Uniform Beam Simulation Technique for Beam Scans : NuMI, LBNF

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Motivation

- Aim:
 - Create single high-statistics uniform simulation sample for each beam variable
 - Can generate as many random samples as possible from a single uniform beam sample
 - Can avoid generating multiple nominal simulation samples – reduces expensive computing resource & grid time

- Allows to do beam scan studies in simulation
- Study different beam configurations i.e., beam spot size, beam shape etc.
- ML studies, need large statistics in simulated sample to understand correlation b/w MM observation & target incidents

Uniform Beam Simulation for NuMI

• From uniformly distributed proton throws, weights for different proton beam settings calculated using Eqn.



Random throws along horizontal beam positions to generate a uniform proton beam sample

Example of calculated weights for a selected beam setting for $\sigma = 1.5 \text{ mm} \& 1.0 \text{ mm}$

Uniform Beam Simulation for NuMI



Horizontal Proton Beam Position

- Uniform proton beam position generated by random throws along X & Y
- Only recorded if a neutrino candidate at neutrino detector from hadron decay

Vertical Proton Beam Position

Uniform Beam Simulation for NuMI

Vertical Proton Beam Position

Horizontal Proton Beam Position





POT Estimation





POT Comparison b/w Uniform & Nominal





Beam Profile Comparison b/w Uniform & Nominal





Muon Flux Profile Comparison b/w Uniform & Nominal

MM1:Uniform:Slice0: -0.2 cm



MM1:Nominal:Slice0 : -0.2 cm

~ 3% difference at some edge pixels – random statistical fluctuations

MM1:Uniform/Nominal:Slice0

Muon Momentum Comparison b/w Uniform & Nominal









Actual beam scans with muon monitors

Study scans with uniform beam simulation with Muon Monitor 1 & 2



• Study beam spot size changes

Beam Spot Size: σ = 0.08 cm



Beam Spot Size: $\sigma = 0.15$ cm







Muon Monitor 1: σ = 0.15 cm



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• Machine Learning studies



- Uniformly distributed sample used to generate Gaussian beam profiles for different selected beam parameters
- Beam positions, widths etc. can be varied post-processing once one Uniform sample is generated
- Computational overhead greatly reduced



LBNF Uniform Beam Simulation



Geant 4 geometry: fins in xy plane

5 beam samples generated by applying Gaussian weights





LBNF Uniform Beam Simulation





Comparing Uniform & Nominal LBNF Beam profiles



A comparison of neutrino events by setting up different beam and horn configurations



A comparison of neutrino events by setting up different beam and horn configurations







- Added uniform proton beam X & Y information in HaDeS simulation by placing a Tracking Plane at HaDeS location
- User can choose beam range, shown here b/w +/-10 mm along beam x





For different gaussian slices of the proton beam look at corresponding distributions of charged particles at HaDeS





For different Gaussian slices of the proton beam look at corresponding distributions of charged particles at HaDeS









0.06 0.08

0.1 Momentum X [GeV] ×10³

9000

8000

7000

6000

5000 4000

3000

2000

1000

Added uniform proton beam X & Y information in AlcoveTracks Tree •





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Alcove Tracking Plane 1:





Alcove Tracking Plane 2:





Alcove Tracking Plane 3:





Alcove 2 Y [cm]



Alcove 2

00 -8	0 -60	-40	-20	0	20	40	60 Alcov	80 ve 2 X [cr	100 n]	
6672.66	7135.91	7061.21	7391.5	7351.26	7370.7	7139.96	6992.92	6418.12		6500
_										7000
 	8831.54	9800.16	9738.96	9959.18	9772.8	9600.25	9012.6	7784.71		7500
8404.59	9975.66	10481	10516.8	10587.9	10607.6	10196.4	9902.37	8359.53		
8613.1	10185.6	10414.2	10712.6	11174.8	10763.2	10573.3	10027.8	8694.91		8000
	10291.7	10741.8	10710.8	110/9	11109.7	10834.6	10325.1	8957.54	_	8500
-		40744.0	40740.0	44070		40004.0	40205.4		-	9000
	10323	10622.3	10799.8	10833	10843.3	10598.7	10388.8	9052.91		9500
	10100.9	10479	10783.8	10671.7	10662	10582.2	10083.1	8584		1000
8263.92	9660.64	10162.9	10394.3	10469.1	10308.1	10013.9	9912.19	8416.85		1050
-										1050
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Remarks

- Effective way to generate many beam configuration possibilities without running the MC generator
- Extensive validation performed for NuMI b/w uniform beam & nominal beam simulation
- Can perform beam scans, beam spot size and horn current studies in simulation
- Can generate large statistics to split data into training and test for ML application

- Code changes have been applied to LBNF simulation
- Could be useful for beam scan studies for LBNF with simulation