



Progress of BdNMC work

Shaghayegh Atashi June 28, 2017

Outline

- Update on partonic production channel
- Putting info in events.dat file into a TTree and placing cuts on the data
- Some interesting observations

Update on parton_production channel

- + Reminder: corresponds to the dark matter production process $p{+}N \to V^* \to \chi/\chi^{_\dagger}$
- I wanted to see what these events look like in events.dat
- I need 2 externally generated cvs files containing data points of differential V production cross section for p-p and p-n collisions
 - Patrick said he can generate those file if I give him the V masses that I'm interested in (he has the FORTRAN code, can't redistribute it)
 - This is eventually going to be incorporated in BdNMC

Putting BdNMC's output information into a TTree:

• Reminder:

BdNMC outputs a data file containing info about the particles involved in the interactions. For example, some events from a data file outputted by BdNMC is shown here. The format is:

particle name px		ру	pz	\mathbf{E}	X	У		Z	t	
Run 1495052956 event 1										
eta	0.259824	-0.198728	3.08678	3.15205						
V	0.267948	-0.0747792	2.75542	2.79816						
DM	-0.00796544	0.00861999	1.8036	1.80364						
proton	-0.342382	-0.192742	0.132485	1.02581	-2.1939	2.37418	496.759	1.6570	/5e-06	
endevent 1										
event 2										
eta	-0.512015	-0.241737	2.33848	2.46764						
V	-0.447128	-0.203878	2.29495	2.38081						
DM	0.00205929	-0.0015099	0.924071	0.924088						
proton	-0.297628	-0.242418	0.186791	1.03082	1.10585	-0.810828	496.231	1.6552	8e-06	
endevent 2										

• x,y,z, and t are only shown for the signal particle (particle that the DM scatters off)

Ttree that stores the information in events.dat:

These are

arrays of

size n

The branches:

- event_num: event number
- run_number

n :#particles in each event

- \cdot Nth part
- · particle type (Char_t)
- Int corresponding to particle type
- \cdot px (GeV)
- · py (GeV)
- · pz (GeV)
- · E (GeV)

n_scatt: # scattering particles in each event

- Nth part (for scattering particles)
- particle type (Char_t) (for scattering particles)
- Int corresponding to particle type (for scattering particles)
- px (for scattering particles) (GeV)
- · py (for scattering particles) (GeV)
- \cdot pz (for scattering particles) (GeV)
- \cdot E (for scattering particles) (GeV)
- X (in m, for scattering particles)
- \cdot Y (in m, for scattering particles)
- $\cdot ~~Z$ (in m, for scattering particles)
- Time (in s, for scattering particles)

These are arrays of size n_scatt

These branches only get filled for signal particles (using the size of the line)

Ttree that stores all the information in events.dat

Everything works:

- Save the tree in a .root file
- Call MakeClass() on the tree in the .root file
- MakeClass() automatically generates some files
 - Here, I can impose cuts on the info in the tree and create separate histograms with these cuts (eg px histogram for all scattered protons, all scattered neutrons, etc)
 - Save these additional histograms in another .root file
- Can look at momentum, energy, angular, position/time distributions
- Plan: look at these distributions for
 - dark photon
 - DM
 - Scattered particles and
 - see how they change with different model parameters
 - Compare V distributions for different production channels

- Nextfew slides: the distributions for a sample parameter card (to get an idea of what they look like
- Geometry for the angular distributions:



Some histograms for an example parameter card (Run 1497905251)

- MiniBooNE-like experiment epsilon = 1e-3 dark_matter_mass= 0.01 GeV dark_photon_mass = 0.1 GeV alpha_D = 0.1 POT= 2e20 beam_energy = 8.9 GeV Production_channel: pi0_decay Signal_channel: NCE_nucleon



Parameters:

- MiniBooNE-like experiment epsilon = 1e-3 dark_matter_mass= 0.01 GeV dark_photon_mass = 0.1 GeV alpha_D = 0.1 POT= 2e20 beam_energy = 8.9 GeV Production_channel: pi0_decay Signal_channel: NCE_nucleon



y momenta of all dark photons (GeV)

Parameters:

- MiniBooNE-like experiment epsilon = 1e-3 dark_matter_mass= 0.01 GeV dark_photon_mass = 0.1 GeV alpha_D = 0.1 POT= 2e20 beam_energy = 8.9 GeV Production_channel: pi0_decay Signal_channel: NCE_nucleon

py (GeV) h_px_py_V 60 Entries 10000 0.6 Mean x -0.000203Mean y -0.0004950 RMS x 0.078 0.4 RMS y 0.07768 40 0.2 30 20 -0.2 10 -0.40 -0.4 -0.2 0.2 0.4 0 px (GeV)

x momenta vs y momenta of all dark photons (GeV)

June 28, 2017

- MiniBooNE-like experiment

epsilon = 1e-3

POT= 2e20

dark_matter_mass= 0.01 GeV dark_photon_mass = 0.1 GeV alpha_D = 0.1 beam_energy = 8.9 GeV

Magnitude of Total Momenta of All Dark Photons (GeV)

Production_channel: pi0_decay Signal_channel: NCE_nucleon

pz (GeV)



Energy (GeV)

Parameters:

- MiniBooNE-like experiment epsilon = 1e-3 dark_matter_mass= 0.01 GeV dark_photon_mass = 0.1 GeV alpha_D = 0.1 POT= 2e20 beam_energy = 8.9 GeV Production_channel: pi0_decay Signal_channel: NCE_nucleon



Angular distribution of dark photons: theta(degrees)

Parameters:

- MiniBooNE-like experiment epsilon = 1e-3 dark_matter_mass= 0.01 GeV dark_photon_mass = 0.1 GeV alpha_D = 0.1 POT= 2e20 beam_energy = 8.9 GeV Production_channel: pi0_decay Signal_channel: NCE_nucleon



Angular distribution of dark photons: phi(degrees)

June 28, 2017



And the same thing for DM particles, scattered particles, etc

Looking at dark photon distributions:

Parameters: - MiniBooNE-like experiment epsilon = 1e-3 dark_matter_mass= 0.01 GeV dark_photon_mass = varying alpha_D = 0.1 POT= 2e20 beam_energy = 8.9 GeV Production_channel: pi0_decay Signal_channel: NCE_nucleon

Run1498246615, mass_V=0.02 GeV Run1498247168, mass_V=0.03 GeV Run1498247730 mass_V=0.05 GeV Run1498500989, mass_V= 0.1 GeV Run 1498241455, mass_V= 0.2 GeV Run1498244748 , mass_V = 0.3 GeV Run1498245876, mass_V = 0.4 GeV Run1498248978, mass_V = 0.8 GeV Run1498251170, mass_V = 0.95 GeV

Run1498246615, mass_V=0.02 GeV

Run1498500989, mass_V= 0.1 GeV Run1498245876, mass_V = 0.4 GeV Run1498247168, mass_V=0.03 GeV Run 1498241455, mass_V= 0.2 GeV Run1498248978, mass_V = 0.8 GeV
$$\label{eq:constraint} \begin{split} Run1498247730 \ mass_V &= 0.05 \ GeV \\ Run1498244748 \ , \ mass_V &= 0.3 \ GeV \\ Run1498251170 \ , \ mass_V &= 0.95 \ GeV \end{split}$$





Angular distribution of dark photons: (degrees), From BdNMC Run 1498246615



Run1498247168, mass_V=0.03 GeV

Run 1498241455, mass_V= 0.2 GeV Run1498248978, mass V = 0.8 GeV Run1498247730 mass_V=0.05 GeV Run1498244748 , mass_V = 0.3 GeV Run1498251170, mass V = 0.95 GeV

Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498247168



Angular distribution of dark photons: o(degrees), From BdNMC Run 1498247168



Run1498247168, mass_V=0.03 GeV Run 1498241455, mass_V= 0.2 GeV Run1498248978, mass_V = 0.8 GeV

Run1498247730 mass_V=0.05 GeV

Run1498244748 , mass_V = 0.3 GeV Run1498251170, mass_V = 0.95 GeV

Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498247730



Angular distribution of dark photons: o(degrees), From BdNMC Run 1498247730



18

Run1498247168, mass_V=0.03 GeV Run 1498241455, mass_V= 0.2 GeV Run1498248978, mass_V = 0.8 GeV
$$\label{eq:constraint} \begin{split} Run1498247730 \ mass_V &= 0.05 \ GeV \\ Run1498244748 \ , \ mass_V &= 0.3 \ GeV \\ Run1498251170 \ , \ mass_V &= 0.95 \ GeV \end{split}$$

Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498500989



Angular distribution of dark photons: o(degrees), From BdNMC Run 1498500989



Run1498247168, mass_V=0.03 GeV Run 1498241455, mass_V= 0.2 GeV Run1498248978, mass V = 0.8 GeV
$$\label{eq:result} \begin{split} Run1498247730\ mass_V &= 0.05\ GeV\\ Run1498244748\ ,\ mass_V &= 0.3\ GeV\\ Run1498251170\ ,\ mass\ V &= 0.95\ GeV \end{split}$$

Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498241455



Angular distribution of dark photons: o(degrees), From BdNMC Run 1498241455



20

Run1498247168, mass_V=0.03 GeV Run 1498241455, mass_V= 0.2 GeV Run1498248978. mass V = 0.8 GeV Run1498247730 mass_V=0.05 GeV Run1498244748 , mass_V = 0.3 GeV

V = 0.8 GeV Run1498251170. mass V = 0.95 GeVAngular distribution of dark photons: θ (degrees), From BdNMC Run 1498244748



Angular distribution of dark photons: o(degrees), From BdNMC Run 1498244748



Run1498247168, mass_V=0.03 GeV Run 1498241455, mass_V= 0.2 GeV Run1498248978, mass_V = 0.8 GeV Run1498247730 mass_V=0.05 GeV Run1498244748 , mass_V = 0.3 GeV Run1498251170, mass_V = 0.95 GeV

Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498245876



Angular distribution of dark photons: o(degrees), From BdNMC Run 1498245876



LOG of Frequency

10

 Run1498247168, mass_V=0.03 GeV Run 1498241455, mass_V= 0.2 GeV **Run1498248978, mass_V = 0.8 GeV** Run1498247730 mass_V=0.05 GeV Run1498244748 , mass_V = 0.3 GeV Run1498251170, mass_V = 0.95 GeV

Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498248978



Run1498247168, mass_V=0.03 GeV Run 1498241455, mass_V= 0.2 GeV Run1498248978, mass V = 0.8 GeV Run1498247730 mass_V=0.05 GeV Run1498244748, mass_V = 0.3 GeV Run1498251170, mass_V = 0.95 GeV

Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498251170



Angular distribution of dark photons: o(degrees), From BdNMC Run 1498251170





-100

-150

-50

0

50

100

150

θ (°)

Run1498246615, mass_V=0.02 GeV Run1498247168, mass_V=0.03 GeV Run1498247730 mass_V=0.05 GeV Run1498500989, mass_V= 0.1 GeV Run1498241455, mass_V= 0.2 GeV Run1498244748, mass_V = 0.3 GeV Run1498245876, mass_V = 0.4 GeV Run1498248978, mass_V = 0.8 GeV Run1498251170, mass_V = 0.95 GeV

Some observations about theta with varying mass_V:

- Theta histograms look sinusoidal (more so for large m_V)
- There's a dip in the theta histograms at -90 and 90

25

• The next few slides show momenta, energy, and angle distributions for all the runs (with diff mass_V) for comparison





§2000 E

ਛੋ1800 <u>–</u>

1600

1400

1200 1000

800

600

400 E

05

700 LLLL

600

500

400

300 F

200

100 [

0[

700

600

500

400

300

200

100 F 0

-0.6

-0.4

-0.2

-0.4

0.2

200

y momenta of all dark photons (GeV), From BdNMC Run 1498247730



S.Atashi

0.2

0.4

z momenta of all dark photons (GeV), From BdNMC Run 1498247730







z momenta of all dark photons (GeV), From BdNMC Run 1498247168

h nz

Entries

Mean BMS 10000 1.596 1.182

10

pz (GeV)



100 H

350

300

250

200 F

150

100

50

Jan 350

300

250

200

150

100 F

50

350

^풀 300년

250

200

150

100

50

0



 $\label{eq:response} \begin{array}{l} Run1498246615,\ mass_V=0.02\ GeV\\ Run1498247168,\ mass_V=0.03\ GeV\\ Run1498247730\ mass_V=0.05\ GeV\\ Run149850989,\ mass_V=0.1\ GeV\\ Run1498241455,\ mass_V=0.2\ GeV\\ Run1498244748,\ mass_V=0.3\ GeV\\ Run1498245876,\ mass_V=0.4\ GeV\\ Run1498248978,\ mass_V=0.8\ GeV\\ Run1498251170,\ mass_V=0.95\ GeV\\ \end{array}$

z momenta of all dark photons (GeV), From BdNMC Run 1498246615





z momenta of all dark photons (GeV), From BdNMC Run 1498247168

z momenta of all dark photons (GeV), From BdNMC Run 1498241455

z momenta of all dark photons (GeV), From BdNMC Run 1498248978

h pz V

10000

1.596

pz (GeV)

10000

2.077

1.299

0

10

pz (GeV)

10000

1.318

h_pz_V

Entries

Mean

RMS

Underflow

Overflow

h_pz_V

Entries

Mean

RMS

Underflow

Overflow

Entries

Underflow

Overflow

Mean

RMS

LOG of frequency

Ē

10

1官

LOG of frequency

LOG of frequency

10

10

1旨

pz (GeV)

10

10

10²

z momenta of all dark photons (GeV), From BdNMC Run 1498247730



Same slide as before, different scales

10

pz (GeV)



Magnitude of Total Momenta of All Dark Photons (GeV), From BdNMC Run 1498247168

Magnitude of Total Momenta of All Dark Photons (GeV), From BdNMC Run 1498247730







Energy of all dark photons (GeV), From BdNMC Run 1498246615



Energy of all dark photons (GeV), From BdNMC Run 1498247168

Energy of all dark photons (GeV), From BdNMC Run 1498247730





Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498246615





Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498247168





Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498248978



Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498247730



Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498244748



Angular distribution of dark photons: 0 (degrees), From BdNMC Run 1498251170



Angular distribution of dark photons: (degrees), From BdNMC Run 1498246615





Angular distribution of dark photons: ϕ (degrees), From BdNMC Run 1498247168



Angular distribution of dark photons: (degrees), From BdNMC Run 1498247730

LOG of frequency

LOG of frequ





Angular distribution of dark photons:
(degrees), From BdNMC Run 1498251170



Later on:

Parameters: - MiniBooNE-like experiment epsilon = 1e-3 **dark_matter_mass= varying** dark_photon_mass = 0.1 GeV alpha_D = 0.1 POT= 2e20 beam_energy = 8.9 GeV Production_channel: pi0_decay Signal_channel: NCE_nucleon

Recall Pi0 decay: $\pi^0 \longrightarrow \gamma + V^{(*)} \longrightarrow \gamma + \chi^{\dagger} + \chi$

- V is on-shell V, V^{*} is off-shell V (on-shell means it satisfies the Einstein energy-momentum relation)
- → Note: The parameters above corresponds to on-shell V production

And repeat for other model parameters

Next steps

- Study the distributions
 - Suggestions welcome (is there anything specific that I should look at?)
- Go back to figuring out how BdNMC calculates the # of scattering events, find out what pmax is
- Reminder from way back: For each production channel i: $signal_events[i] = \frac{ninteractions[i]}{trials} \times vnumtot \times pmax \times efficiency,$
 - Where ninteractions is the samplesize that the user inputs in the parameter card

(basically the code does x trials until samplesize scattering events are generated)

- Vnumtot is the total dark photons produced that decay into dark matter particles (outputted when you run BdNMC)
- And total_signal_events is the sum of signal events for all production channels

Backup

(no backup slides here)