

iDM Readout-Level Acceptance

Tom Eichlersmith

he/him/his

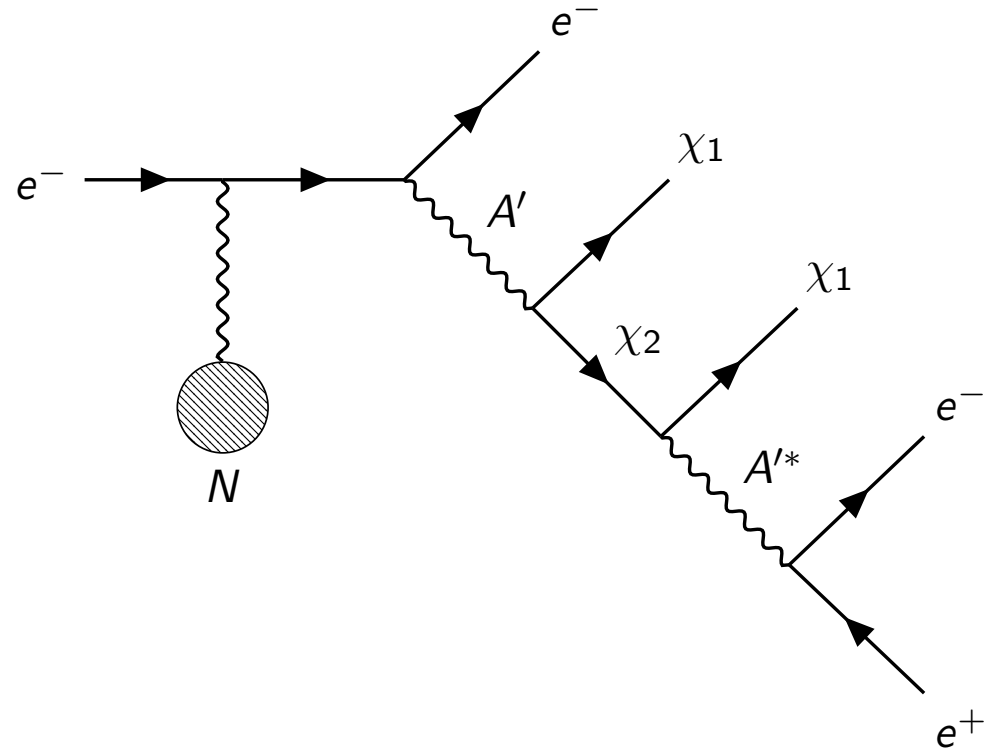
University of Minnesota

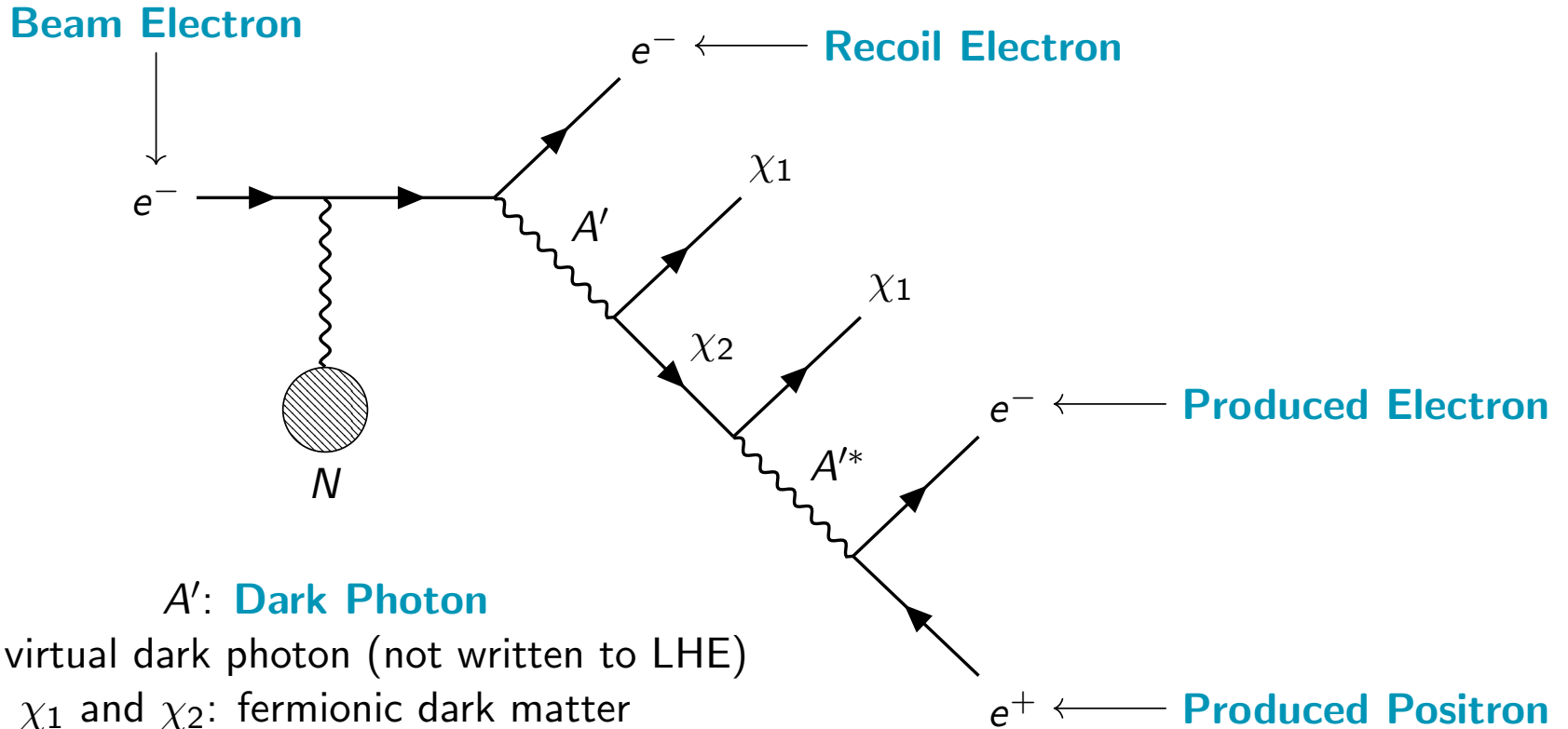
eichl008@umn.edu

August 22, 2023

Signal Sample Generation

- Have MADGRAPH model that calculates this diagram.
- Model now integrated into and being run from hps-mc
- Events displaced randomly and simulated
- Readout and reconstructed with standard 2016 steering files





A' : **Dark Photon**

A'^* : virtual dark photon (not written to LHE)

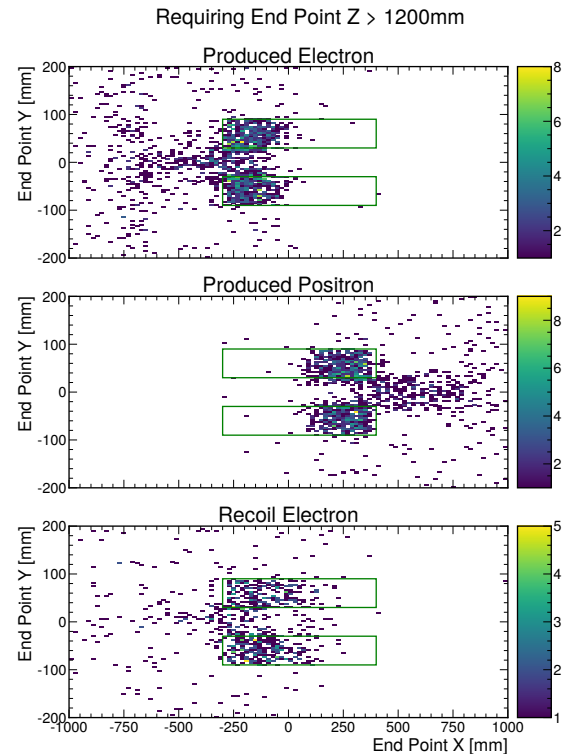
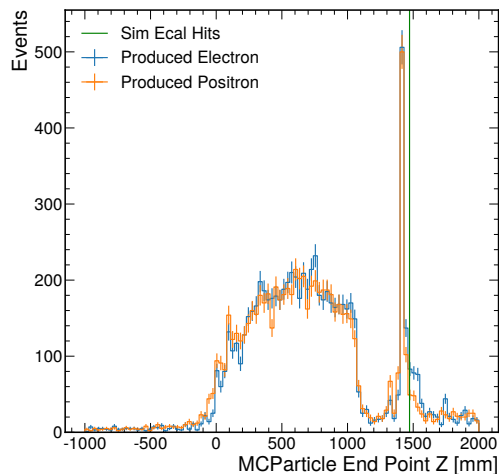
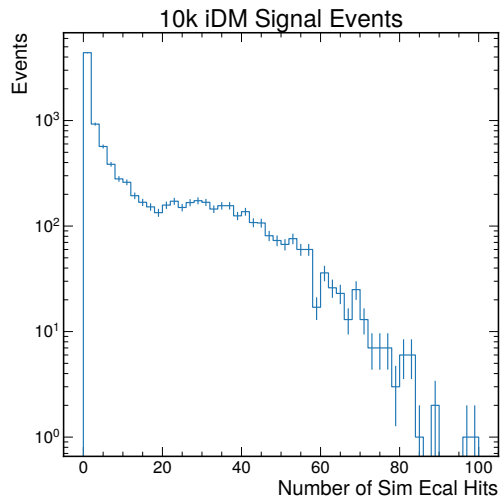
χ_1 and χ_2 : fermionic dark matter

χ_2 width is what causes the displacement

Woes Continue

The number of events being output by the full chain is
 ~ 10 out of the input 10k.

This can be understood by looking at the truth-level information.



Soldier On

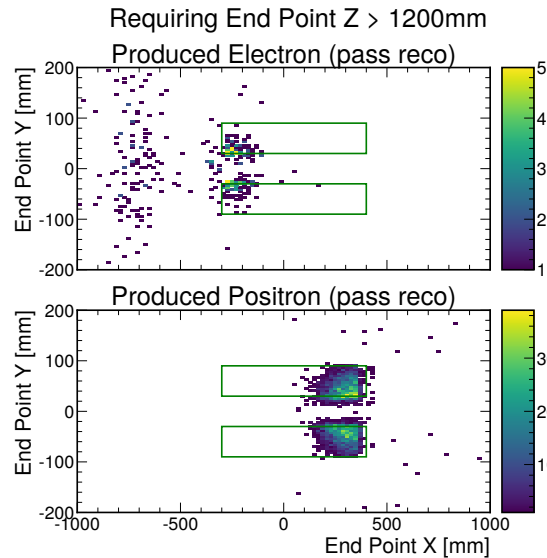
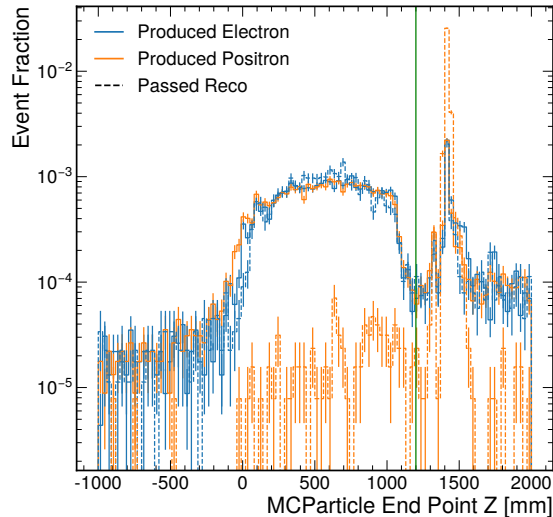
So what if our rate is small, it's still non-zero.



Generate a large (200 run) signal sample with $\Delta = 0.6m_\chi$, $m_{A'} = 3m_\chi$, $m_\chi = 30\text{MeV}$

Readout+Reco Selection

The standard steering files appear to be selecting the appropriate events.

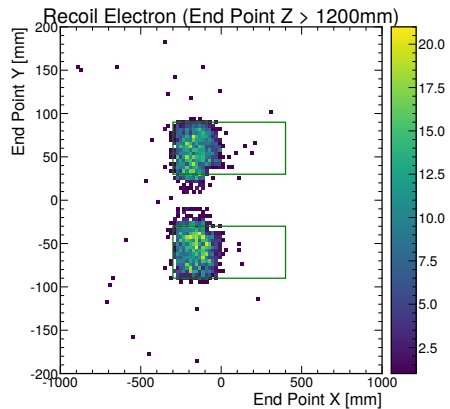
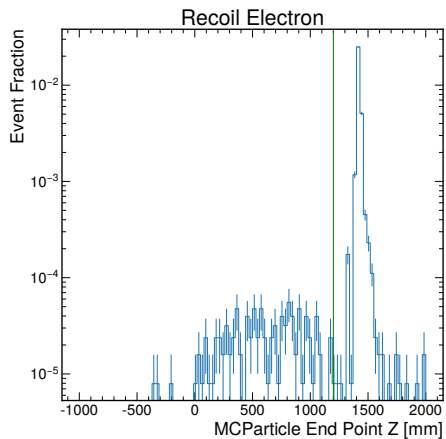


- Events selected have produced positron mostly ending in ECal volume
- Produced electron still smeared pretty widely

Uh Oh

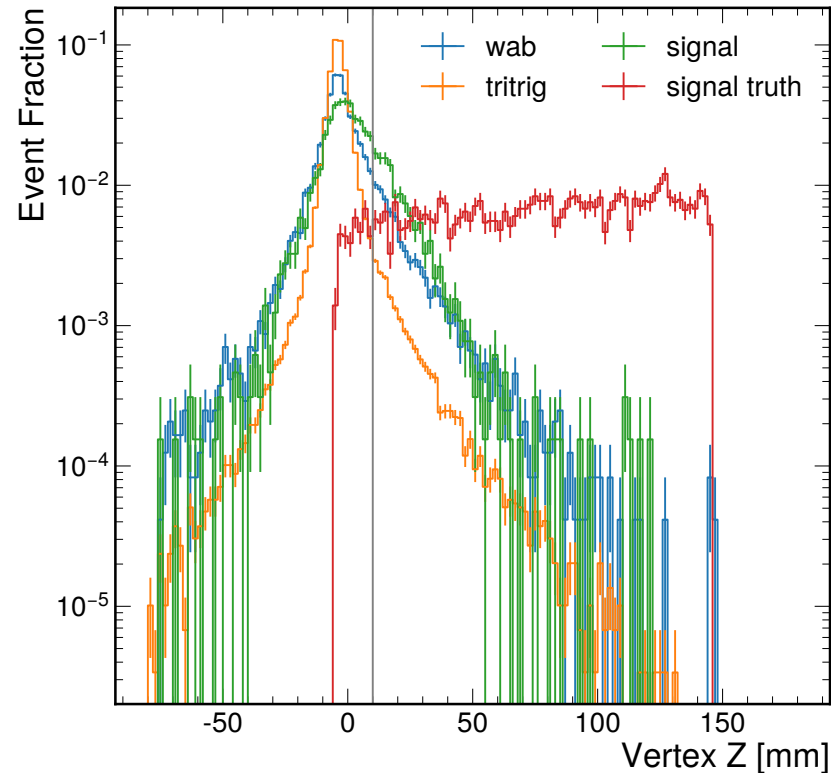
This is a hallmark sign of the detector “choosing” the wrong electron.

Inspect the Recoil

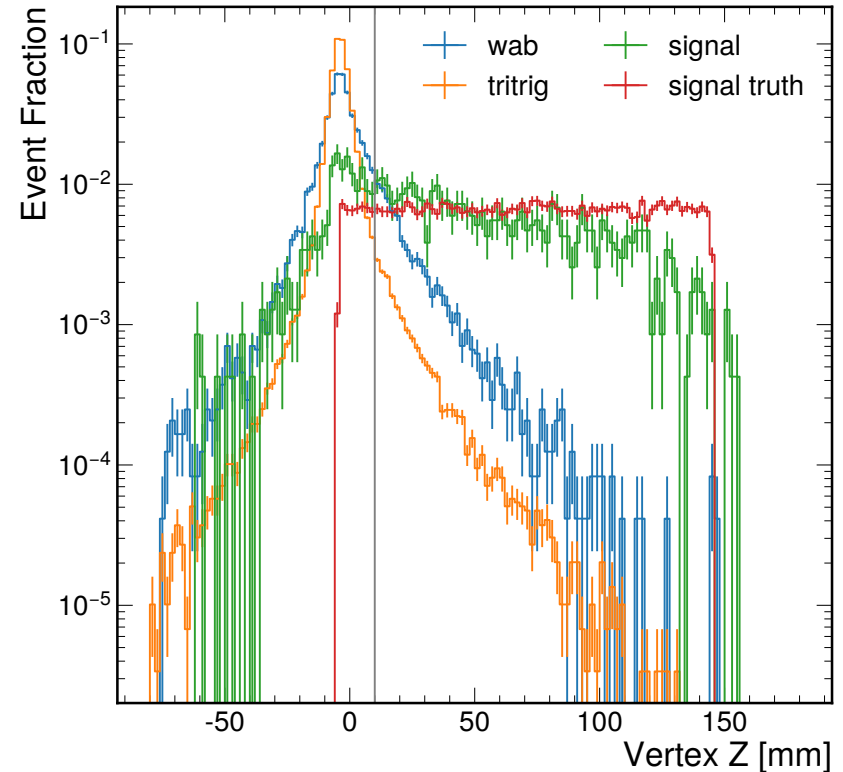


Large Fraction

A majority of the events accepted by the readout+reco chain have the recoil electron be *the* electron in the event.



- Increasing m_χ has the kinematic benefit of getting more energy to the produced pair at the downside of production rate loss
- The approximate uniformity of the reconstructed signal (as compared to the signal truth) is encouraging – move forward using this parameter set to study the expected number of events.



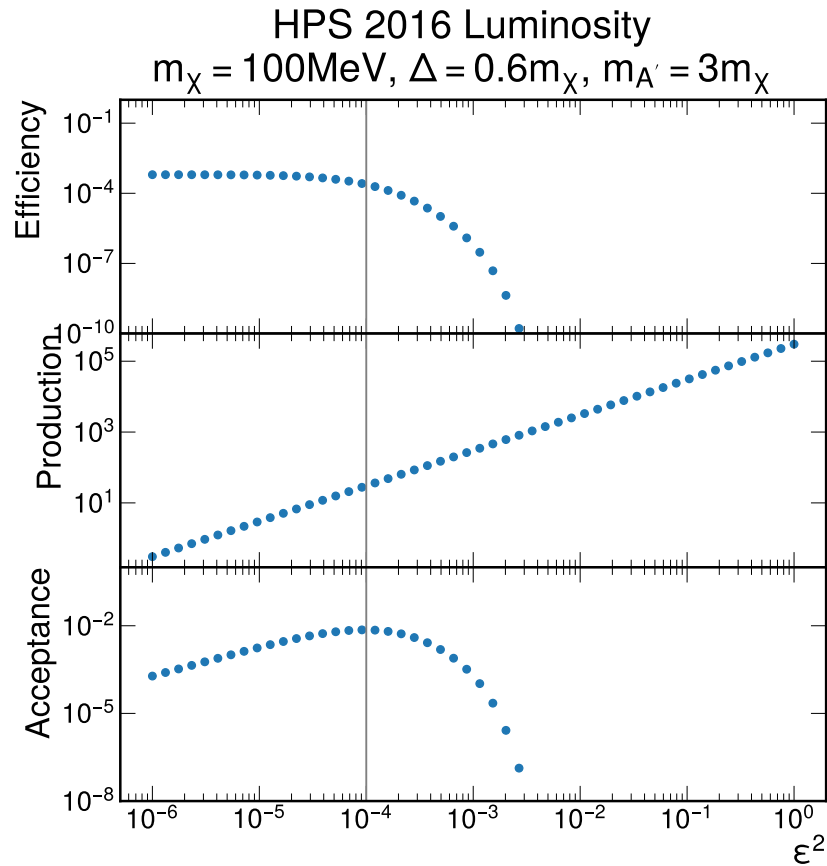
Expected Number of Events



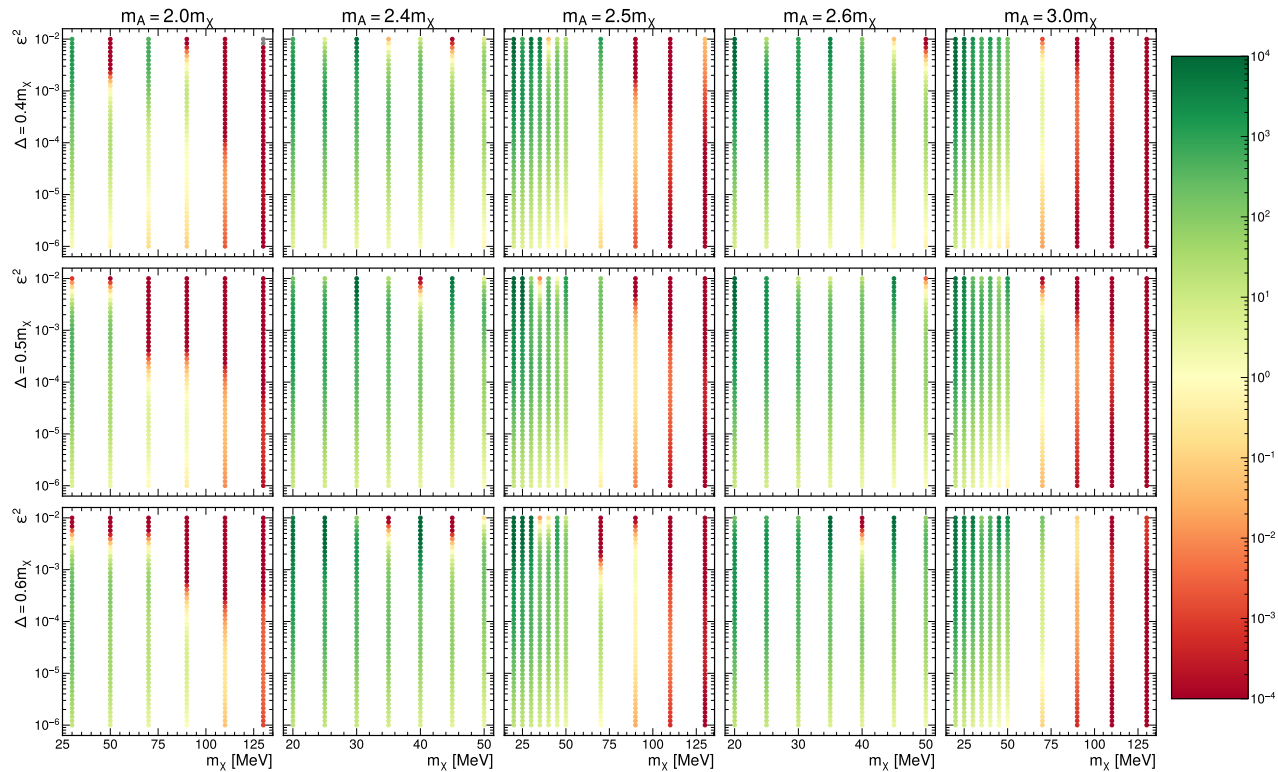
Y Axes

- **Efficiency** – efficiency of entire analysis chain (including z-cut and reweighting for ϵ dependence)
- **Production** – total events produced with HPS 2016 Lumi and beam
- **Acceptance** – product of efficiency and production, estimate of expected events in analysis

See the characteristic “bump”. Yay!



Broaden this Search



- $m_{A'} \in \{2.0, 2.4, 2.5, 2.6, 3.0\} m_\chi$
- $\Delta \in \{0.4, 0.5, 0.6\} m_\chi$
- $m_\chi \in (20, 130) \text{ MeV}$
- **fixed z cut at 10mm**

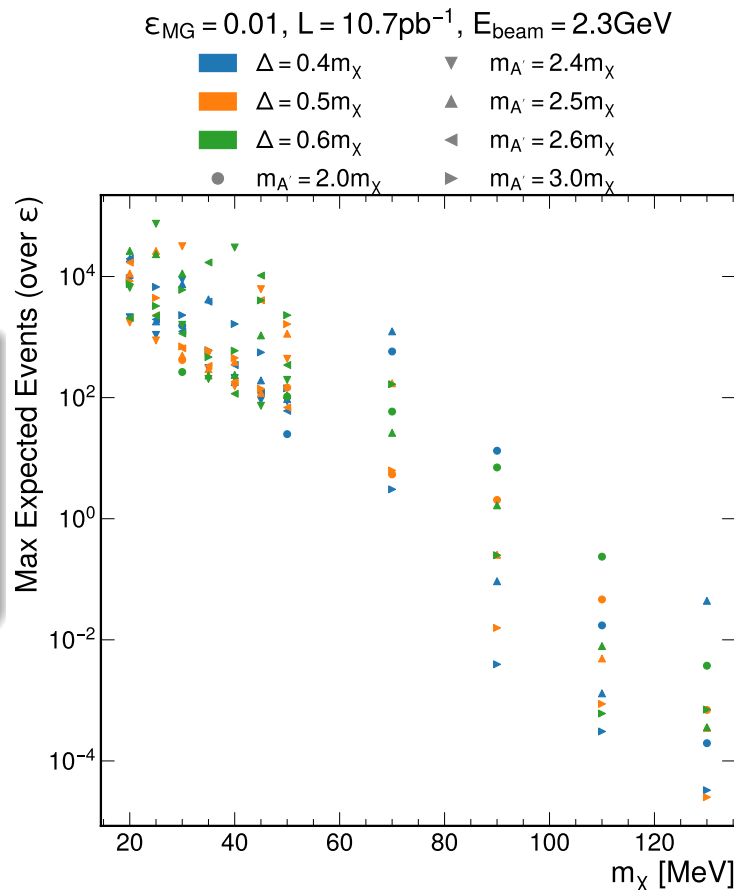
Torn between high-mass helping improve acceptance and low-mass improve production rate.

Condense this heat-map by getting maximum possible over ϵ .

Qualitative Conclusions

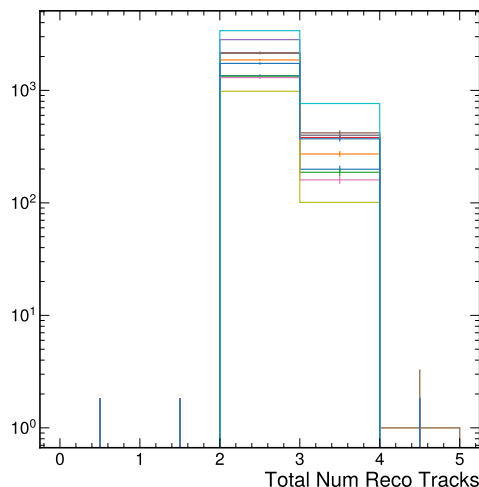
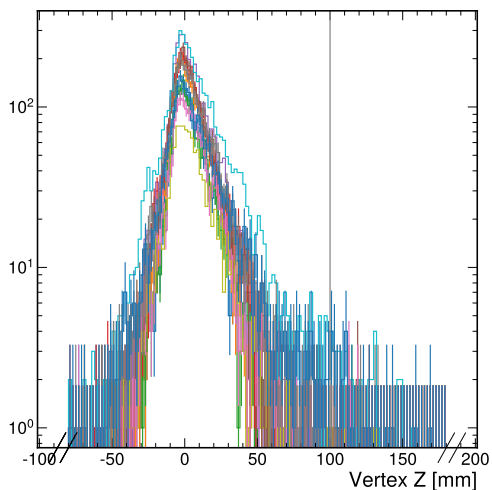
- Low-Mass Production Rate is “winning” the tug-of-war
- Higher mass dominated by decreasing production rate

What if we try to look for these few events?



Appears that these samples simply lucked into higher reach.

Few events at high z . Only $\sim 1/4$ have another reconstructed track.



These are all the samples whose expected number of events have a maximum above one thousand for some choice of ϵ .

Summary

- Moved to used recon-level determination of acceptance to be more realistic
- Observing competition between production rate wanting low m_χ and kinematics wanting high m_χ
- **No “goldilocks” zone is observed.** The readout efficiency is too poor, the reconstruction does not observe the produced electron, or the production rate is too low.

Next

- Write these conclusions and steps to reproduce into internal note for future reference

Questions

Mixed-Up Notation $A' \equiv Z' \equiv Z_D$

1. Model provided to me by Stefania Gori – able to generate iDM from pp collisions in that state.
2. Updated the model for eN fixed target by porting over the `frblock` parameters and couplings from the *dark photon MG4 model* in `hps-mc`.
3. Observed issues with phase space accessibility as the dark photon mass was lowered.
4. Conferred with Tim and Stefania who confirmed this was non-physical behavior and most likely a bug.
5. Removed dark photon – standard nucleus coupling which resolved this phase space issue.¹
6. Integrated the model into `hps-mc` to share with collaboration.
7. Update/patch to set $\epsilon = 1$ in the model so it can be included in displacement studying later

¹ I suspect that the way I put in the nucleus-photon interaction caused interference between the dark photon and the standard photon diagrams, leading to a closing of the phase space as the dark photon mass was lowered and began to appear more like a standard photon.

Parameter	Block	Default	Description
Mchi	dm	0.1	m_χ Average fermion dark matter mass in GeV
dMchi	dm	0.02	Δ Difference between fermion DM masses in GeV
Map	hidden	1	$m_{A'}$ dark photon mass in GeV
Fixed by HPS Design			
GAN	frblock	~ 0.3	SM photon-nucleon coupling
GZPN	frblock	~ 0.3	Dark photon-nucleon coupling
Anuc	frblock	184	atomic weight of nucleus in amu
Znuc	frblock	74	atomic number of nucleus
Disconnected from Rate in HPS			
MHsinput	hidden	200	dark higgs mass in GeV
epsilon	hidden	0.01	SM-dark photon mixing strength
kap	hidden	10^{-9}	quartic dark higgs interaction strength
aXM1	hidden	127.9	$1/\alpha_D$

Table: Relevant MADGRAPH/MADEVENT parameters available in param_card.dat

Parameters

What are some limitations on these parameters?



Kinematic

Avoid kinematic, cosmological limits and/or degeneracy into different model.

$$2m_e < \Delta < \frac{2}{3}m_\chi \quad m_{A'} > 2m_\chi$$

Lifetime

A DM survey paper [▶ ArXiv 1807.01730](#) Eq (24)

$$\Gamma(\chi_2 \rightarrow \chi_1 l^+ l^-) \propto y \left(\frac{\Delta}{m_1} \right)^5 m_1 \quad y \equiv \epsilon^2 \alpha_D \left(\frac{m_\chi}{m_{A'}} \right)^4$$

Technically, we don't actually use this equation for any calculations since it has pretty strict requirements on the parameters (mainly Δ we wish to avoid). In reality, I use MADGRAPH/MADEVENT to calculate the width of χ_2 and then scale that width linearly with ϵ^2 .

- $\Delta > 0$ so χ_1 and χ_2 are actually different mass states
- $\Delta > 2m_e$ so χ_2 will decay to $\chi_1 e^+ e^-$
- $\Delta < m_\chi$ so that the mass of χ_1 is real $m_1 > 0$
- $\Delta < \frac{2}{3}m_\chi$ so $\Delta \lesssim \mathcal{O}(1)m_1$ so “DM freezeout is dominantly controlled by SM fermions”²
- $m_{A'} > 2m_\chi$ so a real A' decays to $\chi_2 \chi_1$
- $m_{A'} < E_{\text{beam}}$ so a real A' can be produced
- $m_{A'}/m_\chi$ upper limit is defined by cross section – too high and the cross section is too low for it to be produced within HPS’s data set
- $m_\chi > 0$ obviously the dark fermions need to be massive
- $m_\chi < 2m_\mu$ to avoid losing cross section to muon pairs compared to electron pairs

² ▶ [ArXiv 1807.01730](https://arxiv.org/abs/1807.01730) Section III.5

TriTrig and WAB

Produced by Cam and available at SLAC.

`/sdf/group/hps/mc/2pt3GeV/HPS-PhysicsRun2016-Pass2/{tritrig,wab}/ecal_trig_res`

Signal

Used [tomeichlersmith/hps-prod](#) container release [2023-07-10](#)

- $m_{A'} = 3m_\chi$, $\Delta = 0.6m_\chi$, $m_\chi = 30\text{MeV}$ and $m_\chi = 100\text{MeV}$
- Run the `idm` job in `hps-mc` 200 times (iterating the random seed)
 - ▶ Note: Only 122 runs of the 100MeV mass point succeeded, the failures were due to slurm evacuating my jobs so a user with higher prio could run.
- Merge resulting reconstructed slcio files into a single file
- Tuplize reconstructed slcio file with [hpstr:ptrless](#)