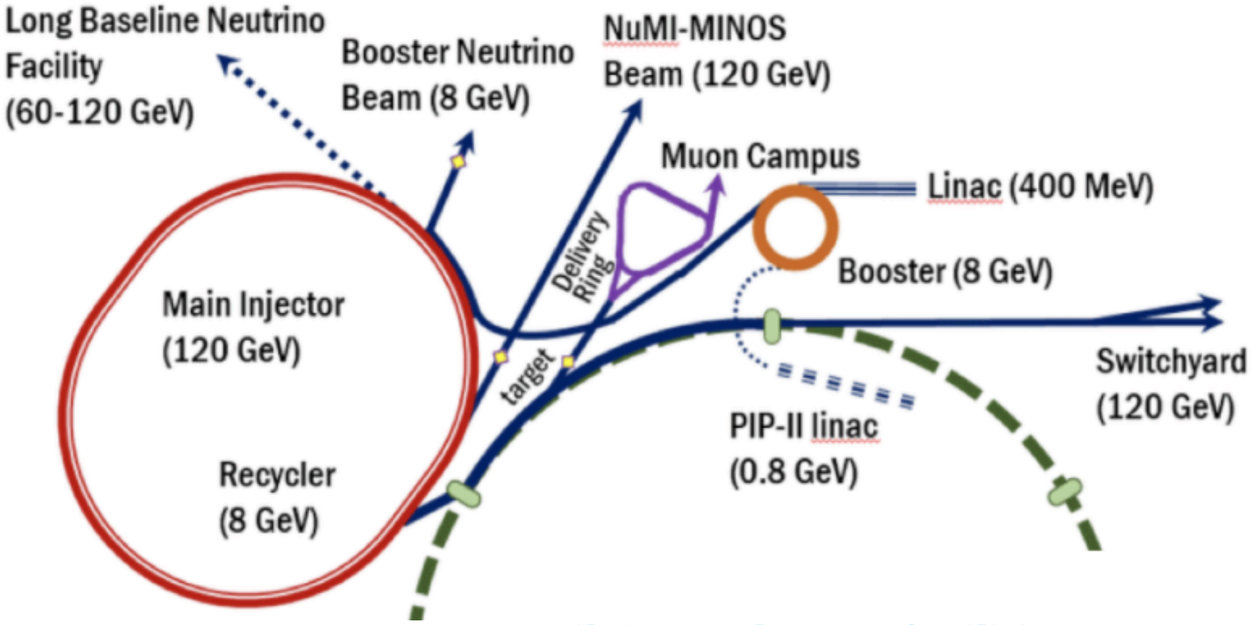
[1] https://arxiv.org/abs/1912.06140



** NOT AN LDMX ENDEAVOR

https://arxiv.org/pdf/1804.03144.pdf

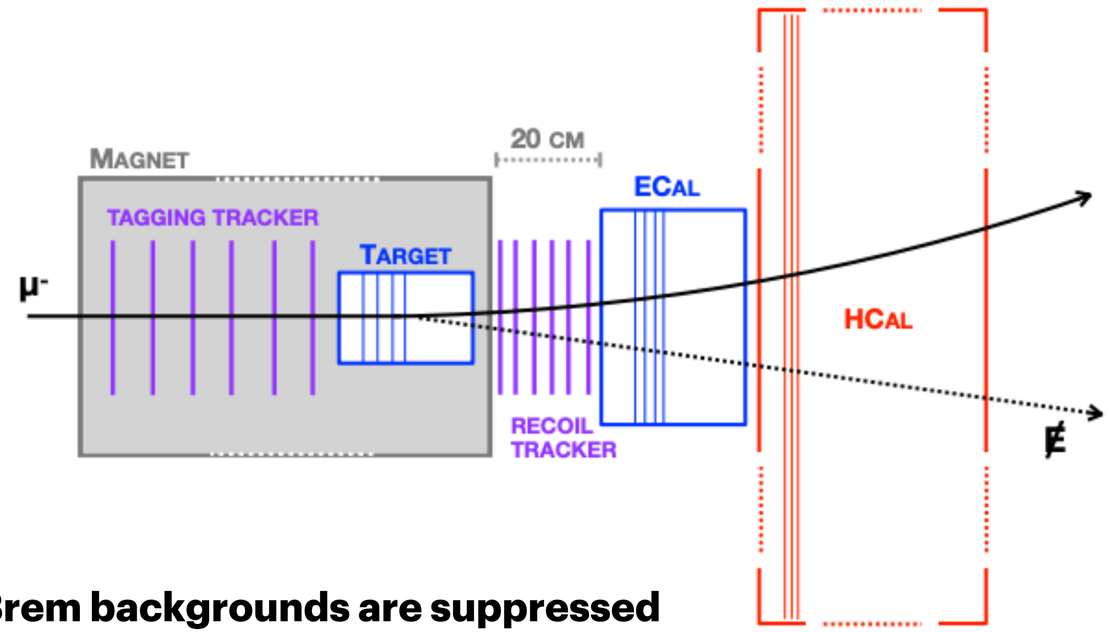
Muon-philic physics



Fermilab accelerator facilities

Can achieve 10^{10} MOT in O(months) : Phase 1
Can achieve 10^{13} MOT in O(years): Phase 2

Muon Misssing Momentum (M^3) experiment



Brem backgrounds are suppressed by m_e/m_μ

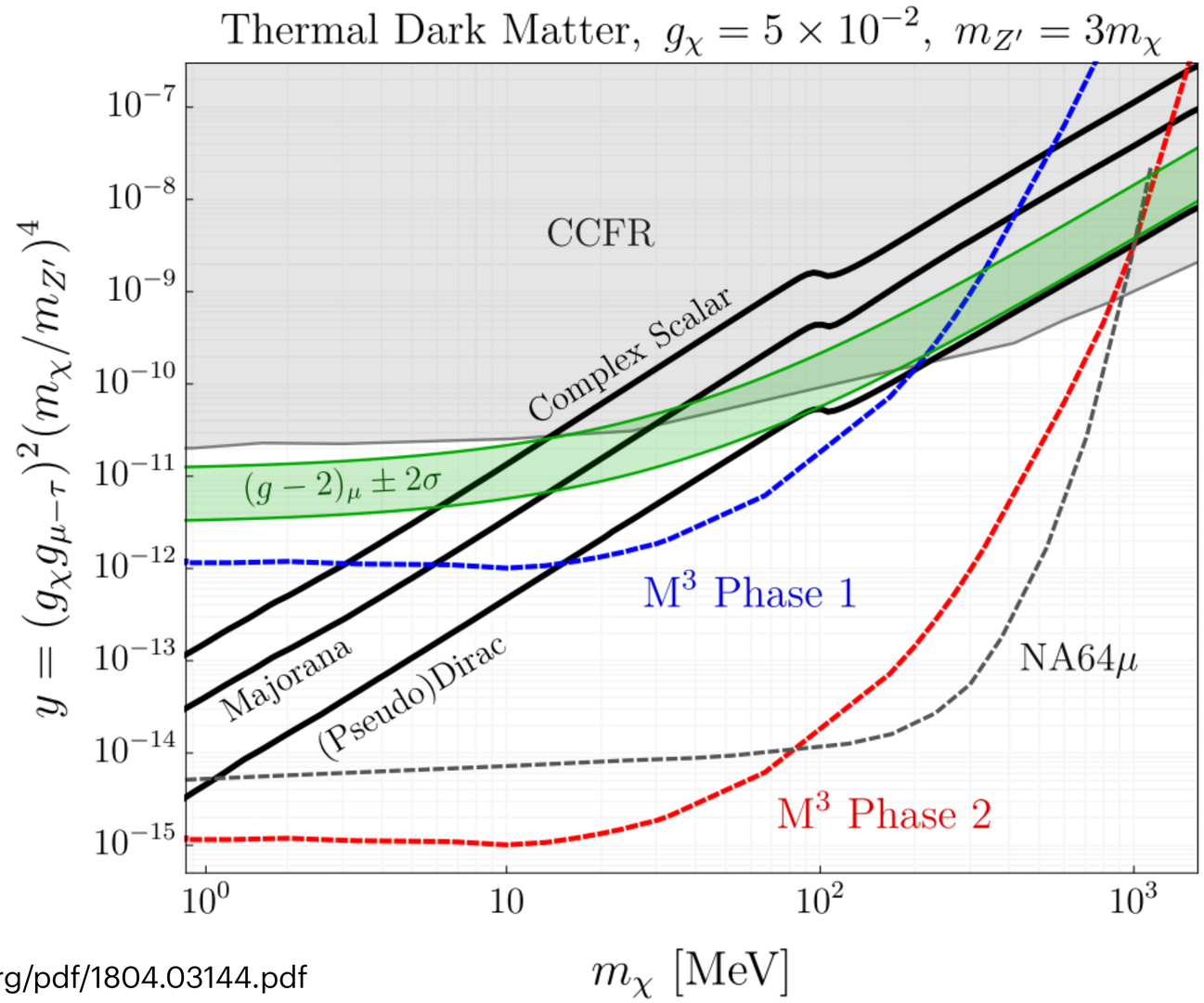
Thicker, active target boosts signal and helps reduce backgrounds.

Neutrals are detected by downstream calorimeters

** NOT AN LDMX ENDEAVOR

Muon-philic physics

- Small-scale MC support claims that M^3
- With phase 1 statistics, we could probe the remain viable parameter space in an invisibly decaying ($L_\mu - L_\tau$)-mediator can explain $(g\text{-}2)_\mu$



https://arxiv.org/pdf/1804.03144.pdf

Summary

- Electron fixed-target collisions are a powerful probe of the physics that could help explain the existence of weakly interacting thermal relics
- LDMX will employ:
  - a unique detector configuration to perform a robust analysis of SM backgrounds and characterize signals
  - a low current, high repetition rate beam to acquire a high statistics dataset capable of discovering or constraining a wide variety of thermal relic targets
- LDMX has received **funding** from the **DOE** and a **Swedish foundation** through Lund University
  - detector prototype is underway
- The LESA beamline has also received funding and is under construction
- While dark matter is the primary focus of LDMX, new ideas are constantly developing to utilize LDMX, or LDMX-like detector configurations to produce a richer set of physics
  (eN measurements for DUNE, visible mediator decays, muon-philic forces with M^3)