Uniform Beam Simulation Technique for Beam Scans and Machine Learning Studies at Fermilab

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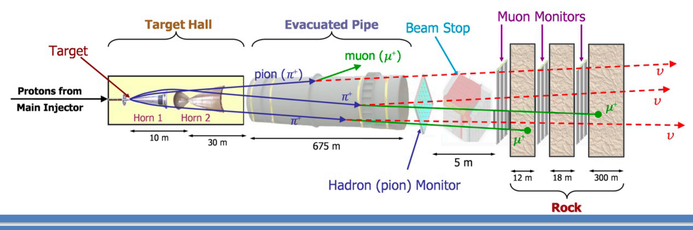
Introduction

We propose a technique to generate multiple simulation samples with high statistics. Simulation time and computing resources can be significantly reduced by simulating a single high statistics sample with a uniform distribution on beam parameters. This is done by calculating a Gaussian weight, then applying the weight to all measurements in postprocessing.

Advantages:

- **Ability to generate as many as random samples.**
- **Reduces the waiting time on generating samples.**
- **Allowing to study different beam configurations such as beam spot size, beam shape, etc.**
- **Helpful for simulation based ML studies.**

120 GeV/c momentum protons from the Main Injector are striking with a graphite target to produce mesons. Charged mesons are focused into the decay pipe. The decay of pions and kaons produces muons and muon-neutrinos. This muon-neutrino beam is delivered to neutrino experiments such as NOvA.

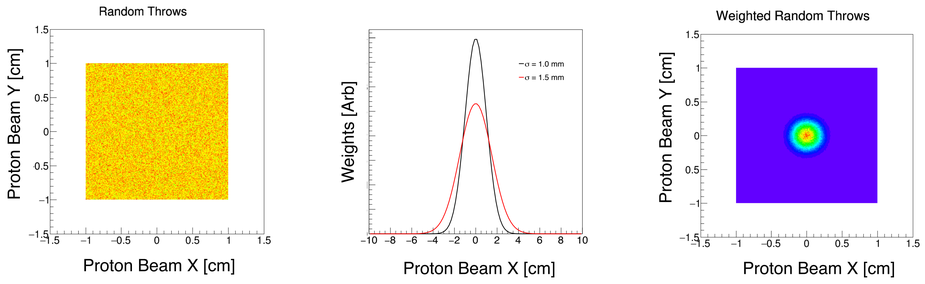


Simulation Technique

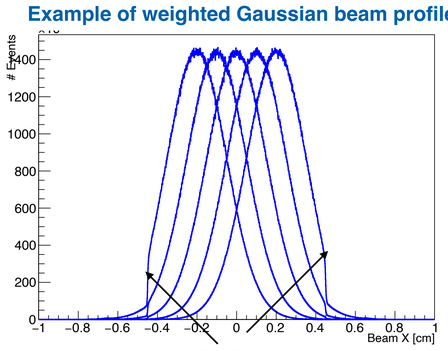
- **Prepare uniformly distributed large simulation samples on beam variables for a selected range.**
- **Calculate the gaussian weights according to the settings of the studying variable.**
- **Apply corresponding weights on observable variables.**

$$w_i = \frac{1}{2\pi\sigma_x\sigma_y} \cdot exp\left\{ -\frac{(x_i-\mu_x)^2}{2\sigma_x^2} - \frac{(y_i-\mu_y)^2}{2\sigma_y^2} \right\}$$

Uniform beam ➡ **Gaussian weights** ➡ **Gaussian Beam**

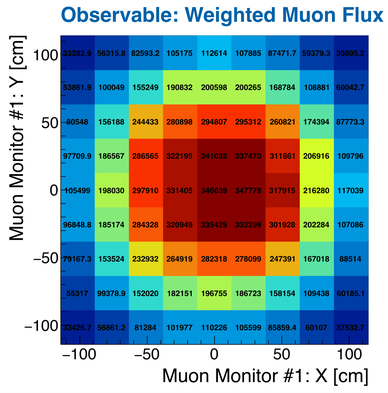


Example of weighted Gaussian beam profiles



Edges of the target

Observable: Weighted Muon Flux

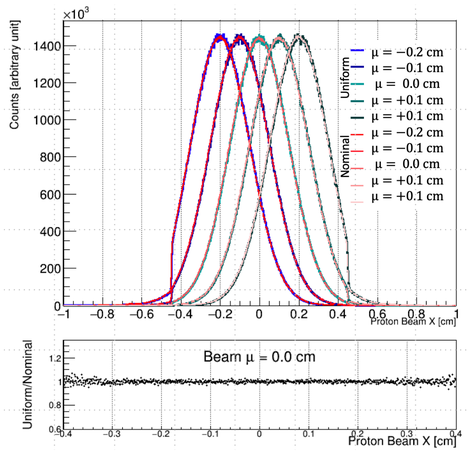


Validation

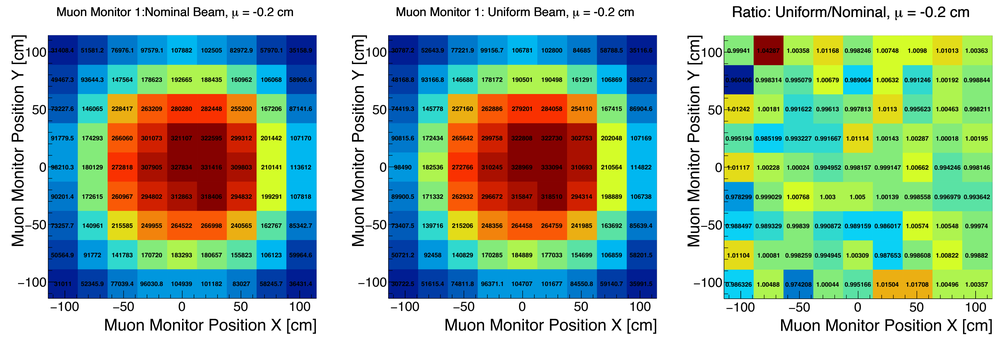
The technique has been validated by comparing the reproducibility of the nominal simulation results from the uniform simulation samples. Here we have used the NuMI beam simulation to cary out the validation validation studies following tests:

- **Testing statistical reproducibility.**
- **Testing kinematics reproducibility.**

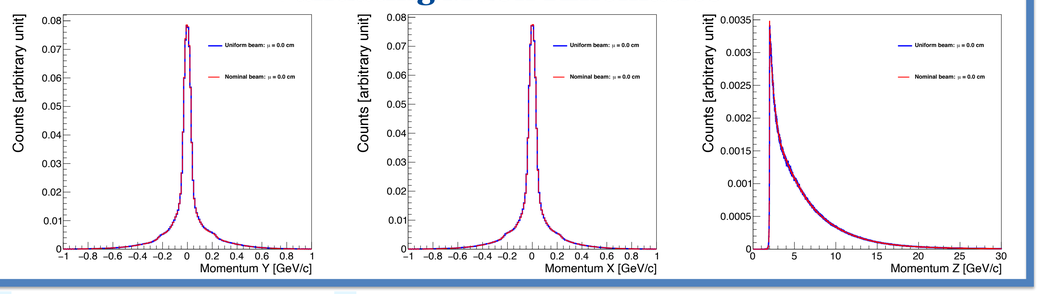
Validating Beam Profile



Validating Muon Flux at the Muon Monitor 1

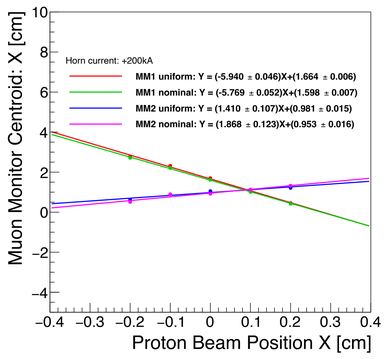


Validating Muon Kinematics

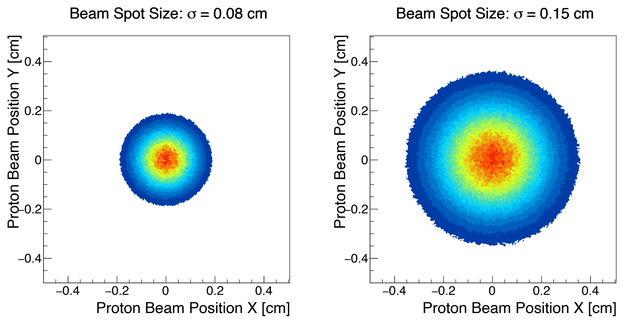


Applications

- ➡ **Beam scan studies**
- ➡ **Beam spot size studies**
- ➡ **LBNF simulation studies**
- ➡ **Machine learning applications**



Muon flux centroid response to the horizontal beam scan with 200 kA horn current settings



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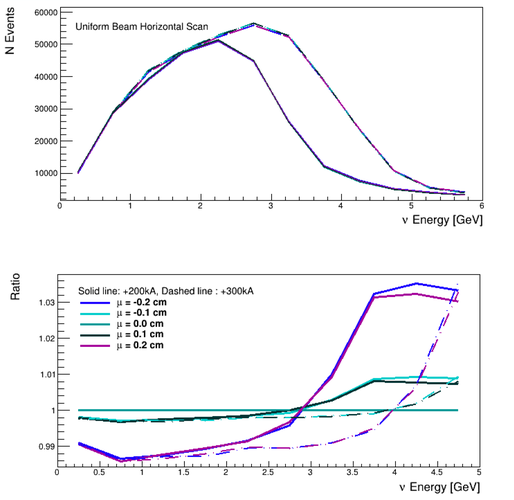
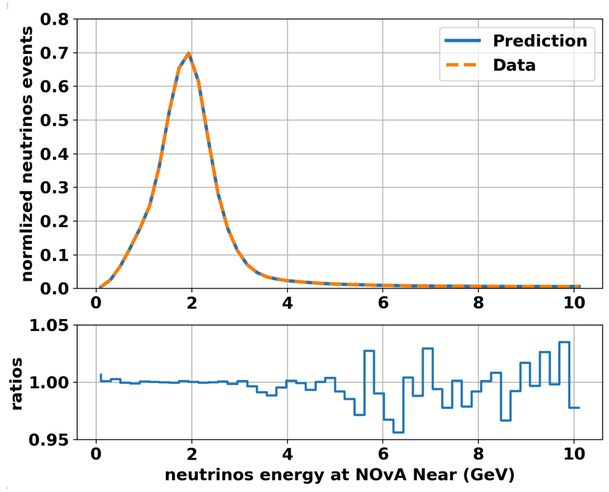


A comparison of neutrino events by setting up different beam and horn current configurations



An example of predicting neutrino flux at the NOvA near detector using a ML algorithm.
We have generated more than 50,000 samples for the training algorithm.

Remarks

- **This technique is easy and effective to generate many beam configuration possibilities without running the MC generator.**
- **We can save the waiting time for generating MC samples.**
- **We have validated the uniform beam simulation technique with the nominal beam simulation.**
- **We are able to do the beam scans, beam spot size and horn current studies by using this technique.**
- **This technique is useful to prepare large MC data samples for ML studies.**

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