Partially contained samples in the Super-Kamiokande atmospheric neutrino oscillation analyses

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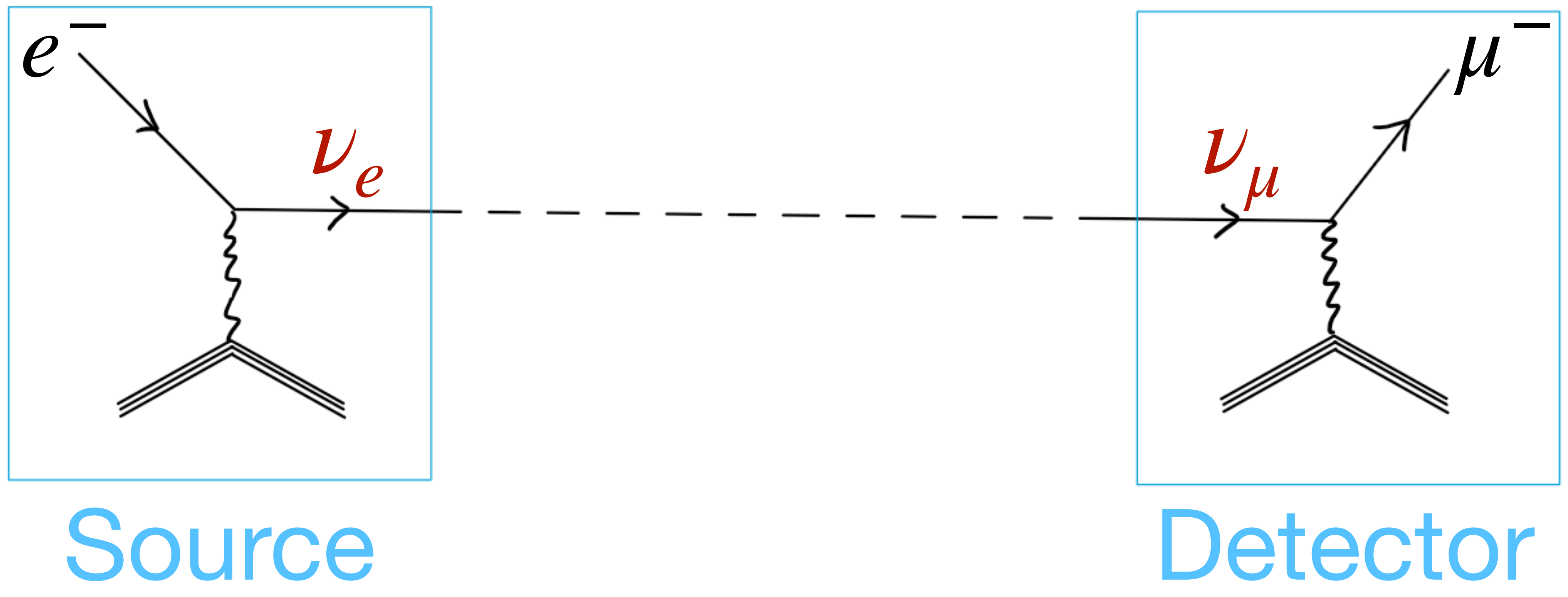
Atmospheric neutrino oscillation analyses

Neutrinos are massless in the Standard Model, but …



multiple experiments have observed neutrino oscillations.

↓

Neutrinos are not massless and the mass basis is not the same as the flavor basis:

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = U_{PMNS} \begin{bmatrix} \nu_{m_1} \\ \nu_{m_2} \\ \nu_{m_3} \end{bmatrix}$$

Atmospheric neutrinos: produced when cosmic ray particles collide with atomic nuclei in our atmosphere.

First proof of oscillations of atmospheric neutrinos: Super-Kamiokande 1998.  /2, T. Kajita, 2015

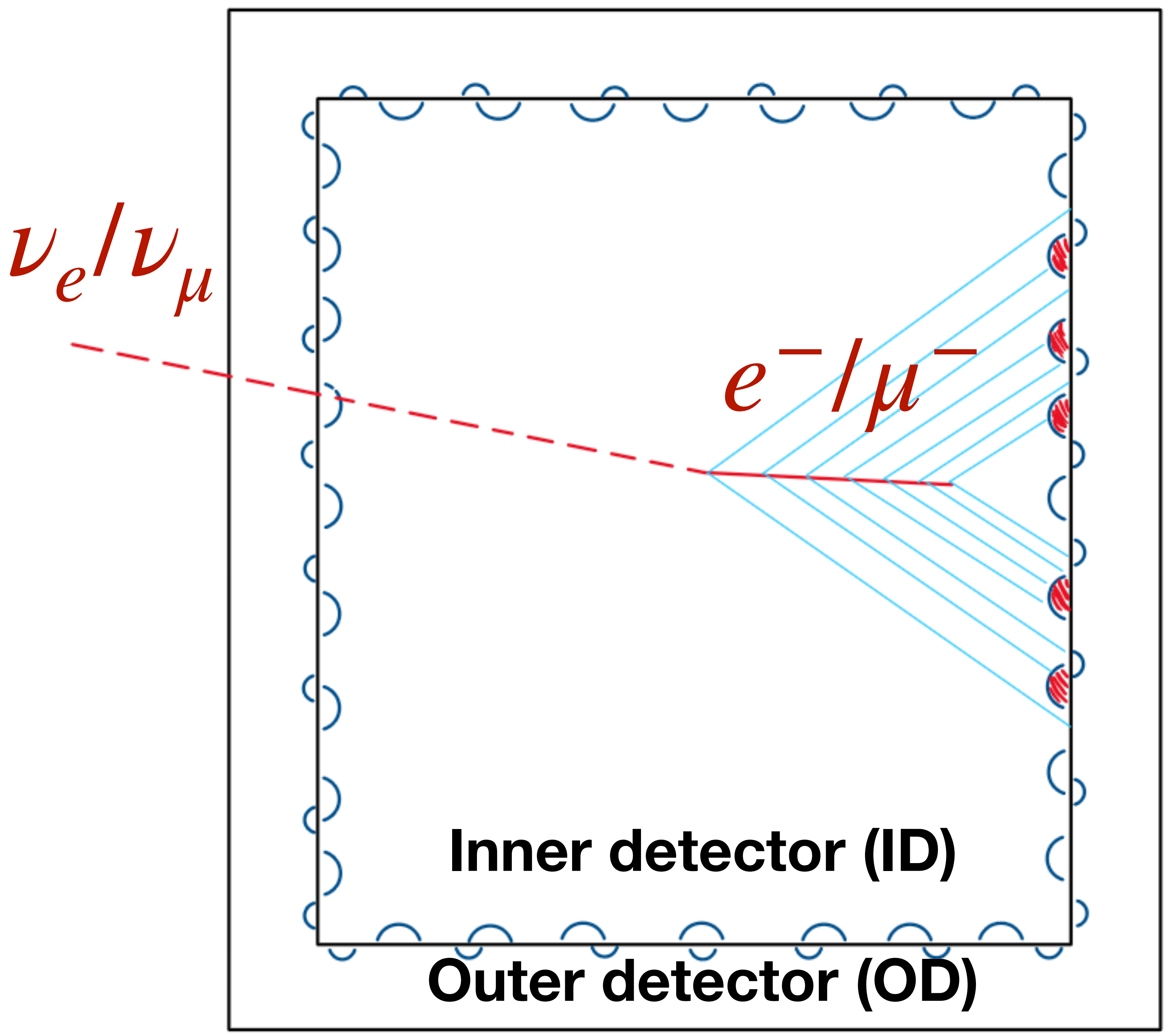
Experimental study at Super-Kamiokande is still ongoing, with more and more precise measurements of the PMNS matrix elements and neutrino masses (or rather differences between squared neutrino masses).

Super-Kamiokande detector and event topologies

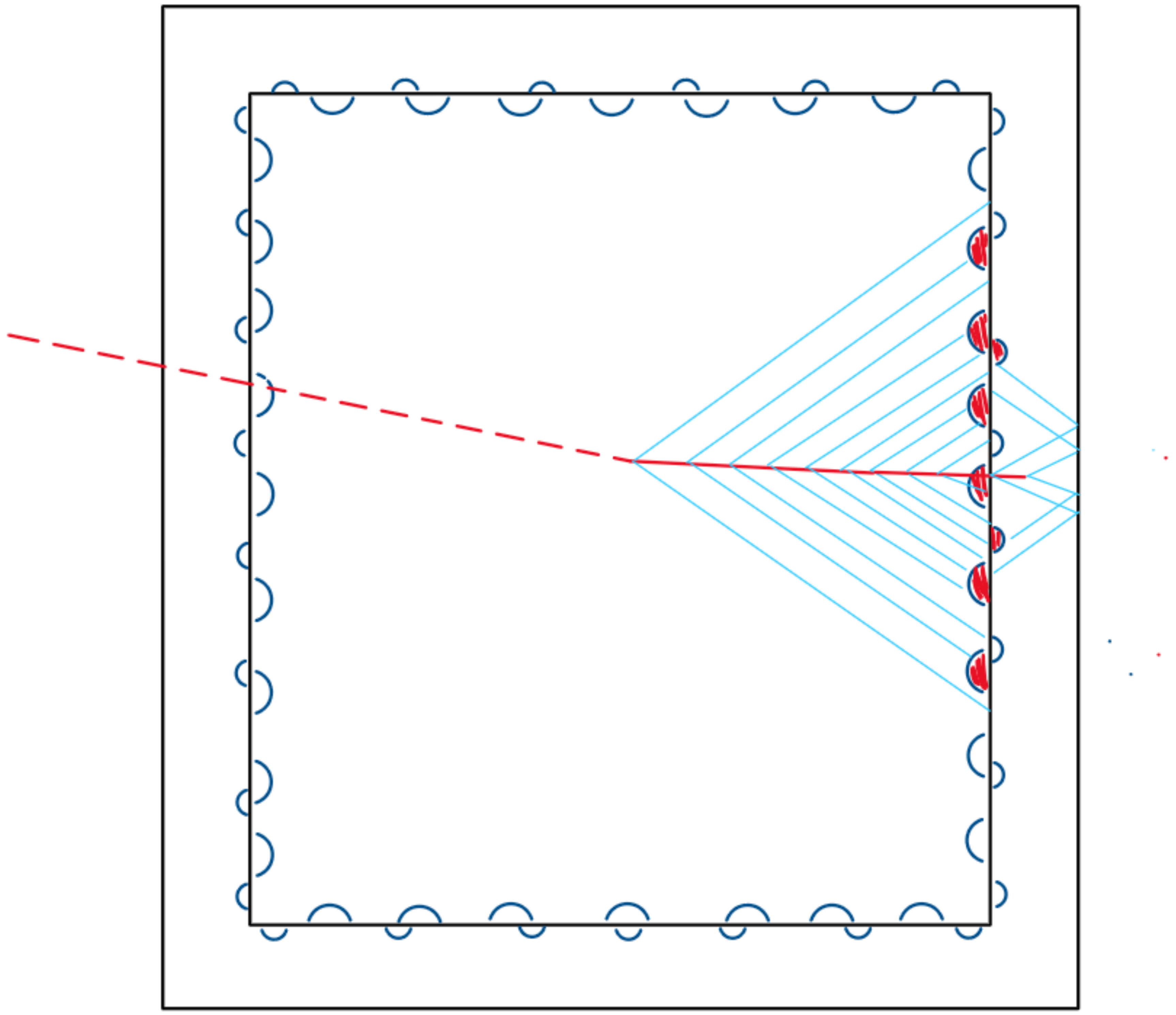
Super-Kamiokande - 50 kiloton water Cherenkov detector located in Japan.

Charged particles created in the neutrino interaction produce Cherenkov radiation, which is detected by the photomultiplier tubes (PMTs).

This information is then used to reconstruct the flavor, energy and direction of neutrino.



Fully contained (FC) event: lepton doesn't leave the ID.



Partially contained (PC) event: lepton leaves the ID and creates Cherenkov light in the OD.

Fully contained and partially contained events

Longer tracks

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Bigger neutrino energies

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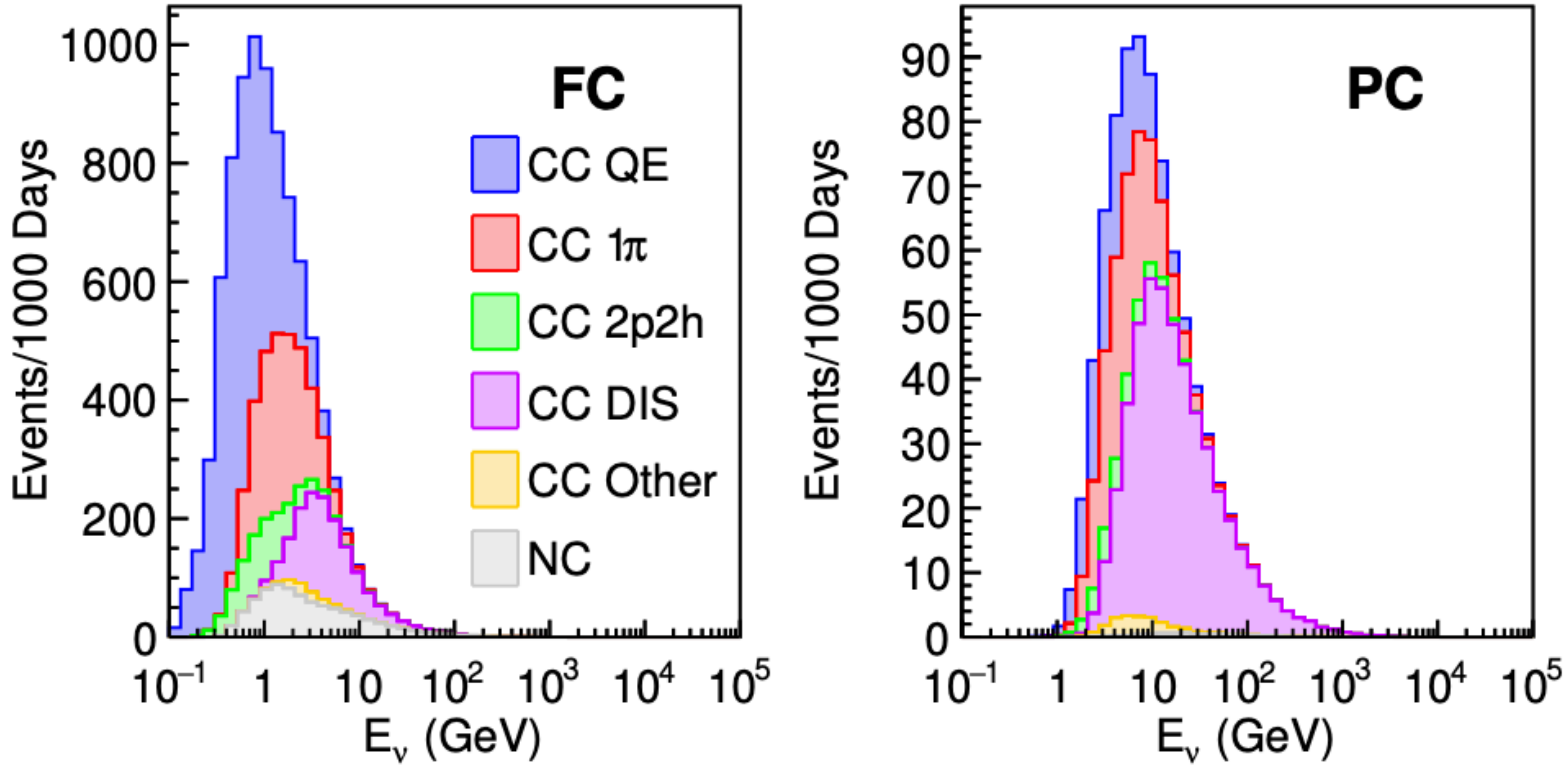
Different neutrino interactions

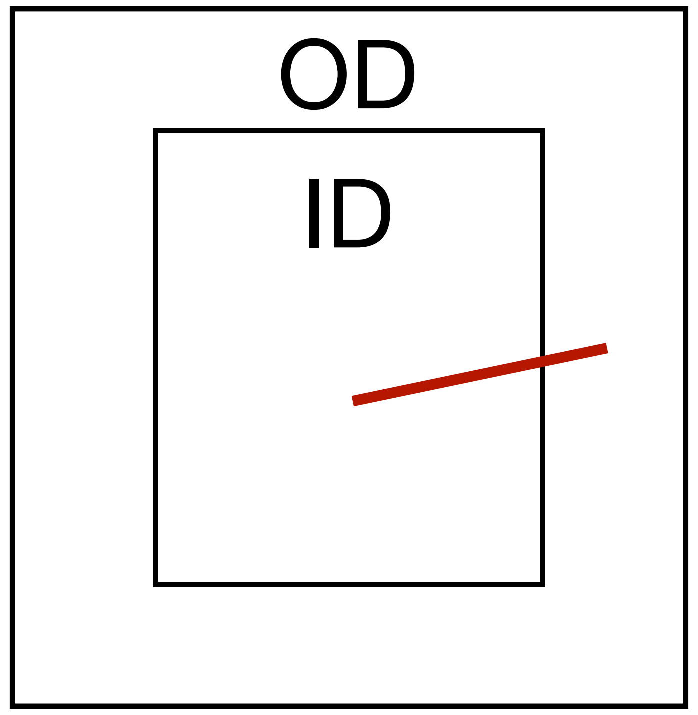


Simulated neutrino energy distributions

https://doi.org/10.1103/PhysRevLett.134.011801

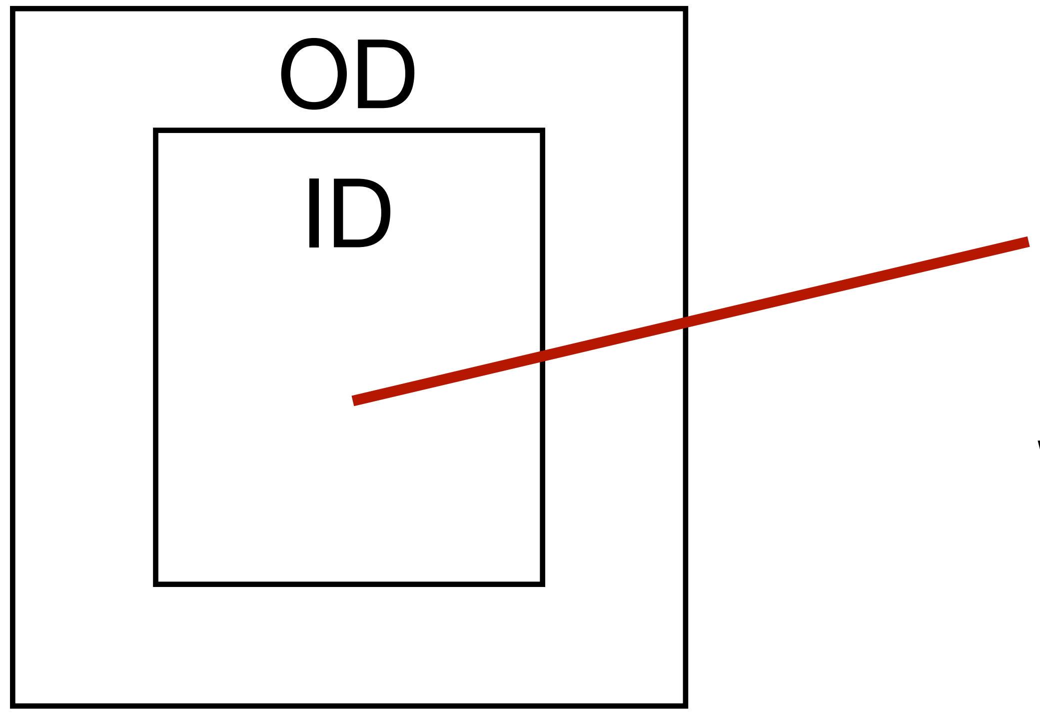
Stopping and through-going events

Lepton can stop in the OD,



PC stopping event

or it can go through the OD and leave the detector



PC through-going event

Lepton energy is unknown

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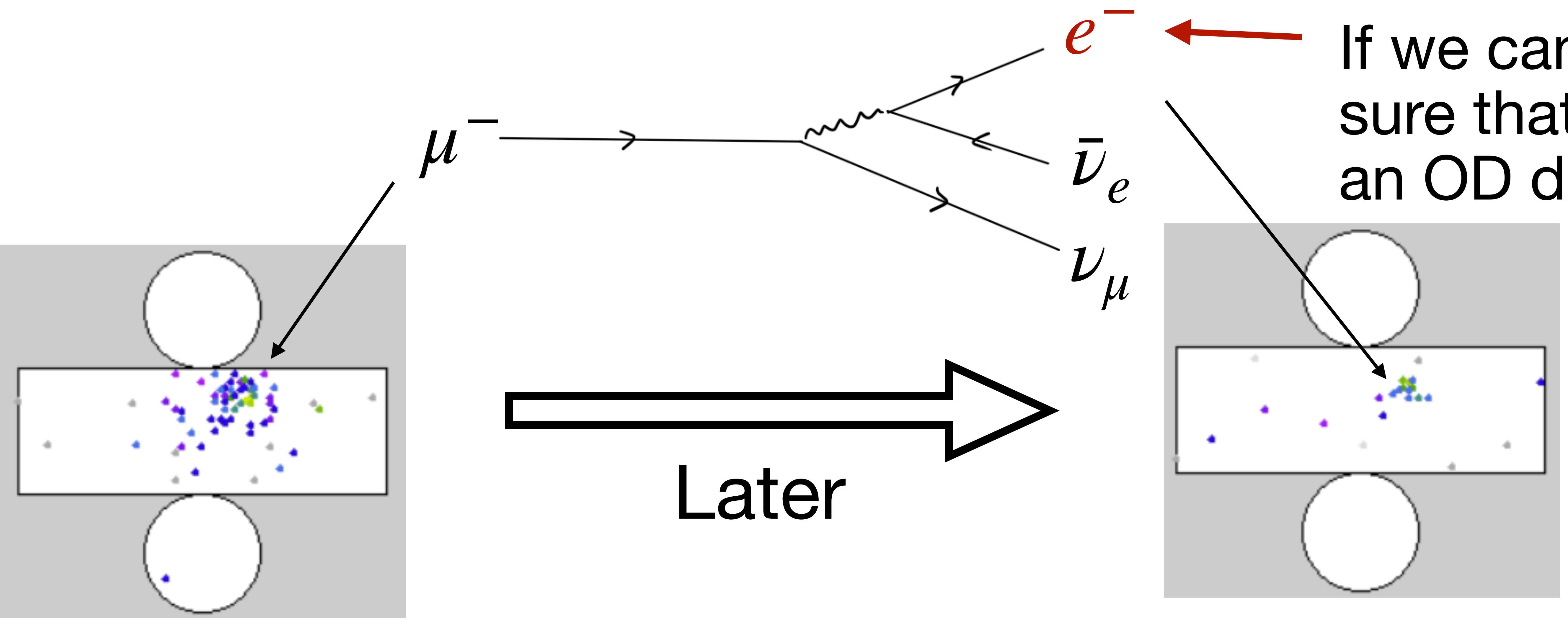
We have to separate PC events into these two classes in order to improve the energy resolution

My work: introduce new variables that are sensitive to particles leaving the OD and then use machine-learning algorithms to construct a stopping/though-going classifier.

PC stopping/through-going classifier

- Classifier uses 4 variables (they are described in the backup slides)
- One of the variables corresponds to OD decay electrons:

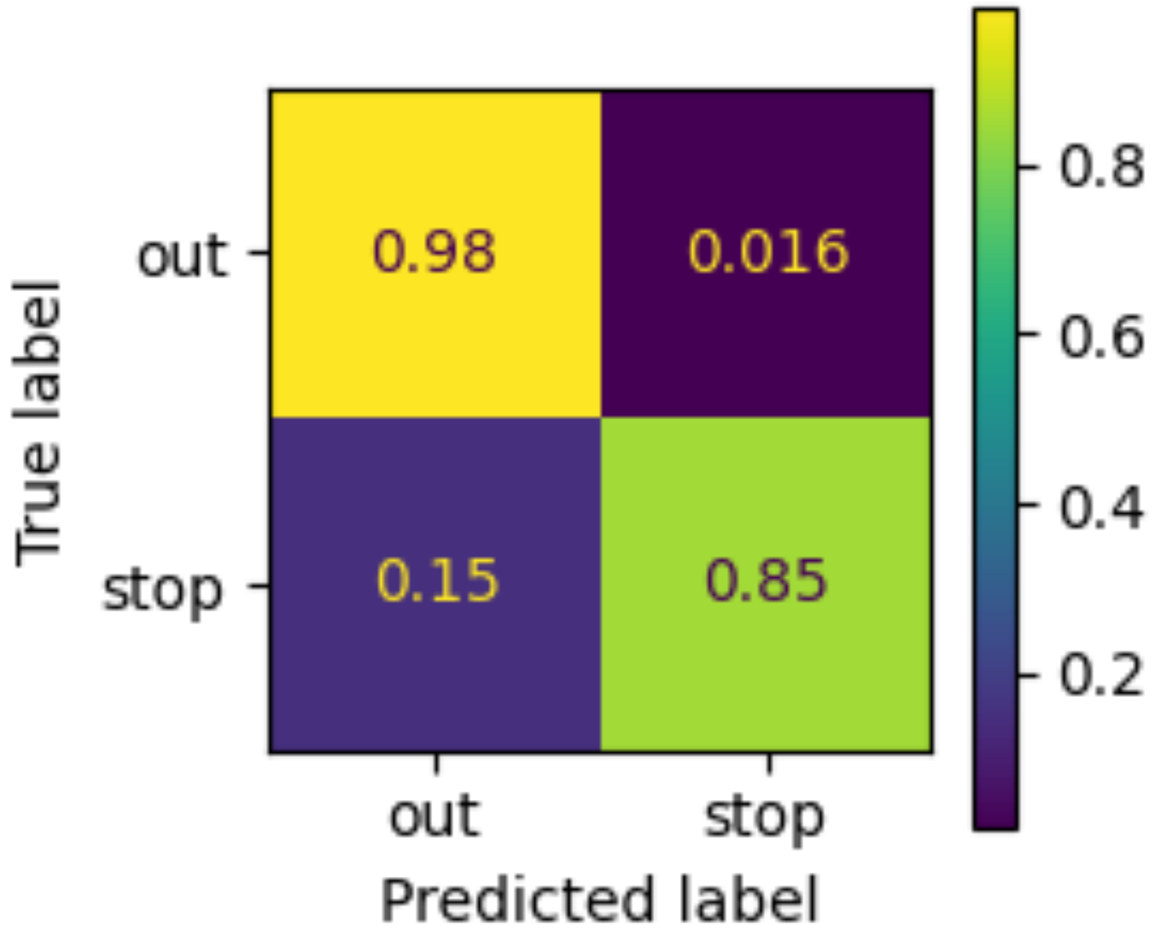


If we can identify this decay electron, then we can be sure that muon didn’t leave the detector. For this reason, an OD decay electron tagging algorithm was developed.

We look for a cluster of hit OD PMTs that is preceded by „darkness”. Additional cuts removing dark noise hits and after-pulse hits have to be applied.

- Boosted Decision Tree performs the classification

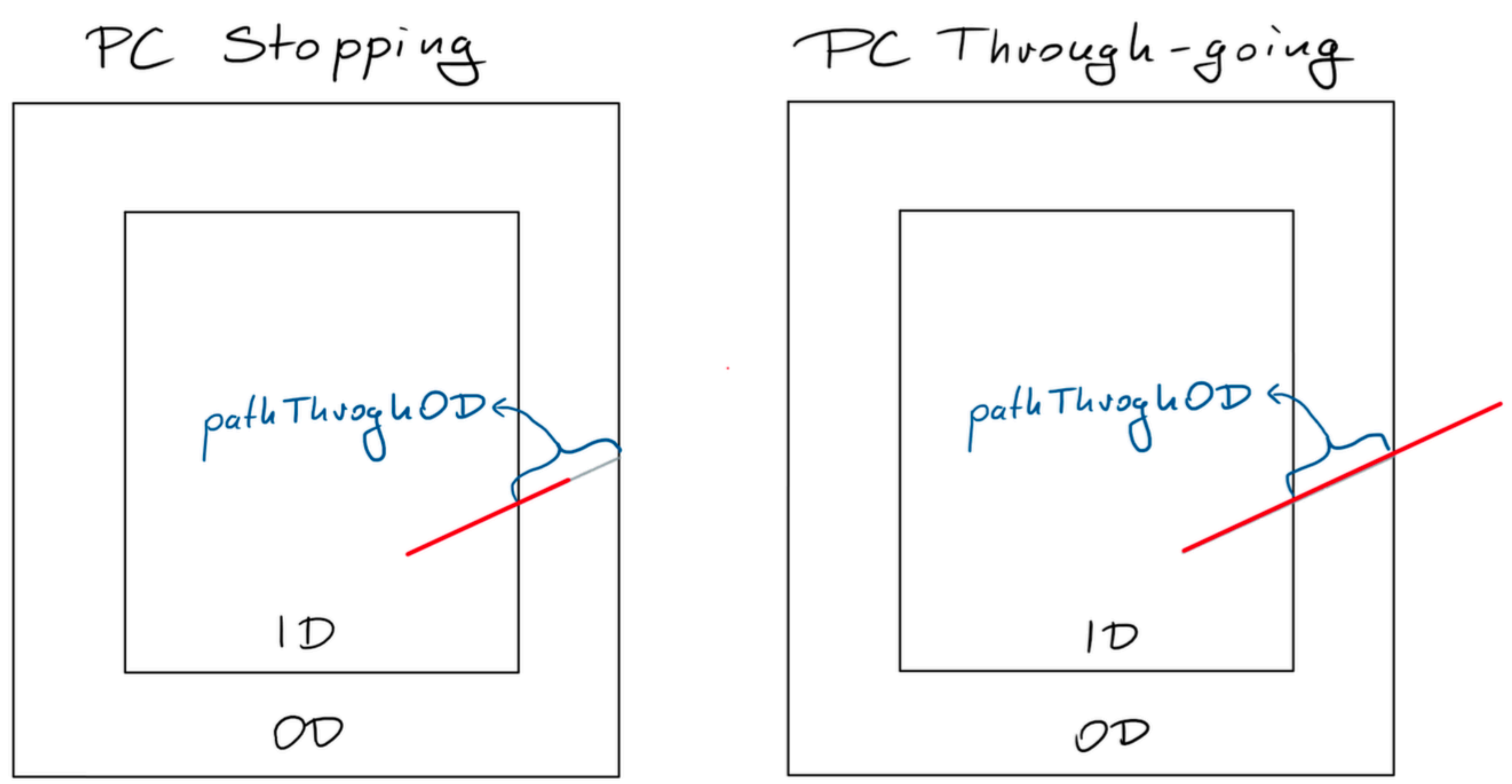
performance

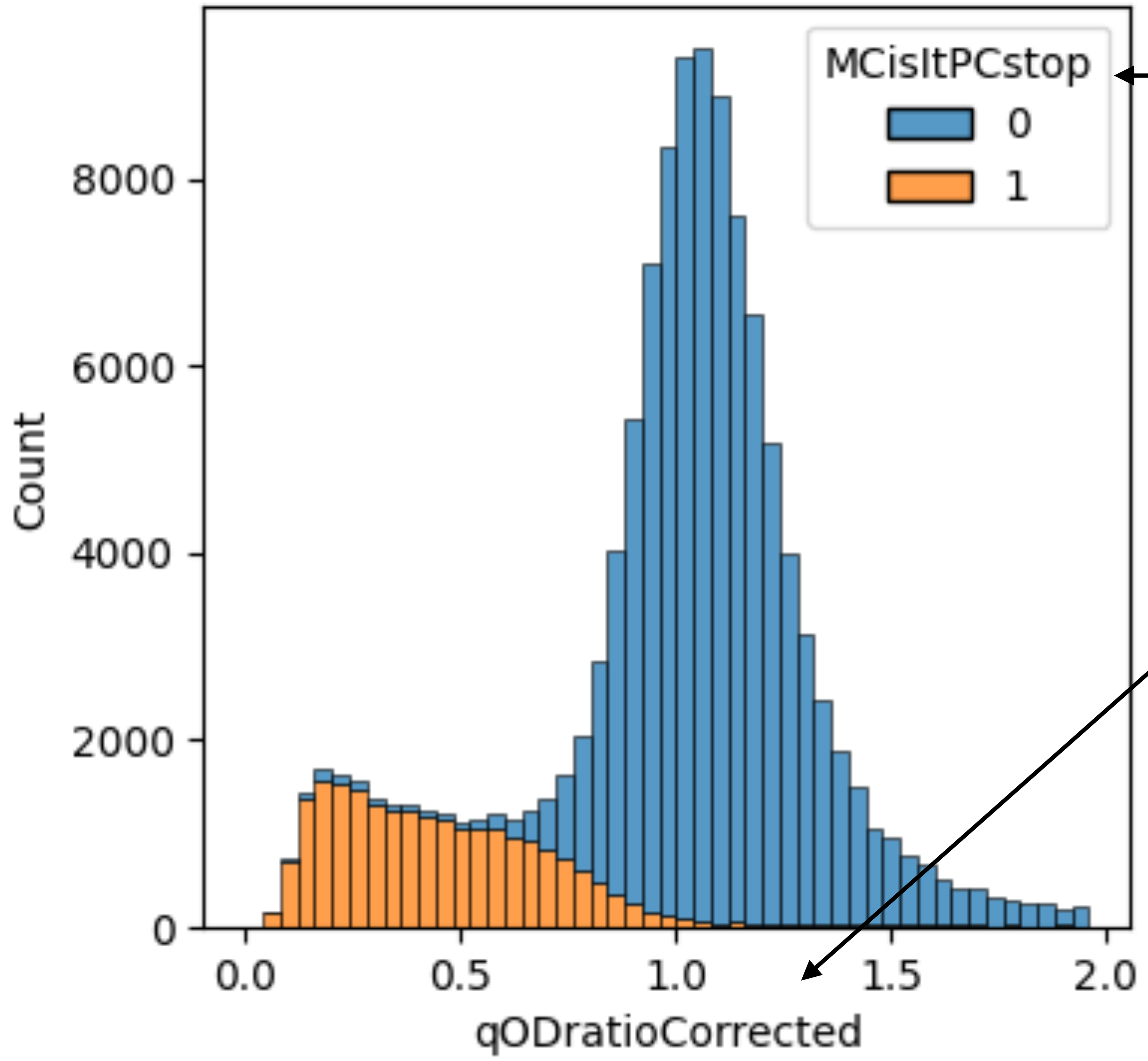


- Classifier will be used in the future atmospheric neutrino oscillation analyses

BACKUP SLIDES

Charge ratio





pathThroughOD - extrapolated path length in OD based on the reconstructed direction (we don't need to know the end point of the track in order to reconstruct it).

If a PC stopping and a PC through-going events have the same **pathThroughOD**, we expect that the PC stopping event will produce less charge in the OD.

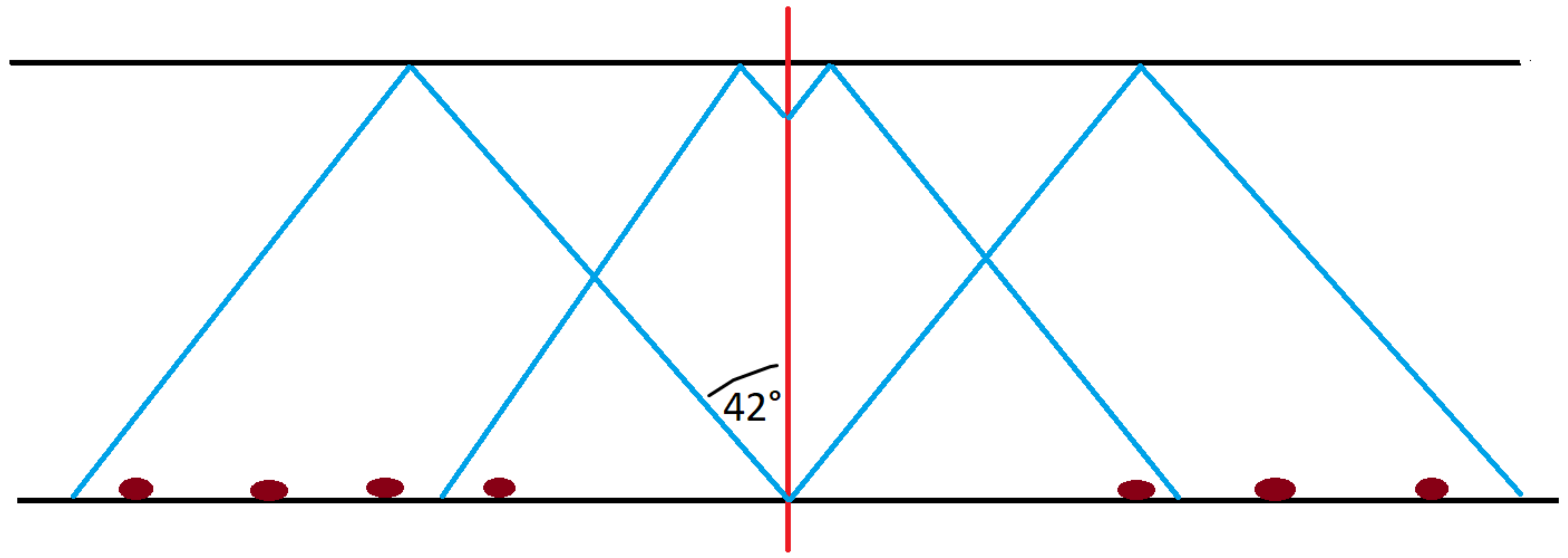
Thus, if **q_observed/pathThroughOD** is small, we suspect that it is a PC stopping event, while if it is big, we suspect that it is a PC through-going event.

MCisItPCstop = 1 for true PC stopping events and 0 for true PC through-going events

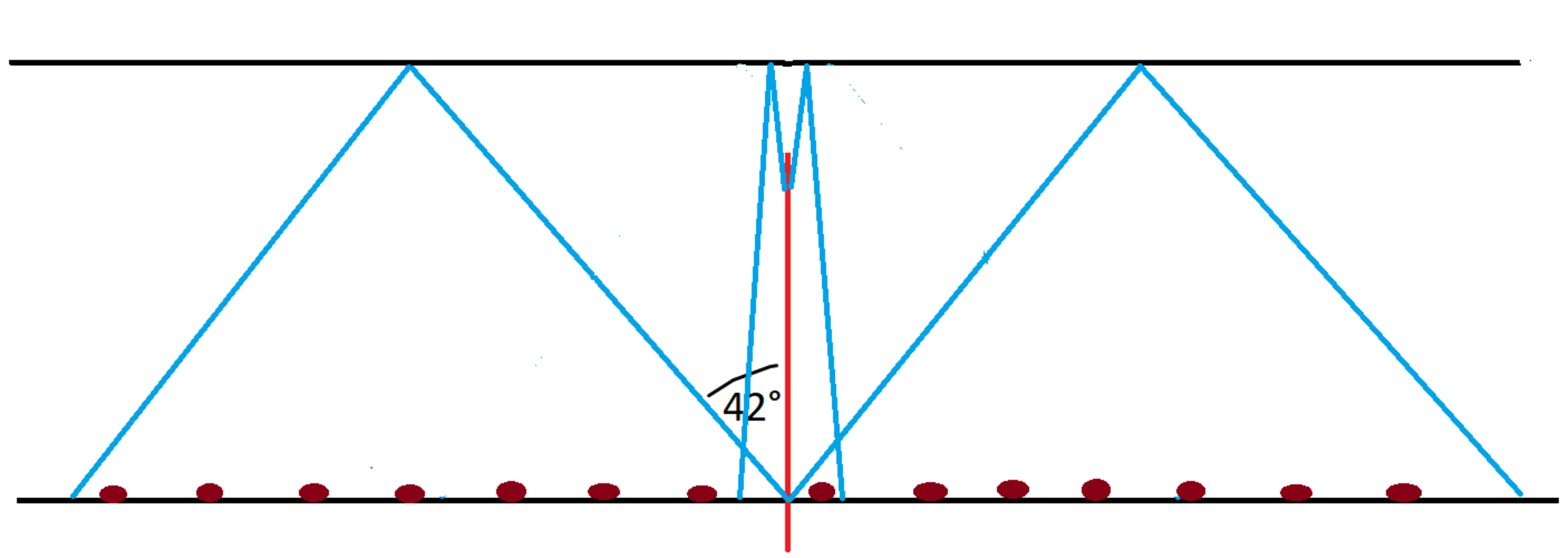
qODratioCorrected = q_observed/pathThroughOD times some **normalization factor**, which depends on the region of OD and is chosen by demanding that the mean of the distribution of **qODratioCorrected** is equal to 1.

Concentration of OD hits

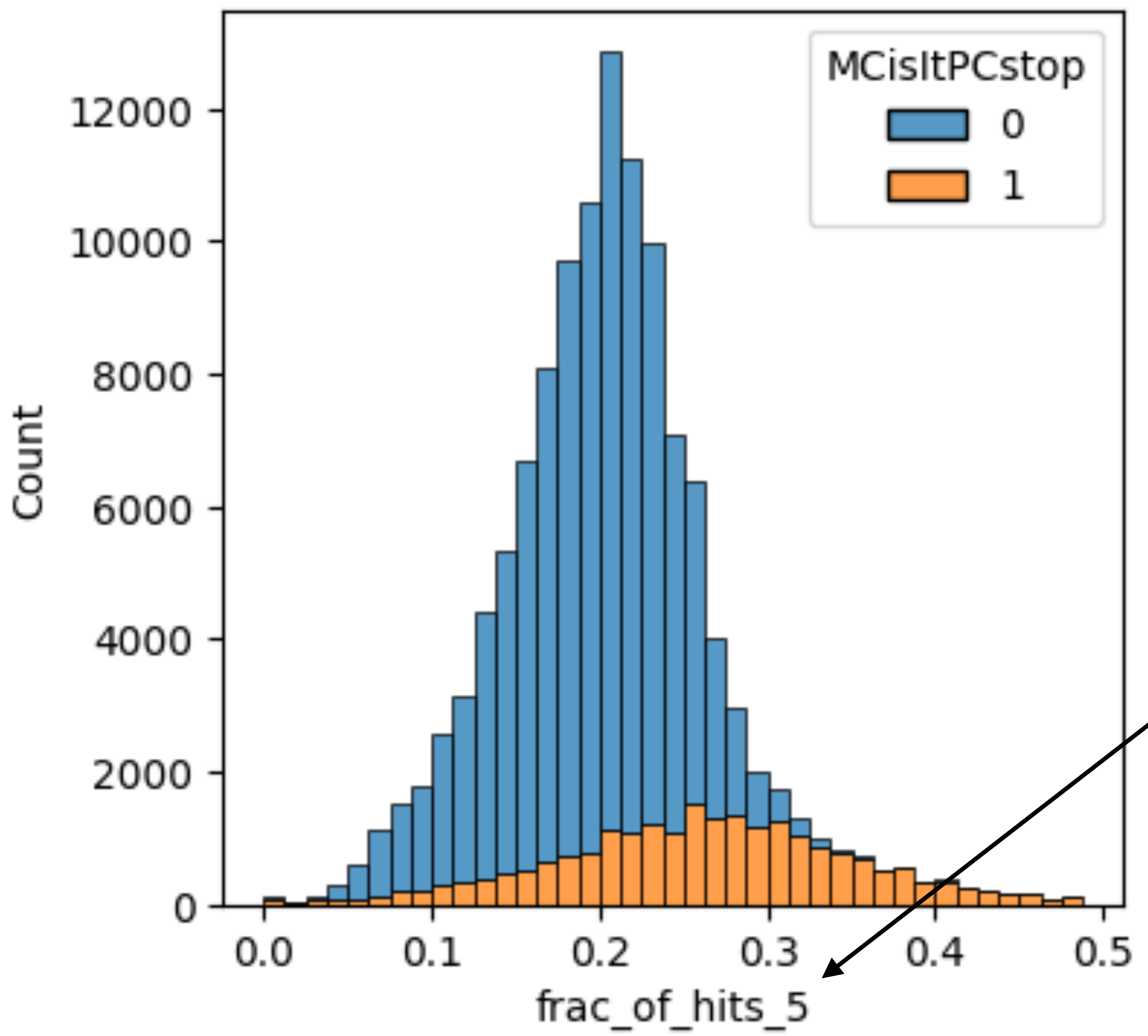
Lets consider two tracks (perpendicular to the OD wall), one through-going and one stopping:



Through-going: constant Cherenkov angle, hits should not be concentrated around OD entry



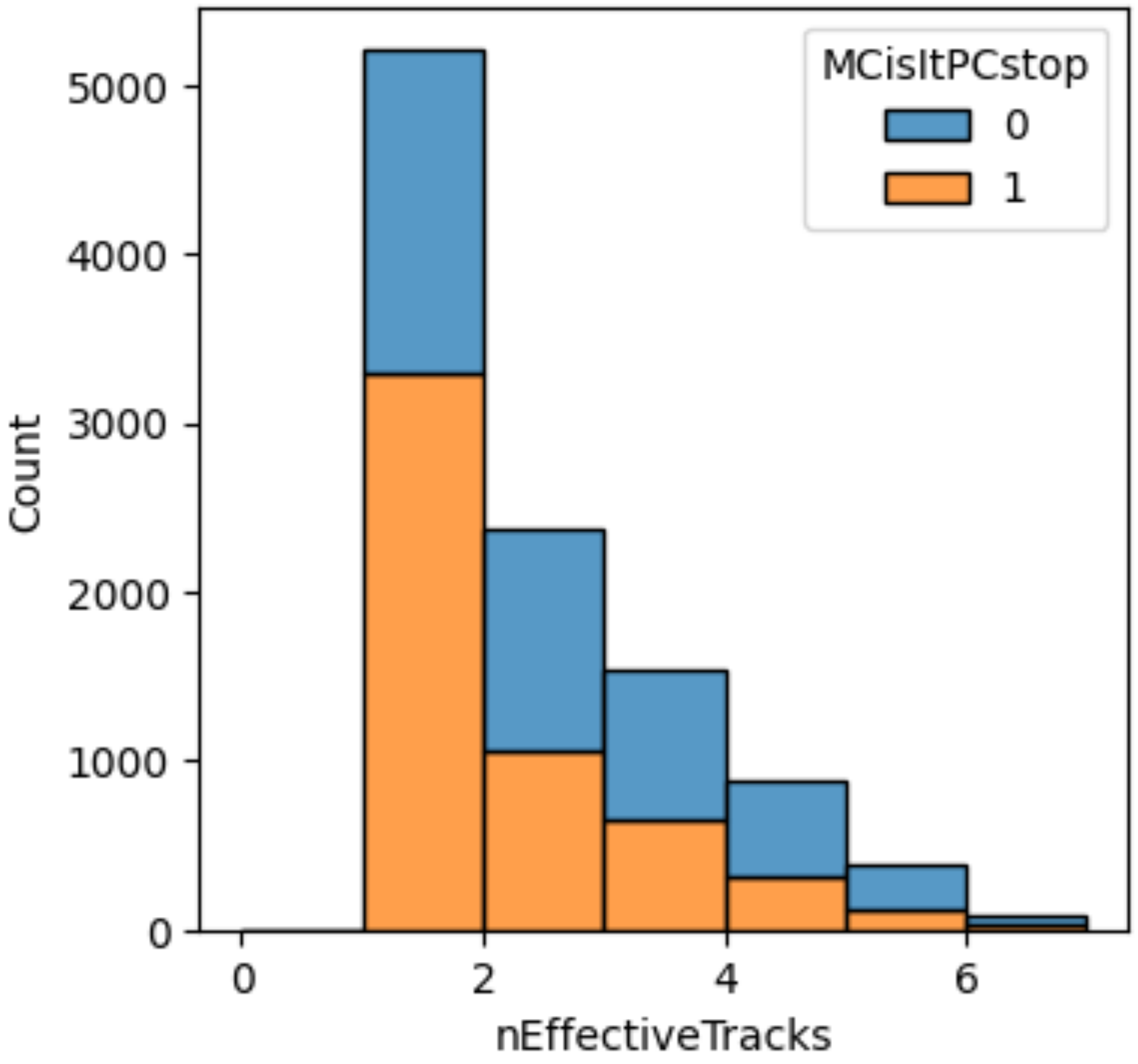
Stopping: Cherenkov angle goes to zero at the end, bigger fraction of hits around OD entry



frac_of_hits_5 = fraction of OD hits with distance from the OD entry < 5m

nEffectiveTracks

nEffectiveTracks = number of Cherenkov rings (+1 if we identify overlapping rings). PC stopping events are created in a CCQE interaction more frequently than PC through-going events, thus they produce single ring more frequently.



For events with charge ratio $\in [0.6, 0.8]$