Supernova Trigger in the Daya Bay Reactor Neutrino Experiment

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(On behalf of Daya Bay Collaboration)

ACAT 2013
May 16-21, 2013
Outline

- Daya Bay Reactor Neutrino Experiment
- Supernova burst neutrinos
  - Importance
  - Energy & Timing Spectrum
  - Expected SNv 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)

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

Promt: \(e^+\) annihilation  
Delay: neutron capture  
Neutrino events: coincidence in time and energy

\[
0.3\,\text{b} \quad \rightarrow + p \rightarrow D + \gamma (2.2\,\text{MeV}) \quad (\text{delayed}) \quad 180\mu s
\]

\[
50\,\text{kb} \quad \rightarrow + Gd \rightarrow Gd^* \rightarrow Gd + \gamma's (8\,\text{MeV}) \quad (\text{delayed}) \quad 28\mu s \quad 0.1\%\text{Gd}
\]

- Three experimental halls

**Far**
- Target mass: 80(Gd) + 80(LS) ton
- Baseline: 1600m to LA, 1900m to DYB
- Overburden: 350m
- Muon rate: 0.04Hz/m²

**Daya Bay near**
- Target mass: 40(Gd) + 40(LS) ton
- Baseline: 360m
- Overburden: 98m
- Muon rate: 1.2Hz/m²

**Ling Ao near**
- Target mass: 40(Gd) + 40(LS) ton
- Baseline: 500m
- Overburden: 112m
- Muon rate: 0.73Hz/m²

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Anti-electron-neutrino Detector

Components:
- Overflow Tank
- Calibration Pipe
- Top Reflector
- Cable Dry Box
- PMT Cables
- Radial Shield
- PMTs
- 3-m Acrylic Vessel
- 4-m Acrylic Vessel
- Bottom Reflector
- Stainless Steel Tank
- Oil
- GdLS

Dimensions:
5 m
Importance of SNv study

- SNv 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
  - ...

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**SNν Spectra**

![Graph showing SNν Spectra](image)


**Integrated over 10s**

**Reactor Neutrino**

![Graph showing Reactor Neutrino](image)

**Prompt ν\textsubscript{e} burst**

![Graph showing Prompt ν\textsubscript{e} burst](image)

**Accretion**

![Graph showing Accretion](image)

**Cooling**

![Graph showing Cooling](image)

>95% luminosity within 10s


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**Note:** The images and graphs are placeholders for actual content. The text is formatted to represent the information accurately.
**Expected SNv Events**

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

<table>
<thead>
<tr>
<th>Detector</th>
<th>Type</th>
<th>Location</th>
<th>Mass[kt]</th>
<th>Events</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>IceCube</td>
<td>Ice Cherenkov</td>
<td>South Pole</td>
<td>0.6/OM</td>
<td>$10^6$</td>
<td>Running</td>
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<tr>
<td>Super-K IV</td>
<td>Water</td>
<td>Japan</td>
<td>32</td>
<td>7000</td>
<td>Running</td>
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<tr>
<td>LVD</td>
<td>Scintillator</td>
<td>Italy</td>
<td>1</td>
<td>300</td>
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<tr>
<td>KamLAND</td>
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<td>Japan</td>
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<td><strong>Daya Bay</strong></td>
<td>Scintillator</td>
<td>China</td>
<td>0.32</td>
<td>100</td>
<td>Running</td>
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<td>Borexino</td>
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<td>HALO</td>
<td>Lead</td>
<td>Canada</td>
<td>0.079</td>
<td>tens</td>
<td>Almost ready</td>
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<tr>
<td>ICARUS</td>
<td>Liquid argon</td>
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<td>0.6</td>
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</tr>
</tbody>
</table>

*Data from George 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 the [muon-induced fast neutron background] than one single detector
  - Increase Signal-to-Background ratio, thus increase sensitivity of SN explosion
## Compared with SK

<table>
<thead>
<tr>
<th></th>
<th>Daya Bay</th>
<th>Super-K</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target Mass</strong></td>
<td>0.32 kt</td>
<td>22.5 kt; other experiments the same magnitude; the fourth L.S. in the world and increase 10.6%</td>
</tr>
<tr>
<td><strong>Energy Resolution</strong></td>
<td>0.3 MeV @10 MeV</td>
<td>1.6 MeV@10 MeV</td>
</tr>
<tr>
<td><strong>Threshold</strong></td>
<td>0.7 (2) MeV</td>
<td>10 MeV</td>
</tr>
<tr>
<td><strong>Powerful Bkg rejection</strong></td>
<td>8 AD deploying in three sites</td>
<td>Other experiment one module or in the same site</td>
</tr>
<tr>
<td><strong>Latency</strong></td>
<td>~10s</td>
<td>need complicated reconstruction (exclude spallation neutron) &gt;5min</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>100% to 20kpc</td>
<td>100% to 100kpc</td>
</tr>
<tr>
<td><strong>Pointing</strong></td>
<td>no</td>
<td>SuperK yes</td>
</tr>
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</table>
Daya Bay is **online** looking for increases in multi-AD signals in a 10s-time-window with **low latency**.
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 SNv
Selection Result

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

Gd neutron capture

Acc coincident background

H neutron capture

with all cuts

w/o energy cut

AD trigger rate:
(Near site) DYB ~0.015Hz  LA ~0.012Hz
FAR ~0.0012Hz
Single AD SN$_\nu$ Selection Efficiency

GdLS

Single AD SN$_\nu$ efficiency: ~70%

LS

\[ f_\nu(E) \propto E^\alpha e^{-\frac{(\alpha+1)}{E_{av}}} \]

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)

<p>| | | | | | | | | | |</p>
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<tbody>
<tr>
<td>AD1</td>
<td>AD2</td>
<td>AD3</td>
<td>AD4</td>
<td>AD5</td>
<td>AD6</td>
<td>SUM</td>
<td>COUNT</td>
<td>RATE(Hz)</td>
<td></td>
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<td>-----</td>
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<td>0</td>
<td>2</td>
<td>75527</td>
<td>0.00461788</td>
<td></td>
</tr>
</tbody>
</table>

**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**

This cut: 1 - 0.897 = 0.103Hz  
~1/10s
Illustration for Trigger Table & Trigger Cut

1. Enumeration and re-order by probability

2. Set the cut

PDF

1 - Accumulated Probability

P-value like

Trigger Cut e.g. 1/year

Combination

Combination
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

- $pdf$
- $P$-value like
- Trigger Cut e.g. 1/year
Correlation between ADs

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

<table>
<thead>
<tr>
<th>Correlation</th>
<th>AD1</th>
<th>AD2</th>
<th>AD3</th>
<th>AD4</th>
<th>AD5</th>
<th>AD6</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD1</td>
<td>1</td>
<td>0.0027</td>
<td>0.0007</td>
<td>-0.0003</td>
<td>-0.0002</td>
<td>0.0002</td>
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<td>AD2</td>
<td>-</td>
<td>1</td>
<td>0.0007</td>
<td>-0.0004</td>
<td>0.0003</td>
<td>-0.0002</td>
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<td>AD3</td>
<td>-</td>
<td>-</td>
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<td>0.0002</td>
<td>-0.0002</td>
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<td>AD4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>0.0009</td>
<td>0.0007</td>
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<tr>
<td>AD5</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>1</td>
<td>0.0011</td>
</tr>
<tr>
<td>AD6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

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.

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 SN\(\nu\) events (SN1987A-type)
  \[
  F_{\bar{\nu}_e} = 2.18 \times 10^{11} \text{cm}^{-2} \frac{L_{\bar{\nu}_e}}{5 \times 10^{52} \text{erg}} \frac{12 \text{MeV}}{E_{av}} \left(\frac{10 \text{kpc}}{D}\right)^2
  \]

- Within 10 seconds \(~98\%\) events

- Single AD efficiency to SN\(\nu\) \(~70\%\)

- **Trigger Cut**
  - Determined by trigger table
  - Background trigger rate < 1/120 days

- Each combination case trigger rate of SN
  - Assuming AD mutually independent
  - Poisson distribution
  - Neglecting relative AD differences <1\%
Sensitivity Calculation

- 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

Sensitivity for 1987A-type SN

- **6AD**
- **8AD prediction**
- **Target Mass Only**

Galaxy Center (~8.5 kpc)
Milky Way Edge (<24 kpc)

90% sensitivity ~ $3.6 \times 10^{-50} \text{ kpc}^2/\text{kt} \cdot \text{Erg}$

**Independent variable**

**Sensitivity function**
Detector $(M \times L/D^2)$

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
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.