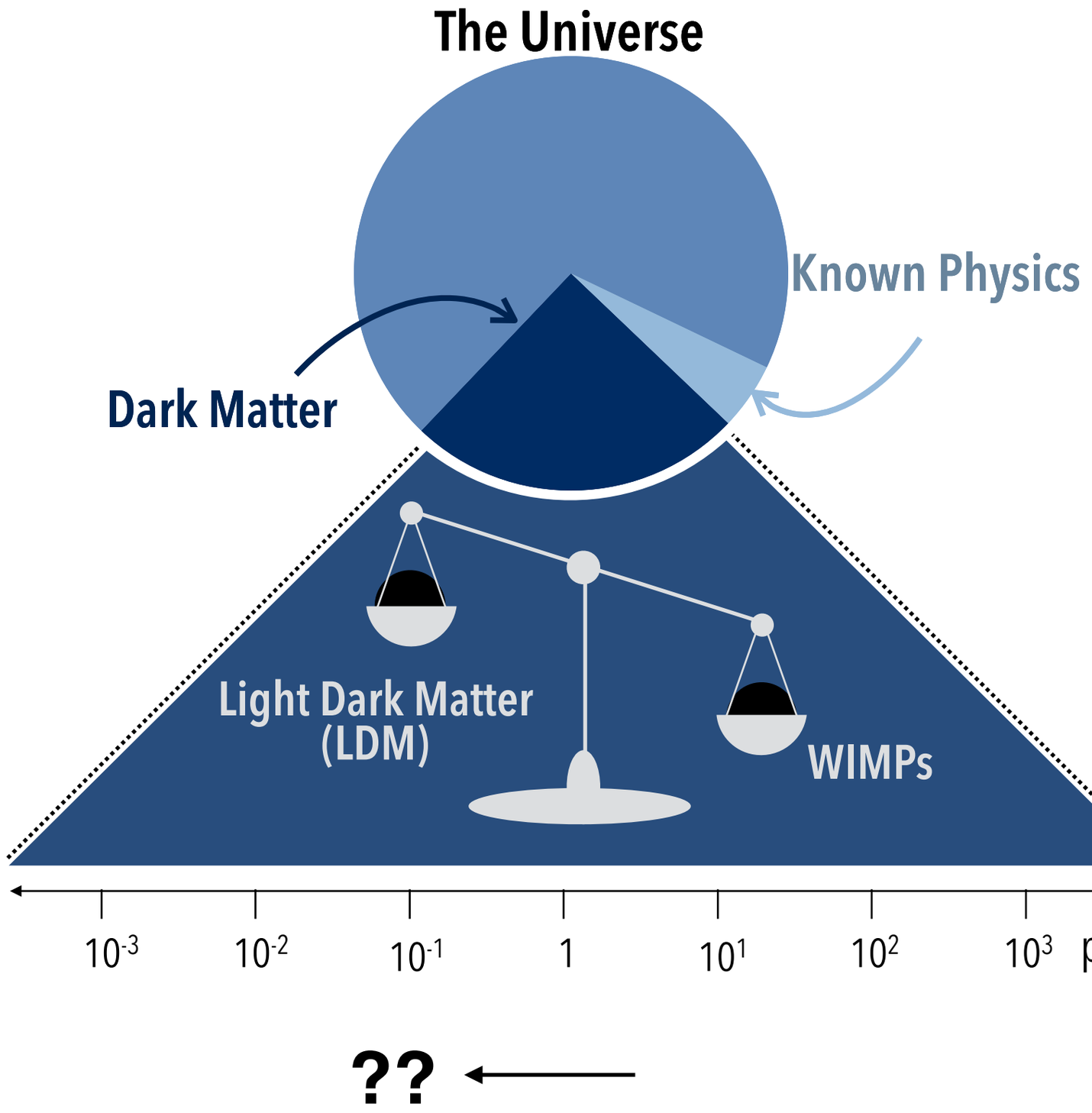
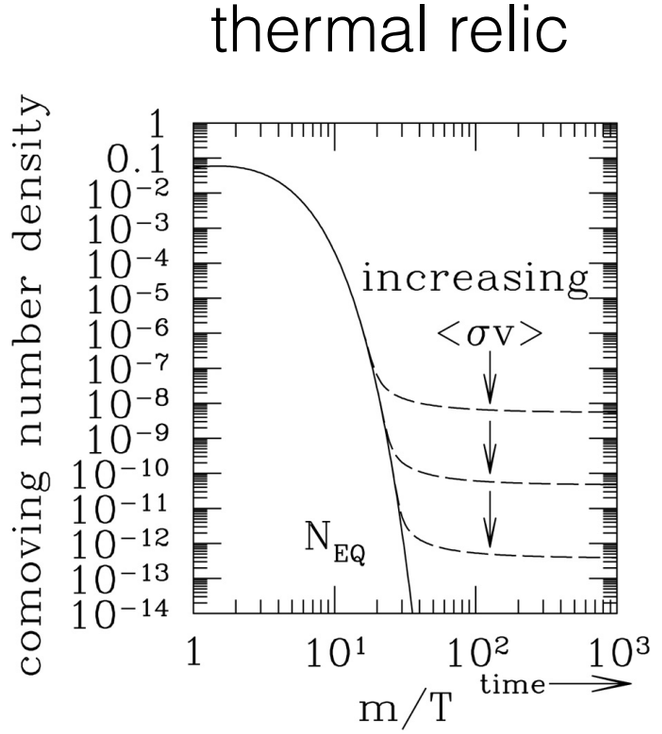

The Universe
Known Physics
Dark Matter
Light Dark Matter
(LDM)
WIMPs
10-3
10-2
10-1
1
101
102
103
particle mass
[GeV]
??


thermal relic
comoving number density
1
0.1
10−2
10−3
10−4
10−5
10−6
10−7
10−8
10−9
10−10
10−11
10−12
10−13
10−14
increasing
<σv>
NEQ
1
101
102
103
m/T
time

LDMX - A Light Dark Matter eXperiment

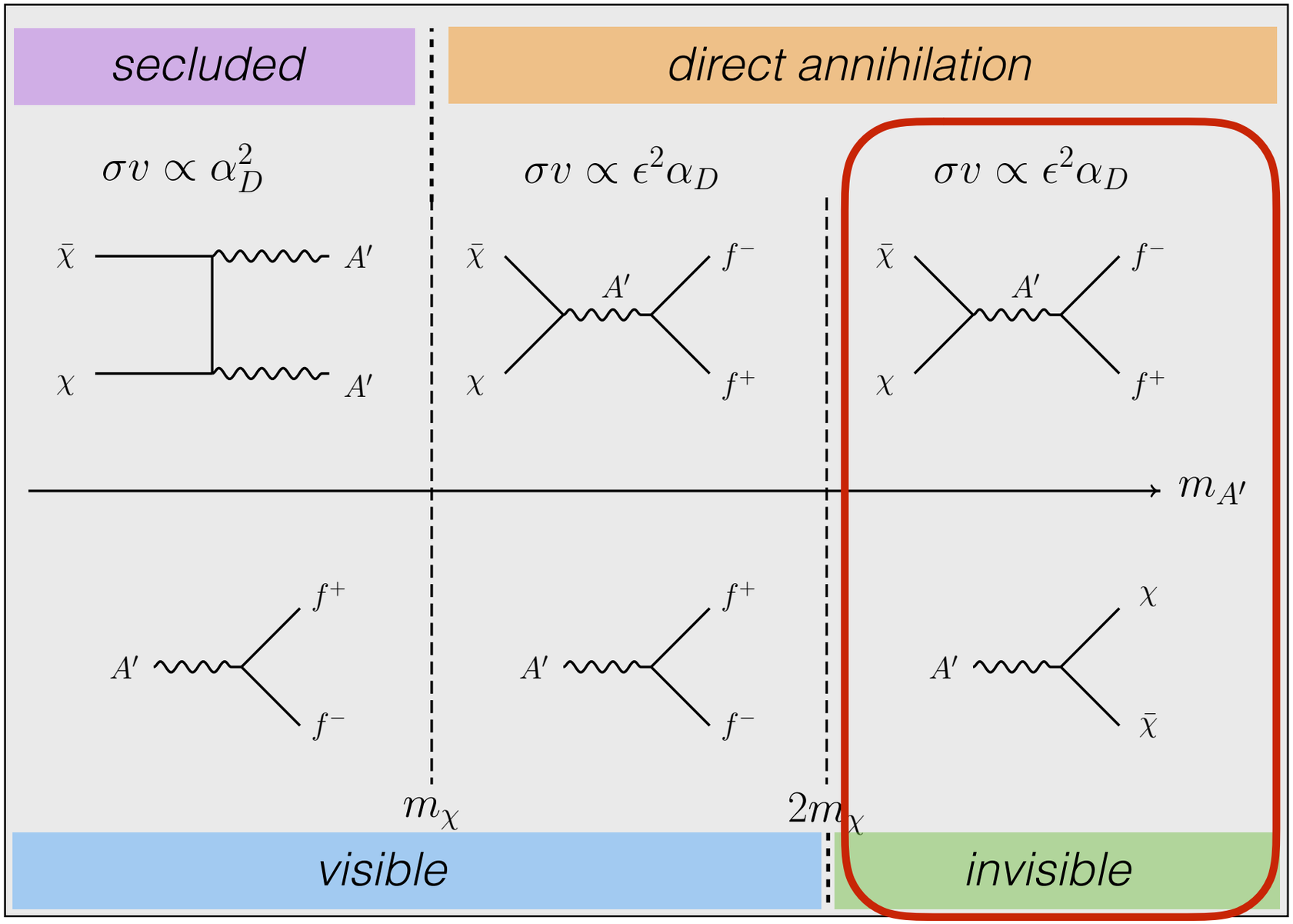
Preparing for Dark Matter Particle Discovery

Ruth Pöttgen

Göteborg, 12 June 2018

Light Thermal Relic

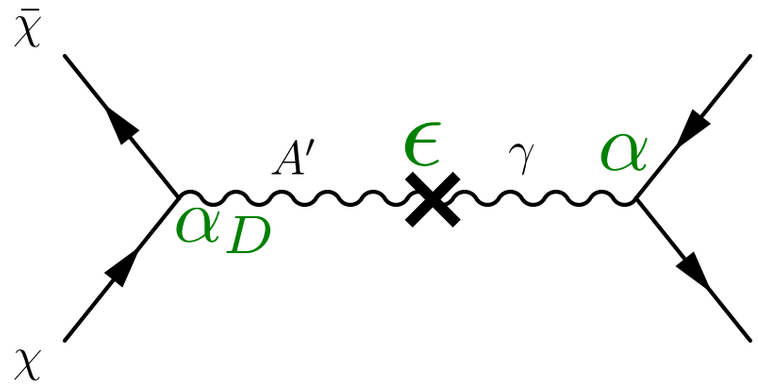
- thermal relic —> mass constraint & minimum annihilation cross section
  - WIMP too light —> annihilation inefficient —> overproduction of DM
    - Lee-Weinberg bound: m_χ > some GeV
- new, light mediator —> additional annihilation channel

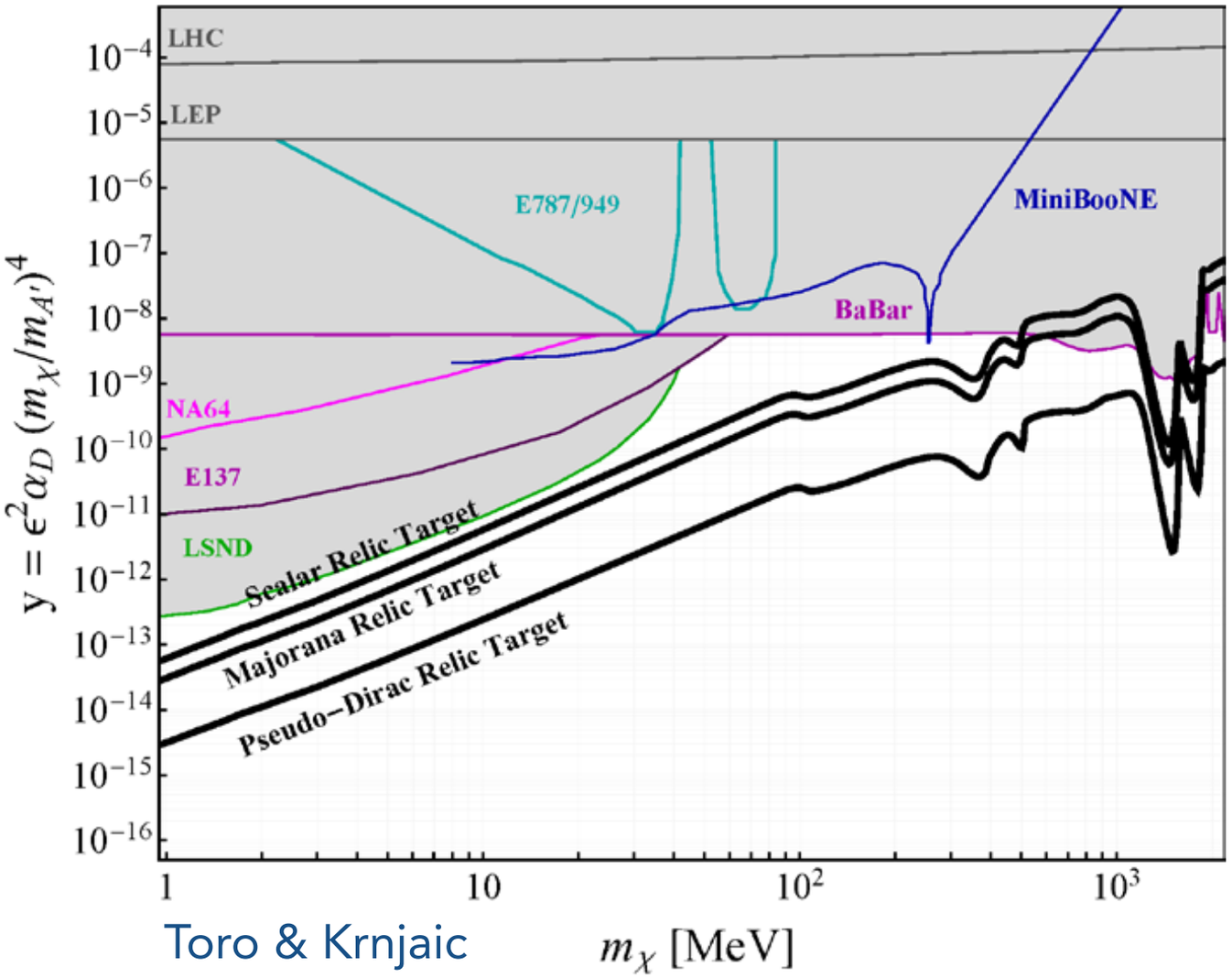


Thermal Targets

- representative model: **Dark Photon, A'** (vector mediator)
  - kinetic mixing with photon (ε)
  - annihilation cross section ~ $y\, m_\chi^{-2}$

$$y = \varepsilon^2 \alpha_D (m_\chi / m_{A'})^4$$





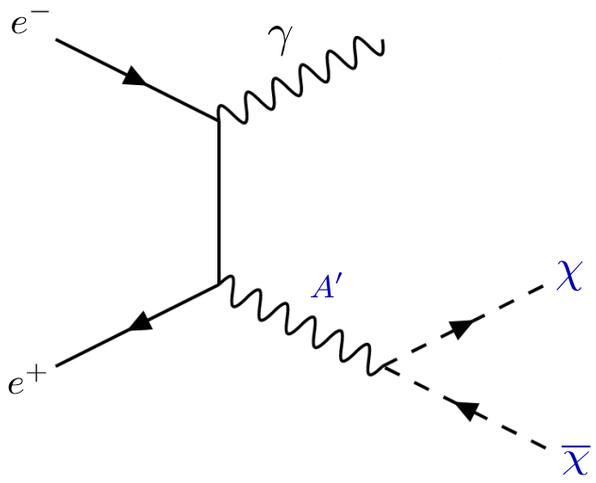
Toro & Krnjaic

- $\alpha_D = 0.5$, $m_\chi/m_{A'} = 1/3$ (conservative)
- clear experimental *'thermal targets'*

Why fixed-target?

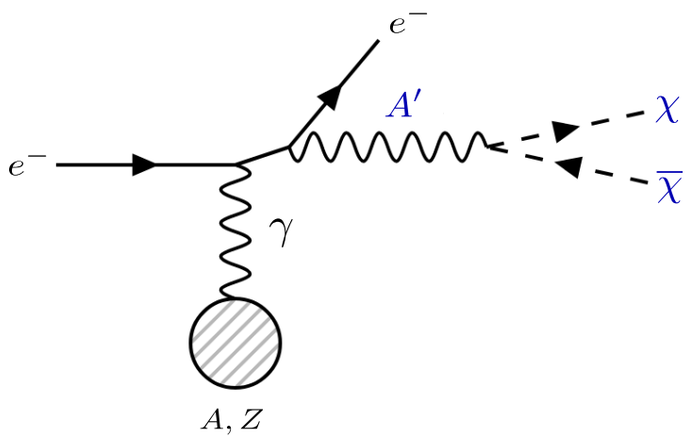
- maximise DM yield (**production** & detection **efficiency**)

- collider
  ($m_{A'} << E_{cm}$)

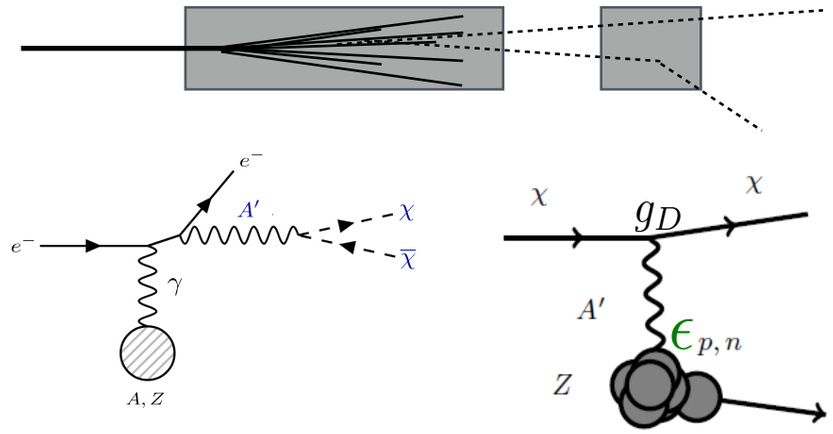


- fixed target

dark bremsstrahlung



- beam-dump



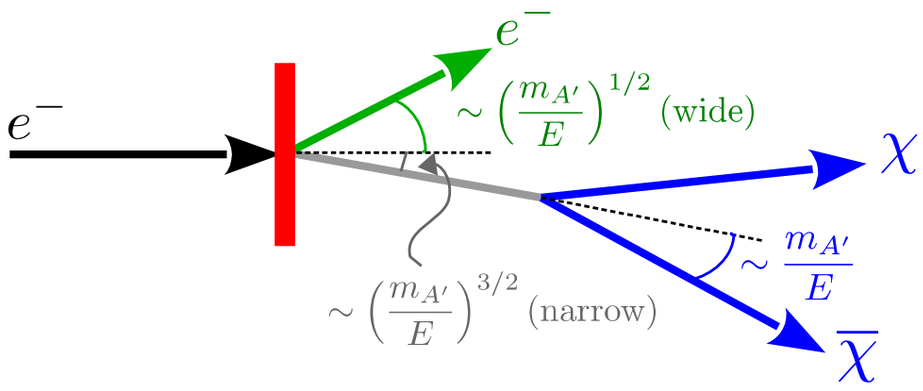
$$\sigma_{\text{coll}} \propto \frac{\varepsilon^2}{E_{\text{cm}}^2} \quad \ll \quad \sigma_{\text{FT}} \propto \frac{Z^2\varepsilon^2}{m_{\text{A'}}^2}$$

$$\frac{\sigma_{\text{FT}}}{\sigma_{\text{coll}}} \propto Z^2\left(\frac{E_{\text{cm}}}{m_{\text{A'}}}\right)^2 \quad >> 1$$

$$N \propto \varepsilon^2(1-\varepsilon^2) \approx \varepsilon^2 \quad \gg \quad N \propto \varepsilon^4$$

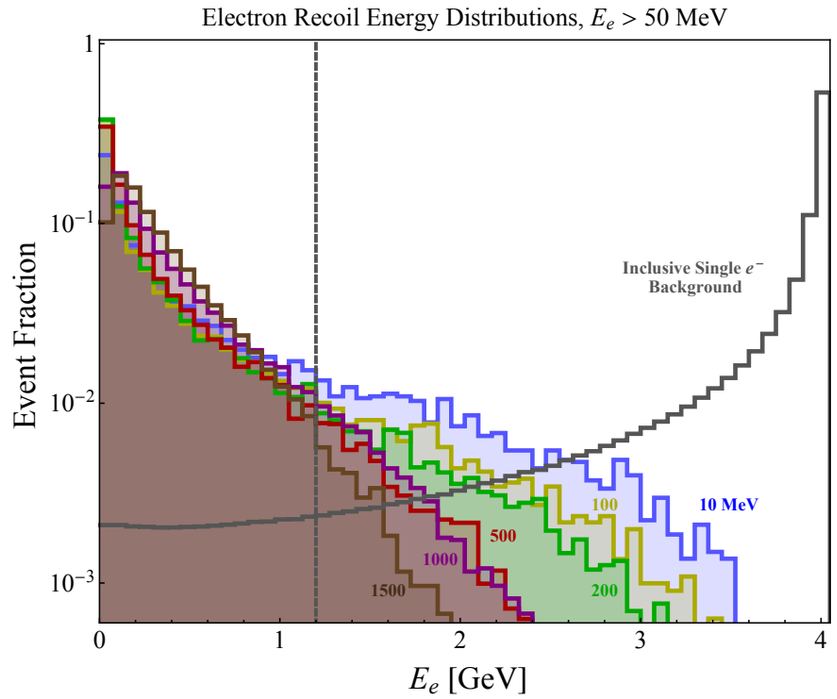
Kinematics & Experimental Layout

- due to mass of mediator, kinematics distinctly different from SM bremsstrahlung



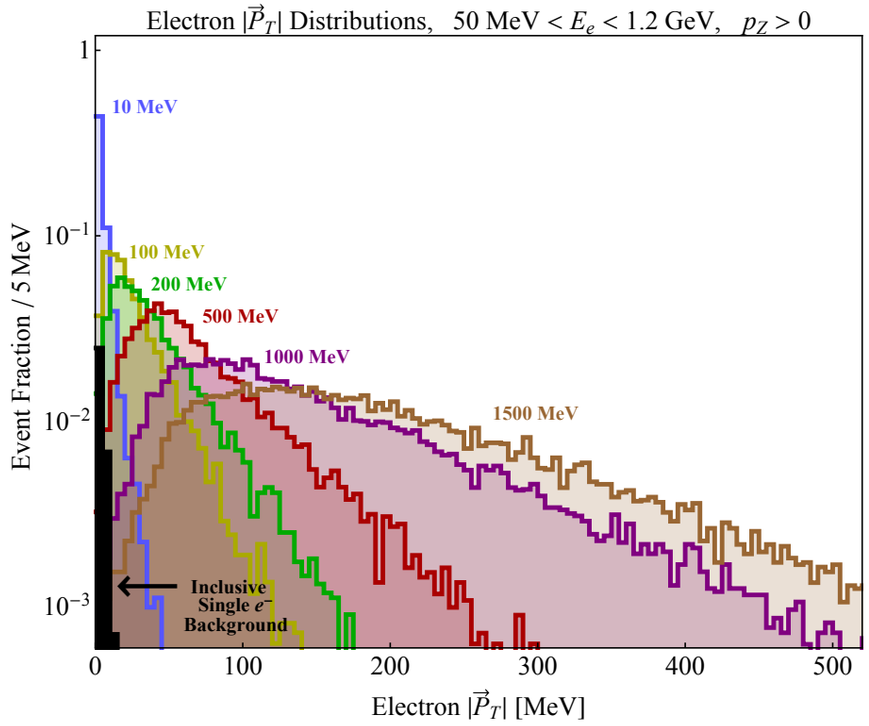
$$\frac{d\sigma}{dx} \propto \frac{\alpha^3}{\pi} \frac{\epsilon^2}{m_e^2 \cdot x + m_A^2(1-x)/x}$$

$$x = \frac{E_A}{E}$$

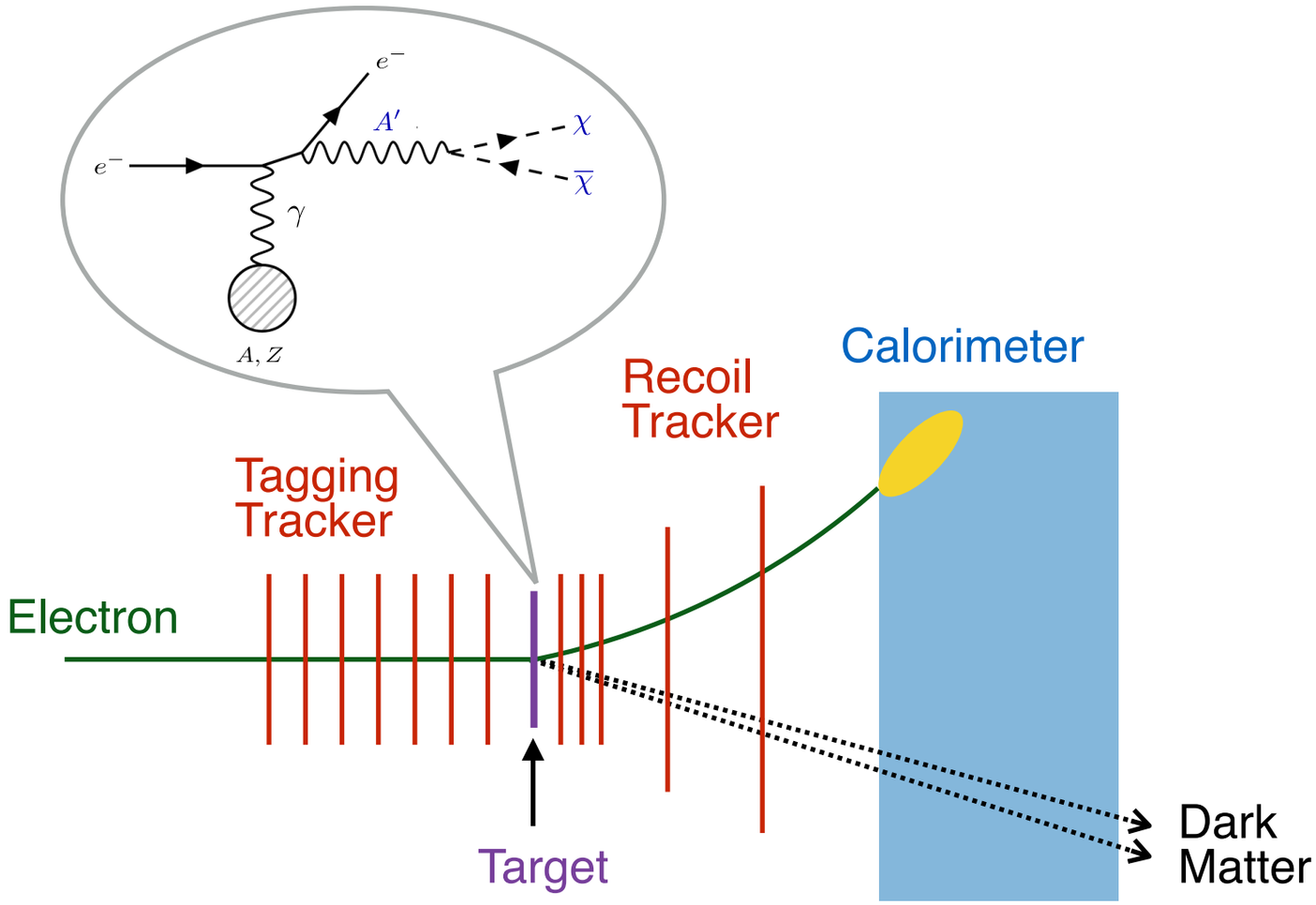


- mediator carries most of the energy
  —> soft recoil electron, large missing energy

- recoil electron gets transverse ‘kick’
  —> large missing transverse momentum



Conceptual Layout

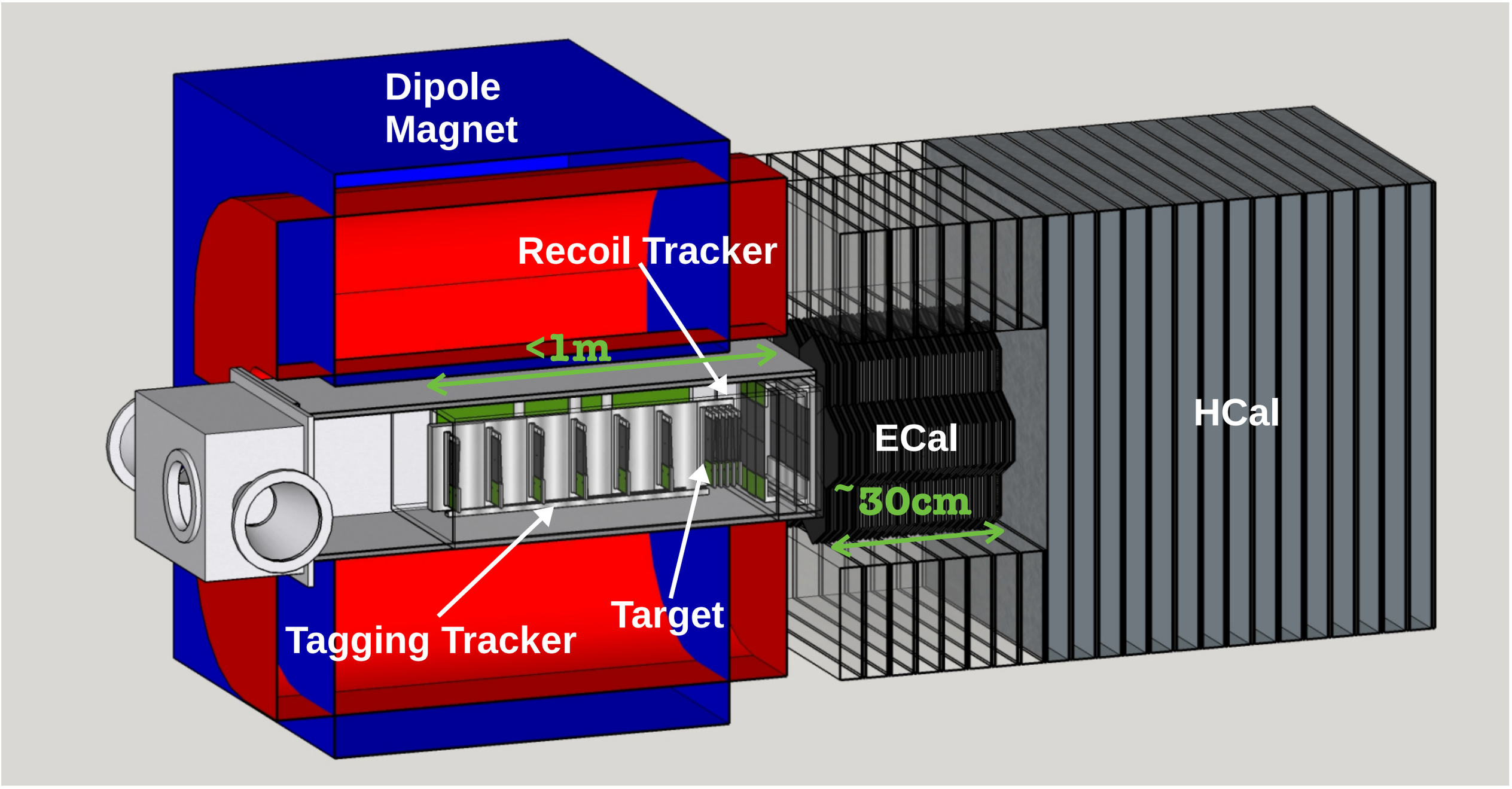


- plan in **two phases**
  - phase 1:
    - 4GeV, 46 Mhz, $<n_e>=1$ —> 4×10^{14} EOT
  - phase 2:
    - 8GeV, ≤186 MHz, $<n_e>=5$ —> 10^{16} EOT

- **detector** requirements:
  - high-rate capabilities
  - radiation hard
- fast, low-mass tracking
- fast, radiation hard, granular em calorimeter
- efficient hadronic calorimeter

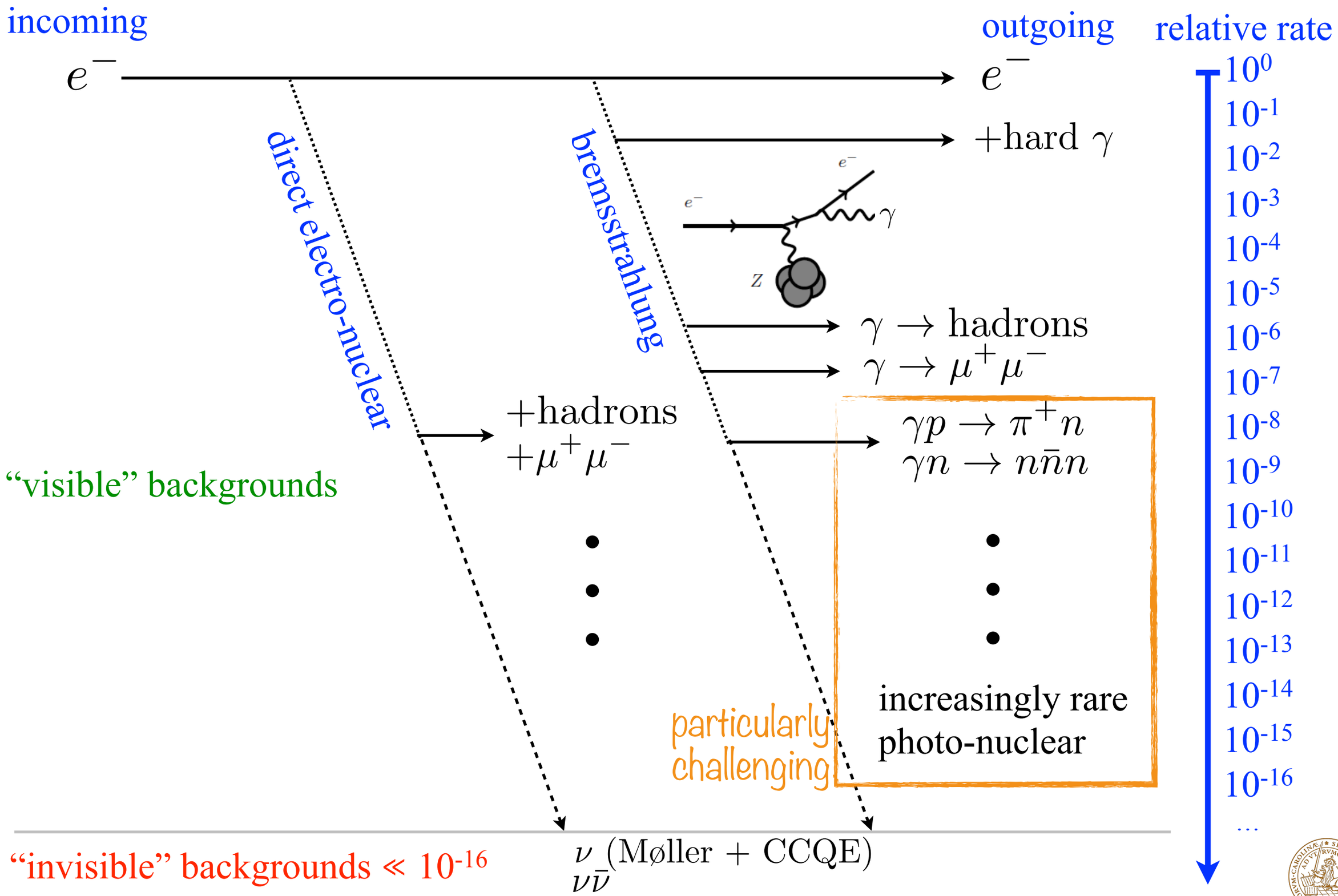
- reconstruct each electron
- **beam** requirements:
  - multi-GeV
  - low current
  - high repetition rate
  - large beam spot
- candidates:
  - **DASEL**@SLAC (4/8 GeV)
  - CEBAF@JLab (≤12 GeV)
  - eSPS@CERN (3.5 - 16 GeV)

LDMX Detector



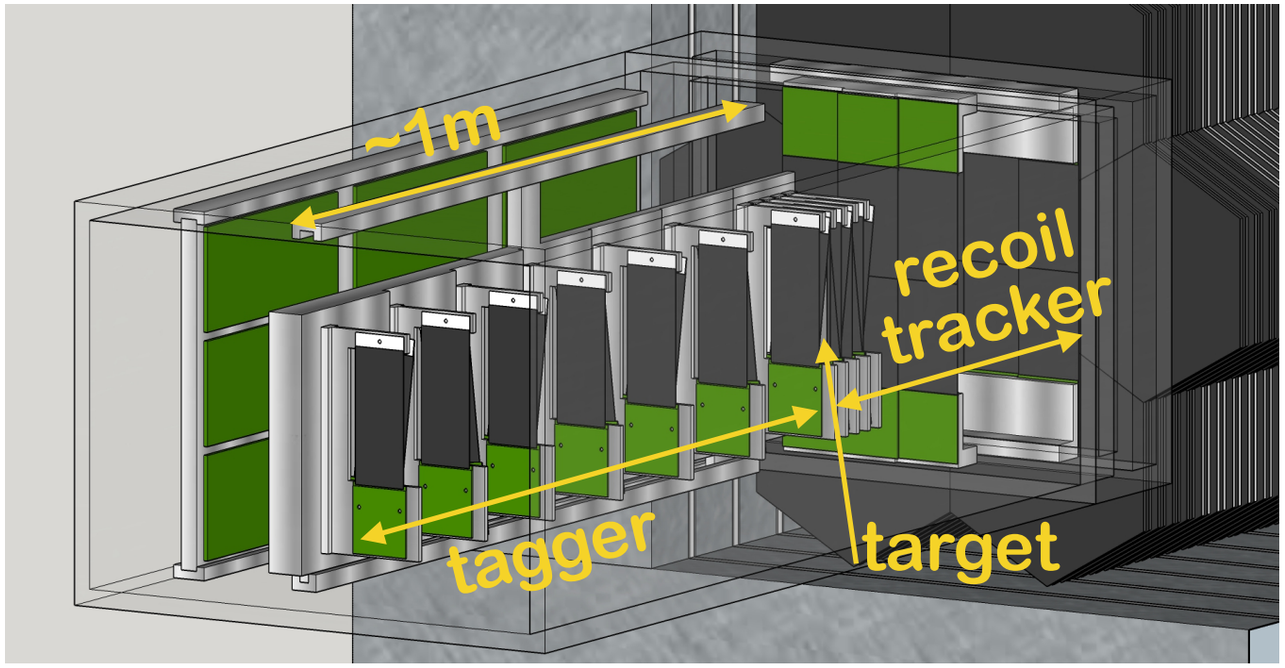
Caltech Fermilab SLAC NATIONAL ACCELERATOR LABORATORY UCSB UNIVERSITY OF CALIFORNIA SANTA BARBARA UNIVERSITY OF MINNESOTA UNIVERSITY OF CALIFORNIA SANTA CRUZ LUNDS UNIVERSITET

Background Challenges



Tracking System

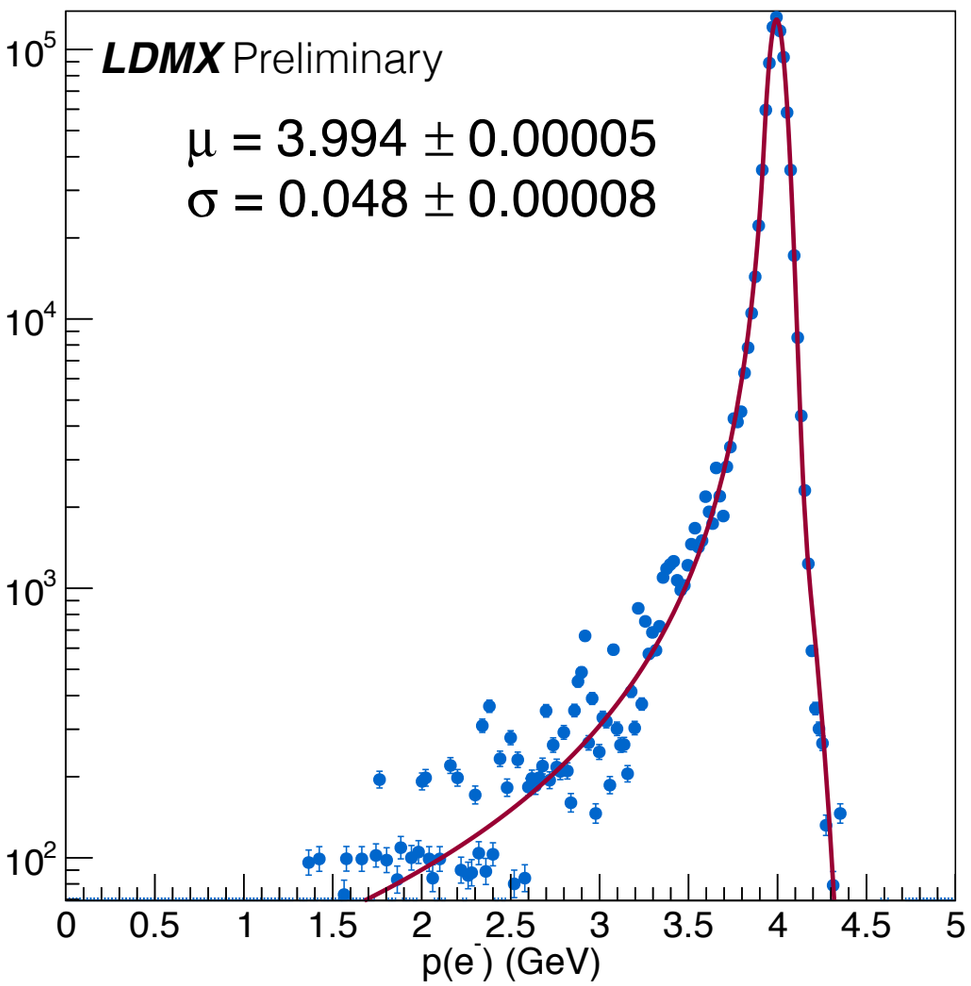
- tracking system consists of **two parts**, separated by target

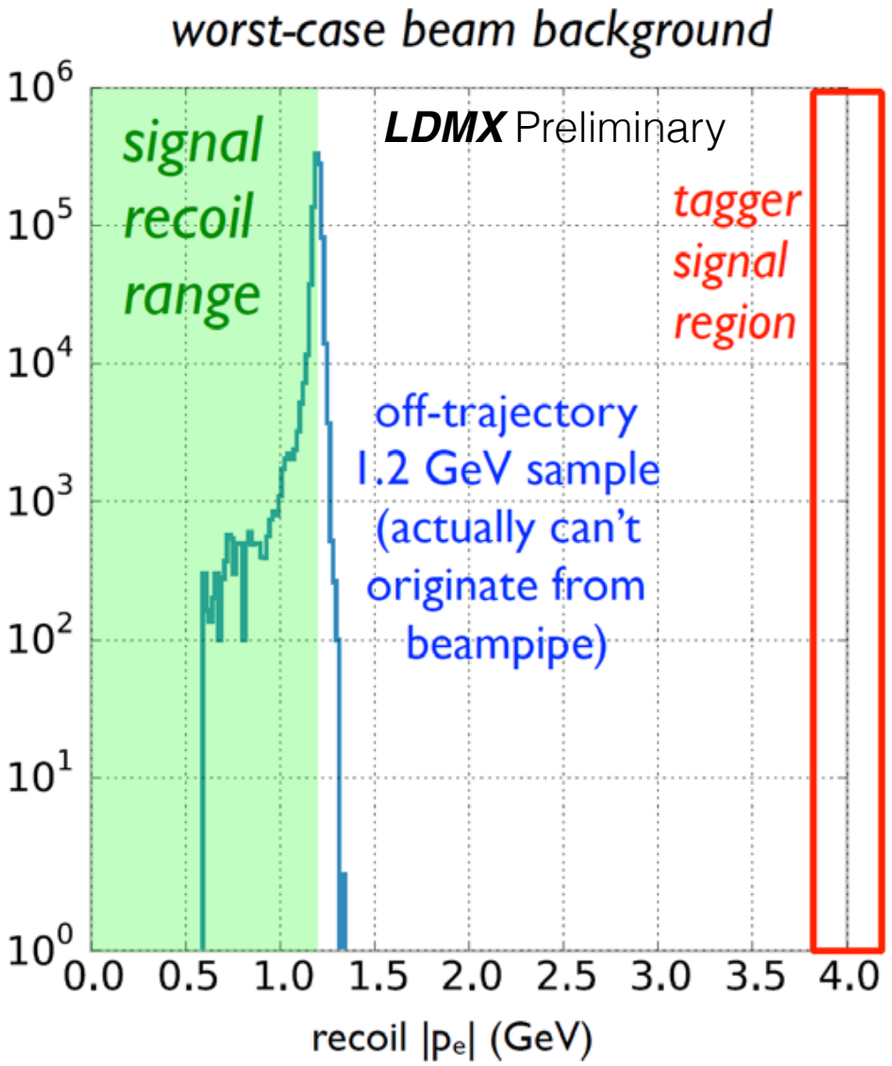


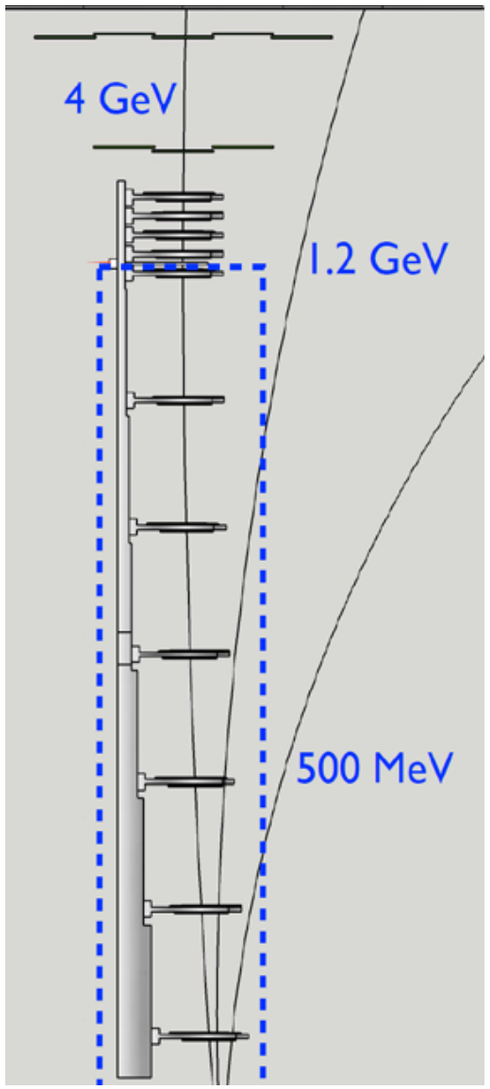
- simplified copy of Silicon Vertex Tracker (SVT) of HPS experiment
  - fast (2ns hit time resolution)
  - radiation hard
  - technology well understood

- *tagging* tracker
  - in 1.5T dipole field
  - measure incoming electron
    - momentum filter
    - impact point on target
- *recoil* tracker
  - in fringe field
  - measure recoil electron
    - momentum
    - position
- *target*
  - ~0.1 - 0.3 X_0 tungsten
  - balance signal rate and momentum smearing

Tagging Tracker

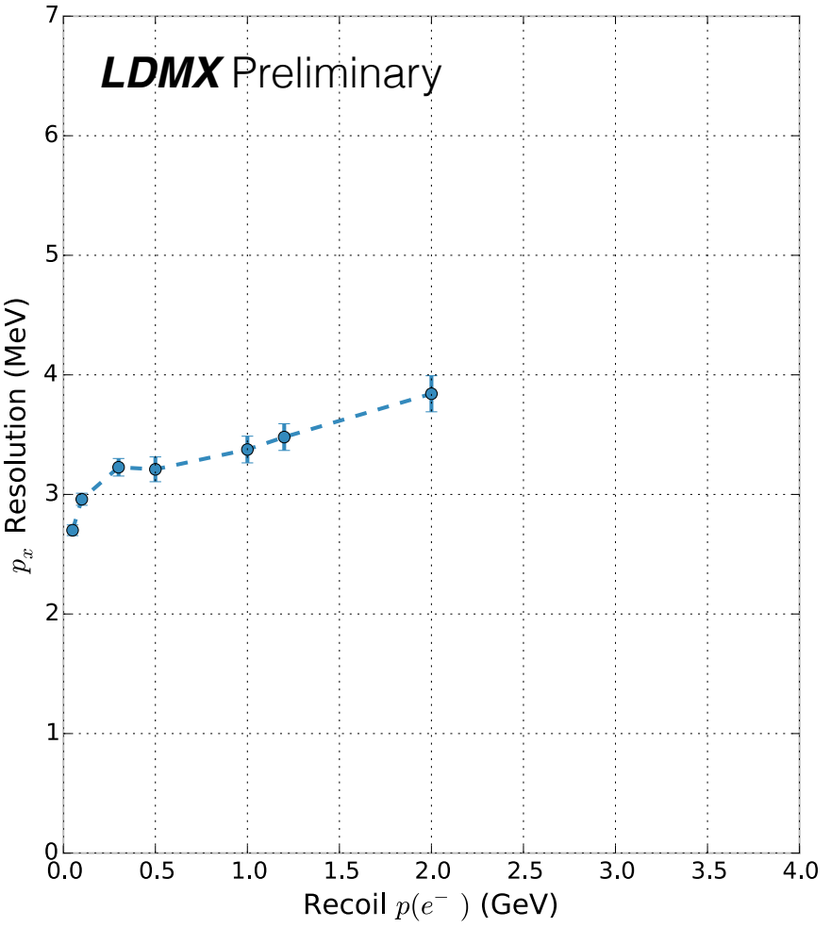


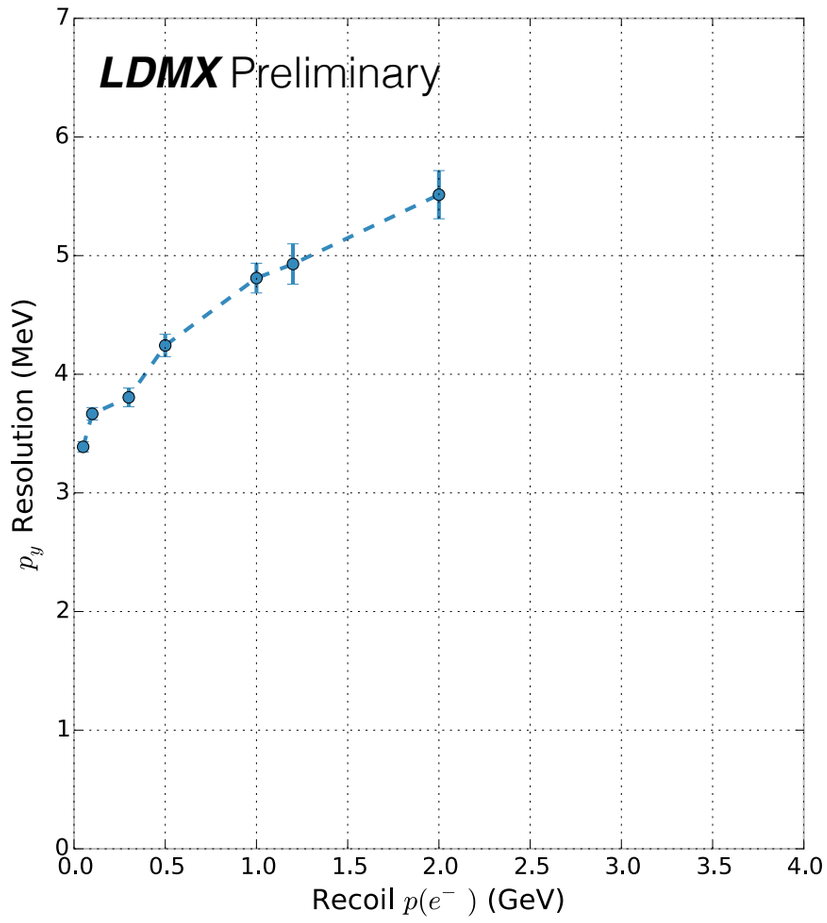


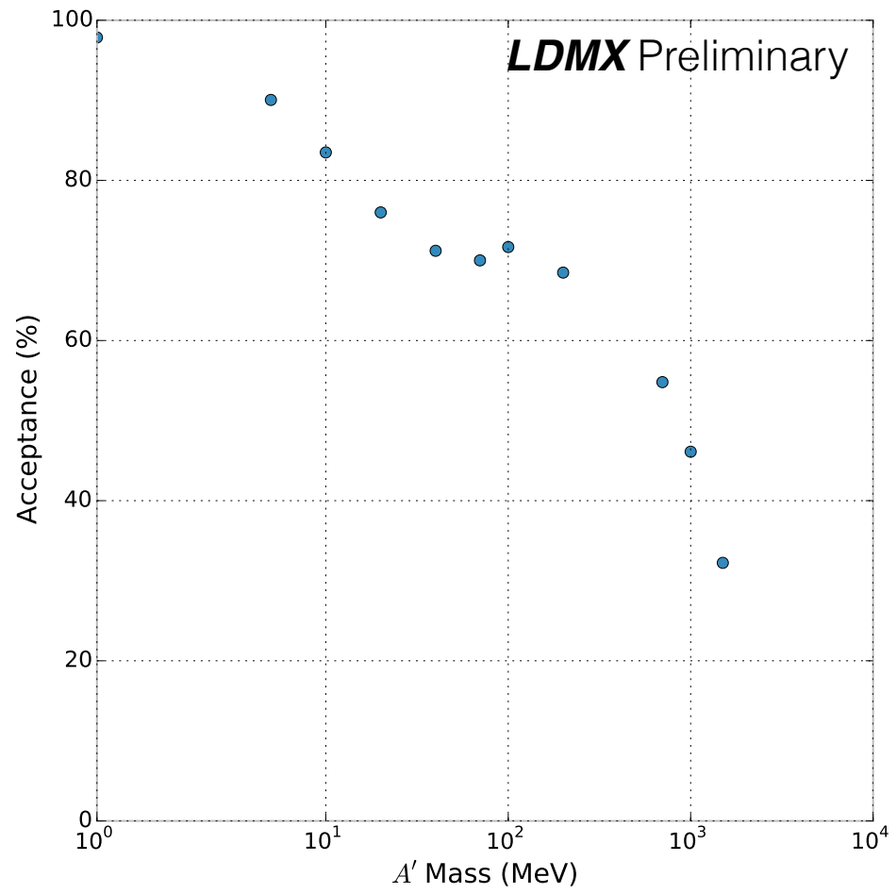


- excellent momentum resolution
- highly efficient in rejecting beam-induced backgrounds

Recoil Tracker







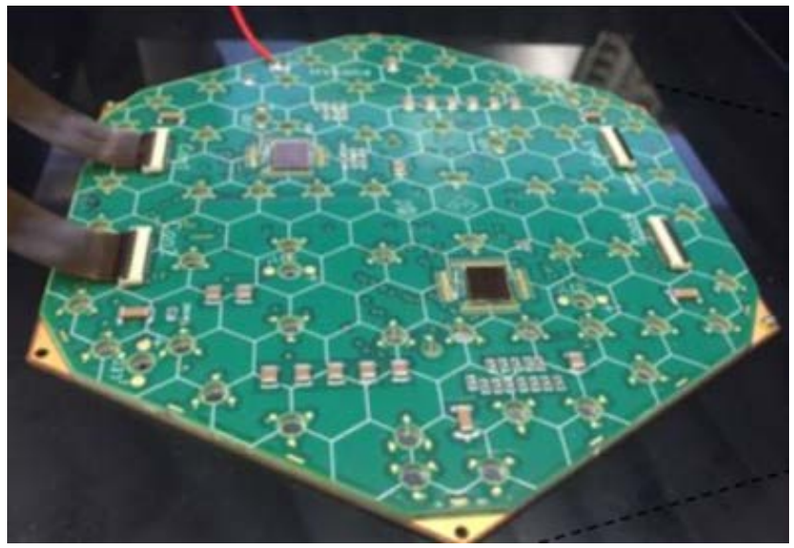
- resolution limited by 4 MeV from multiple scattering in (full) target

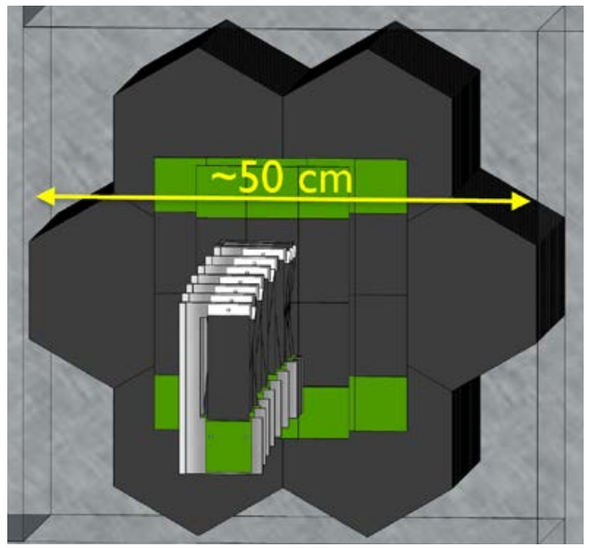
- good acceptance over wide mass range

Electromagnetic Calorimeter (ECal)

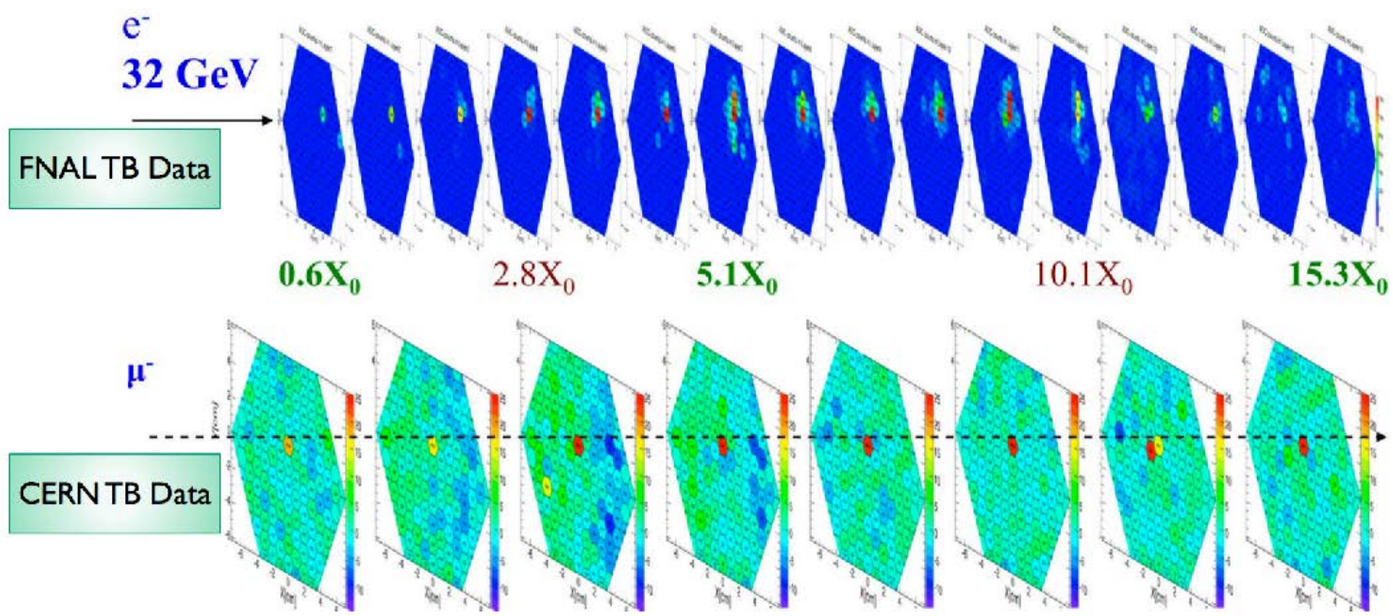
- ECal shopping list:
  - fast
  - radiation hard
  - dense
  - high-granularity
  - deep (containment)

very similar to forward SiW sampling calorimeter for CMS@HL-LHC → design based on this

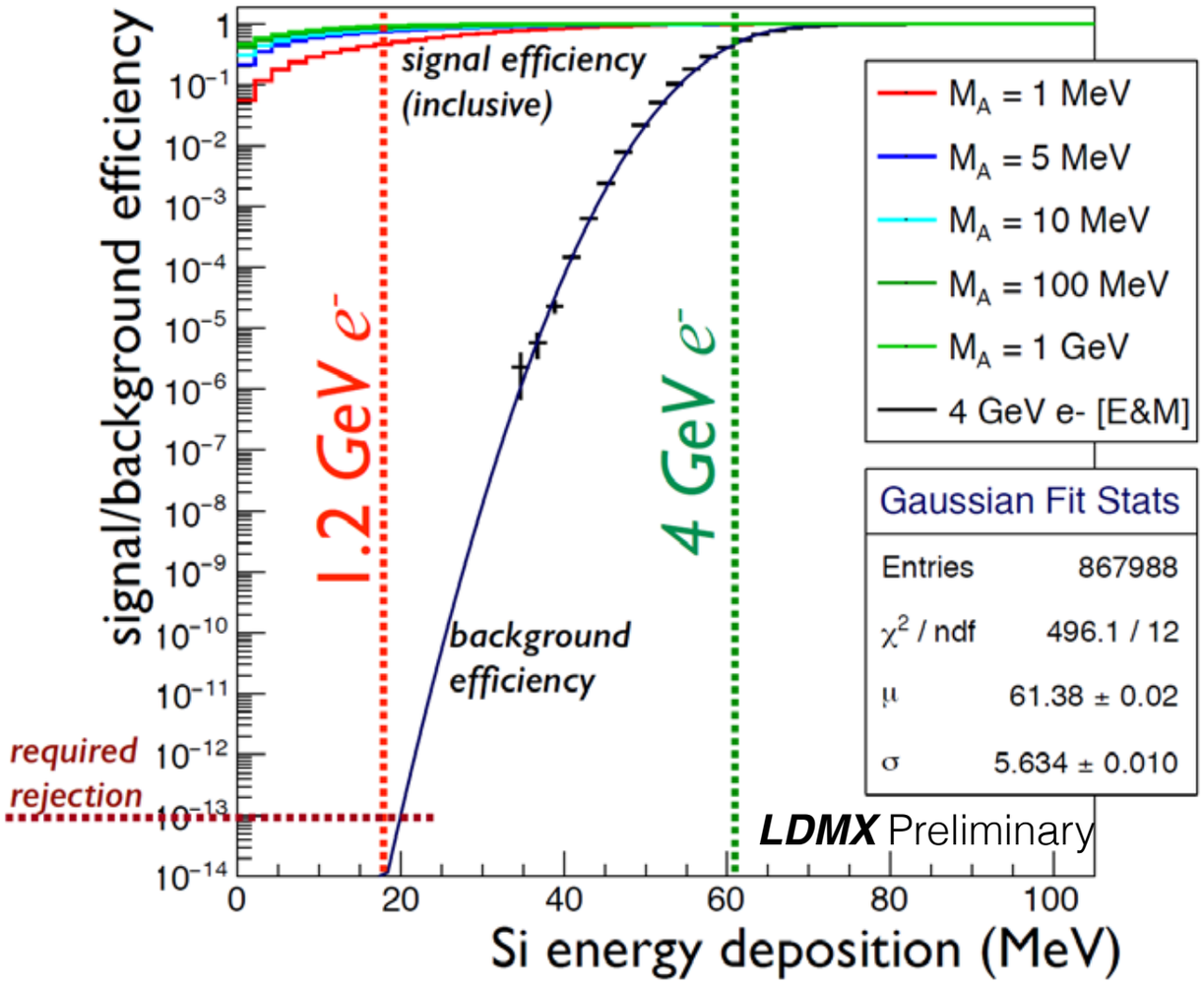


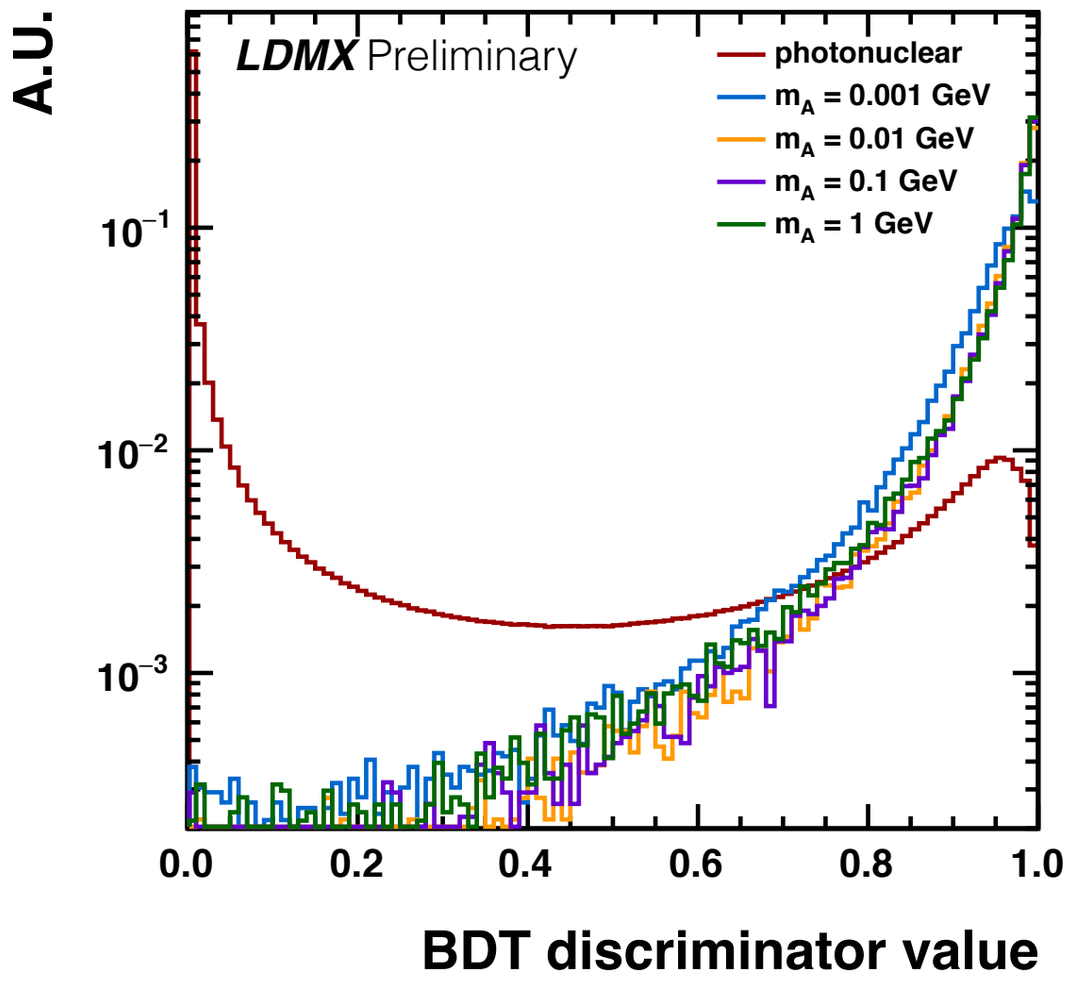


- in LDMX:
  - 40 radiation lengths deep
  - 30 layers, 7 modules each
  - central modules with higher granularity (up to 1000 channels)
    - high granularity allows MIP 'tracking' —> important tool in background suppression



Electromagnetic Calorimeter (ECal)

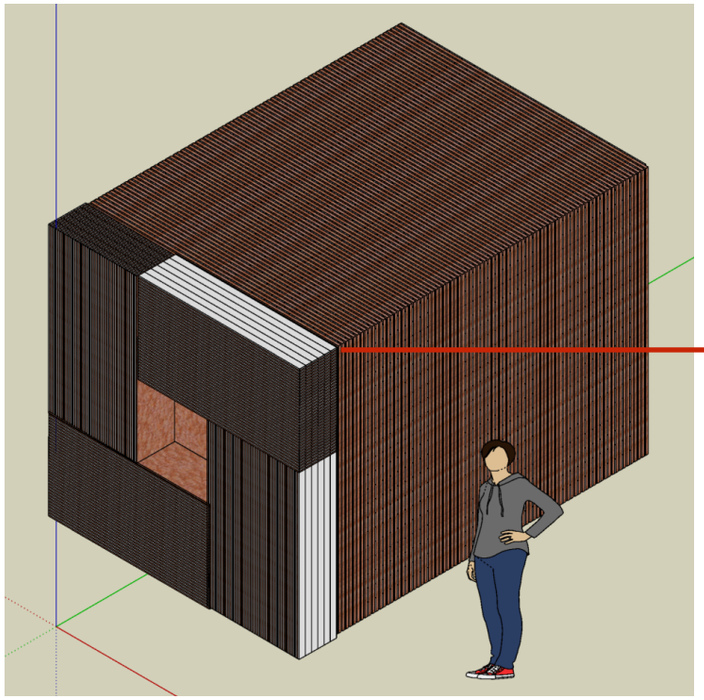


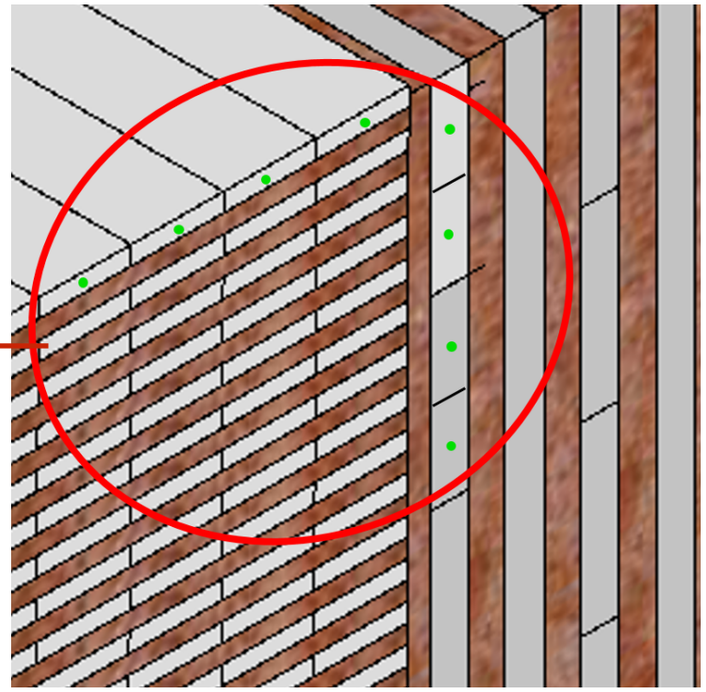


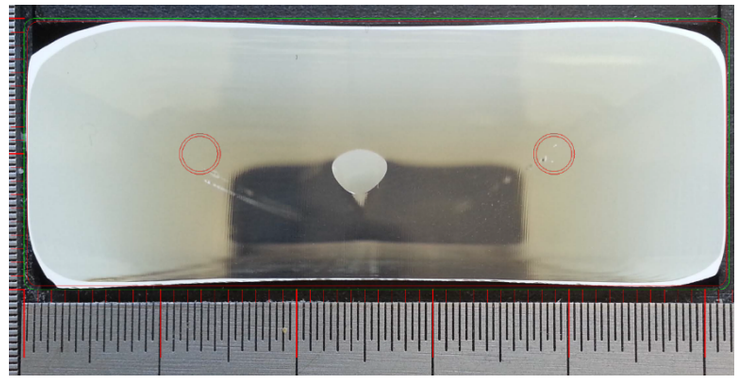
- preliminary simulation studies show very promising results in terms of background suppression

Hadronic Calorimeter (HCal)

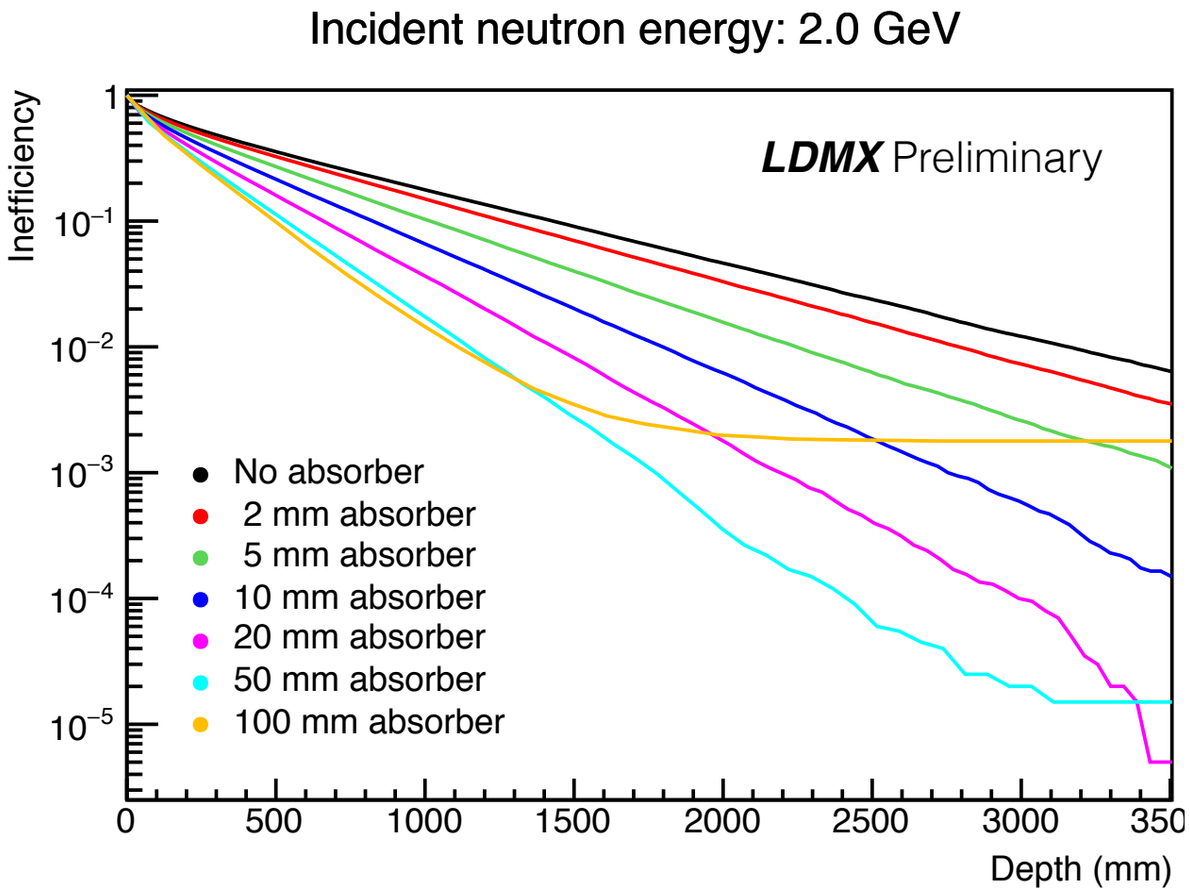
- essential **veto** instrument
- goal: catch ~everything that makes it out of the ECal
  - in particular: photo-nuclear reactions that produce only neutral particles
    - e.g. $\gamma n \rightarrow n n \bar{n}$
- surround ECal as much as possible
- be as efficient as possible for both low- and high-energy neutrons
  - **plastic scintillator + absorber** (steel)

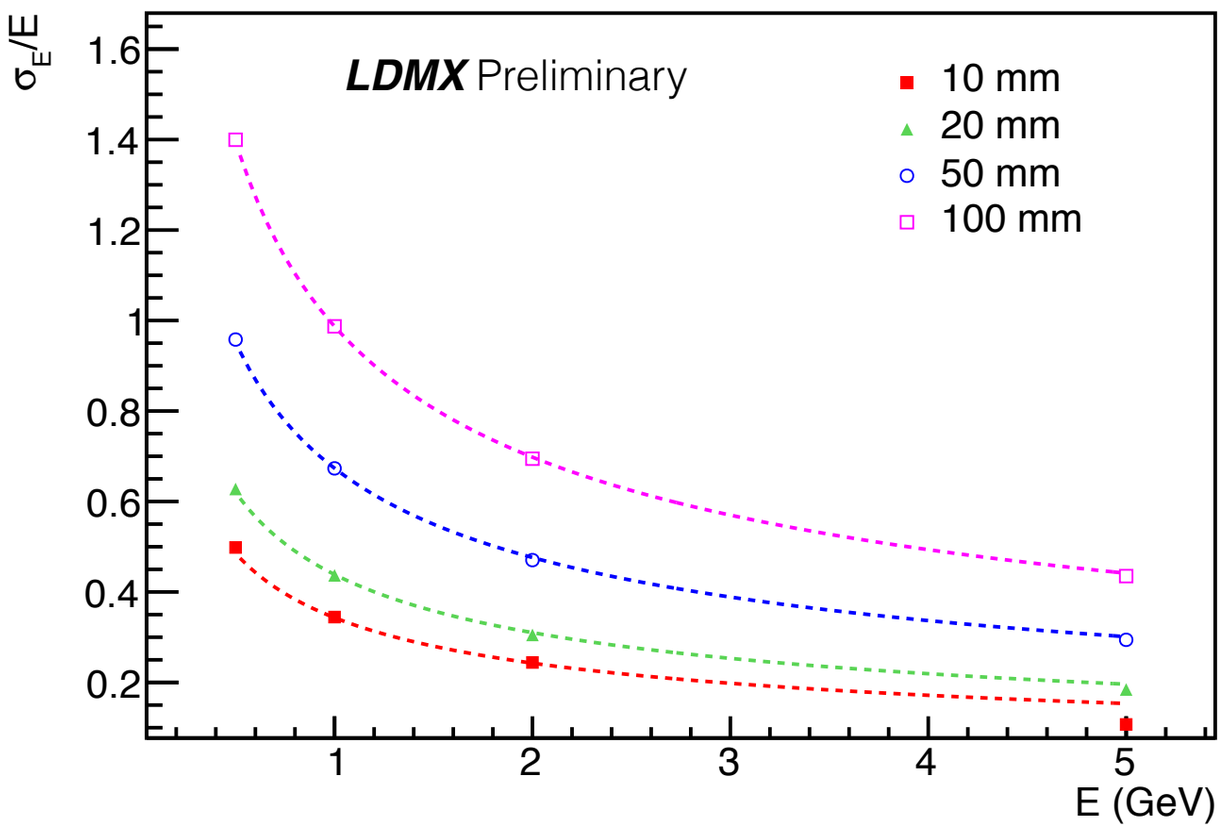






Hadronic Calorimeter (HCal)



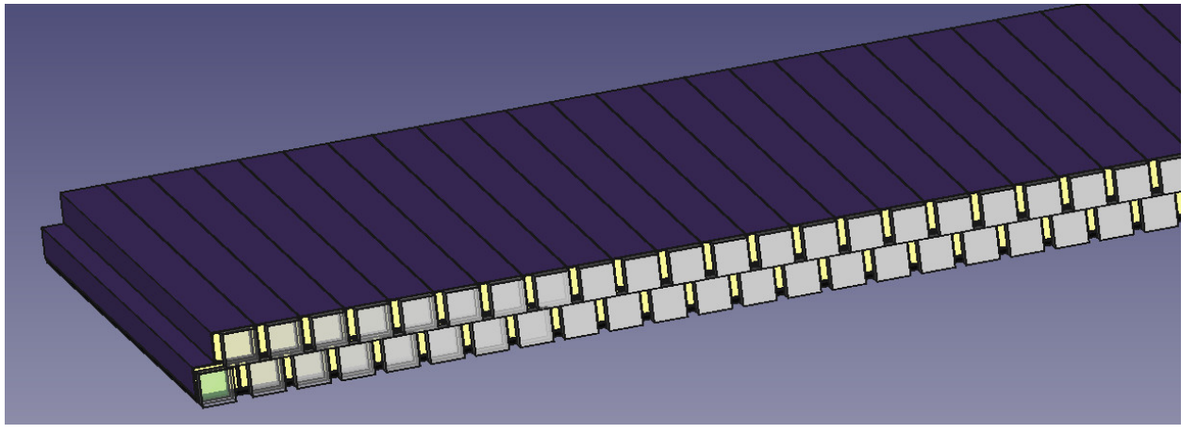


- preliminary simulation studies show potential to get close to 0 background in phase 1, while retaining decent energy resolution

Triggering

- use missing energy signature
  - reject ~beam-energy signals (non interacting e^-, bremsstrahlung,…)
  - use energy deposition in first 20 ECal layers

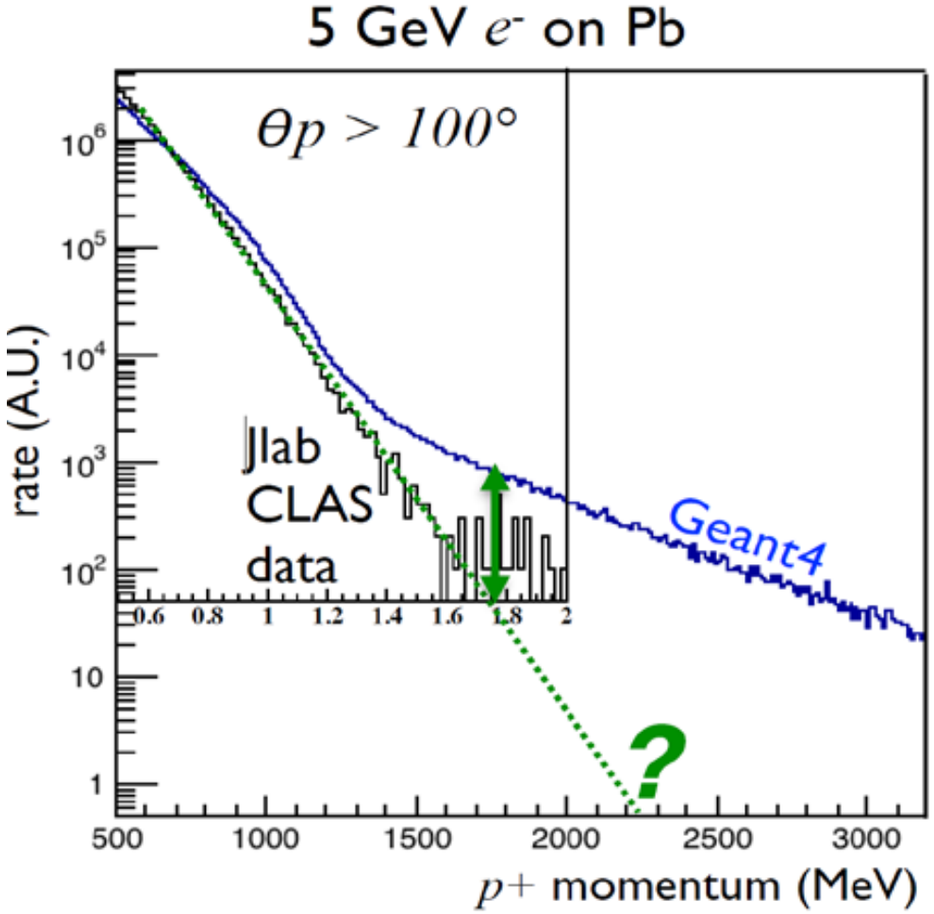
- to avoid triggering on empty bunches: (segmented) scintillator behind target
  - also helps getting an estimate of actual number of electrons
    - crucial for phase 2

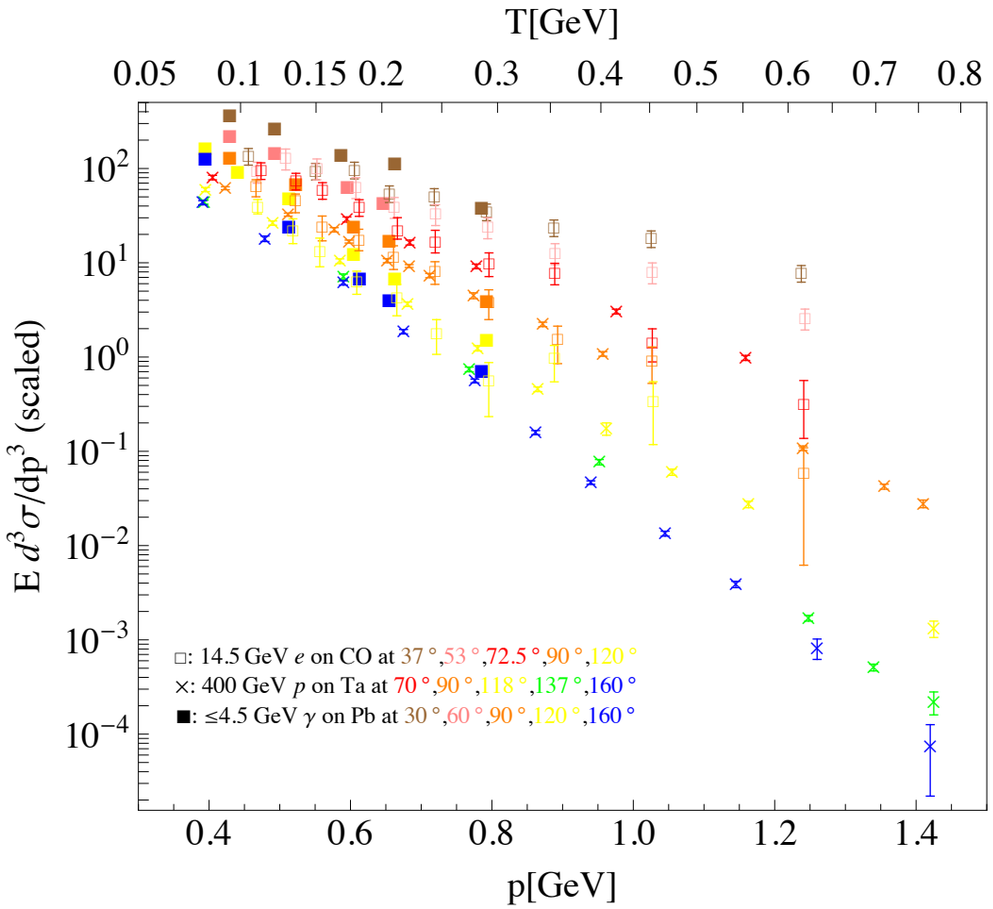


Trigger	Prescale factor	Rate (Hz)
Physics Trigger	1	*4000*
Background-Measurement Triggers		*500*
ECAL Missing-Energy $>$ 1 GeV	5000	100
HCAL hit $>$ 2 MIP	1000	100
HCAL hit $>$ 20 MIP	1	100
HCAL MIP track		200
Detector-Monitoring Triggers		*500*
Zero-bias (trigger scintillator ignored)	4.6×10^5	100
Beam-arrival (trigger scintillator)	1.5×10^5	300
Empty-detector (trigger scintillator veto)		100
Total Trigger Budget		5000

Photonuclear Background

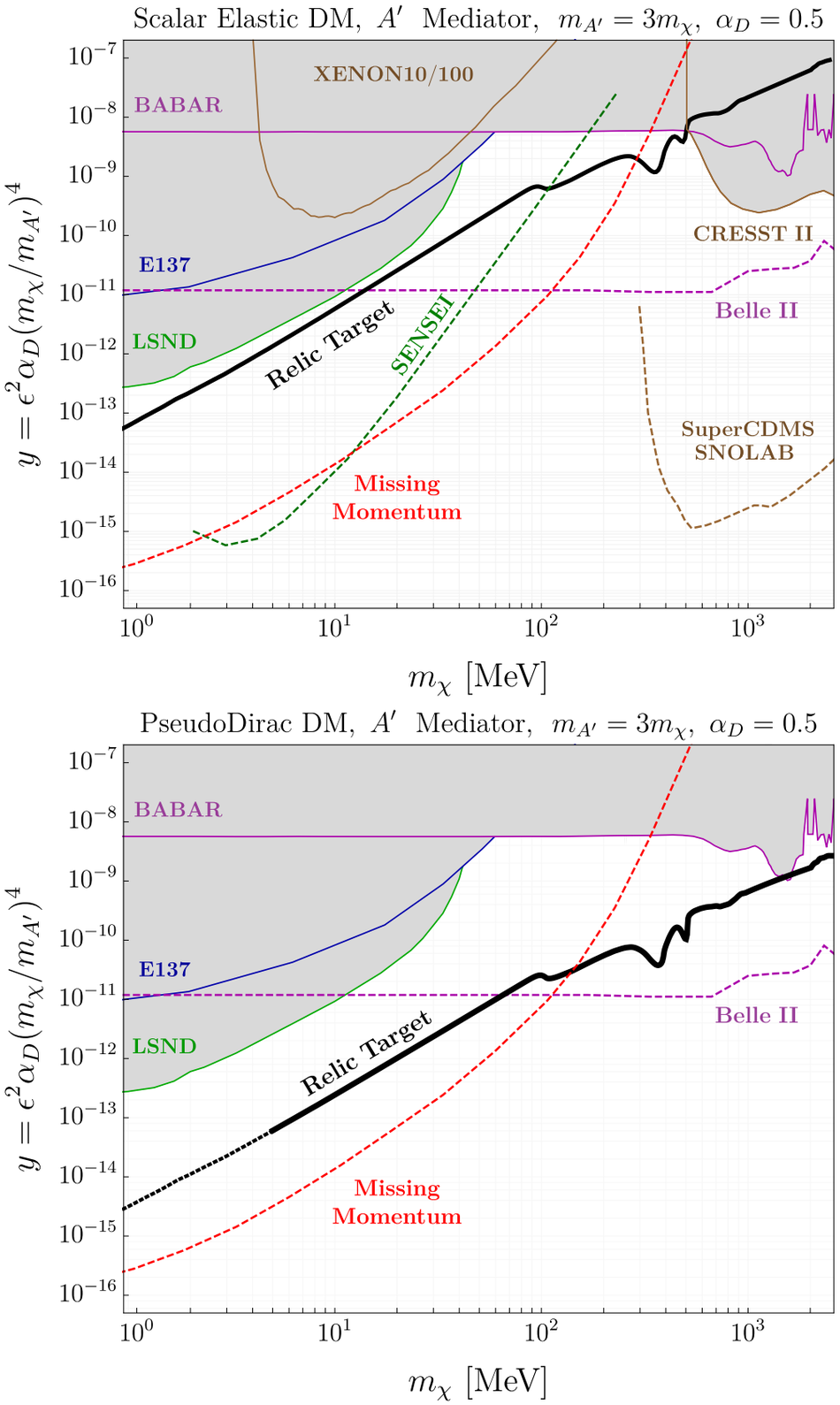
- important background to reject efficiently
- Geant4 seems to overproduce such events in the tails (not tuned to data)

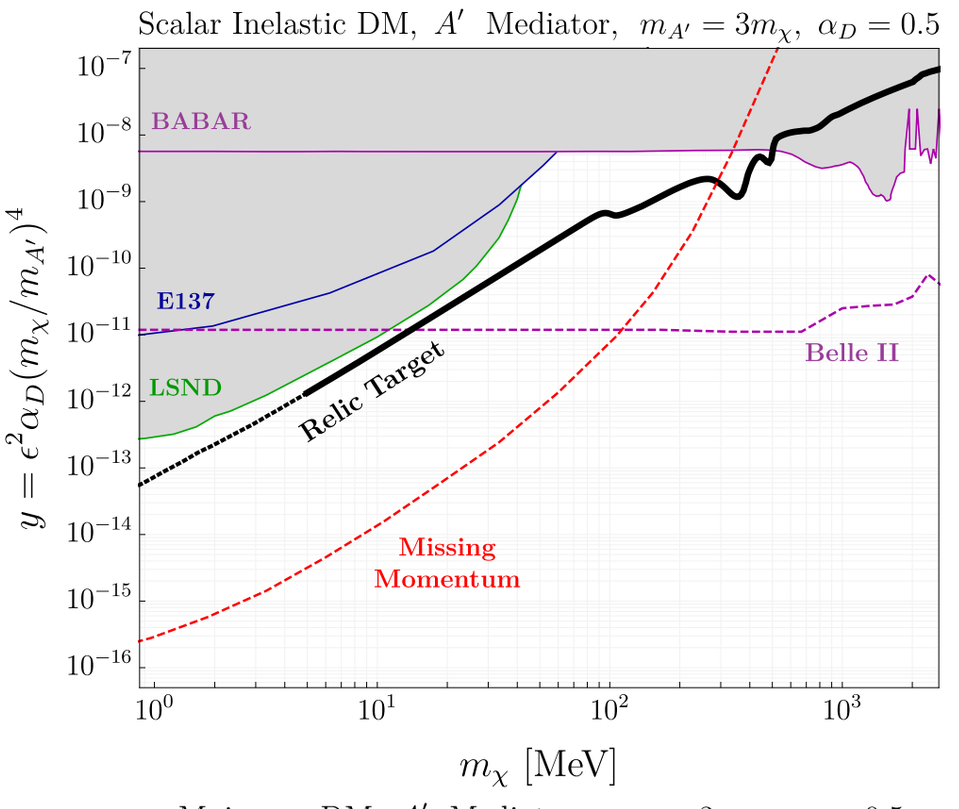


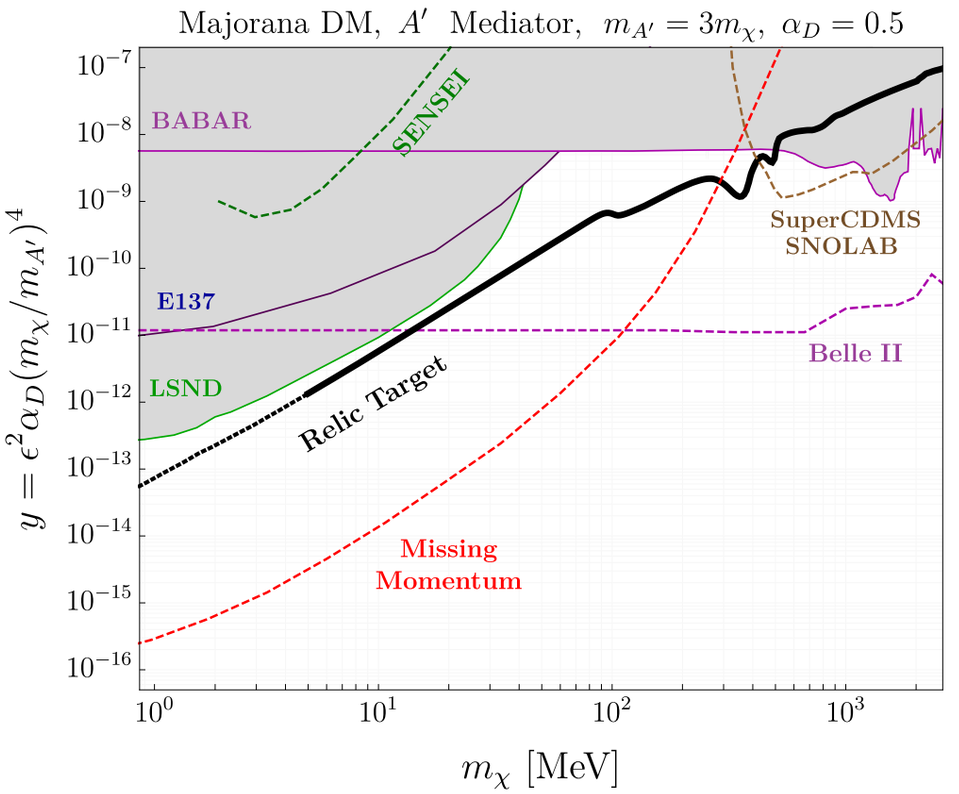


- recently improved understanding of the origin of these events
- gives confidence that close to 0 background in phase 1 achievable

Sensitivity







- α_D = 0.5, $m_{A'}/m_\chi$ =3 (conservative, weakest bounds)
- unprecedented sensitivity and ability to test all thermal targets over most of the MeV - GeV range

Further Potential

- also sensitive to
  - DM with quasi-thermal origin (asymmetric DM, SIMP/ELDER scenarios)
  - new invisibly decaying mediators in general, improve sensitivity for Dark Photon
  - displaced vertex signatures from DM co-annihilation or SIMP model
  - milli-charged particles

- plus measurement of photo- and electro-nuclear processes (for future neutrino experiments)

Conclusion & Outlook

- light, thermal relic Dark Matter well motivated
- fixed-target, missing-momentum approach provides unprecedented sensitivity
- LDMX the only such experiment on the horizon
  - start of data-taking in early 2020s
- potential to probe thermal targets in MeV - GeV range
  - complements direct detection
- more generally, sensitive to broad range if sub-GeV physics

Light Dark Matter eXperiment (LDMX)

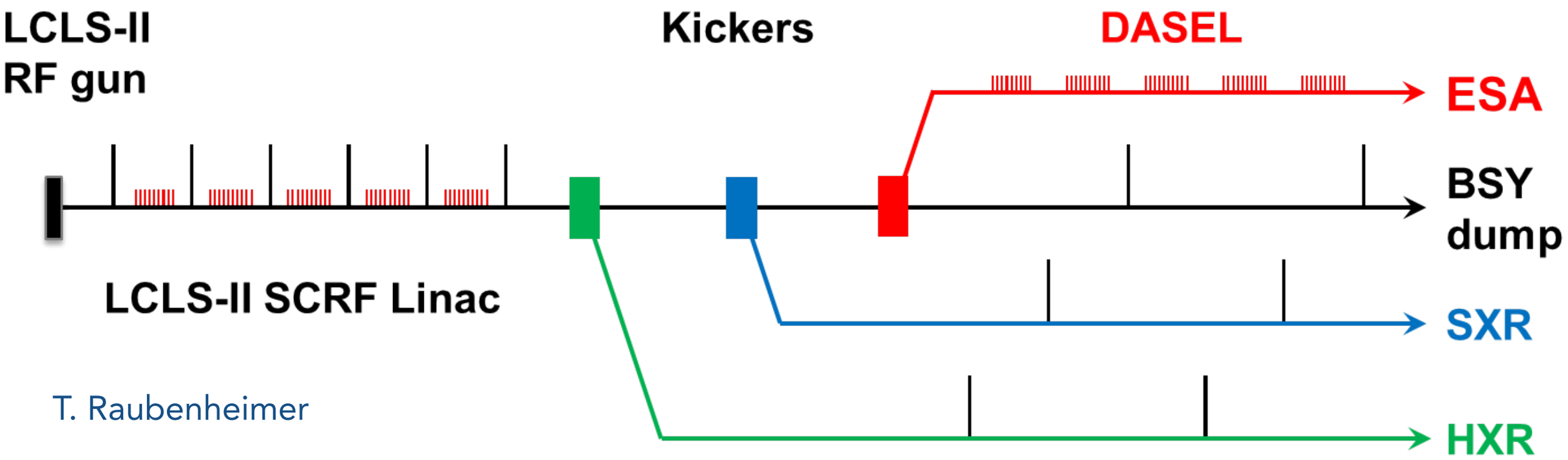
Torsten Åkesson,[1] Owen Colegrove,[2] Giulia Collura,[2] Valentina Dutta,[2] Bertrand Echenard,[3] Joshua Hiltbrand,[4] David G. Hitlin,[3] Joseph Incandela,[2] John Jaros,[5] Robert Johnson,[6] Gordan Krnjaic,[7] Jeremiah Mans,[4] Takashi Maruyama,[5] Jeremy McCormick,[5] Omar Moreno,[5] Timothy Nelson,[5] Gavin Niendorf,[2] Reese Petersen,[4] Ruth Pöttgen,[1] Philip Schuster,[5,8] Natalia Toro,[5,8] Nhan Tran,[7] and Andrew Whitbeck[7]

[1]*Lund University, Department of Physics, Box 118, 221 00 Lund, Sweden*
[2]*University of California at Santa Barbara, Santa Barbara, CA 93106, USA*
[3]*California Institute of Technology, Pasadena, CA 91125, USA*
[4]*University of Minnesota, Minneapolis, MN 55455, USA*
[5]*SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*
[6]*Santa Cruz Institute for Particle Physics,*
University of California at Santa Cruz, Santa Cruz, CA 95064, USA
[7]*Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*
[8]*Perimeter Institute for Theoretical Physics, Waterloo ON N2L 2Y5, Canada*

Additional Material

DASEL

- Dark Sector Experiments at LCLS-II
  - parasitic operation, no competition for beam time (≠ JLab)

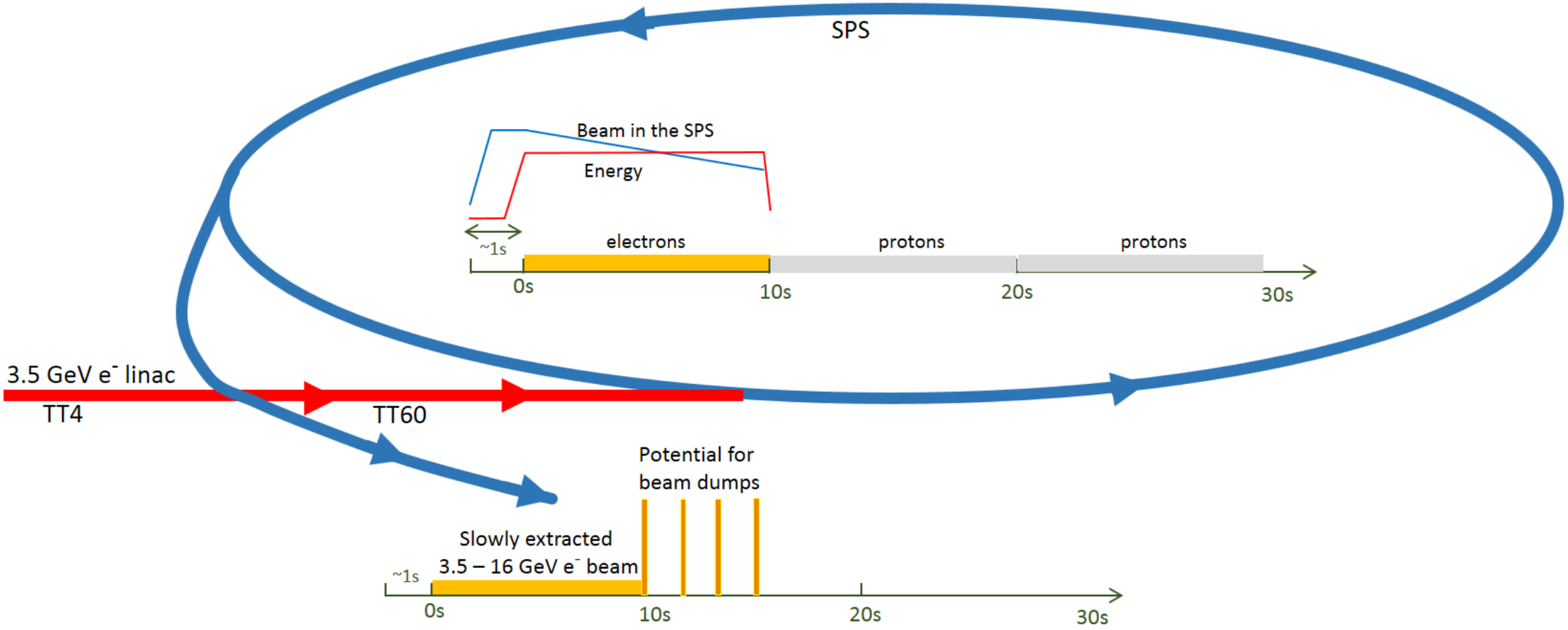


- 4 or 8 GeV
- 46 MHz (phase 1, 4×10^{14} EOT), 186 MHz (phase 2, 10^{16} EOT)

Beam Alternatives

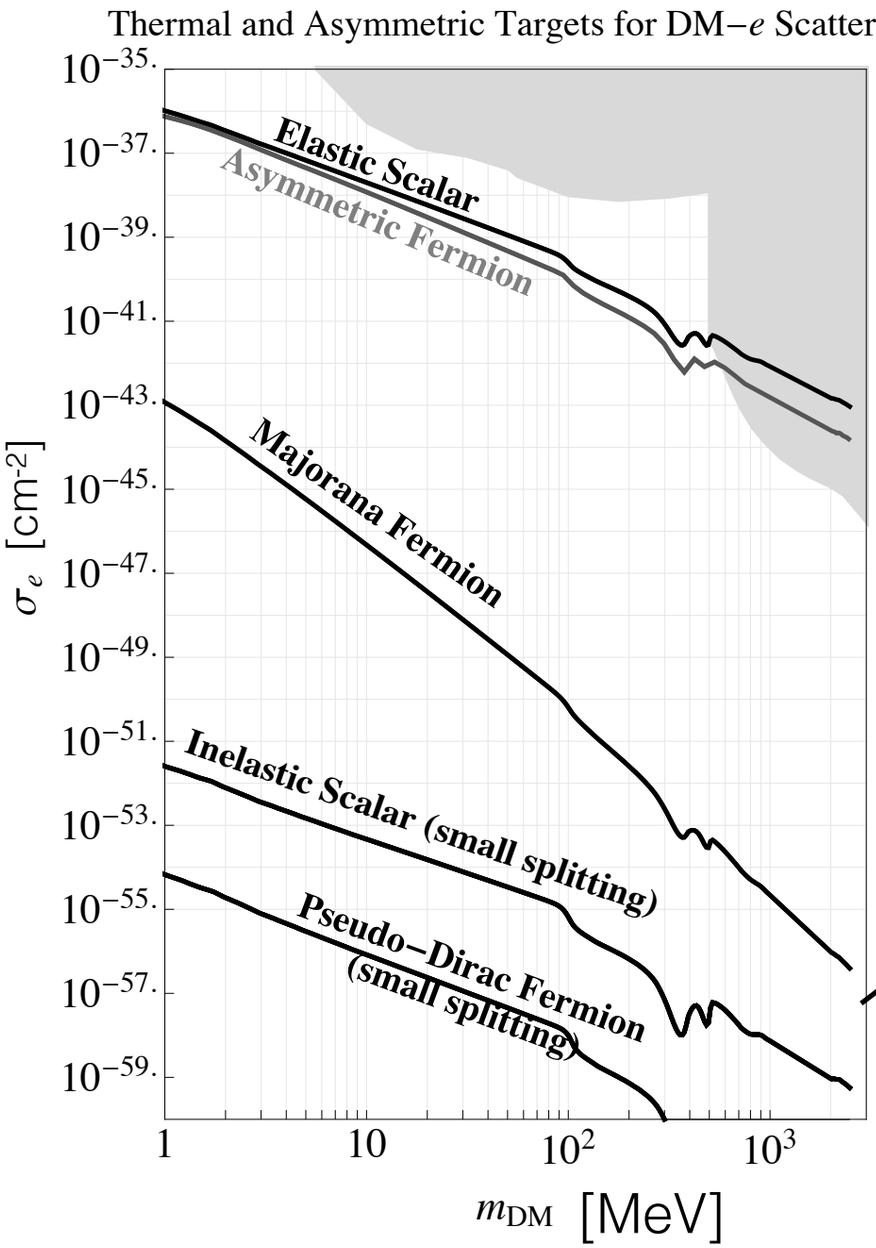
- Continuous Electron Beam Accelerator Facility (CEBAF, Jefferson Lab)
  - 11-12 GeV, 50 - 450 nA, 500 MHz spacing
  - (high) competition for beam time

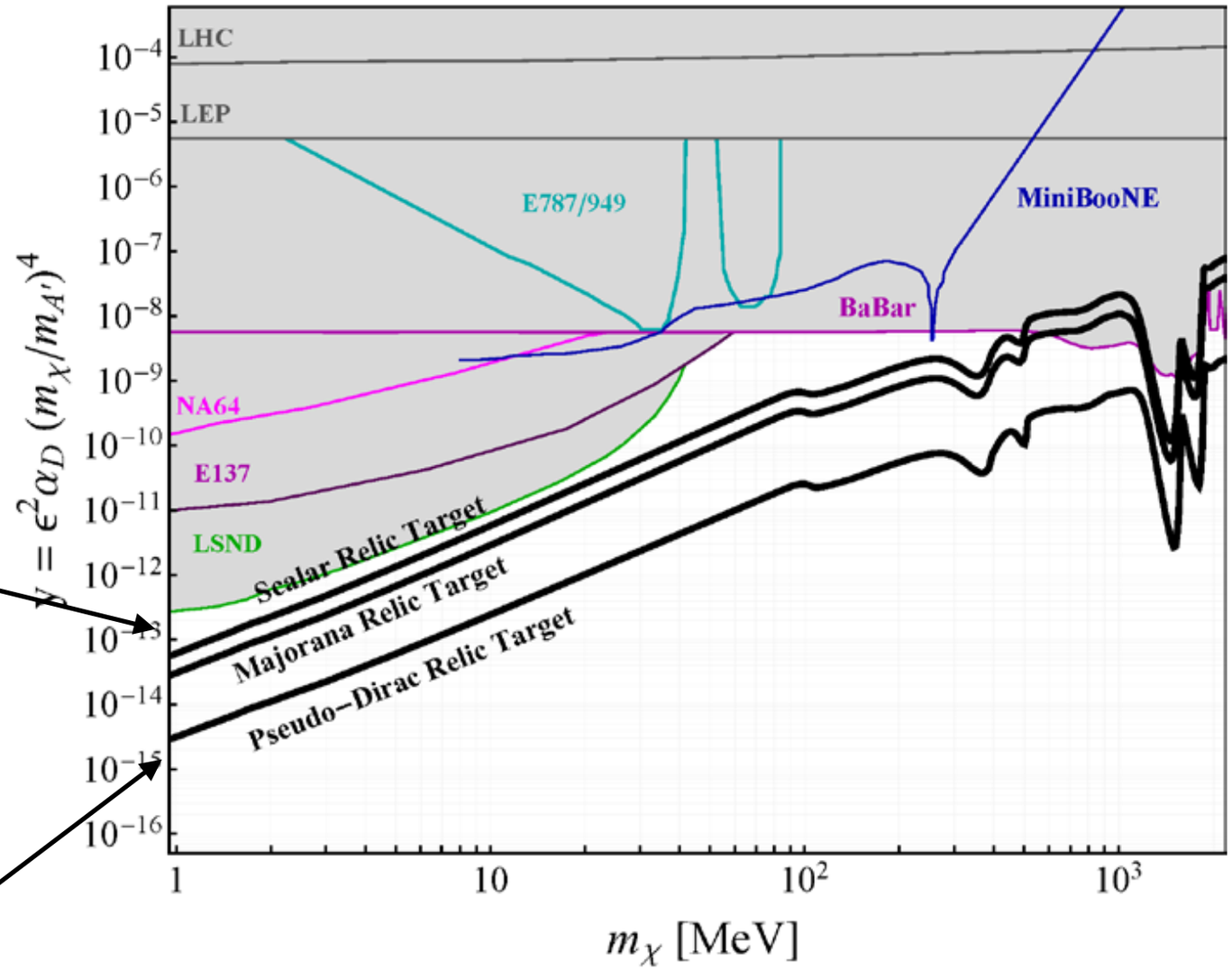
- CERN (new Linac into SPS, active field of study!) [arxiv:1805.12379]
  - flexible: 3.5 - 16 GeV, n_e = 1 - 40, multiples of 5 ns spacing
  - adjustable beam size
  - some sharing of beam time



Direct Detection and Accelerators

- direct detection: scattering cross section spin/velocity dependent

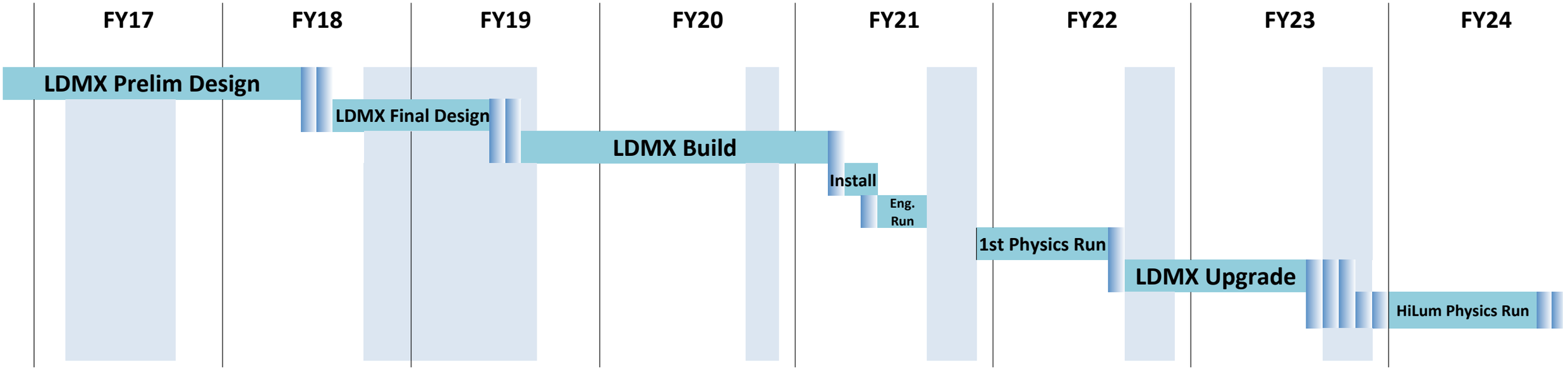




- at accelerators: relativistic production —> velocity/spin dependency reduced
  - thermal targets are all in reach!

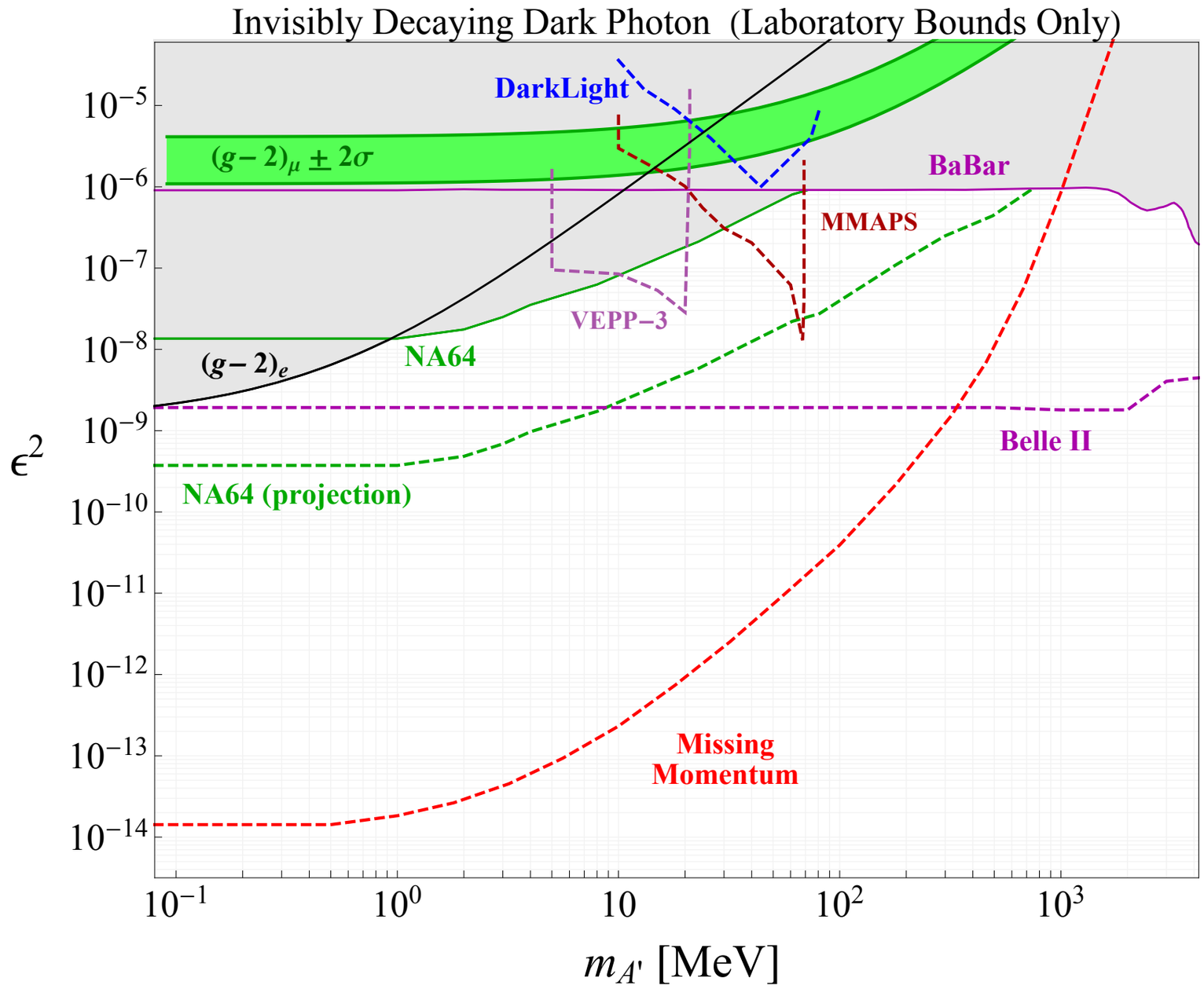
Timeline

- from T. Nelson at **US Cosmics Vision Workshop**



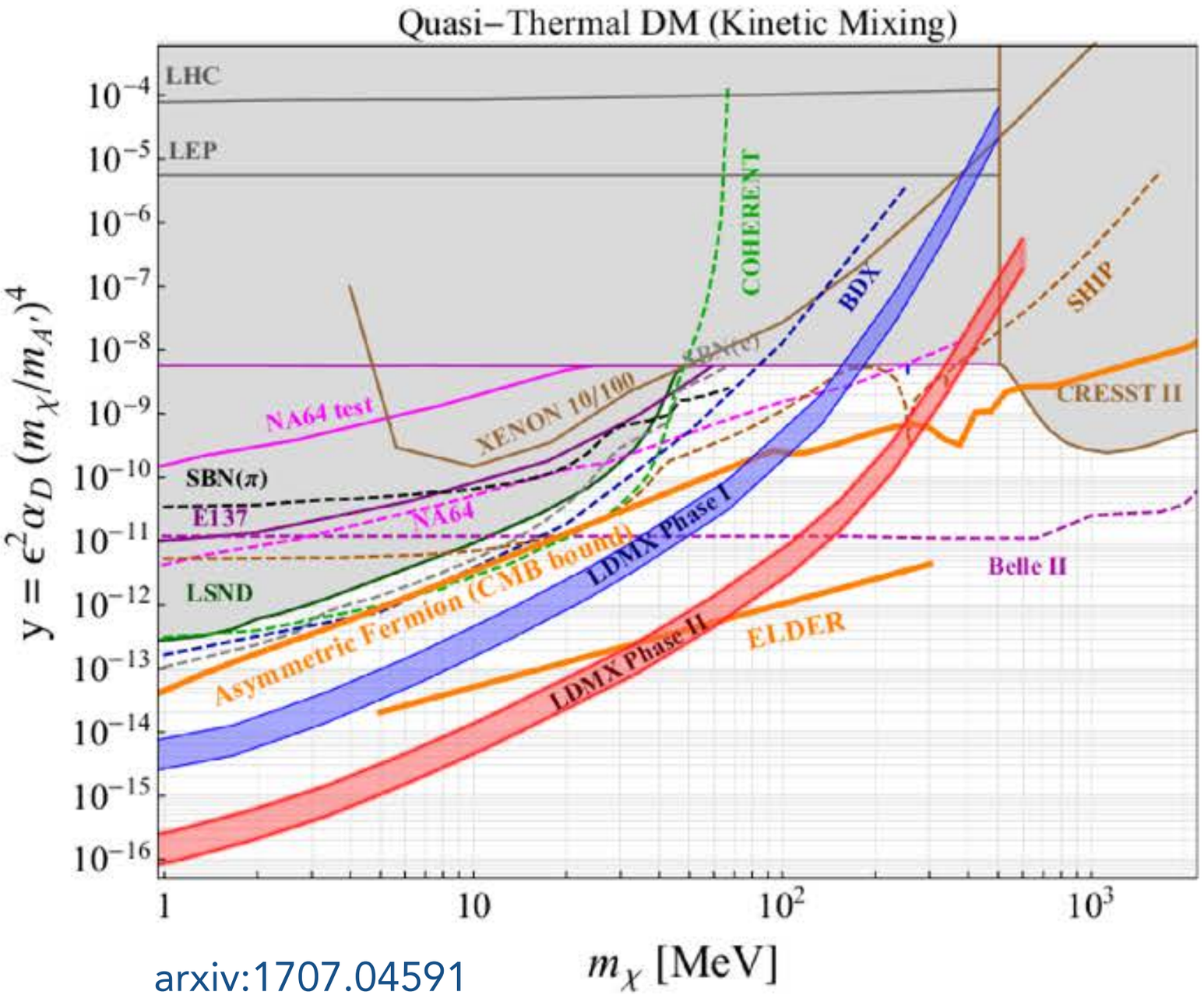
Further Potential

- improve sensitivity for invisibly decaying Dark Photon



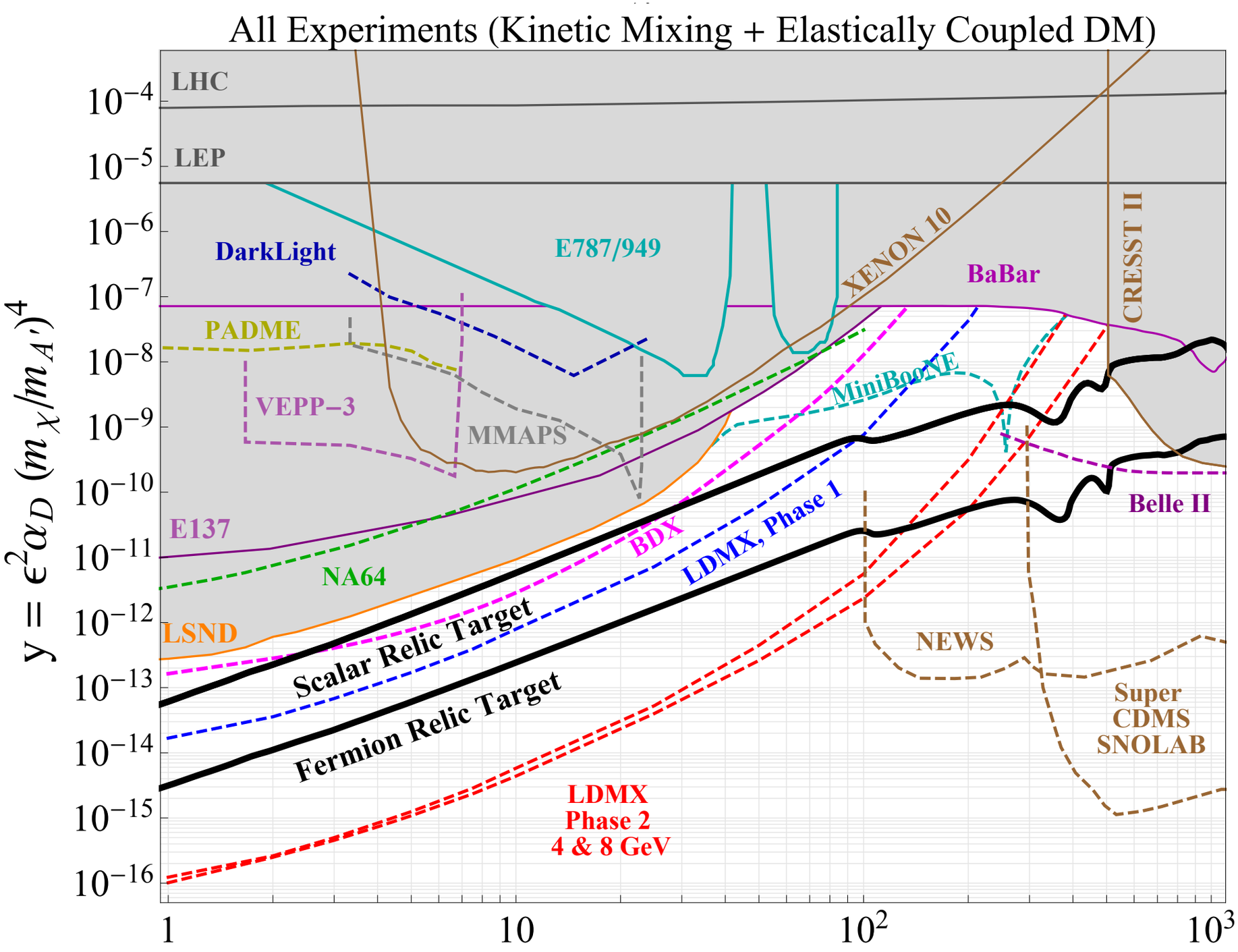
Further Potential

- explore DM with quasi-thermal origin (asymmetric DM, SIMP/ELDER scenarios)



arxiv:1707.04591

Comparison with experiments



EPJ Web Conf., 142 (2017) 01020