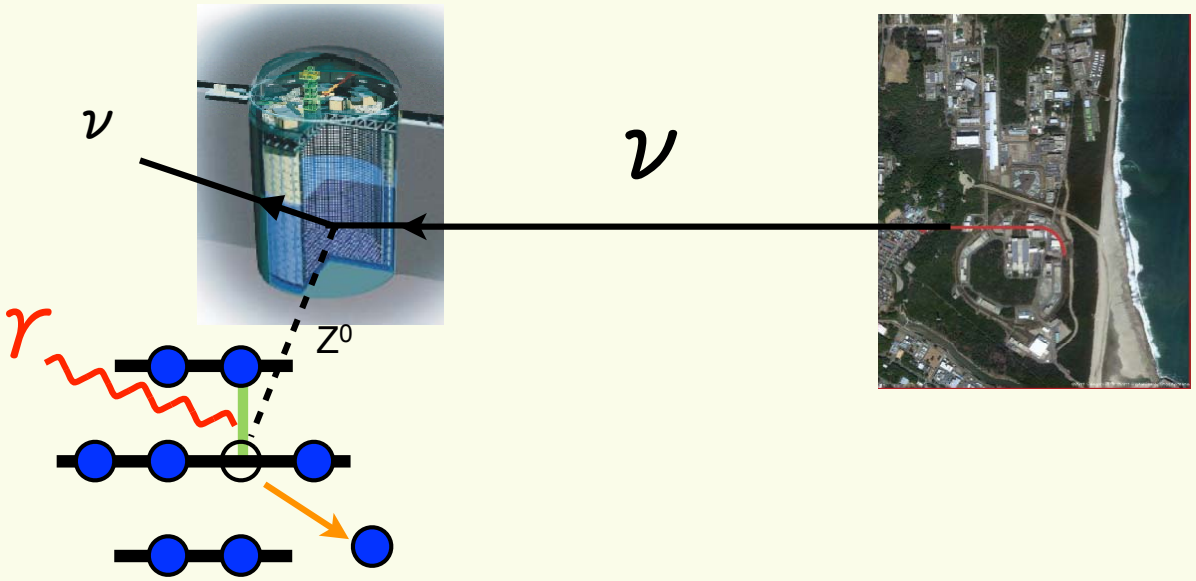
The observation of gamma rays via neutral current interaction at Super-Kamiokande using the T2K neutrino beam



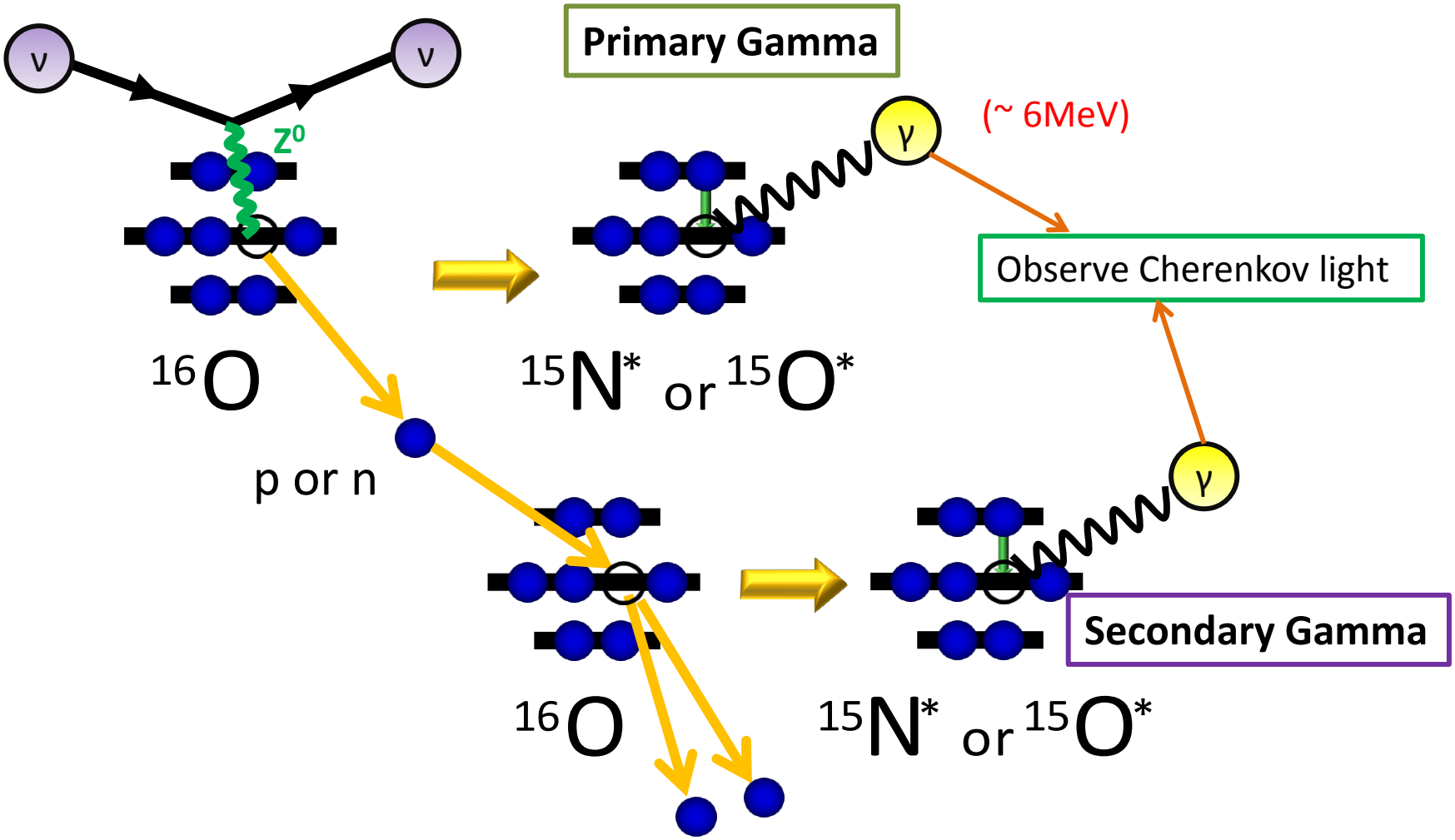
- Introduction
- Analysis
- Result
- Summary

Yusuke Koshio for T2K collaboration
Okayama university

NUFACT / 29th August, 2014

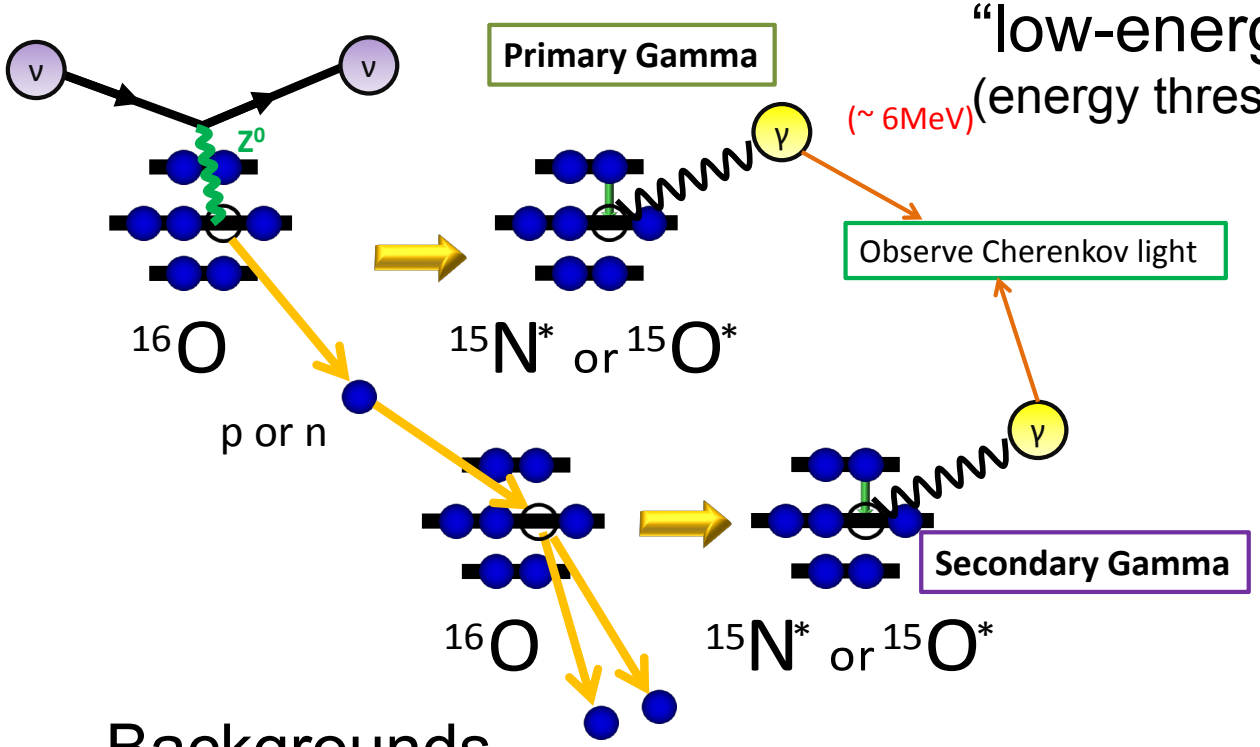
What is a target?

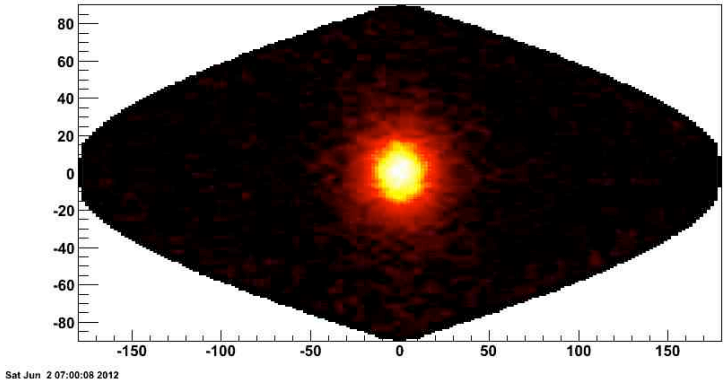
De-excitation gamma ray after NCQE interaction



Signal and Background

Signal : ~6MeV gammas
possible to observe in Super-K
"low-energy" sample
(energy threshold is 3.5MeV for solar neutrinos)



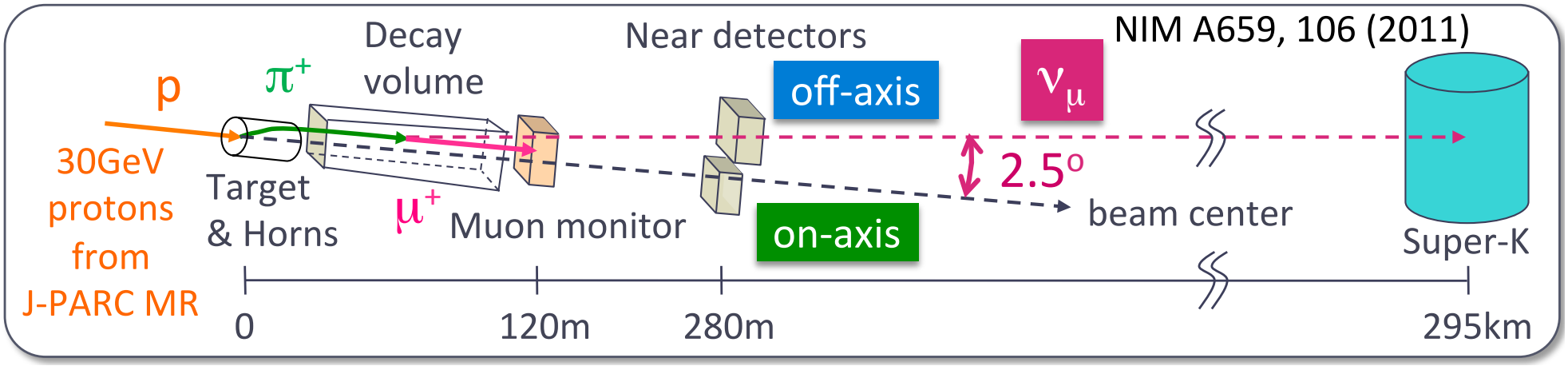


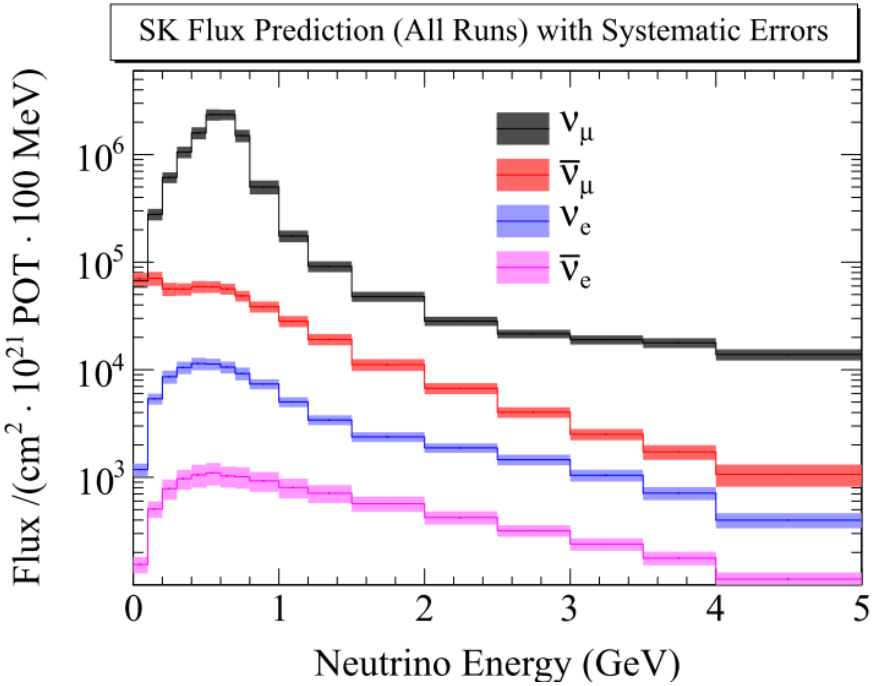
Backgrounds
- ν beam related : NC-other interactions, CC interactions.
- ν beam un-related : gamma rays from radioactive impurity, decay-e, etc.

Motivation

- ✓ No previous measurement of Neutral Current Quasi-Elastic (NCQE) scattering on oxygen at hundreds of MeV with de-excitation gamma rays.
- ✓ Gamma rays produced by atmospheric neutrinos are one of the main background in supernova relic neutrino search in Super-K.
- ✓ NC samples can be used to search for sterile neutrino oscillations.
- ✓ The similar sample used in this “low-energy” sample can also be used to search for low-mass dark matter.

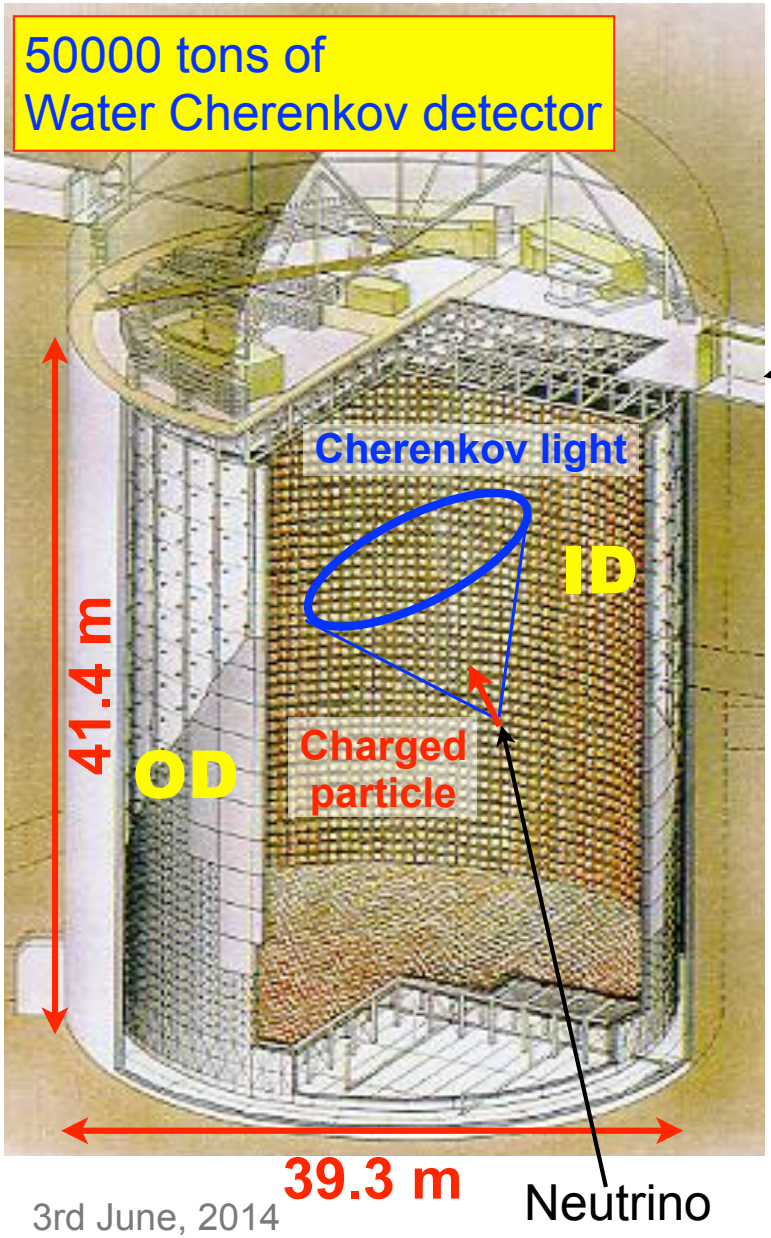
T2K experiment

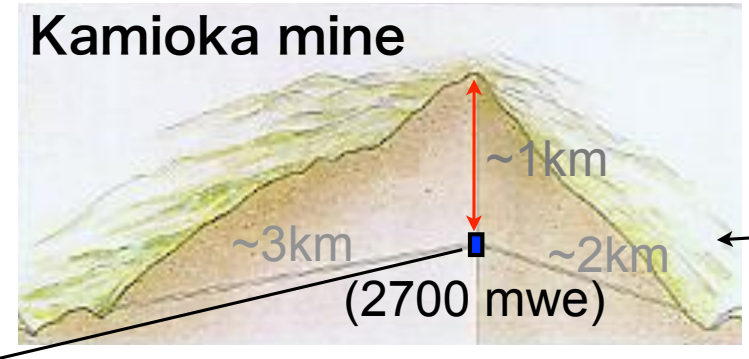




- ✓ Off-axis (2.5 degree) beam
- ✓ Energy peak is at 630MeV
- ✓ NCQE interactions are dominant in the NC samples in this energy region's NC sample in T2K-SK data.

Super-Kamiokande

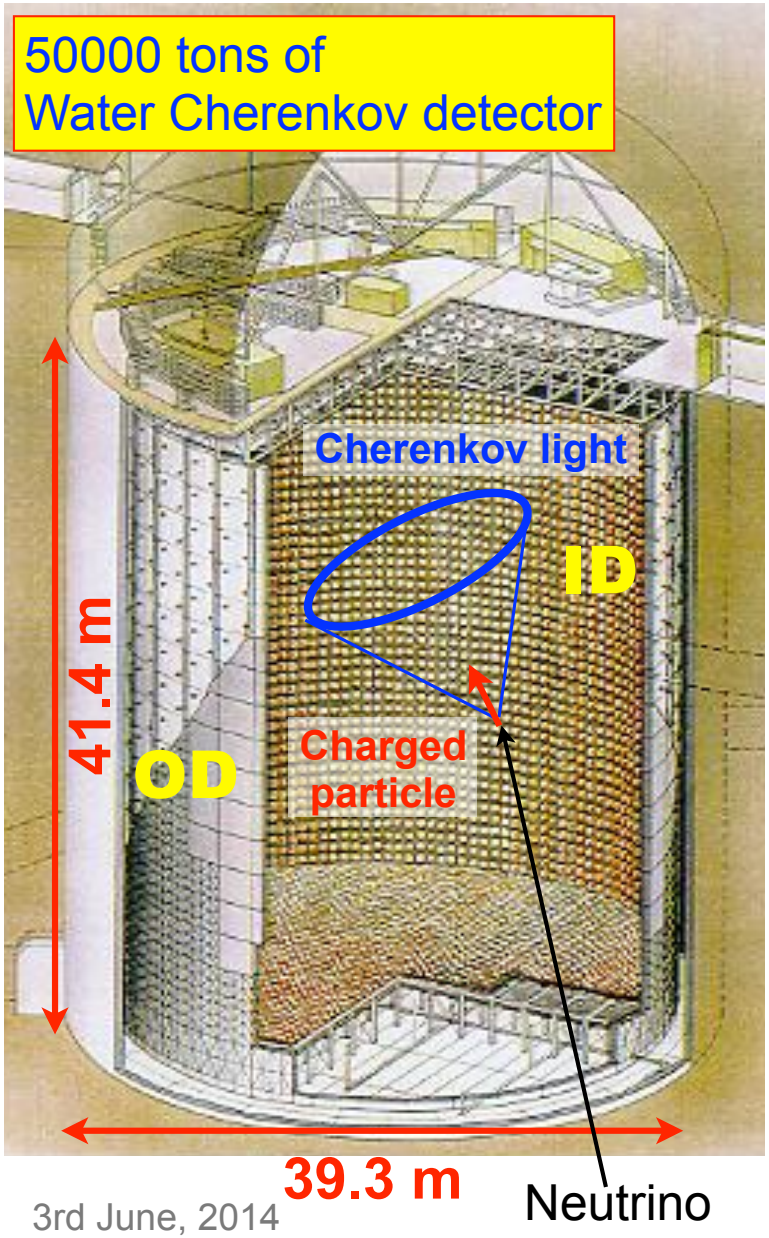




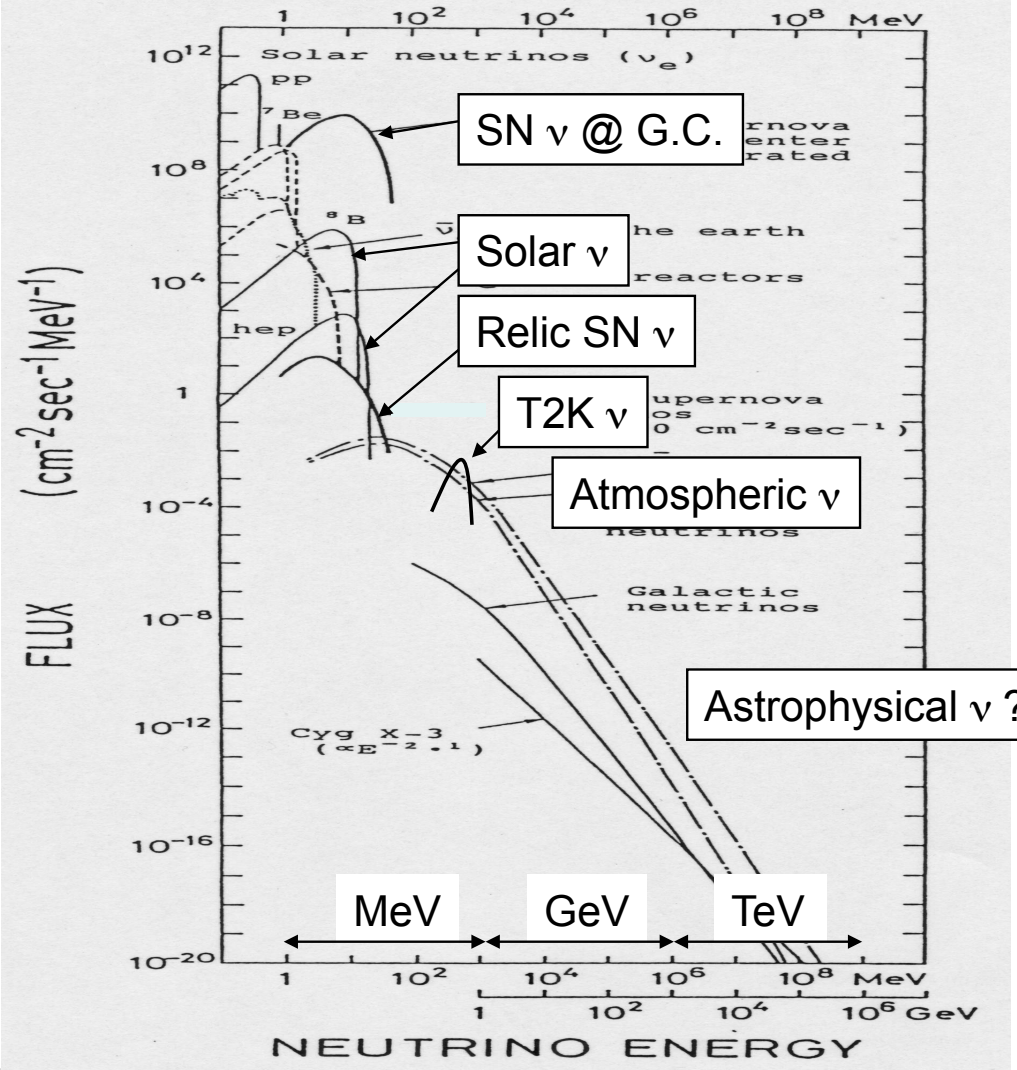
Phase	Period	# of PMTs (coverage)	Energy threshold (MeV)
SK-I	1996.4 ~ 2001.7	11146 (40%)	4.5
SK-II	2002.10 ~ 2005.10	5182 (20%)	6.5
SK-III	2006.7 ~ 2008.8	**11129 (40%)**	4.5
SK-IV	**2008.9 ~**		**3.5**

New electronics system had been installed before T2K started.

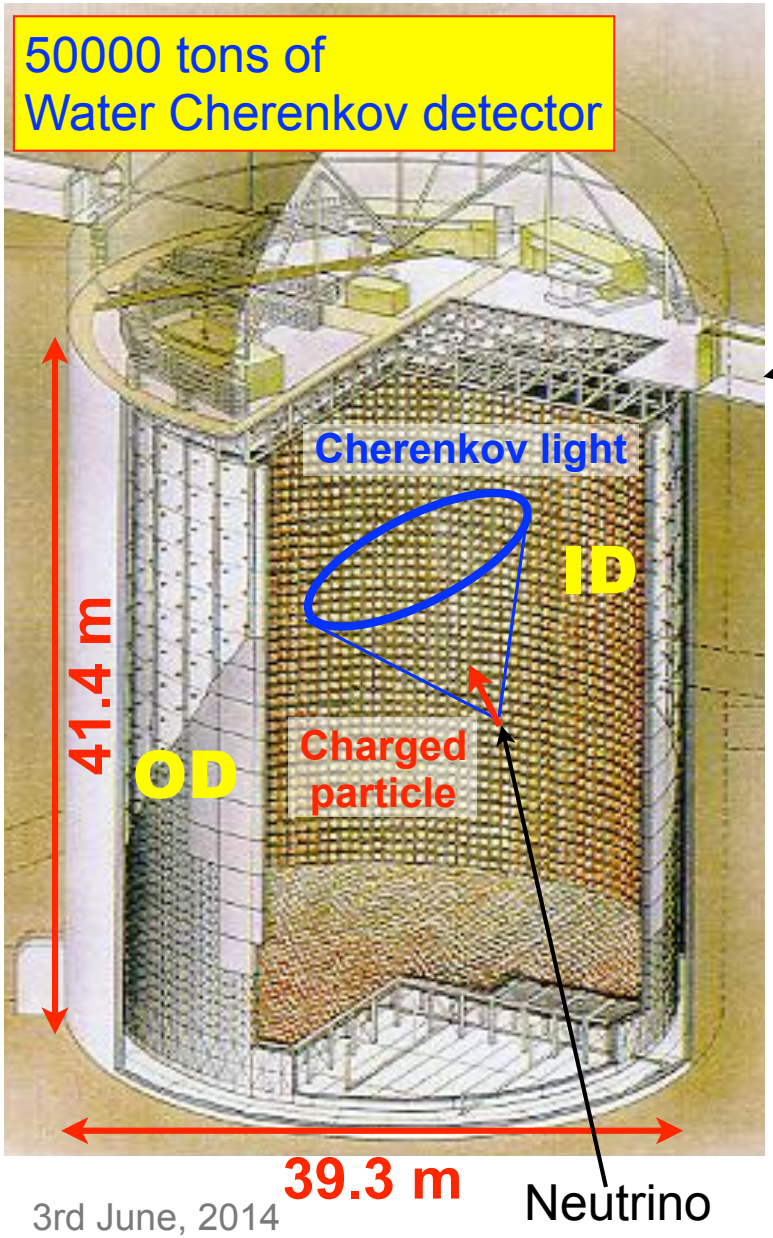
Super-Kamiokande

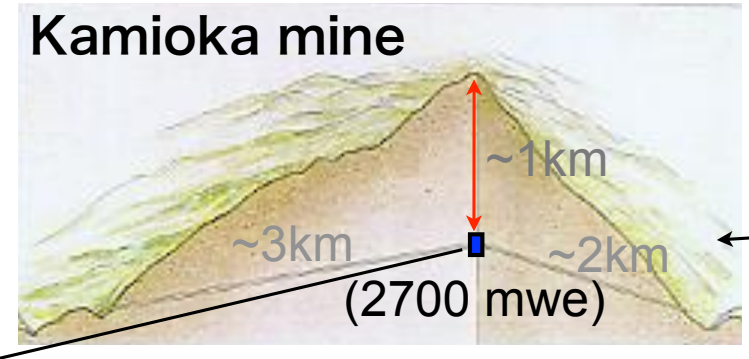


Multi-purpose detector



Super-Kamiokande

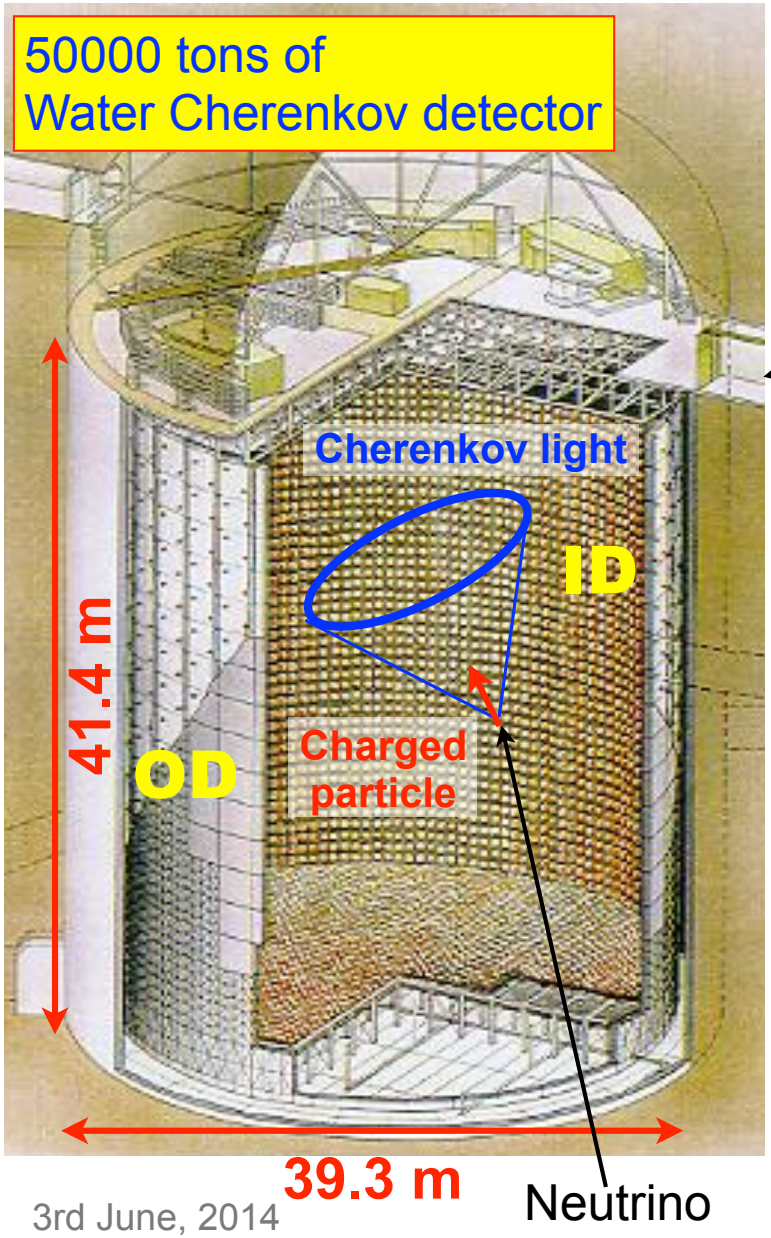


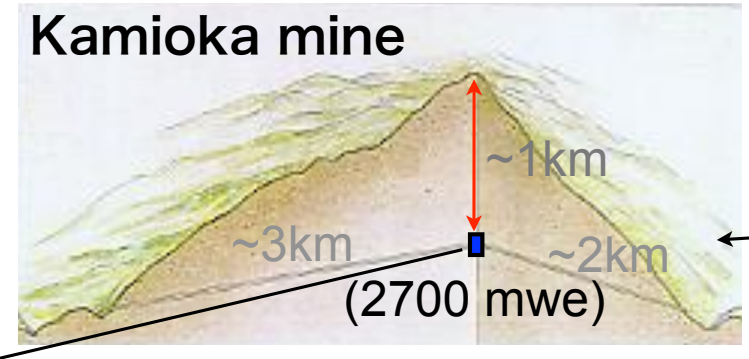


Phase	Period	# of PMTs (coverage)	Energy threshold (MeV)
SK-I	1996.4 ~ 2001.7	11146 (40%)	4.5
SK-II	2002.10 ~ 2005.10	5182 (20%)	
SK-III	2006.7 ~ 2008.8	**11129 (40%)**	
SK-IV	**2008.9 ~**		**3.5**

New electronics system had been installed before T2K started.

Super-Kamiokande



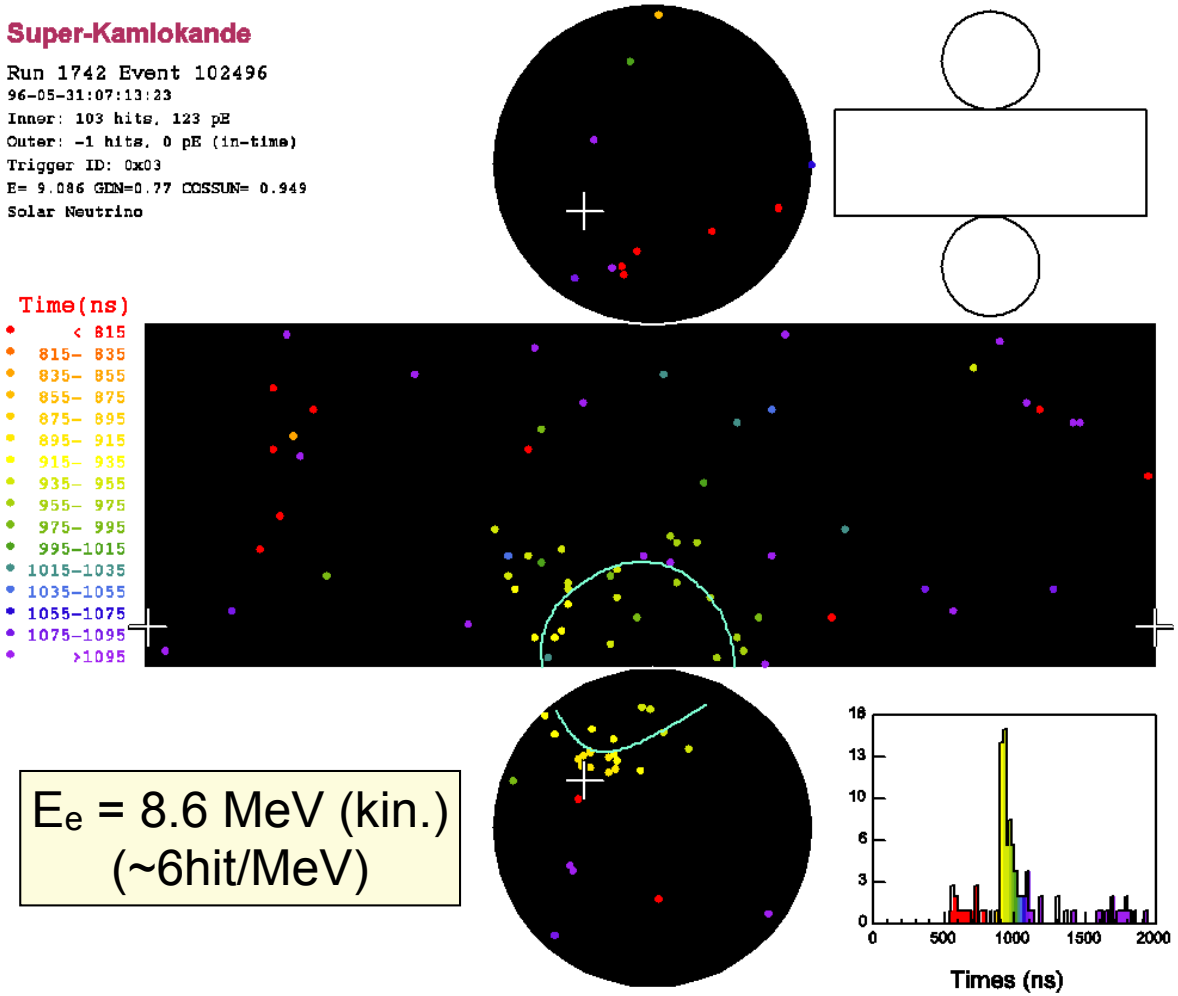


Phase	Period	# of PMTs (coverage)	Energy threshold (MeV)
SK-I	1996.4 ~ 2001.7	11146 (40%)	4.5
SK-II	2002.10 ~ 2005.10	5182 (20%)	6.5
SK-III	2006.7 ~ 2008.8	**11129 (40%)**	4.5
SK-IV	**2008.9 ~**		**3.5**

New electronics system had been installed before T2K started.

“Low energy” events in Super-K

Typical event



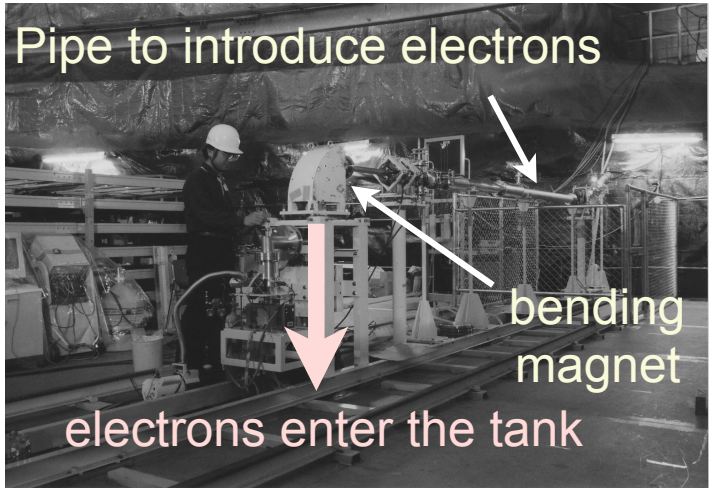
E_e = 8.6 MeV (kin.)
(~6hit/MeV)

Detector performance

	resolution (10 MeV)	information
vertex	55cm	hit timing
direction	23deg.	hit pattern
energy	14%	# of hits.

well calibrated by LINAC and DT
within 0.5% precision

LINAC system over there



Top of the Suer-K tank

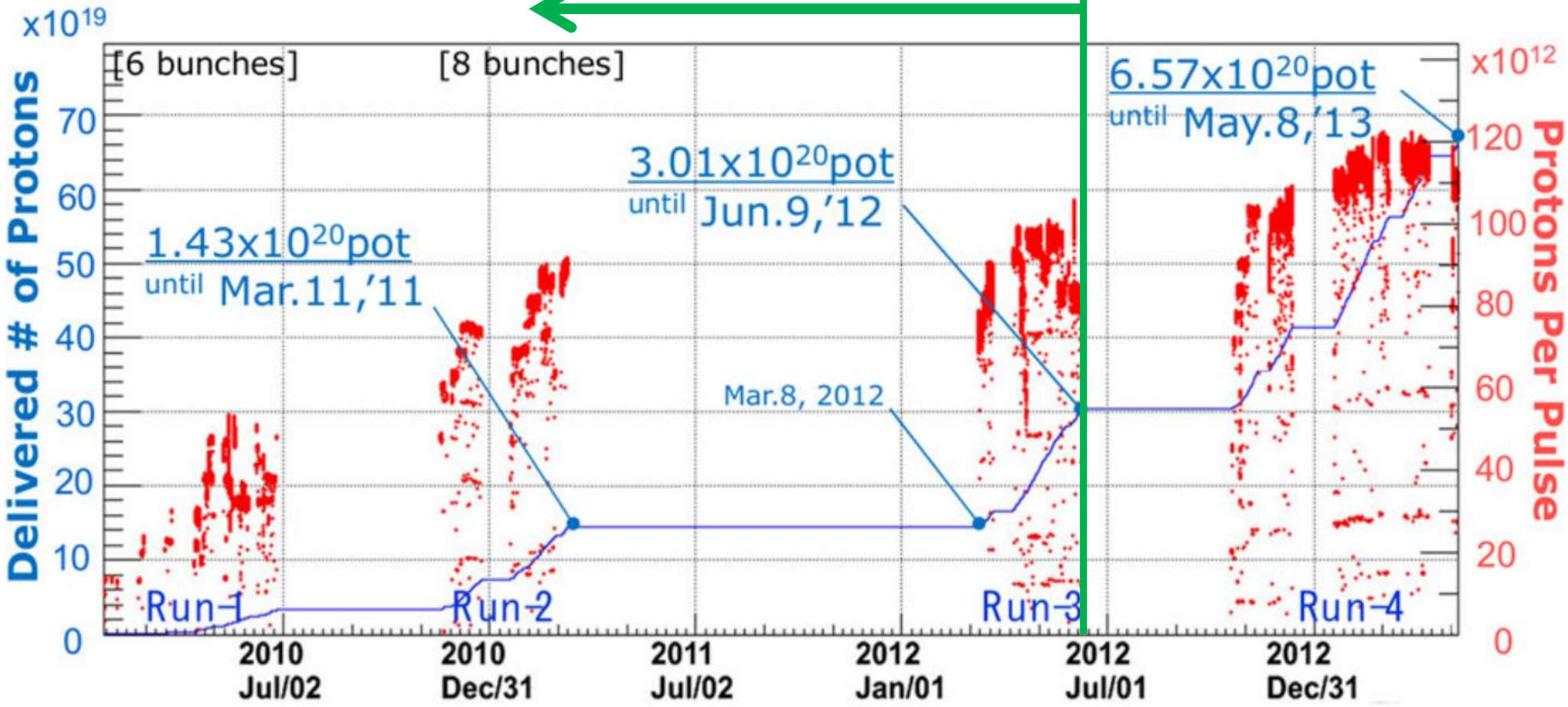
MC production

1. Neutrino flux : simulated with FLUKA & Geant3, constrained by monitoring and external experiments.
2. NEUT : Spectral function model(Ankowski et. al.*) for NCQE scattering and gamma ray generation.
3. Detector simulation : Geant3, GCALOR to simulate Cherenkov photons and neutrons which produce secondary gamma rays.

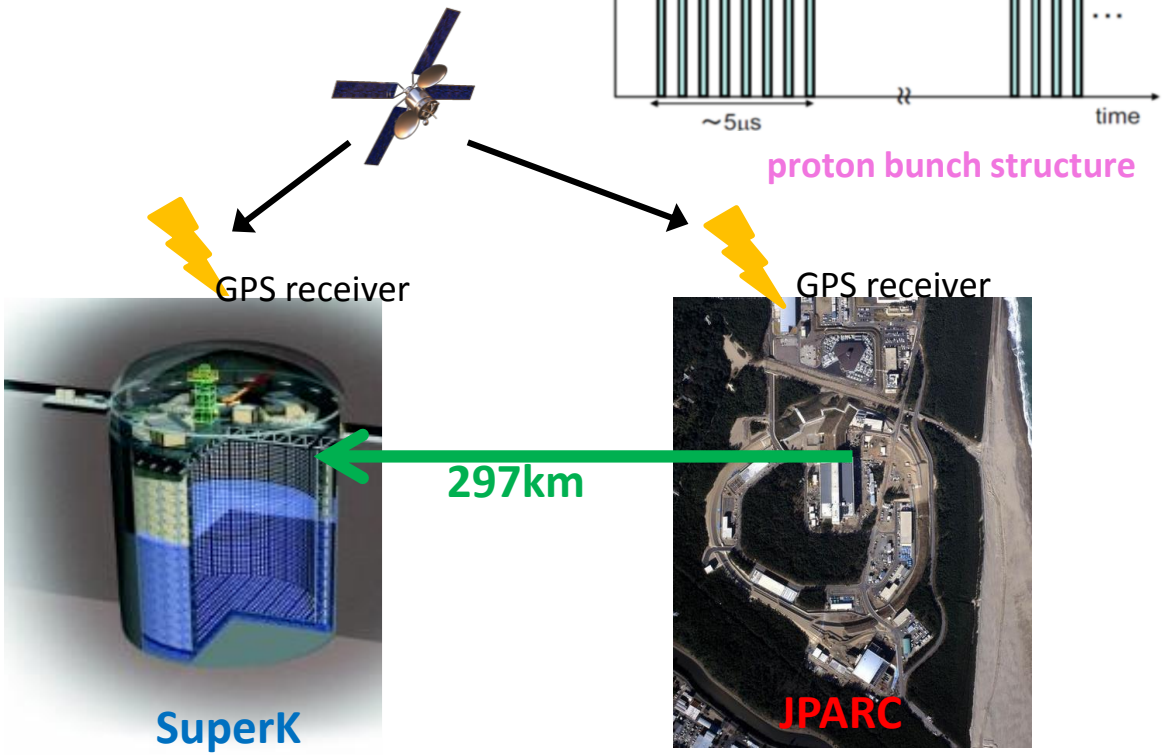
(*) Theoretical calculation of the cross section for nucleon knockout in oxygen by neutrino above 100MeV
Physical Review Letter 108, 052505 (2012)

Data set for this analysis

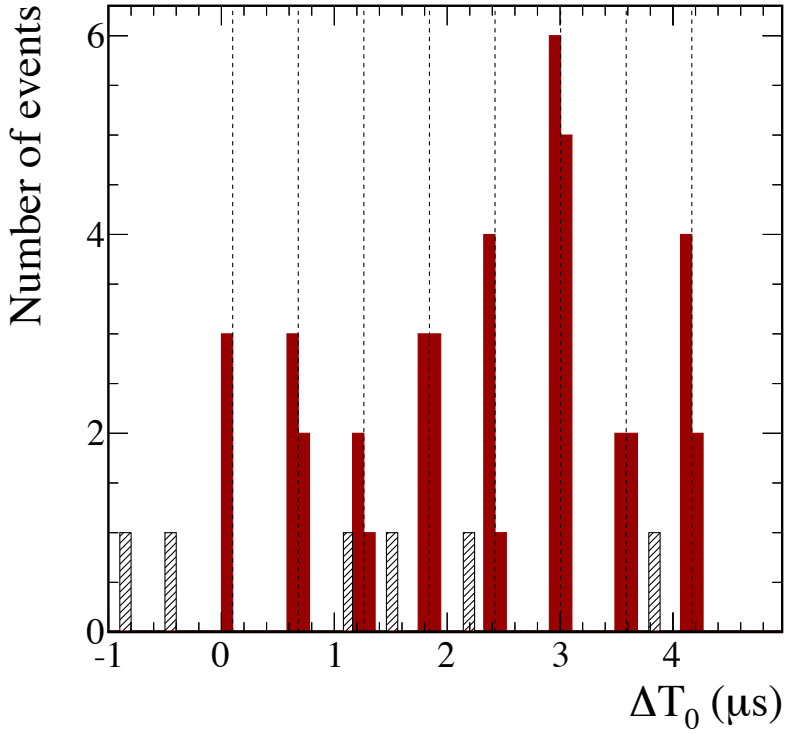
Run1~3 data result are
analyzed and reported here.



Neutrino beam spill structure

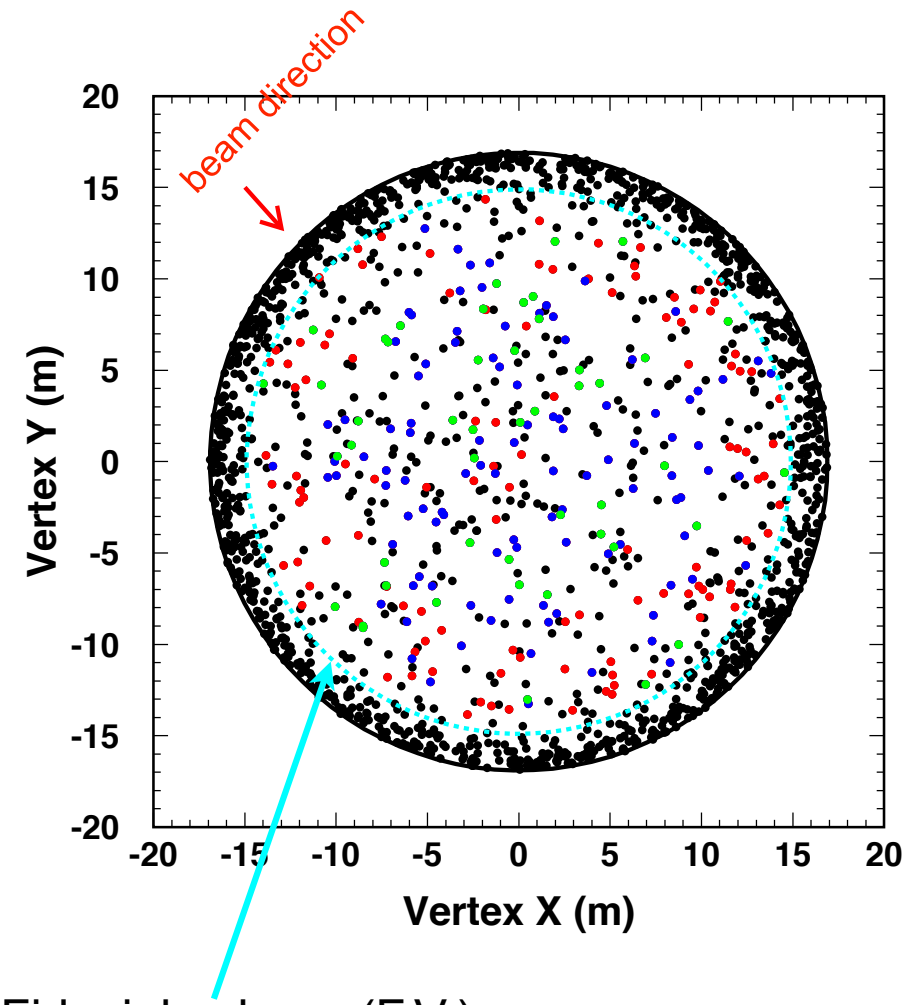


proton bunch structure

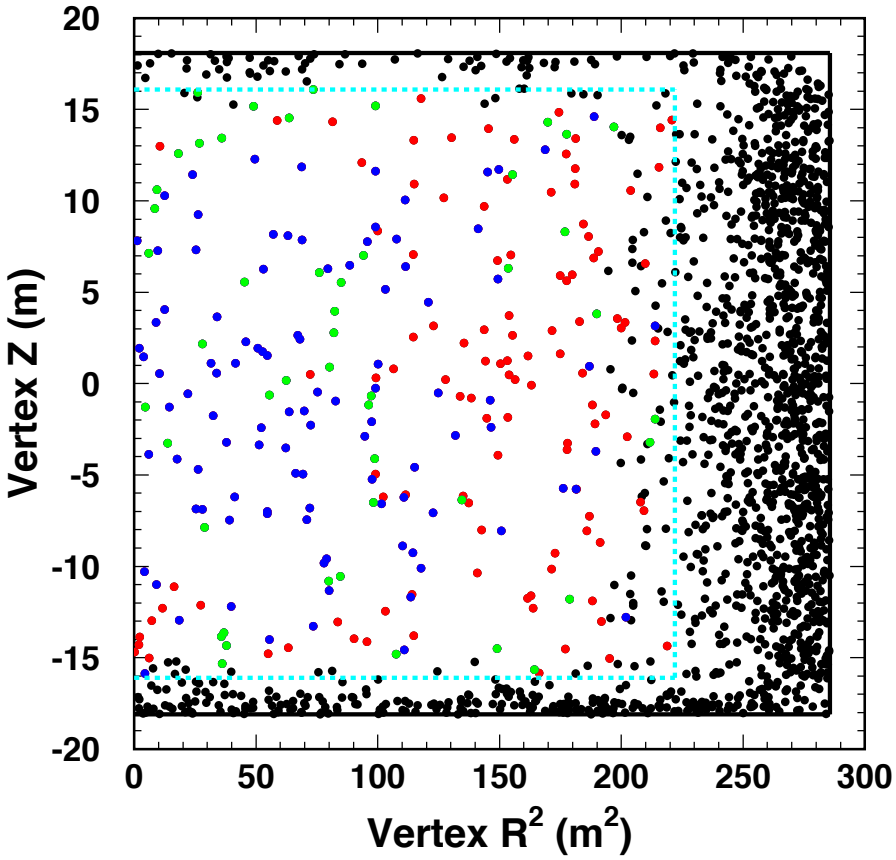


Only events within ±100ns from the bunch are used to reduce radioactive background.

Vertex distribution

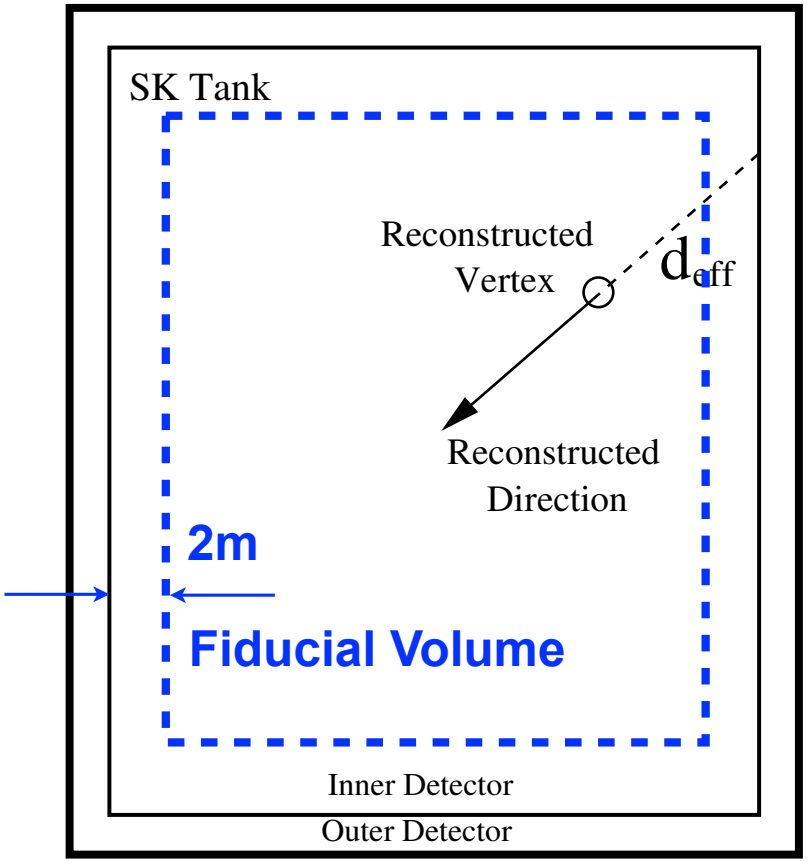


Fiducial volume (F.V.)
2m from the wall



Black : Before FV cut, Red : After tight FV cut,
Blue : gamma cut, Green : Fit quality cut

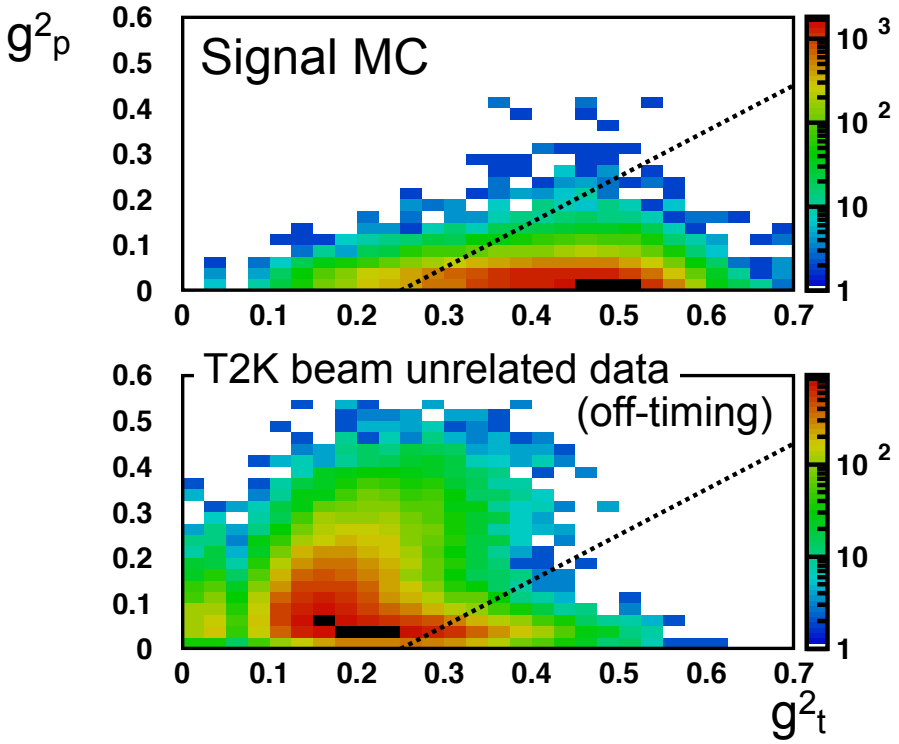
Reduction of gamma rays from radioactive impurity

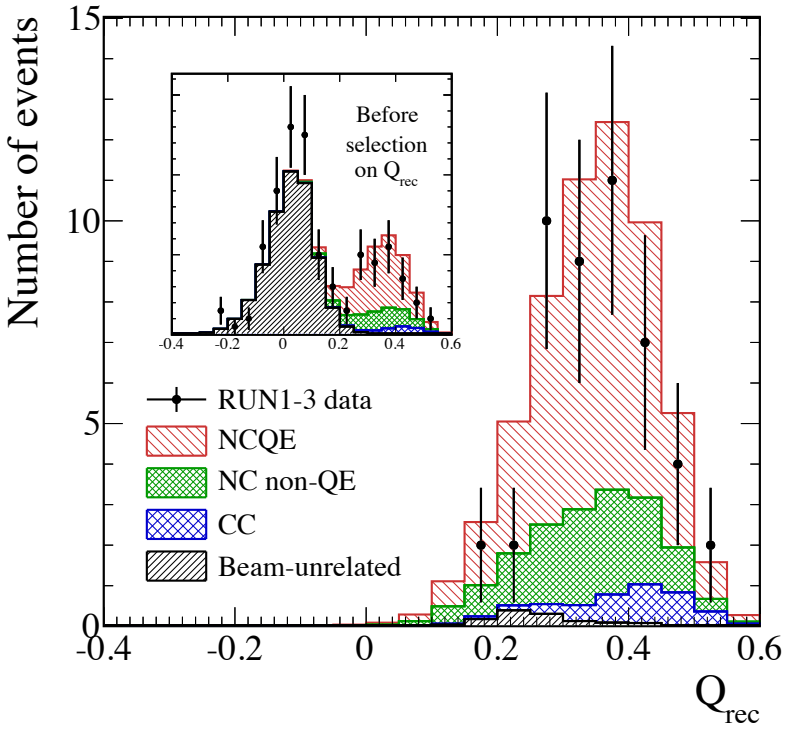


- ✓ Super-K PMT&Cover contain radioactive impurity.
- ✓ Rock around Super-K, too.
- ✓ The following cuts are applied
  - 2m from the wall (FV cut)
  - tight FV cut, which depends on energy, events with lower energy are tighter cut in E<5MeV.
  - “effective distance” from the wall cut, which also depends on energy.

Fit quality cut

- ✓ Some of beam unrelated background are remained because of the mis-reconstructed.
- ✓ The fit quality value $Q_{rec}=g^2_t - g^2_p$ is effective to remove those backgrounds.

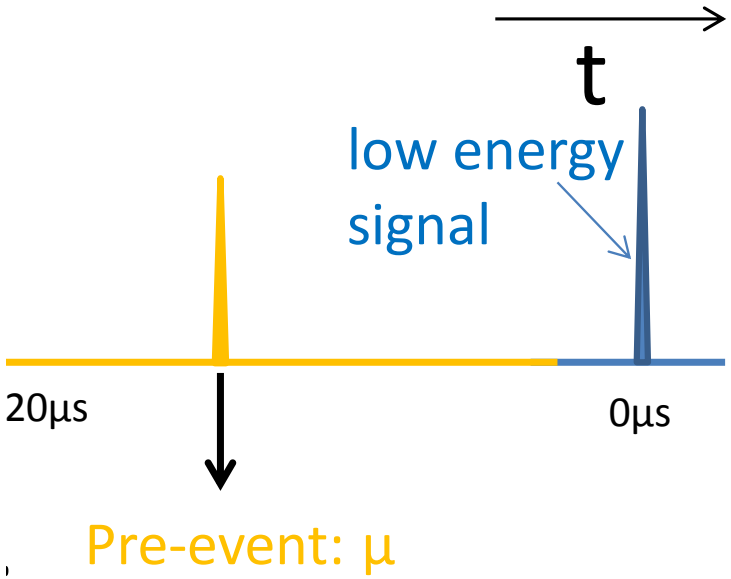




Other reductions

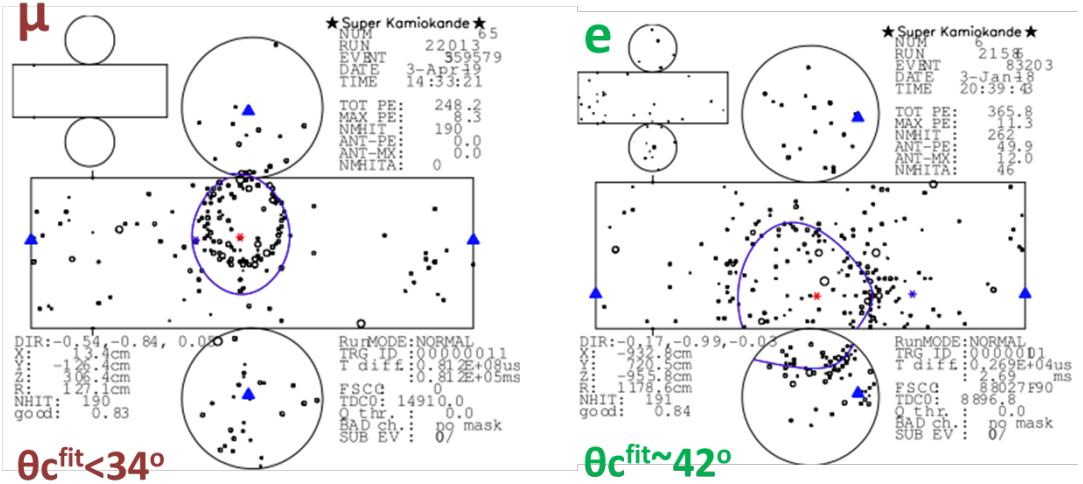
Pre-event cut

Remove decay electron from CC interaction muon

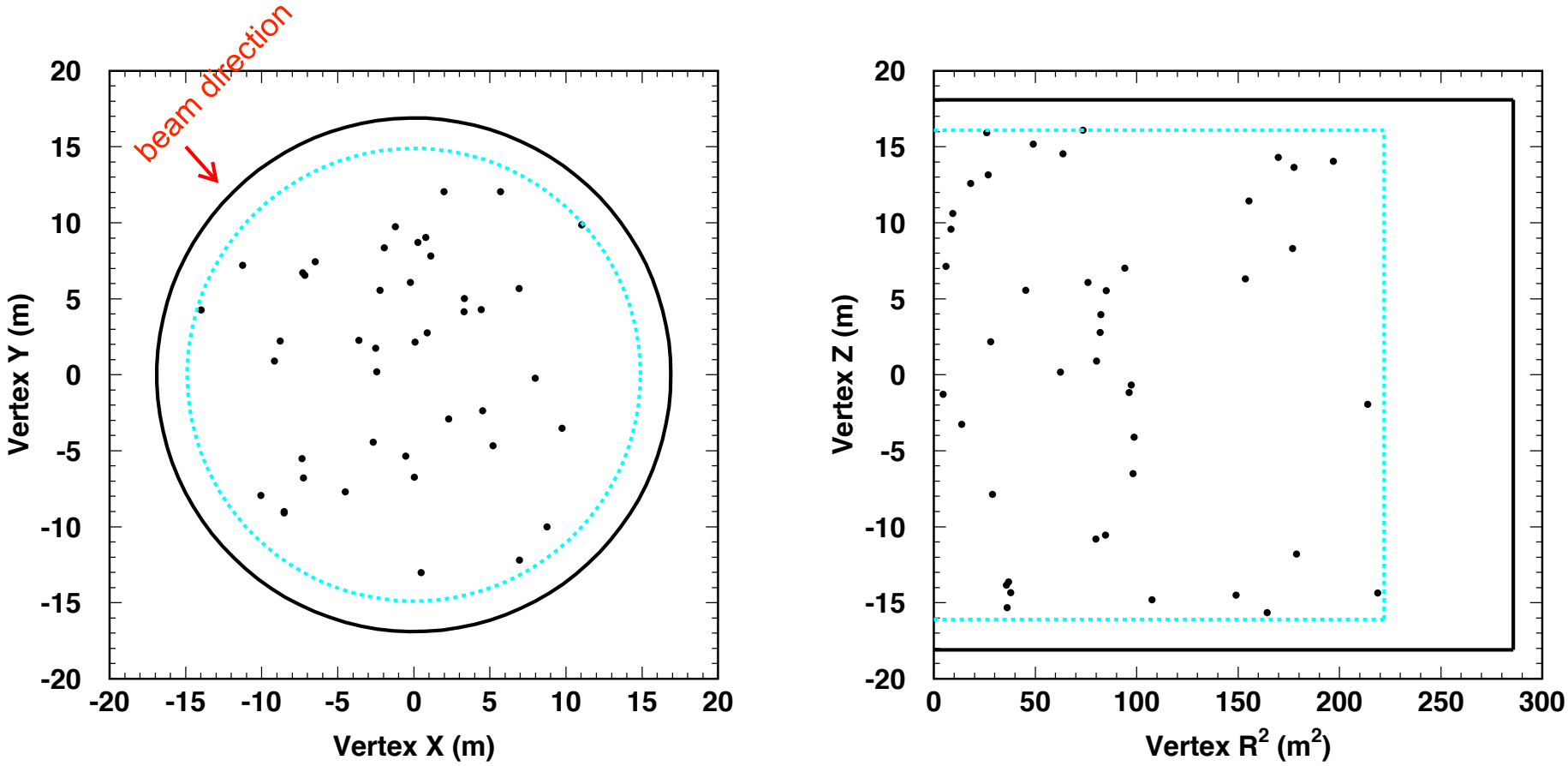


Cherenkov opening angle

Remove remaining low energy muons

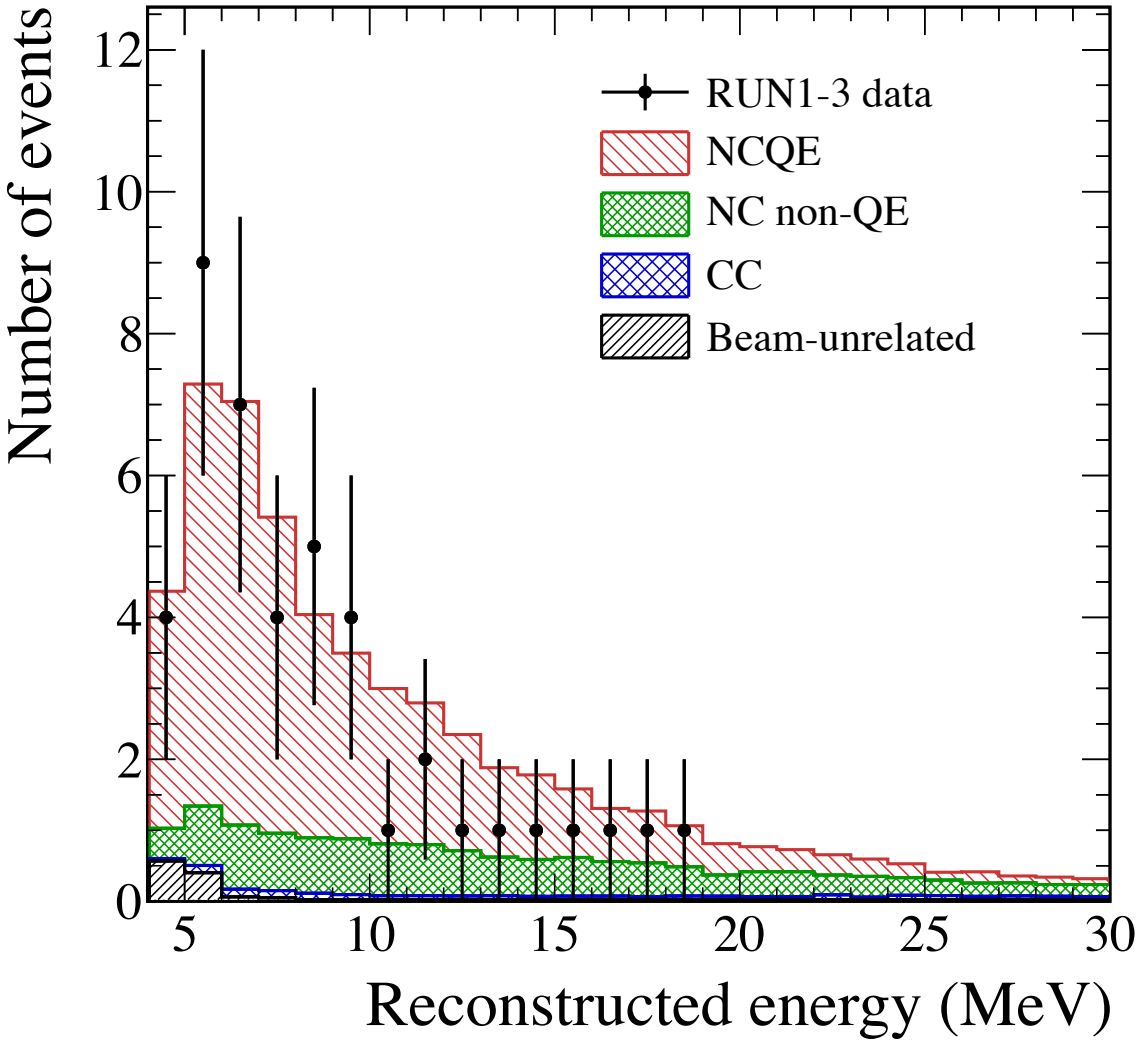


Vertex distribution after reduction



Uniform in the whole volume

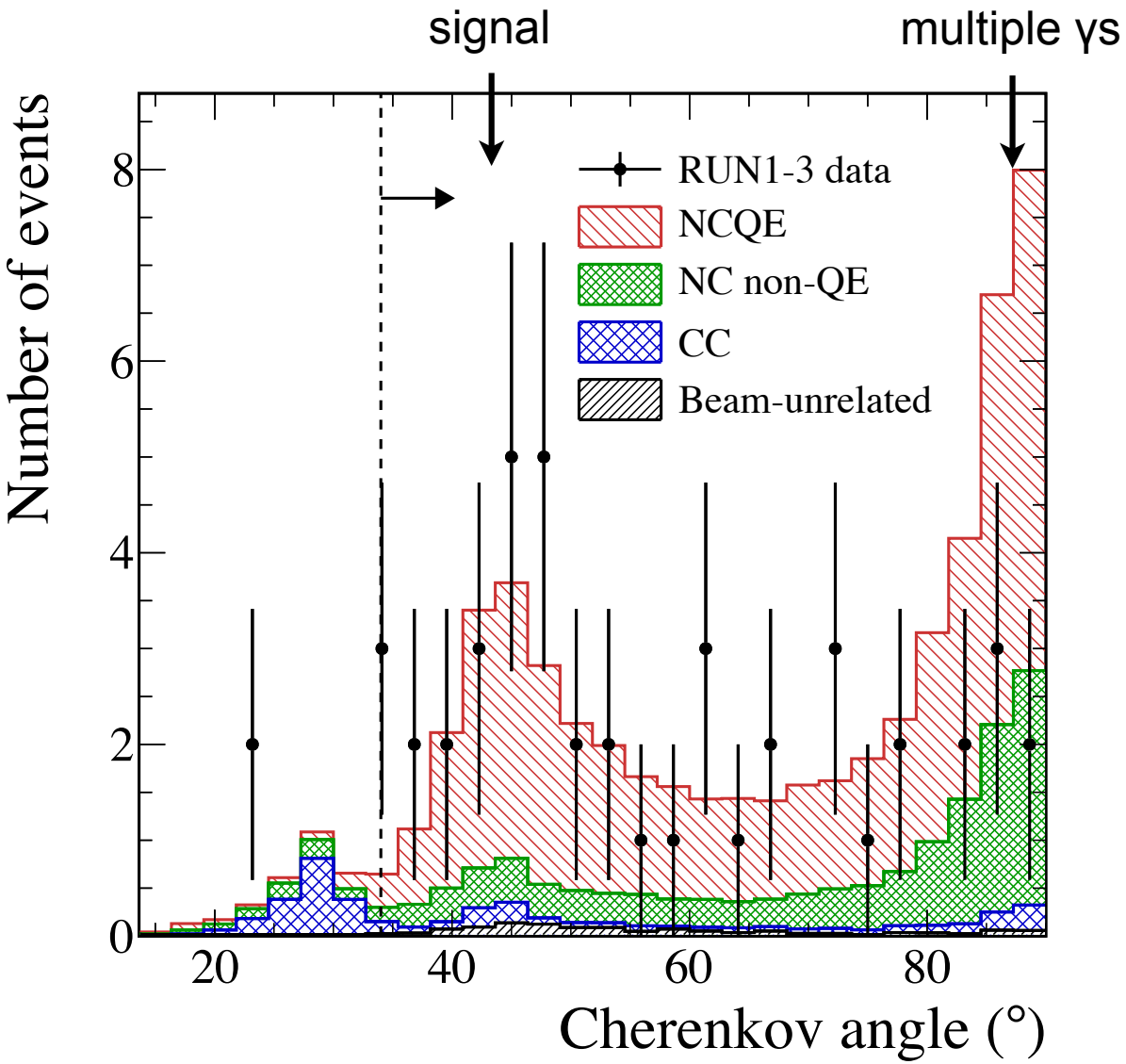
Observed events

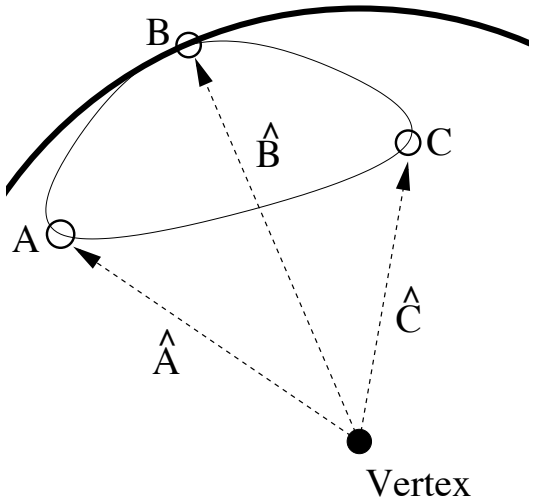


43 candidates are found.
The energy distribution is consistent with MC.
MC predicts 55.7 events.

Expected number of events		
NCQE	**39.17**	**70.3%**
NC others	13.16	23.6%
CC	2.18	3.9%
beam unrelated	1.2	2.2%
Total	55.7	100%

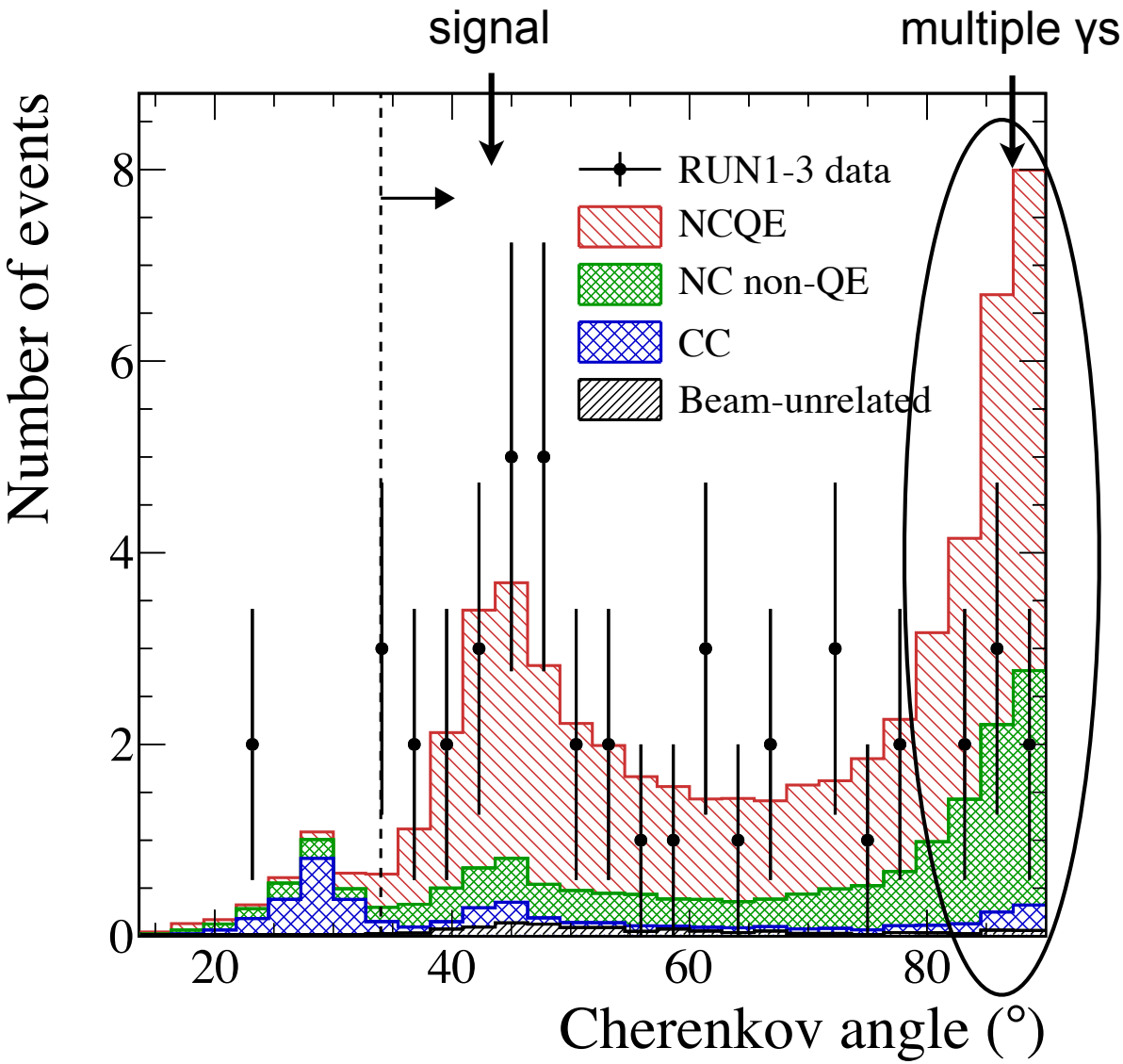
Observed events





calculate angles with all the possible combination of three hit PMTs

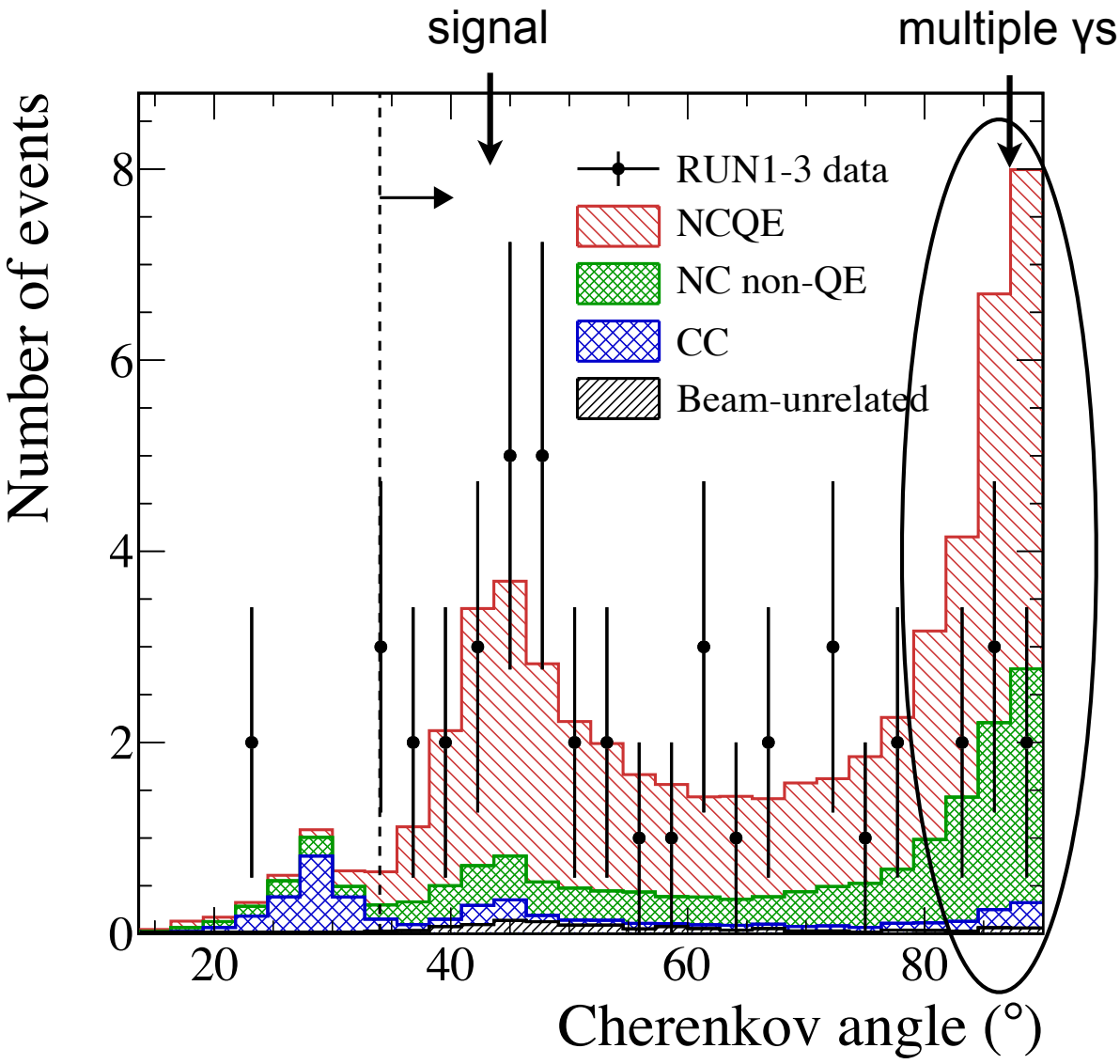
Observed events

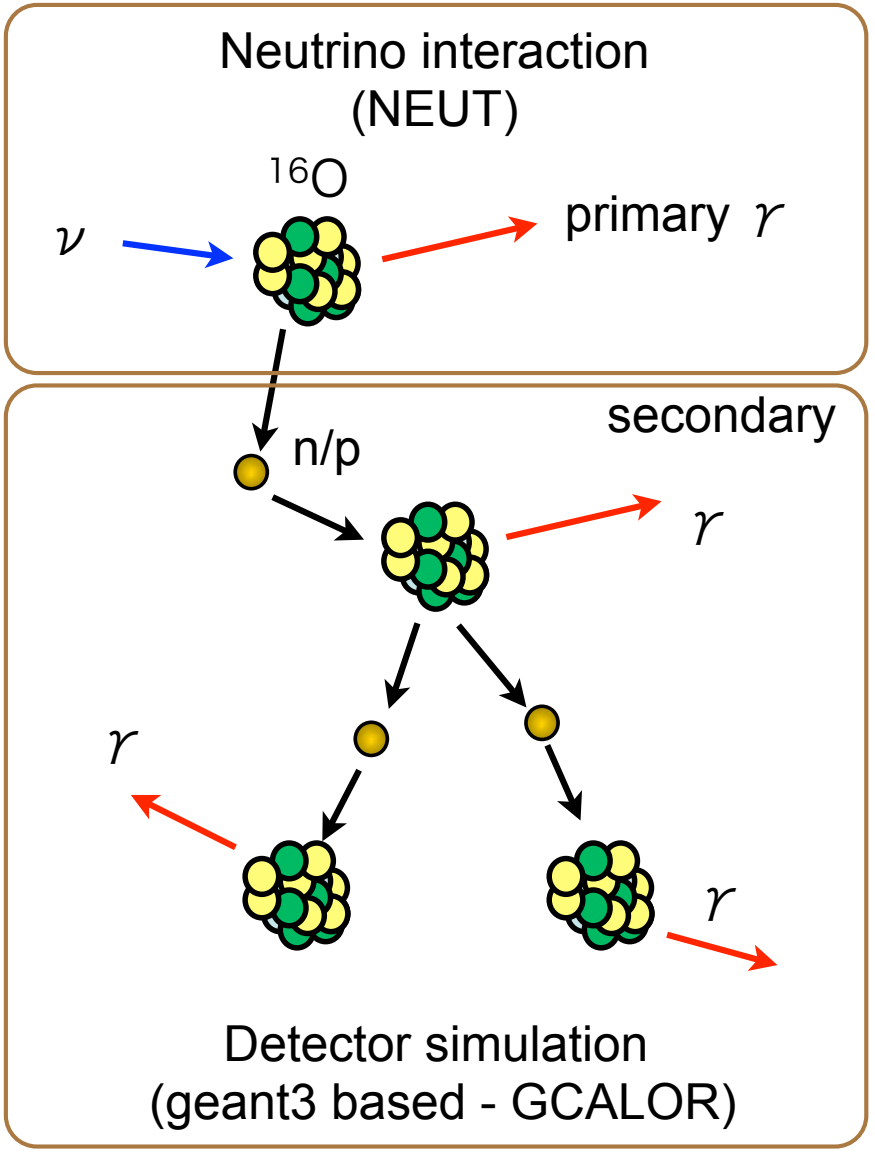


Discrepancies between data and MC at large Cherenkov angle.

Studies are ongoing.

Secondary gamma differences?





Systematic uncertainties

Fraction of sample	Signal NCQE 69%	NC non-QE 25%	CC 4%	Beam unrel. 2%
Flux	11%	10%	12%	--
Cross section	--	18%	24%	--
Primary γ production	10%	3%	6%	--
Secondary γ production	13%	13%	7.6%	--
Detector response	2.2%	2.2%	2.2%	--
Oscillation parameter	--	--	10%	--
Total	20%	25%	30%	0.8%

NCQE cross section

$$< \sigma^{obs}_{\nu,NCQE} >= \frac{N^{obs} - N^{exp}_{bkg}}{N^{exp} - N^{exp}_{bkg}} < \sigma^{theory}_{\nu,NCQE} >$$

$$N^{obs} = 43$$
$$N^{exp} = 55.7$$
$$N^{exp}_{bkg} = 17.3$$

2.01×10^{-38} cm^2

preliminary

$$< \sigma^{obs}_{\nu,NCQE} >= 1.35 \times 10^{-38} cm^2$$
$$68\% C.L. (1.06, 1.94) \times 10^{-38} cm^2$$