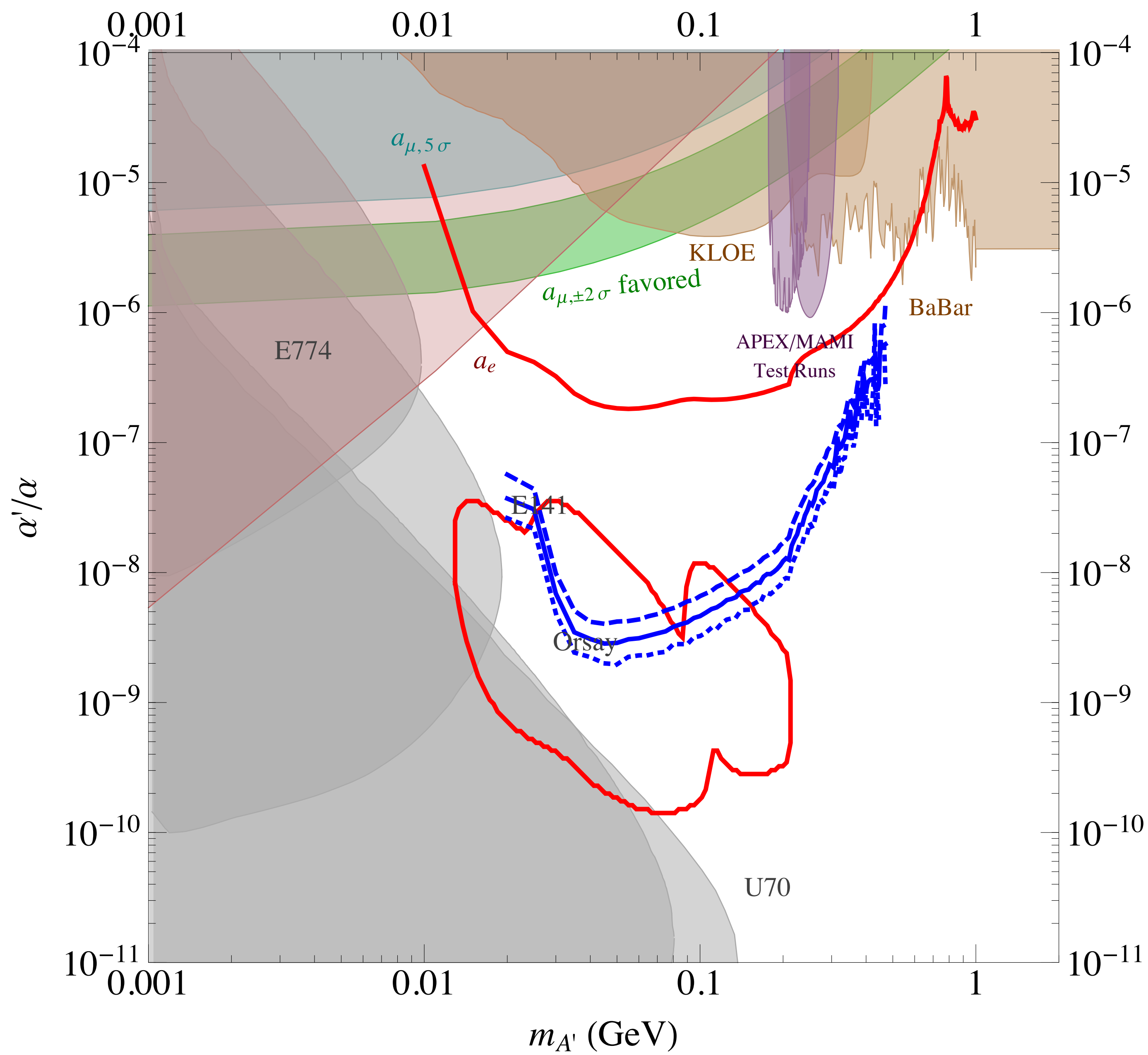
Thoughts on Future Heavy Photon Searches

Matt Graham,
Takashi Maruyama, } actual work
Tim Nelson ← crazy ideas

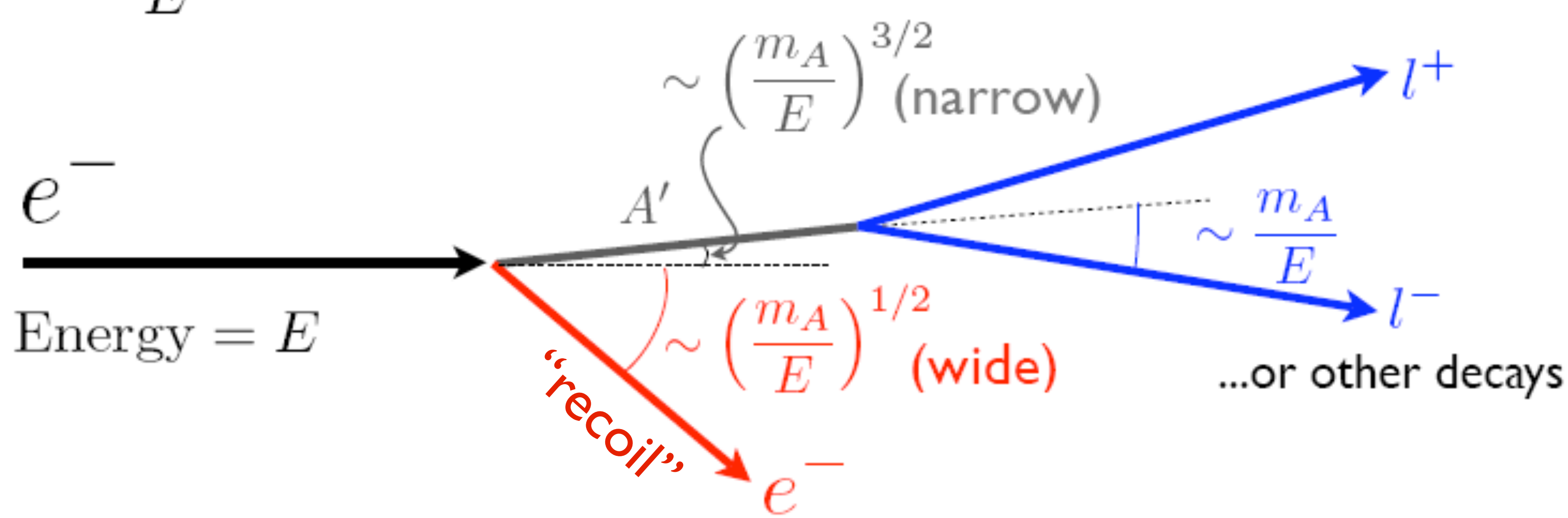


Fixed Target Kinematics

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

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

Kinematics **very different** from massless photon bremsstrahlung



Heavier product (here A')
takes most of beam energy

$$E_A \sim E - m_A$$
$$E_e \sim m_A$$

Efficient reconstruction of A' decays needs large, forward acceptance:

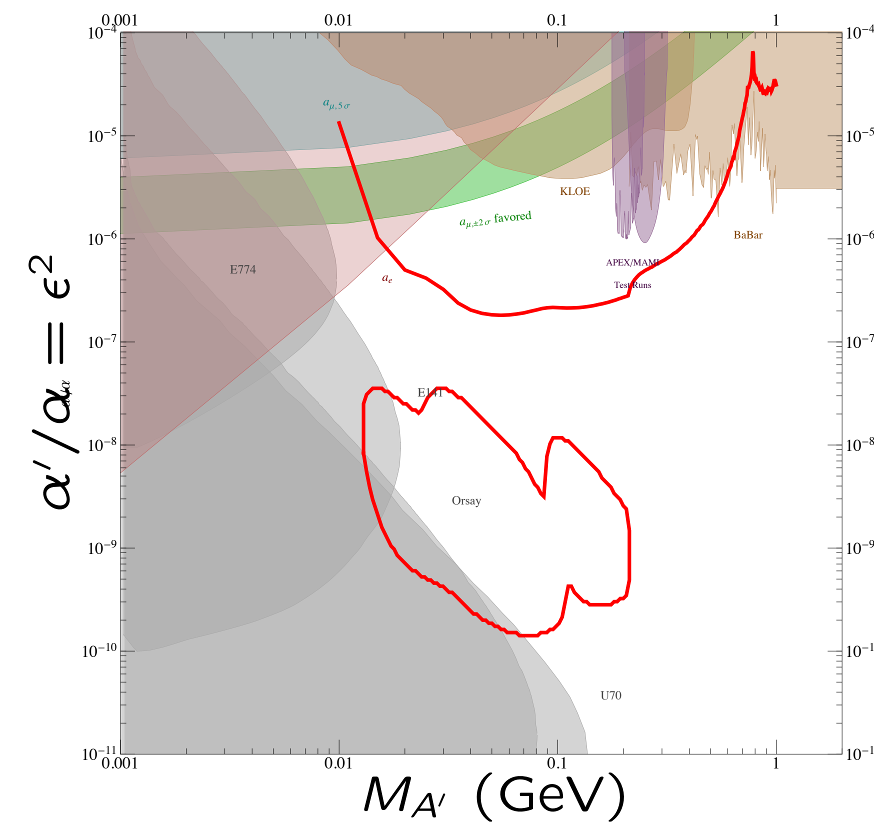
$\theta_{decay} = m_{A'}/E_{A'}$ (~200 MeV/6 GeV = 33 mrad)

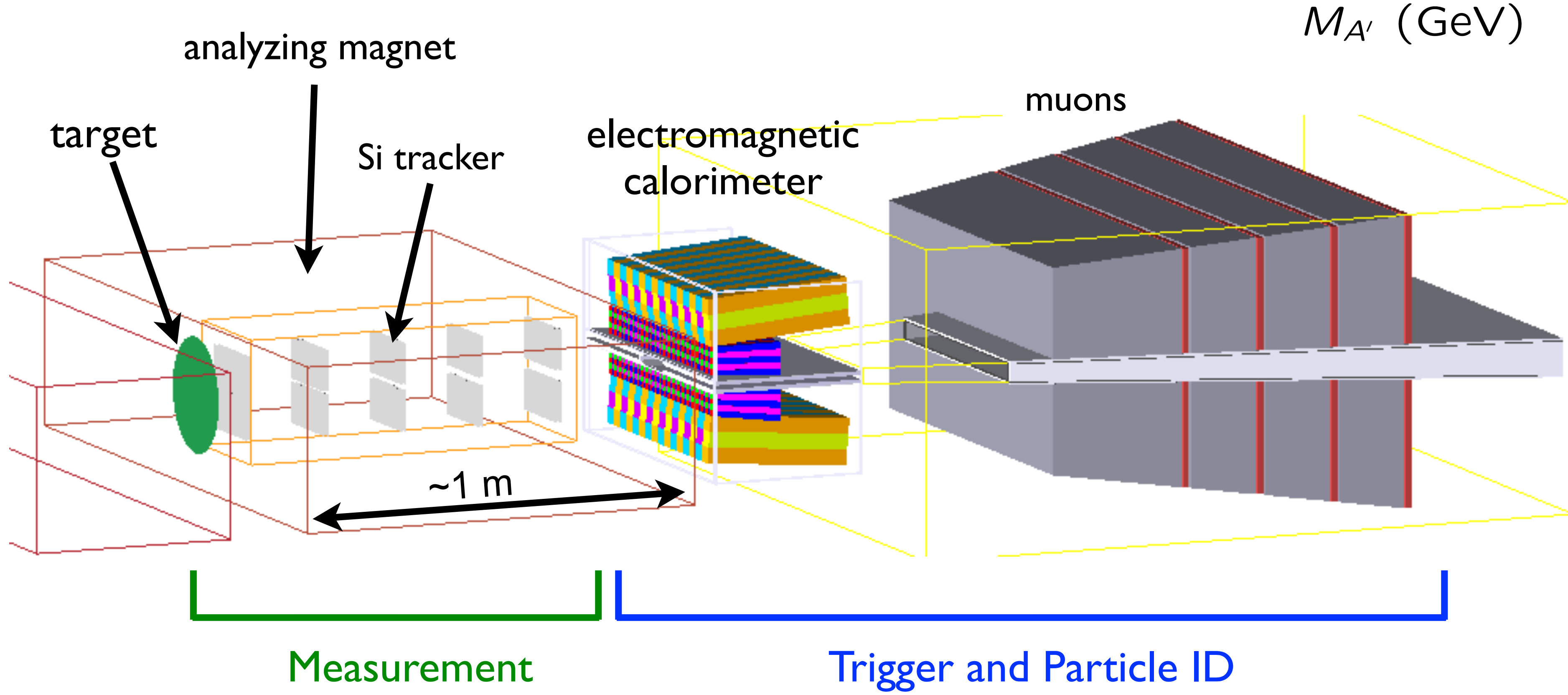
HPS Introduction

Sensitivity in this region relies upon abilities to precisely...

- determine invariant mass of A′ decay products (estimate momentum vectors)
- distinguish A′ decay vertexes as non-prompt (extrapolate tracks to origin)

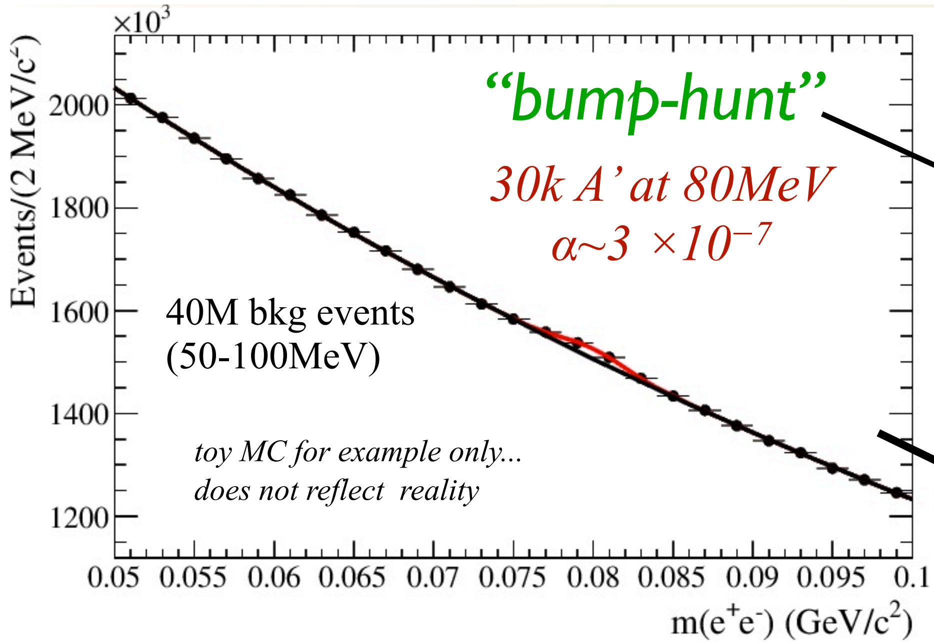
Placement of a tracking and vertexing system immediately downstream from a target and inside an analyzing magnet provides both measurements with high acceptance from a single, relatively compact detector.





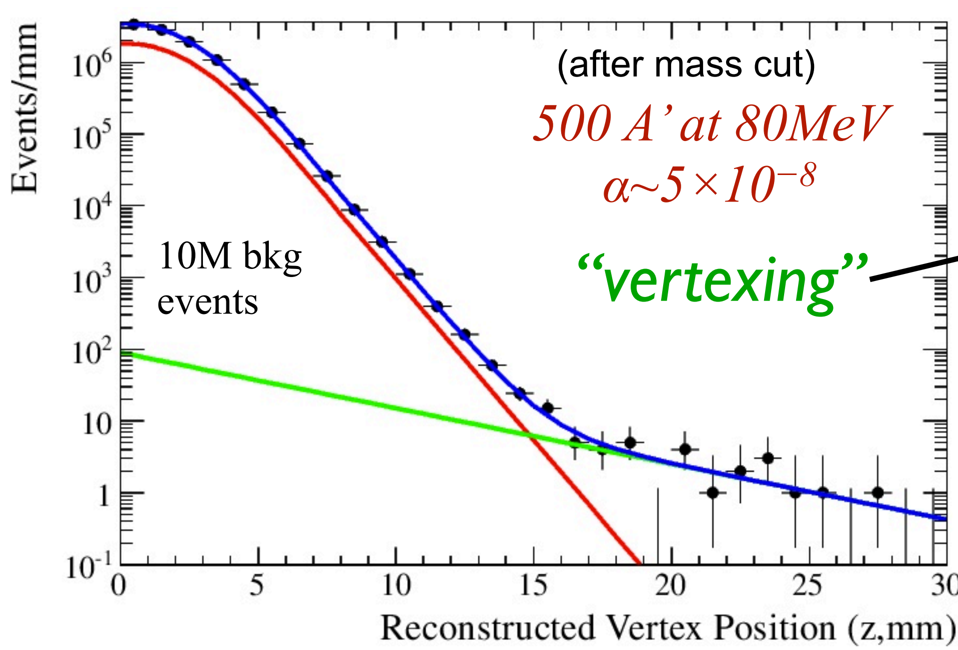
HPS Challenges

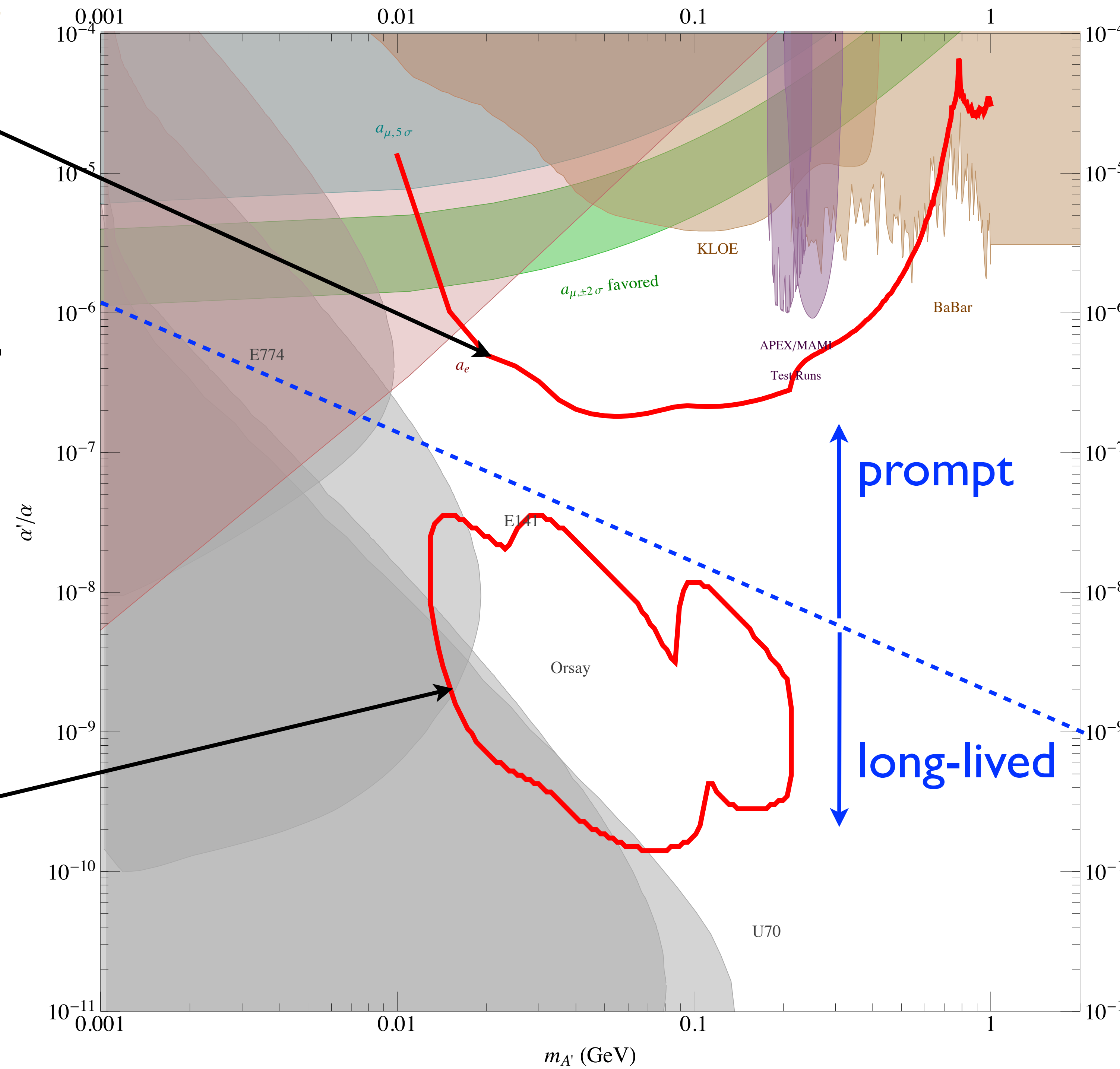
Large signal, *HUGE* background



vertexing

Small signal, *NO* background





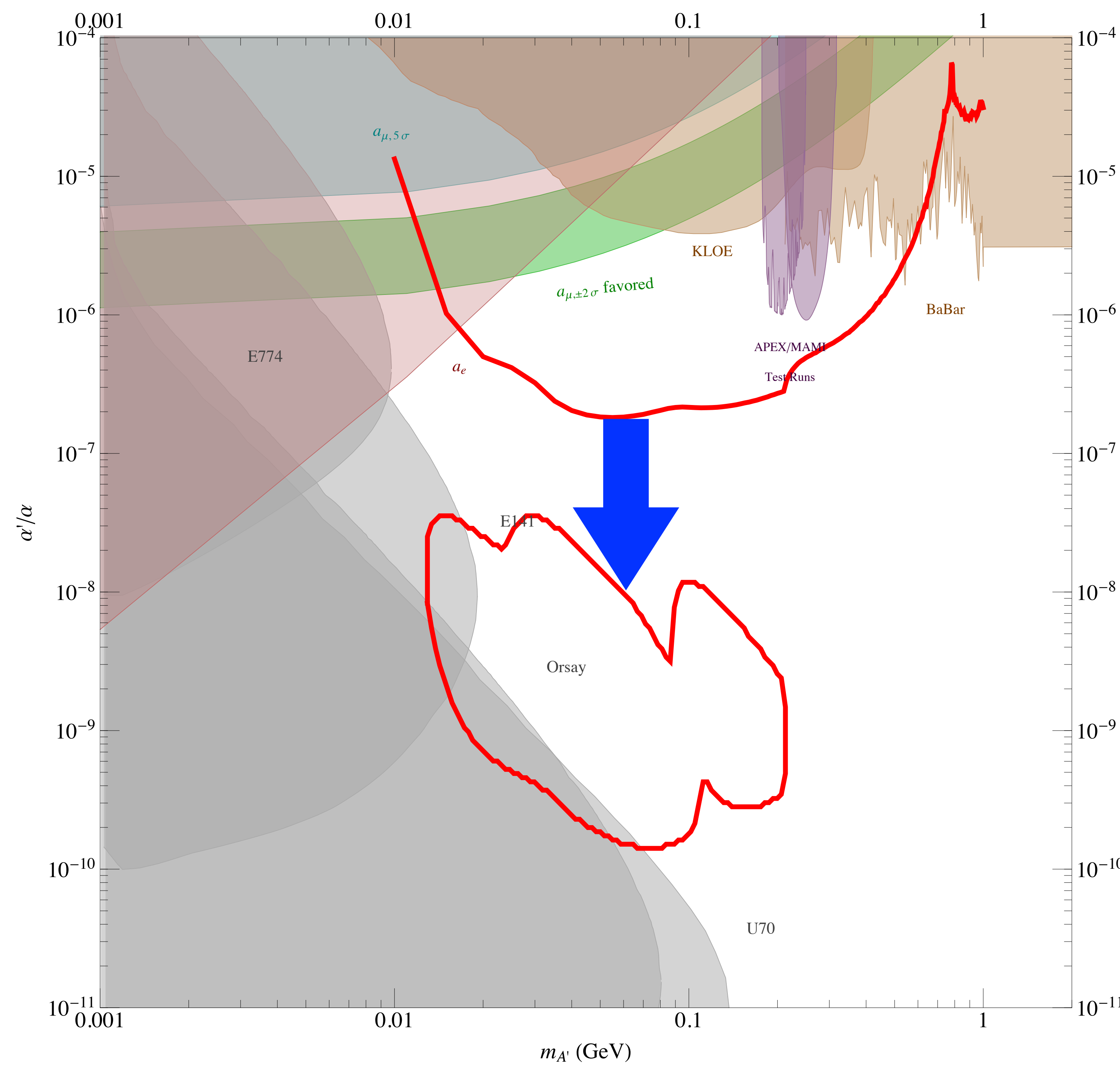
Improving HPS Bump-hunt

Eliminate backgrounds. After cuts,

- 1/4 radiative (irreducible)
  - improve mass resolution
- 3/4 Bethe-Heitler
  - improve mass resolution
  - use recoil kinematics

Collect much larger datasets

- intensity / target thickness
- running time



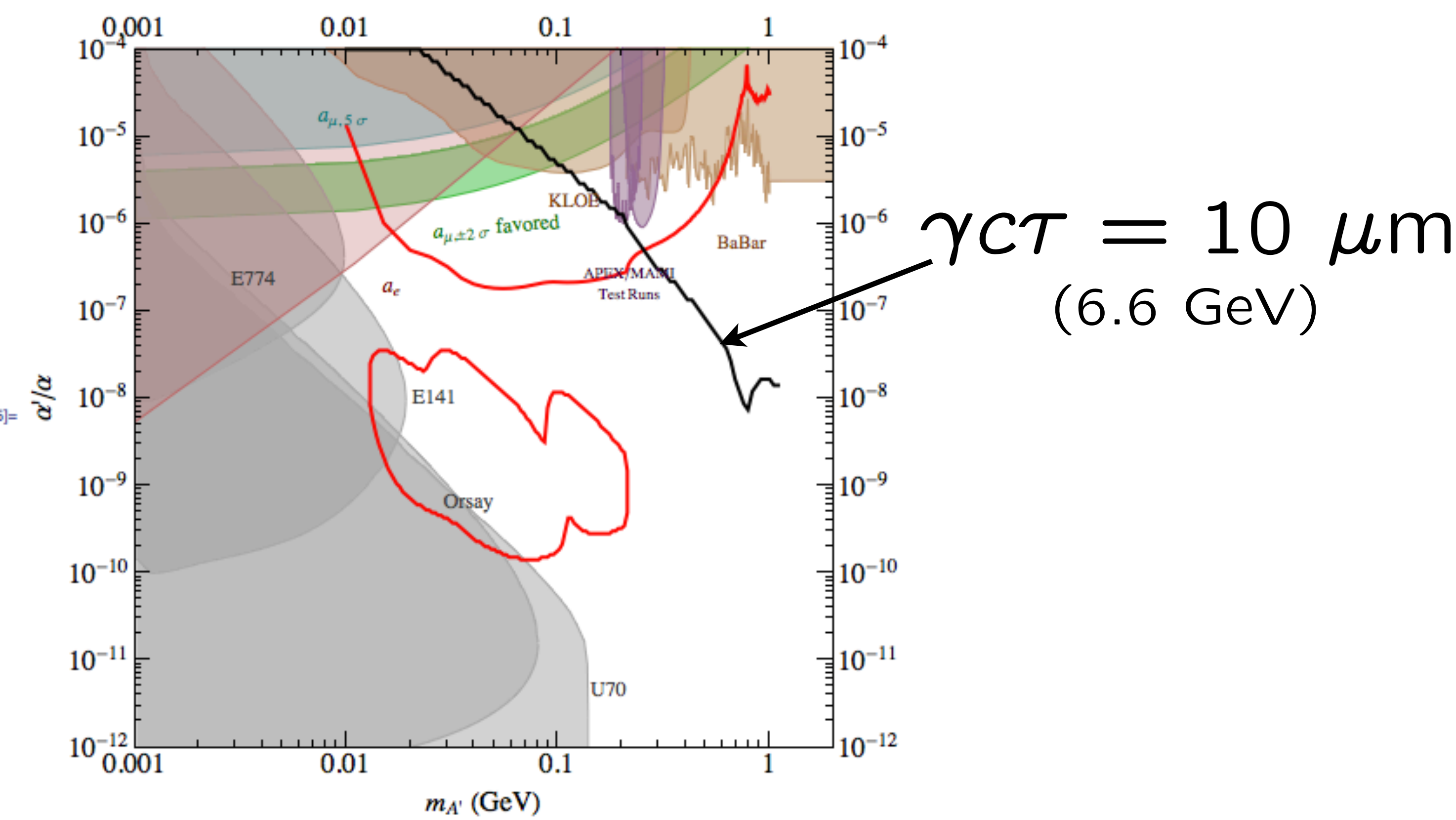
Improving Mass Resolution

Reach $\propto 1/\sqrt{\sigma_M}$:

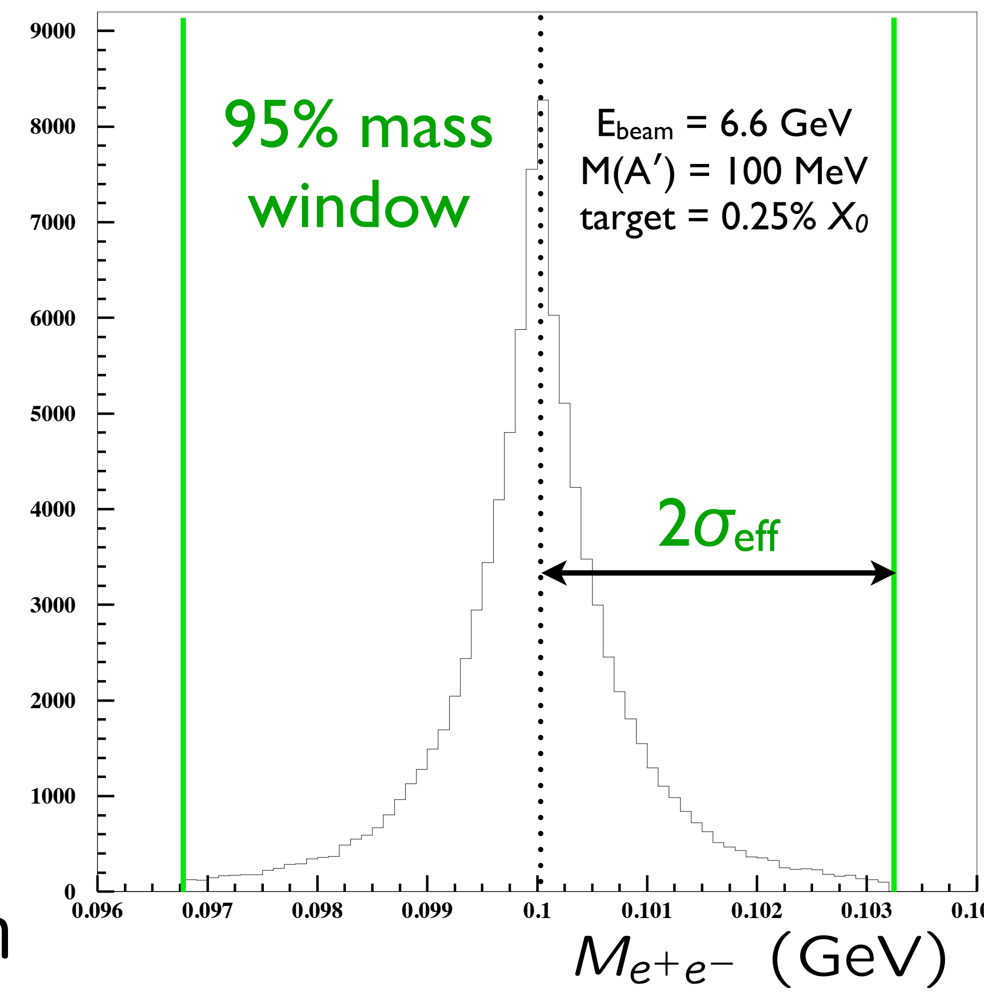
➡*would need big improvements*

- larger lever arms $(\$\ \alpha\, l^2)$
- thinner detectors (factor of ~2?)
- *recoil e^- reconstruction*

There is a fundamental limit from scattering of prompt A′ decay products in the target



Mass distribution with perfect detector



Target thickness (X_0)	Ideal-detector σ_{eff} (MeV)
0.125% = 4 μm W	1.04
0.25% = 8 μm W	1.58
0.5% = 16 μm W	2.46
1% = 32 μm W	3.98

Using Recoil Kinematics

Bethe-Heitler kinematics are very different from (irreducible) radiative tridents:

- Even after simple kinematic cuts...

  $E(e^+), E(e^-) > 0.5$ GeV

  $E(e^+)+E(e^-) > 0.8\ E_{beam}$

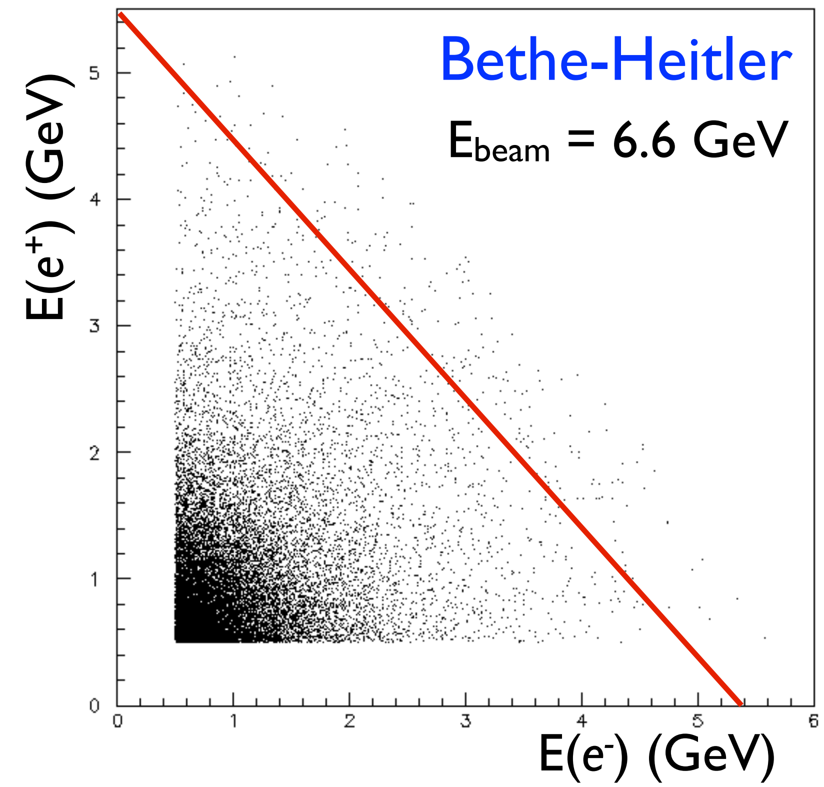
  BH tridents still the dominant background

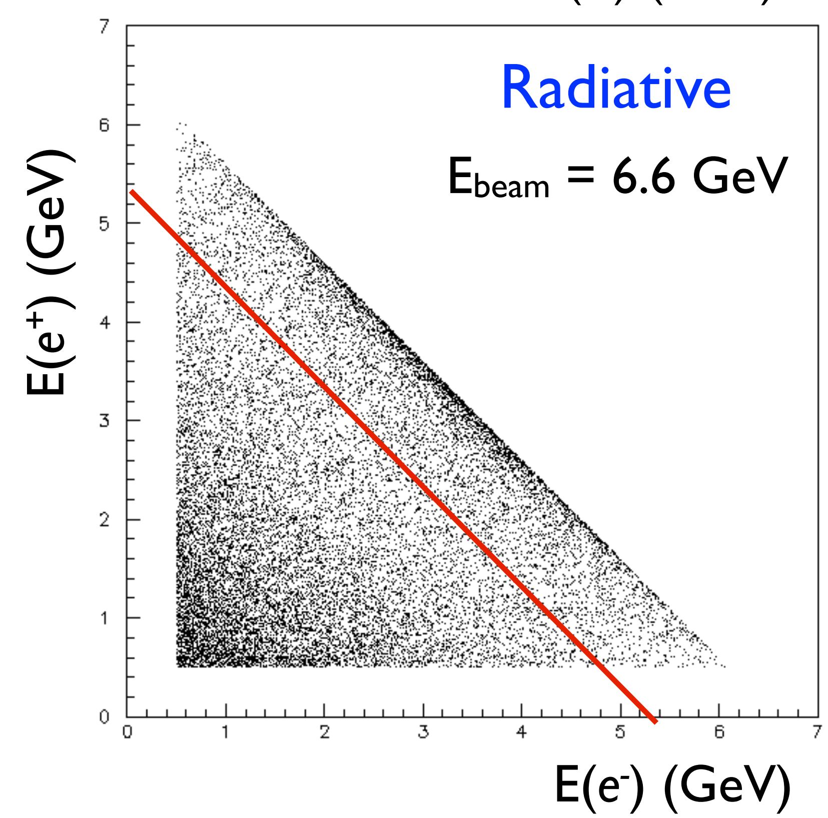
- recoiling primary e⁻ *produced more forward for BH*: encoded in e^+e^- pair, but with poor resolution

- Idea: measure recoil momentum to distinguish radiative events from BH.

  - detector for signal recoil (confirmation) ... requires very large detector

  - detector for BH recoil (veto) ... requires only small detector





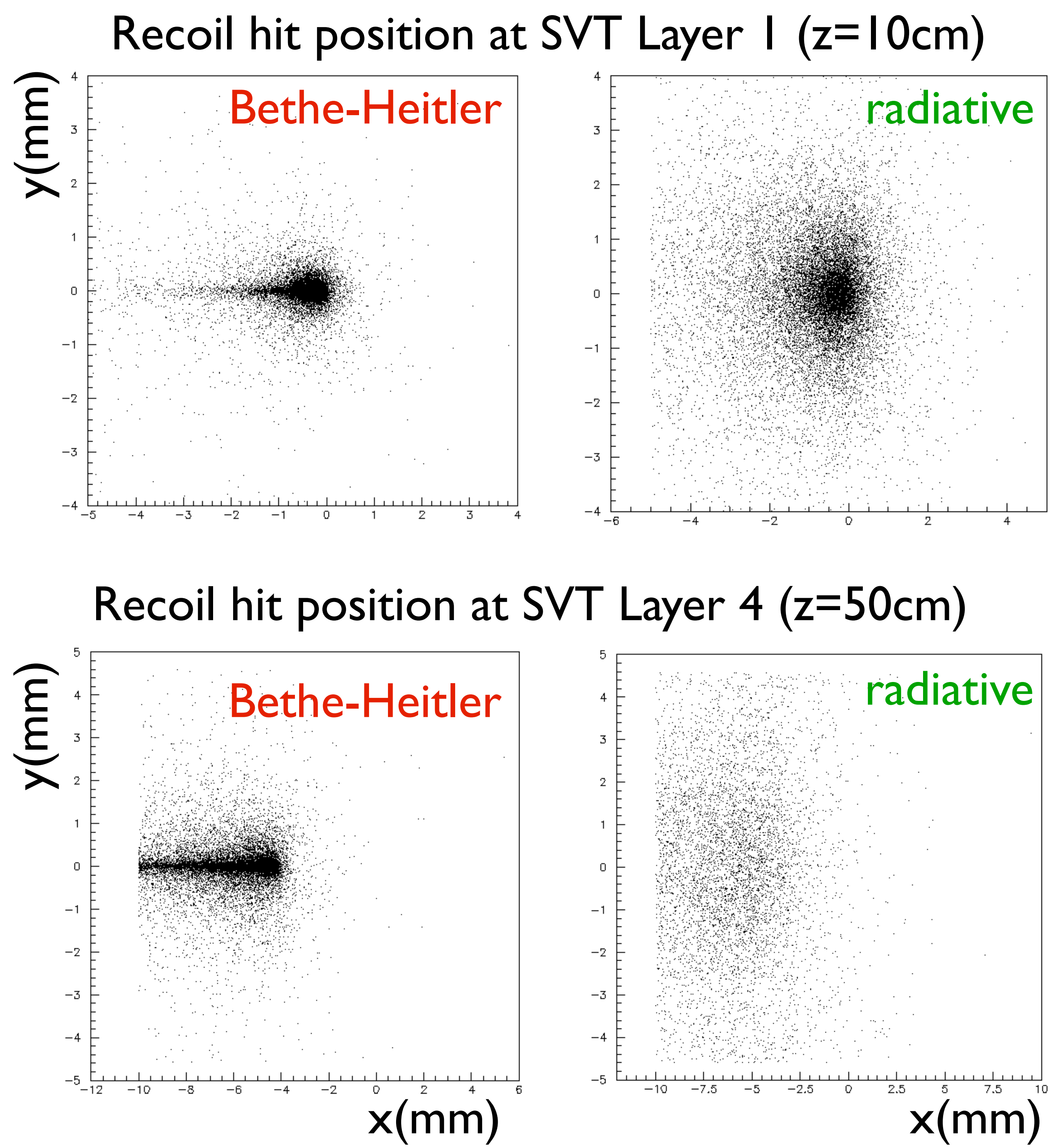
Vetoing BH Recoils

Good news:

After all cuts, there is a clear difference between the distribution of BH and radiative (A′) recoils in the detector

Bad news:

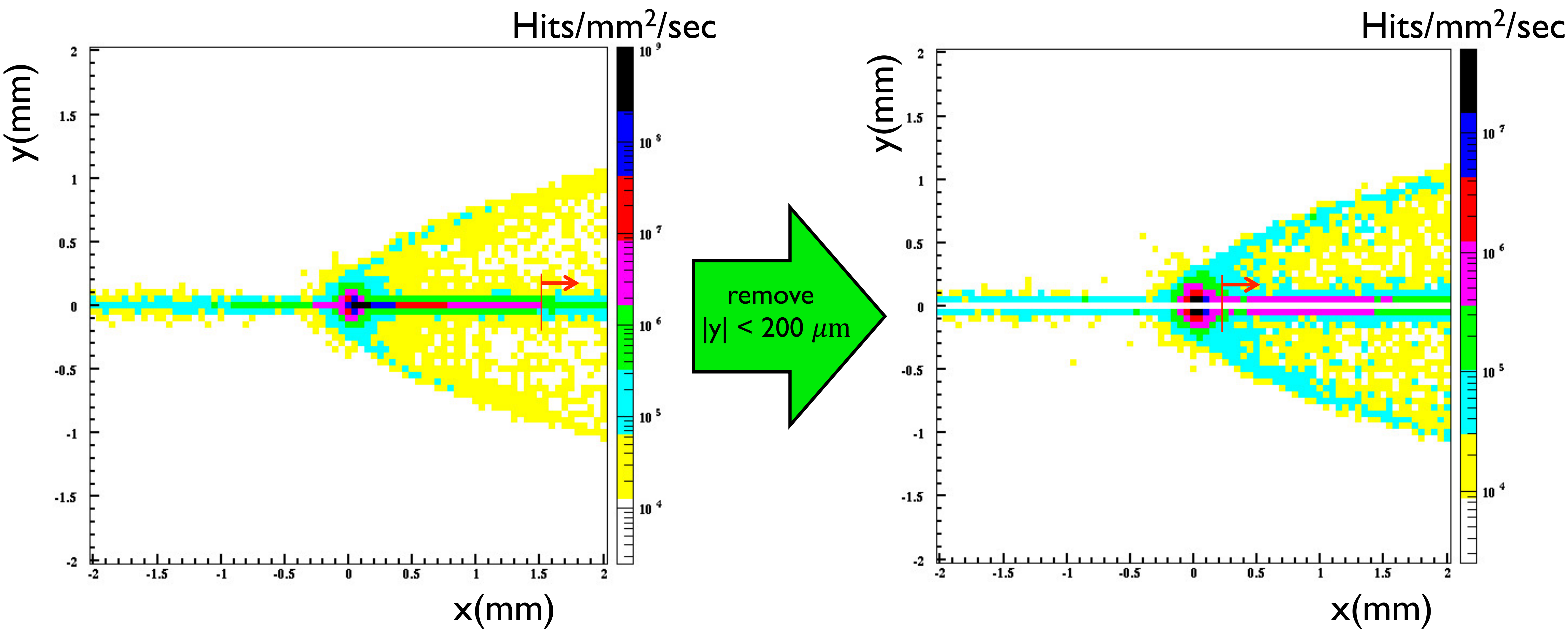
BH recoils are so focused in the "wall of flame" that detecting them will be difficult due to beam backgrounds



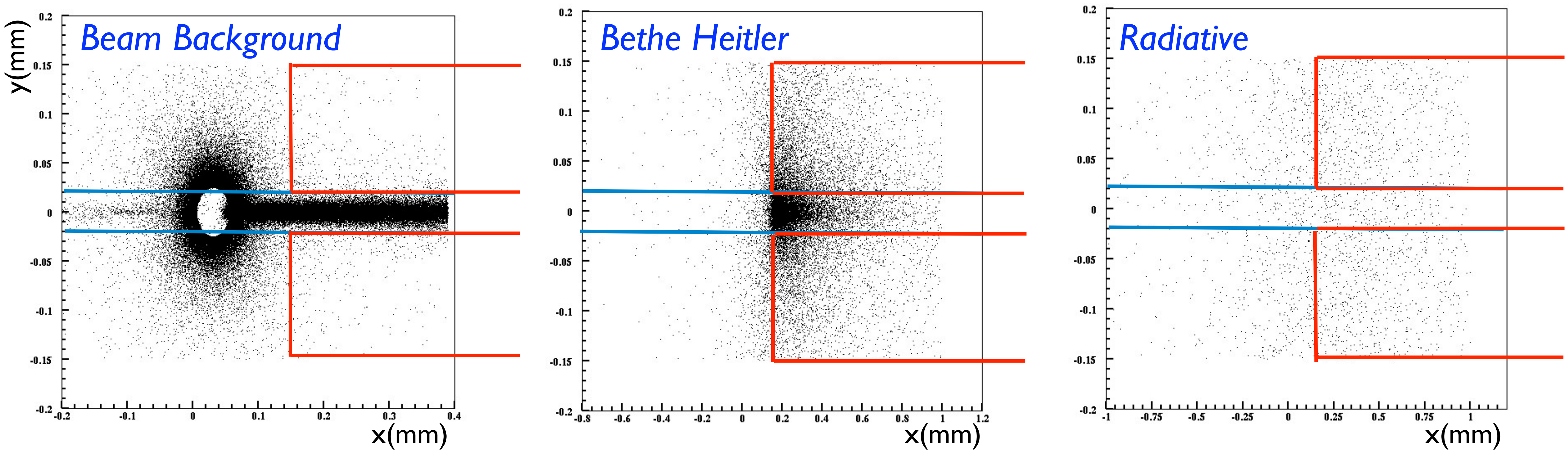
Vetoing BH Recoils

Use existing NA62 Gigatracker pixels as straw man:
1.4 MHz/mm², 100 ps time resolution

Beam Background Hit Density in Layer 1 at 6.6 GeV 100 nA



Vetoing BH Recoils



Simplistic test: veto any event with recoil track having hit in L1 of recoil detector:

	σ (μb) HPS Accepted	σ (μb) HPS Accepted after veto
BH	0.75	0.50
Rad	0.19	0.17
BH/Rad ratio	**4.1**	**2.9**

Will be additional gain with properly reconstructed production angle, but still a tough sell

Collecting Larger Datasets - HPS^2

Need 2-3 orders of magnitude:
more running time won't work.

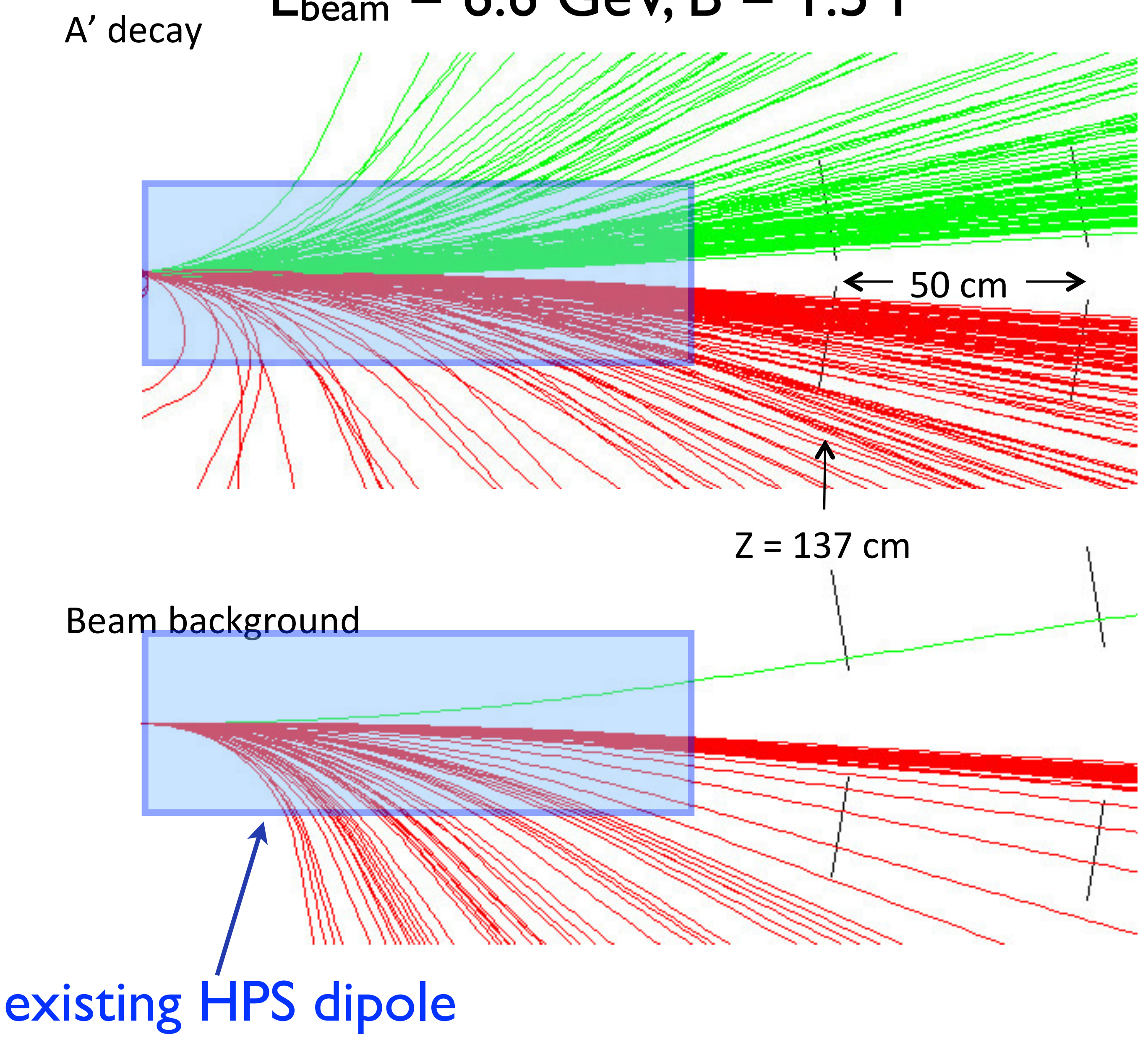
Need more luminosity X acceptance

➡double-arm HPS downstream of existing dipole

- radiation tolerant
- high-rate capable

Similar to APEX but with much larger acceptance

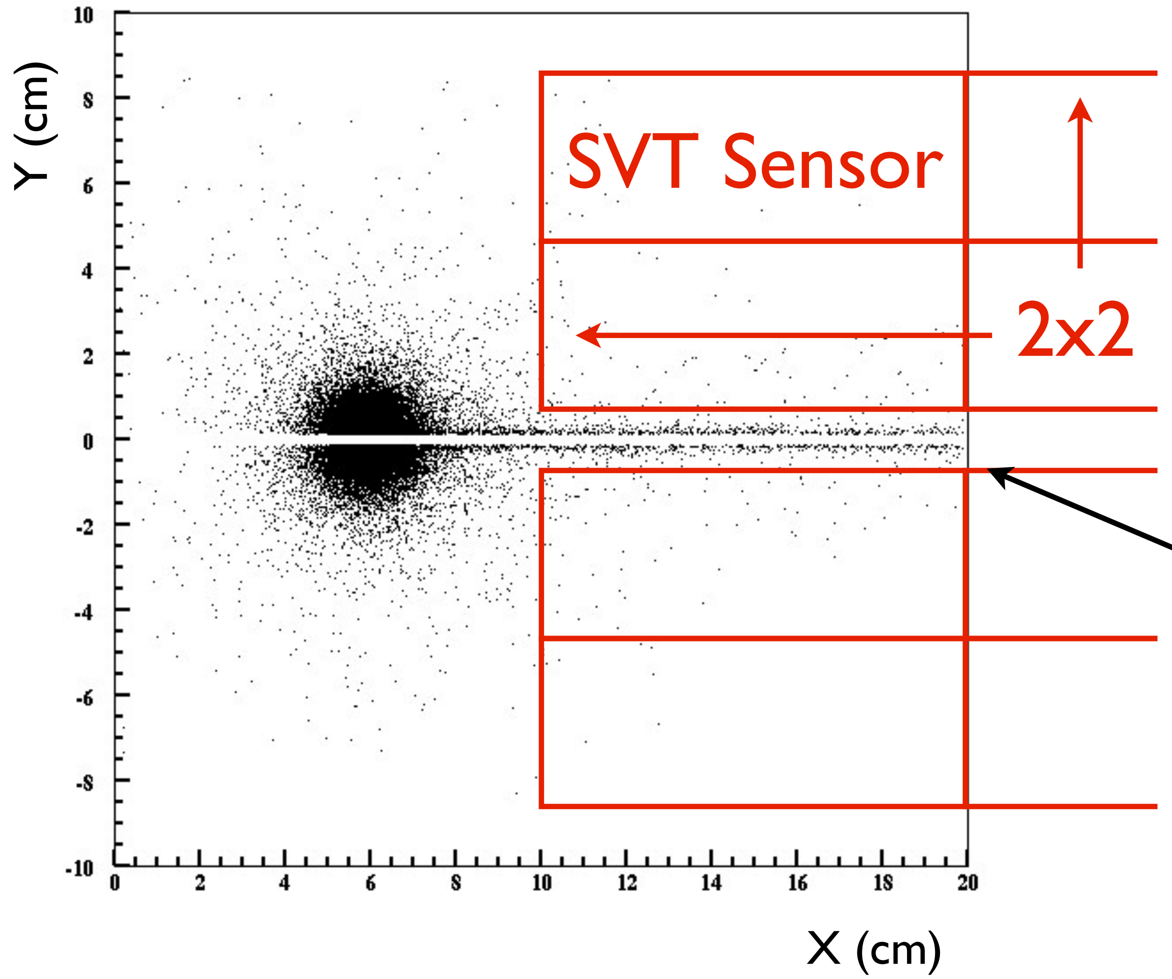
E_{beam} = 6.6 GeV, B = 1.5 T



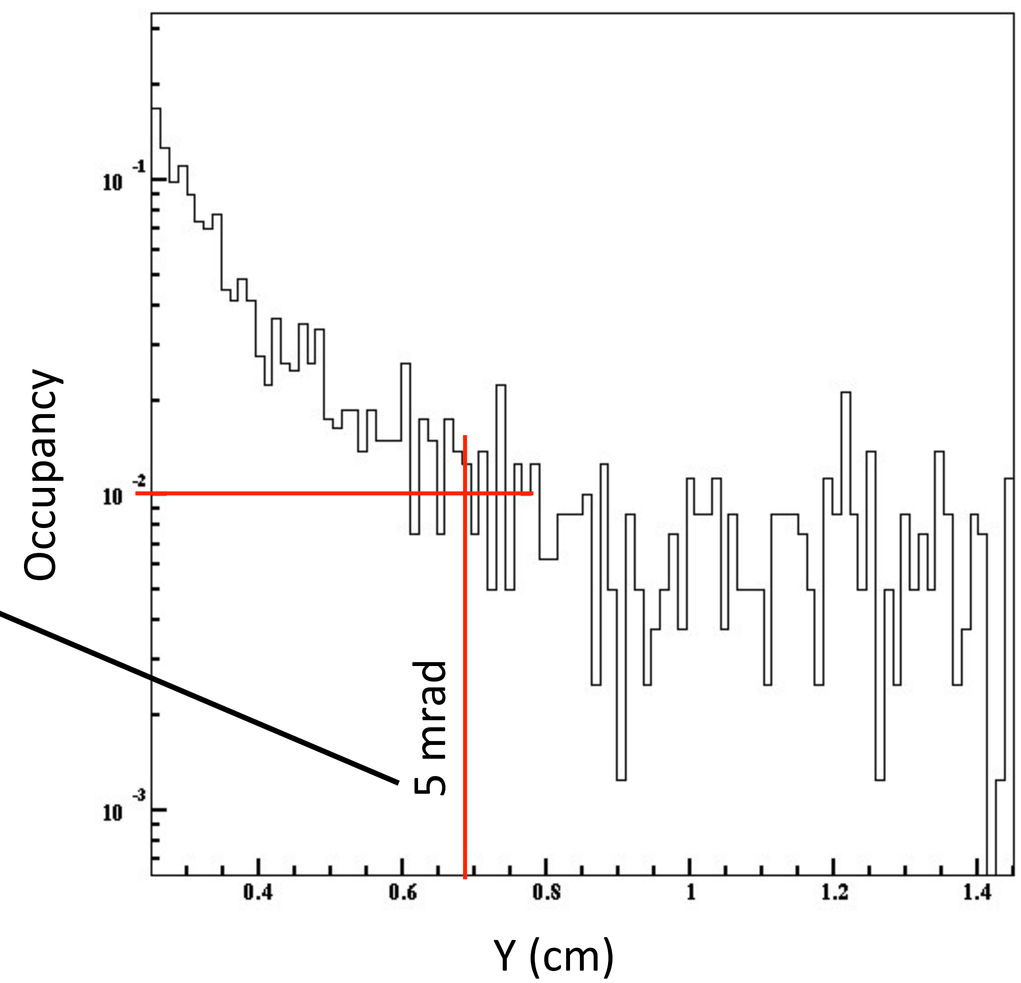
HPS^2 Dead Zone

Dead zone can be much smaller...

Beam Backgrounds



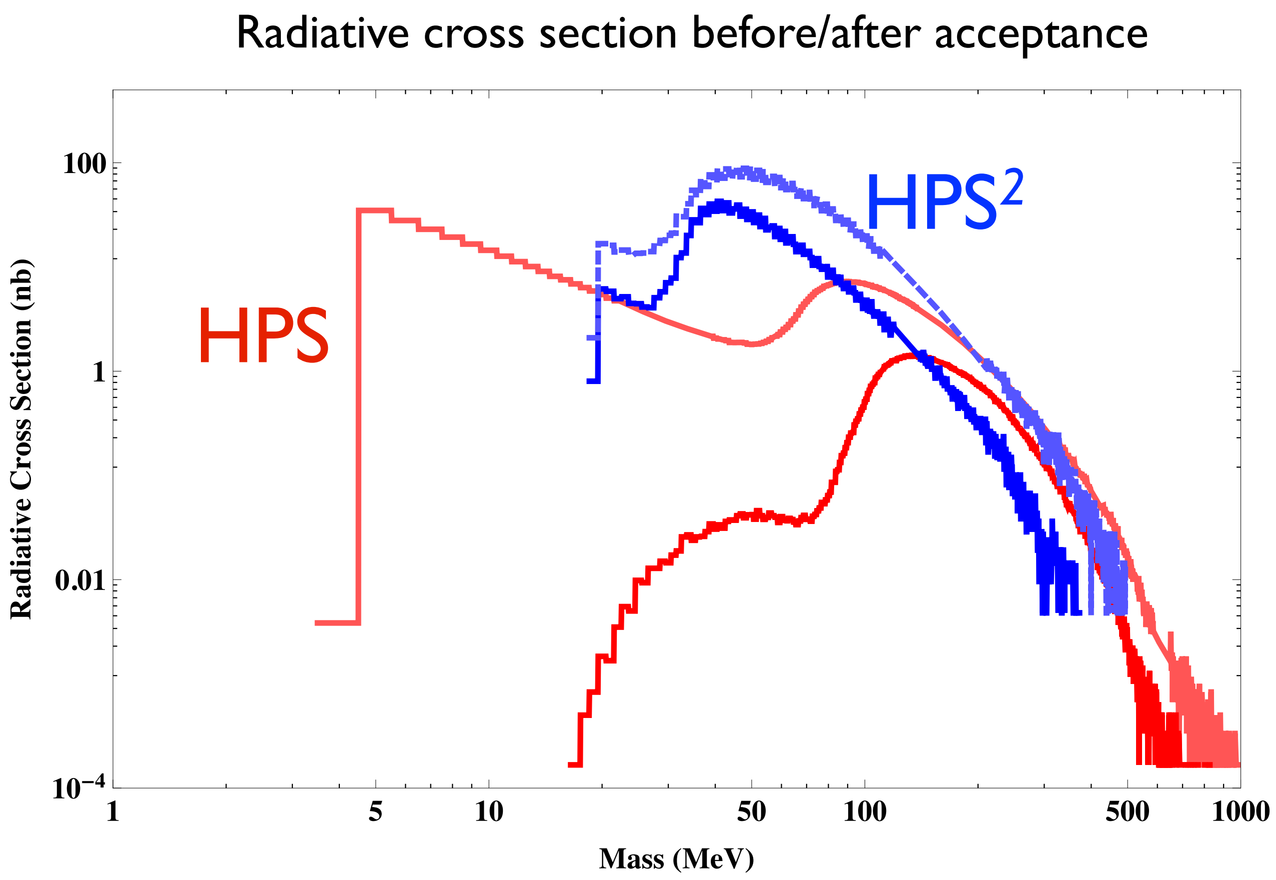
10 μA @ 6.6 GeV on 2.5% X_0 target

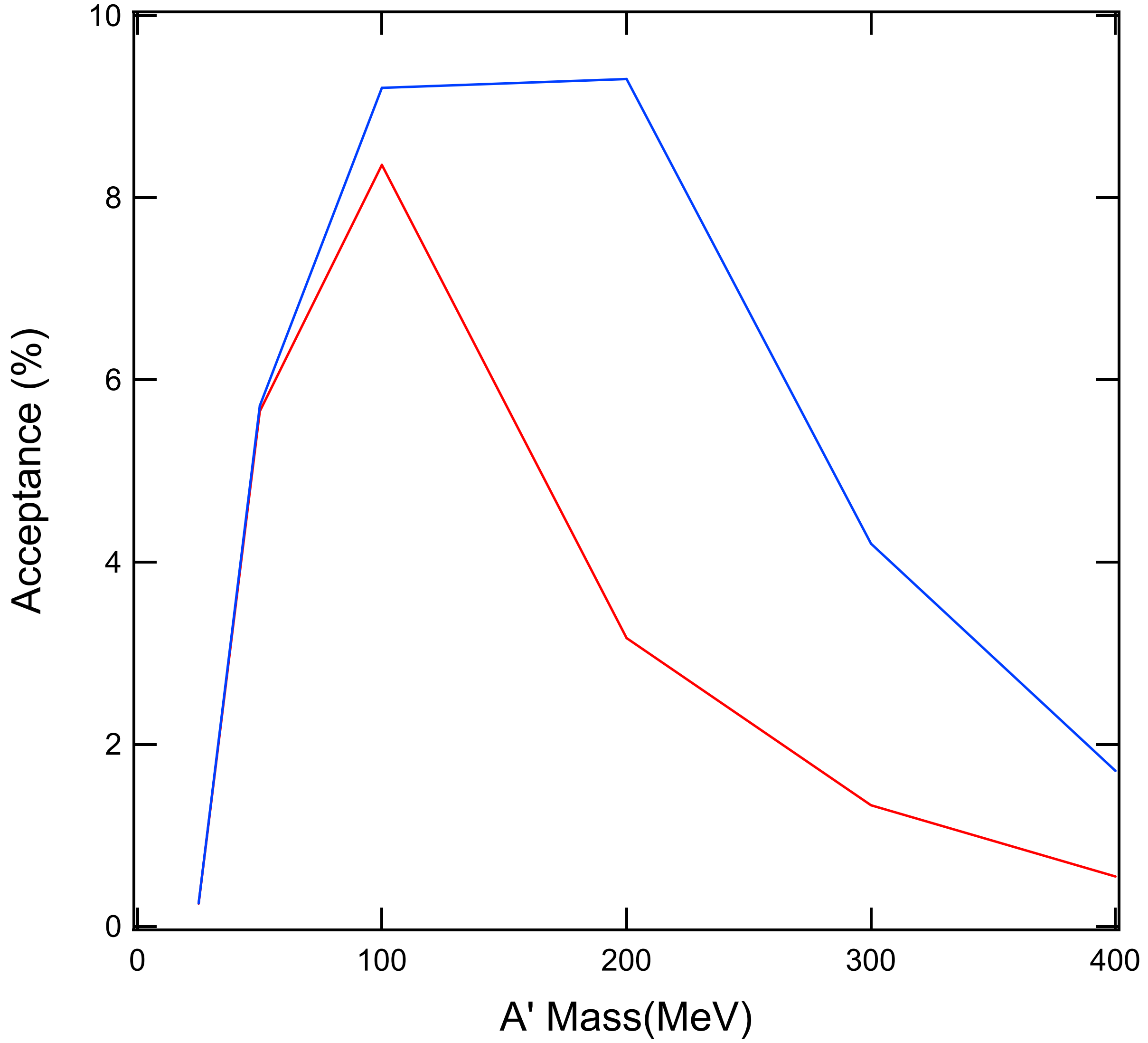


HPS^2

... resulting in much higher acceptance at low mass

E_{beam} = 6.6 GeV

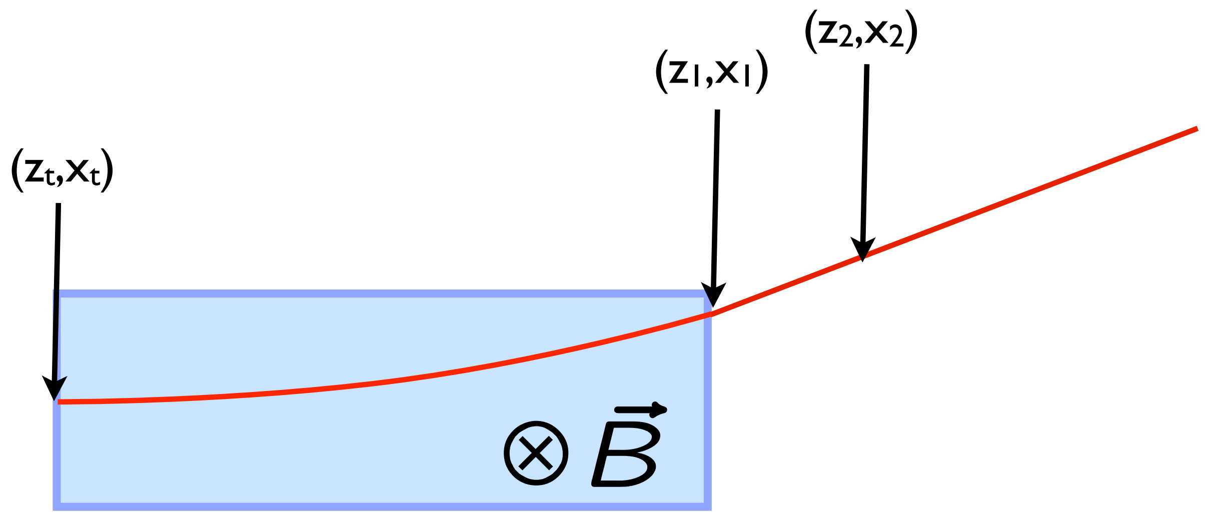




HPS^2 Mass Resolution

Assume:

- Same sensors as current SVT
- Same material budget as current SVT
- Same magnet as current SVT
- Silicon outside B-field
- Ability to constrain to target
(vertexing is possible but not trivial)



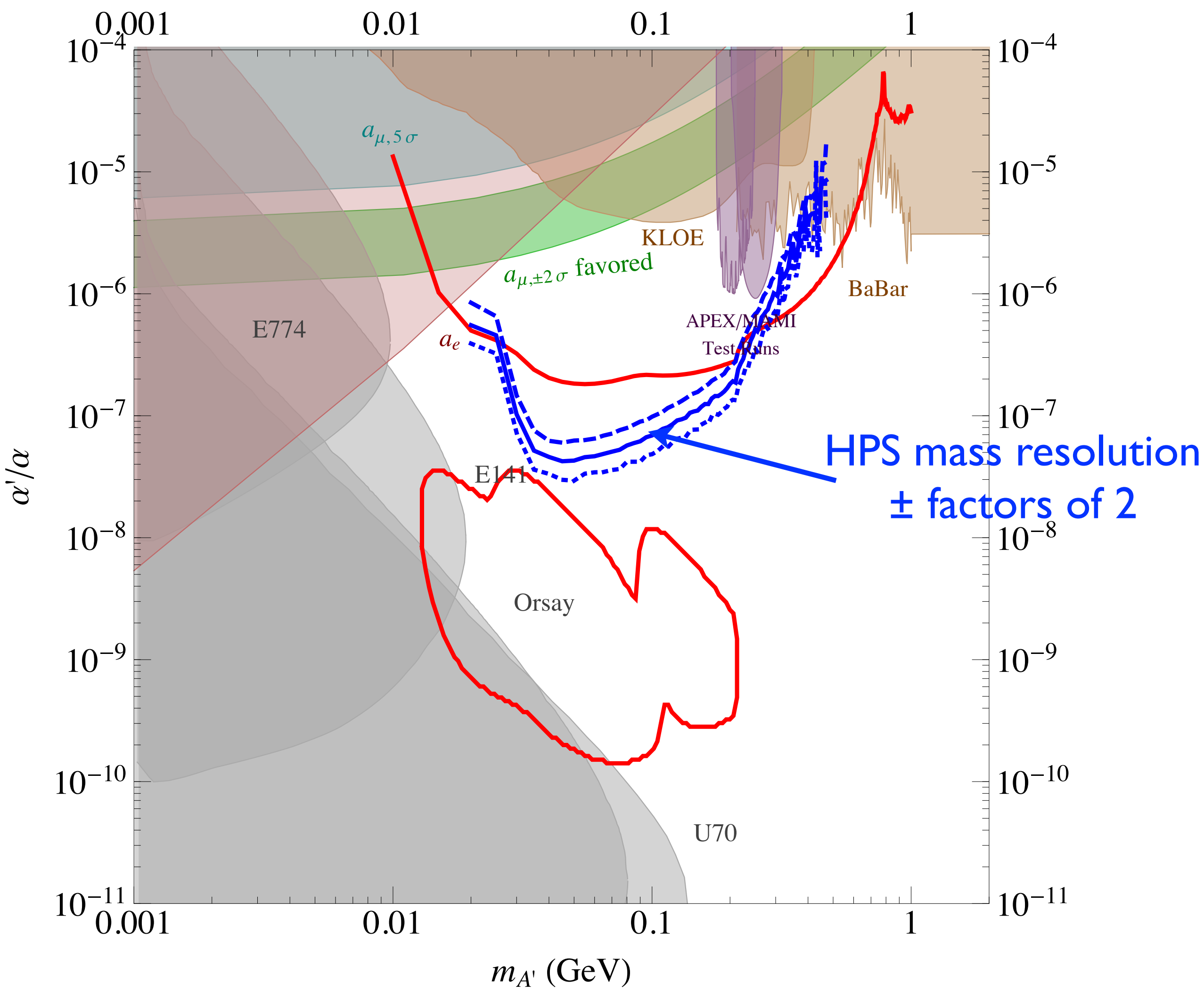
Toy model of track reconstruction at E_{beam}=6.6 GeV gives:

@ |p| = 1.3 GeV	@ |p| = 3.3 GeV
$\frac{\sigma_p}{p} = 0.4\%$	$\frac{\sigma_p}{p} = 0.3\%$
$\frac{\sigma_\phi}{\phi} = 0.25$ mrad	$\frac{\sigma_\phi}{\phi} = 0.55$ mrad

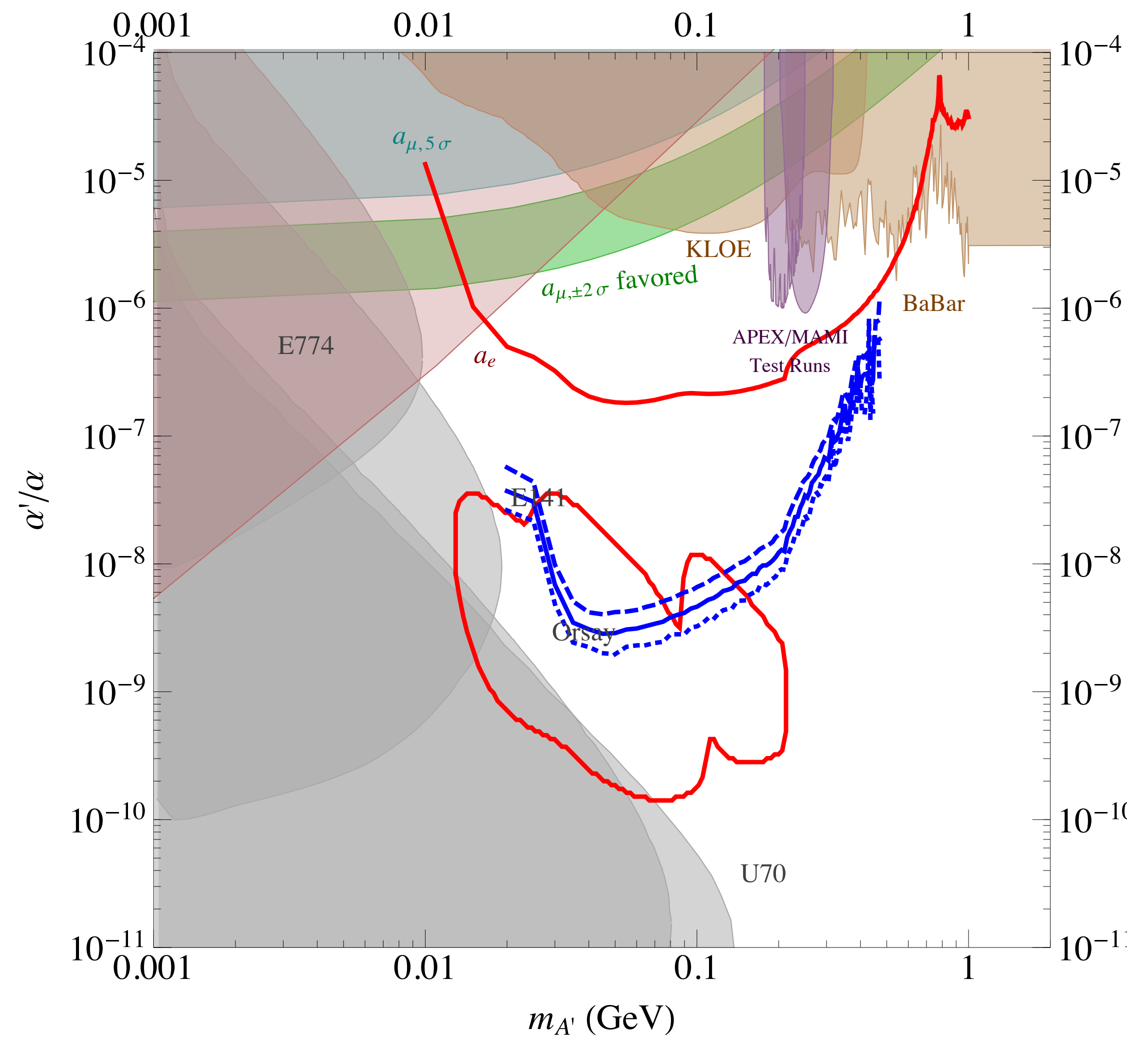
These are much better than current HPS resolutions

HPS^2 Reach - *6.6 GeV only*

15 days a 450 nA w/ 0.25% X_0 target



15 days a 10 μA w/ 2.5% X_0 target



This concept would easily close "Mont's Gap."

Improving Vertexing Reach

Improve Vertex Resolution

- Reduce material:
  difficult at these rates

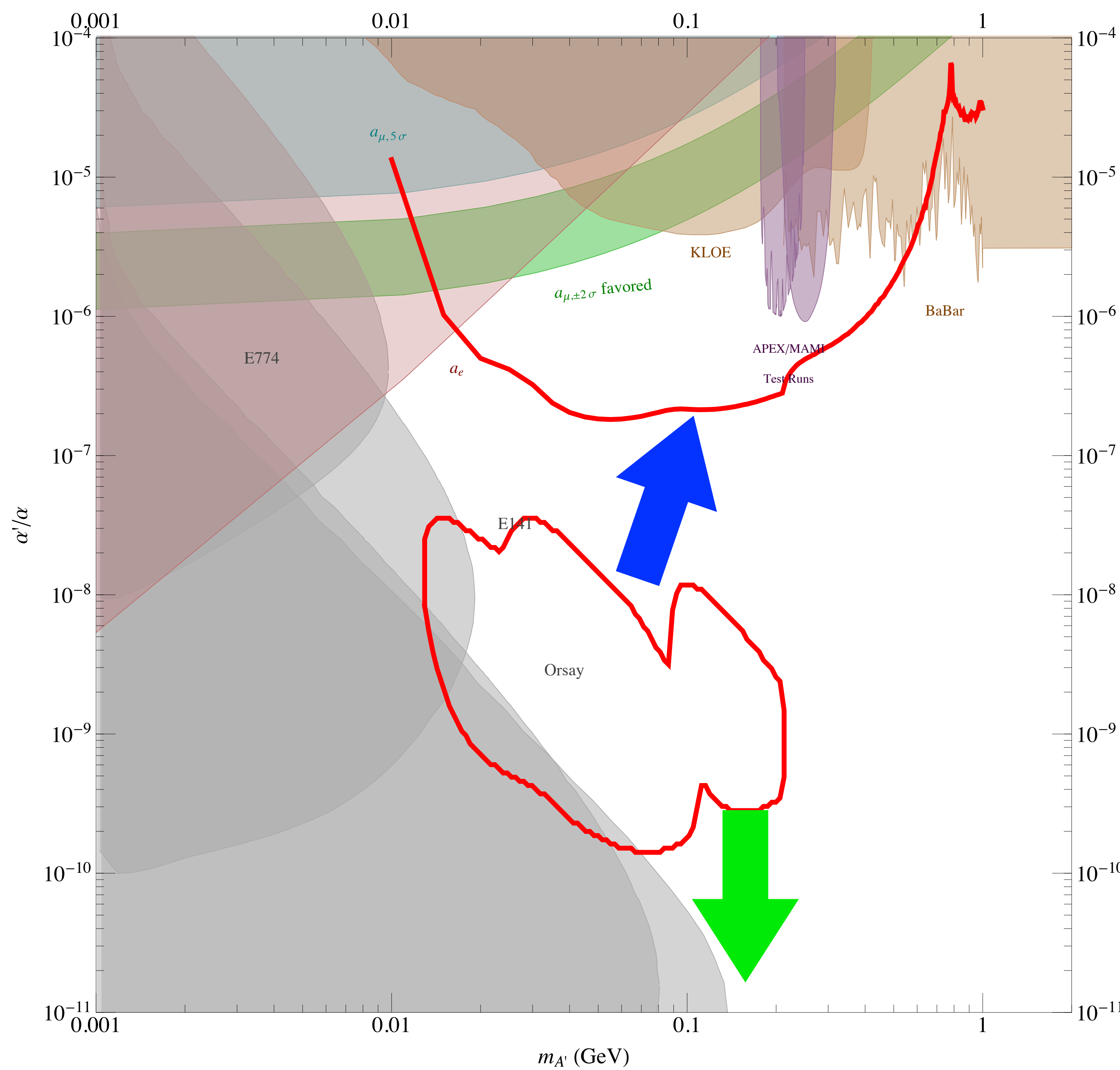
- Move L1 closer to target:
  difficult at these rates

$\gamma c\tau \ \alpha \ 1/\epsilon^2$ ⇒ hard to gain reach

Increase luminosity and acceptance for longer lifetimes

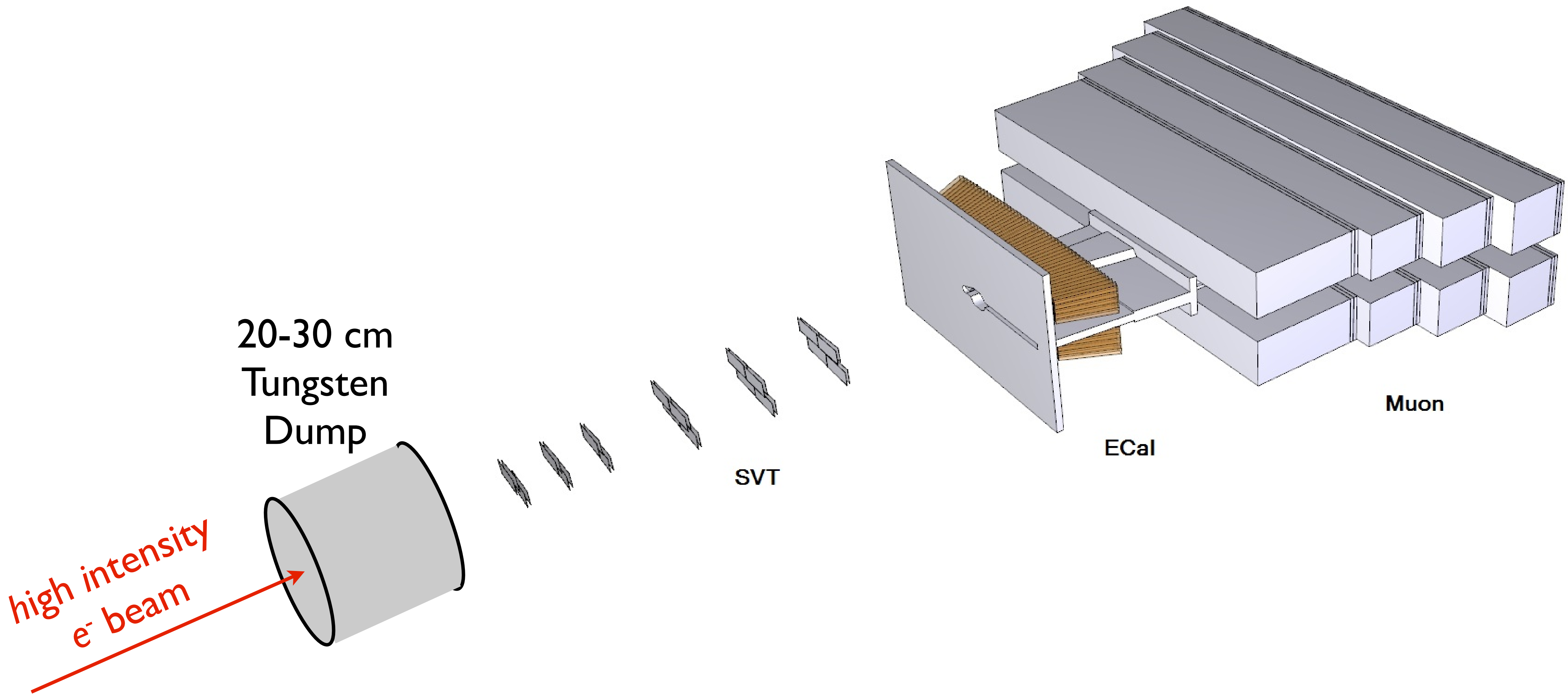
- increase intensity and target thickness

- increase distance to target



Improving Vertex Reach - *hi*HPS

Run HPS downstream of a shallow tungsten dump



Huge increase in luminosity, eliminates backgrounds

*hi*HPS Limitations

Radiation:

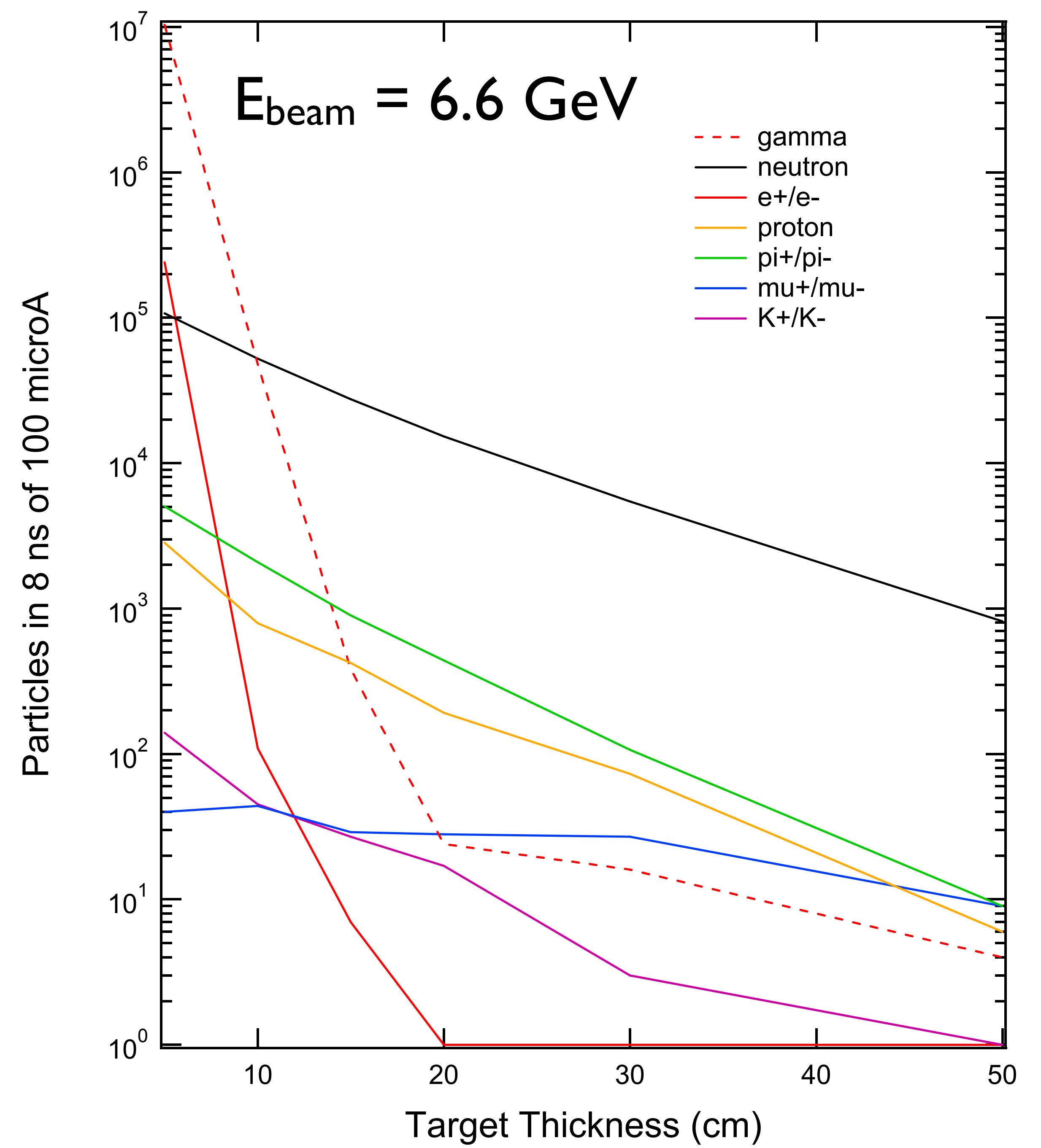
- Tracker is illuminated with large flux of forward-going fast neutrons
- At 100 μA, current SVT survives about *15 hours* for 20 cm dump

➡30 cm dump reduces flux by factor ~4

Power:

- Dump absorbs entire beam power: *660 kW* @ 100 μA at 6.6 GeV.
- Cooling for dump will be difficult

Operate at 10 μA for 1 month: q_{tot} = 20-25 C



*hi*HPS Occupancies

Hit/track occupancies are managable:

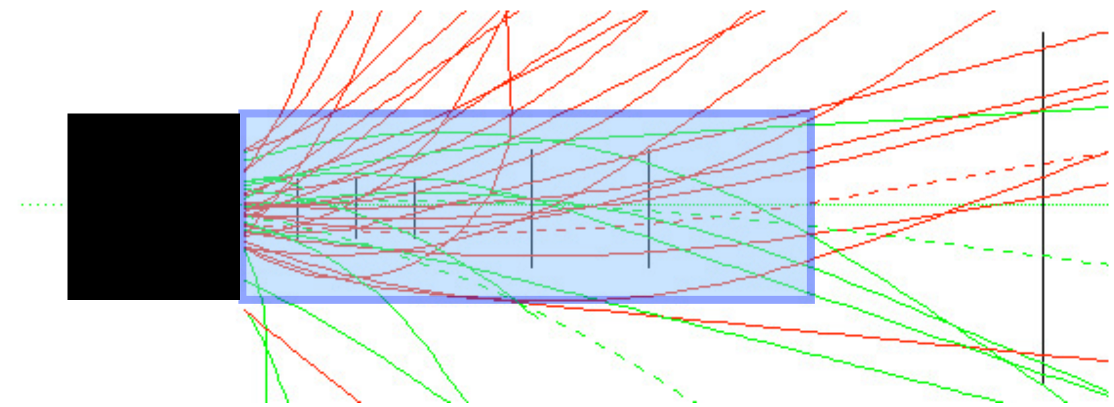
- Average ~4 charged tracks in each half of SVT per 8 ns window
- Mostly $\pi/p/\mu$. Rate of $e^{\pm}$ negligible

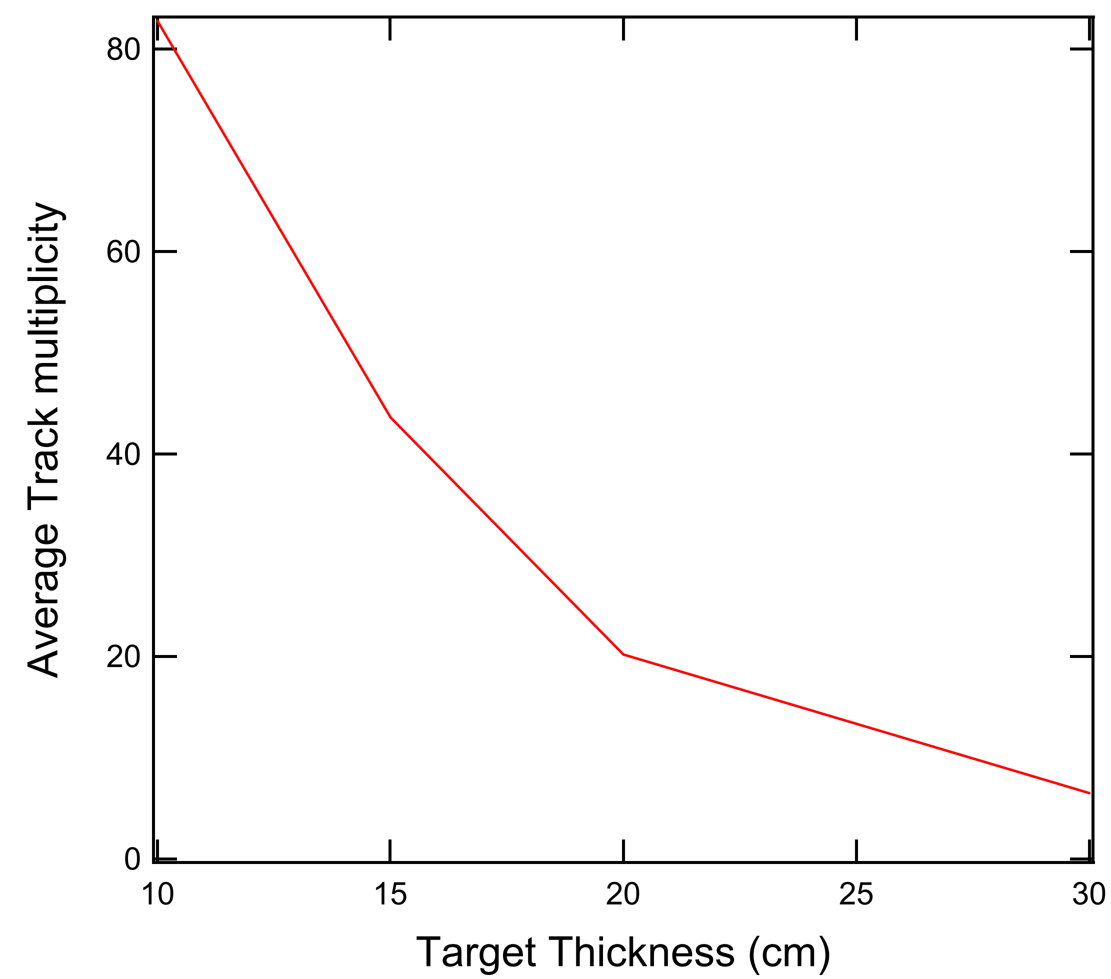
Once we...

- Trigger on pairs with ECal
- Require matching tracks
- Require tracks make vertex
- Require vertex downstream of target

Expect a zero-background experiment

Charged tracks in 8 ns



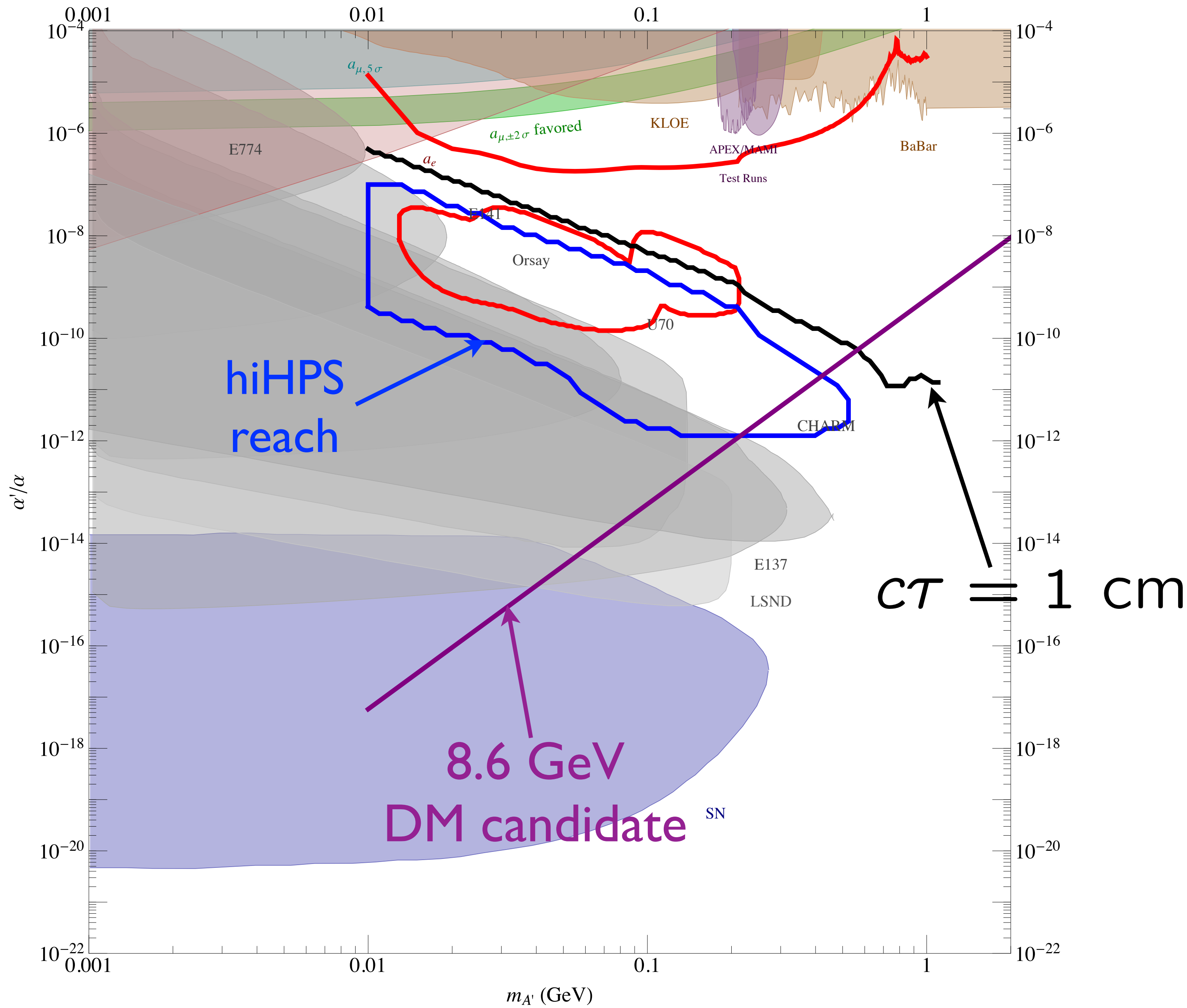


*hi*HPS Reach

Significant improvement over previous dump experiments:

- Covers a large fraction of HPS vertexing reach.
- Extends low-coupling sensitivity to new mass regime
- Intersects region interesting for low-mass DM candidates.

10 day 6.6 GeV run @ 10 μA



Conclusions

- Rethinking the HPS experiment, augmenting existing detector elements and/or deploying them on a larger scale can greatly enhance reach
- Nearly all of most interesting parameter space below $M_{A'} < 200$ MeV (and *most* below 500 MeV) can be covered with these concepts
- Although somewhat more complex, both of these concepts are still relatively inexpensive
- There will be more crazy ideas to follow these in the coming months and years. The next (very tough) nut is higher masses, which will be fun to think about how to crack!