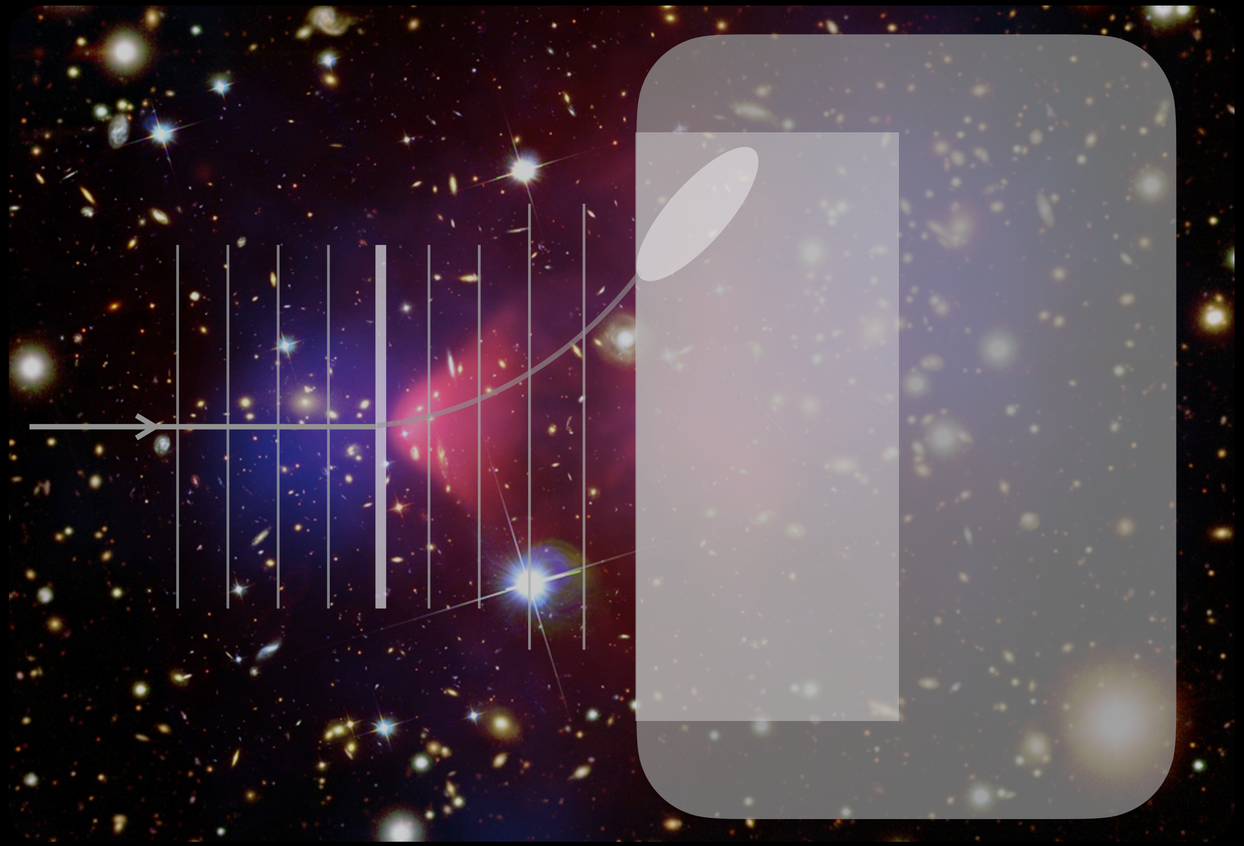
# LDMX

# Light Dark Matter eXperiment — Status, Plans and Prospects



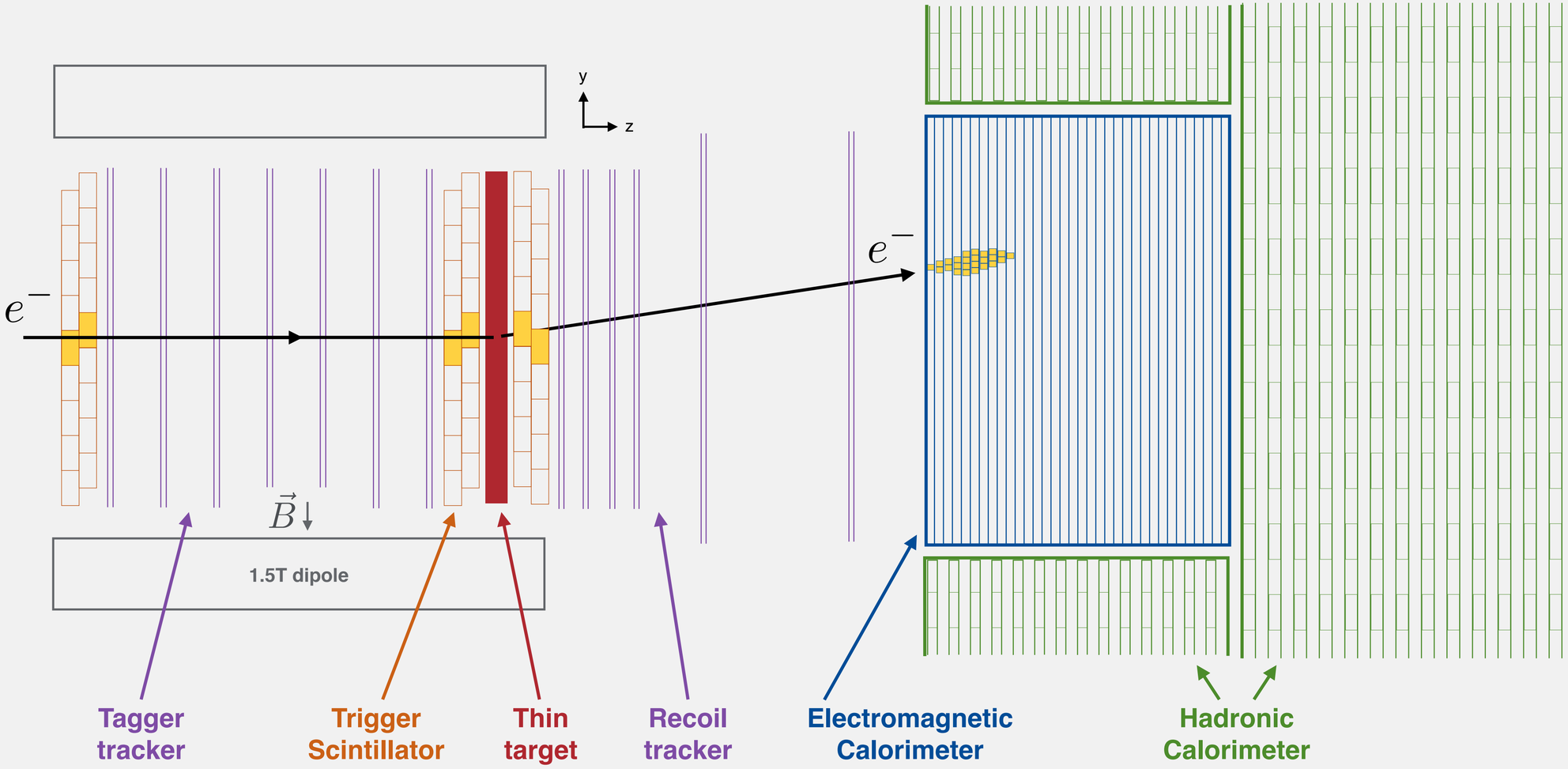
Fysikdagarna

June 2022

Ruth Pöttgen, Lund University

# LDMX

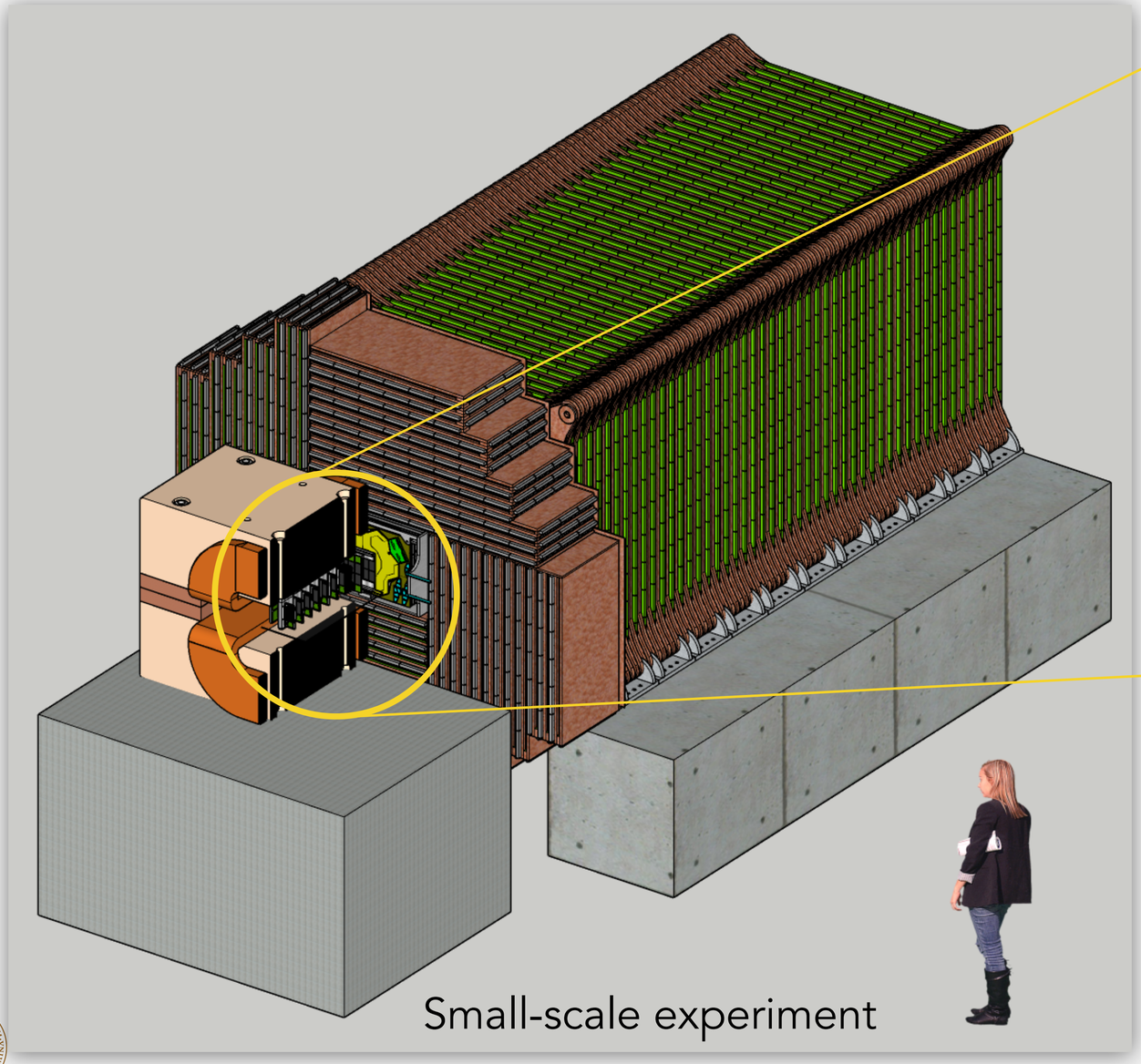
*Individually* measure (missing) energy/transverse momentum for up to $10^{16}$ $e^-$ scattering off a (thin) target (*)

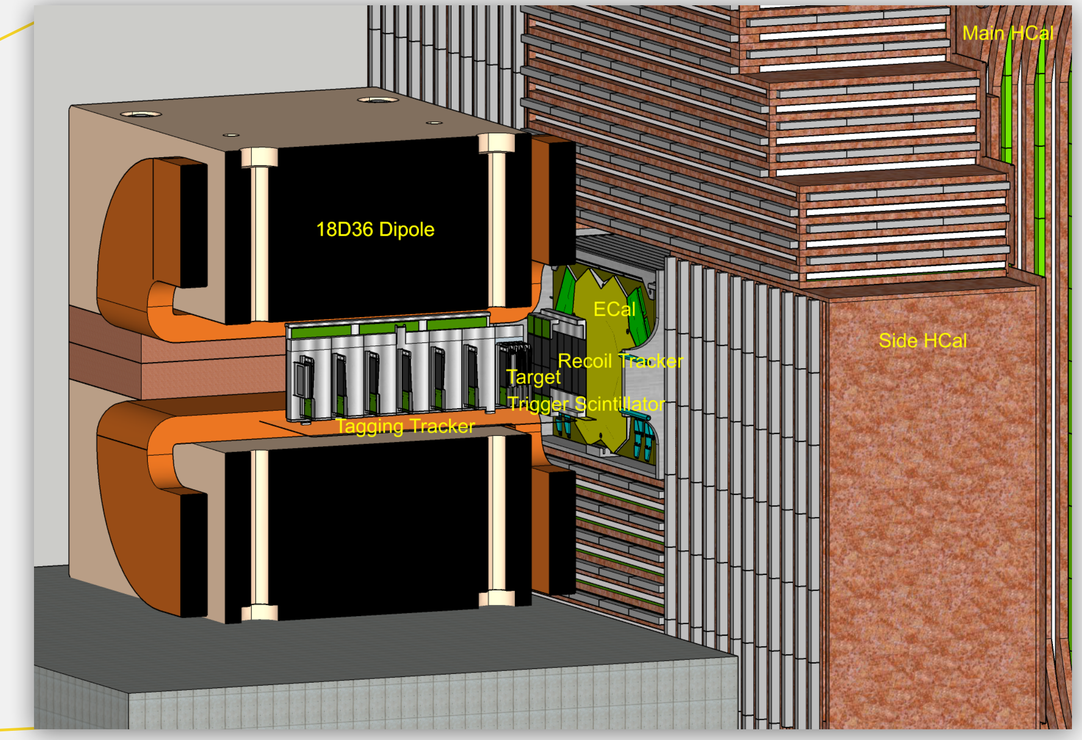



(*) Requires special beam properties, only available at SLAC in the near future

# 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

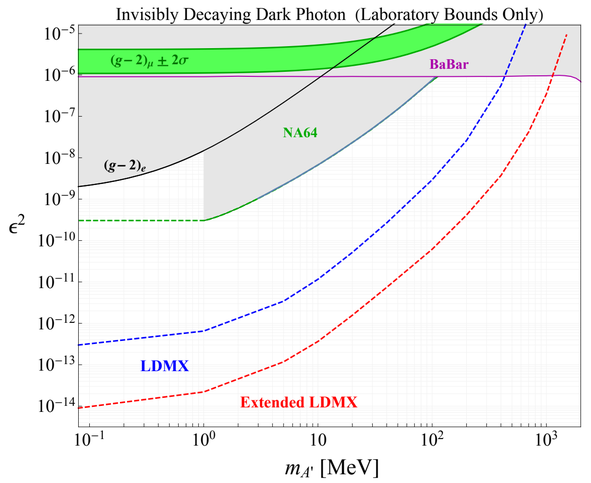
# LDMX Potential

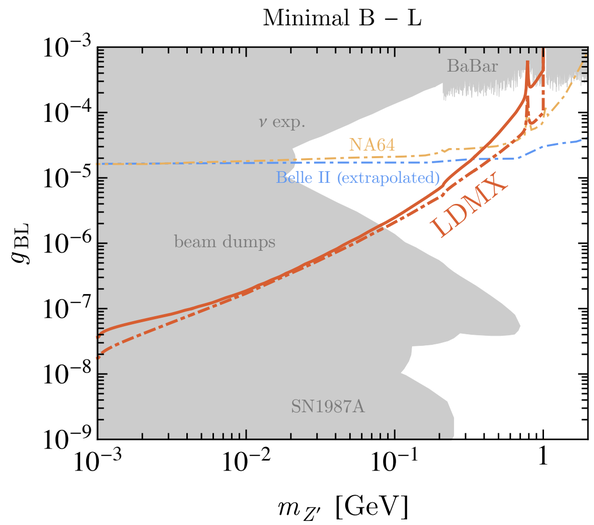
Sensitive to rich spectrum of invisible and visible signatures of new physics

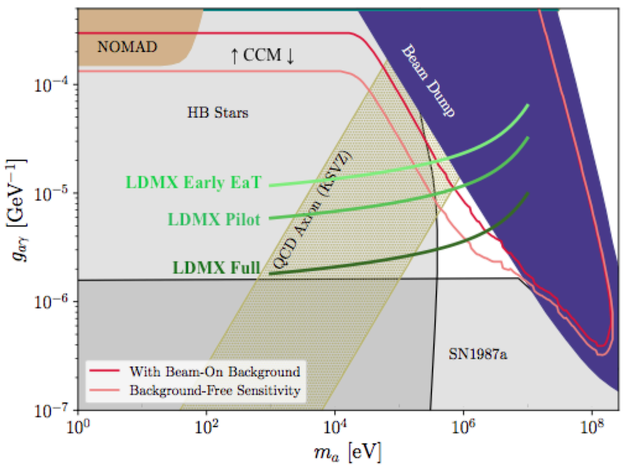
- ***Light (sub-GeV) thermal relic dark matter***
- Dark matter with quasi-thermal origin (asymmetric, SIMP/ELDER scenarios)
- New invisibly decaying mediators in general (A' one example)
- Displaced vertex signatures (e.g. co-annihilation, SIMP)
- Milli-charged particles
- ALPs…

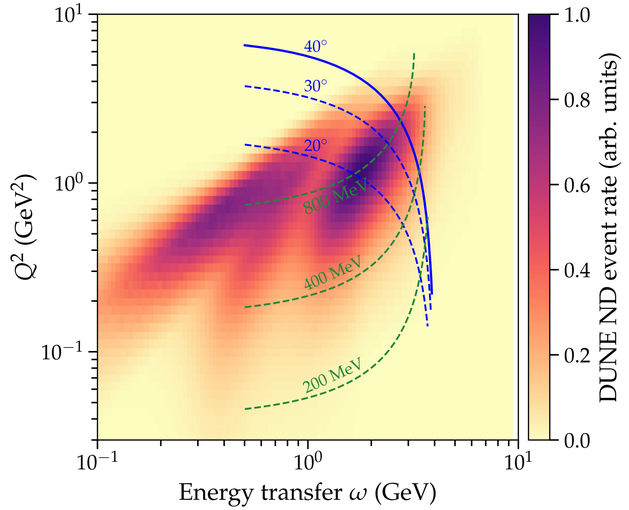
[arxiv:1807.01730](arxiv:1807.01730) [arxiv:2203.08192](arxiv:2203.08192)

In addition: ***Measurement*** of photo- and electro-nuclear processes (for neutrino experiments), e.g. [Phys. Rev. D 101, 053004](Phys. Rev. D 101, 053004)



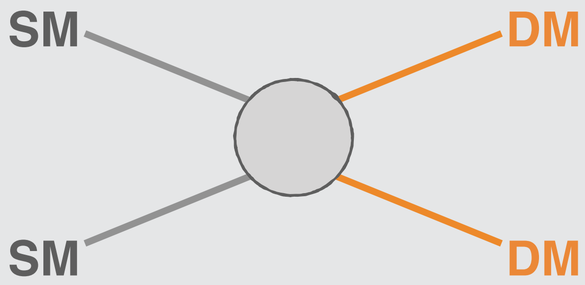



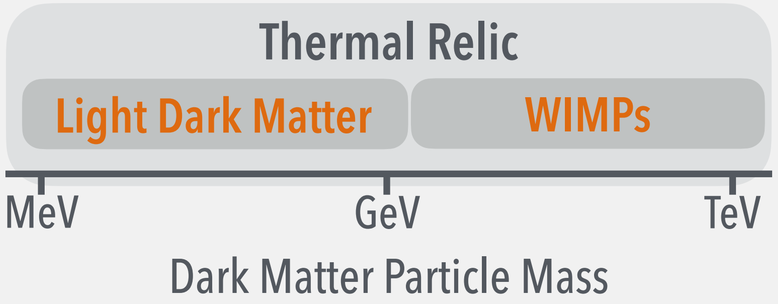



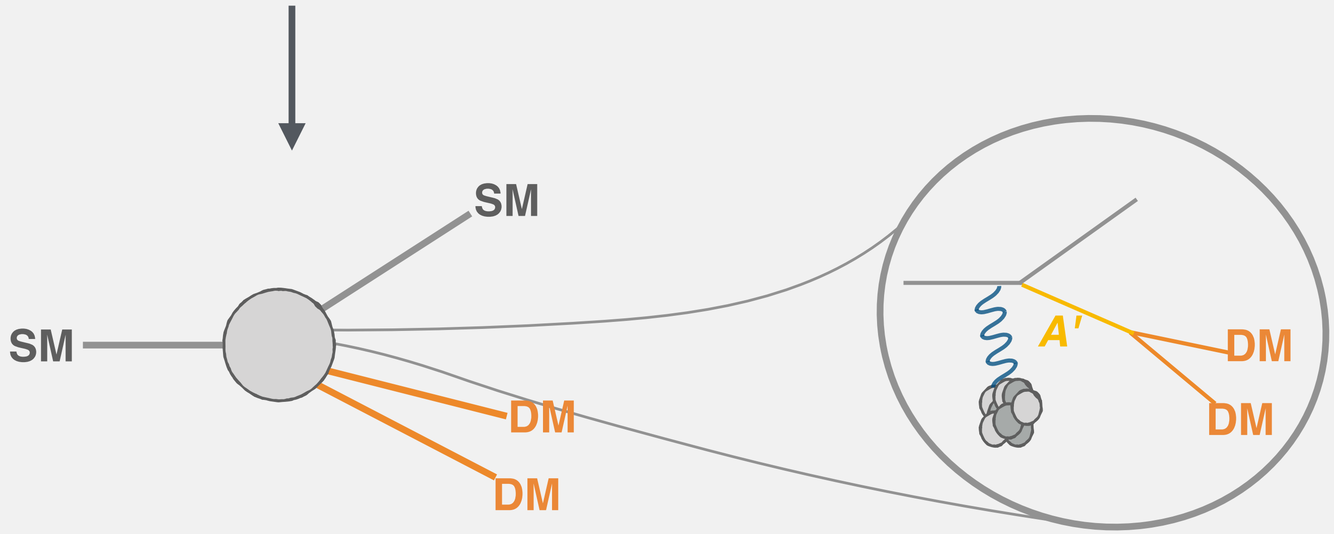
# Why sub-GeV dark matter?

**Thermal origin** of Dark Matter




Allowed mass range: MeV - TeV




Production mechanism at accelerators

*Benchmark model*:

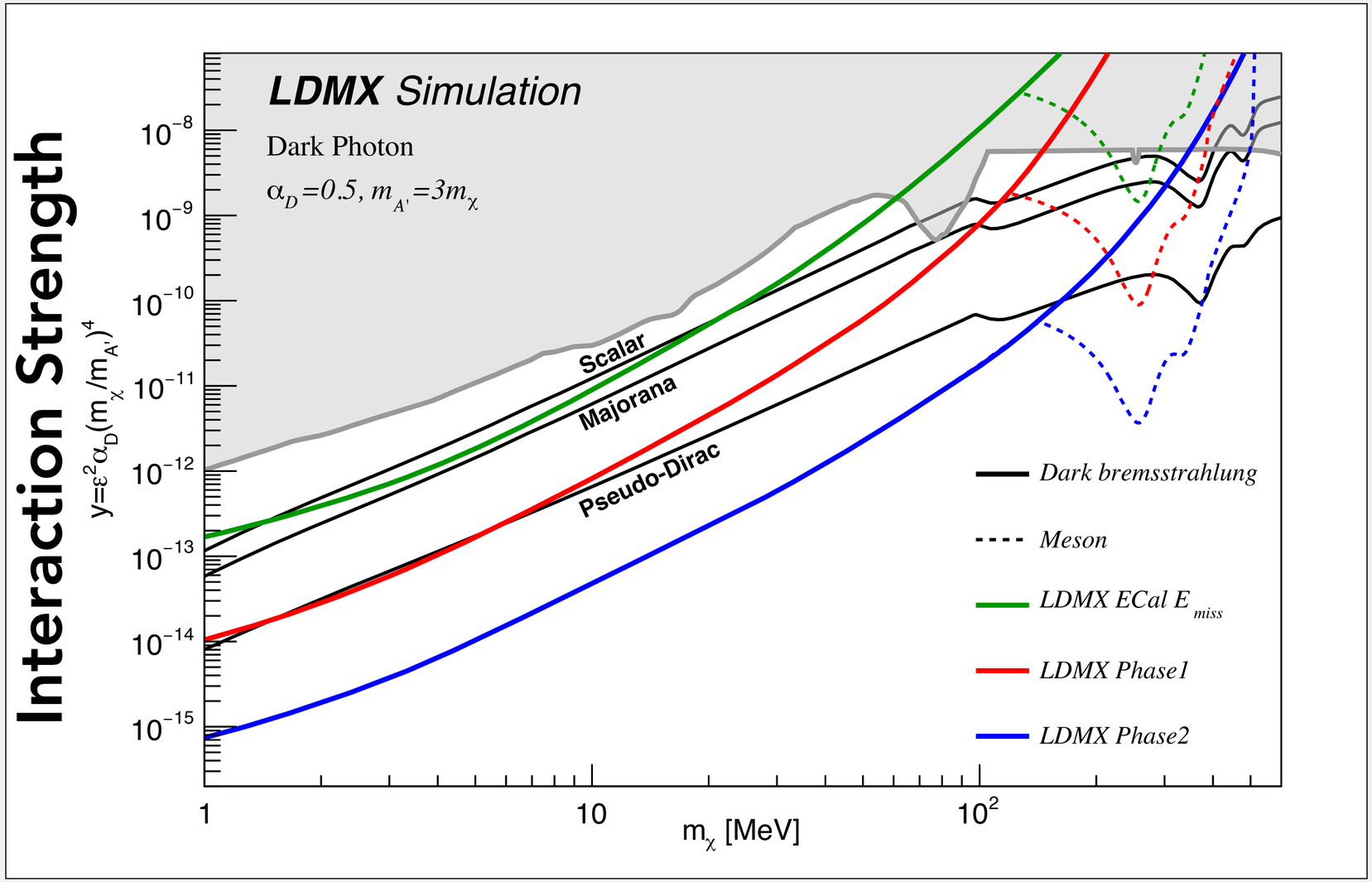
**Dark photon** (A') as new light mediator

$m_{A'} > 2m_{\chi}$ —> invisible decay

Production e.g. via dark bremsstrahlung or invisible meson decays

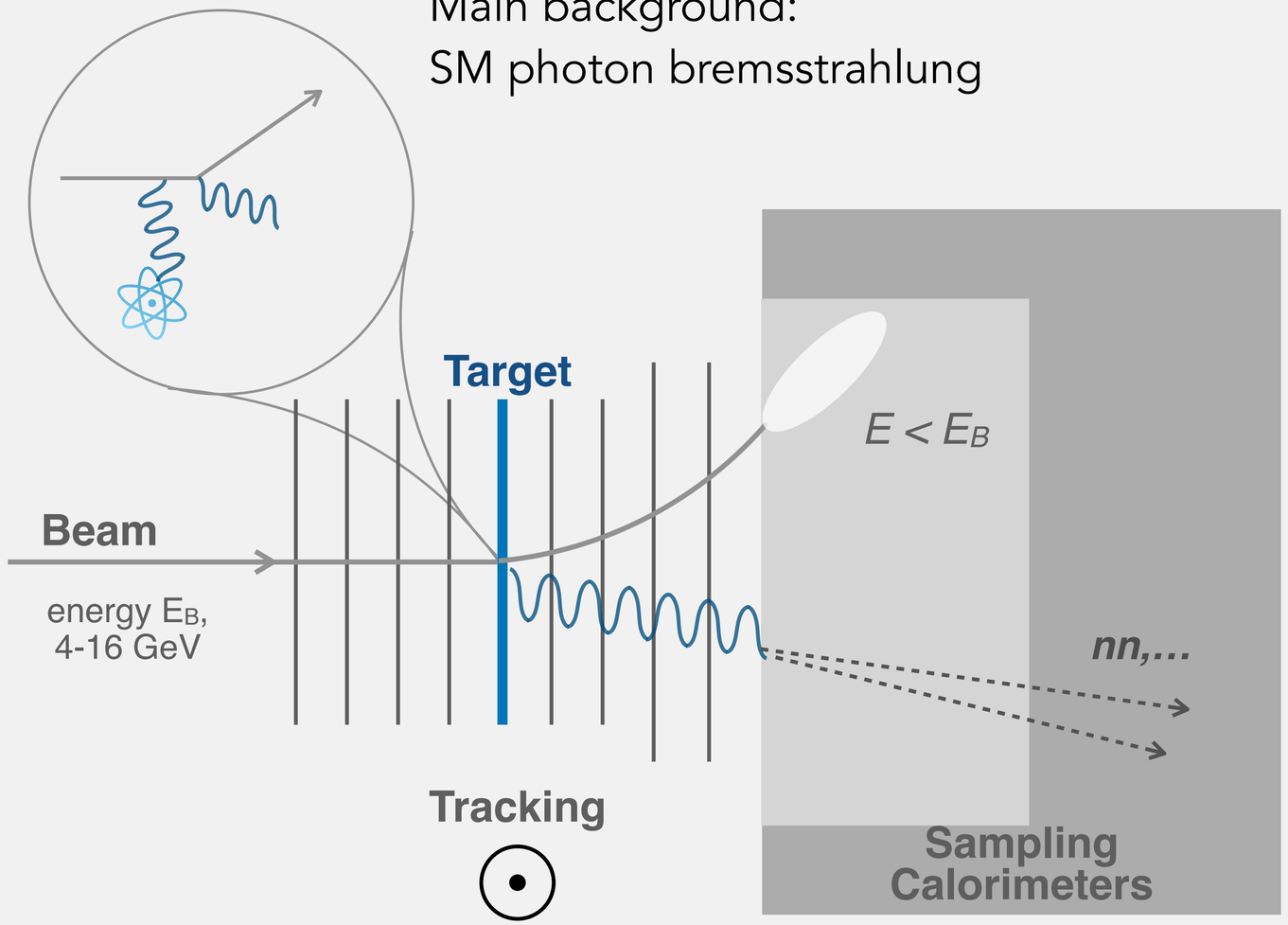
Phys. Rev. D 105, 035036 (2022)

# Projected Sensitivity



# Challenges for LDMX

Main background:
SM photon bremsstrahlung




Particularly challenging:

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

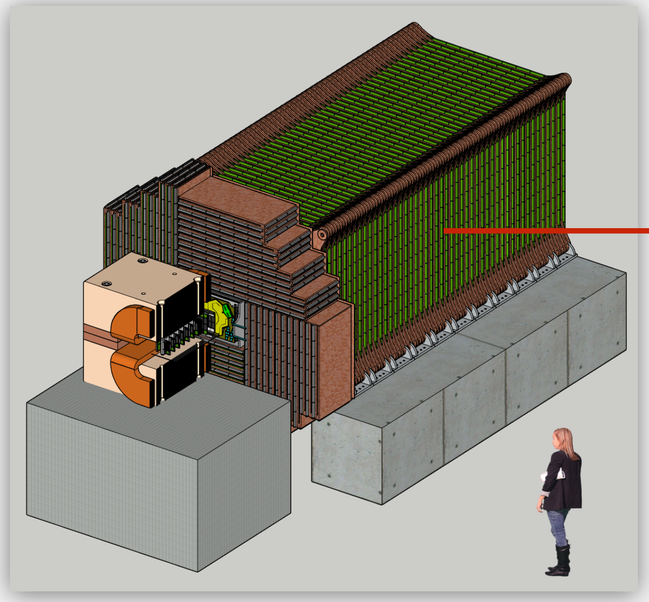
Design drivers, especially for HCal!

# Hadronic Calorimeter

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

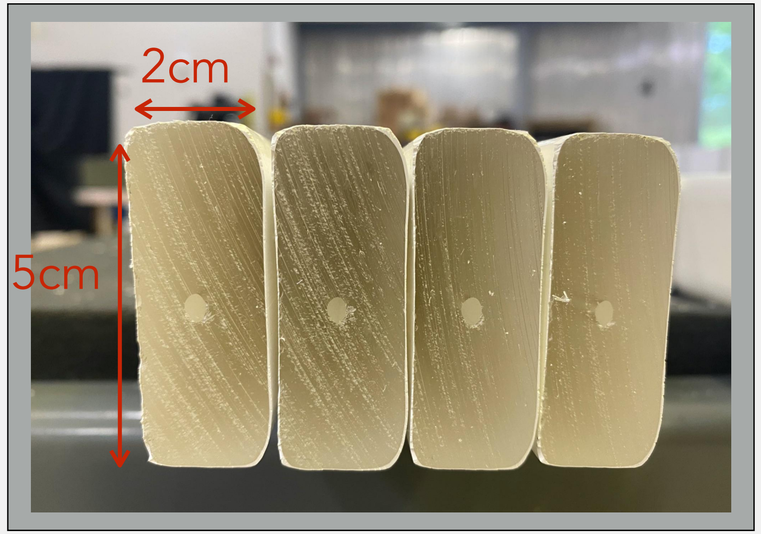
- Inefficiency of ~$10^{-6}$

- 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



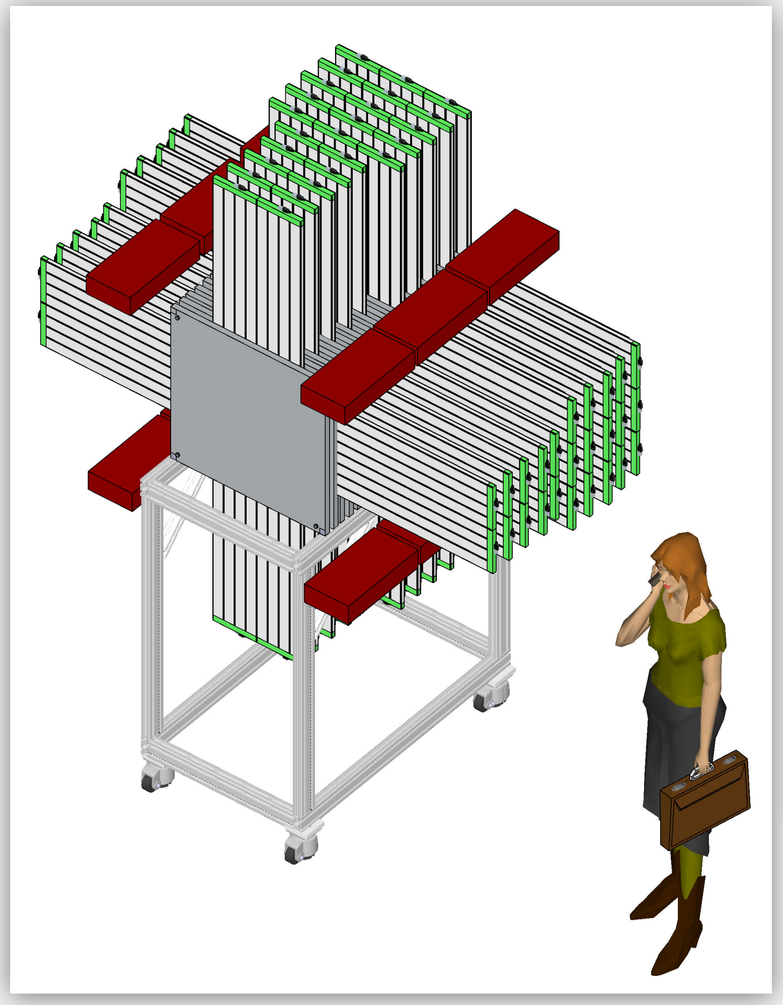

**Prototype for beam tests at CERN (April 2022 )**

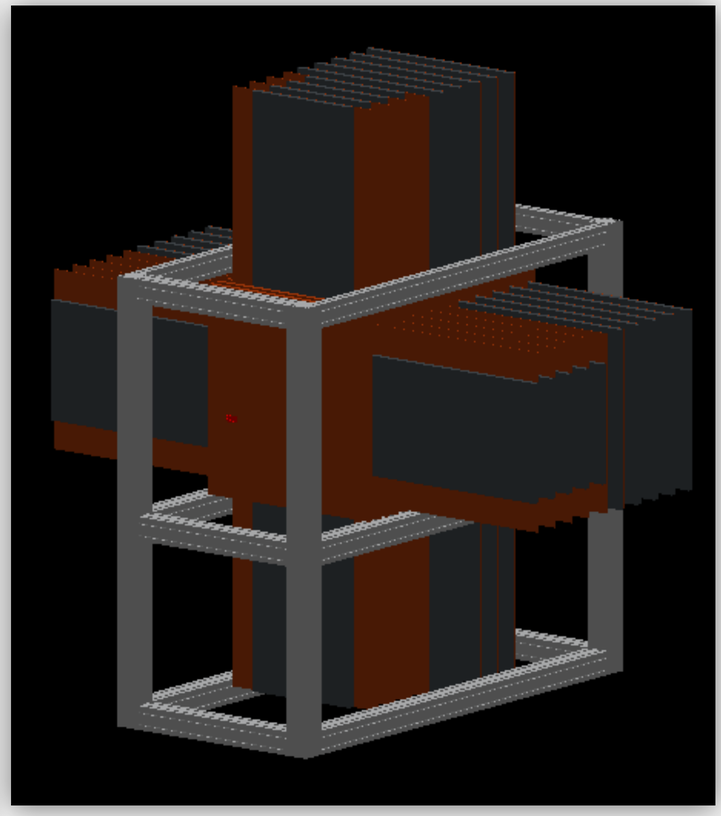
*See poster by Péter György*

# HCal Prototype & Test Beam

Goals:

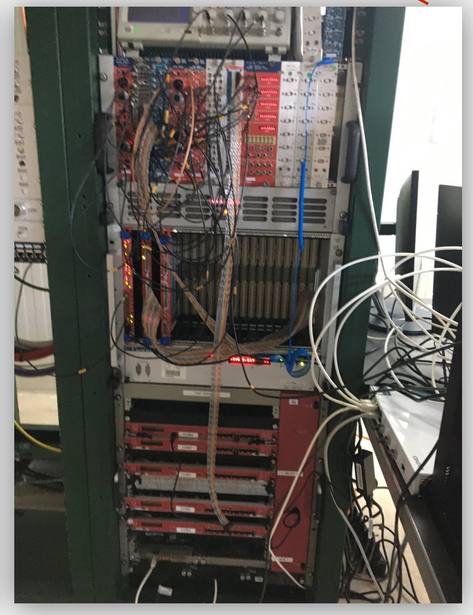
- Validate simulations against data
- Test mechanical and electronic designs
- Practice readout chain & data acquisition

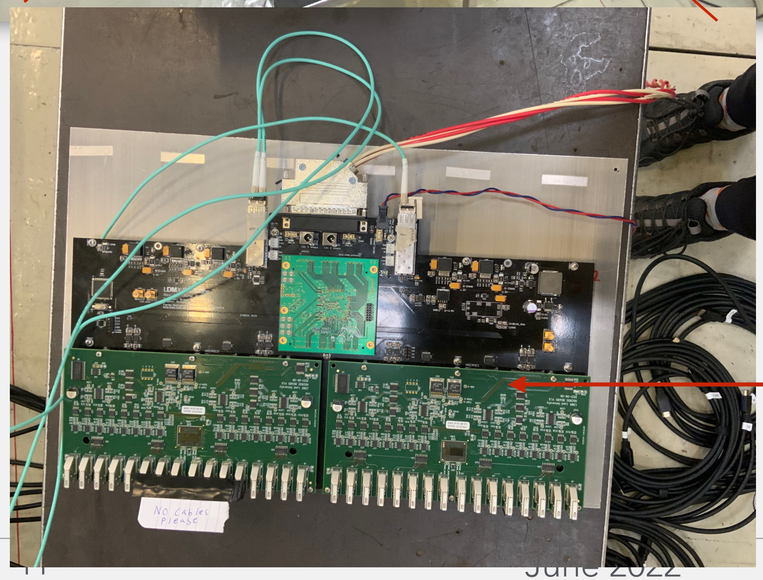




# Test Beam

# Test Beam

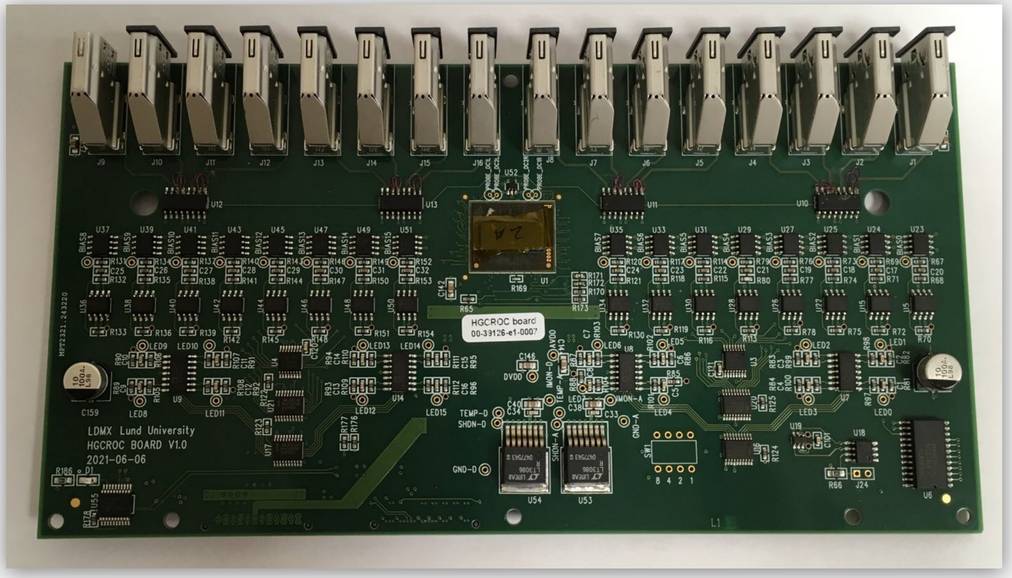


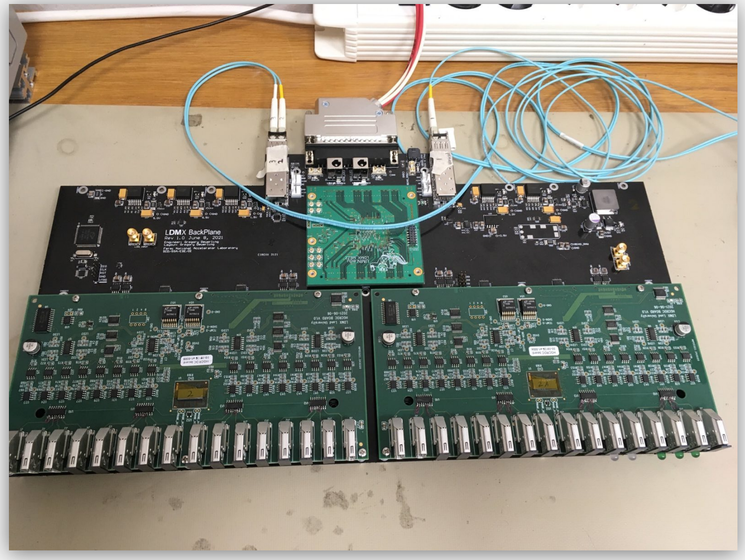


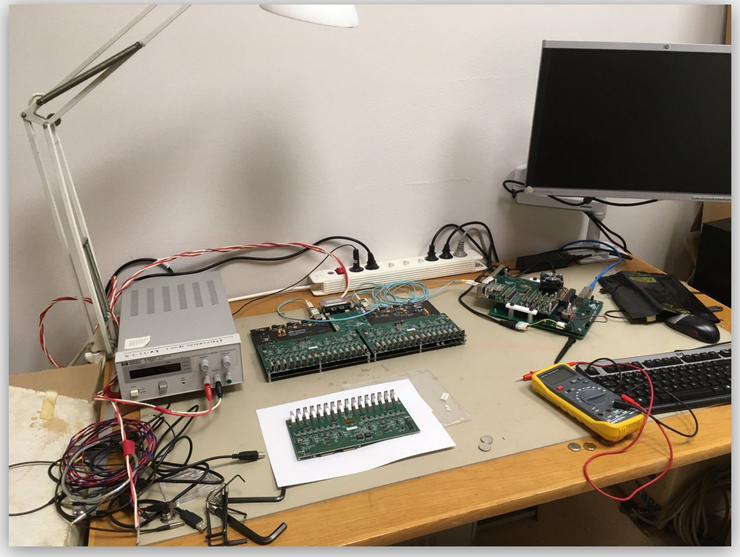
"HGCROC Board",
designed in Lund

# Test Beam Electronics

Continuing work on the readout system in Lund

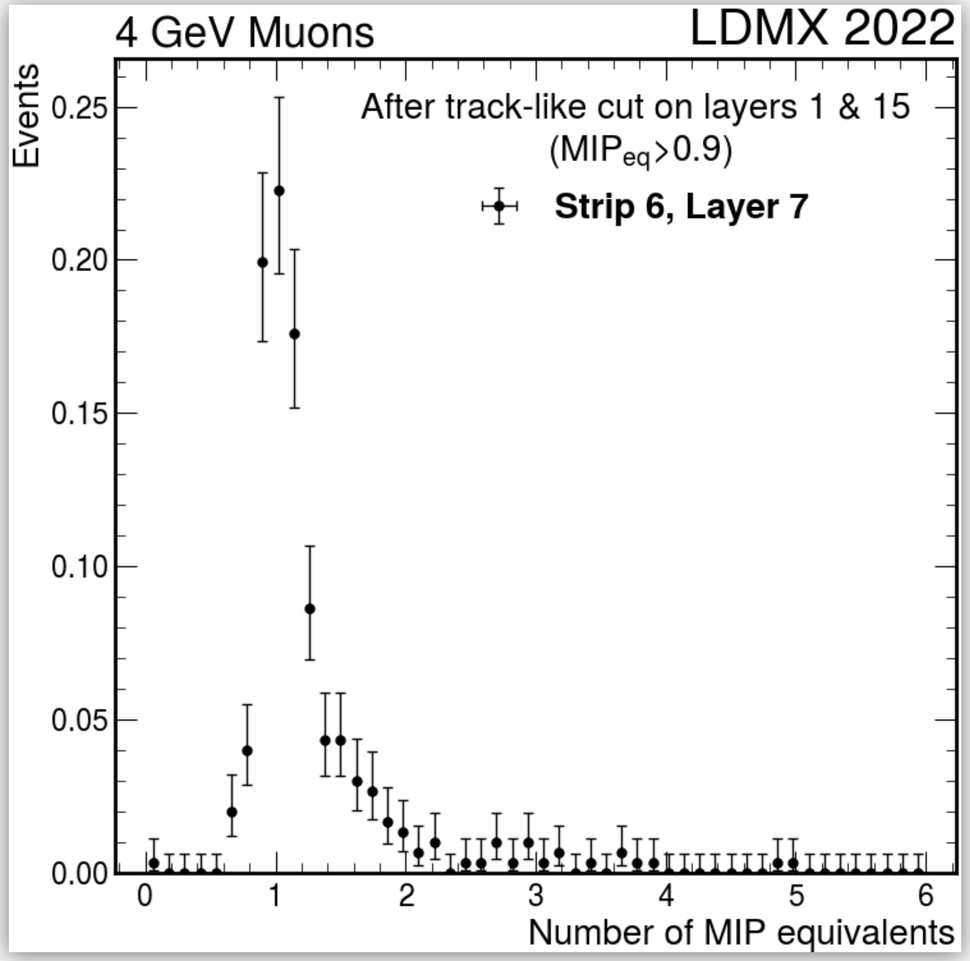


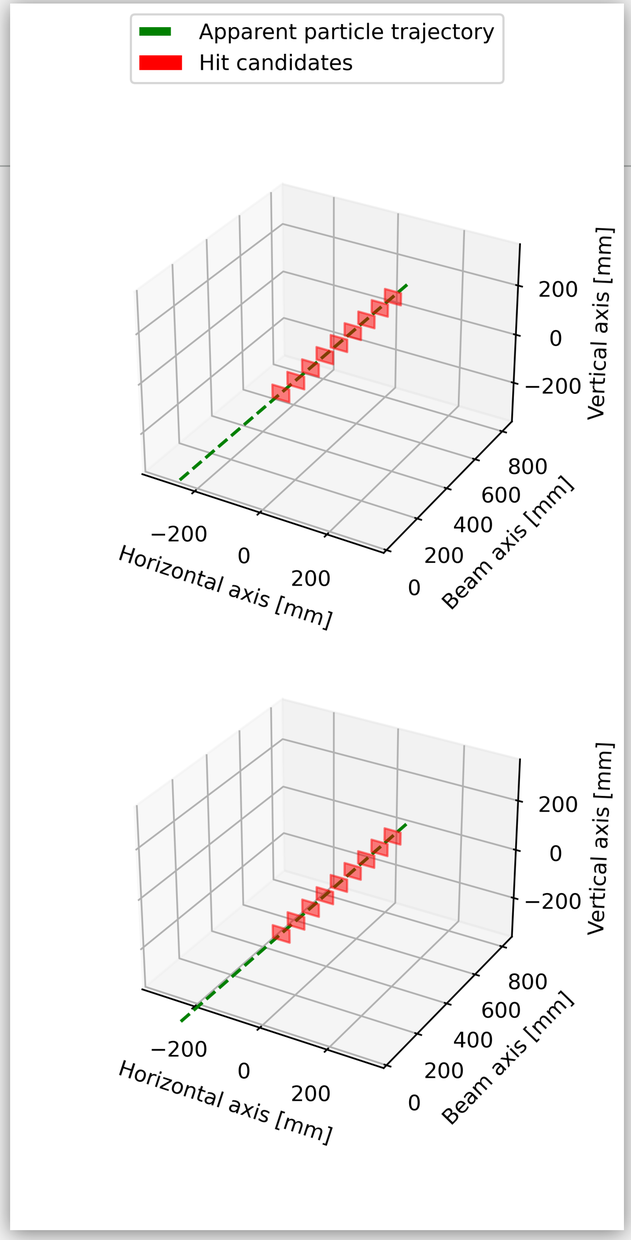



# Test Beam Data

Analysis of data is work in progress




Starting to understand & verify basic properties of the device

# Change of Topic!


**Rejection of the Photon Induced Background in LDMX at 8 GeV**

Erik Wallin

Thesis submitted for the degree of Master of Science
Project duration: 9 months

Supervised by Ruth Pöttgen and Torsten Åkesson

Department of Physics
Division of Particle Physics
June 2022

# 8 GeV Background Veto

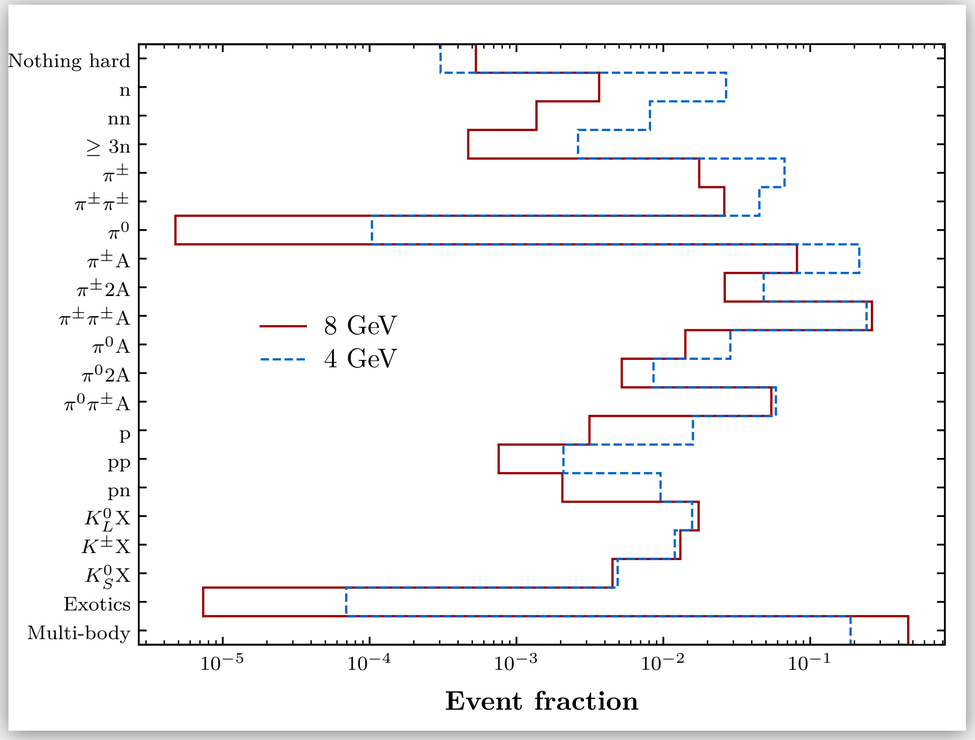
Recently completed masters' project by Erik Wallin

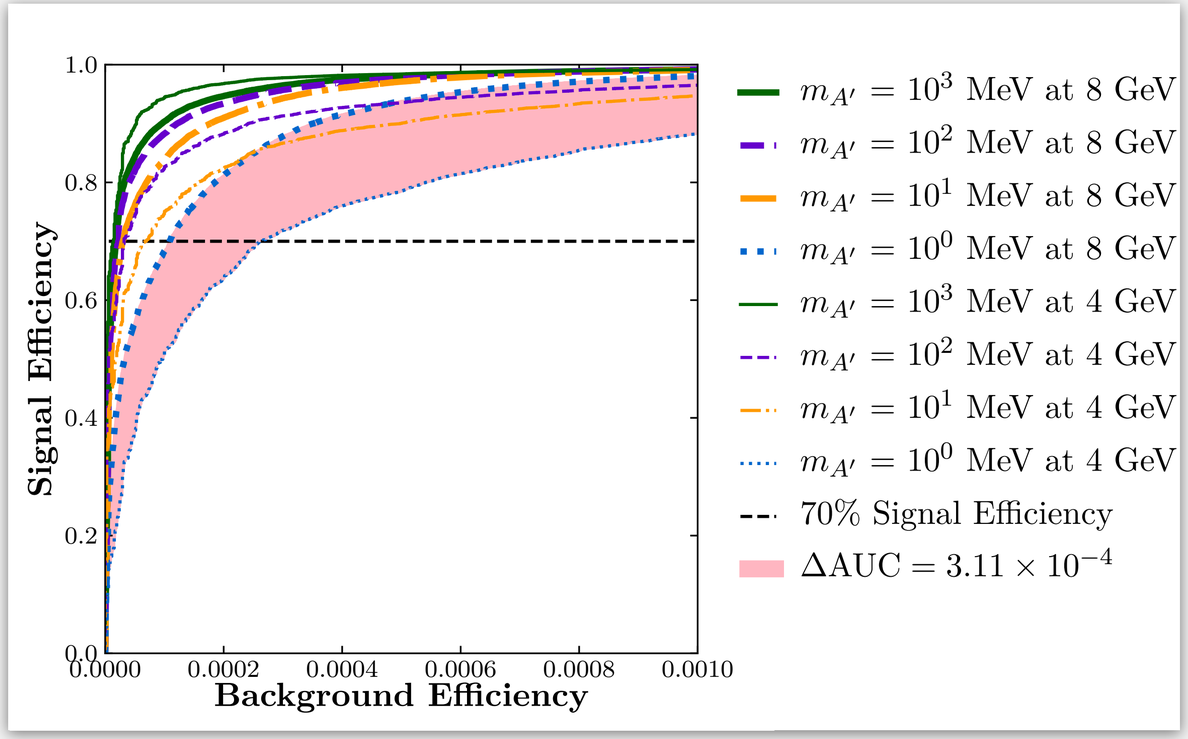
Majority of LDMX data will be taken at 8 GeV!

Advantages: Higher signal yields

Challenging background scaling as $1/E^3$

More energy "to be seen" (harder to fake missing energy signature)




**Expect improved background rejection at ~same signal efficiency**

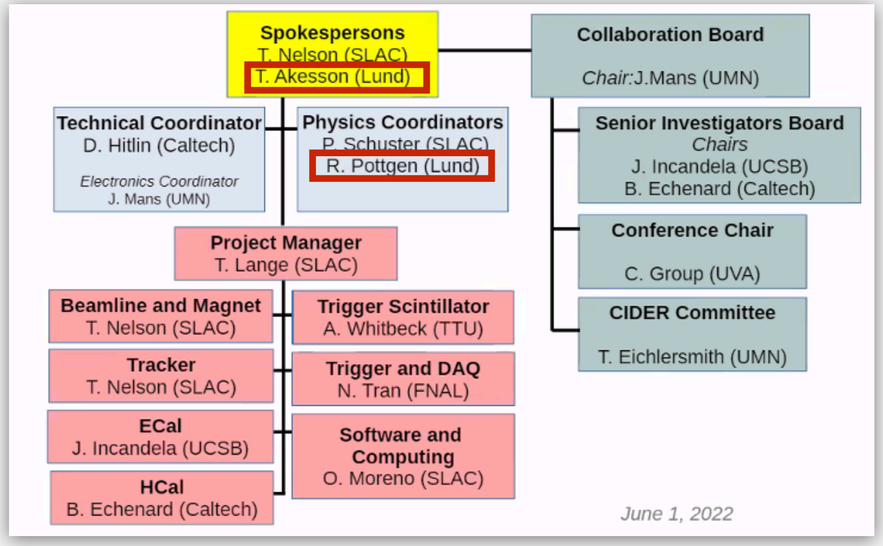
# LunDMX Group

Three senior staff:


Hannah Herde

RP

Torsten Åkesson




Postdoc:

Lene Kristian Bryngemark

LU/Stanford via KAW scholarship

Co-coordinator/lead developer for distributed computing system, LDCS

Ph.D. students:

Einar Elén

Erik Wallin (from Sep.)

Master students:

Lisa Andersson Loman

Péter György

Researcher: *Balazs Konya*
(Co-coordinator for LDCS)

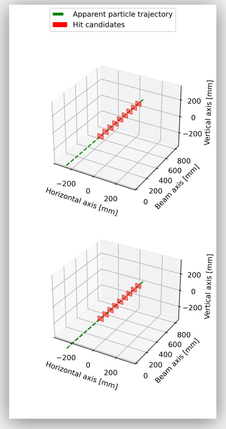
Engineer: *Lennart Österman*

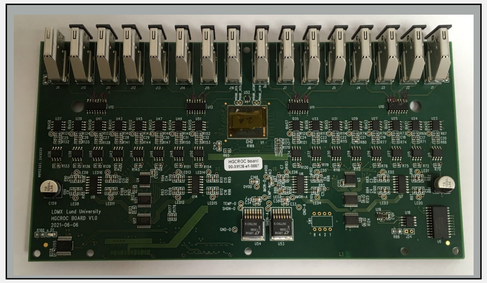
Bachelor student: *Jesper Strobel*

# What we do

HCal prototype/testbeam See poster by Péter

(LU initiative made possible thanks to Crafoord Foundation)

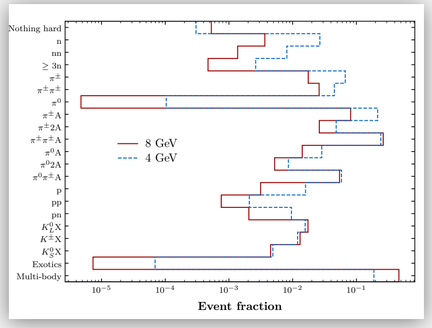


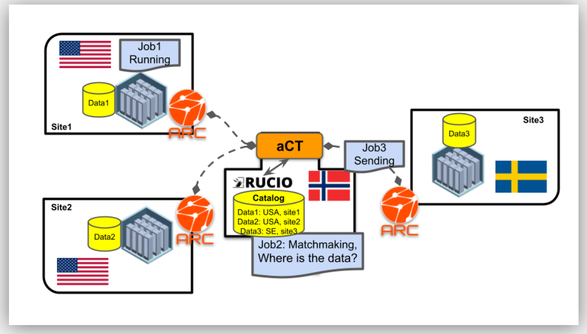
Readout Electronics for HCal (prototype)

Studies at higher beam energy

General physics modelling studies, generator comparisons




Lightweight Distributed Computing System (LDCS):
LU initiative, piloted by LU/Caltech/UCSB within
LDMX plus Oslo (D. Cameron) arxiv:2105.02977




Funded by
Crafoord Foundation, Knut and Alice Wallenberg Foundation, See talks by Timon Emken and Taylor Gray
L'Oréal-UNESCO FWIS, Royal Physiographical Society of Lund, Swedish Research Council

# Summary & Outlook

- LDMX powerful tool to search for new physics in forward electron scattering
- Can achieve outstanding sensitivity to sub-GeV dark matter (in O(years))
- Recent milestones in terms of detector development and physics studies
- LU group leading activities in various areas
- First data early 2025

The next few years will be exciting!

More information:

LDMX Confluence Webpage (with links to talks etc.)

Arxiv:1808.05219 (White Paper)

J. High Energ. Phys. 2020, 3 (2020) (Photon Veto Paper)

Arxiv:2203.08192 (Snowmass contributed White Paper)

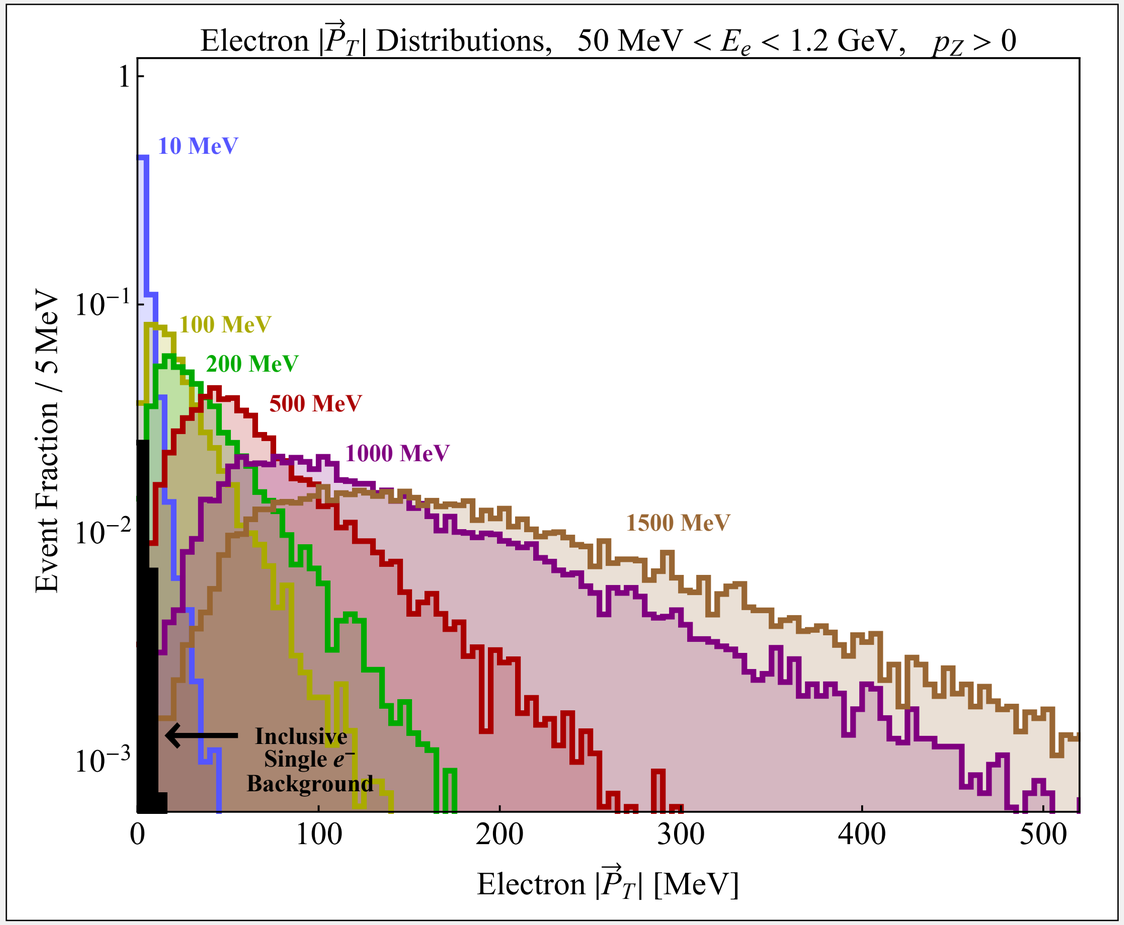

*[Craig Group & Son]*

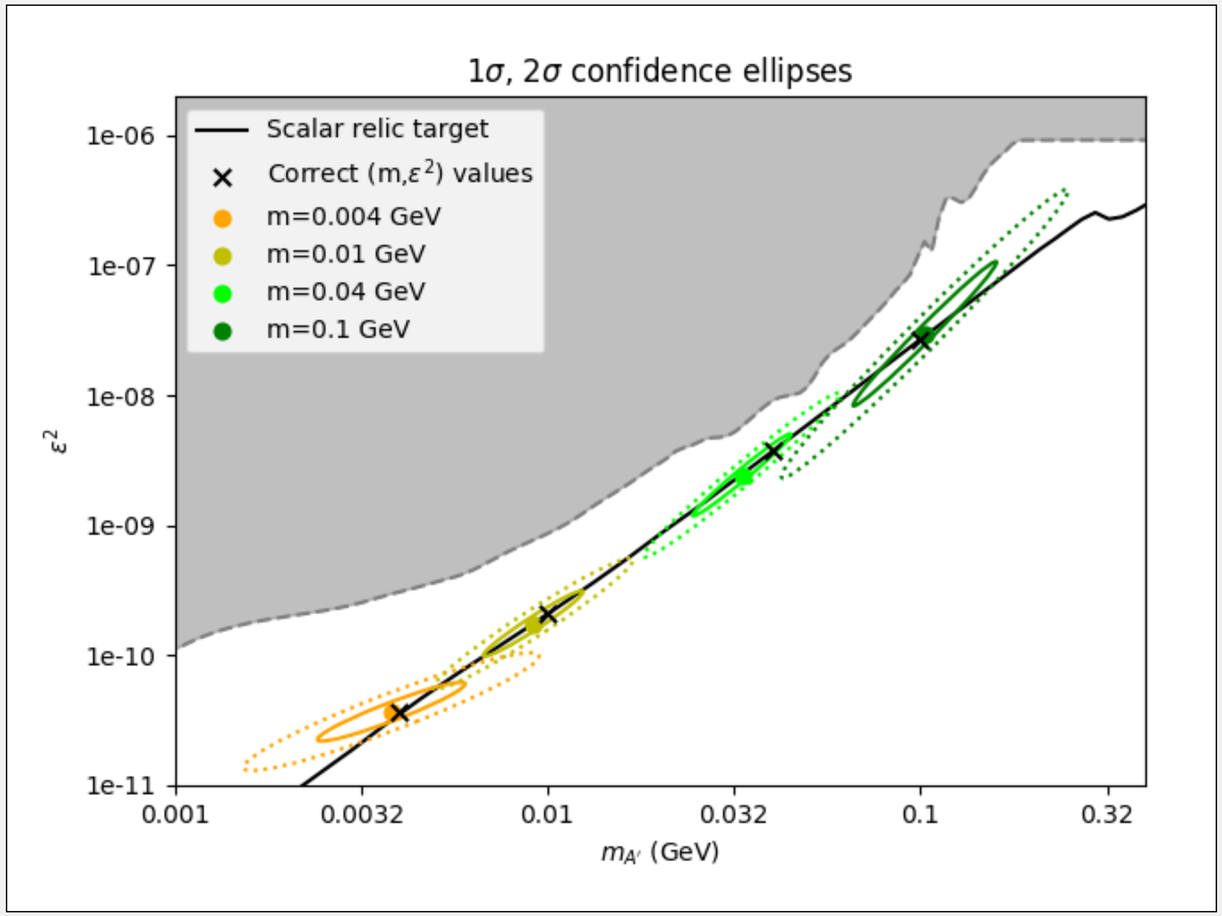
# Thank you!

# Additional Material

# Strengths of LDMX

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

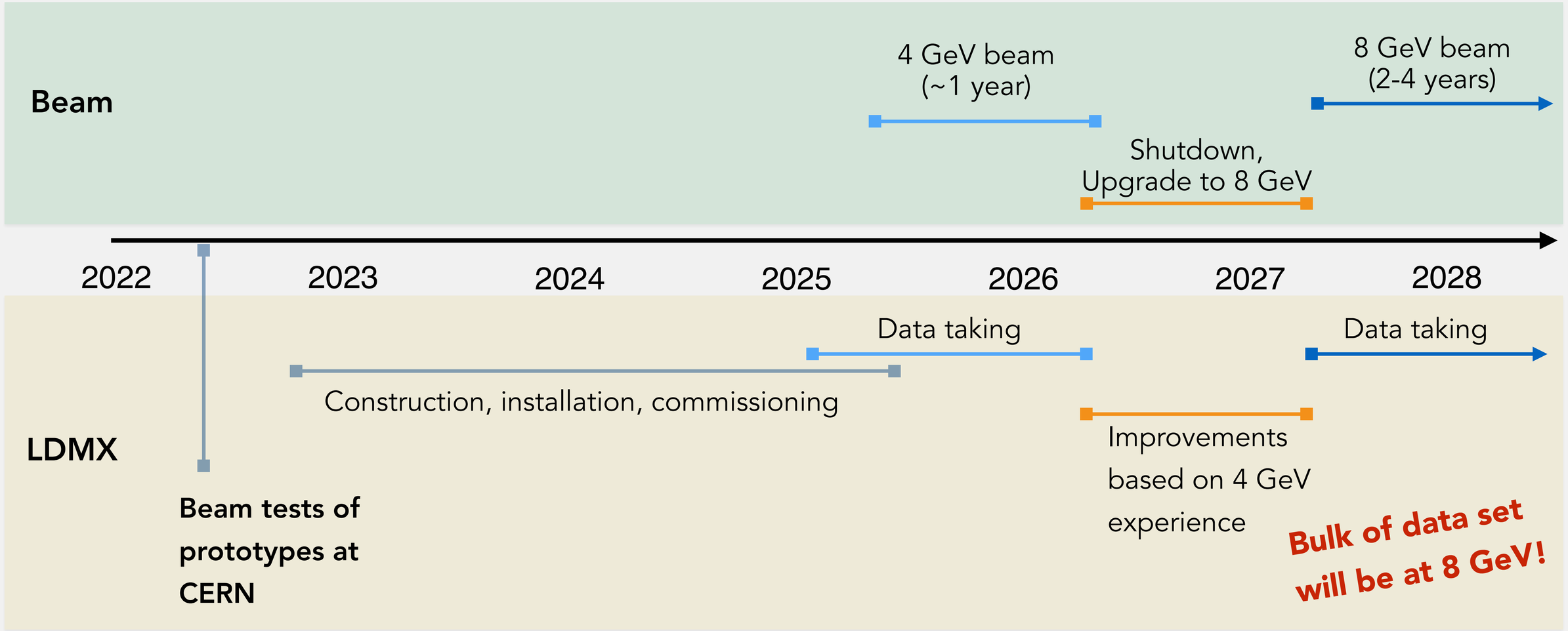



Not possible with missing energy only!

# Potential LDMX Timeline

Conditional on funding situation



# The Beam

Goal: *Individually* measure (missing) energy/transverse momentum
for up to $10^{16}$ electrons scattering off a (thin) target

Requires special **beam properties**:

**Energy** ideally 4 GeV < $E_B$ < 20 GeV

**High duty-cycle** to gather sufficient statistics despite

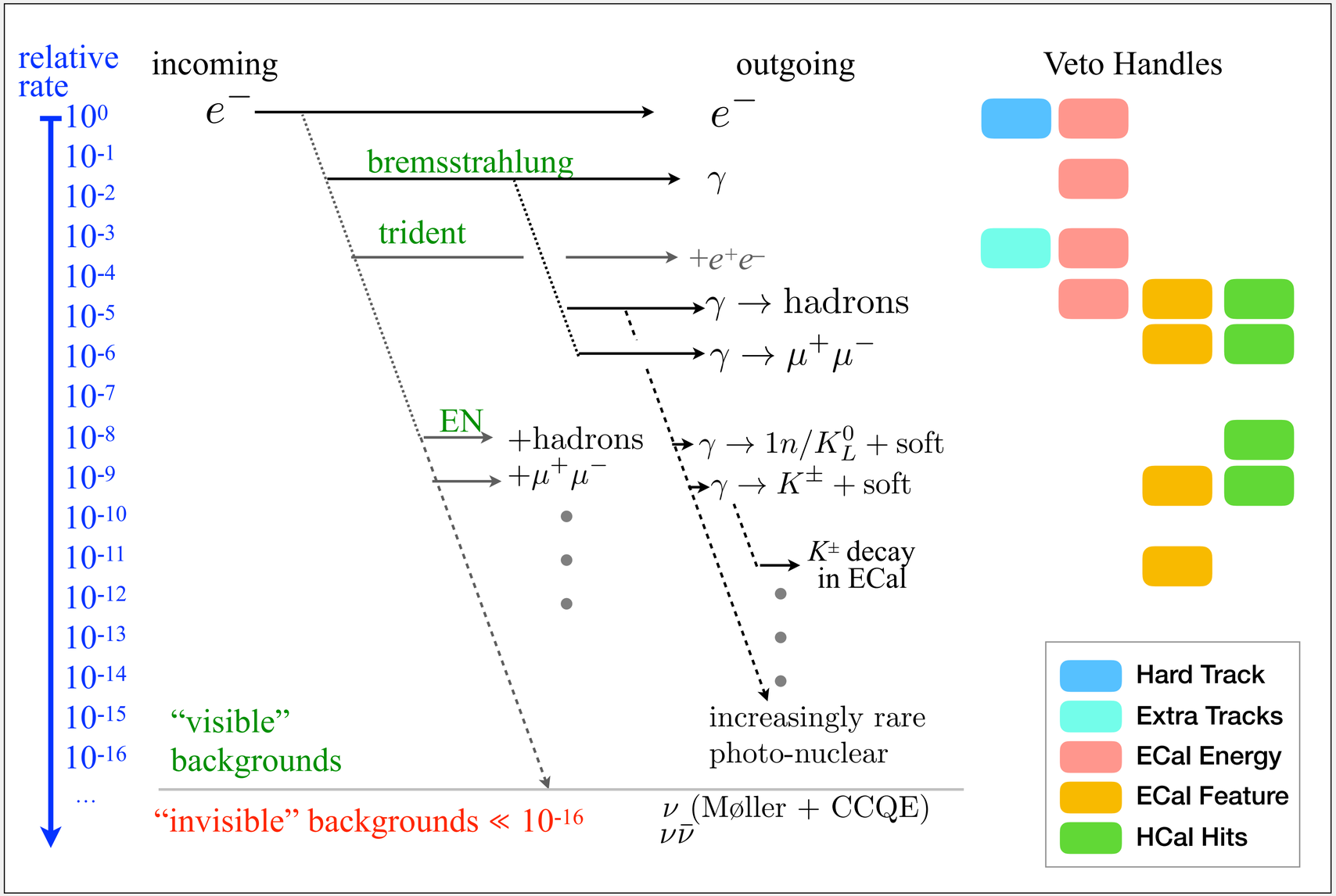
**Low intensity** (≤10 $e^-$ per bunch) to resolve individual $e^-$,
helped by **large beam spot**

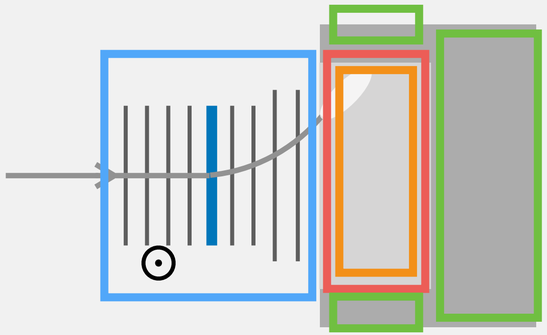
Choices:

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

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

# Backgrounds



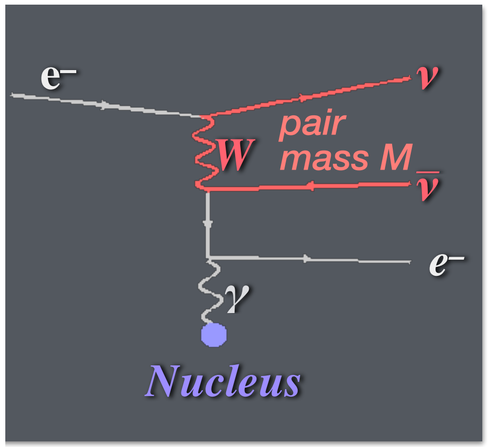



**essentially only instrumental backgrounds**

# Neutrino Backgrounds

## Prompt Neutrino Reactions

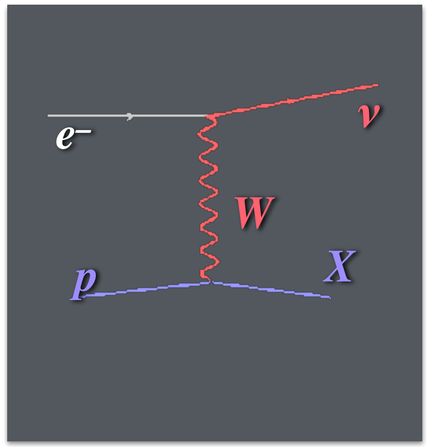
*Neutrino Tridents*




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

irreducible

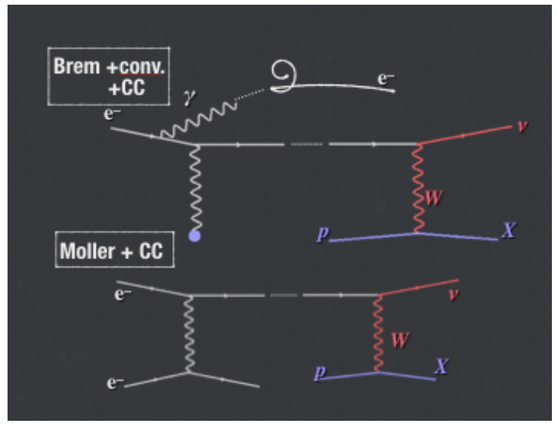
*Charged Current*




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

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

*CCQE+…*




$N_{\nu+Brem+conv.}/N_e$
$\sim 10^{-16}$ (E/4GeV)
x $(T_{target}/0.1\ X_0)^3$
a bit reducible
curler track veto, cut out Moller kinematics

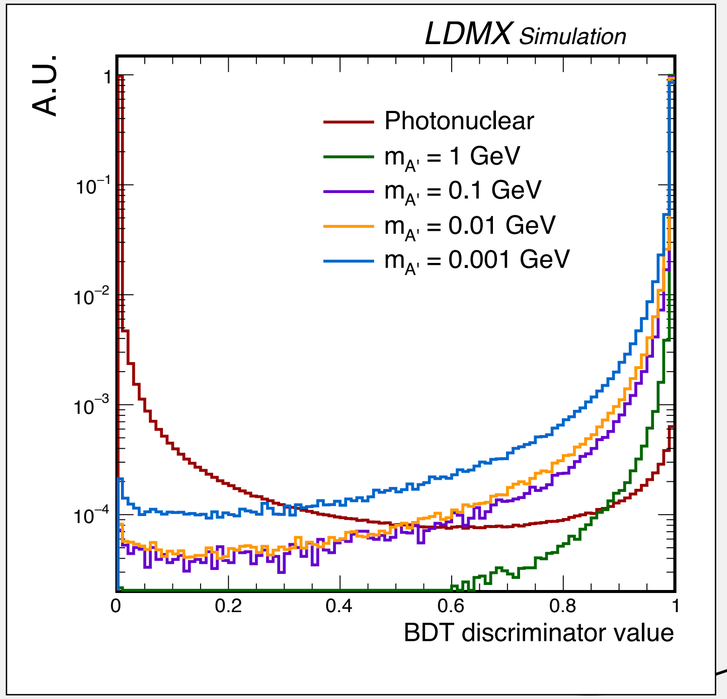
slide by Natalia Toro

# Analysis Strategy

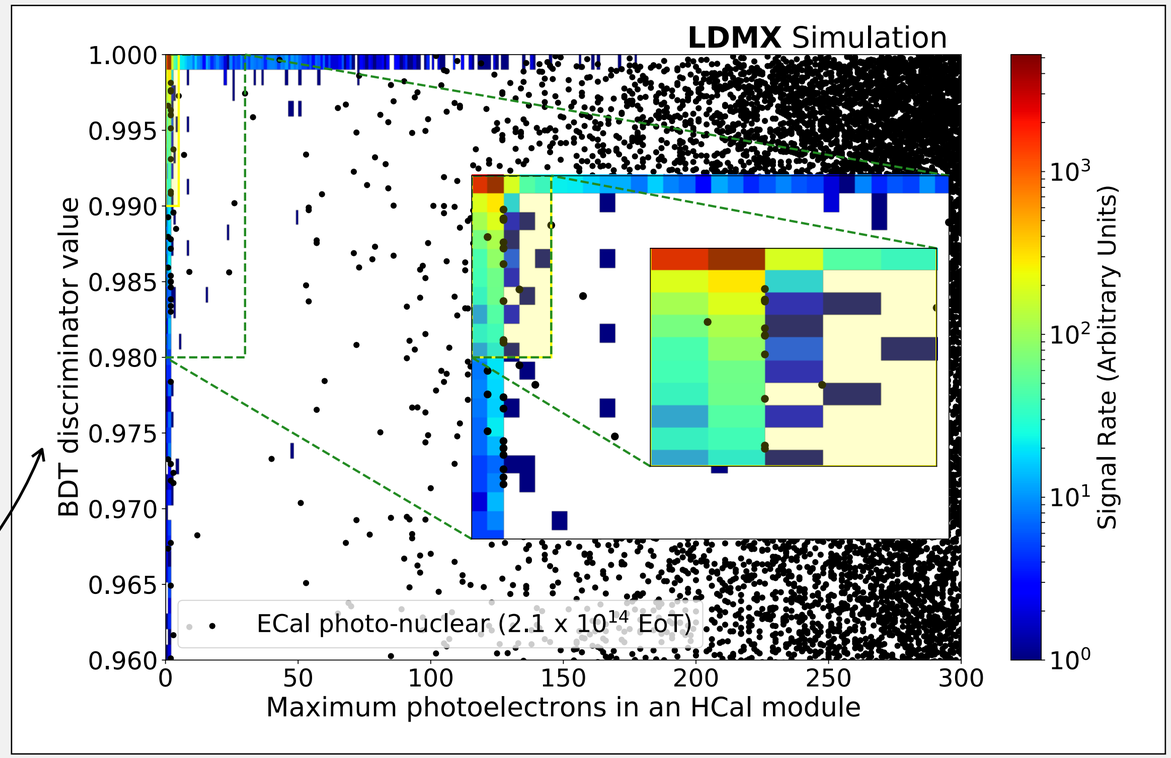
JHEP04(2020)003

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**

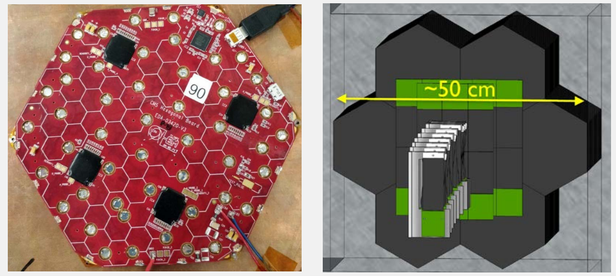
beam requirements:
- low current, high duty-cycle

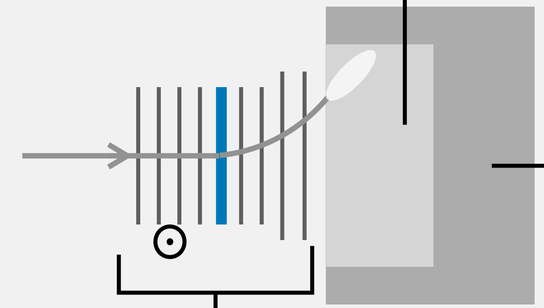
**primary**, multi-GeV e-beam

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

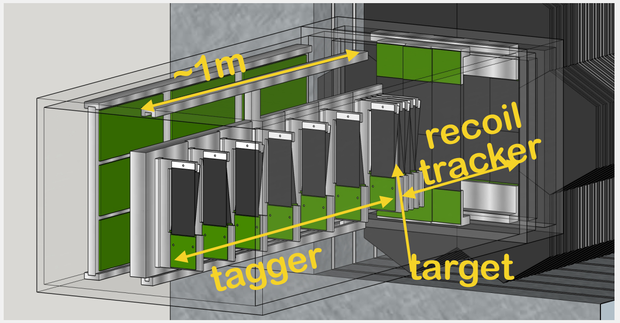
**leverage techniques from existing/planned experiments**

**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')

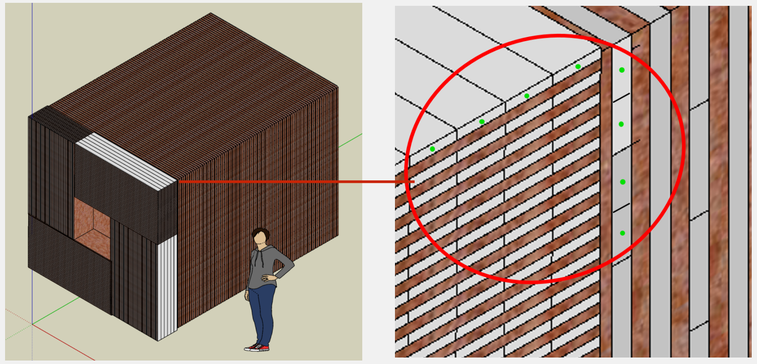


simplified copy of Silicon Vertex **Tracker** of *HPS*@JLab (visible Dark Photon search)



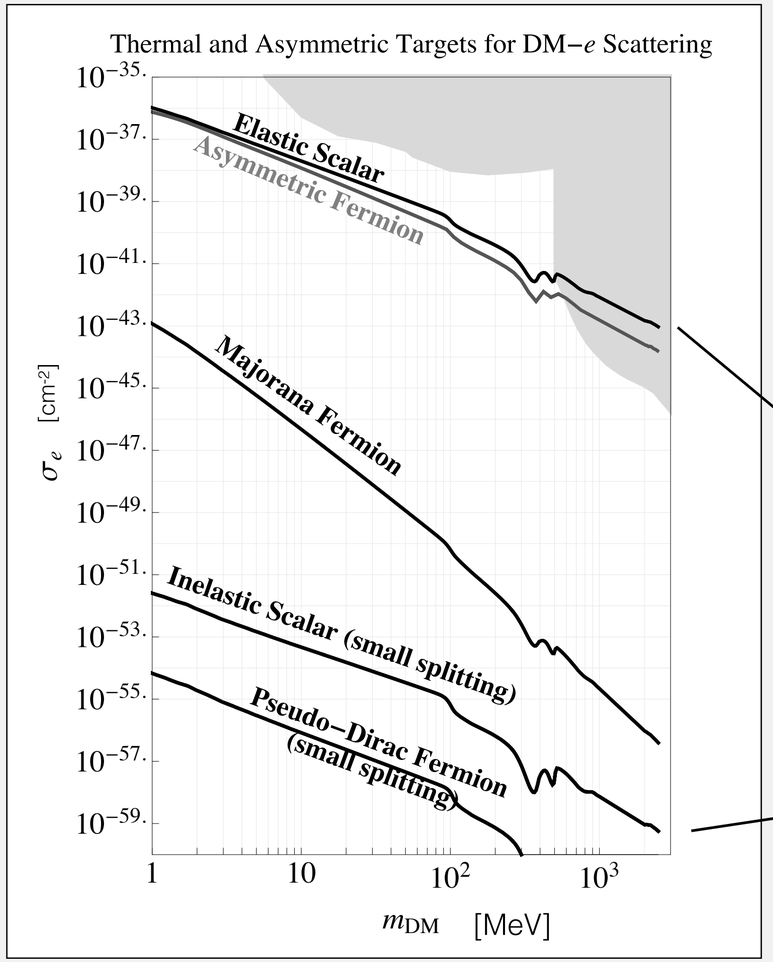

**HCal** inspired by *Minos/Mu2e*
- plastic scintillator with steel absorber
- readout via WLS fibres
- **optimise for neutral hadron rejection**



# Why not only direct detection?

direct detection:

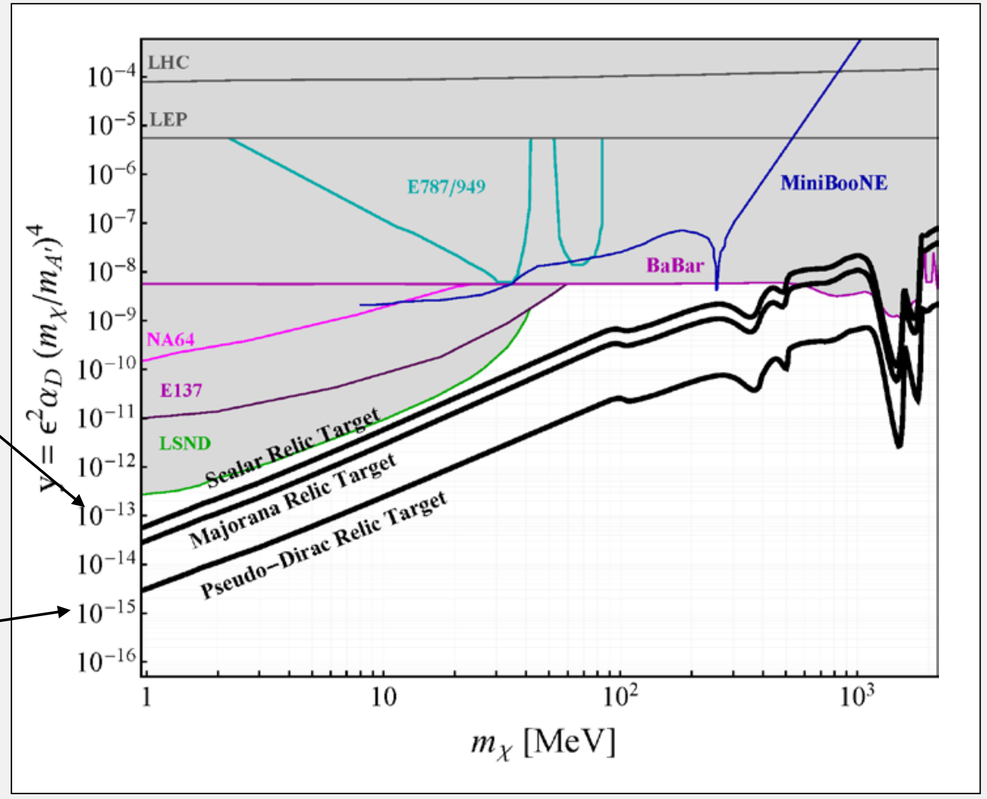
strong spin/velocity dependency




at accelerators: relativistic production

—> spin/velocity dependency reduced

all thermal targets in reach!



# Hadronic Calorimeter

Benchmark example:

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

Absorber thickness?

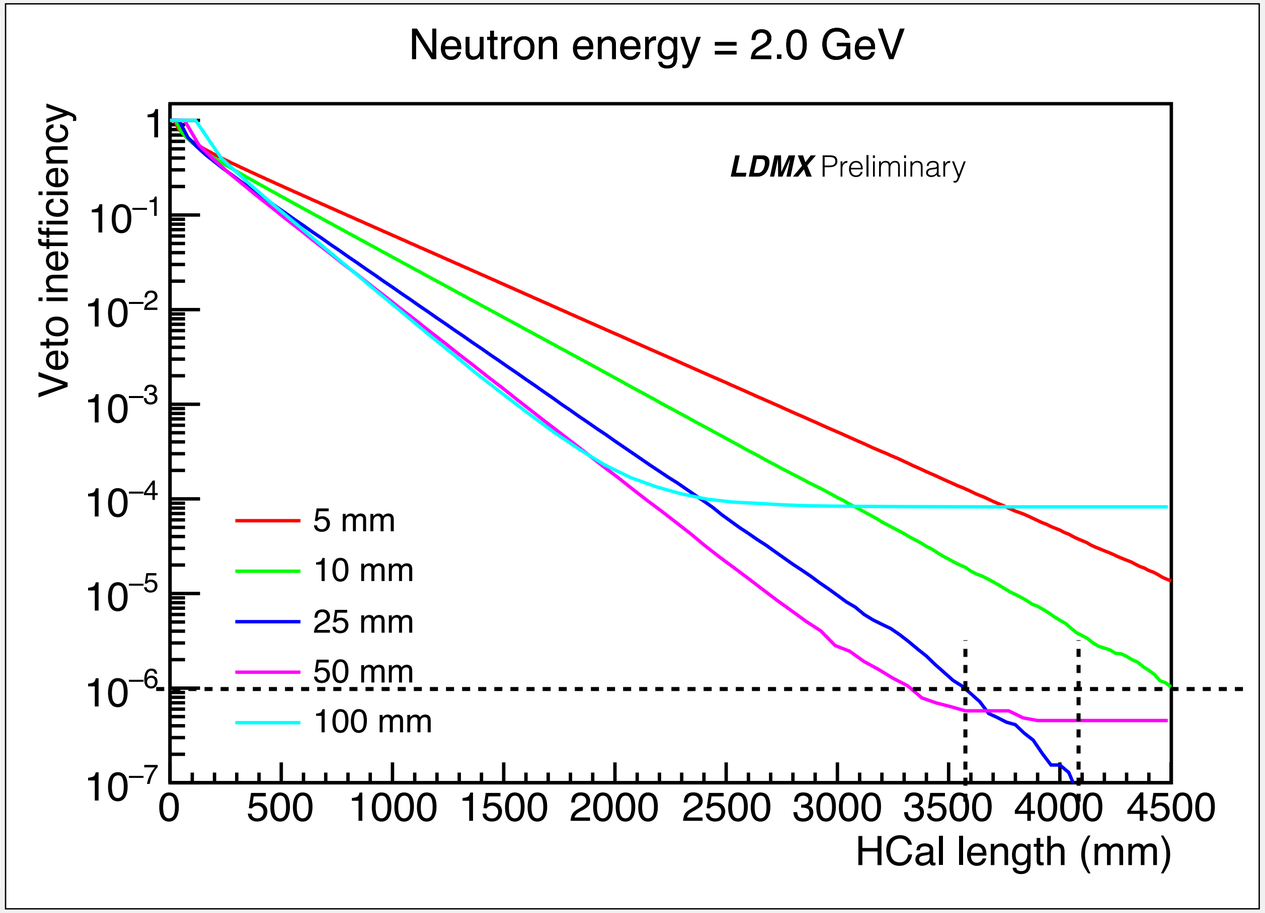
- too thick: neutrons 'get stuck'

—> no signal in scintillator

- too thin: detector needs to be very large

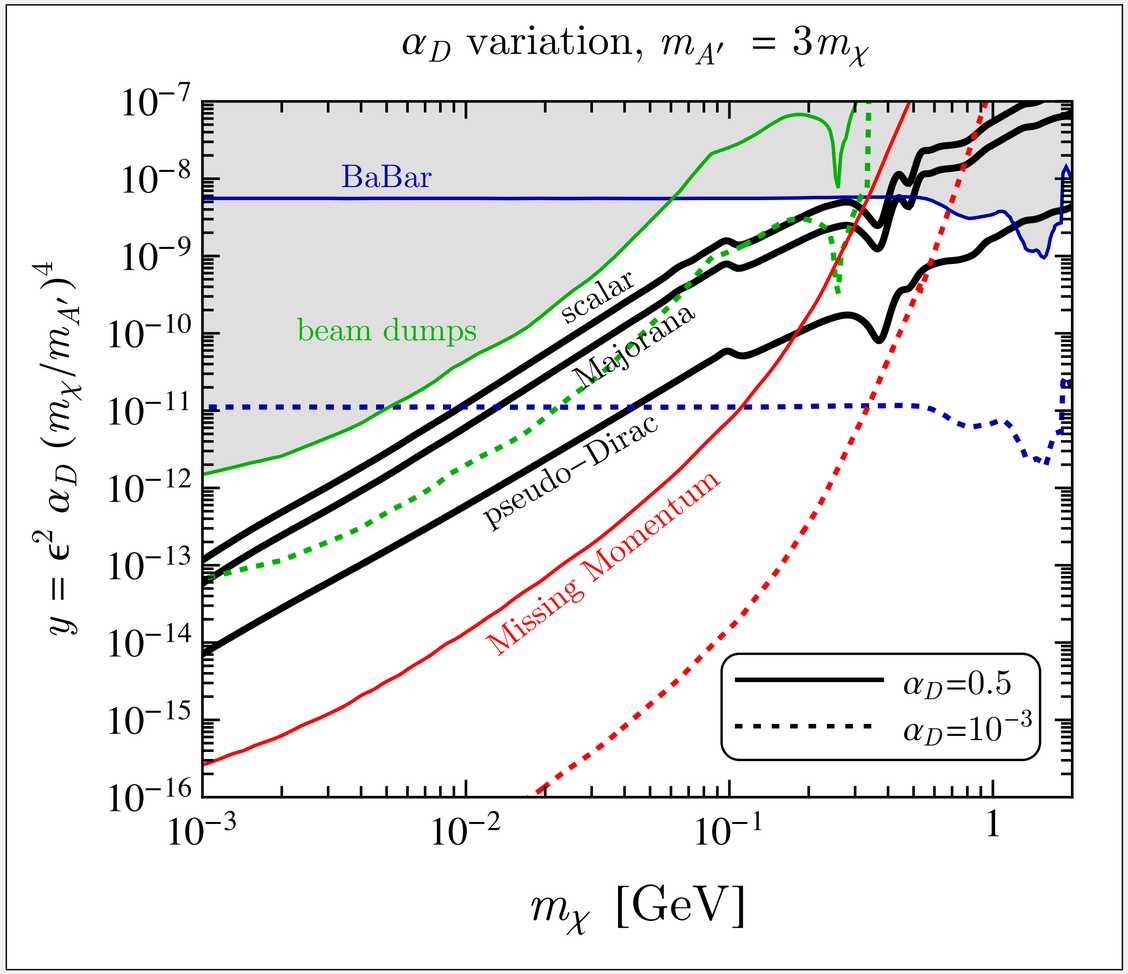
Currently assuming 25mm, 4m deep, transverse size 2-3m

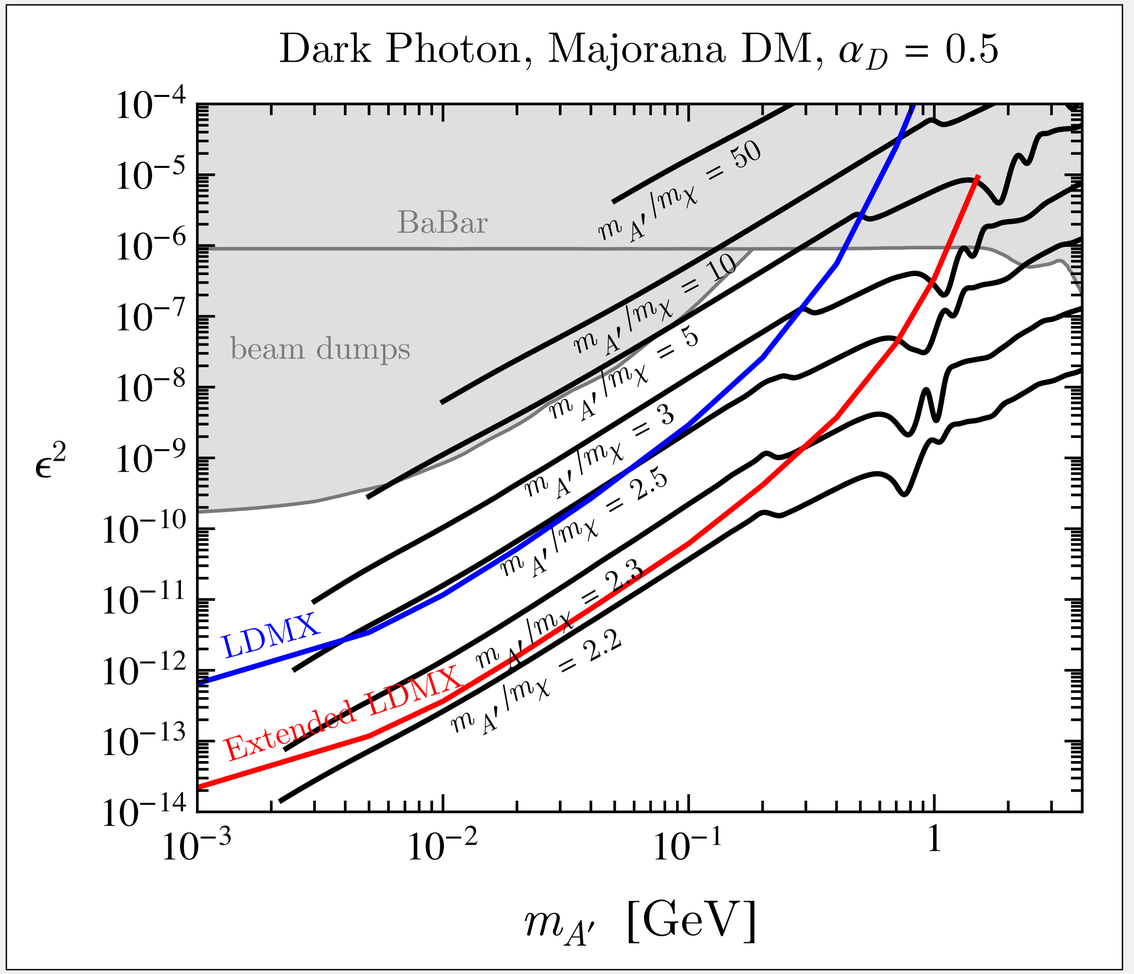
"Side HCal" around the ECal: Similar configuration, few λ deep



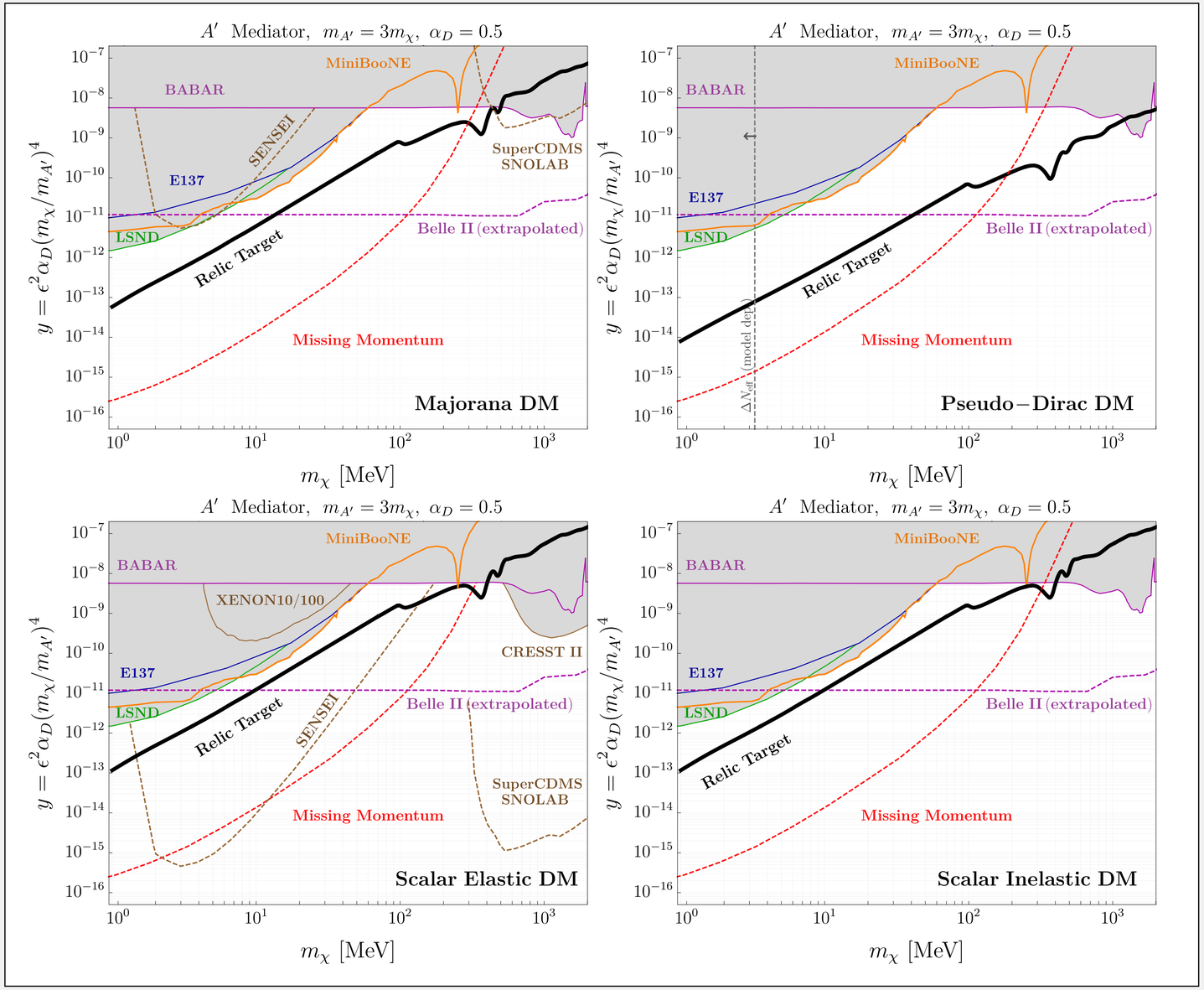

Finalisation of design parameters ongoing

# Parameter Dependence



# Various Future Projections



# LESA @ LCLS-II @ SLAC

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

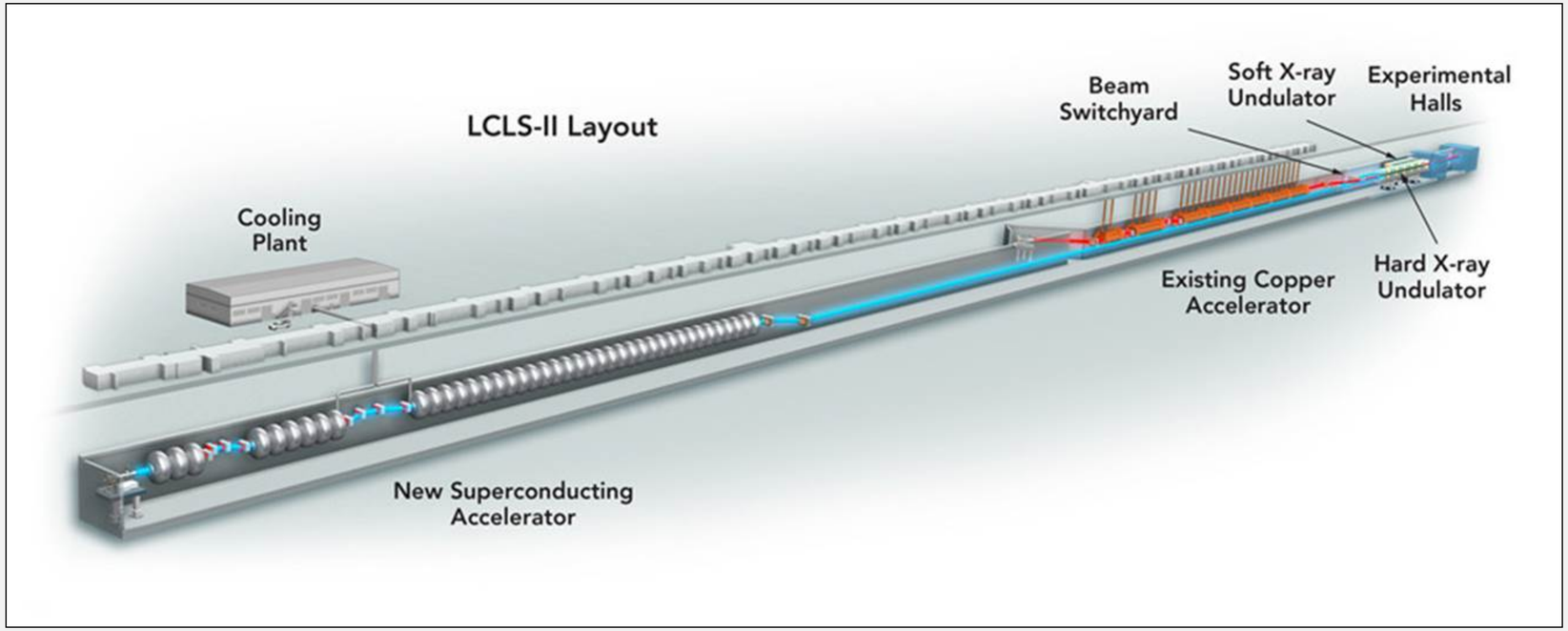
*Linac to end station A*

Energy: 4 (8) GeV

Bunch frequency: ~40 MHz (186 MHz)

$4x10^{14}$ EoT year 1

Parasitic



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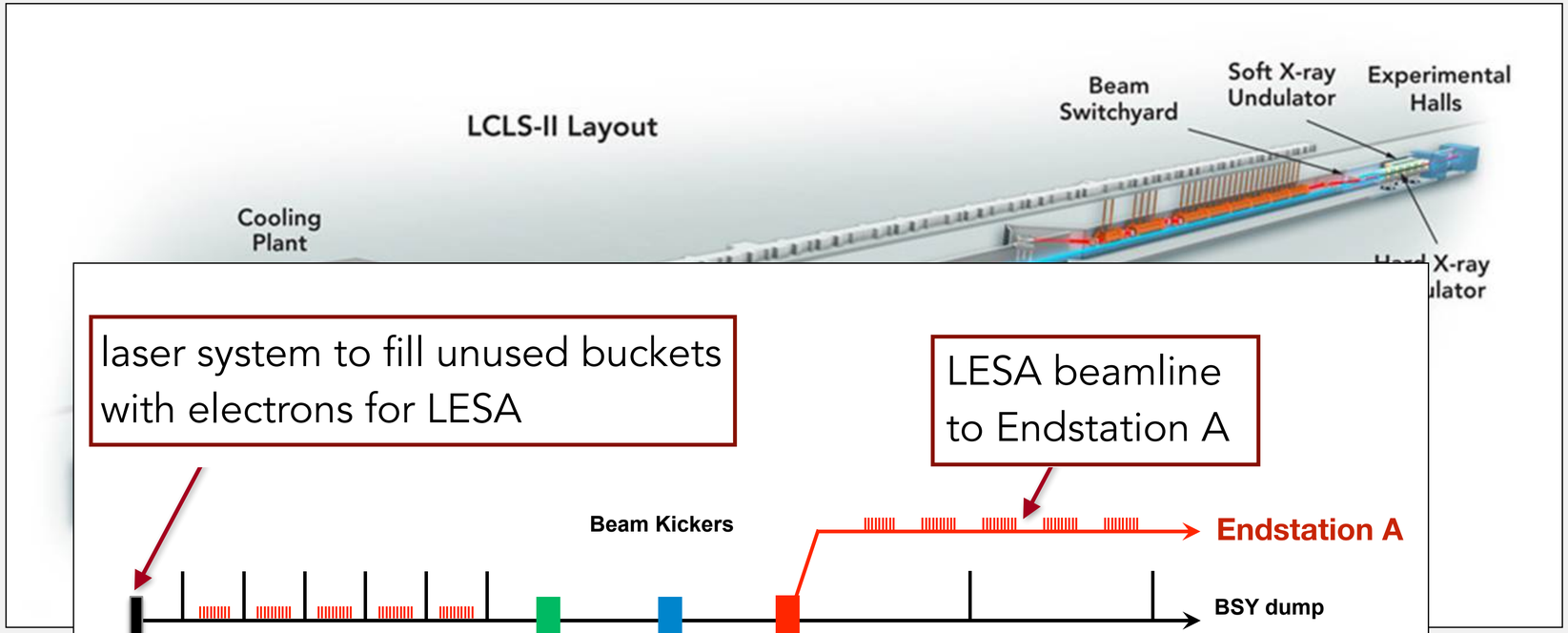

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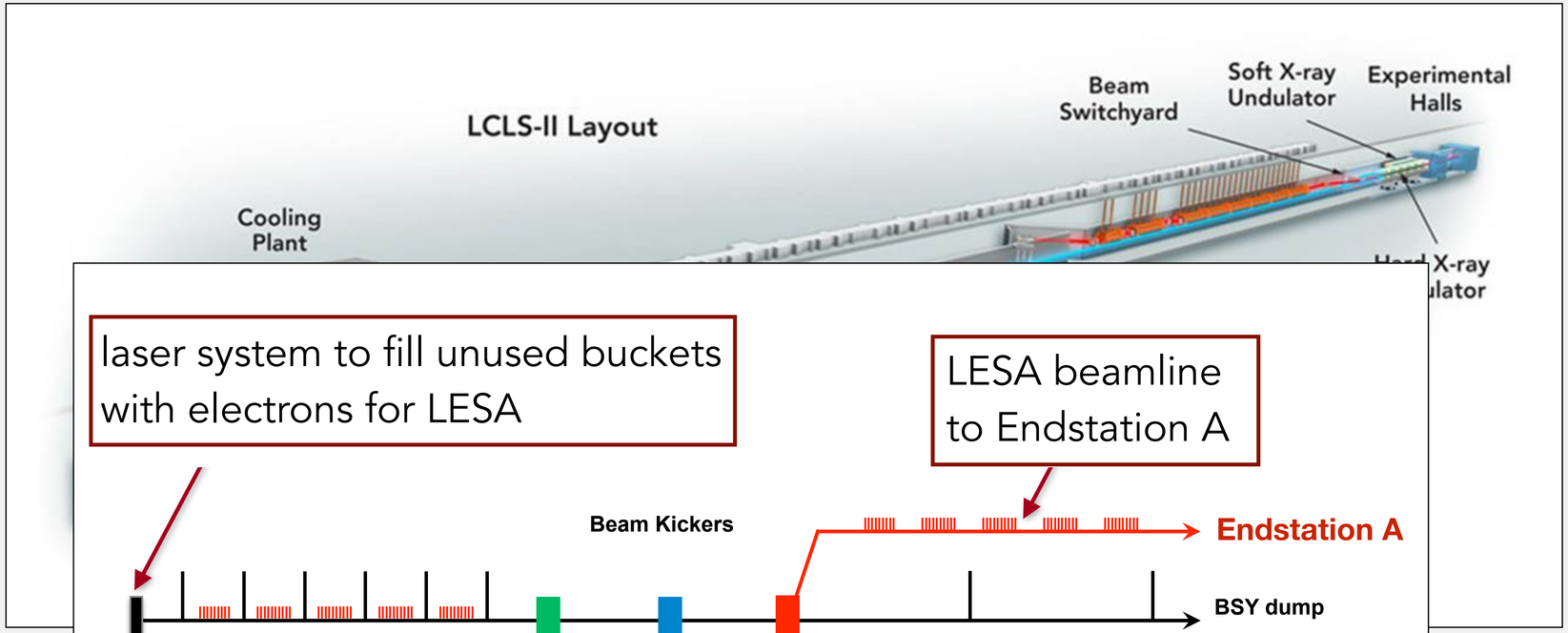
S30 Accelerator Improvement Project (kicker & ~100m beamline – ending in beam switchyard) currently under construction



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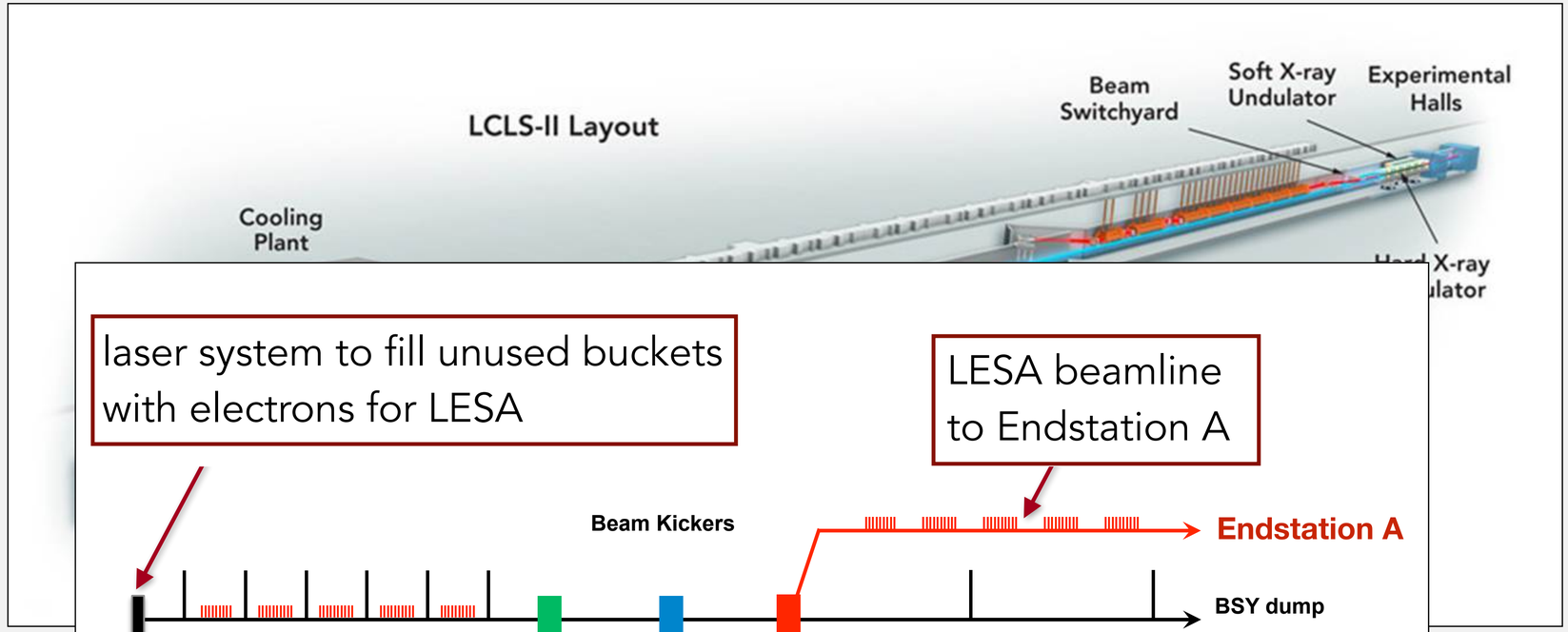
S30 Accelerator Improvement Project (kicker & ~100m beamline – ending in beam switchyard) currently under construction

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

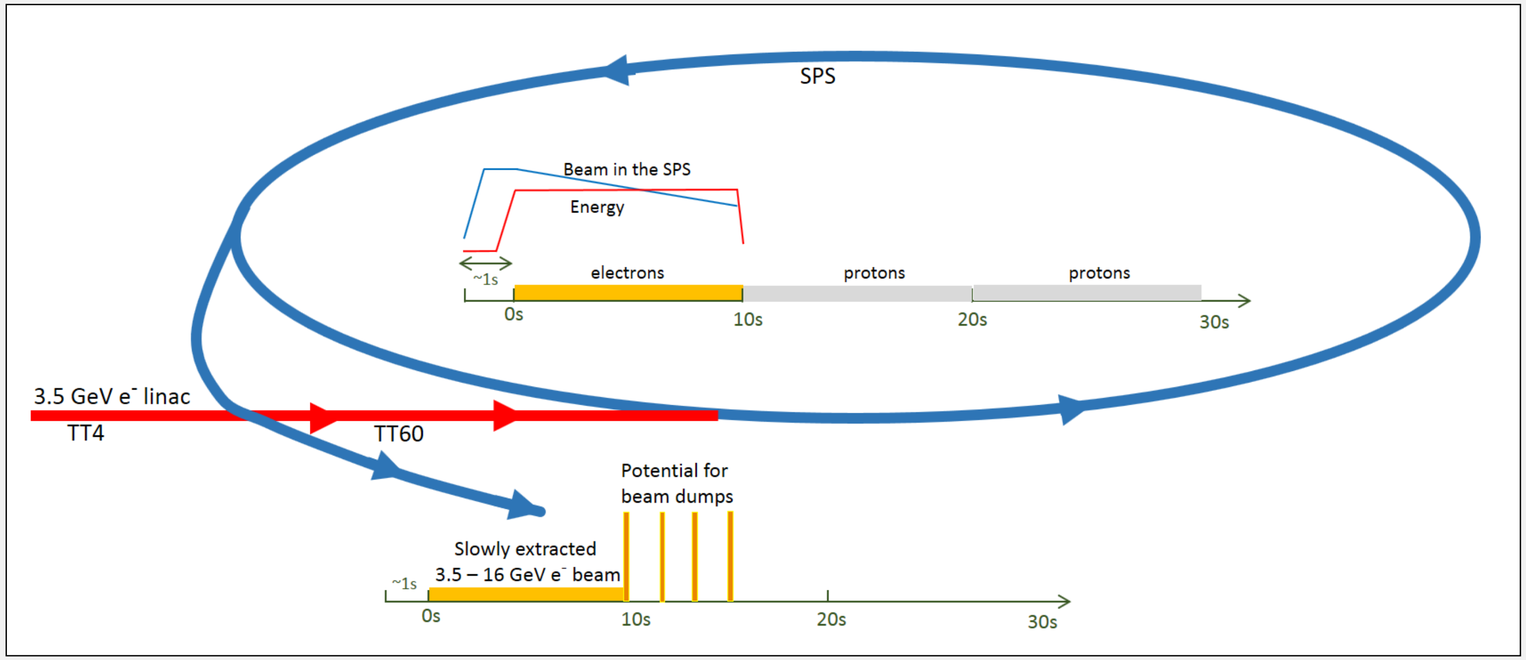
expression of interest to SPSC in October 2018, https://cds.cern.ch/record/2640784

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