Super-K Gd

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for Super-K collaboration

20150804@JPARC

Workshop for Neutrino Programs with facilities in Japan

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- Introduction to SK-Gd
- Physics motivations
- Study of Gd effect to SK
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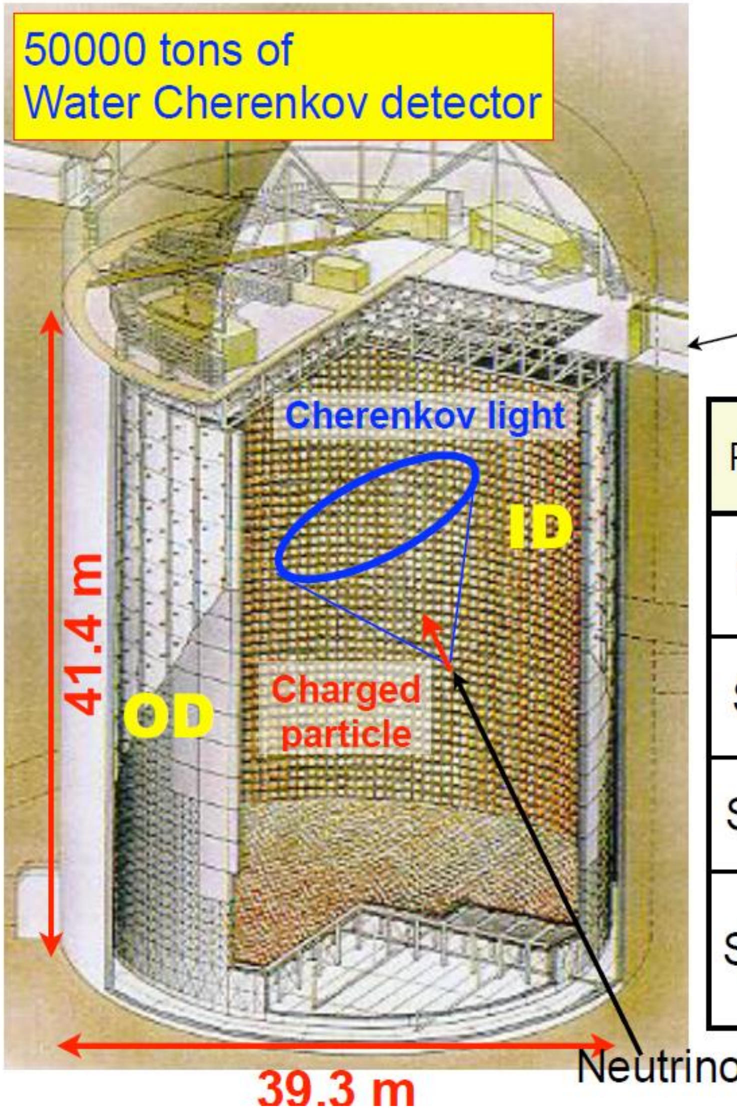
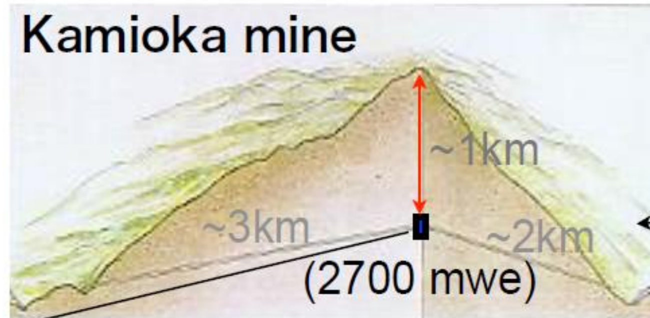
Super-Kamiokande





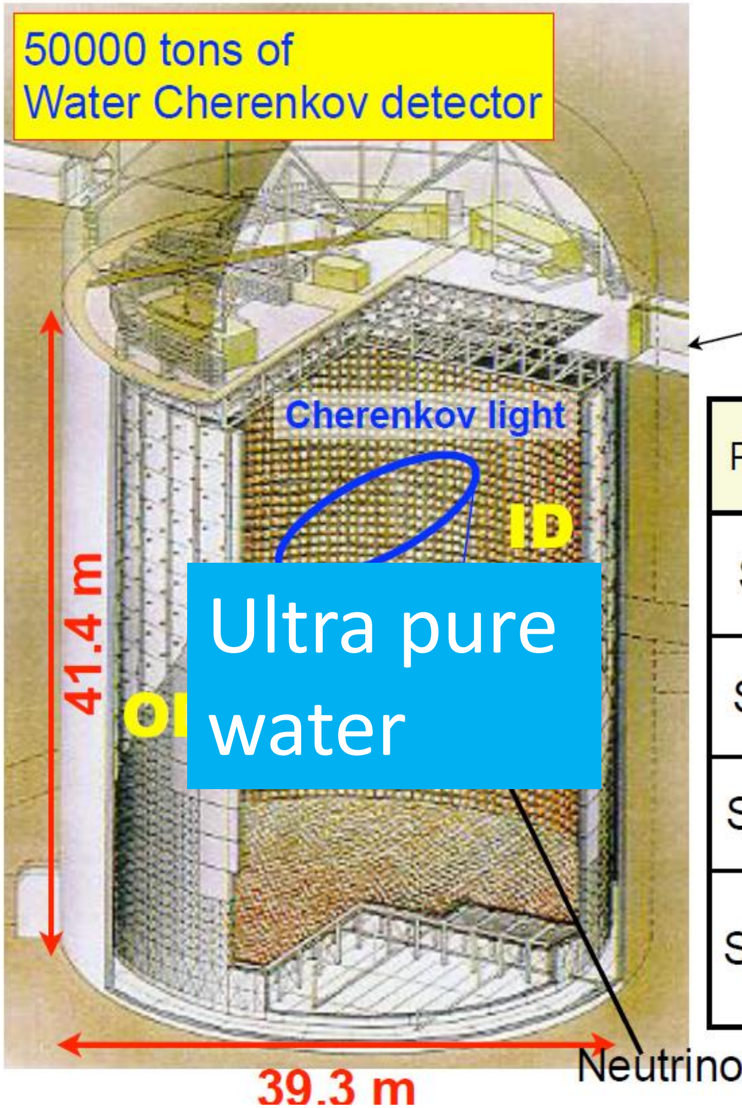
(For Solar neutrino analysis)

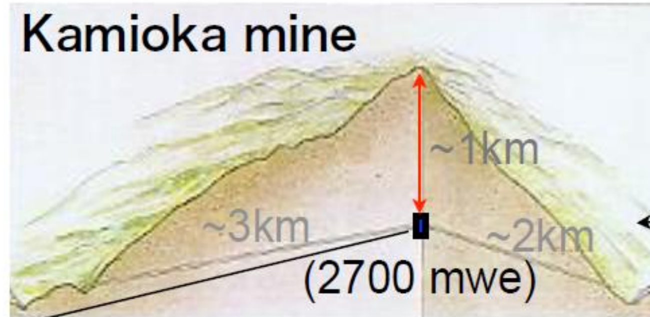
Phase	Period	Livetime (days)	Fiducial vol. (kton)	# of PMTs	Energy thr.(MeV)
SK-I	1996.4 ~ 2001.7	1496	22.5	11146 (40%)	4.5
SK-II	2002.10 ~ 2005.10	791		5182 (20%)	6.5
SK-III	2006.7 ~ 2008.8	548	22.5 (>5.5MeV) 13.3 (<5.5MeV)	11129 (40%)	4.5
SK-IV	2008.9 ~	1669	22.5 (>5.5MeV) 13.3 (4.5<E<5.5) 8.8 (<4.5MeV)		**3.5**

total **4504** days

(coverage) (Kinetic energy)

Super-Kamiokande





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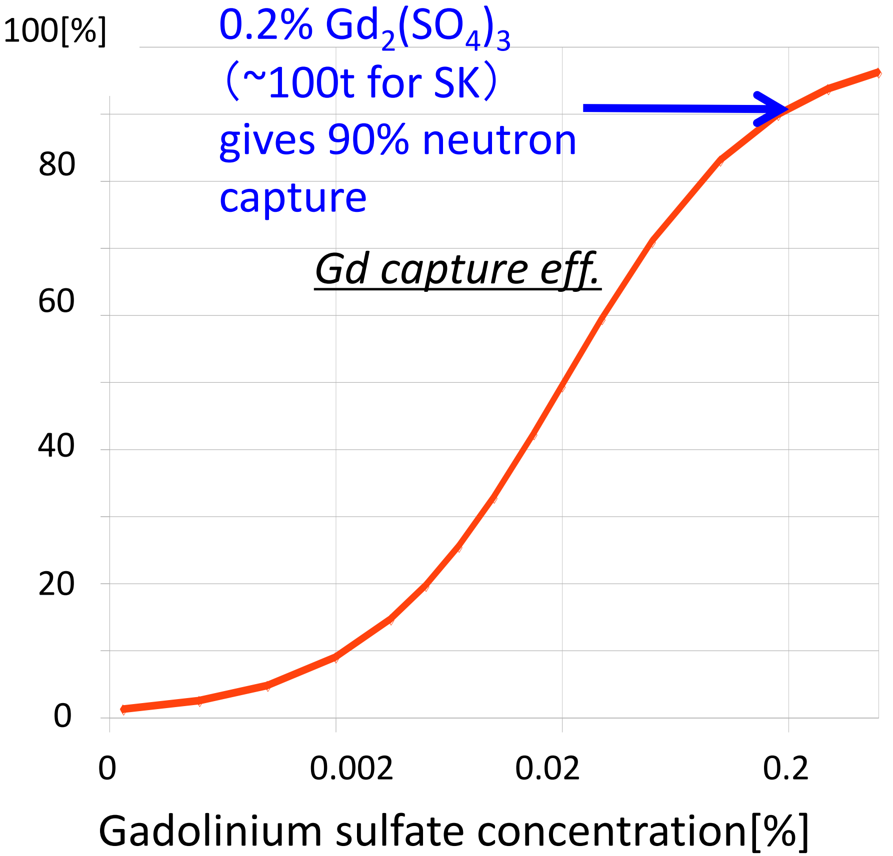
Super K-Gd

Beacom and Vagins PRL93,171101 (2004)

- Large cross section for thermal neutron (48.89kb)
- Neutron captured Gd emits 3-4 γ ray in total 8 MeV
- **We can tag $\bar{\nu}_e$ by using the delayed coincidence technique.**



Physics targets:

(1) Supernova relic neutrino (SRN)

(2) Improve pointing accuracy for galactic supernova

(3) Precursor of nearby supernova by Si-burning neutrinos

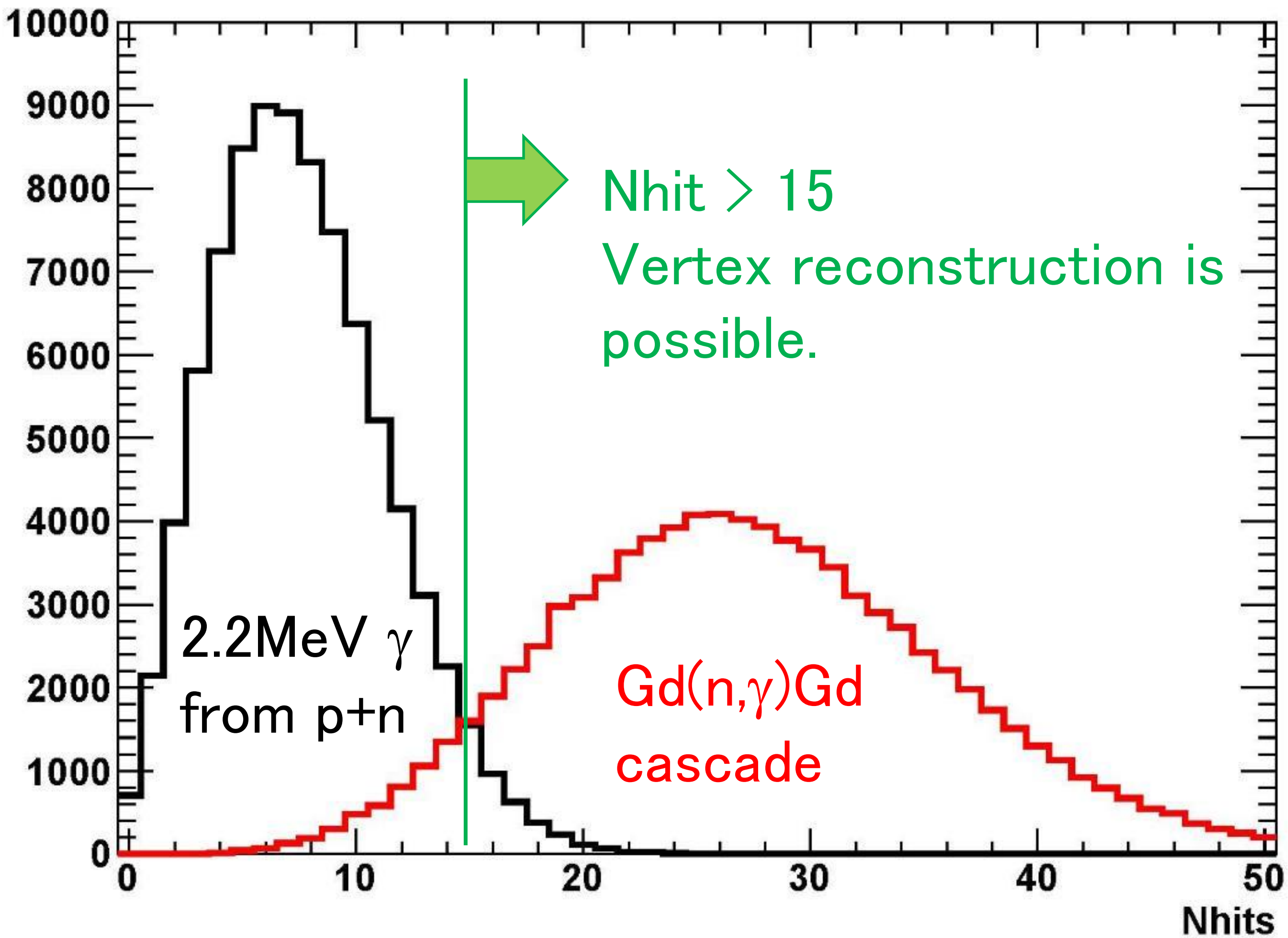
(4) Reduce proton decay background

(5) Neutrino/anti-neutrino discrimination (Long-baseline and atm nu's)

(6) Reactor neutrinos

Why Gd (not 2.2MeV γ) for neutron tagging

Number of hit PMT (Nhit) distributions



Efficiency and fake probability

2.2MeV γ: Efficiency: 10～20%, fake probability: ～10^{-2}

Gd(n,γ)Gd: Efficiency: >80%, fake probability: <10^{-4}

History of SK-Gd project

2002 Nov. collaboration meeting

Started to discuss GADZOOKS!

2006 May. Gd Advisory Committee was formed.
list up R&D items and specifications

2007 Nov. collaboration council

It was suggested to make a test tank and study feasibility.

2009 EGADS was started.
A 200 ton test tank was constructed.

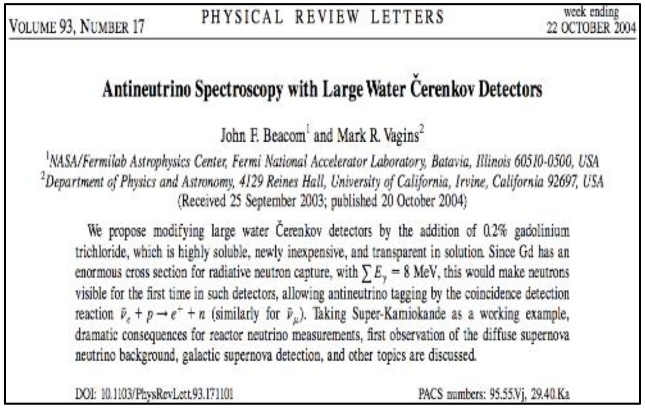
2013 0.2% $Gd_2(SO_4)_3$ was dissolved to EGADS before mounting PMTs and transparency was measured.

2013 summer 240 PMTs installed to EGADS

2014 Oct. – 2015 May Dissolved 0.2% $Gd_2(SO_4)_3$ again and measuring water transparency and scattering ratio.

2015 Jun. collaboration council

GADZOOKS! was approved. → SK-Gd



VOLUME 93, NUMBER 17 PHYSICAL REVIEW LETTERS week ending 22 OCTOBER 2004

Antineutrino Spectroscopy with Large Water Čerenkov Detectors

John F. Beacom[1] and Mark R. Vagins[2]
[1]NASA/Fermilab Astrophysics Center, Fermi National Accelerator Laboratory, Batavia, Illinois 60510-0500, USA
[2]Department of Physics and Astronomy, 4129 Reines Hall, University of California, Irvine, California 92697, USA

(Received 25 September 2003; published 20 October 2004)

We propose modifying large water Čerenkov detectors by the addition of 0.2% gadolinium trichloride, which is highly soluble, newly inexpensive, and transparent in solution. Since Gd has an enormous cross section for radiative neutron capture, with $\sum E_\gamma = 8$ MeV, this would make neutrons visible for the first time in such detectors, allowing antineutrino tagging by the coincidence detection reaction $\bar{\nu}_e + p \to e^+ + n$ (similarly for $\bar{\nu}_\mu$). Taking Super-Kamiokande as a working example, dramatic consequences for reactor neutrino measurements, first observation of the diffuse supernova neutrino background, galactic supernova detection, and other topics are discussed.

DOI: 10.1103/PhysRevLett.93.171101 PACS numbers: 95.55.Vj, 29.40.Ka

Official statement from Super-K collaboration

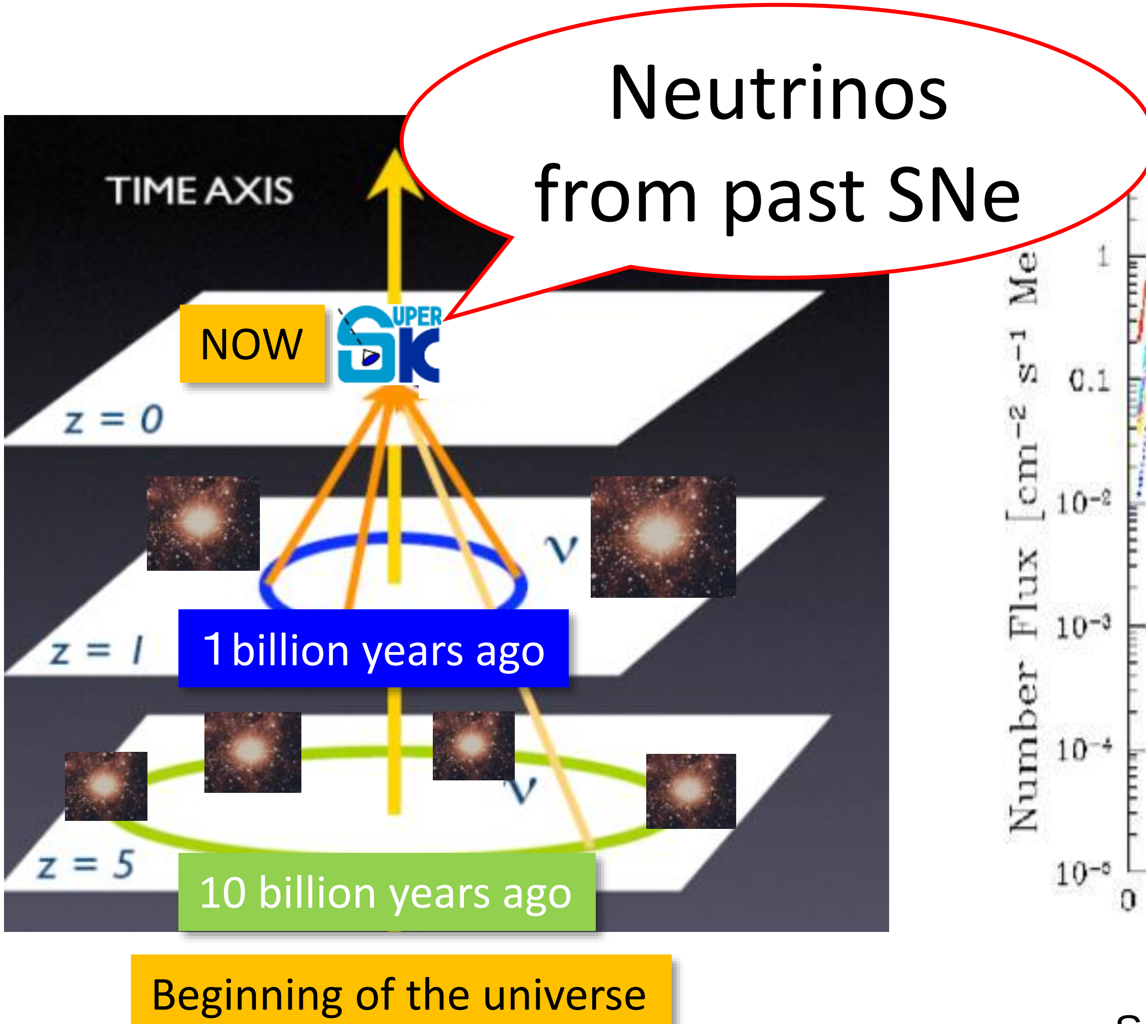
On June 27, 2015, the Super-Kamiokande collaboration approved the SuperK-Gd project which will enhance anti-neutrino detectability by dissolving gadolinium to the Super-K water.

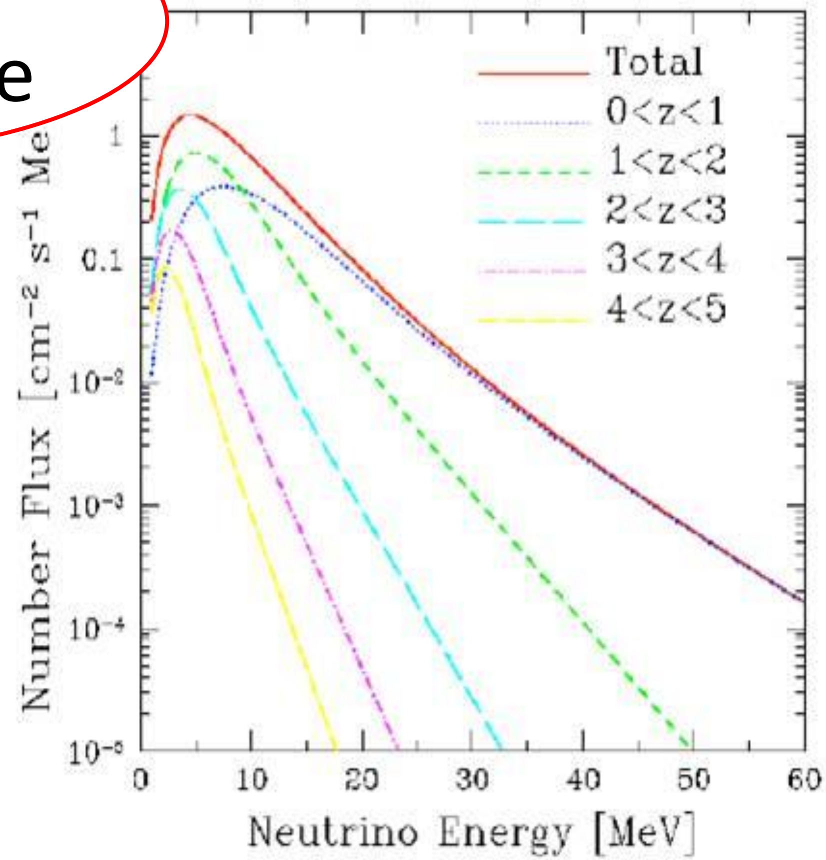
The actual schedule of the project including refurbishment of the tank and Gd-loading time will be determined soon taking into account the T2K schedule.

Physics motivation

Supernova Relic Neutrino (SRN)

10^{10} stellar/galaxy $\times 10^{10}$ galaxy $\times$ 0.3%(become SNe) ~$O(10^{17})$SNe



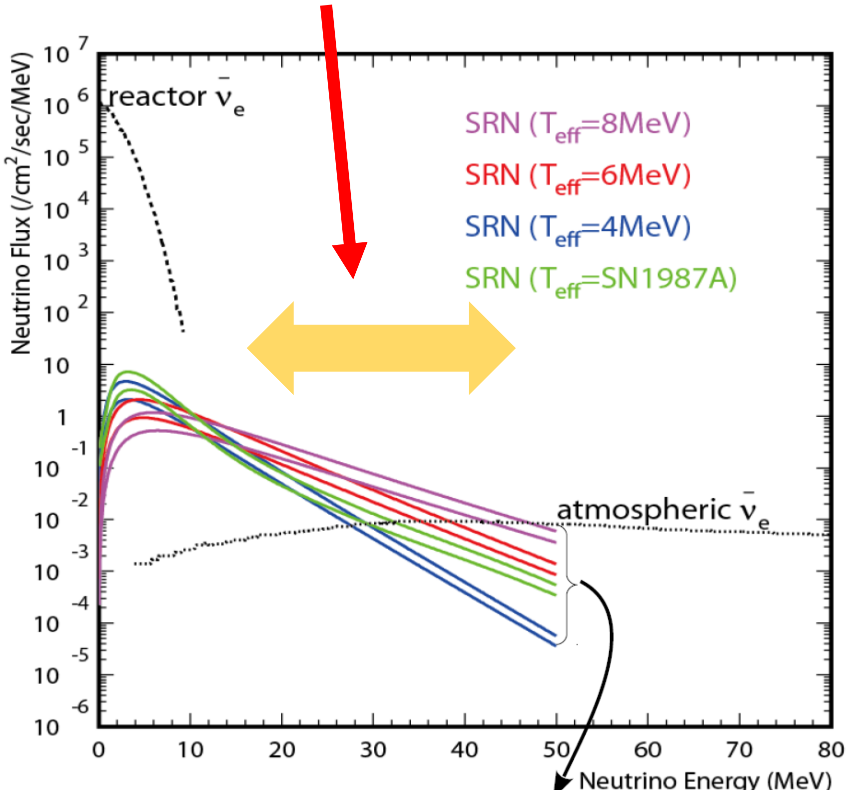


S.Ando, Astrophys.J. 607, 20(2004)

Theoretical flux prediction : 0.3~1.5 /cm2/s (17.3MeV threshold)

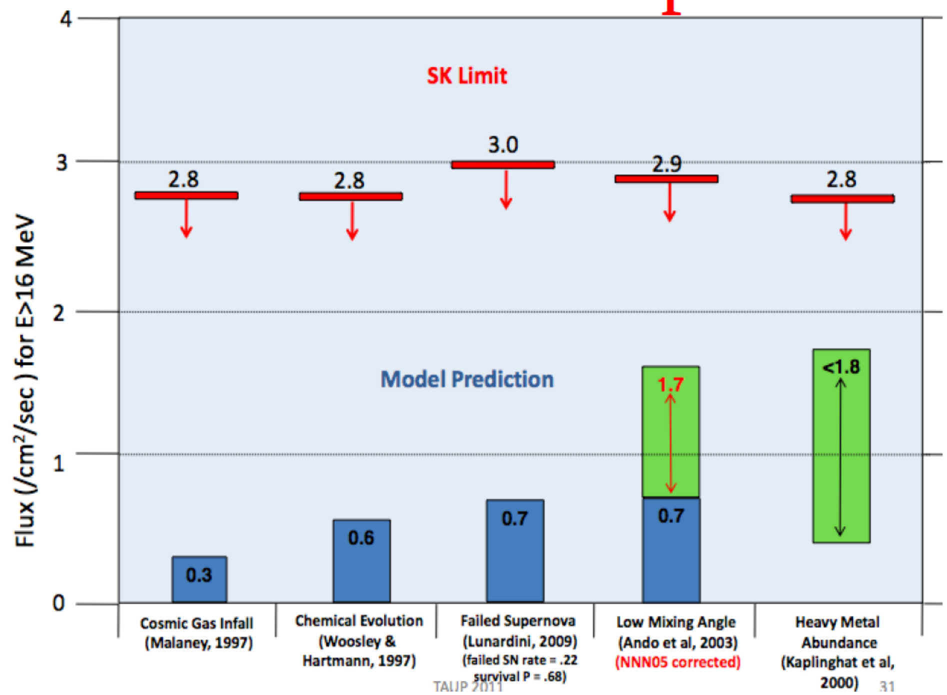
Search for SRN at Super-K

Search window for SRN at SK : From ~10MeV to ~30MeV



Phys.Rev. D 79, 08013 (2009)

Flux limit at Super-K

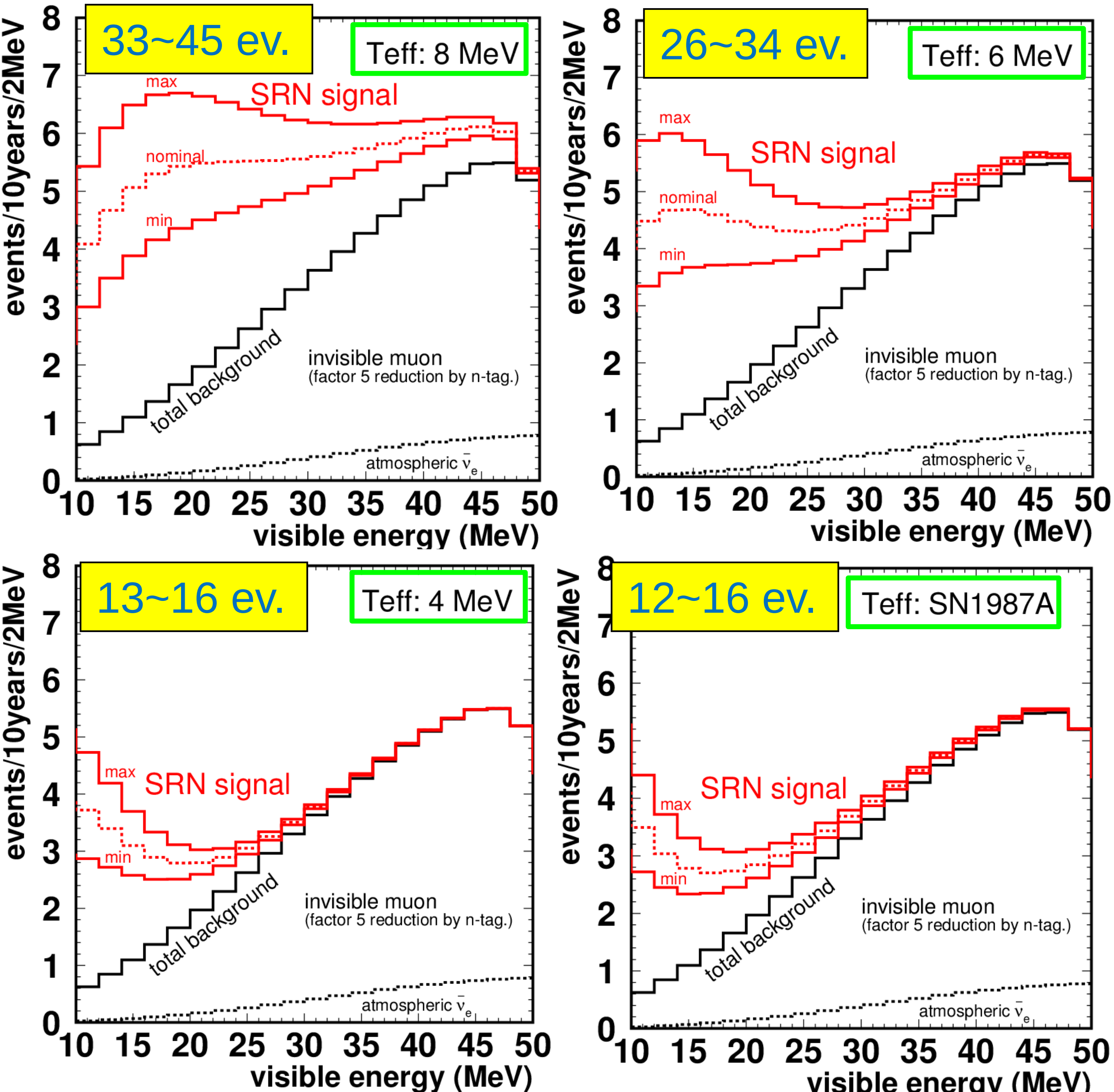


Phys. Rev. D 85, 052007 (2012)

Now SRN search is limited by BG.

We need BG reduction by the neutron tagging!

SRN: Expected signal and background in SK-Gd 10yr



Expect number of events in 10 years in E_{total} =10-30 MeV

Assuming

Capture efficiency of 90% and Gd gamma detection efficiency of 74%.

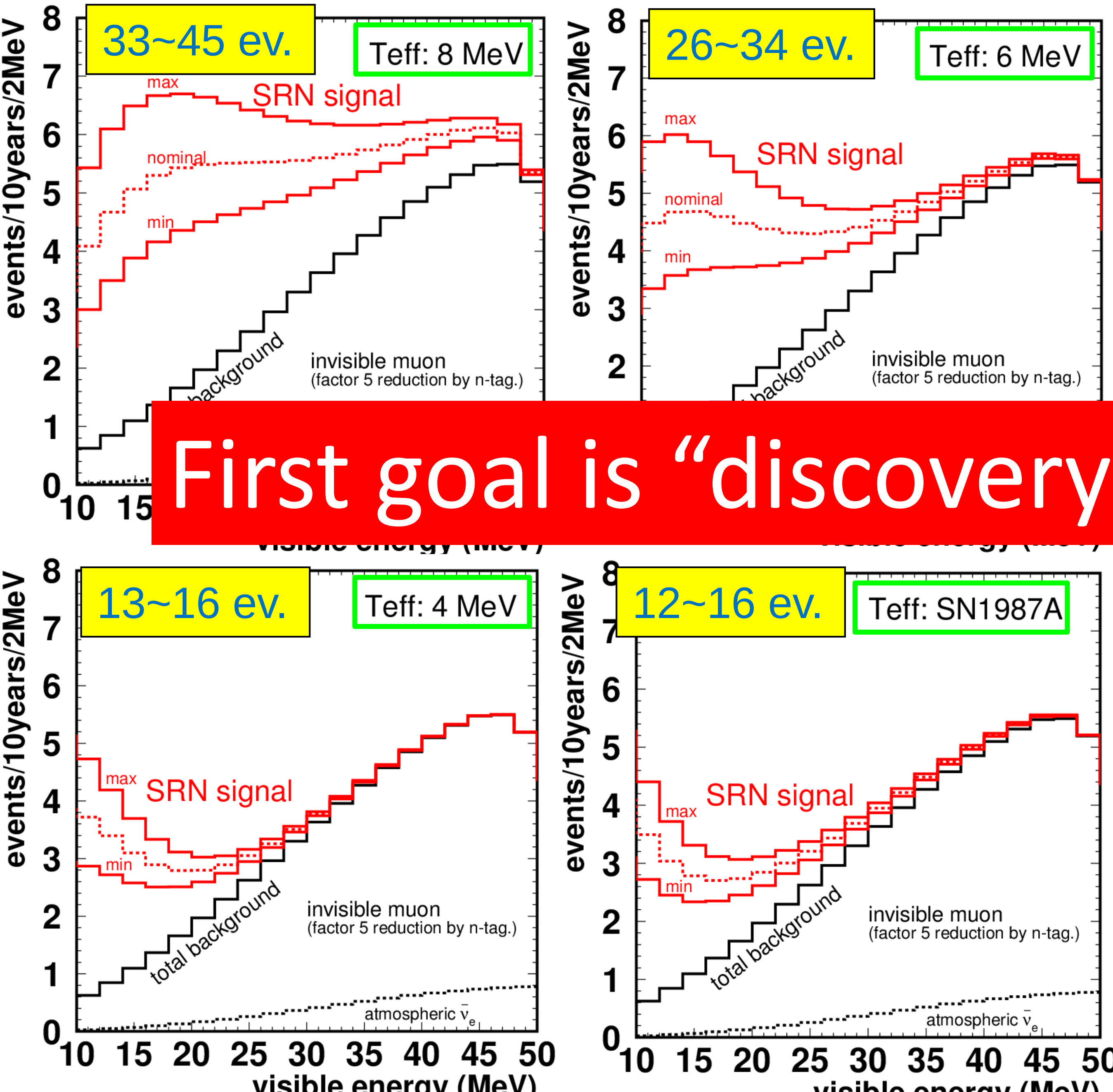
Invisible muon B.G. is 35% of the SK-IV invisible muon BG.

Min/nominal/Max are due to uncertainties in astronomy.

Background: ~18 ev.

SRN flux from Horiuchi et al. PRD, 79, 083013 (2009)

SRN: Expected signal and background in SK-Gd 10yr



Expect number of events in 10 years in E_{total} =10-30 MeV

Assuming

Capture efficiency of 90% and Gd gamma

of

is

35% of the SK-IV invisible muon BG.

First goal is "discovery" of SRN

Min/nominal/Max are due to uncertainties in astronomy.

Background: ~18 ev.

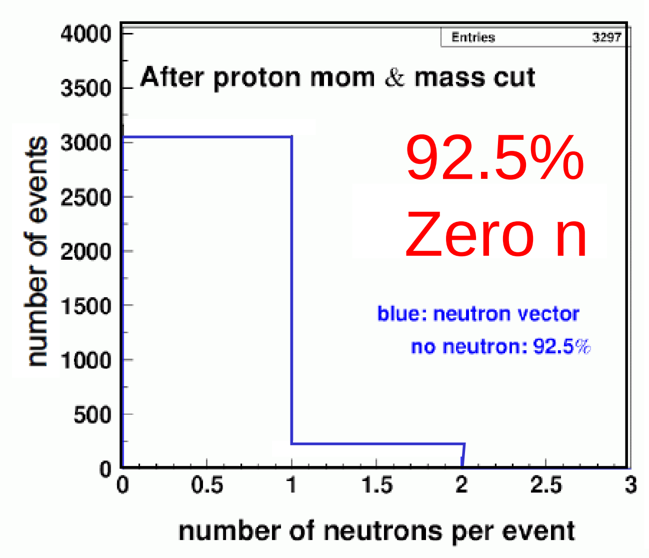
SRN flux from Horiuchi et al. PRD, 79, 083013 (2009)

Improvement for Proton decay

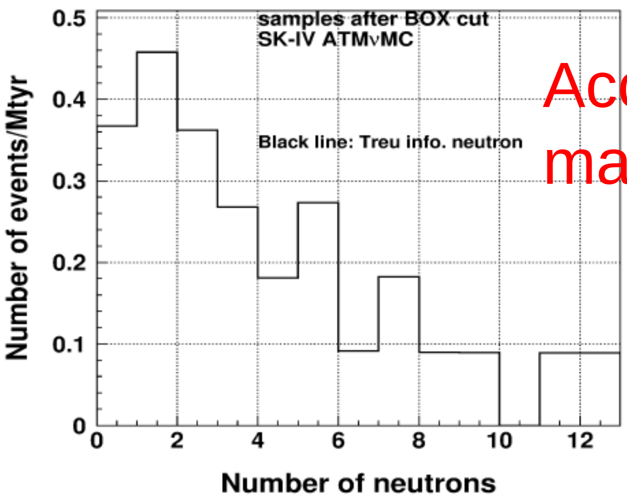
by Haga

Neutron multiplicity for

$P \rightarrow e^{+}\pi^{0}$ MC



Atmospheric ν BG



<u>If one proton decay event is observed at Super-K after 10 years</u>

Current background level: 0.58 events/10 years

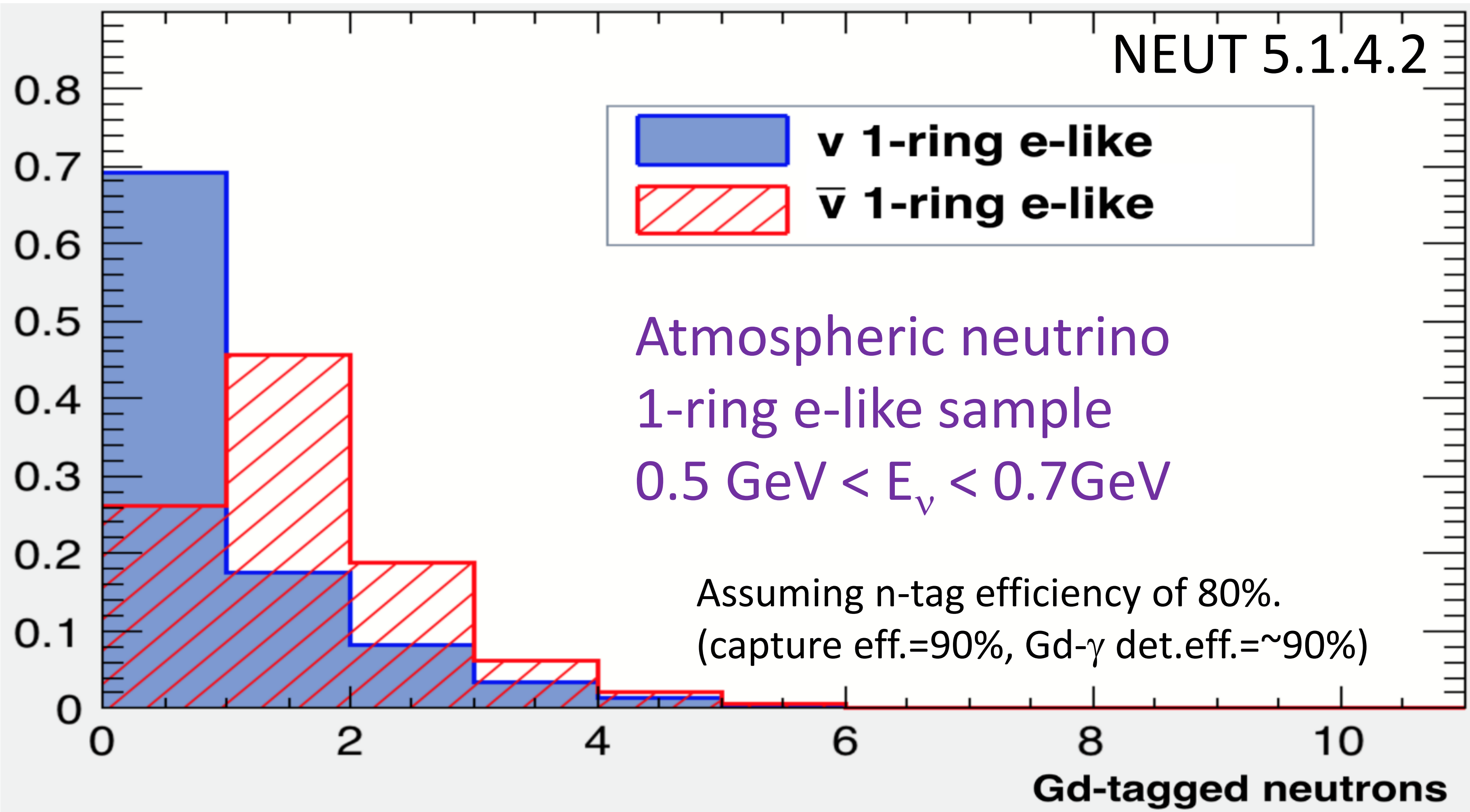
Background with neutron anti-tag: 0.098 events/10 years

Background probability will be decreased from 44%(w/o n) to 9%(w/ n).

Improvement for T2K

By Pablo

Number of tagged neutrons in T2K energy range

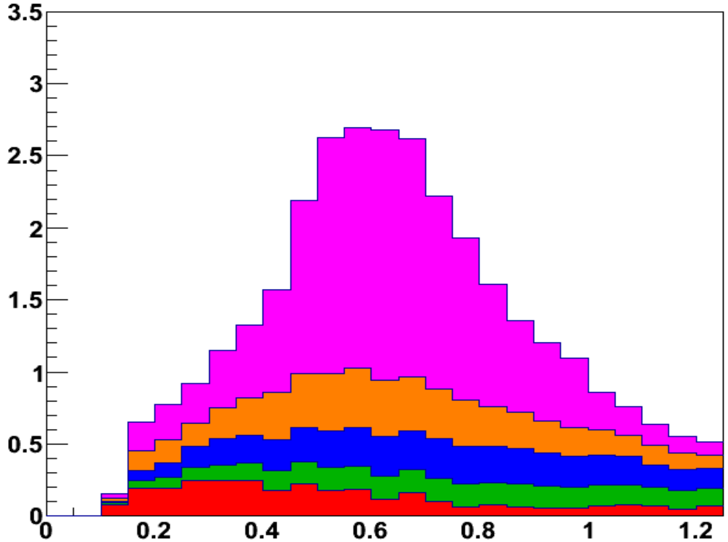


Using n-tagging information, $\bar{\nu}_e$ ID (ν_e missID) eff. ~70%(30%)

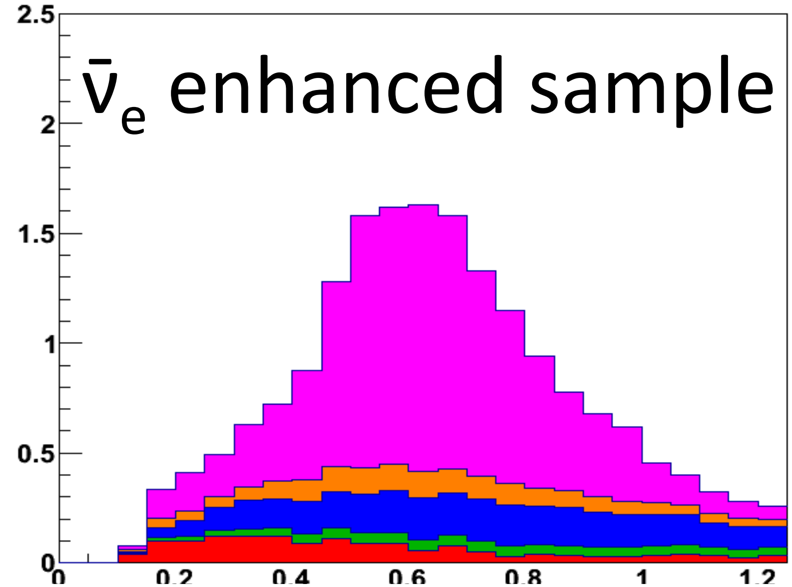
$\bar{\nu}_e$ enhanced sample in anti mode appearance analysis

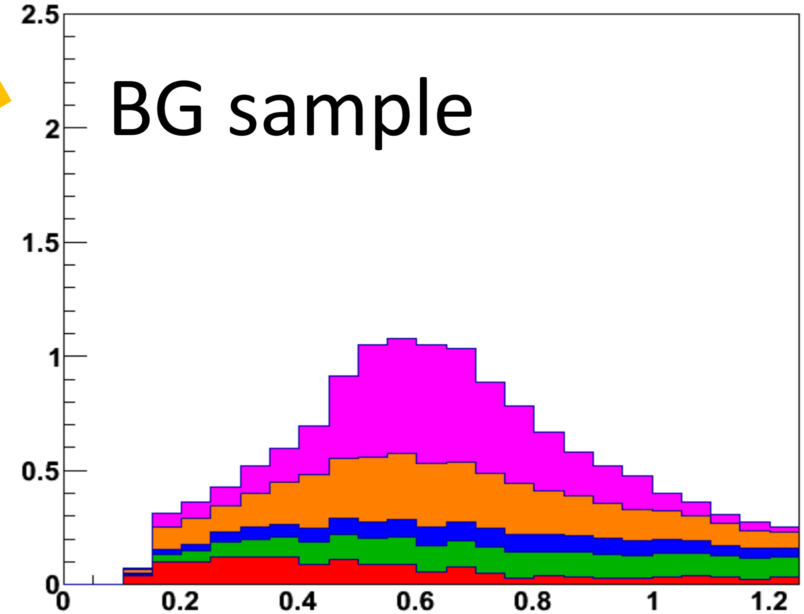
Signal $\bar{\nu}_e$, Signal ν_e

$\bar{\nu}_e$, ν_e, ν_μ and $\bar{\nu}_\mu$



Erec[GeV]





Erec[GeV]

Number of events @ 3.9×10^{21} POT

Osc parameters: $\sin^2 2\theta_{13}=0.1$,

$\delta cp=$ **-90°** , $\Delta m^2_{32} = 0.0024 eV^2$, $\sin^2\theta_{23}=0.5$, NH

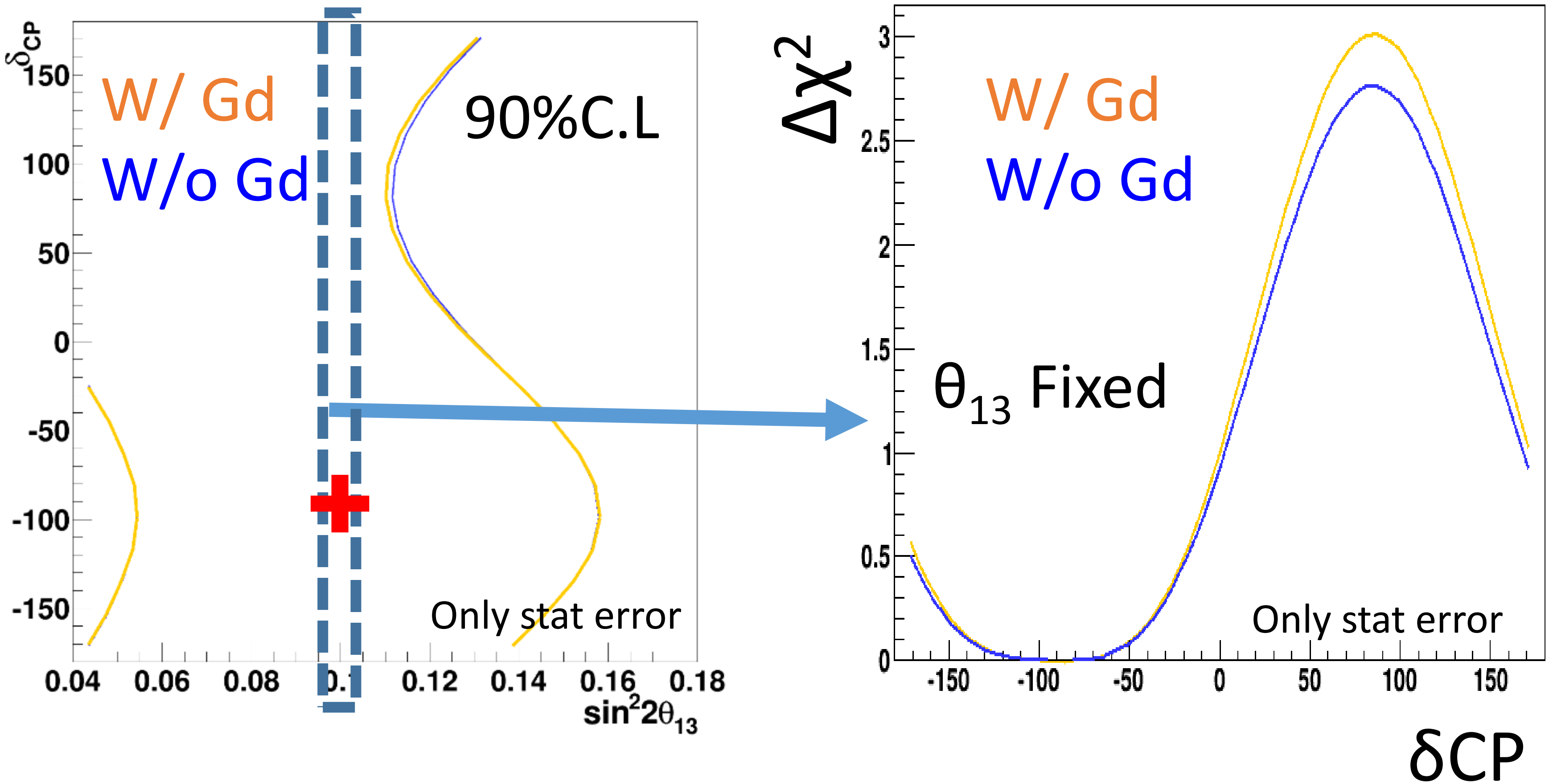
$\bar{\nu}_e$ ID (ν_e missID) eff. =70%(30%)
is assumed w/o energy dependence

Note: Directional information of e/e+ is not used

Anti mode 3.9×10^{21} Appearance Contour

True parameters: $\sin^2 2\theta_{13}$=0.1,δcp=-90°

Δm^2_{32} = 0.0024eV^2 (Fixed), $\sin^2\theta_{23}$=0.5(Fixed), NH(Fixed)



Study Gd effect to SK

Study items to achieve SK-Gd

☑Gd water transparency must be similar to SK water

☑Effect of Gd to detector materials

☑Effect of Gd water quality to physics analysis

☑How to stop leak of SK detector
(But still exploring improved methods)

☐Reduction of radioactive backgrounds in Gd powder
(only affects Lowe analysis)

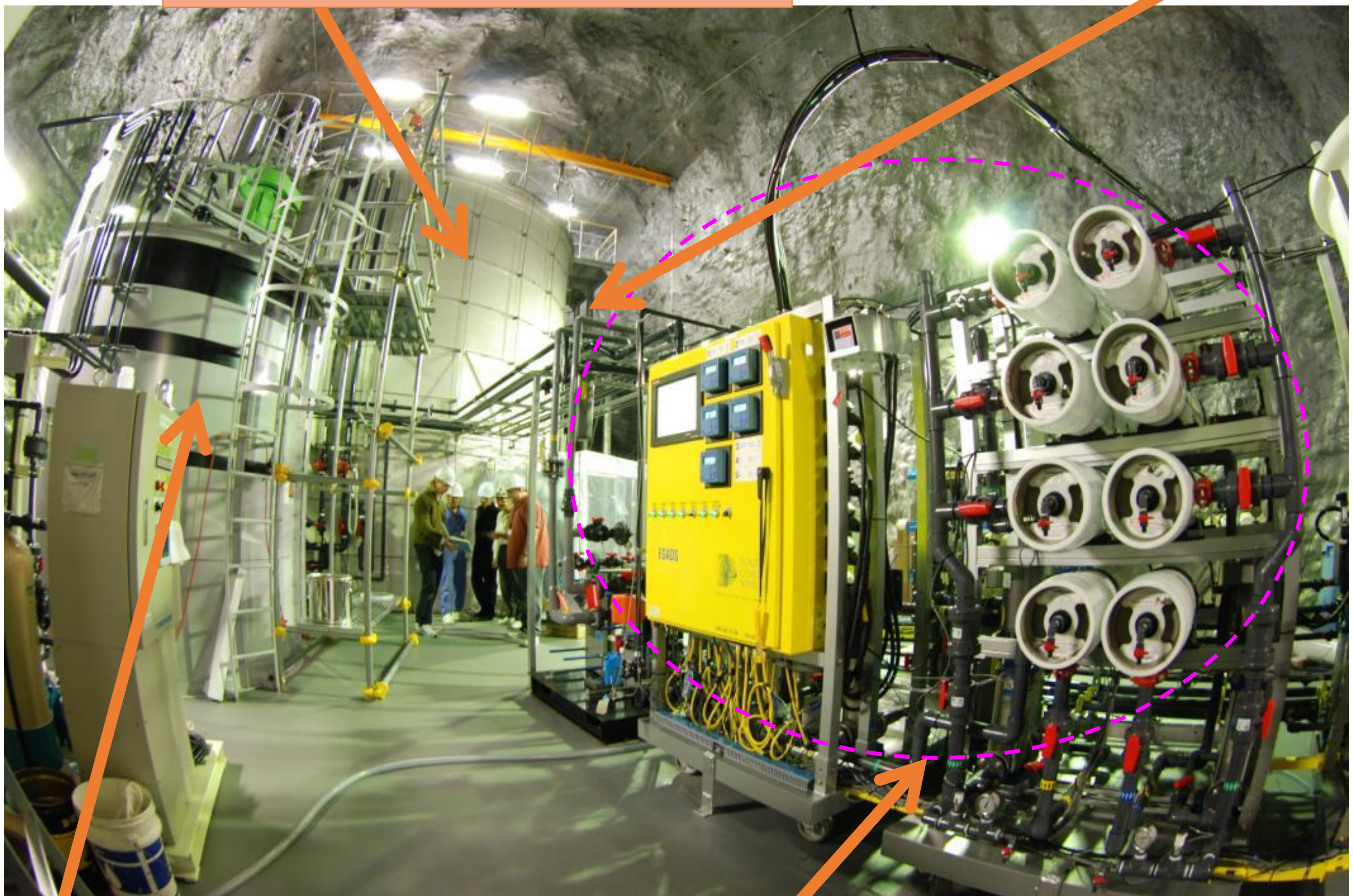
☑ : done, ☐ : under study

EGADS

Evaluating Gadolinium's Action on Detector Systems

Transparency measurement (UDEAL)

200 m^3 tank with 240 PMTs



15m^3 tank to dissolve Gd

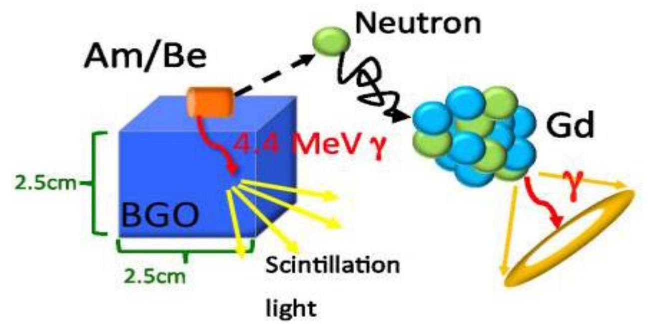
Gd water circulation system (purify water with Gd)

EGADS detector: Baby-Kamiokande

One of main goals for EGADS is to study the Gd water quality with actual detector materials.
Thus, the detector fully mimic Super-K detector.
: SUS frame, PMT and PMT case, black sheets, etc.

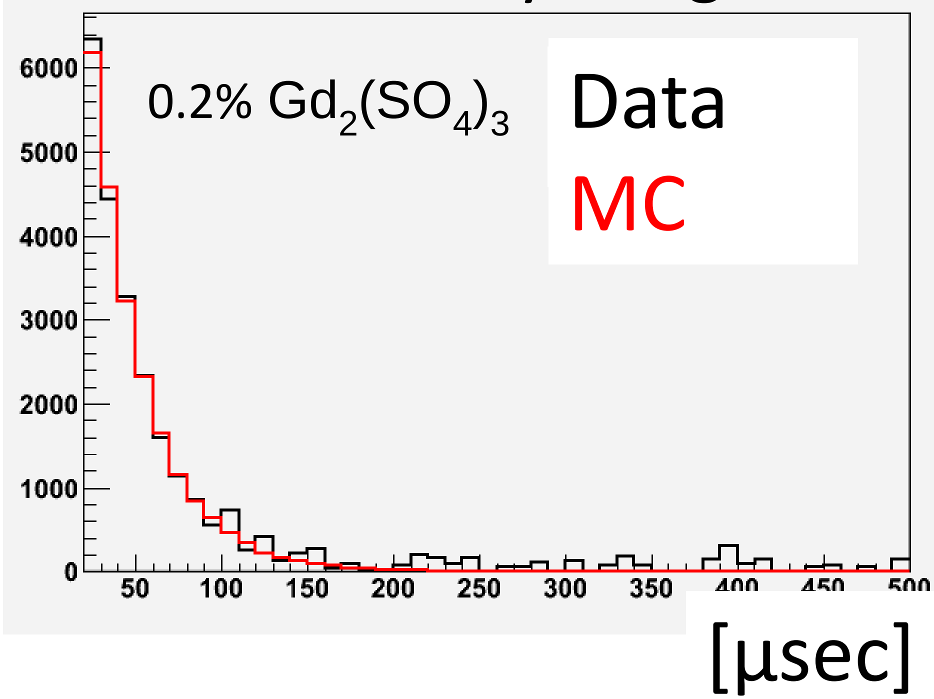
Gd dissolving test has been performed since Oct.2014. and finished Apr. 2015

Neutron capture signal@EGADS

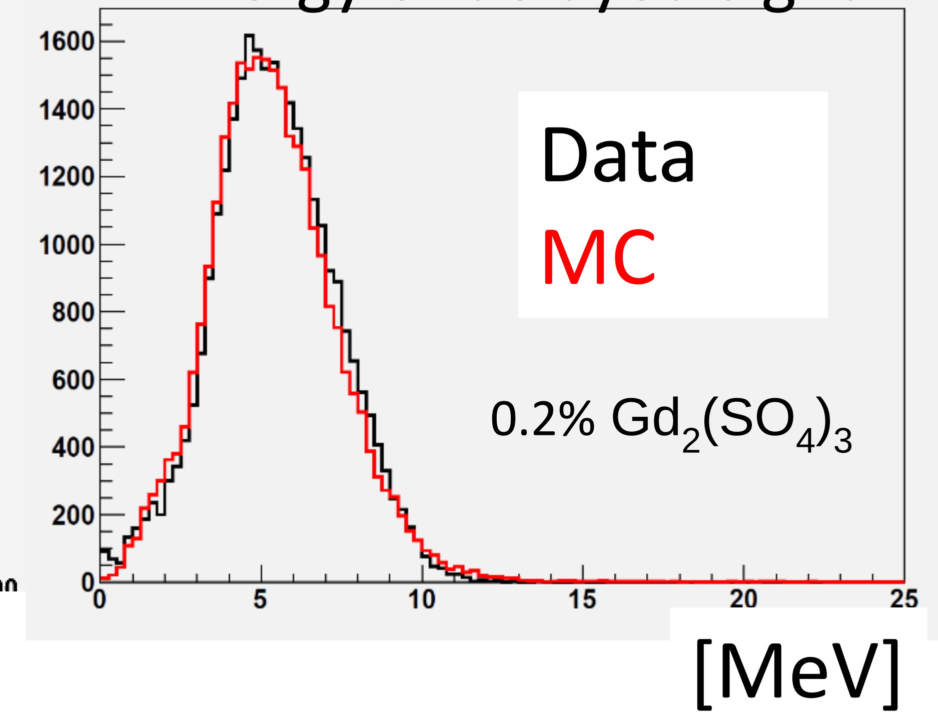


by Xu et al.

Time to delayed signal



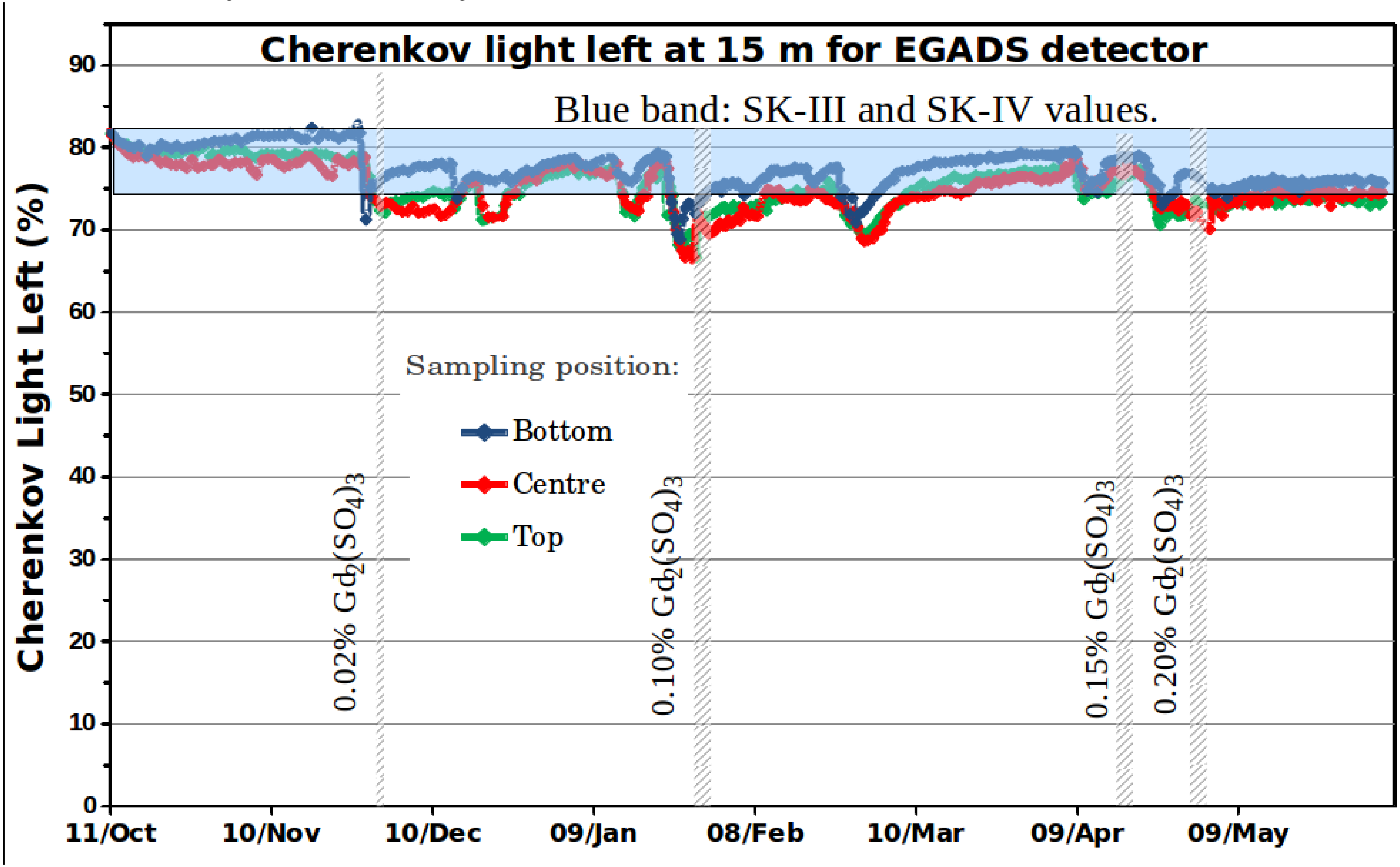
Energy of delayed signal



Average capture time [μsec]

	2178±76ppm	1055±37ppm	225±8ppm
Data	29.89 ± 0.33	51.48 ± 0.52	130.1 ± 1.7
MC	30.05 ± 1.14	53.47 ± 1.77	126.2 ± 2.8

Transparency of Gd water with PMTs

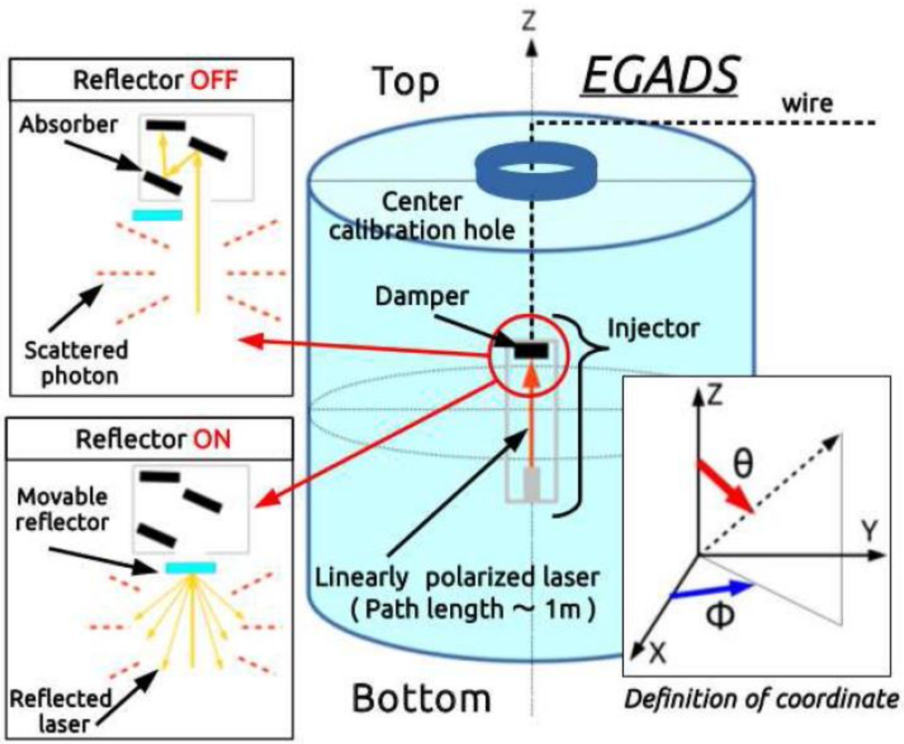


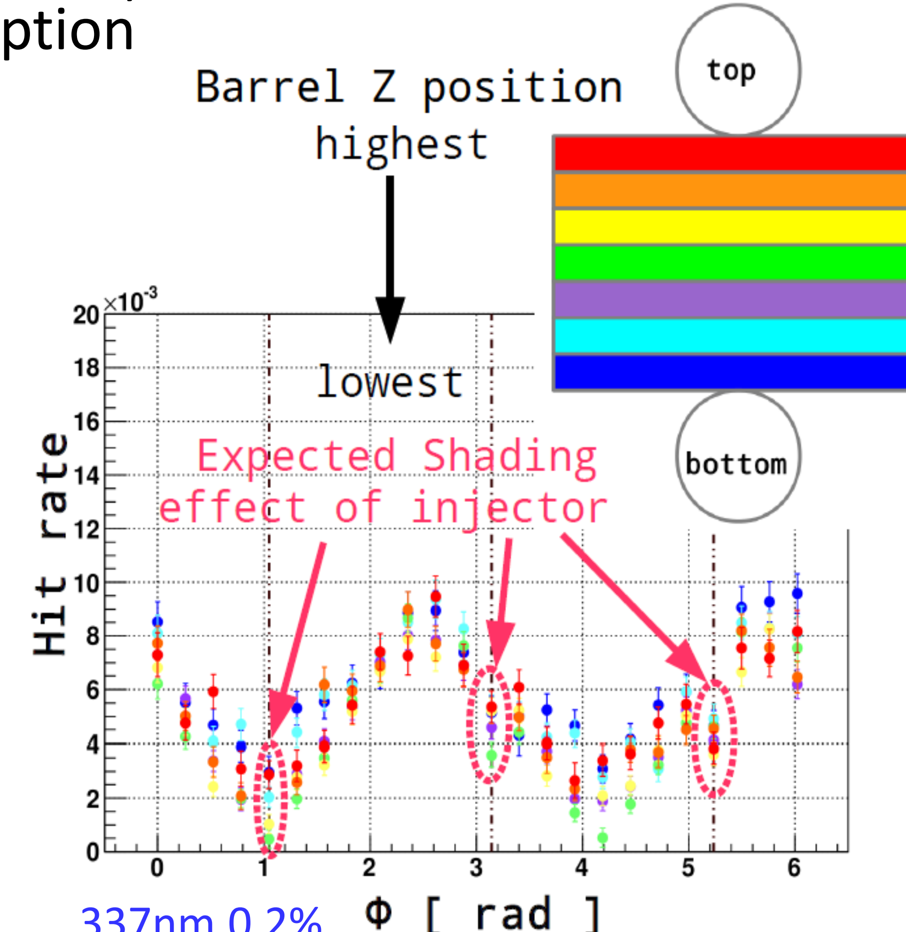
The light left at 15 m in the 200m^3 tank was ~75% for 0.2% $Gd_2(SO_4)_3$, which corresponds to ~92% of SK-IV pure water average.

Rayleigh Scattering measurement

By Akutsu, et al.

Total attenuation coefficient : **α** (prev. slide)
α＝β＋γ where **β** : scattering, **γ**:absorption
We want to know **β** and **γ** separately.





337nm,0.2%

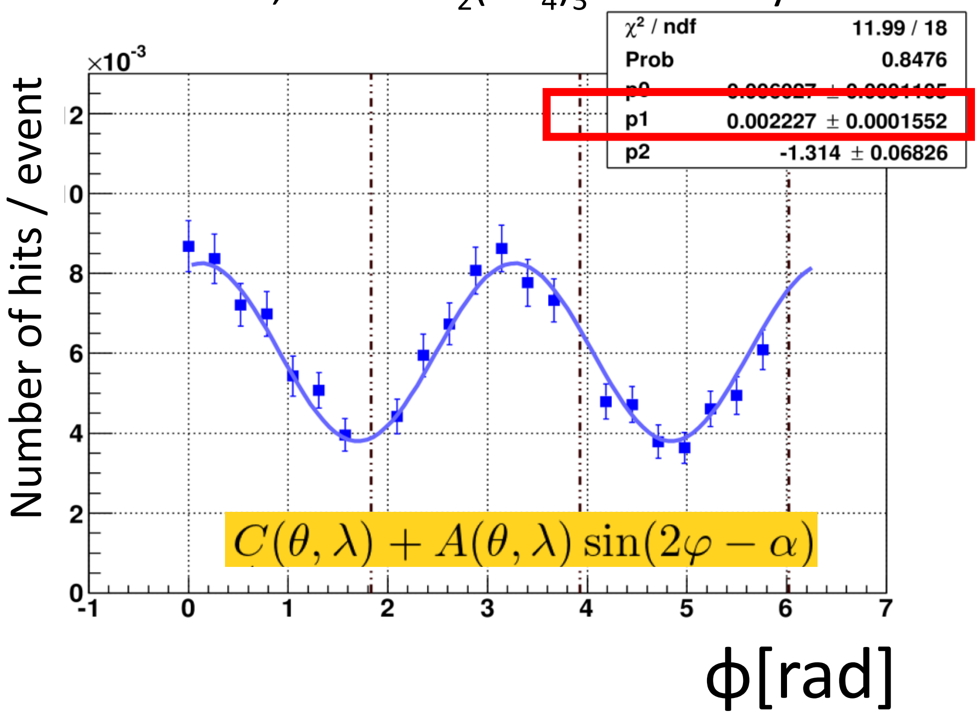
Comparison of data between 0.1% and 0.2% $Gd_2(SO_4)_3$ water ($\beta_{0.2\%}/\beta_{0.1\%}$) for wavelength: 337nm, 375nm, 405nm

Measurement of scattering amplitude and its reproducibility

Angular dependence of Rayleigh scattering: $\left(\frac{d\sigma}{d\Omega}\right)_{Rayleigh} \propto (1 - \sin^2\theta\cos^2\varphi)$

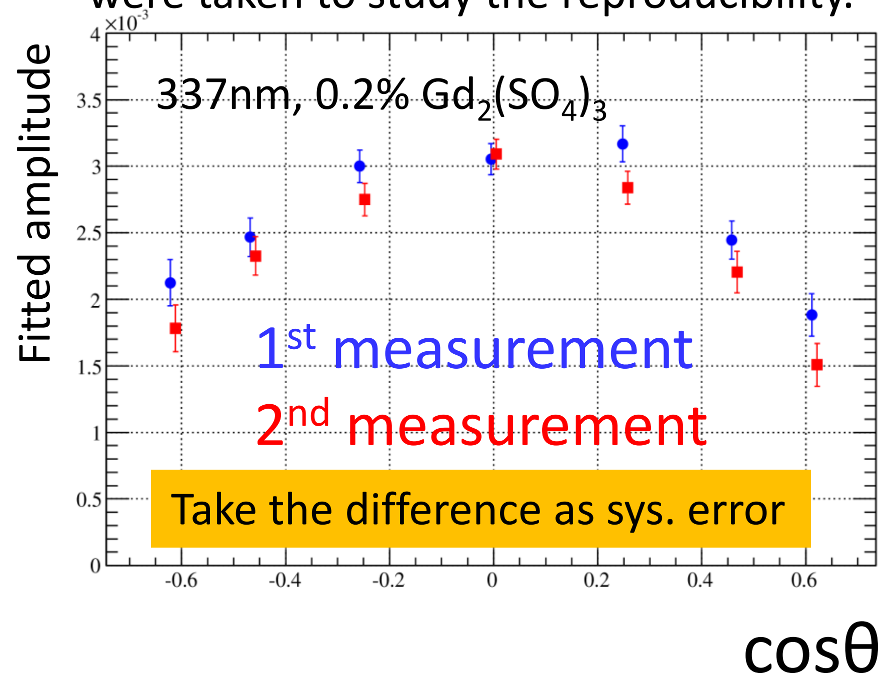
Example of fitting one barrel layer

337nm, 0.2% $Gd_2(SO_4)_3$ lowest layer



Example of reproducibility

2 data sets for every configuration were taken to study the reproducibility.

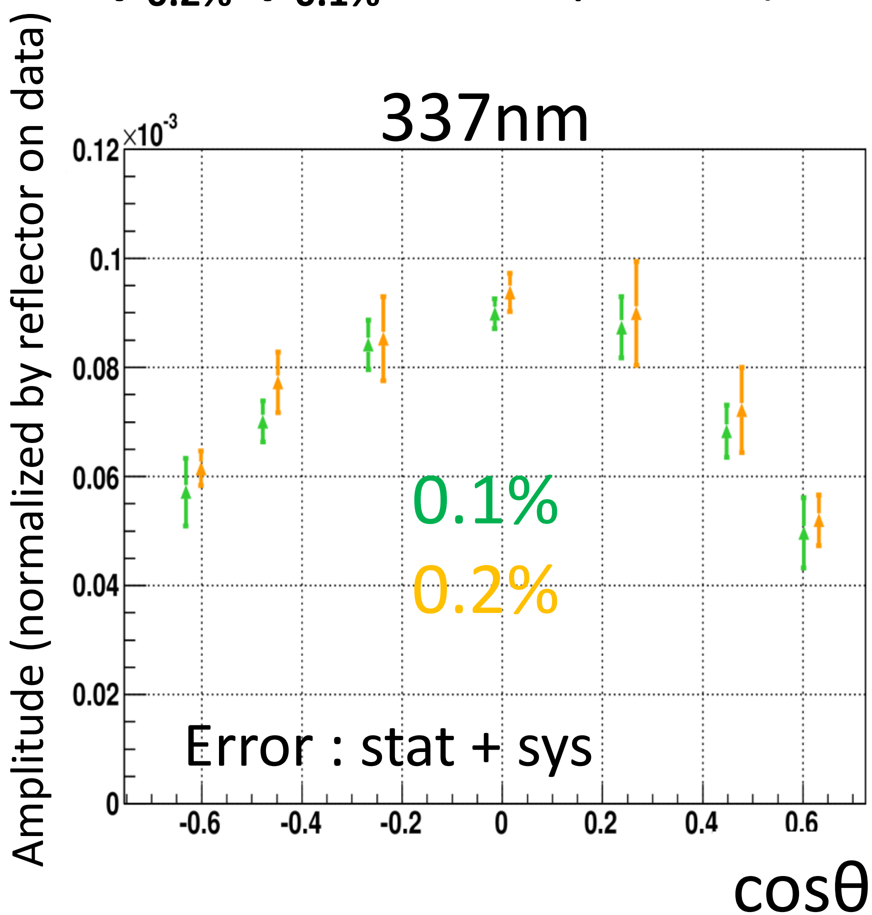


We confirmed that at every configuration, the reproducibility is ~10% due to uncontrolled systematics (beam halo and its reflection etc.)

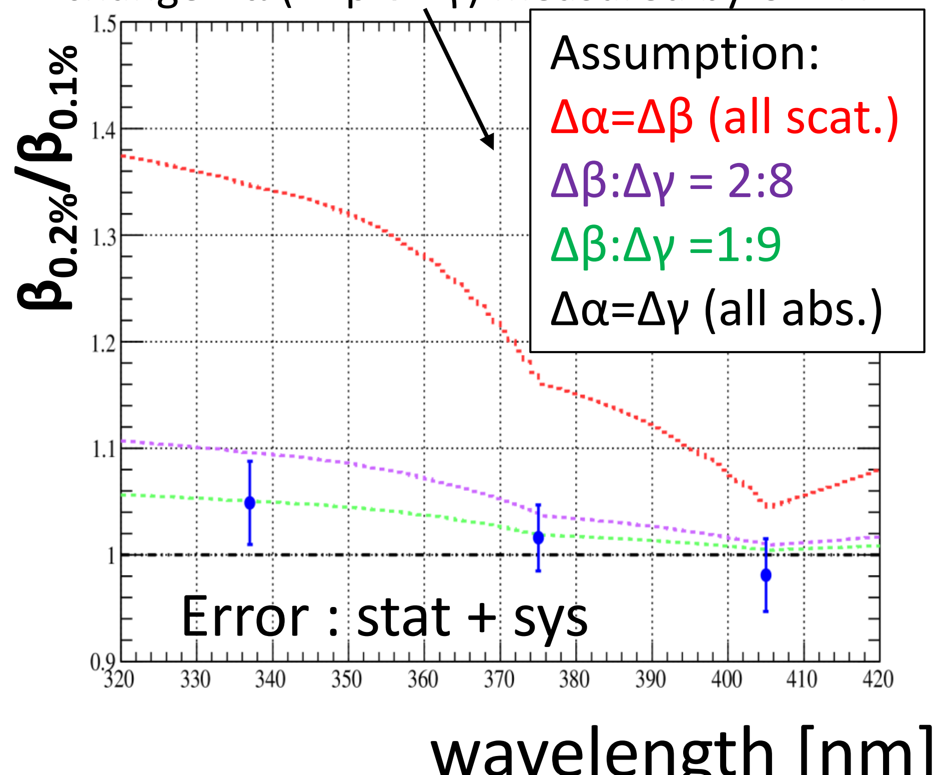
Comparison between 0.1% and 0.2% Gd water

Assume BG which affects to the amplitude is negligible, then

$\boldsymbol{\beta_{0.2\%}/\beta_{0.1\%}} \sim$ Amplitude(0.2%)/Amplitude(0.1%)



Dashed line: Expectation from total attn. change Δα (=Δβ＋Δγ) measured by UDEAL



No significant increase of scattering was observed.

(for simulation, Δβ:Δγ =1:9 case was taken)

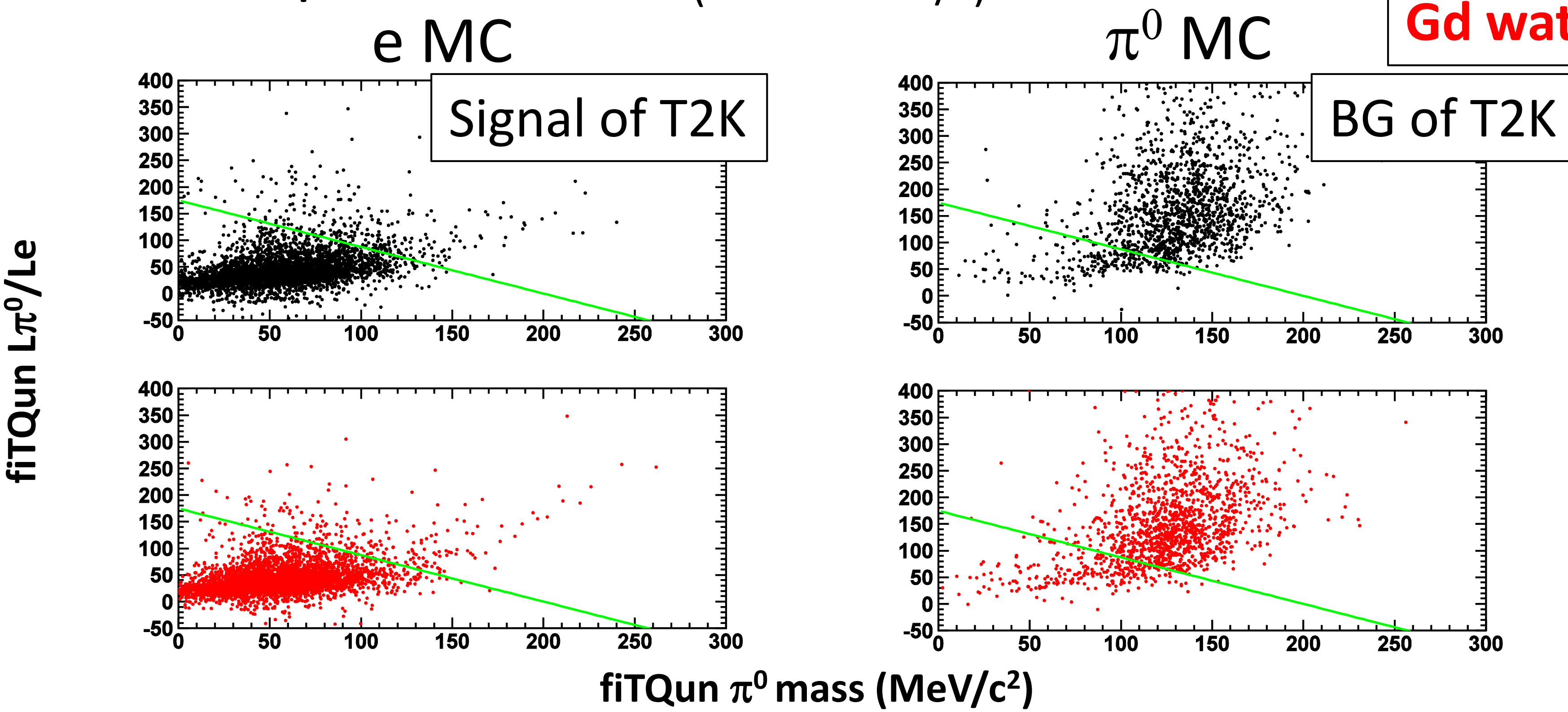
Effect on High energy (atm.ν, T2K)

	Pure water	Gd water
Momentum resolution		
electron (500MeV)	4.9%	4.9%
muon(500MeV)	2.5%	2.5%
Miss-PID(%)		
muon(500MeV)→e-like	0.59 ± 0.12	1.00 ± 0.15
π^0(500MeV)→ T2K1Re	4.7 ± 0.3	6.1 ± 0.4
Number of T2K events (nu-mode $3.9*10^{21}$ POT)		
Appearance signal	98.5	97.7
Appearance BG	24.6	25.2
Disappearance signal	622.2	623.8
Disappearance BG	45.6	48.6

e/π^0 separation (ex. 500MeV/c)

By Mine

pure
Gd water



e MC, det. ε(%)

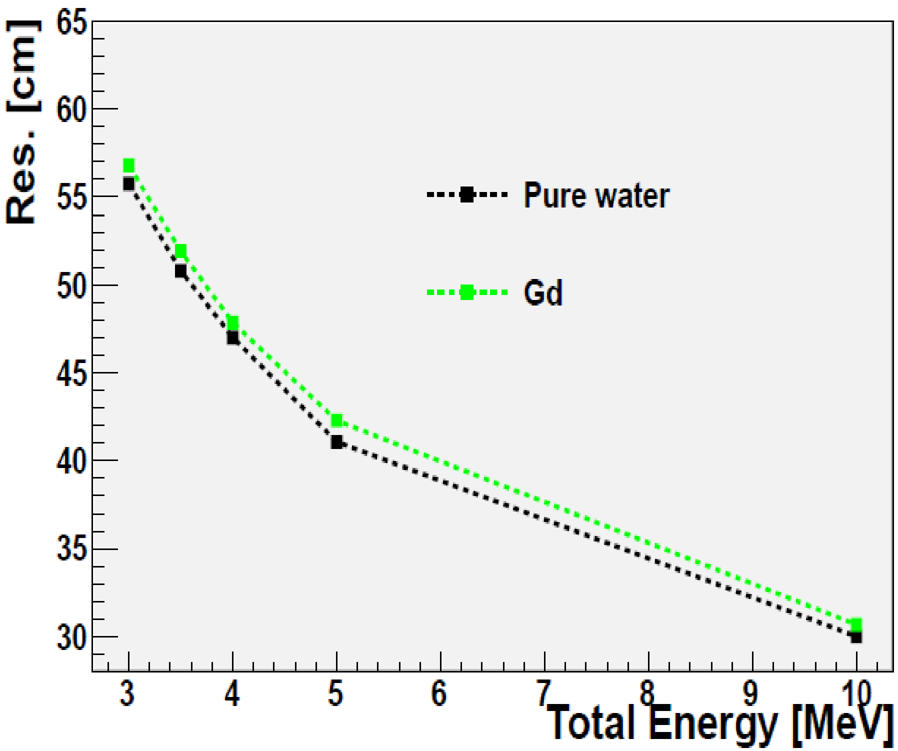
true (MeV/c)	pure	Gd water
250	92.9±2.1	91.9±2.1
500	89.3±2.0	88.4±2.0
1000	75.7±1.8	77.7±1.8

π^0 MC, remain ε(%)

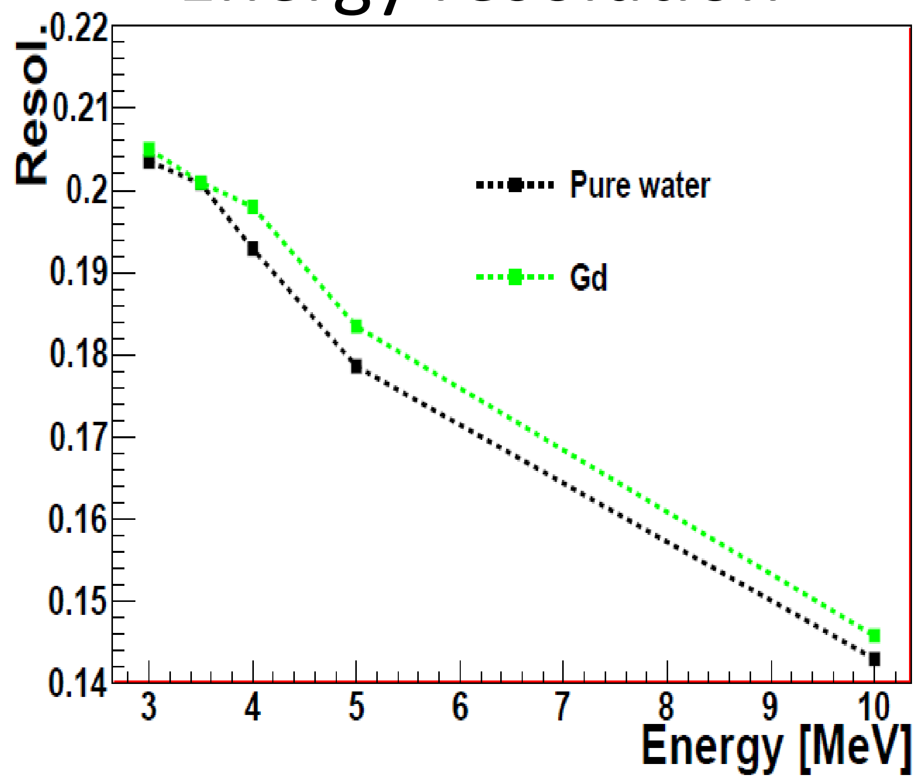
true (MeV/c)	pure	Gd water
250	1.7±0.2	1.9±0.2
500	4.7±0.3	6.1±0.4
1000	15.8±0.7	16.7±0.7

Effect on Low energy (solar ν, SRN)

Vertex resolution



Energy resolution



Note that plots are 0 suppressed

Acceptable for existing Lowe analyses.

Baseline method to stop SK tank leak

Cover welded places with sealing materials.

Cover with two layers.
Lower layer is BIO-SEAL 197 which sneak into small gaps, and upper layer is a material which allows more displacement.

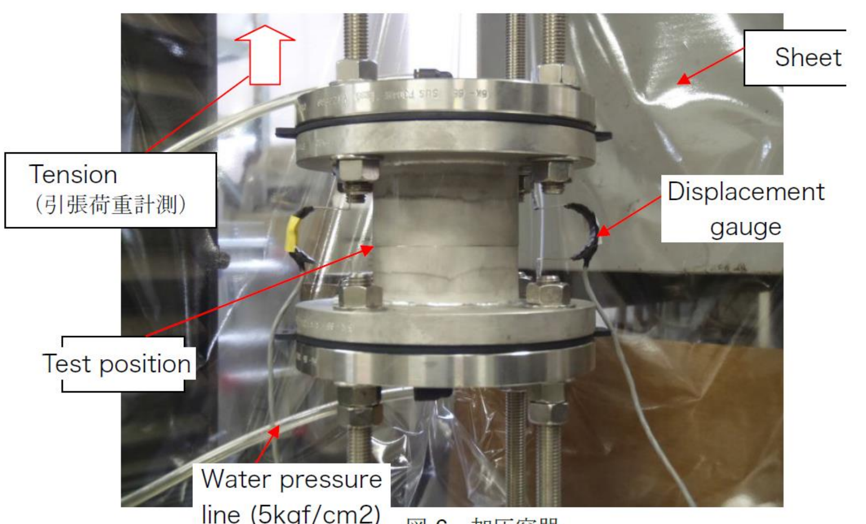
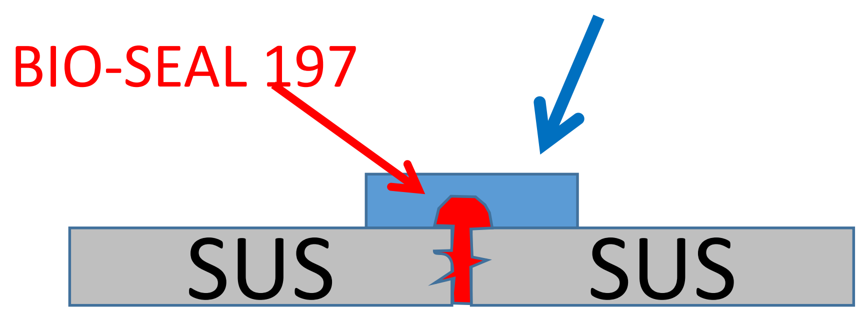


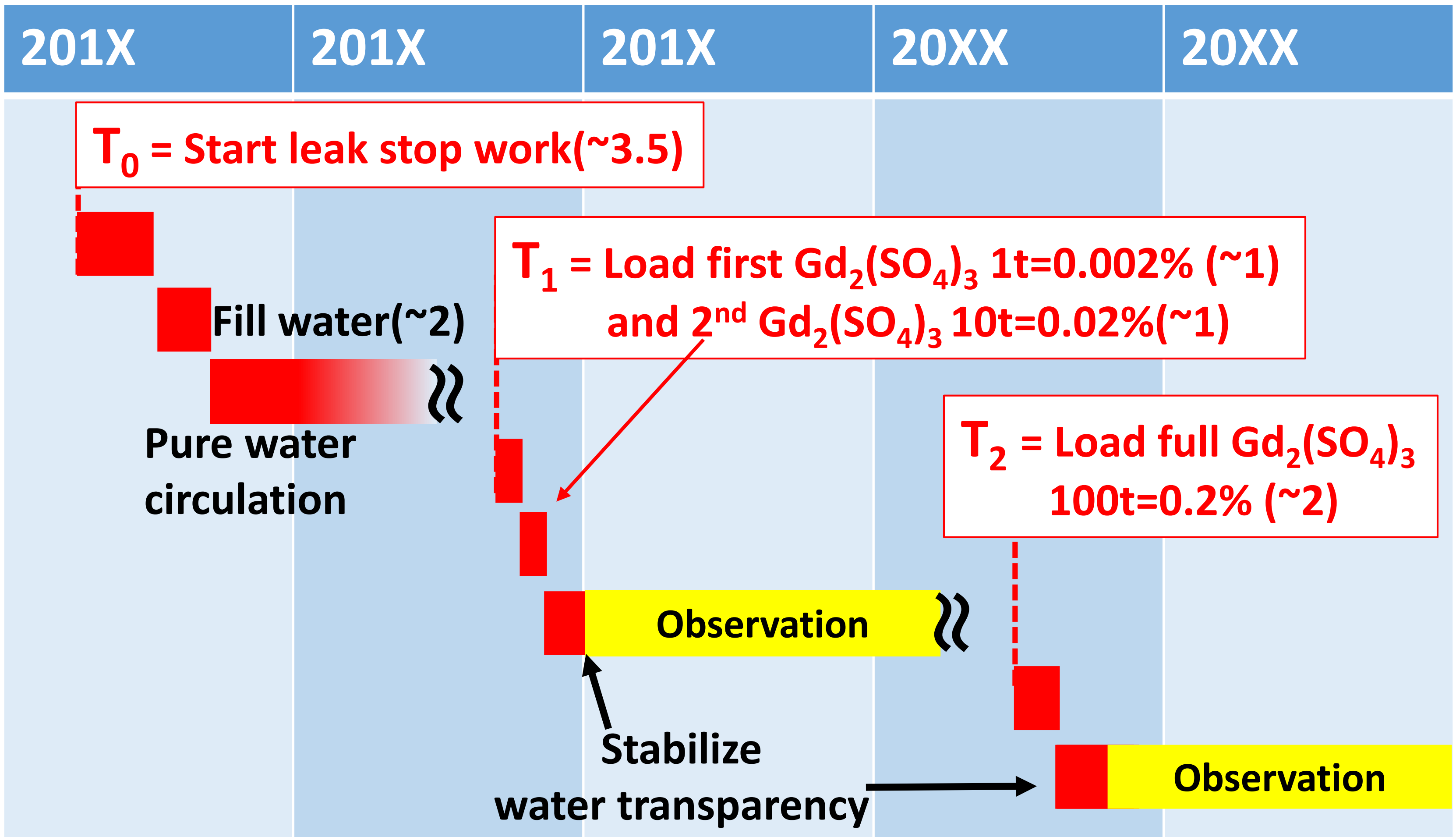
図-6　加圧容器

Current candidate; MineGuard



Timeline of SK-Gd

Numbers in parentheses are months to be taken for the work



In order to set T_0, T_1,&T_2, T2K schedule will be also taken into account

Summary

- SK-Gd project (was known as GADZOOKS!) started in 2002
- EGADS started in 2009 to evaluate Gd effect to SK.
- In 2015, we achieved resolving 0.2% (target value) of Gd sulfate after PMT installation without a large loss of water quality.
- Most of listed items to study Gd effect were studied, and confirmed that there is no showstopper.
- Finally, SK-Gd was accepted by Super-K in June 2015.
- Let’s enjoy neutron tagging physics with SK-Gd!