Neutrino fluxes from νSTORM

Paul Kyberd
Protons on target produce $\pi$

Some $\pi$ captured & transferred to ring

$\pi$ in the ring decay and produce $\mu$

Some $\mu$ captured and circle the ring

$\mu$ decay - some $\nu$ interact in detector

Losses are such that end to end simulation is unfeasible.
Multiple Simulations

$\pi$ Production $\text{Fluka/Mars}$
$\pi$ capture & transfer $\text{BDSim/G4Beamline}$
$\pi$ decay produces $\mu$ $\text{nuSim}$
$\mu$ Orbit $\text{BDSim/G4Beamline}$
$\nu$ Production $\text{nuSim}$
$\nu$ Interaction $\text{GENIE/Geant4}$

Four complex simulations

Two simple ones
$\pi$ decay to $\mu$ – simple: two body; single channel
$\mu$ decay to $\nu$ – simple: three body, formula; single channel (effectively)

All need linking together
nuSim

We have designed a framework, which can:

- take the parameterised pion production distributions and use accelerator design software to create a pion distribution.

- decay those pions into muons

- use accelerator design software to create a captured muon distribution.

- decay those muons into neutrinos

- Propagate the neutrinos to the detector

- the resulting “flux file” seed GENIE
  The Genie output to design the detector GEANT4 and to determine physics reach
Current Status

Pion production: from NuMI data

Pion distribution from target nuSTORM performance. Detailed modelling being done

Muon production distribution from nuSIM

Muon ring capture from “Racetrack FFAG muon decay ring for nuSTORM with triplet focussing” arXiv:1806.02172v2 [physics.acc-ph]

Neutrino production distribution and propagation to the detector plane from nuSIM
π Production efficiency

The number of (useful) pions is around 0.1 per proton over the required energy range.

We have are starting studies specific for this incarnation of nuSTORM.
Detailed simulation of the pion transfer line are underway.

This parameterisation corresponds to the outline design specifications.

Muon spectrum at production

Muon spectrum at production

Muon spectrum at production

Muon spectrum at production
Captured muons

Figure 6: Stable motion in the horizontal Poincare map for maximum initial amplitude over 100 turns for $p_0$ in JBT. The ellipse shows a 1 mm.rad unnormalized emittance.

Figure 7: Stable motion in the vertical Poincare map for maximum initial amplitude over 100 turns for $p_0$ in JBT. The ellipse shows a 1 mm.rad unnormalized emittance.

Using the plots from “Racetrack FFAG muon decay ring for nuSTORM with triplet focussing”


Muon spectrum in acceptance
Captured muons

The ring will be tuned to accept the forward going muons.

This gives a spectrum like this

Red line is a parabolic fit.
μ Production efficiency

<table>
<thead>
<tr>
<th>Mean pion Energy</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>0.4%</td>
</tr>
<tr>
<td>2</td>
<td>0.6%</td>
</tr>
<tr>
<td>3</td>
<td>1.2%</td>
</tr>
<tr>
<td>4</td>
<td>2.5%</td>
</tr>
<tr>
<td>5</td>
<td>5.1%</td>
</tr>
<tr>
<td>6</td>
<td>5.4%</td>
</tr>
</tbody>
</table>

Muons into the ring acceptance “Beaming” increases acceptance with energy.
ν production

We use a parameterised spectrum for the muons in the ring. A parabolic energy spectrum and a position and angle distributions derived from the target ring specifications.

Its shape agrees with the simulation of the pion decay.
ν to detector acceptance

<table>
<thead>
<tr>
<th>Mean muon Energy</th>
<th>Efficiency</th>
</tr>
</thead>
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<tr>
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<td>8.2%</td>
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<tr>
<td>3</td>
<td>11.7%</td>
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<tr>
<td>4</td>
<td>14.5%</td>
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<tr>
<td>5</td>
<td>17.2%</td>
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<tr>
<td>5.5</td>
<td>18.5%</td>
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</table>

Propagate the neutrinos decays from those muons travelling round the nuSTORM ring to a “detector”

Less Energy dependence
Still favours higher Energies
Flux files

Total efficiency is around 0.03%

The result of all this is a set of flux files, which correspond to the position, angle and energy of the neutrinos which hit the front face of a “detector plane.”

The plane is located 50m downstream of the end of the production straight, with (0,0) on the axis of the production straight.

Work has started on using those files to generate neutrino interactions using GENIE and looking at final state kinematic distributions to determine detector parameters.
If we define a detector 5 by 5 around the (0,0) point we can look at the neutrino fluxes as a function of Energy.

The two plots assume the same number of circulating muons. Higher Energy give more muons per proton. What is the best way to get 0.5 GeV ν’s?
\( \nu \) interaction "rates"

Number of interactions per incident \( \nu \) varies with \( \nu \) energy.

\[
\begin{array}{|c|c|c|}
\hline
\text{E numu} & \text{Entries} & 18356 \\
& \text{Mean} & 2.495 \\
& \text{Std Dev} & 1.206 \\
\hline
\end{array}
\]

\[
\begin{array}{|c|c|c|}
\hline
\text{event rate numu} & \text{Entries} & 18356 \\
& \text{Mean} & 3.077 \\
& \text{Std Dev} & 1.11 \\
\hline
\end{array}
\]

\( <\text{muon Energy}> = 5.5 \text{ GeV} \)

Distribution of \( \nu \) energies

Relative event rate: weighting flux with \( \nu \) energy

\( \nu \) fluxes from vSTORM

Paul Kyberd
Summary

π Production Fluka/Mars

π capture & transfer BDSim/G4Beamline

1st iteration nearing completion

π decay produces μ

complete

μ Orbit BDSim/G4Beamline

In progress

ν Production complete

ν Interaction GENIE/Geant4

Preliminary distributions
Wiki and datasets

There is a wiki, which contains information on the status of the project

nustorm.org

And the datasets are also available at

data.nustorm.org

<Energy>

<table>
<thead>
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<th>muon</th>
<th>GeV</th>
<th>Events</th>
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<tr>
<td>2</td>
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<tr>
<td>5.5</td>
<td>250k</td>
<td></td>
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</tbody>
</table>

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