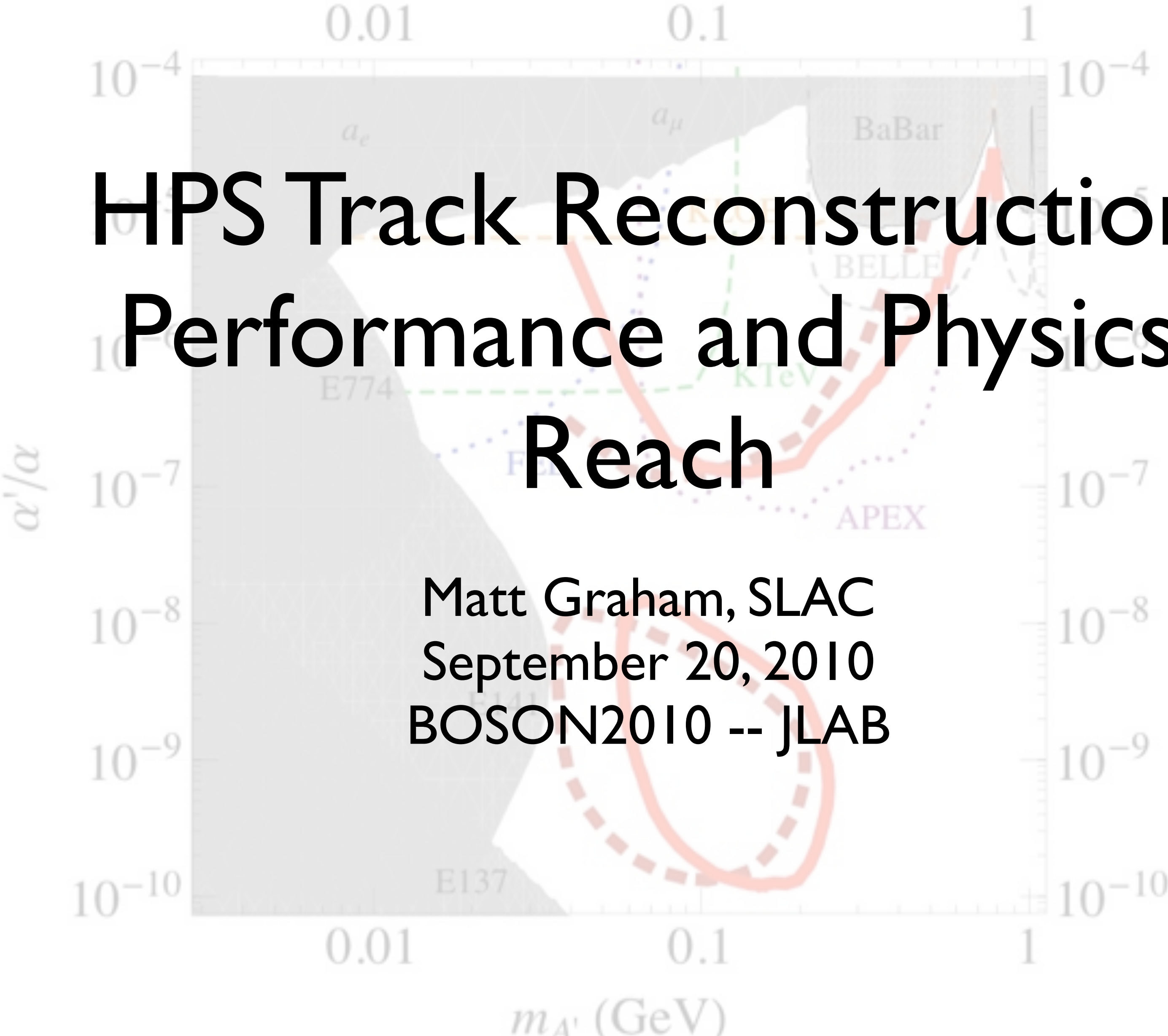

HPS Track Reconstruction Performance and Physics Reach

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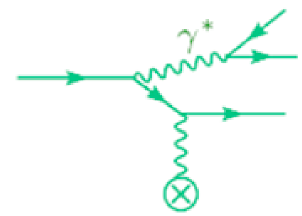
BOSON2010 -- JLAB

Intro

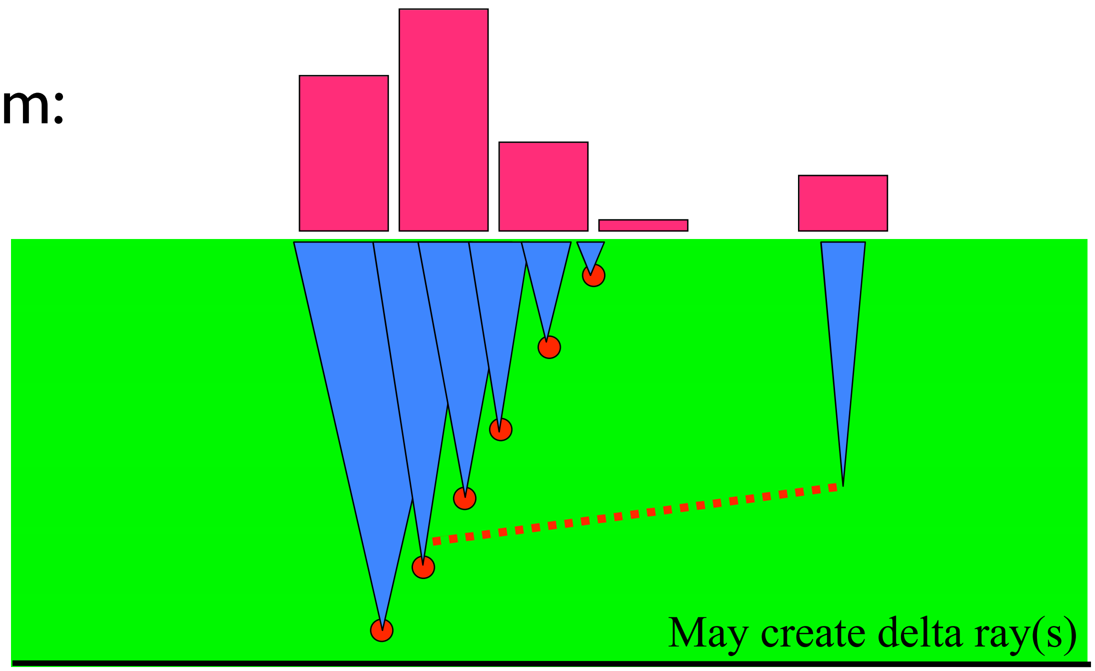
$$\frac{d\sigma\left(e^- Z \to e^- Z\,(A' \to e^+ e^-)\right)}{d\sigma\left(e^- Z \to e^- Z\,(\gamma^* \to e^+ e^-)\right)} = \left(\frac{3\pi\epsilon^2}{2\,N_{eff}\,\alpha}\right)\left(\frac{m_{A'}}{\delta m_{A'}}\right)$$



- We want to search for the A' decay over a large background of mostly Bethe-Heitler and radiative events
- We will take two approaches: a brute force "bump-hunt" and a lower background displaced-vertex/bump-hunt search
  - covers different part of the α'/α parameter space
- As already mentioned, need very good mass and vertexing performance out of the HPS detector
- By "very good" we mean ~1-2% Δm/m and rejection of prompt vertices of $\sim 10^{-6}$ level around ~1cm from target
- We use a detailed tracker simulation ("lcsim") to optimize the detector layout and estimate our performance

org.lcsim simulation

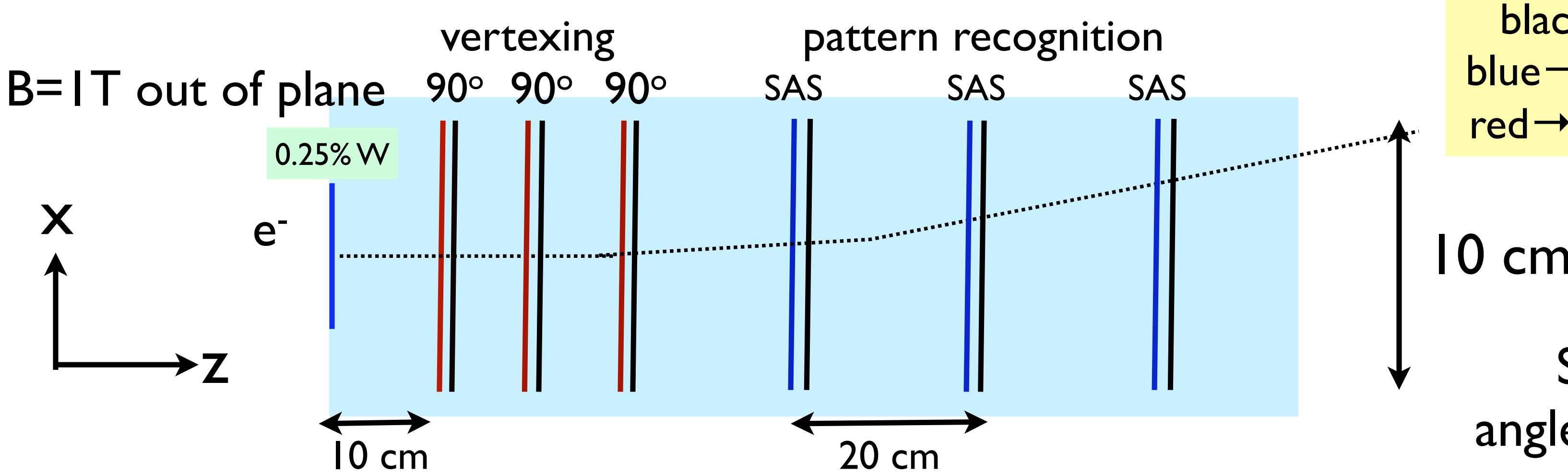
- We use the org.lcsim package for tracker optimization studies
  - designed for linear collider studies, java-based package allows for quick-and-easy testing of many different detector layouts
- Uses GEANT4 to simulate interactions with active and dead material
- Full digitization algorithm:
  - energy deposited in slices, drifted to surface accounting for diffusion and Lorentz angle
  - appropriate readout of strips is accounted for



org.lcsim reconstruction

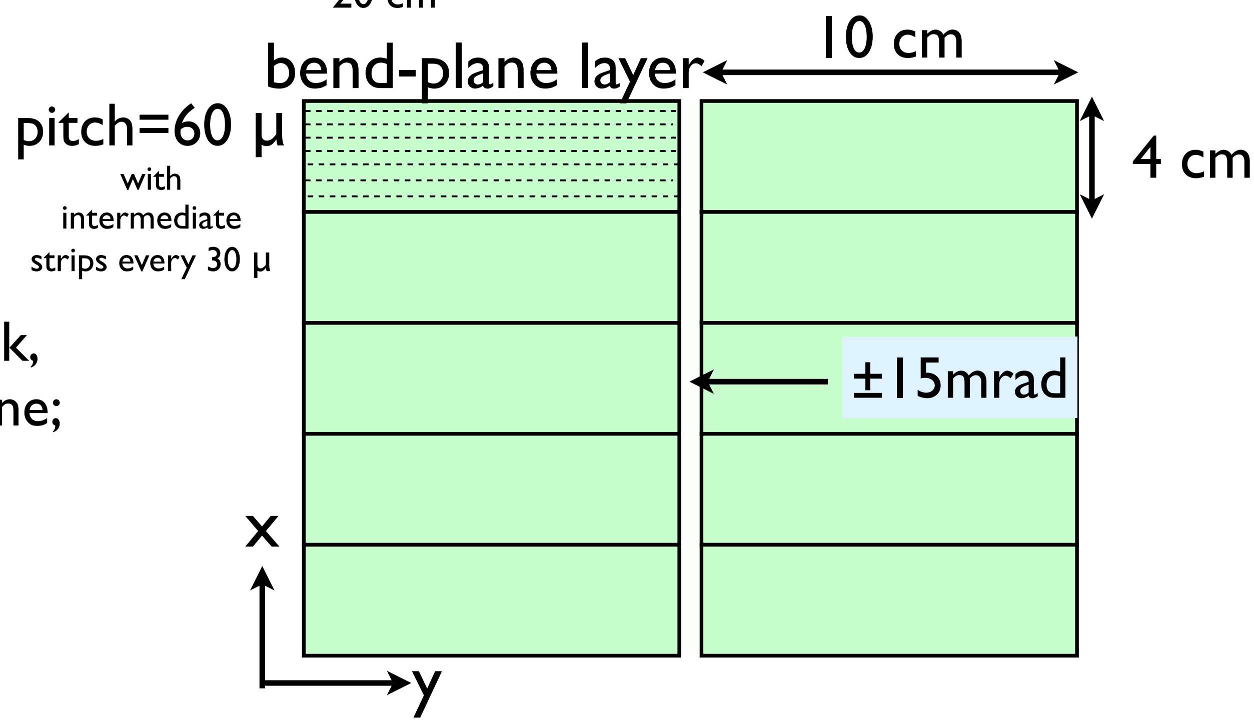
- org.lcsim also contains track-finding and track-fitting algorithms
  - uses same geometry for simulation/reconstruction
- Track-finding uses a “seed-confirm-extend” approach
  - helix fit is performed for each additional hit added
  - multiple scattering accounted for
  - require tracks to have minimum number of hits, pass goodness-of-fit (χ^2), some basic direction cuts
- For what I’ll show, we’ve used an “inside-out” strategy requiring hits at least in the first 5 layers (6th optional)
  - done some preliminary studies dropping the layer 1 requirement...will not show

Layout and Setup



black→Bend
blue→SAS-Bend
red→Non-bend

Stereo angle=50mrad



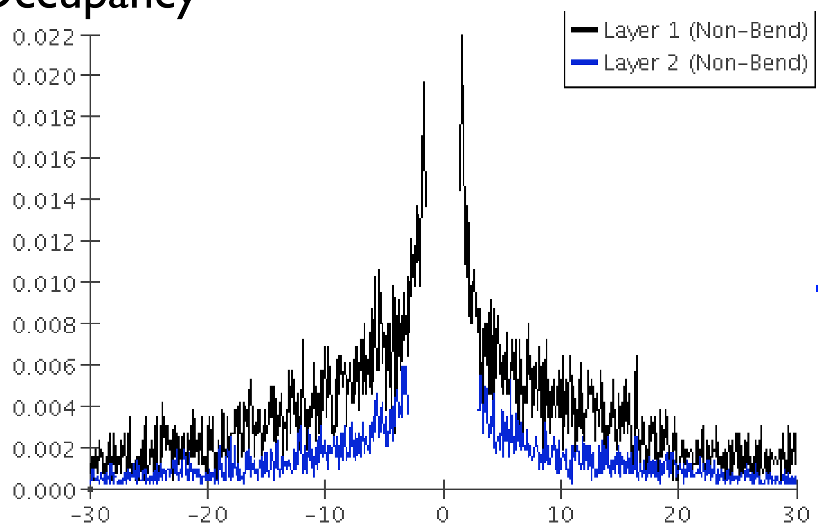
Silicon is 320μ thick, "services"=0.2%/Plane; detector is in ***vacuum***

Tracking Performance Studies

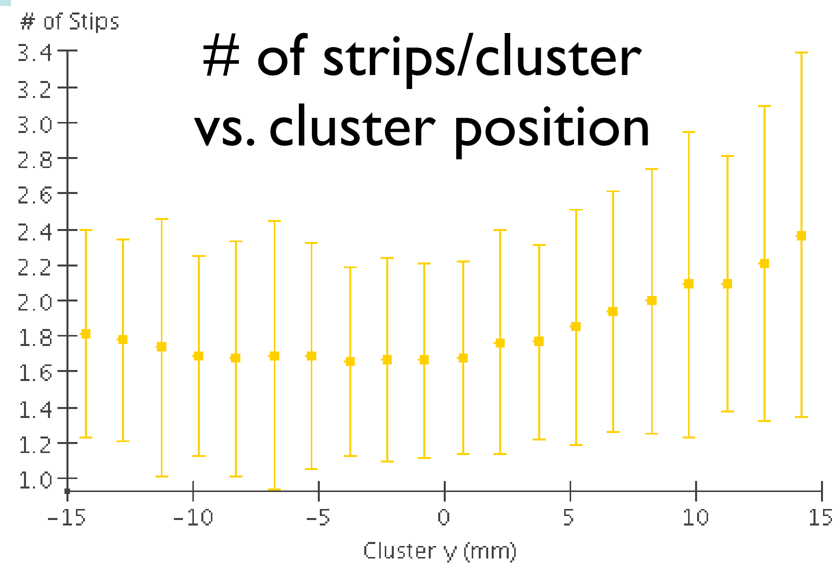
- For most studies shown here, we've included radiative events at a certain mass atop "beam background"
  - simulate the beam by passing 7.5ns×400nA electrons/event though the target
  - radiative bkg simulated by taking A' events decaying promptly at the target
- For vertexing, need to investigate tails down to 10^{-6} after acceptance+efficiency!
  - generated one mass point (200MeV) with >100M events
  - a couple of others with ~30M events
  - others, small samples just to check acceptances

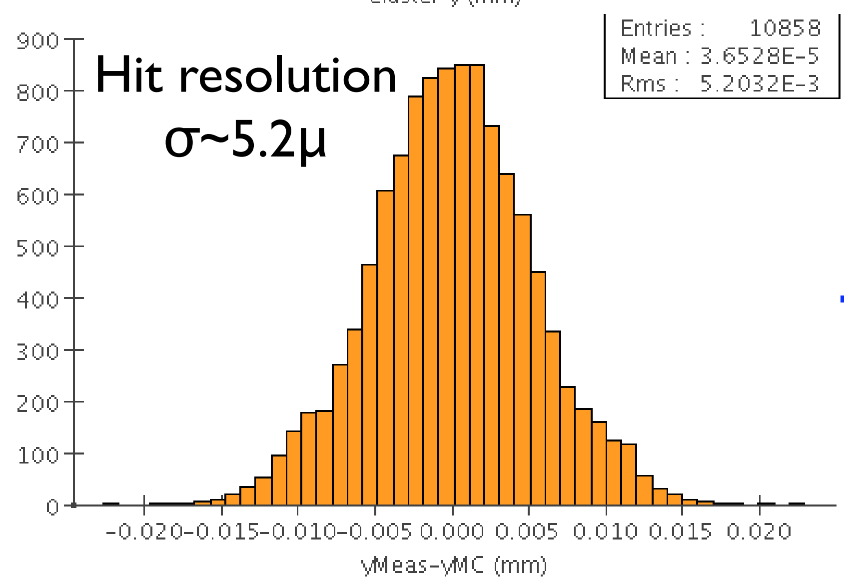
Occupancies etc...

Occupancy



y position(mm)

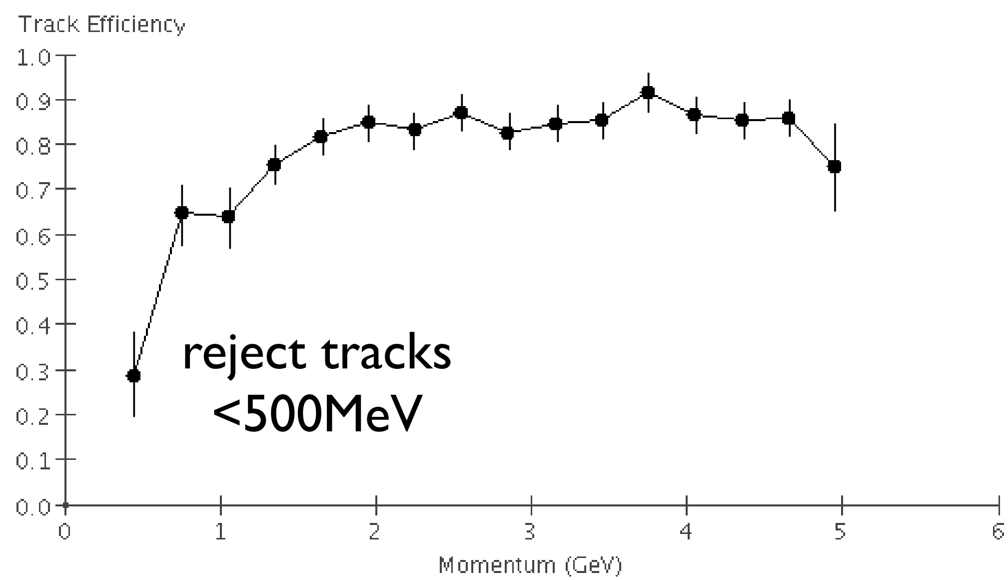




- occupancy in line with expectations (considering ~1.8 strips/particle)
- single hit resolution ~5.2μ

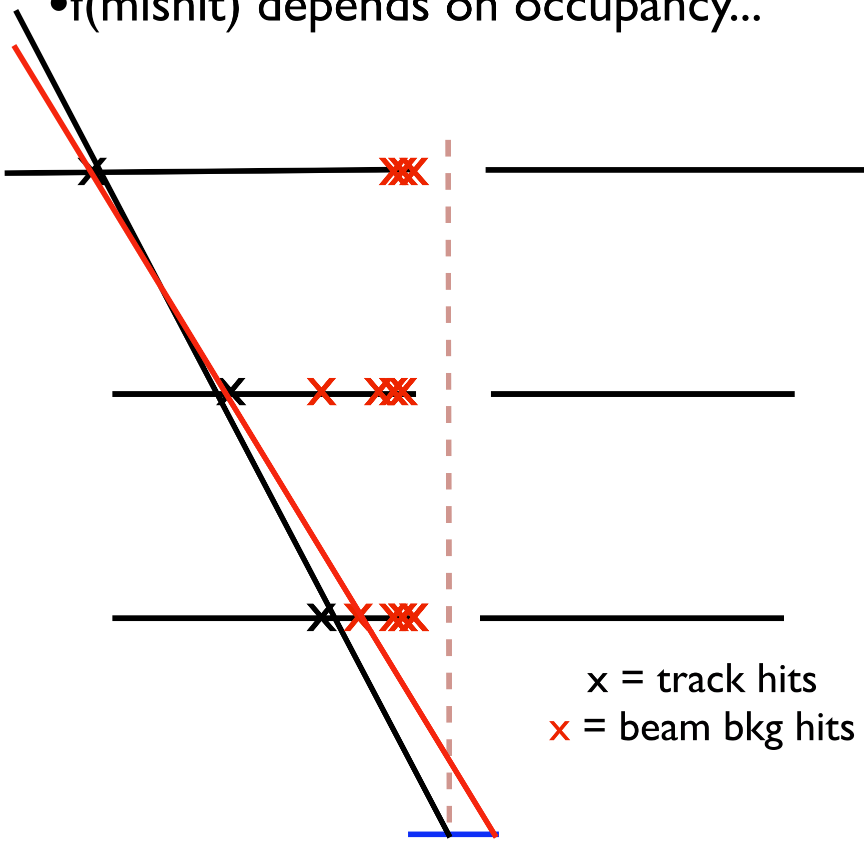
Tracking Efficiency

- Separate "tracking efficiency" from acceptance by requiring particle to pass through at least first 5 layers
- efficiency is ~80-90% and roughly independent of mass and beam energy
- mostly constant with momentum and angles

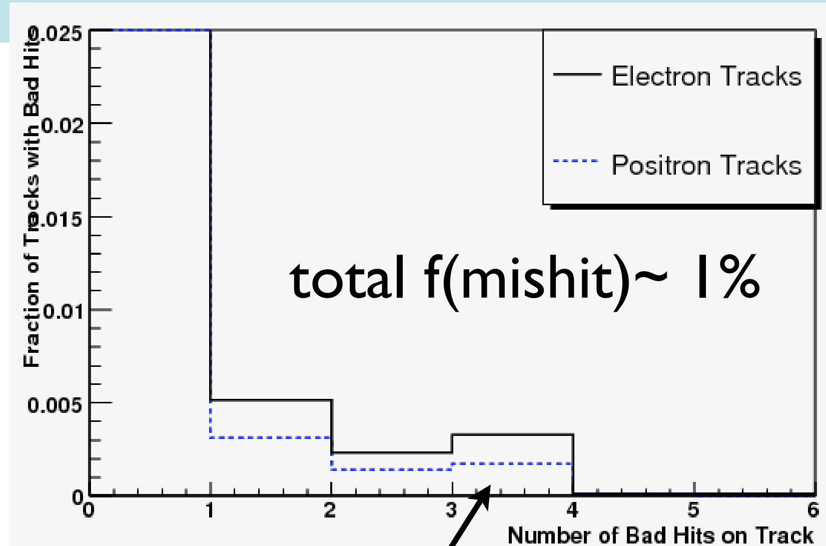


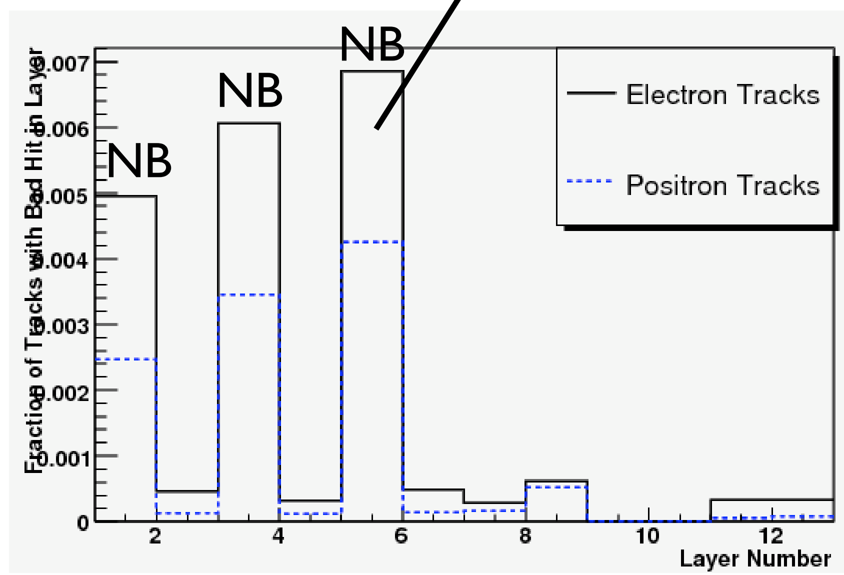
Mis-matched hits on tracks

- algorithm selects hits that minimize the track χ2...sometimes it picks the wrong hit.
- greatly effect the track/vertex parameters
  - f(mishit) depends on occupancy...



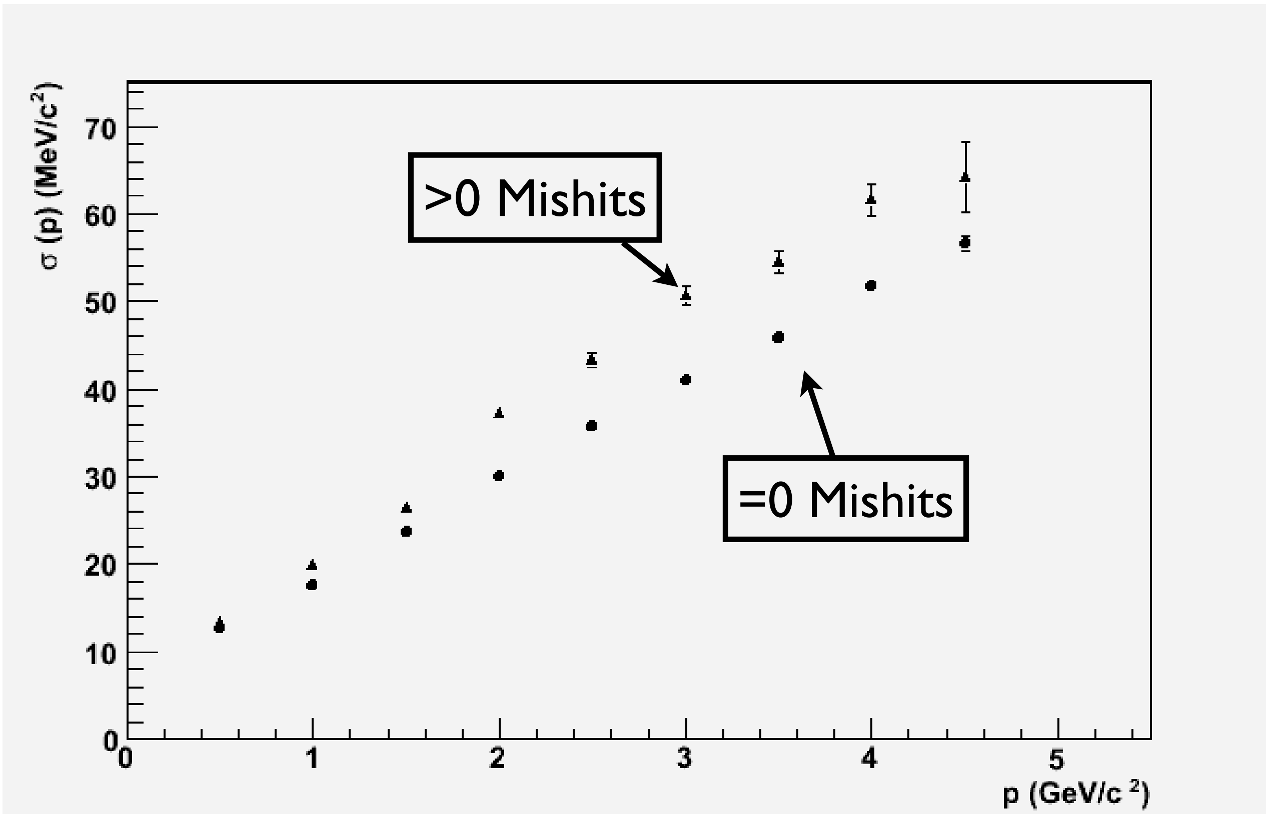
x = track hits
x = beam bkg hits





plots are updated from proposal...after vertexing cuts

Track Momentum Resolution



$\sigma_p/p \sim 1\text{-}1.5\%$

(this plot was made without layer 2)

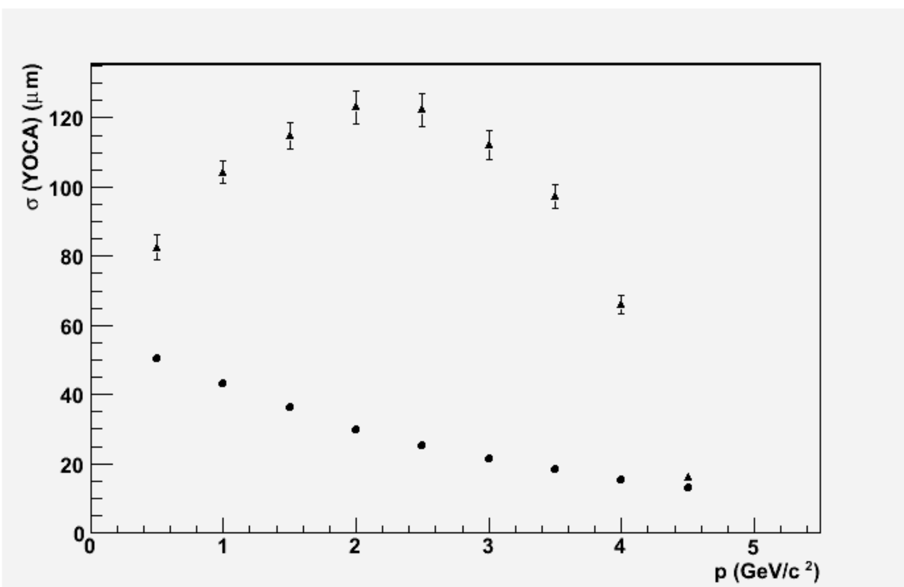
Track Spatial Resolution

•we quantify the spacial resolution by looking at the POCA to the beam axis...the distance in the non-bend plane is YOCA; bend plane is XOCA

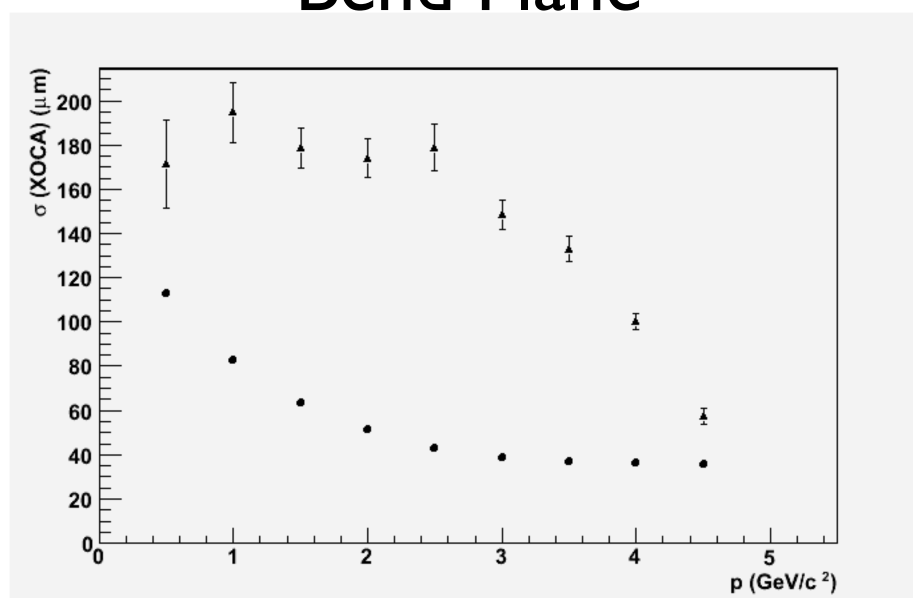
σ(YOCA)~15-45μ
σ(XOCA)~30-90μ

measured in prompt decays

Non-Bend Plane



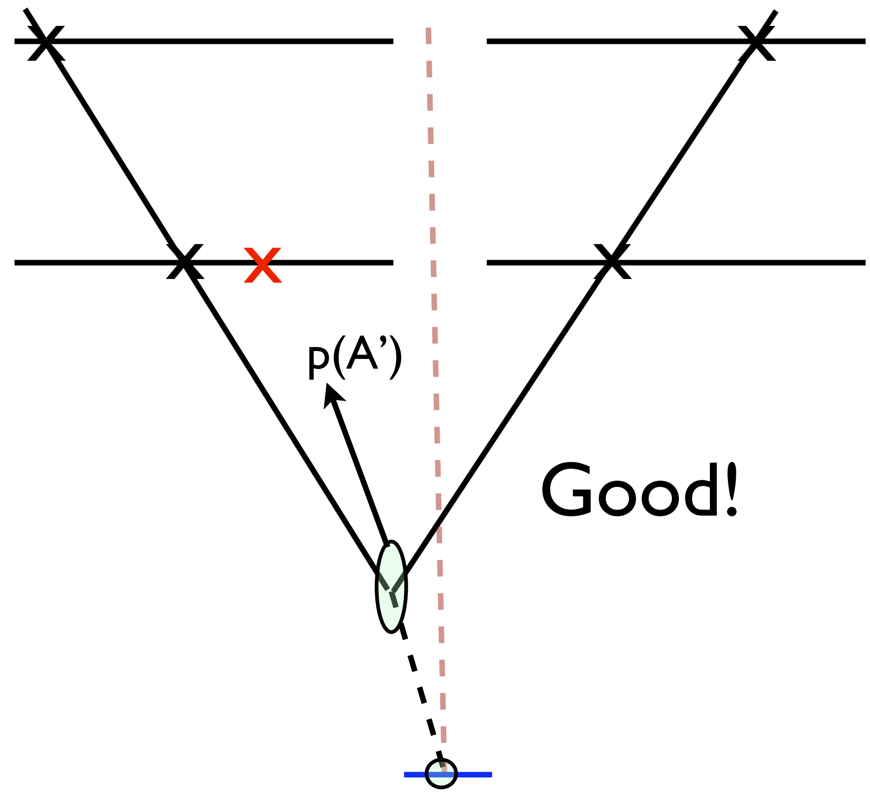
Bend Plane



(these plots were made without layer 2)

Vertexing

- All oppositely charged tracks combined to form an A' candidate
- Use the measured track parameters to create a vertex where the A' candidate is constrained to point back to the beamspot



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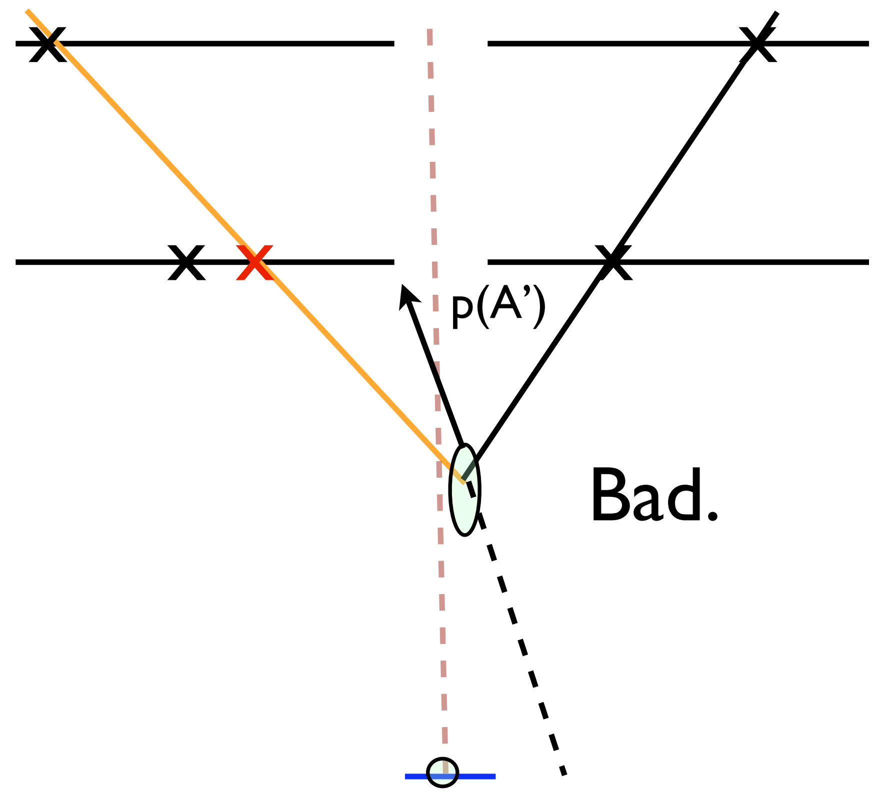
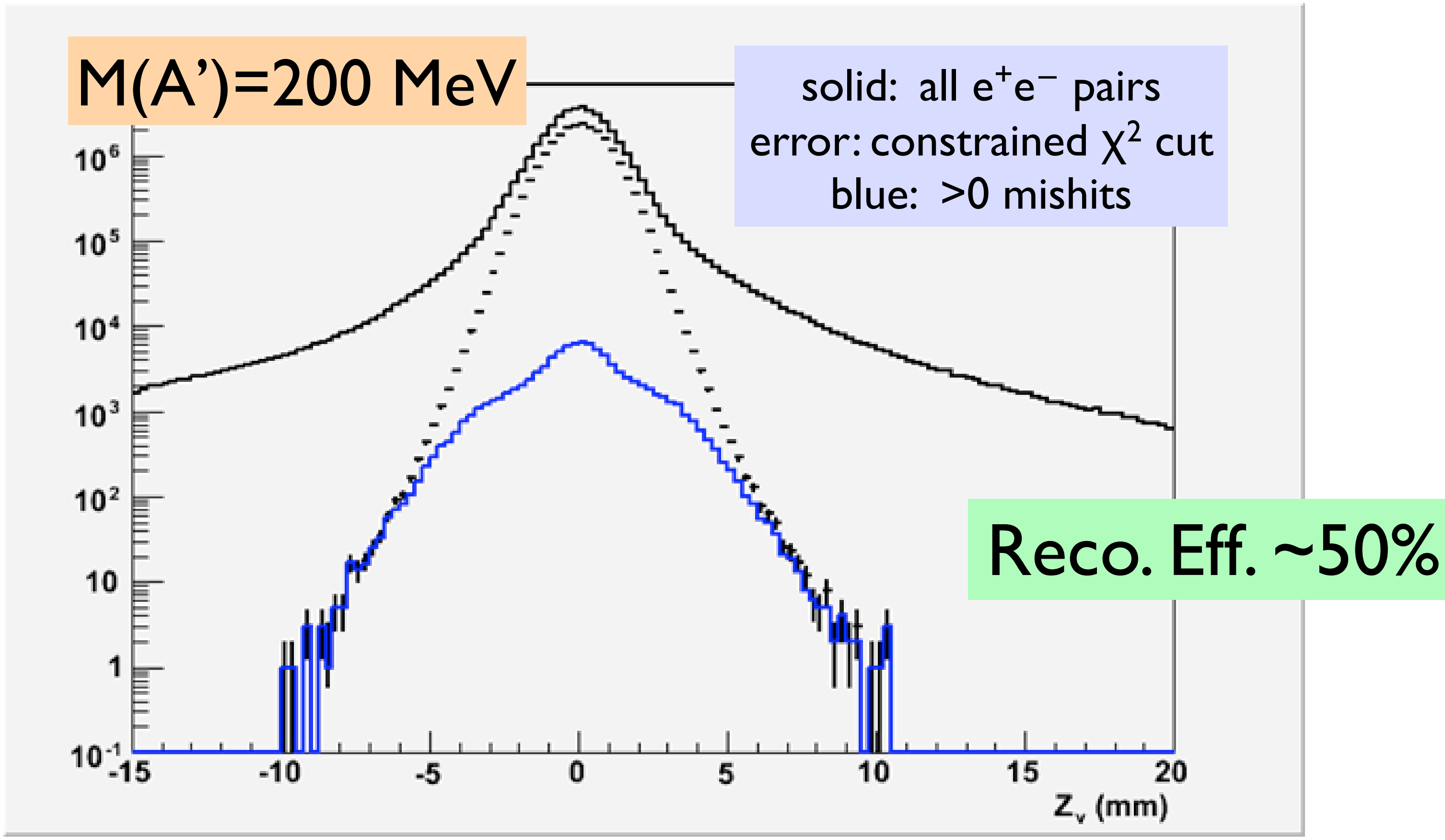


Vertex Position Resolution



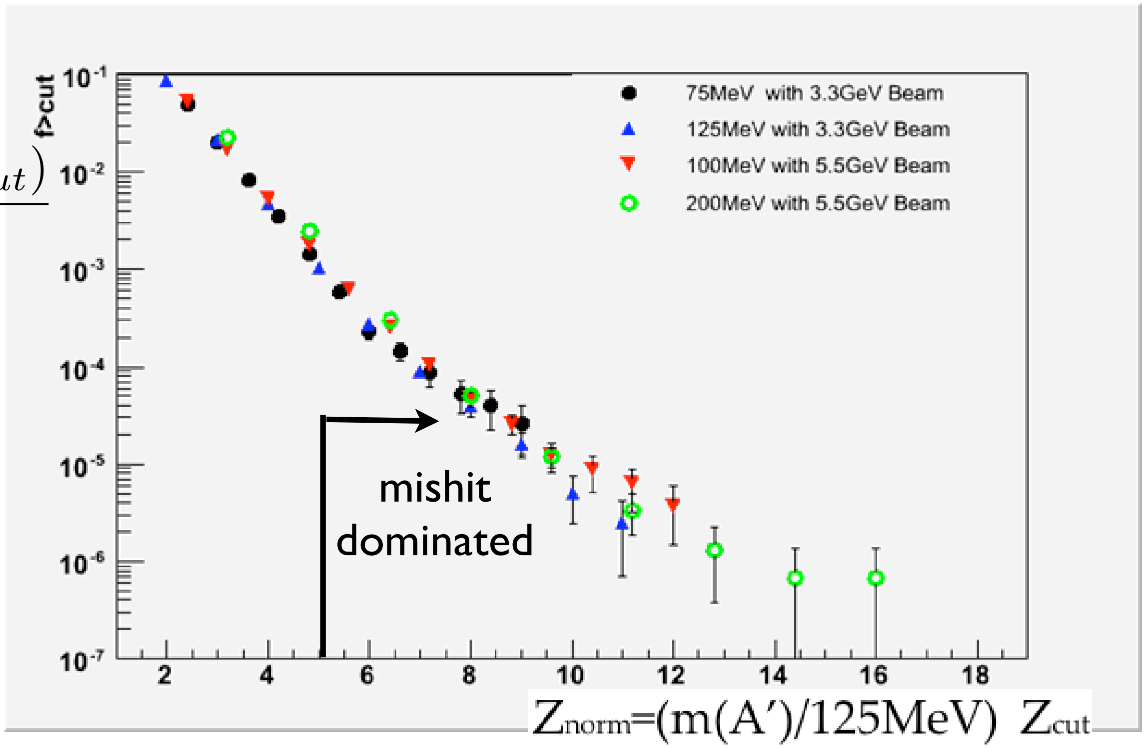
We are able to obtain $>10^{-6}$ rejection @ 1cm

Prompt Vertex Rejection

Error on vertex position dominated by MS errors on the opening angle determination... ***naively*** expect the vertex resolution to scale like:

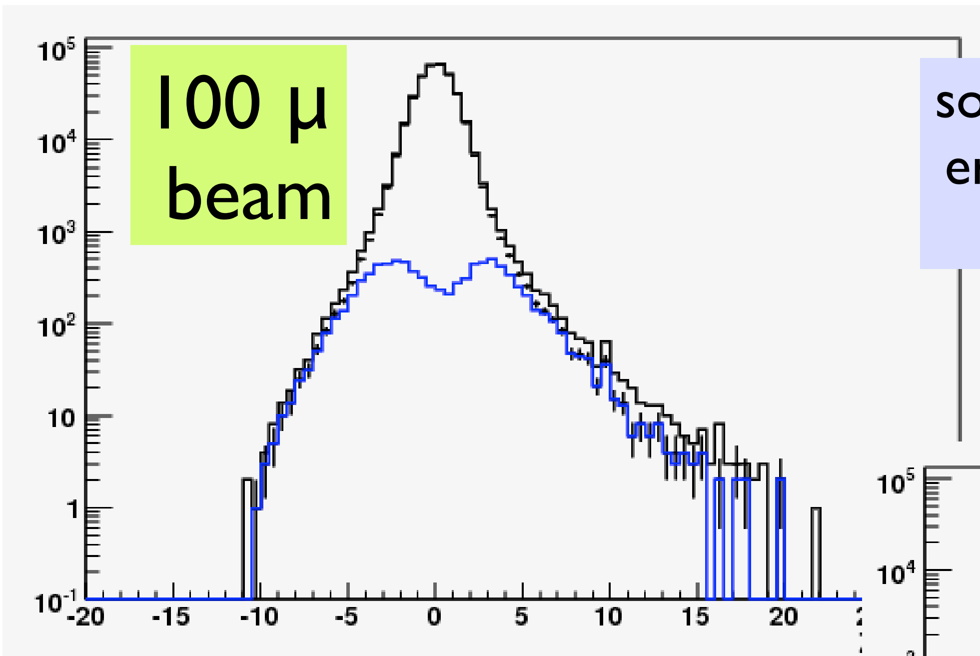
$$\frac{\sigma(\theta)}{\theta} \sim \frac{(1/E)}{(m/E)} \sim \frac{1}{m}$$

$$Rejection = \frac{N(Z > Z_{cut})}{N(Reco)}$$

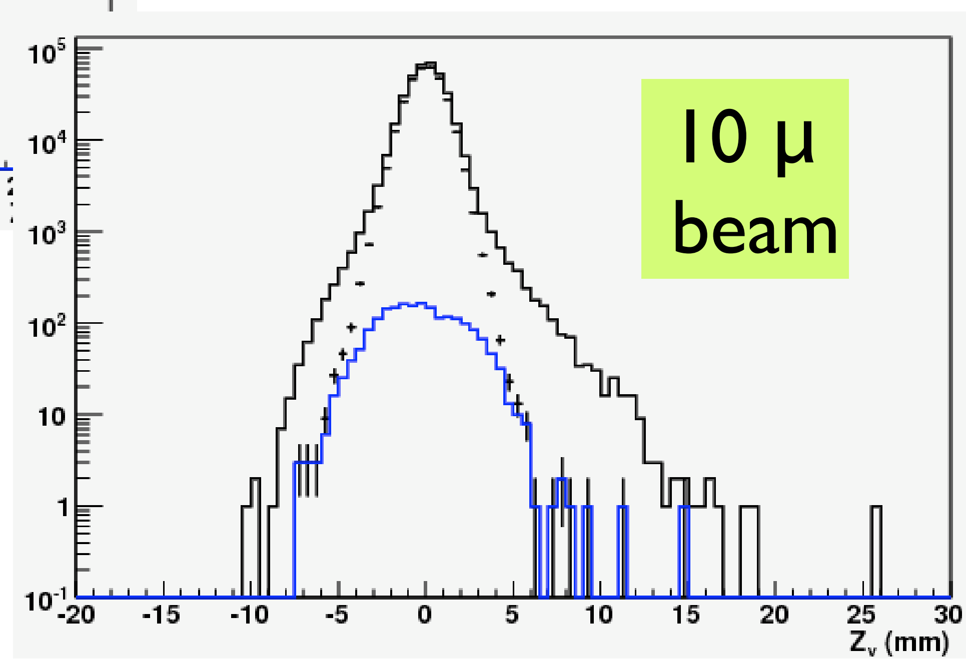


This scaling also appears to work for the tails as well...!

Beamspot: we need it small!



solid: base cuts (unconst)
error: constrained χ^2 cut
blue: mishit L1



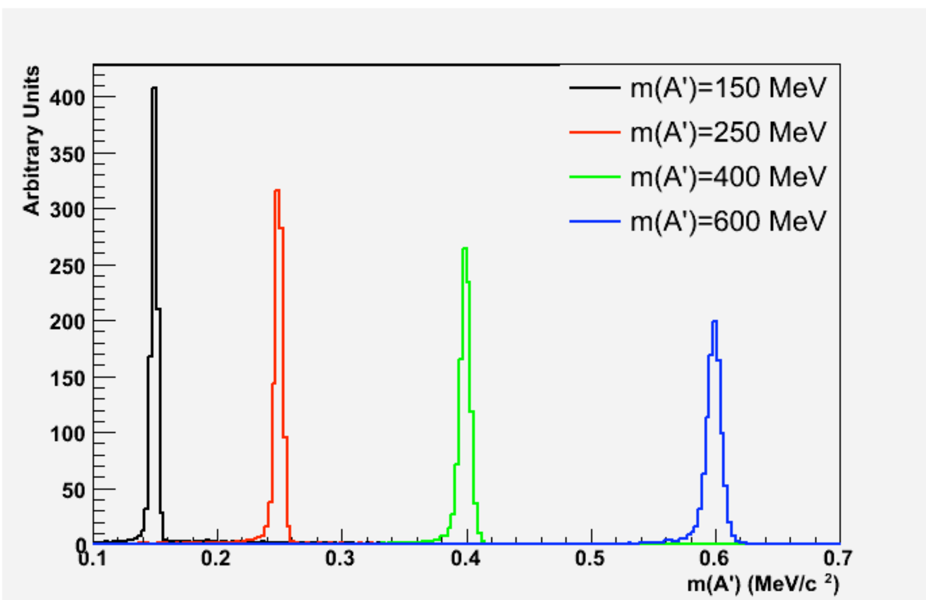
- beamspot constraint does not help much if BS is too big
  - makes sense since unconstrained vertex resolution ~100μ
- smaller the better...still need to study how small, squeeze in one dimension, etc

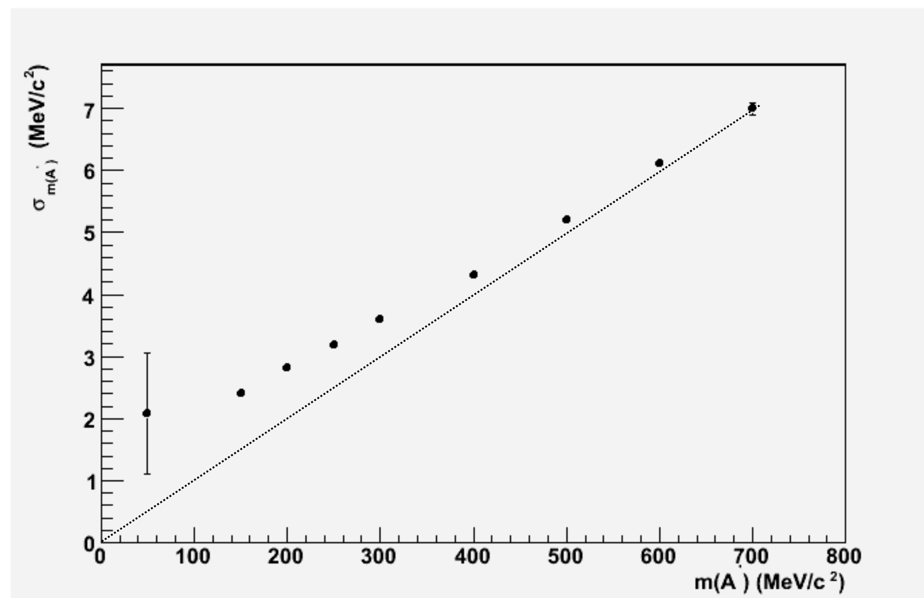
Mass Resolution

expect resolution
to scale with opening angle

$\sigma \sim m/E$

...haven't implemented beamspot constrained mass calculation yet...should improve the resolution!





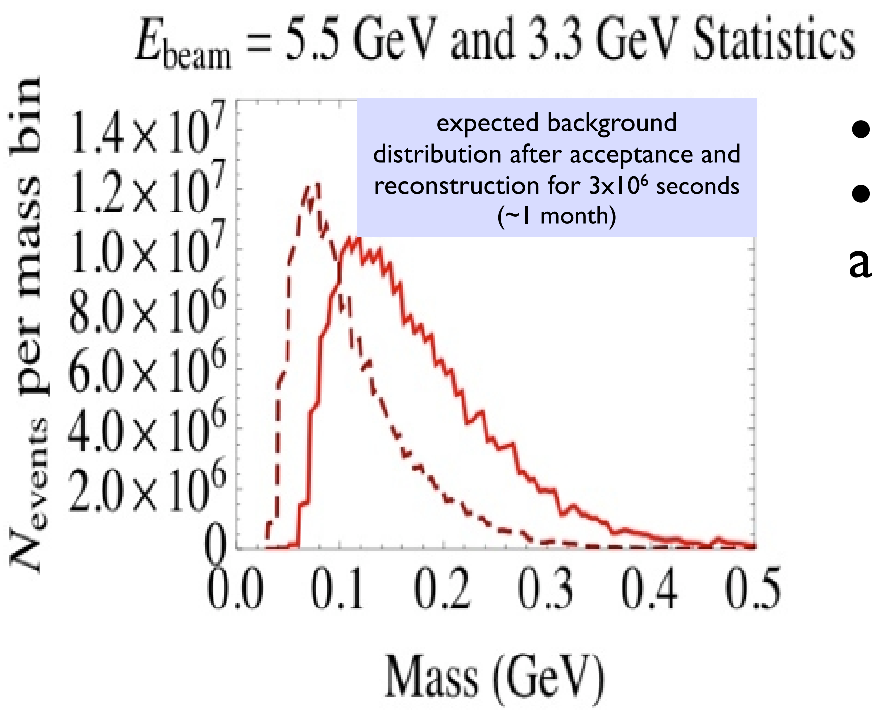
Tracking Performance Summary

- Based on our simulation studies, we are able to achieve vertexing and mass resolutions that will allow us to explore a large parameter space (see next)
- There are a few caveats...simulation doesn't include:
  - misalignment
  - noisy/dead strips
  - imperfect knowledge of B-field etc....
- ...on the other hand, there are more tricks to play to improve the tracking and vertexing
  - full position+timing track fit
  - cluster shape/isolation requirements
  - Kalman filter to obtain track parameters
  - full use of A' kinematic info etc, etc...
- *We are confident that our current estimated performance is conservative and will get better.*

Physics Reach Calculation: Bump Hunt

- calculate the signal significance as a function of mass and coupling

$$\left(\frac{S}{\sqrt{B}}\right)_{bin} = \left(\frac{N_{radiative}}{N_{total}}\right)\sqrt{N_{bin}}\left(\frac{3\pi\epsilon^2}{2\,N_{eff}\,\alpha}\right)\left(\frac{m_{A'}}{\delta m_{A'}}\right)\epsilon_{bin}$$

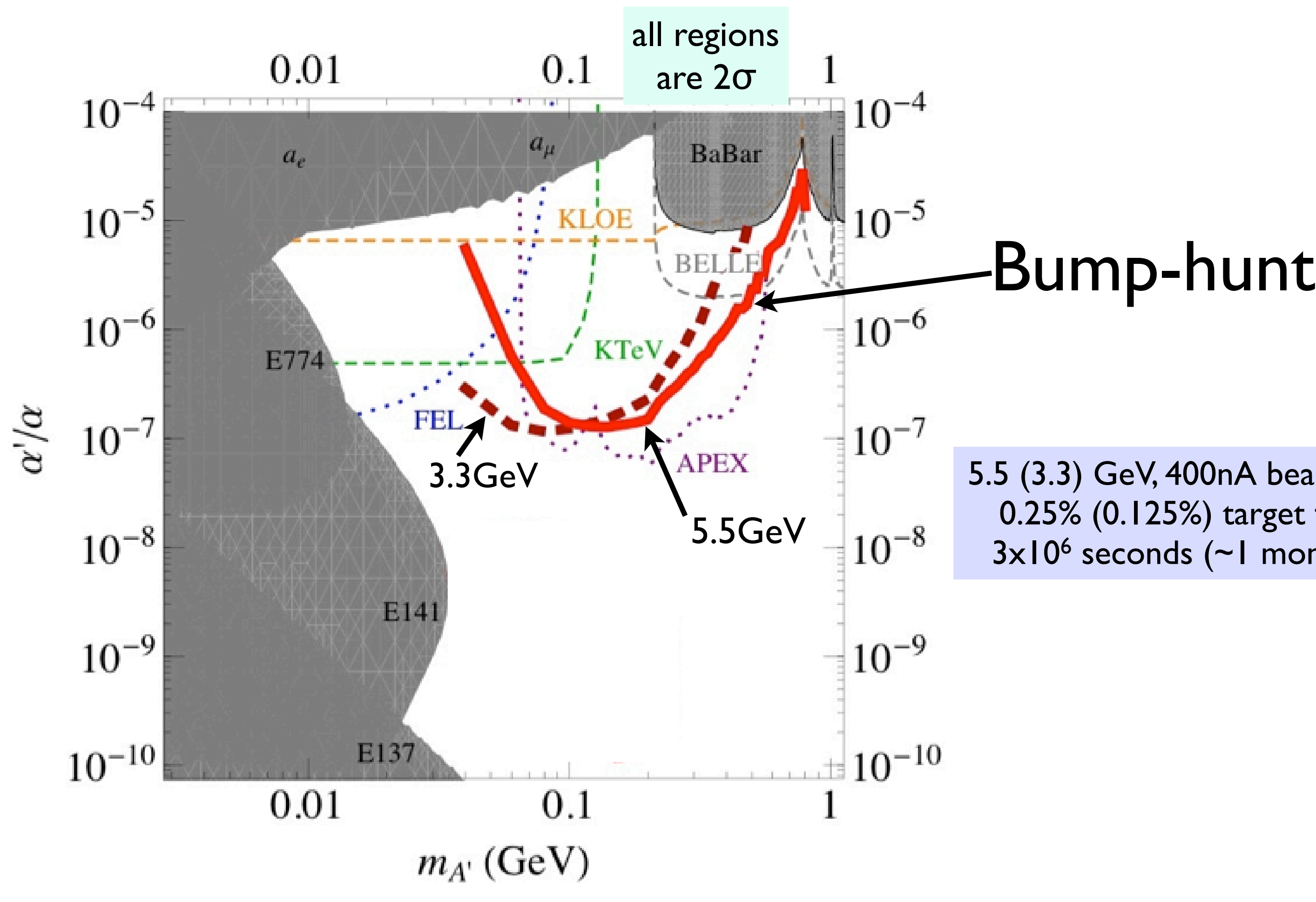


- N_{total} includes radiative and BH events
- N_{bin} includes geometric acceptance and trigger/tracking efficiencies

$$N_{bin} \equiv \epsilon^2_{reco} \times \epsilon_{stat}(m_{A'}) \times \sigma_{trigger} \times L.$$

- ϵ^2_{reco}: $(0.85)^2$ tracking eff. (no vertexing)
- $\epsilon_{stat}(m_{A'})$: Fraction of *all* events in δm_A
- $\sigma_{trigger}$: total xsection accepted by trigger

Bump-hunt α′/α Reach



5.5 (3.3) GeV, 400nA beam on 0.25% (0.125%) target for $3x10^6$ seconds (~1 month)

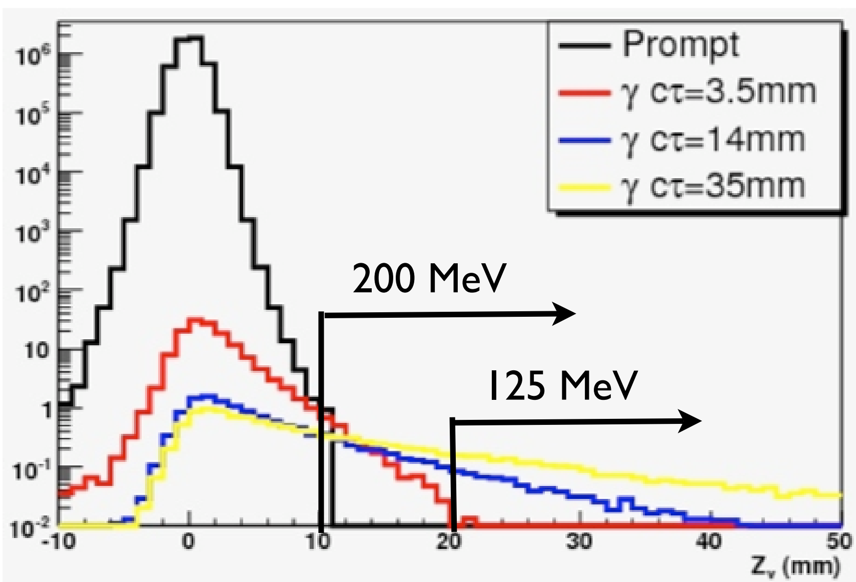
Physics Reach Calculation: Vertexing

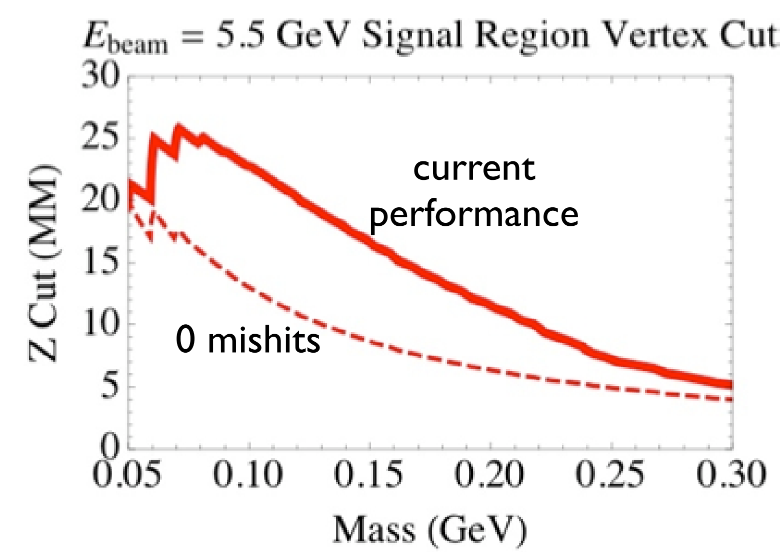
$$\epsilon_{sigeff}(zcut) \cong \epsilon_{vtx} \times \left(e^{-\left(\frac{zcut}{\gamma c\,\tau}\right)} - e^{-\left(\frac{zmax}{\gamma c\,\tau}\right)} \right)$$

$$\left(\frac{S}{\sqrt{B}}\right)_{bin,zcut} = \left(\frac{S}{\sqrt{B}}\right)_{bin} \frac{\epsilon_{sigeff}(zcut)}{\sqrt{\epsilon_{rejection}(zcut)}} > 2$$

and require >2.4 expected signal events and ~0.5 background events

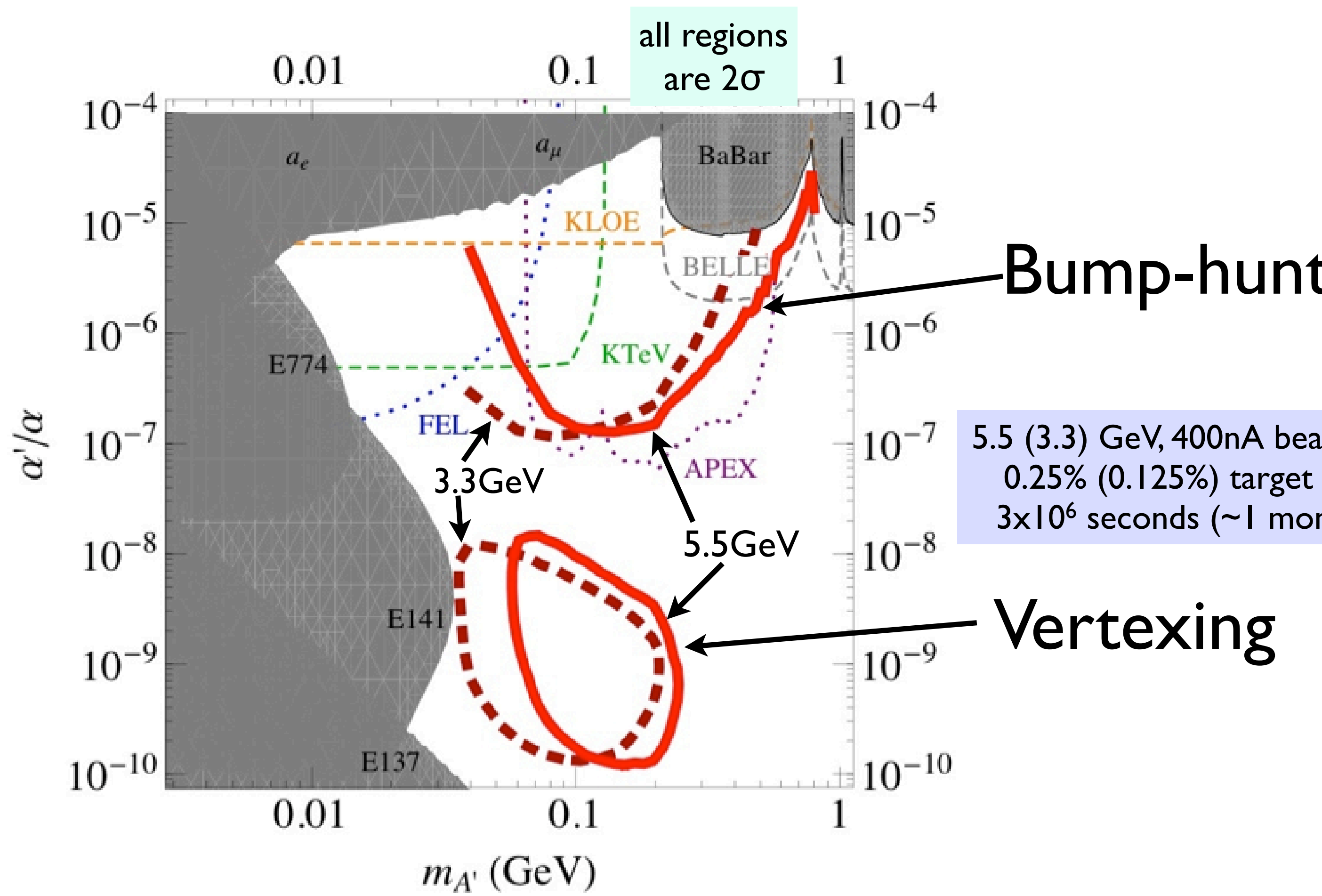
- optimize the minimum value of z_{cut}
- z_{max} set to 20cm...
  - preliminary studies show we can track efficiently out to there...probably can go further
- use scaled prompt rejection factors (like on slide 14)





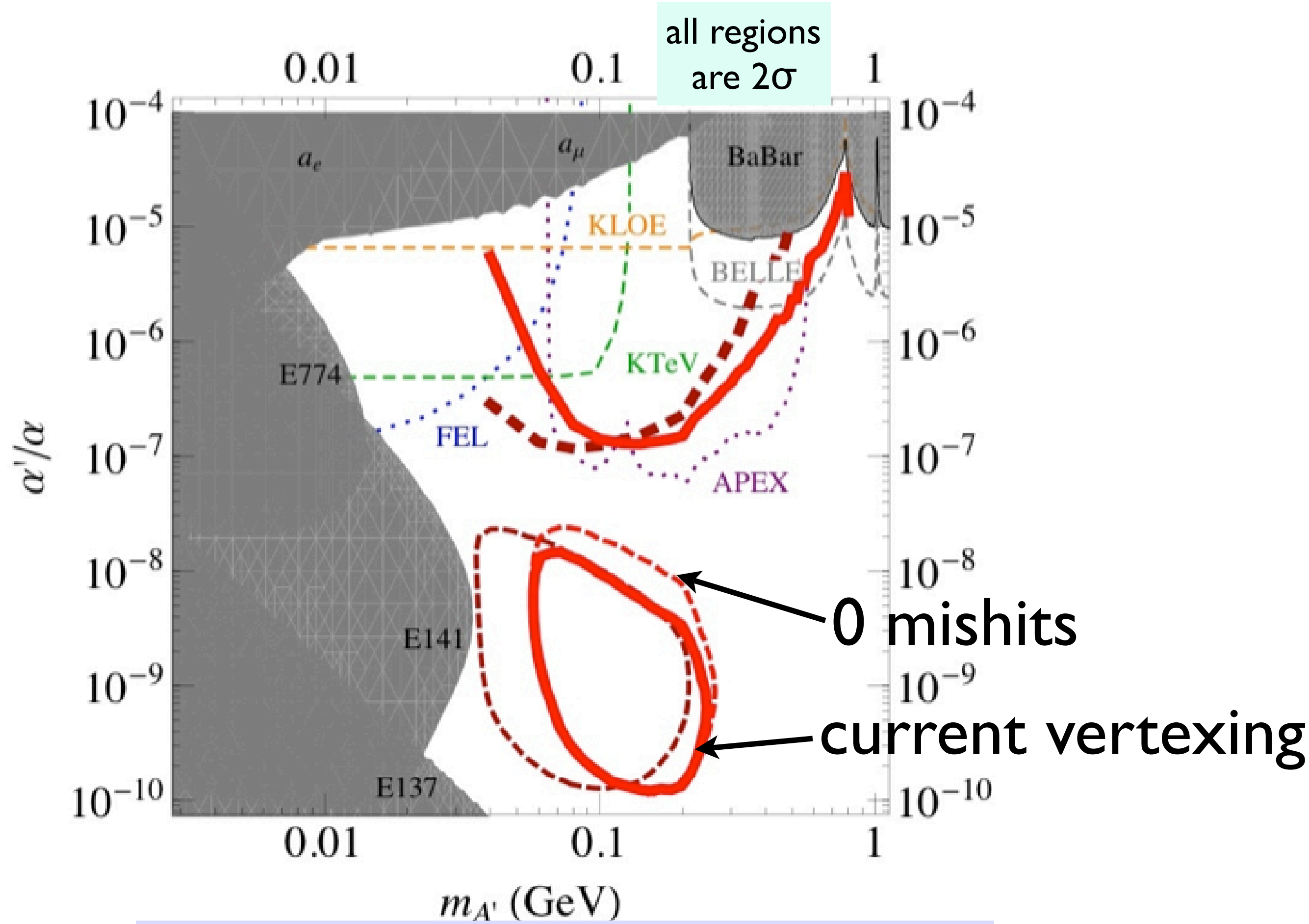
event yields are for 3×10^6 seconds (~1 month)

HPS α´/α Expected Reach



5.5 (3.3) GeV, 400nA beam on 0.25% (0.125%) target for 3×10^6 seconds (~1 month)

α'/α Reach: 0 Mishits...



Assuming efficiency stays the same, but we can remove the mishit-tails

Conclusions

- We've optimized the tracker layout to give good efficiency and excellent track quality
- With our current estimated performance, we will cover a significant and unique range of parameter space
  - also, it's a significantly *interesting* region
- Lots of work to do in the next few months to optimize the tracking and vertexing algorithms, but we are sure we can improve on the current performance

Vertex Resolution Mass Dependence

Error on vertex position dominated by MS errors on the opening angle determination...

naively expect the vertex resolution to scale like:

$$\frac{\sigma(\theta)}{\theta} \sim \frac{(1/E)}{(m/E)} \sim \frac{1}{m}$$

...for the (Gaussian) core of the resolution, this scaling seems to work