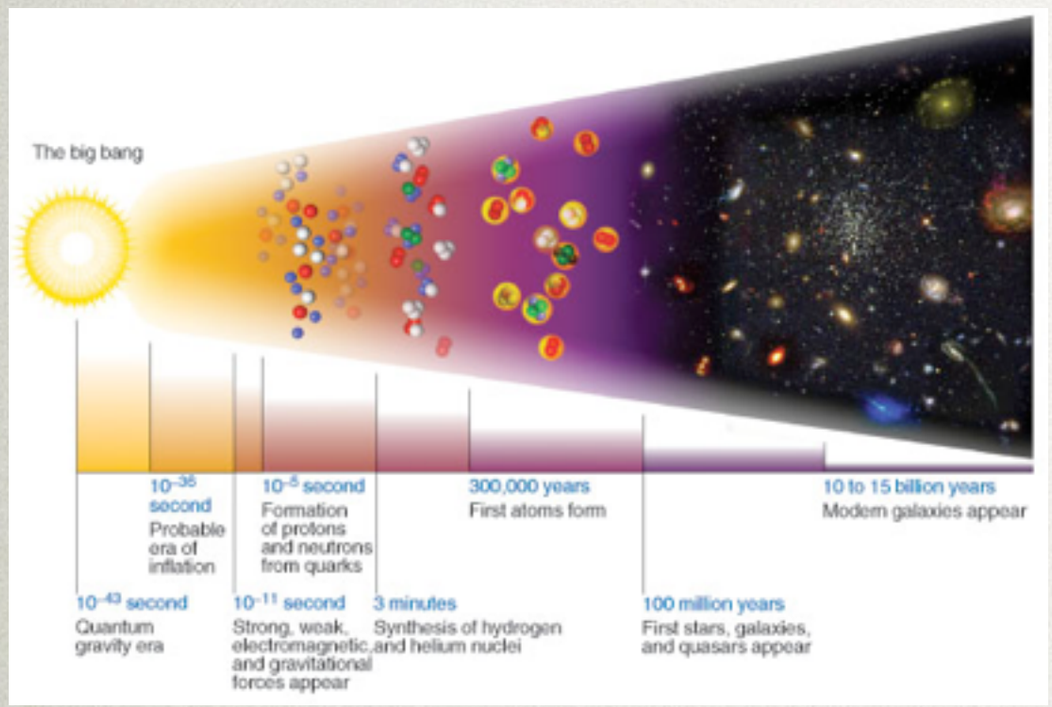
Light Dark Matter at Accelerators:

A Brief Survey

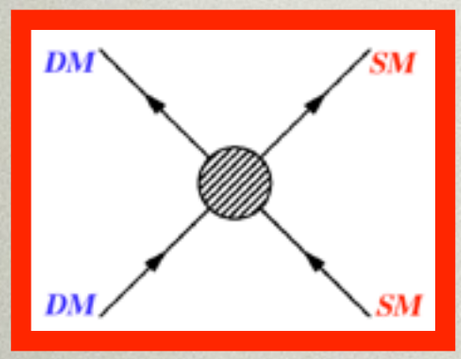
Outline

- [ ] Defining the challenge
- [ ] Four Strategies
- [ ] Where are we now? Where may the field be in 5 years?

What do we learn about Light Dark Matter from its Abundance?

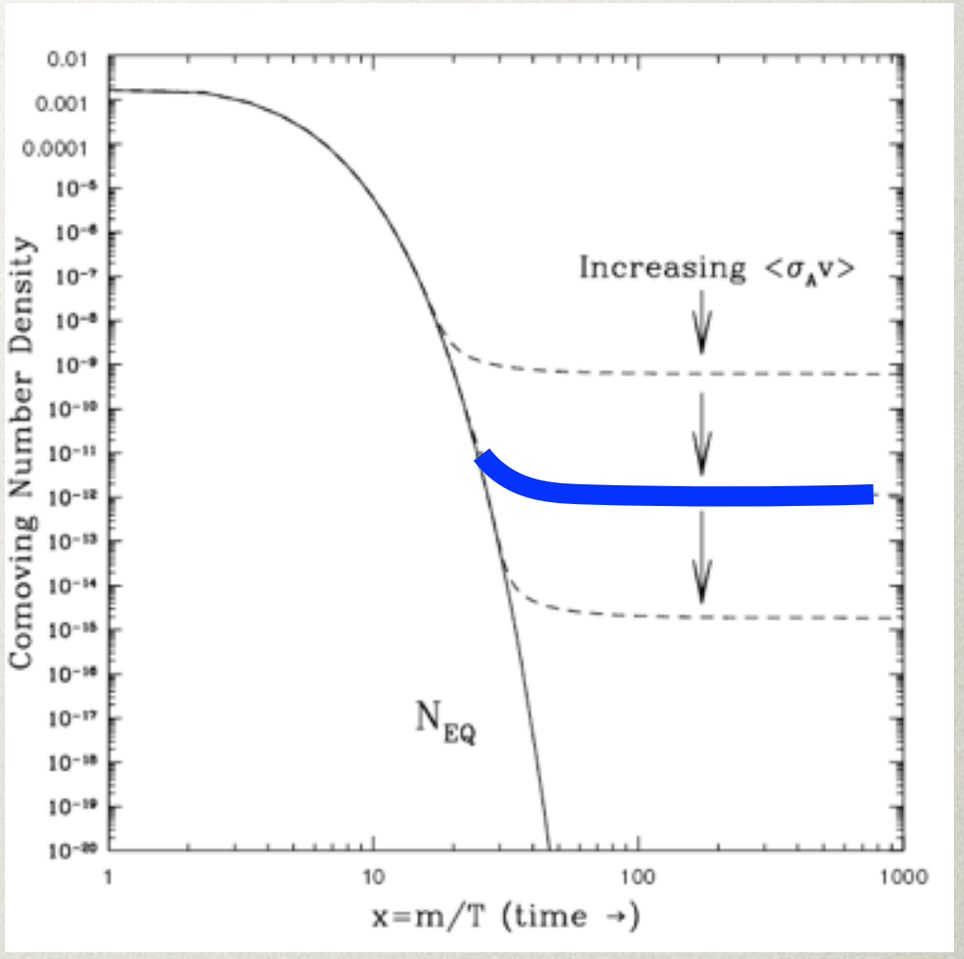


As Universe cools below DM mass, density decreases as $e^{-m/T}$



Dark Matter interacts with SM to stay in equilibrium…

Eventually dark matter particles can't find each other to annihilate



and a (minimal) DM abundance is left over to the present day

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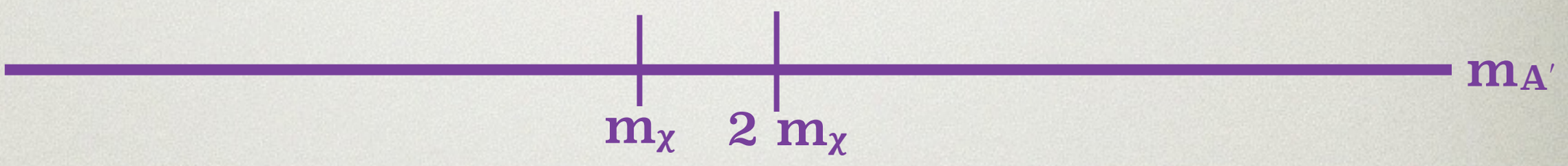

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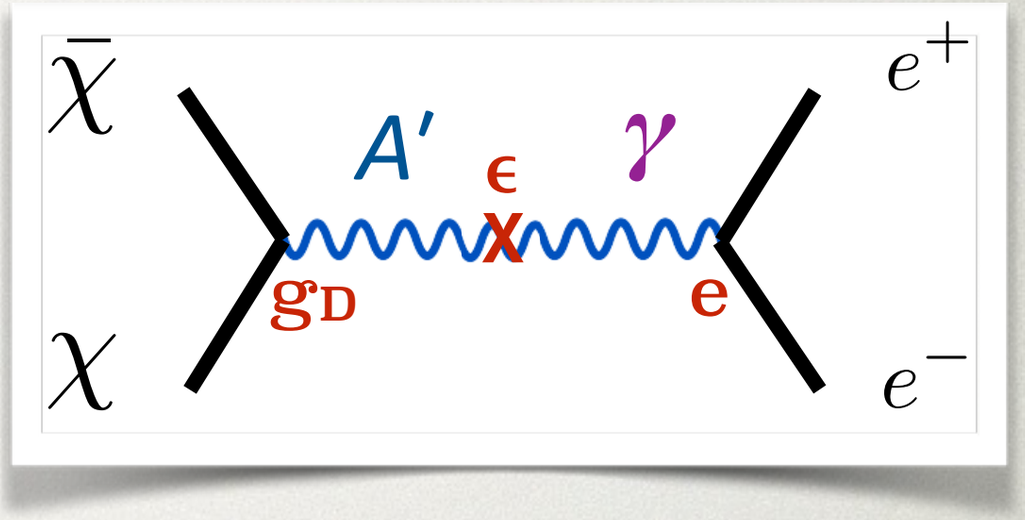
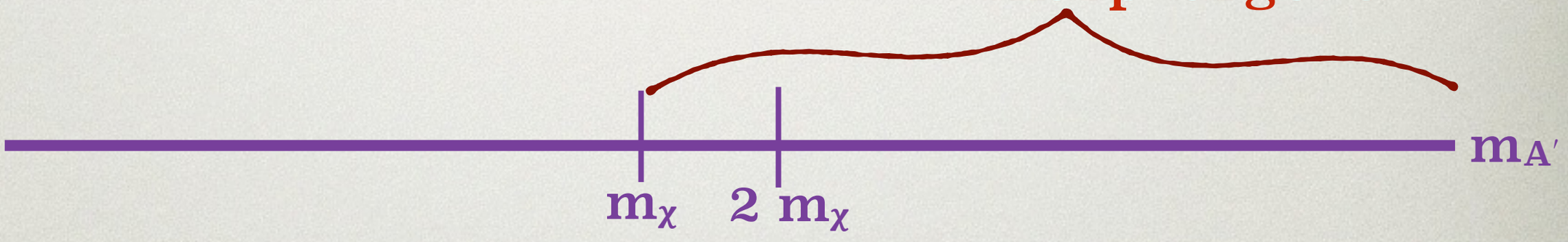


Abundance set by $g_D\epsilon/m_{A'}^2$

$\Rightarrow$ sharp target ϵ!



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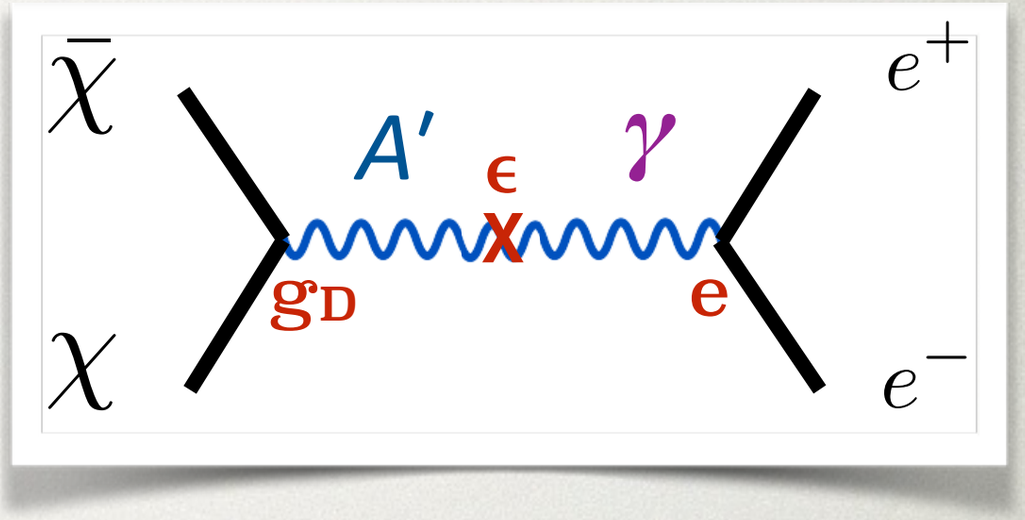

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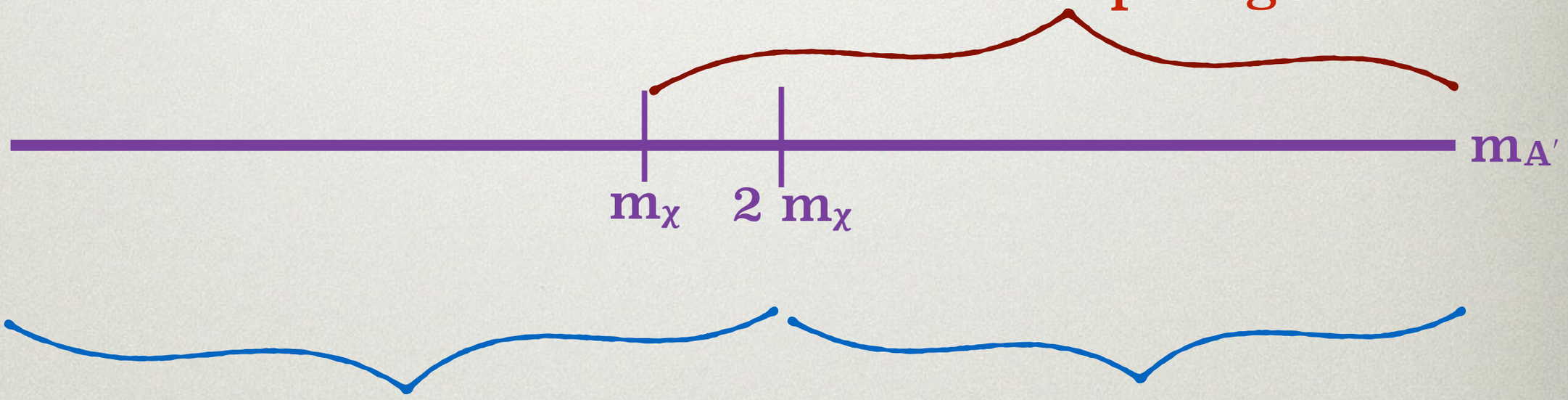

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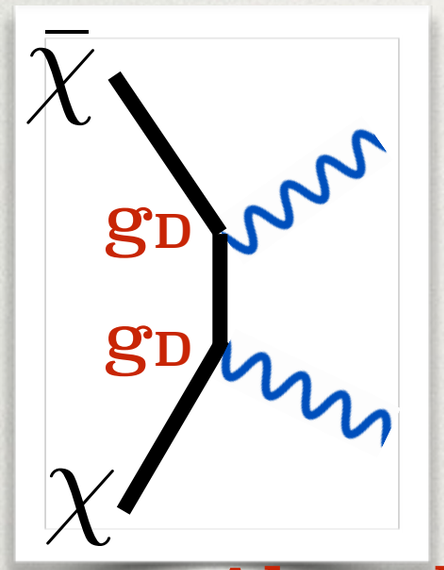
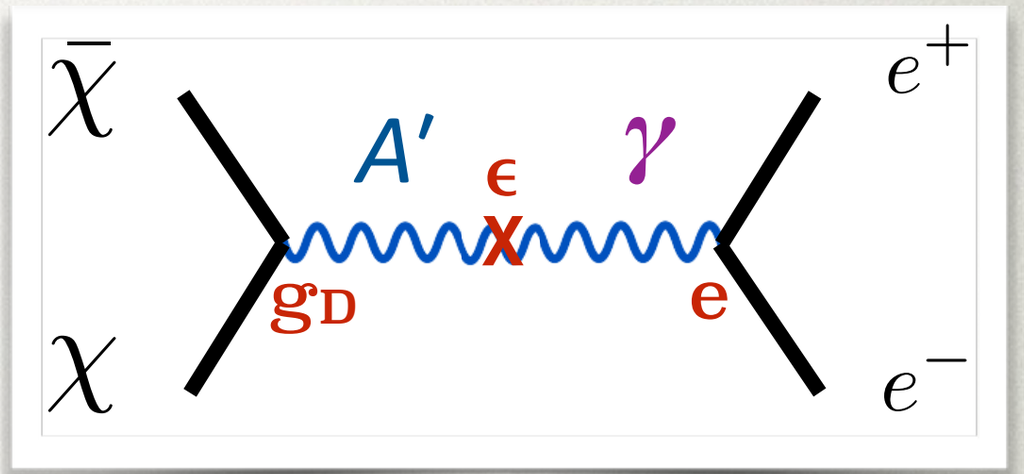
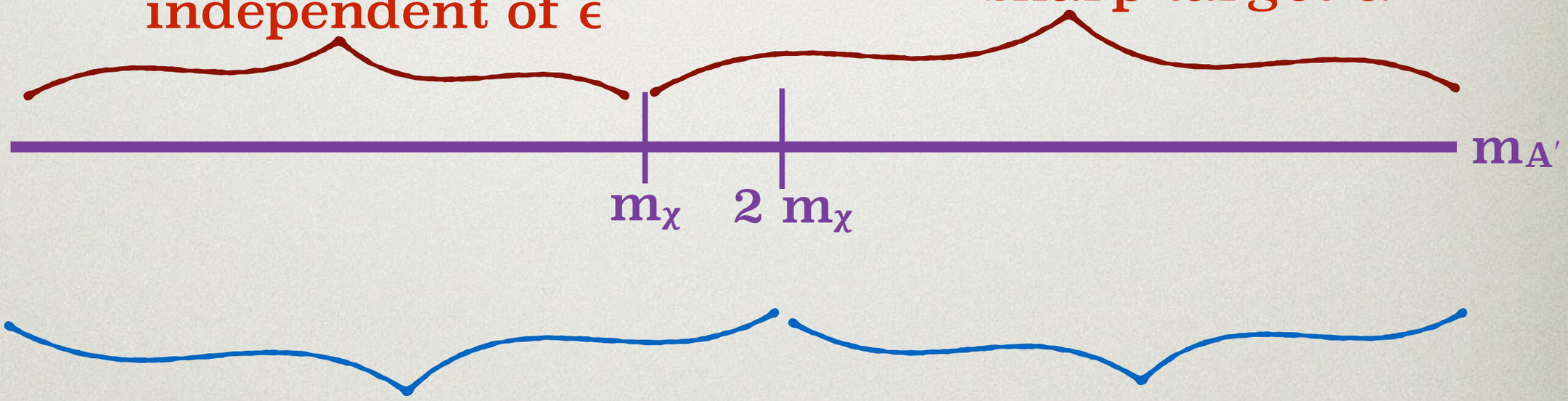




Abundance set by small g_D – independent of ϵ

Abundance set by $g_D\epsilon/m_{A'}^2$ ~ ⇒ sharp target ϵ!



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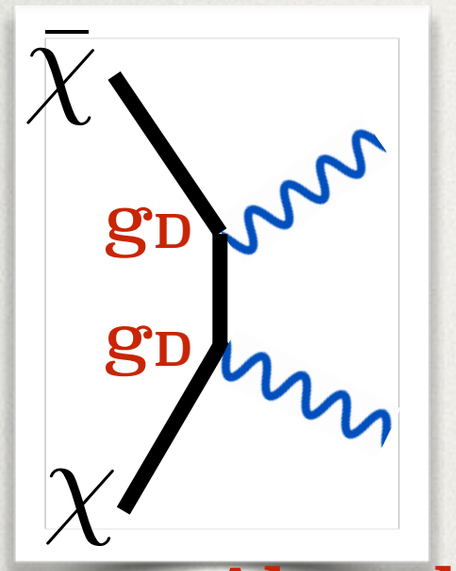

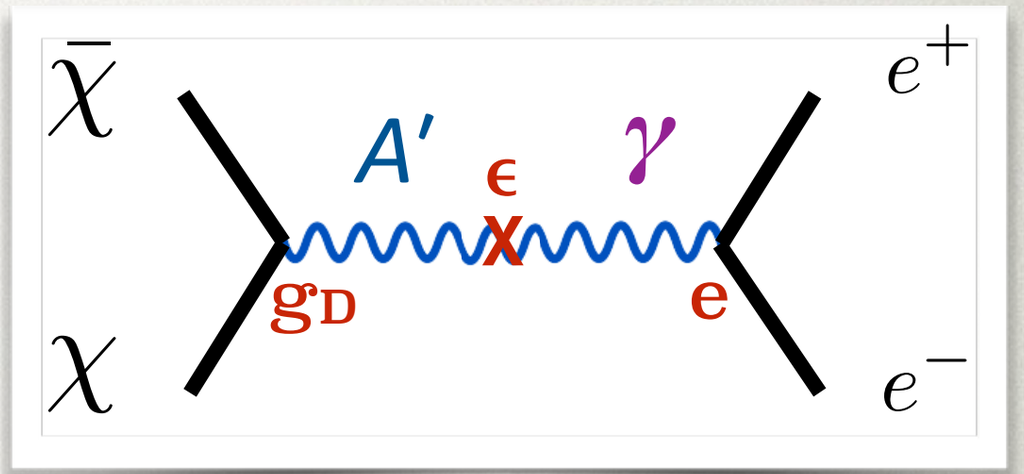

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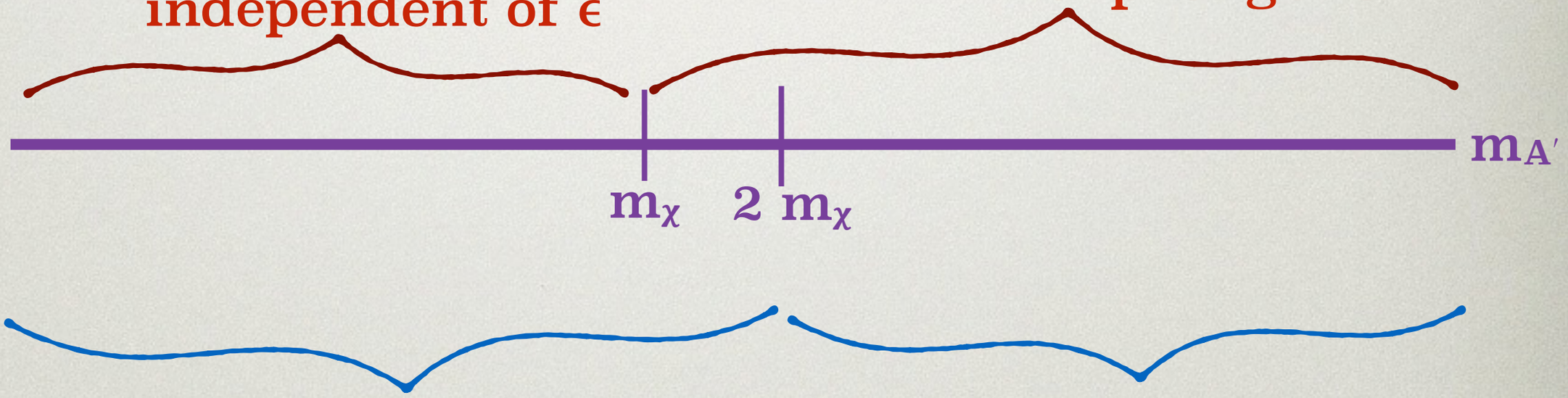


Visible A'

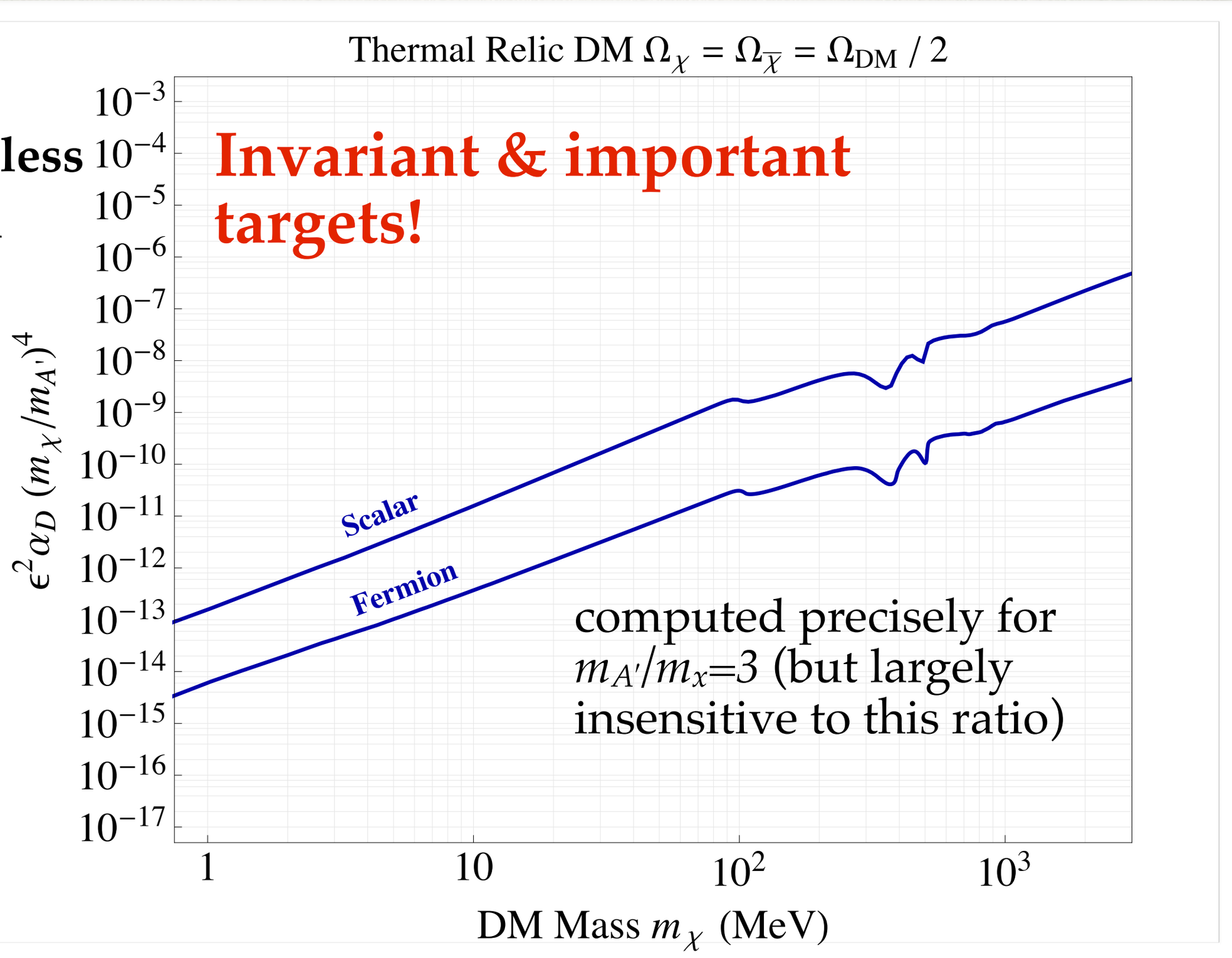
Invisible A'

I'll focus on this case but experiments are also sensitive to the other

The Thermal Origin Target

(for vector portal)

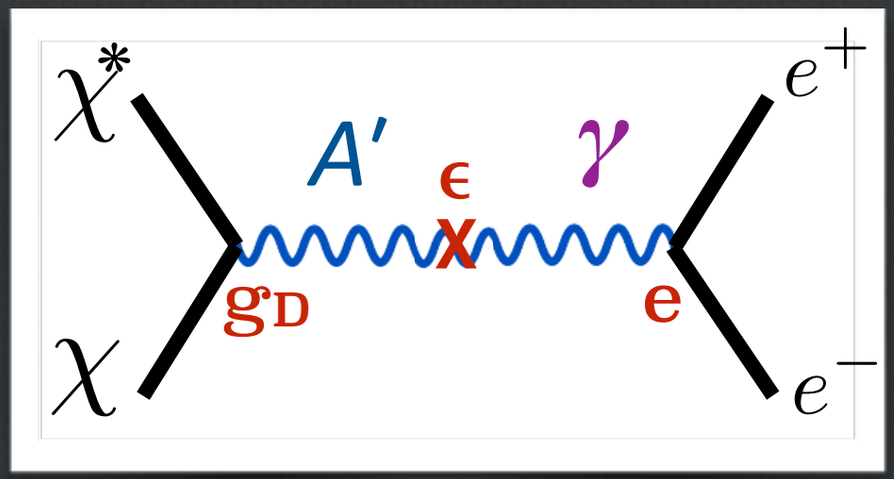
Natural dimensionless interaction strength



Two obstacles to Direct Detection

- Invisibly low energy transfer to nuclei
  - Can look for e- recoils (but bkg!)

- Possible mass splitting of DM particles (“inelastic” DM) can make these scattering processes kinematically forbidden for halo dark matter
  - May not affect accelerator signal (splitting $\Delta m <$ MeV), or lead to displaced or prompt e^+e^- pair



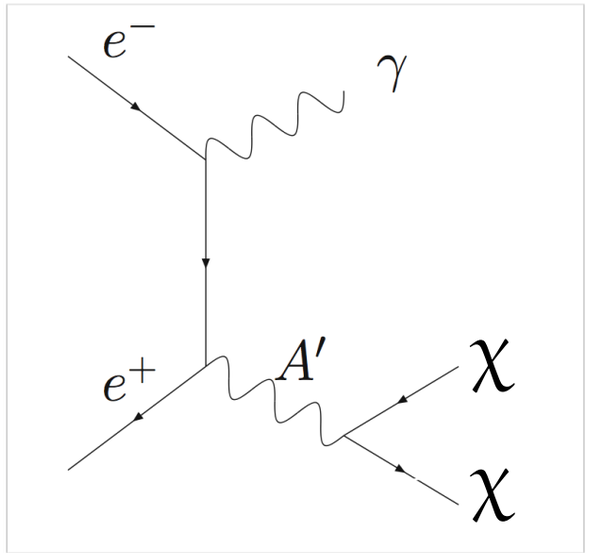
Detection Strategies

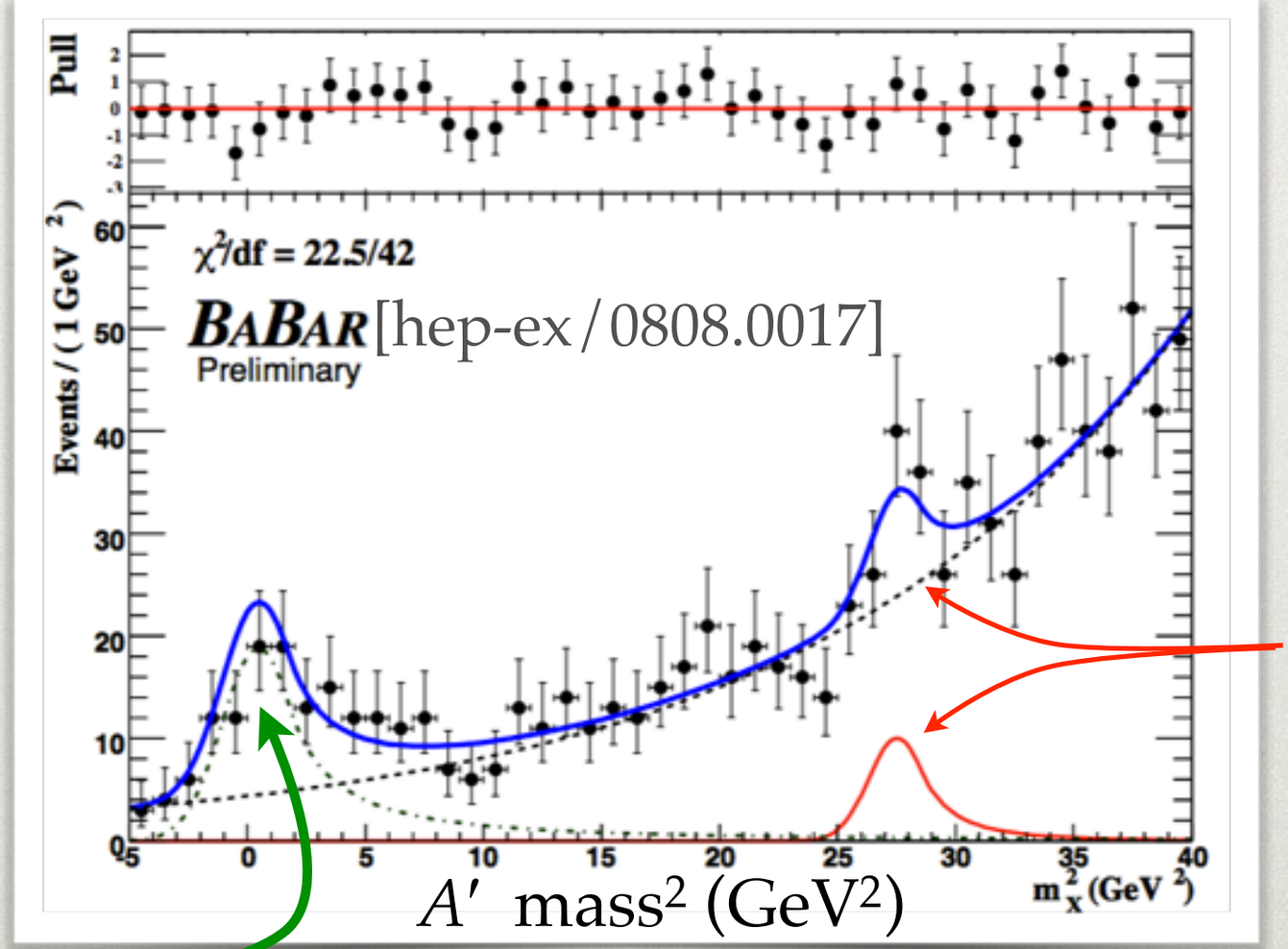
- ☐ Missing mass (collider or fixed-target)
- ☐ Beam dump (p or e- beam) with DM scattering detection
- ☐ Missing energy/momentum

- ☐ LHC missing energy? **NOT** useful here (buried under QCD, low rate)

Missing Mass: Today

$A' \rightarrow \chi\,\chi$ decay constrained by BaBar search





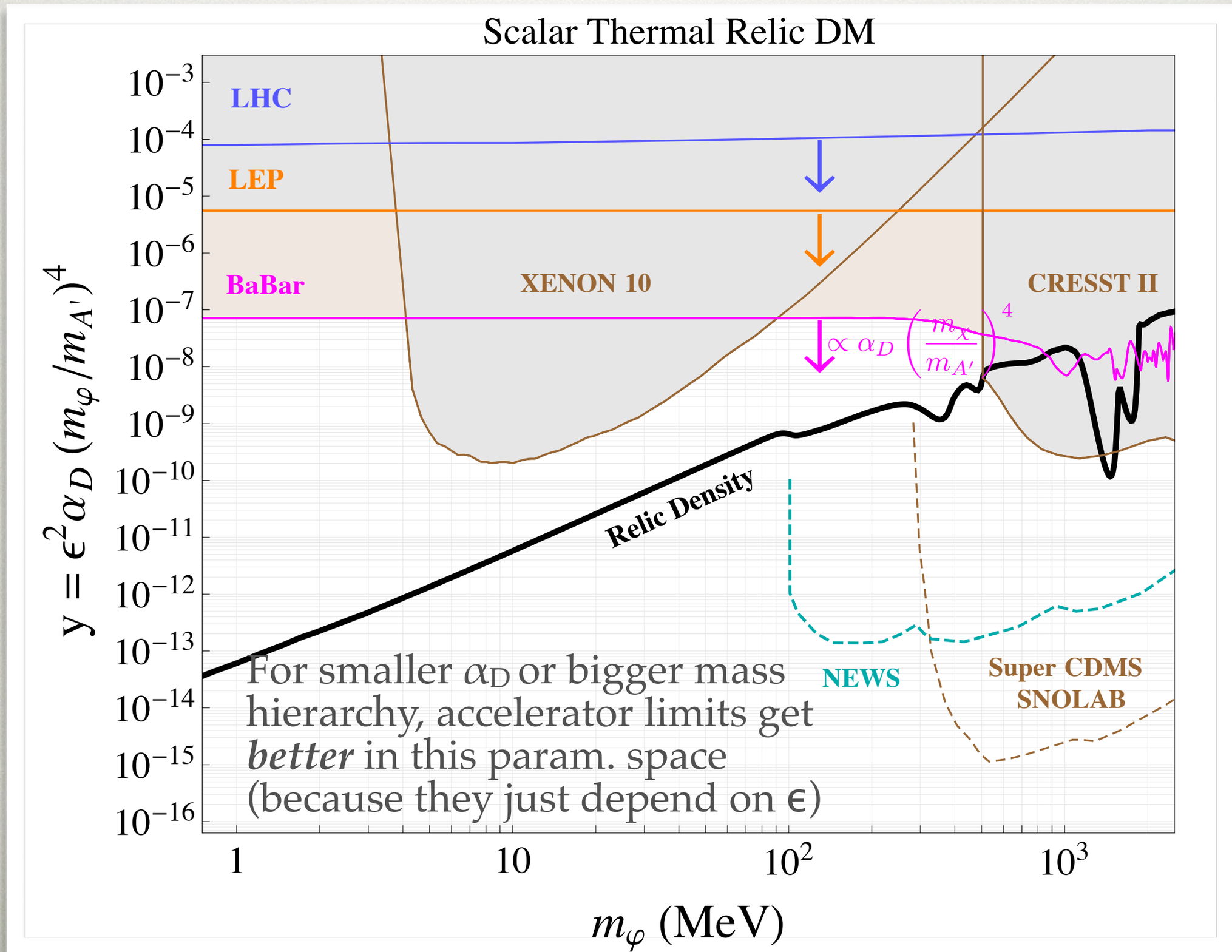
signal fit (not significant)

2γ background (signal-faking) **Limits sensitivity for $m_{A'} \lesssim$ GeV**

Unique advantage over other approaches: it's a bump!

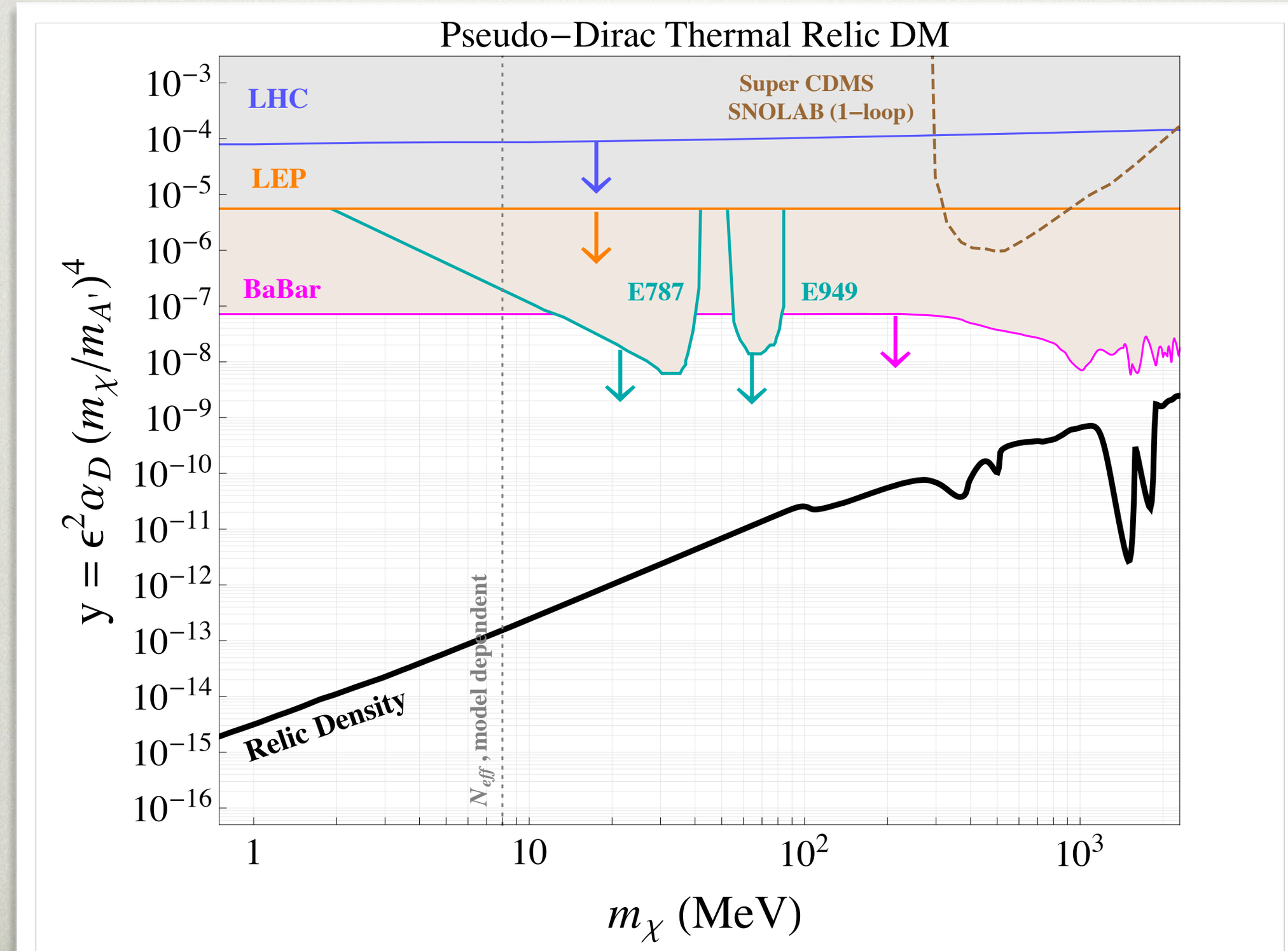
Sensitivity vs. Target

Scenario: Scalar DM

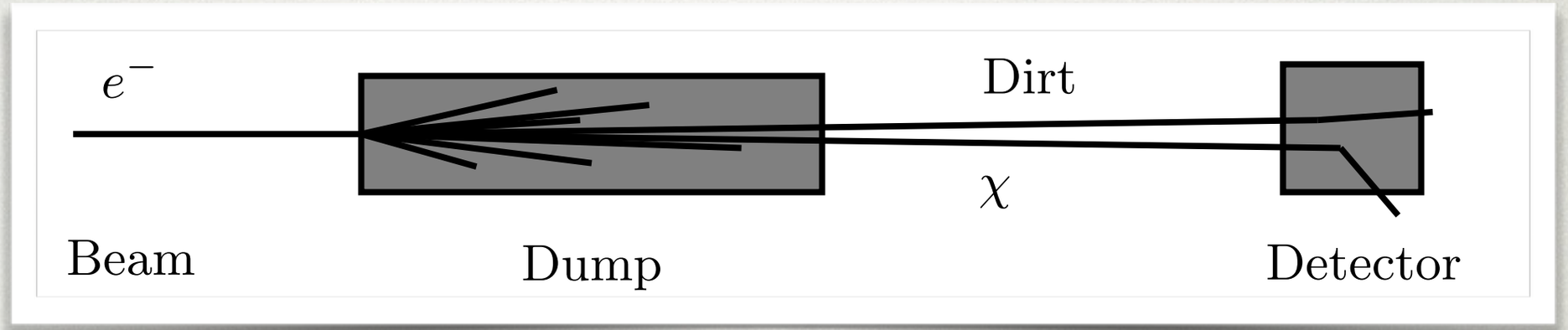


Sensitivity vs. Target

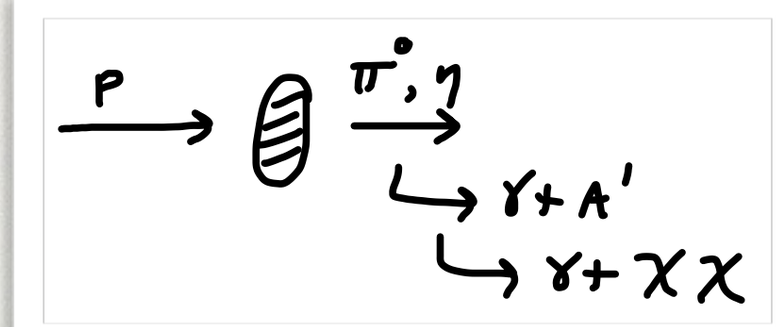
Scenario: Fermion inelastic (pseudo-Dirac) DM



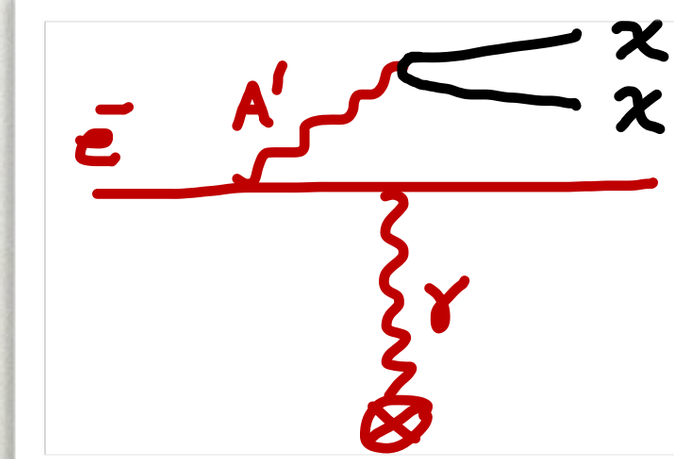
Beam Dumps

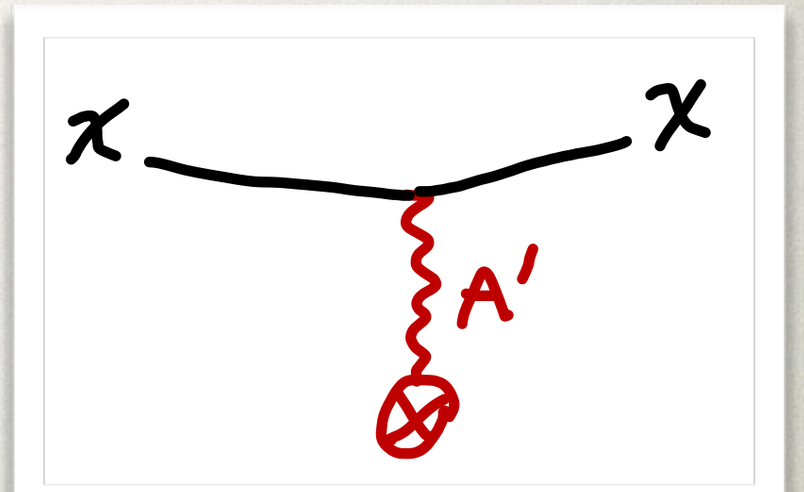


0906.5614,
1107.4580,1205.3499
Batell,DeNiverville,
McKeen, Pospelov, Ritz



Izaguirre, Krnjaic, PS
& Toro
PRD.88.114015 and
1403.6826





nuclear dissociation;
nucleon, nucleus, or
electron recoil

Good sensitivity (from theorists) for LSND (proton beam + electron scattering)

Beam Dumps: Today

LSND: 10^{23} 800 MeV protons on target; ν-e elastic scattering data used to set limit on DM production ($\pi^0 \to \gamma A' \to \gamma\chi\chi$) with subsequent χ-e scattering

Batell et al arXiv:0906.5614 [hep-ph].

E137: 30 C of 20 GeV electrons on target, 8 X_0 shower calorimeter detector; no beam-related events seen ⇒ limit on χ-e scattering above 1–3 GeV recoil energy

Batell et al arXiv:1406.2698 [hep-ph].

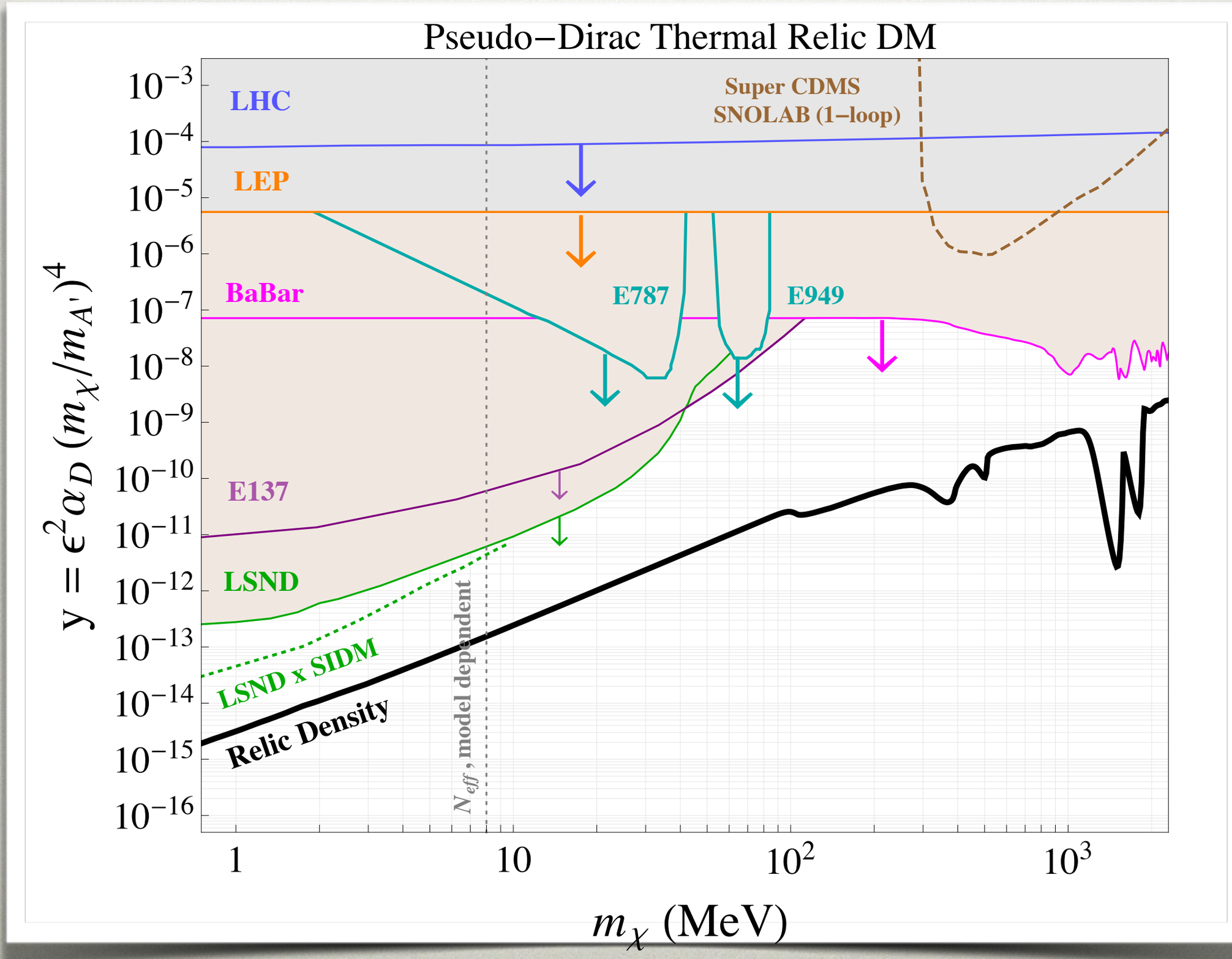
...Near Future...

MiniBoone: Dedicated 2013-14 run in "dump mode" sensitive to A' production in π^0 or η^0 decay (~2 10^{20} pot); using time-of-flight to distinguish from ν background

T2K: Ongoing analysis of Super-K data for χ-O NCQE events using time-of-flight

Beam Dumps: Today

Scenario: Inelastic fermion DM



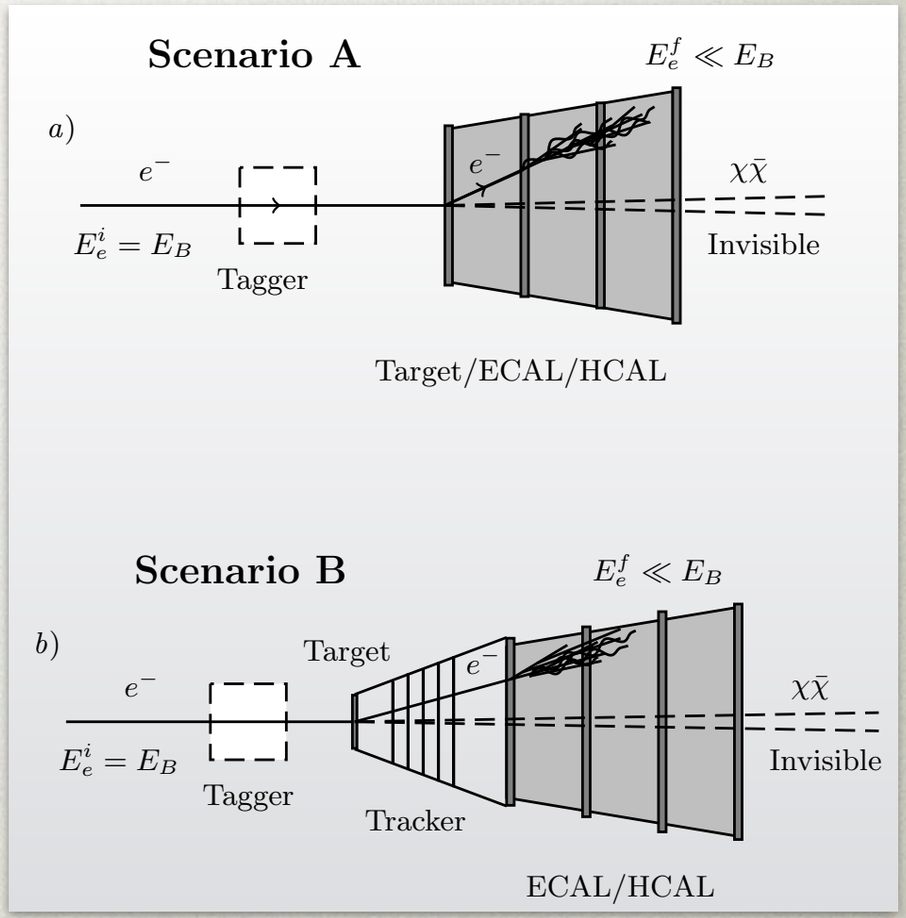
Missing Energy/Momentum

Use distinctive kinematics of A′ (or DM pair) production in e^- beam:

A′ carries most of the incident beam energy ⇒

- Recoiling e– has low energy
- Not accompanied by other visible particles
  (detectable with calorimetry alone, e.g. P348 at CERN)

- With tracking, e^- p_T measurement and e/γ discrimination allow further background rejection



Missing Mass: Future

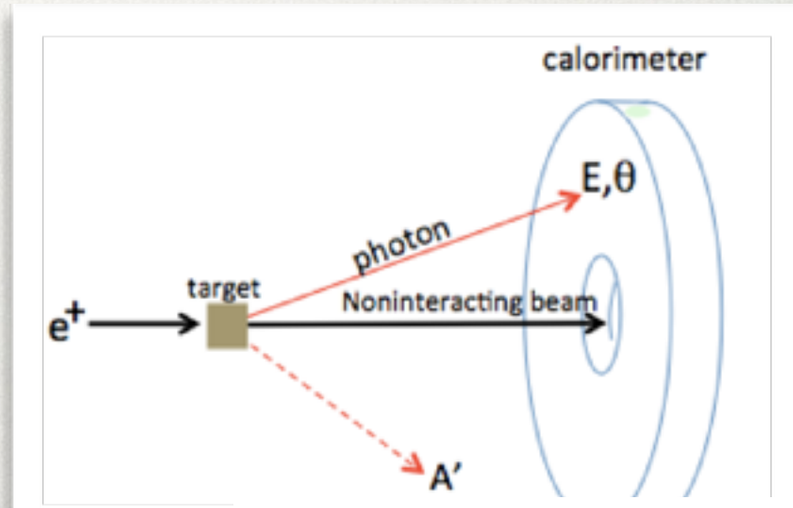
Belle II

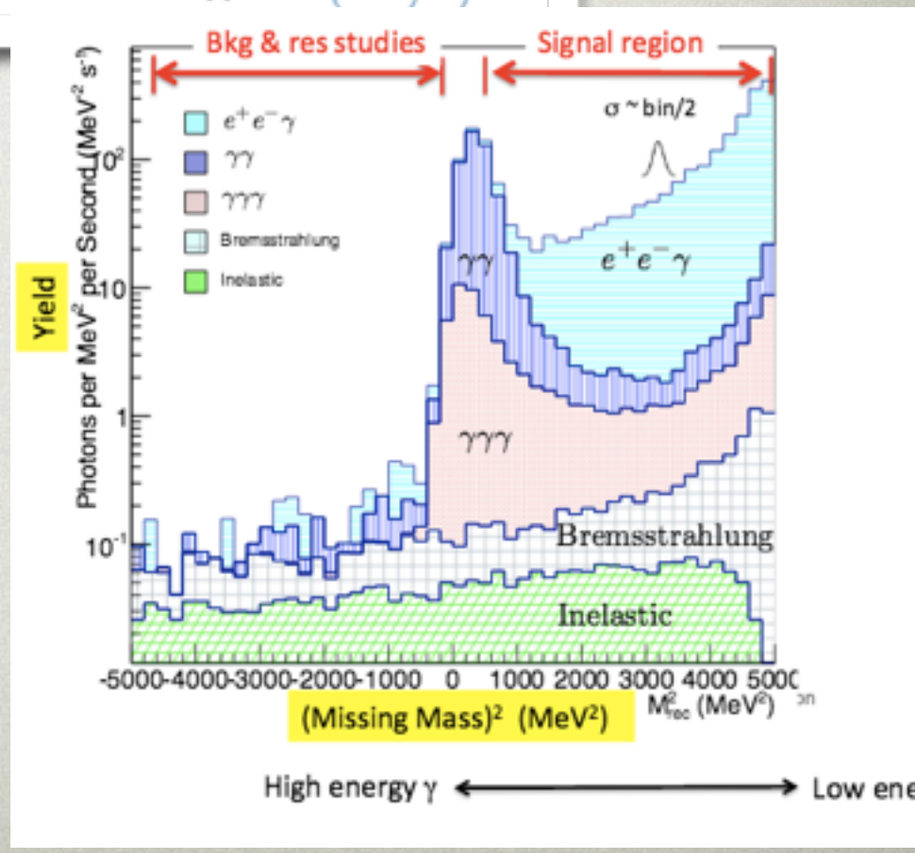
Since BaBar is background-limited, statistics won't help. Any improvement must rely on better γ veto and/or energy resolution

- For discovery, really need resolution — won't improve dramatically
- Low-mass limit proportional to γγ rejection power (10^{-7} @ BaBar)
- Rouven & co: could search with **converted** photons help? (1309.5084)

Positron fixed-target

Proposals using e^+ beams on target e^- (Cornell, VEPP-3)





Missing Mass: Future

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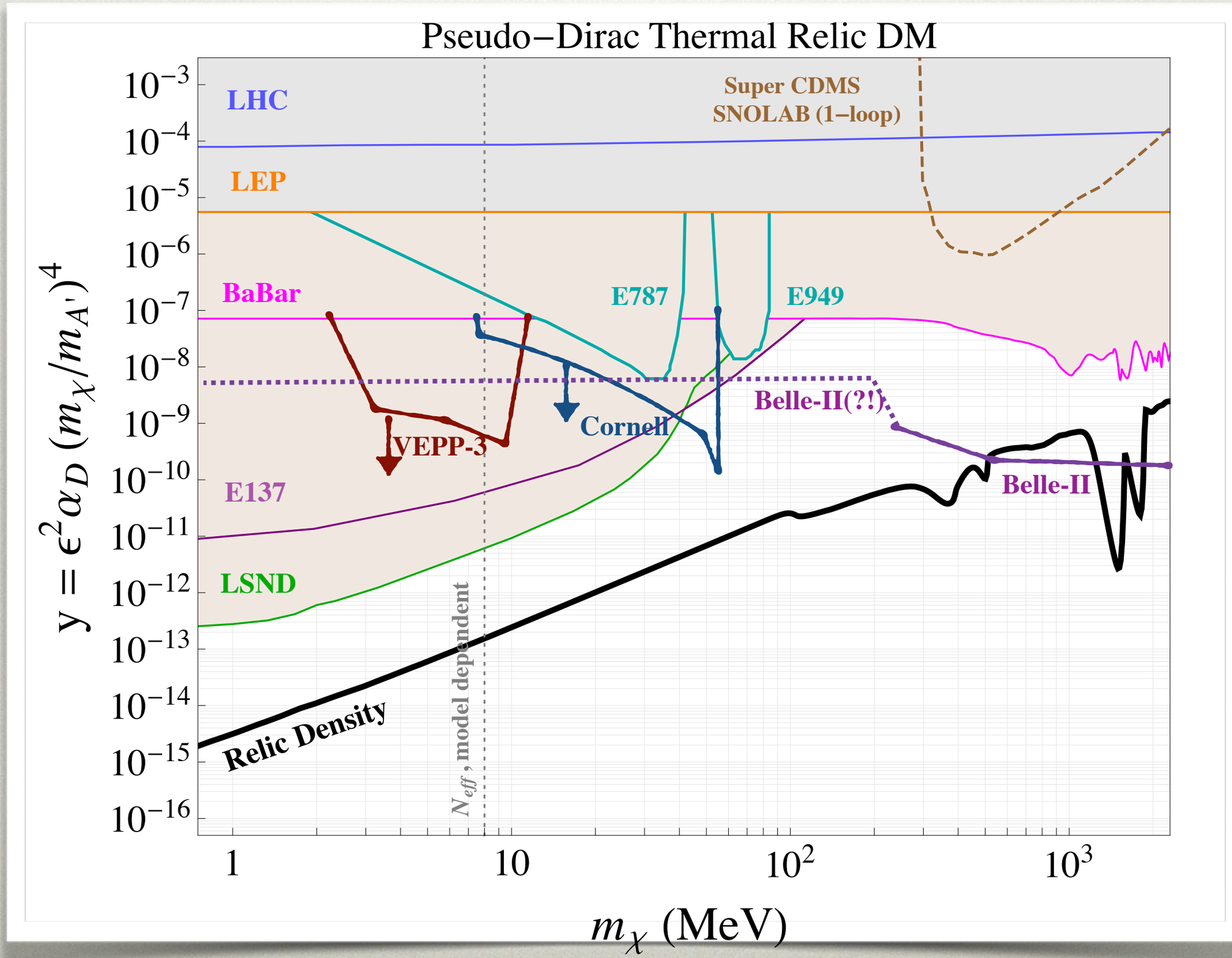
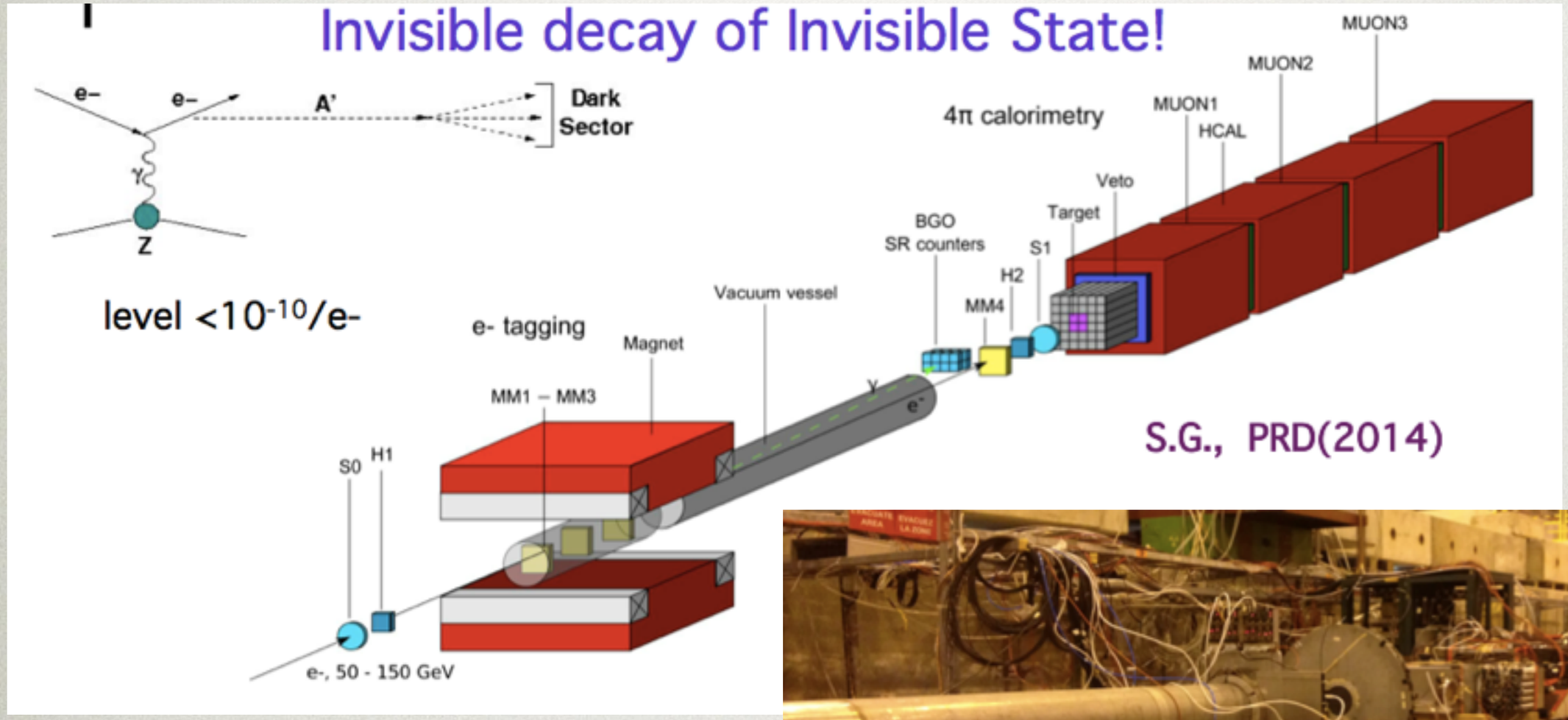
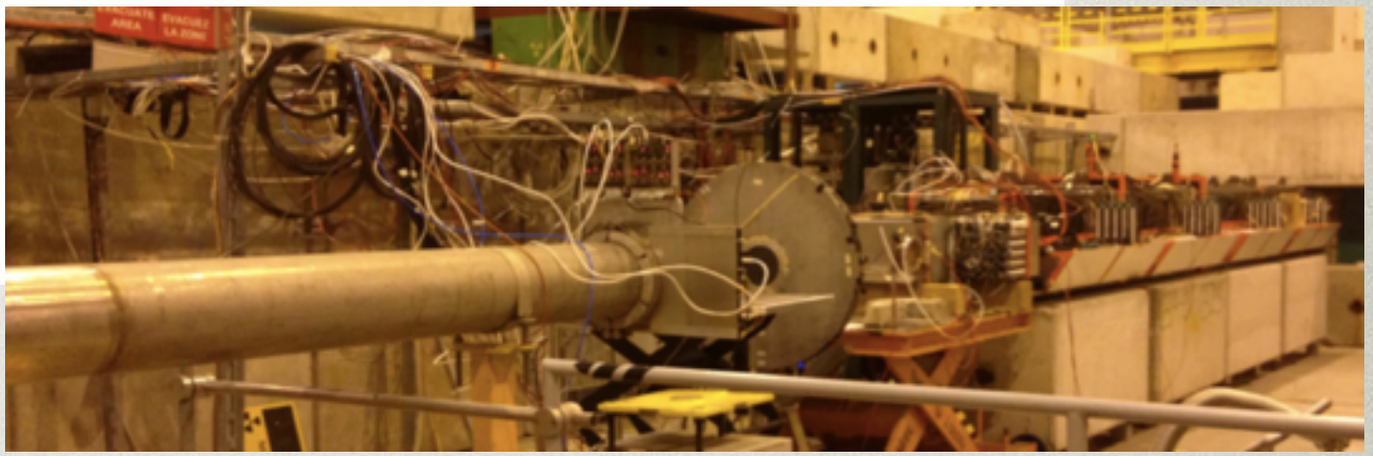


Missing Energy: Future

P348 in CERN SPS west area – test run this year, more to come





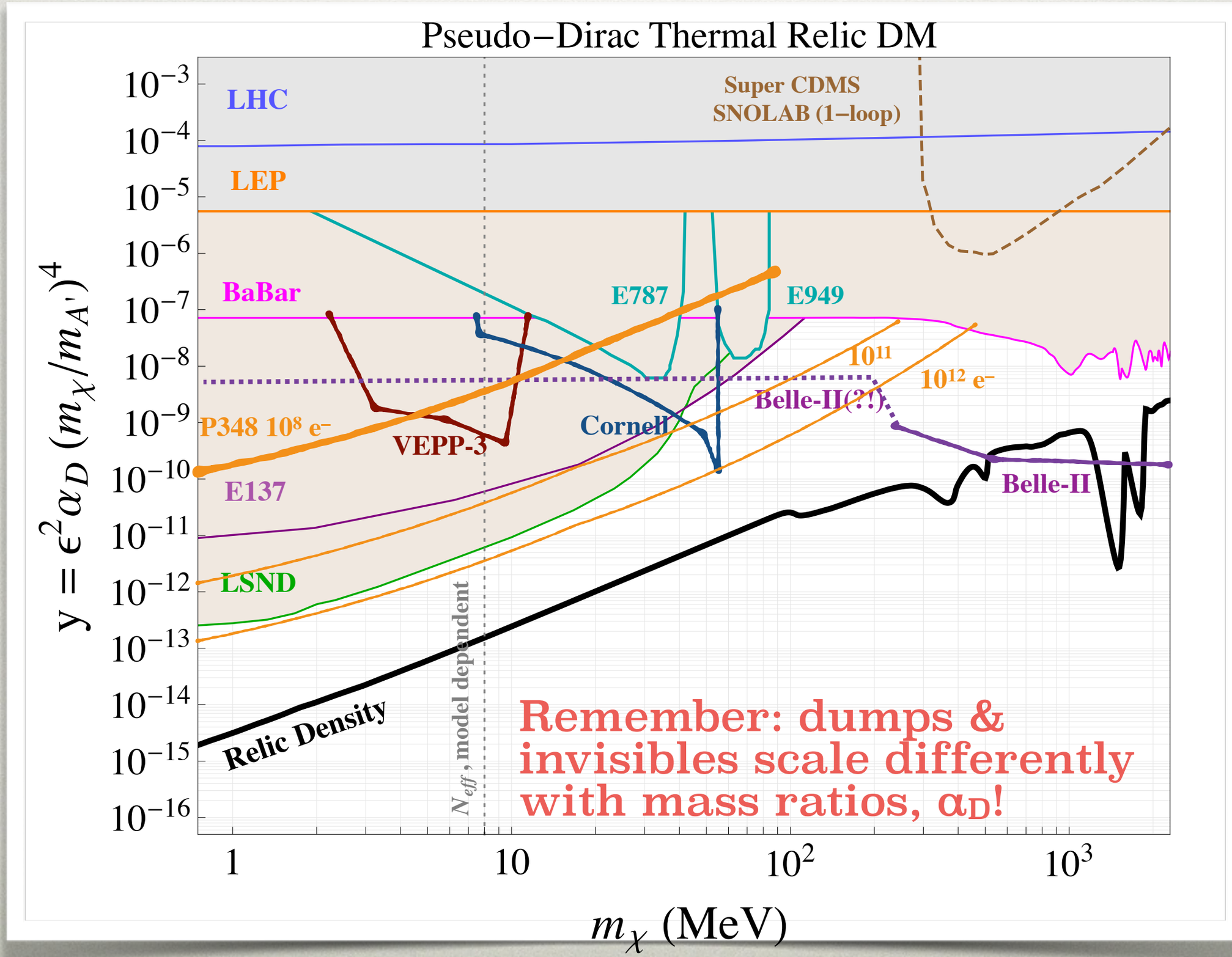
Current run: 10^8 electrons on target w/ good bkg rejection

Ultimate few x 10^{11} electrons?

<1% hadron contamination of beam

Missing Energy: Future

Scenario: Inelastic fermion DM



NEXT PROSPECTS

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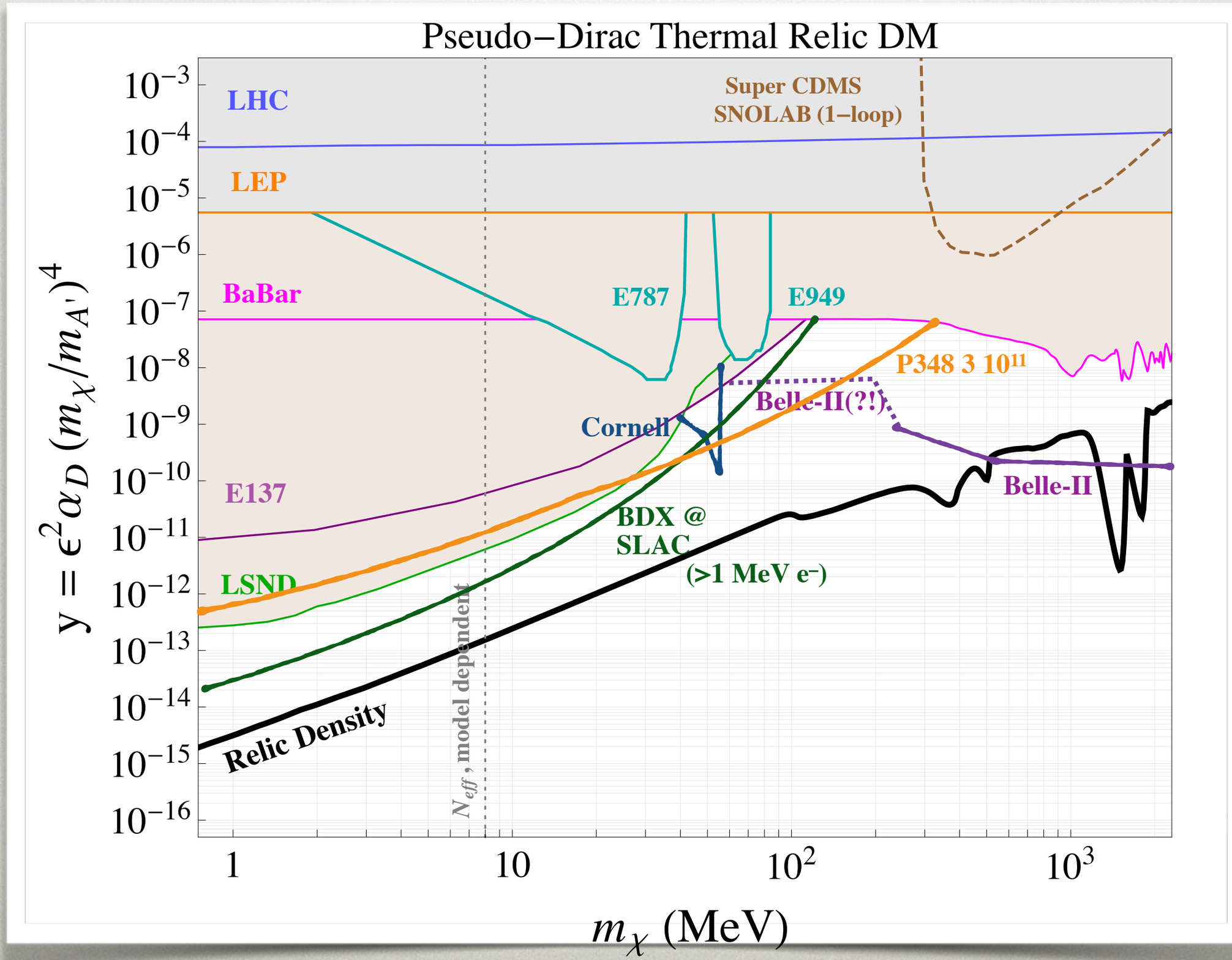

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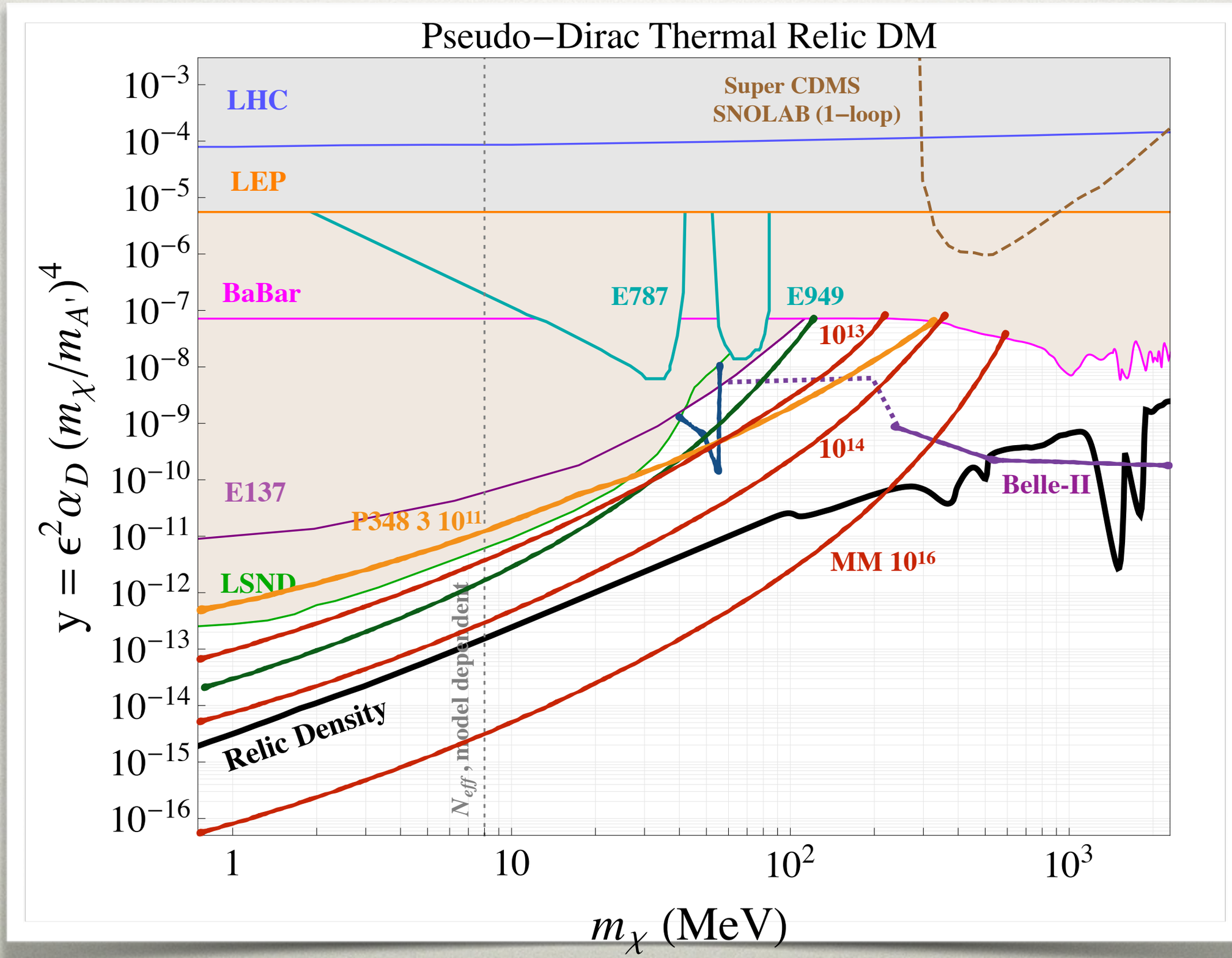

Complementarity

- Missing mass & missing momentum get better @ small α_D relative to beam dumps

- Inelastic DM can yield prompt or displaced e+e- pair
  - Makes dump search easier
  - Invisibles harder (prompt case) or dedicated but probably tractable search (displaced case)

- Always good to have two ways of seeing the same physics