New Results from RENO

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On behalf of the RENO Collaboration

KNRC, Seoul National University

(March, 12, 2013)

NuTel 2013

RENO

$\nu \sim\sim \theta_{13}$

KNRC

Korea Neutrino Research Center

◆ **Last result on PRL:**

Ahn et al (RENO collab.), PRL 108, 191802 (2012)

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(stat.) \pm 0.019(syst.)$$

◆ For the **New result**

<u>Statistics:</u>

-- about twice more data

<u>Systematics:</u>

-- Improved background estimation/reduction

(Li/He background, fast N, flasher removal)

-- Improved energy scale calibration

Outline

- Introduction
- Experimental setup & detector
- Data-taking & data set
- Improvements in data analysis
- Results
- Summary

YongGwang (靈光) :

RENO Collaboration

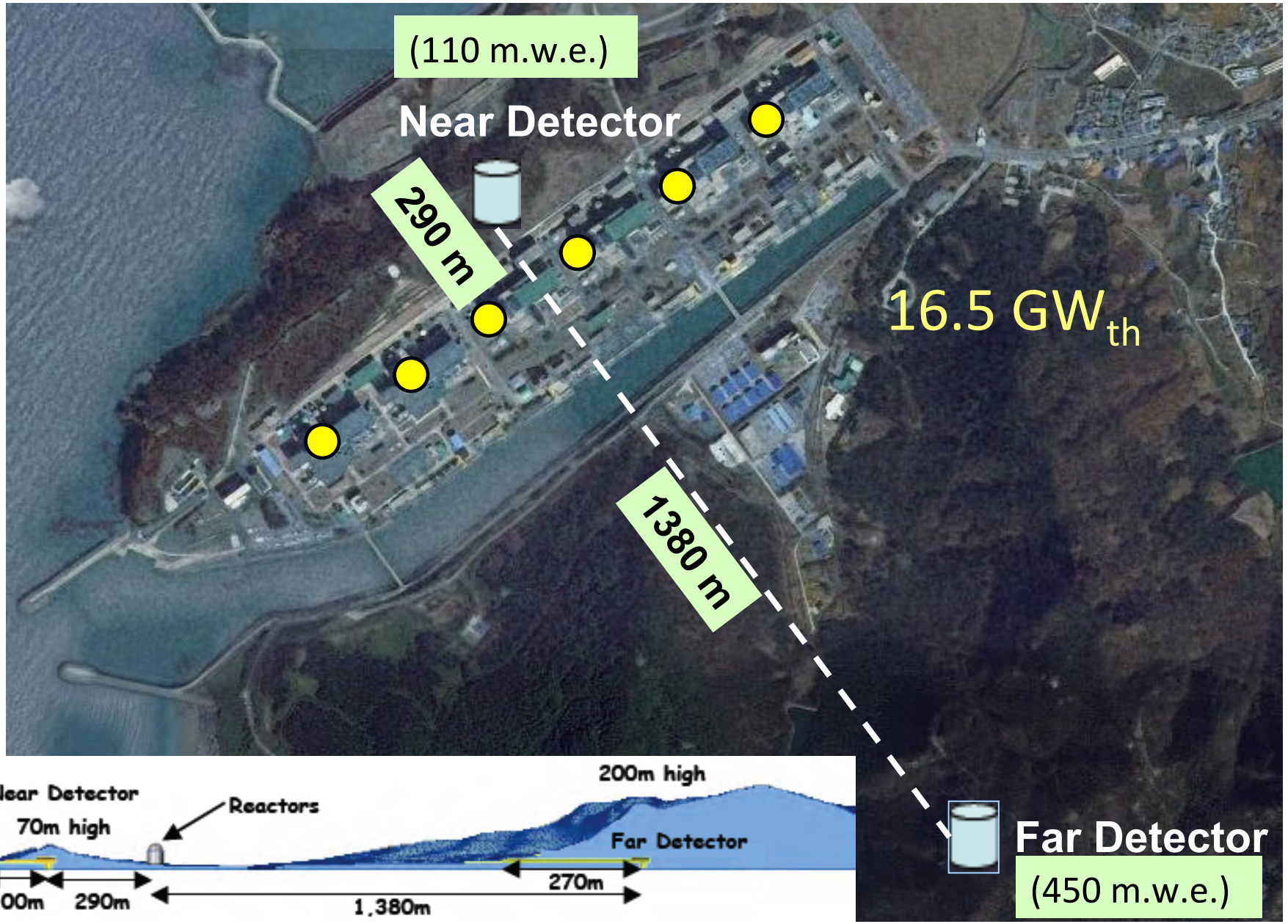
12 institutions and 40 physicists

- Chonbuk National University
- Chonnam National University
- Chung-Ang University
- Dongshin University
- Gyeongsang National University
- Kyungpook National University
- Pusan National University
- Sejong University
- Seokyeong University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University

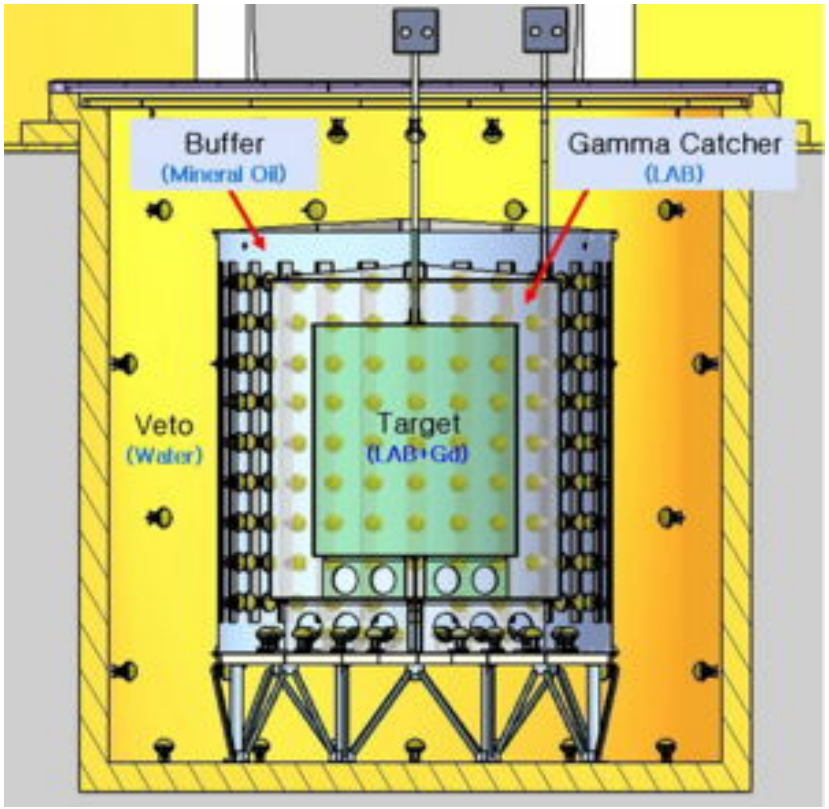
- **Total cost : $10M**
- Start of project : **2006**
- The first experiment running with both near & far detectors from **Aug. 2011**

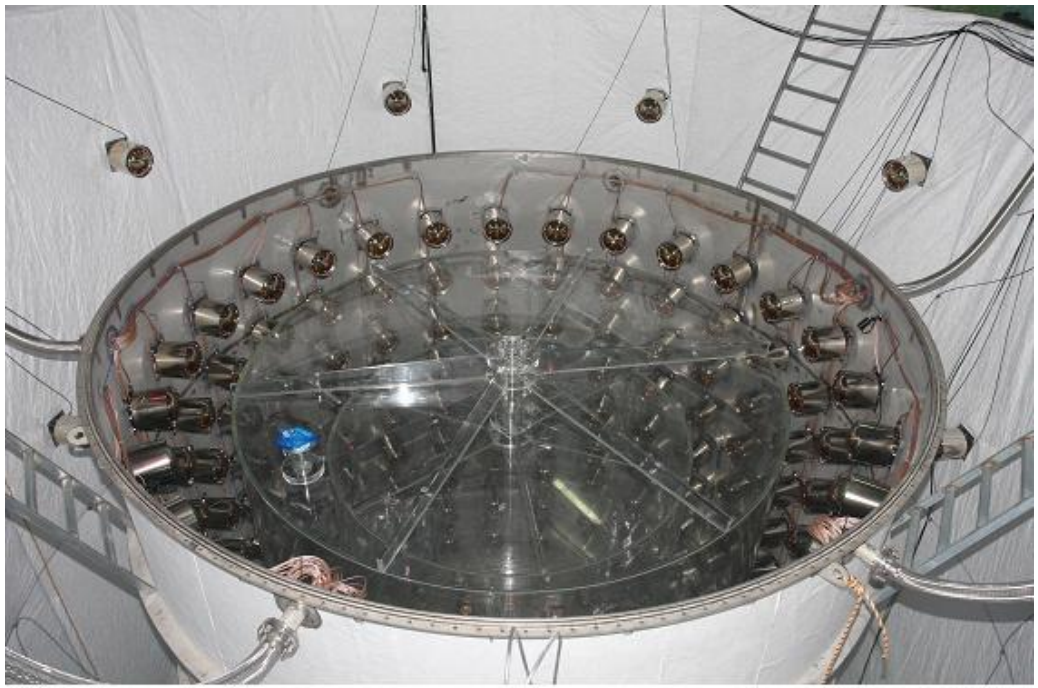
서울대 김수봉 교수가 이끄는 RENO 실험팀. 30여년간 관측에 실패한 마지막 중성미자 변환상수를 밝히기 위해 프랑스 중국과 치열한 경주를 벌이고 있다.

RENO Experimental Setup



RENO Detector

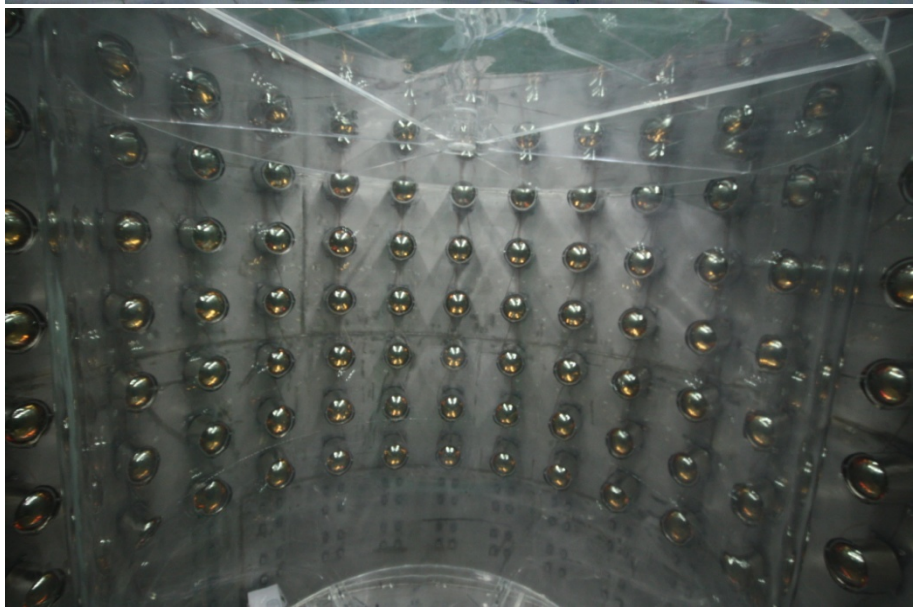




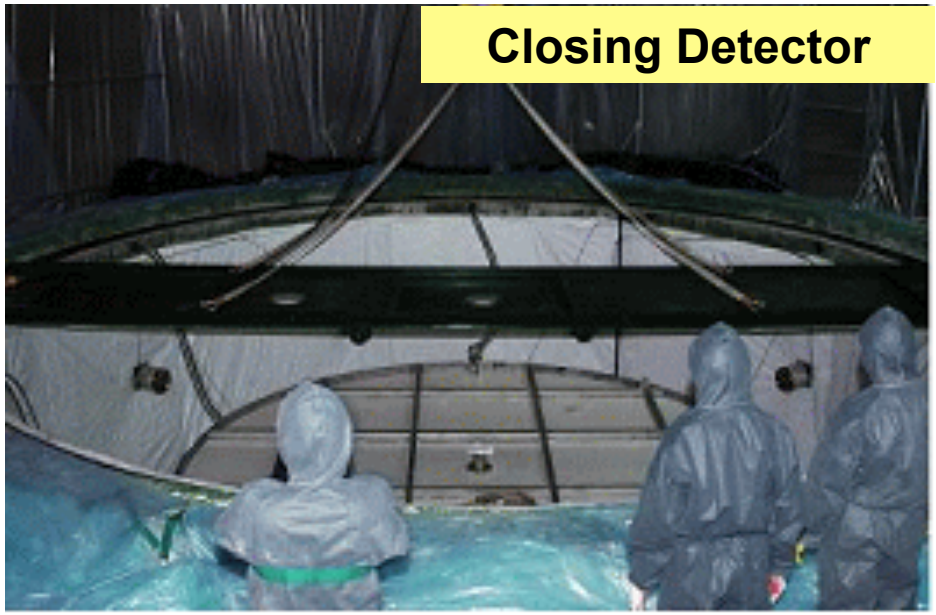
- 354 ID +67 OD 10” PMTs
- Target : 16.5 ton Gd-LS, R=1.4m, H=3.2m
- Gamma Catcher : 30 ton LS, R=2.0m, H=4.4m
- Buffer : 65 ton mineral oil, R=2.7m, H=5.8m
- Veto : 350 ton water, R=4.2m, H=8.8m

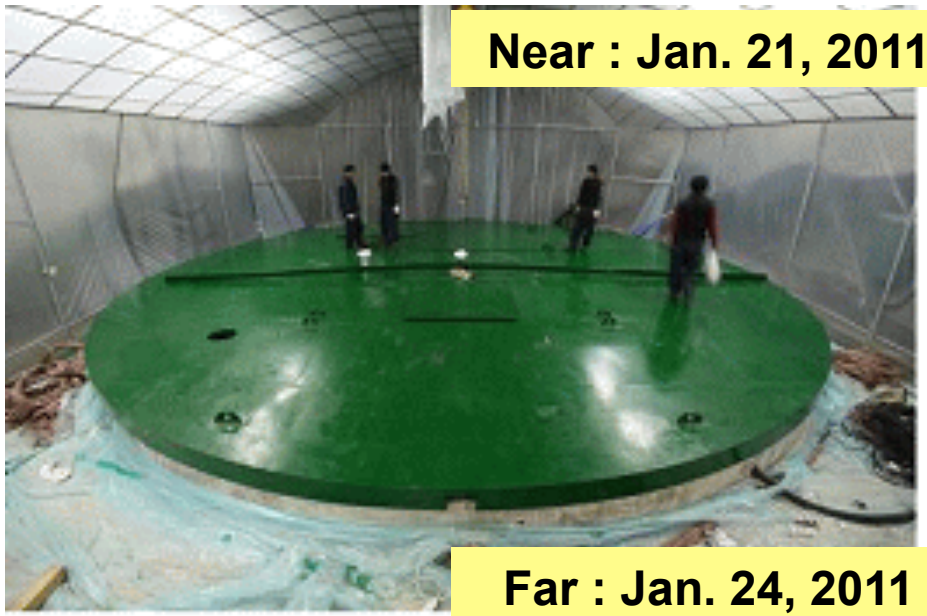
PMT Mounting and Detector Closing

PMT mounting: Aug-Oct. 2010



Closing Detector





Near : Jan. 21, 2011

Far : Jan. 24, 2011

Detection of Reactor Antineutrinos

Inverse beta decay

(prompt signal)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

~180 μs

+ p → D + γ (2.2 MeV)

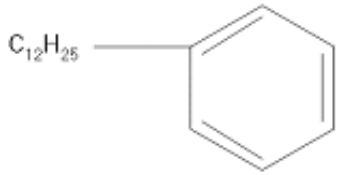
(delayed signal)

~30 μs
(0.1% Gd)

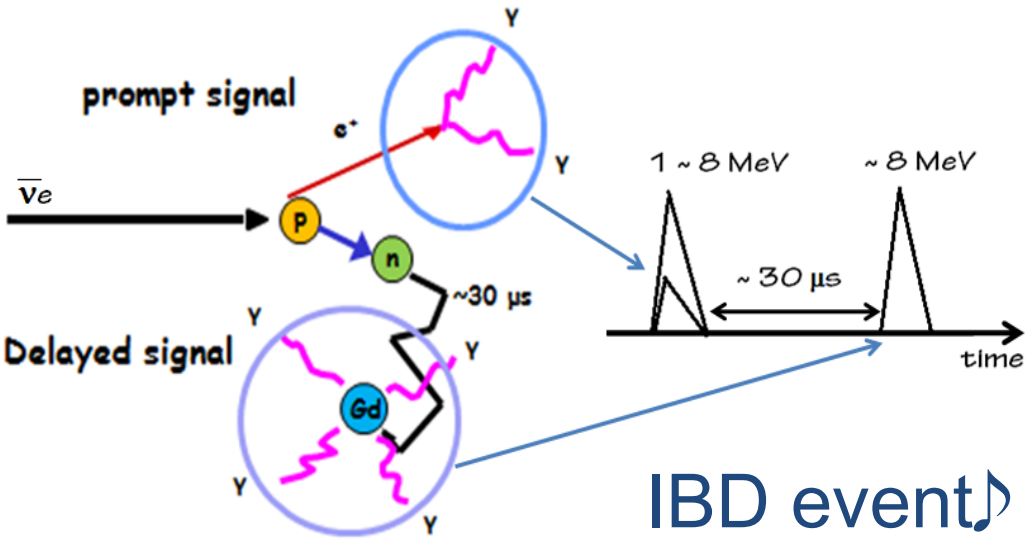
+ Gd → Gd + γ's (~8 MeV)

Higher captured cross section
& Additional gammas in Gd-LS detector

C_nH_{2n+1}-C_6H_5 (n=10~14)



Linear Alkyl Benzene (LAB)

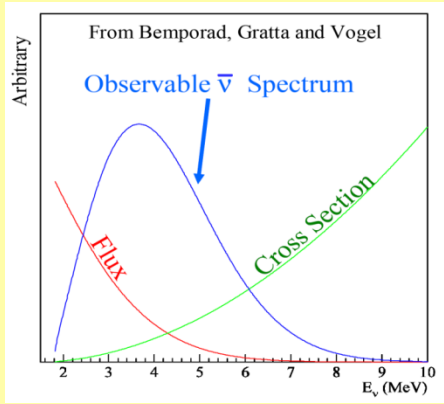


IBD event♪

Neutrino energy measurement ♪

$$E_{\bar{\nu}} \cong T_{e^+} + T_n + (M_n - M_p) + m_{e^+}$$

10-40 keV 1.8 MeV



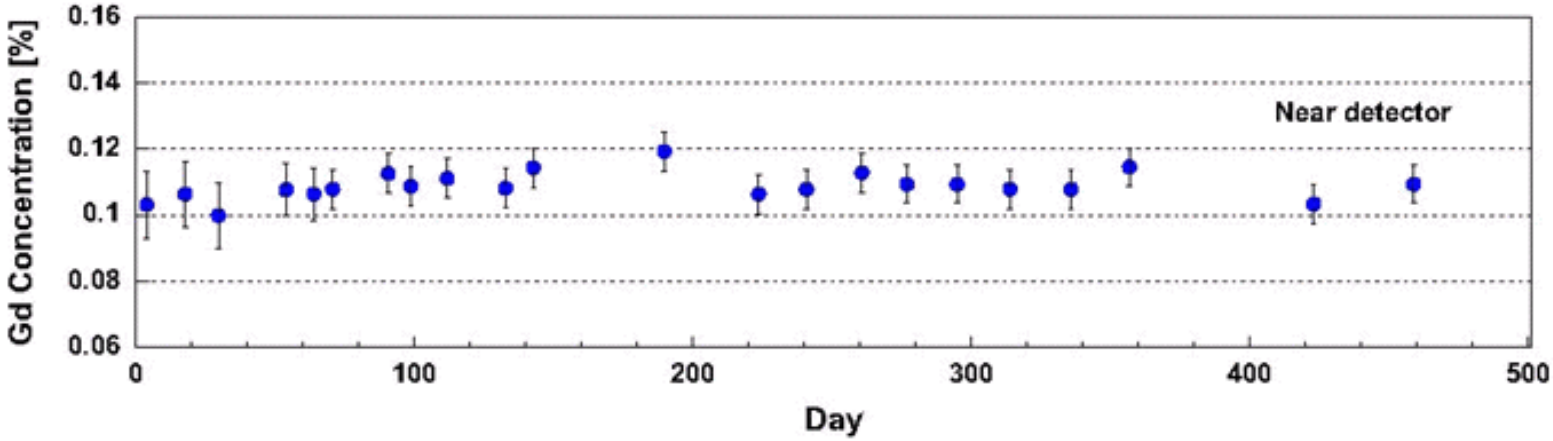
Stability of Gd Loaded Liquid Scintillator

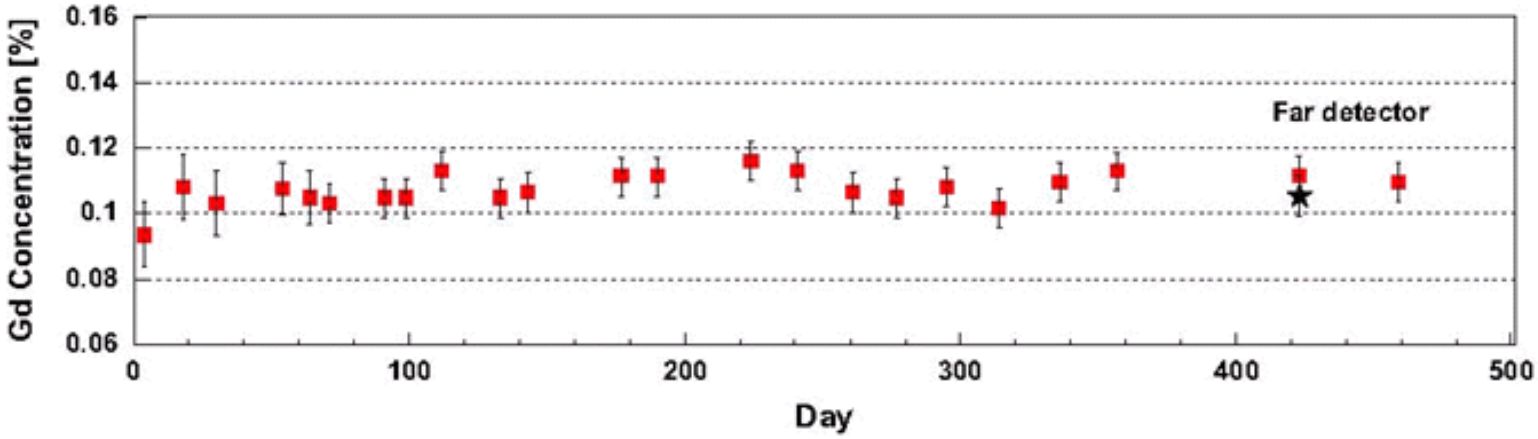
* Stable light yield : ~250 pe/MeV

* Stable transparency at 430 nm

* Stable Gd concentration (0.11%)

NIM A, 707, 45-53
(2013. 4. 11)

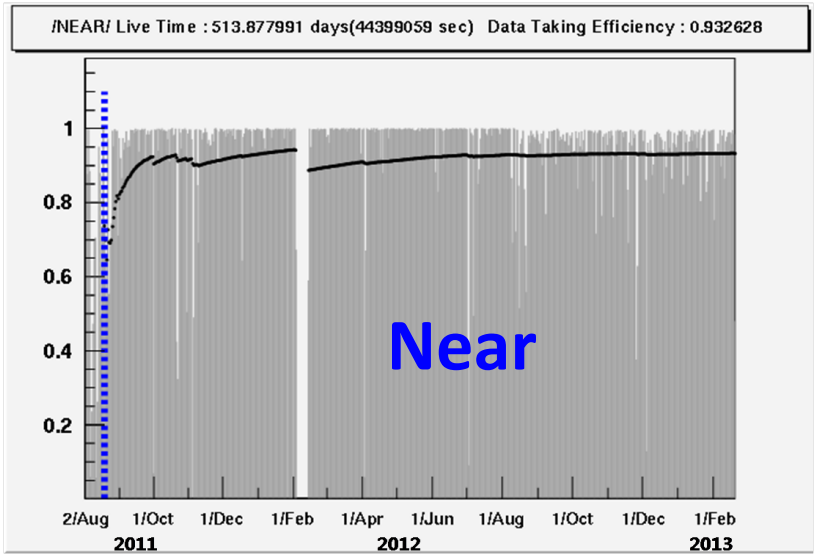


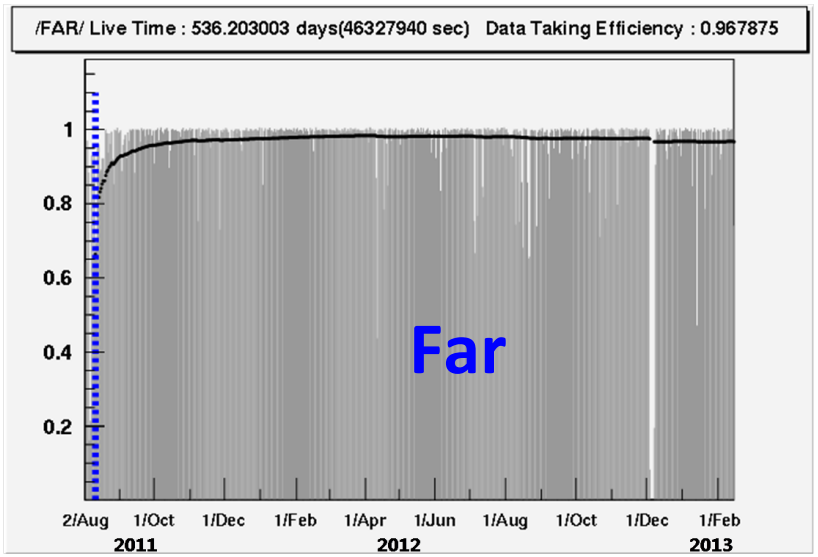


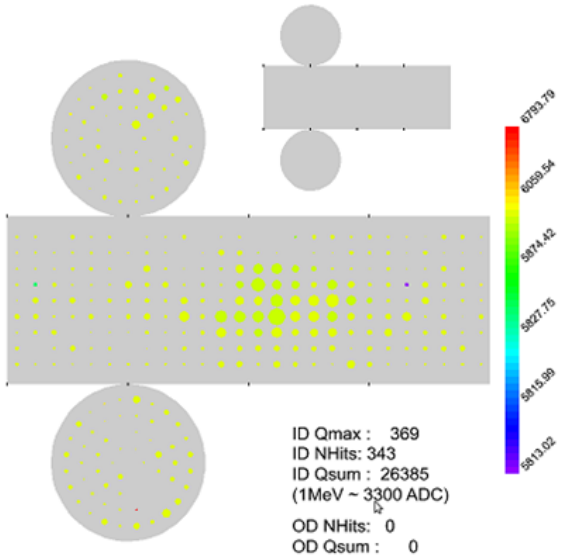
Data-Taking & Data Set

- Data taking began on Aug. 1, 2011 with both near and far detectors.
- Data-taking efficiency > 90%.
- Trigger rate w/ the threshold energy of 0.5~0.6 MeV: 80 Hz (Far Detector)
- Data-taking period > 510 days
  Aug. 11, 2011 ~ Present

- Data-taking efficiency







A candidate for a neutron captured by Gd

Improvements in Data Analysis

- Better estimation of Li/He background :

$$2.59 \pm 0.75 / day \rightarrow 3.61 \pm 0.60 / day \quad \text{(far)}$$

$$12.45 \pm 5.93 / day \rightarrow 13.73 \pm 2.13 / day \quad \text{(near)}$$

(more improvement soon on the errors…)

- Improved flasher removal : reduction of accidental background

- Reduction of fast neutron background :

$$0.97 \pm 0.06 / day \rightarrow 0.68 \pm 0.04 / day \quad \text{(far)}$$

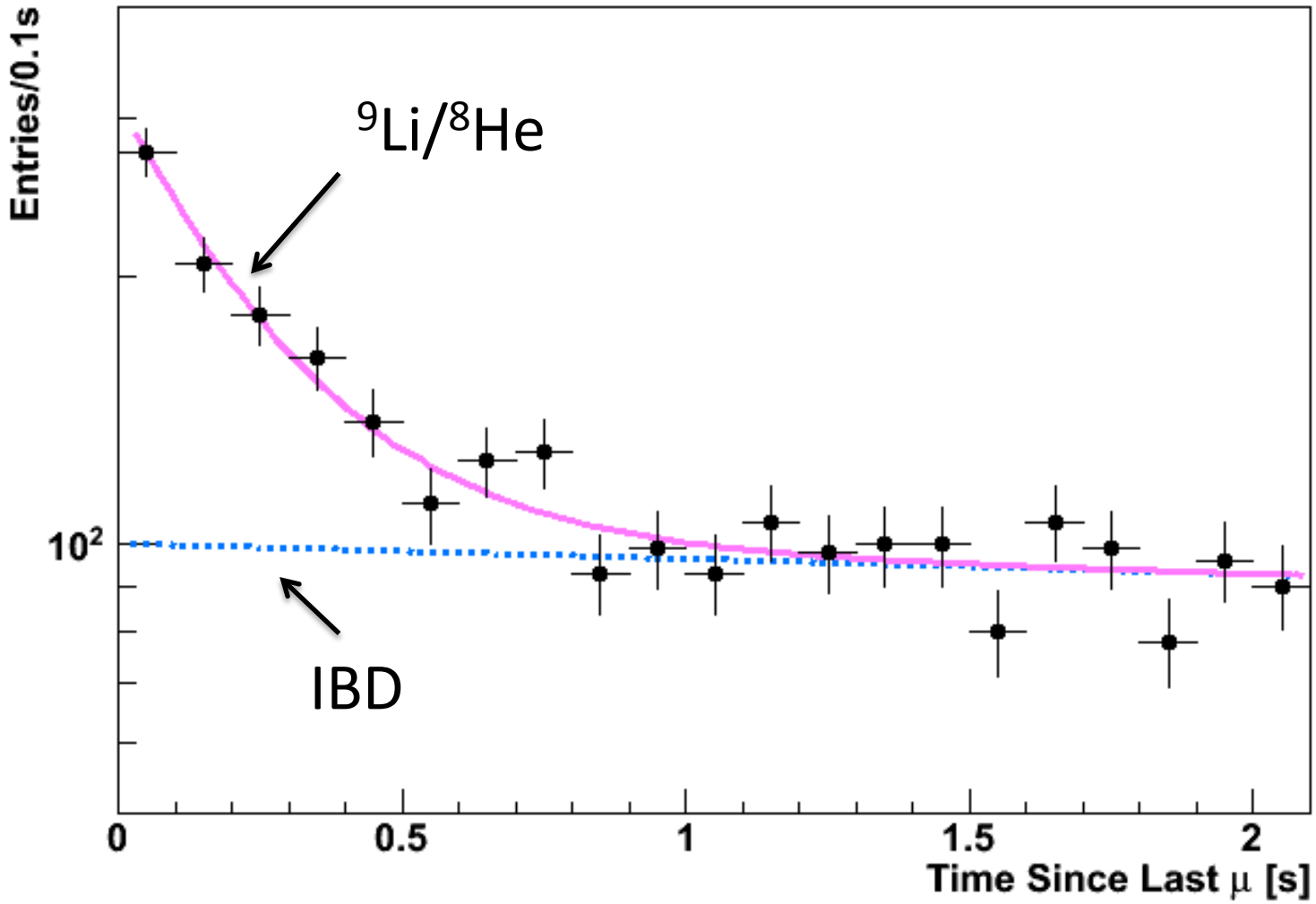
$$5.00 \pm 0.13 / day \rightarrow 3.14 \pm 0.09 / day \quad \text{(near)}$$

- Major efforts on energy calibration : accurate energy scale

- Selection of clean data sample

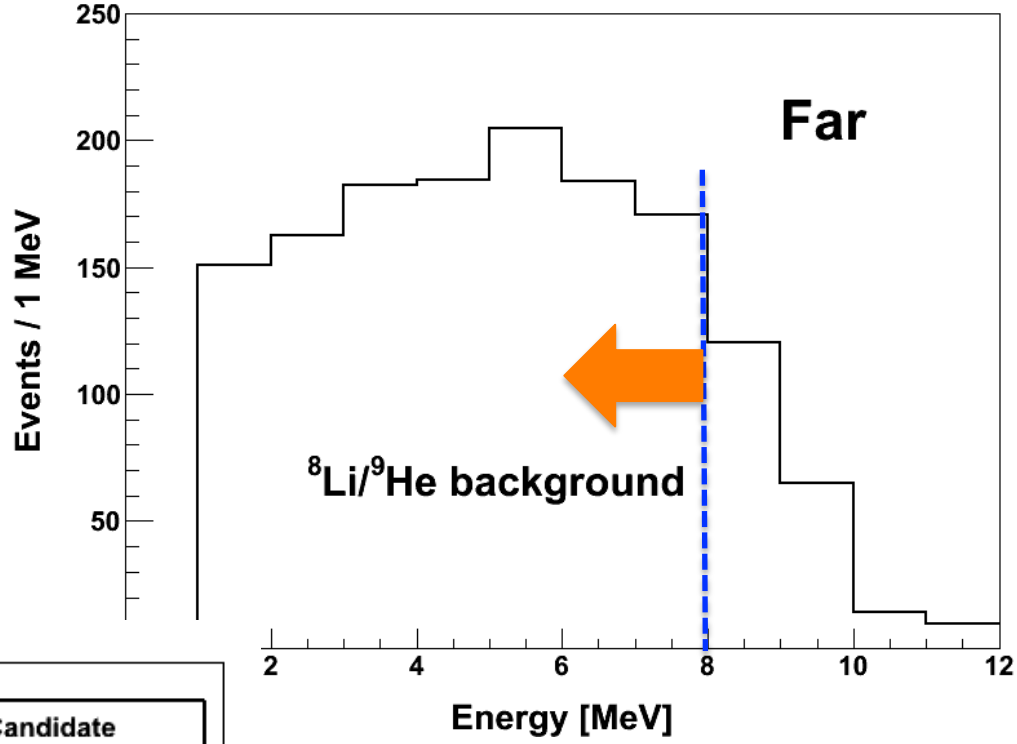
^{9}Li/^{8}He Background

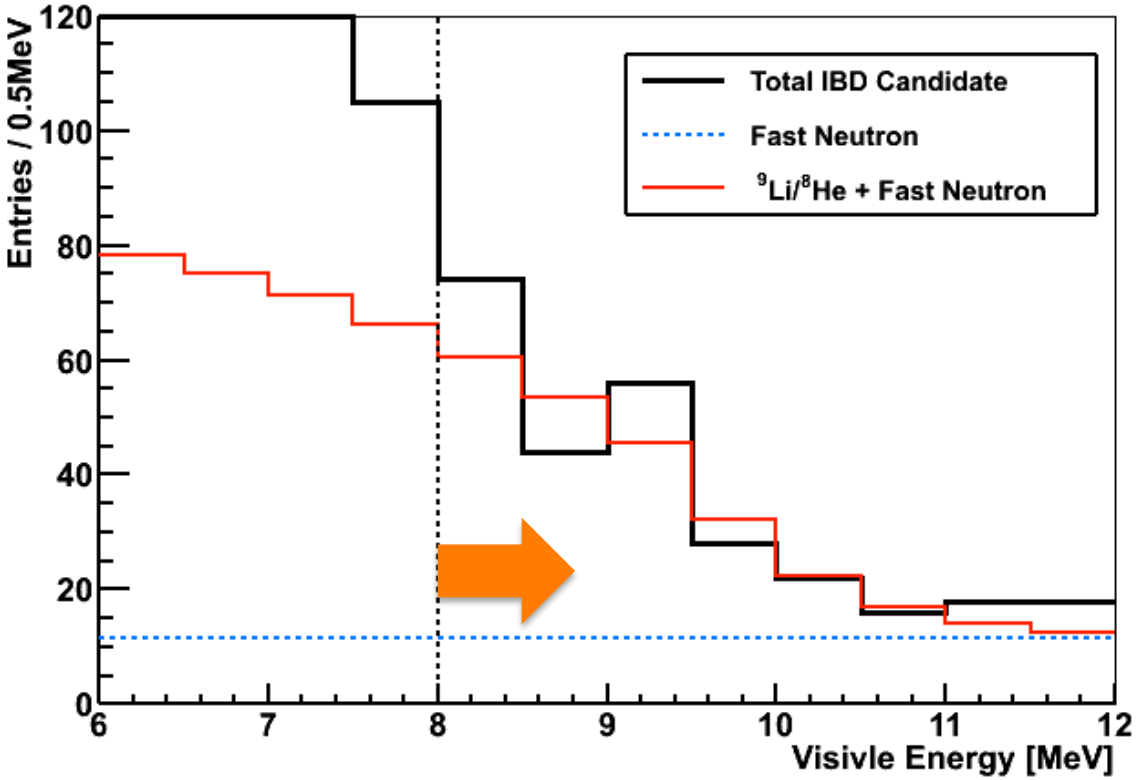
^{9}Li/^{8}He are unstable isotopes emitting (β,n) followers and produced when muon interact with carbon in the LS.



^{9}Li/^{8}He Background Estimation

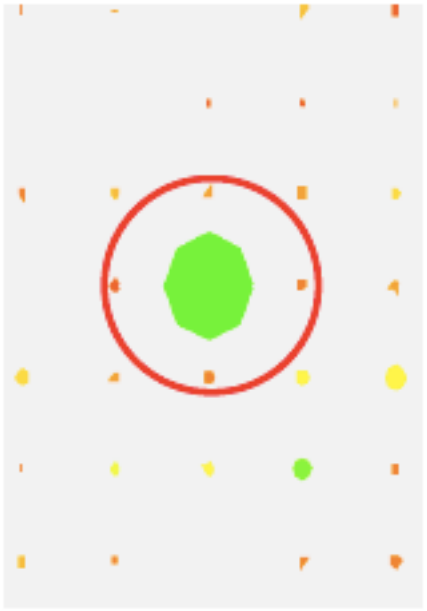
Scaling method





Li/He Selection:
> 1.3 GeV muon within 500 msec

Flasher Characteristics



"Flasher PMT" event

Normal event

Anti-isolation variable R

$$R_n = \frac{\overline{n}_n}{n_{max}}$$

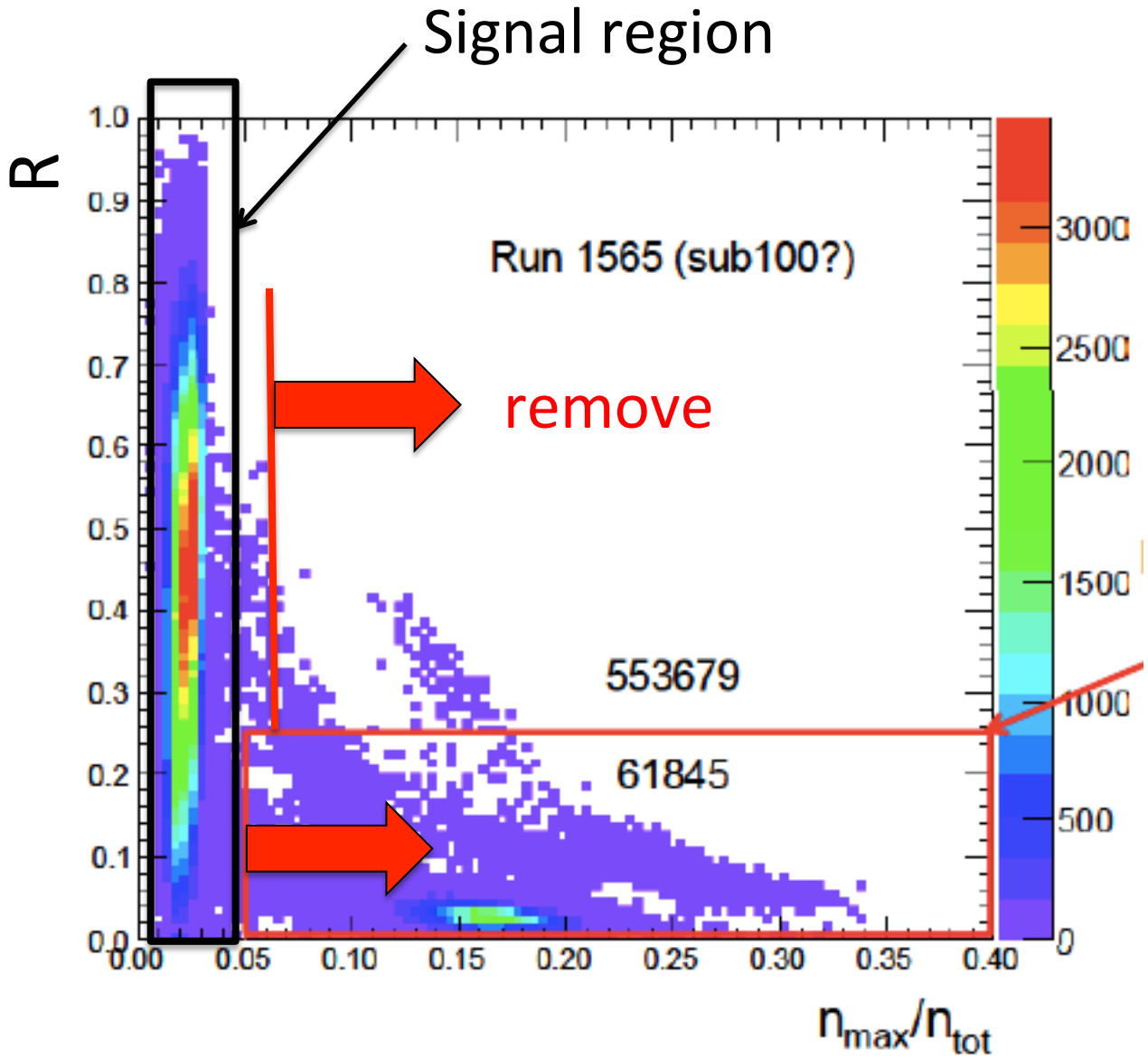
$$\overline{n}_n \equiv \frac{\sum n_i}{N_{nb}}$$

$\sum n_i$ ← Sum of NPEs in the neighbouring PMTs

N_{nb} ← Number of neighbouring PMTs

→ Smaller R value for flasher events.

Flasher Removal Cut



$R > 0.26$ &&
$n_{max}/n_{tot} > 0.06$

OR

$R < 0.25$ &&
$n_{max}/n_{tot} > 0.05$

Cf Contamination (I)

- Tiny fraction of Cf calibration source dissolved into Gd-LS after Oct. 13, 2012 :

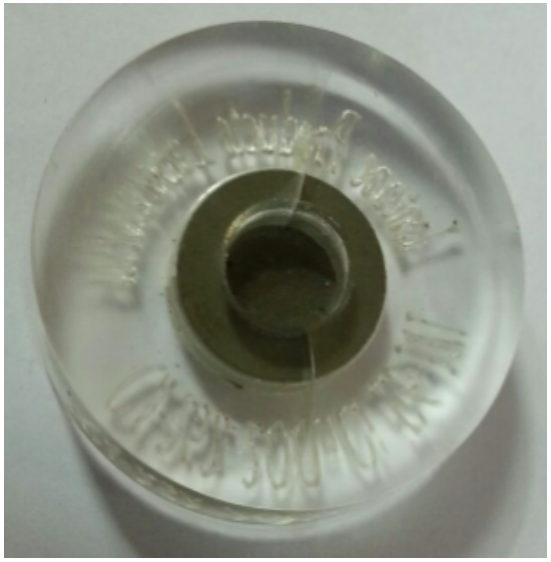
  - Loose O-ring in the source container → LS into the container

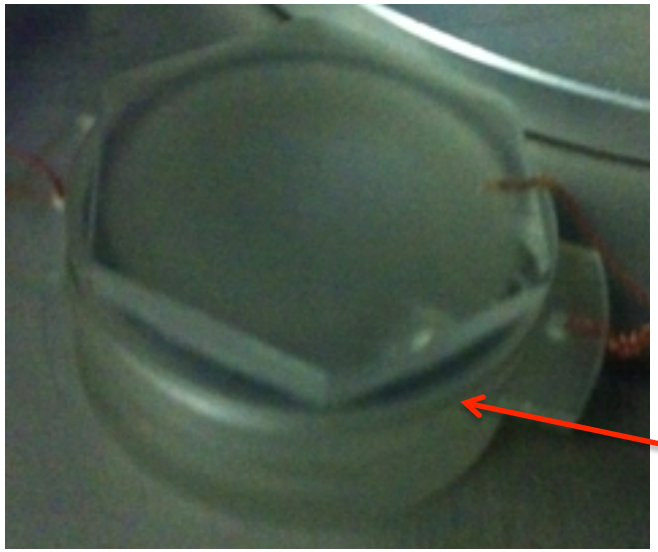
    → Cf out of its disc package → Cf contamination on gloves

    → Cf contamination on the container surface & dissolved into LS

  - Cf at the bottom of target (confirmed by event vertex)

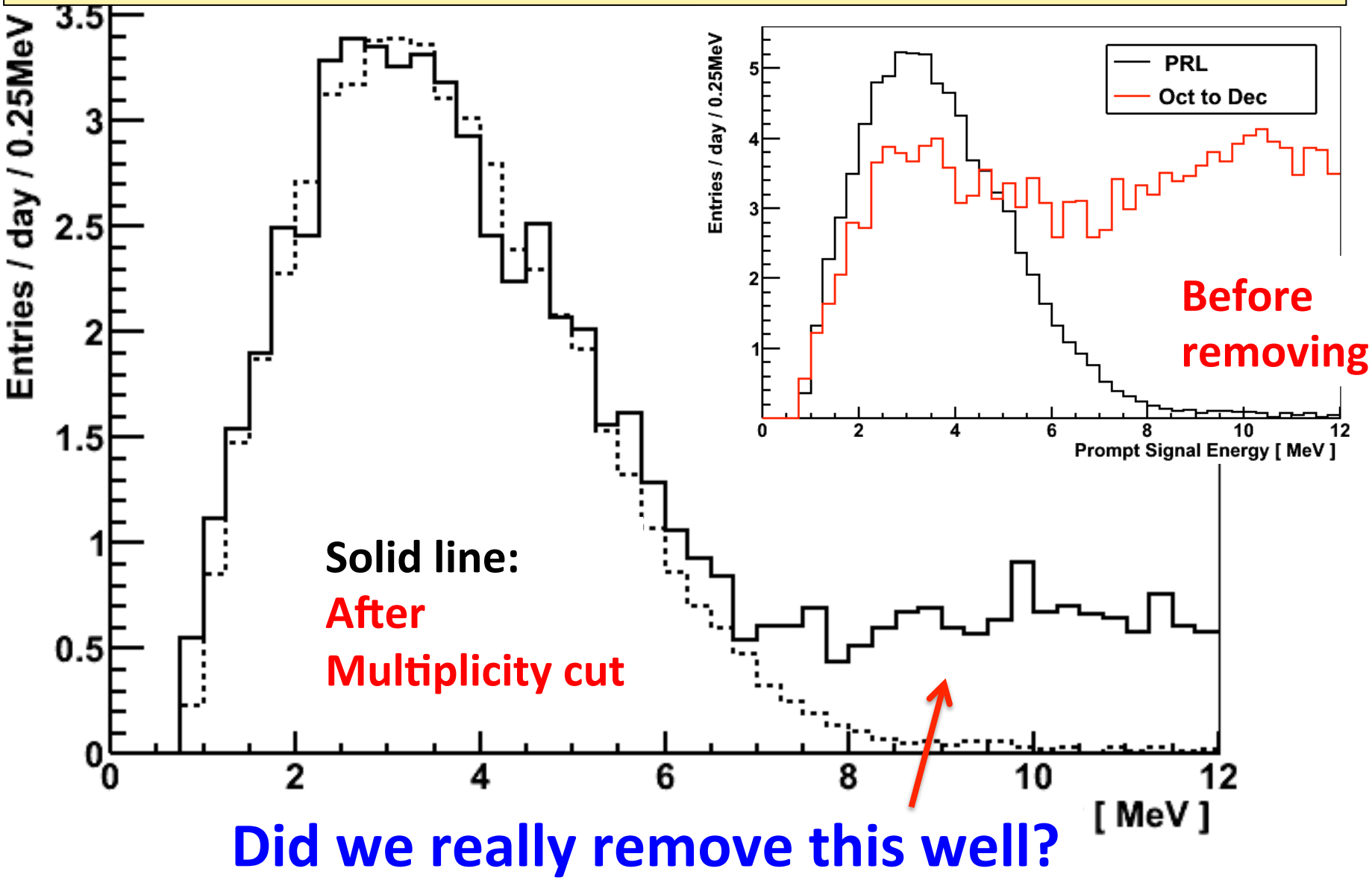
Cf252 source





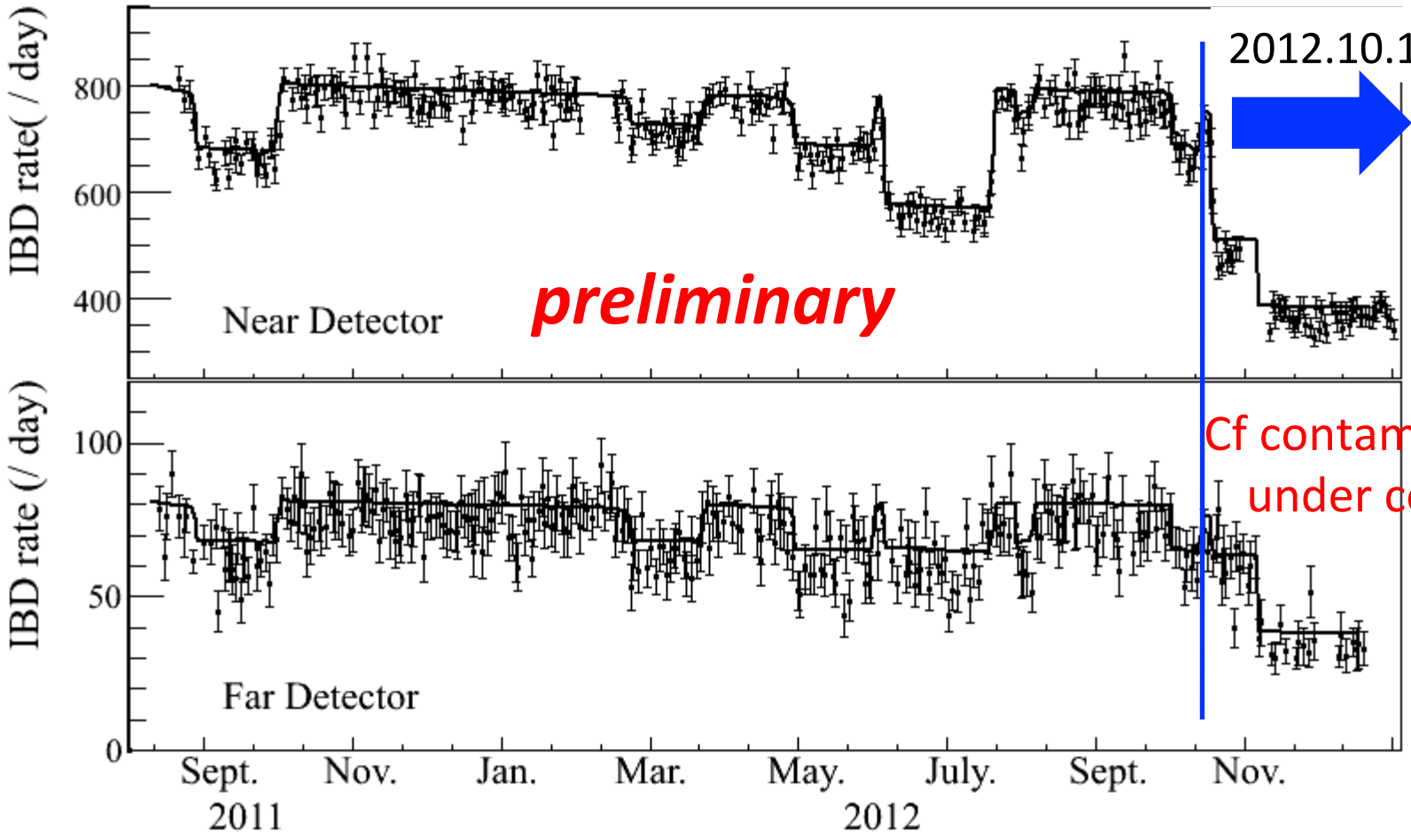
Cf Contamination (II)

- Removal by a multiplicity cut & subtraction by its energy shape :



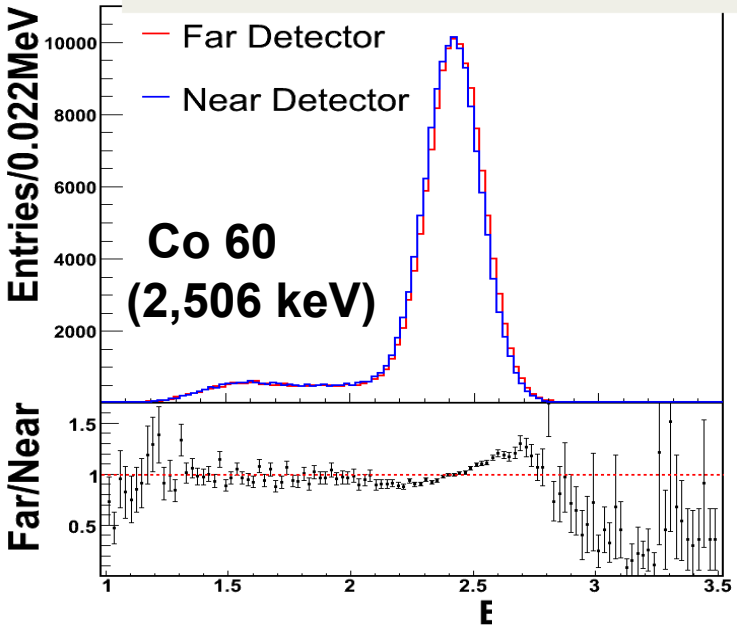
Did we really remove this well?

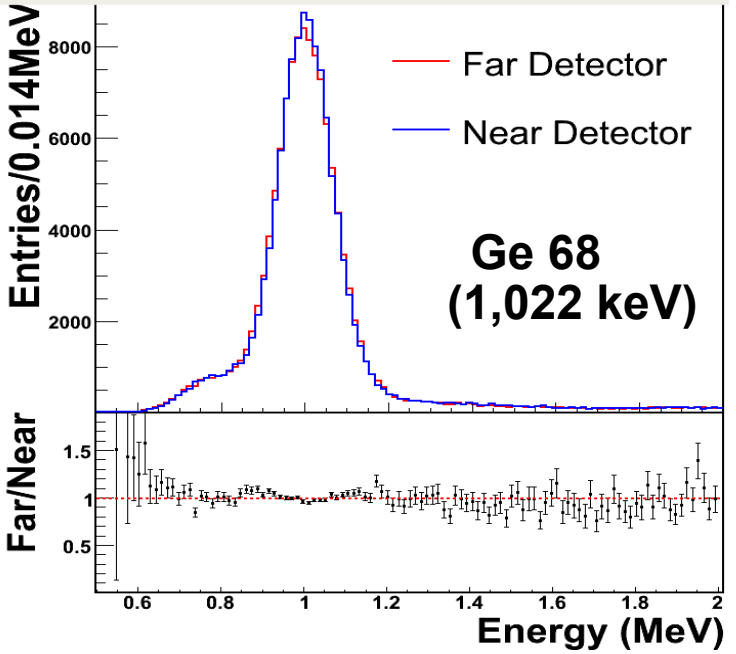
Observed Daily IBD Rate

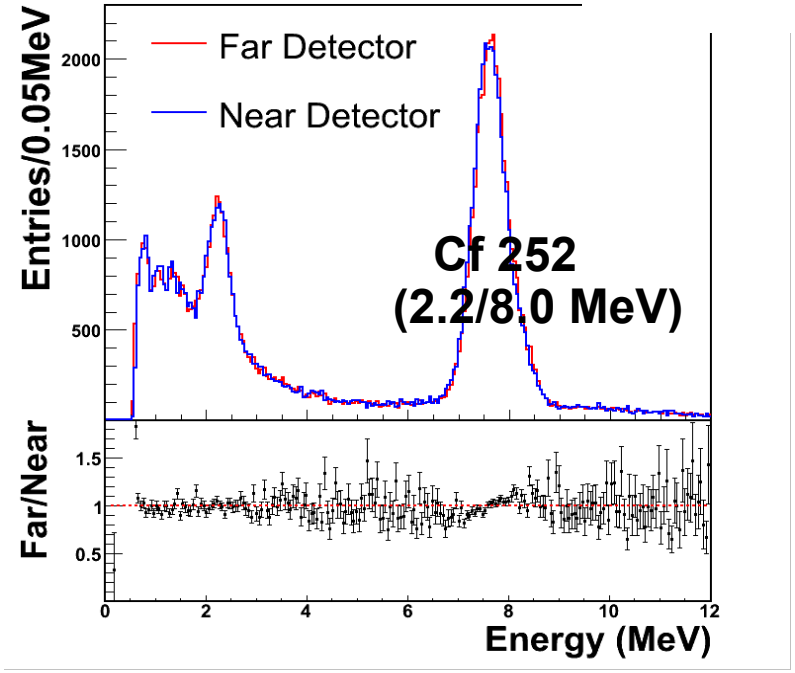


- Solid line is predicted rate from the neutrino flux calculation.
- Observed points have very good agreement with prediction.
- It's the accurate flux measurement.

Energy Calibration

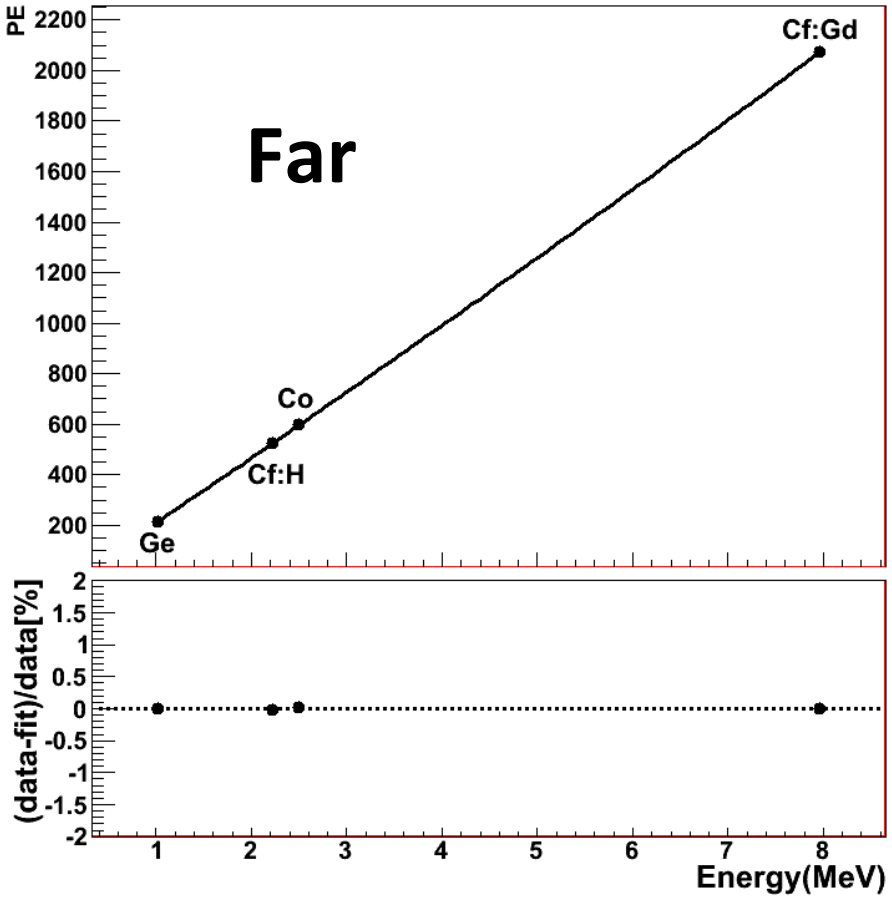


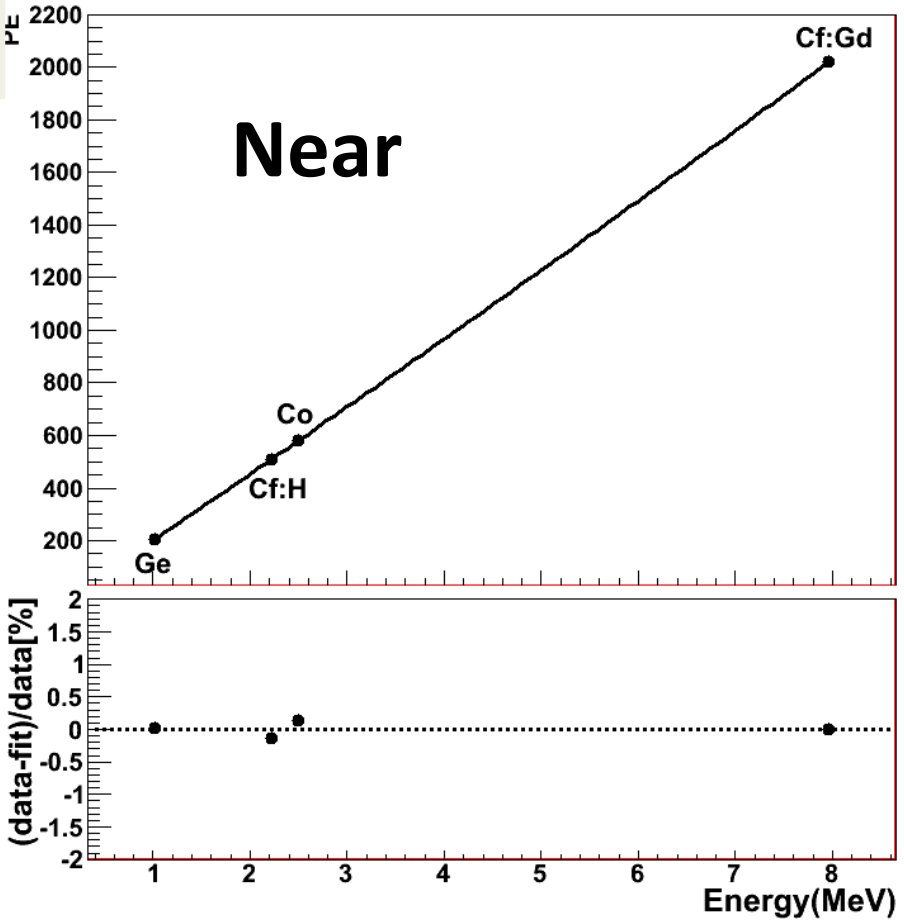




Energy Calibration

PE → MeV conversion fnc

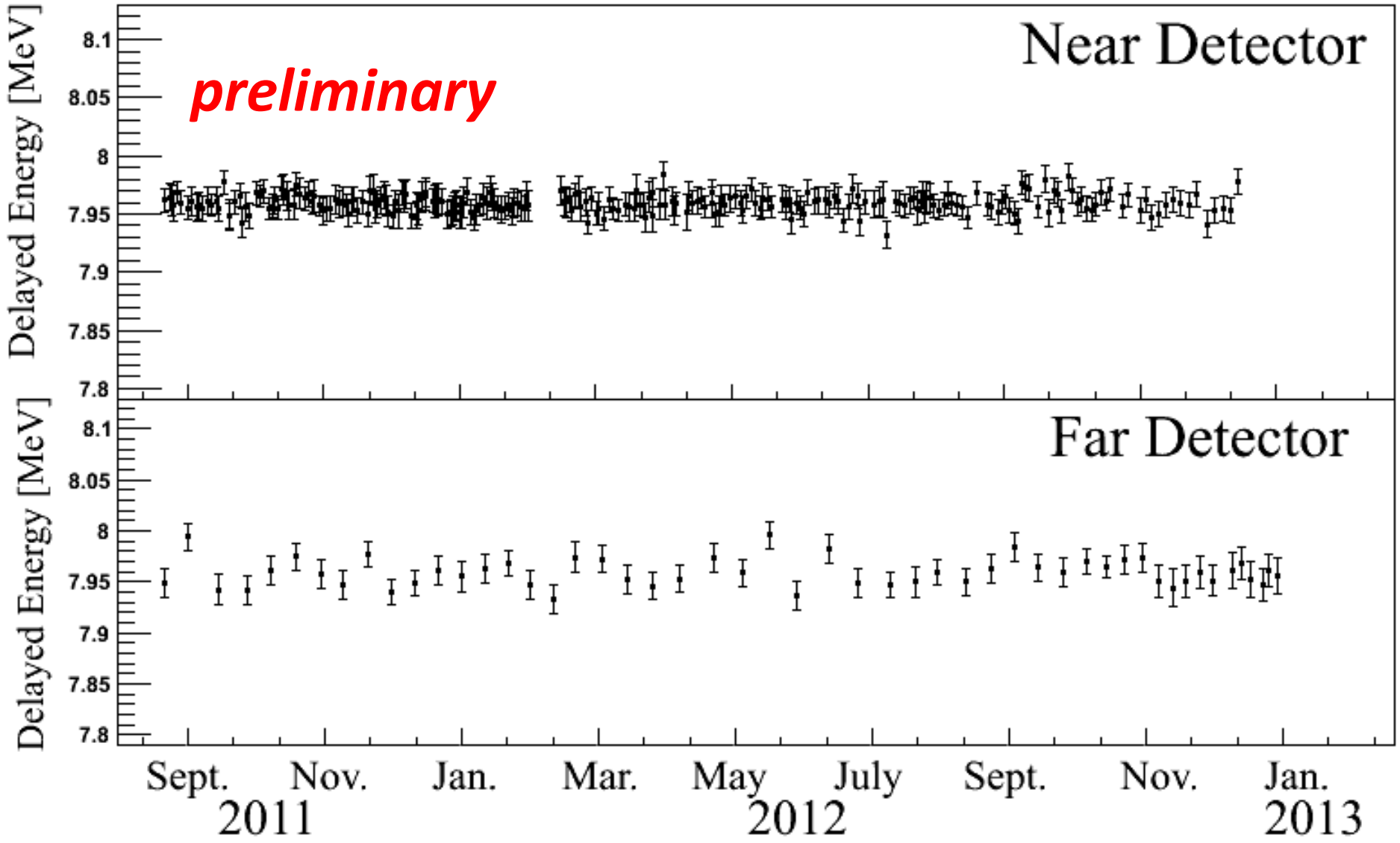




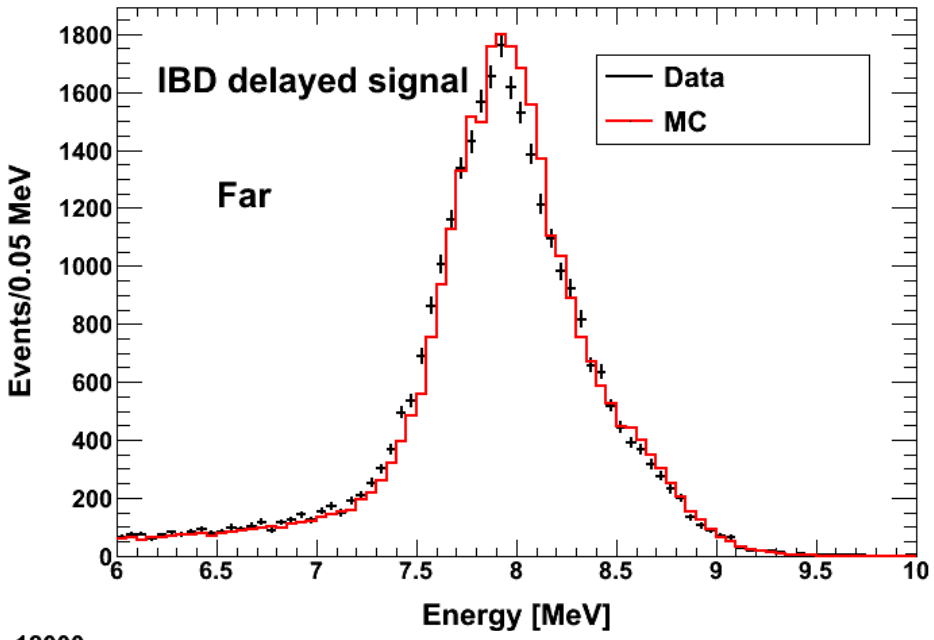
Fitting accuracy: 0.1 %

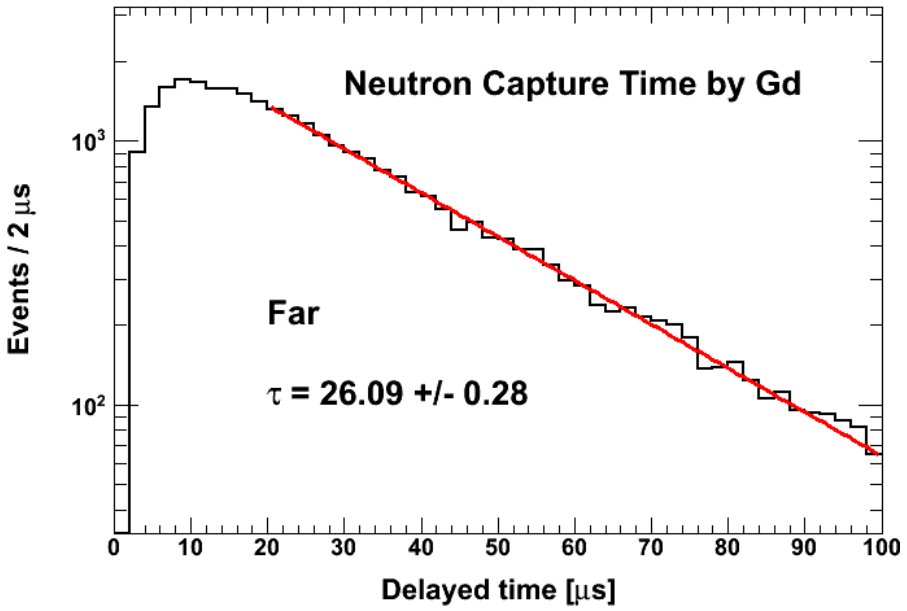
Detector Stability of Energy Scale

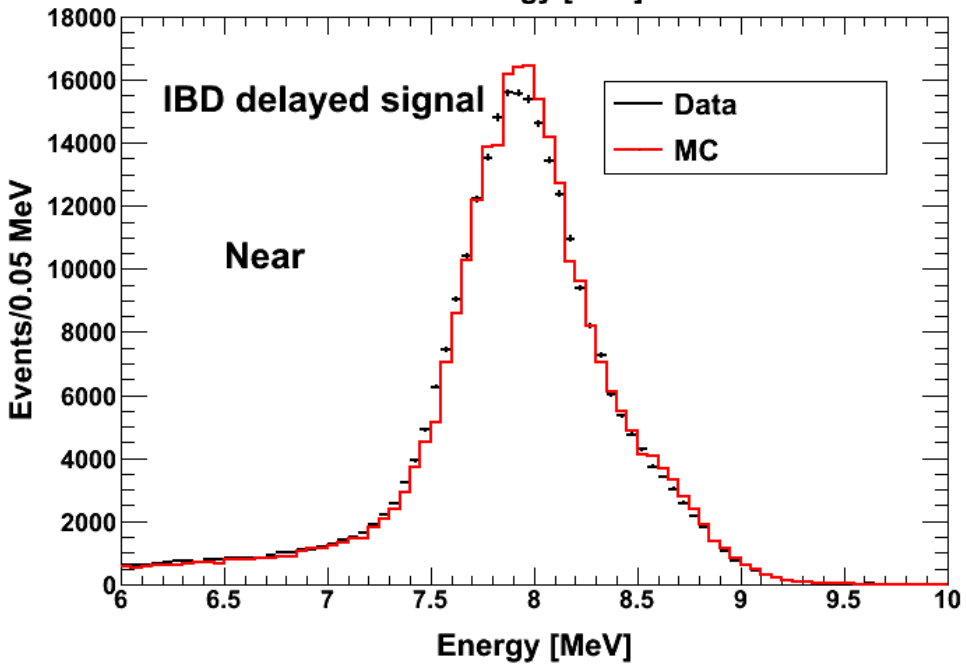
- IBD candidate's delayed signals (capture on Gd)

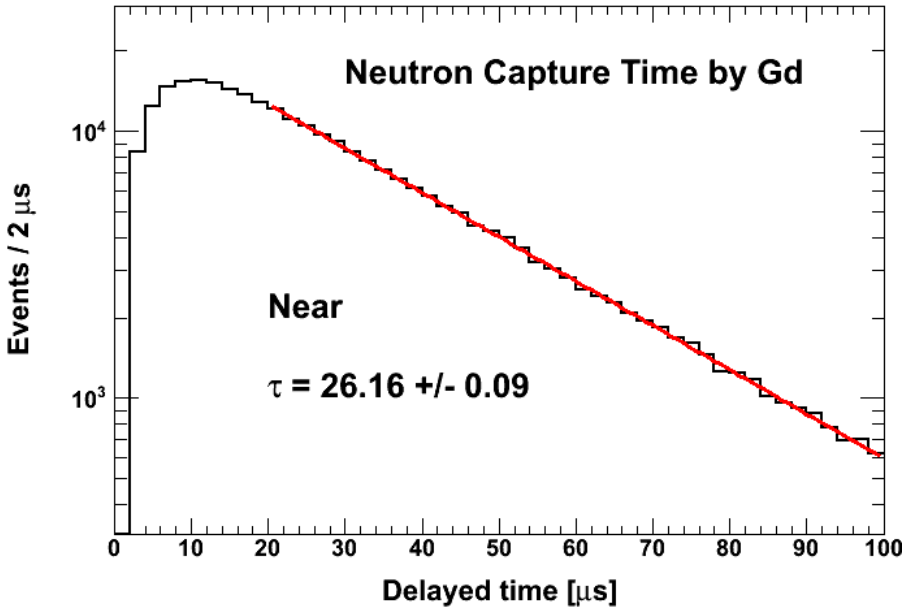


Spectra & Capture Time of Delayed Signals









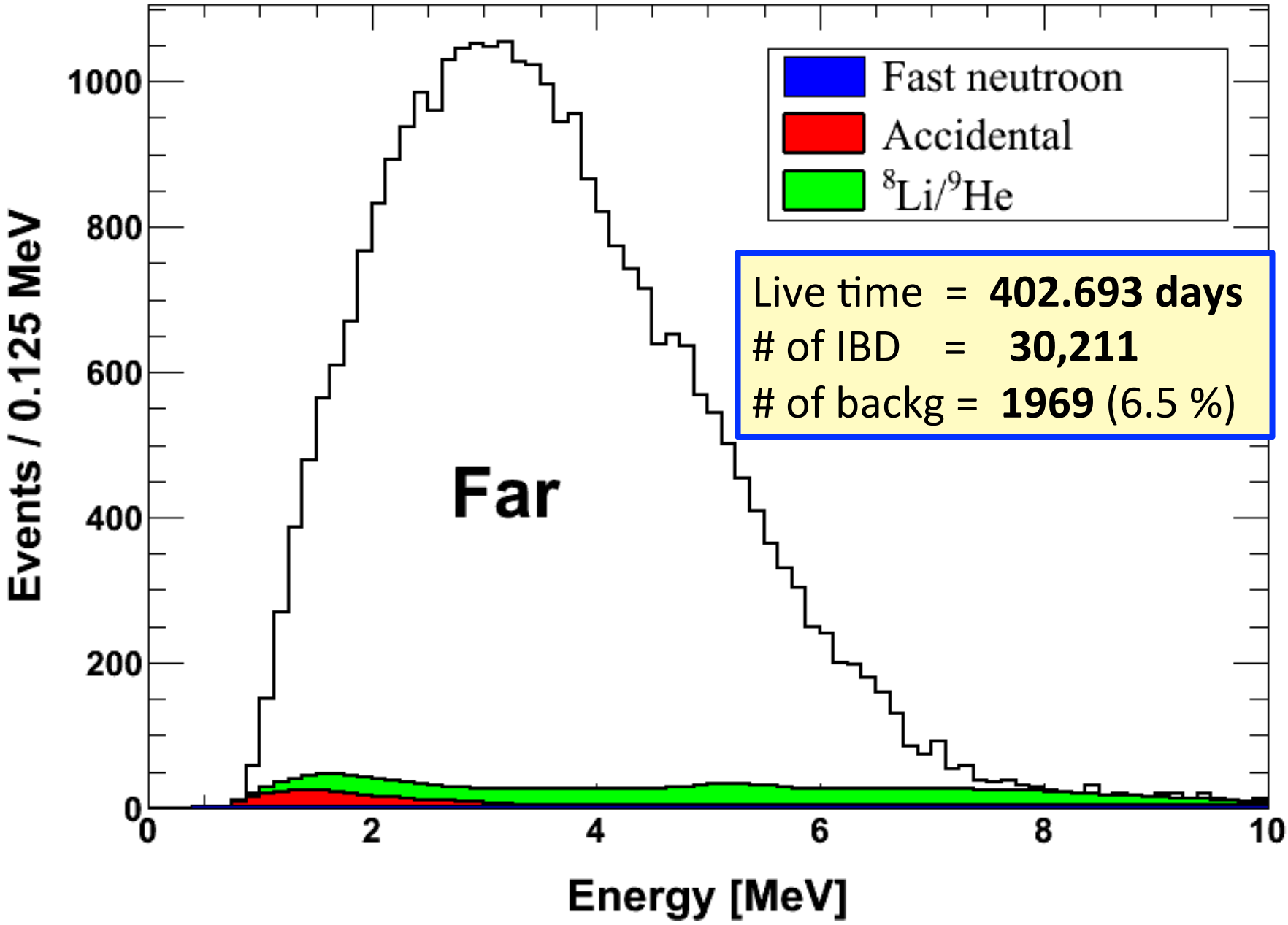
New Result

preliminary

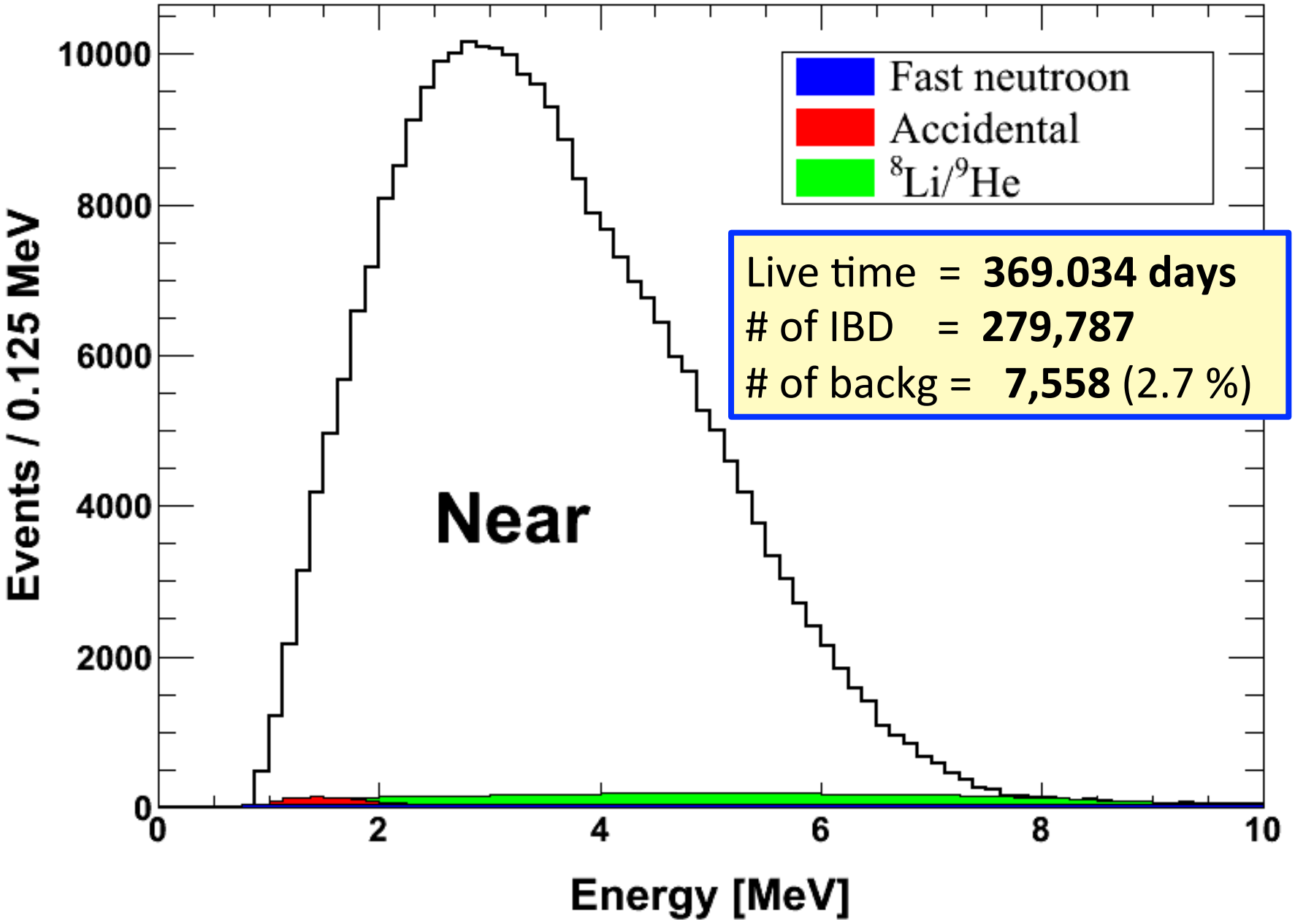
(prompt energy < 10 MeV)

	Near (PRL)	Near (New)	Far (PRL)	Far (New)
# of IBD events	153,807	279,787	17,062	30,211
Total Background rate (/day)	21.73 +- 5.93	20.48 +- 2.13	4.3 +- 0.75	4.89 +- 0.60
Accidental backgr ound (/day)	4.30 +- 0.06	3.61 +- 0.05	0.68 +- 0.03	0.60 +- 0.03
Fast neutron backg round (/day)	4.98 +- 0.16	3.14 +- 0.09	1.03 +- 0.07	0.68 +- 0.04
Li/He background (/day)	12.45 +- 5.93	13.73 +- 2.13	2.59 +- 0.75	3.61+- 0.60
DAQ Live-time (days)	192.42	369.034	222.06	402.693
Detector efficiency (%)	64.7 +- 0.14	61.99 %	74.5 +- 0.14	71.37 %

Measured Spectra of IBD Prompt Signal



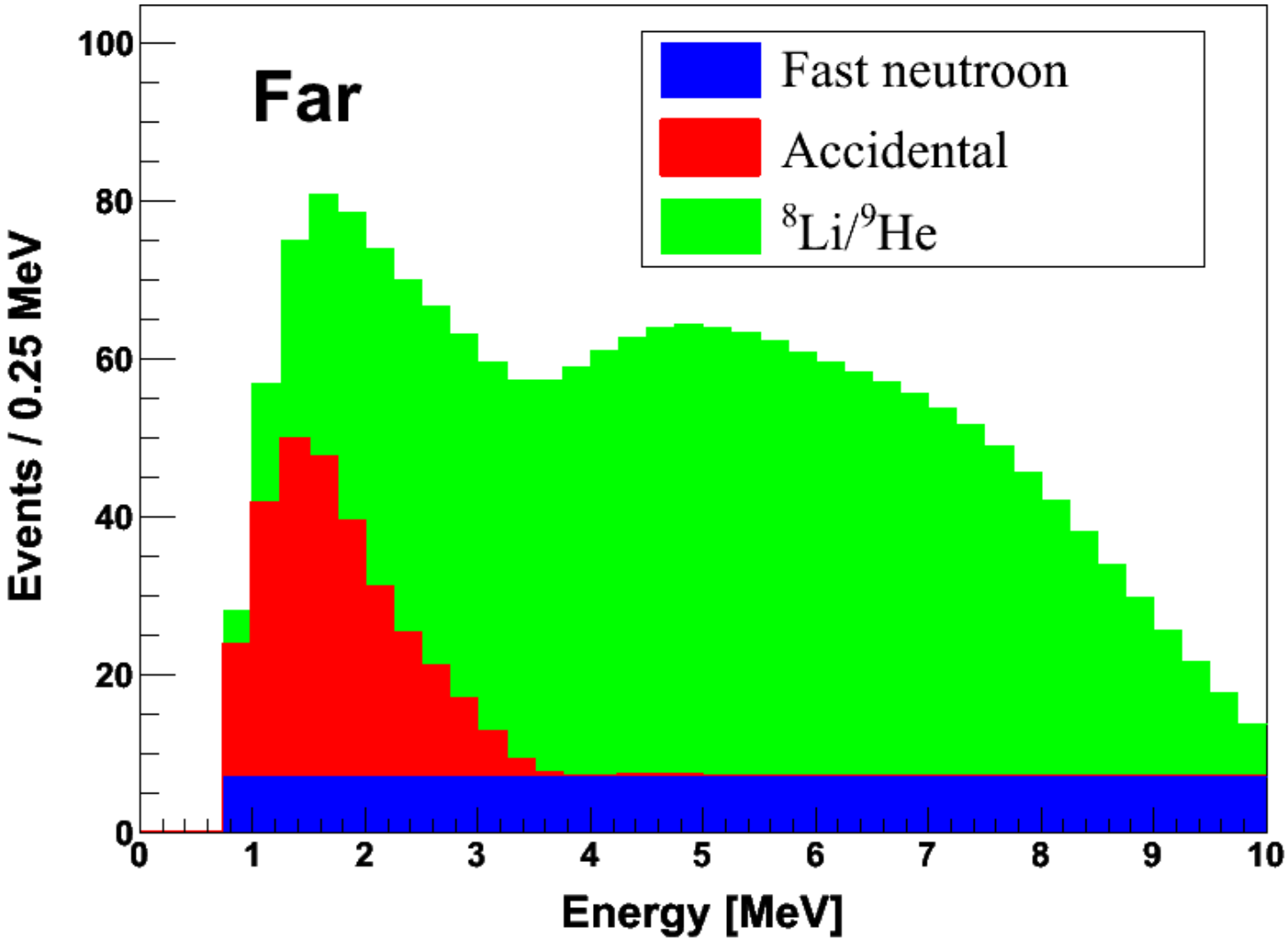
Measured Spectra of IBD Prompt Signal



Backgrounds

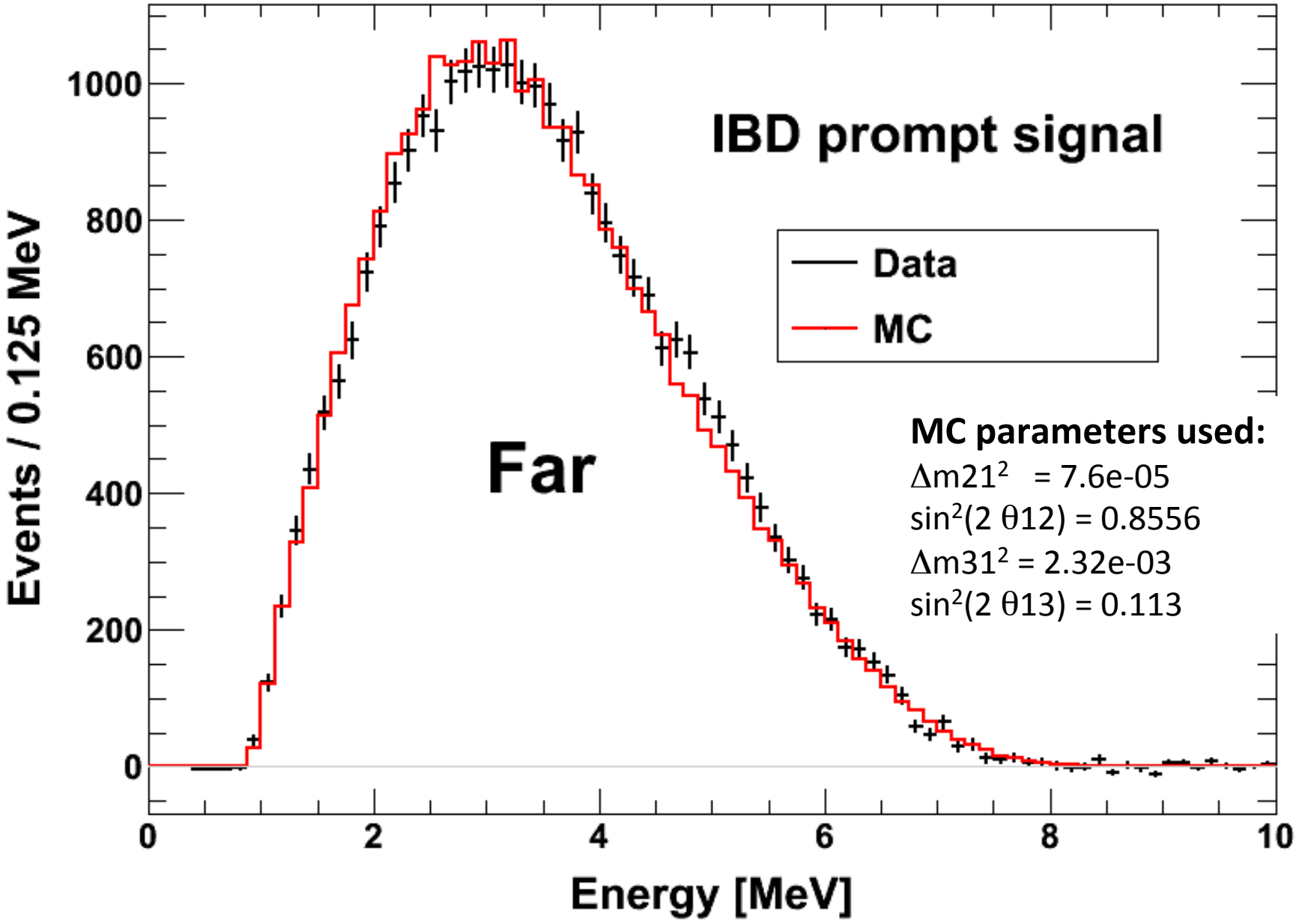
* Backgrounds shape and rates are well understood.

*Total 6.5 % background at Far & 2.7 % background at Near.



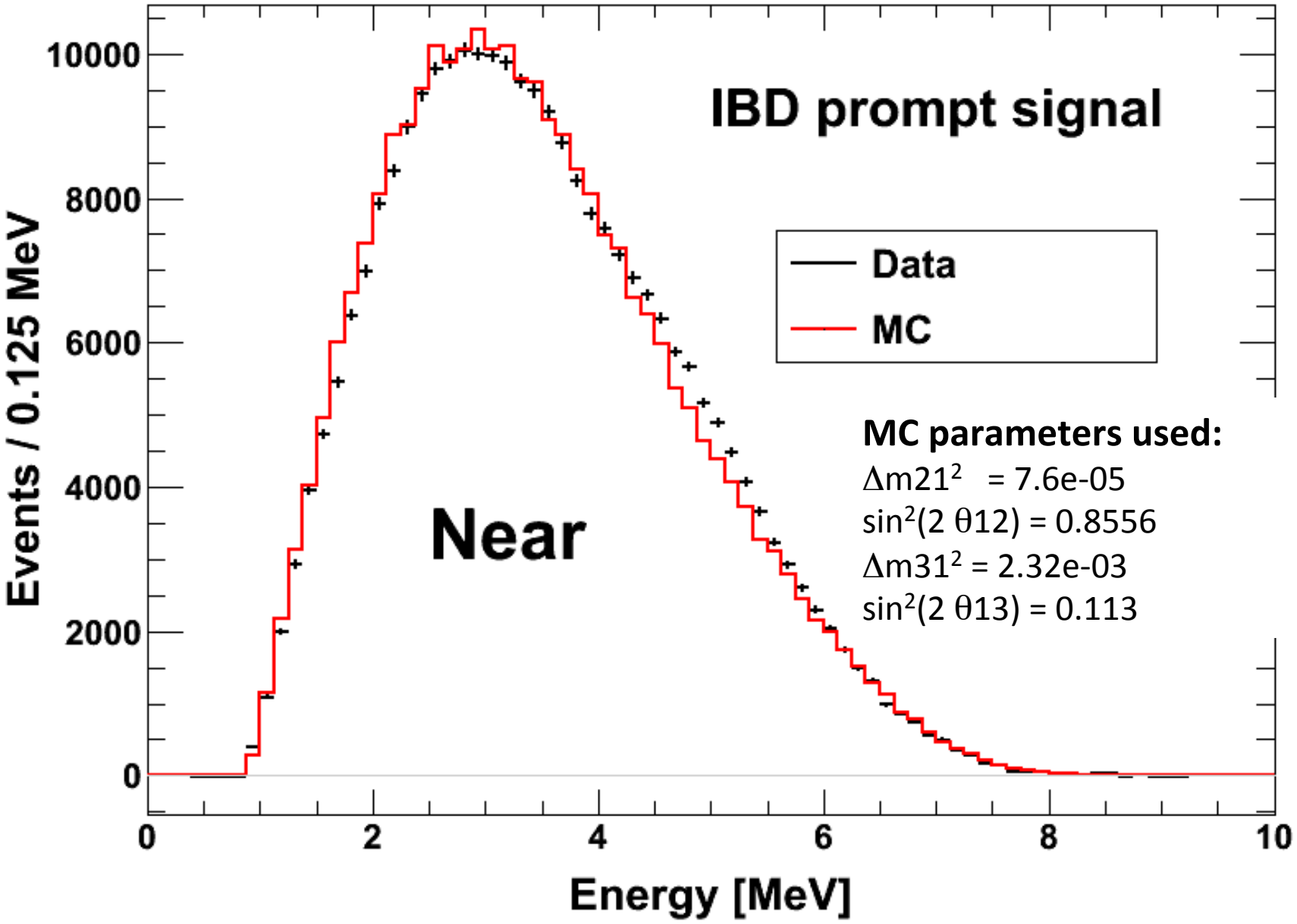
Data vs. MC

Data & MC match very well !



Data vs. MC

Data & MC match very well !



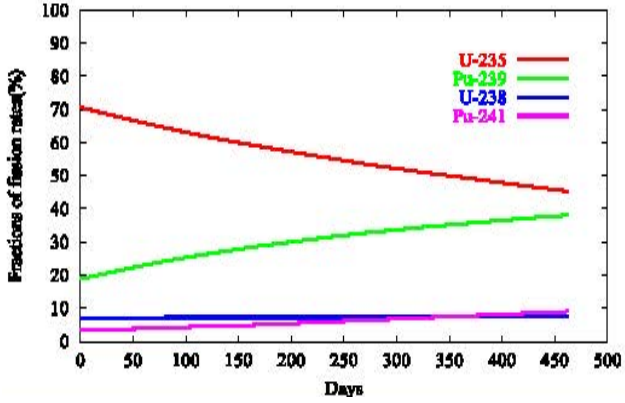
Expected Reactor Antineutrino Fluxes

- Reactor neutrino flux

$$\Phi(E_\nu) = \frac{P_{th}}{\sum_{i}^{isotopes} f_i \cdot E_i} \sum_{i}^{isotopes} f_i \cdot \phi_i(E_\nu)$$

- P_{th} : Reactor thermal power provided by the YG nuclear power plant
- f_i : Fission fraction of each isotope determined by reactor core simulation of Westinghouse ANC
- $\phi_i(E_\nu)$: Neutrino spectrum of each fission isotope
  [* P. Huber, Phys. Rev. C84, 024617 (2011)
  T. Mueller *et al*., Phys. Rev. C83, 054615 (2011)]
- E_i : Energy released per fission
  [* V. Kopeikin *et al*., Phys. Atom. Nucl. 67, 1982 (2004)]

Isotopes	James	Kopeikin
^{235}U	201.7±0.6	201.92±0.46
^{238}U	205.0±0.9	205.52±0.96
^{239}Pu	210.0±0.9	209.99±0.60
^{241}Pu	212.4±1.0	213.60±0.65



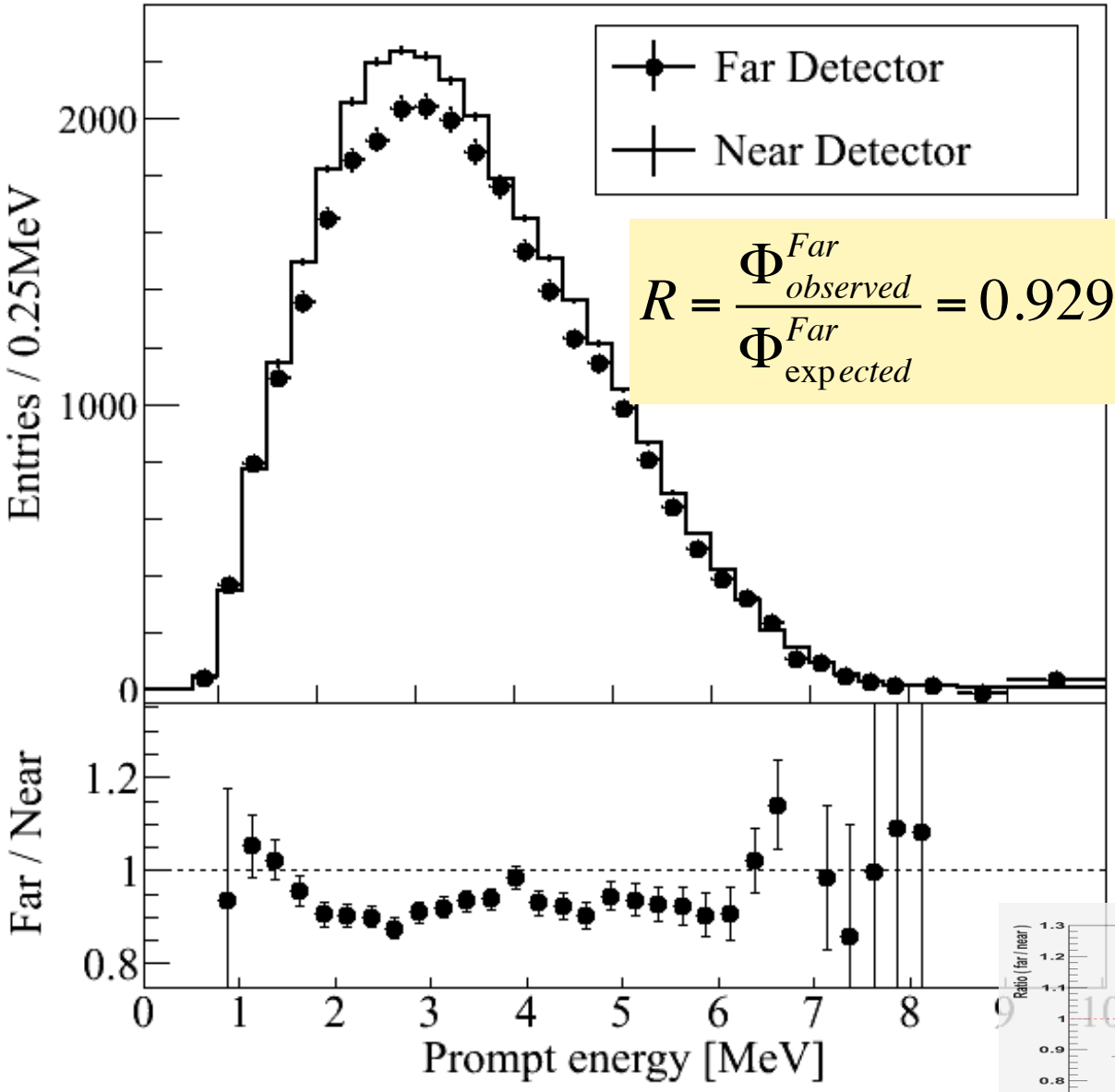
Detection Efficiency & Systematic Uncertainties

Criteria	Detection efficiency (%)
The fraction of neutron captures on Gd	86.52 ± 0.7
Flasher cut & Prompt energy cut	96.19 ± 0.11
The 6.0M	
Time coi	
The spill	
Commor	
Muon ve	
Multiplic	
The tota	

Reactor	Uncorrelated(%)	Correlated(%)
Thermal power	0.5	-
Fission fraction	0.7	-
Fission reaction cross section	-	1.9
Reference energy spectra	-	0.5
Energy per fission	-	0.2
Combined	0.9	2.0

Detection	Uncorrelated(%)	Correlated(%)
IBD cross section	-	0.2
Target protons	0.10	0.5
Prompt energy cut	0.01	0.1
Flasher cut	0.01	0.11
Gd capture ratio	0.10	0.7
Delayed energy cut	0.10	0.46
Time coincidence cut	0.01	0.44
Spill-in	0.08	0.71
Muon veto cut	0.02	0.02
Multiplicity cut	0.04	0.06
Combined	0.20	1.31

Reactor Antineutrino Disappearance



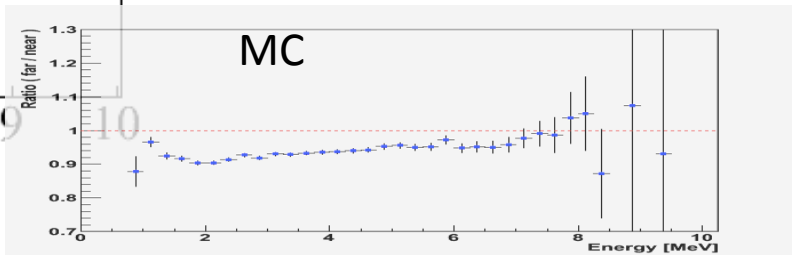
preliminary

$$R = \frac{\Phi^{Far}_{observed}}{\Phi^{Far}_{\exp ected}} = 0.929 \pm 0.006(stat.) \pm 0.009(syst.)$$

- A clear deficit in rate

  (7 % reduction)

- Consistent with neutrino oscillation in the spectral distortion



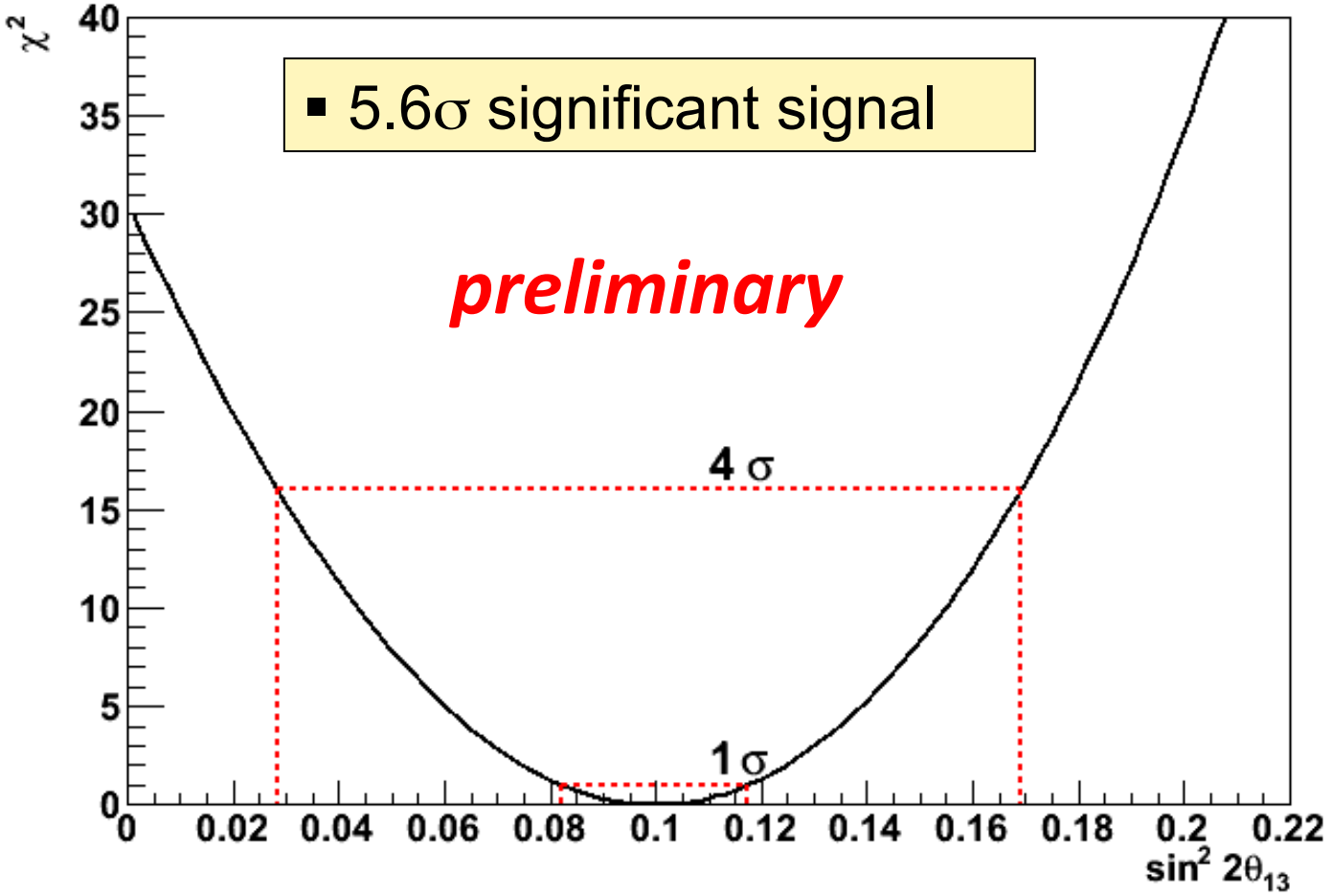
Neutrino Reduction at Far

New PRL	Far reduction [%]
< 7 MeV	7.19 %
< 8 MeV	7.19 %
< 9 MeV	7.24 %
< 10 MeV	7.24 %
< 12 MeV	7.24 %

Neutrino reduction
at Far remains
Stable (within 0.05 %)
beyond 7 MeV
where there is no oscillation.

Definitive Measurement of θ_{13}

$$\sin^2 2\theta_{13} = 0.100 \pm 0.010(stat.) \pm 0.015(syst.)$$



Summary

- RENO was the first experiment to take data with both near and far detectors, from August 1, 2011 and data taking goes smoothly.

- RENO has collected about 510 days of neutrino data so far and improved systematic uncertainties and energy calibration.

- RENO observed a clear disappearance of reactor antineutrinos.

$$R = 0.929 \pm 0.006(stat.) \pm 0.009(syst.)$$ ***preliminary***

- RENO's new result (402 live days): **conservative**

$\sin^2(2\theta_{13}) = 0.100 +/- 0.010 (stat.) +/- 0.015 (sys.)$

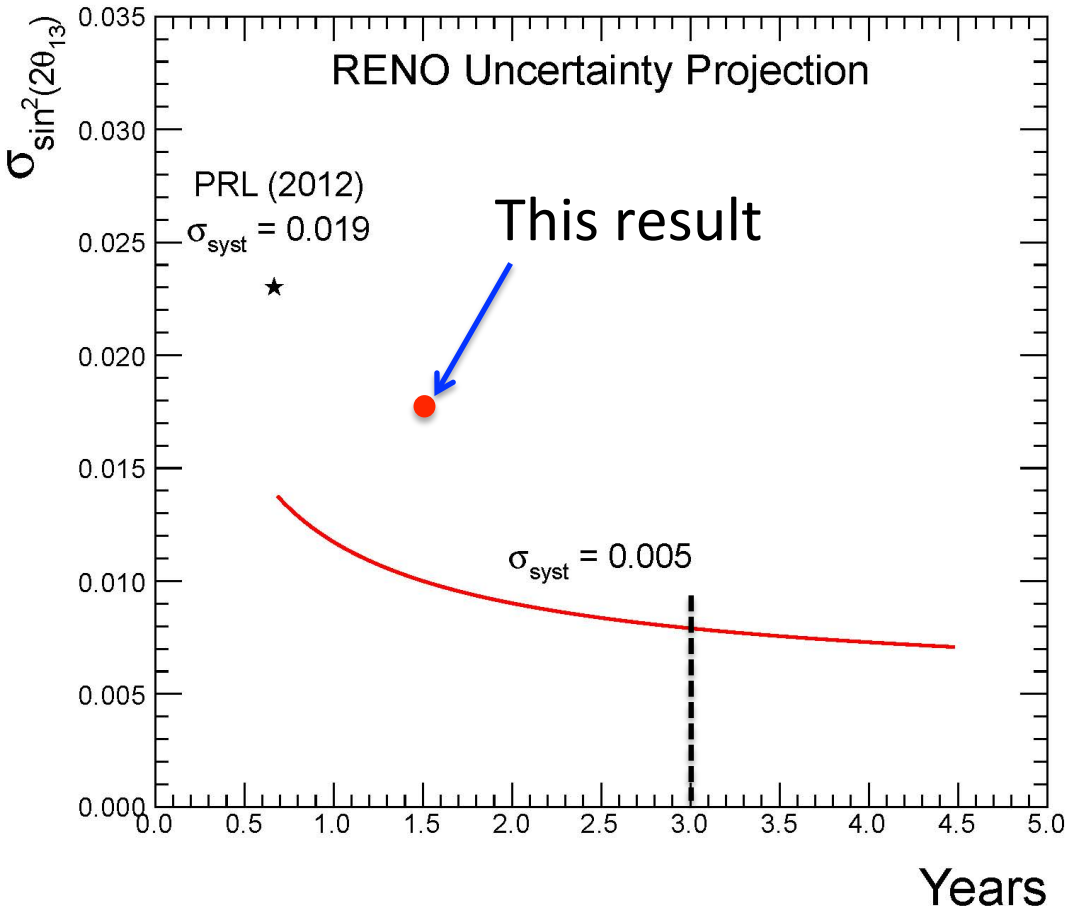
** **There is a room to improve sys. error (to be improved soon).**

Future Plan for Precision Measurement of θ_{13}

RENO

$$\sin^2 2\theta_{13} = 0.100 \pm 0.010(stat.) \pm 0.015(syst.)$$

(402 days) 0.100 ± 0.018 (5.6 σ) ⇒ ± 0.01 (10 σ) (3 years)



w/ 3 years of data:

Stat. error: 0.006
Sys. error: < 0.010

Tot. error: < 0.011

RENO-50 Workshop at Seoul

- **When:** June 13 – 14, 2013
- **Where:** Seoul National Univ., Korea

Please register ASAP!

http://home.kias.re.kr/MKG/h/reno50/

** Don't miss RENO-50 poster by Dr. JS Park.