

Update from the
Light Dark Matter eXperiment

A hand-drawn diagram on a chalkboard. At the top, a horizontal line with several small blue circles represents a beam of particles. A single blue circle with an 'e' inside is at the top right. A cluster of orange and white circles is on the left, with a dashed line curving away from it. Two purple circles with 'X' marks are in the center. The background is dark green chalkboard paint.



Ruth Pöttgen
Partikeldagarna
Lund, Sep 2026

A hand-drawn diagram on a chalkboard. It shows a coordinate system with a vertical y-axis and a horizontal x-axis. A white curve starts from the left, goes up, and then curves down towards the x-axis. The letters 'DMX' are drawn in large, white, blocky letters across the middle of the diagram. The background is dark green chalkboard paint.

Update from the
Light Dark Matter eXperiment

The diagram shows a horizontal beam of particles, represented by small blue circles, entering from the left. A cluster of orange and red circles is positioned below the beam. A dashed line curves from the cluster towards the right. Two purple circles with black 'X' marks are located below the dashed line. A single blue circle with a black 'e' is at the top right.



Ruth Pöttgen
Partikeldagarna
Lund, Sep 2026

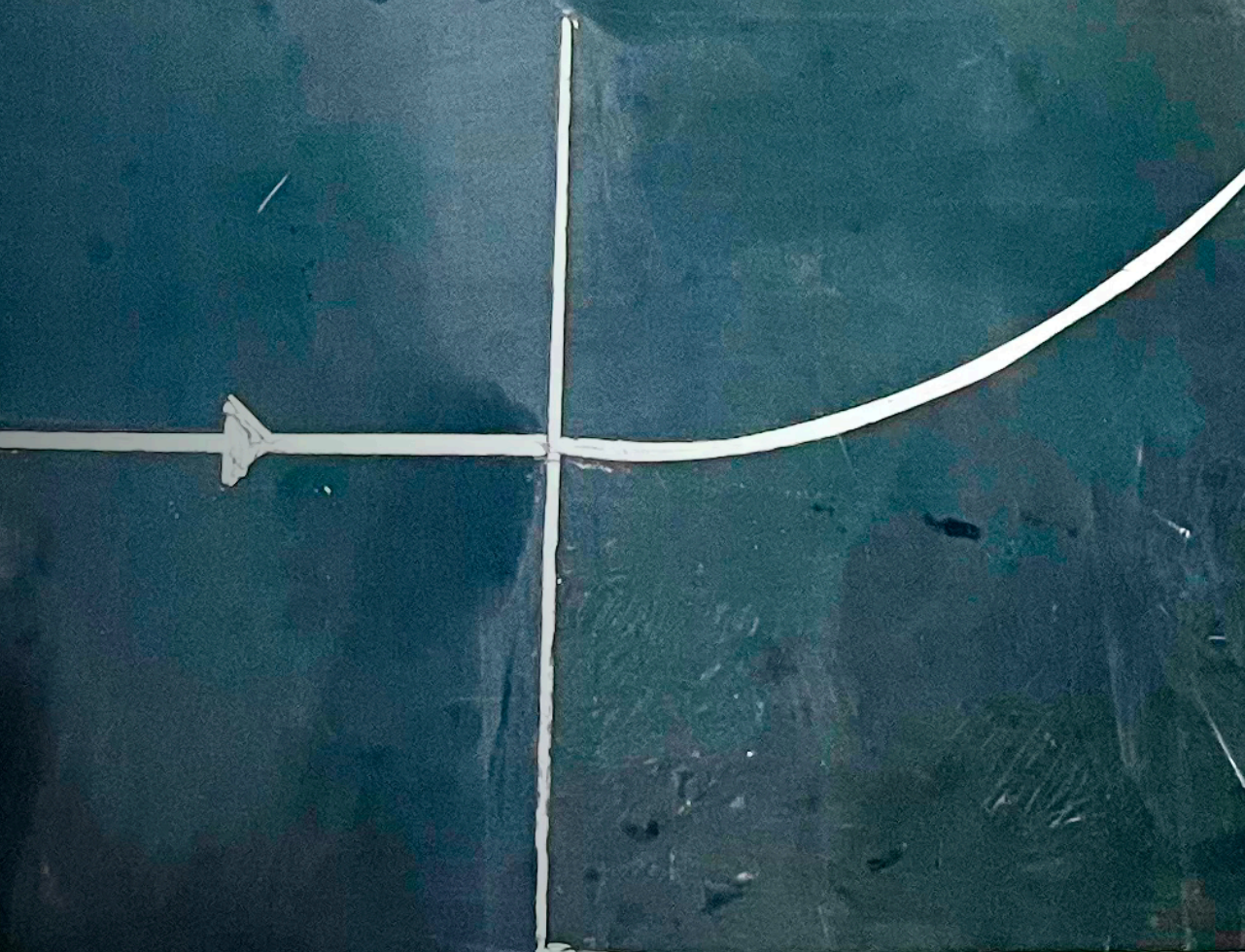
The diagram shows a coordinate system with a vertical y-axis and a horizontal x-axis. A white curve starts from the left, rises to a peak, and then descends. The letters 'DMX' are drawn in large, white, blocky font across the middle of the graph.



A hand-drawn diagram on a chalkboard. At the top, a blue circle with an 'e' and a minus sign is connected by a line to a horizontal track of several blue circles. A dashed line curves from the track down to a cluster of orange and white circles. Two purple circles with 'X' marks are positioned below the dashed line.

Update from the Light Dark Matter eXperiment

$m_{\text{DM}} \sim 1 \text{ MeV} - 1 \text{ GeV}$



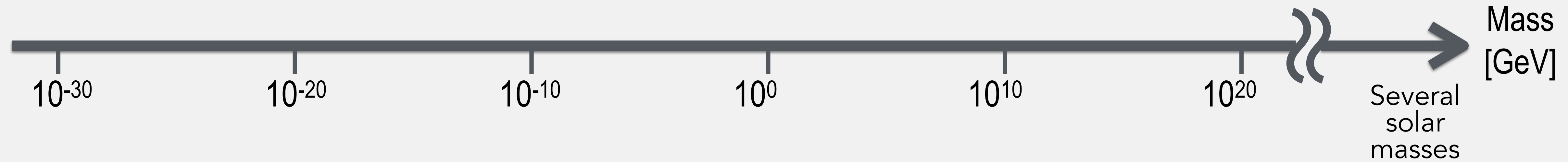
A hand-drawn diagram on a chalkboard. It shows a horizontal line with an arrow pointing to the right, which then curves upwards and connects to the letter 'D' of the word 'DMX'.

DMX

Ruth Pöttgen
Partikeldagarna
Lund, Sep 2026

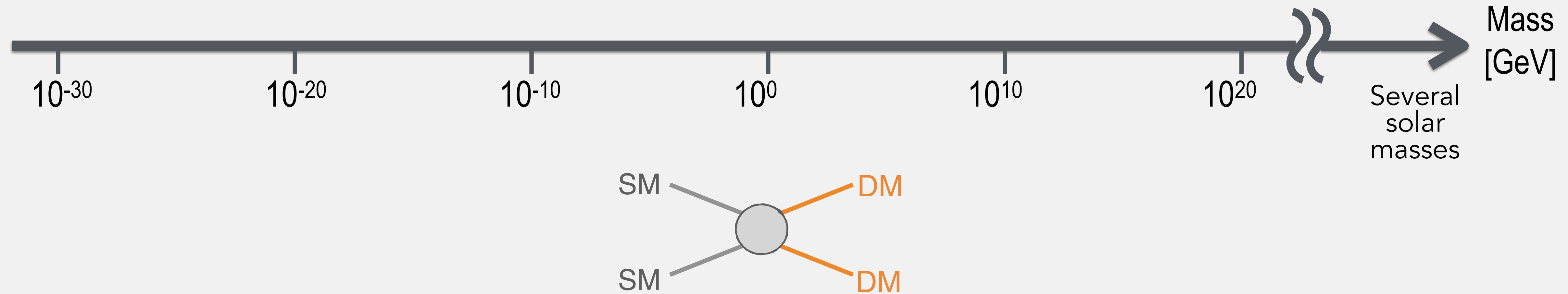
Why MeV - GeV?

Possible dark matter masses given astronomical observations:



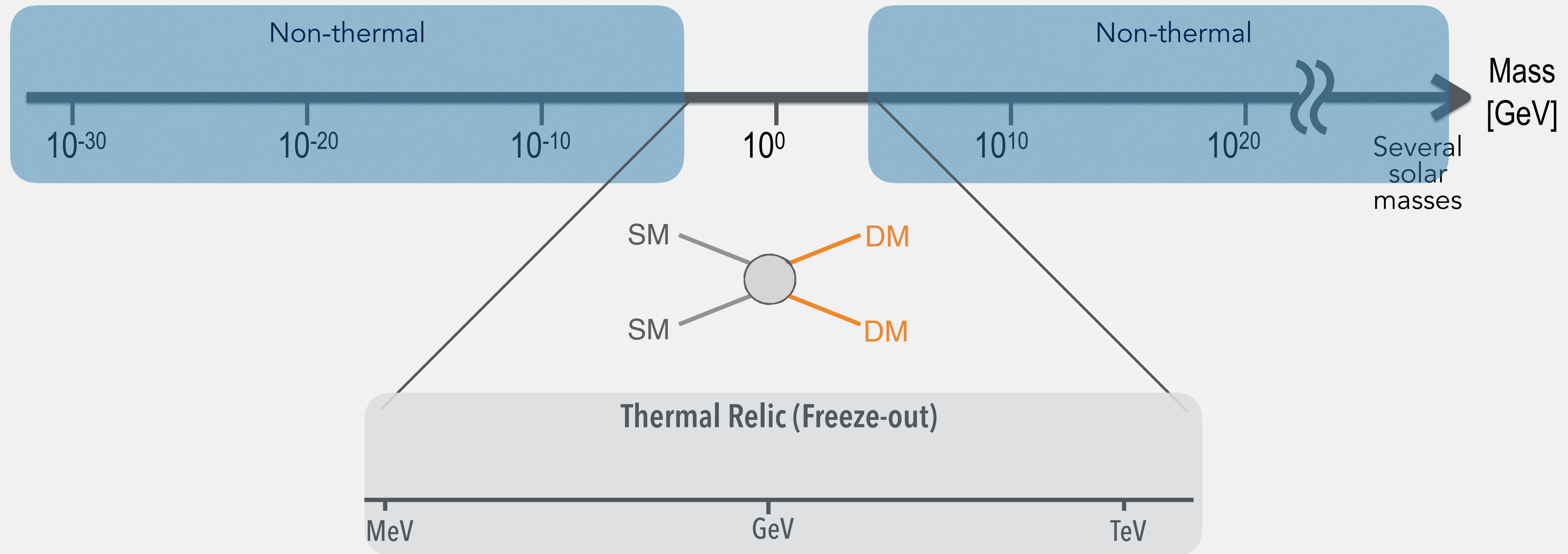
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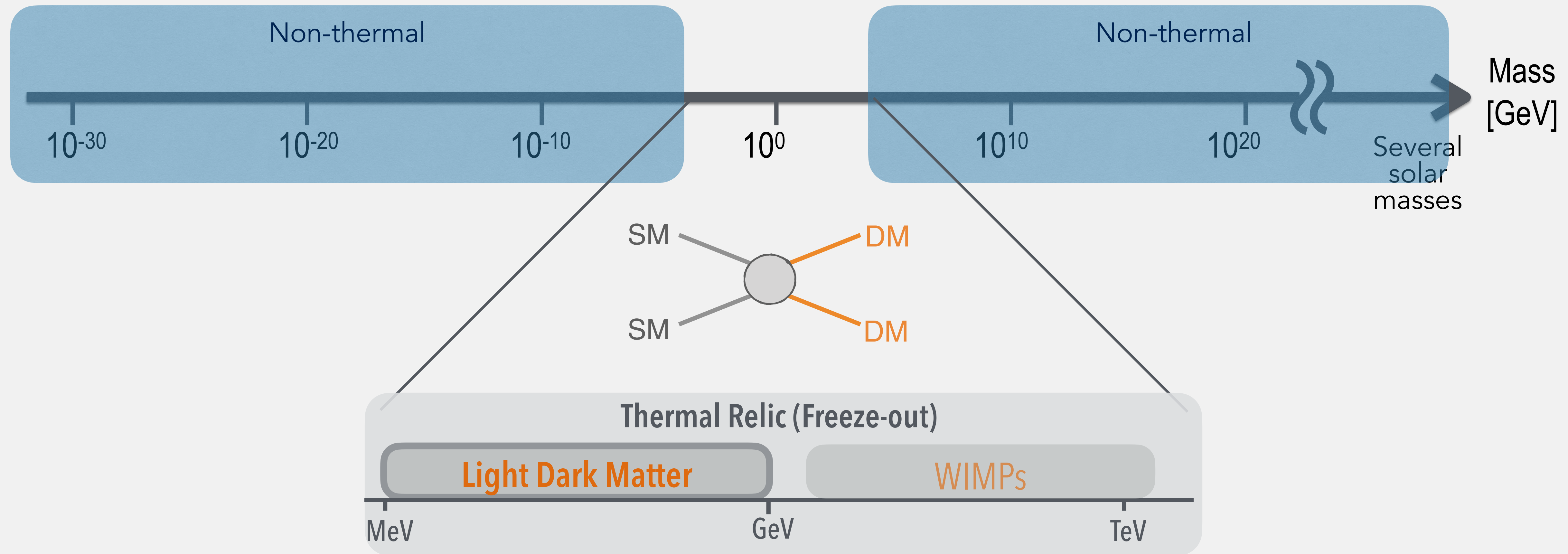
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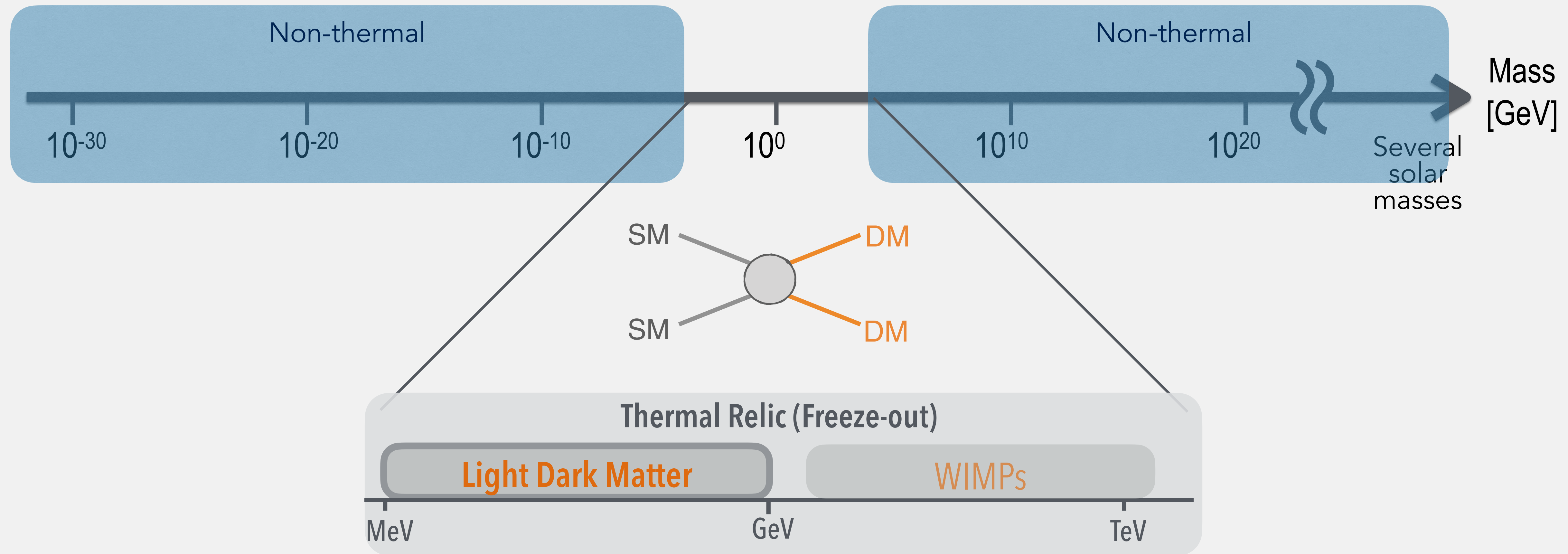
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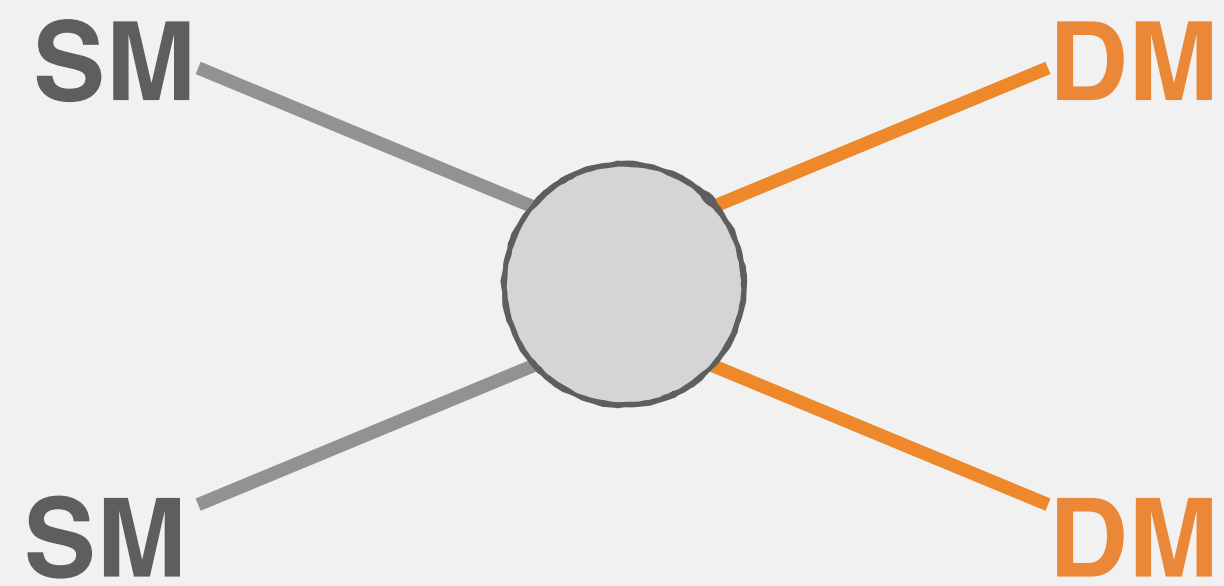
Possible dark matter masses given astronomical observations:



Requires experimental approaches beyond canonical WIMP searches

How to make sub-GeV scale DM

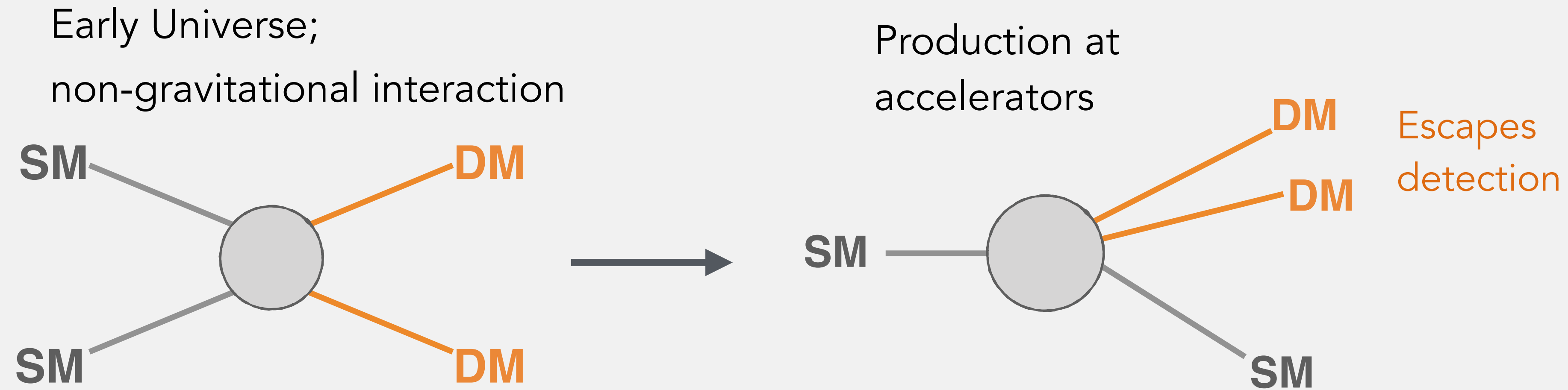
Early Universe;
non-gravitational interaction



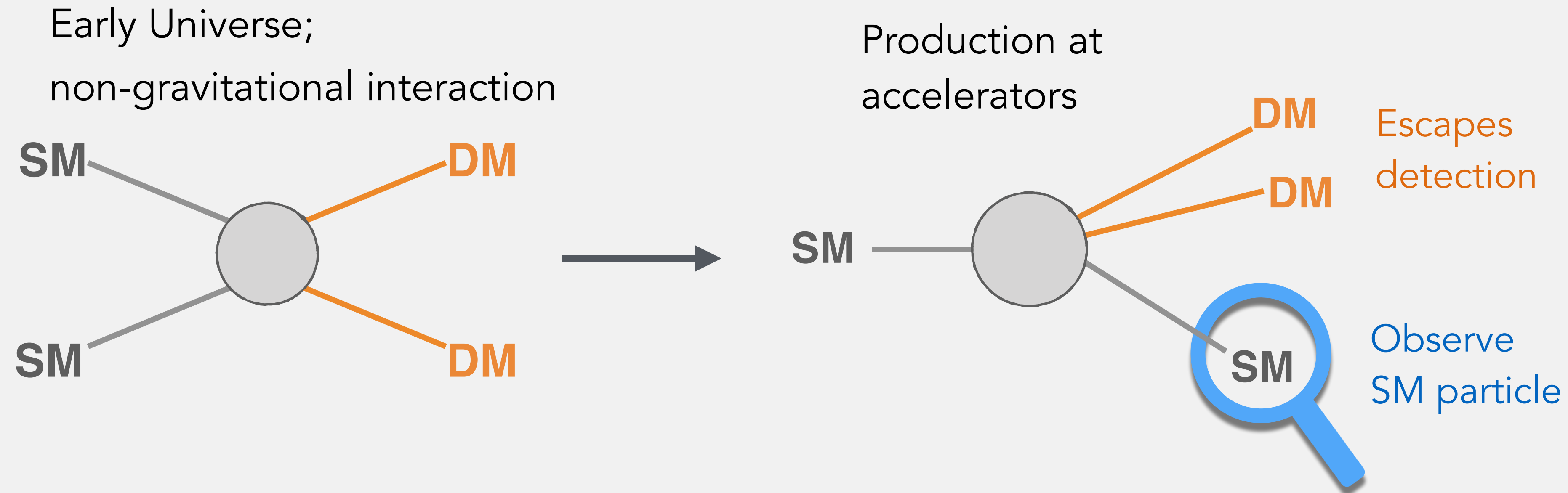
How to make sub-GeV scale DM



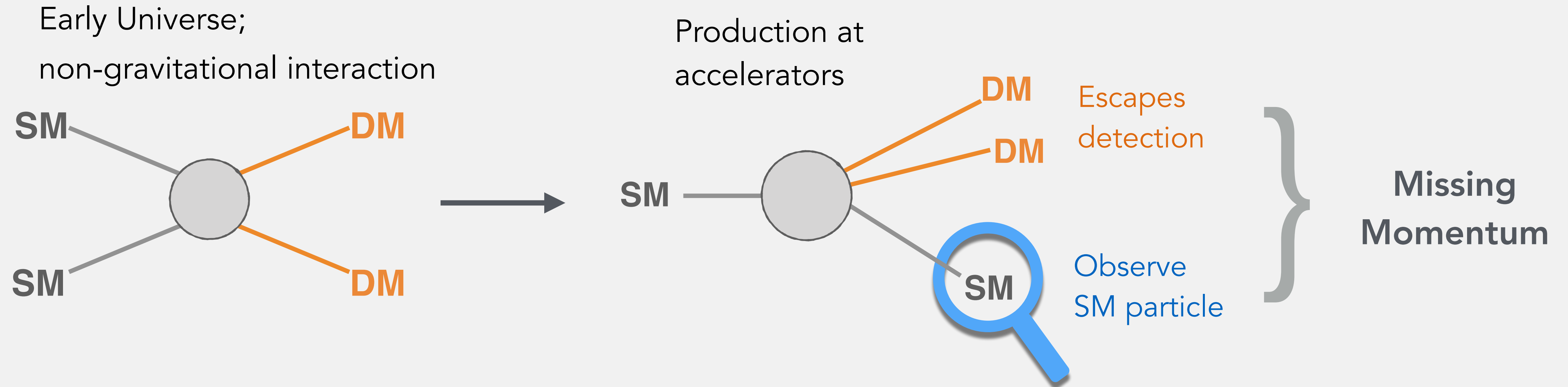
How to make sub-GeV scale DM



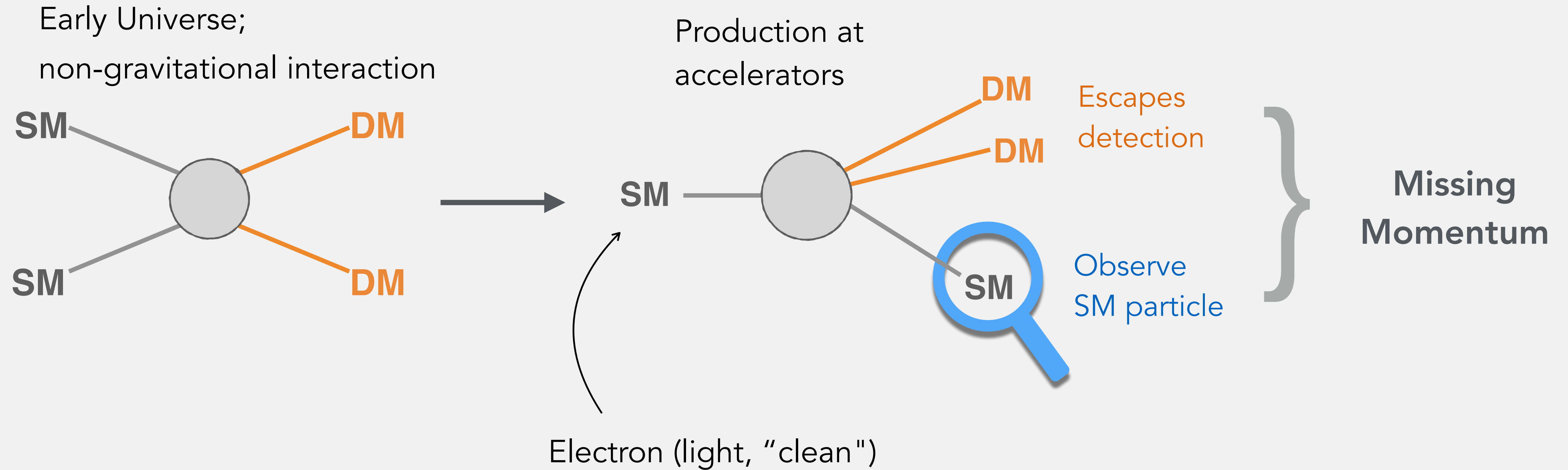
How to make sub-GeV scale DM



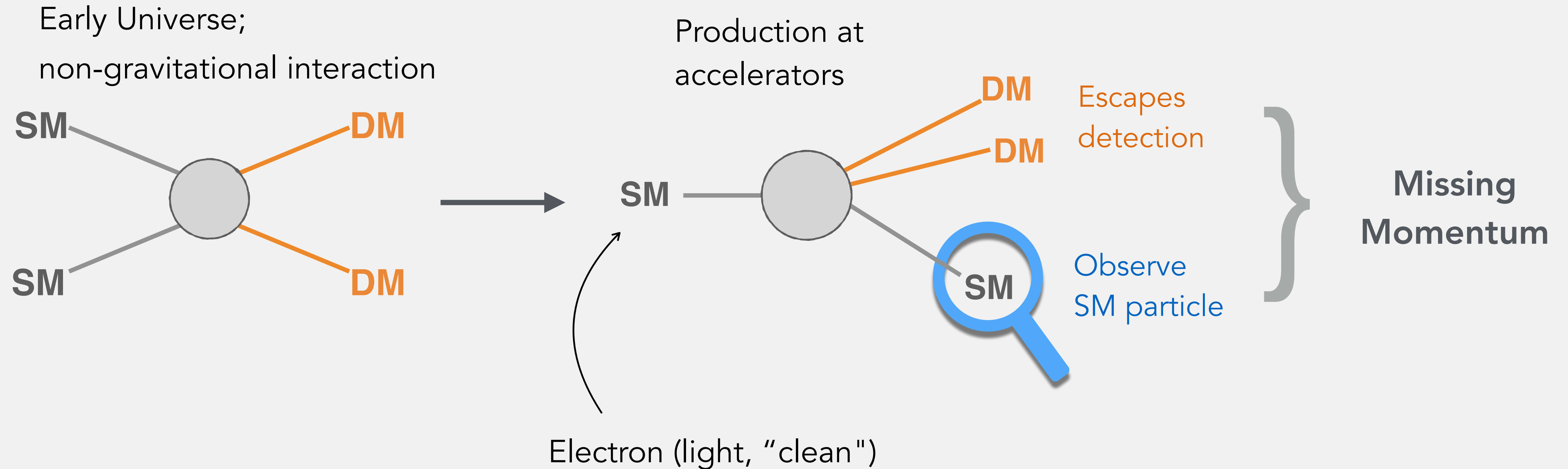
How to make sub-GeV scale DM



How to make sub-GeV scale DM

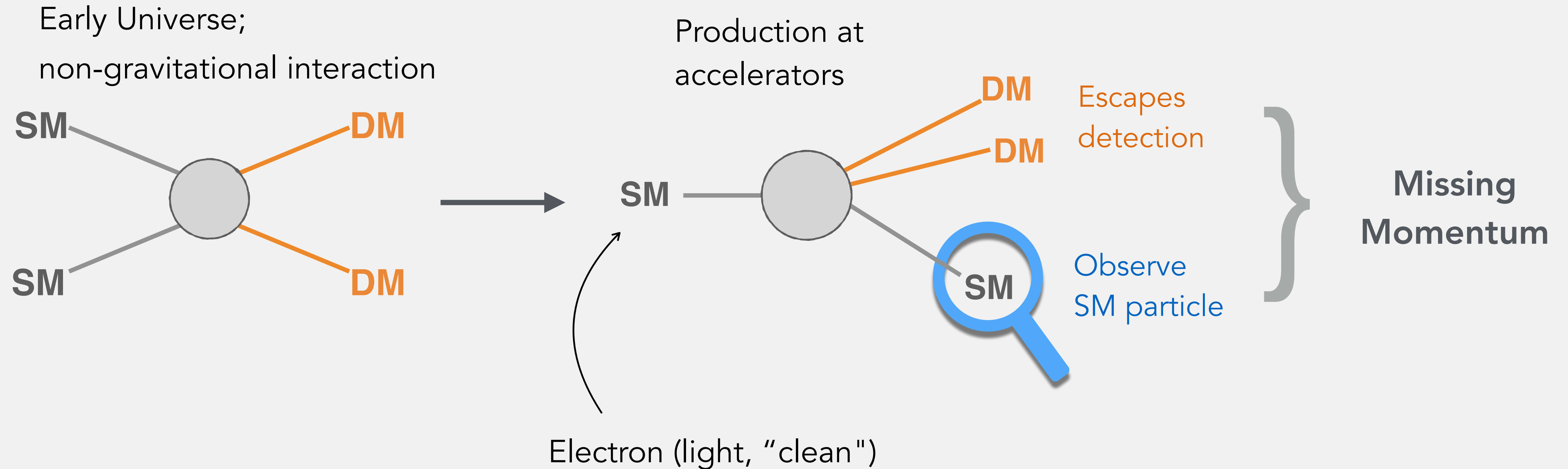


How to make sub-GeV scale DM



To probe models consistent with observed relic abundance: $10^{14} - 10^{16}$ electrons on target (EoT)

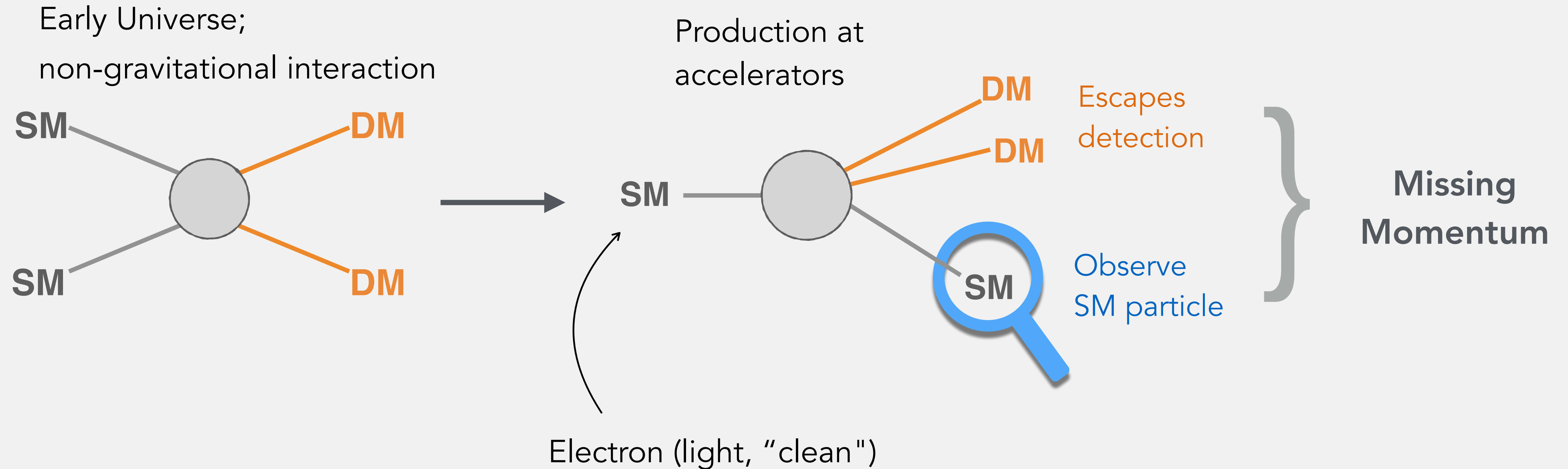
How to make sub-GeV scale DM



To probe models consistent with observed relic abundance: $10^{14} - 10^{16}$ electrons on target (EoT)

+ measure ***each of them individually!***

How to make sub-GeV scale DM

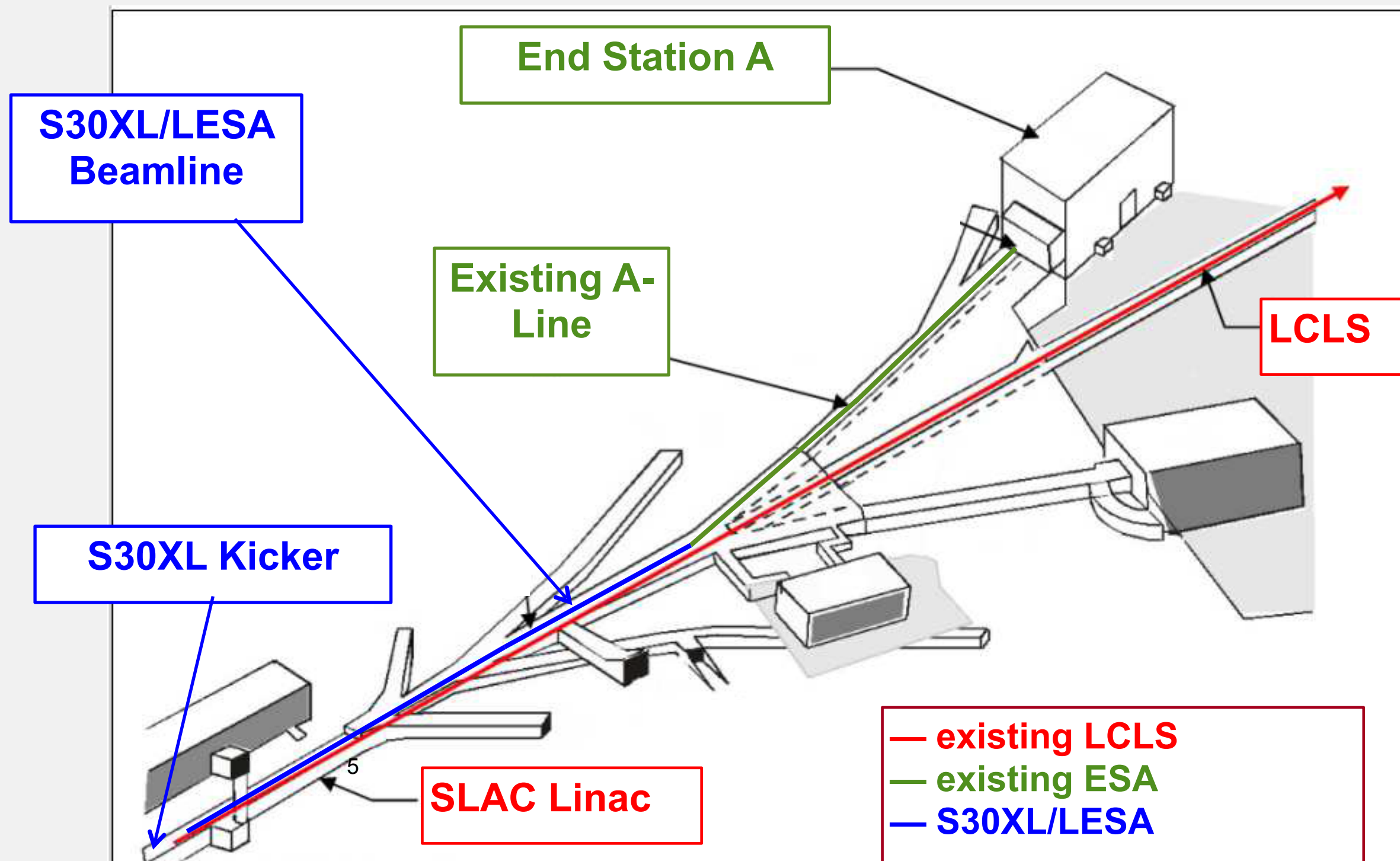


To probe models consistent with observed relic abundance: $10^{14} - 10^{16}$ electrons on target (EoT)

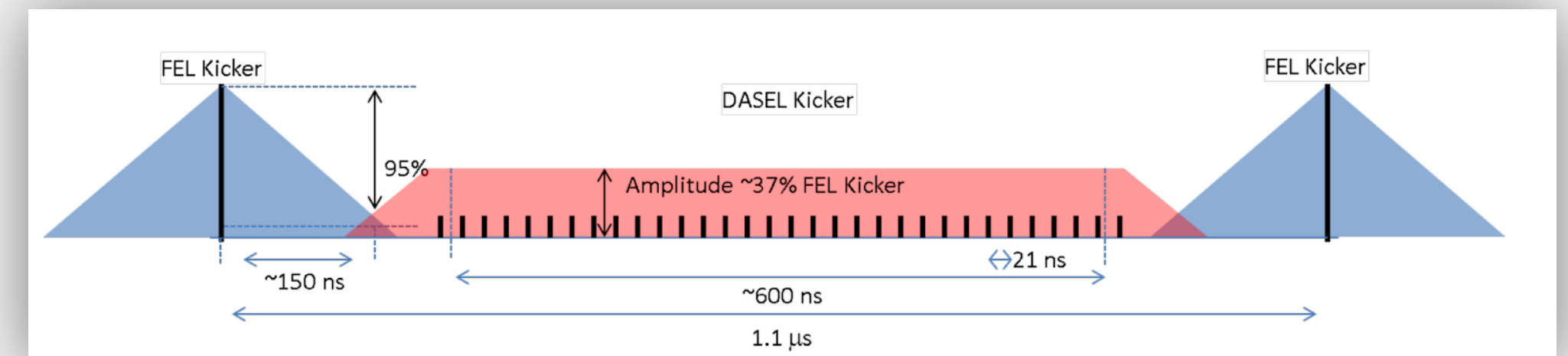
+ measure ***each of them individually!***

—> Special beam!

Dedicated beamline completed in late 2025 (~\$17M, DOE)



[arXiv:2205.13215](https://arxiv.org/abs/2205.13215)



Parasitic!

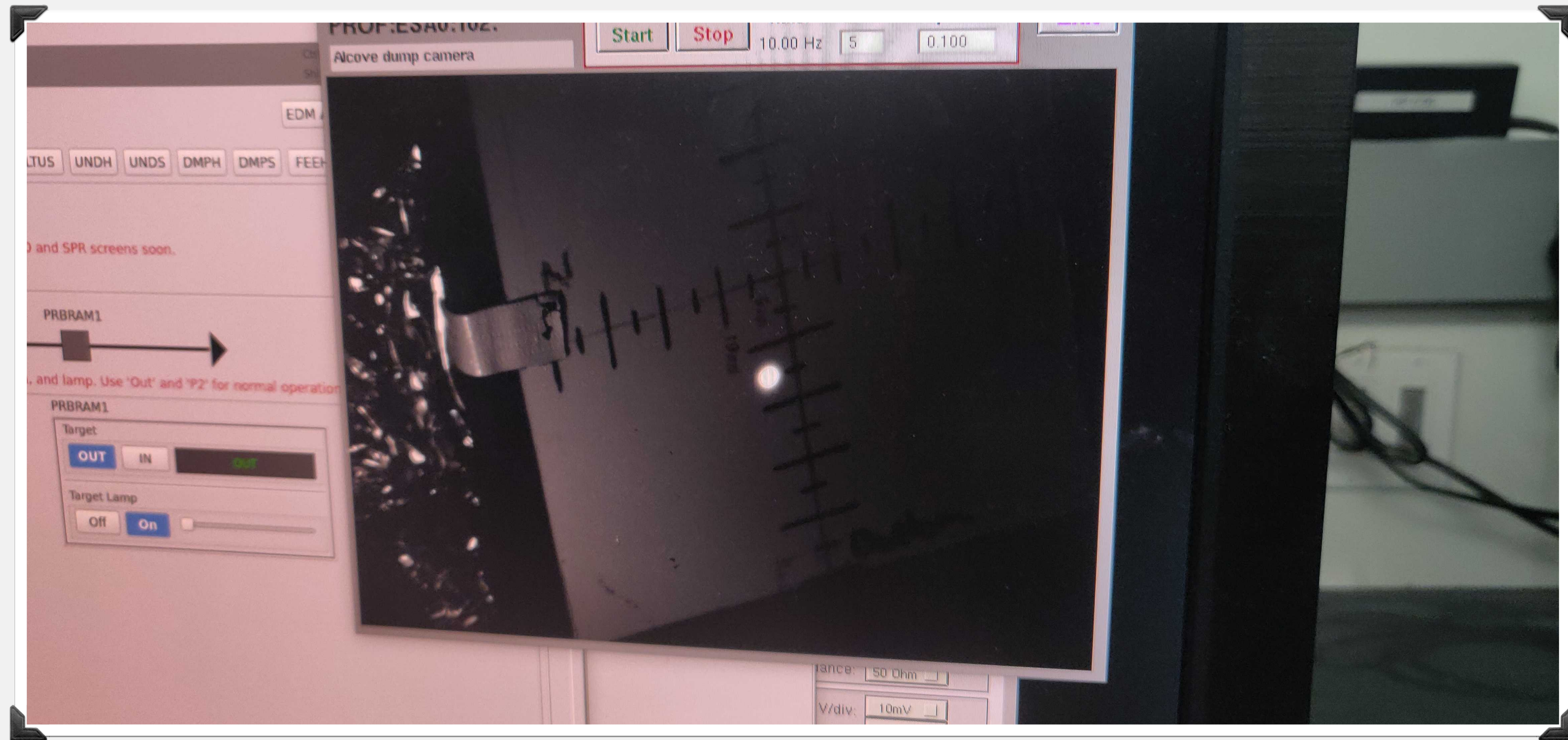
Energy: 8 GeV (start 2027), 4 GeV until 2025

Bunch frequency: ~40 MHz (186 MHz)

With $\langle \mu \rangle = 2$: 4×10^{14} EoT in 12 months

Milestone early 2025: Dark current characterisation [J NIMA \(2026\) 171709](#)

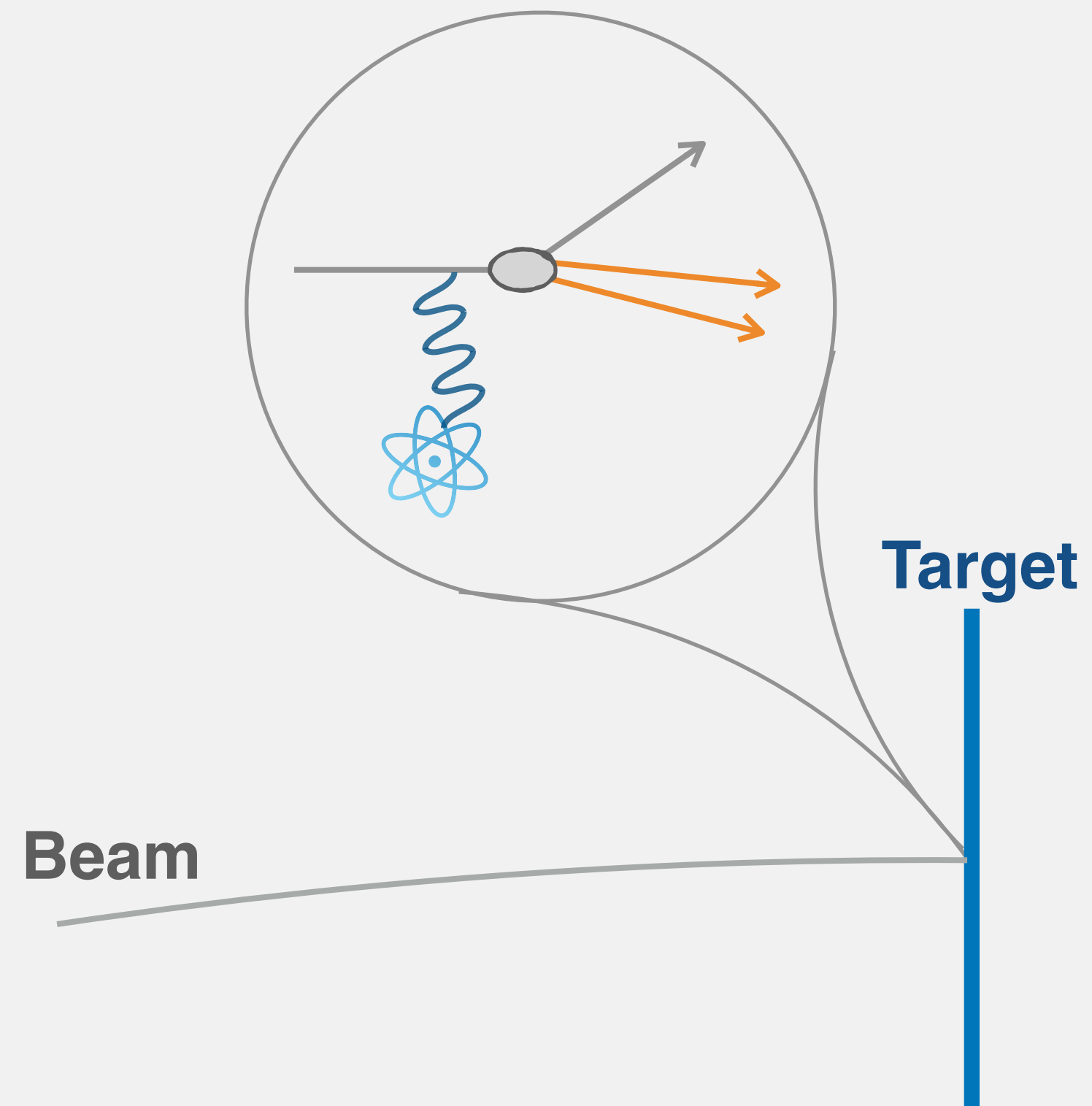
28 Nov 2025: First beam to ESA since 2018 (FEL pulse)



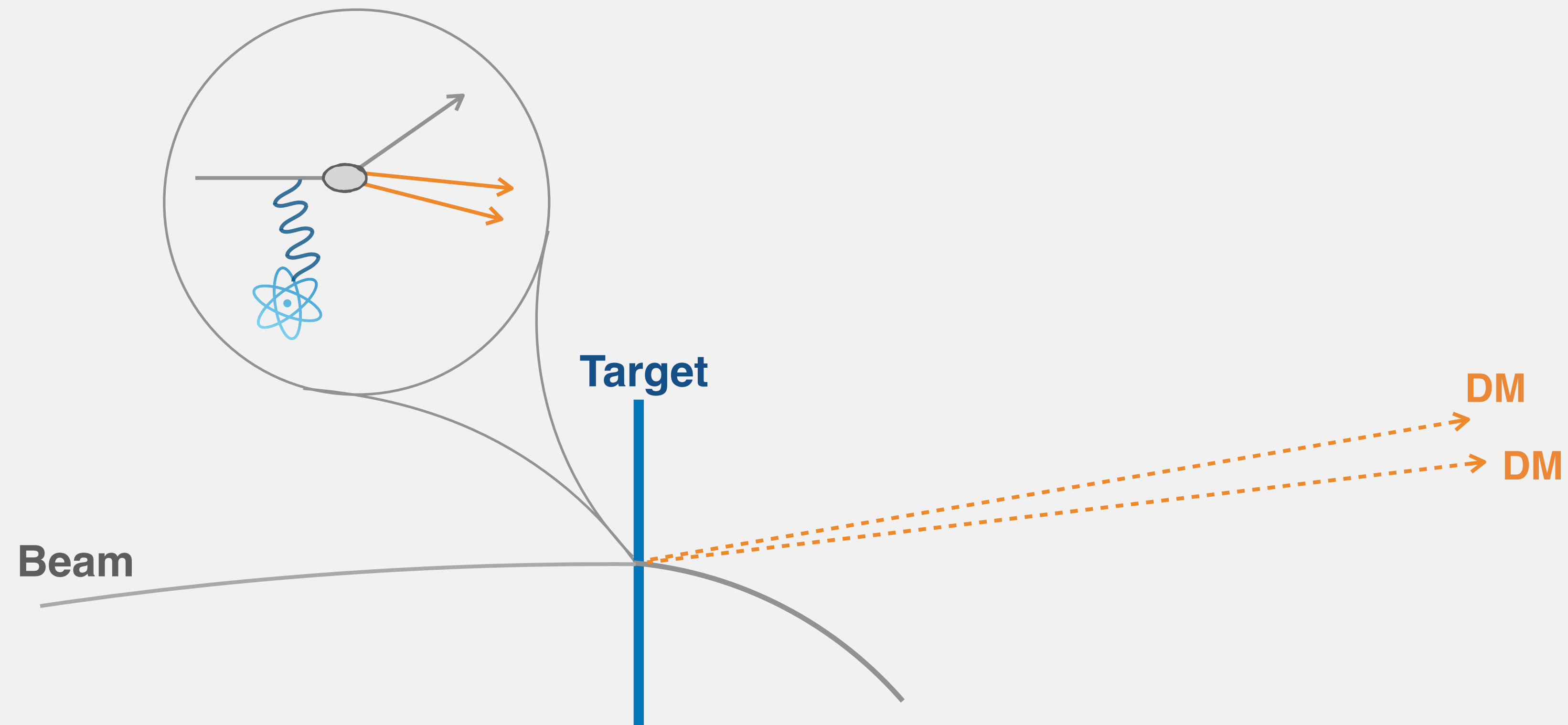
LDMX Concept (from above)



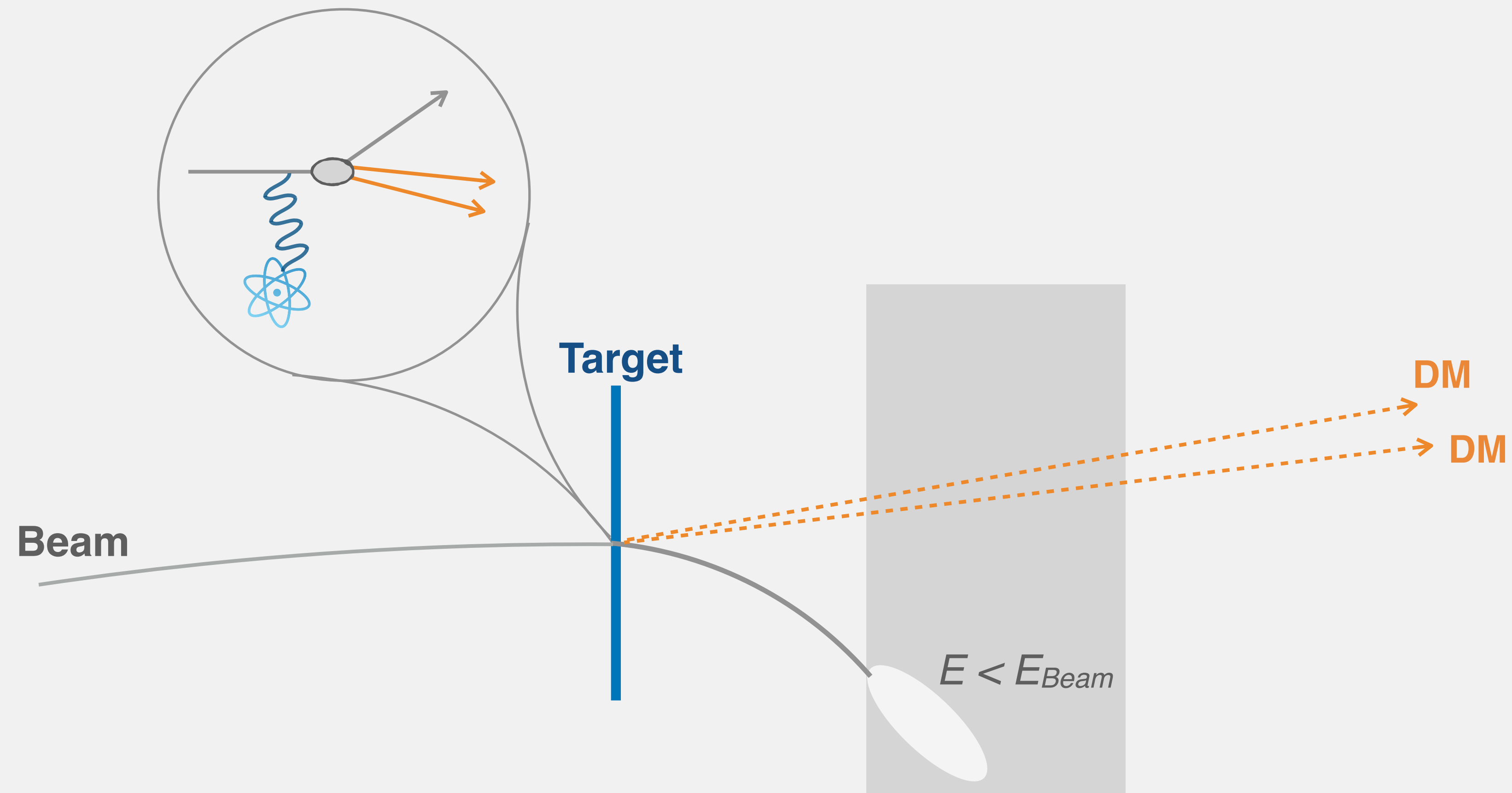
LDMX Concept (from above)



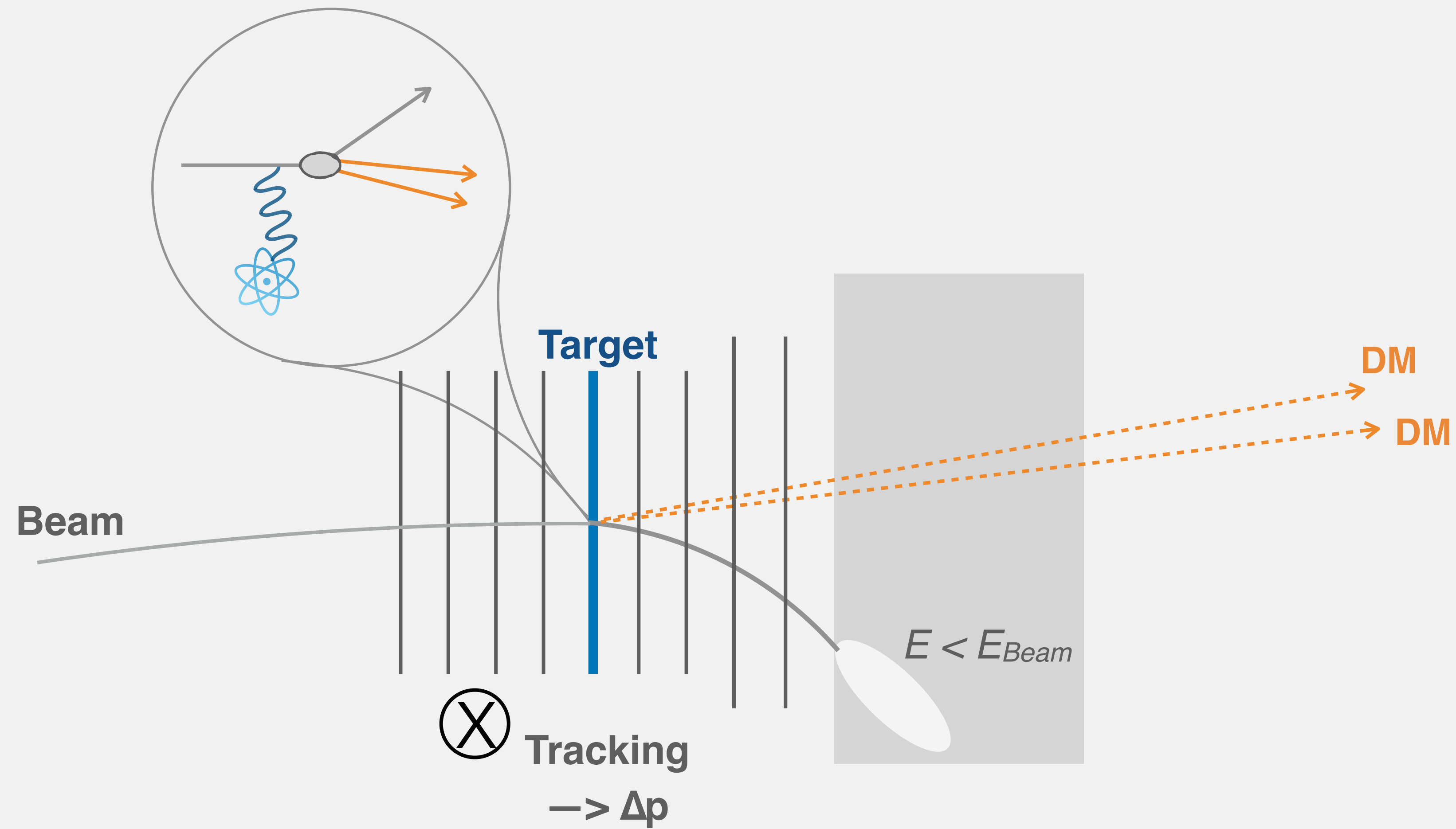
LDMX Concept (from above)



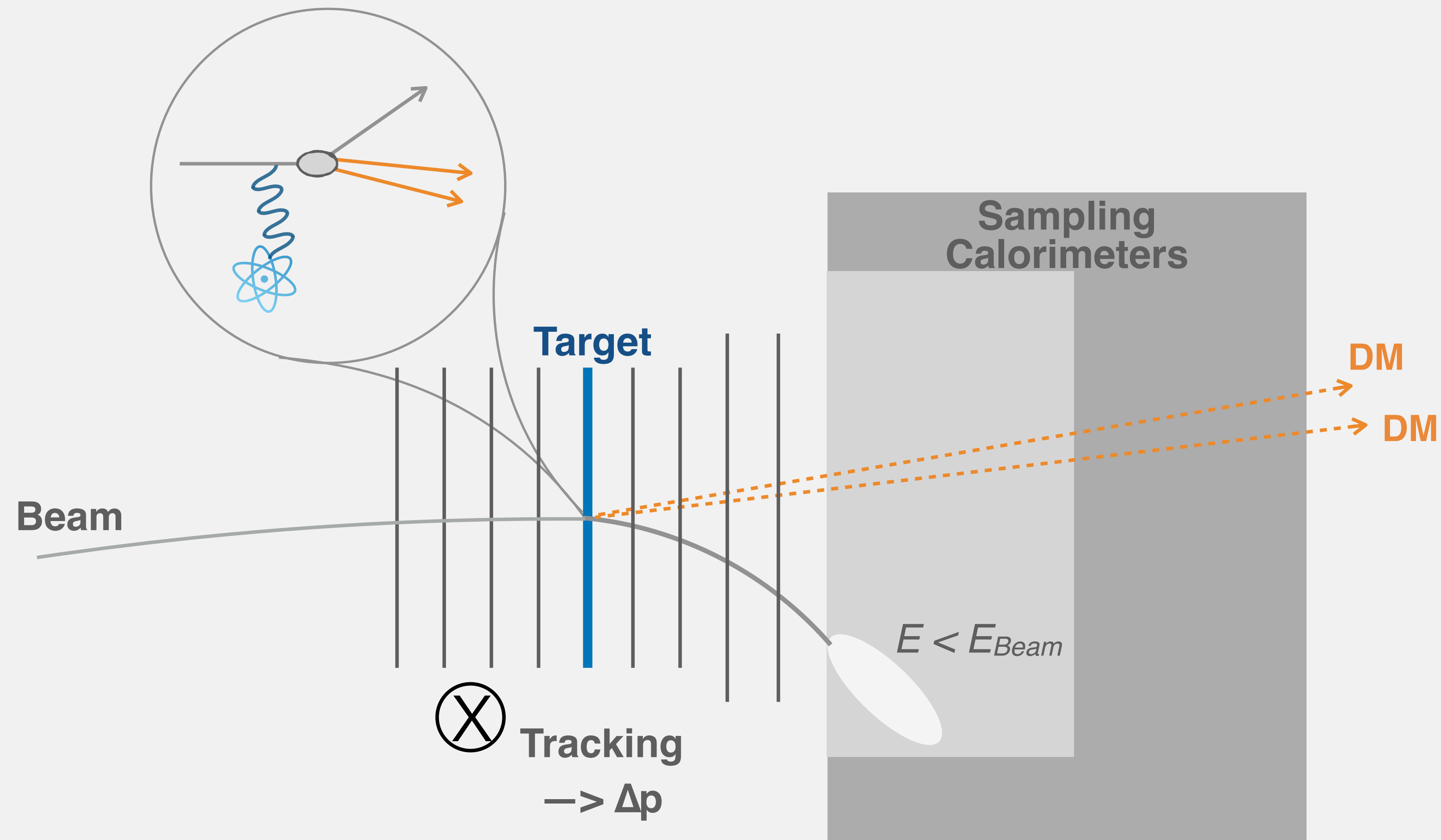
LDMX Concept (from above)



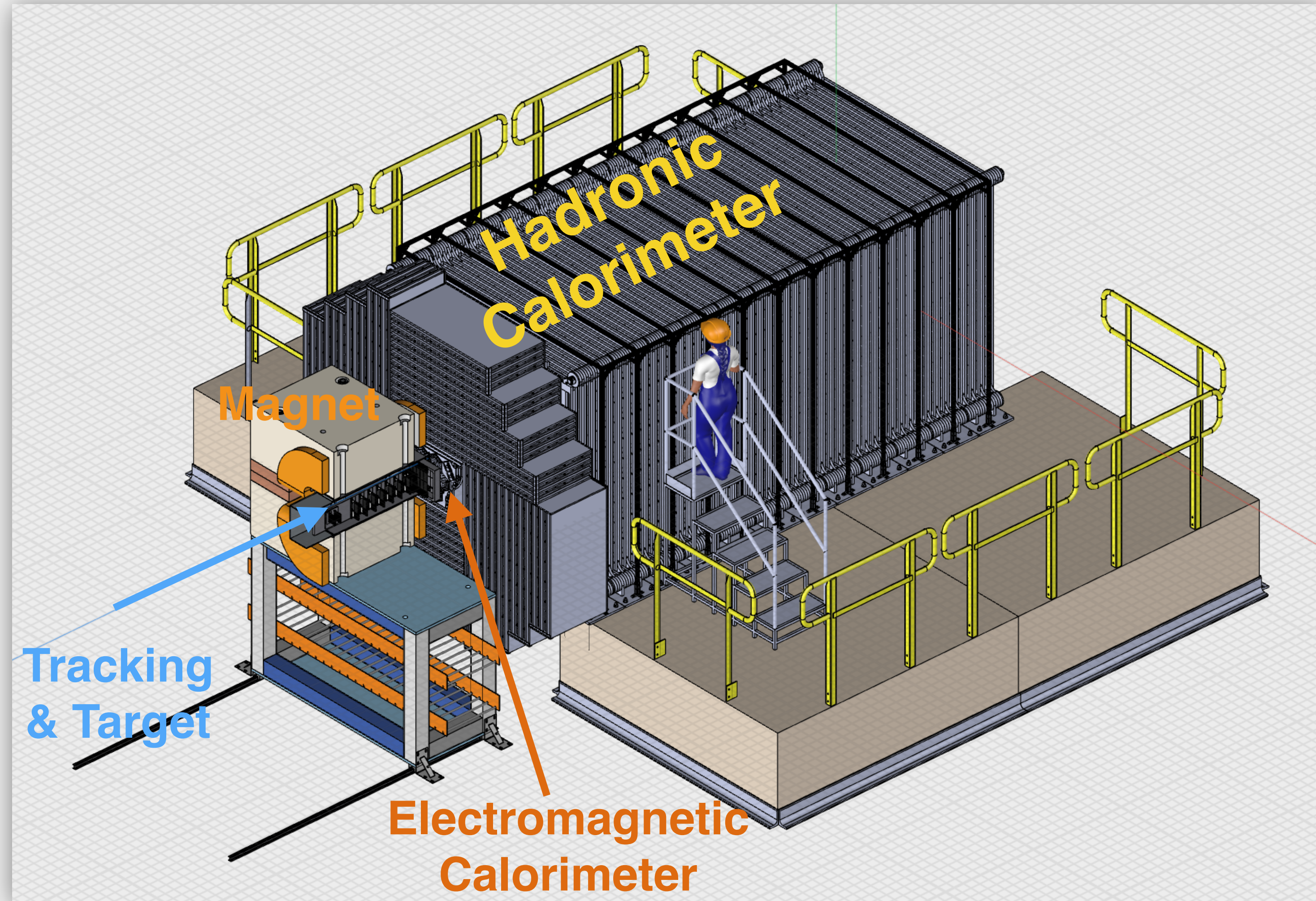
LDMX Concept (from above)



LDMX Concept (from above)



LDMX Experiment



Draw on proven designs:

- Tracker: HPS SVT
- ECal: CMS HGCal
- HCal: Mu2e CRV
- TS: CMS HCal

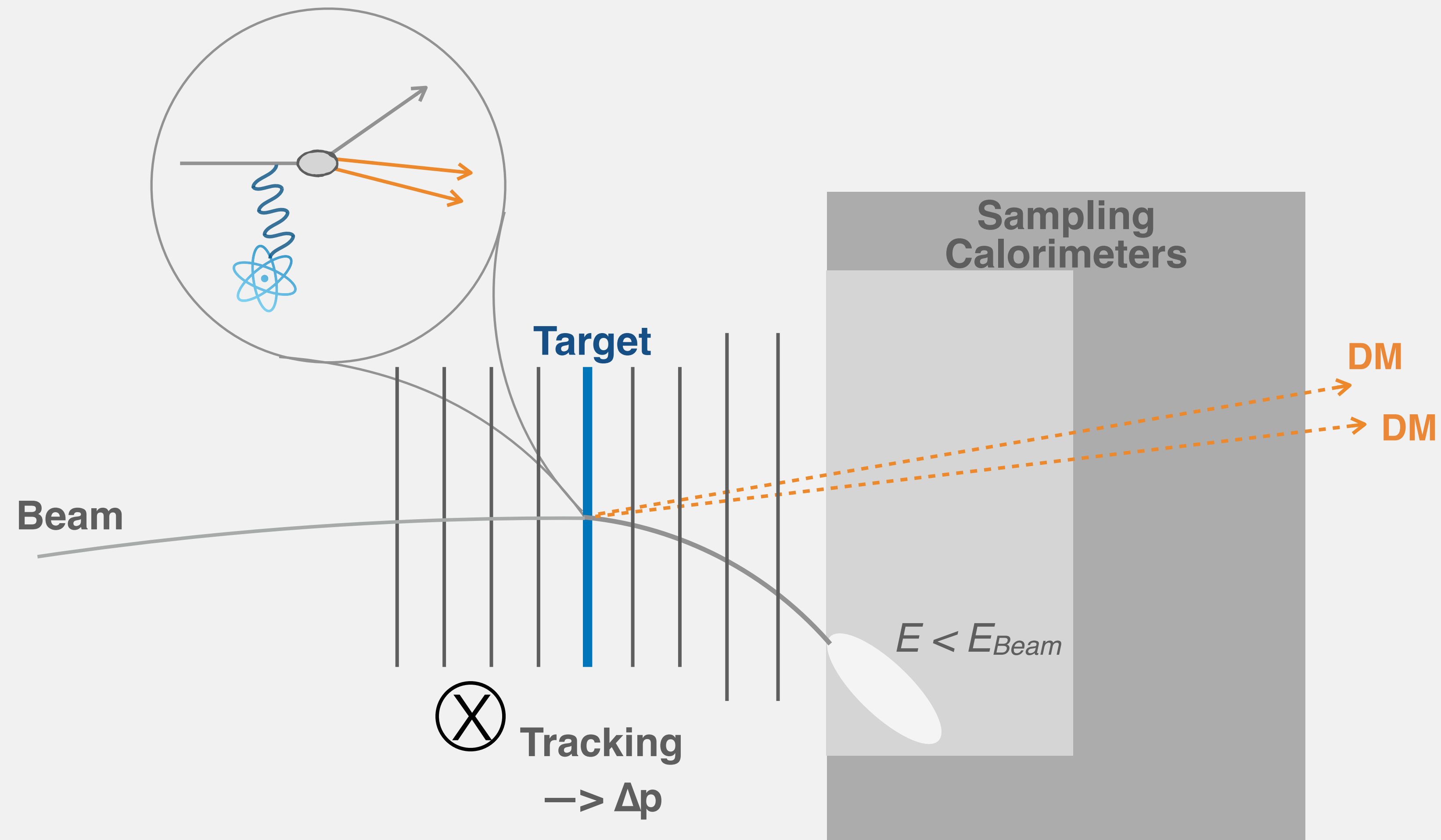
Want more details?



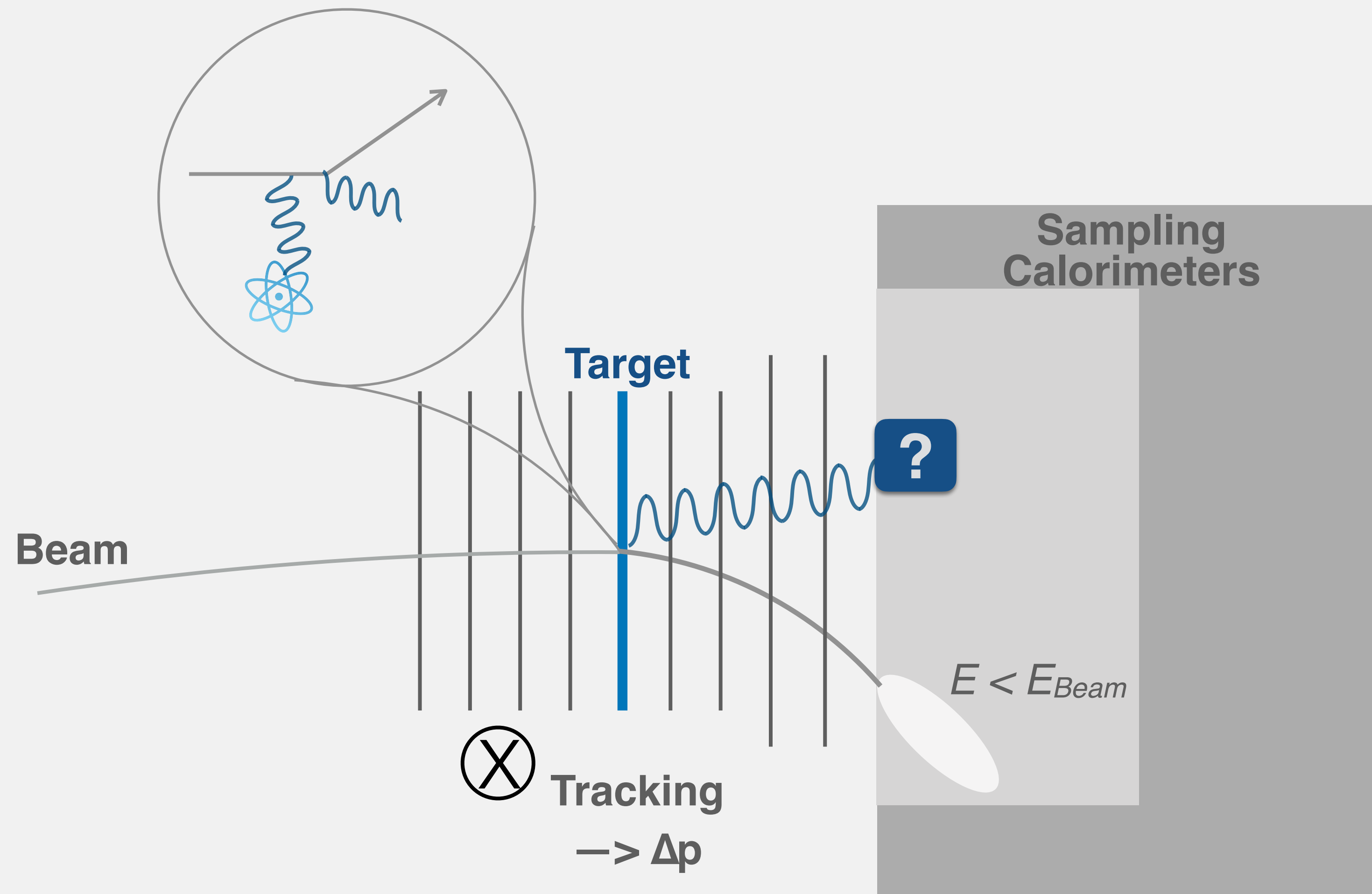
+ Verena Hehl's
talk on HCal
Electronics!

[arxiv:2508.11833](https://arxiv.org/abs/2508.11833)

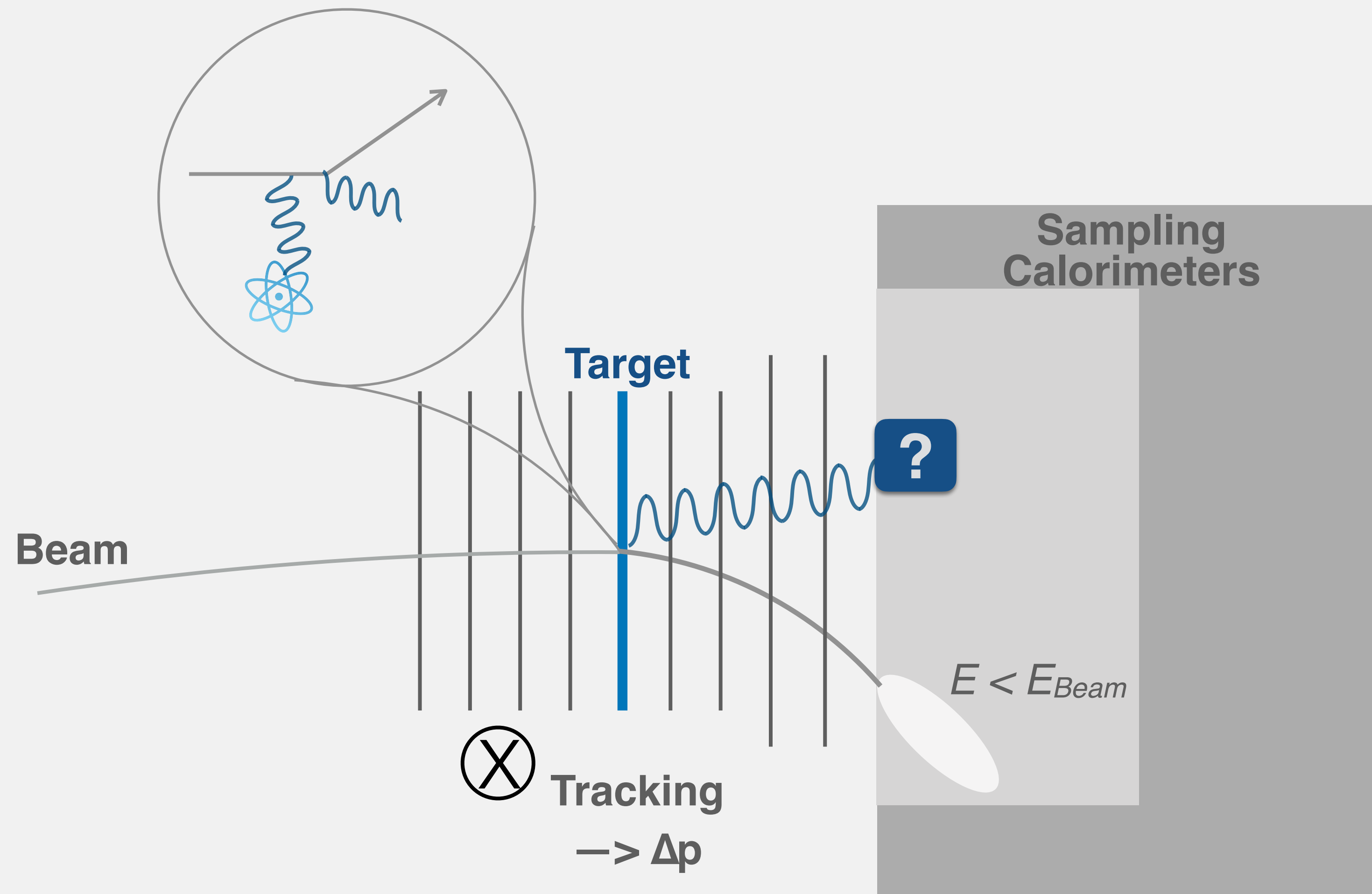
Reminder: Signal (Very rare)



Main Background Source (Much less rare)

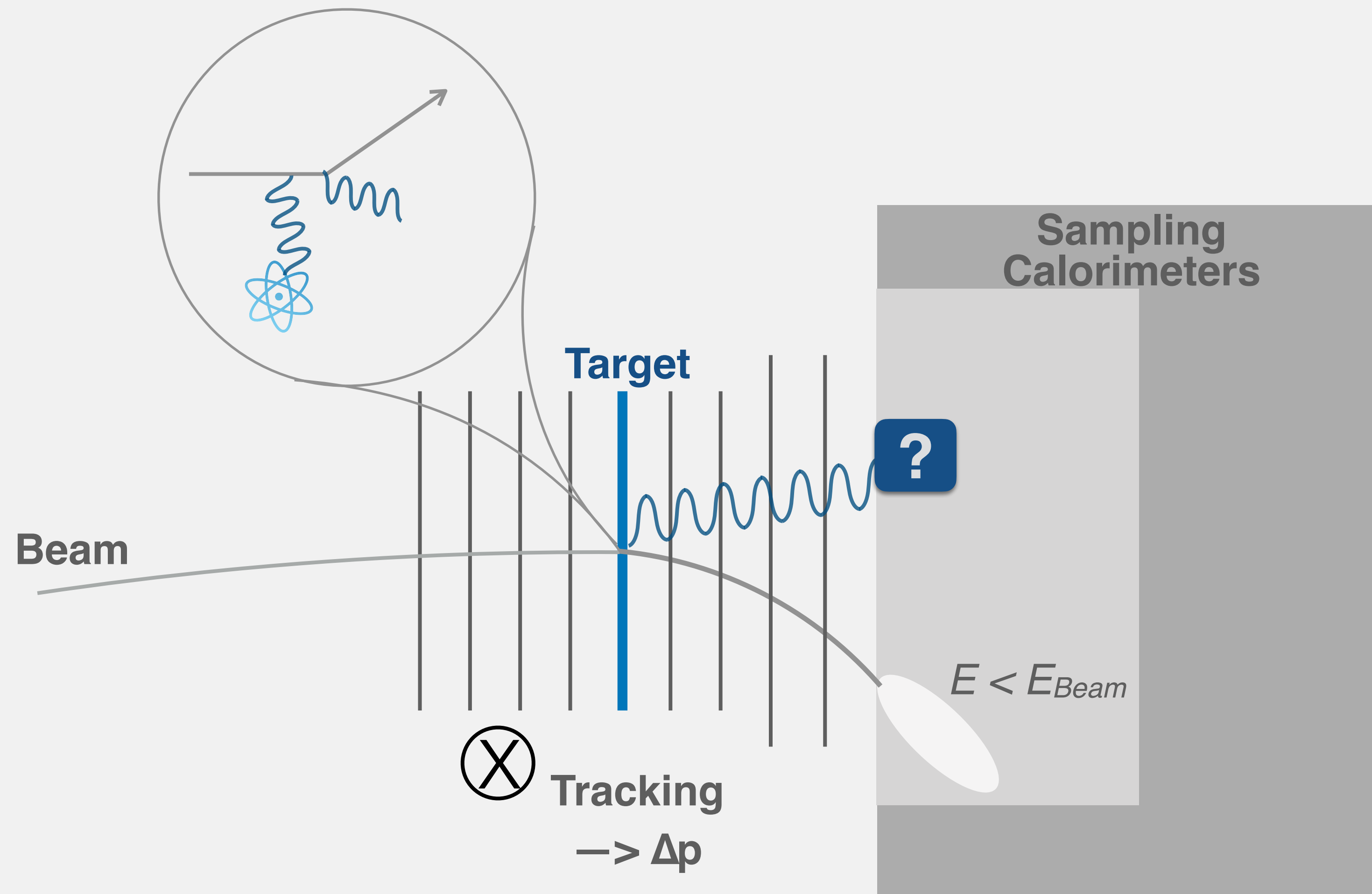


Main Background Source (Much less rare)



Many possible fates of the photon.

Main Background Source (Much less rare)

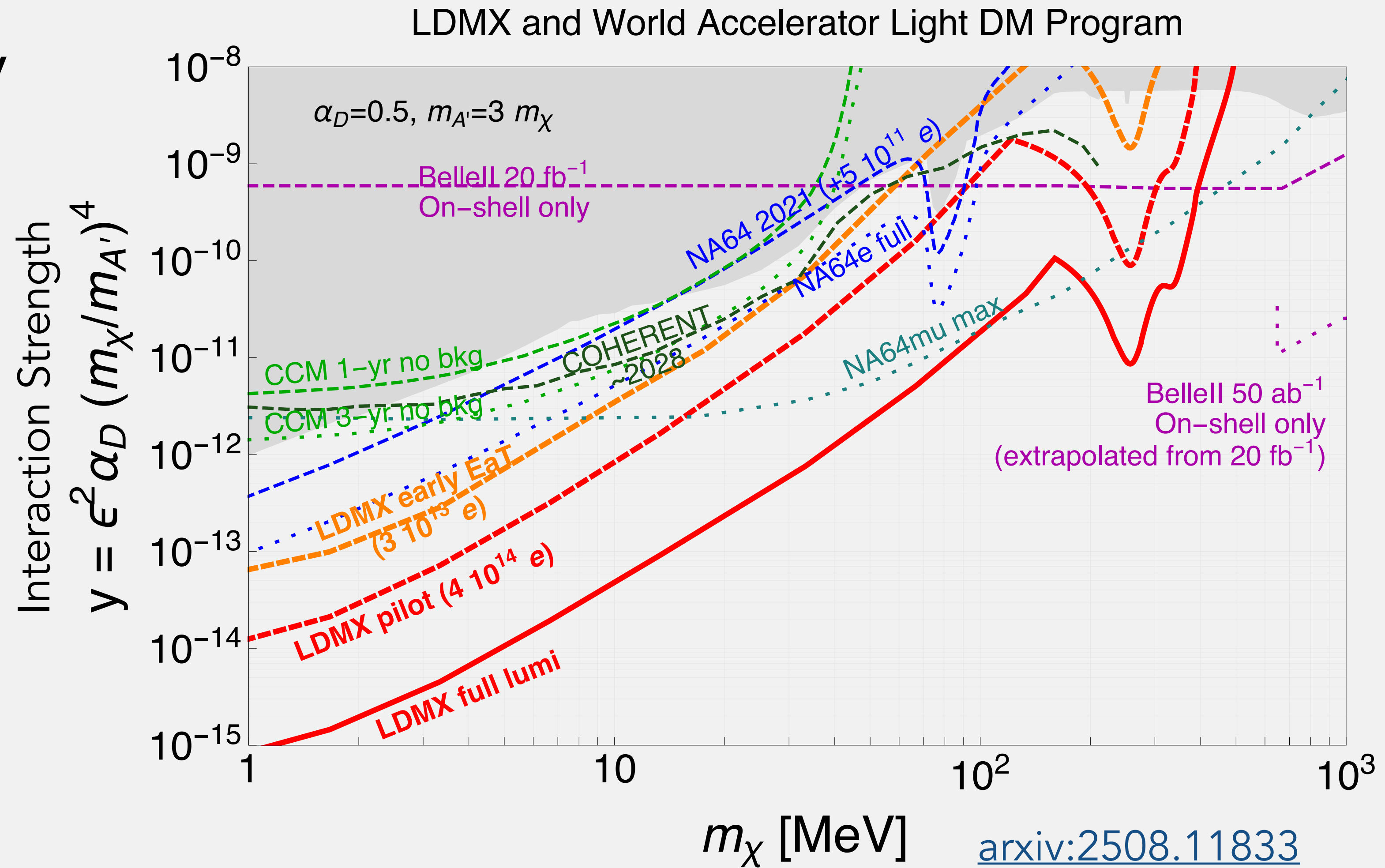


Many possible fates of the photon.

Our studies: We can reject photon-induced backgrounds down to 10^{-13} .

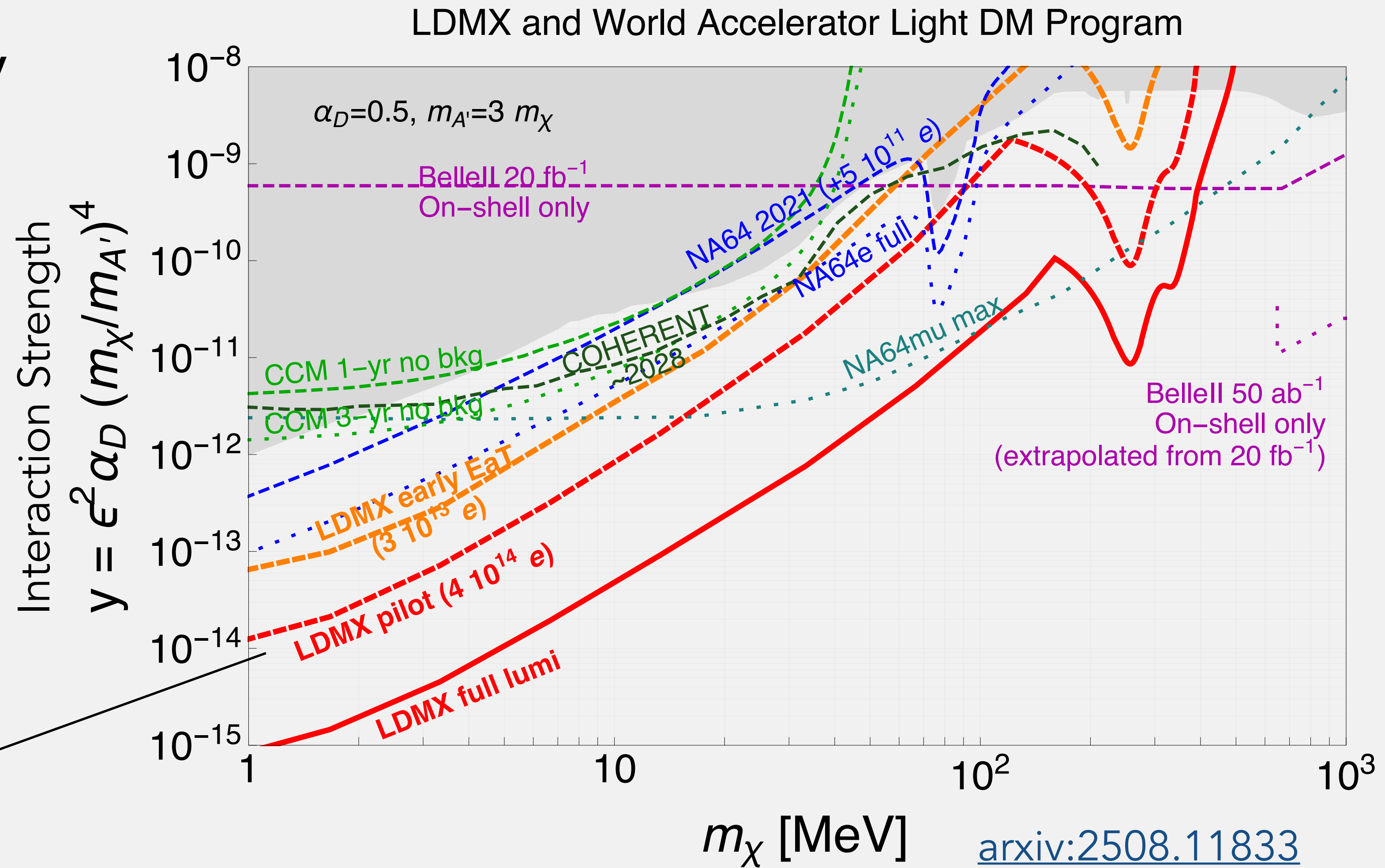
Sensitivity to LDM

Competitive sensitivity
over wide mass range



Sensitivity to LDM

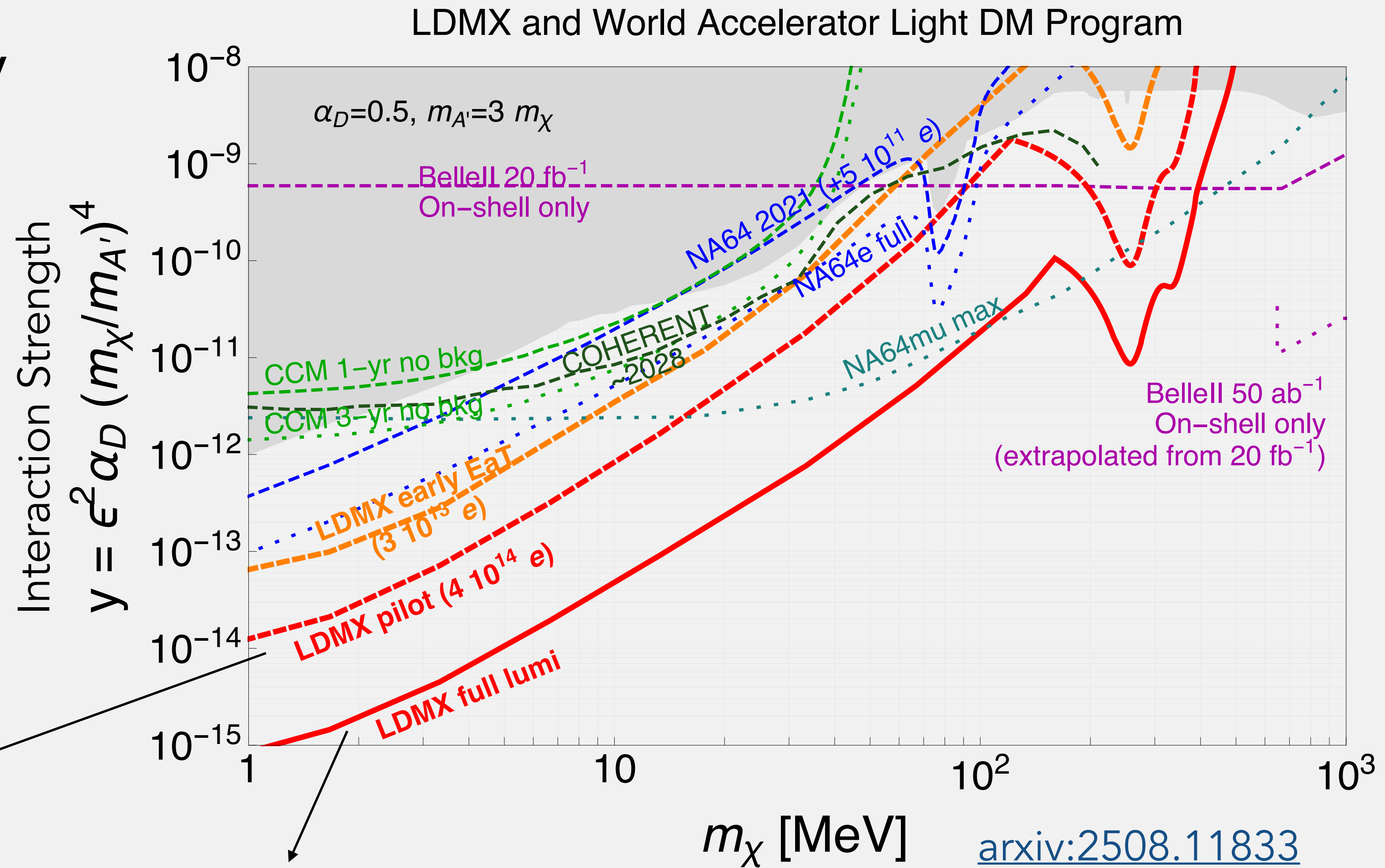
**Competitive sensitivity
over wide mass range**



~1 year data taking
with $\langle \mu \rangle = 2$

Sensitivity to LDM

Competitive sensitivity
over wide mass range

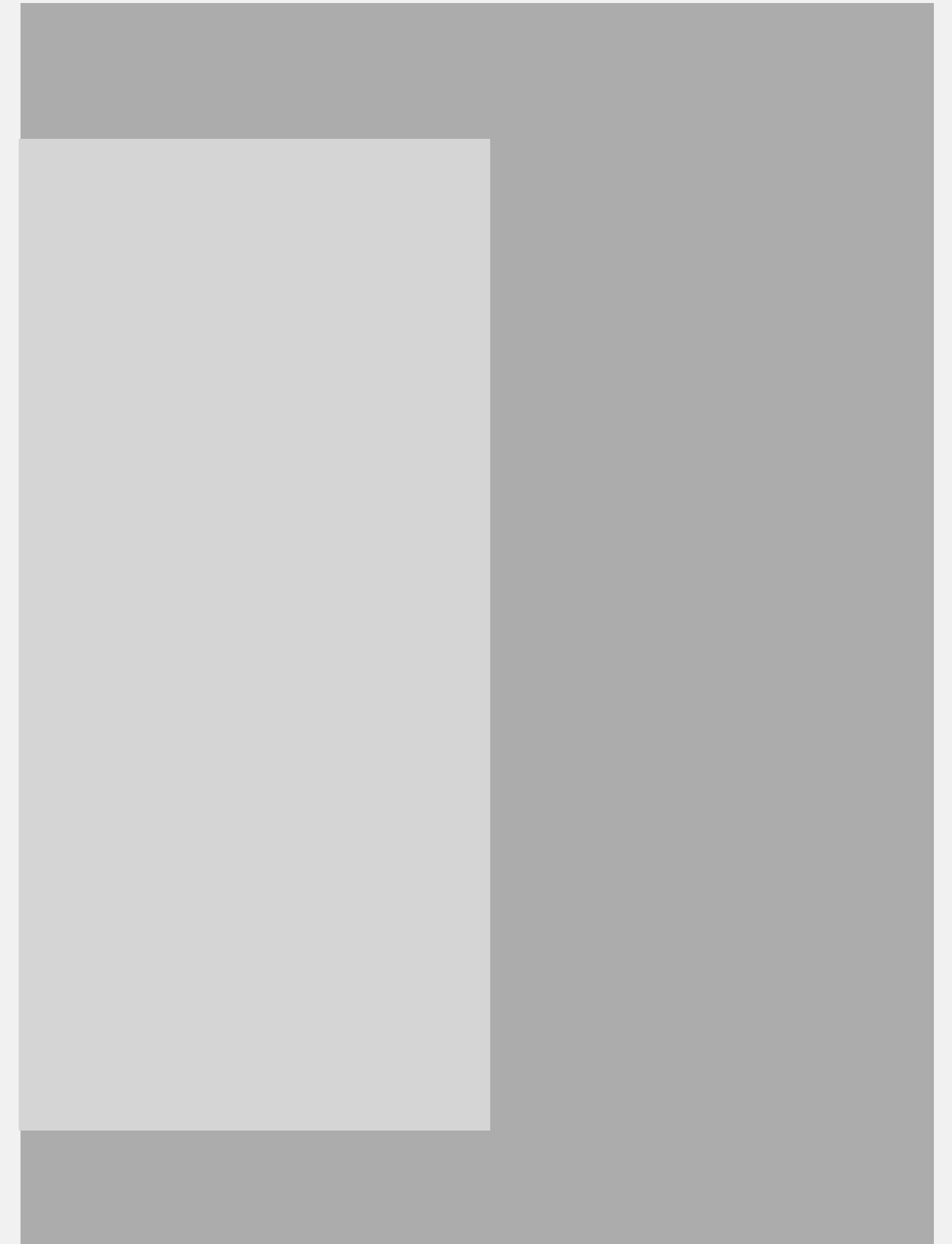
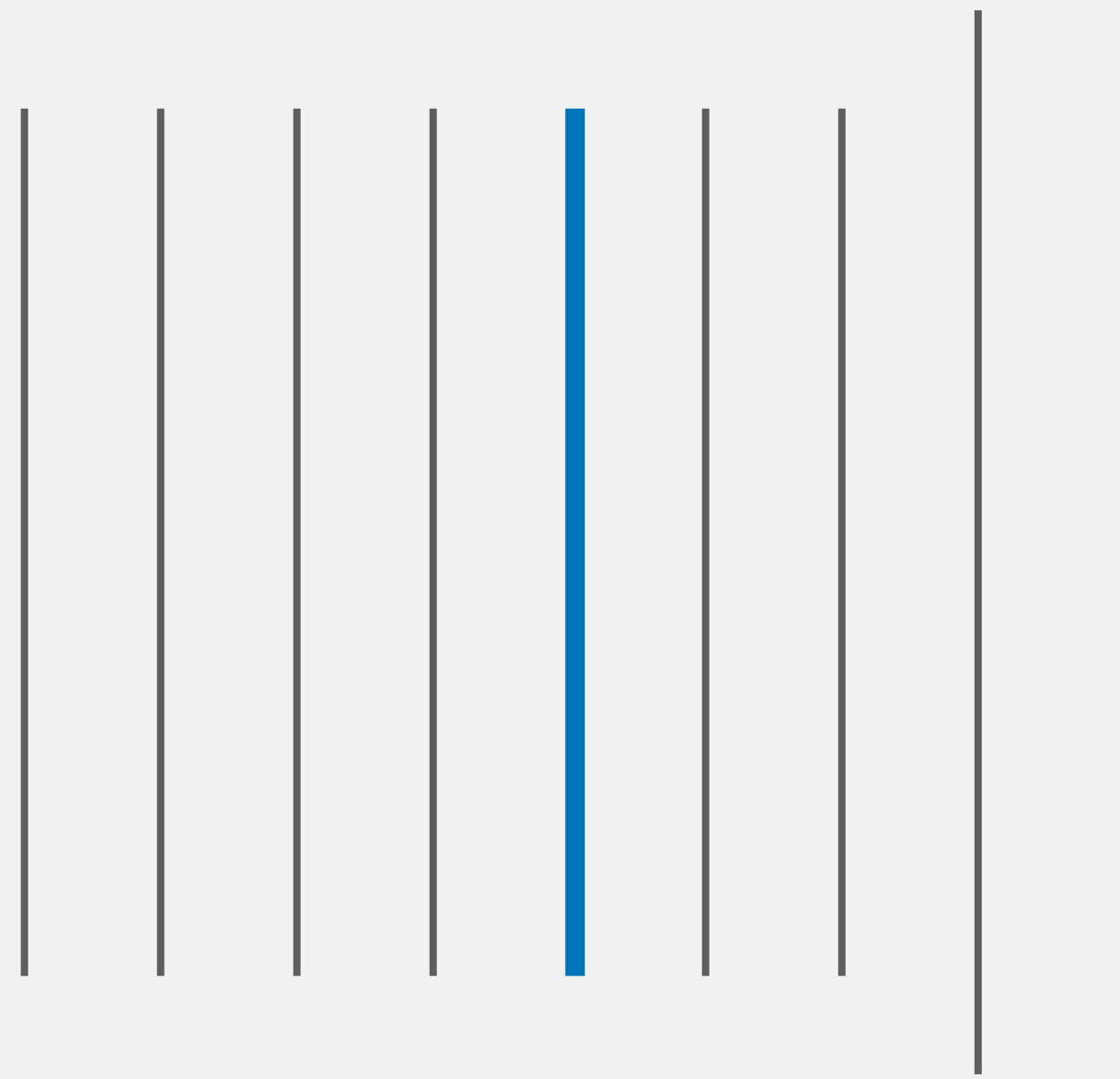


Several Electrons (Pile-Up)

Need to handle higher electron multiplicities!

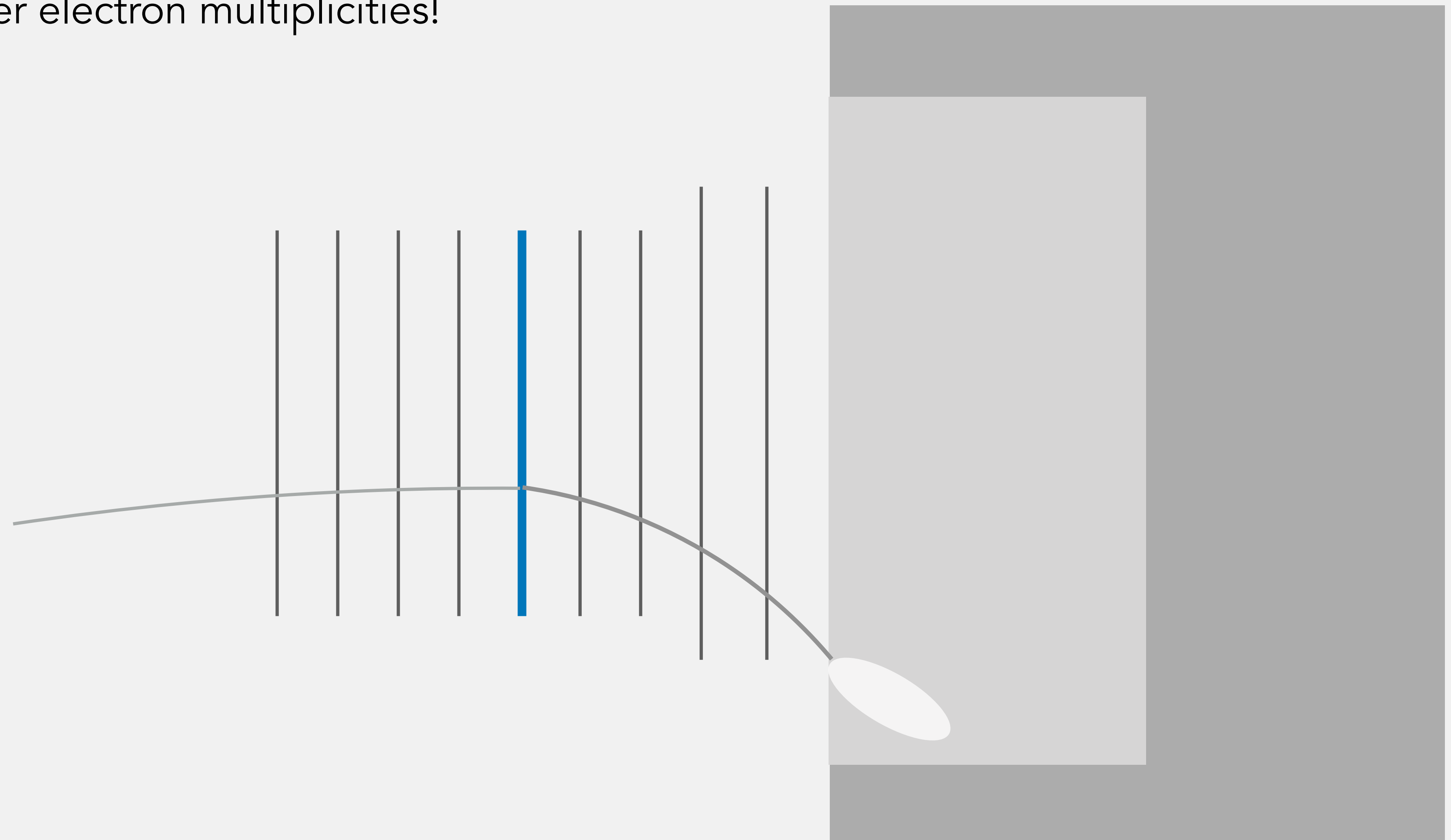
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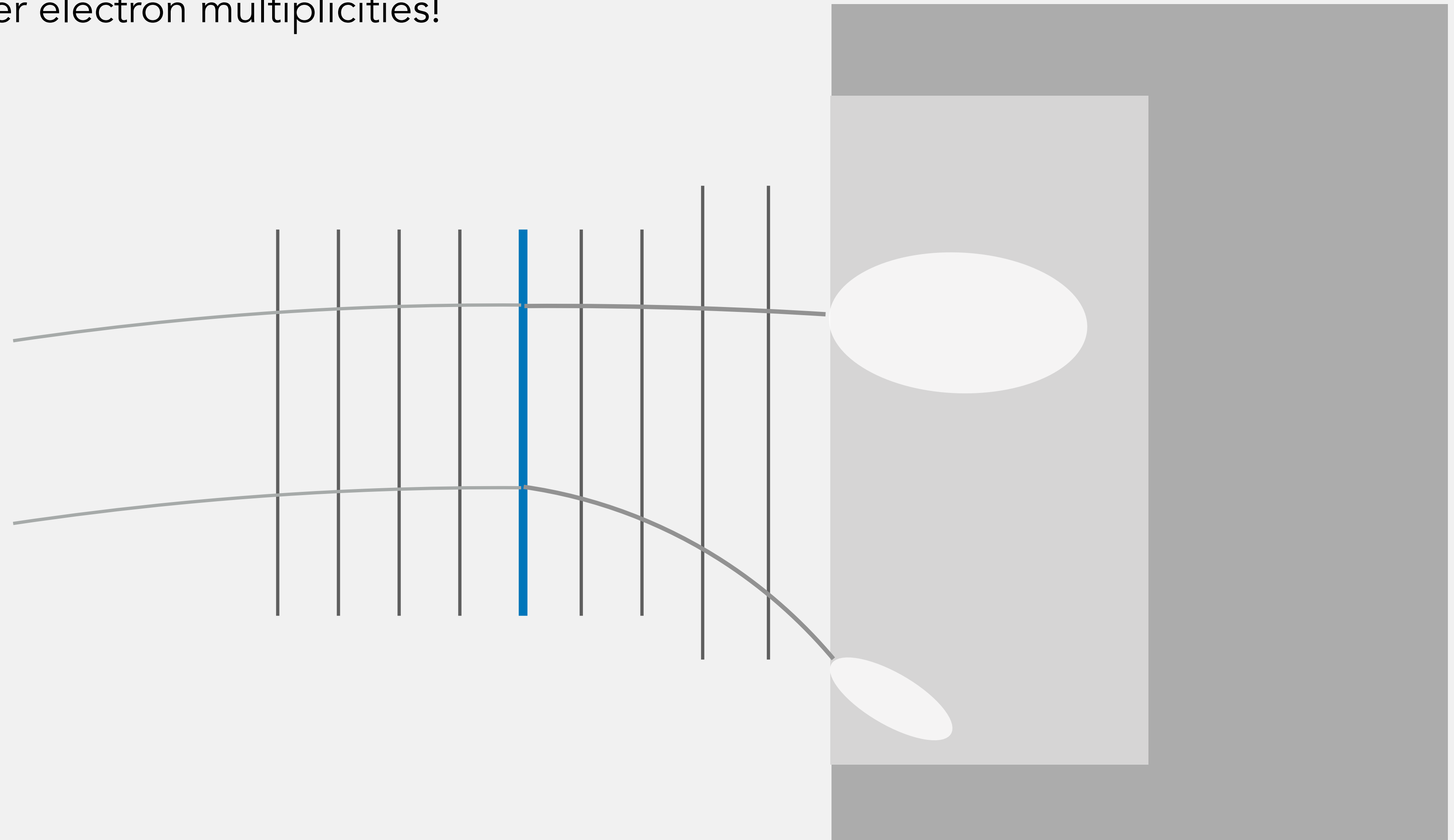
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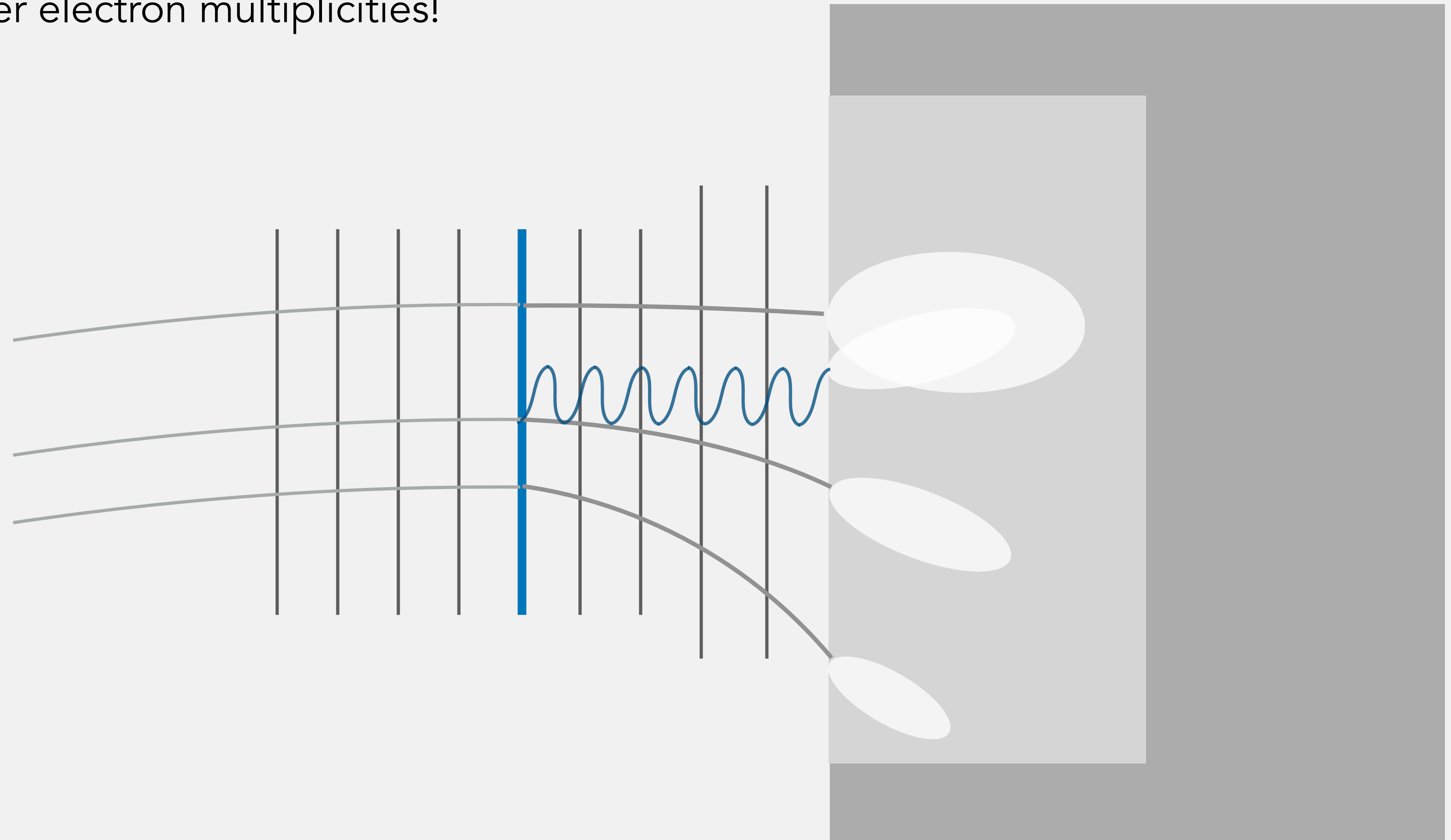
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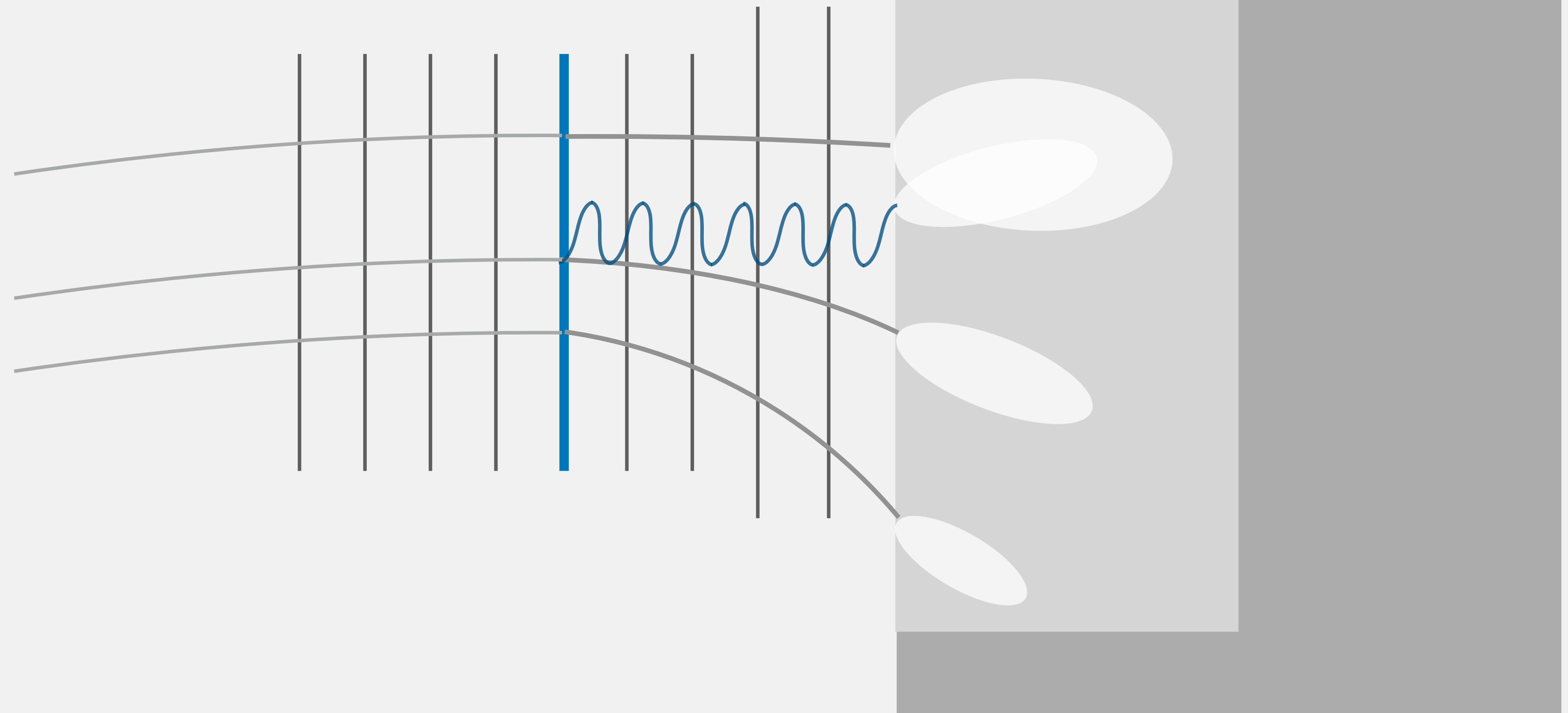
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Several Electrons (Pile-Up)

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—> **Measure n_e event-by-event**



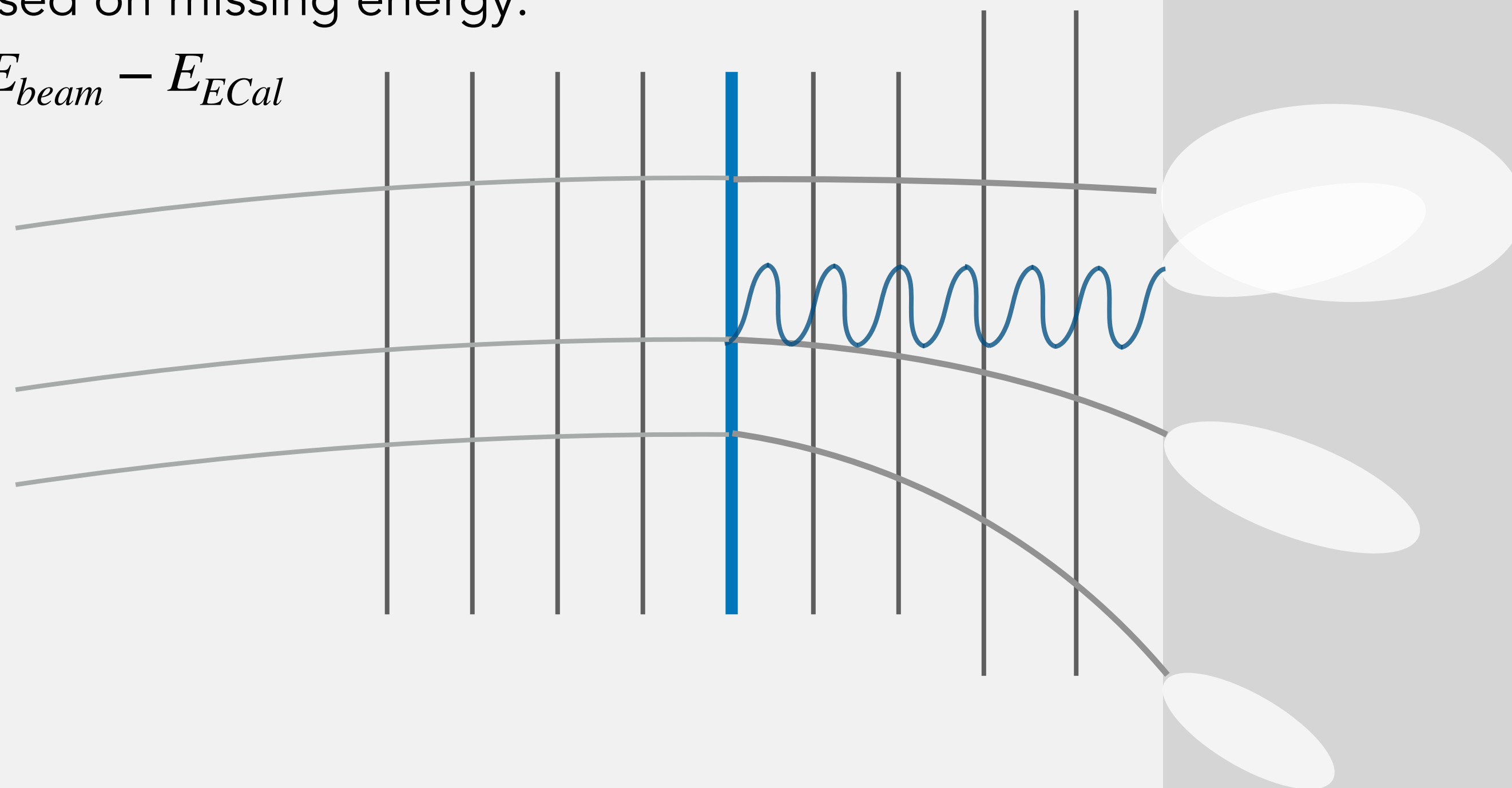
Several Electrons (Pile-Up)

Need to handle higher electron multiplicities!

—> **Measure n_e event-by-event**

Trigger based on missing energy:

$$E_{th}^{miss} = n_e E_{beam} - E_{ECal}$$



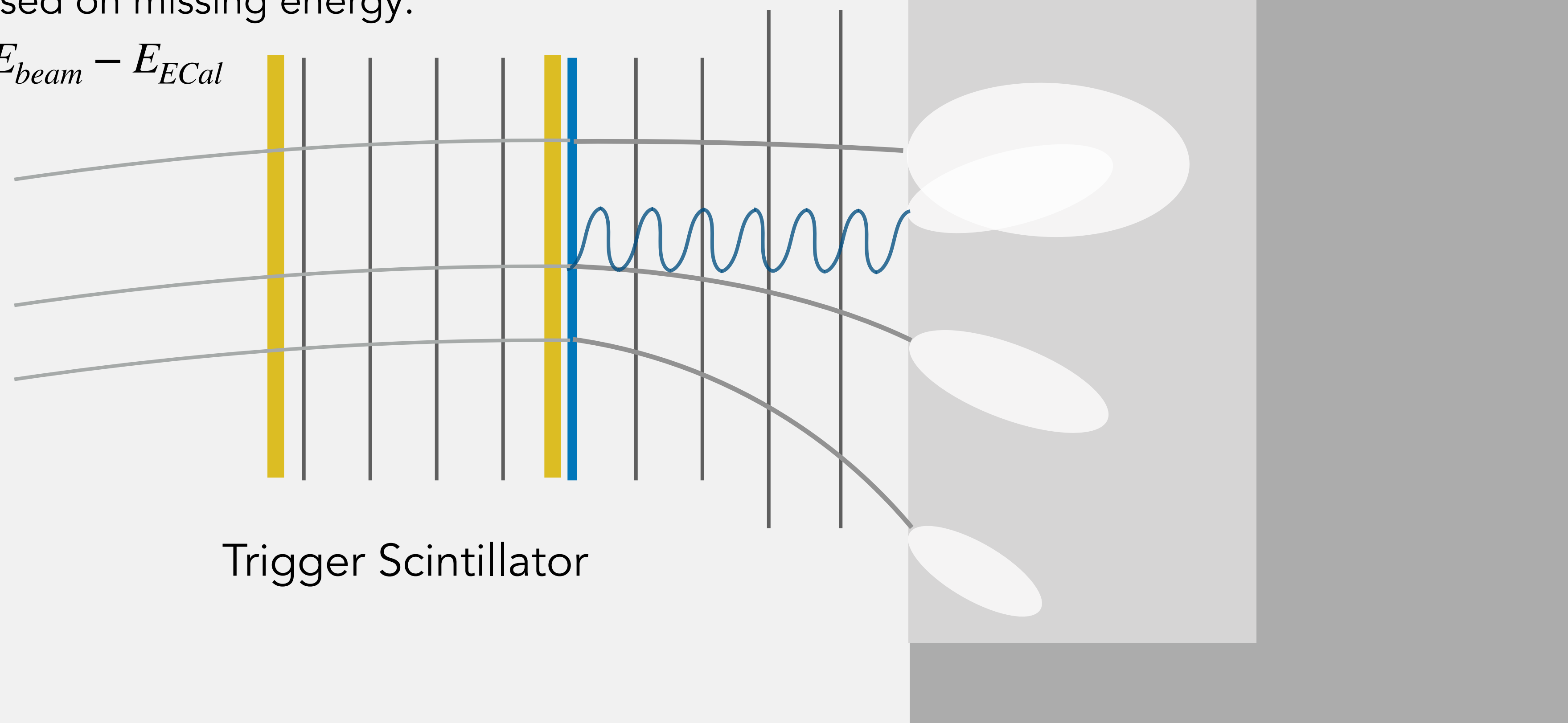
Several Electrons (Pile-Up)

Need to handle higher electron multiplicities!

—> **Measure n_e event-by-event**

Trigger based on missing energy:

$$E_{th}^{miss} = n_e E_{beam} - E_{ECal}$$



Trigger Scintillator

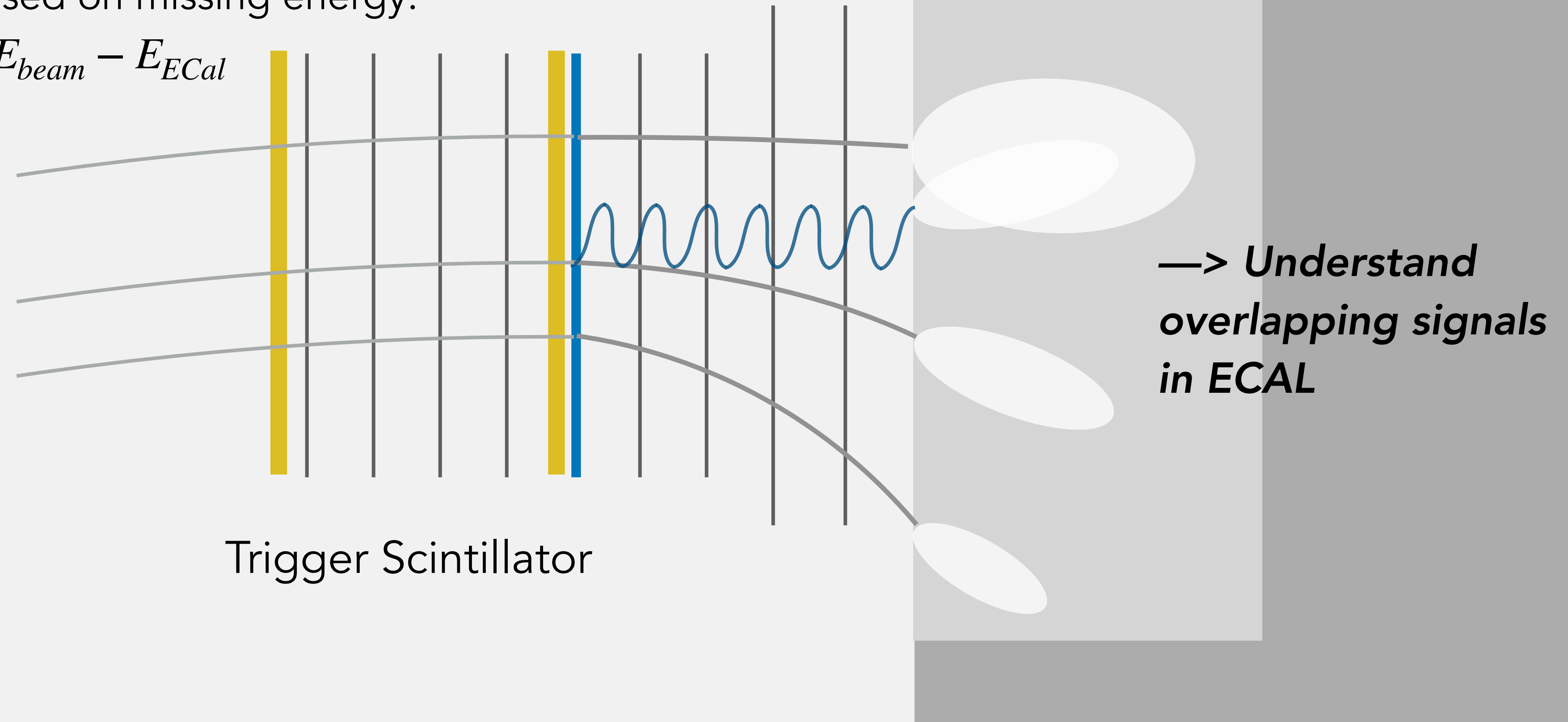
Several Electrons (Pile-Up)

Need to handle higher electron multiplicities!

—> **Measure n_e event-by-event**

Trigger based on missing energy:

$$E_{th}^{miss} = n_e E_{beam} - E_{ECAL}$$



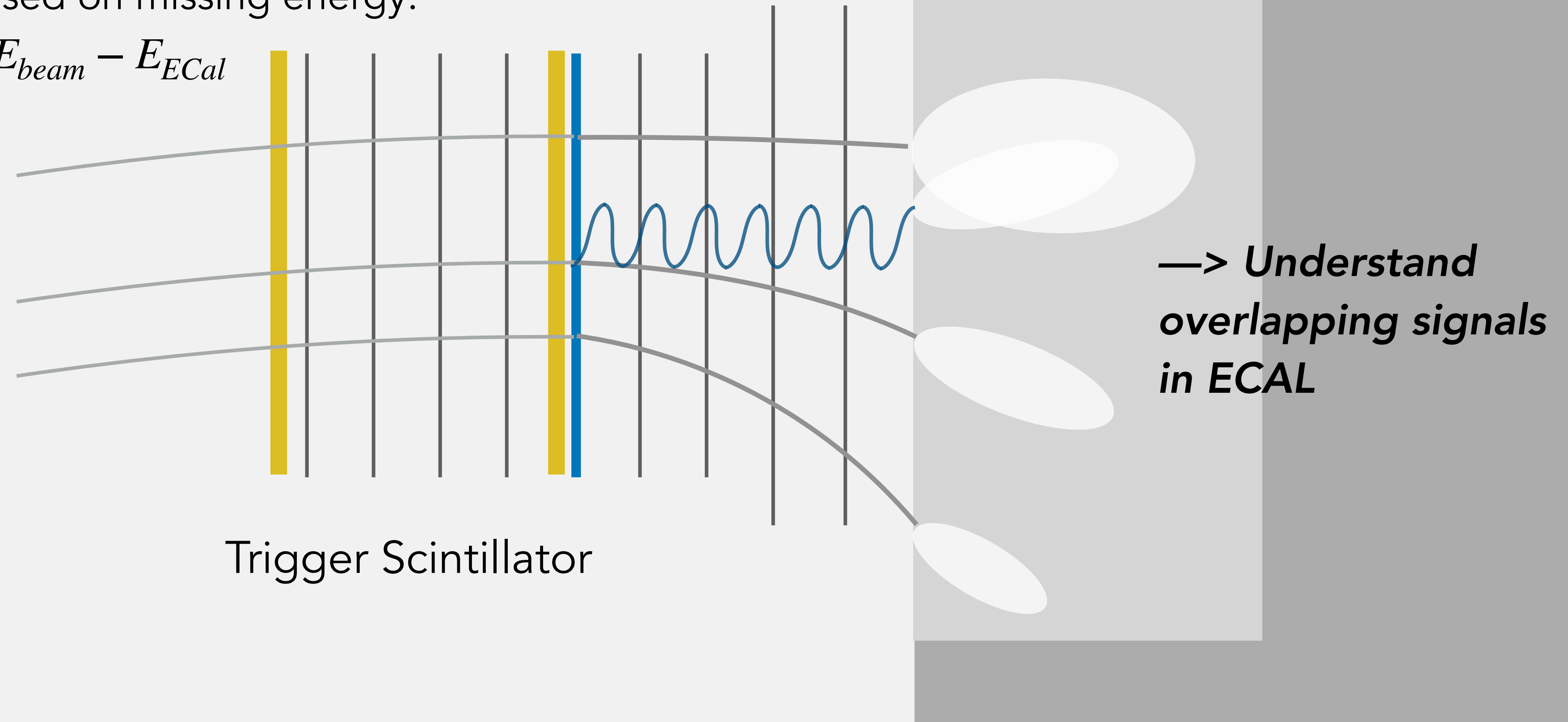
Several Electrons (Pile-Up)

Need to handle higher electron multiplicities!

—> **Measure n_e event-by-event**

Trigger based on missing energy:

$$E_{th}^{miss} = n_e E_{beam} - E_{ECAL}$$



Promising first results in Design Report, more work to do

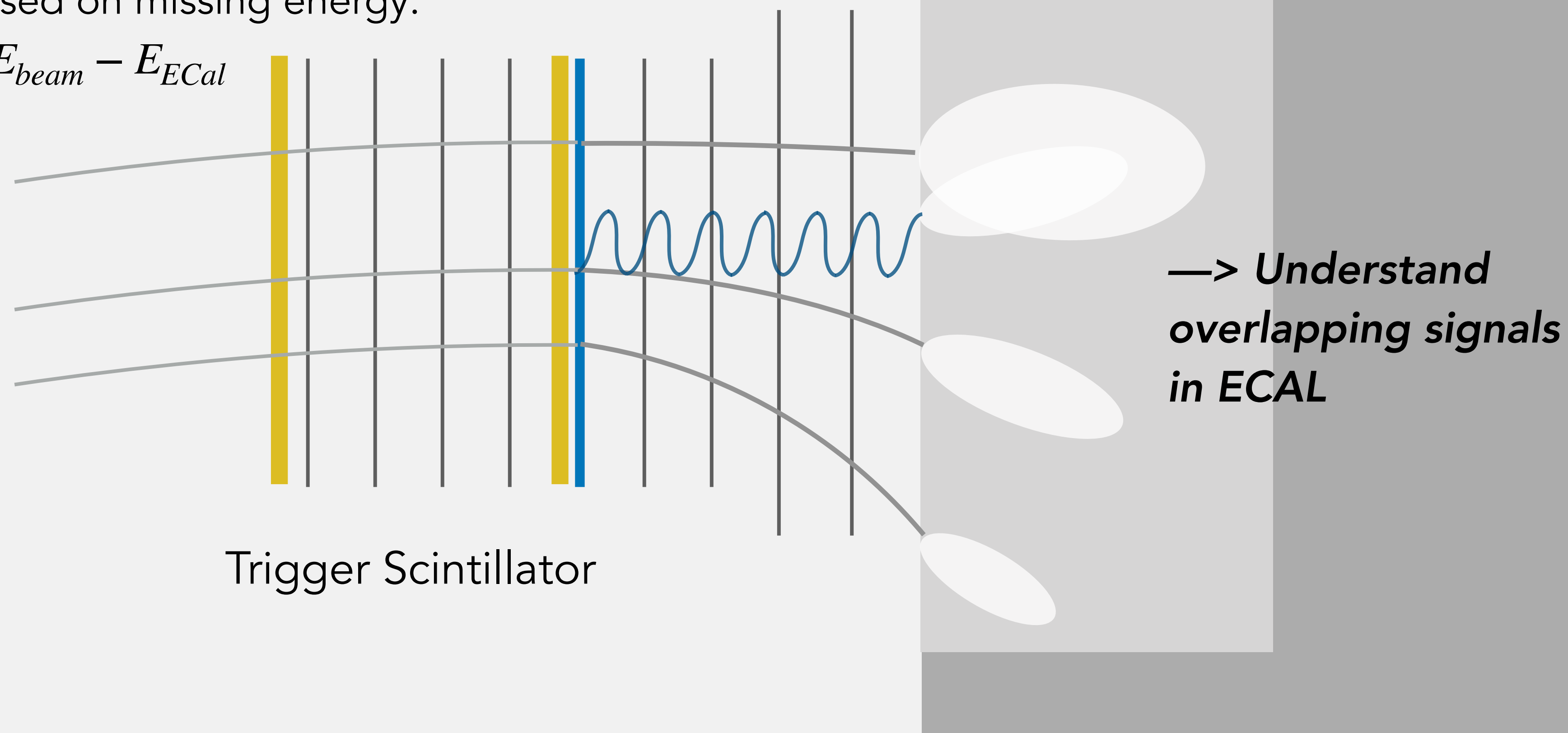
Several Electrons (Pile-Up)

Need to handle higher electron multiplicities!

—> **Measure n_e event-by-event** (See backup for LU work)

Trigger based on missing energy:

$$E_{th}^{miss} = n_e E_{beam} - E_{ECAL}$$

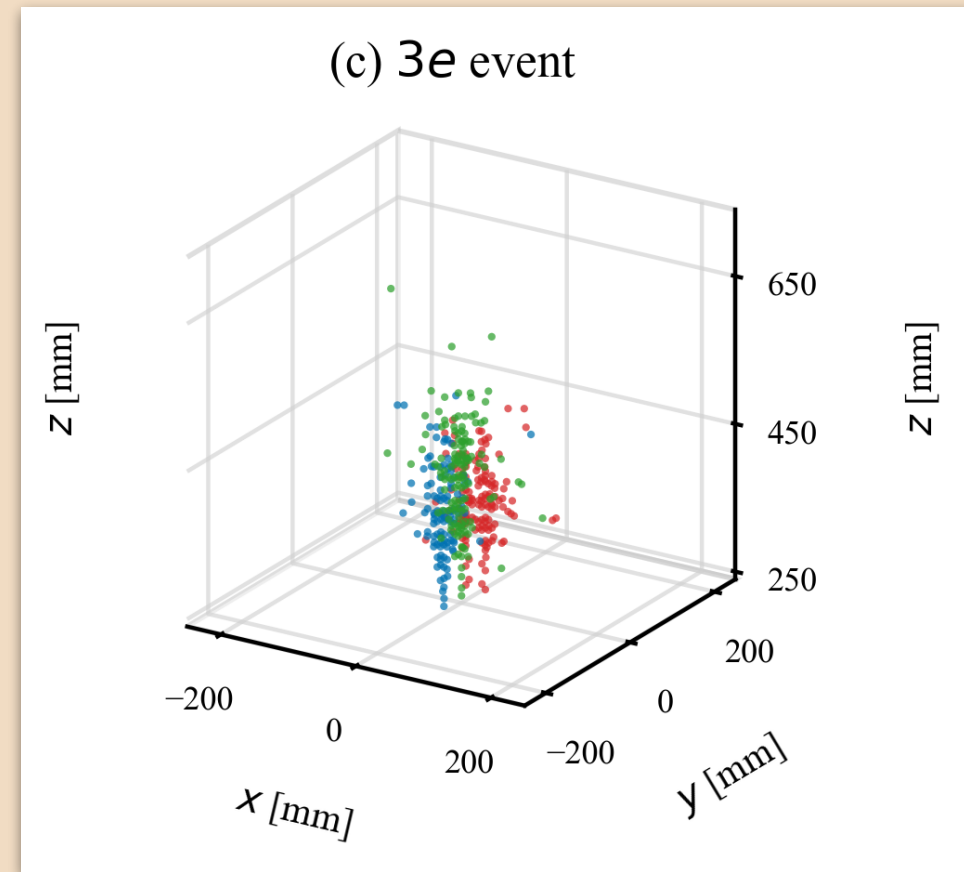


Promising first results in Design Report, more work to do

Pile up in Lund

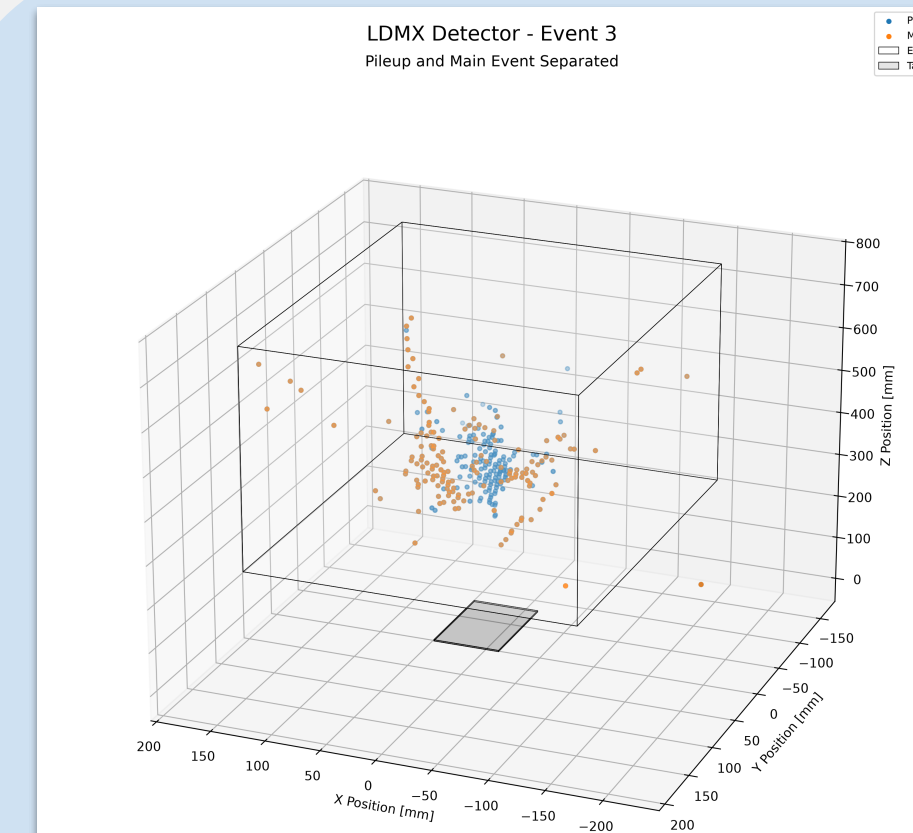
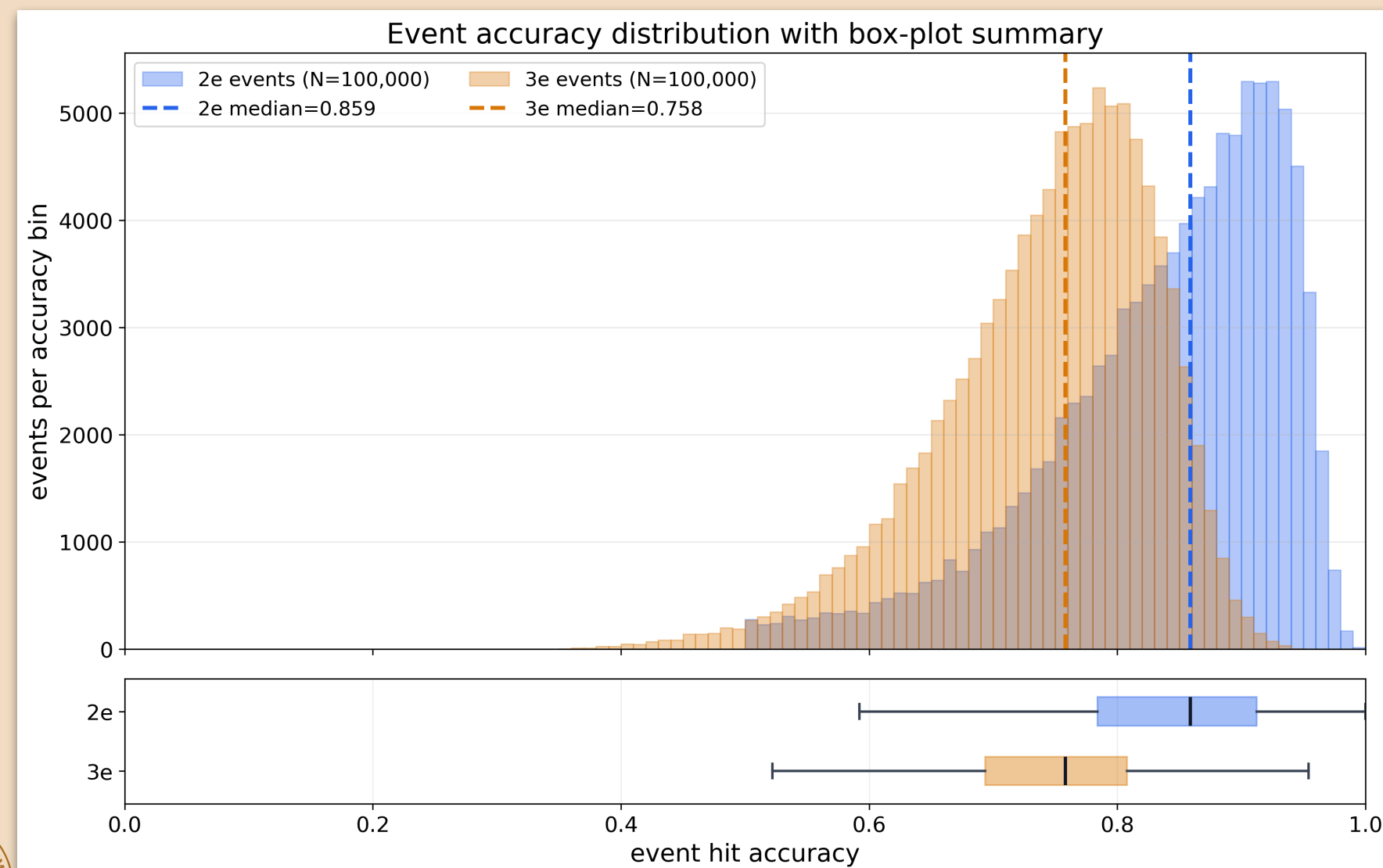
Understand overlapping signals in ECAL

LK Bryngemark, RP, Hans Alin, with students



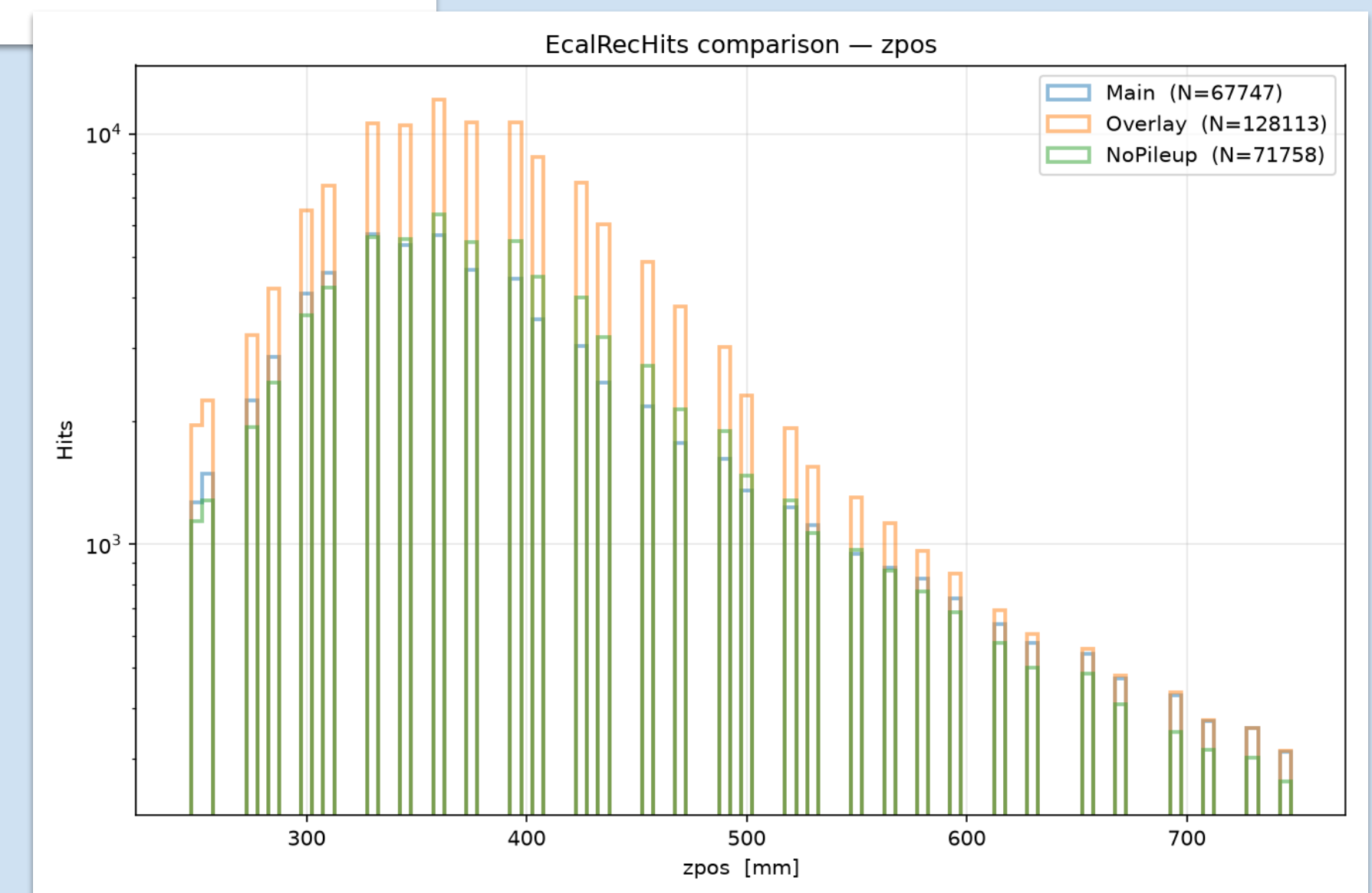
Neural Nets for hit assignment in Showers

Eliot Montesino Petrén, MSc



Pile-up removal

Hans Alin, Ph.D. student



Computing and software development at LU

Castalia: A portal between PYTHIA8 and GEANT4

Einar Elén^{a,*}, Luis Sarmiento Pico^a

^a Lund University, Department of Physics, Box 118, 221 00 Lund, Sweden

Abstract

We present Castalia (from the Castalian spring where pilgrims and priests would cleanse themselves before consulting Pythia, the oracle at Delphi), a C++17 software library that bridges the physics modeling capabilities of the general purpose Monte Carlo event generator PYTHIA8 [1] into the detector transport infrastructure of GEANT4 [2, 3, 4]. Traditionally, event generation and particle transport is treated as an entirely factorized process. While such a scheme is natural at collider experiments, it is not a foundational necessity and the hard distinction in fact prevents new developments in one area from benefiting the other. Moreover, the factorisation fundamentally breaks down in several important contexts such as fixed target and beam dump, and future high energy collider experiments, as well as cosmic ray physics.

Castalia allows physicists familiar with PYTHIA8 and its surrounding ecosystem to directly contribute to GEANT4 applications without being familiar with the GEANT4 internals, as well as for GEANT4 application developers to embed a physics model written in a PYTHIA8 program into their GEANT4 application without having to rewrite the model in GEANT4. Longer term, we aim for Castalia to be able to both extend and enhance the capabilities of existing GEANT4 and PYTHIA8 modeling with the strengths of the other. We illustrate these two goals with a selected subset of Castalia's capabilities: A dark photon-like model for a scenario like the SHiP [5] experiment with dark mediator production in the initial scattering, within hadronic showers, and through the decays of neutral mesons, and a comparison of the building blocks for hadronic models in GEANT4 between the built in GEANT4 alternatives and what PYTHIA8 offers.

PROGRAM SUMMARY

Program Title: Castalia 1.0

CPC Library link to program files: (to be added by Technical Editor)

Developer's repository link: (if available)

Licensing provisions(please choose one): GPLv3

Programming language: C++17

Supplementary material:

Solution method(approx. 50-250 words): Additional comments including restrictions and unusual features (approx. 50-250 words):

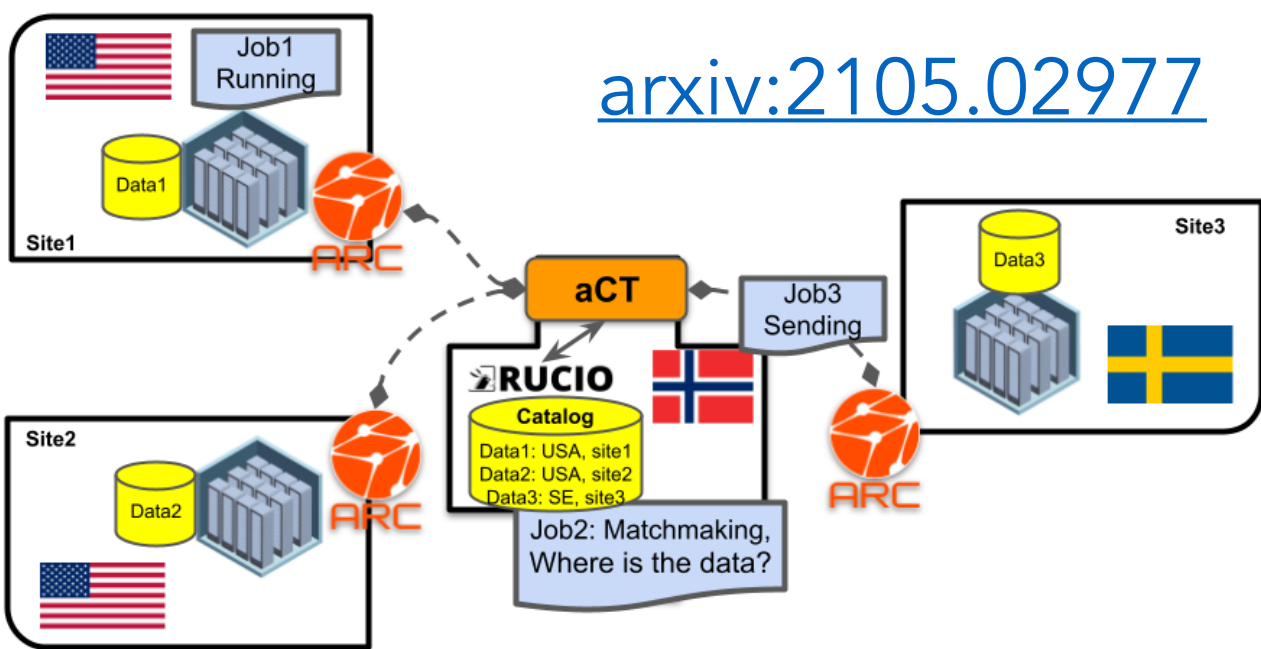
* Items marked with an asterisk are only required for new versions of programs previously published in the CPC Program Library.

Keywords: GEANT4, PYTHIA8, Monte Carlo simulations, Hadronic interactions, Detector modeling

CASTALIA (Einar Elén, Pico Sarmiento)

Interface that allows mix-and-match of features from PYTHIA8 and Geant4, circumvents the usual factorisation of the two

Paper coming soon!



Lightweight Distributed Computing System (LDCS):

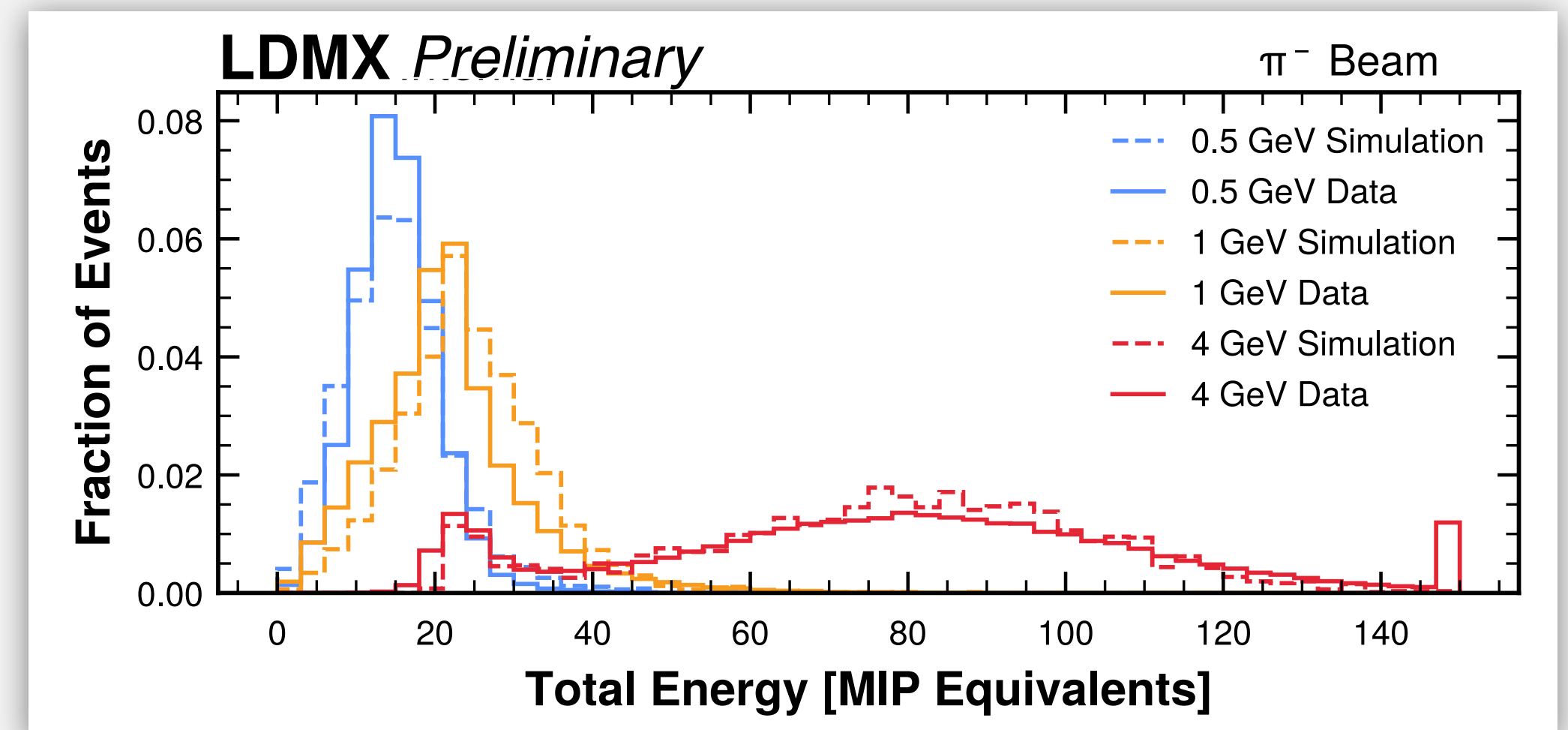
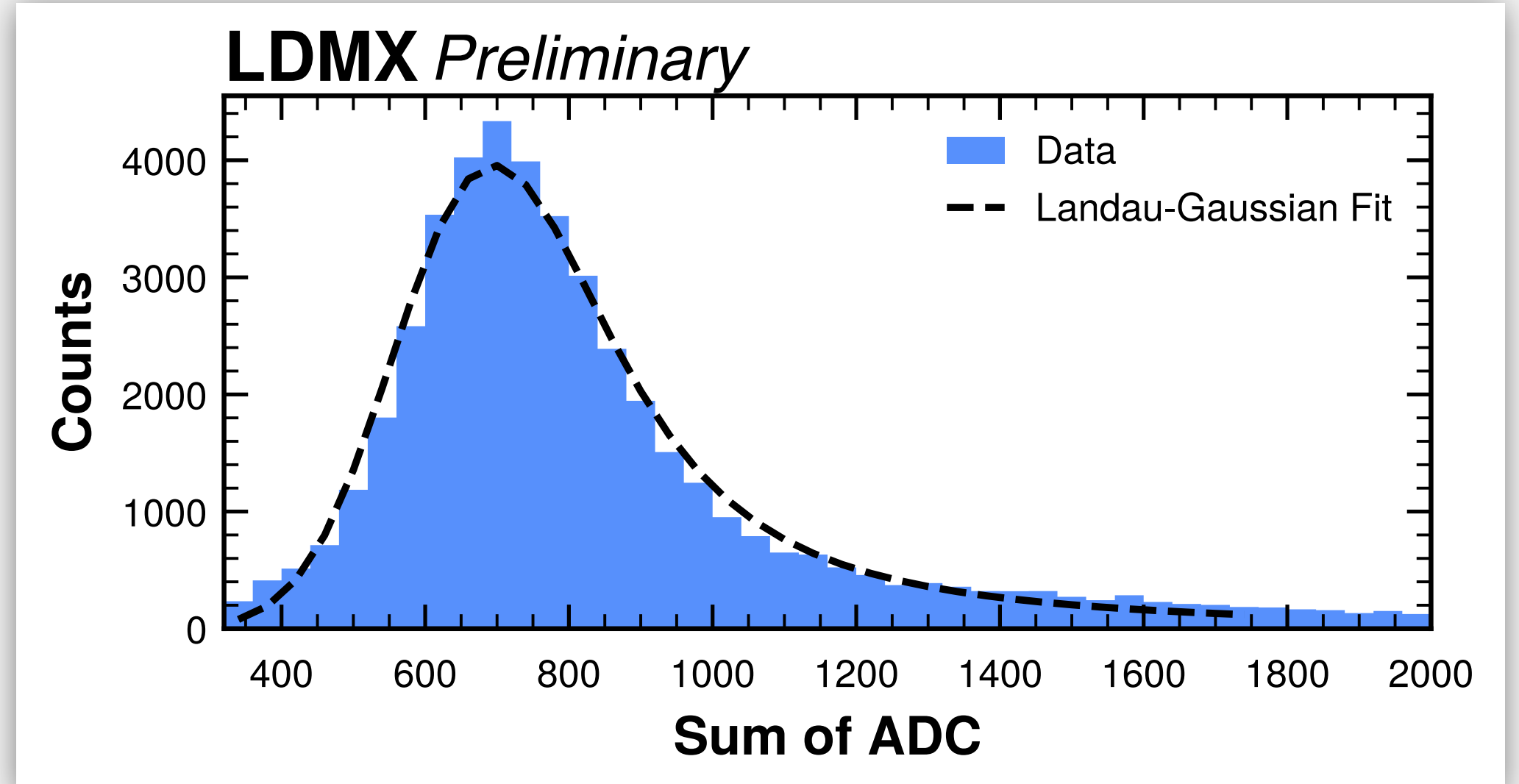
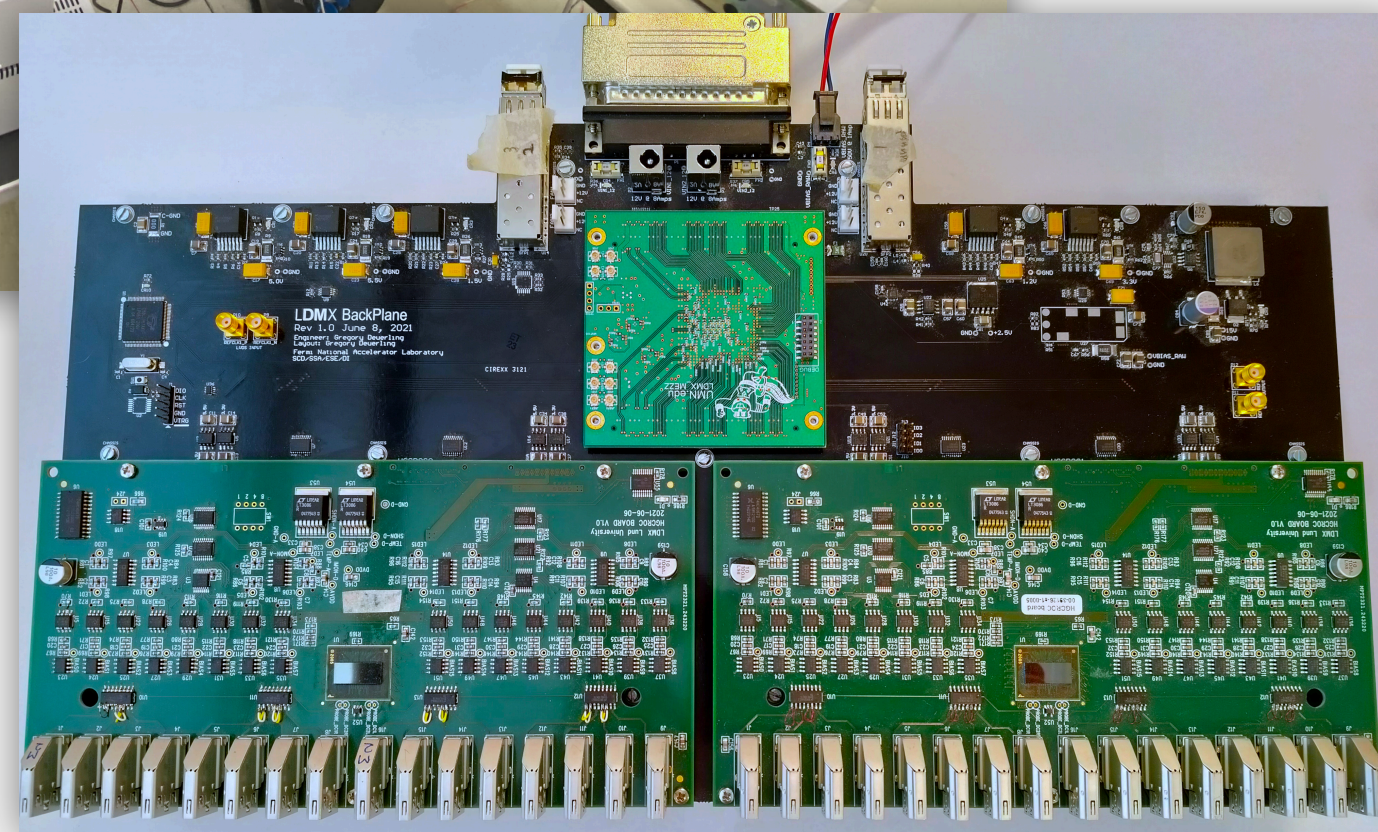
For small-scale experiments that do not have THE GRID, but still need larg-ish, shared simulations + proper bookkeeping

Other Recent and Upcoming Milestones

CERN Testbeam

Large fraction of LunDMX on site, Erik Wallin lead analyser HCal

2022: HCal (and trigger scintillator) beam tests at CERN



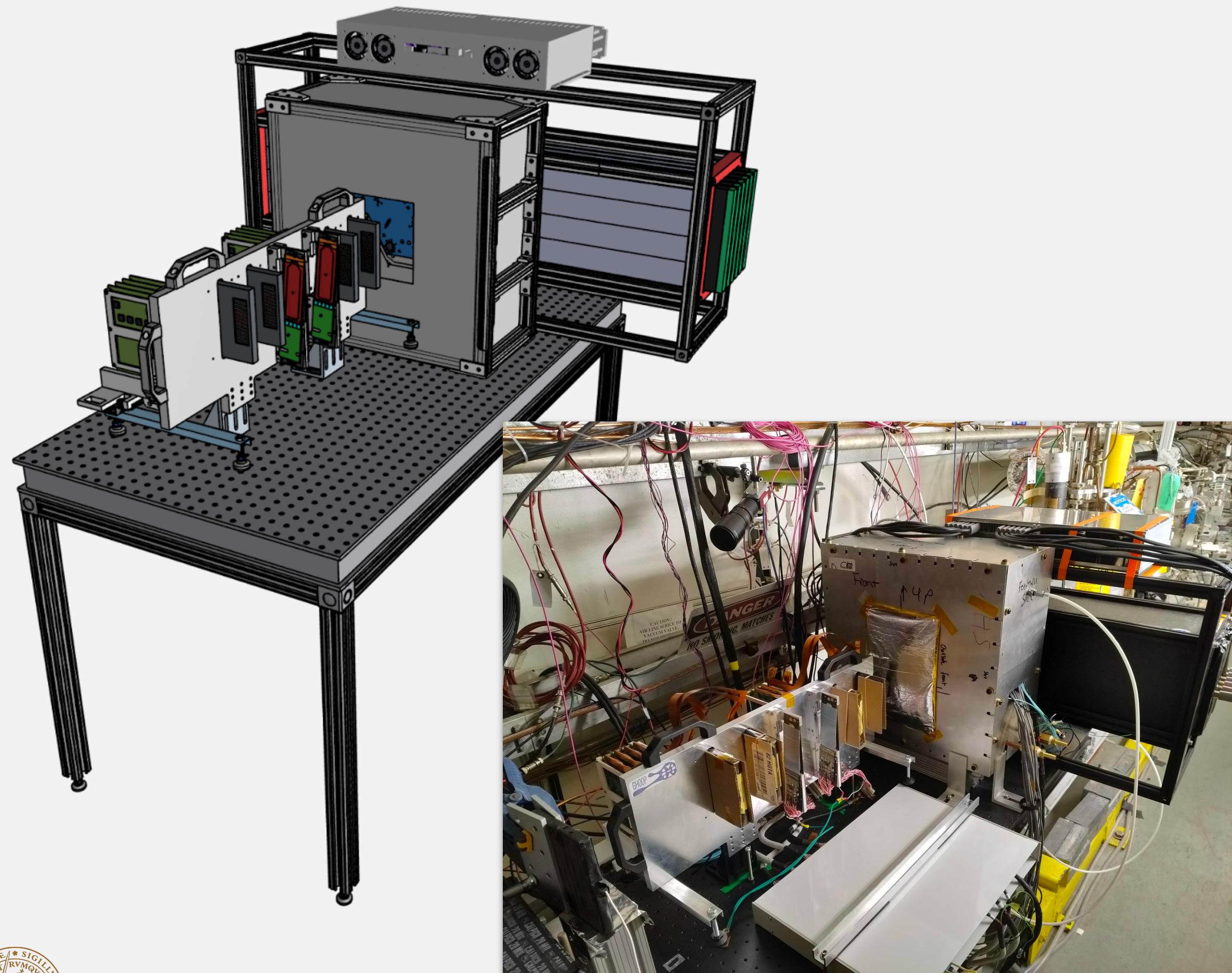
Paper on HCal results coming soon

ESA Slice-Test

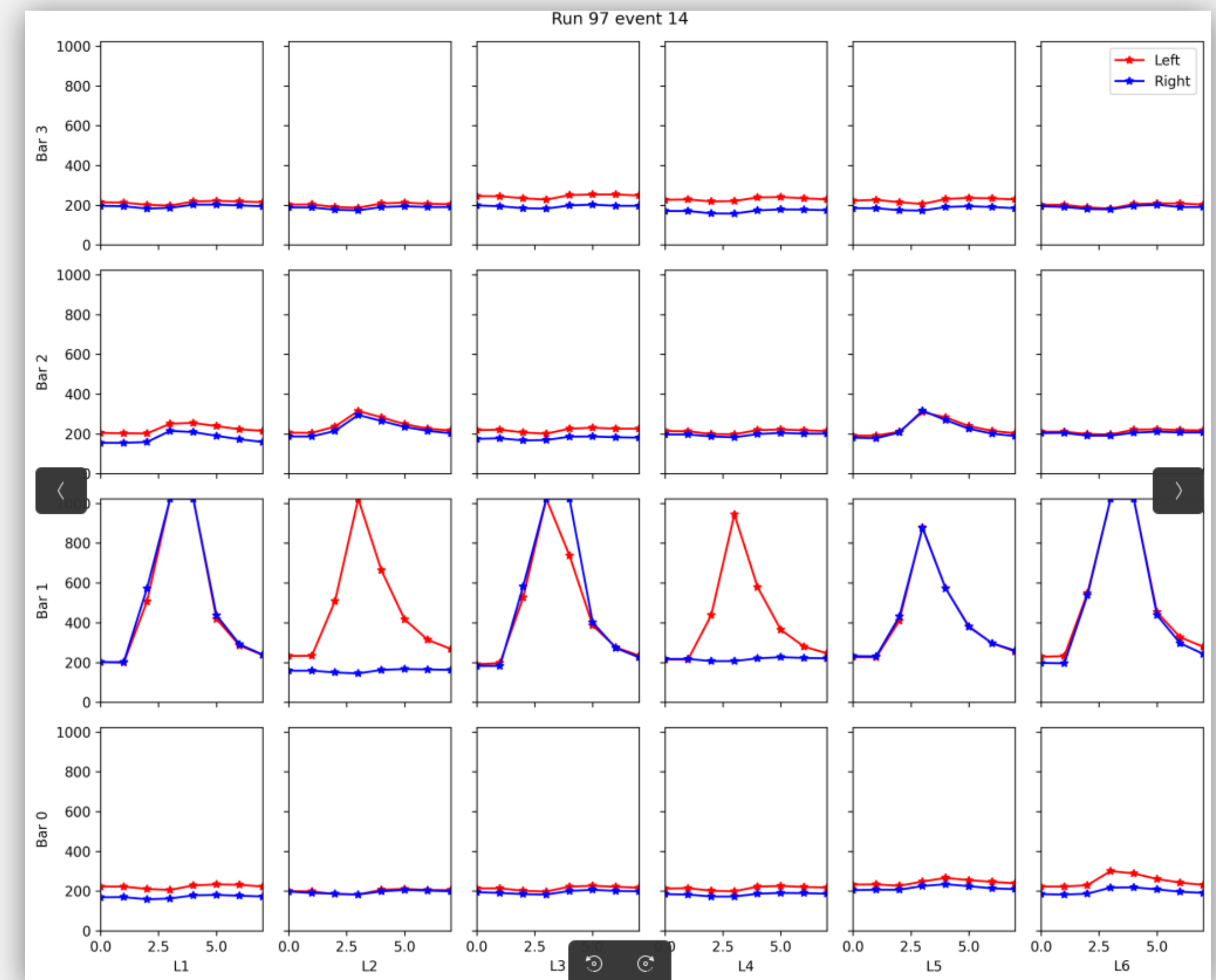
CJ Barton & Erik Wallin on site, Hannah Herde co-coordinator

Late 2025: Setup with prototypes/DAQ for all subsystems in End-station A (where LDMX will be)

Learned a lot about subsystems and beamline.



3 GeV electrons hitting HCal scintillators

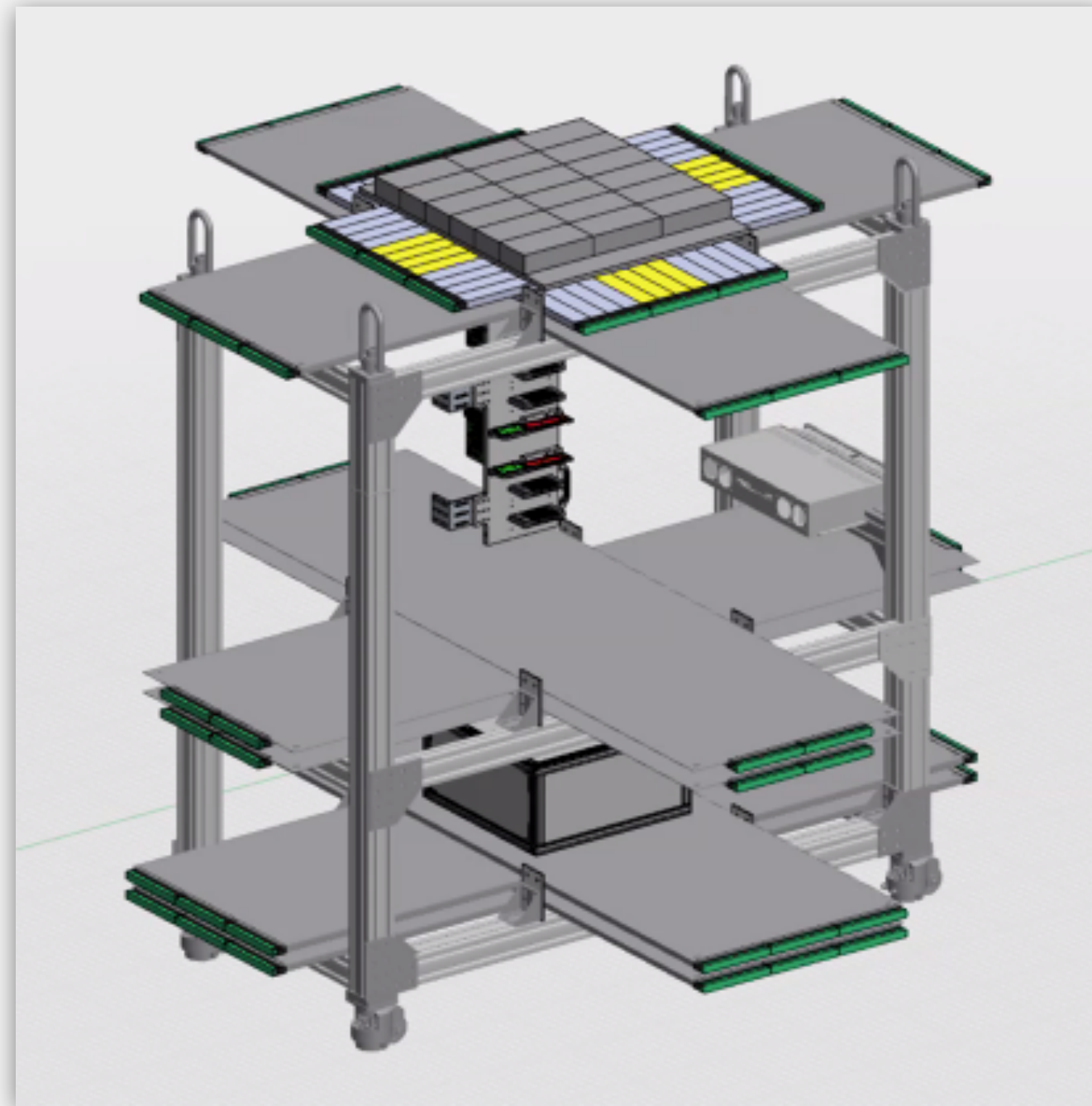
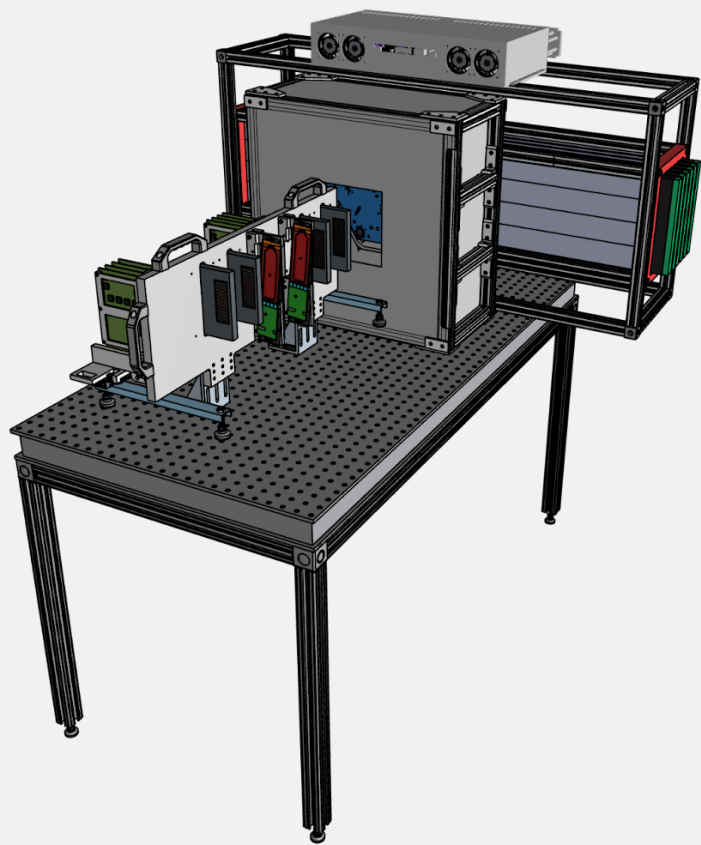


Coming up

LCLS-II shut down since end of 2025, upgrade to 8 GeV

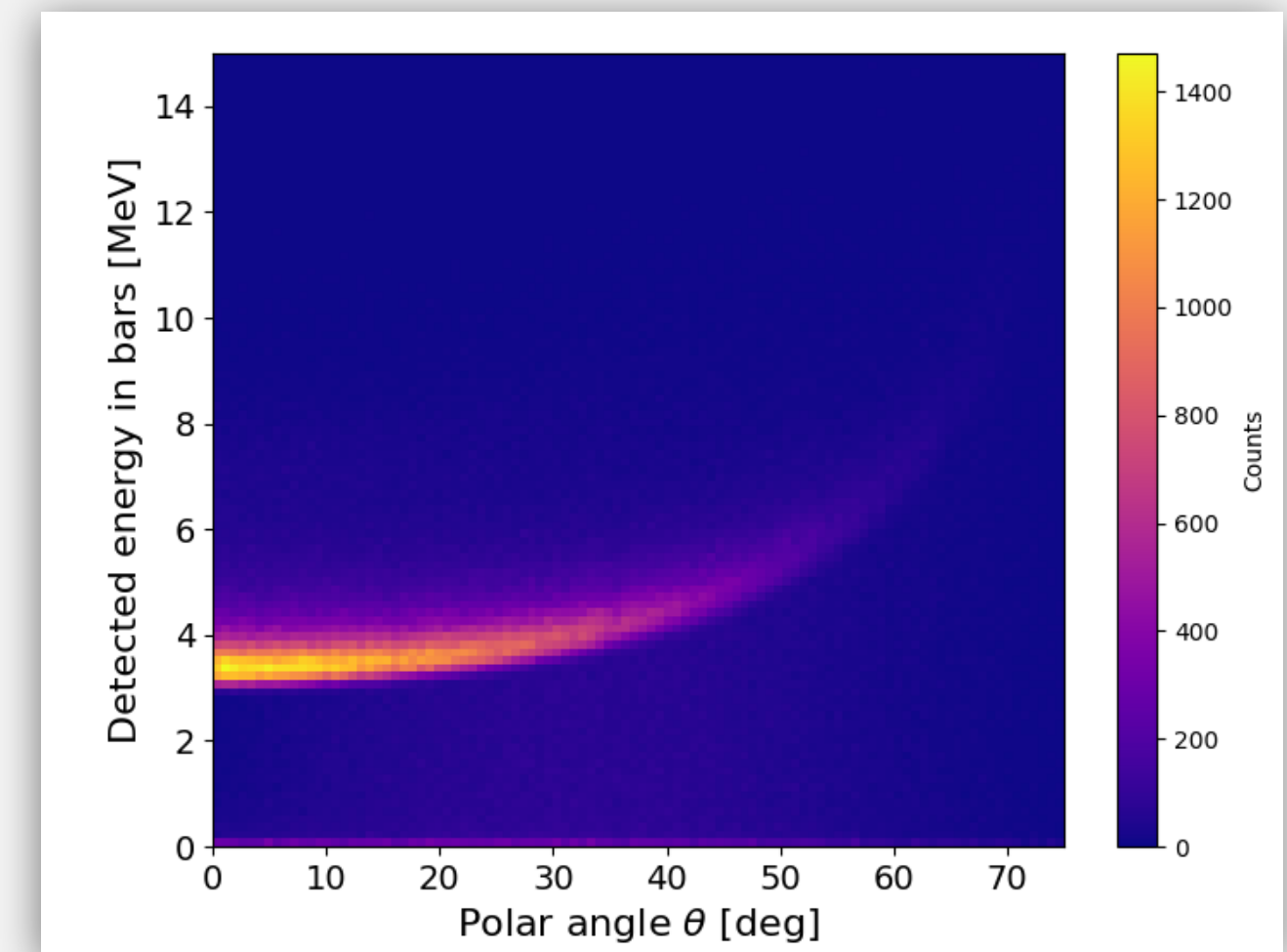
Expected back: Summer 2027 —> Beam tests with more complete detector setup

For now: Cosmics test with h/w from CERN+ESA test beam (Fall 2026)



Geometry implementation & simulation

Wilde Hedin, BSc



Summary

- LDMX powerful tool to search for sub-GeV dark matter
- Recent milestones in detector development and physics studies
- LU group actively contributing in various areas
- More detector tests during 2026/27

Looking forward to new
things to share next year!

More information:

[LDMX Confluence Webpage \(with links to talks etc.\)](#)

LDMX White Paper: [arxiv:1808.05219](#)

New physics with LDMX: [Phys. Rev. D 99, 075001](#)

Electro-nuclear measurements for DUNE: [PhysRevD.101.053004](#)

Photon Veto Paper, 4 GeV: [J. High Energ. Phys. 2020, 3 \(2020\)](#)

Snowmass contributed White Paper: [arxiv:2203.08192](#)

Photon Veto Paper, 8 GeV: [JHEP12\(2023\)092](#)

ECal as Target analysis [JHEP12\(2025\)150](#)

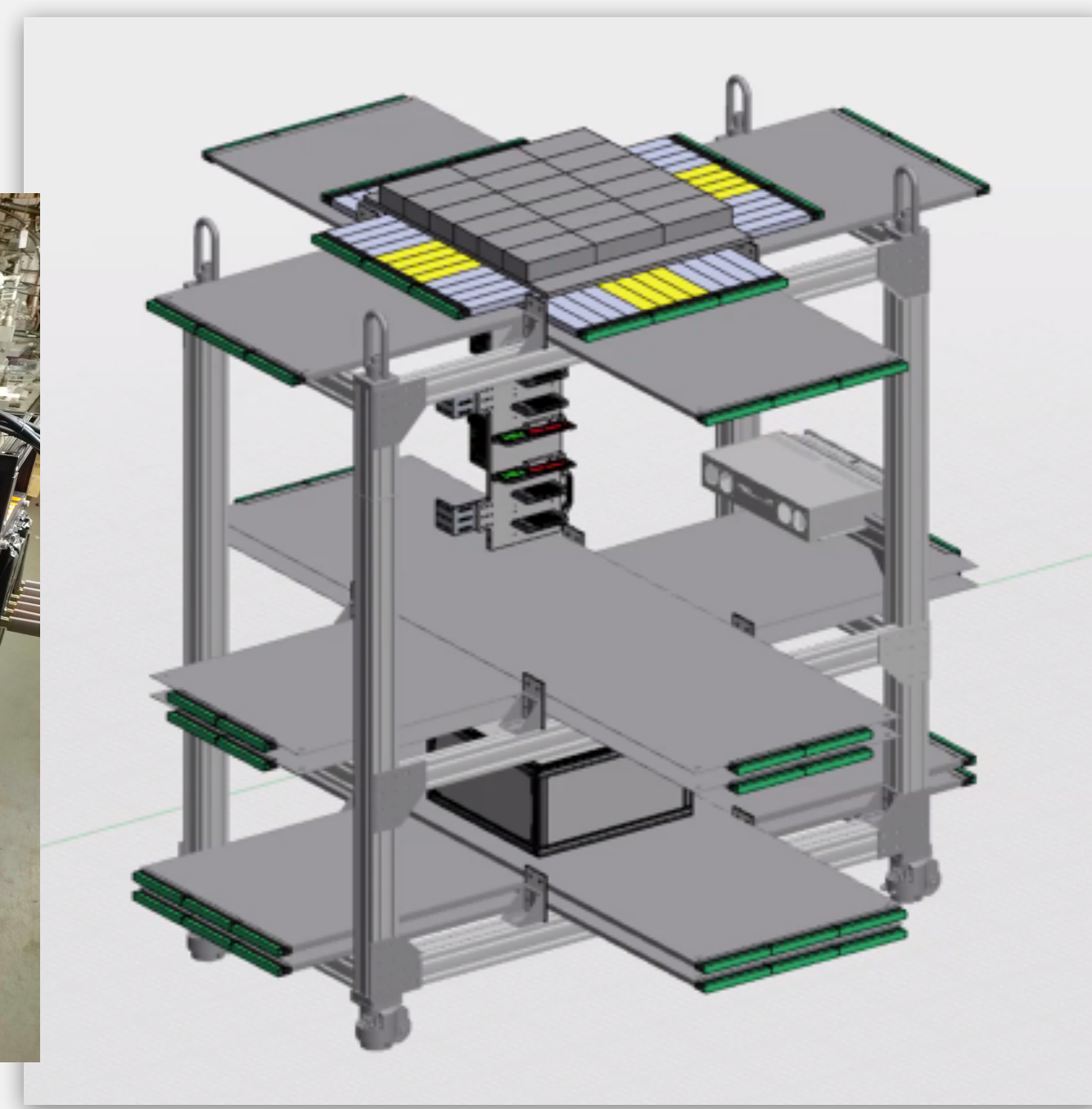
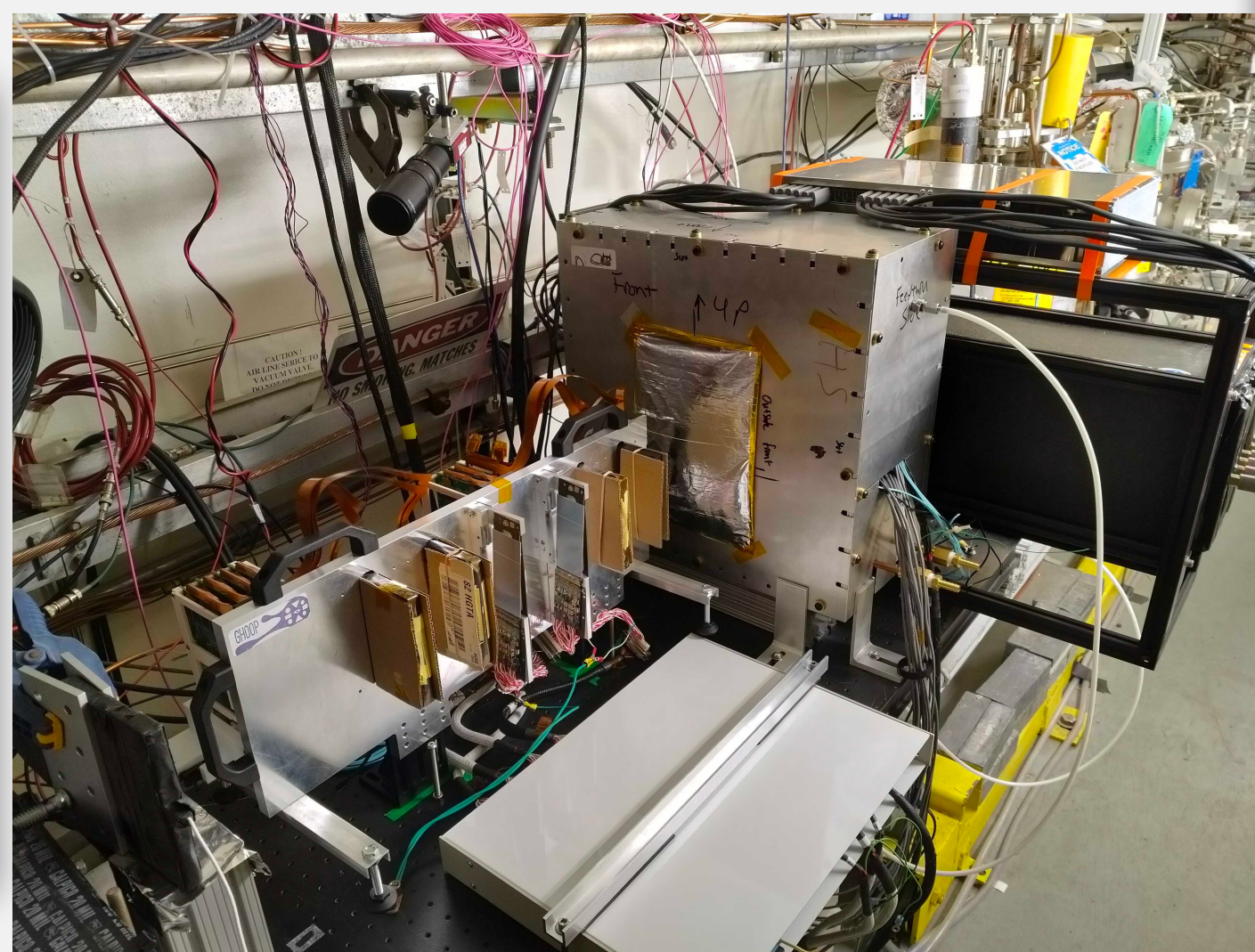
LESA Dark Current [J NIMA \(2026\) 171709](#)

Visible signatures [JHEP08\(2026\)062](#)

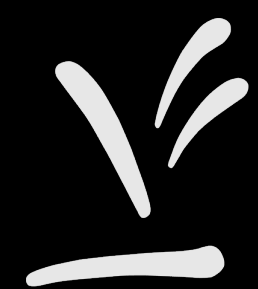
Design report [arxiv:2508.11833](#)



[Craig Group & Son]



Thank you!



Swedish
Research
Council

Crafoord foundation

*Knut and Alice
Wallenberg
Foundation*



U.S. DEPARTMENT OF
ENERGY



Additional Material

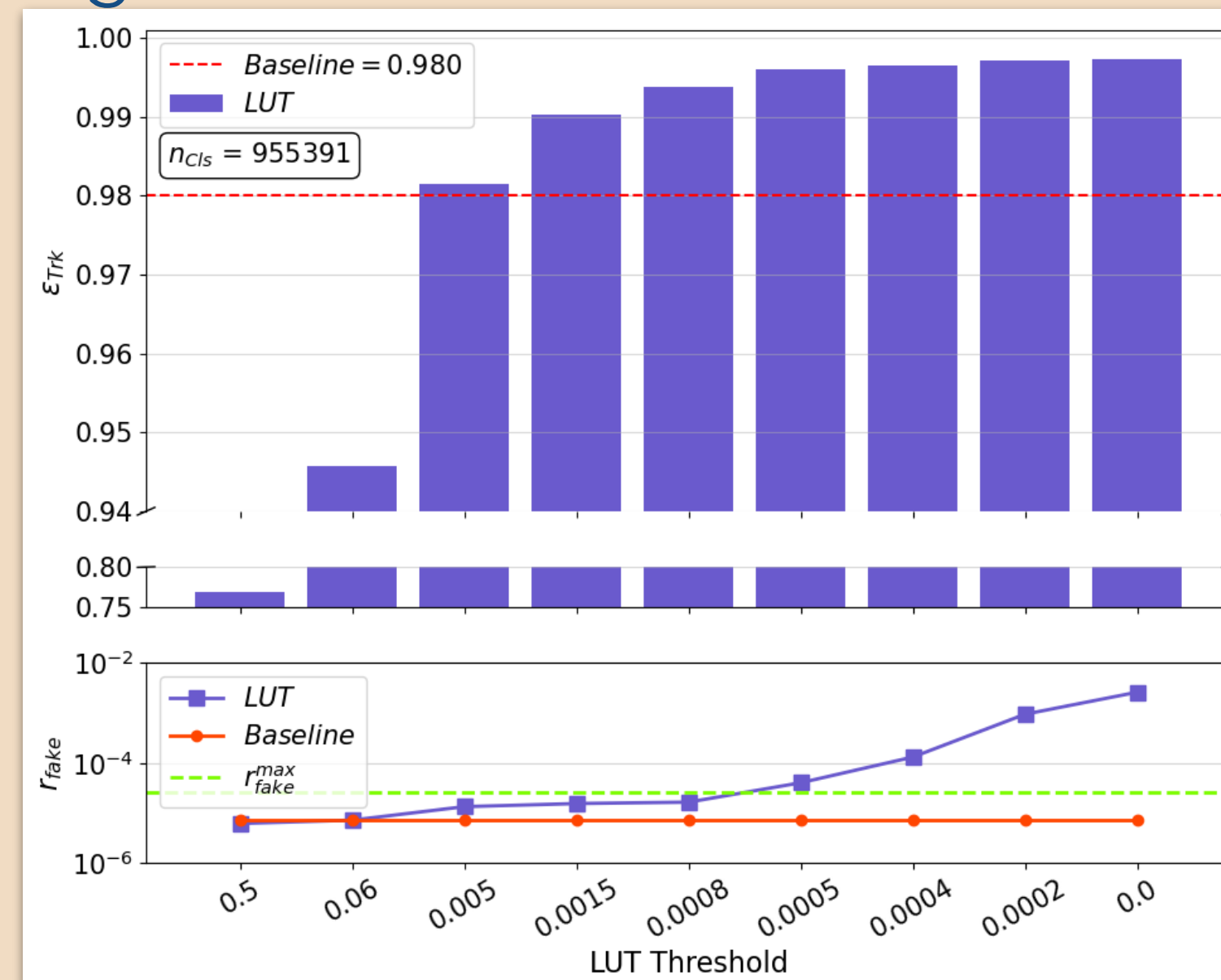
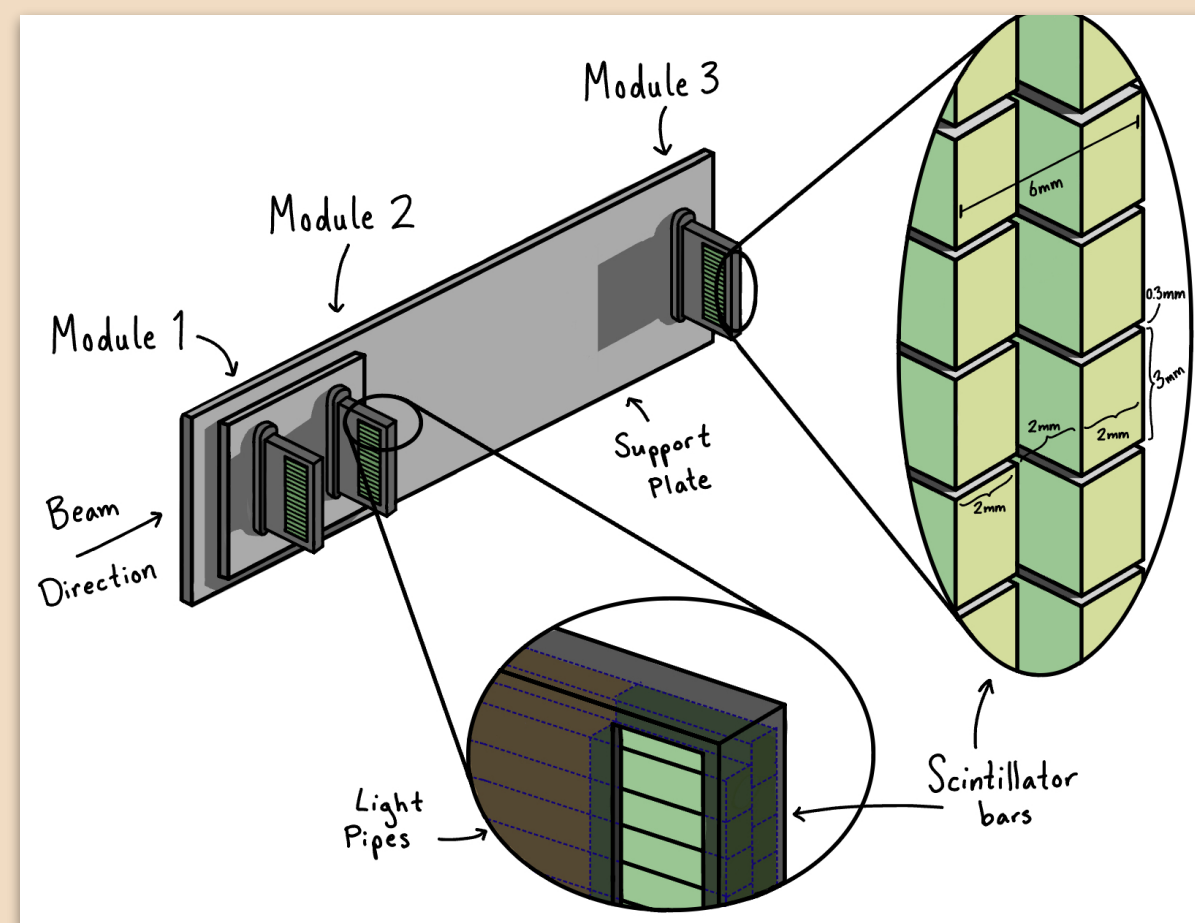
Pile up in Lund

Measure n_e event-by-event LK Bryngemark with students

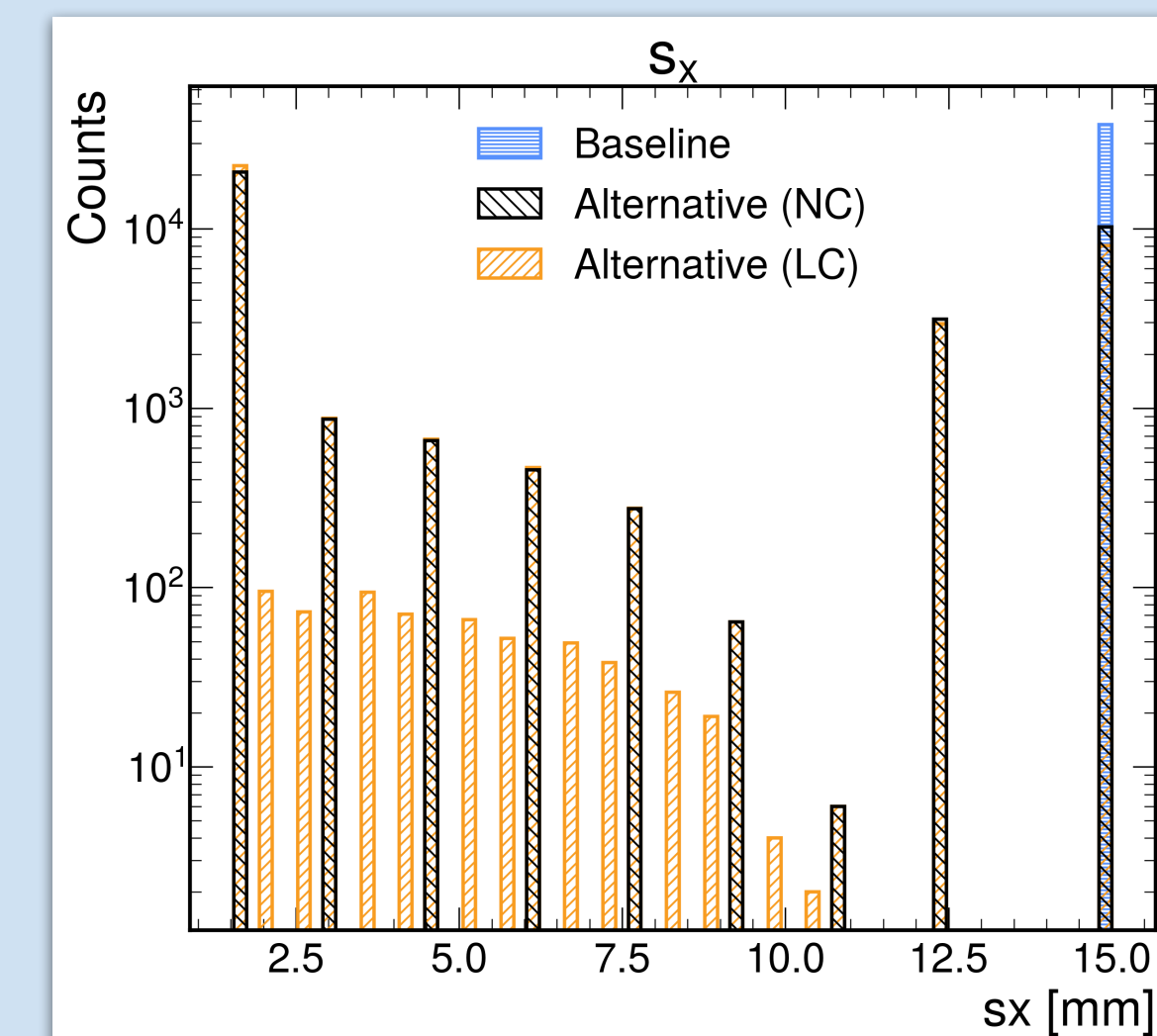
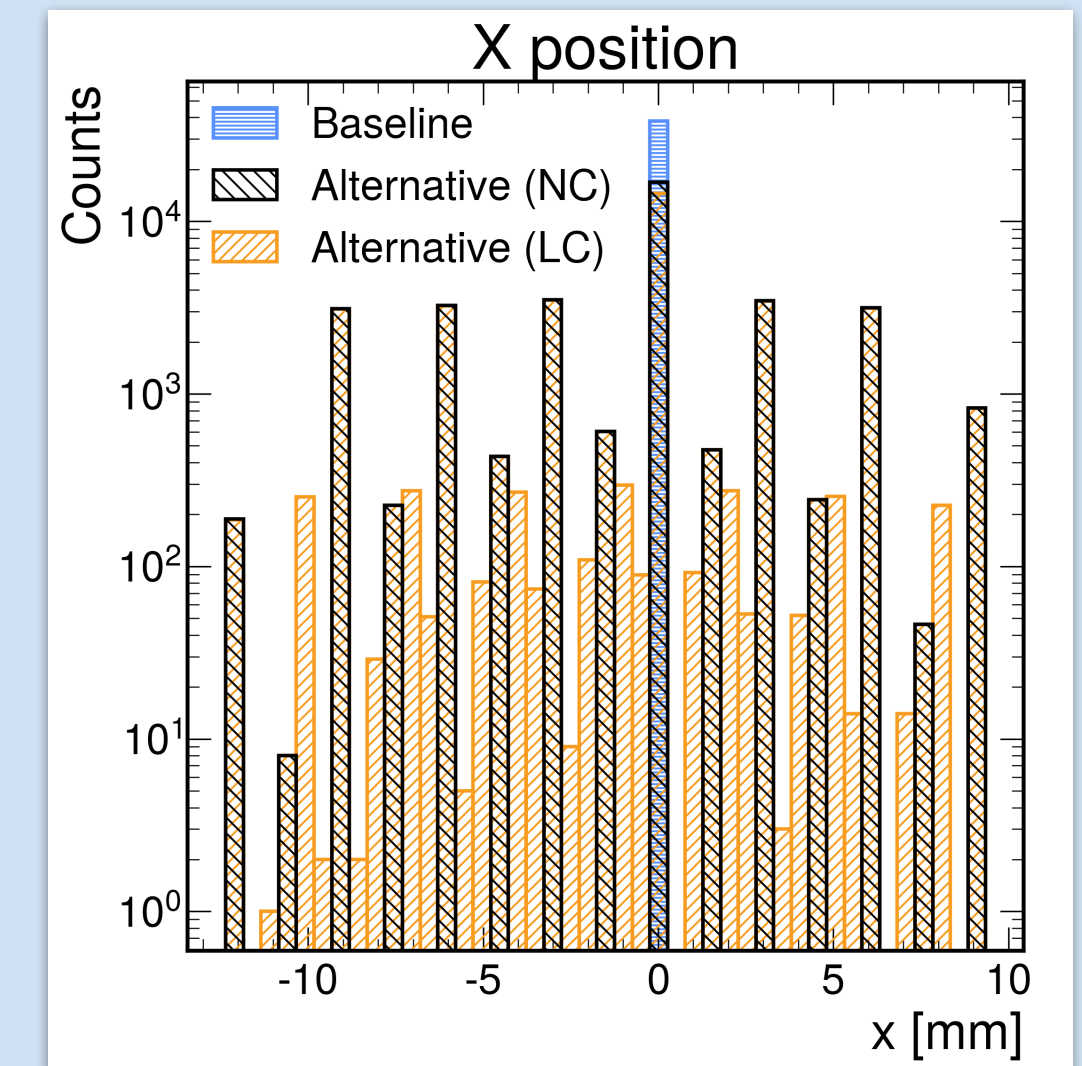
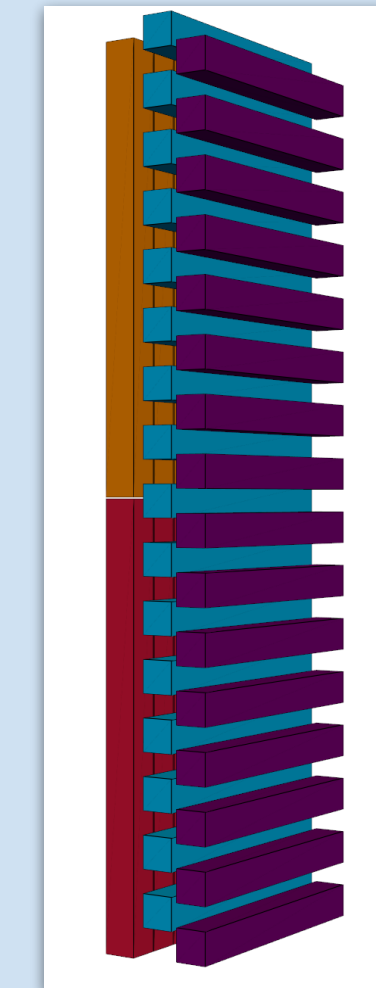
Performance studies of default design
+ exploration of alternative designs

Pattern-based electron counting

Lucia Kvarnstorm Meissner, BSc



Add vertical TS bars Ricardo Fernandes, BSc



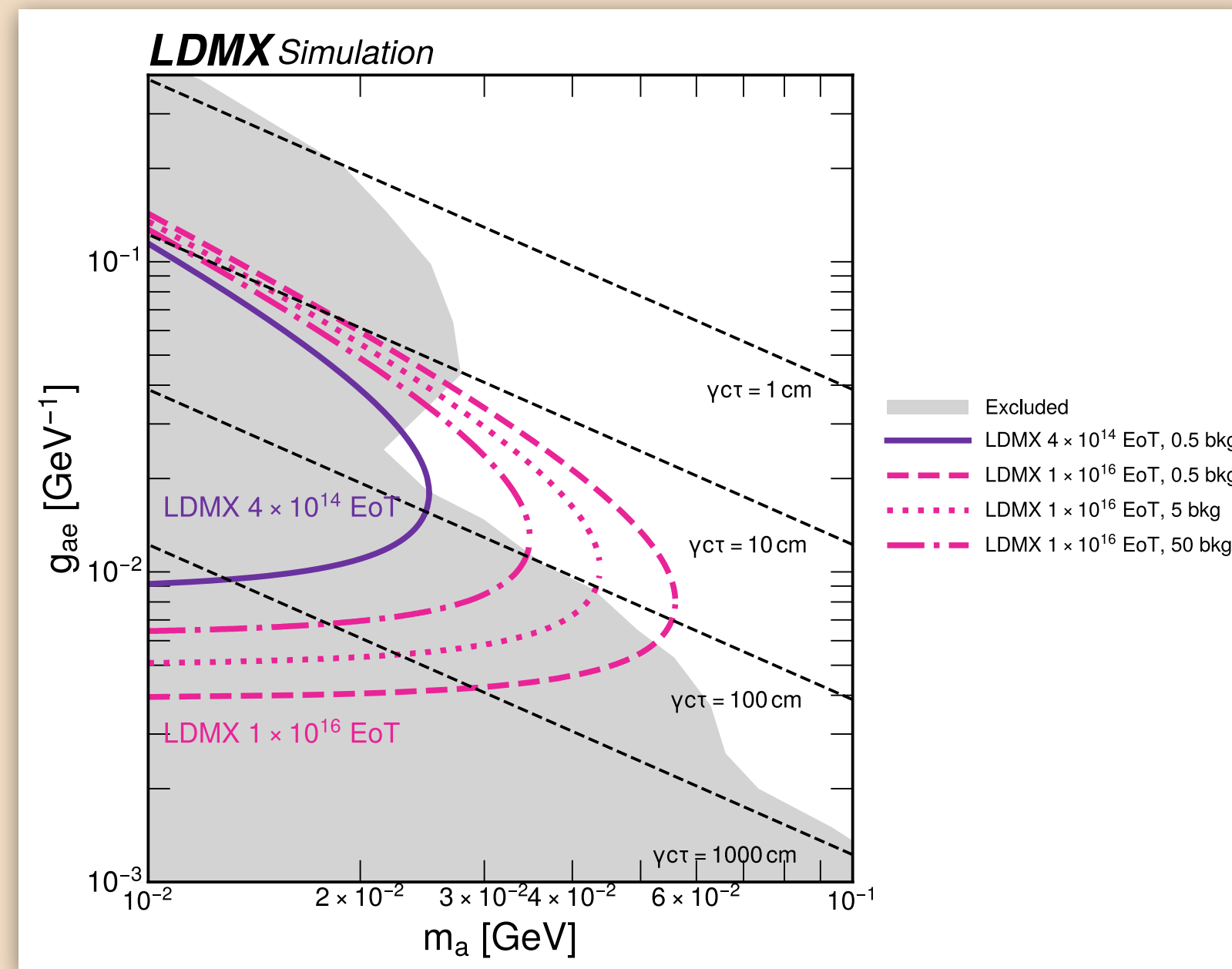
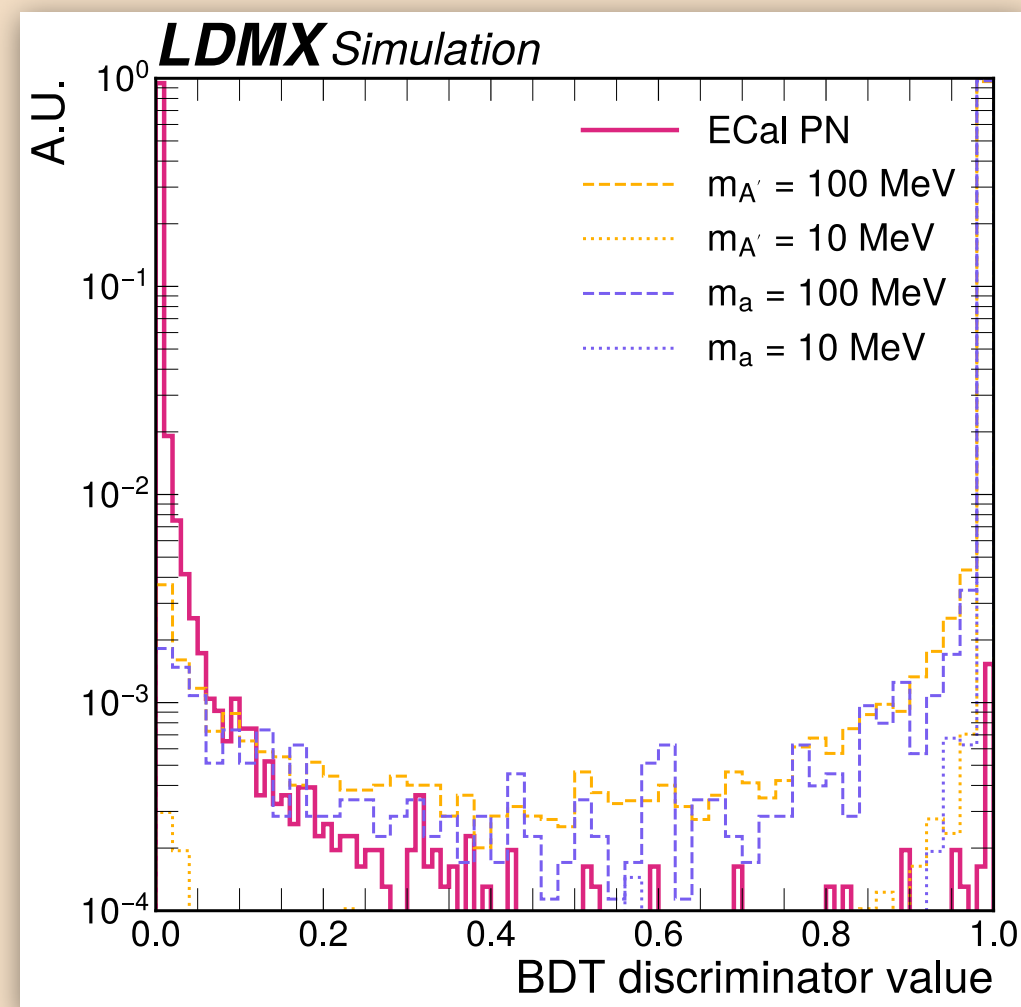
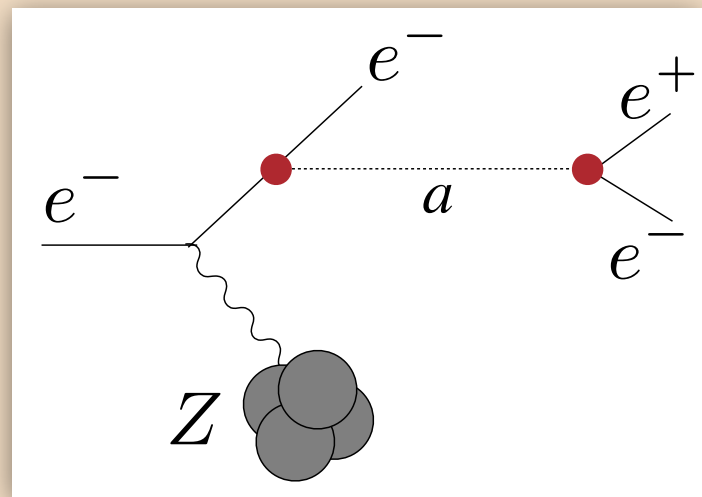
Visible final states

Erik Wallin, CJ Barton, RP with student

From e.g. long-lived particles, ALPs...

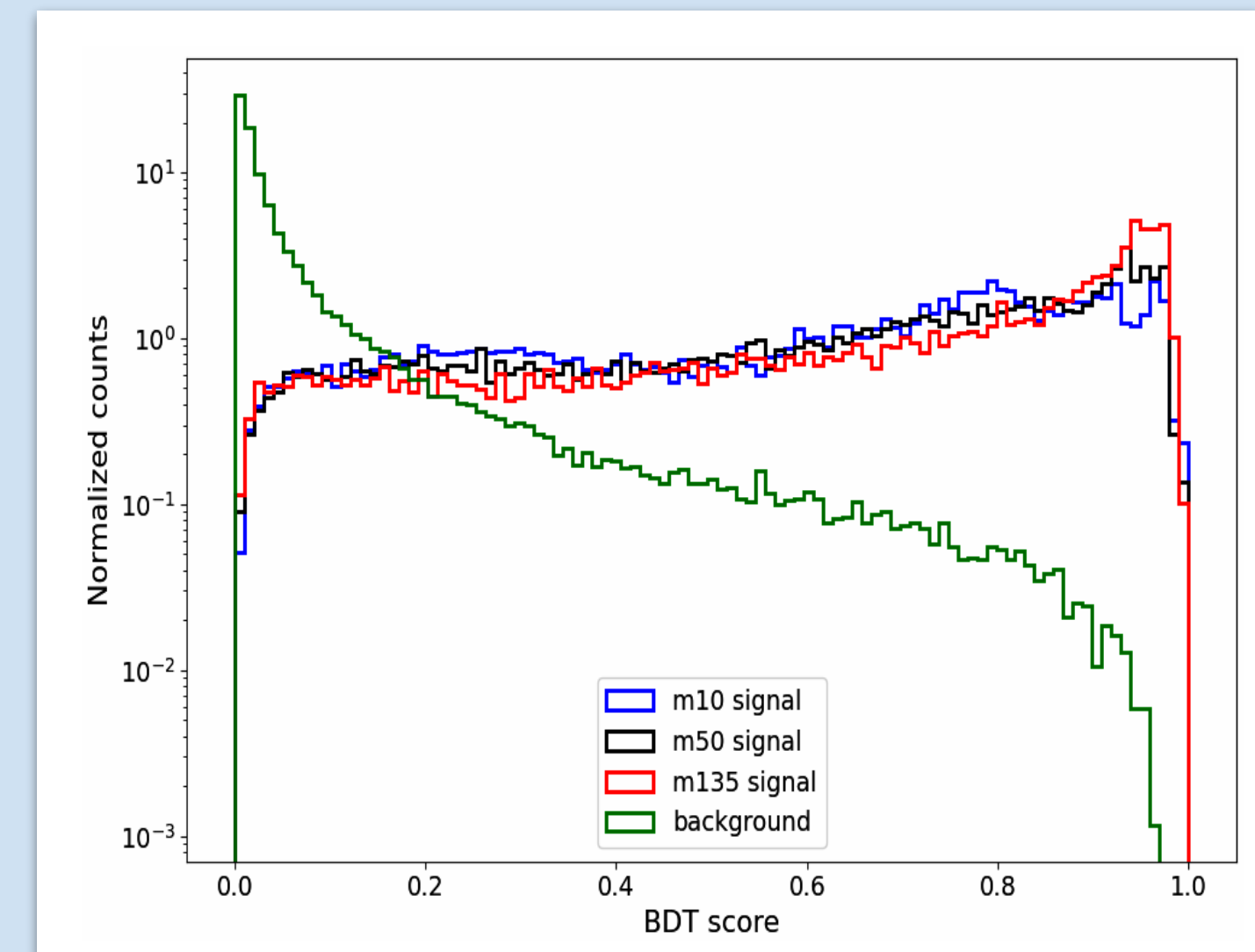
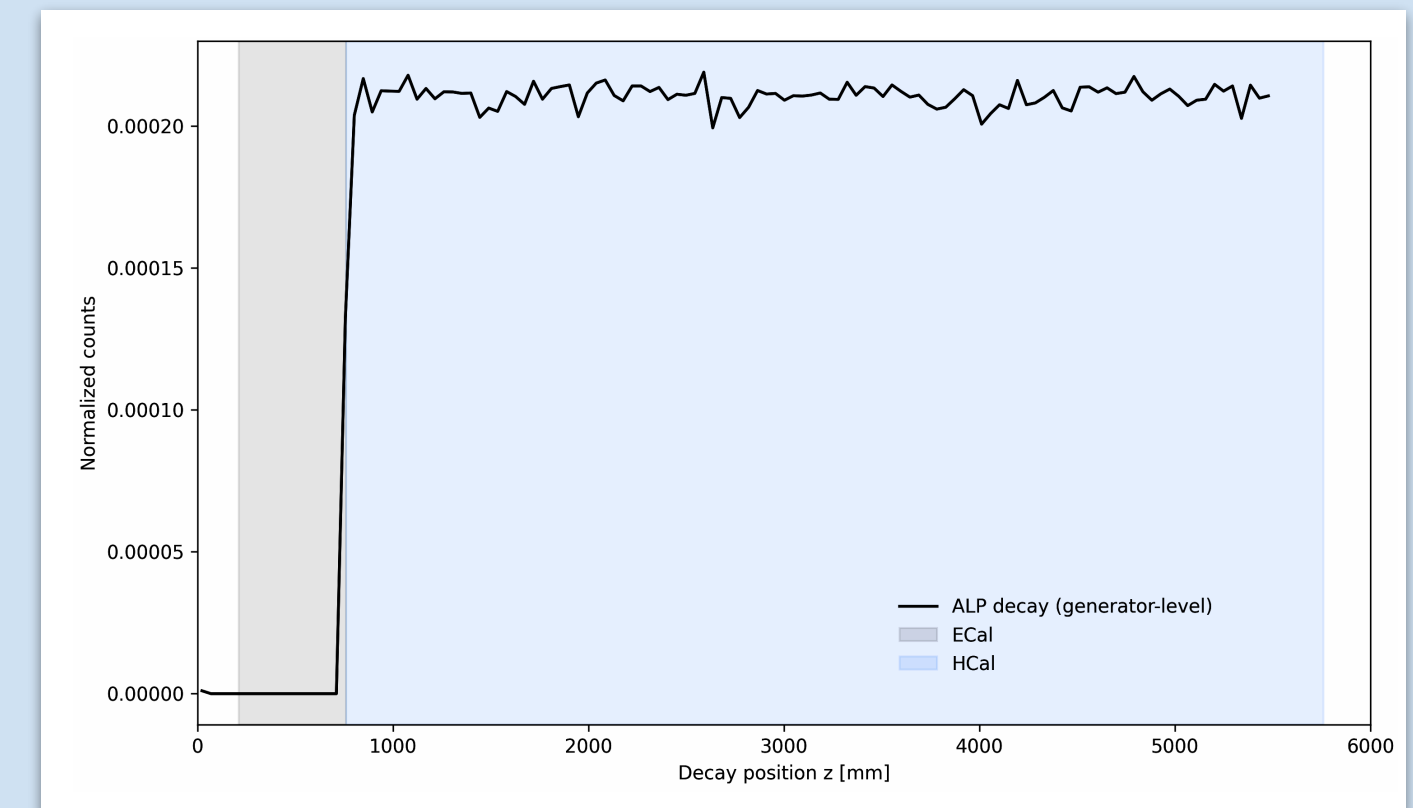
Focussing on coupling to electrons

[JHEP08\(2026\)062](#)



Sensitive to new ALP parameter space

Photon Coupling Anton Holmberg, BSc

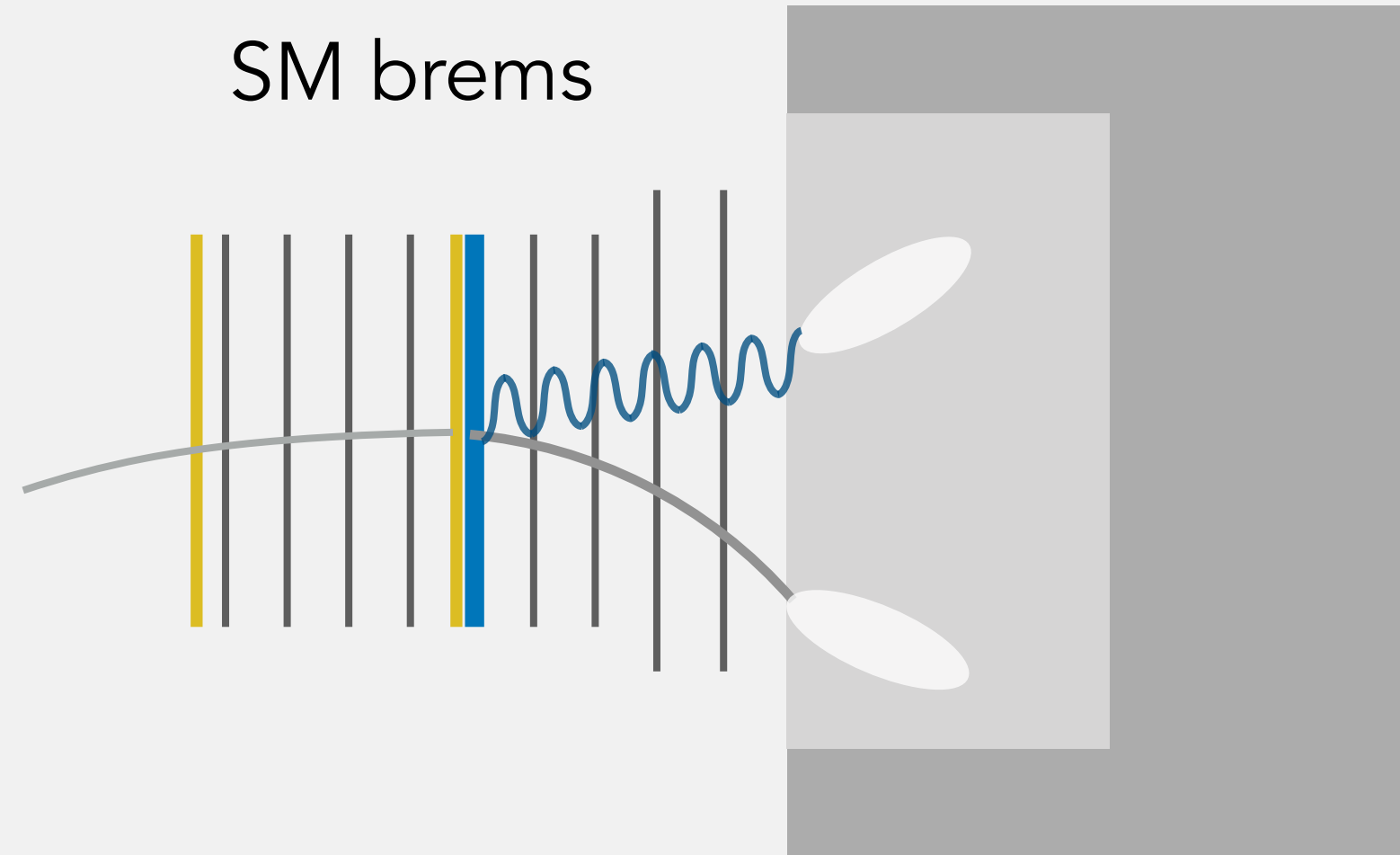


Background Processes

Relative rate:

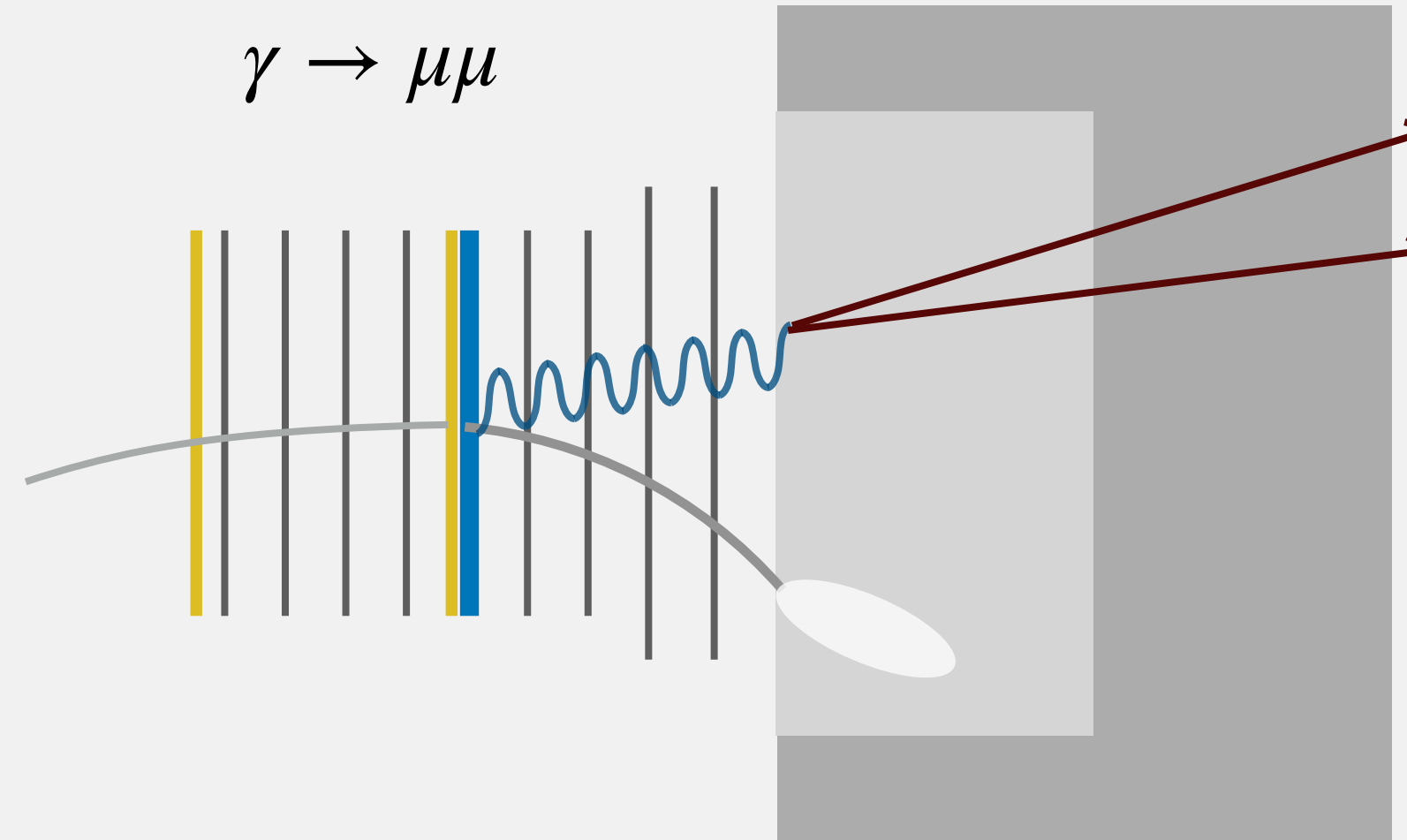
10^{-2}

SM brems



10^{-6}

$\gamma \rightarrow \mu\mu$

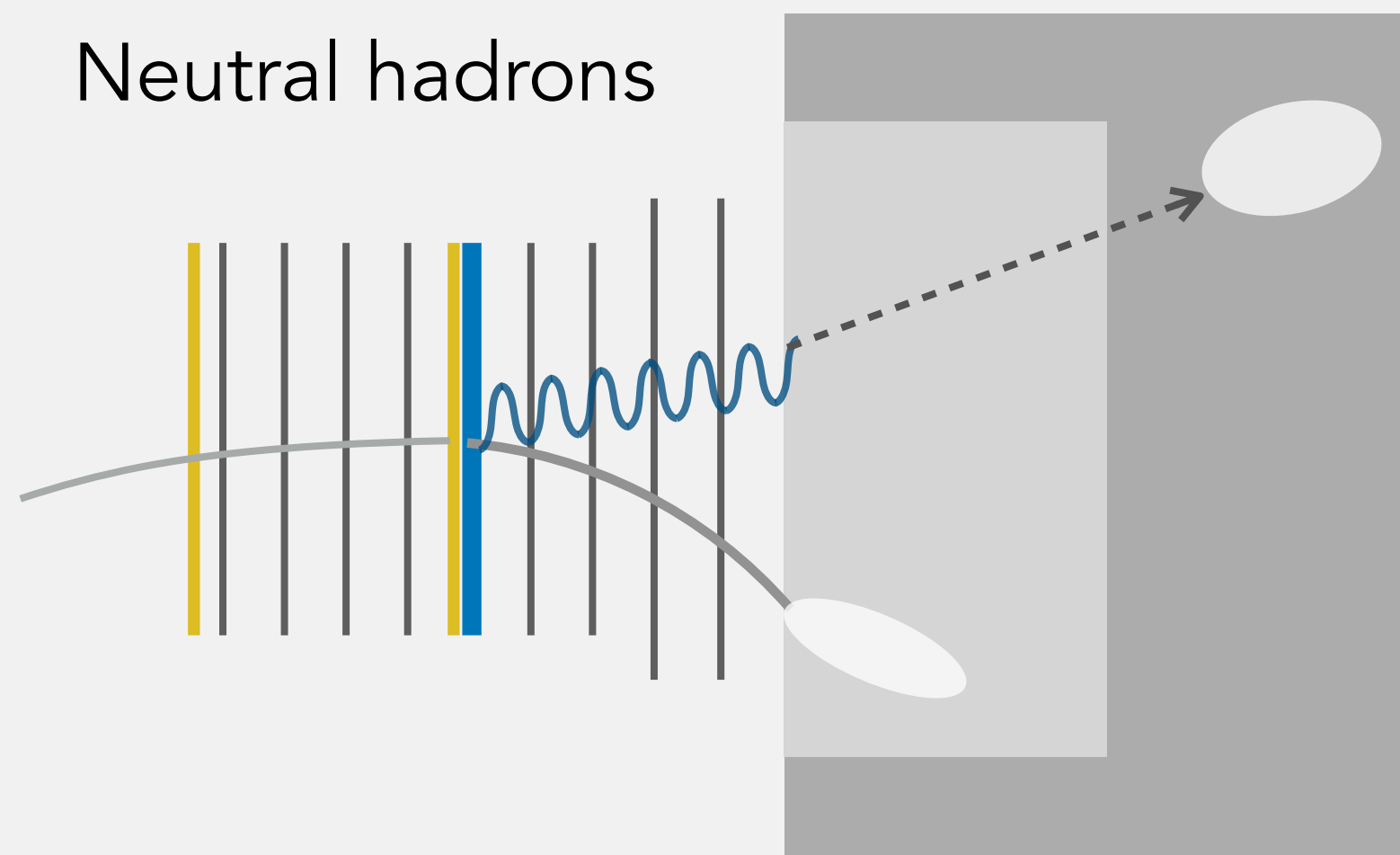


"Easy"

Relative rate:

10^{-8}

Neutral hadrons



Kaon production

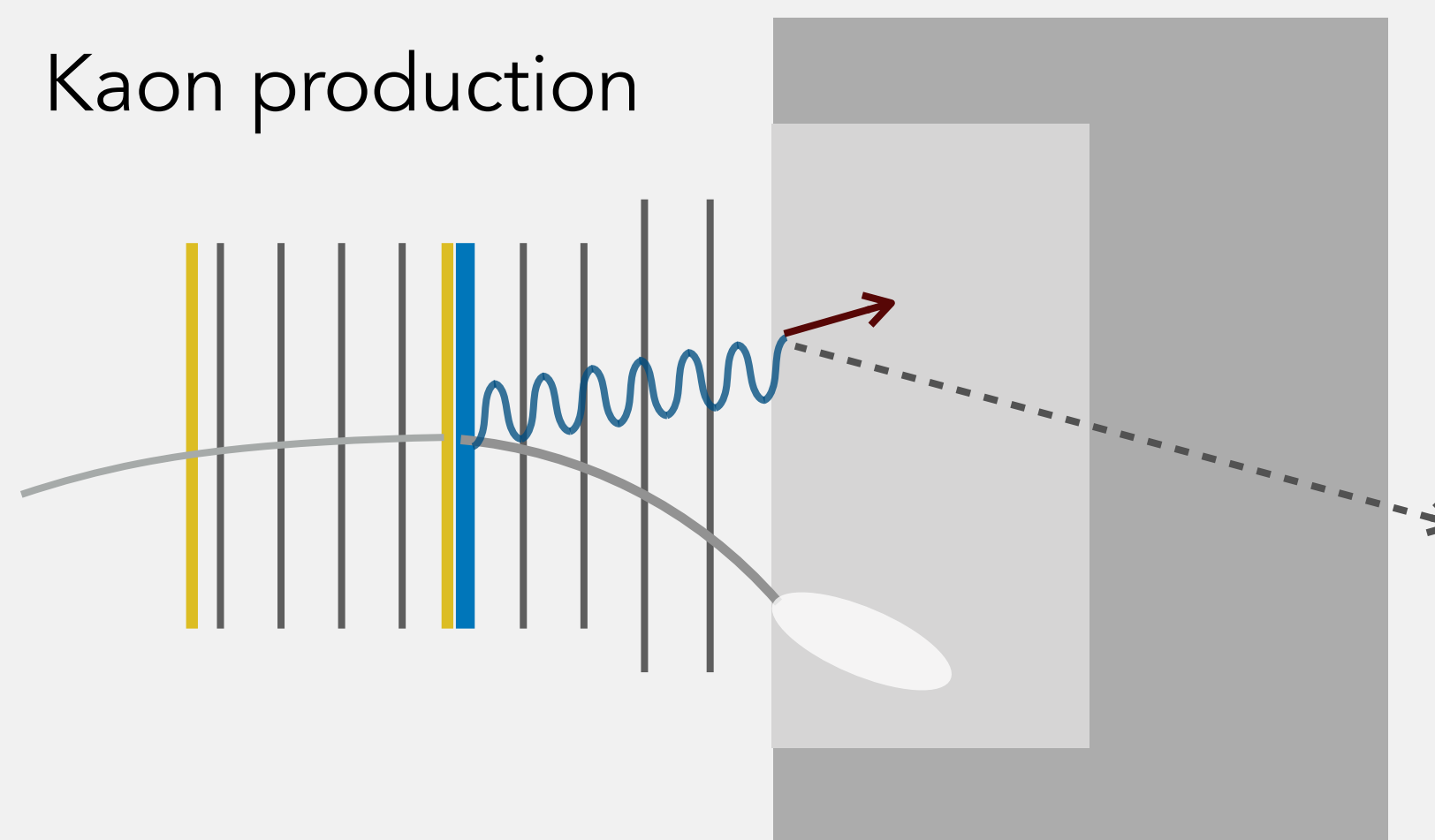


Photo-nuclear reactions with only **single veto handle**

Not so easy.

But our studies indicate we can do it.



Background Rejection

Detailed Geant4 based study of most challenging backgrounds

BDT-based analysis (default*):

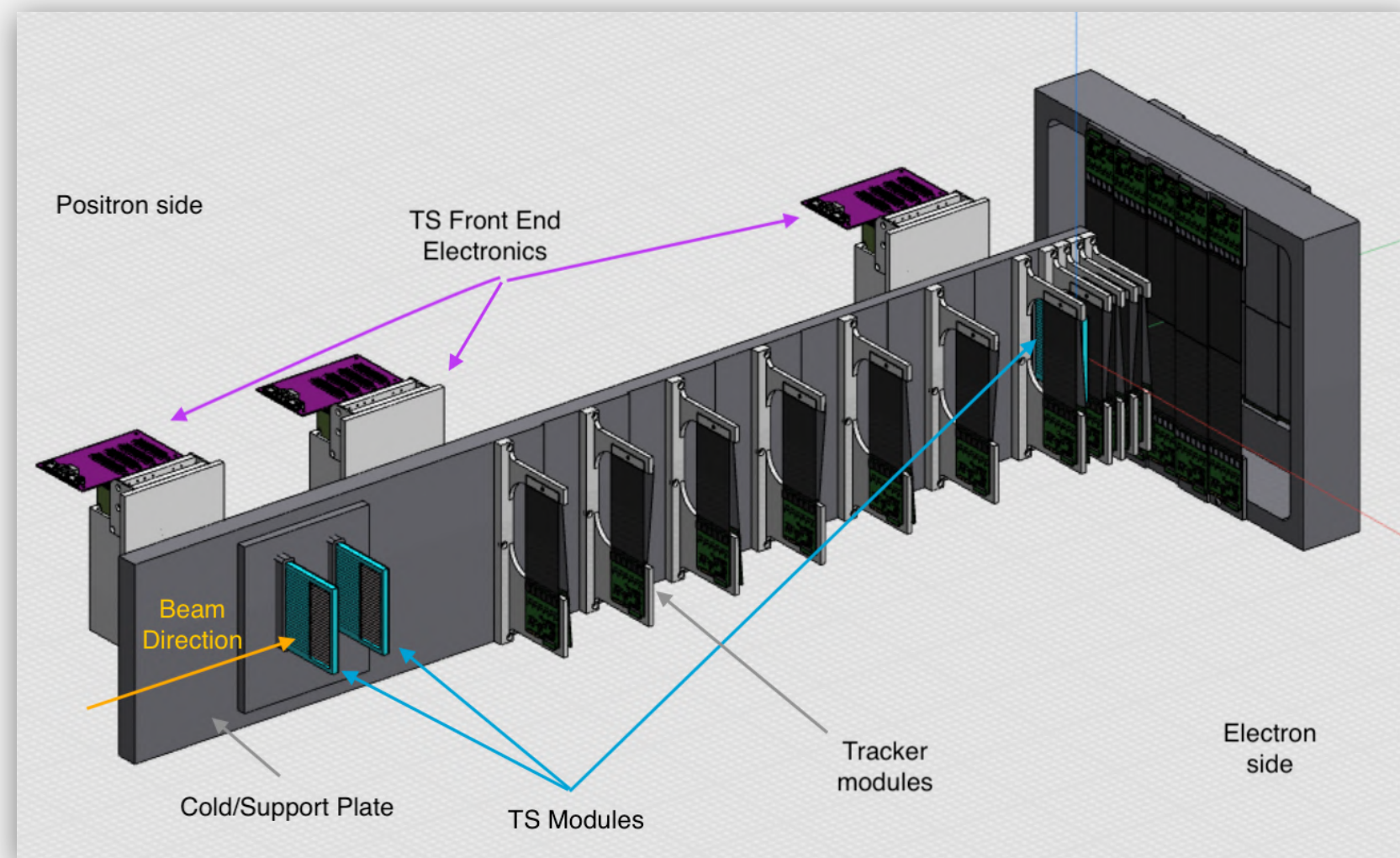
Cut	Number of Background Remaining			
	target PN	target conv.	ecal PN	ecal conv.
EoT equivalent	10^{14}	10^{15}	10^{14}	10^{14}
All / Acceptance	1,941,296	7,091,907	299,299,867	18,720,663
Triggered	756,661	4,280,536	170,993,364	14,042,193
$p_{\text{tagger}} > 5.6 \text{ GeV}$	745,494	4,224,191	168,725,637	13,856,953
$N_{\text{recoil}} = 1$	72,927	21,625	154,191,349	12,685,692
Ecal BDT > 0.9974	1,529	<1	64,353	<1
$N_{\text{straight}} < 3$	1,412	<1	61,771	<1
HCal maxPE < 8	<1	<1	2	<1

Signal efficiency 50-70% for dark photon benchmark model

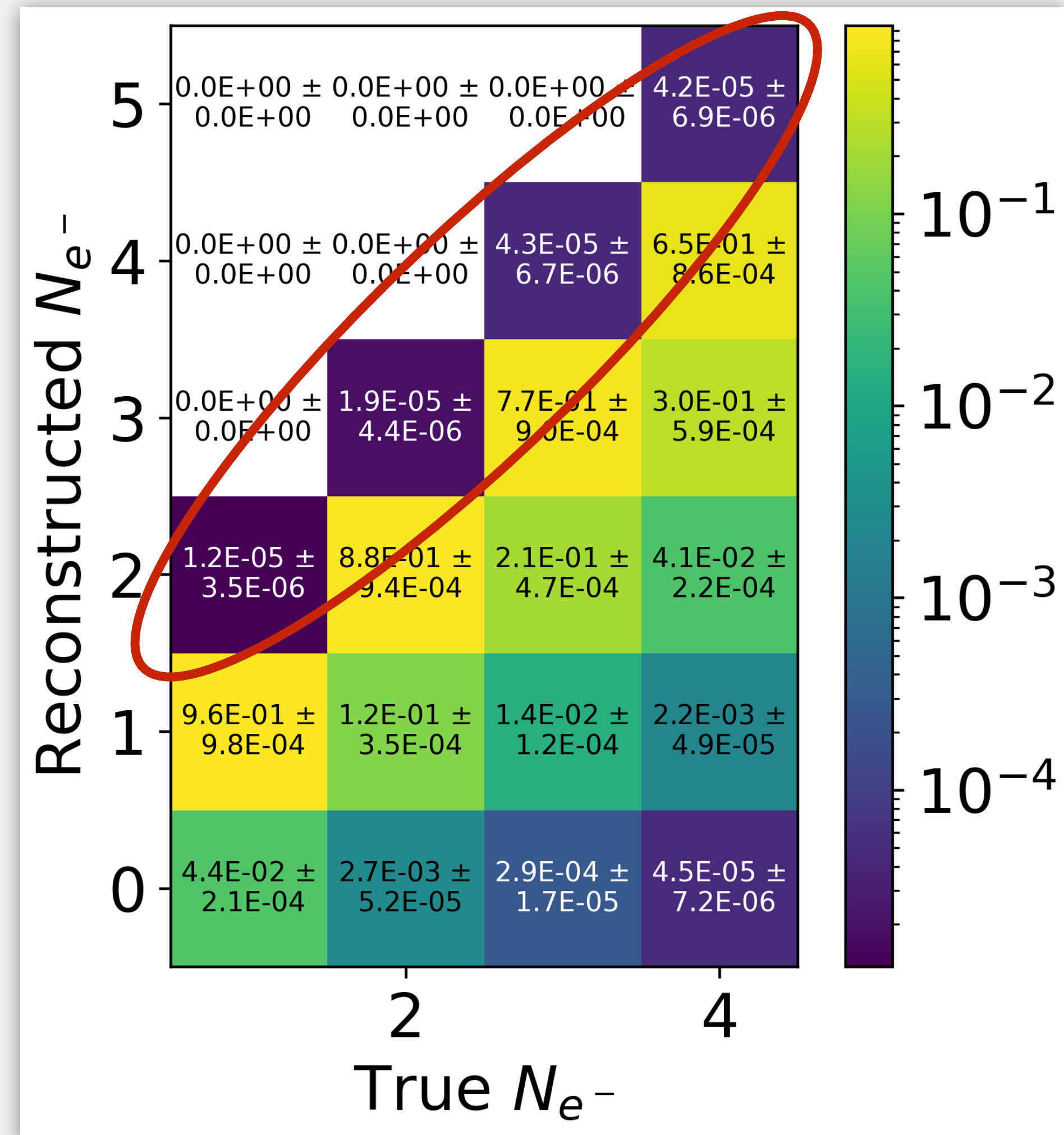
*Also GNN and cut-based vetoes in design report

Several Electrons — Trigger

[arxiv:2508.11833](https://arxiv.org/abs/2508.11833)



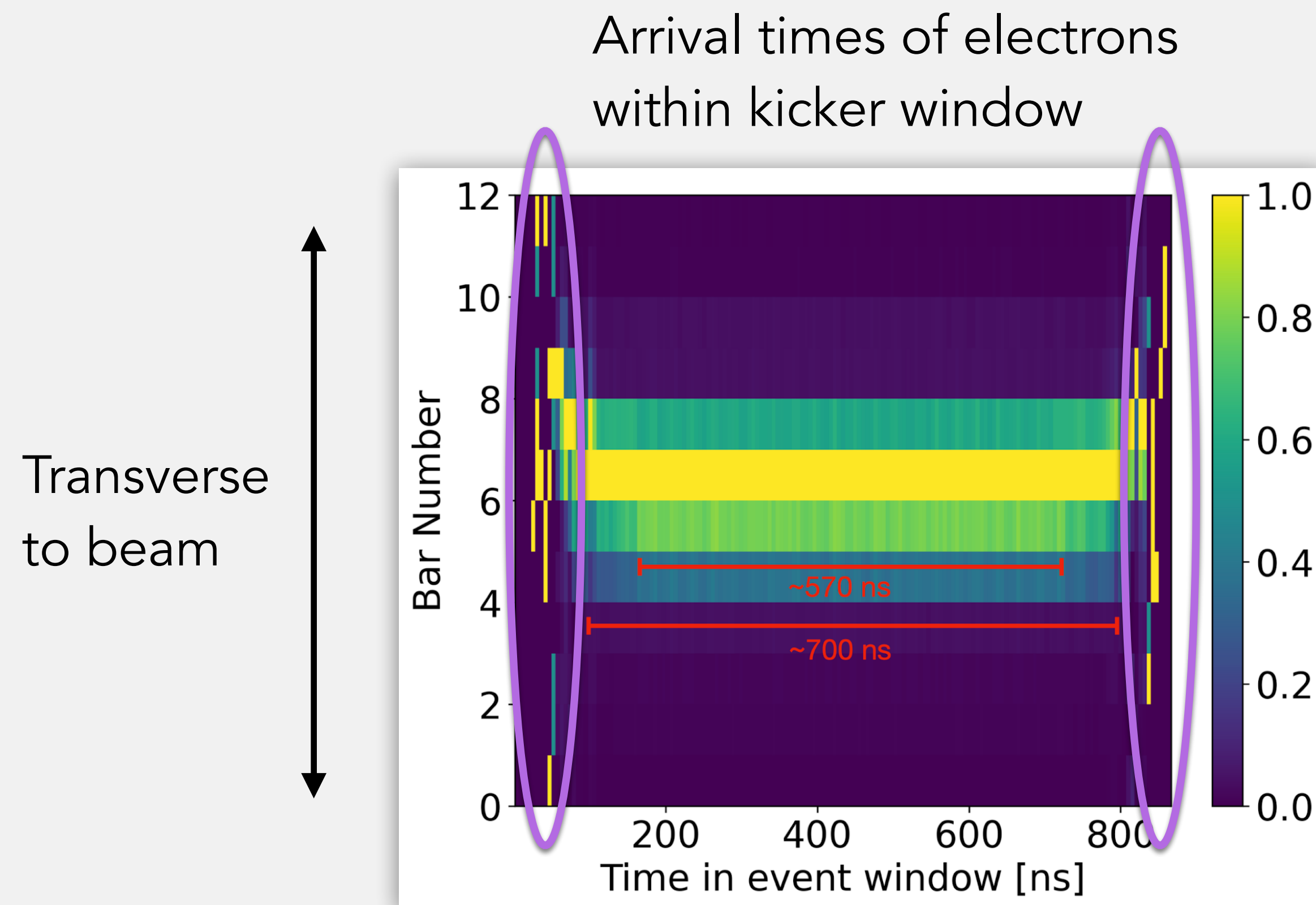
Avoid electron overcounting
—> Fake missing energy



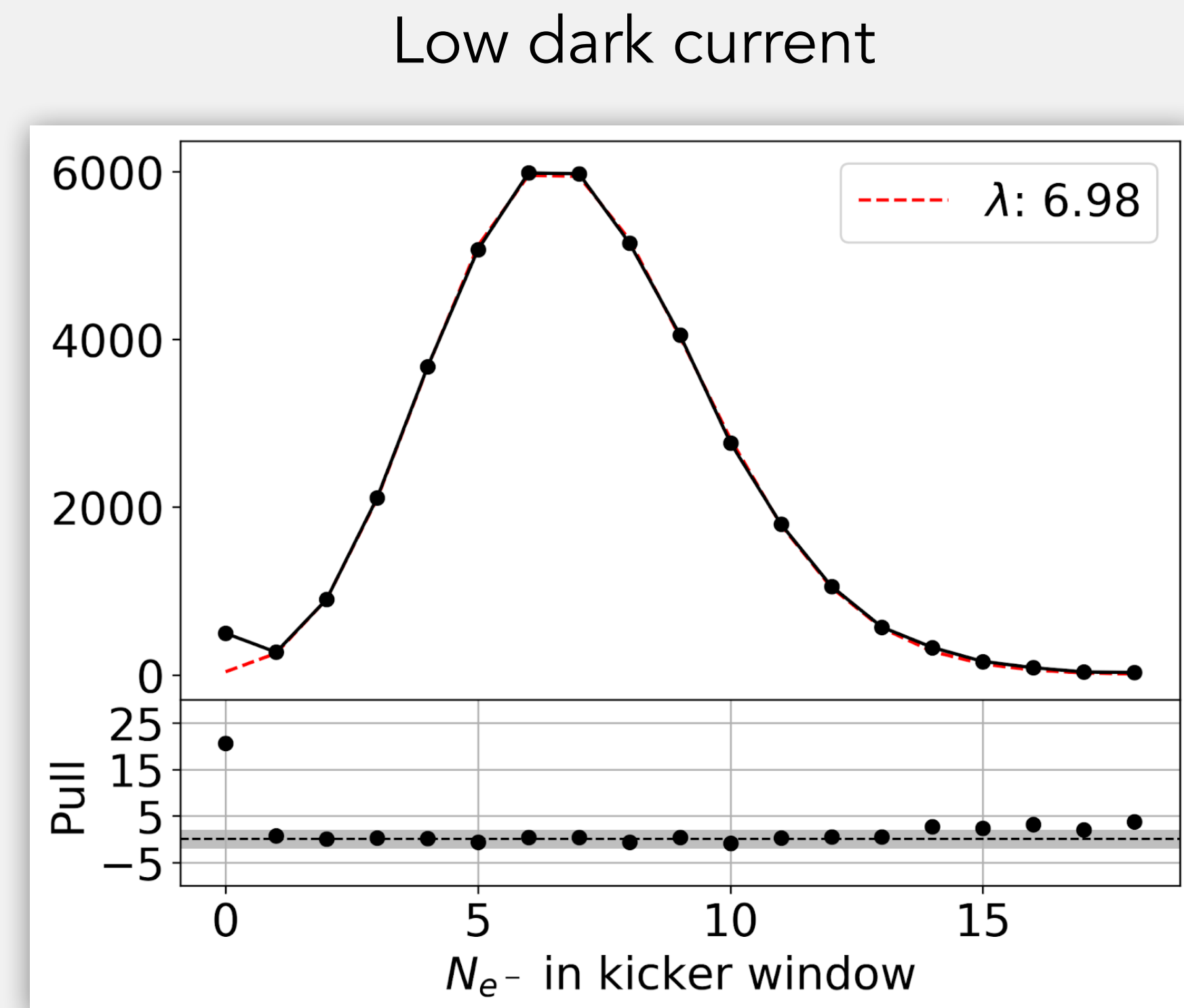
First Beam Studies at SLAC

Feb/March 2025: Placed a trigger scintillator module at end of S30 transfer line (S30XL)

—> Measure dark current + demonstrate parasitic running with LCLS-II



Kicker magnet ramping



Sufficient electrons

First run: 4×10^{14} electrons in $O(1)$ year

Eventually: Up to 10^{16} electrons in $O(10)$ years

With only single-e events: 10^{16} EoT take 60 years

—> Need more than one electron at a time

Beam will have Poisson distribution around mean value $\langle \mu \rangle$

With **$\langle \mu \rangle = 2$** and **capability to analyse both 1e and 2e events**

4×10^{14} in 12 months

5×10^{15} in 12 years

10^{16} in 25 years

With **$\langle \mu \rangle = 2$** and **capability to analyse up to 4e events**

10^{16} in 12 years

Ballpark numbers for LDMX

	Amount	Emission Factor	Total	Comments
Steel (HCal)	~80t	0.4 - 2.3 [1]	32 - 184 t	Depends on supplier, recycling fraction
Aluminum (HCal)	~3t	14.3 (World Average) 6.5 (North America) [2]	43 t 19.5t	Depends on supplier, recycling fraction
Extruded Polystyrene (HCal)	~8t	6.9 [3]	55 t	Emission factor not exactly for the extrusion process LDMX will use
Silicon (ECal)	~6kg	11.3 (world average) [2]	68 kg	
Energy consumption	2 GWh/year	220kg/MWh [4]	440t/year	Dominated by magnet, based on numbers for CA 2020
LunDMX group's flights to SLAC	20/year	~5t/roundtrip [5]	100t/year	Assuming that e.g. Collaboration meetings and shift taking can be combined
LDMX Collaboration Meeting	3/year	~70t/meeting	210t/year	Assuming location in the US, little dependence on where exactly
Operations (24/7)	2700 shifts/year	<i>Depends on institute</i>	~200t/year	Very simplistic model for shift distribution, but not unrealistic, would mean 40% from LU

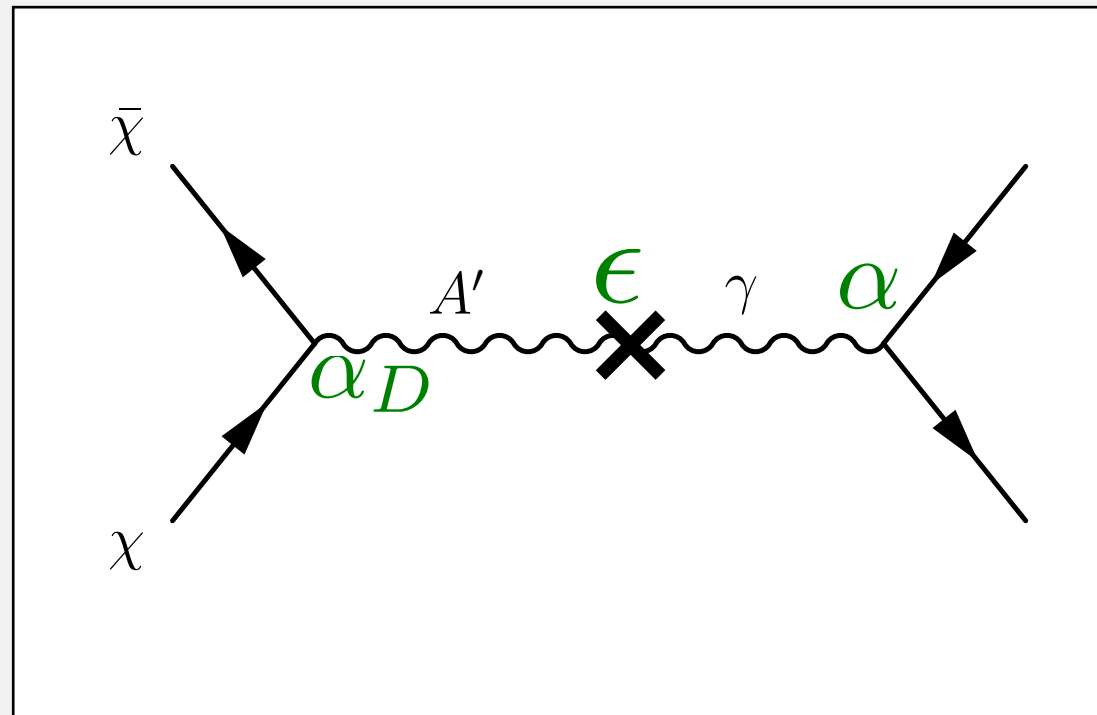


Reducing *time needed* to collect sufficient statistics crucial for reducing emissions! —> **Multi-e**

Benchmark Model

Dark (Heavy) Photon (A')

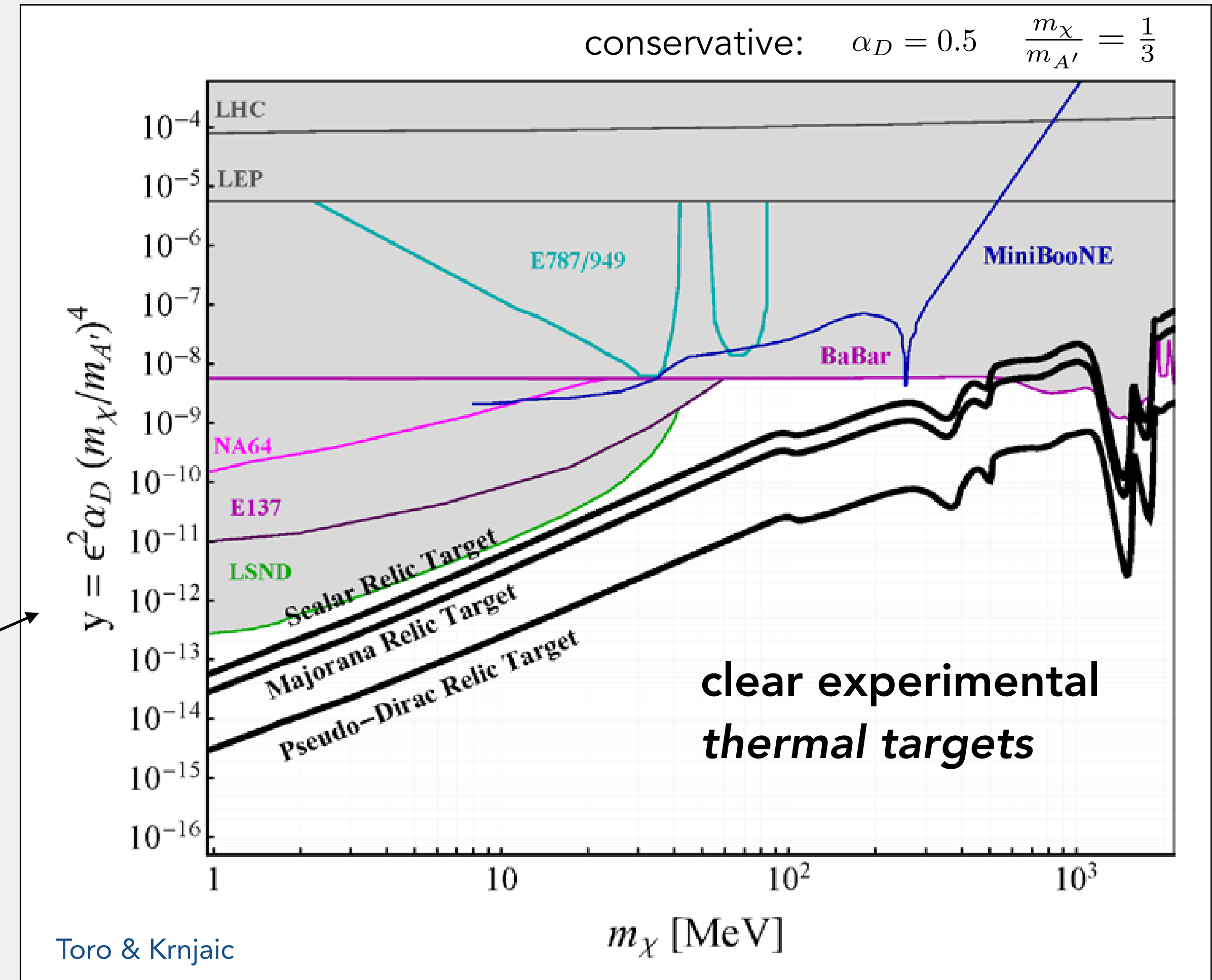
- spin-1 particle, mass $m_{A'} \neq 0$ (MeV - GeV)
- mixes with photon (ϵ)



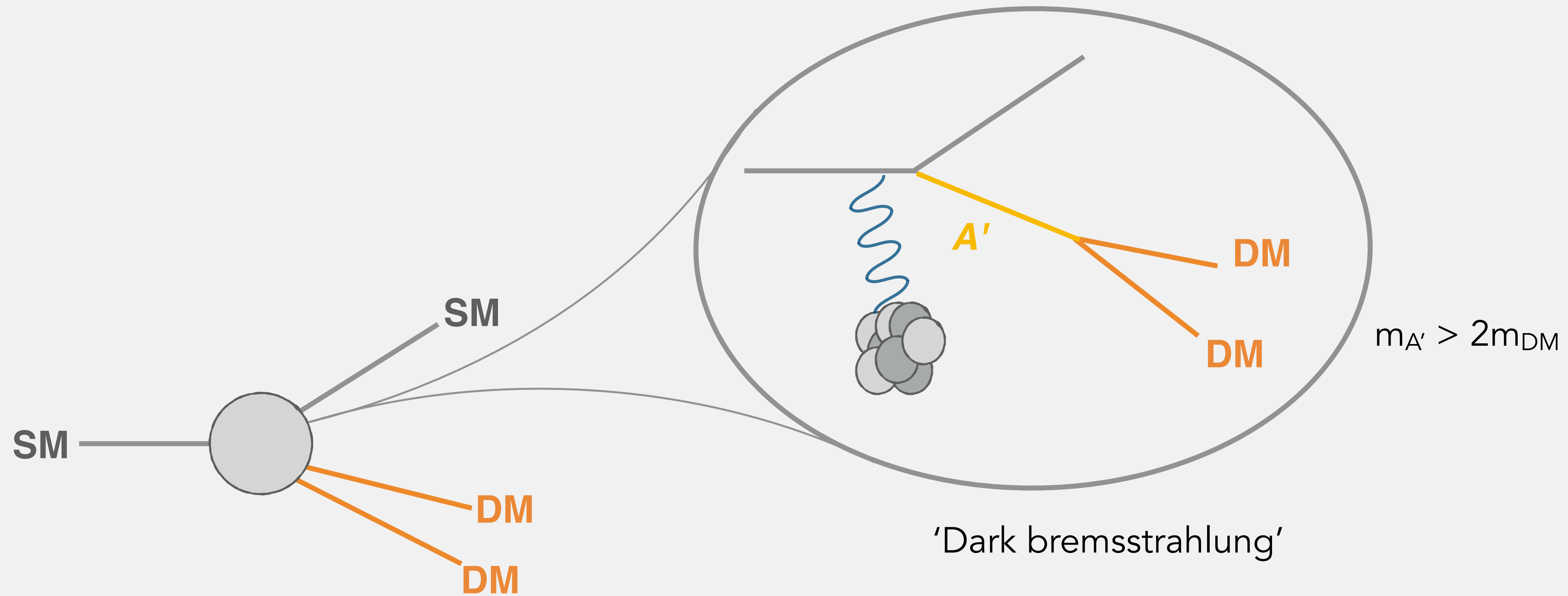
$$\sigma v \sim \alpha_D \epsilon^2 \frac{m_\chi^2}{m_{A'}^4} \sim \alpha_D \epsilon^2 \frac{m_\chi^4}{m_{A'}^4} \frac{1}{m_\chi^2} \sim y \frac{1}{m_\chi^2}$$

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

Interaction strength



Accelerator Production



Main background: 'Ordinary' bremsstrahlung
of a SM photon

LDMX Potential

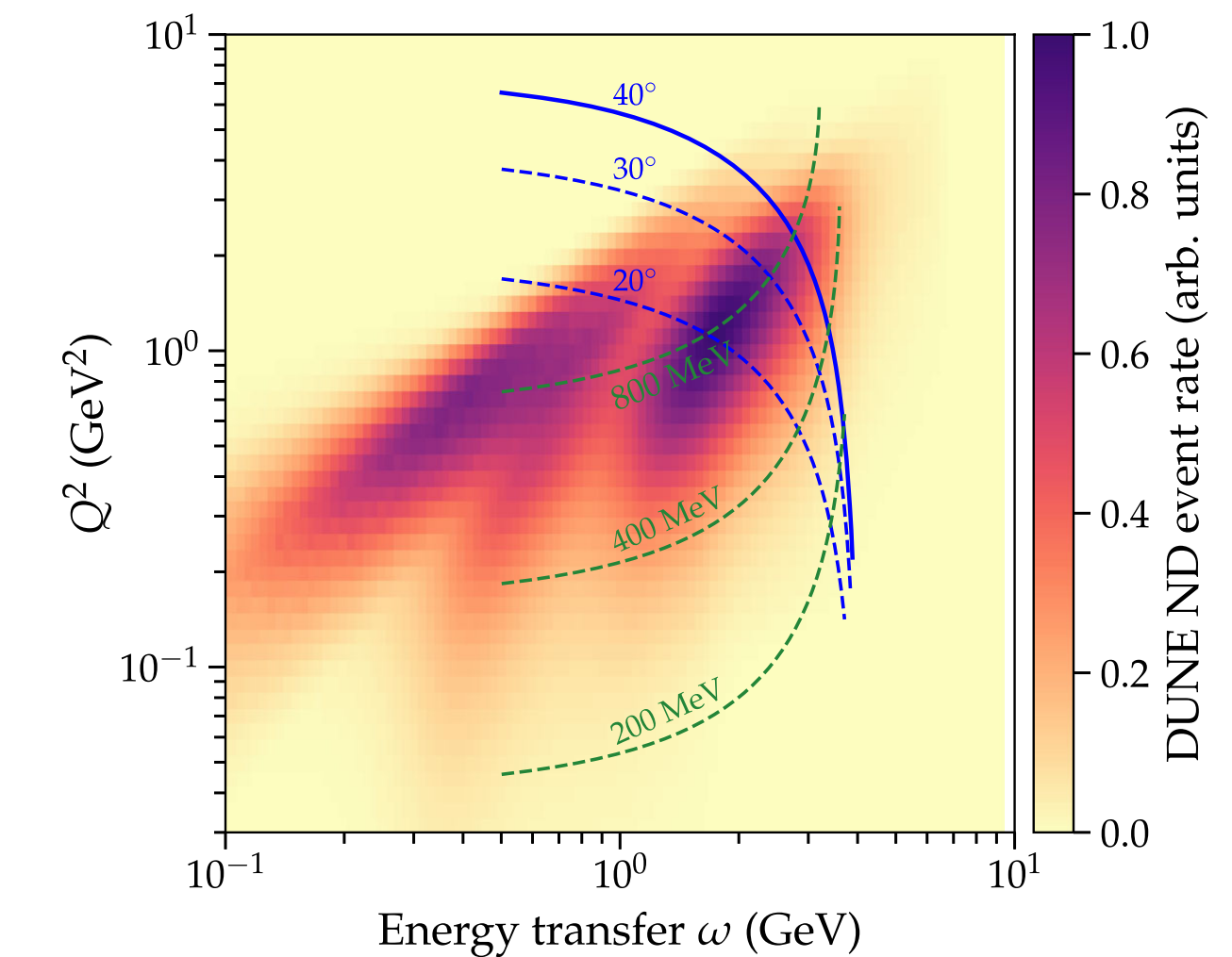
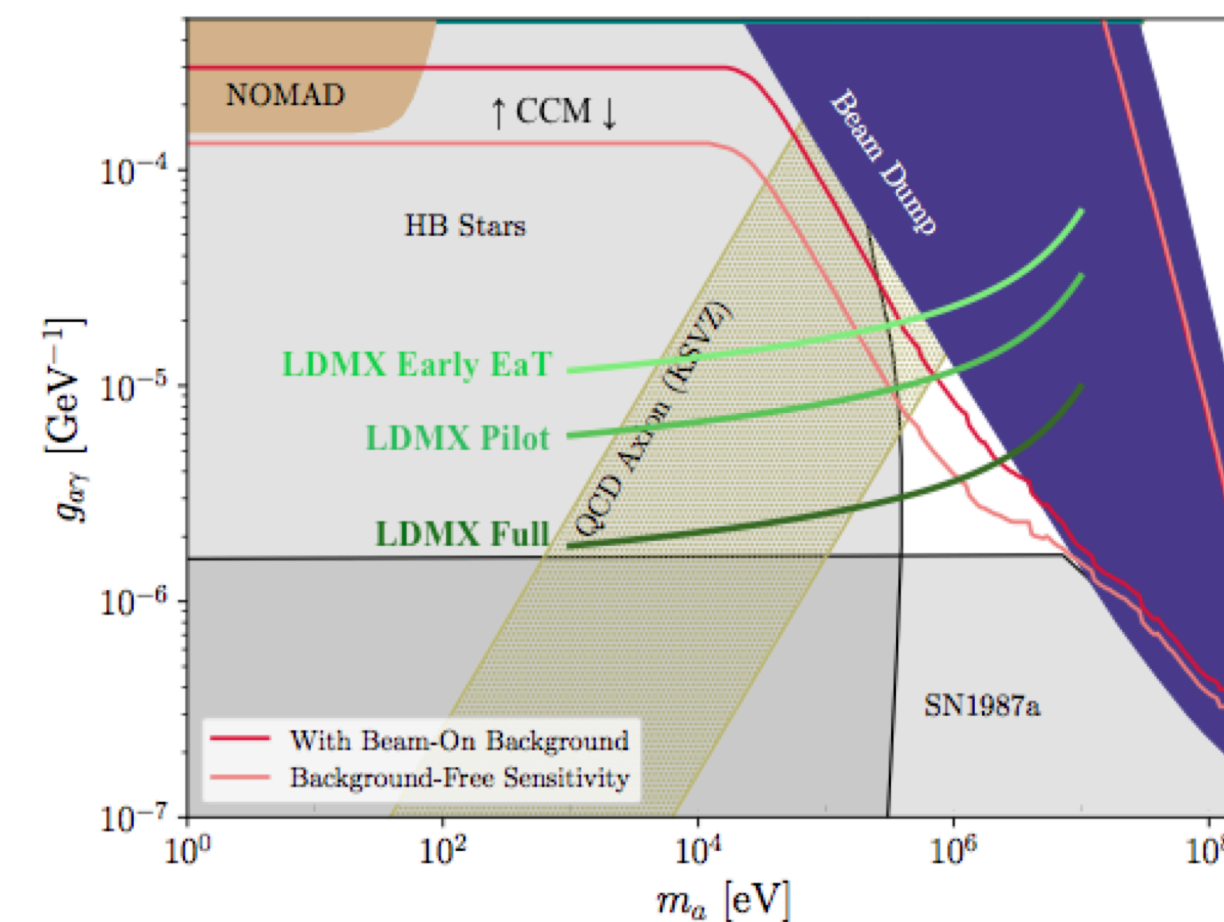
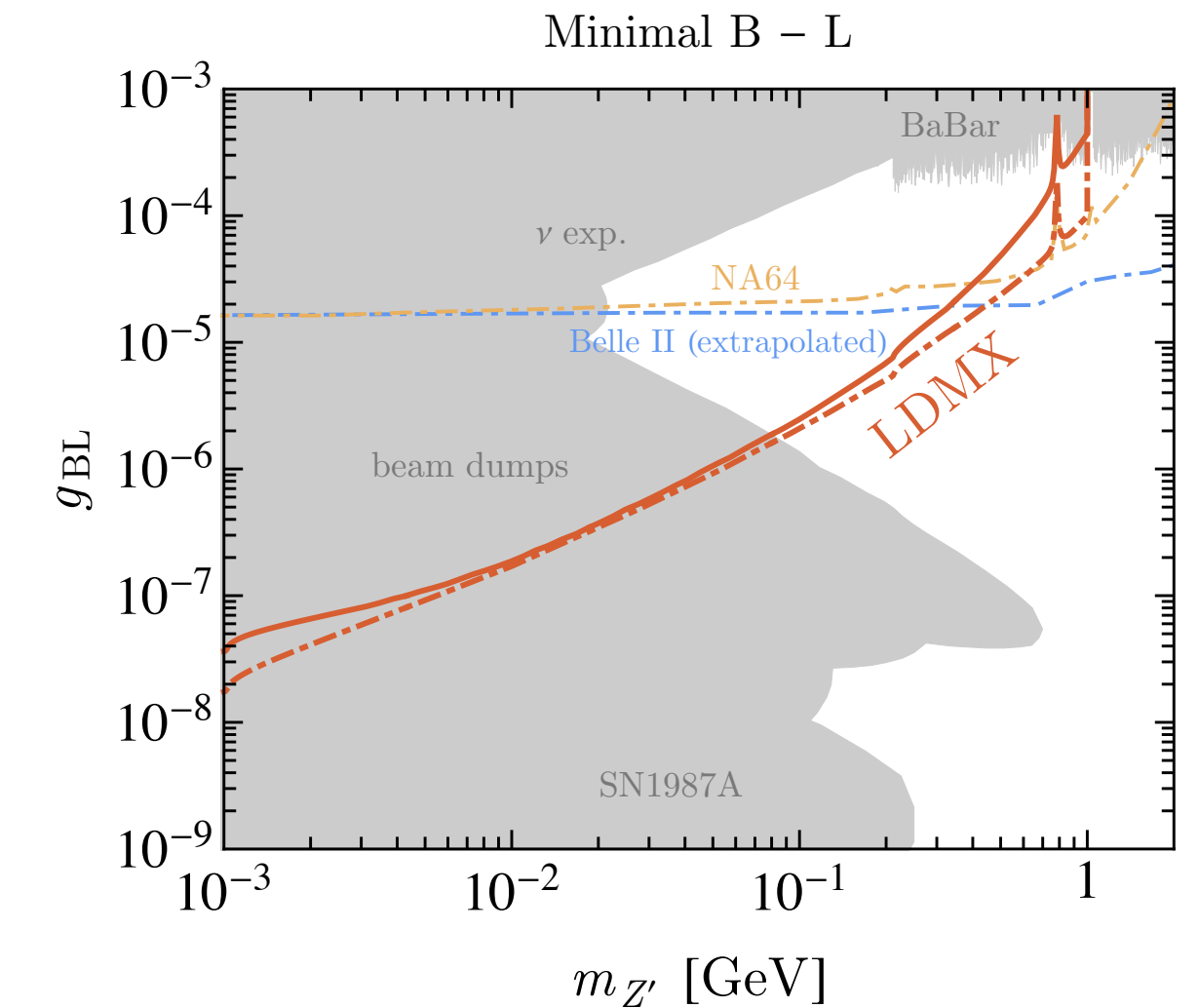
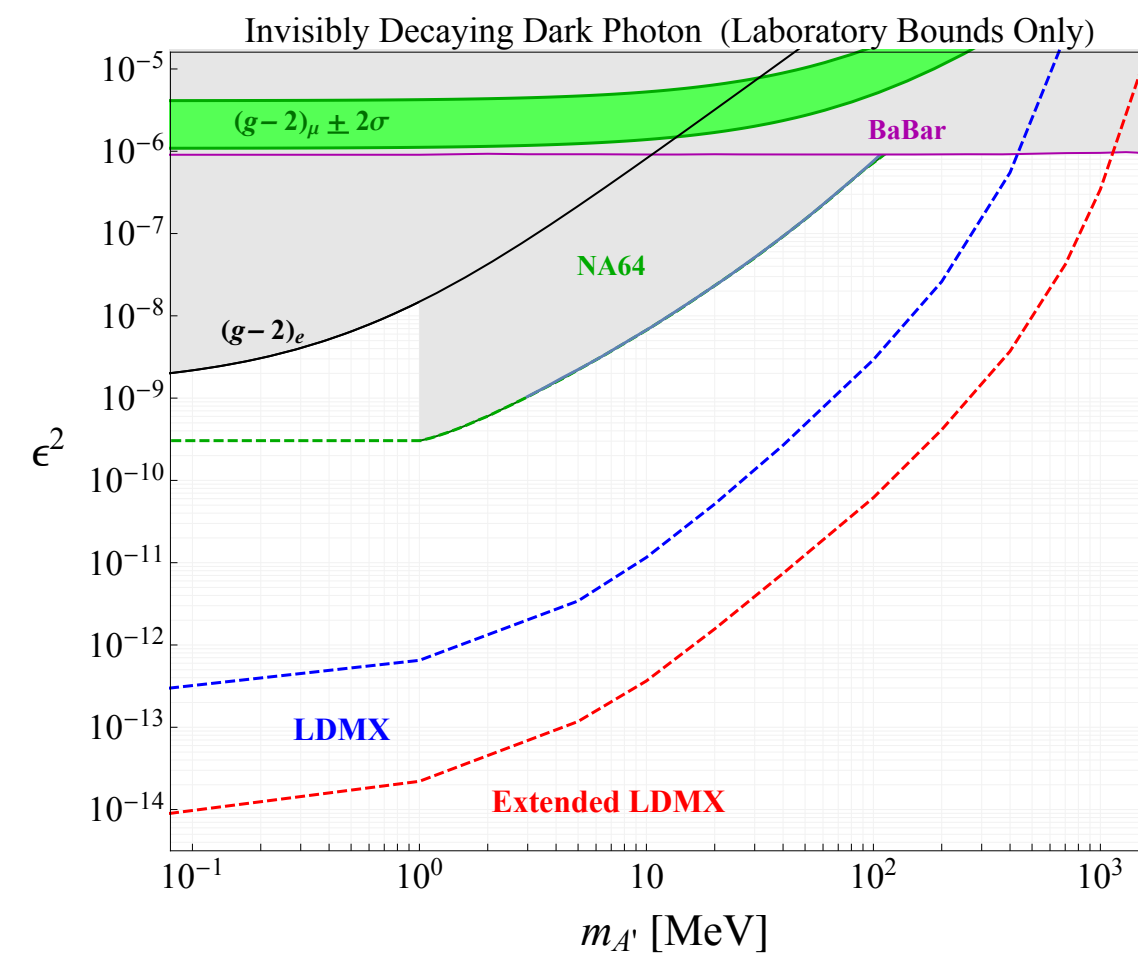
Sensitive to rich spectrum of invisible and visible signatures of new physics

- **Light (sub-GeV) thermal relic dark matter**
- Dark matter 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
- ALPs...

[arxiv:1807.01730](https://arxiv.org/abs/1807.01730) [arxiv:2203.08192](https://arxiv.org/abs/2203.08192)

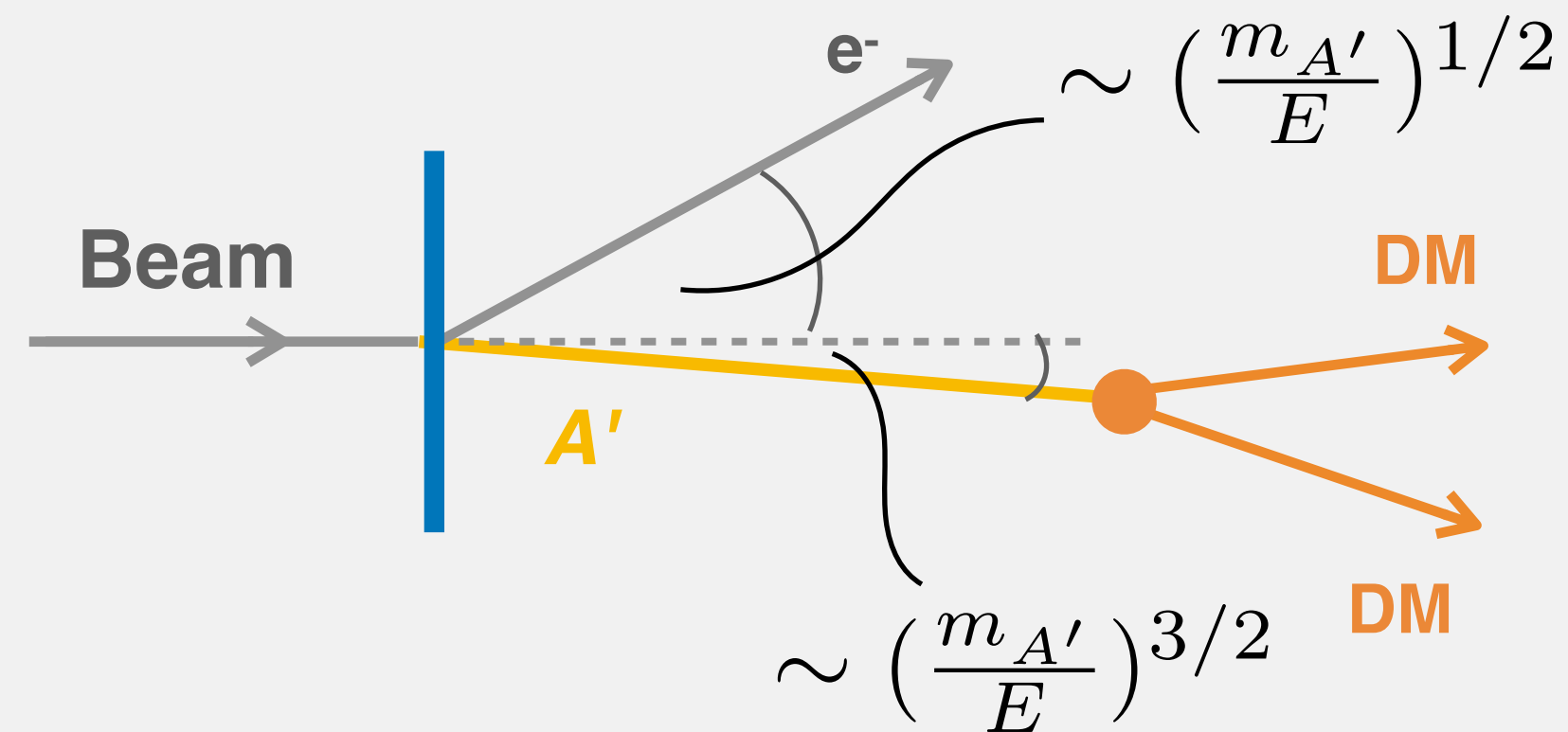
In addition: **Measurement** of photo- and electro-nuclear processes (for neutrino experiments), e.g.

[Phys. Rev. D 101, 053004](https://arxiv.org/abs/2203.08192)

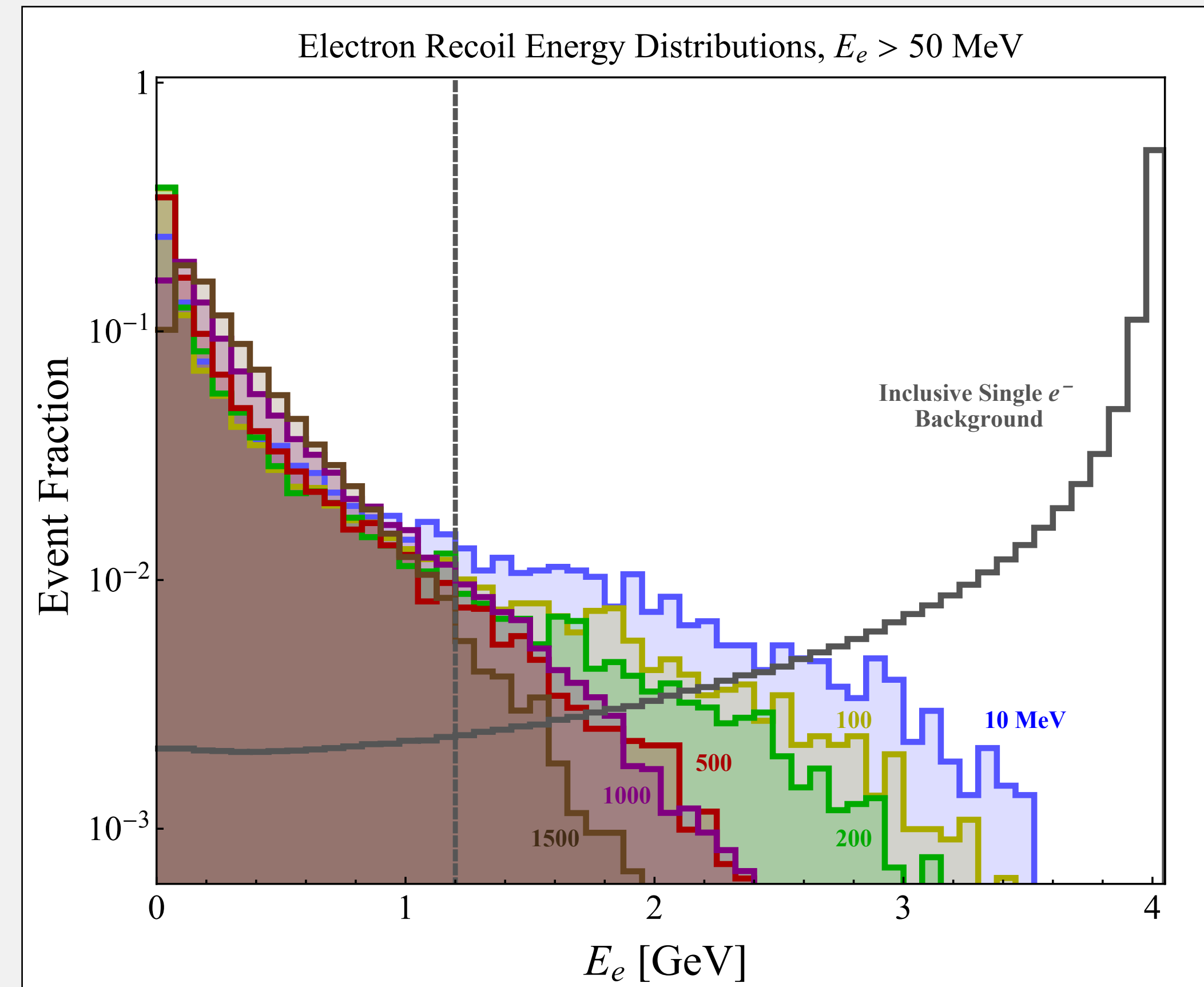


Kinematics

Very different from SM bremsstrahlung,
the main background

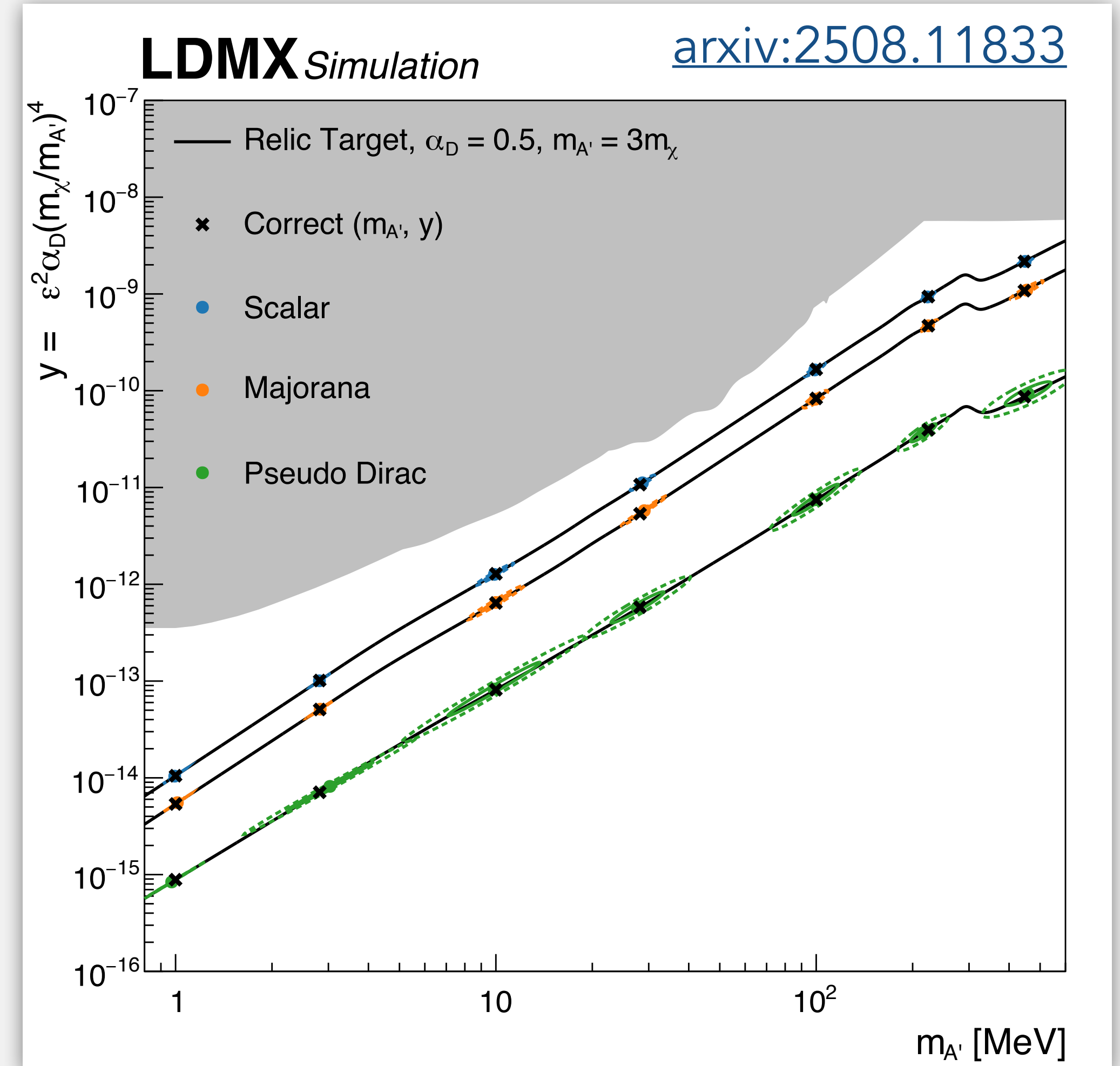
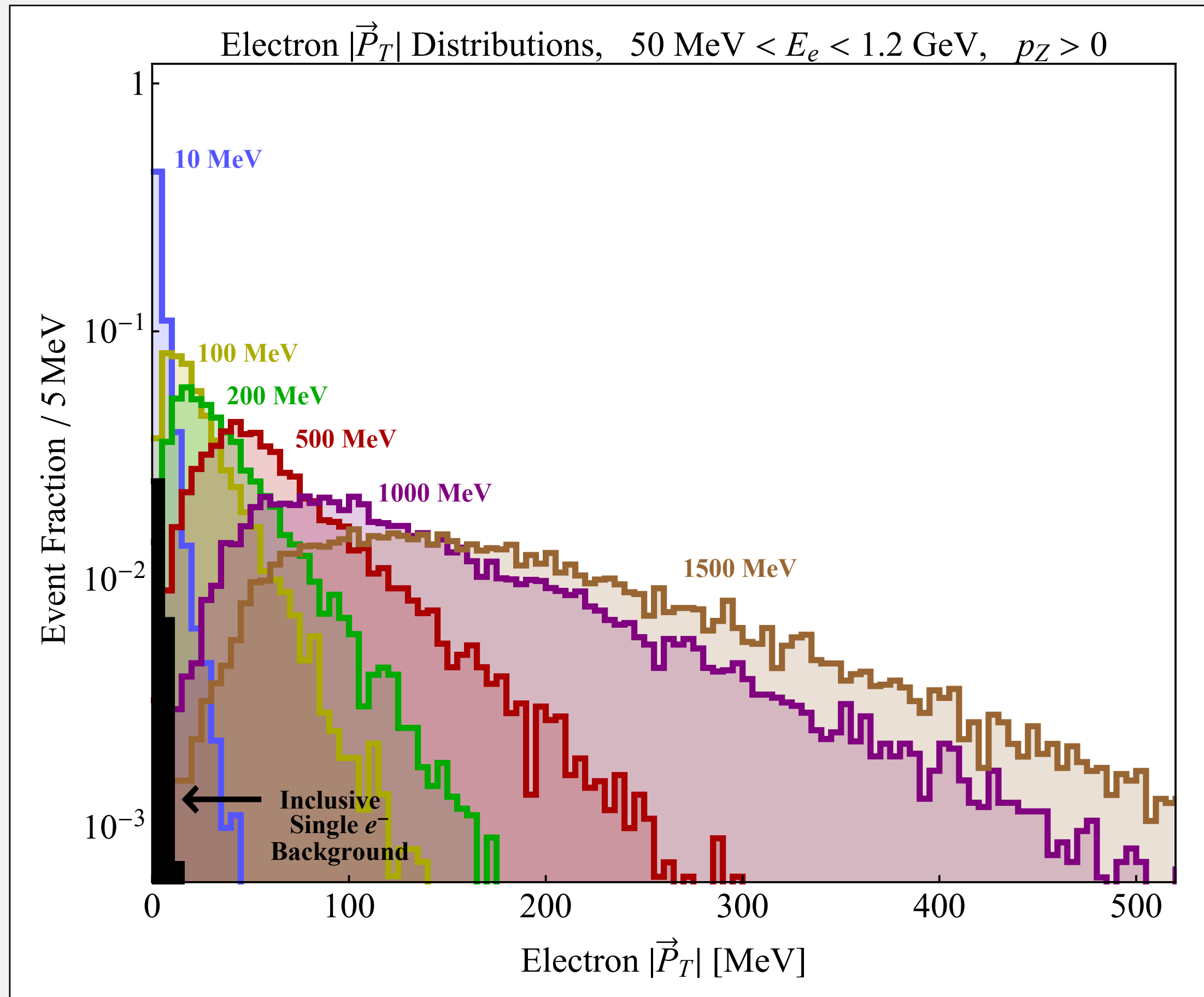


Mediator carries most of the energy
—> soft recoil electron, large missing energy



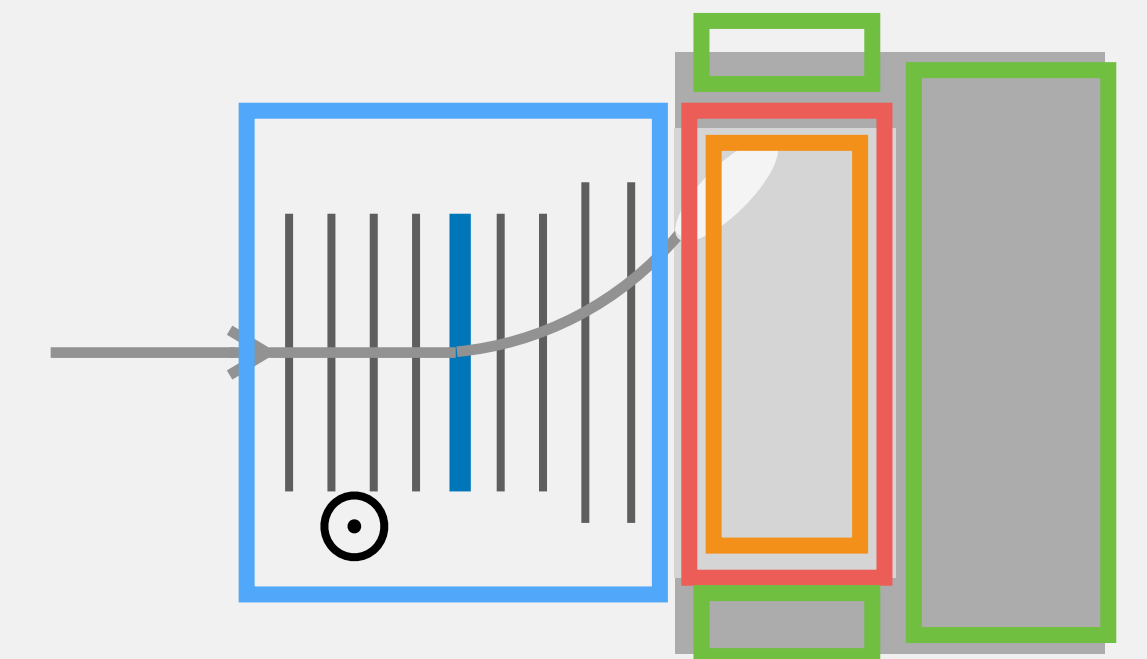
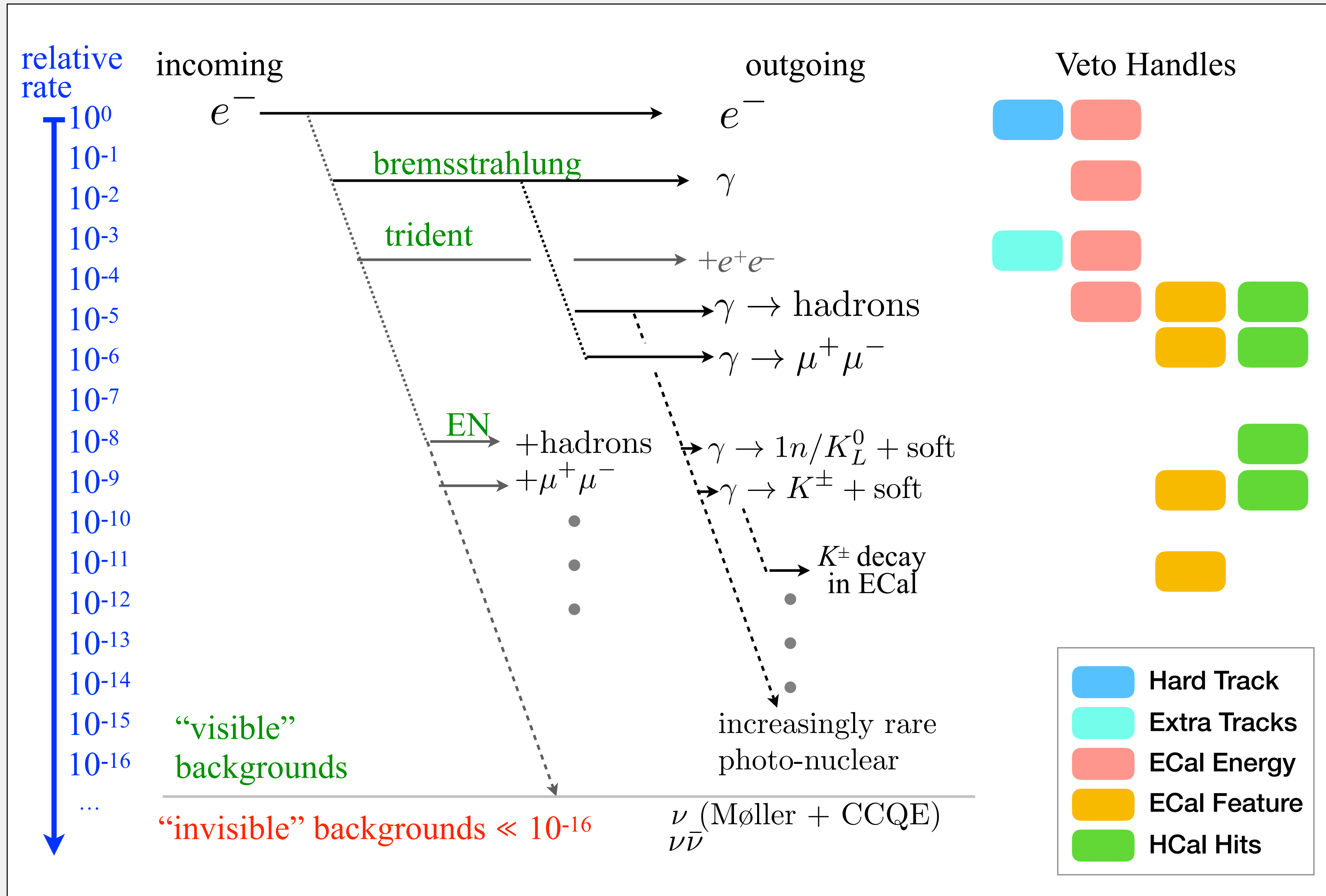
Strengths of LDMX

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



Assuming 10^{16} EoT

Backgrounds

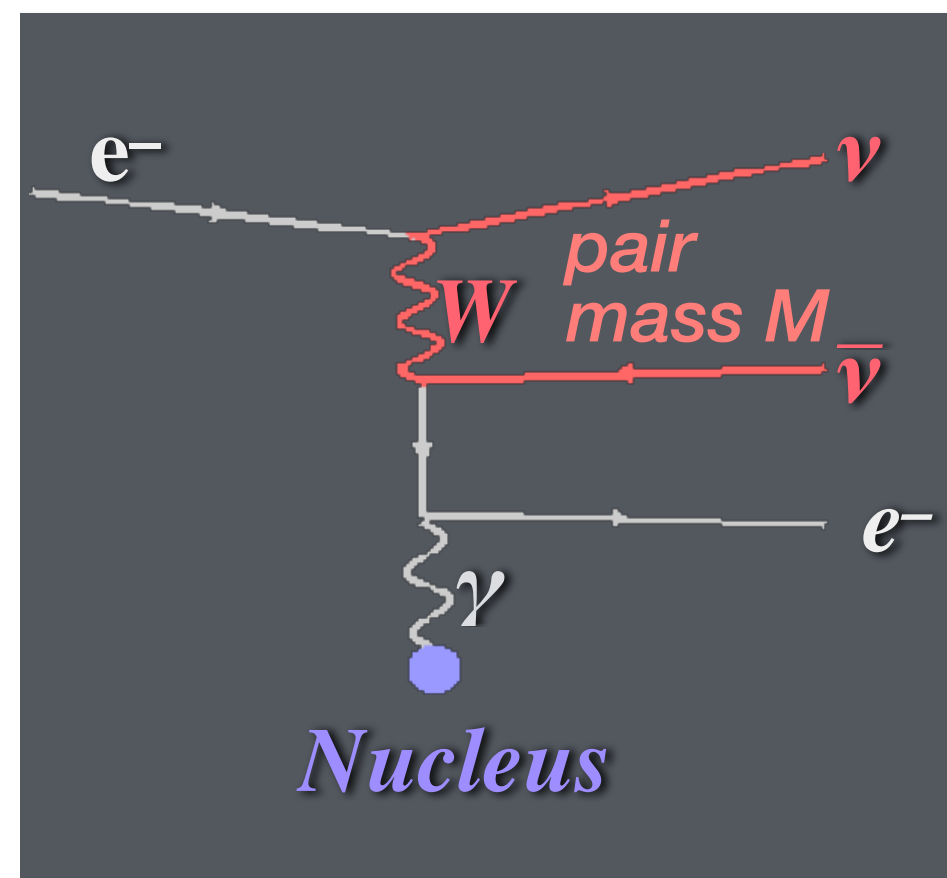


essentially only
instrumental backgrounds

Neutrino Backgrounds

Prompt Neutrino Reactions

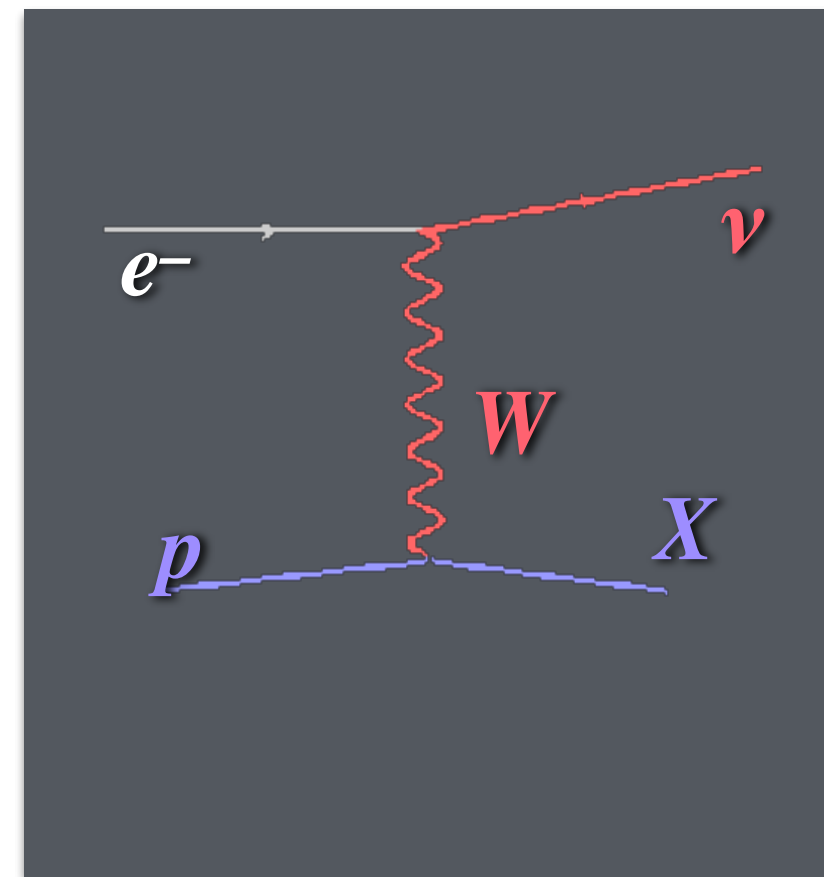
Neutrino Tridents



$$N_{\nu}/N_e \sim 10^{-19} (E/4\text{GeV})$$

irreducible

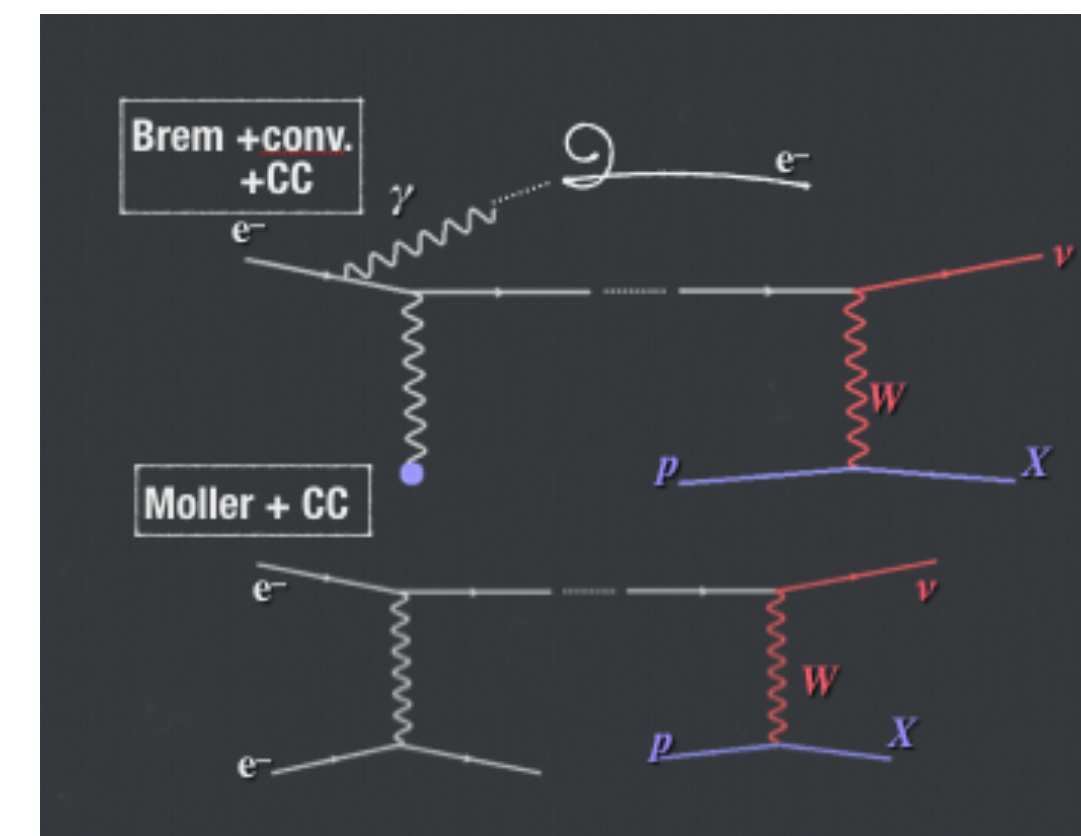
Charged Current



$$N_{\nu}/N_e \sim 10^{-14} (E/4\text{GeV})$$

no recoil electron
(bkg missing energy
search, not for us)

CCQE+...



$$N_{\nu+\text{Brem}+\text{conv.}}/N_e \sim 10^{-16} (E/4\text{GeV}) \times (T_{\text{target}}/0.1 X_0)^3$$

a bit reducible
curler track veto, cut out
Moller kinematics

slide by Natalia Toro

Detector Design

design paper on arxiv
[arxiv:1808.05219](https://arxiv.org/abs/1808.05219)

extremely rare signal

—> need large statistics

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

↓
beam requirements:

- low current, high duty-cycle

primary, multi-GeV e-beam

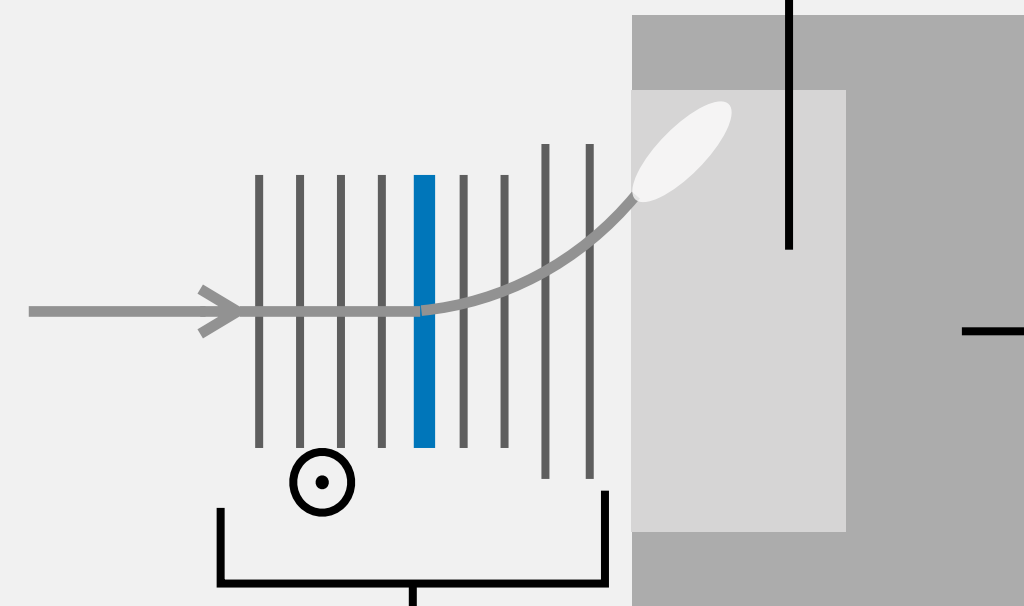
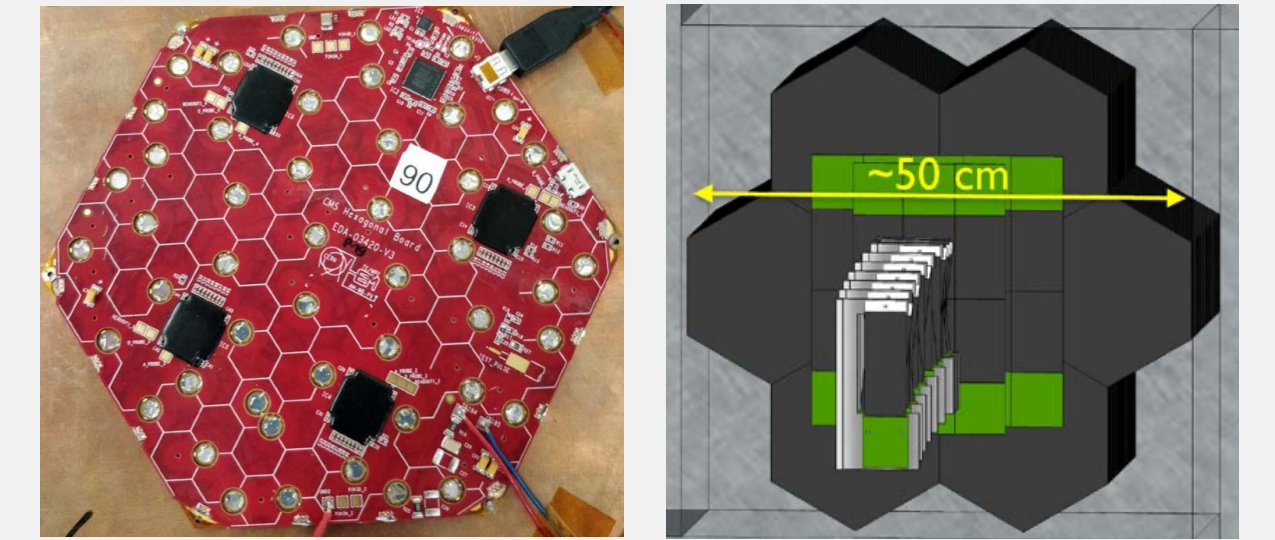
↓
detector requirements:

- high-rate capabilities
- radiation hard
- high-granularity

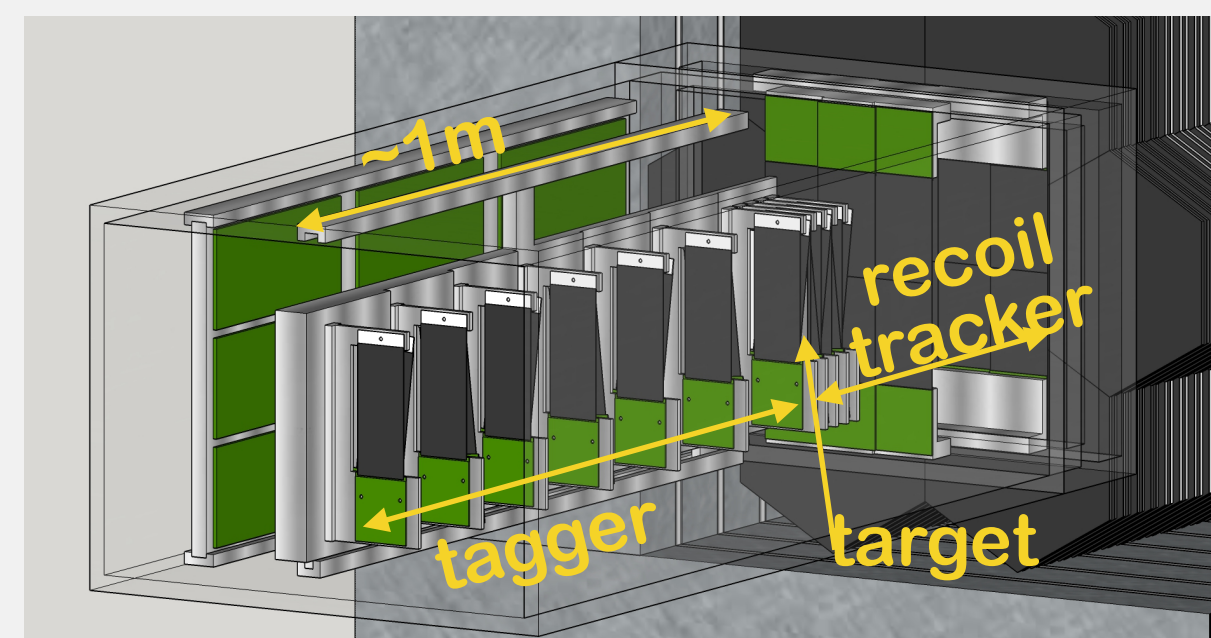
leverage techniques from
existing/planned experiments

ECal: draw on design of CMS SiW HGCal

- 32 layers with 7 modules each, $40 X_0$
- fast, radiation hard, dense
- high granularity (MIP 'tracking')

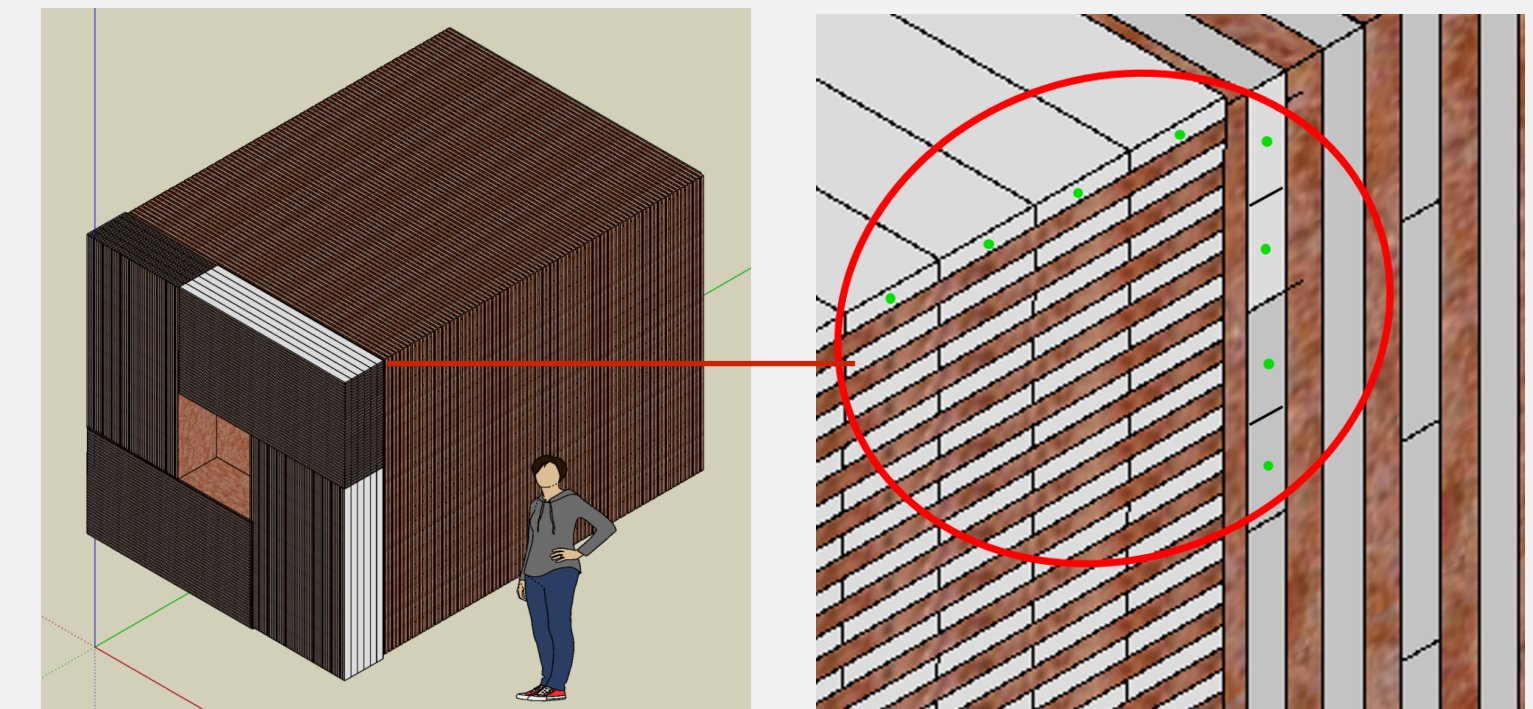


simplified copy of Silicon
Vertex **Tracker** of *HPS@JLab*
(visible Dark Photon search)

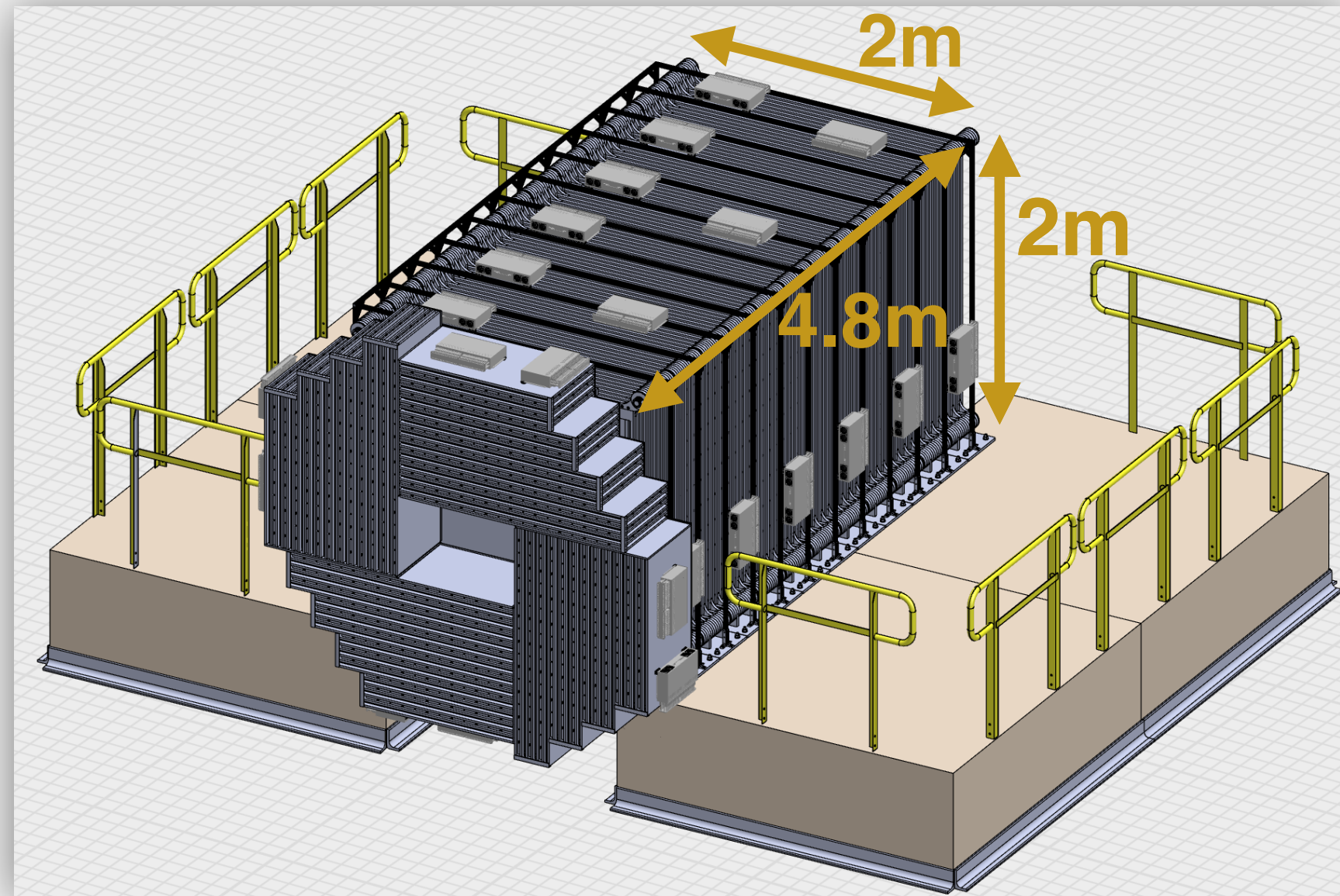


HCal inspired by *Minos/Mu2e*

- plastic scintillator with steel absorber
- readout via WLS fibres
- **optimise for neutral hadron rejection**

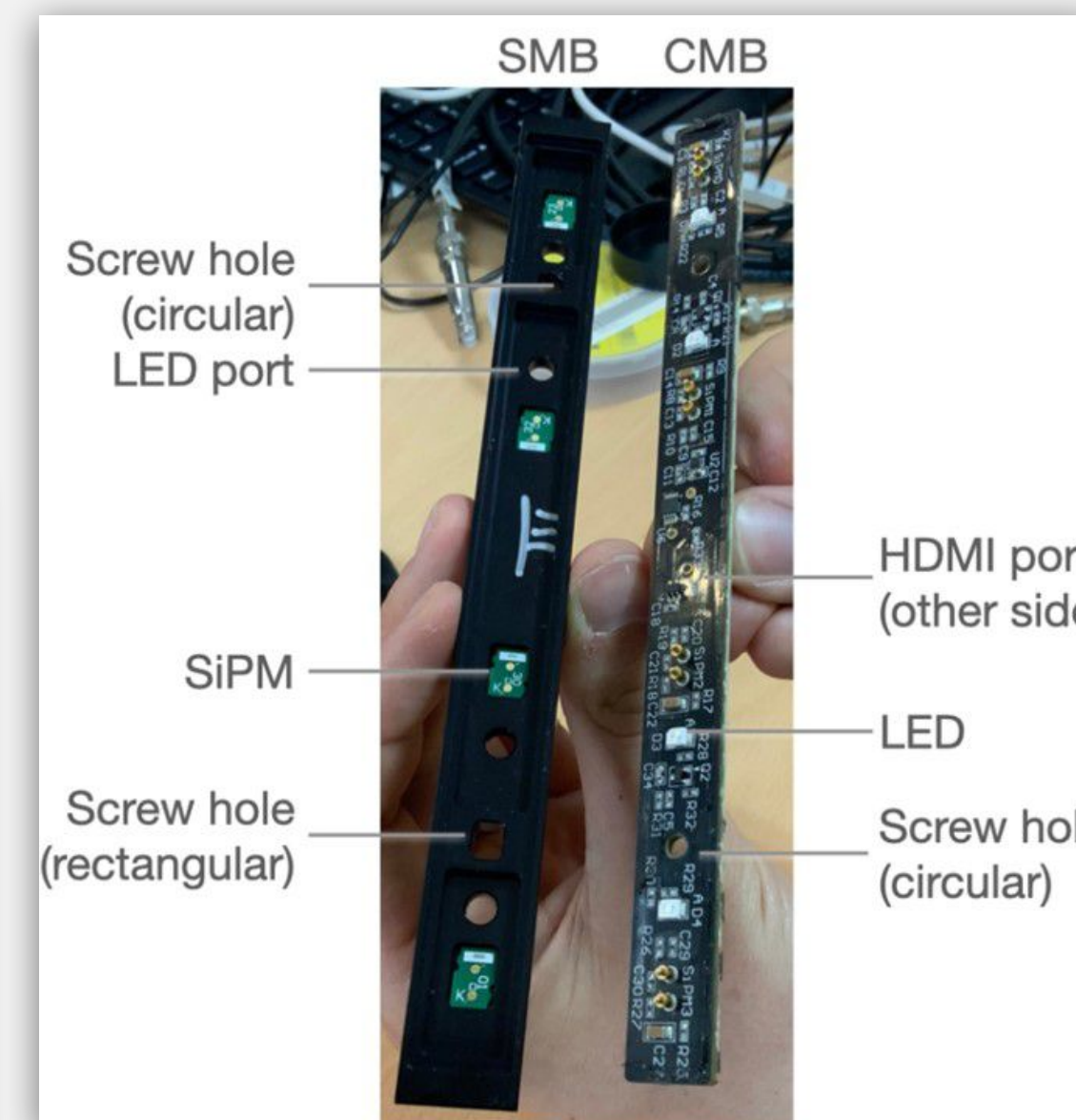
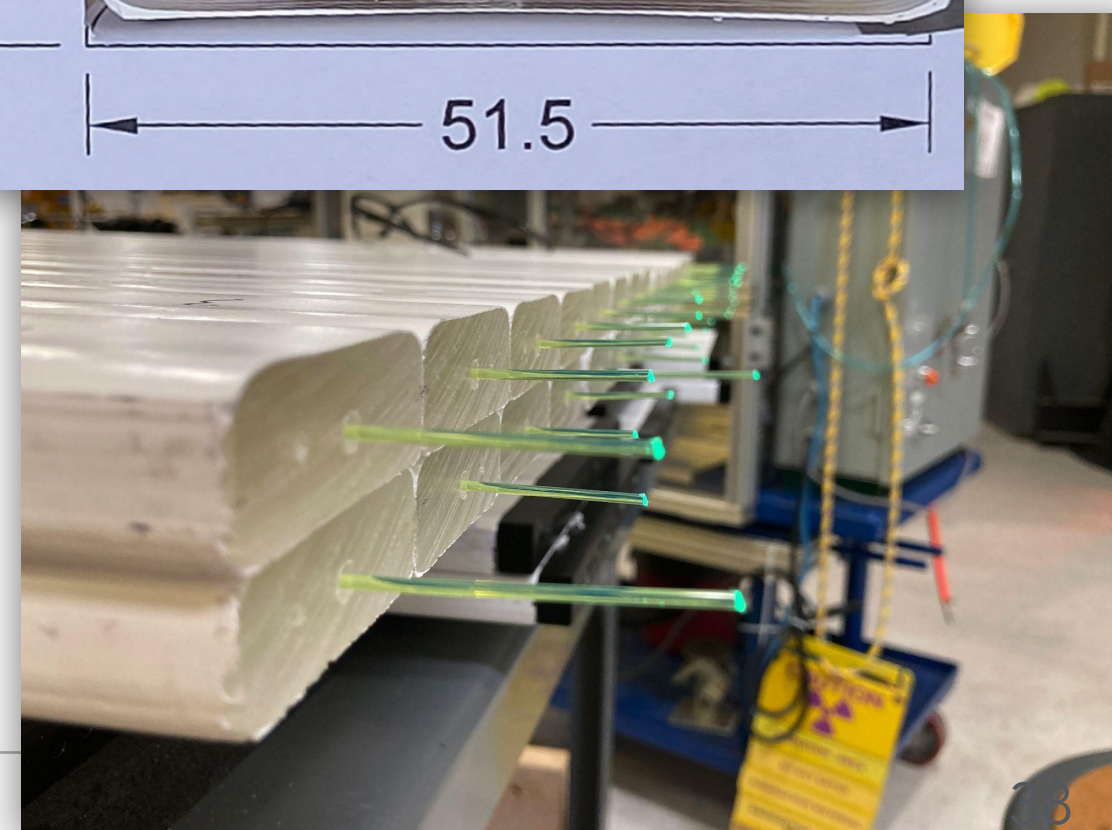
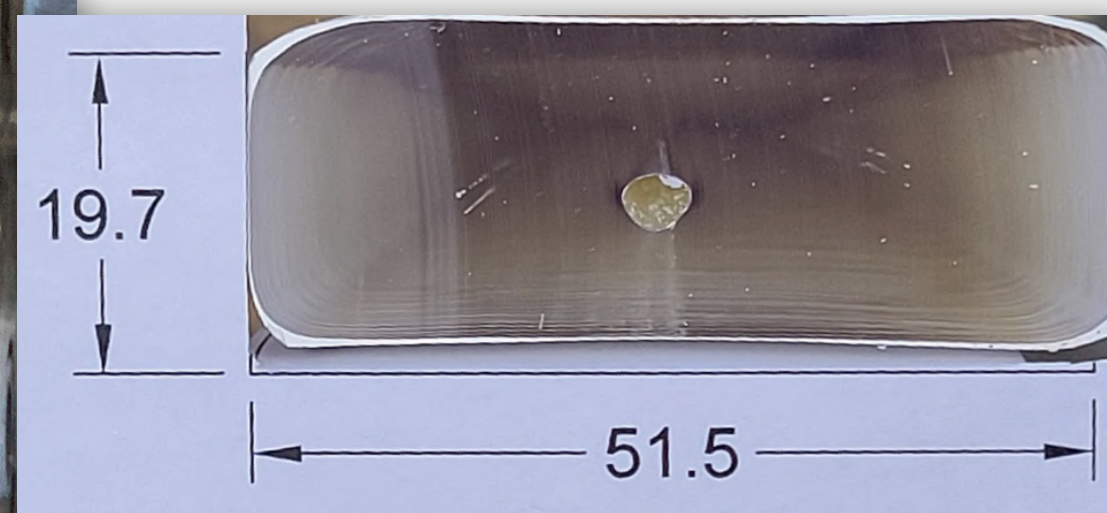
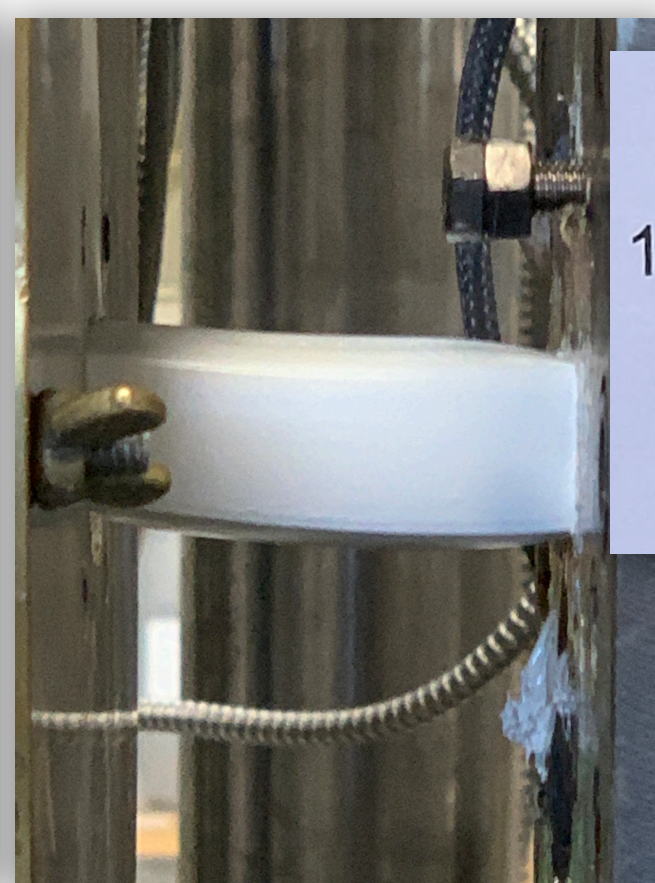
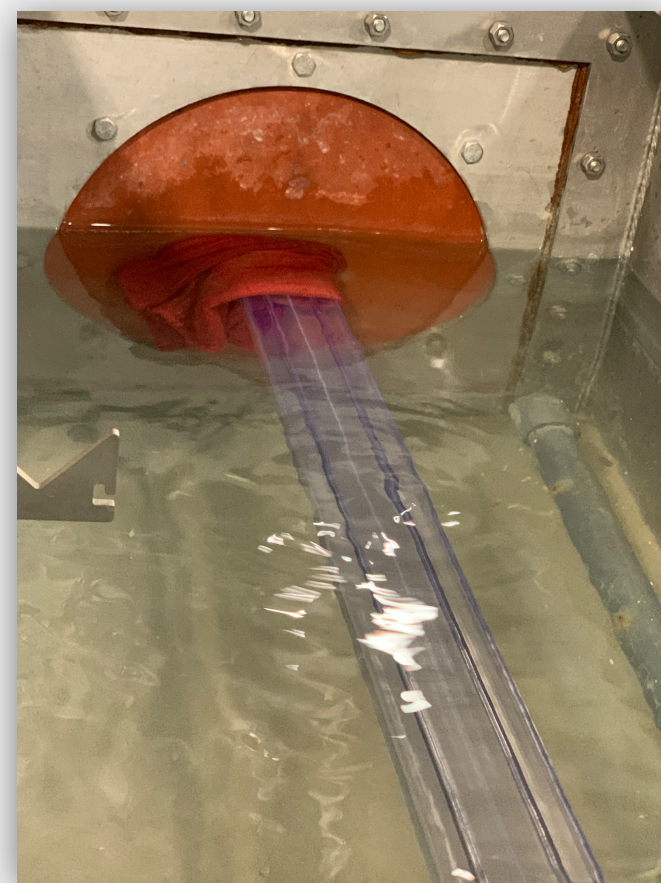


Hadronic Calorimeter (probably skip)



- Highly efficient **veto** of neutral hadrons (n , K^0_L)
- Steel absorber (back: 25mm, side: 20mm)
 - Single-neutron inefficiency of 10^{-6} (17λ)
- Plastic scintillator (2m x 5cm x 2cm)
- Read out via SiPMs
- Readout electronics developed & tested at LU

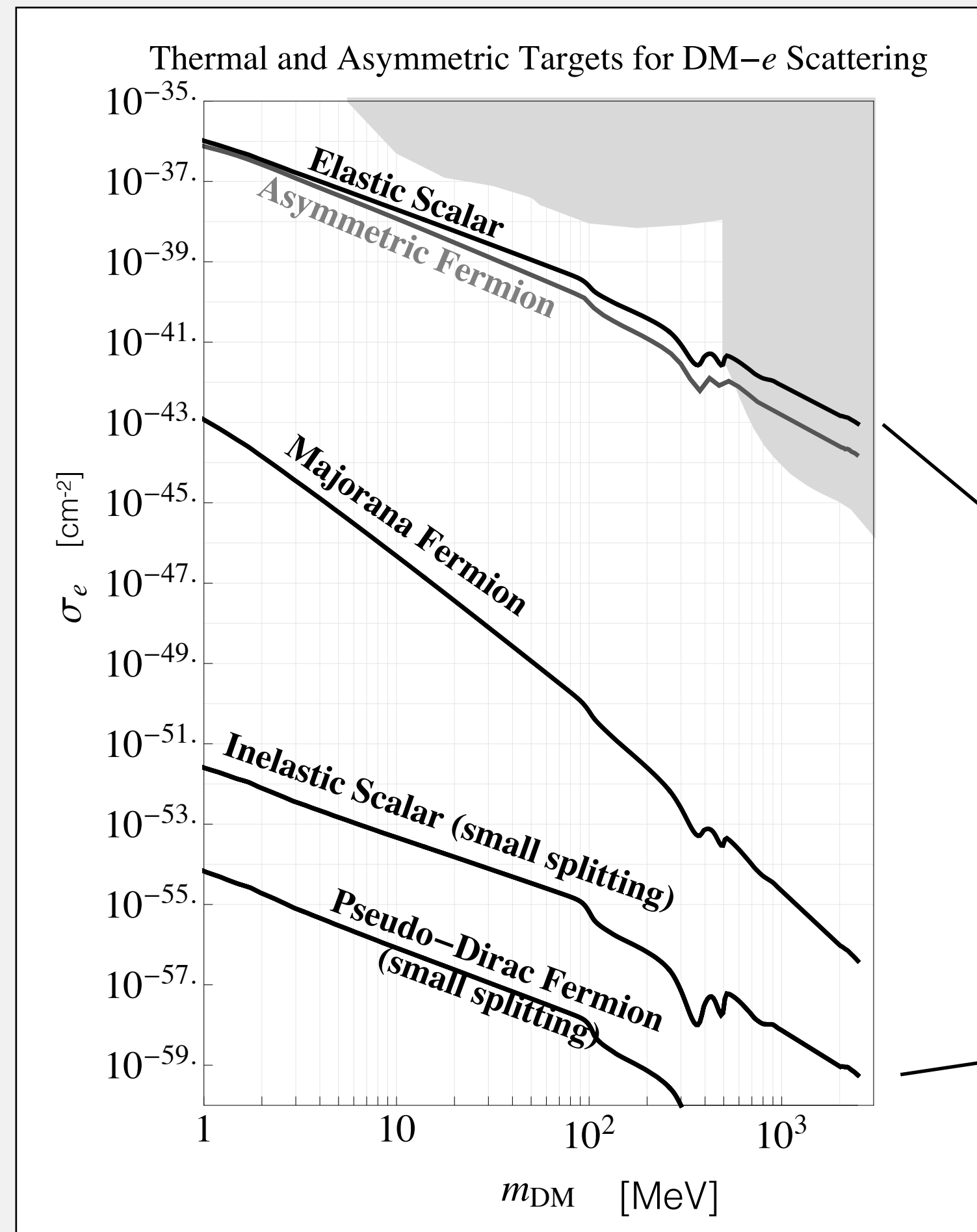
—> Verena Hehl's talk



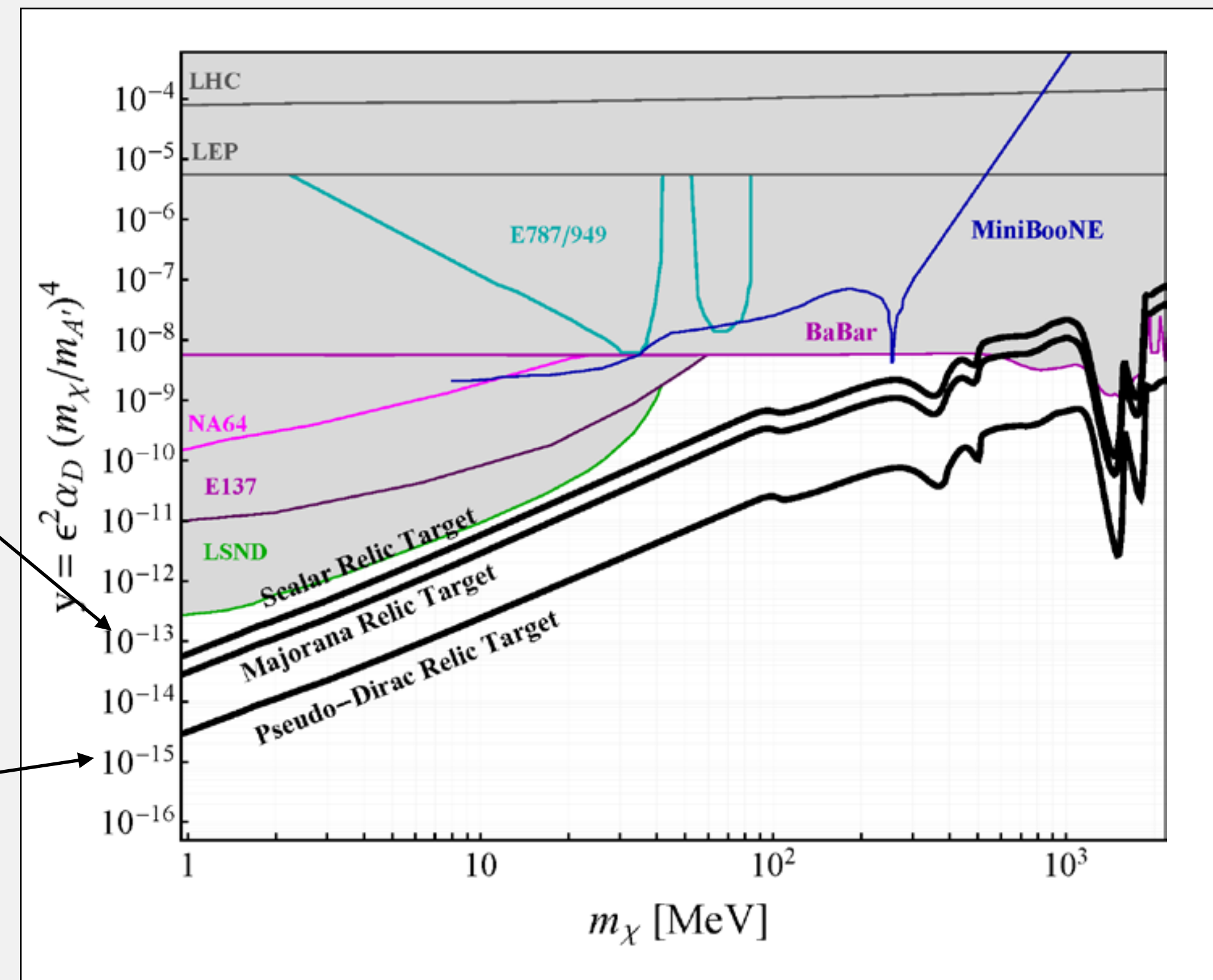
Combine into 'quadbars'

Why not only direct detection?

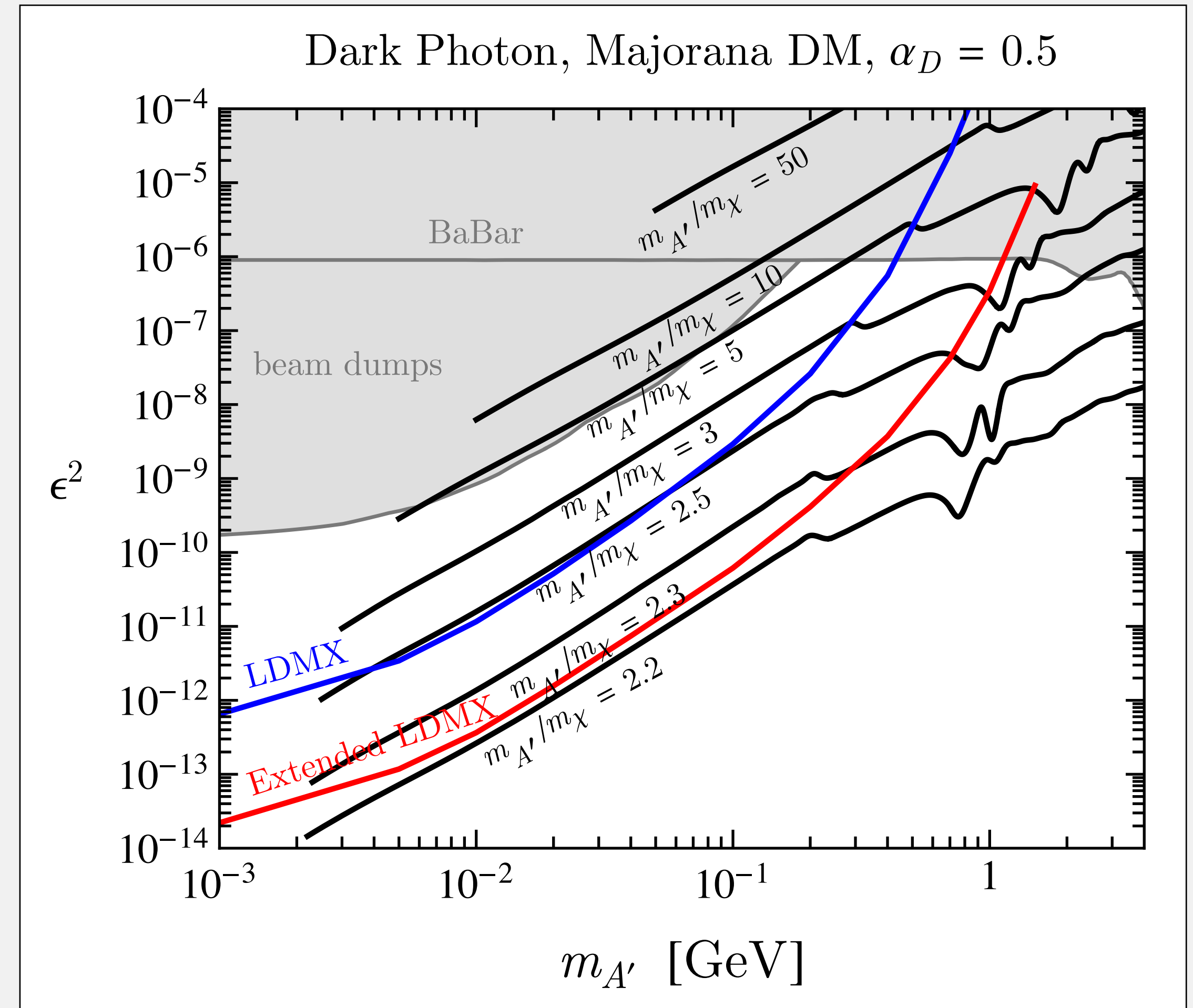
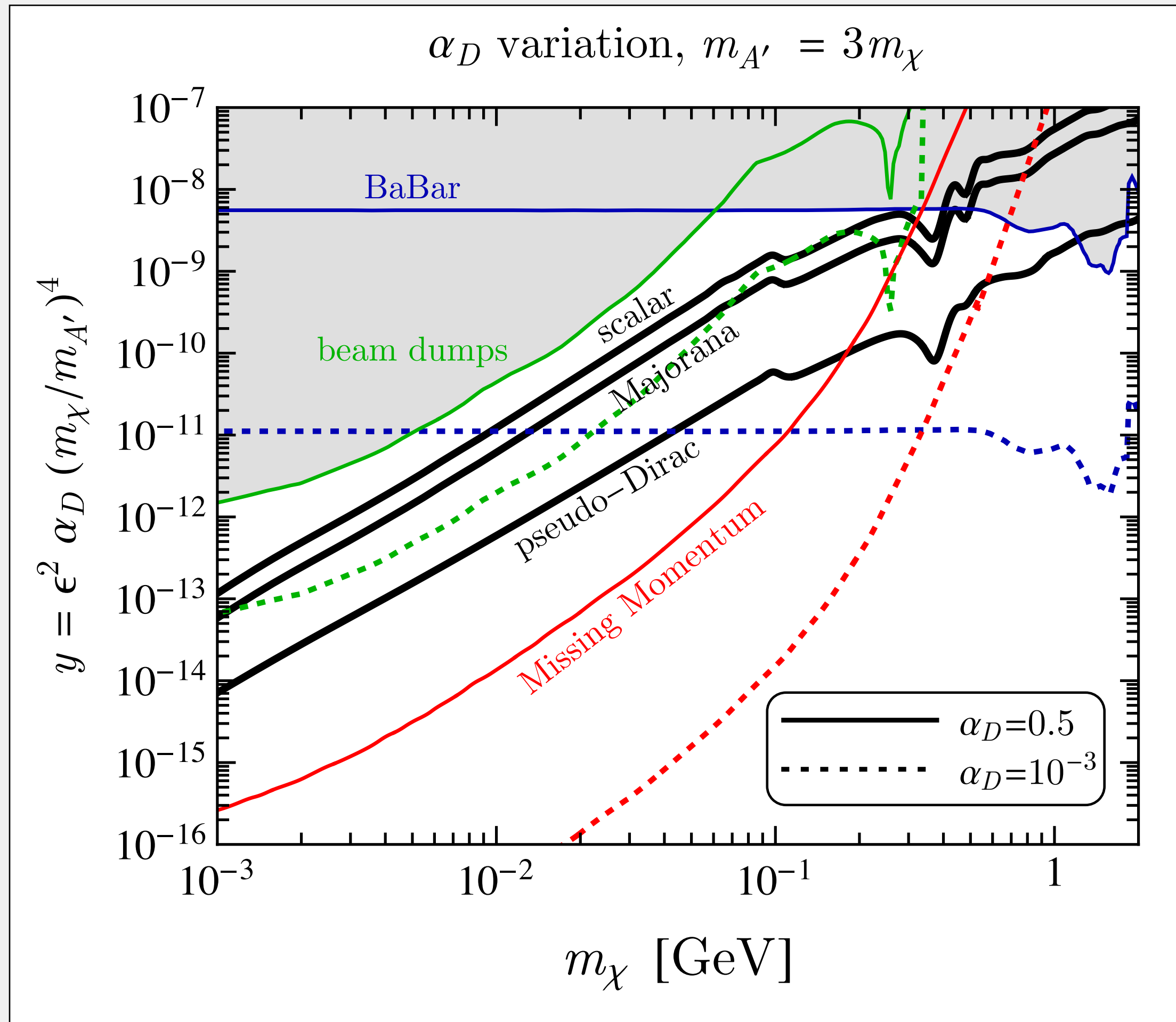
direct detection:
strong spin/velocity dependency



at accelerators: relativistic production
—> spin/velocity dependency reduced
all thermal targets in reach!



Parameter Dependence



Various Future Projections

