iDM Generator-Level Acceptance

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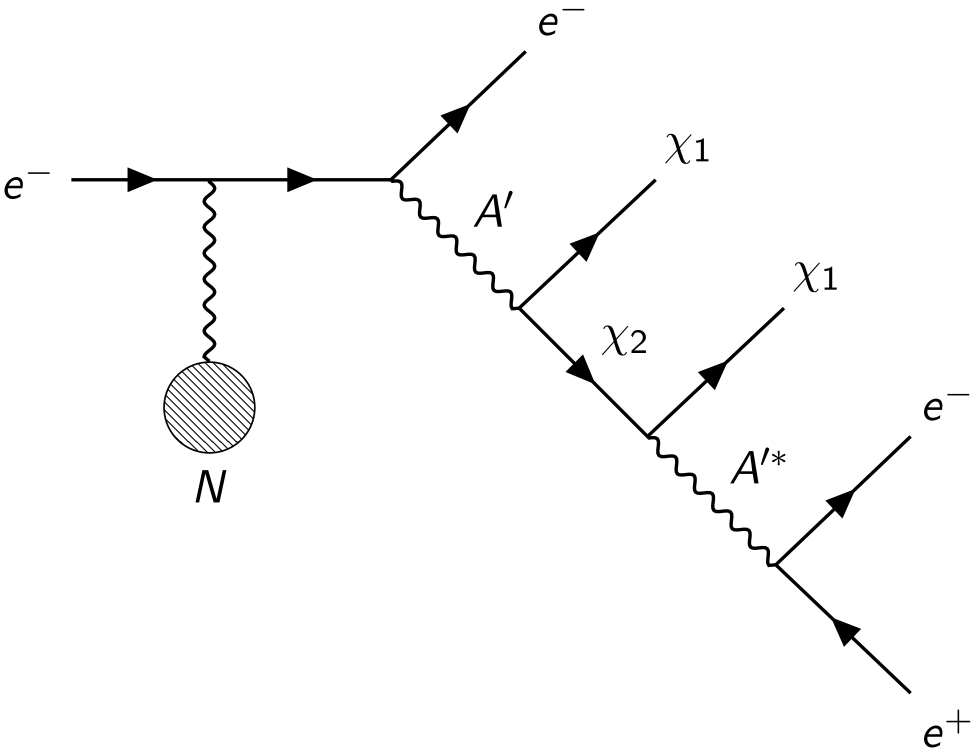
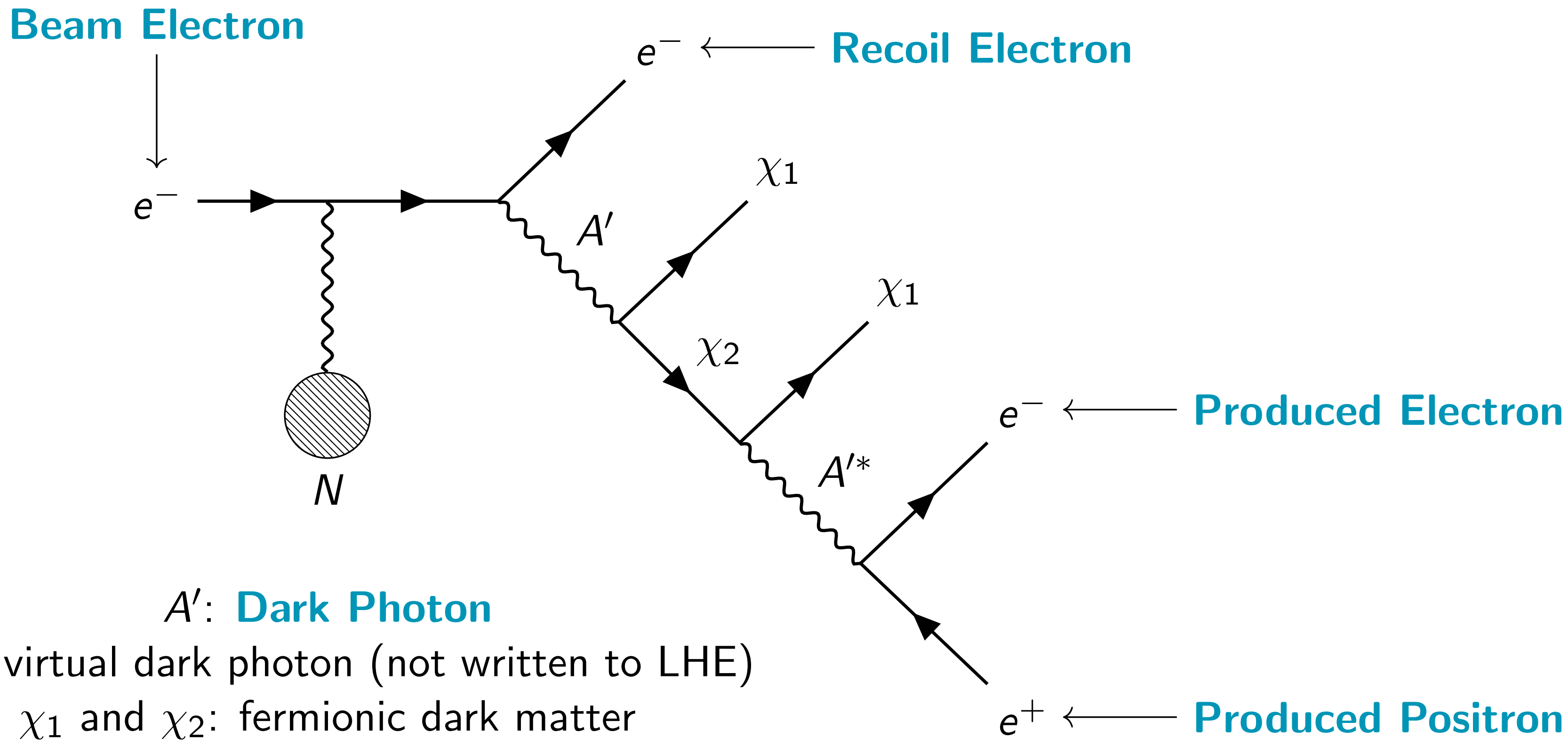
Status

Production Rate

- Have MadGraph model that calculates this diagram.
- Found complexity preventing access to HPS beam-energy phase space
- Model now integrated into and being run from hps-mc
- **Including production rate**



Vocabulary



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

Parameters

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	1.	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.

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

Lifetime

A DM survey paper ArXiV 1807.01730 Eq (24)

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

Geometric Acceptance

Need to study ourselves (this presentation).

HPS Acceptance

Rough approximation by two generator-level cuts:

1. Trigger Energy Threshold[1]: $E_{e^+} > 150\text{MeV}$ and $E_{e^-} > 150\text{MeV}$ and $E_{e^+} + E_{e^-} > 600\text{MeV}$
2. Angular Minimum: $\theta_{yz} > 0.015$ for both e^+ and e^-, using $\tan(\theta_{yz}) \approx p_y/p_z$

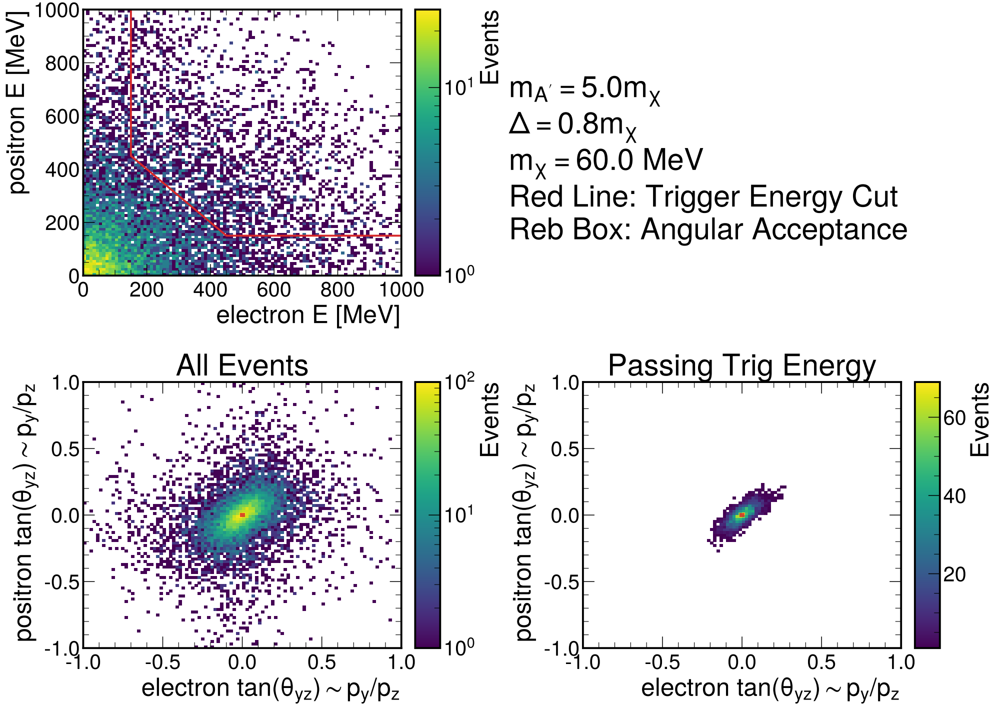
Satisfying both of these criteria is “in acceptance” for this presentation.

Started with a broad survey of parameters.

$m_\chi \in \{30, 60, 90, 120, 150, 180, 210\}\text{MeV}$ $\quad m_{A'} \in \{2, 3, 5\} * m_\chi$ $\quad \Delta \in \{0.1, 0.4, 0.8\} * m_\chi$

[1] for 2016 data run

Example Acceptance Plot



- Trigger energy cut really hurts us – focus on increasing energy of produced pair
- Angular spread looks good initially, but that is mainly due to low energy of pair

All of these plots are uploaded to agenda in a tar-ball.

Production Rate

Currently

Calculate dark photon production rate using its proportionality to radiative tridents.

$$\sigma_{A'} \propto \left. \frac{d\sigma_{\gamma^*}}{dm_{e^+e^-}} \right|_{m_{e^+e^-}=m_{A'}}$$

Mix-in acceptance along the way.

$$N_{A'\mathrm{sig}} = \frac{3\pi m_{A'}\epsilon^2}{2N_{\mathrm{eff}}\alpha} \frac{f_{\mathrm{rad}}}{\zeta} \frac{dN_{\mathrm{CR}}}{dm_{\mathrm{reco}}} \Theta A_{V_D} E_{\mathrm{vtx}}(\epsilon^2)$$

See excellent talks on SIMP production rate by Alic.

Proposal

MadGraph/MadEvent calculates σ for us.

$$N_{\mathrm{sig}} = \sigma_{\mathrm{iDM}}\ \mathcal{L}\ A_{V_D}\ E_{\mathrm{vtx}}(\epsilon^2)$$

Working on setting $\epsilon = 1$ in MG/ME now.
Should I? Not sure how helpful that is.

Obvious Downside

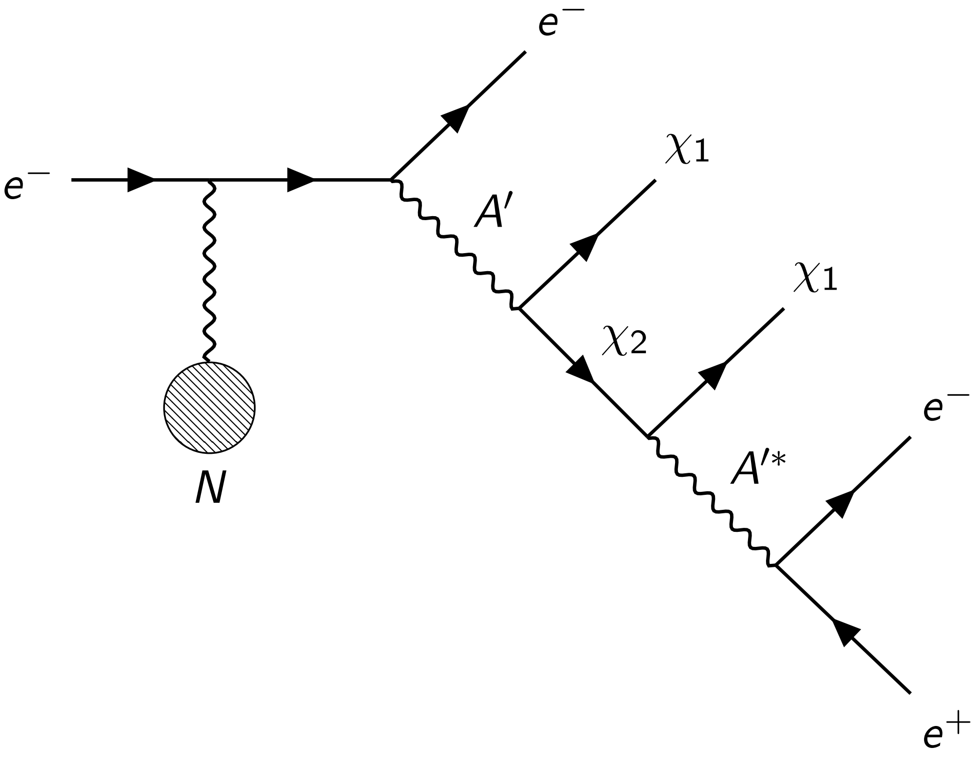
No avenue for data-based estimate of production rate. **Not sure how bad this is...**

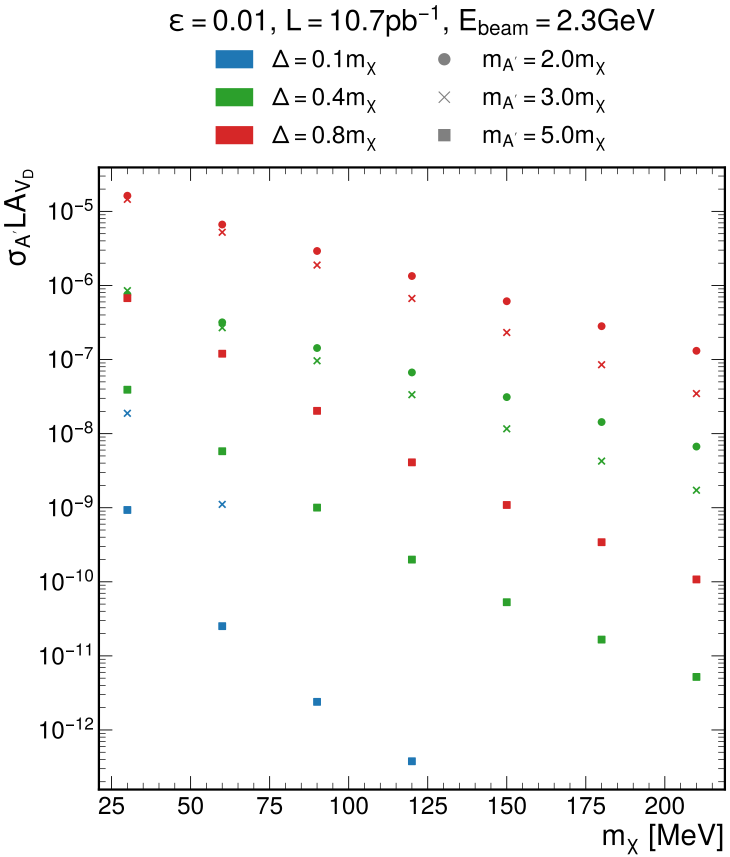
- In SIMP/iDM case, how distorted does the data-based estimate get from the necessary MC-based factors?
- MG/ME is doing an ETL calculation, isn't that accurate enough?
- Current SIMP estimates use MC for trident prod estimate anyways...

MG/ME-based Production Rate

- σ_{iDM} includes *both* production and decay (i.e. ϵ^4)
- $\mathcal{L}$ is set by HPS data-set
- A_{V_D} is fraction of prompt events accepted
- $E_{\mathrm{vtx}}(\epsilon^2)$ accounts for displaced decay vertex
- ϵ_{MG} is the ϵ value used during the MG run

$$N_{\mathrm{sig}} = \sigma_{\mathrm{iDM}}\ \mathcal{L}\ A_{V_D}\ \frac{\epsilon^2}{\epsilon_{\mathrm{MG}}^4} E_{\mathrm{vtx}}(\epsilon^2)$$





$\sigma_{A'} \mathcal{L} A_{V_D} \sim$ Prompt Events Produced in Acceptance for 2016 beam energy and luminosity if $\epsilon = 0.01$

Getting the Pair More Energy

- Increasing Δ (blue→green→red) reserves less energy for χ_1 mass and so more can go into pair
- Increasing $m_{A'}$ (circles → crosses → squares) requires more energy to go into initial dark photon production but severely decreases the overall cross section.

Summary and Plans

Summary

- Well on our way to effectively studying iDM in HPS
- Current look is strongly limited by production rate, more study necessary

Questions Still to Answer

- How should I calculate the production rate?
  - Plan: compare iDM model to SIMP model, compare SIMP MG rate to current SIMP rate
- How much does the full detector simulation impact these acceptance numbers?
  - Plan: move to using recon-level determinations of acceptance.
- Are the parameters we have access to already excluded?
  - Plan: Re-apply Alic's reach calculation infrastructure to this use case.

Questions

MG iDM Model History

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.[2]
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

[2] 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.

iDM Parameter Limitations

- $\Delta > 0$ 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"[3]
- $m_{A'} > 2m_\chi$ 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
- $m_\chi > 0$ obsiously the dark fermions need to be massive
- $m_\chi < 2m_\mu$ to avoid losing cross section to muon pairs compared to electron pairs

[3] ArXiV 1807.01730 Section III.5