Supernova Early Warning in the Daya Bay Reactor Neutrino Experiment

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(for the Daya Bay Collaboration)

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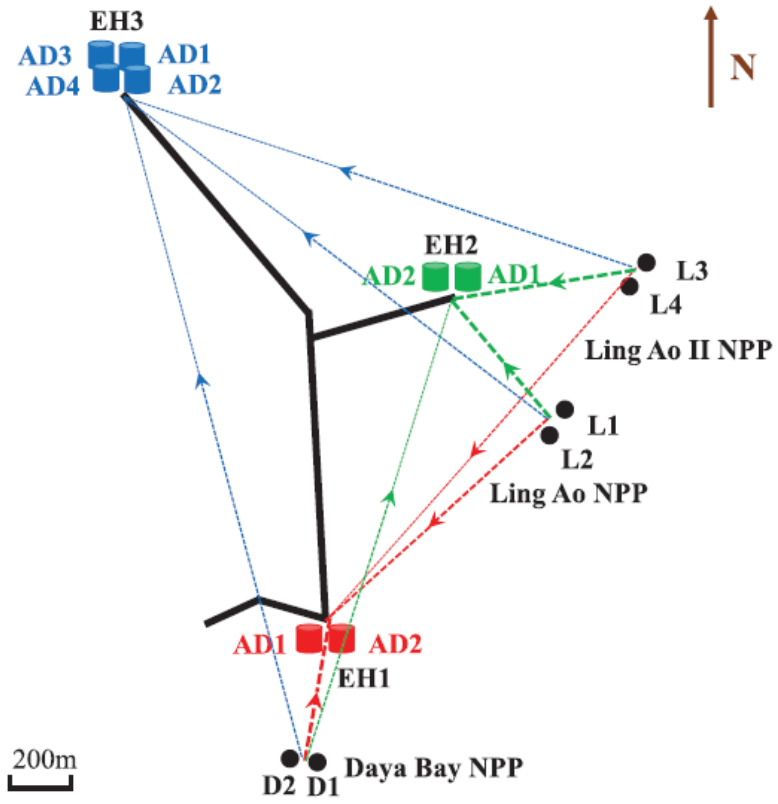
Importance of SNν Study

- SNν are a key diagnostic for the dynamics of core collapse and SN explosion
  - ~99% of the stellar collapse gravitational binding energy
  - Arrive a few hours before optical SN explosion (Early Warning)
  - SN explosion rate ~0.01/year in kpc ~1/year in Mpc
- Neutrino properties
  - Oscillation
  - Mass hierarchy
  - Matter effect
- Contribute to astrophysics and cosmology
- Joint analysis with gravitational wave experiment

DayaBay Neutrino Experiment

3 sites, 8 antineutrino detectors (ADs)

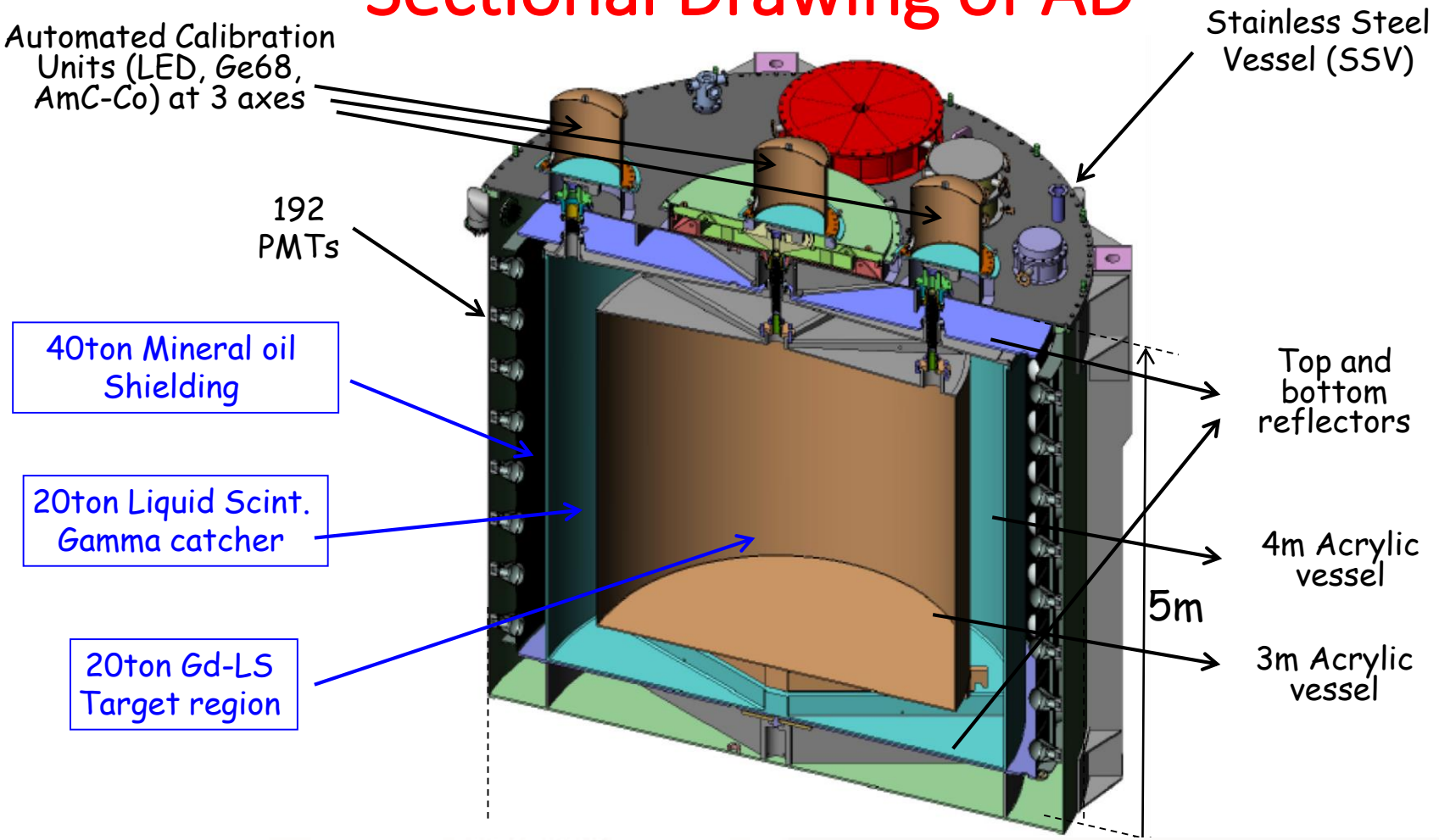


Far: 4 ADs
Target mass: 80 (GdLS) +80 (LS) ton
1600 m to LA, 1900 m to DYB
Overburden: 350 m
Muon rate: 0.04 Hz/m2

Ling Ao near: 2 ADs
Target mass: 40 (GdLS) +40 (LS) ton
Baseline: 500 m
Overburden: 112 m
Muon rate: 0.73 Hz/m2

Daya Bay near: 2 ADs
Target mass: 40 (GdLS) + 40 (LS) ton
Baseline: 360 m
Overburden: 98 m
Muon rate: 1.2 Hz/m2

Sectional Drawing of AD



IBD signal Process:

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

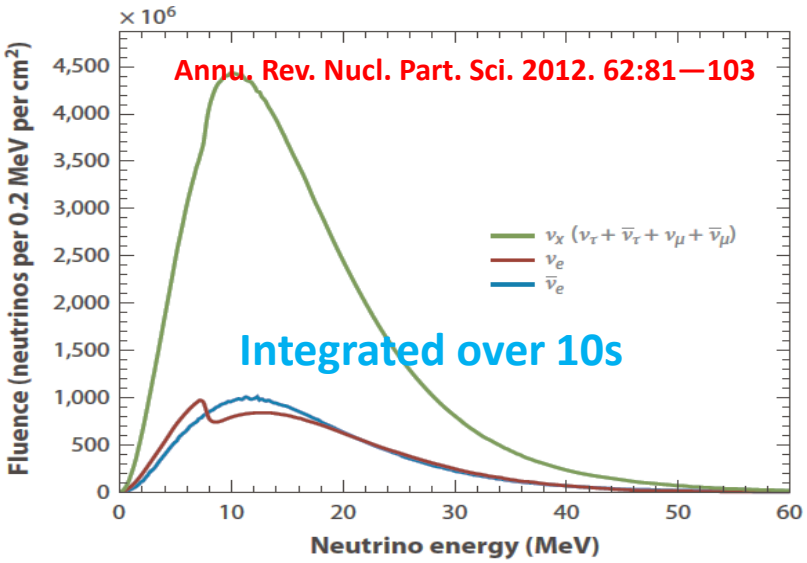
Prompt: e^+ annihilation Delay: neutron capture

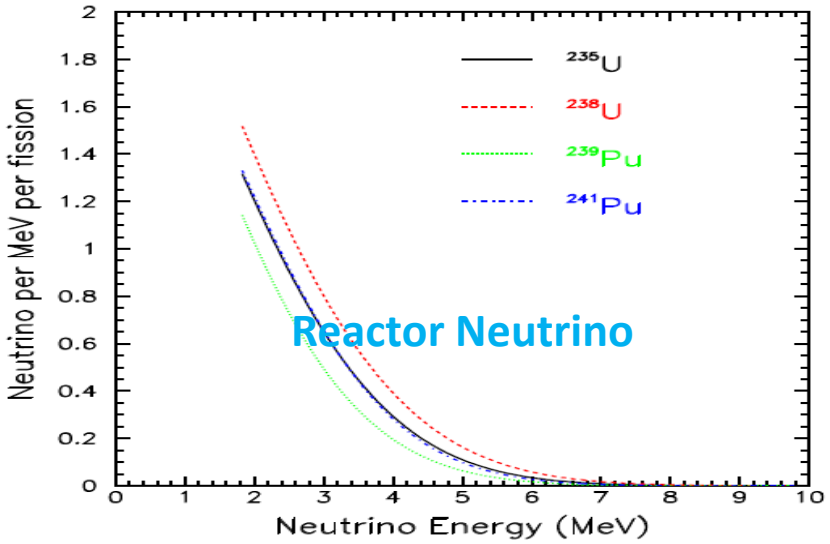
Neutrino events: coincidence in time and energy

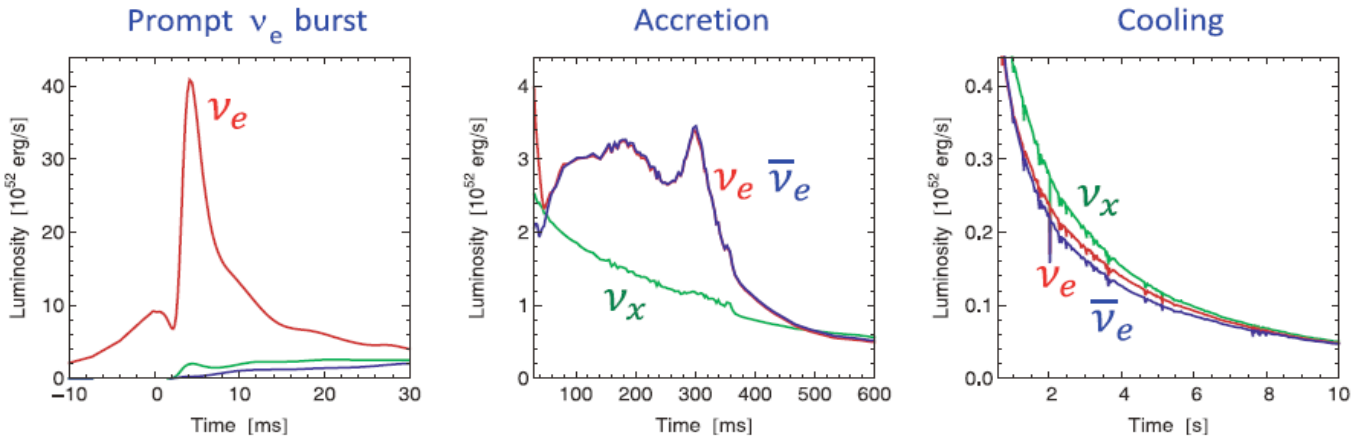
0.3b $\rightarrow + p \rightarrow D + \gamma\,(2.2\ MeV)$ *(delayed)* 180μs

50kb $\rightarrow + Gd \rightarrow Gd^* \rightarrow Gd + \gamma$'s *(8 MeV)* *(delayed)* 28μs 0.1%Gd

SNν Energy and Time Spectra







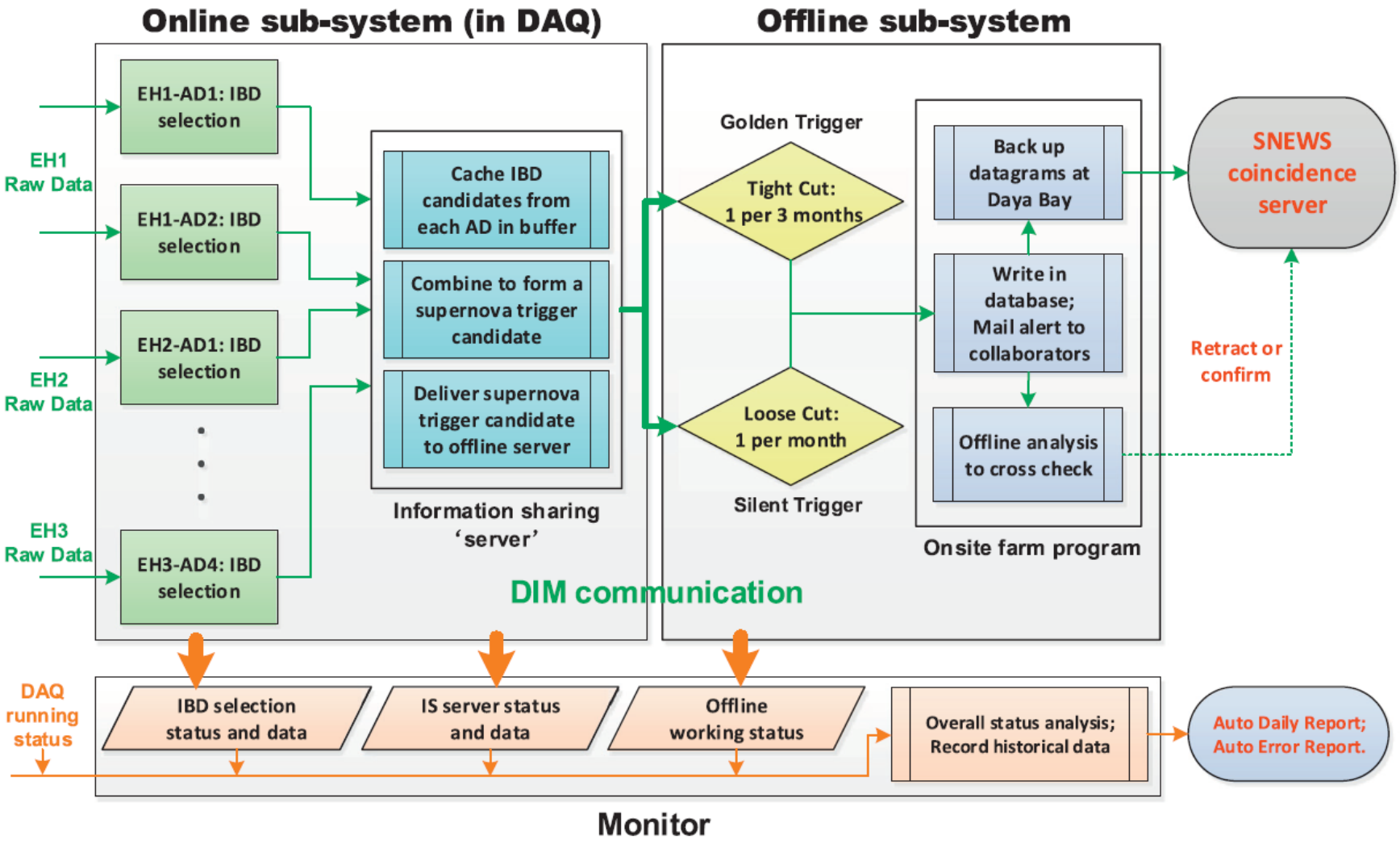
>95% luminosity within 10s

T. Fischer et al. Astron. Astrophys. 517(2010) A80

Supernova Online Trigger in DYB

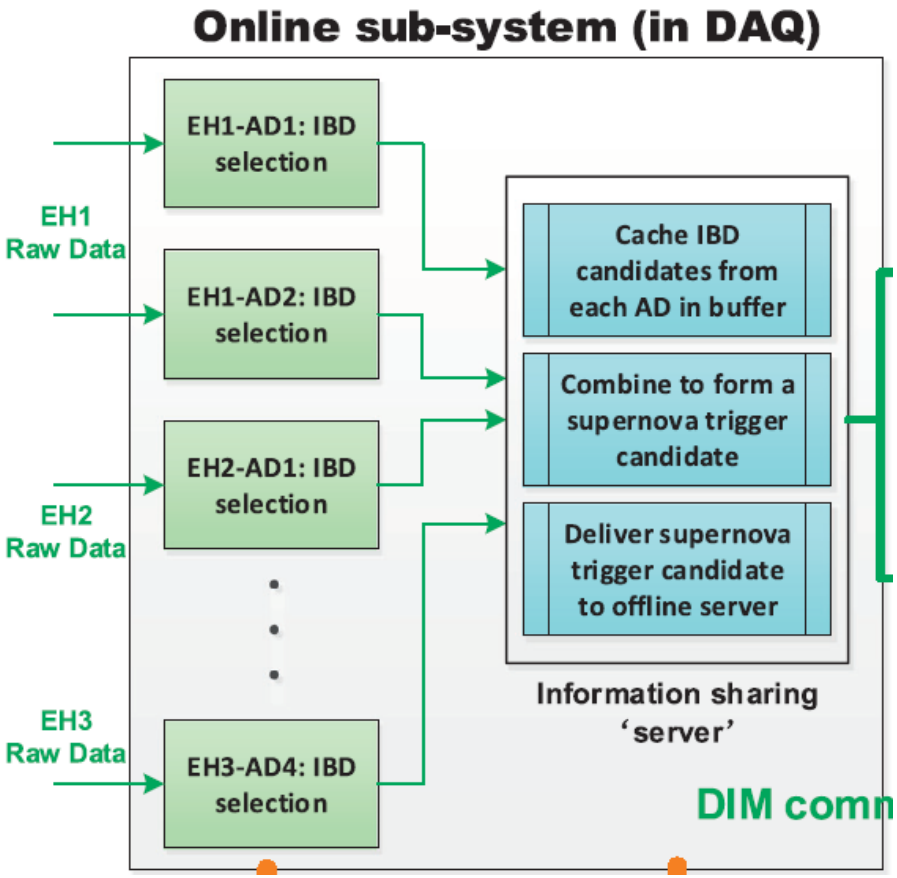
- Energy Resolution: ~3% @10MeV
- Time accuracy: **GPS** < 200ns
- Energy Threshold: 0.7MeV
- **Time latency: ~10s**
- **8 AD deployment in 3 experiment sites 1km apart from each other**
  - Better rejection to muon-induced fast neutron background than one single detector
  - Increase Signal-to-Background ratio, thus increase sensitivity of SN explosion

Supernova Trigger Flow Chart



Online Sub-system

1. IBD event online reconstruction
2. Cache each AD's IBD selection to supernova trigger server
   - Count the events within 1s for each AD labelled with timestamp
3. Sending each-AD trigger info to offline part
4. Send running status (per second) to monitor system



Online Reconstruction

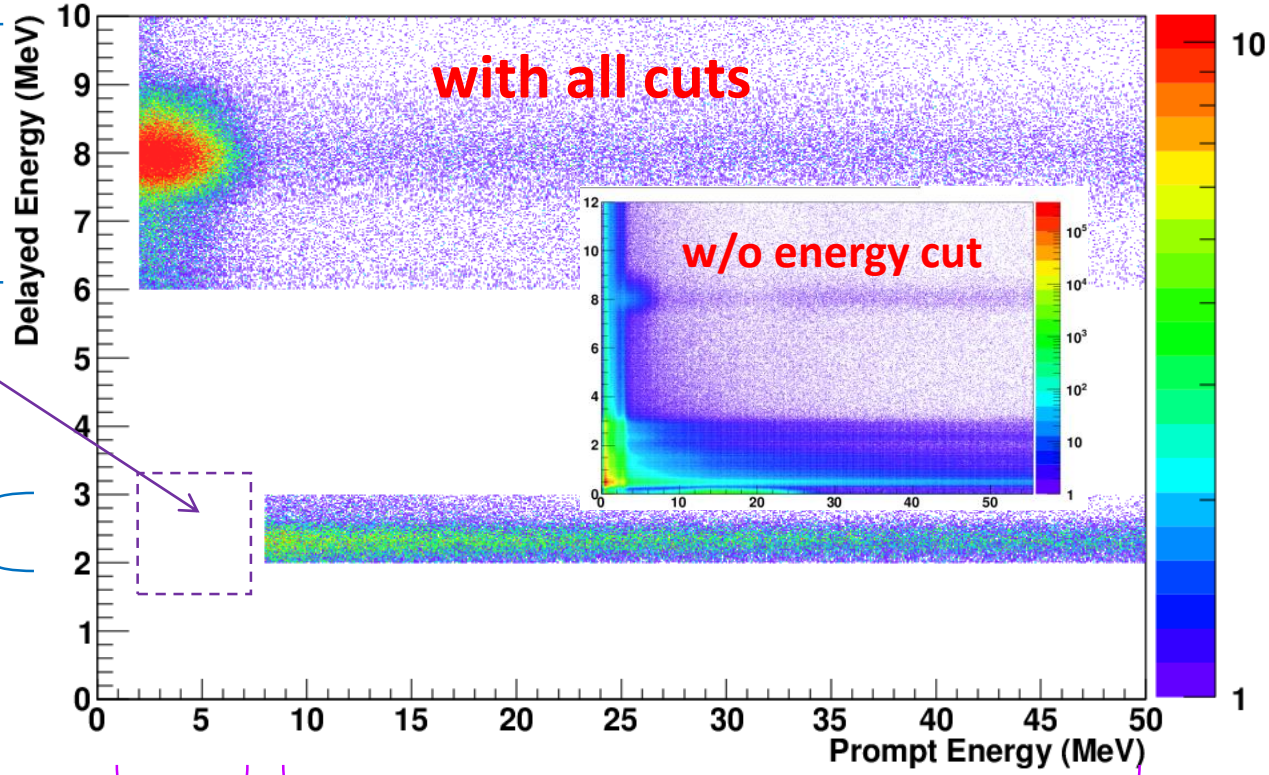
- Energy Reconstruction: $E = \dfrac{\text{ADC Sum}}{[\text{Average PMT Gain}] \cdot [\text{Average Energy Scale}]}$
  - PMT Gain: ~19 ADC per PE for all ADs
  - EnergyScale: ~170 PE/MeV for all ADs
- Vertex Reconstruction: $\mathbf{X} = \dfrac{\sum_{\text{PMT}} \text{ADC}_{\text{PMT}} \cdot \mathbf{X}_{\text{PMT}}}{\sum_{\text{PMT}} \text{ADC}_{\text{PMT}}}$
- Two key points for online reconstruction:
  - PMT Gain: minor influence on supernova trigger (1% error)
  - EnergyScale: minor influence on supernova trigger (1% error)
- Cut: prompt-delayed distance and time

Online Signal Selection

Gd neutron capture

Acc coincident background

H neutron capture

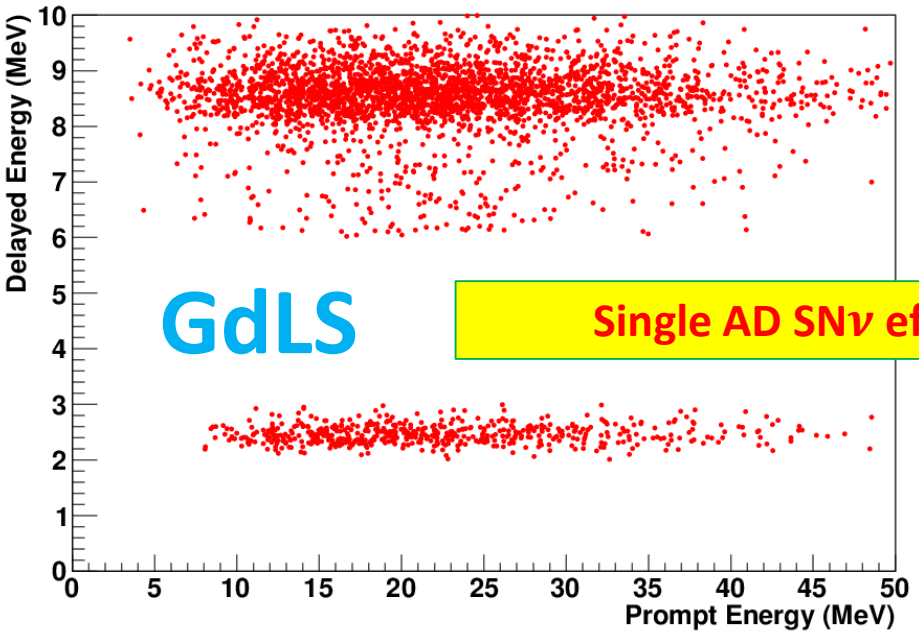


Selection Cut:

1. PMT Flasher
2. Muon Veto
3. Time Coin.
4. Multiplicity
5. Prompt-Delayed Distance
6. Energy cut

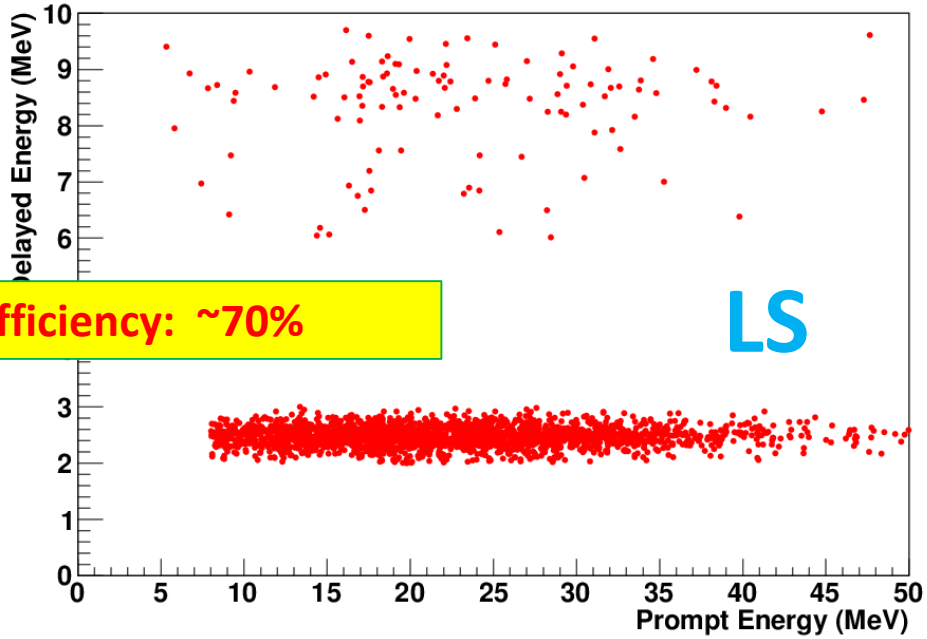
Background trigger rate per AD:
(Near site) DYB ~0.015Hz LA ~0.012Hz
FAR ~0.0012Hz

Single AD SNν Selection Efficiency

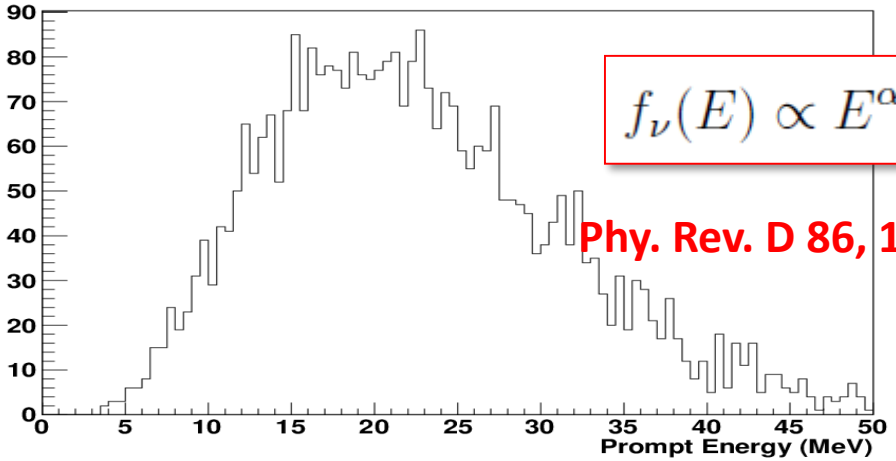


GdLS

Single AD SNν efficiency: ~70%

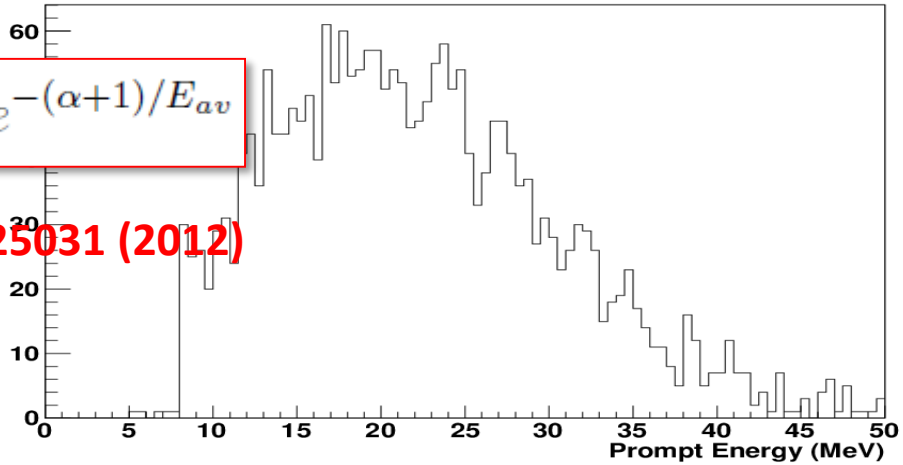


LS



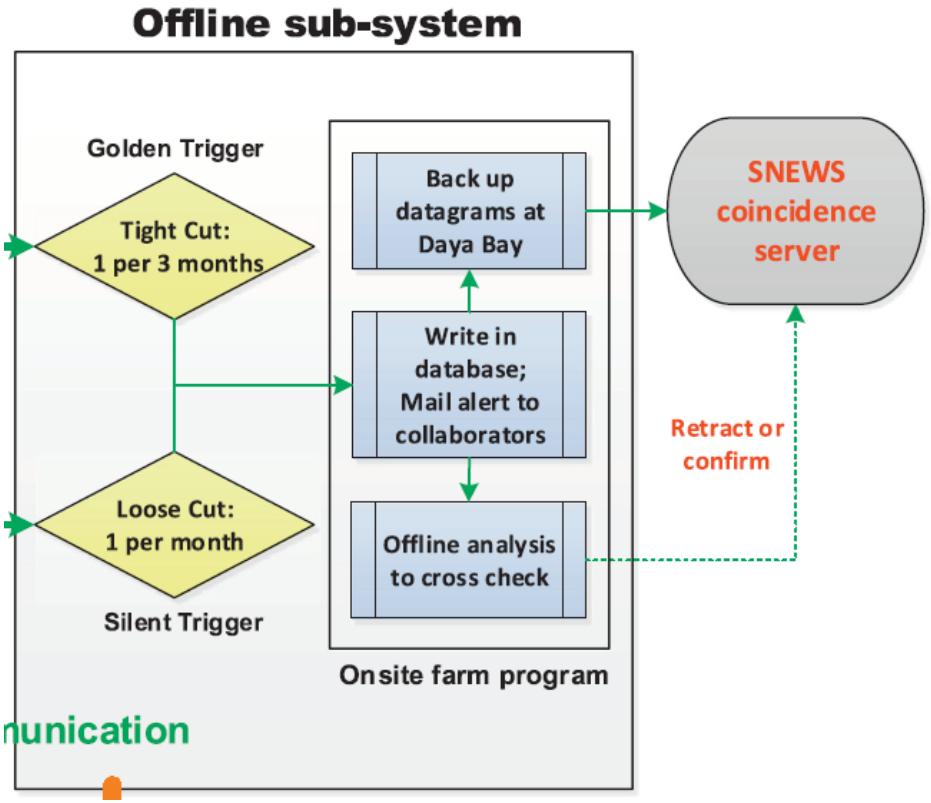
$$f_\nu(E) \propto E^\alpha e^{-(\alpha+1)/E_{av}}$$

Phy. Rev. D 86, 125031 (2012)



Offline Part and Monitor

1. Combine all ADs' event counts
   - Every 1s sum up the event counts in the previous 10s for each AD
   - Form a ***combination case*** of the event counts in the same 10s of all ADs
2. Judge the supernova trigger
   - Set supernova trigger cut: sets false trigger rate
   - Judge combination case against supernova trigger table
3. Alert to SNEWS by mail application
4. Auto-write into database
5. Send status to monitor system



Trigger Table & Trigger Cut

- Study potential background to supernova triggers
- List of combination cases ordered by trigger rate for sliding 10 seconds

Dataset: P12E (Dec. 24, 2011 ~ Jul. 28, 2012) (6 AD period)

AD1	AD2	AD3	AD4	AD5	AD6	SUM	COUNT	RATE(Hz)
0	0	0	0	0	0	0	10325376	0.63131593
0	1	0	0	0	0	1	1561089	0.09544837
1	0	0	0	0	0	1	1552738	0.09493778
0	0	1	0	0	0	1	1234517	0.07548105
1	1	0	0	0	0	2	239280	0.0146301
0	1	1	0	0	0	2	188711	0.0115382
1	0	1	0	0	0	2	186826	0.01142295
0	0	0	1	0	0	1	131401	0.00803414
0	0	0	0	1	0	1	130820	0.00799862
0	0	0	0	0	1	1	128114	0.00783317
0	2	0	0	0	0	2	120530	0.00736947
2	0	0	0	0	0	2	117117	0.00716079
0	0	2	0	0	0	2	75527	0.00461788

Sum: 0.897Hz

This cut: 1 – 0.897 = 0.103Hz ~1/10s

DYB near site: ~0.015Hz

LA near site: ~0.012Hz

Far site: ~0.0012Hz

A descending order

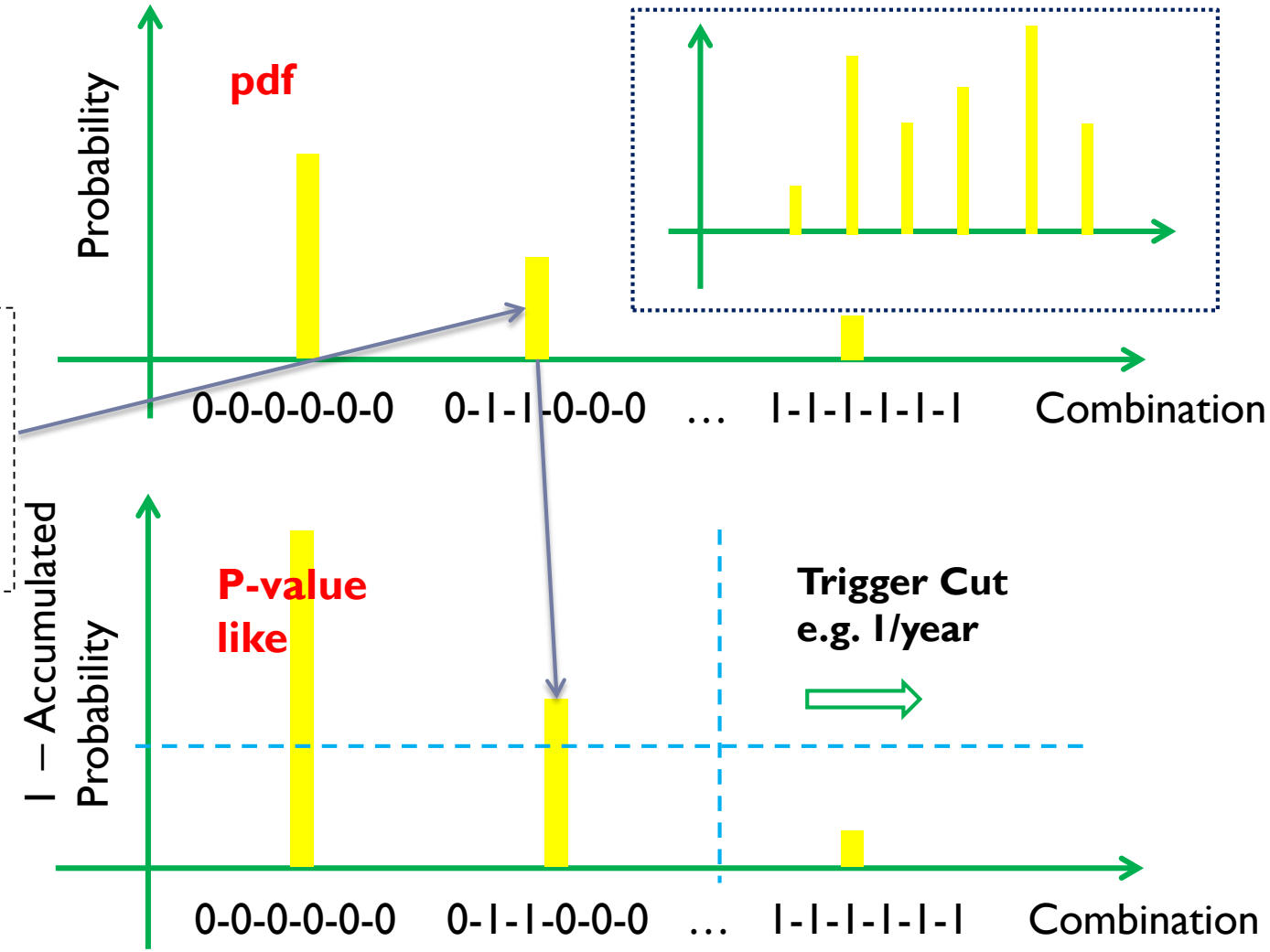
Combination case 1-0-1-0-0-0 means 10s counts from AD1 to AD6

Trigger Table & Trigger Cut

1.Enumeration and re-order by probability

Fast neutron suppressed here: Low prob for coincidences in multi-ADs apart

2.Set the cut



Correlation between ADs Considered

- ✓ From the measured trigger table, correlation between ADs for supernova trigger could also be measured.
- ✓ Statistic error ~0.0006

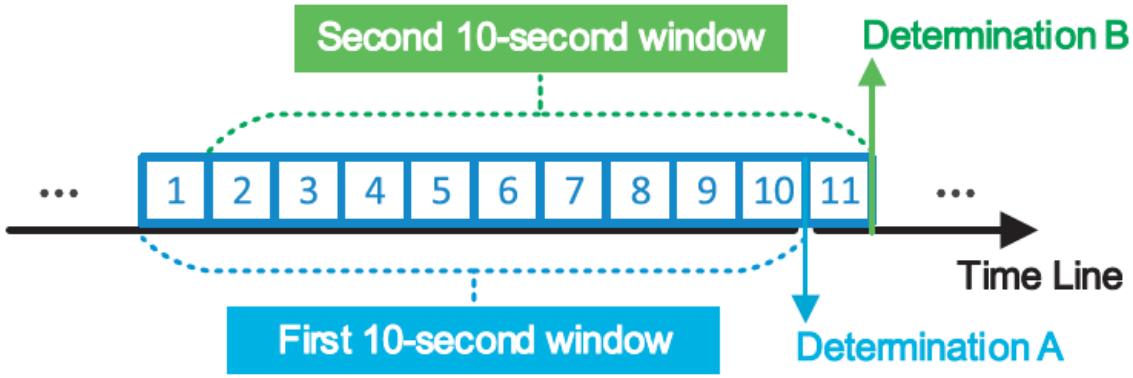
	Correlation	AD1	AD2	AD3	AD4	AD5	AD6
Dyb	AD1	1	0.0027	0.0007	-0.0003	-0.0002	0.0002
Dyb	AD2	-	1	0.0007	-0.0004	0.0003	-0.0002
	AD3	-	-	1	0.0002	-0.0002	-0.0002
Far	AD4	-	-	-	1	0.0009	0.0007
Far	AD5	-	-	-	-	1	0.0011
Far	AD6	-	-	-	-	-	1

Main reason for the correlation: The muon gets through the detectors in one site and induces fast neutron in the path.

SNEWs Trigger Reprocessing

- Supernova Trigger should be identical and independent to all ADs.
  - A χ^2 cut is applied to remove the triggers which has very non-uniform trigger distribution in 8 ADs.
  - Expected value for each AD is avg. of total events.
  - Cut: 18.475 (ndf=7, 99%C.L.)
  - E.g, 0 0 0 0 0 0 4 4 is removed out of golden trigger.
  - *Packing consecutive supernova triggers*

$$P_{\mathrm{SNEWS}} = \frac{P_{\mathrm{DYB}}}{\bar{N}}$$



Workload of Supernova Trigger to Data-taking System

- Process the raw data file using same program as online
- Check the avg. time of filling one event
- Physics Run
  - Supernova ON / Supernova OFF: 100%+8%

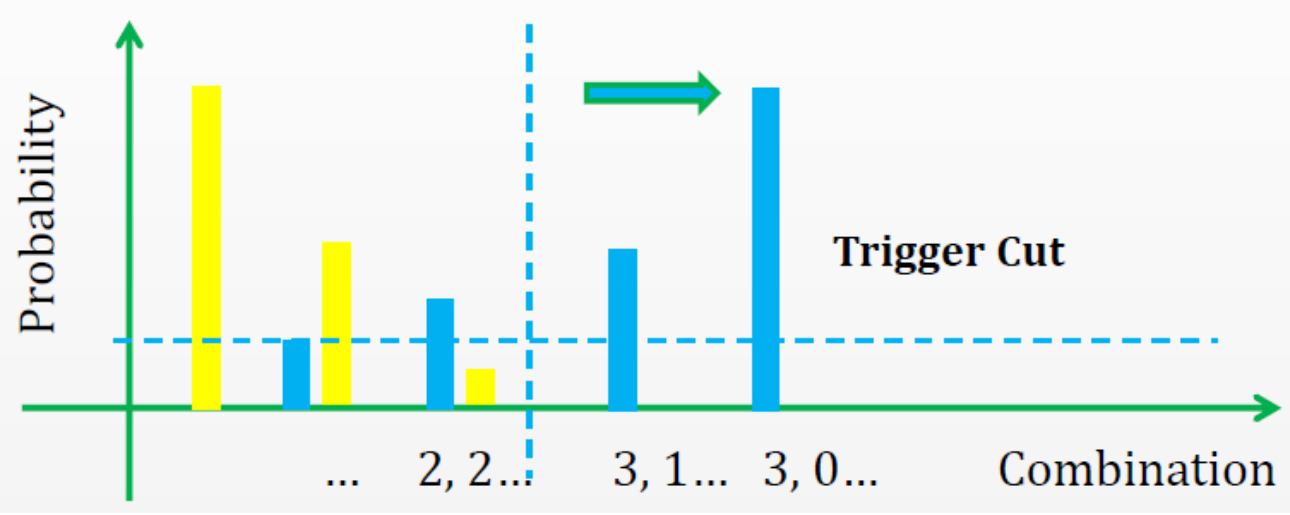
  - Red: Supernova Trigger Program (8% of Green, 0.4% of Blue)
  - Green: Histogram Filling Program
  - Blue: Total data taking time
- 1kHz Pedestal Run
  - Supernova ON / Supernova OFF: 100%+20%

Online Sensitivity

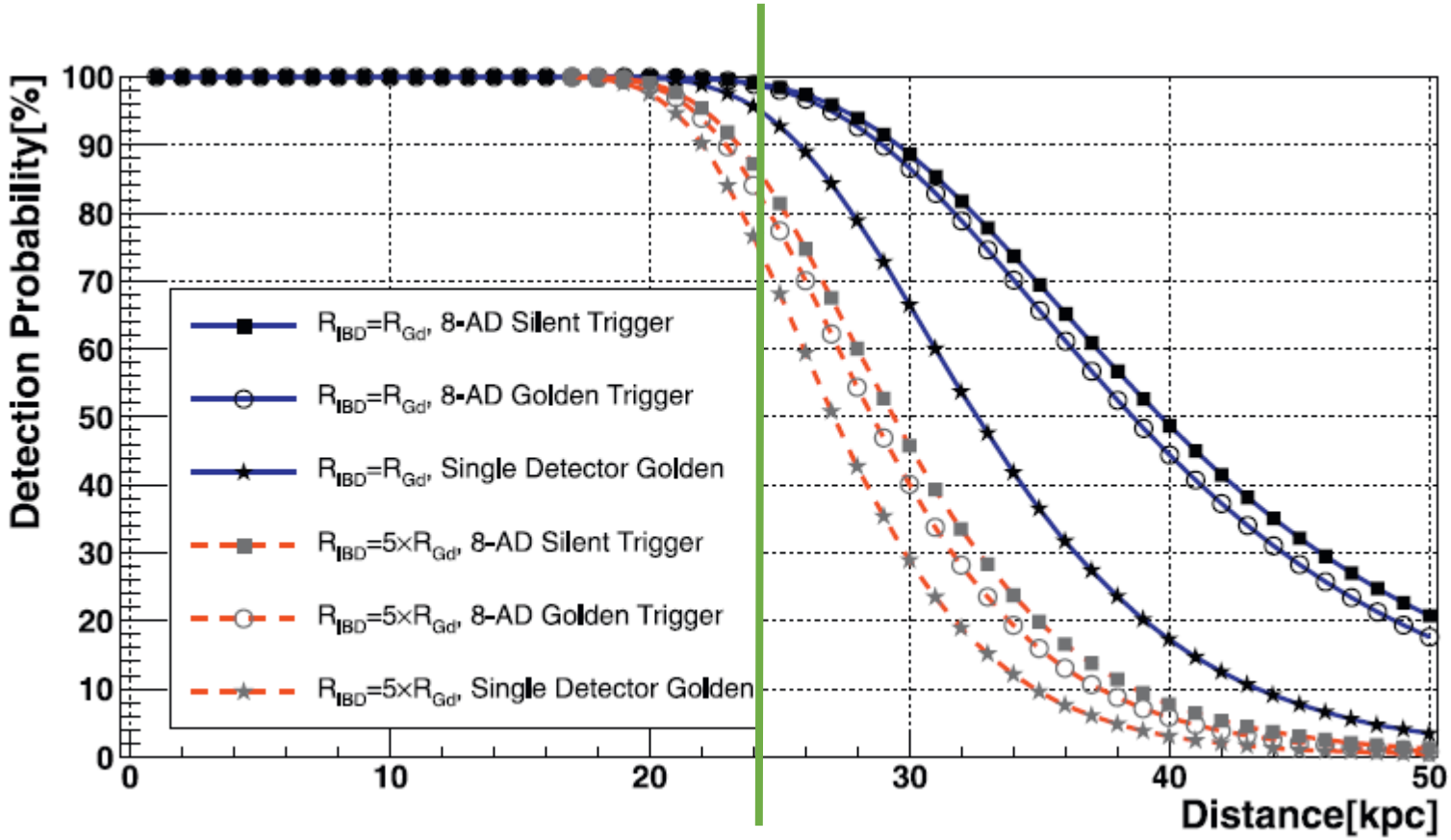
- Expected SNν events (SN1987A-type)

$$N_{\mathrm{AD}} = N_0 \times \frac{L_{\bar{\nu}_e}}{5 \times 10^{52}\mathrm{erg}} \times \left(\frac{10\ \mathrm{kpc}}{D}\right)^2$$

- Within 10 seconds ~98% events
- Single AD efficiency to SNν ~70%
- Determine total detection probability



Daya Bay SNν Trigger Performance



Milky Way Edge (<24kpc)

Summary for Supernova Online Trigger

Function	Performance	Advantage
IBD selection, Combination, Control the false alarm rate	Entire design works smooth and effective.	Low Energy Threshold
		Better Energy Resolution than water
Database, Email Alert, DAQ status cross check	Workload to DAQ: extra 8% for physics run (0.4% data taking time)	Time Accuracy
		Online Detection Probability > 94% within Milky Way
	Time Latency from trigger to alarm ~10s	Equivalent Target Mass ~0.8kt

Thanks.
Questions and comments are welcome.