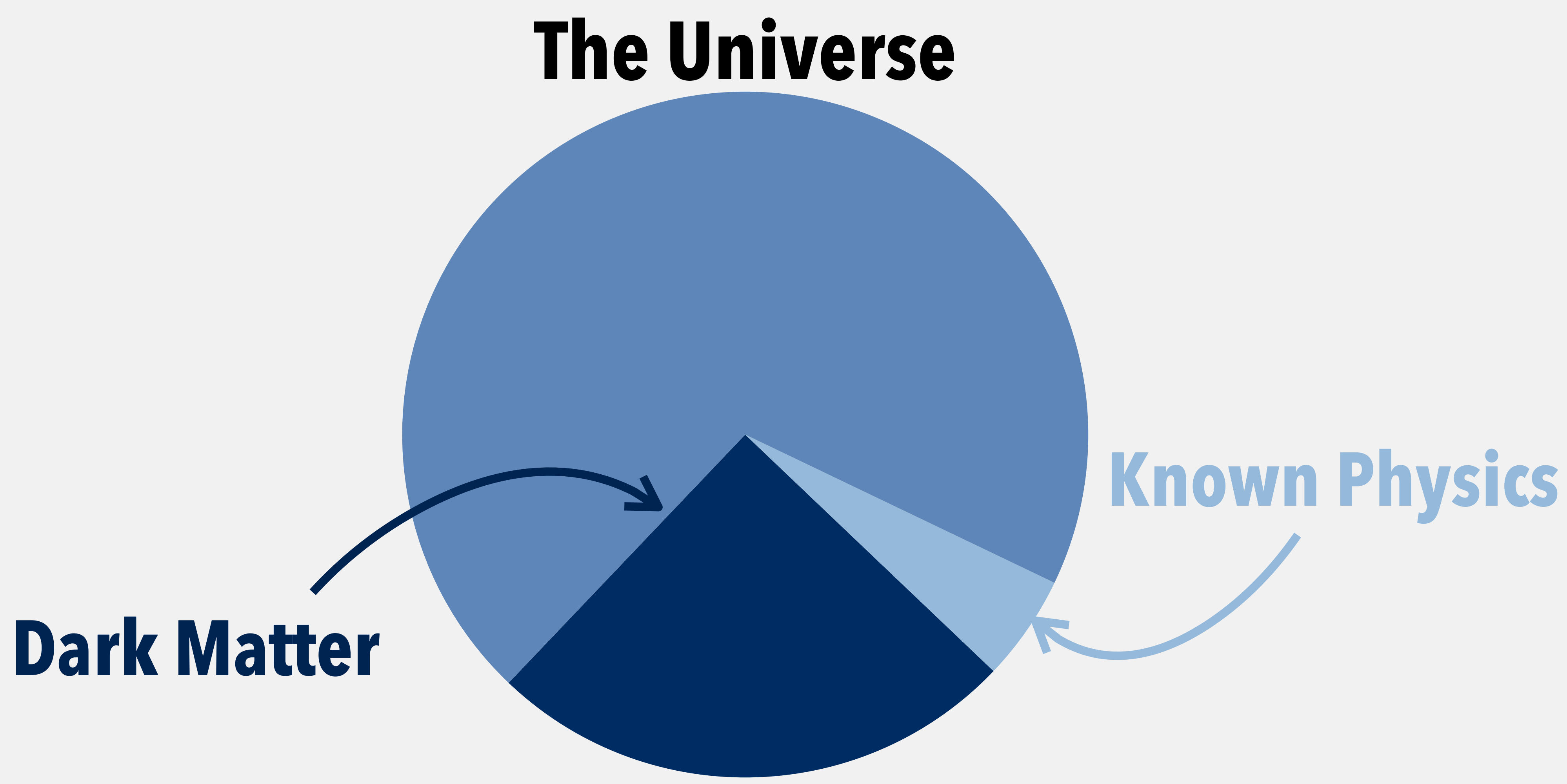
LDMX Light Dark Matter Experiment

TeVPA 2018, Berlin

27 August 2018

Ruth Pöttgen

What is light? (in this talk)



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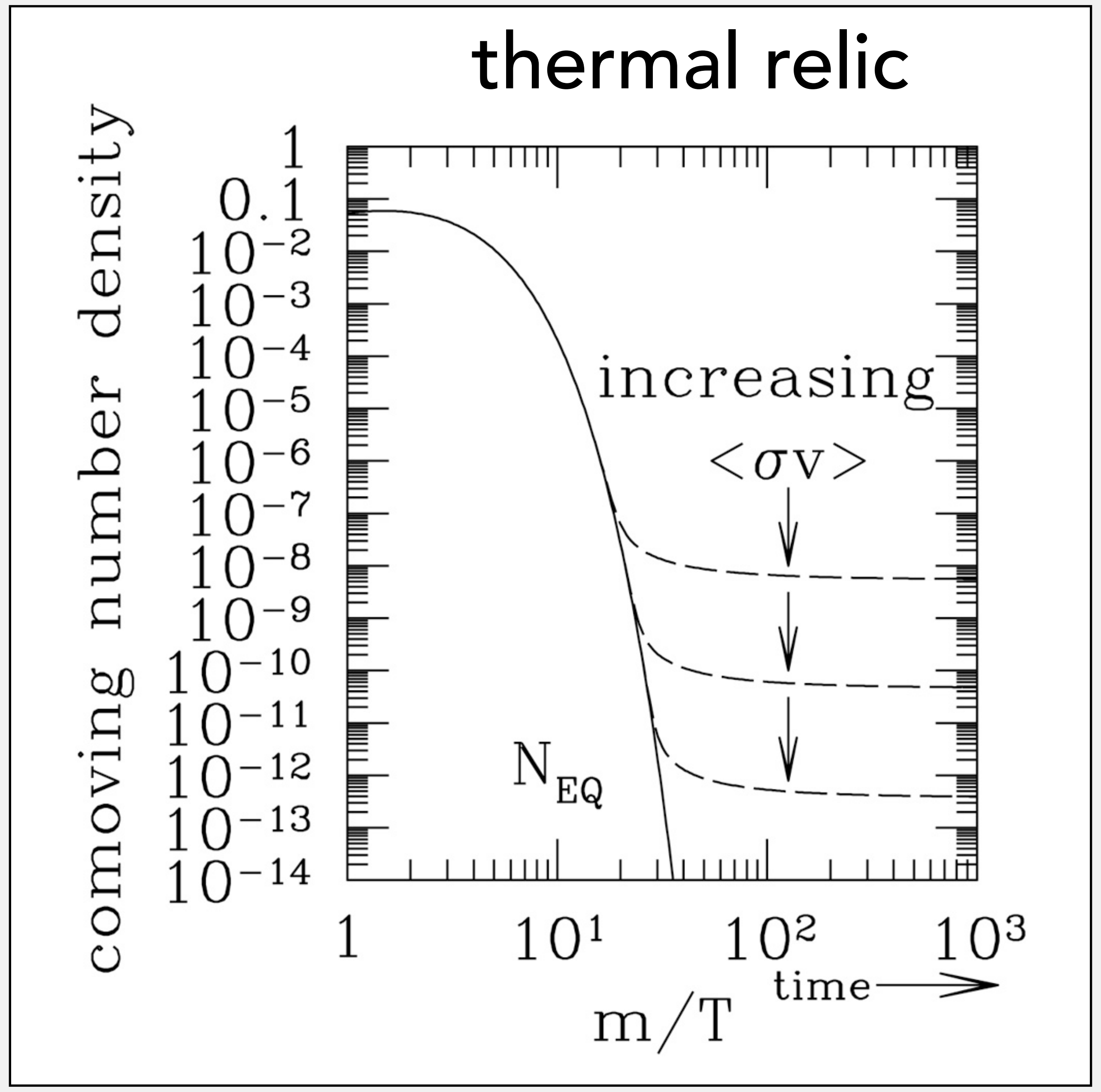

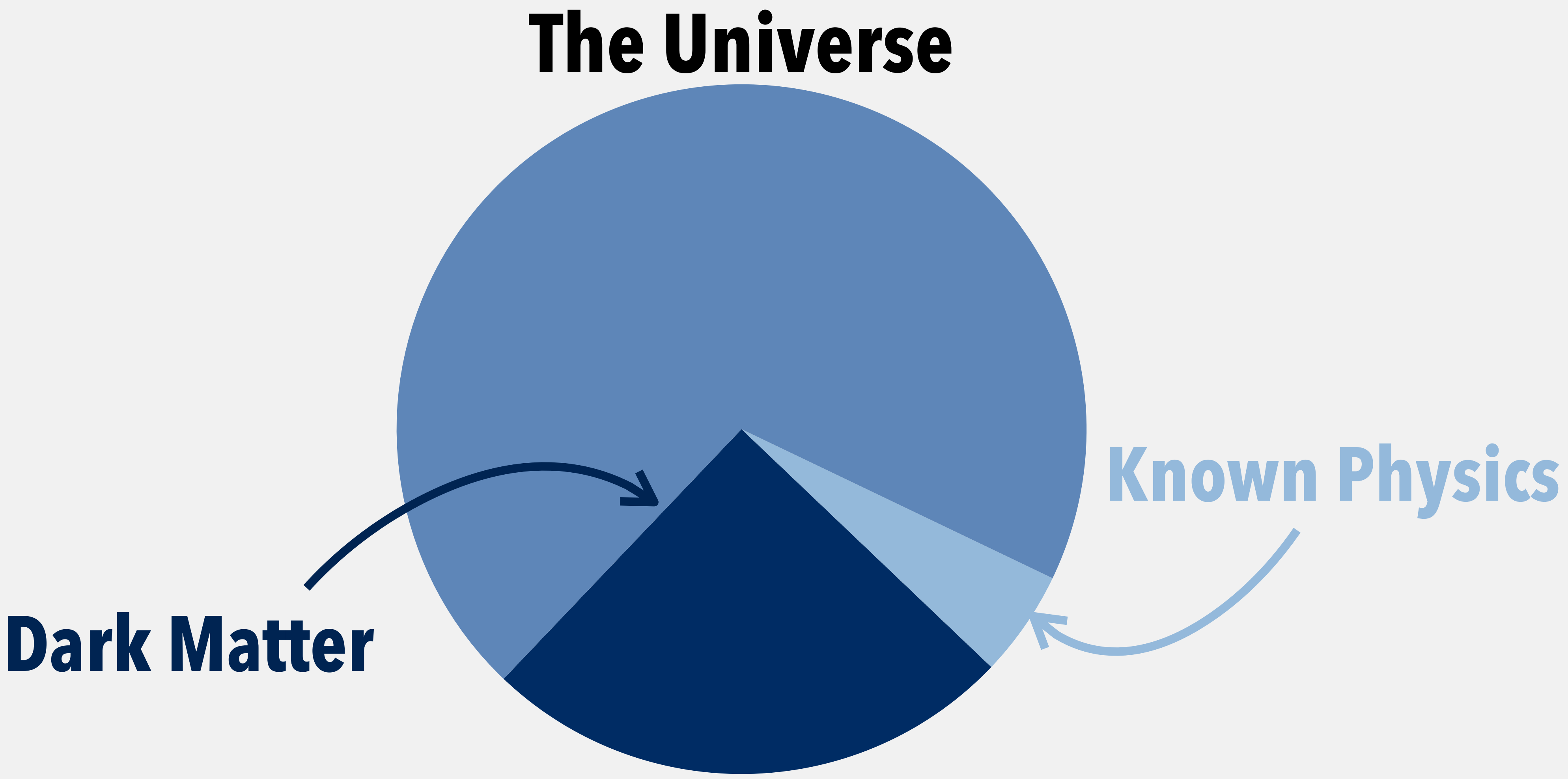

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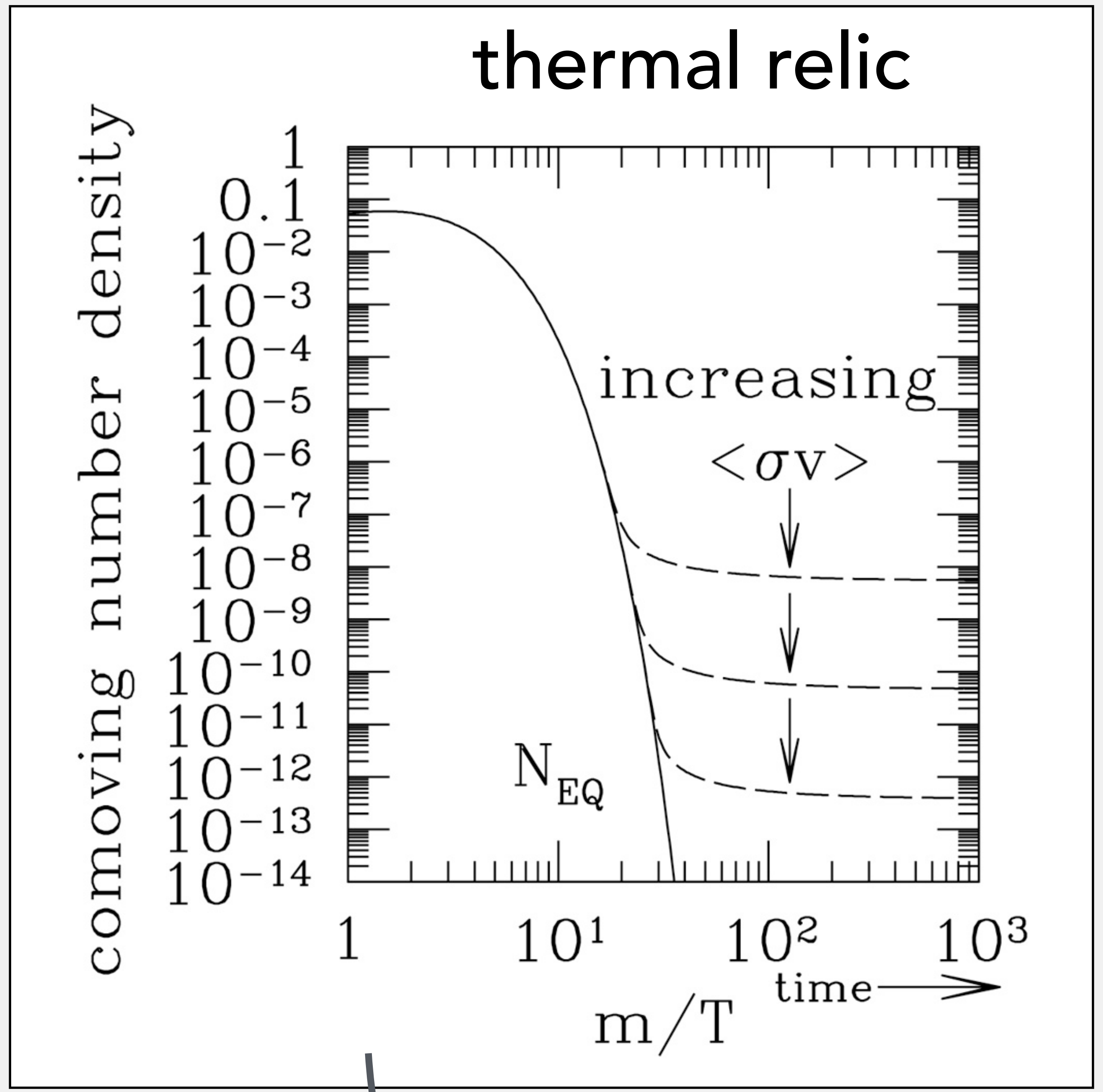

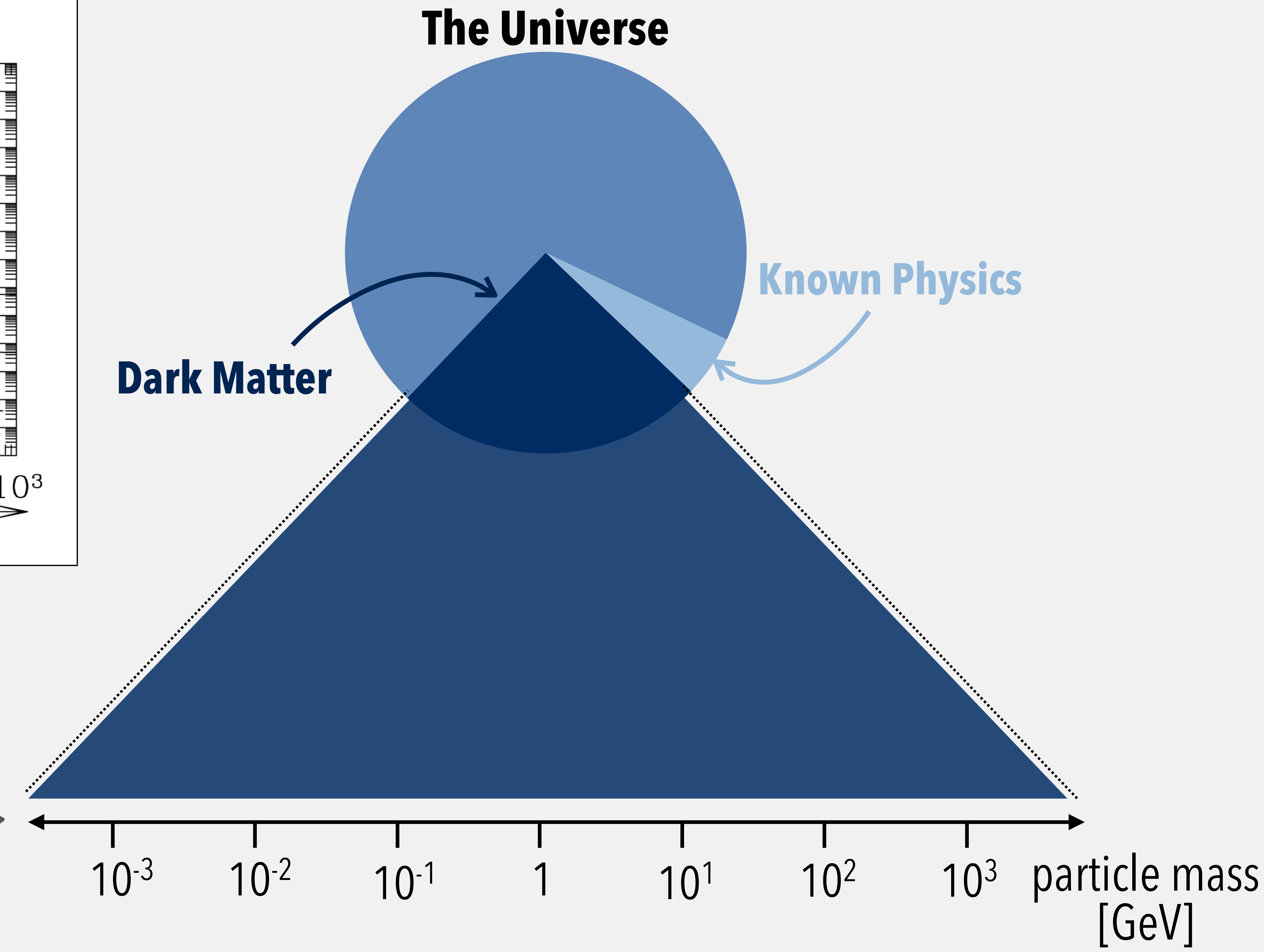

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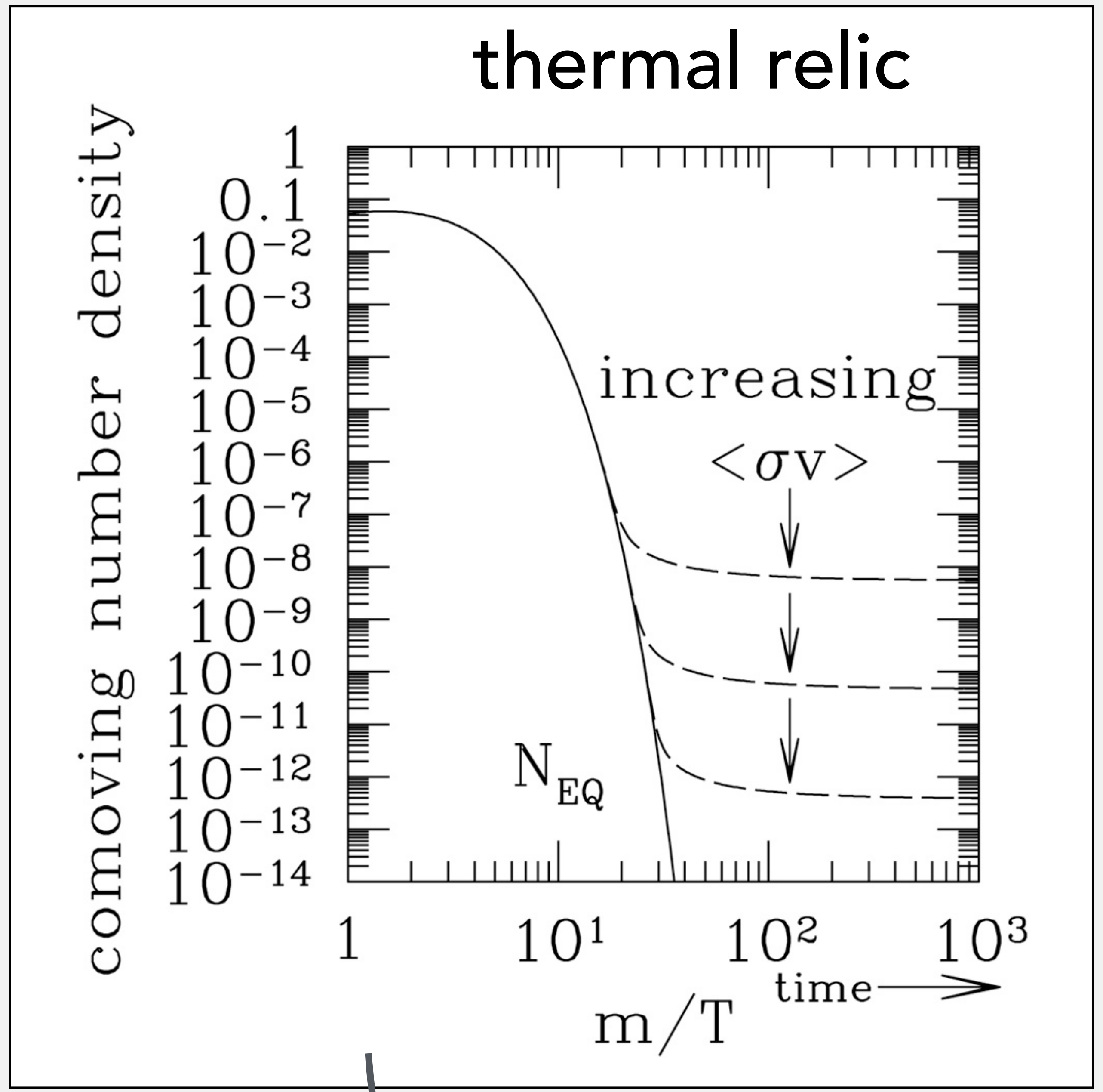

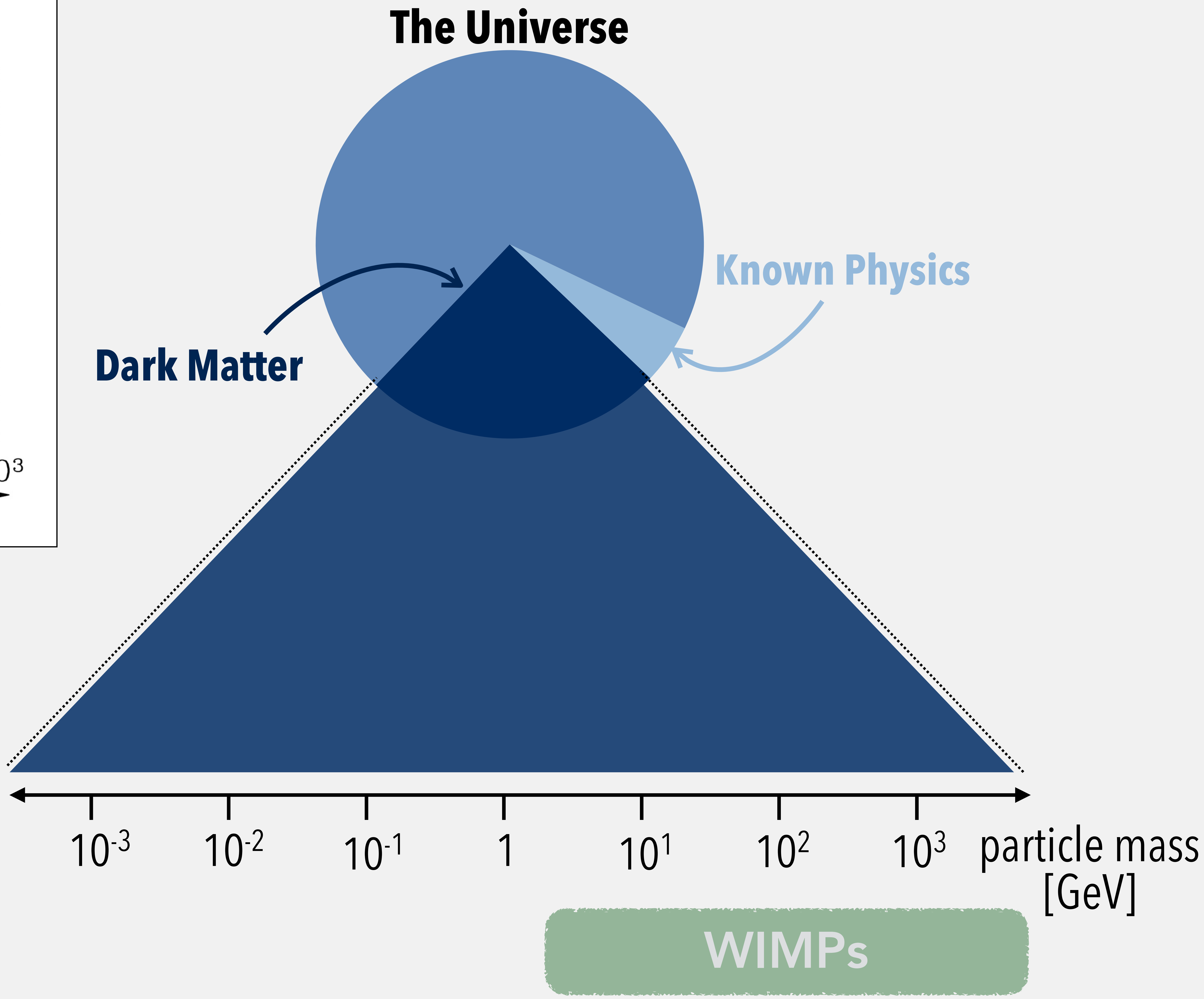

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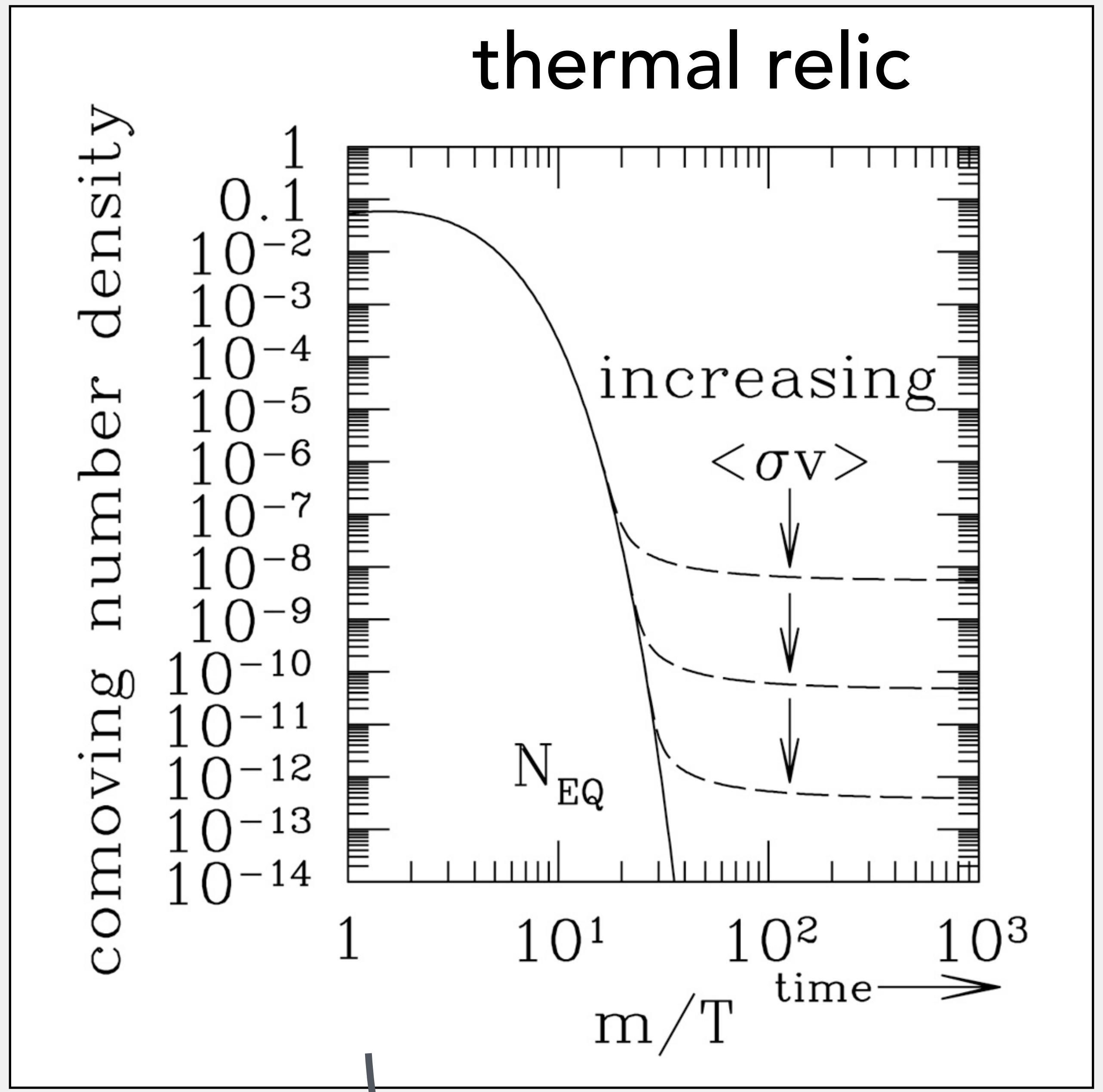

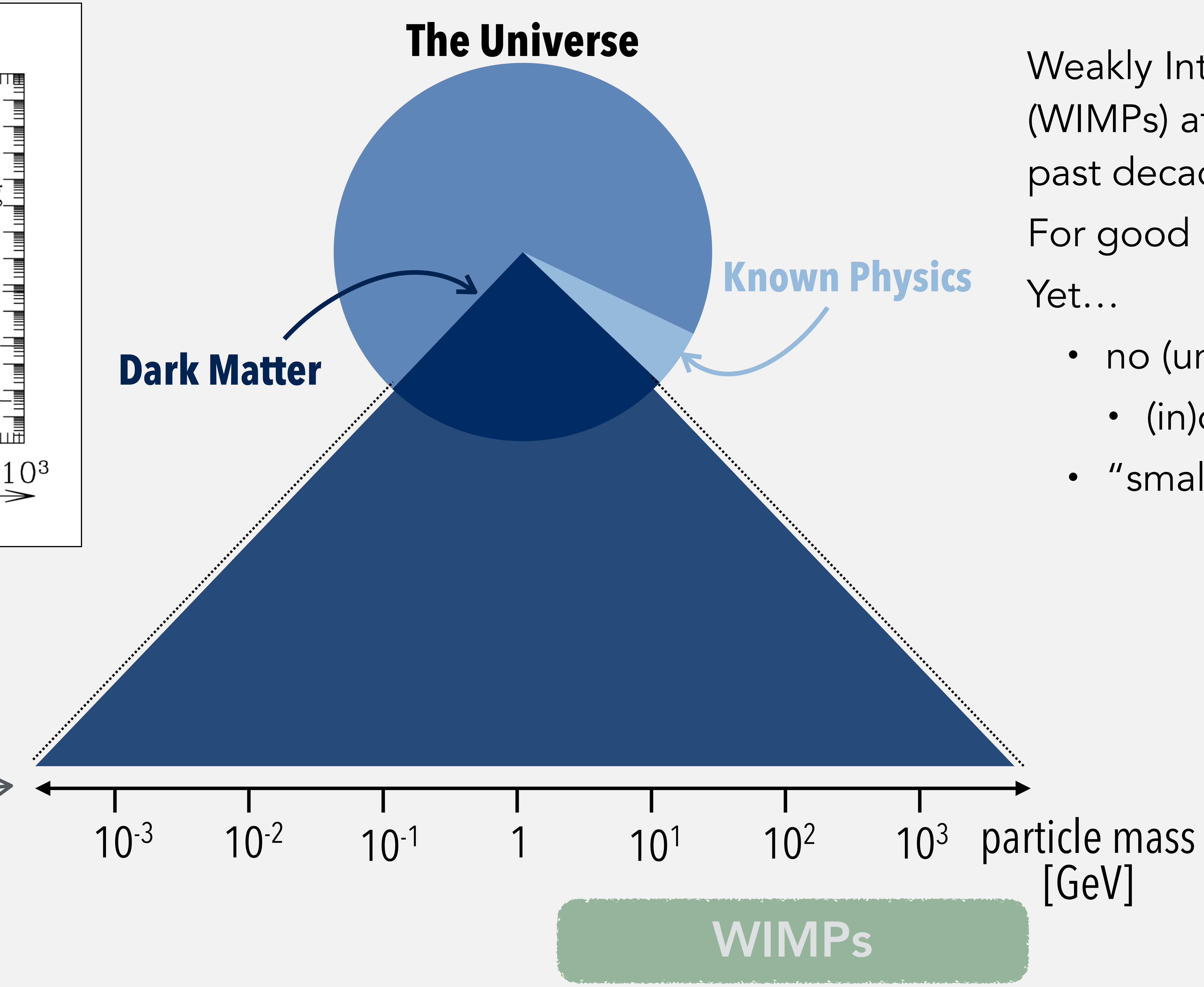

Weakly Interacting Massive Paticles (WIMPs) at centre of attention in past decades.

For good reasons!

Yet…

- no (unambiguous) observation
  - (in)direct detection, LHC
- "small-scale crisis" of cold DM

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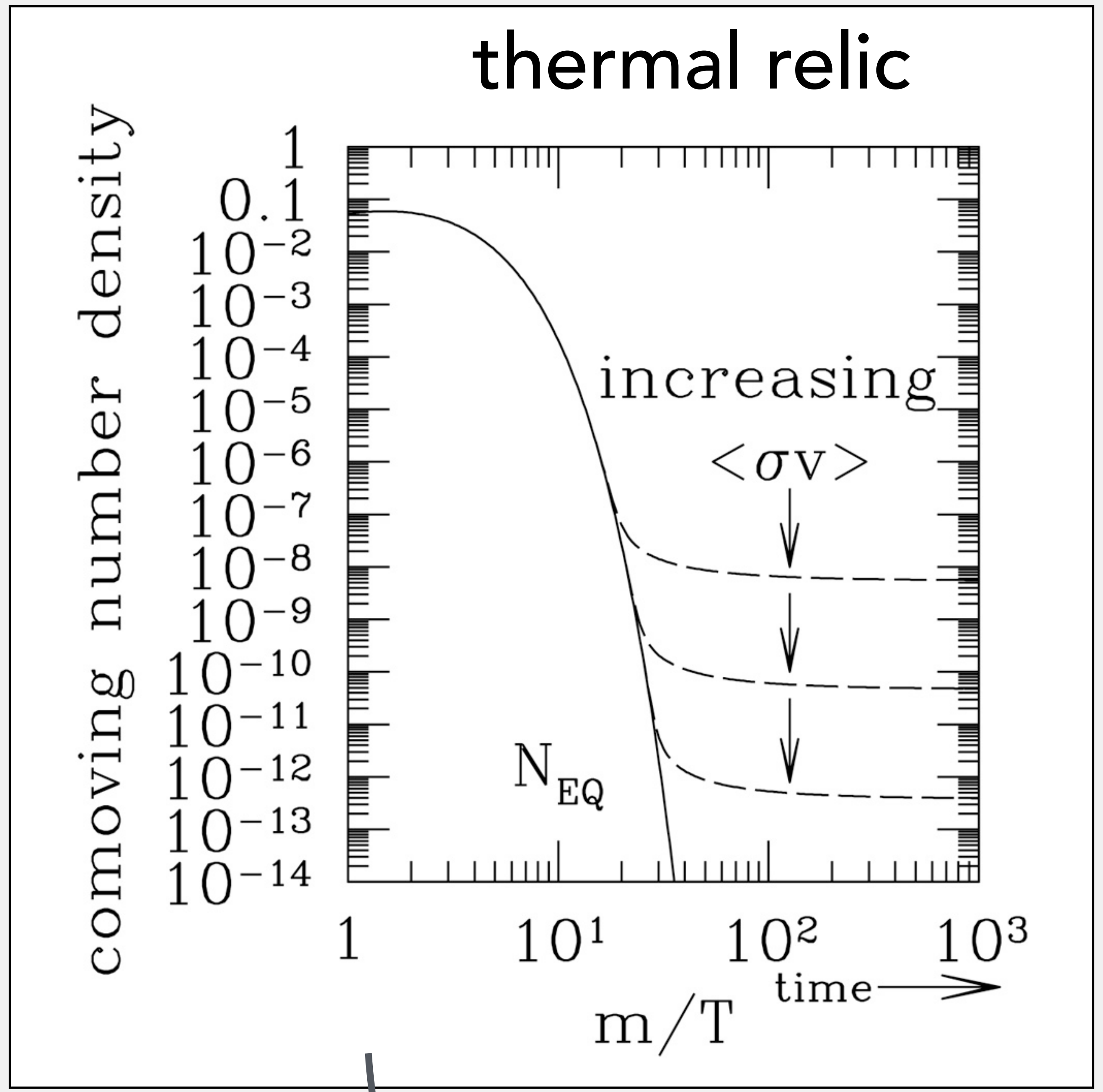

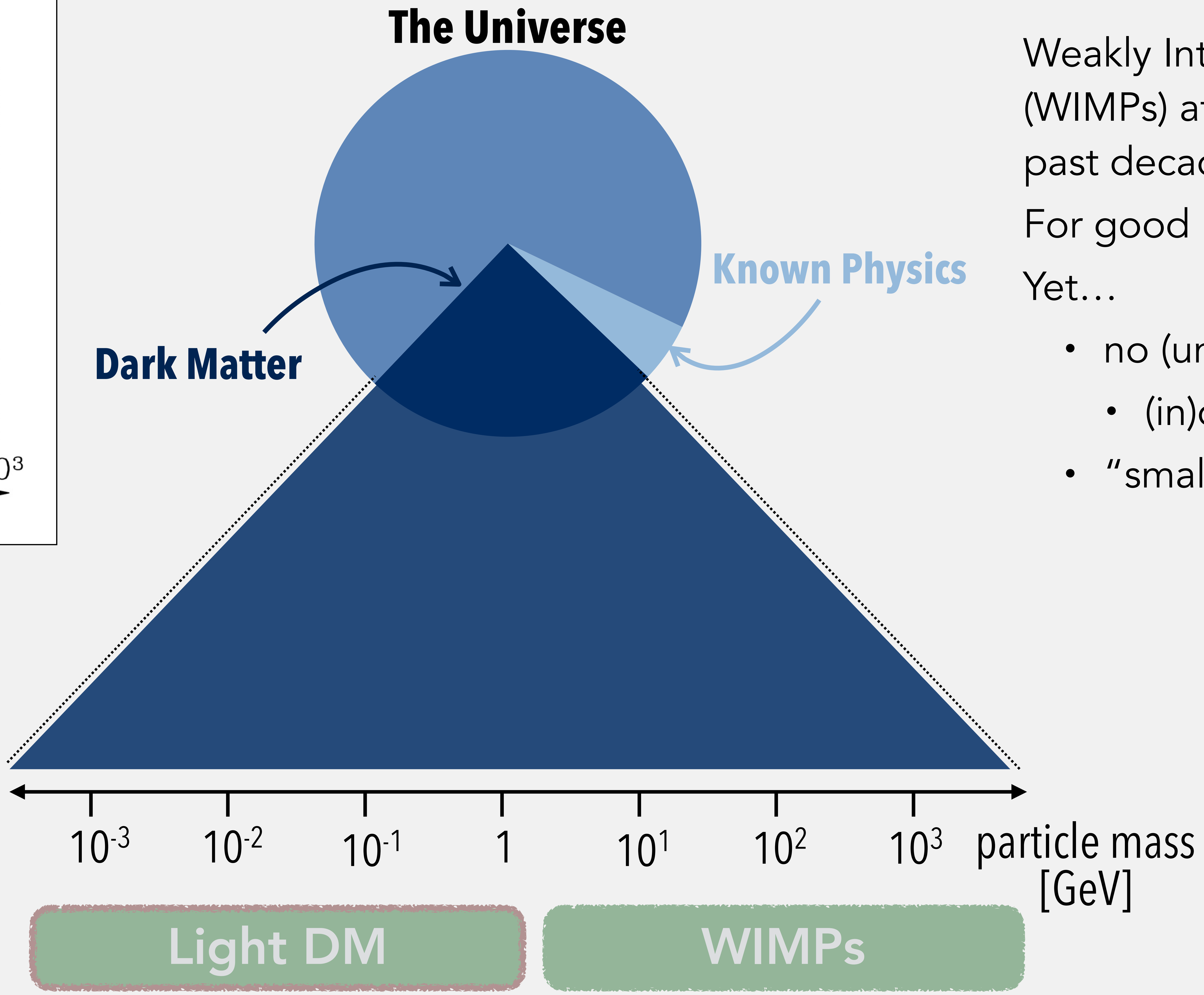

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How to realise LDM

if WIMPs 'too light' (m_χ< few GeV)

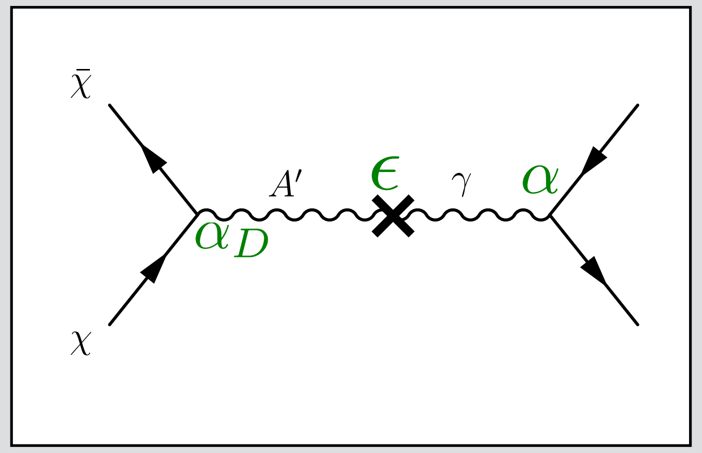
- annihilation into SM inefficient
  - overproduction of DM
- *Lee-Weinberg-bound*

introduce new, light mediator

- additional annihilation channel
  - correct relic abundance
- if heavier than $2m_\chi$: *invisible* decay into DM dominates

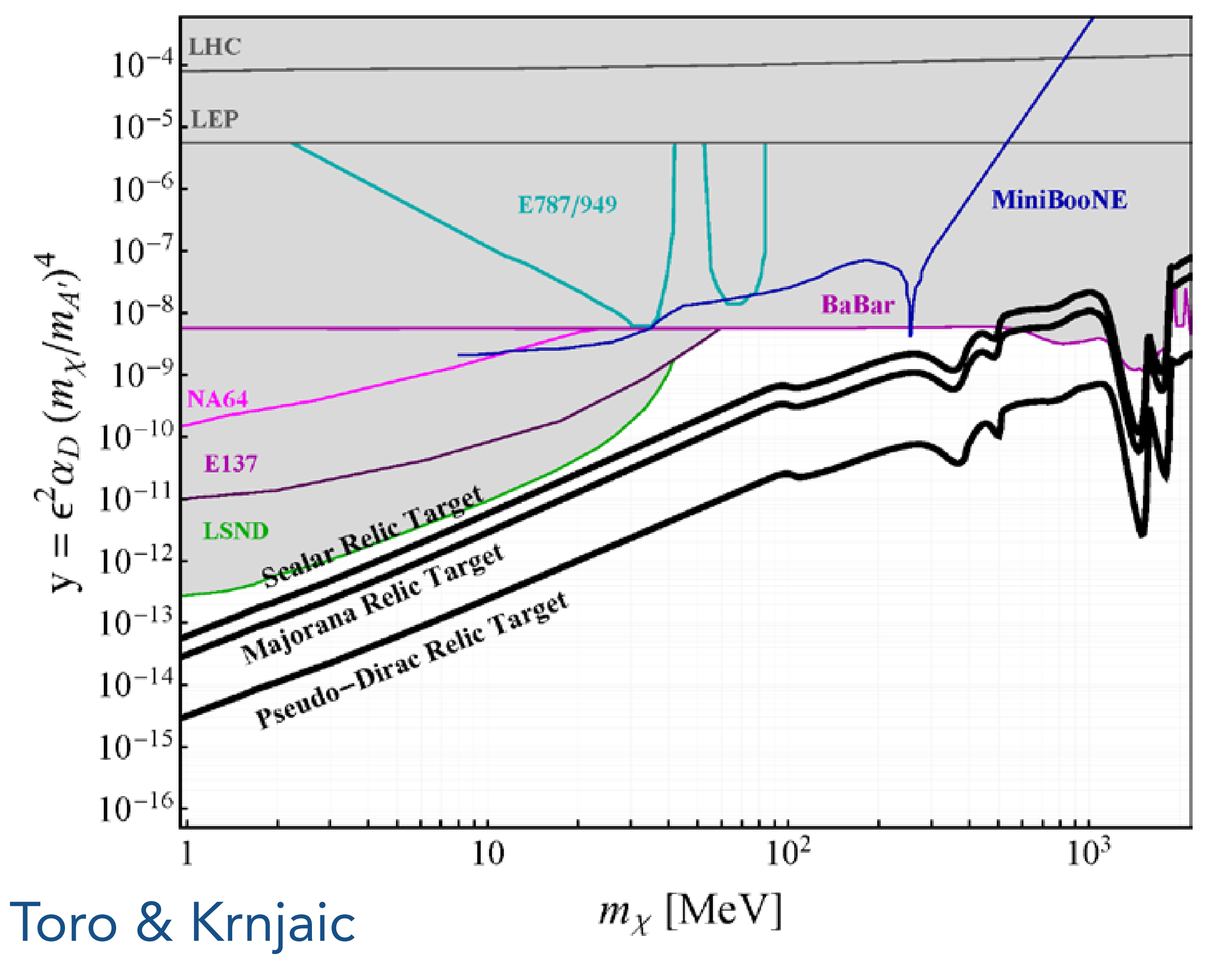
representative benchmark model: Dark Photon (A')

- vector mediator
- kinetically mixes with photon (ε)
- annihilation cross section



$$\sigma v \sim \alpha_D \varepsilon^2 \frac{m_\chi^2}{m_{A'}^4} \sim \alpha_D \varepsilon^2 \frac{m_\chi^4}{m_{A'}^4} \frac{1}{m_\chi^2} \sim y \frac{1}{m_\chi^2}$$

$$y = \alpha_D \varepsilon^2 \frac{m_\chi^4}{m_{A'}^4}$$



Toro & Krnjaic

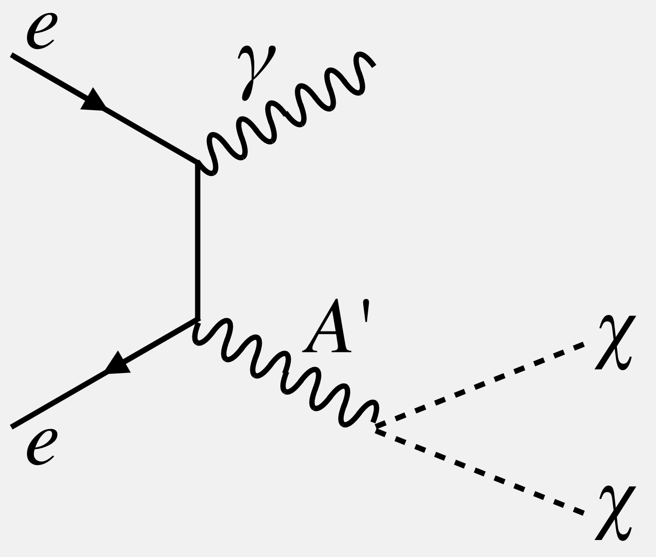
clear experimental *thermal targets*

conservative:

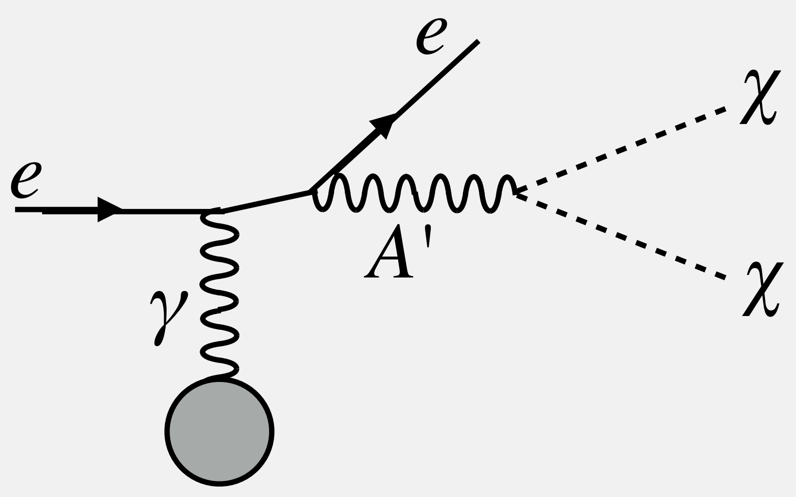
$$\alpha_D = 0.5 \qquad \frac{m_\chi^4}{m_{A'}^4} = \frac{1}{3}$$

Complimentary Approaches

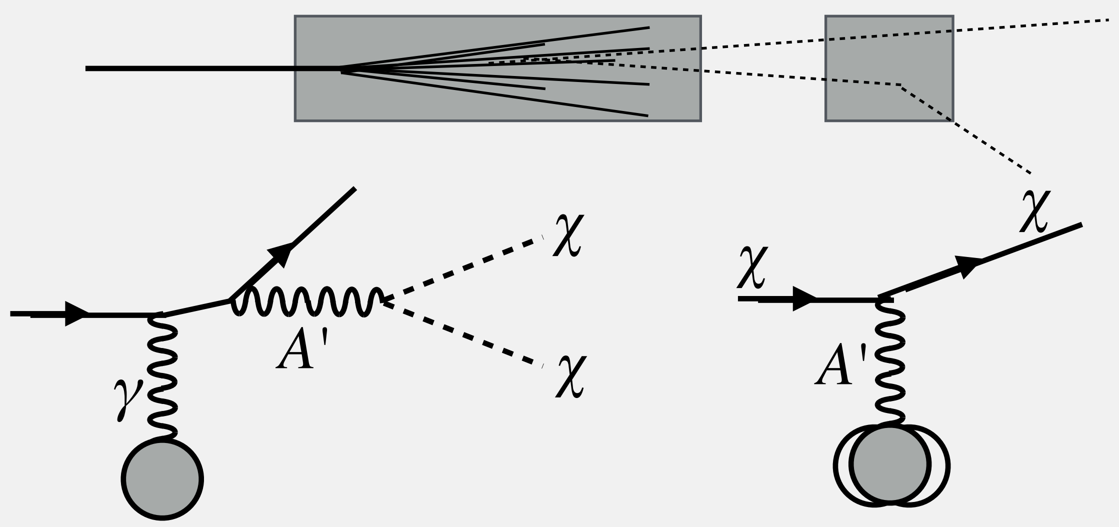
collider



fixed target



beam dump



$\sigma_{\text{coll}} \propto \frac{\varepsilon^2}{E^2_{\text{cm}}}$ << $\sigma_{\text{FT}} \propto \frac{Z^2 \varepsilon^2}{m^2_{\text{A'}}}$

$N \propto \varepsilon^2 (1 - \varepsilon^2) \approx \varepsilon^2$ >> $N \propto \varepsilon^4$

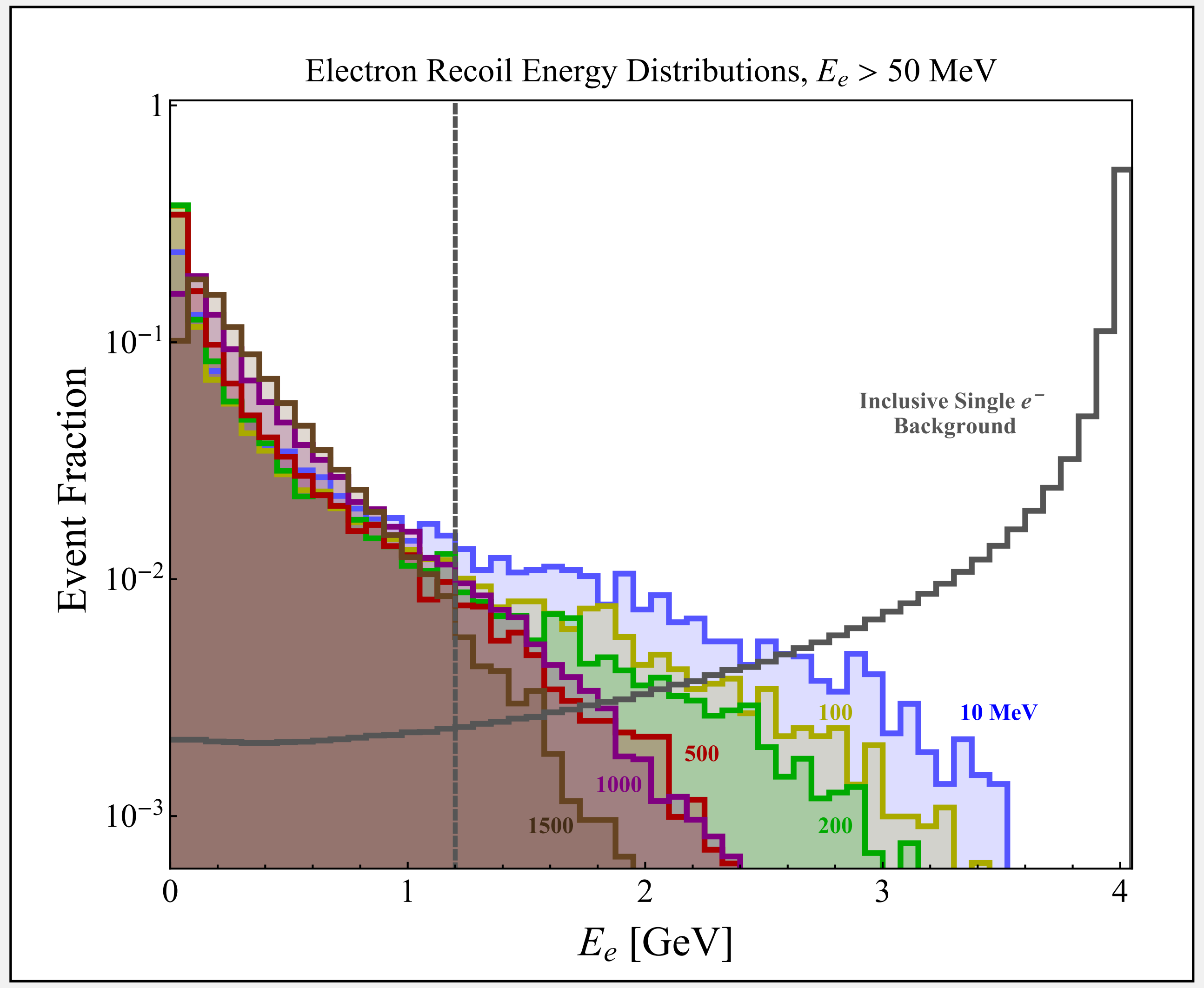
Fixed target **maximises DM yield** (production & detection efficiency)

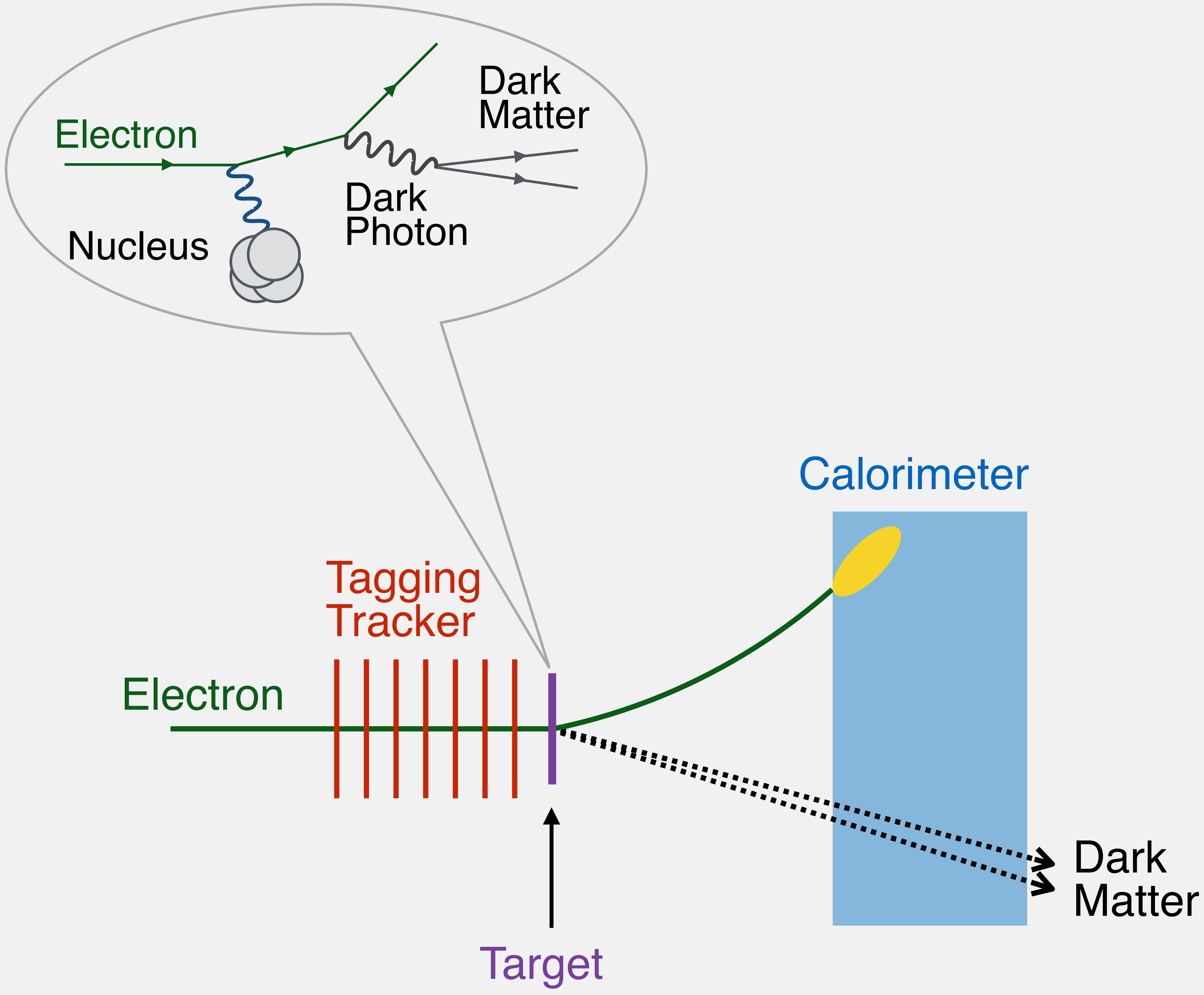
Fixed Target Experiment

electron undergoing bremsstrahlung of dark photon

kinematics very different from SM bremsstrahlung

- large missing (transverse) momentum





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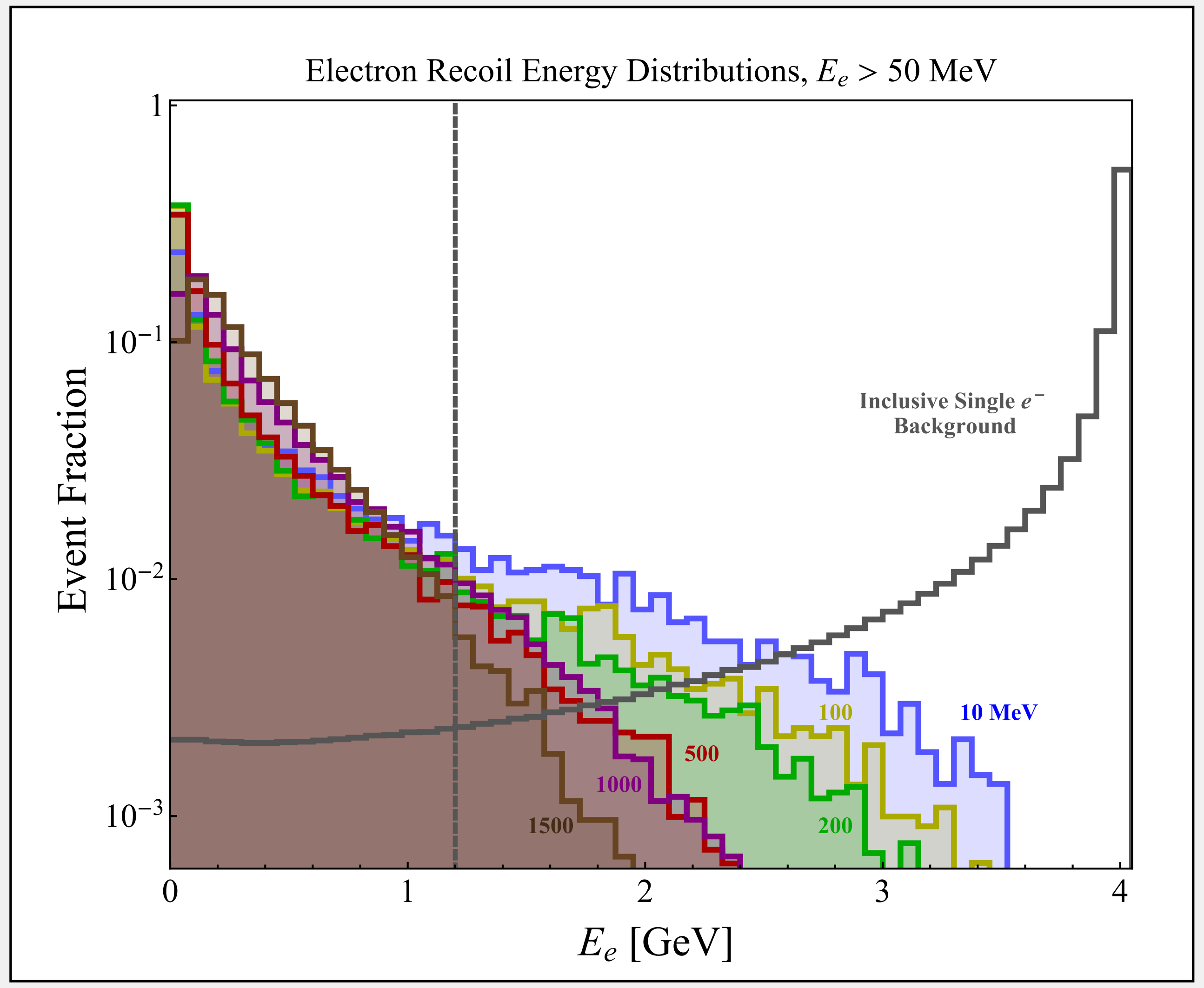

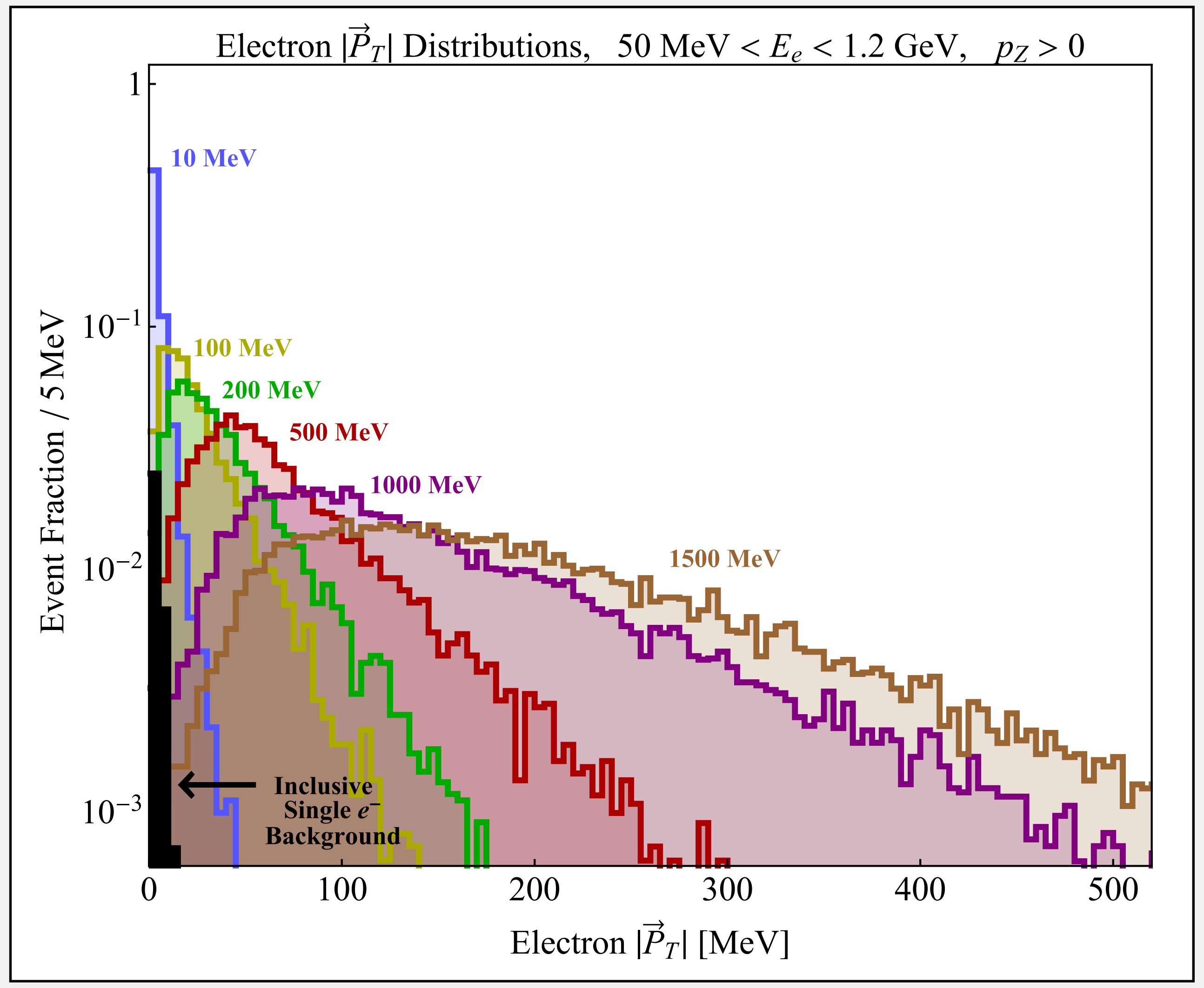

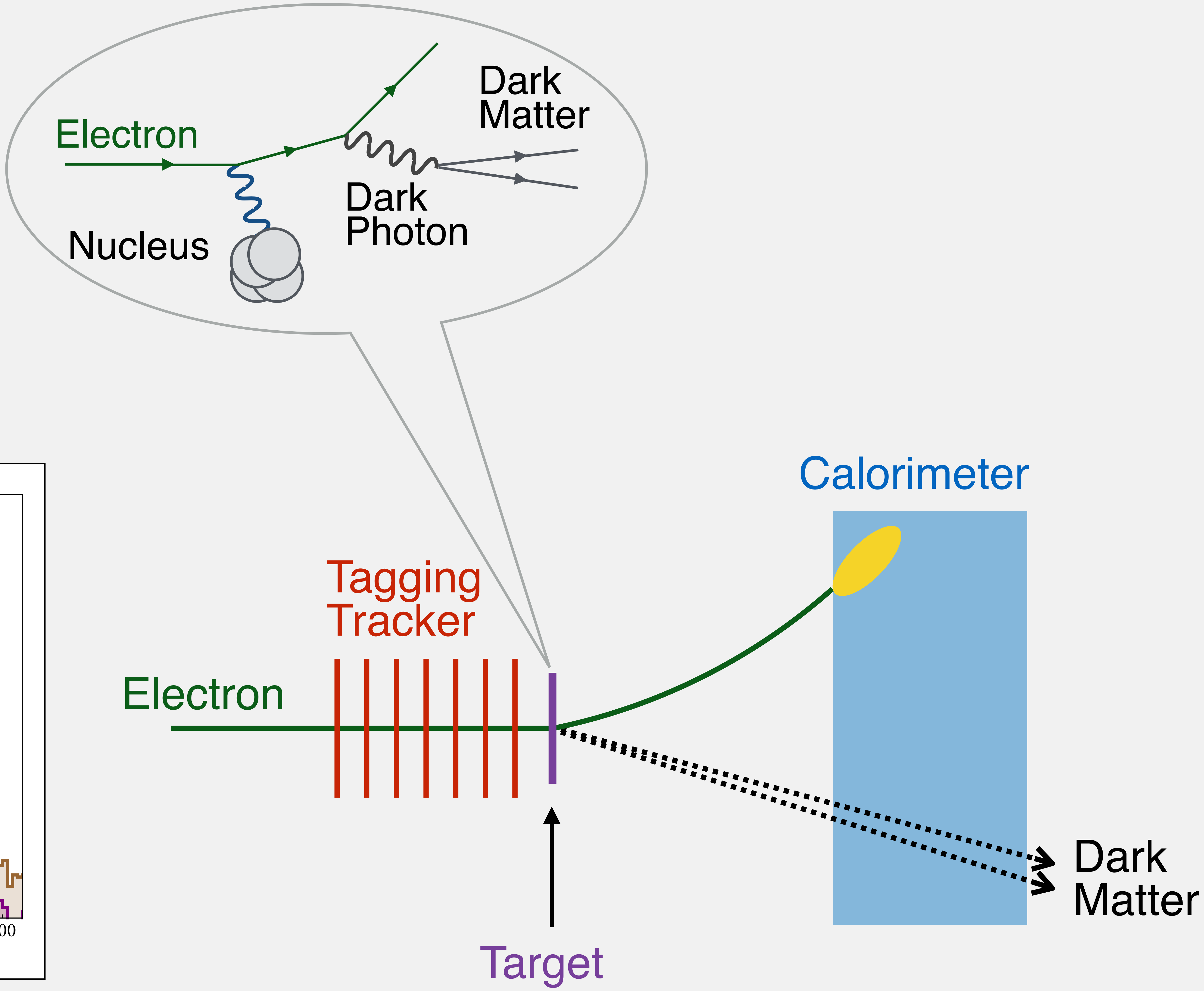

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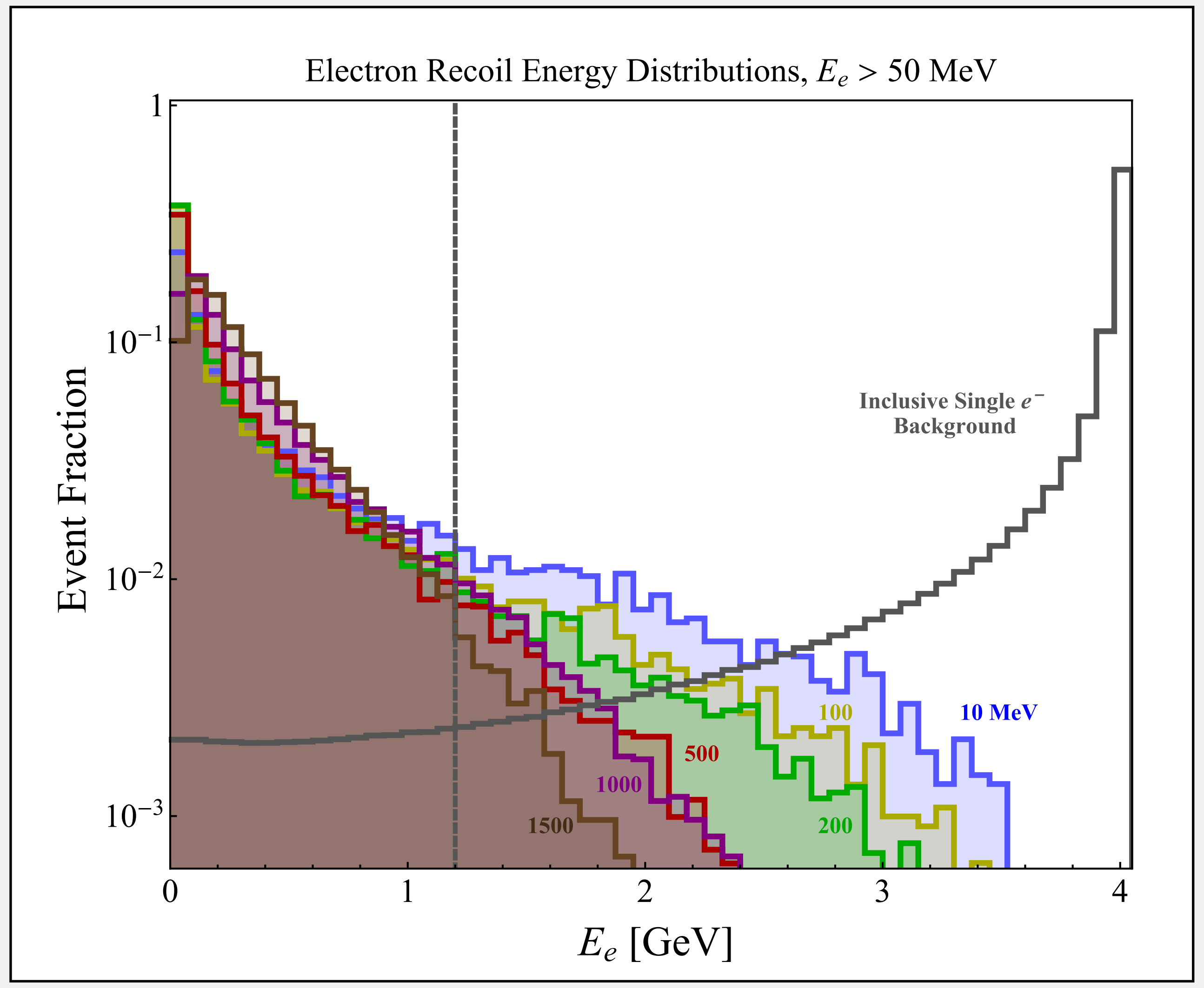
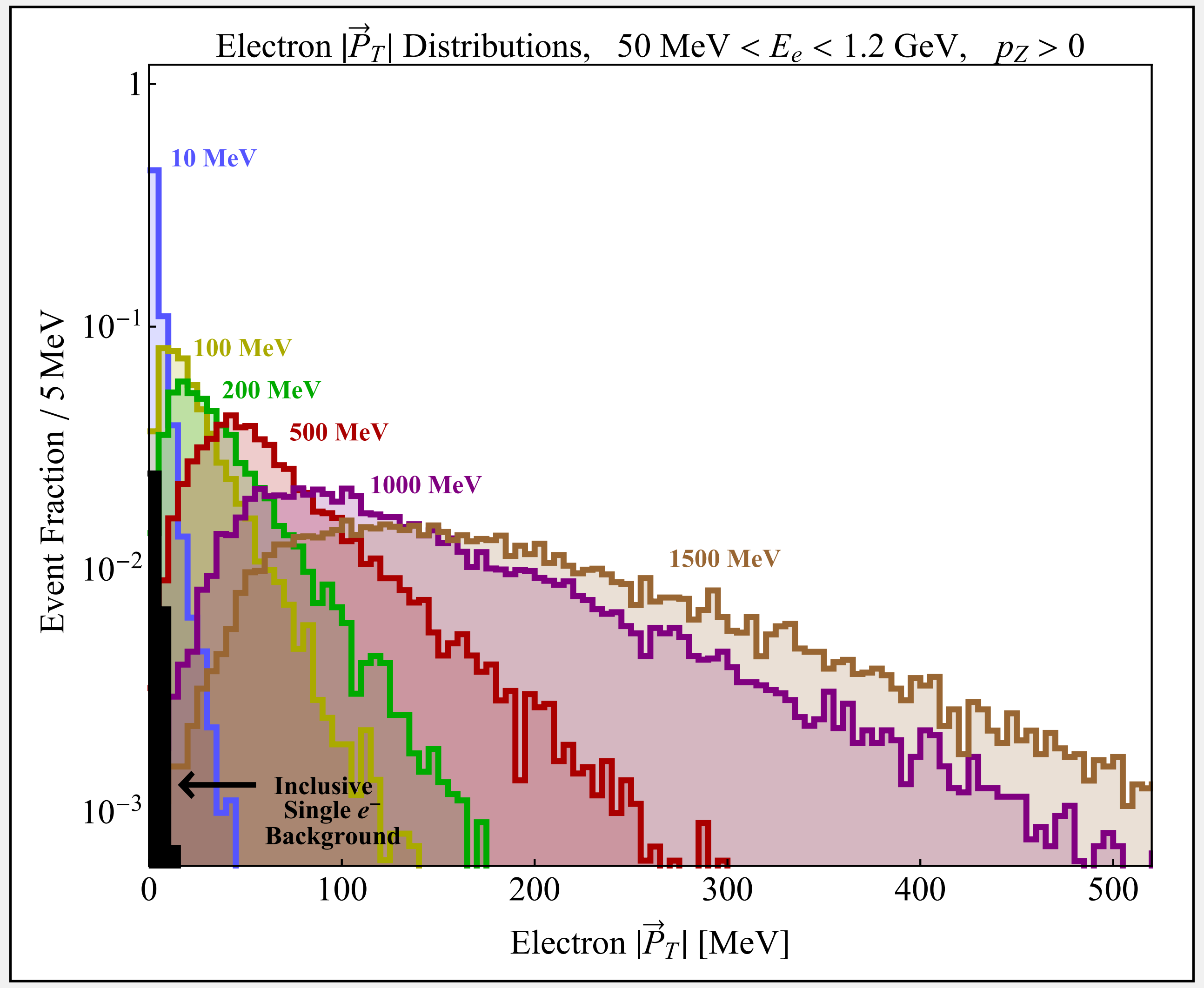
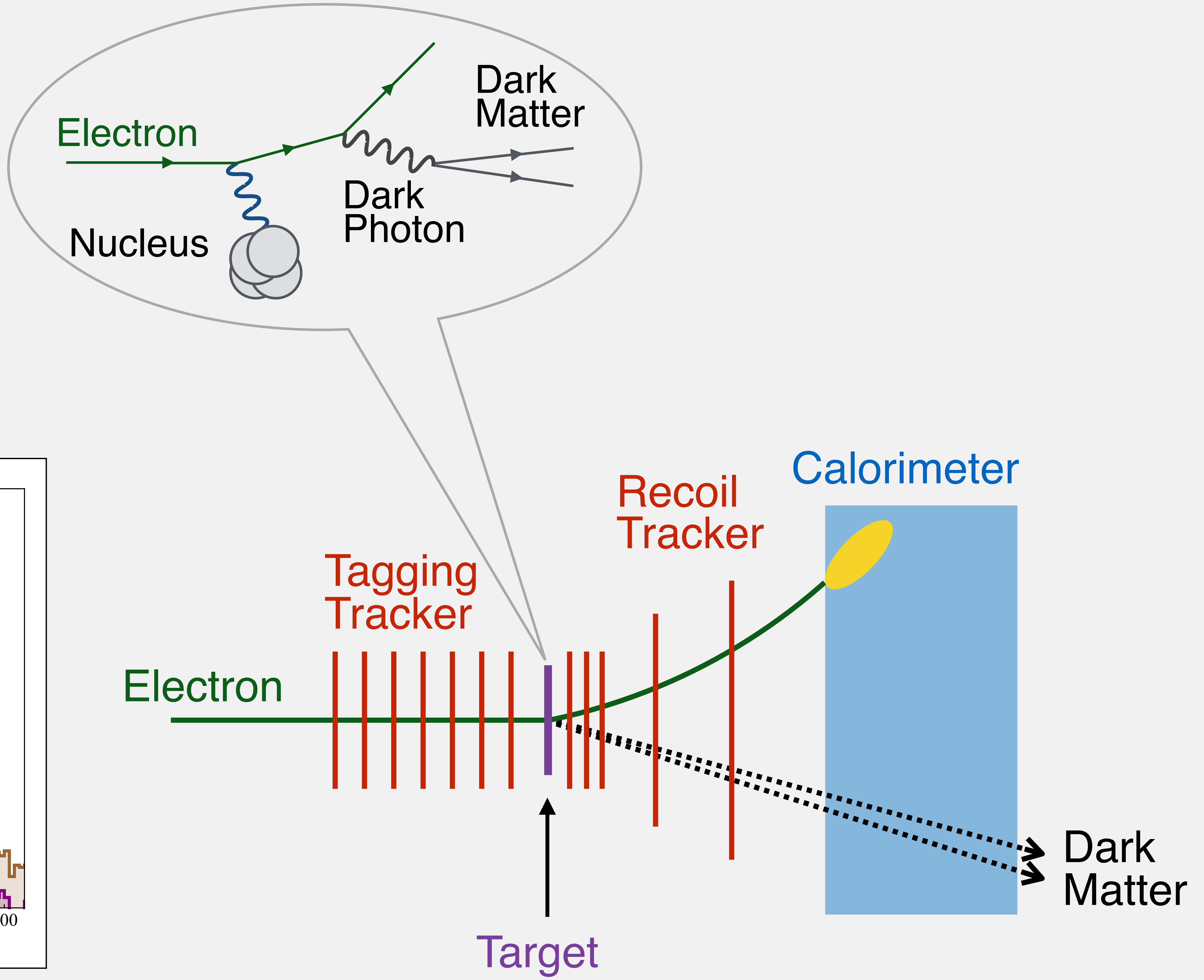






Detector Design

extremely rare signal events —> need large statistics

goal: 10^{14} - 10^{16} EoT in few years

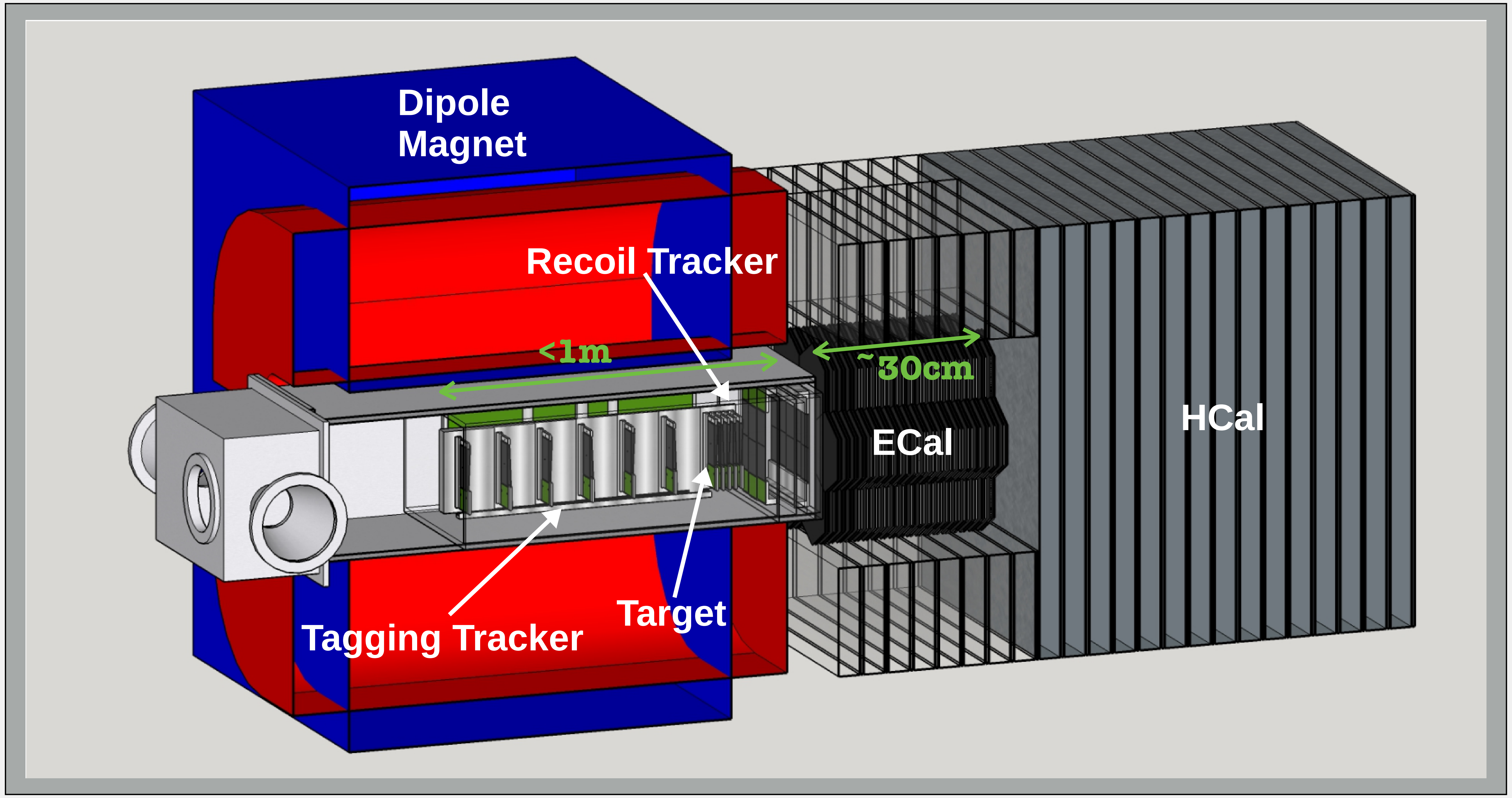
default: 4/8 GeV @ 46/186 MHz at SLAC

detector requirements:

- high-rate capabilities
- radiation hard

leverage techniques from existing/planned experiments

design paper new on arxiv!
arxiv:1808.05219



Caltech · Fermilab · SLAC National Accelerator Laboratory · UCSB University of California Santa Barbara · University of Minnesota · University of California Santa Cruz · Lunds Universitet

Tracking System

simplified copy of Silicon Vertex Tracker (SVT) of HPS experiment@JLab (visible Dark Photon search)

- fast (2ns hit time resolution)
- radiation hard
- technology well understood

tagging tracker

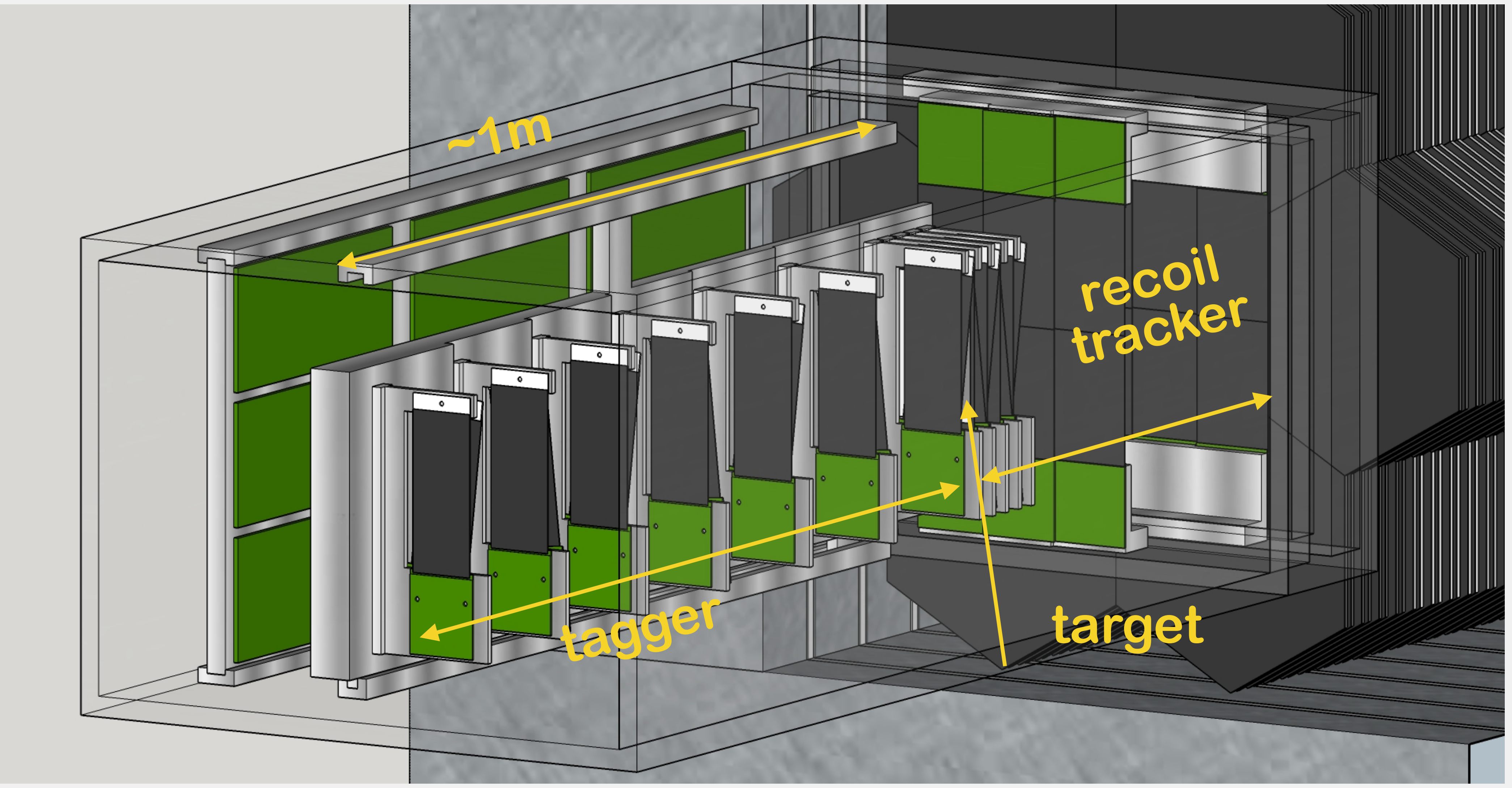
- in 1.5T dipole field
- measure incoming electron
  - momentum filter
  - impact point on target

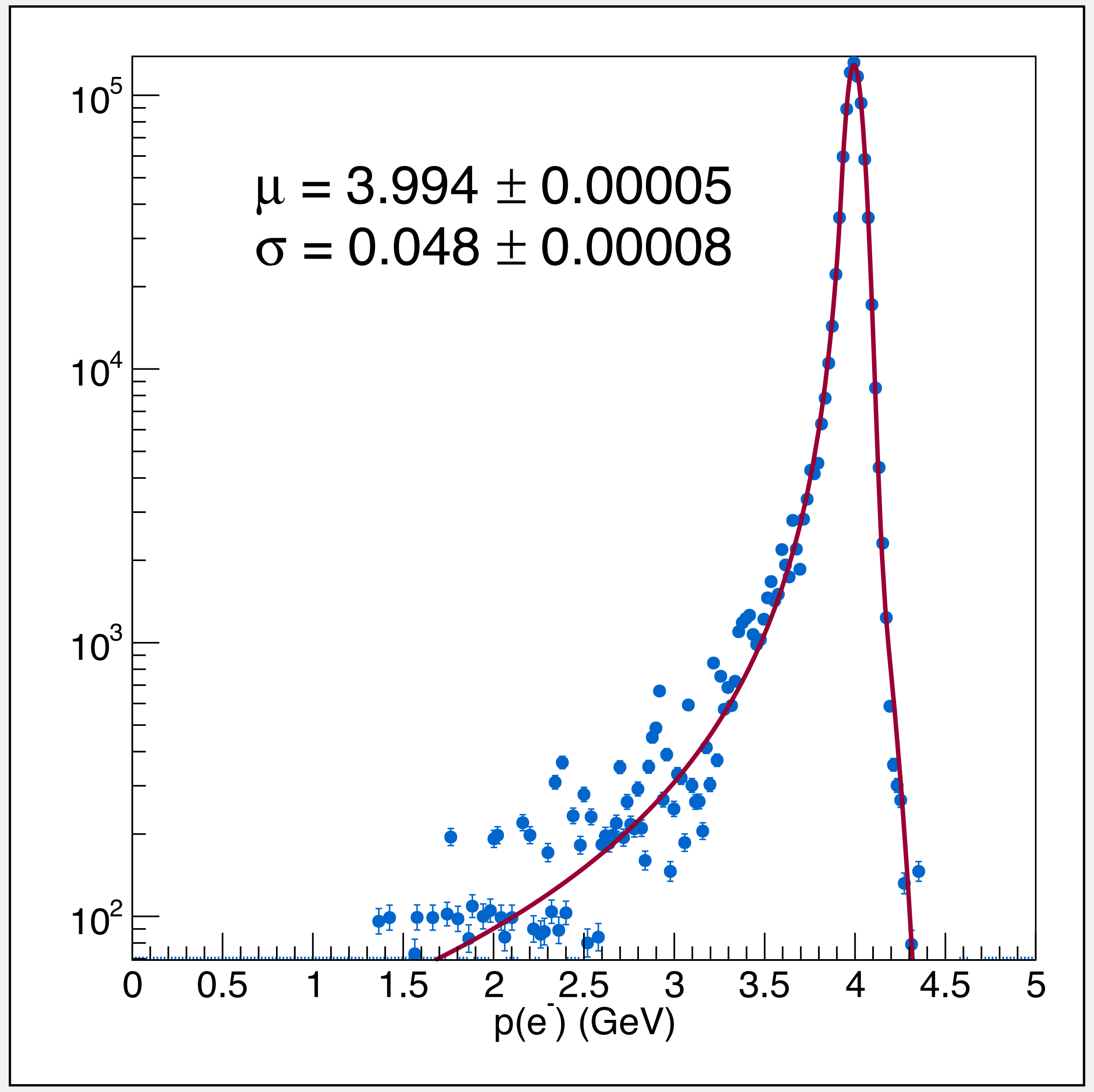
recoil tracker

- in fringe field
- measure recoil electron

target

- ~0.1 - 0.3 X_0 tungsten
- balance signal rate & momentum smearing

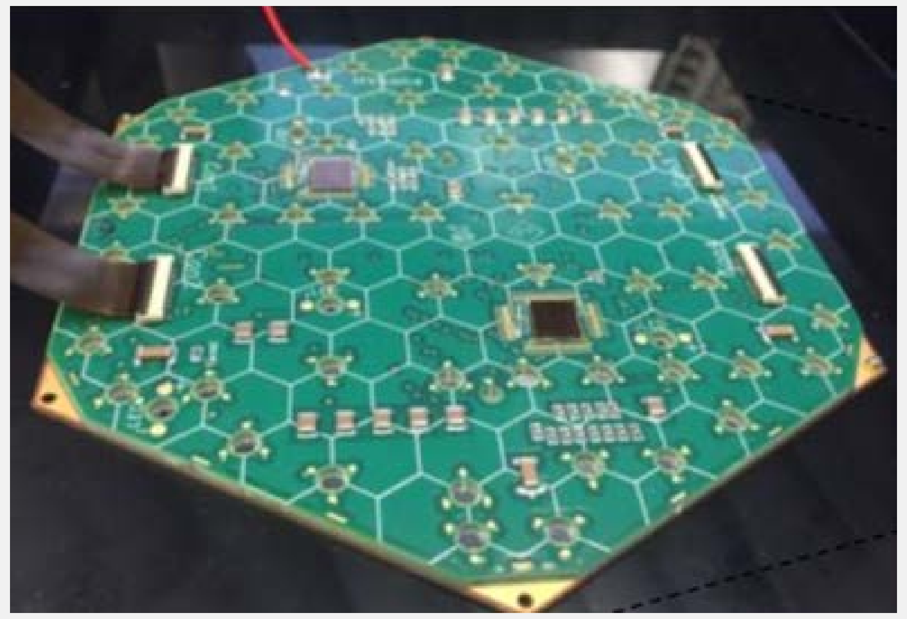


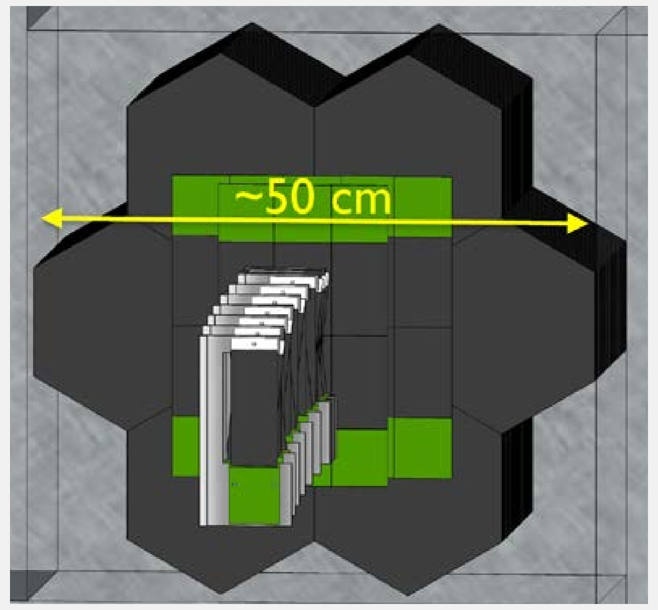


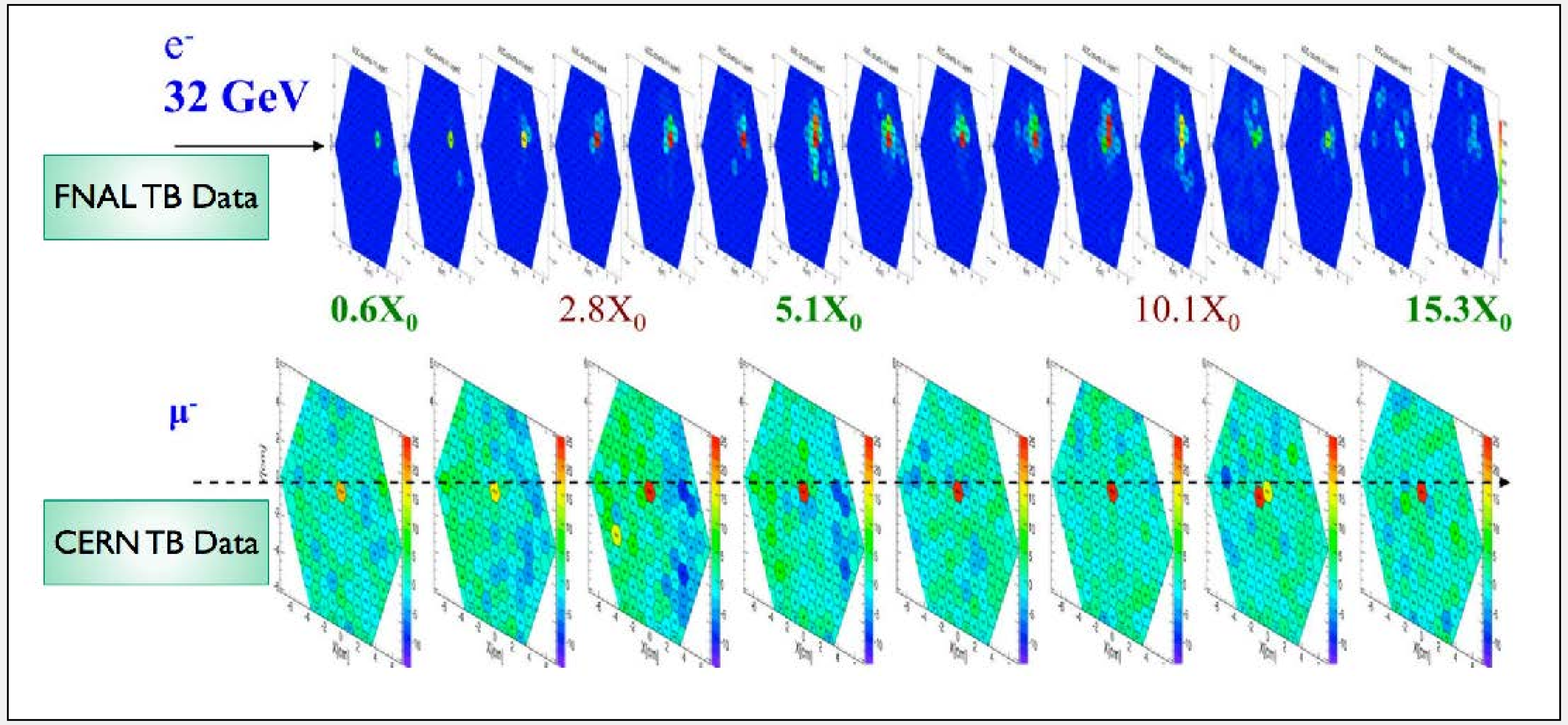
Electromagnetic Calorimeter

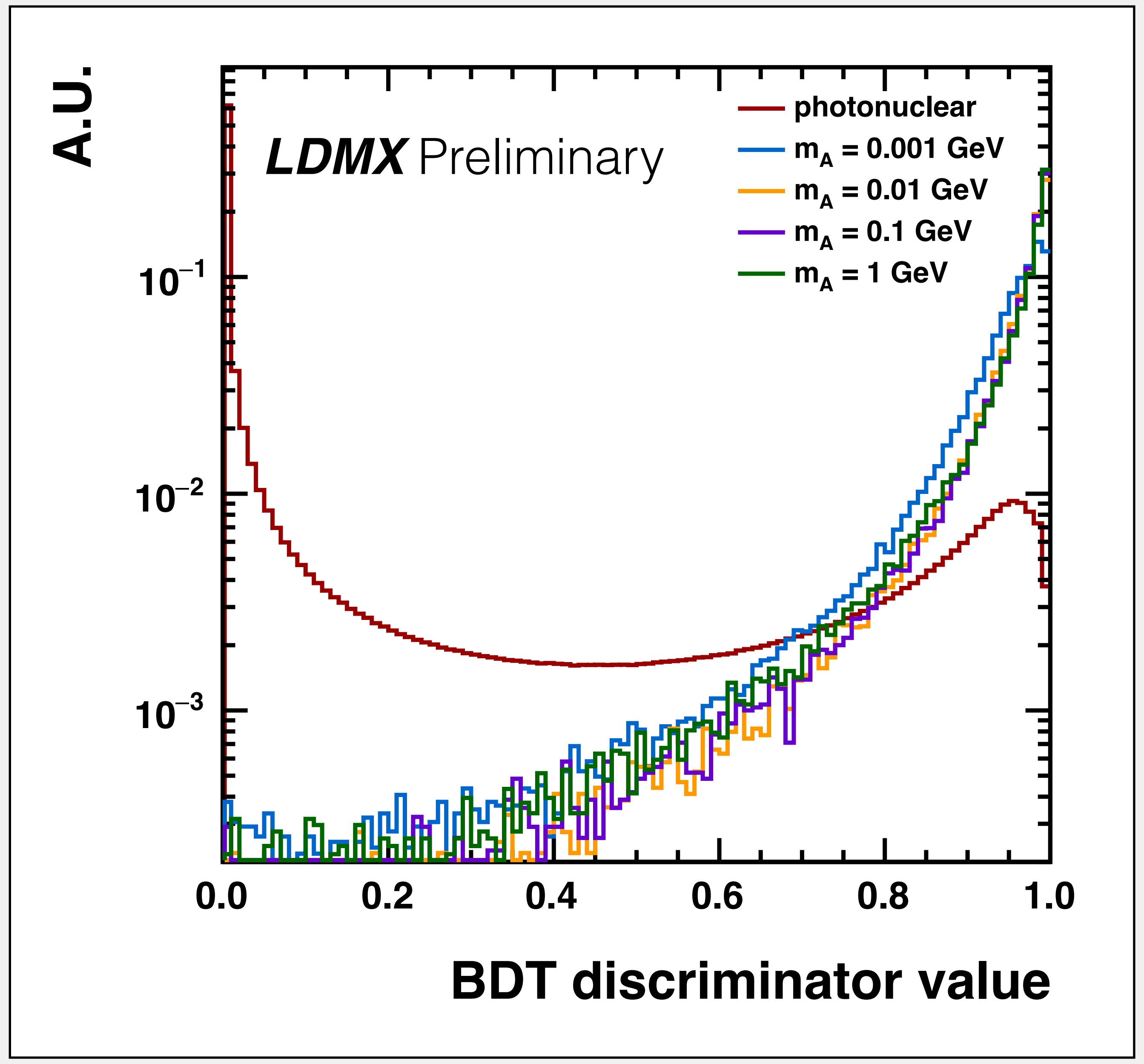
ECal

- draw on design of CMS forward SiW calorimeter upgrade
  - 32 layers with 7 modules each, 40 X_0
  - fast, radiation hard, dense
  - high granularity (MIP ‘tracking’)
    - potentially increase granularity in central module





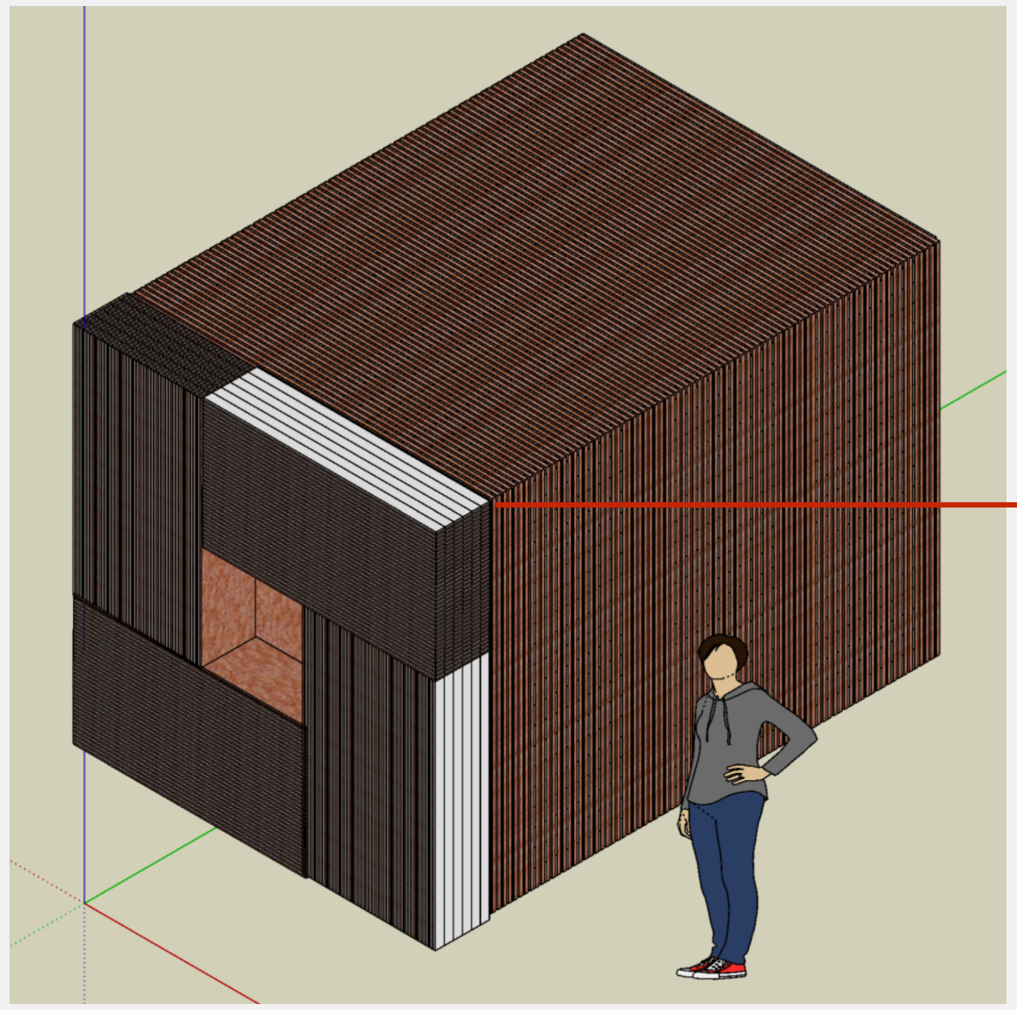


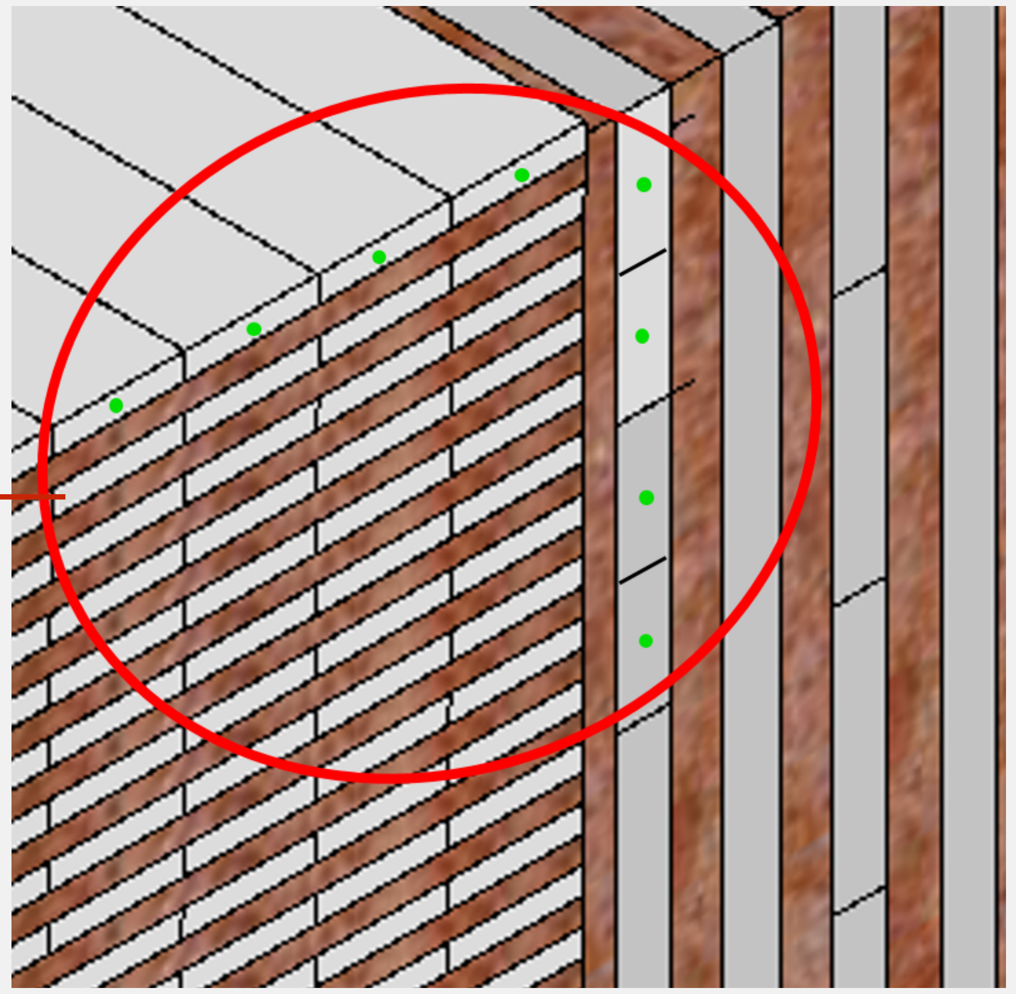


Hadronic Calorimeter

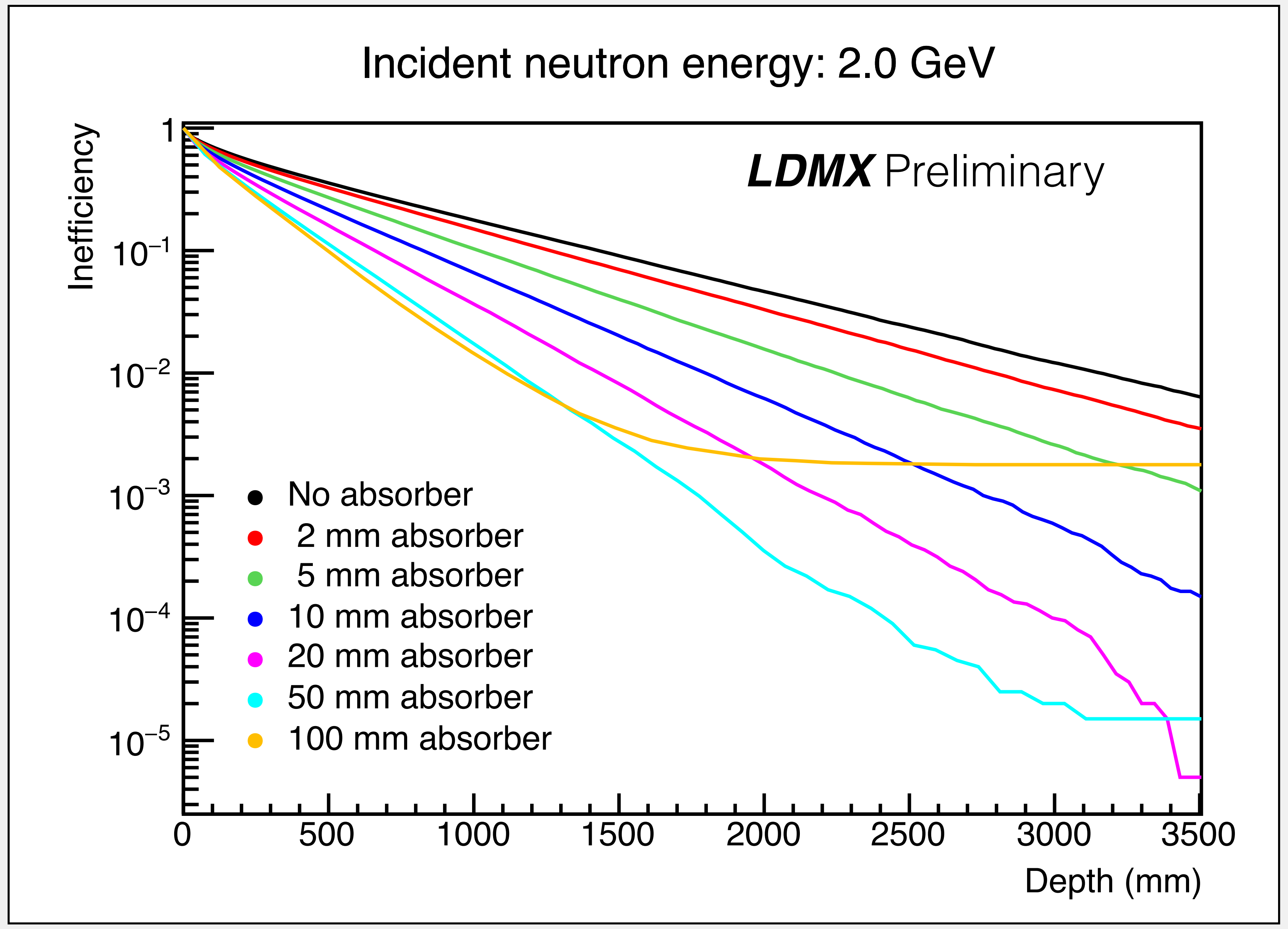
HCal

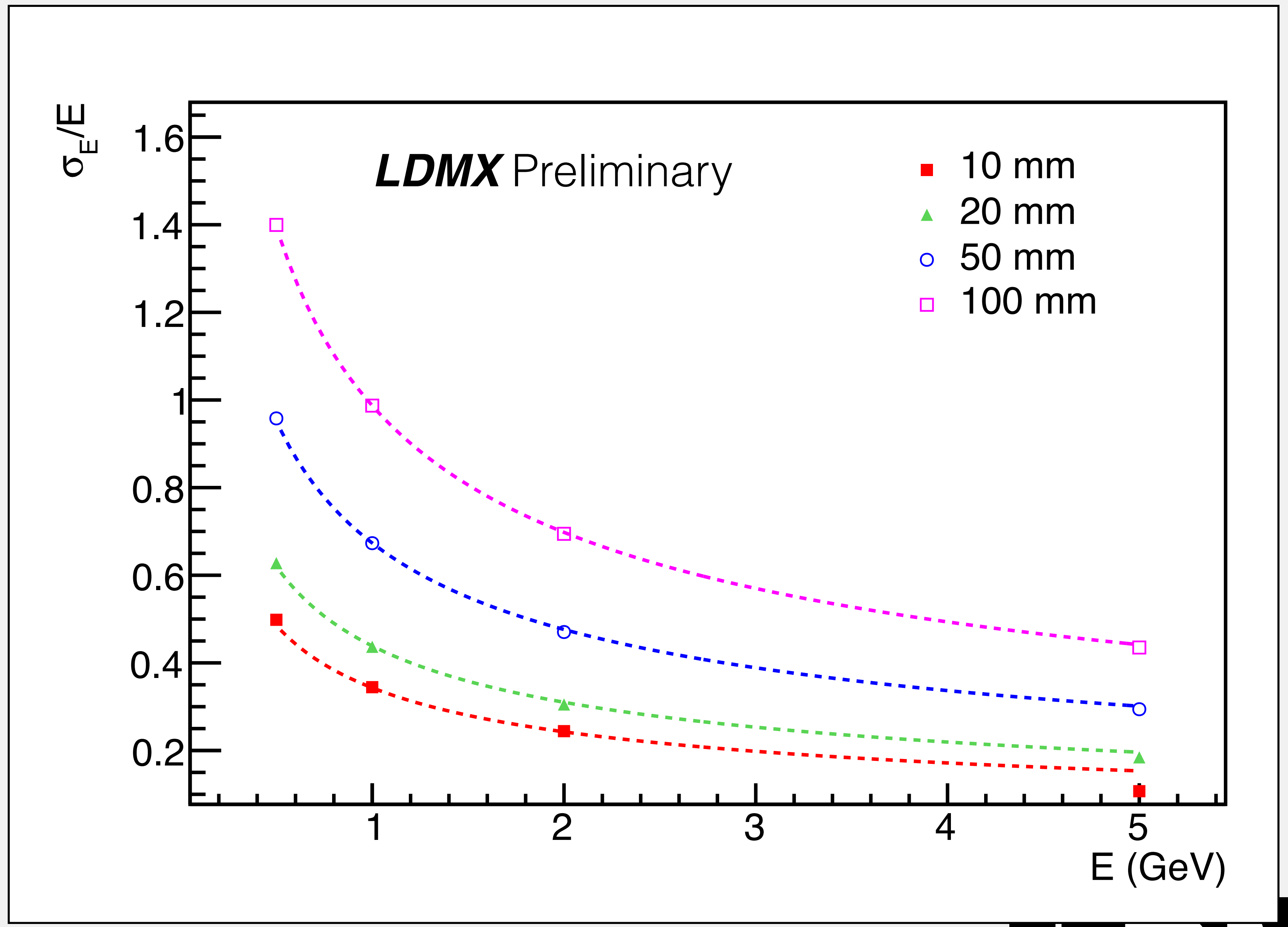
- need highly efficient **veto** for low- and high-energy neutrons
- plastic scintillator with steel absorber
- surround ECal as much as possible (back and side)



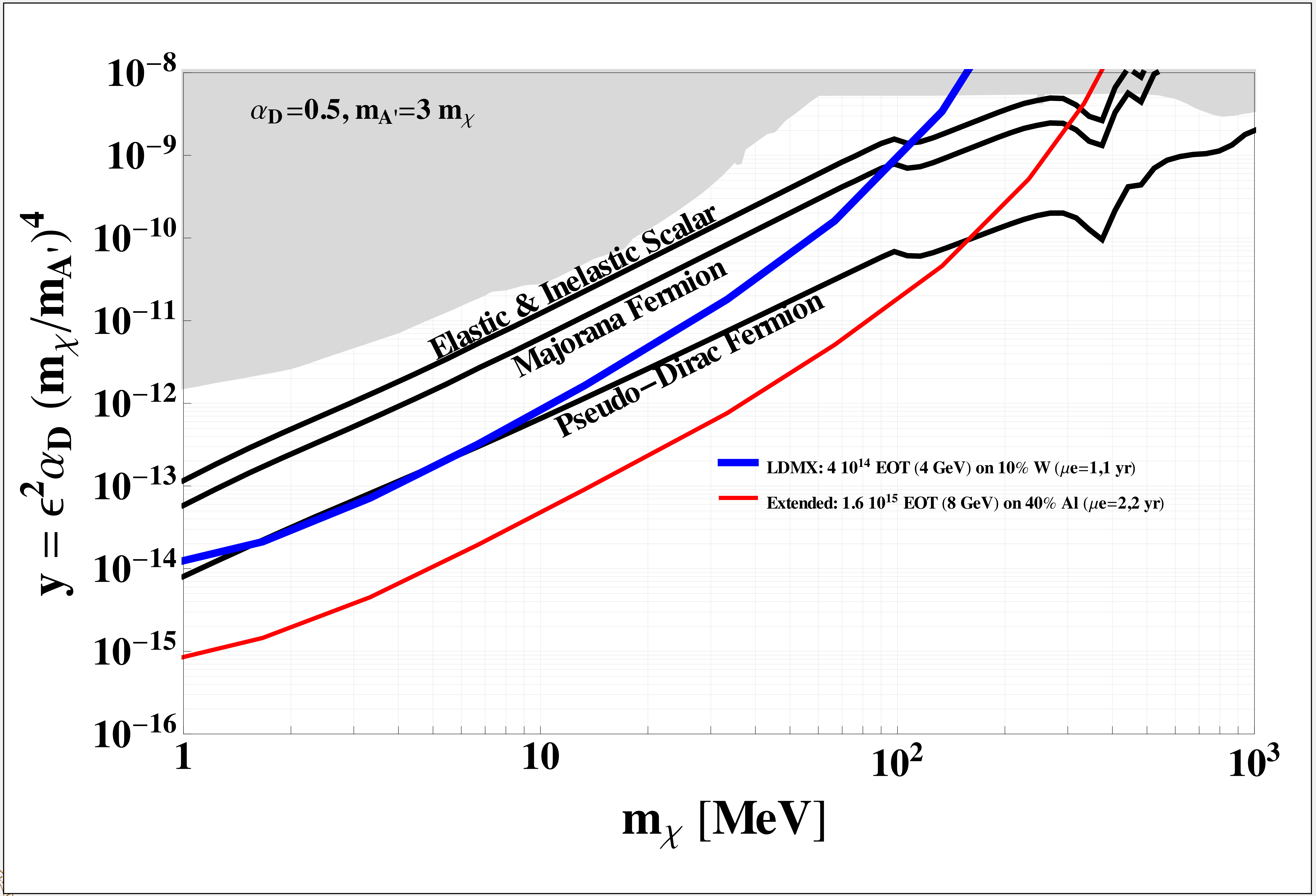


preliminary simulation studies show potential to get close to 0 background in phase 1, while retaining decent energy resolution





Projected Sensitivity



LDMX can explore a lot of new parameter space

sensitive to various thermal targets already with phase 1

ultimately potential to probe all thermal targets up to O(100) GeV

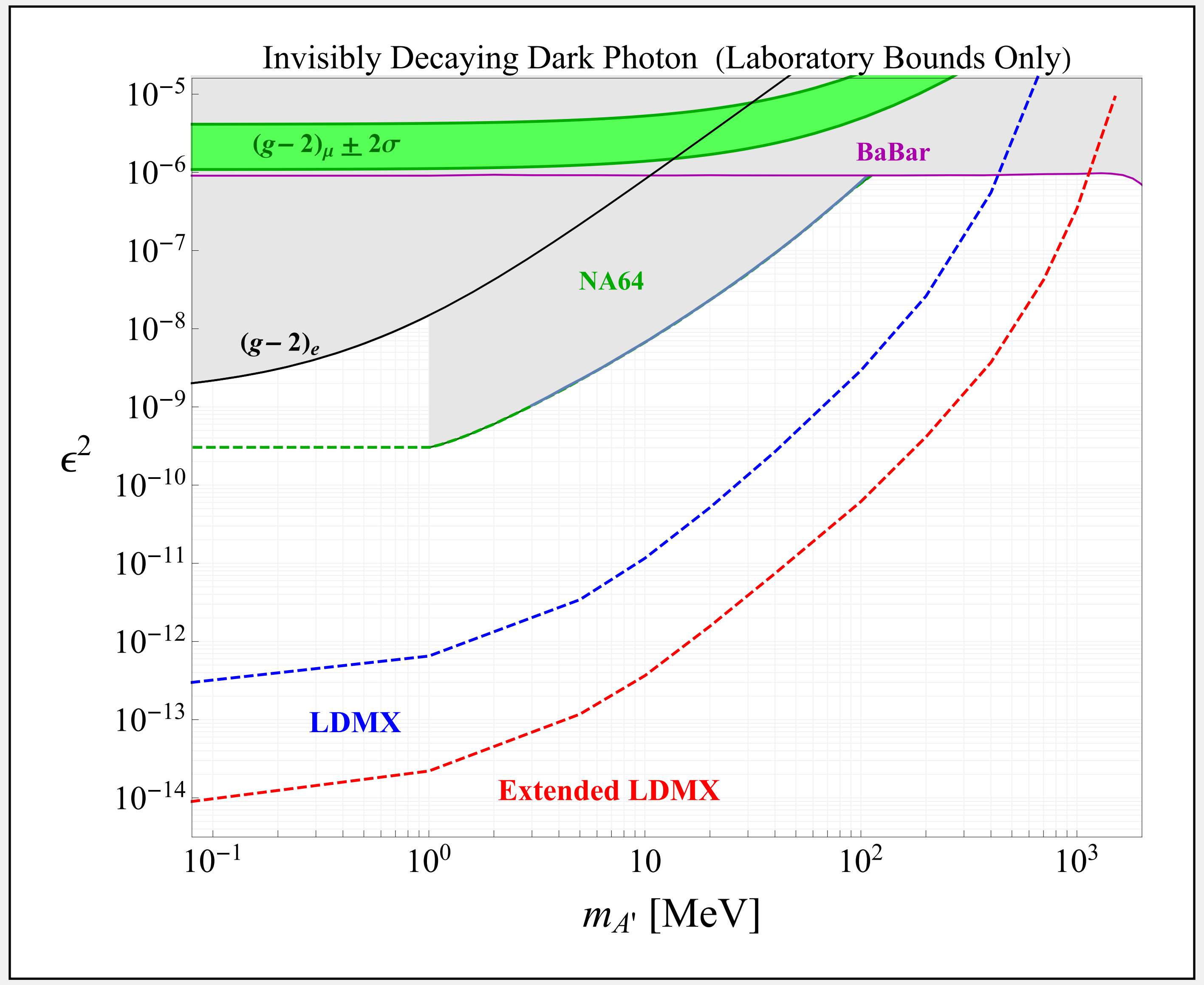
timescale: few years

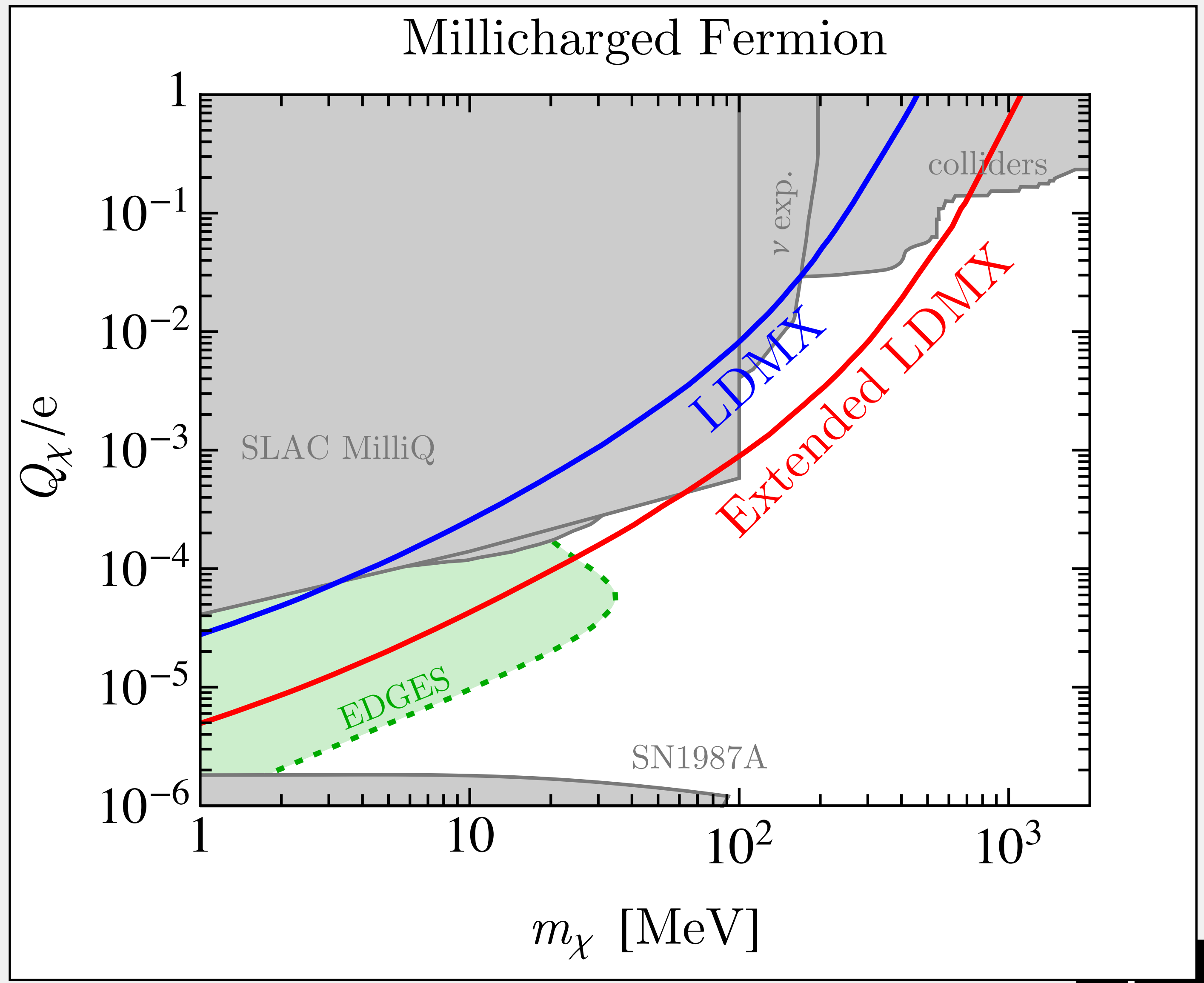
Further Potential

also sensitive to

- DM with quasi-thermal origin (asymmetric, SIMP/ELDER scenarios)
- new invisibly decaying mediators in general (A' one example)
- displaced vertex signatures (e.g. co-annihilation, SIMP)
- milli-charged particles

in addition: *measurement* of photo- and electro-nuclear processes (for neutrino experiments)





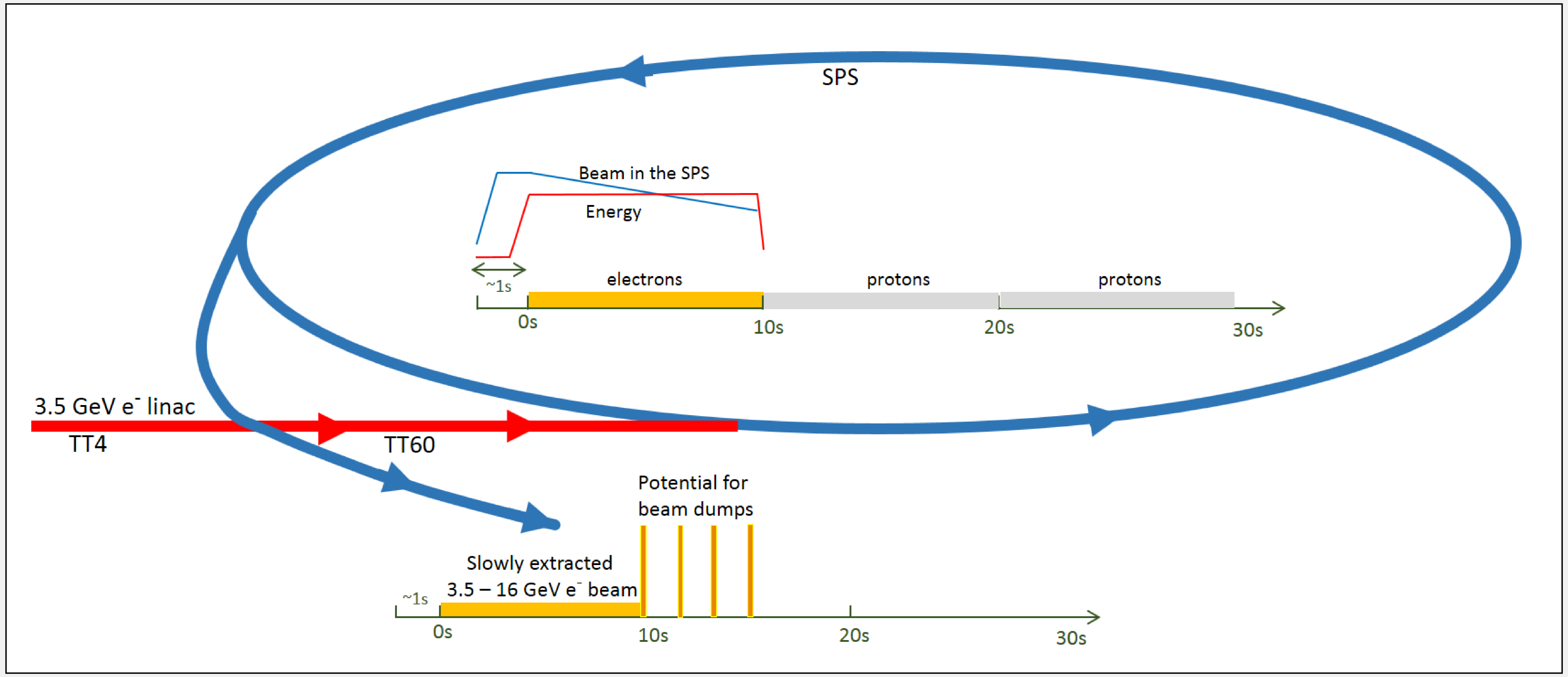
A special beam…

requirements for an experiment like LDMX

- multi-GeV (ideally ~15 GeV)
- low current (resolve individual particles)
- large beam spot (separation of particles)
- high repetition rate (high integrated number of EoT)

triggered idea of having a **new Linac into SPS@CERN**, quickly became active field of study arxiv:1805.12379

- 3.5 GeV Linac as injector to SPS
- large number of electrons can be filled within 2s
- slow extraction over 10s
- can run in parallel with other SPS programme



flexible parameters:

- energy: 3.5 - 16 GeV
- electrons per bunch: 1 - 40
- bunch spacing: multiples of 5 ns
- adjustable beam size

Summary

- light, thermal relic Dark Matter well motivated
- fixed-target, missing-momentum approach provides unprecedented sensitivity
- LDMX the only such experiment on the horizon
  - start of data-taking in early 2020s
- potential to probe thermal targets in MeV - GeV range
  - complements direct detection
- more generally, sensitive to broad range if sub-GeV physics

Collaboration

Light Dark Matter eXperiment (LDMX)

Torsten Åkesson,[1] Asher Berlin,[2] Nikita Blinov,[2] Owen Colegrove,[3] Giulia Collura,[3] Valentina Dutta,[3] Bertrand Echenard,[4] Joshua Hiltbrand,[5] David G. Hitlin,[4] Joseph Incandela,[3] John Jaros,[2] Robert Johnson,[6] Gordan Krnjaic,[7] Jeremiah Mans,[5] Takashi Maruyama,[2] Jeremy McCormick,[2] Omar Moreno,[2] Timothy Nelson,[2] Gavin Niendorf,[3] Reese Petersen,[5] Ruth Pöttgen,[1] Philip Schuster,[2] Natalia Toro,[2] Nhan Tran,[7] and Andrew Whitbeck[7]

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[3]University of California at Santa Barbara, Santa Barbara, CA 93106, USA
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[5]University of Minnesota, Minneapolis, MN 55455, USA
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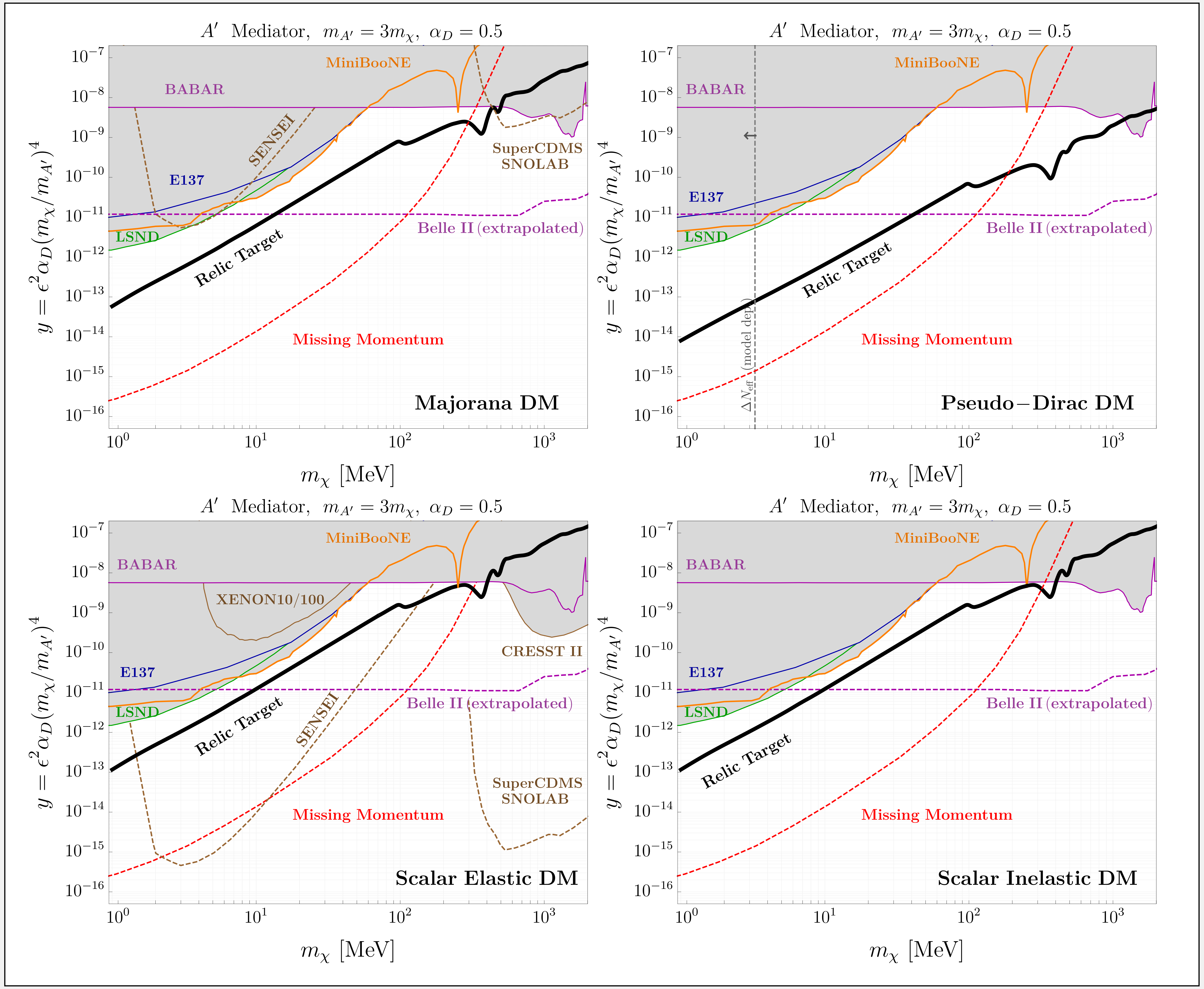
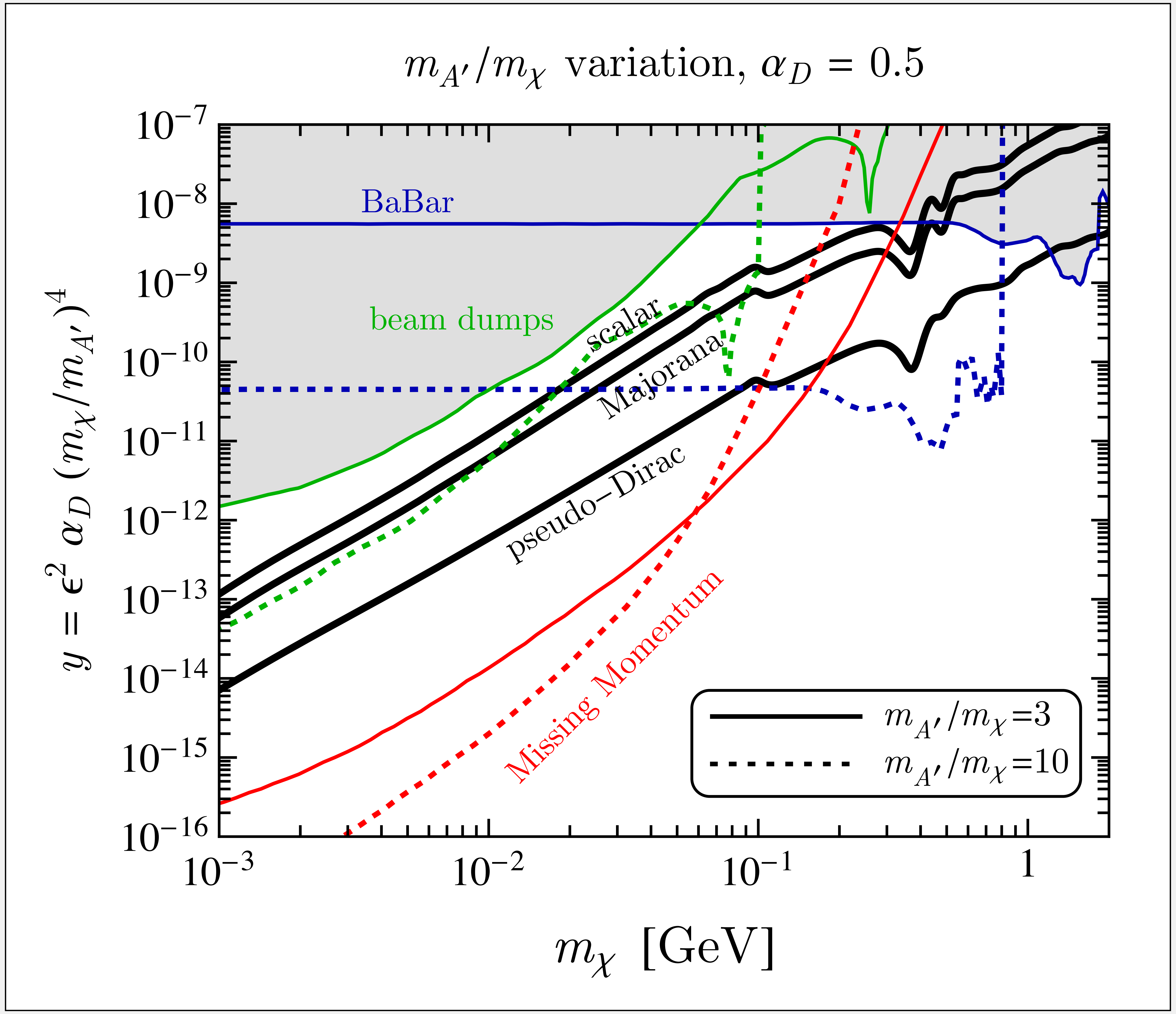
[7]Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

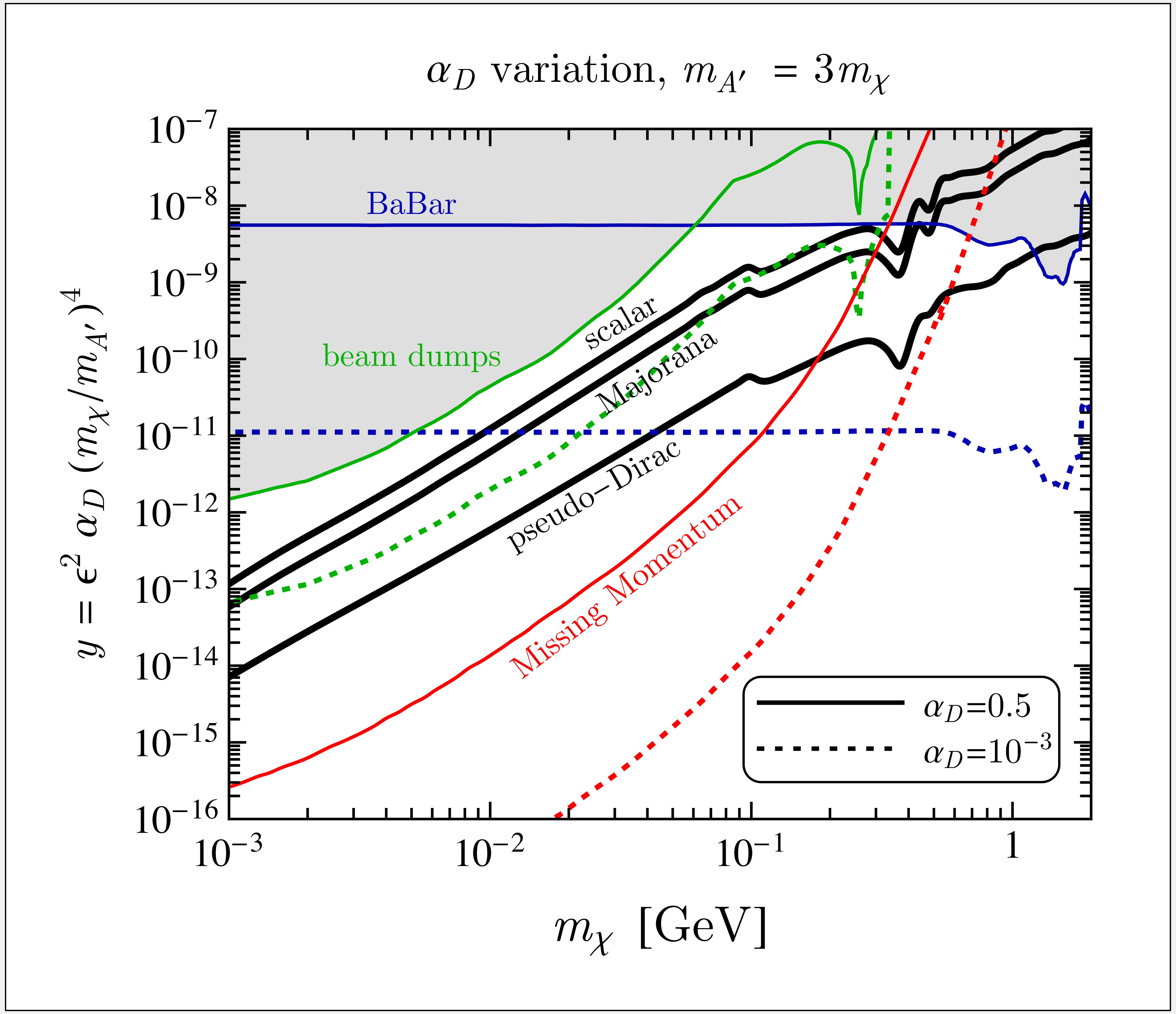
Additional Material

Various Future Projections

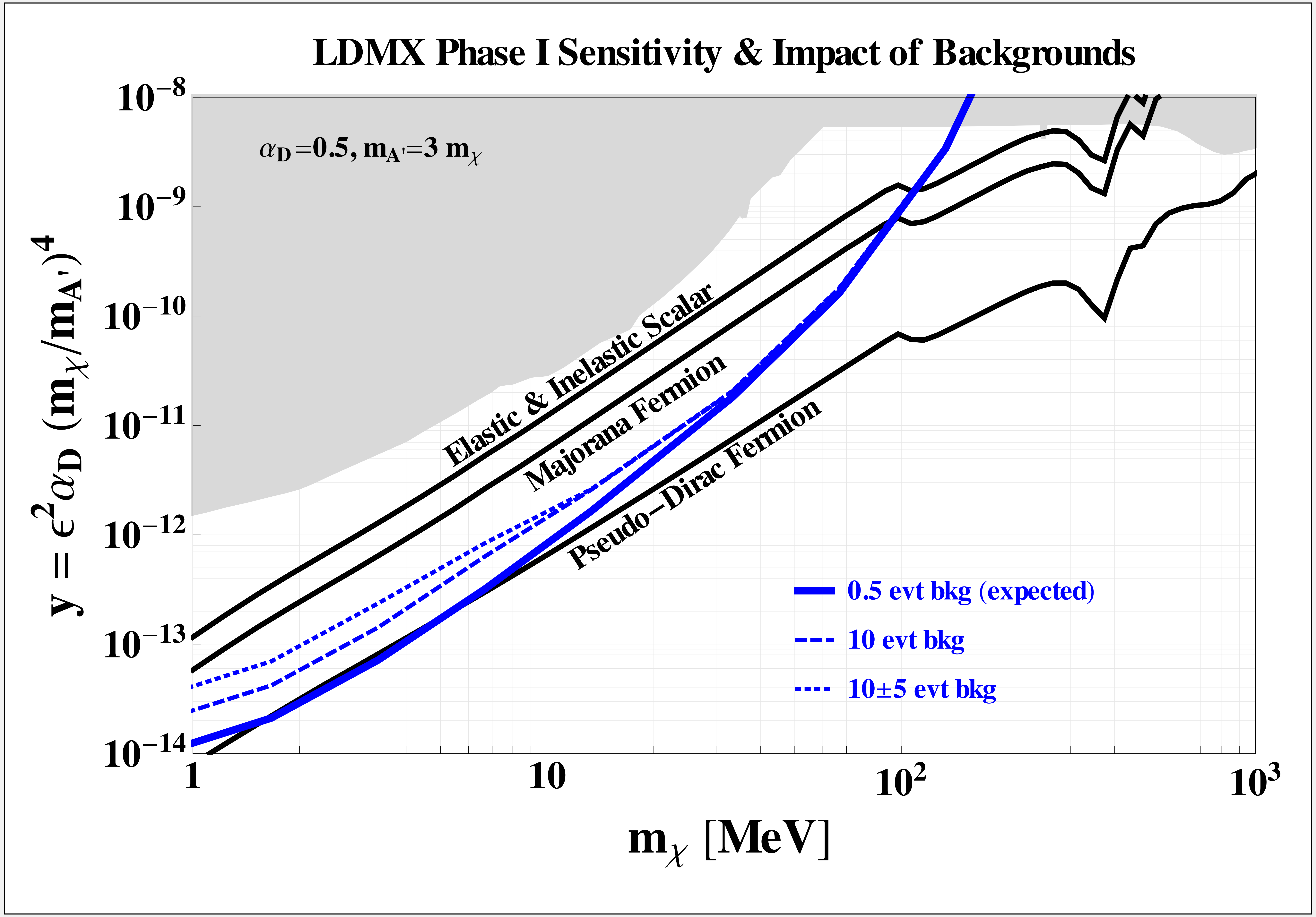


Parameter Dependency





Impact of Backgrounds



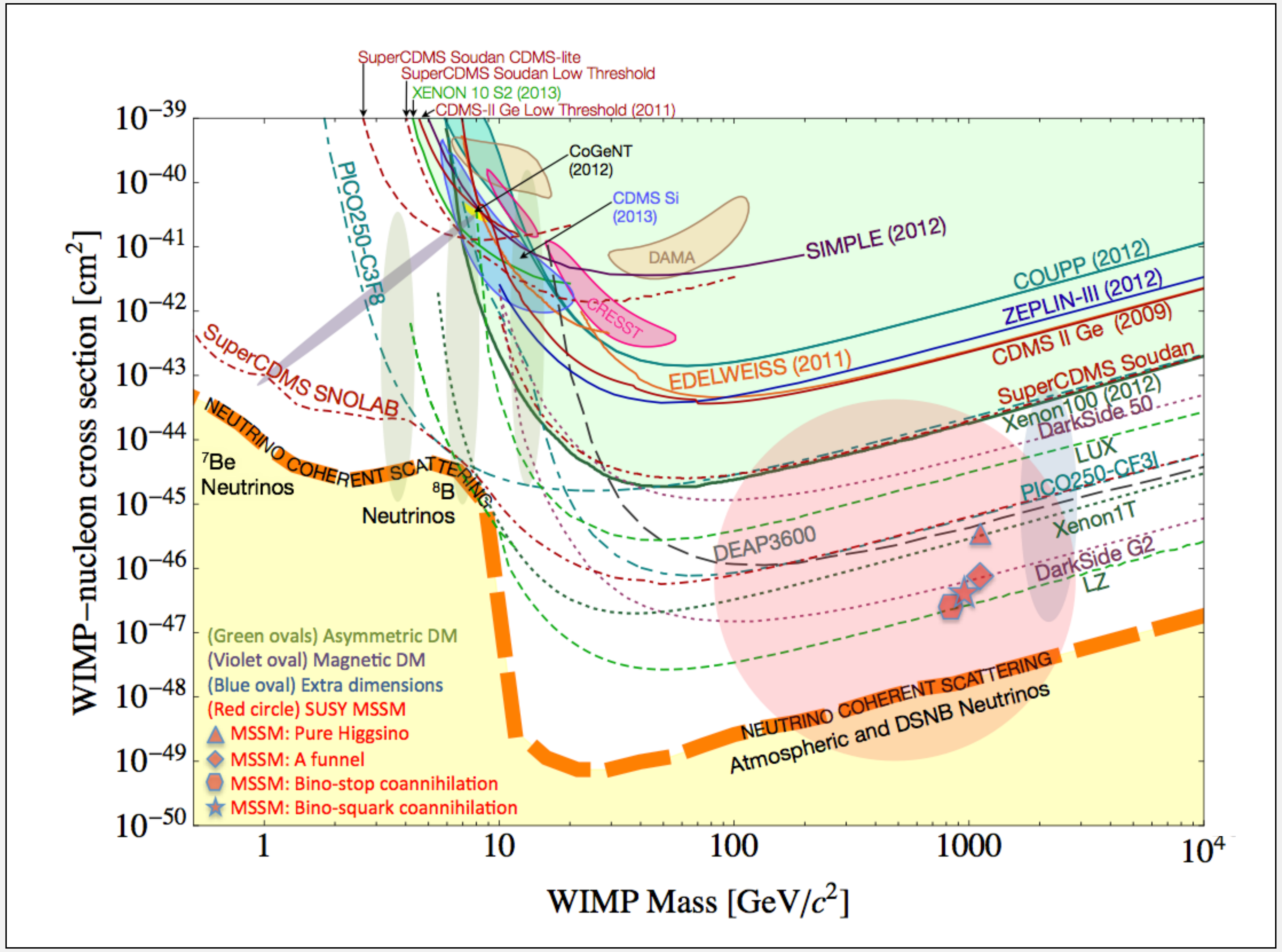
Direct Detection

Direct detection: **nuclear** recoil due to WIMP scattering

- sensitivity drops quickly below few GeV

Many new ideas in recent years to get to lower masses

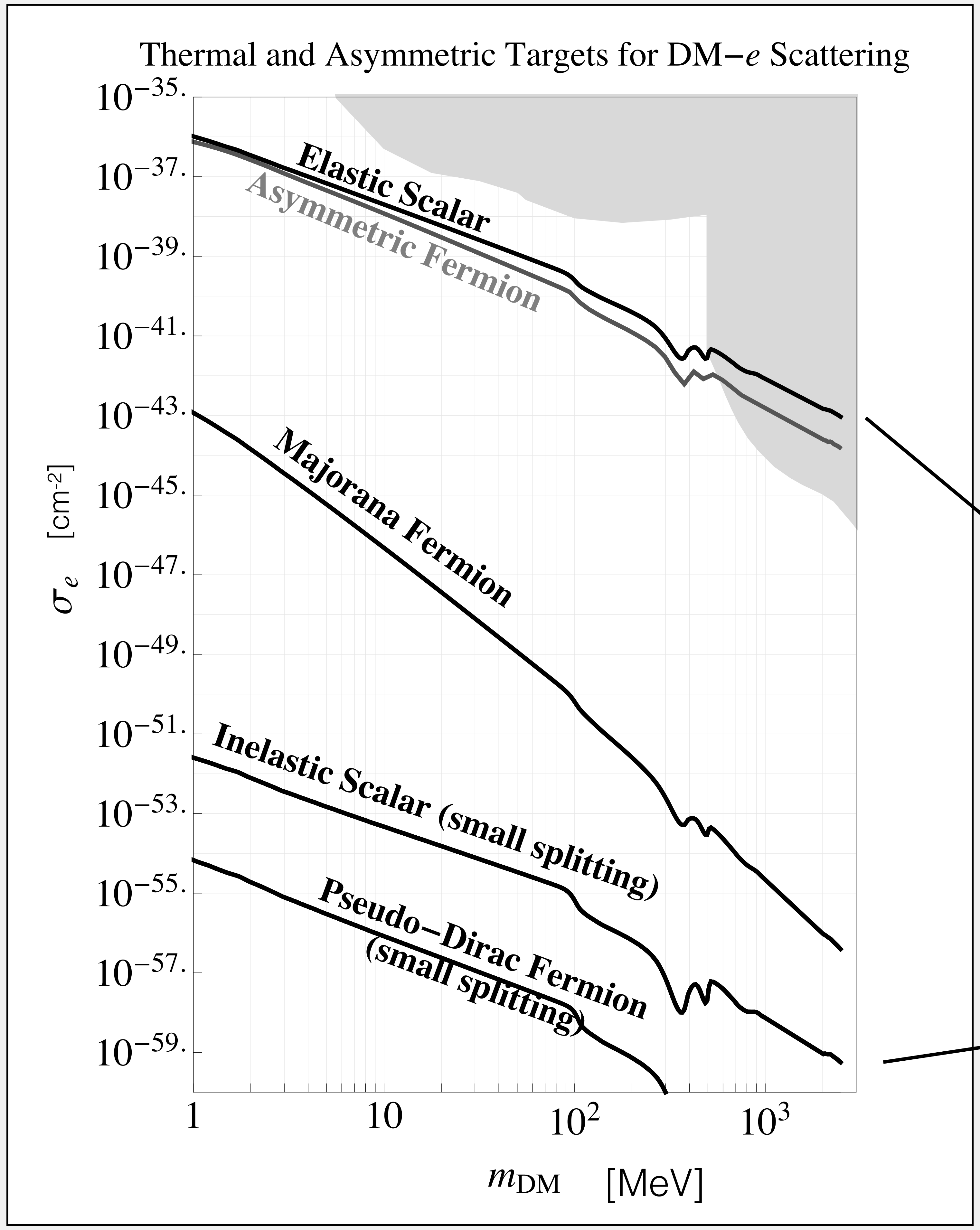
- needs lower energy threshold
  - examples:
    - electron-DM scattering
    - semiconductors



Why not just direct detection?

direct detection:

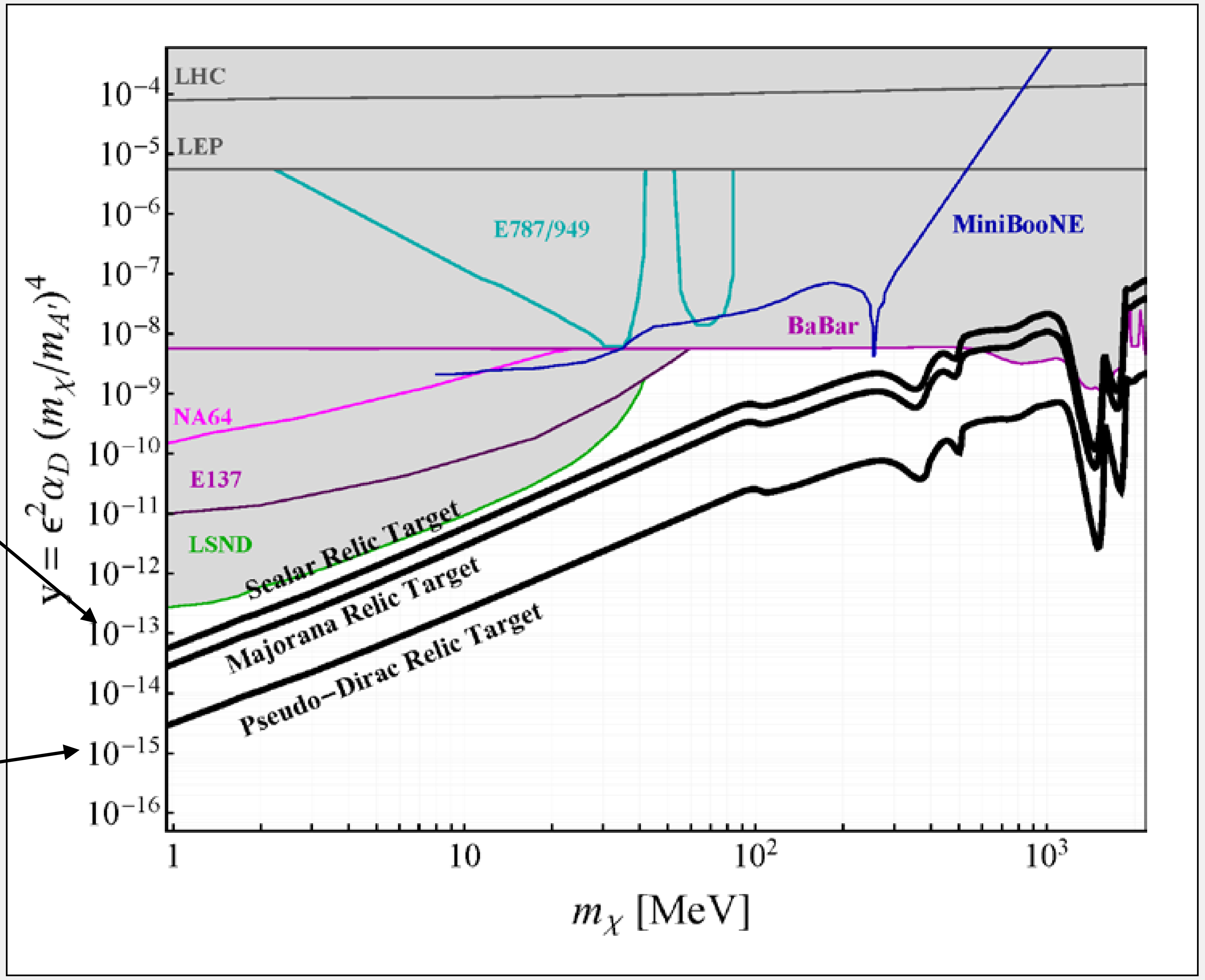
strong spin/velocity dependency



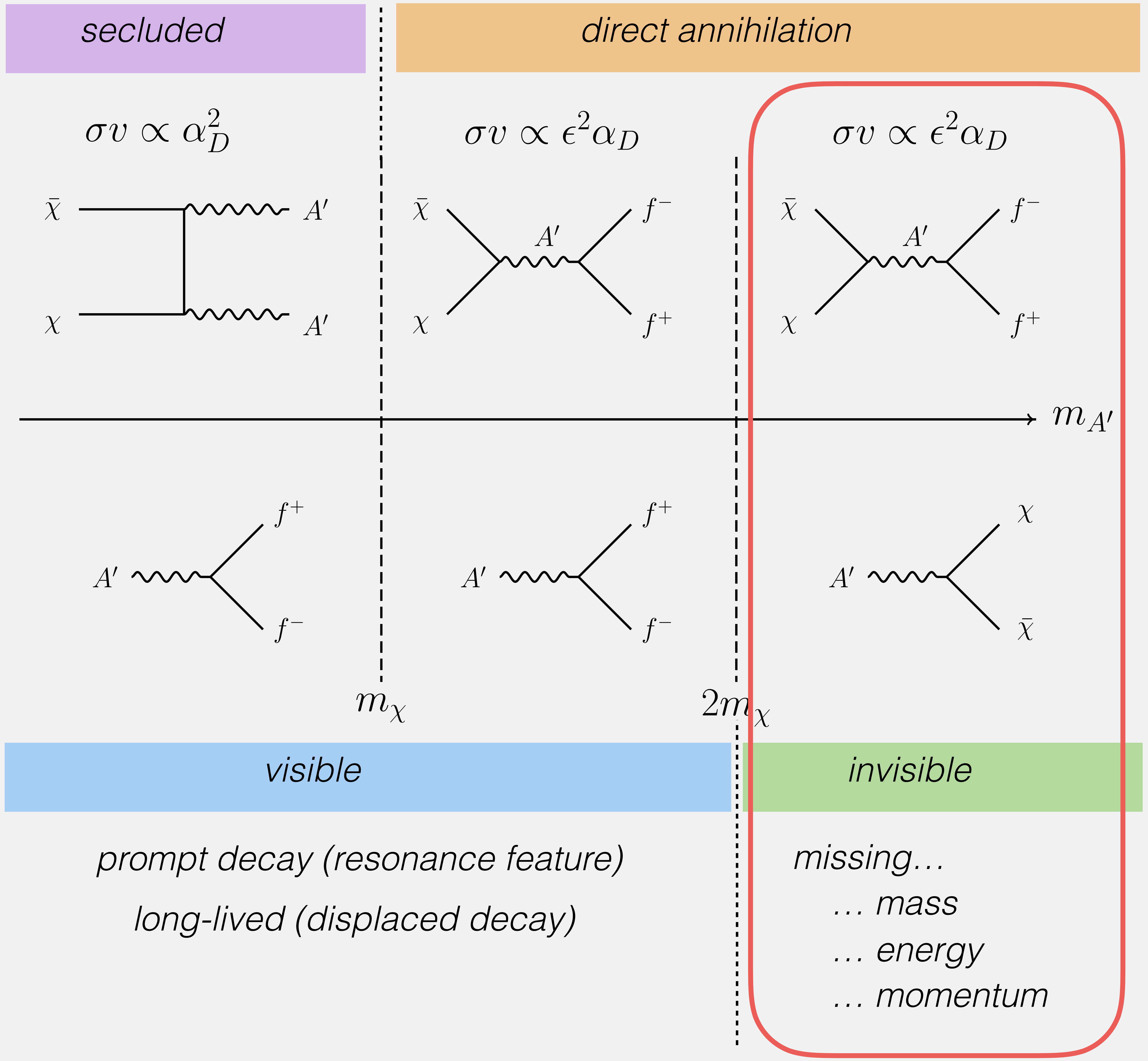
at accelerators: relativistic production

—> spin/velocity dependency reduced

all thermal targets in reach!



Signatures


secluded
direct annihilation
$\sigma v \propto \alpha_D^2$
$\sigma v \propto \epsilon^2 \alpha_D$
$\sigma v \propto \epsilon^2 \alpha_D$
$m_{A'}$
m_χ
$2m_\chi$
visible
invisible
prompt decay (resonance feature)
long-lived (displaced decay)
missing…
… mass
… energy
… momentum

Backgrounds