Progress of BdNMC work

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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 $p+N \rightarrow V^* \rightarrow \chi/\chi^\dagger$
- 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 py pz E x y 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         1.65705e-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         1.65528e-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:

The branches:

- event_num: event number
- run_number

n :#particles in each event

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

These are arrays of size n

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)
- pz (for scattering particles) (GeV)
- E (for scattering particles) (GeV)
- X (in m, for scattering particles)
- Y (in m, for scattering particles)
- 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)

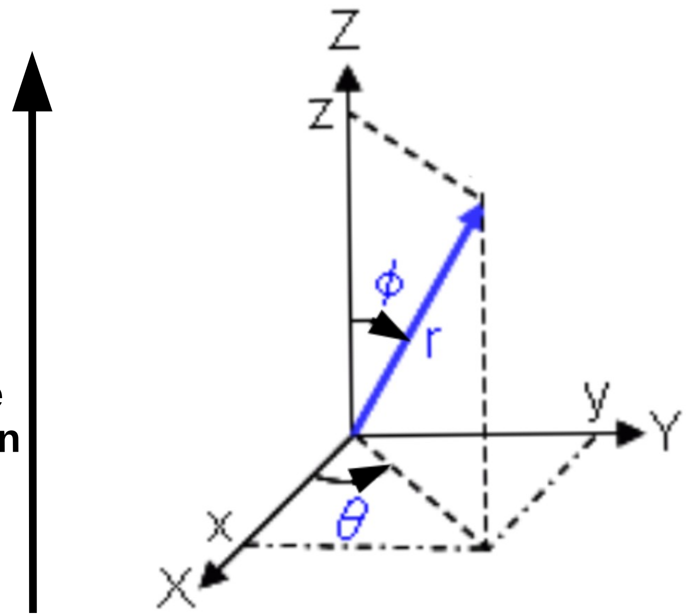
Ttree that stores all the information in events.dat

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:

Particle beam is along the z direction



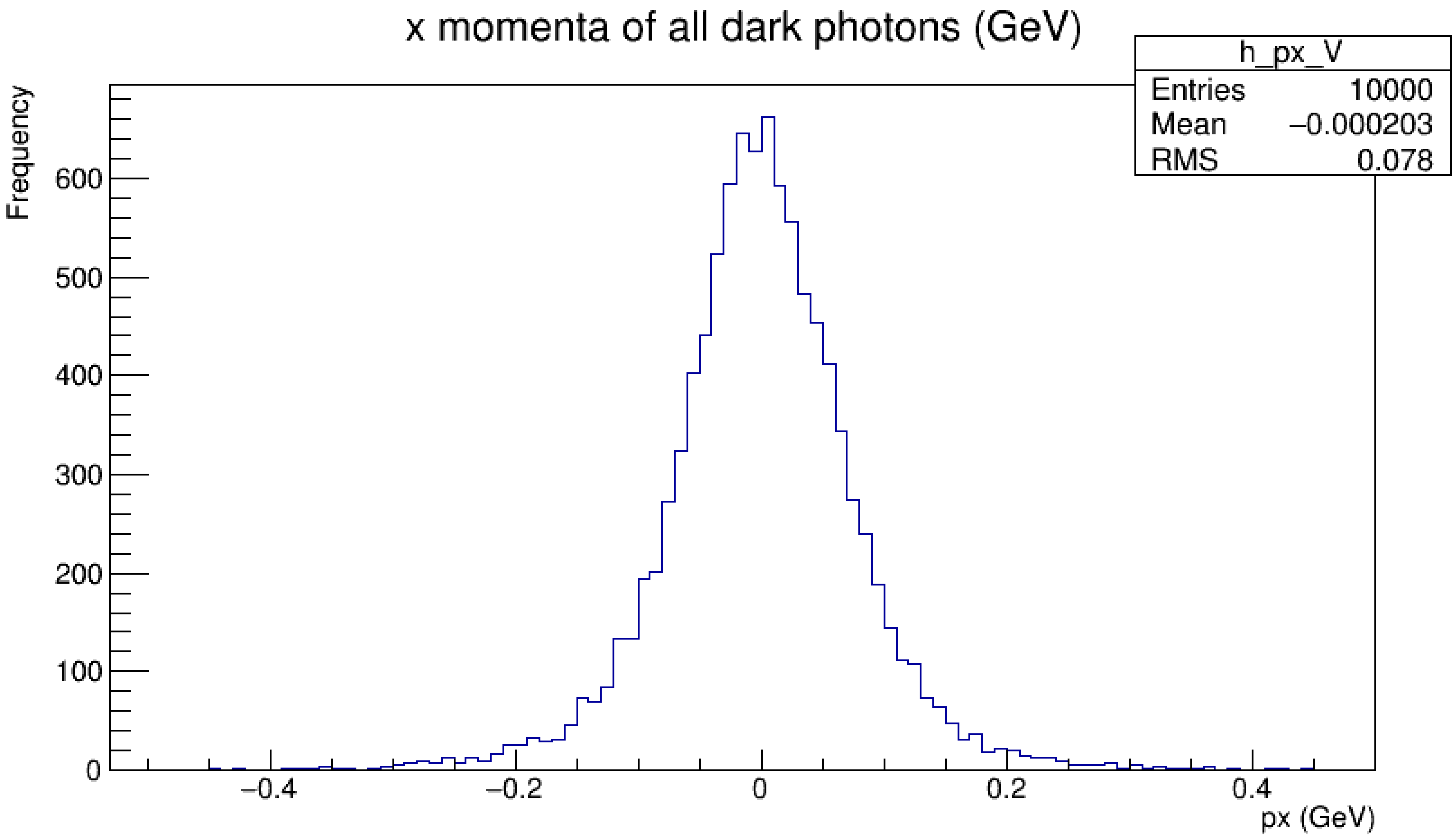
$$\theta = tan^{-1}\frac{y}{x}$$

$$\phi = tan^{-1}\frac{\sqrt{x^2+y^2}}{z}$$

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



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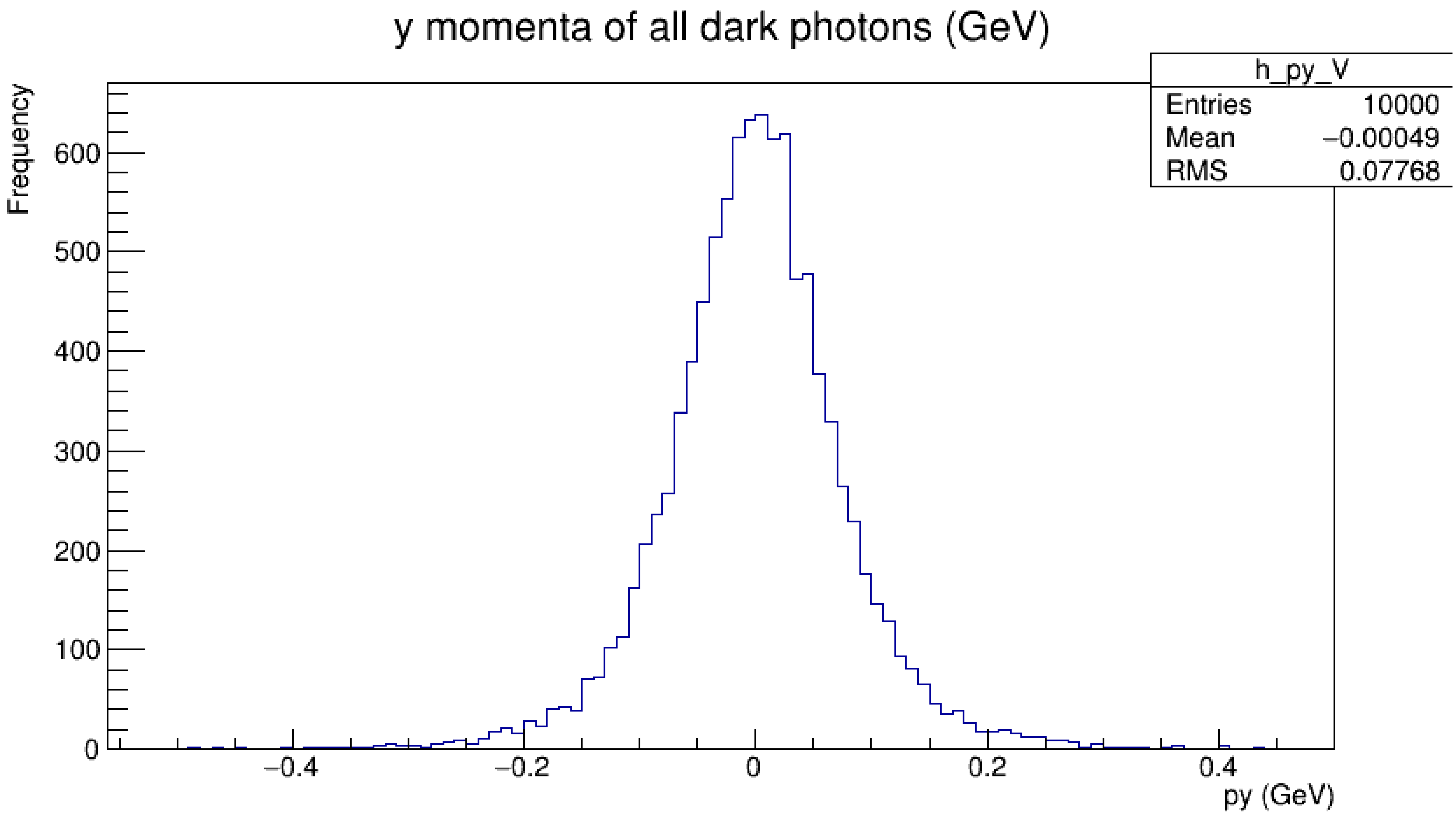

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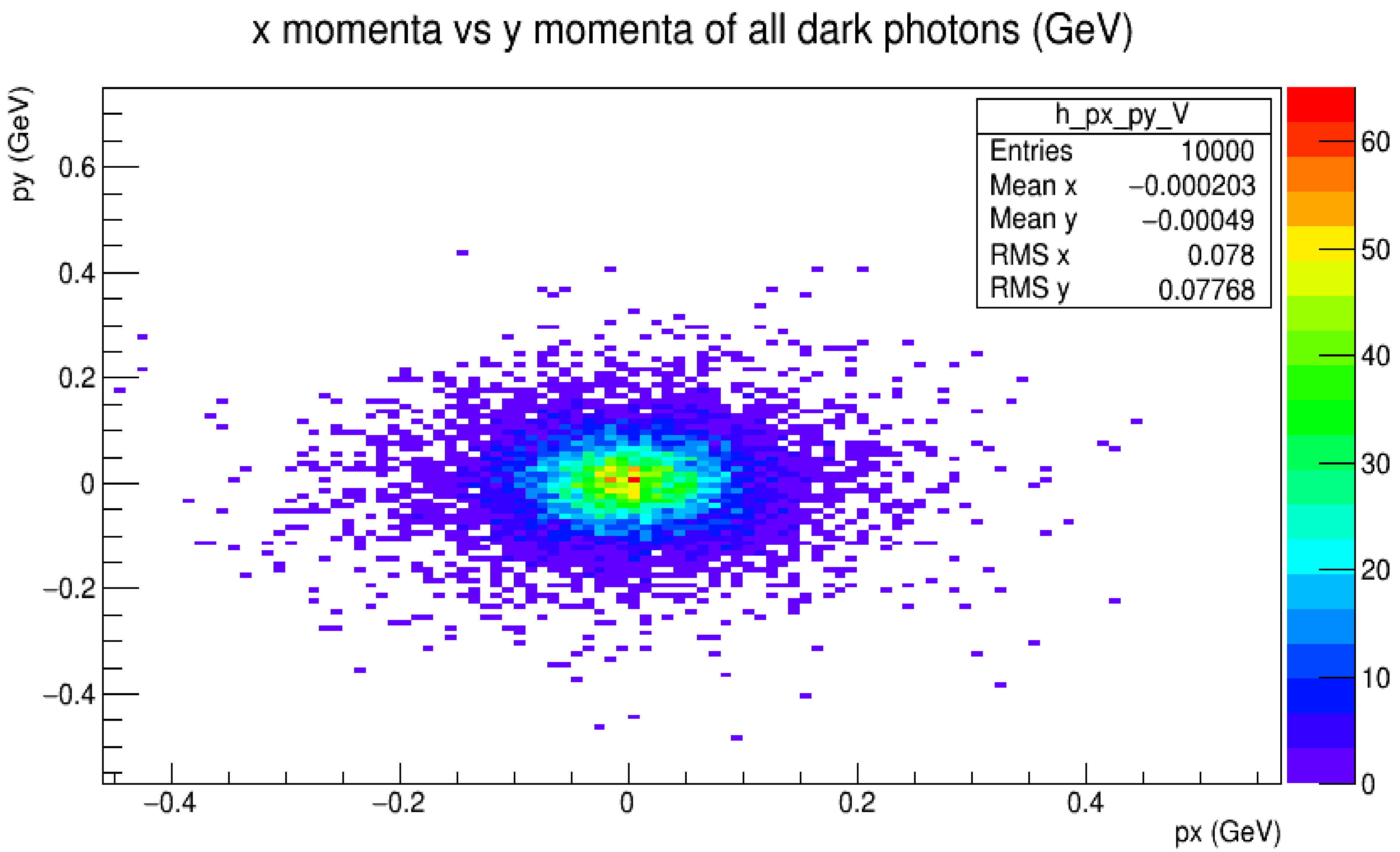

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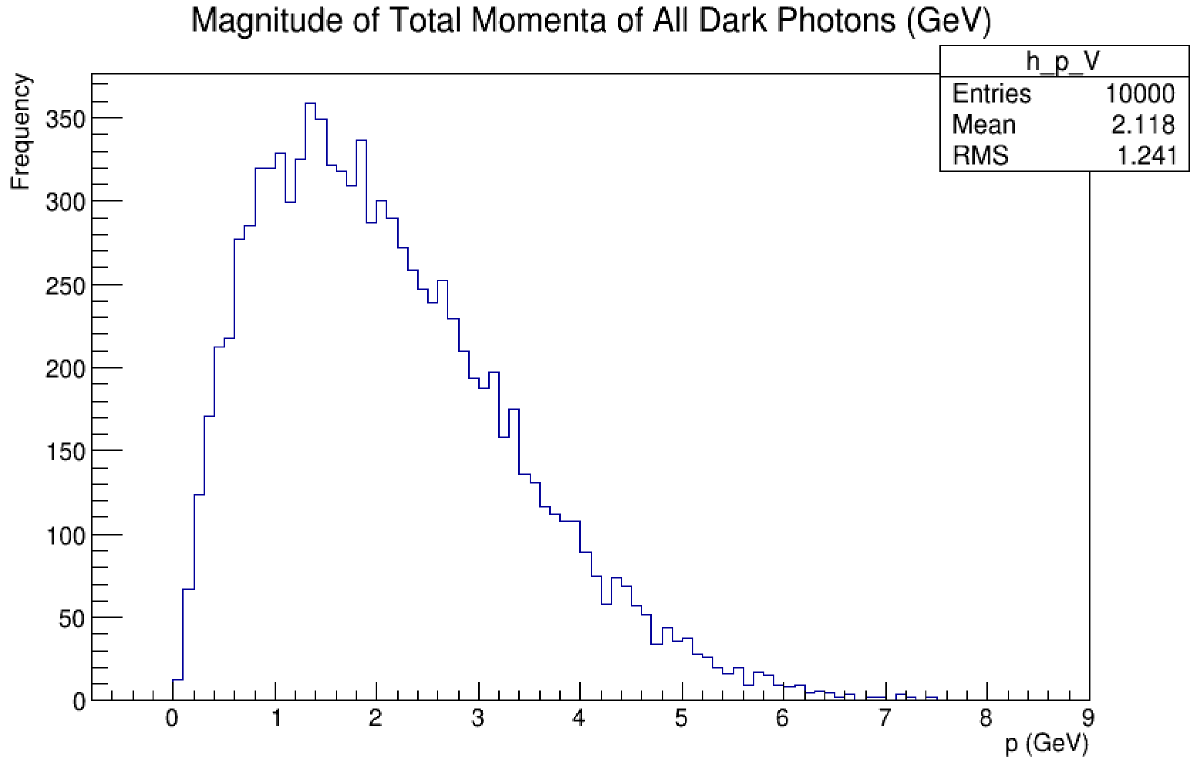

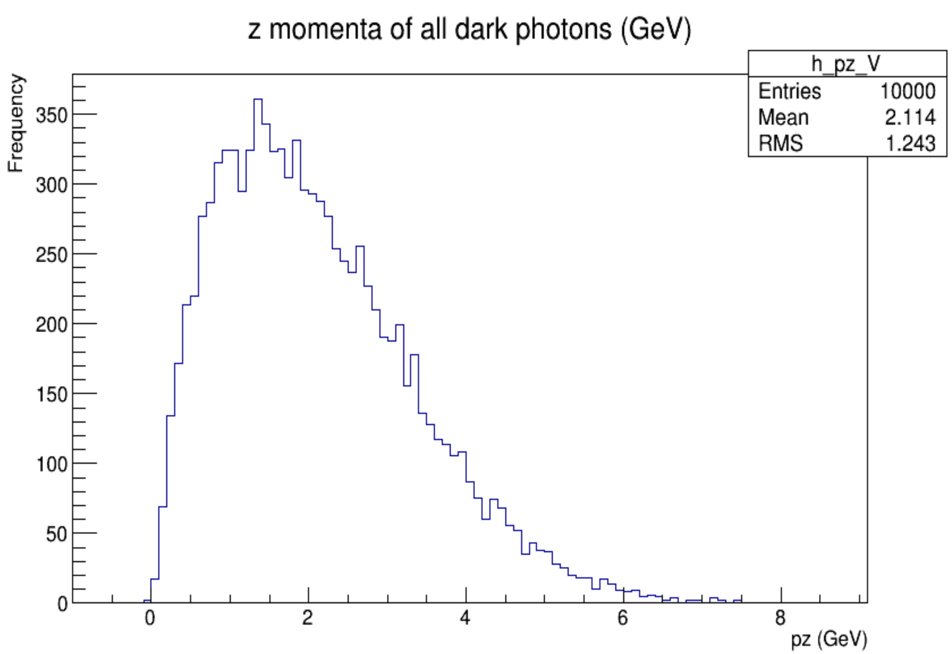

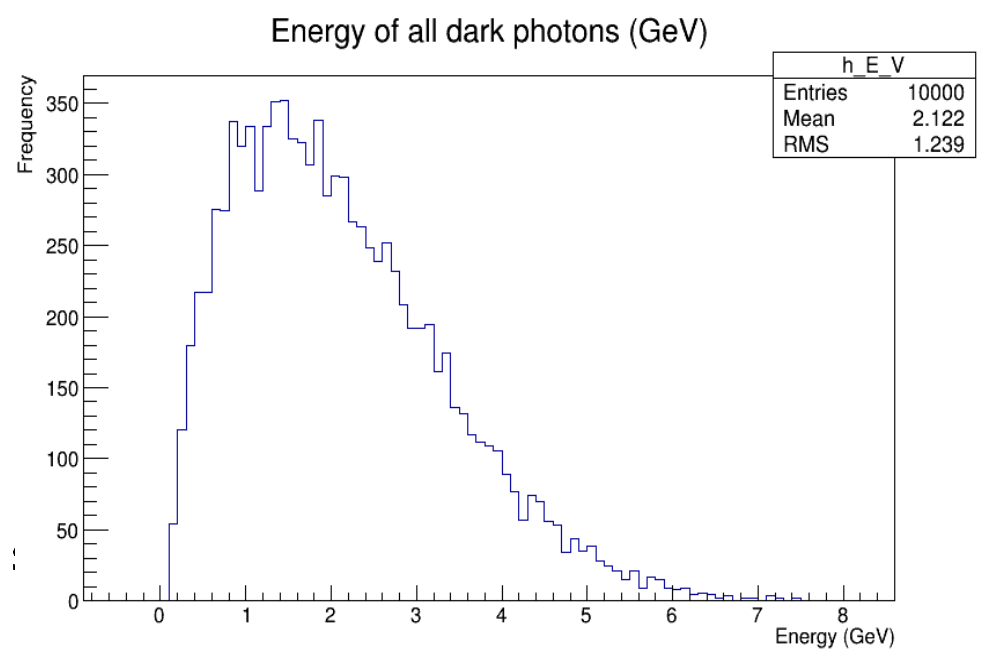

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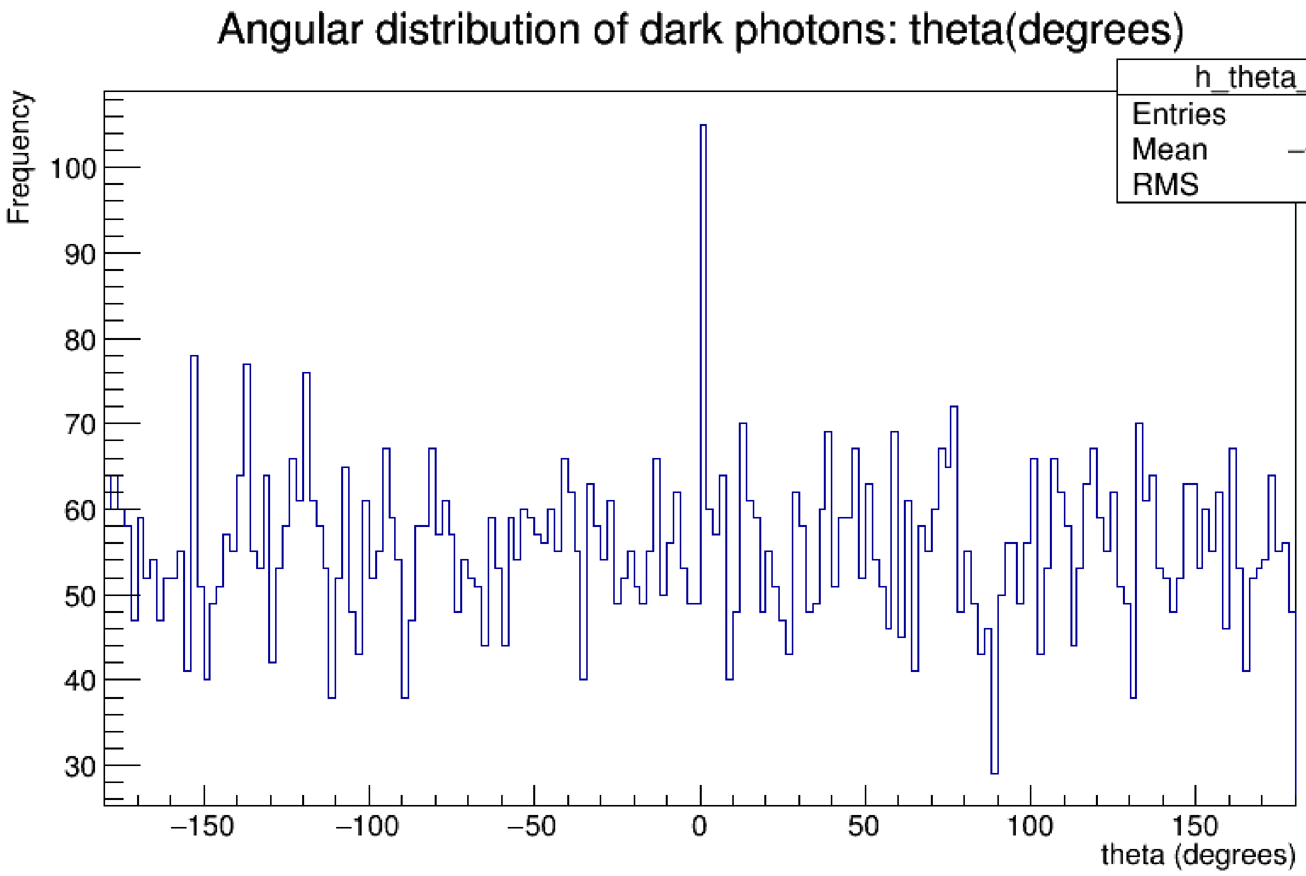

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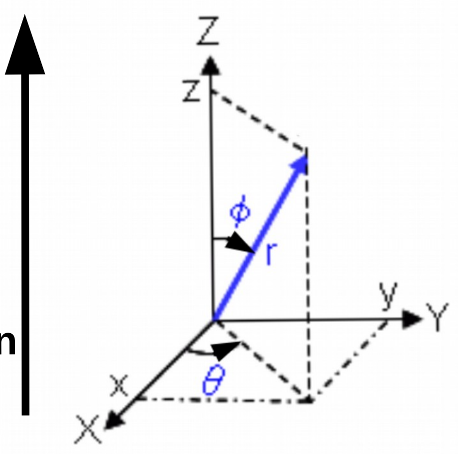

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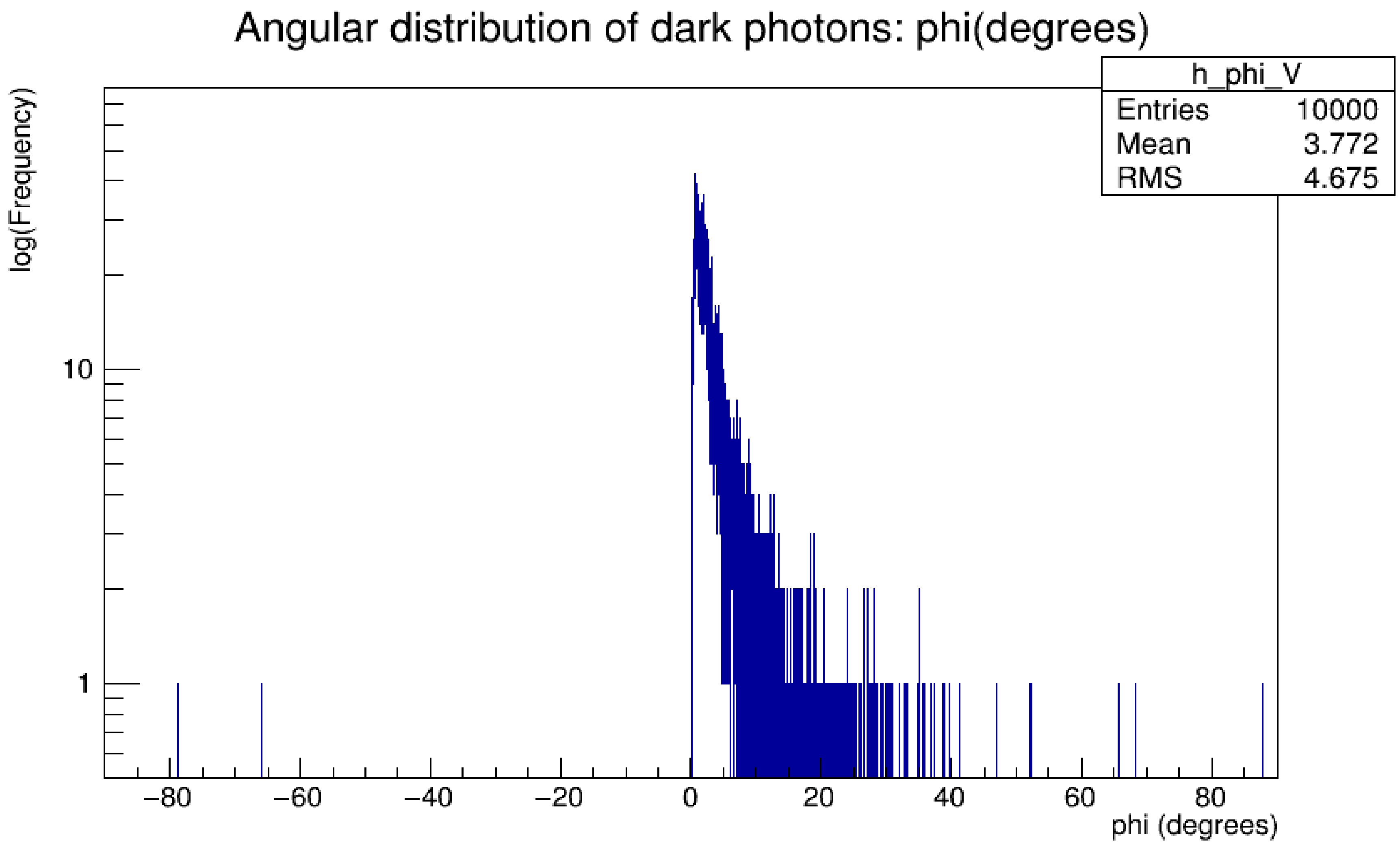

And the same thing for DM particles, scattered particles, etc

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**
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Run1498244748 , **mass_V = 0.3 GeV**
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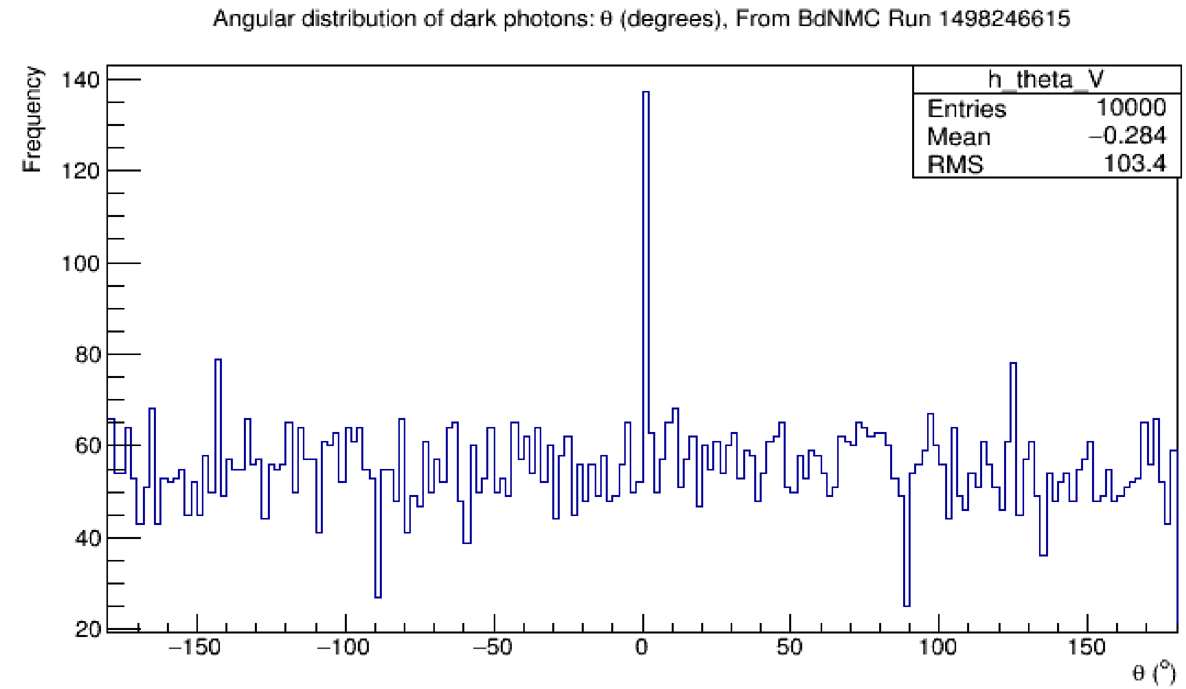

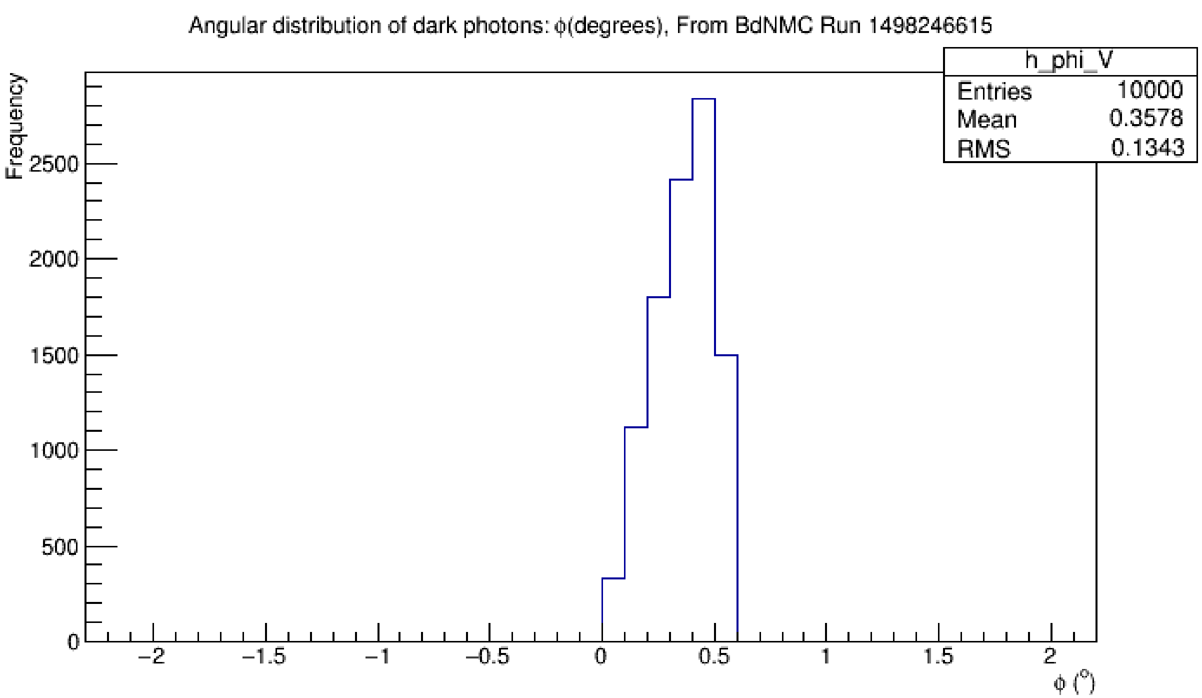

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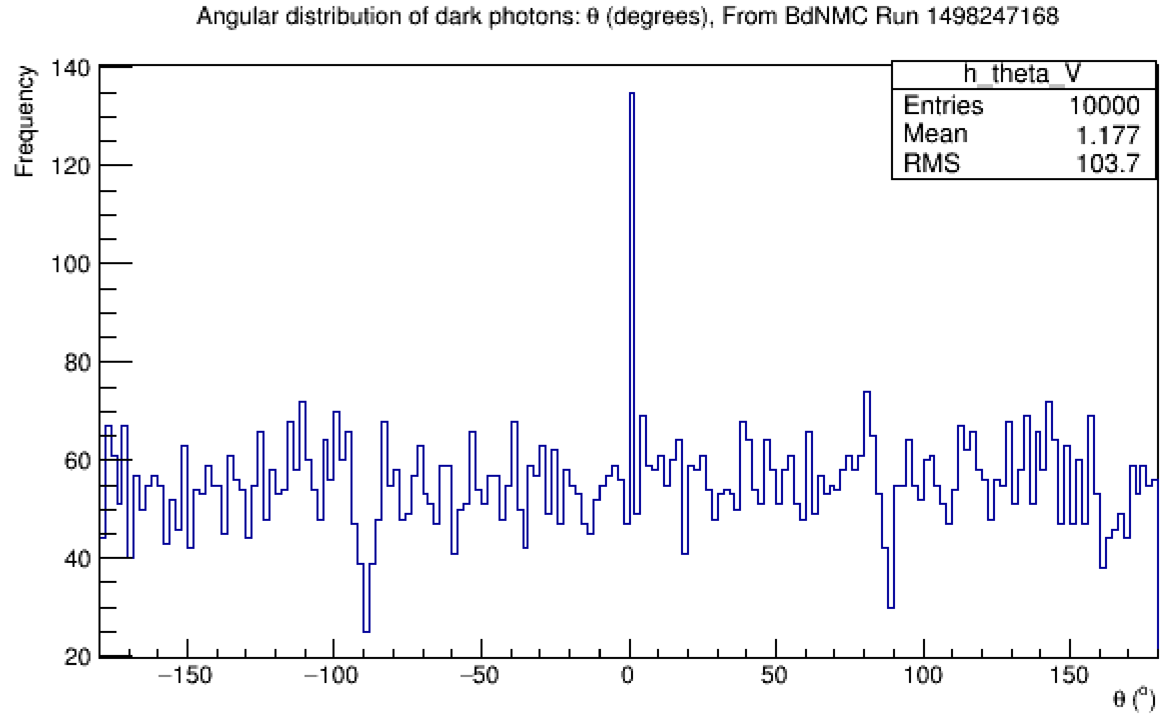

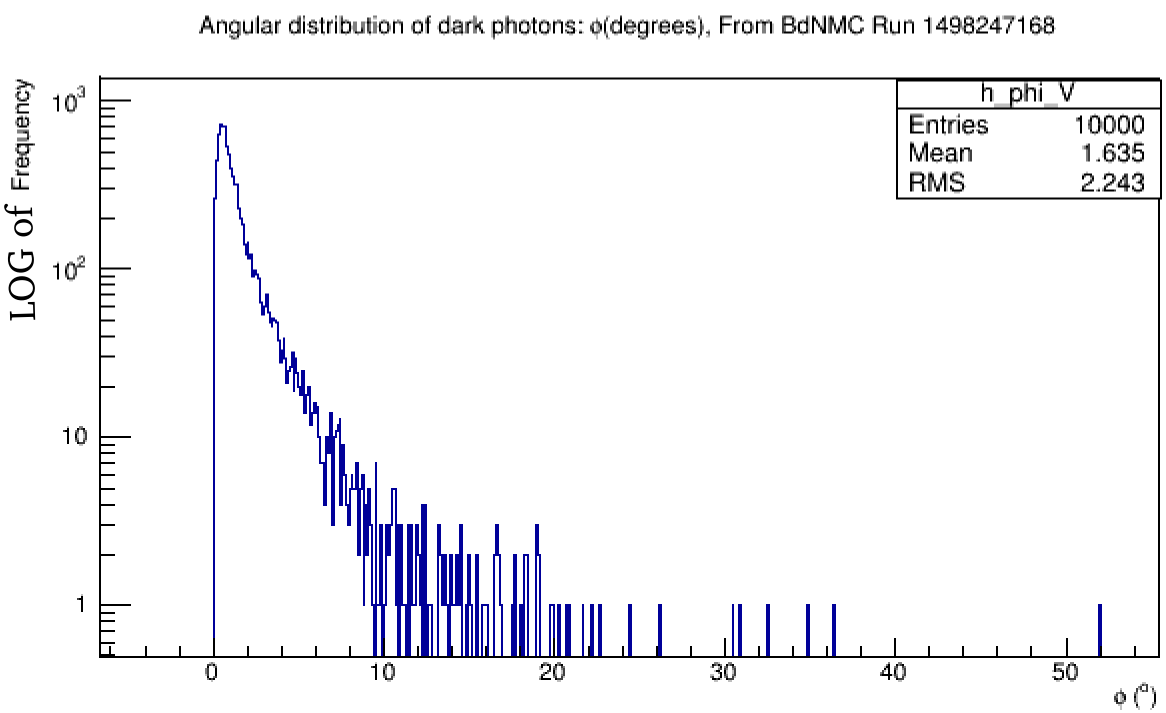

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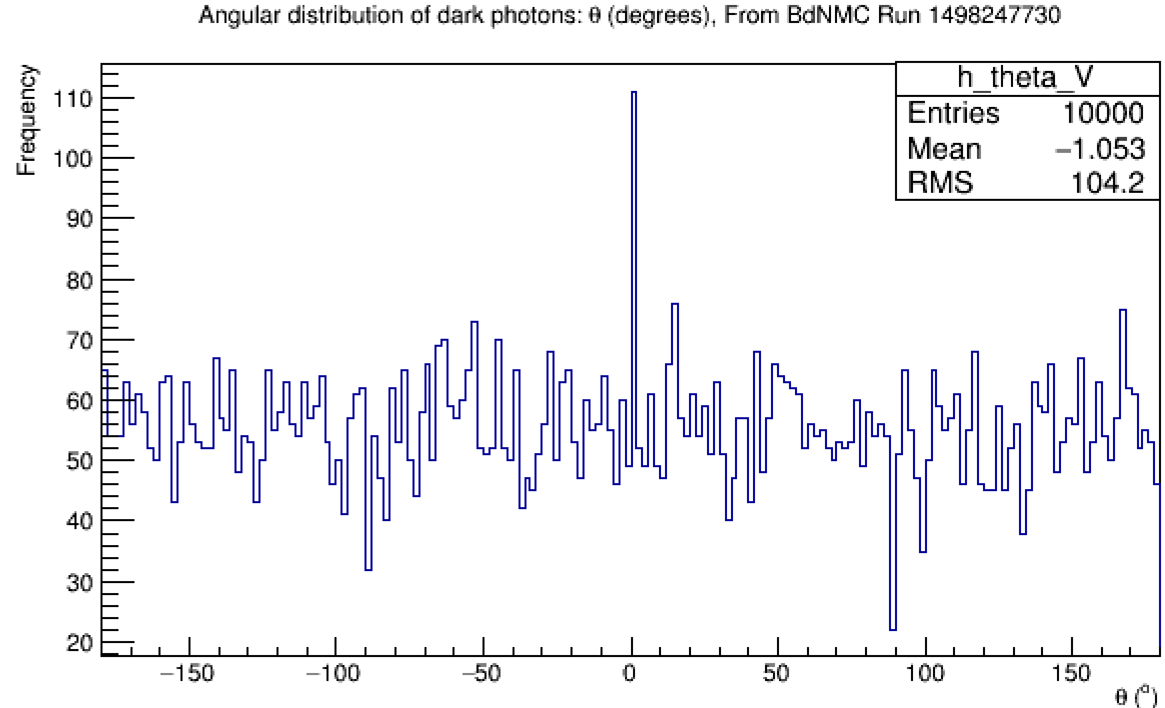

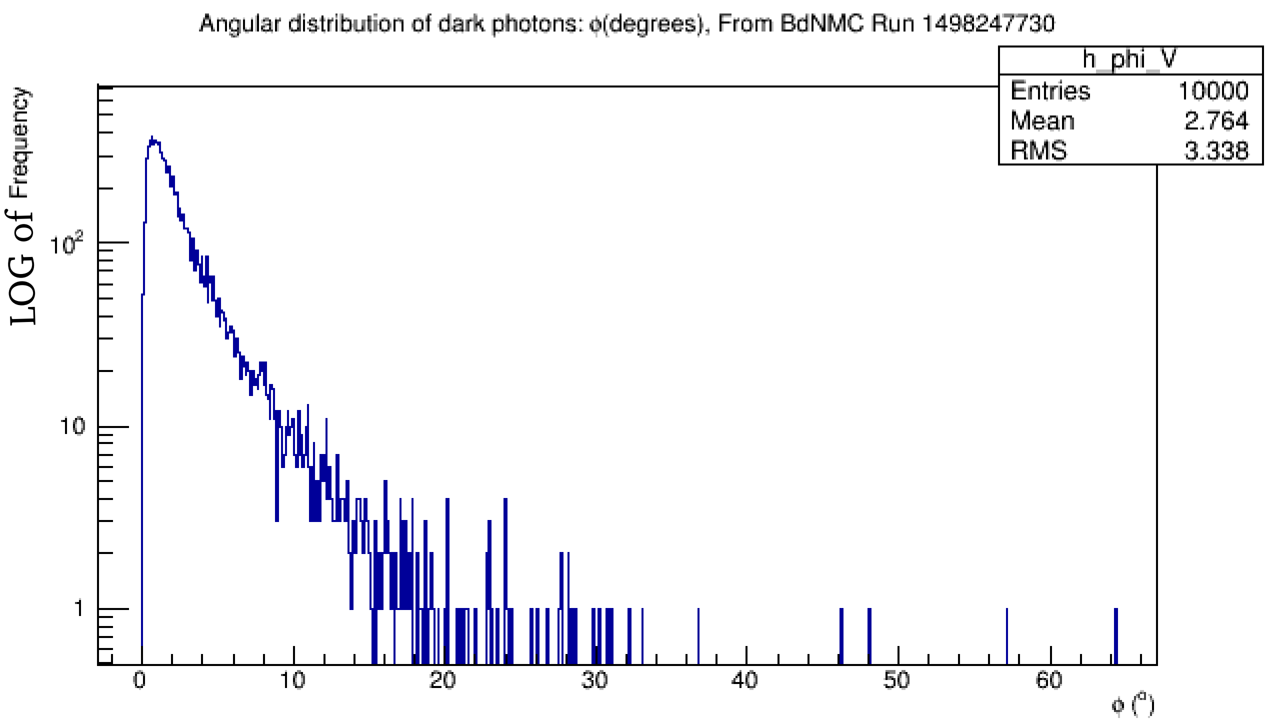

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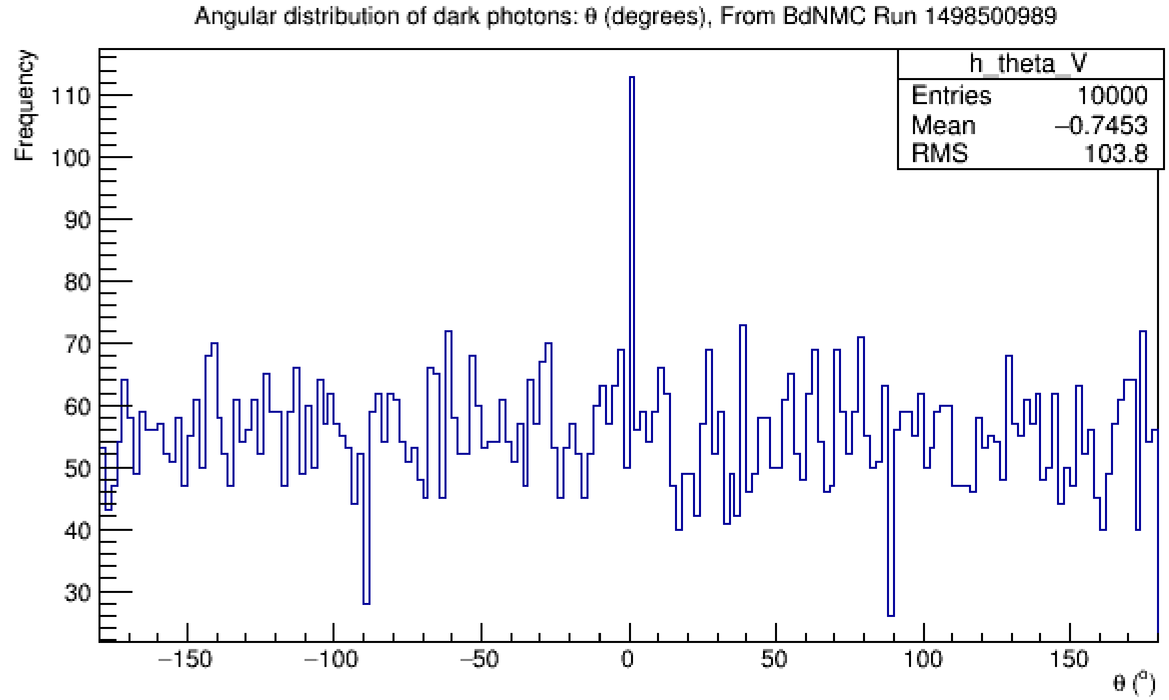

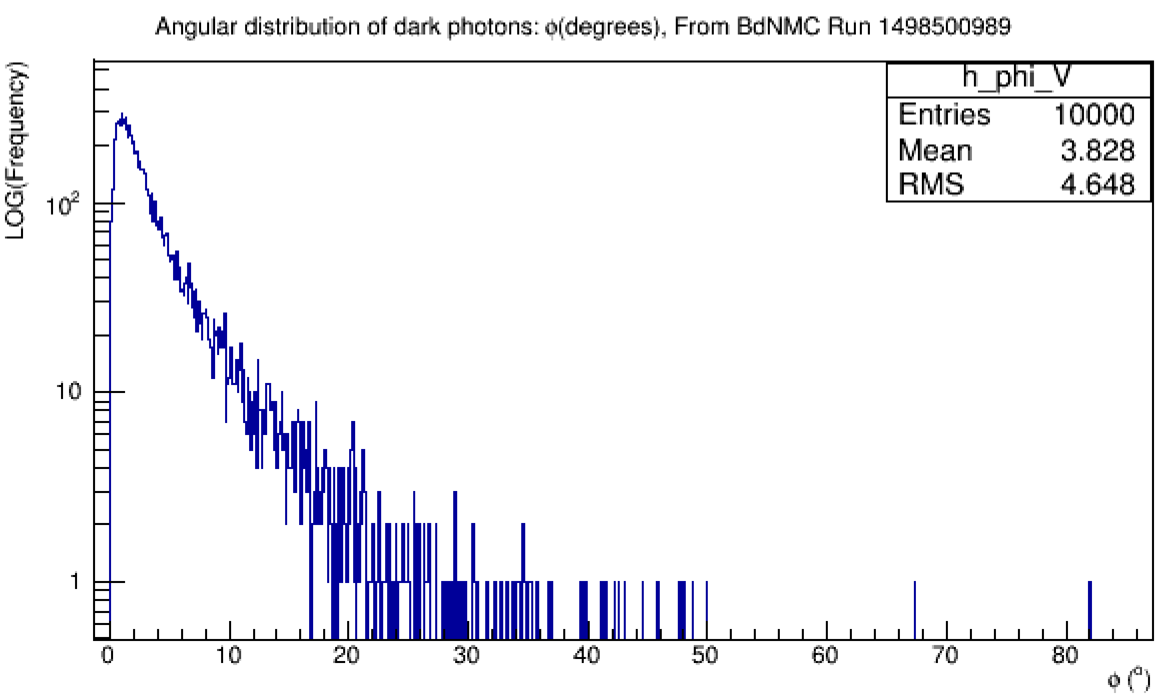

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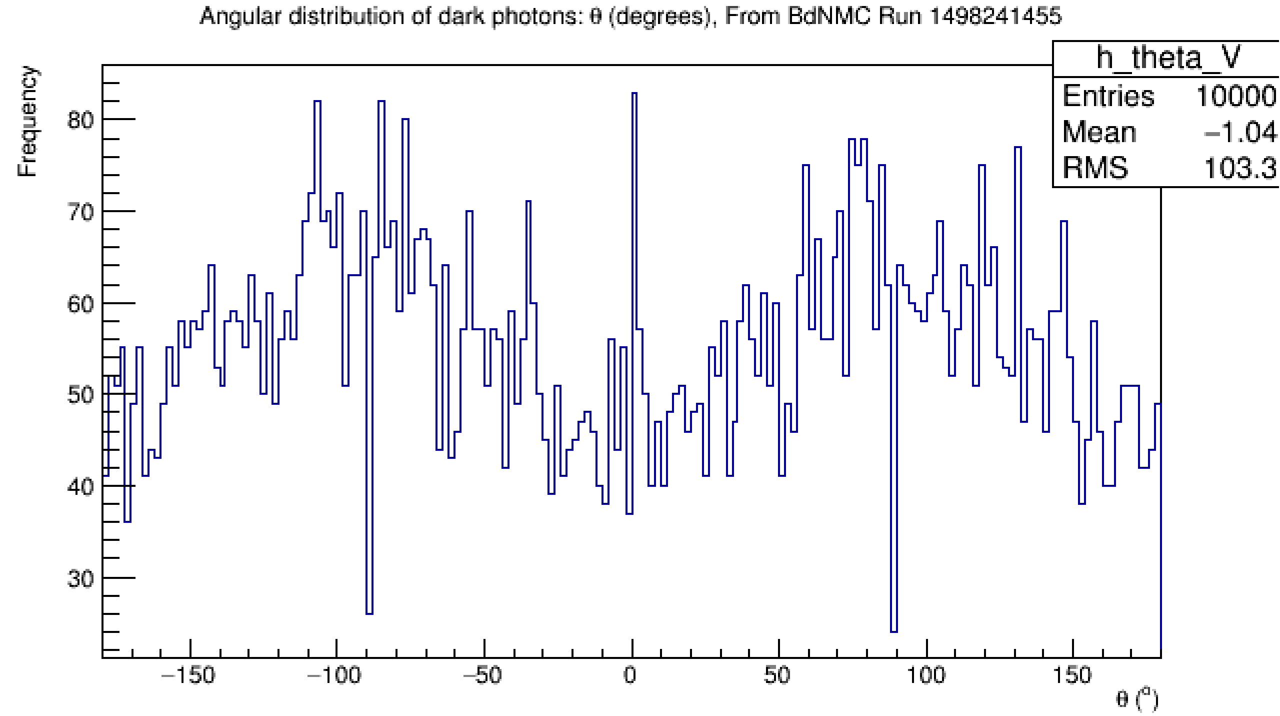

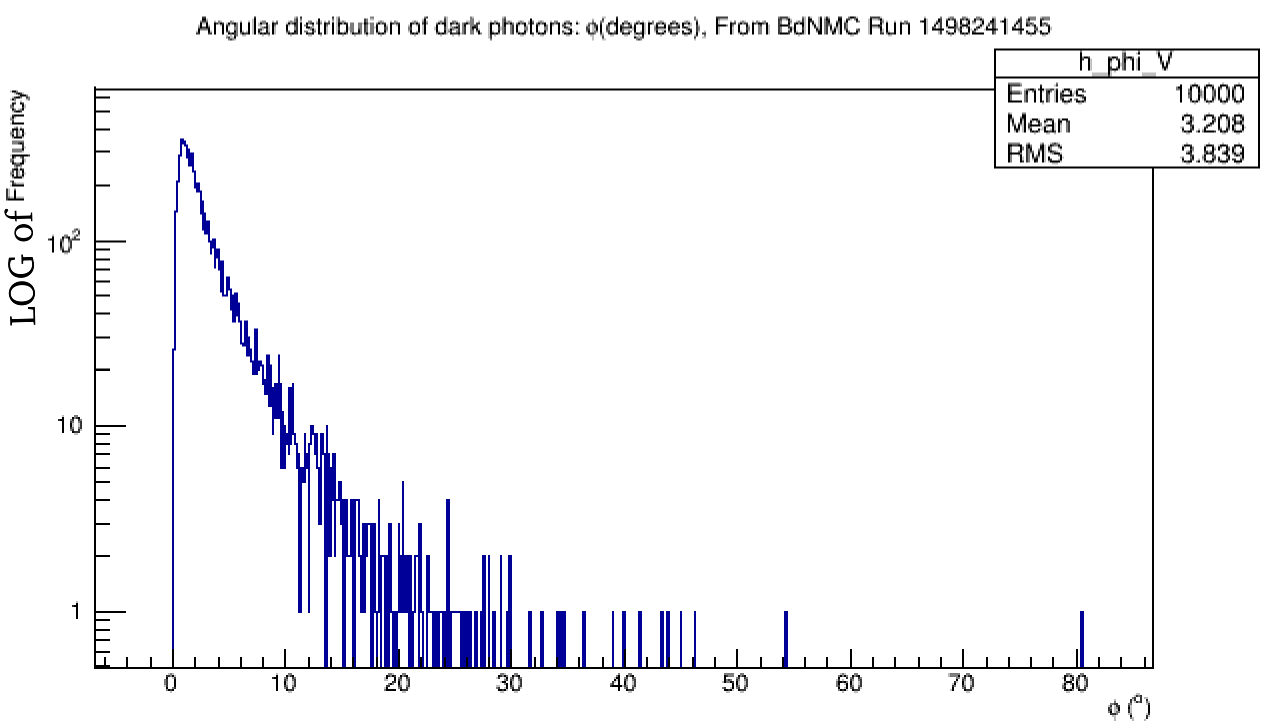

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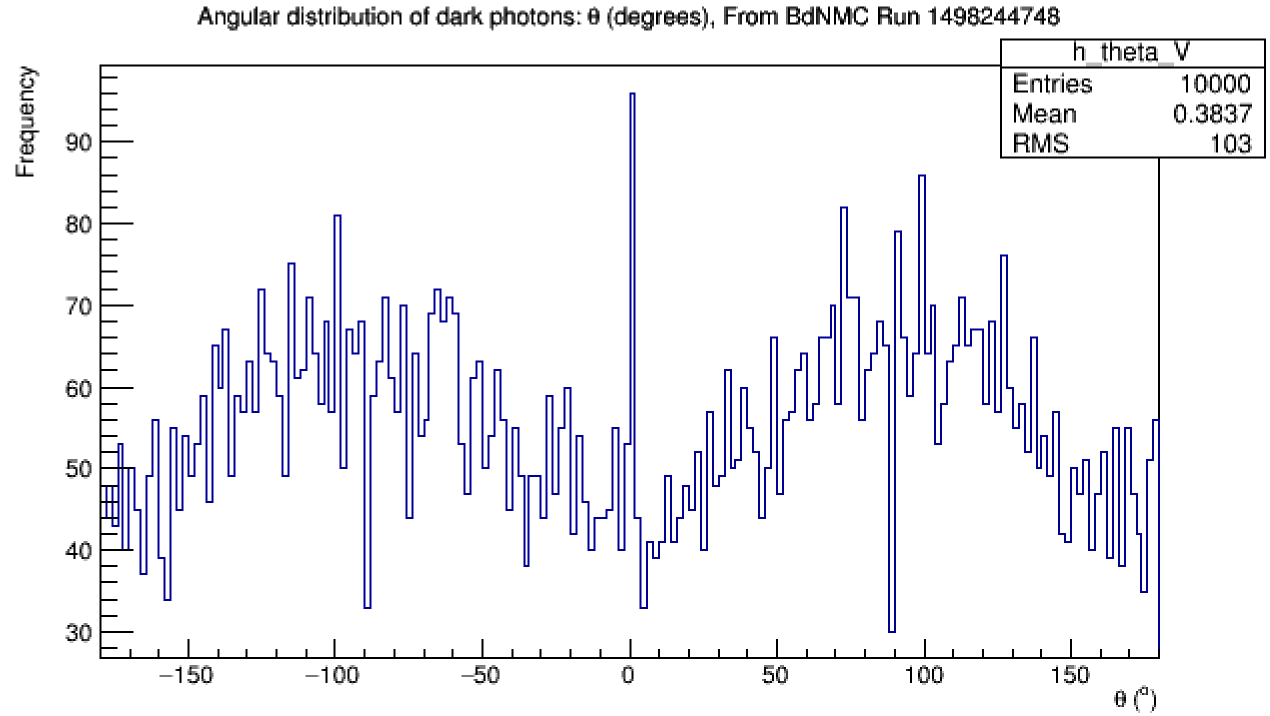

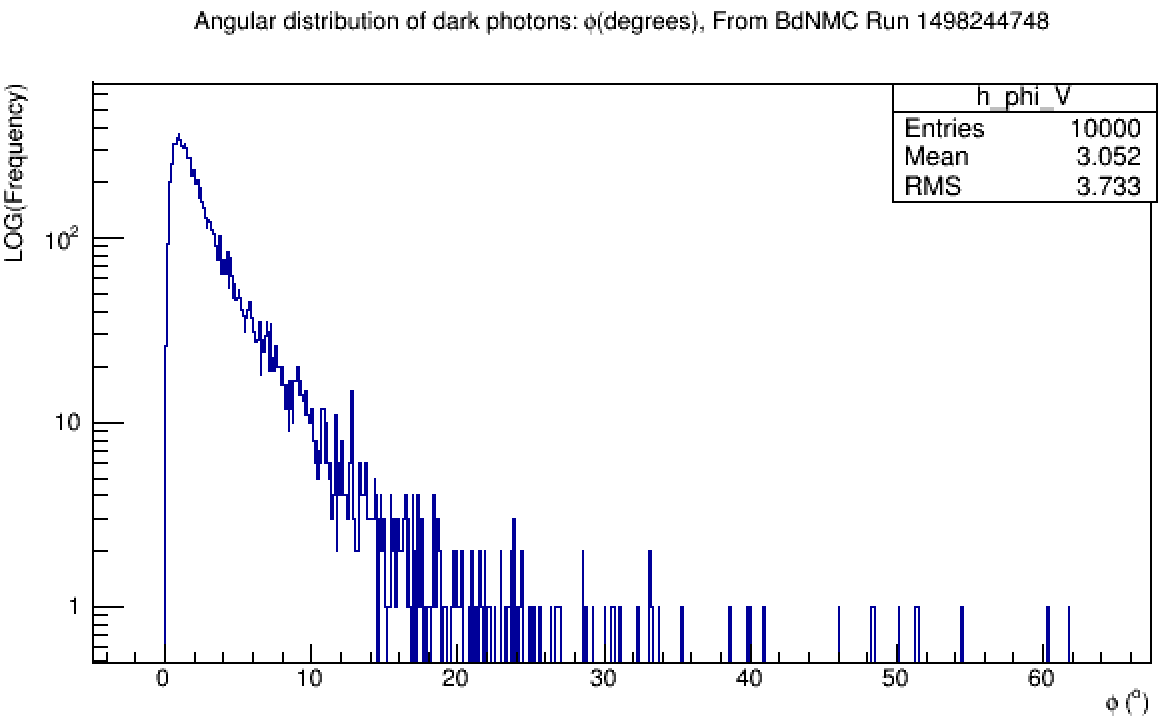

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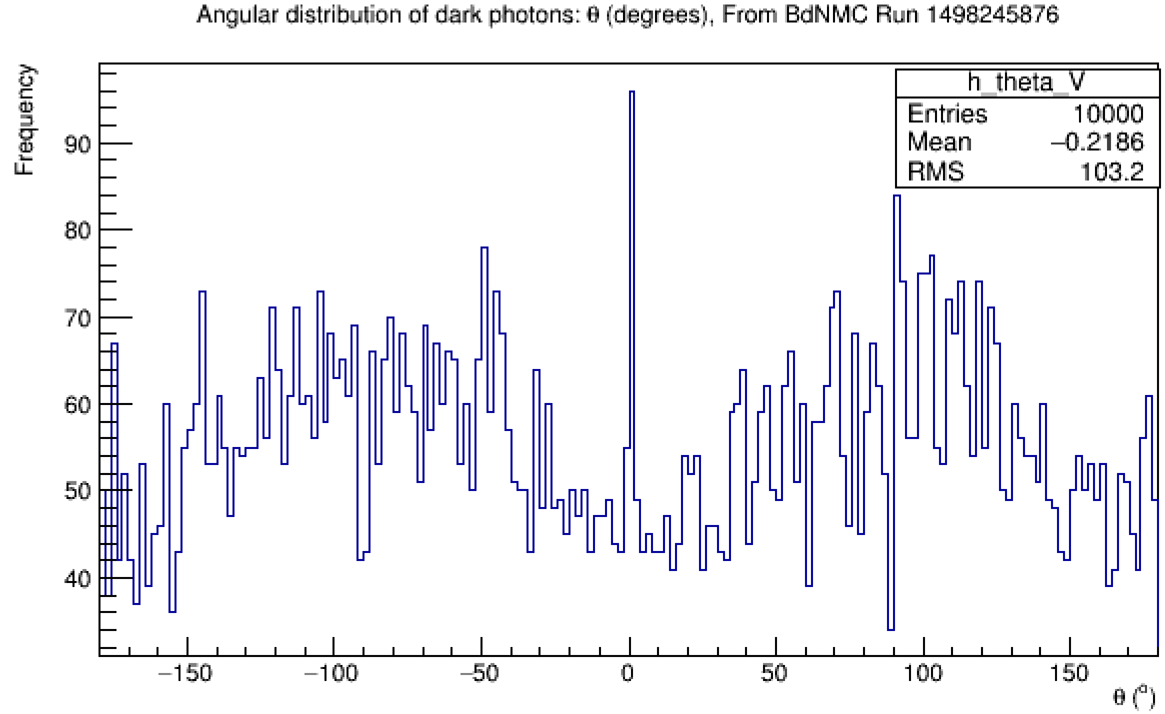

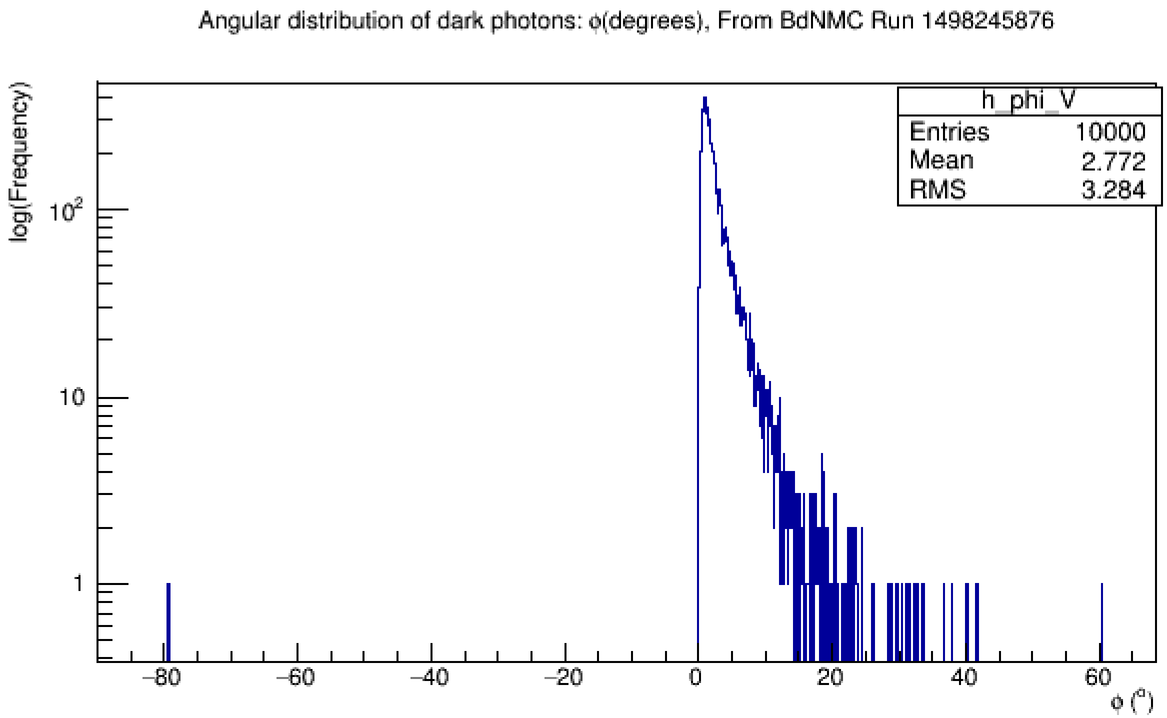

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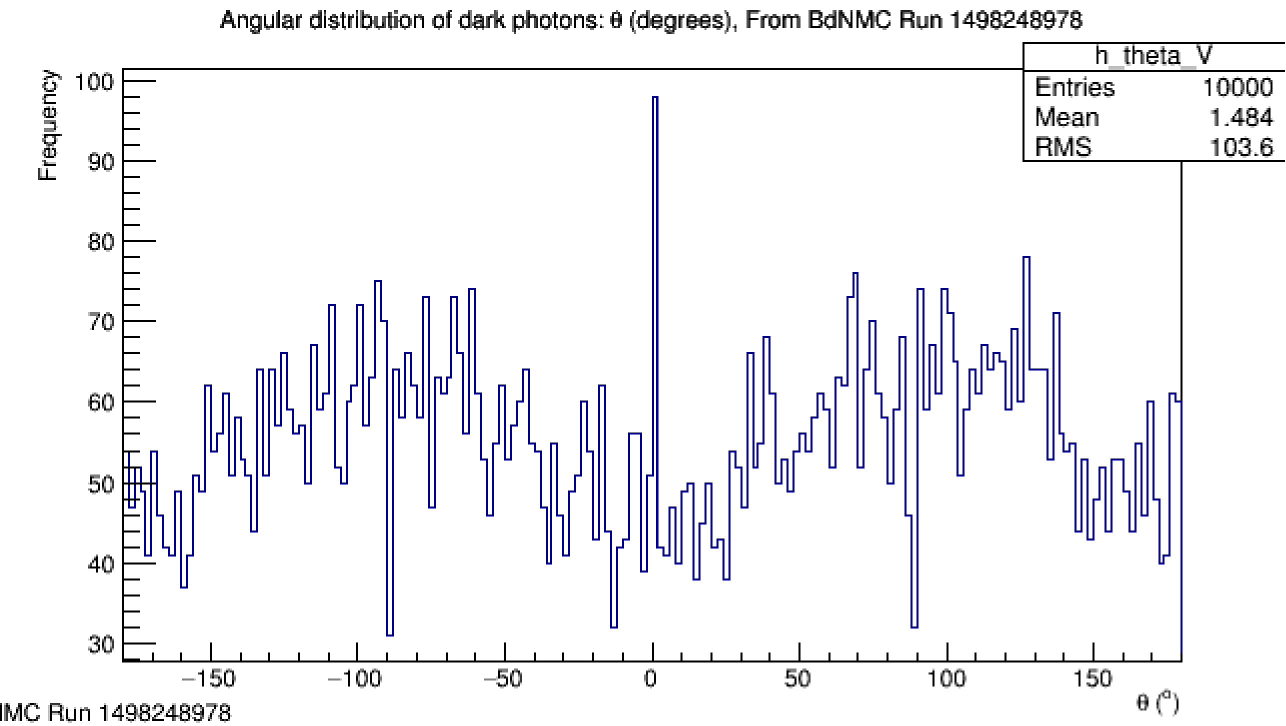

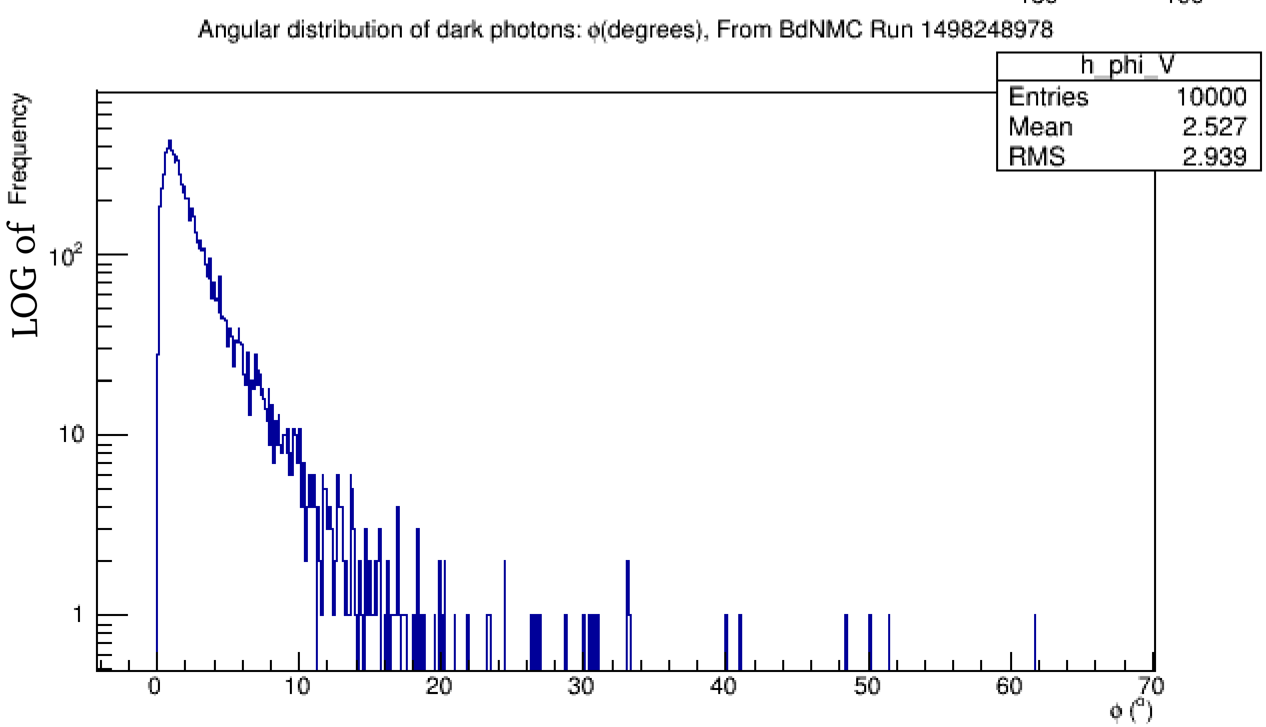

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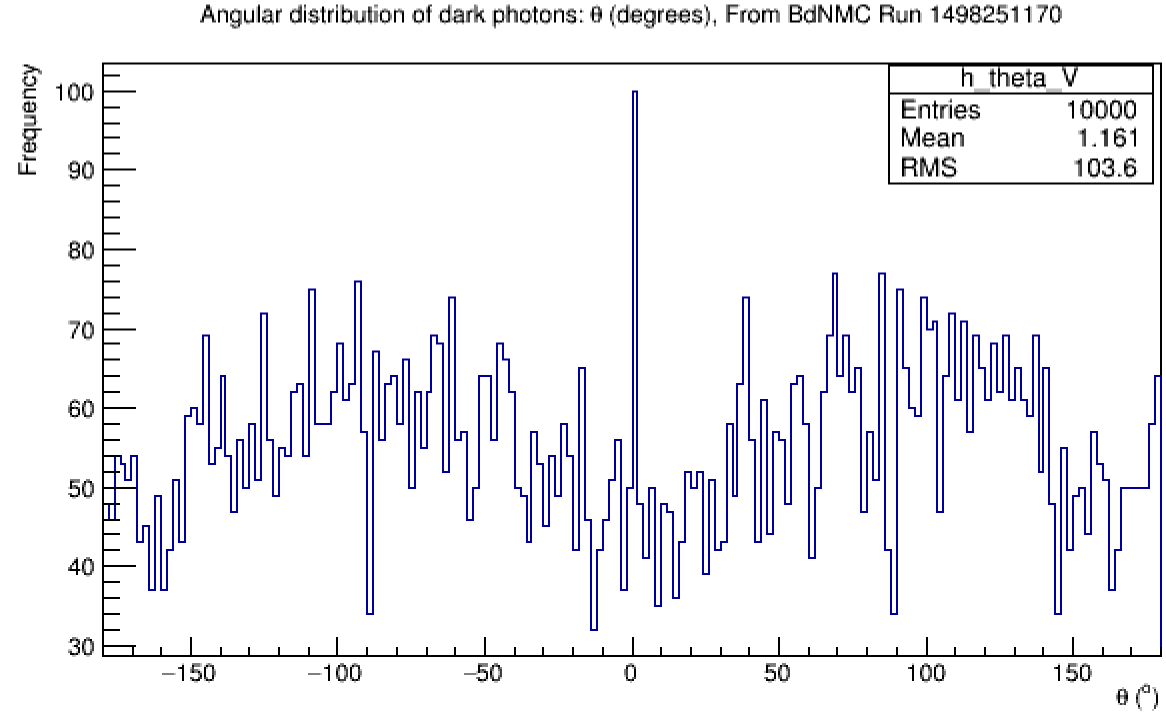

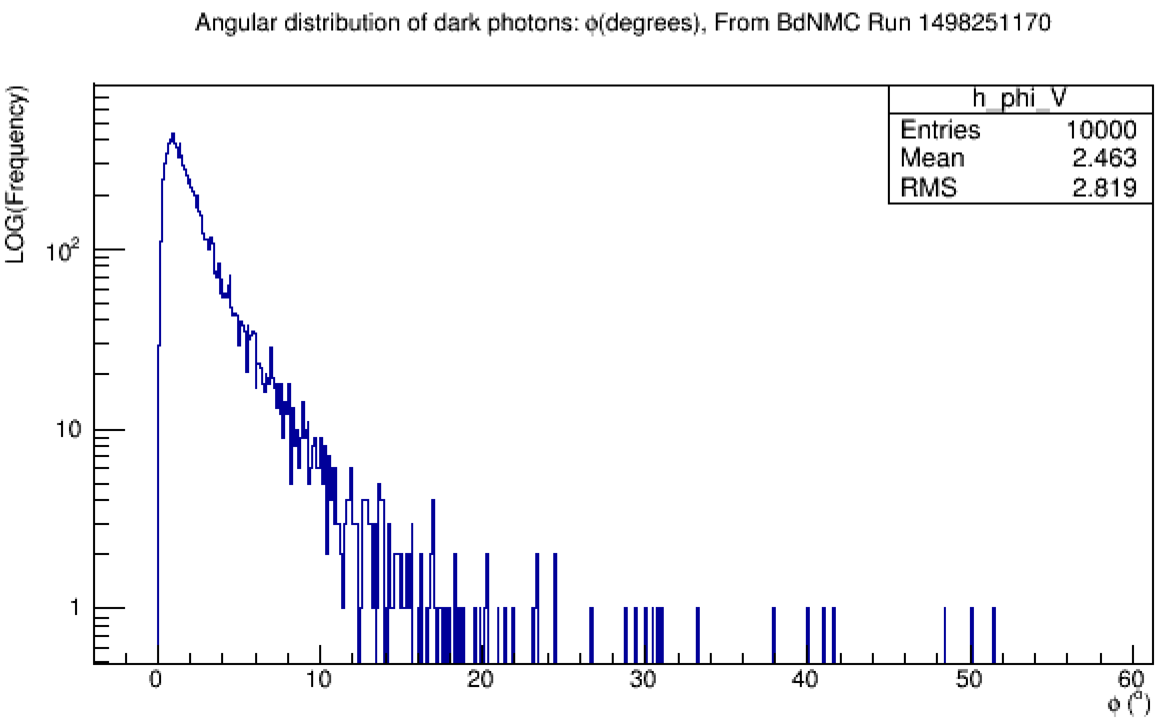

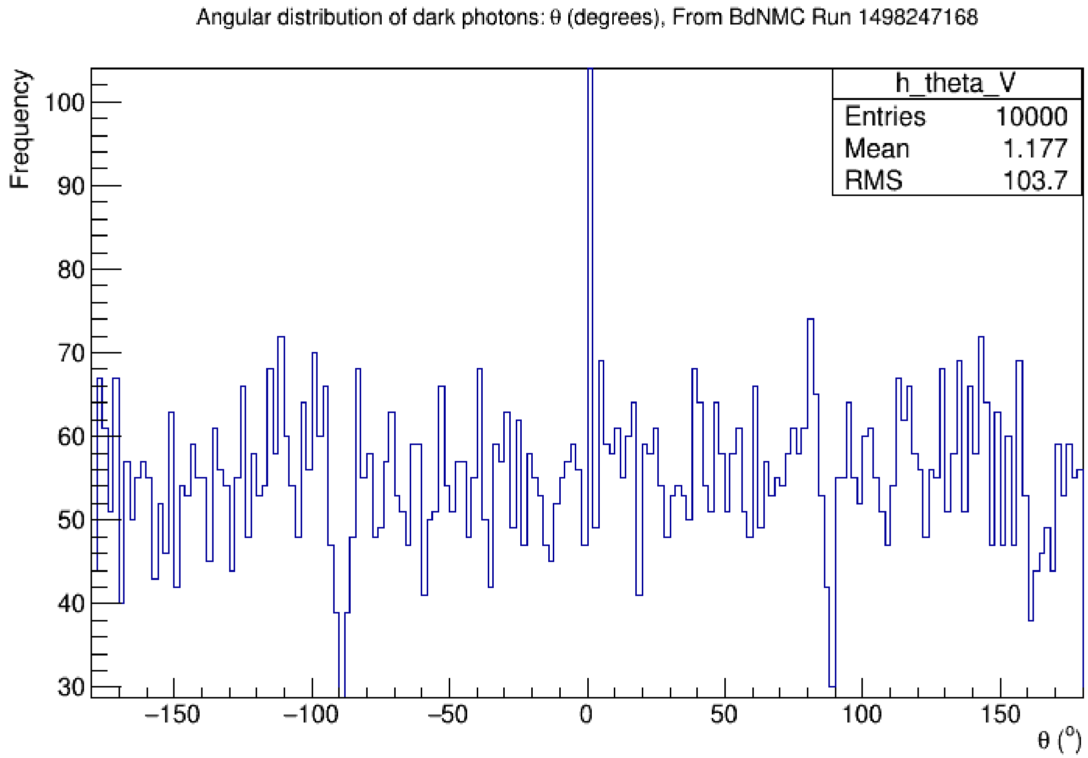

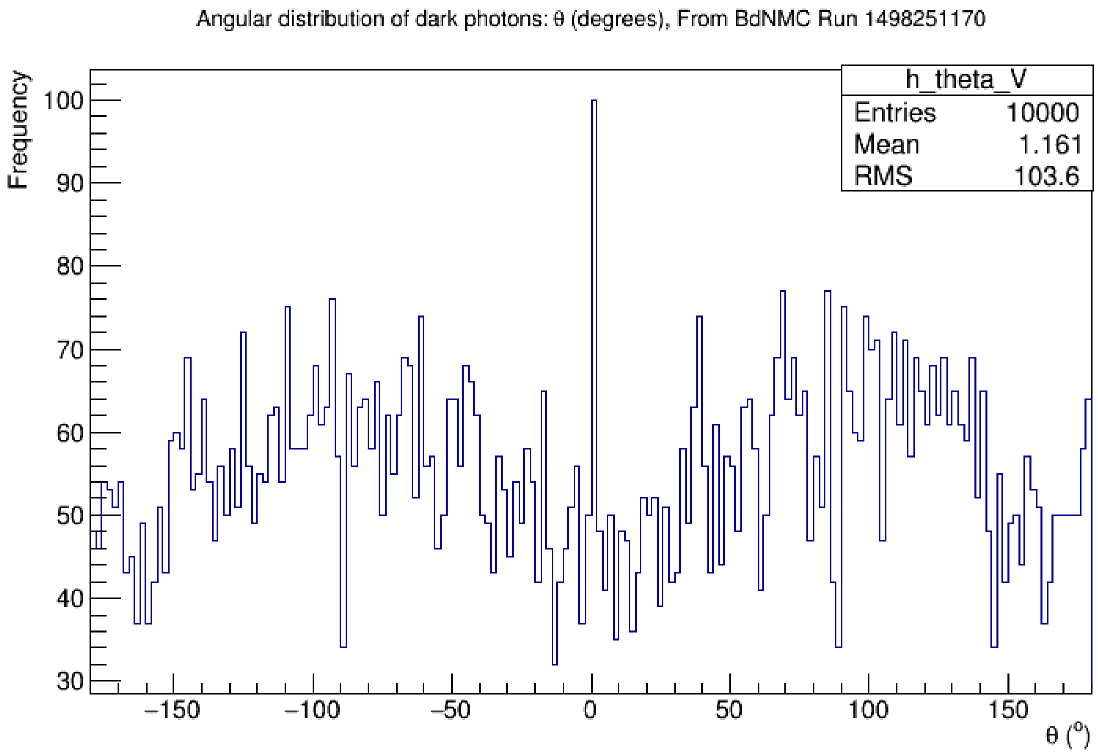

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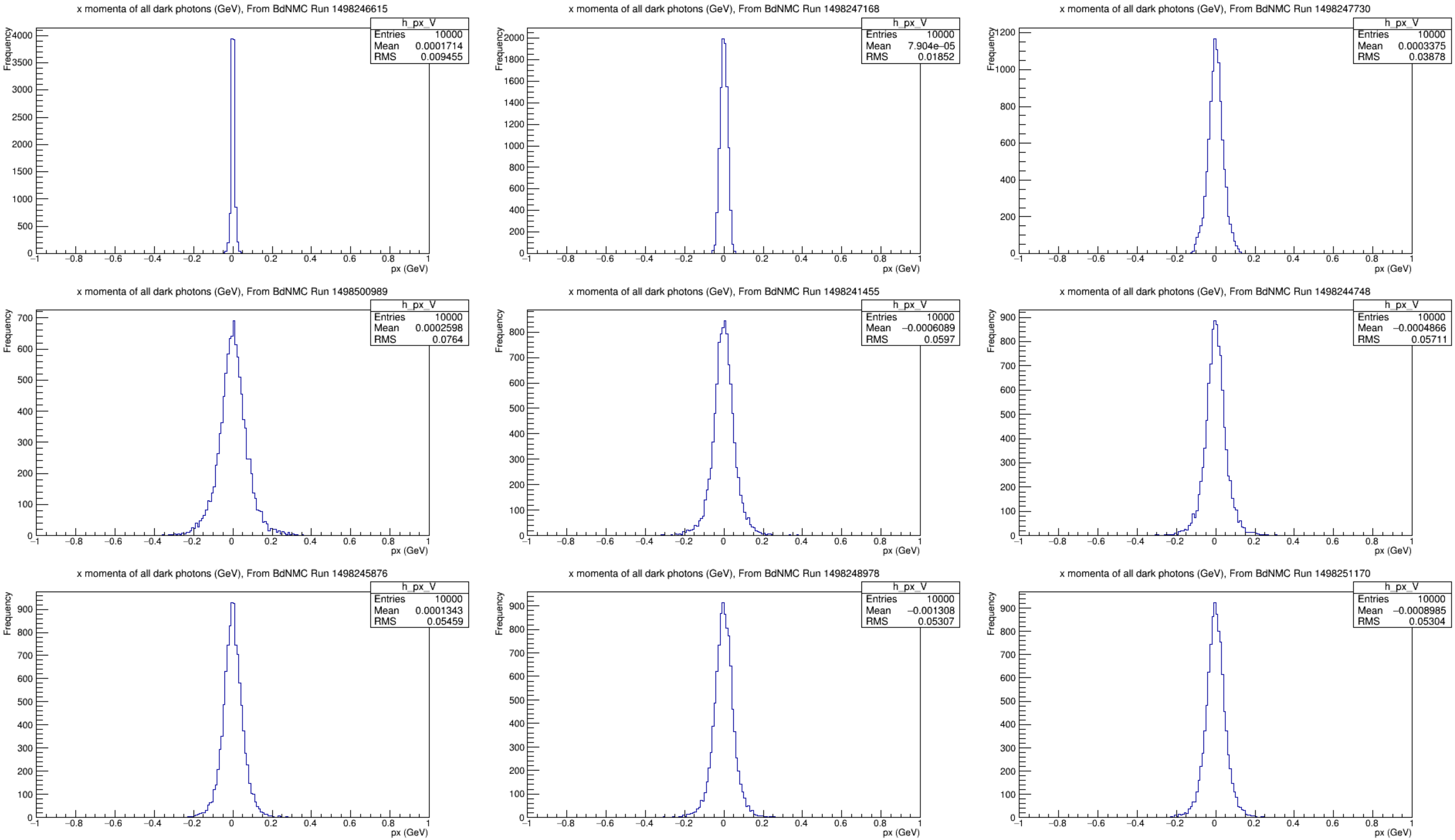
Some observations about theta with varying mass_V:

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

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



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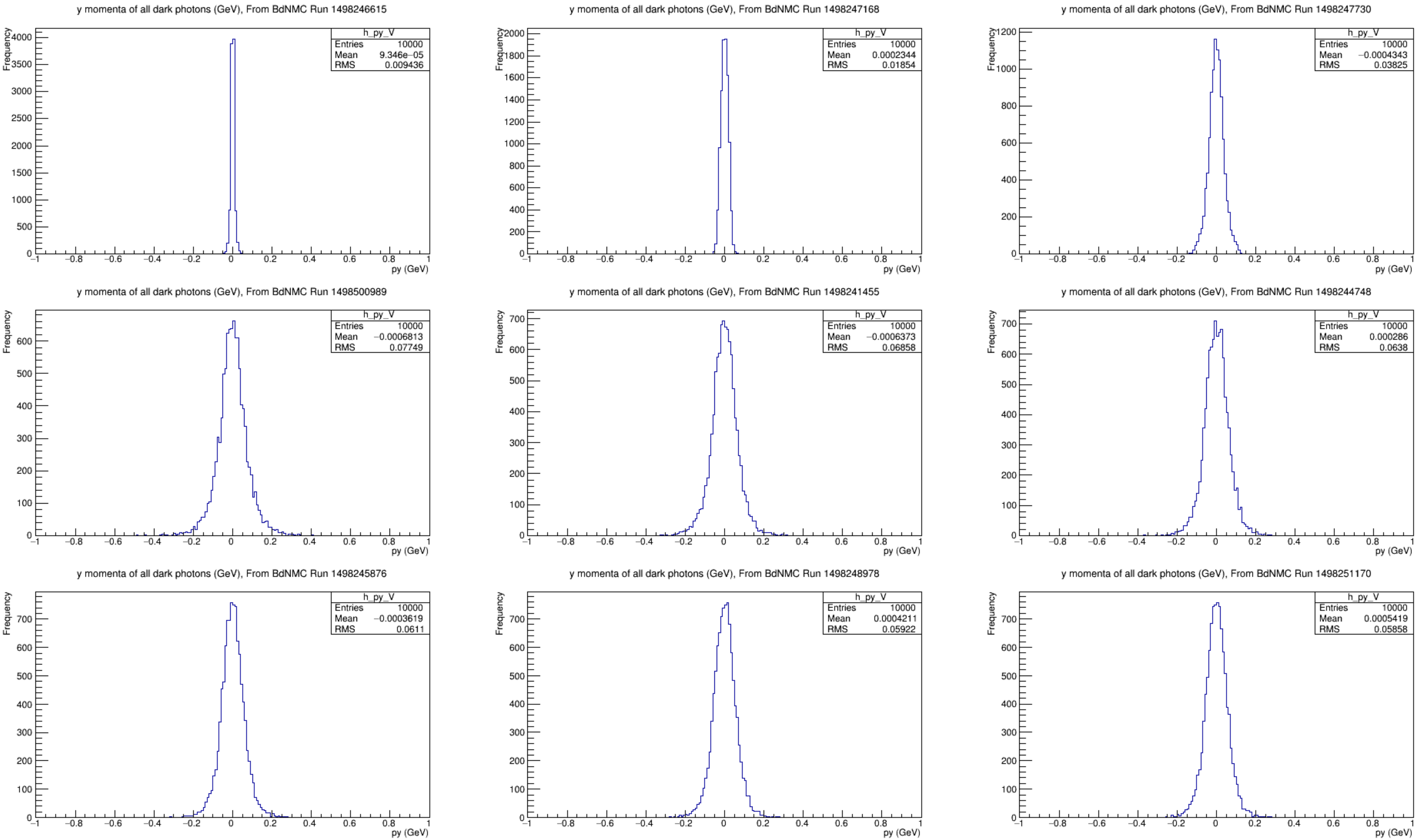

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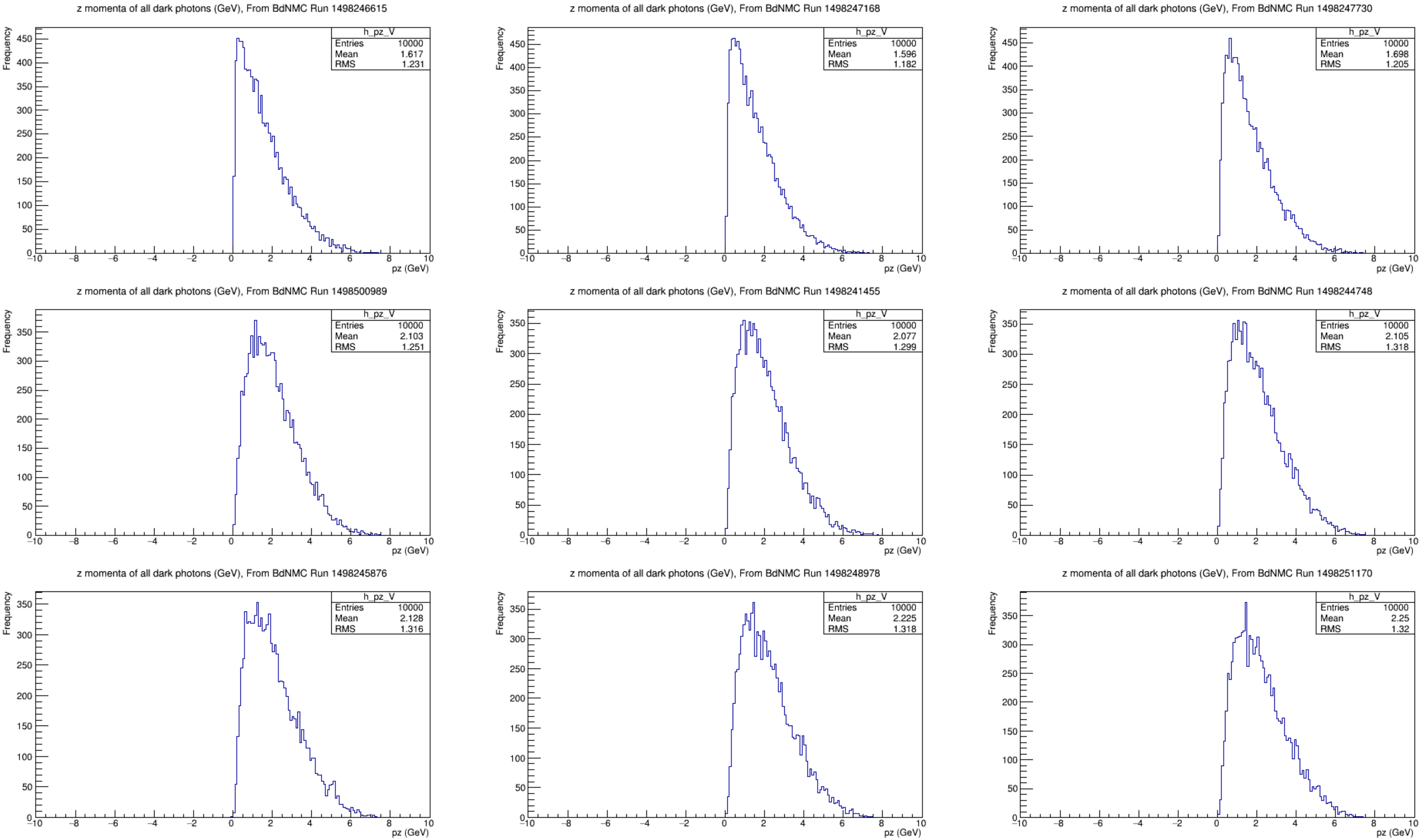

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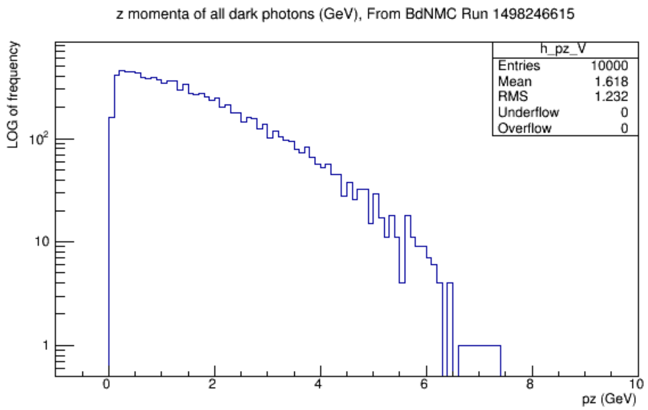
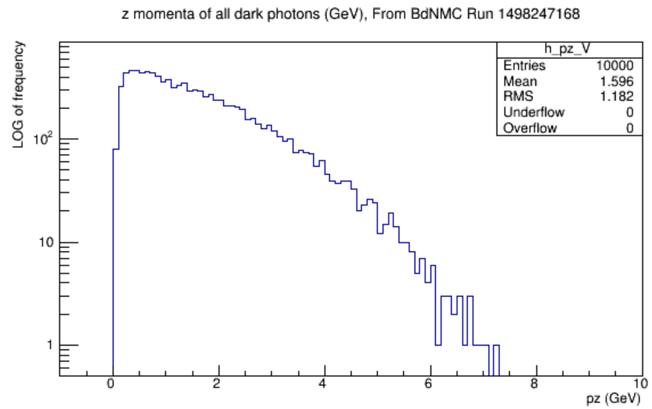
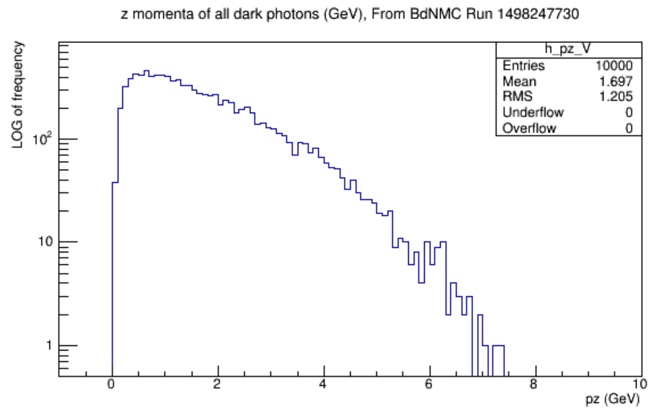
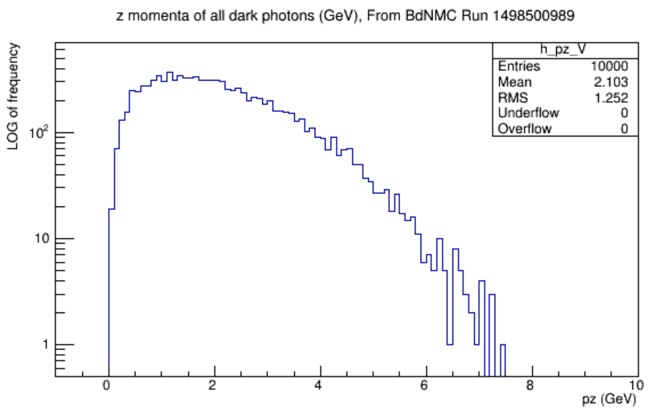
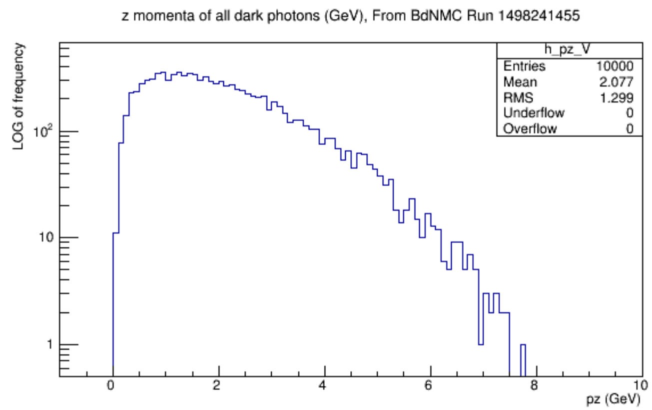
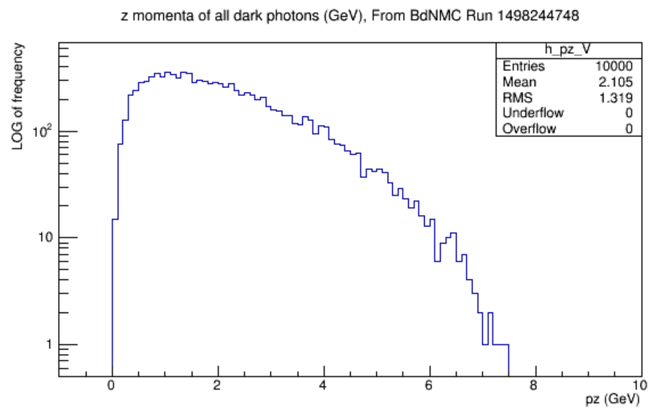


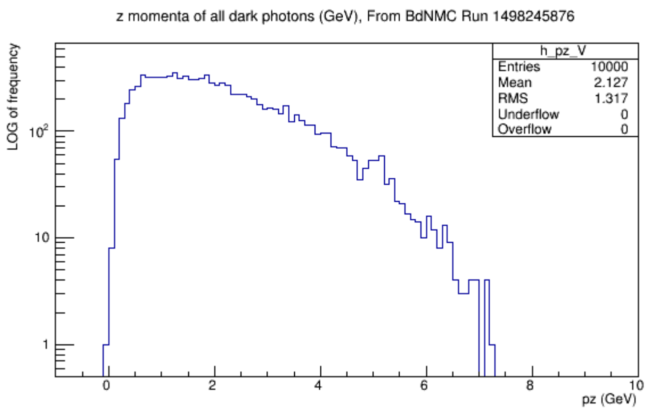


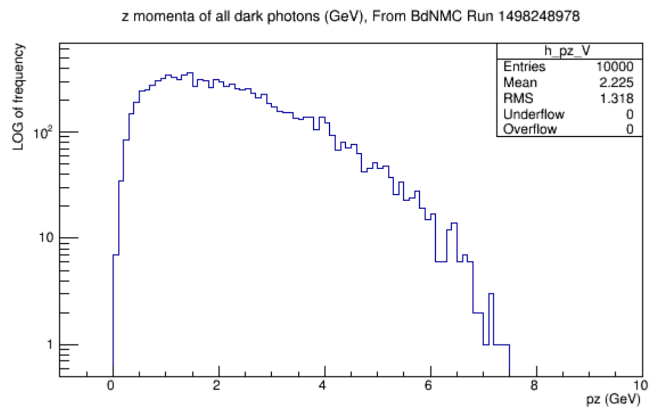


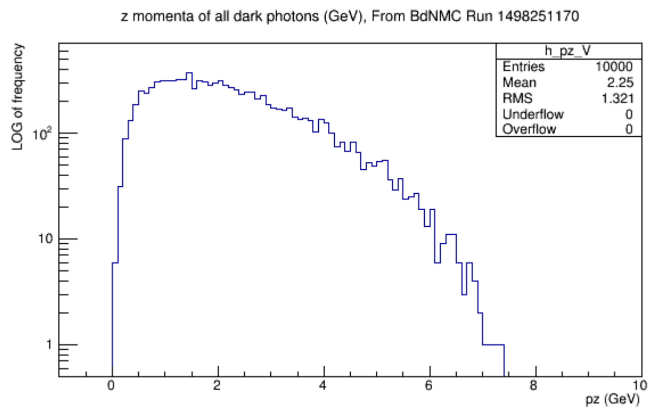






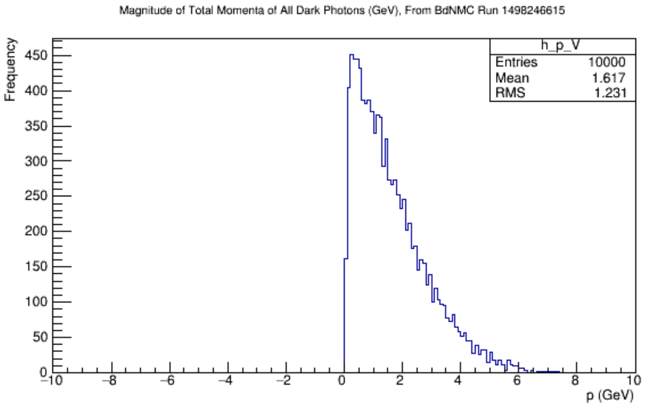


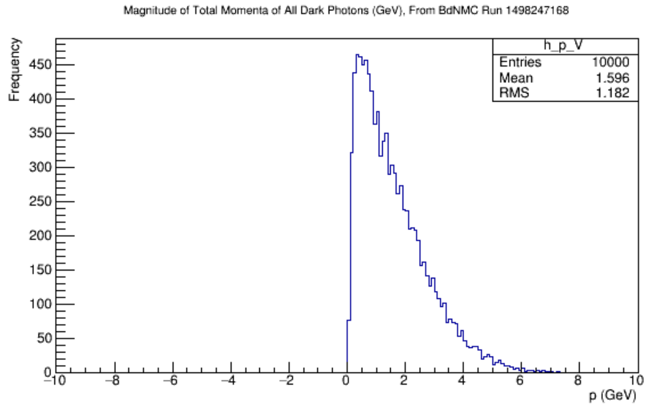


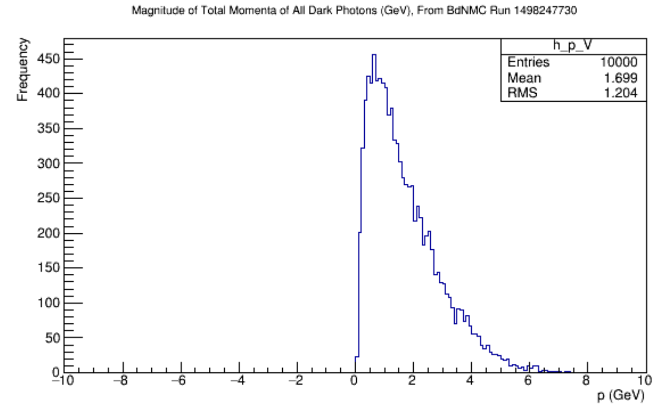


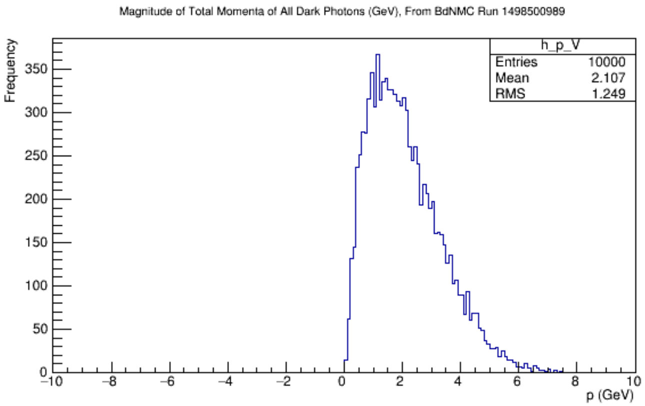
Run1498246615, mass_V=0.02 GeV
Run1498247168, mass_V=0.03 GeV
Run1498247730 mass_V=0.05 GeV
Run1498500989, mass_V= 0.1 GeV
Run 1498241455, mass_V= 0.2 GeV
Run1498244748 , mass_V = 0.3 GeV
Run1498245876, mass_V = 0.4 GeV
Run1498248978, mass_V = 0.8 GeV
Run1498251170, mass_V = 0.95 GeV

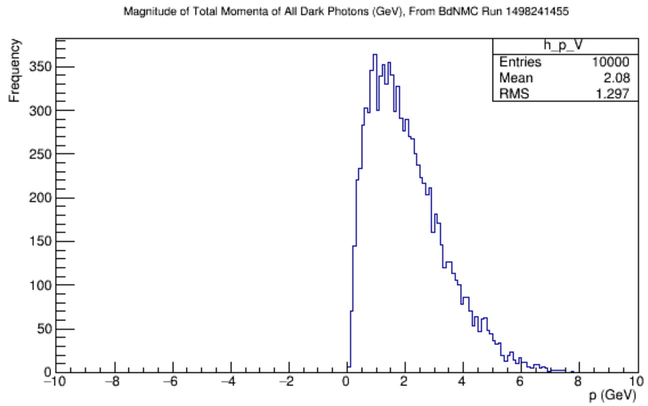
Same slide as before, different scales

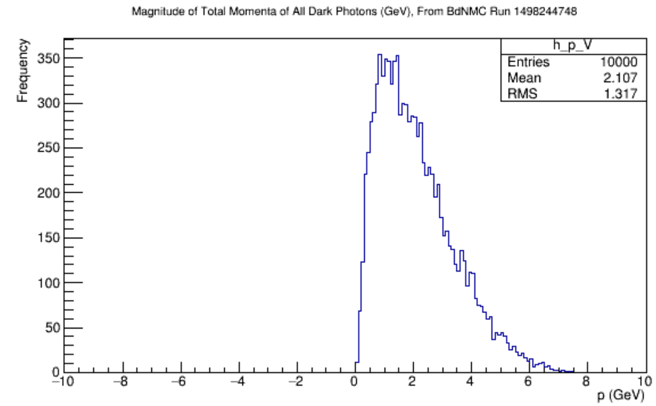


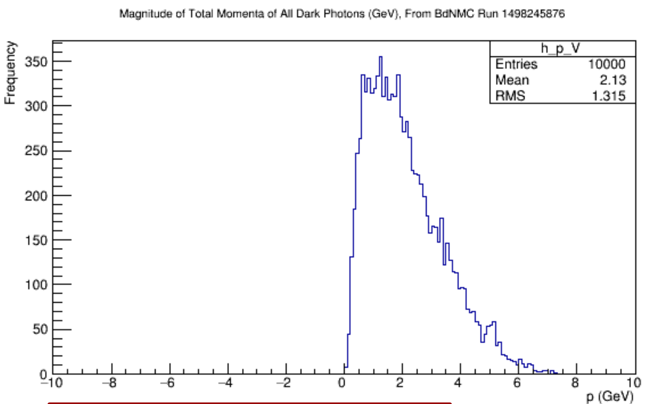


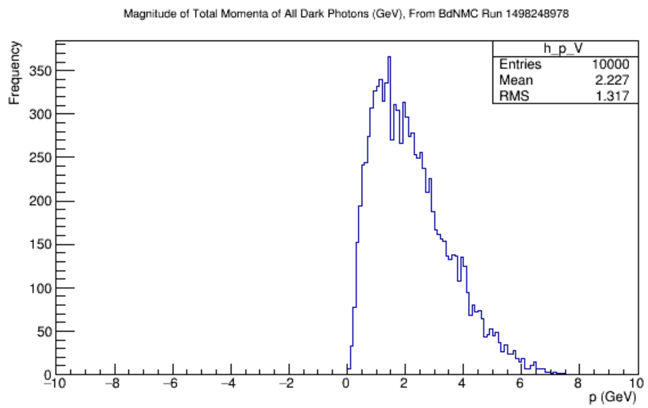


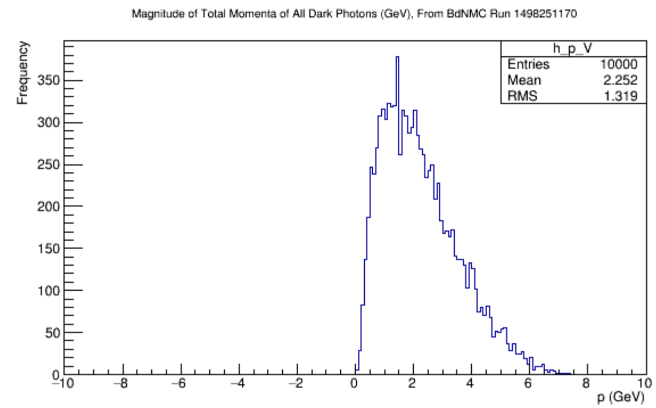




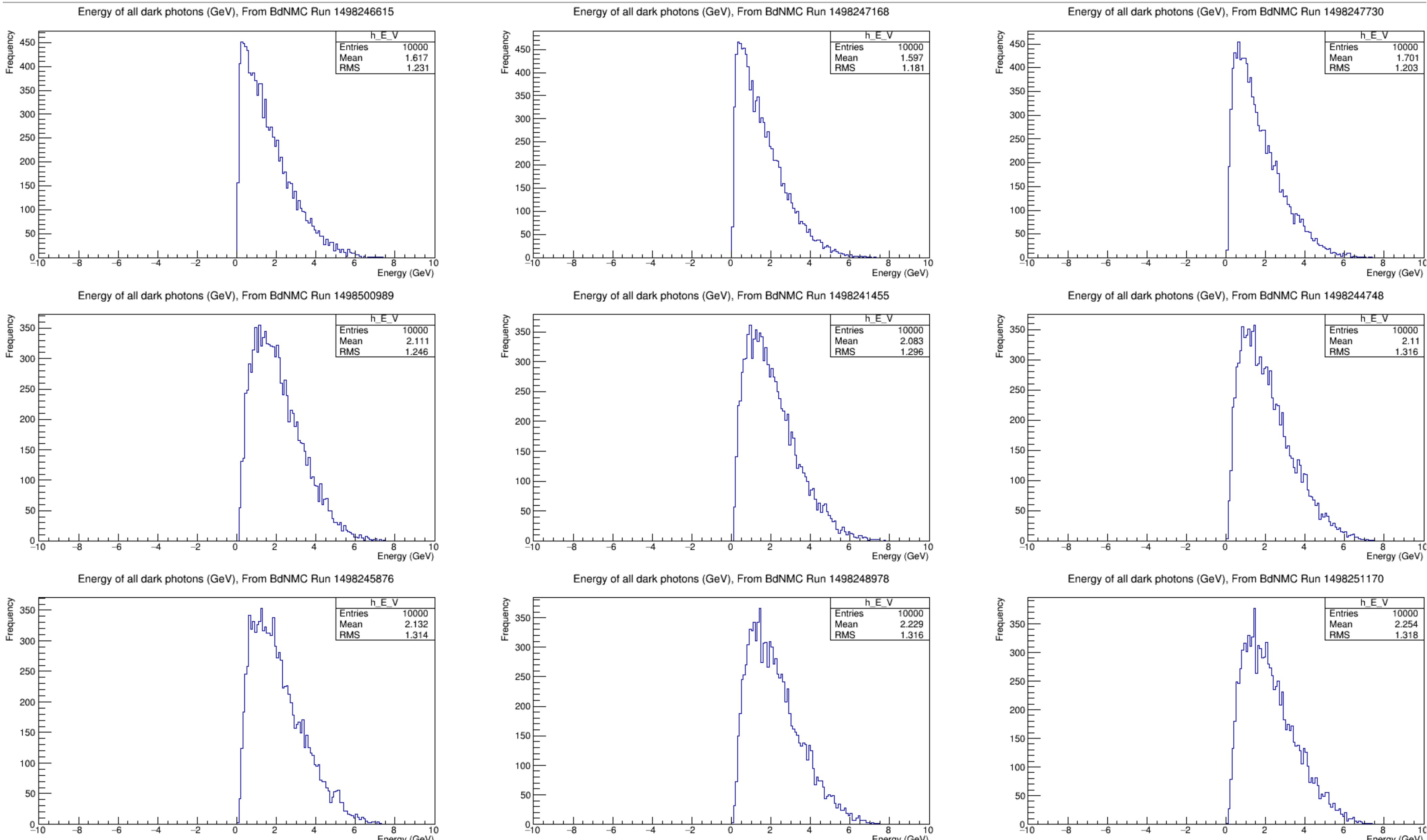




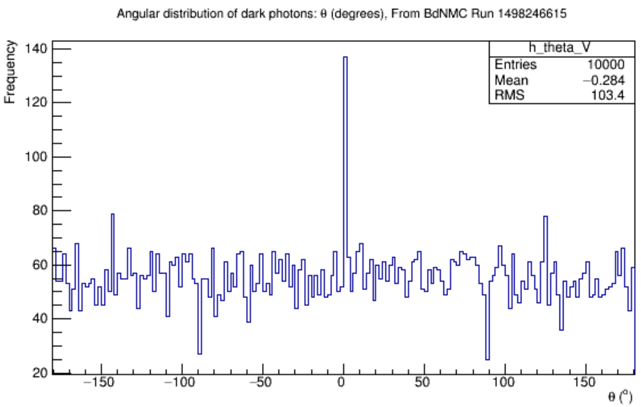


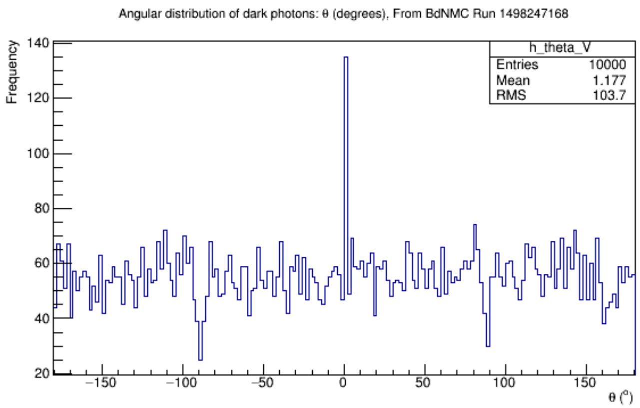


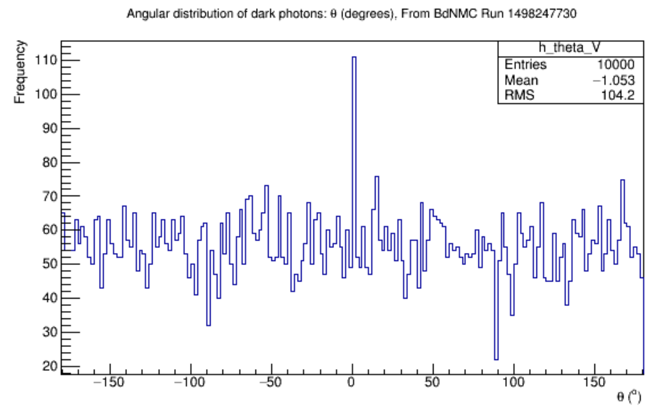
Run1498246615, mass_V=0.02 GeV
Run1498247168, mass_V=0.03 GeV
Run1498247730 mass_V=0.05 GeV
Run1498500989, mass_V= 0.1 GeV
Run 1498241455, mass_V= 0.2 GeV
Run1498244748 , mass_V = 0.3 GeV
Run1498245876, mass_V = 0.4 GeV
Run1498248978, mass_V = 0.8 GeV
Run1498251170, mass_V = 0.95 GeV

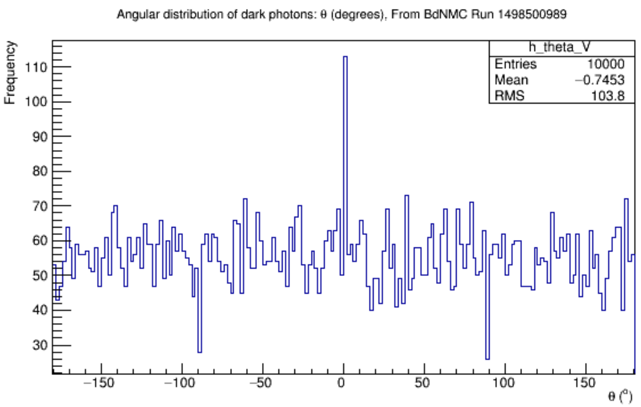


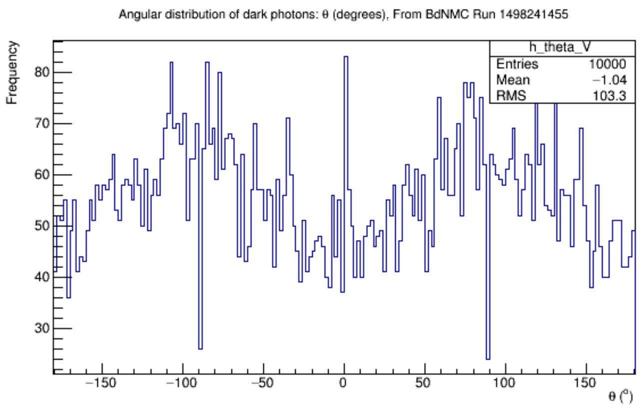
Run1498246615, mass_V=0.02 GeV
Run1498247168, mass_V=0.03 GeV
Run1498247730 mass_V=0.05 GeV
Run1498500989, mass_V= 0.1 GeV
Run 1498241455, mass_V= 0.2 GeV
Run1498244748 , mass_V = 0.3 GeV
Run1498245876, mass_V = 0.4 GeV
Run1498248978, mass_V = 0.8 GeV
Run1498251170, mass_V = 0.95 GeV

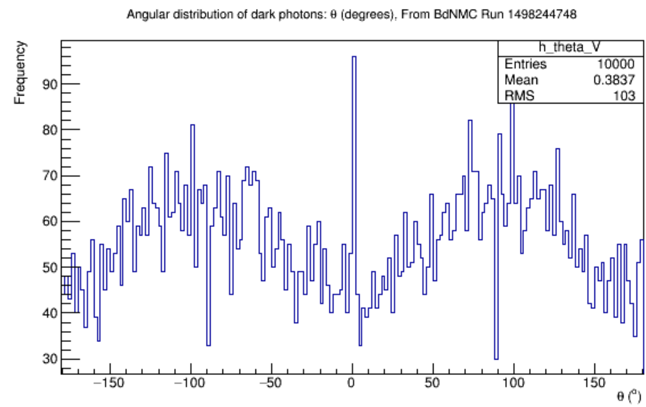


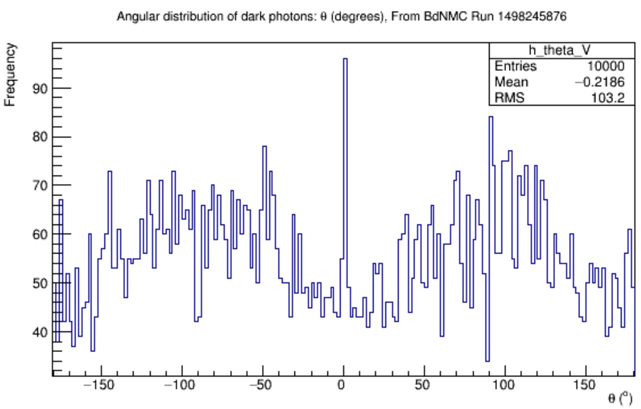


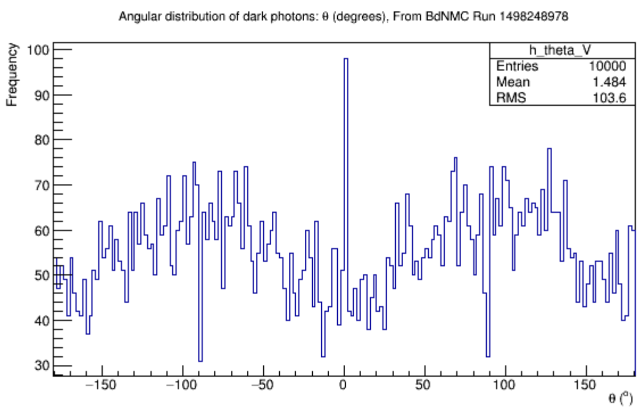


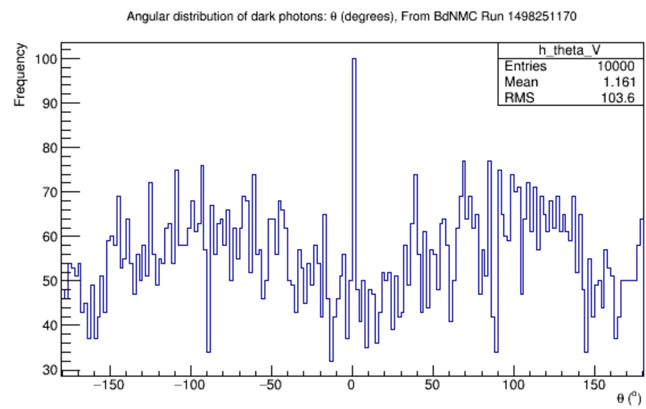












Run1498246615, mass_V=0.02 GeV
Run1498247168, mass_V=0.03 GeV
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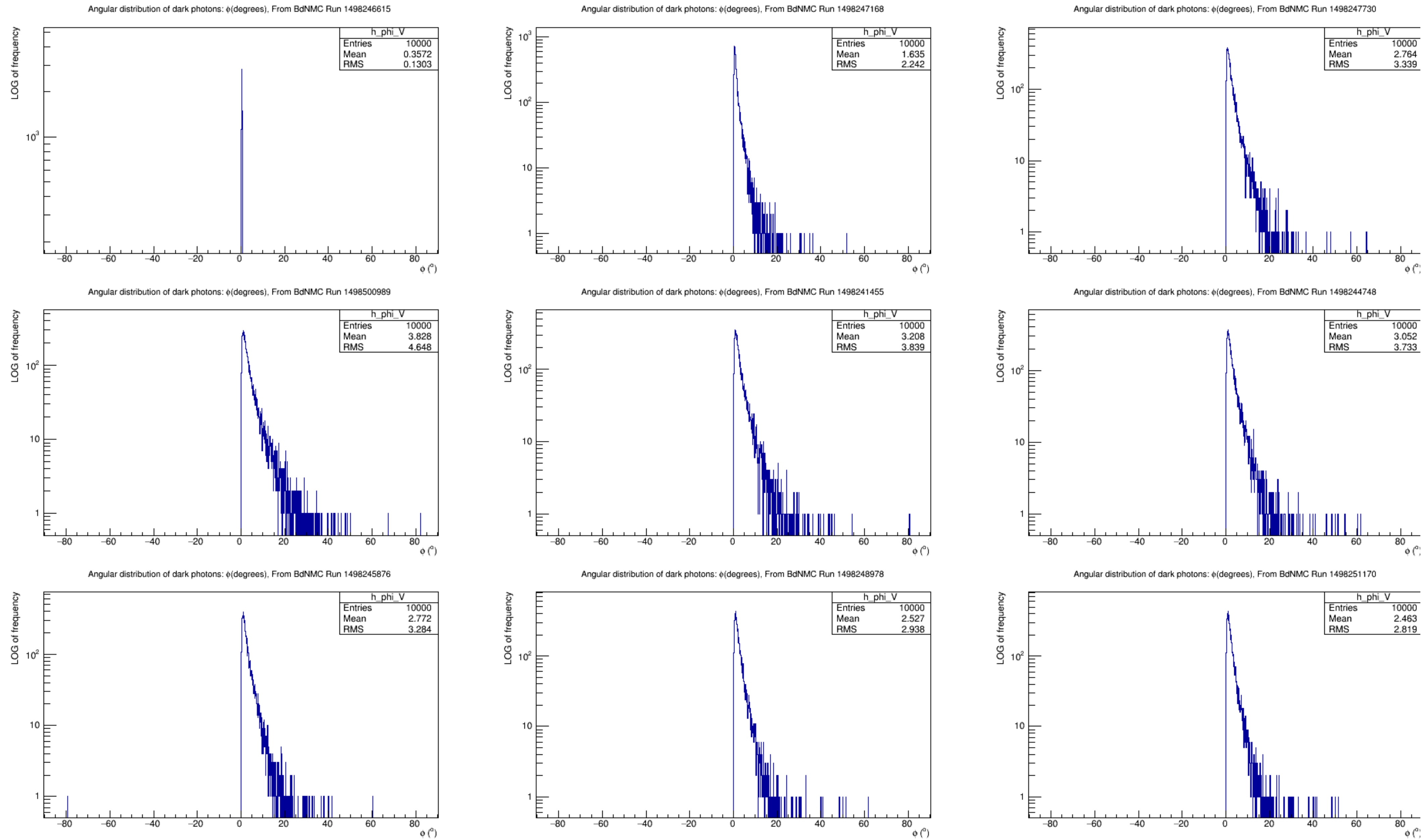
Run1498245876, mass_V = 0.4 GeV
Run1498248978, mass_V = 0.8 GeV
Run1498251170, mass_V = 0.95 GeV



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

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:

$$\texttt{signal\_events}[i] = \frac{\texttt{ninteractions}[i]}{\texttt{trials}} \times \texttt{vnumtot} \times \texttt{pmax} \times \textbf{efficiency},$$

  - 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)