2016 High P-sum with z_0 Cut

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Background and Motivation

The cut on z_0 has seen good performance in background rejection while maintaining good efficiency on macroscopically displaced vertices from the SIMP signal process.

Hope

Maybe this cut can provide improved sensitivity of HPS to the "vanilla" dark photon model.
$e^- N \to e^- N A' \to e^- N e^- e^+$

Goal

Follow same procedure for estimating sensitivity as prior displaced vertex analysis but using the new samples and the SIMP control region (High P-Sum) cuts.

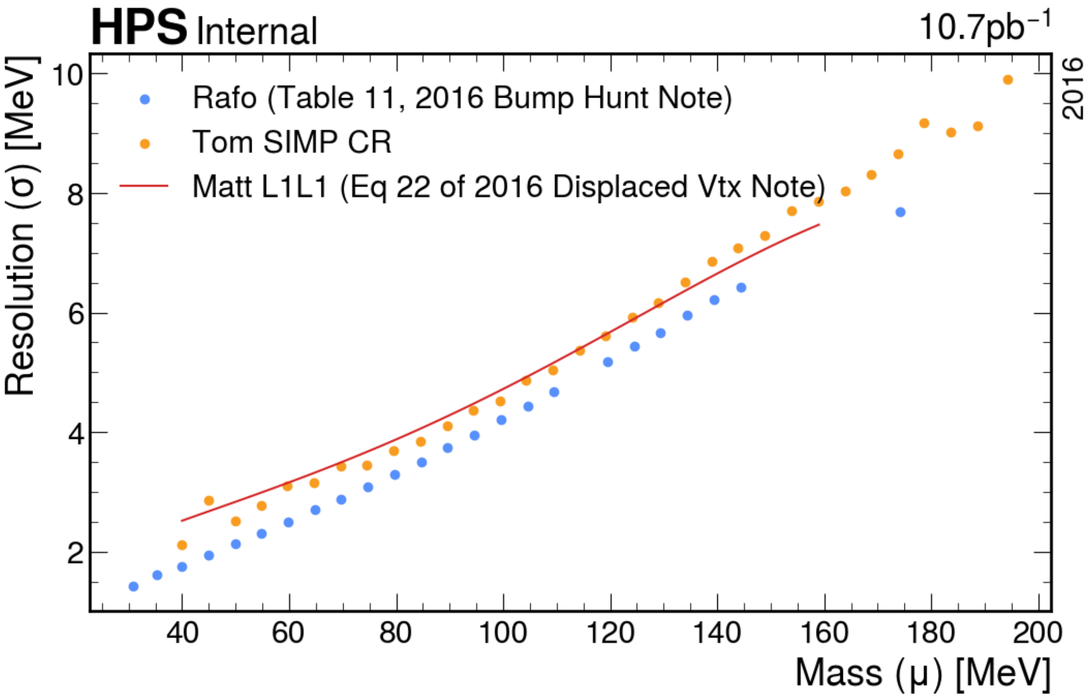
Ingredients

For a given ϵ and $m_{A'}$, assuming we haven't discovered signal events, we need the **expected signal** that we "should" have seen and the **maximum signal allowed** by the (presumably signal-less) data.

- Mass Resolution σ
- Radiative Fraction f_{rad}
- Trident Differential Production $dN_{\gamma^*}/dm_{\text{reco}}$

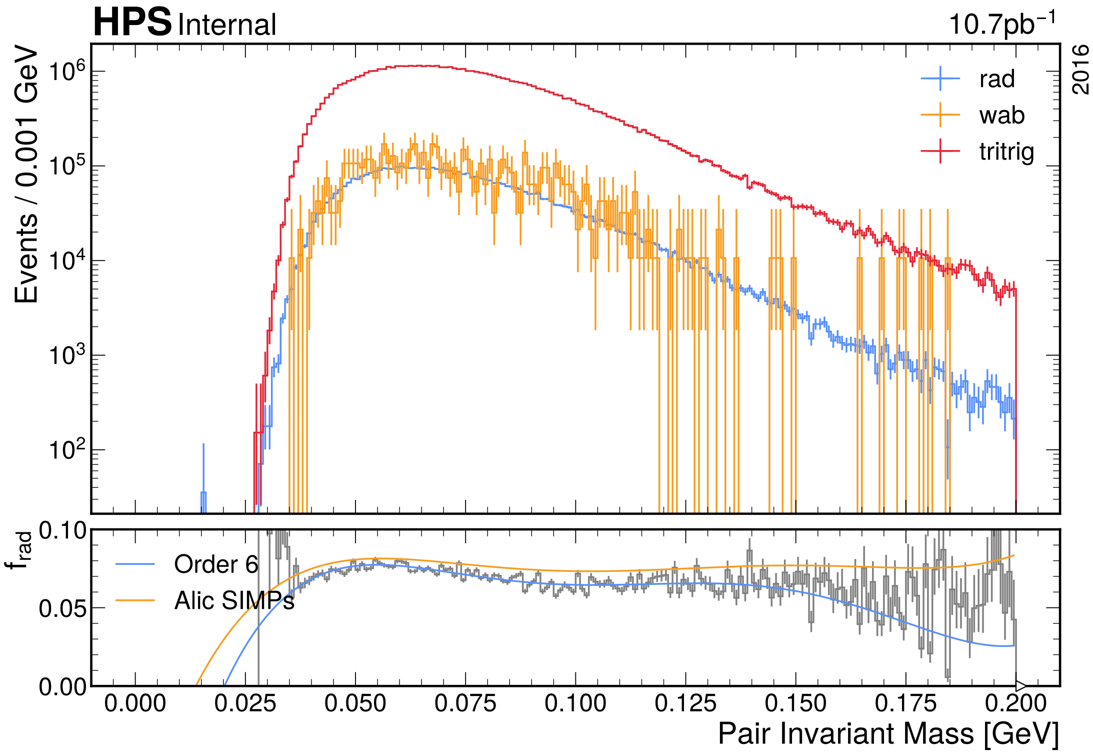
$$N_{\text{prompt}} = \epsilon^2 \frac{N_{\text{prompt}}}{\epsilon^2} = \epsilon^2 \left(\frac{3\pi}{2\alpha} m_{A'} f_{\text{rad}} \frac{dN_{\gamma^*}}{dm_{\text{reco}}} \right) \quad \text{and} \quad c\tau = \frac{\alpha}{3\epsilon^2} m_{A'} \left(1 + 2\frac{m_e^2}{m_{A'}^2} \right) \sqrt{1 - 4\frac{m_e^2}{m_{A'}^2}}$$

Mass Resolution



- Used displaced dark photon samples and the SIMP Control Region (High P-sum) selection
- Observe resolution behaving similar to that reported by Matt in the 2016 Displaced Vertex Note and only slight worsening compared to bump hunt reported by Rafo

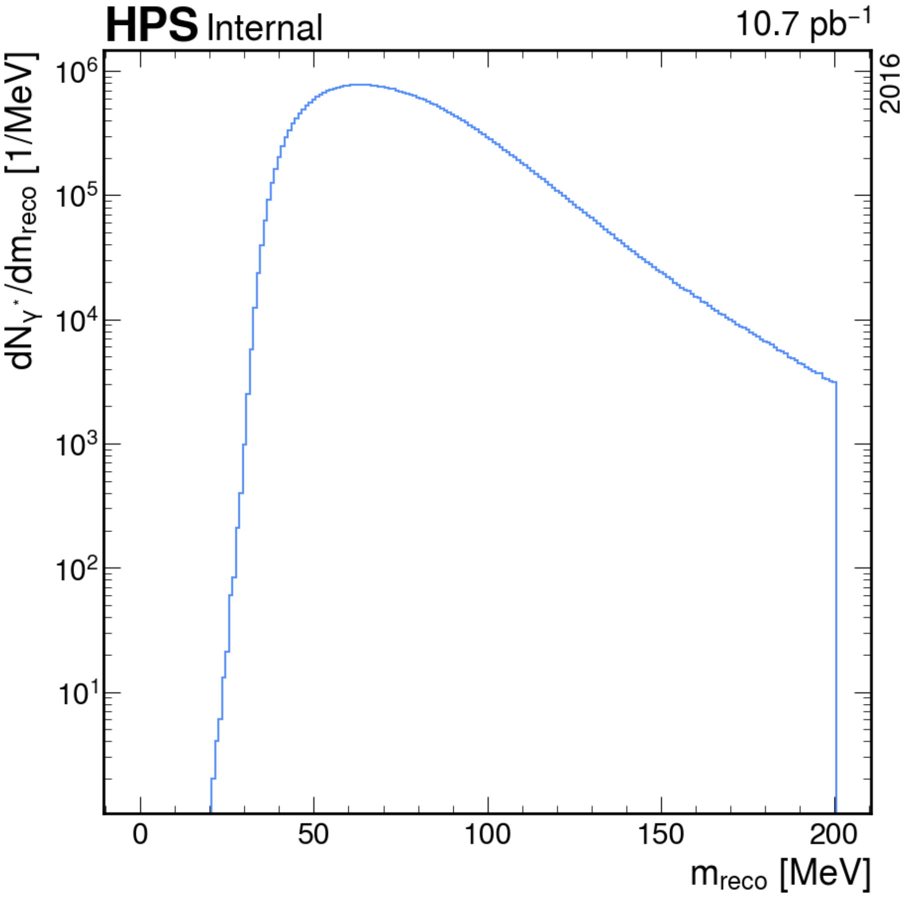
Radiative Fraction



$$f_{rad} = \frac{\frac{dN_{\gamma^*}}{dm_{true}}}{\frac{dN_{bkgd}}{dm_{reco}}} \rightarrow \frac{N_{rad}}{N_{wab} + N_{tritrig}}$$

- Used same Tri-Trig, WAB, and Radiative MC samples as being used within SIMP analysis
- Not identical fit, but main separation is in region where HPS does not have sensitivity anyways due to total trident production rate.

Trident Differential Production



- 100% 2016 data sample within SIMP CR
- Following shape and magnitude of previous estimates

Pause

Only **minor** differences in ingredients so far which can largely be blamed on differences in samples.

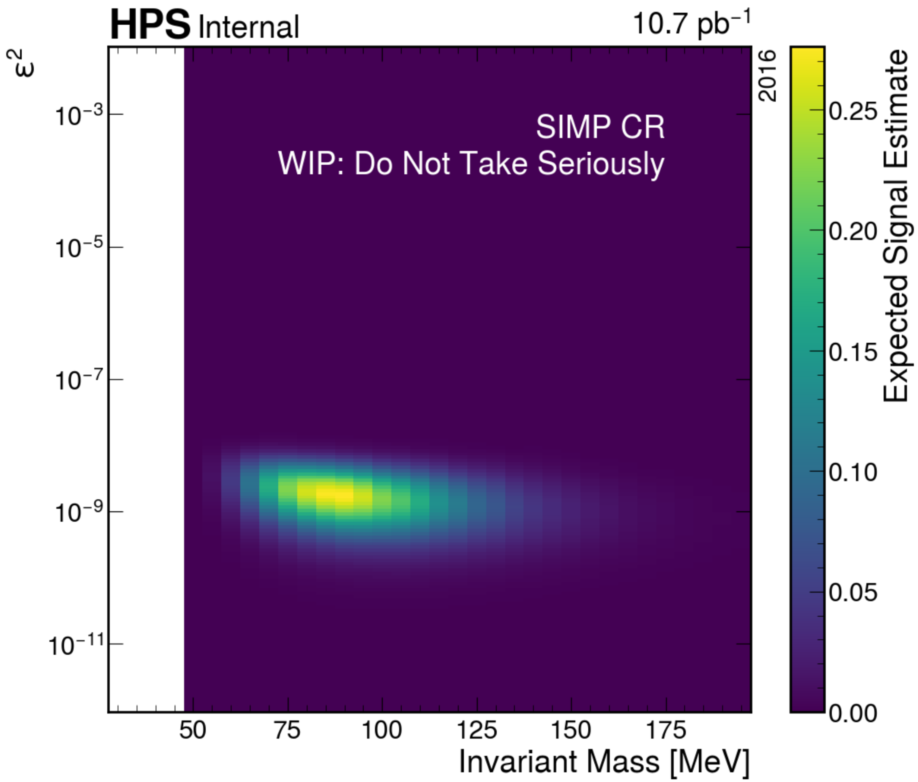
Following same procedure from original note.

▸ tomeichlersmith/hps-exclusion

Cuts

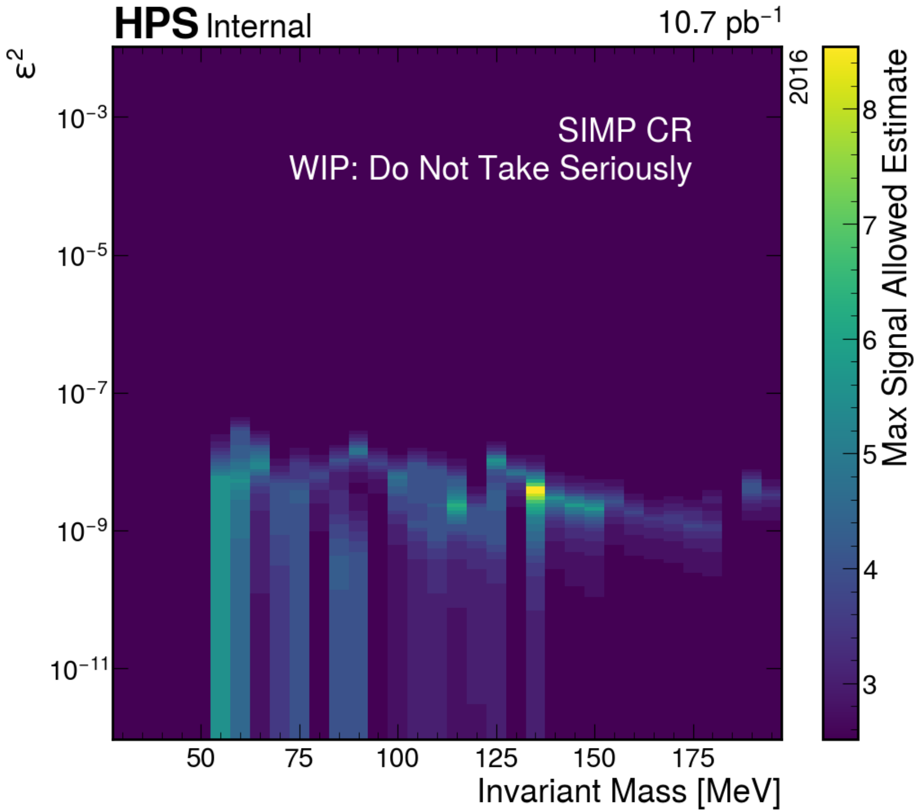
- $P_{\text{sum}} > 1.9$ GeV
- L1 Requirement for both tracks in event
- Exactly one vertex in event
- Significance of Vertex Projection to Target < 2.0
- $m_{A'} - 1.25\sigma < m_{\text{reco}} < m_{A'} + 1.25\sigma$
- $z > z_{\text{target}}$
- $|z_0|/\text{mm} > 1.08 - 7.44 \times 10^{-3}(m_{\text{reco}}/\text{MeV}) + 1.59 \times 10^{-5}(m_{\text{reco}}/\text{MeV})^2$
- $\Delta z/\text{mm} < 21.2 + 0.166(m_{\text{reco}}/\text{MeV})$

Expected Signal



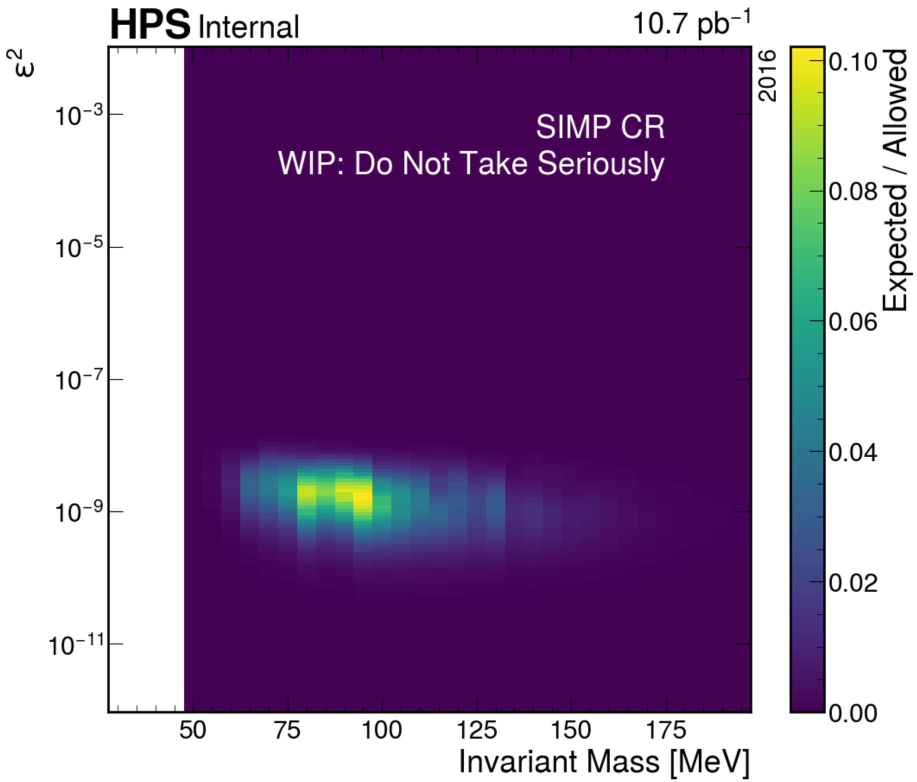
- Peaking around 0.3 as is seen in the original result
- Similar mass and ϵ region as well

Max Signal Allowed



- As estimated by OIM using the signal distribution over z as the CDF to cast events in z into uniformly-distributed events in some variable X.
- Not too much out of the ordinary besides a mass bin that has a few surprising events within it leading to higher-than-average maximum allowed.

Result



- Again, similar to previous result for L1L1 only.
- **Do not** have access to original result and so I cannot make a more quantitative comparison.

Questions

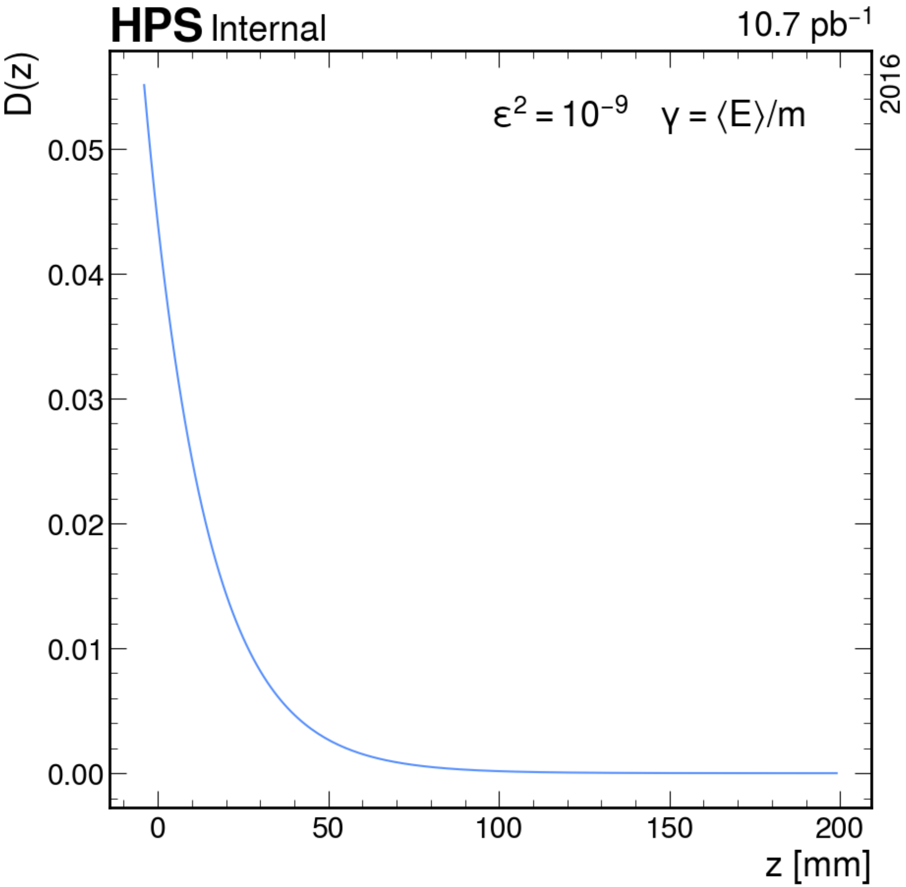
Expected Signal Calculation Detail

Need to re-weight events by their z such that passing fraction represents the number of expected signal at that decay distance.

$$D(z) = \frac{\epsilon^2}{\langle\gamma\rangle c\tau_{\epsilon=1}} \exp\left[\frac{(z_{\text{target}} - z)\epsilon^2}{\langle\gamma\rangle c\tau_{\epsilon=1}}\right]$$

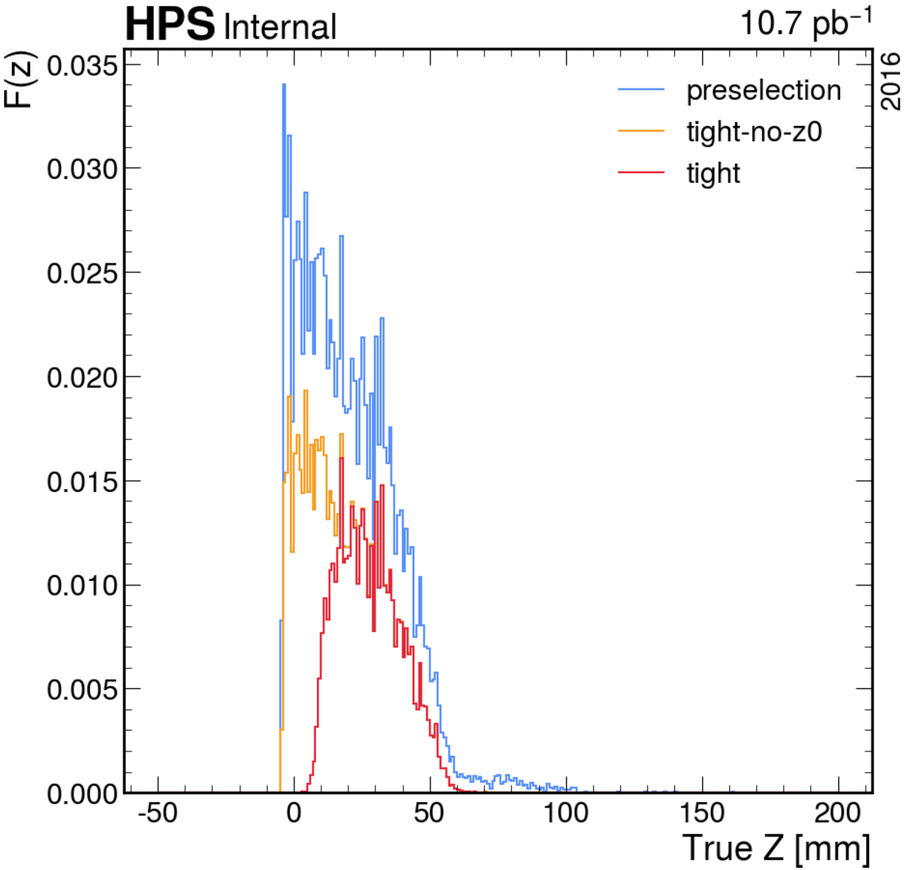
To explain the expected signal calculation procedure, let's walk through an example for $m_{A'} = 100\text{MeV}$.

Decay Weights



- Following expected decaying shape, peaking at target
- Seems reasonable...

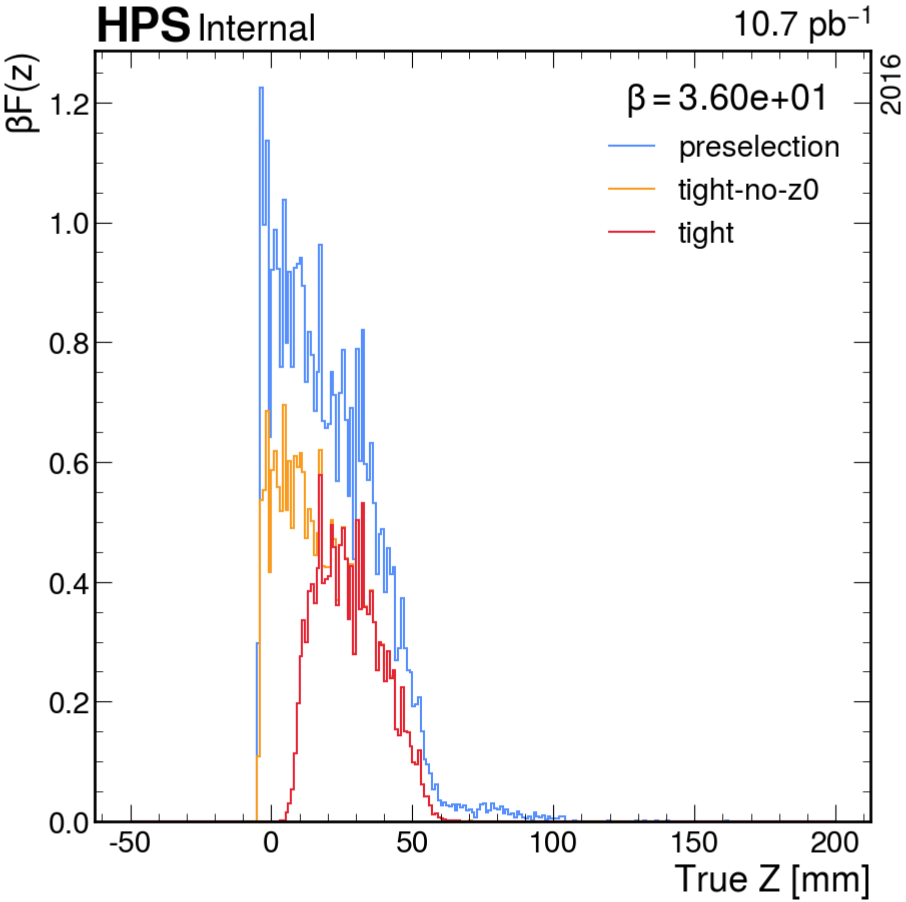
Selection Efficiency over z



- How likely a given signal event passes the selection criteria
- Includes factors for readout acceptance *and* analysis acceptance

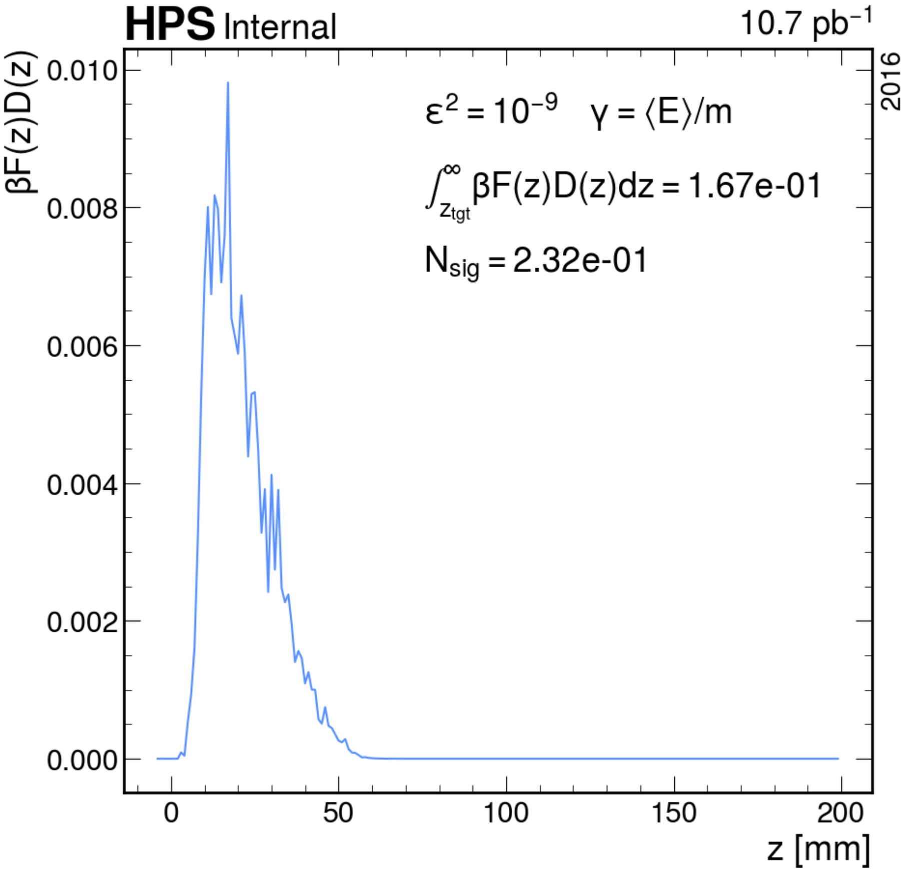
But readout acceptance is already accounted for within the data-driven estimate of the trident differential production rate. $\Rightarrow$ Re-scale $F(z)$ so that it equals 1 at the target.

Re-Scaled Selection Efficiency over z



- Calculate β by averaging over the four bins nearest the target
- Puts the pre-selection distribution near 1 within statistical uncertainty at the target.

Result



- Combining $\beta F(z)$ and $D(z)$ gives us the integral we should sum over to obtain the probability a given produced signal event remains within acceptance
- Multiplying this probability by the total number of produced signal (as estimated by the trident differential production) gives an estimate for the expected number of signal events.

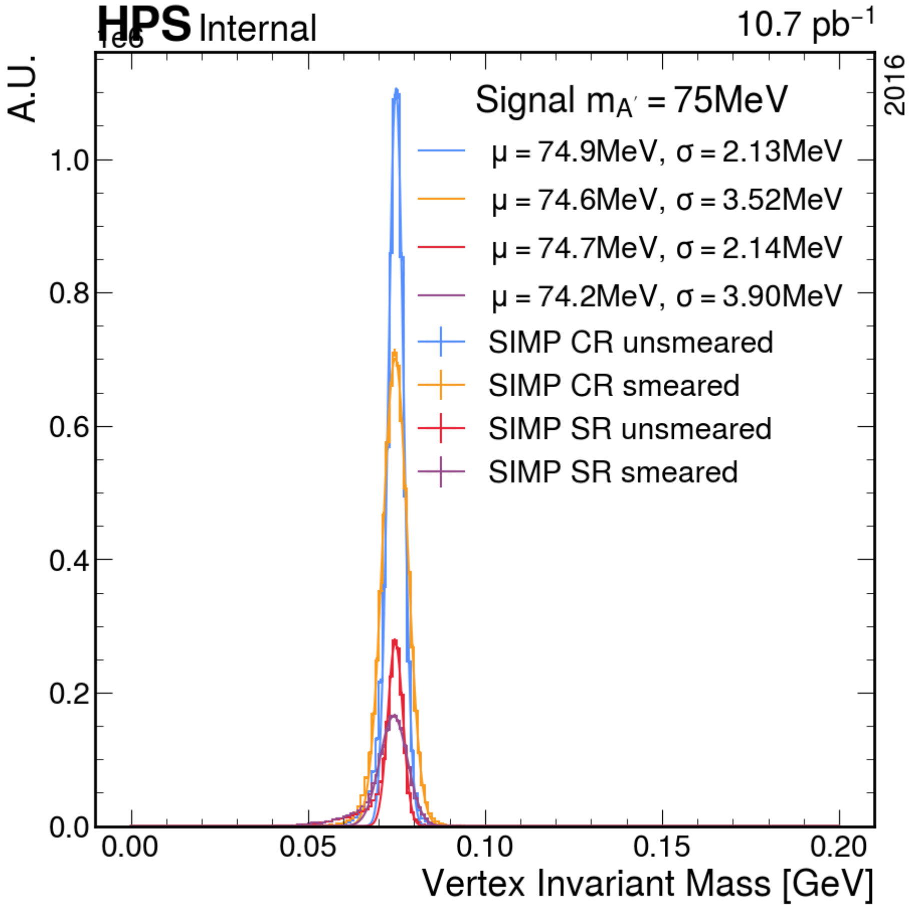
Mass Resolution Detail

Re-Evaluate 2016 Mass Resolution

Due to a variety of simulation and reconstruction patches and updates.

- Signal samples generated and reconstructed by Cam
  - Added to sample list for Pass4b on confluence ▸ pass4b for 2016 MC
- Applied momentum smearing with hpstr
  - Code in ▸ hpstr PR 187
- Plotted and fit in notebook
  - Selecting vertices whose tracks have been strictly matched to truth-level "rad" electrons (i.e. not contaminated with recoil electrons)

More Similar Selection



- Reduction in low-side tail distorting results
- Resulting resolution σ still deviating more from previous estimate, but at a much smaller scale

For Comparison

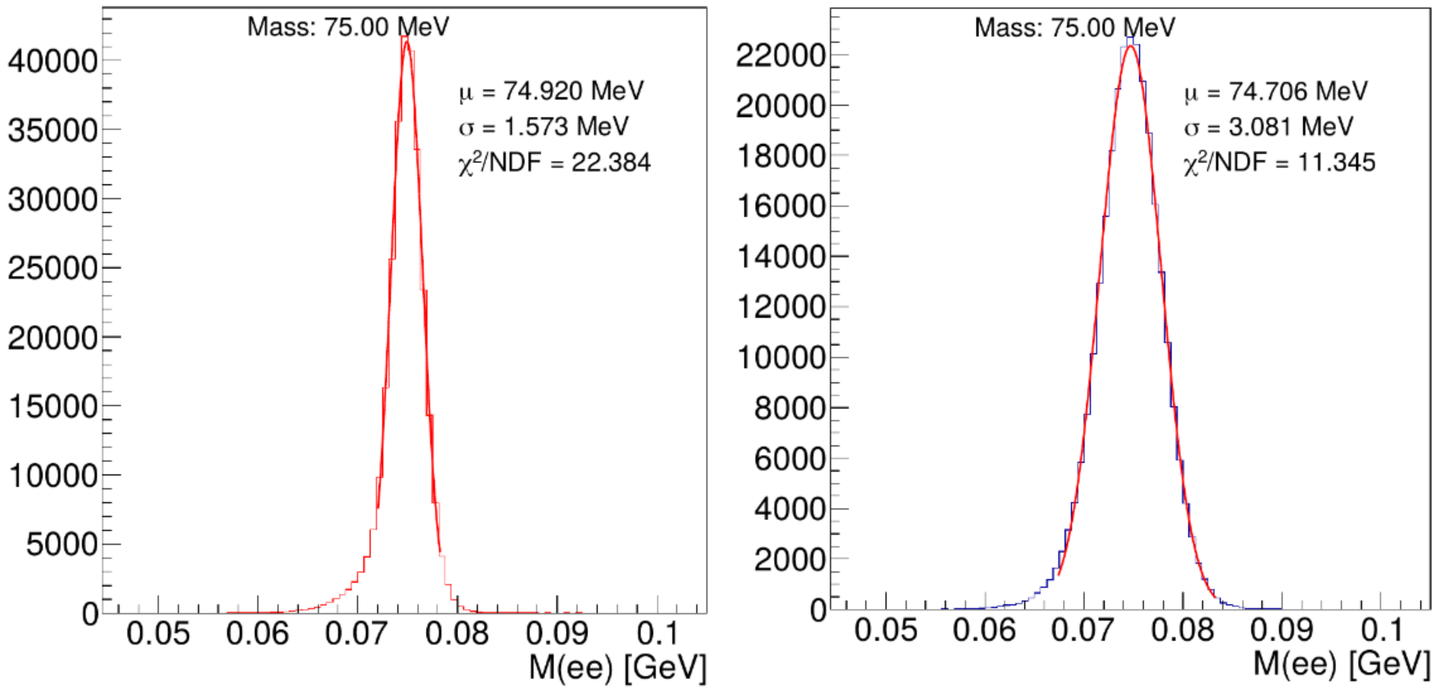
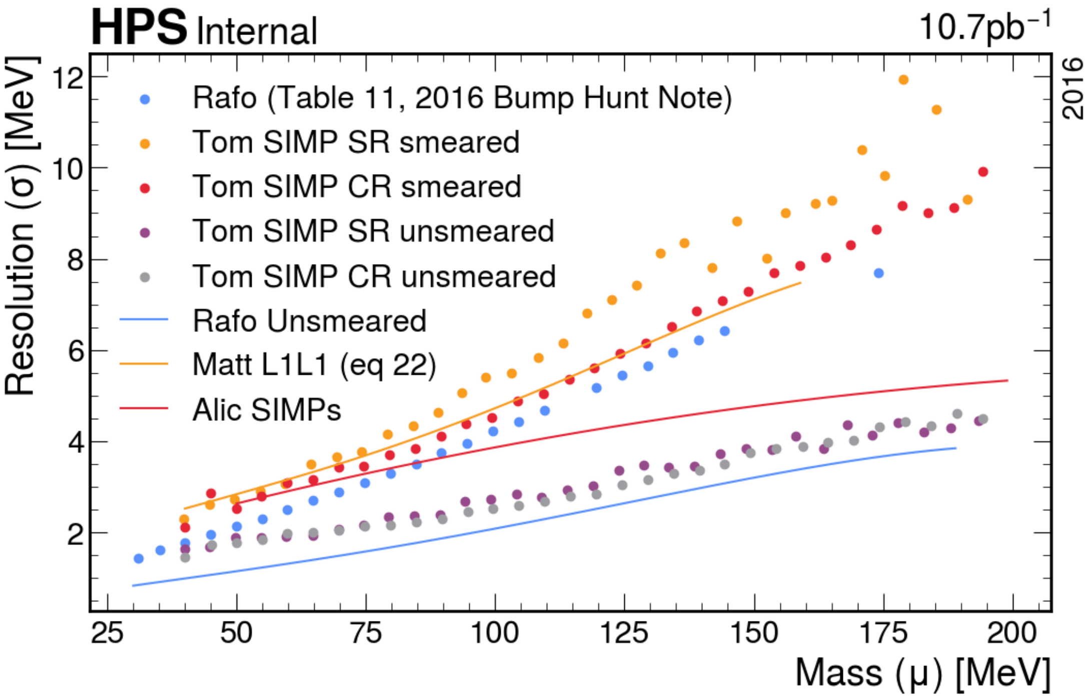


Figure 28: Mass distribution for 75 MeV A′ MC. Left: unsmeared mass, right: smeared mass

Figure: From Rafo's 2016 Bump Hunt Internal Note end of Section 4.

Looks like fit is restricted to mass peak (which makes sense and is something I am also doing)

All Mass Resolutions Available to Me



- Able to use newer generated samples to produce mass resolution estimates including track smearing
- Observing slight worsening in resolution (increase in σ) compared to previous estimate

How I evaluated the resolution

Goal : Center (mean μ) and Width (std dev σ) of peak

Two stage process

1. Find Peak

Iterative approach

1. Calculate μ and σ from the bins
2. Remove bins further than $N\sigma$ away from μ
3. Repeat until stable (i.e. no bins are being removed)

For the results here, I chose $N = 2$.

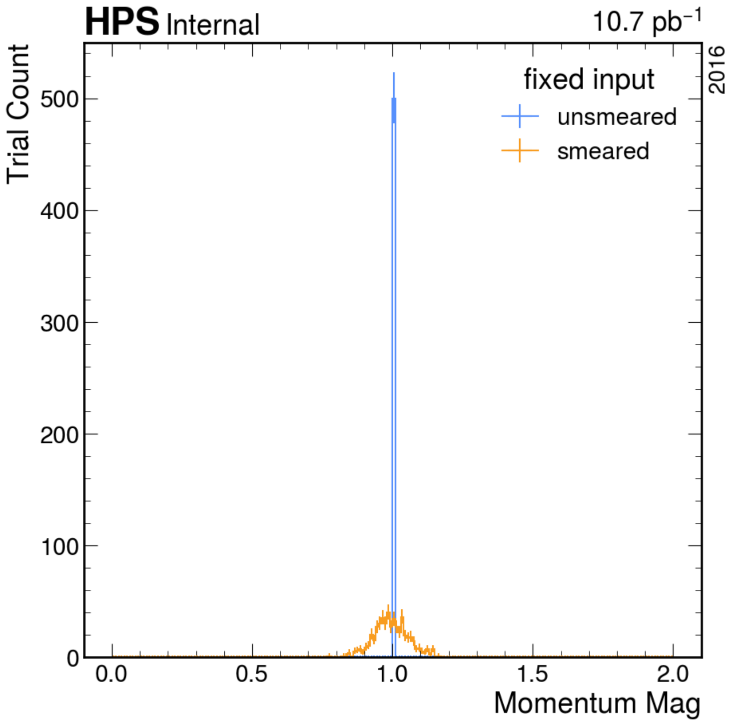
2. Fit Normal Distribution

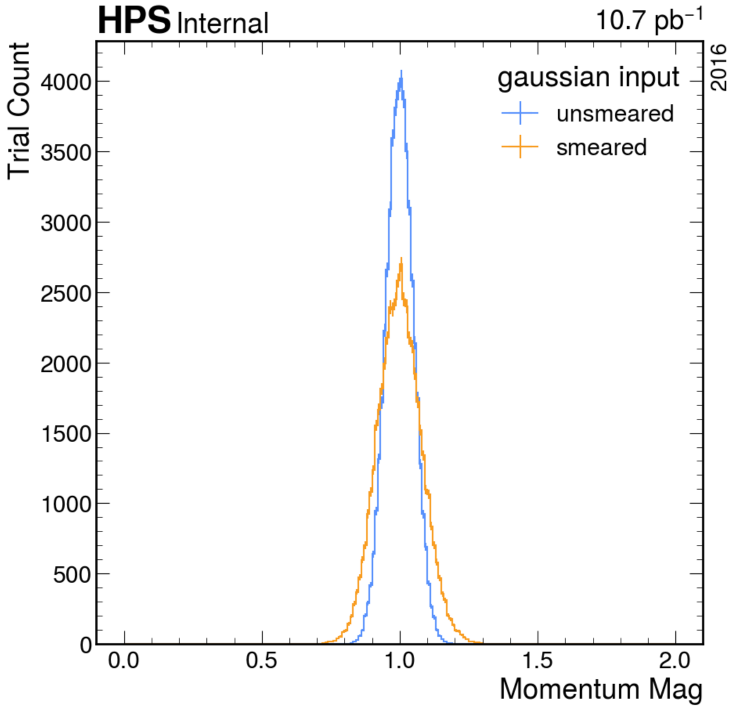
- Actually fitting a "scaled" normal distribution which is just a normal distribution multiplied by some scale (basically ends up being the integral of the fit range if fit is good).
- Only fitting to the range of bins selected in Stage 1 above.
- Using uncertainty on bin content as errors of data points in fit.
- μ and σ taken from this fit.

Direct Testing of Smearing Tool

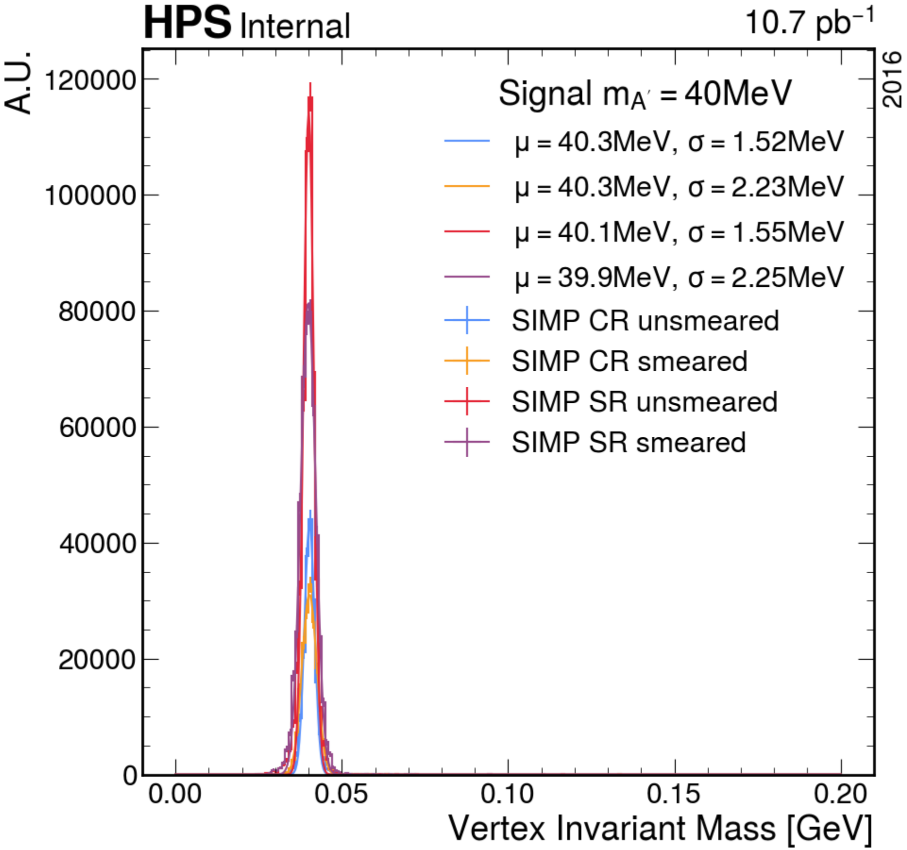
Manually constructing tracks with known input momenta and then applying smearing.

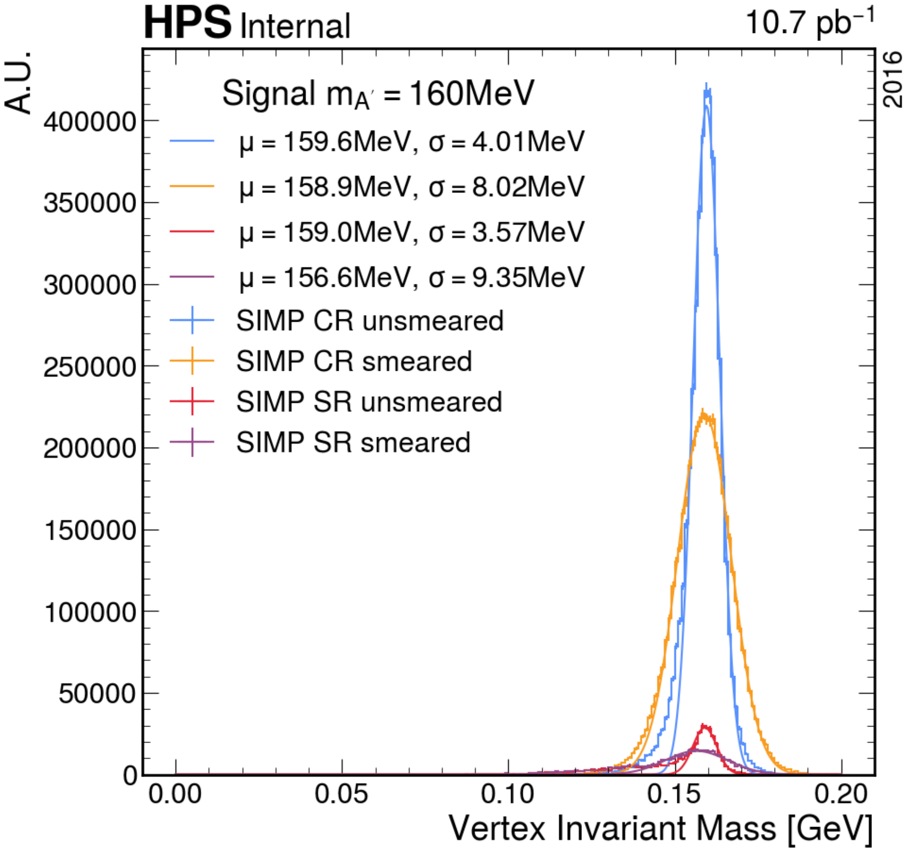
✓ **Get expected results** ✓





Mass Extrema





Selection Comparison

Not thoroughly checked!!

SIMP CR

1. L1 Requirement
2. $P_{\text{sum}} > 1.9$ GeV
3. Electron matched to truth rad electron
4. Single Vertex Candidate

SIMP SR

1. L1 Requirement
2. $P_{\text{sum}} < 1.9$ GeV
3. $P_{\text{sum}} > 1.0$ GeV
4. Electron matched to truth rad electron
5. Single Vertex Candidate

Rafo Tables 4 and 7

1. Preselection
   - $\chi^2 < 12$, Goodness of PID < 10, cluster-track time diff < 6 ns for both tracks
   - Electron track has $P < 2.15$ GeV
2. $P_{\text{sum}} < 2.4$ GeV
3. $P_{\text{sum}} > 1.9$ GeV
4. $|\Delta t_{\text{cluster}}| < 1.43$ ns
5. Single Vertex Candidate