2016 SIMP Optimum Interval Method Results on 10% Data

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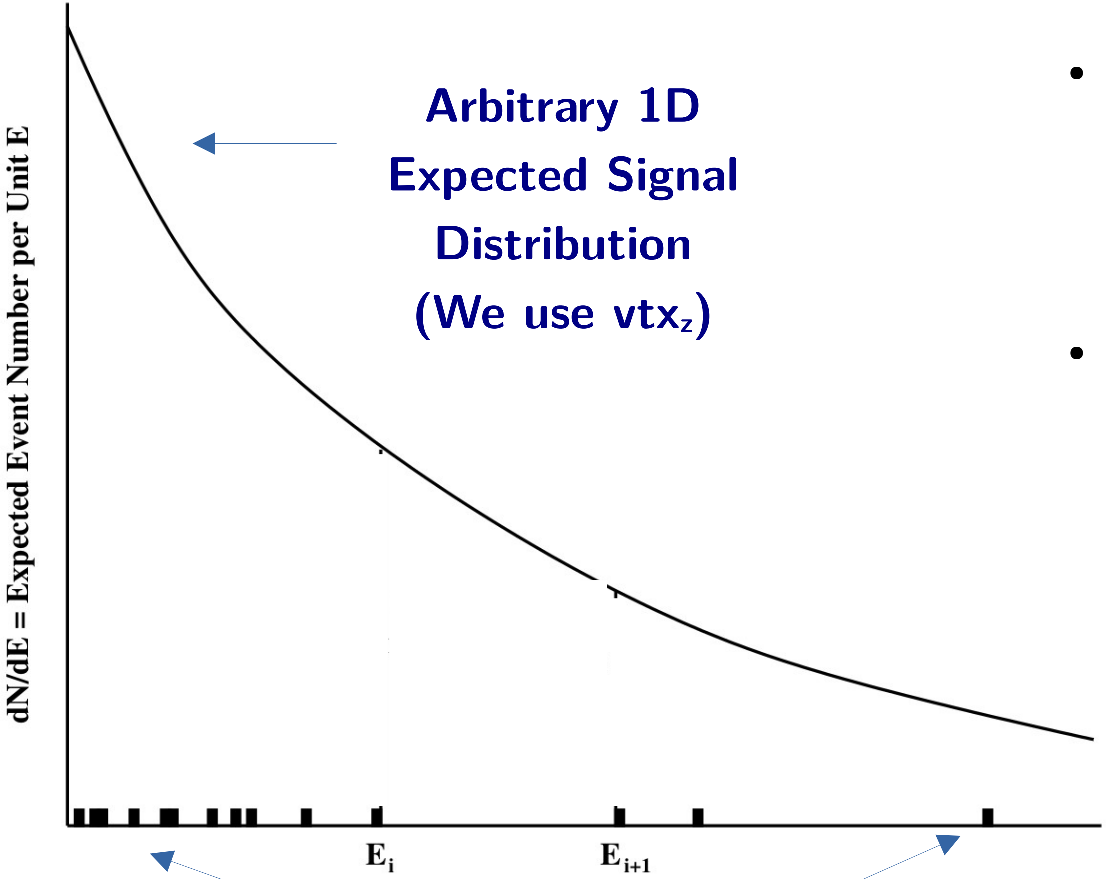
Introduction

- Tight cut variables studied using 10% Data
- First Optimization Results: **V0 Projection Significance, DeltaZ, and |Z0| Tight Cuts**
  - No more zcut, background almost completely eliminated
  - *Will study re-ordering and re-optimizing with 100% blinded Data (pending committee approval)
- **Setup Optimum Interval Method** code to work for SIMPs
  - Referenced Matt's code to transform data based on signal acceptance*efficiency, and set 90% upper limit on mean expected signal μ using OIM
  - Generate μ exclusion lookup table with CMS toy MC python code *thanks Tom!
- **Expect to exclude 65 MeV dark vectors with 90% confidence in 10% Data alone**
  - Although...MC signal has no hit killing or momentum smearing
- **Show OIM results for all masses (at 5 MeV intervals) and ε**
- **Full lumi 90% exclusion contour estimate at the end...**

Introduction to Optimum Interval Method (OIM)

*My understanding of it anyways. Looking for feedback

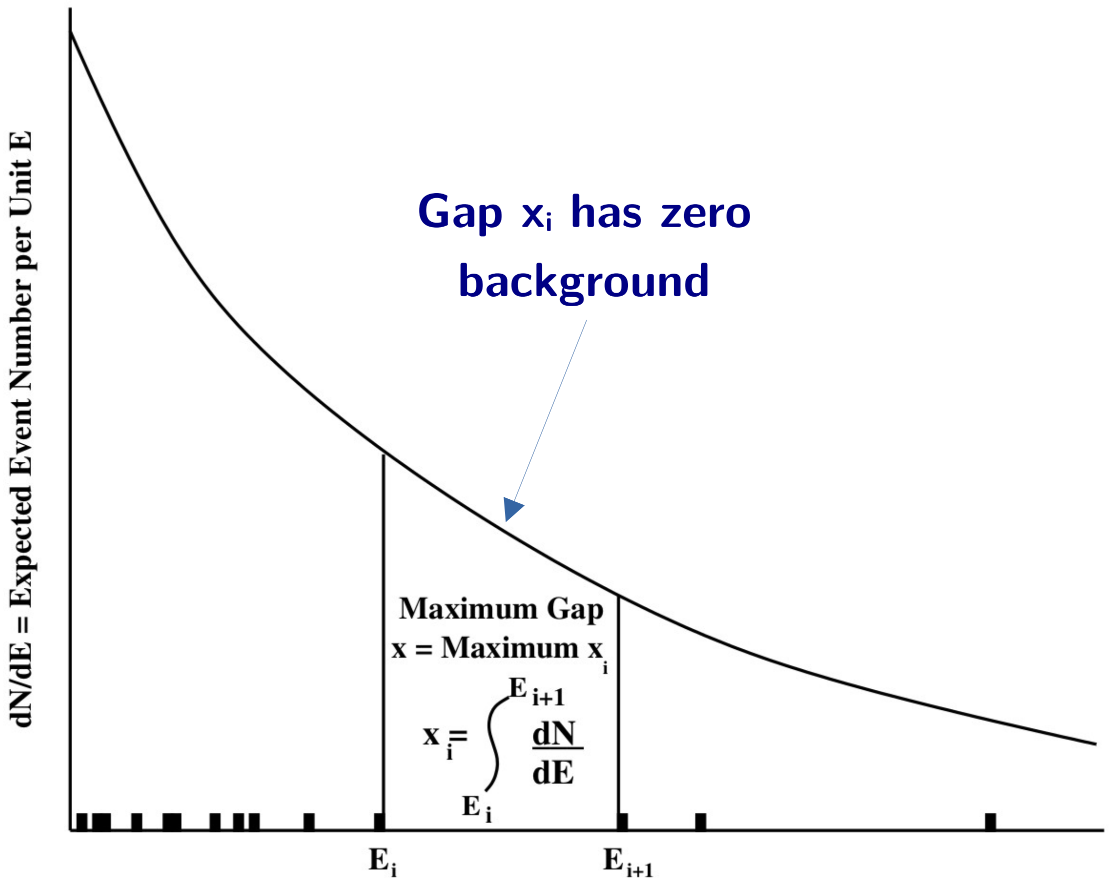
OIM Introduction



- Can't exclude possibility that unknown background source is large enough to account for all events in data (black squares)
- Can only set upper limit on expected signal rate
  - Maybe some black squares are signal
  - How large does signal rate need to be before we can exclude it with 90% confidence (the black squares inconsistent with the signal hypothesis)

OIM Introduction

Maximum Gap Method

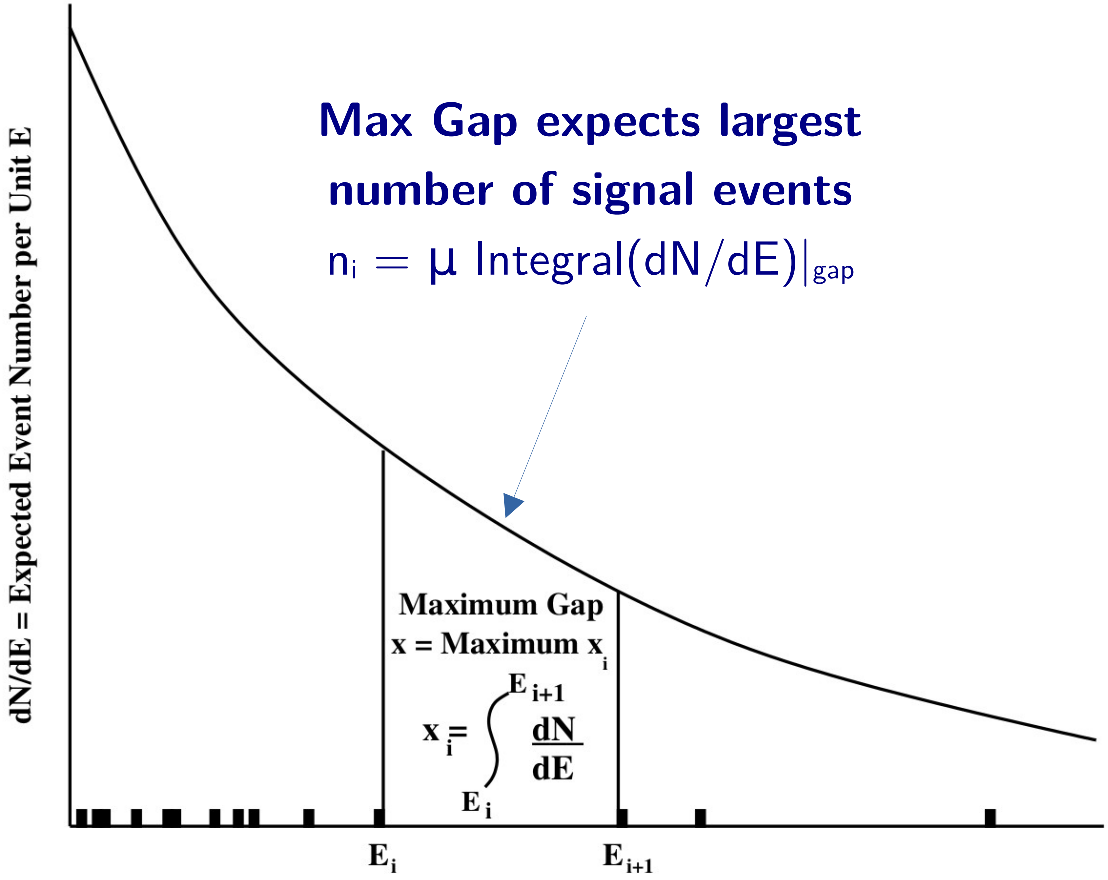


OIM Introduction

Maximum Gap Method

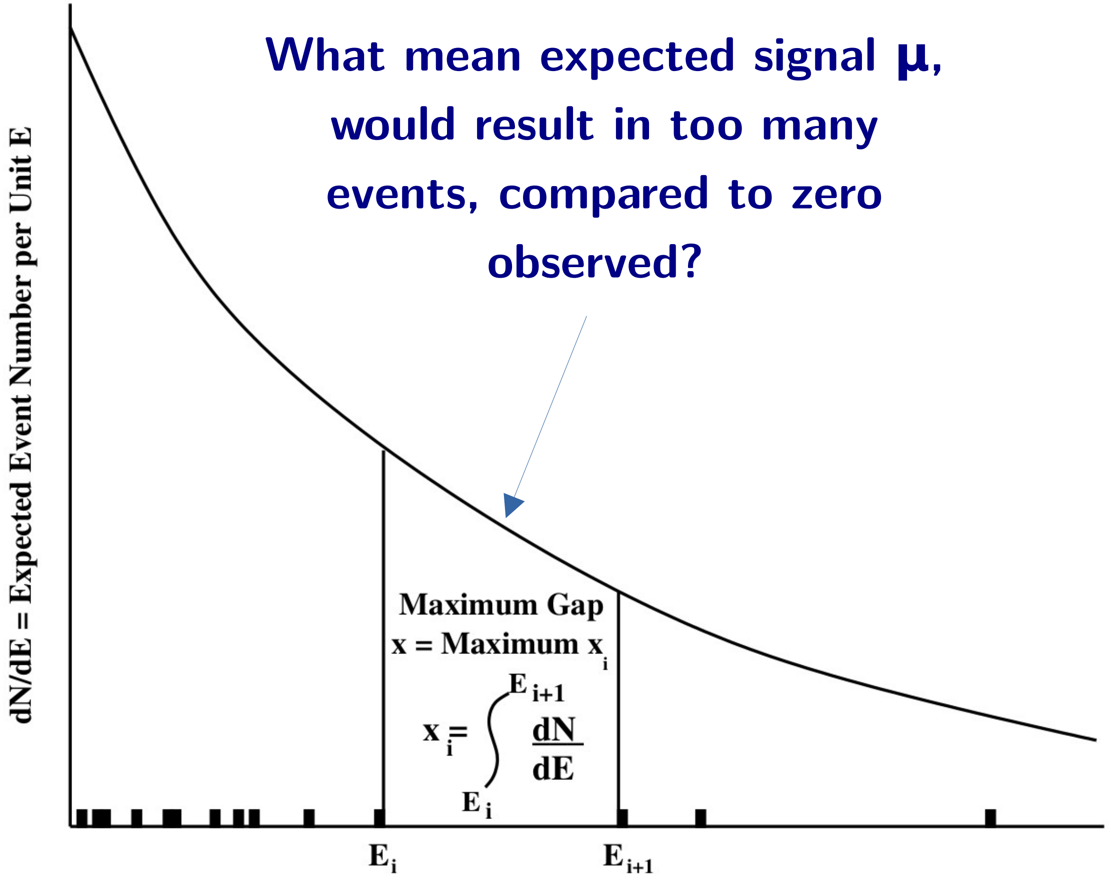
Max Gap expects largest number of signal events

$n_i = \mu$ Integral$(dN/dE)|_{gap}$



OIM Introduction

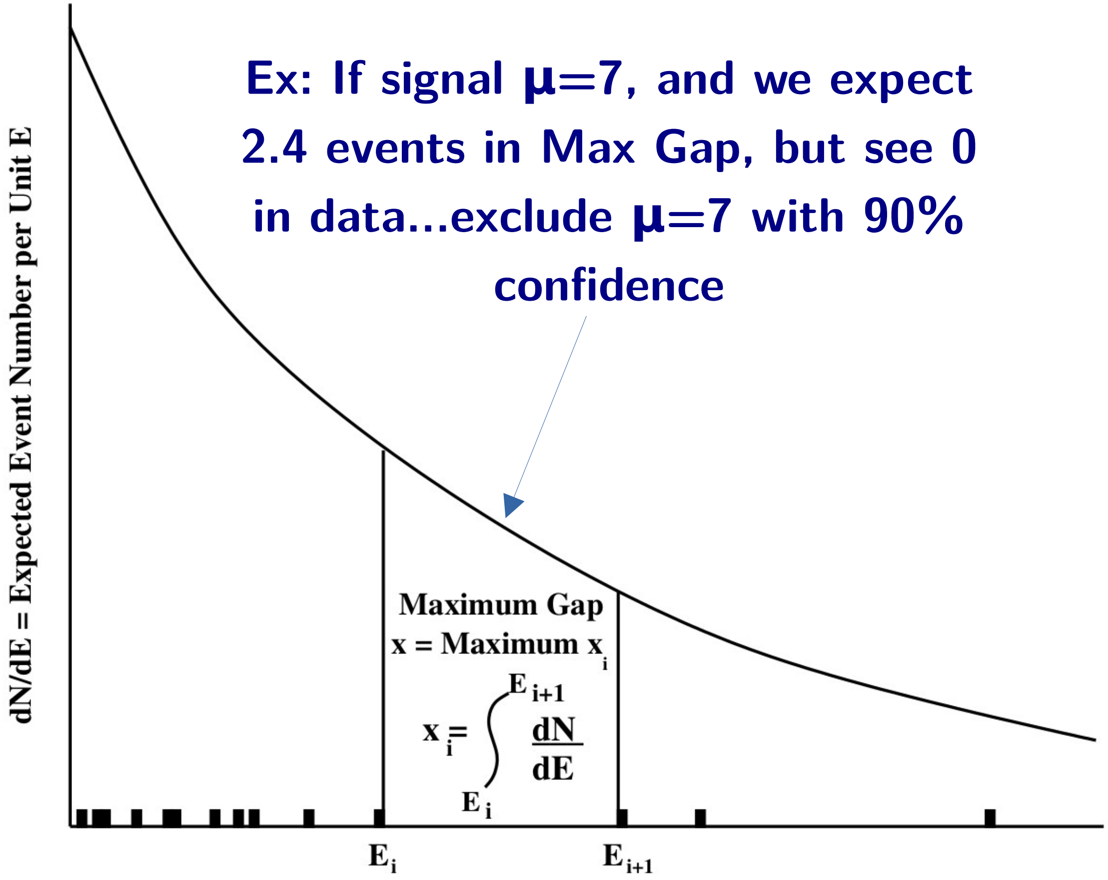
Maximum Gap Method



OIM Introduction

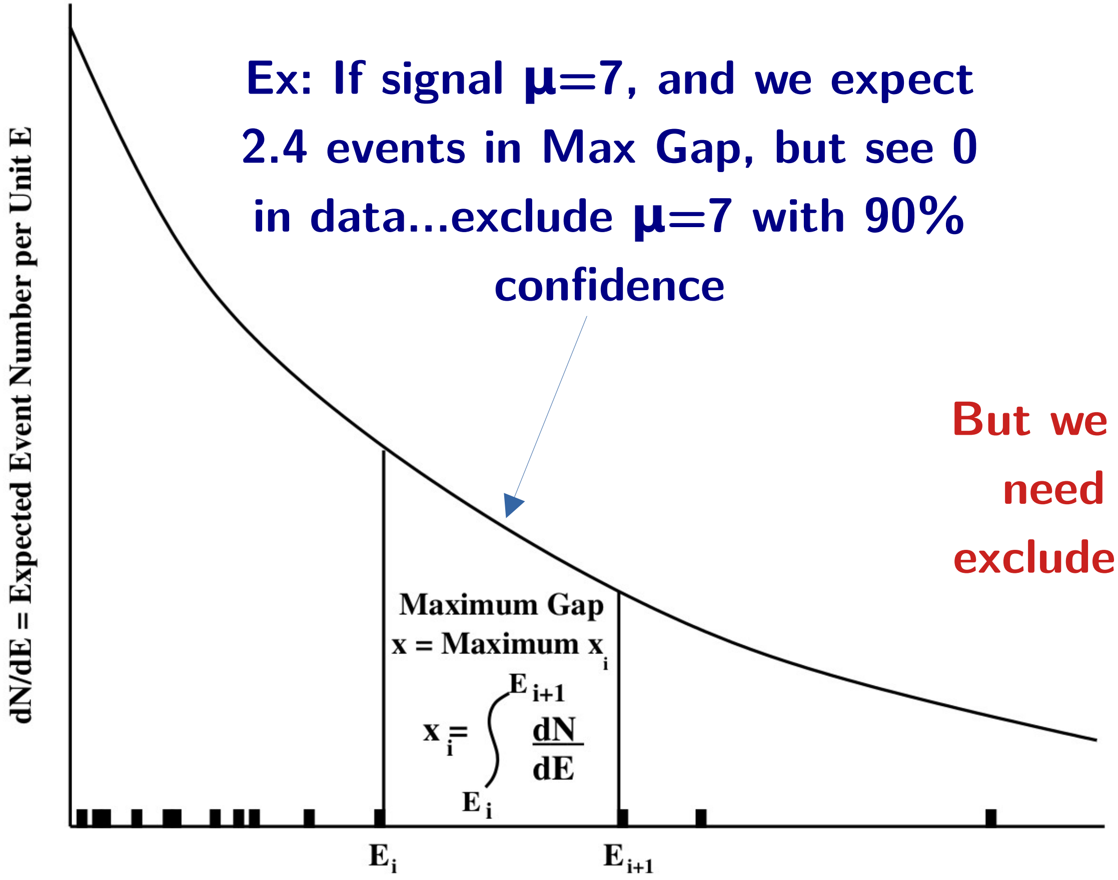
Maximum Gap Method

Ex: If signal μ=7, and we expect 2.4 events in Max Gap, but see 0 in data...exclude μ=7 with 90% confidence



OIM Introduction

Maximum Gap Method



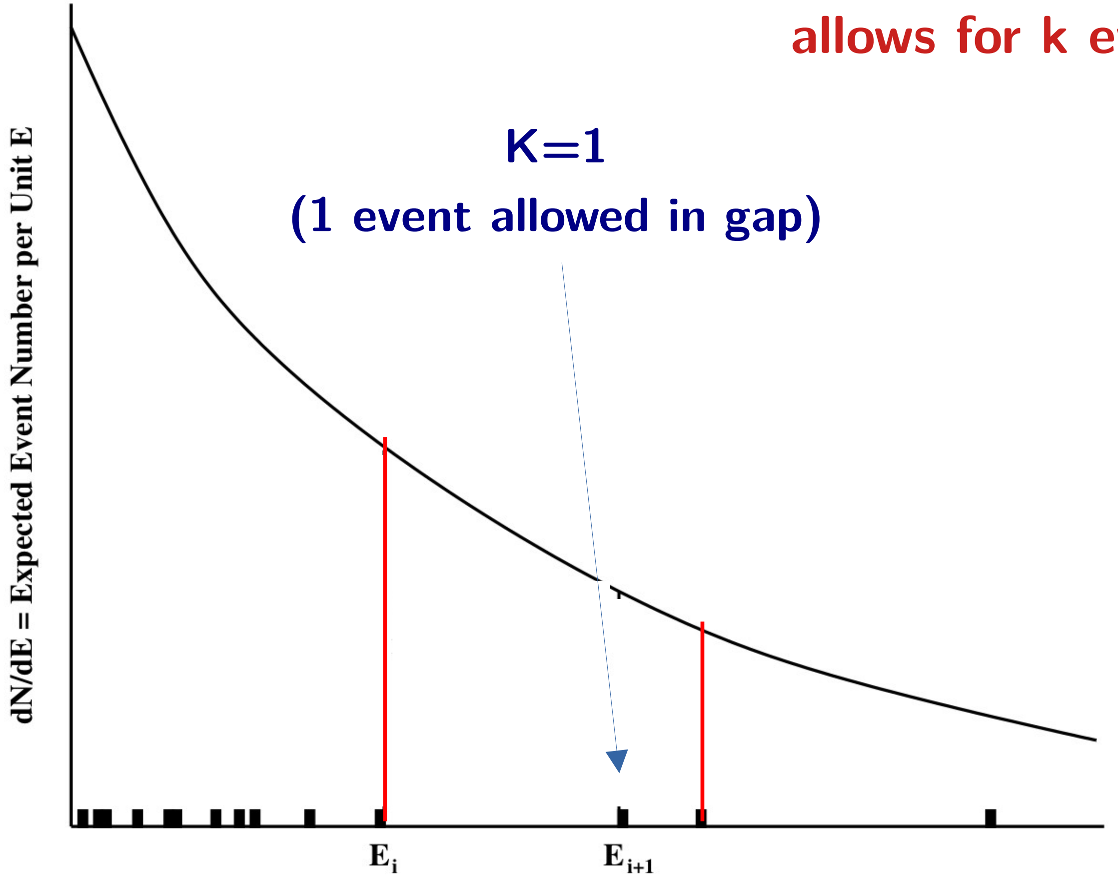
Ex: If signal μ=7, and we expect 2.4 events in Max Gap, but see 0 in data...exclude μ=7 with 90% confidence

But we don't necessarily need zero events to exclude...introduce OIM

OIM Introduction

Optimum Interval Method

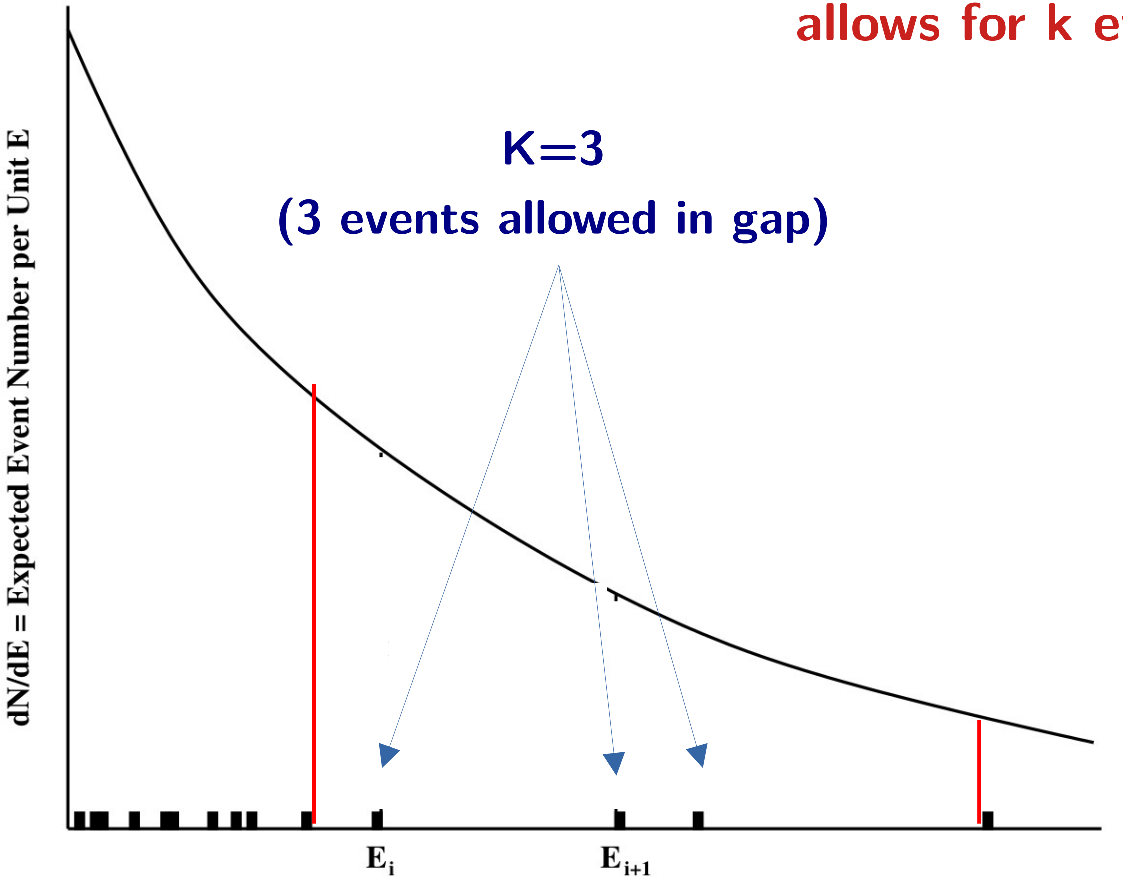
allows for k events in gaps



OIM Introduction

Optimum Interval Method

allows for k events in gaps

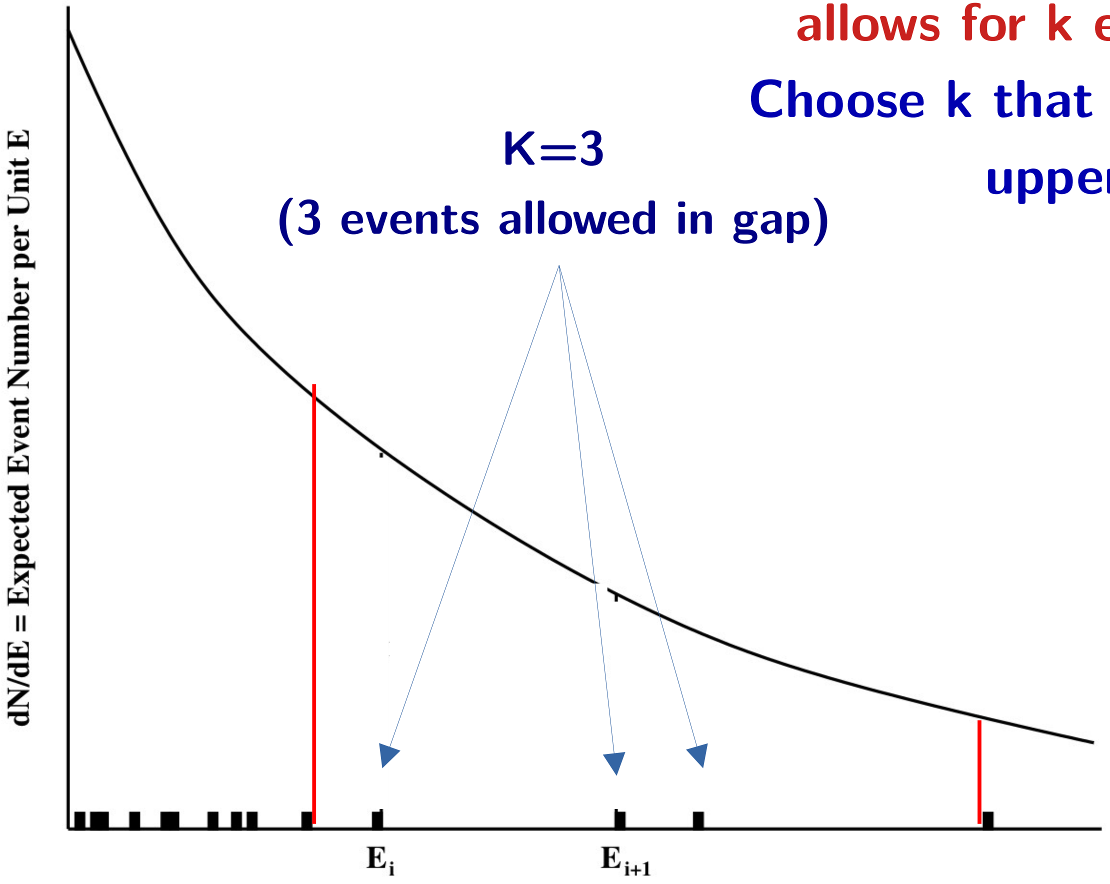


OIM Introduction

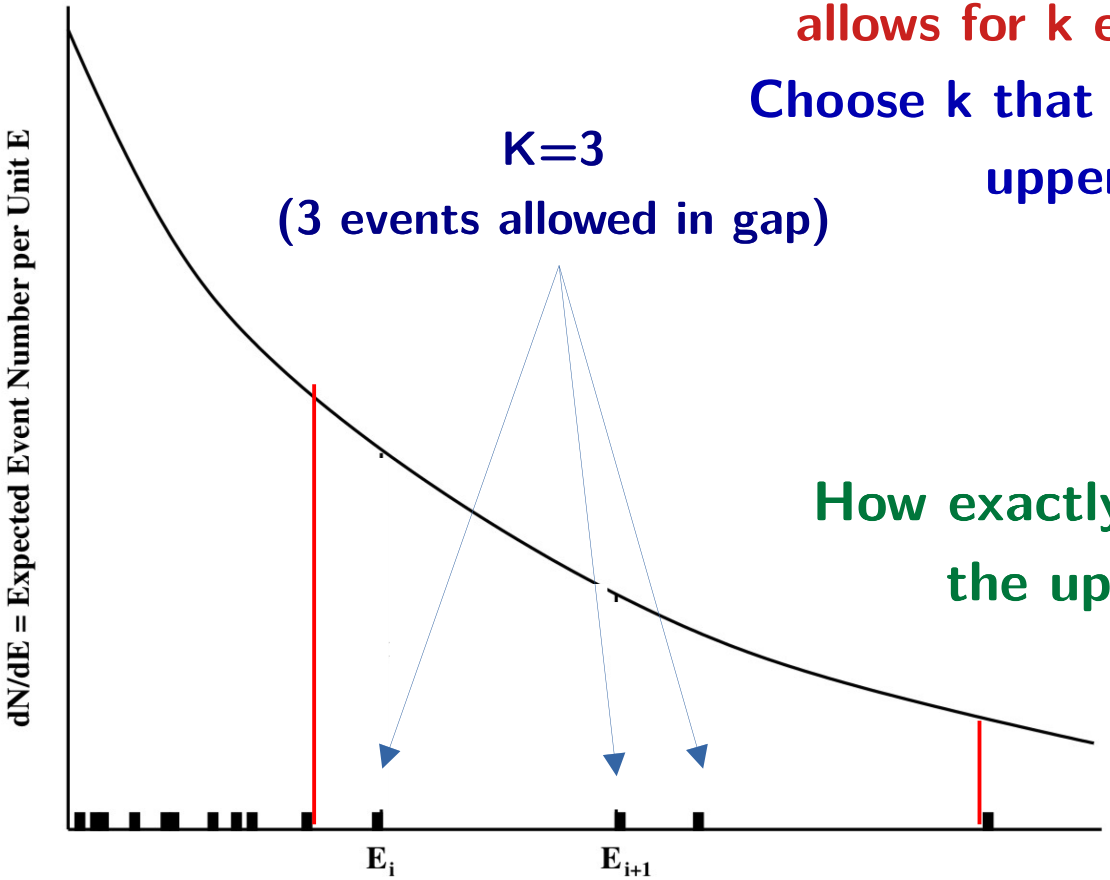
Optimum Interval Method

allows for k events in gaps

Choose k that gives best 90% upper limit



OIM Introduction



Optimum Interval Method

allows for k events in gaps

Choose k that gives best 90% upper limit

How exactly do we calculate the upper limit...?

SIMPs OIM Introduction

SIMPs OIM Introduction

*All SIMP parameters (except ε) are fixed to the typical values

10% Data with Tight Cuts

Mass window is 2.5*MassRes

No Hit Killing or MC Momentum Smearing

Expected Signal calculation defined in Note

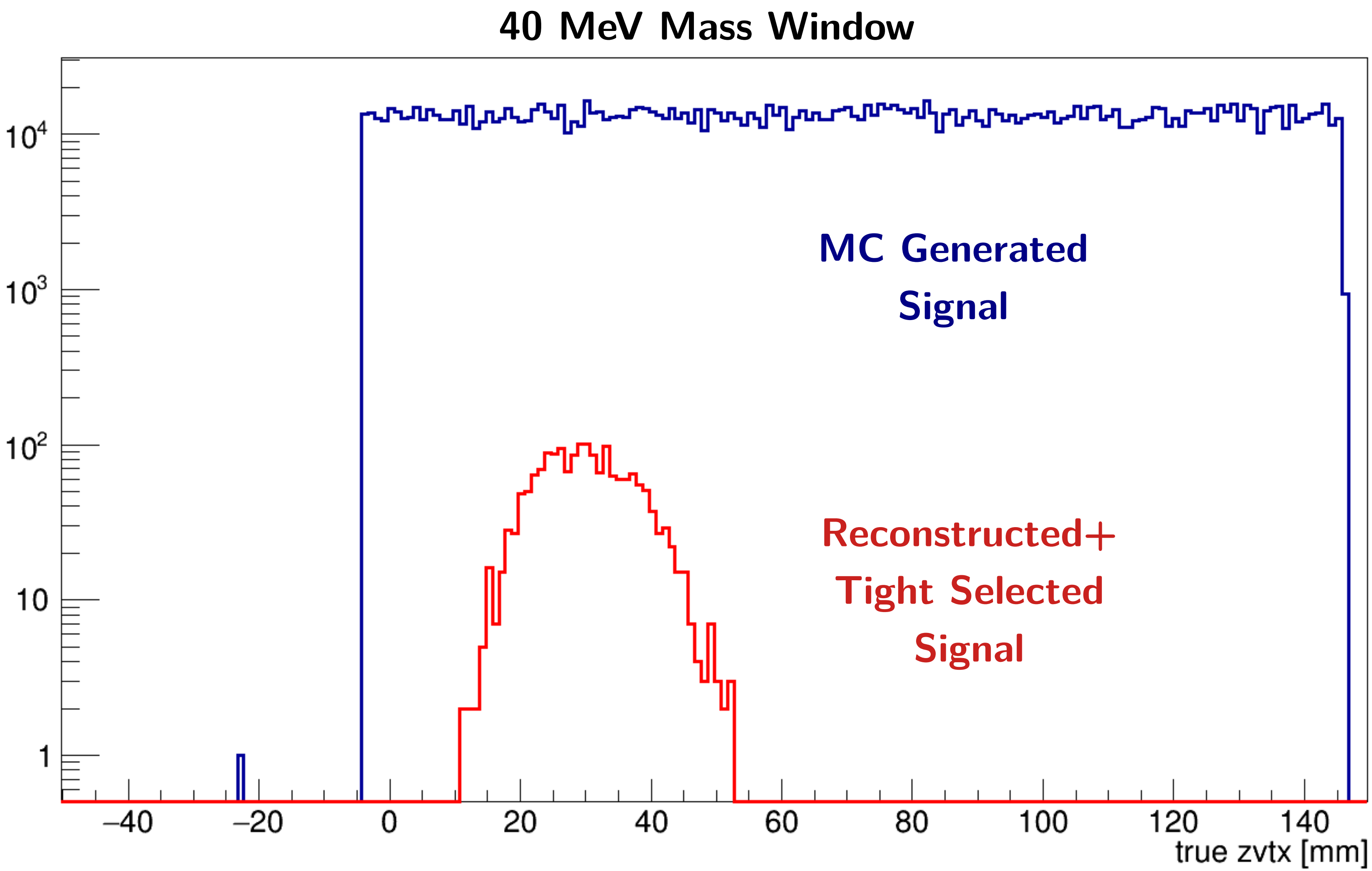
Table 10: Tight Cuts Optimized Using 10% Data

Cut	**Condition**
Target Projected Vertex Significance Cut ($V0_{proj}$)	$V0_{\text{proj}} < 2.0$
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

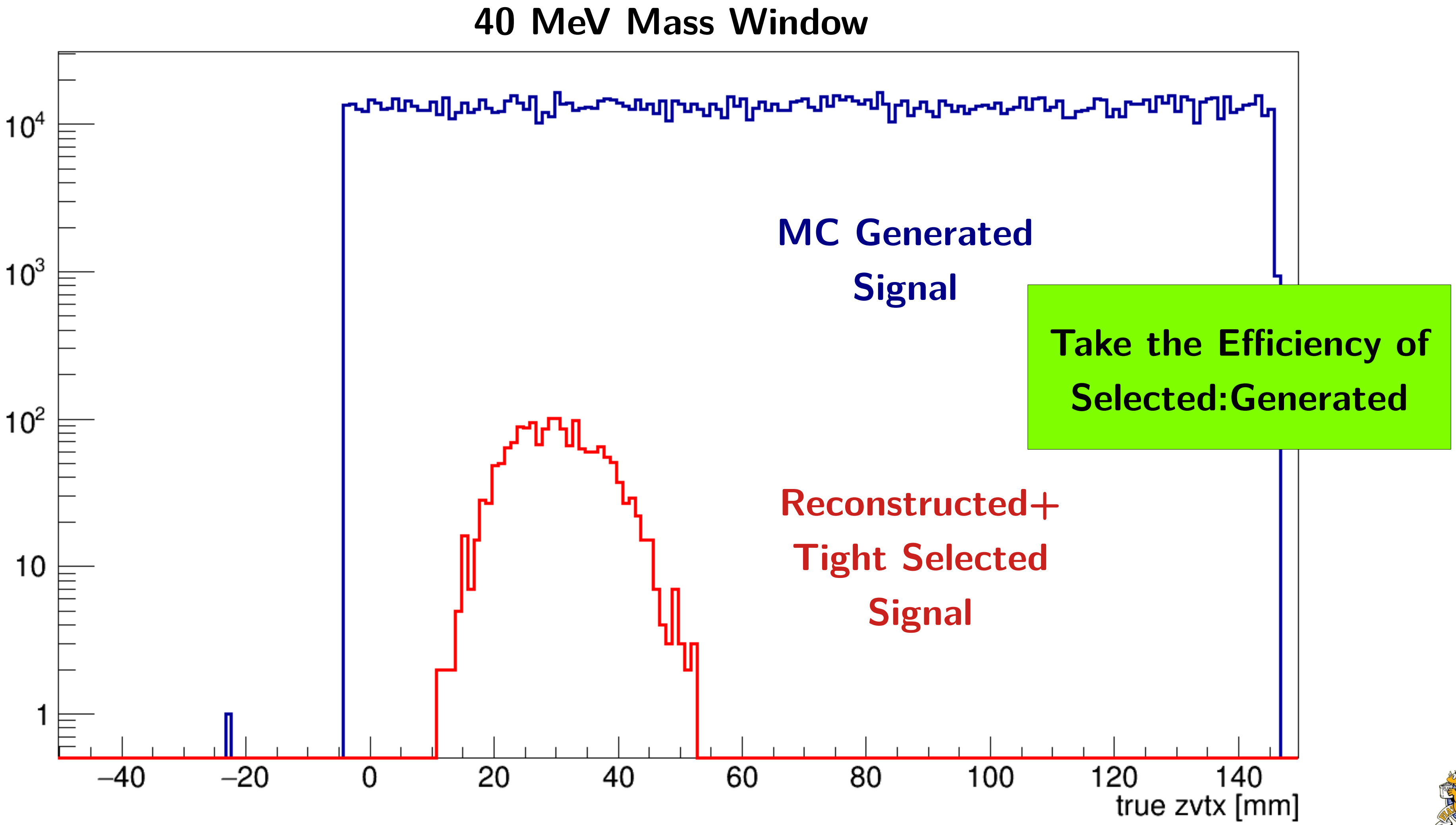
SIMP OIM Introduction

- For each signal mass hypothesis…
- Get the signal acceptance*efficiency F(z)
- Re-weight F(z) for the rho and phi vector mesons, and combine to get $F(z,\varepsilon)_{\rho+\phi}$
- Transform the data based on the signal assumption (uniform normalized distribution)
- Find the maximum gap size in the transformed data variable
  - For each possible value of k
- Compare the maximum gap observed in data to the expected maximum gap distribution, when we assume that the expected signal mean μ is true
- Find the value of μ that can be excluded with 90% confidence

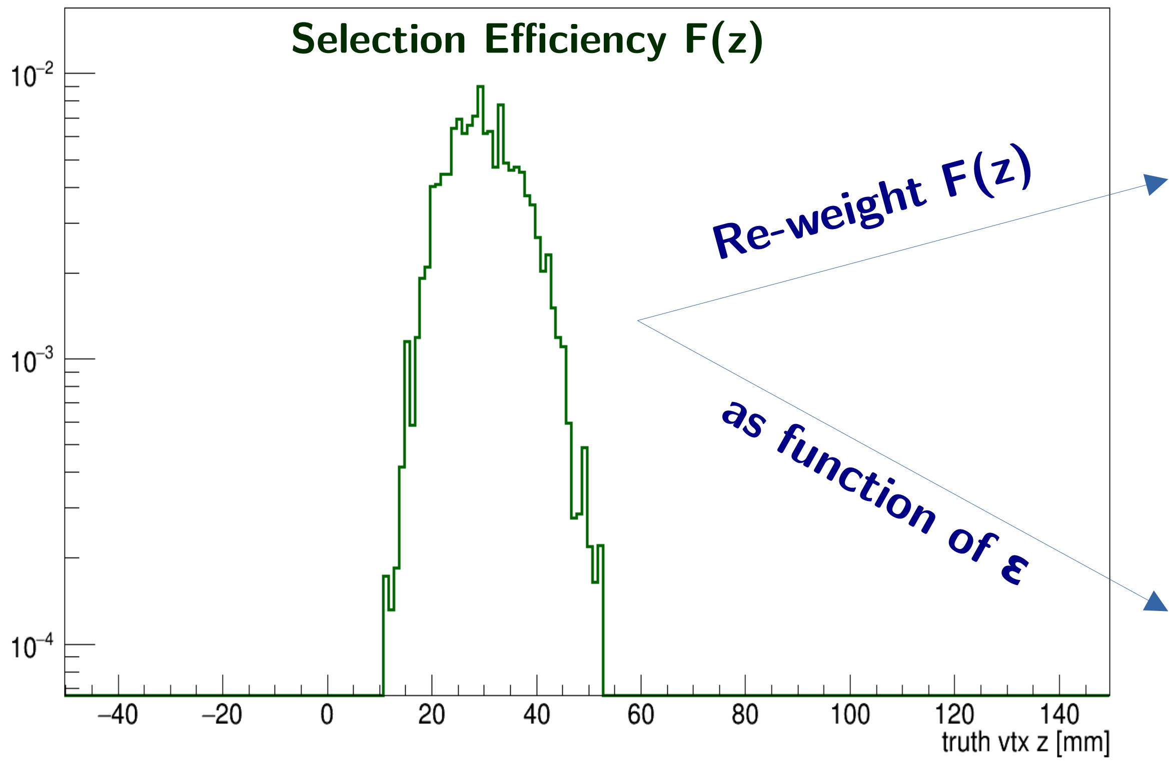
SIMP Signal Acceptance and Eff



SIMP Signal Acceptance and Eff



SIMP Signal Acceptance and Eff



Rho Meson

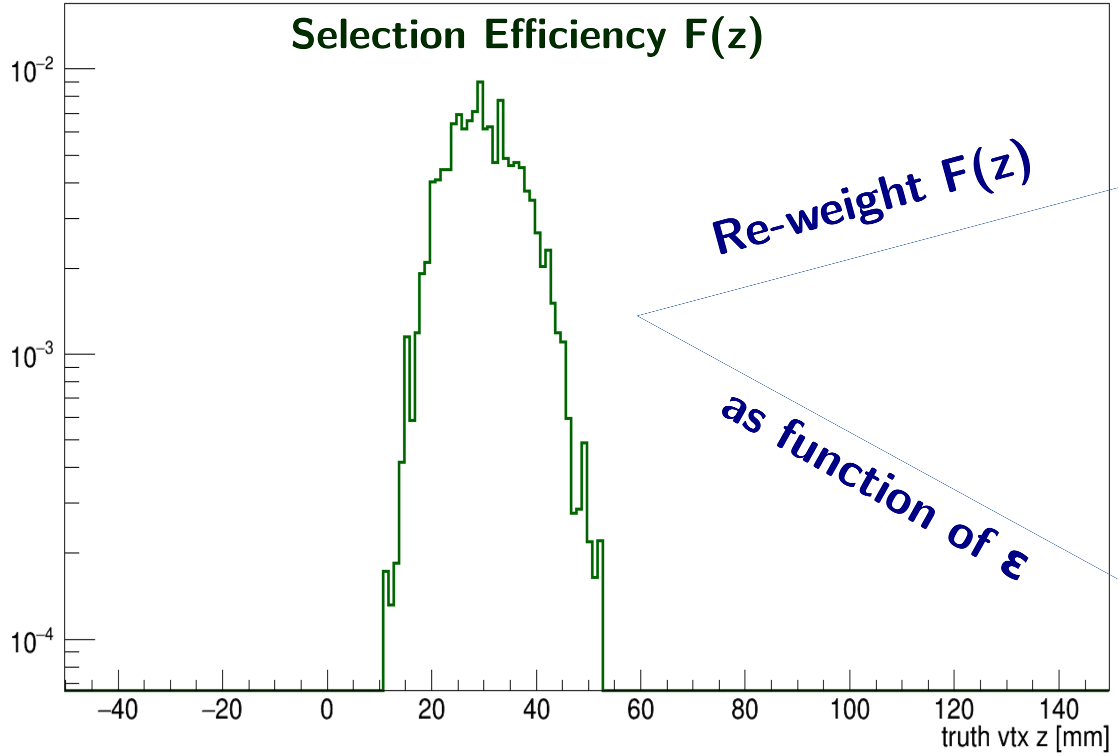
$$BR(A' \to \rho\pi)\left(\frac{BR(A' \to \rho\pi)}{BR(A' \to \rho\pi) + BR(A' \to \phi\pi)}\right)\frac{exp^{\left(\frac{z_{target}-z}{\gamma c\tau}\right)}}{\gamma c\tau}$$

Phi Meson

$$BR(A' \to \phi\pi)\left(\frac{BR(A' \to \phi\pi)}{BR(A' \to \rho\pi) + BR(A' \to \phi\pi)}\right)\frac{exp^{\left(\frac{z_{target}-z}{\gamma c\tau}\right)}}{\gamma c\tau}$$

***Other SIMP parameters are fixed**

SIMP Signal Acceptance and Eff



Re-weight F(z)

as function of ε

Rho Meson

$$BR(A' \to \rho\pi)\left(\frac{BR(A' \to \rho\pi)}{BR(A' \to \rho\pi) + BR(A' \to \phi\pi)}\right)\frac{exp^{\left(\frac{z_{target} - z}{\gamma c\tau}\right)}}{\gamma c\tau}$$

Combine to get $F(z,\varepsilon)_{\rho+\Phi}$

Phi Meson

$$BR(A' \to \phi\pi)\left(\frac{BR(A' \to \phi\pi)}{BR(A' \to \rho\pi) + BR(A' \to \phi\pi)}\right)\frac{exp^{\left(\frac{z_{target} - z}{\gamma c\tau}\right)}}{\gamma c\tau}$$

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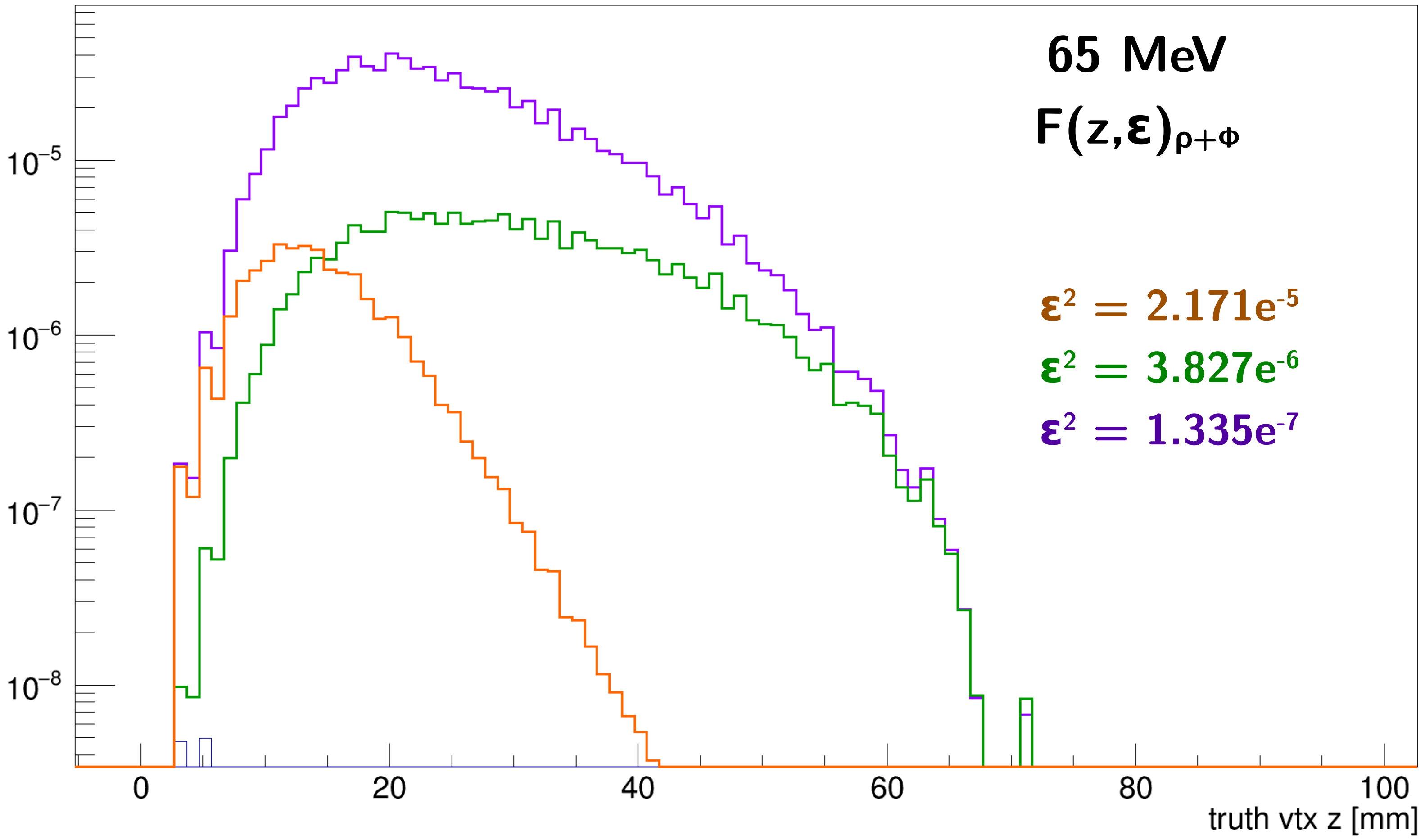
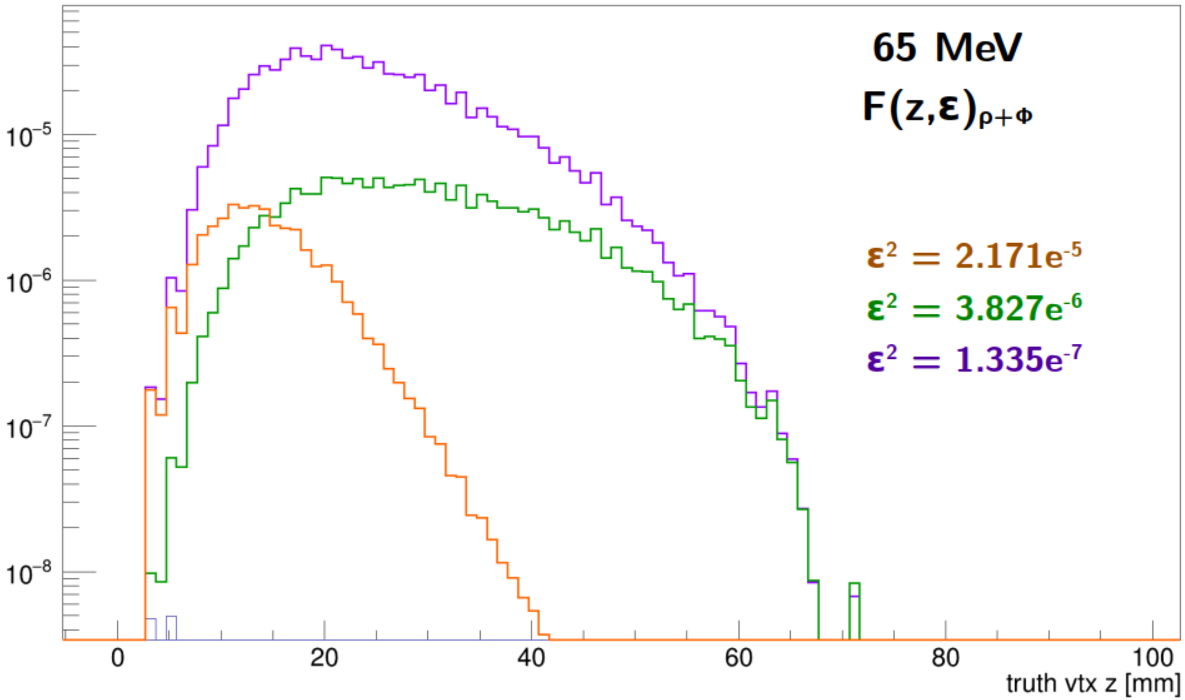
SIMP Signal Acceptance and Eff



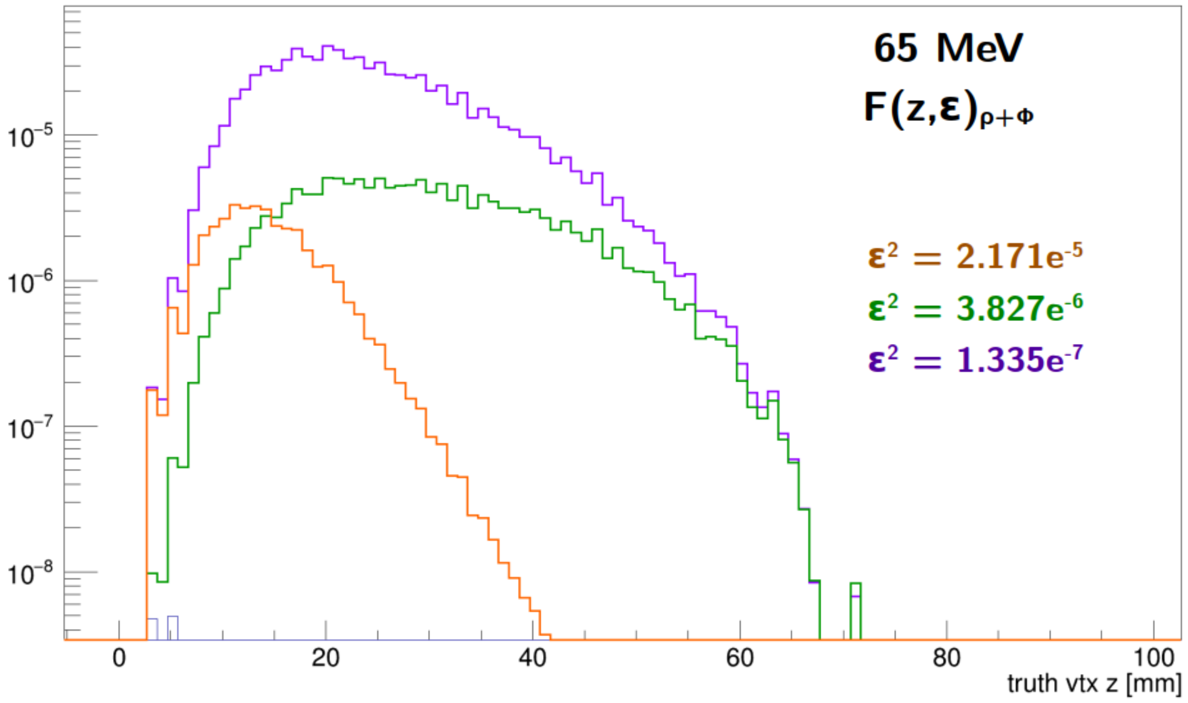
SIMP Expected Signal

Expected Signal Calculation



$$N_{A'sig}(m_{A'},\epsilon) = \frac{3\pi m_{A'}\epsilon^2}{2N_{eff=1}\alpha}\frac{f_{rad}}{f_{acc}}\frac{dN_{CR}}{dm_{reco}}\int_{z_{tar}}^{\infty} \mathrm{F}(z,\varepsilon)_{\rho+\Phi}\,dz$$

SIMP Expected Signal



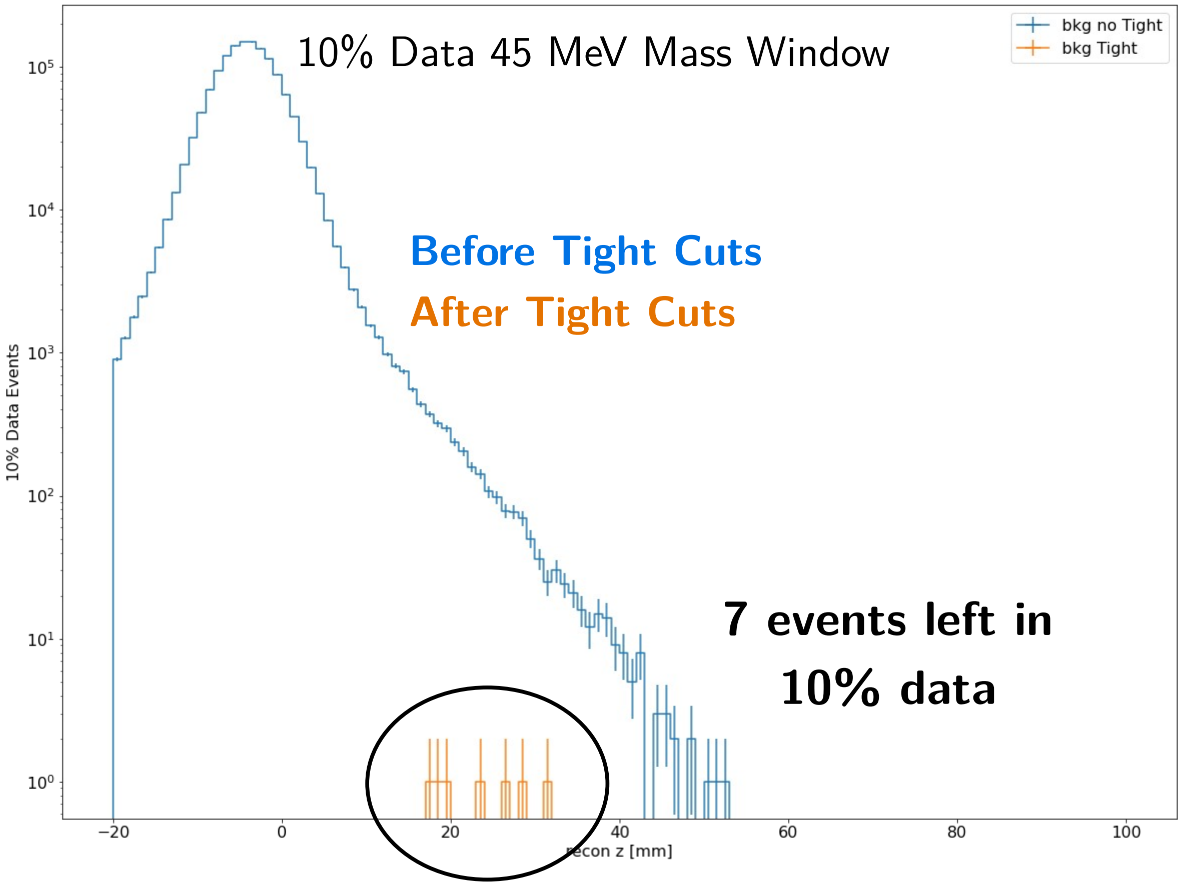
Transform Signal F(z,ε) into normalized uniform distribution

$$X = \int_{z_{tar}}^{\infty} F(z,\varepsilon)_{\rho+\Phi}\, dz \; - \; \int_{vtx_z}^{\infty} F(z,\varepsilon)_{\rho+\Phi}\, dz$$

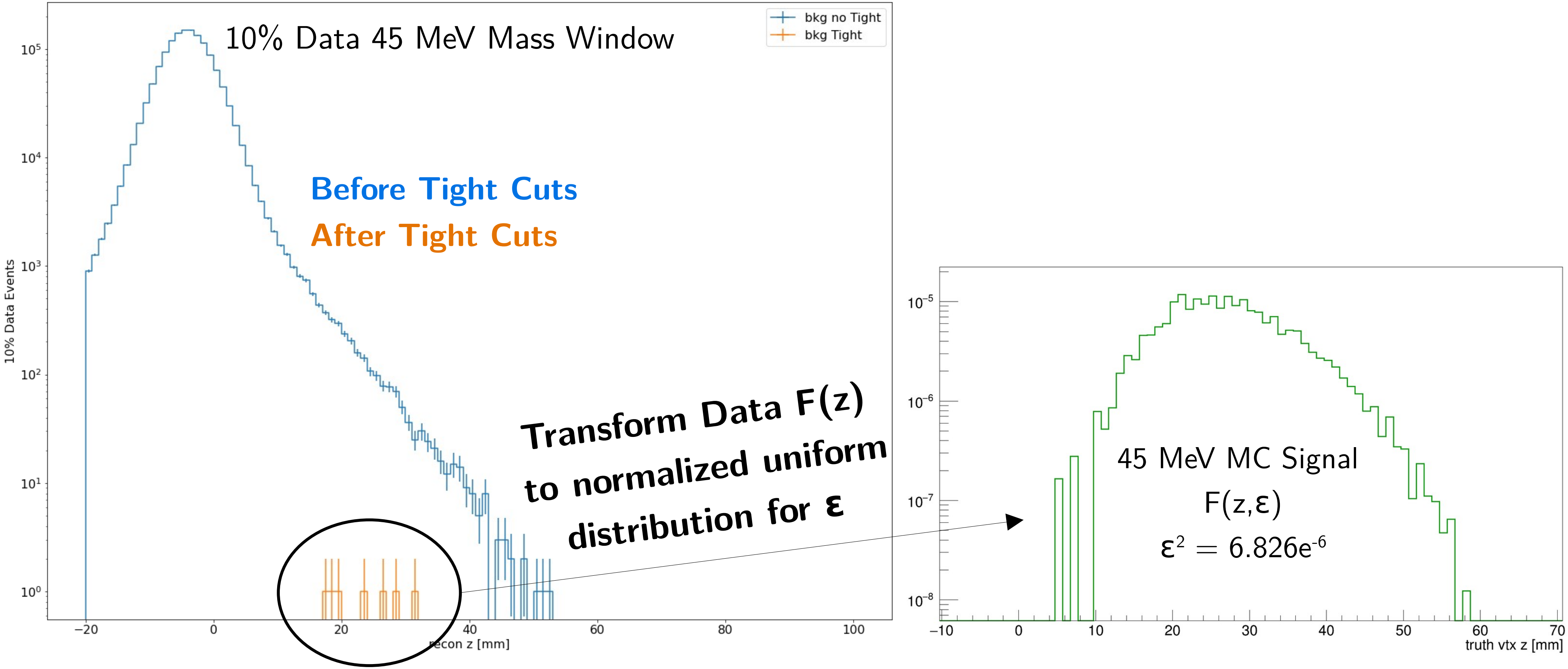
***we don't actually have to do this for signal...but we will transform data this way to use OIM**

10% Data Transformation for OIM

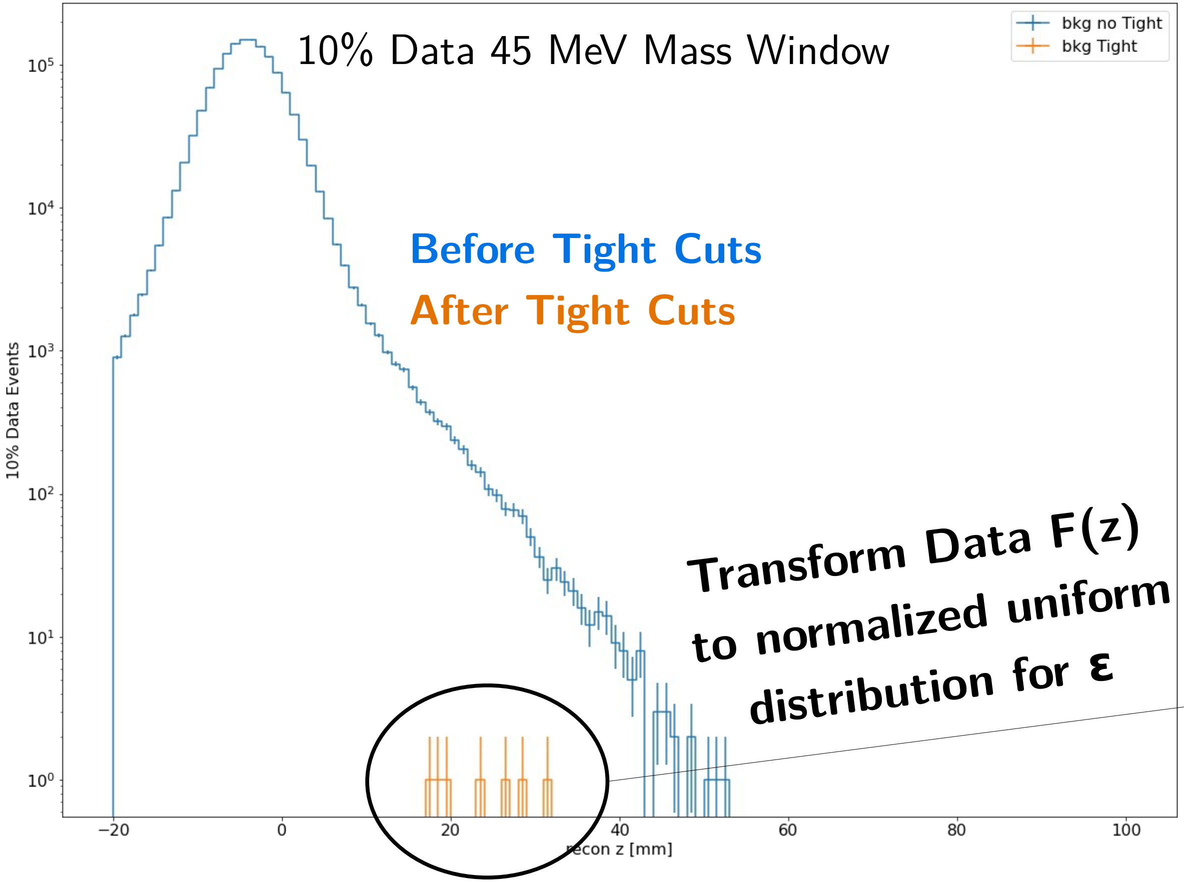
SIMP 10% Data Transformation



SIMP 10% Data Transformation



SIMP 10% Data Transformation

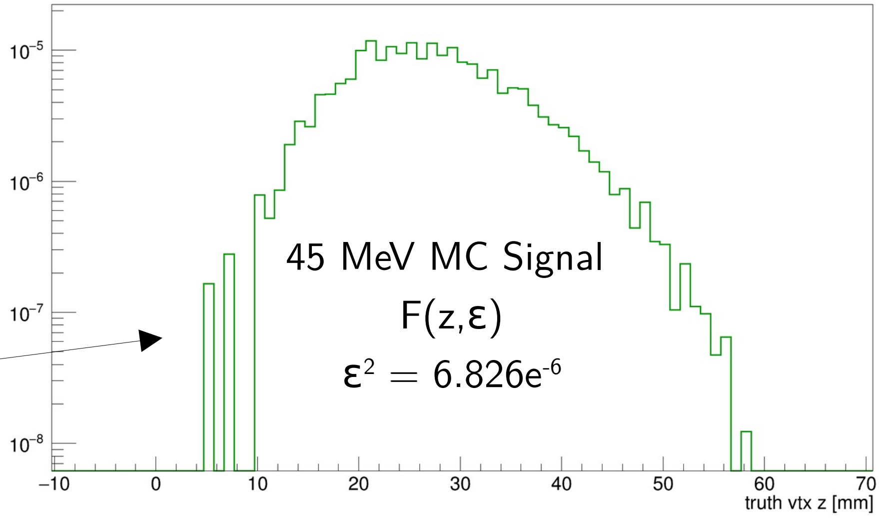


Transform Data F(z) to normalized uniform distribution for ε

For each event in Data

$$X = \int_{z_{tar}}^{\infty} F(z,\varepsilon)_{\rho+\Phi}\,dz \;-\; \int_{vtx_z}^{\infty} F(z,\varepsilon)_{\rho+\Phi}\,dz$$

Data



SIMP 10% Data Transformation

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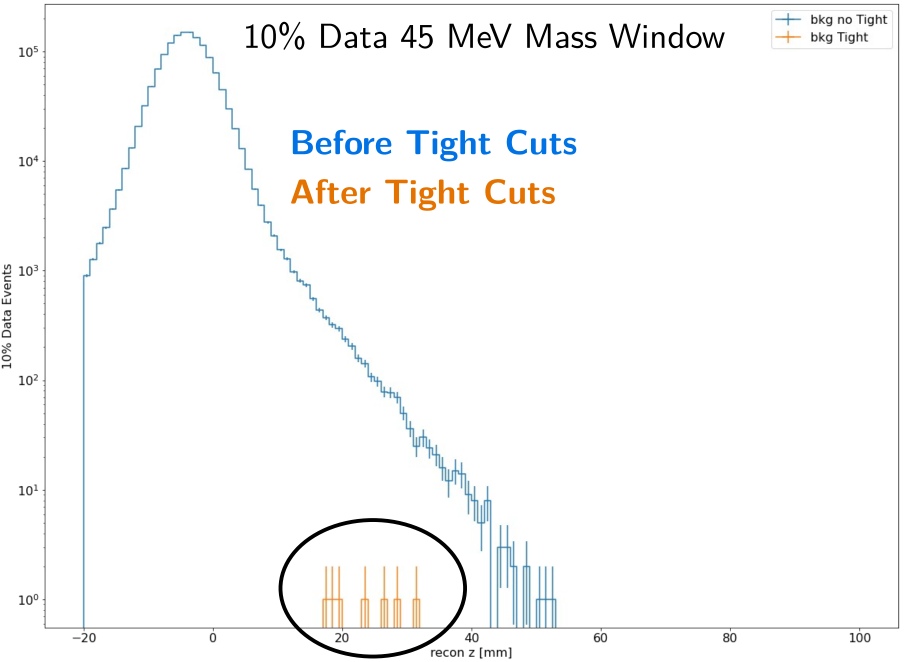
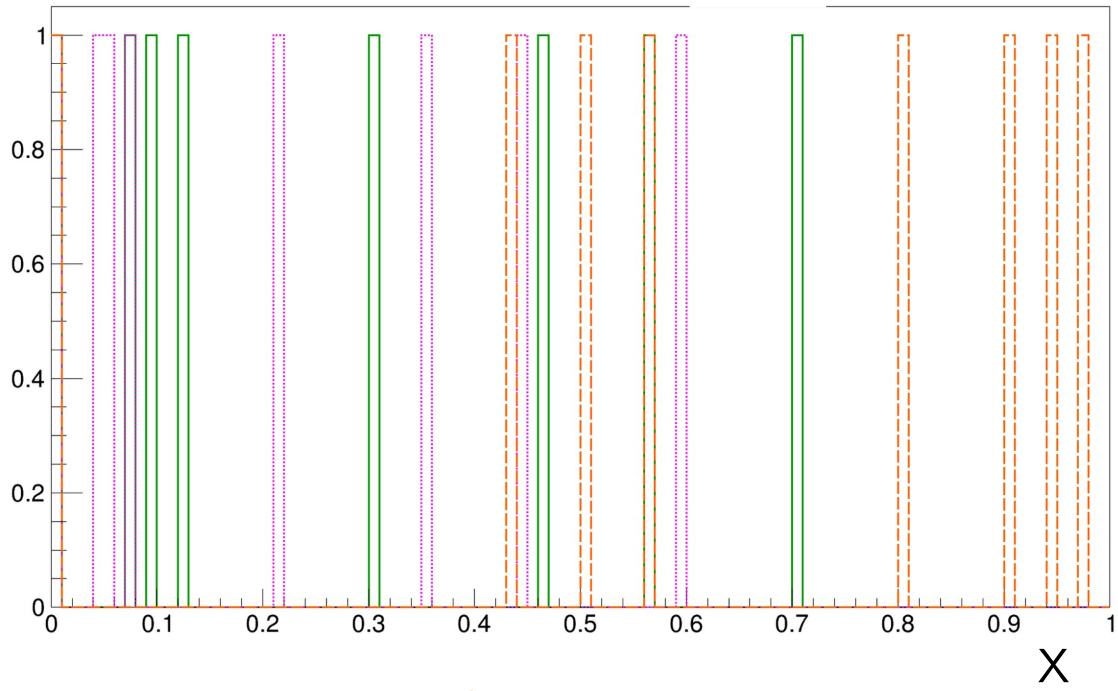




Transform Data F(z) to normalized uniform distribution for ε

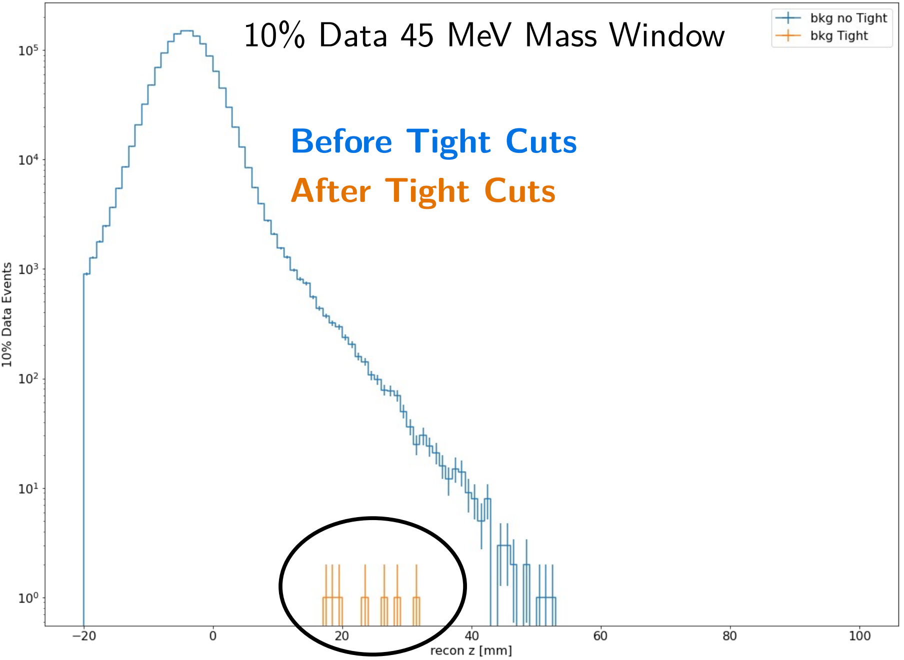
$\varepsilon^2 = 4.347e^{-5}$

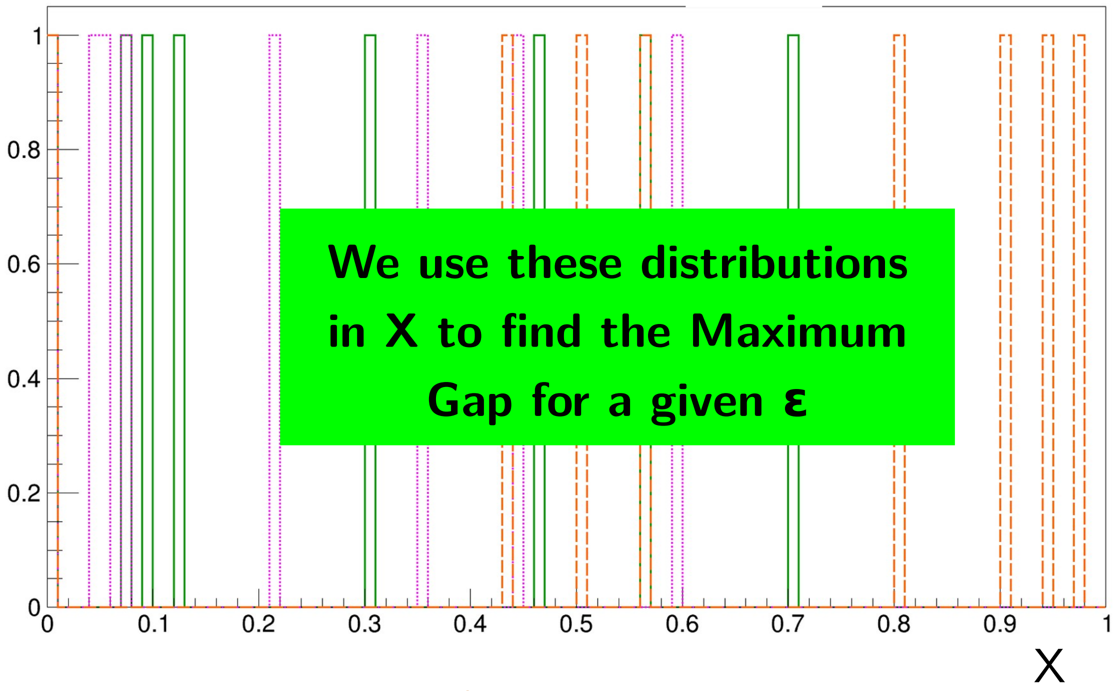
$\varepsilon^2 = 6.826e^{-6}$

$\varepsilon^2 = 9.548e^{-7}$

SIMP 10% Data Transformation

$$X = \int_{z_{tar}}^{\infty} F(z,\varepsilon)_{\rho+\Phi}\, dz \;-\; \int_{vtx_z}^{\infty} F(z,\varepsilon)_{\rho+\Phi}\, dz$$





Transform Data F(z) to normalized uniform distribution for ε →

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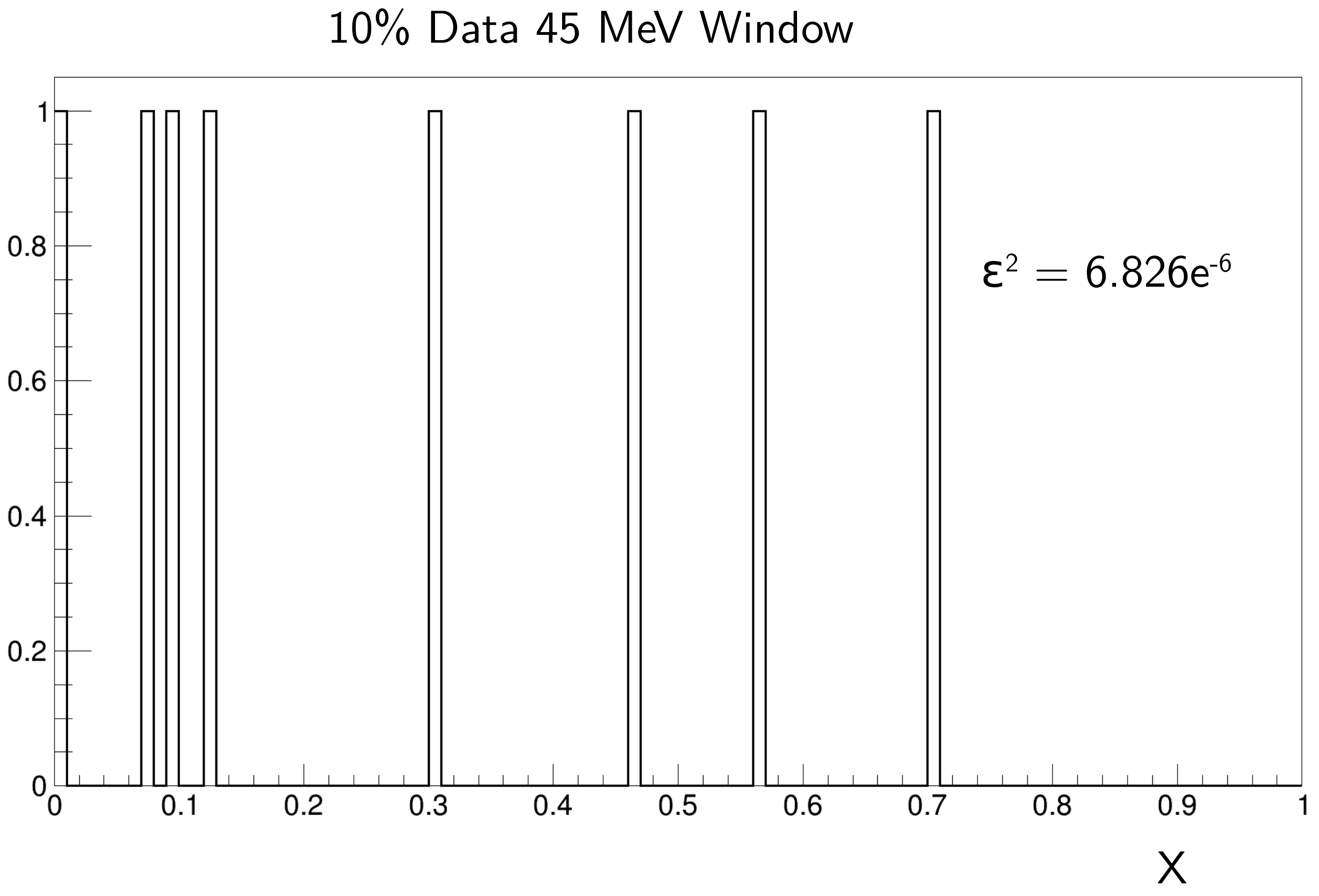
Finding a 90% Upper Limit

Maximum Gaps in Data



Get maximum gap $\Delta X(k)_{max}$ for all possible values of k

Loop through range of mean expected signal μ

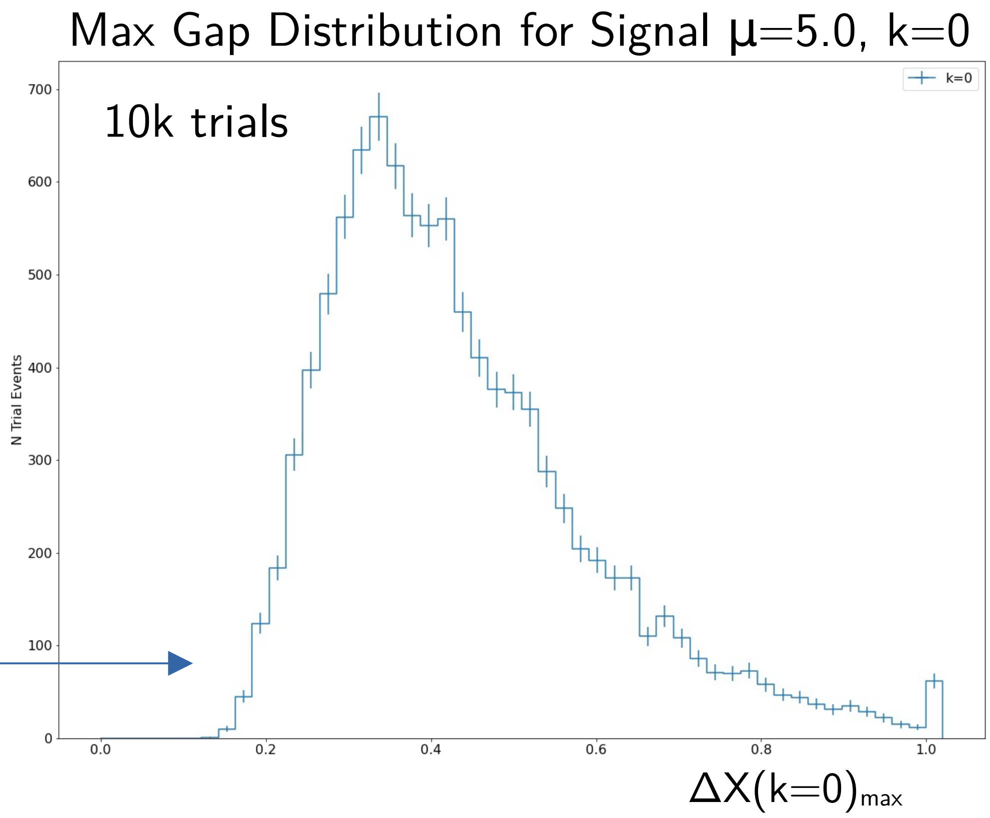
For each μ and k, how extreme is $\Delta X(k)_{max}$?

How do we check extremeness? Use a toy MC generated lookup table...

Toy MC Lookup Table

- Generate lookup table using toy MC in python
- **Assume signal with mean μ is true, what does the distribution of Max Gaps look like?**
- For Expected Signal mean μ
  - **Generate n trials** of
    - m events (**from Poisson with mean μ**)
    - **random uniform samples between 0-1**
  - For each trial, **get $\Delta X(k)_{max}$ for all possible k**

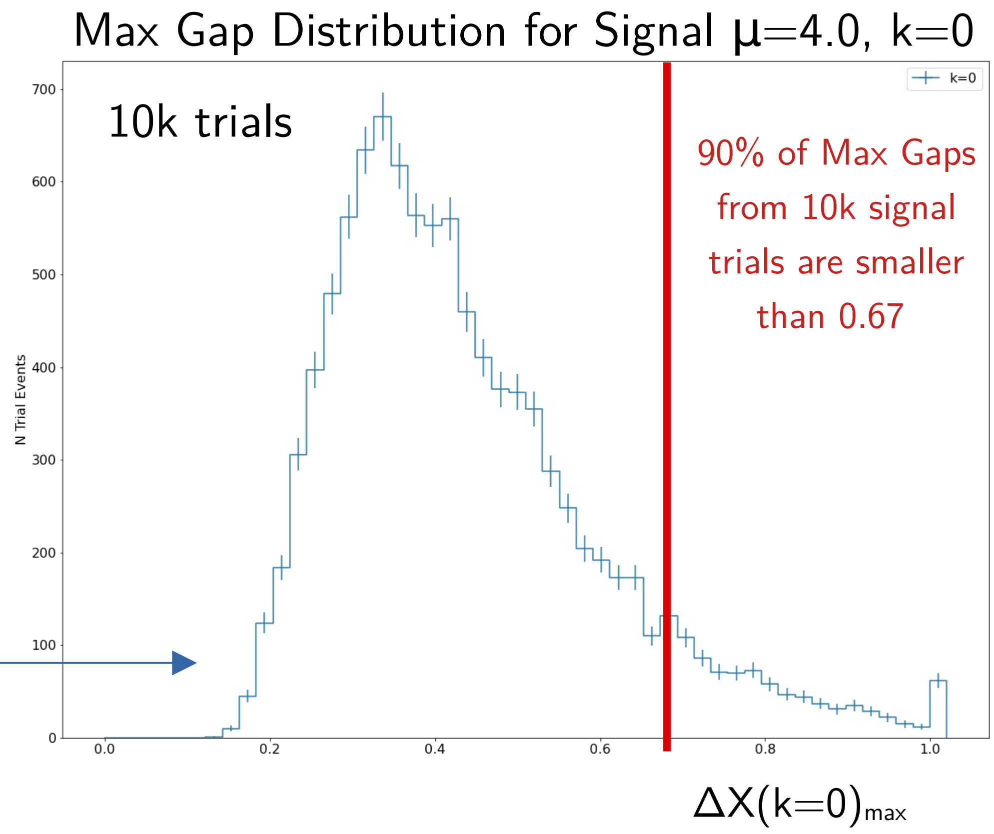
- Build the Max Gap distribution for mean μ, with k events allowed in gap



Toy MC Lookup Table

- Generate lookup table using toy MC in python
- **Assume signal with mean μ is true, what does the distribution of Max Gaps look like?**
- For Expected Signal mean μ
  - **Generate n trials** of
    - m events (**from Poisson with mean μ**)
    - **random uniform samples between 0-1**
  - For each trial, **get $\Delta X(k)_{max}$ for all possible k**

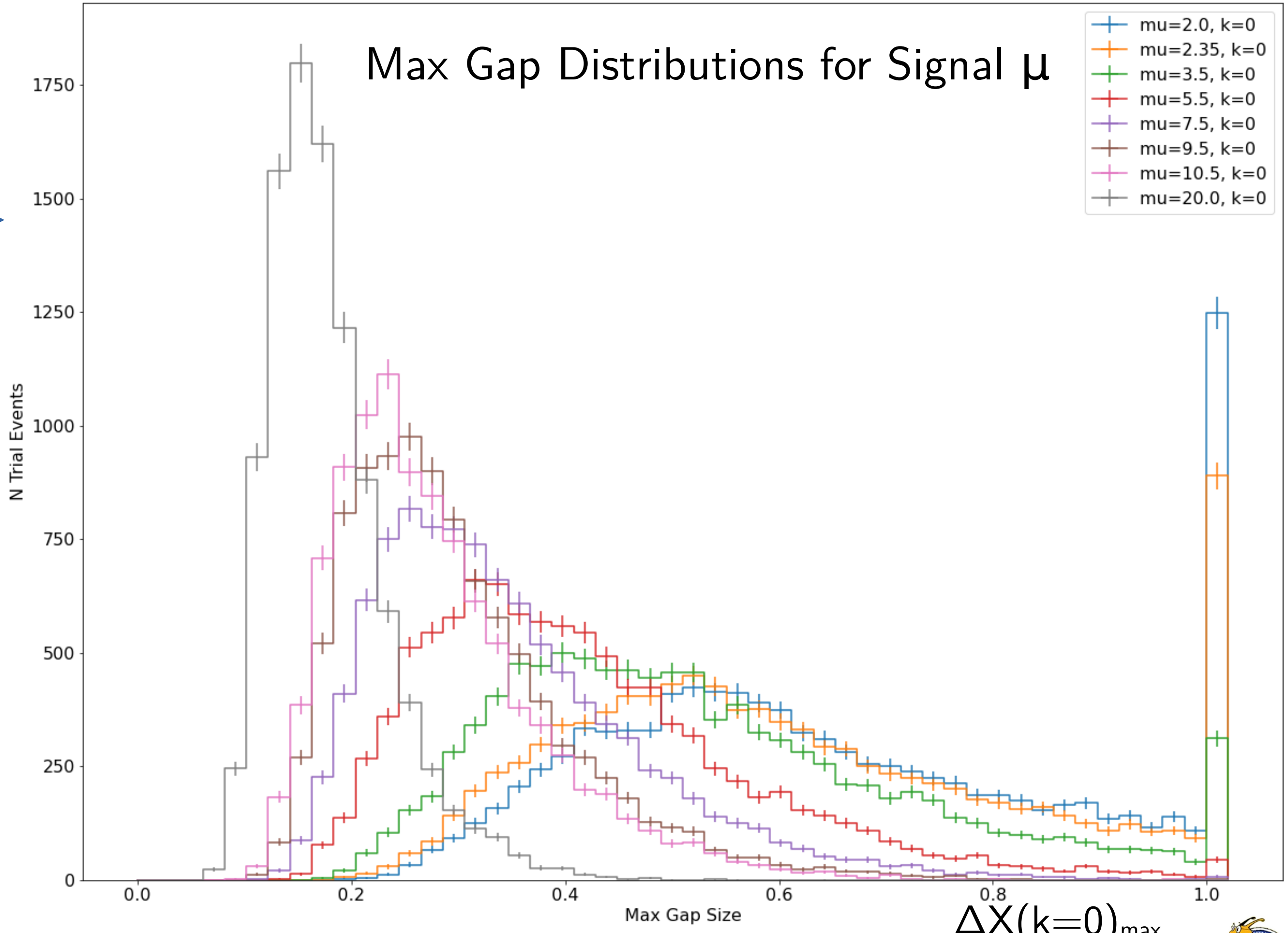
- Build the Max Gap distribution for mean μ, with k events allowed in gap
- **If Max Gap in Data falls outside 90% of this distribution, exclude μ with 90% confidence**



Toy MC Lookup Table

- **For fixed value of k**
- **Max Gap distribution for each expected signal mean μ** →
- Larger μ is more peaked
- Eventually, large enough μ can be excluded with 90% confidence, given the observed Max Gap in data

  *Unless there's so much data that the Max Gap size is too small…but then we can make the gaps larger with k…



$\Delta X(k=0)_{max}$

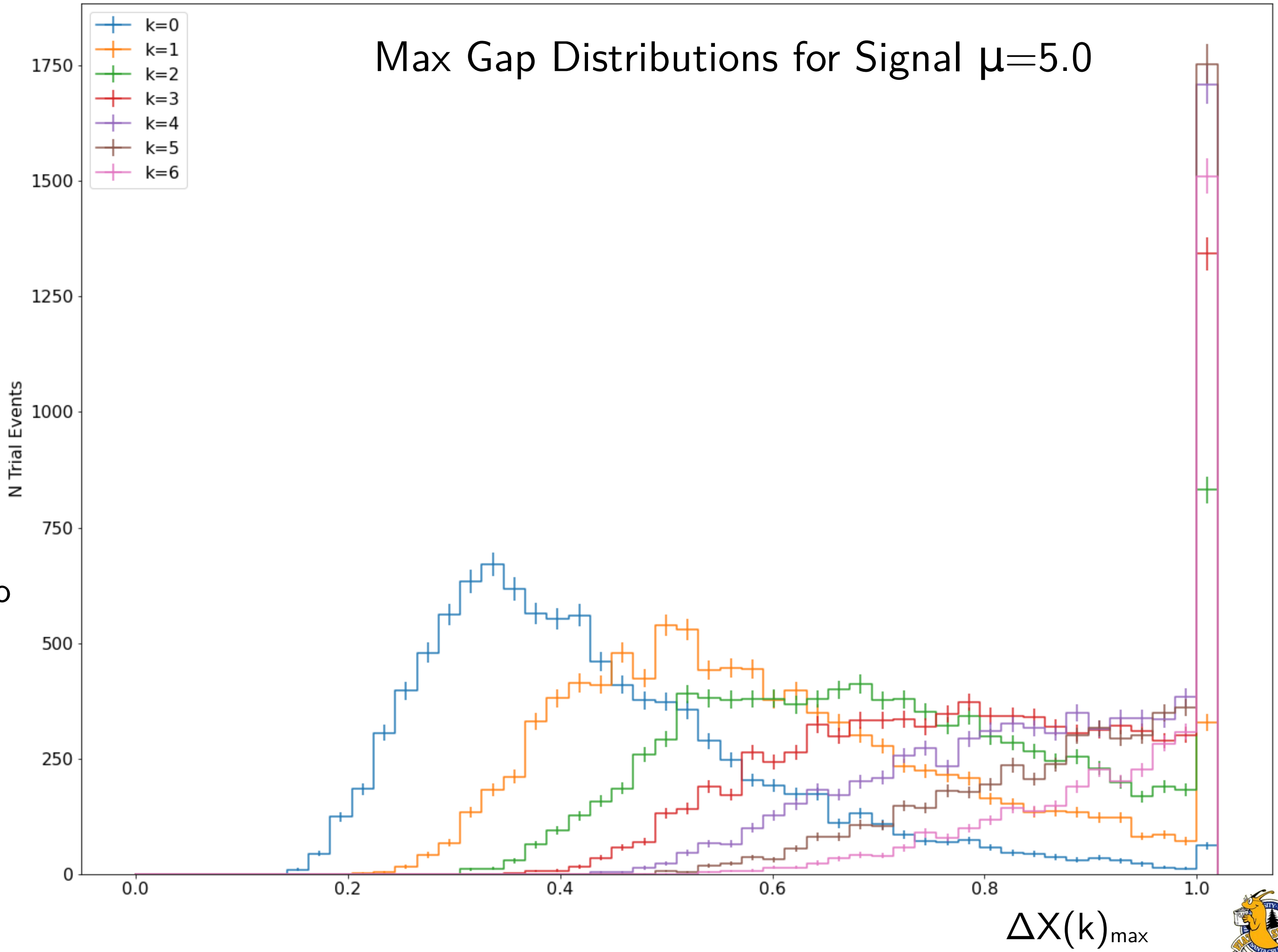
Toy MC Lookup Table

- **For fixed value of μ**

- **Get a different Max Gap distribution for every k events allowed in gap**

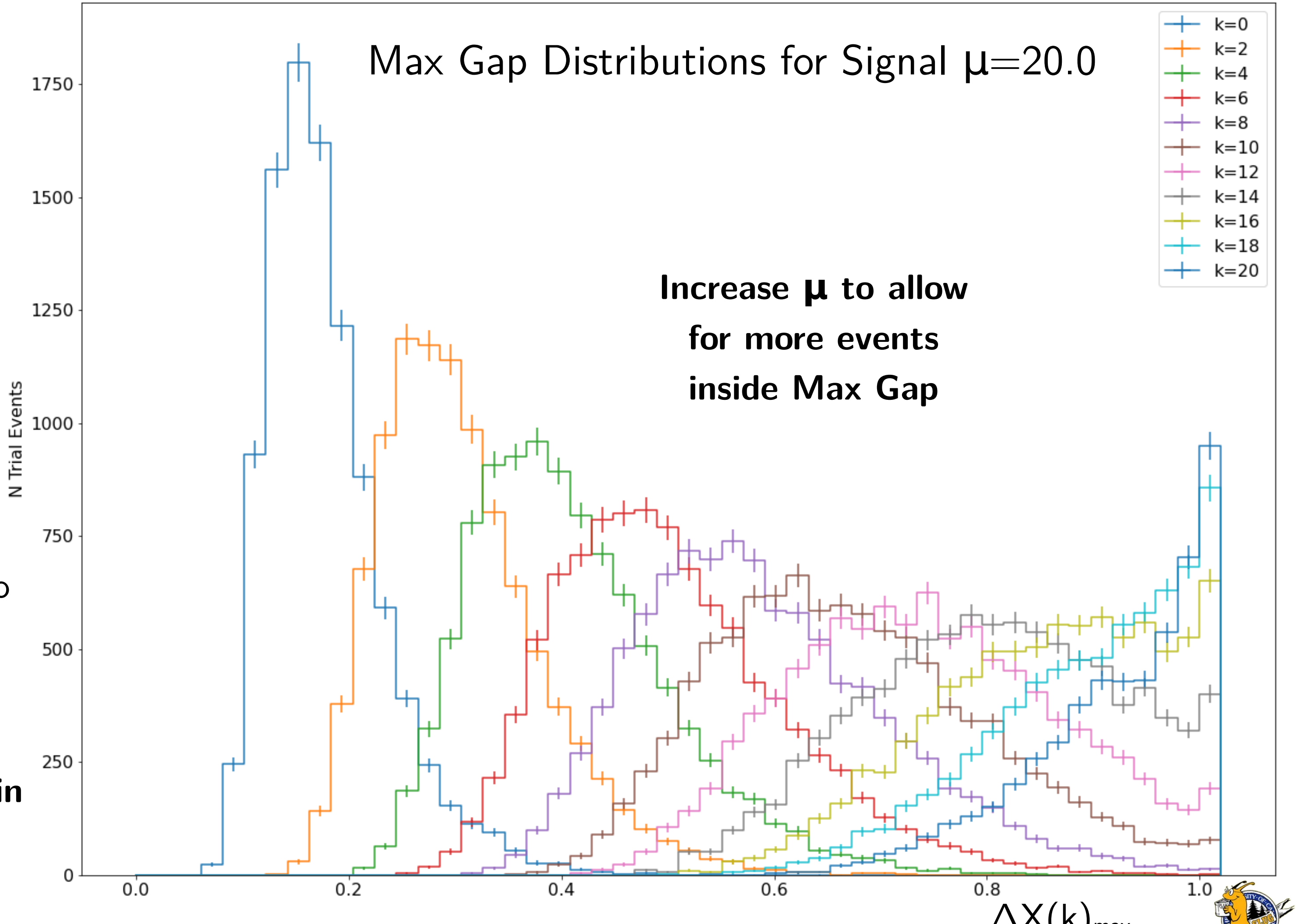
- Allowing more k gives us larger gap sizes to work with

- Eventually, for a given μ, k is too large to ever exclude at 90%

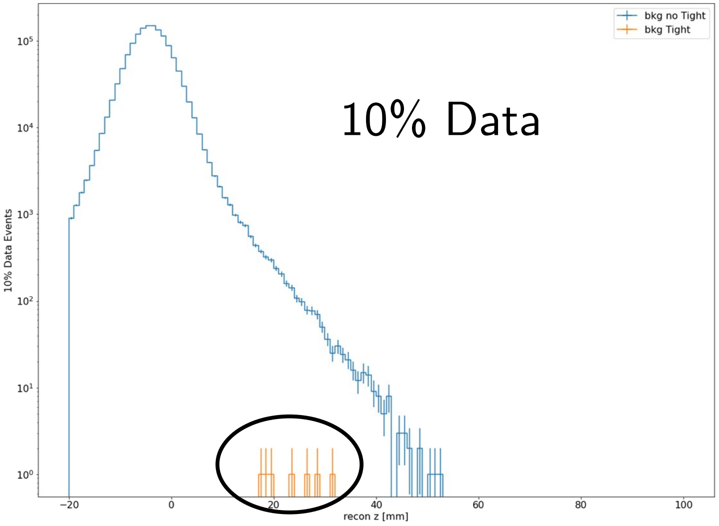


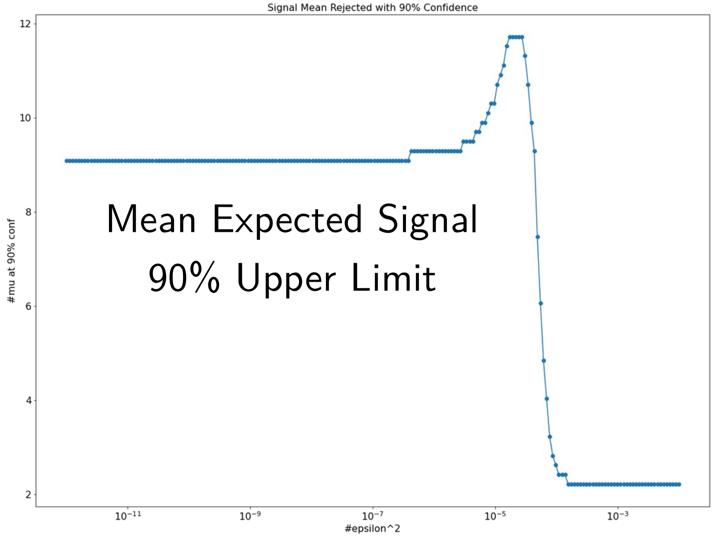
Toy MC Lookup Table

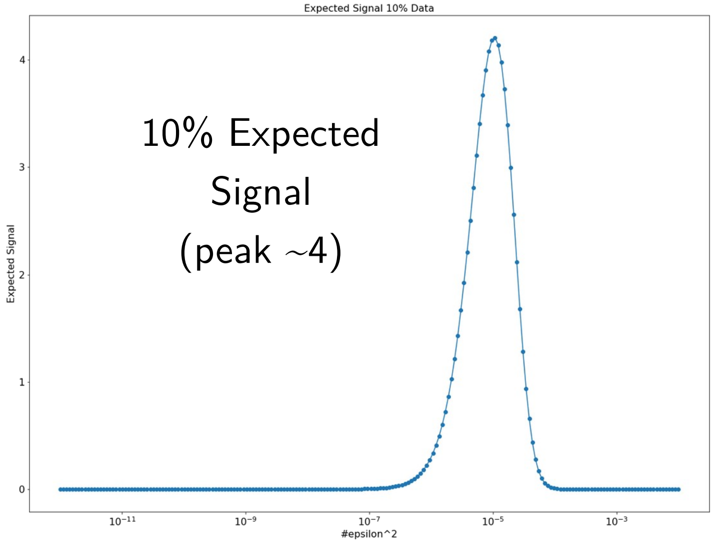
- **For fixed value of μ**
- **Get a different Max Gap distribution for every k events allowed in gap**
- Allowing more k gives us larger gap sizes to work with
- Eventually, for a given μ, k is too large to ever exclude at 90%
- **Increasing μ allows 90% exclusion with more events k in gap**

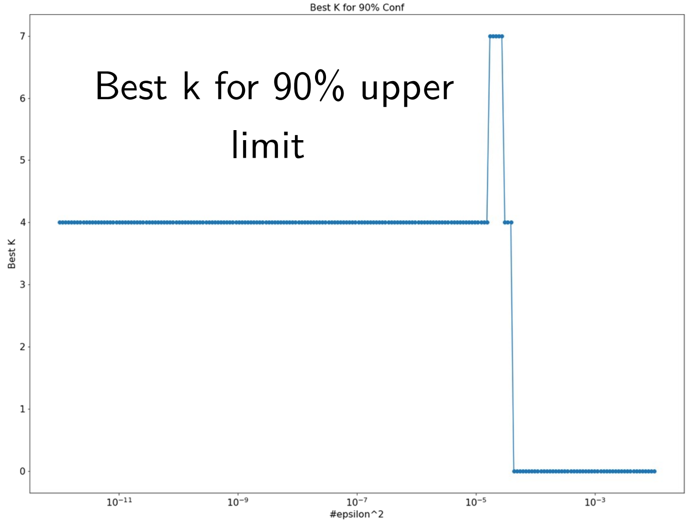


Example Result: 45 MeV 10% Data



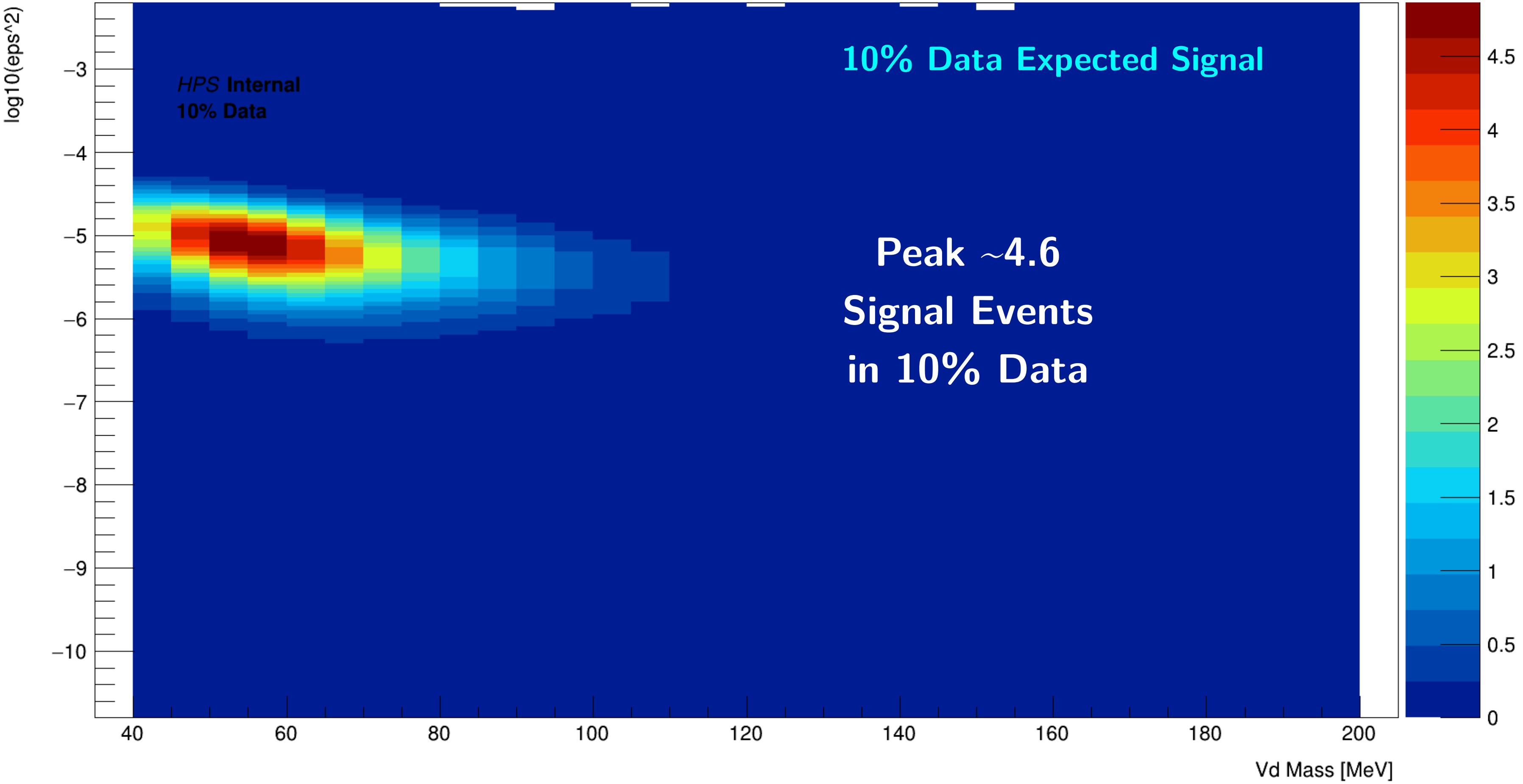




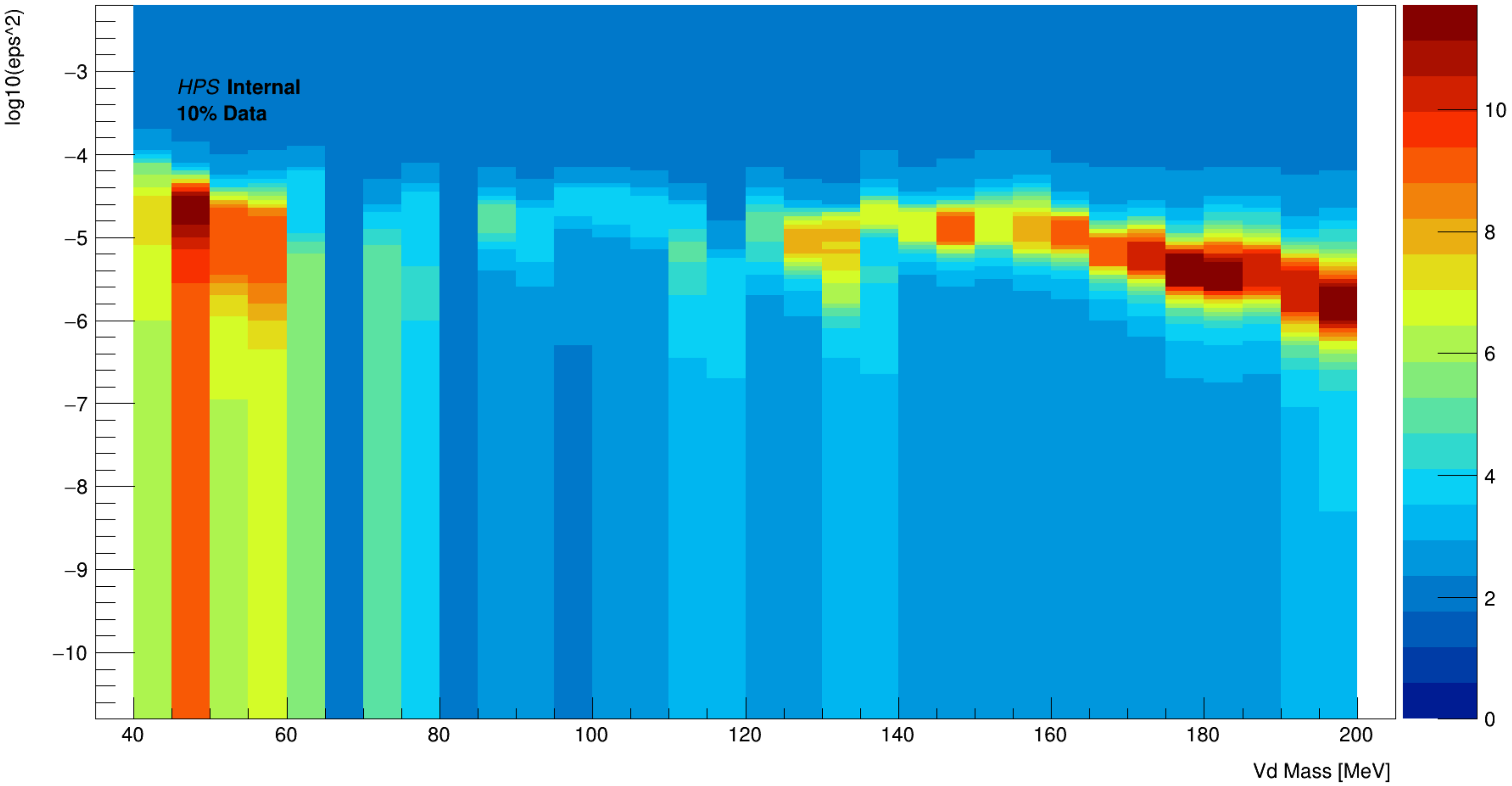


10% Data 90% Upper Limit Results
All Masses

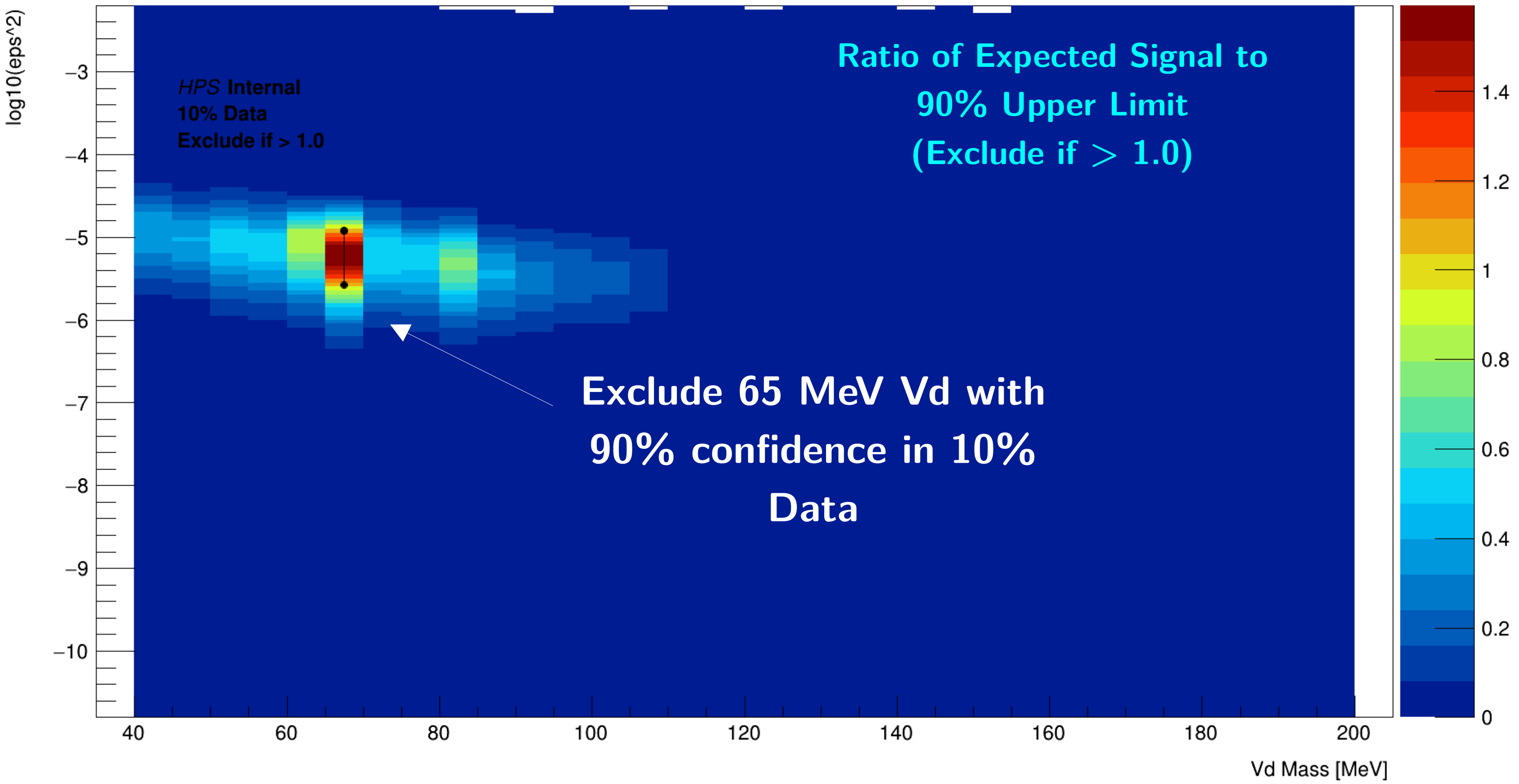
10% Data – Expected Signal



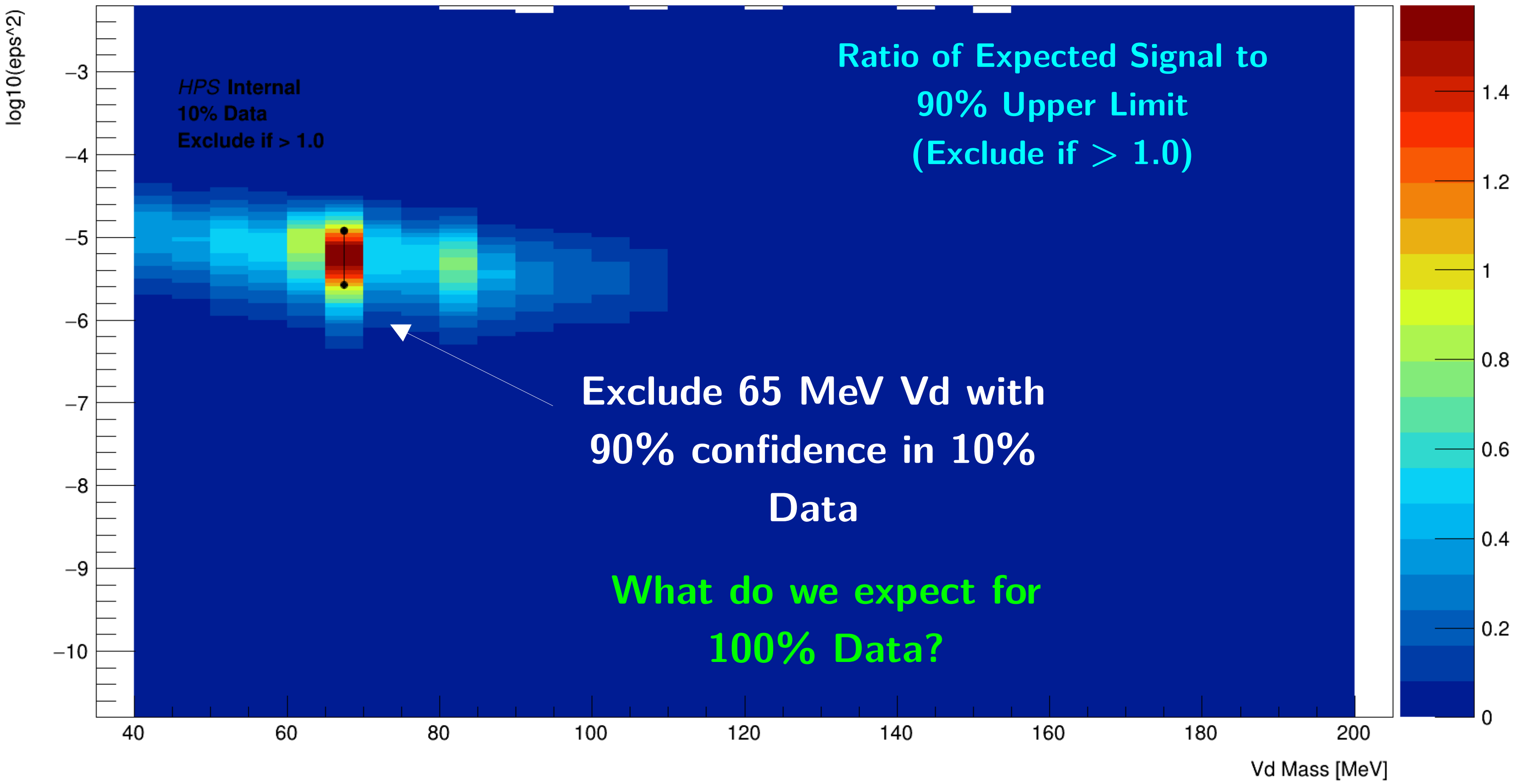
10% Data – Expected Signal 90% Upper Limit



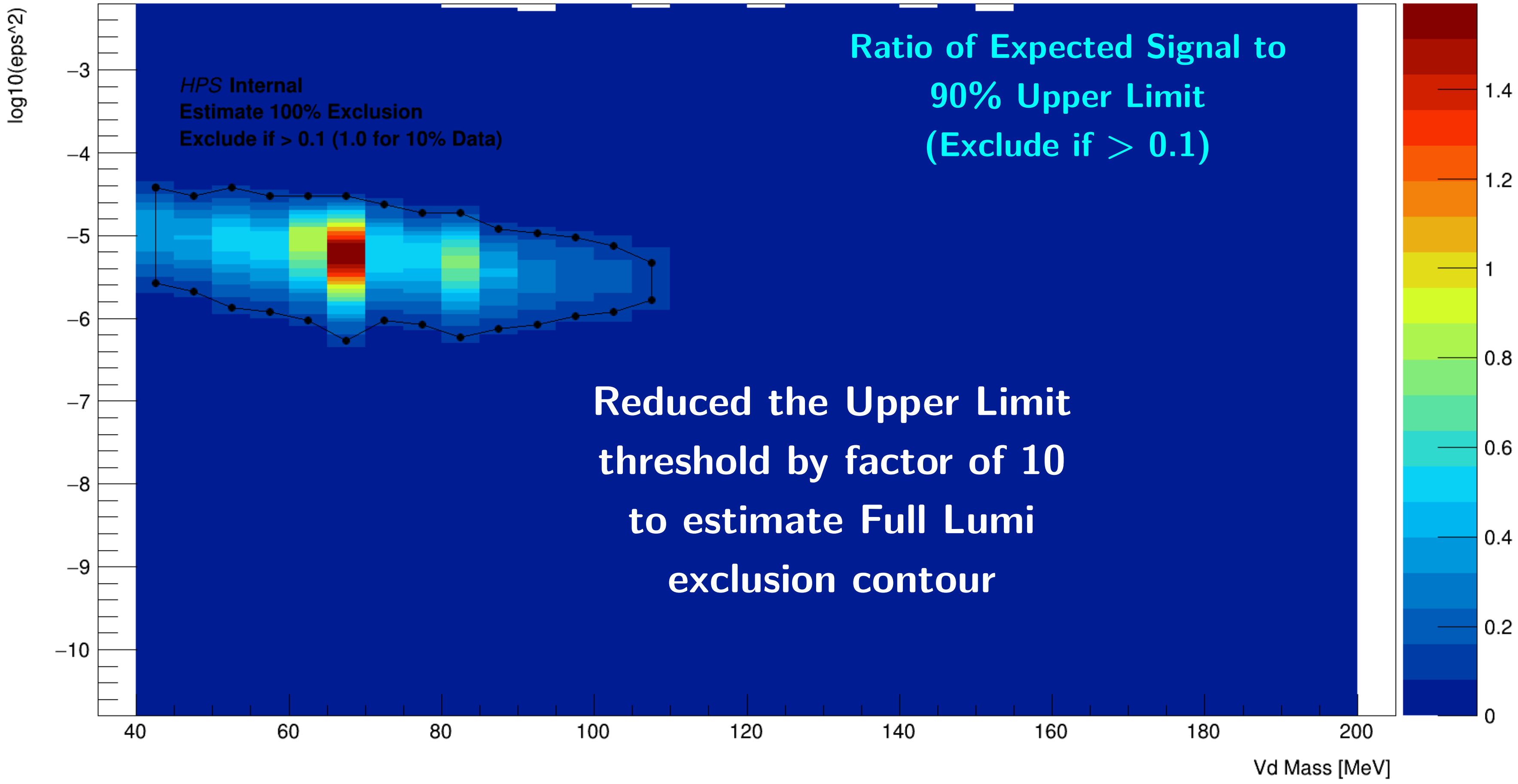
10% Data – 90% Exclusion Contour



10% Data – 90% Exclusion Contour

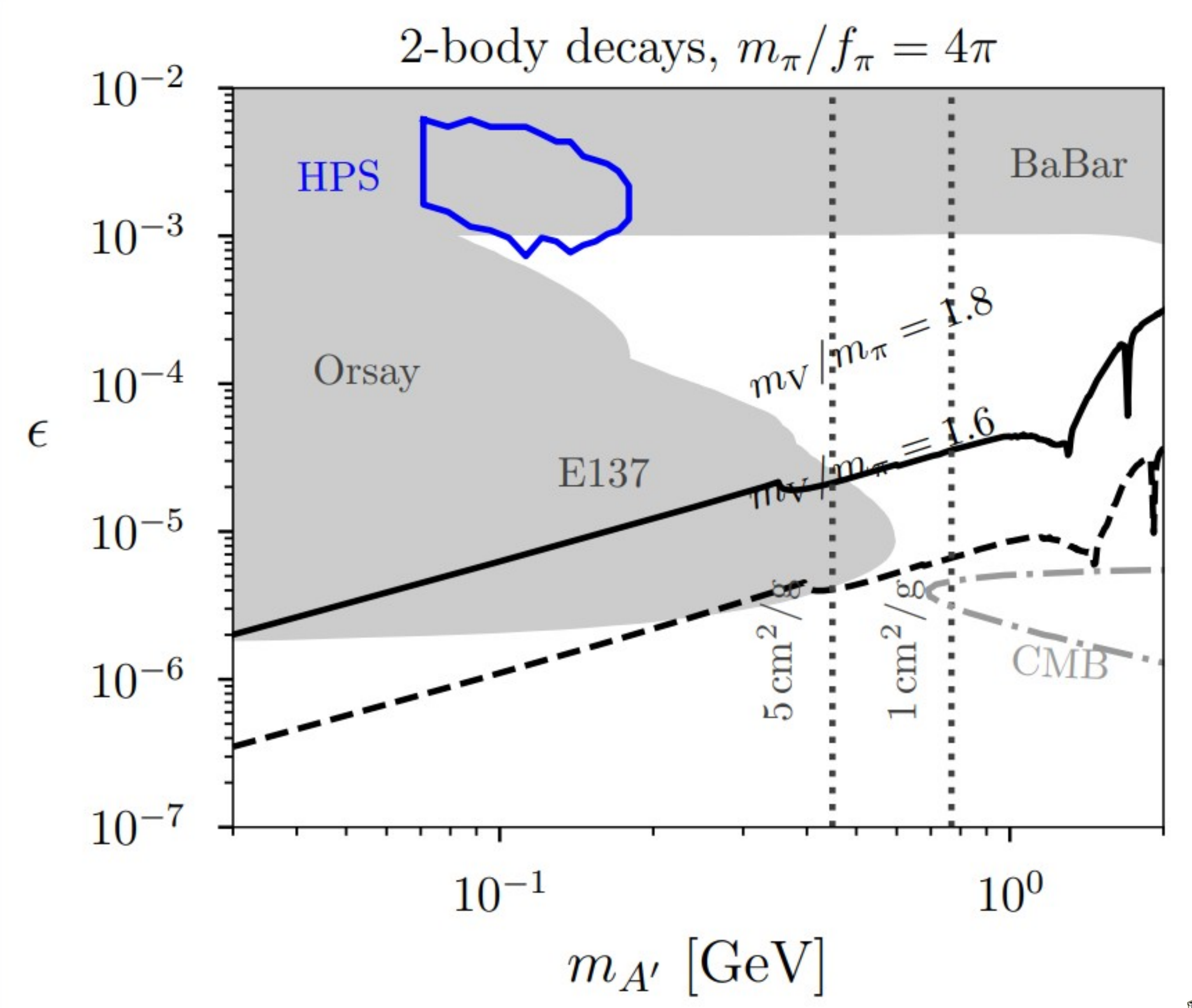


Full Lumi Estimate – 90% Exclusion Contour



Full Lumi Estimate – 90% Exclusion Contour

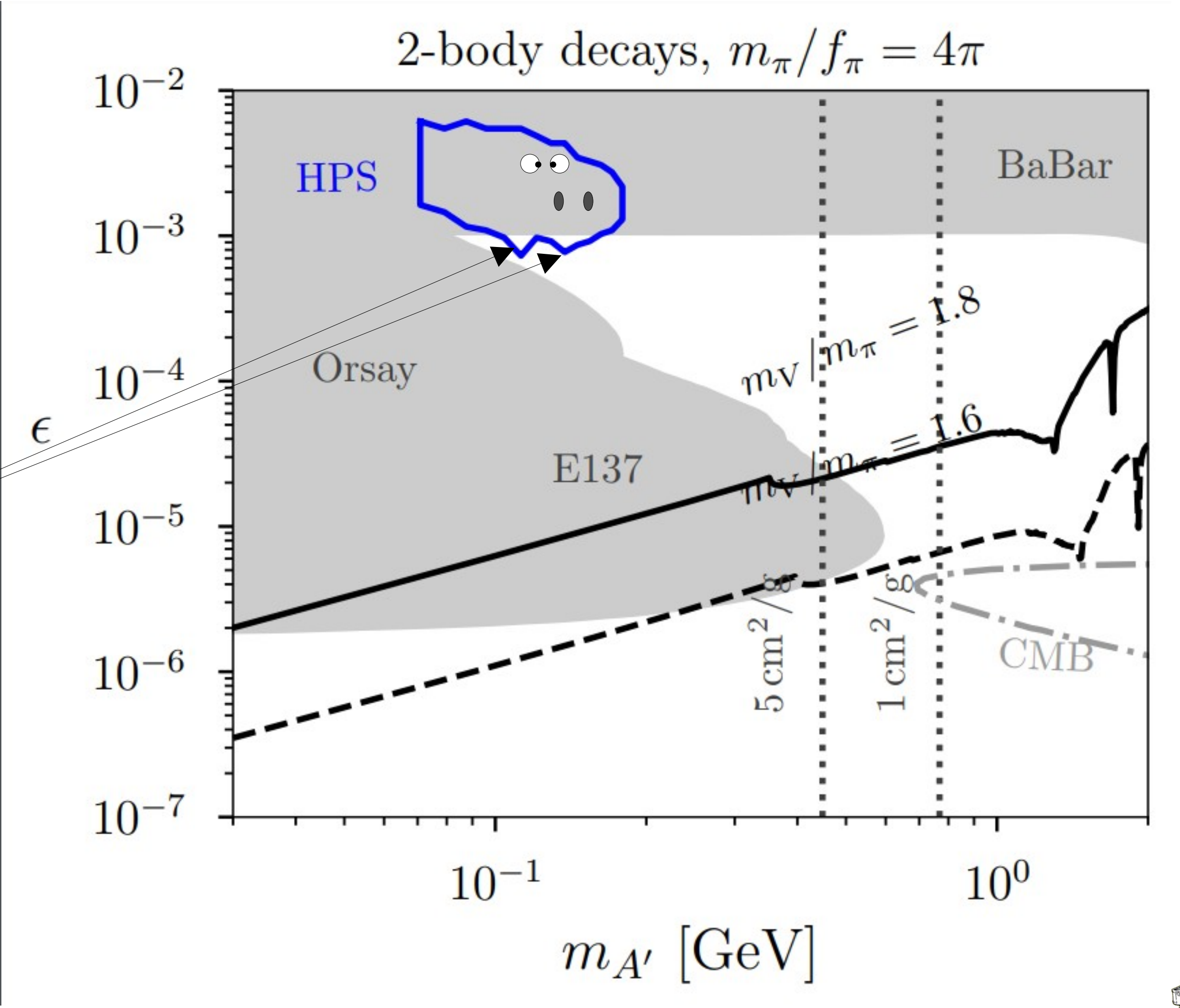
Estimated 90% Exclusion Contour for Full Luminosity, using 10% Data



Full Lumi Estimate – 90% Exclusion Contour

Estimated 90% Exclusion Contour for Full Luminosity, using 10% Data

Snake-bite into new territory



Summary and Conclusion

- **Optimum Interval Method ready to roll *probably**
  - Increase lookup table stats, μ resolution
- With new analysis technique (|z0| cut instead of z cut), **10% Data not actually blind…**
  - Set 90% upper limit* on 65 MeV Dark Vectors for a decent range of ε^2
  - ***NO MC Momentum smearing or hit killing here yet!**
- Need to convert mean expected signal to limit on cross-section as done in 2016

Next Steps

- Higher stats SIMP MC at 1 MeV intervals coming soon, will have hit killing and smearing
- **Want one more pass at Tight cut value optimization with 100% Data in CR, and 100% Data in SR above 130 MeV** (well beyond sensitivity)
- **Awaiting approval**…will use the better MC then