2016 SIMP 10% Result

HPS Collaboration Meeting 06/2024

Alic Spellman

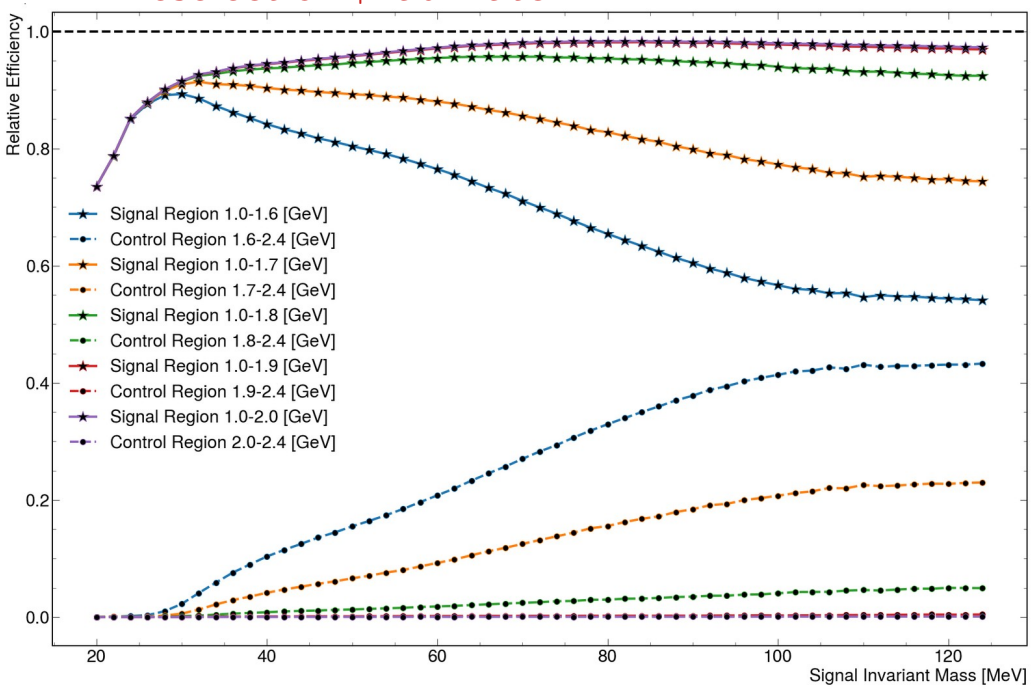
06/04/2024

Introduction

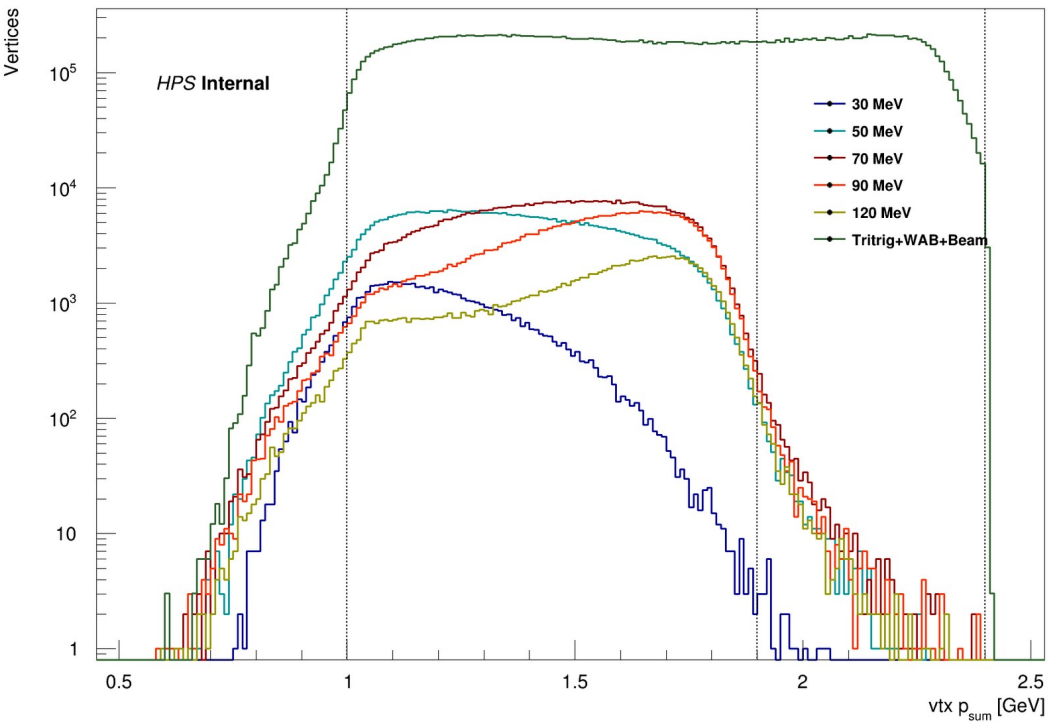
- New Pass4b MC with hit killing processed, 2 MeV signal intervals with larger stats
- Only thing missing from MC side is momentum smearing
  - Current implementation (or my running of it) doesn't look right...need to validate
- Two high-z cuts (target projection + impact parameter) get our background down to a very low rate
- Goal is to complete search for signal in 10% data, document process in analysis note, and get approval to unblind
- The biggest obstacle to unblinding is having a good way to estimate the expected background
  - We use "ABCD" method, which uses left+right mass sidebands, and the impact parameter
  - Works pretty well
- Perform p-value calculation at 1 MeV intervals of width $2\sigma_{mass}$
- No discovery in 10% data :O
- Calculate region of exclusion in 10% data using Optimum Interval Method

Signal and Momentum Regions

Preselection+radMatch



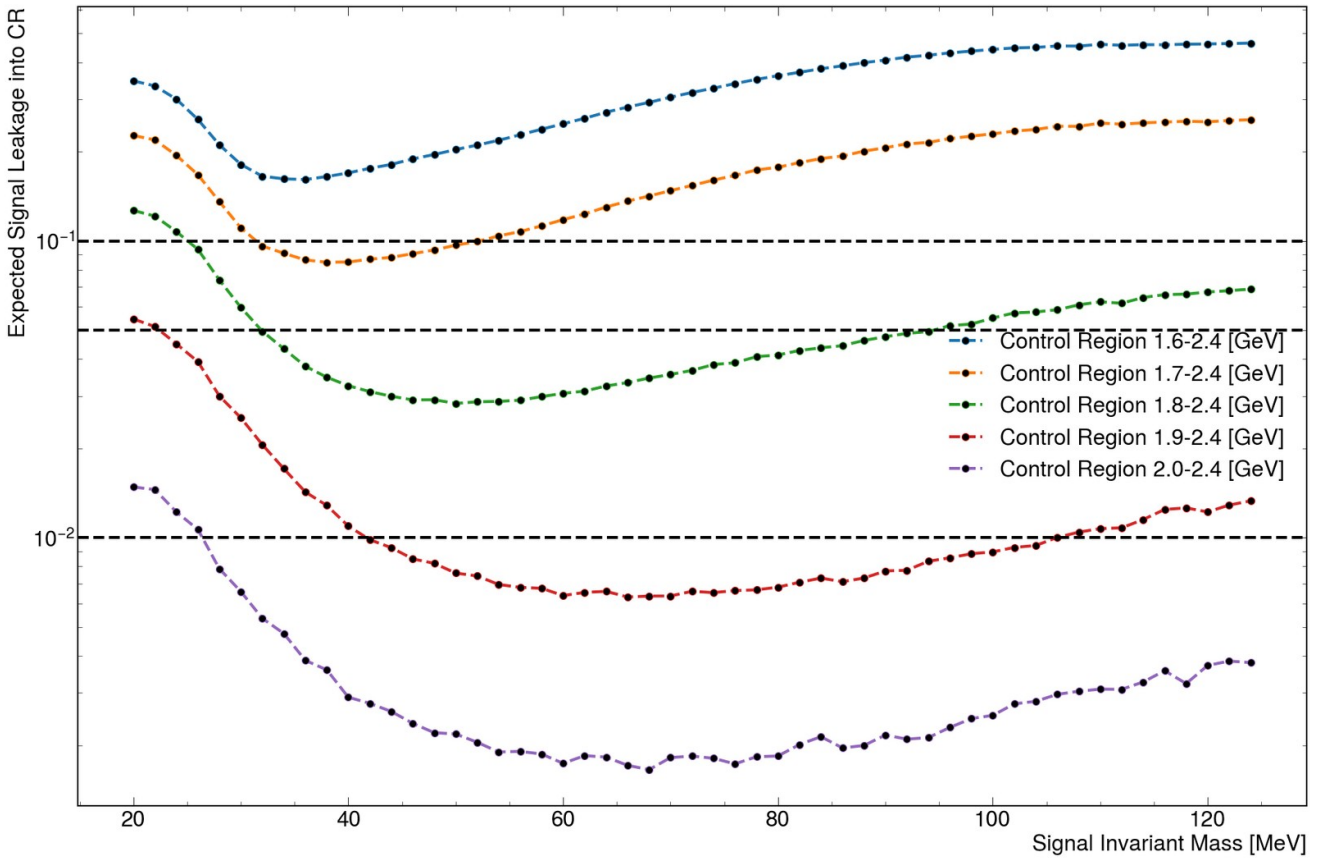
Preselection+radMatch



Signal Contamination in Control Region

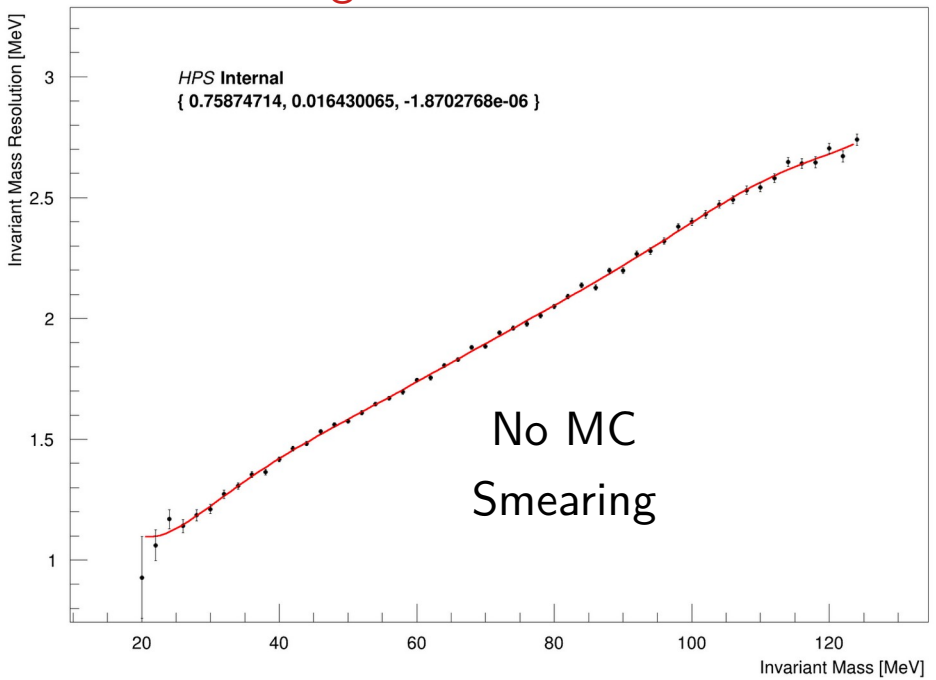
- Possible contamination in CR
- Remove truth matching requirement
- Normalize Signal Psum starting from
  1.0 GeV $<$ Psum
- O(1%) contamination

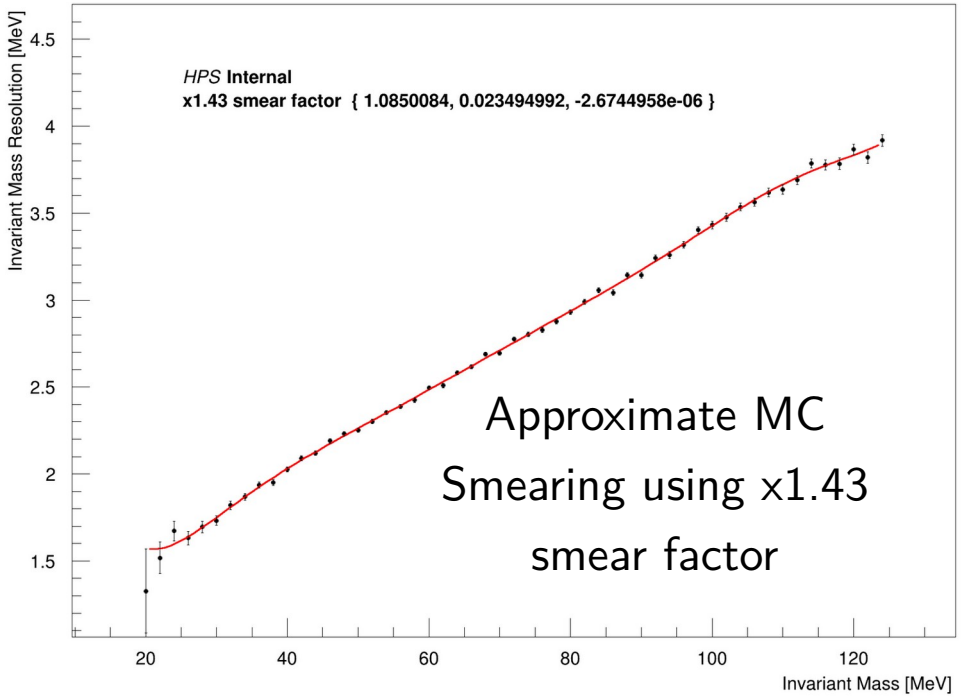
Preselection



Mass Resolution

RadMatchTight SR

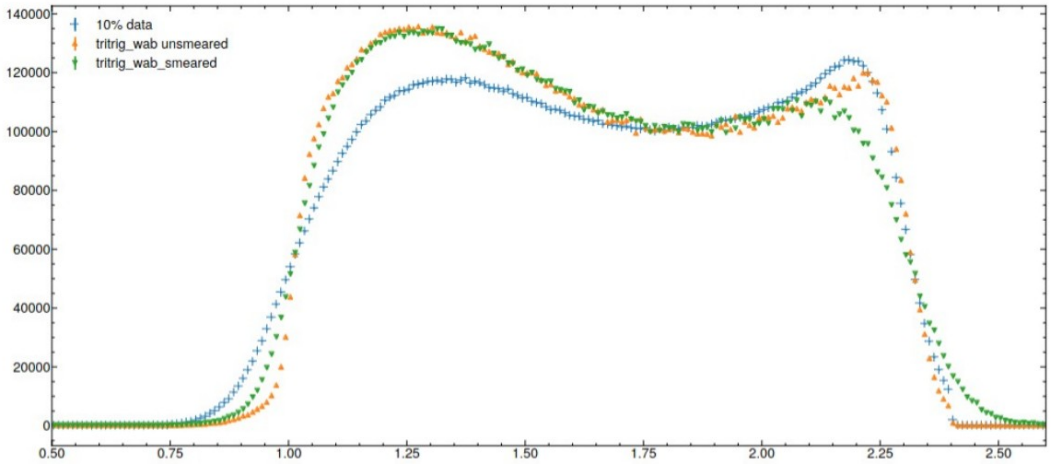


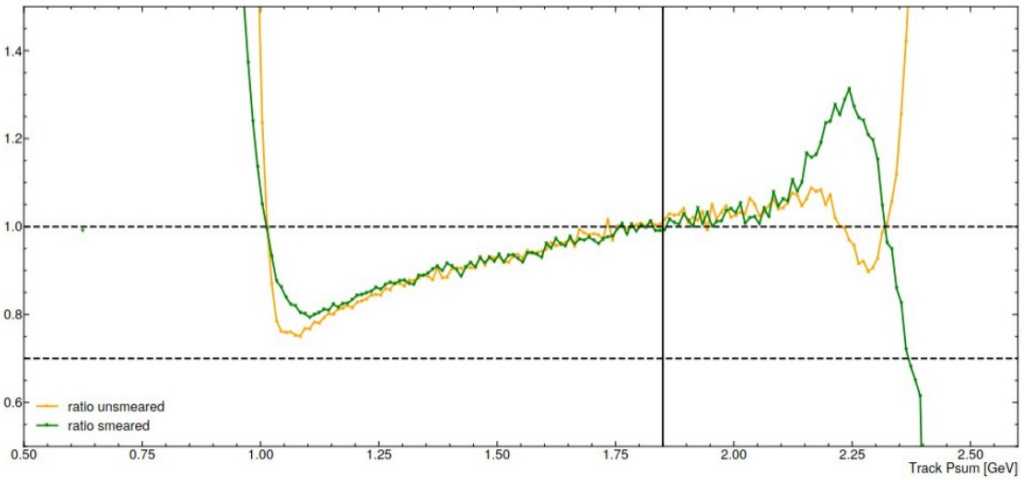


- Still need to fix MC P smearing and then recalculate mass resolution
- *dont have higher mass samples with hit killing available

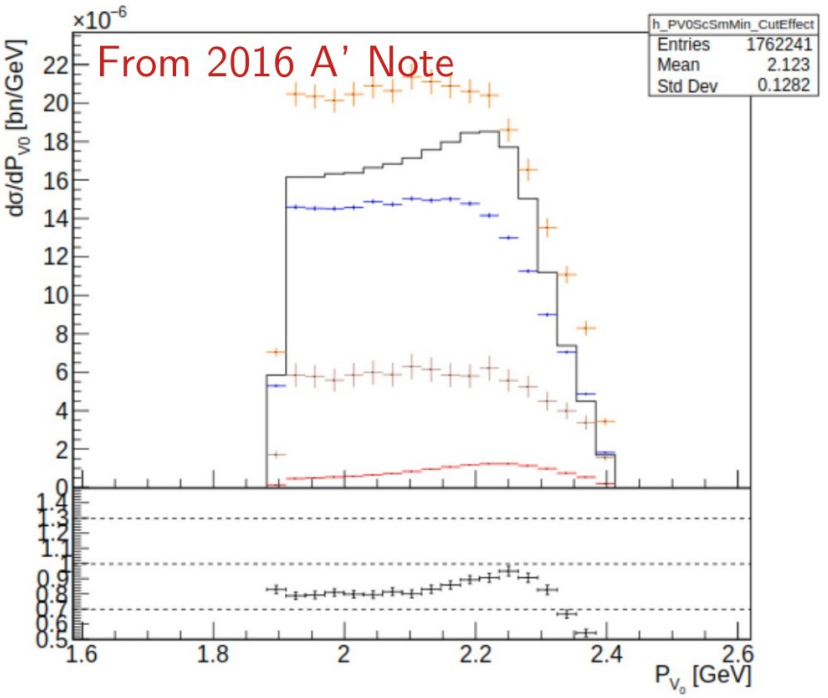
Momentum Smearing

- I tried running momentum smearing implemented in hpstr
- Looks like too much smearing
- PF suggested a few checks that I have yet to do

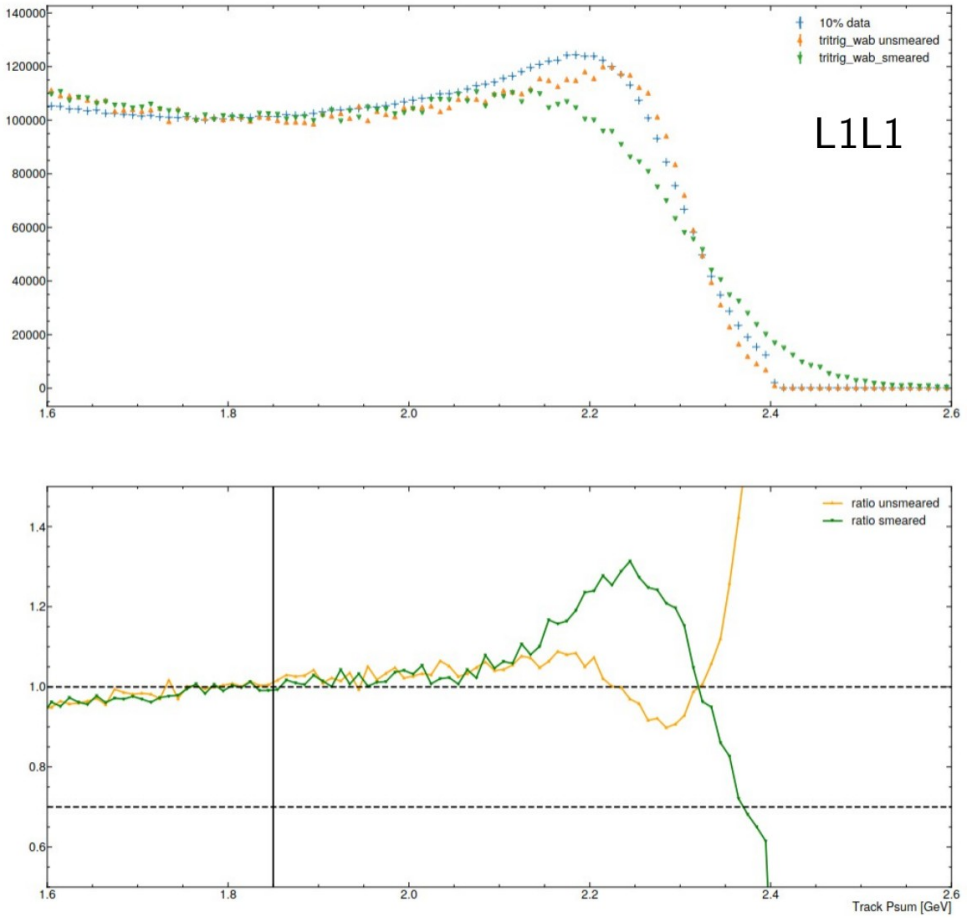




Momentum Smearing

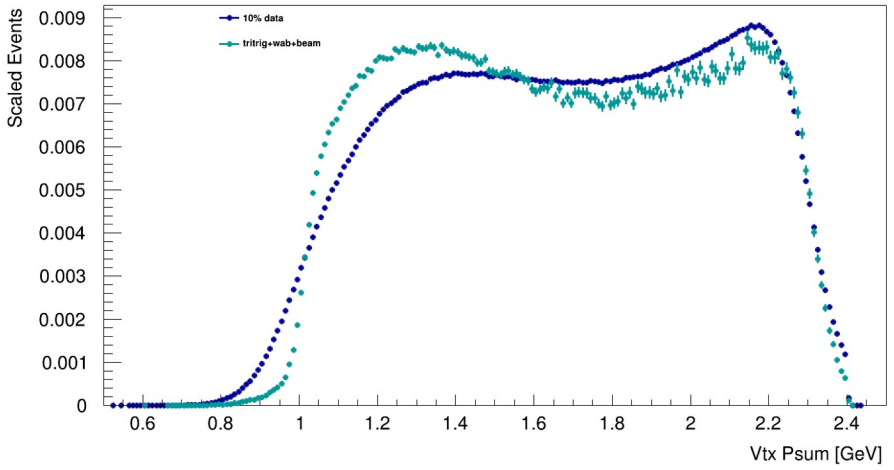


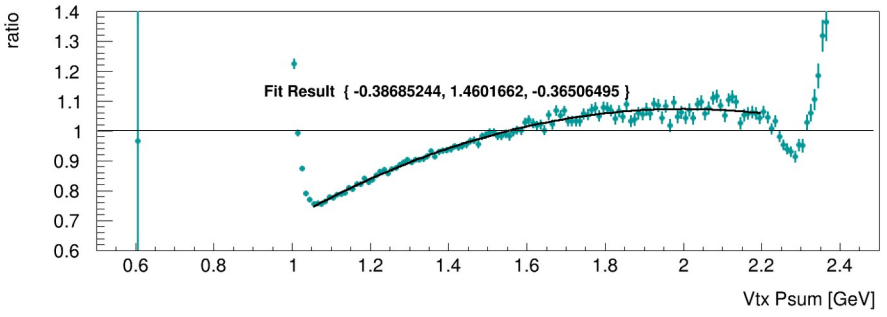
Unclear if momentum smearing is applied when this plot was made...



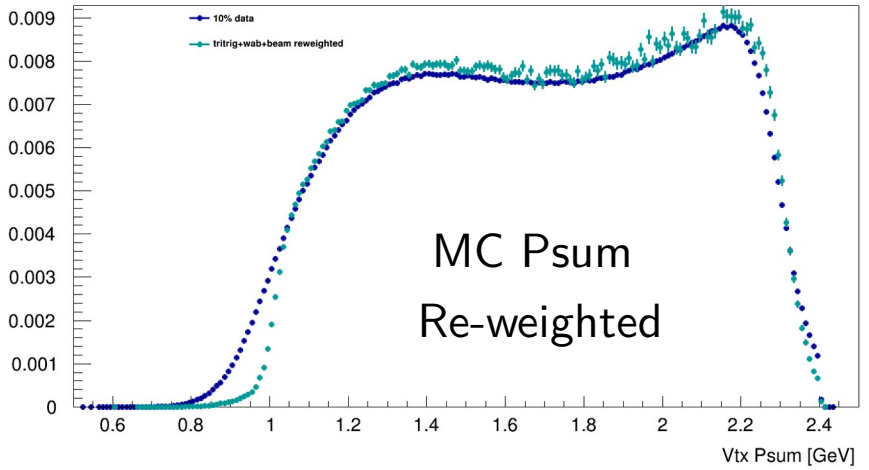
Data/MC Psum

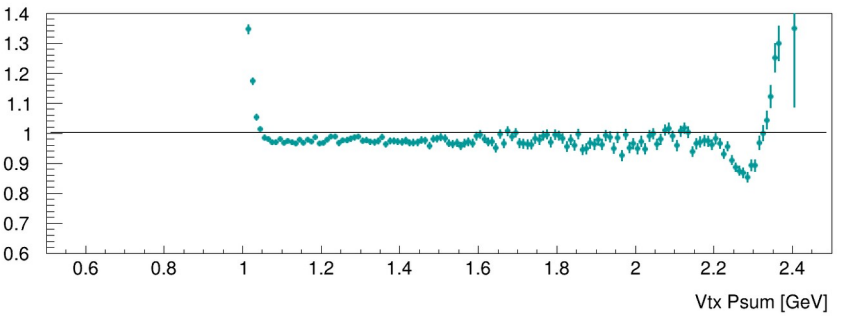
Preselection





Preselection





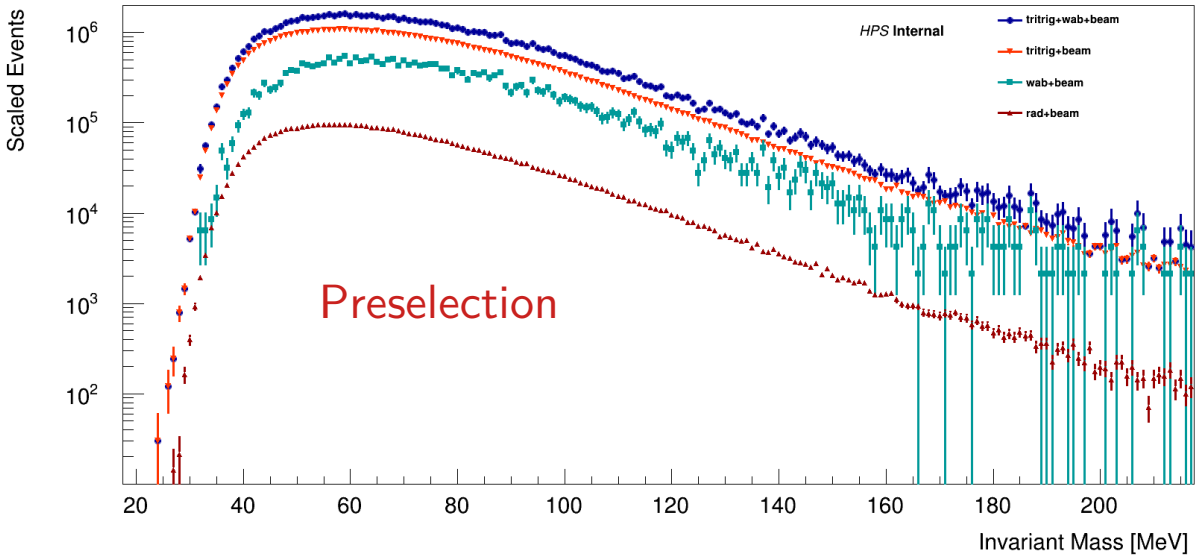
- Should we re-weight before or after L1L1?

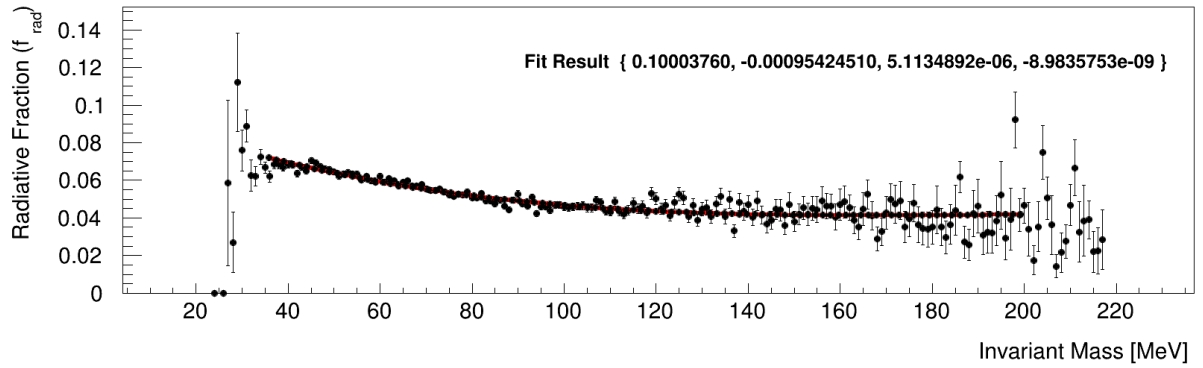
Radiative Fraction

- Pass4b (hit killing)
  - 10k tritrig+beam
  - 10k wab+beam
  - 10k rad+beam

- No p smearing
- Preselection and $1.9 < \text{Psum} < 2.4$

- Fit 35-200 MeV with 3rd order polynomial



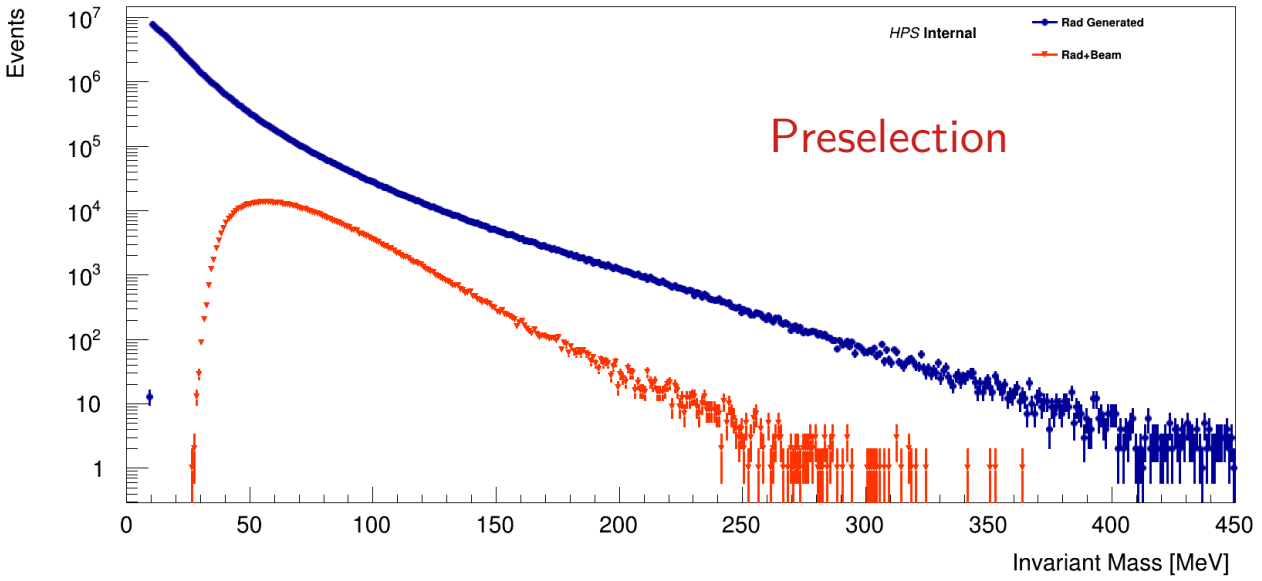


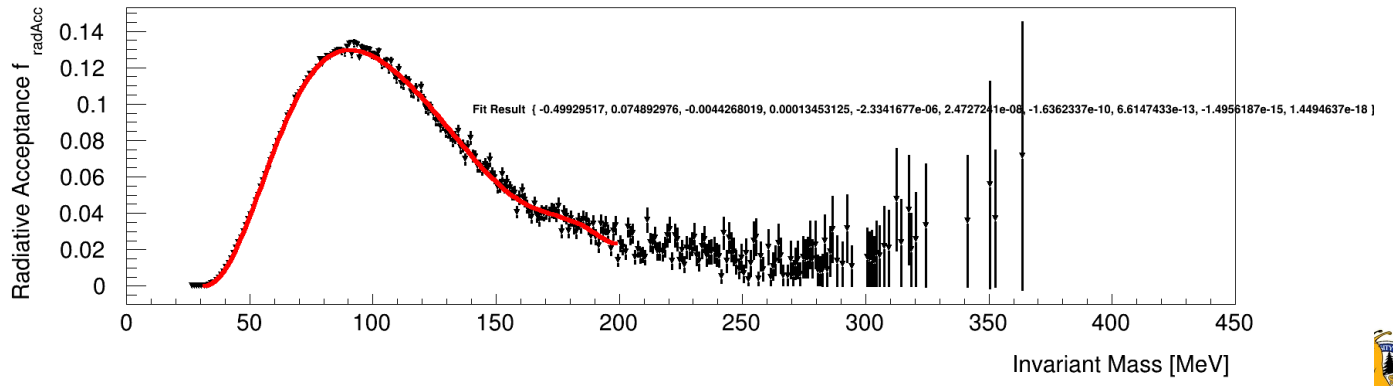
Radiative Acceptance

- Pass4b with hit killing
  - 10k rad nobeam slic files
  - 10k rad+beam recon

- No p smearing
- No Psum re-weighting
- Preselection and
  $1.9 < \text{Psum} < 2.4$

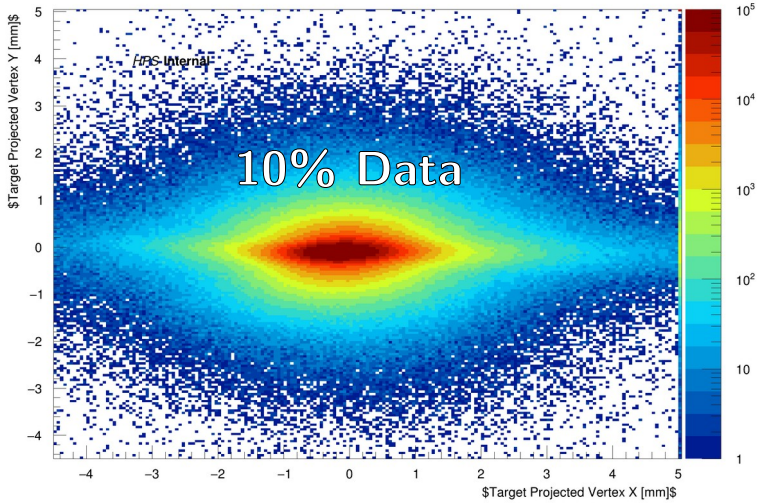
- Fit 30-200 MeV with 9th order polynomial

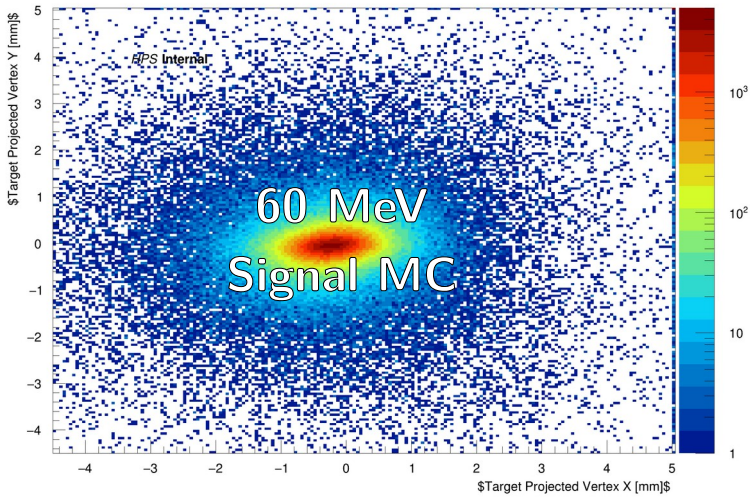




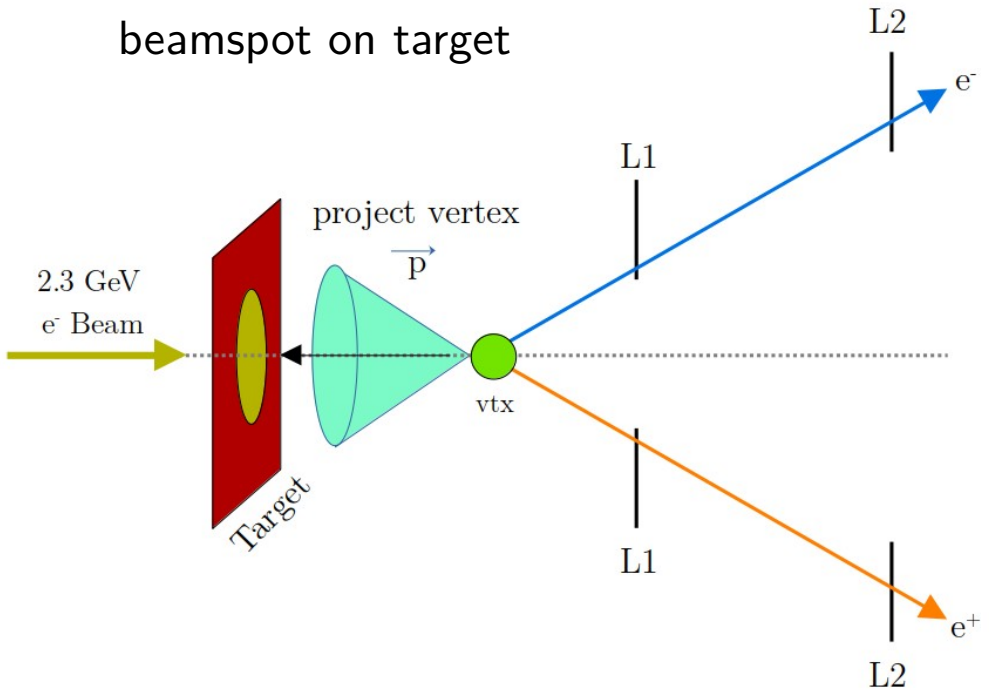
High-Z Cuts
Target Projection Significance

Target Projected Vertex Significance





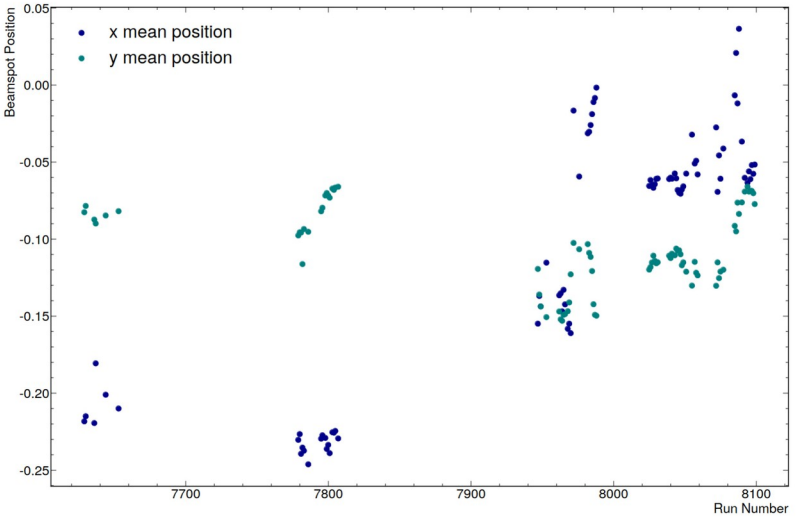
Vertex should project back to beamspot on target

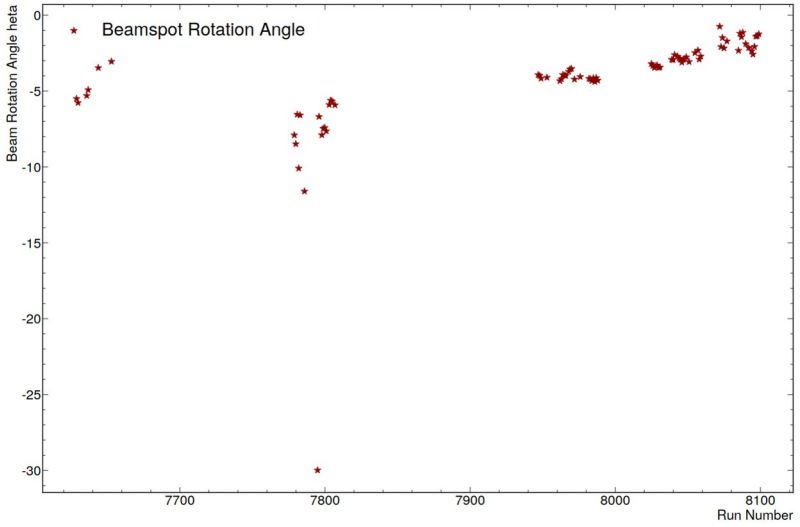


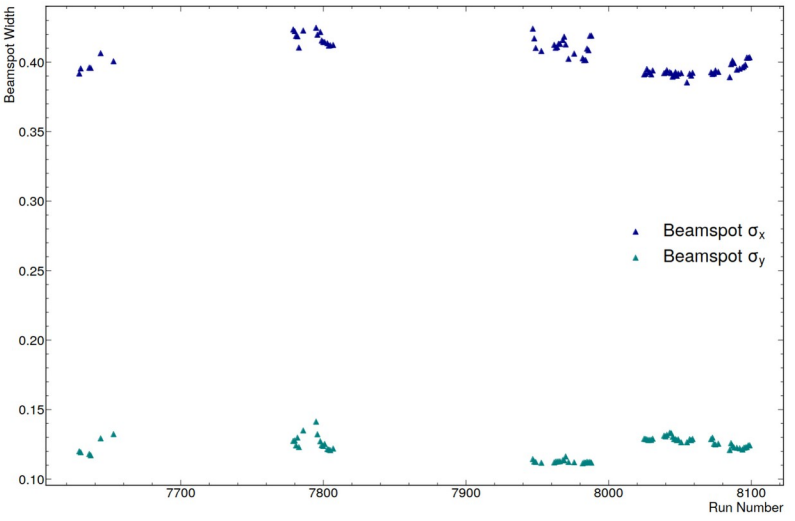
Need to characterize run-dependent beamspot in data

Characterize Beamspot

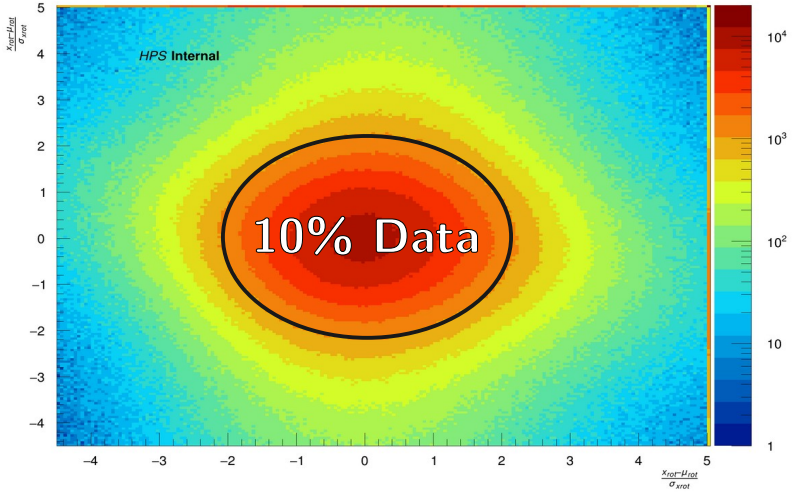
- Project Preselection vertices back to target position using vertex momentum
- Fit with 2D rotated Gaussian, and save fit results

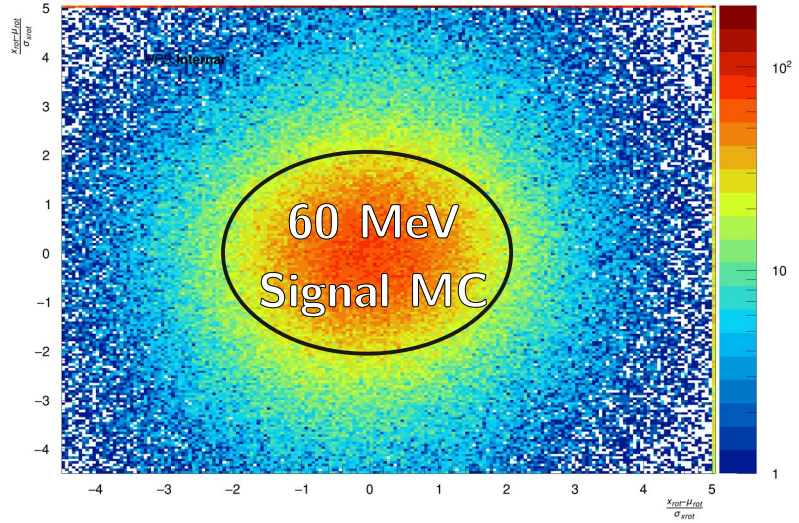




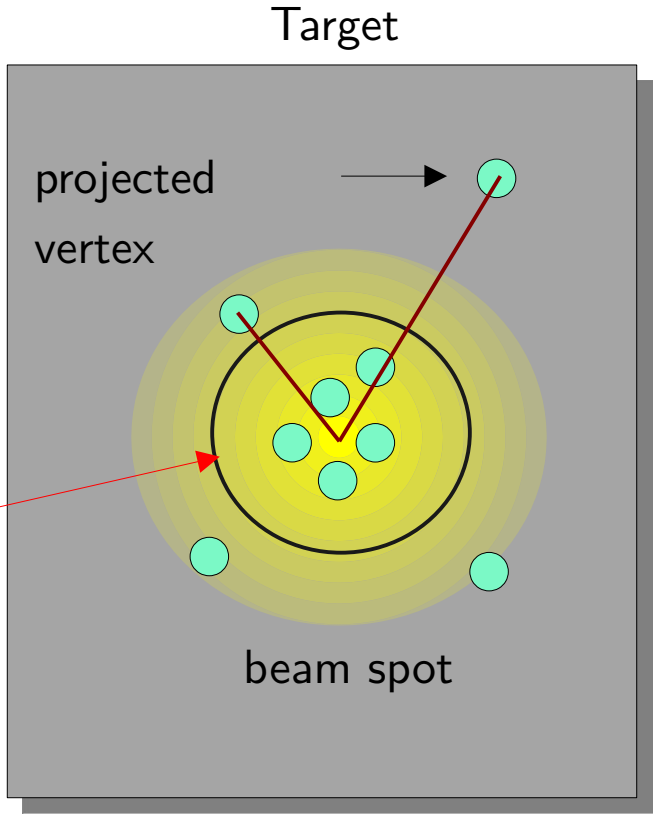


Target Projected Vertex Significance

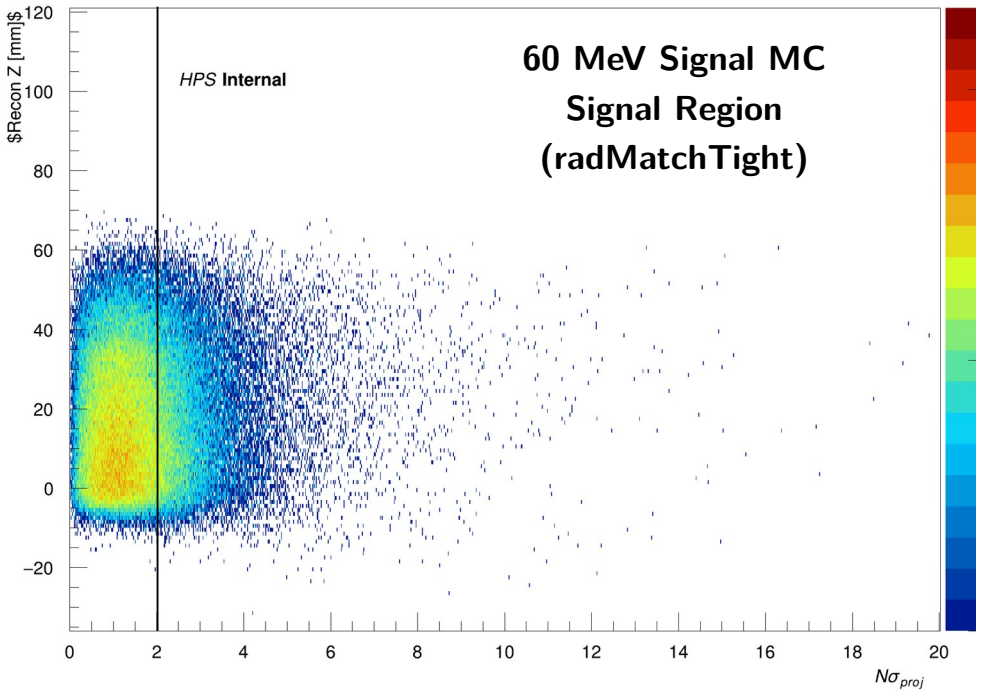


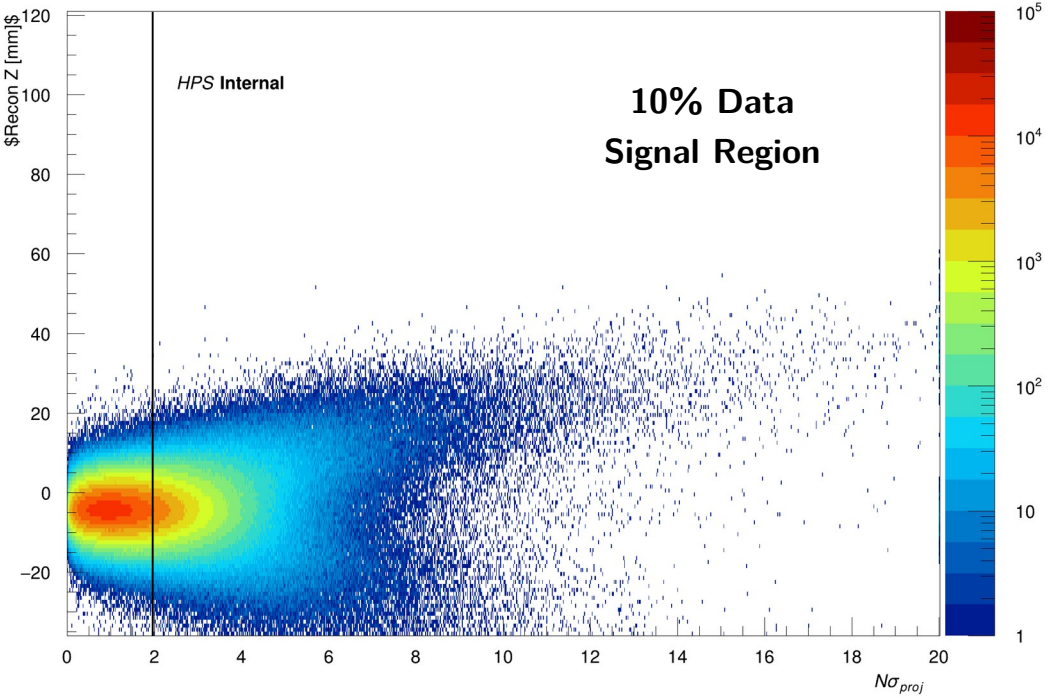


Cut events with radius $>$ Nσ



Target Projected Vertex Significance



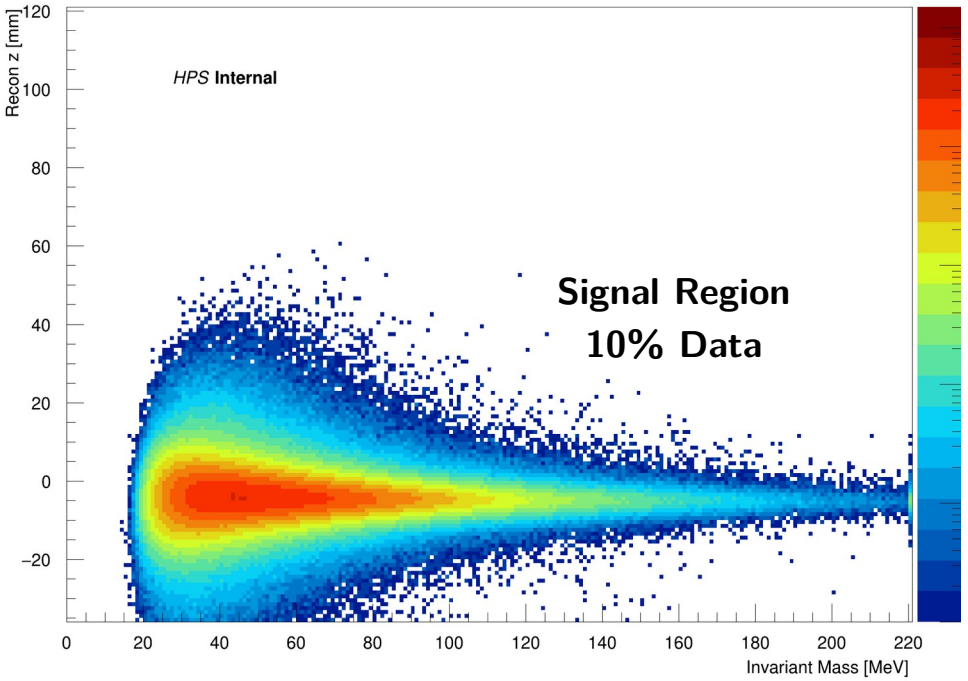


Example Cut:

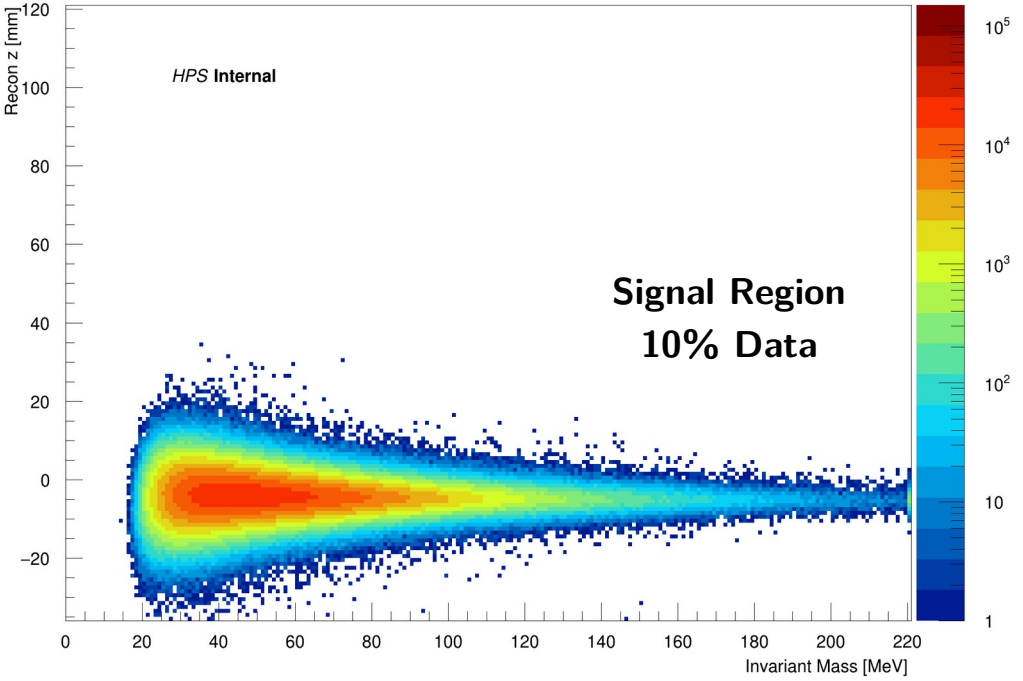
$N\sigma_{proj} < 2.0$

$$N_{\sigma proj} = \sqrt{N^2_{\sigma x_{rot}} + N^2_{\sigma y_{rot}}}$$

Target Projected Vertex Significance

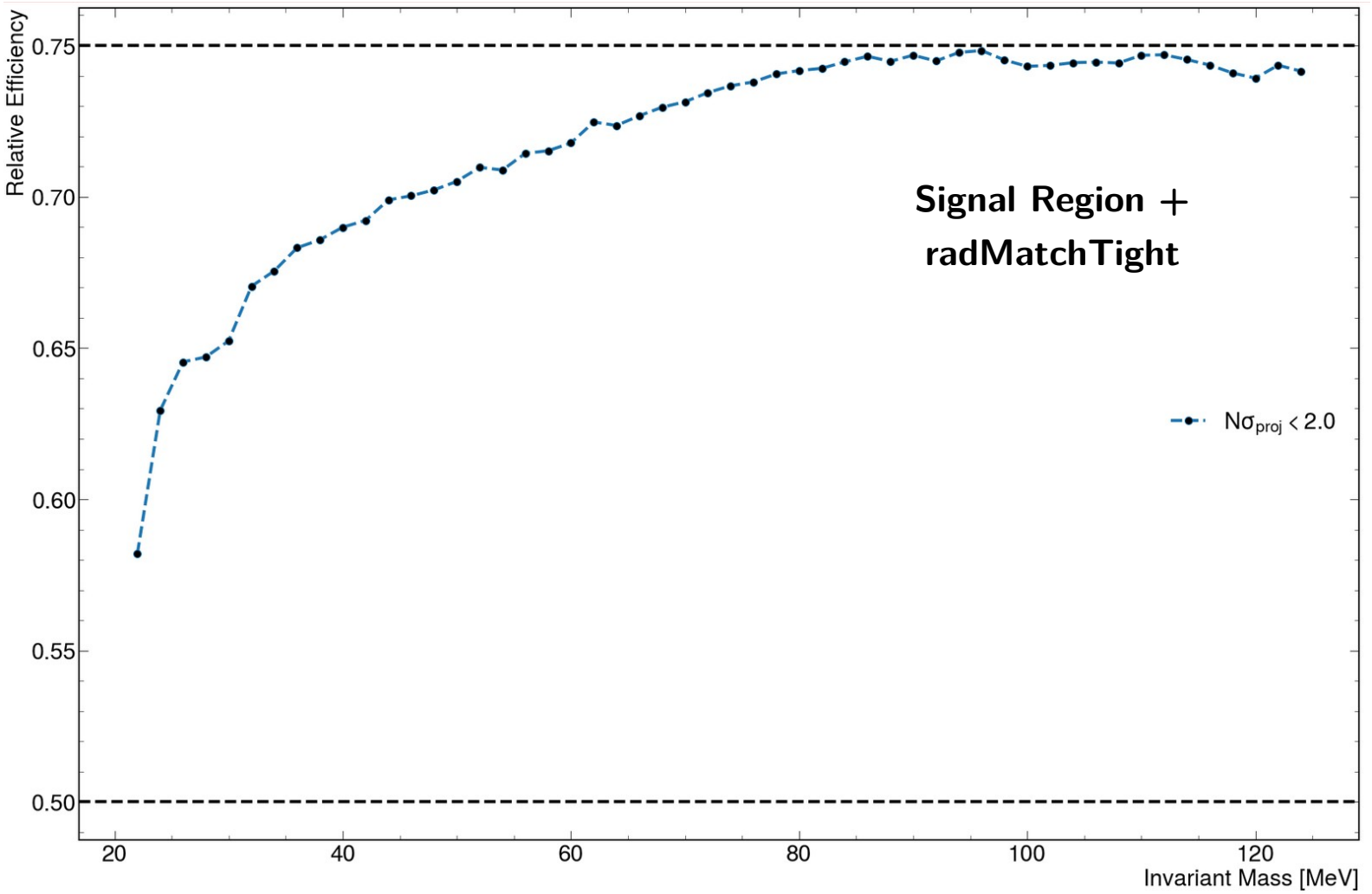


Before Target Projection Cut



After $N\sigma_{proj} < 2.0$

Target Projected Vertex Significance – Signal Efficiency

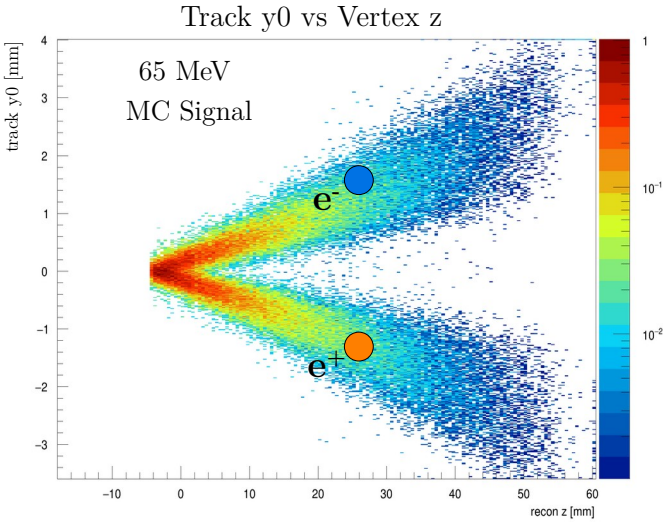


High-Z Cuts

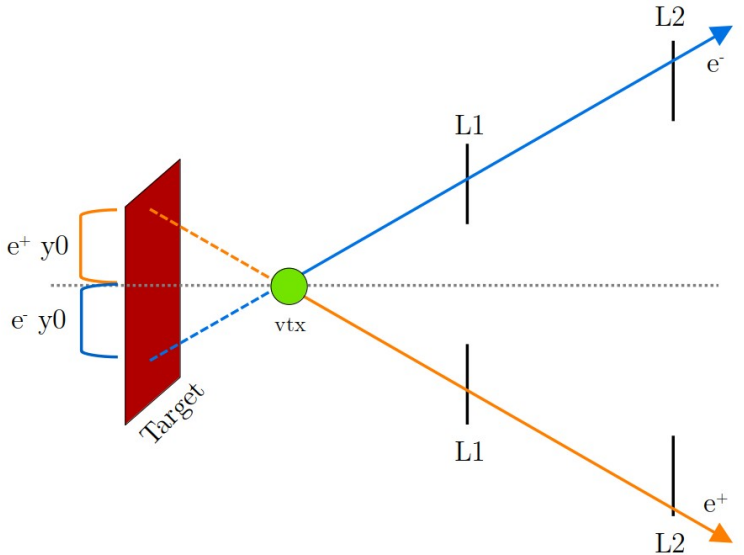
Track Impact Parameter z0 (or ‘y0’)

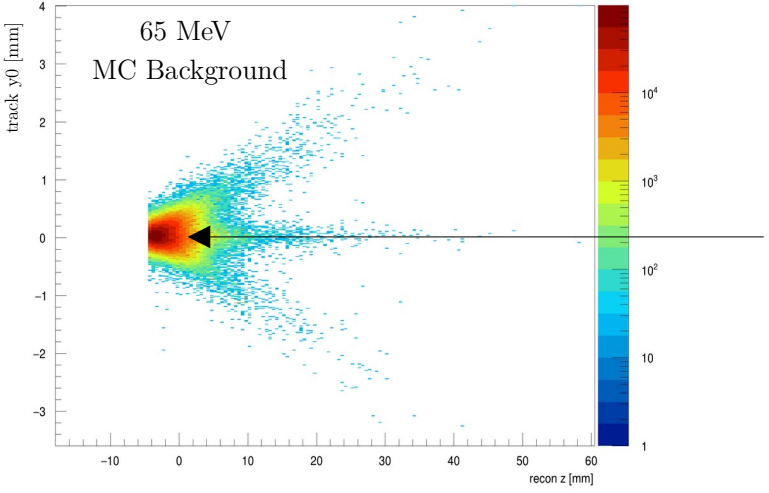
Can we change this internally to y0? It’s less confusing

High-Z Cut: Track Impact Parameter y0

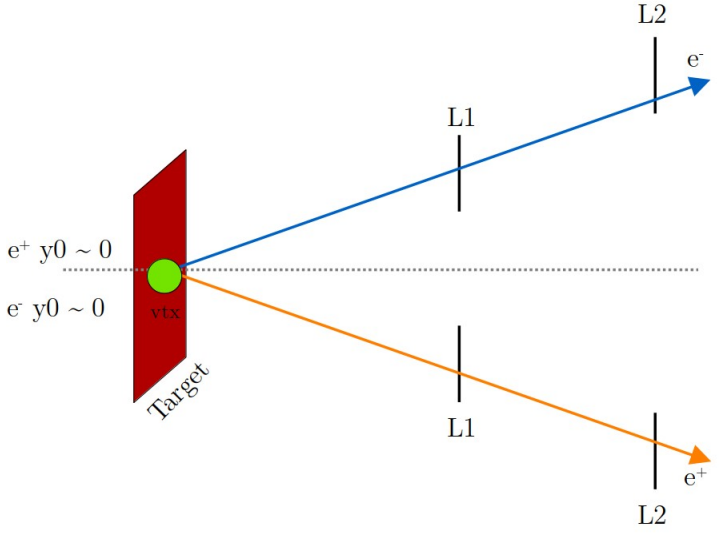


True displaced signal should have symmetric impact parameters that increase linearly with vertex z

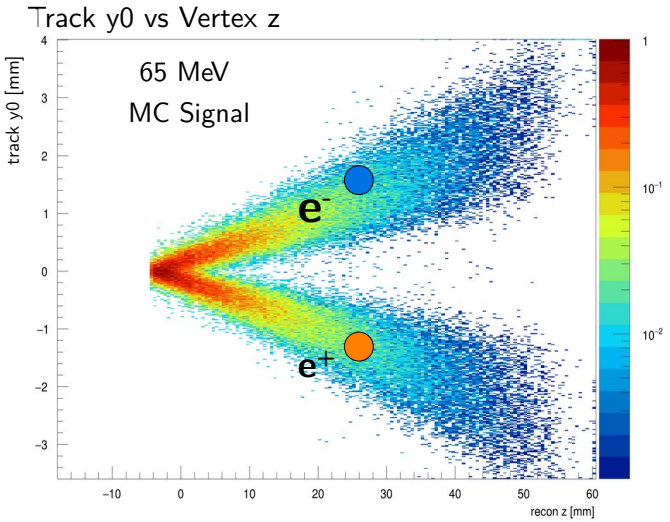


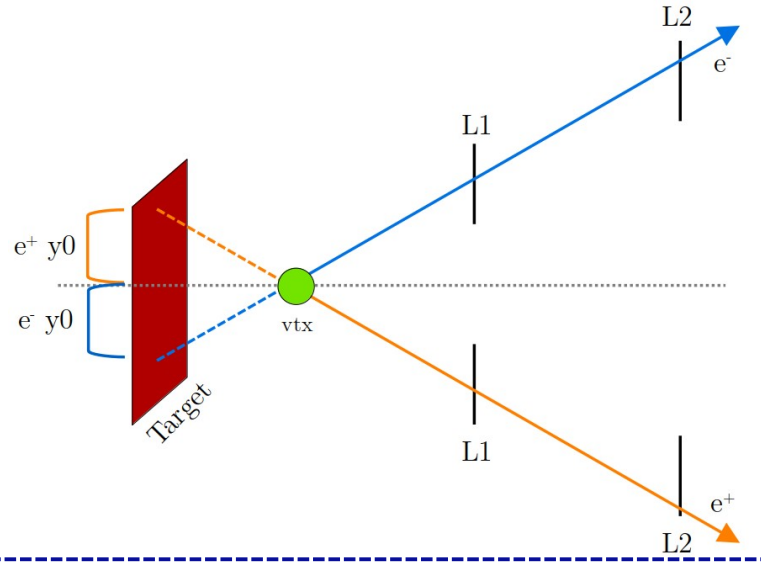


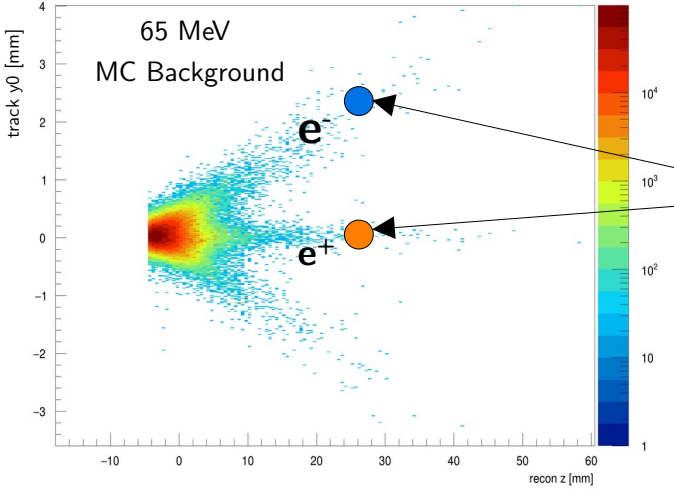
Prompt events should have two tracks with y0 close to 0mm



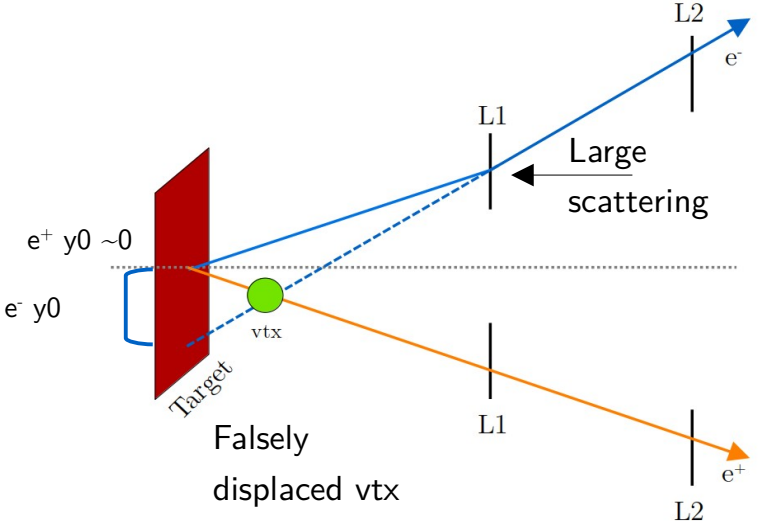
High-Z Cut: Track Impact Parameter y0







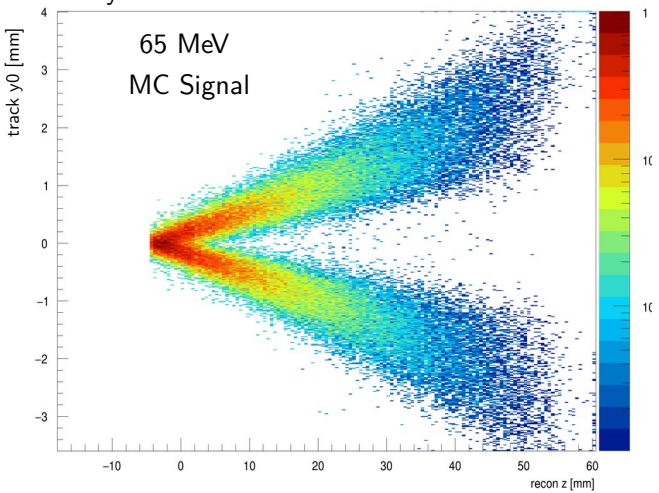
Tracks asymmetric in y0
form false displaced vertex

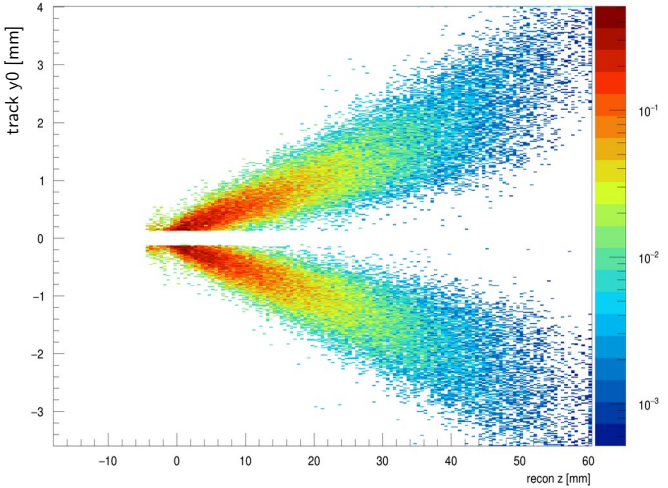


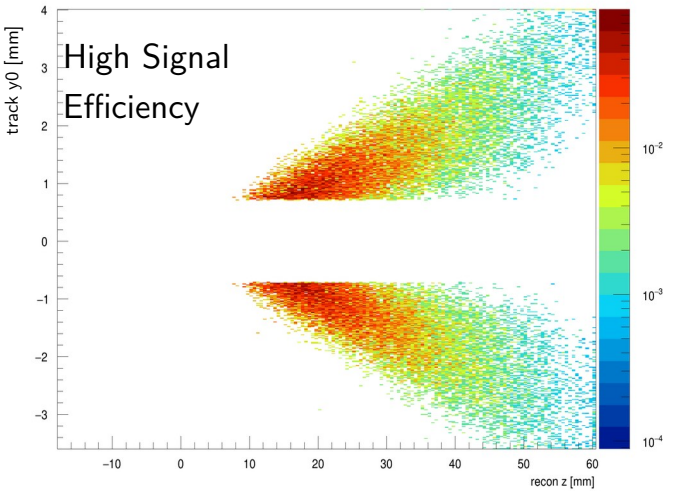
Falsely
displaced vtx

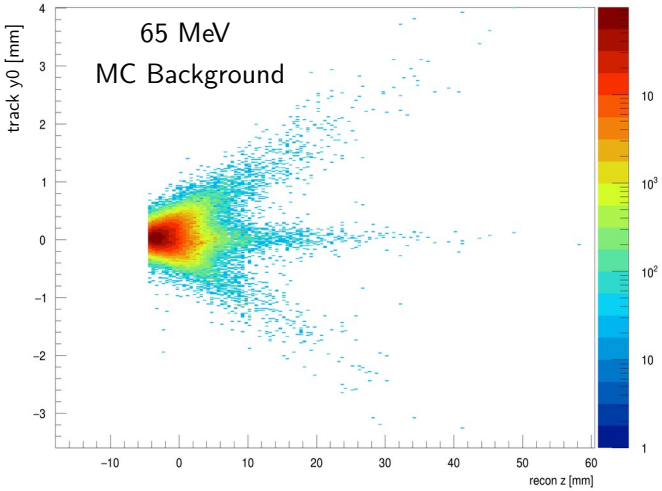
High-Z Cut: Track Impact Parameter y0

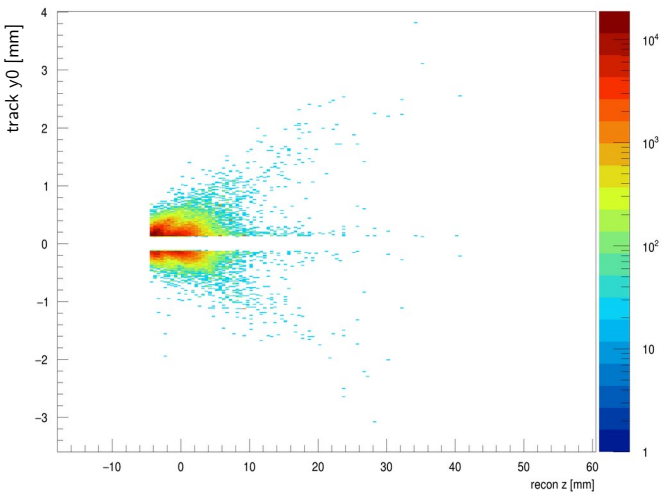
Track y0 vs Vertex z

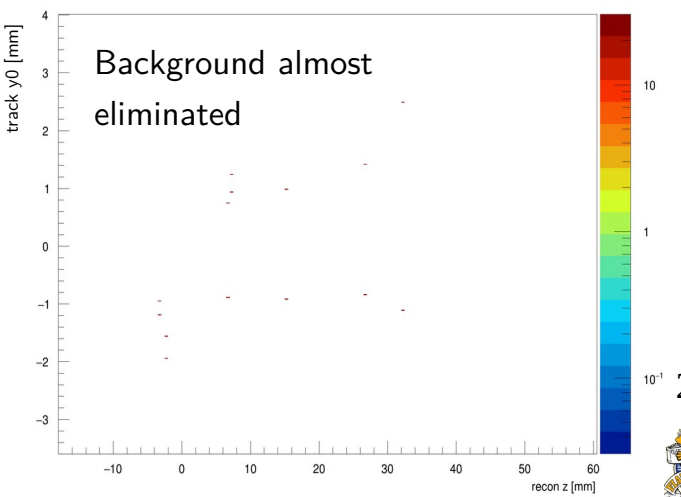




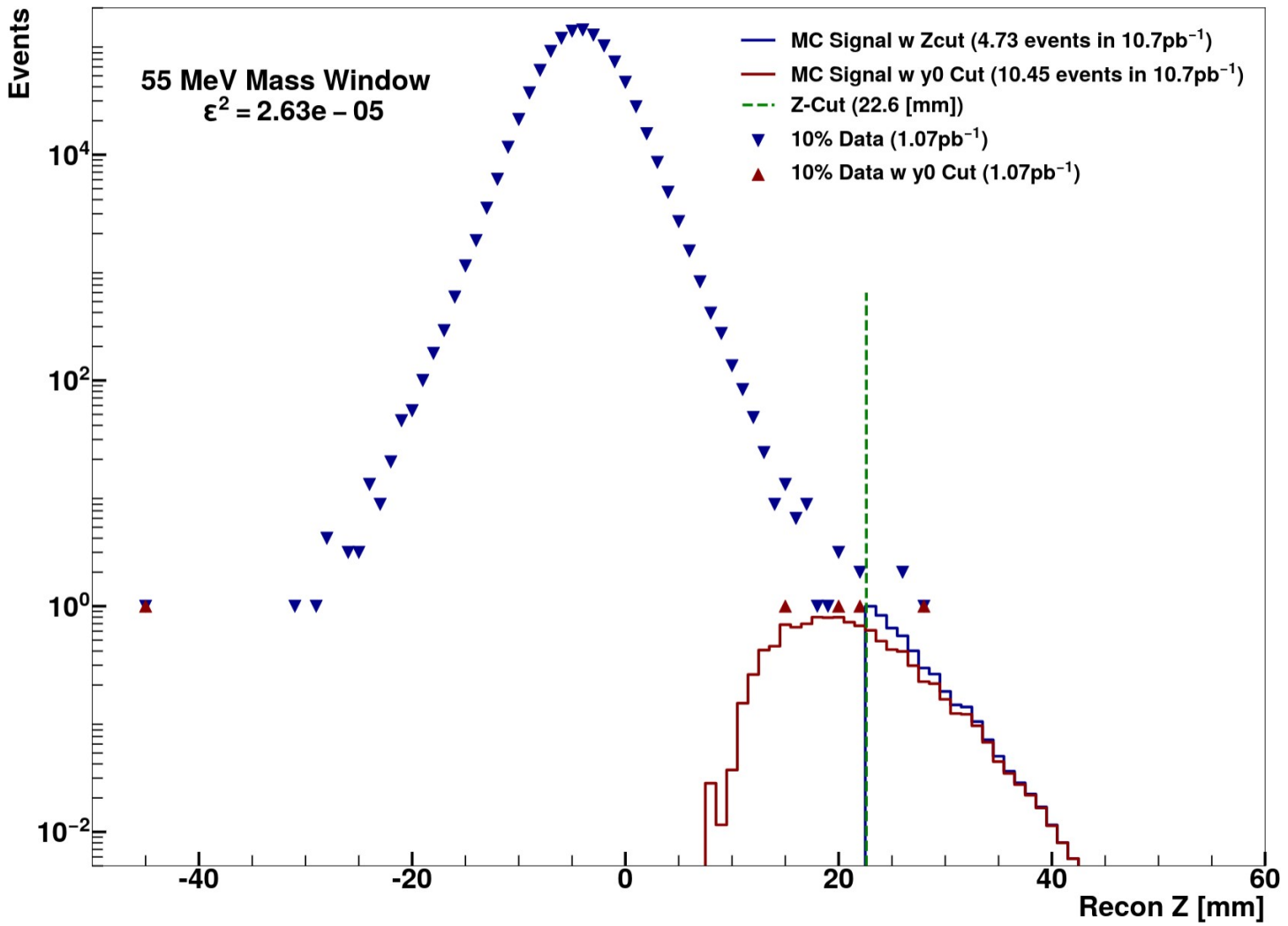






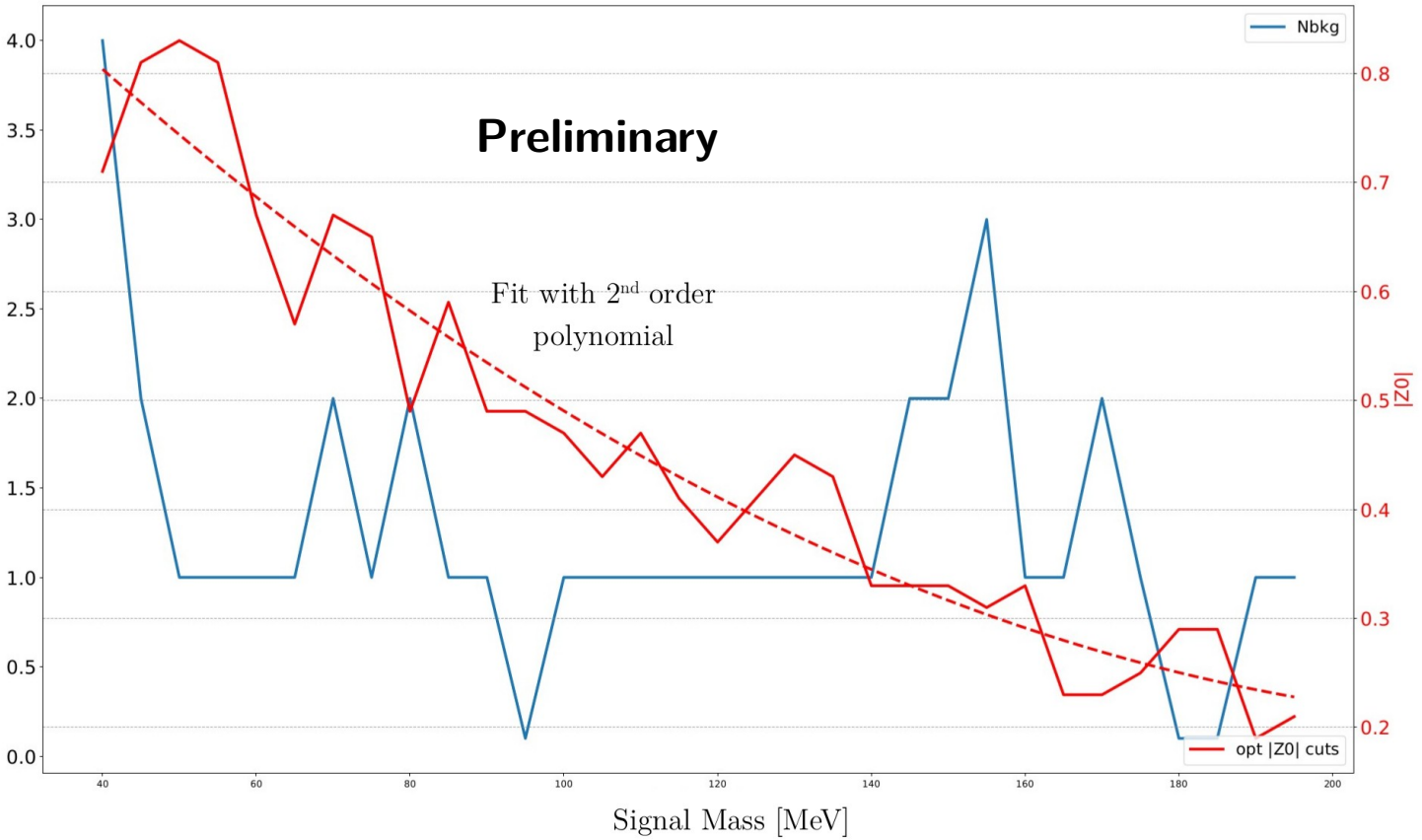


New vs Old Style Analysis

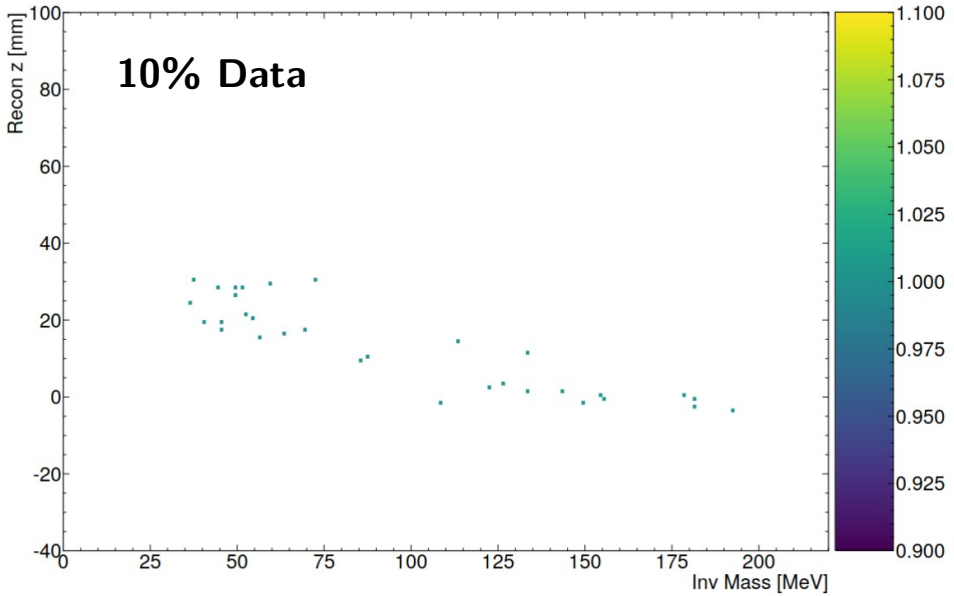


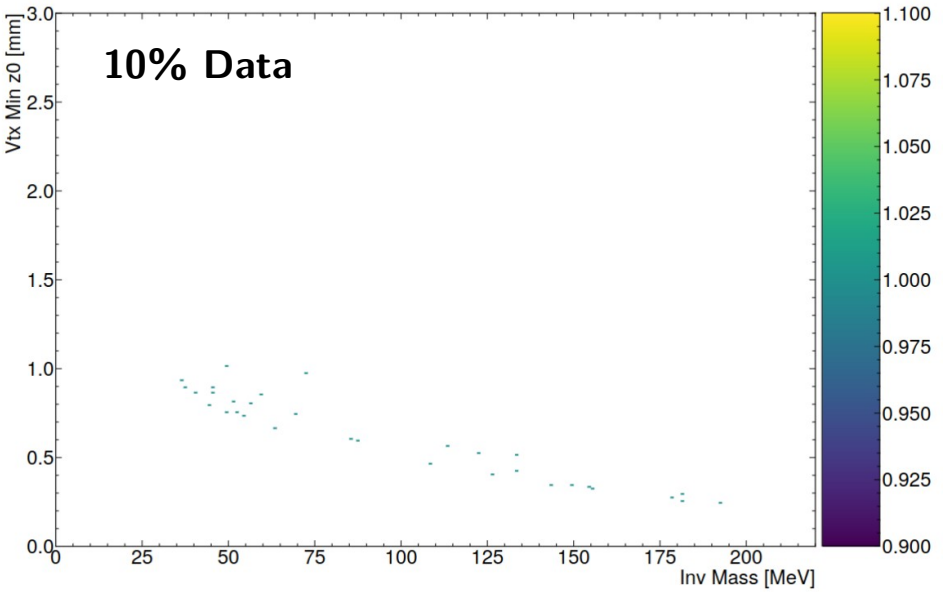
High-Z Cut: Track Impact Parameter y0

- Current iteration of the z0 (or y0) impact parameter cut
- "Optimized" using 10% data Zbi



High-Z Cuts: Remaining Events in 10% Data

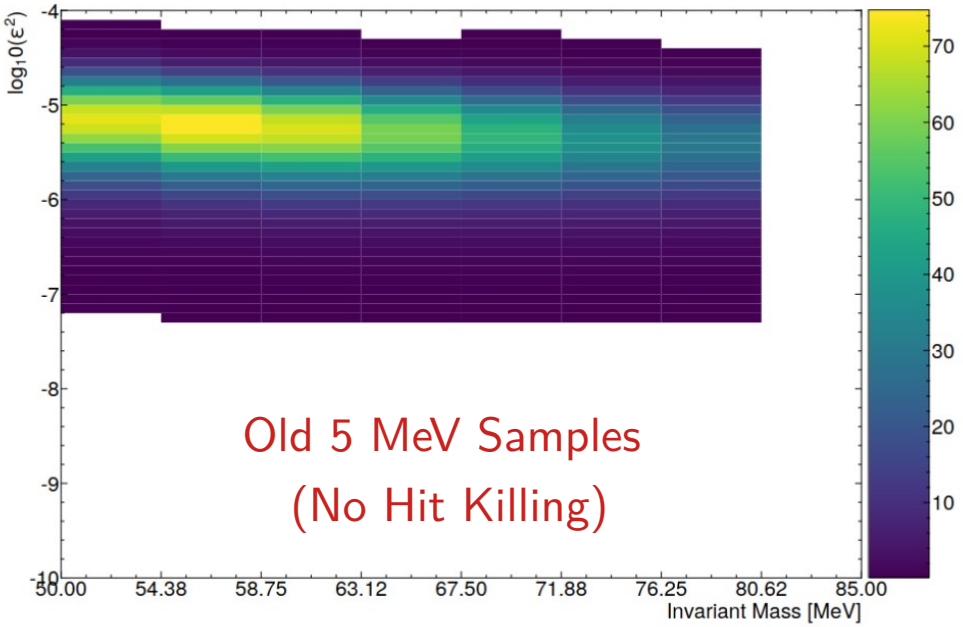


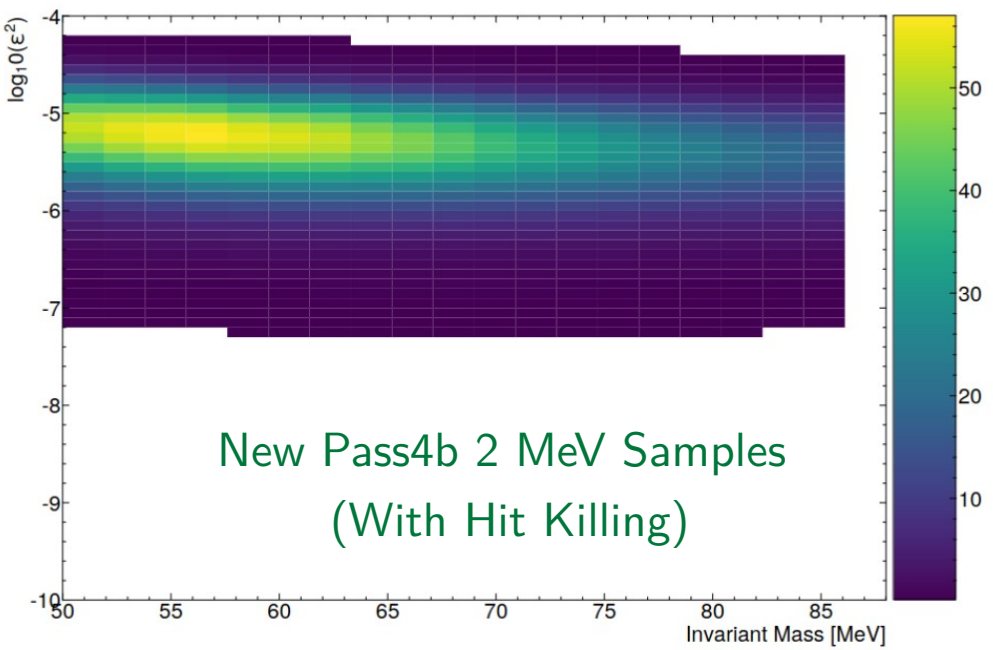


- Background in 10% Data largely eliminated by Target Projection + Impact Parameter cuts
- Expected signal in 10% Data is non-zero, so we want to be careful about chasing the remaining events
- Still want to do another pass at the impact parameter cut before unblinding

2016 SIMP Expected Signal
With Pass4b MC Signal

Expected Signal Pass4b MC

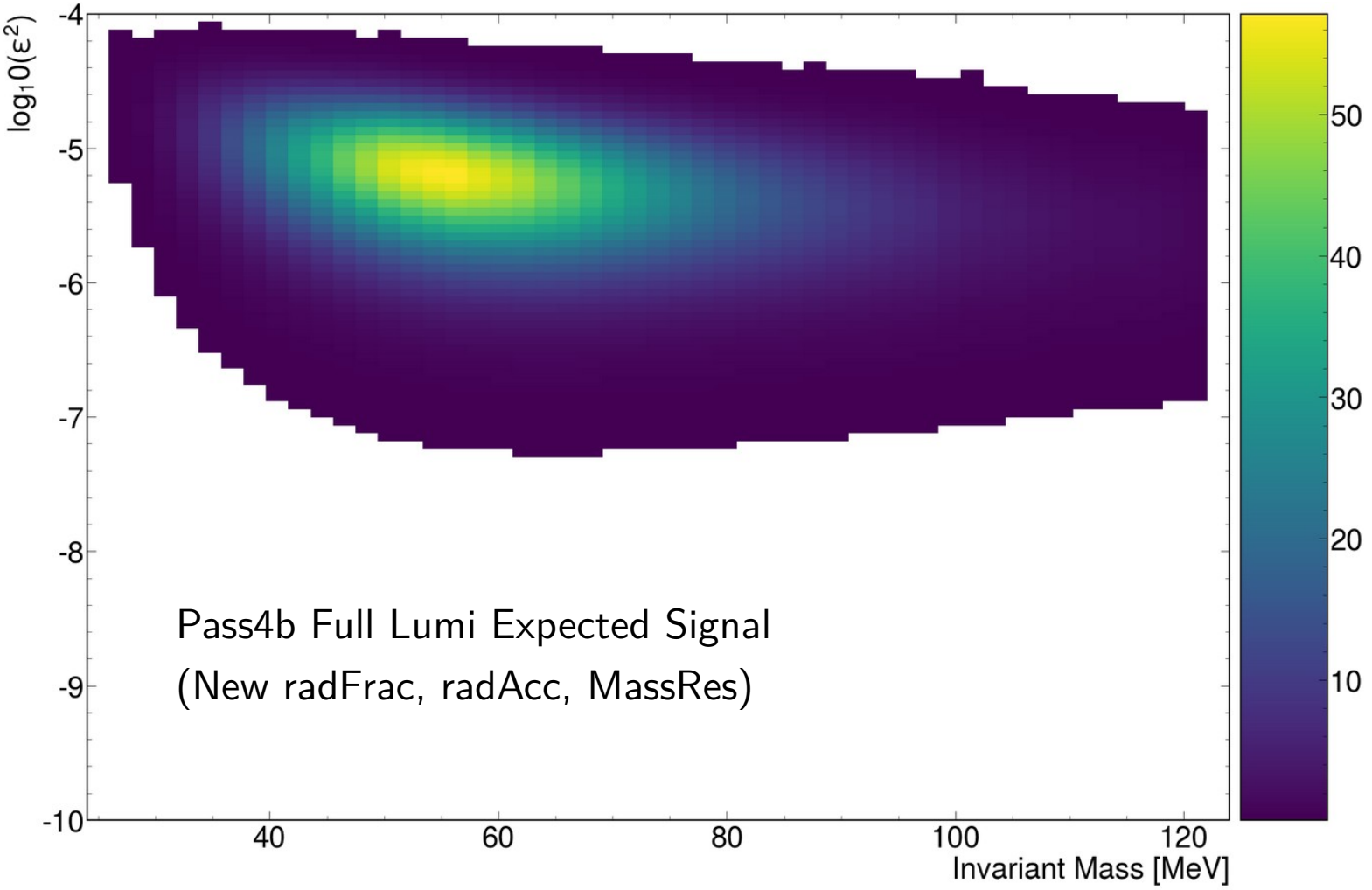




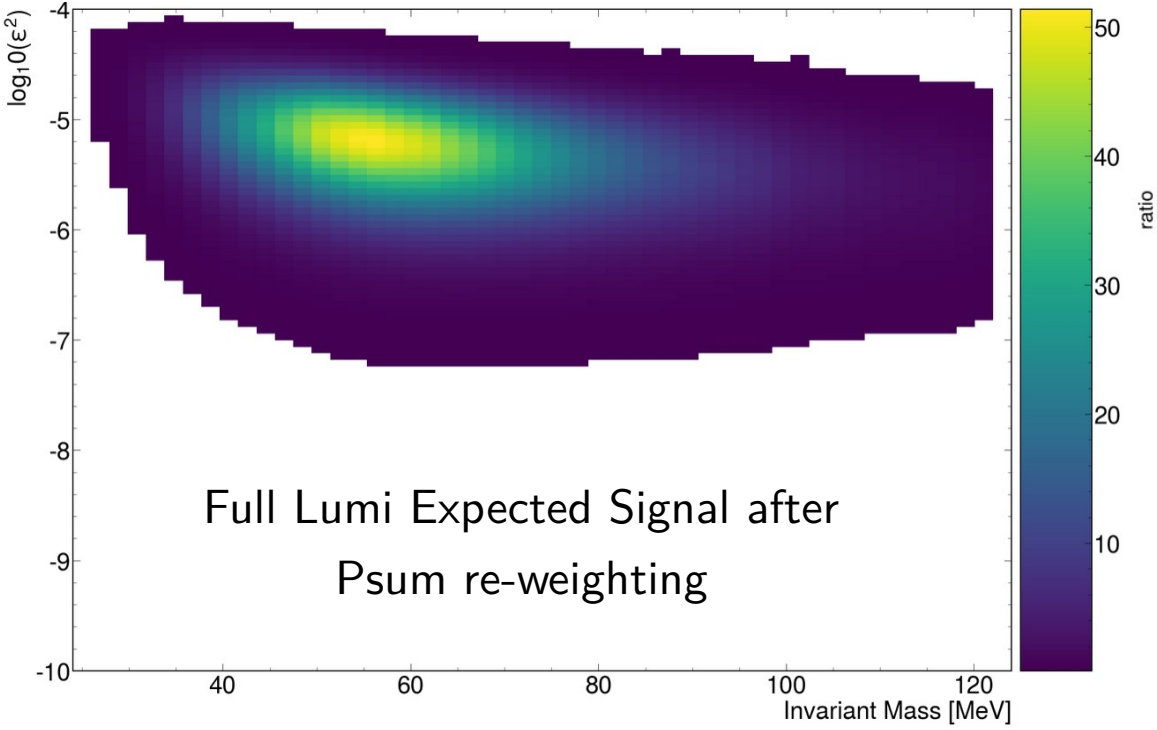
Compare 100% Data expected signal using new pass4b

Preselection eff identical
5% Less eff with L1L1
25% drop in expected signal

Expected Signal Pass4b MC

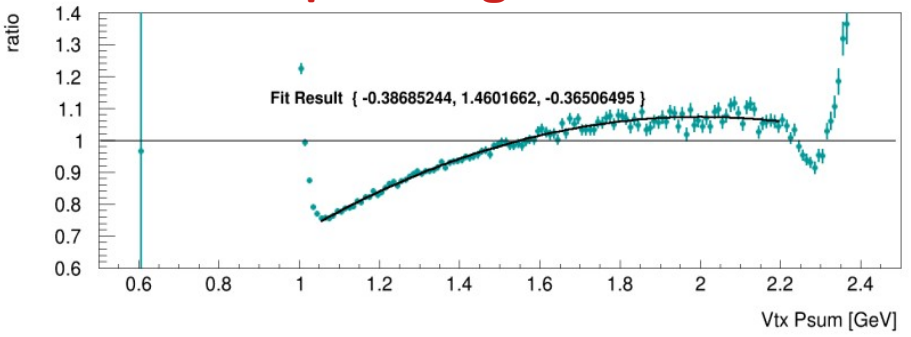


Expected Signal Pass4b MC – Psum Re-weighted



Full Lumi Expected Signal after Psum re-weighting

Cap re-weight at 1.0



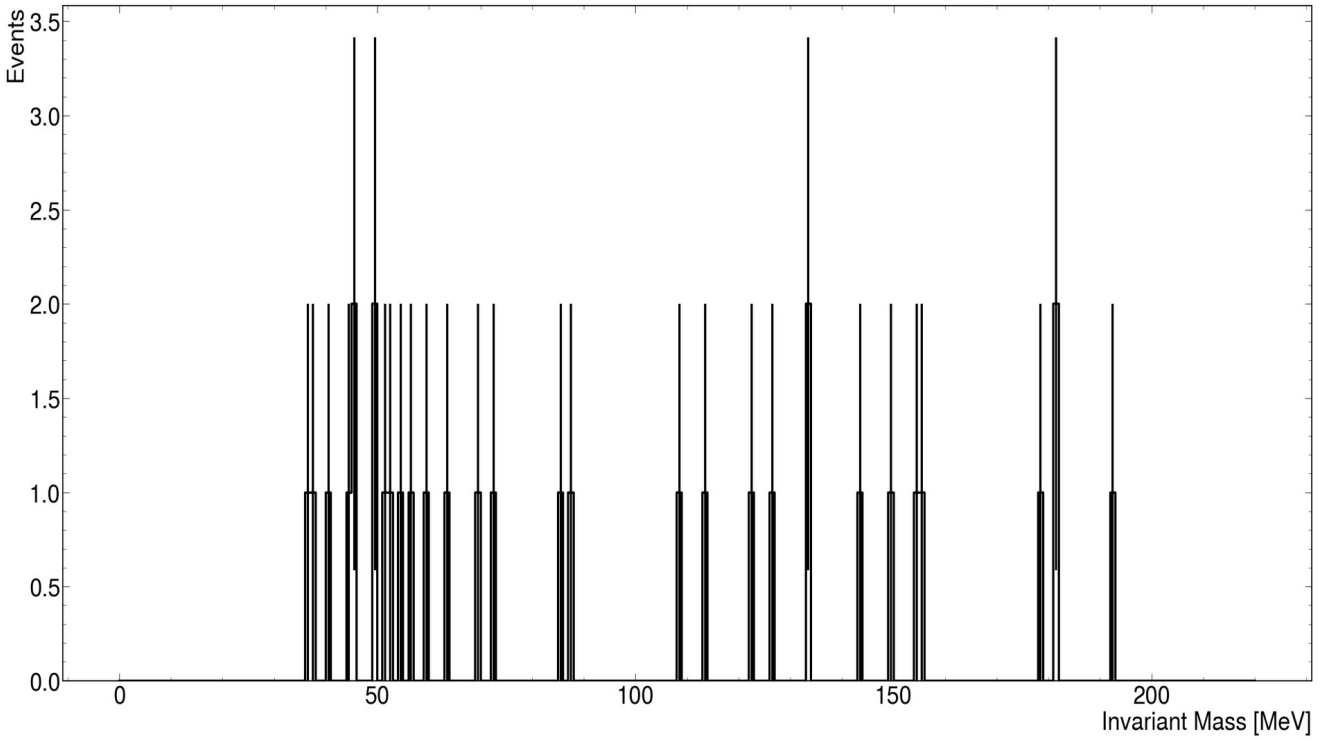
Doesn't hurt us much

(Signal Psum peaks 1.4-1.8)

Searching For Signal
10% Data

Estimating the Expected Background

- These are all the remaining events in 10% Data after Preselection+Tight+High-Z
- Perform search for signal in windows 2σ wide, centered every 1 MeV
- How can we estimate the expected background in a given search window?



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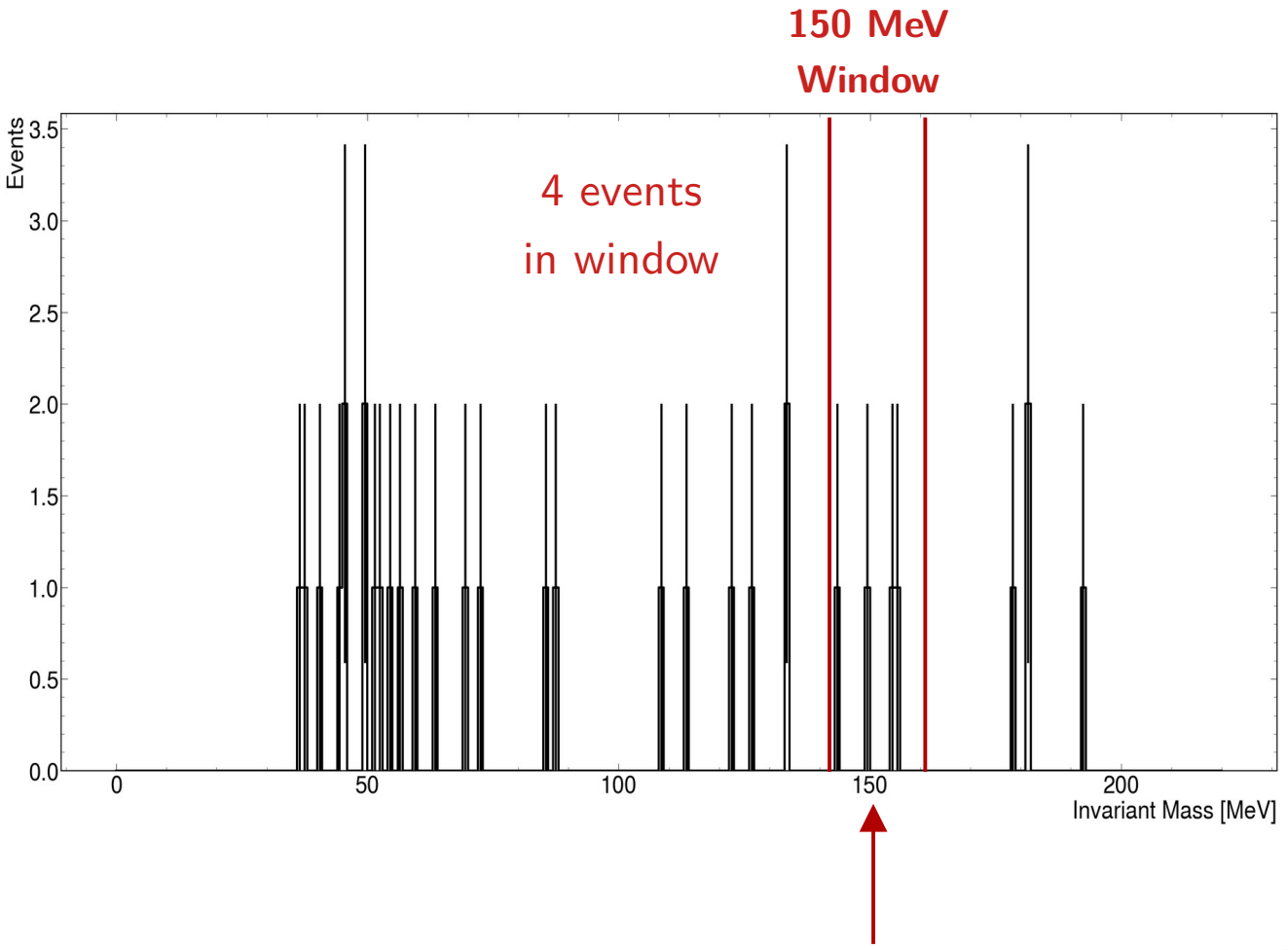
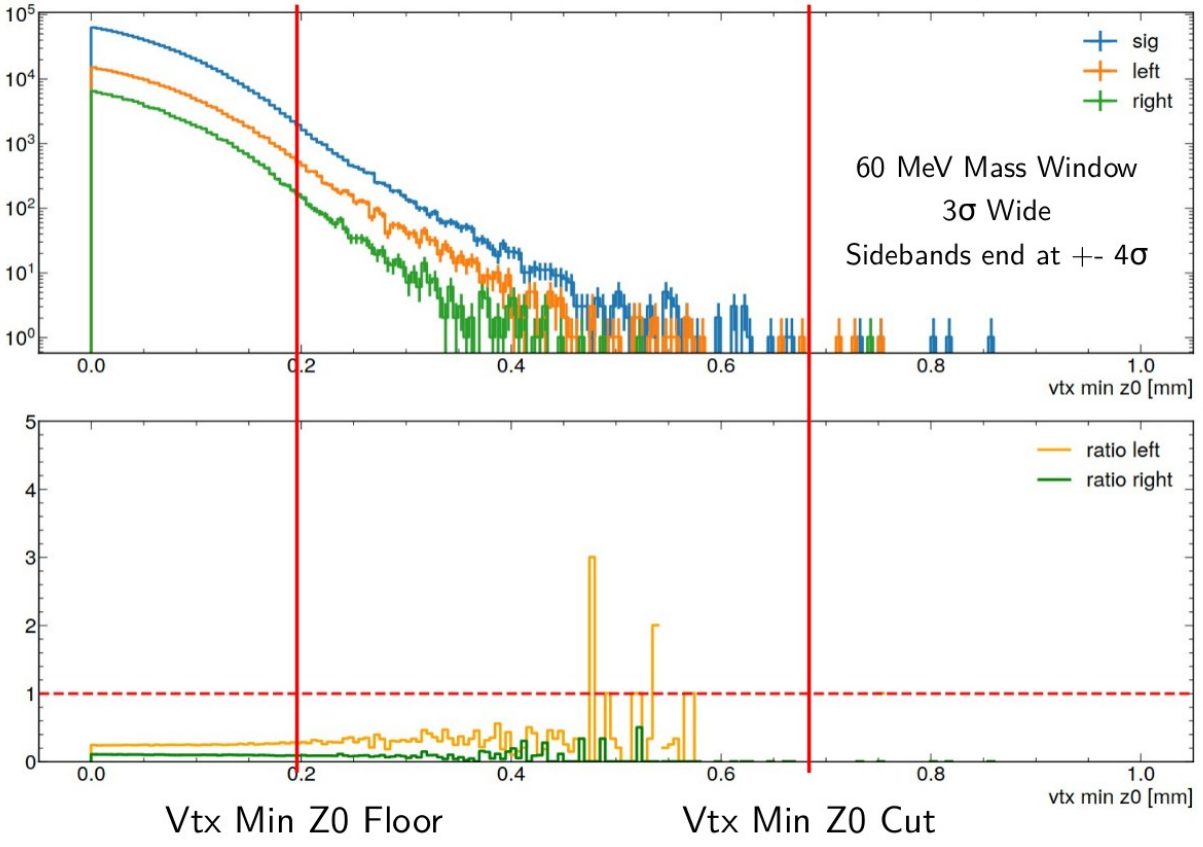
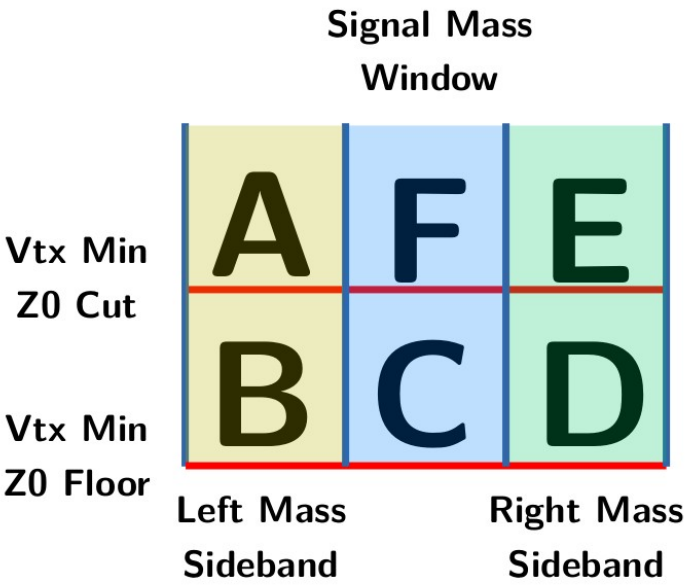


Estimating the Expected Background

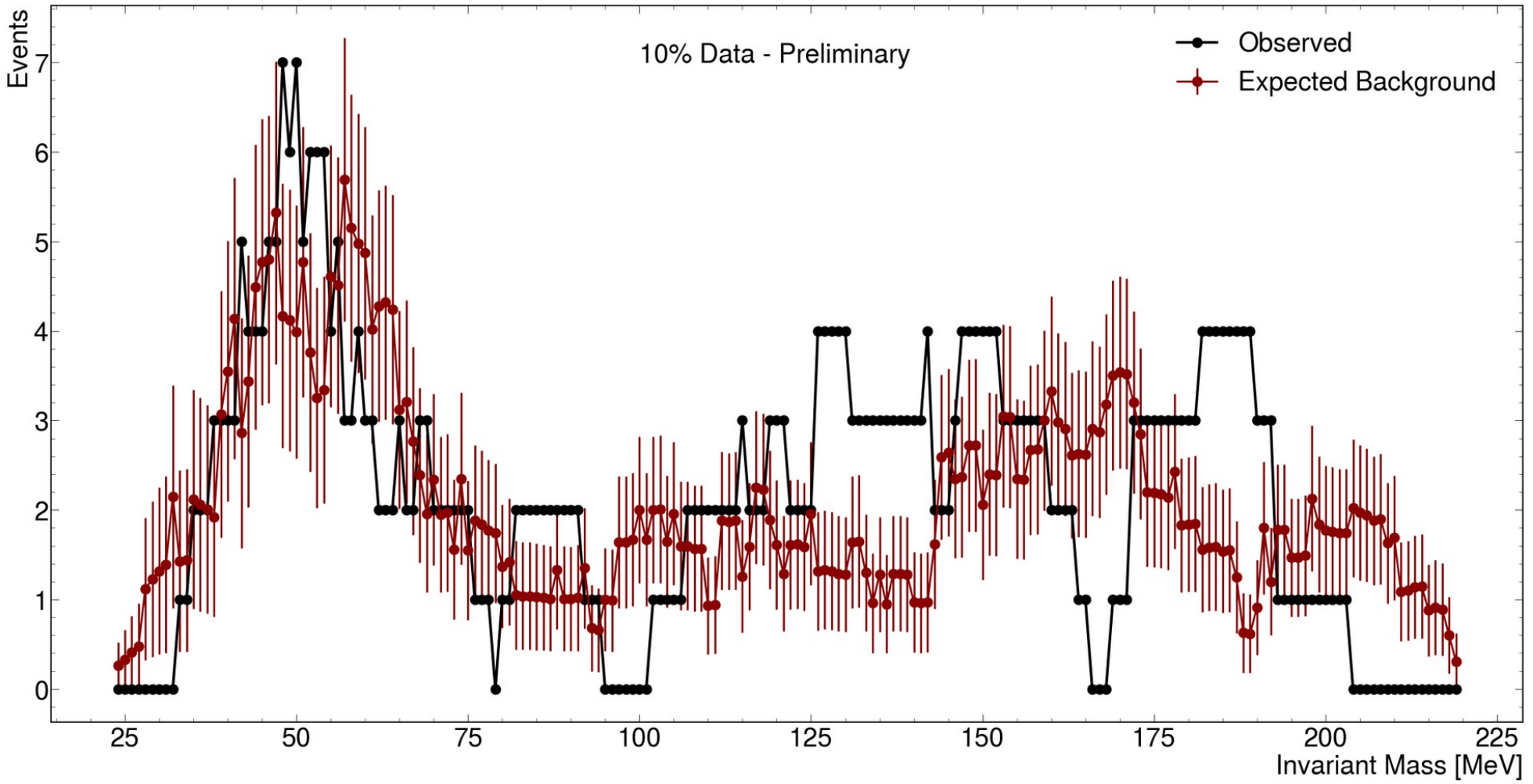




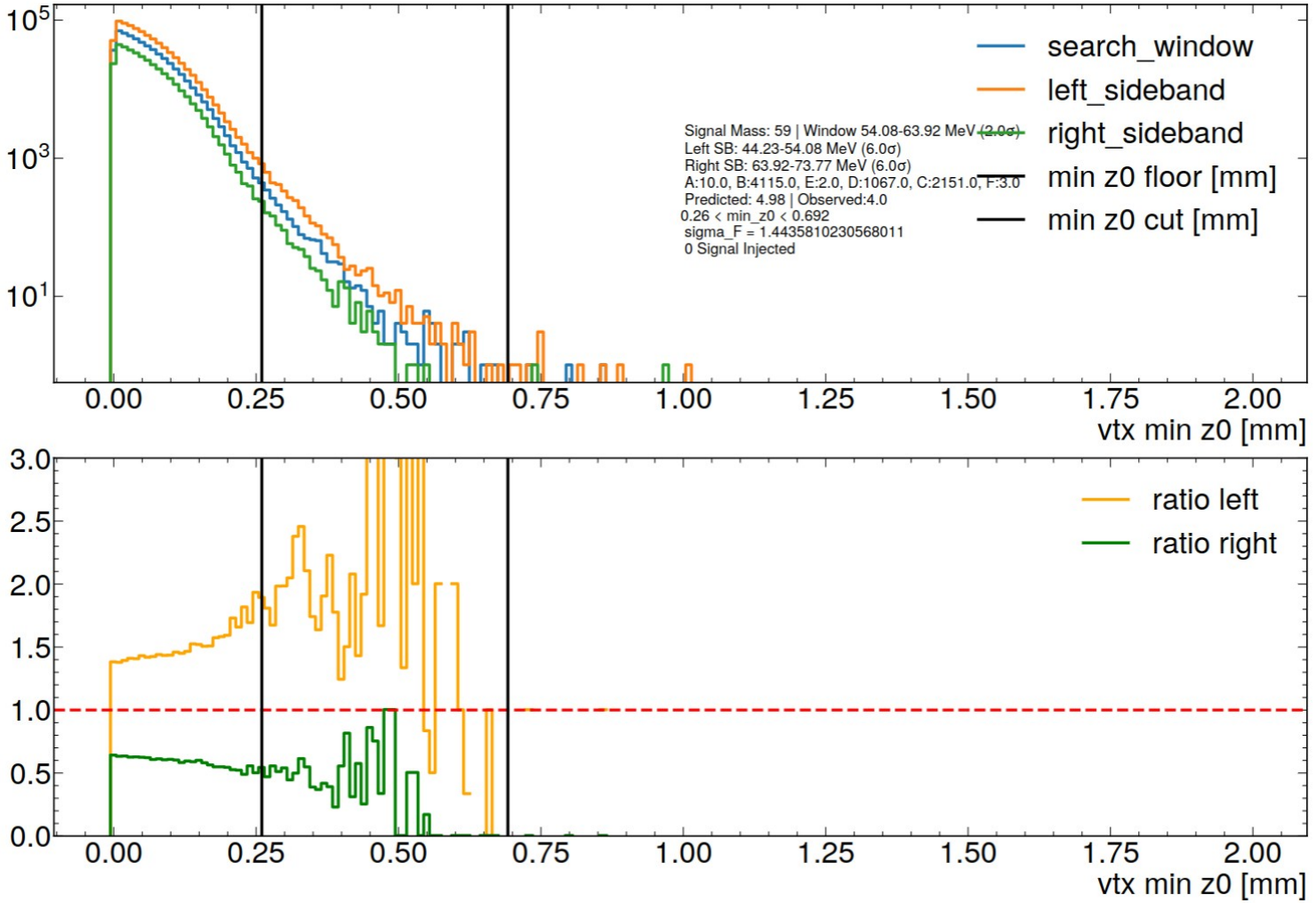
$$(A+E)/(B+D)*C = F$$

*If A+E = 0, set A+E =1

Estimating the Expected Background

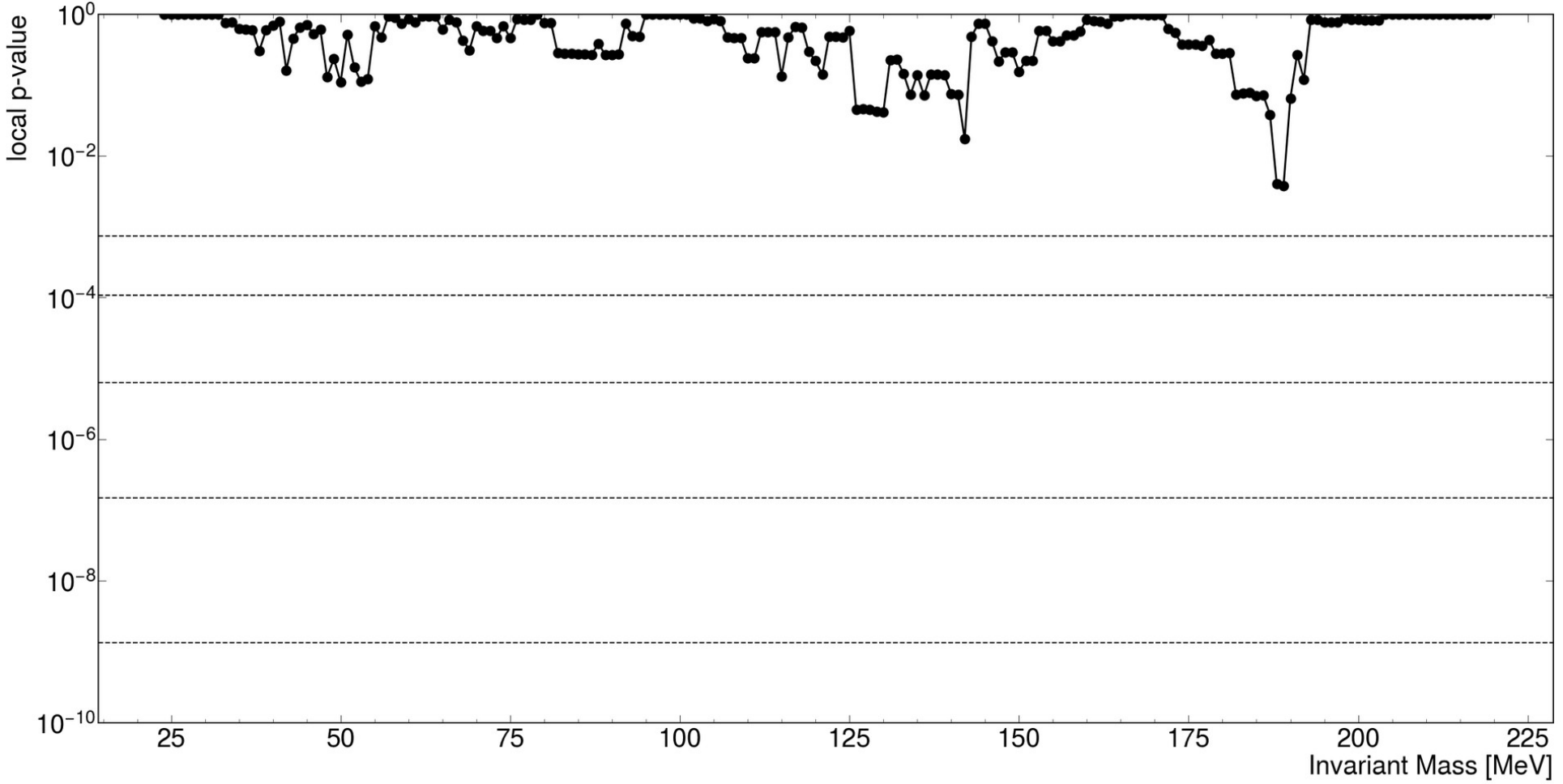


Estimating the Expected Background



- Region F: 3.0
- Predicted: 4.98
- Observed with all cuts: 4

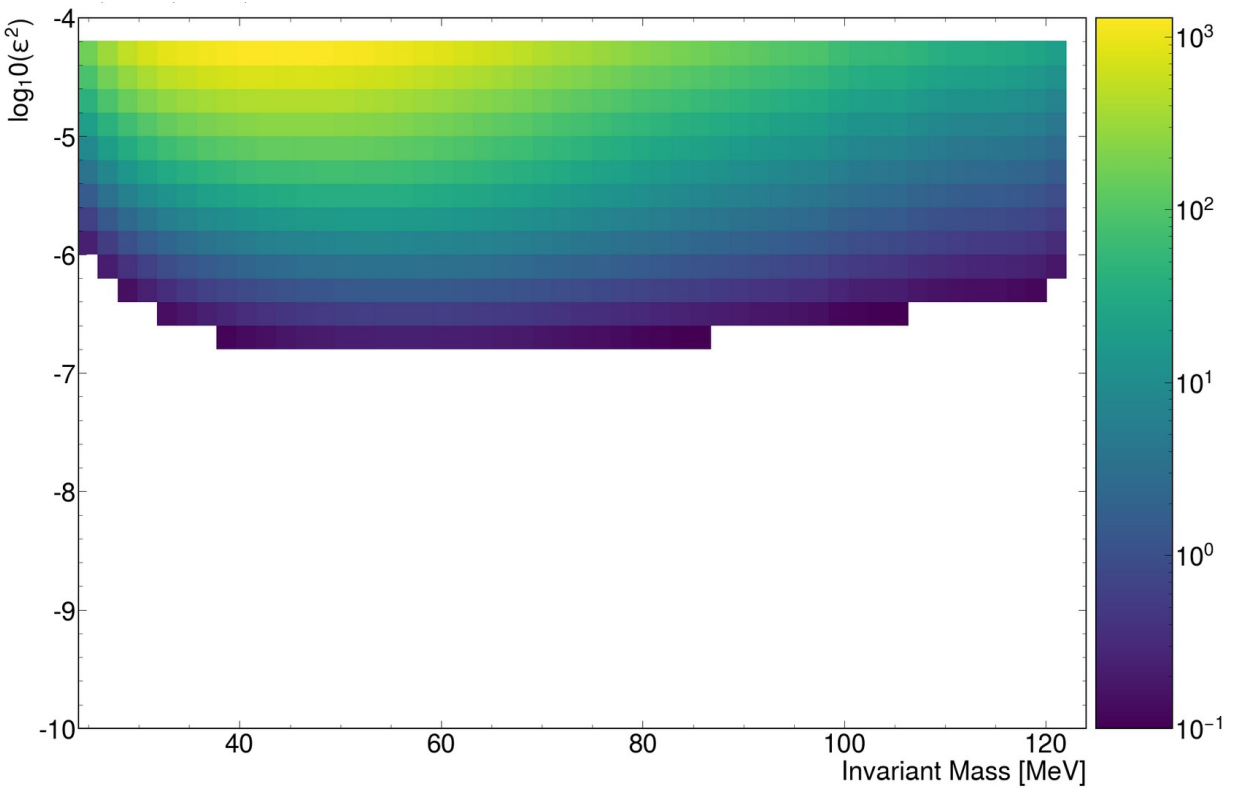
10% Data P-Values



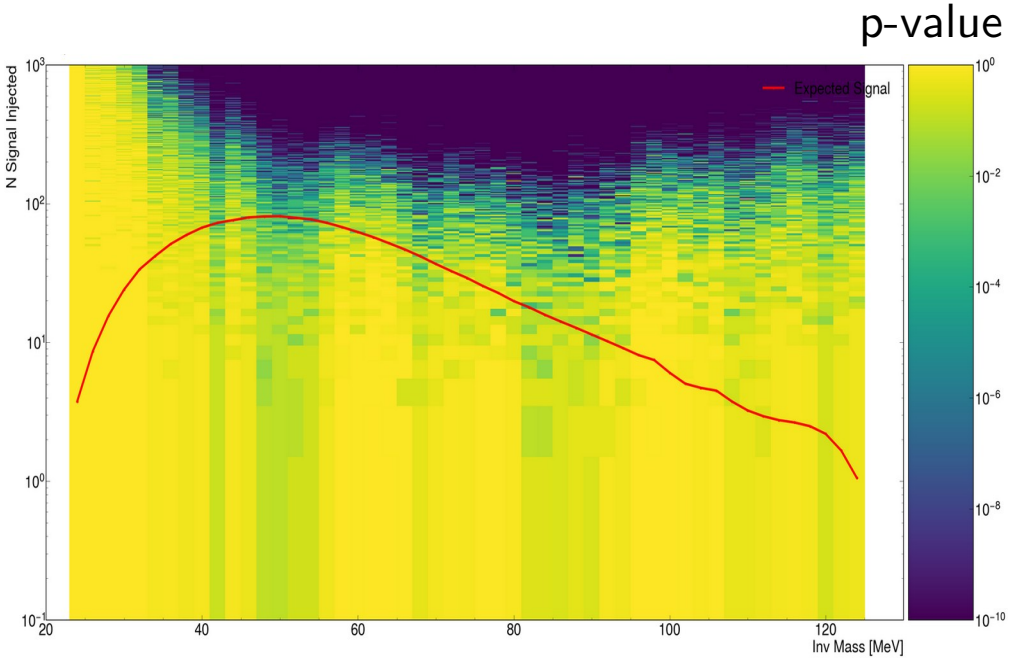
Signal Injection Scans
10% Data

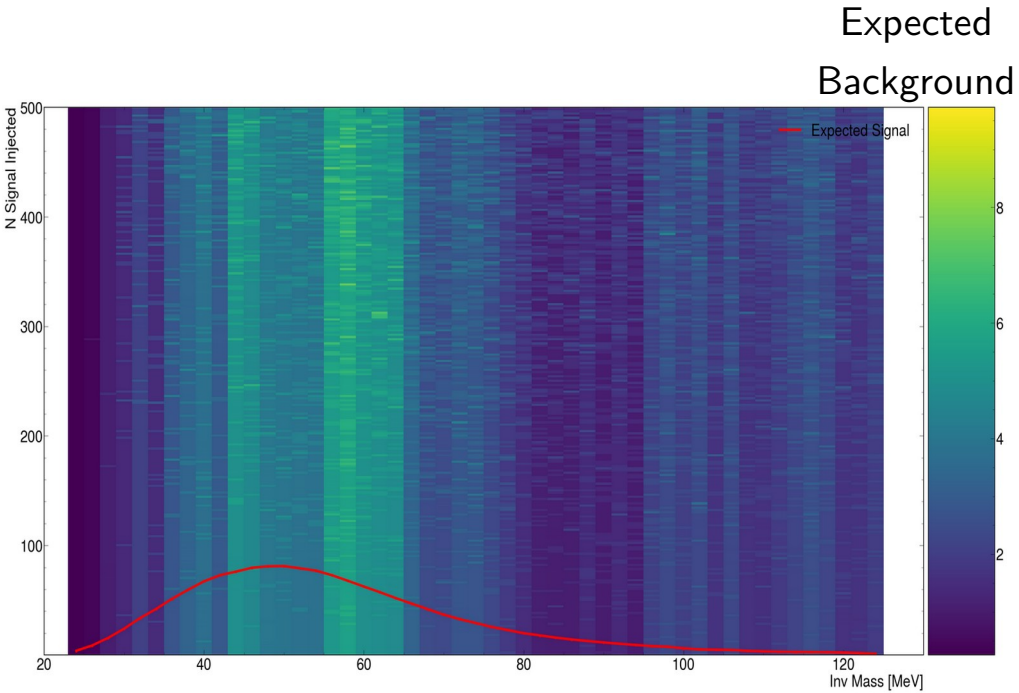
Signal Injection Scan

- Thrown MC Signal and inject into data before applying high-z cuts and mass selection
- Signal rate before cuts is quite high for some values of ε O(1000 events)
- Show p-value results (for a few ε) as a function of signal injected



Signal Injection Scan – P Values



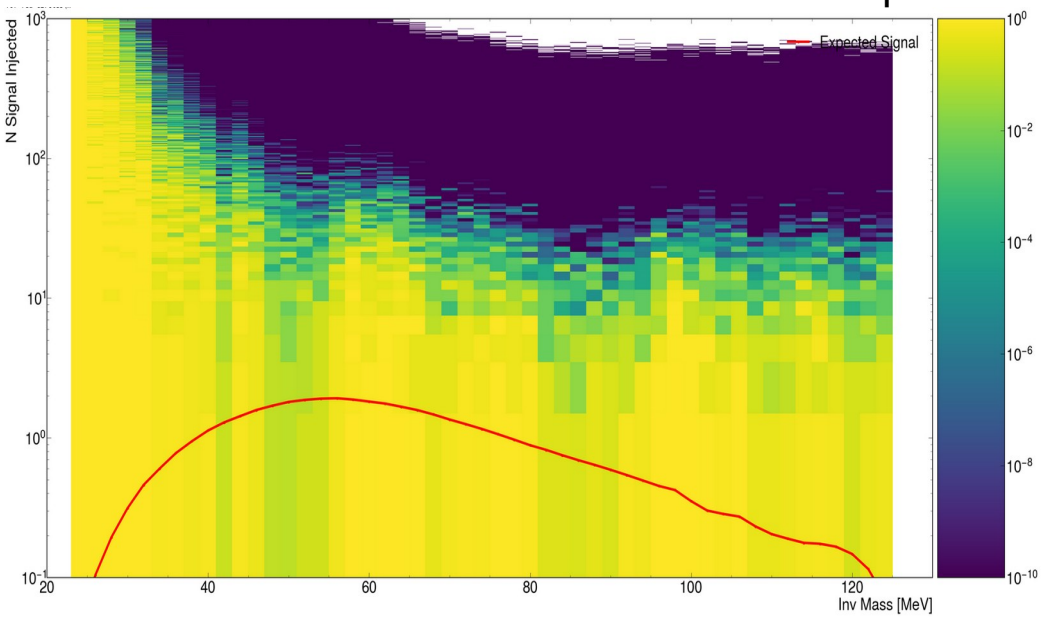


- $\varepsilon^2 = 6.3\text{e-}06$
- Red line is expected signal before high-z cuts

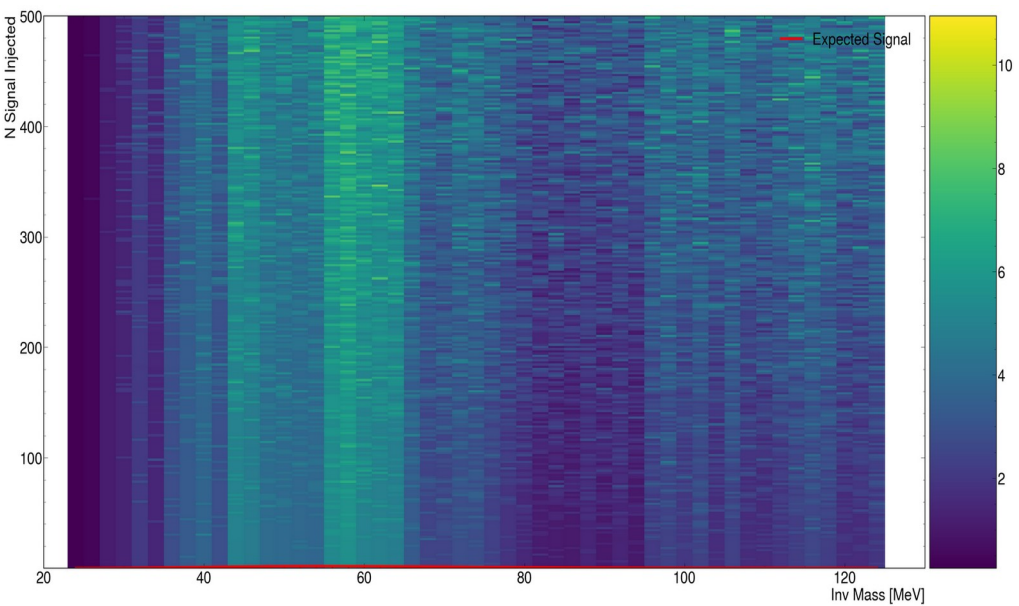
- Expected background estimate remains flat with signal injection

Signal Injection Scan – P Values

p-value



Expected Background

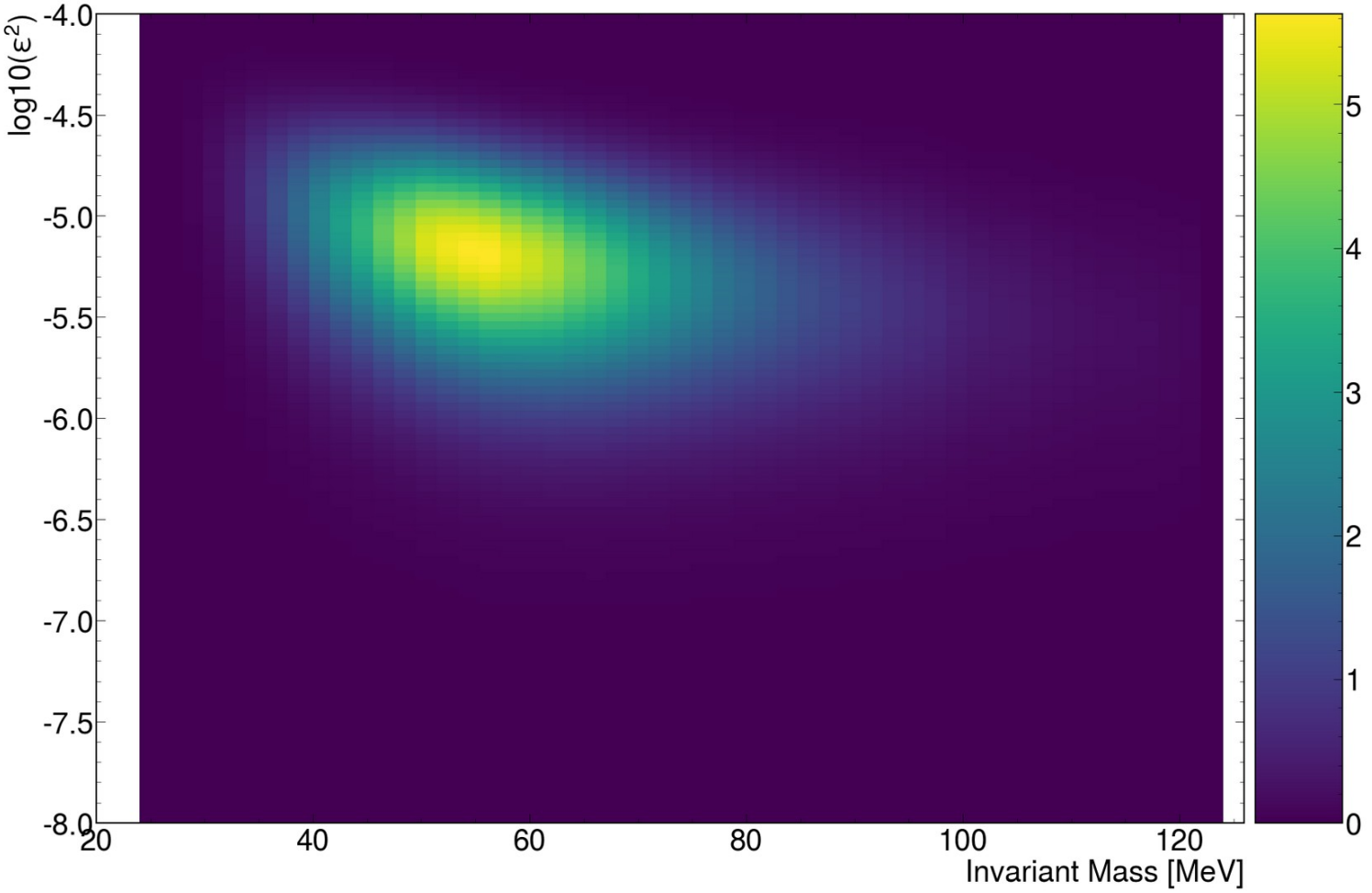


- $\varepsilon^2 = 6.3\text{e-}07$
- Red line is expected signal before high-z cuts

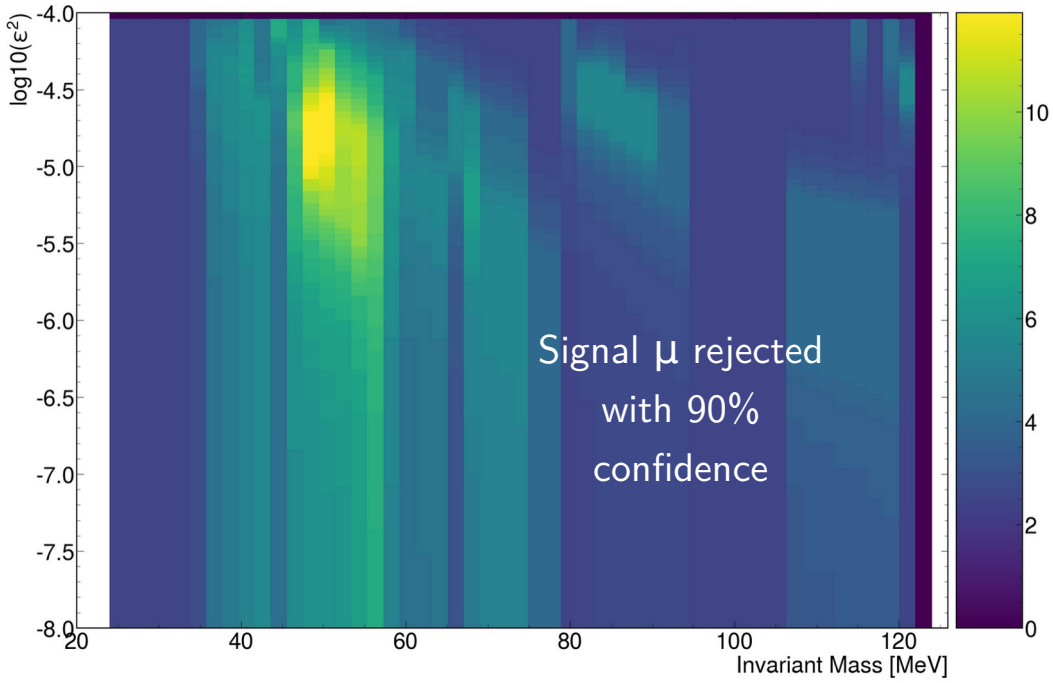
- Expected background estimate remains flat with signal injection

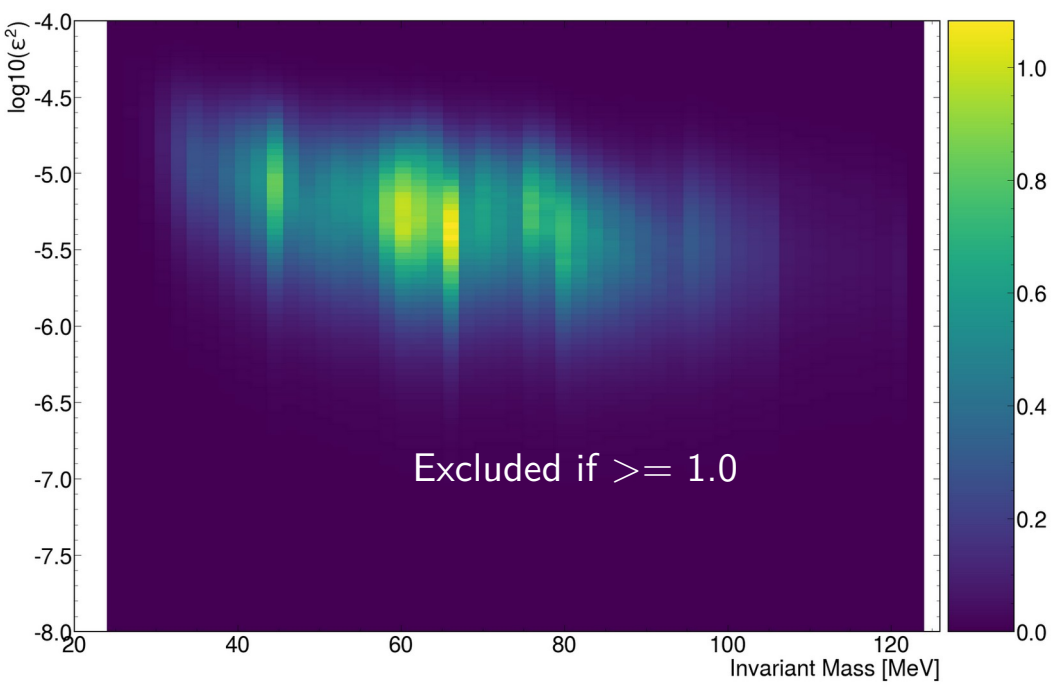
10% Data Exclusion
Using Optimum Interval Method

10% Data Expected Signal



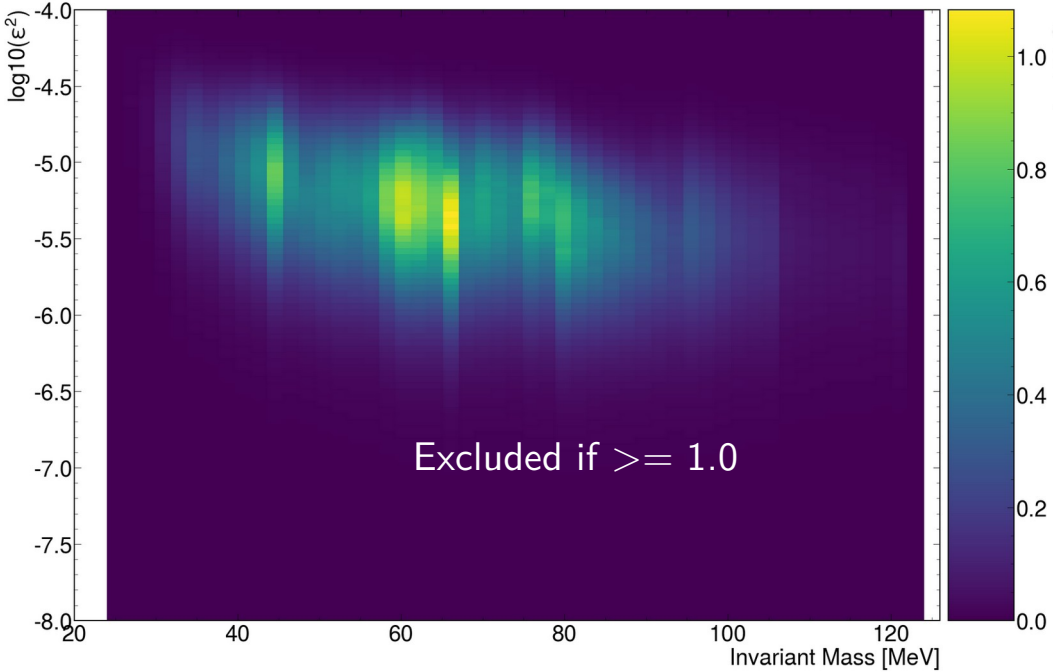
10% Data Exclusion

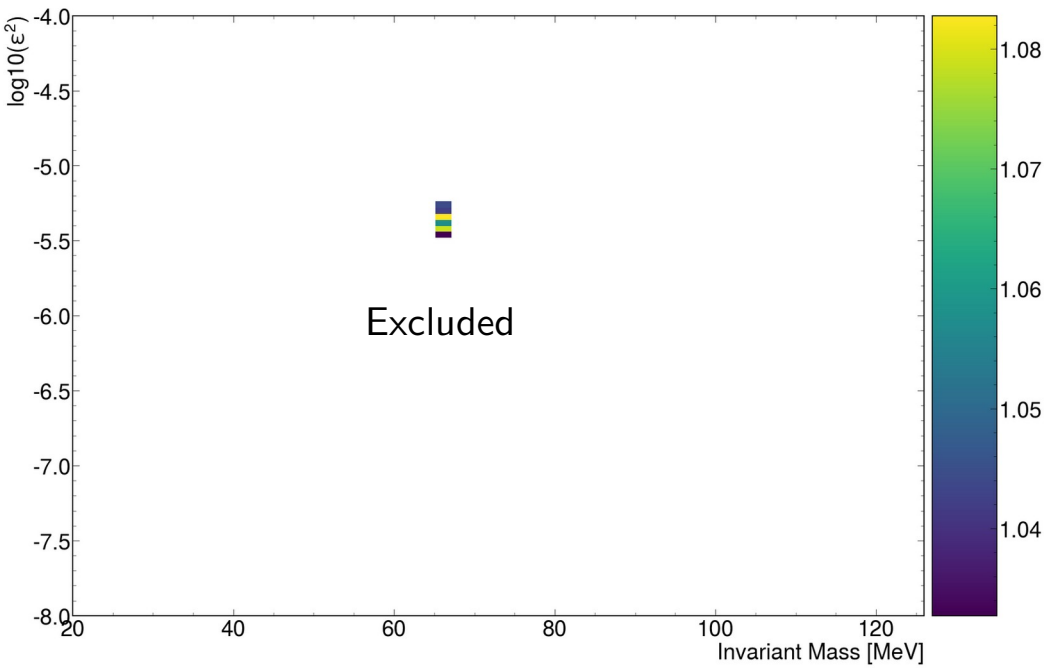




*Missing the statistical penalty?

10% Data Exclusion





*Missing the statistical penalty?

Summary

I. **Momentum Resolution**
   i. Finalize MC smearing
   ii. Systematic

II. **Data/MC Psum**
   i. Use Psum-reweighting to account for mis-match in trigger efficiency (presumably) at low psum

III. **Radiative Fraction**
   i. Reprocess after psmearing
   ii. Systematic

IV. **Radiative Acceptance**
   i. Reprocess after psmearing
   ii. Systematic with misalignments

V. **Target Projection Significance**
   i. Systematic

VI. **Finalize Impact Paramter Cut (Z0)**
   i. Probably just want to keep shape and tighten a bit
   ii. Systematic

VII. **ABCD Method Validation Studies**
   i. 100% CR data, and 100% SR $>$ 135 MeV
   ii. Tritrig+WAB+Beam

VIII. **Optimum Interval Method**
   i. I forgot about the statistical penalty

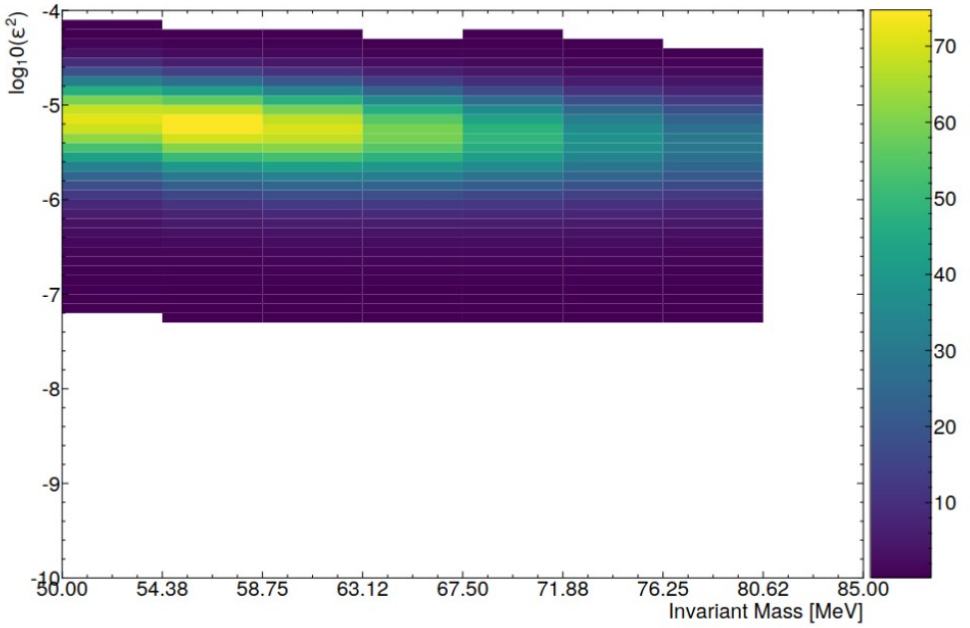
I think most of the framework is ready to go.

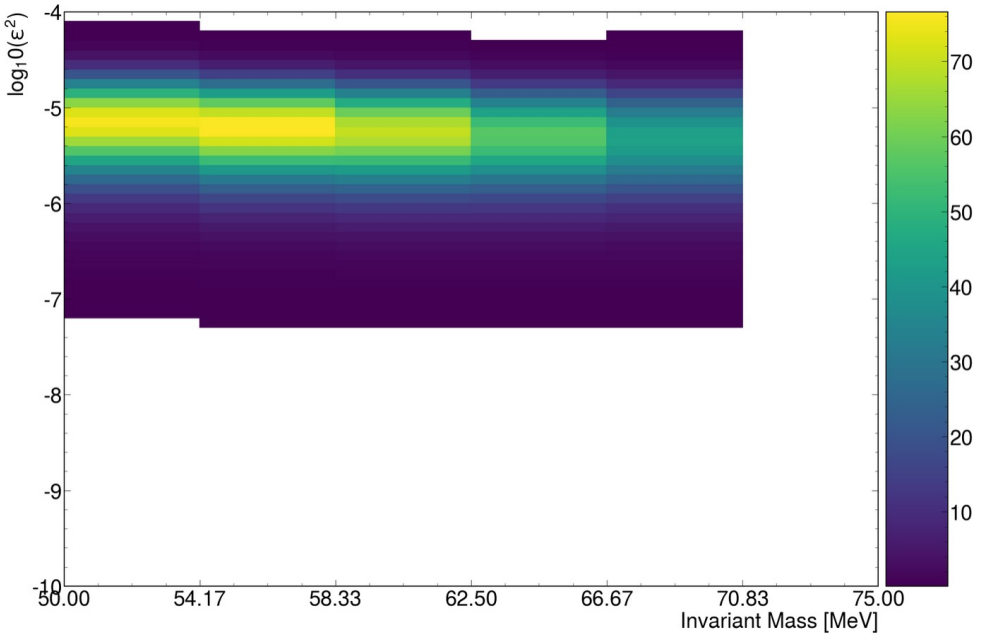
Just need to sort out the momentum smearing issue, and then re-process the MC samples

Backup

Expected Signal Pass4b MC – New Components

Using new radFrac, radAcc, and mass Res





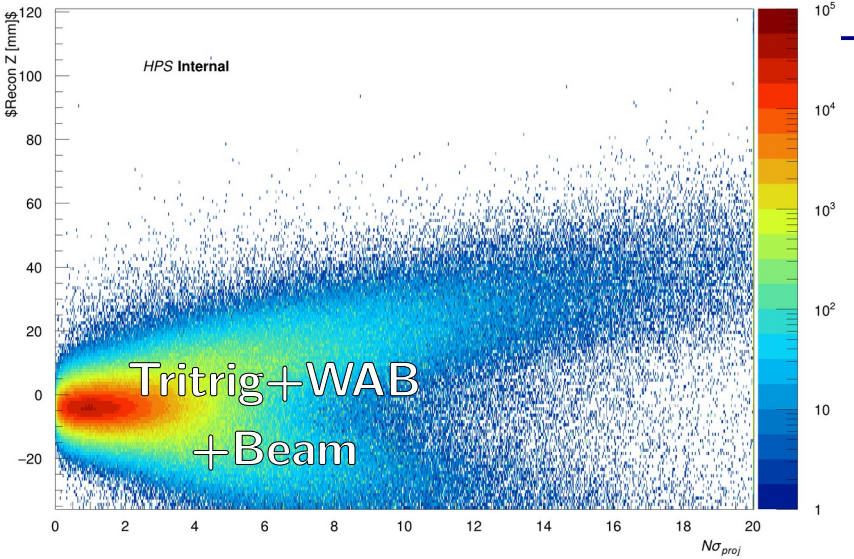
Target Projected Vertex Significance

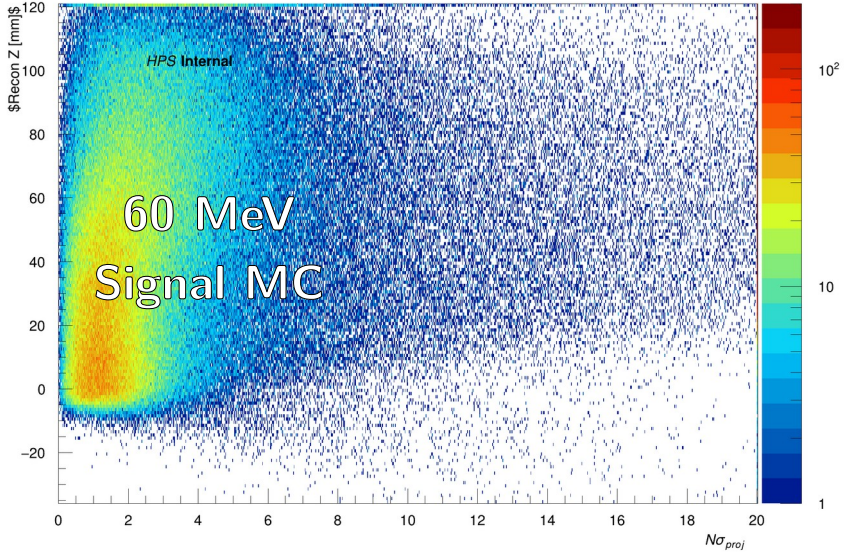
Preselection

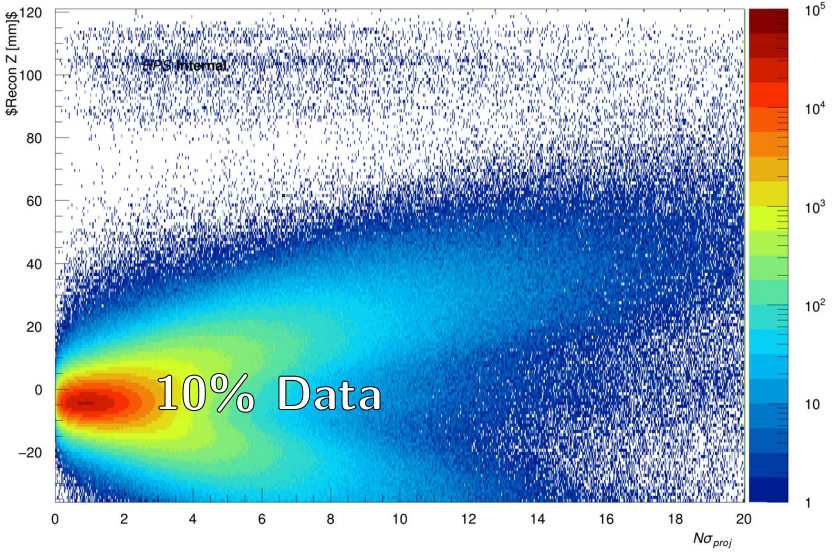
target projection vertex significance

versus recon z

$$N_{\sigma proj} = \sqrt{N^2_{\sigma x_{rot}} + N^2_{\sigma y_{rot}}}$$







Event Selection

Reconstruction Level

Cut Description	Requirement
ECal clusters in opposite volumes	$e^- Cluster_y \times e^+ Cluster_y < 0$
Track-Cluster Time Difference (Data)	$\lvert Track_t - Cluster_t - 56\,\text{ns}\rvert < 10\,\text{ns}$
Track-Cluster Time Difference (MC)	$\lvert Track_t - Cluster_t - 43\,\text{ns}\rvert < 10\,\text{ns}$
Track-Cluster X Position Difference	$\lvert x_{TrackatEcal} - x_{Cluster}\rvert < 20.0\,\text{mm}$
Track-Cluster Y Position Difference	$\lvert TrackAtEcal_y - Cluster_y\rvert < 20.0\,\text{mm}$
Cluster Time Difference	$\Delta_t(Cluster_{e^-}, Cluster_{e^+}) < 2.5\,\text{ns}$
Beam electron cut	$p_{e^-} < 2.15\,\text{GeV}$
Vertex Momentum	$p_{Vtx} < 2.8\,\text{GeV}$

Preselection

Cut Description	Requirement
Trigger	Pair1
Track Time	$\lvert Track_t\rvert < 6\,\text{ns}$
Cluster Time Difference	$\Delta_t(Cluster_{e^-}, Cluster_{e^+} < 1.45\,\text{ns}$
Track-Cluster Time Difference	$\Delta_t(Track, Cluster) < 4.0\,\text{ns}$
Track Quality	$Track\,\chi^2/n.d.f. < 20.0$
Beam electron cut	$p_{e^-} < 1.75\,\text{GeV}$
Minimum Hits on Track	$N_{2dhits}\,Track > 7.0$
Unconstrained Vertex Quality	$Vtx_{\chi^2} < 20.0$
Vertex Momentum	$p_{e^-+e^+} < 2.4\,\text{GeV}$

Layer Requirement

Cut Description	Requirement
Layer 1 Requirement	e^- and e^+ have L1 axial+stereo hit
Layer 2 Requirement	e^- and e^+ have L2 axial+stereo hit

Signal and Control Regions

Cut Description	Requirement
Control Region Momentum	$1.9\,\text{GeV} < P_{e^-} + P_{e^+} < 2.4\,\text{GeV}$
Signal Region Momentum	$1.0 < P_{e^-} + P_{e^+} < 1.9\,\text{GeV}$

High-Z Cuts

Cut	Condition
Target Projected Vertex Significance Cut ($V0_{\text{proj}}$)	$V0_{\text{proj}} < 2.0$
DeltaZ Cut (Δz_{track})	$\Delta z_{track} < 21.2005 + 16.61e^{-2}(m)$ mm
Flat Z0 Cut ($\lvert z0\rvert$)	$\lvert z0\rvert < -4.681e^{-03}(m) + 0.921$ mm

Preliminary

SIMP Model Parameters

- **Six key SIMP parameters**
- 1. A' mass
- 2. A' kinetic mixing strength ε
- 3. HS $U_D(1)$ coupling α_D
- 4. Dark pion mass
- 5. Dark vector mass
- 6. Dark pion decay constant f_π

SIMP Parameter Constraints

$m_{A'} < 2m_\mu$ and $m_{A'} < 2m_V$
$m_{A'} > m_V + m_\pi$ and $m_{A'} > 2m_\pi$
$m_V < 2m_\pi$ and $m_V < 2m_\mu$
$\alpha_D < 1$
$10^{-6} < \epsilon < 10^{-2}$
$m_\pi / f_\pi < 4\pi$

Benchmark Parameters [4]

- $\alpha_D = 0.1$
  - $m_{A'}/m_{\pi D} = 3$
  - $m_{VD}/m_{\pi D} = 1.8$
  - $m_{\pi D}/f_{\pi D} = 4\pi$