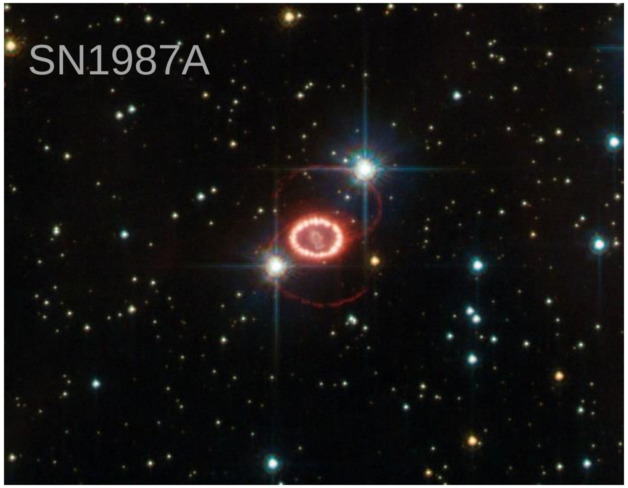
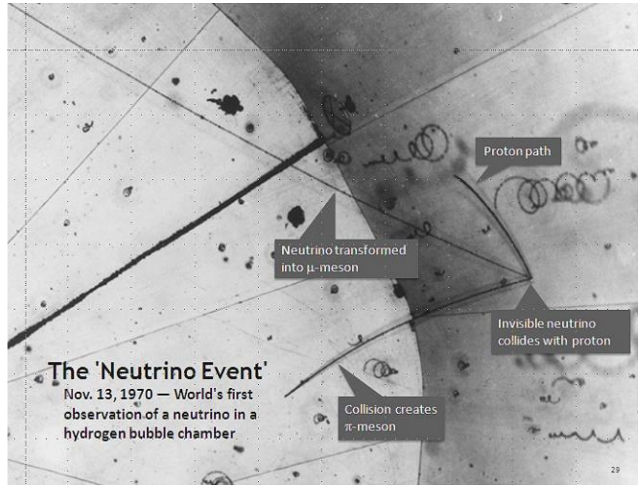
CJPL

Neutrino Experiment





Supernova Burst Neutrinos at Jinping

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Outline

- Introduction
- Supernova Burst Neutrinos (SNν)
  - Energy & Timing spectra
  - Identification and expected number of SNν
- Online Searching for Supernova Neutrino Burst
  - IBD signature and selection efficiency
  - Trigger strategy
  - Implementation (Daya Bay as an example)
  - Pointing capability
  - Detection probability
- Discussion & Summary

Introduction I

- SNν is important in studying supernova dynamics
  - ~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 physics
  - Oscillation
  - Mass hierarchy
  - Matter effect
  - …
- Contribute to astrophysics and cosmology
- Joint analysis with gravitational wave experiment
- …

Introduction II

- Jinping
  - Low cosmogenic backgrounds
  - Low reactor $\bar{\nu}_e$ neutrinos
  - Possible multiple detectors
  - Water-based liquid scintillator (WbLS)

- Sensitive to Supernova Burst Neutrinos
  - Online trigger (early warning, join SNEWS ?)
  - Offline analysis

Supernova Burst Neutrinos

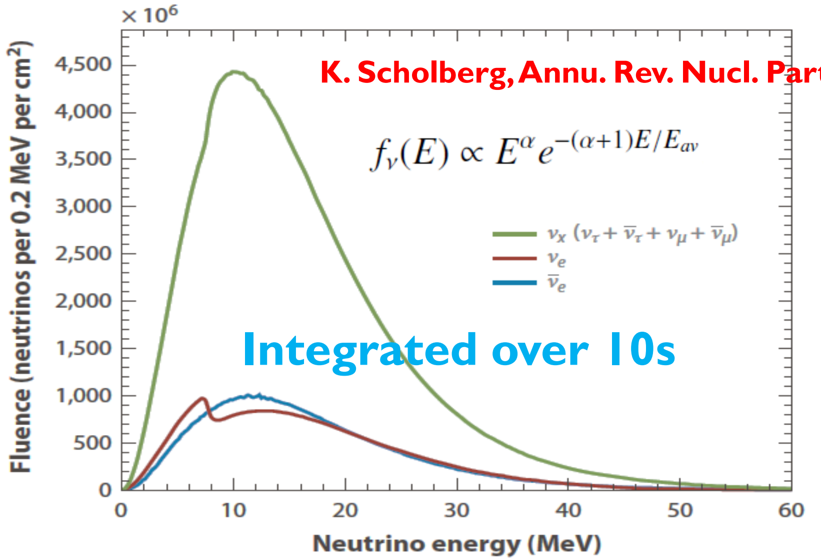
1987A-type in this slides:

Eav ~12 MeV

luminosity ~3×10^{53} erg (1/6 in the form of $\bar{\nu}_e$)

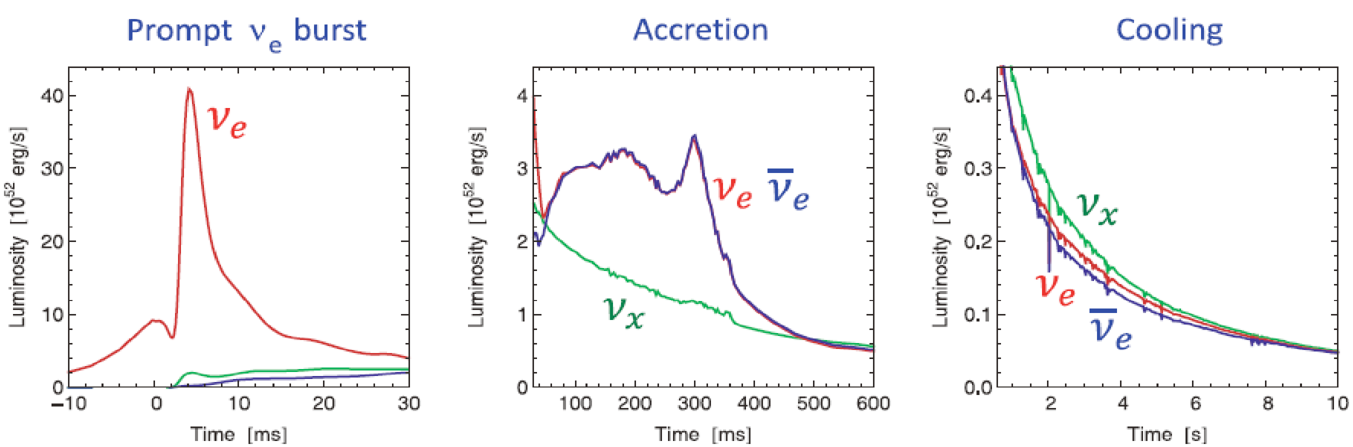
…

Energy and Timing Spectra



K. Scholberg, Annu. Rev. Nucl. Part. Sci. 2012. 62:81—103

Backgrounds (quite low rate):
<10 MeV: reactor/geo $\bar{\nu}_e$, Li9/He8, fast neutron
>10 MeV: atmospheric neutrinos



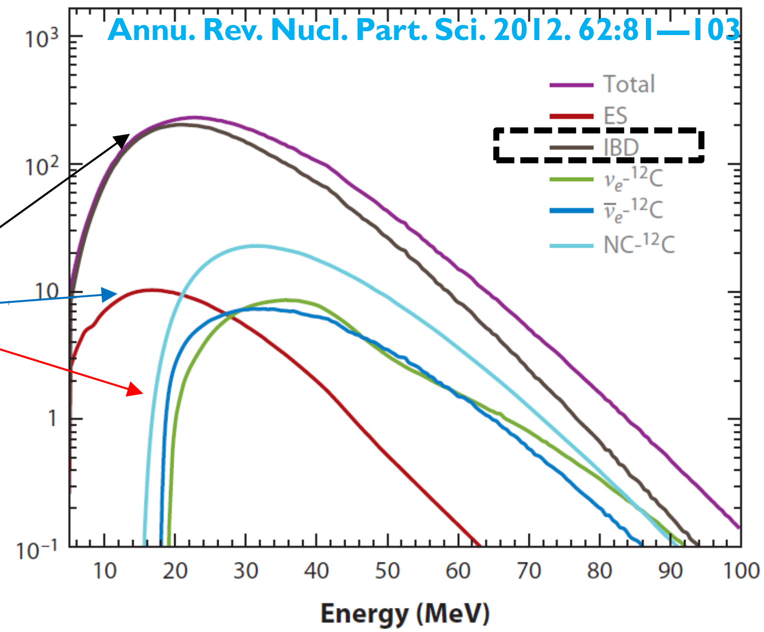
Almost 100% luminosity within 10s

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

Identification and expected number of SNν

- SNν identified primarily through IBD interactions in liquid scintillator

Why IBD?
1. Magnitude
2. Prompt-delayed coincidence
3. Energy threshold



SNν events for different reaction channels

- 1kt WbLS. ~300 SNν events through IBD at 10 kpc
  - N ∝ L(luminosity)/D(distance)^2, N should be corrected with selection efficiency and muon veto efficiency, etc for realistic calculation

Experiments in SNEWS

- SNEWS (Supernova Early Warning System)
  - Collaborate worldwide experiments sensitive to SNν, to provide the astronomical community with a very high-confidence early warning

Detector	Type	Location	Mass (kt)	N_{IBD}	E_{th} (MeV)	
IceCube	*L.S. Ch.	Antarctic	0.6/PMT	N/A	-	
Super-K	Water Ch.	Japan	32	7000	7.0	Pointing
LVD	Scint.	Italy	1	300	4.0	
KamLAND	Scint.	Japan	1	300	0.35	
Borexino	Scint.	Italy	0.3	100	0.2	
Daya Bay	†M.S. Scint.	China	0.33	110	0.7	

* Long-String Cherenkov † Multiple-Site Scintillator

  - What about Jinping (Wb)LS?

Pointing capability:

✓ Result from the Cherenkov light of electron of neutrino-electron scattering

✓ Pointing powerful telescopes or facilities to the SN event

Online Searching for Supernova Neutrino Bursts

Search for any IBD signal increase in a single or multiple detectors within sliding 10-second windows

Three 'P's:
- Positive
- Prompt
- Pointing

IBD signature and selection efficiency

- $\bar{\nu}_e + \mathrm{p} \rightarrow e^+ + n$
  - Prompt signal: positron kinetic energy (scintillation plus a few percent Cherenkov) and annihilation (2×0.511-MeV γ's)
  - Delayed signal: $n + H \rightarrow D + \gamma$ (2.2 MeV, ~200us)

- Efficiency (~50%) based on Daya Bay nH study:
  - Prompt energy cut (10-50 MeV): 88%
  - Delayed energy cut (peak in 3σ): 67.4% (conservative)
  - Time-coincidence cut (400 us): 84.6%
  - Vertex distance cut (1000 mm): ~98%

Trigger Strategy (1 or 2 1.5kt detector)

- Low background rate (1.5 kt (Wb-) liquid scint.)
  - 10-50MeV: <1/yr (refer to SRN background estimation)
  - 10-second window: ~ZERO

- For one single detector, trigger: ≥ 2 IBD signals in 10s
- For two detectors, trigger: ≥ 2 IBD signals in total in 10s
  - Non-trigger: (0,0), (0,1), (1,0)
  - Uniformity check (a χ^2 cut) assuming SNν uniformly distributed in detectors to suppress non-astrophysical bursts (e.g. electronic noise)

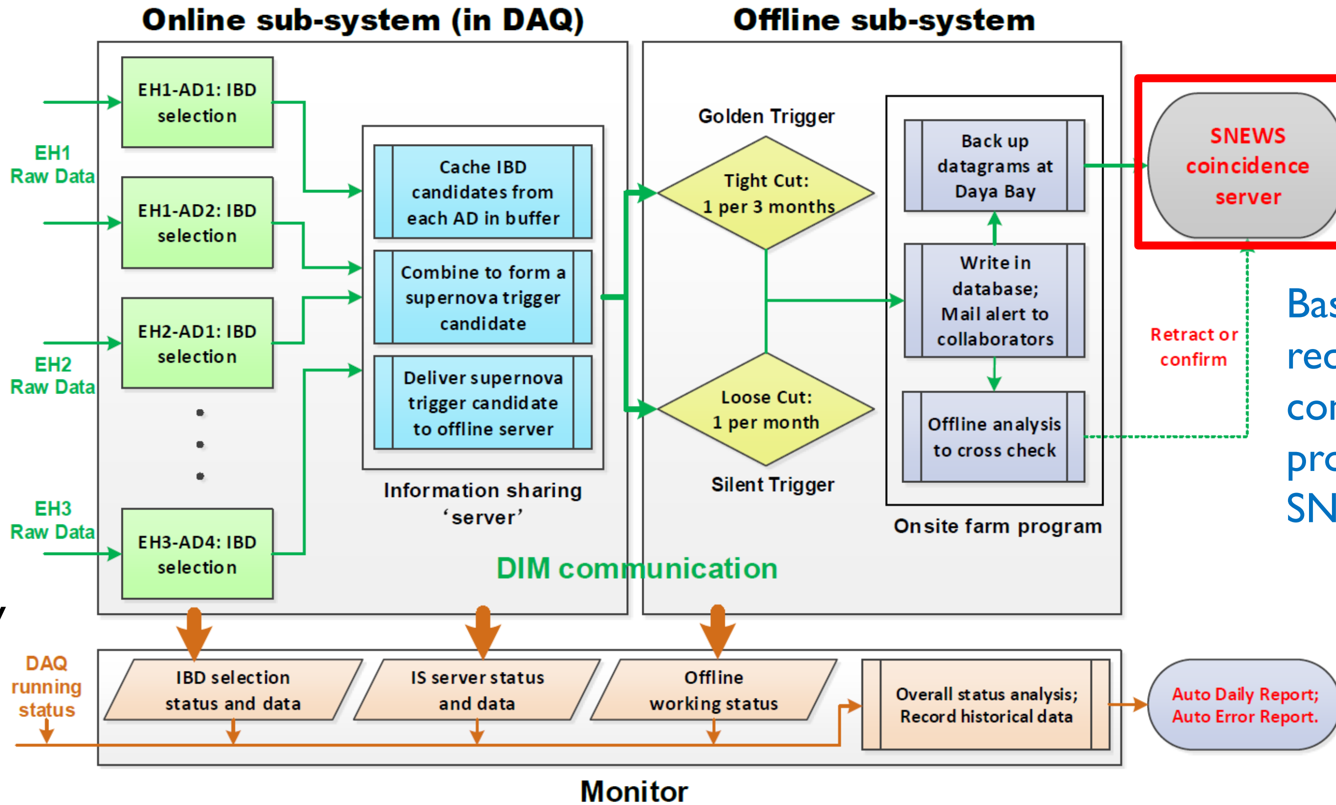
Note:
1. The background coincidence rate surviving the trigger strategy can be calculated precisely
2. The trigger strategy can be tuned due to a background coincidence rate threshold
3. The correlation between two detectors can be well handled

Positive

Implementation (Daya Bay arXiv.1505.02501)

Prompt (<10s)

1. No complicated event reconstruction
2. Simple trigger strategy



Based on the requiring communication protocol by SNEWS (tarball)

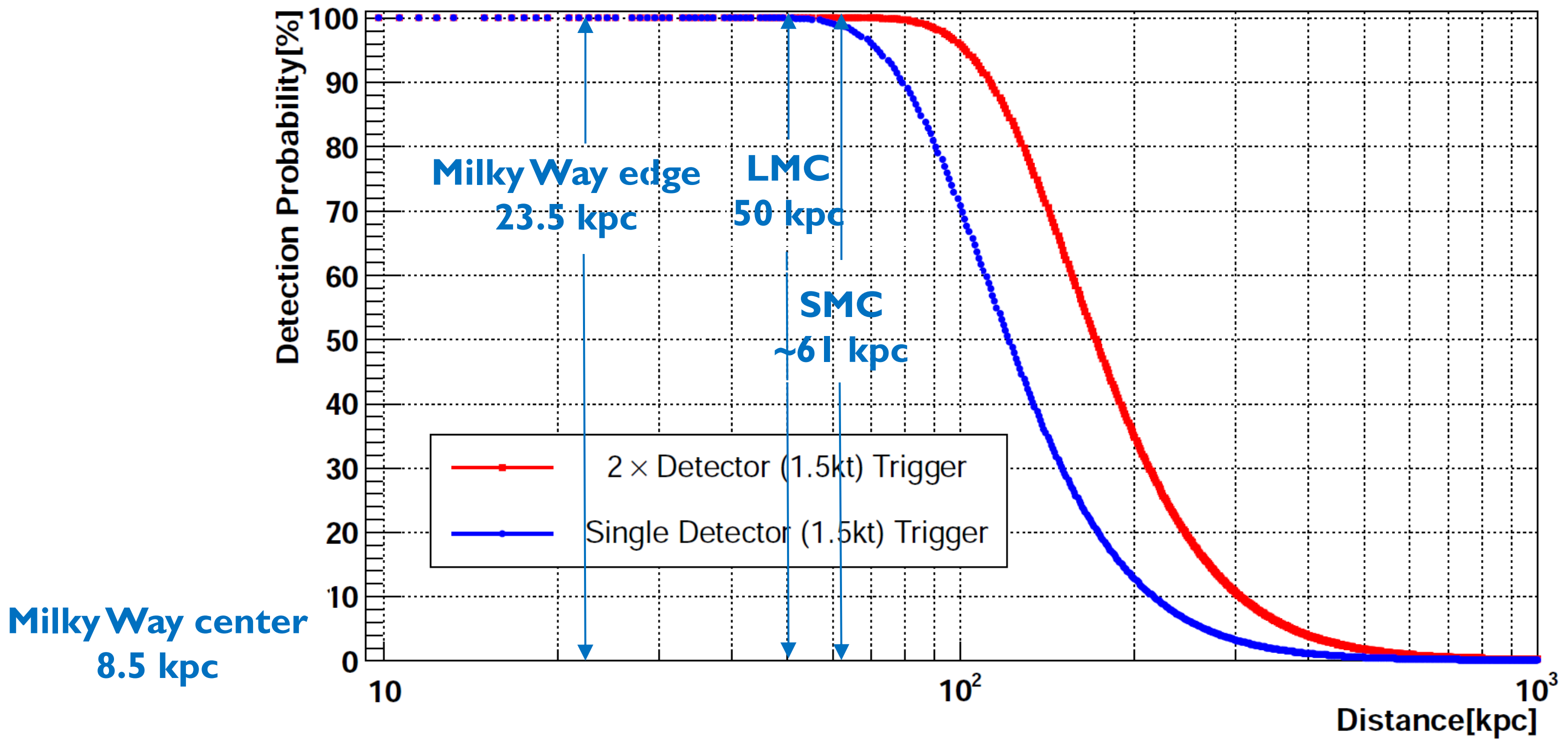
- Embedded in the existing DAQ
- Software-based trigger system (information sharing, DIM communication, etc.)
- Basic on-site computation sources

Pointing capability

- Water-based liquid scint. (3 kt)
  - Cherenkov light
  - Neutrino-electron scattering → pointing capability (only SK now)
  - With ~40% total PMT coverage, the angular resolution for a 1987A-type supernova burst at Milky Way center is ~4°.
    - Larger target mass/PMT coverage will improve the angular resolution by larger stats.
    - Size of single PMT should not be too large which geometrically determines the lower bound of angular resolution.

Detection probability

- Sum the probabilities of the triggers surviving the trigger strategy



- The 2nd best across the world (SuperK: 100% to 100 kpc)
  - Benefit mainly from quite low background rate

Discussion

- Optimize IBD selection (efficiency) to achieve better detection prob.
  - A larger selection efficiency (~80% even more)
- Small target mass: 2×1.5 kt = 3.0 kt (SuperK: 22.5 kt)
- Low energy threshold < 1MeV (Wb-)LS
  - Sensitive to full SNν spectrum
    - Various models
    - Red shift (large impact on Mpc distance SN bursts), Eav may change from 12 to 6 MeV
- Multiple small detectors
  - Due to deep rock cover
  - Robust against backgrounds (benefit trigger strategy)

Discussion (Cont'd)

- Offline analysis prospect
  - live time ?
  - quite low background
  - Inspiring detection probability
  - low energy threshold
  - Identify different flavors of SNν from other channels (~10%)
    - WbLS particle identification

Summary

- Jinping is a competitive laboratory to set up online supernova trigger based on (Wb-)liquid scintillator.
  - Positive and Prompt and Pointing
  - Only one to satisfy the three 'P's ?
- Only a few kt (Wb-)LS can reach the best detection probability of supernova neutrino bursts.
- Most likely to have one of the lowest energy threshold for supernova burst neutrino detection and an excellent ν-flavor identification ?