Machine Learning for Large Water Cherenkov Detector

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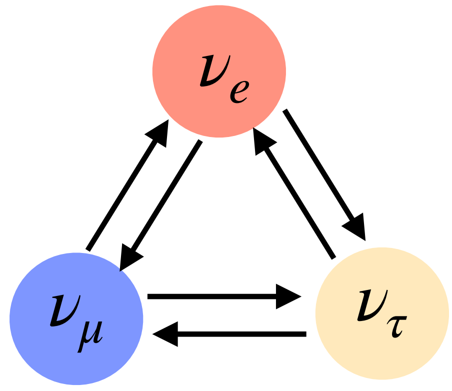
Neutrinos

There are 3 known flavors of neutrinos in the standard model.

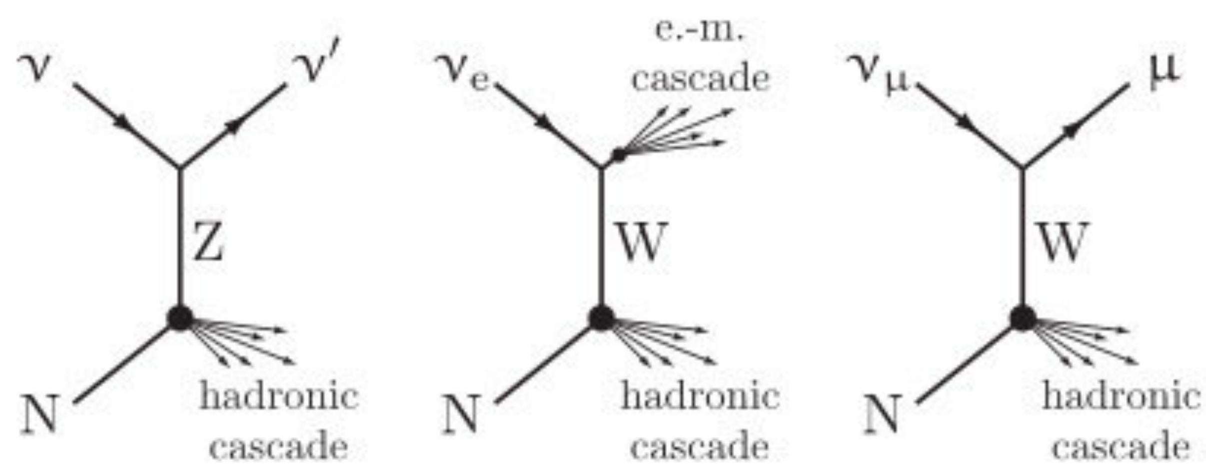
Neutrinos have masses (but very light).

Neutrinos undergo flavor oscillations (neutrino oscillations).



Neutrino Interaction

Interact only through the weak interaction (except gravity).

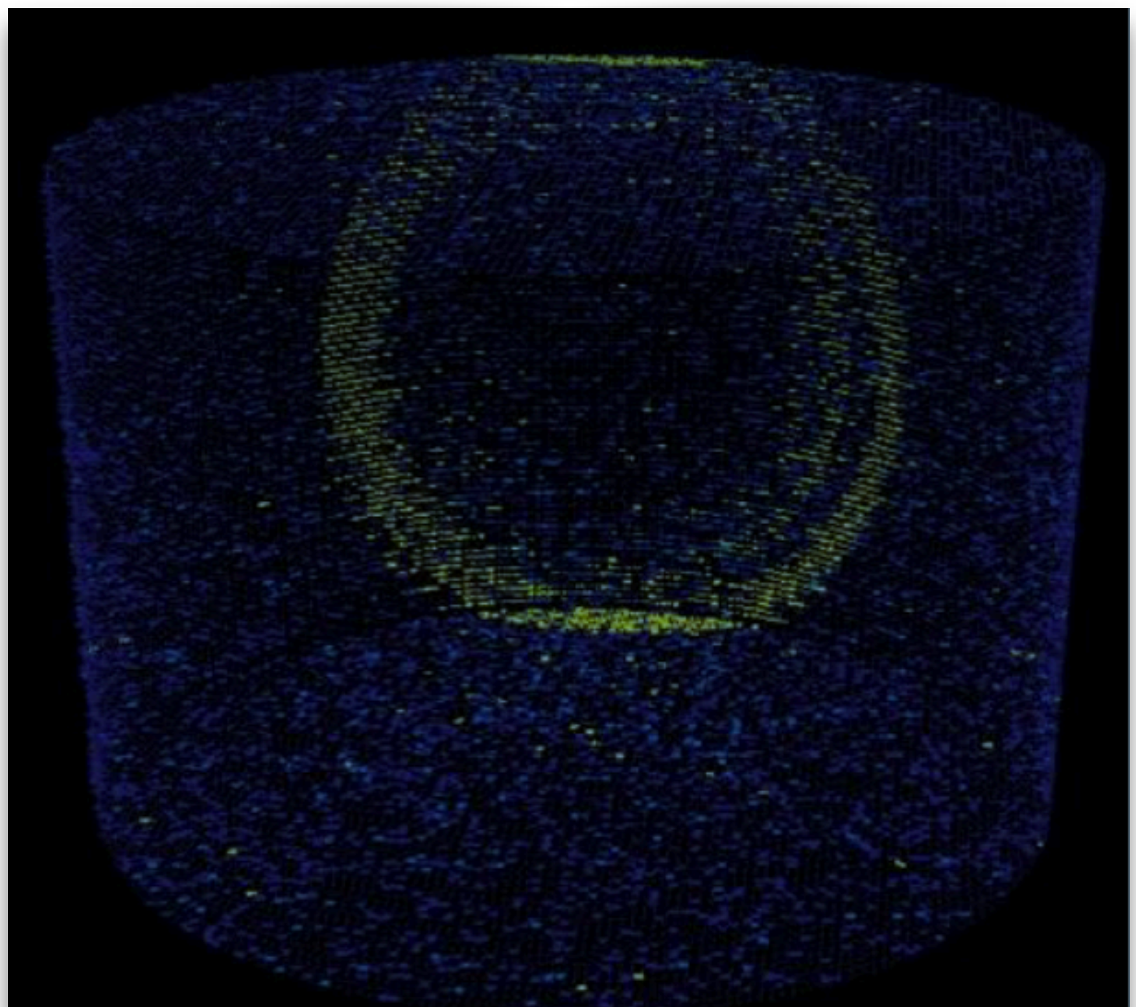


The chance of interacting with matter is extremely small.

Few MeV neutrino’s mean free path in steel would be 10 light-years.

A larger detector is better.

KNO (Korean Neutrino Observatory)



- KNO is a next generation water Cherenkov detector proposed to be built in Korea as a neutrino telescope.

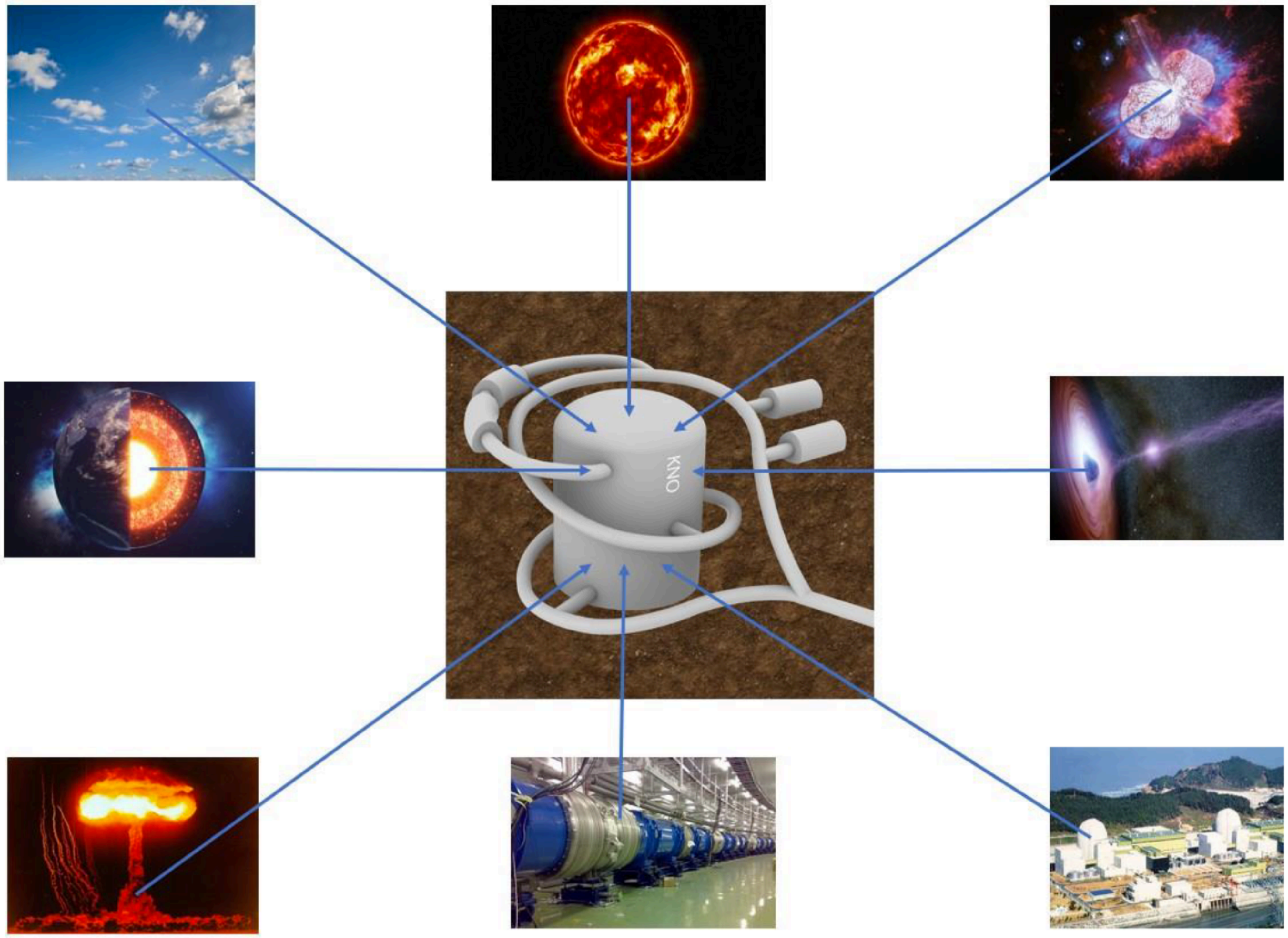
Baseline design

- Cylindrical shape
- Various sizes and configurations being studied
  - ~500 kton
  - photon sensor (PMT) coverage 10~40% ($\mathcal{O}(10^4)$ PMTs)

- The KNO is expected to measure leptonic CP violation and to observe astrophysical neutrinos

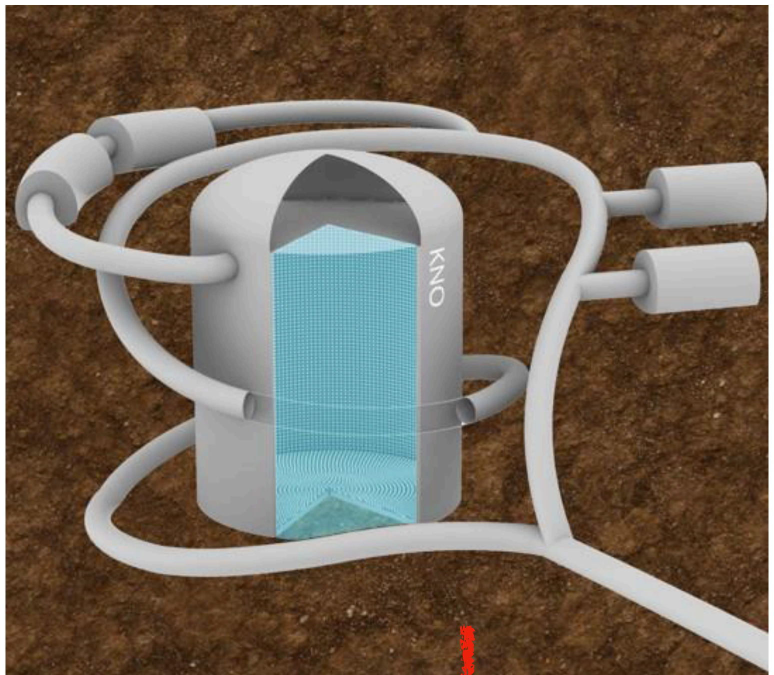
- Funding?

KNO (Korean Neutrino Observatory)

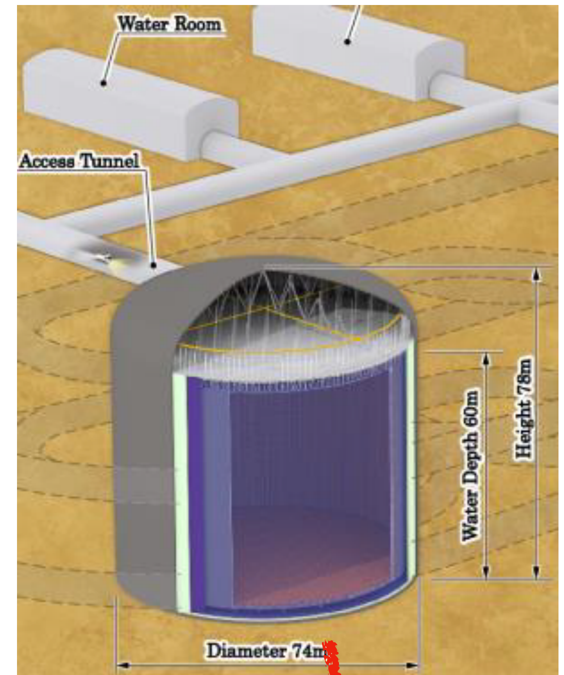


…and proton decay

KNO for Neutrino Beam Physics

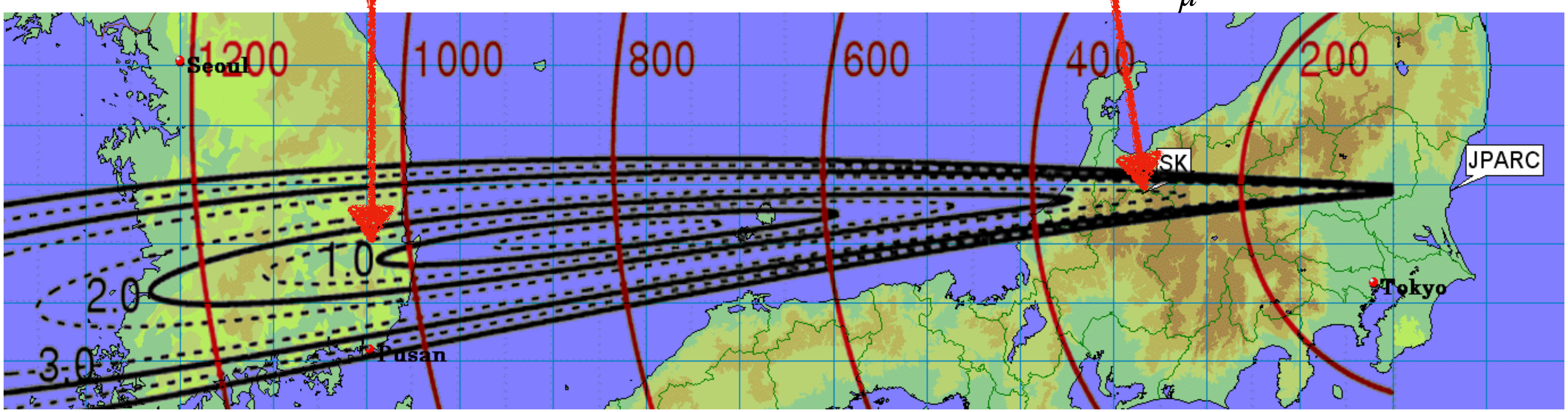


KNO



Hyper-Kamiokande (HK)

ν_μ beam from JPARC



see hep-ph/0504061

KNO (Korean Neutrino Observatory)

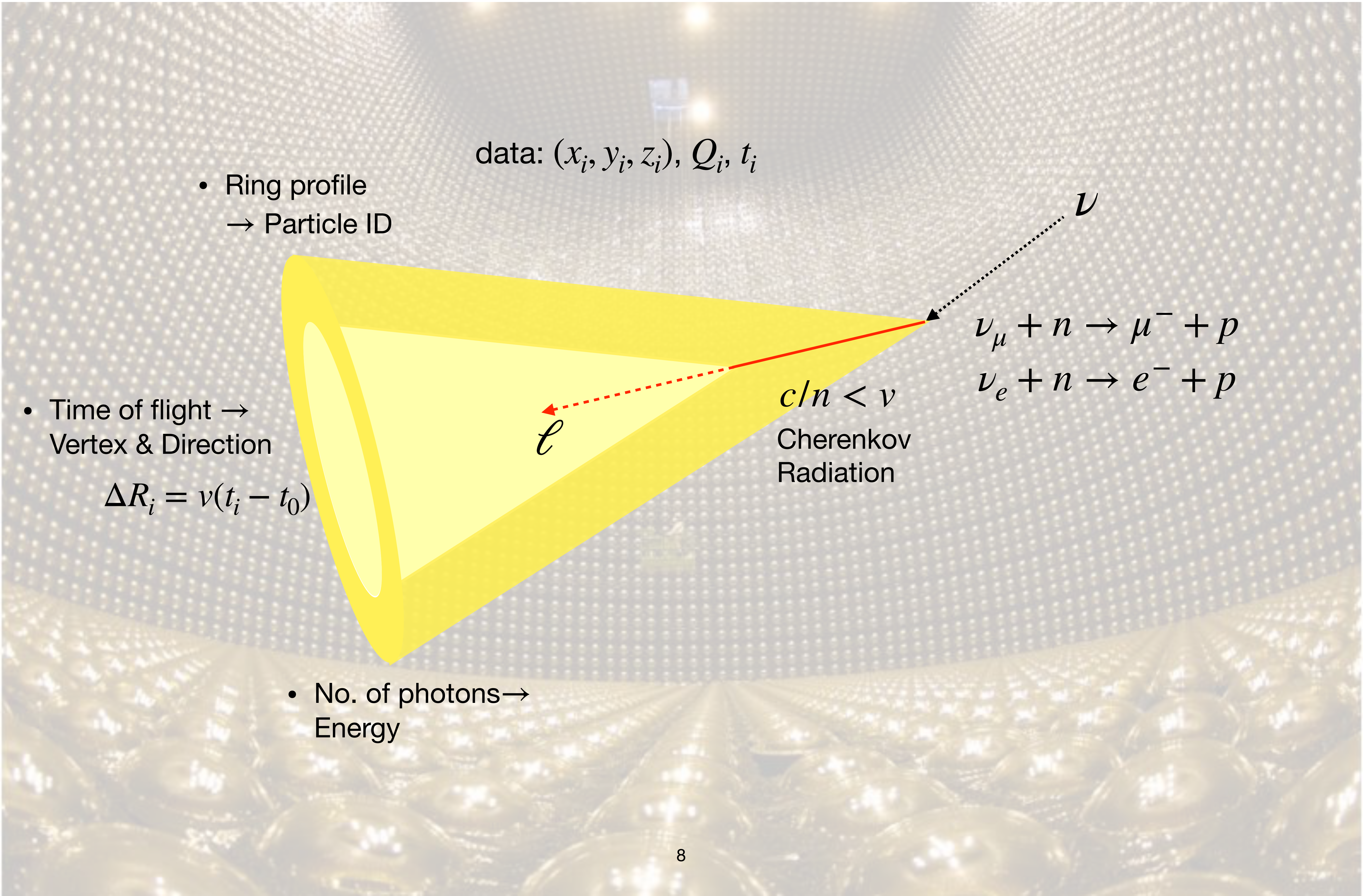
Pros

- 1st and 2nd oscillation maxima at KNO → more sensitive to leptonic CP violation
- larger overburden (~1000 m) → better sensitivity to neutrinos of astronomical origin (solar/SN/galactic..)
- longer baseline (~1100 km) → better determination of neutrino mass hierarchy and better sensitivity to non-standard neutrino interactions

Cons

- neutrino beam flux at KNO is ~ 10 times smaller than HK flux due to longer baseline
- construction will be started later than HK (2021 ~)

Neutrino Event Reconstruction



Machine Learning Based Event Reconstruction

Traditional event reconstruction methods are based on likelihood like maximizers.

- large size data per event (PMTs)
- for better resolution, more complex the algorithms
- long running time

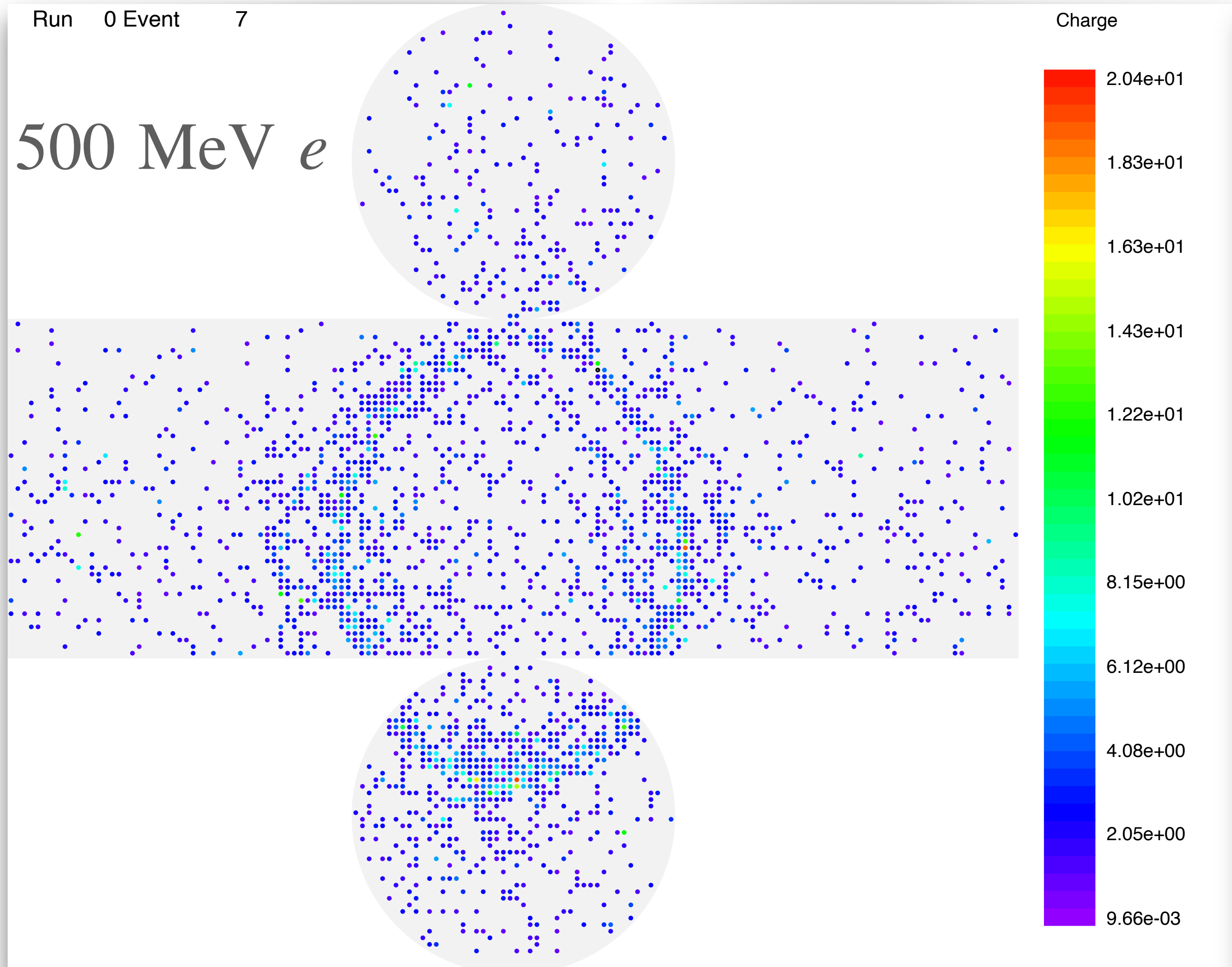
Machine learning algorithms

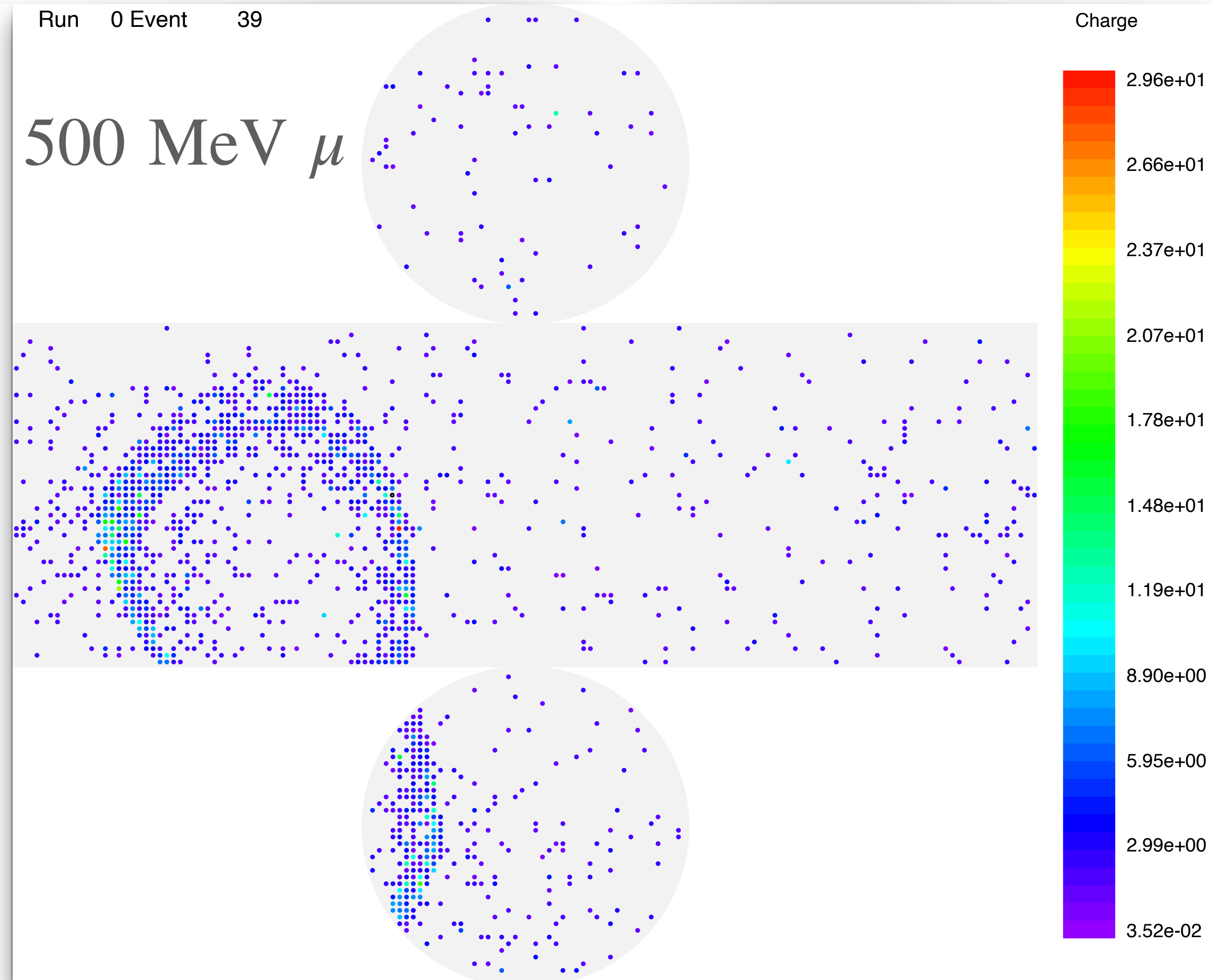
- have potential to use all available information without detector model assumptions / approximations
- fast to run once neural networks have been trained
- common throughout HEP applications
- but many new challenges…

Samples for the study

- Use Monte Carlo samples
  - WCSim, GEANT4 based Monte Carlo package, specifically built for Water Cherenkov Detector simulation
- Shoot electrons and muons isotropically inside the detector volume.
- Compare to a well studied detector: SK
- Try the easiest: Particle Identification (e, μ)

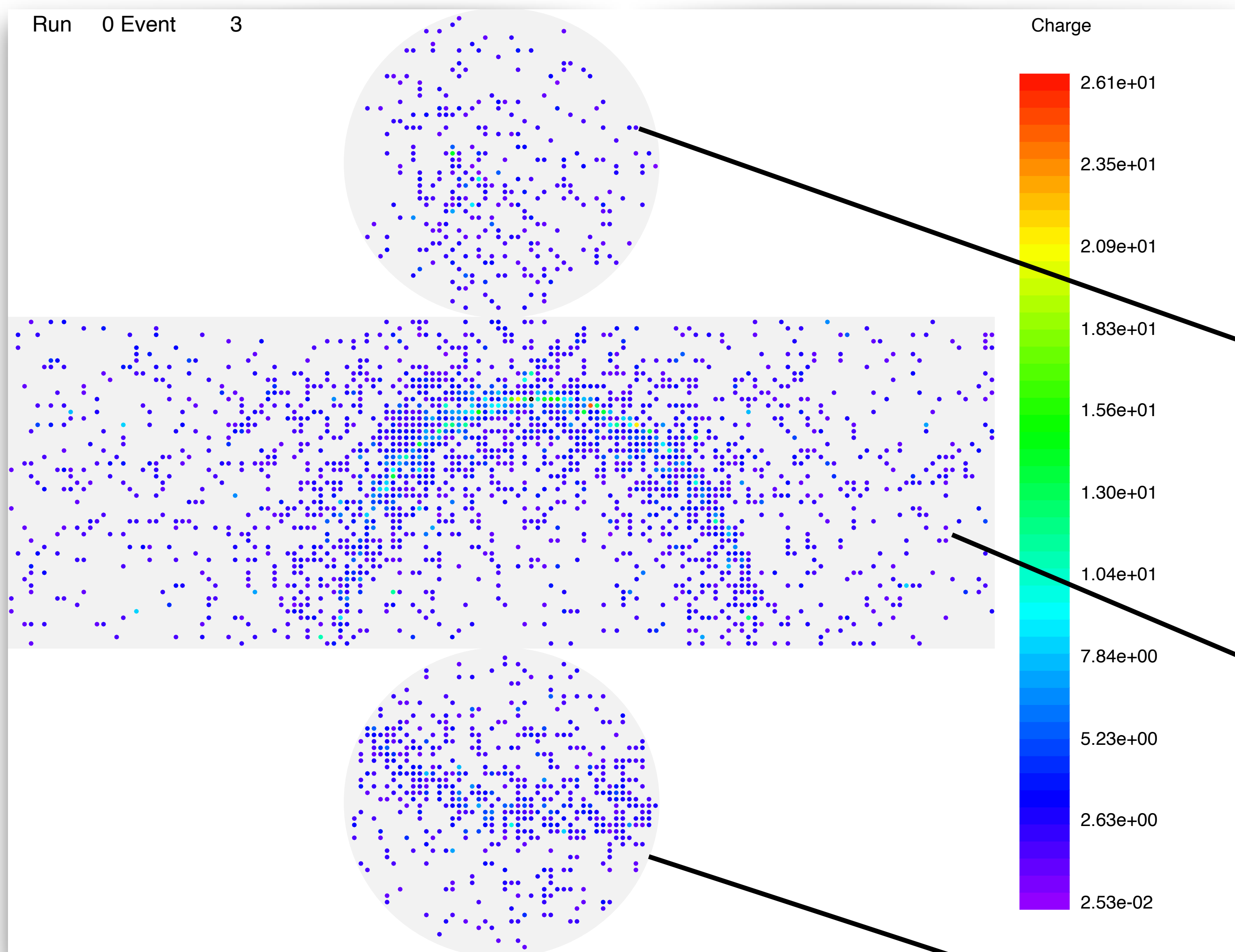
Particle Identification (e, μ)





Muon events have sharply defined ring edge than electron events

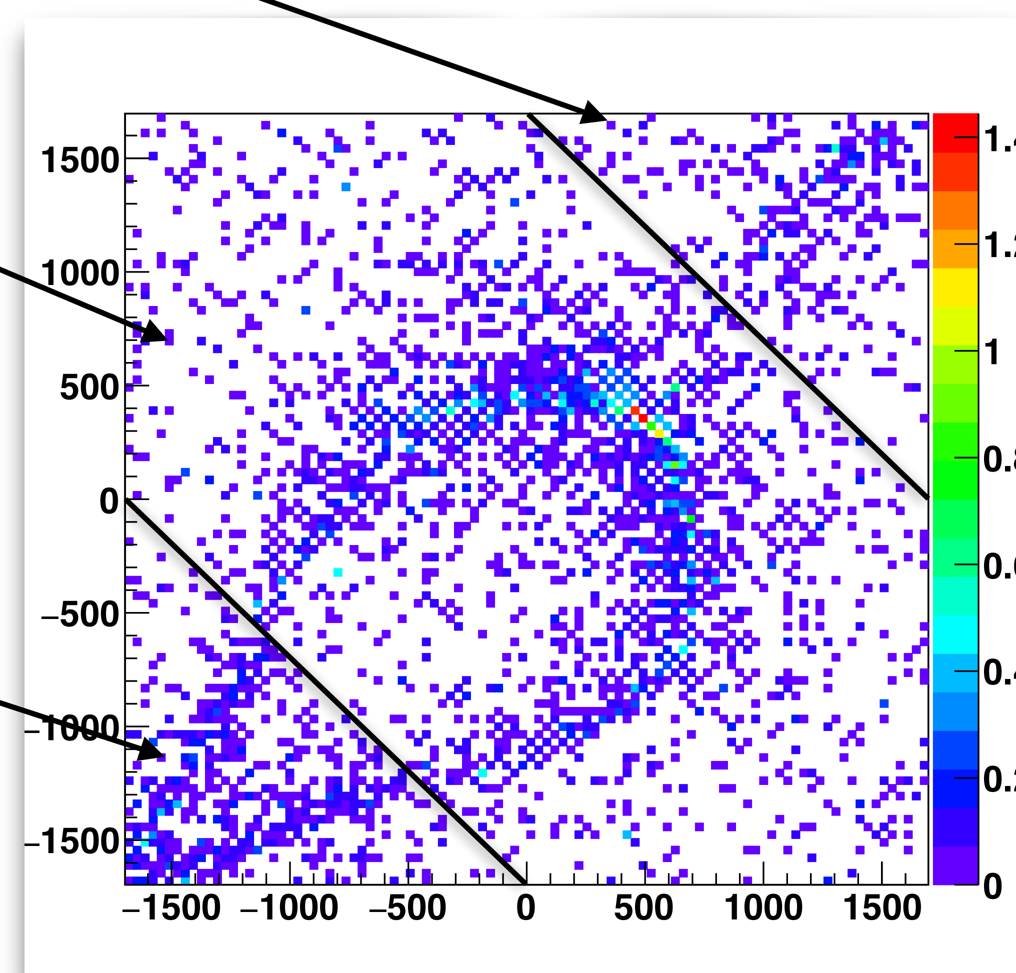
Particle Identification (e, μ)



- Hitmap convolution: 11146 PMTs on a cylinder into 100x100 pixel square

talk by N. Prouse
ICHEP, 2020.07.29

- Used 2D CNN: 20k training/ validation samples

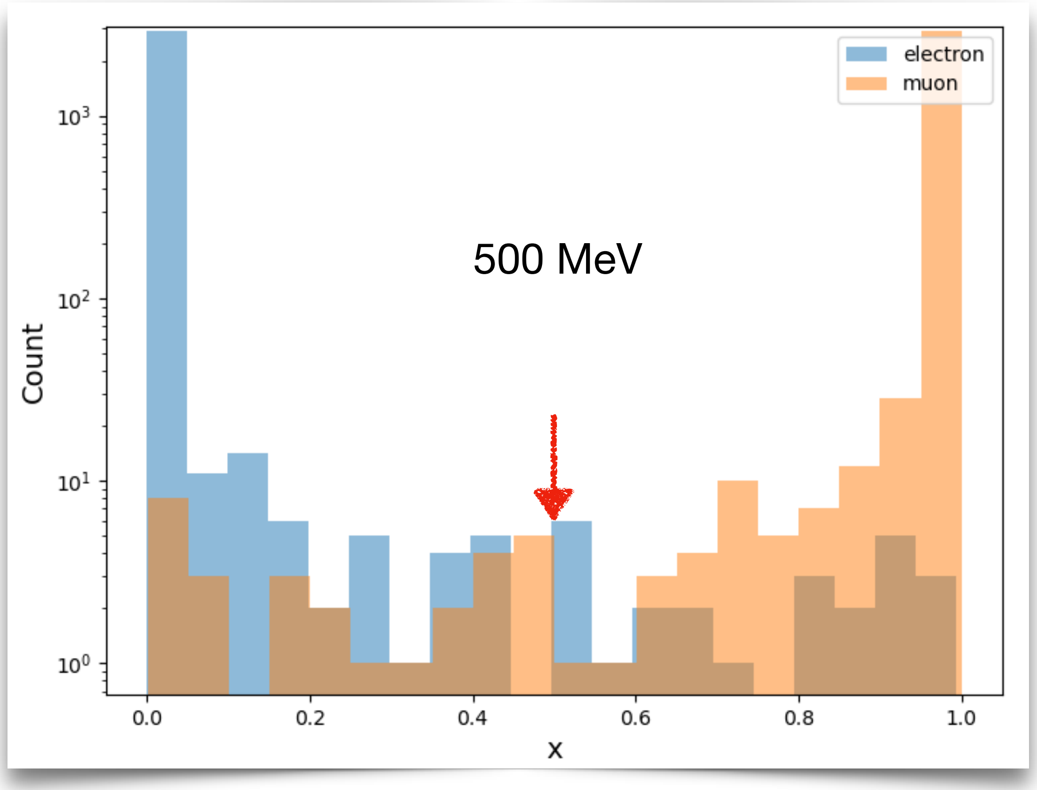


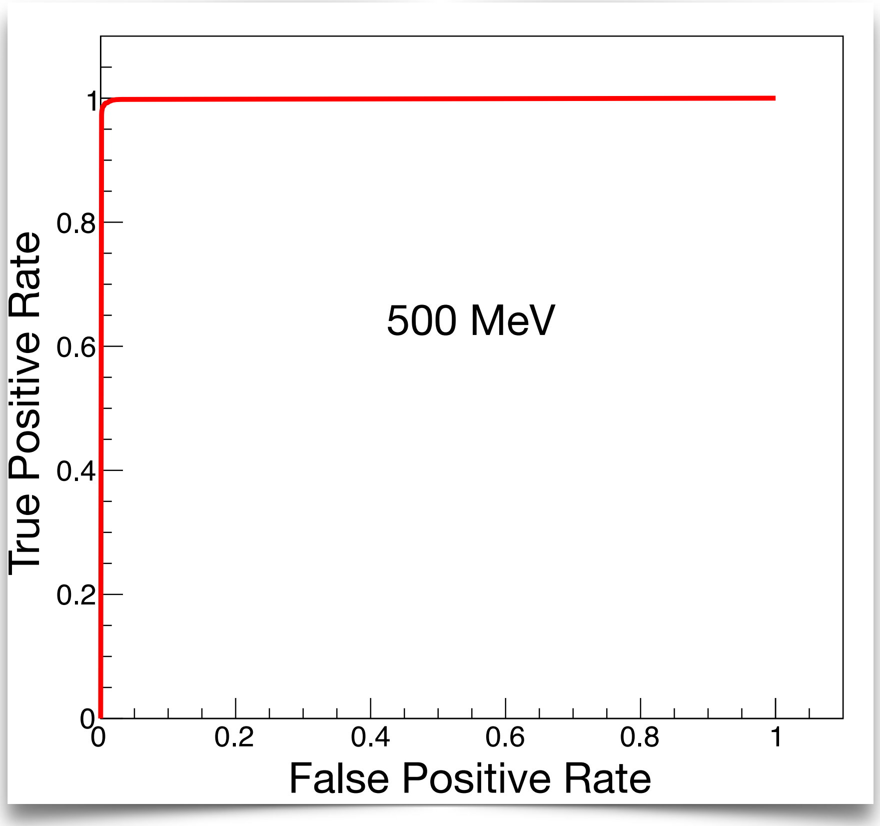
Particle Identification (e, μ)

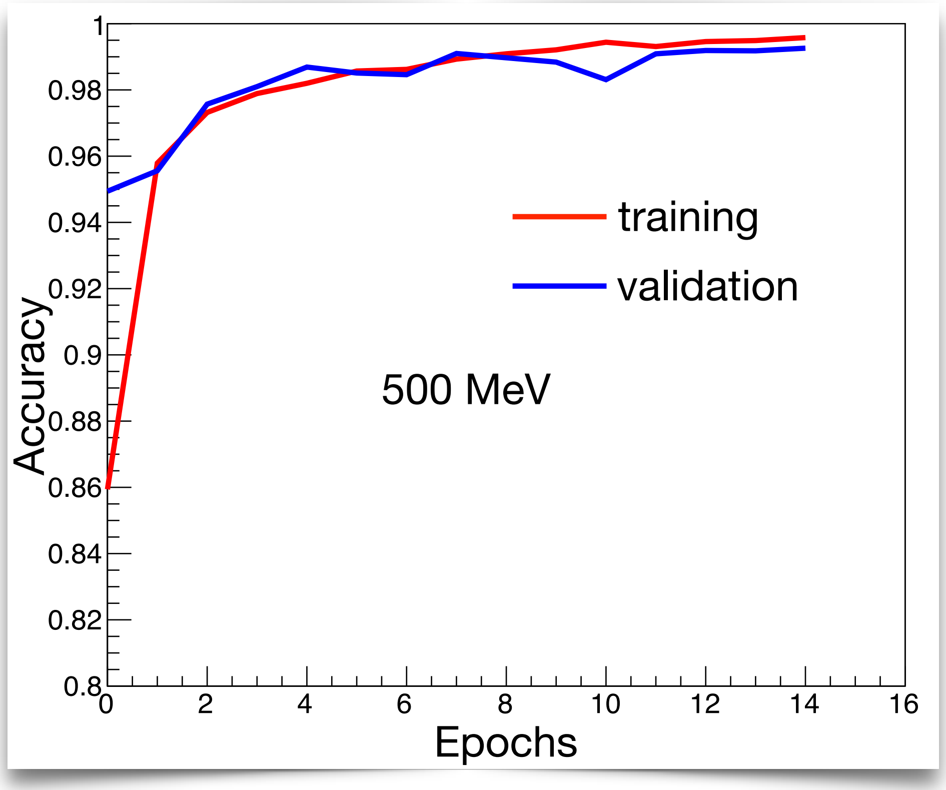
Accuracy: Discriminator trained with 500 MeV samples

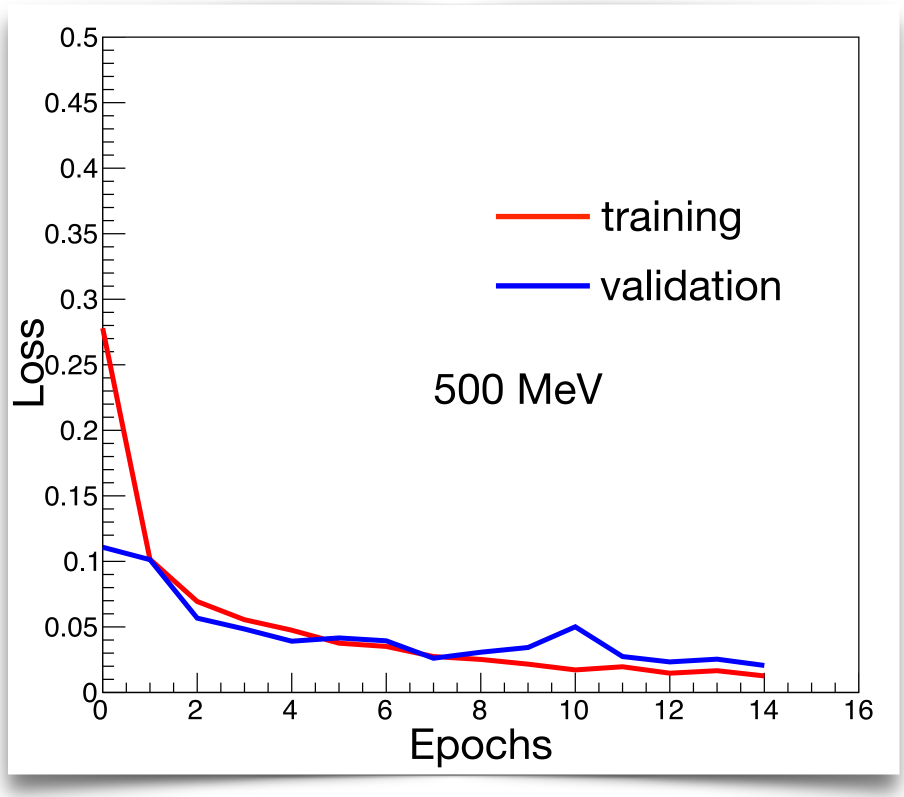
test sample energy (MeV)*	particle	Allowed vertex distance to the detector wall	
		1 m	2 m
500	muon	98.80 ± 0.14	99.45 ± 0.07
	electron	99.00 ± 0.20	99.56 ± 0.12
600	muon	98.71 ± 0.25	99.21 ± 0.18
	electron	98.99 ± 0.23	99.56 ± 0.15
400	muon	99.40 ± 0.13	99.67 ± 0.09
	electron	96.72 ± 0.94	97.64 ± 0.68

Particle Identification (e, μ)



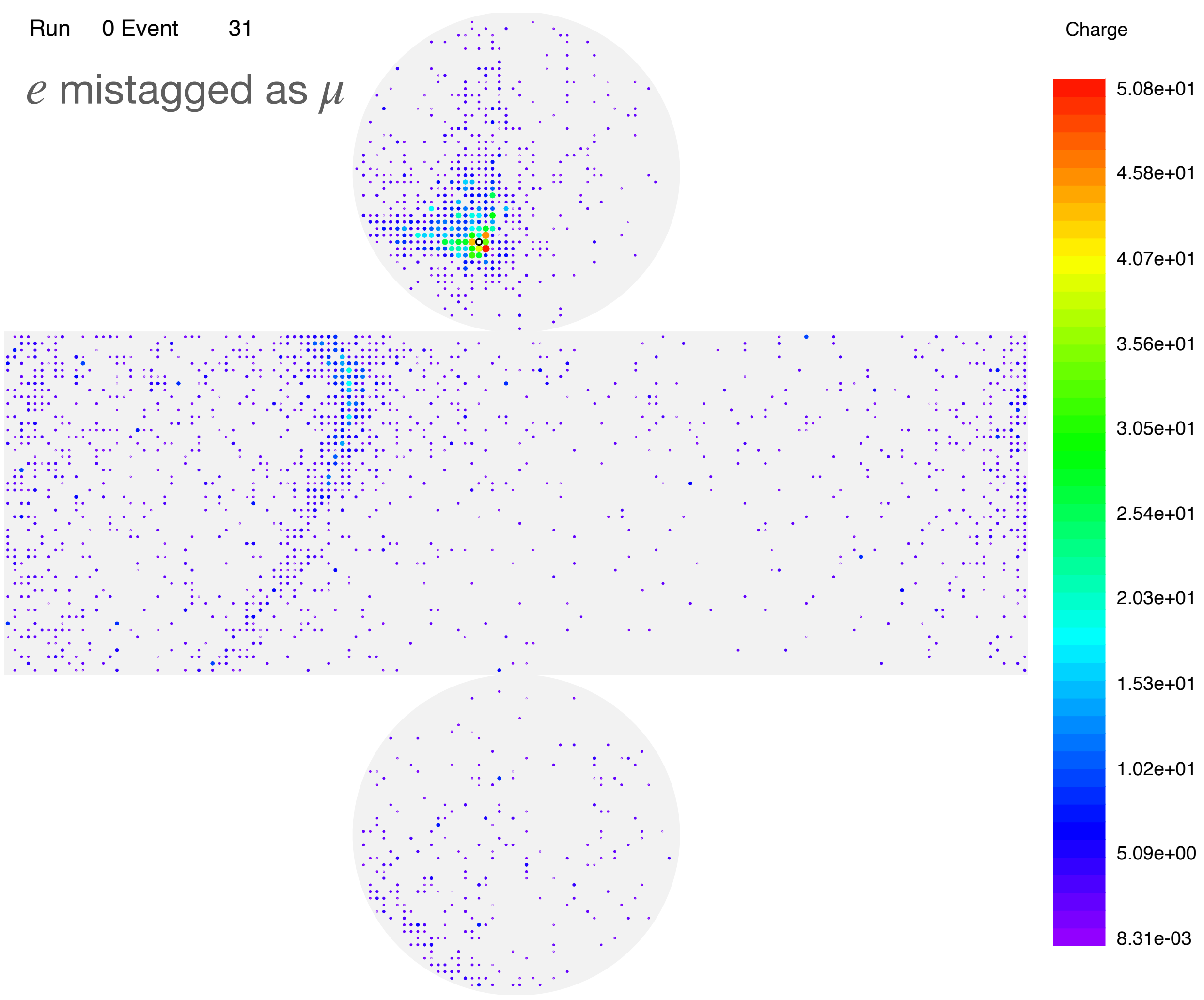


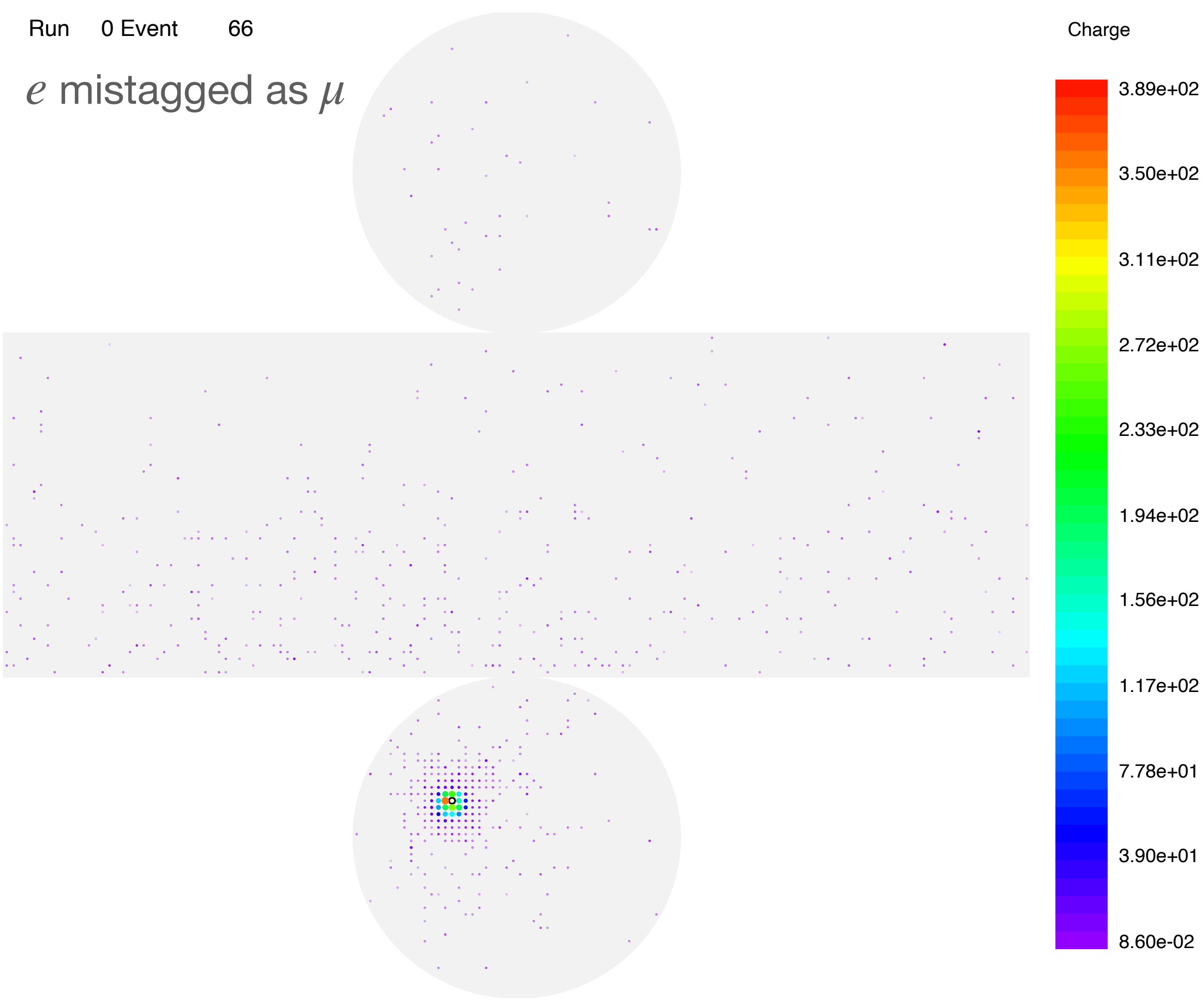




Particle Identification (e, μ)

False Identification: Event vertex close to walls





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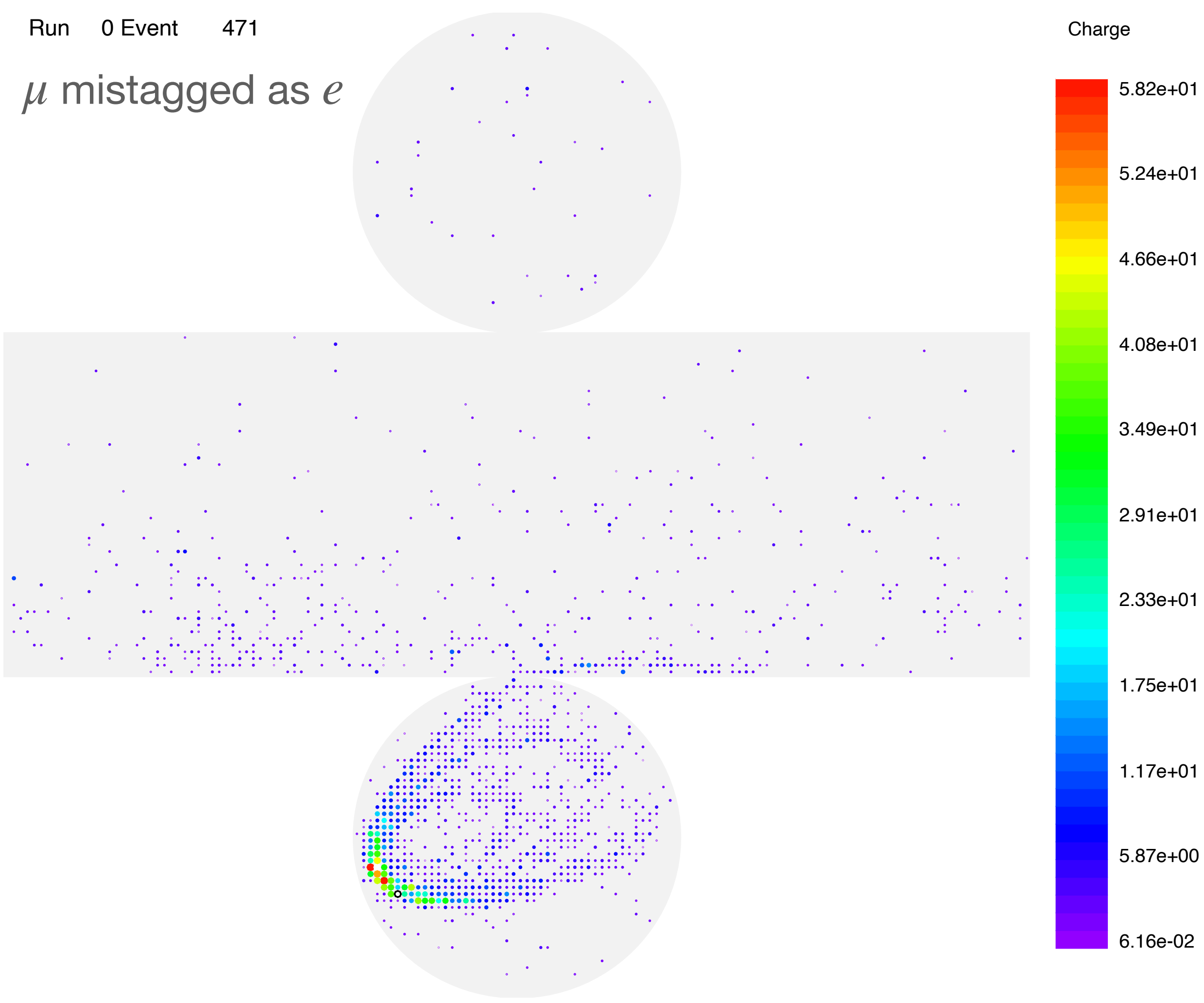
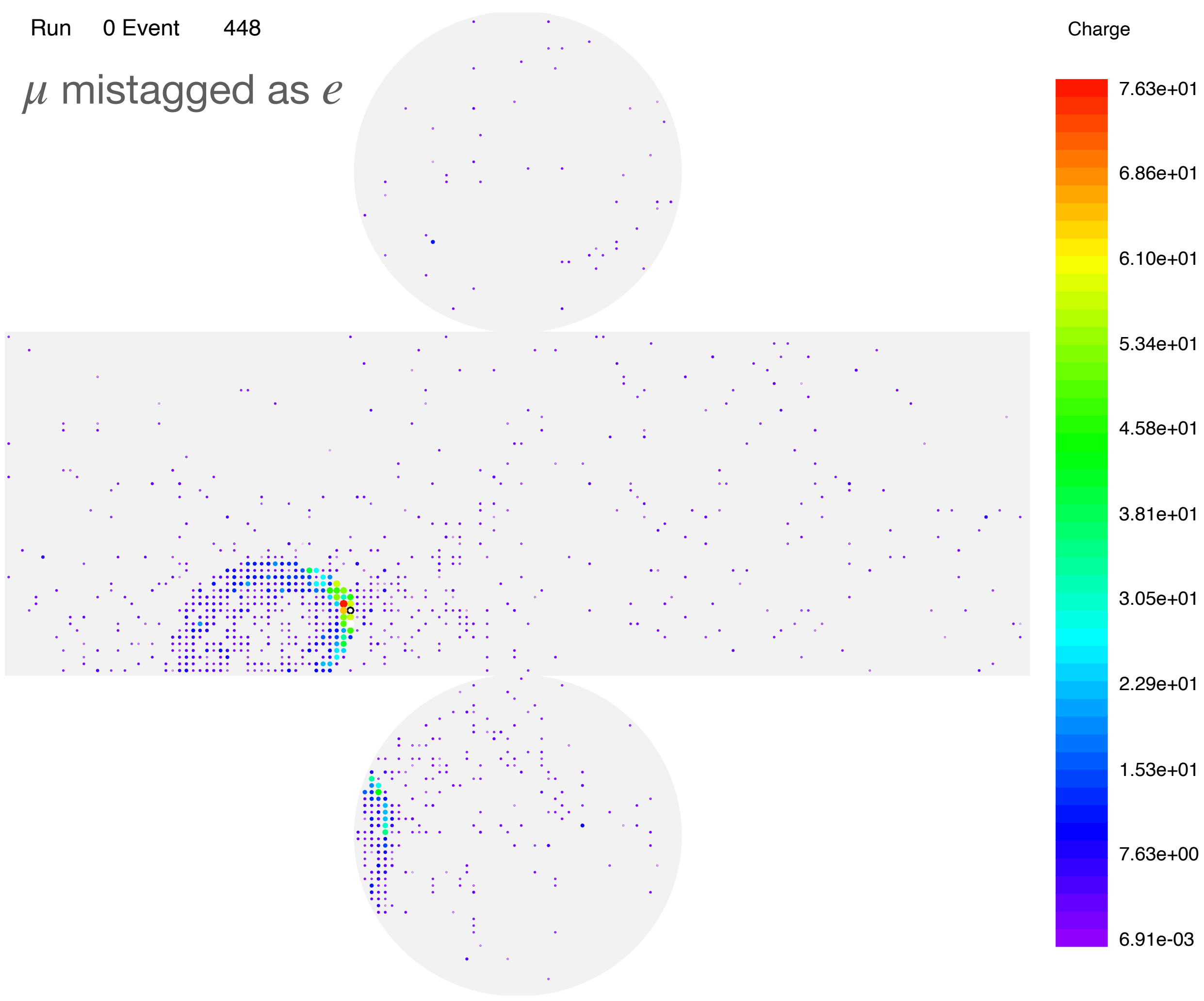
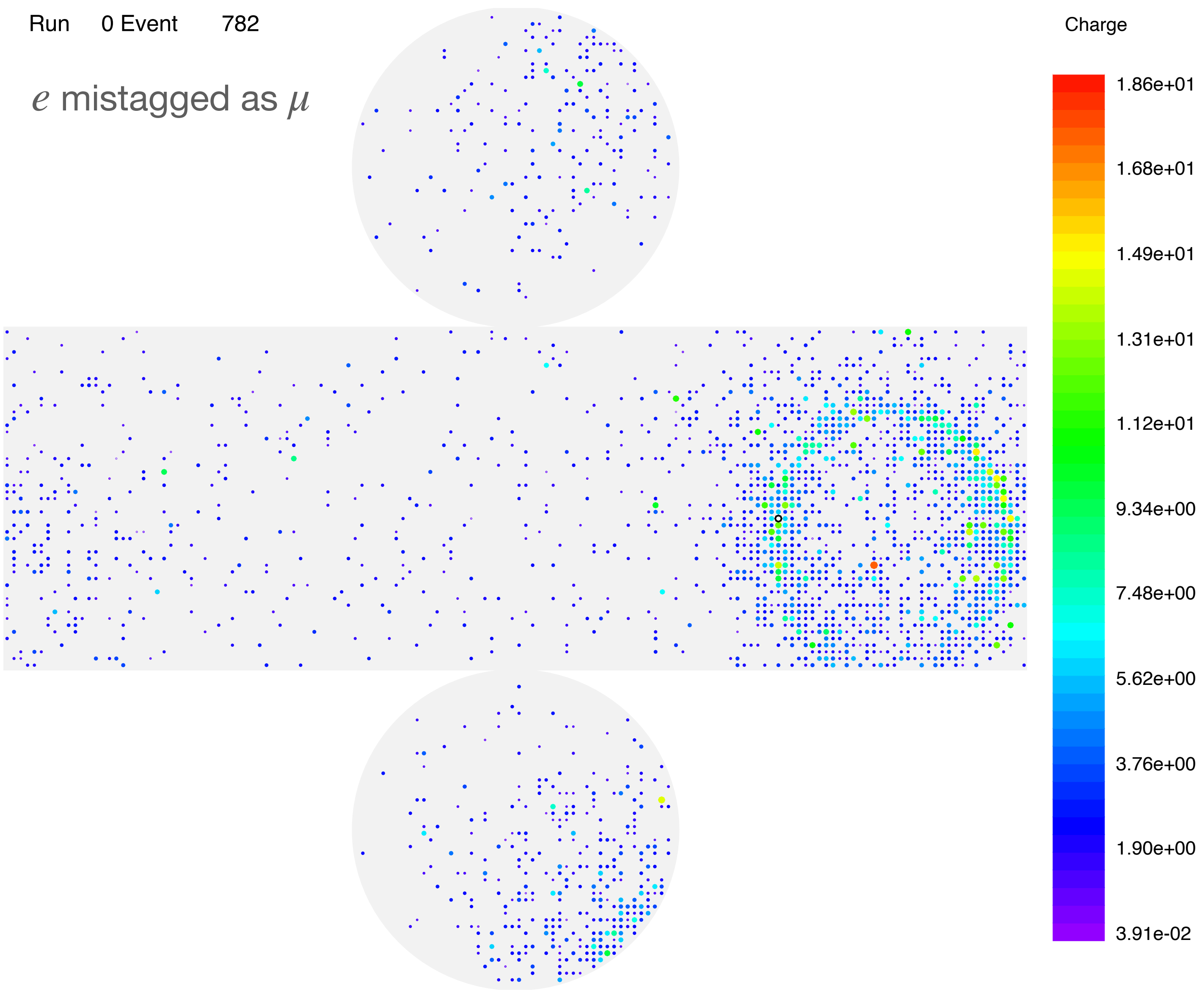




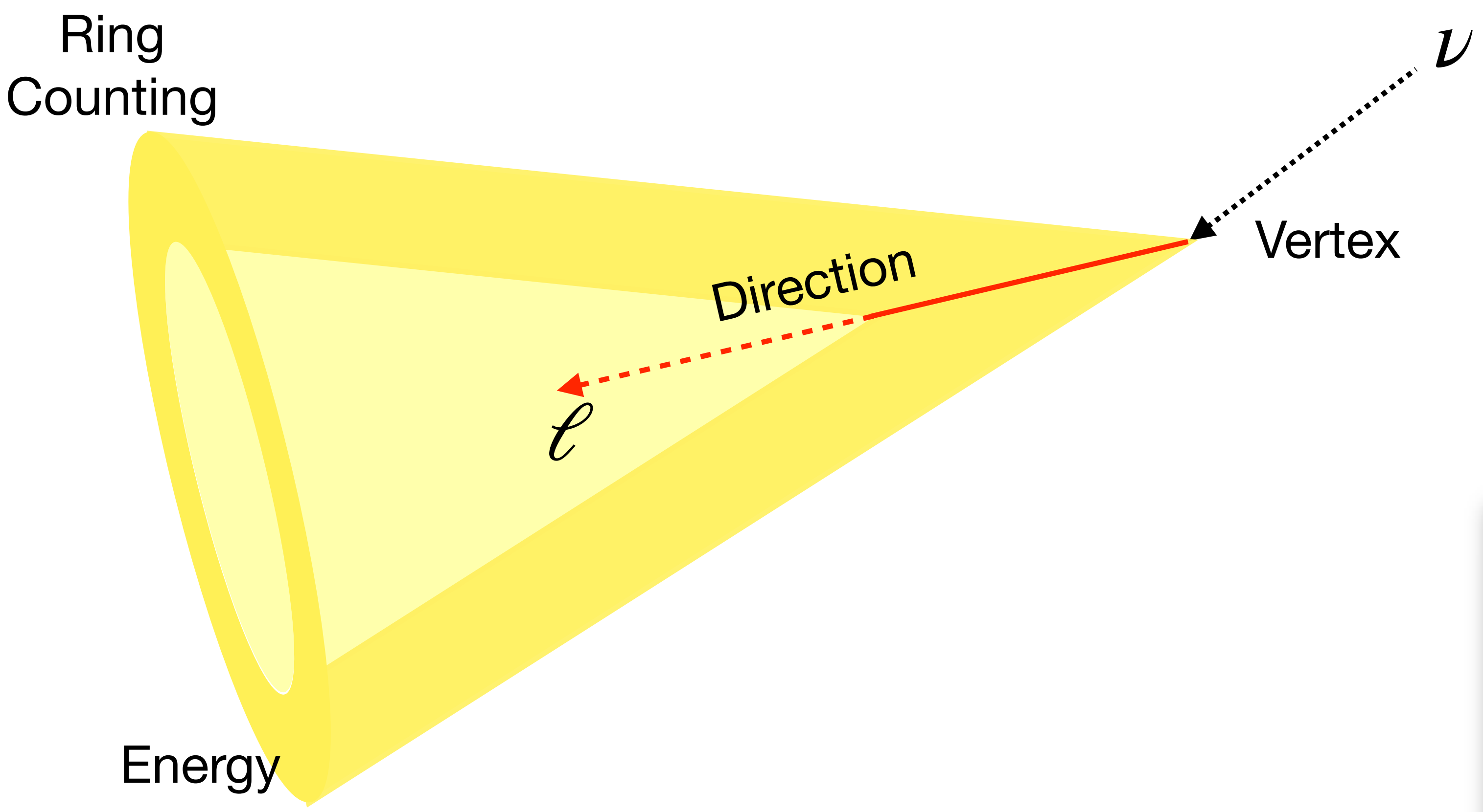
Particle Identification (e, μ)

False Identification: ?

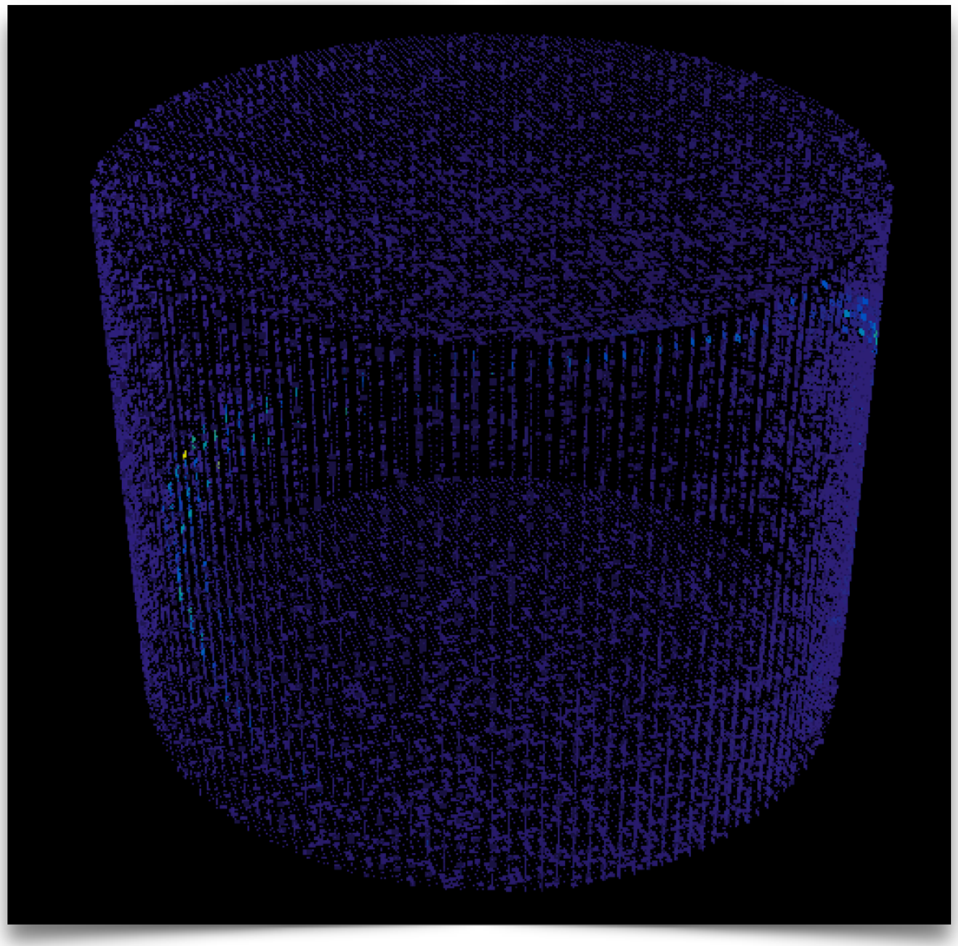
vertex away from the wall



To be explored



PointNet (point cloud NN) appears to be suitable for 3D detector geometries, each point representing a PMT with (Q, t).



Summary

- KNO is proposed for a large scale water Cherenkov neutrino detector.
- Machine learning for particle identification has shown a lot of potential.
- There are a lot of work to be done in event reconstruction with machine learning.