Simps at HPS

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Matt Solt

Introduction

HPS has potentially sensitivity to Strongly Interacting Massive Particles (Simps)

Simps are part of a hidden SU(3) sector motivated by “Simp Cosmology”

Preliminary Simp reach plots for 2016 running presented as well as future work

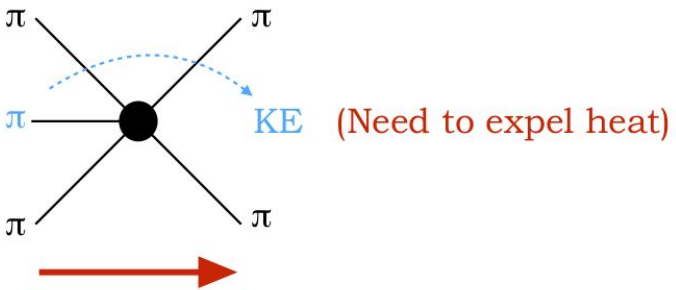
Instructions on simp reach and intermediate plots

Old Simp Talk and New Simp Paper!

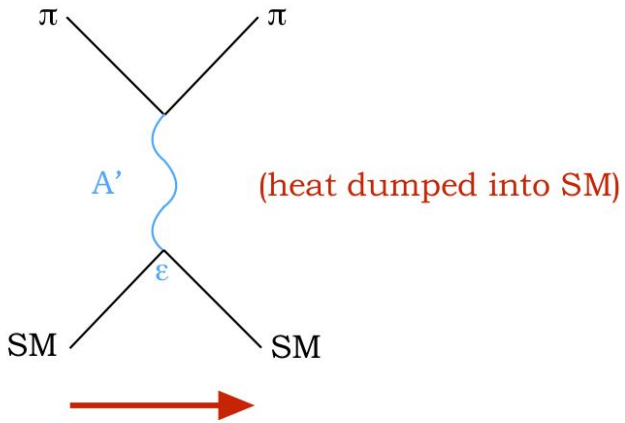
Simp Cosmology

Dark matter is composed of a dark pion that undergoes a 3 -> 2 mechanism

Wimp Miracle mχ ~ 100 GeV; **Simp Miracle mχ ~ 0.01 - 0.1 GeV**



$$m_\pi \sim \alpha_\chi \left(T_{\rm eq}^2 m_{\rm pl}\right)^{1/3} \sim \alpha_\chi \times 1\ {\rm GeV}$$

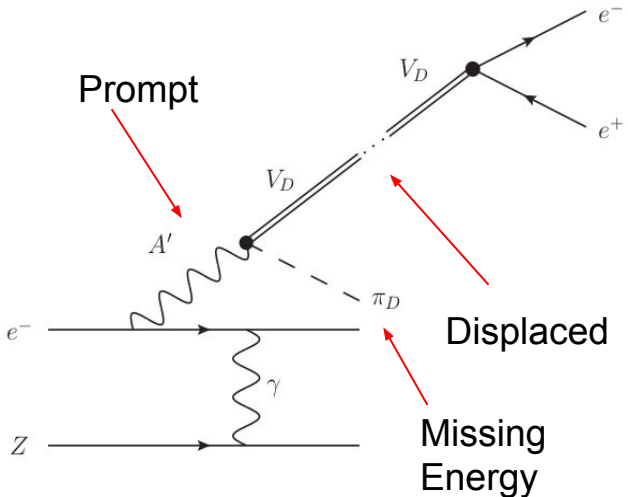


Simps at HPS

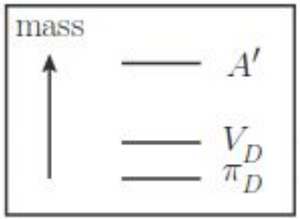
Prompt A', Displaced dark V, and Missing Energy π

Same A' kinematics and cross sections as minimal model

Produce high rate of A's (large ε), displaced dark V



Assume Mass Hierarchy



Simp Model Parameters

Simp model is a 6 parameter model;

$m_{A'}$

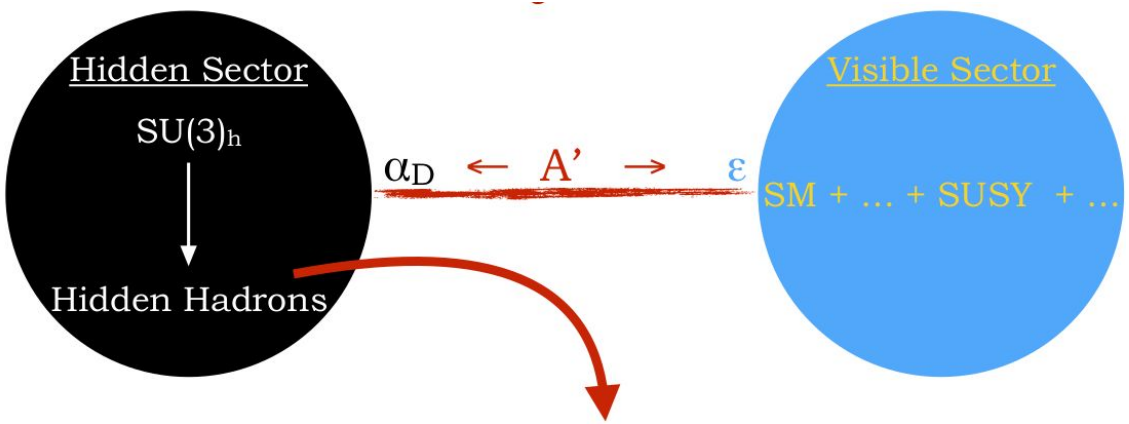
m_V (mass of dark vector)

m_π (mass of dark pion)

ε

α_D (dark coupling constant)

m_π/f_π (dark pion decay constant)



pions "π" $\equiv \pi^0$, η^0 , K^0 , $\overline{K^0}$, $\pi^\pm$, $K^\pm$

vector mesons "V" $\equiv \rho^0$, ω , ϕ , K^{*0} , $\overline{K^{*0}}$, $\rho^\pm$, $K^{*\pm}$

Theoretical Constraints

$\alpha_D < 1$ (by perturbativity); theorists like $\alpha_D \sim 0.01$ but I loosen this assumption

$\varepsilon < 10^{-2}$ (suppresses reactions in early universe)

$\epsilon \gtrsim 10^{-6.3}(m_{A'}/10^{-2}\mathrm{GeV})^{1/2}$ (for $\alpha_D = 10^{-2}$, $m_{A'} = 3m_{\pi_D}$, $m_{V_D} = 1.8$) (Simp Cosmology)

$m_\pi/f_\pi < 4\pi$ (by perturbativity); $m_\pi/f_\pi \sim 3$ - 4 for a wide range of masses

$m_{V_D}/m_{\pi_D} \sim \frac{4\pi}{\sqrt{N_c}(m_{\pi_D}/f_{\pi_D})}$ (from EFT), $N_C = 3$ (number of colors in dark QCD)

Mass hierarchy: $m_{A'} > 2m_\pi$ (Simp Cosmology);

$m_V < 2m_\pi$ and $m_V + m_\pi < m_{A'}$ (HPS visible)

Decay Widths of Interest

$$\Gamma(A' \to \pi_D \pi_D) = \frac{2\alpha_D}{3} m_{A'} \left(1 - \frac{4m_{\pi_D}^2}{m_{A'}^2}\right)^{3/2} \left(\frac{m_{V_D}^2}{m_{A'}^2 - m_{V_D}^2}\right)^2$$

Not detectable by HPS

$$\Gamma(A' \to V_D \pi_D) = \frac{\alpha_D T_V}{192\pi^4} \left(\frac{m_{A'}}{m_{\pi_D}}\right)^2 \left(\frac{m_{V_D}}{m_{\pi_D}}\right)^2 \left(\frac{m_{\pi_D}}{f_{\pi_D}}\right)^4 m_{A'} \beta(x,y)^{3/2}$$

$$T_V = \begin{cases} 3/4 & \rho_D \\ 3/2 & \phi_D \\ 18 & \text{total} \end{cases}$$

Detectable by HPS
(focus of this talk)

where $x = m_{\pi_D}/m_{A'}$, $y = m_{V_D}/m_{A'}$ and

$$\beta(x,y) = \left(1 + y^2 - x^2 - 2y\right)\left(1 + y^2 - x^2 + 2y\right).$$

$$\Gamma(A' \to V_D V_D) = \frac{\alpha_D}{6} f(r) m_{A'},$$

where $r = m_{V_D}/m_{A'}$ and

$$f(r) = \left(\frac{1 + 16r^2 - 68r^4 - 48r^6}{(1 - r^2)^2}\right)\sqrt{1 - 4r^2}$$

Potentially detectable by HPS
(to be explored in the future)

Plus the usual A' -> e+e- decay width. Included but very small effect

Simp Model Parameters

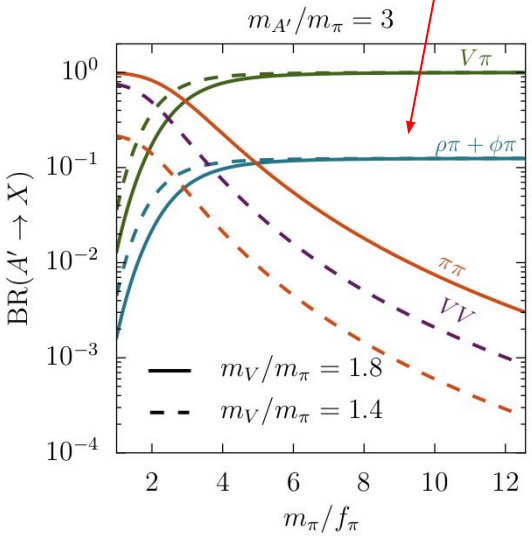
A' rate $\propto \varepsilon^2$; Branching ratio ~ 0.1

$\Gamma(V \to e^+e^-) \propto \varepsilon^2 \alpha_D f_\pi^2$

Tweaking these 3 parameters can dramatically change cτ values!

$$\Gamma(V_D \to \ell^+\ell^-) = \frac{16\pi\alpha_D\alpha\epsilon^2 f_{\pi_D}^2}{3m_{V_D}^2}\left(\frac{m_{V_D}^2}{m_{A'}^2 - m_{V_D}^2}\right)^2 \sqrt{1-\frac{4m_\ell^2}{m_{V_D}^2}}\left(1+\frac{2m_\ell^2}{m_{V_D}^2}\right) m_{V_D} \times \begin{cases} 2 & \rho_D \\ 1 & \phi_D \end{cases}.$$

BR of interest



Parameter Ranges and Assumptions

Fixed Mass ratios - $m_{A'}:m_V:m_\pi = 3:1.8:1$

Alpha_dark = 0.1, 0.01, 0.001 (0.01 is “natural”)

$m_\pi/f_\pi = 3, 4, 4\pi$

Only look at A’ -> V + π, V -> e+e-

Assume $\gamma = E_{beam} / m_V * ½$

A’ rates determined by 2016 bumphunt (Sebouh), radiative fraction assumed to be 0.15

2016 data luminosity only for L1L1 (require e+e- hits in layer 1)

Cuts

isPair1 eleHasL1 posHasL1	Event Cuts
|eleClT-posClT|<2 eleClY*posClY<0	Cluster Cuts
TrkChisq<30 |ClT-TrkT-52|<4 MatchChisq<10	Track Cuts
bscChisq<10 bscChisq-uncChisq<5 Isolation Cut	Vertex Cuts
eleP<ebeam*0.4 posP<ebeam*0.4 ebeam*0.4<uncP<ebeam*0.65	Simp Cuts

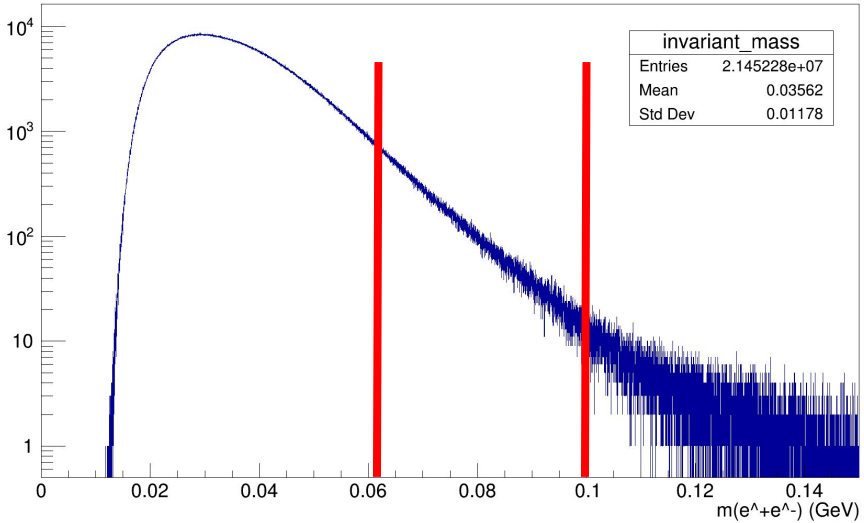
*No radiative or wab cuts, added “Simp Cuts”

Mutually exclusive backgrounds with minimal A’ model!

Rates

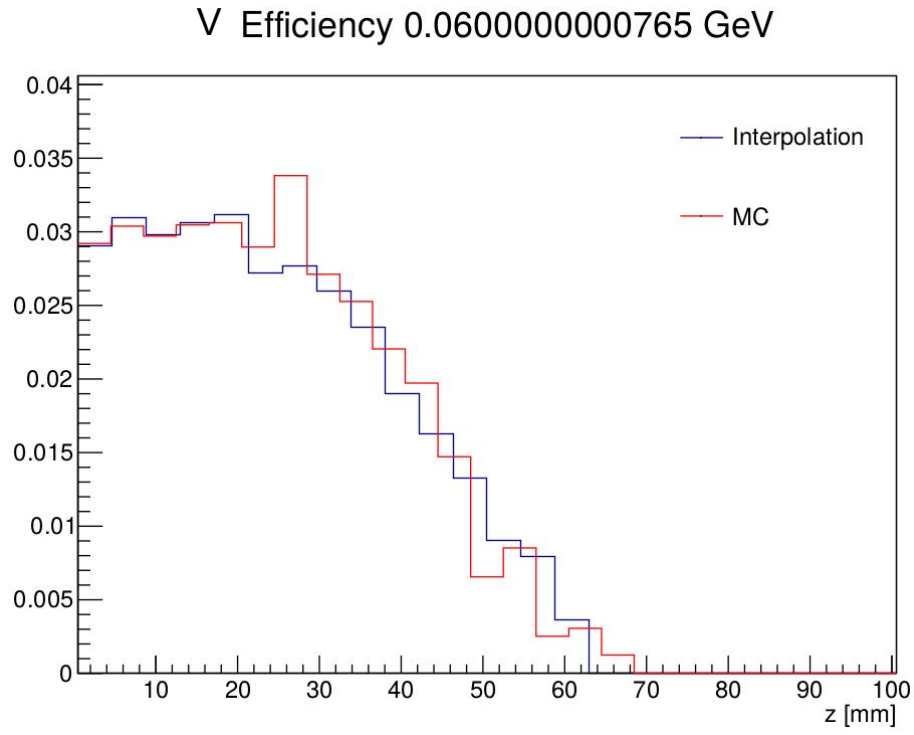
Rates for Dark Vectors and A’s cannot be normalized in the same way

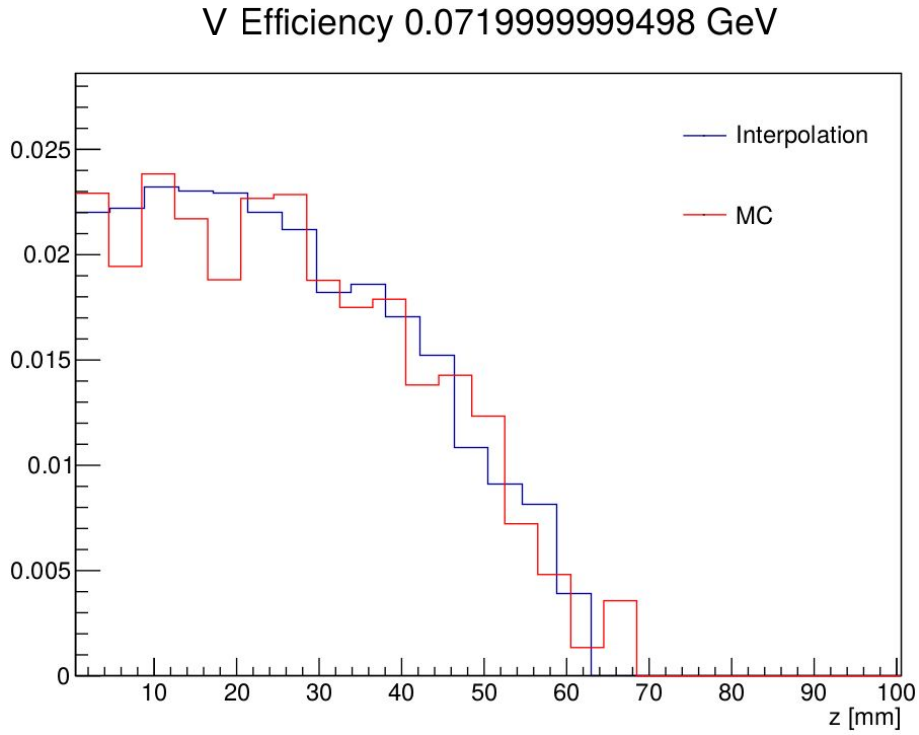
Grab prompt A’ rate from bunt hunt for a given A’ mass (Sebouh’s cuts)



Efficiency

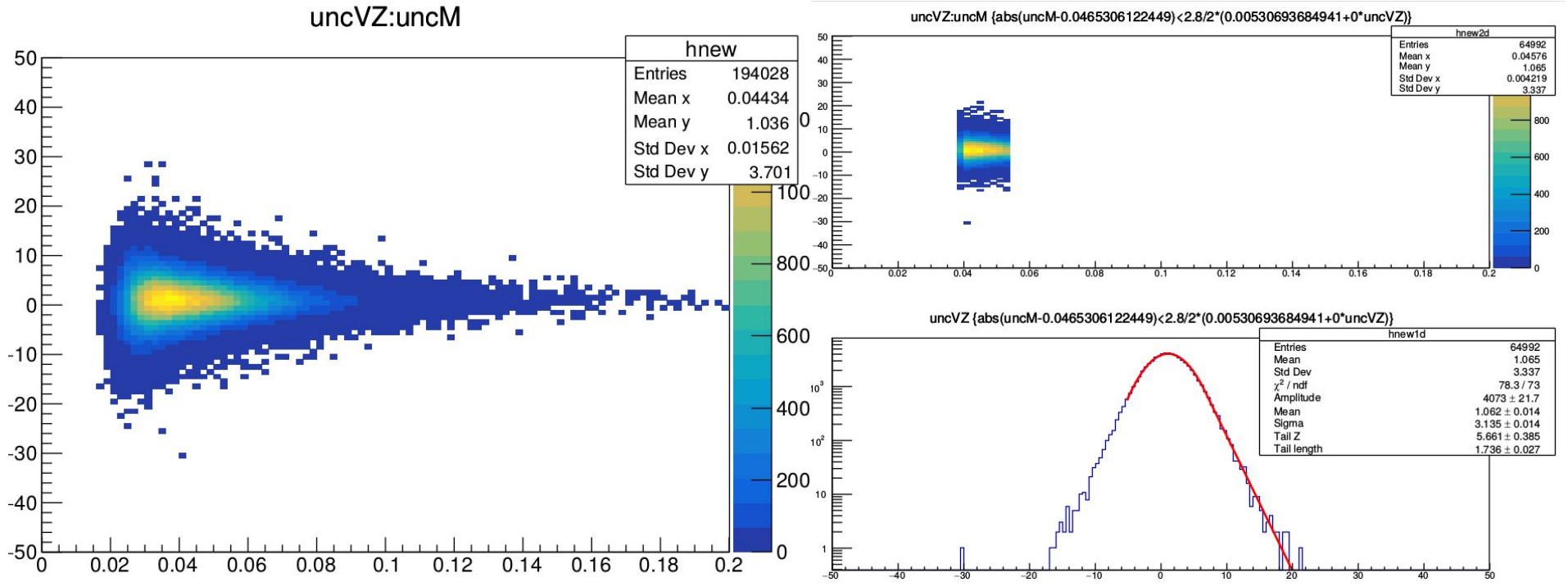
Acceptance*efficiency after all cuts (using interpolation method)





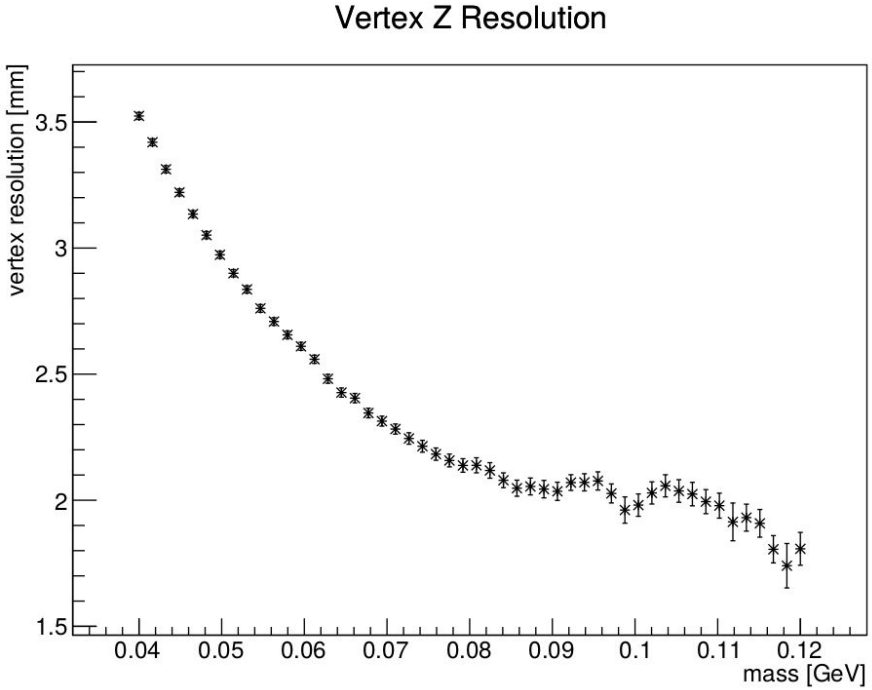
MC Backgrounds and Tail Fits

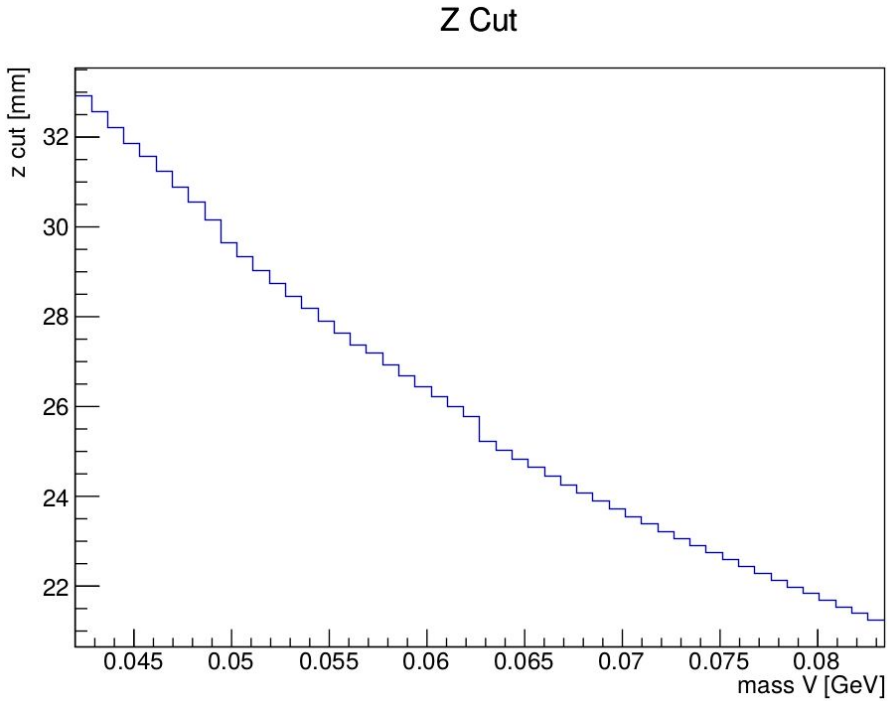
The usual method of background fit in slices of mass to determine z cuts is used



Vertex Resolution and Z Cuts

Vertex resolution and z cut scaled to 2016 luminosity



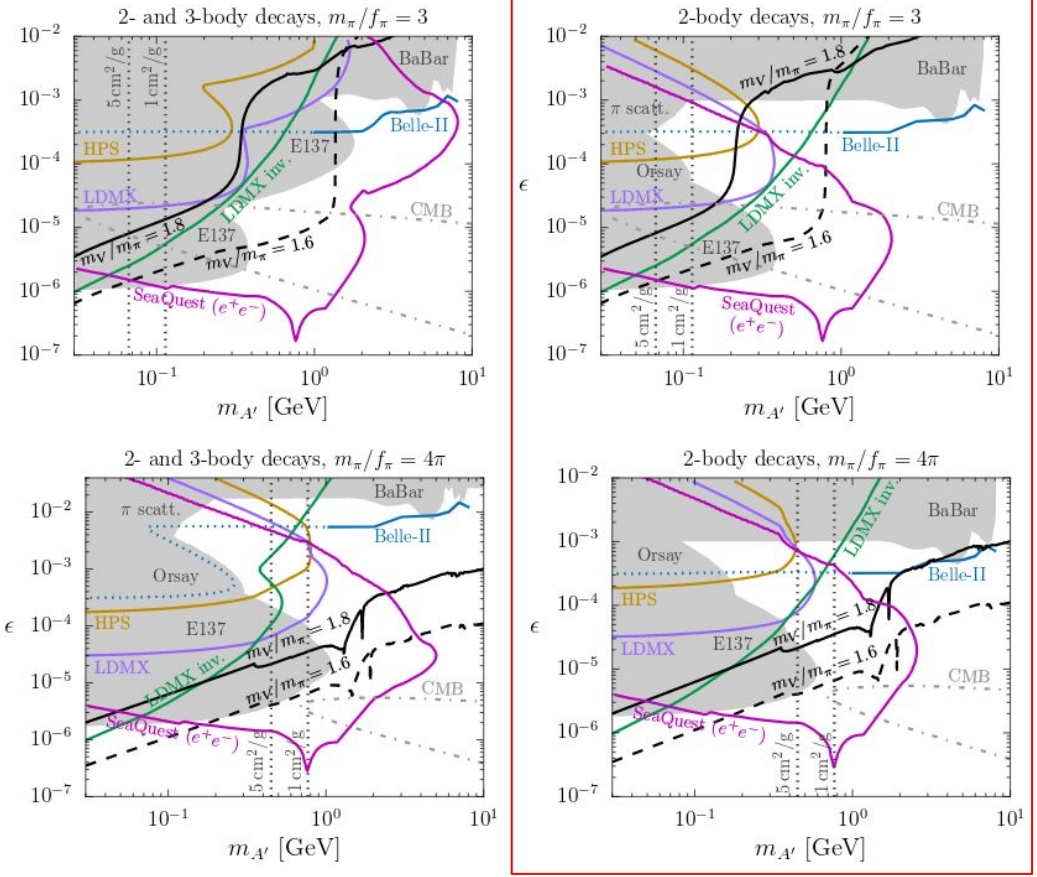


Reach from Theorists' Calculations

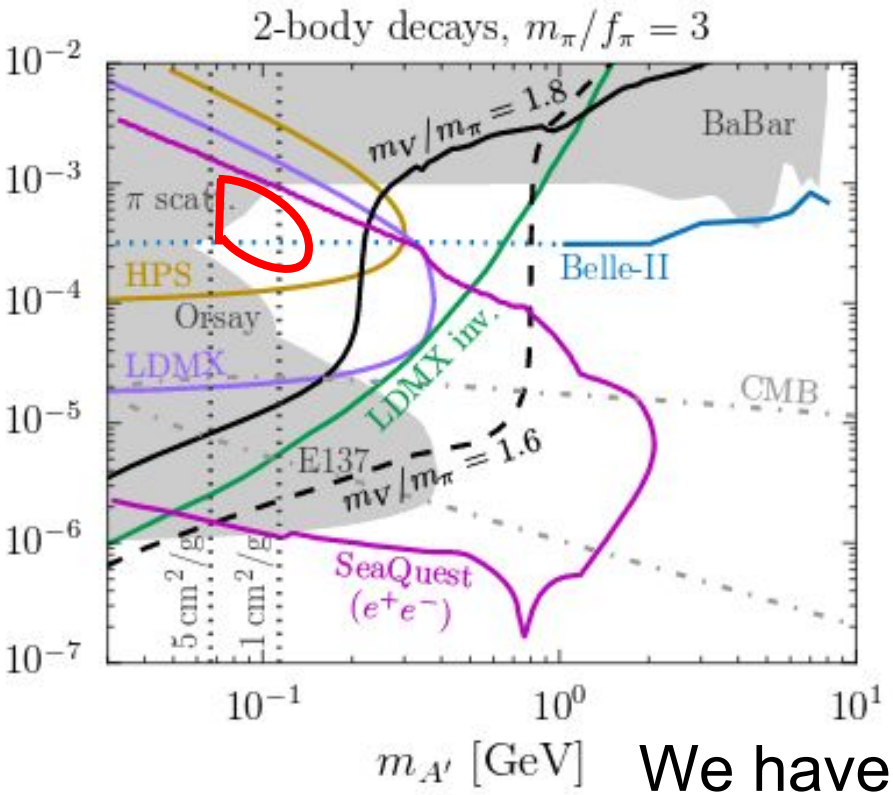
Theorists assumed 5% acceptance between 1-8 cm and ~5-10 detectable events

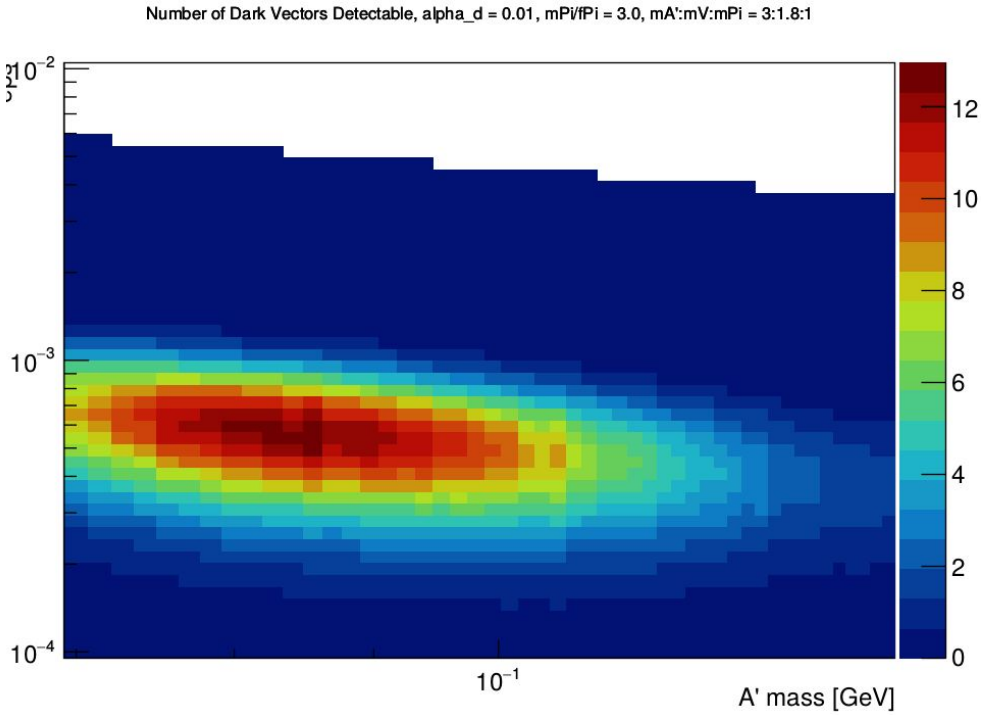
I simulated acceptance (0%-3%) and Z cut (2-3 cm) and use the typical 2.3 expected event benchmark

Not a direct comparison



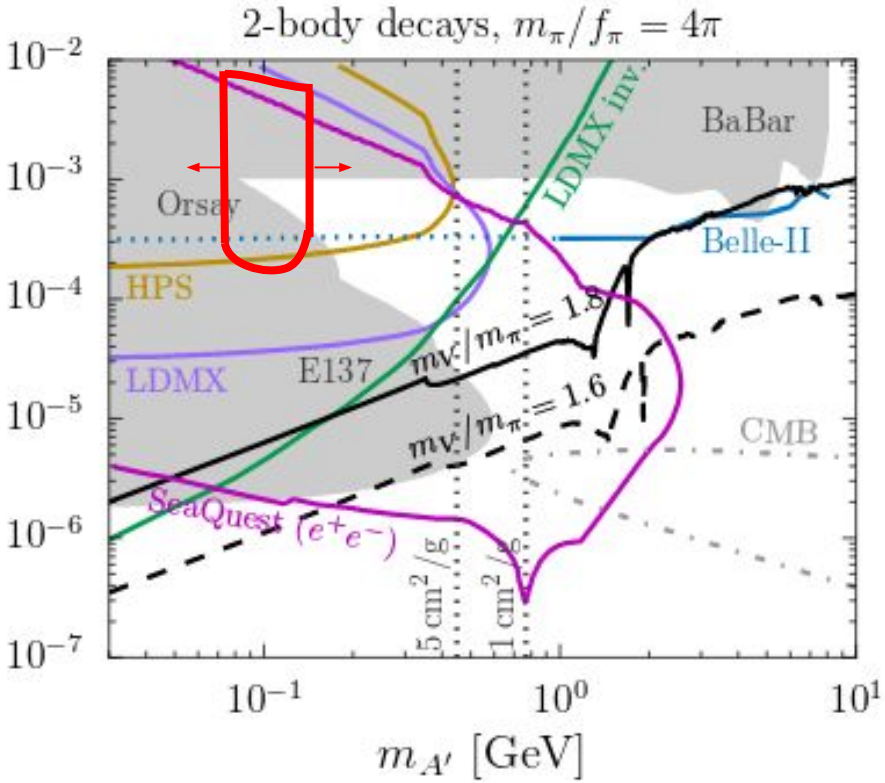
Reach plots: $\alpha_D = 0.01$; $m_\pi/f_\pi = 3$

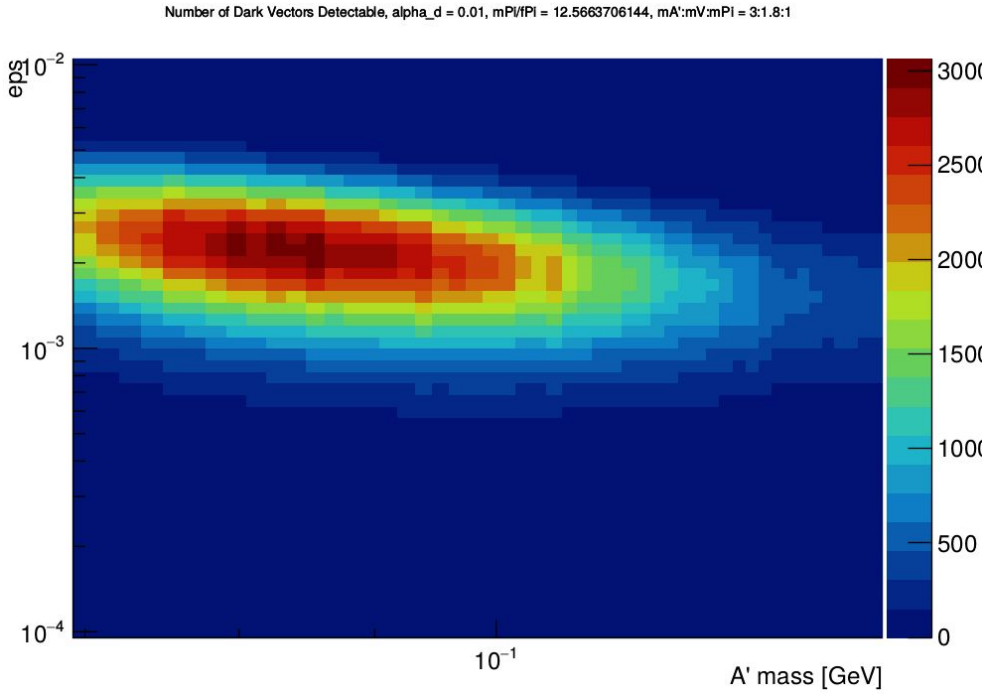




We have reach in new territory!!

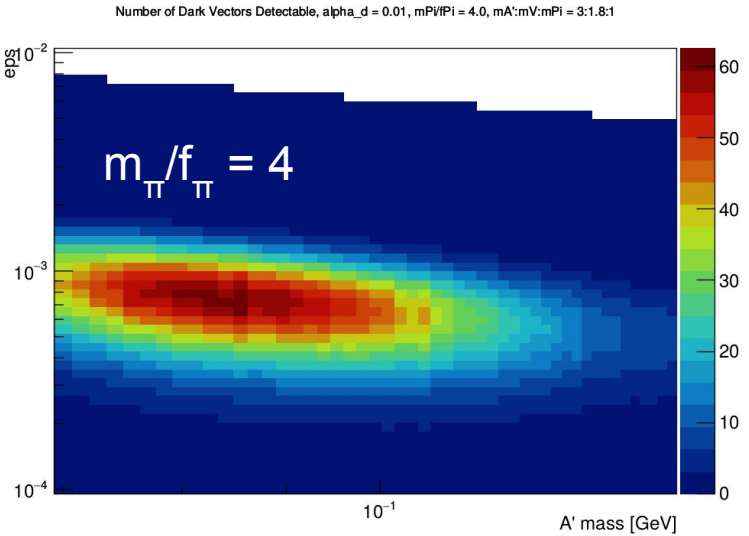
Reach Plots: $\alpha_D = 0.01$; $m_\pi/f_\pi = 4\pi$

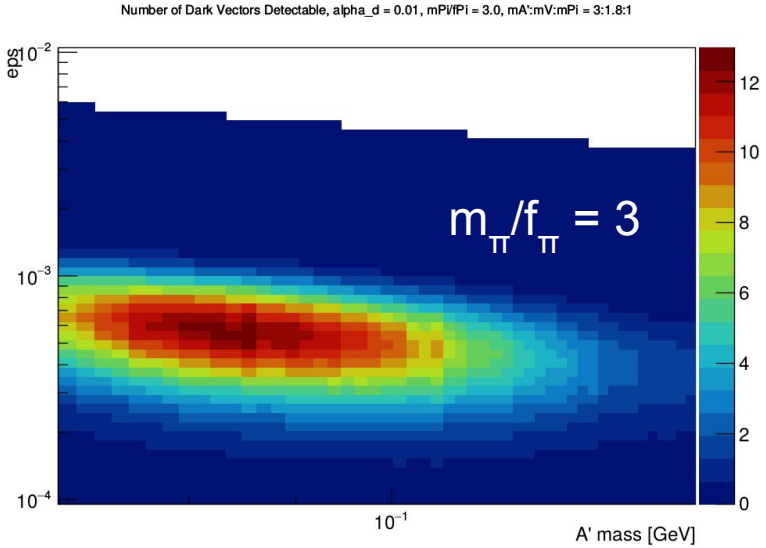


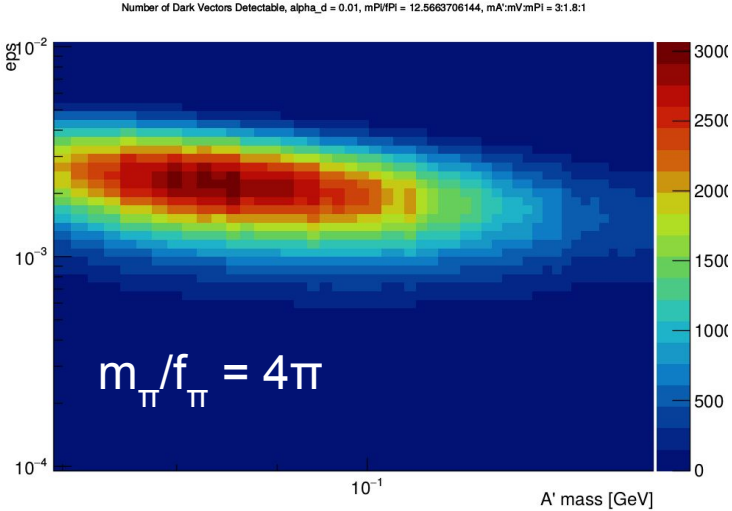


Reach Plots: variable m_π/f_π

$c\tau \propto 1 / (\varepsilon^2 \alpha_D f_\pi^2)$; $\alpha_D = 0.01$

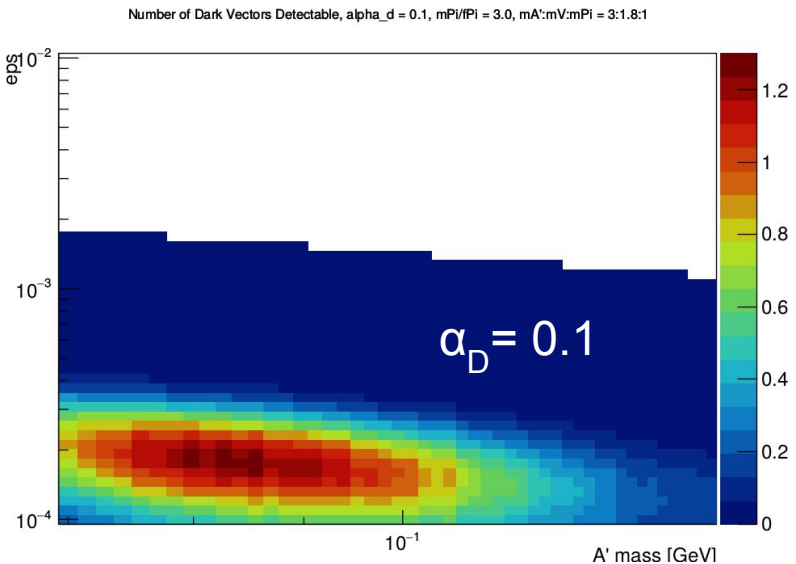


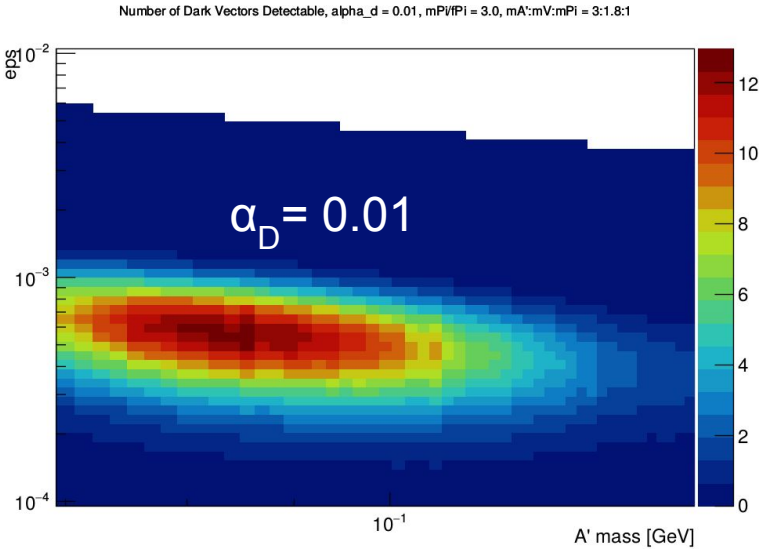


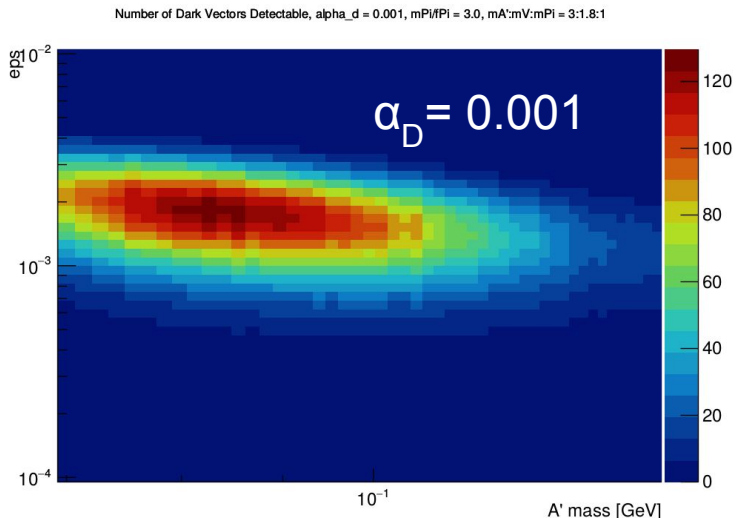


Reach Plots: variable α_D

$c\tau \propto 1 / (\varepsilon^2 \alpha_D f_\pi^2)$; $m_\pi/f_\pi = 3$

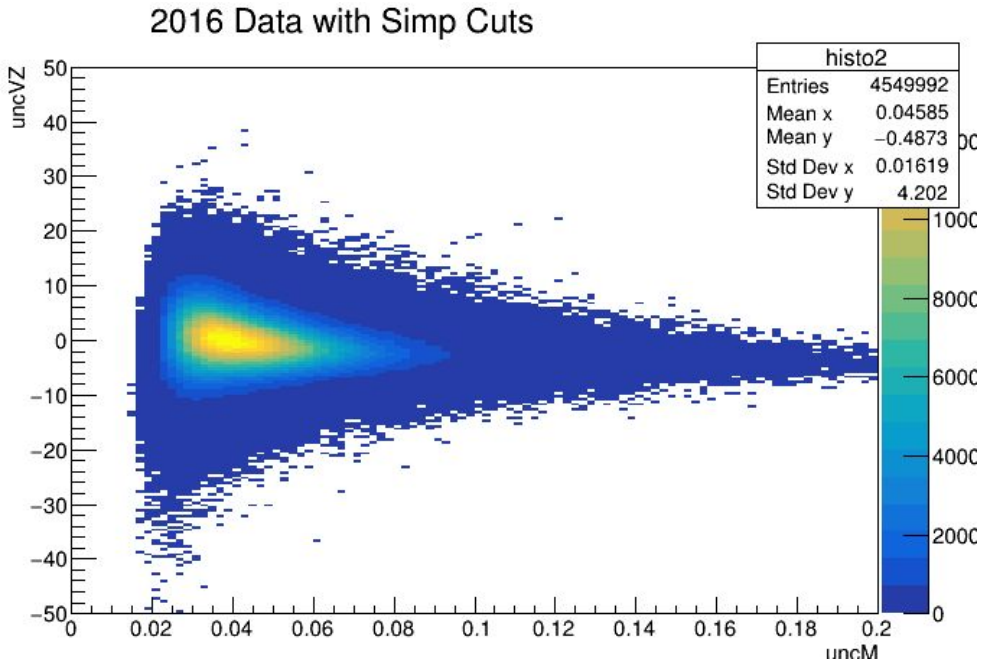


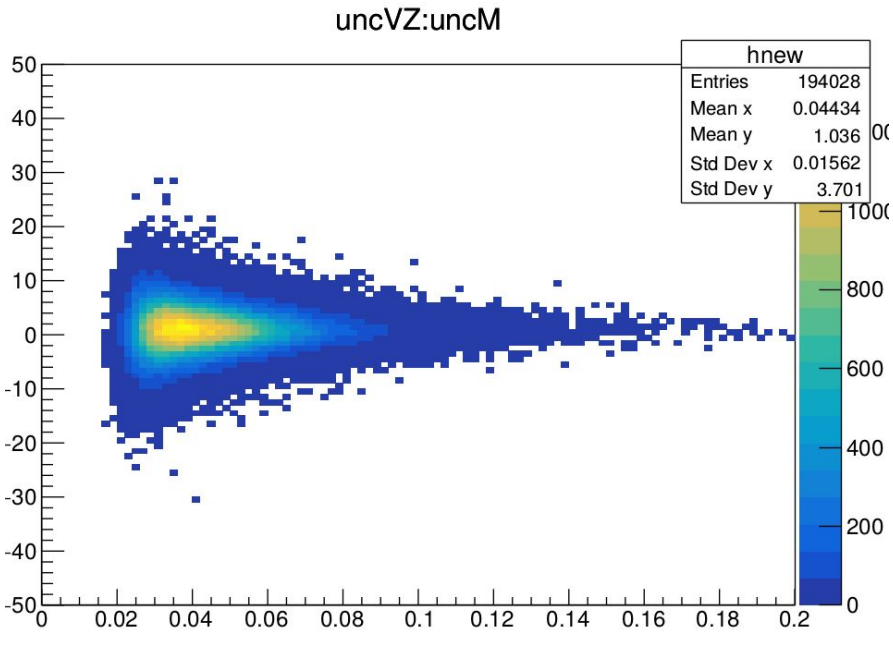




Quick Look at Data 2016 (L1L1)

10 % 2016 data (left) and MC (right) with Simp Cuts



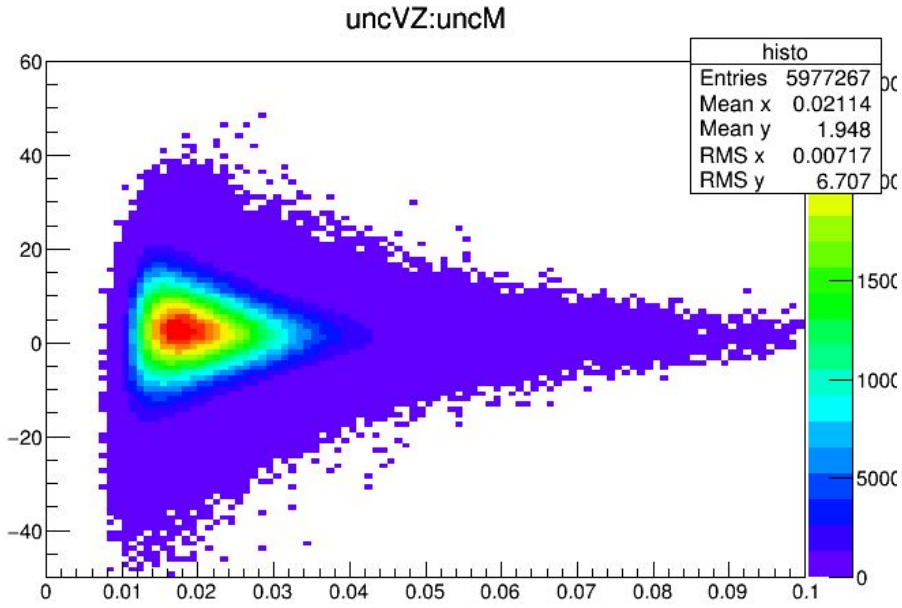


In the future, compare z cuts between data/MC

Quick Look at Data 2015 (L1L1)

Full 2015 MC with Simp Cuts + V0 target extrapolation cuts

Need to look at data



Moving Forward and Conclusions

Simps are a viable model of exploration in new parameter space with current and future HPS data

Discuss with theorists, also someone else should check calculations

Increase the mass range (some reach plots get cut off)

Look at 2015 Data. Do we have Simp reach in 2015 data? Probably somewhere in 6D parameter space

Devise more optimal cuts, and perhaps new cuts

Open the 2V decay channel (mA’:mV:mπ = 3:1.4:1), and perhaps a few others

How does this impact our future analysis efforts and publication plans?

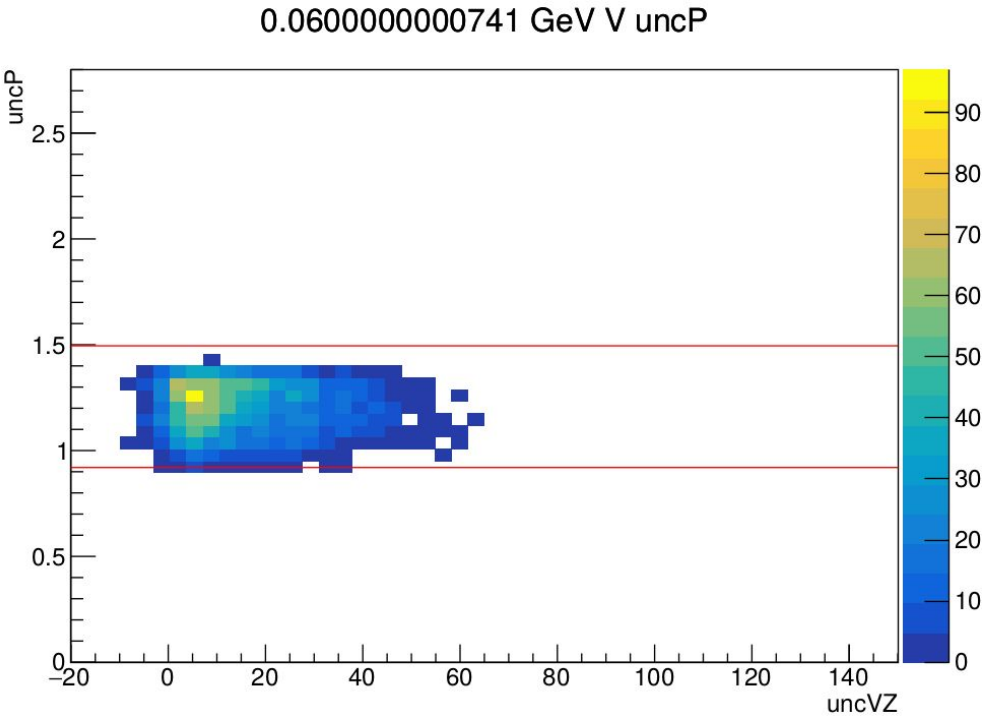
Issues and Concerns

Gamma is not constant (right)

tritrig-WBT issues

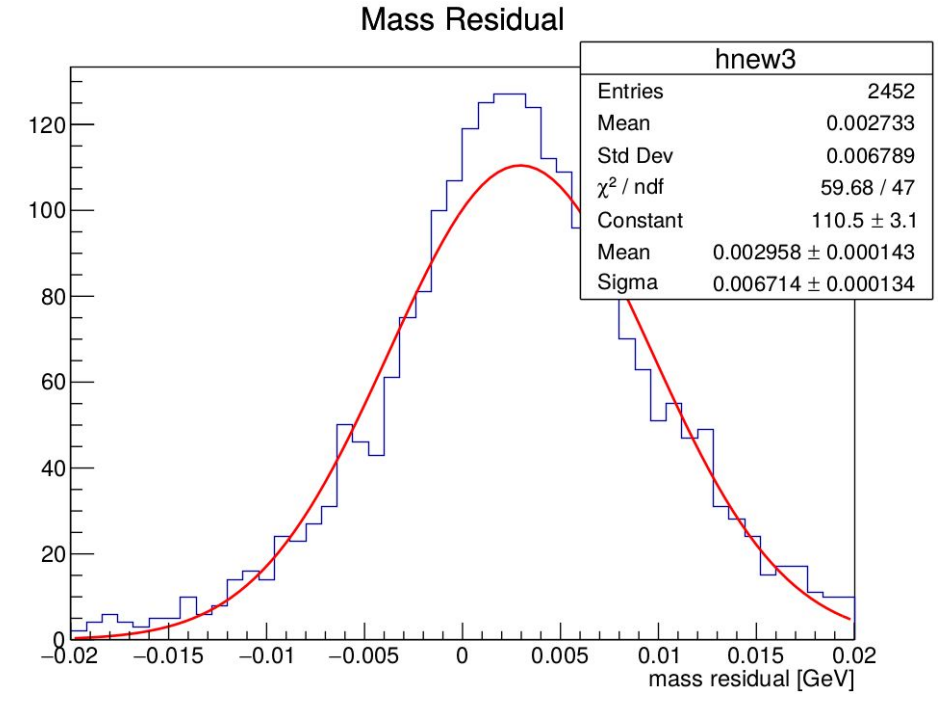
Normalization issues - cross section from tritrig + generator level cuts. Is there another way?

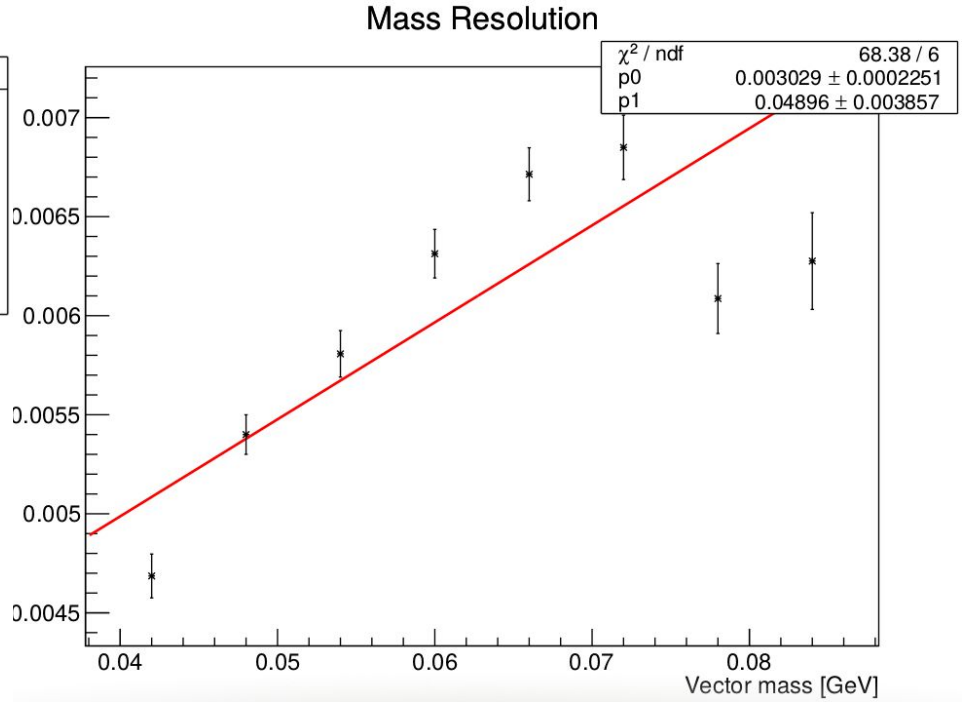
Mass resolution issues (next slide)



Mass Resolution

Mass residual is off-center and mass resolution appears non-linear





Reach Contours