HNL Fluxes Generation With MadGraph

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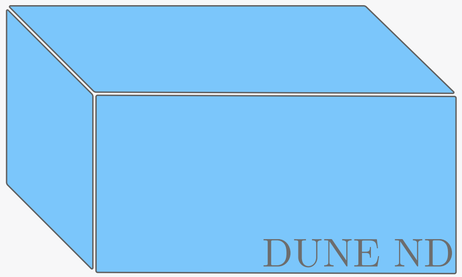
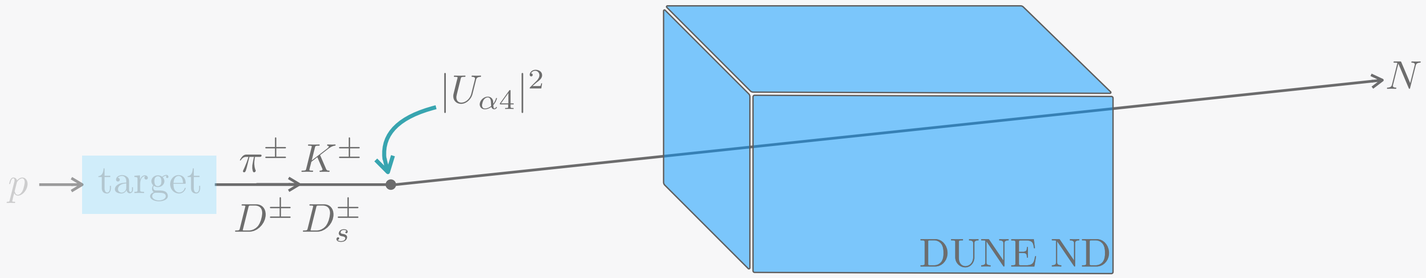
Ingredients for HNL Fluxes Generation



- Fluxes of mesons produced in the target
  - π and K (D and D_s) from the TDR n-tuples*
  - D and D_s and τ simulated with Pythia + GEANT4 → Z. Pavlovic

*most up to date optimized 3-horn design (1.5m target) by L. Fields et al.

Ingredients for HNL Fluxes Generation

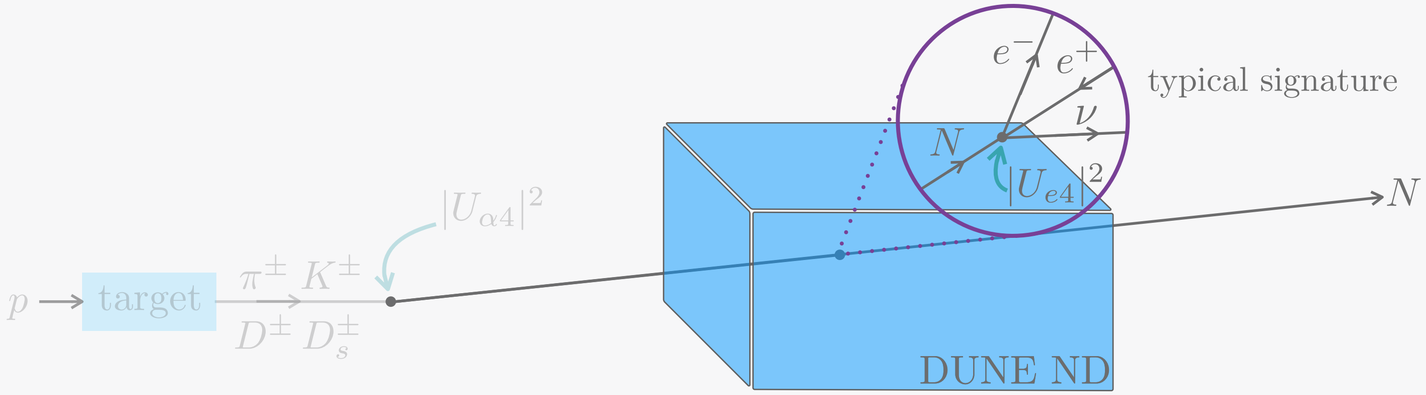


- Fluxes of mesons produced in the target
- Events of HNL production via meson decays

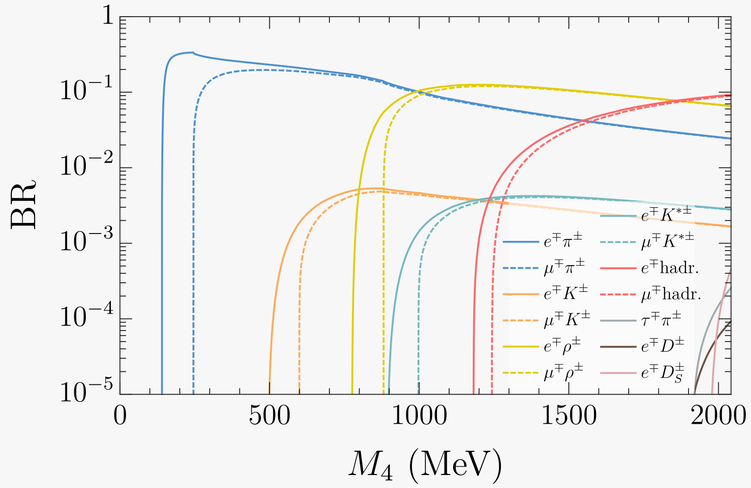
Parent	2-body decay	3-body decay
$\pi^+ \to$	$e^+ N_4$	—
	$\mu^+ N_4$	
$K^+ \to$	$e^+ N_4$	$\pi^0 e^+ N_4$
	$\mu^+ N_4$	$\pi^0 \mu^+ N_4$
$\tau^- \to$	$\pi^- N_4$	$e^- \overline{\nu} N_4$
	$\rho^- N_4$	$\mu^- \overline{\nu} N_4$

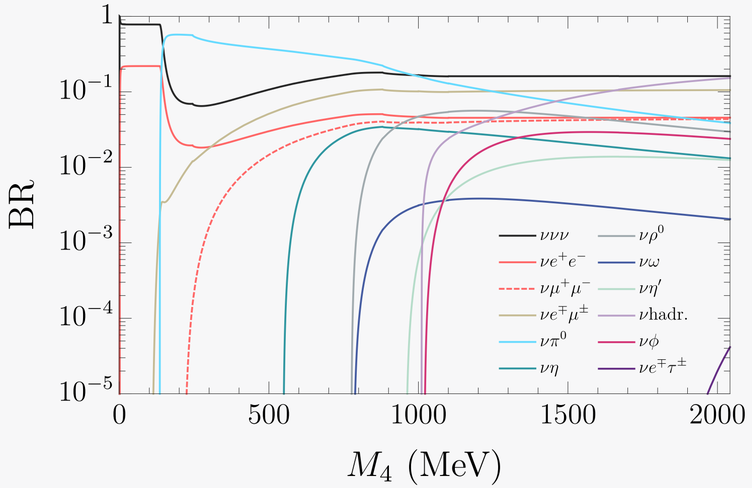
Parent	2-body decay	3-body decay
$D^+ \to$	$e^+ N_4$	$e^+ \overline{K^0} N_4$
	$\mu^+ N_4$	$\mu^+ \overline{K^0} N_4$
	$\tau^+ N_4$	
$D_s^+ \to$	$e^+ N_4$	—
	$\mu^+ N_4$	
	$\tau^+ N_4$	

Ingredients for HNL Fluxes Generation

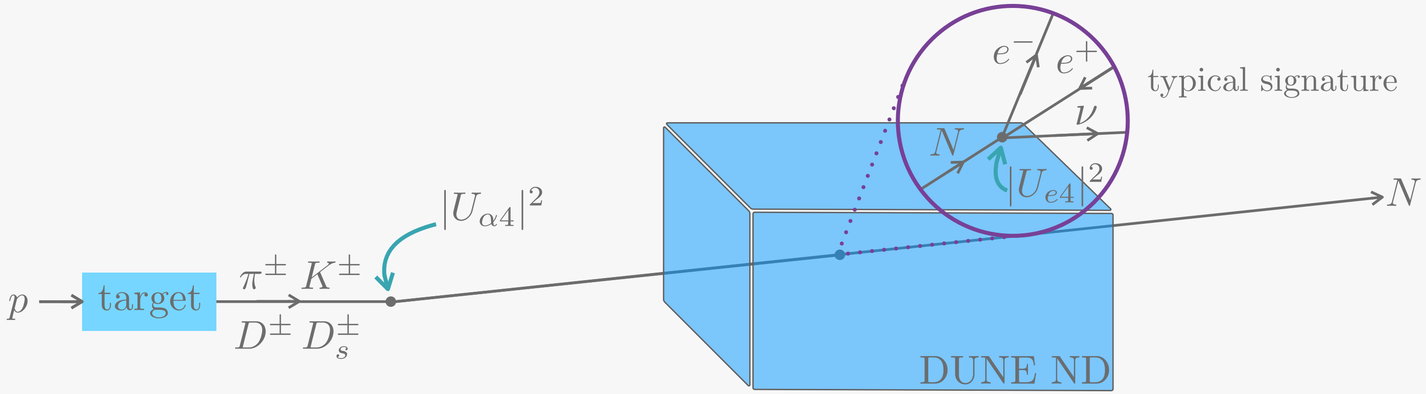


- Fluxes of mesons produced in the target
- Events of HNL production via meson decays
- Events of HNL decays into SM particles





Ingredients for HNL Fluxes Generation



- Fluxes of mesons produced in the target
- Events of HNL production via meson decays
- Events of HNL decays into SM particles

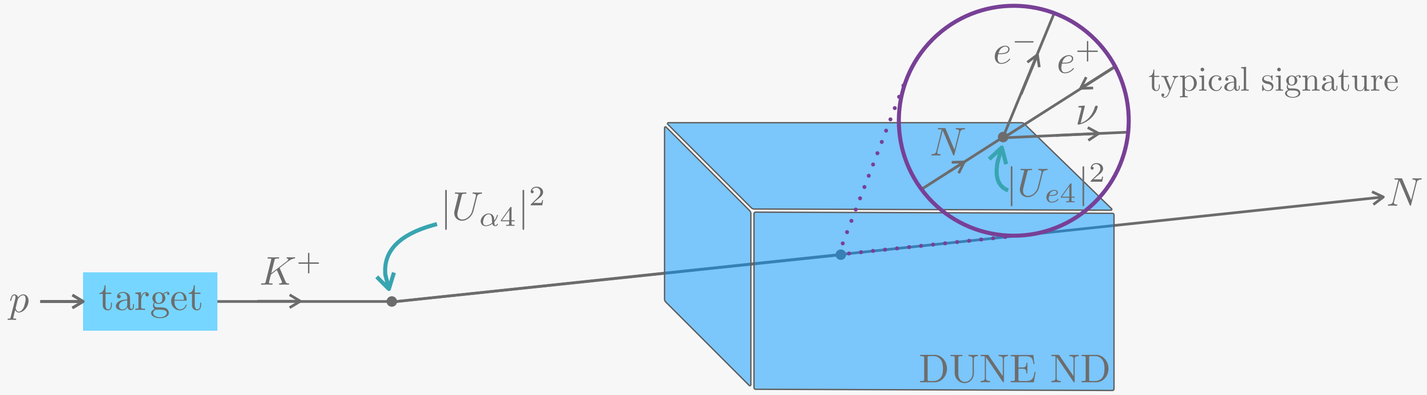
Generated with MadGraph5

FeynRules model file* with the effective theory describing HNL-meson interactions

*publicly available as ancillary file of arXiv: 2007.03701

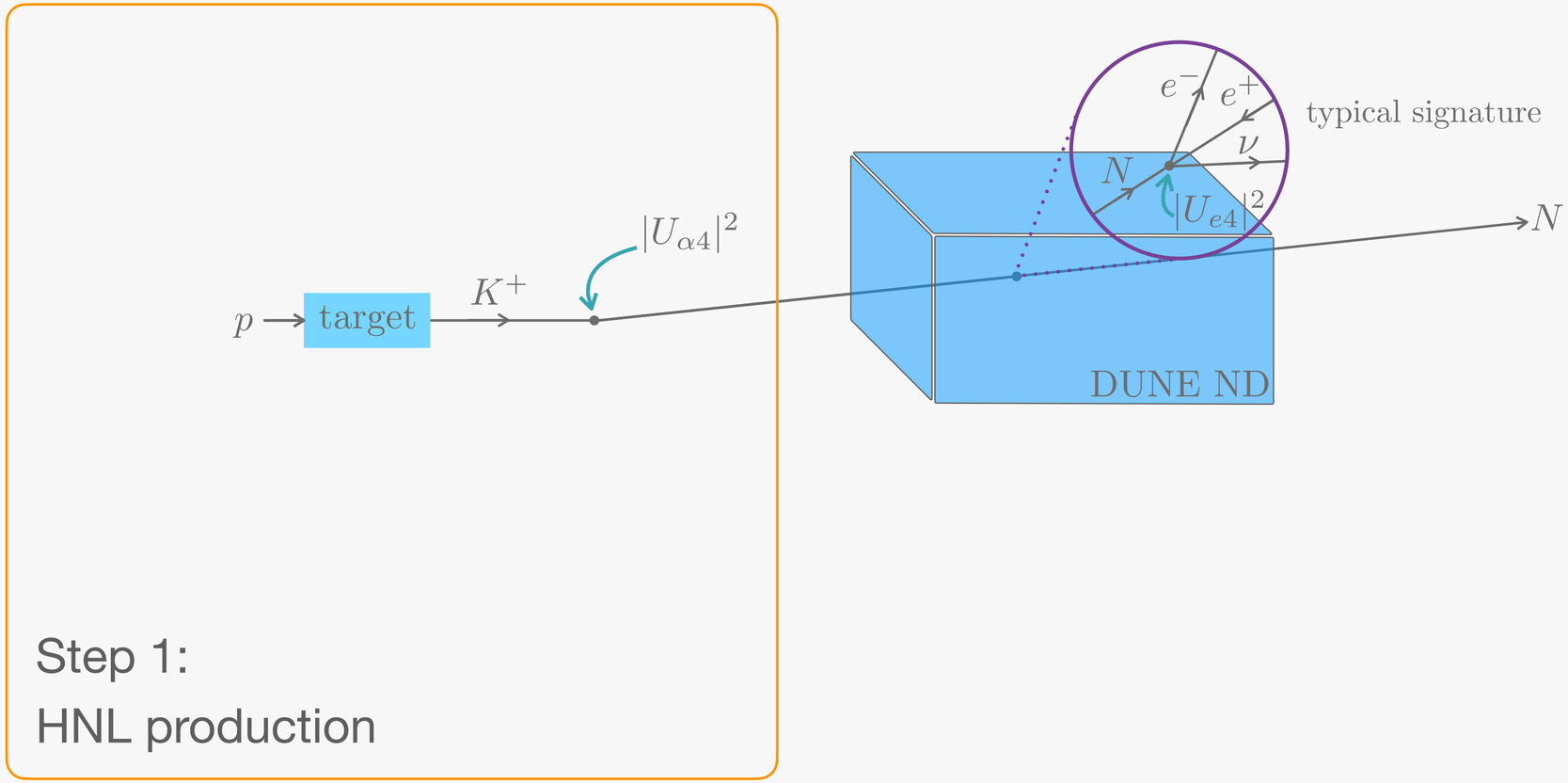
Ingredients for HNL Fluxes Generation

Example considering HNL created via K^+ decay



Ingredients for HNL Fluxes Generation

Example considering HNL created via K^+ decay

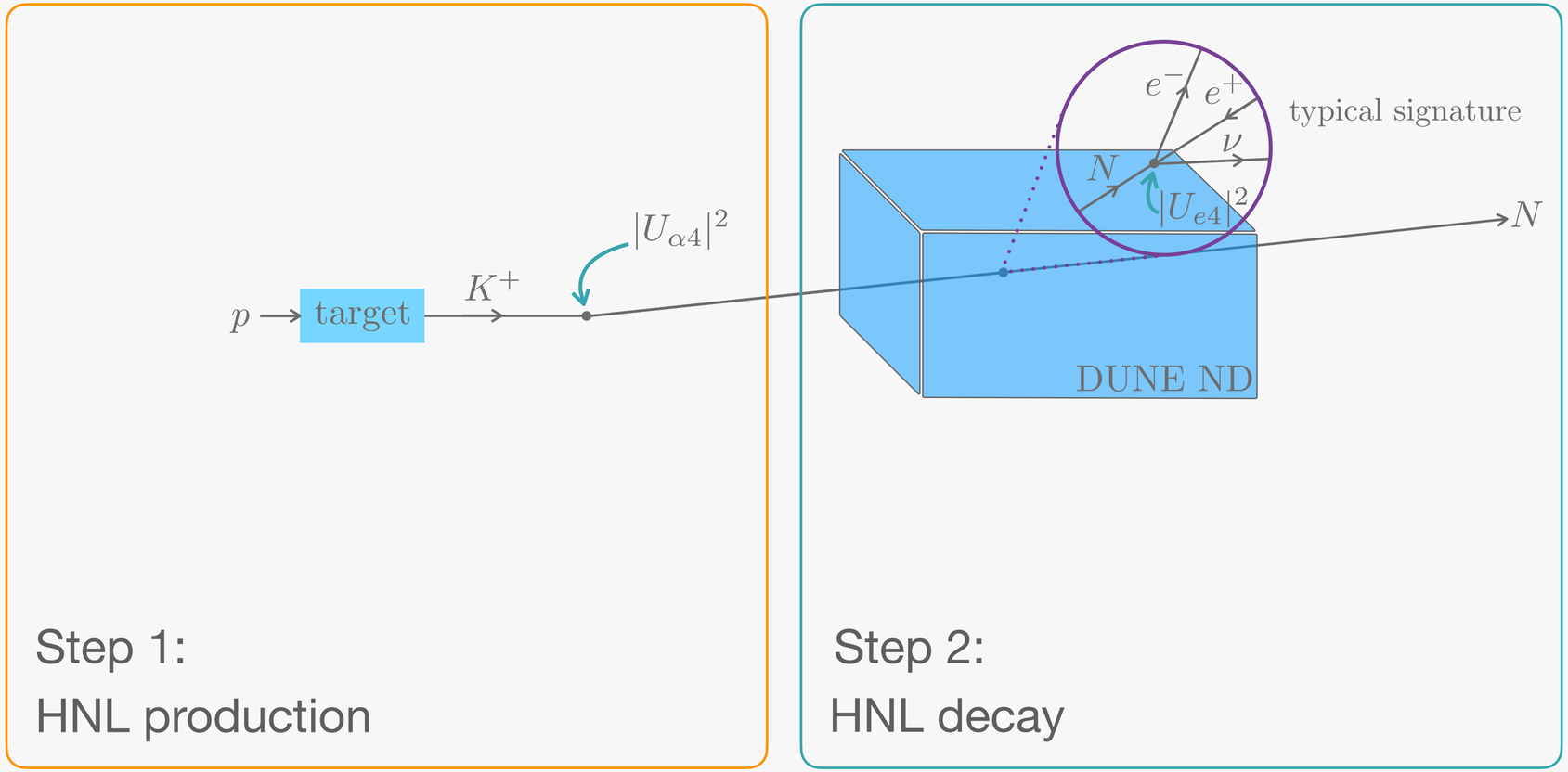


Step 1:

HNL production

Ingredients for HNL Fluxes Generation

Example considering HNL created via K^+ decay



Step 1:
HNL production

Step 2:
HNL decay

Step 1: HNL Production

Step 1: HNL Production

- MadGraph HNL events from meson decays

```
mg5_aMC>
   import model effective_HeavyN_Dirac_UFO
   generate k+ > n1 lepton QED <= 2
   add process k+ > n1 lepton meson QED <= 2
   launch
   set MN4 0.05
   set thetae 0.001
   set thetamu 0
   set thetatau 0
   set nevents 100000
```

2-body + 3-body kaon decays

HNL mass

$|U_{\alpha 4}|^2$

# of events

Step 1: HNL Production

- MadGraph HNL events from meson decays

  MG output:

  kaon_decay_50Mev.lhe

Step 1: HNL Production

- MadGraph HNL events from meson decays

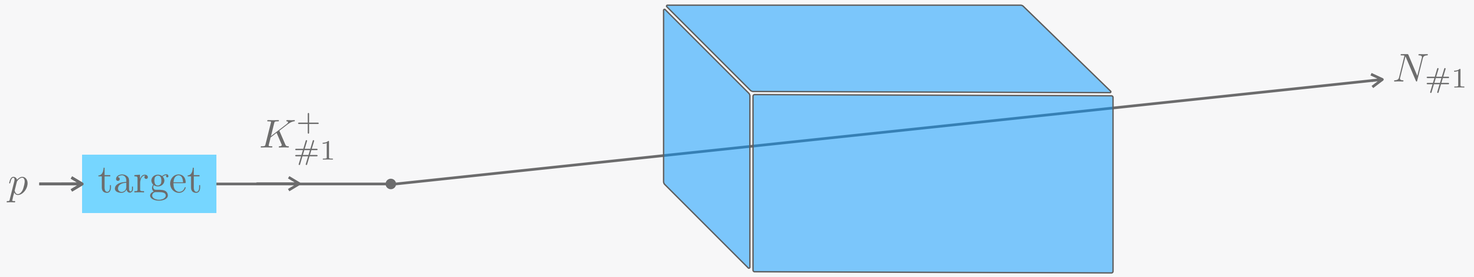
MG output:

kaon_decay_50Mev.lhe

- K^+ fluxes from TDR n-tuple

# x	y	z	px	py	pz	weight
-0.893351	-7.19023	306.405	0.00147399	-0.0722823	0.98955	120
84.9599	-123.99	15384.6	0.237416	-0.348232	43.6417	4
-3.32223	-0.496629	126.54	-0.127274	-0.041156	2.38537	109.091
24.3667	-18.0481	2146.35	0.0378792	-0.0275051	3.01461	40
. . .						

Each MG event matched to one K^+ in the histogram and boosted to the lab frame



Step 1: HNL Production

- MadGraph HNL events from meson decays

MG output:

kaon_decay_50Mev.lhe

- K^+ fluxes from TDR n-tuple

# x	y	z	px	py	pz	weight
-0.893351	-7.19023	306.405	0.00147399	-0.0722823	0.98955	120
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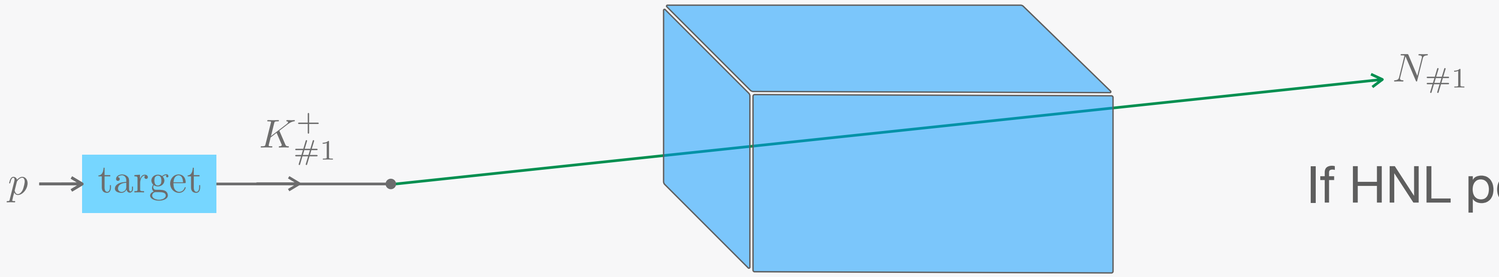
Each MG event matched to one K^+ in the histogram and boosted to the lab frame



If HNL pointing* the ND

Step 1 output file: HNL flux file

# Px	Py	Pz	MN	x_decay	y_decay	z_decay	Meson_width	BR_Meson	Meson_weight
0.00518398	-0.000368844	1.02619	0.05	-0.00893351	-0.0719023	3.06405	1.04313e-23	0.774359	120

*a tilt angle α = 0.101 due to the beam inclination with respect to the horizontal is considered

Step 1: HNL Production

- MadGraph HNL events from meson decays

  MG output:

  kaon_decay_50Mev.lhe

- K^+ fluxes from TDR n-tuple

# x	y	z	px	py	pz	weight
-0.893351	-7.19023	306.405	0.00147399	-0.0722823	0.98955	120
84.9599	-123.99	15384.6	0.237416	-0.348232	43.6417	4
-3.32223	-0.496629	126.54	-0.127274	-0.041156	2.38537	109.091
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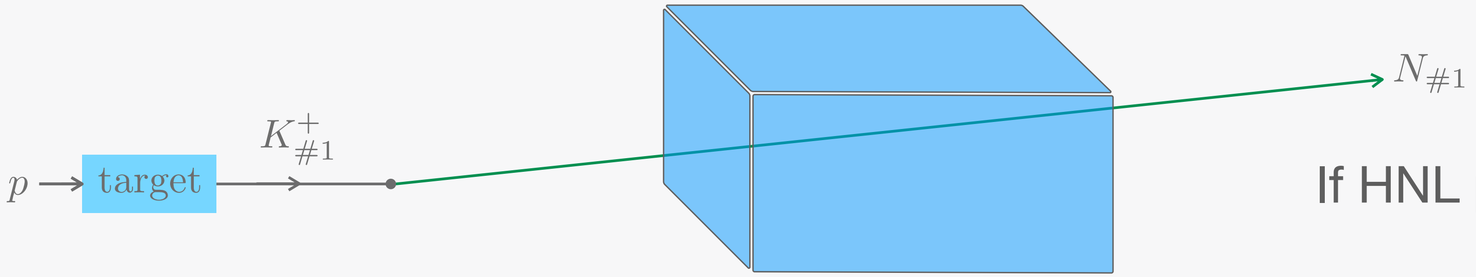
Each MG event matched to one K^+ in the histogram and boosted to the lab frame



If HNL pointing the ND

Step 1 output file: HNL flux file

# Px	Py	Pz	MN	x_decay	y_decay	z_decay	Meson_width	BR_Meson	Meson_weight
0.00518398	-0.000368844	1.02619	0.05	-0.00893351	-0.0719023	3.06405	1.04313e-23	0.774359	120

taken from K^+ flux file

Step 1: HNL Production

- MadGraph HNL events from meson decays

  MG output:

  kaon_decay_50Mev.lhe

- K^+ fluxes from TDR n-tuple

# x	y	z	px	py	pz	weight
-0.893351	-7.19023	306.405	0.00147399	-0.0722823	0.98955	120
84.9599	-123.99	15384.6	0.237416	-0.348232	43.6417	4
-3.32223	-0.496629	126.54	-0.127274	-0.041156	2.38537	109.091
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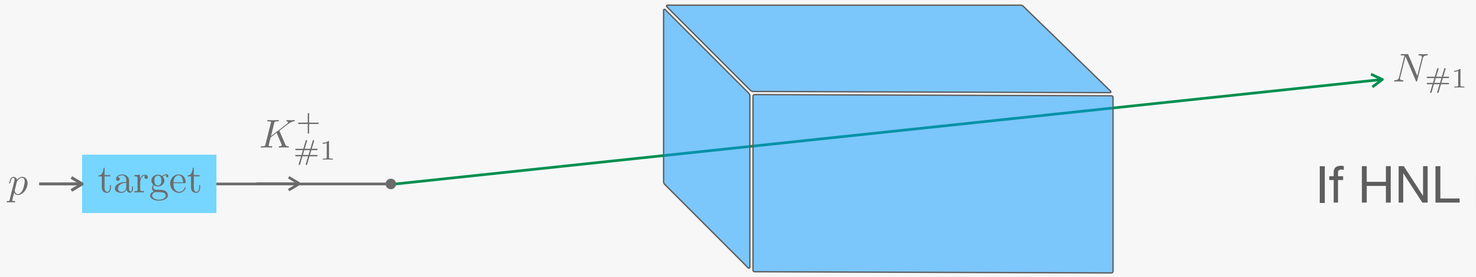
Each MG event matched to one K^+ in the histogram and boosted to the lab frame



If HNL pointing the ND

Step 1 output file: HNL flux file

# Px	Py	Pz	MN	x_decay	y_decay	z_decay	Meson_width	BR_Meson	Meson_weight
0.00518398	-0.000368844	1.02619	0.05	-0.00893351	-0.0719023	3.06405	1.04313e-23	0.774359	120

taken from .lhe MG file

Step 1: HNL Production

- MadGraph HNL events from meson decays

  MG output:

  kaon_decay_50Mev.lhe

- K^+ fluxes from TDR n-tuple

# x	y	z	px	py	pz	weight
-0.893351	-7.19023	306.405	0.00147399	-0.0722823	0.98955	120
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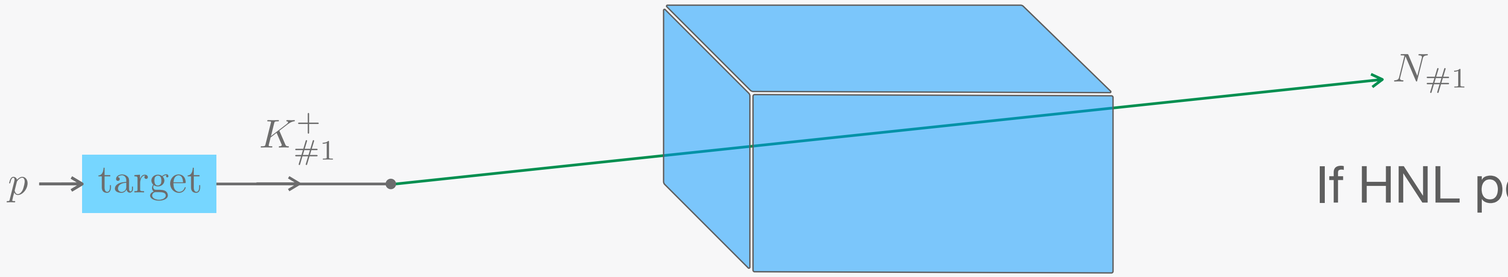

If HNL pointing the ND

Step 1 output file: HNL flux file

# Px	Py	Pz	MN	x_decay	y_decay	z_decay	Meson_width	BR_Meson	Meson_weight
0.00518398	-0.000368844	1.02619	0.05	-0.00893351	-0.0719023	3.06405	1.04313e-23	0.774359	120

computed with the script

Step 1: HNL Production

- MadGraph HNL events from meson decays

MG output:

kaon_decay_50Mev.lhe

- K^+ fluxes from TDR n-tuple

# x	y	z	px	py	pz	weight
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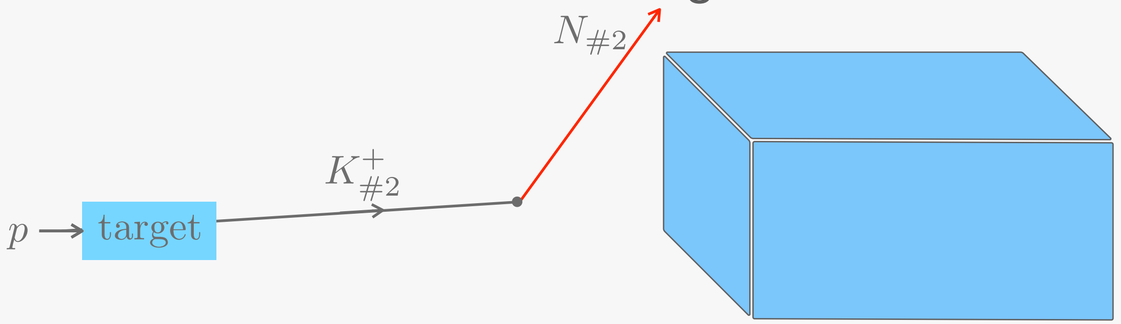

If HNL pointing the ND

Step 1 output file: HNL flux file

# Px	Py	Pz	MN	x_decay	y_decay	z_decay	Meson_width	BR_Meson	Meson_weight
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Step 1: HNL Production

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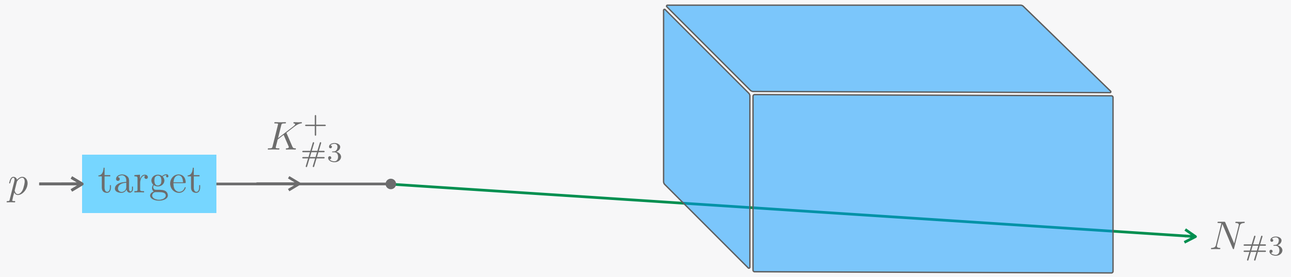
Each MG event matched to one K^+ in the histogram and boosted to the lab frame



If HNL pointing the ND

Step 1 output file: HNL flux file

# Px	Py	Pz	MN	x_decay	y_decay	z_decay	Meson_width	BR_Meson	Meson_weight
0.00518398	-0.000368844	1.02619	0.05	-0.00893351	-0.0719023	3.06405	1.04313e-23	0.774359	120
0.0114722	-0.00399517	2.21981	0.05	-0.0332223	-0.00496629	1.2654	1.04313e-23	0.774359	109.091

Step 1: HNL Production

- MadGraph HNL events from meson decays

MG output:

kaon_decay_50Mev.lhe

- K^+ fluxes from TDR n-tuple

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84.9599	-123.99	15384.6	0.237416	-0.348232	43.6417	4
-3.32223	-0.496629	126.54	-0.127274	-0.041156	2.38537	109.091
24.3667	-18.0481	2146.35	0.0378792	-0.0275051	3.01461	40
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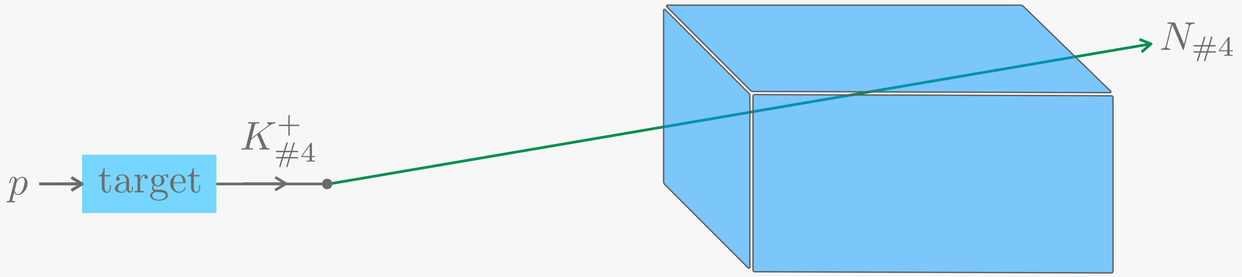
Each MG event matched to one K^+ in the histogram and boosted to the lab frame



If HNL pointing the ND

Step 1 output file: HNL flux file

# Px	Py	Pz	MN	x_decay	y_decay	z_decay	Meson_width	BR_Meson	Meson_weight
0.00518398	-0.000368844	1.02619	0.05	-0.00893351	-0.0719023	3.06405	1.04313e-23	0.774359	120
0.0114722	-0.00399517	2.21981	0.05	-0.0332223	-0.00496629	1.2654	1.04313e-23	0.774359	109.091
-0.00482478	0.000351083	1.08561	0.05	0.243667	-0.180481	21.4635	1.04313e-23	0.225641	40
. . .									

Step 1: HNL Production

- MadGraph HNL events from meson decays

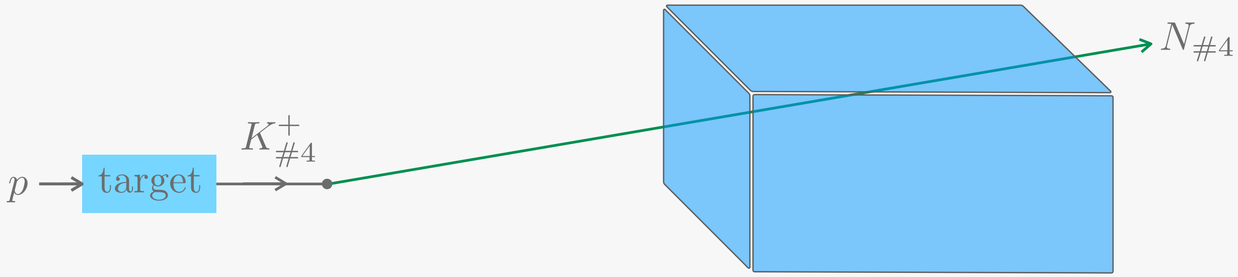
  MG output:

  kaon_decay_50Mev.lhe

- K^+ fluxes from TDR n-tuple

# x	y	z	px	py	pz	weight
-0.893351	-7.19023	306.405	0.00147399	-0.0722823	0.98955	120
84.9599	-123.99	15384.6	0.237416	-0.348232	43.6417	4
-3.32223	-0.496629	126.54	-0.127274	-0.041156	2.38537	109.091
24.3667	-18.0481	2146.35	0.0378792	-0.0275051	3.01461	40
. . .						

Each MG event matched to one K^+ in the histogram and boosted to the lab frame



If HNL pointing the ND

Step 1 output file: HNL flux file

# Px	Py	Pz	MN	x_decay	y_decay	z_decay	Meson_width	BR_Meson	Meson_weight
0.00518398	-0.000368844	1.02619	0.05	-0.00893351	-0.0719023	3.06405	1.04313e-23	0.774359	120
0.0114722	-0.00399517	2.21981	0.05	-0.0332223	-0.00496629	1.2654	1.04313e-23	0.774359	109.091
-0.00482478	0.000351083	1.08561	0.05	0.243667	-0.180481	21.4635	1.04313e-23	0.225641	40
. . .									

2-body K^+ decay

3-body K^+ decay

events-kaon+-50Mev-n1.dat

Step 2: HNL Decay

Step 2: HNL decay. Option A: one decay channel

- MadGraph HNL decay events (one channel)

```
mg5_aMC>
   import model effective_HeavyN_Dirac_UFO
   generate n1 > e+ e- v QED <= 2
   launch
   set MN4 0.05
   set thetae 0.001
   set thetamu 0
   set thetatau 0
   set nevents 10000
```

$N \to e^+ e^- \nu$ decays

Step 2: HNL decay. Option A: one decay channel

- MadGraph HNL decay events (one channel)

  MG output:

  
  ndecay_eev_50Mev.lhe

Step 2: HNL decay. Option A: one decay channel

- MadGraph HNL decay events (one channel)

  MG output:

  ndecay_eev_50Mev.lhe

- HNL fluxes from Step 1

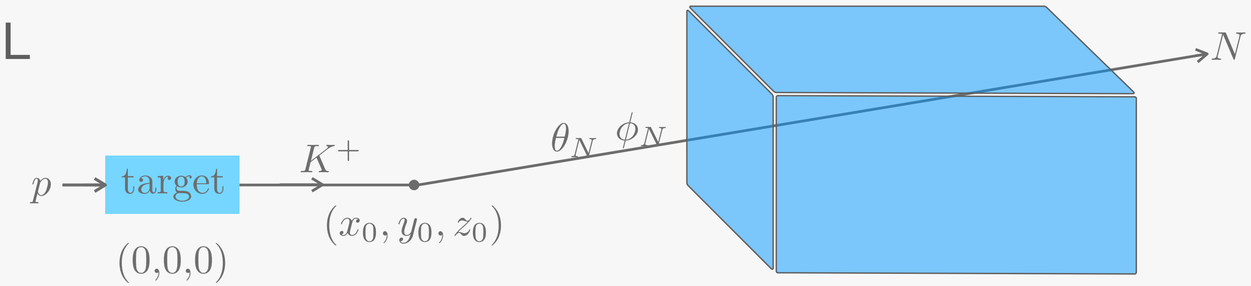
```
#          Px   …      MN       x_decay   …  Meson_width  BR_Meson  Meson_weight
 0.00518398    …    0.05   -0.00893351    …  1.04313e-23  0.774359           120
  0.0114722    …    0.05    -0.0332223    …  1.04313e-23  0.774359       109.091
-0.00482478    …    0.05      0.243667    …  1.04313e-23  0.225641            40
. . .
```

Each MG event matched to one HNL in the histogram and boosted to the lab frame (LF)

Information stored in the MD file

```
### 0
#M_w          N_w     MN USquared      L_lab_N          x_0         y_0       z_0       thetaN      phiN   M_width_CM       BR_M   N_width_CM       BR_N        time_N
120   1.40438e-11   0.05    1e-06   3.5603e+11   -0.0089335   -0.071902   3.06405   0.0050644   1.64183   1.04313e-23   0.774359   1.13565e-26   0.371457   1.91365e-06
#particle.id       EeBoost       PxlabBoost       PylabBoost       PzlabBoost
       12000     0.0266246       -0.0044687       0.00352943       0.0260085
          11      0.718403     -0.000989571        0.0100071        0.718332
         -11      0.282393        0.0106423       -0.0139054        0.281849
. . .
```

Trajectory of the HNL



$$\theta_N = \arccos\left(\frac{P_{zN}}{P_N}\right)$$

$$\phi_N = \arctan\left(\frac{P_{xN}}{P_{yN}}\right)$$

Step 2: HNL decay. Option A: one decay channel

- MadGraph HNL decay events (one channel)

  MG output:

  ndecay_eev_50Mev.lhe

- HNL fluxes from Step 1

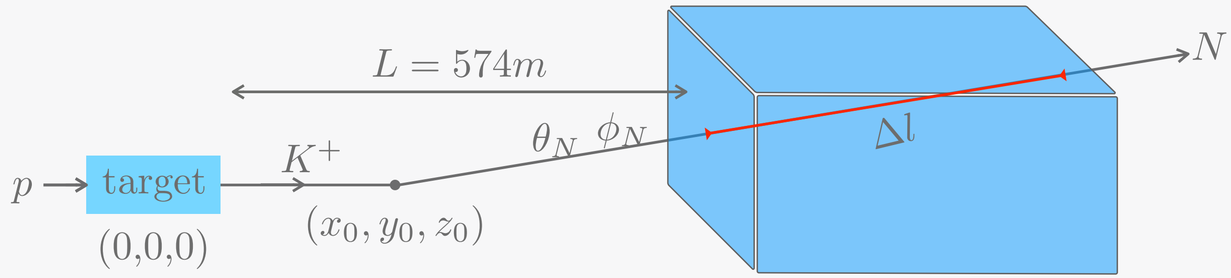
```
#         Px   …     MN      x_decay   …  Meson_width  BR_Meson  Meson_weight
 0.00518398   …   0.05   -0.00893351   …  1.04313e-23  0.774359           120
  0.0114722   …   0.05    -0.0332223   …  1.04313e-23  0.774359       109.091
-0.00482478   …   0.05     0.243667   …  1.04313e-23  0.225641            40
. . .
```

Each MG event matched to one HNL in the histogram and boosted to the lab frame (LF)

Information stored in the MD file

```
### 0
#M_w          N_w    MN USquared     L_lab_N         x_0         y_0      z_0     thetaN     phiN   M_width_CM      BR_M   N_width_CM      BR_N        time_N
120  1.40438e-11  0.05    1e-06  3.5603e+11  -0.0089335  -0.071902  3.06405  0.0050644  1.64183  1.04313e-23  0.774359  1.13565e-26  0.371457  1.91365e-06
#particle.id       EeBoost       PxlabBoost       PylabBoost       PzlabBoost
       12000     0.0266246       -0.0044687       0.00352943        0.0260085
          11      0.718403     -0.000989571        0.0100071         0.718332
         -11      0.282393        0.0106423       -0.0139054         0.281849
. . .
```

HNL weight



$$N_w = e^{-\frac{\Gamma L}{\gamma\beta}}\left(1 - e^{-\frac{\Gamma \Delta l}{\gamma\beta}}\right) \approx \frac{\Gamma \Delta l}{\gamma\beta}$$

Γ total HNL decay width CM

Step 2: HNL decay. Option A: one decay channel

- MadGraph HNL decay events (one channel)

  MG output:

  ndecay_eev_50Mev.lhe

- HNL fluxes from Step 1

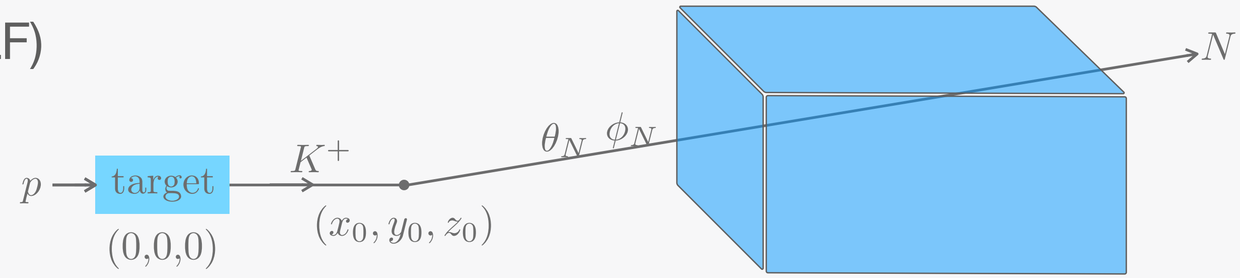
#	Px	…	MN	x_decay	…	Meson_width	BR_Meson	Meson_weight
	0.00518398	…	0.05	-0.00893351	…	1.04313e-23	0.774359	120
	0.0114722	…	0.05	-0.0332223	…	1.04313e-23	0.774359	109.091
	-0.00482478	…	0.05	0.243667	…	1.04313e-23	0.225641	40
. . .								

Each MG event matched to one HNL in the histogram and boosted to the lab frame (LF)

Information stored in the MD file

```
### 0
#M_w         N_w     MN USquared      L_lab_N         x_0         y_0       z_0     thetaN      phiN   M_width_CM       BR_M   N_width_CM       BR_N        time_N
120  1.40438e-11   0.05    1e-06   3.5603e+11  -0.0089335  -0.071902   3.06405  0.0050644   1.64183  1.04313e-23   0.774359  1.13565e-26   0.371457   1.91365e-06
#particle.id       EeBoost      PxlabBoost       PylabBoost      PzlabBoost
       12000     0.0266246       -0.0044687       0.00352943       0.0260085
          11      0.718403     -0.000989571        0.0100071        0.718332
         -11      0.282393        0.0106423       -0.0139054        0.281849
. . .
```

HNL decay length (LF)



$$L_N = \frac{p_N}{M_4 \Gamma}$$

Γ total HNL decay width CM

Step 2: HNL decay. Option A: one decay channel

- MadGraph HNL decay events (one channel)

  MG output:

  ndecay_eev_50Mev.lhe

- HNL fluxes from Step 1

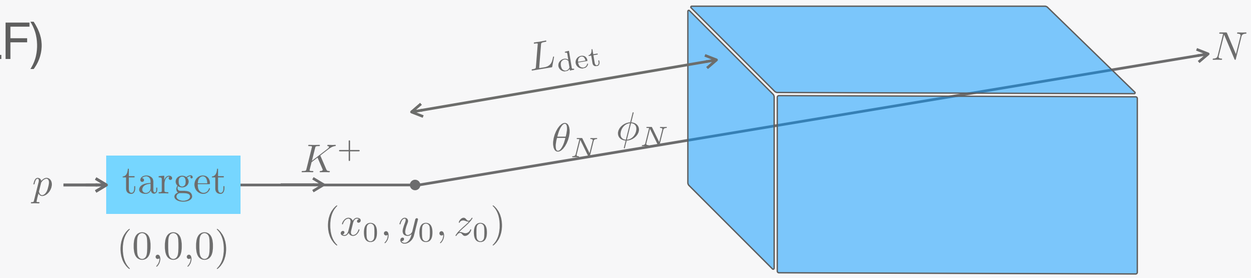
#	Px	…	MN	x_decay	…	Meson_width	BR_Meson	Meson_weight
	0.00518398	…	0.05	-0.00893351	…	1.04313e-23	0.774359	120
	0.0114722	…	0.05	-0.0332223	…	1.04313e-23	0.774359	109.091
	-0.00482478	…	0.05	0.243667	…	1.04313e-23	0.225641	40
. . .								

Each MG event matched to one HNL in the histogram and boosted to the lab frame (LF)

Information stored in the MD file

```
### 0
#M_w         N_w     MN USquared      L_lab_N          x_0         y_0       z_0      thetaN      phiN    M_width_CM       BR_M    N_width_CM       BR_N       time_N
120   1.40438e-11   0.05    1e-06   3.5603e+11   -0.0089335   -0.071902   3.06405   0.0050644   1.64183   1.04313e-23   0.774359   1.13565e-26   0.371457   1.91365e-06
#particle.id       EeBoost       PxlabBoost       PylabBoost       PzlabBoost
       12000     0.0266246       -0.0044687       0.00352943       0.0260085
          11      0.718403     -0.000989571        0.0100071        0.718332
         -11      0.282393        0.0106423       -0.0139054        0.281849
. . .
```

HNL time of flight (LF)



$$t_N = \frac{L_{\rm det}}{\beta c}$$

Step 2: HNL decay. Option A: one decay channel

- MadGraph HNL decay events (one channel)

  MG output:

  ndecay_eev_50Mev.lhe

- HNL fluxes from Step 1

#	Px	…	MN	x_decay	…	Meson_width	BR_Meson	Meson_weight
	0.00518398	…	0.05	-0.00893351	…	1.04313e-23	0.774359	120
	0.0114722	…	0.05	-0.0332223	…	1.04313e-23	0.774359	109.091
	-0.00482478	…	0.05	0.243667	…	1.04313e-23	0.225641	40
. . .								

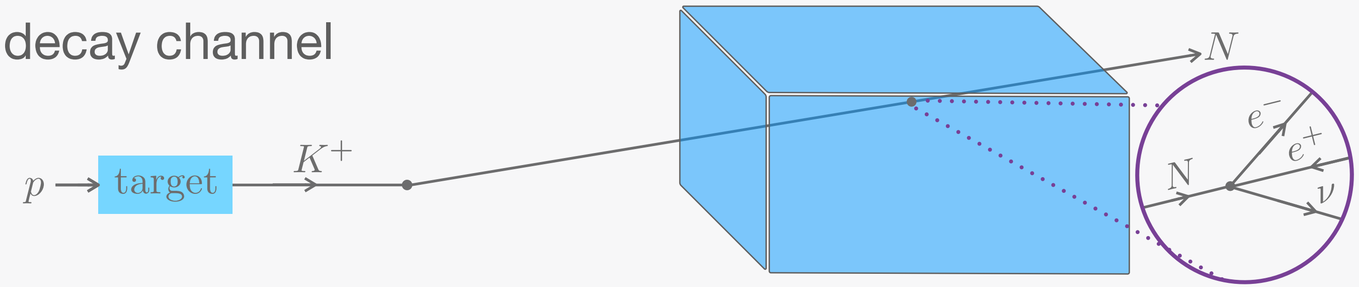
Each MG event matched to one HNL in the histogram and boosted to the lab frame (LF)

Information stored in the MD file

```
### 0
#M_w          N_w     MN USquared      L_lab_N          x_0         y_0       z_0      thetaN      phiN    M_width_CM      BR_M  N_width_CM       BR_N        time_N
120   1.40438e-11   0.05    1e-06   3.5603e+11   -0.0089335   -0.071902   3.06405   0.0050644   1.64183   1.04313e-23   0.774359   1.13565e-26   0.371457   1.91365e-06
#particle.id       EeBoost       PxlabBoost       PylabBoost       PzlabBoost
       12000     0.0266246       -0.0044687        0.00352943        0.0260085
          11      0.718403     -0.000989571         0.0100071         0.718332
         -11      0.282393        0.0106423        -0.0139054         0.281849
. . .
```

$N \to e^+ e^- \nu$

BR of the simulated decay channel



Step 2: HNL decay. Option A: one decay channel

- MadGraph HNL decay events (one channel)

  MG output:

  📄 ndecay_eev_50Mev.lhe

- HNL fluxes from Step 1

```
#         Px   …     MN       x_decay   …  Meson_width  BR_Meson  Meson_weight
 0.00518398   …   0.05  -0.00893351   …   1.04313e-23  0.774359           120
  0.0114722   …   0.05   -0.0332223   …   1.04313e-23  0.774359       109.091
-0.00482478   …   0.05     0.243667   …   1.04313e-23  0.225641            40
. . .
```

Each MG event matched to one HNL in the histogram and boosted to the lab frame (LF)

Information stored in the MD file

```
### 0
#M_w         N_w    MN USquared     L_lab_N         x_0         y_0      z_0     thetaN     phiN   M_width_CM      BR_M   N_width_CM      BR_N       time_N
120  1.40438e-11  0.05    1e-06  3.5603e+11  -0.0089335  -0.071902  3.06405  0.0050644  1.64183  1.04313e-23  0.774359  1.13565e-26  0.371457  1.91365e-06
#particle.id      EeBoost      PxlabBoost       PylabBoost      PzlabBoost
       12000    0.0266246      -0.0044687       0.00352943       0.0260085
          11     0.718403    -0.000989571        0.0100071        0.718332
         -11     0.282393       0.0106423       -0.0139054        0.281849
. . .
```

Output Step 2A: 📄 events-ndecay-eev-50Mev-1e-6-fromkaon+.dat

Repeat Step 2A for all the accesible HNL decay channels

Step 2: HNL decay. Option B: All decay channel

- MadGraph HNL decay events (all channel)

```
mg5_aMC>
   import model effective_HeavyN_Dirac_UFO
   generate n1 > meson lepton QED <= 2
   add process n1 > lepton lepton lepton QED <= 2
   launch
   set MN4 0.05
   set thetae 0.001
   set thetamu 0
   set thetatau 0
   set nevents 100000
```

2-body + 3-body HNL decays

bigger # events!

10^6 limit

Step 2: HNL decay. Option B: All decay channel

- MadGraph HNL decay events (all channel)

  MG output:

  ndecay_50Mev.lhe

- HNL fluxes from Step 1

```
#         Px   …     MN       x_decay   …  Meson_width  BR_Meson  Meson_weight
 0.00518398   …   0.05   -0.00893351   …  1.04313e-23  0.774359           120
  0.0114722   …   0.05    -0.0332223   …  1.04313e-23  0.774359       109.091
-0.00482478   …   0.05      0.243667   …  1.04313e-23  0.225641            40
. . .
```

Each MG event matched to one HNL in the histogram and boosted to the lab frame (LF)

Information stored in the MD file

```
### 0
#M_w          N_w     MN USquared      L_lab_N          x_0         y_0       z_0      thetaN      phiN    M_width_CM      BR_M    N_width_CM       BR_N        time_N
120   1.40438e-11   0.05     1e-06   3.5603e+11   -0.0089335   -0.071902   3.06405   0.0050644   1.64183   1.04313e-23   0.774359   1.13565e-26   0.371457   1.91365e-06
#particle.id       EeBoost       PxlabBoost       PylabBoost       PzlabBoost
       12000     0.0266246       -0.0044687        0.00352943        0.0260085
          11      0.718403     -0.000989571         0.0100071         0.718332
         -11      0.282393        0.0106423        -0.0139054         0.281849
### 1
109.091   6.49214e-12   0.05   1e-06   7.7015e+11   -0.033222   -0.0049663   1.2654   0.0054724   1.90591   1.04313e-23   0.774359   1.13565e-26   0.314661   1.91812e-06
       12000       1.15731        0.0265641        -0.0108905          1.15695
       12000       1.05248       -0.0134862         0.00638912         1.05237
      -12000     0.0106205      -0.00160576        0.000506223        0.0104862
. . .
```

$N \to e^+ e^- \nu$

$N \to \nu\nu\nu$

Output Step 2B: events-ndecay-50Mev-1e-6-fromkaon+.dat

Grid of HNL masses and Mixings

Grid of HNL masses and Mixings

- Grid of HNL masses

  For every parent meson (π, K, D, D_s) perform Step1 + Step2B assuming different M_4

  - n different values of M_4
  - one single value $|U_{\alpha 4}|^2$ for each flavour

  Output:

  2n (3n) MD files for π and K (D and D_s)

- Grid of HNL mixings

  Each MD file can be rescaled to a different value of $|U_{\alpha 4}|^2$: $\times \frac{|U^2_{\alpha 4}|^2_{\text{new}}}{|U^2_{\alpha 4}|^2_{\text{old}}}$

```
### 0
#M_w          N_w*     MN  USquared     L_lab_N         x_0         y_0      z_0     thetaN     phiN   M_width_CM      BR_M  N_width_CM      BR_N        time_N
120  1.40438e-11  0.05    1e-06  3.5603e+11  -0.0089335  -0.071902  3.06405  0.0050644  1.64183  1.04313e-23  0.774359  1.13565e-26  0.371457  1.91365e-06
#particle.id       EeBoost      PxlabBoost       PylabBoost      PzlabBoost
       12000    0.0266246      -0.0044687       0.00352943       0.0260085
          11     0.718403    -0.000989571        0.0100071        0.718332
         -11     0.282393       0.0106423       -0.0139054        0.281849
. . .
```

*valid for $\Gamma L \ll \gamma\beta \Rightarrow N_w \approx \frac{\Gamma \Delta l}{\gamma\beta}$

Grid of HNL masses and Mixings

- Grid of HNL masses

  For every parent meson (π, K, D, D_s) perform Step1 + Step2B assuming different M_4

  - n different values of M_4
  - one single value $|U_{\alpha 4}|^2$ for each flavour

  Output:

  2n (3n) MD files for π and K (D and D_s)

- Grid of HNL mixings

  Each MD file can be rescaled to a different value of $|U_{\alpha 4}|^2$: $\times \frac{|U^2_{\alpha 4}|^2_{\text{old}}}{|U^2_{\alpha 4}|^2_{\text{new}}}$

```
### 0
#M_w         N_w    MN USquared     L_lab_N         x_0         y_0      z_0     thetaN      phiN   M_width_CM      BR_M   N_width_CM      BR_N        time_N
120  1.40438e-11  0.05    1e-06  3.5603e+11  -0.0089335  -0.071902  3.06405  0.0050644   1.64183  1.04313e-23  0.774359  1.13565e-26  0.371457  1.91365e-06
#particle.id      EeBoost      PxlabBoost       PylabBoost      PzlabBoost
       12000    0.0266246      -0.0044687       0.00352943       0.0260085
          11     0.718403    -0.000989571        0.0100071        0.718332
         -11     0.282393       0.0106423       -0.0139054        0.281849
. . .
```

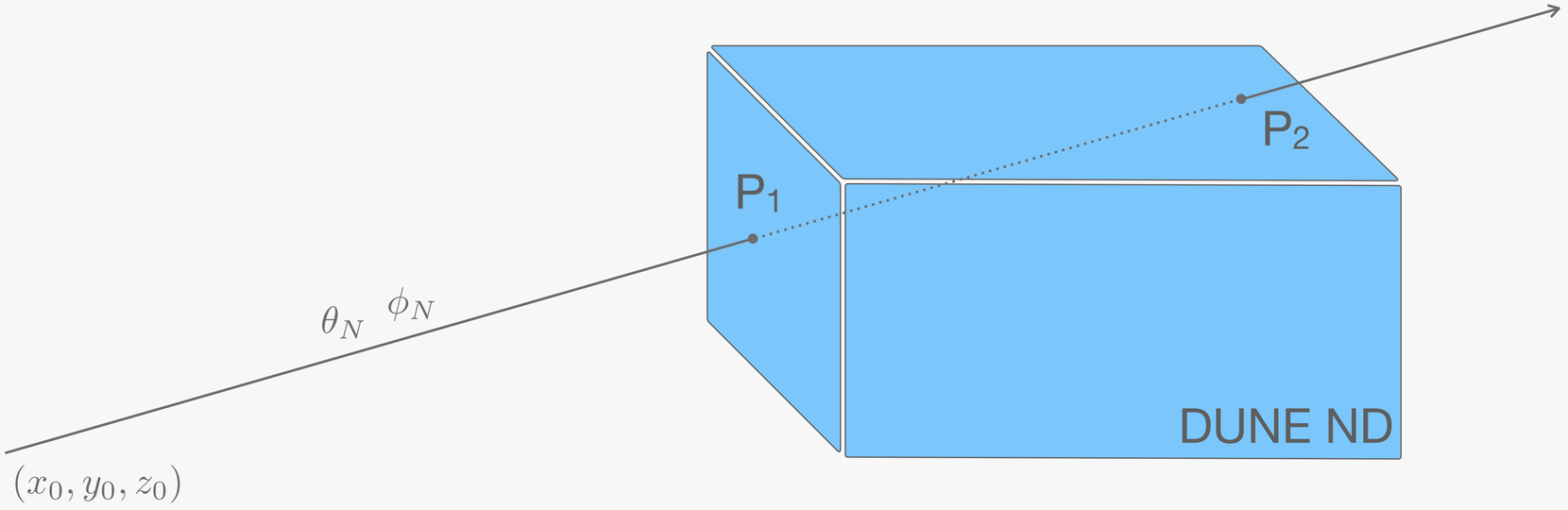
Detector Simulation

Detector Simulation

The MD files contain trajectories of the HNLs intersecting the ND

For each HNL event, the trajectory is defined by (x_0,y_0,z_0) and the angles θ_N and ϕ_N

The trajectory of a given HNL intersects the ND in two points P_1 and P_2

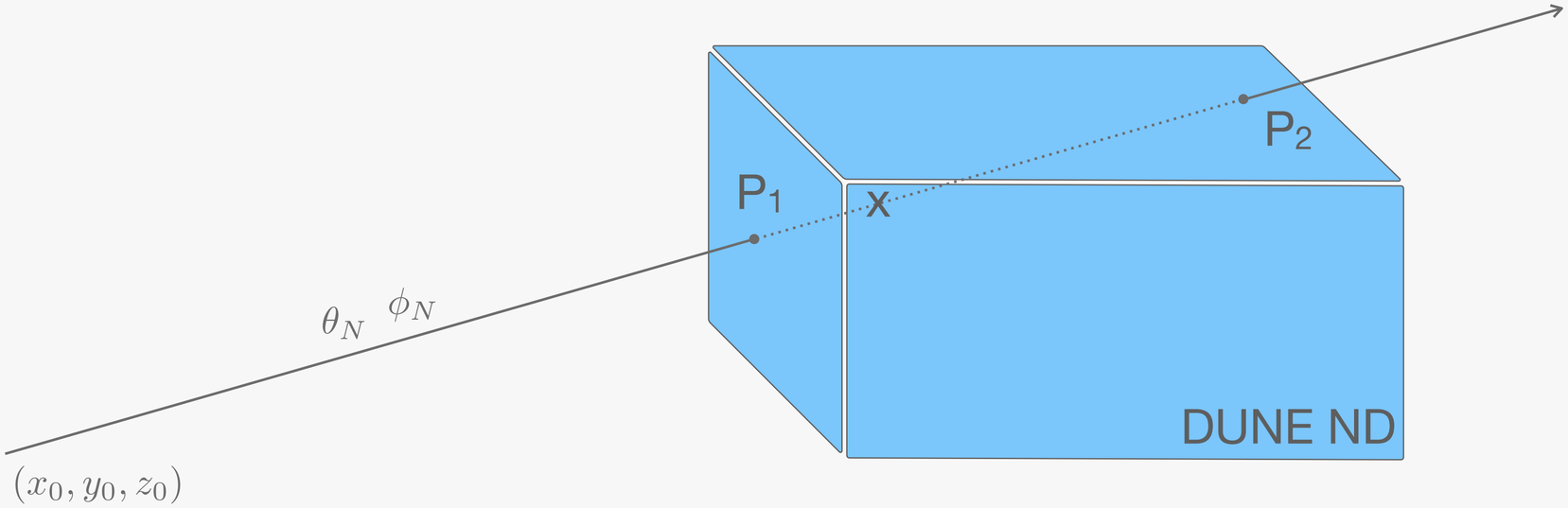


Detector Simulation

The MD files contain trajectories of the HNLs intersecting the ND

For each HNL event, the trajectory is defined by (x_0,y_0,z_0) and the angles θ_N and ϕ_N

The trajectory of a given HNL intersects the ND in two points P_1 and P_2



A random point along the trajectory between P_1 and P_2 can be set as the decay point of the event

Open Discussion

Open Discussion

- Step 2A or Step 2B?
  - Which statistics is needed for proper event reconstruction?
  - Do 10^5 HNL decay events sample well all the different channels in Step 2B?
- Output of the MD file
  - Is the information provided in the MD enough for GArSoft reconstruction?
  - Does GArSoft work with weighted or unweighted events?