NC-1π^0 measurement at the T2K near detector

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for the T2K Collaboration
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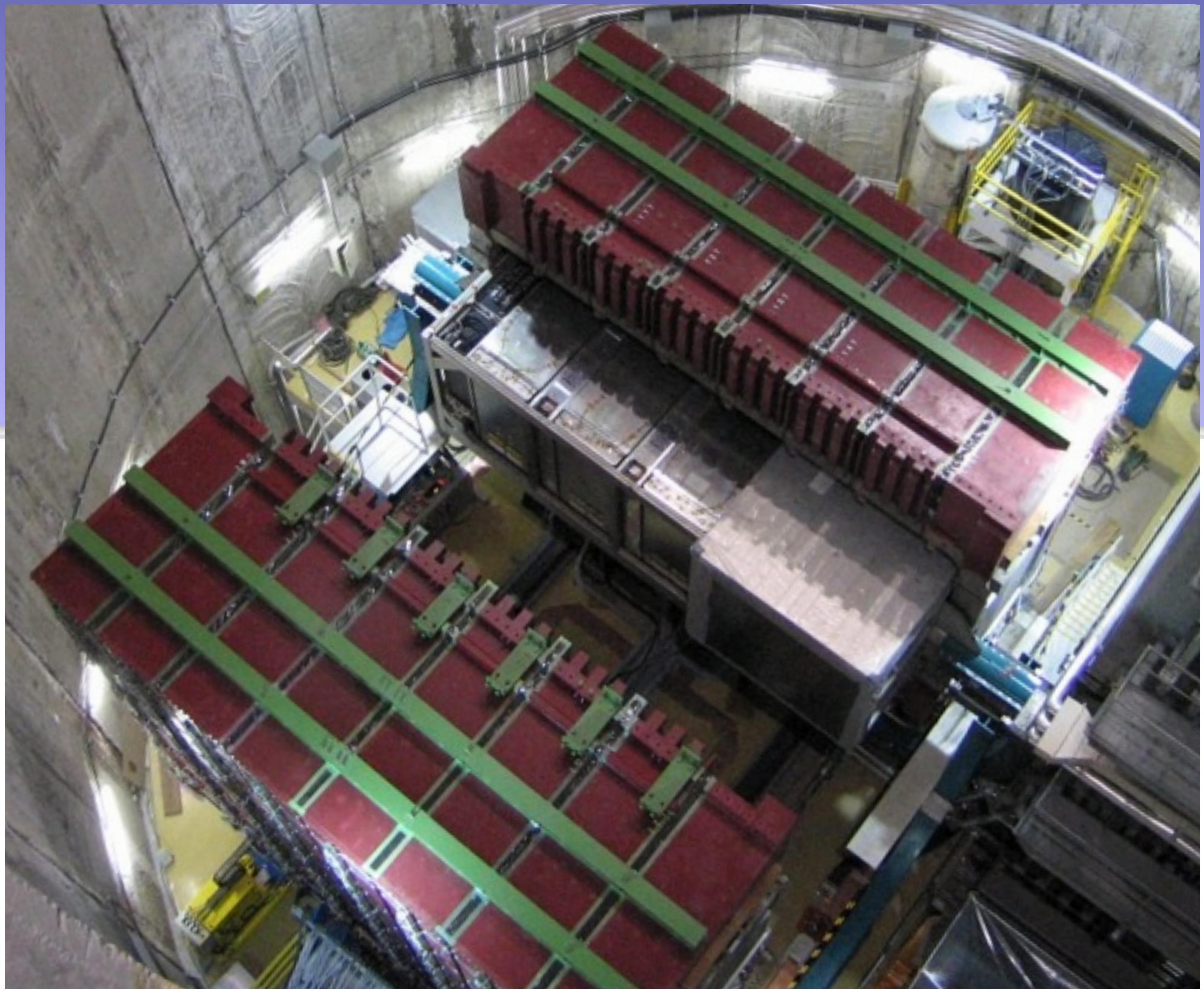


Overview

- T2K overview
- P0D : The π^0 detector
- First result of NC-1π^0 measurement using the P0D with run I+II data
- Outlook

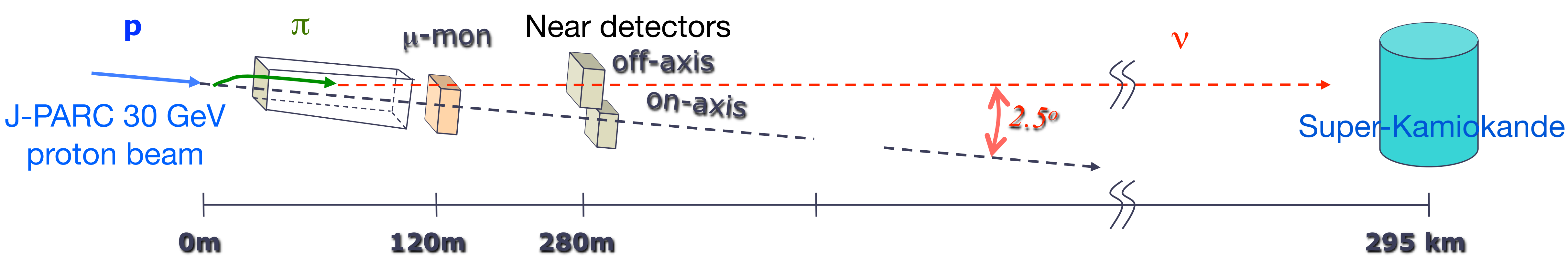
The T2K experiment

T2K is a 2nd generation long baseline precision experiment :

- θ_{13} via $\nu_\mu \rightarrow \nu_e$ appearance
- atmospheric paramaters Δm^2_{23}, θ_{23} via $\nu_\mu \rightarrow \nu_\mu$ disappearance

Off-axis intense neutrino beam

Near detectors to measure unoscillated beam and background interactions



π^0 background in T2K

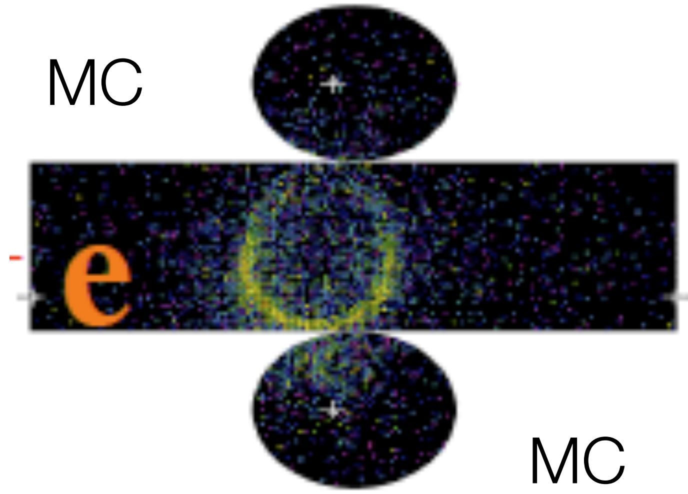
Appearance is observed via CC-QE ν_e interaction recognised as “e-like” ring at SK

- can distinguish muon and electron rings

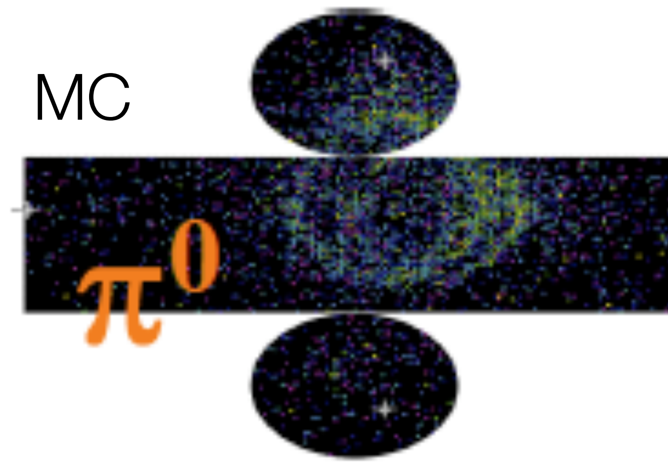
Interaction with one π^0 can mimic a ν_e signal

- γ ring is e-like and second π^0 decay γ ring can be missed
- large uncertainty in π^0 production mode
- not enough statistics at SK to constrain this background to ~10% level

MC



MC

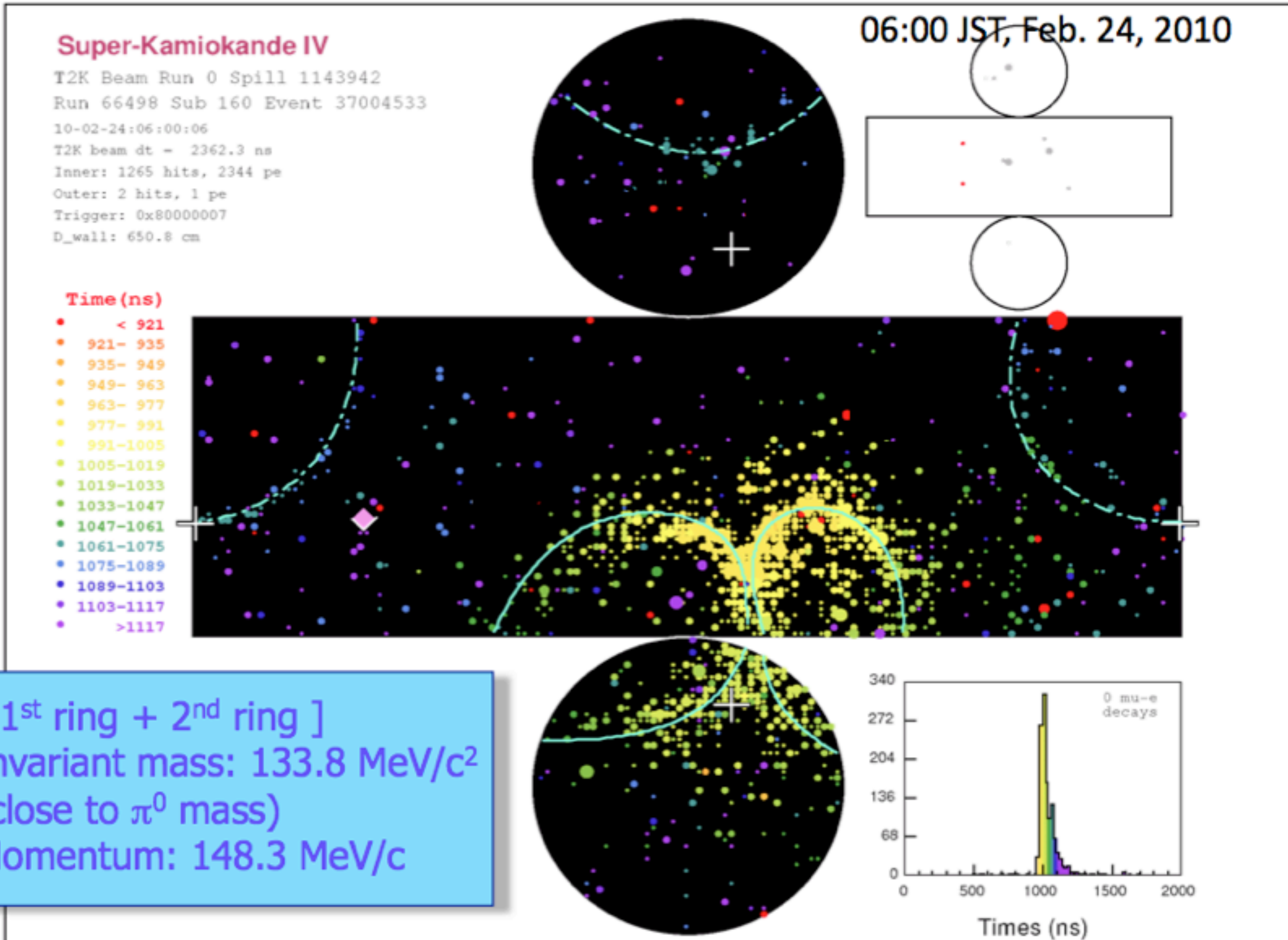


T2K signal and background events at SK

Event category	The predicted number of events $\sin^2 2\theta_{13} = 0.0$	$\sin^2 2\theta_{13} = 0.1$
Total	2.73	9.07
ν_e signal	0.15	6.60
ν_e background	1.42	1.32
ν_μ background	1.02	1.02
$\overline{\nu}_\mu$ background	0.06	0.06
$\overline{\nu}_e$ background	0.08	0.07

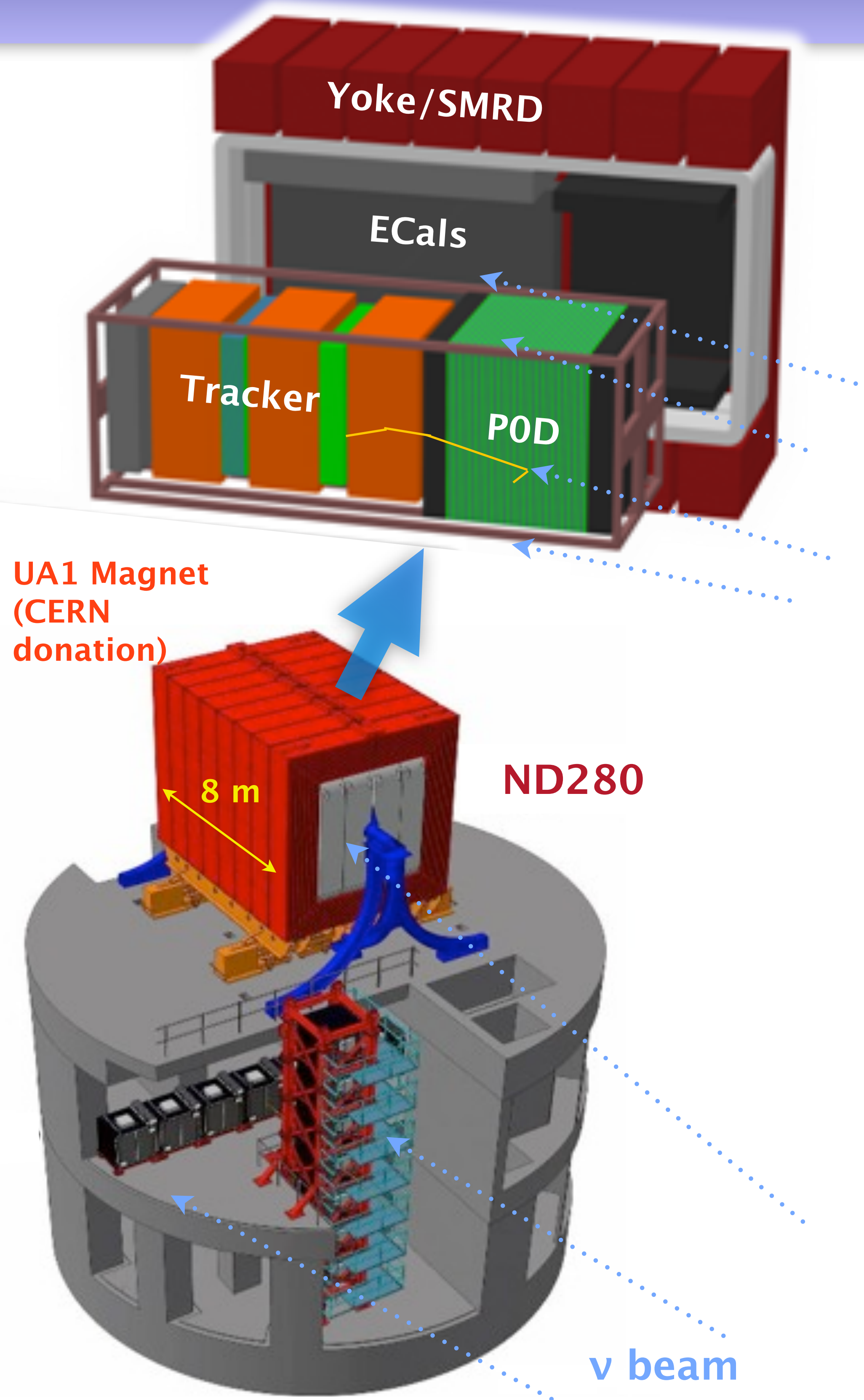
Significant contribution to ν_e appearance background due to NC1π^0

First T2K far detector event



[1^{st} ring + 2^{nd} ring]
Invariant mass: 133.8 MeV/c^2
(close to π^0 mass)
Momentum: 148.3 MeV/c

Near detector at 280m



The Off-axis near detector (ND280) provides

- **Off axis beam measurement based on CCQE**
- **beam nue contamination**
- **Super-K background measurements (NCπ^0)**

Two target regions :

- **The P0D (Brass/Plastic segmented) : π^0 detector**
- **The tracker region : Fined grained plastic detector FGD and TPC**
- **Both region have passive water planes**

Large Calorimeter coverage (Plastic/Pb segmented)

- **PID, hermiticity, active veto**

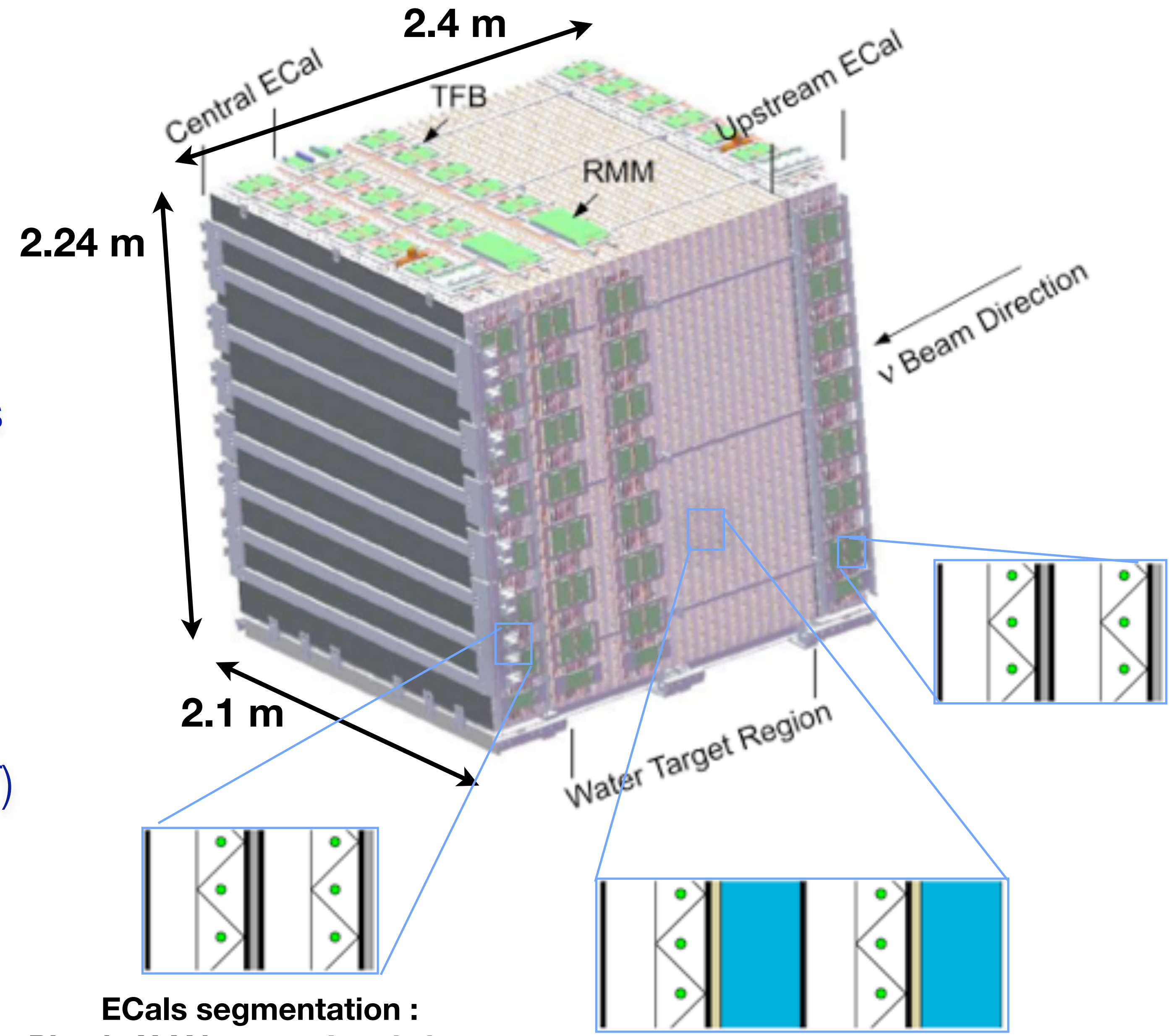
Side Muon ranging detector

- **Neutrino rate, Side muons, cosmics trigger**

Precise cross-section measurements with very large statistics !!!

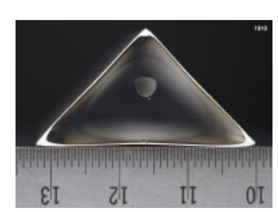
P0D : The π^0 detector

- Dense fine-grained tracking calorimeter to measure π^0 events on H_2O target
  - 40 tracking modules X-Y scintillator bars with WLS fibres and read out by solid state photosensors (MPPC) : 10,400 channels
  - Removable water targets to extract cross-section
  - Total mass 15.8Ton (12.9Ton water OUT)
- Upstream, Central and surrounding P0D ECal modules provide energy containment



ECals segmentation :
Plastic X-Y layers + Lead sheet

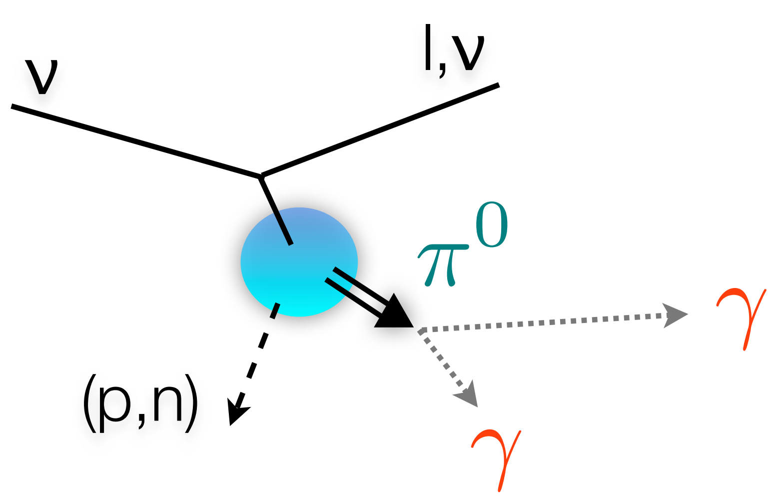
Target region segmentation :
Plastic X-Y layers + Brass + Water bag



Minerva triangular bar
section 3.3 cm x 1.7 cm

NC-1 π^0 signal definition and topology

$$\nu_\mu + N \rightarrow \nu_\mu + N + \pi^0 + X$$

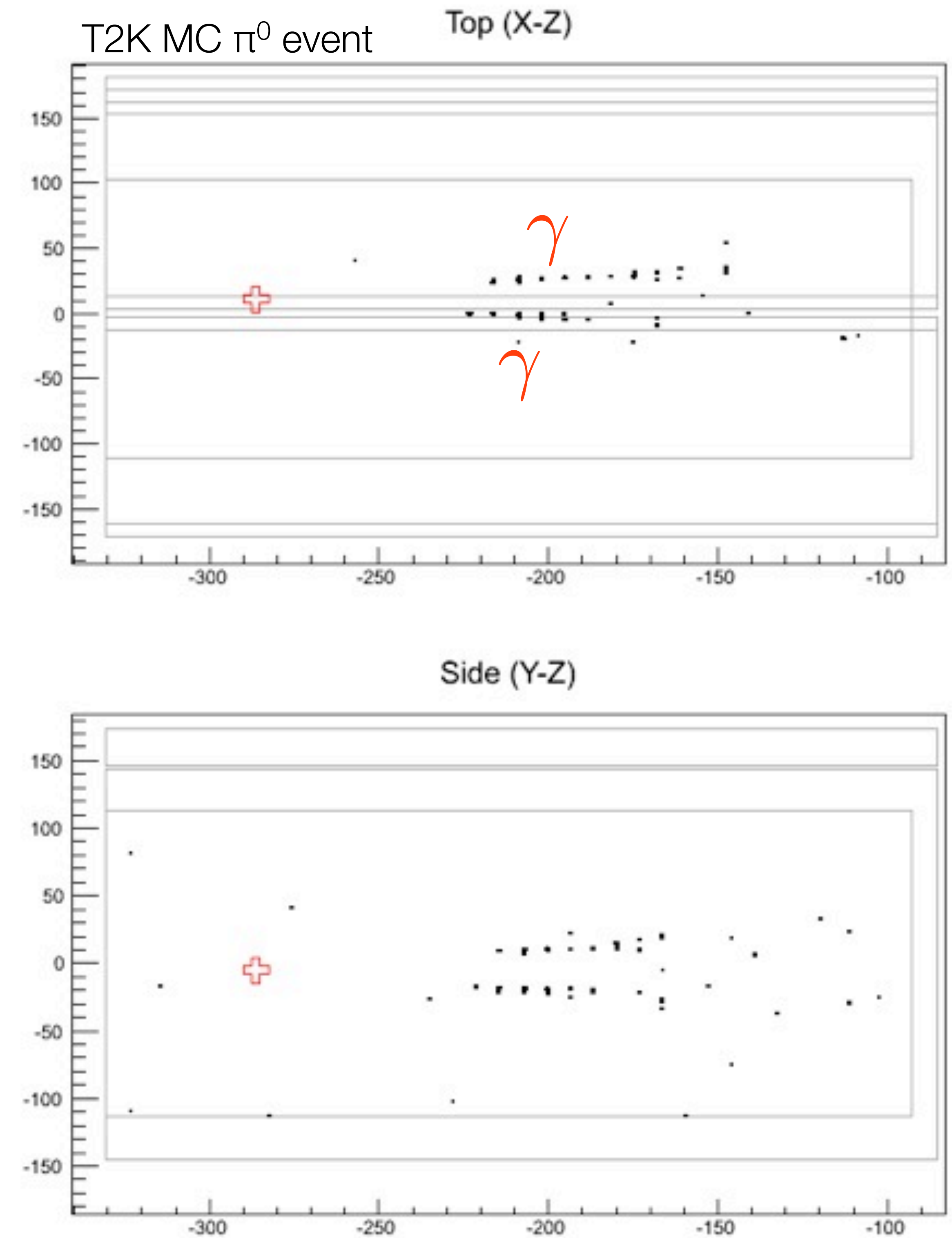


Neutral current interaction

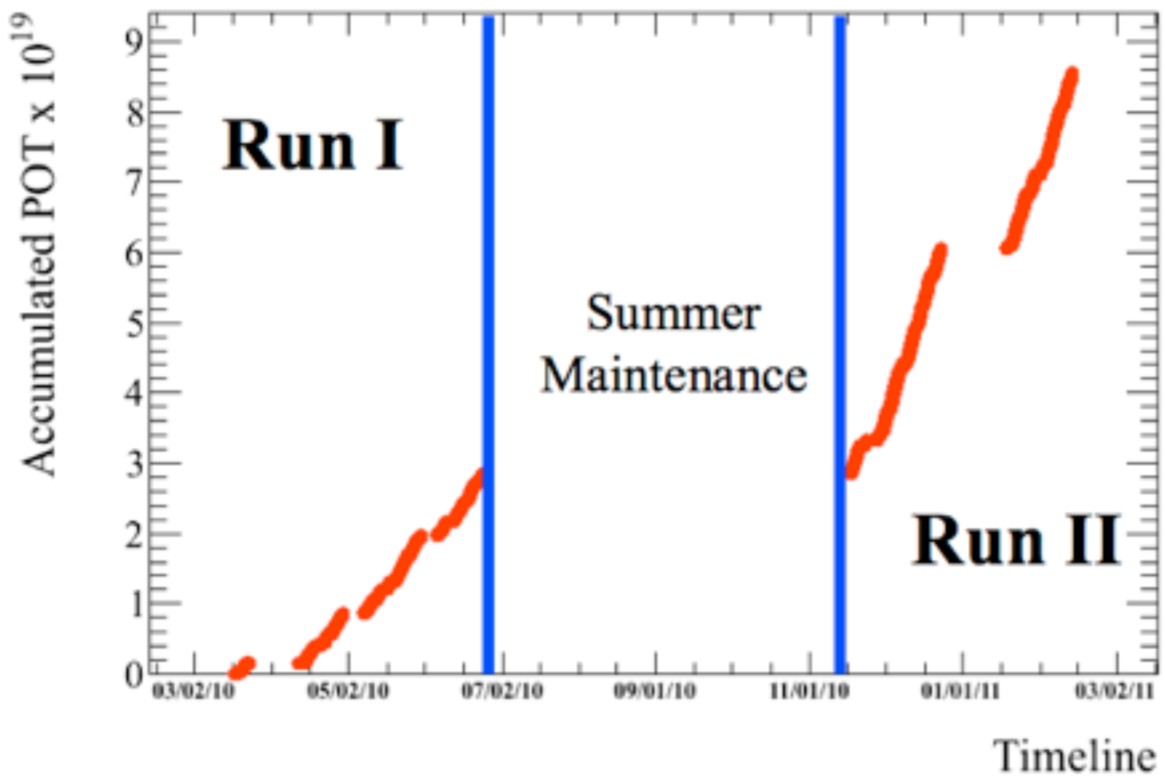
- one π^0 decay
- X : any number of neutrons and protons
- no other particles at vertex

includes

- π^0 via Δ resonances
- Coherent π^0 production
- π^0 from nuclear effects



MC & Data sample



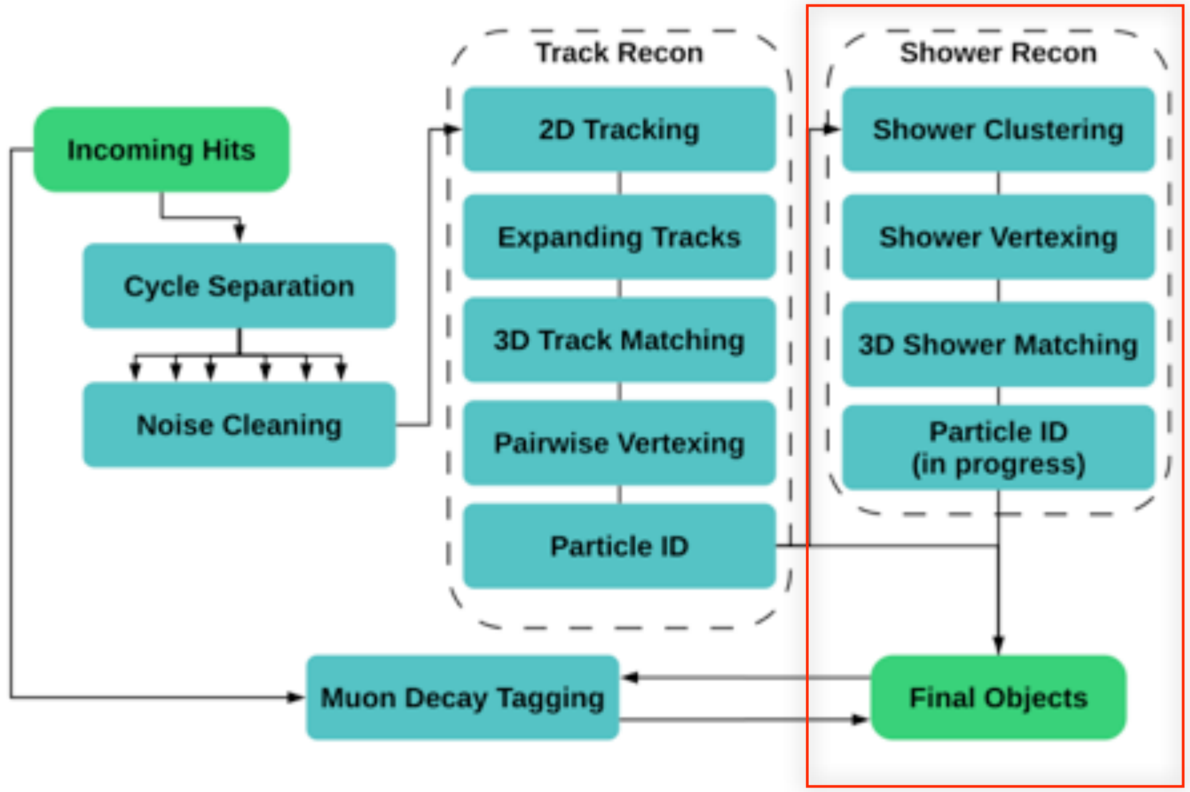
MC sample

- NEUT MC Generator
- Run I (6b/spill) : 55.65 x 10^{19} p.o.t.
- Run 2 : 110.15 x 10^{19} p.o.t

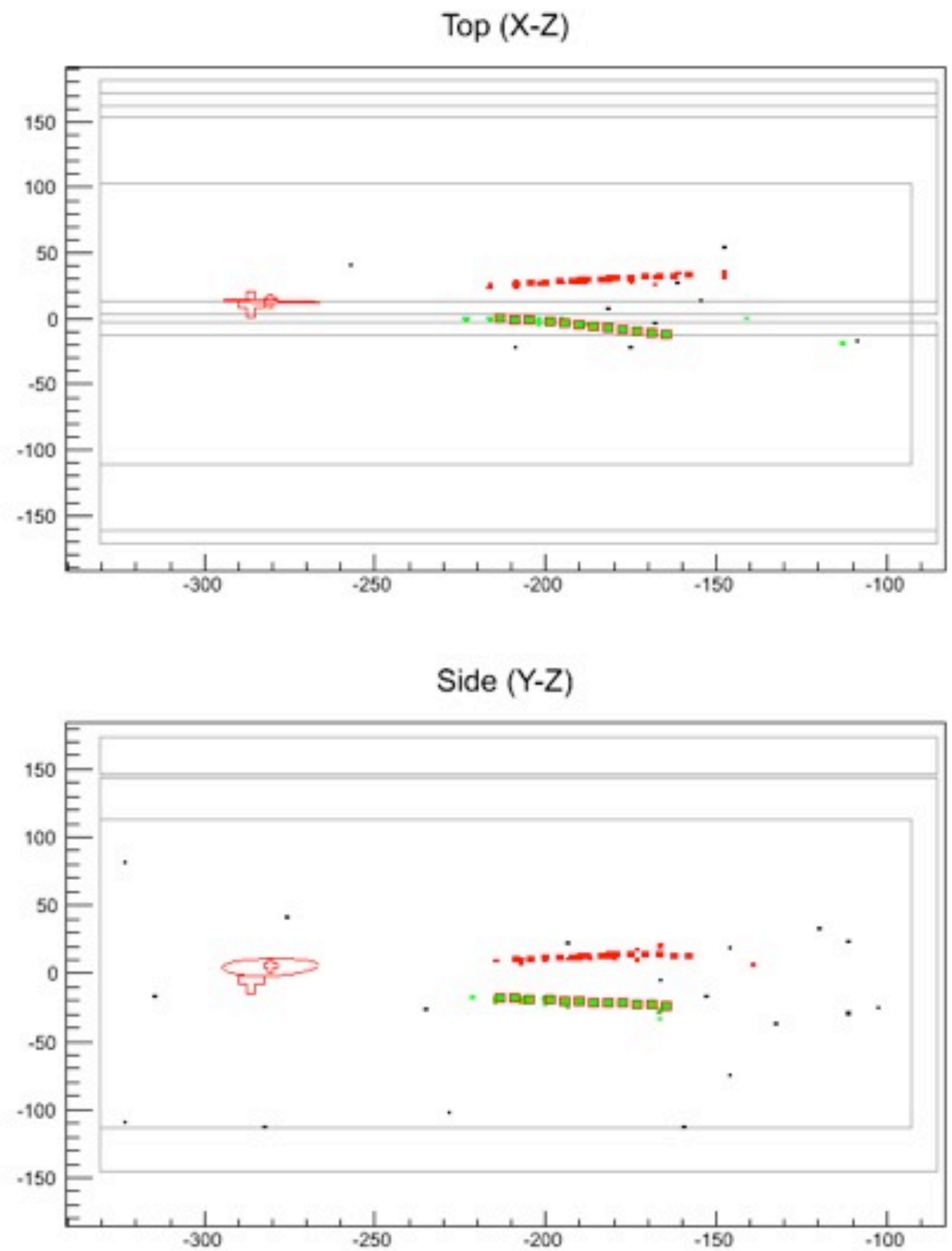
Data Sample :

- Analysis on Water-IN period only
- Good spill selected if P0D and magnet have good detector status
- Run I (6b/spill) : 2.85 x 10^{19} p.o.t.
- Run II (11b/spill) : 5.70 x 10^{19} p.o.t.

P0D γ shower reconstruction



T2K-MC π^0 event



Reconstruction is a two step process

- Reconstruct track followed by shower reconstruction in individual bunch

NC-1π^0 analysis uses shower reconstruction output

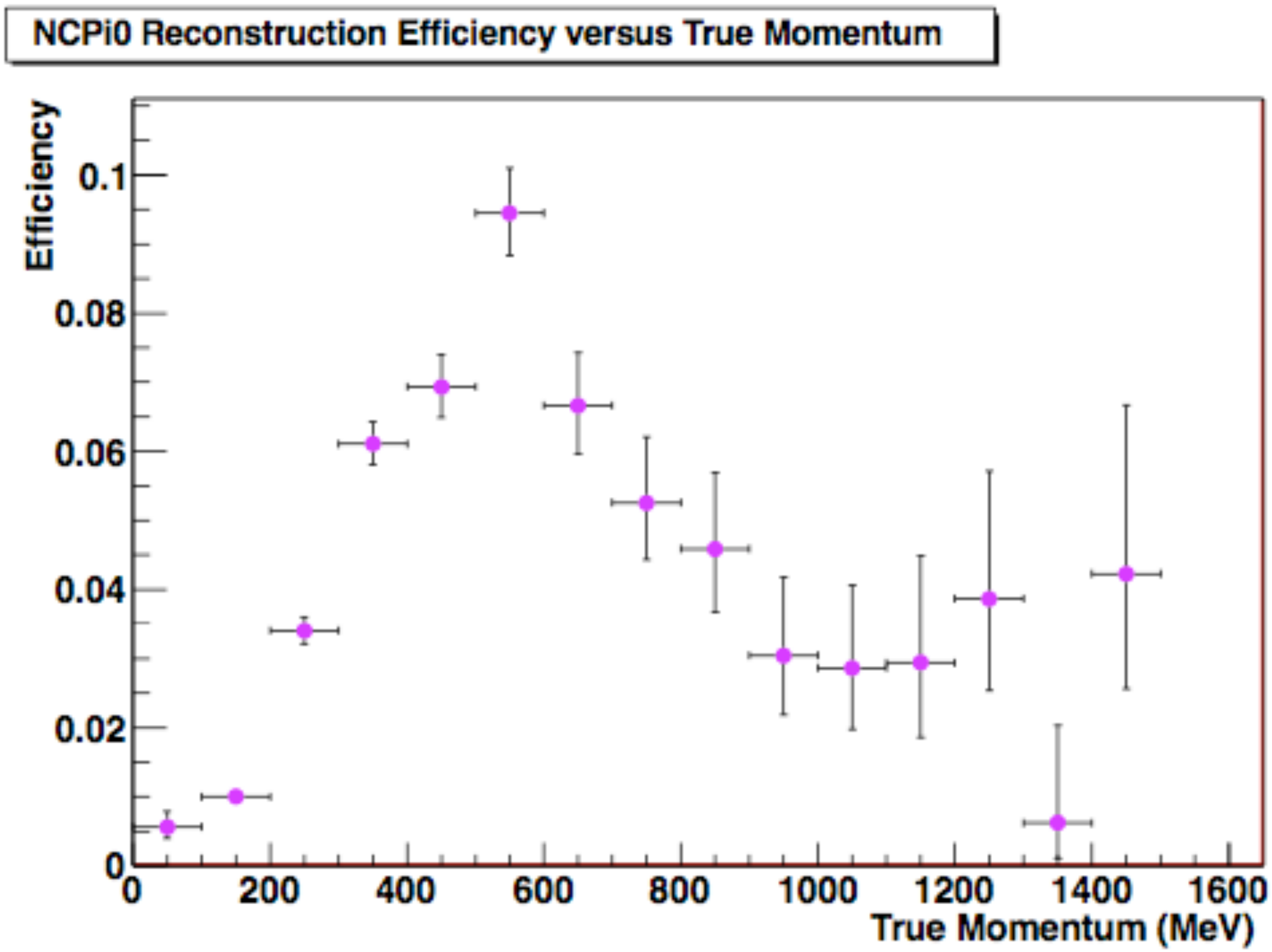
- look for narrow shower-like pattern
- associate reconstructed shower to vertex
- 3D matching
- distance to vertex to test photon shower hypothesis
- Energy based PID to discriminate muon and EM signal

NC-1π^0 Selection

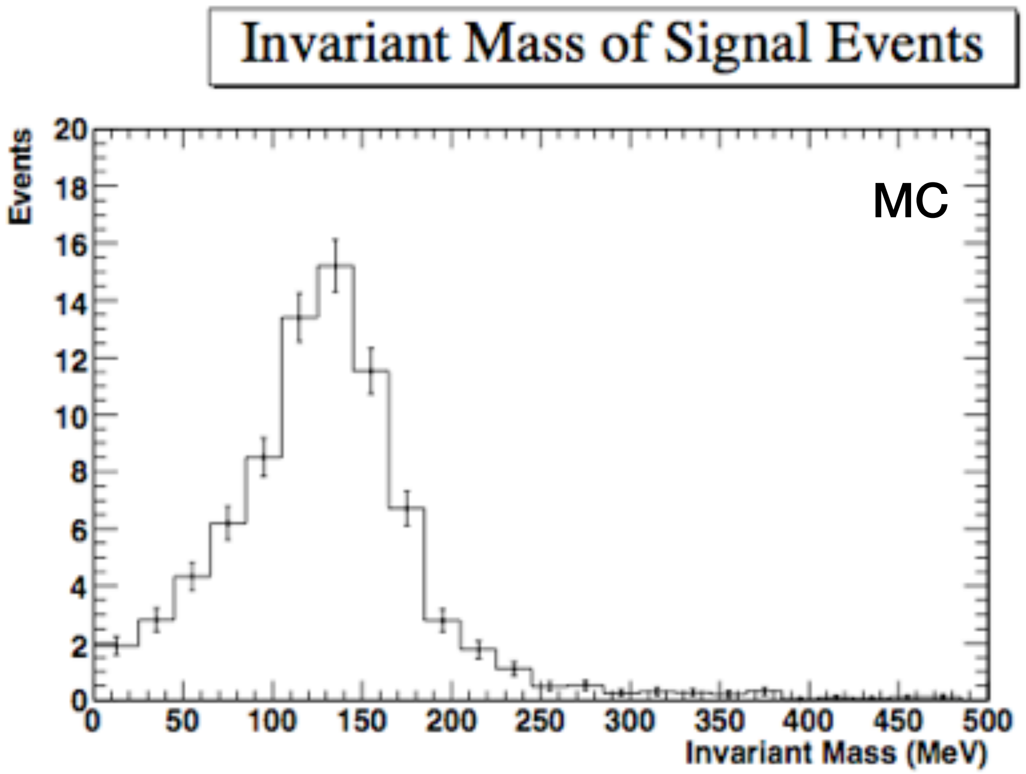
Selection Cut	Data	MC signal	MC backgrounds
Pre-selection event within beam spill	415750	4569.1 ± 16.1	183382.2 ± 100.7
Fiducial vertex in Water target	51736	1716.1 ± 10.3	48117.1 ± 54.1
No **μ**-like reject CC events	11170	1185.5 ± 8.0	10571.8 ± 24.6
2 EM-like	2061	399.0 ± 4.7	1958.1 ± 10.8
No **μ** decay no delayed hit cluster	1536	387.9 ± 4.6	1335.1 ± 2
π^0 direction cut	693	250.4 ± 3.7	616.6 ± 6.8
EM charge additional PID to shower	312	166.7 ± 3.0	223.5 ± 3.5
EM separation	115	79.1 ± 2.1	64.5 ± 1.9

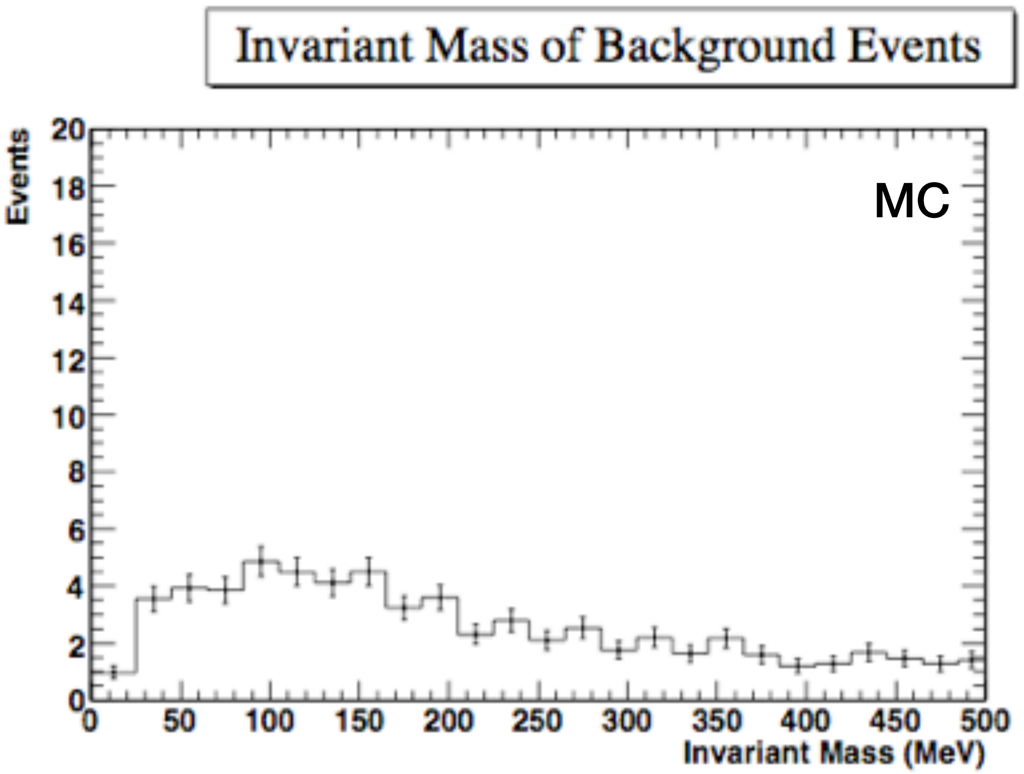
finally calculate π^0 invariant mass $M_{\gamma\gamma} = \sqrt{2E_{\gamma 1}E_{\gamma 2}(1-\cos\theta_{\gamma\gamma})}$

P0D NC-1π^0 reconstruction efficiency



MC reconstructed Invariant Mass





Extract number of signal events using an unbinned Likelihood fit

Invariant mass distributions used as pdf in Likelihood fit

Expected	143.6 ± 2.8			
Signal		79.1 ± 2.1		
Background		64.5 ± 1.9		
Charge Current			40.0 ± 1.5	
Muon				12.2 ± 0.8
Muon + π^0				7.4 ± 0.6
Muon + $\pi^\pm$				11.4 ± 0.8
Muon + other				9.0 ± 0.7
Neutral current			19.8 ± 1.0	
Other				16.5 ± 0.9
$\pi^\pm$				3.3 ± 0.4
Other			4.6 ± 0.5	

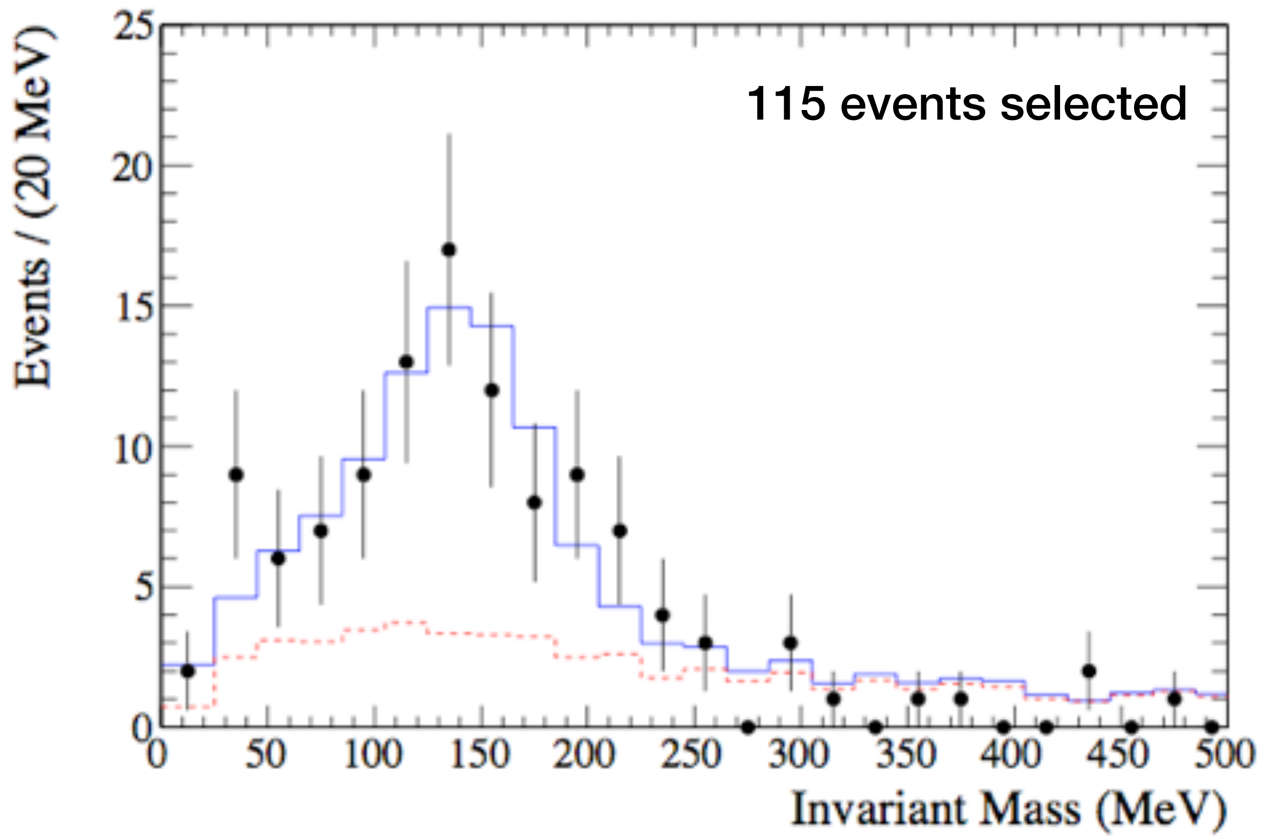
Likelihood fit

$$L_{\text{Total}} = L(\text{E})_{\text{EScale}} \times L(\text{B})_{\text{X-sec}} \times L(\text{S,B})_{\text{Norm}} \times L(\text{E,S,B})_{\text{Shape}}$$

$L_{Total} = L(N_{sig}, N_{bkg}, E_{Scale})$

- Nsig : Number of signal events
- Nbkg : Number of background events
  - Apply NEUT cross section uncertainties to MC background prediction
  - Gaussian with mean of 65 and sigma of 14
- EScale controls the ratio of photoelectrons (PE attributed to a γ) to total energy of γ in MeV
  - Ratio of γ energy to visible energy from MC (0.2PE/MeV)
  - Difference between MC and data due to detector geometry
  - Energy scale systematic is 7%
  - Gaussian with mean 1.0 and sigma 0.07
  - muon energy scale tuned to cosmics and beam data

Result of the fit on data

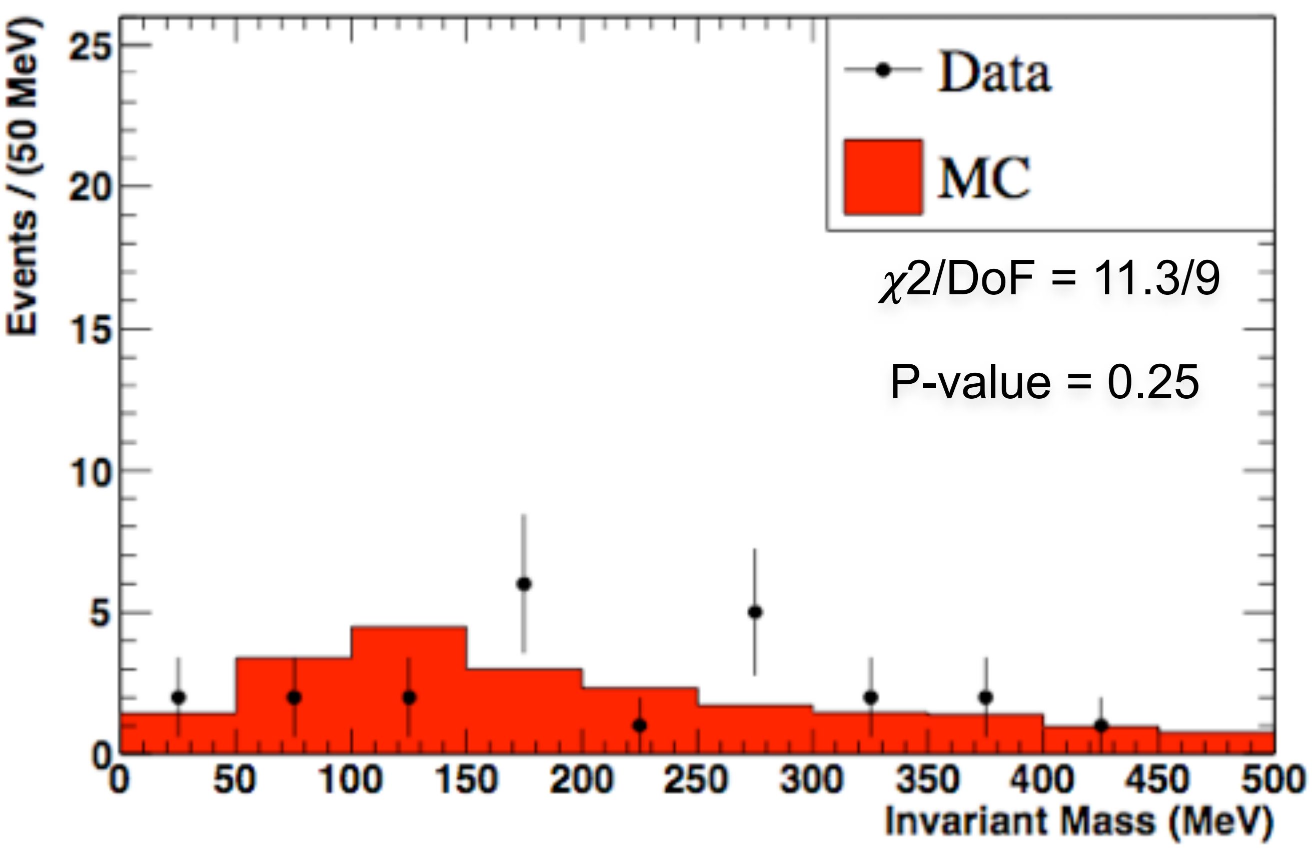


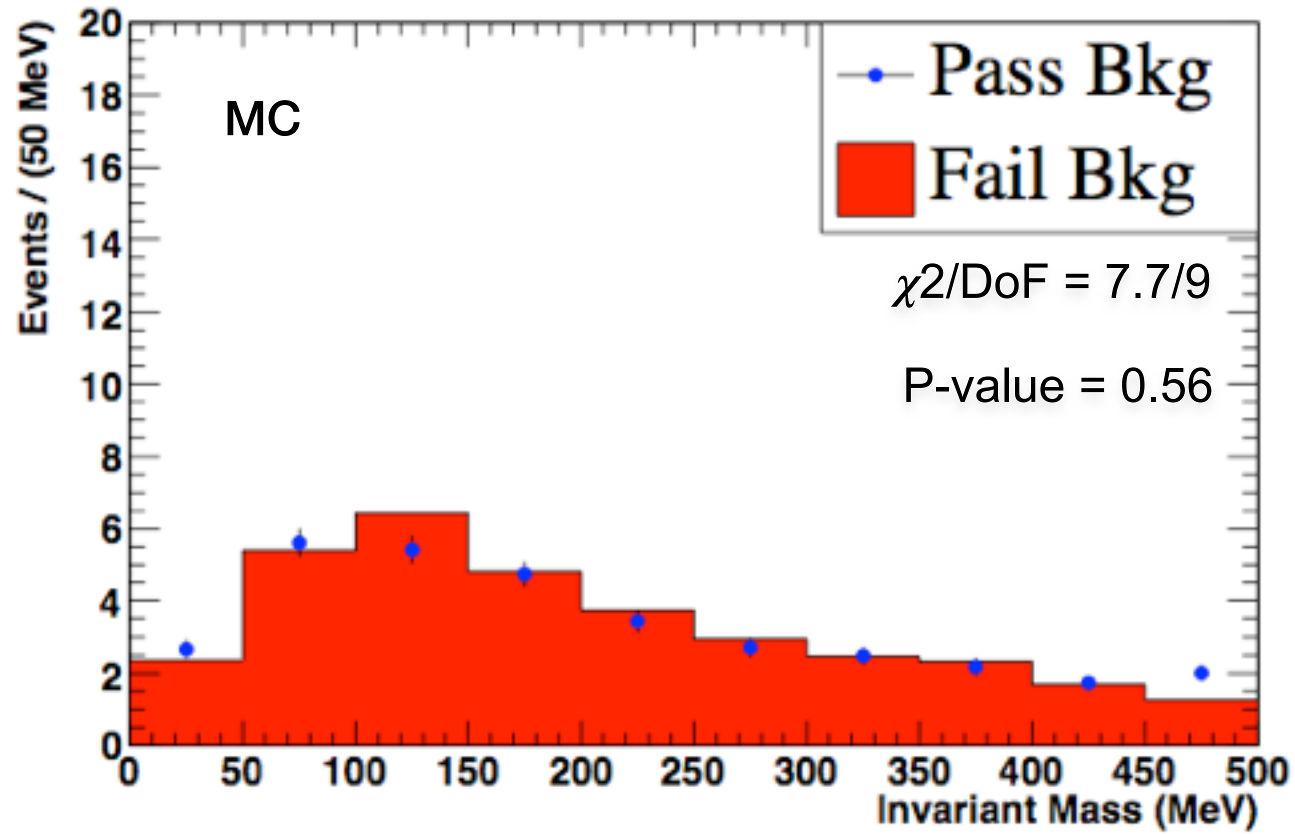
$$r = \frac{N_{\pi^0}^{Data}}{N_{\pi^0}^{MC}} = 0.84 \pm 0.16(stat)$$

	Observed	Expected	Ratio
Signal	66 ± 13	79 ± 2	0.84 ± 0.16
Background	52 ± 10	65 ± 2	0.80 ± 0.16

Fitted E_{Scale} is 0.94 ± 0.03

Sideband analysis





Compare background events with a muon decay signal

- Check consistency of background shape prediction with data
- Check agreement between MC background events passing and failing muon decay cut
- Reiterate likelihood fit procedure on background events (gives 0 ± 4 signal events)

Summary of systematic errors

Source	Error	Contribution to Ratio (%)
Mass Uncertainty	0.8%	0.8%
Detector Alignment	2.5 mm	< 0.1%
Fiducial Volume	7%	7%
Relative Flux Uncertainty	15%	15(6.5)%
Reconstruction Uncertainties	4.7%	4.7%
Energy Resolution	10%	0.5%
Shape Uncertainty	13.7%	13.7%
Total	—	22(17)%

Fiducial volume uncertainty comes from vertex reconstruction biais

Neutrino beam flux uncertainty reduced by normalising to tracker region CC-inclusive measurement

$$\frac{N_{CC}^{Data}}{N_{CC}^{MC}} = 1.036 \pm 0.028(\text{stat}) {}^{+0.044}_{-0.037}(\text{det. syst}) \pm 0.038(\text{phys. model})$$

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Reconstruction uncertainties dominated by PID

Shape uncertainty dominated by total number of background events in side band

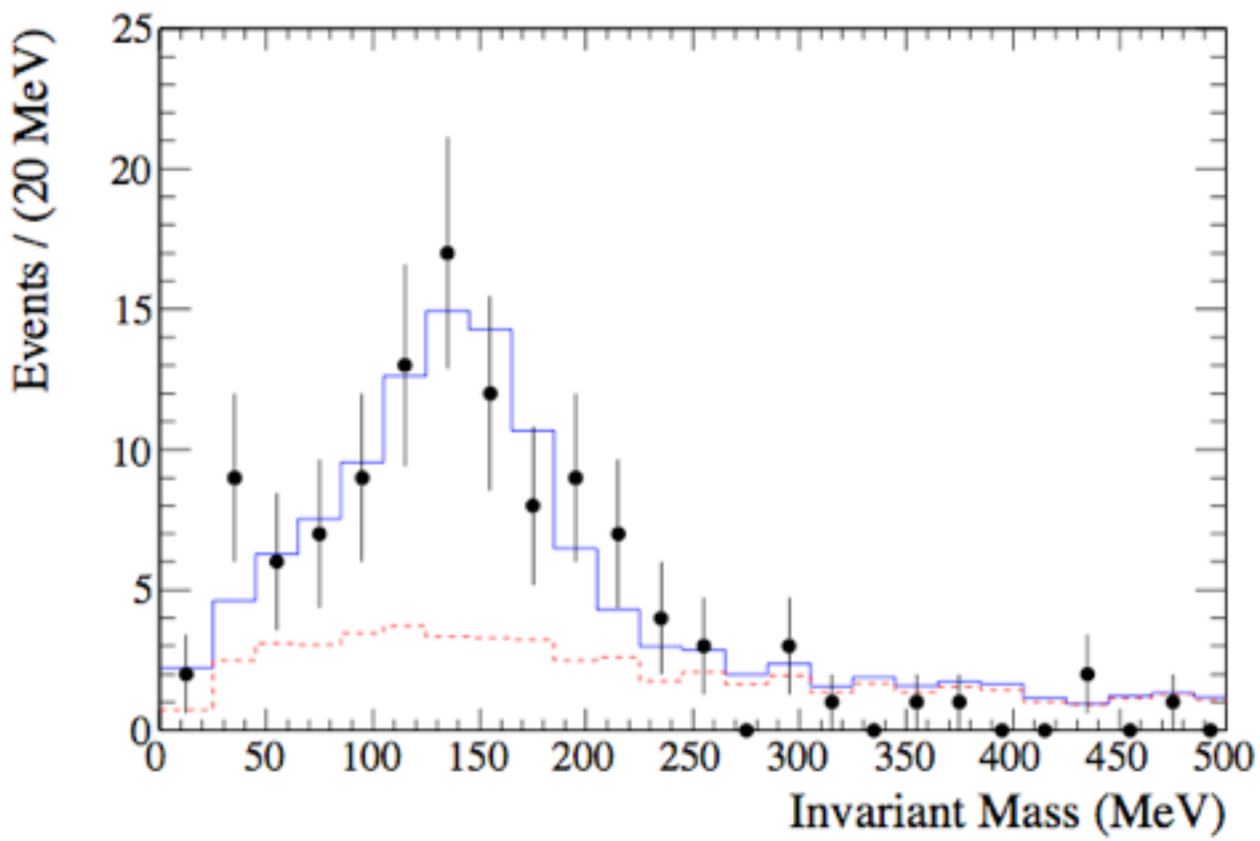
Summary of results

we present a measurement of NC-1π^0 production using 8.55 x 10^{19} p.o.t (Run I+II) in water IN configuration

- data/MC (NEUT) ratio :

$$r = 0.84 \pm 0.16\,(\text{stat}) \pm 0.18\,(\text{sys})$$

- Ratio normalised to tracker CC-inclusive measurement is :



$$R = \frac{N_{\pi^0}^{Data} / N_{\pi^0}^{MC}}{N_{CC}^{Data} / N_{CC}^{MC}} = 0.81 \pm 0.15(stat) \pm 0.14(sys)$$

Outlook

P0D has also ran in water OUT configuration during run III (2011-2012)

- optimisation of selection needed due to different shower sampling fraction and efficiency
- Analysis in progress with result planned in 2013

NC-1π^0 event reconstruction underway in the tracker region (see poster session)

- different topologies accessible : conversion of γ in FGD/TPC region and Calorimeters

H. O'Keeffe poster's

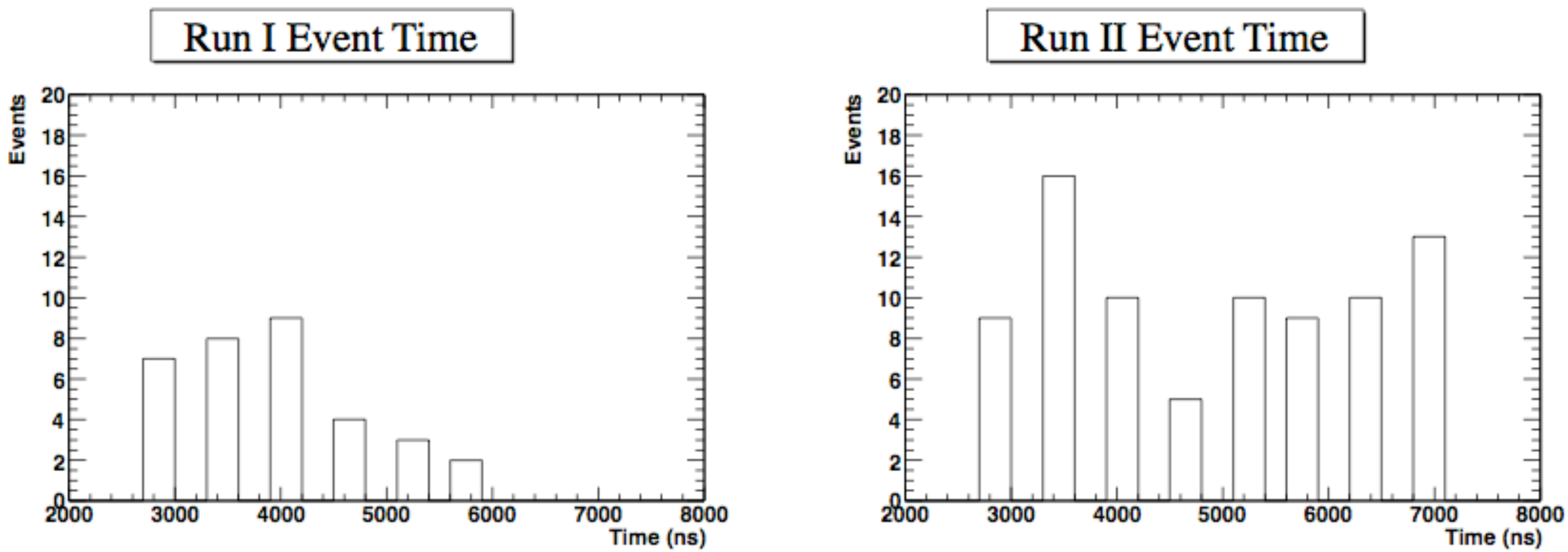
CC-π^0 selections also in progress

M. Batkiewicz's poster's

More results in 2013 : stay tuned !

The end

Selected events time distribution

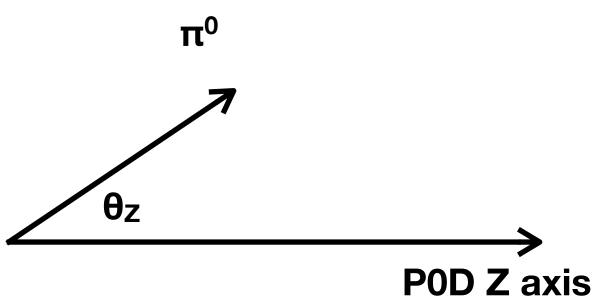


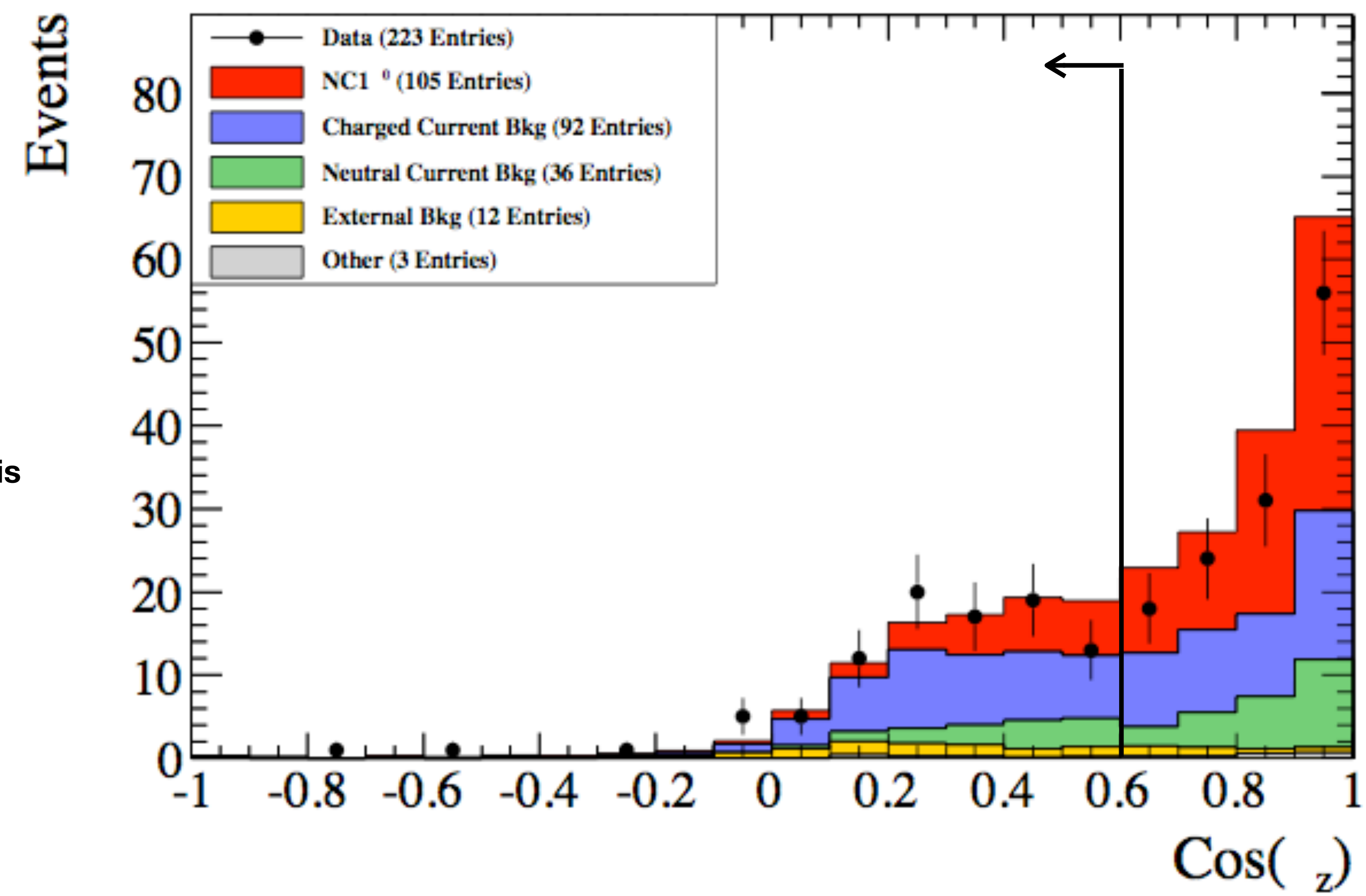
Bin centered at bunch time with 300 ns width (selected time cut)

RUN I : 33 events

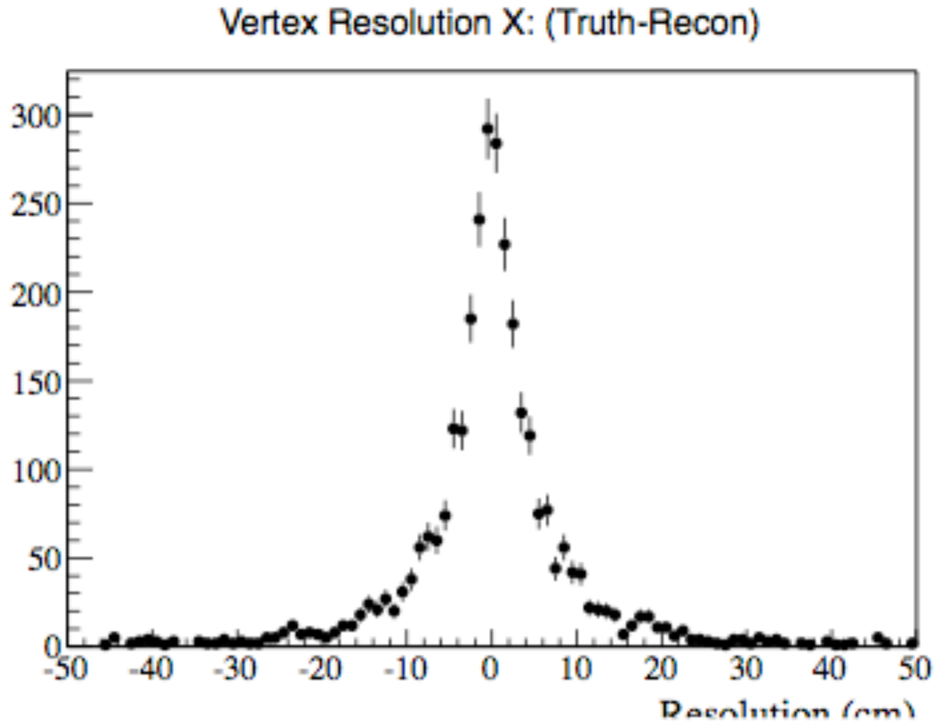
RUN II : 82 events

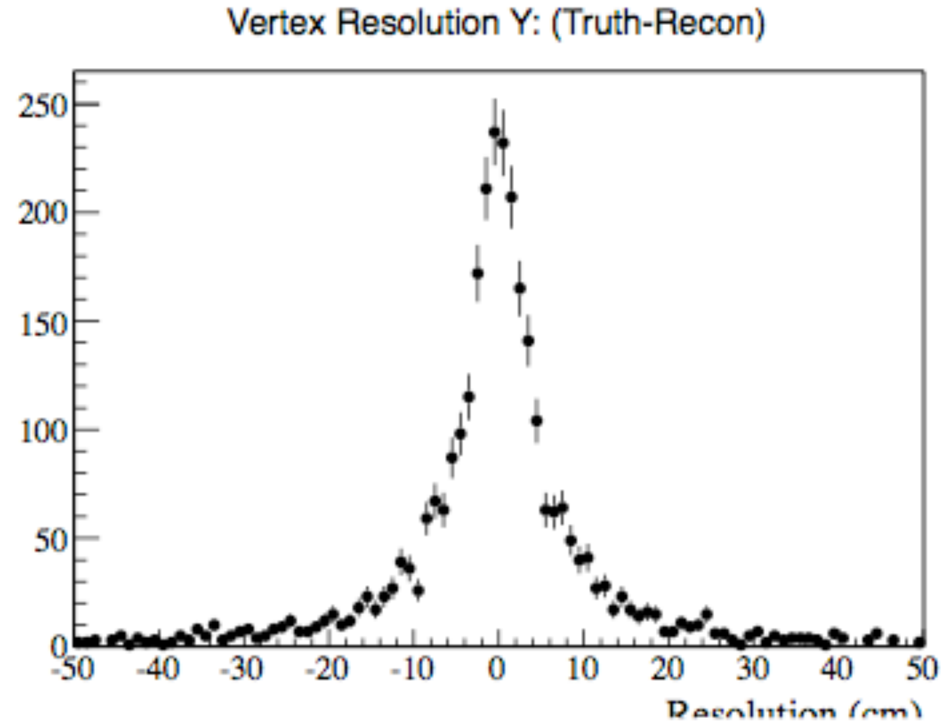
π^0 direction cut

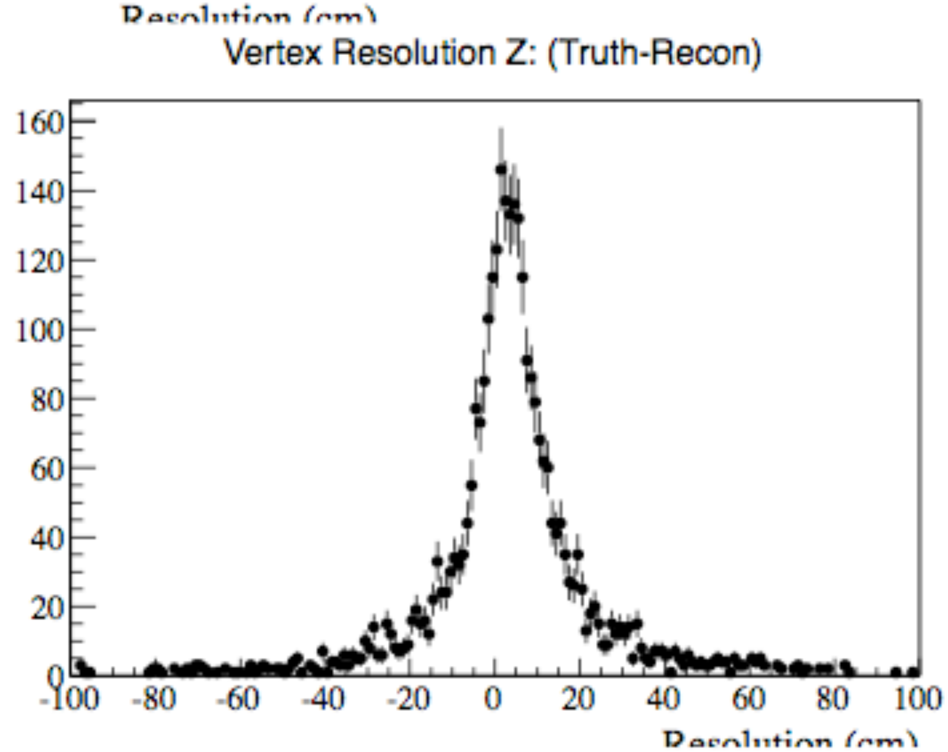




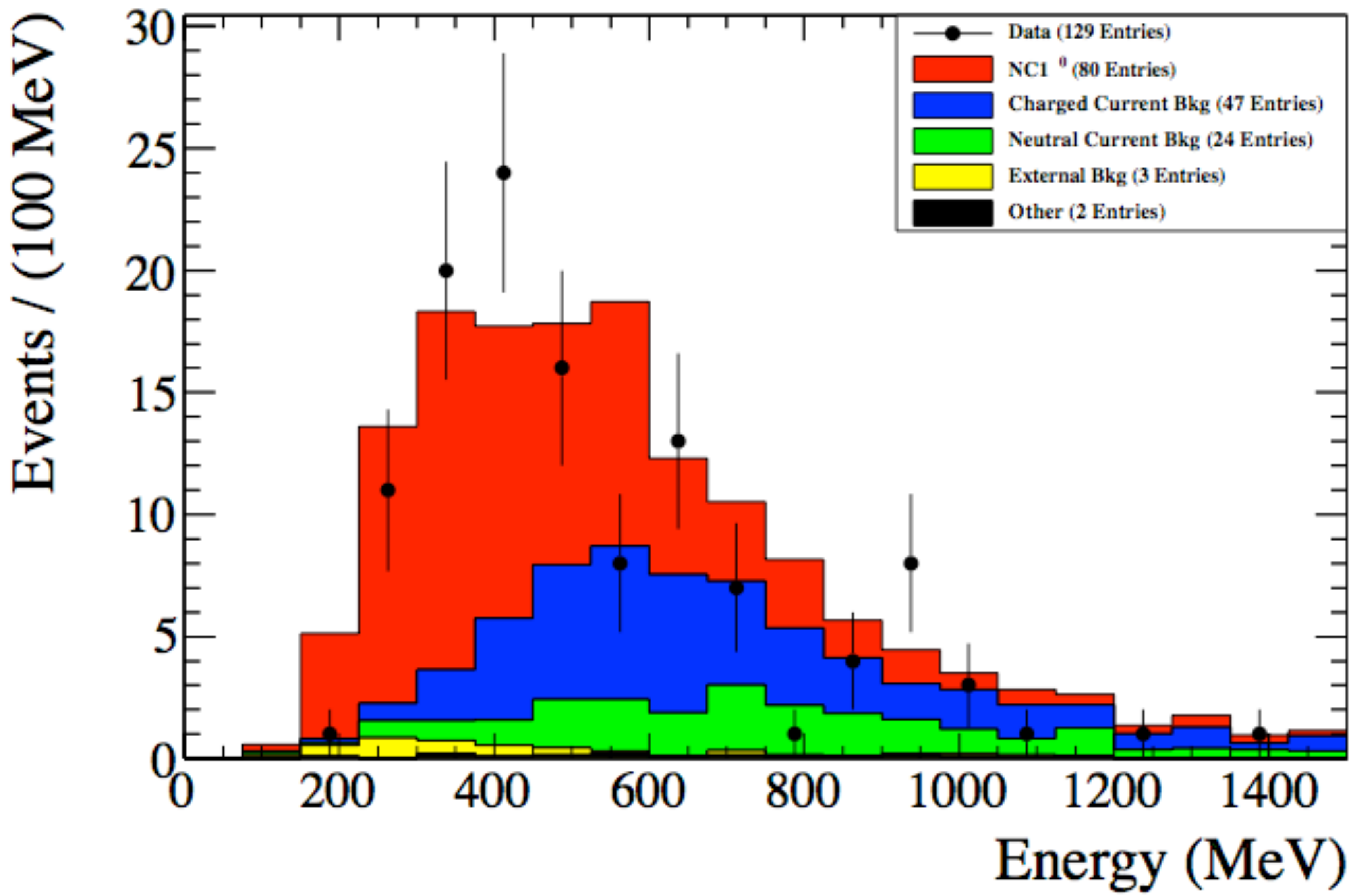
Vertex resolution



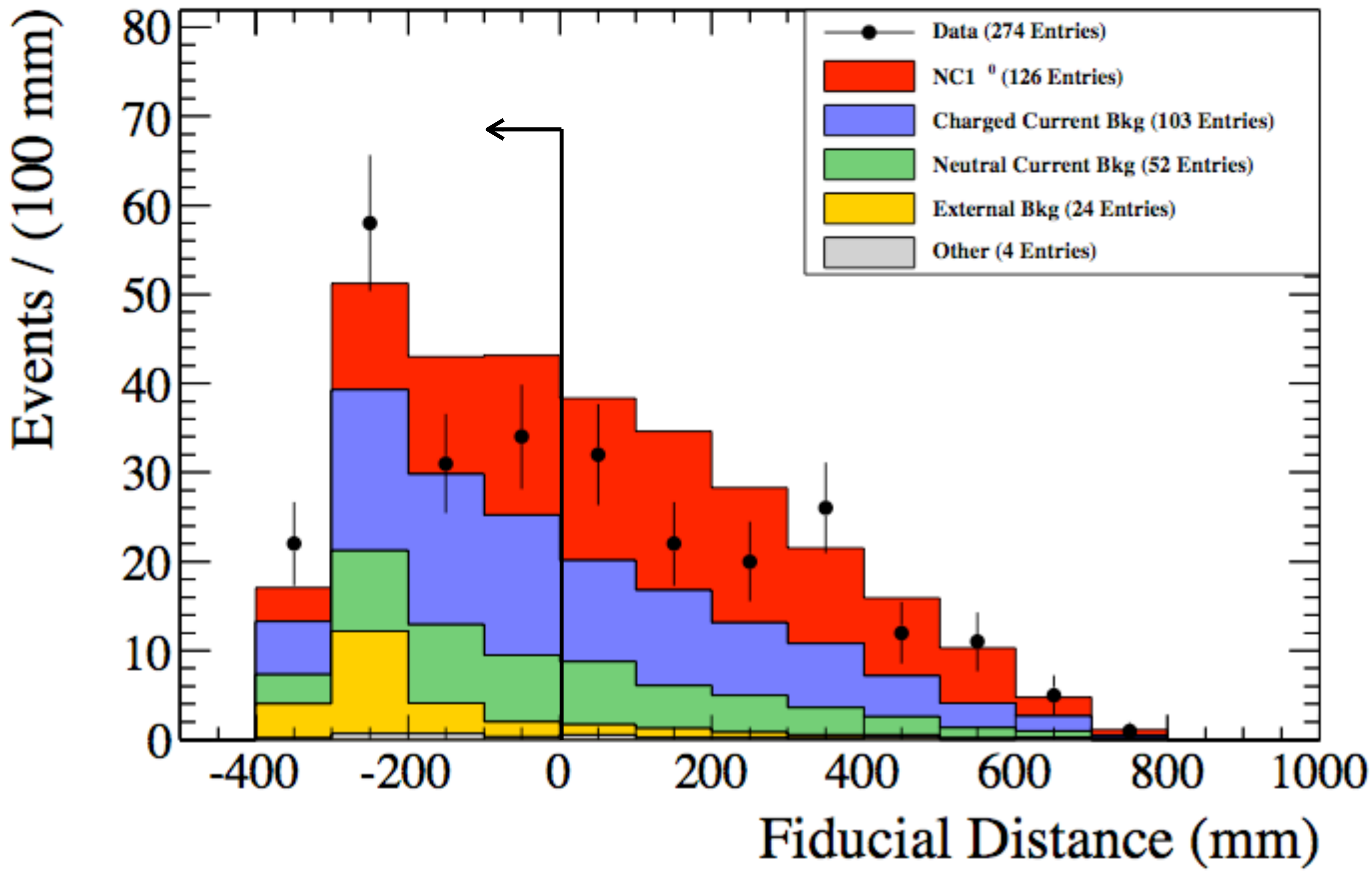




π^0 energy distribution



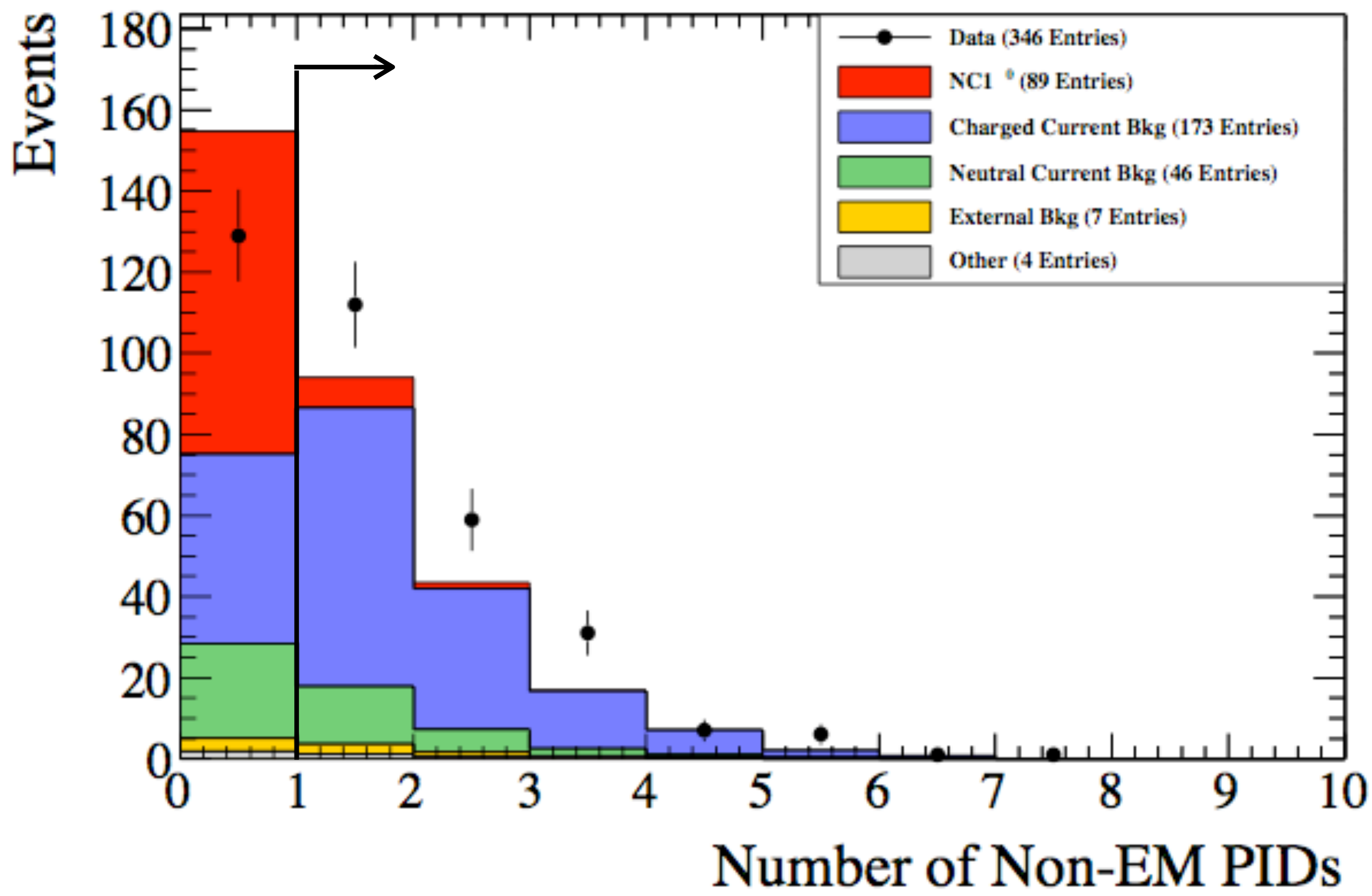
Fiducial Volume selection



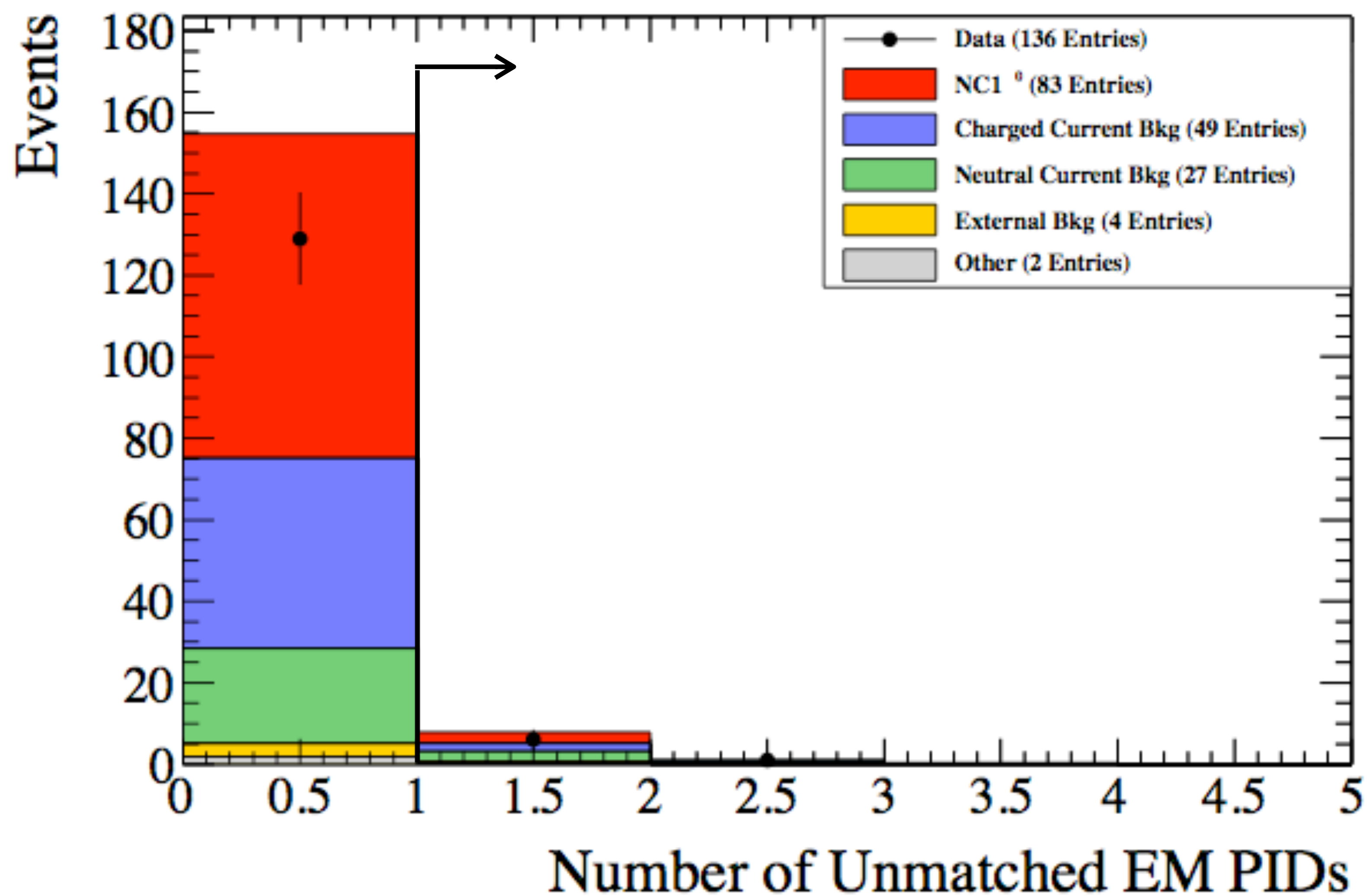
Distance from edge of fiducial volume (before cut)

Fiducial Volume				
Coordinate	Center	$\frac{Width}{2}$	Minimum	Maximum
X	-36	800	-836	764
Y	-1	870	-871	869
Z	-2116	852.5	-2969	-1264

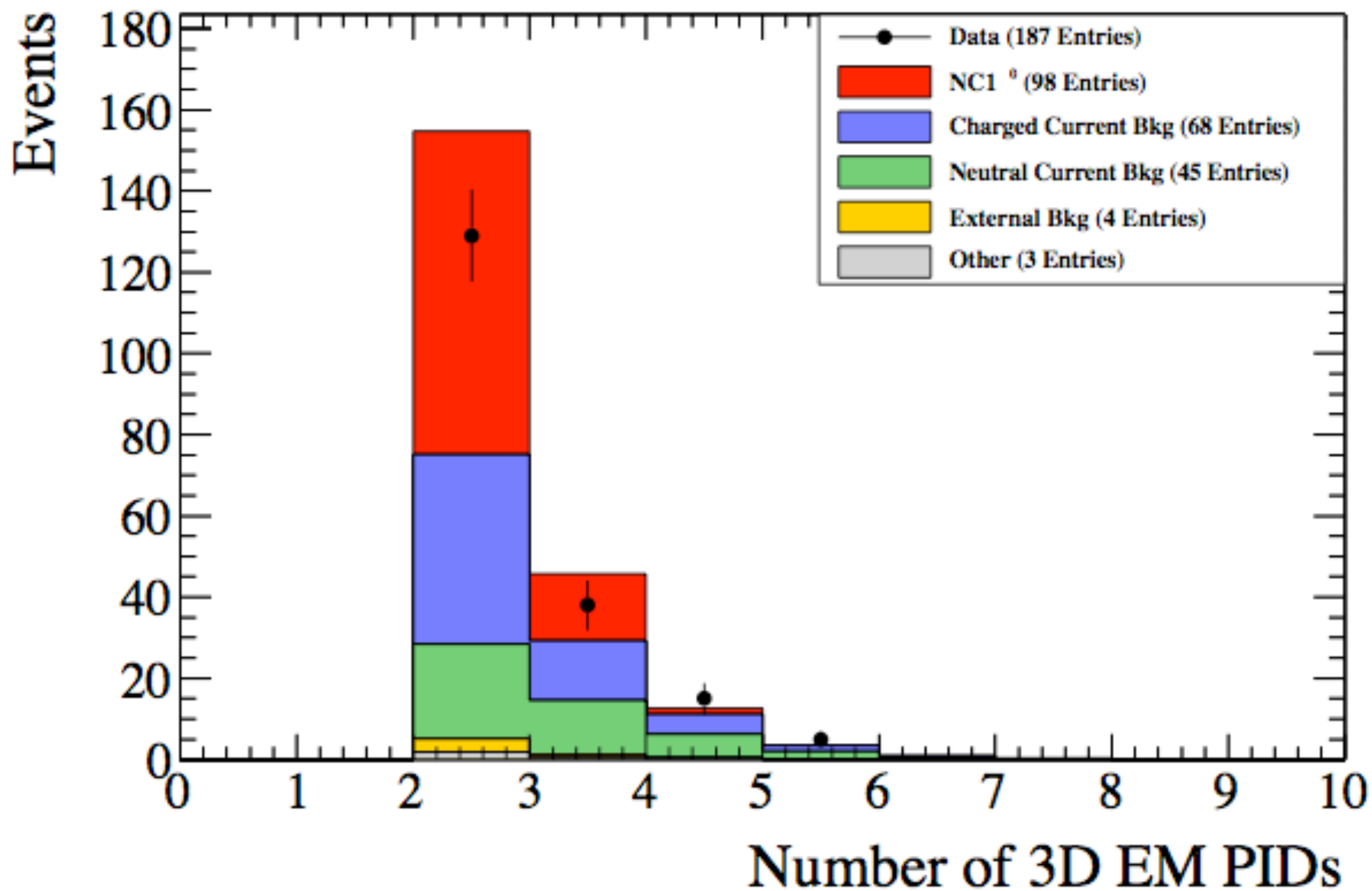
Non Electromagnetic signal



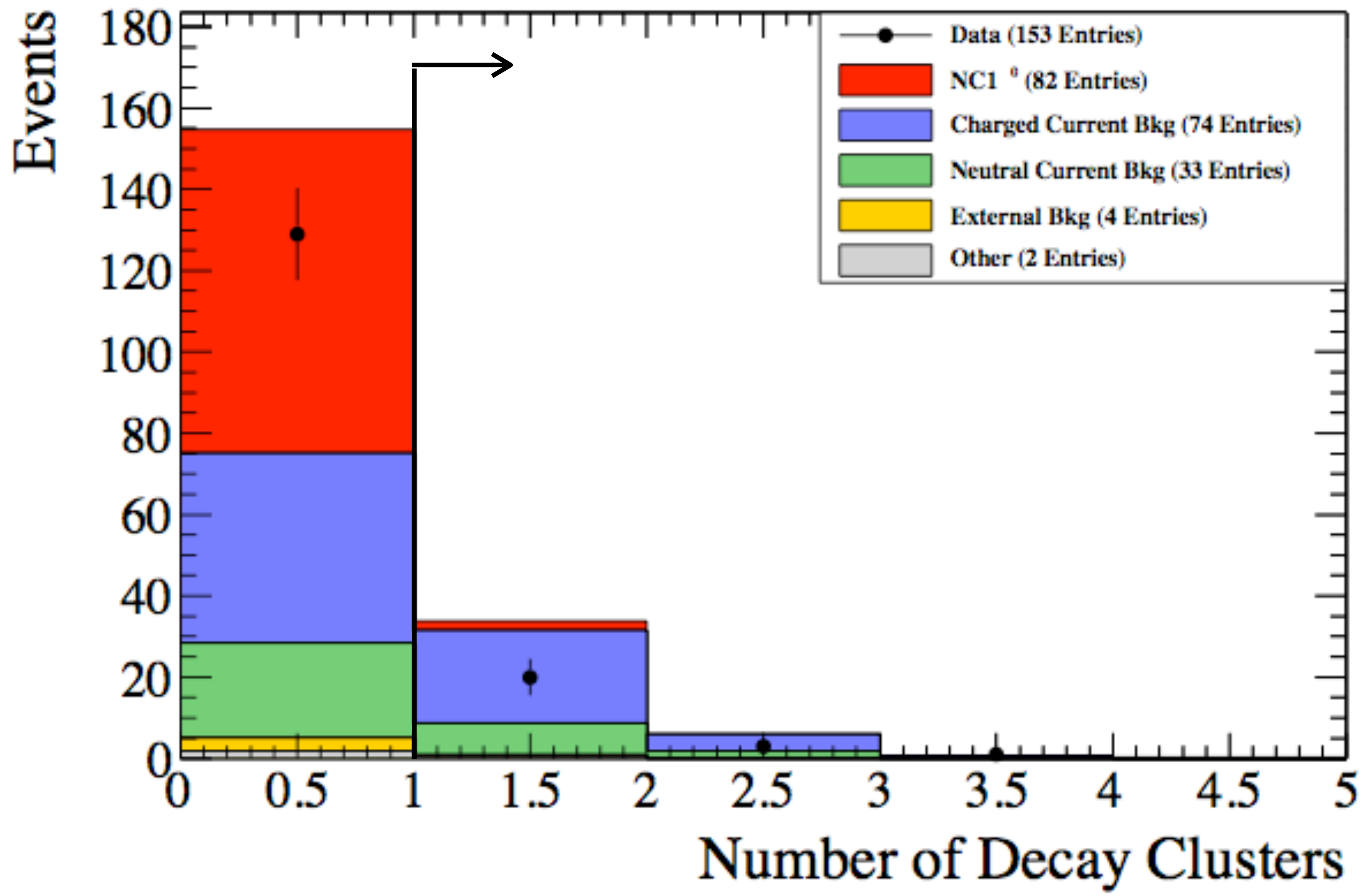
Muon decay cut



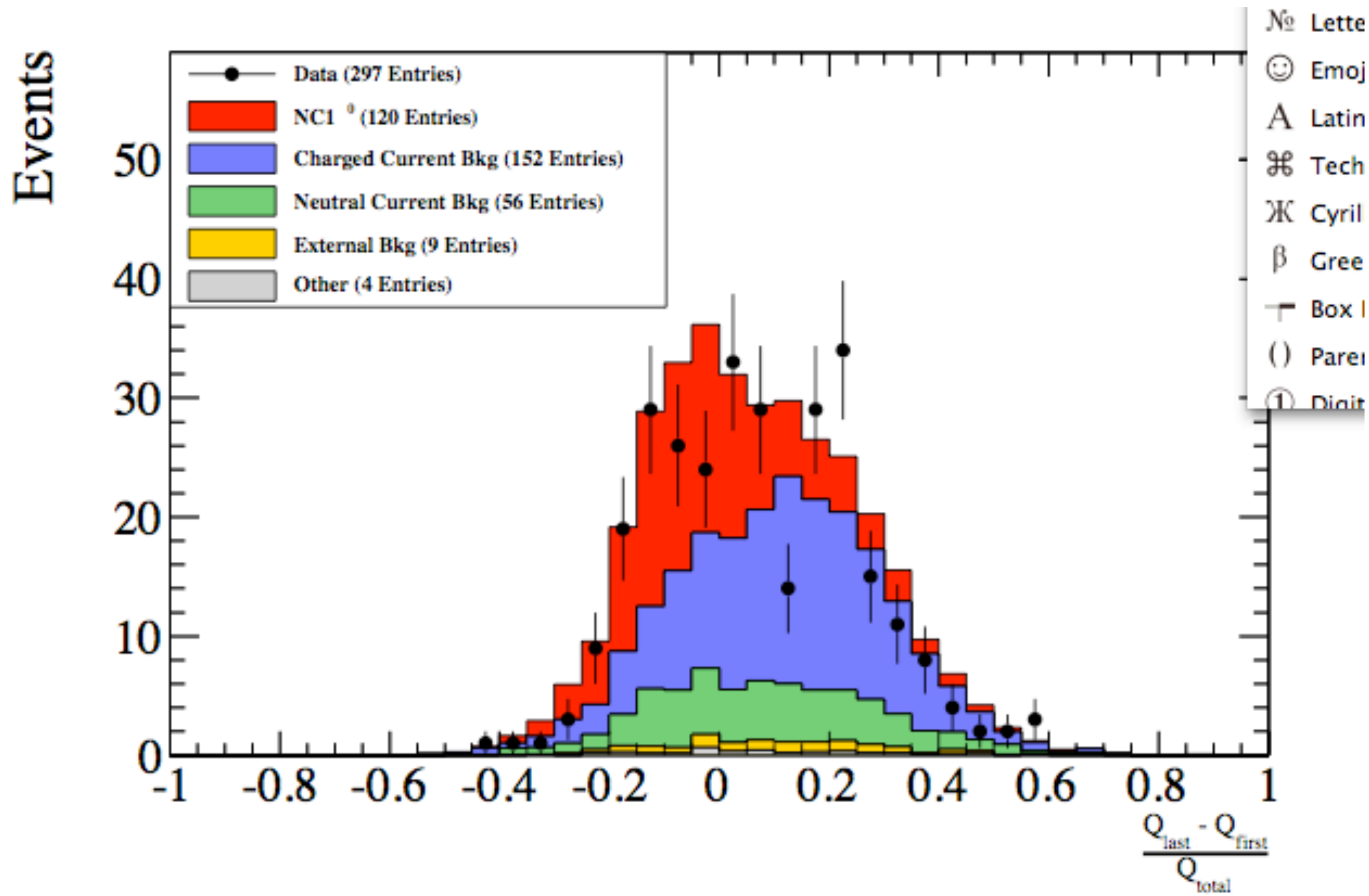
Number of 3D reconstructed EM showers



Muon Decay cut

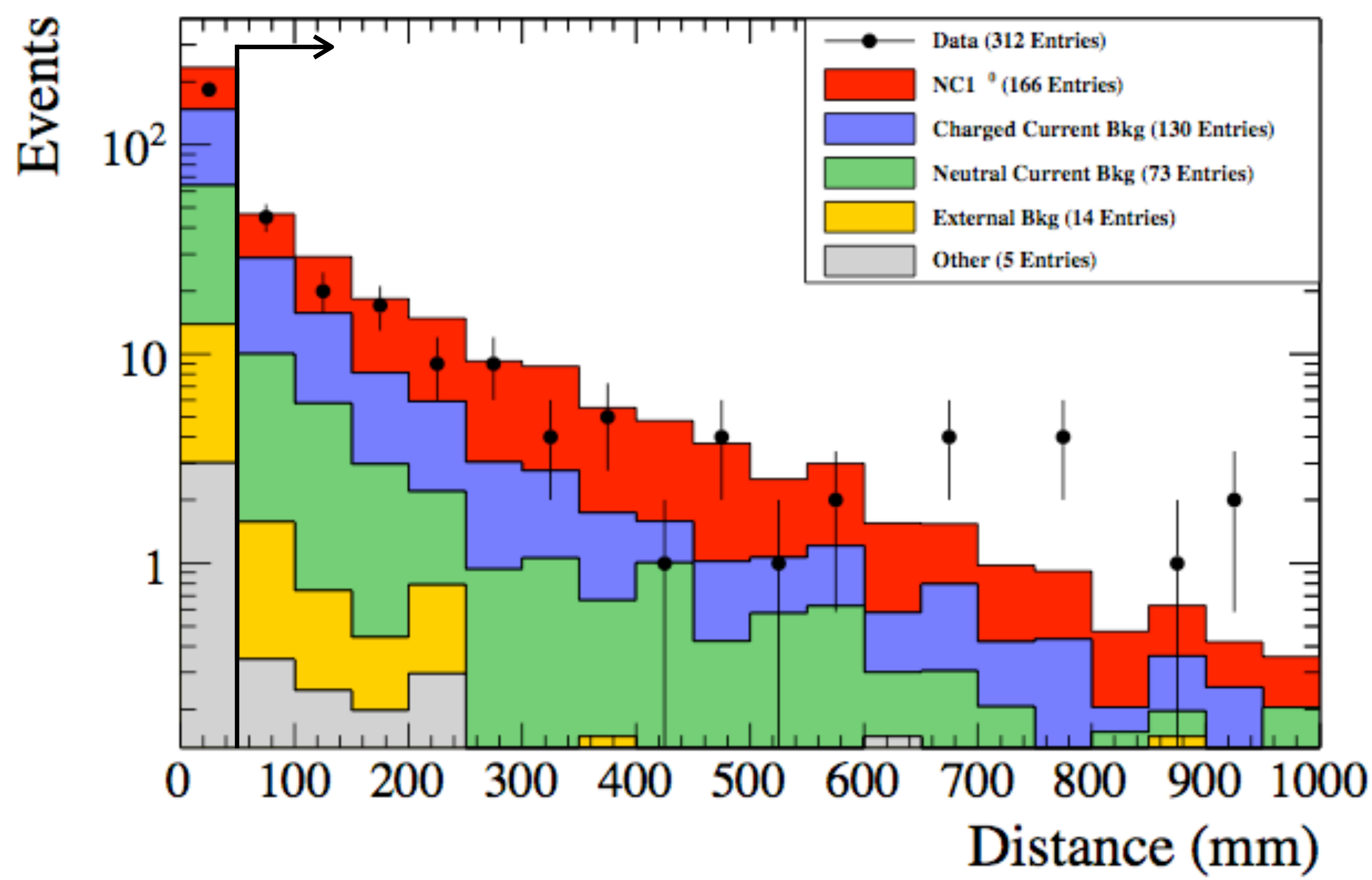


EM-like shower total charge

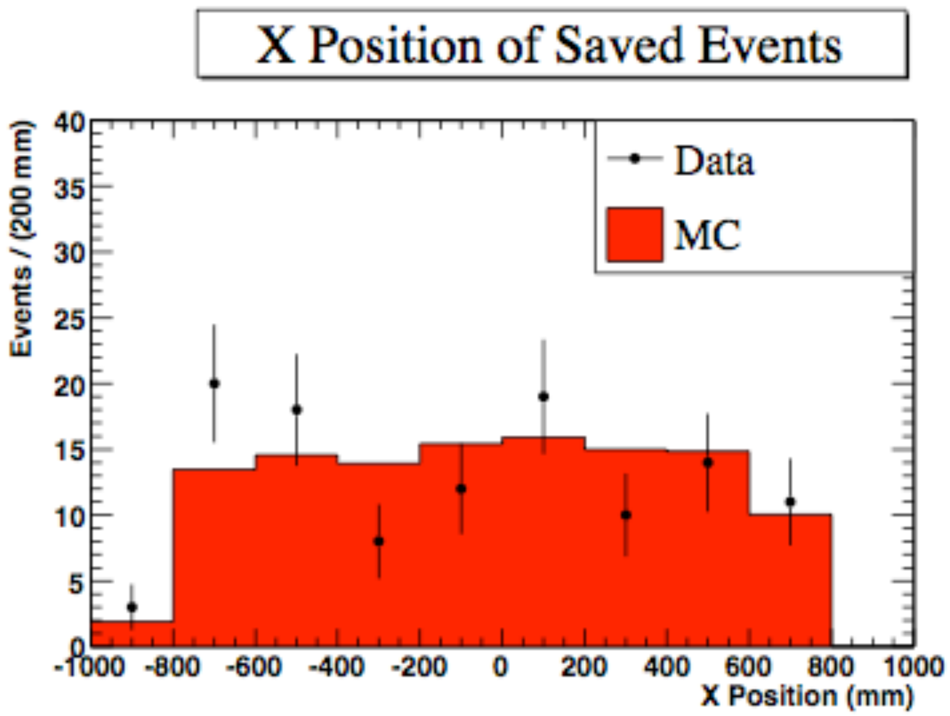


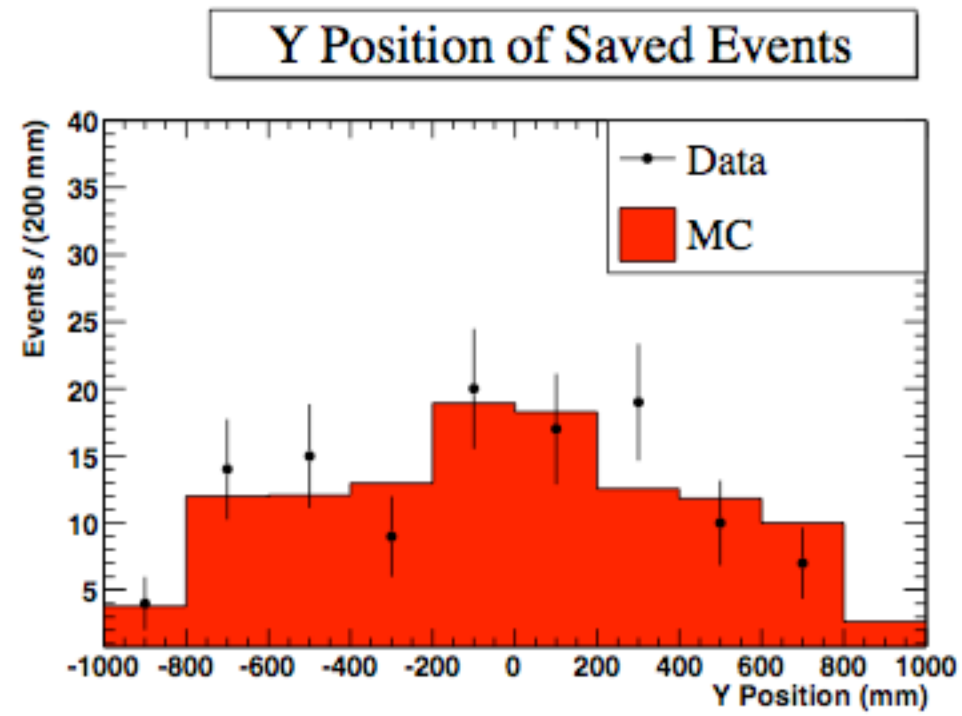
Fractional charge difference between first and last cluster

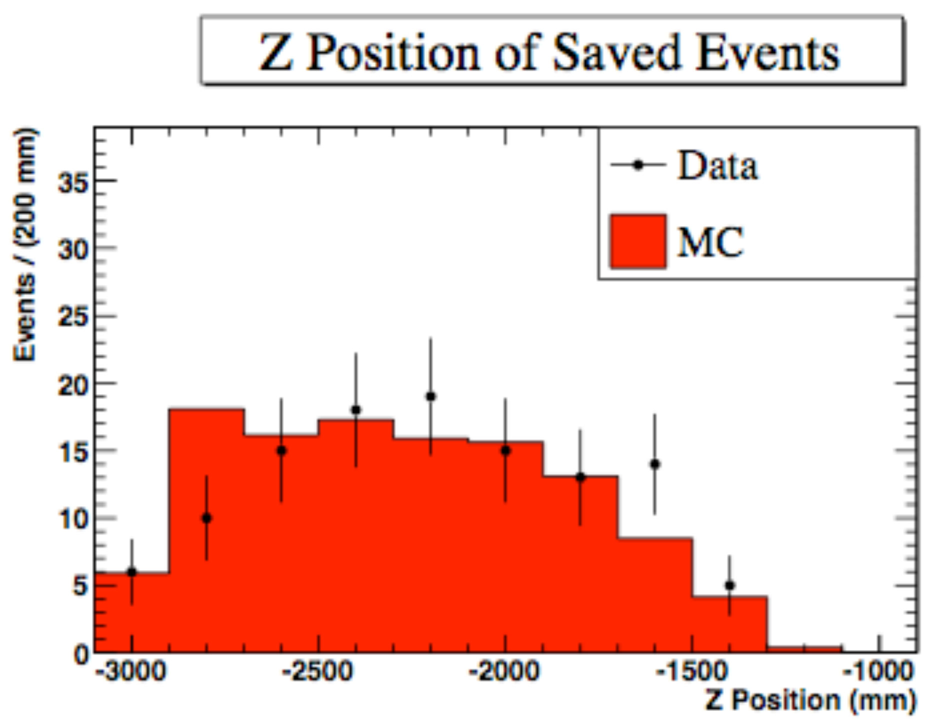
Distance of shower separation



Vertex distribution







Energy reconstruction