Progress and Prospects of LDMX

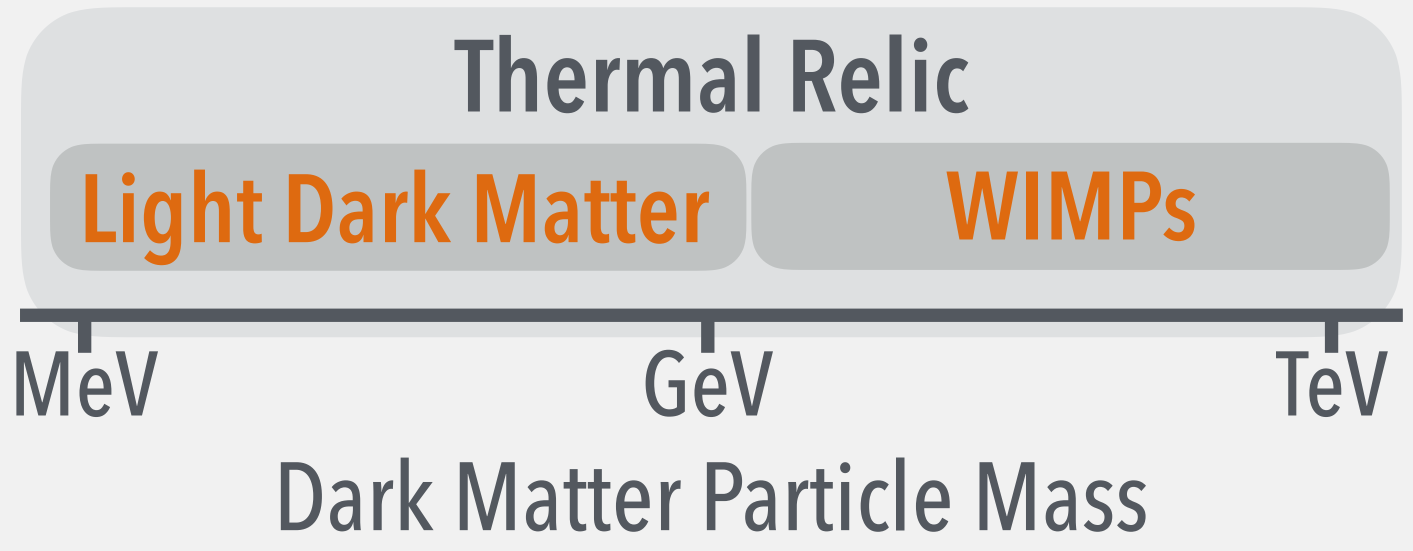
Partikeldagar 2019

Linköping

Ruth Pöttgen

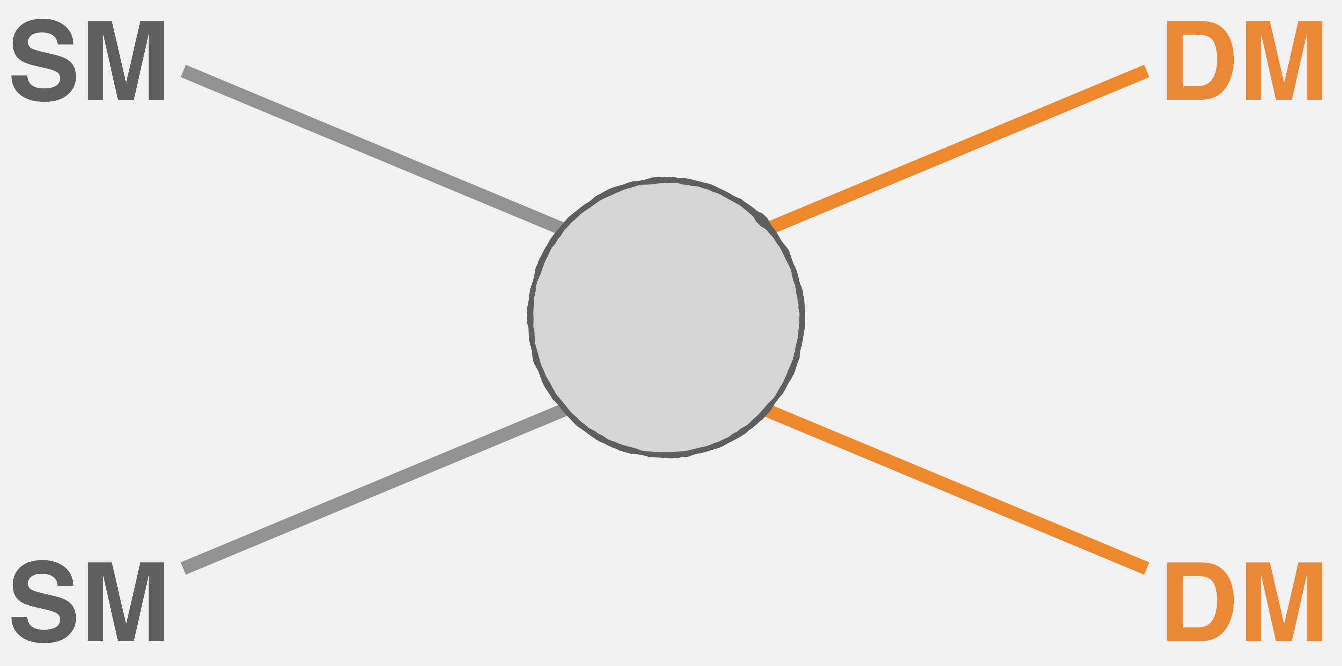
Light Dark Matter at Accelerators

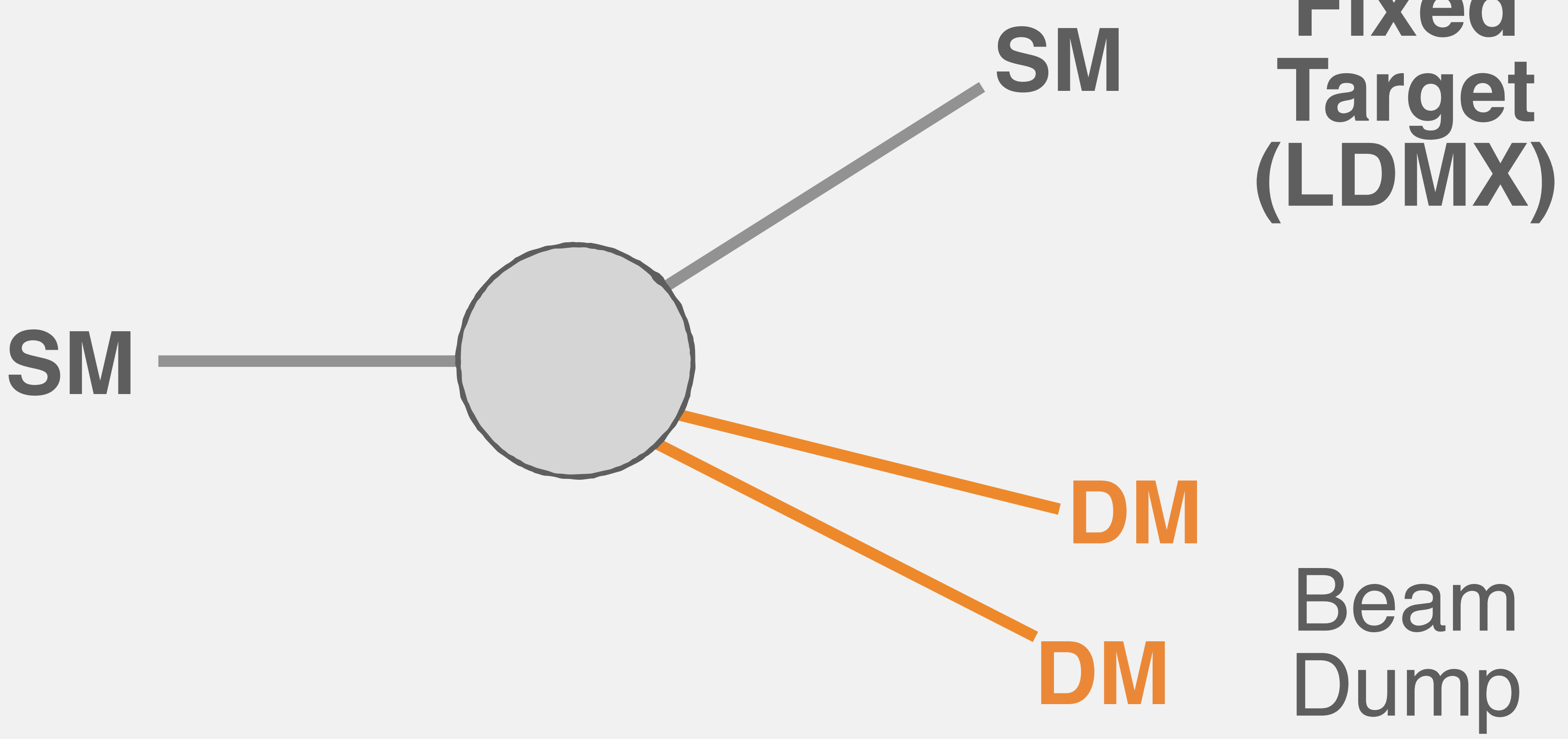
thermal origin of Dark Matter



—> allowed mass range MeV - TeV

—> production mechanism at accelerators/colliders

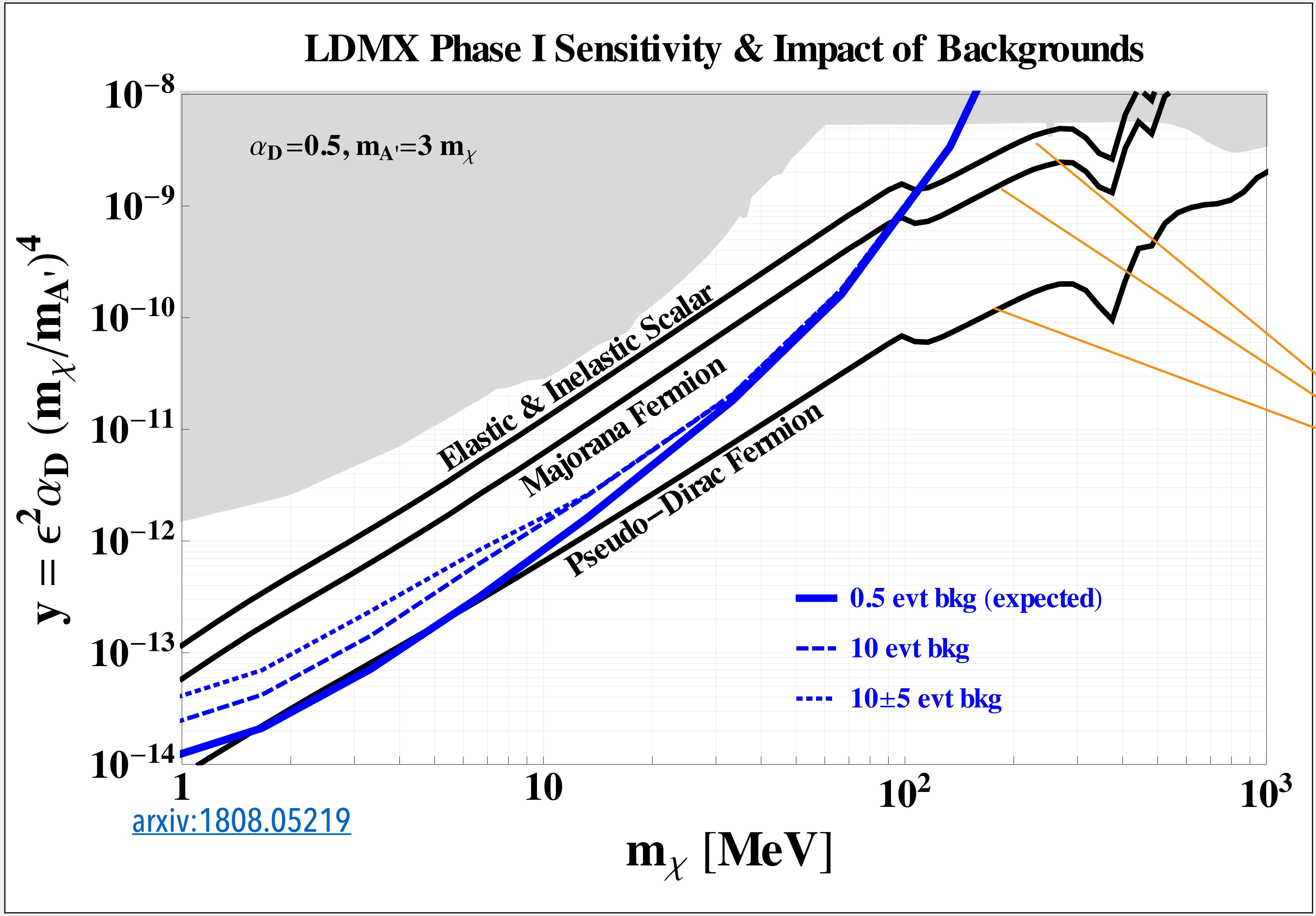




benchmark model: dark photon (A') as new light mediator

Sensitivity Milestones

interaction strength

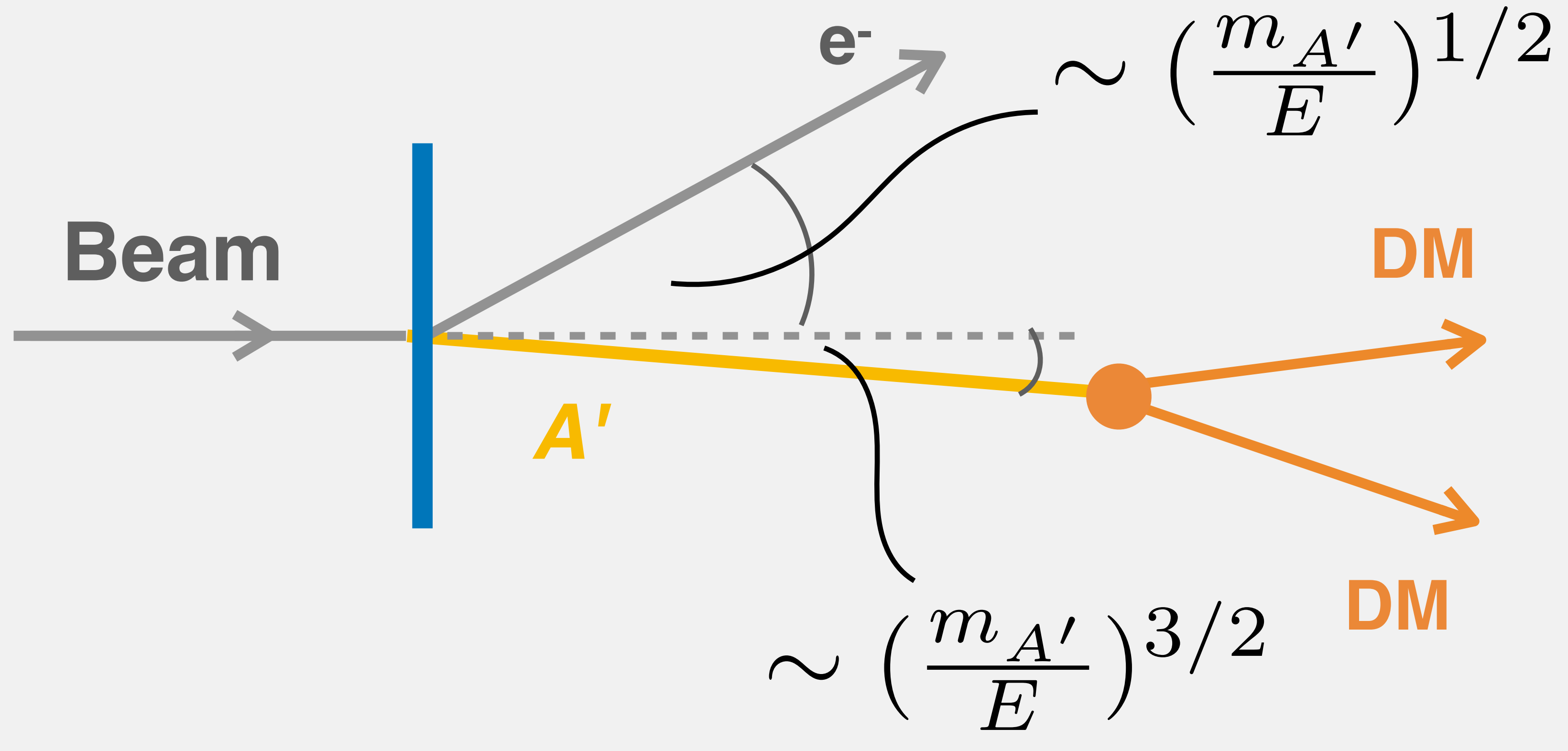


arxiv:1808.05219

thermal targets

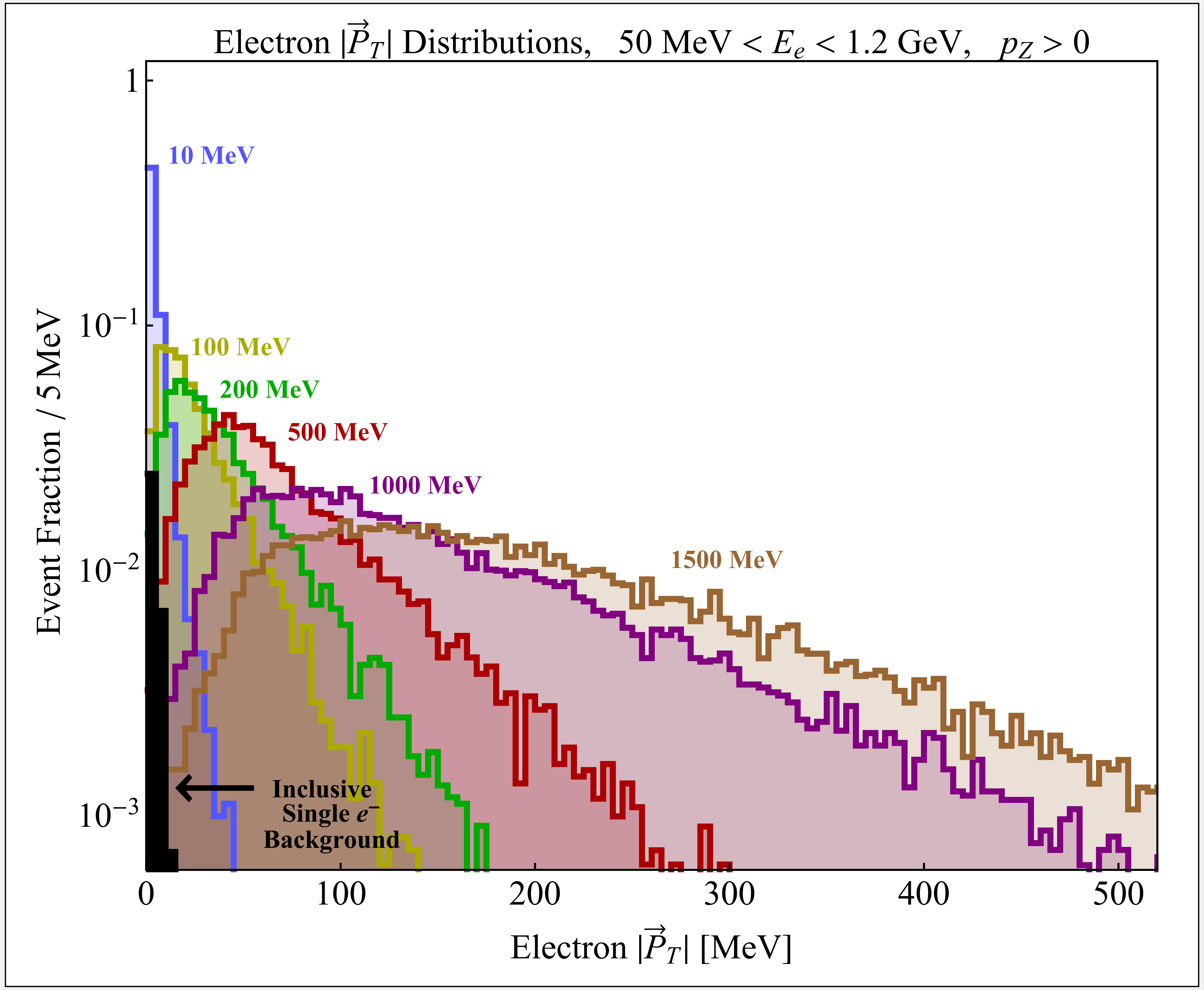
Kinematics

very different from SM bremsstrahlung (main background)



Mediator carries most of the energy
—> soft recoil electron, large missing energy

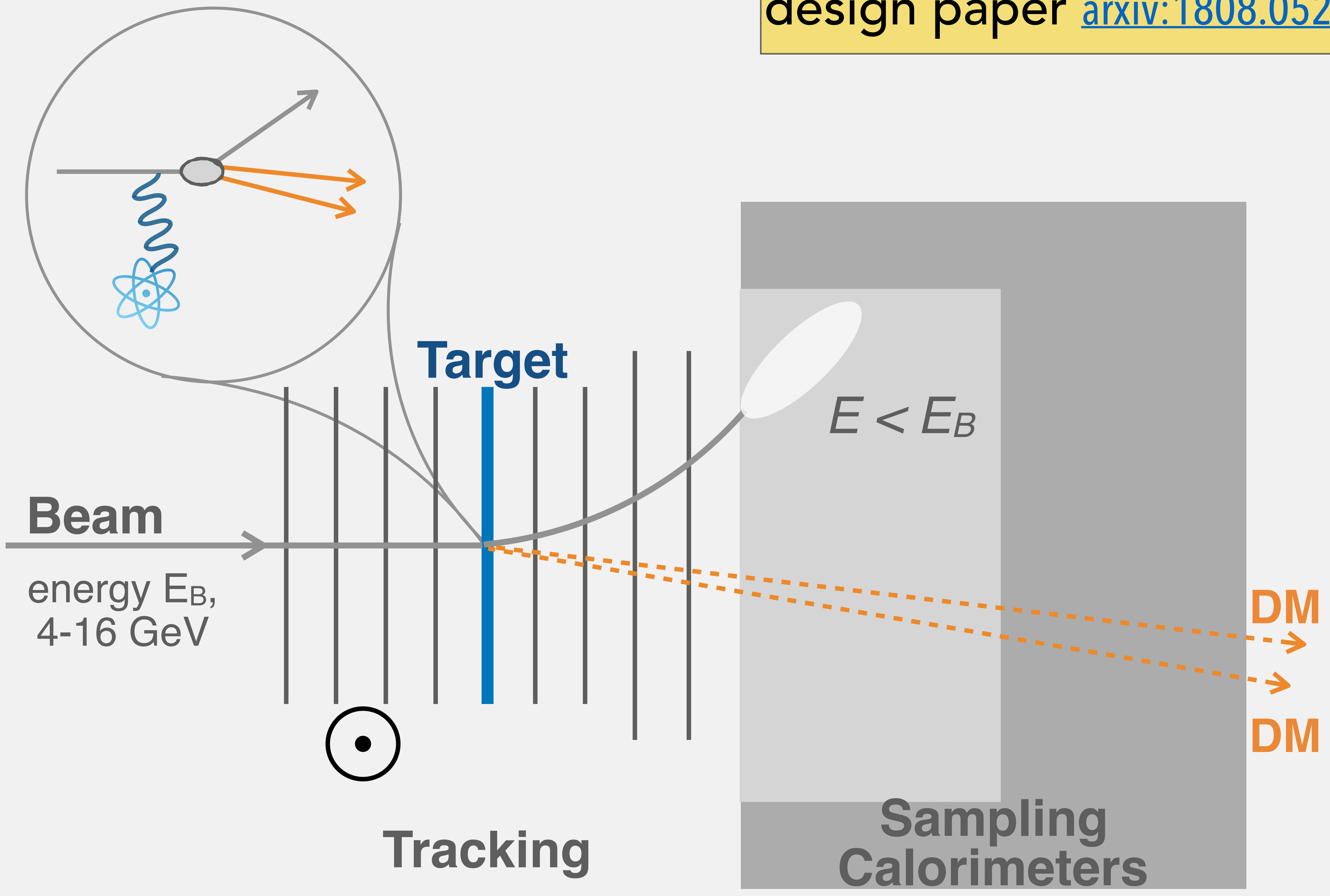
Recoil electron gets transverse 'kick'
—> large missing transverse momentum

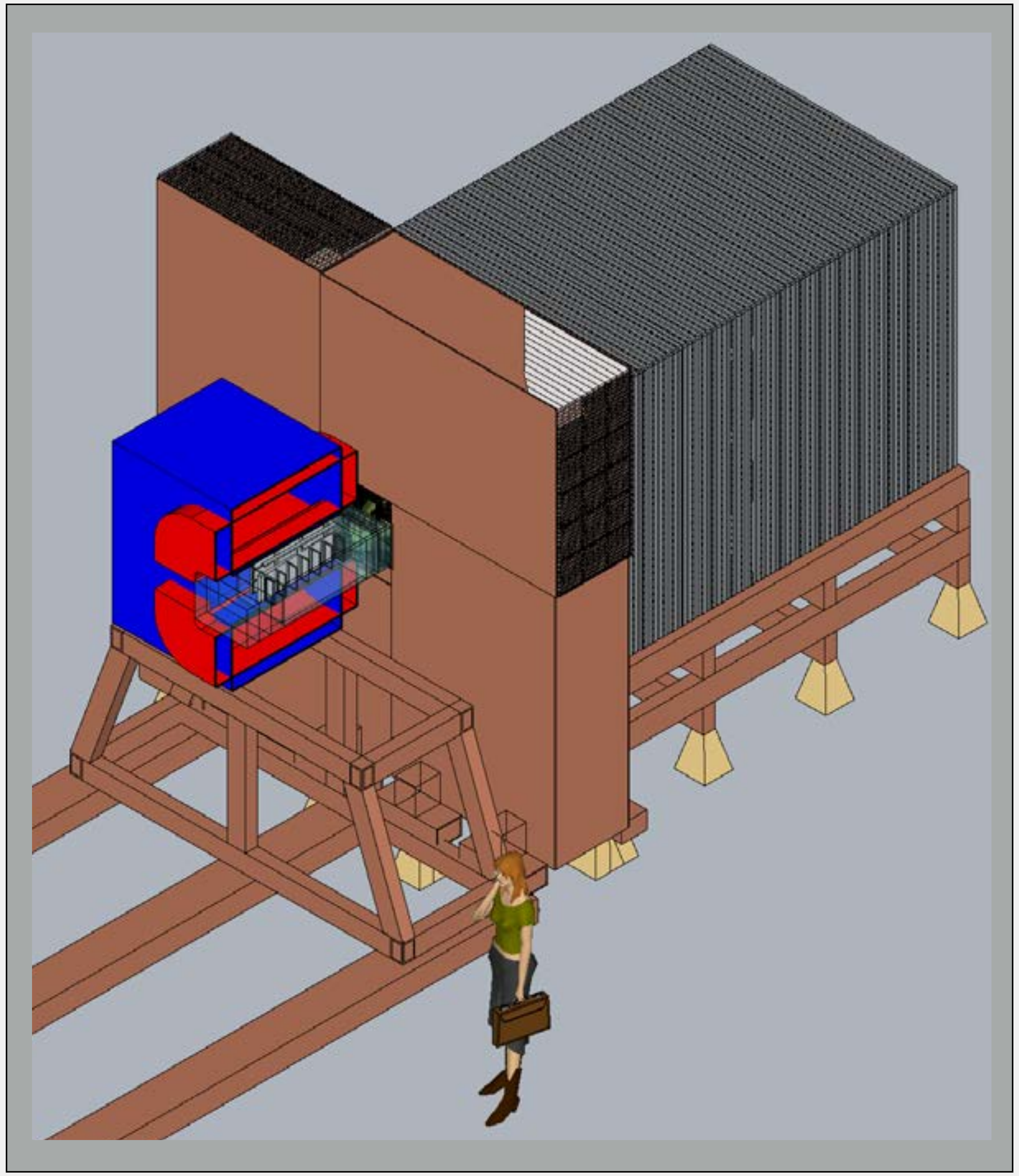


measurement of p_T: strong discriminator AND information about (missing) mass!

LDMX Light Dark Matter eXperiment

design paper arxiv:1808.05219



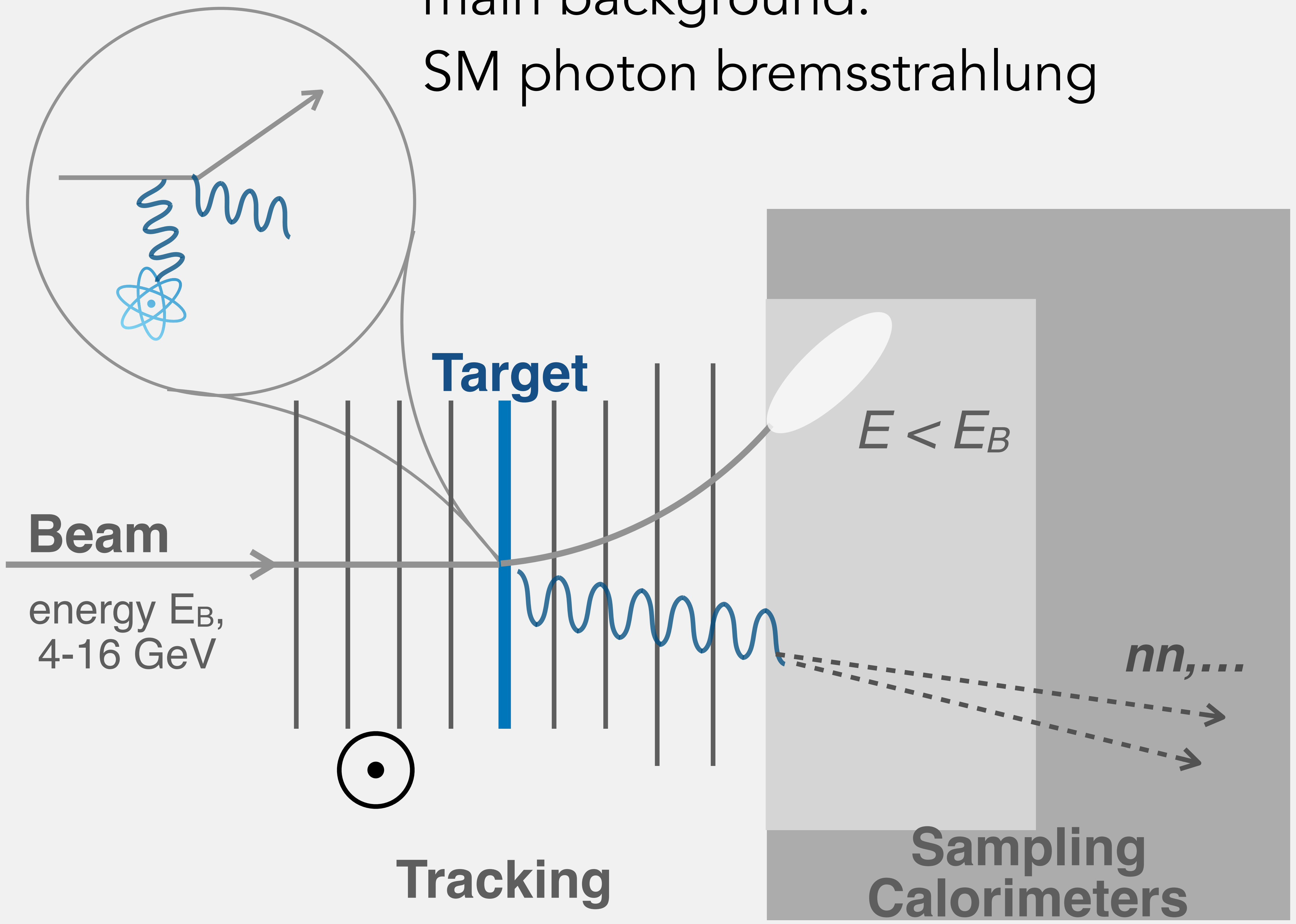


individually measure up to 10^{16} electrons on target (EoT),
missing energy & *missing (transverse) momentum*

small-scale experiment

Background Challenges

main background:
SM photon bremsstrahlung



particularly challenging:

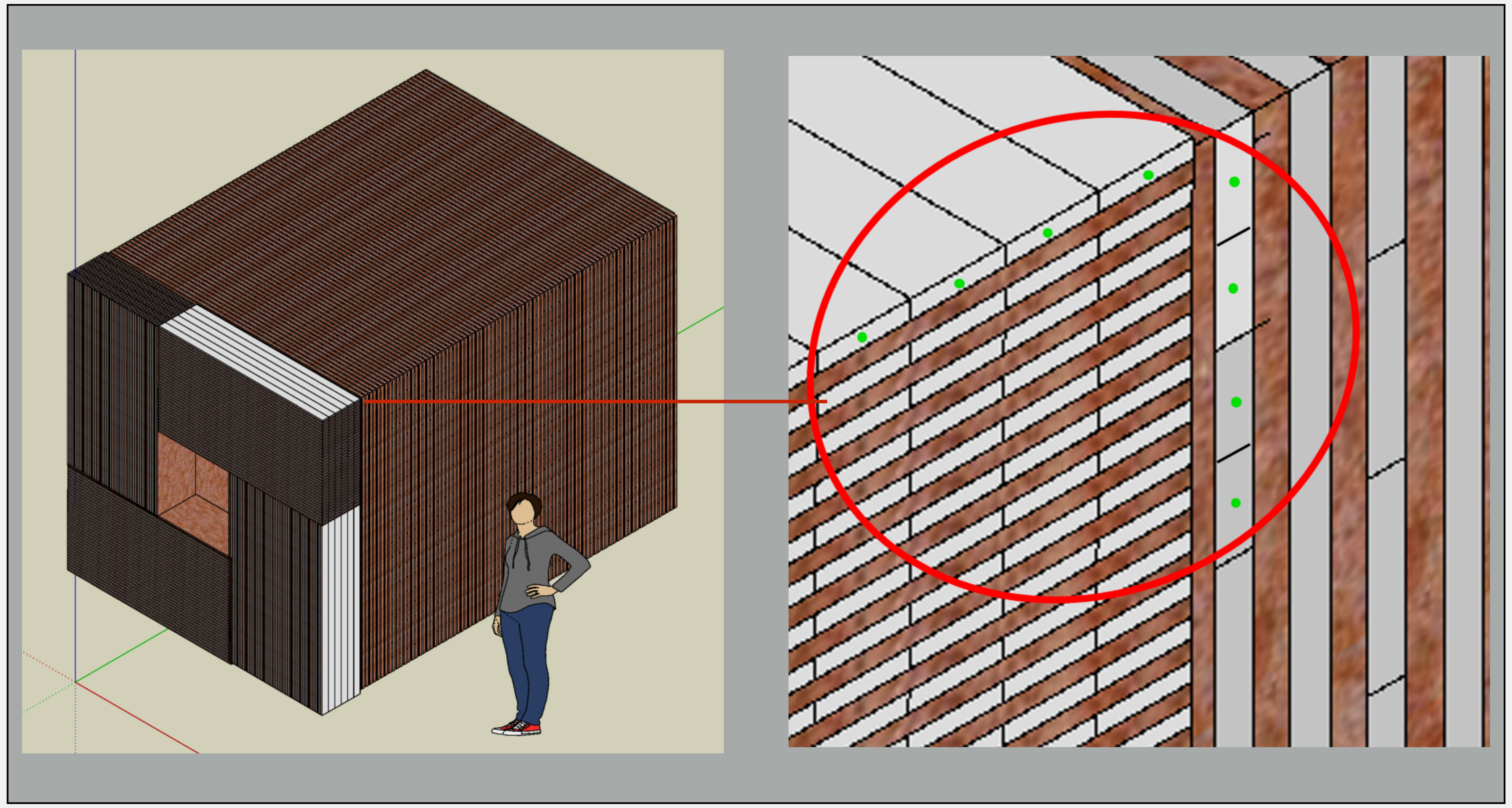
photo-nuclear reactions producing *neutral final states* (relative rate: ~10^{-9})

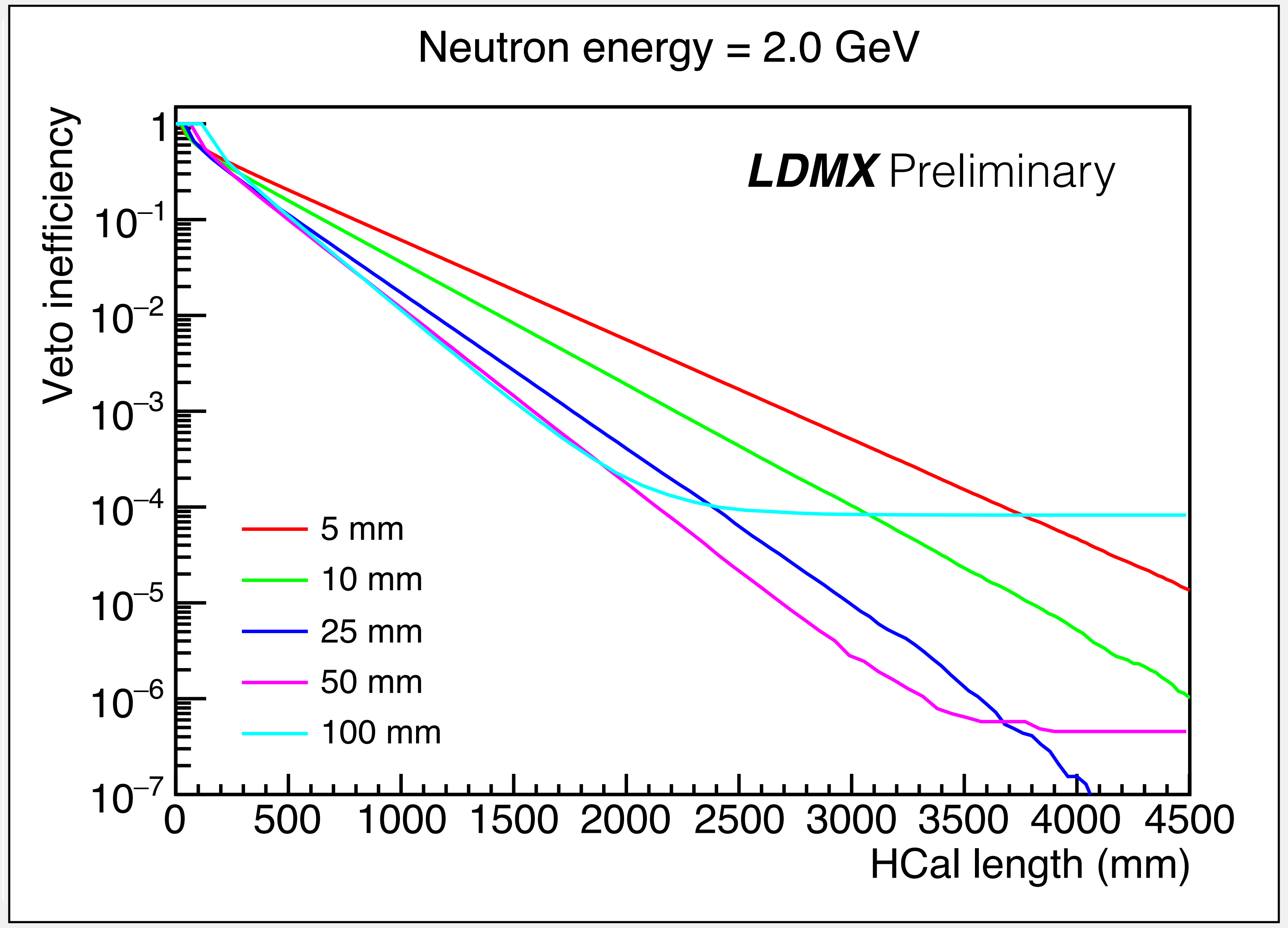
—> most design work recently on HCal to optimise rejection power

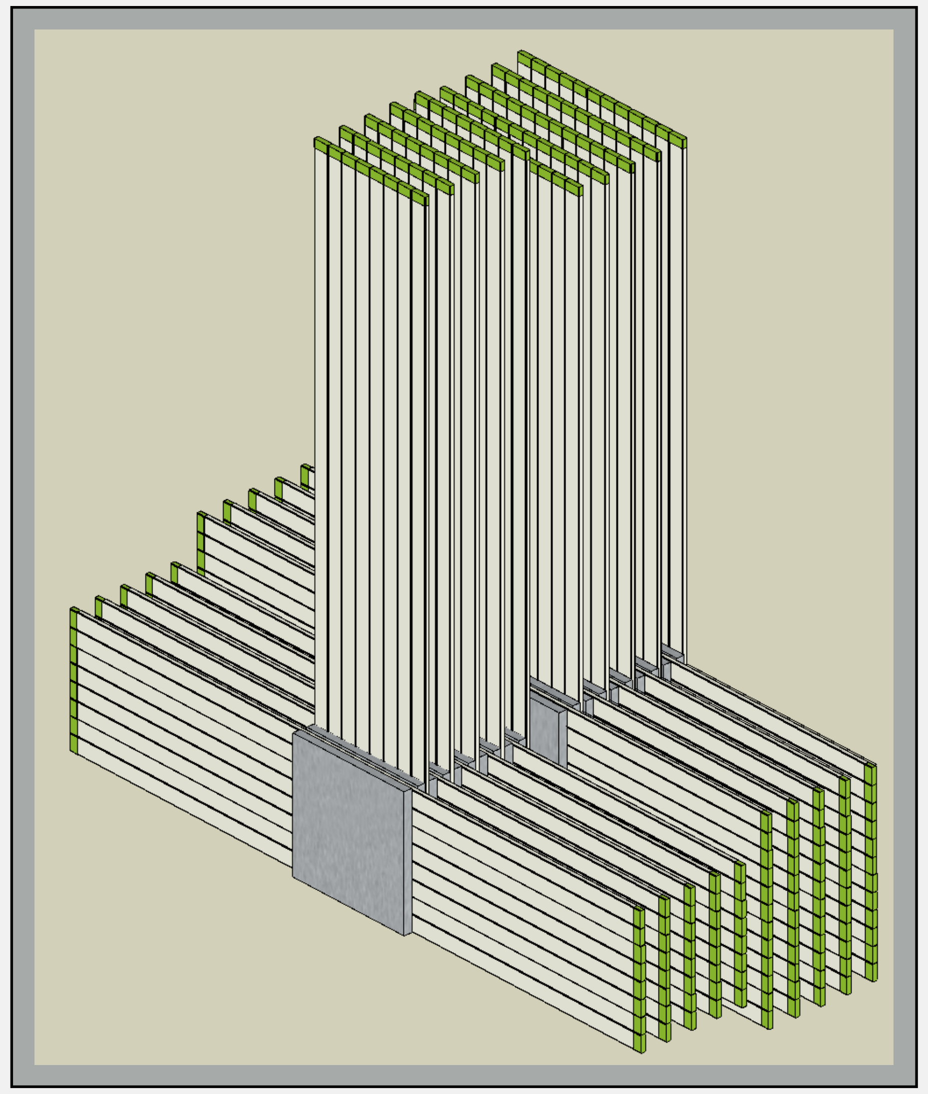
Hadronic Calorimeter

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)







prototype configuration for testbeam planned in 2020,

with support from

Crafoord Foundation and Royal Physiographic Society of Lund

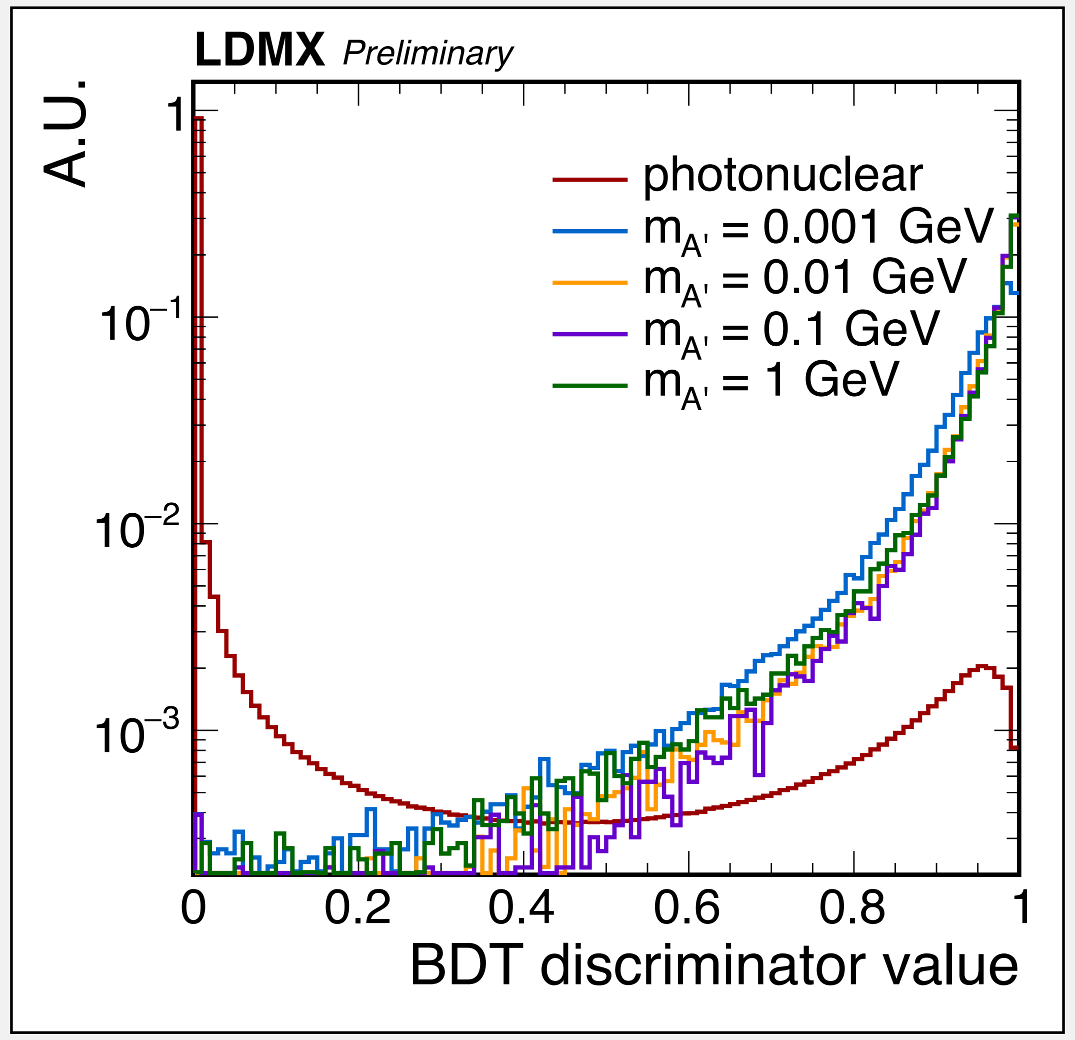
Analysis Strategy

trigger on missing energy

+ combine ECal features into a BDT
+ veto on activity in HCal
+ additional vetoes on activity in trackers/ECal front layer
+ MIP tracking in ECal (**new!**)

---

at 4 GeV: **close to 0-background** for 4e14 EoT
based on simulation studies



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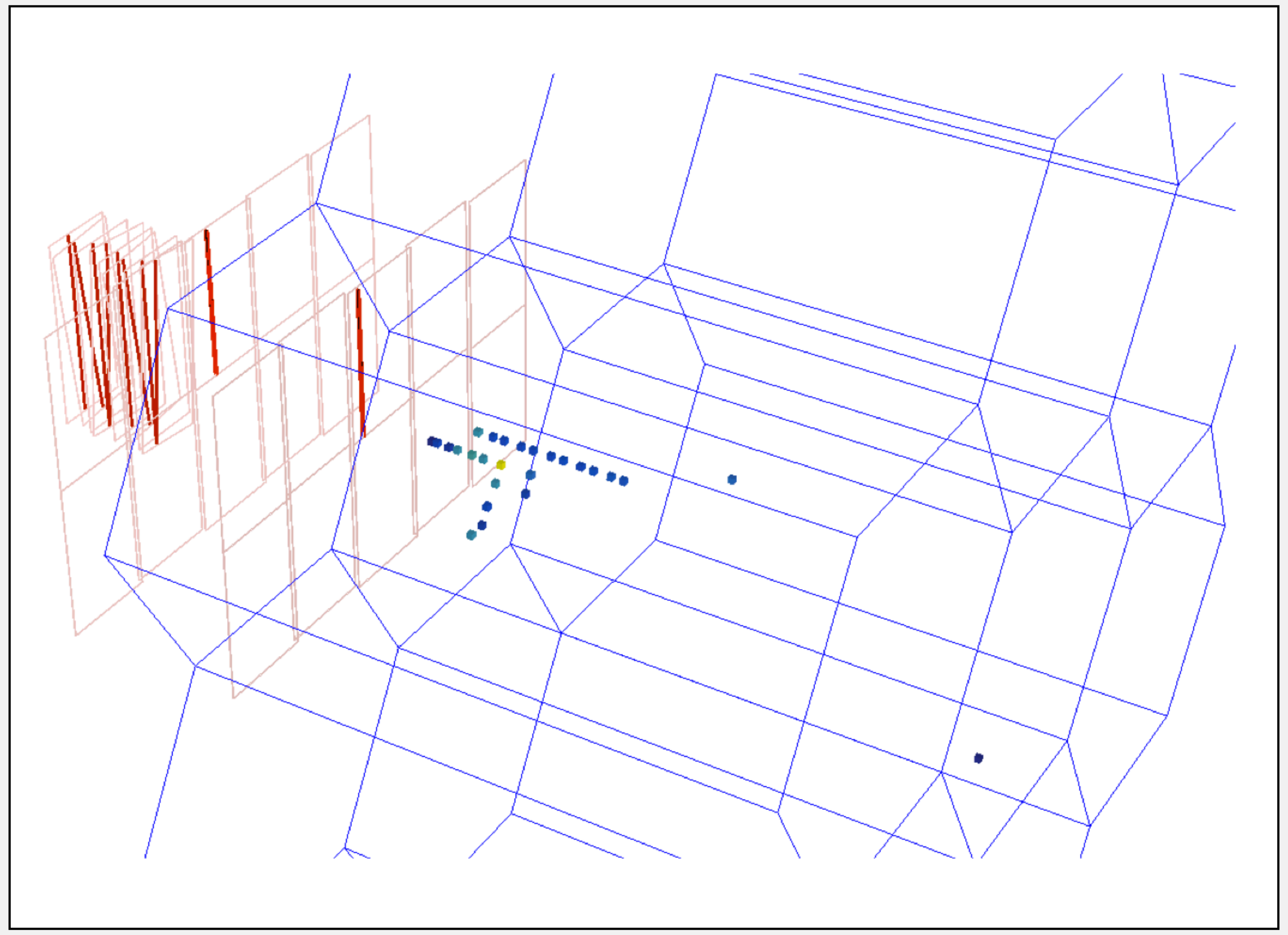

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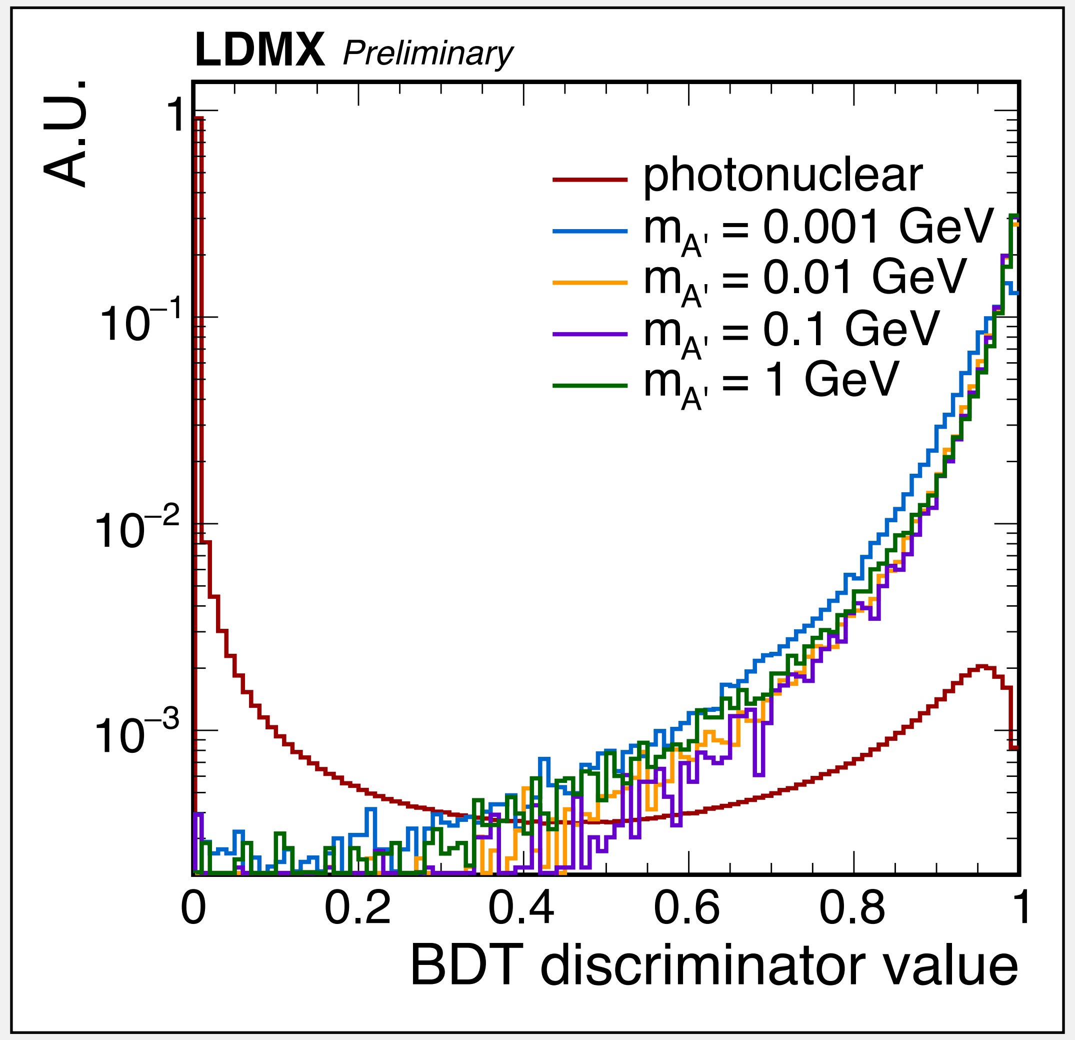
important:

several handles not exploited yet, in particular p_T!

HCal optimisation ongoing

things get easier at higher energy!



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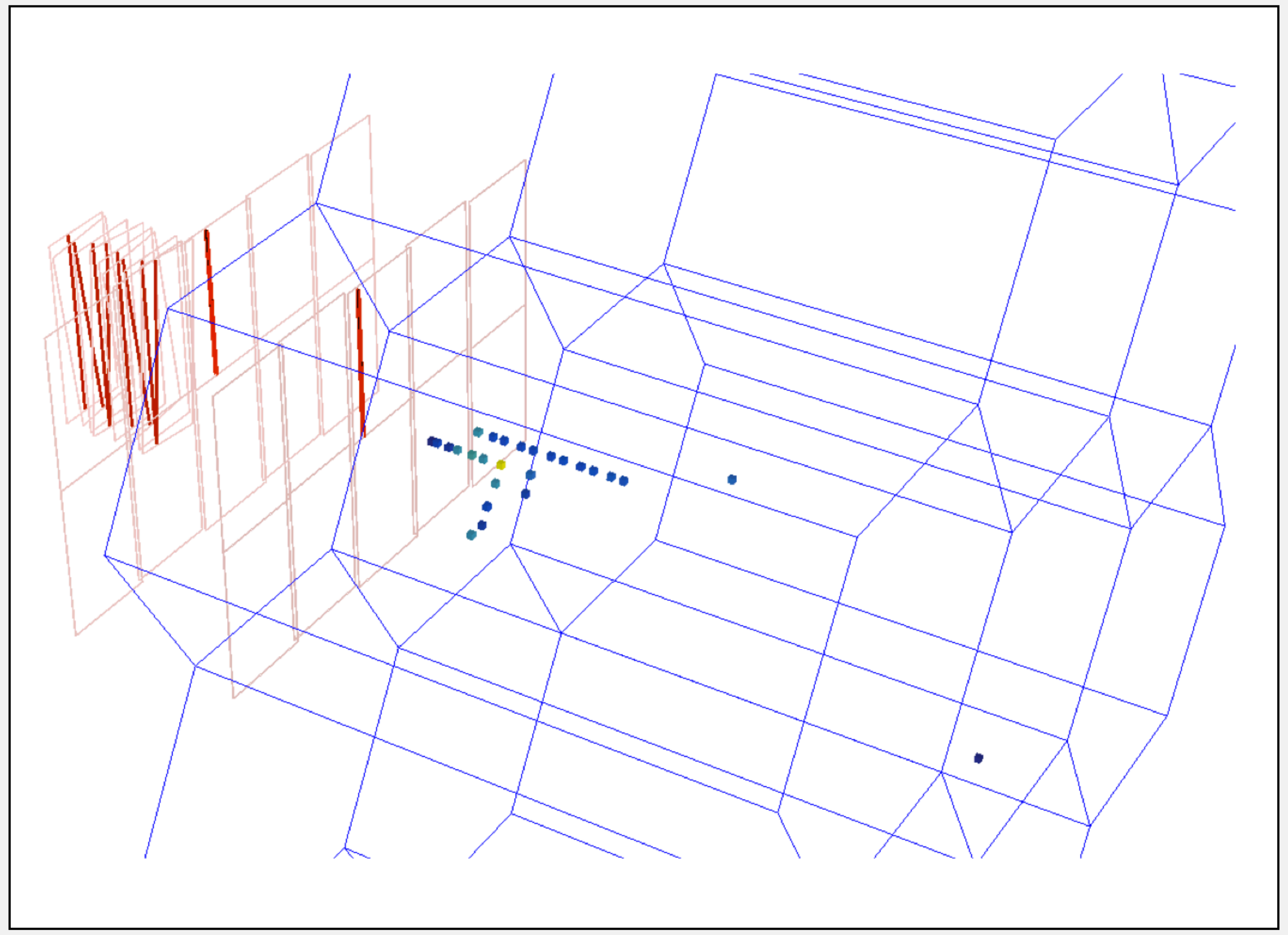

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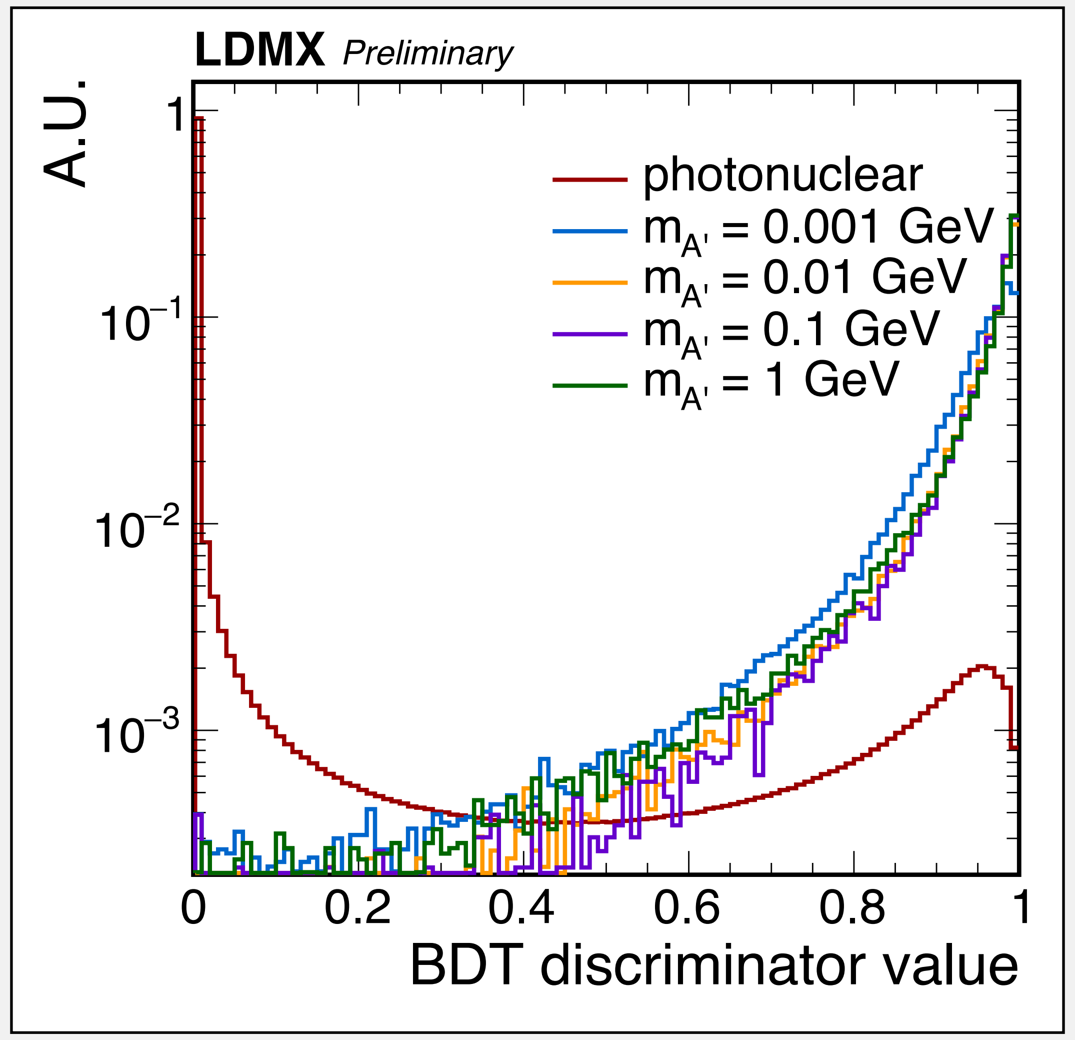
with data:

redundancy in vetoes —> data control samples, verify rejection

comprehensive kinematic information —> establish signal-likeness



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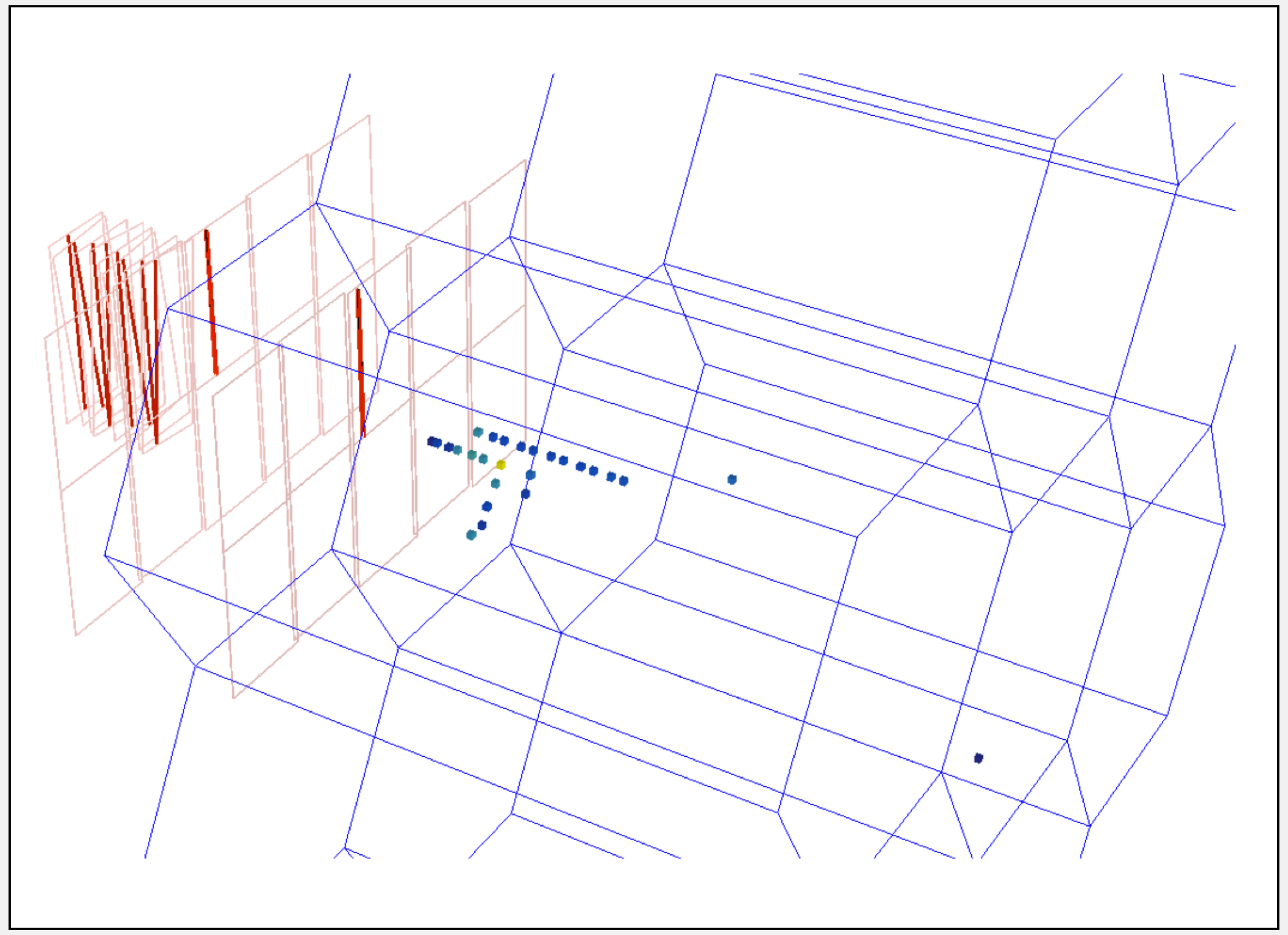
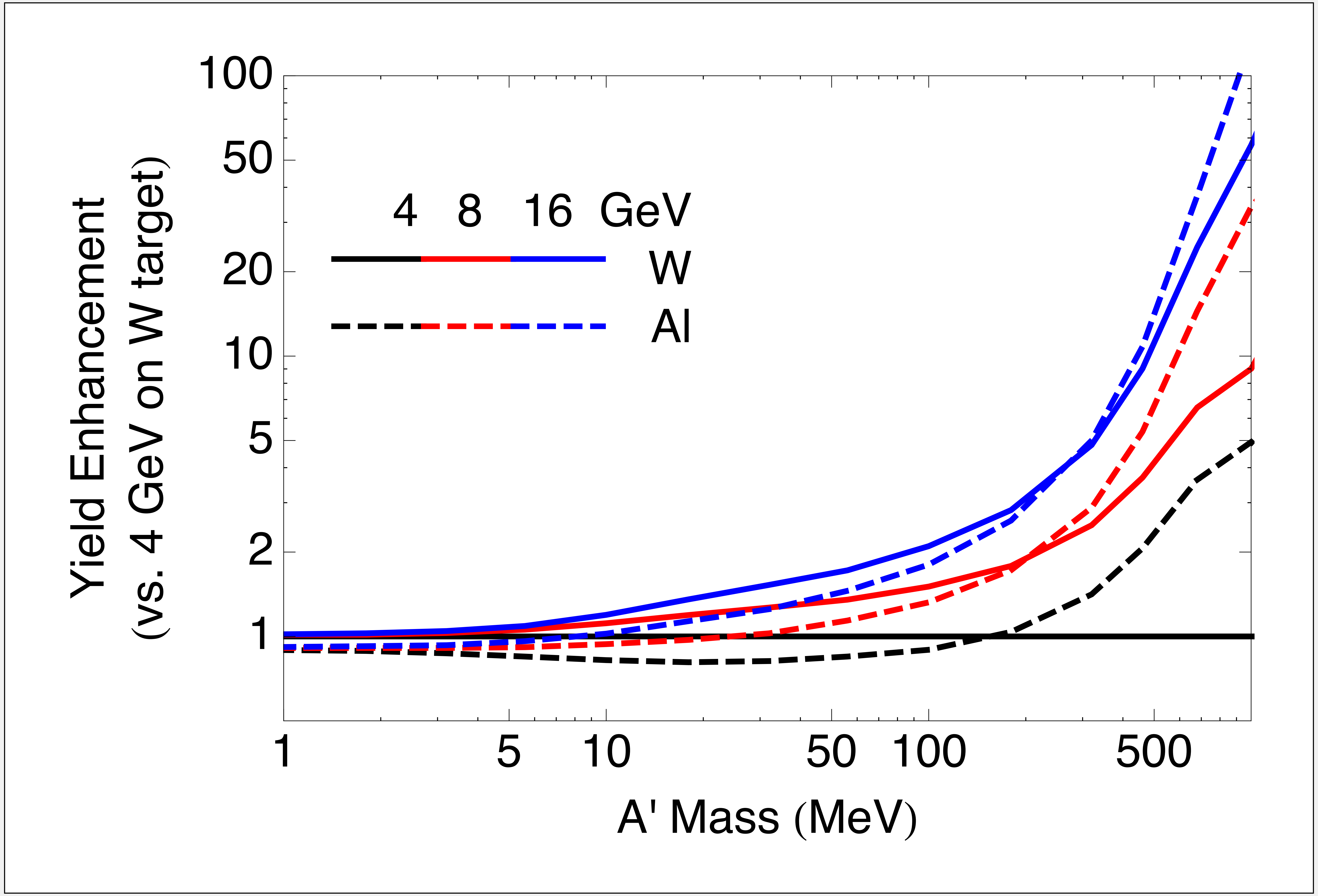


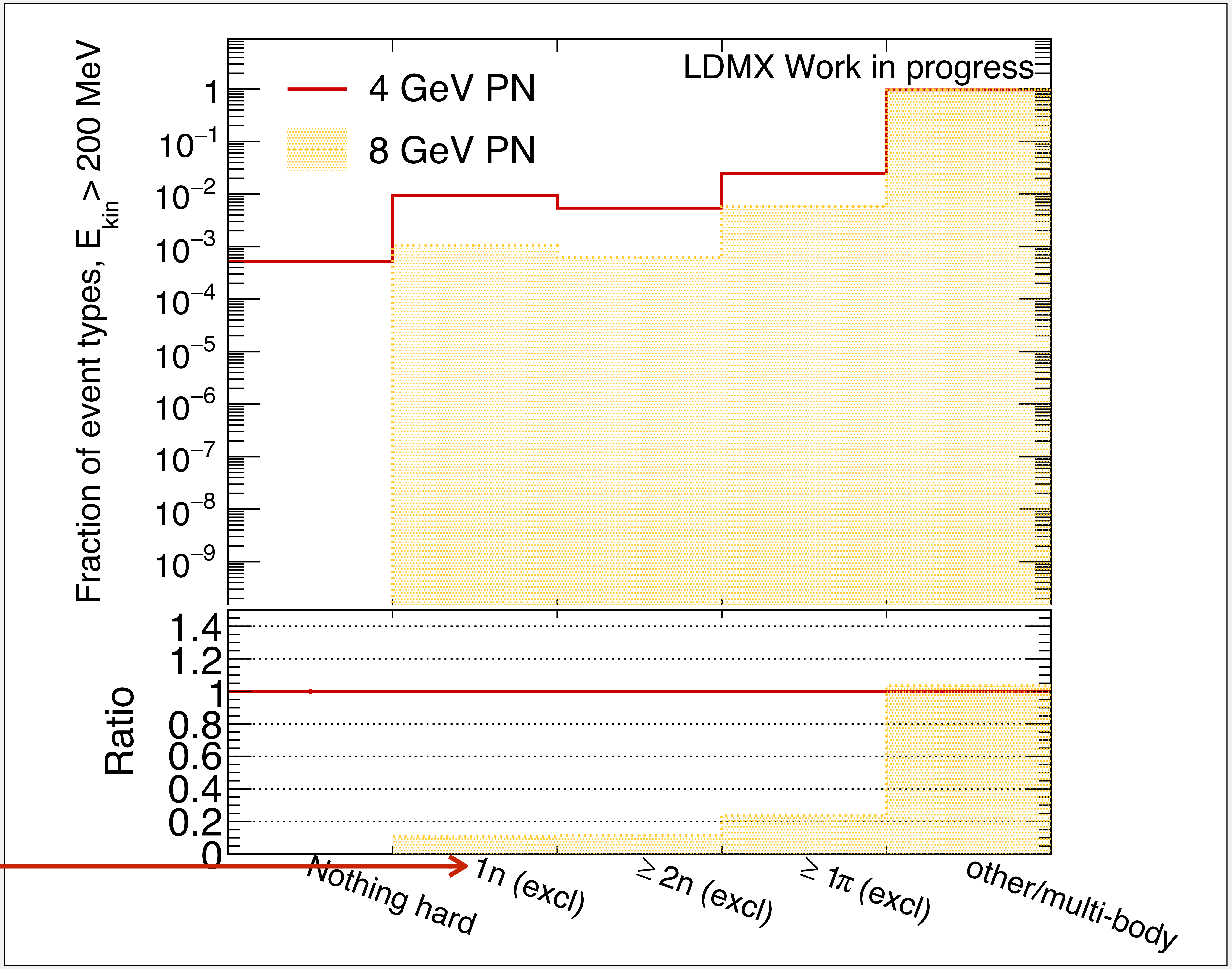
Why higher energy?

increased signal yield



Why higher energy?

improved background rejection possibilities



particularly critical

A special beam

beam **energy** ideally 4 GeV < E_B < 20 GeV

looking for extremely rare signal
—> need very large statistics

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

—> beam with **high duty-cycle**

resolve individual particles
—> **low number** of electrons per bunch (≤10)
—> **large beam spot**

options (still an open question):

SLAC (*default*, first stage)
dedicated transfer line from LCLS-II

CERN (later stage)
new Linac injecting electrons into SPS

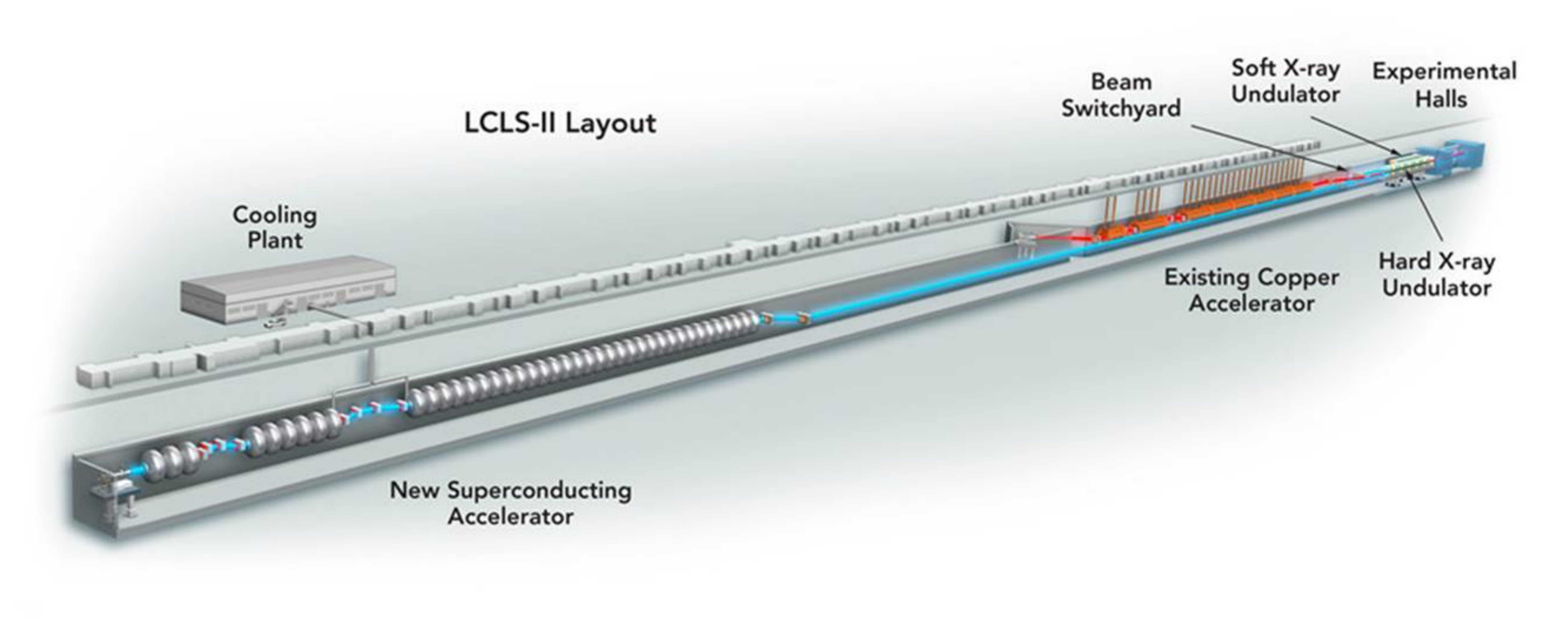
S30XL @ LCLS-II @ SLAC

https://confluence.slac.stanford.edu/display/MME/Publications+and+Presentations

energy: 4 (8) GeV

bunch frequency: 46 MHz (186 MHz)

parasitic



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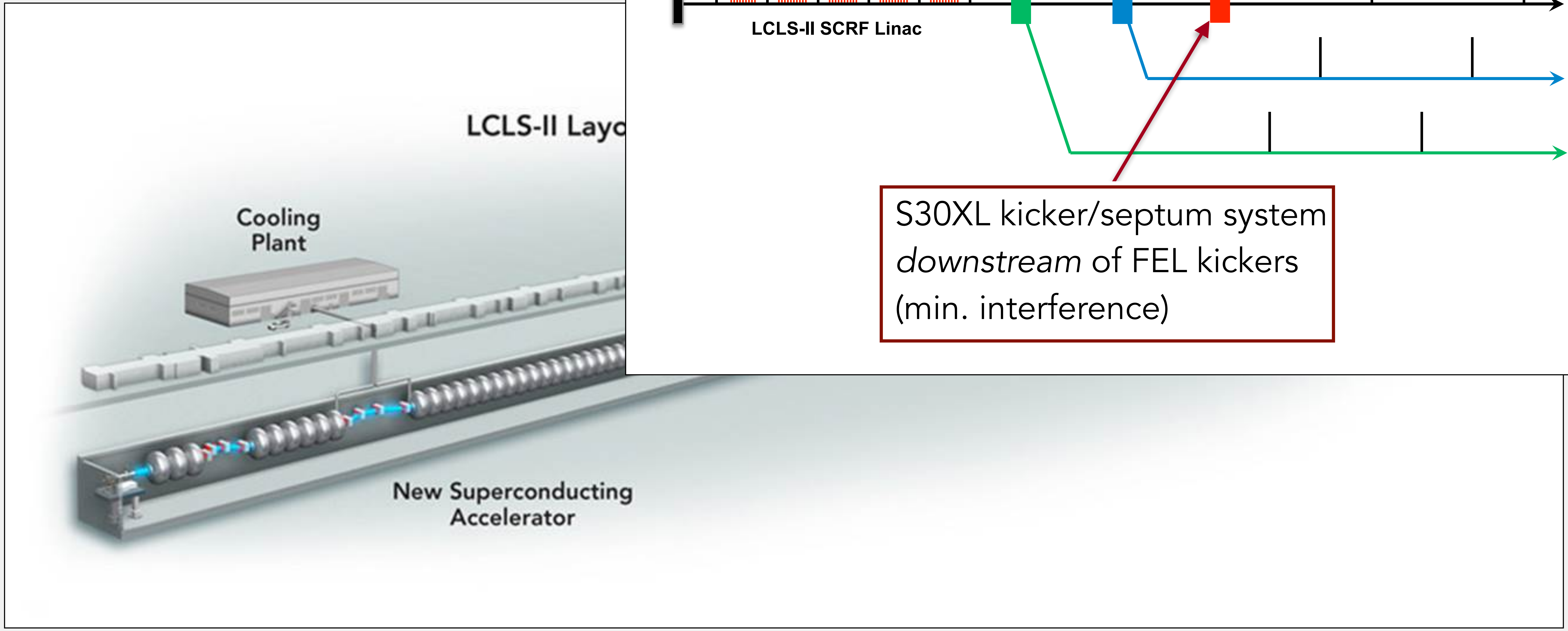
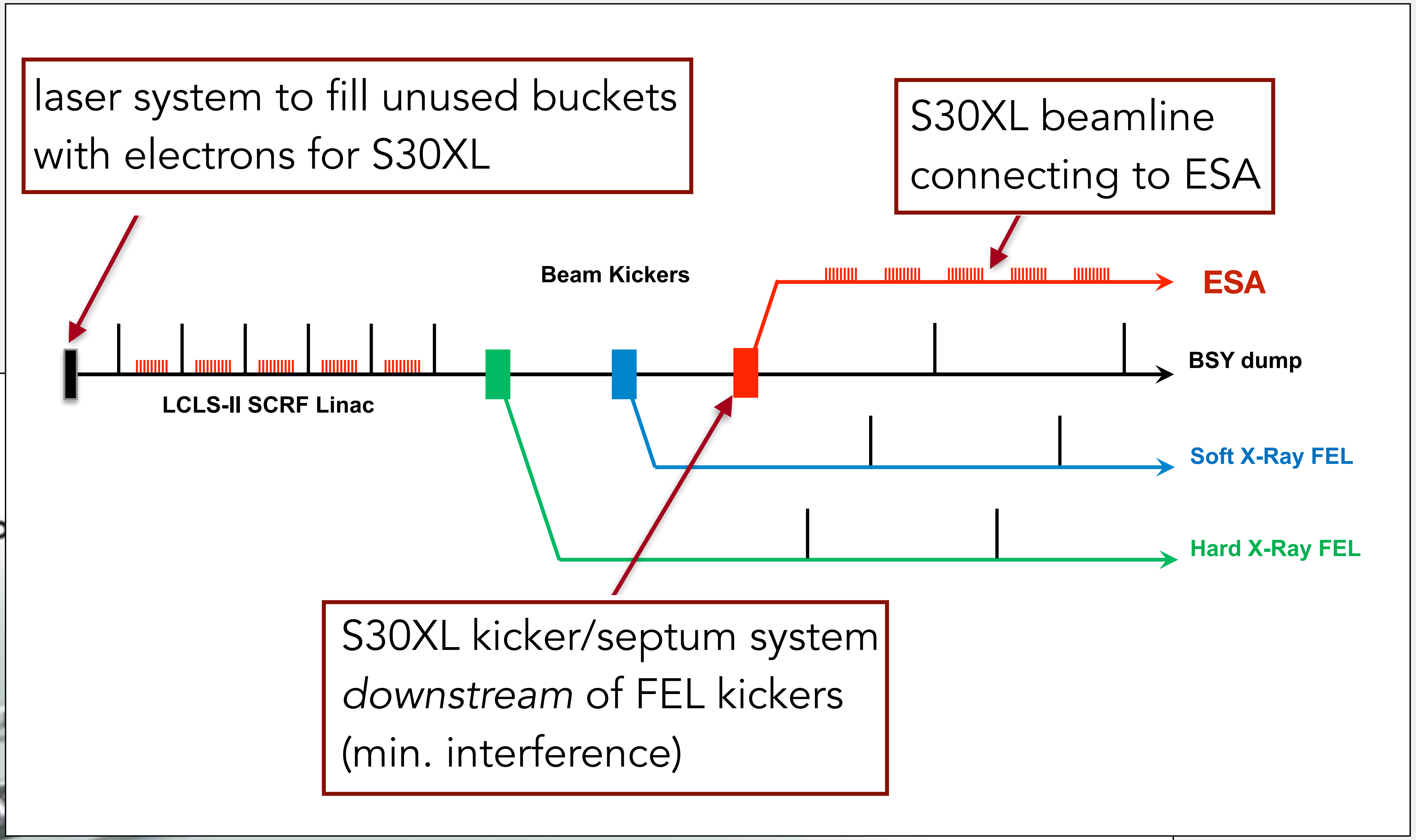


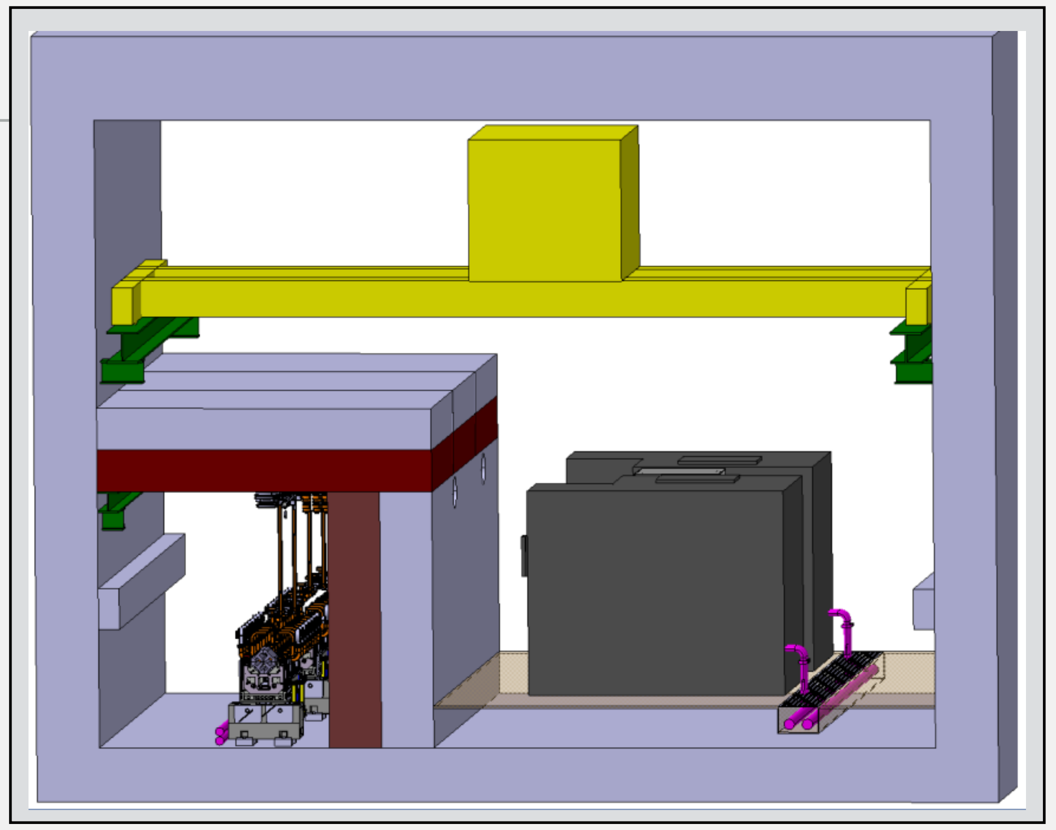


eSPS at CERN

idea ~2 years ago, quickly became active field of study
arxiv:1805.12379 arxiv:1905.07657

Expression of interest to SPSC in October 2018
https://cds.cern.ch/record/2640784

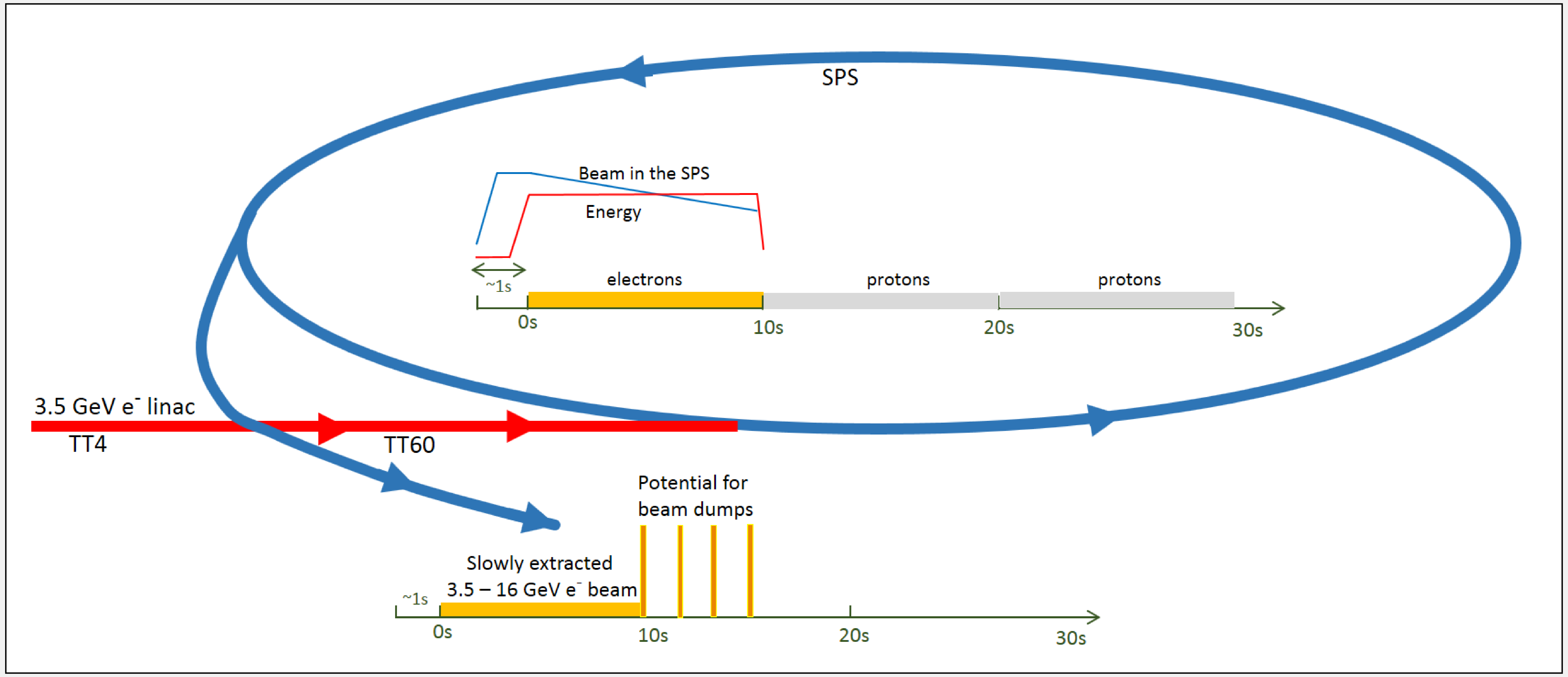
Input to Strategy Update (#36)



- 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:

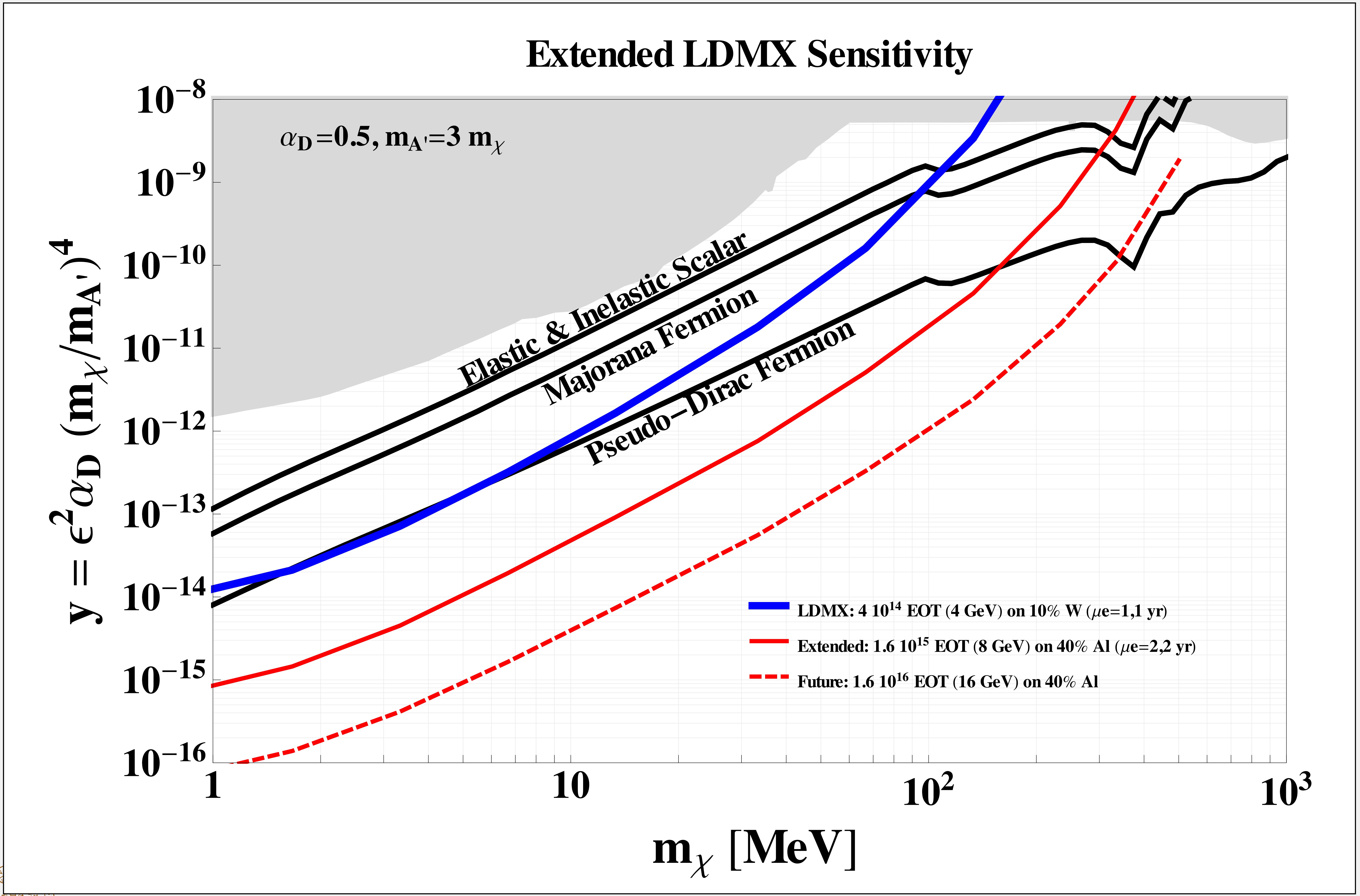
- energy: 3.5 - 16 (20) GeV
- electrons per bunch: 1 - 40
- bunch spacing: multiples of 5 ns
- adjustable beam size



optimal catering for LDMX-like experiment

next step for X-band linac developed for CLIC, accelerator R&D

Projected Sensitivity



LDMX can explore a lot of new parameter space

sensitive to various thermal targets already with "pilot run"

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

timescale: few years

Summary

- light, thermal relic Dark Matter well motivated
- LDMX can achieve outstanding sensitivity (in a few years)
  - complementary probe of thermal targets in MeV - GeV range
  - broad sensitivity to other models
- progress being made on
  - detector design
  - understanding backgrounds
  - mapping out phase-2 (including eSPS)

Latest News

https://kaw.wallenberg.org/en/press/20-ground-breaking-research-projects-receive-grants-totaling-sek-640-million

Project: **"Light Dark Matter"**

Grant: SEK 26,000,000 over five years

Principal investigator: **Professor Torsten Åkesson, Lund University**

with collaborations between

Lund Particle Physics *(Torsten Åkesson, Caterina Doglioni, Ruth Pöttgen et al.)*,

Theoretical Physics *(Stefan Prestel)*, Nuclear Physics *(Luis Sarmiento)*,

Chalmers Theoretical Physics *(Riccardo Catena)*

Stockholm University Astroparticle Physics *(Jan Conrad)*

4 work packages

WP1 Participation in LDMX *(LU particle physics)*

WP2 Simulations of signal + background, integration PYTHIA+GEANT4 *(LU, Chalmers)*

WP3 Data interpretation, Statistical Inference, Global Fits *(LU particle physics, Chalmers, SU)*

WP4 Detector material evaluation for direct detection experiment *(Chalmers, SU)*

slightly older news: Lene Kristian Bryngemark awarded fellowship in The Wallenberg Foundation Postdoctoral Scholarship Program at Stanford University to work on LDMX

Thank you!

Additional Material

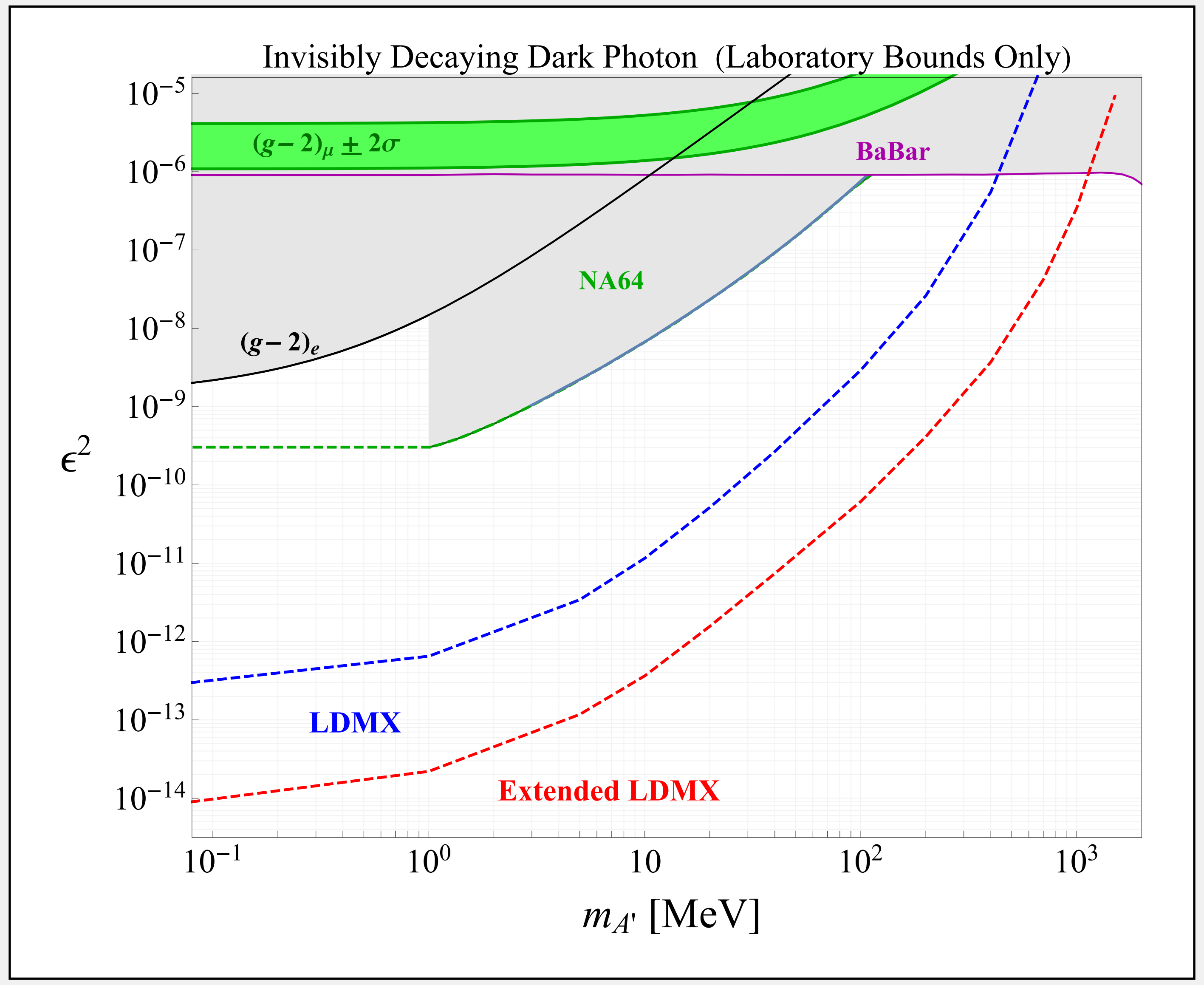
Further Potential

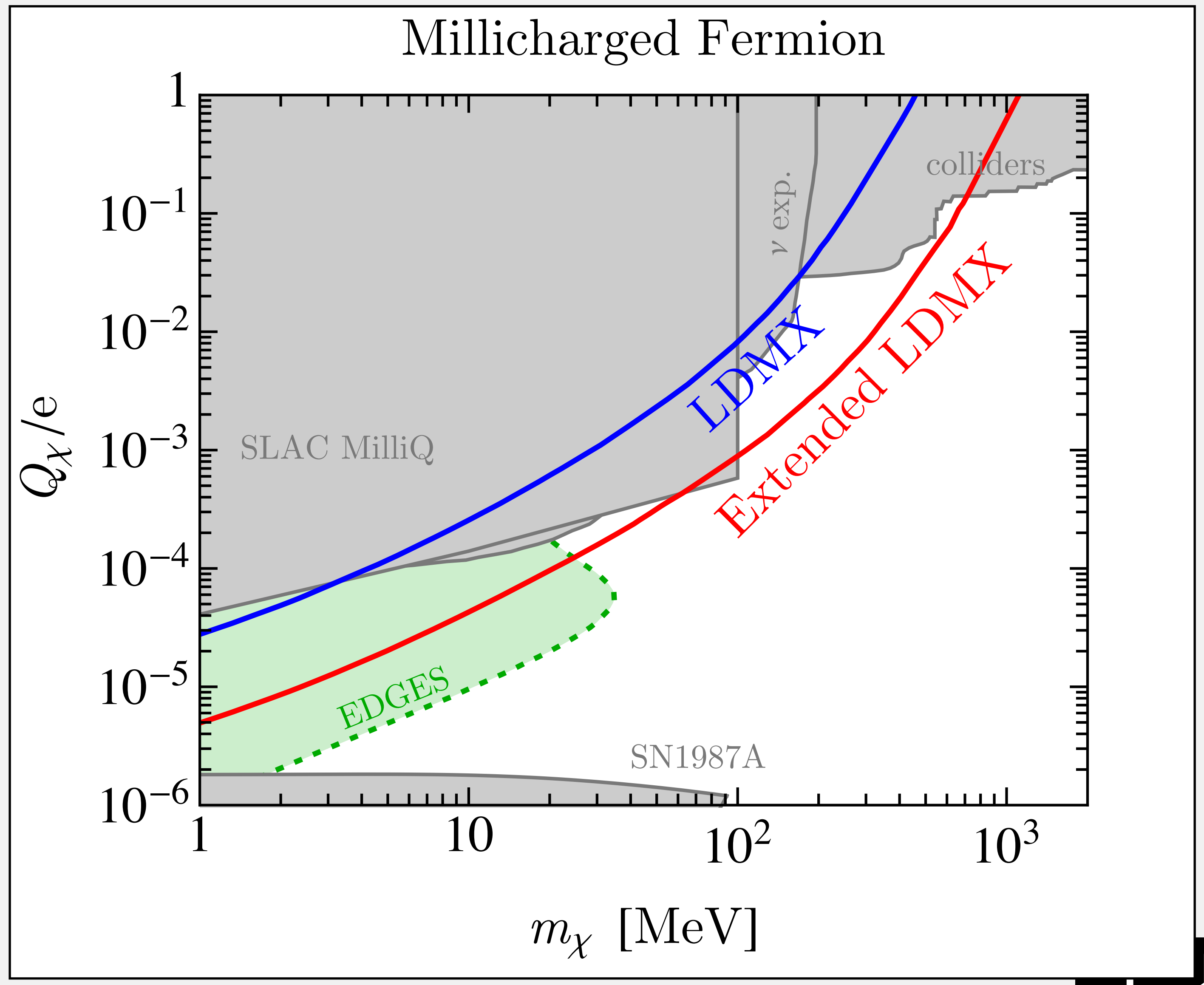
also sensitive to

- 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

(more in Berlin, Blinov, Krnjaic, Schuster, Toro arxiv:1807.01730)

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

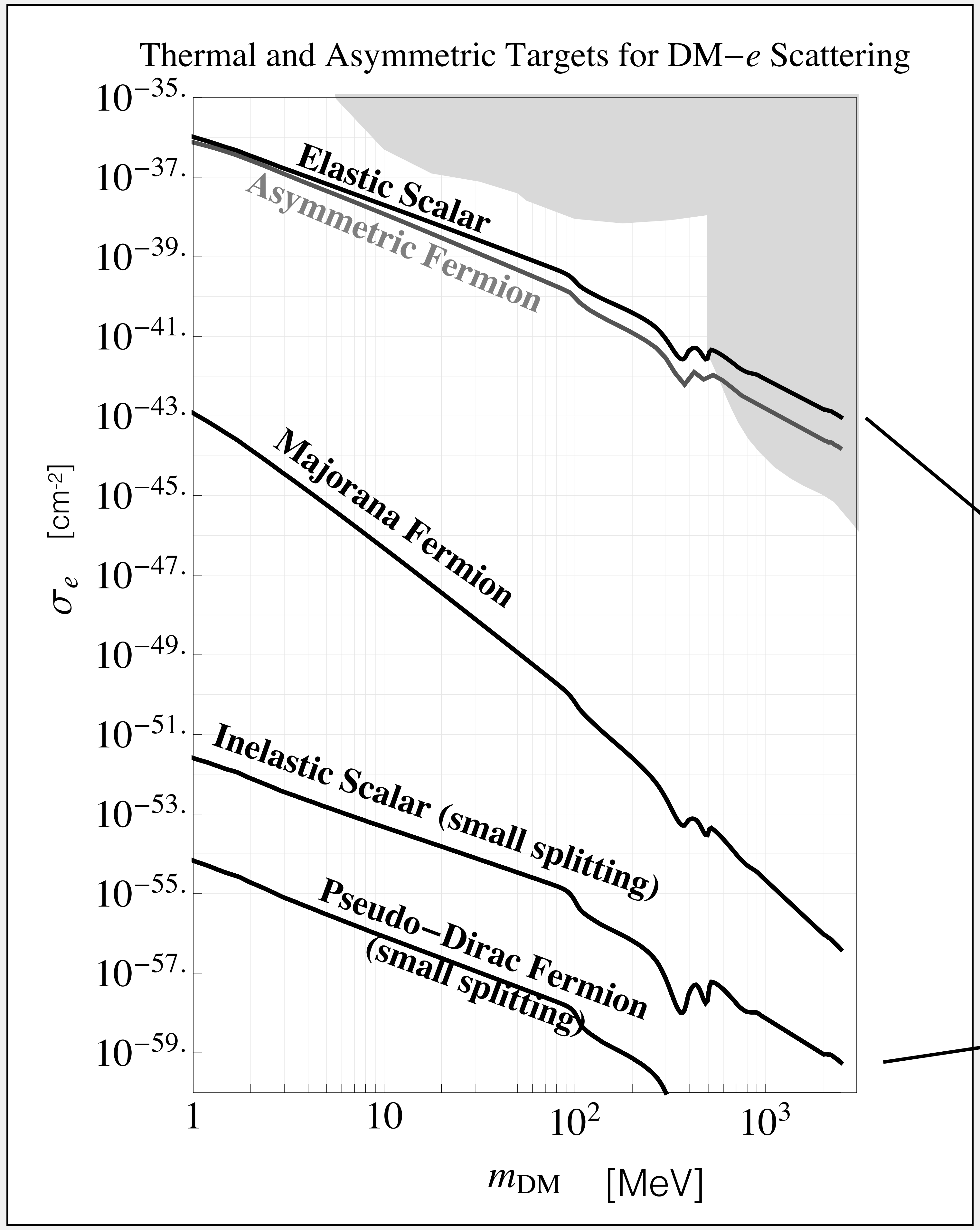




Why not only direct detection?

direct detection:

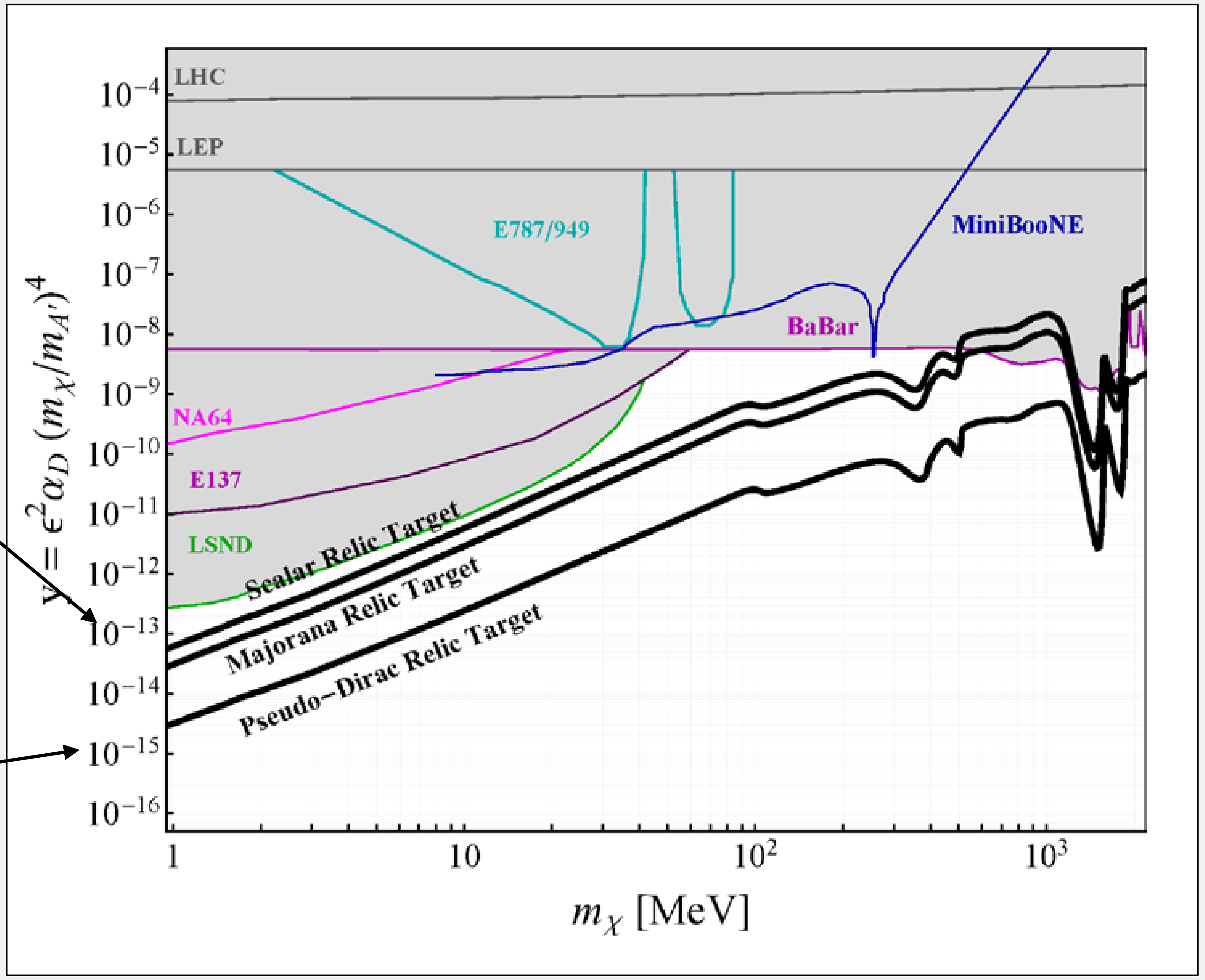
strong spin/velocity dependency



at accelerators: relativistic production

—> spin/velocity dependency reduced

all thermal targets in reach!



How to realise LDM

starting point: thermal relic assumption

- restricts viable mass range
- **minimum** annihilation cross section
  - otherwise overproduction of DM

if WIMPs 'too light' (m_χ< few GeV)

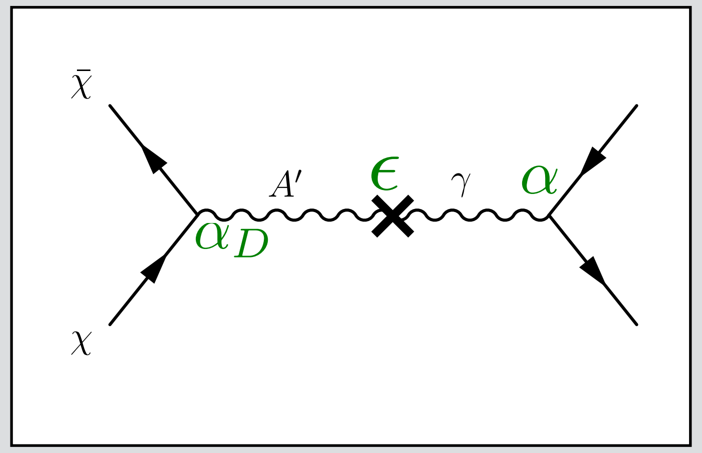
- annihilation into SM inefficient
  - overproduction of DM
- *Lee-Weinberg-bound*

introduce new, light mediator

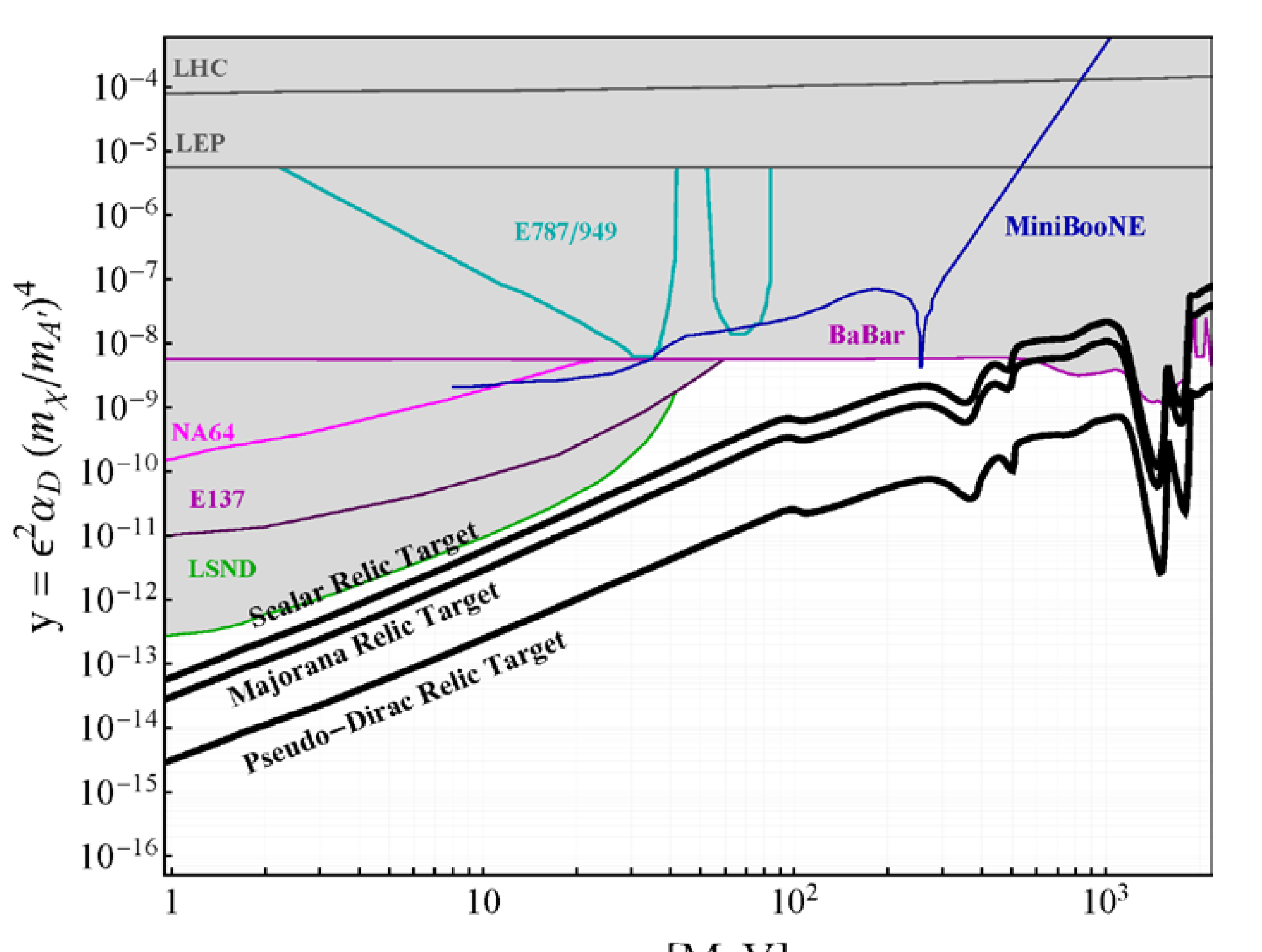
- additional annihilation channel
  - correct relic abundance

representative benchmark model: Dark Photon (A')

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



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



Toro & Krnjaic

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

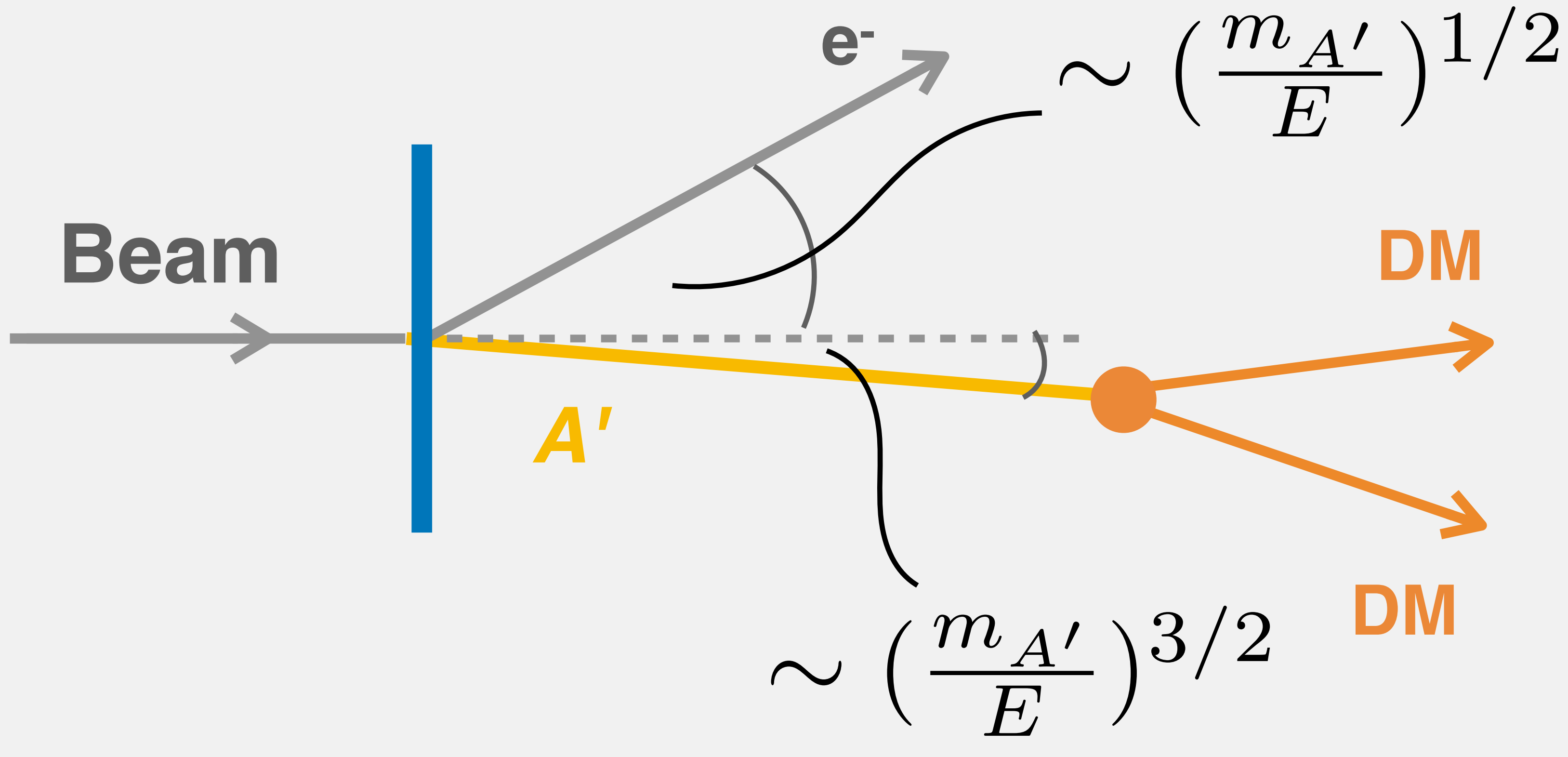
clear experimental thermal targets

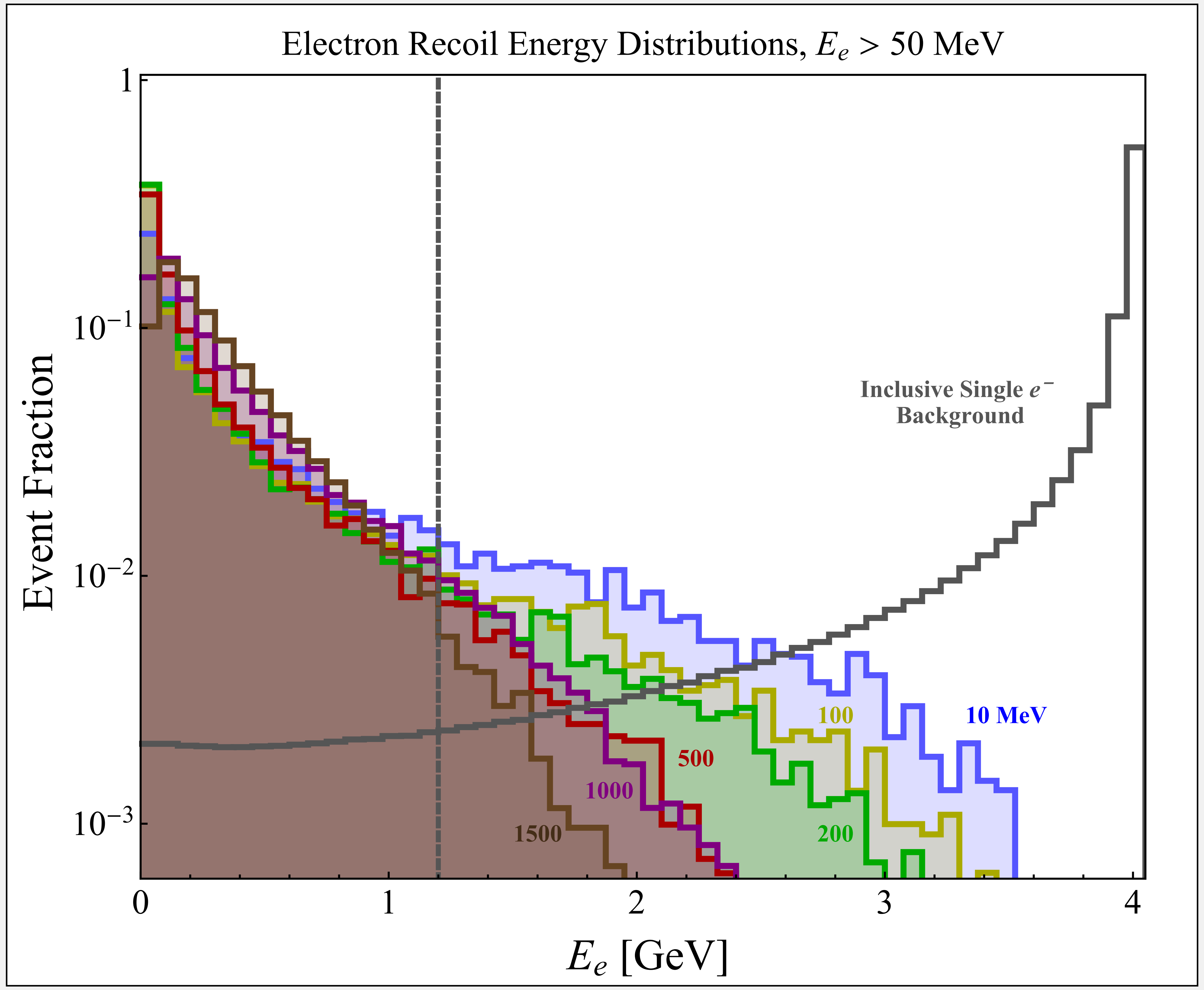
conservative:

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

Kinematics

very different from SM bremsstrahlung (main background)



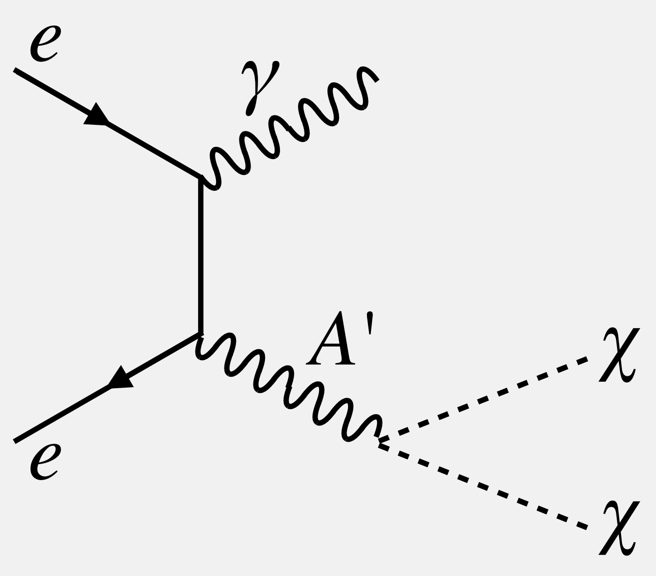


Mediator carries most of the energy

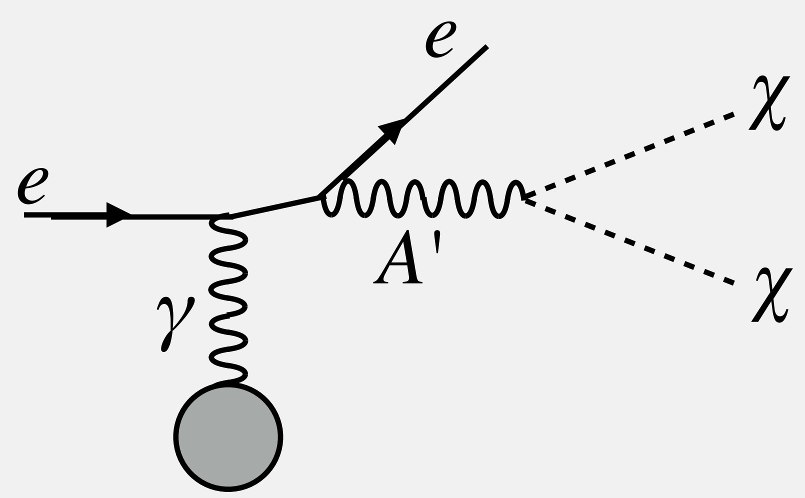
—> soft recoil electron, large missing energy

Complimentary Approaches

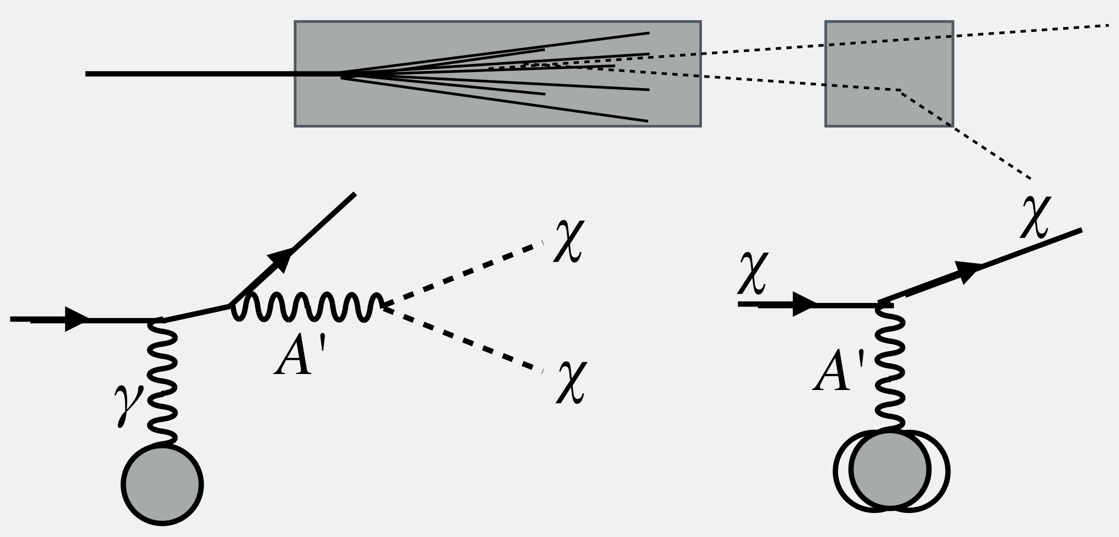
collider



fixed target



beam dump



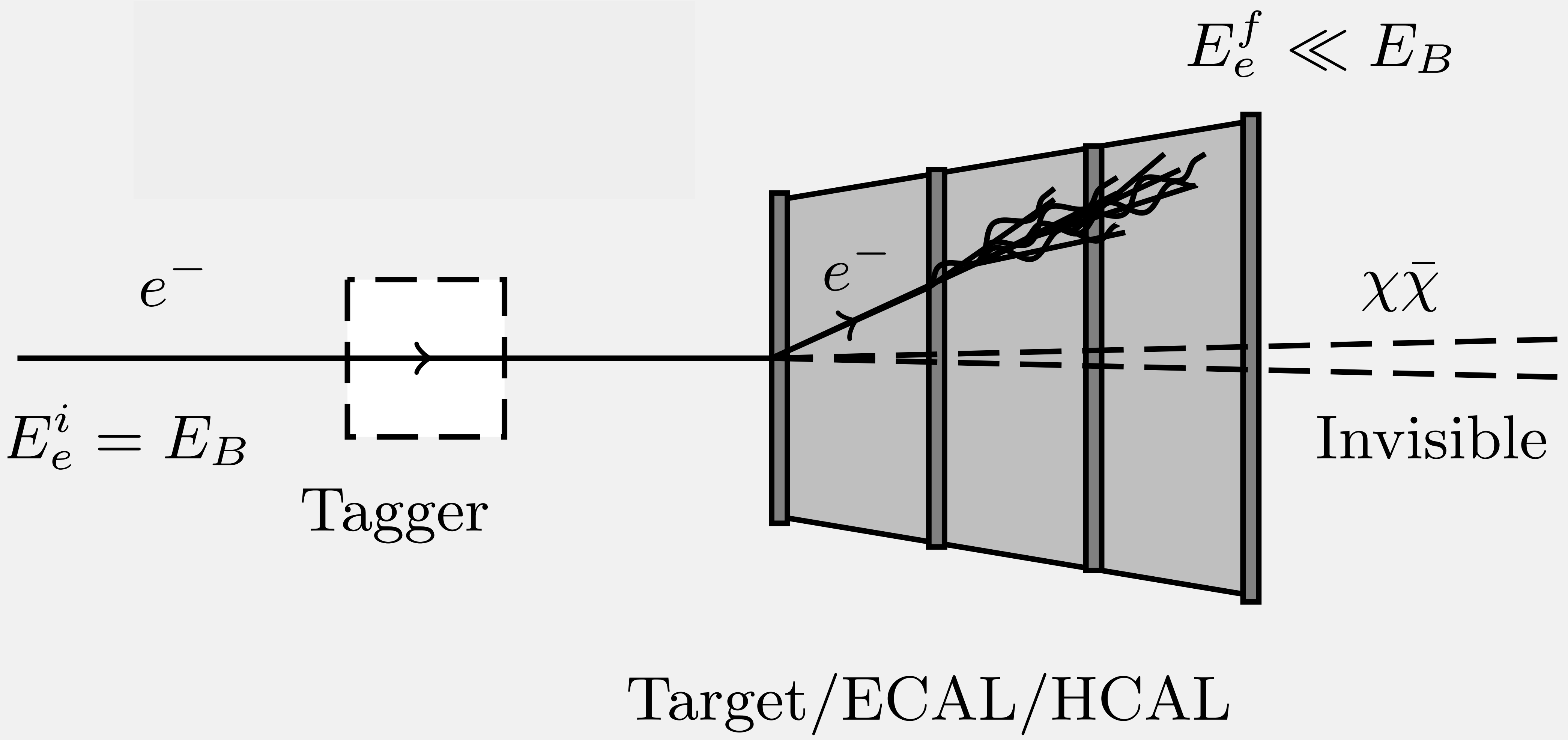
$\sigma_{\rm coll} \propto \frac{\varepsilon^2}{E_{\rm cm}^2}$ « $\sigma_{\rm FT} \propto \frac{Z^2\varepsilon^2}{m_{\rm A'}^2}$ $N \propto \varepsilon^2(1-\varepsilon^2) \approx \varepsilon^2$ » $N \propto \varepsilon^4$

but **"direct DM detection"**

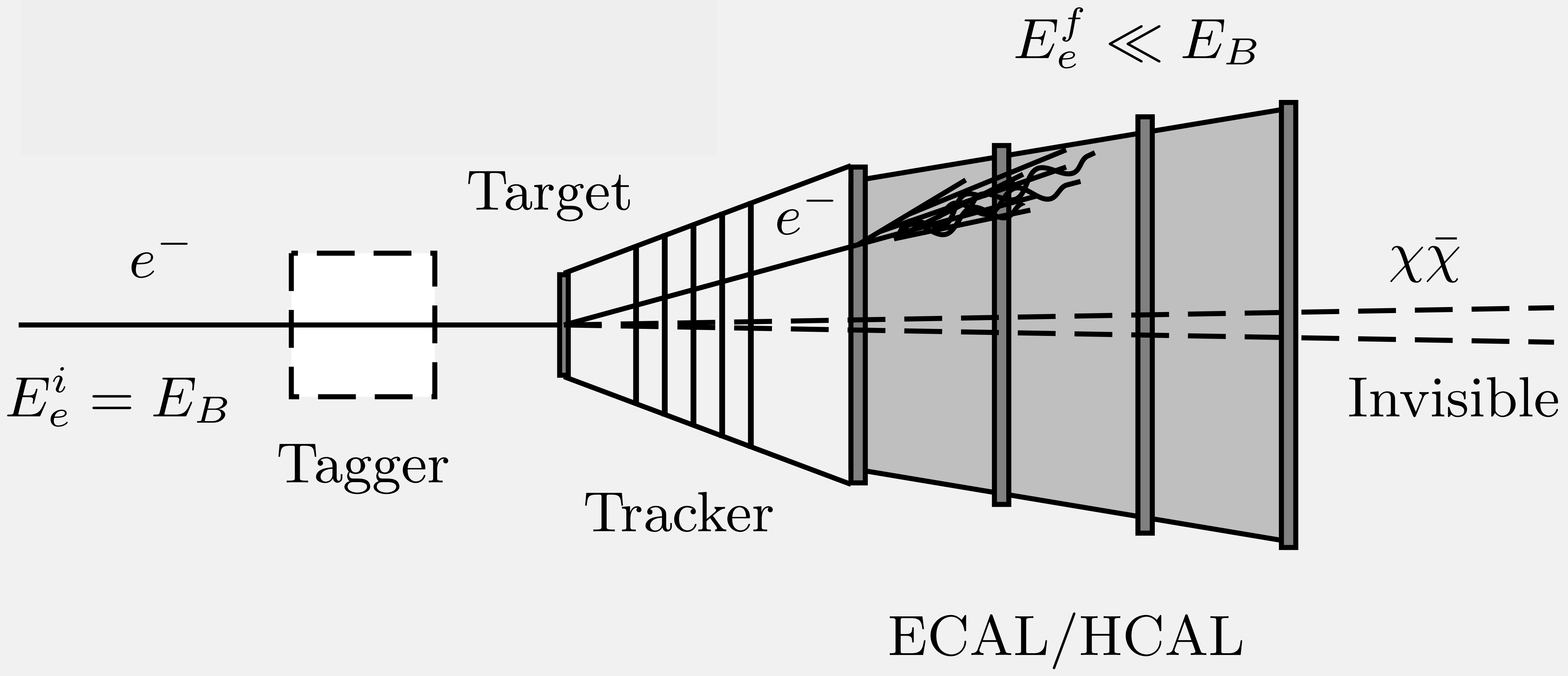
examples (existing or planned)	BaBar Belle II LHC	PADME NA64 **LDMX**	MMAPS VEPP3 DarkLight (II)	E137 LSND BDX	SBNe/pi MiniBooNE SHiP
mass range	0.1 - 10 GeV		MeV - GeV		

Two Approaches

<u>missing energy</u>



<u>missing momentum</u>



higher signal yield/EoT (thicker target)

greater signal acceptance

no e-γ particle ID

includes missing energy

p_T as discriminator & *signal identifier*

e-γ particle ID

Tracking

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

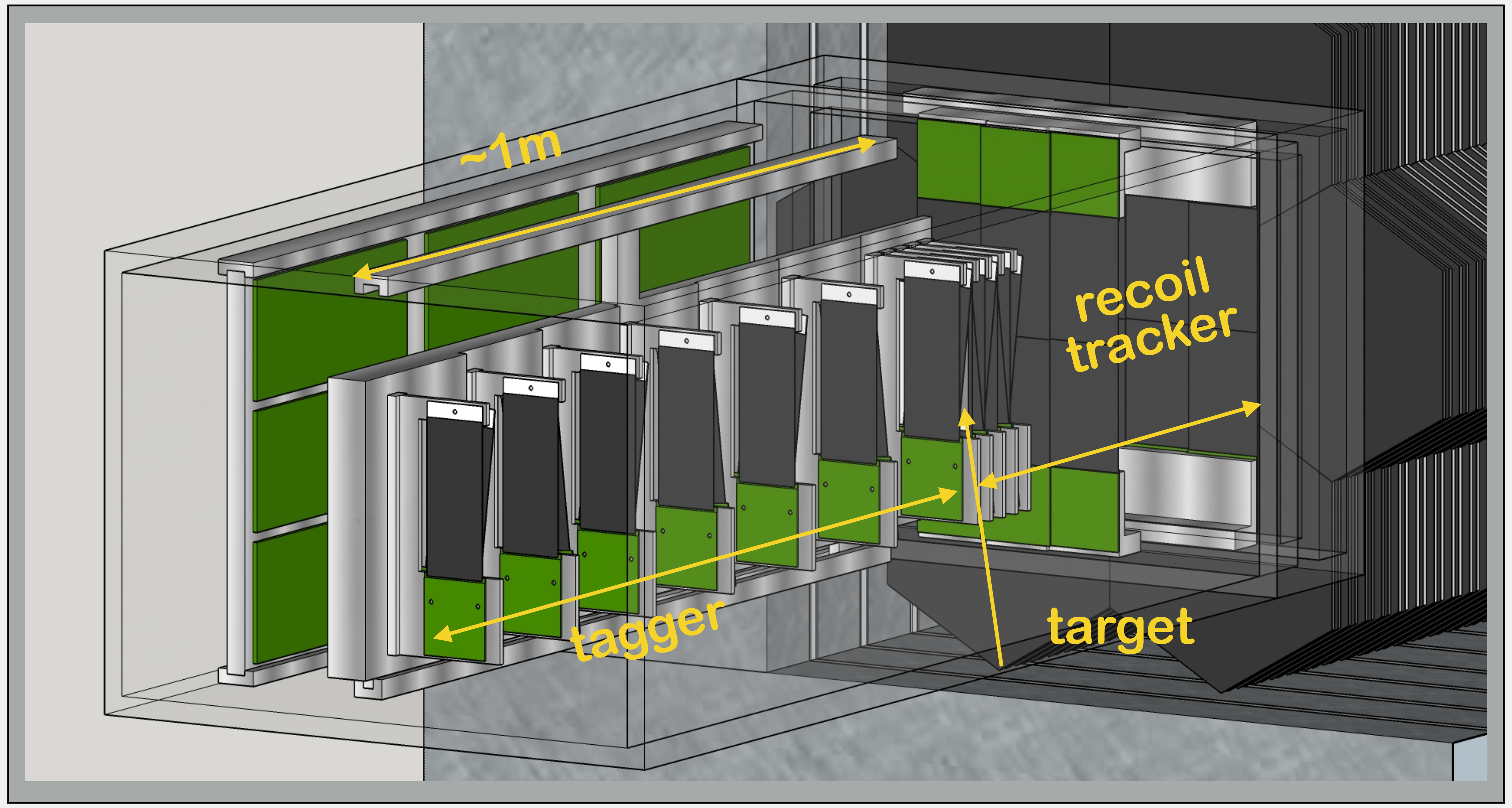
- in 1.5T dipole field
- measure incoming electron
    - momentum filter
    - impact point on target

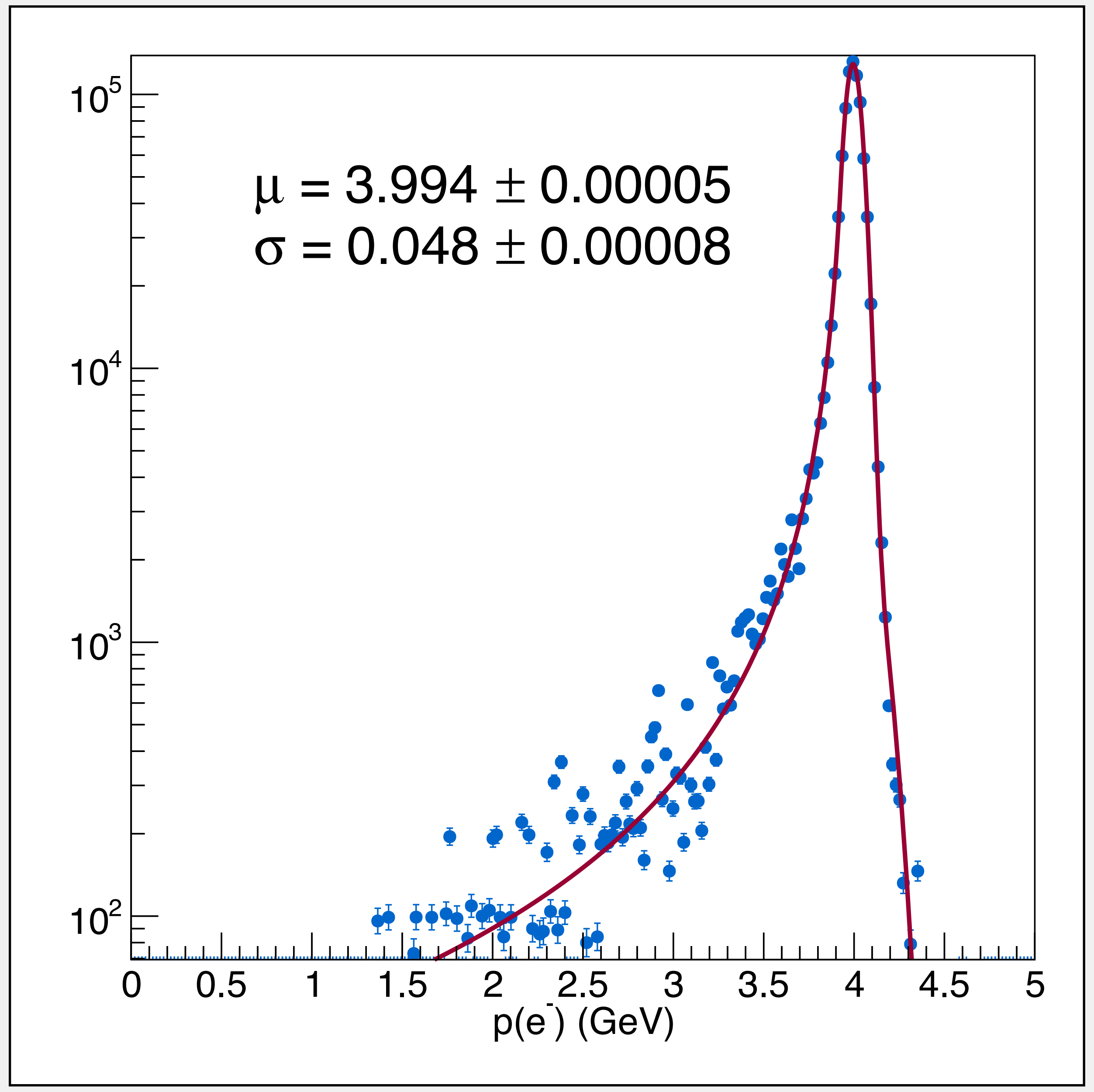
recoil tracker

- in fringe field
- measure recoil electron

target

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

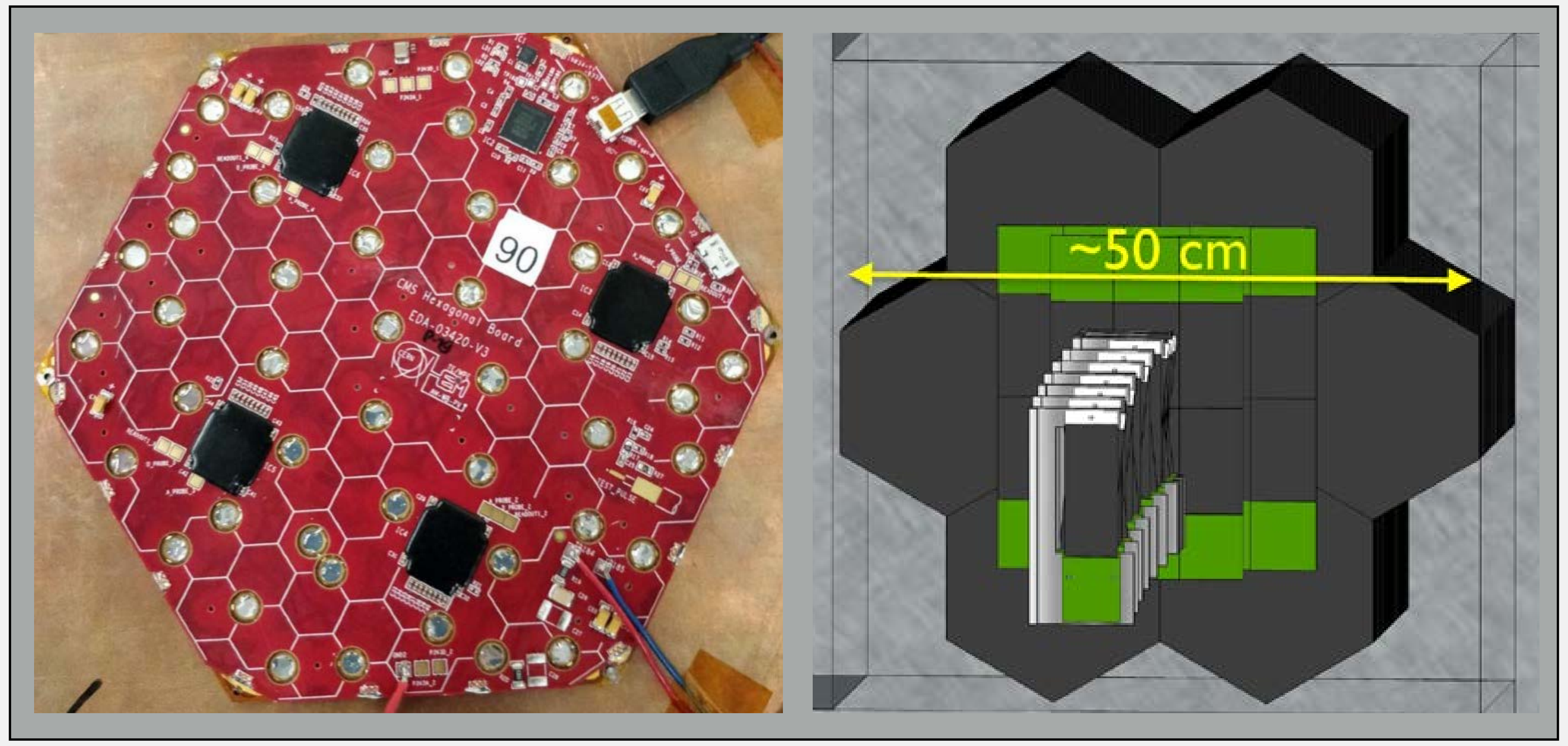


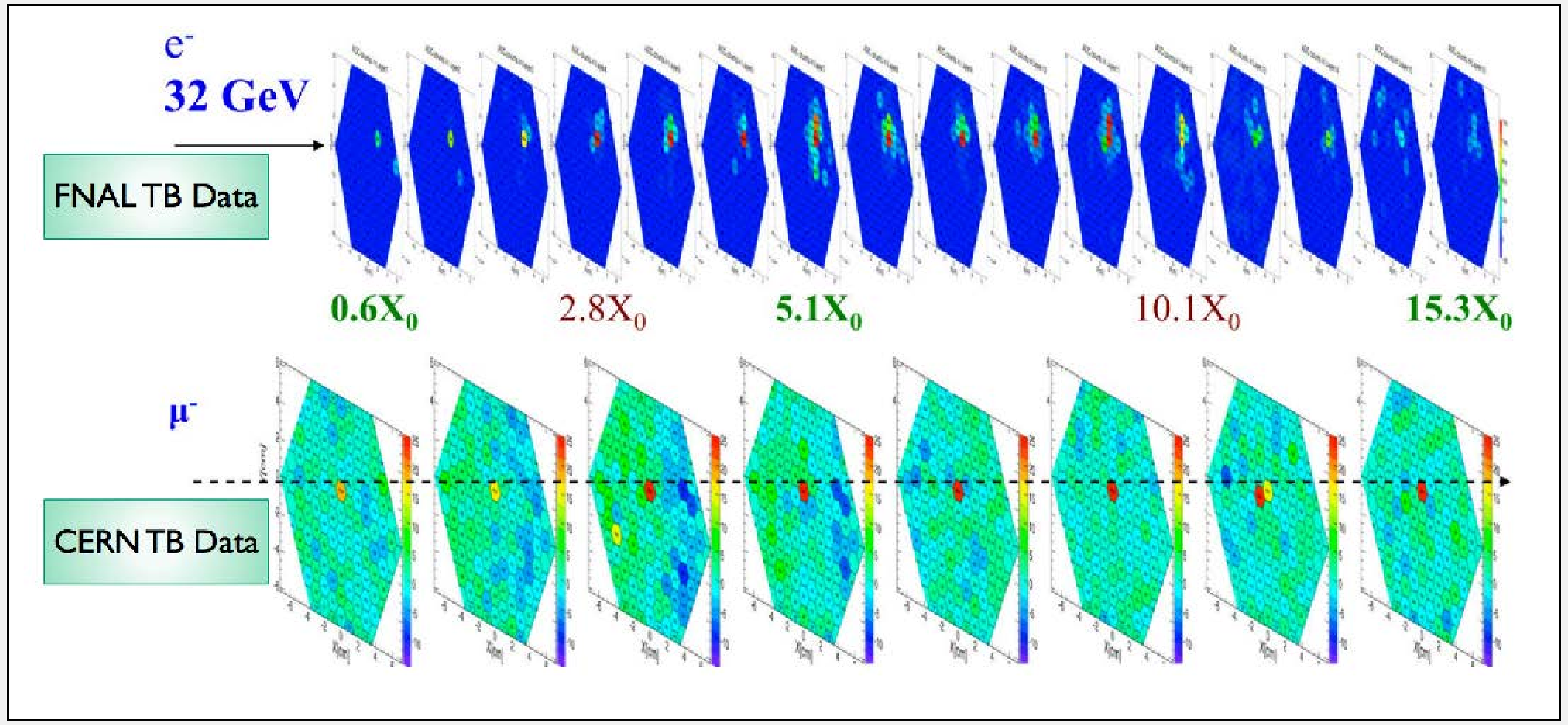


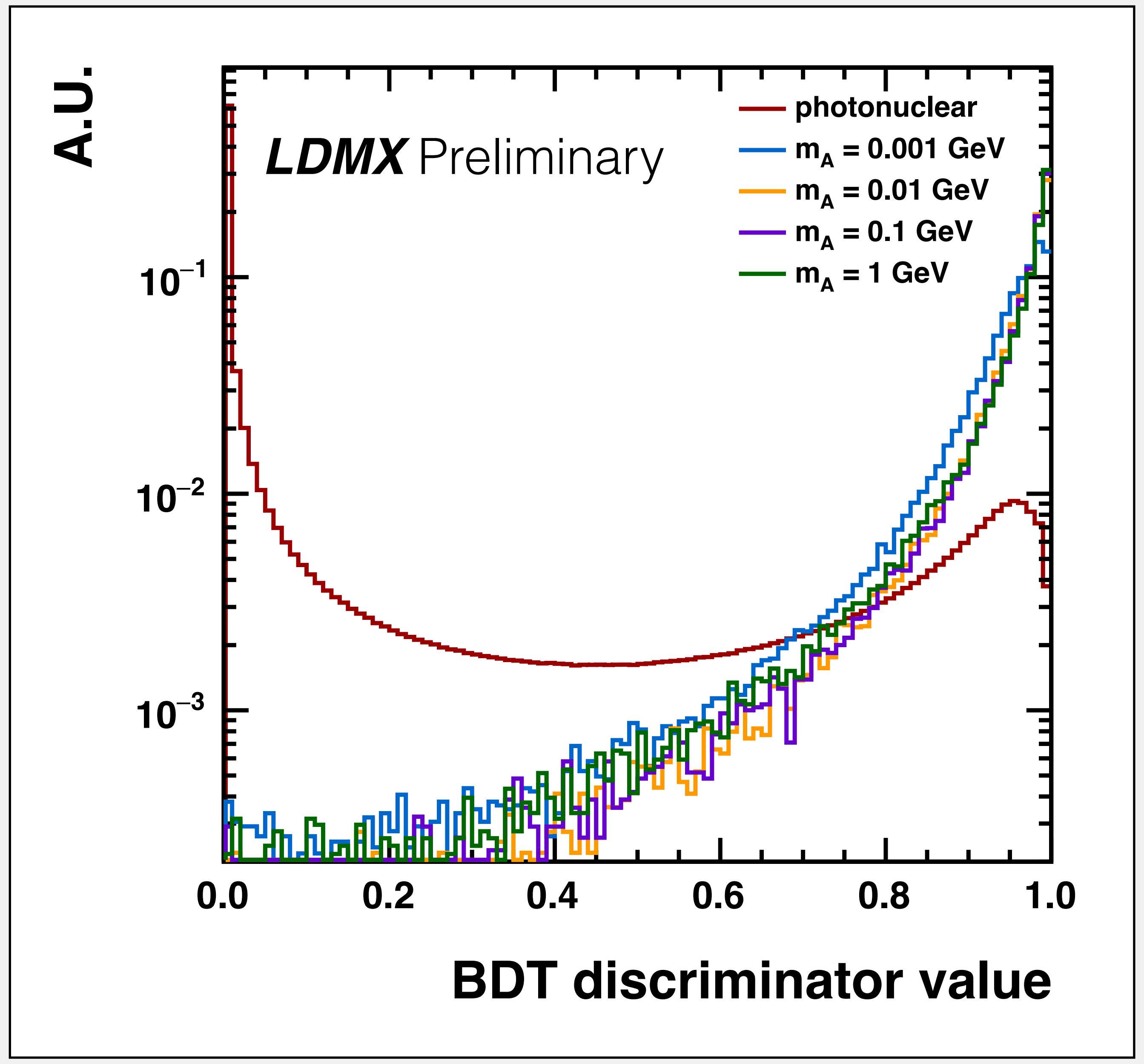
Electromagnetic Calorimeter

ECal

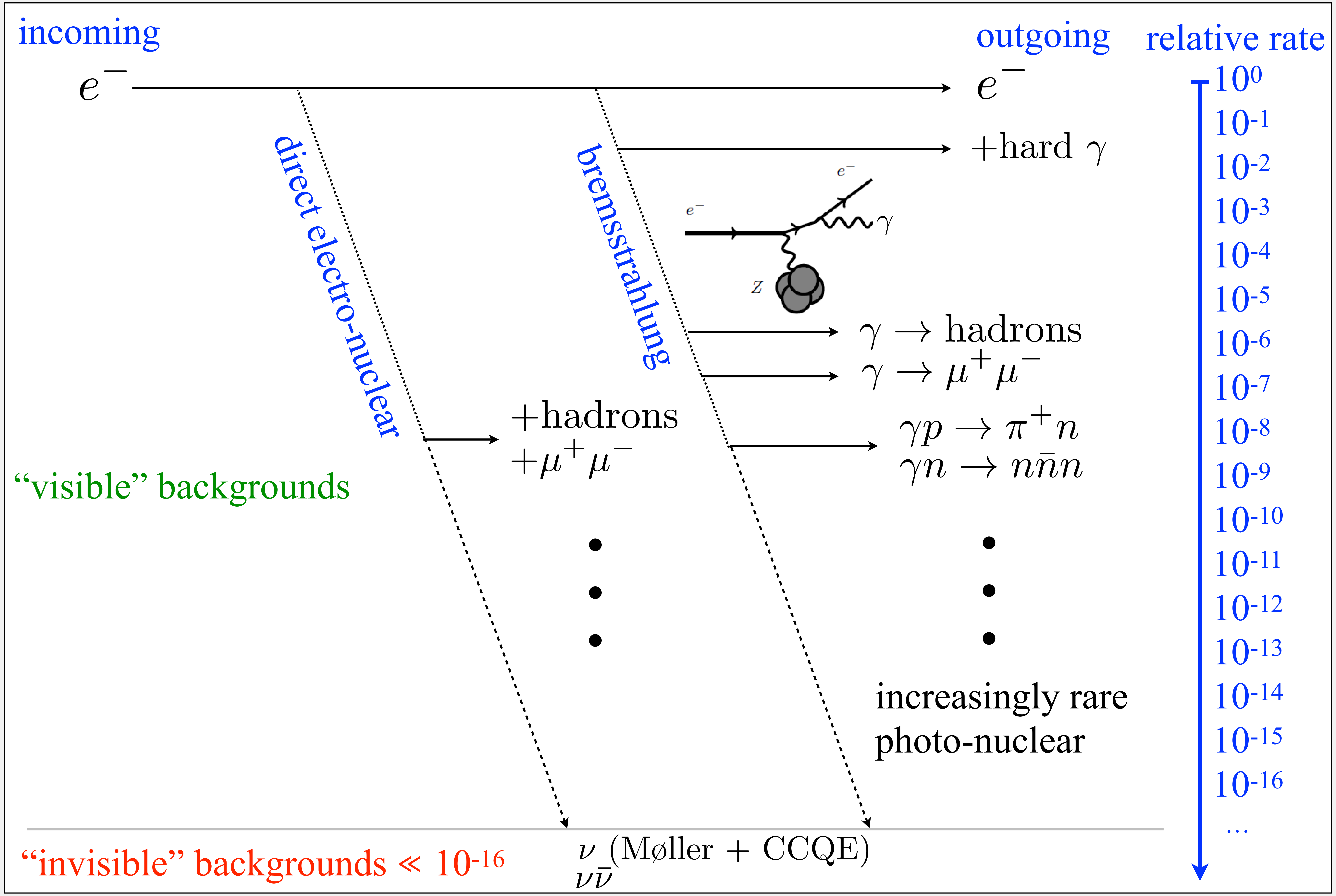
- draw on design of CMS forward SiW calorimeter upgrade
  - 32 layers with 7 modules each, 40 X_0
  - fast, radiation hard, dense
  - high granularity (MIP 'tracking')
    - potentially increase granularity in central module







Backgrounds



essentially only
instrumental backgrounds

Various Future Projections