Recent Results from RENO

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On behalf of the RENO Collaboration

Seoul National University

Sept. 12, 2013

TAUP 2013

Asilomar, Pacific Grove, USA

1st result on PRL 108, 19802 (2012): Data Set A (220 days)

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(stat.) \pm 0.019(syst.)$$ **(4.9 σ)**

2nd result (@NuTel 2013): Data Set B (403 days)

$$\sin^2 2\theta_{13} = 0.100 \pm 0.010(stat.) \pm 0.015(syst.)$$ **(5.6 σ)**

Statistics: about twice more data

Systematics: -- Improved energy scale calibration

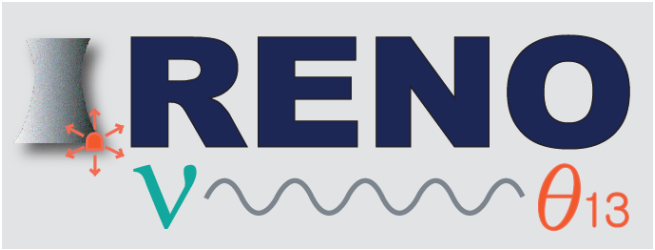
-- Improved background estimation/reduction

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

Updated result (@TAUP 2013): Data Set B (403 days)

Systematics: improved background estimation & its error

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.

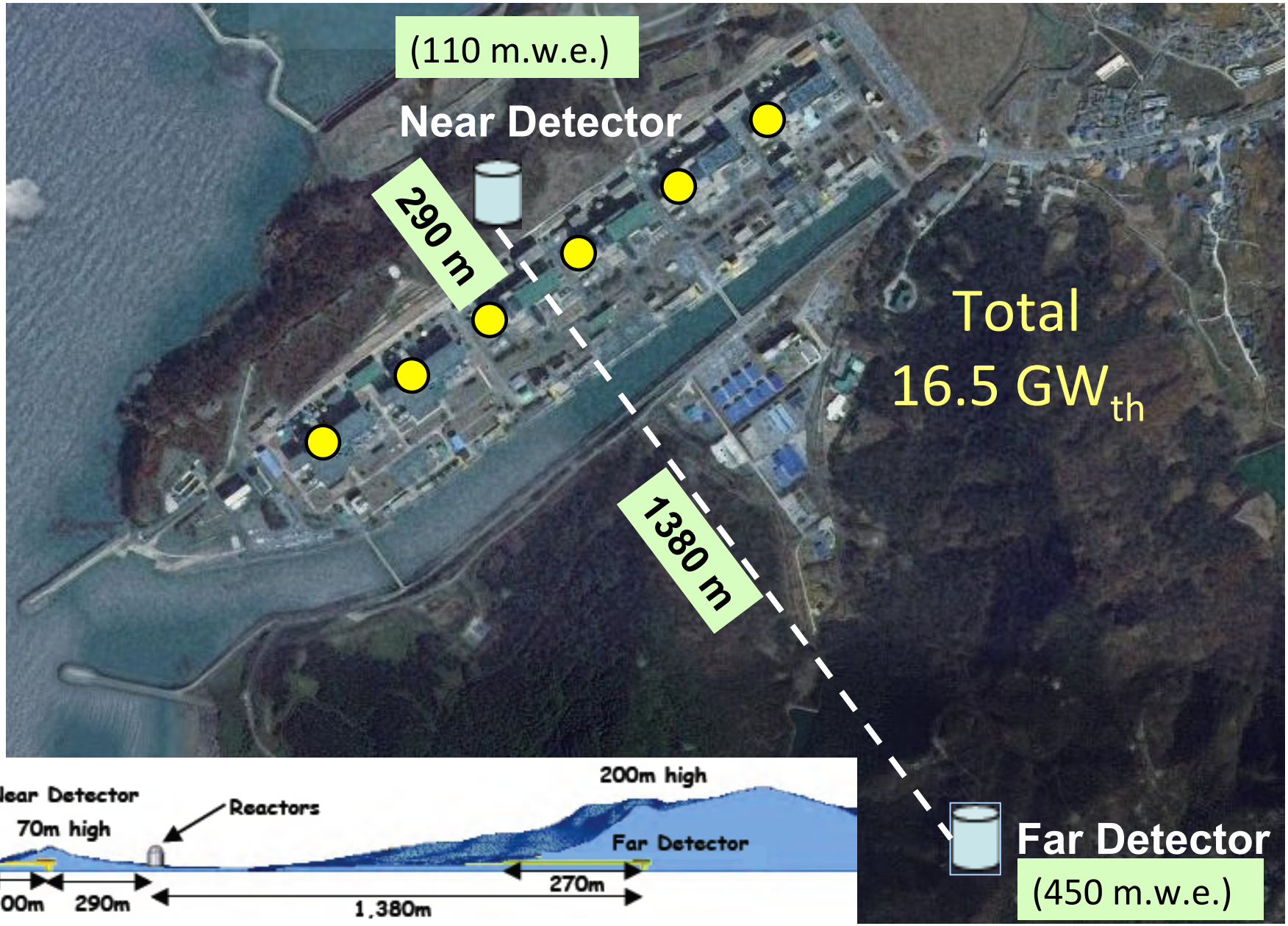
Experimental Site

YongGwang: South west of South Korea
~ 300 km from Seoul

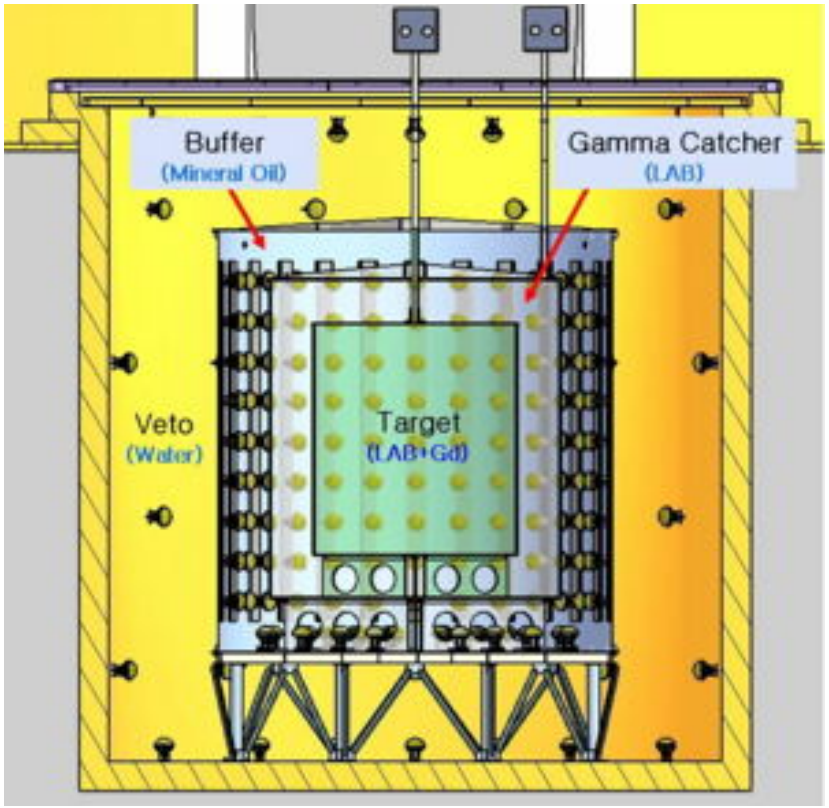
"YongGwang" reactor site

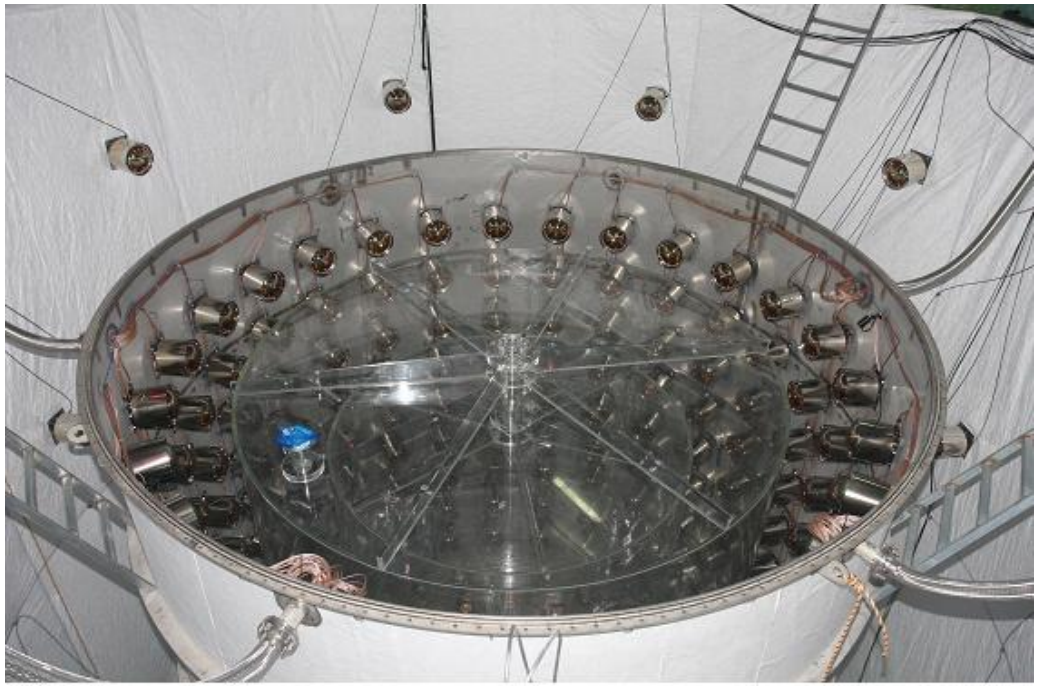
→ "Hanbit" reactor site (new name)

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

RENO Data Taking Status

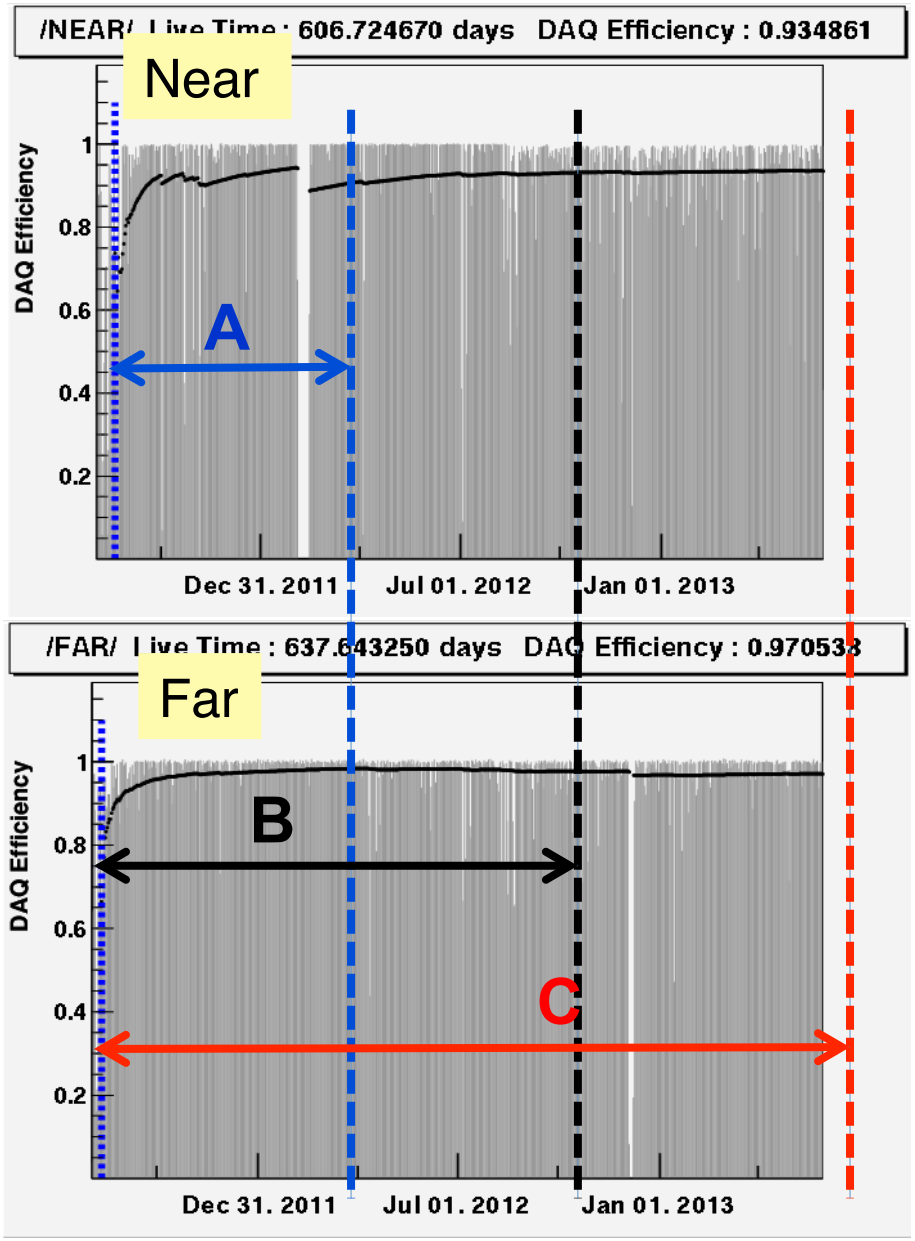
- Data taking began on Aug. 1, 2011 with both near and far detectors. (DAQ efficiency : ~95%)

- **A** (220 days) : **First θ_{13} result**
  [11 Aug, 2011~26 Mar, 2012]
  PRL 108, 191802 (2012)

- **B** (403 days) : **Improved θ_{13} result**
  [11 Aug, 2011~13 Oct, 2012]
  NuTel 2013

- **C** (~700 days) : **Shape+rate analysis** (in progress)
  [11 Aug, 2011~31 Jul, 2013]

- Absolute reactor neutrino flux measurement in progress
  [reactor anomaly & sterile neutrinos]

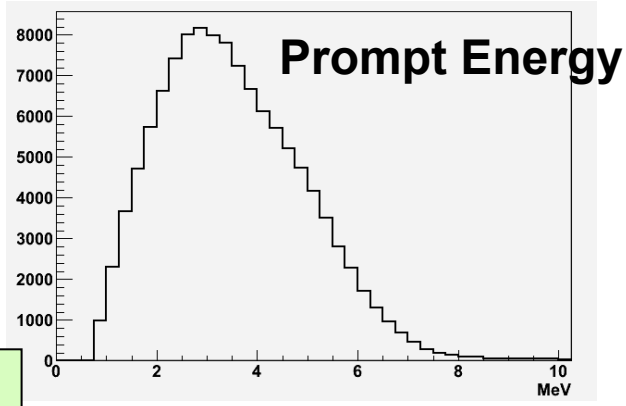


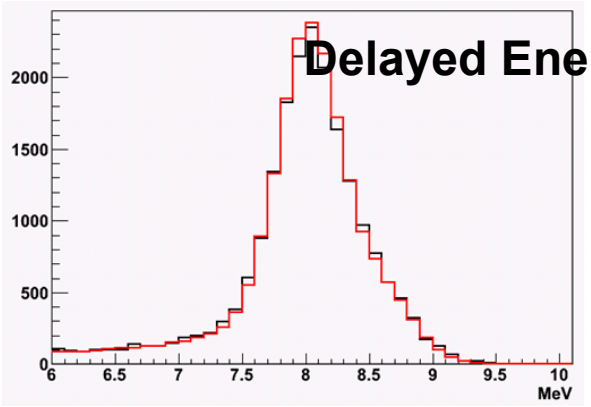
IBD Event Signature and Backgrounds

❑ IBD Event Signature

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

- Prompt signal (e^+) : 1 MeV 2γ's + e^+ kinetic energy (E = 0.8~10 MeV)
- Delayed signal (n) : 8 MeV γ's from neutron's capture by Gd
  ~28 μs (0.1% Gd) in LS♪

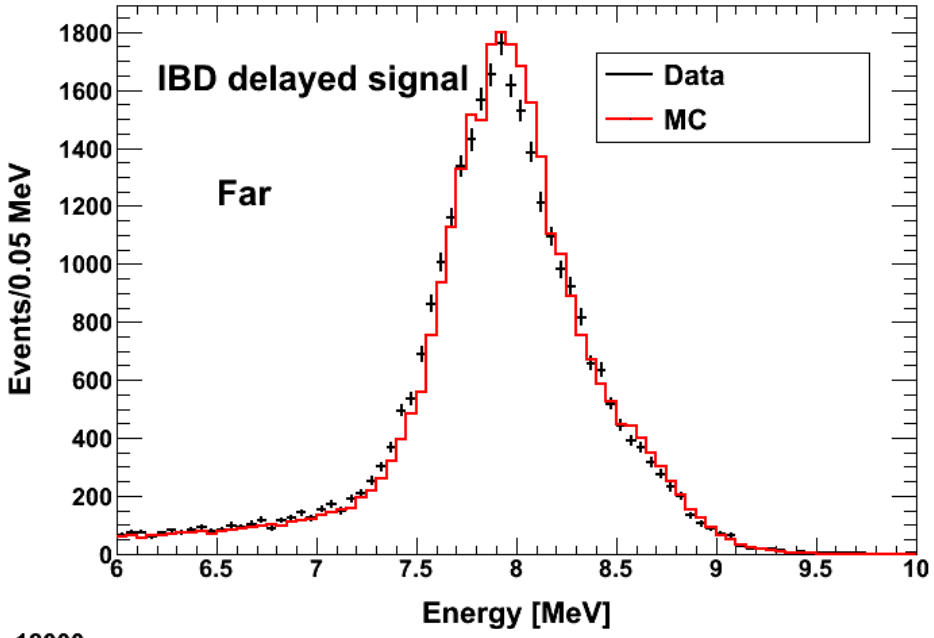


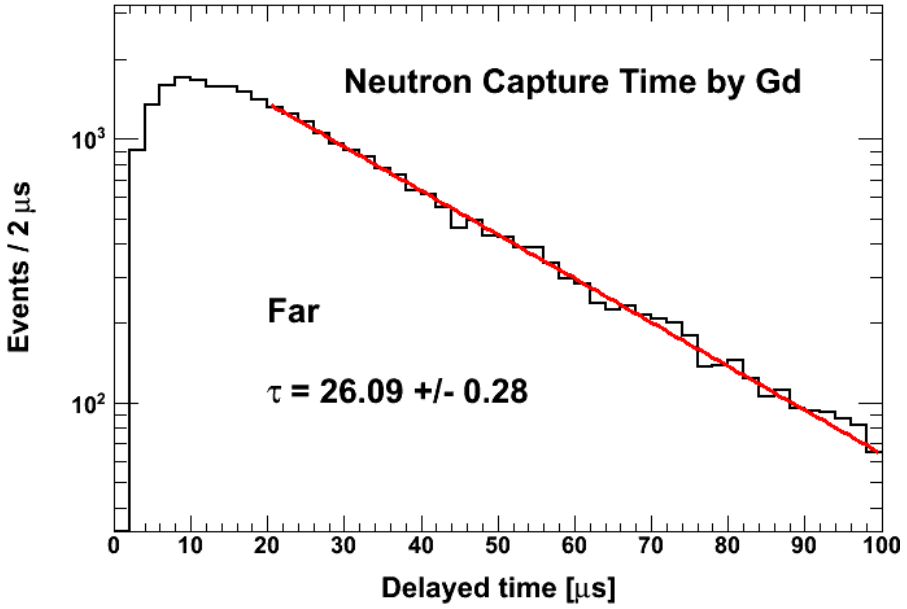


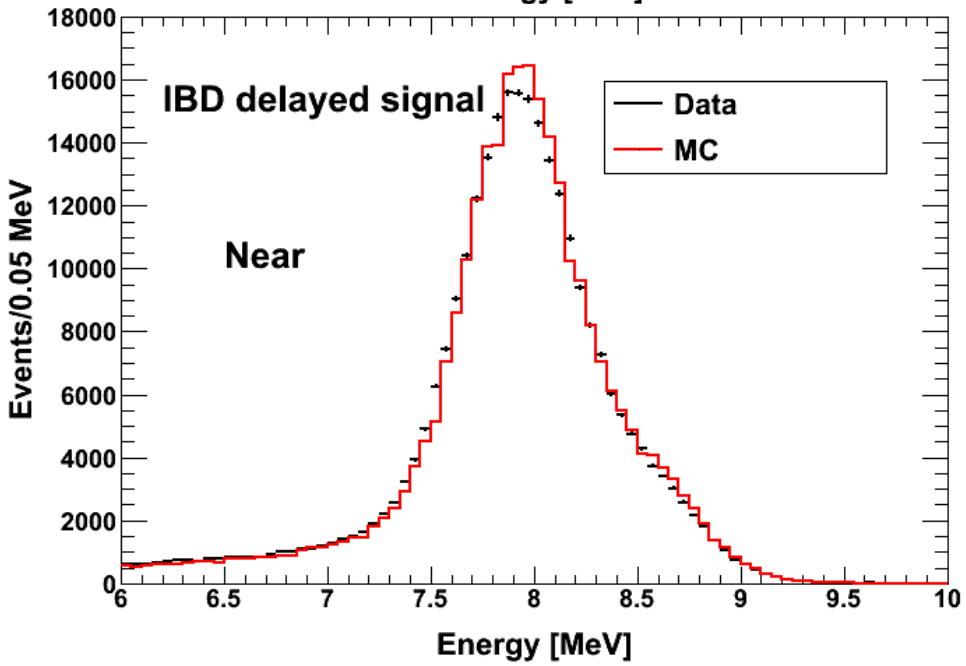
❑ Backgrounds

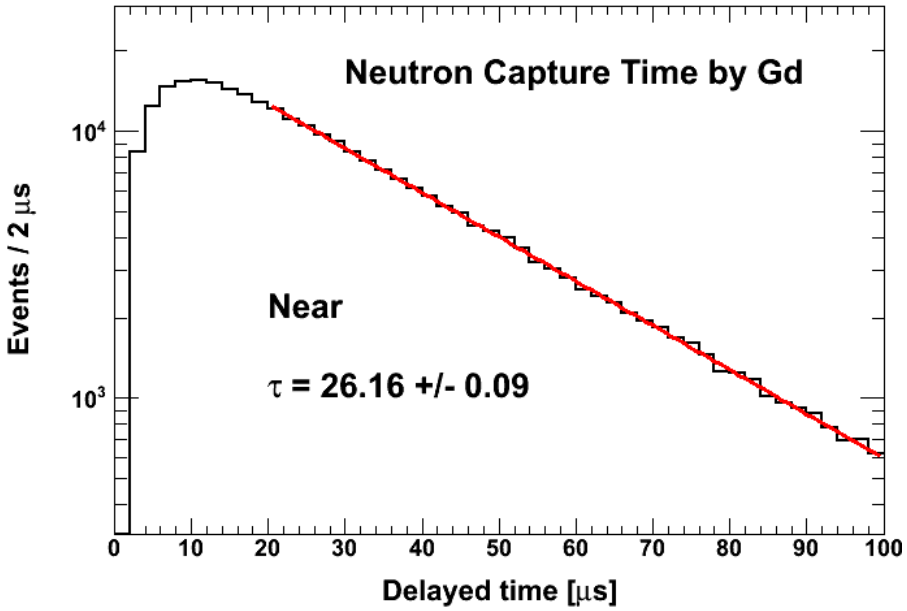
- **Accidental BG**: caused by radioactivity; random coincidence between prompt and delayed signals (uncorrelated)
- **^{9}Li/^{8}He BG**: muon spallation on ^{12}C; β-n followers which mimic signal
- **Fast neutrons:** produced by muons, from surrounding rocks and inside detector (n scattering : prompt, n capture : delayed)

Spectra & Capture Time of Delayed Signals



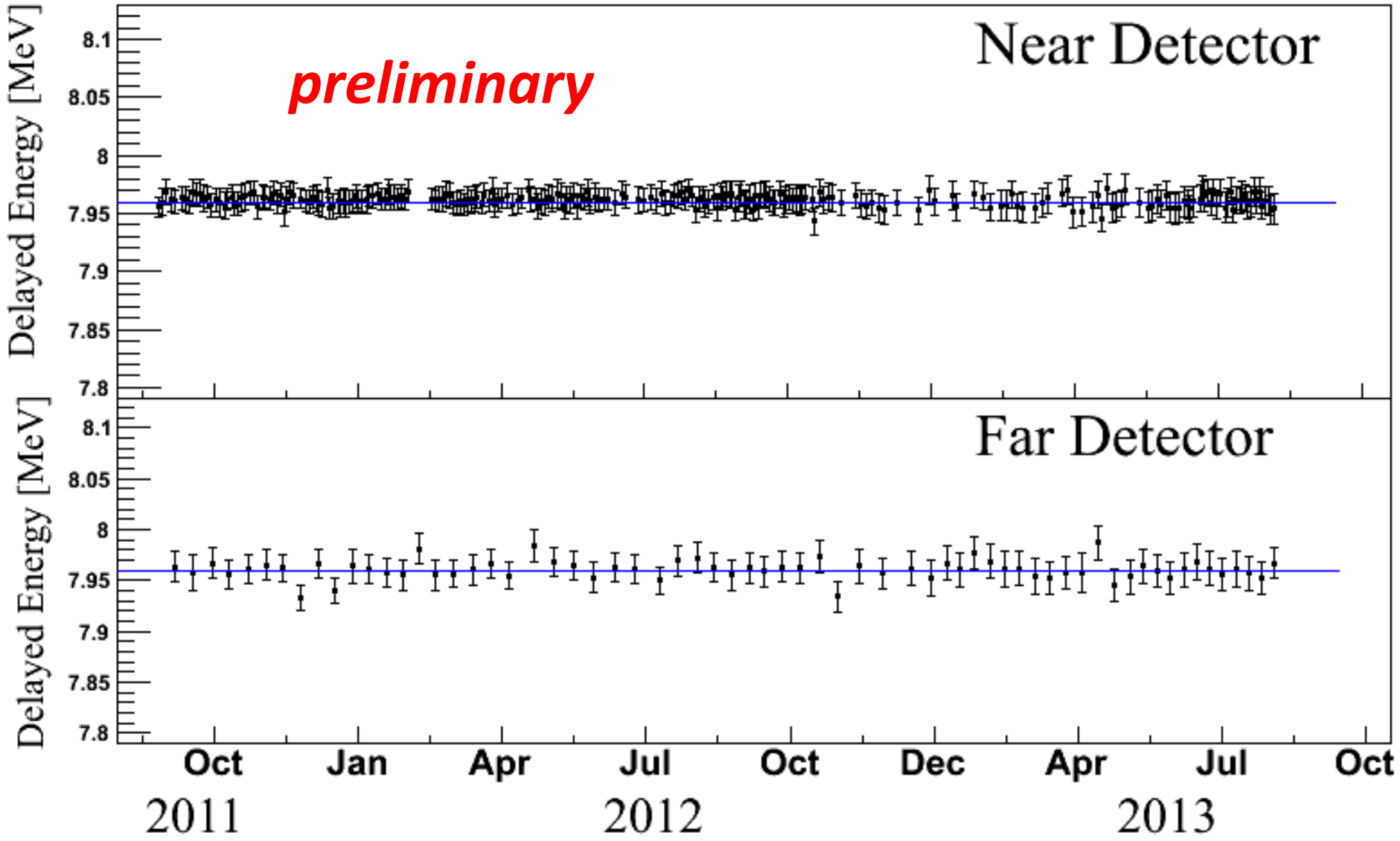




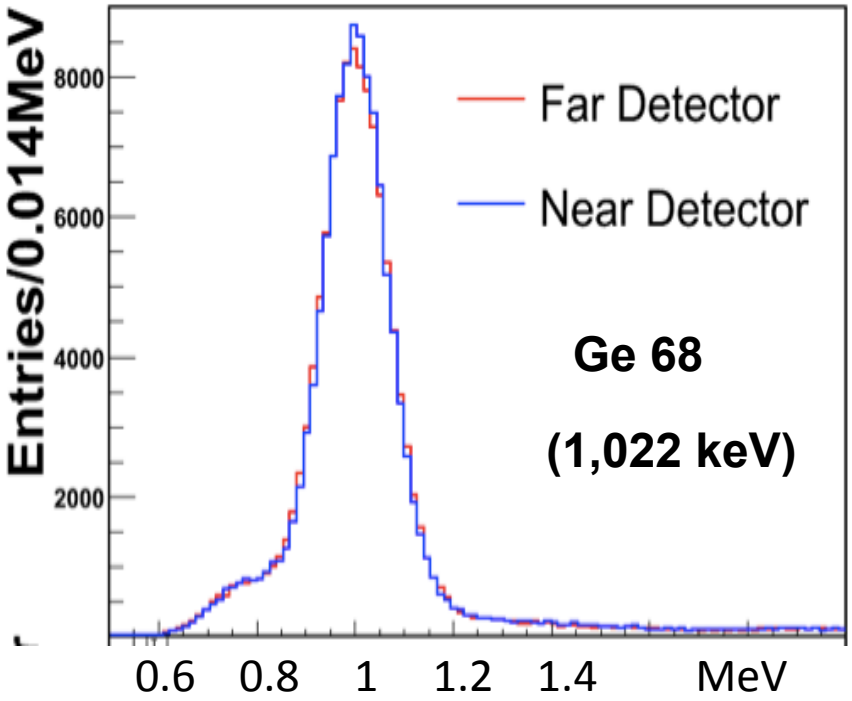


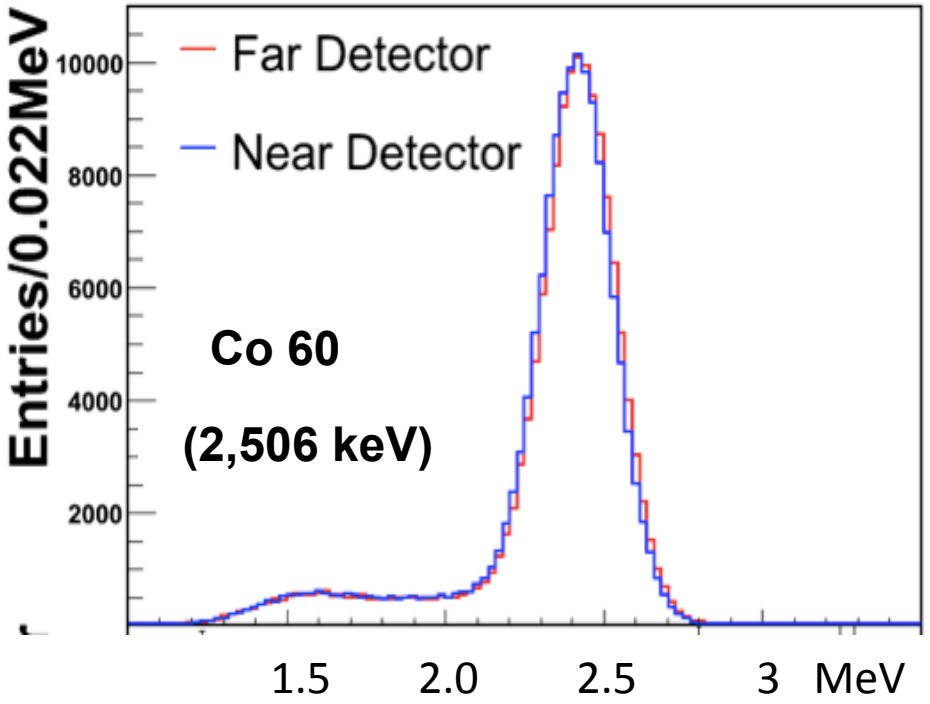
Detector Stability of Energy Scale

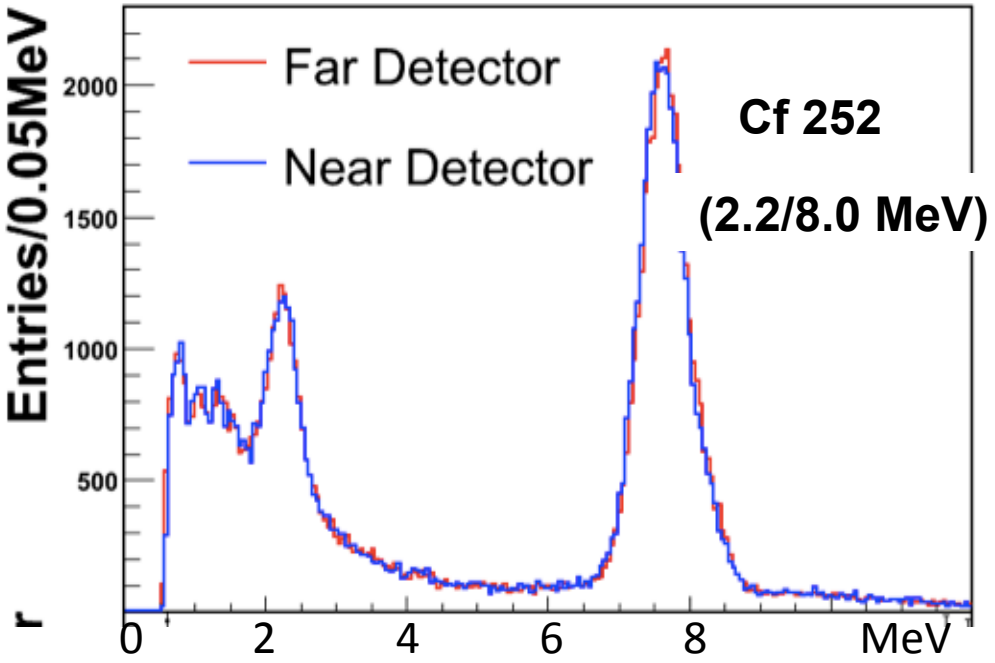
- IBD candidate's delayed signals (capture on Gd)



Energy Calibration

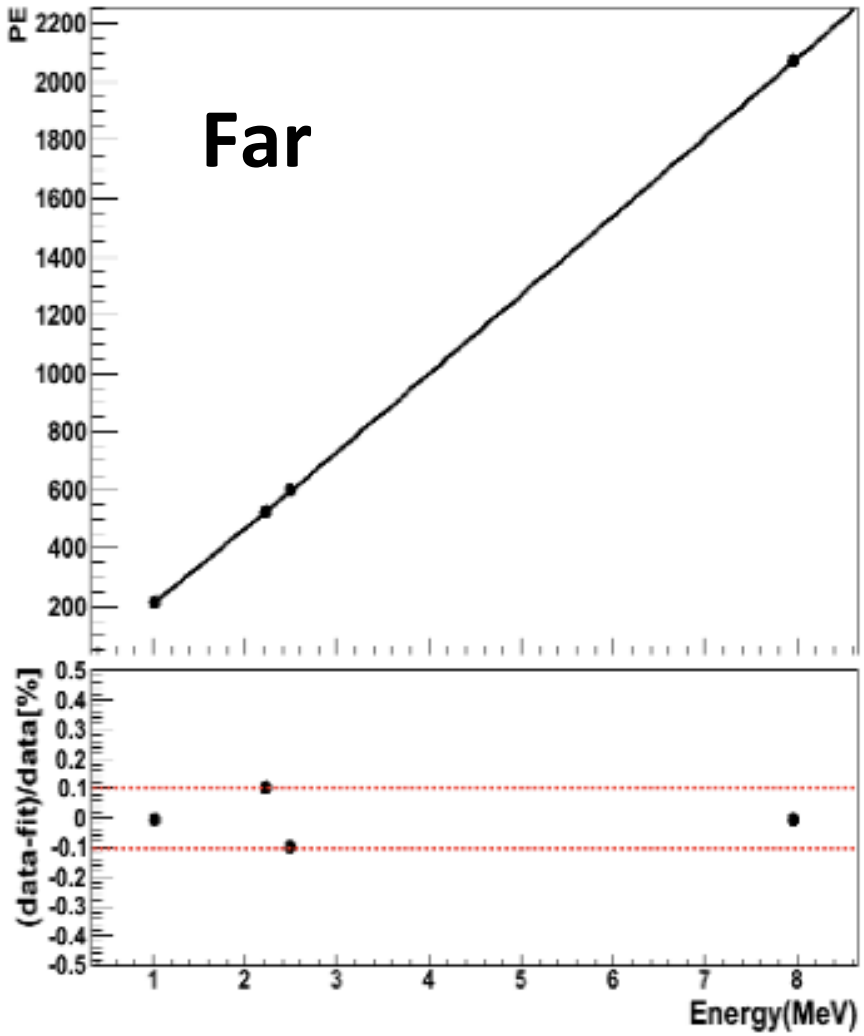


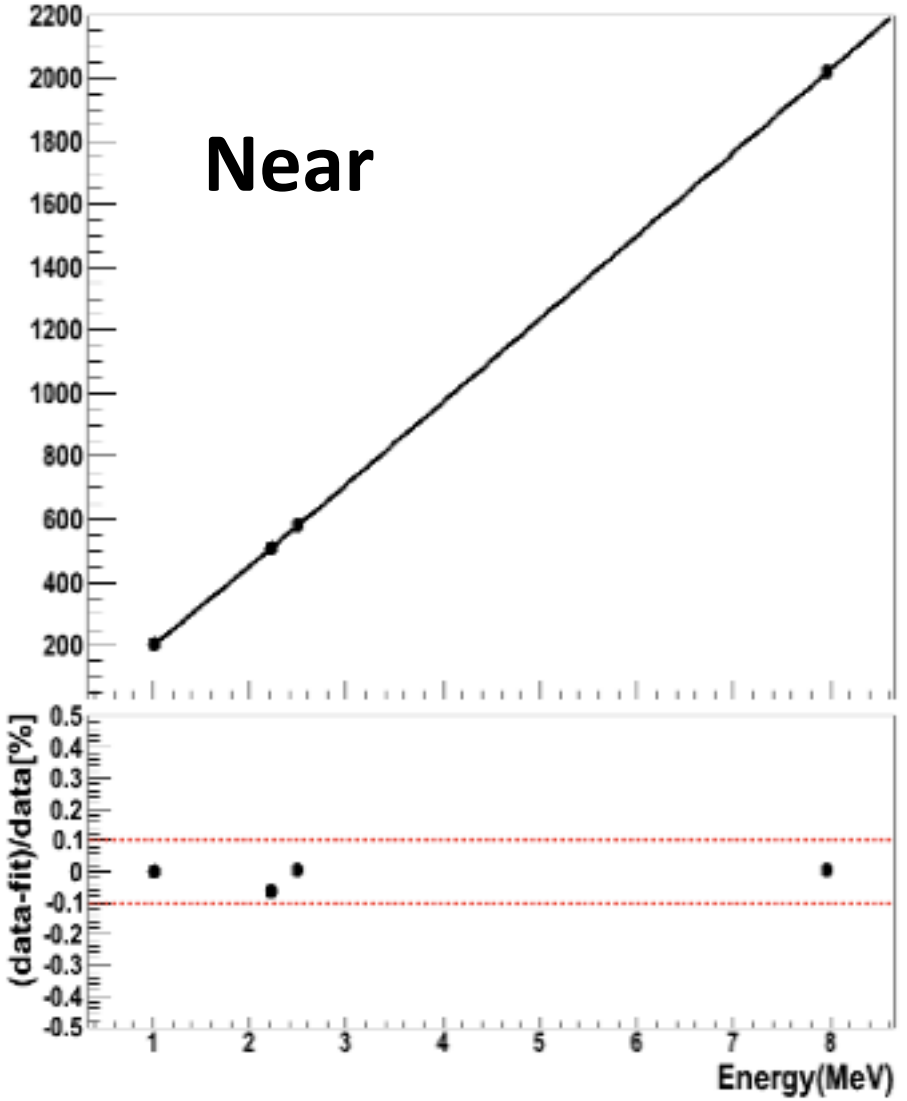




Energy Calibration

PE → MeV conversion fnc

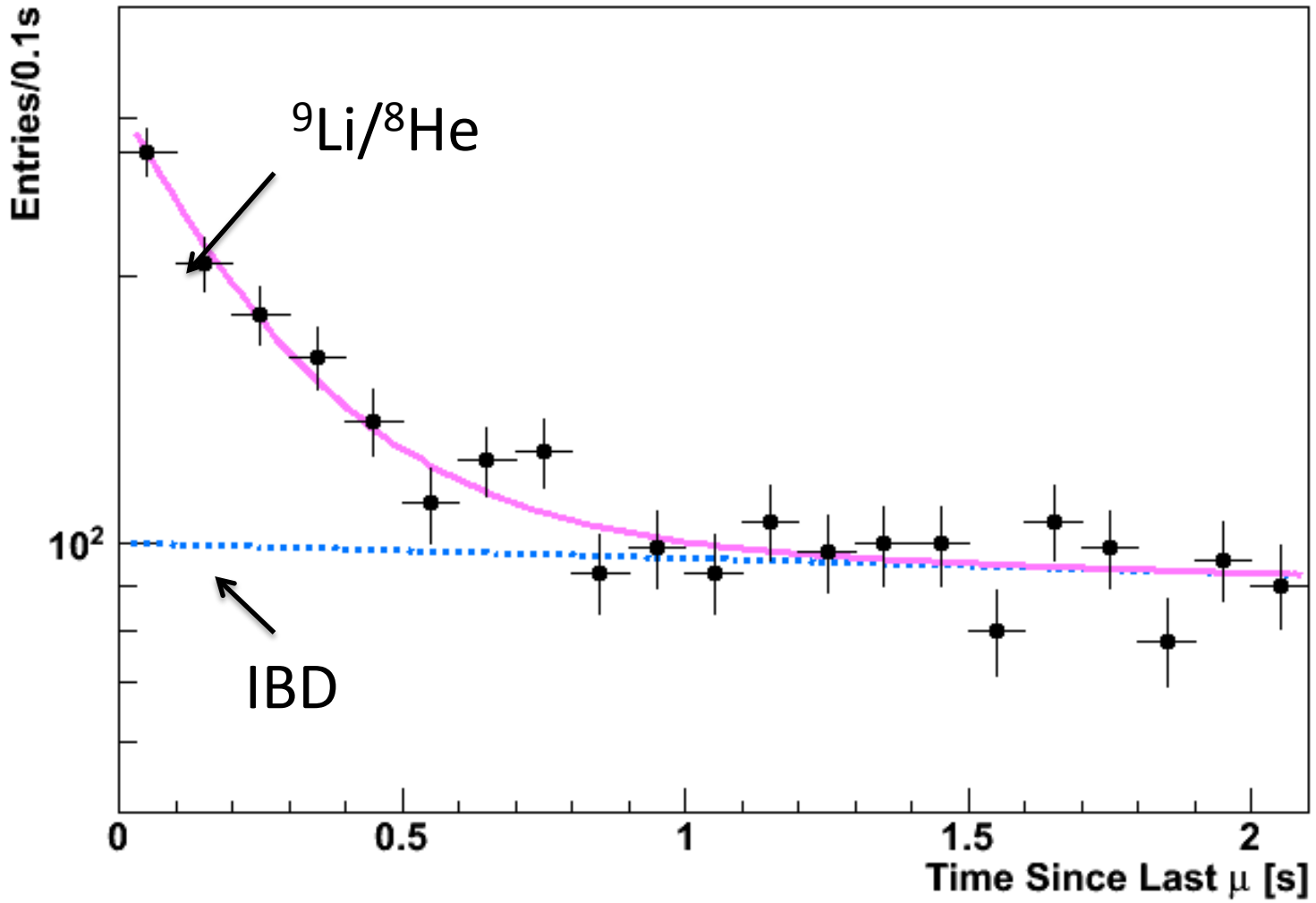




Fitting accuracy: 0.1 %

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

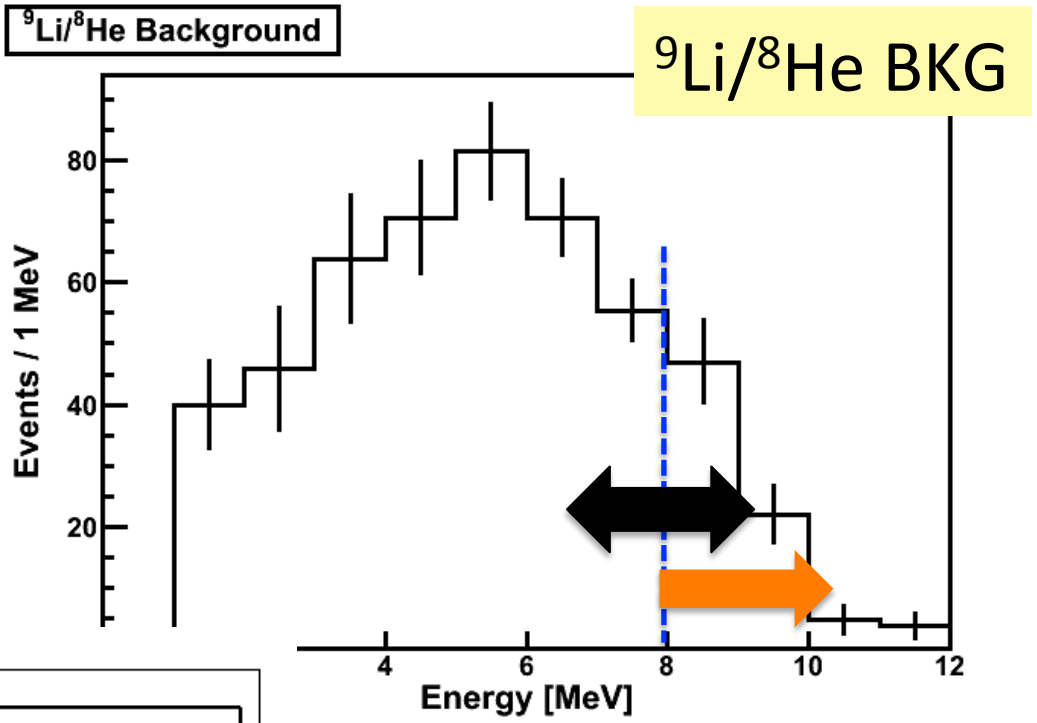
^{9}Li/^{8}He are unstable isotopes emitting (β,n) followers and produced when muon interact with carbon in the LS.

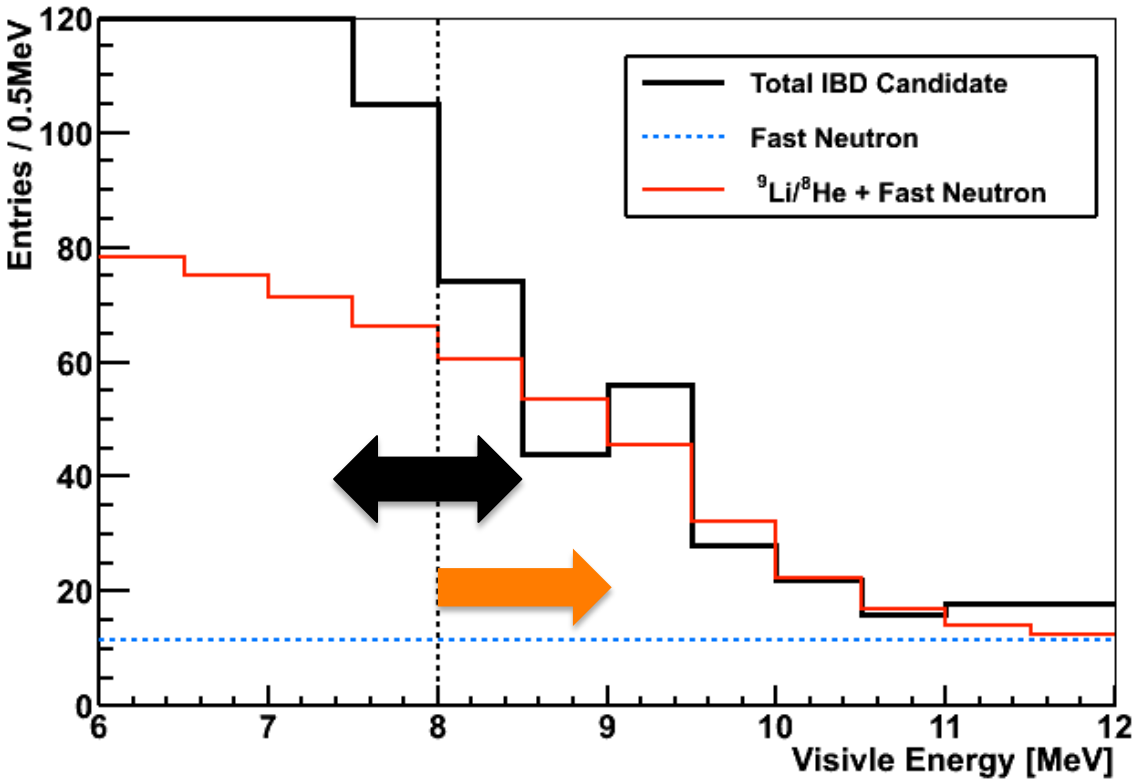


^{9}Li/^{8}He Background Estimation (I)

Scaling method:

$N_{LH} = \alpha * n_{LH}$





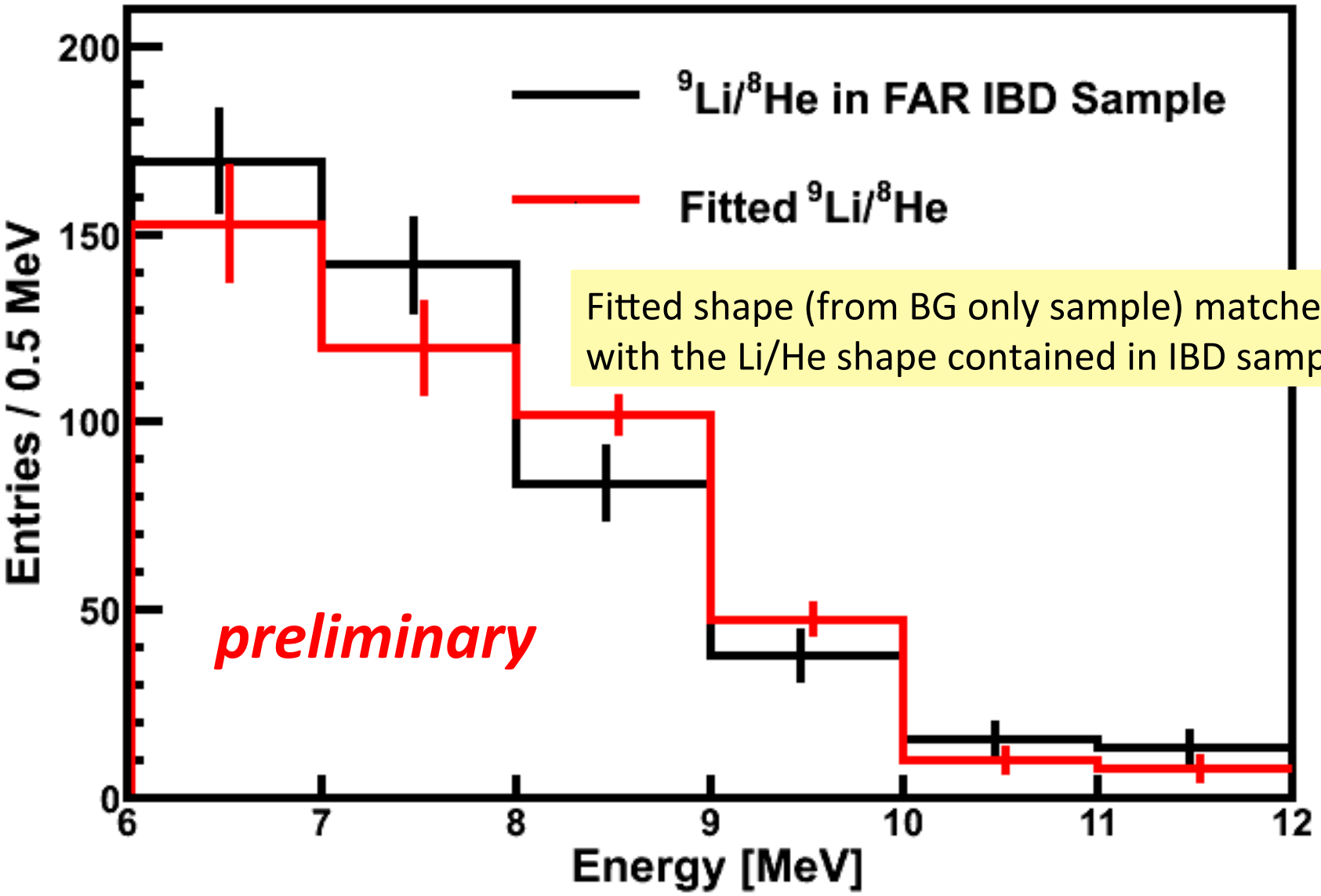
Li/He Selection:

> 1.3 GeV muon within 500 msec

Error improvement:

1) 8 MeV → 6.5 MeV ($\delta\alpha$ improve)
2) Increased statistics of Li/He BG spec. data (δn_{LH} improve)

^{9}Li/^{8}He Background Estimation (II)



Fitted shape (from BG only sample) matches well with the Li/He shape contained in IBD sample.

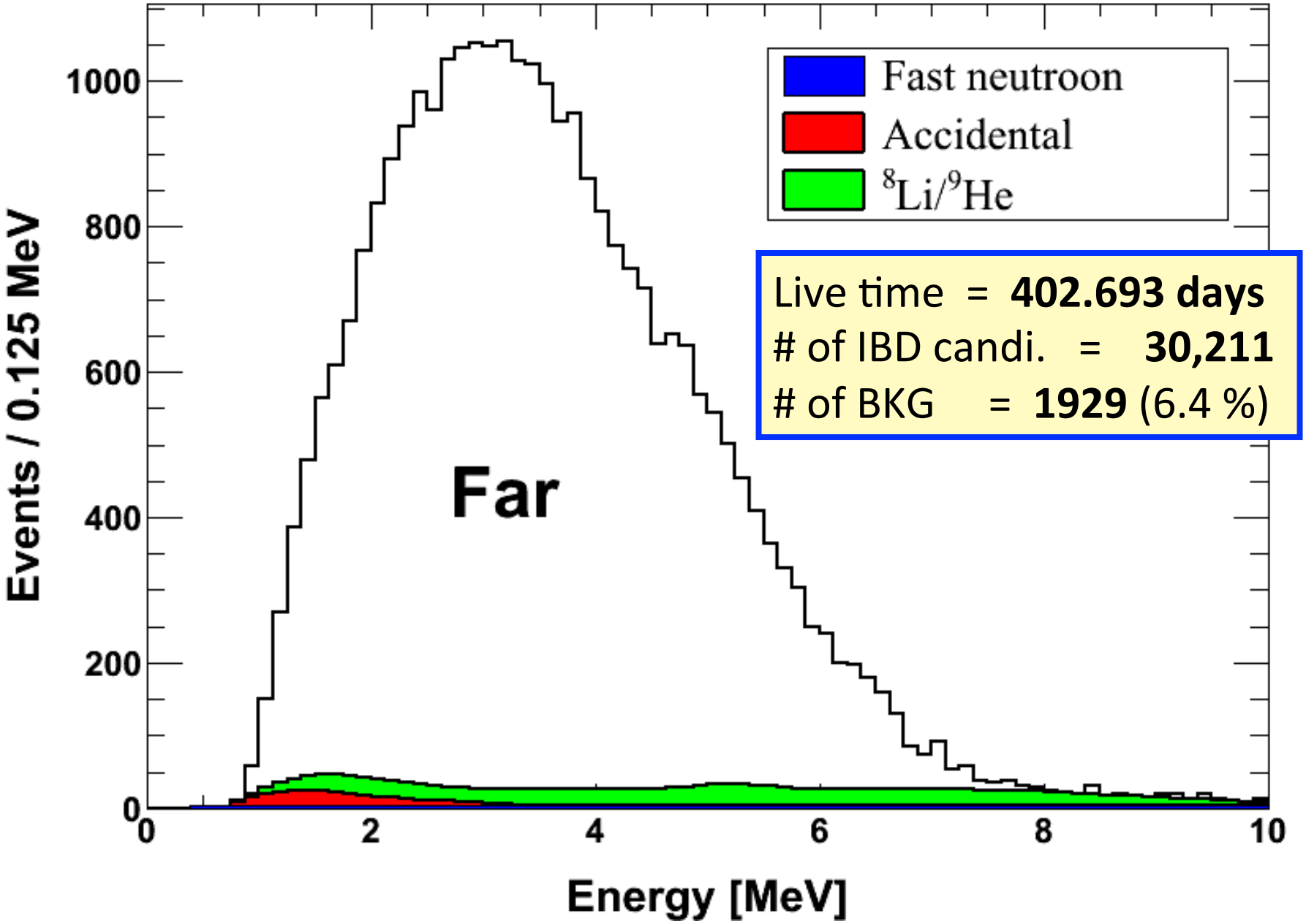
New Result

preliminary

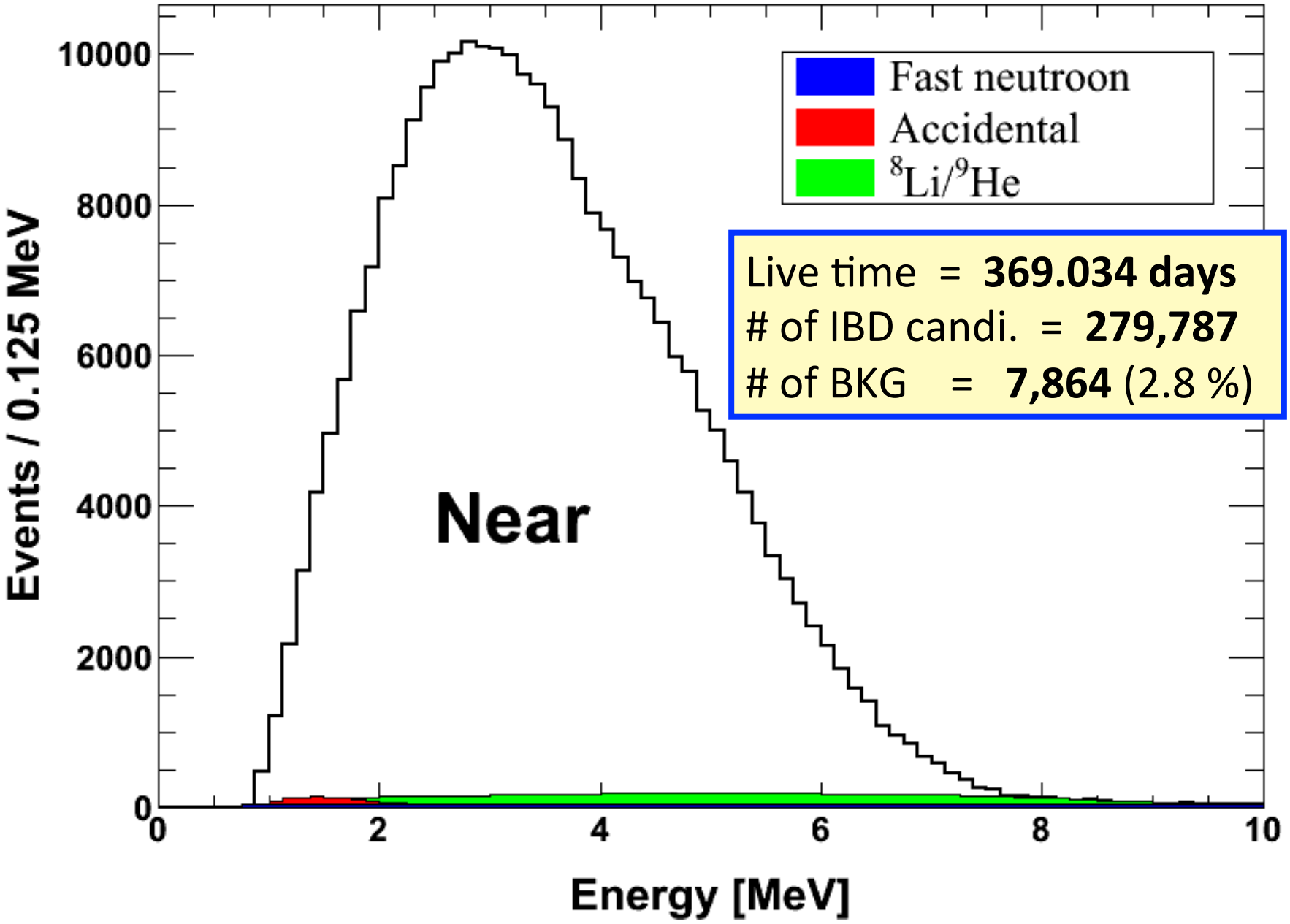
Rate +- Sys. err +- Stat. err (prompt energy < 10 MeV)

	Near (NuTel'13)	Near (TAUP'13)	Far (NuTel'13)	Far (TAUP'13)
# of IBD events	279,787	279,787	30,211	30,211
Total Background rate (/day)	20.48 +- 2.13 +- 0.24	21.31 +- 1.79 +- 0.26	4.89 +- 0.60 +- 0.11	4.80 +- 0.45 +- 0.12
Accidental backgr ound (/day)	3.61 +- 0.05 +- 0.10	3.61 +- 0.05 +- 0.10	0.60 +- 0.03 +- 0.04	0.60 +- 0.03 +- 0.04
Fast neutron backg round (/day)	3.14 +- 0.09 +- 0.09	3.59 +- 0.94 +- 0.10	0.68 +- 0.04 +- 0.04	0.65 +- 0.09 +- 0.04
Li/He background (/day)	13.73 +- 2.12 +- 0.22	13.97 +- 1.52 +- 0.22	3.61 +- 0.59 +- 0. 11	3.55 +- 0.44 +- 0.11
DAQ Live-time (days)	369.034	369.034	402.693	402.693
Detector efficiency (%)	61.99 +- 1.40 %	61.99 +- 1.40 %	71.37 +- 1.19 %	71.37 +- 1.19 %

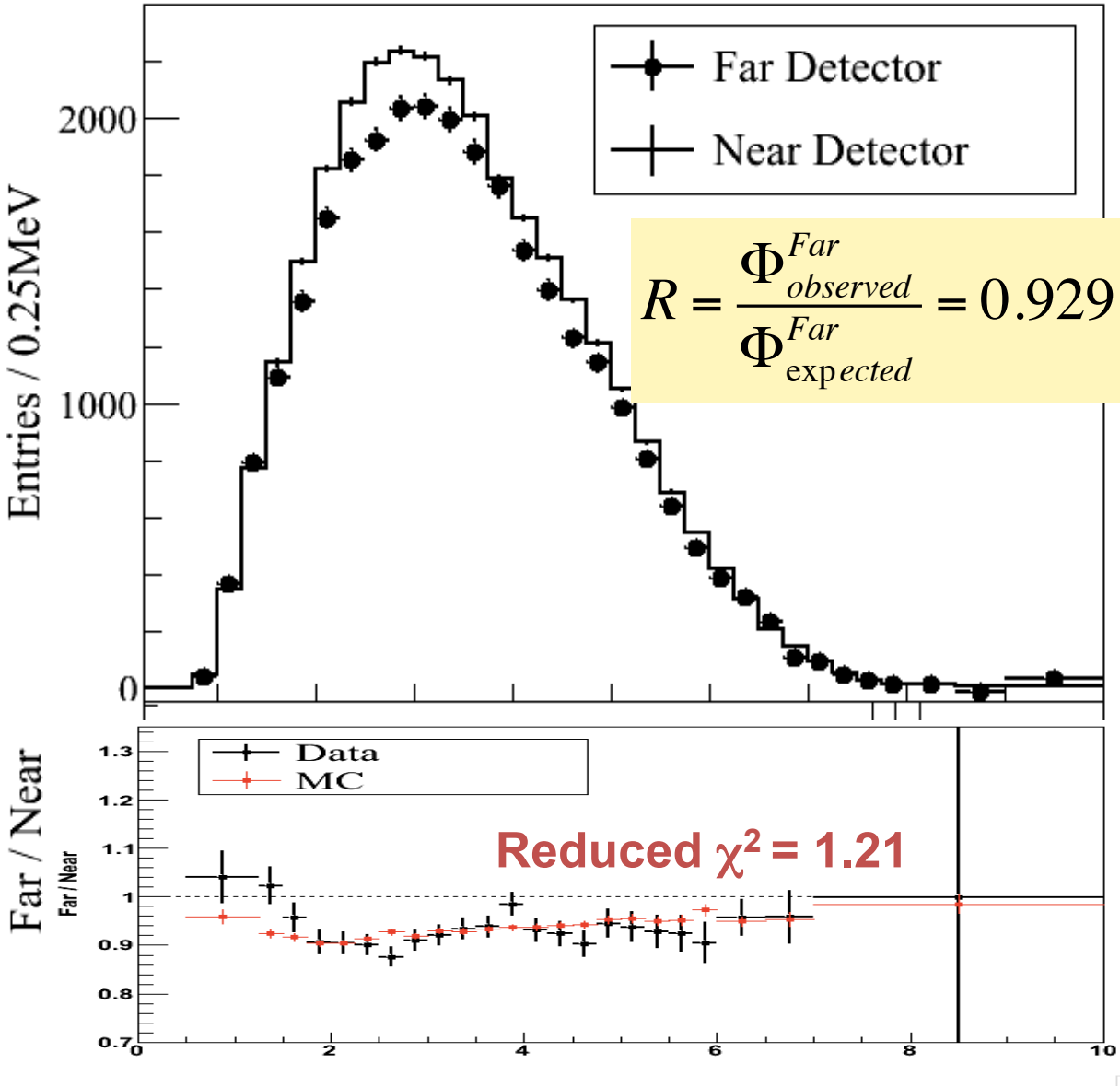
Measured Spectra of IBD Prompt Signal



Measured Spectra of IBD Prompt Signal



Reactor Antineutrino Disappearance



preliminary

$$R = \frac{\Phi^{Far}_{observed}}{\Phi^{Far}_{\exp ected}} = 0.929 \pm 0.006(stat.) \pm 0.007(syst.)$$

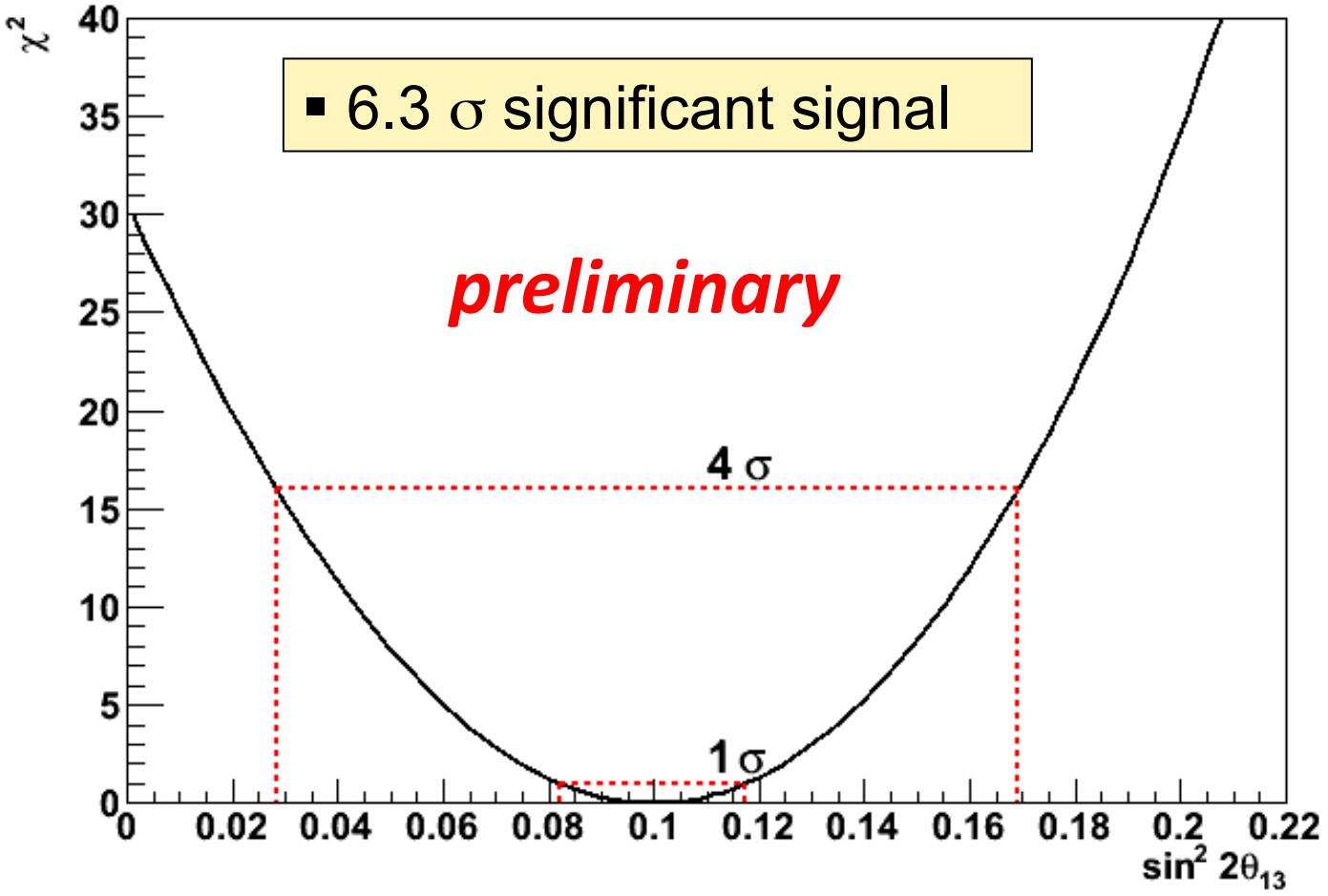
- A clear deficit in rate

  (~ 7 % reduction)

- Consistent with neutrino oscillation in the spectral distortion

Definitive Measurement of θ_{13}

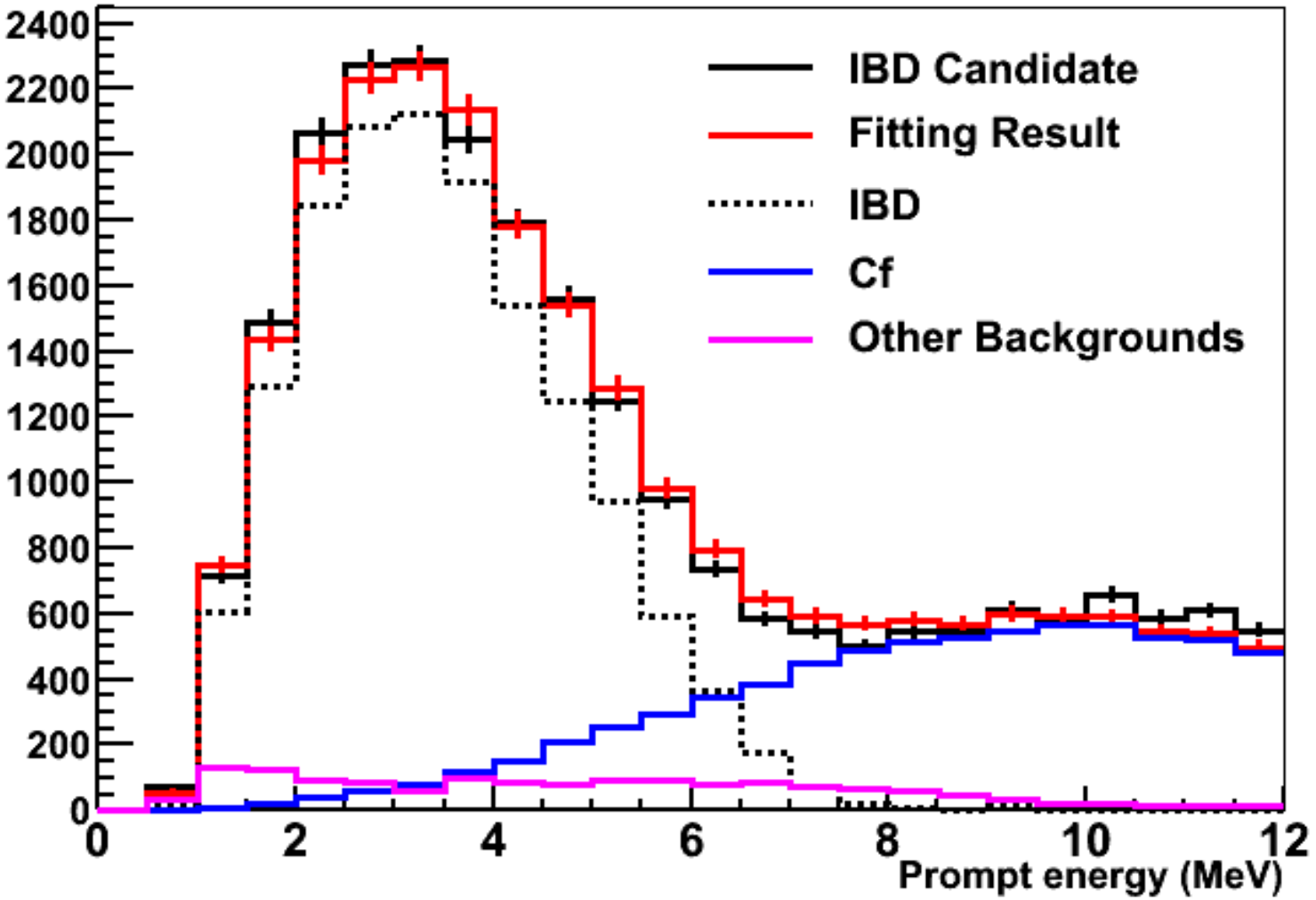
$$\sin^2 2\theta_{13} = 0.100 \pm 0.010(stat.) \pm 0.012(syst.)$$



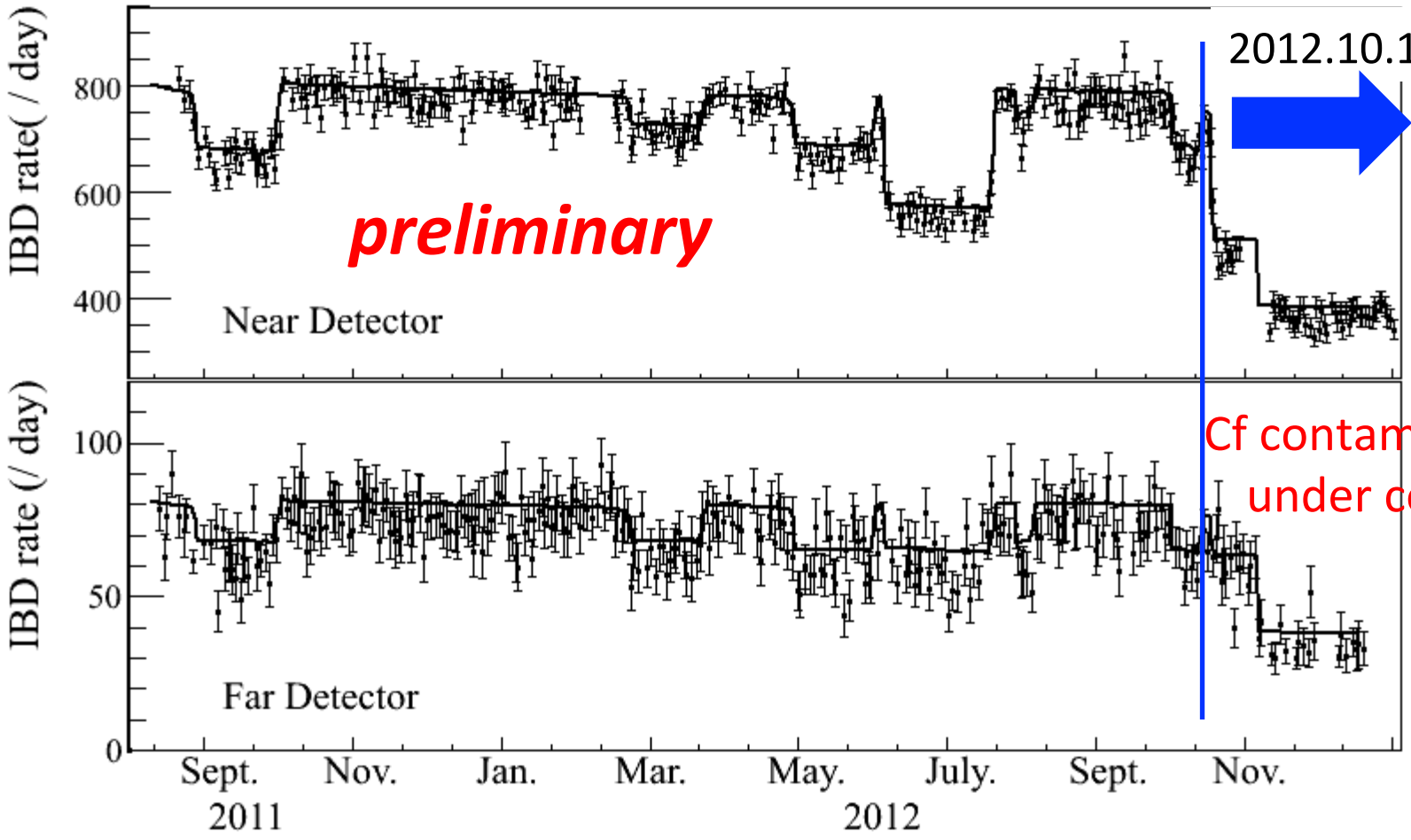
IBD Analysis of ^{252}Cf contaminated data

13th Oct. 2012 ~ 25th July. 2013

IBD (/day) : 54.5094 +- 0.489393
Cf (/day): 26.2655 +- 0.361229

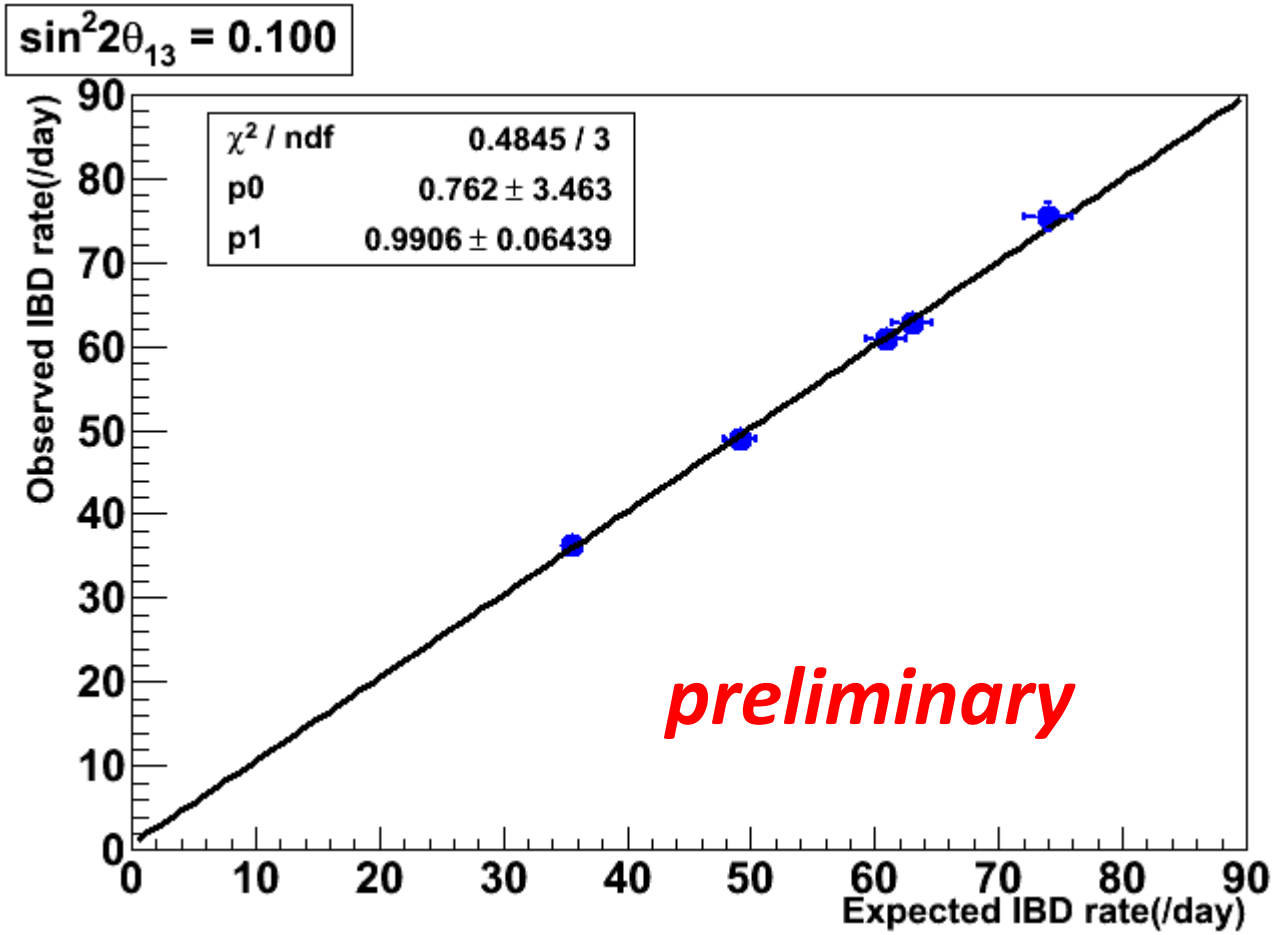


Observed Daily IBD Rate



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

Observed vs. Expected IBD Rates



- ✓ Observed and expected IBD rates match well within oscillation hypothesis.
- ✓ Background subtraction is correctly done.

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 > 700 days of neutrino data so far and improved systematic uncertainties and energy calibration.

- RENO observed a clear disappearance of reactor antineutrinos.

$$R = 0.929 \pm 0.006(stat.) \pm 0.007(syst.)$$ ***preliminary***

- RENO's updated result (403 live days): **(6.3 σ)**

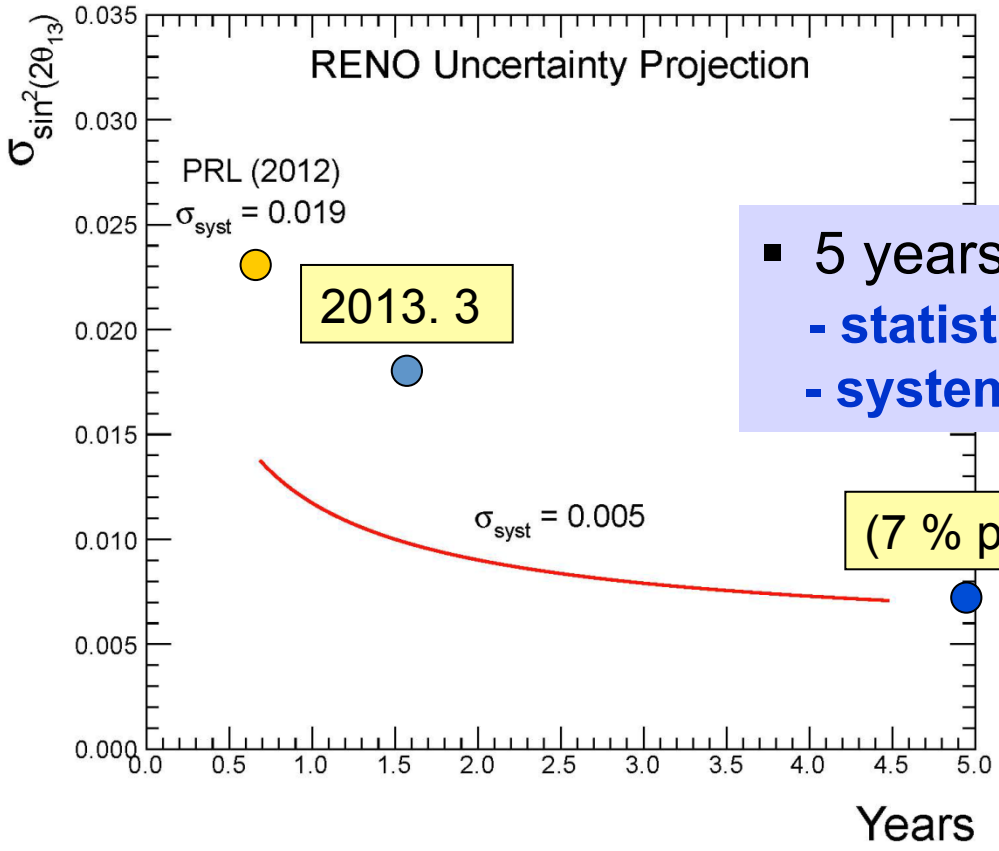
$\sin^2(2\theta_{13}) = 0.100 +/- 0.010 (stat.) +/- 0.012 (sys.)$

- Cf252 contaminated data is well under-control and IBD analysis with the contaminated data set is on-going.

RENO's Projected Sensitivity of θ_{13}

$$\sin^2 2\theta_{13} = 0.100 \pm 0.010(stat.) \pm 0.012(syst.)$$

(403 days) 0.100 ± 0.016 (6.3 σ) (16 % precision) ⇨ ± 0.007 (~ 13 σ) (7 % precision) (5 years)



- 5 years of data : ±0.007 (7% precision)
  - **statistical error : ±0.010 → ±0.005**
  - **systematic error : ±0.012 → ±0.005**

Other Ongoing Analyses

- H capture analysis
- Direct measurement of Δm_{13}^2
- Precise measurement of reactor neutrino flux and spectrum
- Reactor anomaly and sterile neutrinos