Neutron Tagging Technique for Relic Supernova Neutrinos in Super-Kamiokande

Hideki Watanabe

Institute for Cosmic Ray Research, The University of Tokyo,
for the Super-Kamiokande Collaboration

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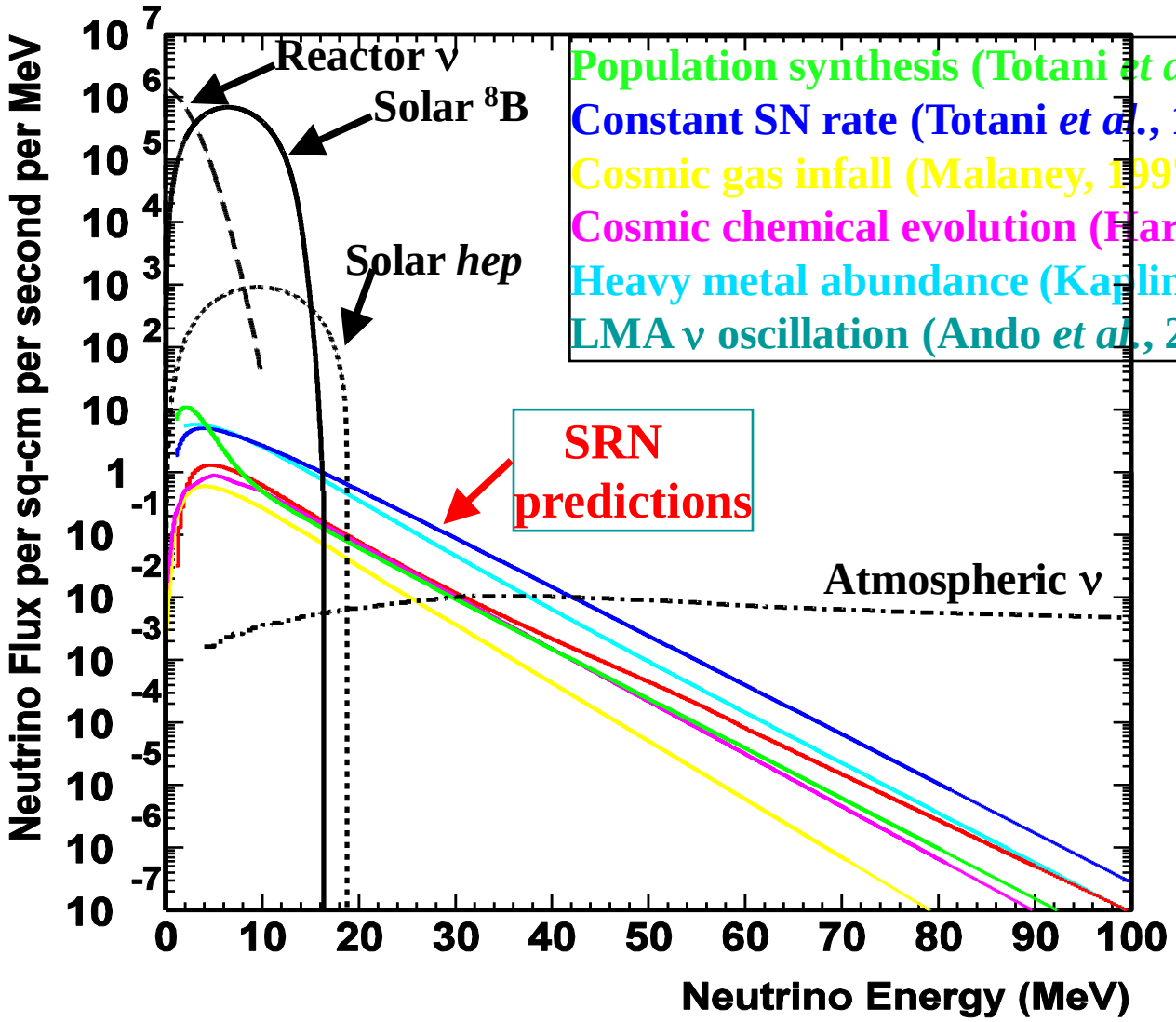
Outline

- Search for Relic Supernova Neutrinos
- Study of Neutron Tagging with Am/Be and BGO Scintillator
- Forced Trigger System
- Data Analysis and Results
- Summary

Search for Relic Supernova Neutrinos



Population synthesis (Totani *et al.*, 1996)
Constant SN rate (Totani *et al.*, 1996)
Cosmic gas infall (Malaney, 1997)
Cosmic chemical evolution (Hartmann *et al.*, 1997)
Heavy metal abundance (Kaplinghat *et al.*, 2000)
LMA ν oscillation (Ando *et al.*, 2002)

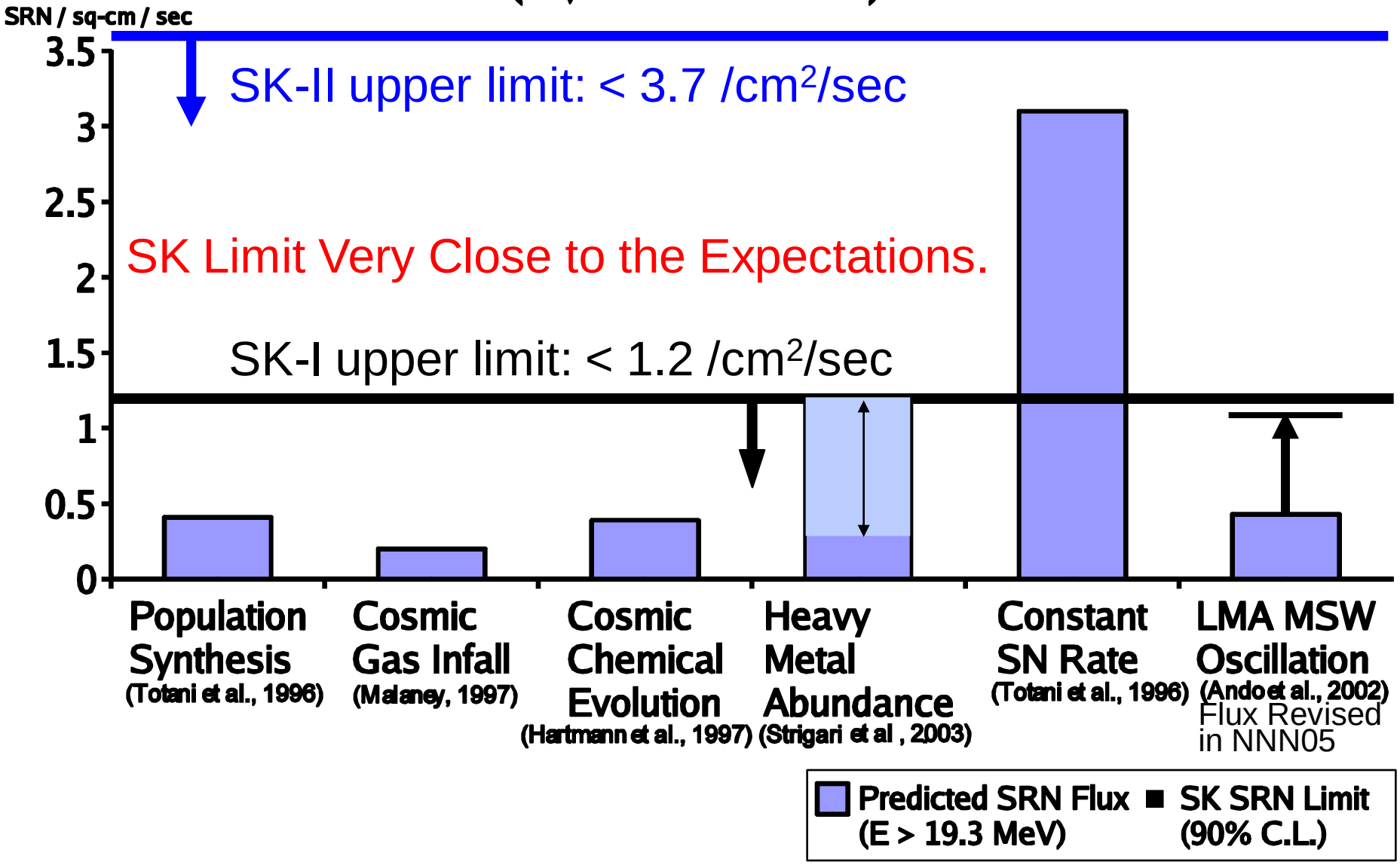
Relic ν's from All Past Core Collapse SNe.

➔ Believed to be Diffused in the Universe.

∴ $\overline{\nu}_e$ Searched via Inverse Beta Decay.

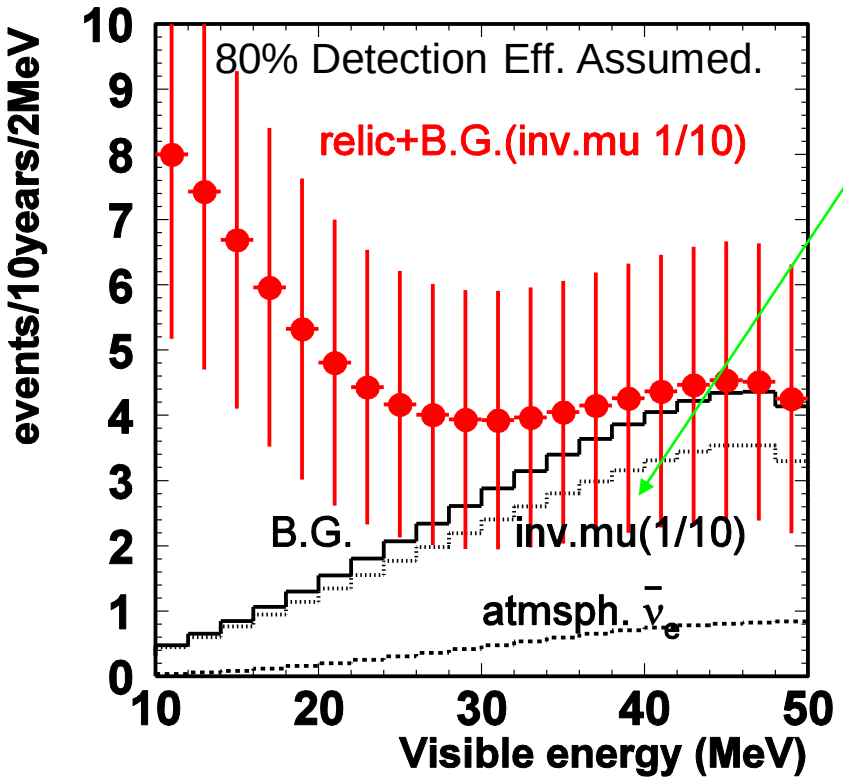
Spallation B.G. Below ~ 15 MeV

SK SRN Flux Limits vs. Theoretical Predictions (E_ν> 19.3 MeV)



Possibility of SN Relic ν Detection

Relic Supernova ν Model Referred to: S. Ando, *et al.* Astropart. Phys.18, 307(2003) with Flux Revised in NNN05.



Reduction of 90 % Invisible μ B.G. Assumed with Neutron Tagging Technique.

In Case of $GdCl_3$ Dissolved into SK with 0.2 % Concentration, 90 % Neutron Detection Efficiency Expected.

➔ Neutron Captured on Gd in 20 ~ 30μs.

∴ Neutron Tagging Leading to Powerful B.G. Rejection.

⇒ Study of Neutron Tagging via Delayed Coincidence in SK Thus Motivated.

Study of Neutron Tagging with Am/Be and BGO Scintillator

[Inverse Beta Decay]

$\overline{\nu_e} + p \rightarrow e^+ + n$

Prompt

$n + p \rightarrow \cdots\cdots \rightarrow n + Gd \rightarrow Gd + \gamma$(Totally 8 MeV)

Delayed

[Am/Be]

$\alpha + {}^{9}Be \rightarrow {}^{12}C^* + n$

Prompt

Detected by BGO to Trigger SK with High Light of Scintillation.

${}^{12}C^* \rightarrow {}^{12}C + \gamma$(4.4 MeV)

$n + p \rightarrow \cdots\cdots \rightarrow n + Gd \rightarrow Gd + \gamma$(Totally 8 MeV)

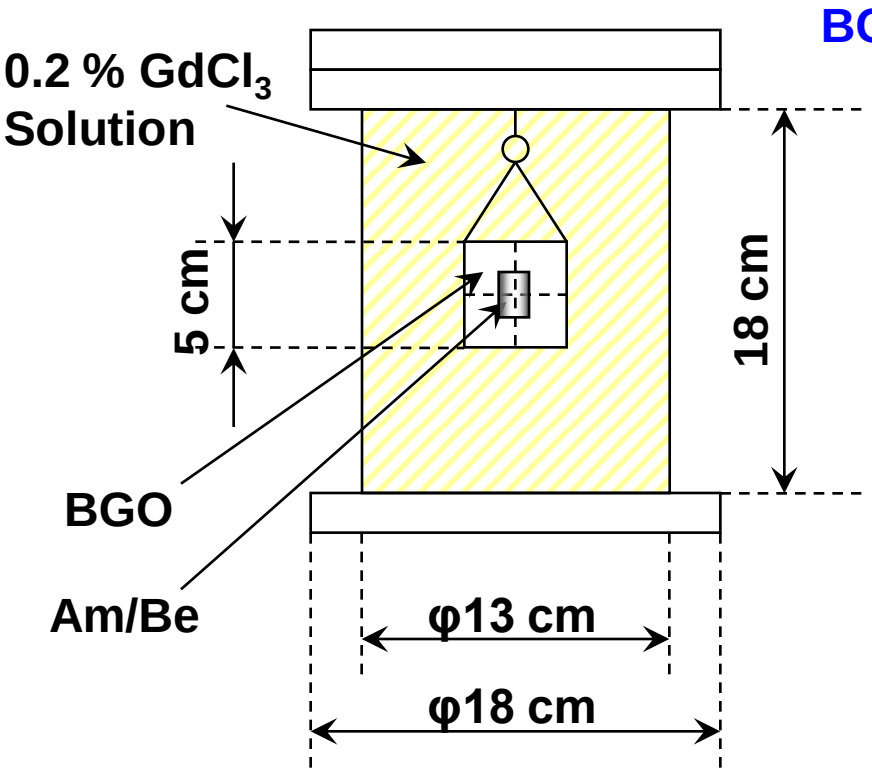
Delayed

⇒ Gadolinium Dissolved in SK Water Proposed & Now Under Discussion.

∴ Feasibility Check with Gd Solution for the Study of Neutron Observation Performed Using Am/Be Radioactive Source & BGO Scintillator.

- $GdCl_3$ Vessel

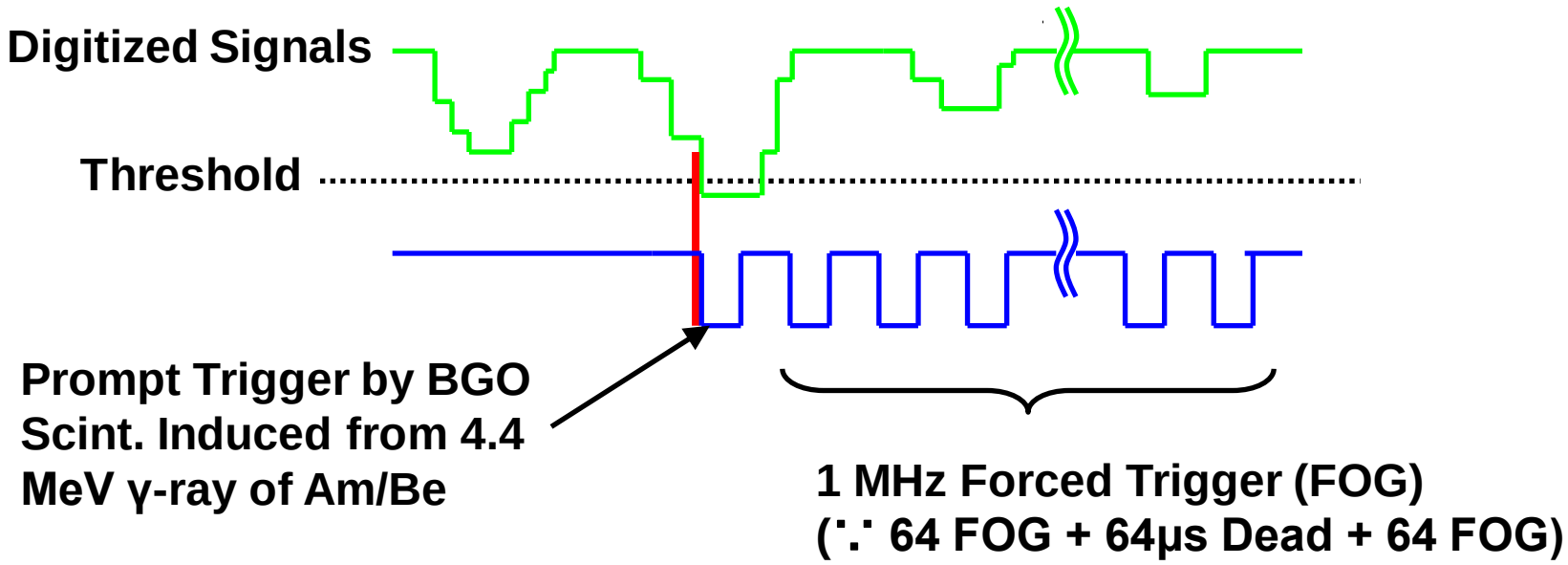
⇒ Acrylic Cylinder. @Center
Placed Am/Be Embedded BGO.



∴ This Apparatus Deployed @Detector Center in SK.

Forced Trigger System

- 1 MHz Forced Trigger Issued after Prompt Trigger with Its Performance of Active 64μs Succeeding Dead 64μs and Active 64μs.



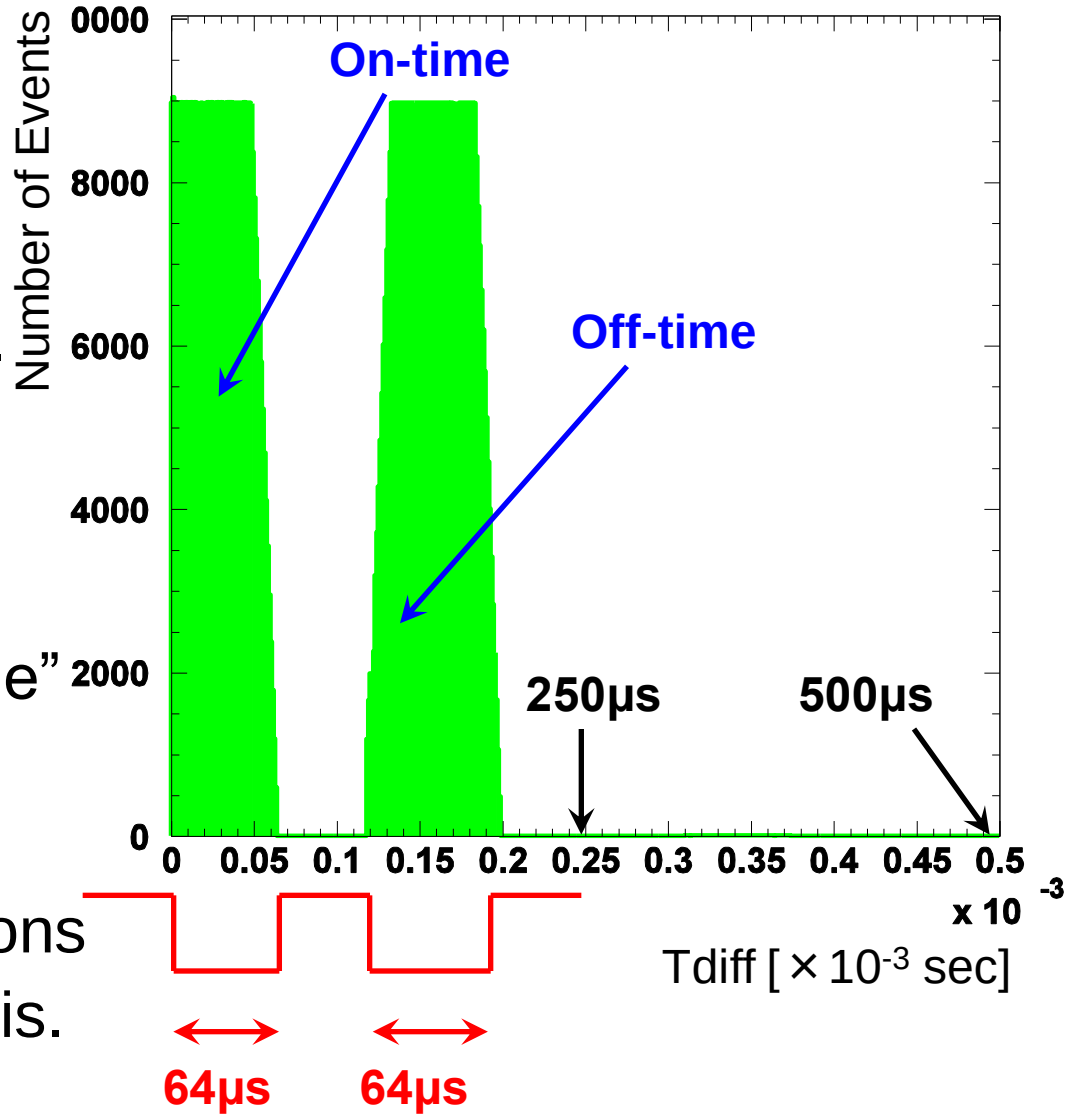
Data Analysis and Results

- Tdiff Distribution

Tdiff = Time Difference
Between Prompt
& Delayed Events.

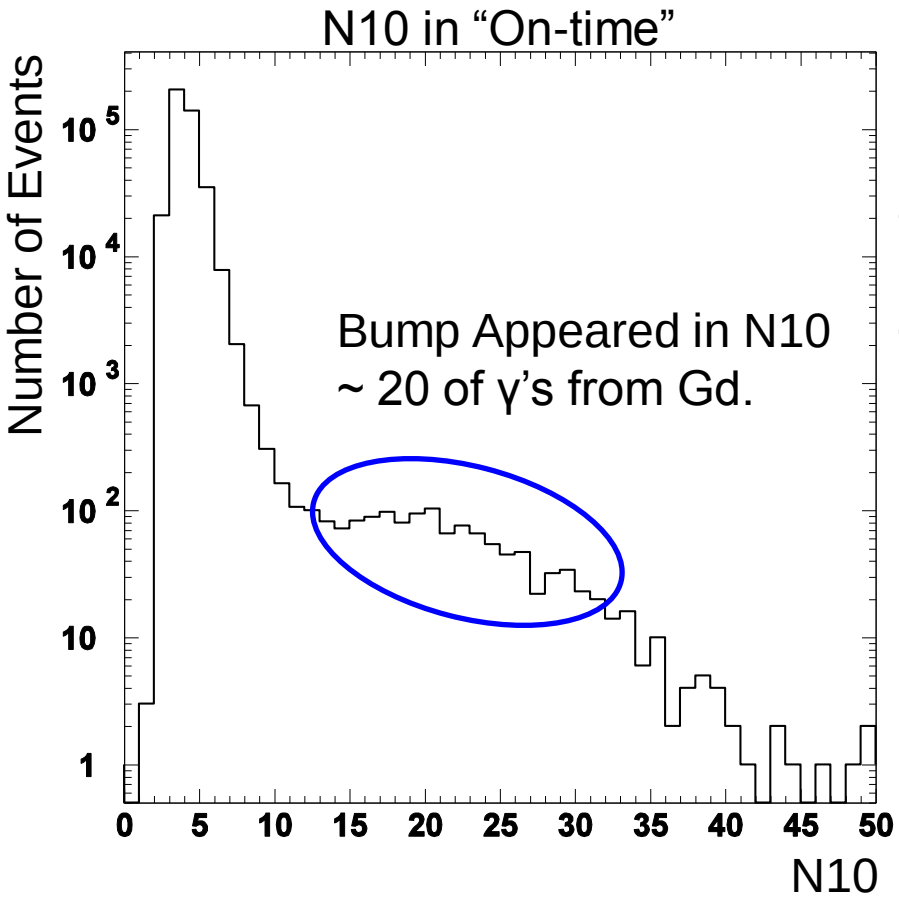
∴ 100 % Detection
Efficiency Guaranteed
in “On-time” & “Off-time”
Region.

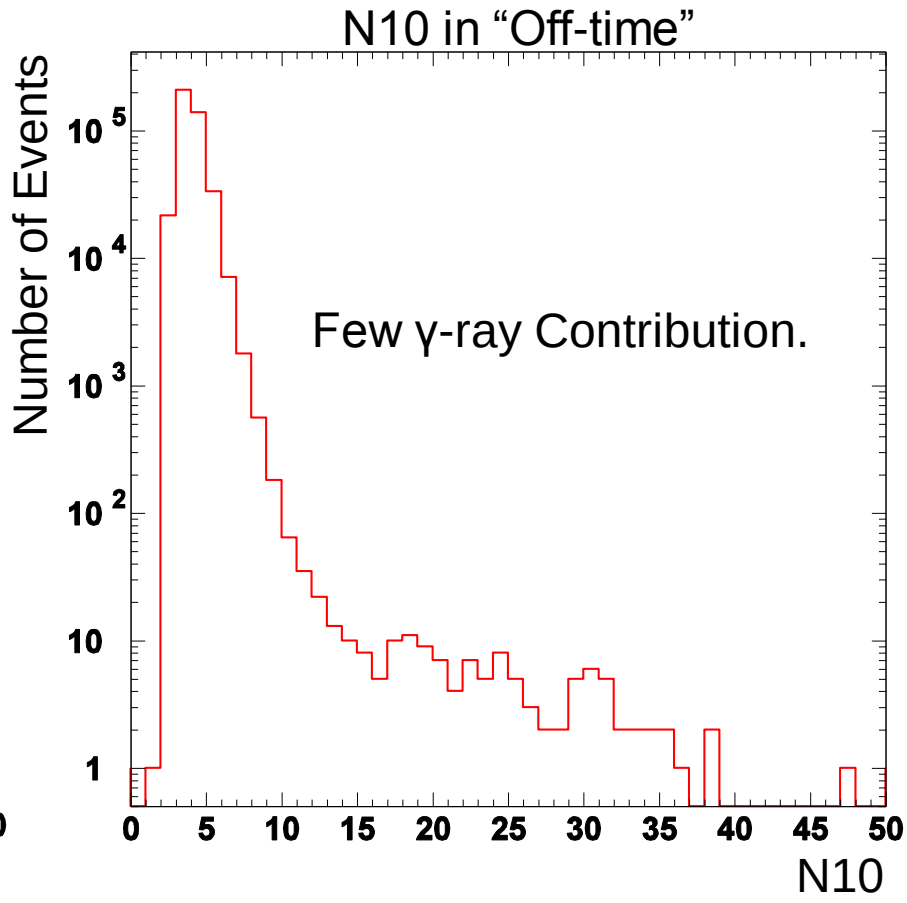
➔ Only These Two Regions
Considered for Analysis.



- N10 Distribution for Signal Extract

N10 = Maximum Number of Hit PMTs within Sliding 10 ns Timing Window with TOF of Photons Subtracted.





∴ Signals Almost Exist in “On-time” Region.

- Rejection of Scintillation Events

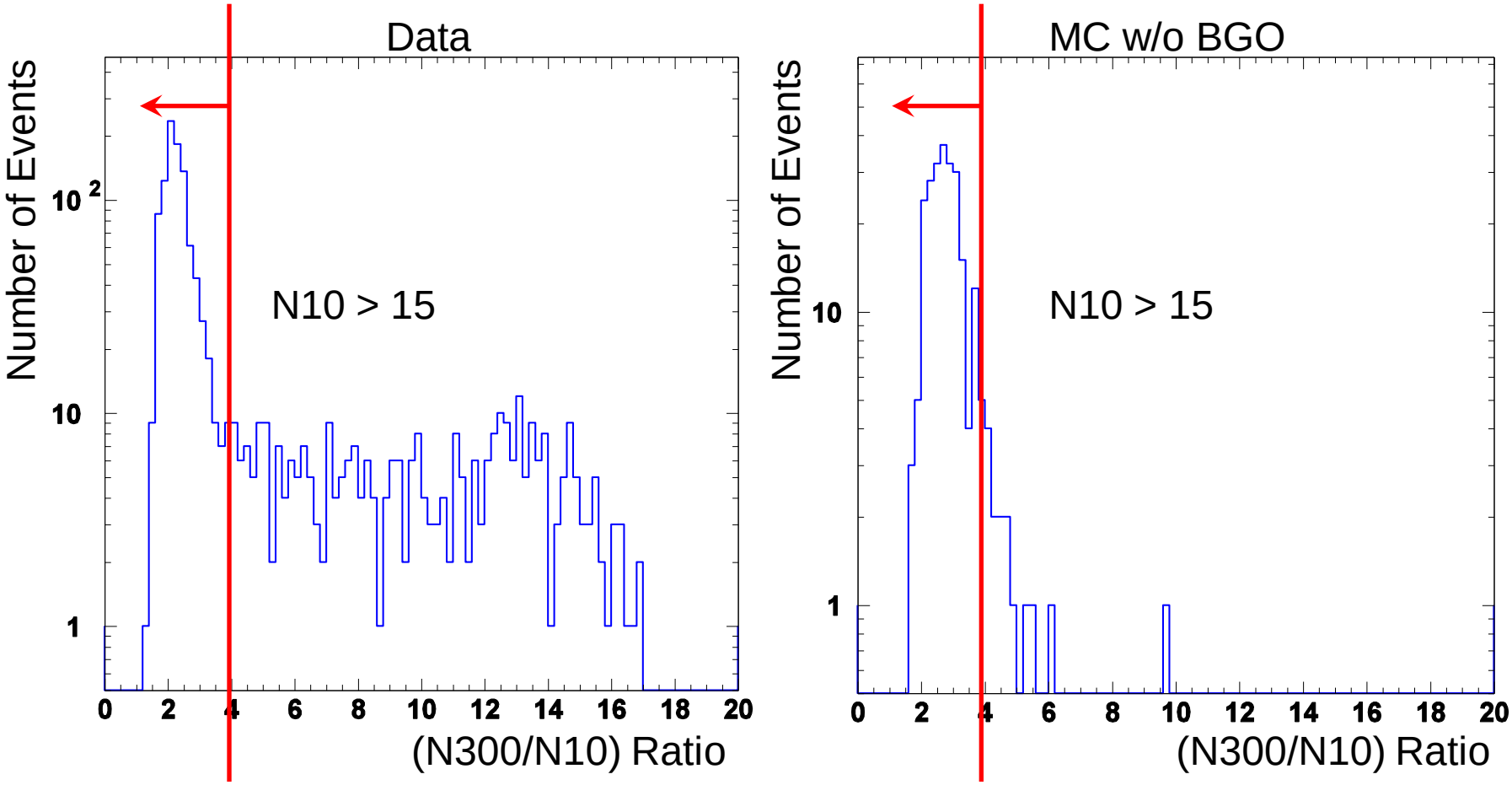
⇒ Discrimination of Scintillation Events to Obtain pure Cherenkov Events of γ's from Gd.

∵ Scintillation Events = γ's from Gd Hitting Deployed BGO to Yield High Light.

↓

Study with the Ratio of Events in:
Wide Time Window (300 ns) to Narrow Time Window (10 ns).
⇒ Larger Ratio of (N300/N10) ⇔ Scintillation-origin.

∵ 300 ns = BGO's Decay Time.

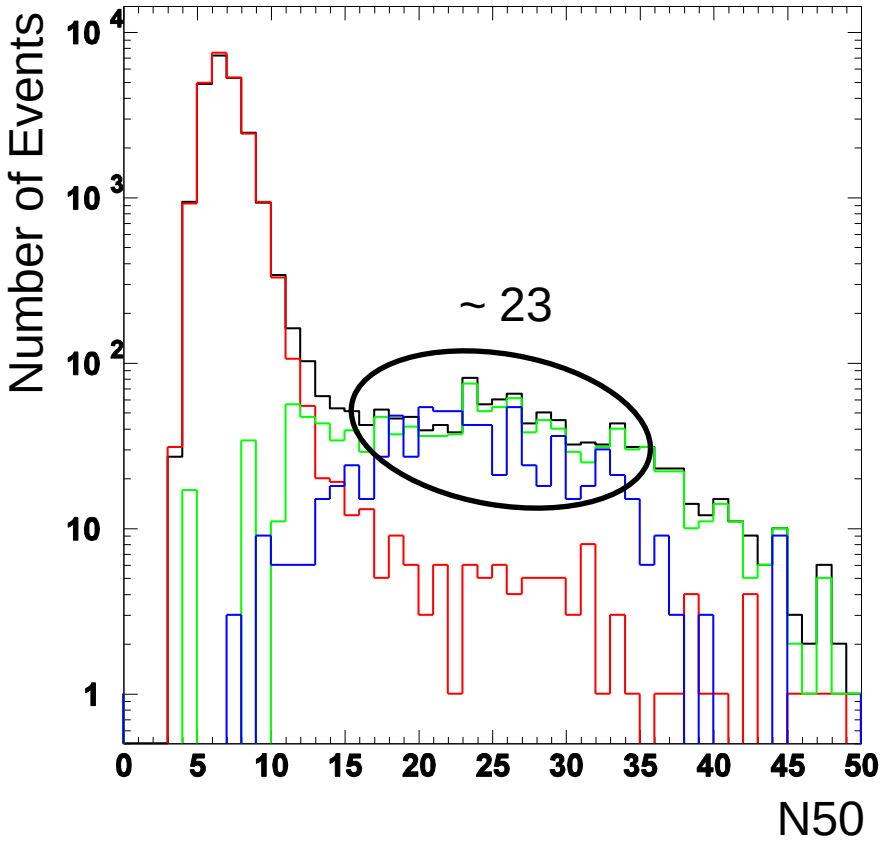


∴ Ratio < 4 Accounted for Analysis.

(∵ Mostly Cherenkov-like Observed. Scintillation-like < 25 %.)

- N50 Distribution After Data Quality Cuts

N50 = Analogous to N10 Except 50 ns of Timing Window Used As Energy Evaluator.

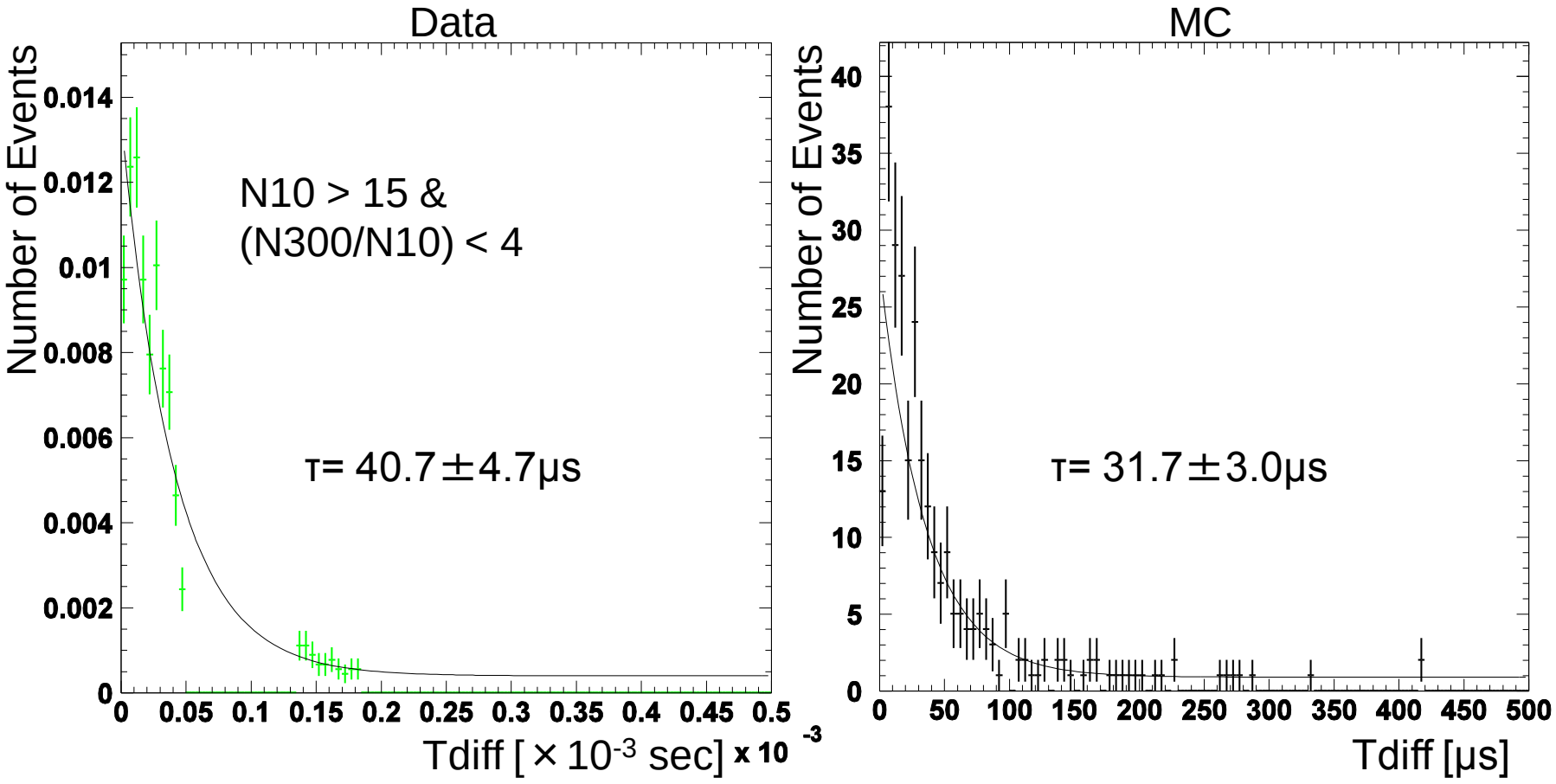


Black: N50 in Tdiff Region 1
Red: N50 in Tdiff Region 2
Green: Subtracted (Black – Red)
Blue: MC

∴ More Clearly Bump of γ's Observed ~ 23 and Consistent with Expected.

- Tdiff Distribution After Data Quality Cuts

⇒ Single Exponential Fitting Conducted.



∴ Consistent with Expectation by MC.

- Computation of Neutron Detection

[MC at First Step (Volume of 0.2 % $GdCl_3$ Solution → ∞)]

⇒ 90 % of Generated Neutrons Captured by Gd.

∴ Experiment Conducted with 2.4 Liters Based on This Understanding.

[Results from Data]

-- Number of Prompt Signals Induced from BGO = 9067

-- Number of Detected Neutrons = 842 ∴ 9.3±0.3 % Efficiency.

[MC with Apparatus Configuration]

-- Efficiency of Data Quality Cuts = 40.5±4.1 %

-- Production Probability of γ's from Gd = 24.2±1.4 %

∴ Observation Probability of γ's = 9.8±4.3 %

➔ Data & MC Consistent in Experiment with 2.4 Liters of $GdCl_3$ Solution.

<< Reaction Inside the 2.4 Liters Vessel >>

-- Total Number of Thermilized Neutrons Captured = 271

-- Captured by Gd's = 242

∴ 90 % of Neutrons Captured by Gd's.

Summary

- R & D with Apparatus of 0.2 %$GdCl_3$ Solution, BGO Scintillator and Am/Be Radioactive Source.

- Study of Neutron Tagging with Forced Trigger System:

-- γ-rays with Total Energy of 8 MeV from Gd Observed and Consistent with Expectation by MC.

-- Data and MC Also Consistent in Tdiff Distribution.

- Observation Probability of γ-rays with Totally 8 MeV:

➔ 90 % Evaluated for Real Case.

∴ Possibility of Identification of $\bar{\nu}_e$ Clarified via the Experiment with 2.4 Liters of 0.2 % $GdCl_3$ Solution.