π^0 cross section measurement at T2K

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IOP Joint HEPP and APP Meeting
3 April 2012

Queen Mary
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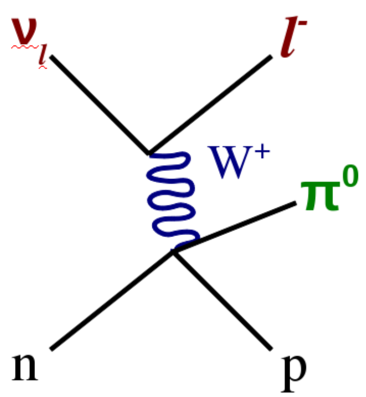
Outline

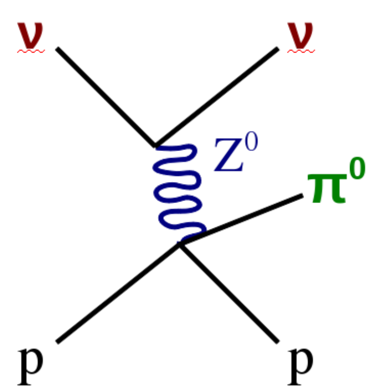
1. π^0 Cross Sections Measurements at Neutrino Experiments
2. π^0 at the T2K Experiment
3. π^0 with the P0D
4. π^0 with the P0DECal

π^0 at ν Experiments

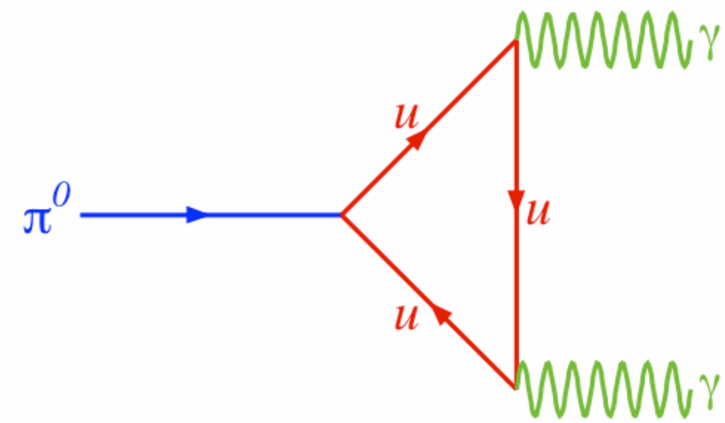
π^0 production is one of the dominating cross sections in the GeV region for neutrino experiments.



$CC\pi^0$



$NC\pi^0$



The π^0 decays producing two gammas 99% of the time. In a rest frame both γ are polarised but in a boosted frame the energies of each of these gammas can vary.

Showering gammas constitute a background for neutrino search in both disappearance and appearance experiments. Knowing the cross section leads to higher precision neutrino oscillation experiments.

π^0 are also interesting as they can probe different nuclear models and effects.

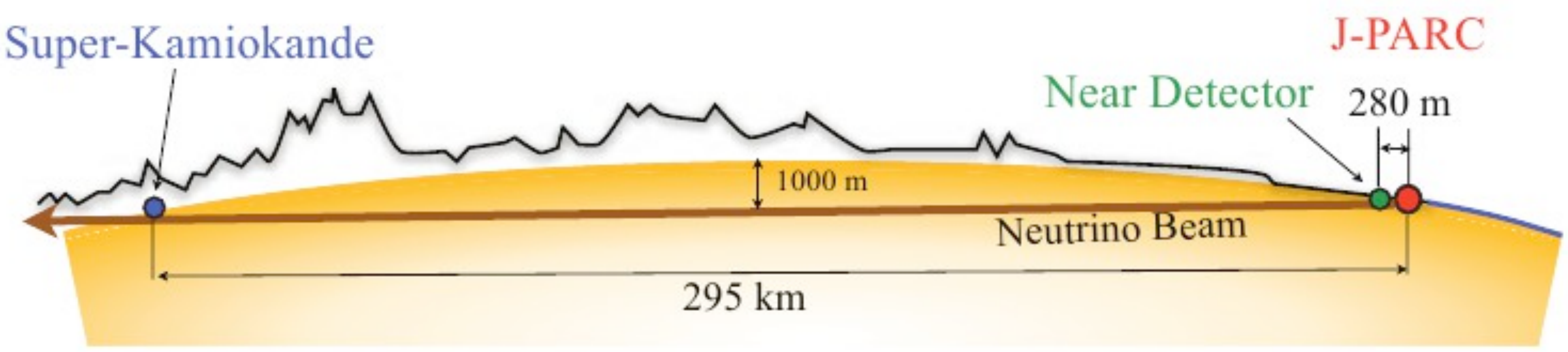
Most π^0 cross section measurements are done as a ratio to the $CC\pi^0$, only one absolute measurement from MiniBooNE experiment so far.

π^0 at T2K

★ The T2K experiment works in energy region below 2GeV where the dominant cross sections is the delta resonance reaction and coherent production (less than 20%).

Probability to measure θ_{13} is small therefore precise knowledge about the background is crucial.

θ_{13} is non zero! hence search δ_{CP} is possible and the precision of the π^0 cross section very important.



★ At the T2K π^0 are measured at at both near and far detector:

The measurement is motivated by the need to constrain the uncertainties in the background contribution of the NC1π^0 interaction to the $\nu_\mu \rightarrow \nu_e$ oscillations.

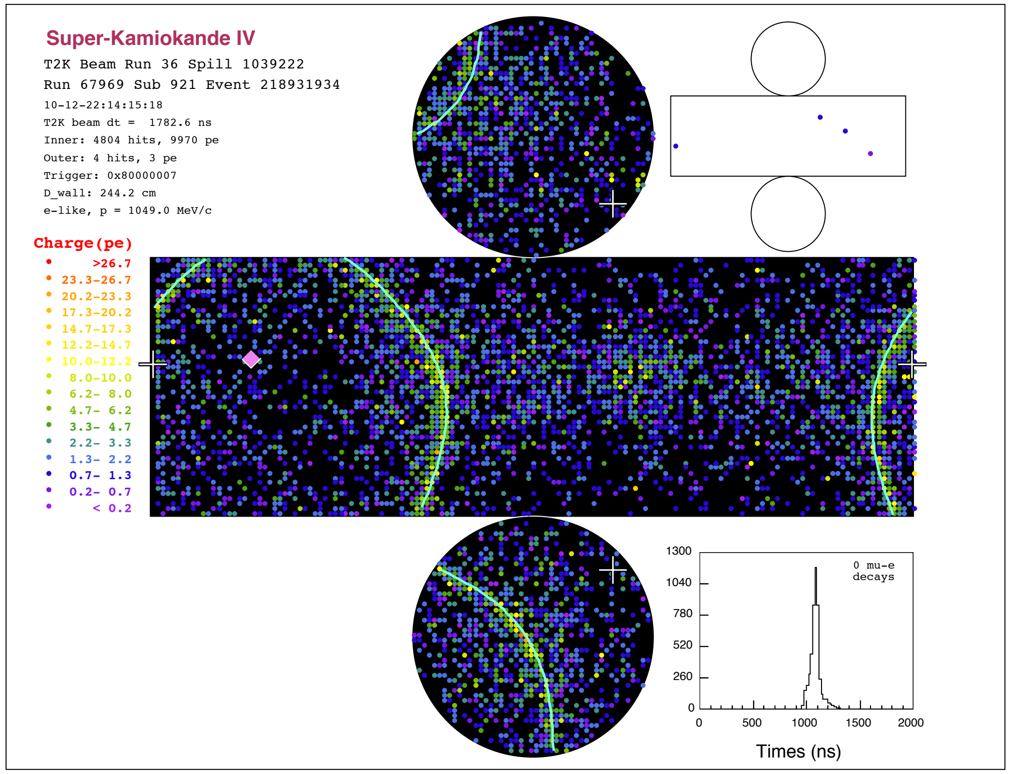
Current oscillation analysis are based on 10^{20} POT data, NEUT neutrino interactions generator.

T2K will be the first experiment to measure absolute π^0 cross section on water.

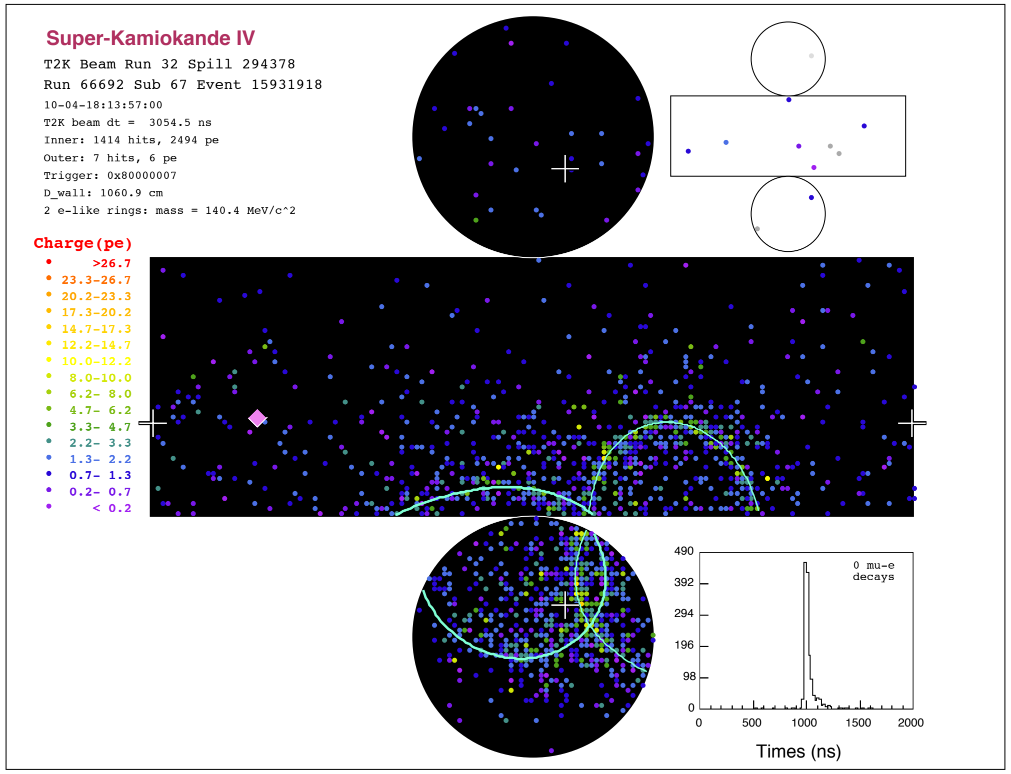
π^0 at Super-Kamiokande

NC π^0 is one of the dominant background sources at SK 34%.

CC π^0 constitutes 0.4% background at SK.



An event display of the final nue candidate event. The circle line shows the fitted Cherenkov ring. The bottom-right figure is the hit timing distribution. For more detailed information of this event.



An event display of a FCFV two-ring \pi^0 event. The invariant mass reconstructed from momenta and direction of the two gamma rings is 140MeV/c^2.

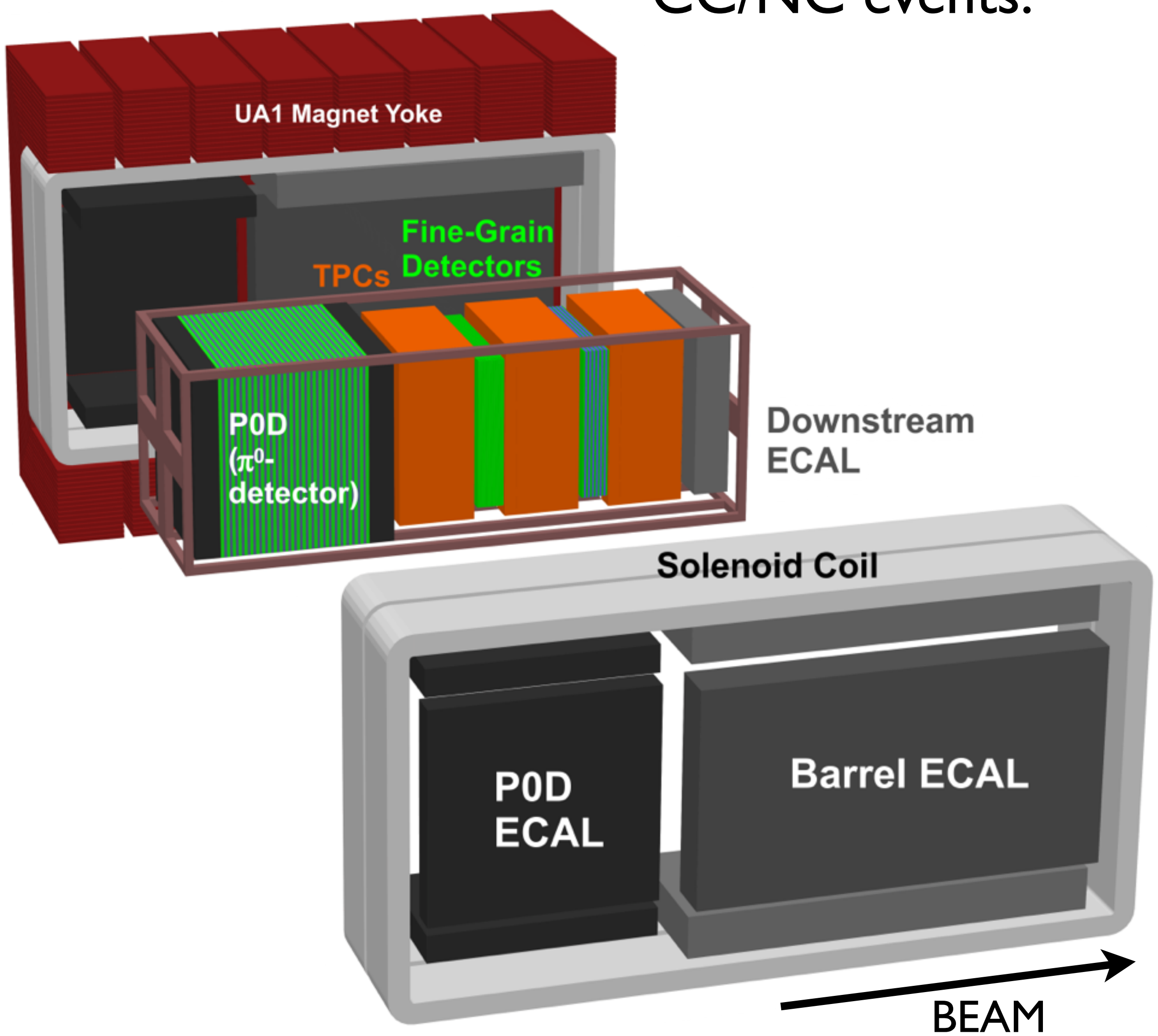
π^0 at the near detector ND280

The π^0 analysis is performed in two regions :

P0D and Tracker

- The **P0D** is π^0 the detector dedicated to measure NC π^0 and CC π^0 channels
- It is composed of alternating water target and scintillator layers
- Will take data with water in and water out to determine inclusive and exclusive π^0 cross section on ^{16}O
- P0D is surrounded by 6 ECal modules constructed with alternating scintillator and Pb foil
- ECAL is UK built.

The **Tracker** is designed for charged current analysis and good discrimination of CC/NC events.



π^0 at the P0D sub detector

P0D - π^0 detector

- The P0D working group developed a **reconstruction package directed to deduce π^0** properties from two showering gammas.
- The event selection criteria to **enhance the invariant mass** distribution. PID still under development.
- The reconstruction accounts for **multiple interactions** in a given beam spill.

Currently analysed data and simulations are made for P0D filled with water and without water.

Charged Current

CC π^0 is studied only as a background.
The most recent results of the CC1π^0 selection show:

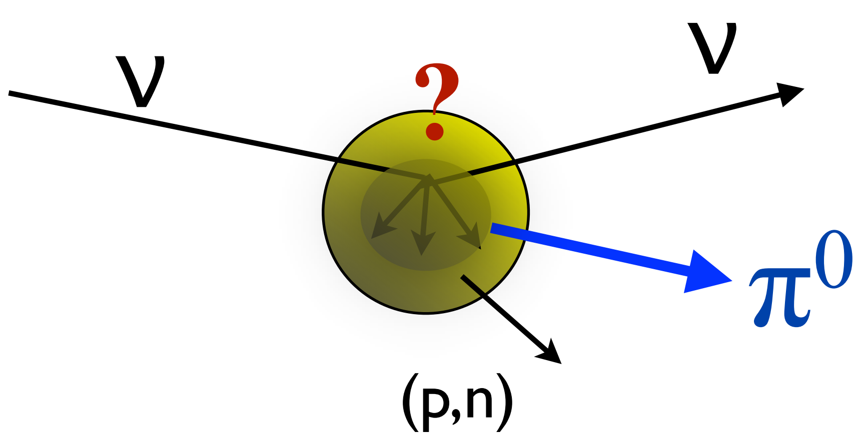
efficiency ~4% & purity ~26% (Analysis under development).

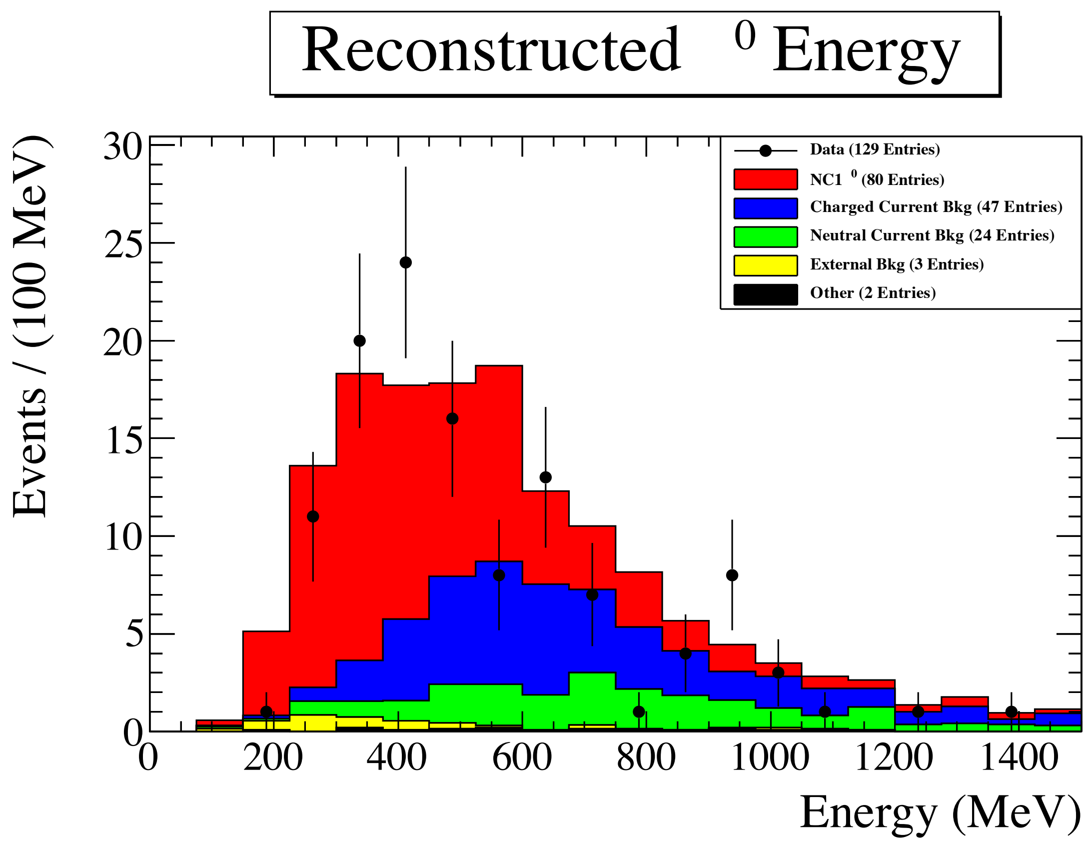
π^0 at P0D

Neutral Current

The **SIGNAL** of the NC1π^0 interaction is based on the presence of particles after the final state interactions:

- no charged leptons,
- no charged mesons, other than π^0 leaving nucleus,
- any number of protons or neutrons is allowed





BACKGROUND

- charged current events with charged lepton in final state
- neutral current other than NC1π^0,
- external background (events from outside P0D)
- other eg. multiple vertices

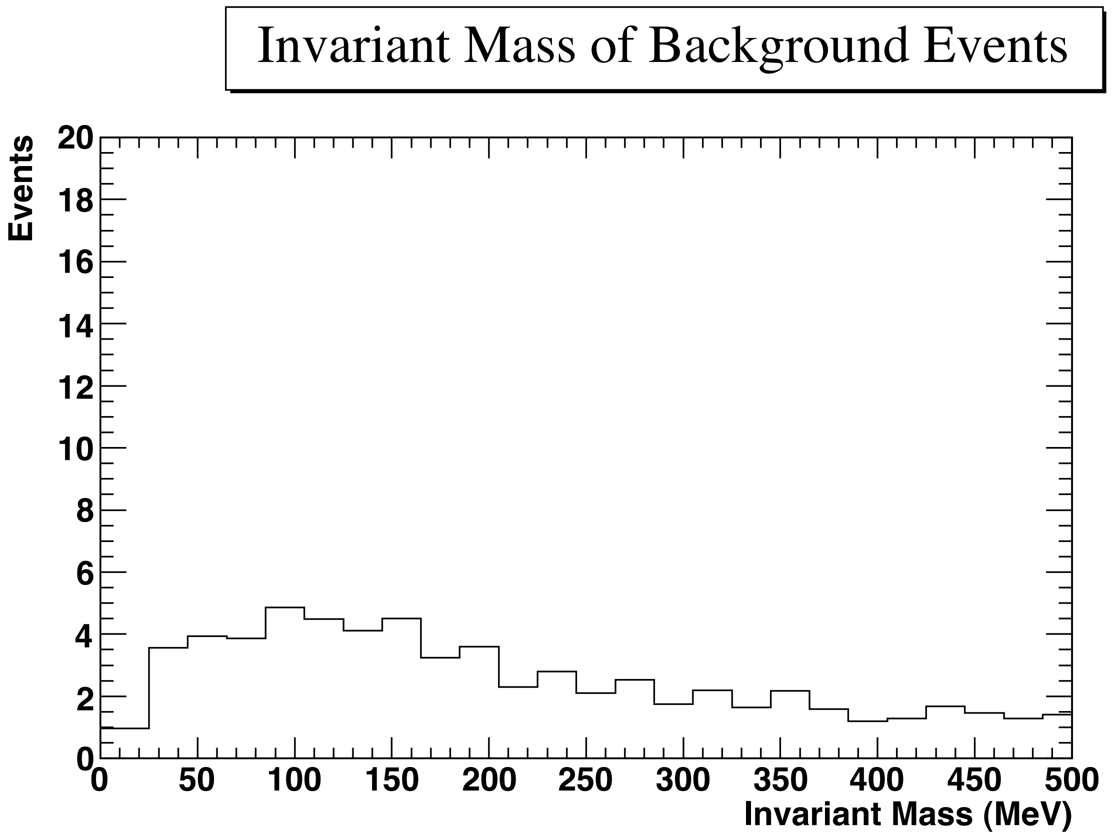
NC1π^0 at the P0D

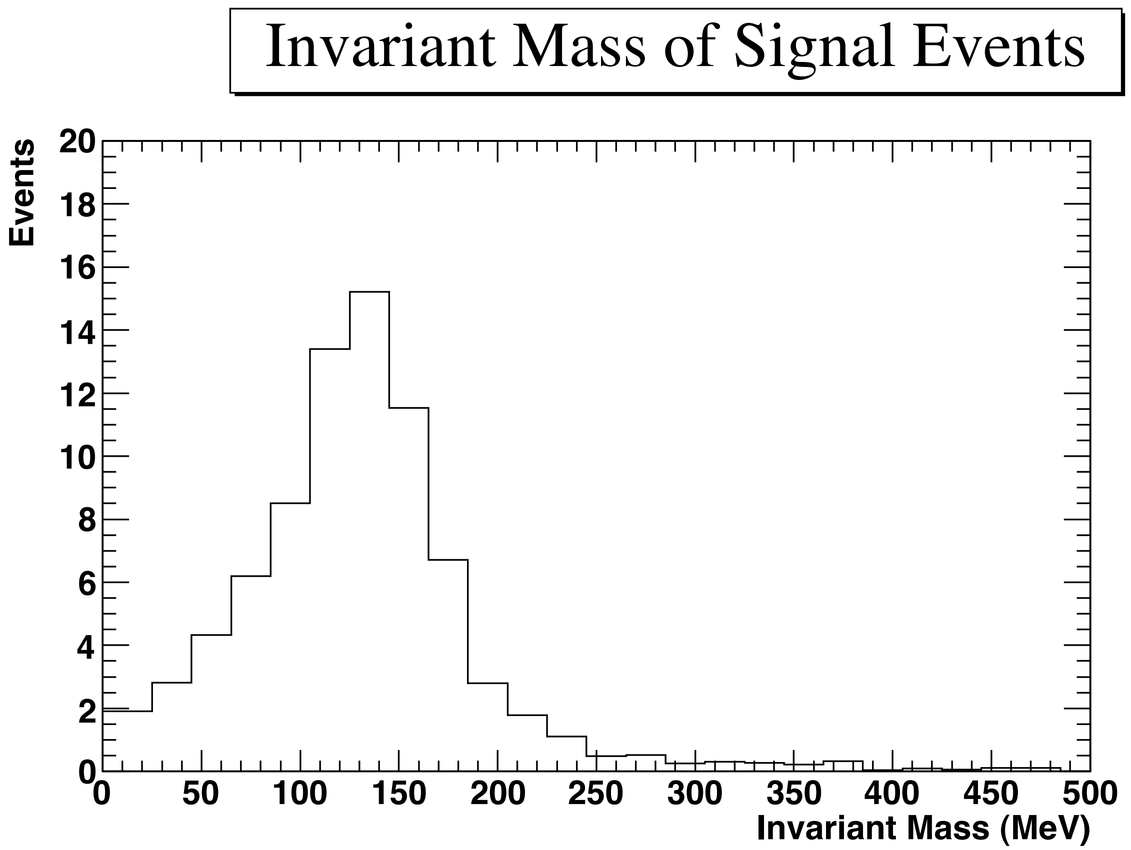
The currently measured ratio of NC1 π^0 data events compared to the number predicted by the Monte Carlo is:

0.84±0.16(stat) [66±13 observed, 79±2 expected]

normalised to the CCπ^0 inclusive measurement in tracker: **0.81±0.13** (stat)±0.17(syst)

Future: water in and water out analysis, preliminary studies show that the water out invariant mass peak can be reconstructed using identical event selection (cuts), more water out data needed - is taken at the moment





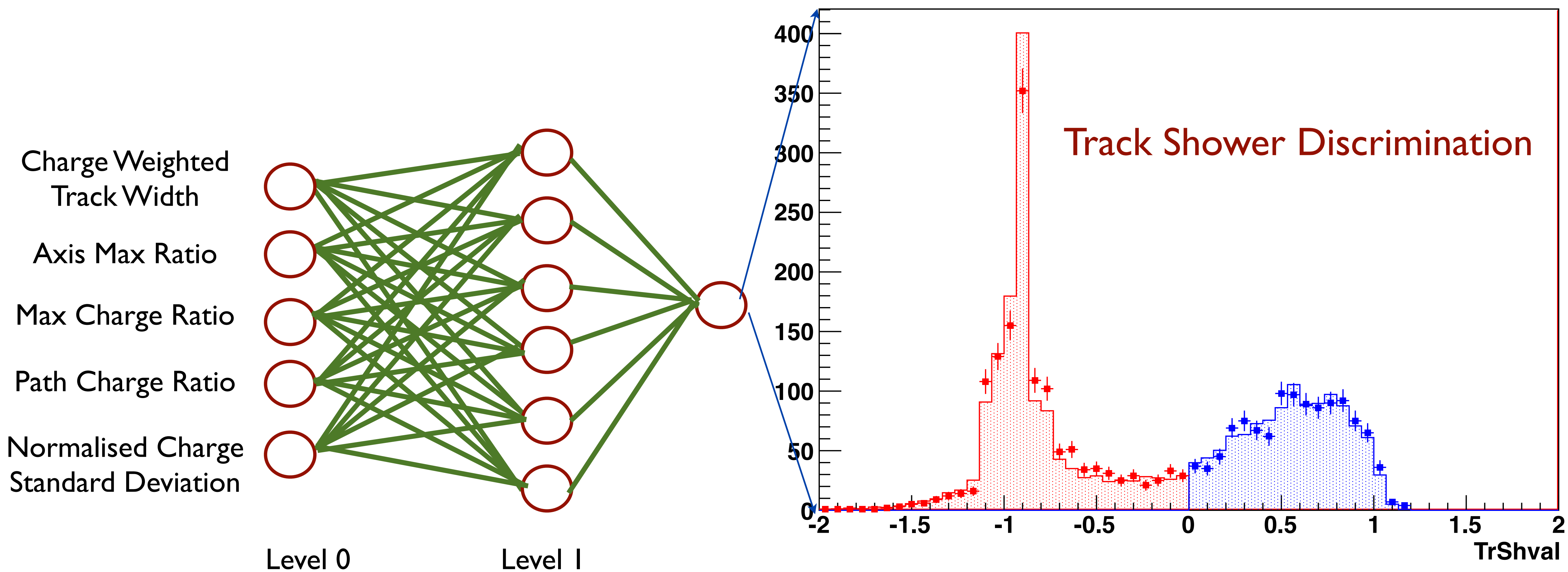
P0DECal Reconstruction

Designed to increase the statistics and to reduce the systematic errors for the standalone P0D:

- Convert non-showering gammas escaping from the P0D
- Detect partially escaping gamma showers
- Veto for cosmic rays

P0DEcal Reconstruction:

- Clustering nearest neighbour hits
- Principle Component Analysis to determine direction
- Neural Network Analysis used for Particle Identification

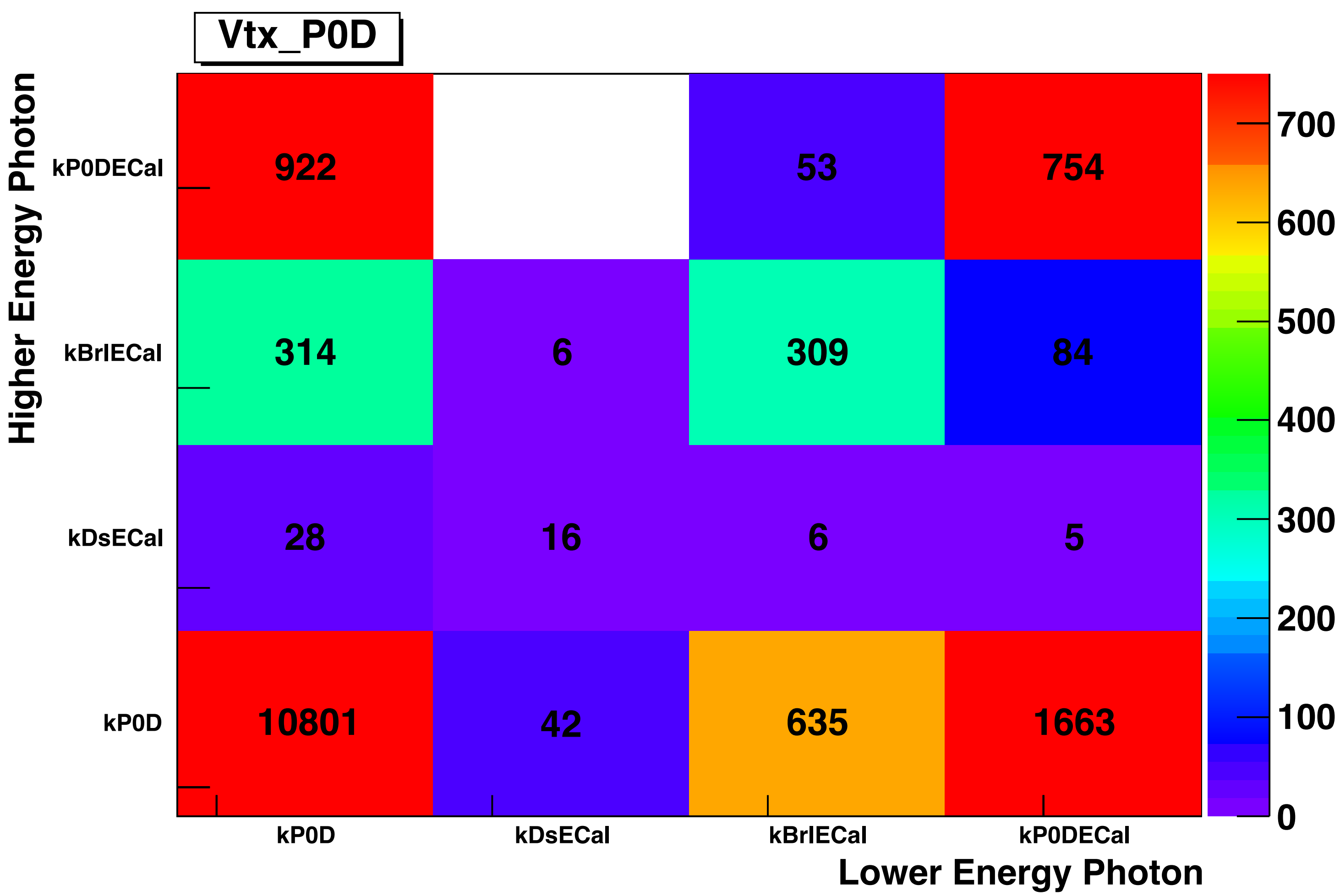


(Shape normalised)

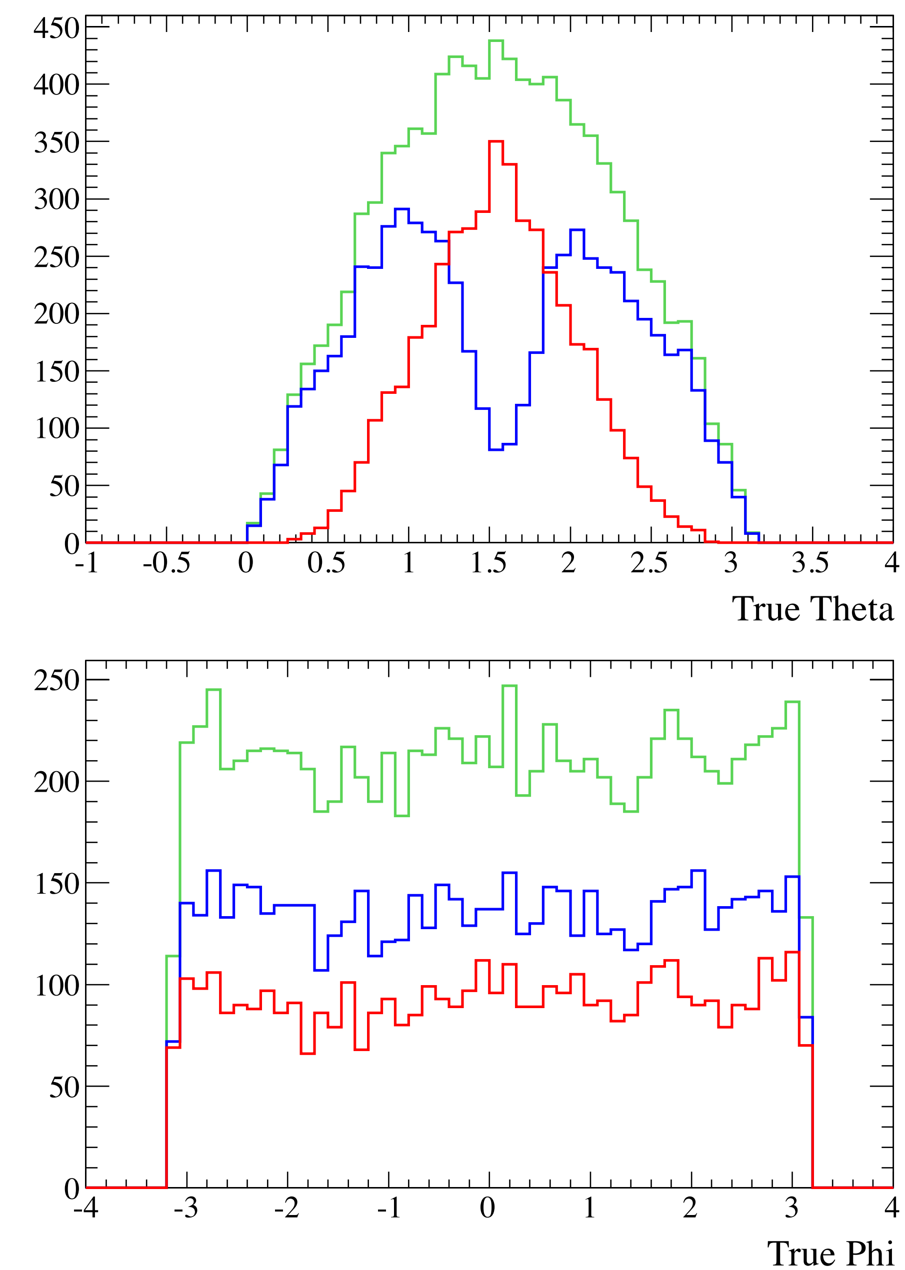
P0D+P0DECal Motivation

True MC studies of π^0 **GAMMAS** showering

in different sub detectors



TRACKS



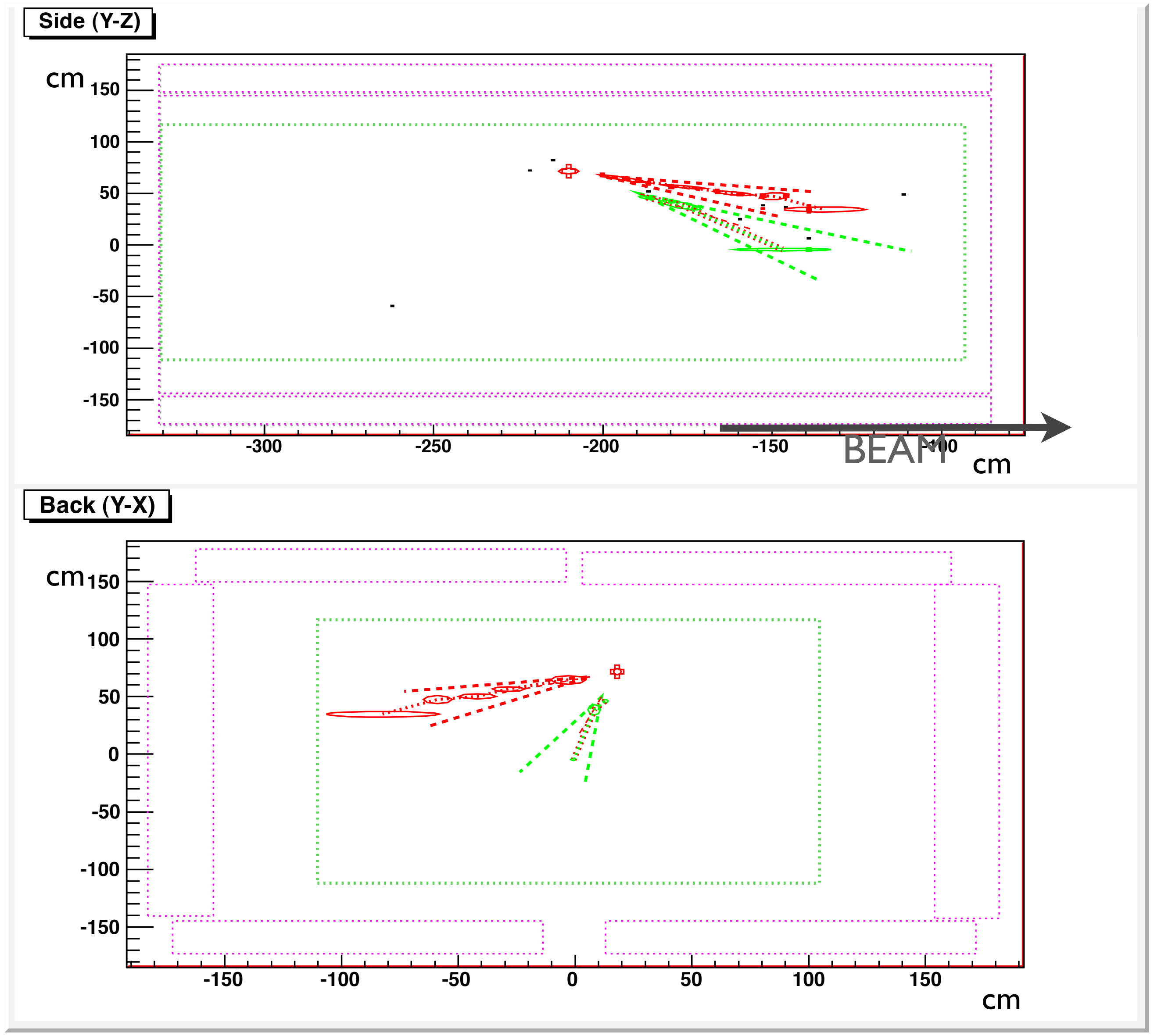
All generated muons (true vertex)

Muons reconstructed in the P0D

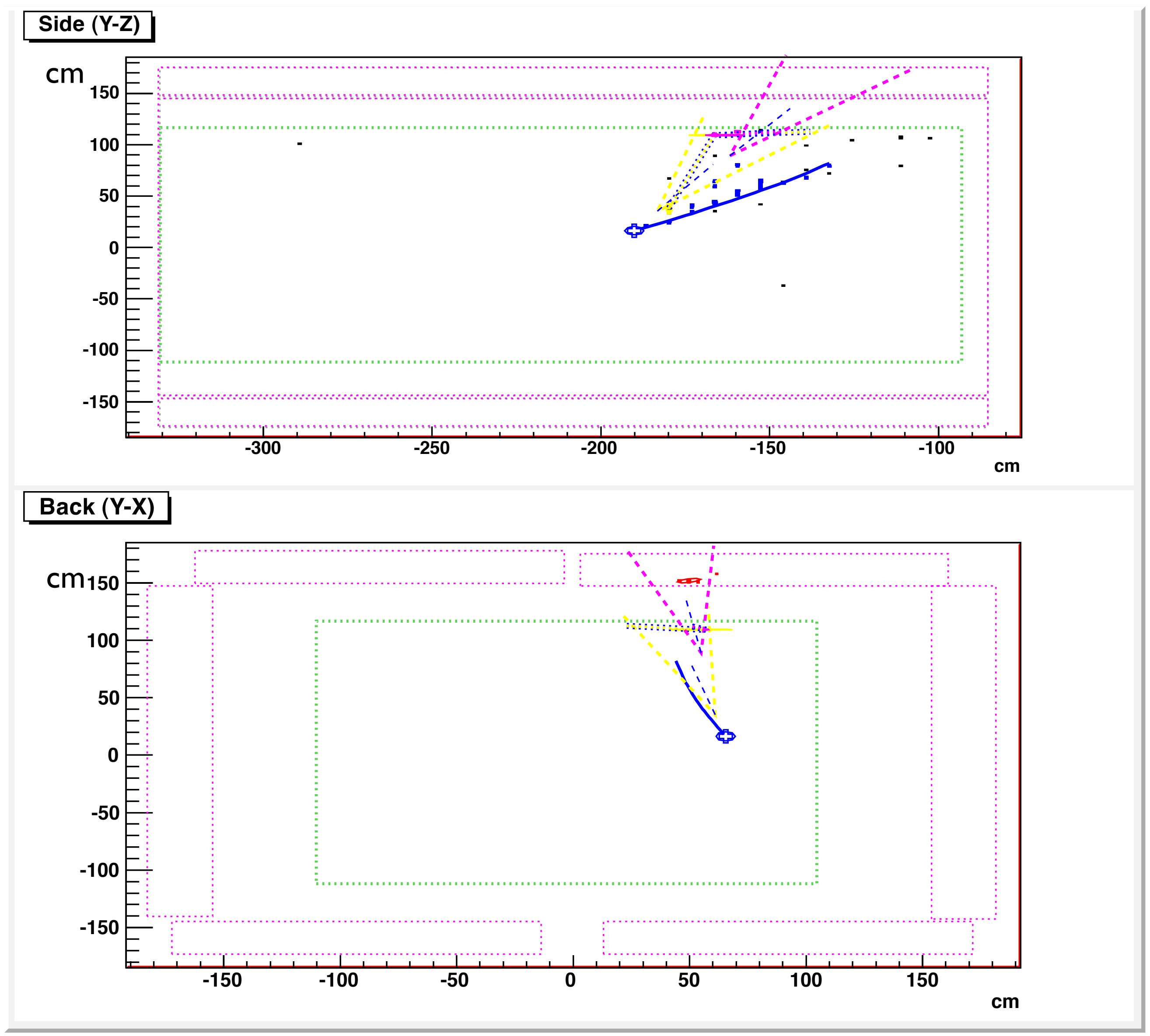
Muons reconstructed in the P0DECal

P0DECal & P0D

NC π^0 event fully contained in P0D(MC)

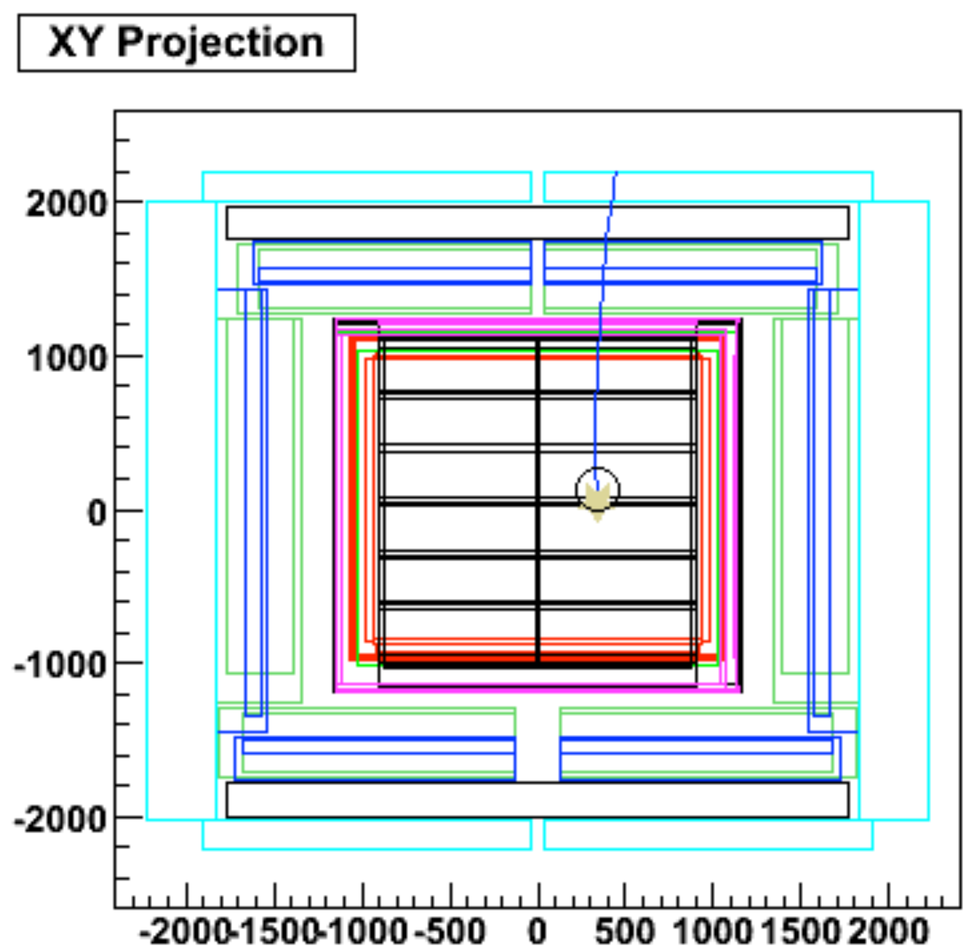


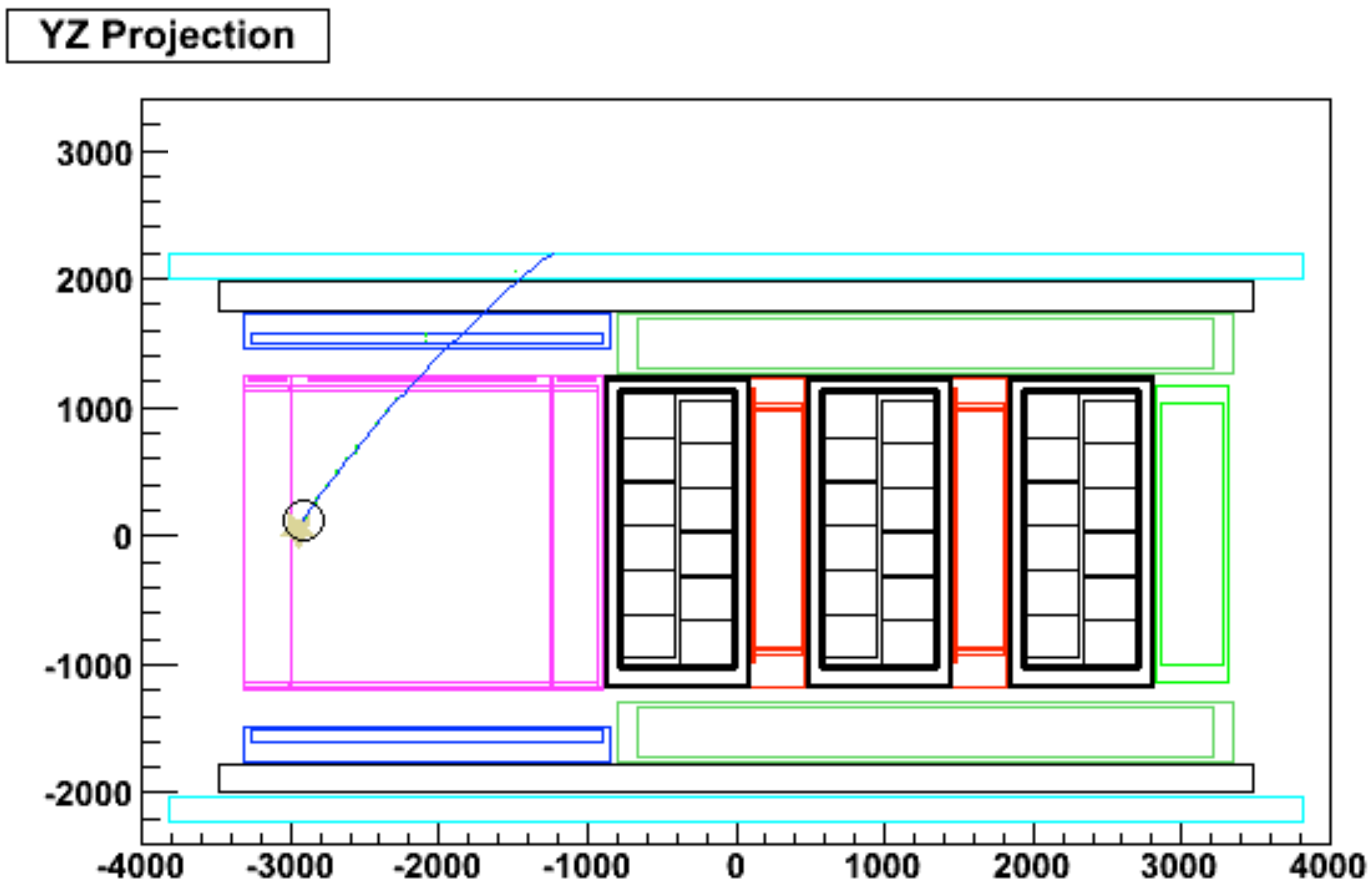
Escaping Gamma Shower



P0DECal & P0D

muon TRACK matching (MC)





Summary

π^0 are important in the neutrino experiments hence precise knowledge is crucial to understand background for current and future measurements.

The T2K experiment has a good potential to precise measurements π^0 cross section on water.

Near detector ND280 performs a number of independent π^0 cross section measurements including electromagnetic calorimeter which can improve standalone sub detectors measurements.

Backup

Recent measurements of NC1 π^0 cross section

Experiment	Detector medium	Energy	Type	Cross section	Error Stat. (sys.)
K2K[1]	1kT water	1.3 GeV	Ratio to the total CC cross section	6.4×10^{-2}	$0.1\ (0.7) \times 10^{-2}$
SciBooNE[2]	Polystyrene C_8H_8	1.1 GeV	Inclusive ratio	7.7×10^{-2}	$0.5(0.5) \times 10^{-2}$
		0.8 GeV	Coherent ratio	0.14×10^{-2}	0.30×10^{-2}
MiniBooNE[3]	Mineral oil CH_2	0.8 GeV	absolute	4.76×10^{-40} cm^2	$0.05\ (0.40) \times 10^{-40}$ cm^2

1. hep-ex/0408134

2. Phys.l Rev. D. 81.3 (2010): 033004, Phys Rev D.81.111102

3.Phys Rev D.81.013005

Backup

NEUT interaction modes

Signal	
Mode	**Fraction (%)**
Coh NCπ^0	51.1
NCNπ^0	43.1
NC$\pi^\pm$	2.4
NCel	1.9

CC Background	
Mode	**Fraction (%)**
CCπ^+	39.9
CCπ^0	21.6
CCQE	19.4
CCmult-π	12.9

NC Background	
Mode	**Fraction (%)**
NCmult-π	35.8
NCη	19.3
NCdis	13.3
NC$\pi^\pm$	13.1
NCNπ^0	10.6
NCel	6.7

π^0 Event Selection

pre selection: good data quality: event within bunches time window, 3D vertex

Implement P0DECal information into standard P0D event selection:

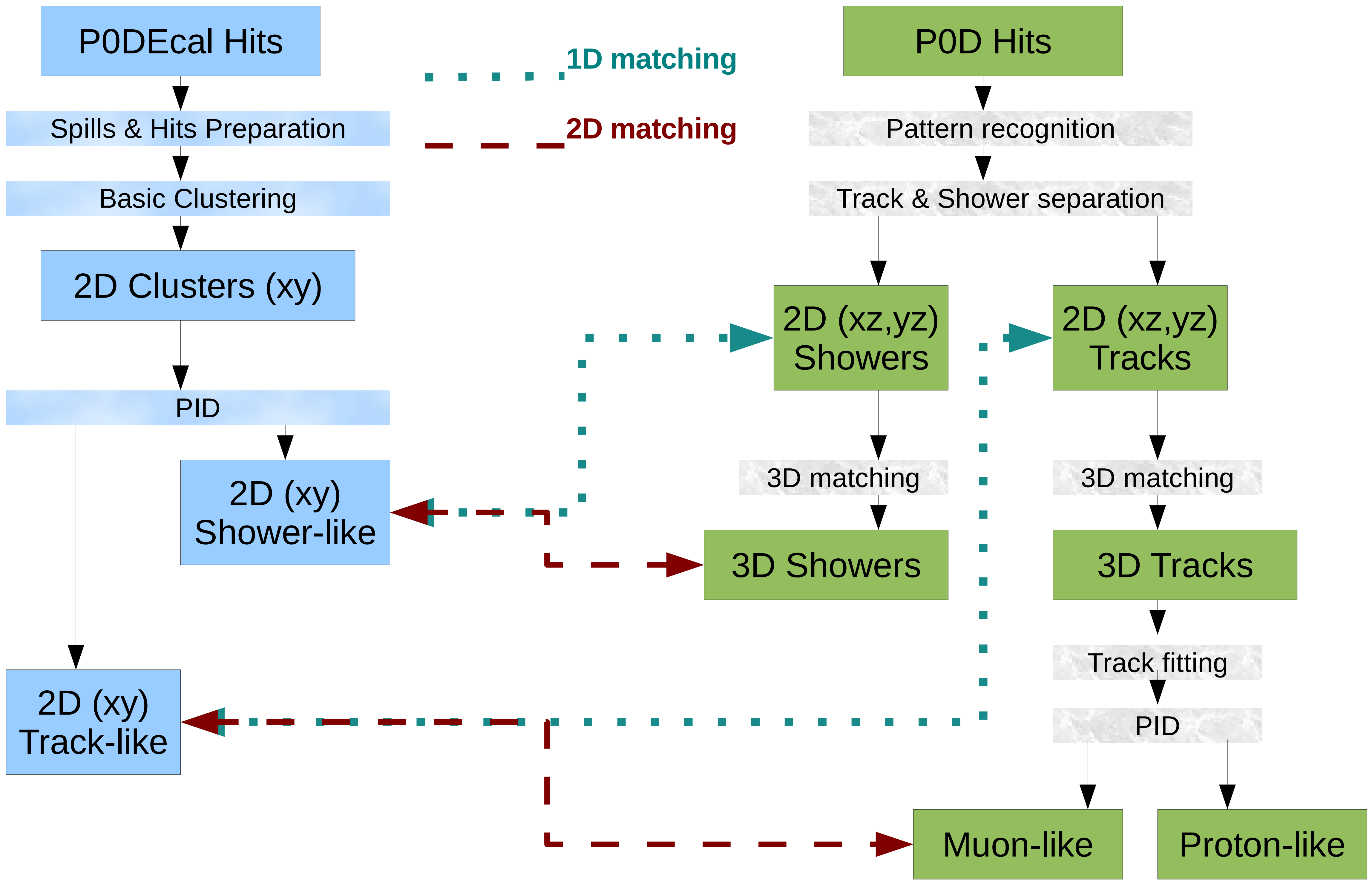
1. vertex within P0D fiducial volume ← extend fiducial volume
2. Non EM PID
3. Unmatched EM
4. Exactly **2 3D** EM showers PID ← for **1 3D** EM shower check P0DECal for

   1 2D shower-like object

5. Decay muon - no Michele electron
6. Pi0 direction
7. Invariant mass
8. shower separation

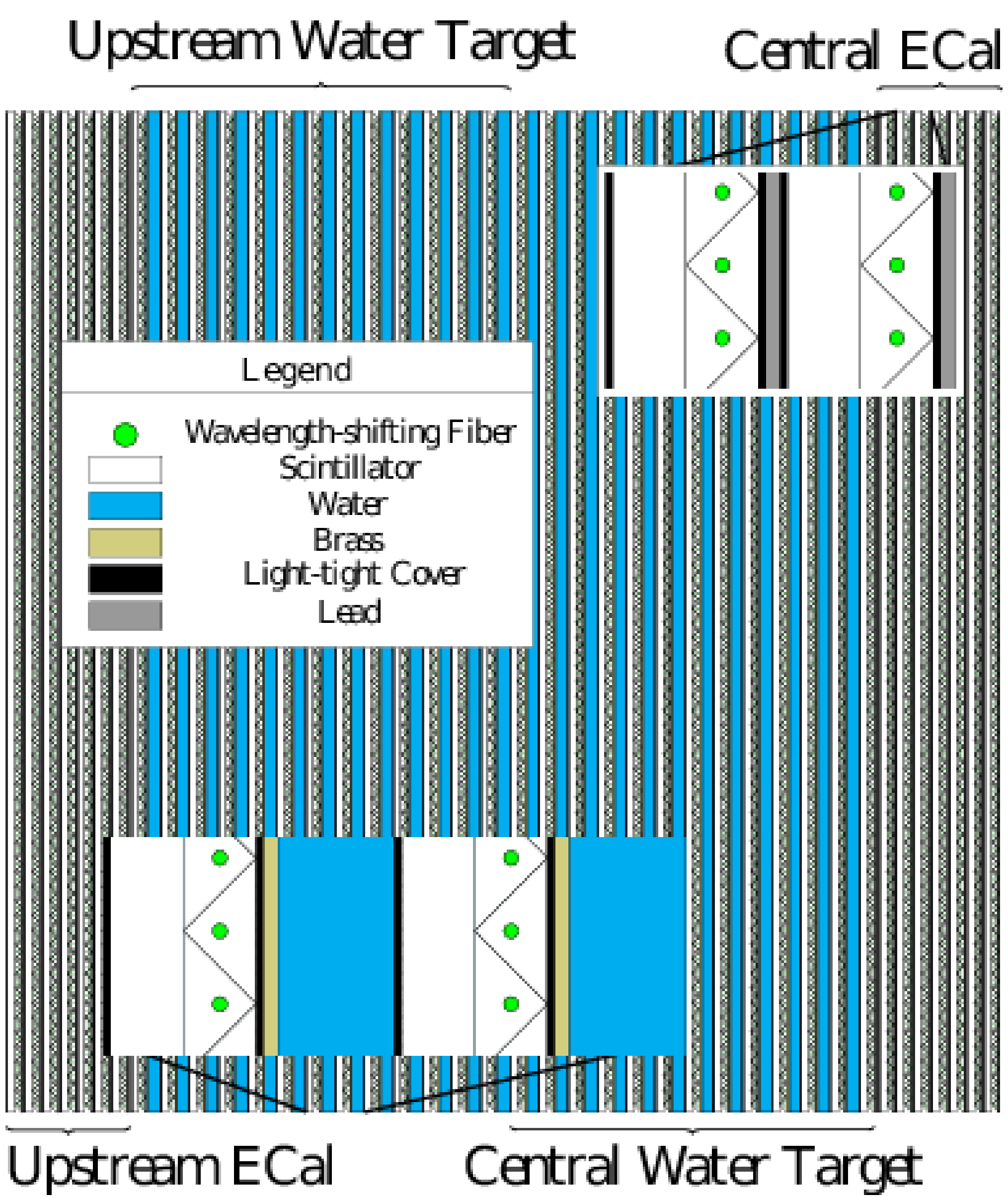
Backup

P0D-P0DECAL matching



Sub Detectors

P0D



P0DECal

- P0DECal consists of 6 modules surrounding P0D sub detector
  - 2 top modules and 2 bottom modules are identical
  - 2 side modules are identical
- each module contains 6 layers of scintillator bars and 4mm lead foil aligned along beam direction only with single side optical readout