

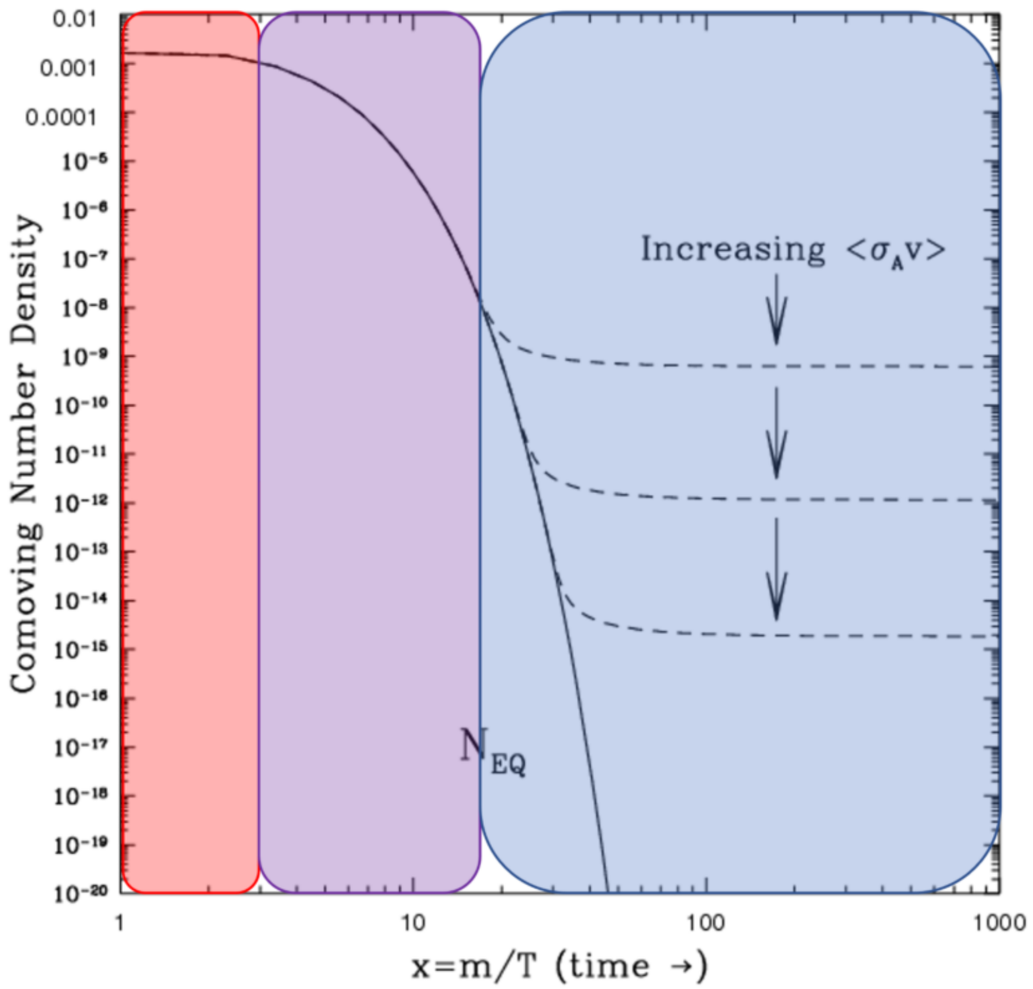
Dark Sector Searches High(?) Luminosity Fixed-Target/ Electron Beam Experiments

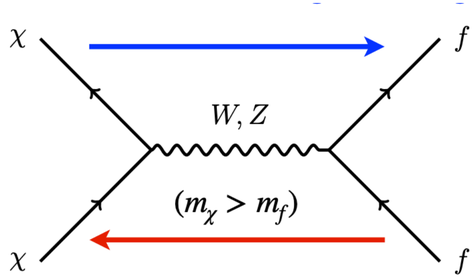
Mathew Graham, SLAC

Thursday October 8, 2026

SLAC NATIONAL ACCELERATOR LABORATORY

Dark Matter Freeze-out: WIMPs and wIMPS





$$\Omega_\chi h^2 \approx 0.1 \Longrightarrow \langle \sigma v \rangle \approx 3 \times 10^{-26}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$$

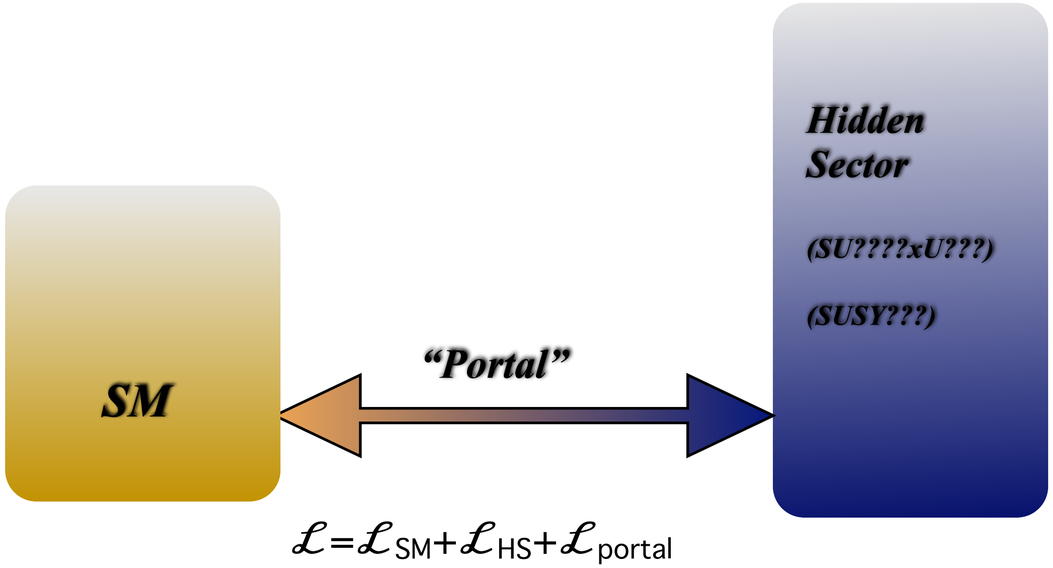
$$\langle \sigma v \rangle \propto \frac{m_\chi^2}{m_Z^4} \Longrightarrow m_\chi \approx 100\ \mathrm{GeV}$$

"WIMP Miracle"

BUT, this doesn't work for $\chi < \sim 2\ GeV$

…χ annihilation too small for weak-scale mediators

Kinetic Mixing and the Dark Photon



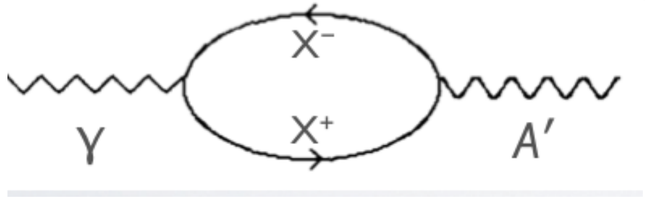
link between SM and hidden sector is weak… good place for DM to hide!

WIMP miracle⇒wiMP miracle

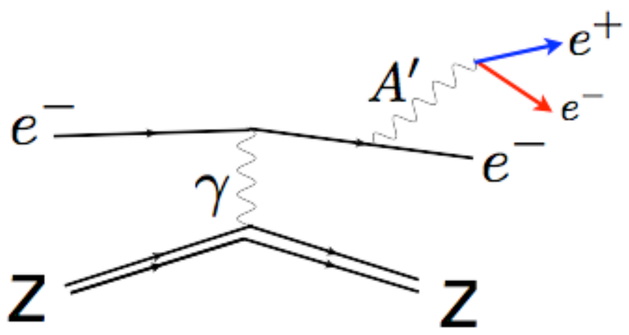
*vector portal mixing with SM photon is very generic…**if there is another U(1) in nature, mixing must occur.***

$$\mathcal{L}_{U(1)'} = -\frac{1}{4}V_{\mu\nu}^2 - \frac{\epsilon}{2}V_{\mu\nu}F^{\mu\nu} + |D_\mu\phi|^2 - V(\phi)$$

Kinetic Mixing term



Dark Photon Production and Decay (at Fixed Target)

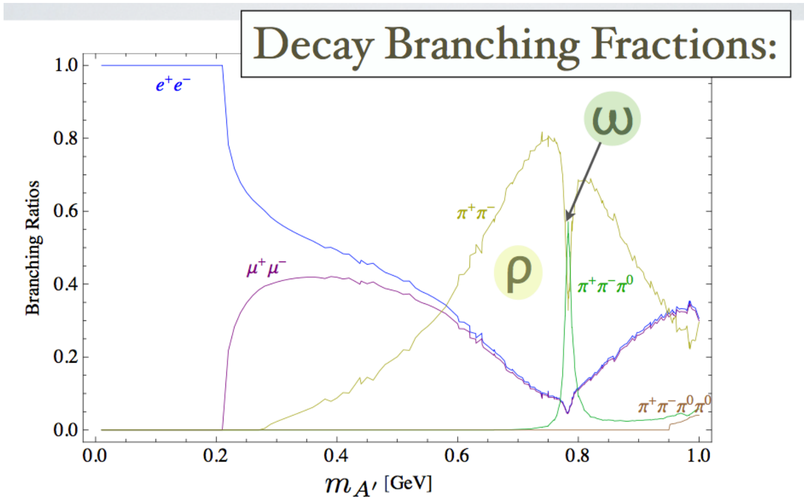


Production is analogous to bremsstrahlung:

$$\frac{d\sigma}{dx} \approx \frac{8Z^2\alpha^3\epsilon^2 x}{m_{A'}^2}\left(1+\frac{x^2}{3(1-x)}\right)\mathcal{L}og$$

- prefers x~1 (i.e. $E_{A'} = E_{beam}$)
- small angle emission dominates

A' ***decays*** back to charged SM fermions with BFs taken from $R(e^+e^-\rightarrow \text{hadrons}/e^+e^-\rightarrow\mu^+\mu^-)$

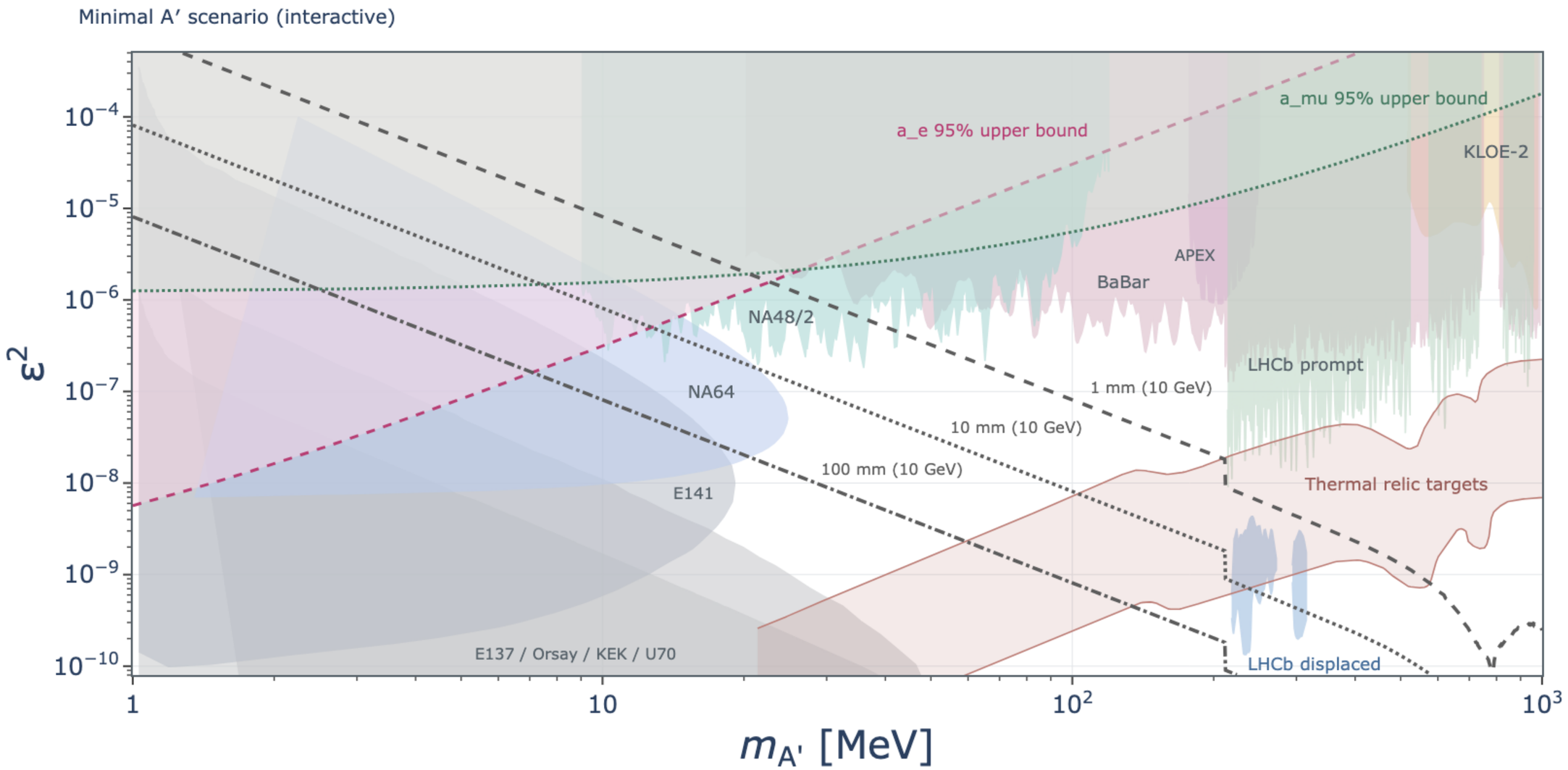


The decay length depends on $m_{A'}$ and ε:

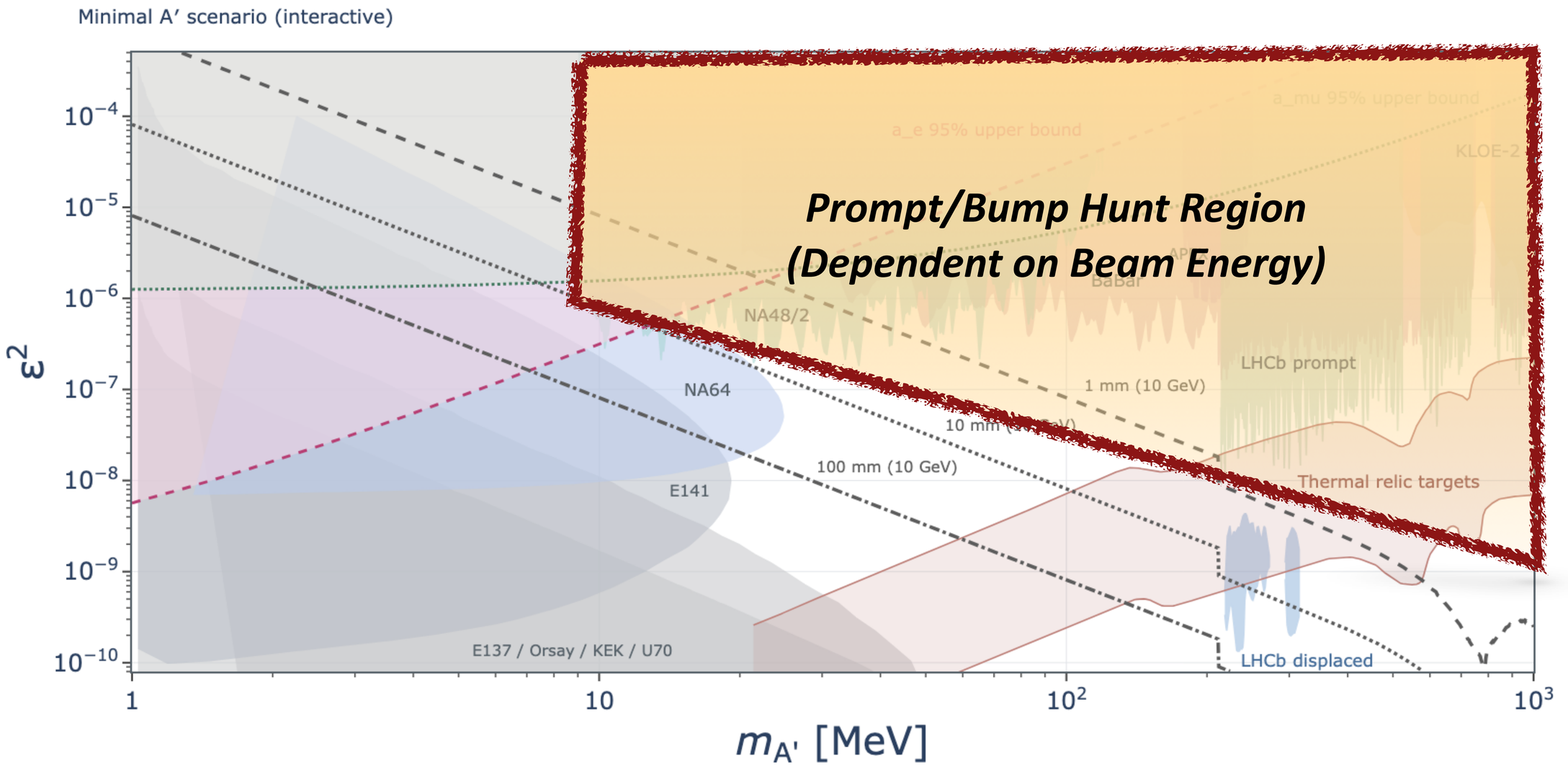
$$\ell_0 \equiv \gamma c\tau \simeq \frac{3E_1}{N_{\text{eff}} m_{A'}^2 \alpha\epsilon^2}$$
$$\simeq \frac{0.8\text{cm}}{N_{\text{eff}}}\left(\frac{E_0}{10\text{GeV}}\right)\left(\frac{10^{-4}}{\epsilon}\right)^2\left(\frac{100\,\text{MeV}}{m_{A'}}\right)^2$$

assumes mA'<mχ i.e. can't decay to hidden sector particles

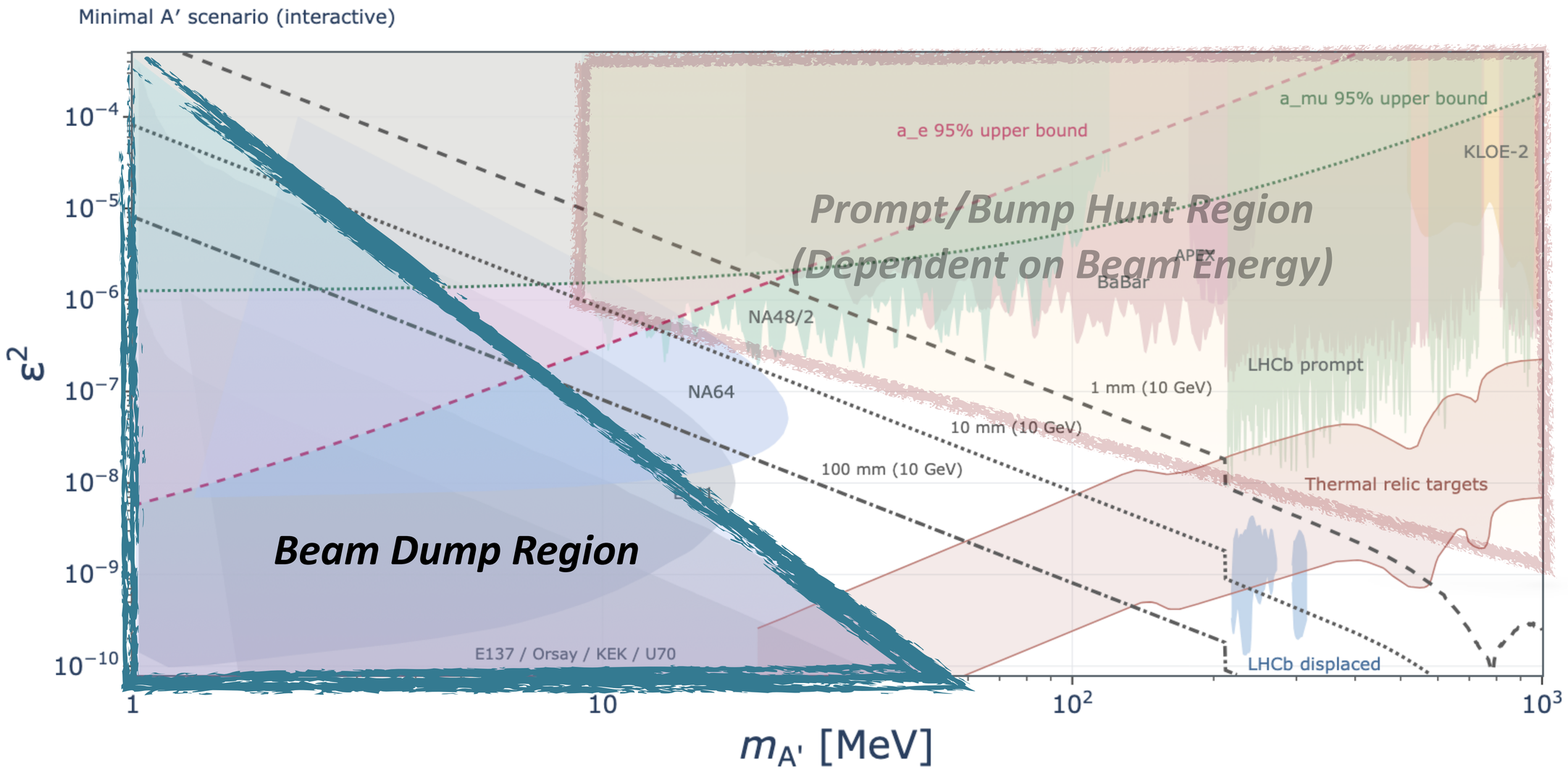
Visibly-Decaying Dark Photon Parameter Space



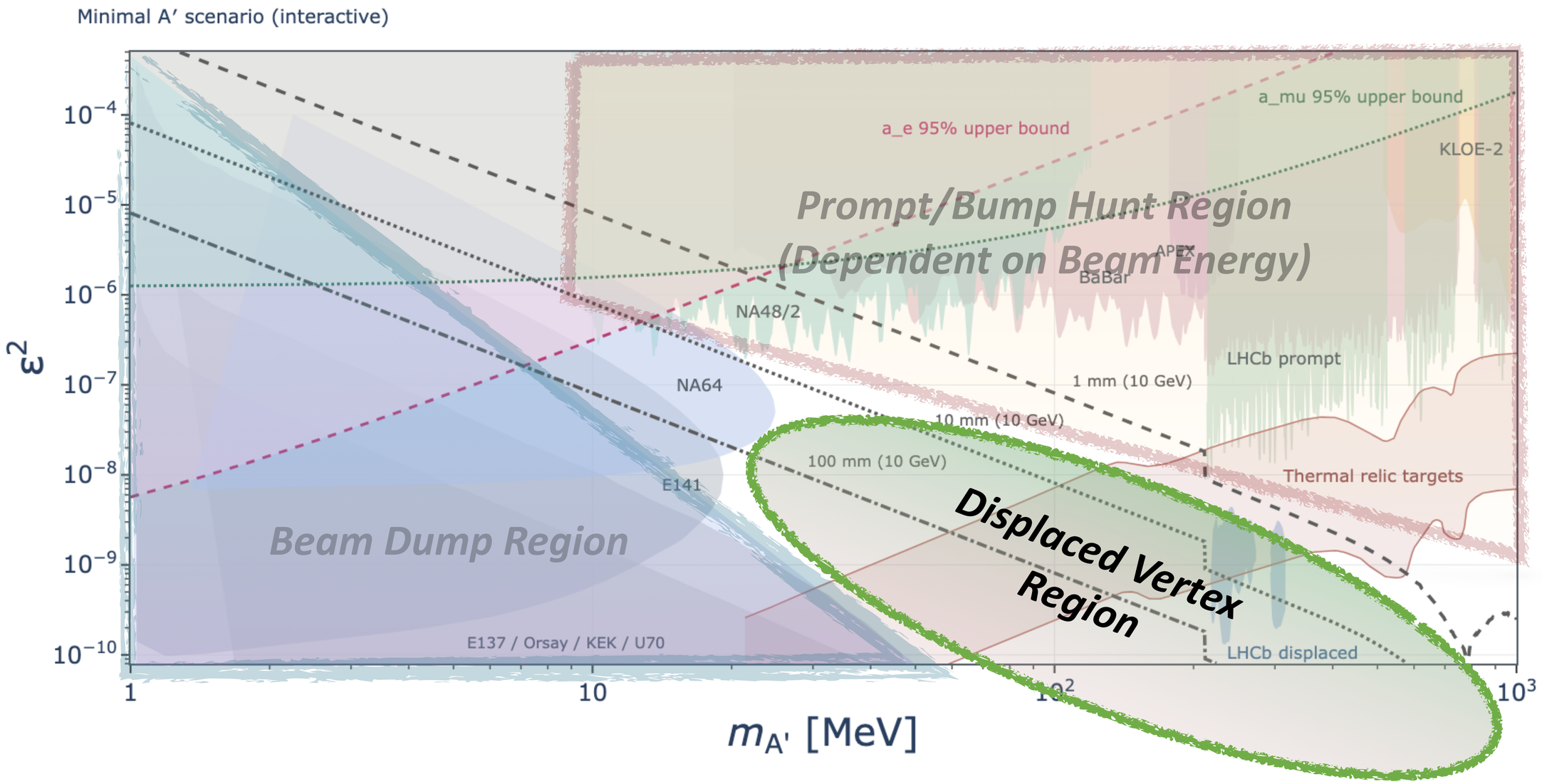
Visibly-Decaying Dark Photon Parameter Space



Visibly-Decaying Dark Photon Parameter Space

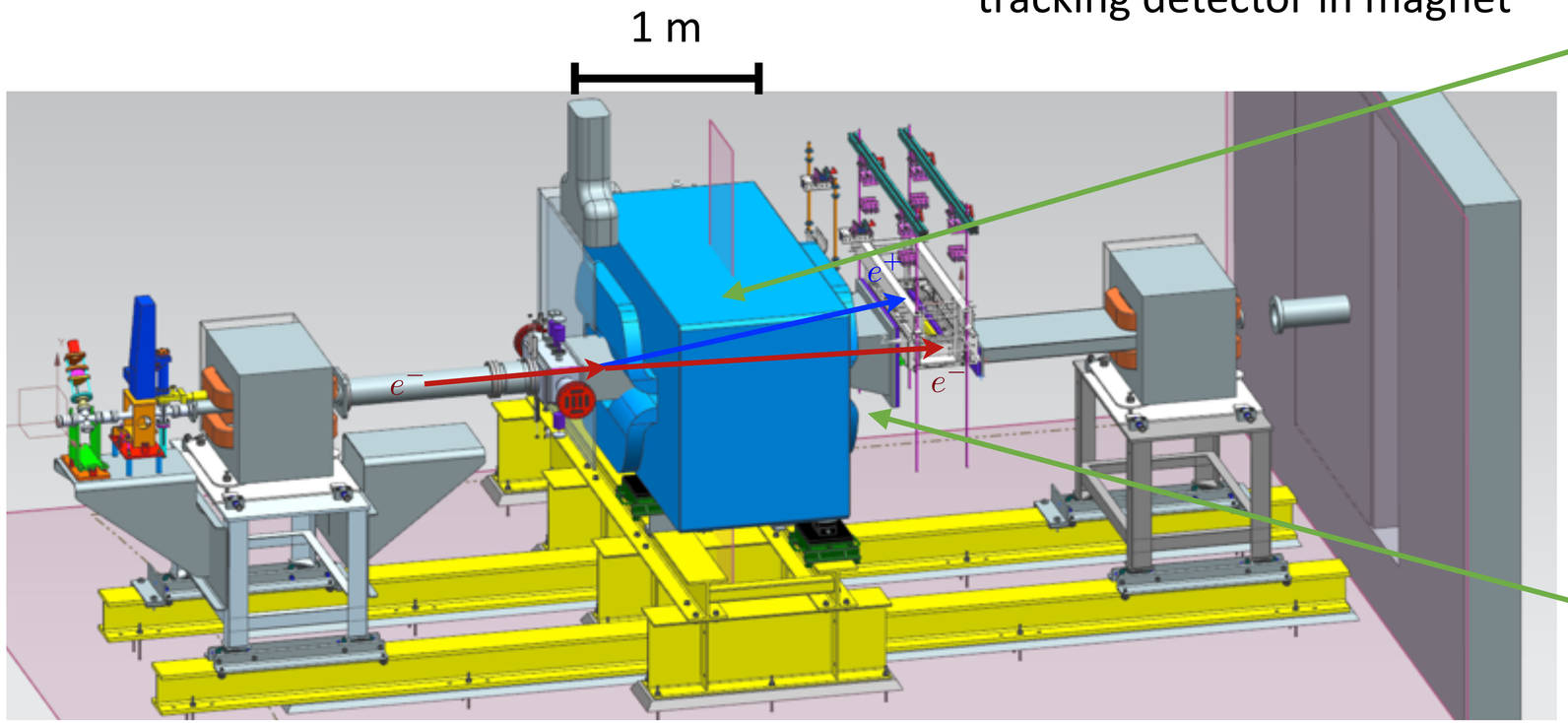


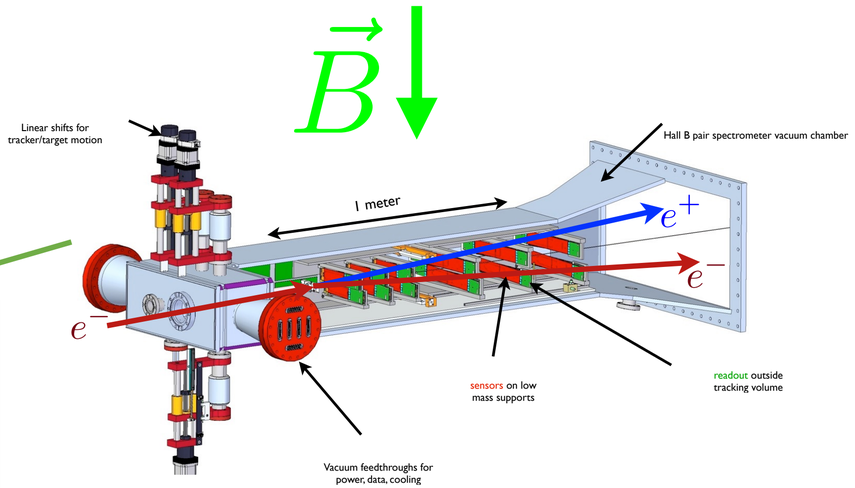
Visibly-Decaying Dark Photon Parameter Space

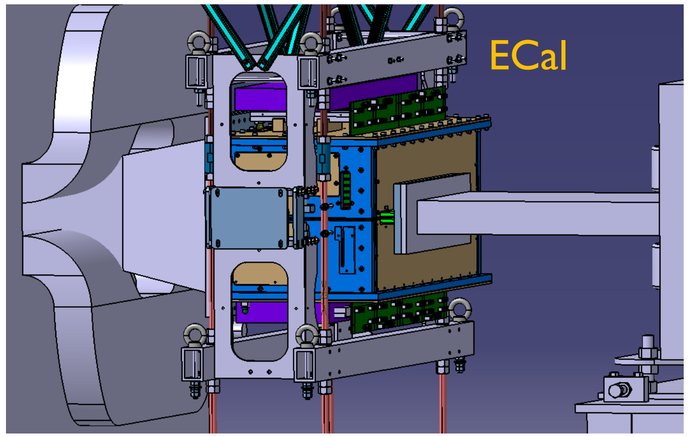


HPS (as a template)

7 module (uv-stereo) Si Strip tracking detector in magnet



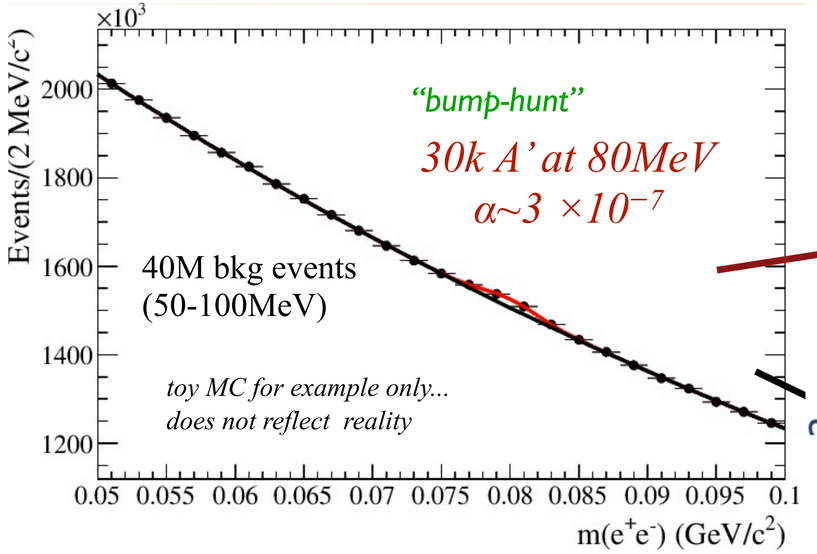




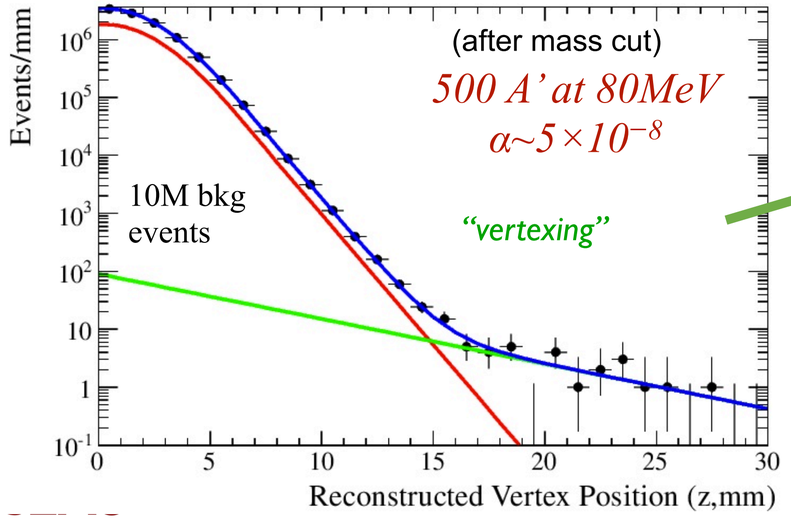
PbW crystal calorimeter for triggering etc.

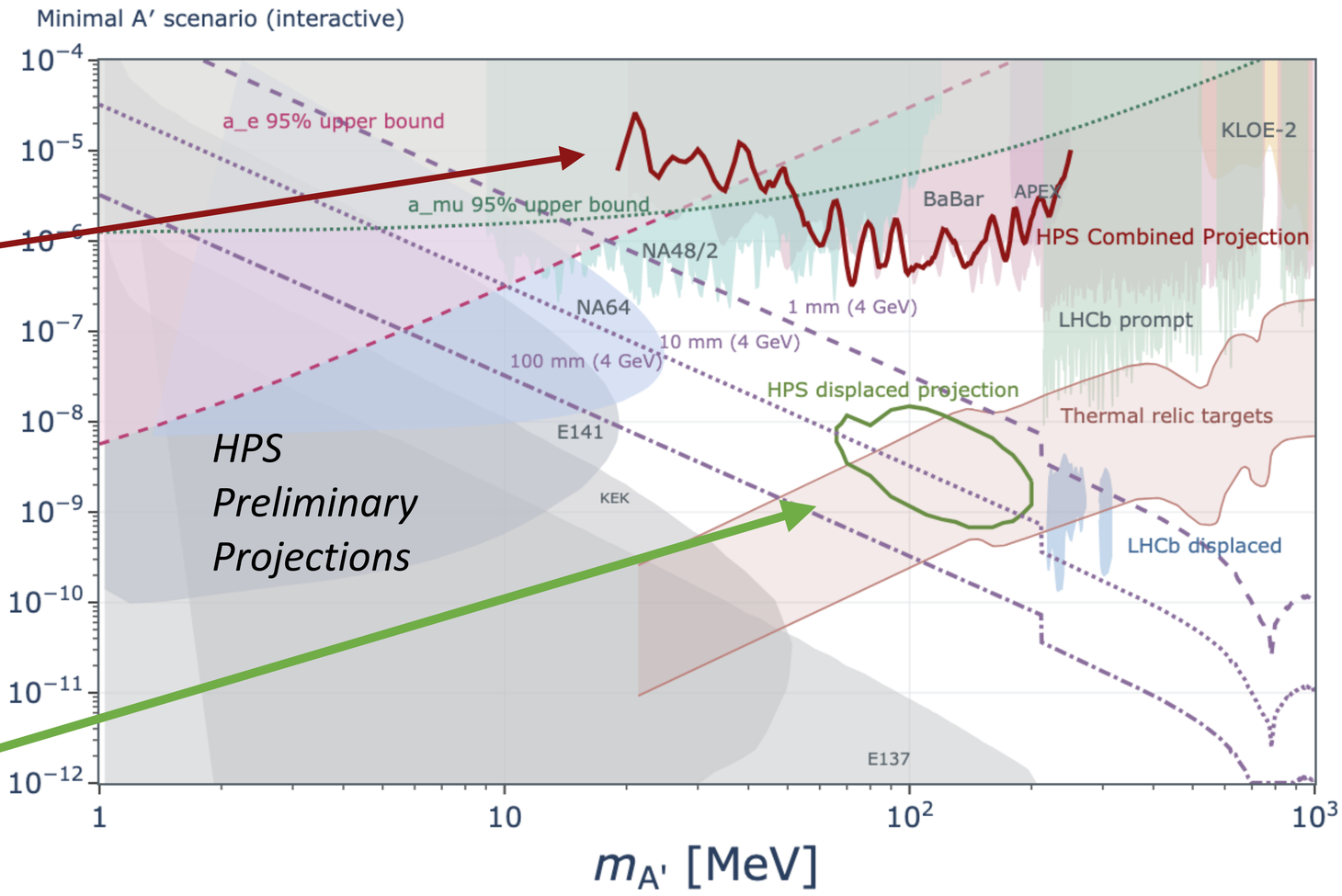
HPS Searches and Reach (it's a long story)

Large signal, *HUGE* background



Small signal, *NO* background





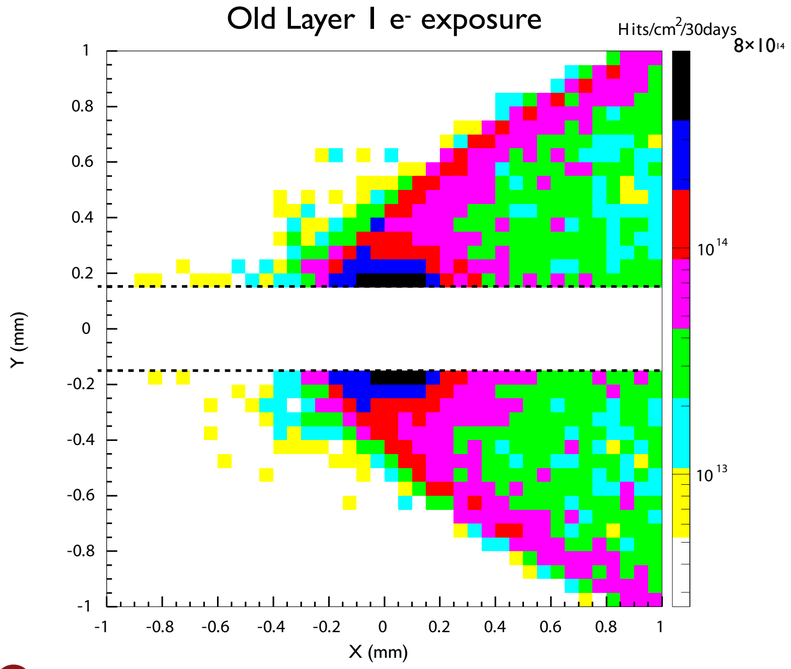
These are HPS ***projections*** including data we have on tape (including 2019 & 2021 runs)

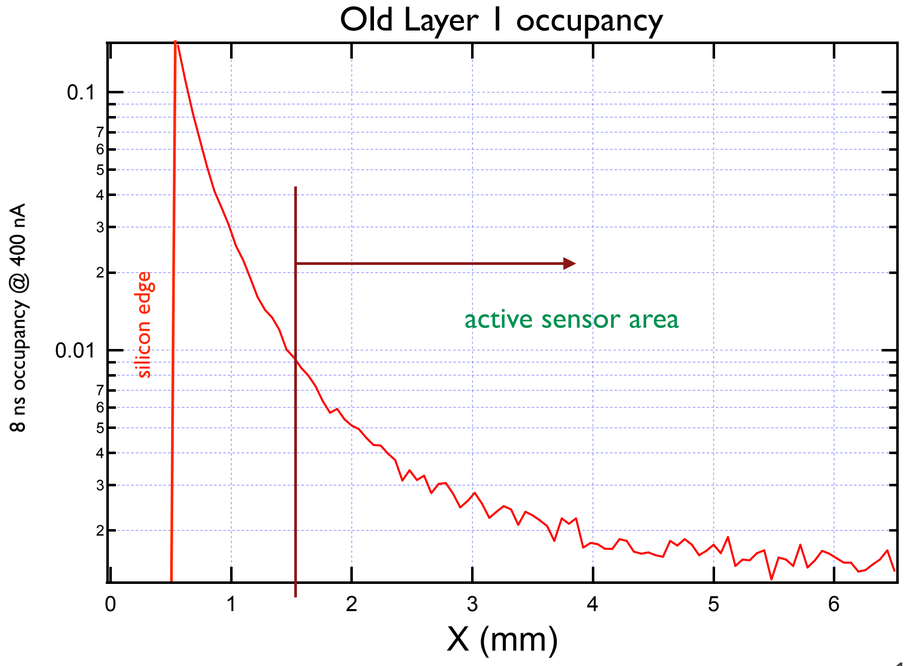
bump-hunt is projection for combined 2015, 2016, 2019 and 2021 data sets

What limits HPS?

The A′ is produced very forward → silicon has to be very close to beam

- we sit at ~15mrad around beam, at closer layers (5/10cm) it's very hot!
  - the 15mrad set's our lower-mass acceptance at a give beam energy
  - requiring ~1% max per/strip occupancy (so we can vertex cleanly) sets the max lumi
    - at e.g. 4 GeV we ran at 200nA on 20um W target



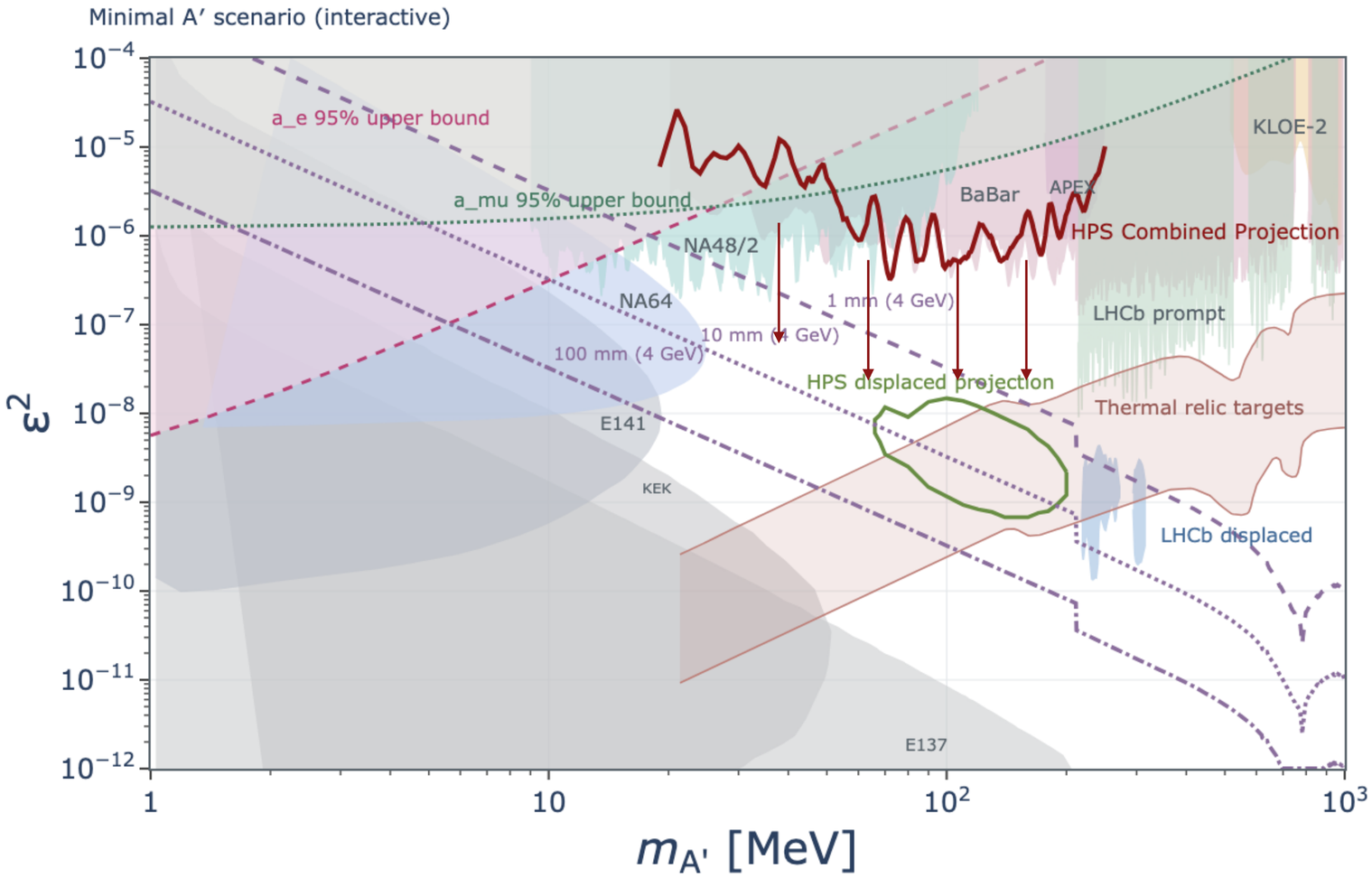


Pushing the bump-hunts down

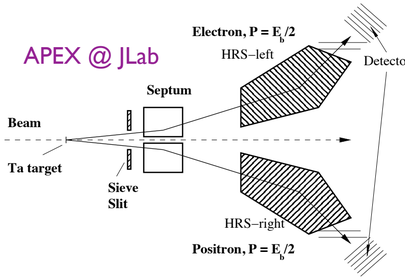
To get the bump-hunt reach to lower coupling need more lumi…that's it.

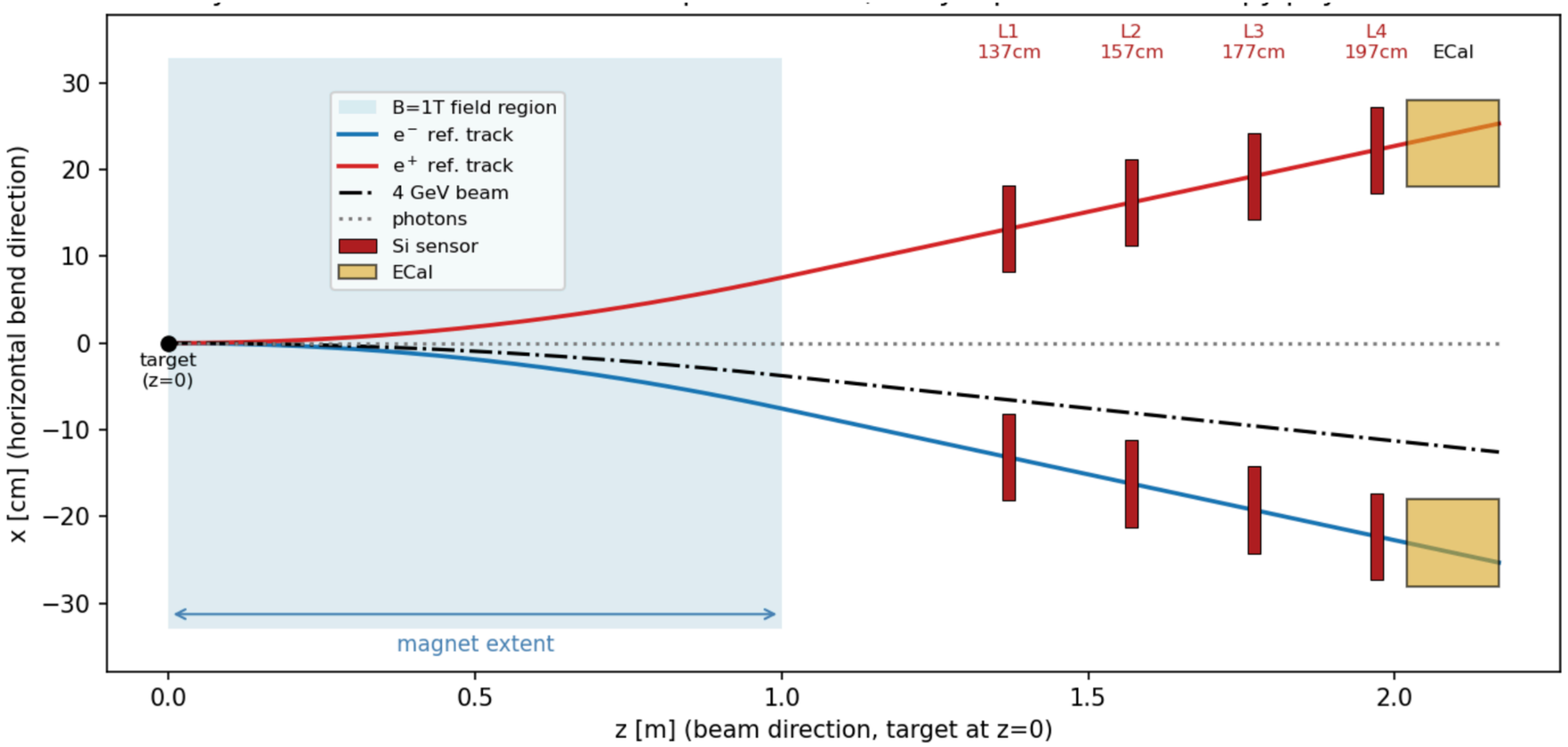
Improves at sqrt($\mathscr{L}$).

To do that, need to get away from the beam (and give up vertexing)



Idea #1: Two-Armed HPS





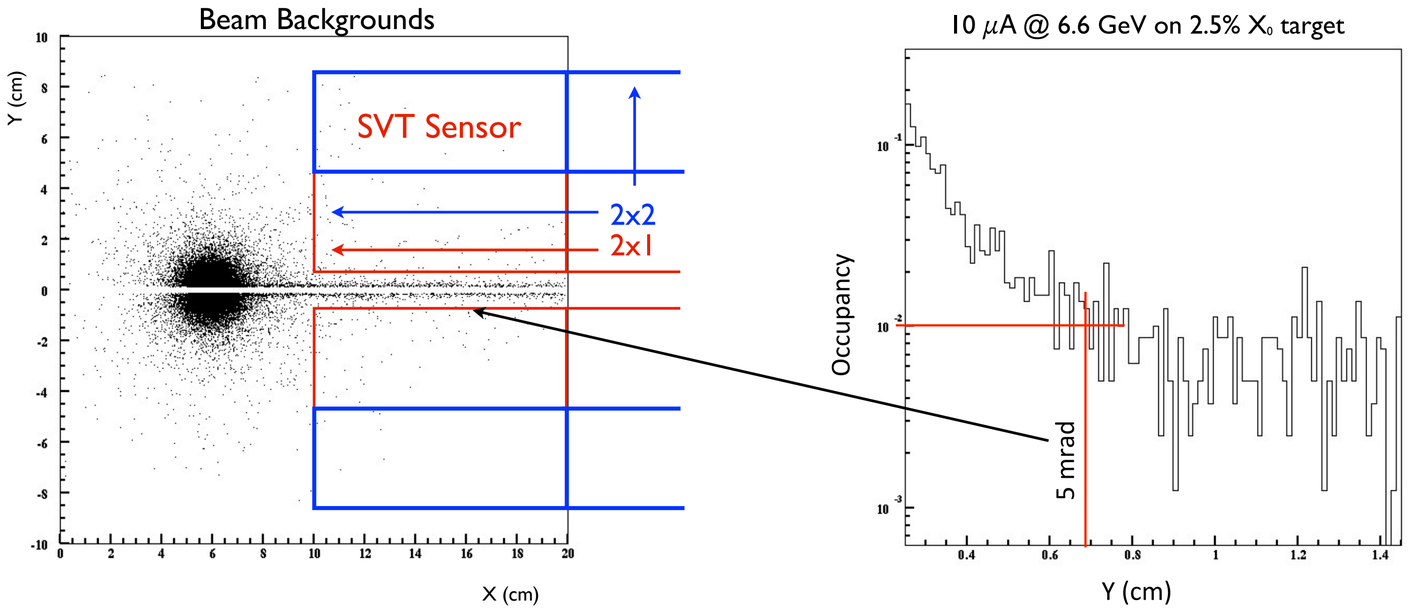
Removes all detectors from magnet ~130cm downstream of target

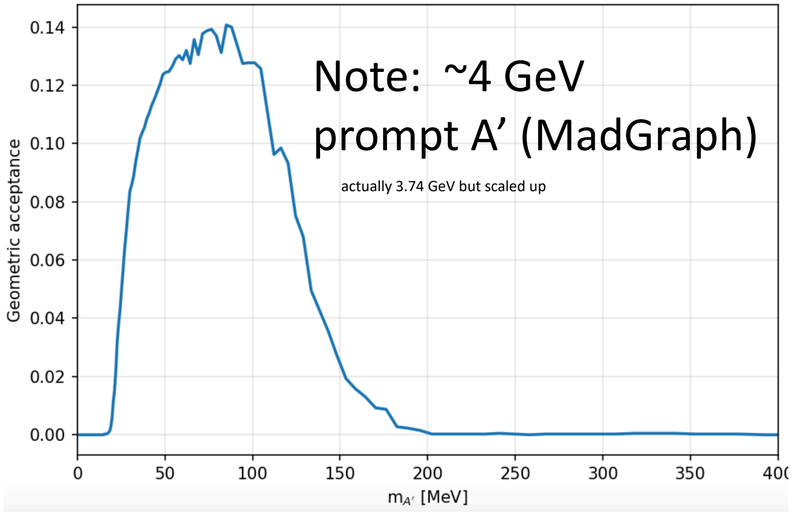
Large separation between electrons & positrons;

Stay off the nominal beam line and photon trajectories at only small efficiency loss

Dead zone for TA-HPS

- Being off the beam trajectory lets us get away with a much smaller vertical gap
  - earlier studies say ~5mrad is safe (at 10uA & 2.5% target)
  - since production cross section falls as $1/m^2$ this improves ***low-mass*** reach significantly
- *Note: early studies were done using 6.6 GeV beam…I switched to 4 GeV for this talk.*

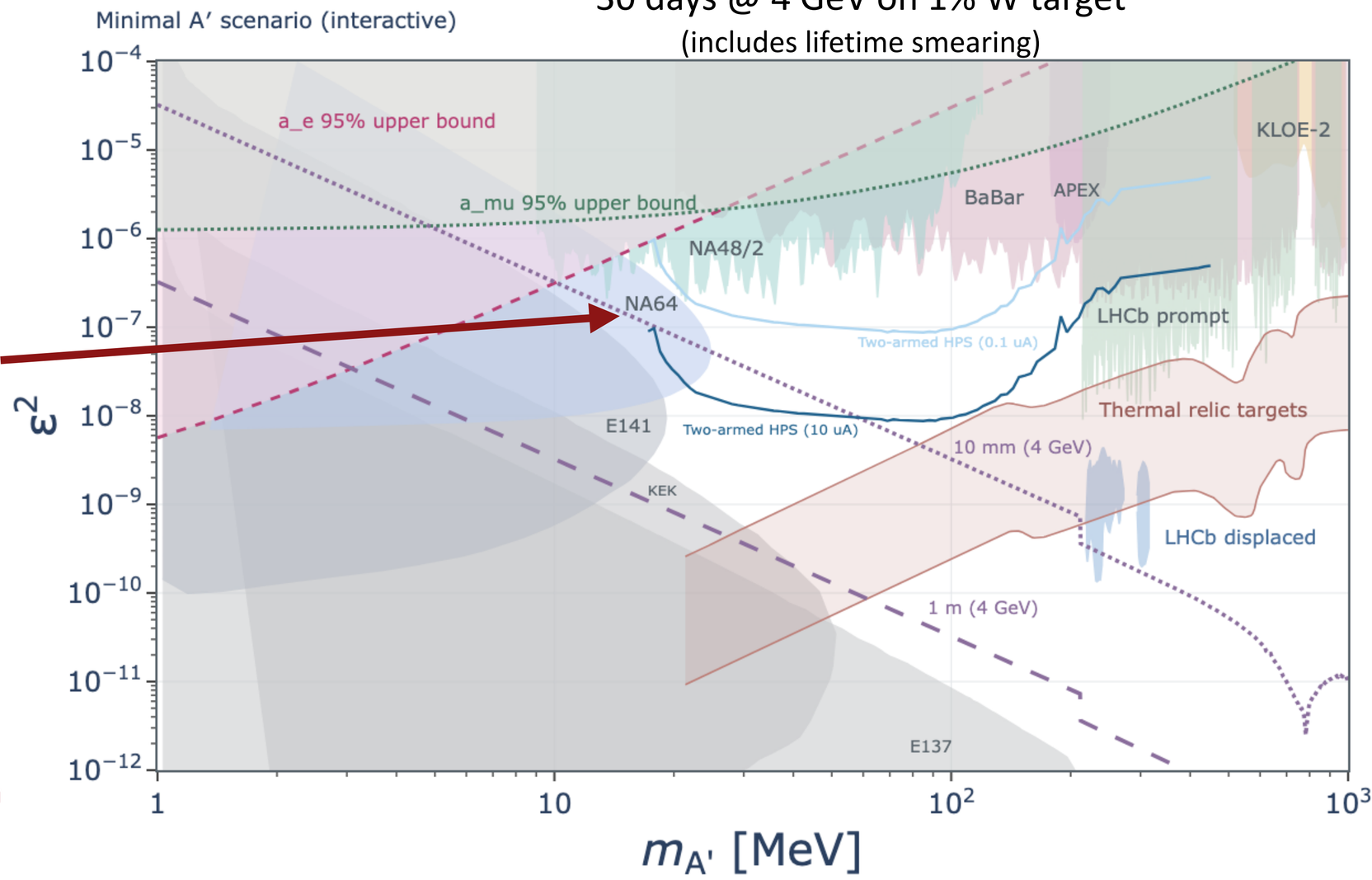




Estimated reach for TA-HPS

- Even with low current (100nA), this setup can reach new parameter space.
- Large lever-arm and constraining vertex to beam spot @ target gives extremely good mass resolution!
- BUT, at low epsilon, these A' will travel significant distances!!!
  - I've tried to account for this by:
    - simulating correct gammactau distribution/epsilon for decays in efficiency
    - degrading the mass resolution depending on expected distortion we'd see for a given m/epsilon

30 days @ 4 GeV on 1% W target
(includes lifetime smearing)

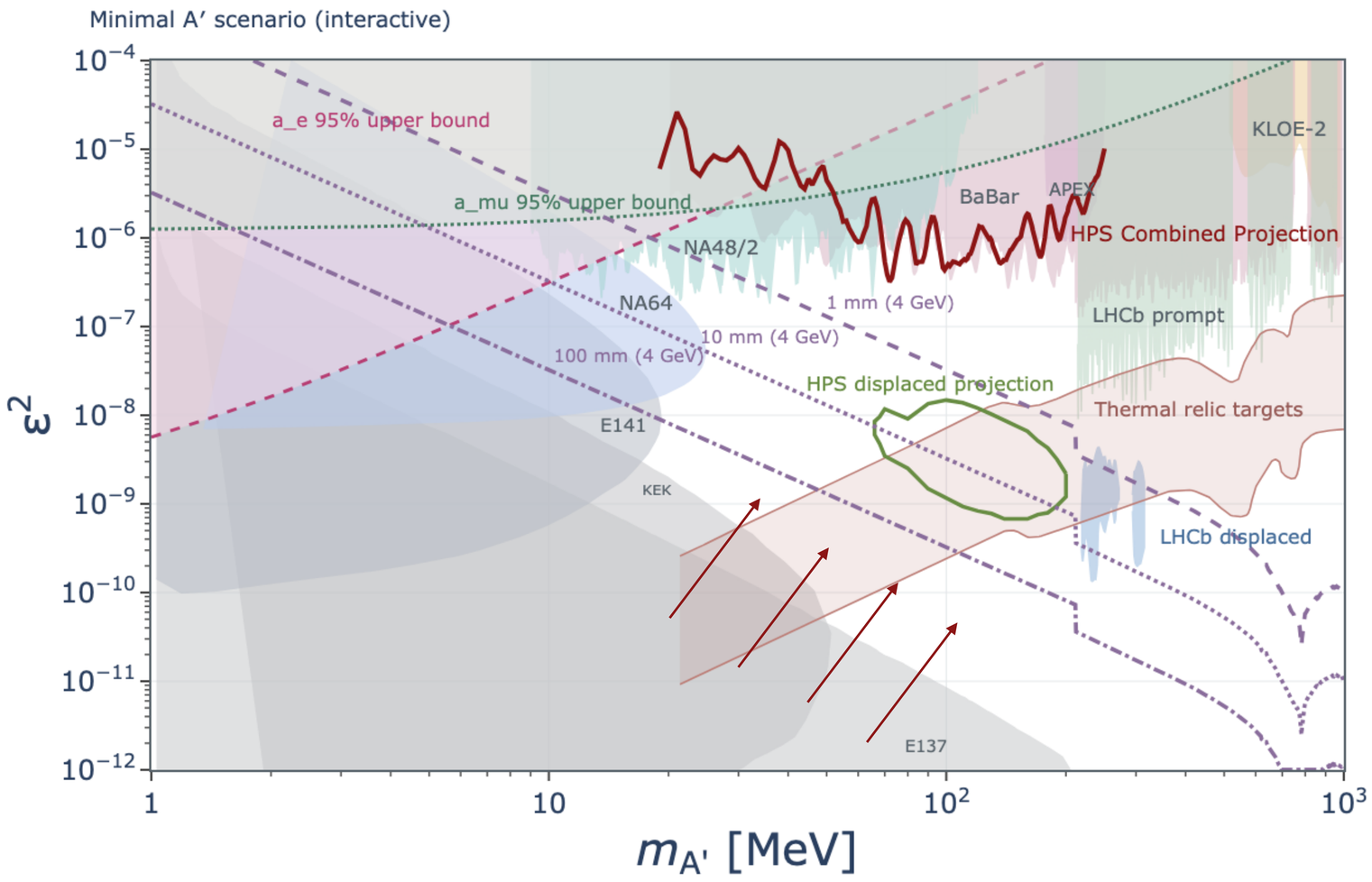


Contours are from very simplified MC, for entertainment purposes only

Pulling the beam dumps up

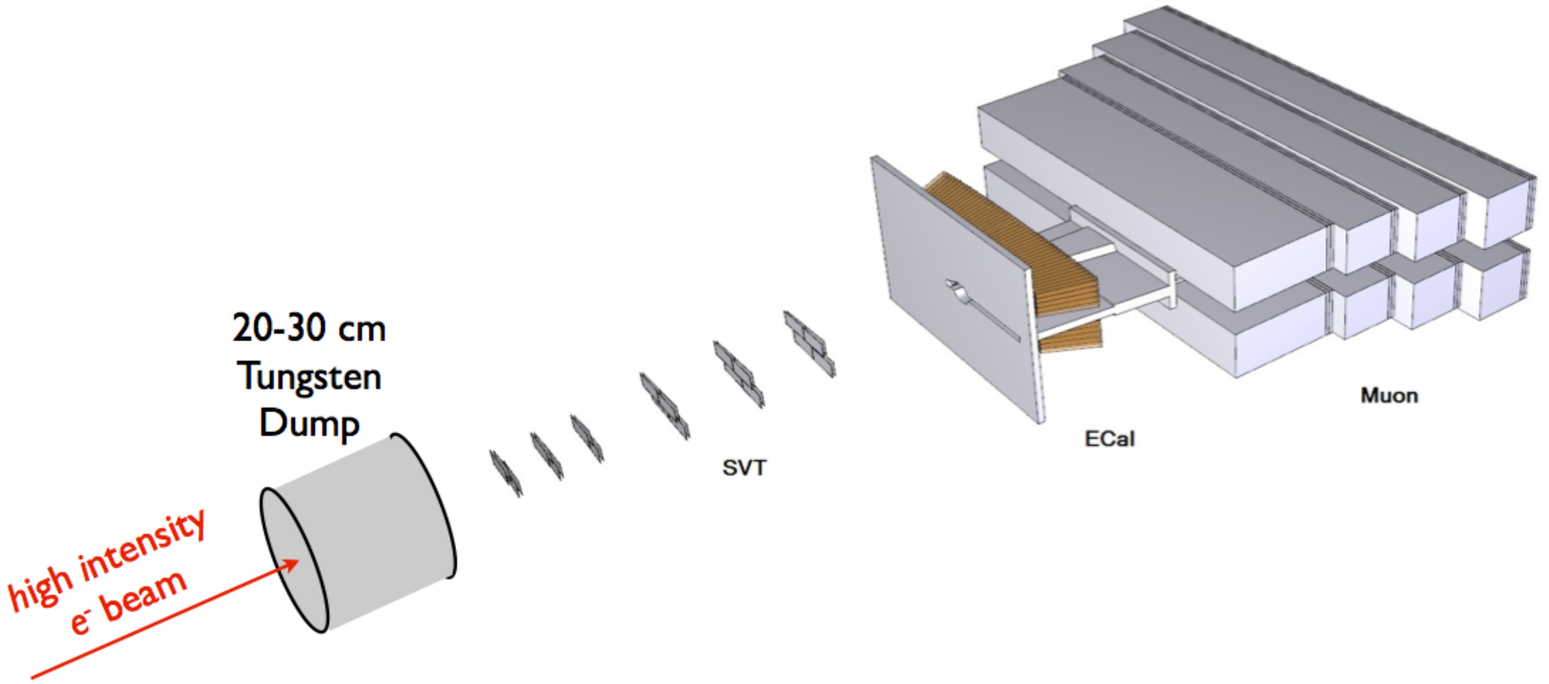
beam dump experiment's diagonal edge is set by the distance of detector from the start of (mostly) the dump.

To push up, need a stumpy dump with detector right after.



…this is a crowded space…
NA62, FASER, DAMSA Pathfinder (CDR) are on trail

Dump HPS



fancy diagram of hps floating in space with W dump instead of thin target

(plus muon detector)

About that dump…

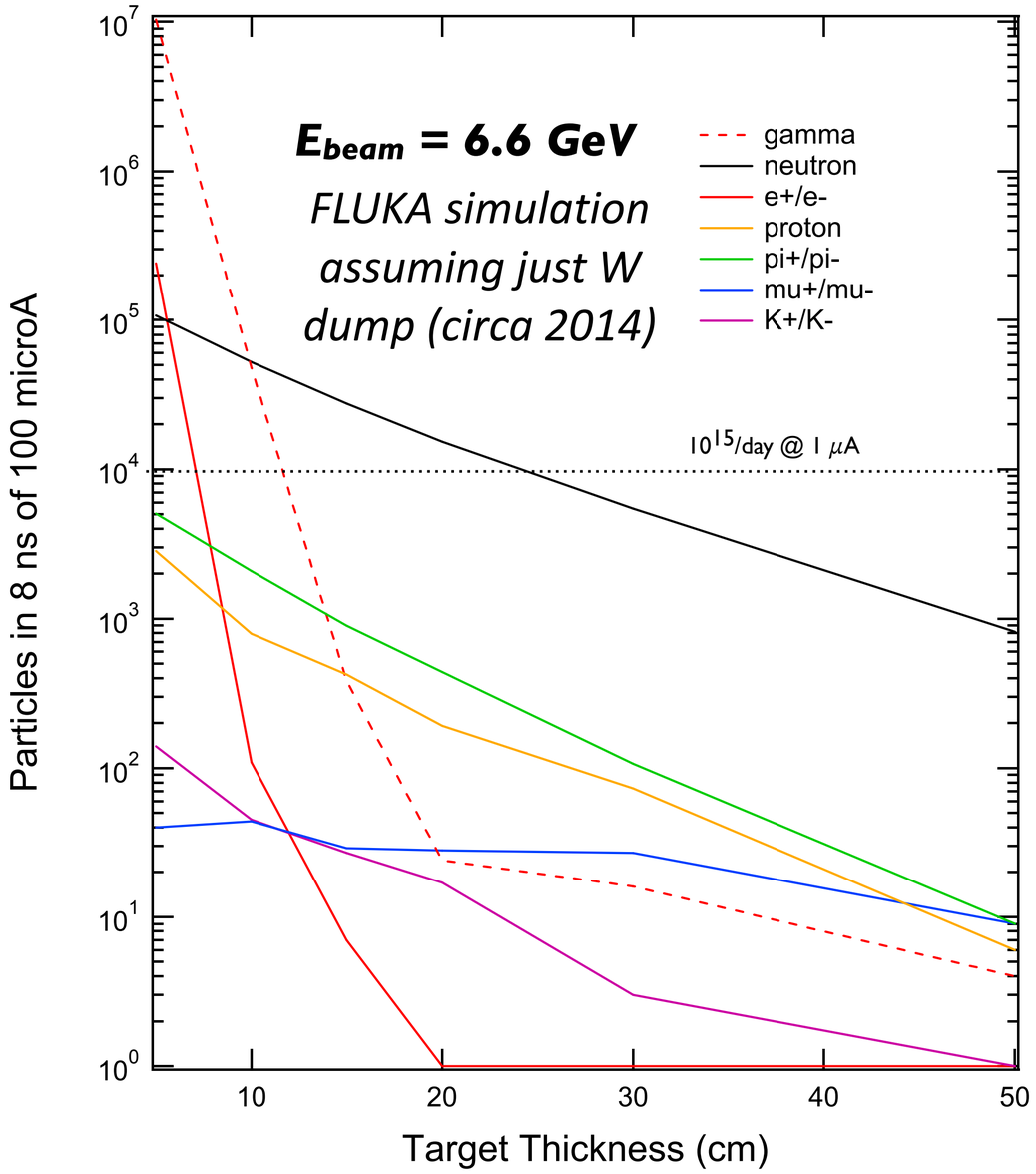
Dump will have to be actively cooled

- kWs of power to go somewhere

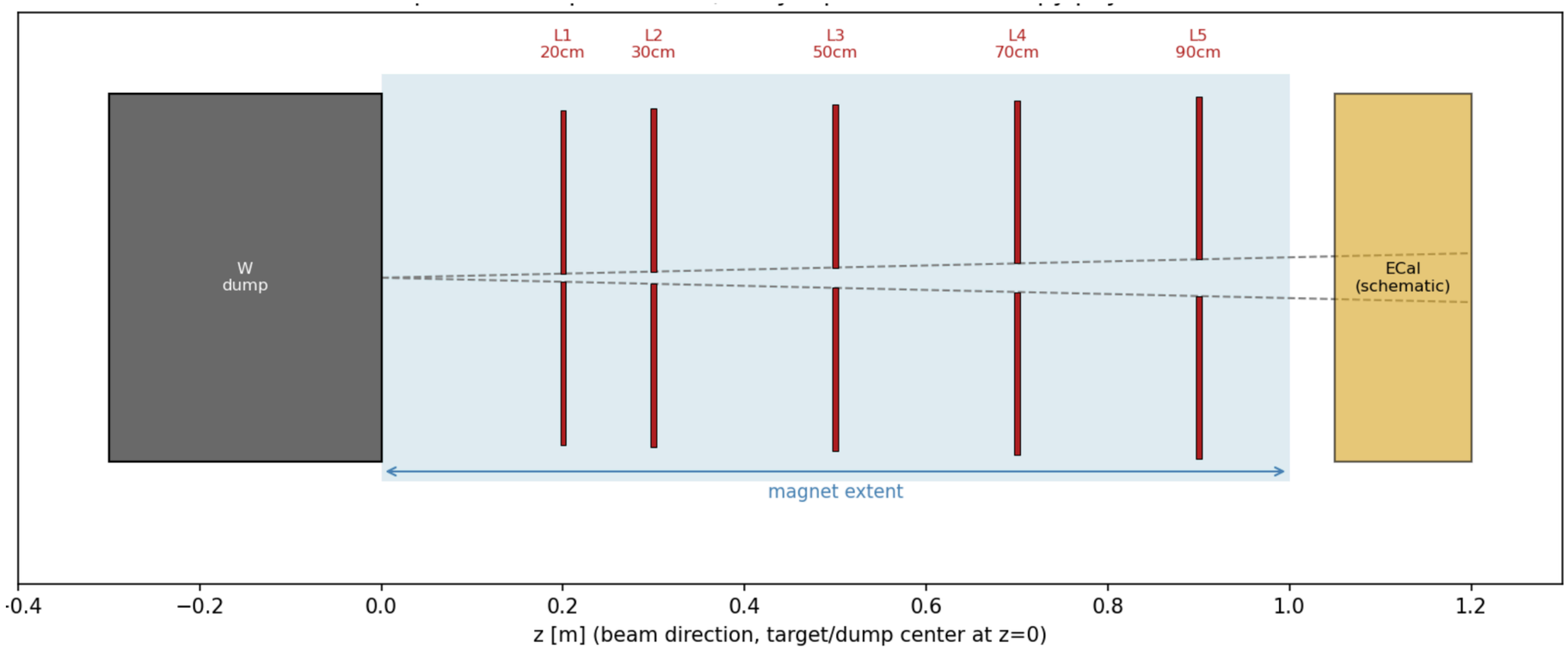
For a W-only target:

- Lots of fast neutrons!
  - note the units on y-axis here (/8ns/100 uA)
  - these are not great for silicon
- assume running at 1uA, still have handful of p/π/μ per 8ns
- photons from hadronic reactions at back of dump?

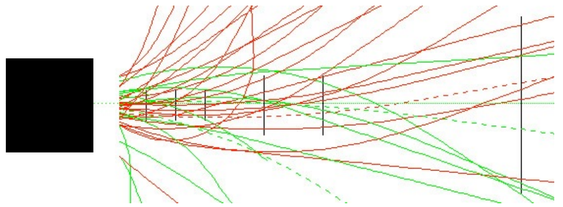
Forward-going A’ only produced in first few radiation lengths



Better(?) schematic of beam-dump-HPS



Charged tracks in 8 ns @ 10μA 6.6 GeV



Let's assume we get beam dump sorted out

- The beam will be ~gone after the dump, charged particles exiting dump will be softer and more spread out → reduce gap to 5mrad
- Look for pairs of charged tracks that give vertex downstream of the dump

Estimated reach for dump-HPS

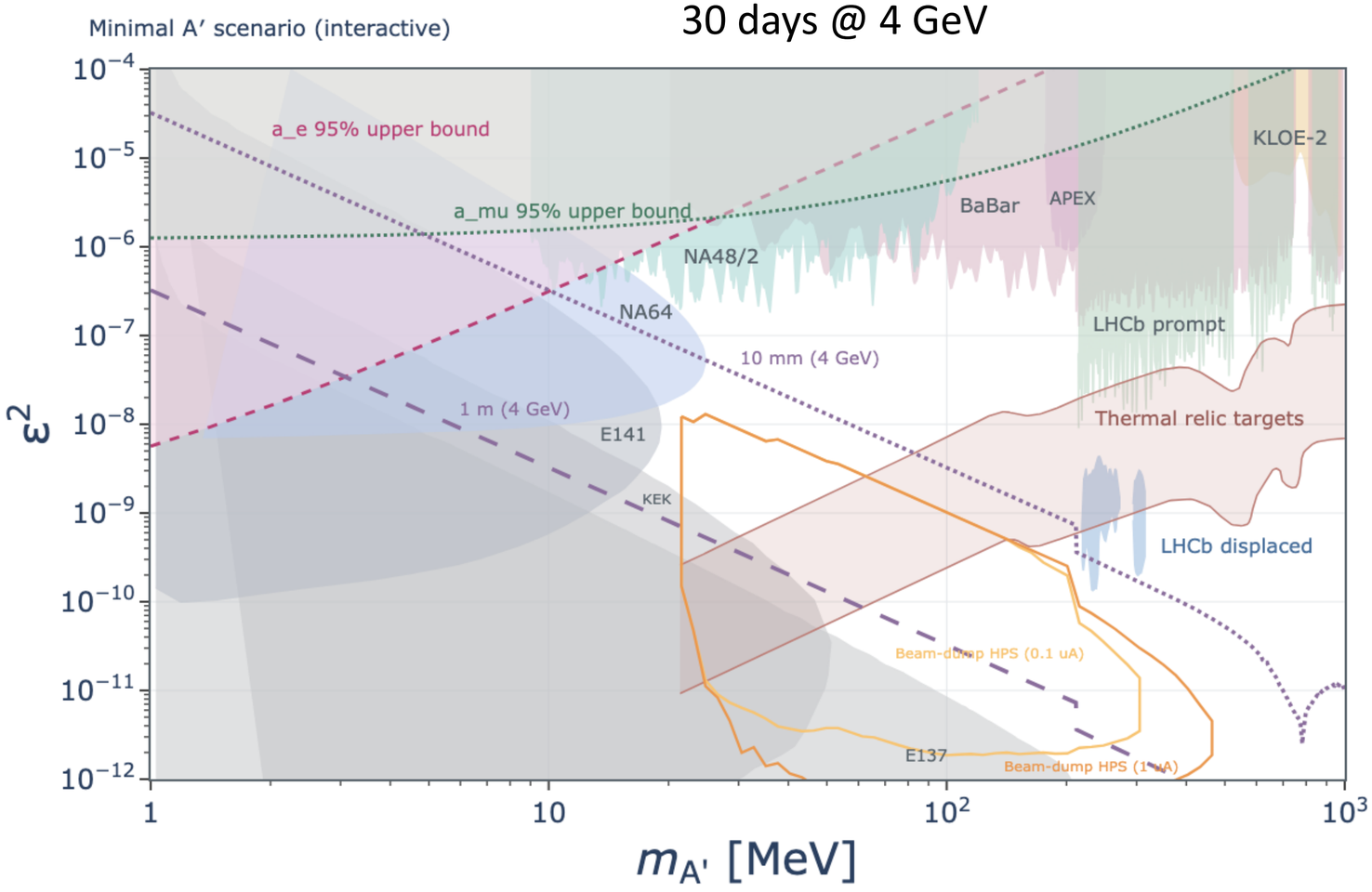
Looks like a beam-dump exclusion:

- lower mass edge set by 5mrad gap
- lower eps edge set by lumi x lifetime
- upper diagonal set by lifetime (too short)

Don't really need a lot of current for this (sorry).

The high-epsilon (higher production rates) gets filled in first. Higher currents push limit down and to higher mass.

30 days @ 4 GeV



Summary & Extras

There is still unexplored parameter space for visible dark photon decays

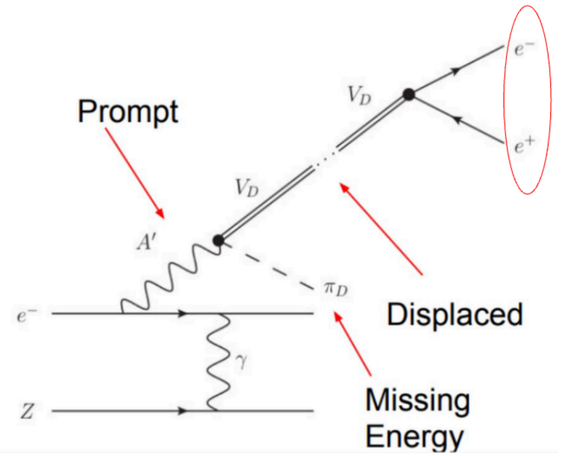
…particularly in the very interesting thermal-freeze-out parameter space

- HPS, X17, NA64, FASER, DAMSA(tbd), SHIP (looming), BELLE II should take some serious bites
- We shouldn't be scared off by these huge future experiments with their claims of covering swaths of parameter space
  - "No battle plan survives contact with the ~~enemy~~ data"
    - of course, this goes for any estimated exclusions in this talk too
  - We've presented two relatively small, quick (in beam-time…design?) experimental concepts that should give significant new reach. Who will pick up and run with them?
- We didn't talk about the m(A')>2m(χ) case: decays to invisibles
  - BDX (JLAB), LDMX(SLAC), NA64, SHIP etc

What about high-lump CLAS?

Yeah, what about CLAS?

- Nominal dark photon → f^+f^- is too forward for most (all?) parameter space
  - at very high current maybe higher mass A′ where opening angle is large?
- There are some really interesting non-minimal dark sector models that give signatures that are not dead-forward
  - SIMPs (Strongly Interacting Massive Particles:
    - A′ decays to $V_D(\rightarrow e^+e^-)\pi_D$(invisible)
  - iDM (interacting Dark Matter):
    - A′ decays to $\chi\chi'(\rightarrow\chi e^+e^-)$



- There are more that could benefit from CLAS' larger angular acceptance, and probably from higher luminosity too (acceptance would still probably be small).