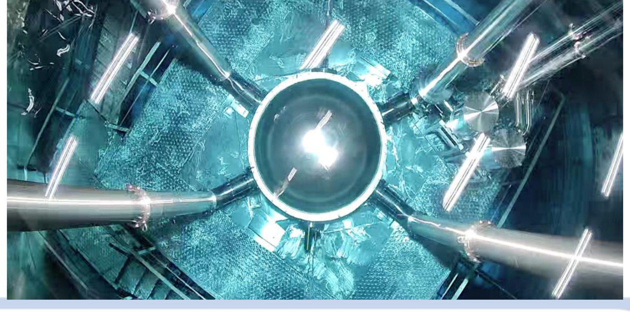

Detecting neutrinos from supernova bursts in PandaX-4T

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1. Introduction

First/only observation of supernova (SN) neutrinos from 1987A.

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Core-collapse SN explosion:

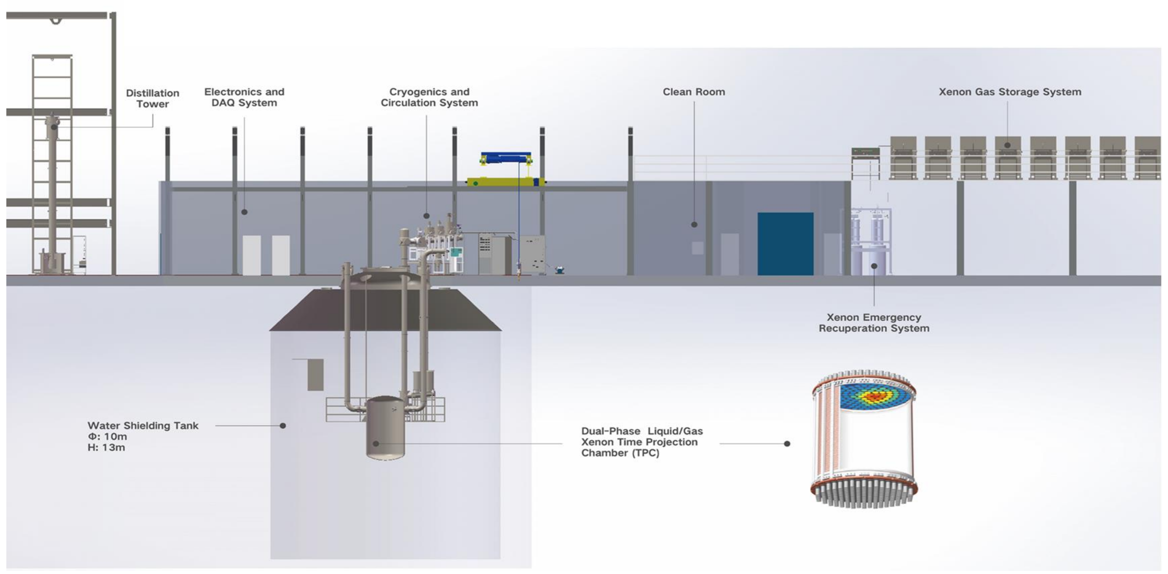
- Approximately three times per century in Milky Way
- Last for ~10 s
- Total energy ~10^{53} erg

Start of neutrino astronomy!

- **Neutrinos arrive on earth much earlier than electromagnetic radiation.**
- **Supernova early warning can be provided for the astronomical community.**

2. PandaX-4T experiment

Dual-phase xenon time projection chamber (TPC) technique to detect dark matter and neutrino.
Locate in Jinping Underground laboratory in China with 2400m o-verburden.



- Sensitive volume: 3.7 tonne liquid xenon
- 3-inch PMTs: 169 top / 199 bottom
- Good discrimination of electron recoil/nuclear recoil
- 3D position reconstruction

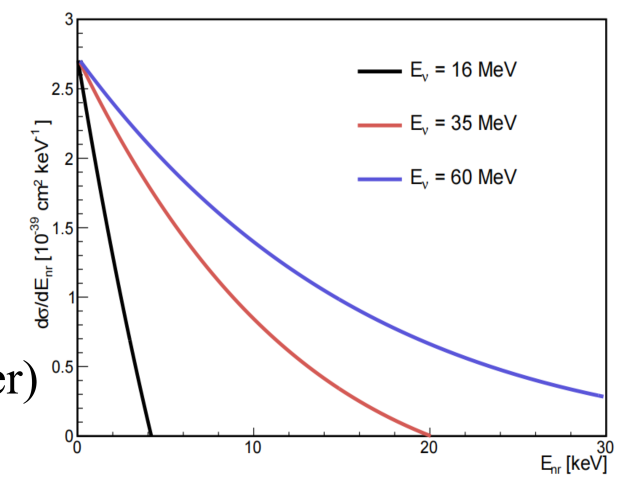
3. Detection of SN neutrinos at PandaX-4T

- **Coherent elastic neutrino-nucleus scattering(CEνNS):**

$$\nu + \text{nucleus} \rightarrow \nu + \text{nucleus}$$

The differential cross section of the CEνNS :

$$\frac{d\sigma}{E_{NR}}(E_\nu, E_{NR}) = \frac{G_F^2 m_A}{4\pi} Q_w^2 \left(1 - \frac{m_A E_{NR}}{2E_\nu^2}\right) \times F^2(q)\Theta(E_{max} - E_{NR})$$

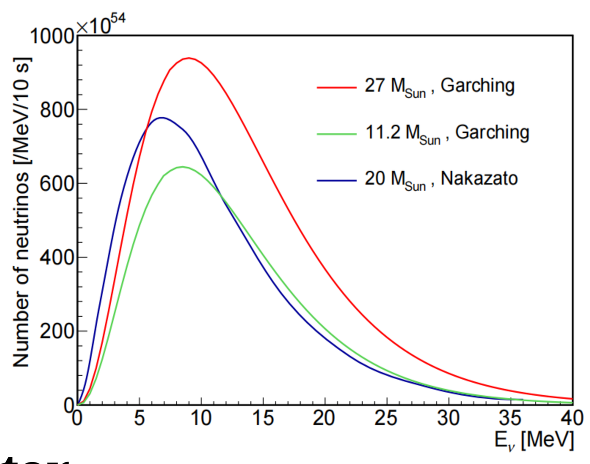


- Sensitive to all neutrino flavors
- $\propto N^2$ (N represents the neutron number)

- **Energy spectrum of SN neutrinos**

For Garching model, it can be characterized using Keil-Raffelt-Janka (KRJ) parametrization:

$$\frac{dF(E_\nu, t_{pb})}{dE_\nu} = \sum_{\nu=1}^{6} L_\nu(t_{pb}) \frac{(1+\gamma(t_{pb}))^{1+\gamma(t_{pb})}}{\langle E_\nu(t_{pb})\rangle^2 \Gamma(1+\gamma(t_{pb}))} \times \left(\frac{E_\nu}{\langle E_\nu(t_{pb})\rangle}\right)^{\gamma(t_{pb})} \exp\left[-\frac{(\gamma+1)E_\nu}{\langle E_\nu(t_{pb})\rangle}\right]$$



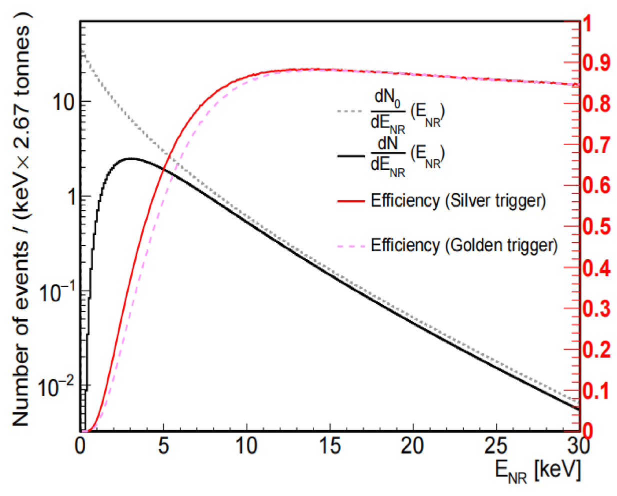
- **Siganl spectrum in liquid xenon detector**

The differential event rate :

$$\frac{dN_0}{dE_{NR}}(E_{NR}) = \frac{m_{det} N_A}{M_A(4\pi D^2)} \int_{E_\nu^{min}}^{\infty} \frac{d\sigma}{dE_{NR}}(E_\nu, E_{NR}) \times f(E_\nu) dE_\nu$$

Considering the detection efficiency:

$$\frac{dN}{dE_{NR}}(E_{NR}) = \epsilon(E_{NR}) \times \frac{dN_0}{dE_{NR}}(E_{NR})$$



The red and pink lines indicate efficiency.

Golden trigger : False alert rate is once a month.

Silver trigger : False alert rate is once a week.

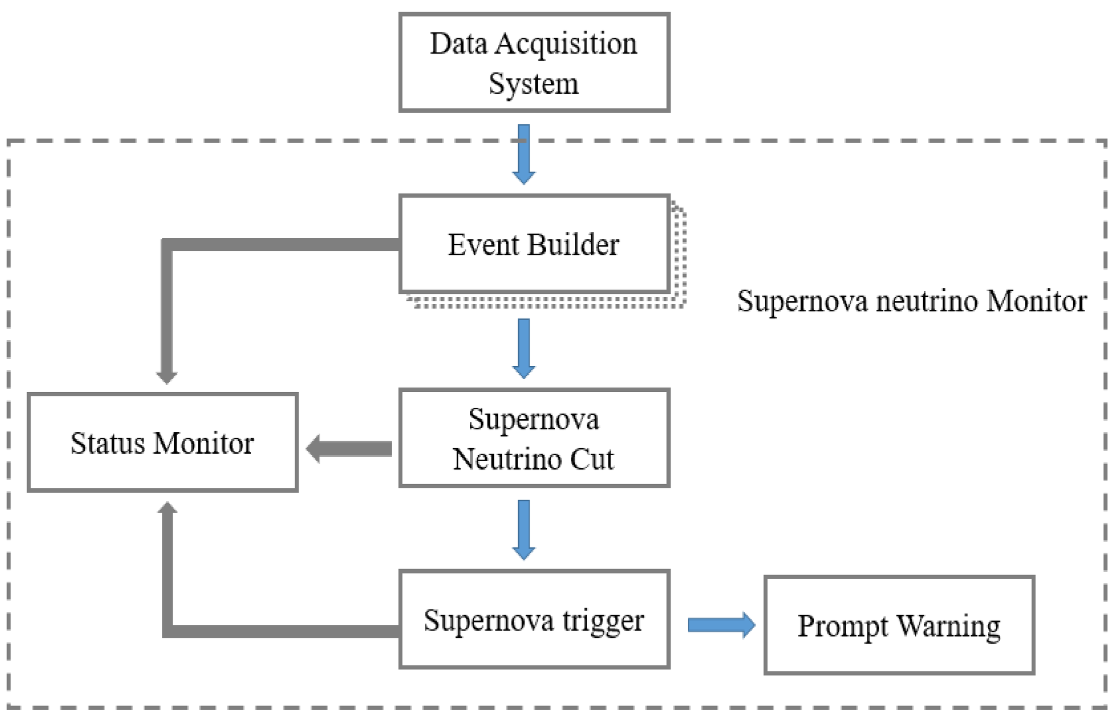
4. SN off-line trigger system of PandaX-4T

Level 1: Preliminary filter to build event.

Level 2: Apply data quality selection to reduce background.

Level 3: The trigger algorithm to search alarm signal.

The entire process takes several minutes for each individual file on average.



5. Estimation of false alert rate & trigger efficiency

- Trigger probability:

$$p(N_{thr}; T_{SN}; r) = 1 - \sum_{n=0}^{N_{thr}-1} \frac{1}{n!} e^{-rT_{SN}} (rT_{SN})^n$$

- The false alert rate per week:

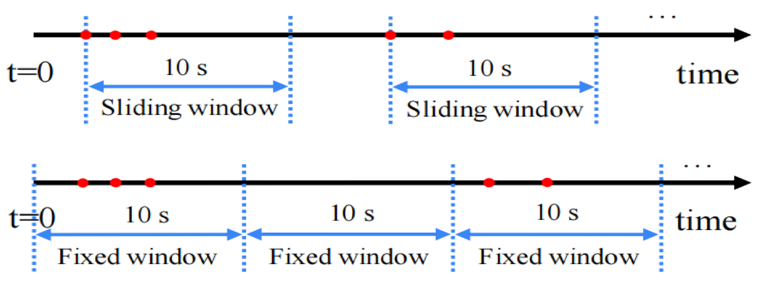
$$R_{false} = \frac{3600 \cdot 24 \cdot 7}{T_{SN}} p(N_{thr}; T_{SN}; r_{bg})$$

The background is nearly negligible.

- The signal trigger efficiency:

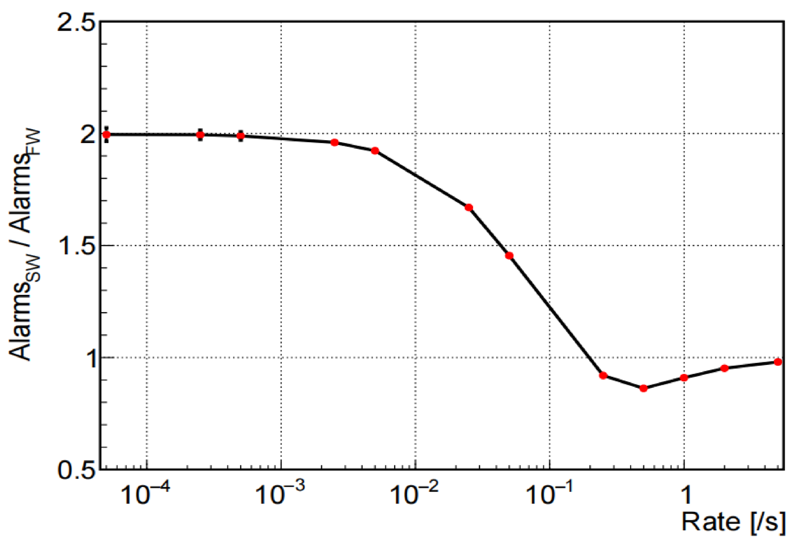
$$\epsilon = p(N_{thr}; T_{SN}; r_{SN})$$

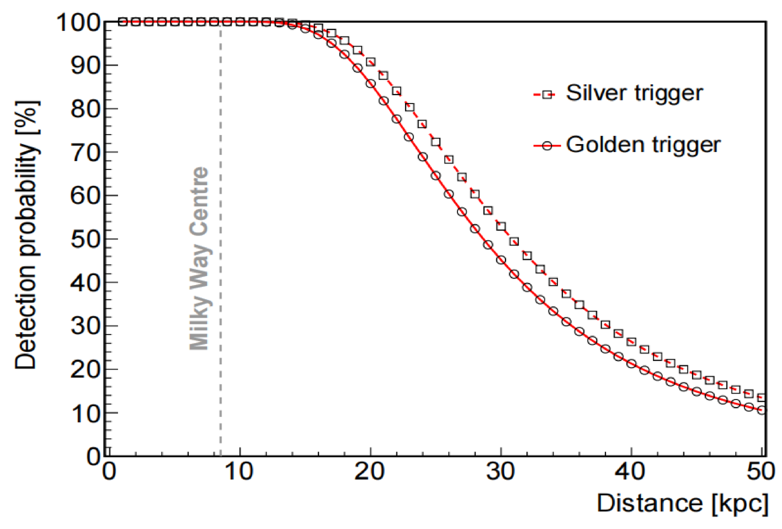
- **~100% probability@10 kpc**
- **678.2 per century on the rate of core-collapse SN explosion in our galaxy out to 10 kpc**



Data type	Rate [/s]	Calendar time	Observed	Expected
DD	3.61×10^{-3}	3.58 days	40	38
AmBe	3.12×10^{-3}	5.7 days	49	46
Physical	3.6×10^{-4}	86.1 days	8	9.8

SN model	Golden alarm		Silver alarm	
	D=10 kpc	168 pc	10 kpc	168 pc
20 $M_\odot$ Nakazato	7.2	2.6×10^4	8.3	2.9×10^4
11.2 $M_\odot$ Garching	6.6	2.3×10^4	7.7	2.7×10^4
27 $M_\odot$ Garching	13.7	4.9×10^4	15.9	5.7×10^4





6. Future prospects

- The relevant electronics is being designed.
- Pandax-4T will apply to join SuperNova Early Warning System (SNEWS).
- PandaX-xT (~40-tonne liquid xenon) has been proposed.

References

[1] Phys. Rev. D 79(8), 083013 (2009)
[2] Astrophys.J. 909 (2021) 2, 169