

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

***Production channel: meson decay***

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**Description of interactions:**  $\chi/\chi^\dagger$  interacts with scattering\_particle

$P + P \rightarrow$  **meson** + something  
 meson  $\rightarrow \gamma + V$   
 $V \rightarrow \chi + \chi^\dagger$   
 $\chi/\chi^\dagger$  scatters with scattering\_particle

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**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 ( $\pi^0$  in pi0\_decay), eta (in eta\_decay), phi (in phi\_decay)** from 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  $\chi + \chi^\dagger$  interact within detector**

$P + P \rightarrow$  meson + something  
 meson  $\rightarrow \gamma + V$   
 $V \rightarrow \chi + \chi^\dagger$   
 $\chi$  scatters with scattering\_particle  
 $\chi^\dagger$  scatters with another scattering\_particle  
 → should be rare (both  $\chi + \chi^\dagger$  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( $\pi^0$  in pi0\_decay), eta (in eta\_decay), phi (in phi\_decay)  
 scattering\_particle1 or 2 = proton, neutron, or electron

**Description of interactions: one of  $\chi/\chi^\dagger$  scatters in the detector, the other intersects the detector but doesn't scatter**P + P  $\rightarrow$  meson + somethingmeson  $\rightarrow$   $\gamma$  + VV  $\rightarrow$   $\chi$  +  $\chi^\dagger$  $\chi/\chi^\dagger$  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( $\pi^0$  in pi0\_decay), eta (in eta\_decay), phi (in phi\_decay)  
 scattering\_particle = proton, neutron, electron

***Production channel: proton bremsstrahlung*****Description of interactions:  $\chi/\chi^\dagger$  interacts with scattering\_particle**p + N  $\rightarrow$  p + N + VV  $\rightarrow$   $\chi$  +  $\chi^\dagger$  $\chi/\chi^\dagger$  scatters with scattering\_particle

N = p or n

---

**Format in events.dat:**

event number

V	px	py	pz				
DM	px	py	pz				
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**

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

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

$\chi$  scatters with scattering\_particle

$\chi^\dagger$  scatters with another scattering\_particle

→ 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  $\chi/\chi^\dagger$  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

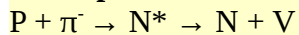
**Production channel: pi-minus\_capture**

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

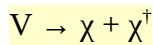
**\* BdNMC gives a negative number of V's, then produces a seg fault.**

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

**Description of interactions:  $\chi/\chi^\dagger$  interacts with scattering\_particle**



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



$\chi/\chi^\dagger$  scatters with scattering\_particle

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

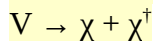
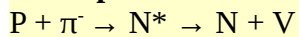
**Format in events.dat:**

event number

$\pi^-$	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**



$\chi$  scatters with scattering\_particle

$\chi^\dagger$  scatters with another scattering\_particle

→ should be rare (both  $\chi + \chi^\dagger$  interact within detector)

N = p or n

**Format in events.dat:**

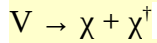
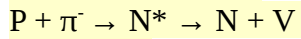
event number

$\pi^-$	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  $\chi/\chi^\dagger$  scatters in the detector, the other intersects the detector**

**but doesn't scatter**



$\chi/\chi^\dagger$  scatters with scattering\_particle

N = p or n

**Format in events.dat:**

event number

$\pi^-$	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

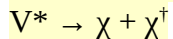
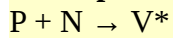
$\pi^-$	px	py	pz				
V	px	py	pz				
DM	px	py	pz				
scatt_part	px	py	pz	x	y	z	t
DM	px	py	pz				

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 brems? (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**



$\chi/\chi^\dagger$  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

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

$P + N \rightarrow V^*$

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

$\chi$  interacts with scattering\_particle

$\chi^\dagger$  interacts with scattering\_particle\_2

→ 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  $\chi / \chi^\dagger$  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  $\chi$  undergoes inelastic NC  $\pi^0$ -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  $\pi^0$  ; pion emerges via the production of a  $\Delta$  (1232) resonance in the following process <sup>1</sup>

$$\chi + N \rightarrow \chi + \Delta$$

$$\Delta \rightarrow N + \pi^0$$

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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  $\pi^0$ -like scattering in the detector (rare), ior one DM particle undergoes NC  $\pi^0$ -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.