Searching for Dark Forces in Electron Fixed-Target Experiments

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with J. D. Bjorken, R. Essig, and P. Schuster (0906.0580)

to appear in PRD

also many thanks to heavy photon search working group:

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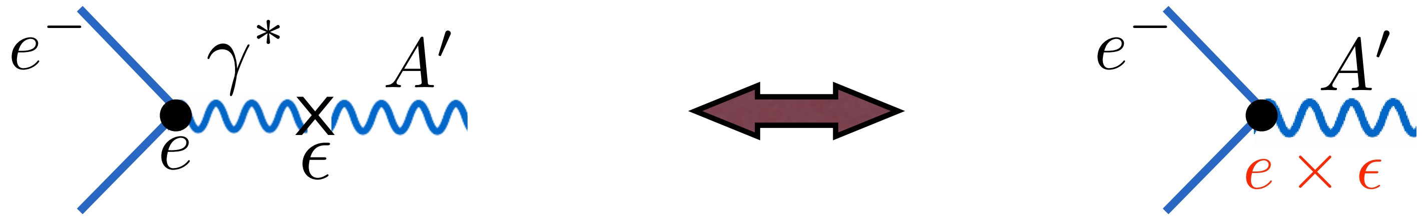
The Model

- Dark gauge boson A´ mixing with photon,
  Mass $m_{A´}$ = 1 MeV – few GeV



- This vertex allows A´ production in any charged-particle scattering.

- Assume A´ decays (only) through photon mixing, i.e. to e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, etc. depending on mass
  $c\tau \sim (m_{A'}\epsilon^2)^{-1}$

  [inclusive and invisible–decay searches (including masses <2 m_e) :
  Afanasev, Aulenbacher, Ringwald, Wojtsekhowsi talks]

Outline

- Advantages of Fixed-Target Experiments (few-GeV e^- beam)

  [see Pospelov's talk for proton beams]

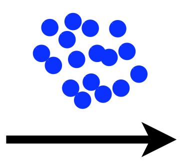
- Navigating A Large Parameter Space
  - Exclusions from Beam Dump Experiments

- Design Considerations for New Experiments

Higher Luminosity

Fixed-Target

10^{11} e^-



~10^{23} atoms in target

N(hard scatter) ~ 0.01 – 1
per electron

e^+e^-

10^{11} e^- 10^{11} e^+

N(hard scatter) ~ 1
per crossing

$\mathrm{O(few)}\ ab^{-1}$ per day

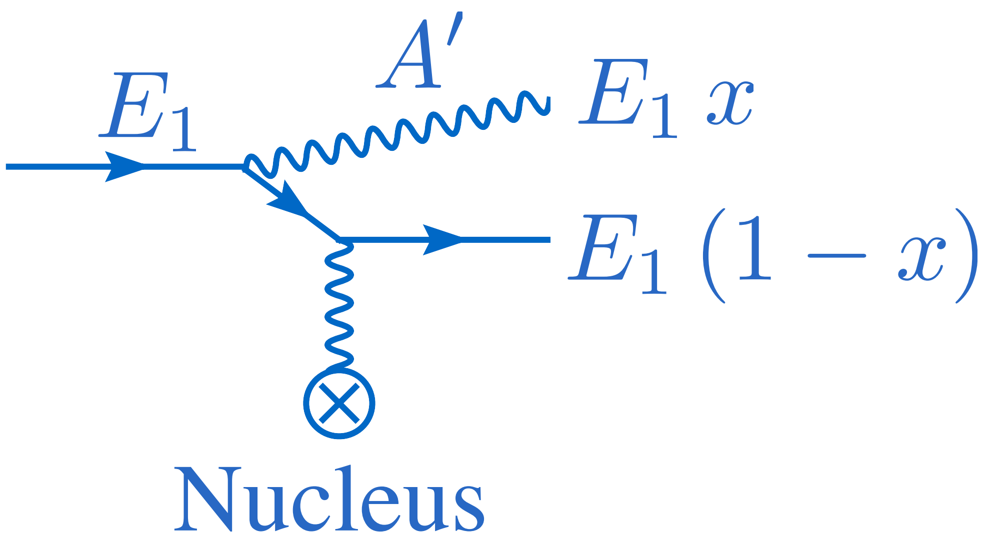
$\mathrm{O(few)}\ ab^{-1}$ per decade

High rate most important when few A´ are produced or for high-background modes

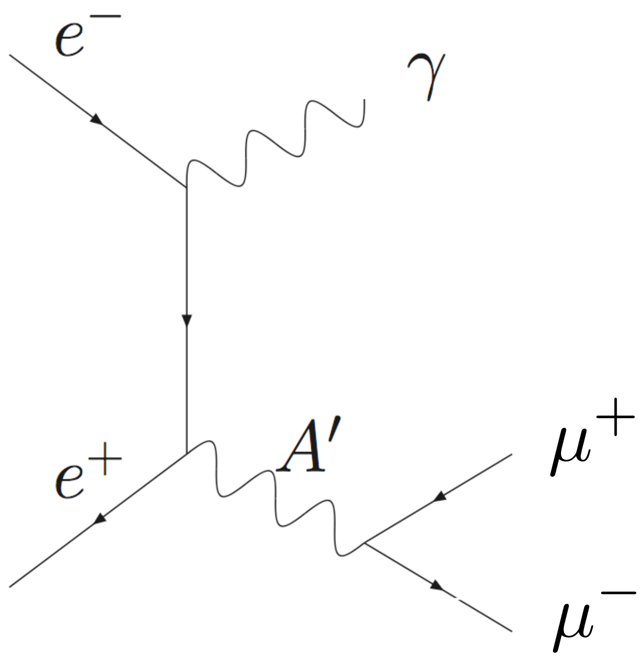
(e^+e^- ideal for larger-rate/low-background decay modes)

Larger Cross-Sections

Fixed-Target



e+e-



$$\sigma \sim \frac{\alpha^3 Z^2 \epsilon^2}{m^2} \sim O(10\ pb)$$

$$\sigma \sim \frac{\alpha^2 \epsilon^2}{E^2} \sim O(10\ fb)$$

- Scales as A´ mass, not beam energy
- Coherent scattering from nucleus

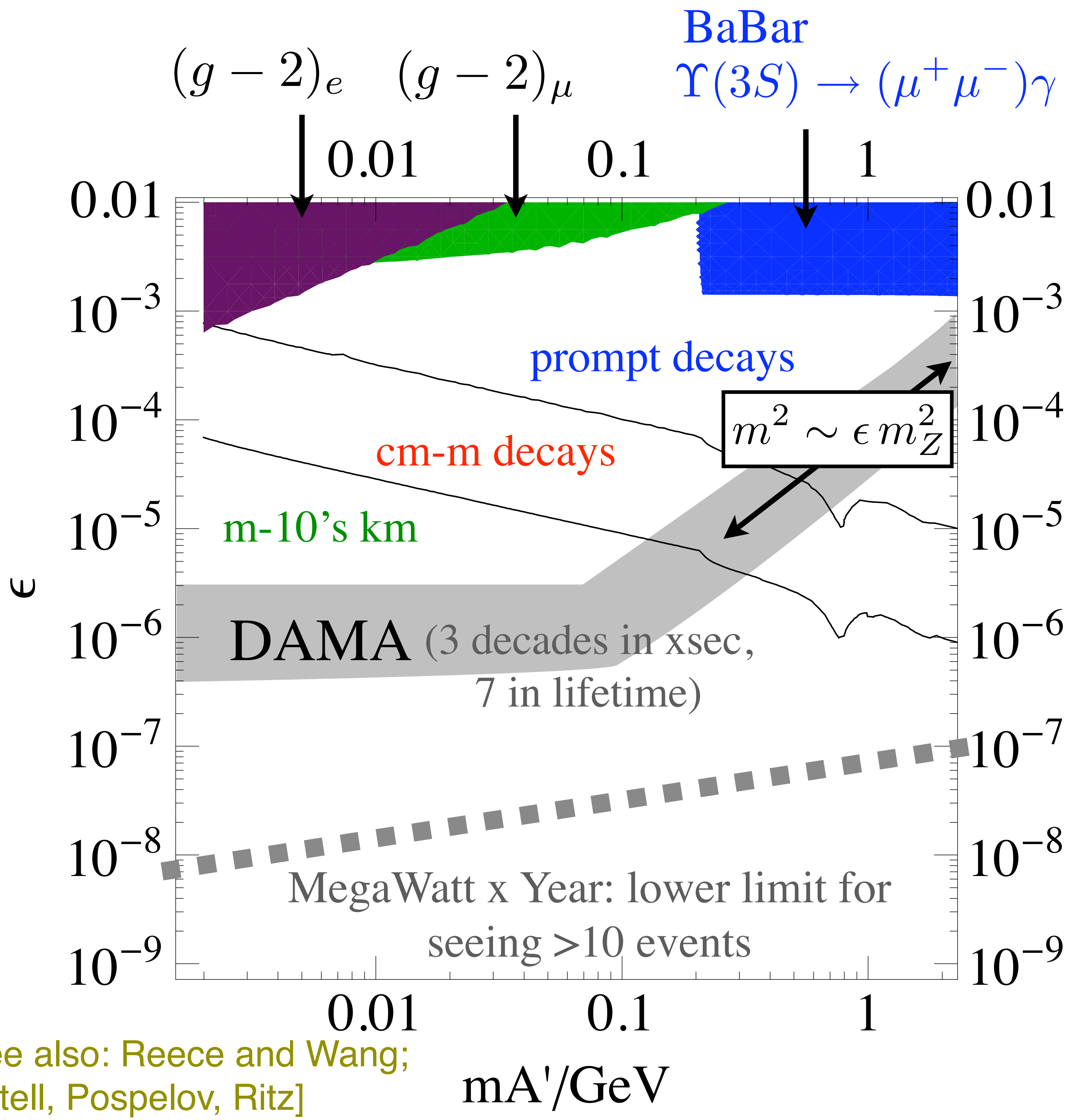
Fixed-Target Territory

- Lifetime

$$\gamma c\tau \approx 1\ \mathrm{mm}\,(\gamma/10)\,\left(10^{-4}/\epsilon\right)^2 \times (100\ \mathrm{MeV}/m_{A'})$$

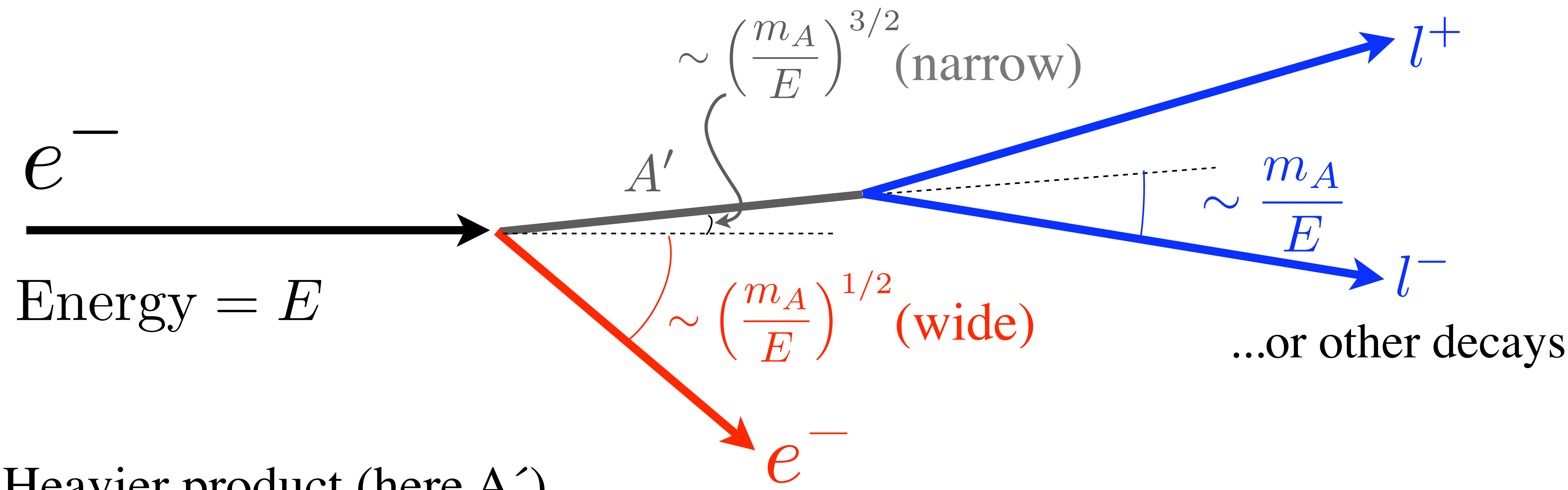
varies over 15 decades

- Kinematics depends on mass
- Multiple detectors needed



[see also: Reece and Wang; Batell, Pospelov, Ritz]

Kinematics and Geometry



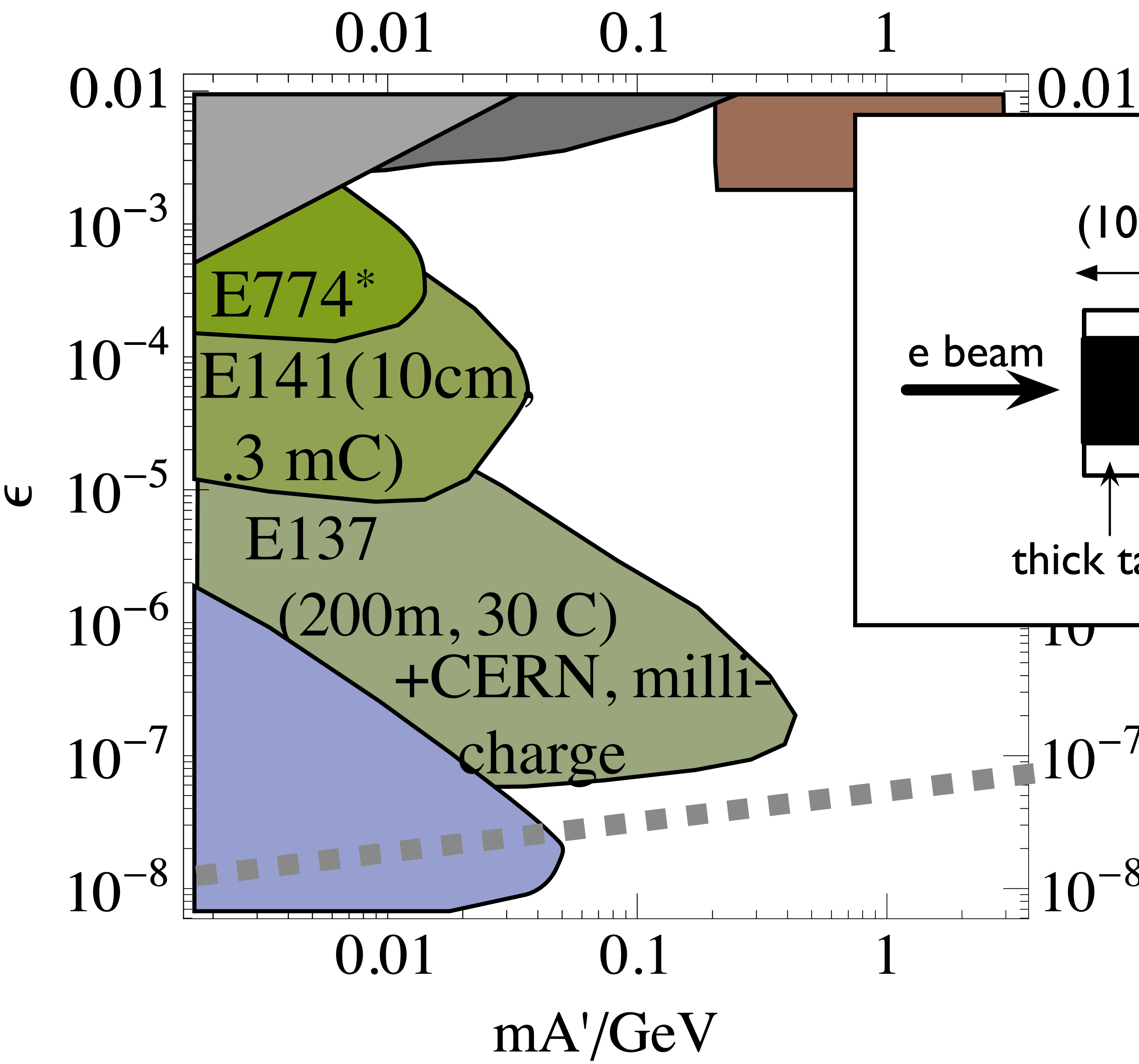
Heavier product (here A´) takes most of beam energy:

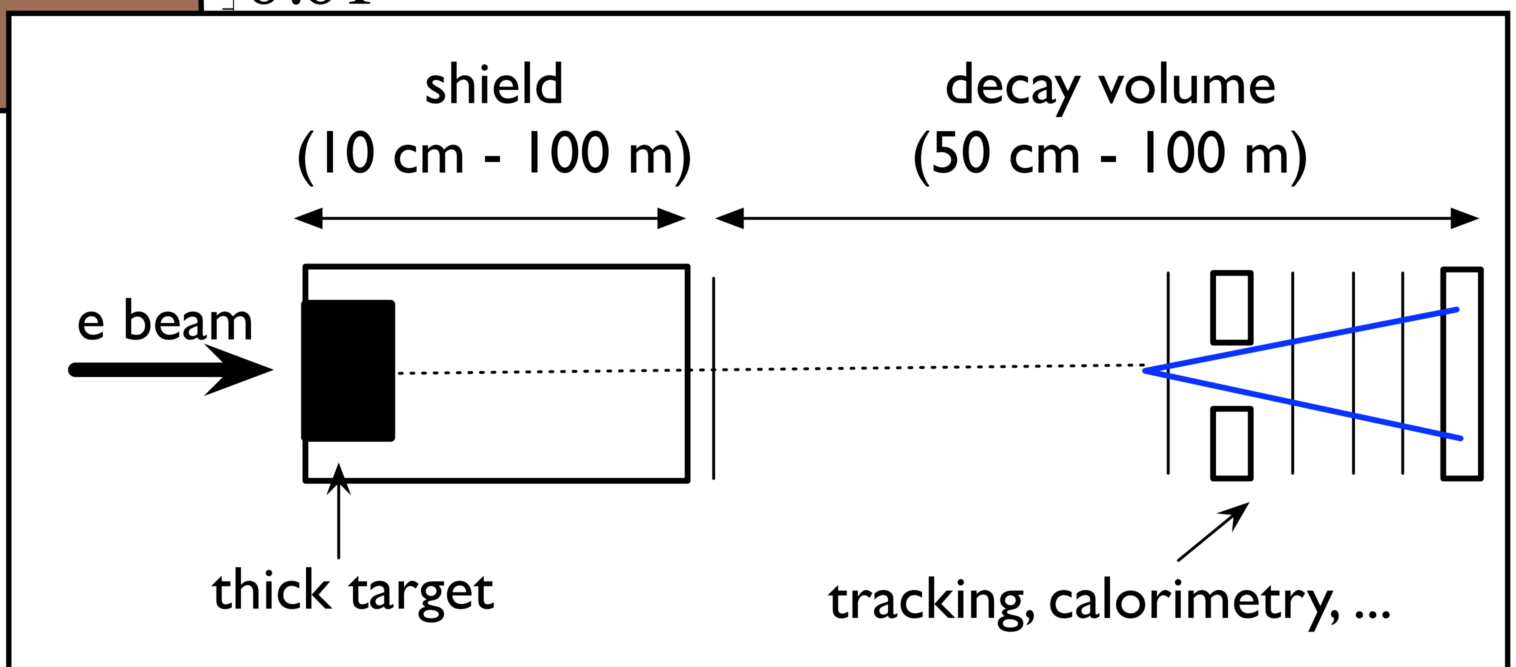
$m_{A'} \gg m_e$ vs. $m_e \gg m_\gamma = 0$ for bremsstrahlung

$E_{e-} \simeq m_{A'}$ $\quad$ $E_{A'} \simeq E_{beam}$

- Forward geometry allows small, purpose-built detector
- Limitation: Beam products also forward!

Searching in Dumps



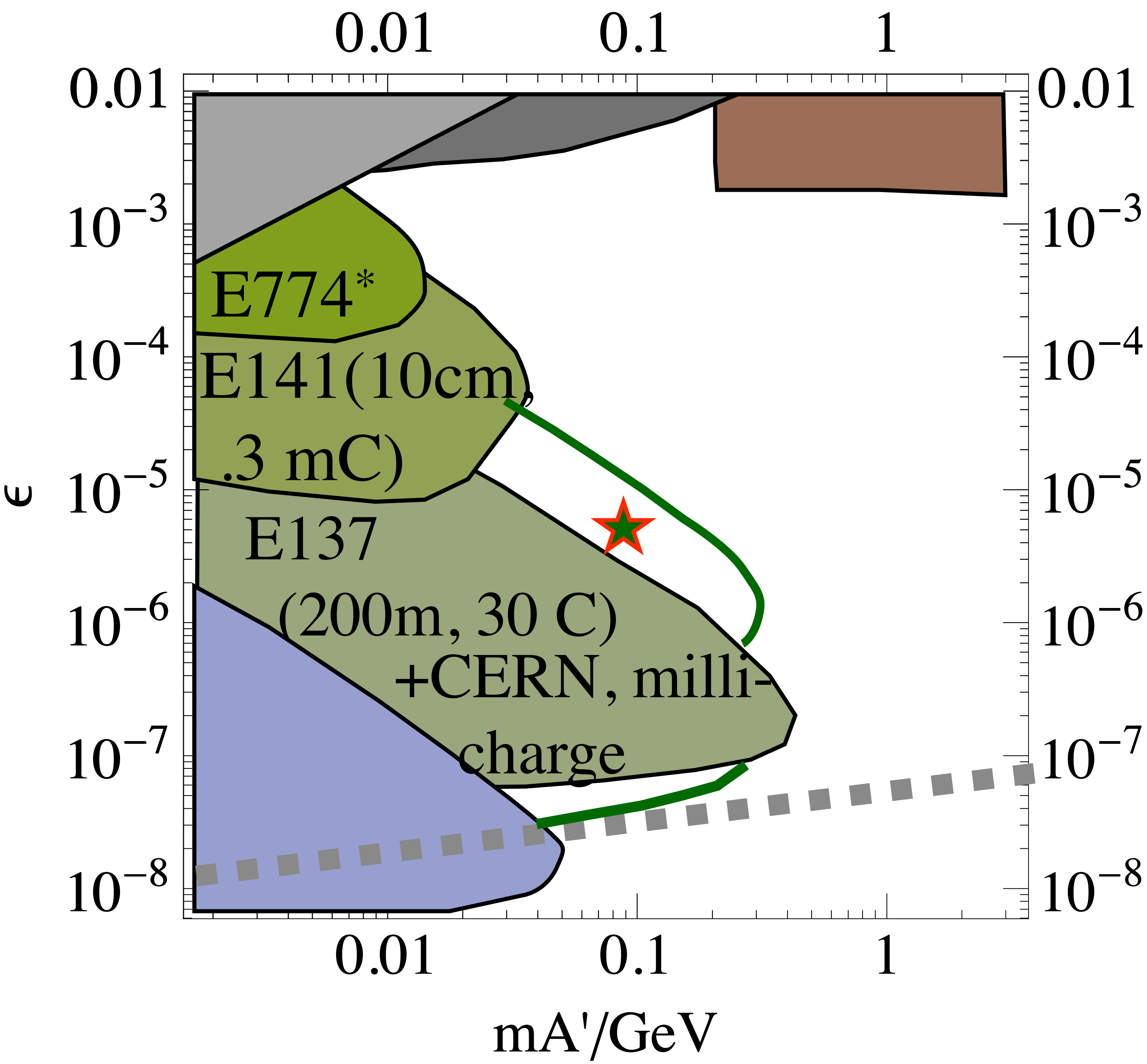


MegaWatt x Year lower limit

(dump experiments also constrain longer-lived decay modes, see Schuster, NT, Yavin to appear)

*E774: 20cm, .3 mC

Searching in Dumps



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★ discoverable with new, low-power beam dump

10^6 seconds @ 100 nA, 6 GeV

one signal event per hour

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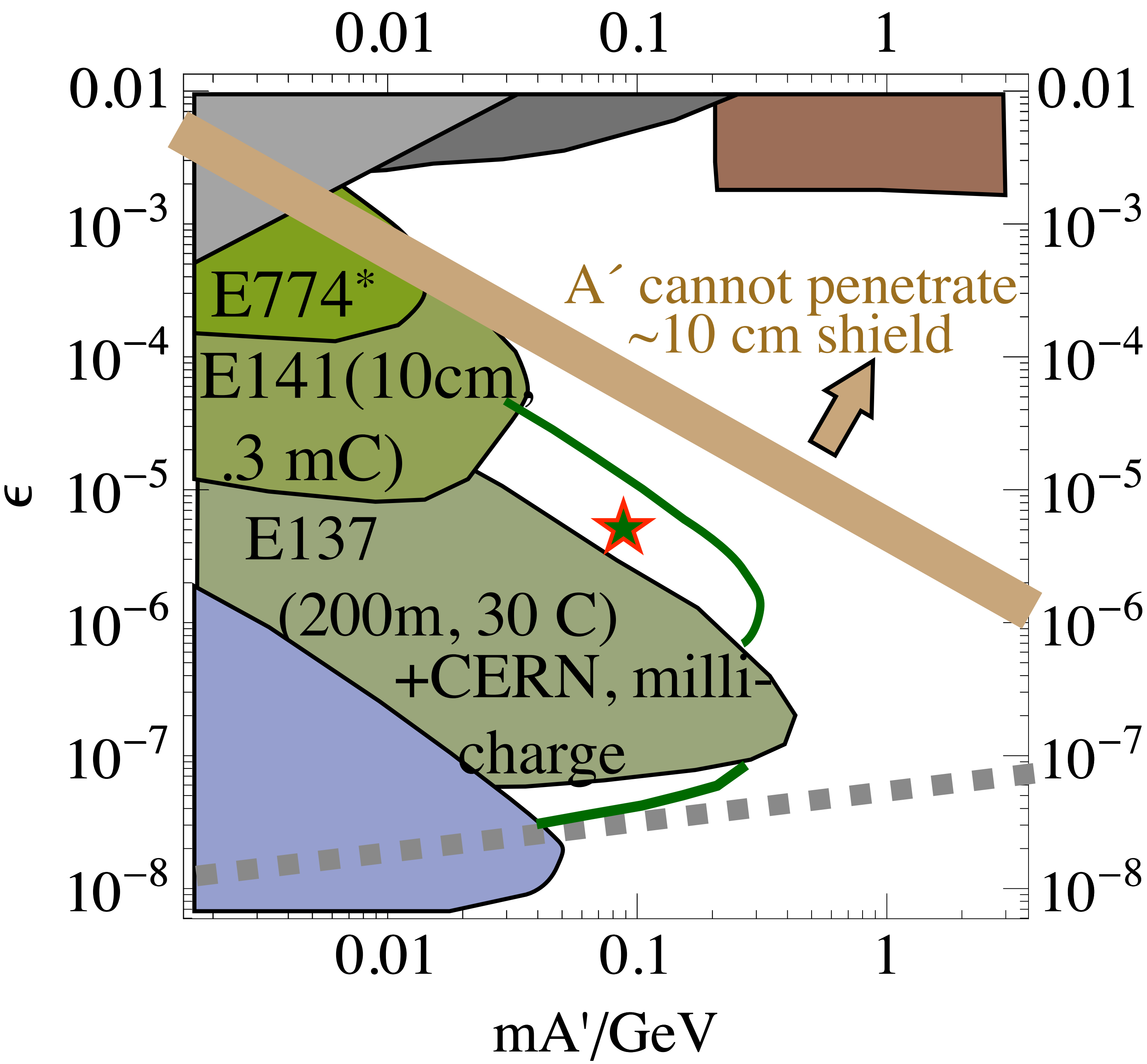

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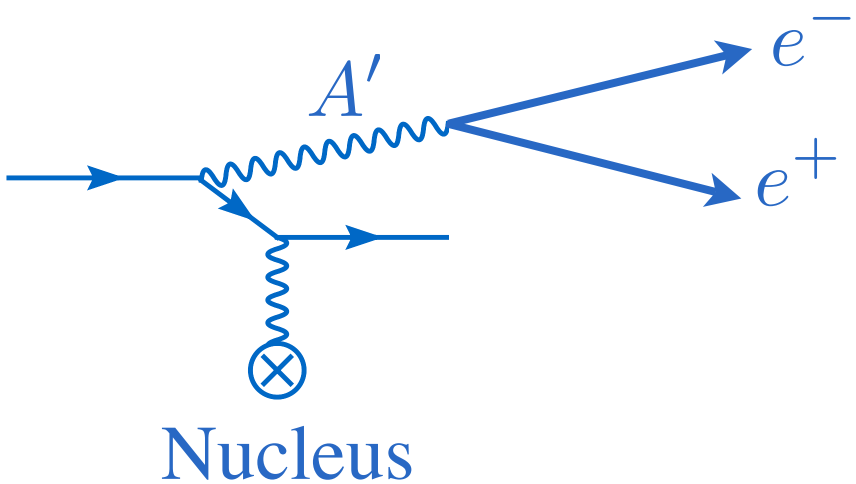
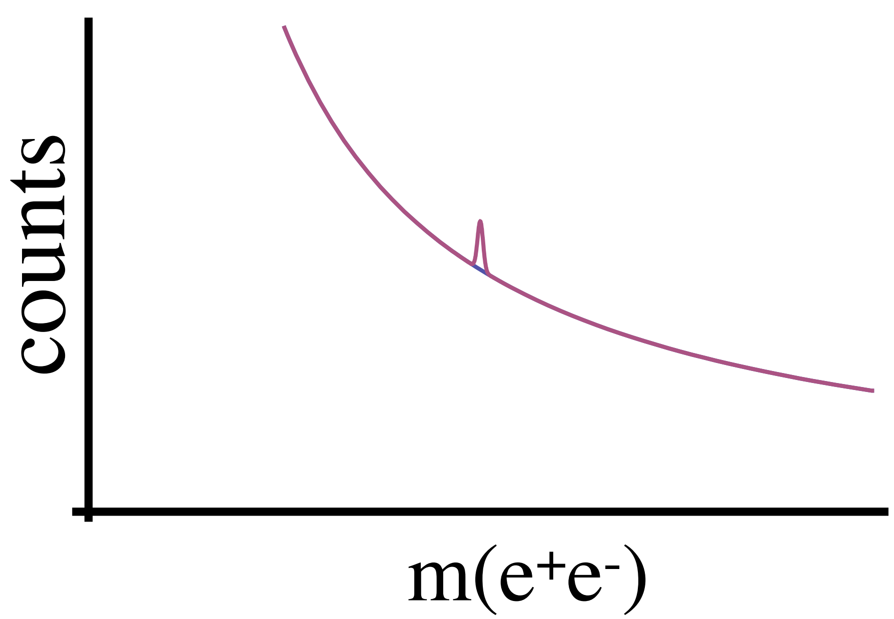
Beyond Beam Dumps

- If you can't stop beam, disturb as little as possible (use thin target <<1 rad. length)
- Resonance search (can assist with vertex)



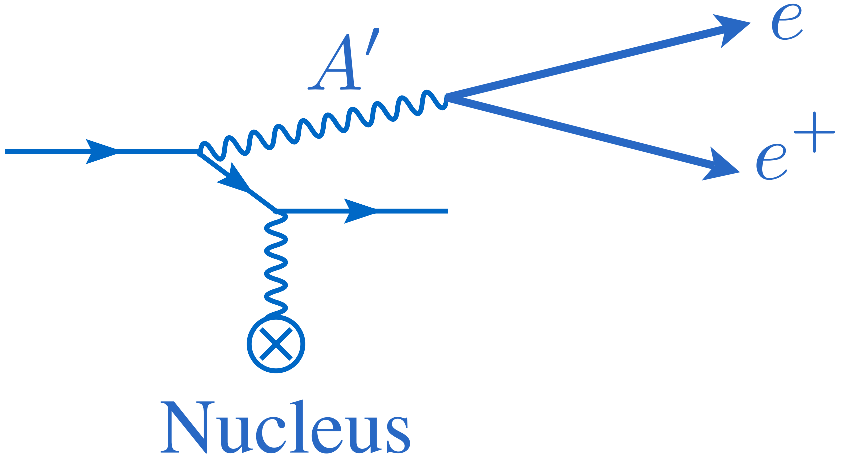
Existing spectrometers may cover new ground! (see P. Bosted's talk in WG)



Signal/background ~ ϵ^2:
50–1000x smaller than shown!!

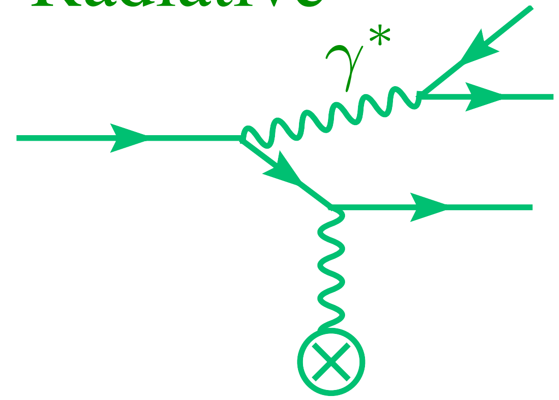
At small $\epsilon \lesssim 10^{-4}$, use vertex to reject background, keep S/B> few%

Signal and Background:



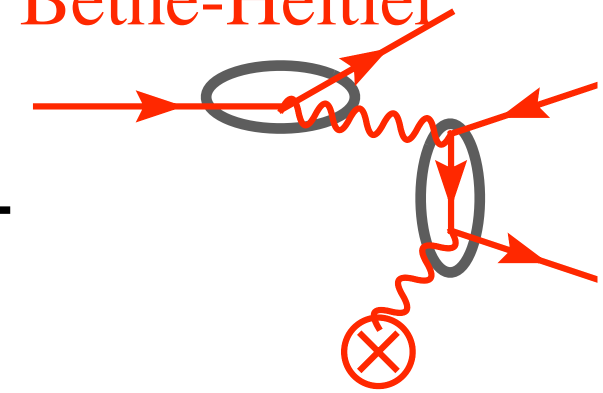
EM backgrounds (trident):

Radiative



\+

Bethe-Heitler



Same kinematics as signal, **IRREDUCIBLE:** (except vertex)

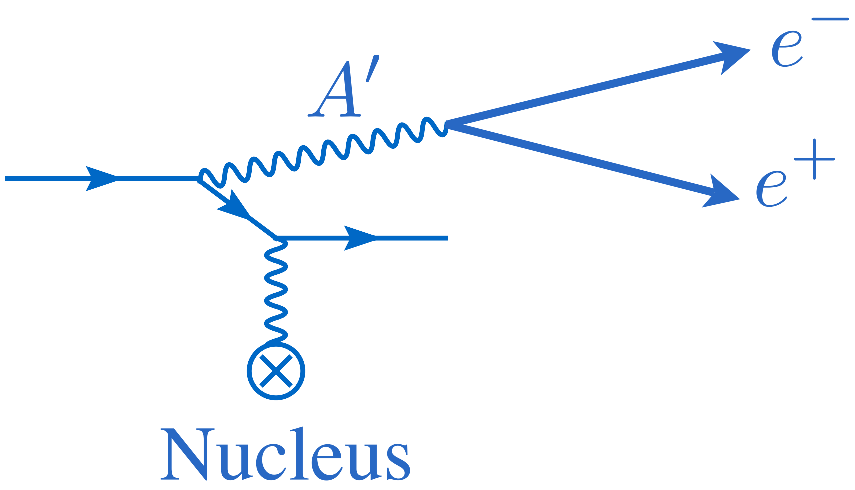
$$S/B = \frac{3\pi}{2\alpha}\frac{m}{\Delta m}\epsilon^2$$

Larger rate, reject using very different kinematics

Generated in modified MadGraph (including all elastic form-factors) to study background rejection
—thanks to J. Alwall for help!

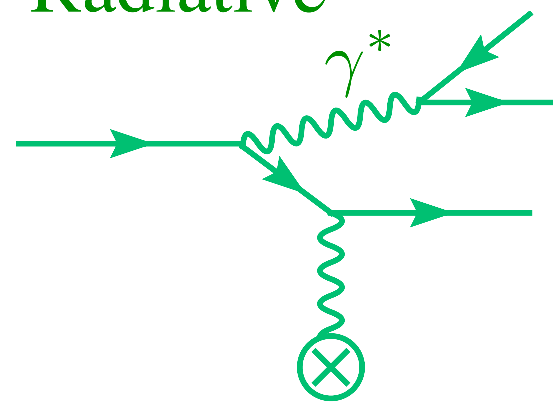
\+ incoherent (eA > eAɣ, ɣA> e^+e^-A) suppressed for thin targets

Signal and Background:



EM backgrounds (trident):

Radiative



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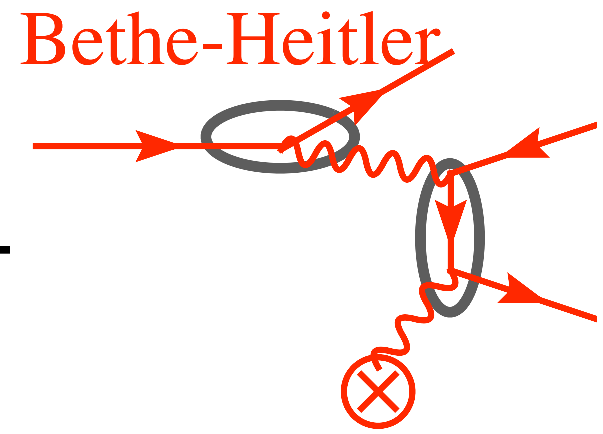

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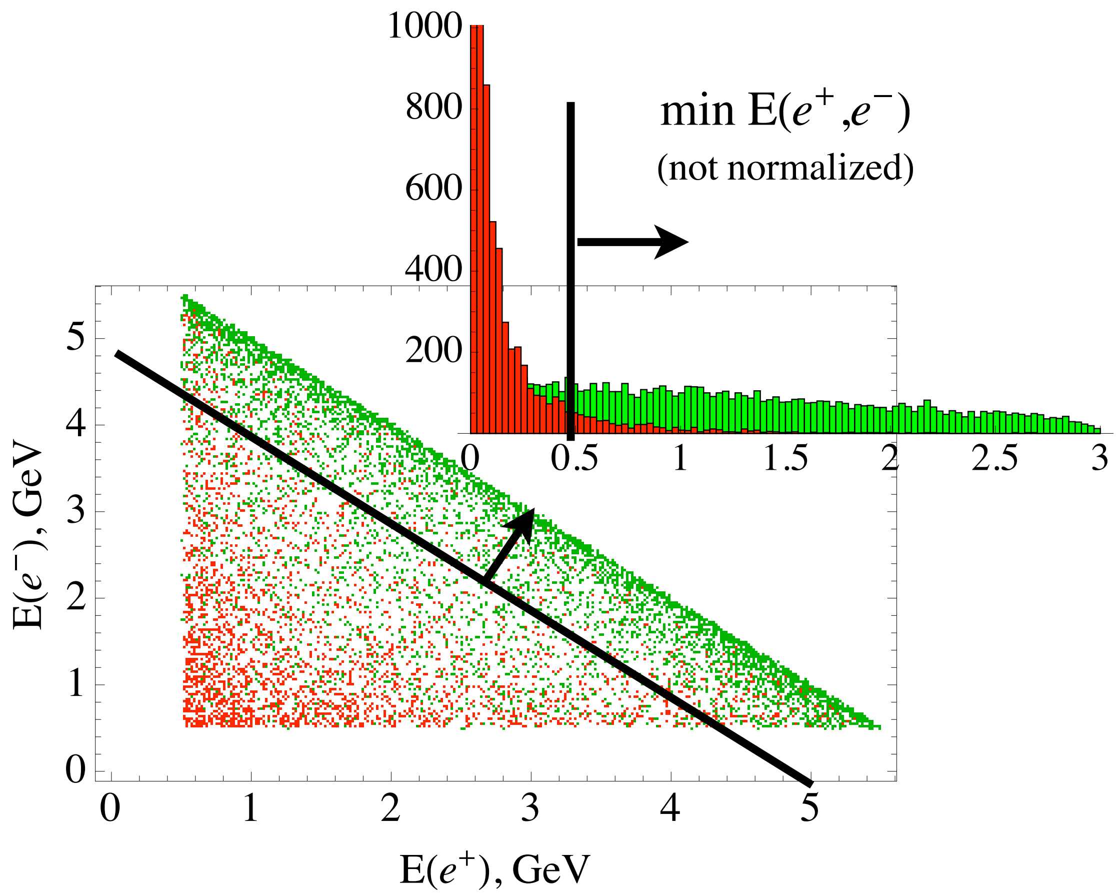


Simple cuts control BH

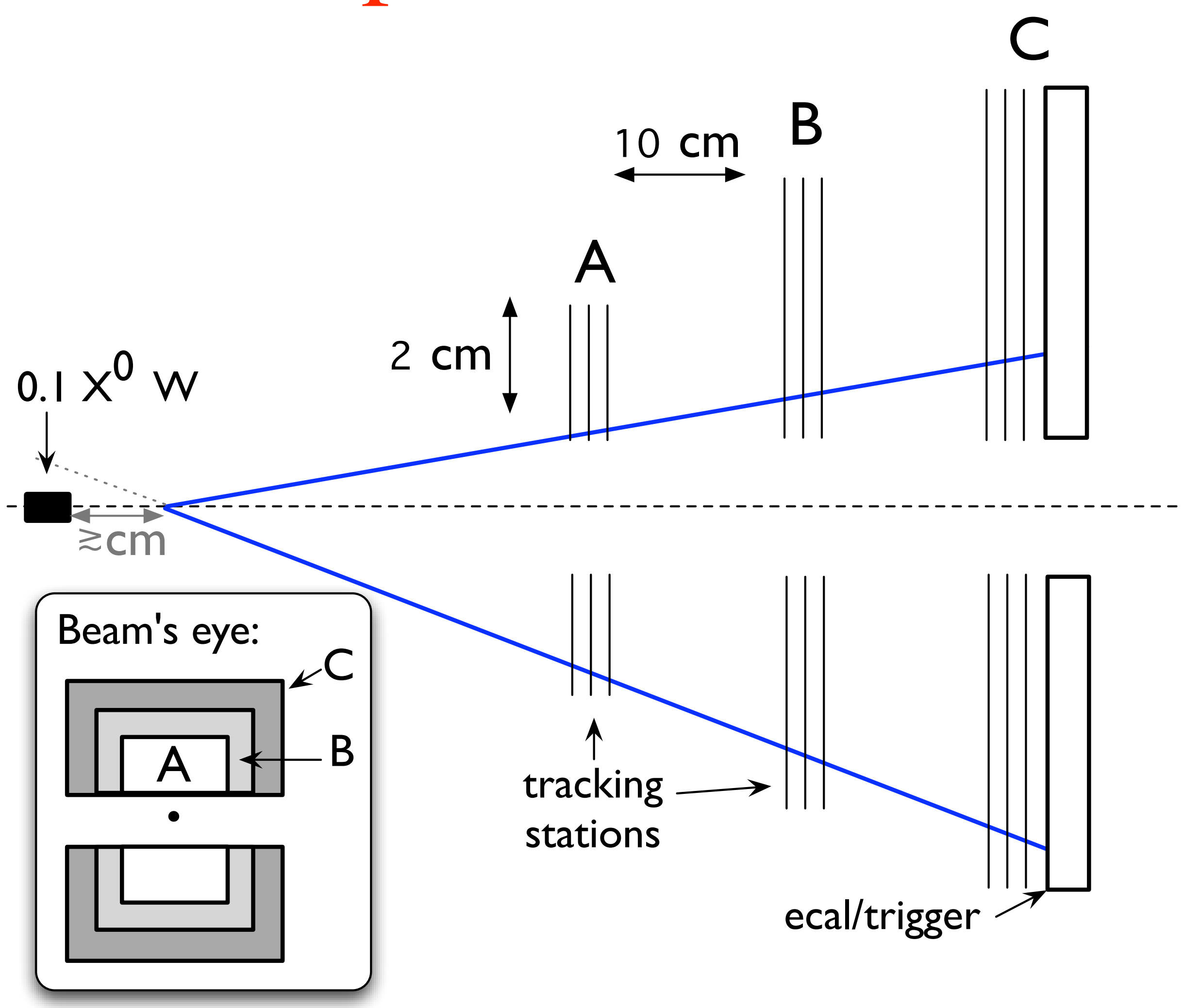
Approaches for New Experiments

To maximize search reach:

- ~1% or better mass resolution
  (kinematic discrimination, S/B)
- Very good forward coverage
  (signal production is peaked forward)
- Fast trigger (high event rate)
- Fast detector, continuous beam
  (control coincidence backgrounds)
- Silicon good for fast precision tracking (use vertex discrimination)

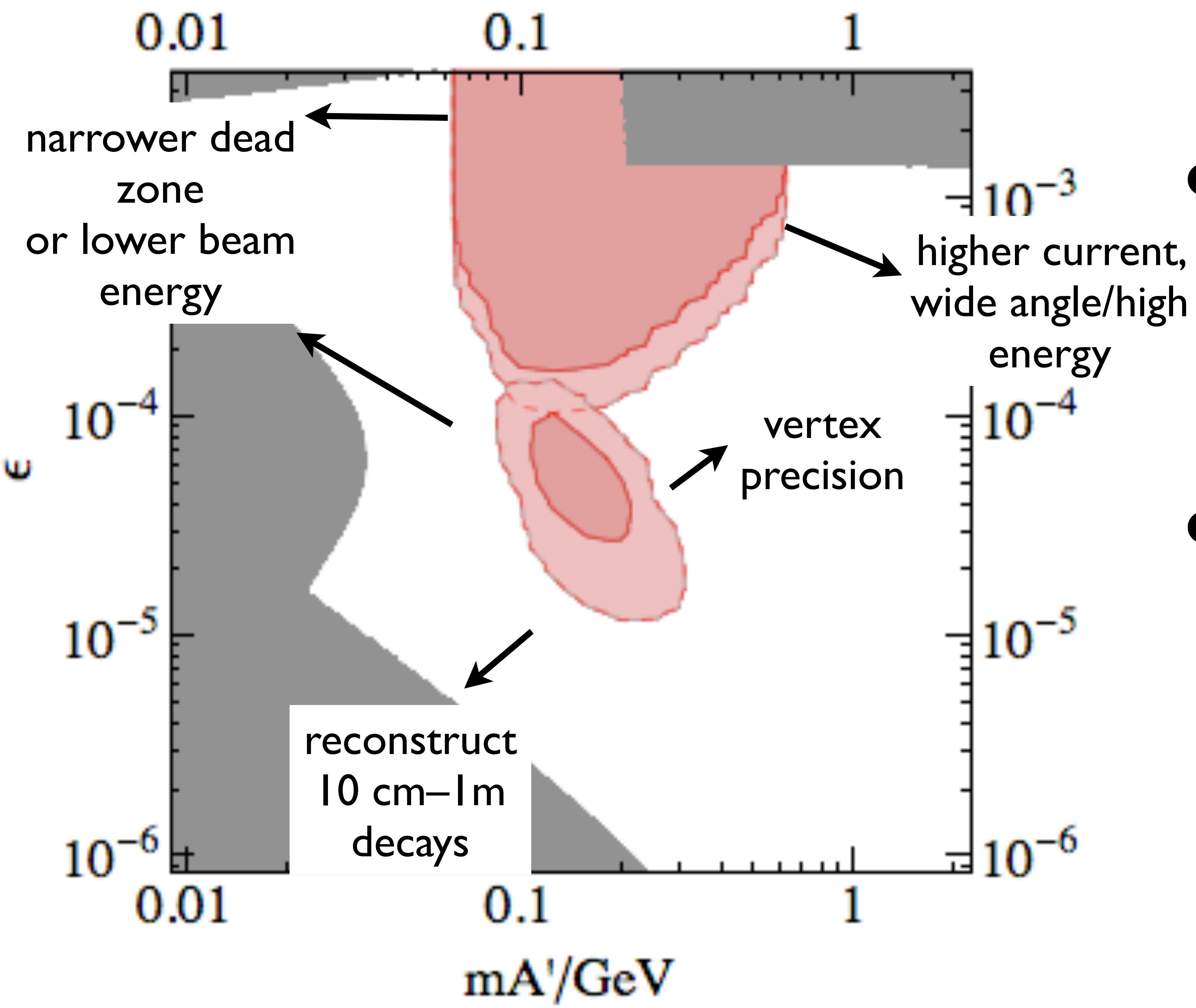
  [T. Maruyama will discuss these technical challenges]

Forward two-arm spectrometer



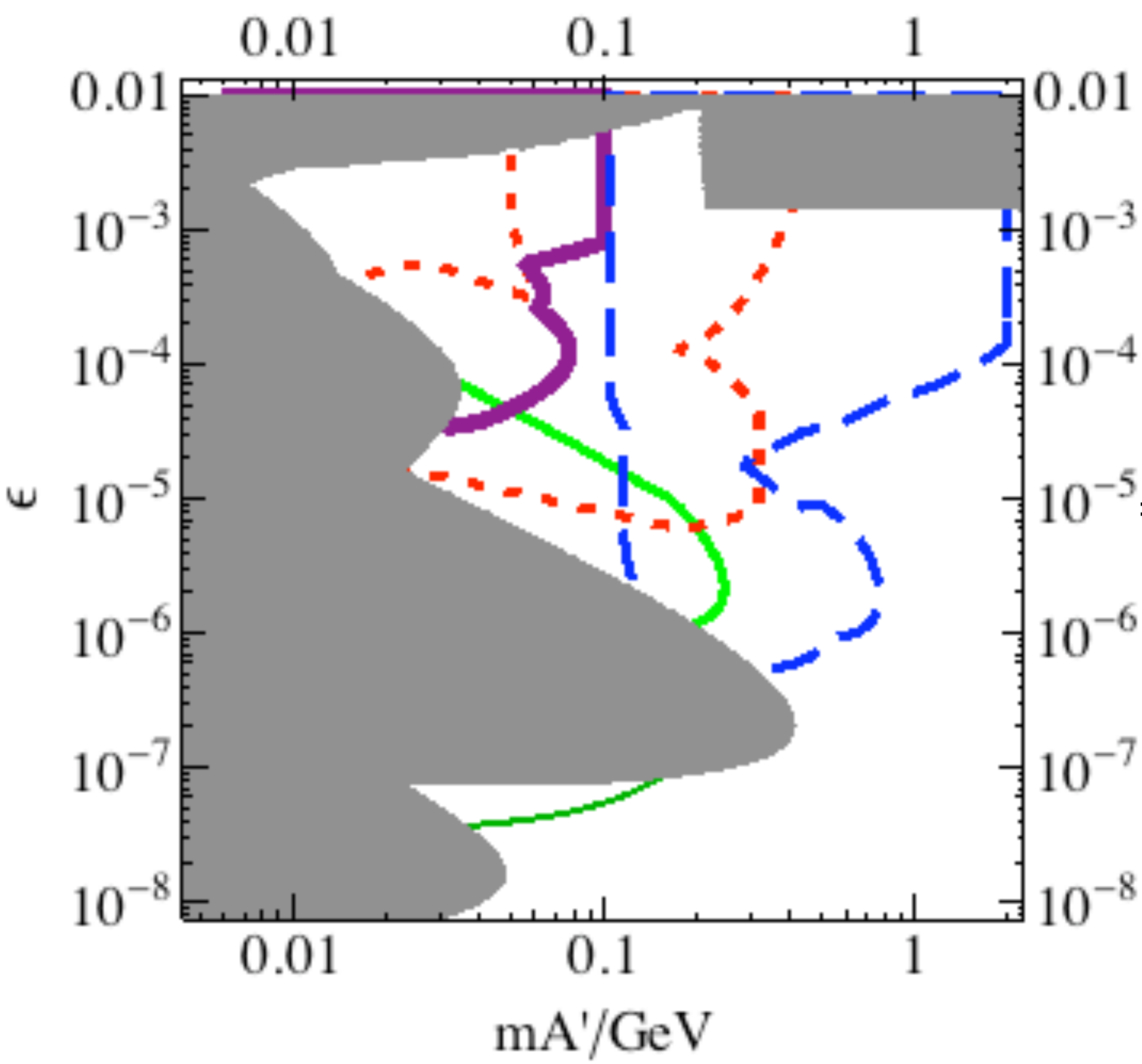
Small with variable geometry

Potential Sensitivity



- For one geometry in 100 nA beam, 0.01 radiation-length target for 10^7 s (14–100 mrad acceptance)
- Different regions can be probed by varying beam energy and/or angular acceptance

Sensitivity of Multiple Geometries



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Low-mass: Silicon tracking ***in*** diffuse beam

(see Fisher's talk for a different approach)

Mid-mass: 2-arm spectrometer (multiple beam energies)

High mass: wider-angle spectrometer (e.g. JLAB Hall A?)

Low coupling: dump experiments

Conclusions

- Fixed-target experiments well suited to search for dark forces – high intensity
  - Also poses unique challenges
- Large parameter space requires multiple search strategies
  - Low coupling/mass: Beam dump experiments
  - High coupling/mass: standard wide-angle spectrometers (e.g. JLab)
  - Large intermediate region for new forward-geometry experiments to explore