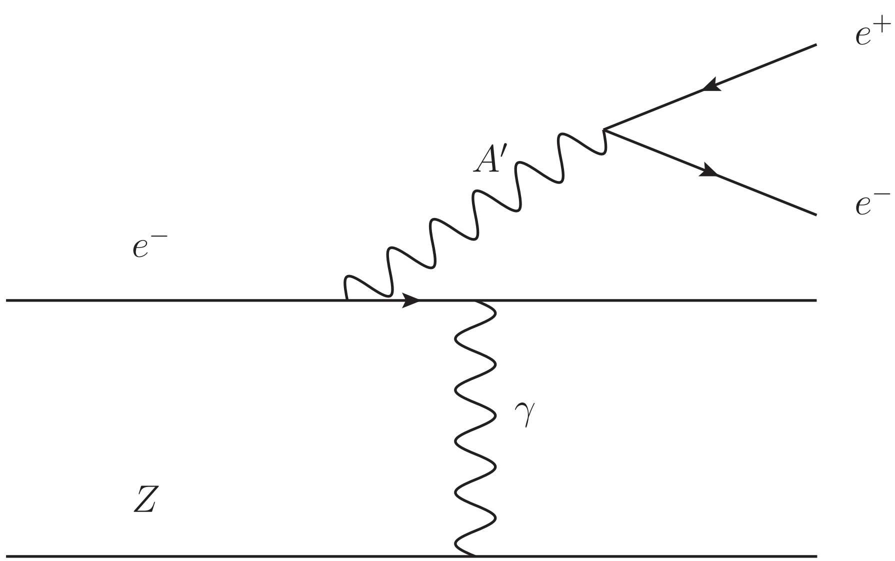
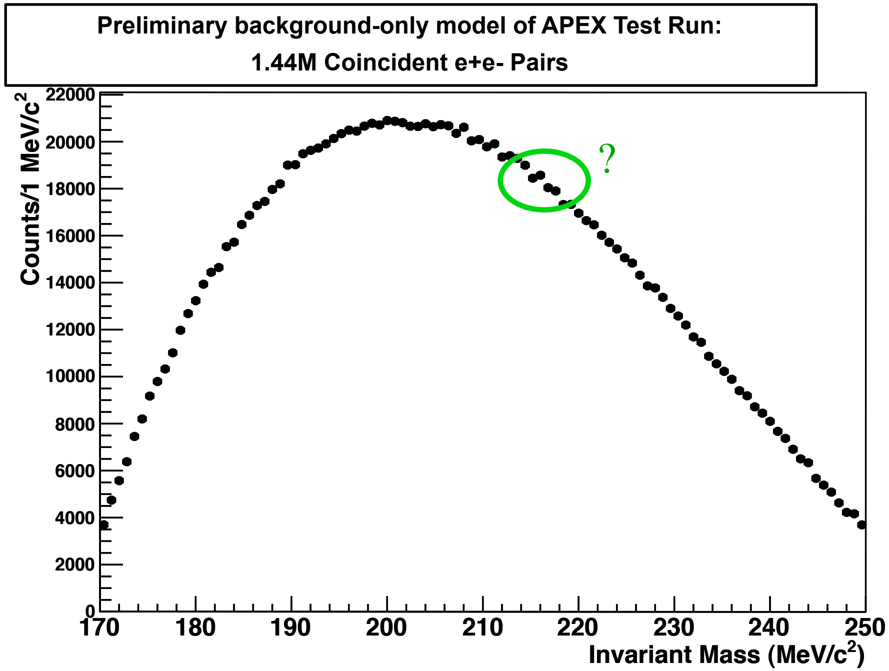
APEX Peak Search

Center for Cosmology and Particle Physics

Looking for a small, narrow resonance in a high-statistics, finely-binned invariant mass spectrum





James Beacham
New York University

on behalf of
*the **APEX Collaboration***
*and the **Hall A Collaboration***
at Jefferson Lab

Outline

1) Goals of the project

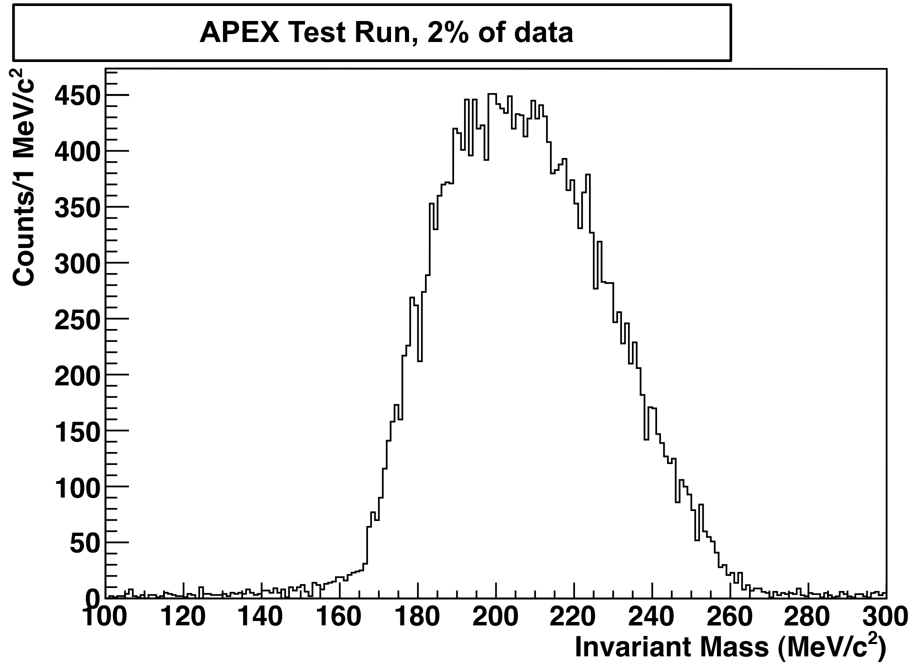
2) Searching for a resonance

3) Setting limits

4) Preliminary model based on APEX test run
   - Projected results and expectations

5) Summary and Conclusions

Goals



Analysis of APEX raw data

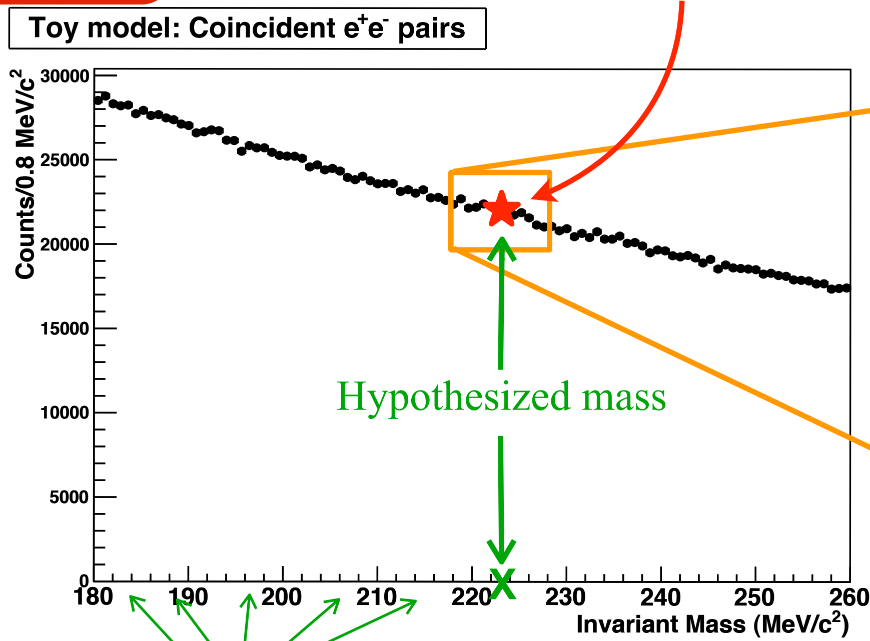
→ invariant mass spectrum

- We want to
  - I) Identify any statistically significant excesses in spectrum
    - Search for small resonances of widths $\leq$ mass resolution
  - II) Set limits on A' cross section, which scales as $\epsilon^2 = \alpha'/\alpha$
    - Determine range in cross section (or ϵ^2) of hypothetical narrow resonance consistent with observed spectrum
- Search will be blind

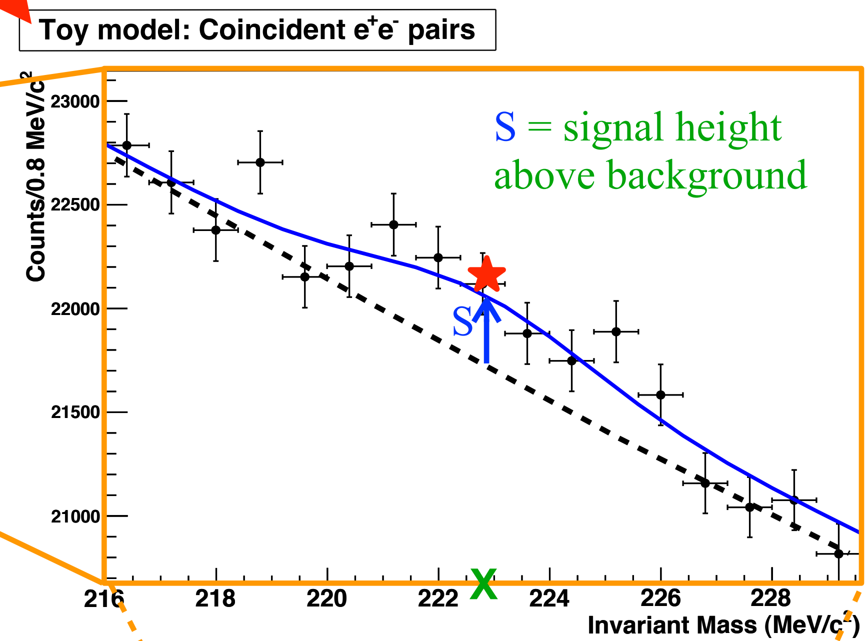
Note: Analysis of APEX test run data ongoing; here we discuss **projected** results from models based on test run

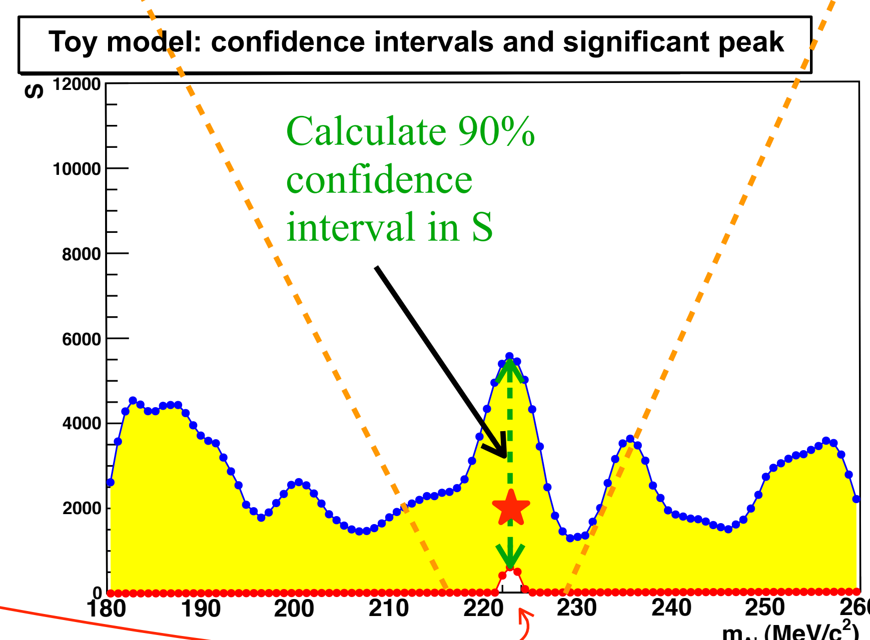
Searching for a Resonance: General Procedure

START True point: $m_{A'} = 222.8\ \mathrm{MeV/c^2}$, S = 2000



Scan along mass; look for excess consistent with mass resolution





END

Significant excess at true point; S = 0 is not in confidence interval, i.e., excess is no longer consistent with background fluctuation

Searching for a Resonance: General Procedure

Searching for a resonance depends on numbers of events only

- Significant excesses of S above background B
  - **NEED:**
    - Knowledge of background shape
    - Mass resolution
  - **DON'T NEED:**
    - Detector acceptances

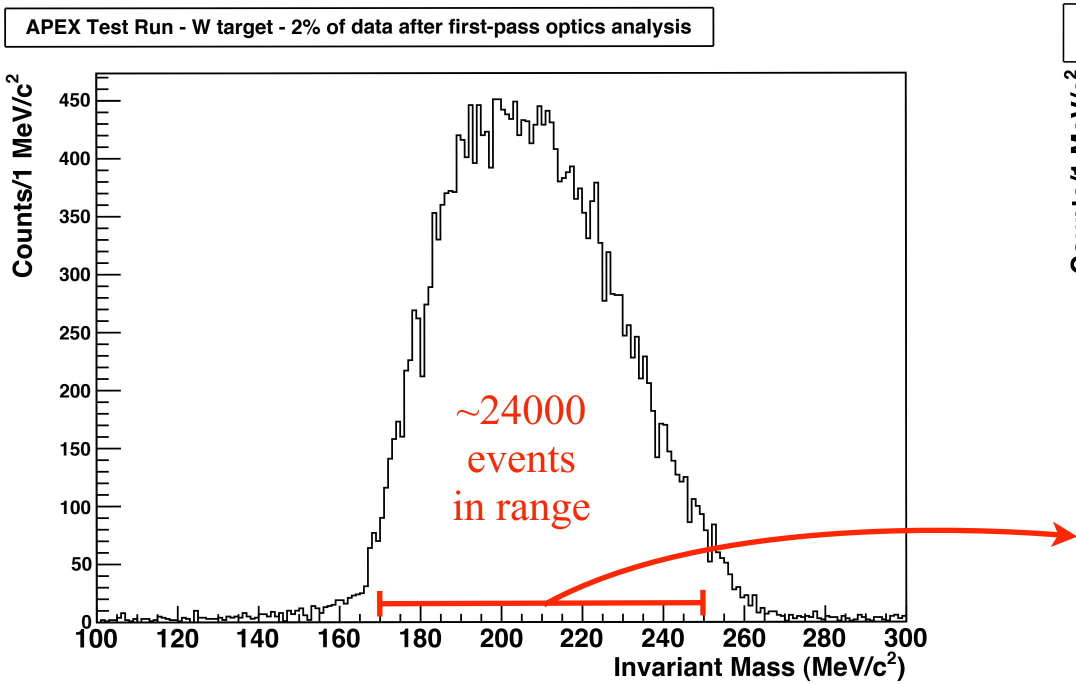
"Look elsewhere" effect

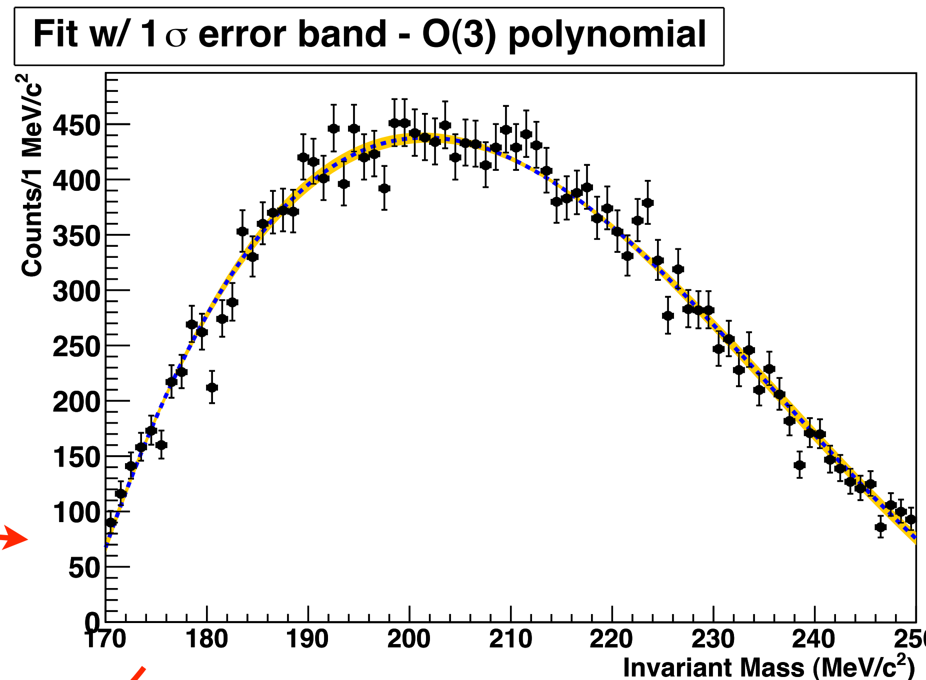
- Each $m_{A'}$ hypothesis equally likely

  $\Rightarrow$ must penalize CL by trial factor

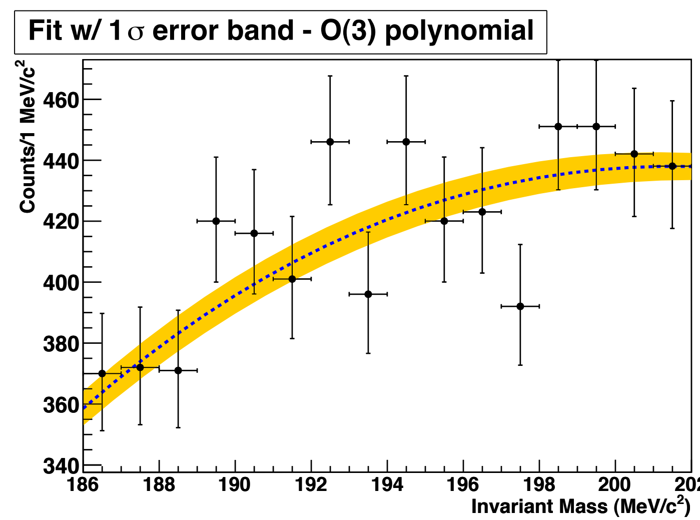
$$\text{p-value} \;\rightarrow\; \text{p-value} \times \text{mass range/resonance width}$$

Background shape





Zoom in to see systematic uncertainty on shape...



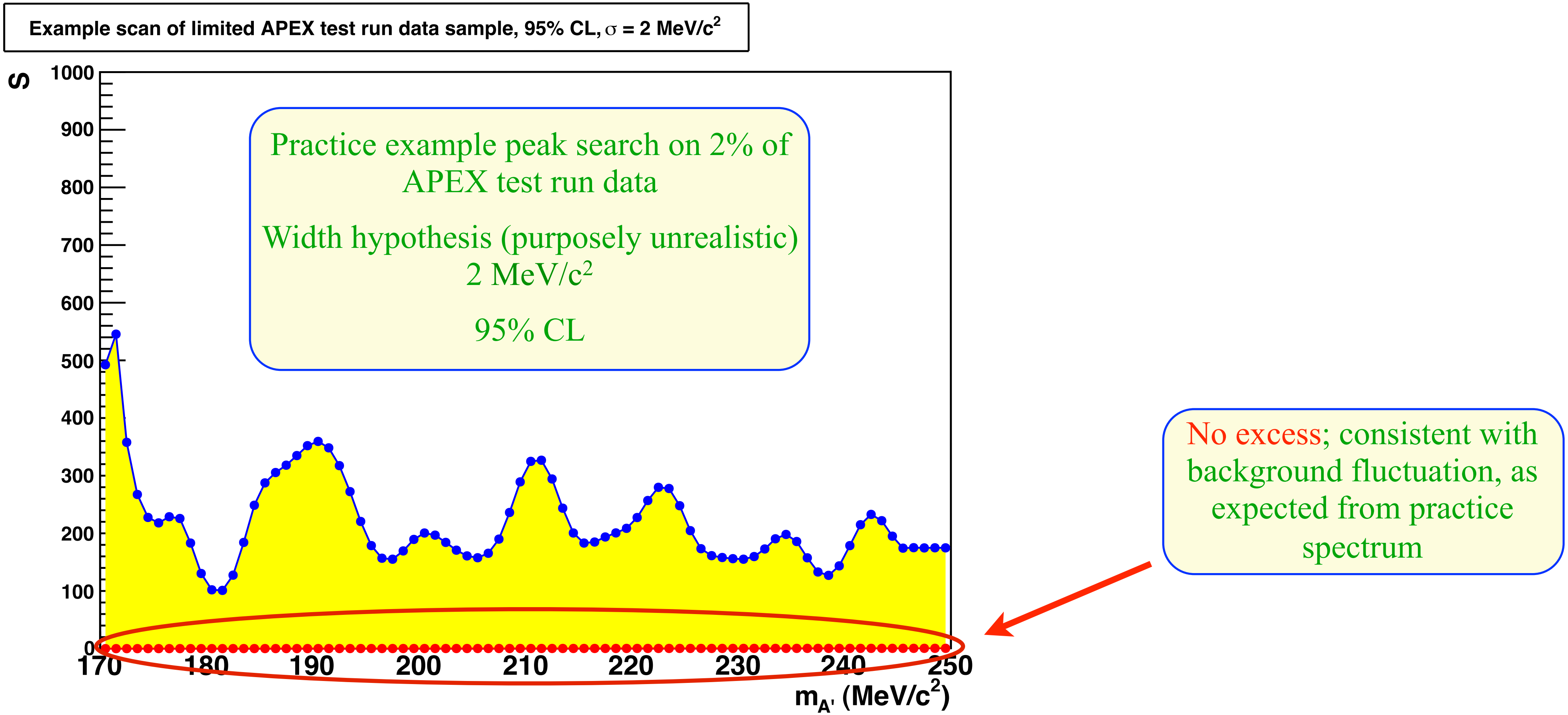
Background model = $O(3)$ polynomial

Systematic uncertainty on shape ~ $\pm$ 8 evts/MeV/c^2

$\Rightarrow$ Shape uncertainty on background ~ 1%

Resonance search **practice example**

- 2% of APEX test run data
- No optics analysis
- Assumption of a mass resolution not realistic for this spectrum
- Couldn't possibly see a significant peak; just a practice example



Setting Limits: General Procedure

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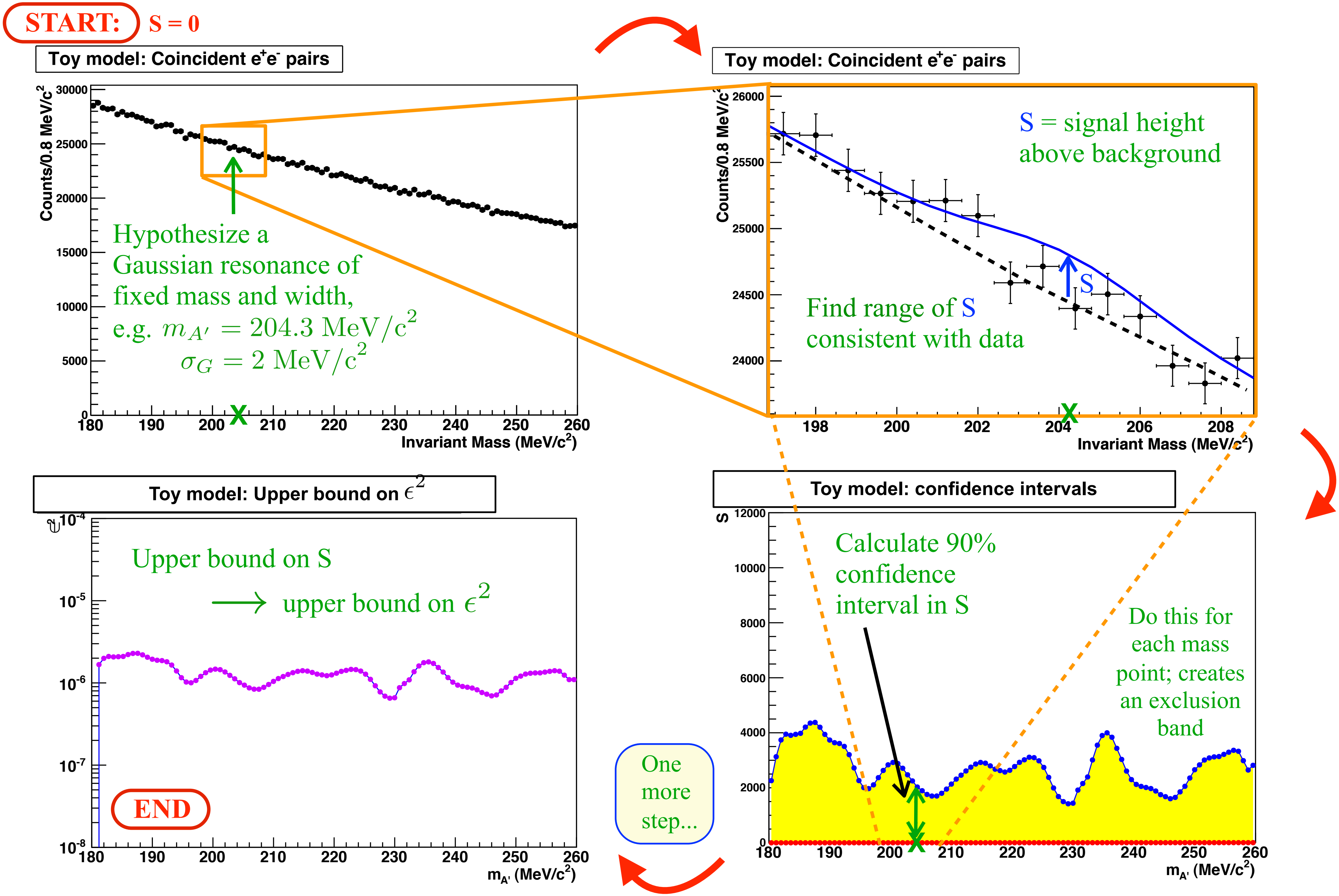
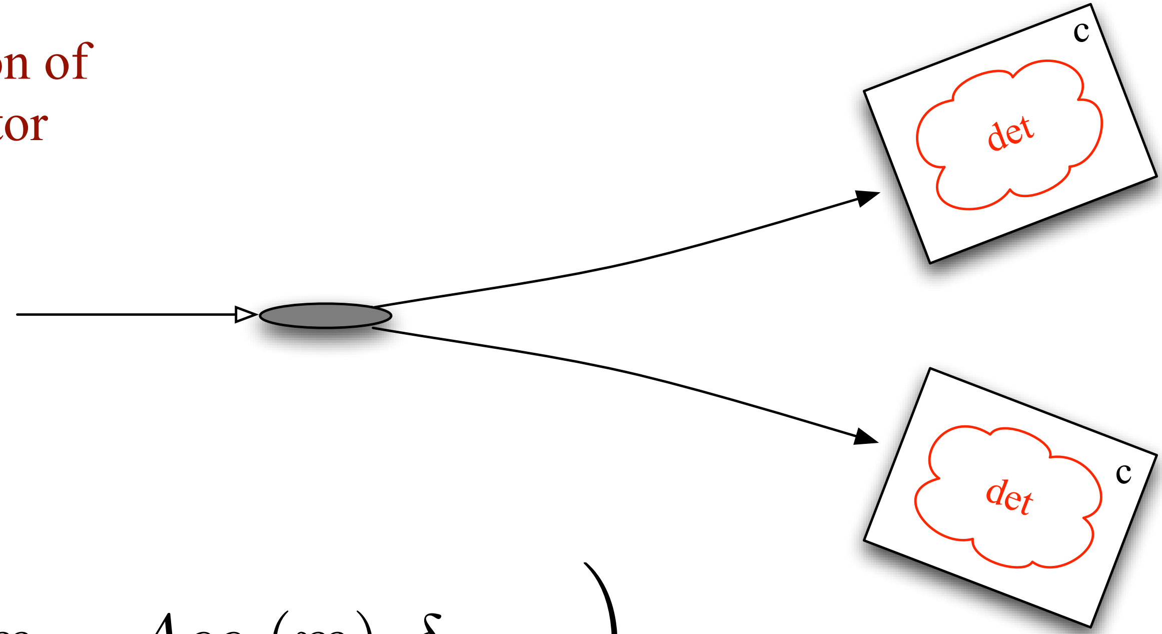


Setting limits is more involved than searching for a resonance

- Need to relate observed number of events to cross section; i.e., need to know detector acceptance and dependence on $\epsilon^2, m_{A'}$

$$\frac{S_{\delta m}^{det}}{B_{\delta m}^{det}} = \frac{\sigma_{A'}^{det}}{\sigma_{b,tot}^{det}} = \frac{\sigma_{A'}^{c}\ Acc_{A'}(m)}{\sigma_{\gamma^*}^{c}\ Acc_{\gamma^*}(m) + \sigma_{BH}^{c}\ Acc_{BH}(m) + \sigma_{\text{other}}^{c}\ Acc_{\text{other}}(m)}$$

σ^c = cross section into idealized region of phase space, c, swept out by the detector volume

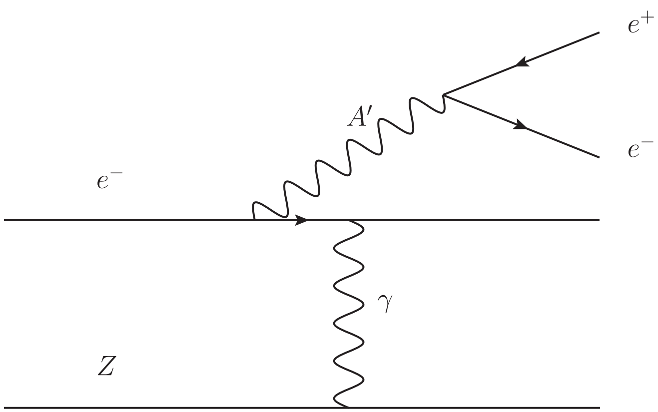


$$\Rightarrow Acc(m) = \frac{\sigma^{det}}{\sigma^{c}}$$

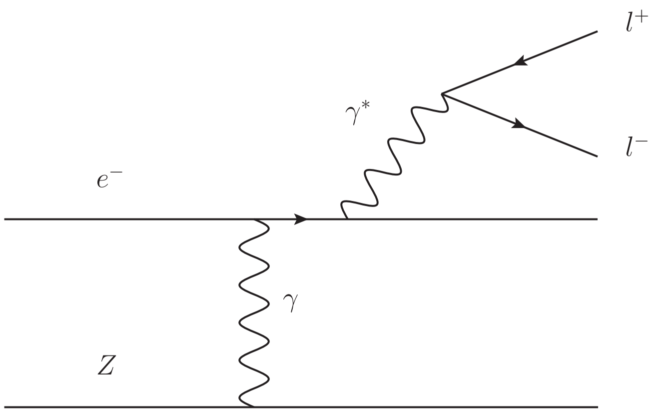
Ultimately: $$\epsilon^2\left(\frac{S_{\delta m}^{det}}{B_{\delta m}^{det}}, m_{A'}, Acc_i(m), \delta_m, \ldots\right)$$

Setting Limits: APEX

Signal

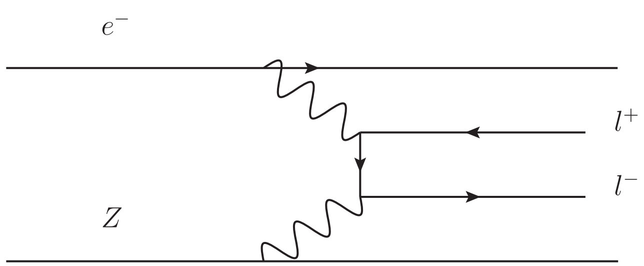


QED Trident Backgrounds



Radiative trident

Kinematically identical within a window around $m_{A'}$



Bethe-Heitler

Bethe-Heitler events are kinematically reducible, but represent a larger total cross section; contribution to irreducible background must be accounted for

Preliminary Model Based on Test Run

The A' cross section is related to the **radiative trident cross section only** by

$$\frac{d\sigma(A')}{d\sigma(\gamma^*)} = \left(\frac{3\pi\epsilon^2}{2N_{\text{eff}}\alpha}\right)\frac{m_{A'}}{\delta m} = \frac{S_{\delta m}}{B^{\gamma^*}_{\delta m}}$$

(See APEX proposal)

within a mass window of width δm $\Rightarrow$

S/B independent of detector acceptance in some mass window

We can

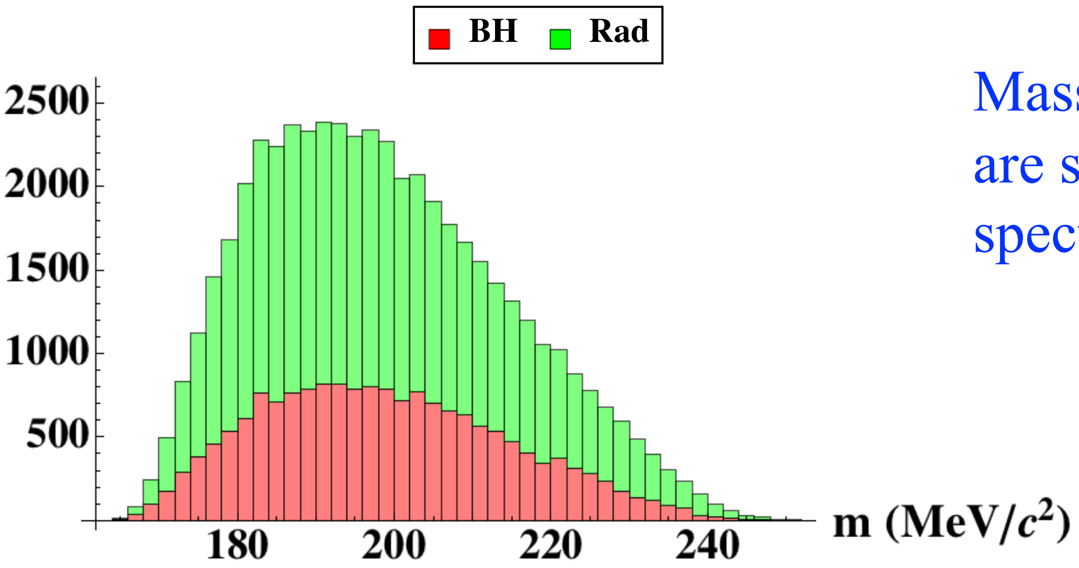
- 1) Exploit the kinematic similarities between A' and γ^* production
- 2) Assume the B-H acceptance is relatively flat in the region *c*, and that its inclusion (with interference effects) will change the background by a factor F

$$Acc_{BH}(m) = Acc_{\gamma^*}(m) = Acc_{A'}(m) \rightarrow \frac{S^{det}_{\delta m}}{B^{det}_{\delta m}} = \frac{S_{\delta m}}{F\ B^{\gamma^*}_{\delta m}} = \left(\frac{3\pi}{2N_{\text{eff}}\alpha}\right)\frac{m_{A'}}{\delta m}\frac{\epsilon^2}{F}$$

$$\epsilon^2(m_{A'}) = \frac{S^{det}_{\delta m}}{B^{det}_{\delta m}}\frac{F\ \delta m}{m_{A'}}\left(\frac{2N_{\text{eff}}\alpha}{3\pi}\right)$$

Preliminary Model: Background Acceptance

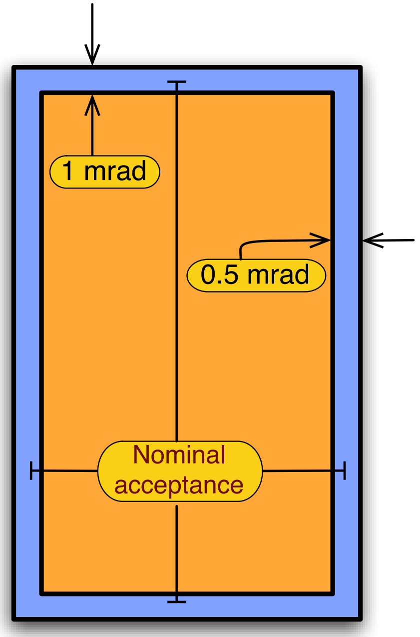
Check assumption on BH and radiative acceptances with Monte Carlo



Mass distribution shapes are similar within idealized spectrometer acceptance

Look at rates of BH and Rad into **inner region** of spectrometers vs. **outer boundary**

- Ratio of BH to Rad **roughly flat**
- Validates assumption of approximately equal *Acc(m)* for preliminary model
- Crude estimates indicate that once interference effects are accounted for, $F \sim \mathbf{5}$



HRS

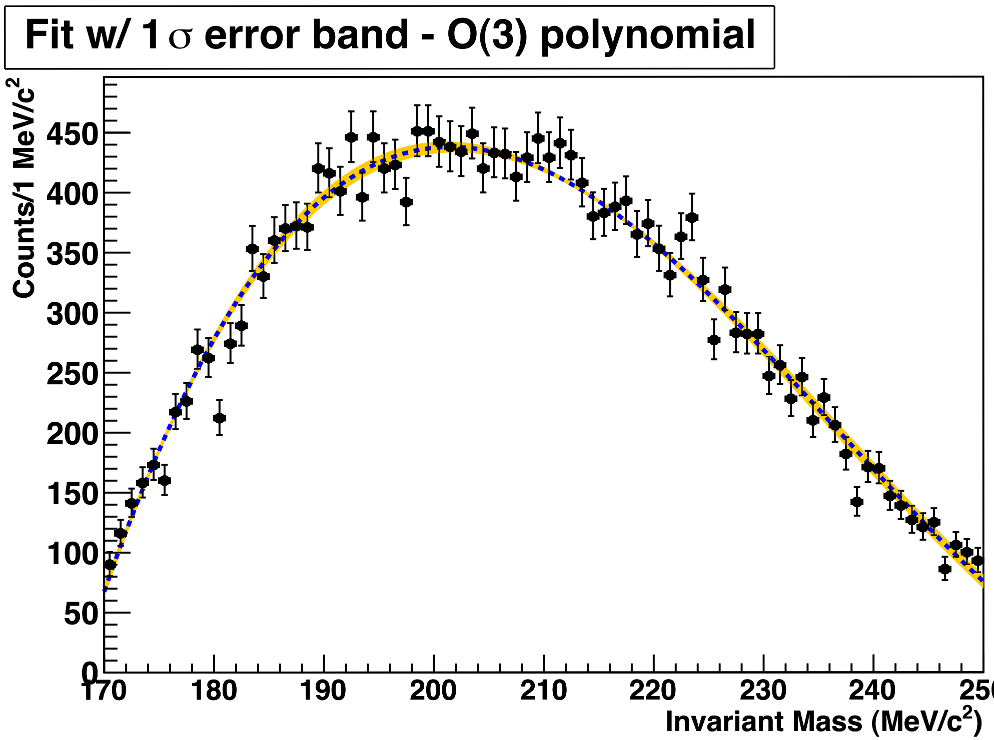
Plans to Move From Preliminary to Full Model

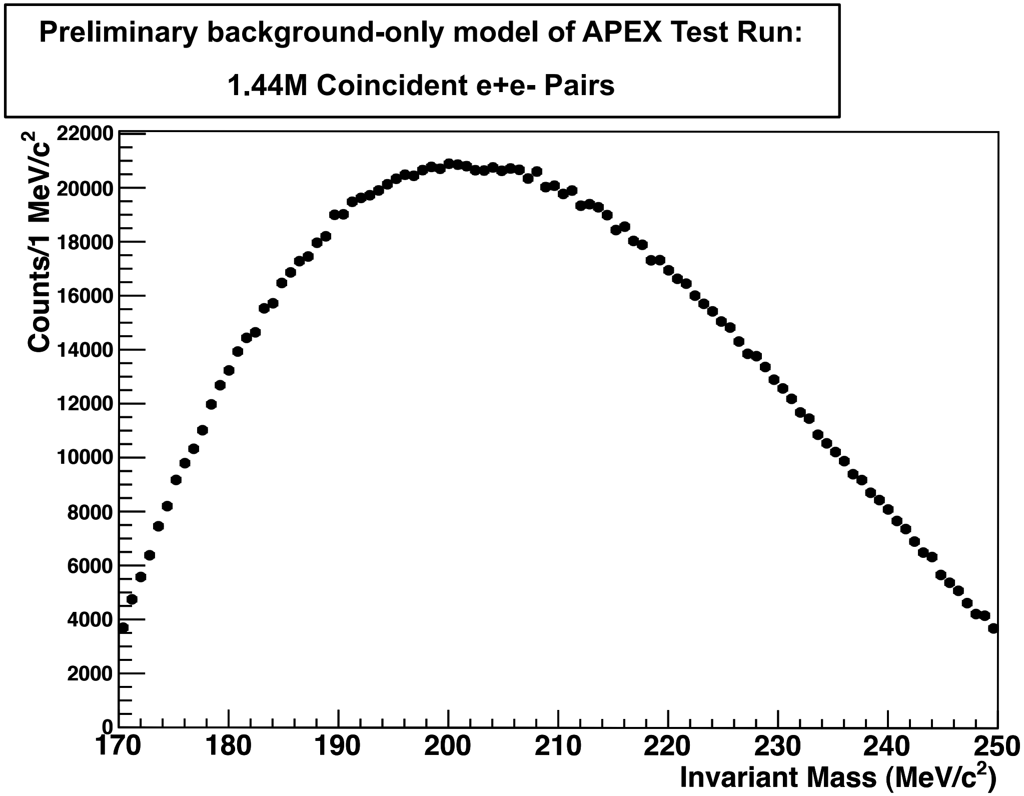
Acceptance strategy

- 1) Standard Hall A Monte Carlo suite, MCEEP, and HAMC (written for another Hall A experiment, PREX), for radiative trident, B-H and other backgrounds
  - Other backgrounds, e.g., Dalitz decays from π^0
  - Estimates indicate negligible, but full analysis must account for it
- 2) Cross-check or replace acceptance functions based on data-driven estimates from single-arm samples of e^- and e^+
  - Determine background process responsible
  - Simulate these processes into idealized detector phase space, c
  - Compare to what we observe in data
  - Arrive at a shape (with arbitrary scaling factor) for this background and this mass range, which gives us the acceptance function
- Both steps will be used for the full analysis of both test run data and that of the full 30-day APEX run

Scaling Up the Preliminary Model

Background shape from limited sample of test run

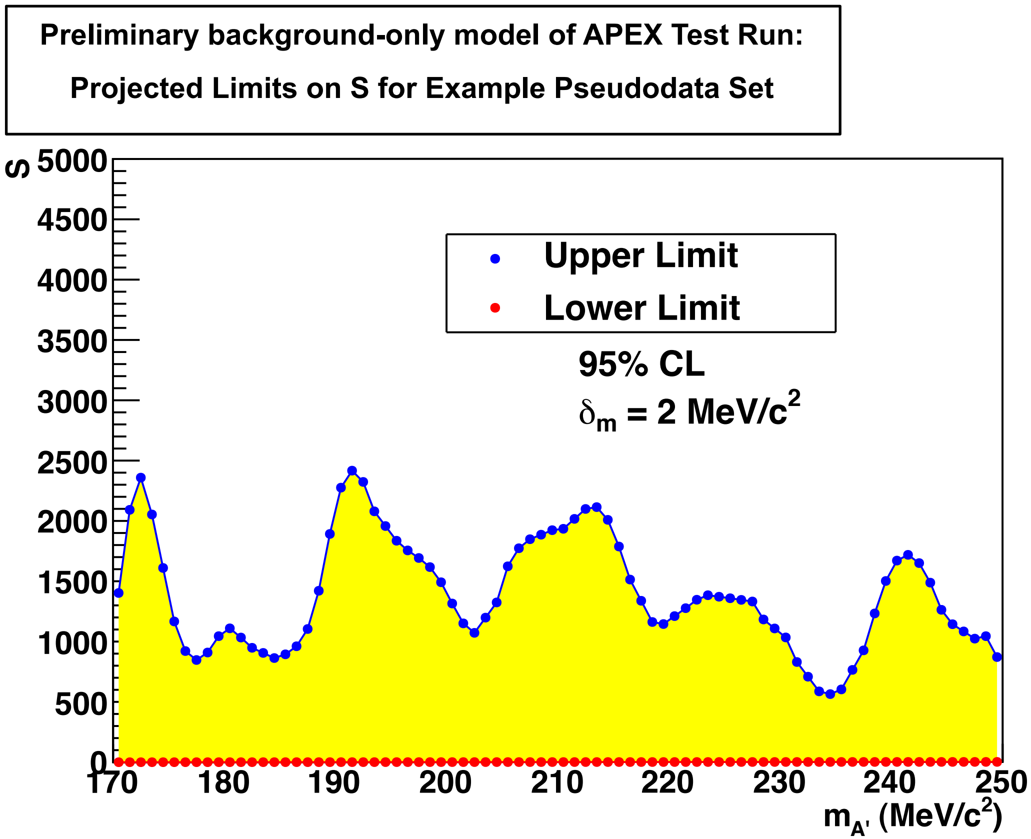




1.44 million events

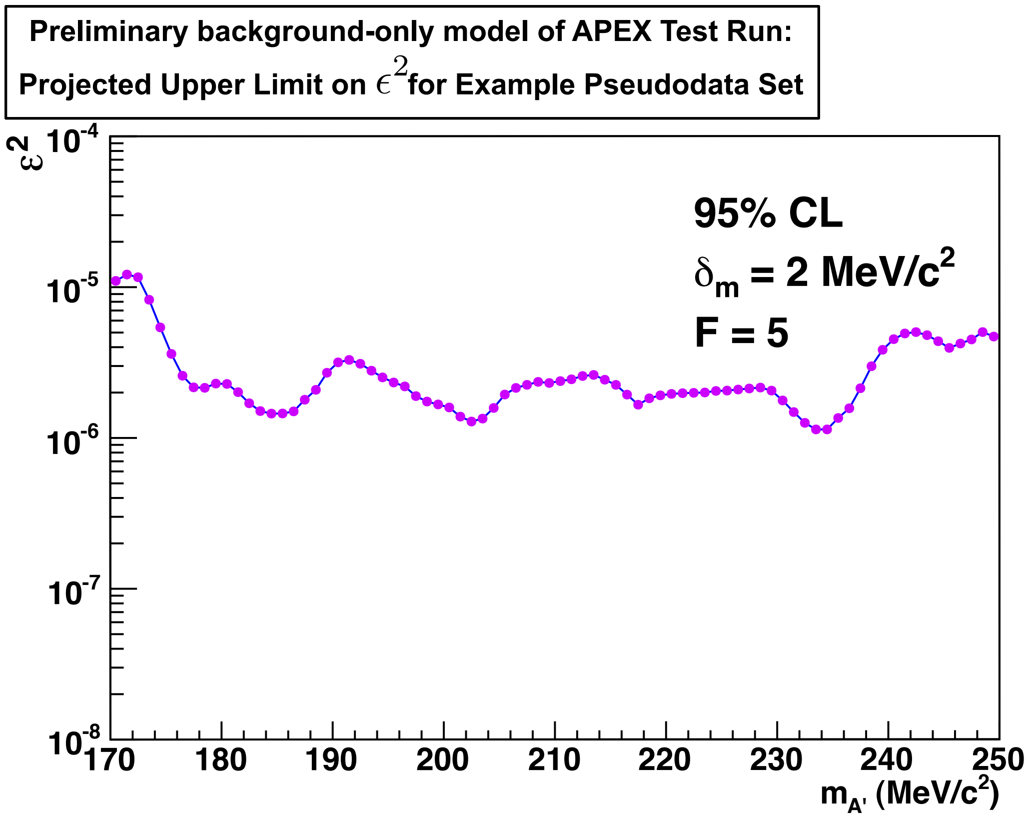
Use shape to generate pseudodata sets with total number of coincident events equal to that of full test run

Preliminary Model of APEX Test Run: Example Pseudodata Set



One example background-only pseudodata set

- Statistical fluctuations evident



Need an ensemble of pseudoexperiments to get expected exclusion

Preliminary Model of APEX Test Run: Expected Results

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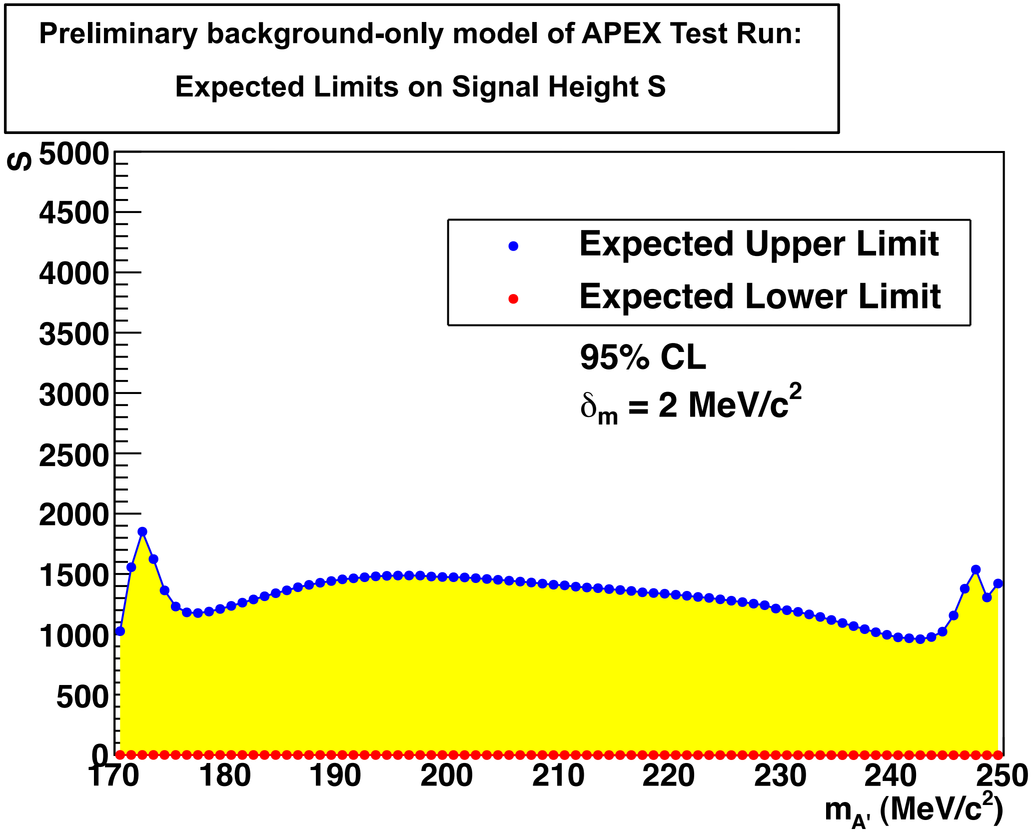
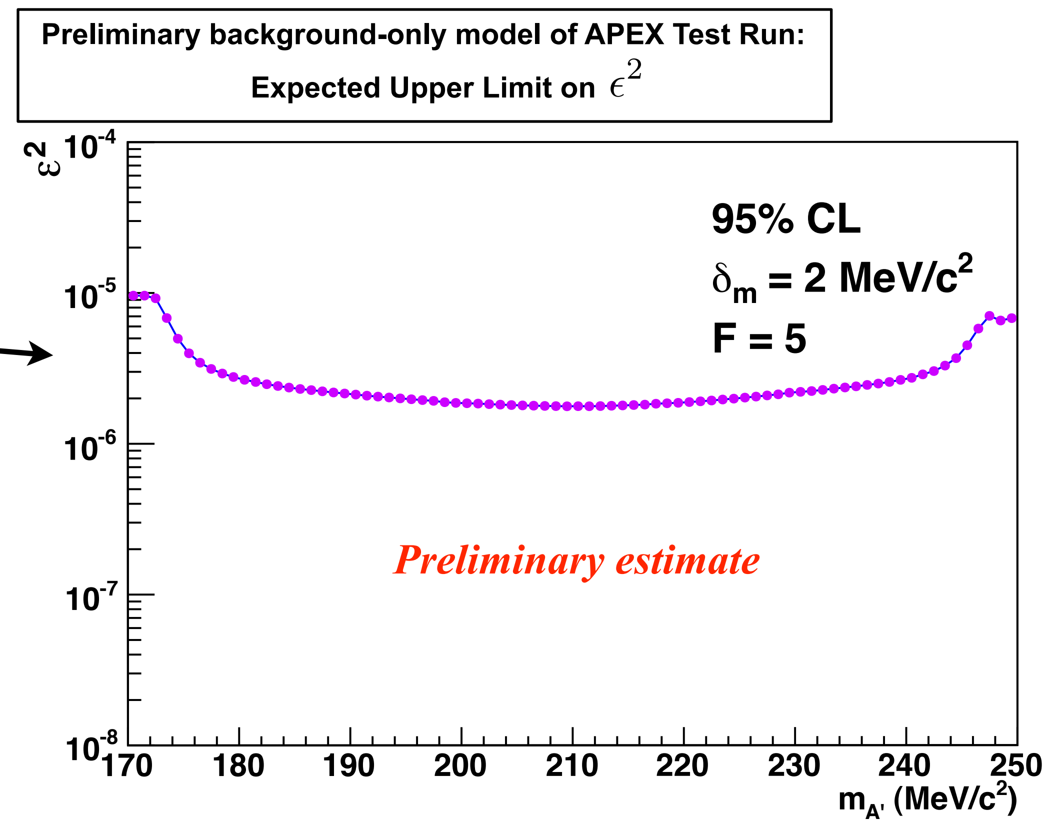


Expected limits on S and exclusion sensitivity in $\epsilon^2 = \alpha'/\alpha$ based on background-only preliminary models from limited sample of test run data, scaled up to full statistics of the test run, i.e., 1.44 M events

$$\epsilon^2(m_{A'}) = \frac{S^{det}_{\delta m}}{B^{det}_{\delta m}} \frac{F\,\delta m}{m_{A'}} \left(\frac{2N_{\text{eff}}\alpha}{3\pi}\right)$$

$F = 5$;
see preceding discussion



Sensitivity to Holes in Momentum Acceptance

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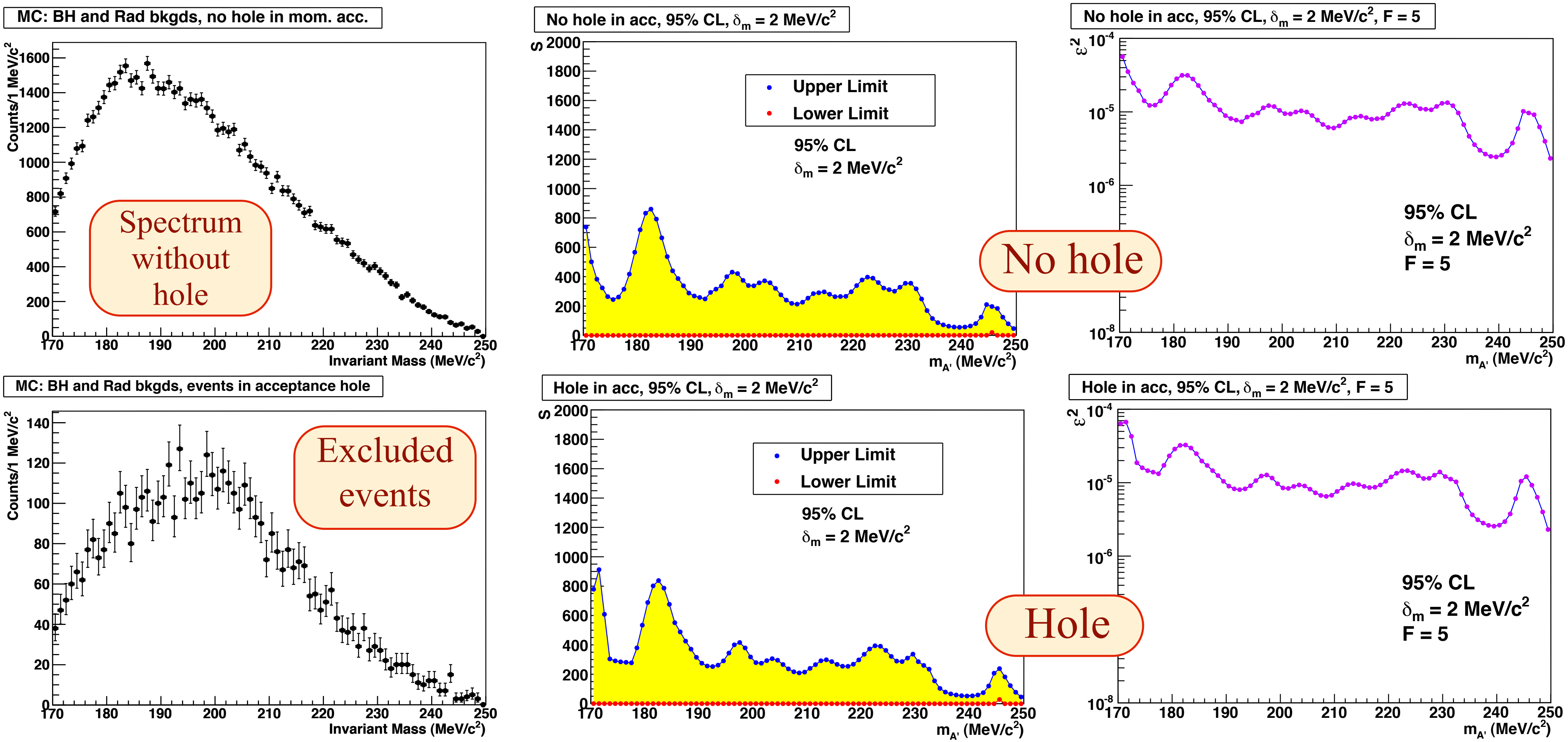
Check robustness of peak search tools

- MC for BH and Rad backgrounds: ~70000 events into nominal HRS acceptance
- Cut out a hole in momentum acceptance: 1130-1135 MeV/c, e^+ arm only



$\Rightarrow$ Holes in momentum acceptance don't cause peaks in mass spectrum

Summary and Conclusions

APEX test run demonstrates potential for A' discovery and strong exclusion on ϵ^2 in full run

- Preliminary projected sensitivity is 30-100 times higher than current limits

Move from preliminary to full model

- Full analysis needed for background shape, acceptances, and mass resolution
- Background factor F
- Understanding of backgrounds and acceptances is ongoing

Peak search machinery developed and robust

APEX at NYU: J.B., Kyle Cranmer