[1]//This document describes all possible events that BdNMC can generate.
//The following is for the dark photon model (not baryonic)
// In progress
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//Last update: Thursday June 08

Production channel: meson decay

Description of interactions: χ/ $\chi^\dagger$ interacts with scattering_particle

P + P → **meson** + something
meson → γ + V
V → χ + $\chi^\dagger$
$\chi/\chi^\dagger$ scatters with scattering_particle

Format in events.dat:

event number

meson	px	py	pz	E				
V	px	py	pz	E				
DM	px	py	pz	E				
scatt_part	px	py	pz	E	x	y	z	t

Notes:

- **meson = neutral pion (π^0 in pi0_decay), eta (in eta_decay), phi (in phi_decay) f**rom Patrick's comments in the code (the parameter card)
- Appendix says these are also possible production channels: omega (omega in omega_decay), rho (in rho_decay) but when I run it with omega_decay, I get “No DM production expected” (maybe there is DM production for only a certain set of model parameters, but I don't know what), and I get a seg fault when I run I with rho_decay => these production channels are probably not yet implemented in BdNMC
- “pi0 and eta decays provide the dominant production channel for sufficiently light DM and mediators” from paper
- scattering_particle = proton, neutron, electron
- scattering off a proton is much more likely than scattering off a neutron (the dominant term in incoherent NC-like nucleon scattering couples to electric charge)

Description of interactions: both χ + $\chi^\dagger$ interact within detector

P + P → meson + something
meson → γ + V
V → χ + $\chi^\dagger$
χ scatters with scattering_particle
$\chi^\dagger$ scatters with another scattering_particle
→ should be rare (both χ + $\chi^\dagger$ interact within detector)

Format in events.dat:

event number								
meson	px	py	pz	E				
V	px	py	pz	E				
DM	px	py	pz	E				
scatt_part	px	py	pz	E	x	y	z	t
DM	px	py	pz	E				
scatt_part2	px	py	pz	E	x	y	z	t

Notes:
meson = pion(π^0 in pi0_decay), eta (in eta_decay), phi (in phi_decay)
scattering_particle1 or 2 = proton, neutron, or electron

Description of interactions: one of χ /$\chi^\dagger$ scatters in the detector, the other intersects the detector but doesn't scatter

P + P → meson + something
meson → γ + V
V → χ + $\chi^\dagger$
χ/ $\chi^\dagger$ scatters

Format in events.dat:

event number								
meson	px	py	pz	E				
V	px	py	pz	E				
DM	px	py	pz	E				
DM	px	py	pz	E				
scatt_part	px	py	pz	E	x	y	z	t

or

event number								
meson	px	py	pz	E				
V	px	py	pz	E				
DM	px	py	pz	E				
scatt_part	px	py	pz	E	x	y	z	t
DM	px	py	pz	E				

Notes:
meson = pion(π^0 in pi0_decay), eta (in eta_decay), phi (in phi_decay)
scattering_particle = proton, neutron, electron

Production channel: proton bremsstruhlung

Description of interactions: χ/ $\chi^\dagger$ interacts with scattering_particle

p + N → p +N + V
V → χ + $\chi^\dagger$
χ/$\chi^\dagger$ scatters with scattering_particle

N = p or n

Format in events.dat:

event number

V	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t

Note: scattering_particle = proton, neutron, electron

Description of interactions: both $\chi + \chi^{\dagger}$ interact within detector

$p + N \rightarrow p + N + V$

$V \rightarrow \chi + \chi^{\dagger}$

χ scatters with scattering_particle

$\chi^{\dagger}$ scatters with another scattering_particle

$\rightarrow$ should be rare (both $\chi + \chi^{\dagger}$ interact within detector)

N = p or n

Format in events.dat:

event number

V	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t
DM	px	py	pz				
scatt_part_2	px	py	pz	x	y	z	t

Note: scattering_particle1/scattering_particle2 = proton, neutron, electron

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Description of interactions: one of χ /$\chi^{\dagger}$ scatters in the detector, the other intersects the detector but doesn't scatter

$p + N \rightarrow p + N + V$

$V \rightarrow \chi + \chi^{\dagger}$

$\chi/\chi^{\dagger}$scatters with scattering_particle

N = p or n

Format in events.dat:

event number

V	px	py	pz				
DM	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t

or

event number

V	px	py	pz
DM	px	py	pz

scatt_part	px	py	pz	x	y	z	t
DM	px	py	pz				

Note: scattering_particle = proton, neutron, electron

Production channel: pi-minus_capture

this is a baryonic production channel, according to the comments in the BdNMC parameter card

**** BdNMC gives a negative number of V's, then produces a seg fault.***

Once I look at some events, I'll have a better idea of what they look like, but for now:

Description of interactions: χ/ $\chi^{\dagger}$ interacts with scattering_particle

$P + \pi^{-} \rightarrow N^{*} \rightarrow N + V$

(as described by Patrick on github where he introduces the features of BdNMC 3.1.5; I'm assuming N= p/n as usual)

$V \rightarrow \chi + \chi^{\dagger}$

χ /$\chi^{\dagger}$scatters with scattering_particle

I haven't see this in BdNMC, but this is more or less what it should look like

Format in events.dat:

event number

π^{-}	px	py	pz				
V	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t

Note: scattering particle = proton, neutron, or electron

Description of interactions: both $\chi + \chi^{\dagger}$ interact within detector

$P + \pi^{-} \rightarrow N^{*} \rightarrow N + V$

$V \rightarrow \chi + \chi^{\dagger}$

χ scatters with scattering_particle

$\chi^{\dagger}$ scatters with another scattering_particle

$\rightarrow$ should be rare (both $\chi + \chi^{\dagger}$ interact within detector)

N = p or n

Format in events.dat:

event number

π^{-}	px	py	pz				
V	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t
DM	px	py	pz				
scatt_part_2	px	py	pz	x	y	z	t

Note: scattering particle = proton, neutron, or electron

Description of interactions: one of χ /$\chi^{\dagger}$ scatters in the detector, the other intersects the detector

but doesn't scatter
$P + \pi^- \rightarrow N^* \rightarrow N + V$
$V \rightarrow \chi + \chi^\dagger$
$\chi/\chi^\dagger$ scatters with scattering_particle

N = p or n

Format in events.dat:

event number

π^-	px	py	pz				
V	px	py	pz				
DM	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t

or

event number

π^-	px	py	pz				
V	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t
DM	px	py	pz				

Note: scattering particle = proton, neutron, or electron

Production channel: parton production

**** need to look at the format of events.dat in bdnmc with this channel; does it look the same as proton bremm? (I get a seg fault when I use his production channel without a distribution and appendix says "parton_V" (the distribution for parton_production) needs externally generated data for V-production at the parton level). Once I look at some events, I'll have a better idea of what they look like, but for now:***

Description of interactions: $\chi/\chi^\dagger$ interacts with scattering_particle
$P + N \rightarrow V^*$
$V^* \rightarrow \chi + \chi^\dagger$
$\chi/\chi^\dagger$ interacts with scattering_particle

N = p or n

***Format in events.dat:**

event number

V	px	py	pz
DM	px	py	pz

scatt_part	px	py	pz	x	y	z	t

scattering_particle = neutron, proton, or electron

Description of interactions: both $\chi + \chi^{\dagger}$ interact within detector

$P + N \rightarrow V^*$

$V^* \rightarrow \chi + \chi^{\dagger}$

χ interacts with scattering_particle

$\chi^{\dagger}$ interacts with scattering_particle_2

$\rightarrow$ should be rare (both $\chi + \chi^{\dagger}$ interact within detector)

N = p or n

Format in events.dat:

event number

V	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t
DM	px	py	pz				
scatt_part_2	px	py	pz	x	y	z	t

scattering_particle = proton, neutron, electron

Description of interactions: one of χ /$\chi^{\dagger}$ scatters in the detector, the other intersects the detector but doesn't scatter

$P + N \rightarrow V^*$

$V^* \rightarrow \chi + \chi^{\dagger}$

$\chi/\chi^{\dagger}$ scatters with scattering_particle

N = p or n

Format in events.dat:

event number

V	px	py	pz				
DM	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t

or

event number

V	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t
DM	px	py	pz				

scattering particle = proton, neutron, electron

(for all production channels) it's possible that the produced χ undergoes inelastic NC π^0-like nucleon scattering:

a situation “where there is sufficient momentum transfer to produce a neutral pion which subsequently decays producing a two-photon signature”
“Incoherent NC π^0 ; pion emerges via the production of a $\Delta(1232)$ resonance in the following process [1]
$\chi + N \rightarrow \chi + \Delta$
$\Delta \rightarrow N + \pi^0$

…..

DM	px	py	pz	E				
recoil_DM	px	py	pq	E				
Delta	px	py	pz	E	x	y	z	t
nucleon	px	py	pz	E				
pi0								

It is possible that both DM particles undergoes NC π^0-like scattering in the detector (rare), ior one DM particle undergoes NC π^0-like scattering in the detector while the other (the DM antiparticle) intersects the detector but does not scatter. Will show what these events look like .

The papers I refer to

1- “Light dark matter in neutrino beams: production modelling and scattering signatures at MiniooNE, T2K, and SHiP” by Patrick de Niverville et al.