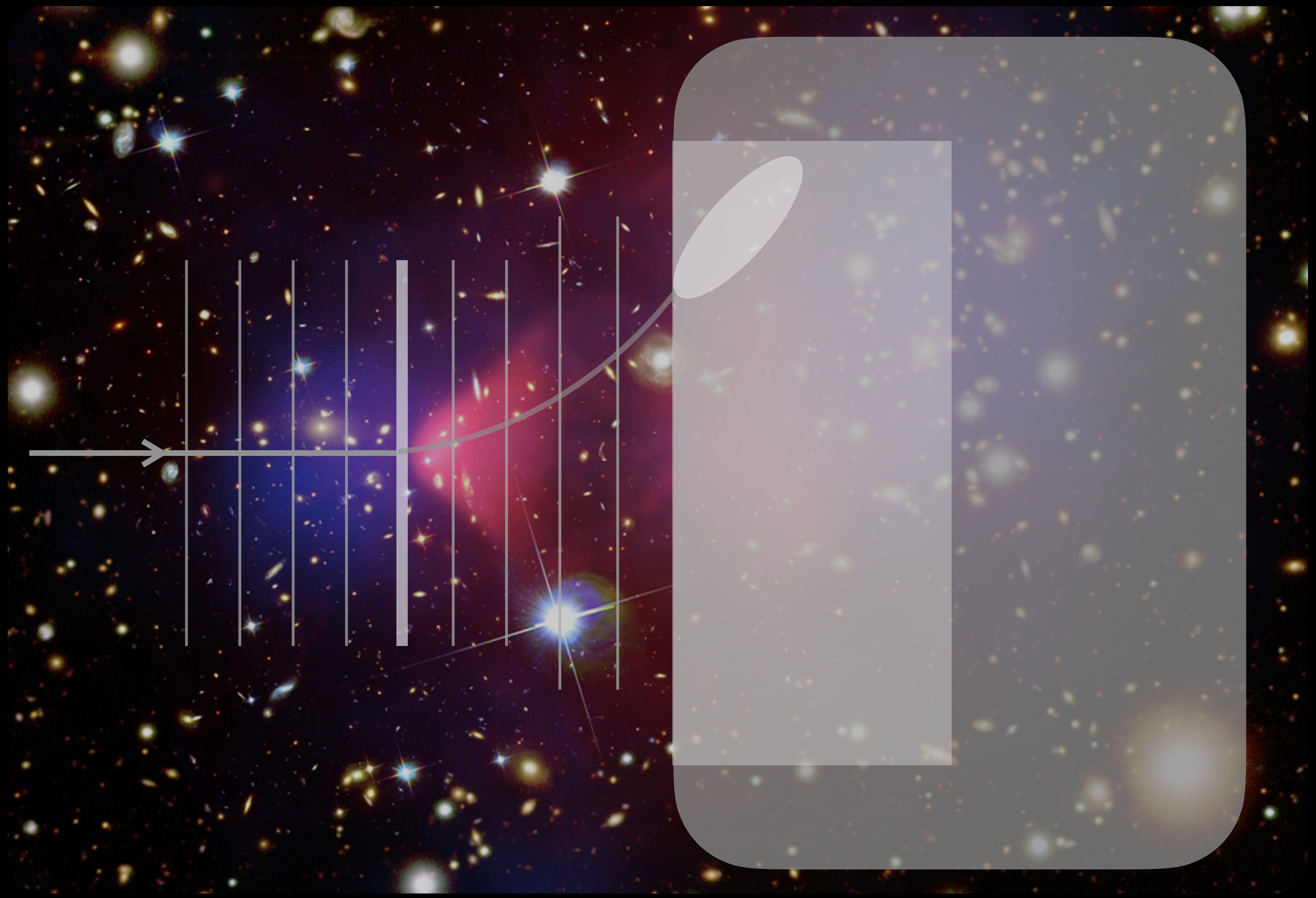
Light Dark Matter eXperiment — Status, Plans and Prospects



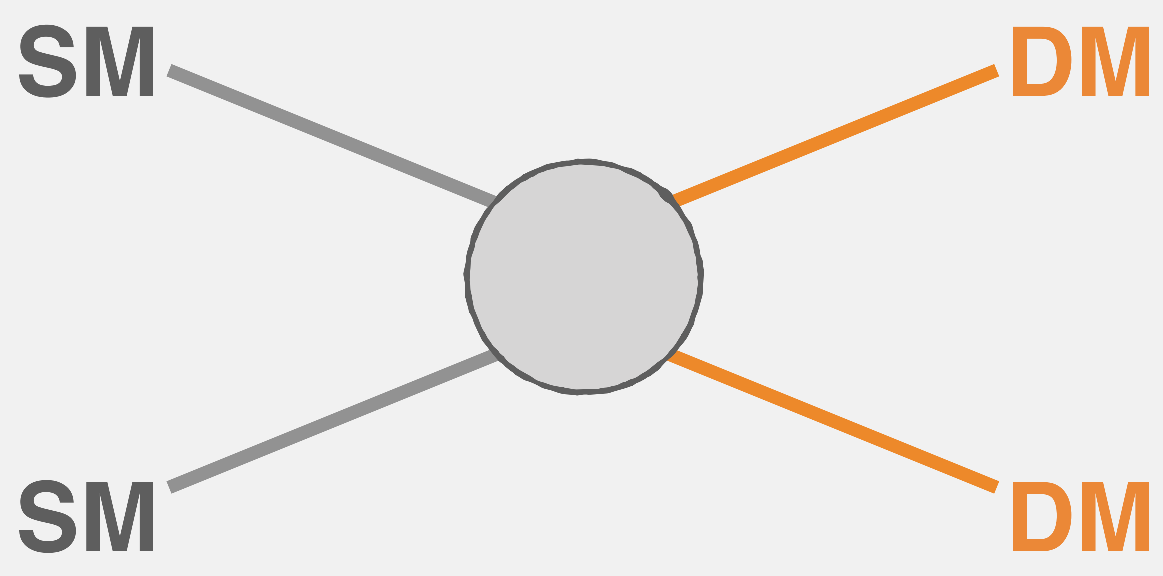
Partikeldagar

22/23 November 2021

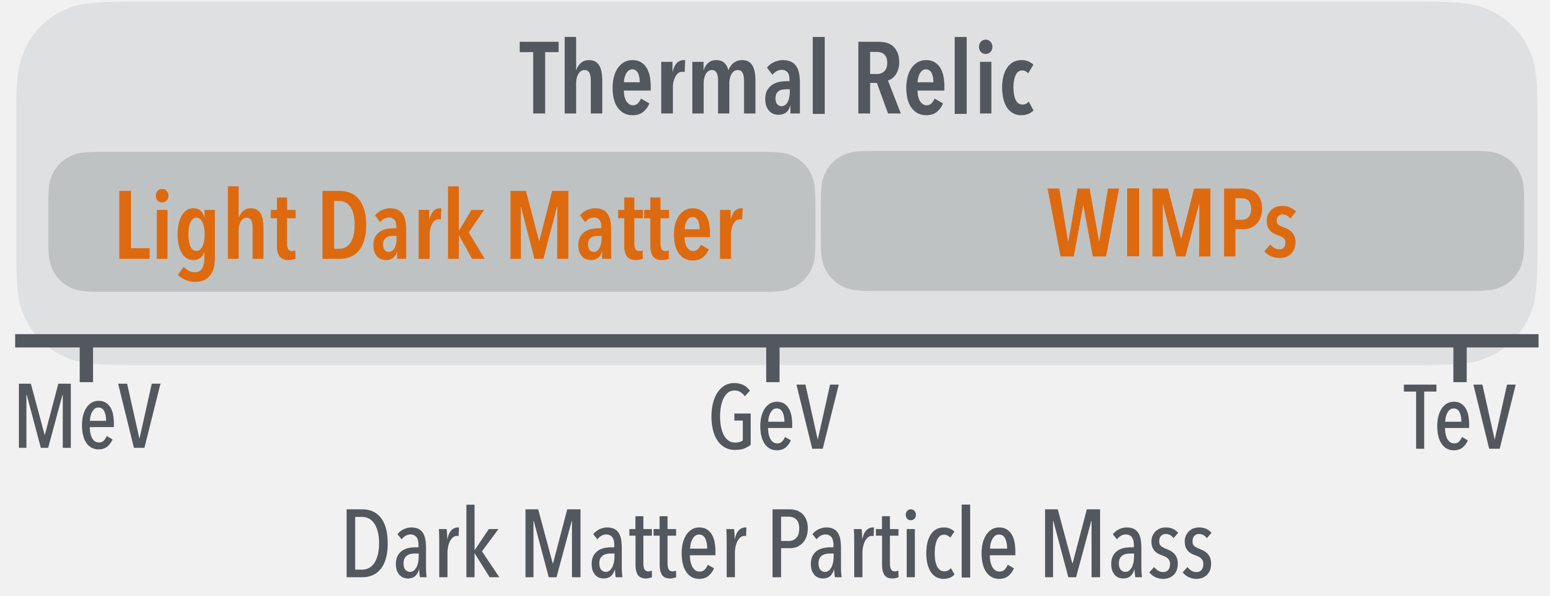
Ruth Pöttgen, Lund University

Light Dark Matter at Accelerators

thermal origin of Dark Matter



—> allowed mass range MeV - TeV



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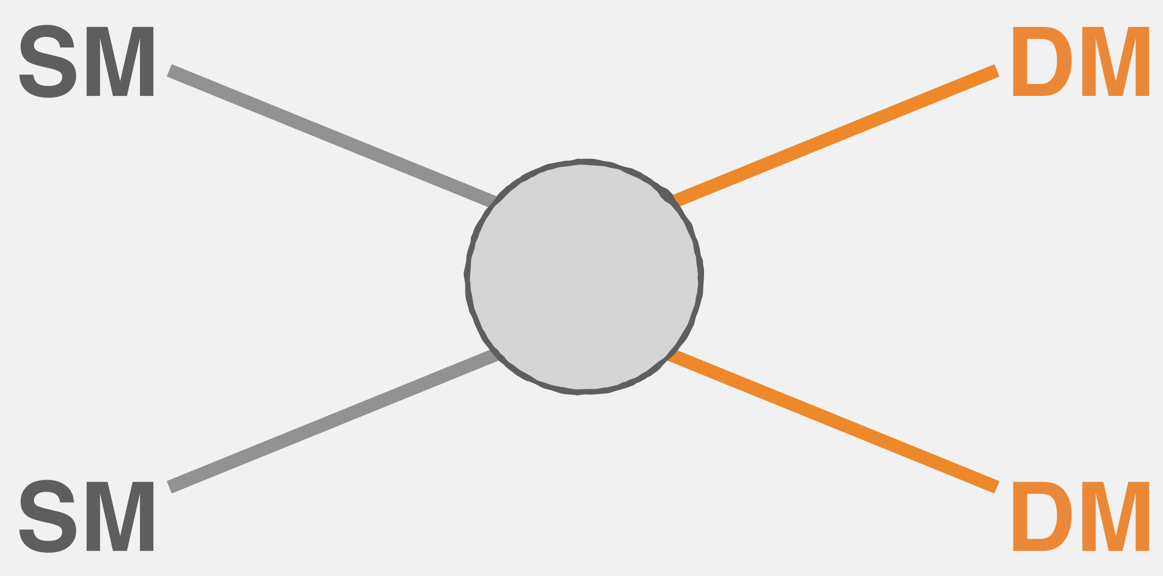

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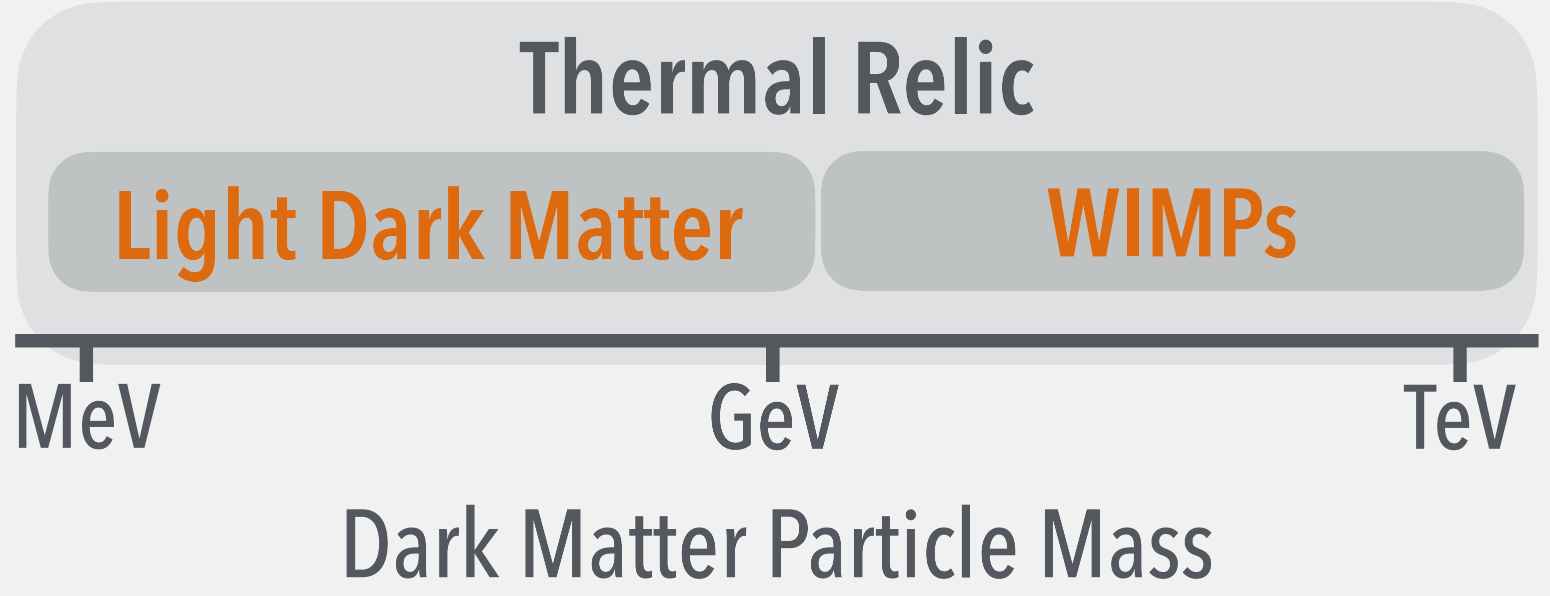
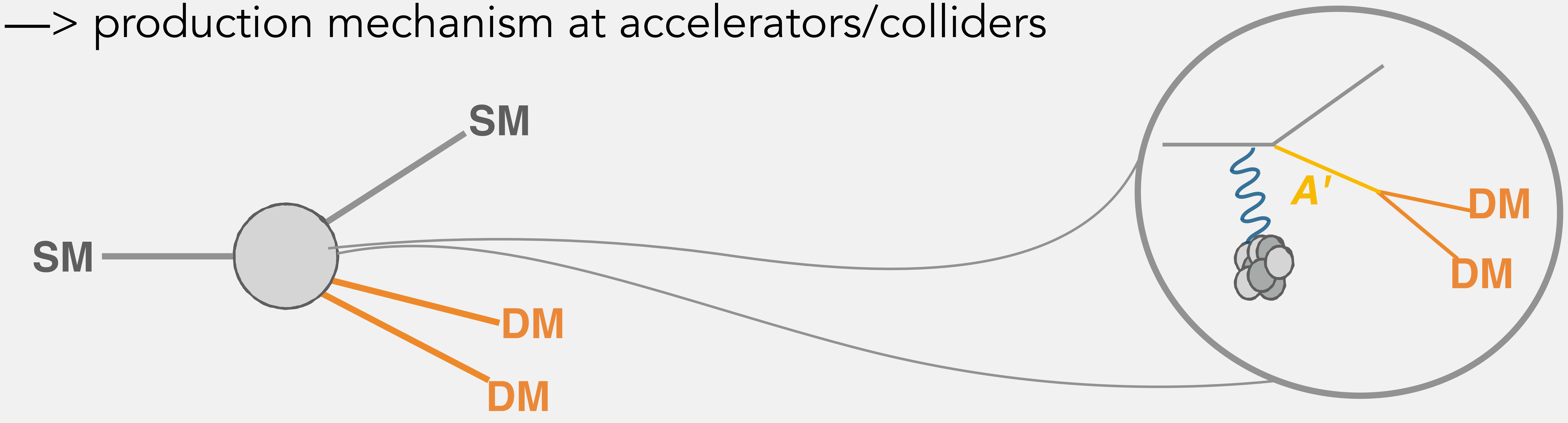


—> production mechanism at accelerators/colliders



Benchmark model:

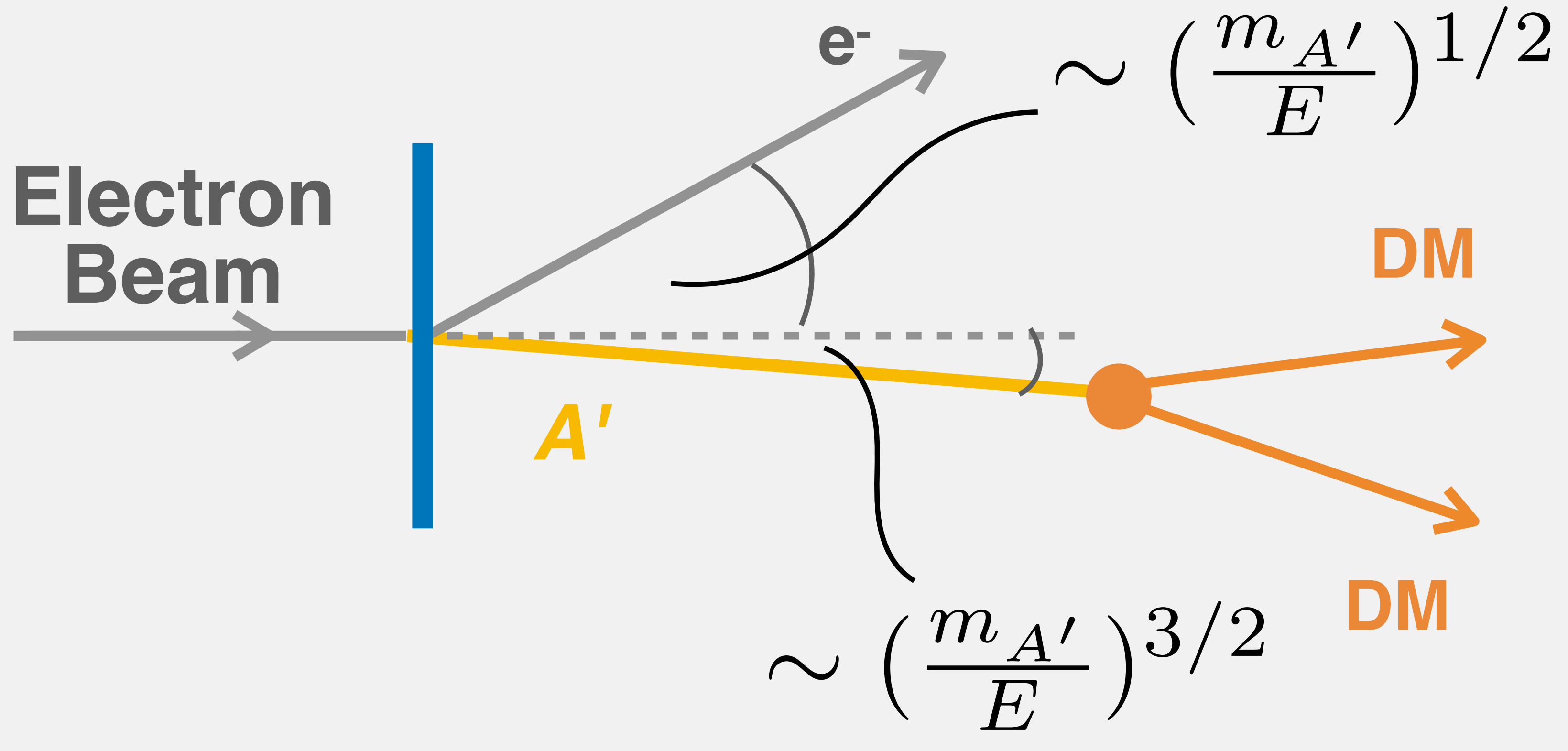
Dark photon (A′) as new light mediator

$m_{A'} > 2m_\chi$

Production e.g. via dark bremsstrahlung

Kinematics

Very different from SM bremsstrahlung,
the main background

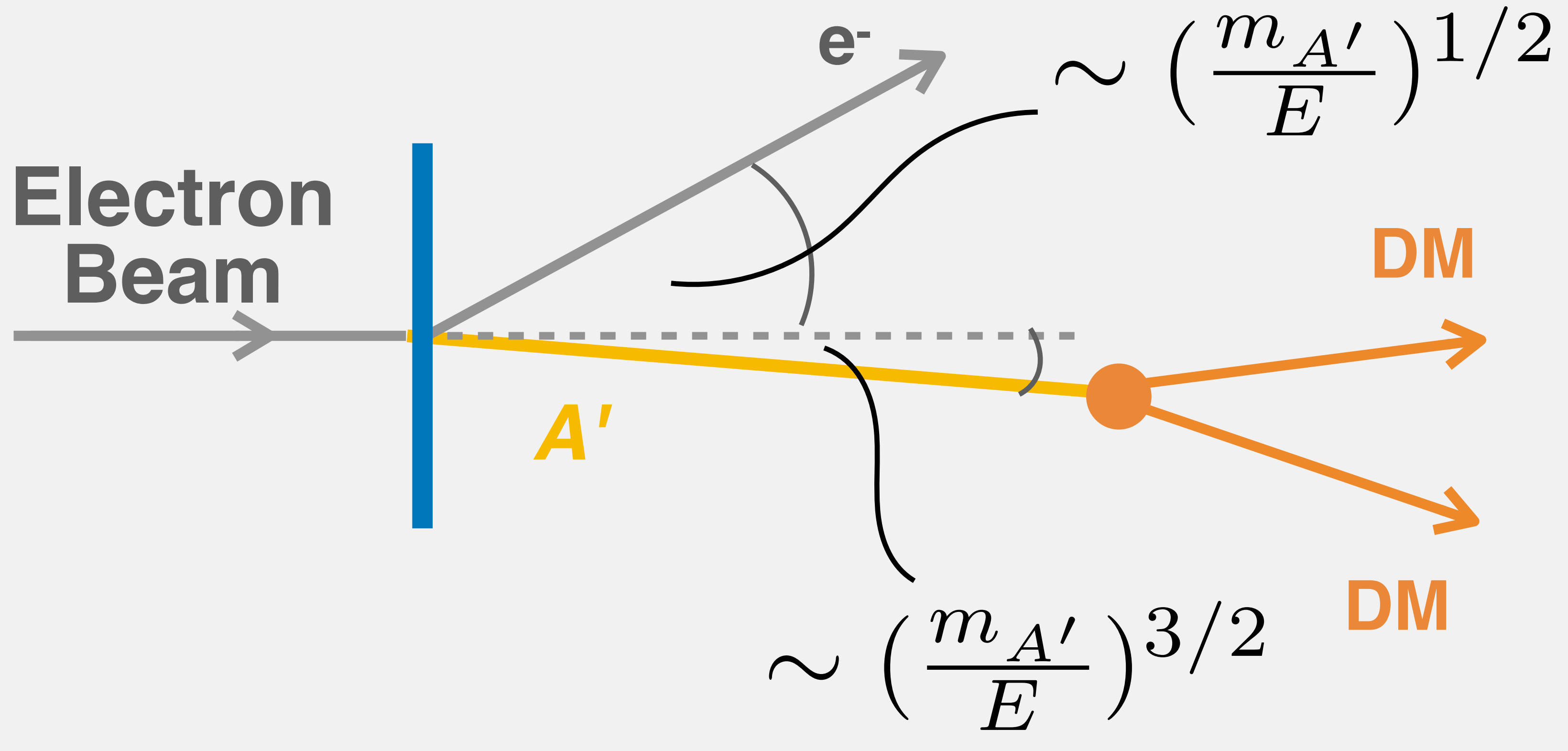


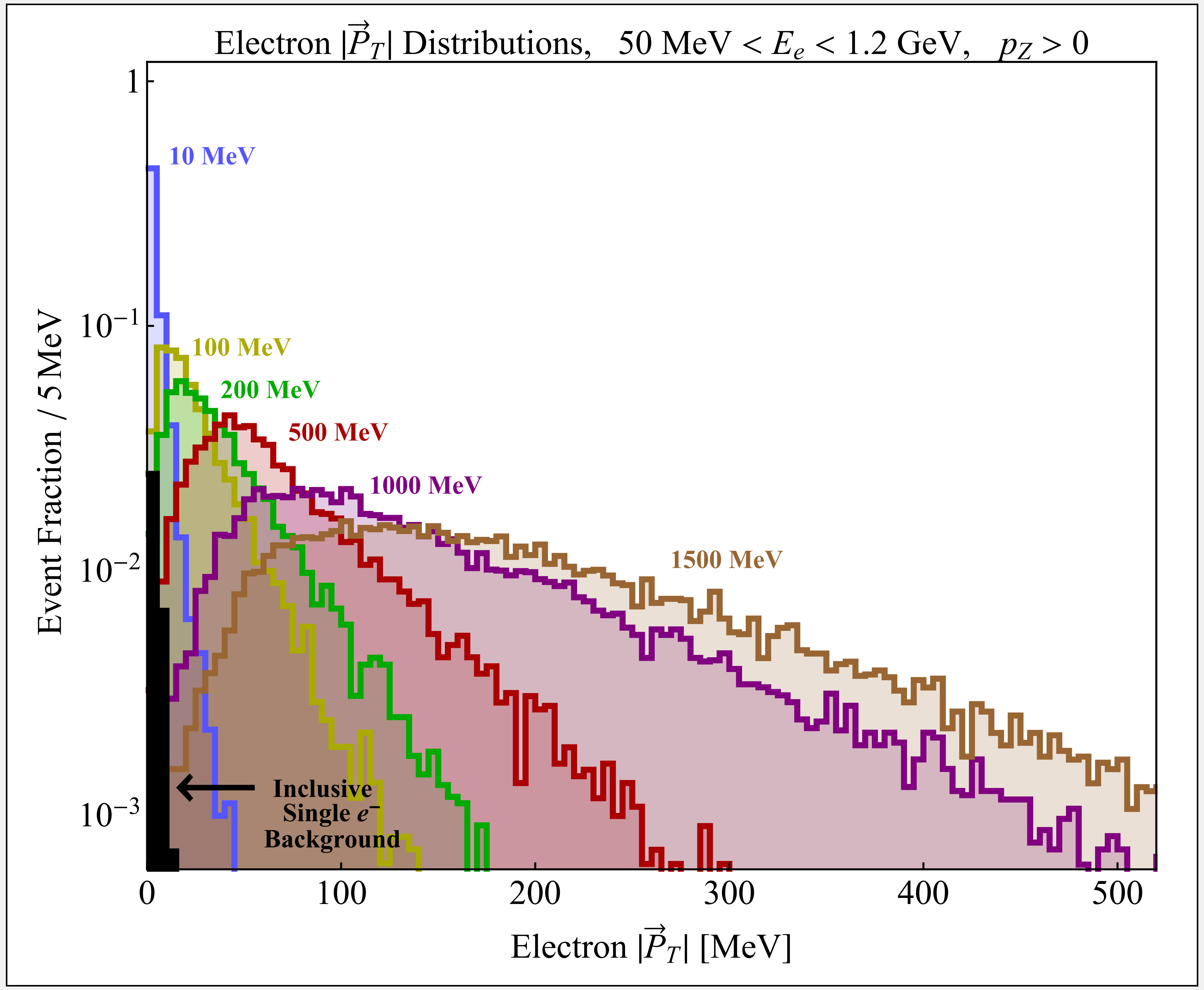
Mediator carries most of the energy
—> soft recoil electron, large missing energy

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

Kinematics

Very different from SM bremsstrahlung, the main background





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

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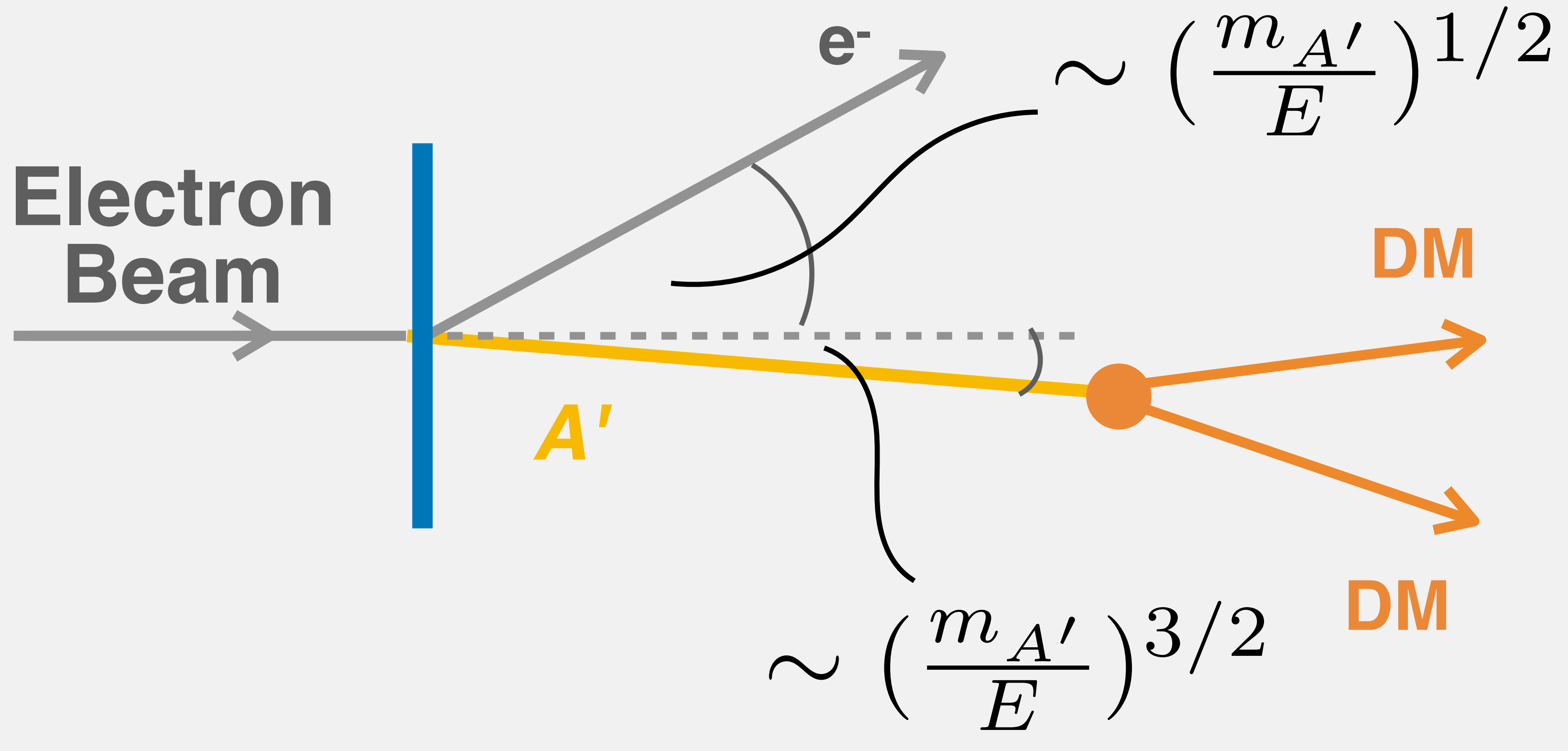
Very different from SM bremsstrahlung, the main background



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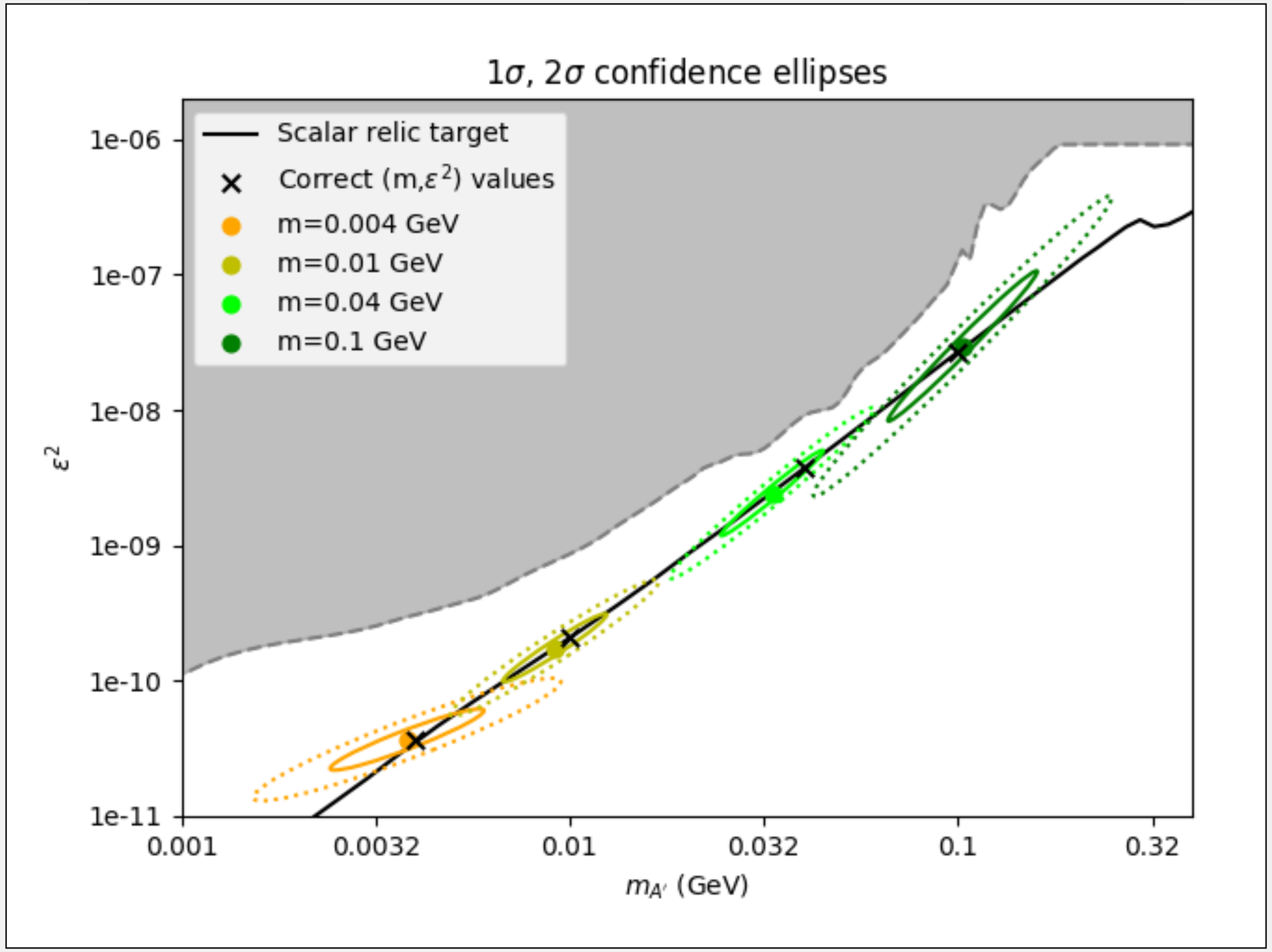
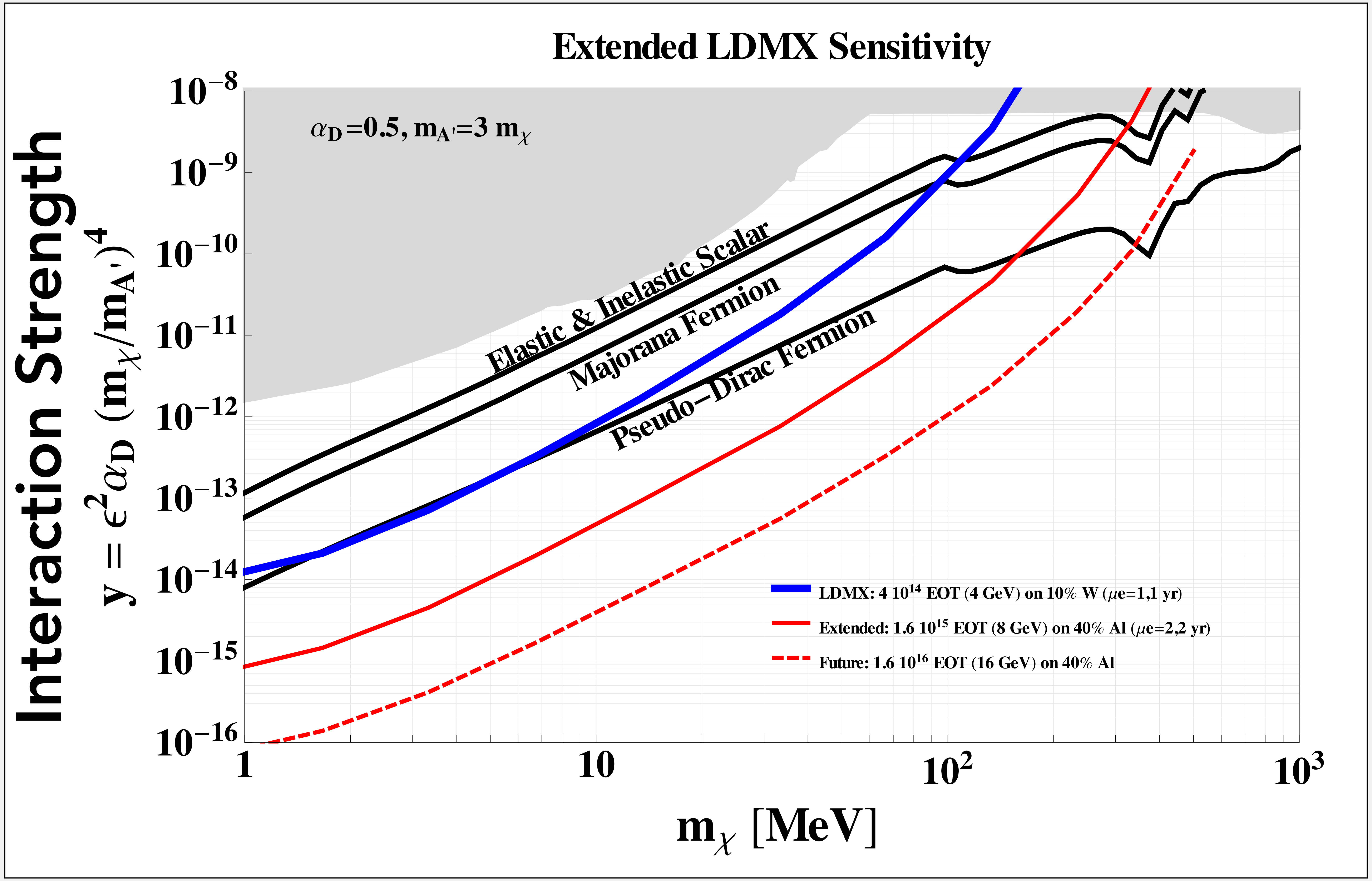


measurement of p_T: strong discriminator AND information about (missing) mass!

Projected Sensitivity



LDMX can explore a lot of new parameter space

Sensitive to several thermal targets already with **pilot run**

Higher energy/intensity allows exploration beyond thermal targets

Timescale: few years

Ultimately potential to probe all thermal targets up to O(100) MeV

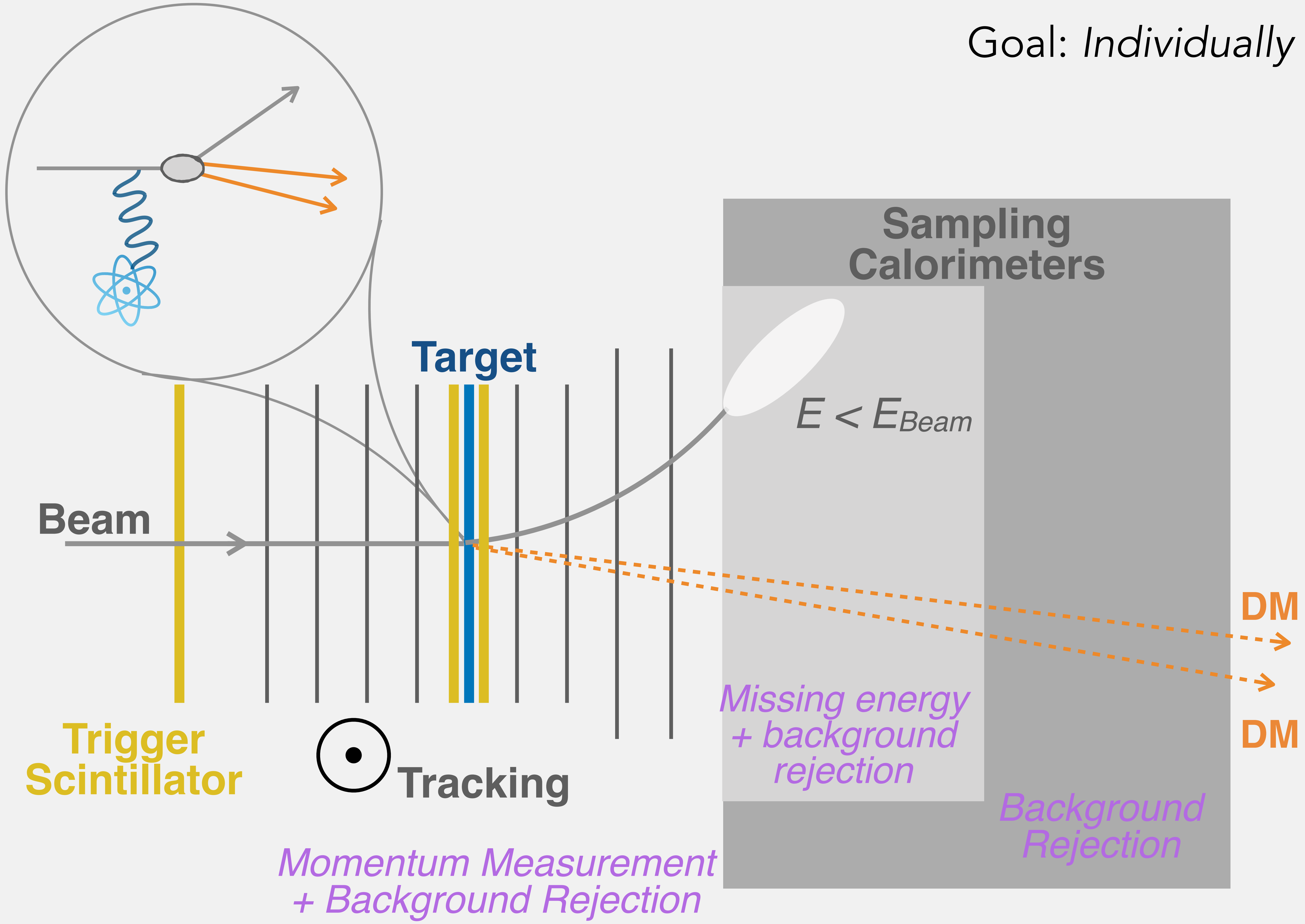
For details of background rejection see JHEP04(2020)003

LDMX — Layout

Light Dark Matter eXperiment

Signal signature: Missing energy & (missing) transverse momentum

Goal: *Individually* measure up to 10^{16} electrons on target (EoT)



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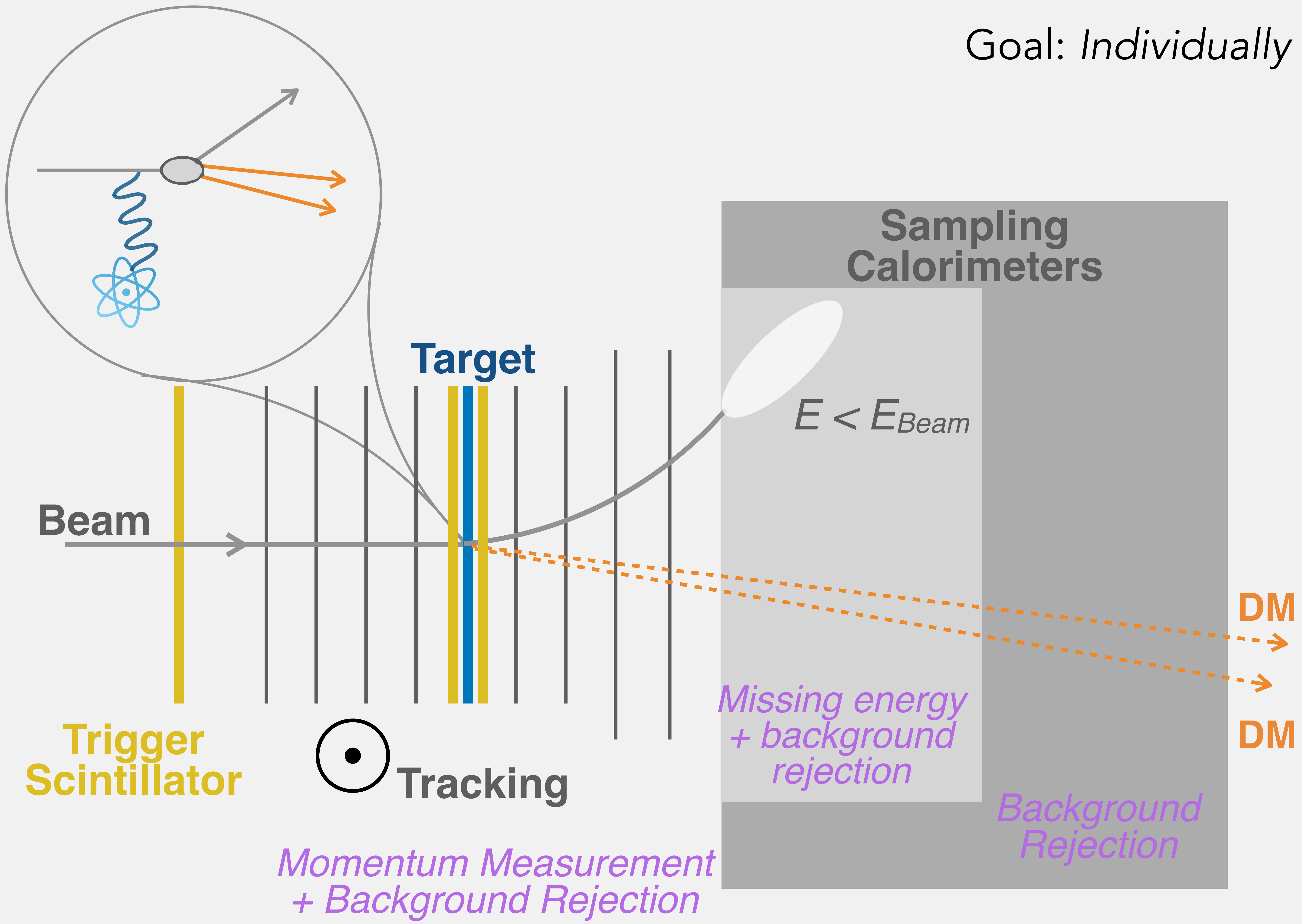

Requires special **beam properties**:

- **Energy** ideally 4 GeV < E_B < 20 GeV
- **High duty-cycle** to gather sufficient statistics despite
- **Low intensity** (≤10 e^- per bunch) to resolve individual e^-, helped by **large beam spot**

Choices:

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

CERN (potentially later stage)
new Linac injecting electrons into SPS

LDMX — Layout

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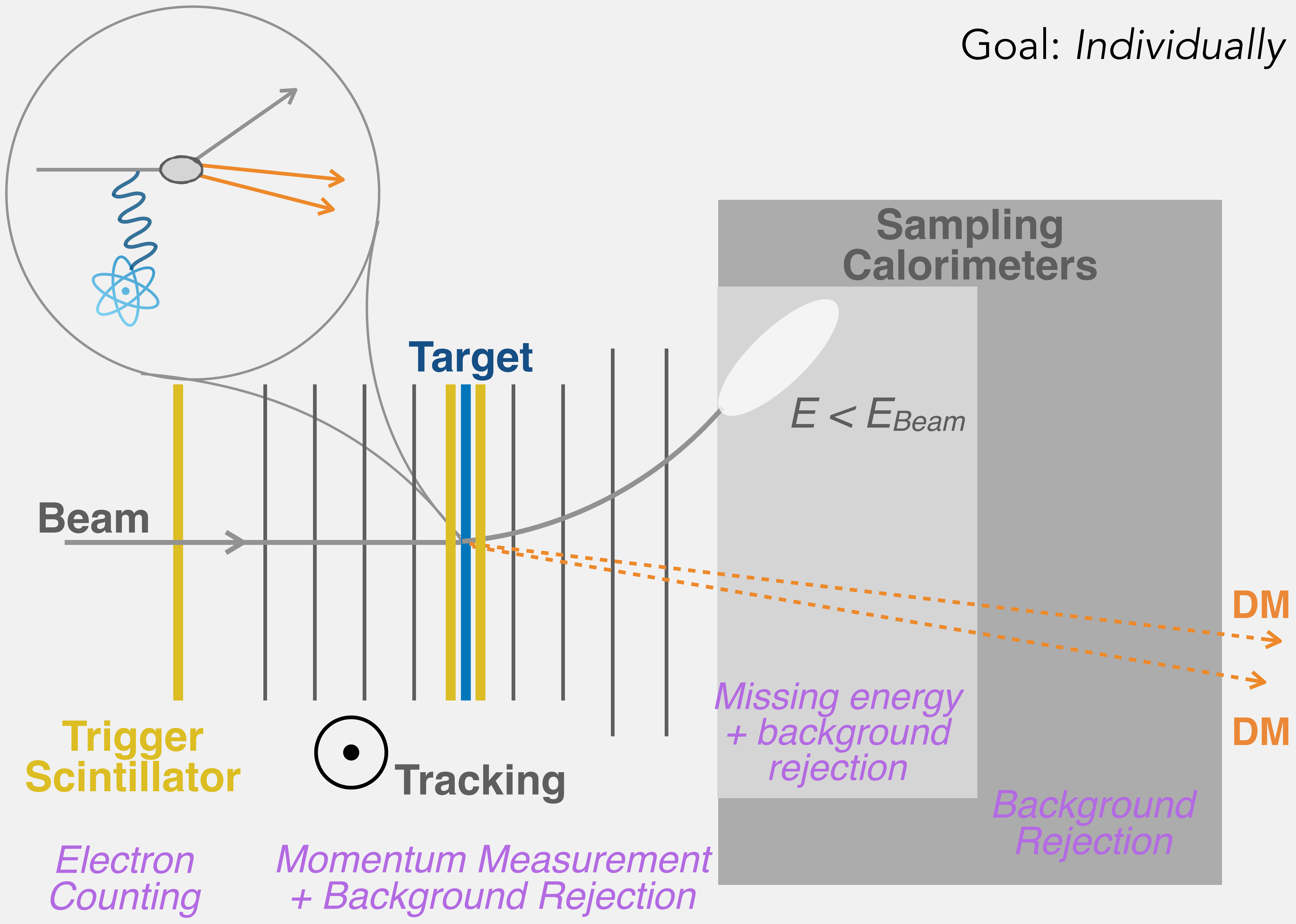

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  dedicated transfer line from LCLS-II
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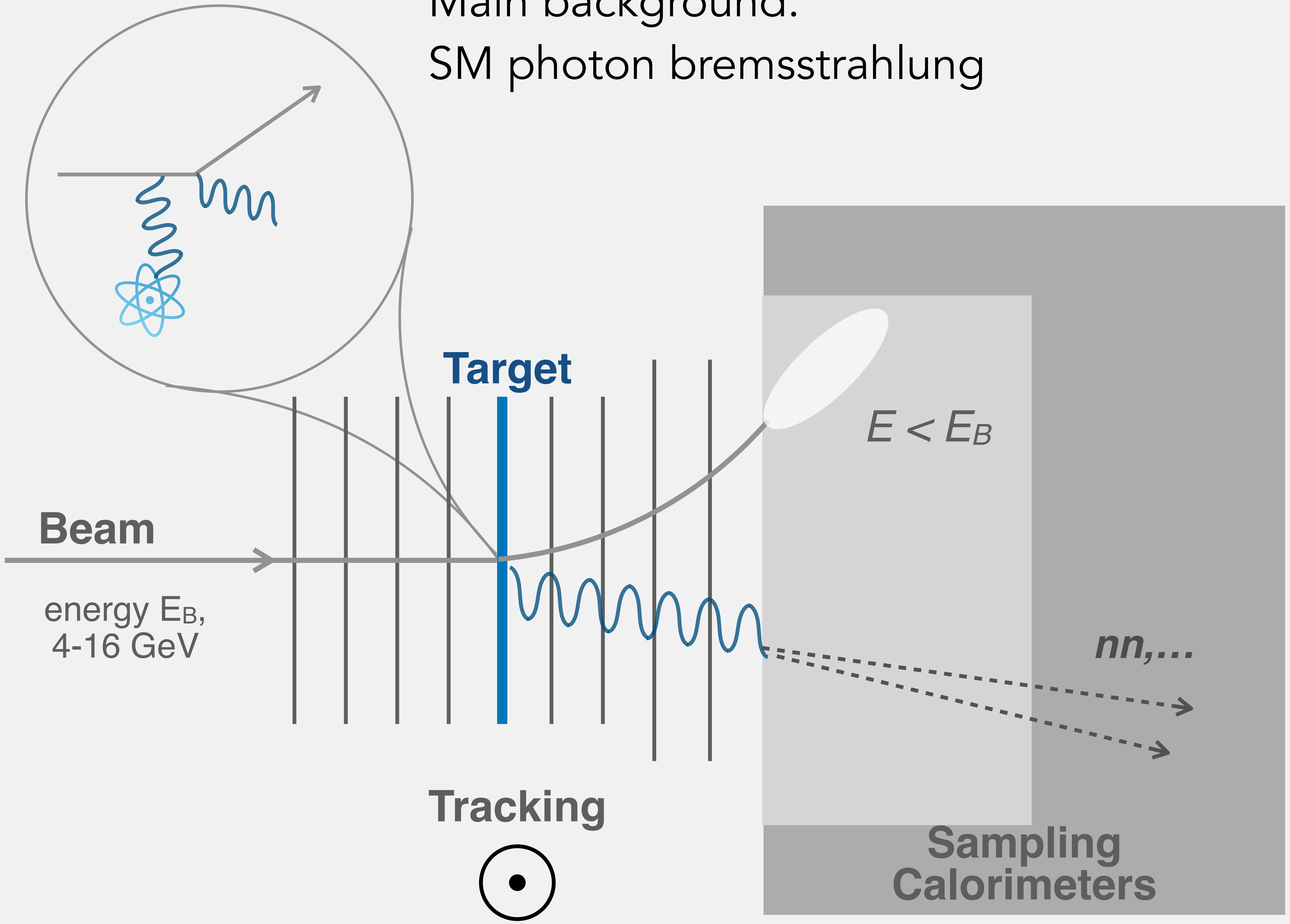
Challenging Backgrounds

Main background:
SM photon bremsstrahlung



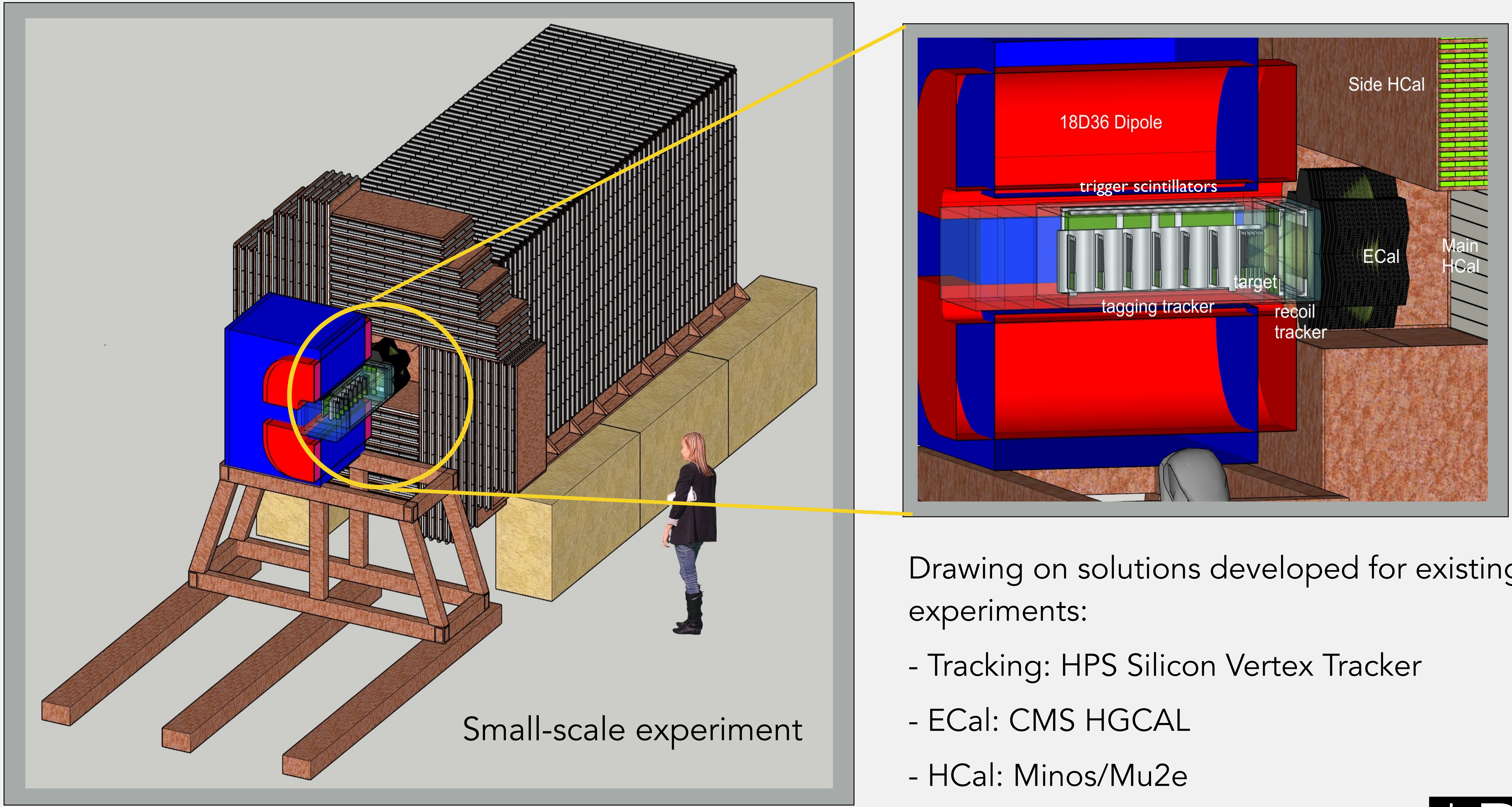
Particularly challenging:

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

Design drivers, especially for HCal!

LDMX — Current Design

design paper on arxiv
arxiv:1808.05219



Drawing on solutions developed for existing experiments:

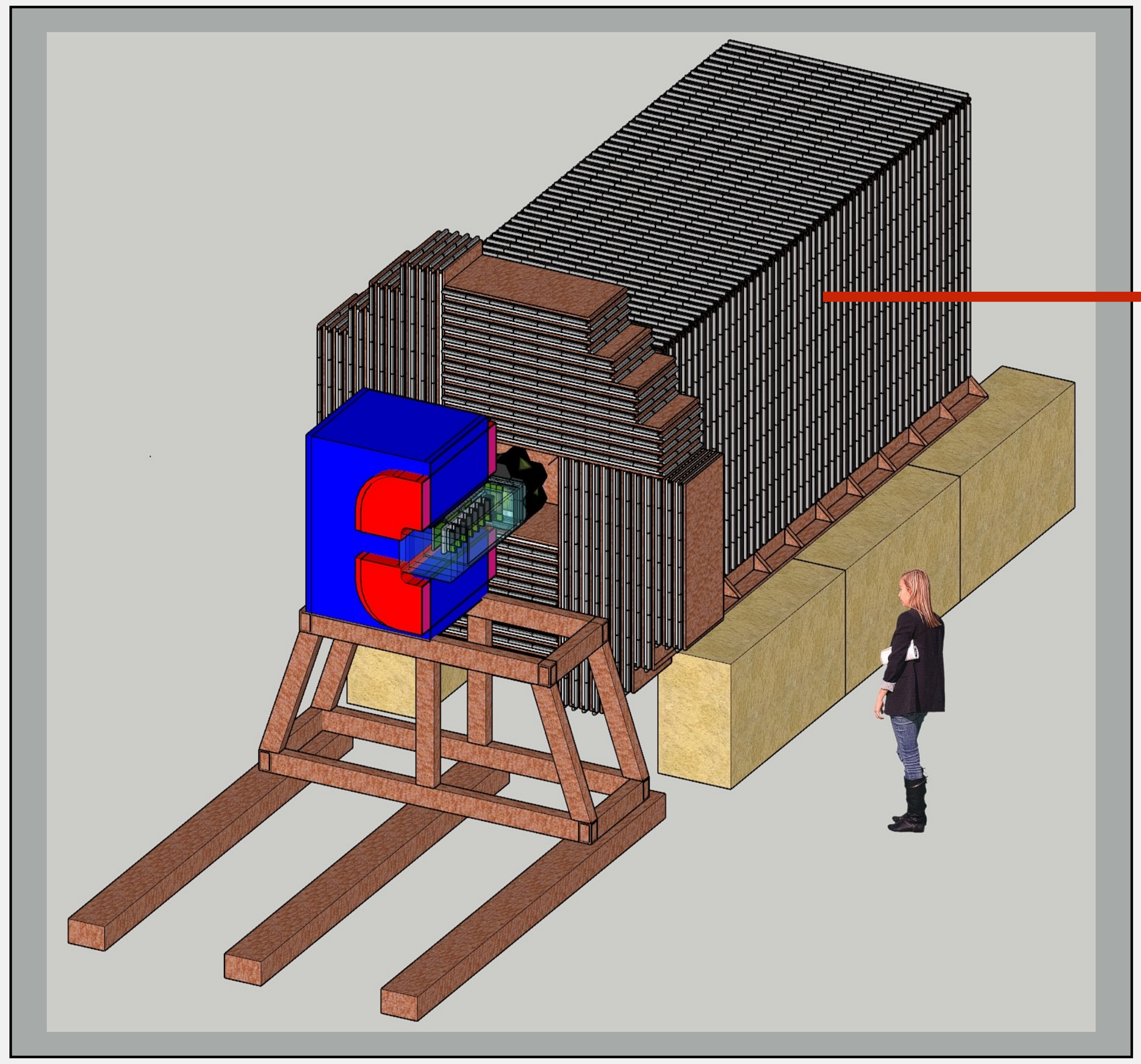
- Tracking: HPS Silicon Vertex Tracker
- ECal: CMS HGCAL
- HCal: Minos/Mu2e

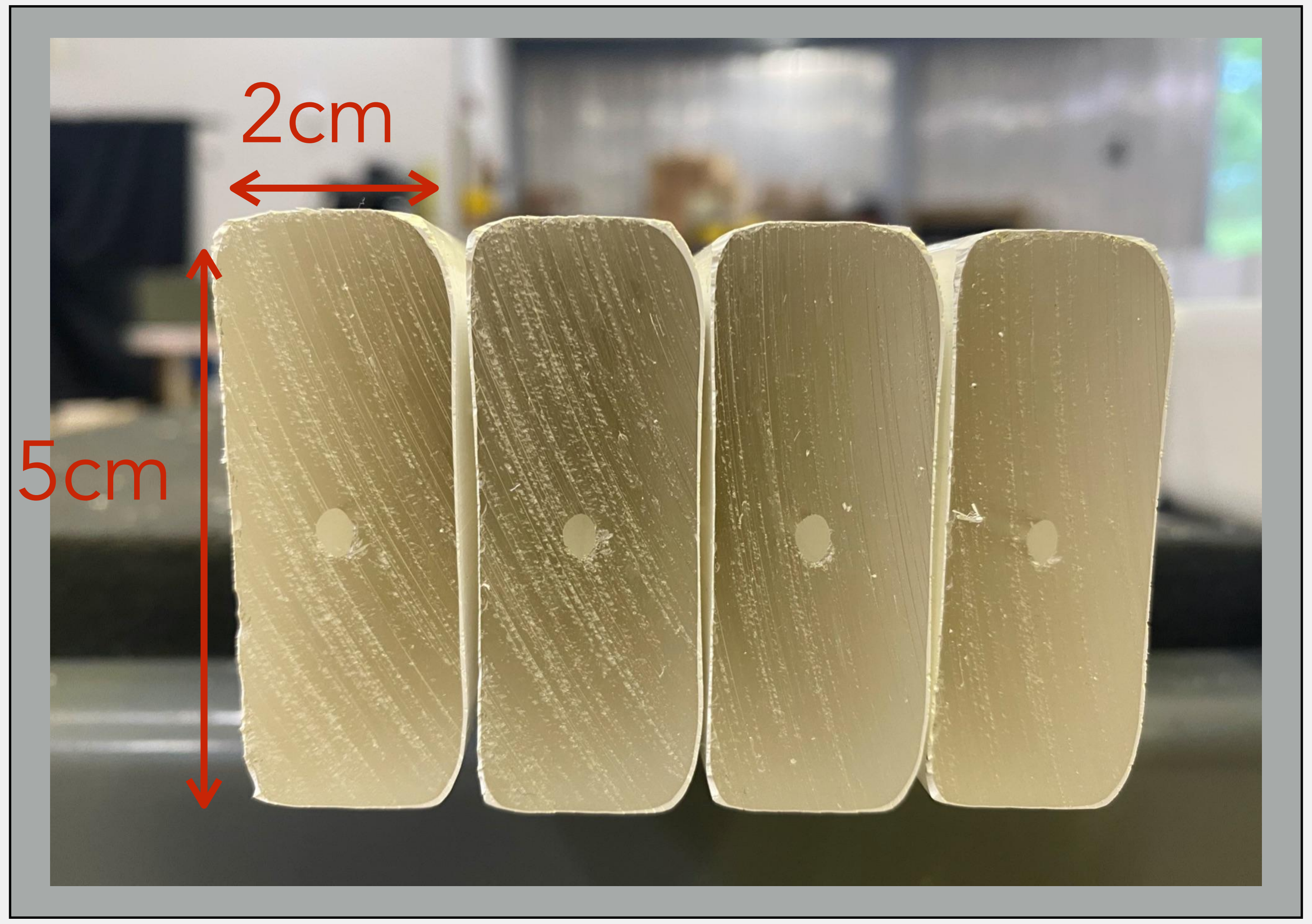
Hadronic Calorimeter

Highly efficient **veto** of neutral hadrons (n, K^0_L)

- Inefficiency of ~10^{-6}

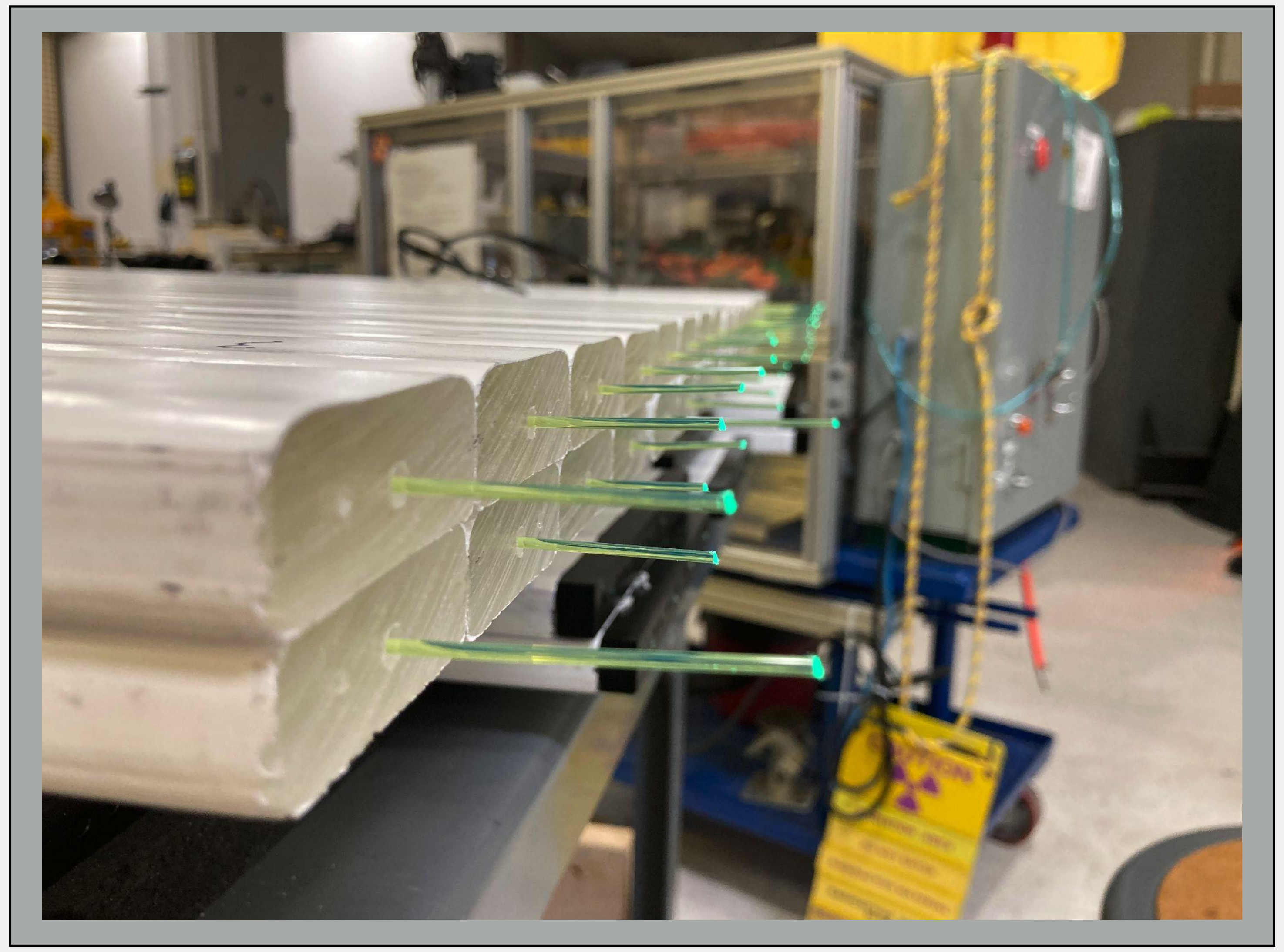
- Steel absorber, plastic scintillator bars
- Wavelength-shifting fiber read out via SiPMs





Main HCal:

- 2m x 2m wide
- 25mm absorber, ~17λ
- alternating x,y orientation of bars
- double ended readout



Prototype for beam tests at CERN (Oct 2021, Mar 2022)

See talk by Péter György

What we do in Lund

HCal prototype/testbeam

See talk by Péter

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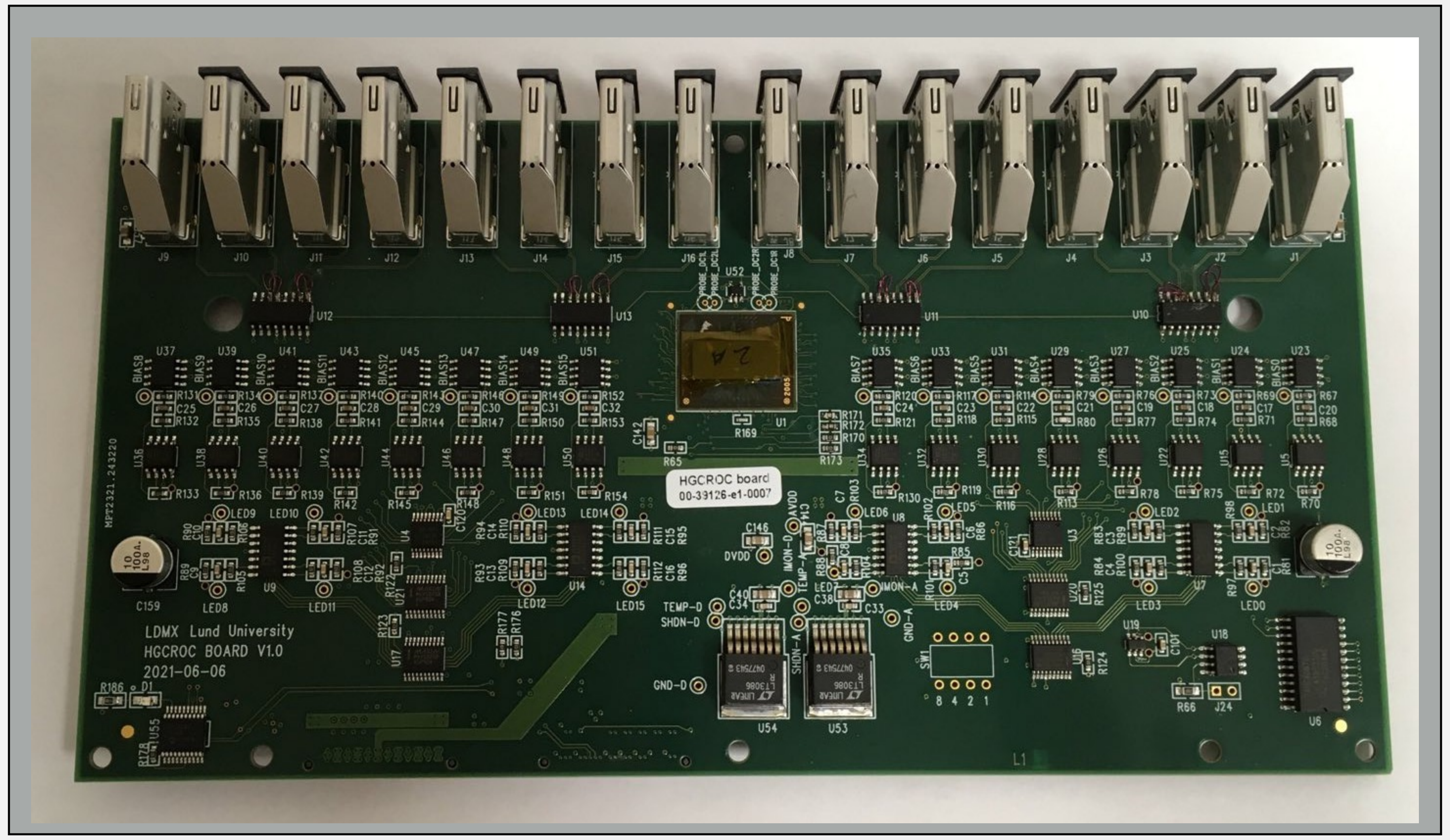
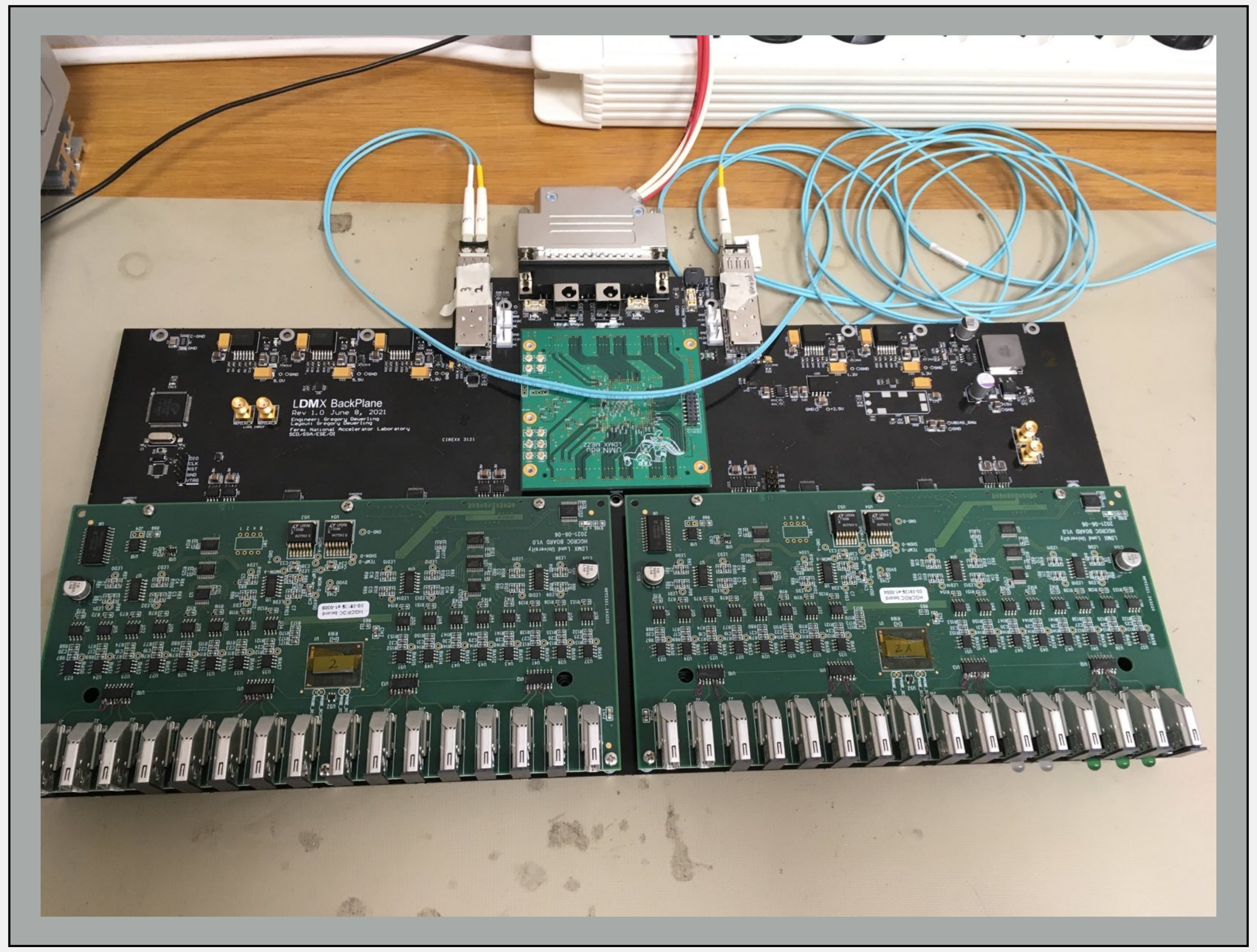
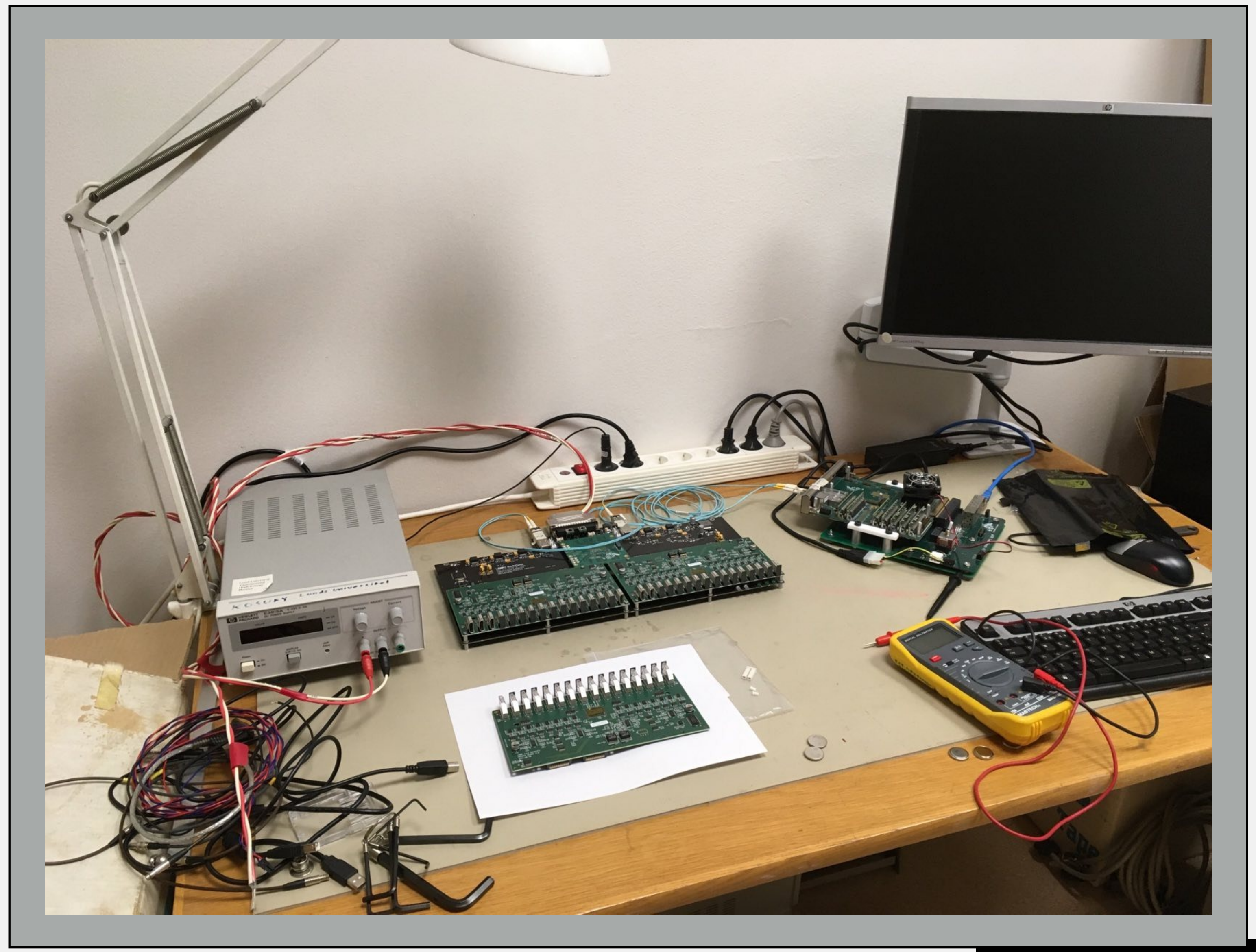
Readout Electronics for HCal (prototype)







What we do in Lund

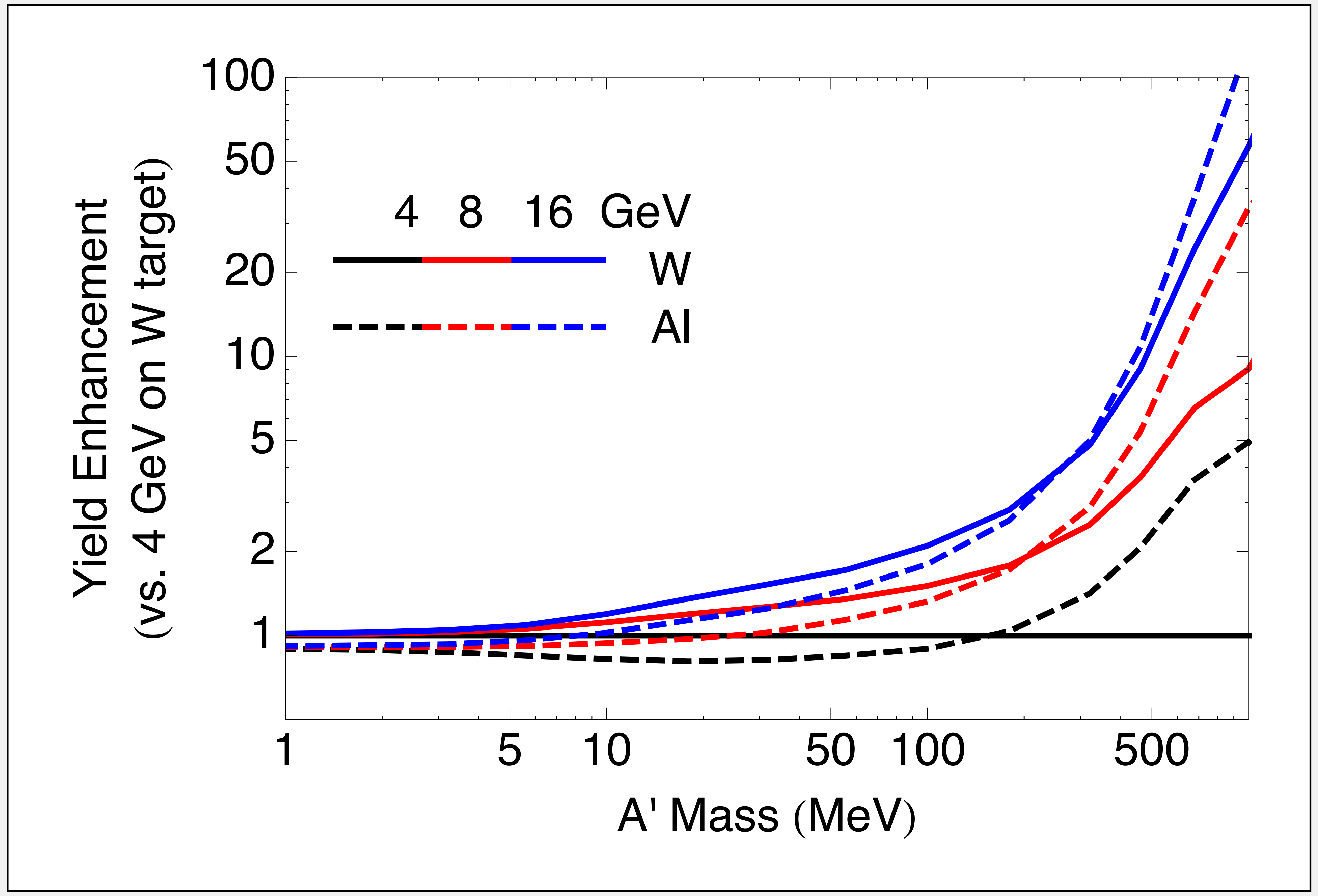
HCal prototype/testbeam

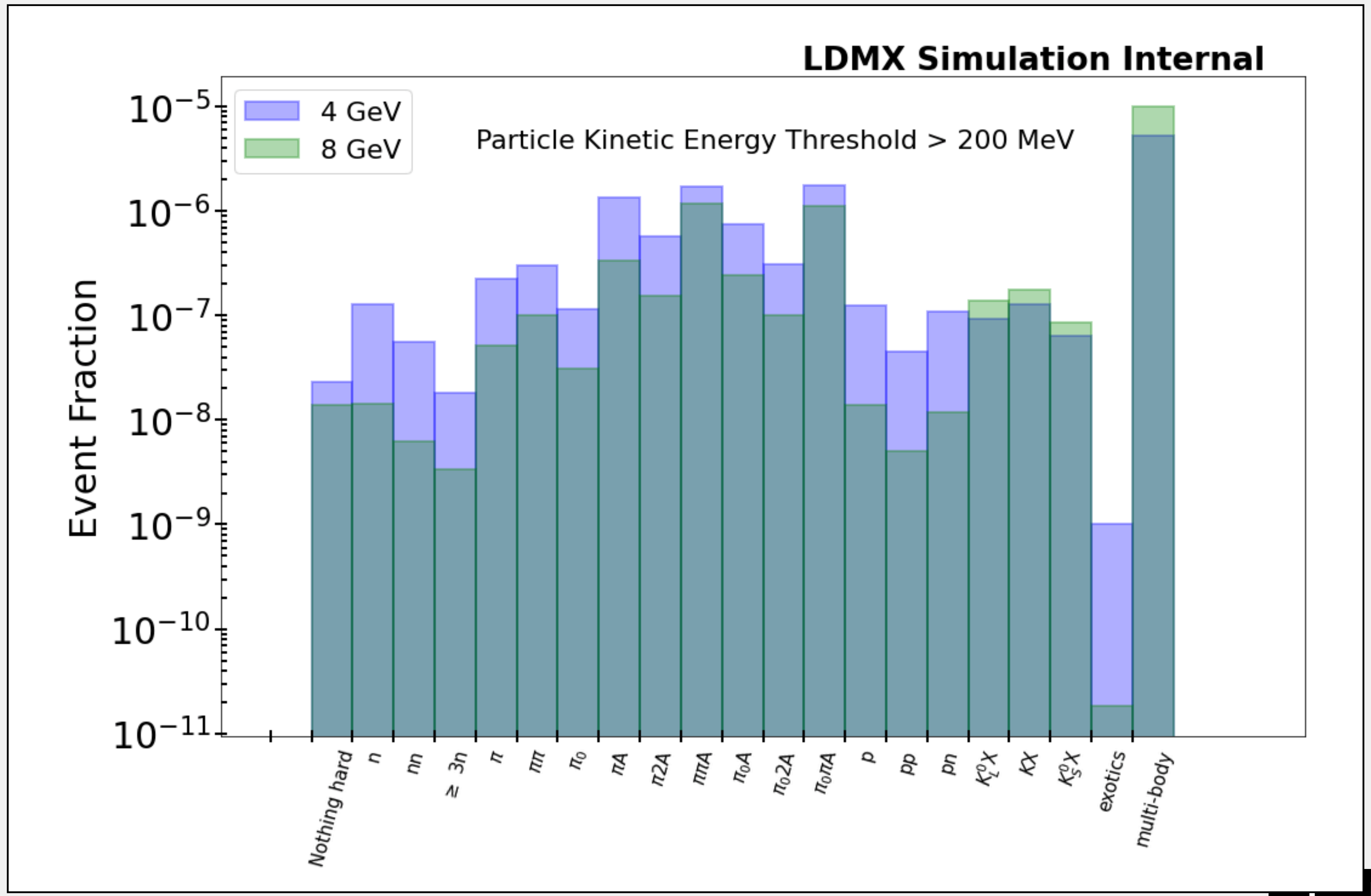
See talk by Péter

Readout Electronics for HCal (prototype)

Study higher beam energy

See talk by Erik Wallin





What we do in Lund

HCal prototype/testbeam

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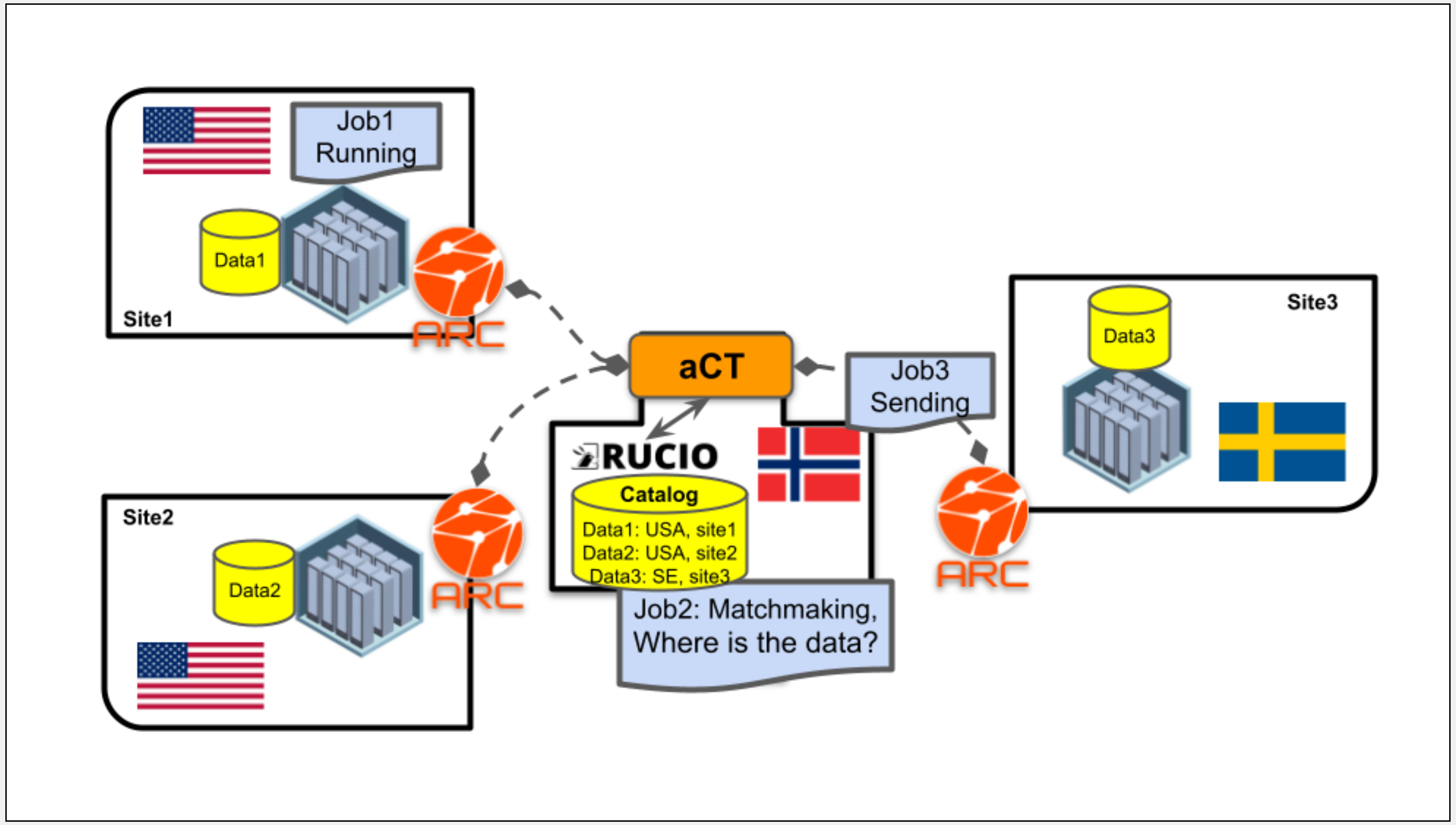
Lightweight Distributed Computing System (LDCS) (collaboration with David Cameron from Oslo)

arxiv:2105.02977



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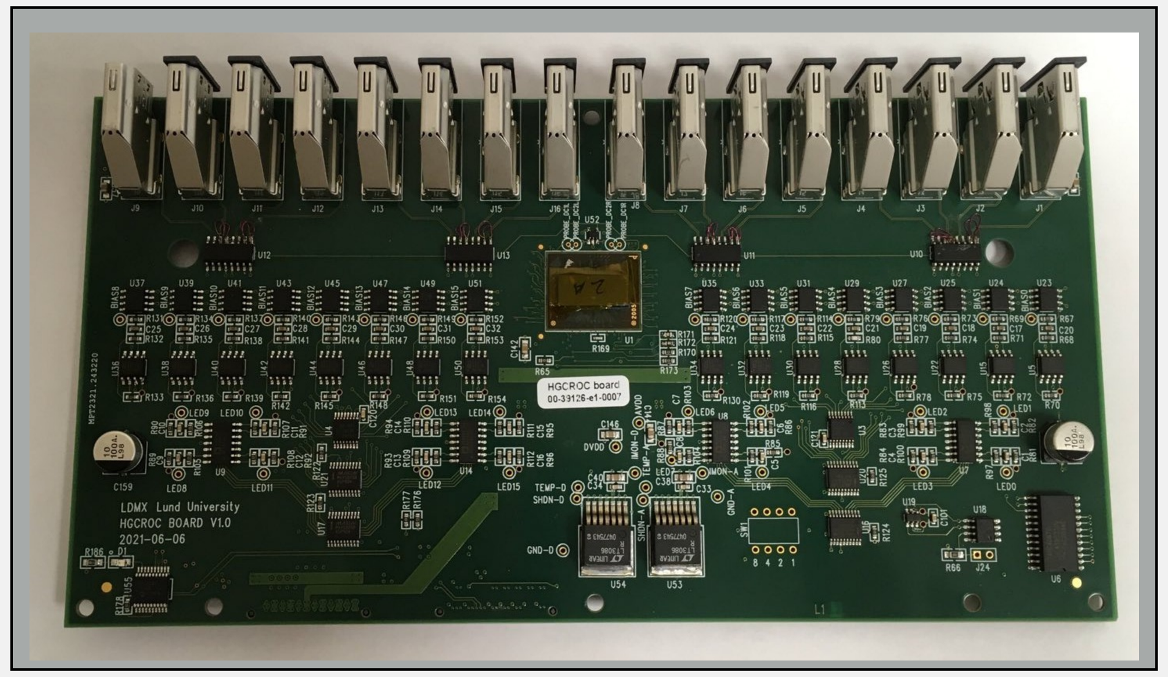

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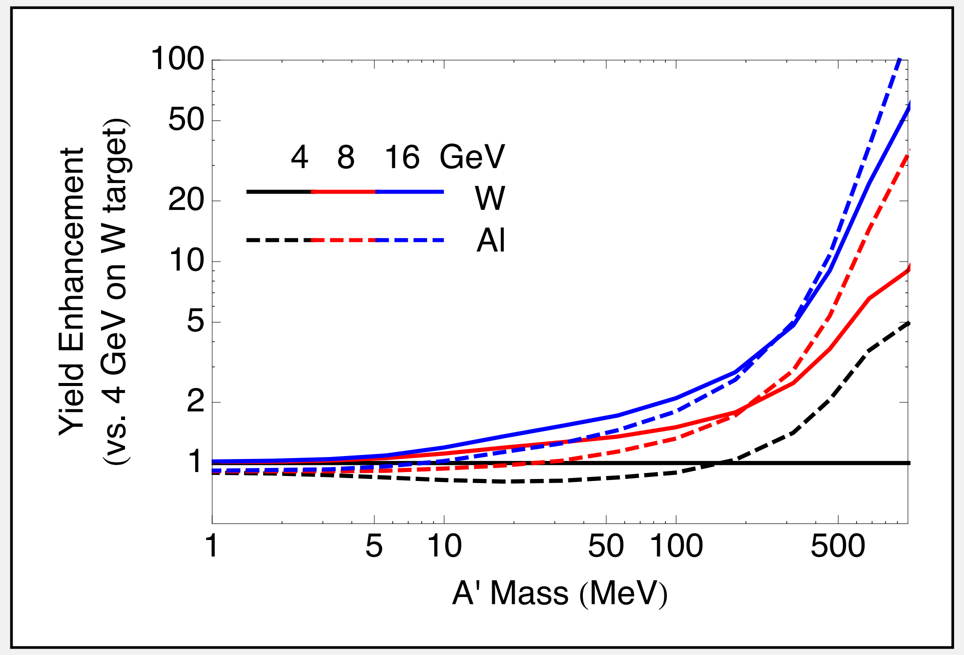

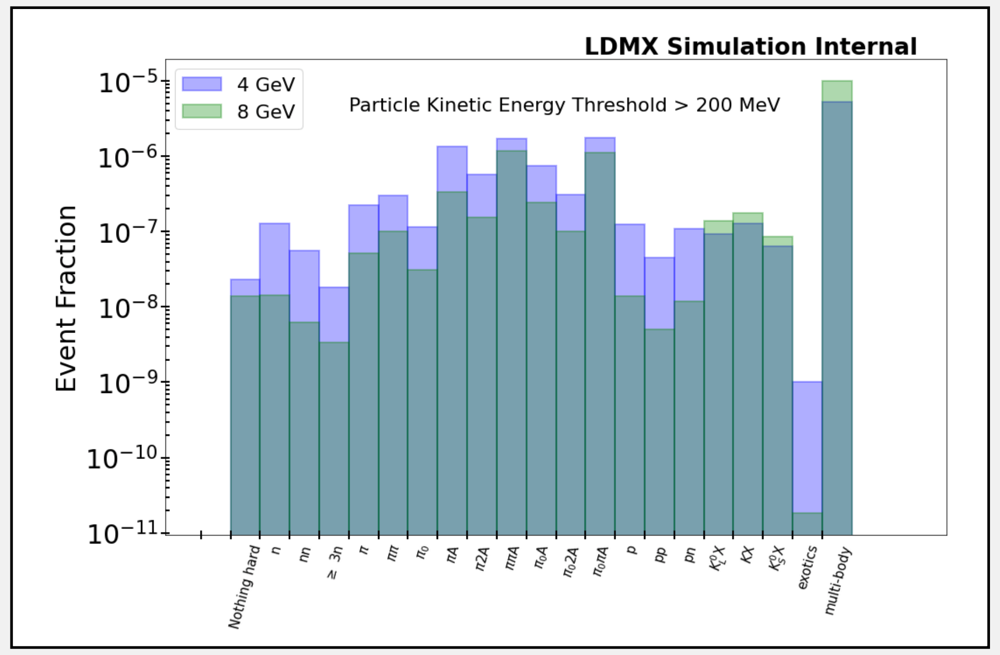

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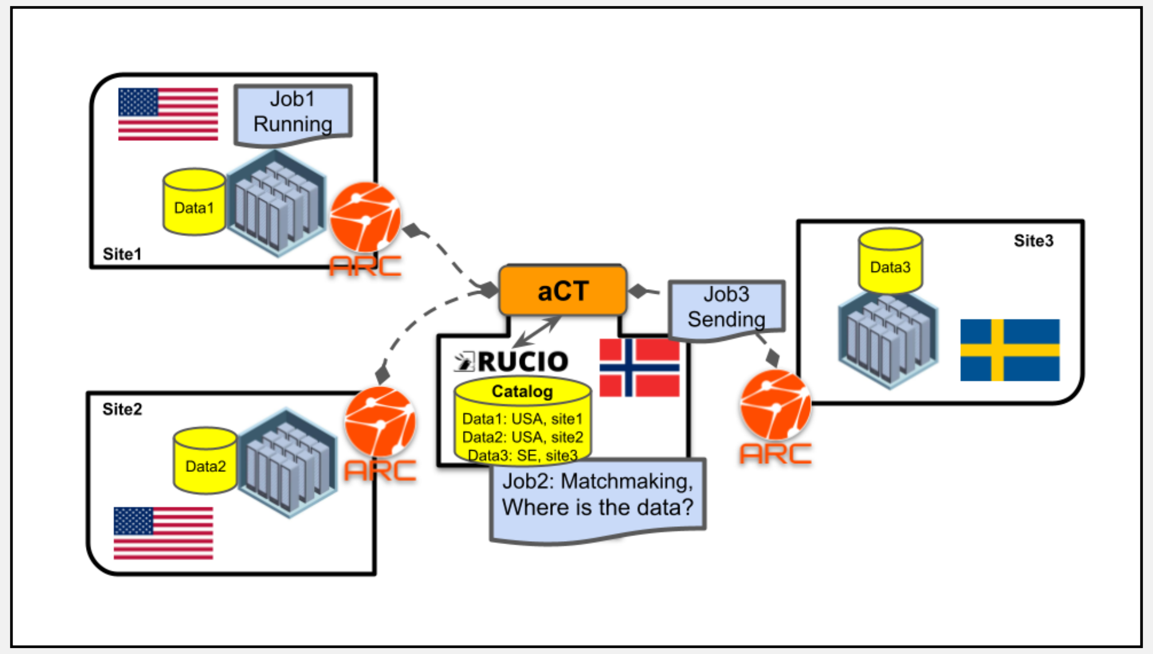

Funded by

See talk by Einar Elén

Crafoord Foundation, Knut and Alice Wallenberg Foundation, L'Oréal-UNESCO FWIS, Royal Physiographical Society of Lund, Swedish Research Council

Summary & Outlook

- Light, thermal relic Dark Matter well motivated
- LDMX can achieve outstanding sensitivity (in O(years))
- Potential to probe thermal targets in MeV - GeV range
- LU group leading activities in various areas
- First commissioning data early 2024

The next few years will be exciting!

Summary & Outlook

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The next few years will be exciting!

[Craig Group & Son]

Thank you!

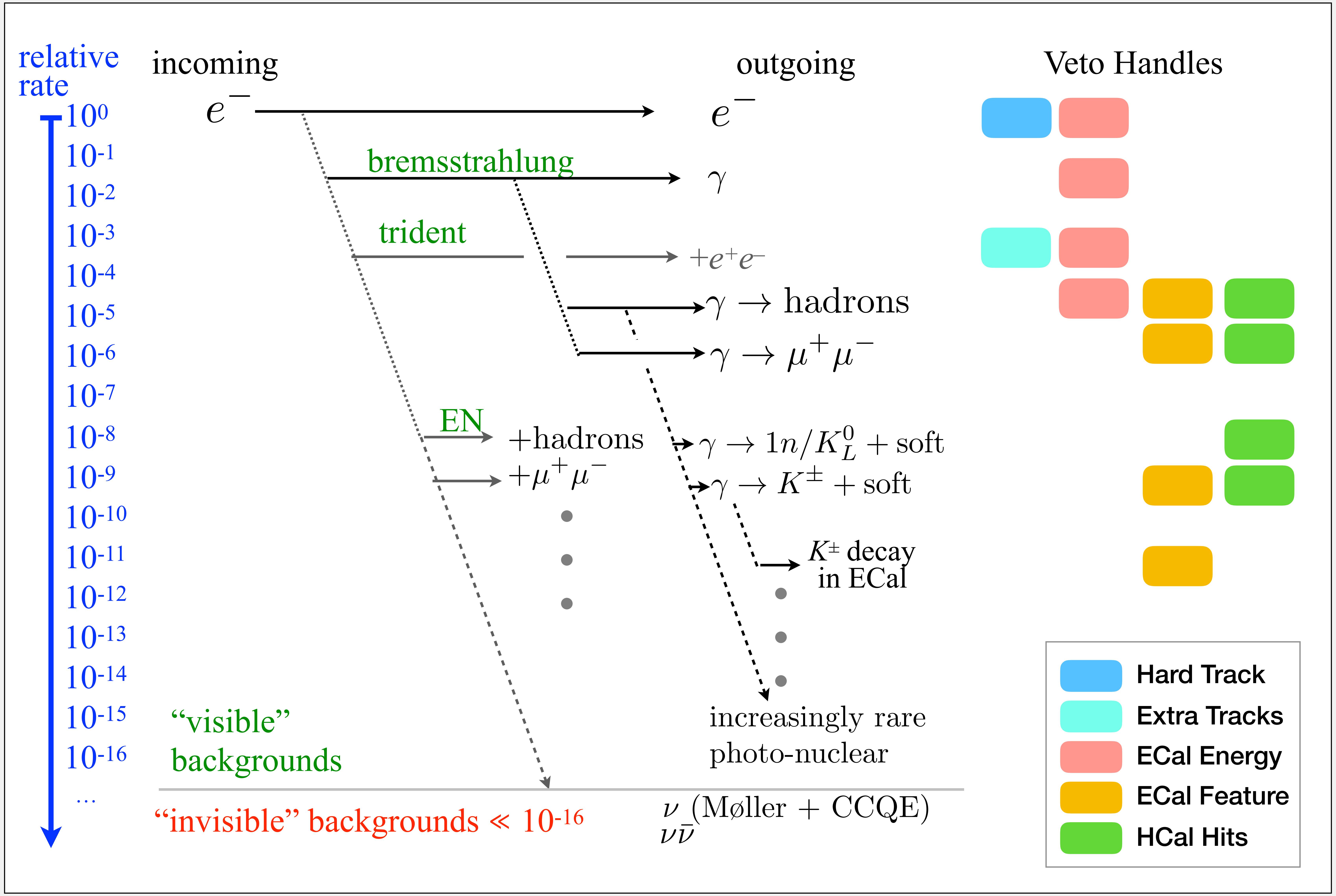
Additional Material

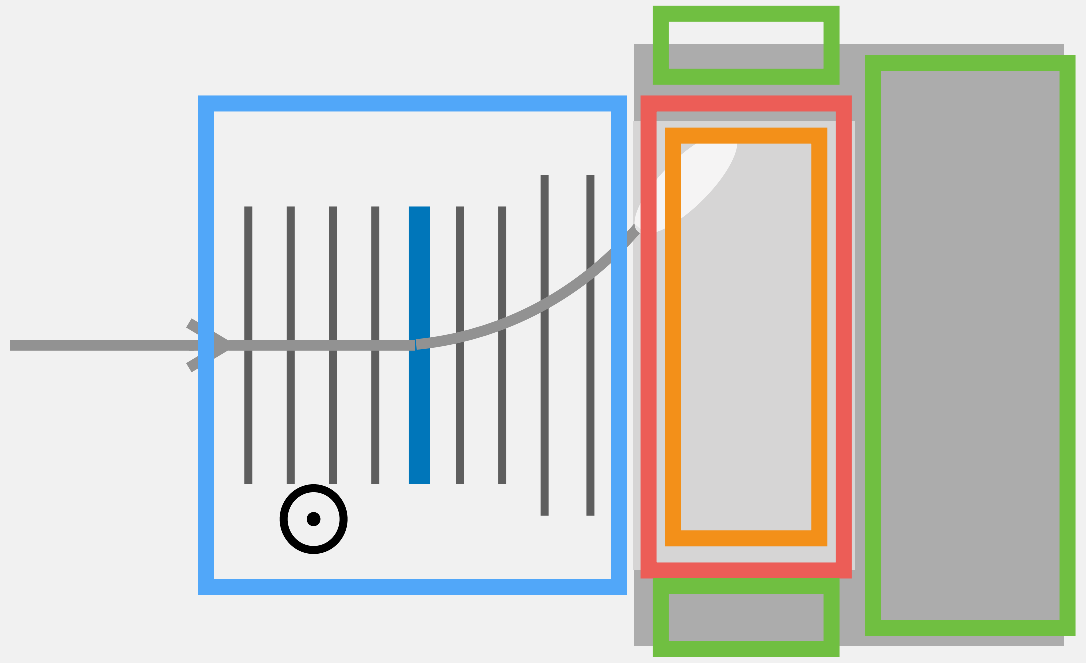
Timeline

Conditional on funding situation

Bulk of the data set will be at 8 GeV!

Backgrounds

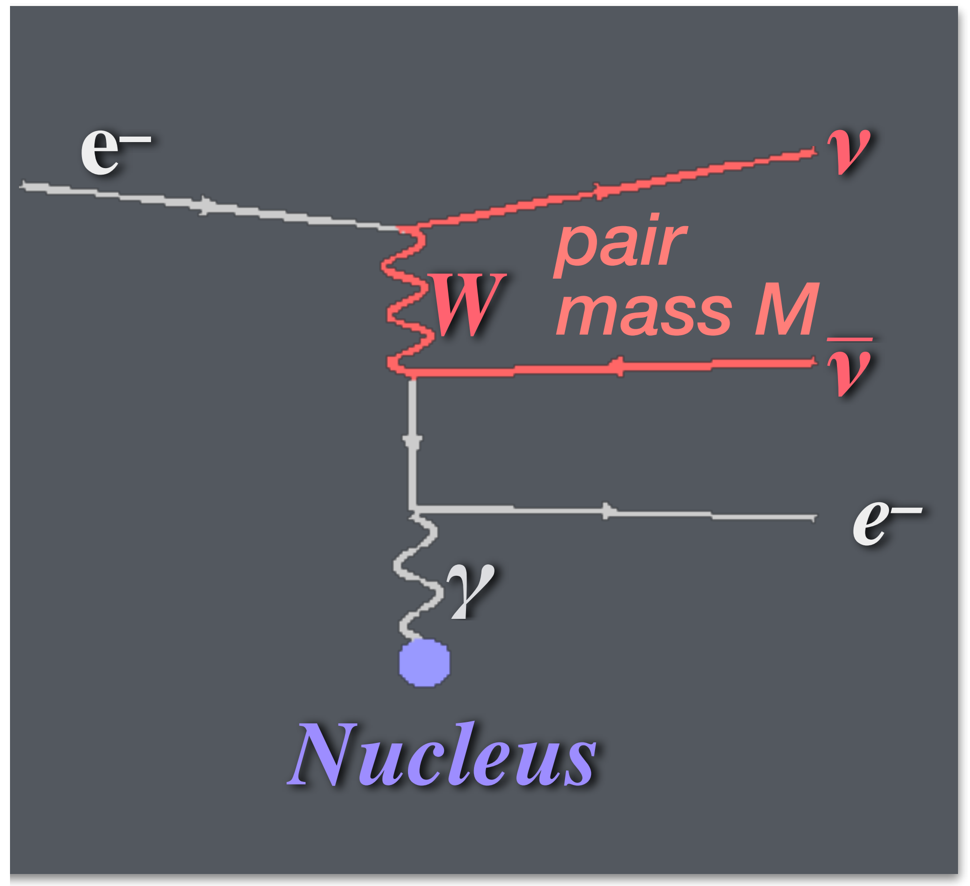
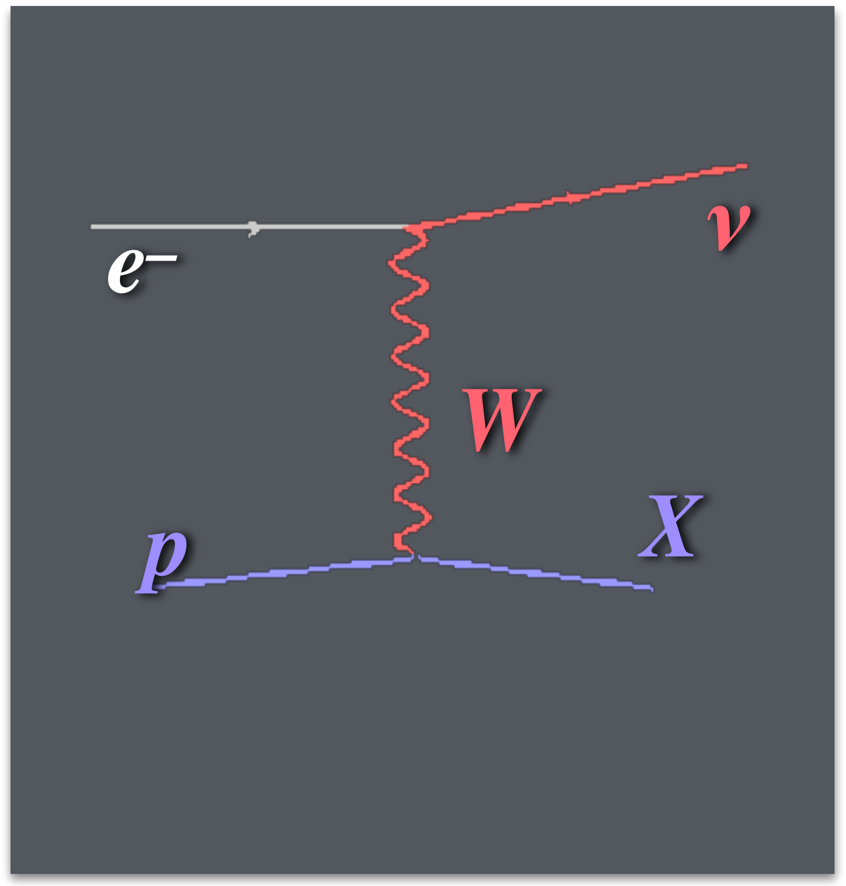
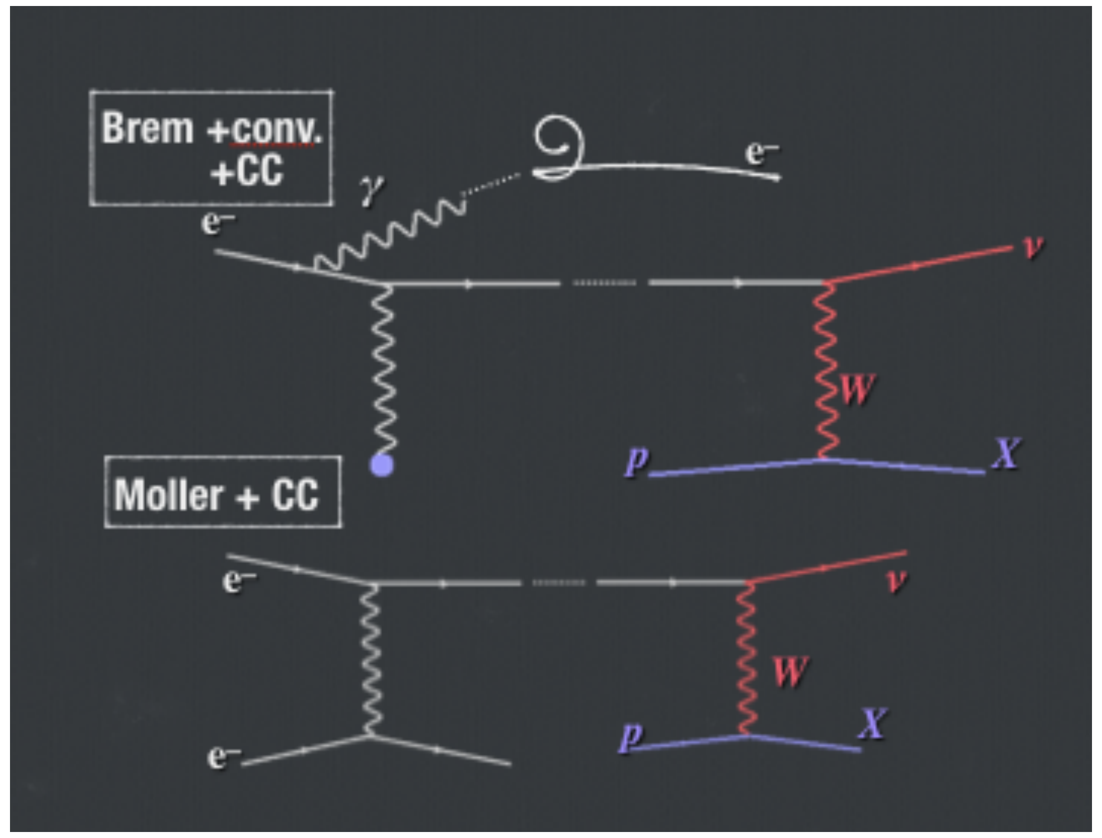




essentially only instrumental backgrounds

Neutrino Backgrounds

Prompt Neutrino Reactions

Neutrino Tridents	*Charged Current*	*CCQE+…*
		

Neutrino Tridents

$N_{\nu\nu}/N_e$

$\sim 10^{-19}$ (E/4GeV)

irreducible

Charged Current

$N_{\nu\nu}/N_e$

$\sim 10^{-14}$ (E/4GeV)

no recoil electron

(bkg missing energy search, not for us)

CCQE+…

$N_{\nu+\text{Brem+conv.}}/N_e$

$\sim 10^{-16}$ (E/4GeV)

x $(T_{\text{target}}/0.1\ X_0)^3$

a bit reducible

curler track veto, cut out Moller kinematics

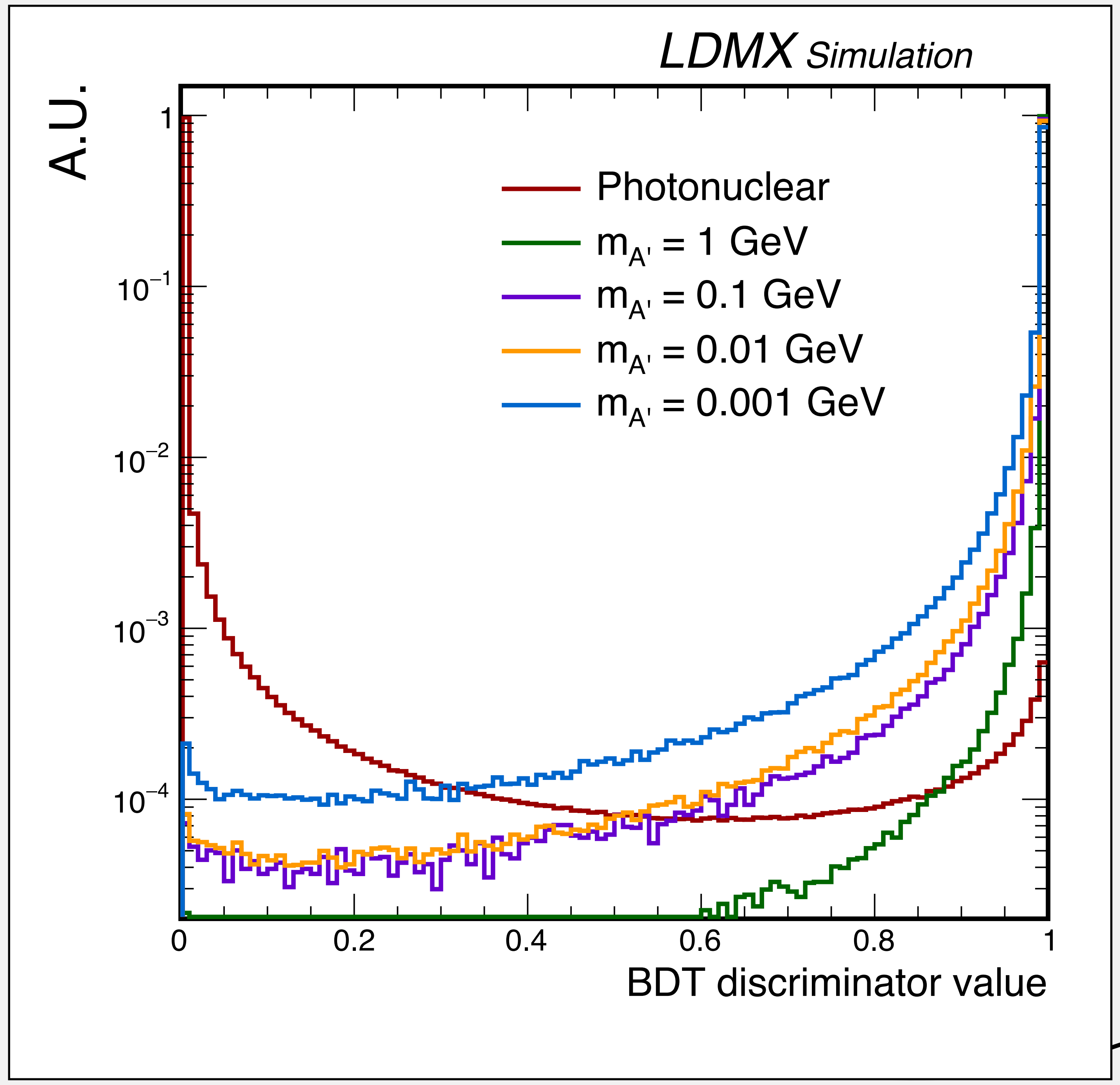
slide by Natalia Toro

Analysis Strategy

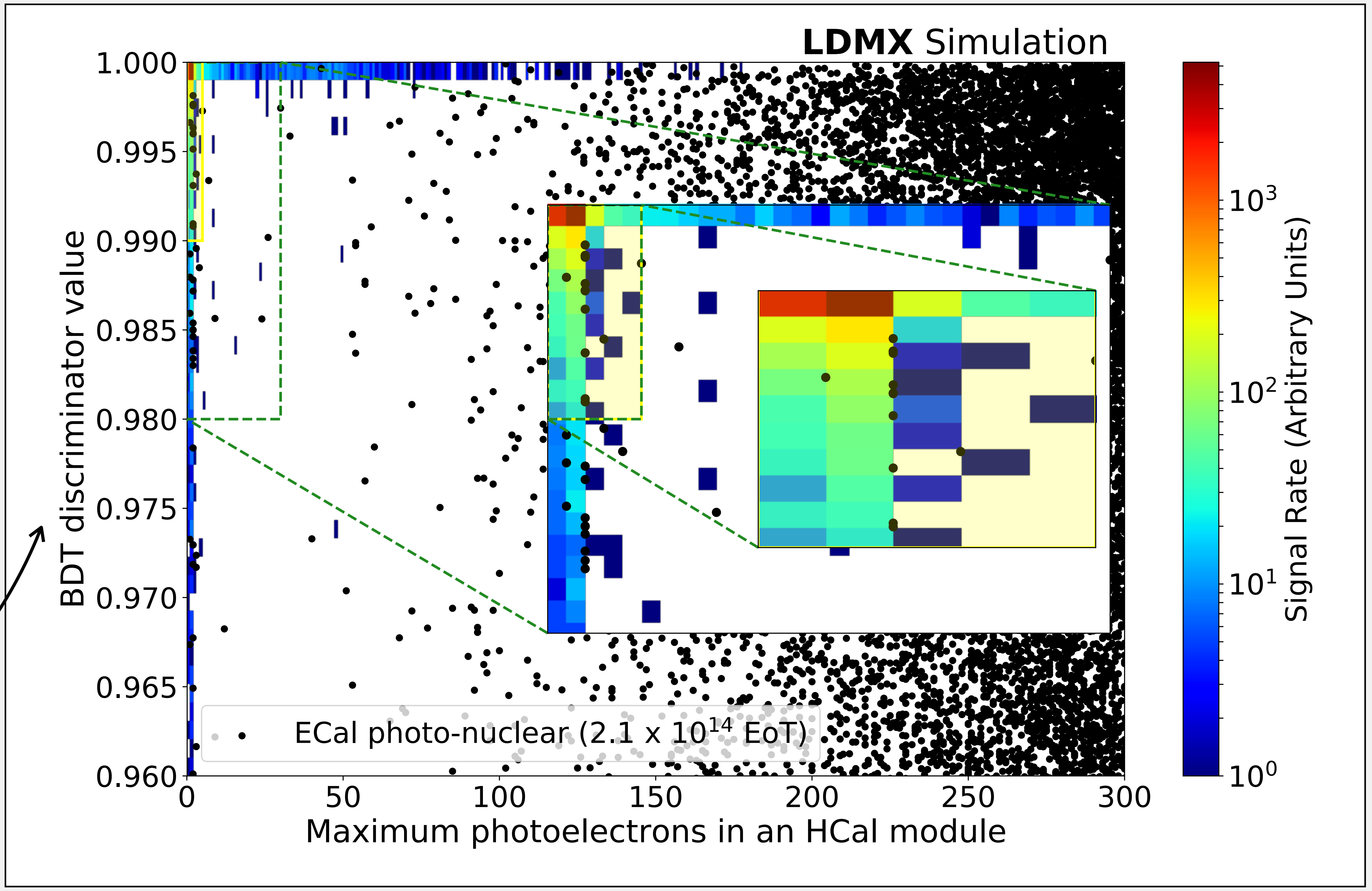
JHEP04(2020)003

trigger on *missing energy* (2.5 GeV)

+ combine ECal features into a BDT



+ veto on activity in *HCal*



+ MIP tracking in ECal

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

Detector Design

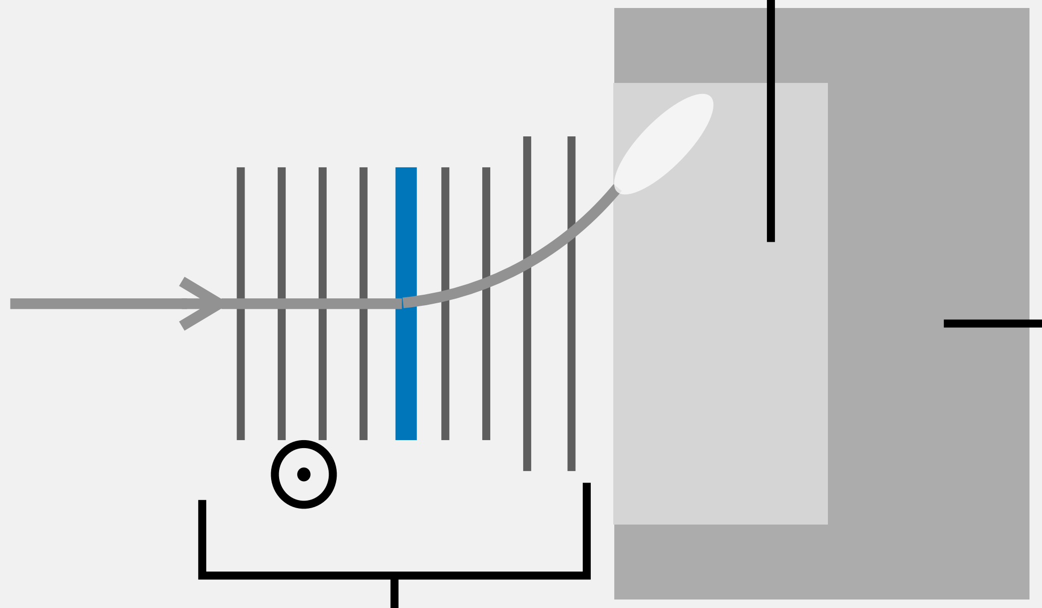
design paper on arxiv
arxiv:1808.05219

extremely rare signal
—> need large statistics

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

beam requirements:
- low current, high duty-cycle

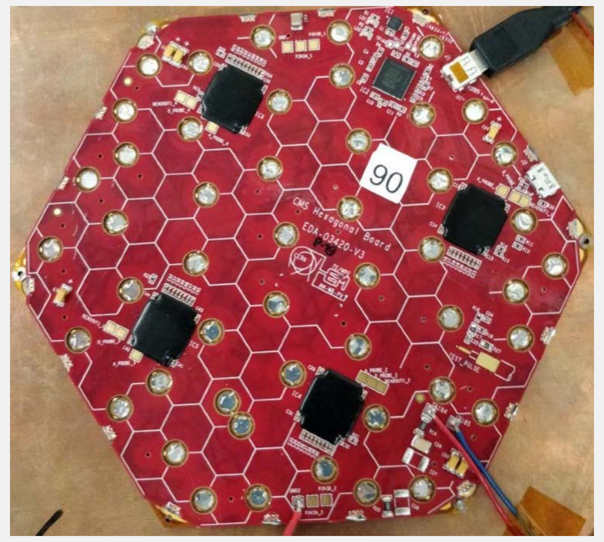
primary, multi-GeV e-beam

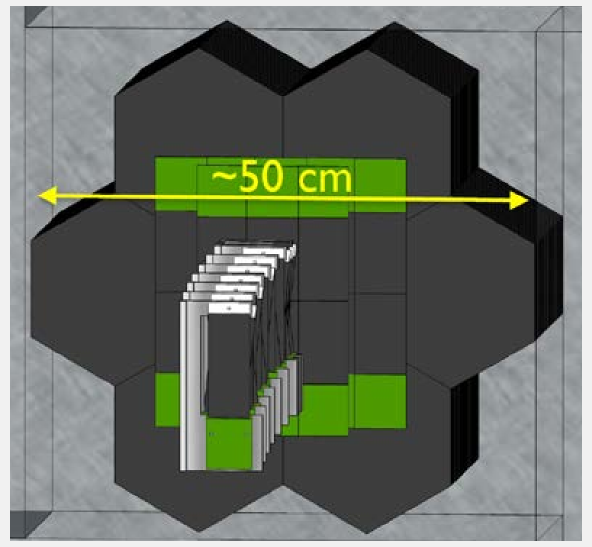


detector requirements:
- high-rate capabilities
- radiation hard
- high-granularity

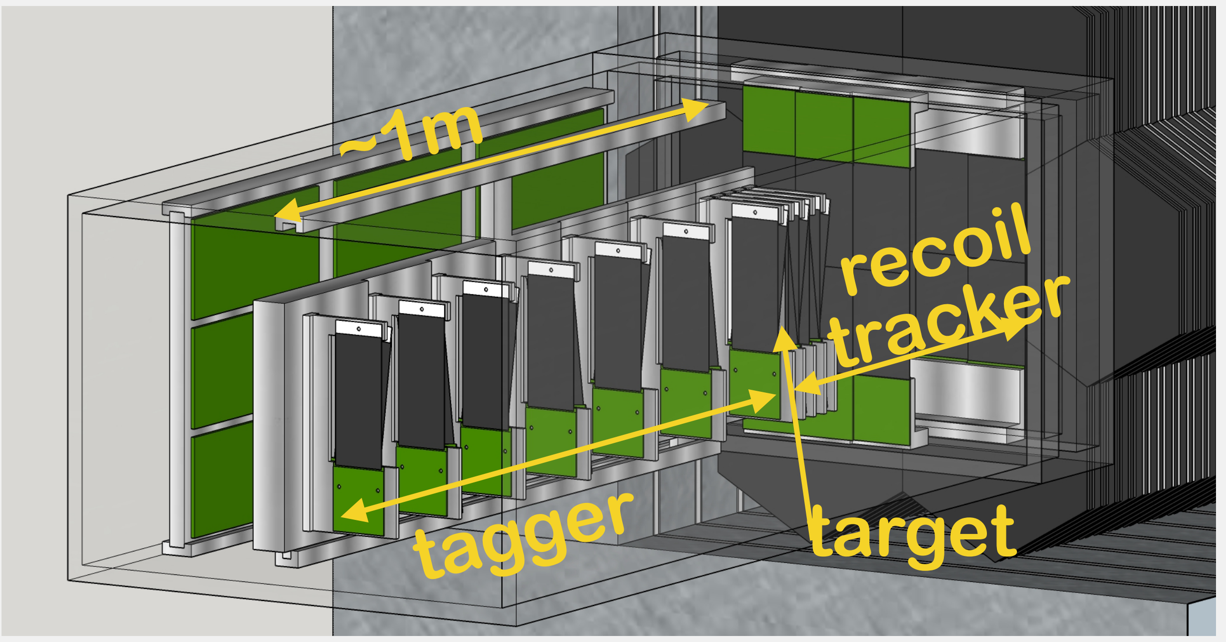
leverage techniques from existing/planned experiments

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')

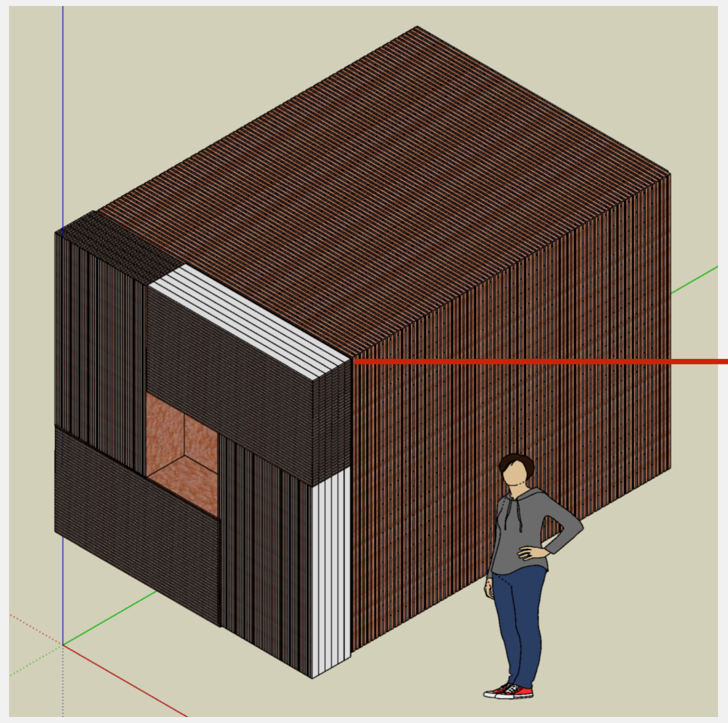


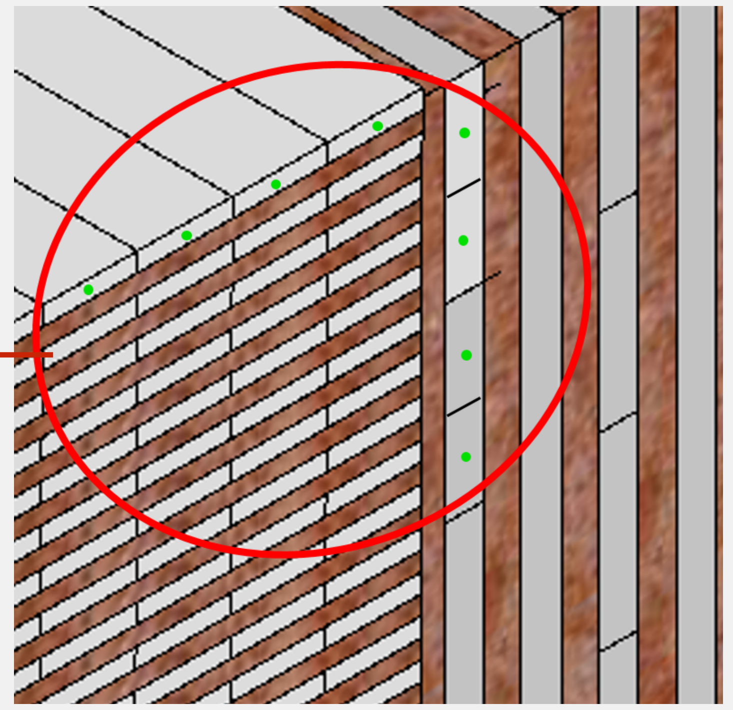


simplified copy of Silicon Vertex **Tracker** of *HPS*@JLab (visible Dark Photon search)



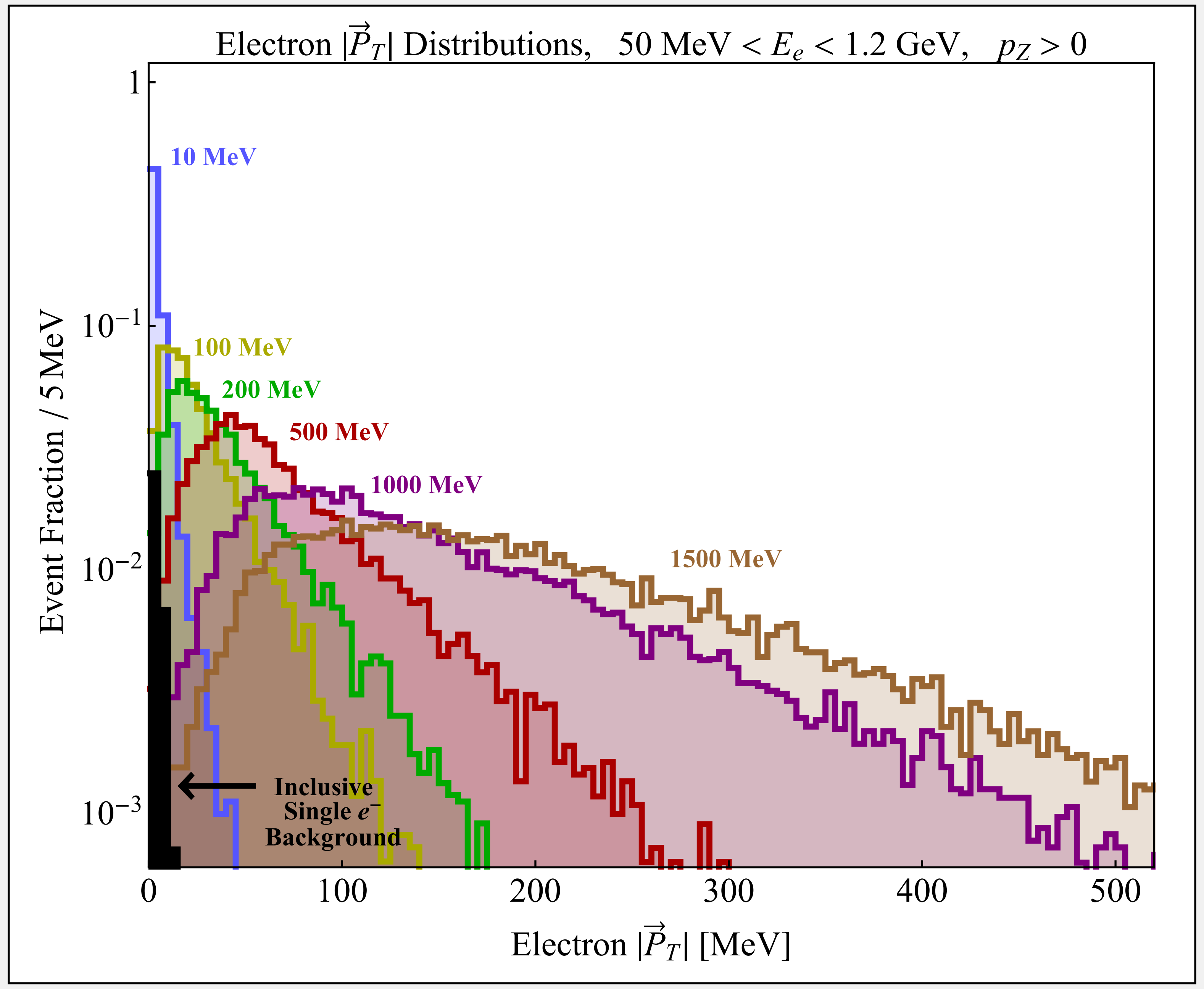
HCal inspired by *Minos/Mu2e*
- plastic scintillator with steel absorber
- readout via WLS fibres
- **optimise for neutral hadron rejection**

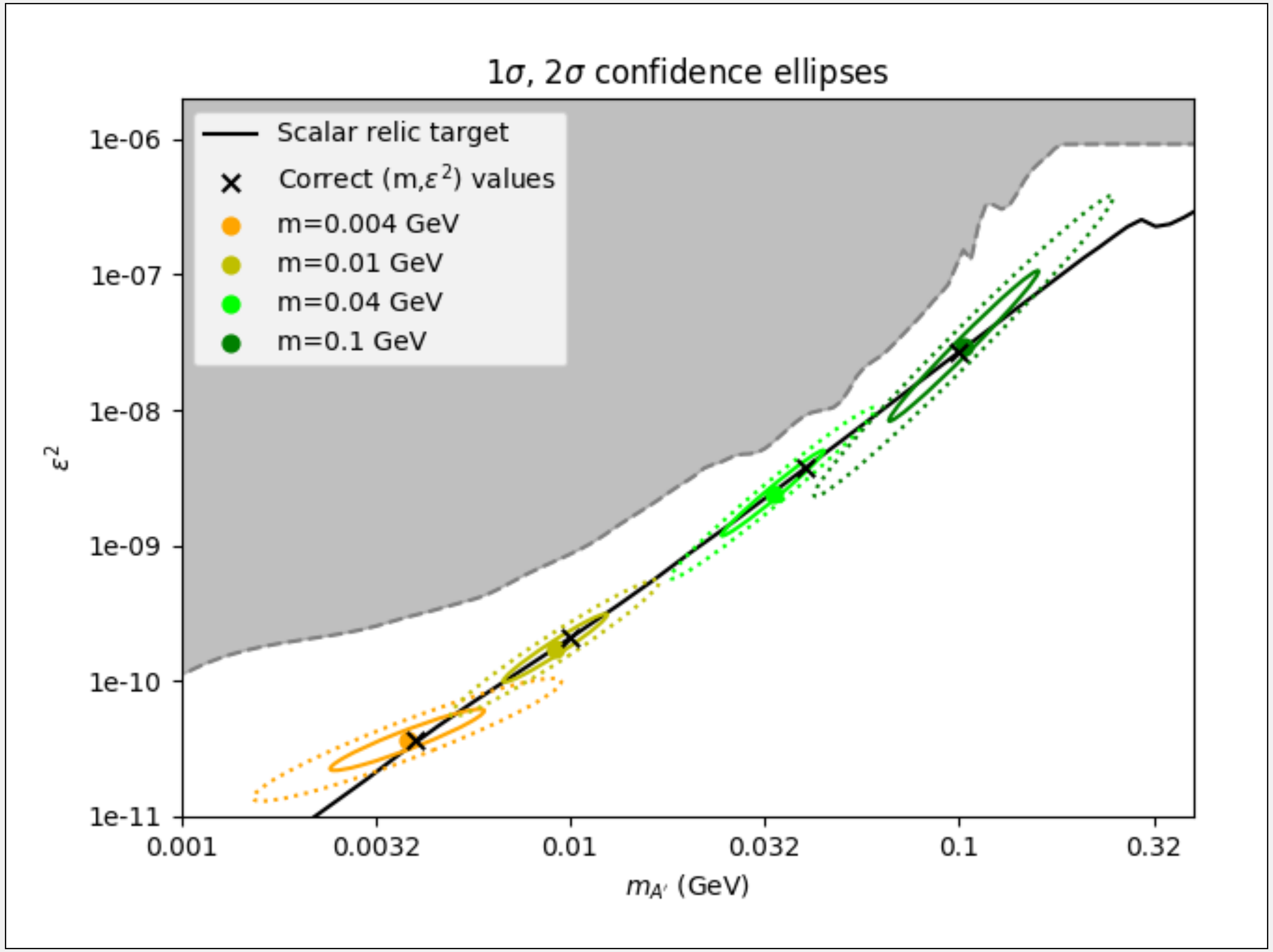




Imagine there's an excess

Measurement production kinematics allows estimation of mediator mass





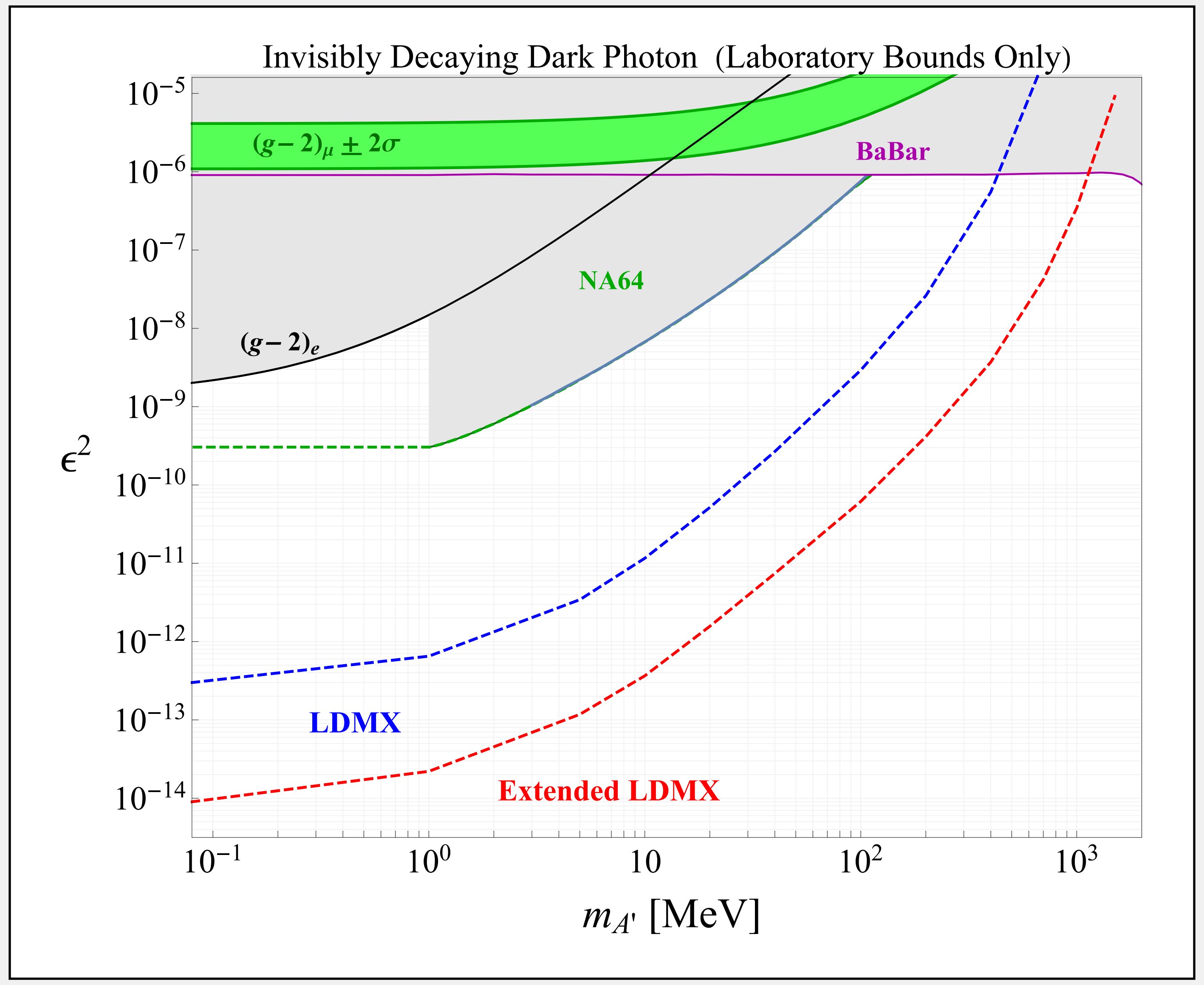
Broader Physics Potential

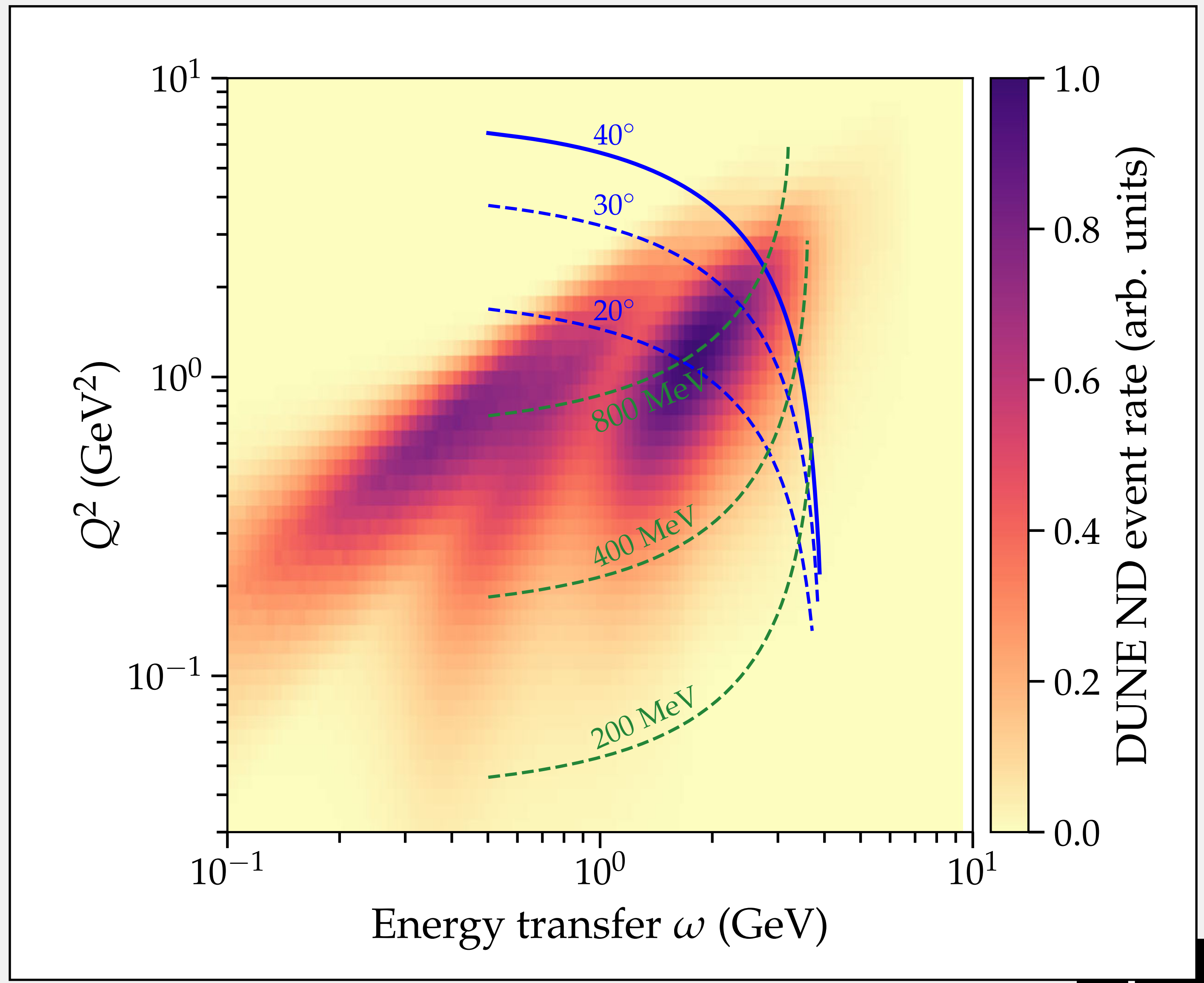
Also sensitive to

- 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, e.g. Phys. Rev. D 101, 053004)

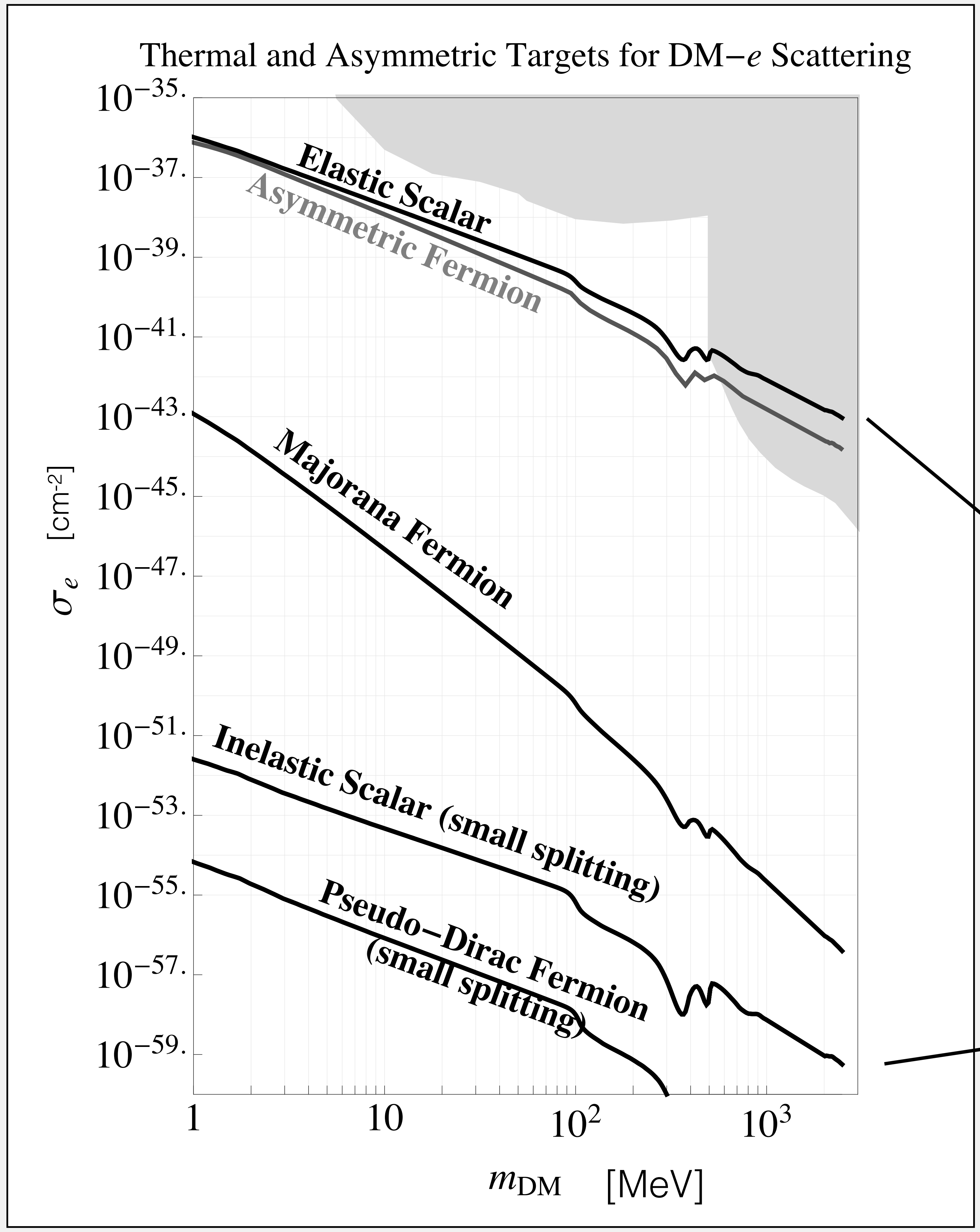




Why not only direct detection?

direct detection:

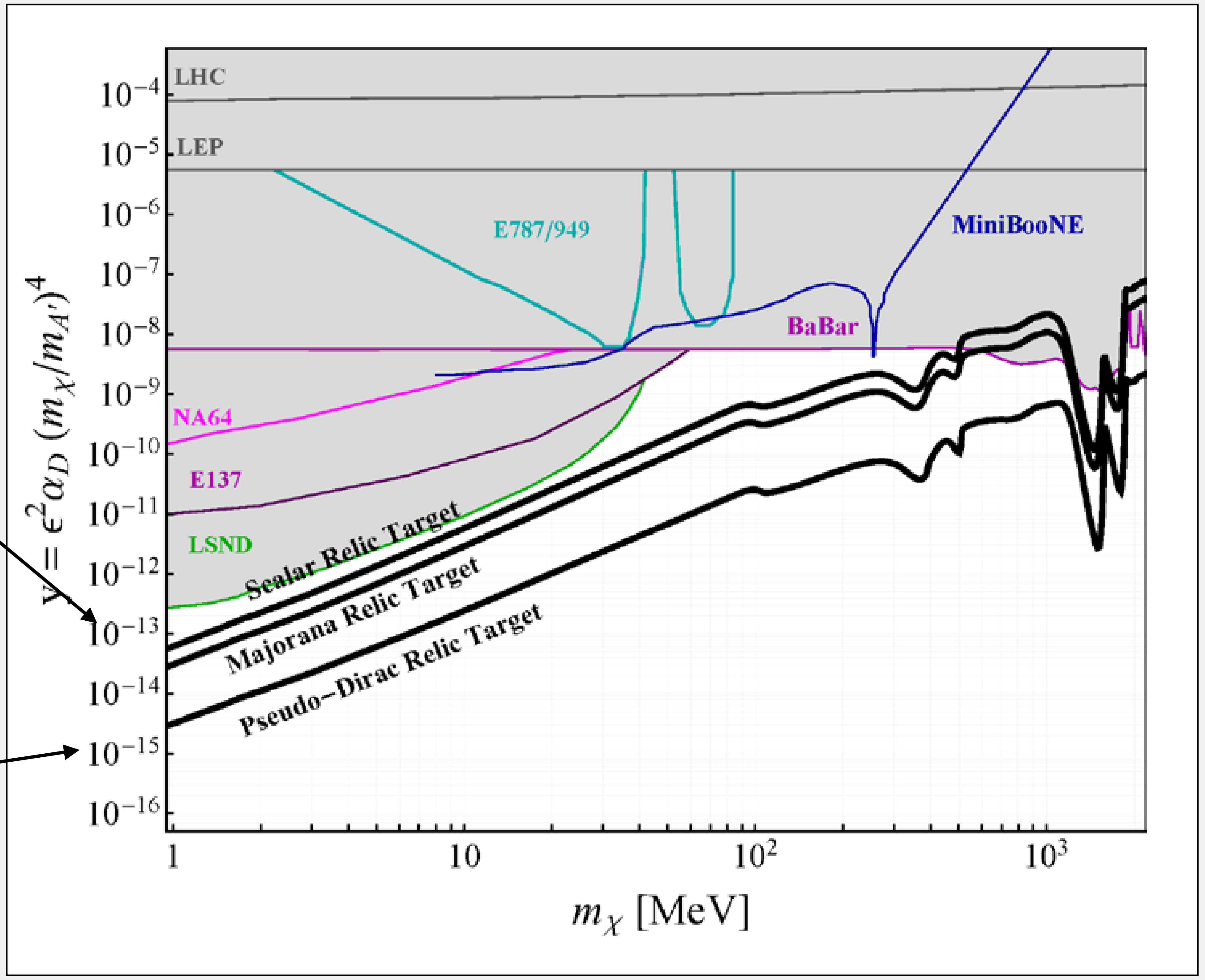
strong spin/velocity dependency



at accelerators: relativistic production

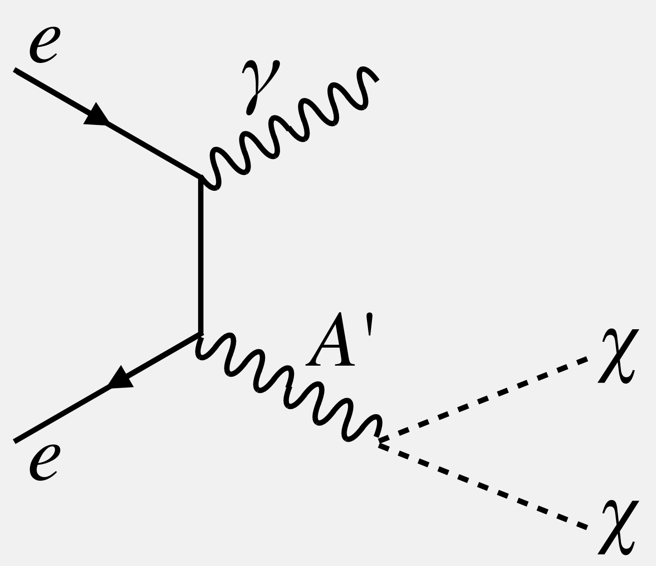
—> spin/velocity dependency reduced

all thermal targets in reach!

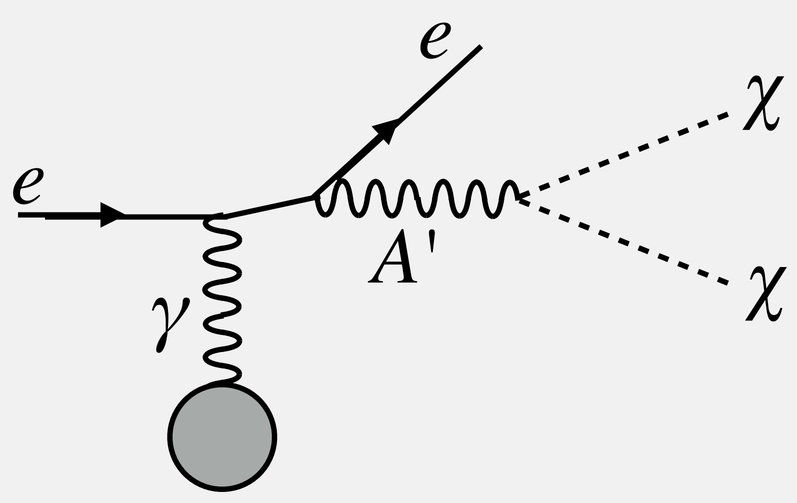


Complimentary Approaches

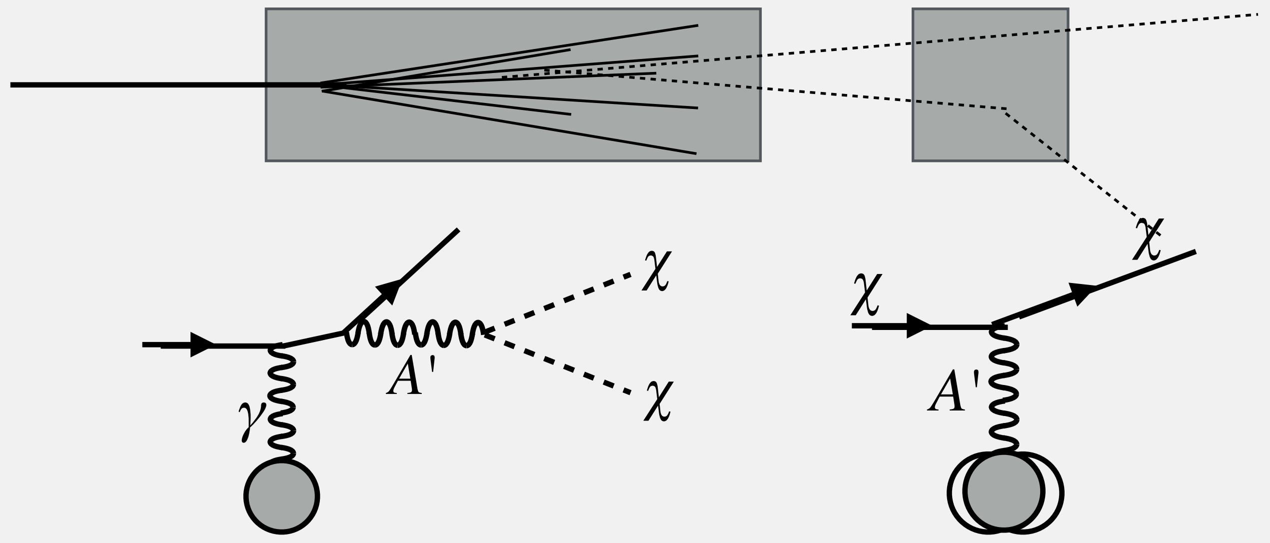
collider



fixed target



beam dump



$\sigma_{\mathrm{coll}} \propto \frac{\varepsilon^2}{E^2_{\mathrm{cm}}}$ << $\sigma_{\mathrm{FT}} \propto \frac{Z^2\varepsilon^2}{m^2_{\mathrm{A'}}}$ $N \propto \varepsilon^2(1-\varepsilon^2) \approx \varepsilon^2$ >> $N \propto \varepsilon^4$

but **"direct DM detection"**

	collider	fixed target		beam dump	
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		

Hadronic Calorimeter

Benchmark example:

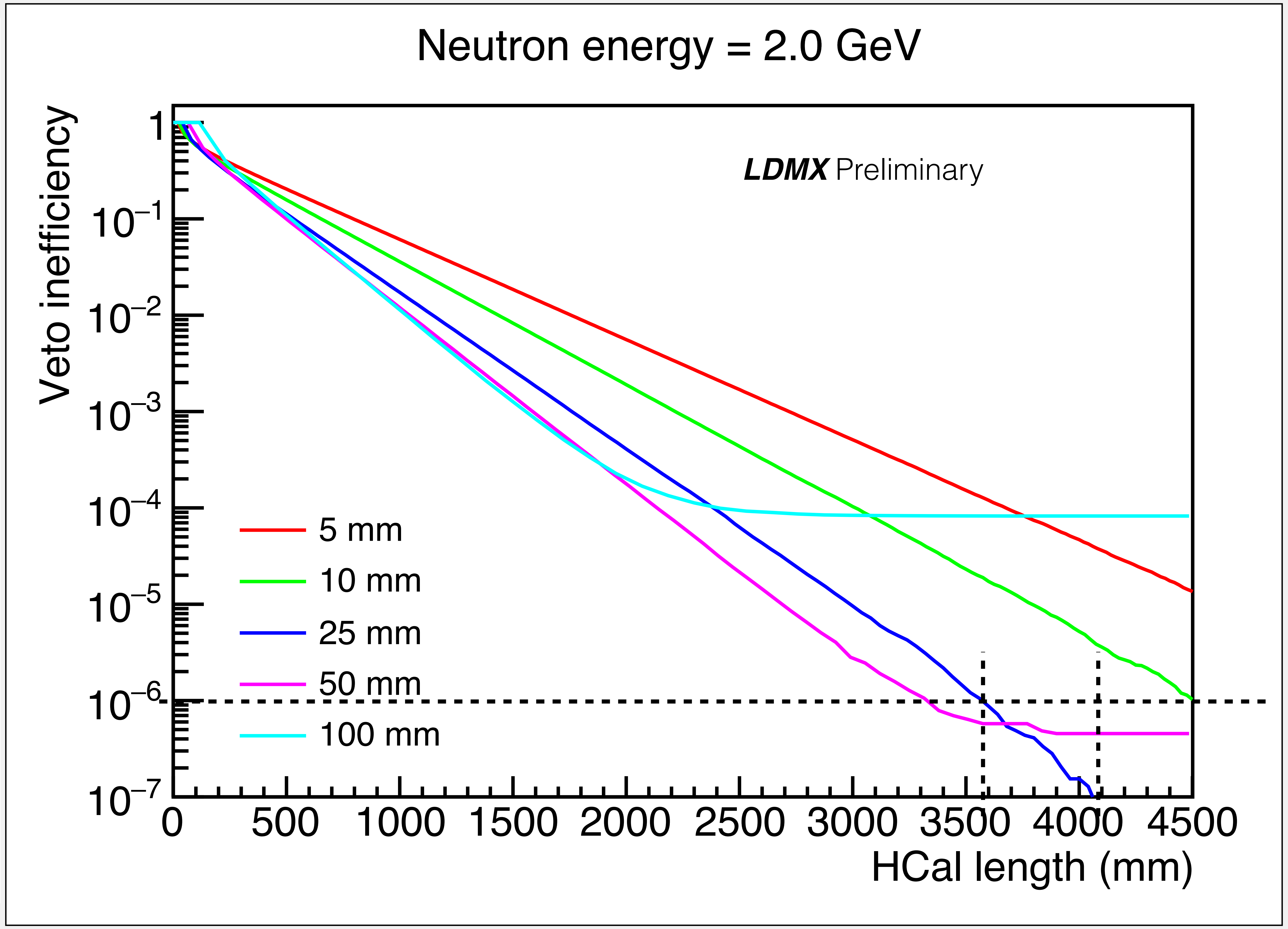
veto inefficiency of at most 10^{-6} for single neutrons (~15λ)

Absorber thickness?

- too thick: neutrons 'get stuck'
  —> no signal in scintillator
- too thin: detector needs to be very large

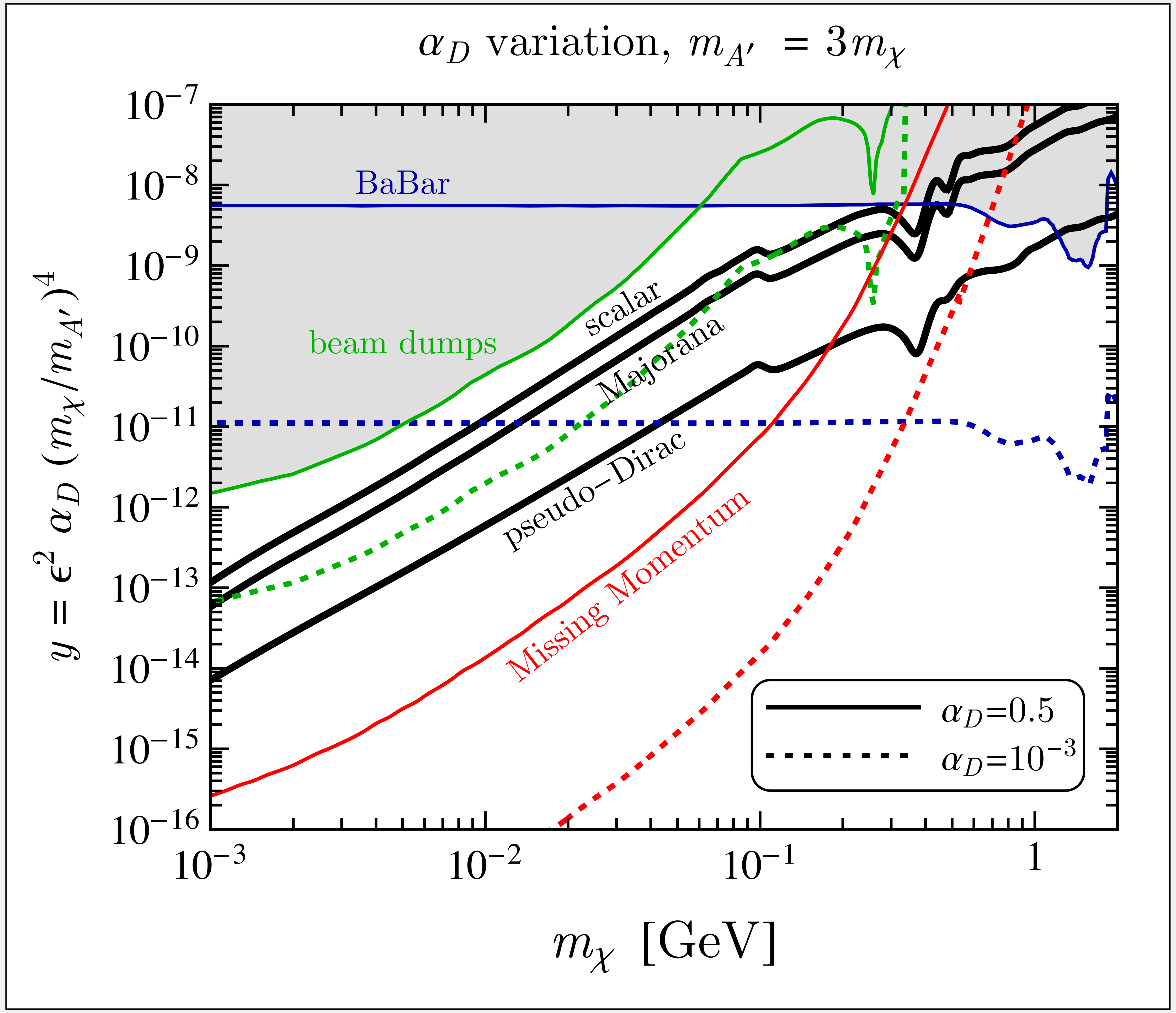
Currently assuming 25mm, 4m deep, transverse size 2-3m

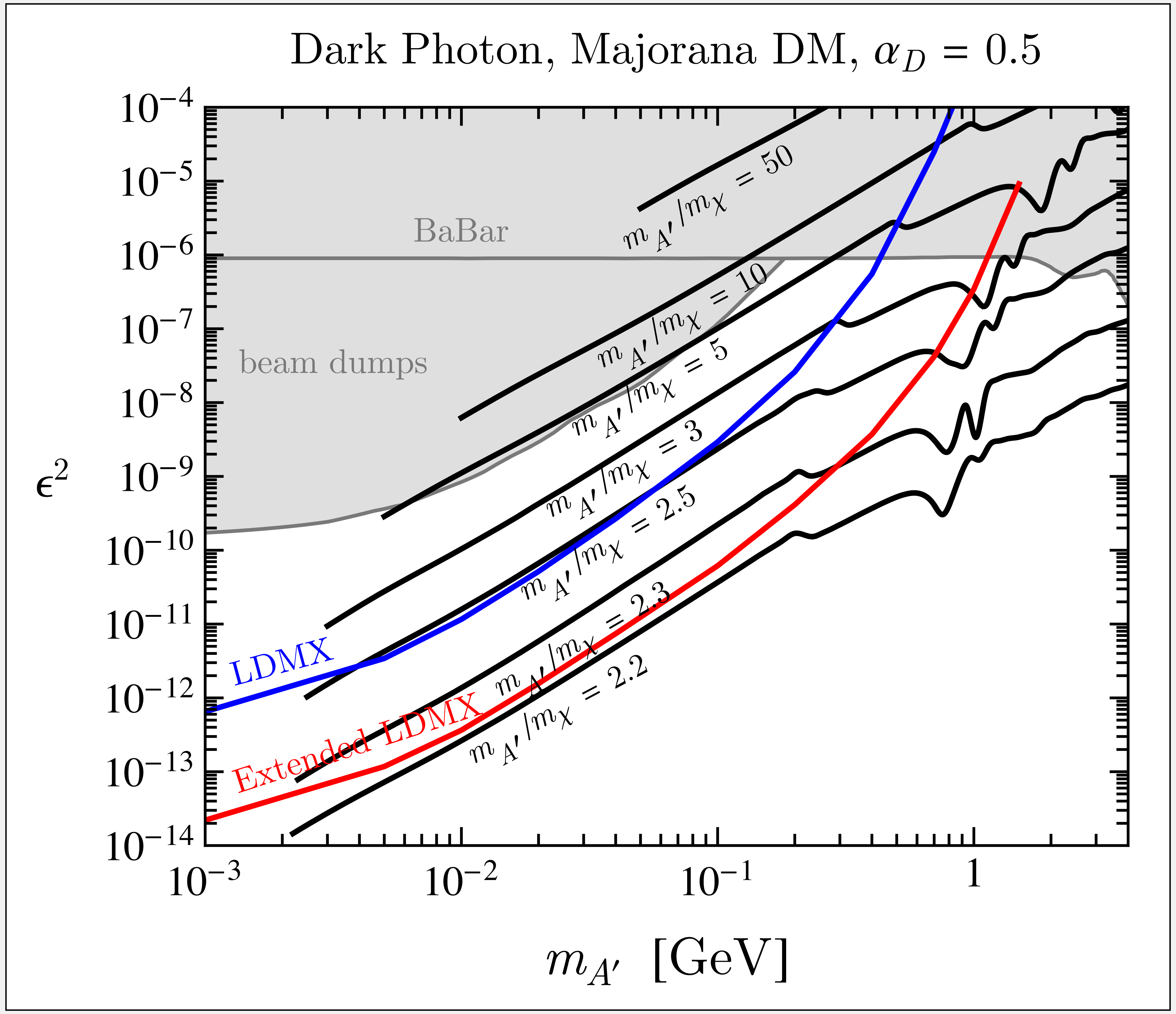
"Side HCal" around the ECal: Similar configuration, few λ deep



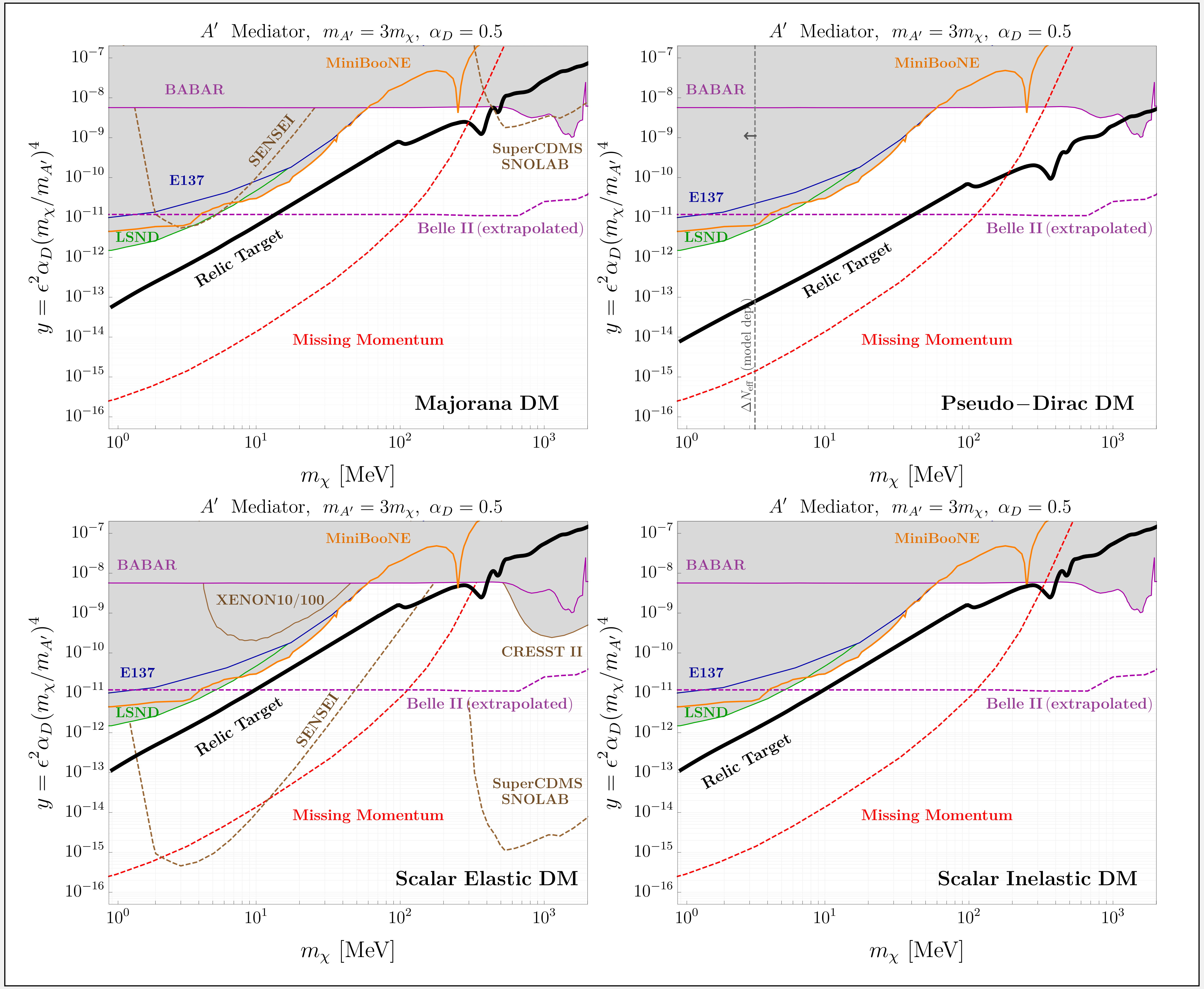
Finalisation of design parameters ongoing

Parameter Dependence





Various Future Projections



LESA @ LCLS-II @ SLAC

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

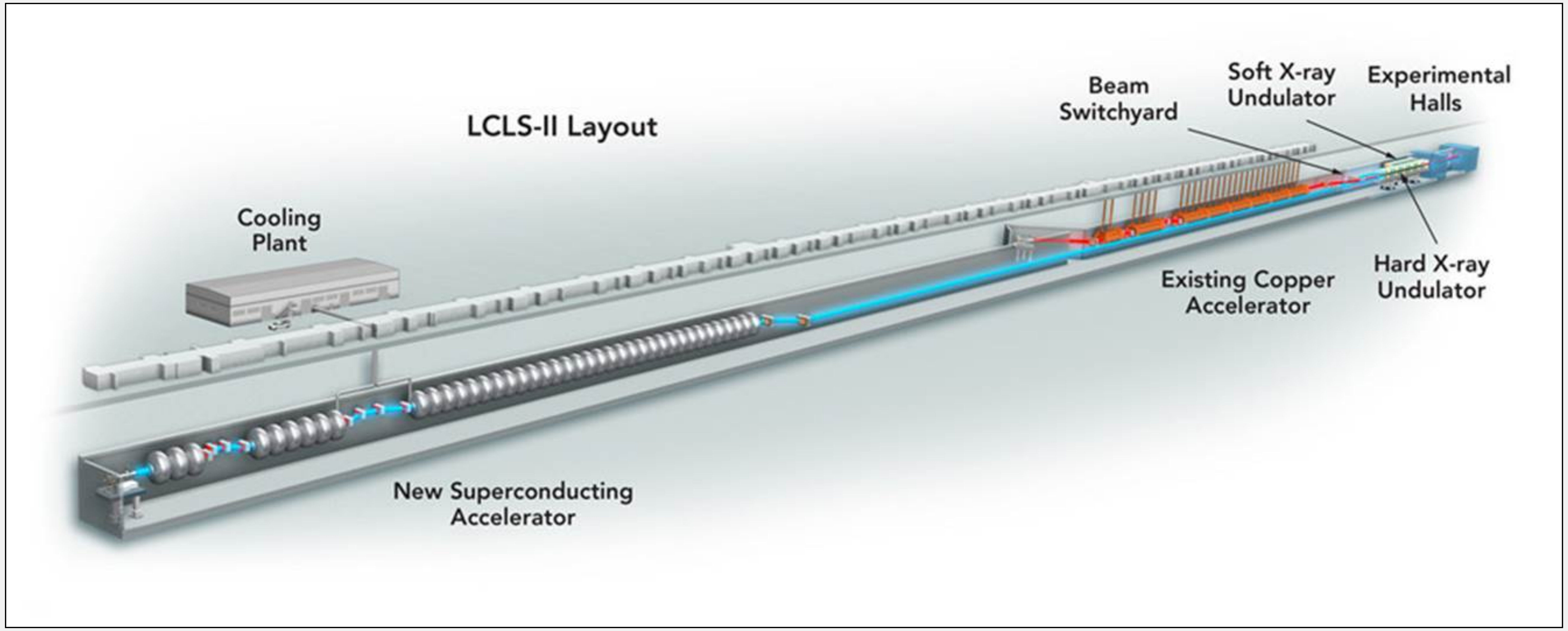
Linac to end station A

Energy: 4 (8) GeV

Bunch frequency: ~40 MHz (186 MHz)

4×10^{14} EoT year 1

Parasitic



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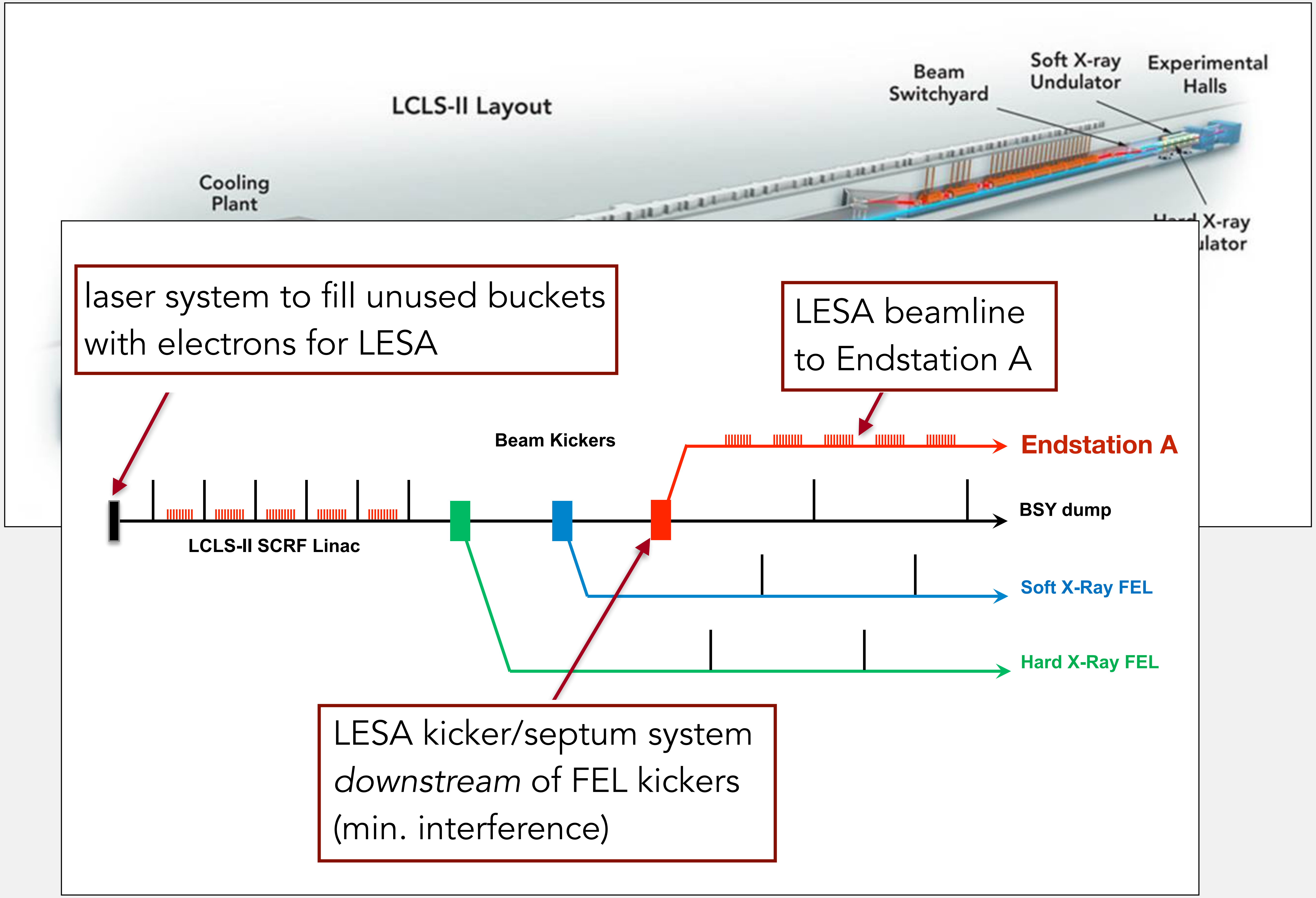

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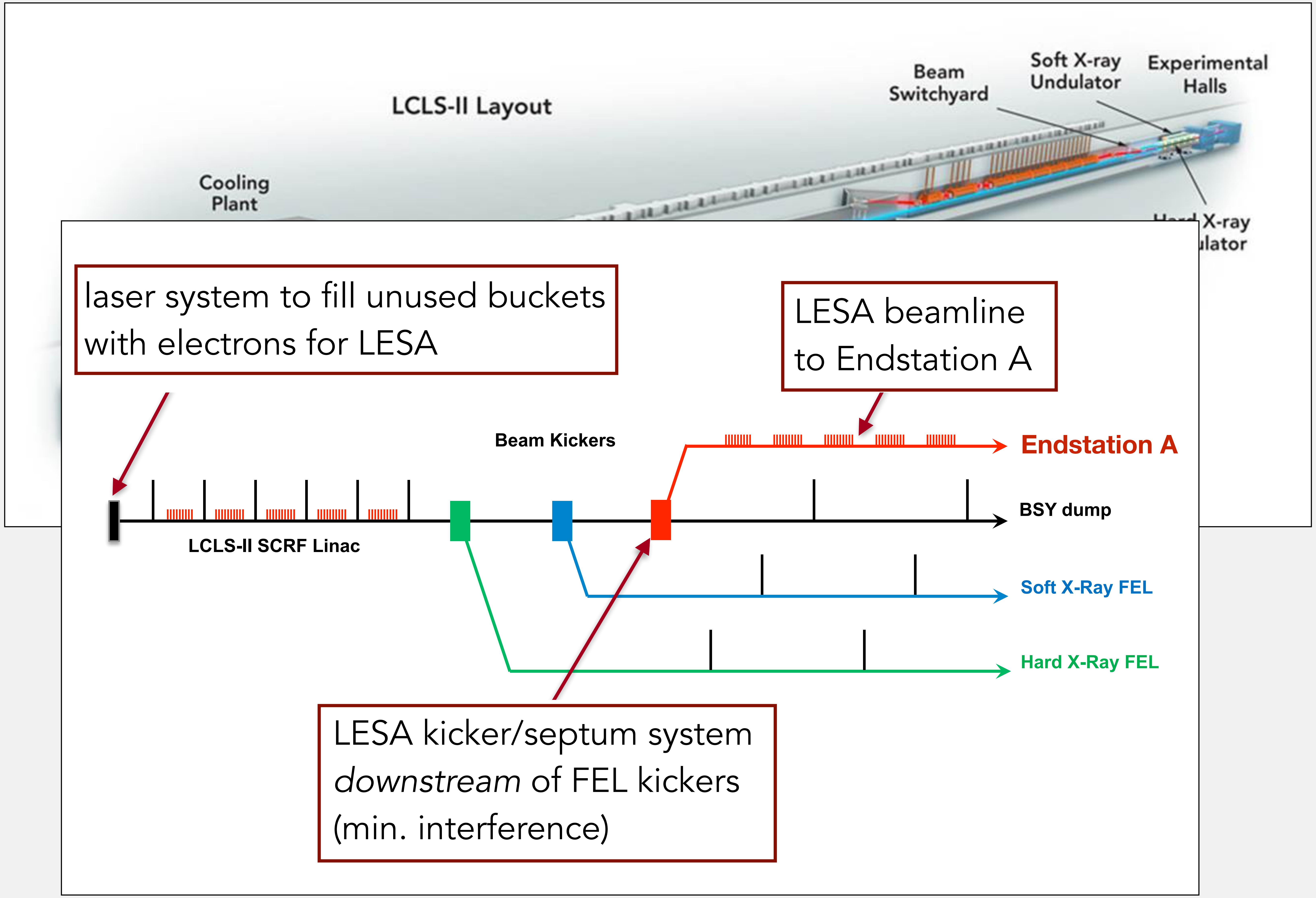
Parasitic

S30 Accelerator Improvement Project (kicker & ~100m beamline – ending in beam switchyard) currently under construction



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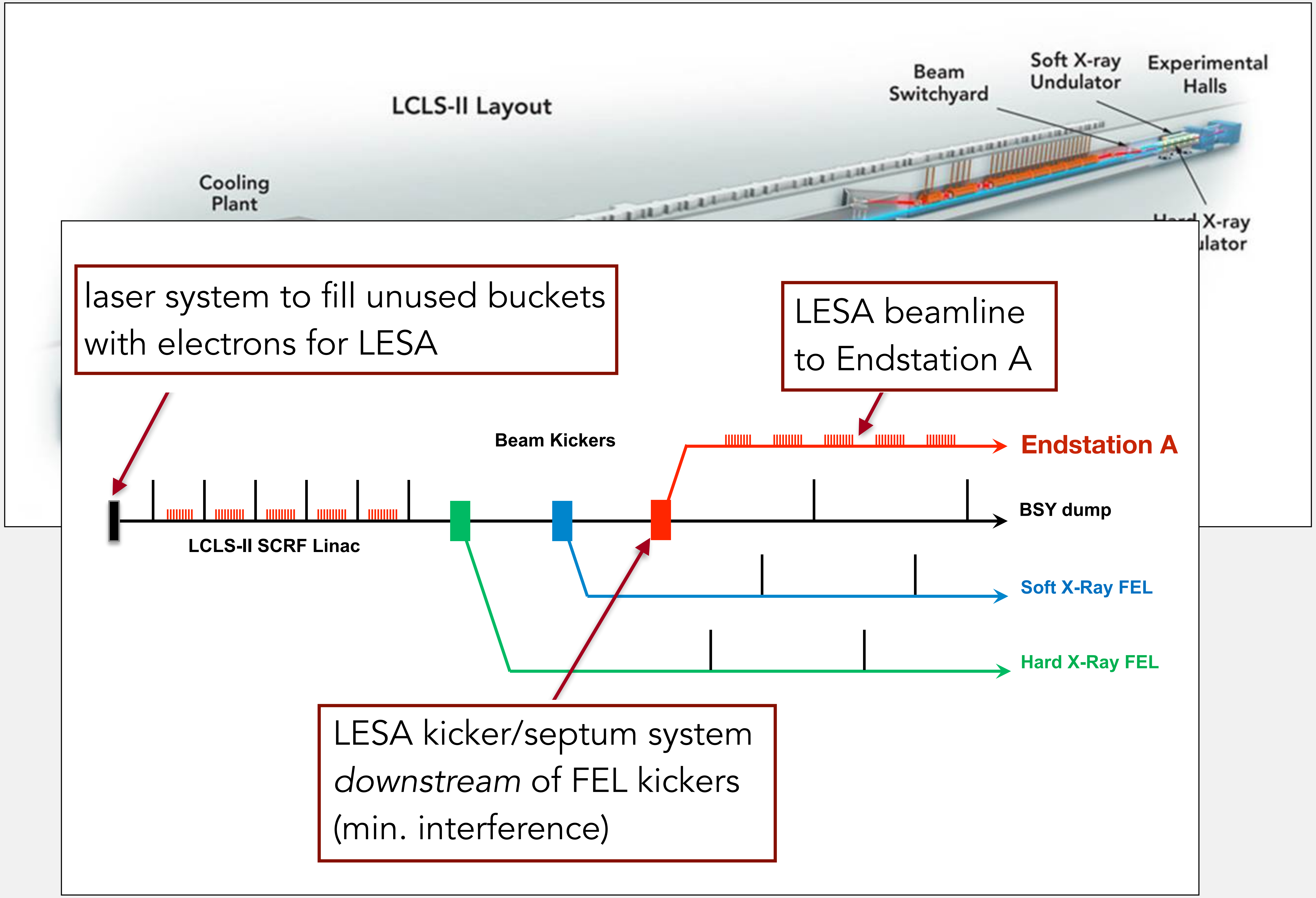
S30 Accelerator Improvement Project (kicker & ~100m beamline – ending in beam switchyard) currently under construction

LESA expected to deliver beam to ESA in late FY23



eSPS at CERN

Get e- back in CERN accelerators, next step for X-band linac developed for CLIC, accelerator R&D

Idea in fall 2017, arxiv:1805.12379 arxiv:1905.07657

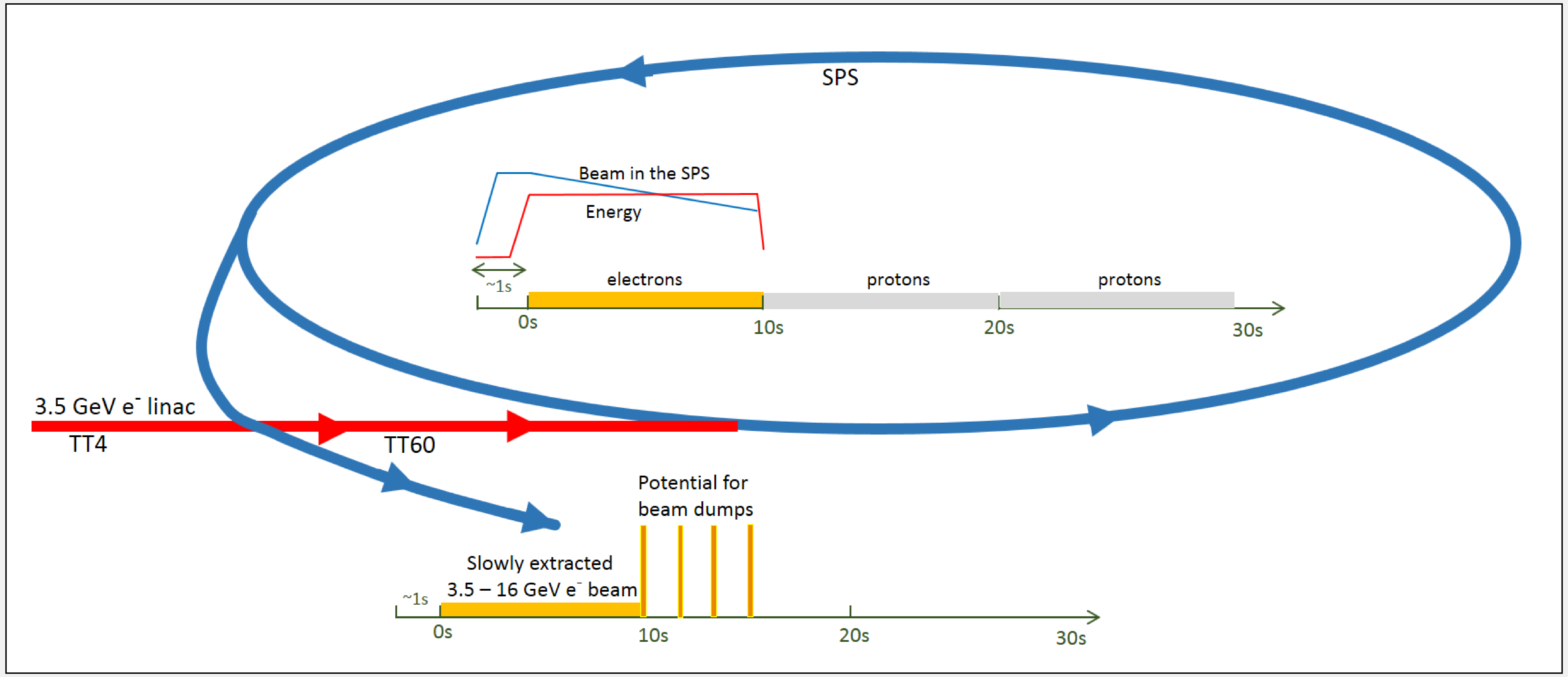
expression of interest to SPSC in October 2018, https://cds.cern.ch/record/2640784

Conceptual Design Report 2020 arxiv:2009.06938

- 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



optimal catering for LDMX-like experiment