Lepton Beams: LDMX@eSPS (NA64++, AWAKE++)

Thanks to colleagues from all three collaborations for input and feedback on the slides!

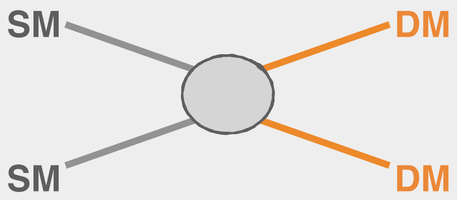
Open Symposium on EPPSU

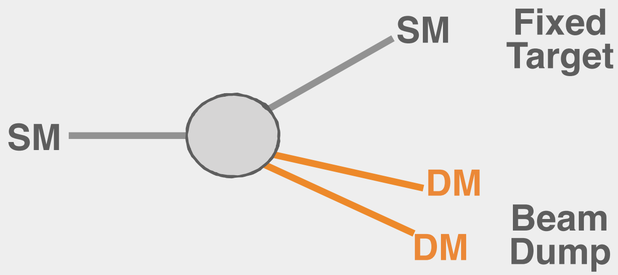
Granada, May 2019

Ruth Pöttgen

Introduction

thermal origin of Dark Matter —> production mechanism at accelerators!





can profit greatly from opportunities and accelerator R&D at CERN!

—> NA64++(e,μ), AWAKE++, LDMX@eSPS

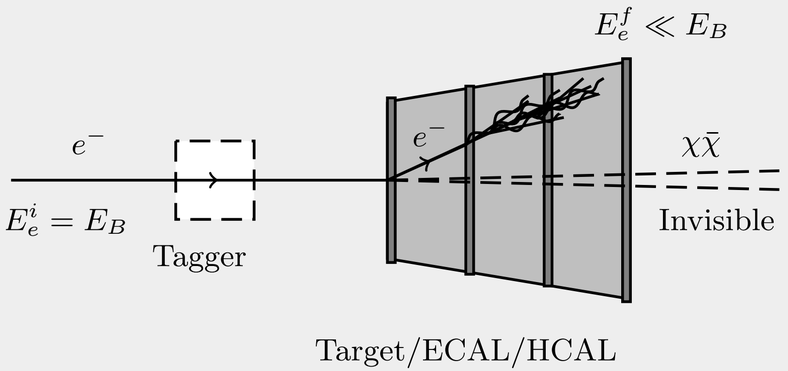
this talk: mostly **LDMX**@eSPS, **invisible** signature (missing energy/momentum)

BUT: experiments have sensitivity to broad range of new phenomena,
both visible and invisible

Missing Something

two approaches here:

missing energy

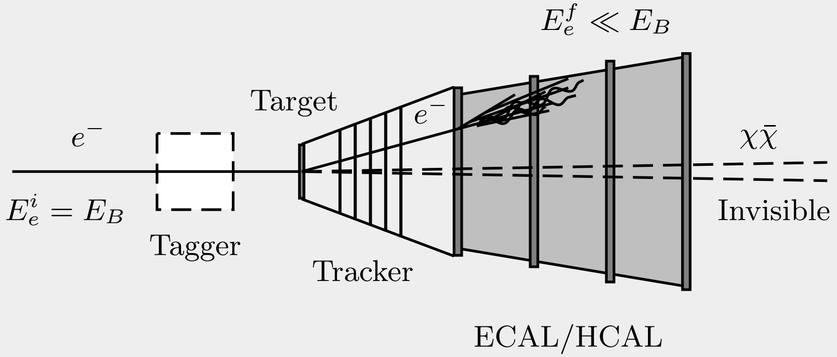


higher signal yield/EoT (thicker target)

greater signal acceptance

no e-γ particle ID

missing momentum



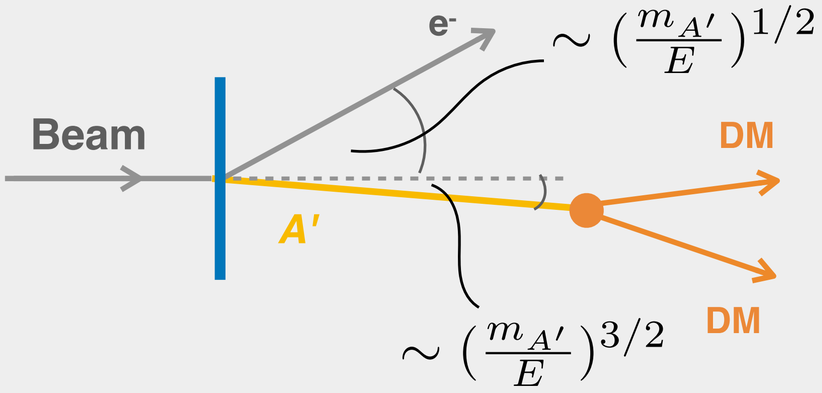
includes missing energy

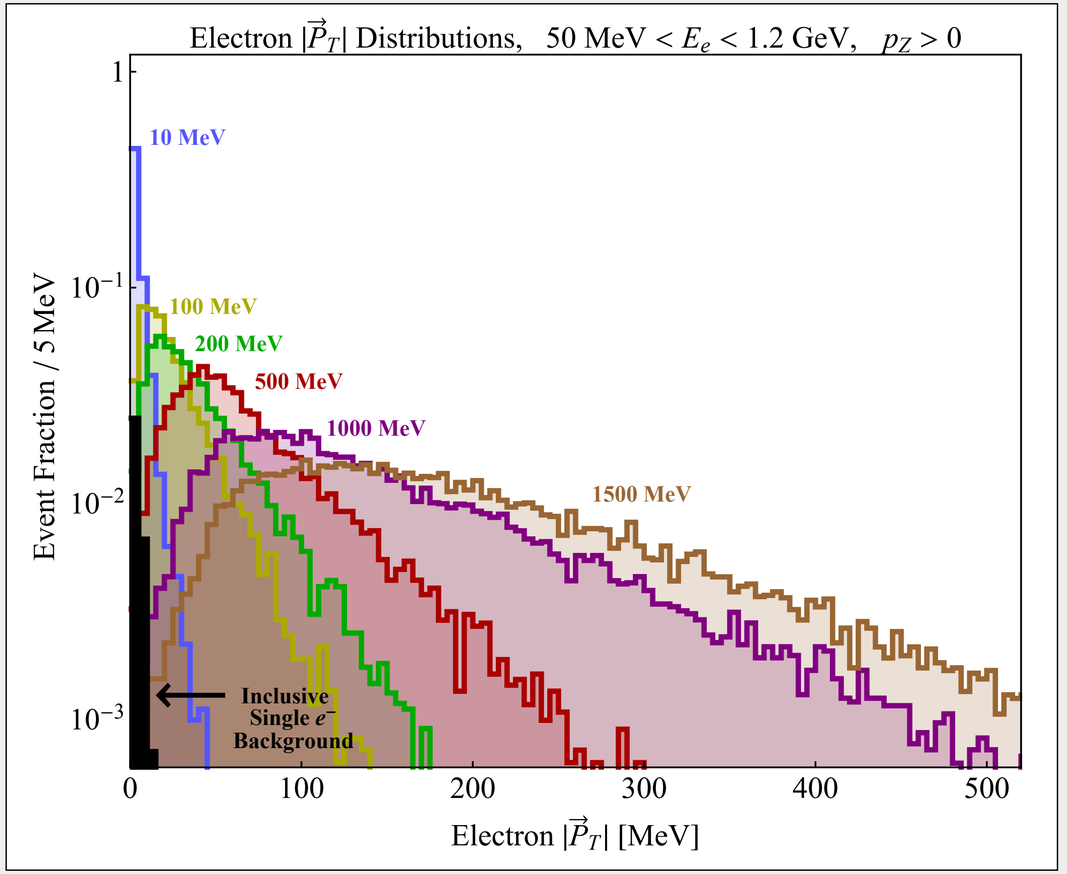
p_T as discriminator & *signal identifier*

e-γ particle ID

Kinematics

very different from SM bremsstrahlung (main background)

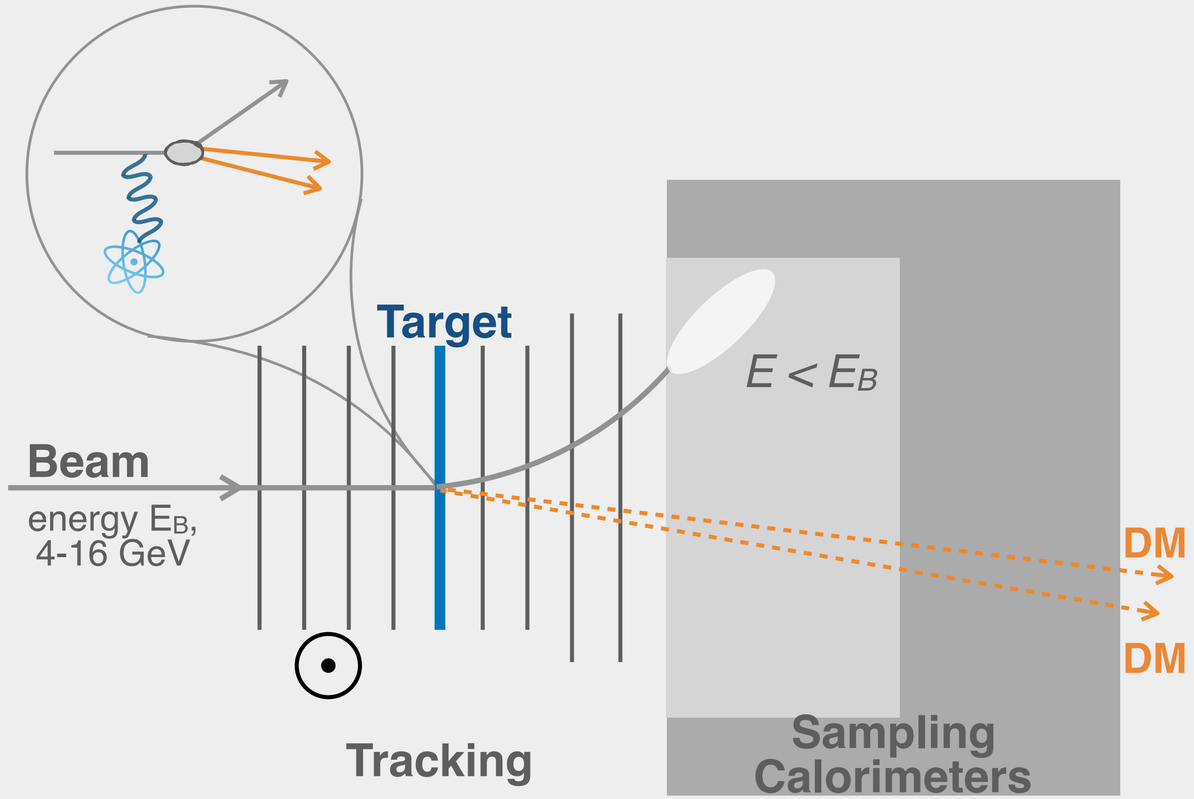


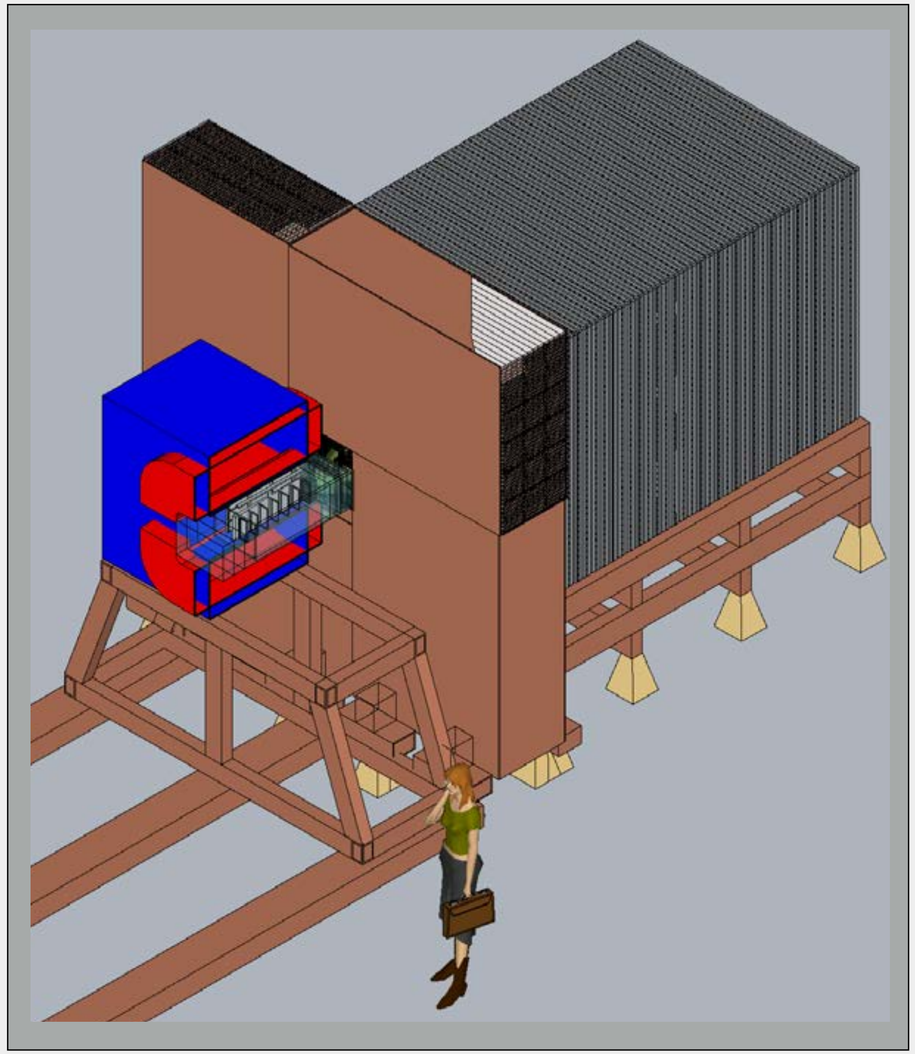


measurement of p_T: strong discriminator AND information about (missing) mass!

LDMX

Light Dark Matter eXperiment





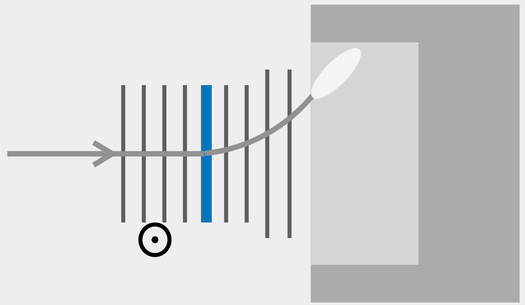
small-scale experiment

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

Detector Design

design paper on arxiv
arxiv:1808.05219

extremely rare signal
—> need large statistics
goal: 10^{14} - 10^{16} EoT in few years



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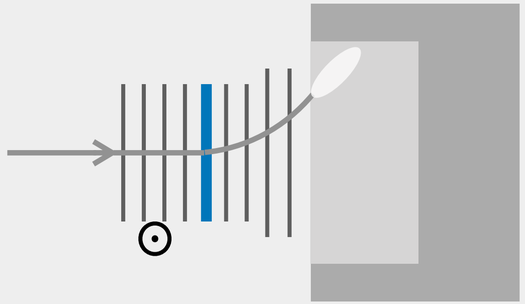

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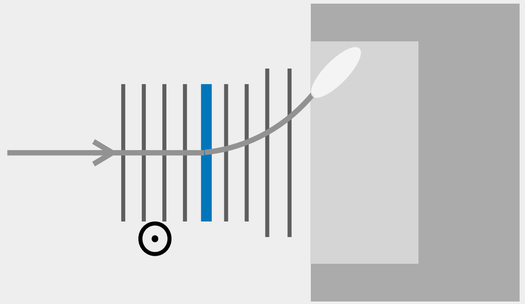

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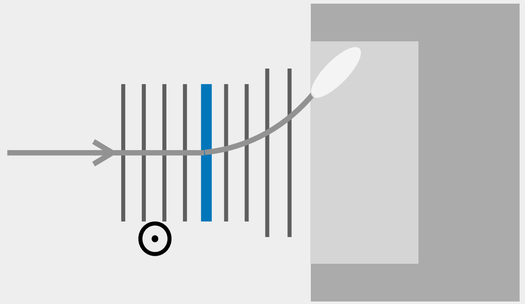

detector requirements:
- high-rate capabilities
- radiation hard
- high-granularity

leverage techniques from existing/planned experiments

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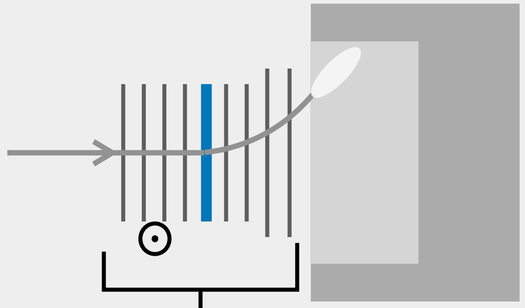
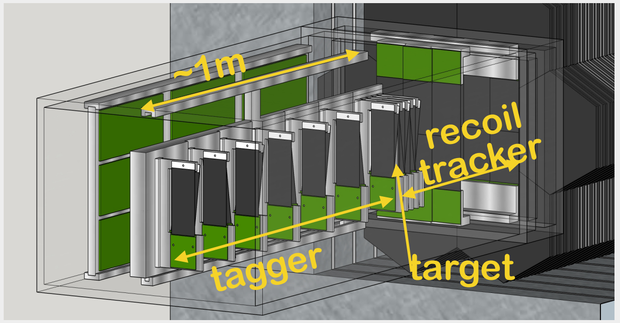


simplified copy of Silicon Vertex **Tracker** of *HPS*@JLab (visible Dark Photon search)



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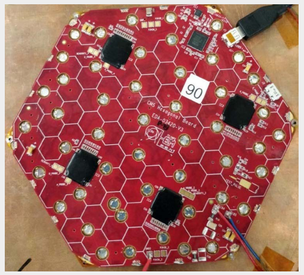
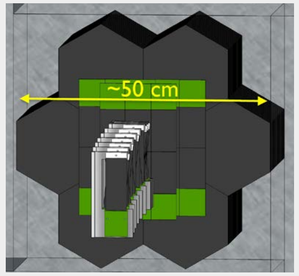
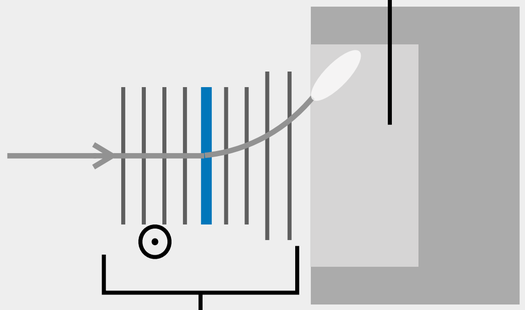
ECal: draw on design of *CMS* SiW HGCal
- 32 layers with 7 modules each, 40 X_0
- fast, radiation hard, dense
- high granularity (MIP 'tracking')







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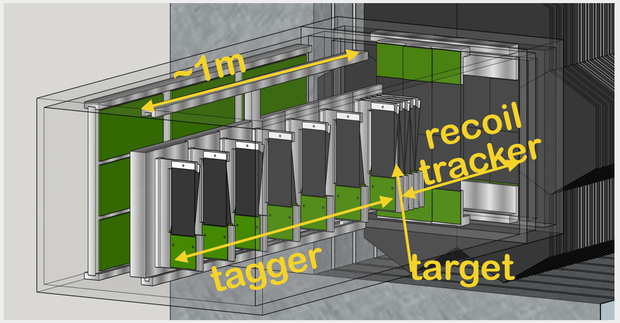

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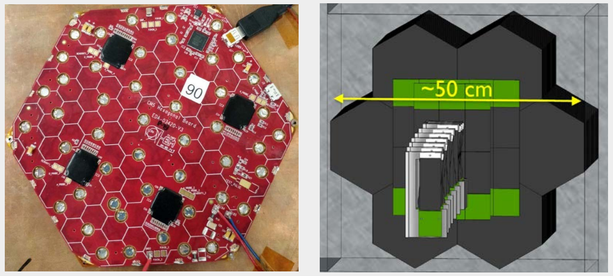

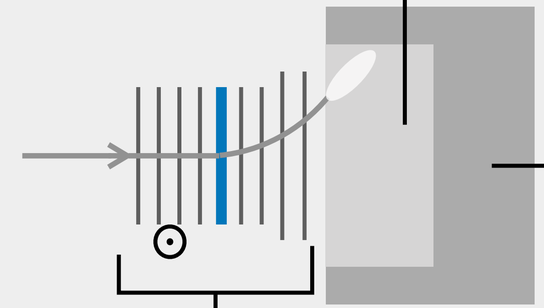

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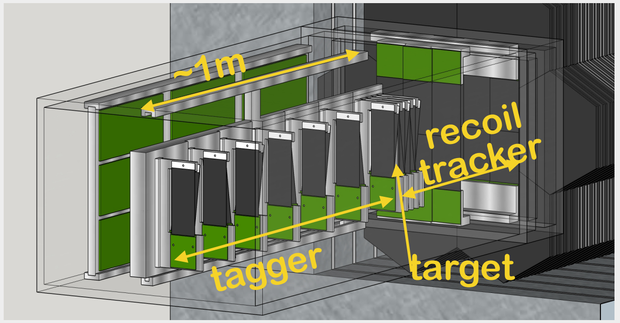
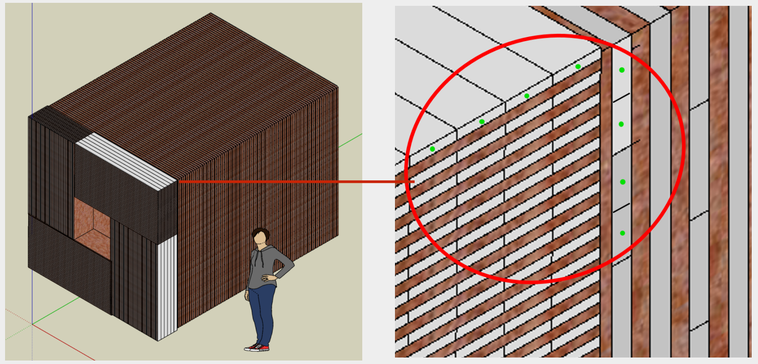


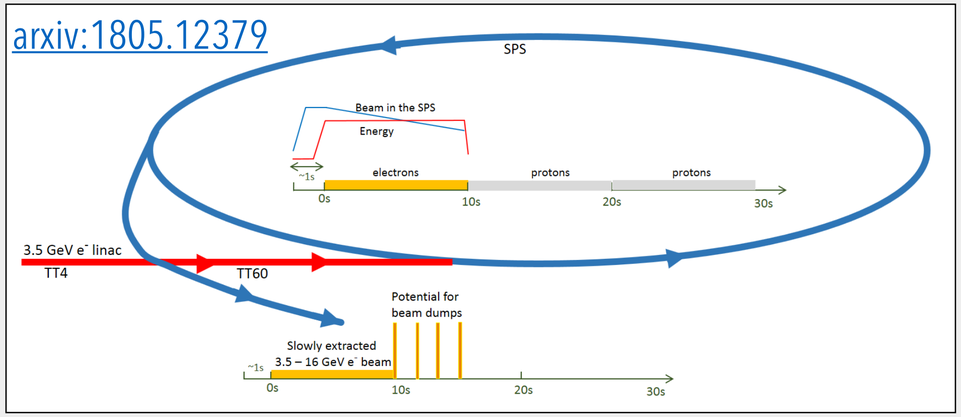
HCal inspired by *Minos/Mu2e*
- plastic scintillator with steel absorber
- readout via WLS fibres
- **optimise for neutral hadron rejection**



Beam

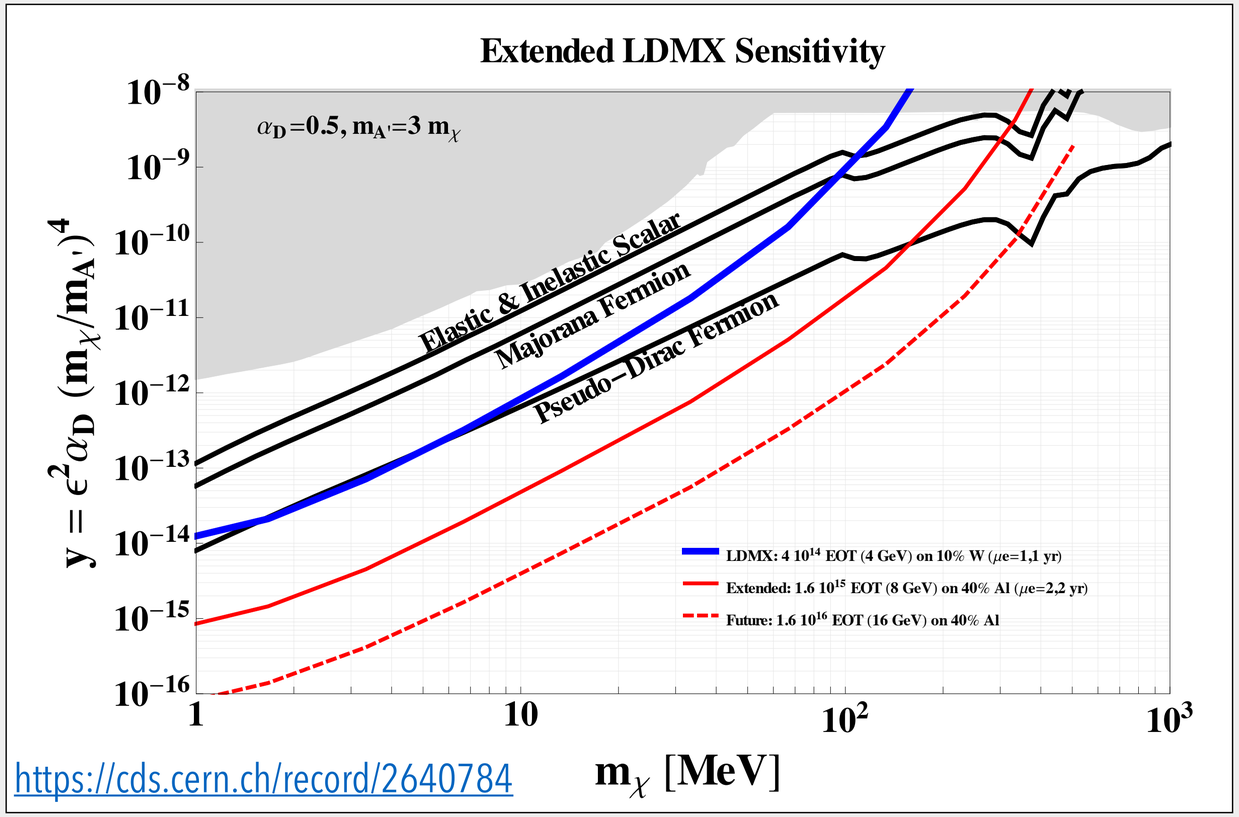
options (neither approved yet)

- dedicated transfer line at LCLS-II at **SLAC**
  - 4 GeV or maximum 8 GeV, parasitic
- eSPS at **CERN** *see Mike Lamont's talk for details*
  - get e- back in CERN accelerators, next step for X-band linac developed for CLIC, accelerator R&D
  - **3.5 - 16 GeV**, flexible beam parameters
    - optimal catering



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

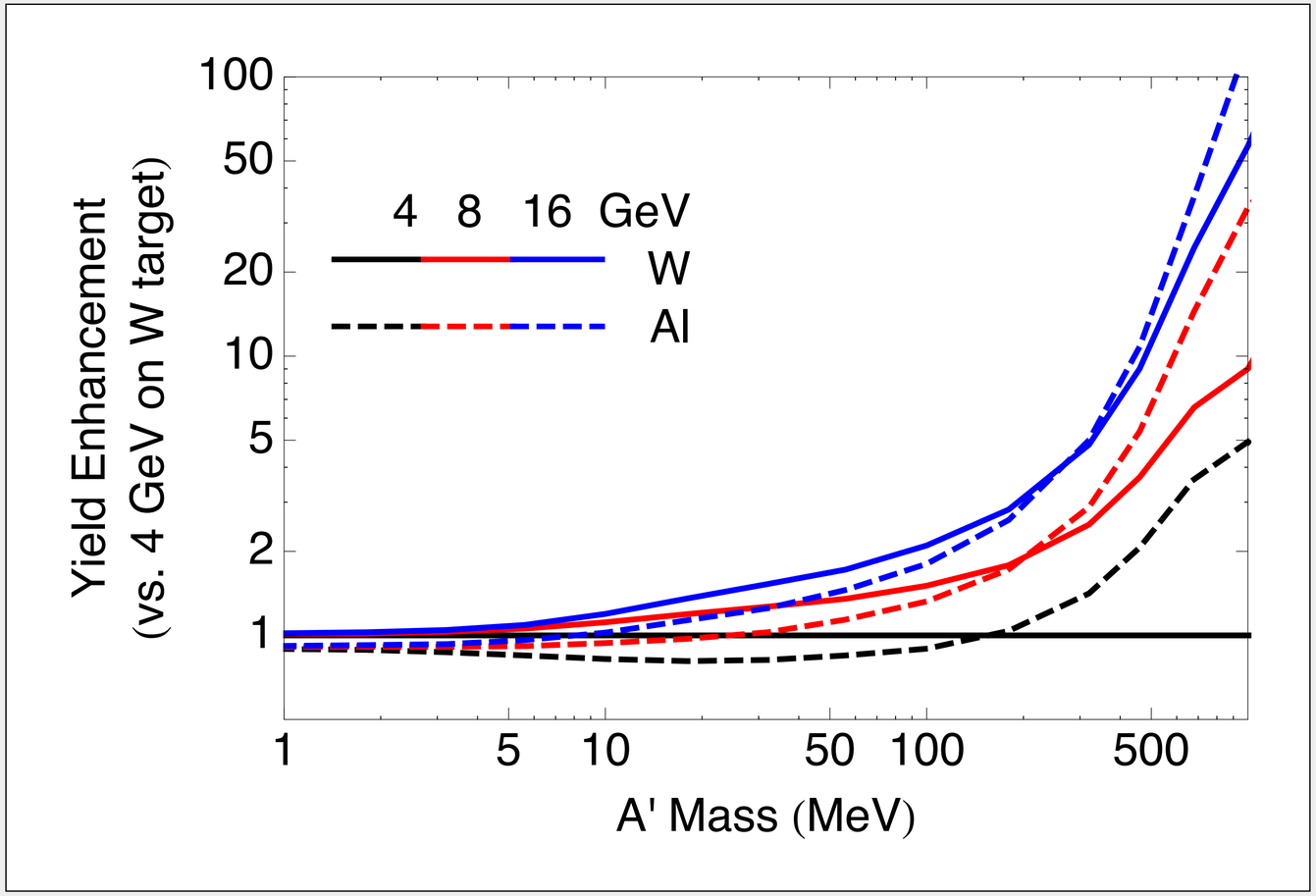
Input to Strategy Update (#36)



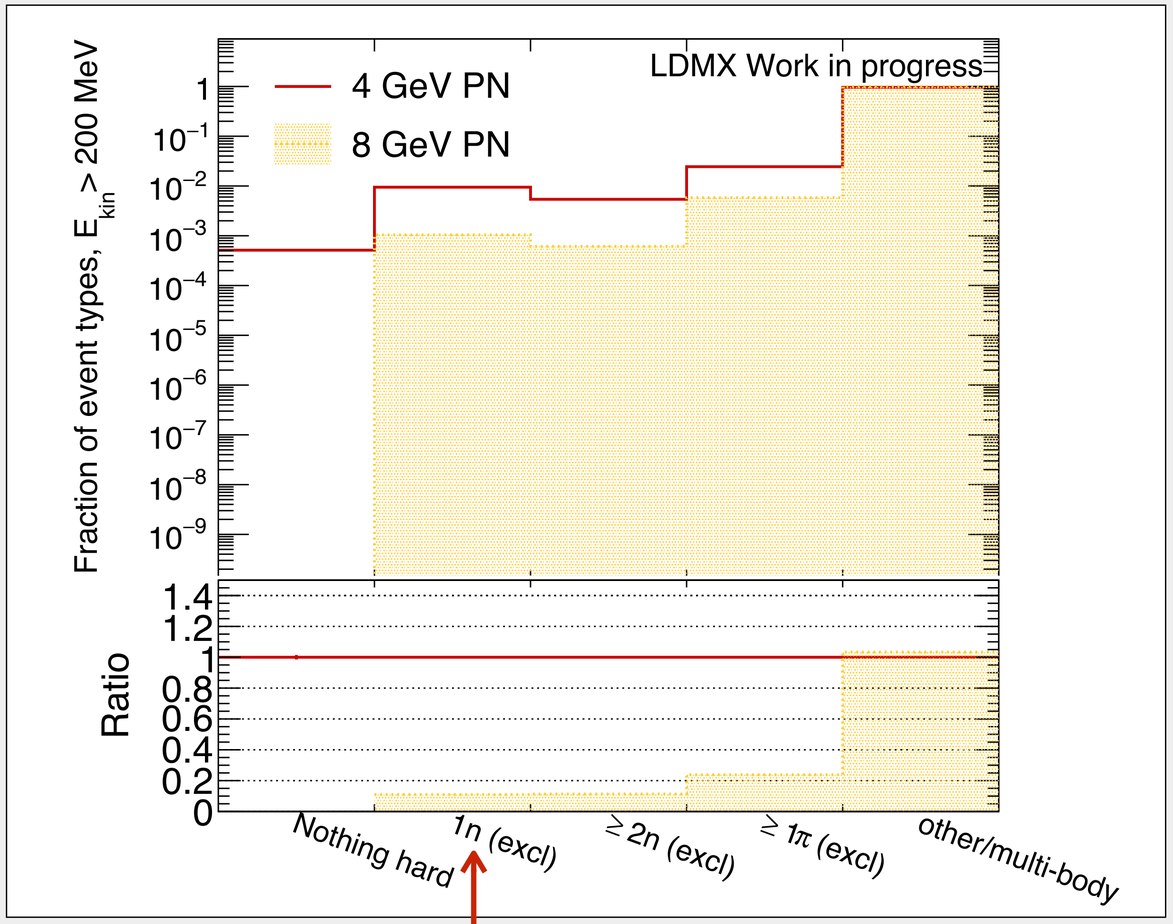
ideally: *2 experimental setups* with reach beyond thermal targets
(full LDMX Collaboration involved in both)

Why higher energy?

increased in signal yield



improved background rejection possibilities



particularly critical

Preliminary 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

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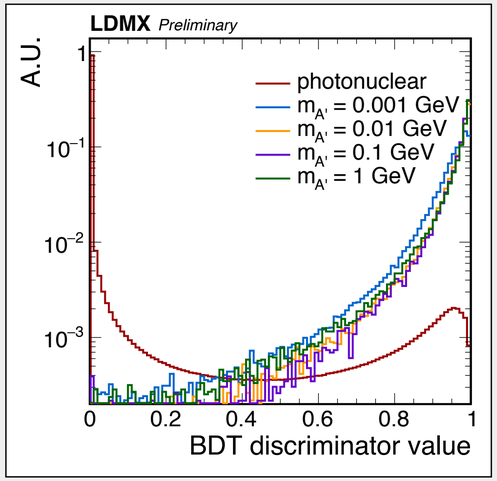
at 4 GeV: **close to 0-background** based on simulation studies



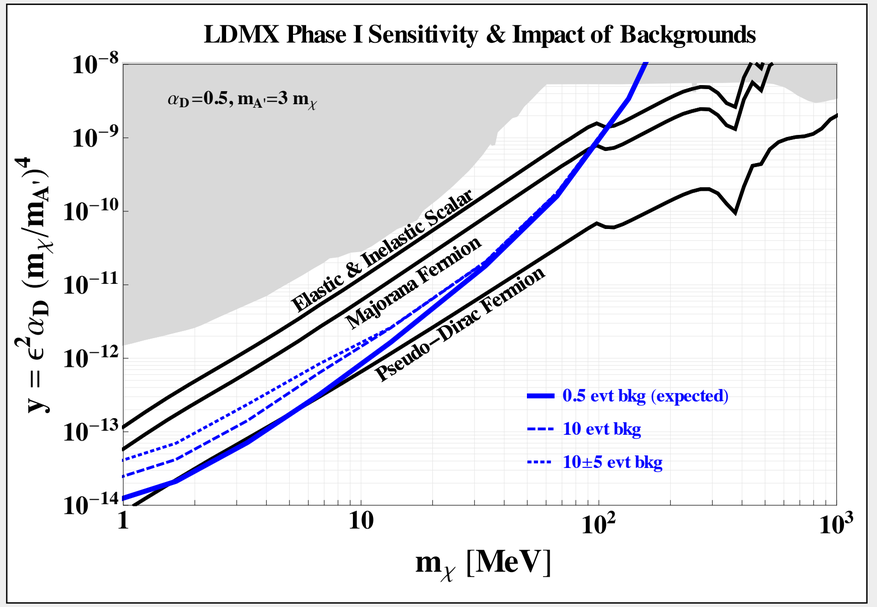
arxiv:1808.05219

important:

several handles not exploited yet, in particular p_T!

HCal optimisation ongoing

things get easier at higher energy!



with data:

redundancy in vetoes —> data control samples, verify rejection

comprehensive kinematic information —> establish signal-likeness

NA64++

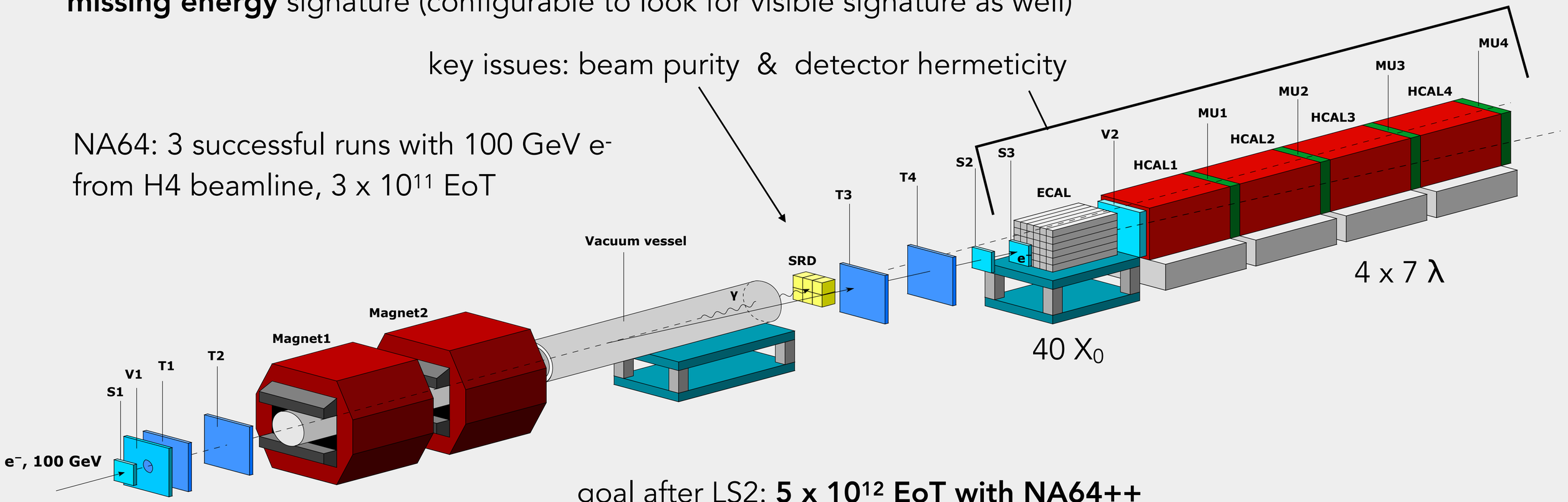
apologies for brevity!

https://indico.cern.ch/event/765096/contributions/3295517/

missing energy signature (configurable to look for visible signature as well)

key issues: beam purity & detector hermeticity

NA64: 3 successful runs with 100 GeV e⁻ from H4 beamline, 3 x 10^{11} EoT



goal after LS2: **5 x 10^{12} EoT with NA64++**

planned upgrades to detector/DAQ to circumvent pile-up limitations

in addition: extend Dark Photon search to muon beams (g-2, Dark Sector)

CERN-SPSC-2018-024 ; SPSC-P-348-ADD-3

AWAKE++

apologies for brevity!

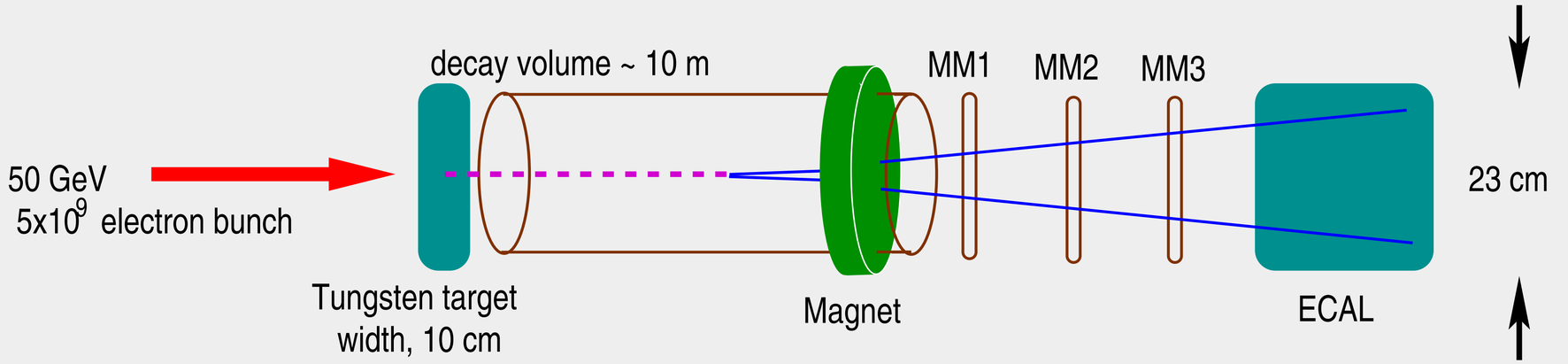
https://cds.cern.ch/record/2651319
https://cds.cern.ch/record/2651302

successful demonstration of AWAKE principle ~1 year ago https://www.nature.com/articles/s41586-018-0485-4

goal after LS2: demonstrate scalability of AWAKE concept by acceleration of e-beam to 5-10 GeV

potential application of the concept: NA64-like experiment

visible configuration —> can use high number of e^-/bunch

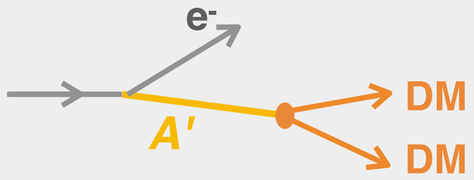


energy of O(50) GeV, 5 x 10^9 e/bunch, 10^{16} EoT integrated luminosity in 12 weeks

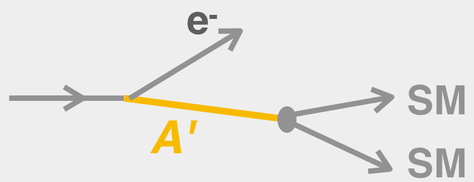
(TeV energies with LHC as driver)

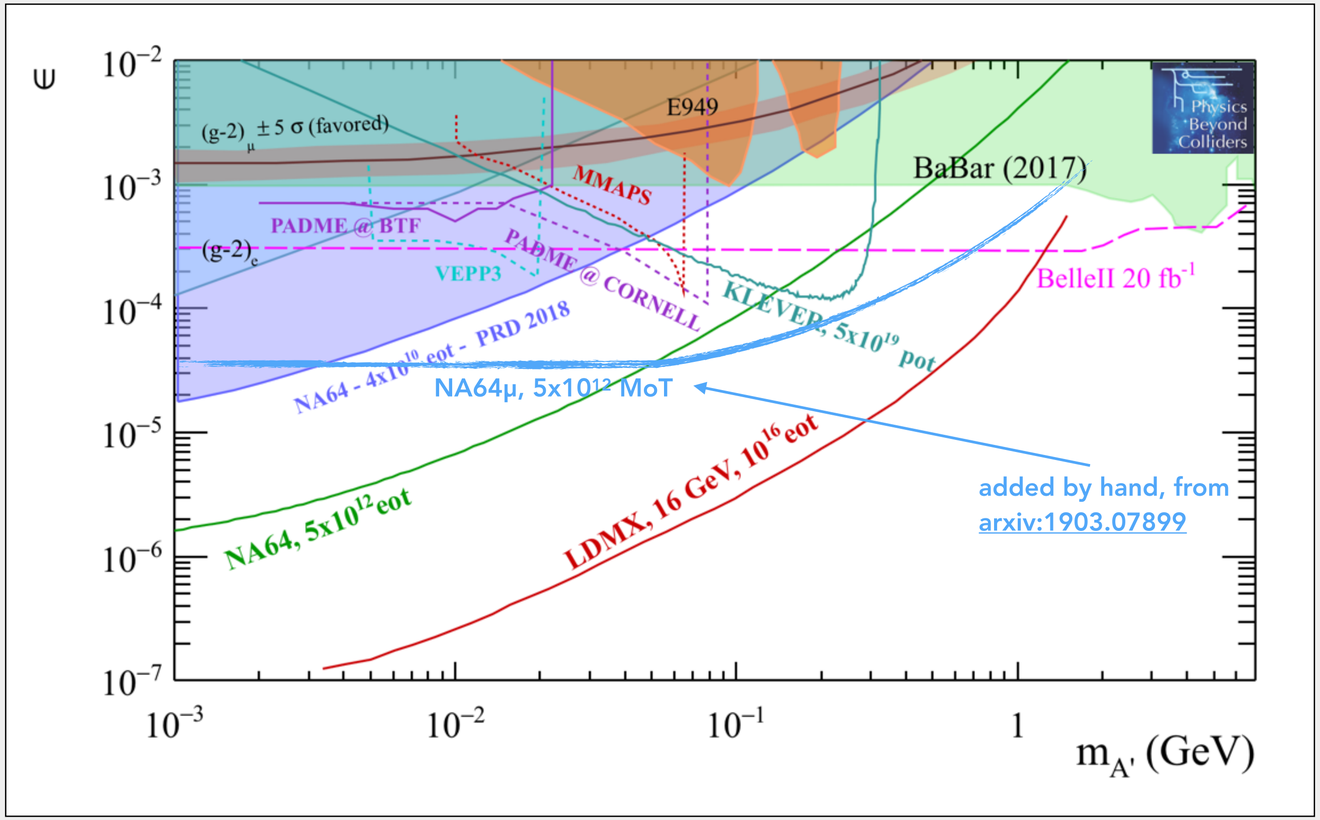
Benchmark Sensitivities (Examples)

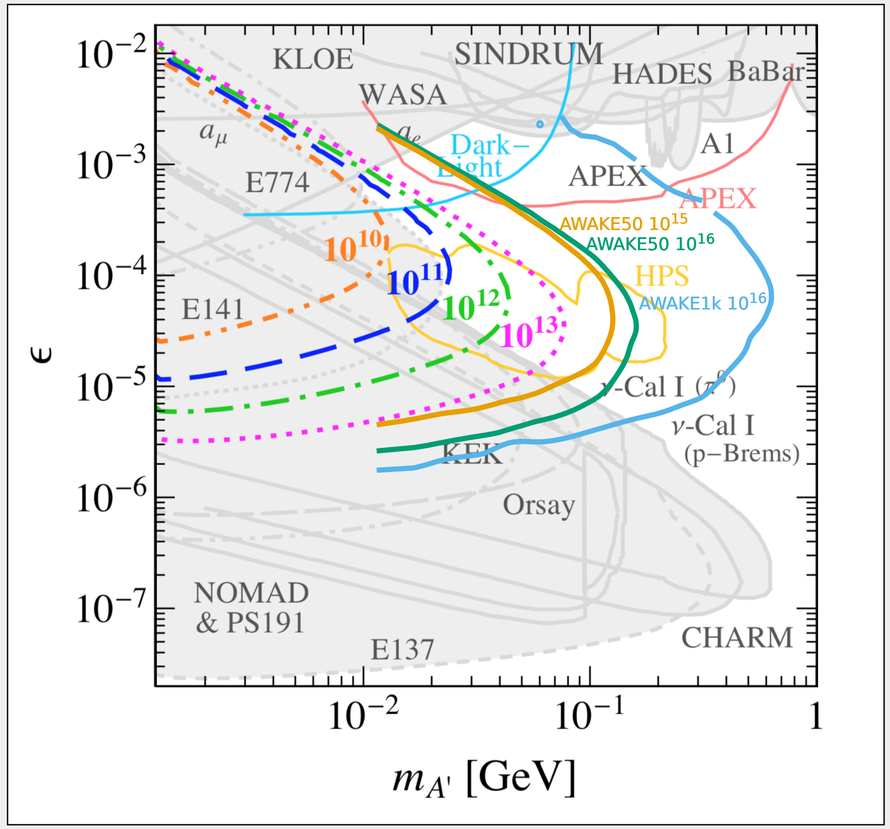
invisible



visible







further sensitivity estimates in backup (and other talks, PBC report)

Summary

lepton-beam fixed-target experiments explore important **new parameter space**

great opportunities possible at CERN within the next <10 years

LDMX benefits significantly from a beam as could be provided by eSPS

in particular in high mass range

extends reach in (coupling, mass)-plane far beyond other e-beam experiments

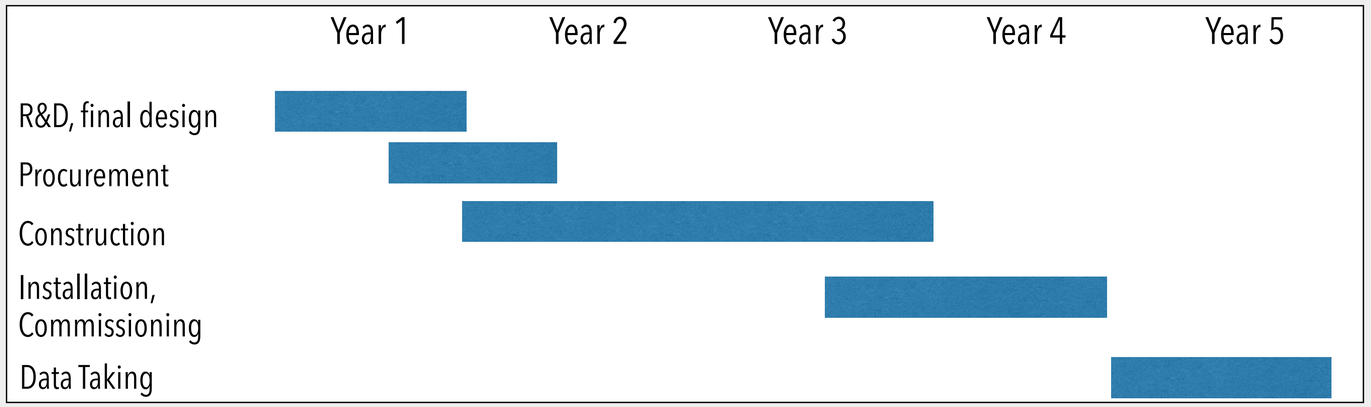
potential for NA64 to considerably extend its reach for invisible signatures

additional coverage in appearance mode with AWAKE++

Additional Material

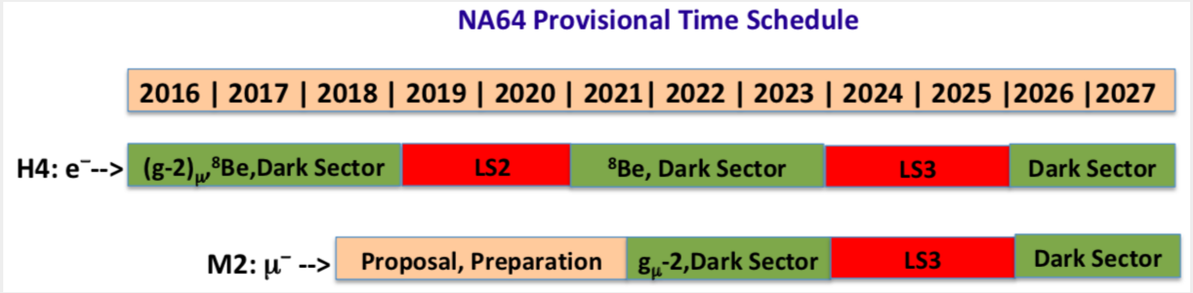
Timelines/Costs

LDMX



detector: ≤ 10M CHF
(excluding computing)

NA64++



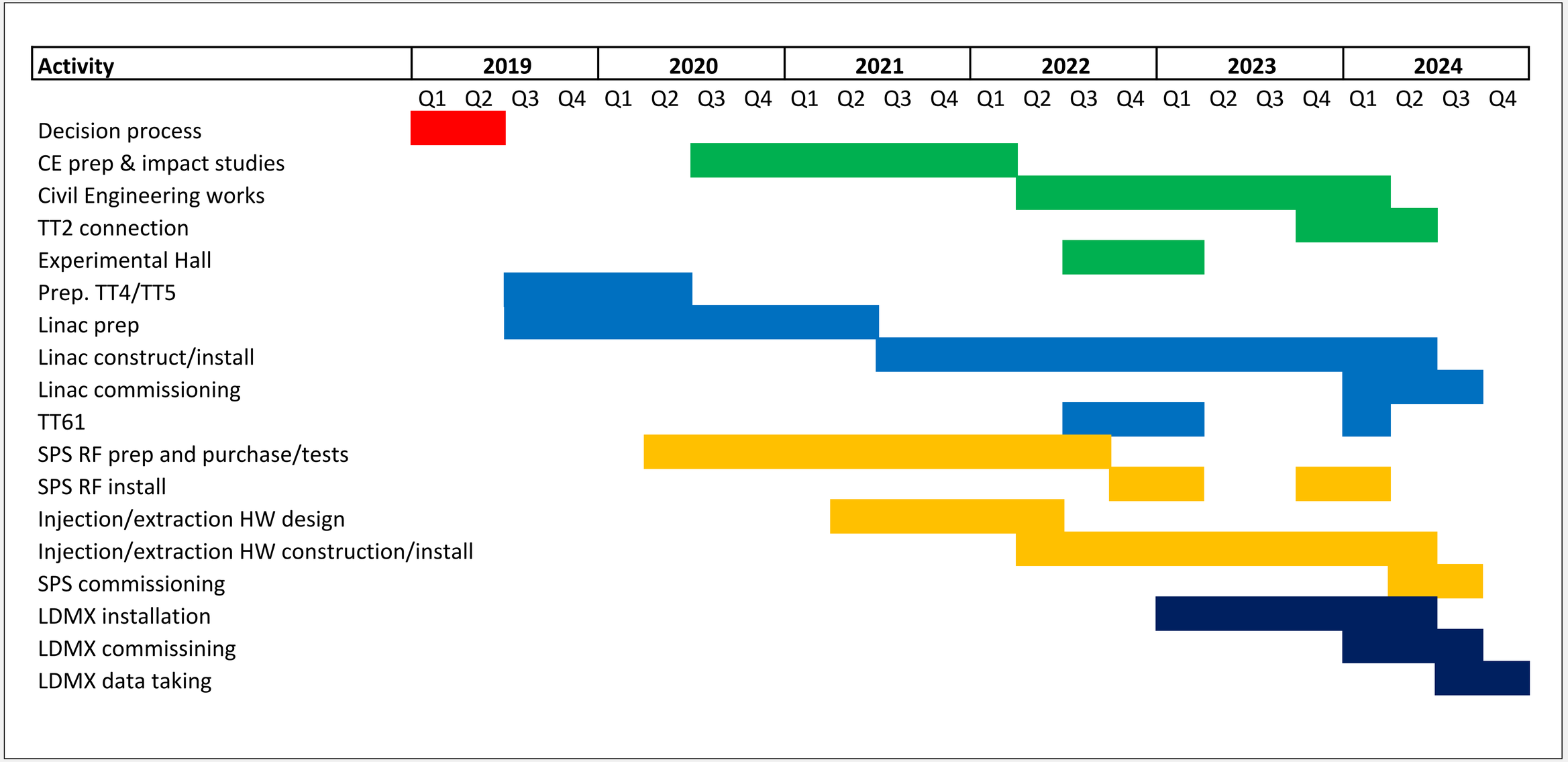
https://cds.cern.ch/record/2300189

upgrade of NA64e: 671k CHF

NA64μ: 1.1M CHF

AWAKE++ installation during LS3 the earliest

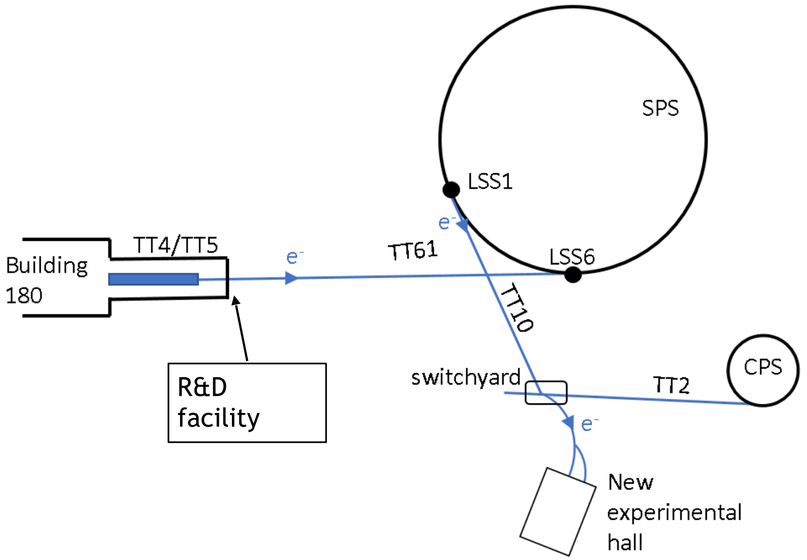
Possible eSPS Timeline

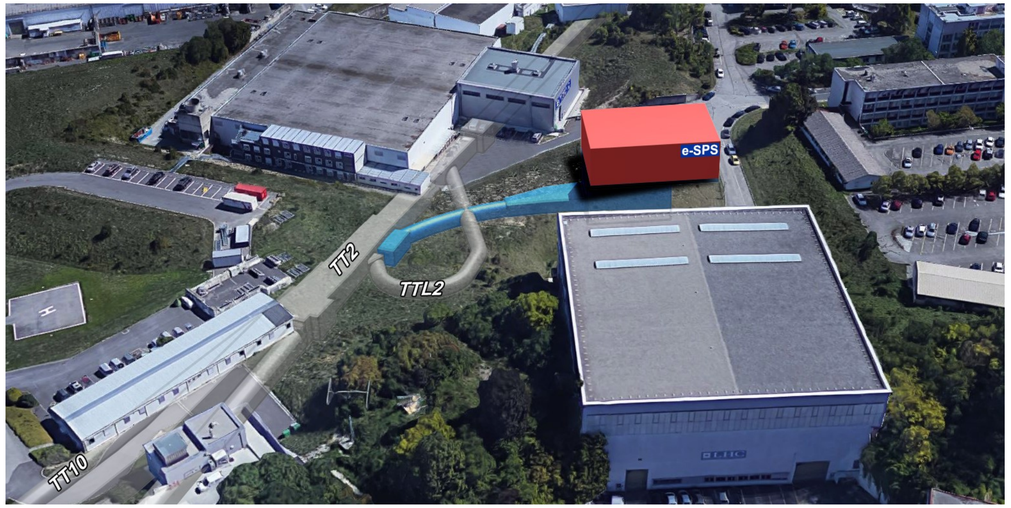


slide courtesy Mike Lamont

eSPS

- ~70 m long X-band based linac (CLIC technology) in TT4-5 accelerates e- to 3.5 GeV
- SPS filled in 1 to 2 s via TT60
- Acceleration to 16 GeV in the SPS
- Slow resonant extraction down the TT10 transfer line in ~10 s
- Beam delivered via the existing TT10 line to the Meyrin site
- A new, short beamline would branch from TT10 to the experimental hall (LDMX)





1

slide courtesy Mike Lamont

eSPS: Feasibility

- **Feasibility - following initial study looks good**
  - Additional RF in SPS to be studied (old LEP or FCC-ee cavities)
- Maximal use of existing structures, small foot print, and thus relatively inexpensive.
- SPS cycle sharing implications
  - ~12 s cycle, 10 s slow extraction giving 1e8 – 1e9 EOT/s
- Material cost: ~80 MCHF

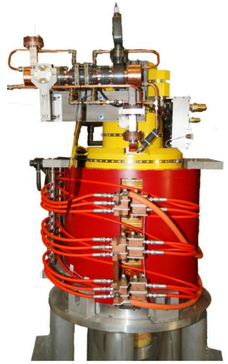
Well developed proposal:
"Dark Sector Physics with a Primary Electron Beam Facility at CERN" presented as EoI to SPSC

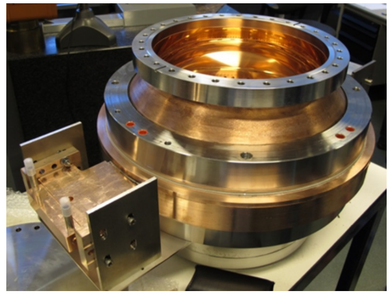
2

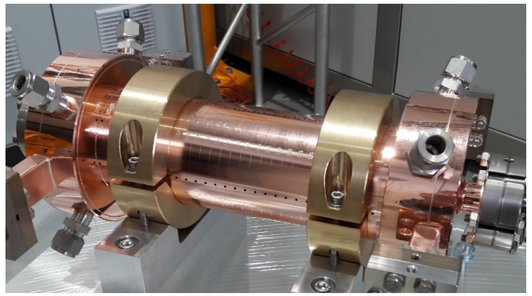
slide courtesy Mike Lamont

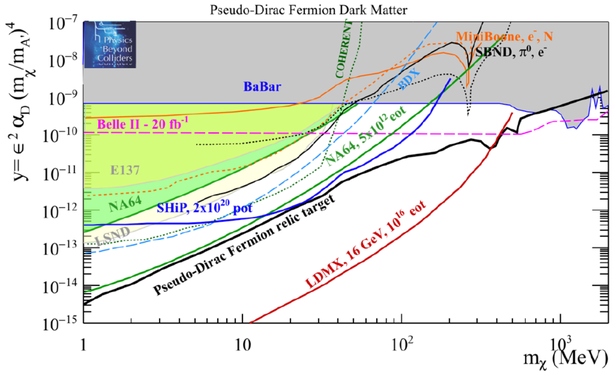
eSPS: Motivation

- **Electrons back in the complex** – good given CERN's apparent long term options
- **Staged deployment of X-band** – return on the significant investment
- Possible deployment of **FCC-ee RF cavities and high-efficiency power generation**
- Strong case made for **accelerator based R&D** and other studies at the linac R&D facility
- Physics case - **unique LDM search reach**





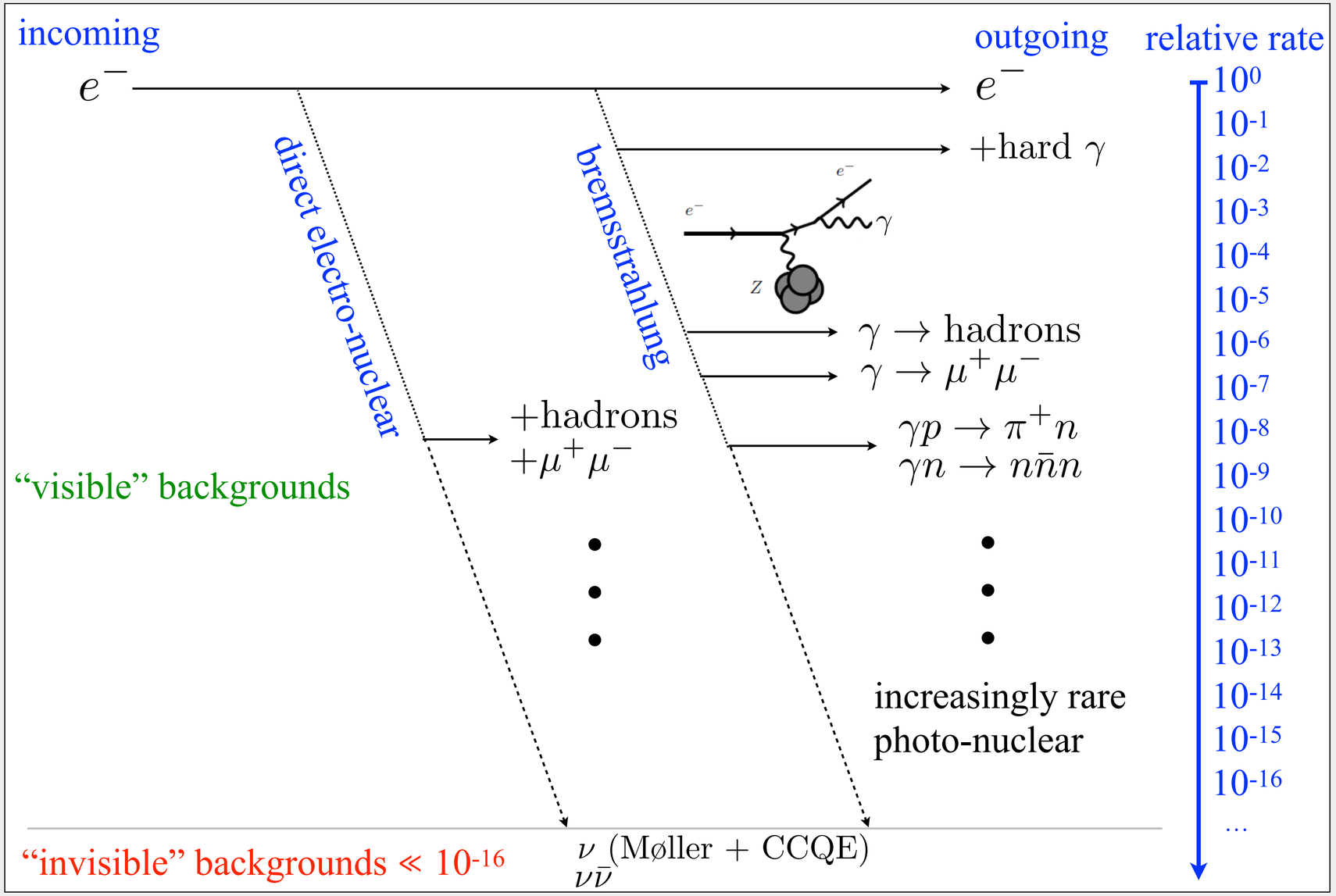




Preparing for future – staged deployment of FCC-ee/CLIC technology while preparing the long term strategic vision; at the same time performing a competitive LDM search - a game changer in the case of positive result and naturally important input to future plans.

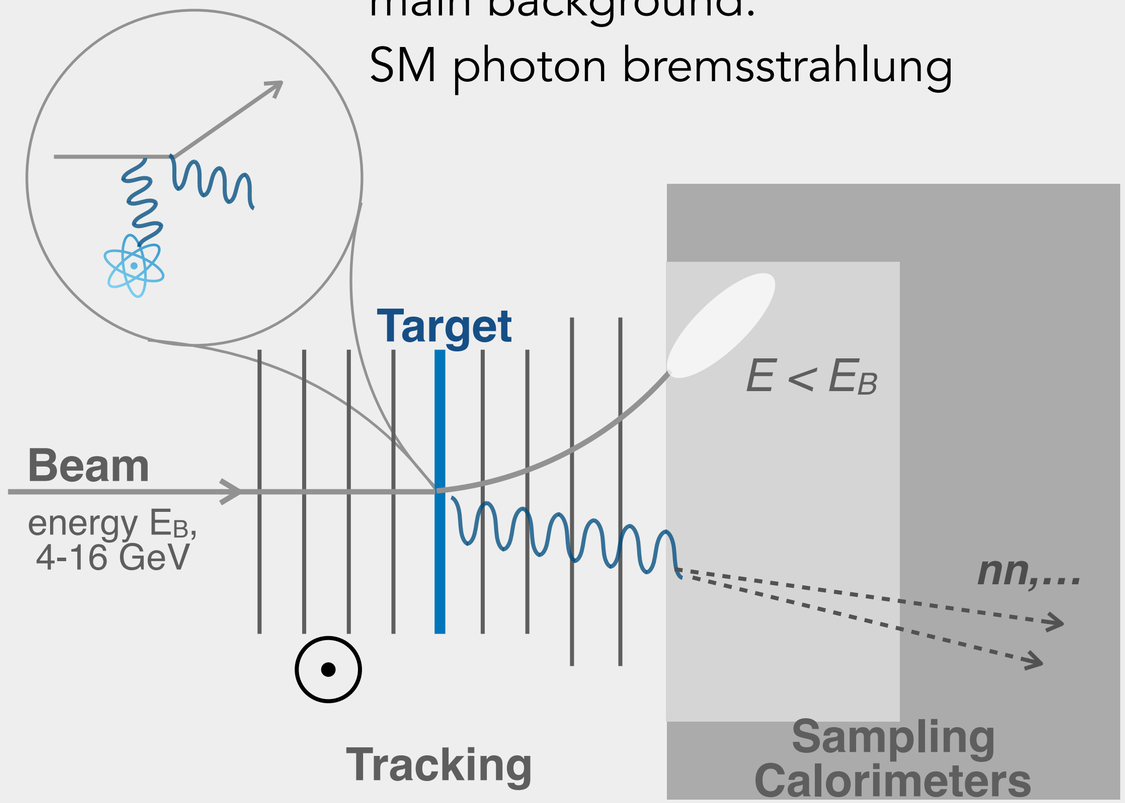
3

Background Overview



Background Challenges

main background:
SM photon bremsstrahlung



particularly challenging:

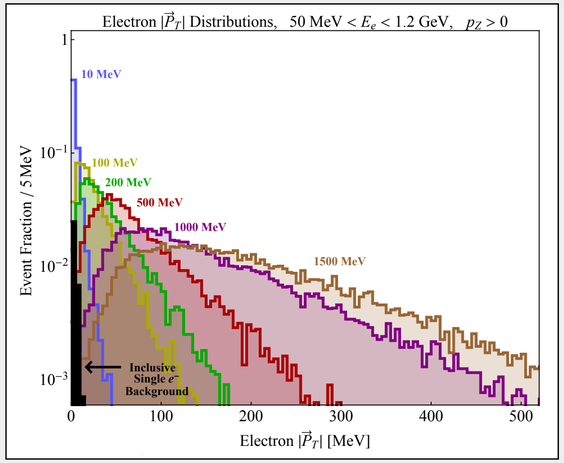
photo-nuclear reactions producing *neutral final states* (relative rate: ~10^{-9})

—> most design work currently on HCal to optimise rejection power, seeking funding for R&D/prototype (testbeam 2020)

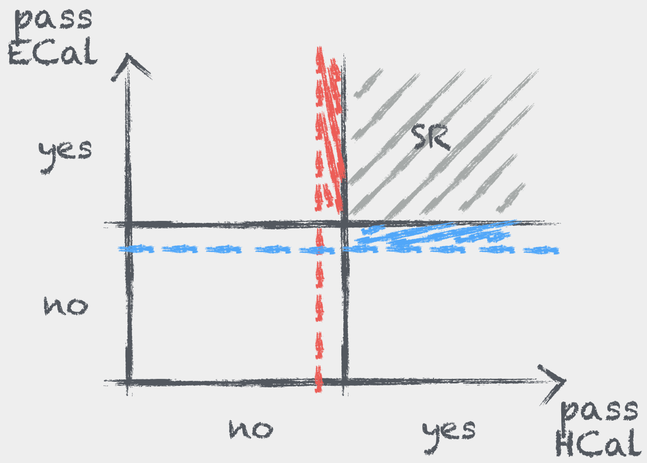
Preliminary Analysis Strategy

What if an excess was observed?

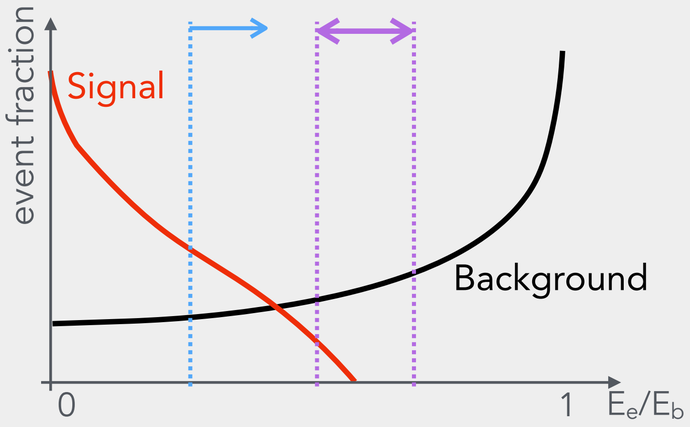
additional kinematic information (wrt missing energy only)
to investigate signal-likeness



test veto efficiency in control samples
(e.g. higher E_e or 'almost missed' by one detector)



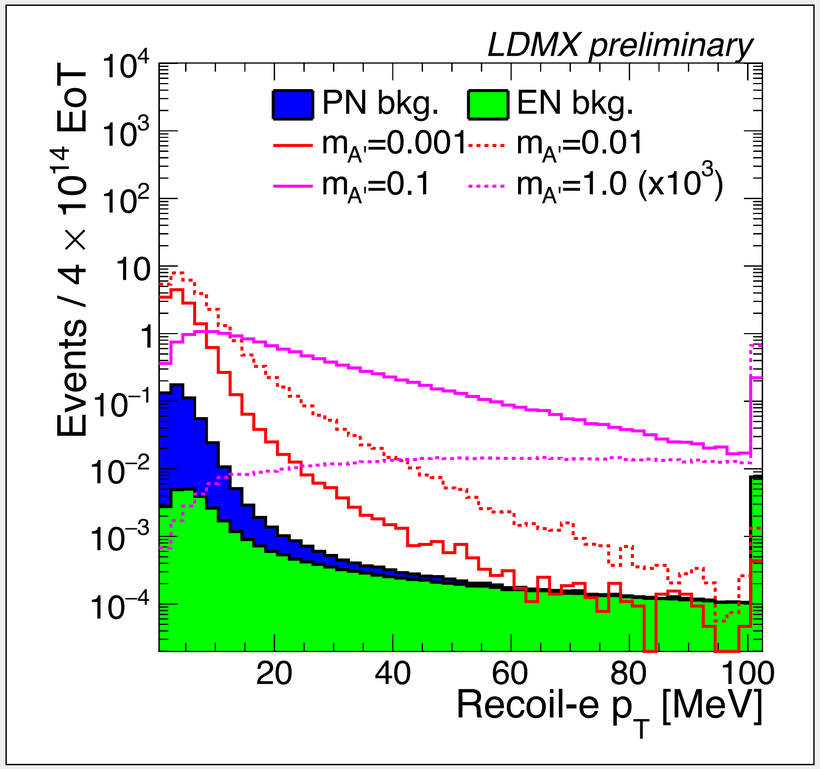
exploit different composition of energy bins
at different beam energies

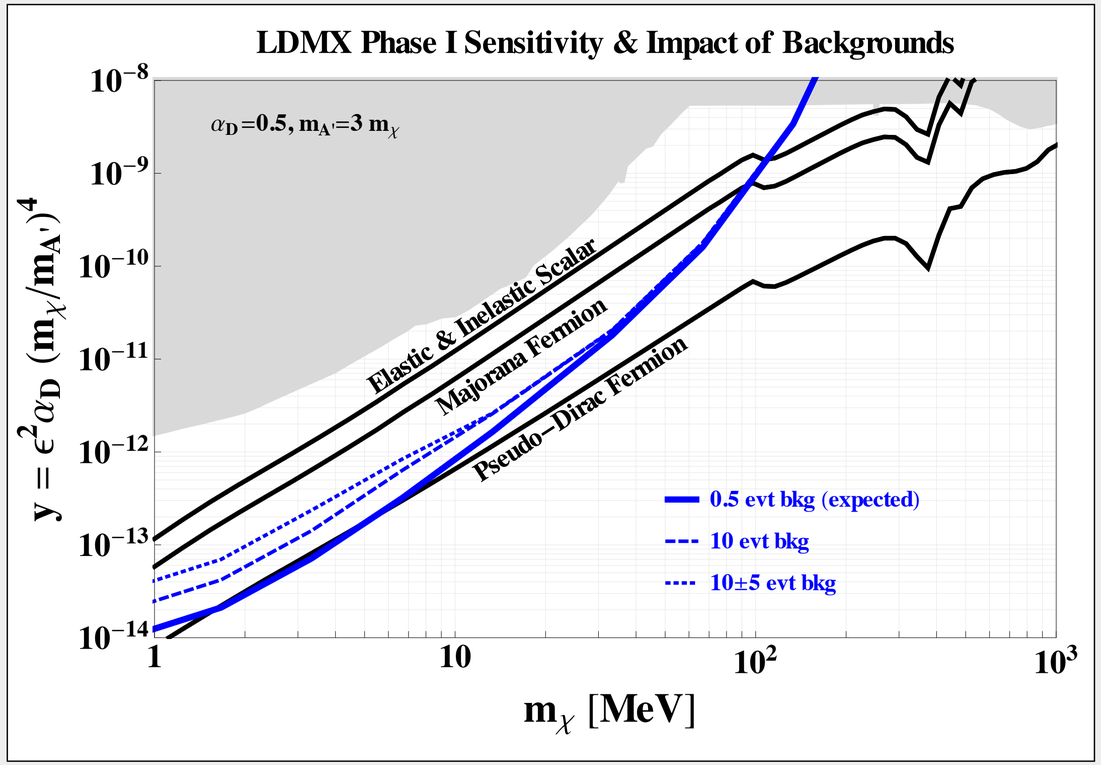


White Paper

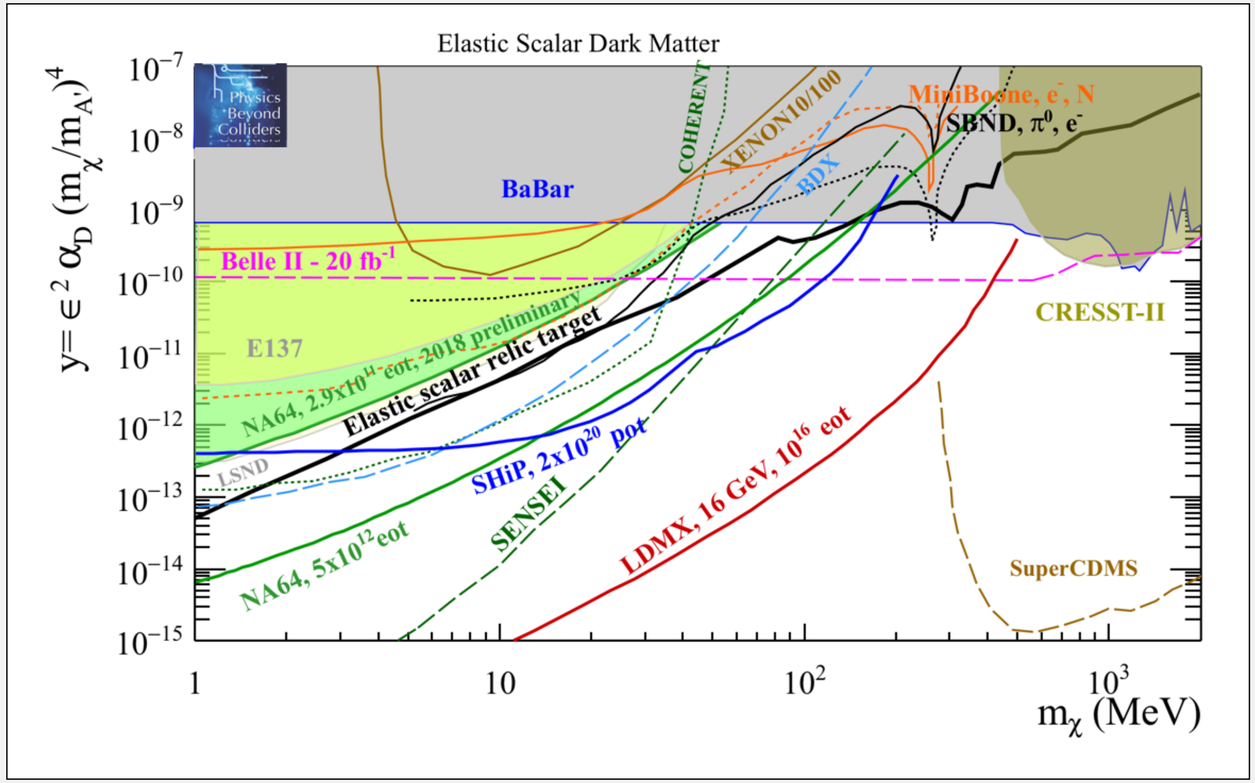
major milestone last year: comprehensive summary of design status arxiv:1808.05219

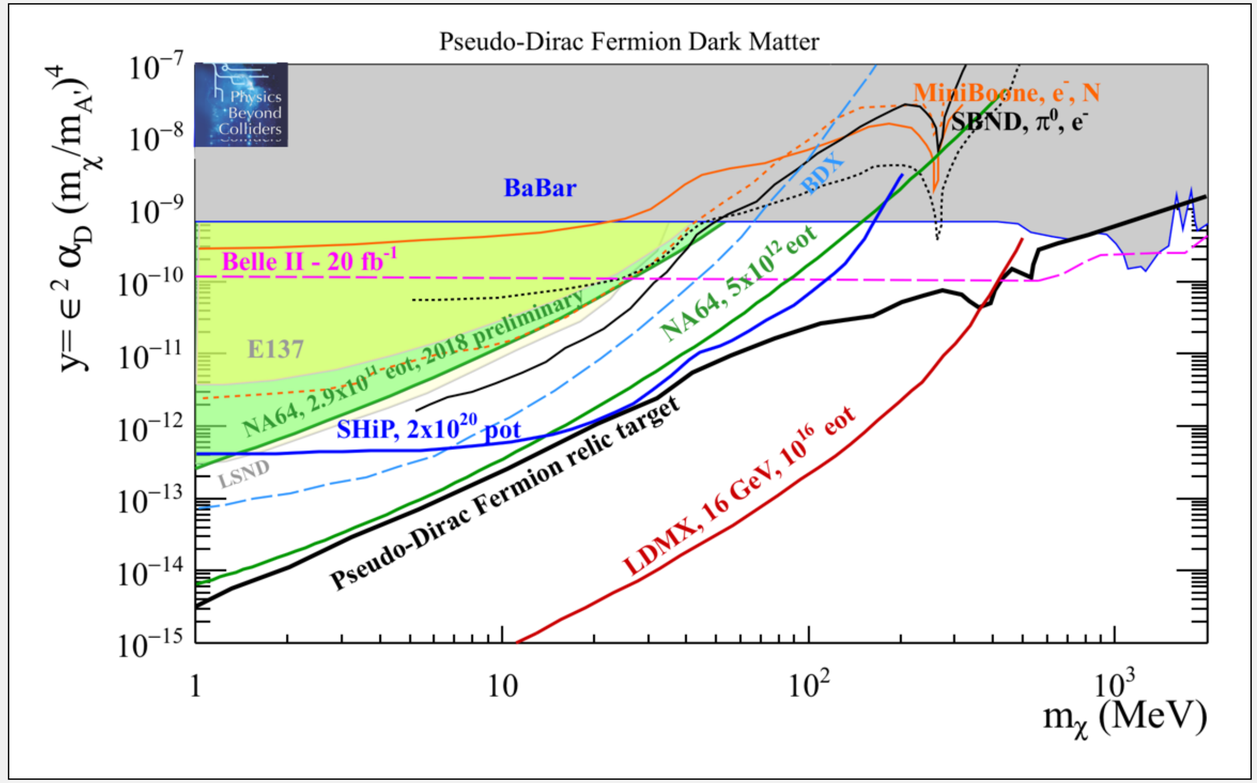
- detailed simulation studies of relevant background processes and their rejection
  - expect <1 background events for 4 x 10^{14} EOT (4 GeV beam energy)





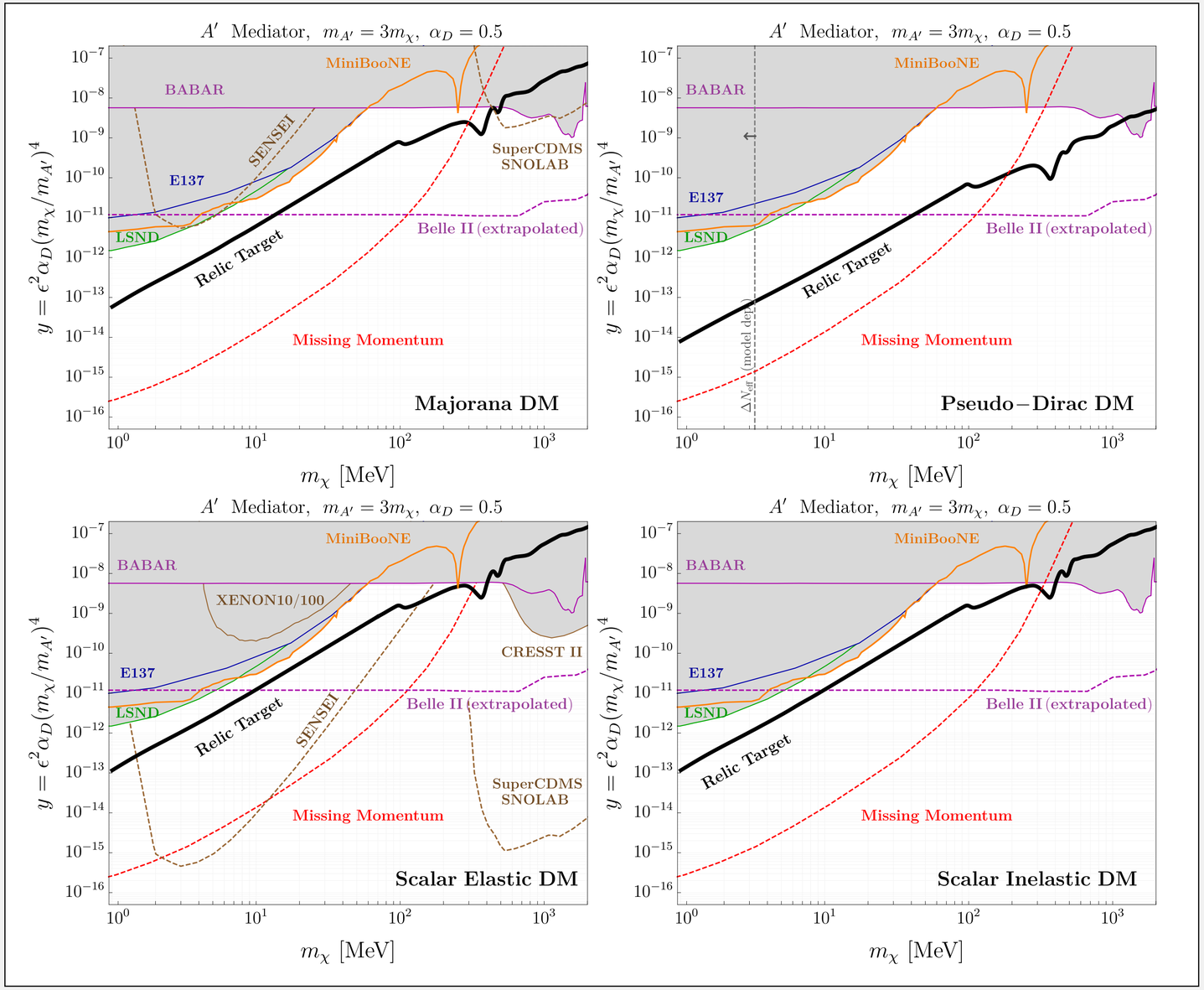
Sensitivities to thermal targets





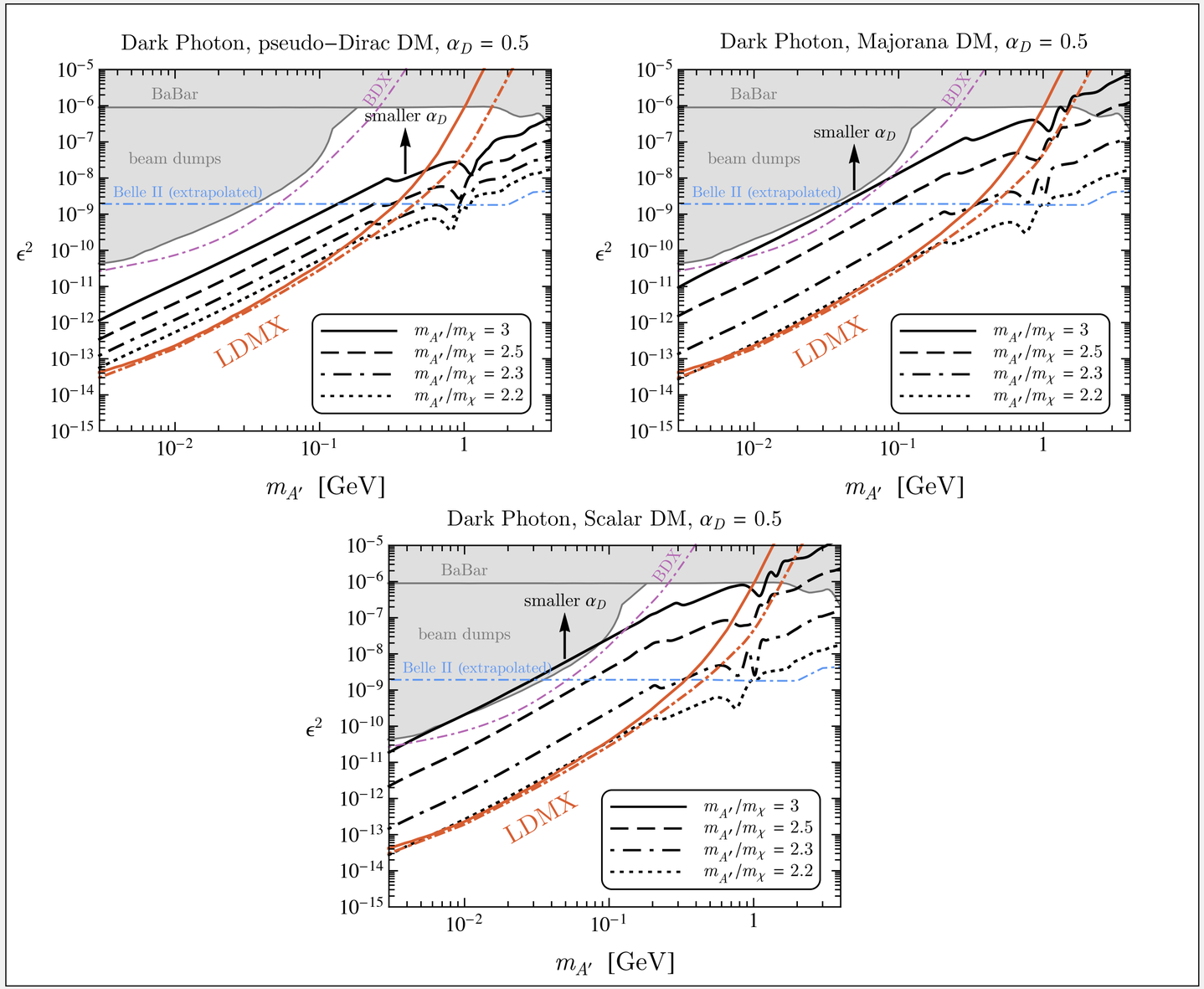
Various Future Projections

arxiv:1808.05219



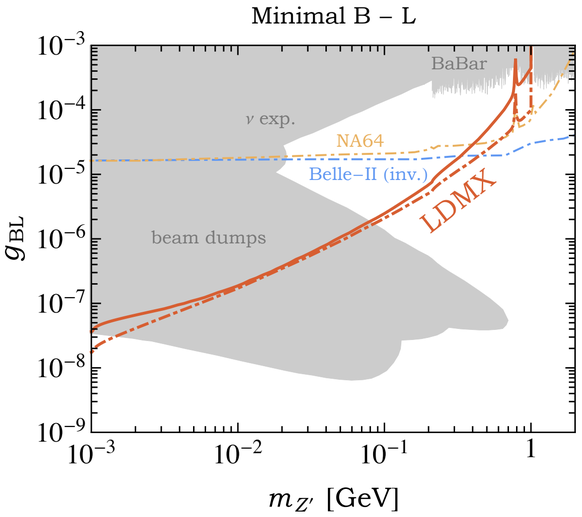
Parameter Dependence

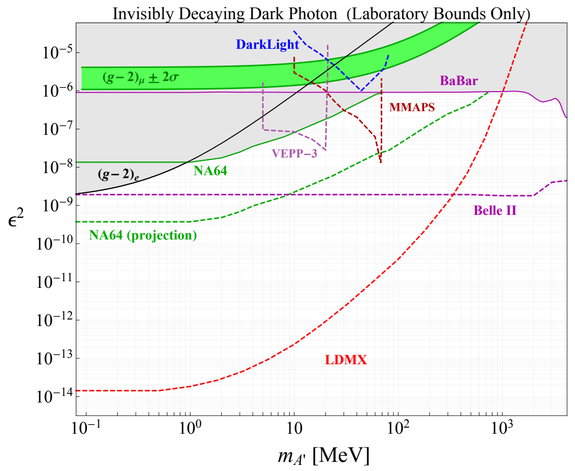
arXiv: 1807.01730

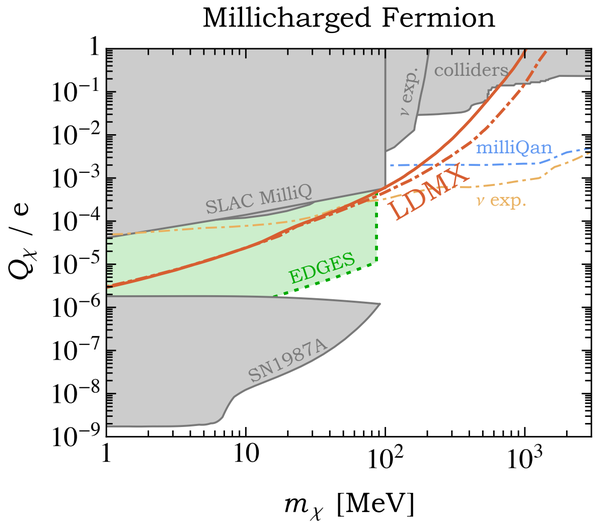


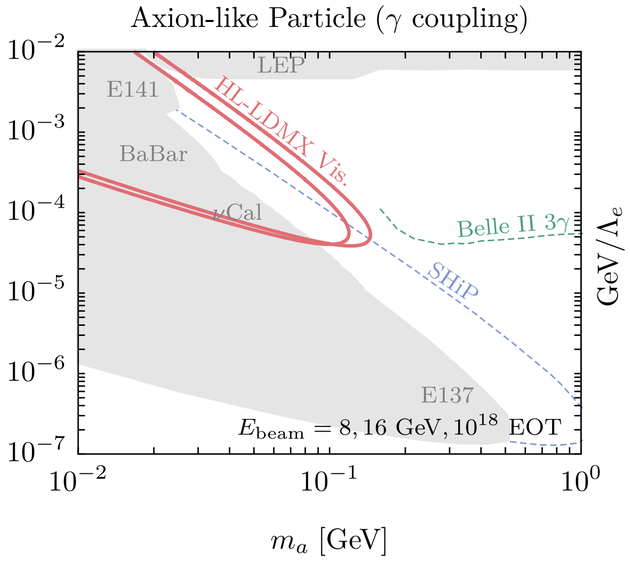
Further Potential for LDMX

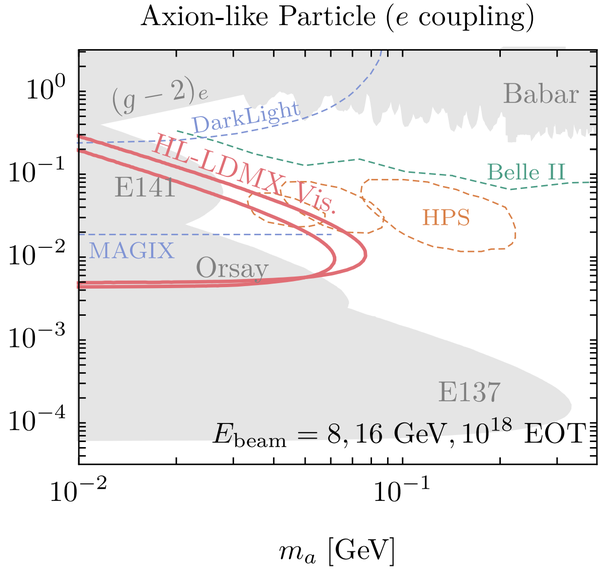
arXiv: 1807.01730

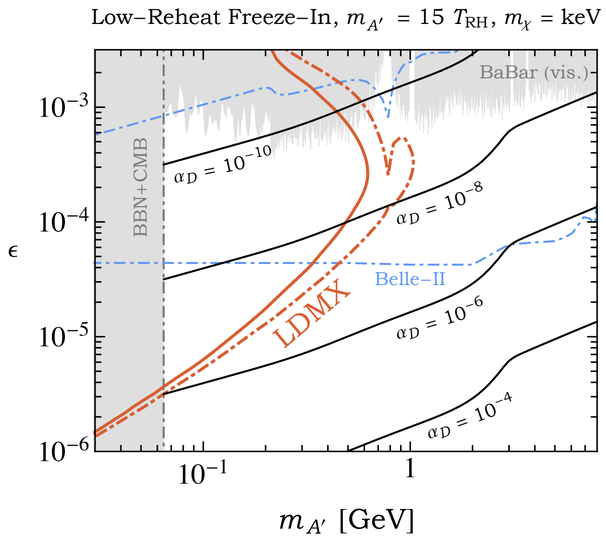












Tracking System

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

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

tagging tracker

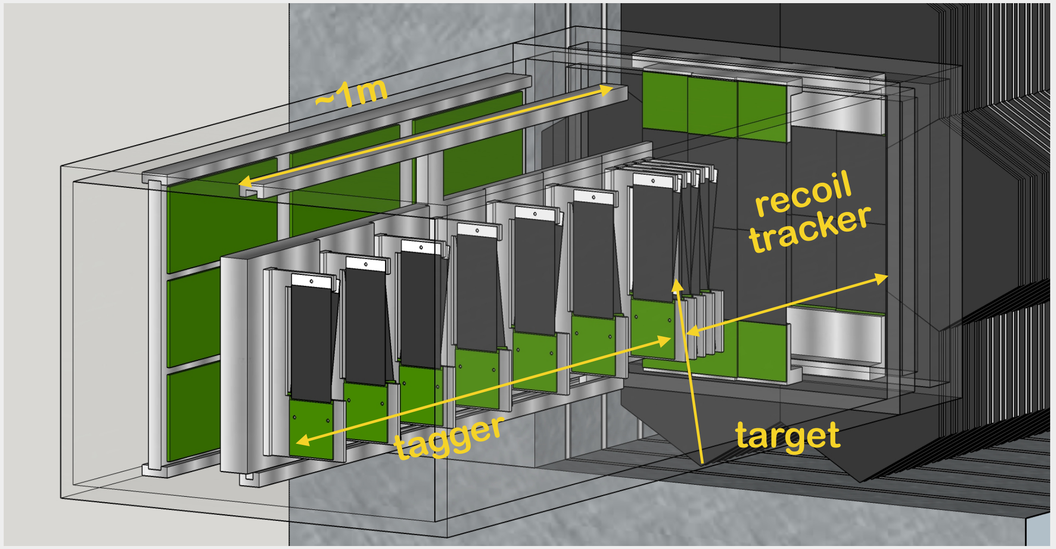
- in 1.5T dipole field
- measure incoming electron
  - momentum filter
  - impact point on target

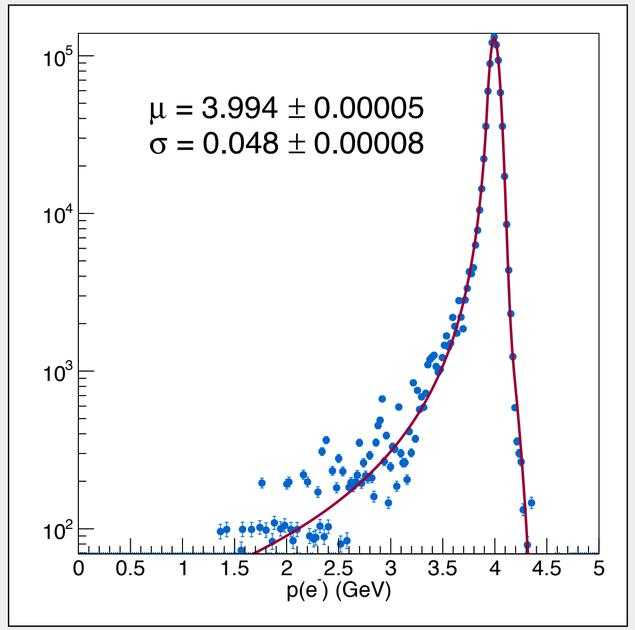
recoil tracker

- in fringe field
- measure recoil electron

target

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

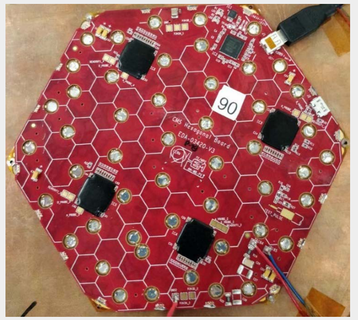


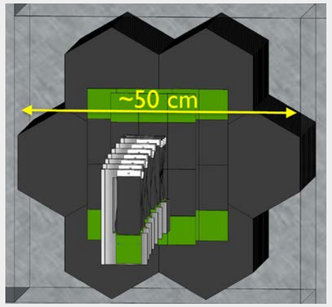


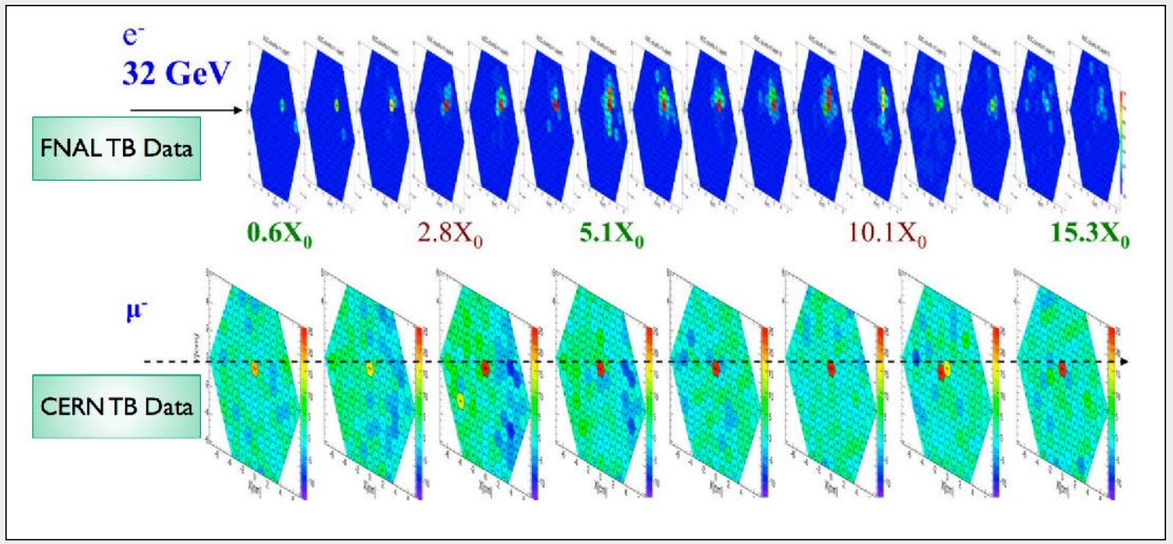
Electromagnetic Calorimeter

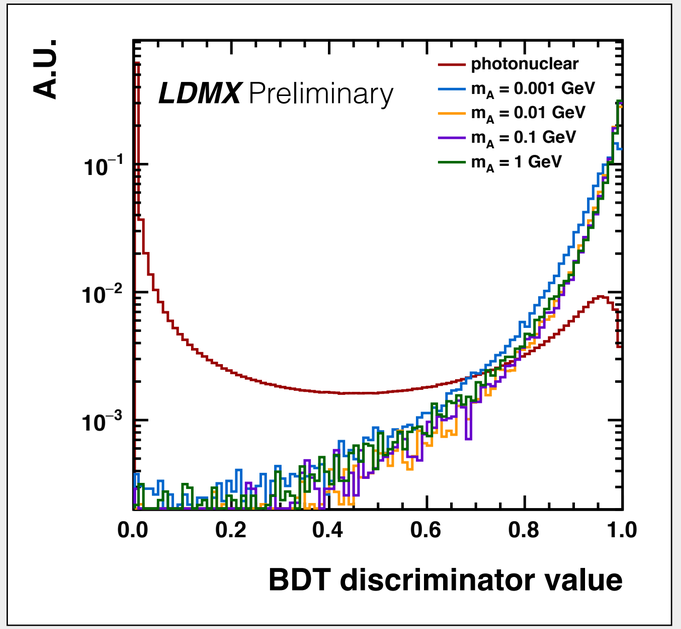
ECal

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





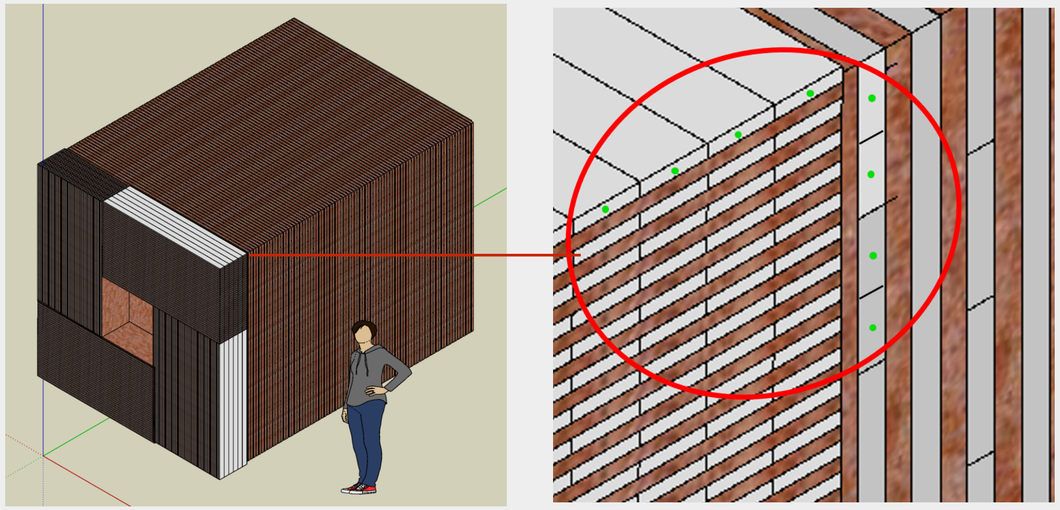




Hadronic Calorimeter

HCal

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



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