Michel Electron study in T2K Near Detector Upgrade SuperFGD

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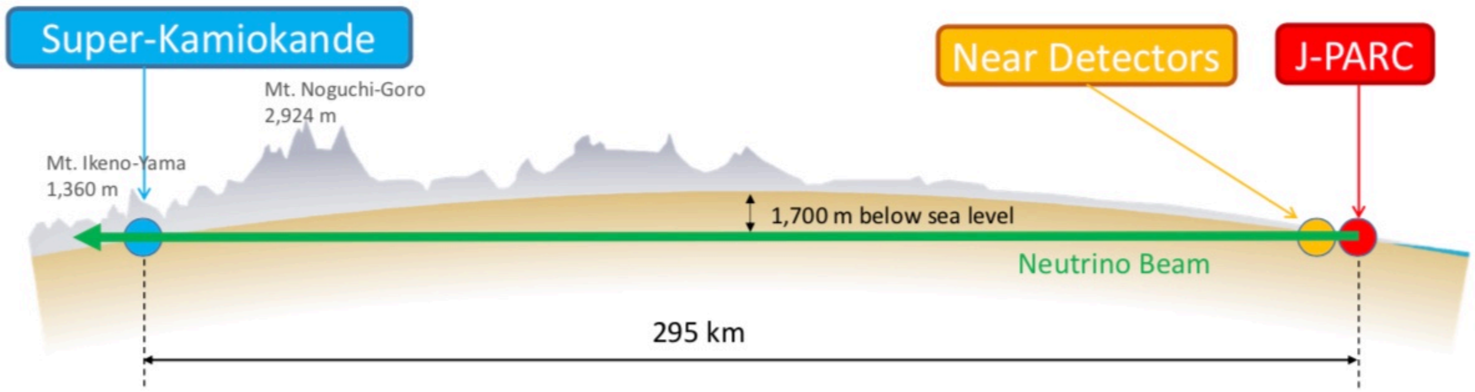
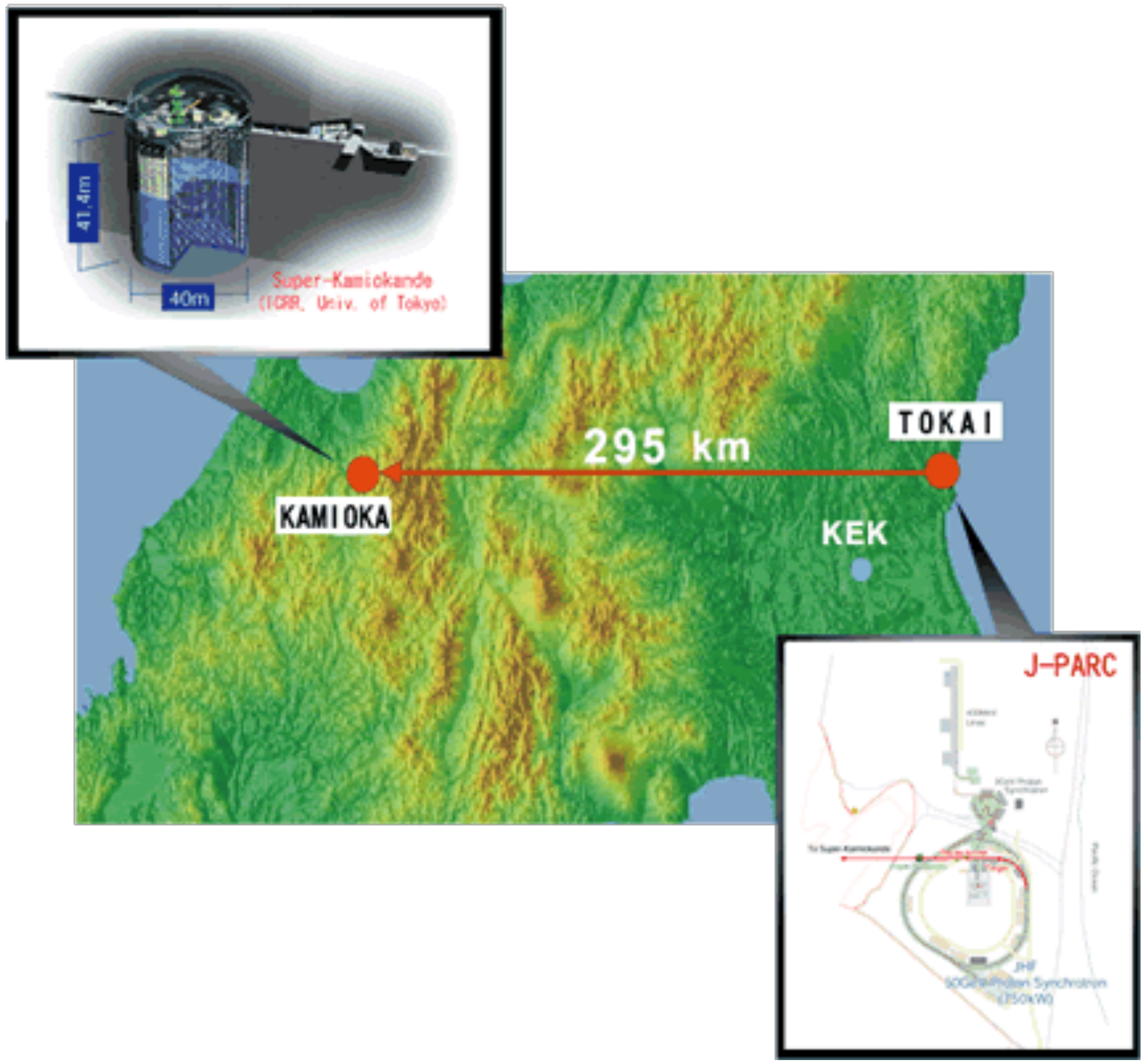
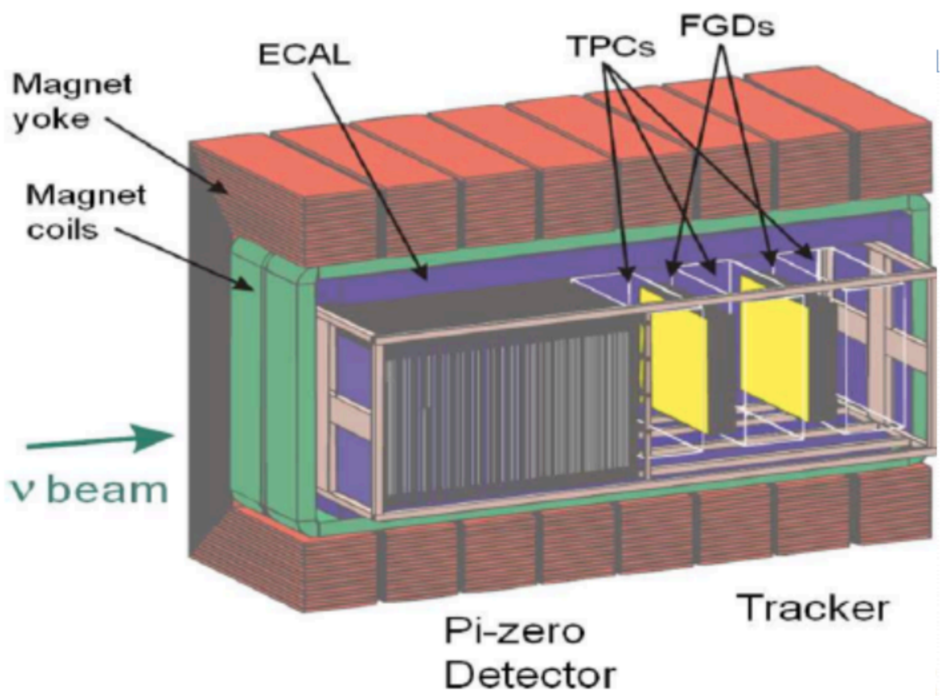
T2K(Tokai to Kamioka)

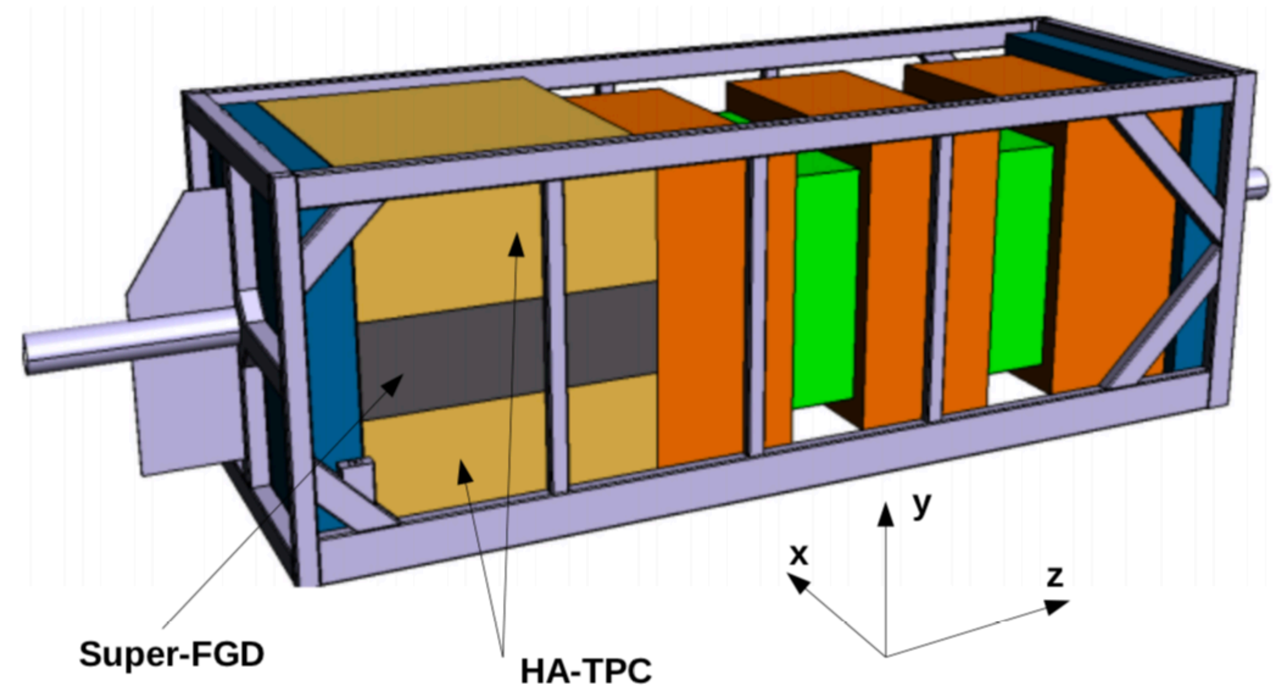




- Neutrino long baseline experiment to explore the CP violation in lepton sector.

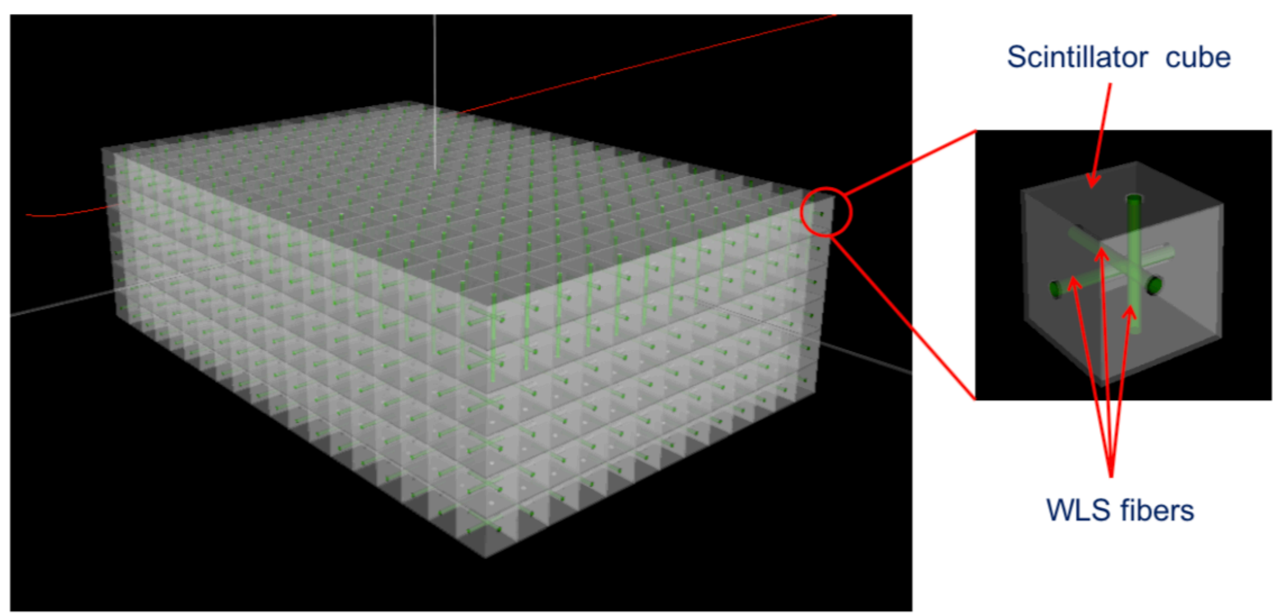
Near detector upgrade





Current detector

Upgrade configuration



SFGD

Super Fine Grained Detector(SFGD)

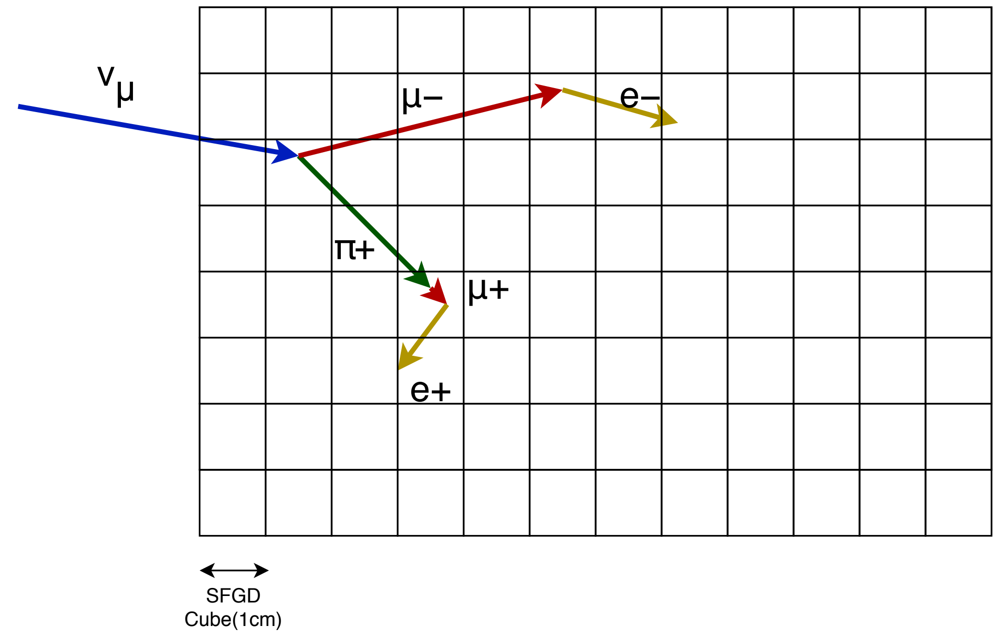
- SFGD consists of ~2 million scintillator cubes of 1cm^3 arranged 184*192*56 with wavelength shifting fibers passing through them in 3 directions.

- This will give 3-dimensional readout capabilities as opposed to a conventional 2-dimensional readout from scintillator bars.

- SFGD is expected to give good position and timing resolution of charged particle track, which will improve the efficiency of detecting muon decayed electrons.

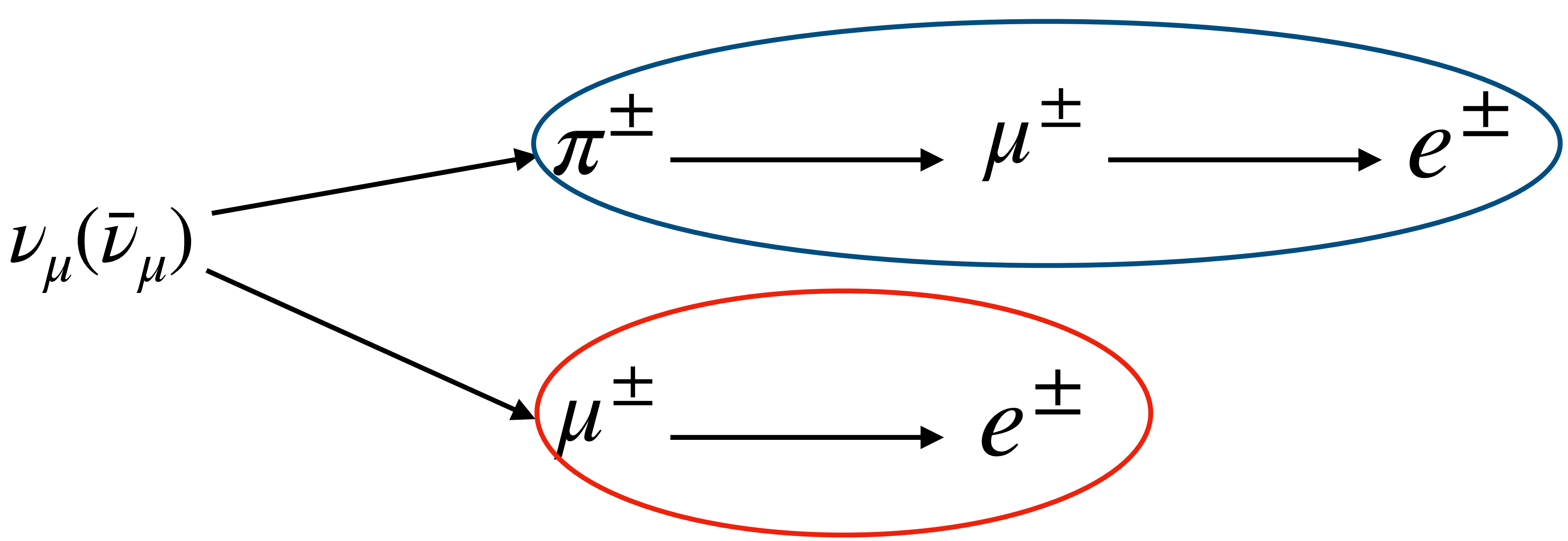
- This plays a crucial role in identifying charged pions generated from the neutrino interactions in the near detector since these pions can decay into muon which in turn decays into electrons also called Michel electrons. In this talk, the event selection method and results are presented.

Goal



- Tag the Pion inside SFGD using the Michel electron resulting from it.

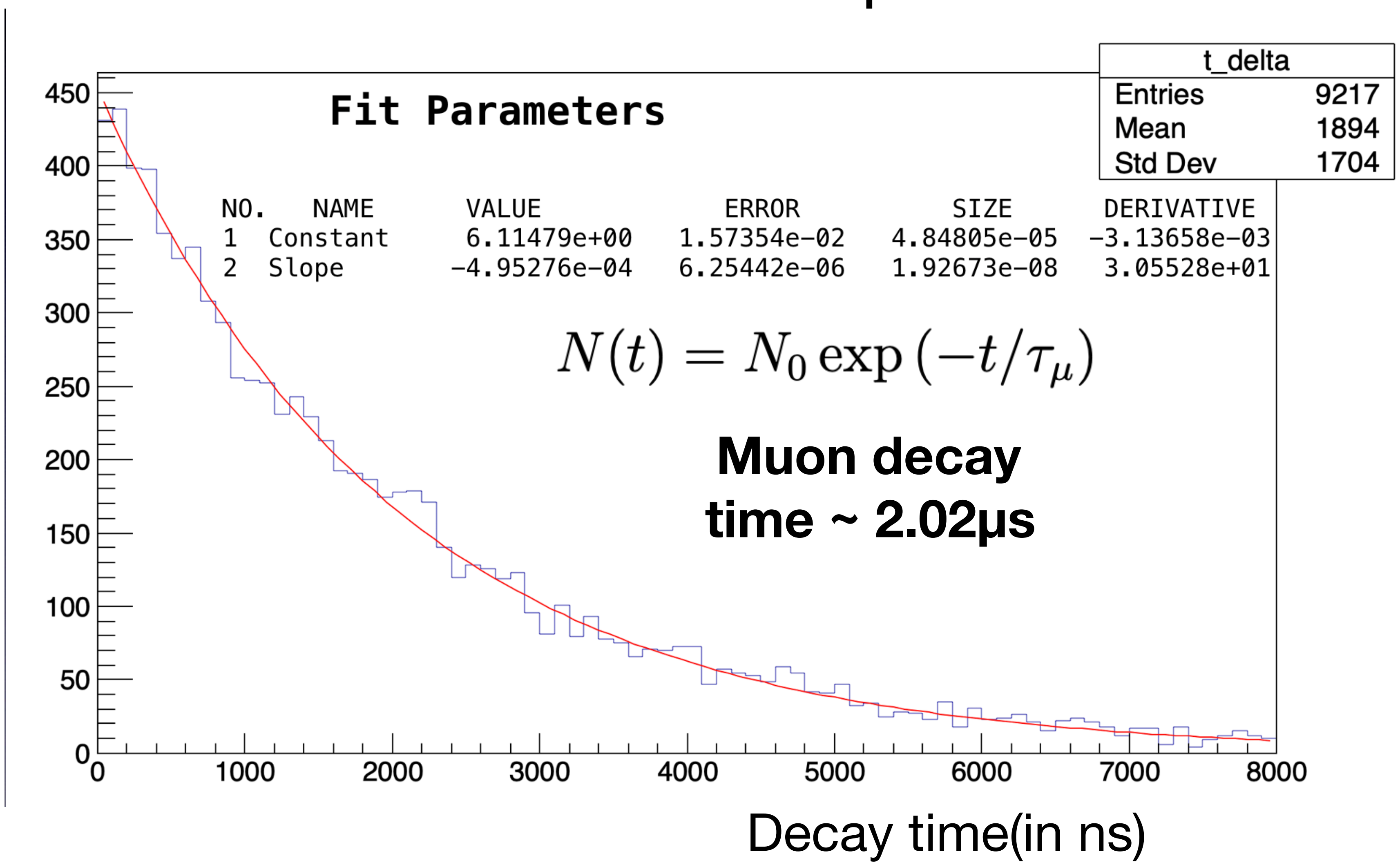
- To distinguish between decay electron coming from primary muons and primary pions



Muon particle gun(Simulated using Geant4 Monte Carlo)

- Started with injecting muons into SFGD and saved the true hit information.

- In each event selected the the latest muon hit time and earliest electron hit time using particle ID tagging. The difference between them is plotted and shown below.



- The plot is fitted to the exponential distribution to get the mean decay time of muon.
- This time is less than the muon decay time of 2.2µs because in matter if muon gets captured before decaying it reduces the effective decay time.

Muon particle gun cont…

- To identify the tracks separately without relying on the true particle id used the DBSCAN clustering algorithm with hit coordinates and hit time.

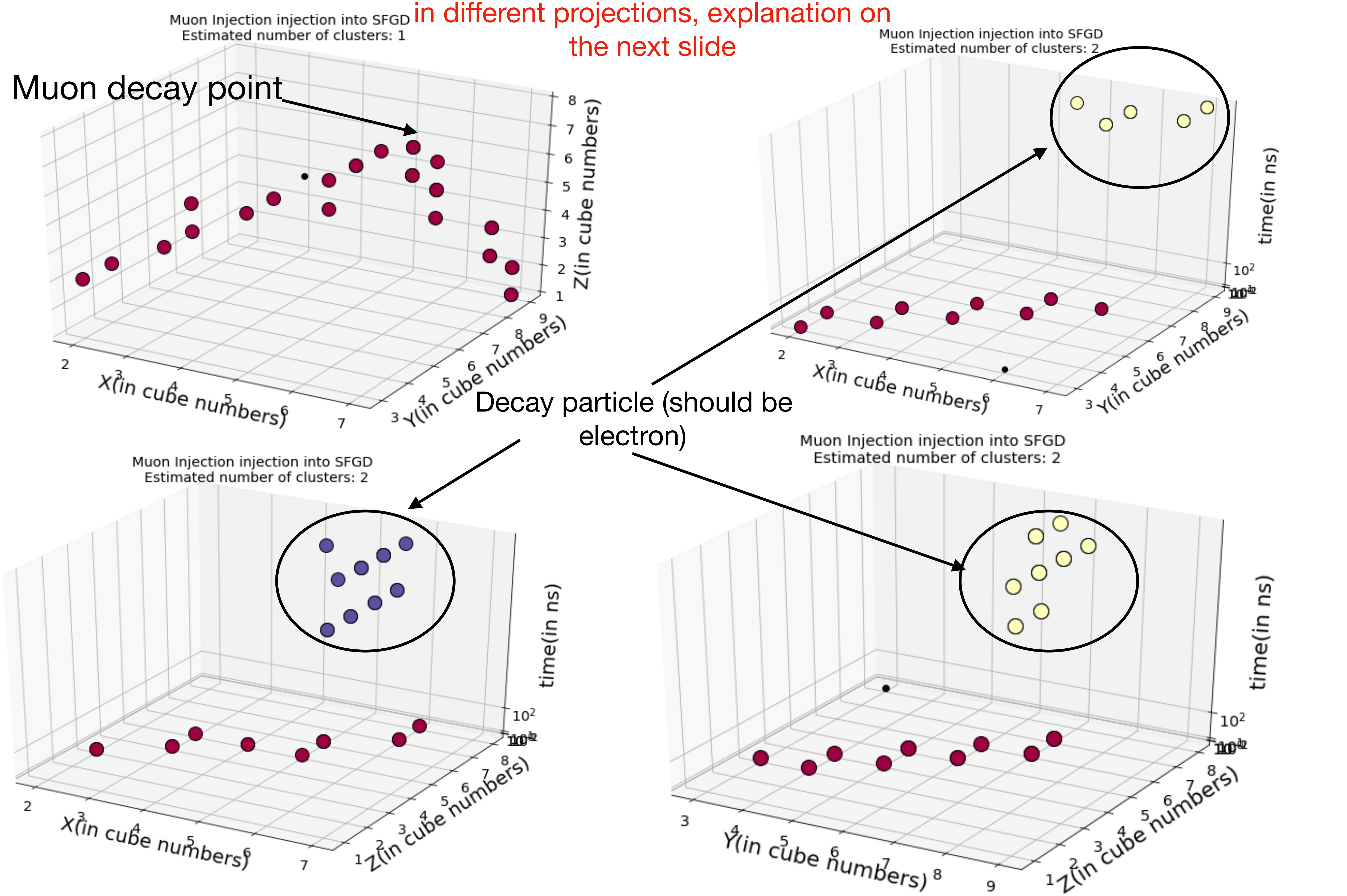
- if(dist($V_1(x, y, z)$-$V_2(x, y, z)$)) $<$ 2 && abs($V_1(t)$-$V_2(t)$)) $<$ 100) add to cluster;

- Collected all the hits from Geant4, rounded off hit coordinates to cube numbers.

- Applied clustering algorithm on the hit cube coordinates and hit times.

DB scan(muon injection)

All these plots correspond to same event in different projections, explanation on the next slide



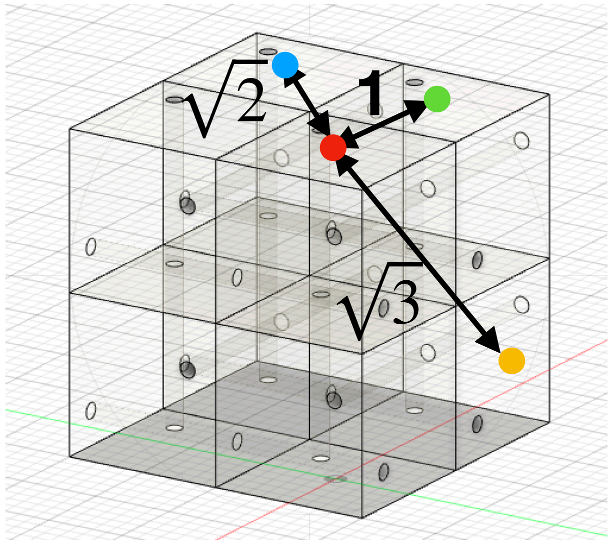
DB scan(muon injection) cont…

- All 4 plots on the previous slides are hits from a muon injection into SFGD clustered using DB scan algorithm. If multiple clusters are found they are plotted using different colors. Black points are hits that didn't make into any cluster(noise).

- Top left is the 3d tracks of muon and decay electron, other 3 are projections of these tracks on to xy, yz, zx planes with hit time on the Z axis.

- Adjusting the clustering parameters it is possible to distinguish muon and electron track due to large decay time.

Cluster pair selection(muon -> electron)

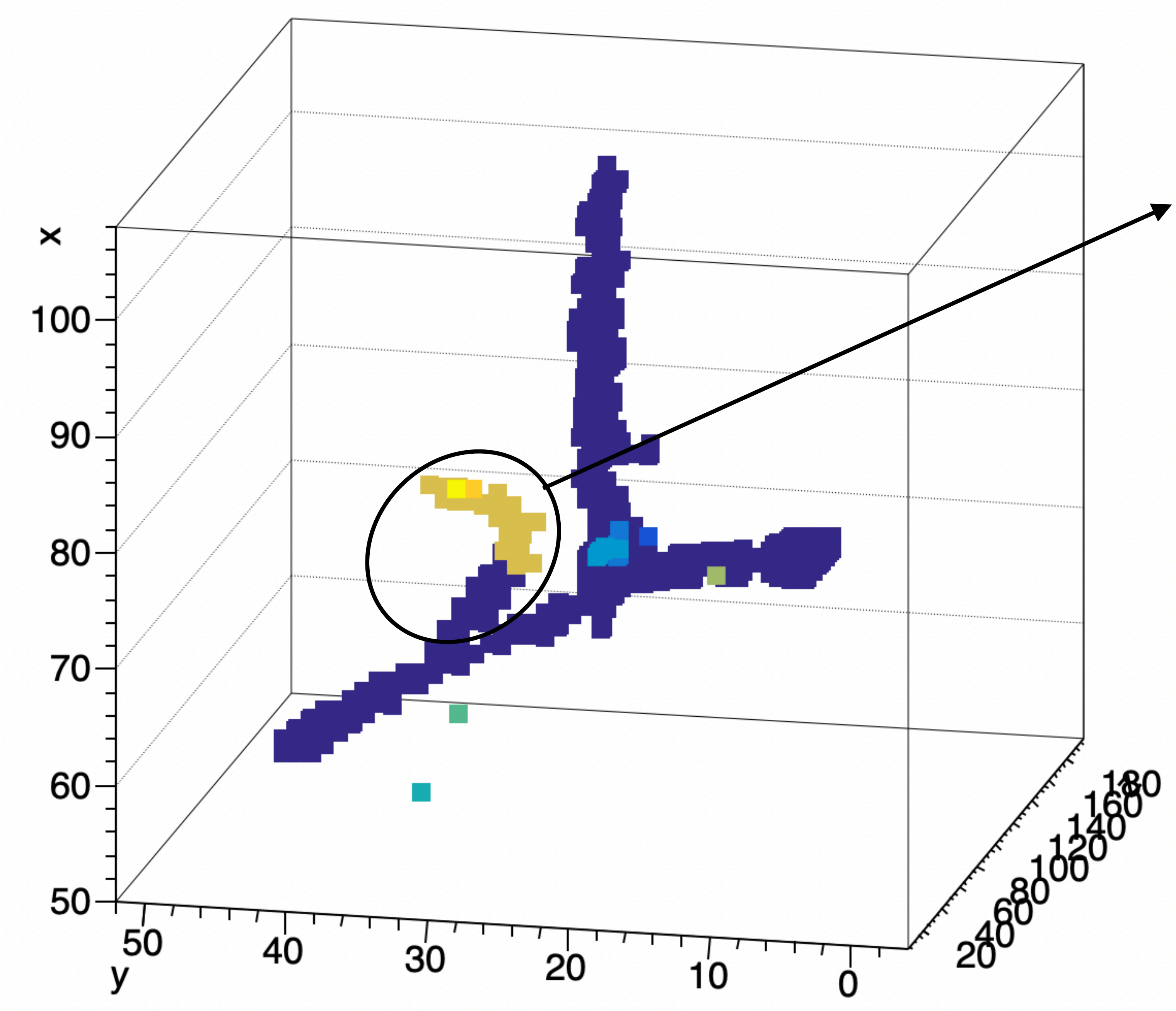


- Event should have minimum 2 clusters with each having track length more than **4cm**.

- Among these clusters if there are any two clusters with minimum distance between them less than **2cm** and separated in time by more than **100ns**. They are considered as muon and decay electron clusters.

Numu interaction

NuMuCC



Michel electron production

How it's done

Generate events using GENIE file(for Numu) and particle gun for muon and pion

↓

Apply reconstruction and import into SFGD framework

Check through true tracks

If an electron with its initial track point inside SFGD originates from a primary muon with process tag of decay or mu_minus_capture_at_rest, save it as primary muon decay.

If a muon decays from a pion and then decays into electron inside the SFGD volume, save it as pion decay.

Set time of reconstructed voxels
if(true time < 100ns) voxel->time = 0
else voxel->time = 1

Apply 4D clustering over voxels, select pairs of clusters that pass through cuts.

- **Cluster length > 4cm**
- **Separated in time by 1(100ns)**
- **Minimum distance between clusters < 2cm**

A. true decay

B. reconstructed

Cont..

A. true decay? B. reconstructed?

A = True decay events

A && B = Correct reconstruction

A && !B = Reconstruction Failed

!A && B = False Positive

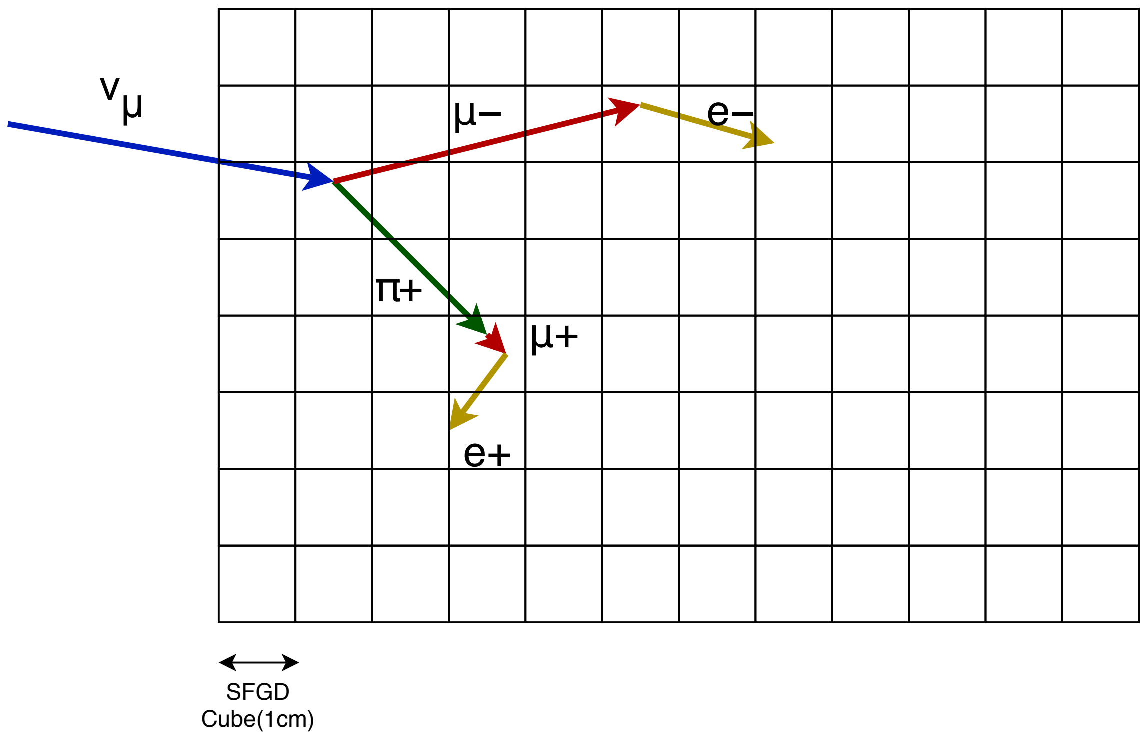
Injected particle (events)	True decay	Correct reconstruction	Failed reconstruction	Efficiency	False postive
μ^{-*} (1000)	929	900	29	0.97	8
μ^{+*} (1000)	999	949	50	0.95	0
π^{-*} (10000)	292	280	12	0.96	3
π^{+*} (1000)	780	751	29	0.97	7
ν_{μ}** (1000)	222	195	27	0.88	6
Anti ν_{μ}** (2000)	149	134	15	0.9	3

* Using Particle gun of central momentum 200MeV placed at the upstream position of SFGD

** Using GENIE MC file(with T2K beam flux information), includes both prim muon -> electron and Pion -> muon -> electron decay chains

Distinguish between Muon and Pion tracks using Decay point

Difference between Primary Pion and Muon tracks



- Since <u>primary Pion decayed muon</u> has very small track length(~ mm) the energy deposited in the decay cube should be much more than the neighboring cubes.

- On the other hand <u>primary muon</u> usually has long enough track length to have a Bragg's peak before the decay point, which means there will be a cube(within 5cm of the decay cube) where the deposited energy is more than the decay cube.

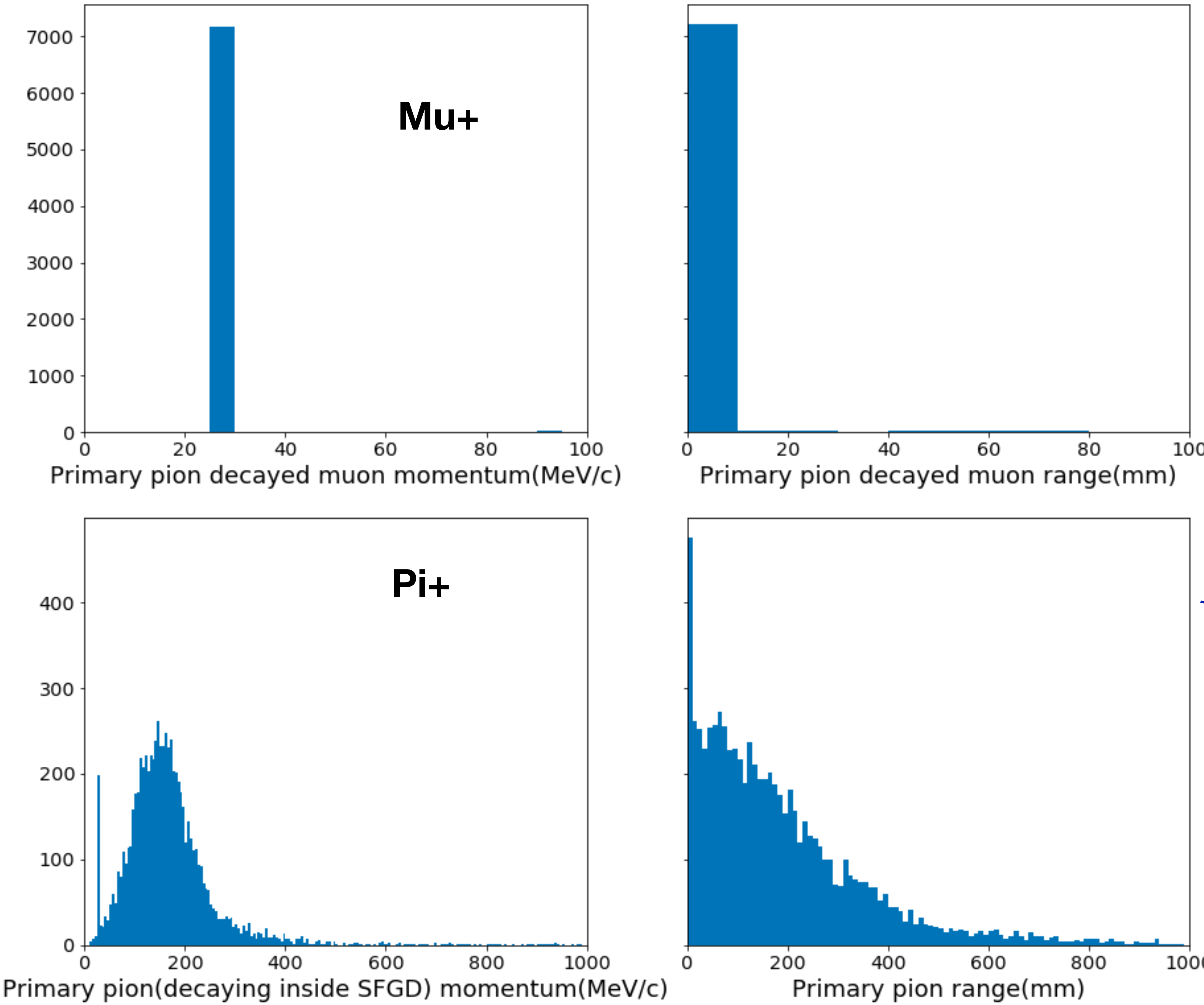
Energy deposition and Bragg's peak trend

- **Primary Pion -> Muon -> electron** almost always happens in one cube, sometimes in two neighboring cubes. So there is either a huge amount of energy in decay cube or similar energies in two neighboring cubes.

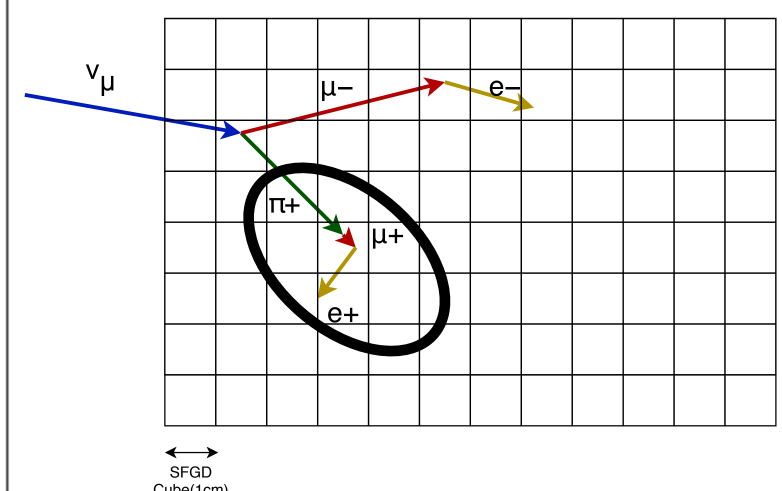
- **Prim Muon -> electron** usually has a Bragg's peak which can be easily identified if it's more than 2cm away from decay point.

Primary pi+ -> mu+ -> e+ chain

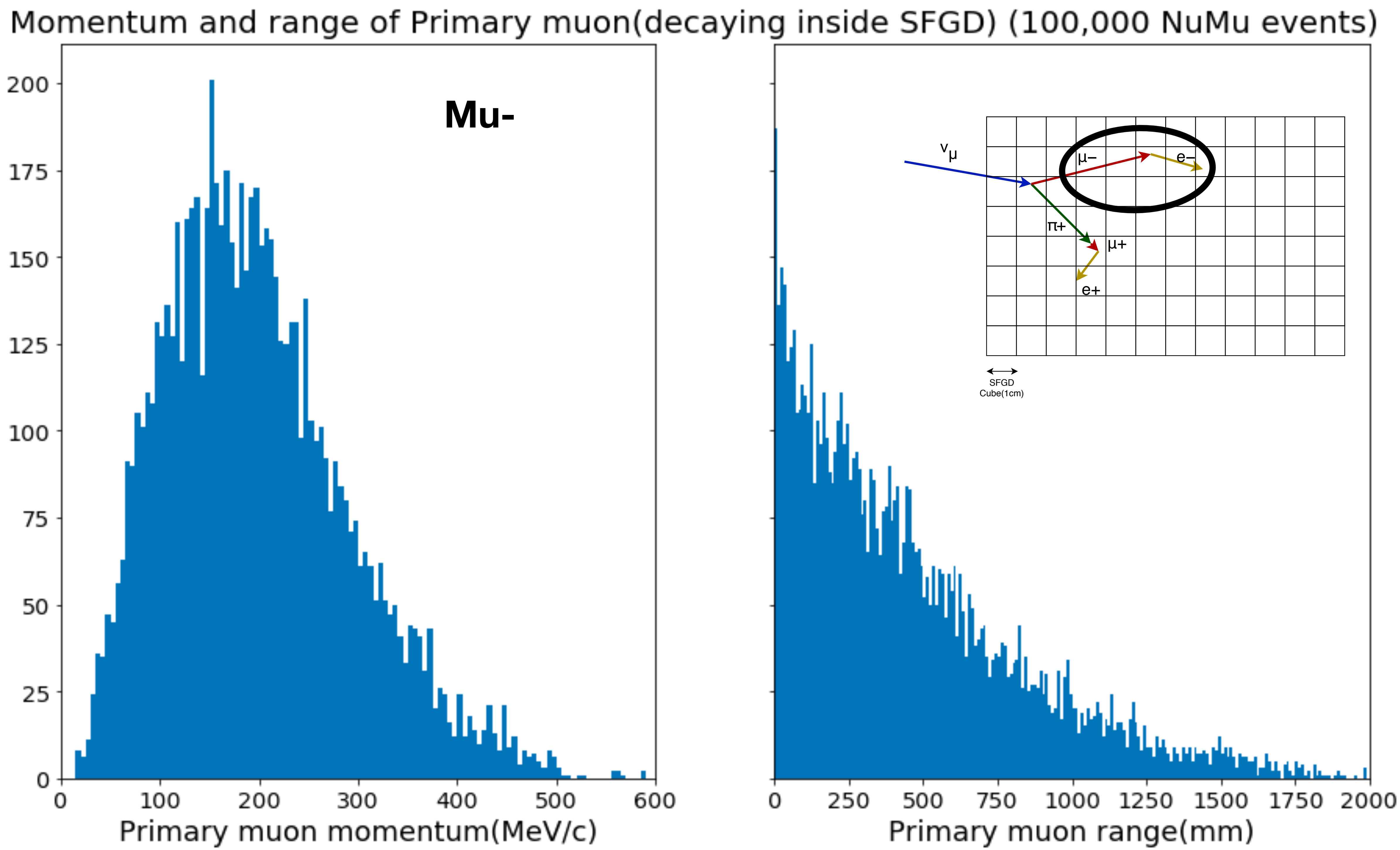
Momentum and range of Primary pion & its decay product muon (100,000 NuMu events)



Muon(top) and Parent primary pion(bottom), momentum(left) and range(right)

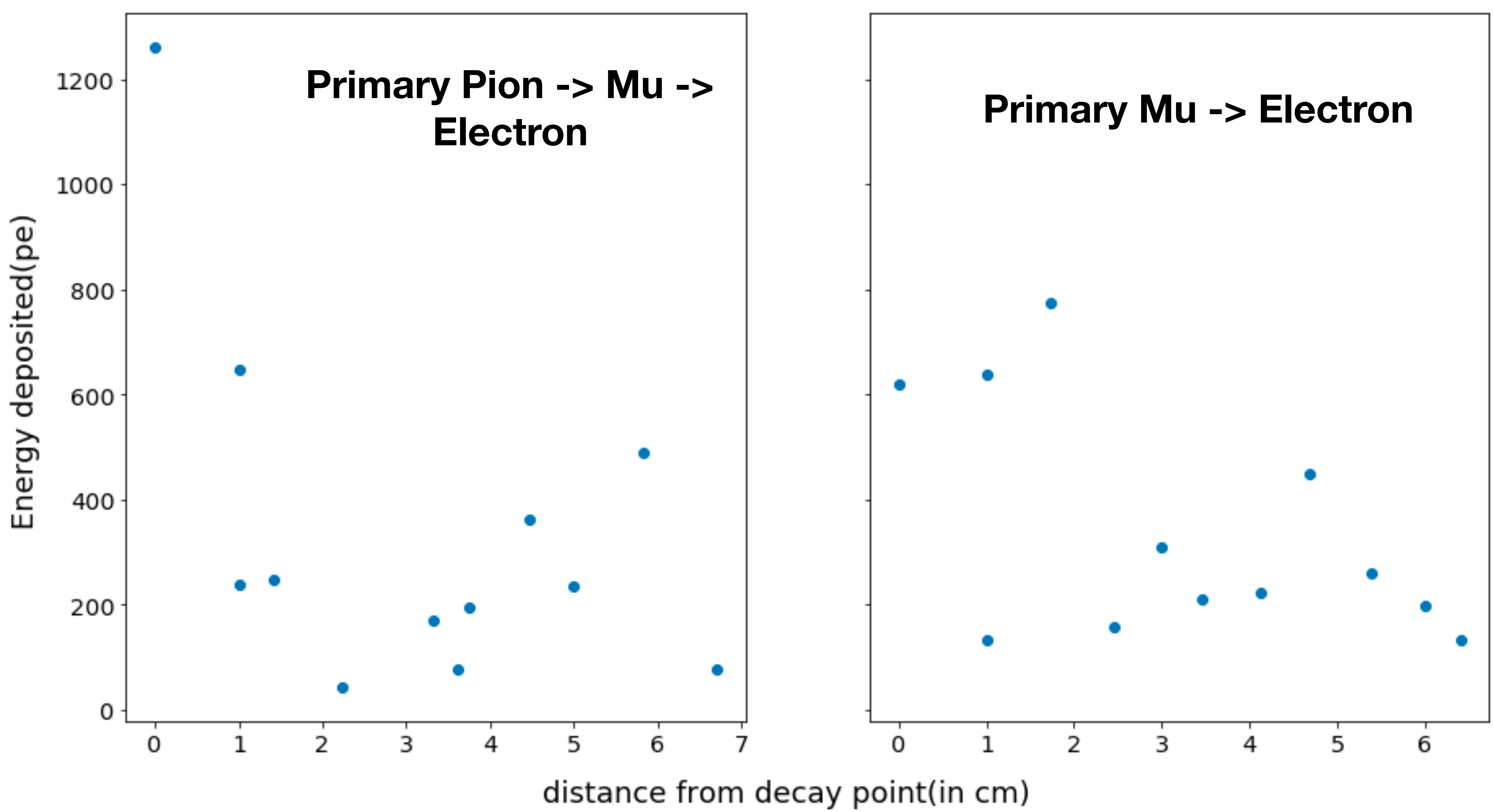


Primary muon(decaying inside SFGD) momentum(left) and range(right)



Energy Deposition in cubes around the decay point

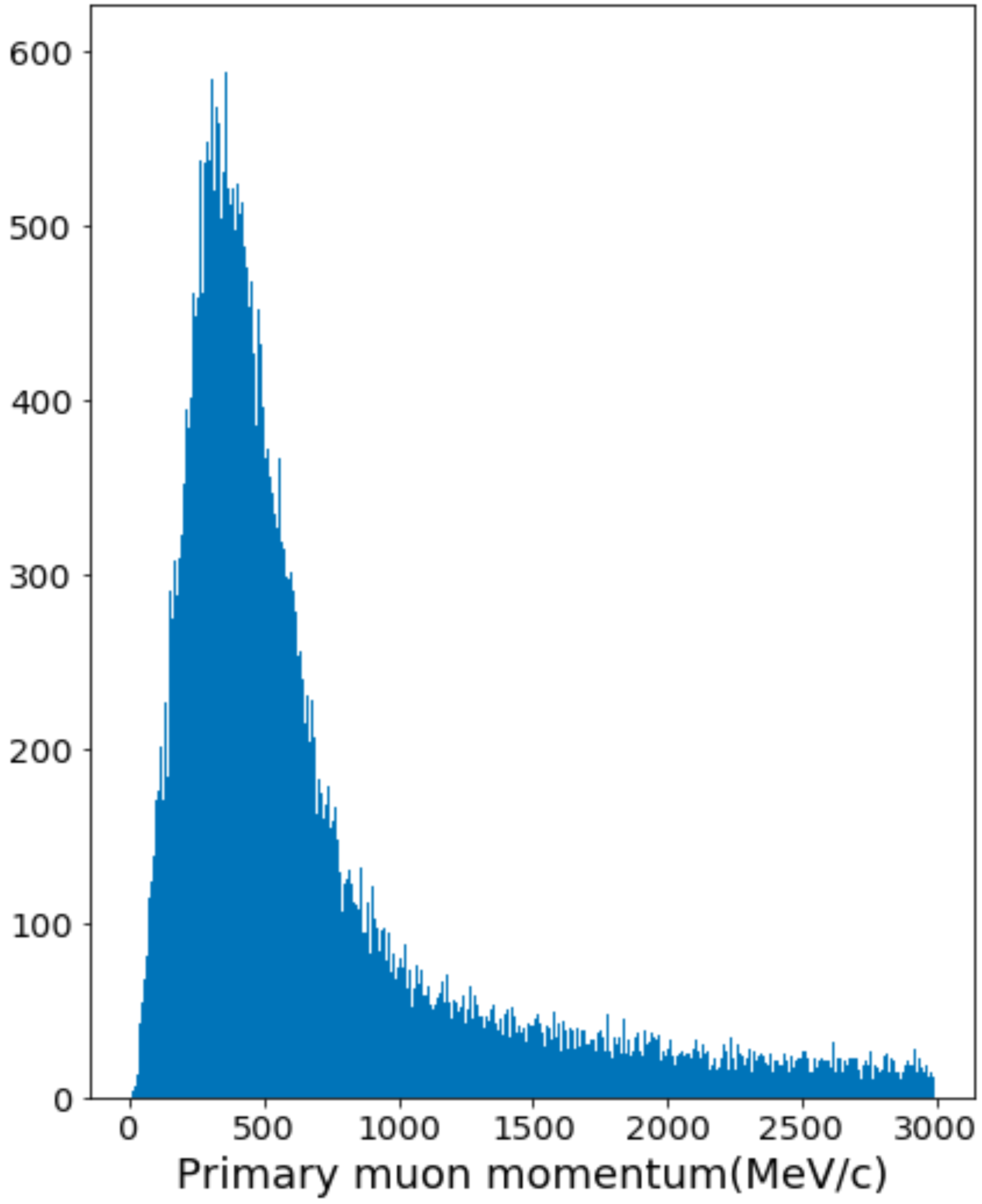
NuMuCC1pi

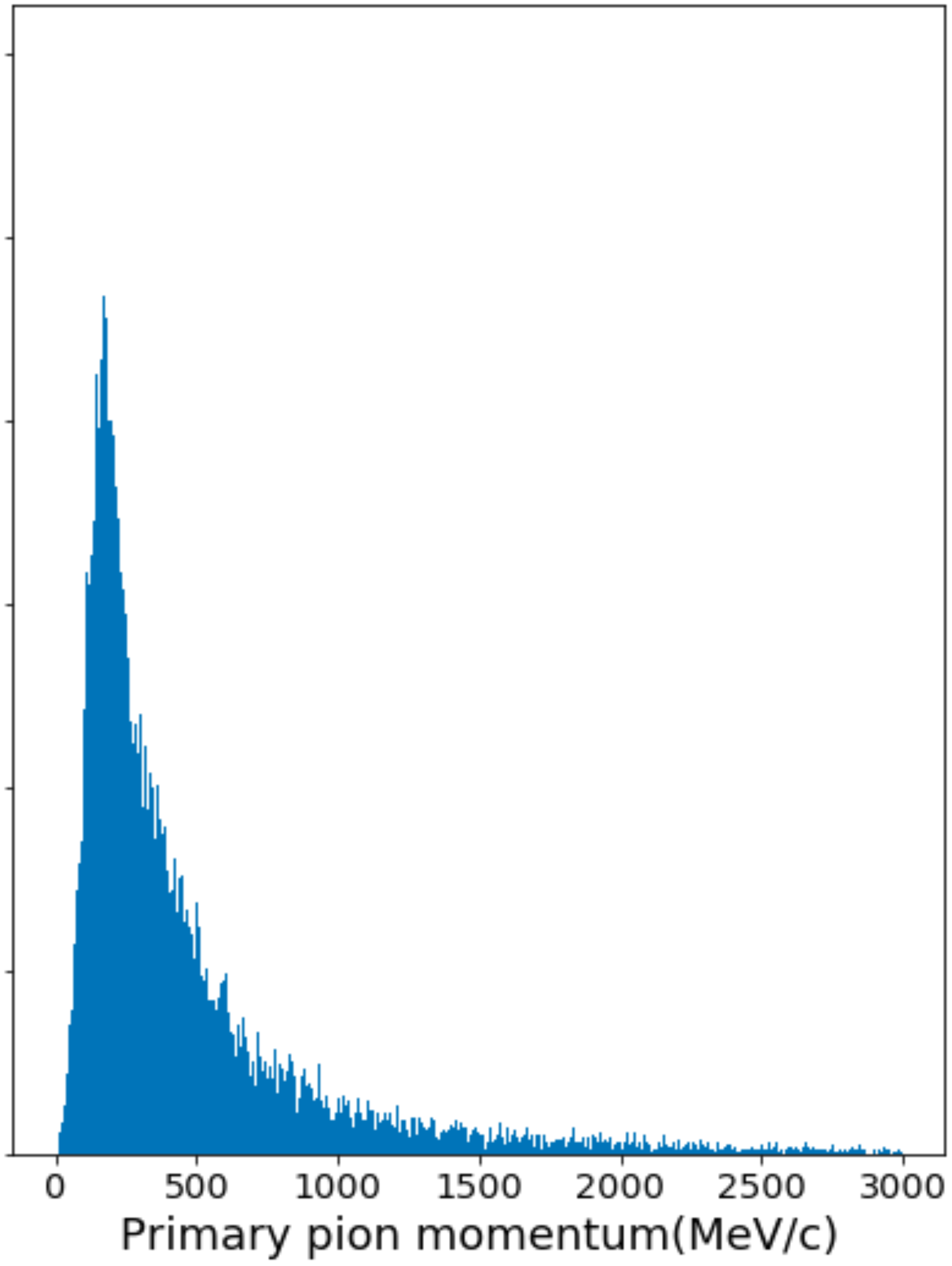


Cont..

- Using some preliminary cut on the ratio of energy deposition near decay point and Bragg's peak cut about 34% of the decay electron origin is identified.
- Decided to include TPC's in the simulations to improve the performance.

Momentum of primary muon and primary pion(produced from numu interaction inside SFGD)





HATPC inclusion using highlandUp

- From the figure shown in the previous slide it’s evident that a lot of primary muons and primary pions can escape from SFGD.
- It the one of them decays inside SFGD and other escapes into TPC’s. It would be possible to tag them in TPC’s and determine which decay in taking place in the SFGD.

Conclusion

- Tested the cuts to identify Michel electrons tracks in SuperFGD with an efficiency of ~90% as opposed current ~56% in current FGD detector.
- Implemented methods to origin of decay electron(Pion or Muon) with some success, need to include TPC's also for better performance.