Supernova Trigger in the Daya Bay Reactor Neutrino Experiment

Hanyu WEI
Center for High Energy Physics
Tsinghua University
(On behalf of Daya Bay Collaboration)

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Outline

- Daya Bay Reactor Neutrino Experiment
- Supernova burst neutrinos
  - Importance
  - Energy & Timing Spectrum
  - Excepted SNν Events
- Daya Bay's supernova online trigger
  - Advantages
  - Work Flow
  - Trigger Strategy
  - Test Run Result
- Sensitivity
- Summary

Detection of Anti-electron-neutrino

- IBD(inverse beta decay)

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

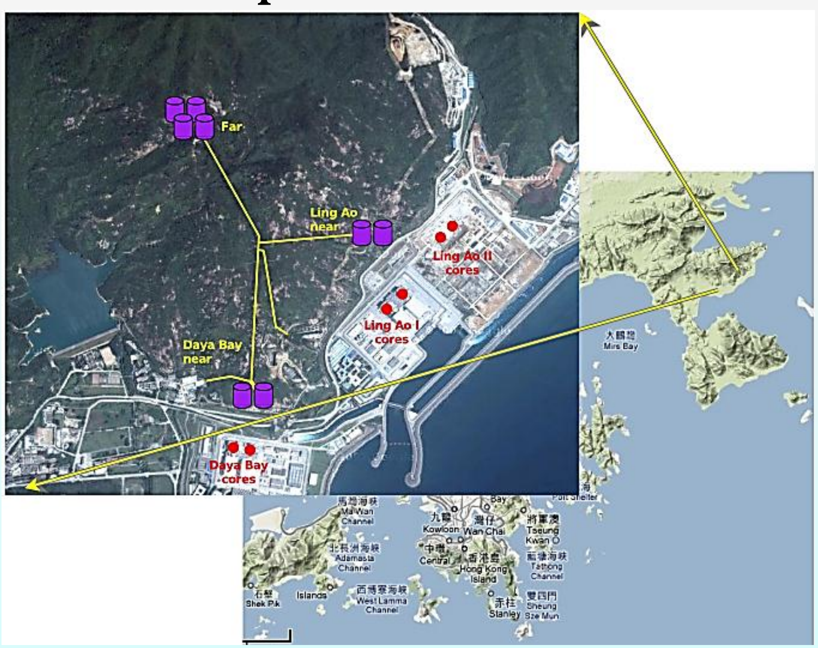
Prompt: e^+ annihilation   Delay: neutron capture

Neutrino events: coincidence in time and energy

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

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

- Three experimental halls

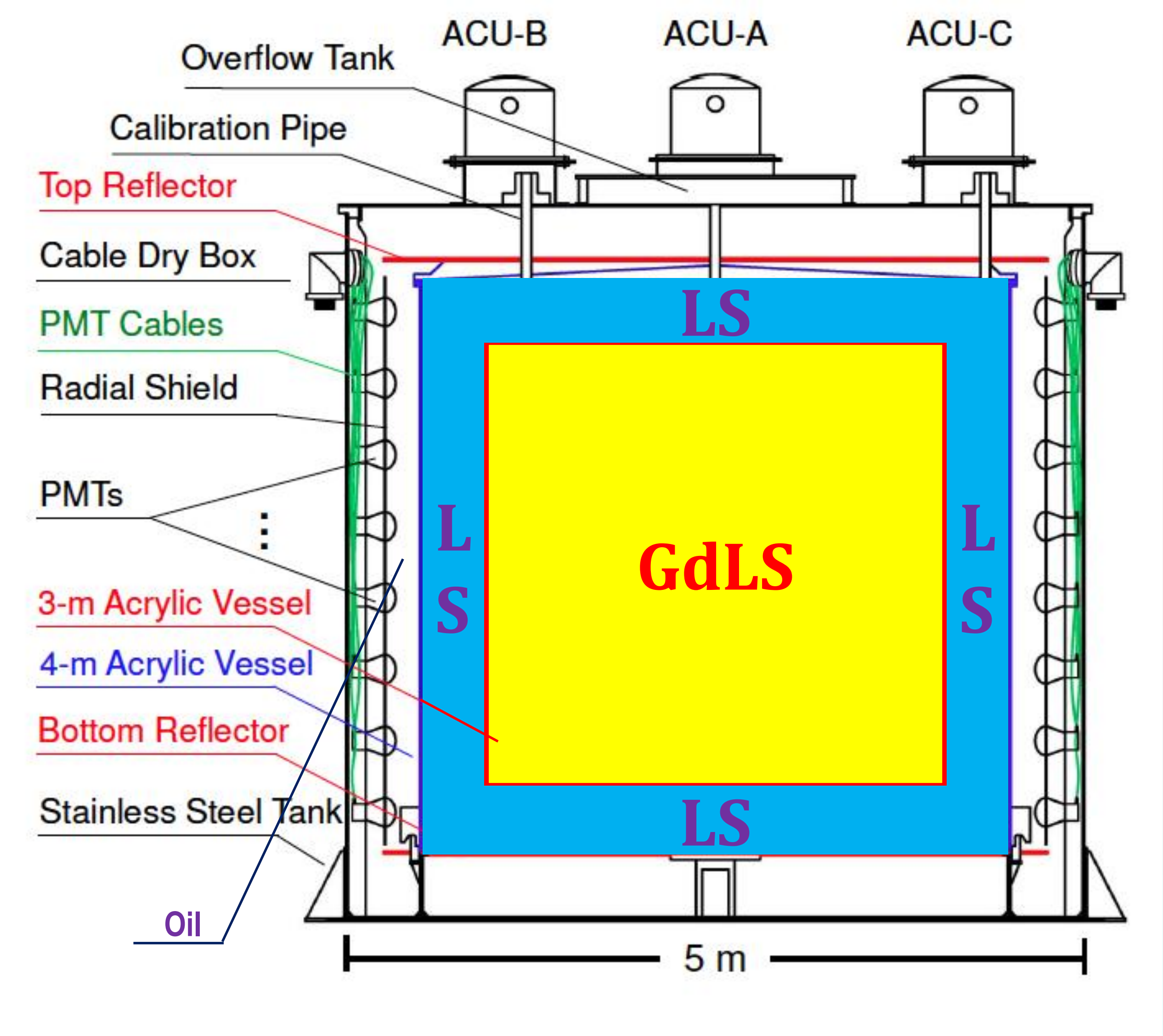


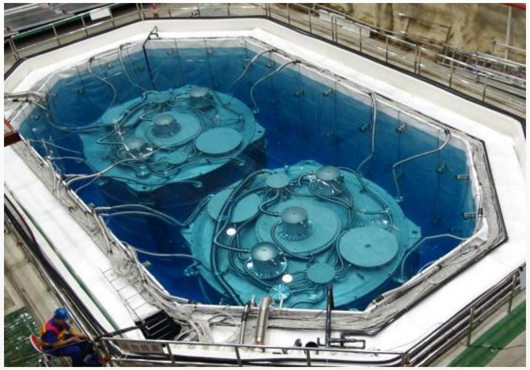
Far
Target mass: 80(Gd) +80(LS) ton
1600m to LA, 1900m to DYB
Overburden: 350m
Muon rate: 0.04Hz/m^2

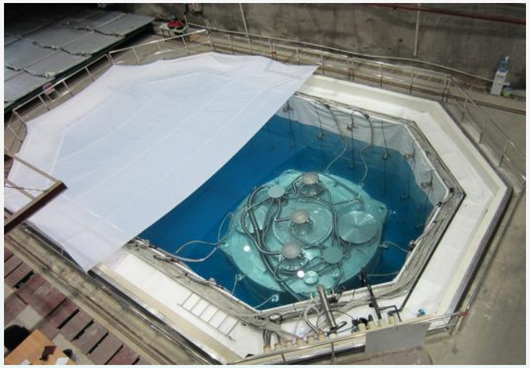
Ling Ao near
Target mass: 40(Gd) +40(LS) ton
Baseline: 500m
Overburden: 112m
Muon rate: 0.73Hz/m^2

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

Anti-electron-neutrino Detector



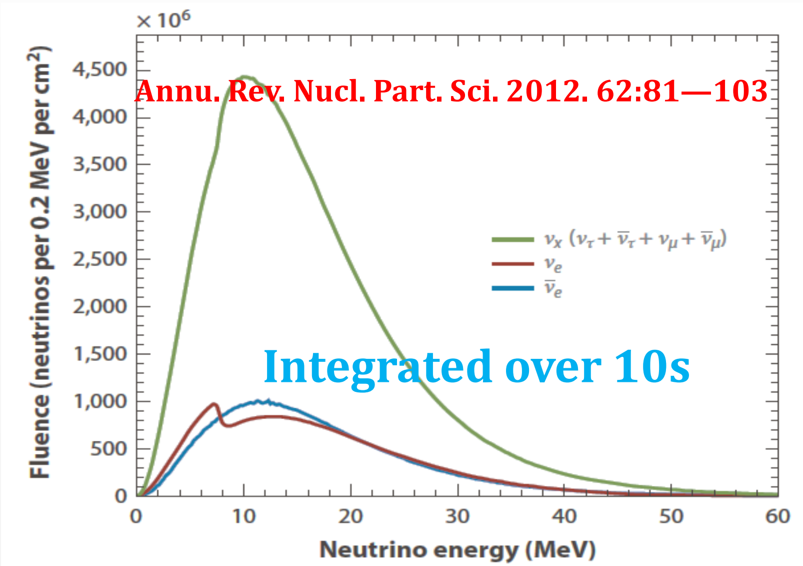


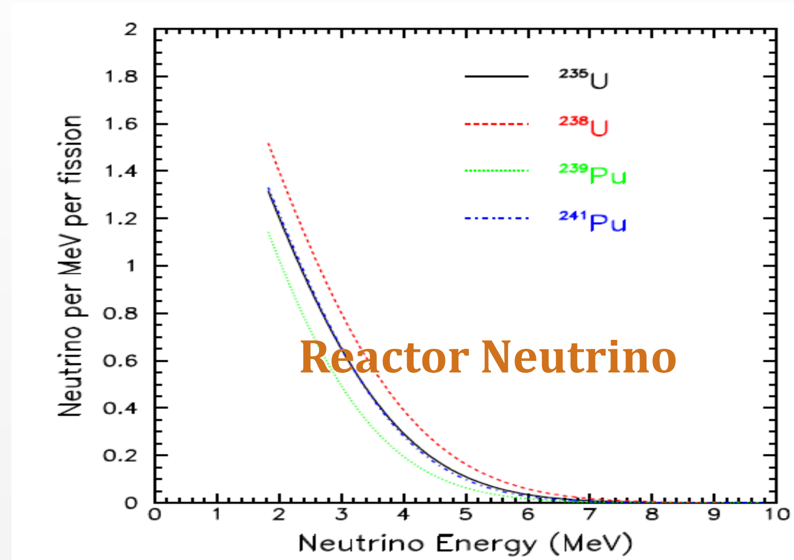


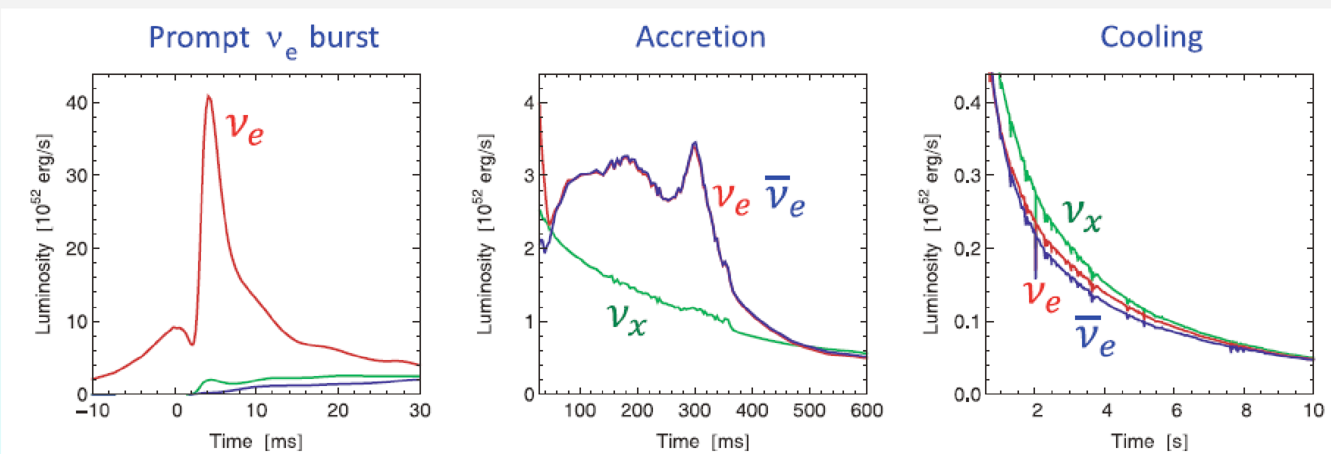
Importance of SNν study

- 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
- ...

SNν Spectra







>95% luminosity within 10s

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

Expected SNν Events

Expected events for a SN at 10kpc (Galaxy Center), emission of 5×10^{52}erg in *anti-eletron-neutrino*, average energy 12MeV, compatible with SN 1987A.

Detector	Type	Location	Mass[kt]	Events	Status
IceCube	Ice Cherenkov	South Pole	0.6/OM	10^6	Running
Super-K IV	Water	Japan	32	7000	Running
LVD	Scintillator	Italy	1	300	Running
KamLAND	Scintillator	Japan	1	300	Running
SNO+	Scintillator	Canada	1	300	Commissioning 2013
MiniBOONE	Scintillator	USA	0.7	200	Running
Daya Bay	**Scintillator**	**China**	**0.32**	**100**	**Running**
Borexino	Scintillator	Italy	0.3	80	Running
BST	Scintillator	Russia	0.2	50	Running
HALO	Lead	Canada	0.079	tens	Almost ready
ICARUS	Liquid argon	Italy	0.6	200	Running

Several tens of neutrinos within 10s
Advantages?

Data from Geoge G. Raffelt, *Neutrinos and the Stars,* arXiv: 1201.1637v2

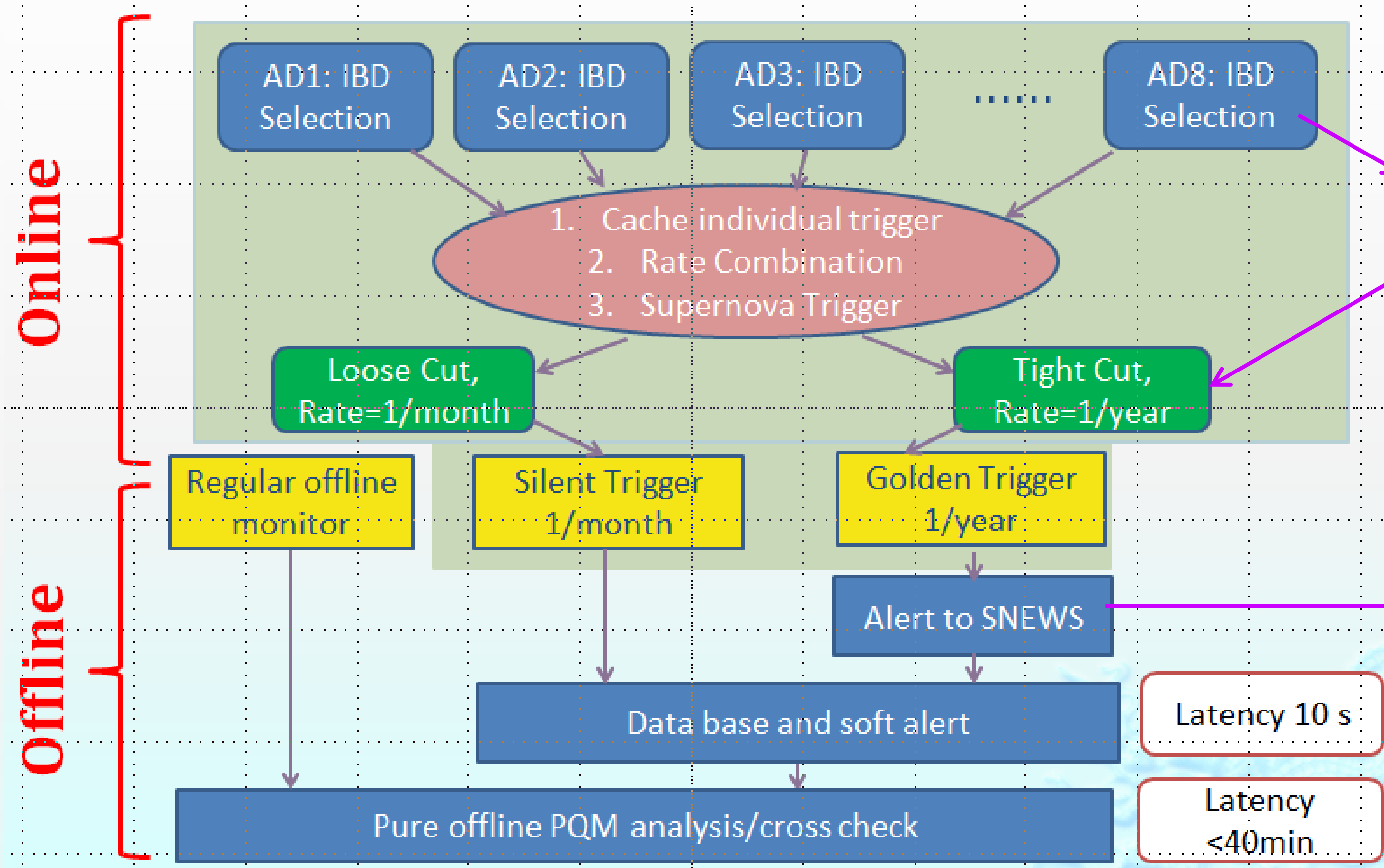
Supernova Online Trigger in DYB

- Better Energy Resolution: ~3% @10MeV
- Time accuracy: **GPS** < 200ns
- Energy Threshold: 0.7MeV (2MeV)
- **Time latency: ~10s**
- **8AD 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

Compared with SK

	Daya Bay	Super-K
Target Mass	0.32kt	22.5 kt; other experiments the same magnitude; the fourth L.S. in the world and increase 10.6%
Energy Resolution	0.3 MeV @10 MeV	1.6MeV@10 MeV
Threshold	0.7 (2) MeV	10 MeV
Powerful Bkg rejection	8 AD deploying in three sites	Other experiment one module or in the same site
Latency	~10s	need complicated reconstruction (exclude spallation neutron) >5min
Sensitivity	100% to 20kpc	100% to 100kpc
Pointing	no	SuperK yes

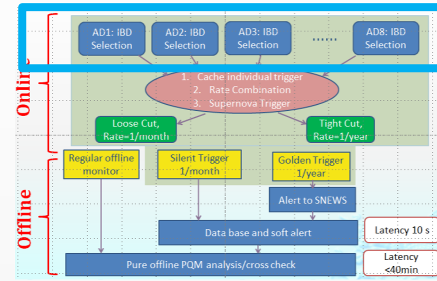
Supernova Online Trigger



Most of the time, selection is background: fast neutron, reactor neutrino …

Daya Bay is online looking for increases in multi-AD signals in a 10s-time-window with low latency.

Online IBD Selection



- An IBD selection program embedded into DAQ
  - Trigger latency ~1s
  - Access to all unpacked raw data
  - Timestamp from GPS
- Selection
  - Simple reconstruction (is different from common offline)
  - Selection cut (optimized using offline reconstructed data)
  - Send IBD candidates to IS (information service of DAQ) server ***promptly***

Criteria for selection:

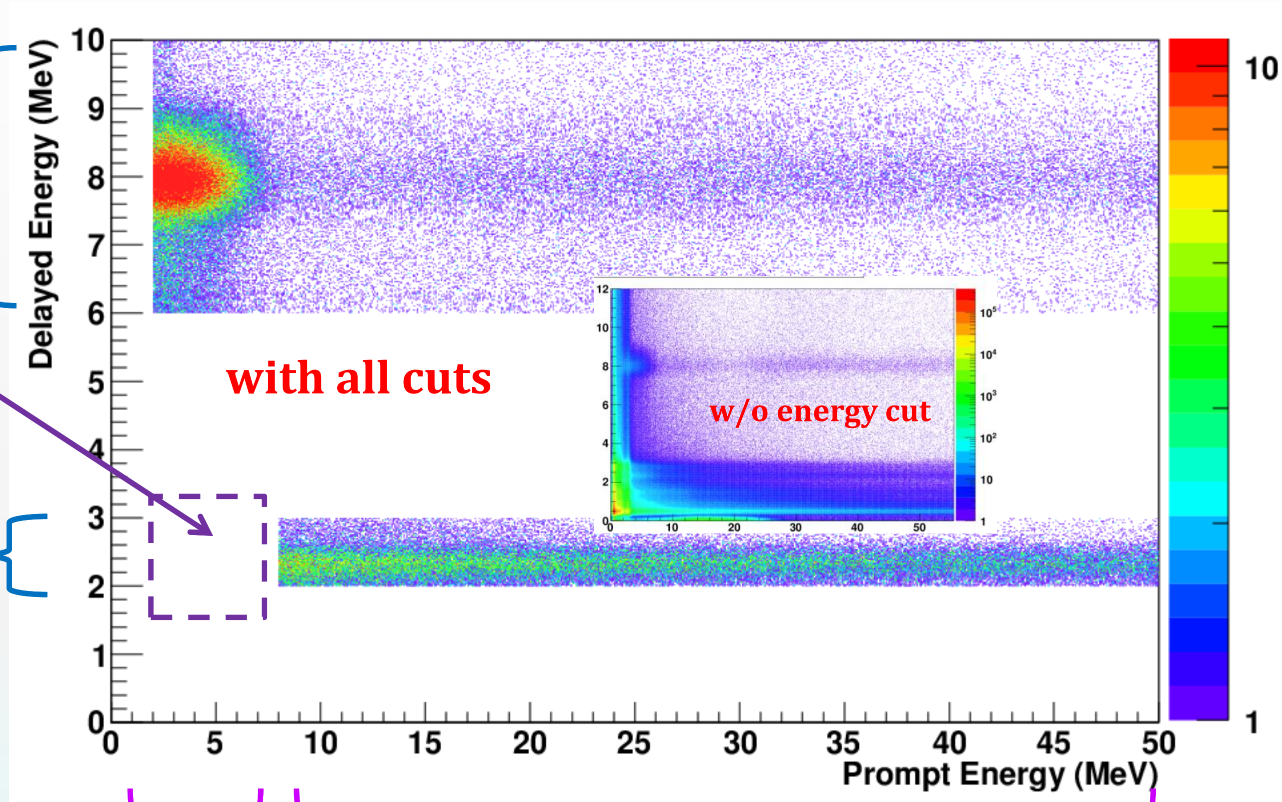
1. **Simple**
2. **Low single AD trigger rate**
3. **High efficiency for SNν**

Selection Result

Gd neutron capture

Acc coincident background

H neutron capture



Reactor Neutrino

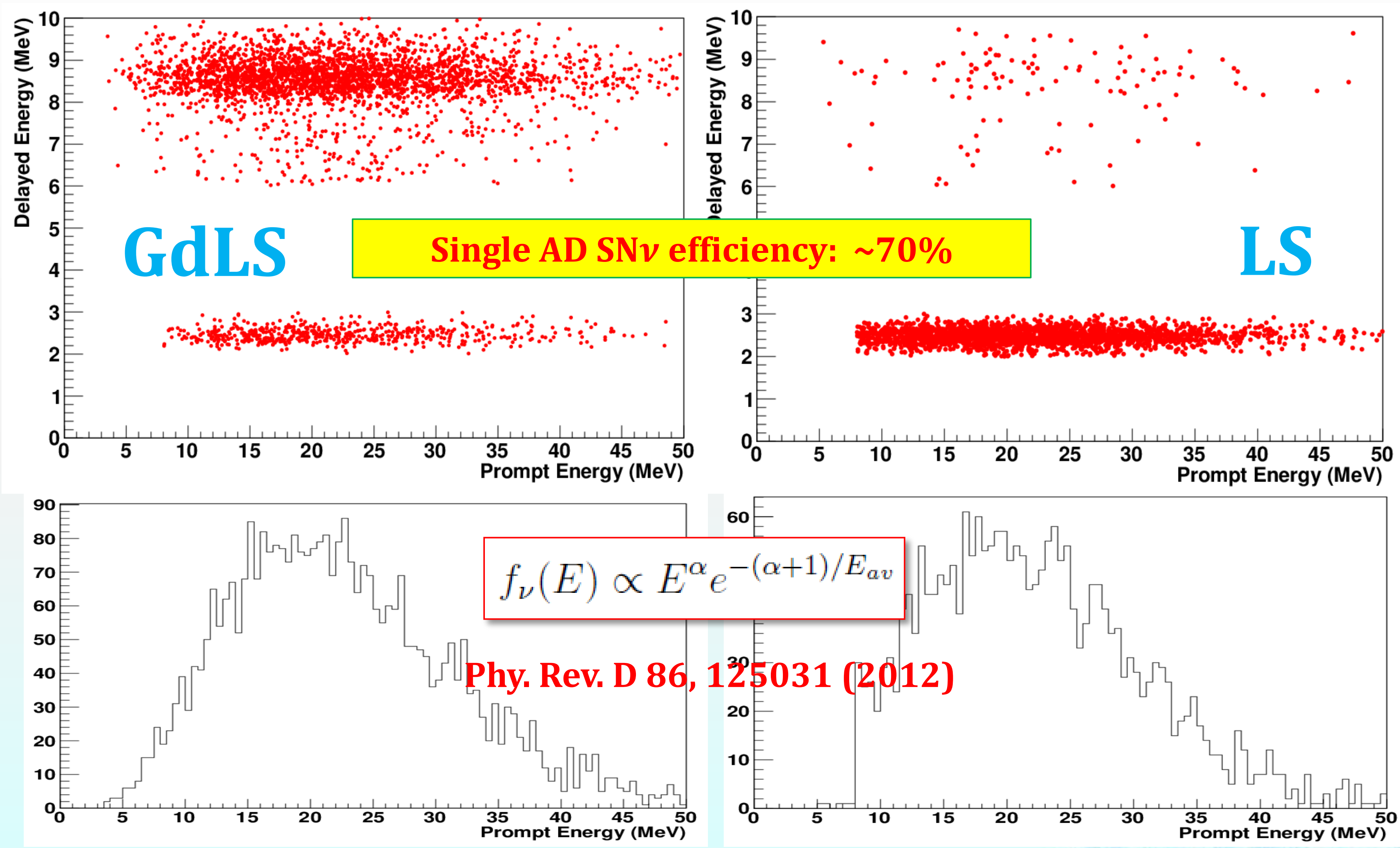
Fast neutron

Selection Cut:

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

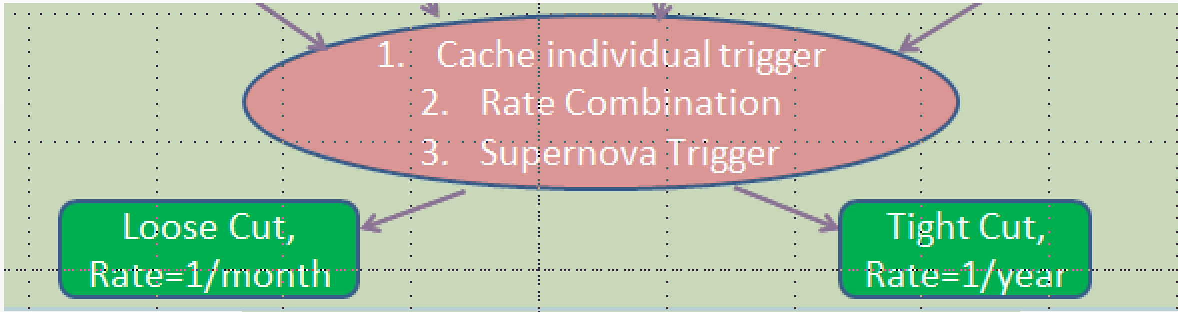
AD trigger rate:
(Near site) DYB ~0.015Hz LA ~0.012Hz
FAR ~0.0012Hz

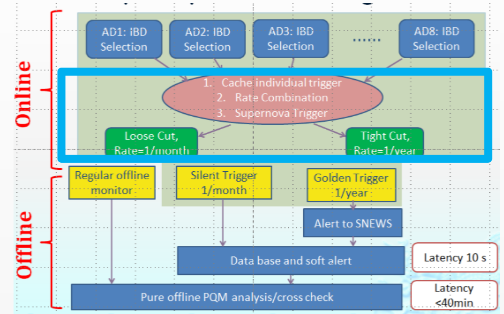
Single AD SNν Selection Efficiency



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

Online Combination and Judgement





1. Cache each AD's IBD selection to supernova trigger server
   - Count the events within 1s for each AD labelled with timestamp
2. 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
3. Judge the supernova trigger
   - Set supernova trigger cut: sets false trigger rate
   - Judge combination case against supernova trigger cut

Trigger Table: combination cases ordered by trigger rate

Trigger Table & Trigger Cut

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

Dataset: All 6-AD data (Dec. 24, 2011 ~ Jul. 28, 2012)

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

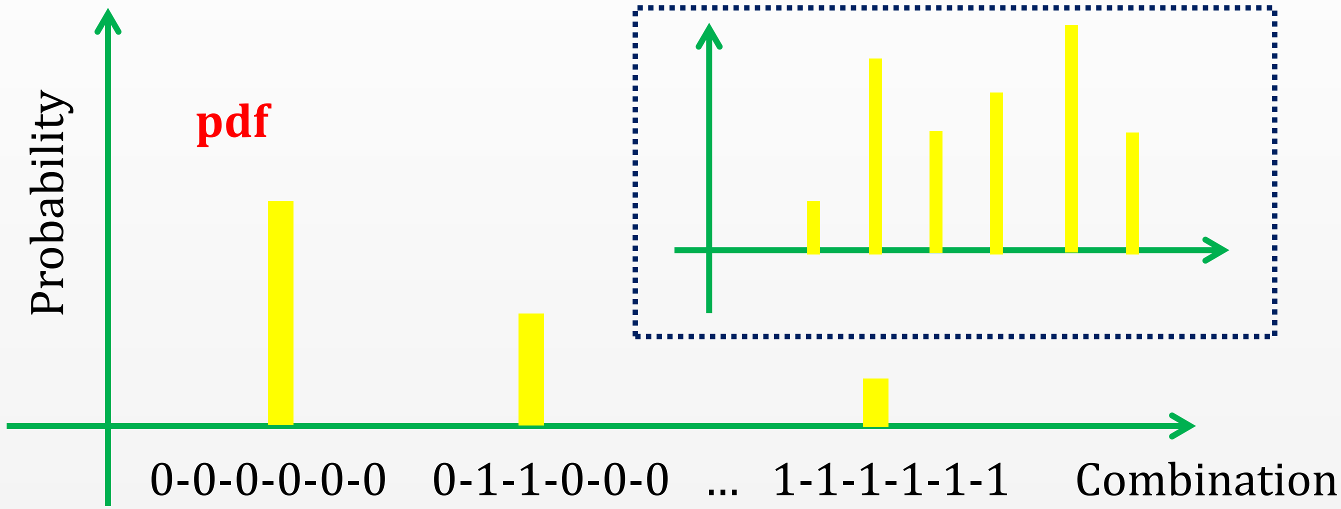
Far site: ~0.0012Hz

A descending order

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

Illustration for Trigger Table & Trigger Cut

1.Enumeration and re-order by probability



2.Set the cut

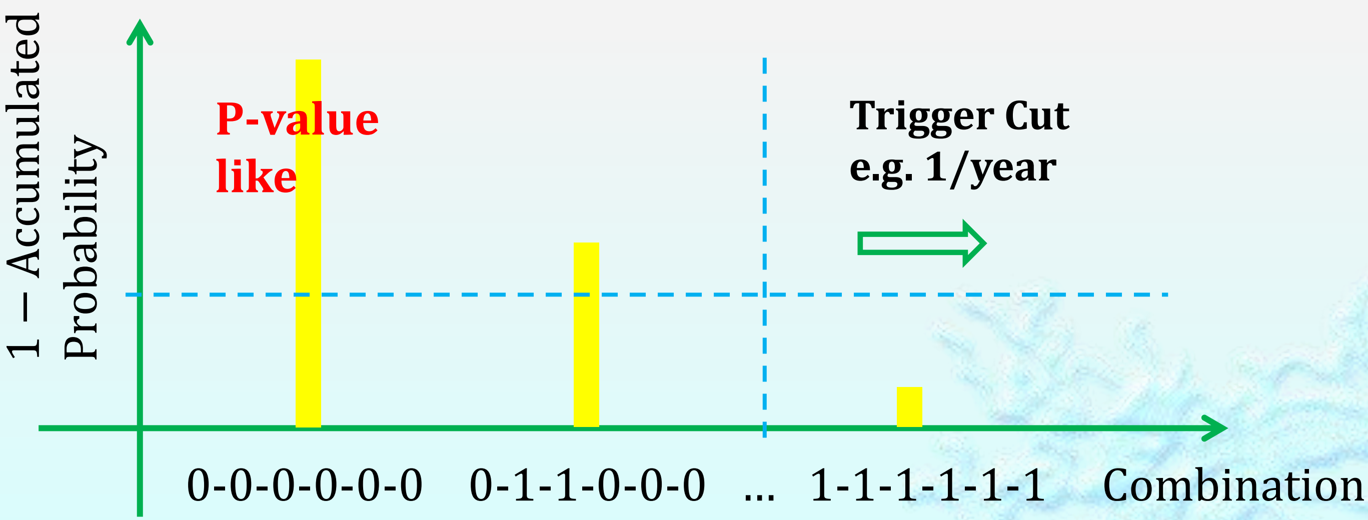
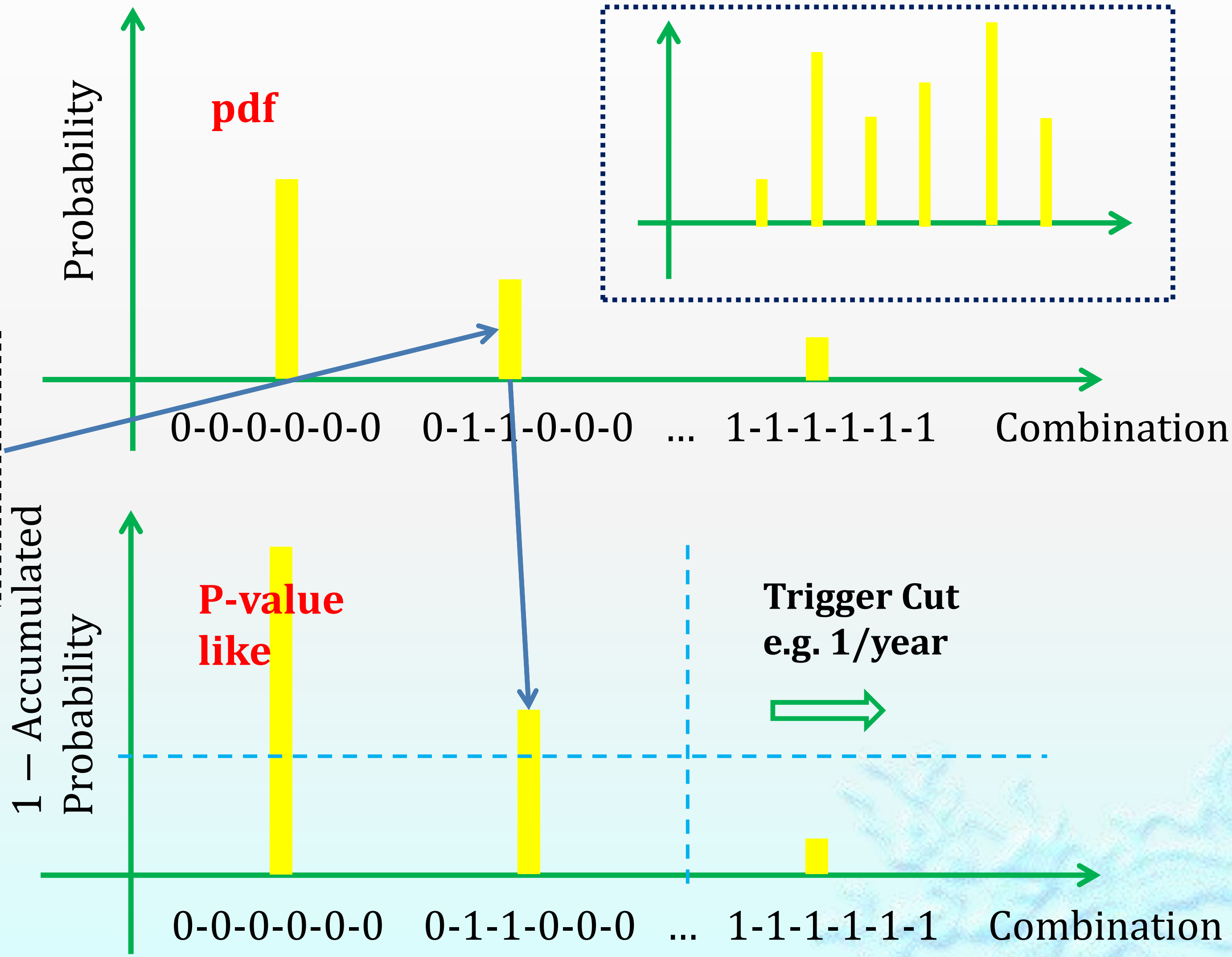


Illustration for Trigger Table & Trigger Cut

1.Enumeration and re-order probability

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

2.Set the cut



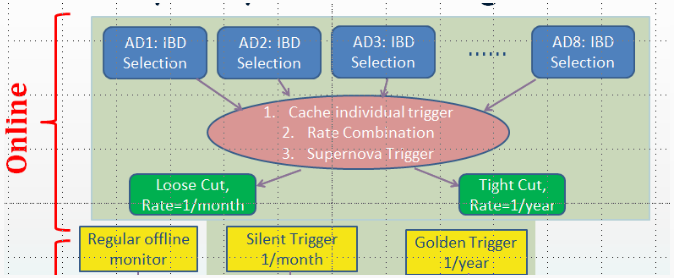
Correlation between ADs

- Advantage of using trigger table instead of theoretical prediction
  - Correlation between ADs
  - Real data, real background

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

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

Test Run Result



- Data Quality Check: Good
- Time consumption:
  - <0.4% of total livetime
  - No block
- Based on previous half year data, the supernova trigger table made a good prediction on false alarm rate.

rate variance

Based on trigger table:
Silent trigger threshold set to 0.373 Hz ± 0.030Hz
Golden trigger threshold set to 0.102 Hz ± 0.014Hz

Real online trigger rate:
Silent: 0.345 Hz
Golden: 0.120 Hz

Real offline trigger rate:
Silent: 0.410Hz
Golden: 0.090Hz

Due to different reconstruction methods online and offline

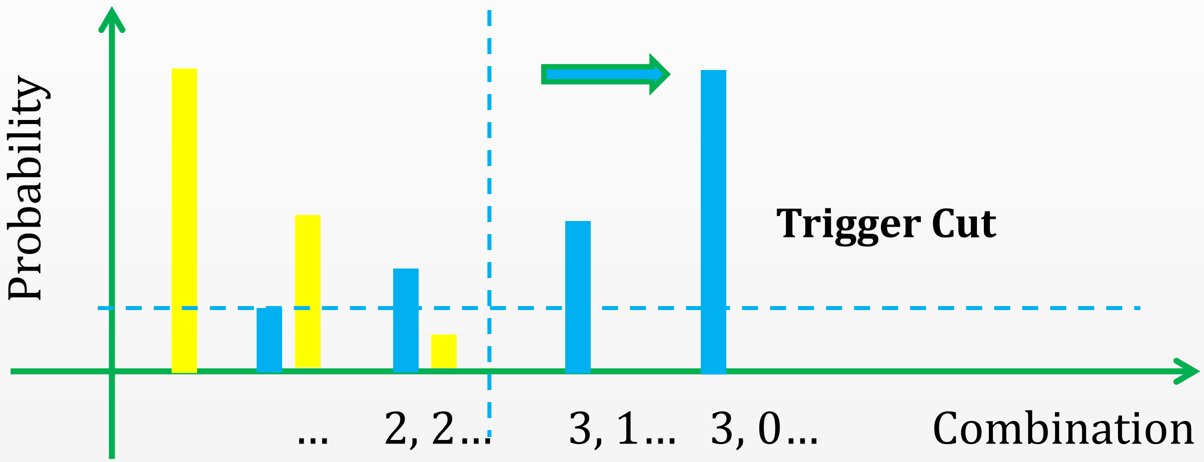
Online Sensitivity

- Expected SNν events (SN1987A-type)

$$F_{\bar{\nu}_e} = 2.18 \times 10^{11} cm^{-2} \frac{L_{\bar{\nu}_e}}{5 \times 10^{52} erg} \frac{12MeV}{E_{av}} (\frac{10kpc}{D})^2$$

- Within 10 seconds ~98% events
- Single AD efficiency to SNν ~70%
- **Trigger Cut**
  - Determined by trigger table
  - Background trigger rate < 1/120days
- Each combination case trigger rate of SN
  - Assuming AD mutually independent
  - Poisson distribution
  - Neglecting relative AD differences <1%

Sensitivity Calculation

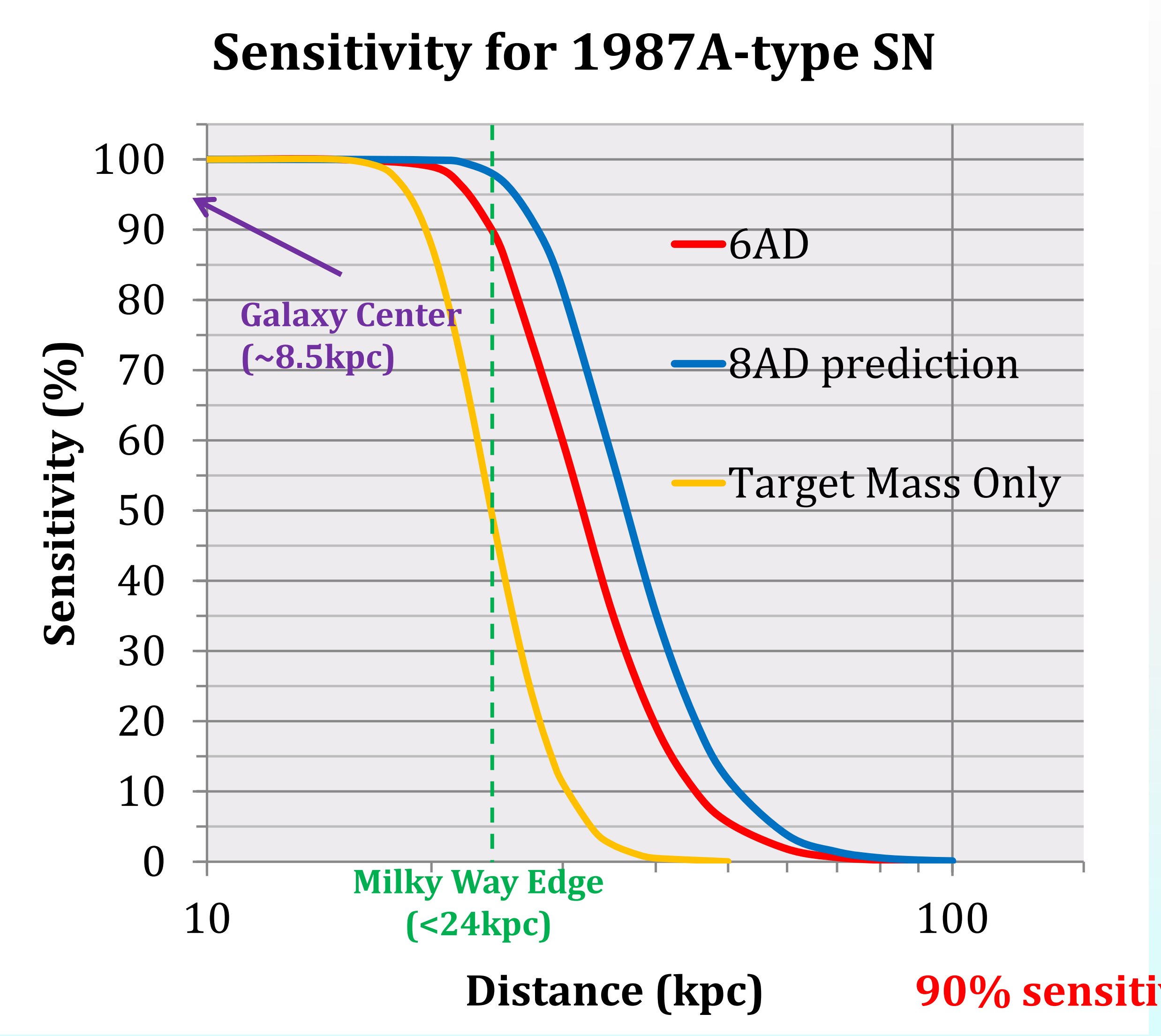


Blue: SN
Yellow: Bkg

- Locate the background in the coordinate axis as before
- For each combination display the SN explosion trigger rate
- Beyond the cut will cause a trigger
  - Sum the probability to get the sensitivity

The sensitivity here is for online supernova early warning system in Daya Bay, not for offline analysis.

Result



Independent variable

Sensitivity function

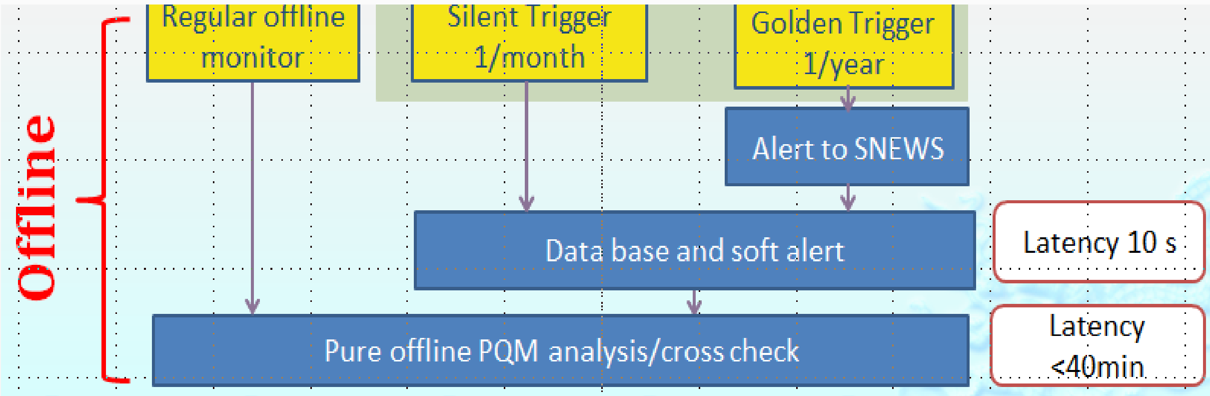
Detector(**M×L/D²**)

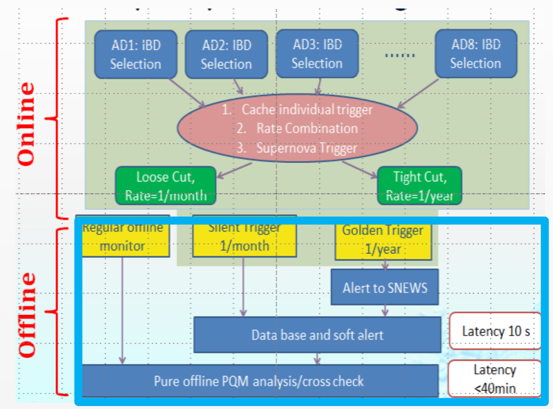
Detector factor: selection cut, efficiency, background, trigger strategy …

6AD: **multi-AD** result
Target Mass Only: Put AD together and just consider the event summation (like **one detector with 6-AD target mass**)
Same trigger cut

90% sensitivity ~ 3.6×10^{-50} kpc²/kt·Erg

Offline Part





- Sending supernova trigger info outside via DIM mechanism to a DIM client
- Alert to SNEWS by mail application
- Auto-write into database
- Regular PQM (Performance Quality Monitoring) cross check

- Coming test run to validate the entire design

Summary

- Daya Bay Reactor Neutrino Experiment has advantages on supernova online trigger
  - Better energy resolution
  - Time accuracy
  - Low energy threshold
  - Low time latency
  - Background suppress with 8AD deployed in 3 sites
- ~100% sensitivity to Galaxy center and ~90% to Milky Way edge with 6-AD data, 8-AD adds ~8% to Milky Way edge.
- Test run preliminarily implies the Daya Bay's supernova online trigger works.
- Daya Bay officially in SNEWS in near future.

Thank you for your attention.