LDMX - A Light Dark Matter eXperiment

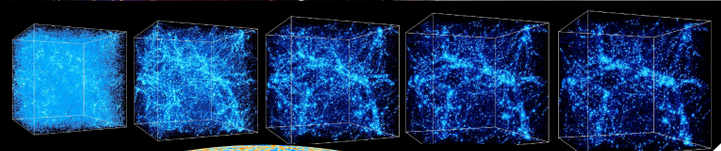
Partikeldagarna, Stockholm

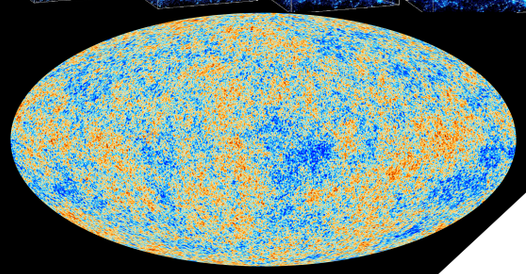
Ruth Pöttgen

7 November 2017

Introduction

- ample evidence for Dark Matter





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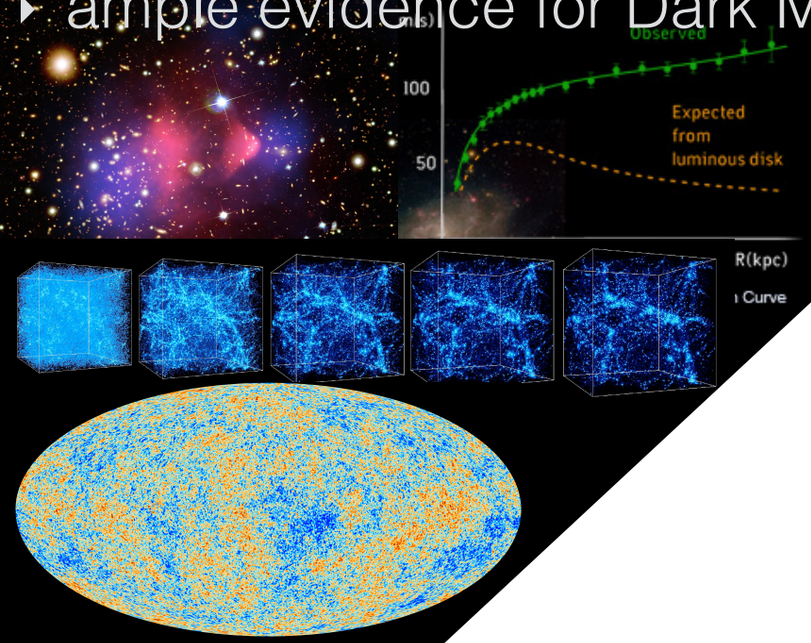

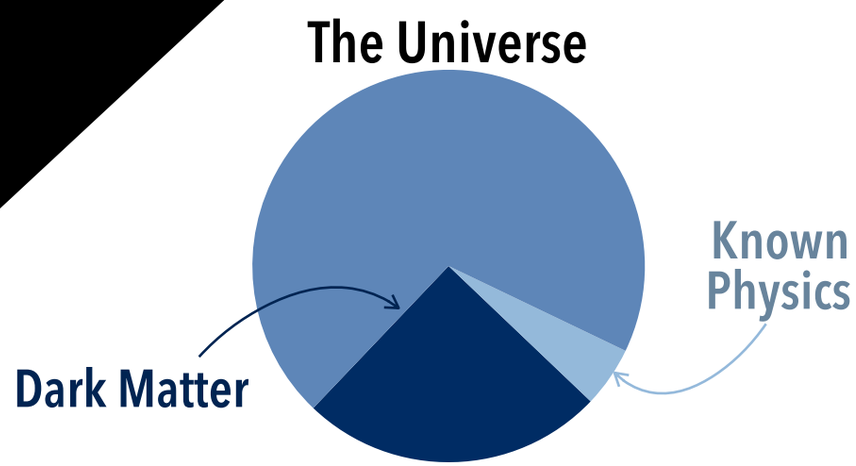

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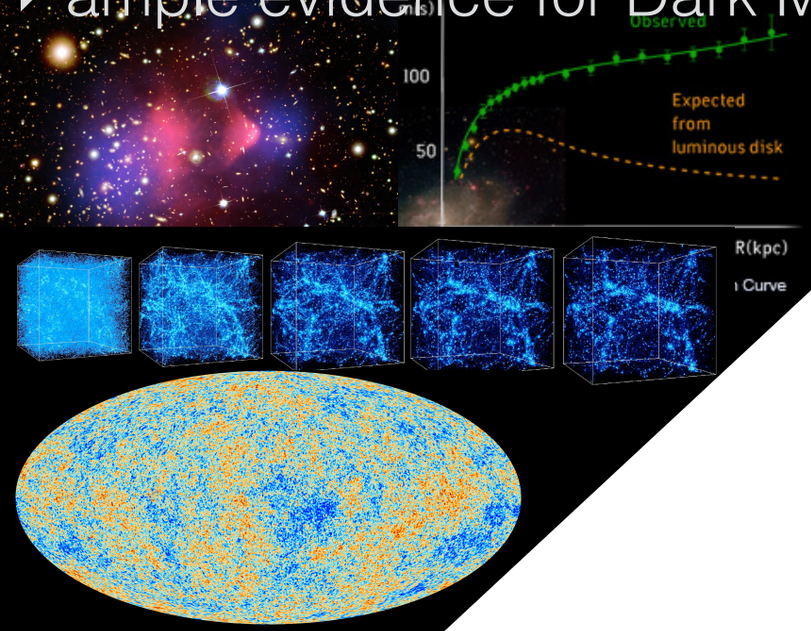
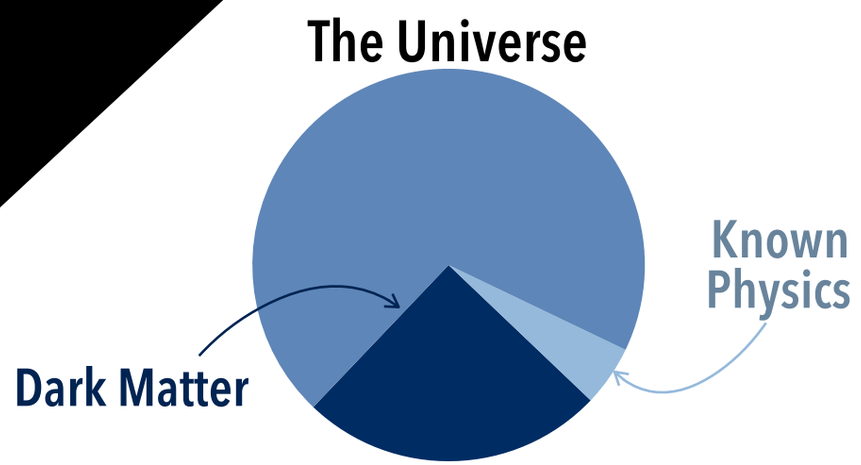
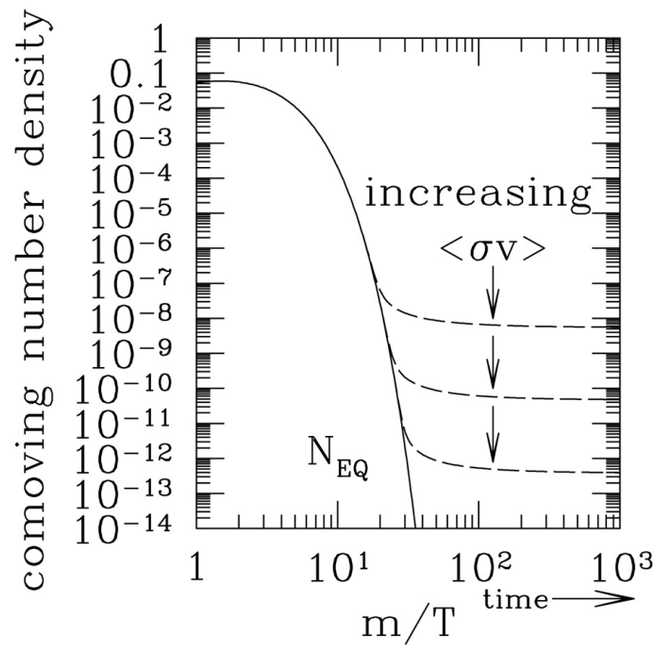




thermal relic



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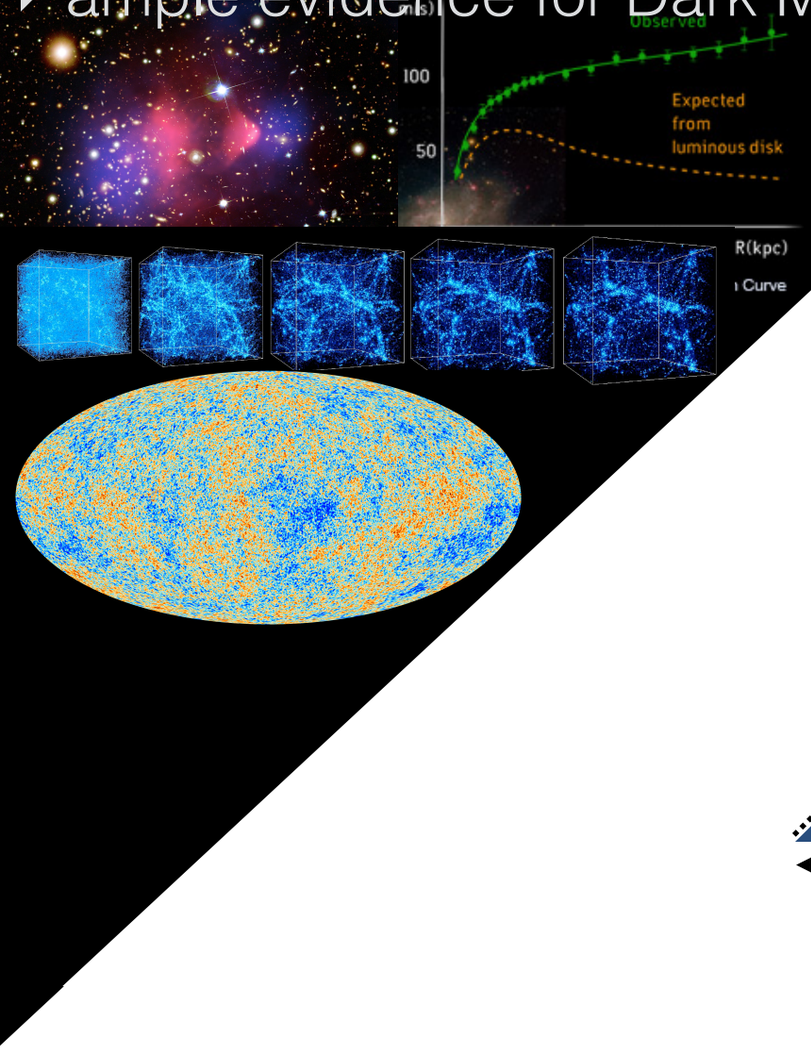

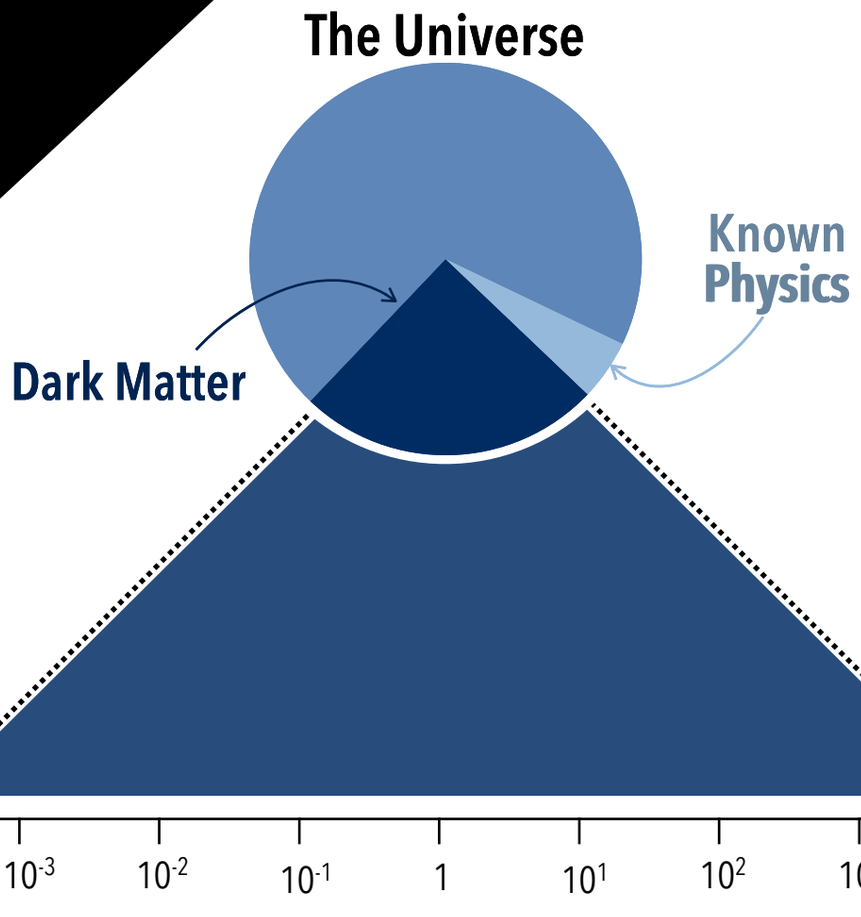

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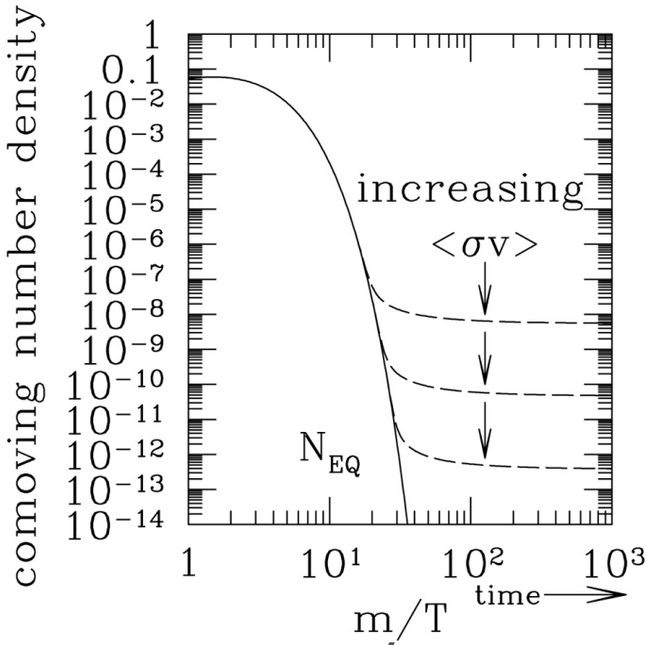

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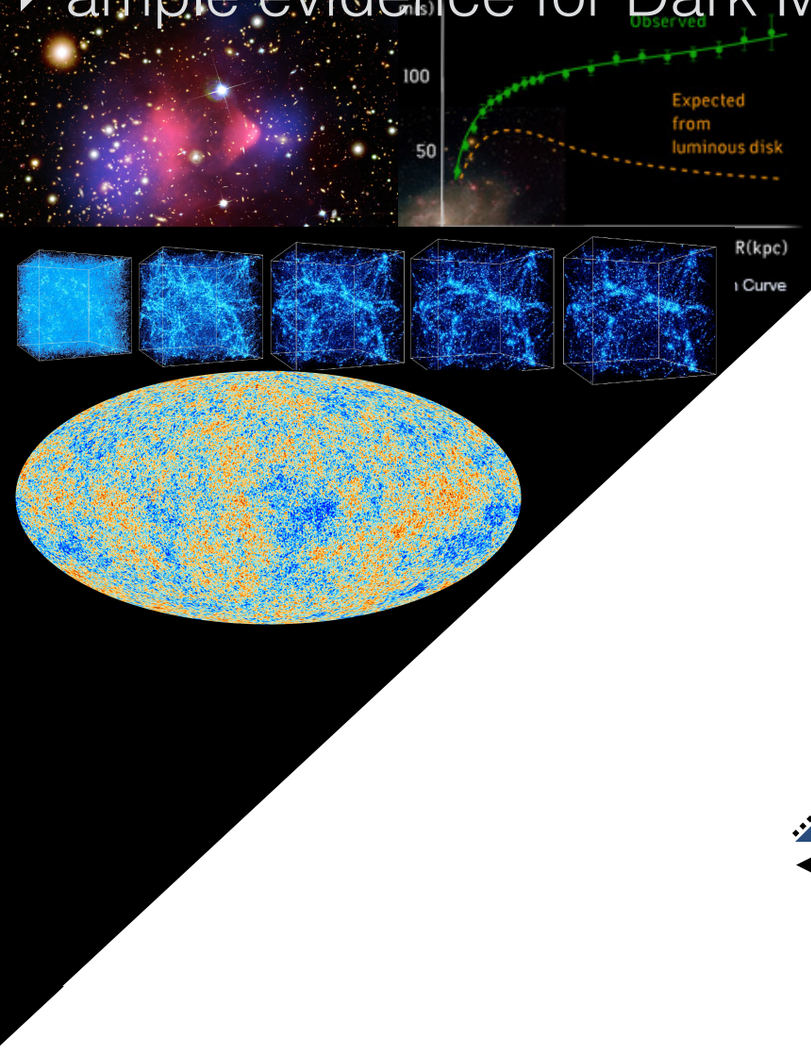

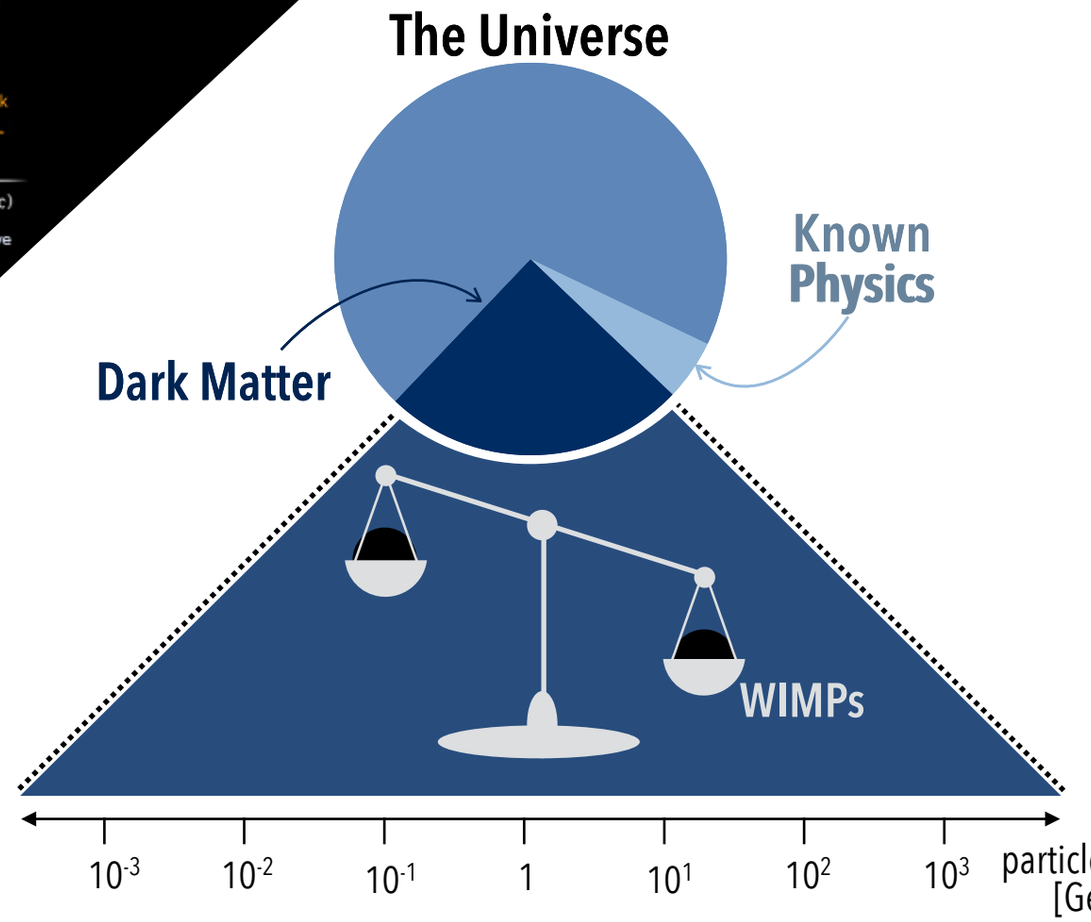

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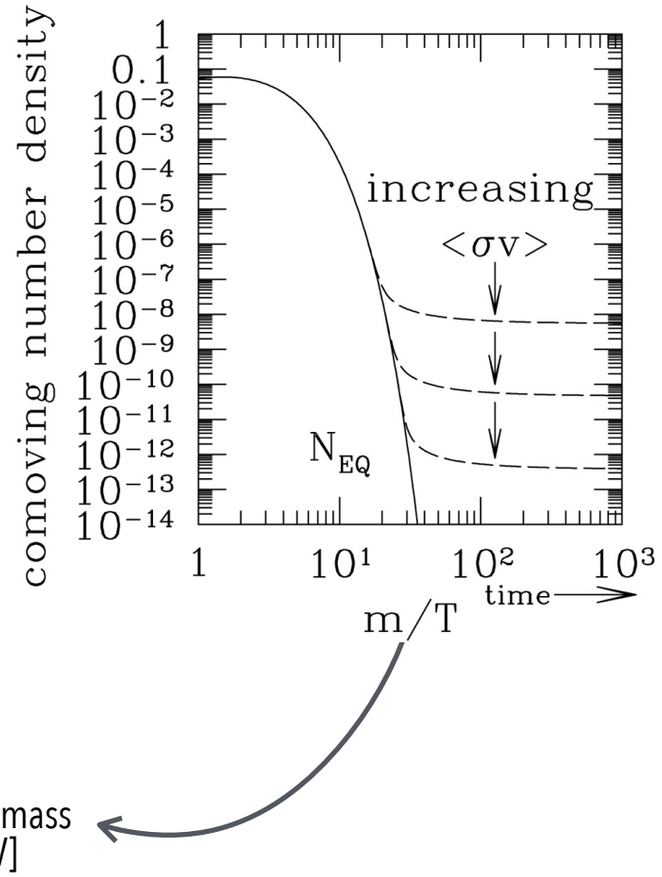

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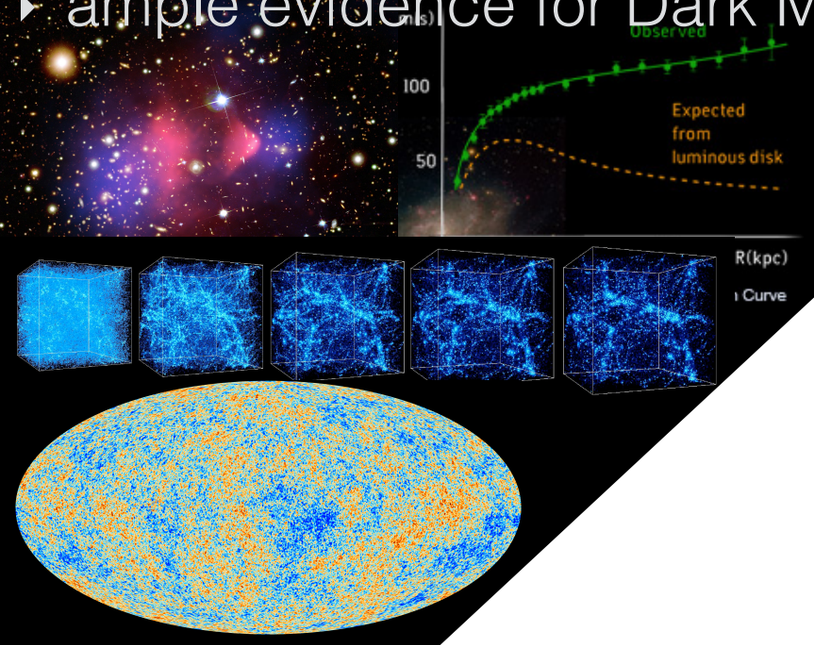

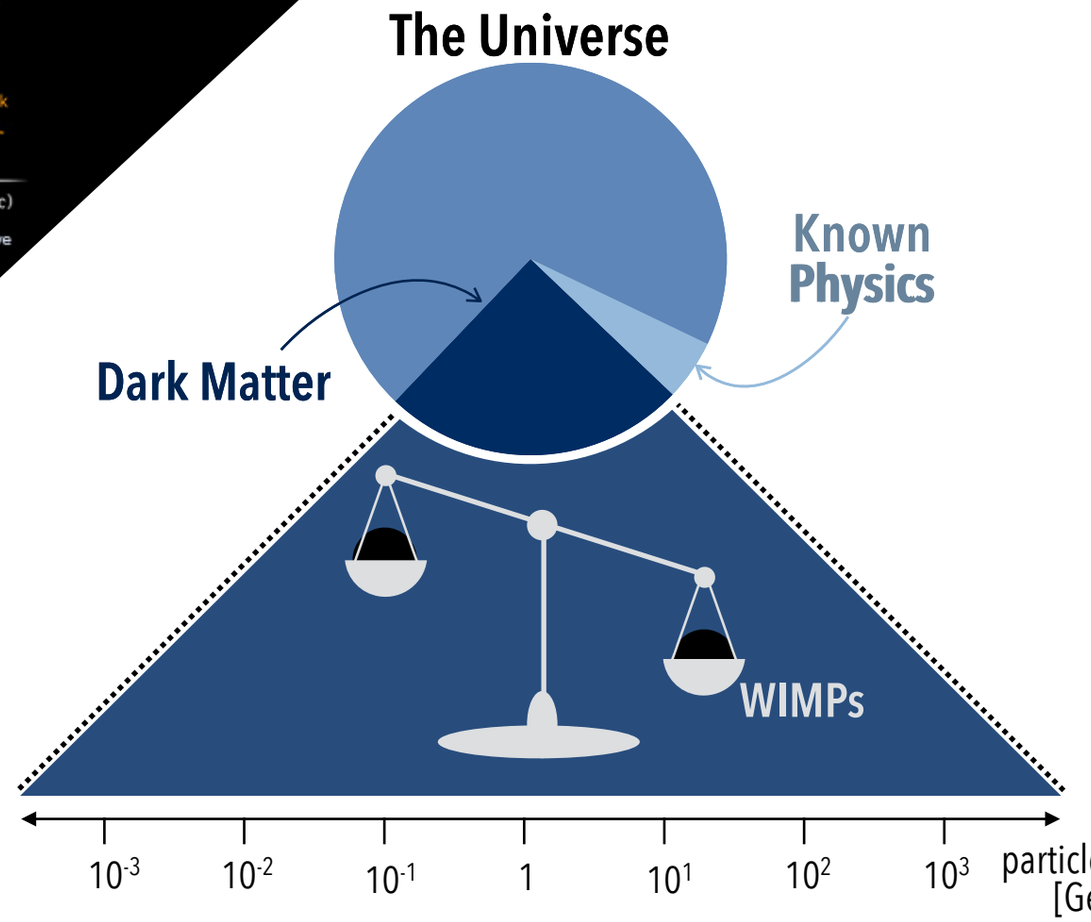

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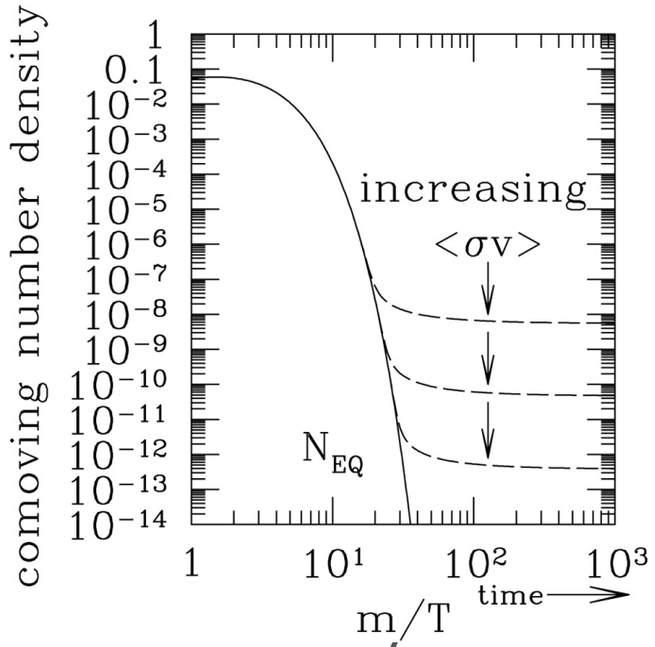

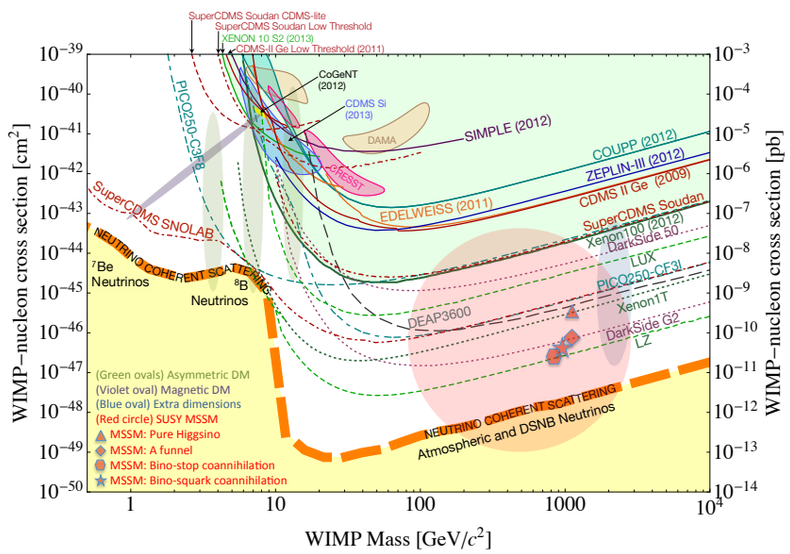

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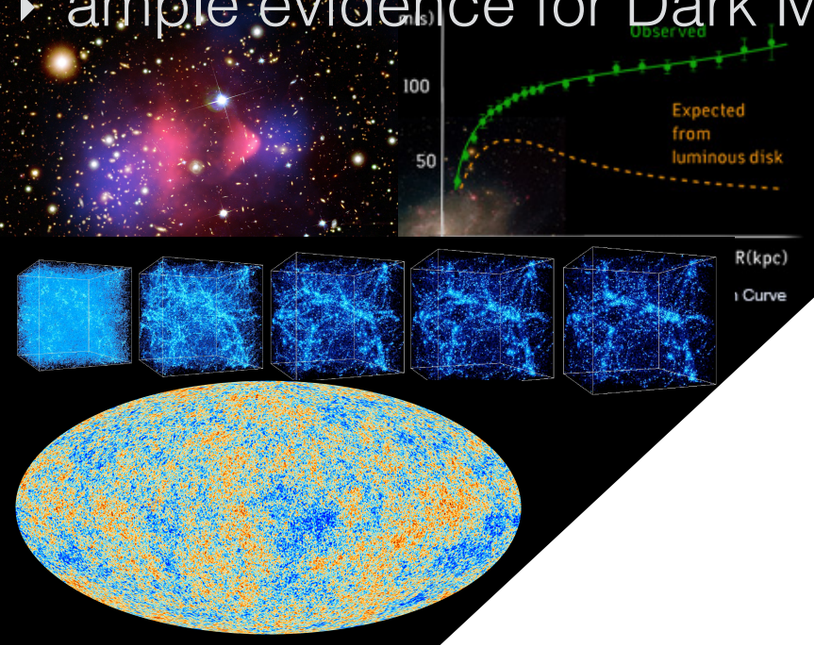

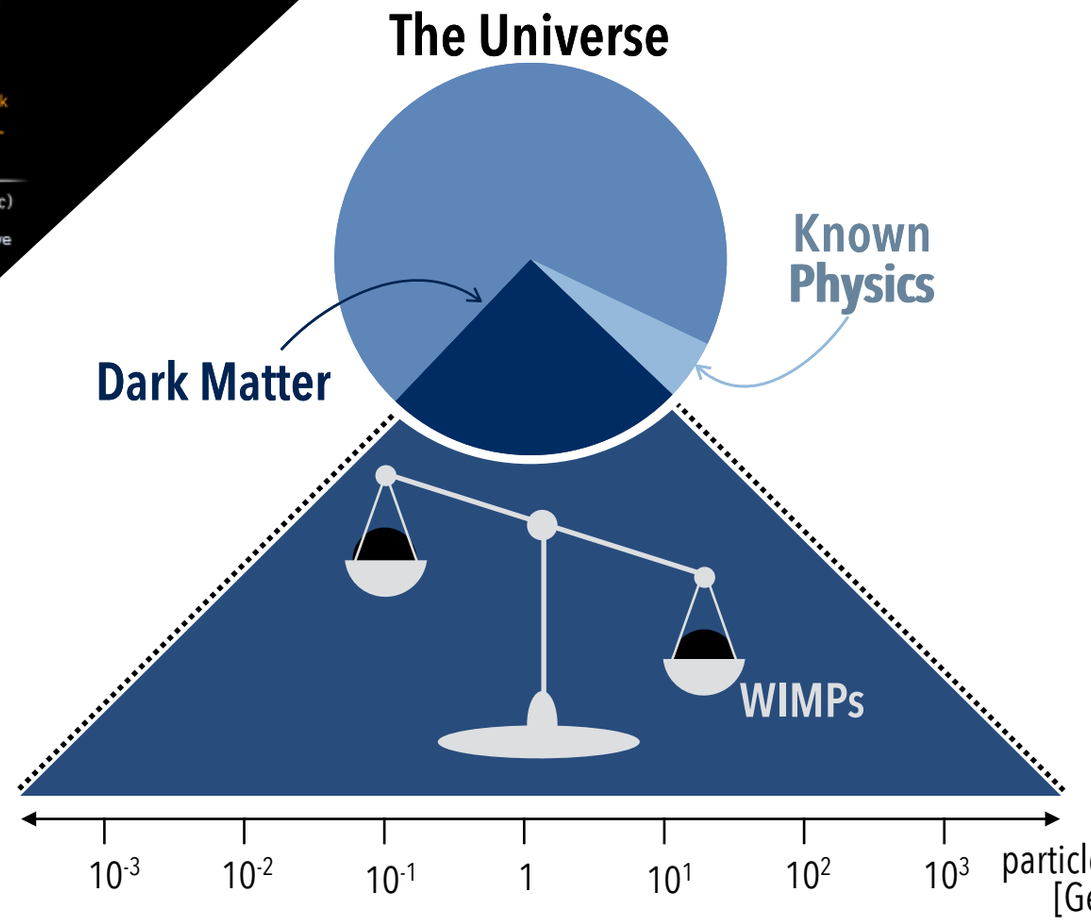

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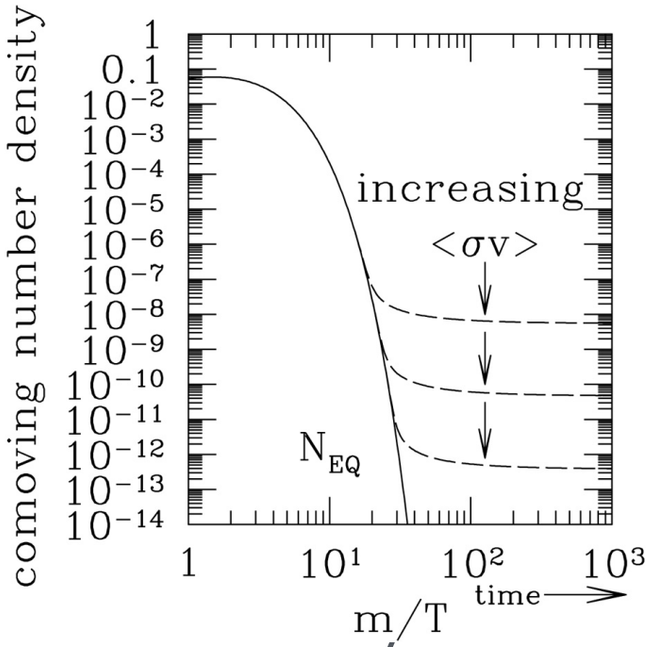

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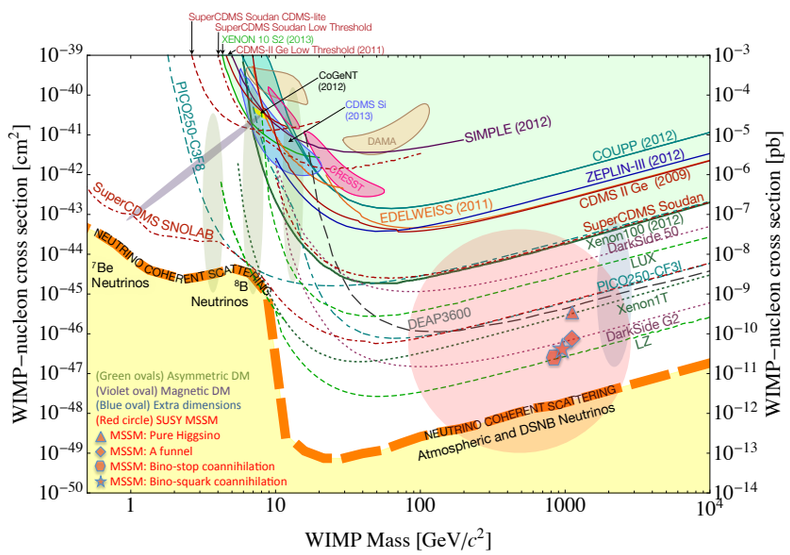

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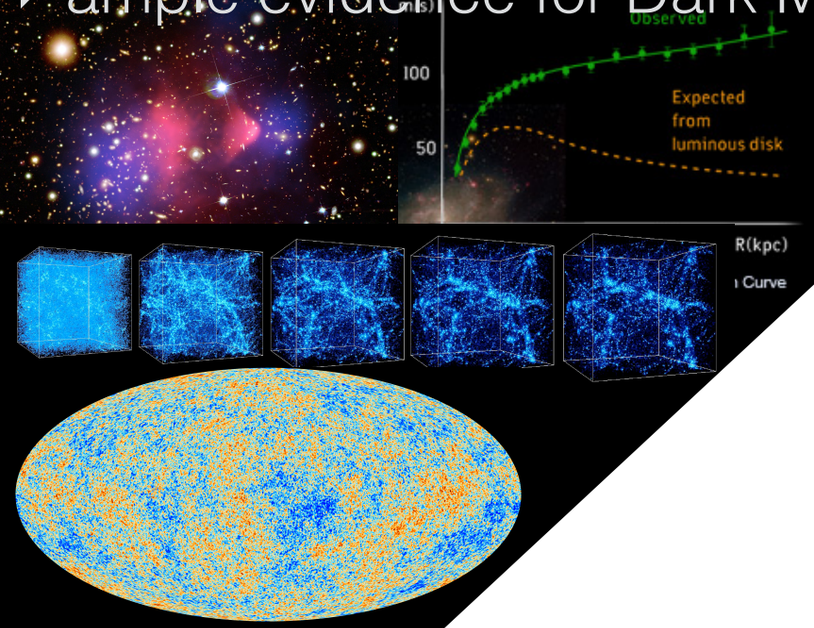

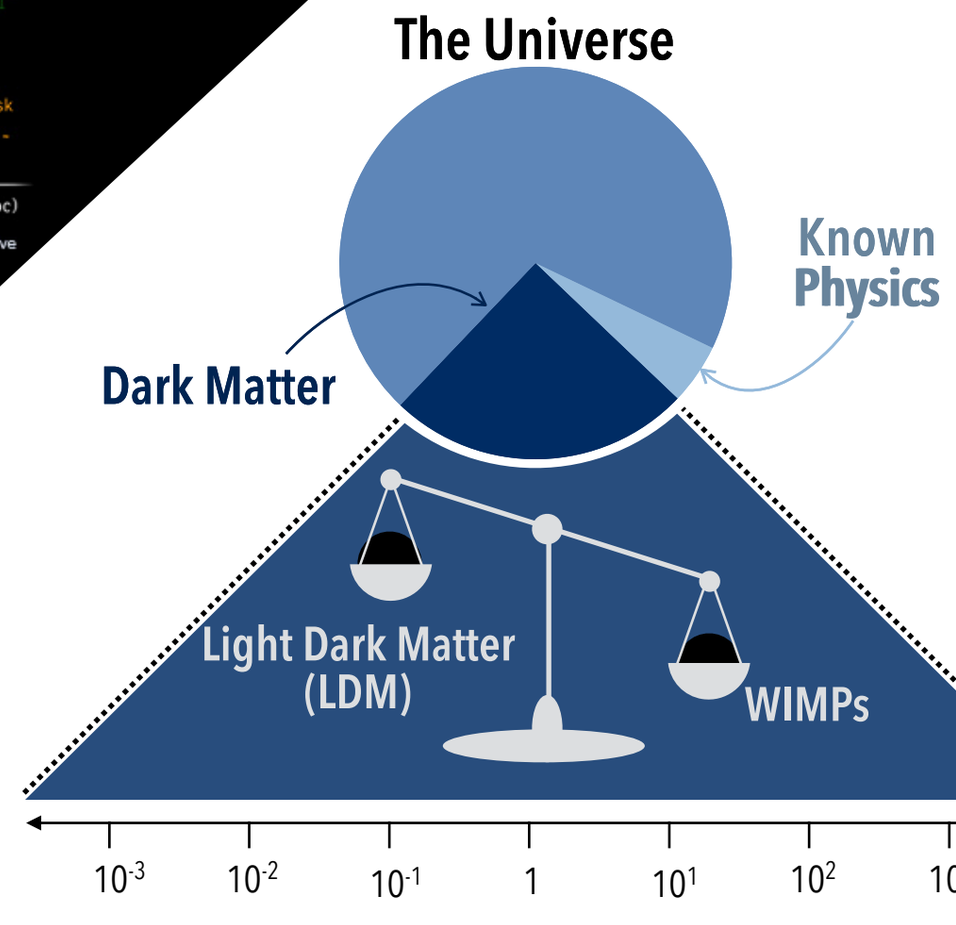

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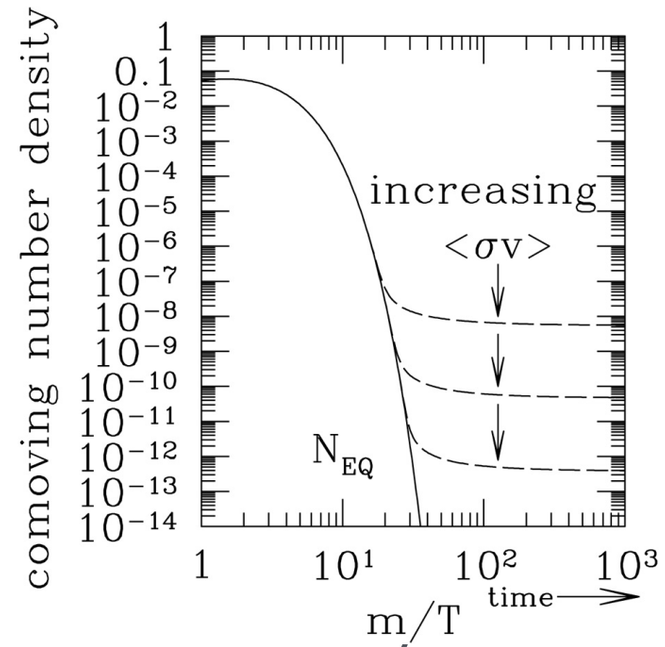

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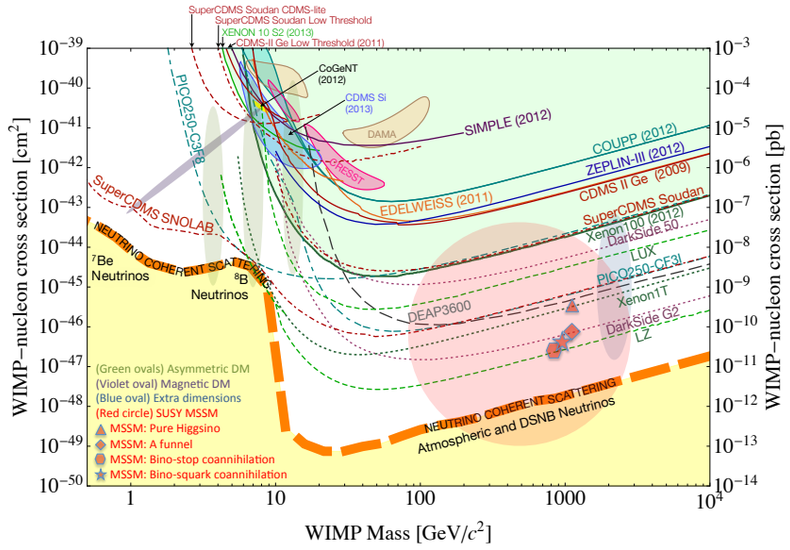
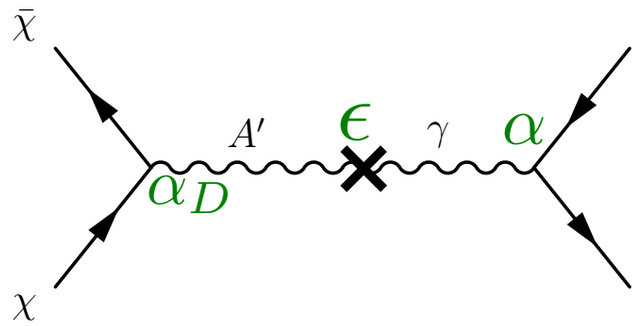


The Model

- 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 channels
  - widely-used minimal but representative model:

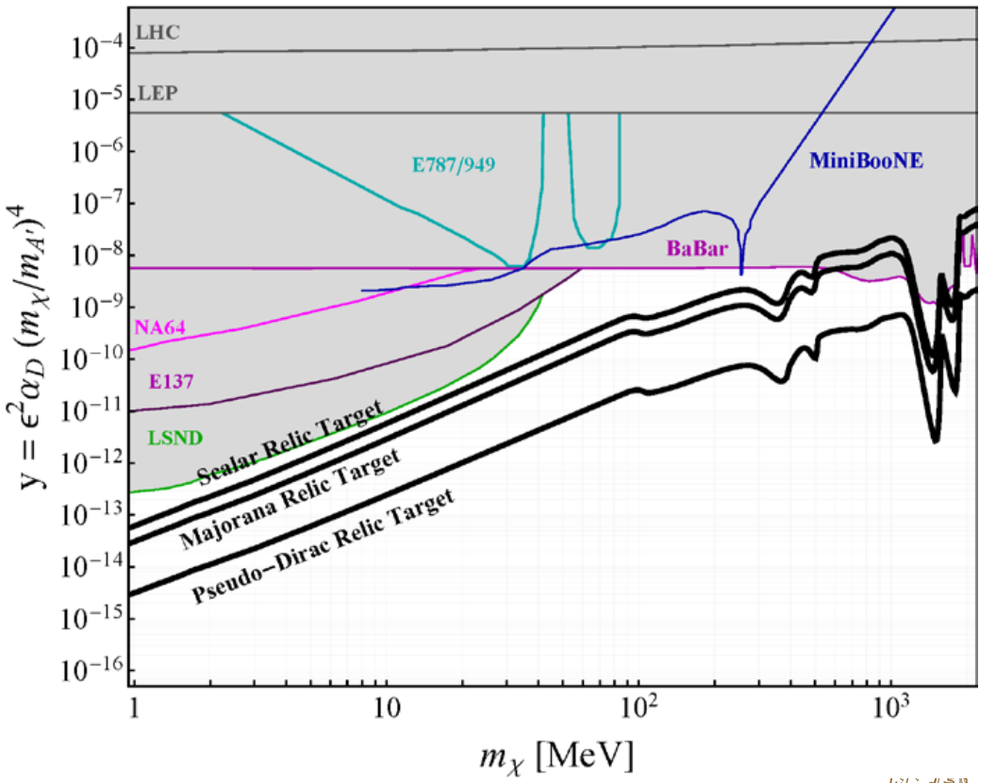
    Dark Photon, A' (vector mediator)



  - kinetic mixing with SM photon (ε)
  - $m_{A'} > 2m_\chi$: **invisible** decay into DM
  - annihilation cross section ~ y * m_χ^{-2}

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

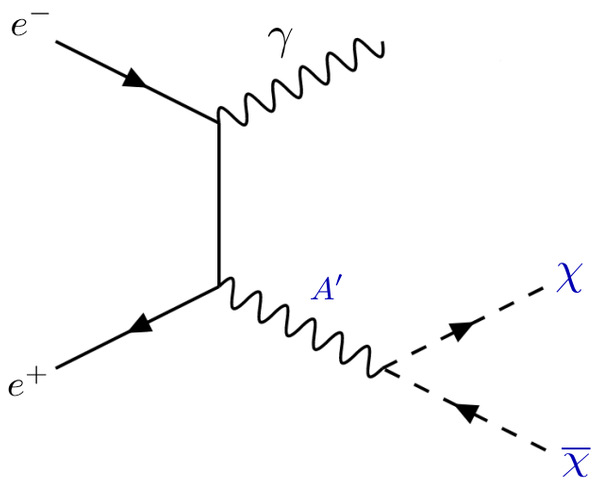
  - clear *'thermal targets'* in y-mass-plane



Why fixed-target?

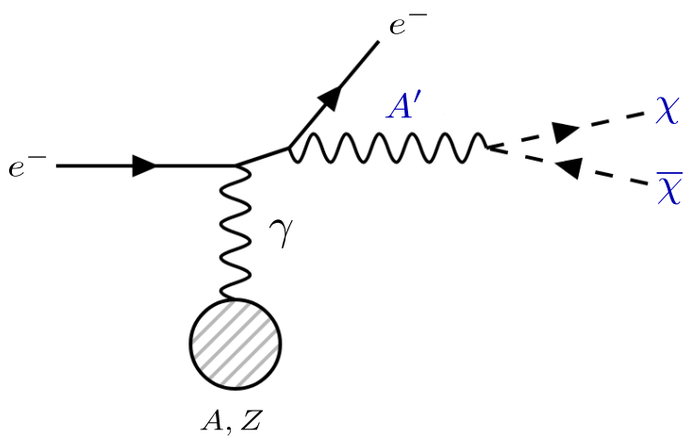
- maximise DM yield (**production** & detection **efficiency**)

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

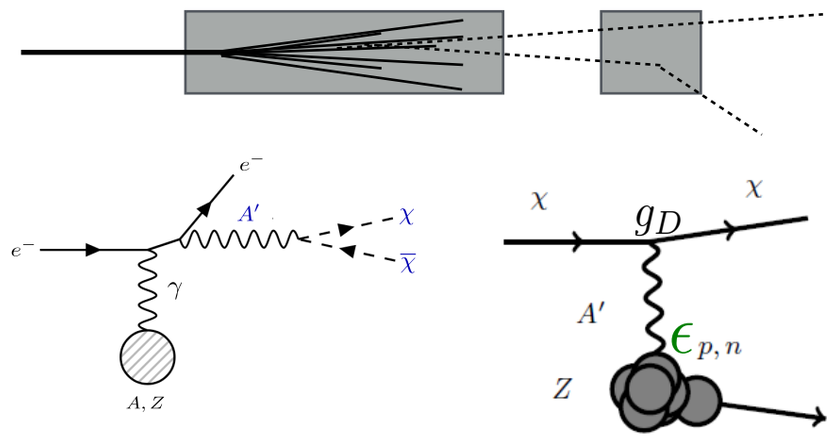


- fixed target

dark bremsstrahlung



- beam-dump



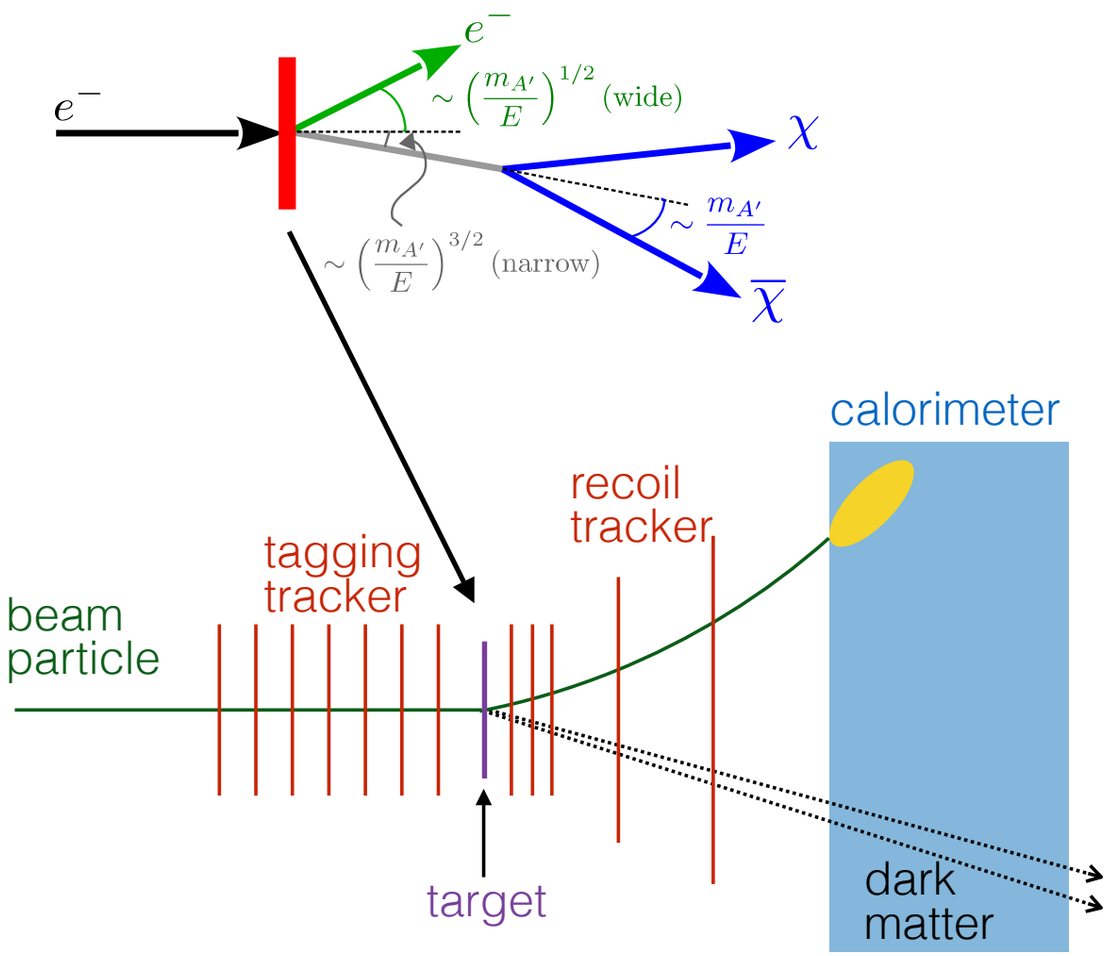
$$\sigma_{\text{coll}} \propto \frac{\varepsilon^2}{E_{\text{cm}}^2} \quad \ll \quad \sigma_{\text{FT}} \propto \frac{Z^2\varepsilon^2}{m_{\text{A'}}^2}$$

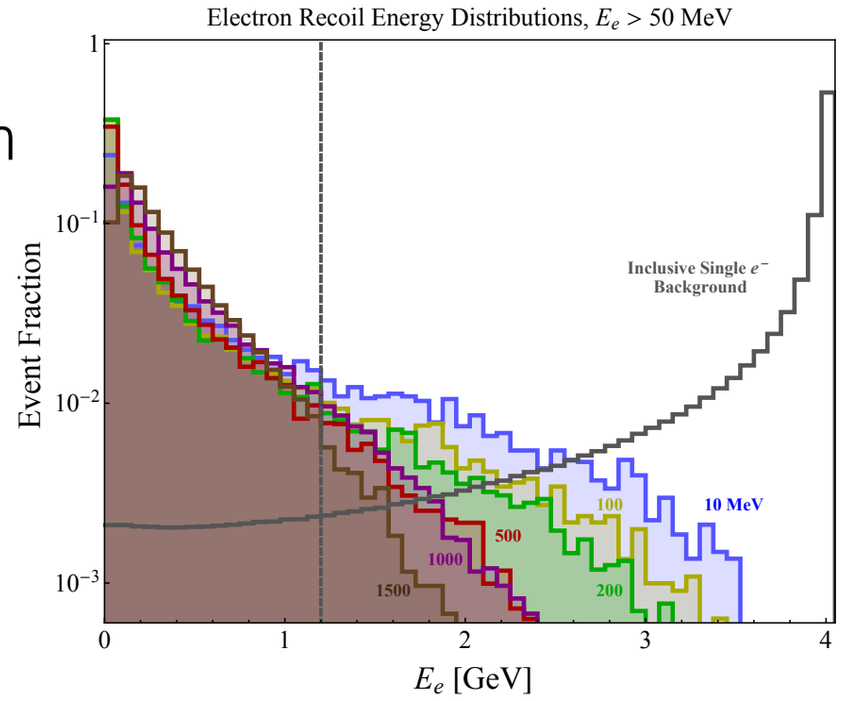
$$\frac{\sigma_{\text{FT}}}{\sigma_{\text{coll}}} \propto Z^2\left(\frac{E_{\text{cm}}}{m_{\text{A'}}}\right)^2 \quad >> 1$$

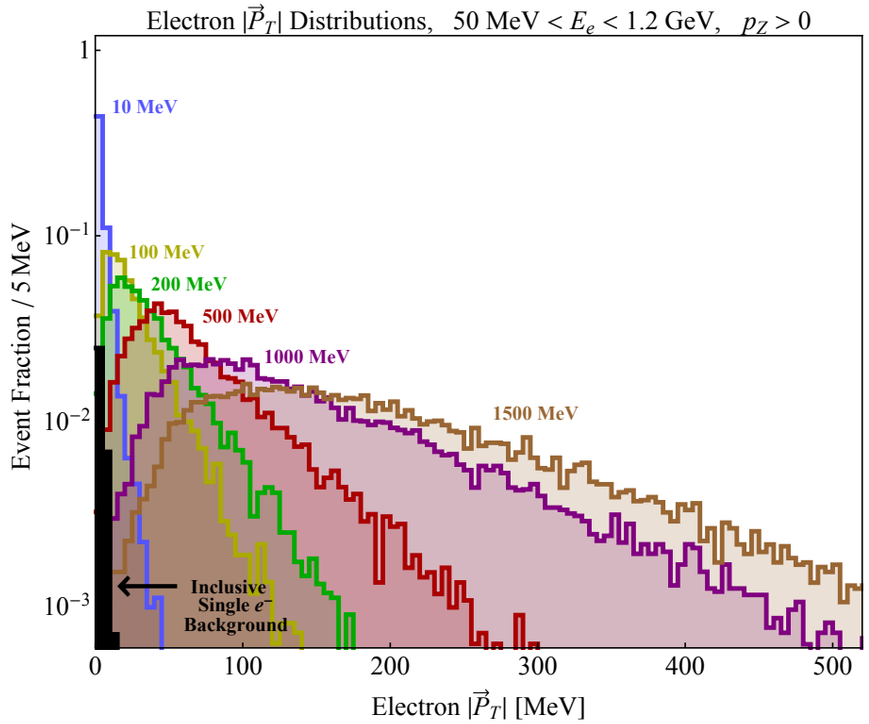
$$N \propto \varepsilon^2(1-\varepsilon^2) \approx \varepsilon^2 \quad \gg \quad N \propto \varepsilon^4$$

Kinematics & Experimental Layout

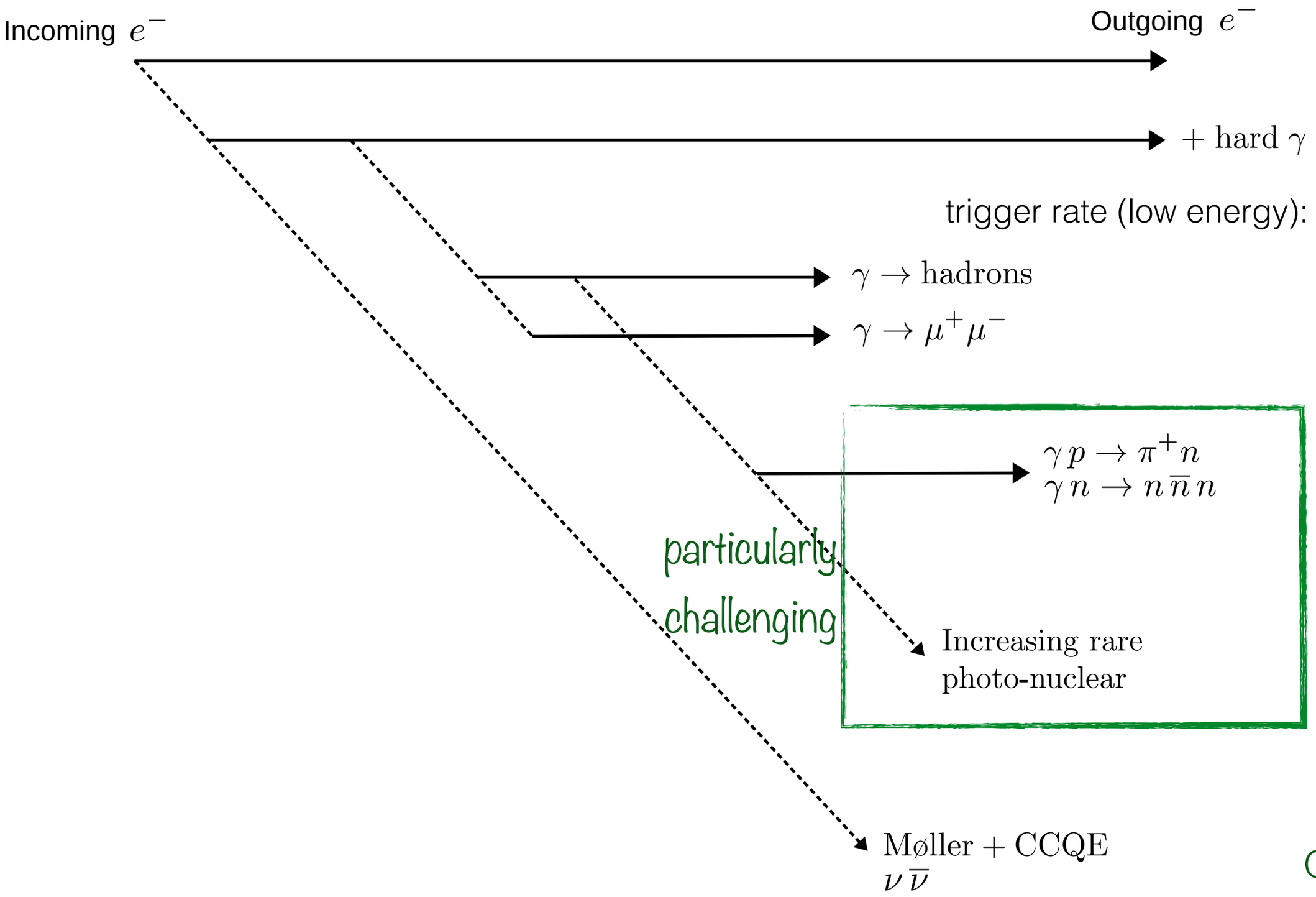
- due to mass of mediator, kinematics distinctly different from SM bremsstrahlung
  - mediator carries most of the energy
    —> soft recoil electron, large missing momentum
  - recoil electron gets transverse ‘kick’
    —> large missing transverse momentum







Background Challenges



40 MHz

MHz

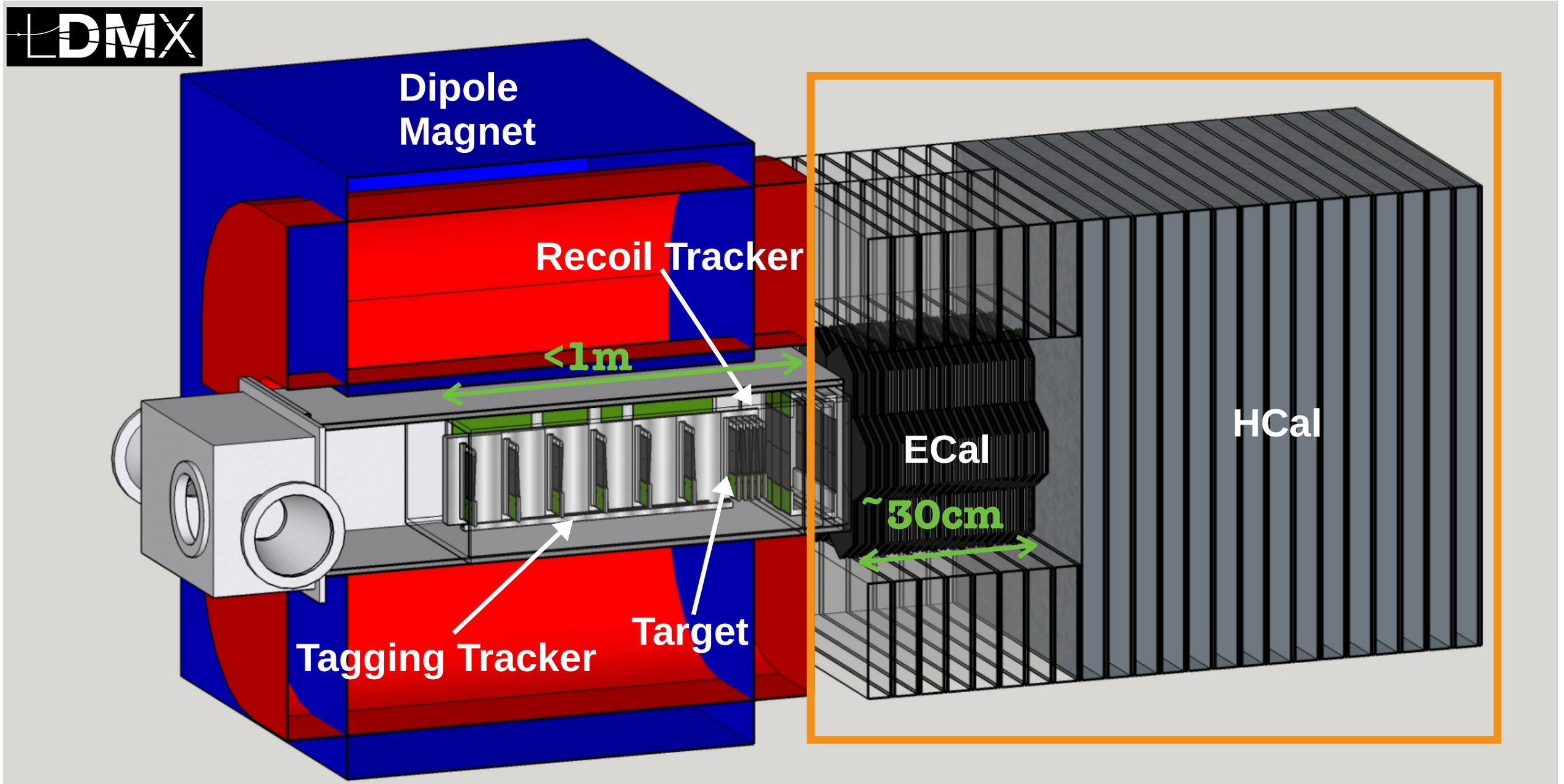
10 kHz

O(100) Hz

O(few/hour)

O(1/many years)

LDMX



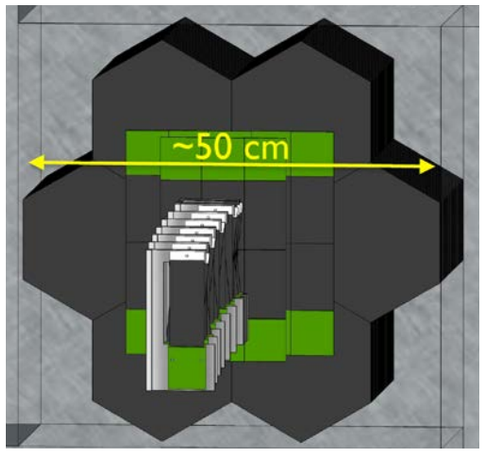
Caltech Fermilab SLAC NATIONAL ACCELERATOR LABORATORY UCSB UNIVERSITY OF CALIFORNIA SANTA BARBARA UNIVERSITY OF MINNESOTA UNIVERSITY OF CALIFORNIA SANTA CRUZ LUNDS UNIVERSITET

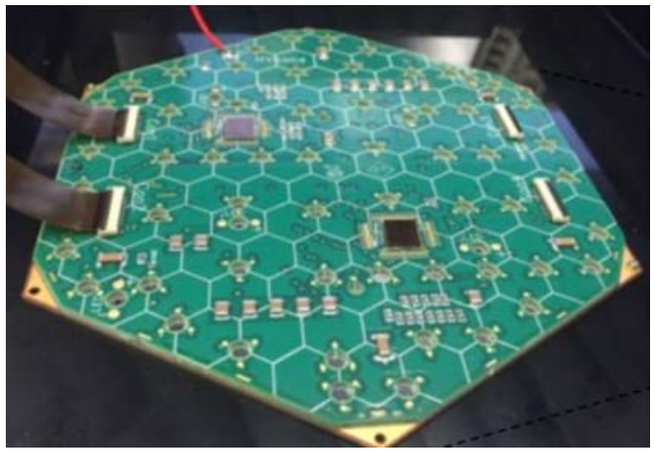
Electromagnetic Calorimeter (ECal)

- to achieve large number of electrons on target (10^{14}-10^{16}): **high-rate beam** (1e/few ns)
  - candidates: DASEL at SLAC (4/8 GeV), CEBAF @ JLab (≤12 GeV)

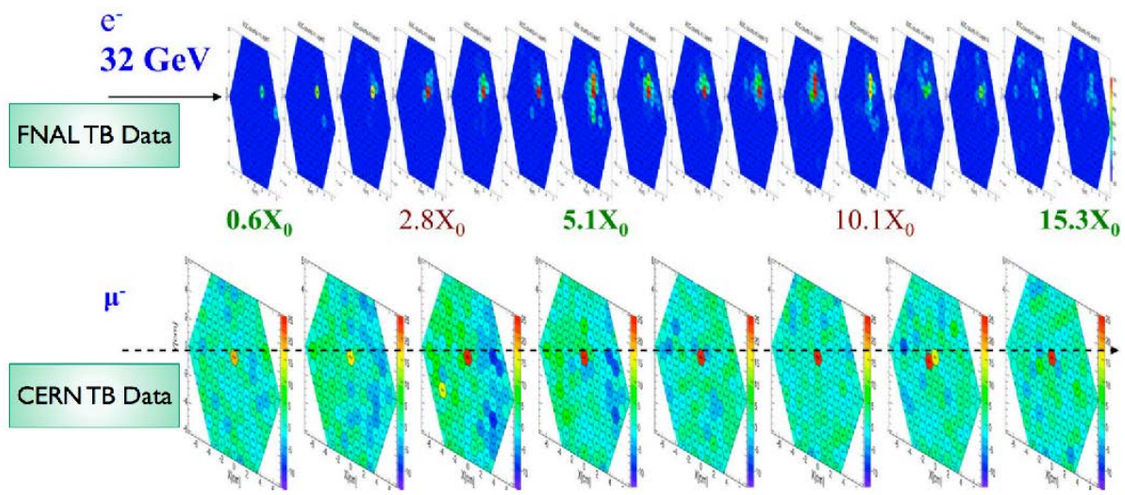
- ECal shopping list:
  - fast
  - radiation hard
  - dense
  - high-granularity
  - deep (containment)

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





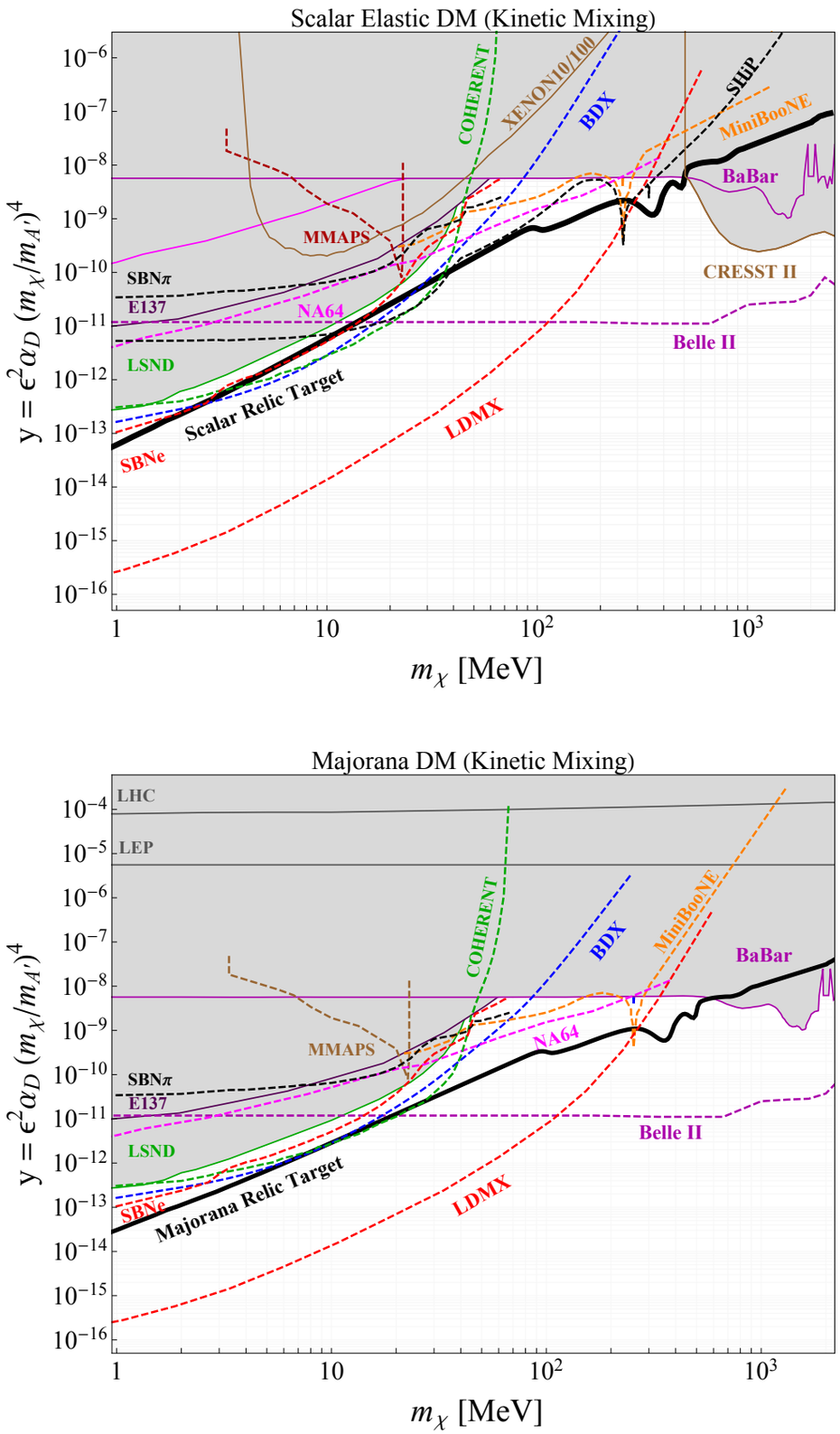
- in LDMX:
  - 40 radiation lengths deep
  - 30 layers, 7 modules each
  - central modules with higher granularity (up to 1000 channels)
    - PCBs to be designed in Lund
  - high granularity allows MIP 'tracking' —> important tool in background suppression

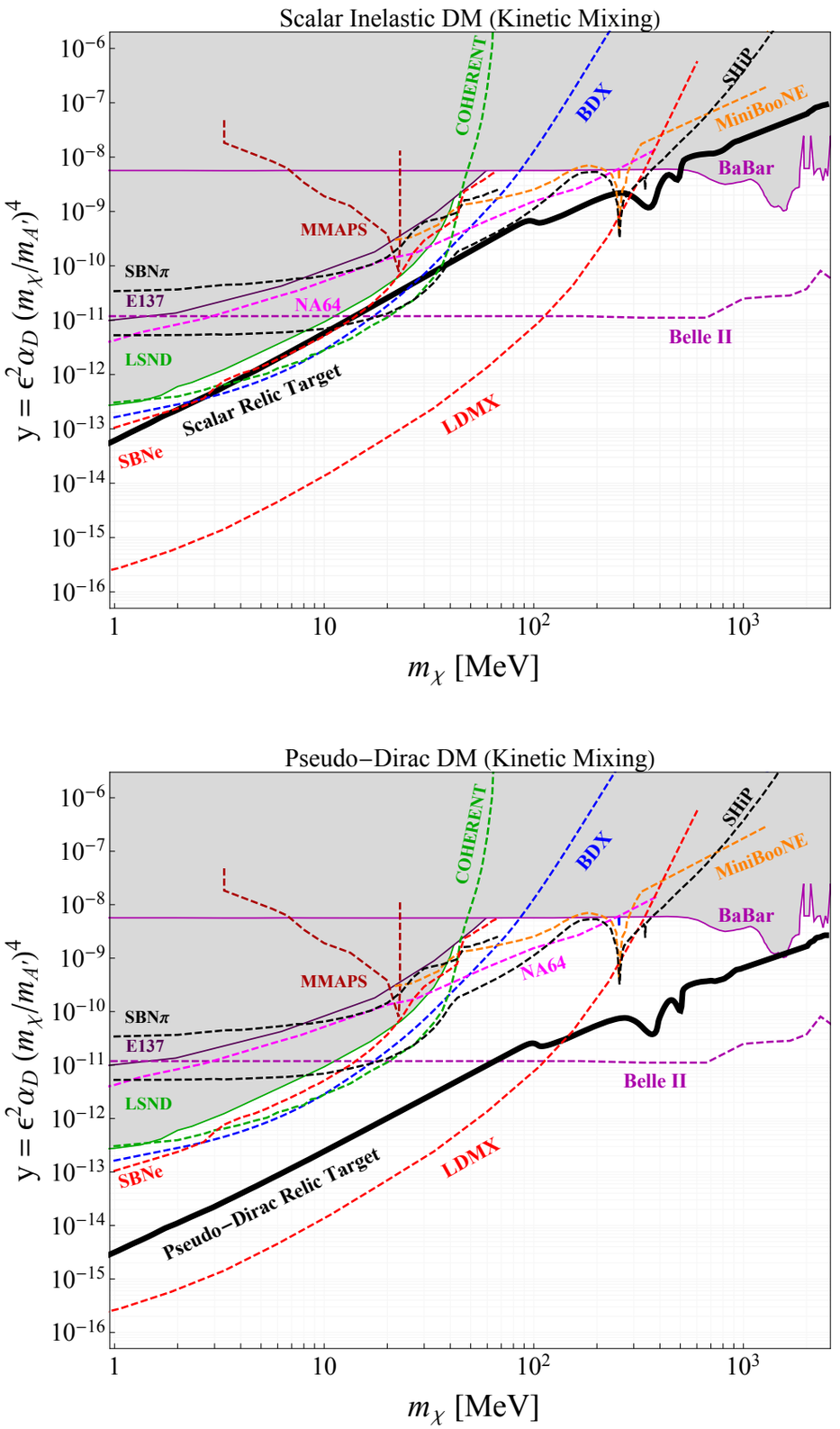


Hadronic Calorimeter (HCal)

- 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. $\gamma n \rightarrow nn\bar{n}$
- surround ECal as much as possible
- be as efficient as possible for both low- and high-energy neutrons
  - baseline: **plastic scintillator + absorber** (steel)
  - design optimisation studies ongoing
    - materials
    - geometry
    - dimensions (largest piece of the experiment)
    - configurations of scintillator/sampling
- develop **in-situ verification** of veto power

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)

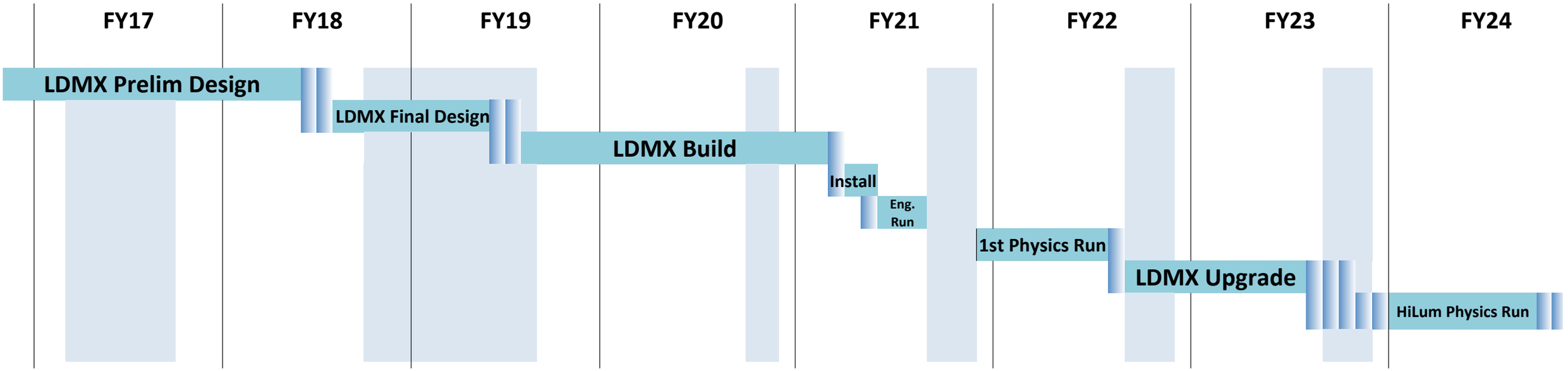
Conclusion & Outlook

- light, thermal relic Dark Matter well motivated
- fixed-target, missing-momentum approach provides best sensitivity
- LDMX the only such experiment on the horizon
  - start of data-taking in early 2020s
- unprecedented potential to conclusively probe thermal targets in MeV - GeV range
- LU to contribute to several aspects of the calorimeter system
- collaboration preparing updated design study ~now
- wider topics of Hidden Sector DM and potential of electron beam facilities to be discussed also at “Physics Beyond Colliders” Workshop at CERN in two weeks: https://indico.cern.ch/event/644287/

Additional Material

Timeline

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



DASEL

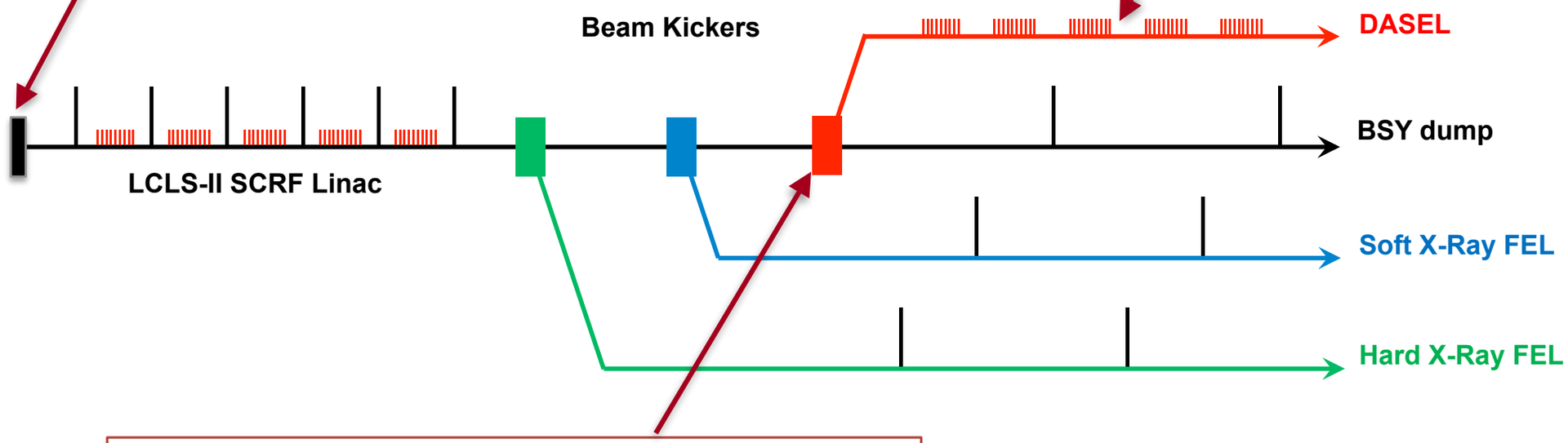
- from T. Nelson at https://confluence.slac.stanford.edu/display/MME/Publications+and+Presentations

DASEL Phase I

SLAC

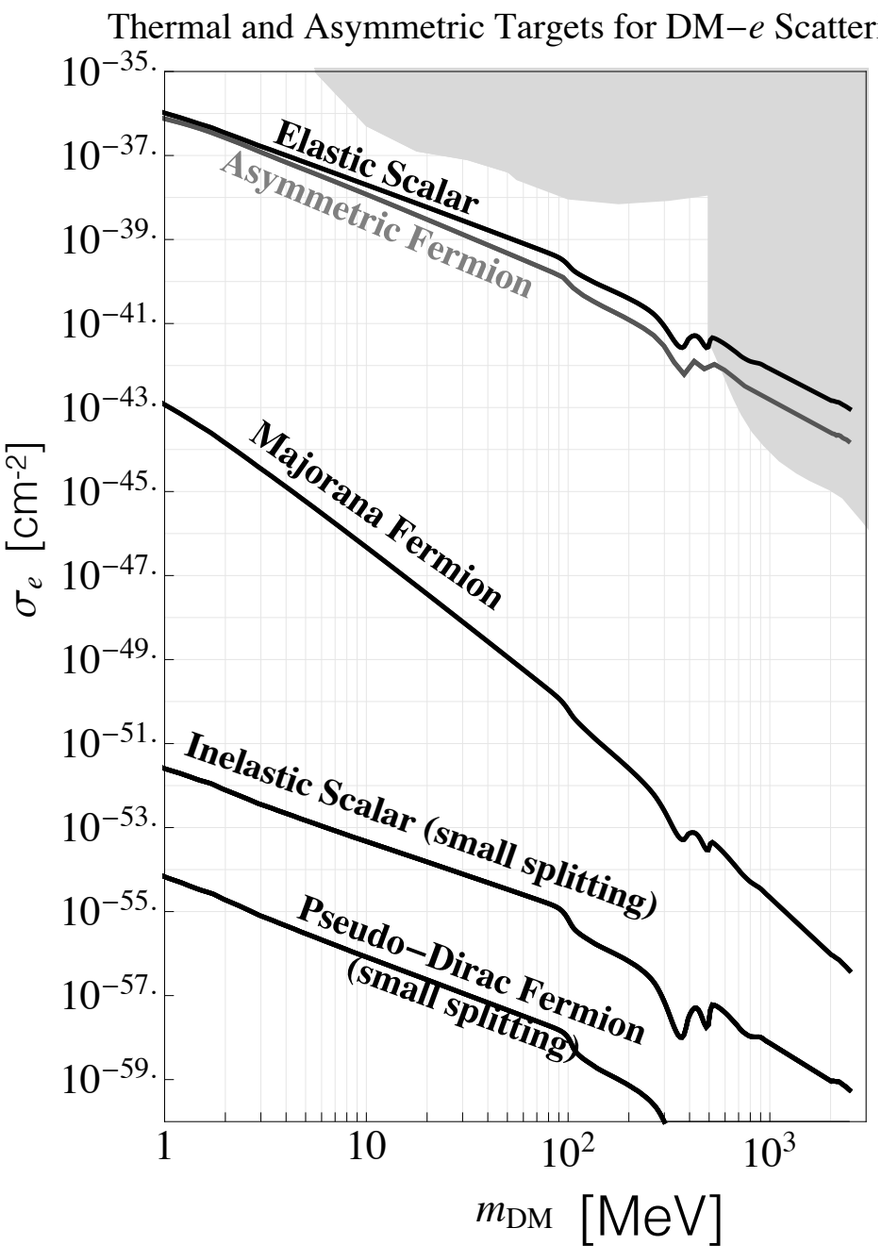
Laser system to fill "unused" buckets with electrons for DASEL
- Use rejected pulses from LCLS-II laser (46 MHz)

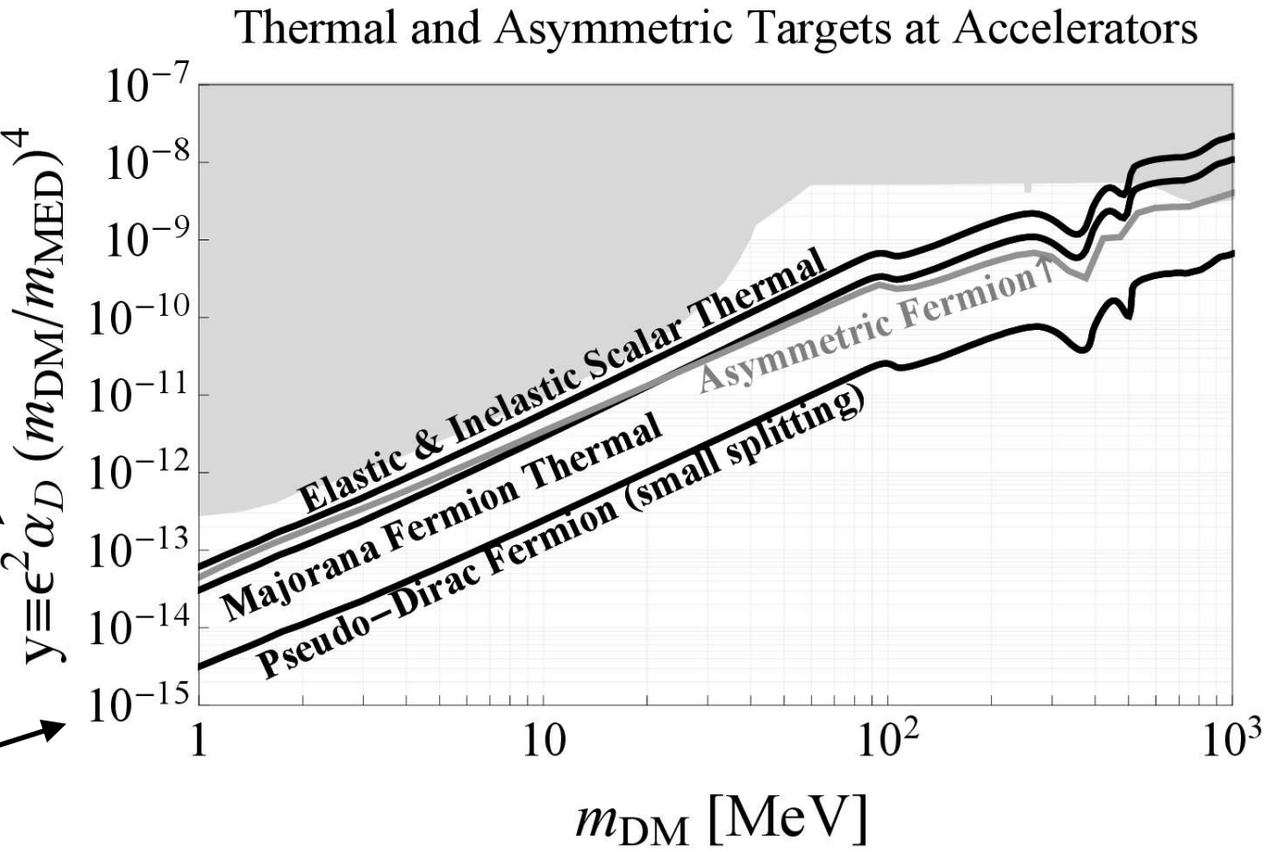
Beamline connecting to ESA line
- 3 dipoles & 11 quads (all refurbished)



DASEL kicker/septum system
downstream of FEL kickers to minimize interference
- Based on LCLS-II design but with longer kicker pulse

Direct Detection and Accelerators

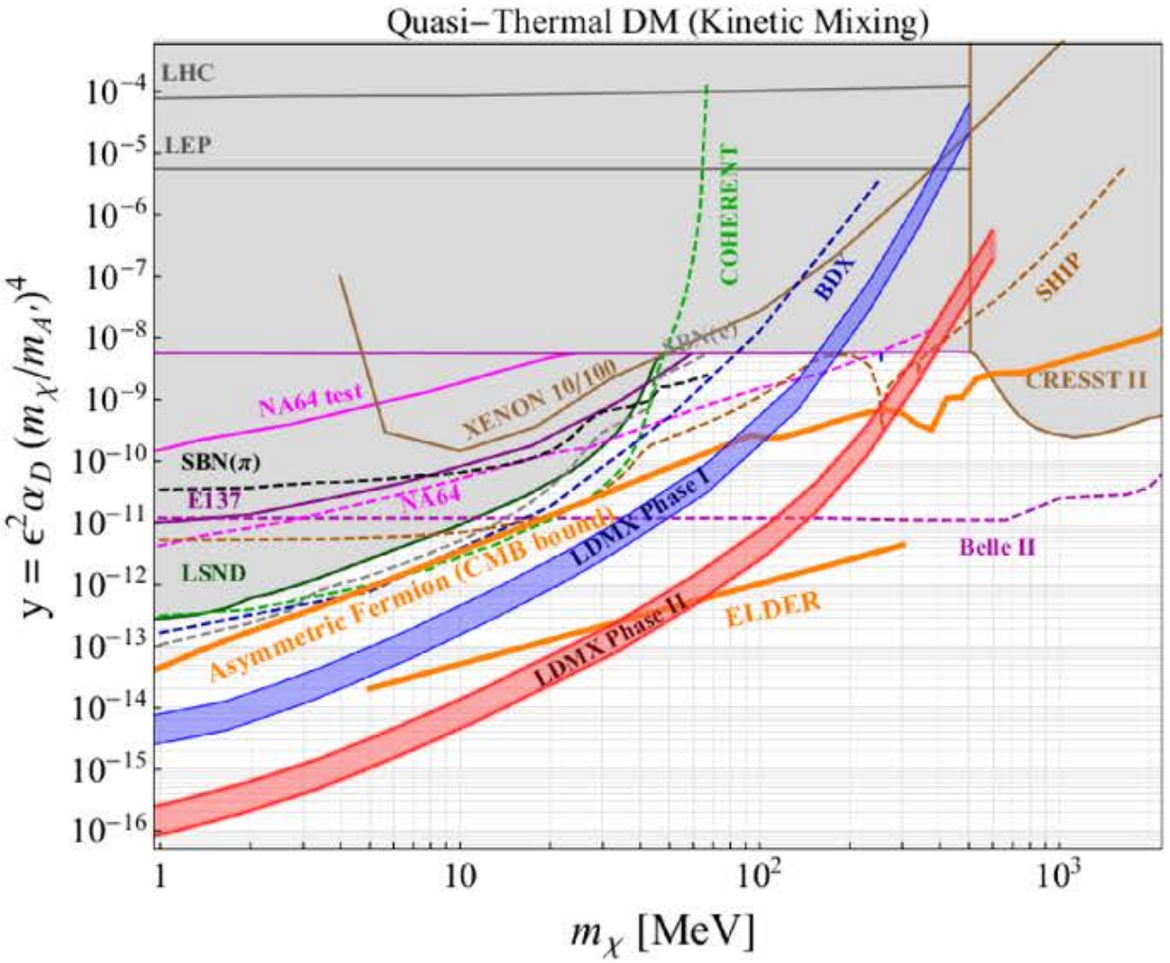




- at accelerators: relativistic production
  —> much smaller velocity/spin dependence
  - thermal targets are all in reach!

Further Potential

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



- improve sensitivity for invisibly decaying Dark Photon