Beam simulations & target studies for the NOvA experiment using G4NuMI

Marco Del Tutto
University of Rome "Sapienza"

Supervisor:
Giulia Brunetti
Fermilab

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The NOvA experiment

The NOvA experiment is designed to study electronic neutrinos oscillated from muon neutrinos.

NOvA: NuMI Off-Axis ν_e Appearance

MuMI: Neutrinos at the Main Injector

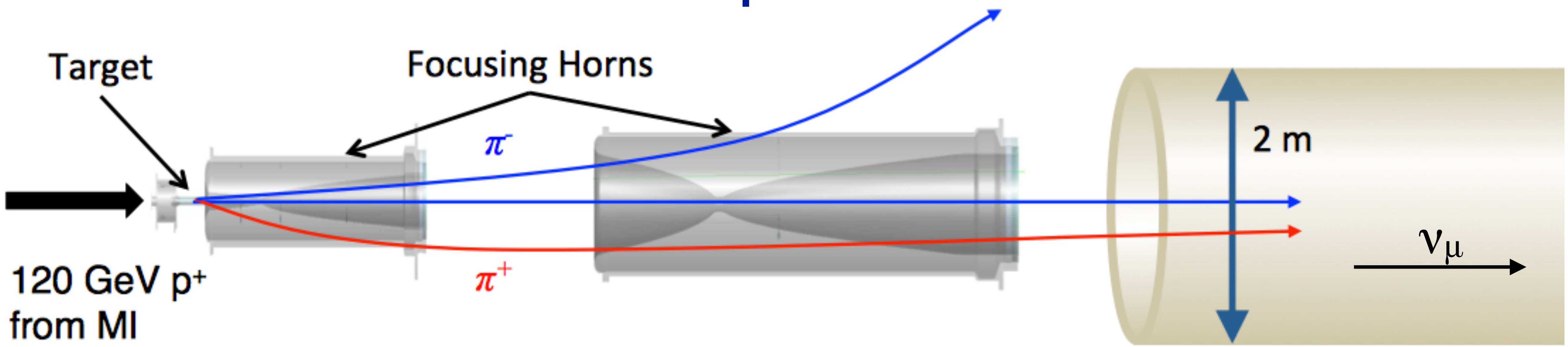
Detectors:

ND: 300 ton

FD: 14000 ton

NOvA near detector

Neutrino production



	NUMI / NOvA
Distance to far detector	810 km
Desired ν energy	2 GeV
Detector Off-beam-axis angle	14 mrad
Beam power (currently)	320 kW
Beam power (capable of)	700 kW
Energy per proton	120 GeV
Number of horns	2
Target length	1.2 m
Distance between target downstream end and horn	0.2 m (not in horn)
Protons/spill	4.9 E13
Repetition rate	1.33 sec

- **target**: 50 graphite fins;
- **two horns**: produce magnetic fields that focus secondaries;
- **decay pipe**: vacuum or He filled.

Monte Carlo simulations

Two different softwares for the simulation:

- **G4NuMi***: a pure Geant4 simulation;
- **Flugg**: **FLU**ka with **G**eant4 **G**eometry (the Monte Carlo is a combination of Fluka, for physics, and Geant4, to describe its geometry).

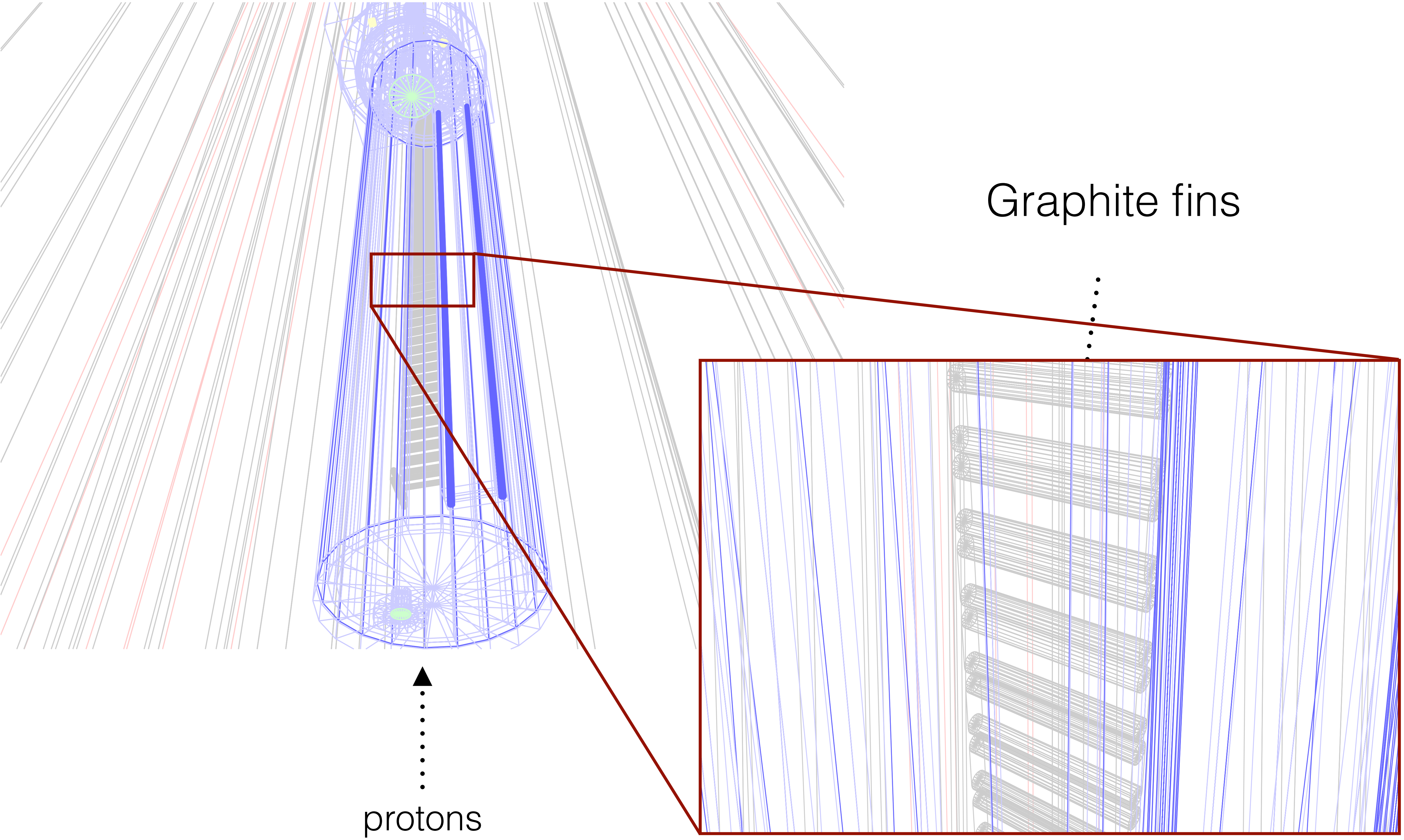
This is the first study with the G4NuMI software.

The whole software framework:

G4NuMI	→	Dk2Nu	→	FluxReader
A pure Geant4 based simulation of the beamline		Ntuple unification		Is a framework designed to make distributions from Dk2Nu flux files

*Geant4 version: geant4-09-06-patch-01a. Physics List: FTFP_BERT.

G4NuMI simulation



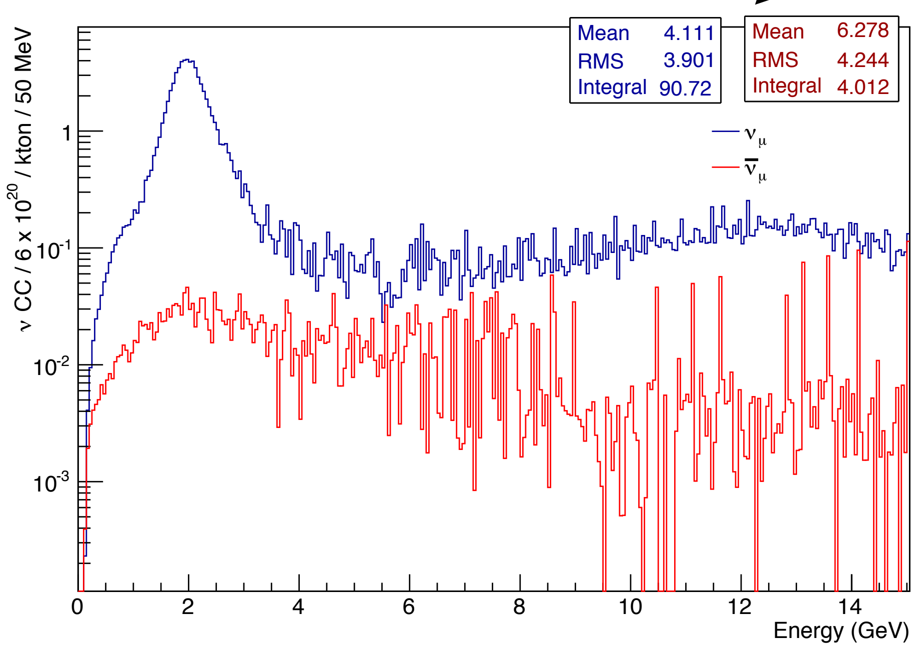
G4NuMI VS Flugg

G4NuMI results

FCH

FD

FD - FHC - CC



ND

ND - FHC - CC

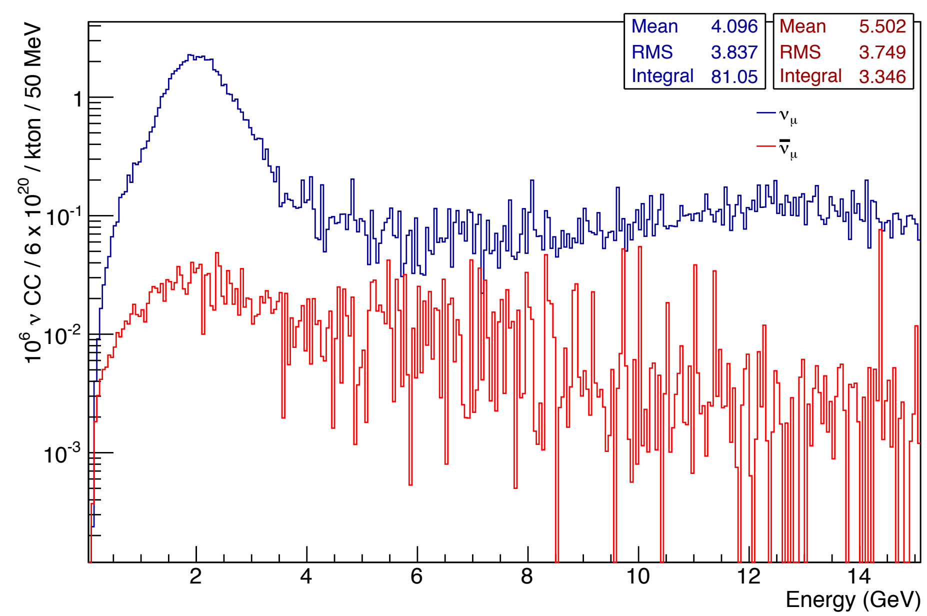


Table 1: *FHC, FD. ratio = Flugg/g4numi for [1,3] GeV.*

	[1,3] GeV g4numi	[1,120] GeV g4numi	[1,3] GeV Flugg	ratio
ν_μ	63.5	99.4	62.1	97.8%
$\bar{\nu}_\mu$	1.1	5.1	1.0	90.9%
TOT	64.6	104.5	63.1	97.7%
$\bar{\nu}_\mu/\nu_\mu$	1.1%		1.6%	

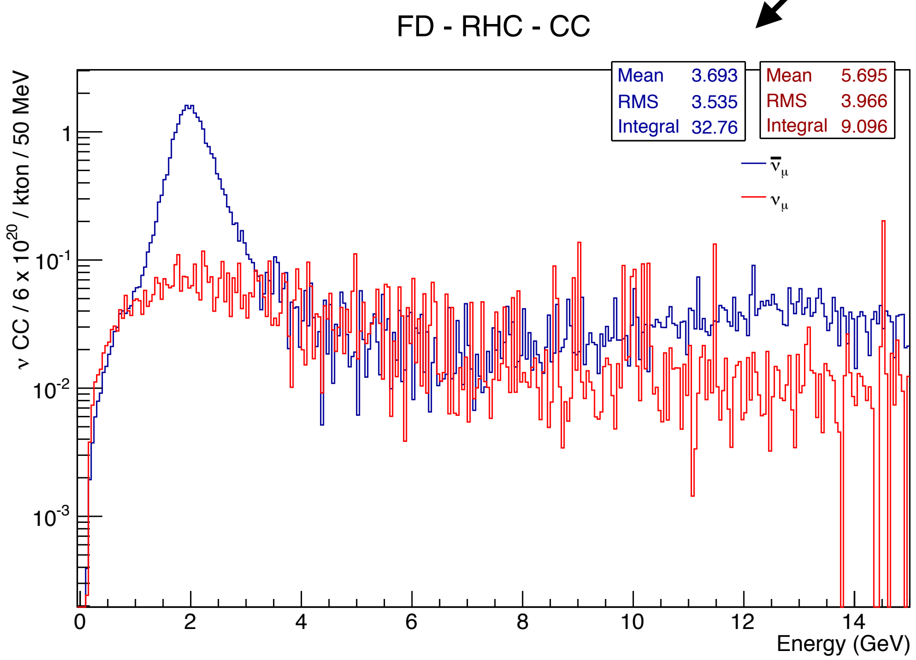
Table 2: *FHC, ND. ratio = Flugg/g4numi for [1,3] GeV.* [$\times 10^6$]

	[1,3] GeV g4numi	[0-120] GeV g4numi	[1,3] GeV Flugg	ratio
ν_μ	53.8	90.1	52.6	97.8%
$\bar{\nu}_\mu$	1.0	4.5	0.9	90.0%
TOT	54.8	94.6	53.5	97.6%
$\bar{\nu}_\mu/\nu_\mu$	1.9%		1.7%	

G4NuMI VS Flugg

At the end of the FHC run, there will be a run with anti-neutrinos.

FD G4NuMI results **ND**



RCH

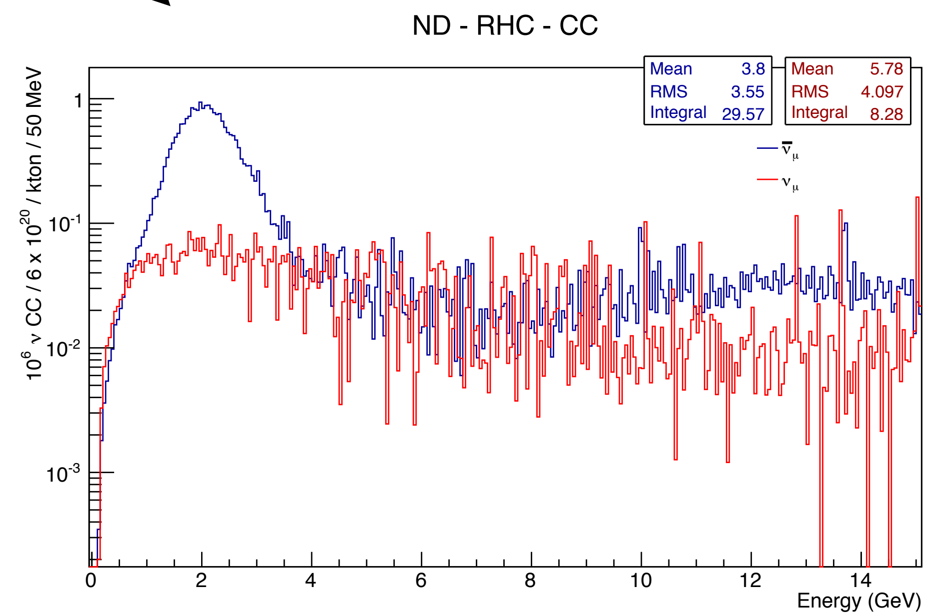


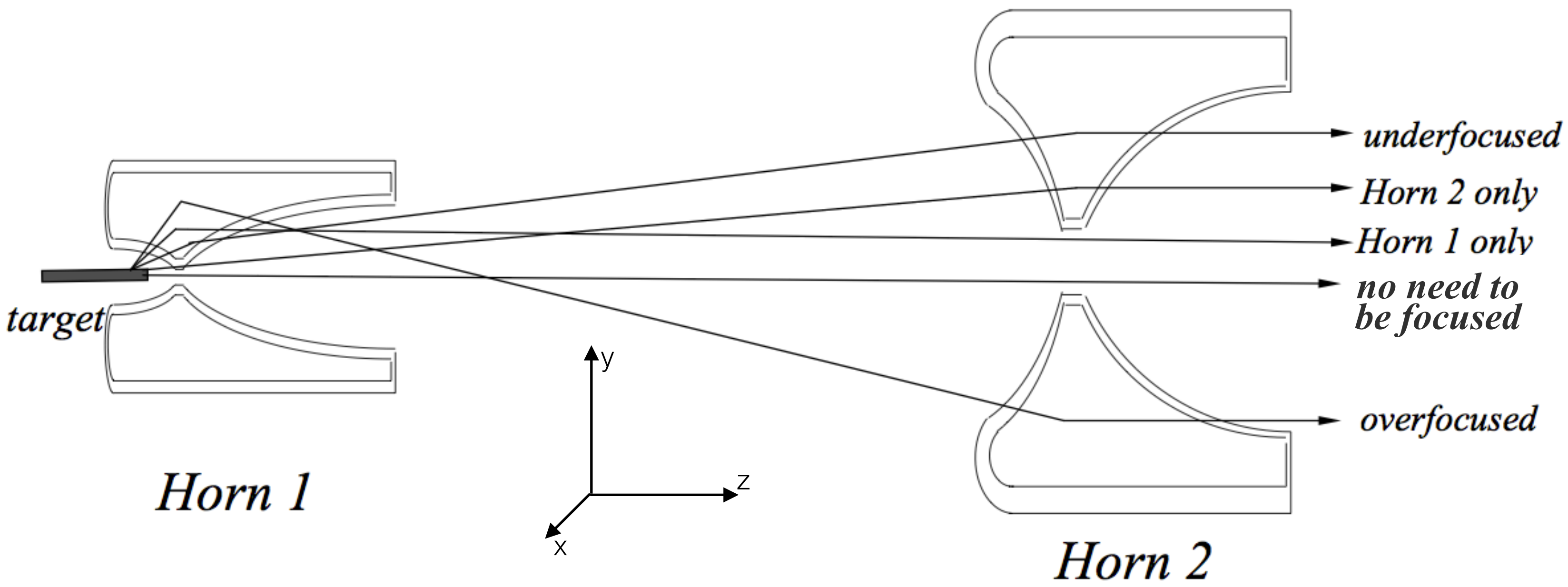
Table 3: *RHC, FD. ratio = Flugg/g4numi for [1,3] GeV.*

	[1,3] GeV g4numi	[0-120] GeV g4numi	[1,3] GeV Flugg	ratio
ν_μ	2.6	12.1	2.4	92.3%
$\bar{\nu}_\mu$	24.4	35.8	22.5	92.2%
TOT	27.0	47.9	24.9	92.2%
$\nu_\mu/\bar{\nu}_\mu$	10.7%		10%	

Table 4: *RHC, ND. ratio = Flugg/g4numi for [1,3] GeV.* [$\times 10^6$]

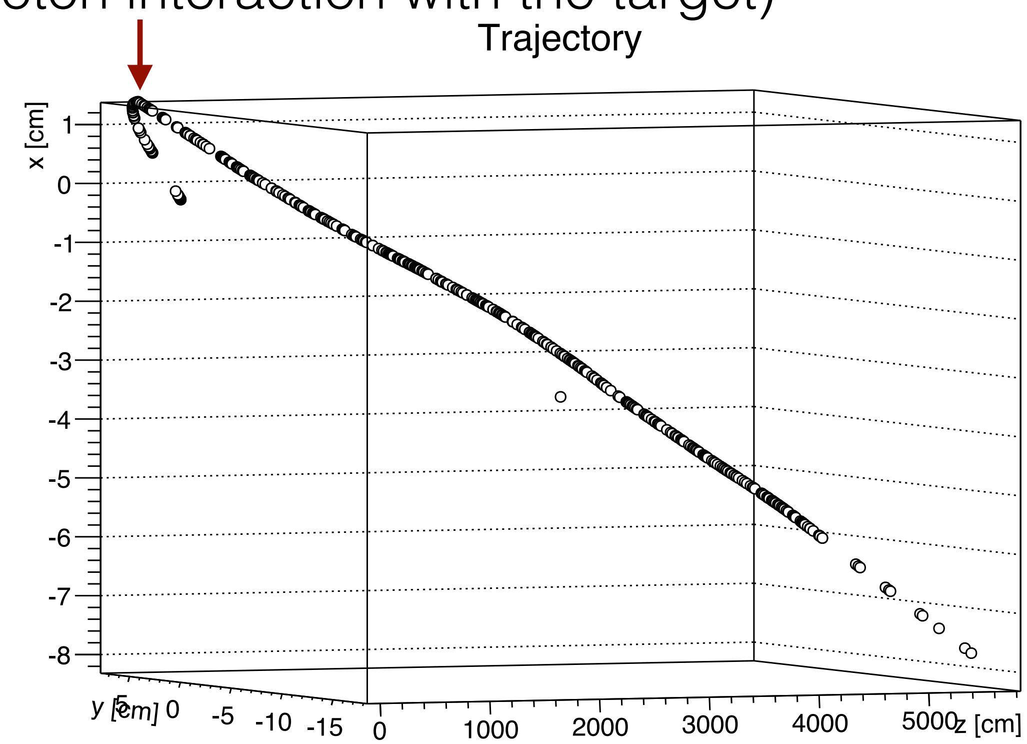
	[1,3] GeV g4numi	[0-120] GeV g4numi	[1,3] GeV Flugg	ratio
ν_μ	2.3	10.6	2.1	91.3%
$\bar{\nu}_\mu$	20.6	32.7	19.1	92.7%
TOT	22.9	43.3	21.2	92.6%
$\nu_\mu/\bar{\nu}_\mu$	11.2%		10%	

Study on π^+ trajectories



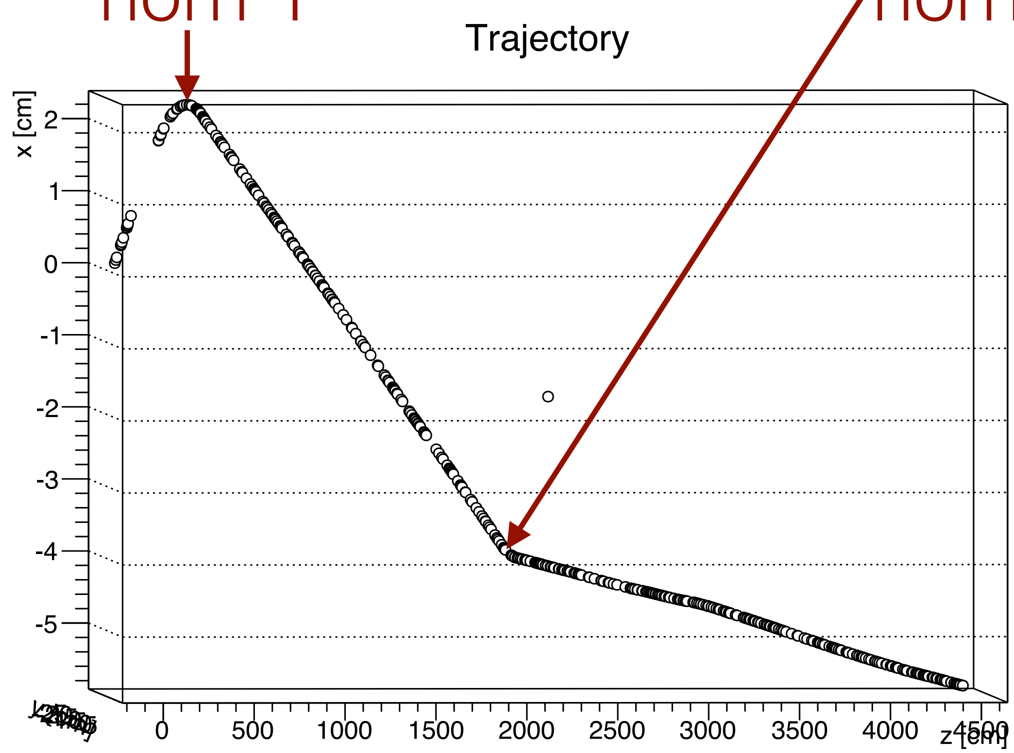
The goal is to find out how many pions need to be focused, how many need only 1 horn…

production vertex
(proton interaction with the target)



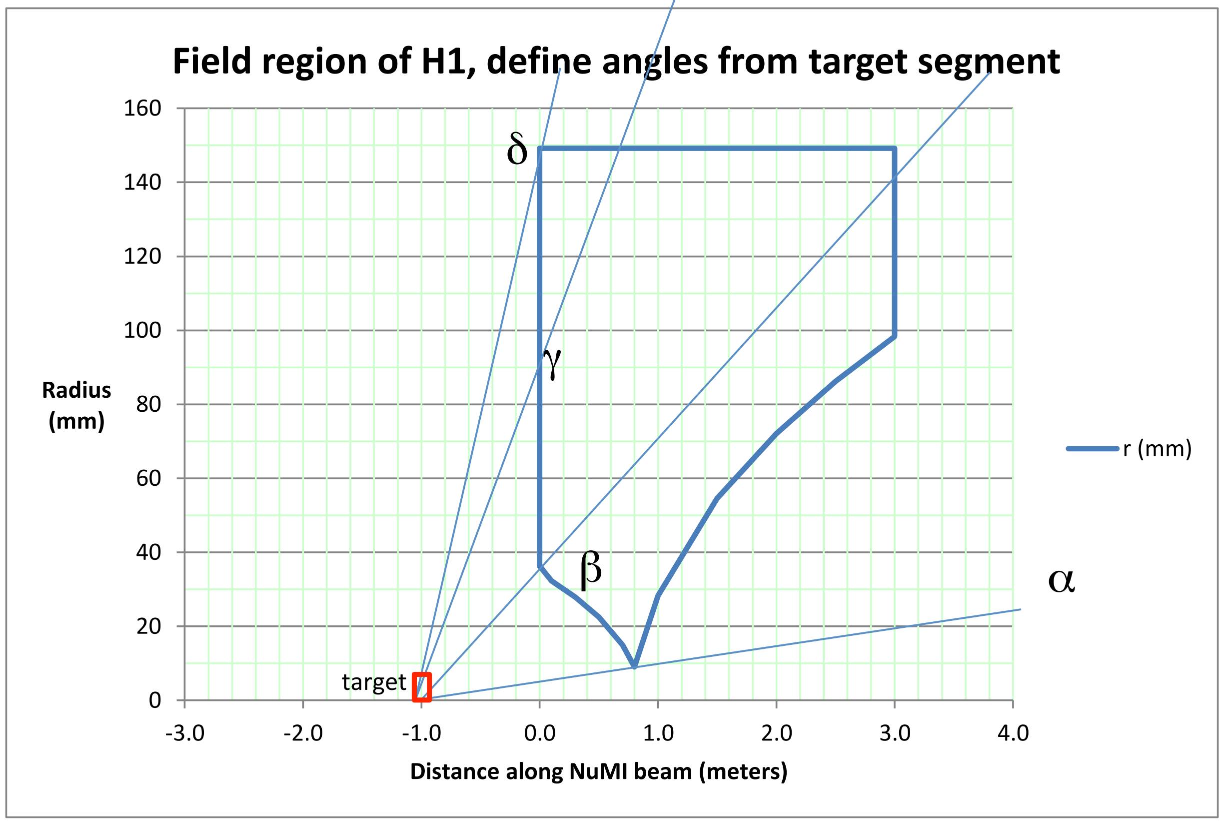
Trajectories for π^+

horn 1
horn 2



Fermilab

Study on π^+ trajectories

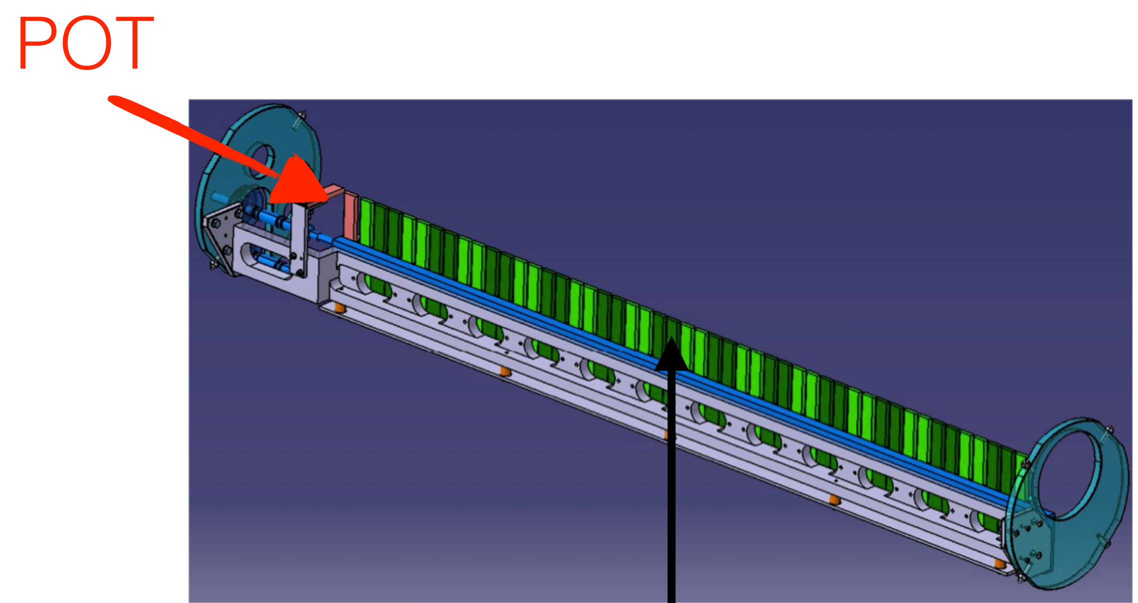


The goal is to find out how many pions need to be focused, how many need only 1 horn…

	Horn 1	ratio H1	Horn 2	ratio H2
$< \alpha$	137	2.7%	145	6.2%
$\alpha - \beta$	2261	44.2%	1814	78.2%
$\beta - \gamma$	1957	38.3%	225	9.7%
$\gamma - \delta$	752	14.7%	137	5.9%
sub TOT	5107		2321	
$> \delta$	1503		694	
TOT	6610		3015	

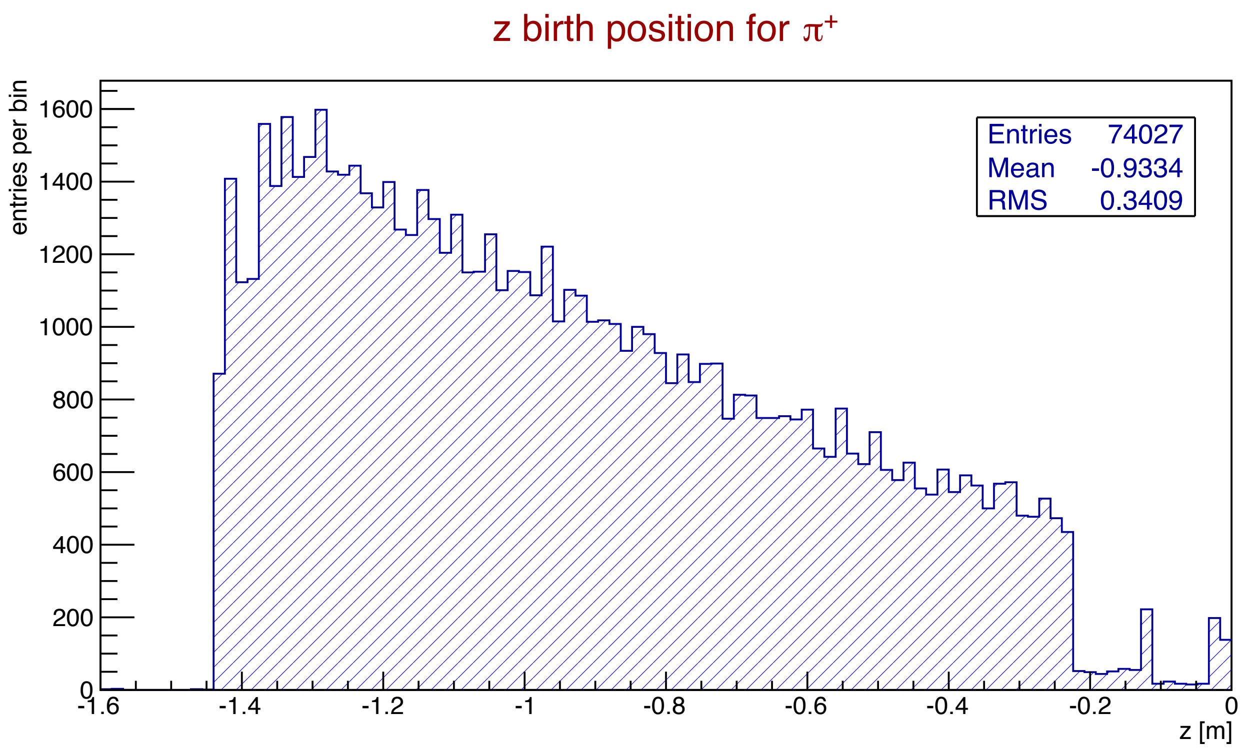
G4NuMI simulation with the current target. In the table there are the number of π^+ that cross the horn inside a specific angle, as in the picture.

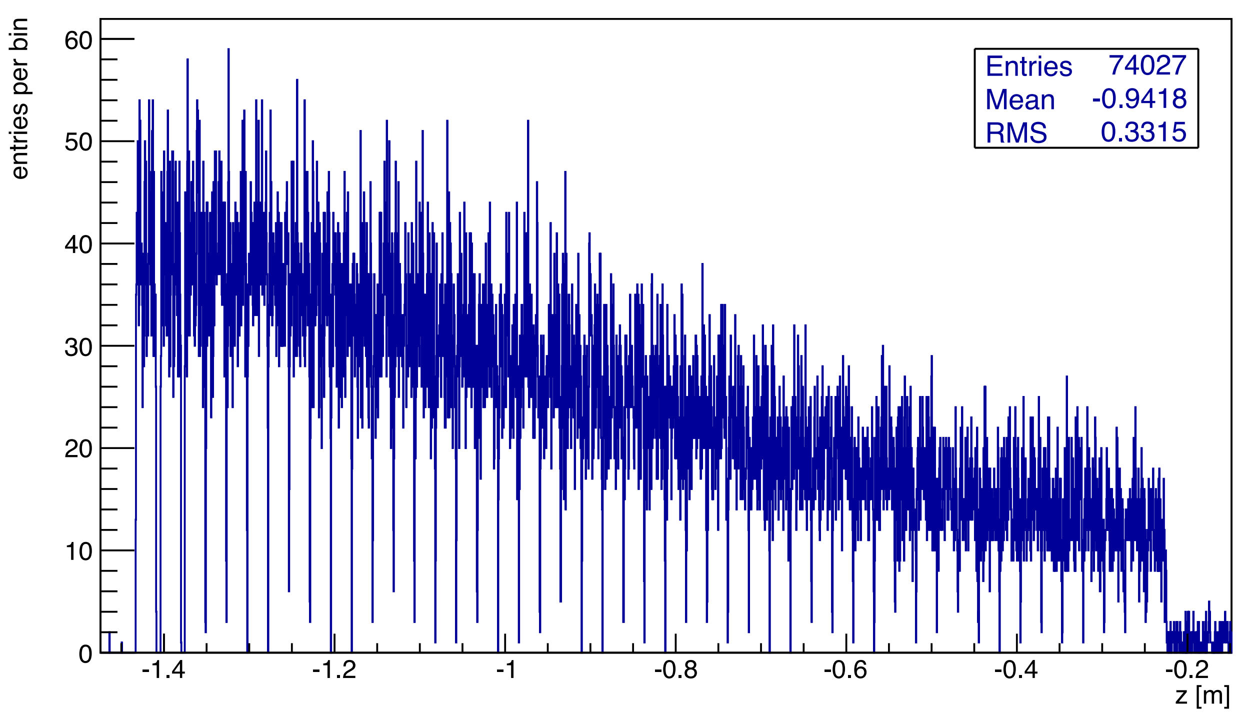
π^+ born in the target from protons



48 graphite fins + 2 budal monitors

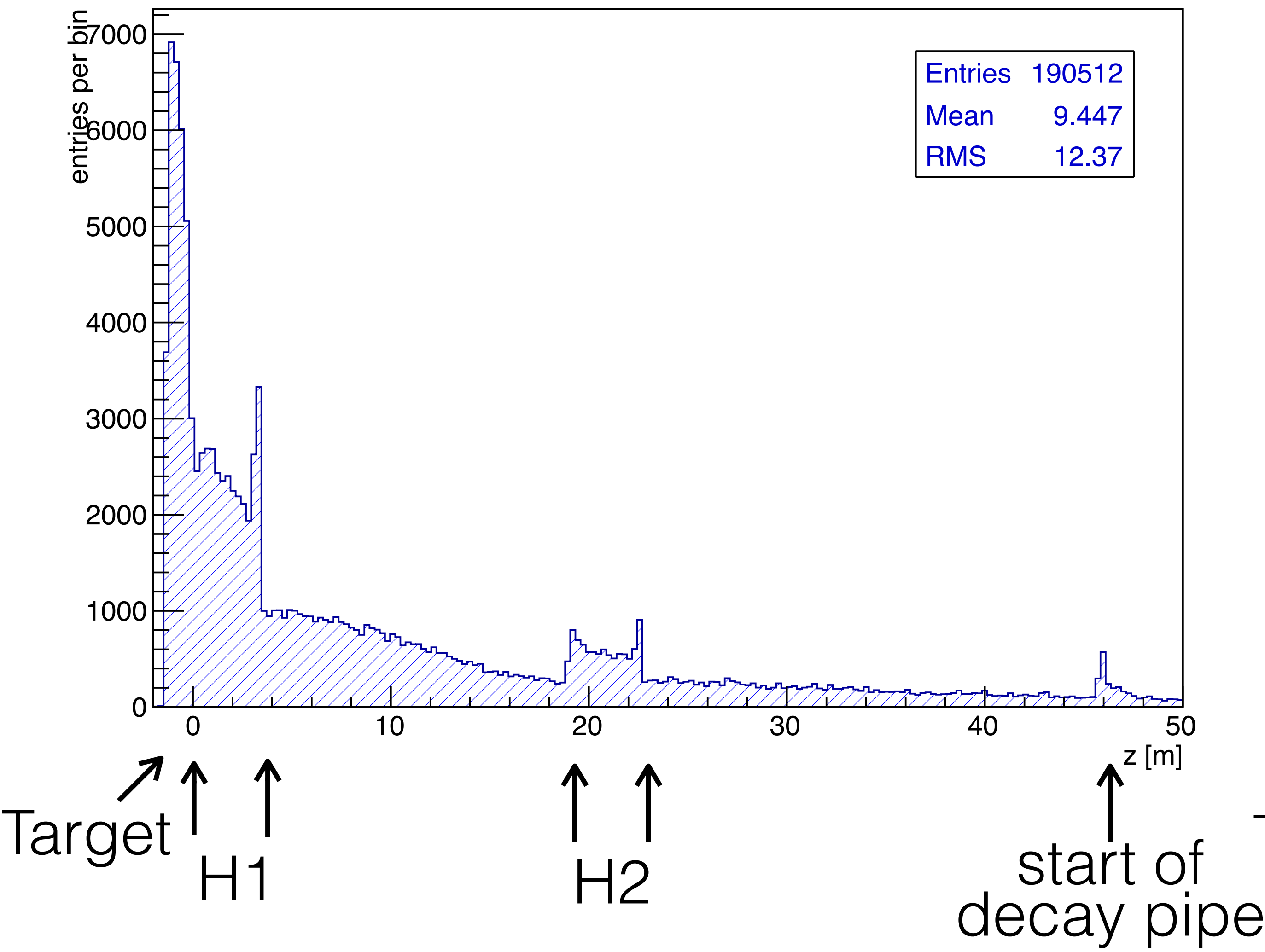
z is the position along the beam line





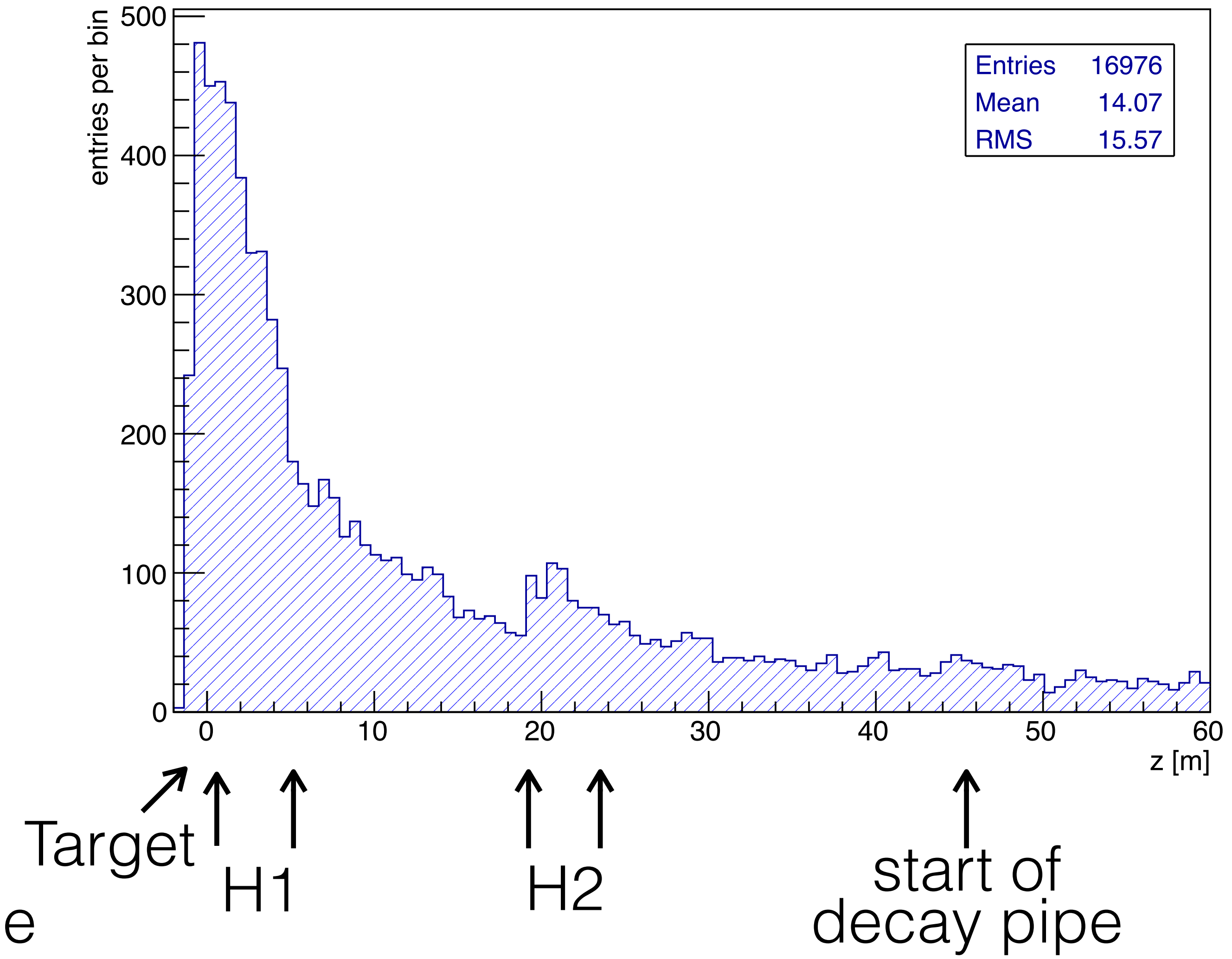
π^+ from others

z birth position for π^+ form other particles



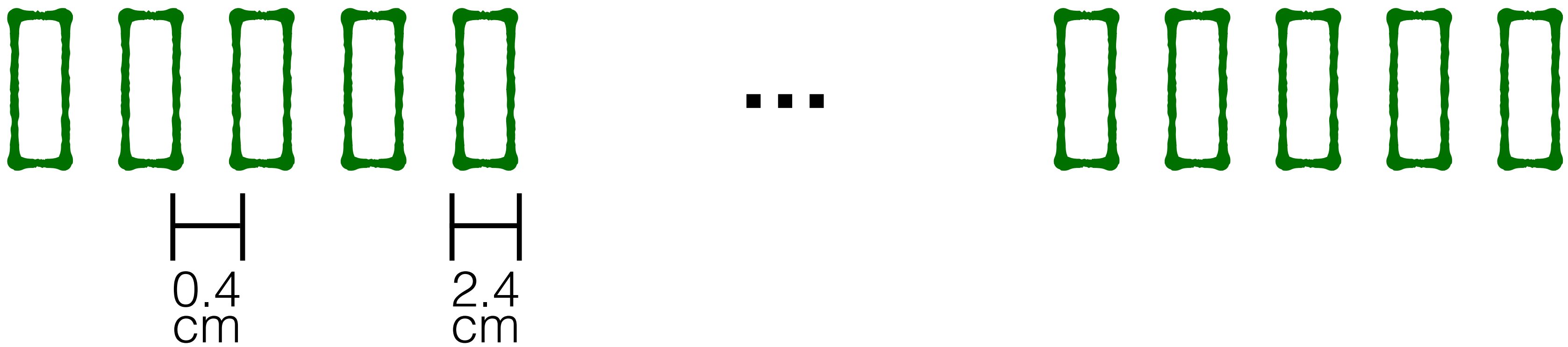
π^+ decayed

z death position for decayed π^+

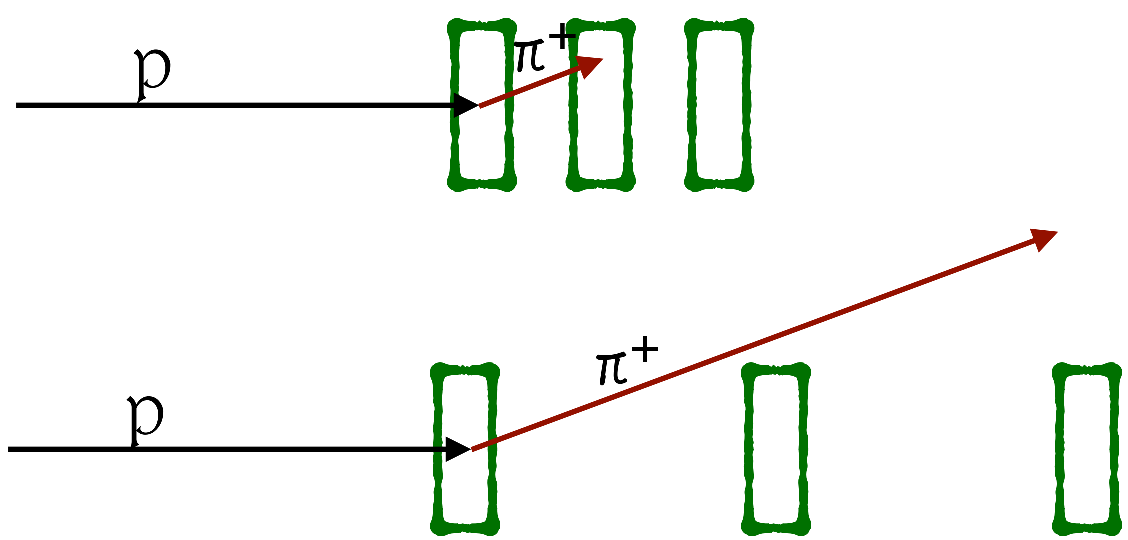


z is the position along the beam line

Inserting gaps between the fins



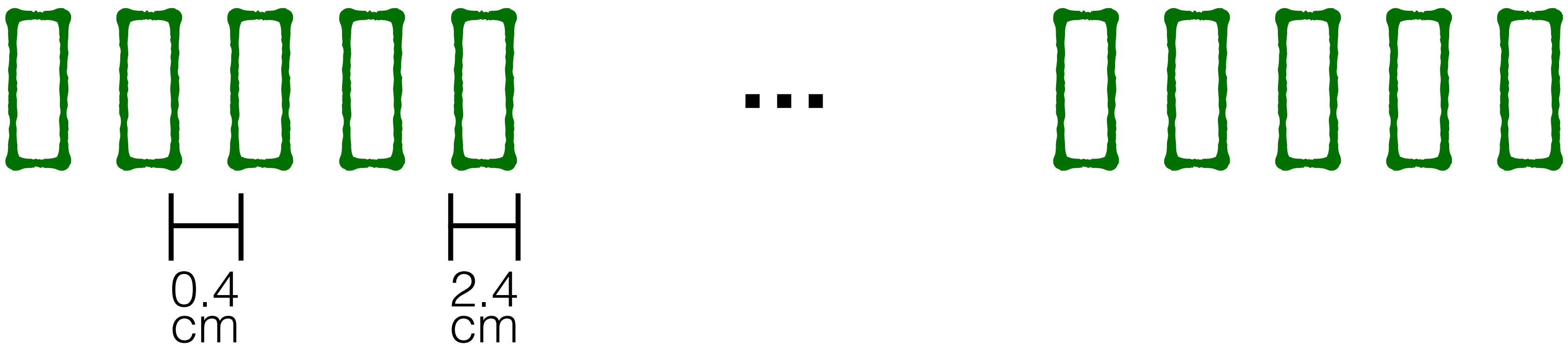
= 48+2 fins



current target

"airy" target ← more secondaries can escape the target

Inserting gaps between the fins



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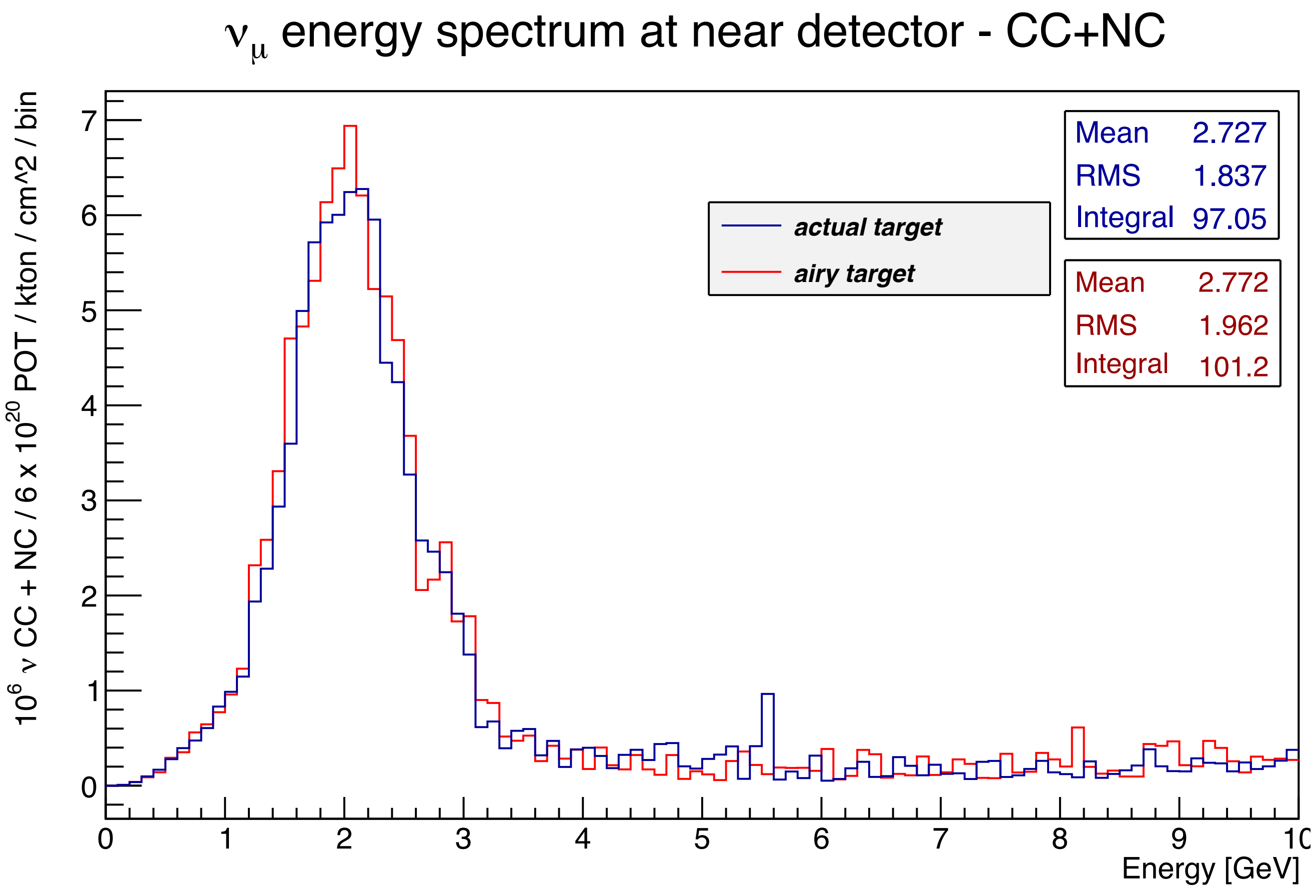

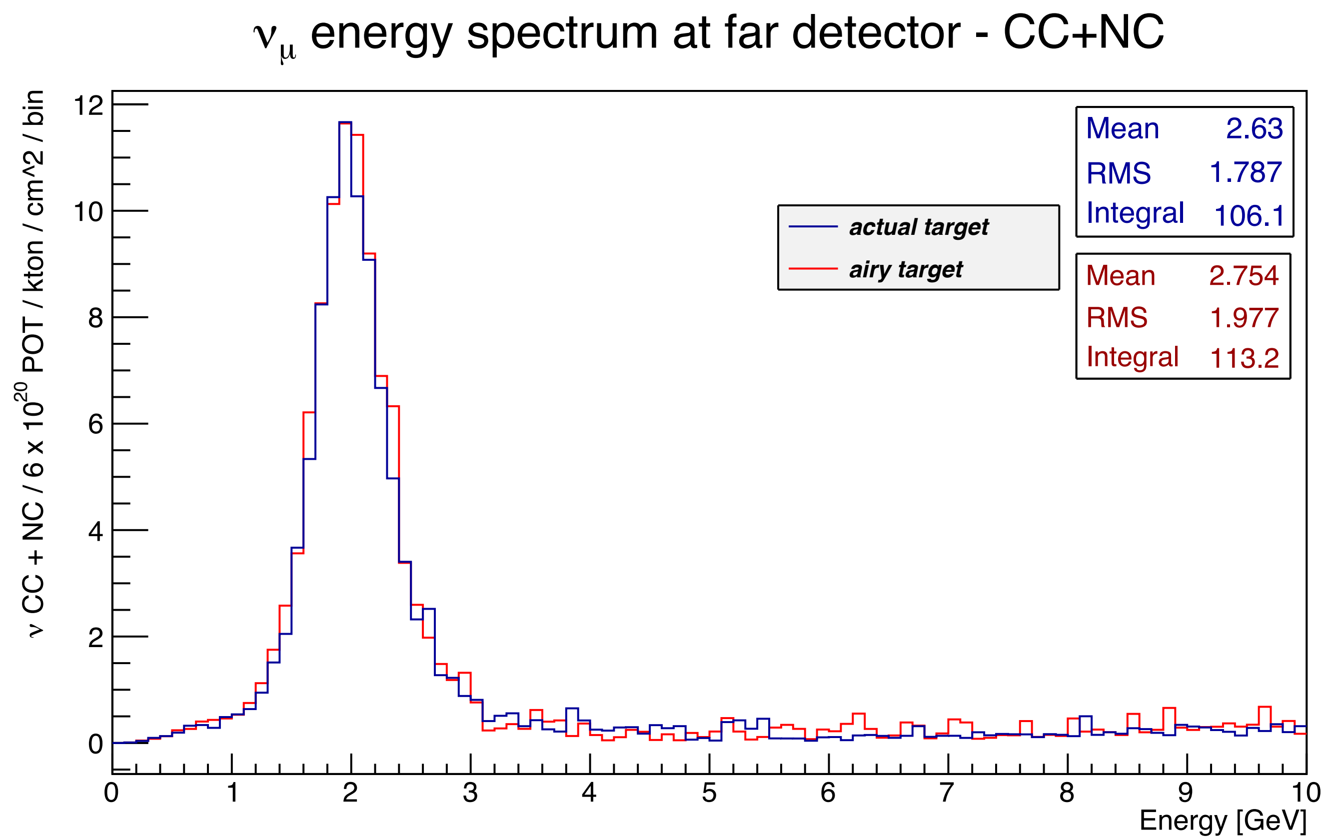

4.3 % more **6.7 % more**

→ increase in the neutrino spectrum.

Conclusions

- The NOvA experiment official flux simulation was done by using Flugg, this is the first study and comparison with G4NuMi, which is very useful.
- Modify the geometry in the simulation can require a lot of time, anyway this first study on the geometry of the target leaves space for further investigation.
- There is the possibility to increase the neutrino flux, but to have a quantitative idea more studies are required.

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