Pi+ total cross-section measurement in ProtoDUNE (Monte Carlo Study)

Ajib Paudel[1], Tingjun Yang[2] , Glenn Horton-Smith[1]

[1]Kansas State University

[2]Fermi National Accelerator Laboratory

March 6, 2019

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Thanks to Flavio and Elena for sharing their experiences from LArIAT and providing valuable help and suggestions for the protoDUNE pion analysis.

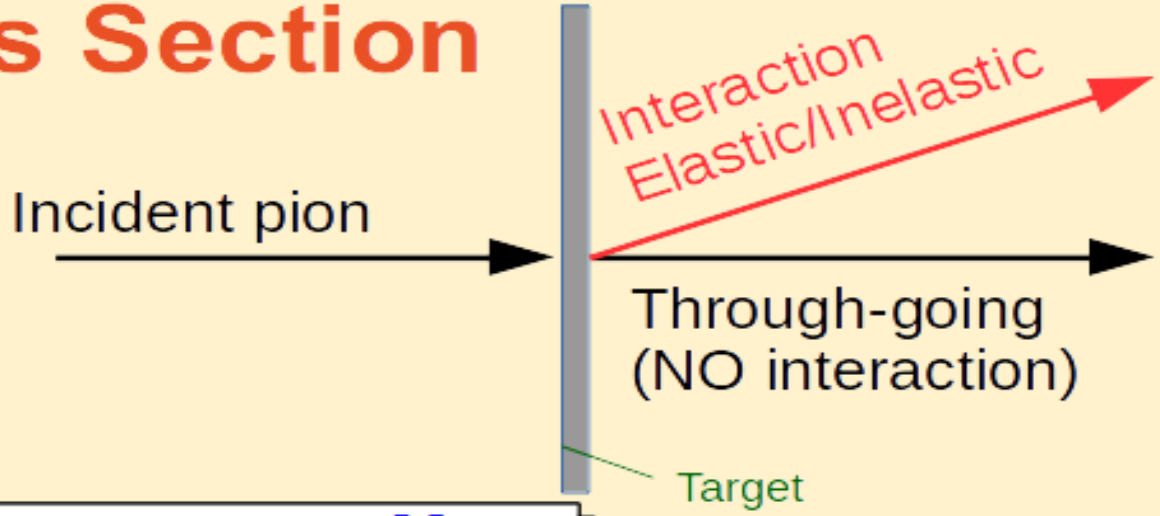
Thanks to Hans Wenzel for helping in the Geant4 studies.

Heng-Ye Liao, and I did MC truth Cross-section studies collaboratively,

also I borrowed some of Heng-Ye's slides which I won’t discuss in detail.

Heng-Ye Liao

Cross Section



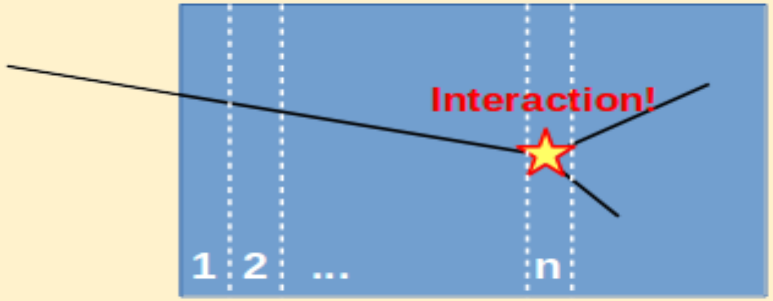
$$XS = \frac{N^{interacting}}{N^{incident}} \cdot \frac{M_a}{d \cdot L \cdot N_a}$$

- $N^{interacting}/N^{incident}$: "Profile" of cross section
- Scaling factor $(S_f := M_a/d \cdot L \cdot N_a)$: constant

$N^{incident}/N^{interacting}$: Number of incident/interacting protons
N_a: Avogadro's number
M_a: Atomic mass of argon
d/L: Density/thickness of argon target

Note: Inelastic interaction in Geant4 is the same as Reaction cross-section in literature

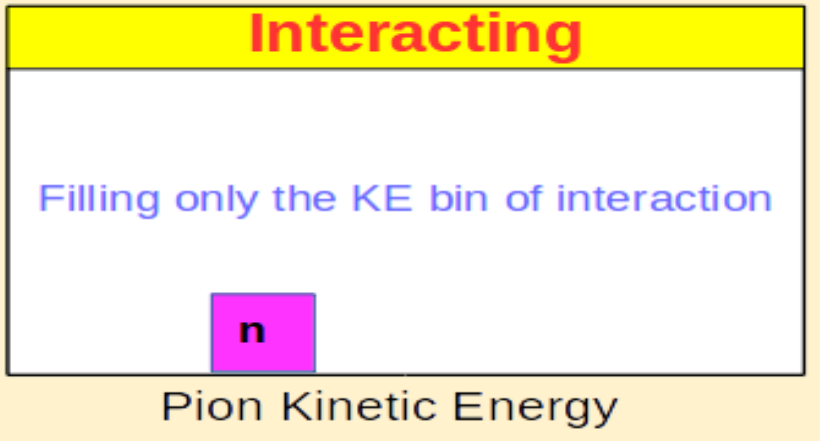
Thin Slice Method

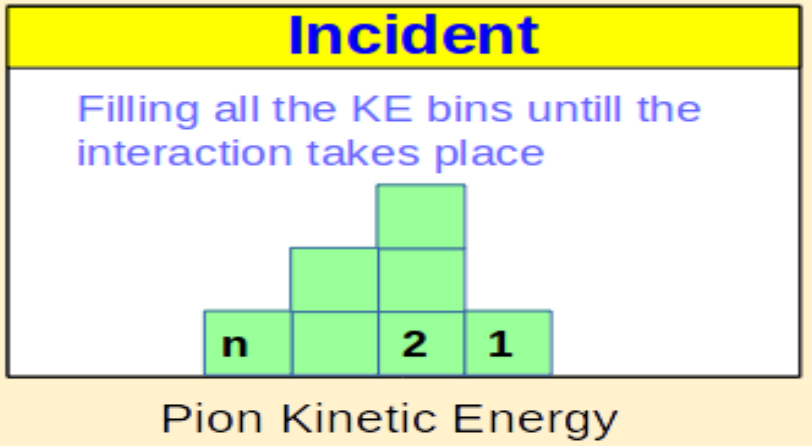


- The thin slice method was developed by the LArIAT experiment
- The granularity of LArTPC
  → Treat wire-to-wire spacing as a series of "thin-slab" targets.
  Each thin-slab is an independent measurement.
- Cross section

$$XS(KE) = S_f \cdot \frac{N(KE)^{interacting}}{N(KE)^{incident}}$$

* Sf ~ 100 barn in our case
(Argon, slab thickness~0.5 cm)

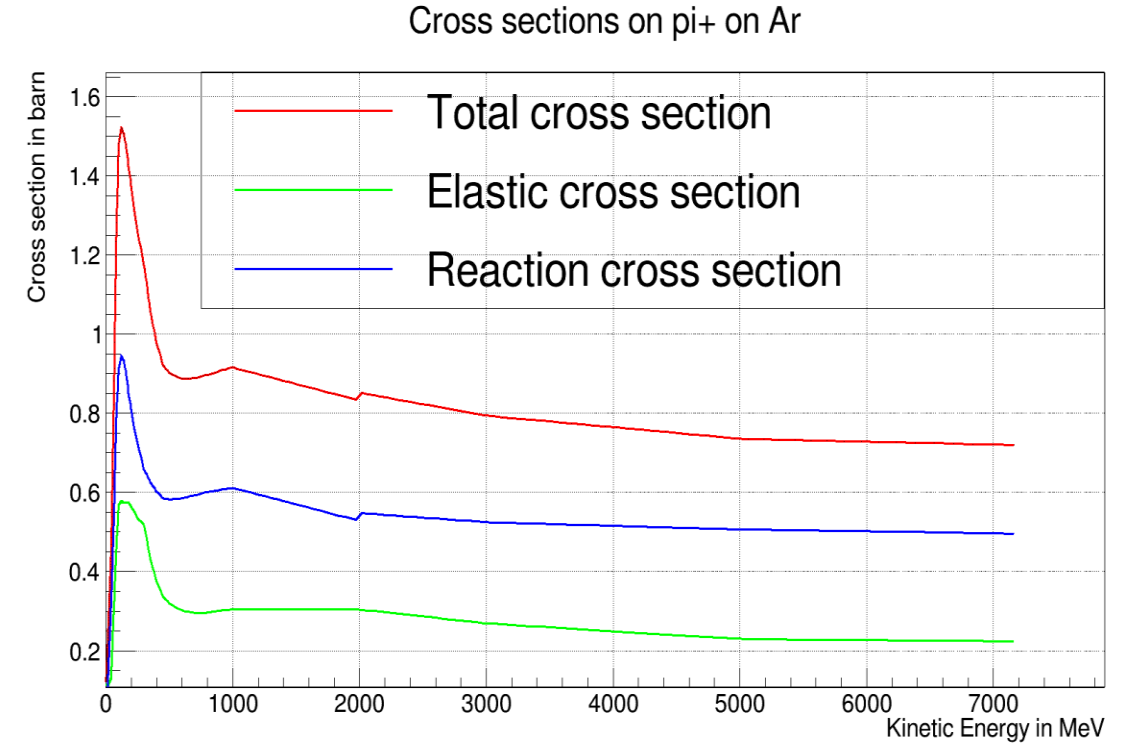




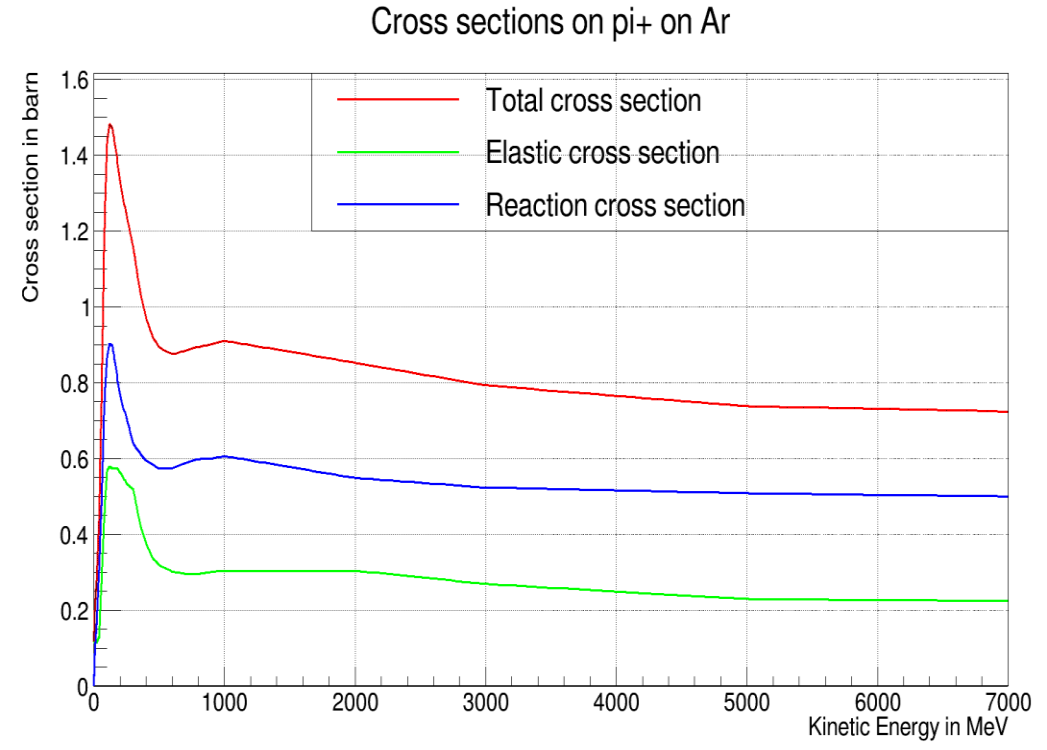
We are using the same approach as LArIAT for calculating the pion-Argon cross-section

Geant4 cross-section: Dr. Hans Wenzel provided all the information to generate geant 4 cross-sections for pi+ off Ar

Geant4 10.3 (which is the version used in LArSoft)



Geant4 10.5



There is a slight difference between the Reaction cross-section for the two Geant4 versions.

One major difference is the kink at 2000MeV for version 10.3 (which is also there in version 10.4) is removed in version 10.5.

Here, $\sigma_{tot} = \sigma_{el} + \sigma_{reaction}$

$\sigma_{reaction} = \sigma_{inelastic} + \sigma_{abs} + \sigma_{chex} + \sigma_{piprod}$, chex=charge exchange

Note: In LArSoft, all the interaction under the reaction category are termed as pi+Inelastic interaction.

Hadronic process for Geant4 version 10.4 and 10.5: Source Dr. Hans Wenzel

Hadronic Processes for pi+ for version 10.4

Process: hadElastic
Model: hElasticLHEP: 0 eV ---> 1.0001 GeV
Model: hElasticGlauber: 1 GeV ---> 100 TeV
Cr_sctns: Barashenkov-Glauber: 0 eV ---> 100 TeV
Cr_sctns: GheishaElastic: 0 eV ---> 100 TeV

Process: pi+Inelastic
Model: FTFP: 3 GeV ---> 100 TeV
Model: BertiniCascade: 0 eV ---> 12 GeV
Cr_sctns: G4CrossSectionPairGG: 0 eV ---> 100 TeV
G4CrossSectionPairGG:
G4PiNuclearCrossSection cross sections
below 91 GeV, Glauber-Gribov above
Cr_sctns: GheishaInelastic: 0 eV ---> 100 TeV

Hadronic Processes for pi+ for version 10.5

Process: hadElastic
Model: hElasticLHEP: 0 eV ---> 1.0001 GeV
Model: hElasticGlauber: 1 GeV ---> 100 TeV
Cr_sctns: Barashenkov-Glauber: 0 eV ---> 100 TeV

Process: pi+Inelastic
Model: FTFP: 3 GeV ---> 100 TeV
Model: BertiniCascade: 0 eV ---> 12 GeV
Cr_sctns: Barashenkov-Glauber-Gribov: 0 eV ---> 100 TeV

Validation of Geant4 cross-section measurements in LArSoft framework using Monte-Carlo truth information:

Heng-Ye and I worked together to developed the module for calculating MC truth cross-section. Thanks to Flavio and Elena for providing the detailed explanation of the method and technical support which made it easy for us to do this analysis.

I generated a sample of 50,000 pi+ with the following fcl parameters:

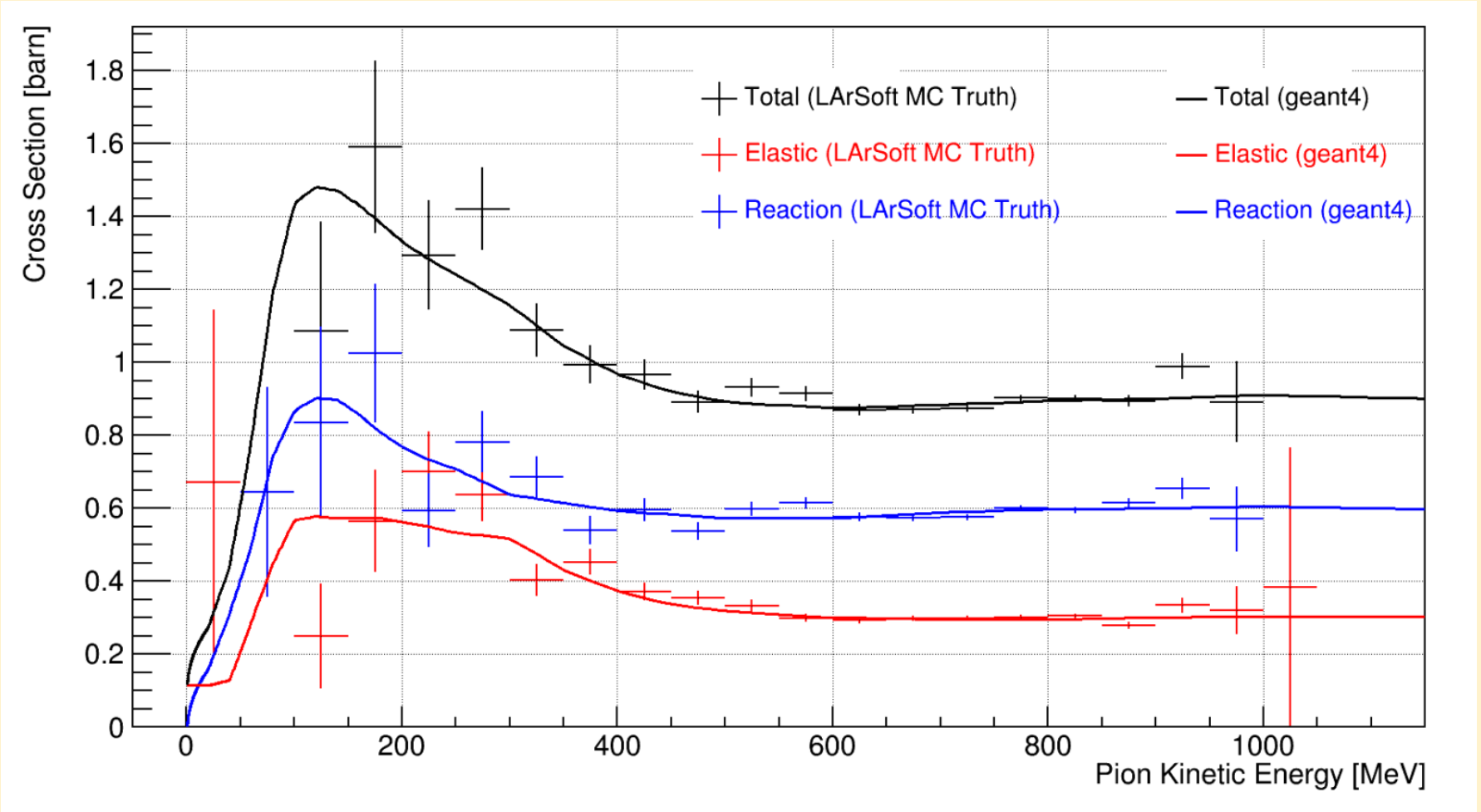
Incident Momentum: 1.0 GeV/c with a Gaussian spread of 5%.

Start X, Y and Z position: (-80cm , 420cm , -10cm)

We passed the generated pi+ through g4 stage of LArSoft, using the standrd fcl file, protoDUNE_g4.fcl
Since we are looking into the MC truth information, lifetime and SCE does not play any role.

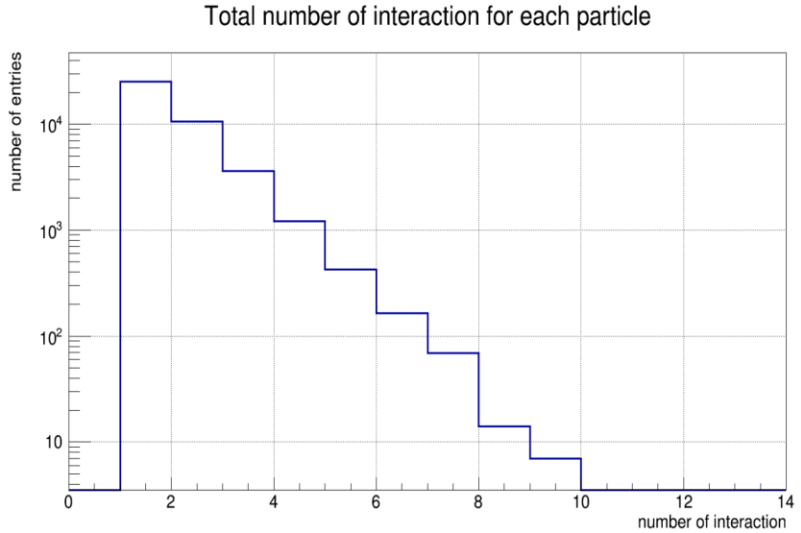
Then we treated protoDUNE TPC as comprising of many thin slices (with thickness 0.4792cm--collection wire plane width) of Liquid Argon and used thin slice method for calculating the cross section as a function of Kinetic Energy.

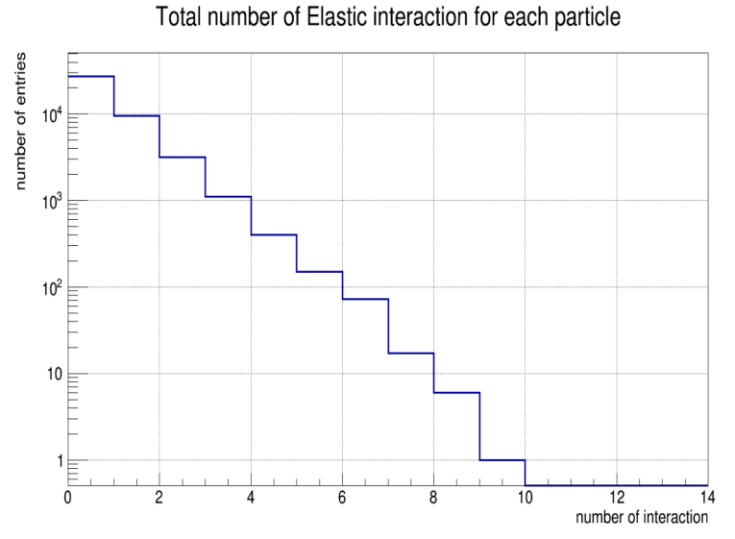
Results for MC truth studies:

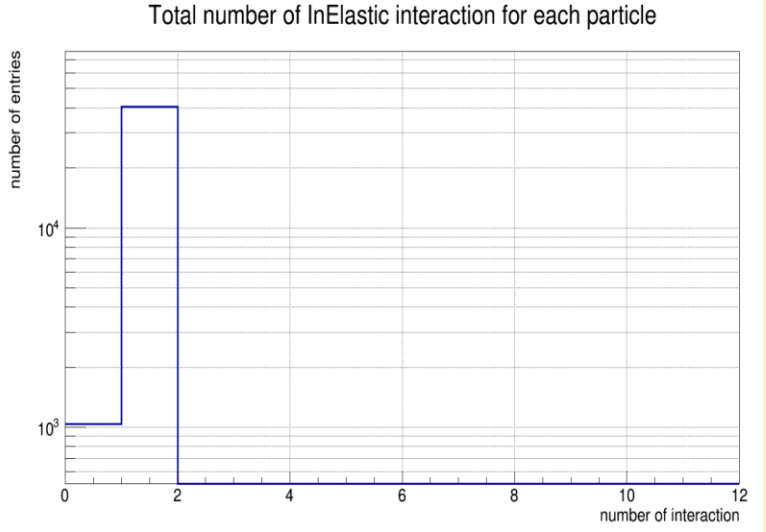


Cross-section calculated using LArSoft truth information are comparable to Geant4 stand-alone program cross section values. At low KE the error bars are big because of low statistics. Although I generated 50,000 1GeV Momentum (Gaussian spread of 5%) pi+, most of those pi+ interact much before losing all their Kinetic Energy so only a few reach the low Kinetic energy bins.

More MC Truth studies:
Each particle trajectory undergoes a few interaction, we used the first interaction point as the interacting point for calculating the cross-section.







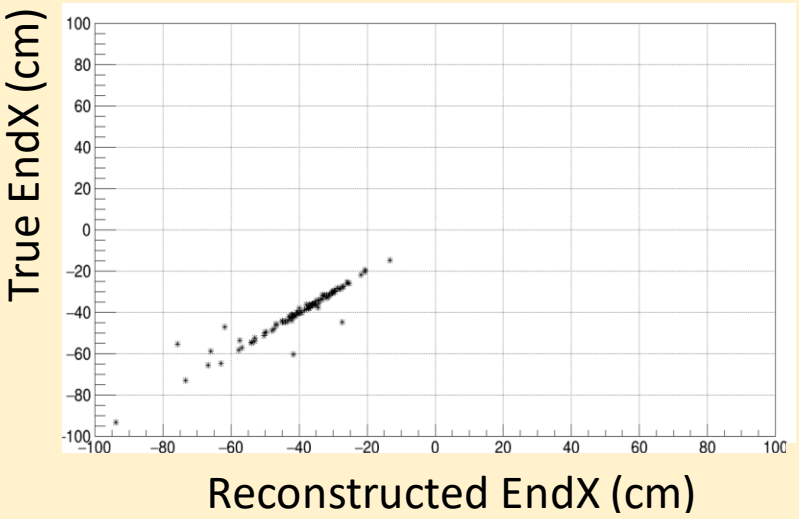
We shoot 50000 pi+ with 1GeV momentum.

We can see each particle trajectory can consists of upto 9 interactions.

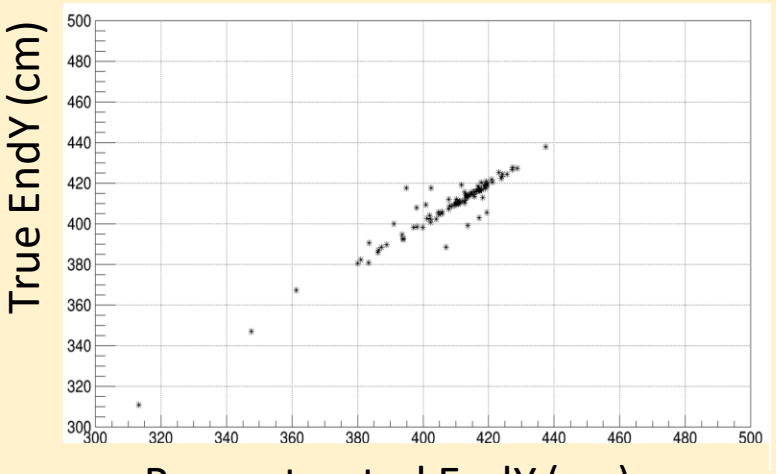
Many Elastic interaction are possible for a single particle while only maximum of one InElastic(or reaction) interaction can occur per trajectory.

Some studies using MCC11 (SCE OFF) reconstructed sample: events~1890 number of pi+ undergoing Inelastic interaction=97
Here I am plotting True End X, Y, Z vs reconstructed XYZ . All these plots are for **Inelastic(or Reaction)** interaction

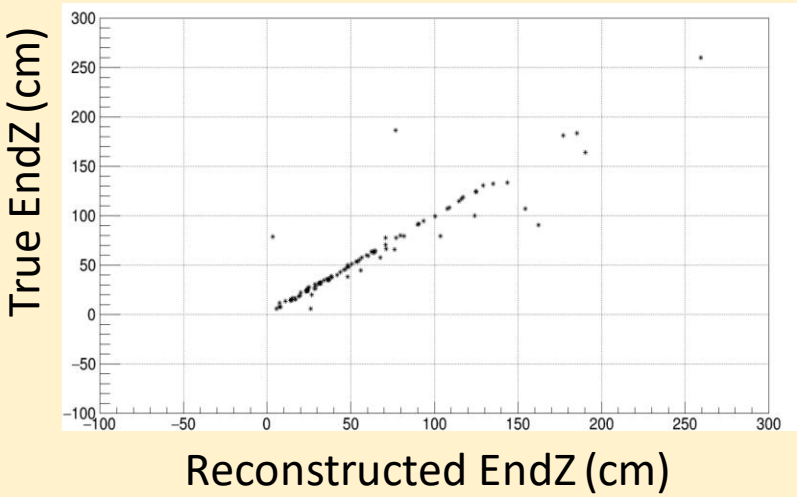
True EndX vs Reconstructed EndX



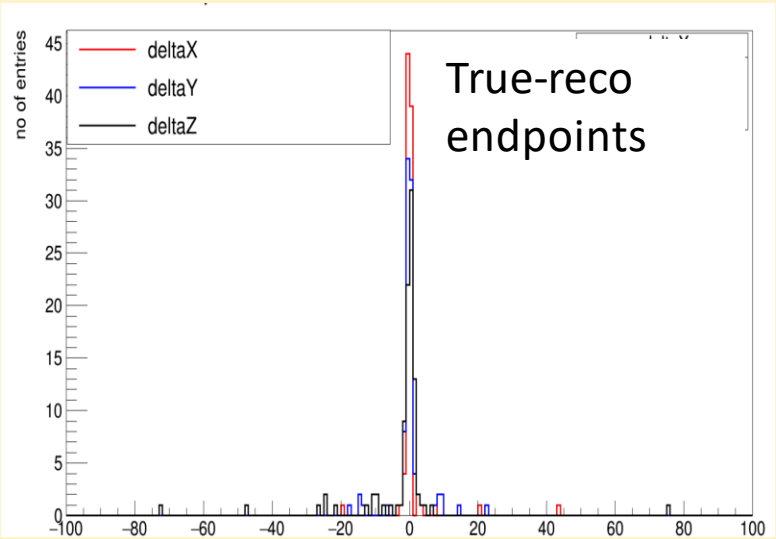
True EndY vs Reconstructed EndY



True EndZ vs Reconstructed EndZ



Difference between True and Reco EndPoints



The sample used is **MCC11 SCE OFF sample**

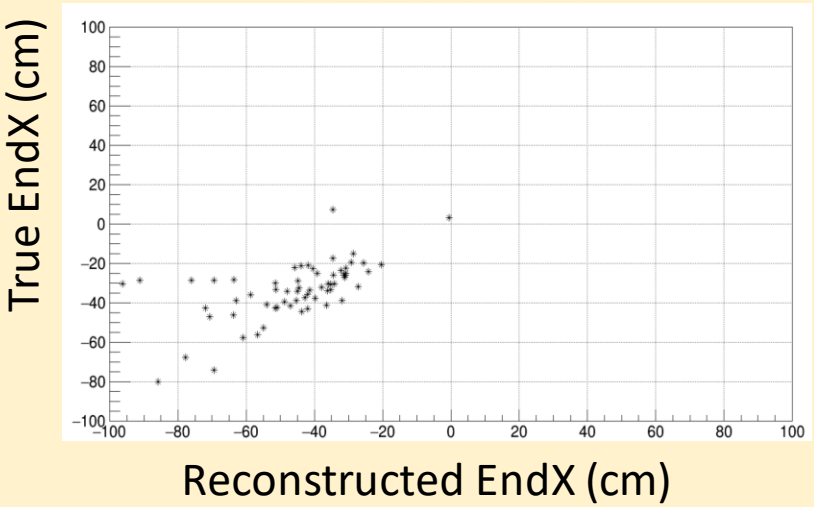
The reconstructed and true EndPoints for the pi+ tracks undergoing Inelastic interaction does not differ by much.

Currently we only have around 1890 events for 1GeV MC samples most of which has positron as the beam particle, only around 160 of them are pi+

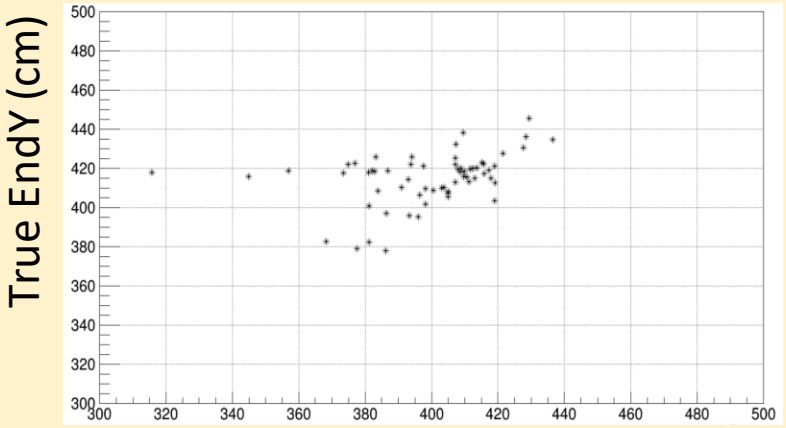
Even multiplying the MCC11 1GeV sample 50 times will give only around 10,000 pi+ .

Some studies using MCC11 reconstructed sample: events~1890 number of pi+ undergoing Elastic interaction=64
Here I am plotting True End X, Y, Z vs reconstructed XYZ . All these plots are for **Elastic** interaction

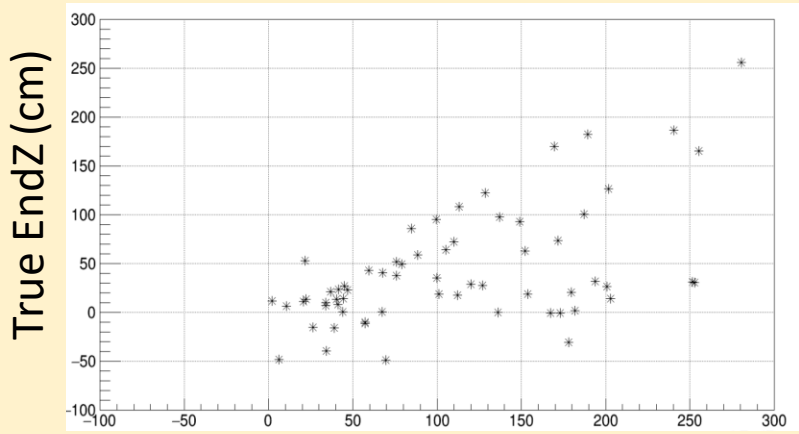
True EndX vs Reconstructed EndX



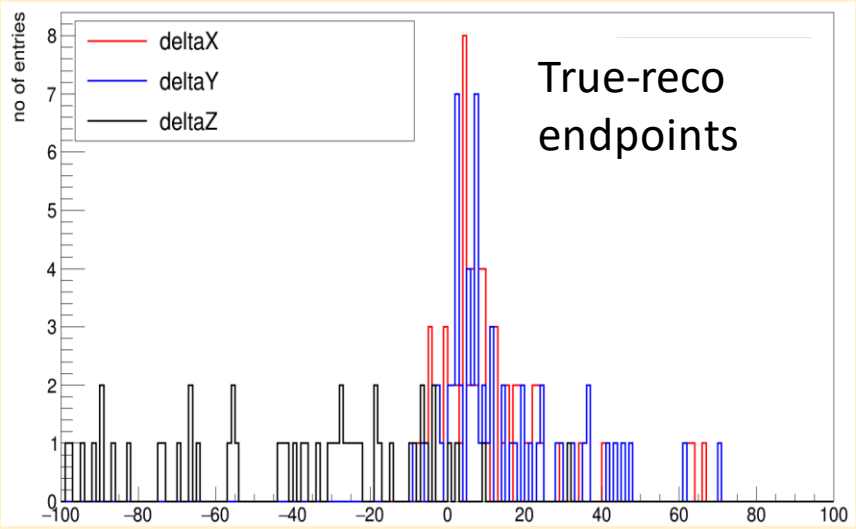
True EndY vs Reconstructed EndY



True EndZ vs Reconstructed EndZ



Difference between True and Reco EndPoints

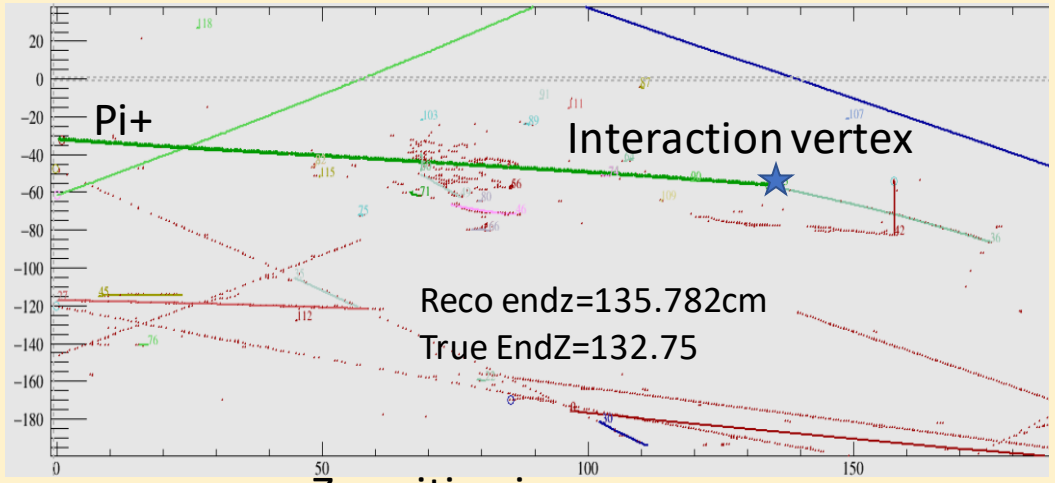


The sample used is **MCC11 SCE OFF sample**

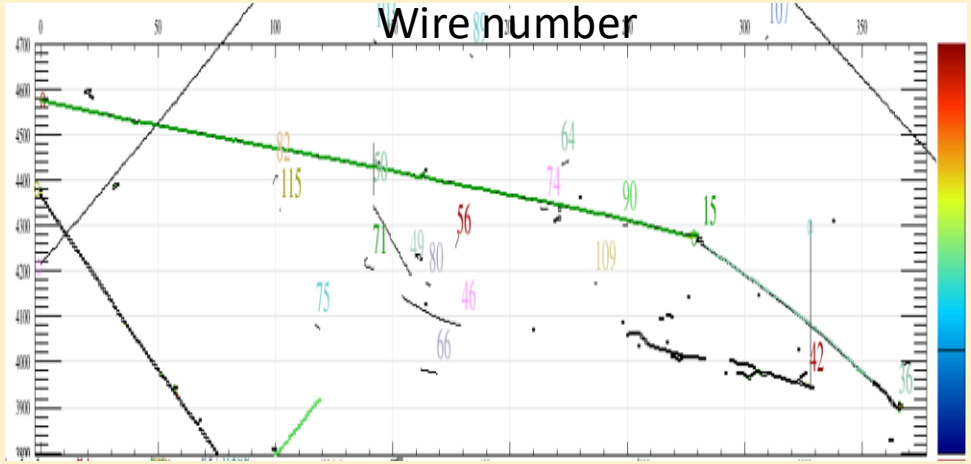
Here the reconstruction does not look good.
It is most evident in EndZ(as the beam particle is incident along Z), reco EndZ is mostly higher than true endZ, this is so because true EndZ gives the point of first interaction, if there is a small bending in the trjectory reconstruction does not notice.

Some MC SCE OFF pi+ events: Some Reaction interactions

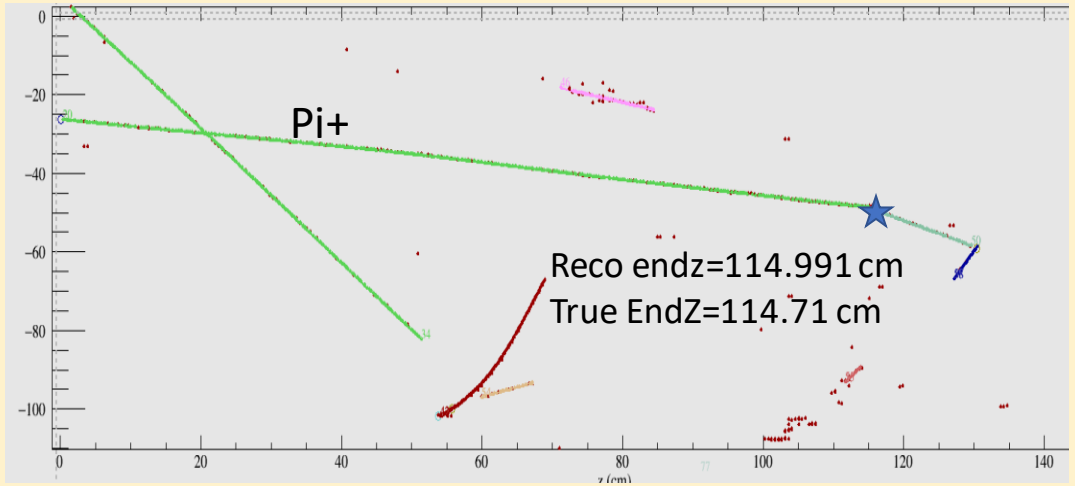
Event 1334 in XZ plane



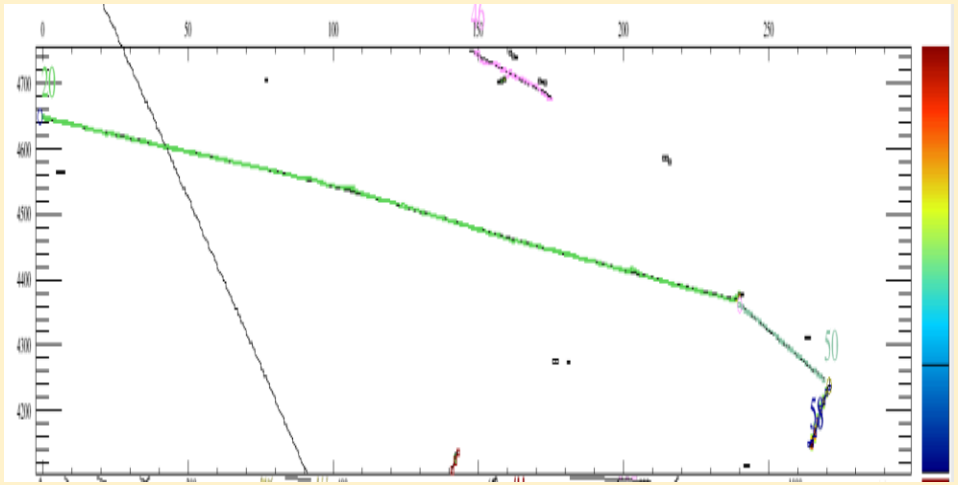
Same event (1334) in wire vs time display



Event 1191

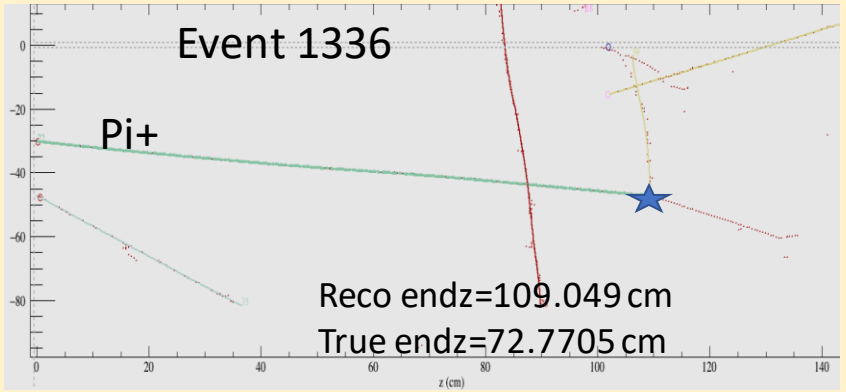


Event 1191

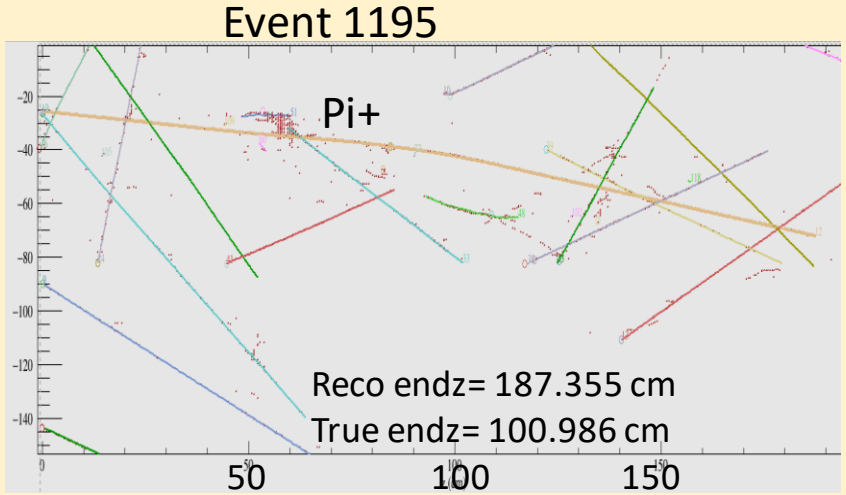


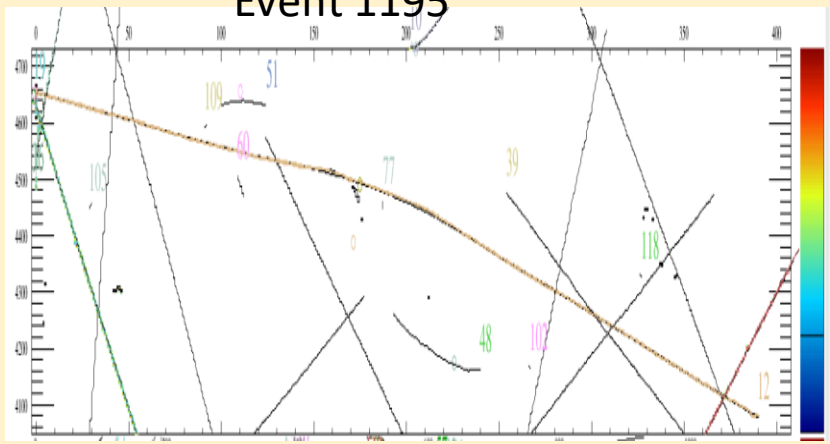
For Reaction interactions End point appears to have been reconstructed quite well
In the next slide we will have a look at some elastic interactions

Some pi+ Elastic interactions(SCE OFF):

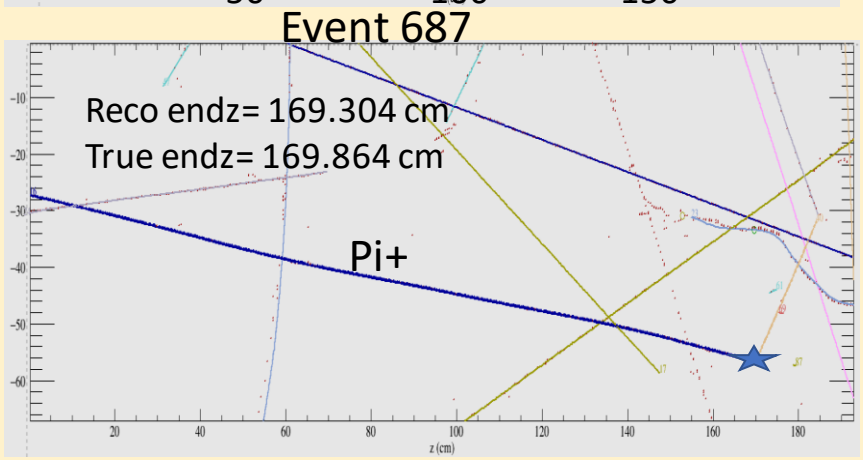


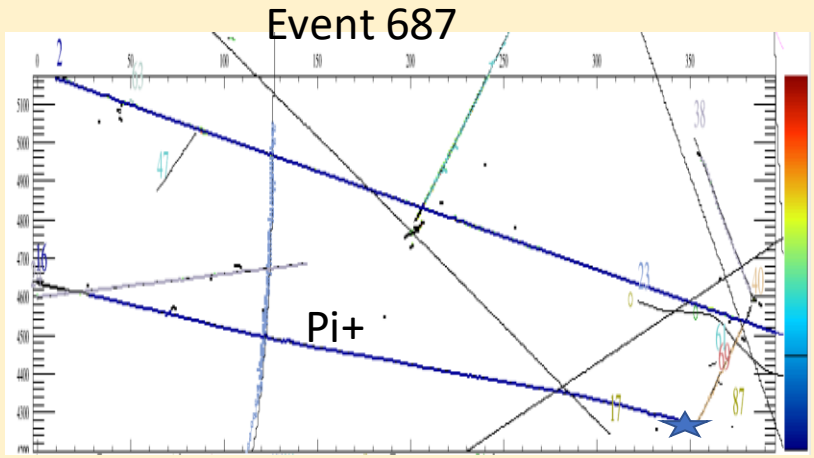
Event:1336
There is no hint of interaction at the true interacting point, of Z=72.7705cm . This is mostly the case if the scattering angle is small





Event:1195
We see a slight bent in trajectory around Z=100cm (the true end point) but the track is reconstructed as a single track until it stops at Z=187.355cm





Event 687
This is one example of Elastic interaction in which End point is well reconstructed. Big scattering angle might have helped in this case.

SUMMARY:

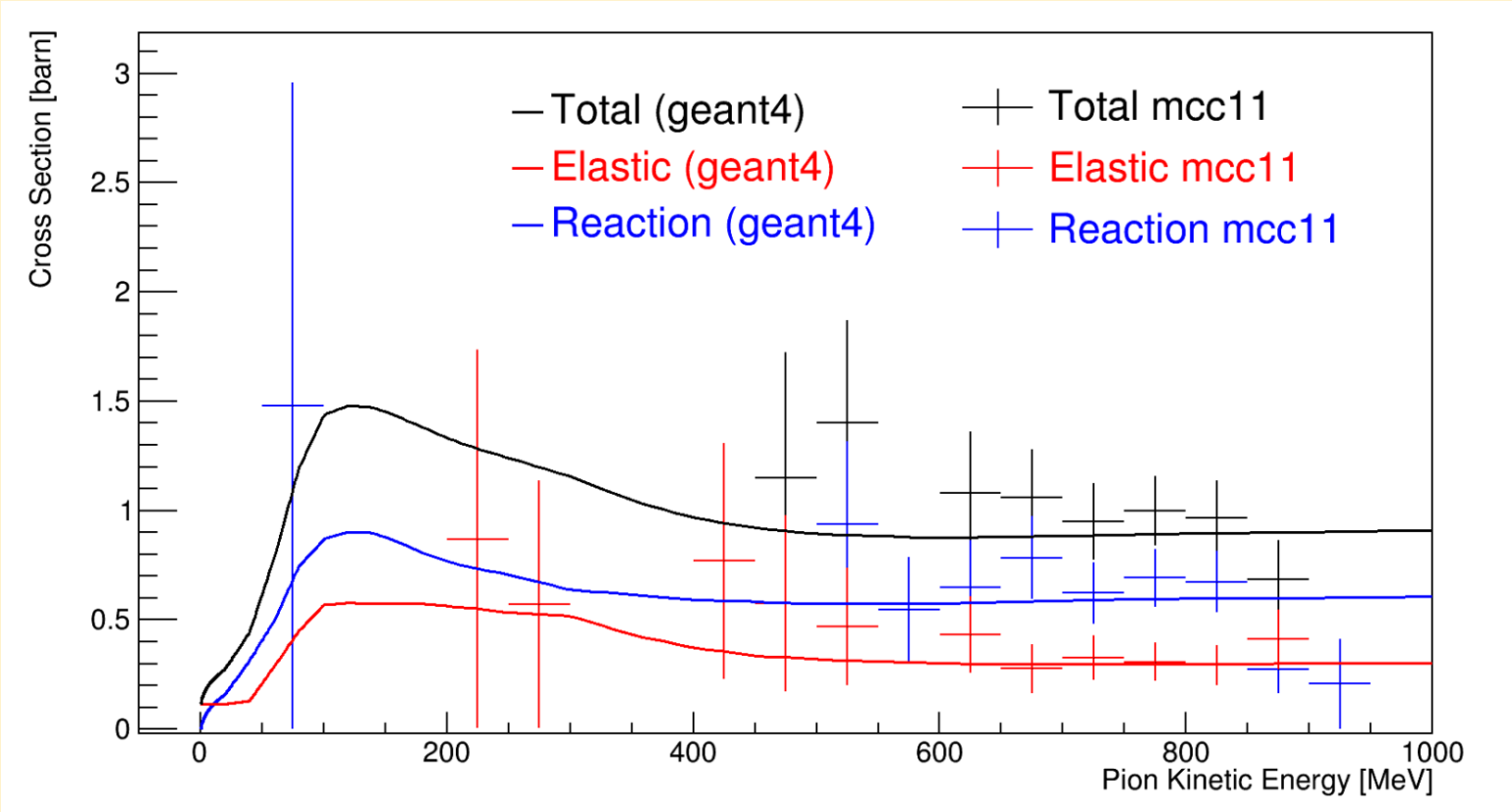
We calculated the cross-section for pi+ off Ar in LArSoft framework using MC Truth information, it agrees with the cross-section values from geant4 stand-alone program.

Inelastic interaction is reconstructed quite well, but there are some issues with the elastic interaction reconstruction. Next plan is to study the scattering angle distribution for pions undergoing elastic scattering and make a cut on the minimum scattering angle that can be reconstructed.

We plan to do the cross-section measurements initially for the SCE OFF sample using reconstructed track and calorimetry information, and eventually move to SCE ON sample and protoDUNE data.

Need a larger MC sample.

Back Up slides:



Cross-section measurement for MCC11 SCE ON sample using Truth information. Only 190 particles.