Supernova Neutrino

Detection with LHAASO-MD

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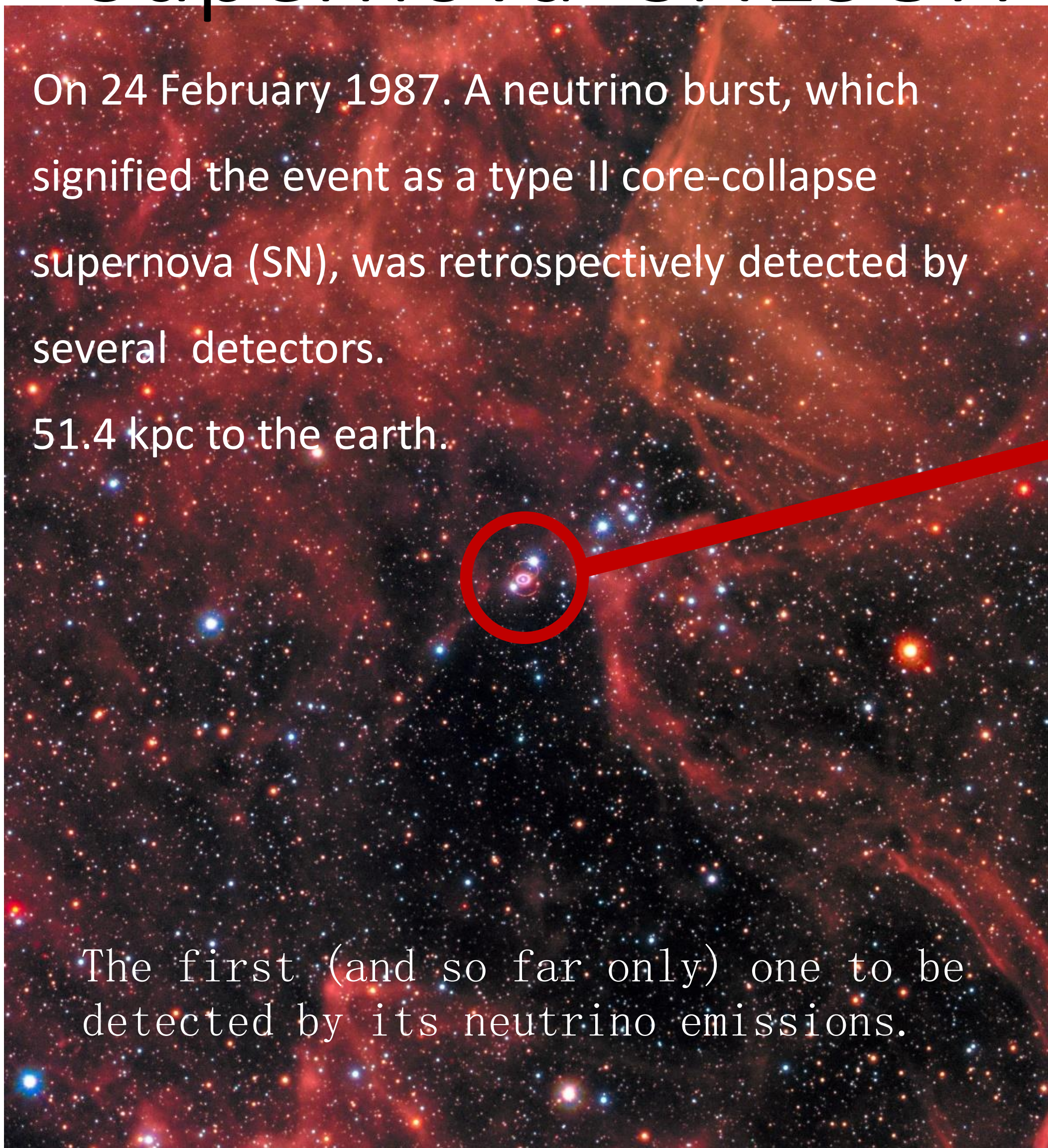
Outline

- Supernova neutrino detection
- Compare LHAASO-MD with other experiments
- LHAASO-MD simulation and data
- Significance estimation
- Summary

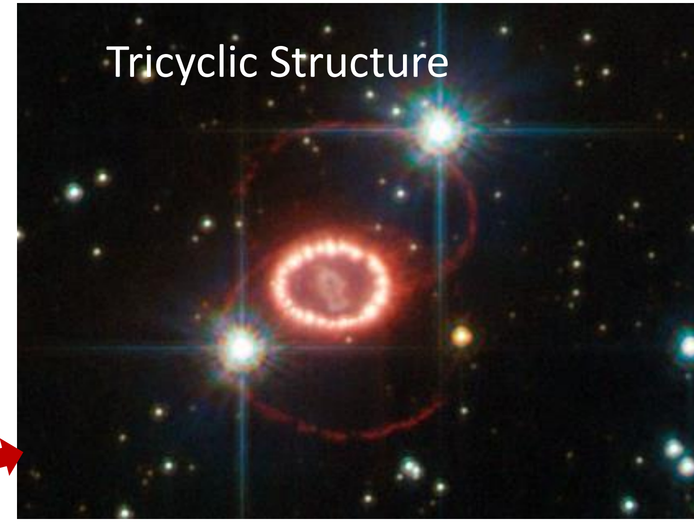
Supernova SN1987A

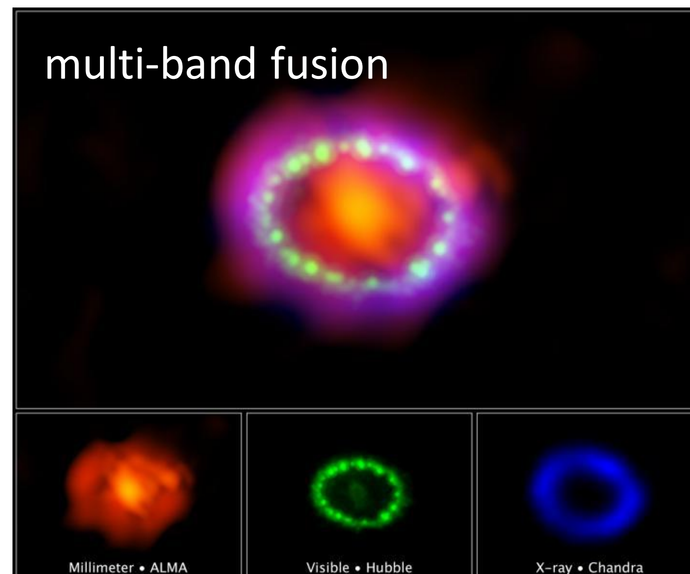


On 24 February 1987. A neutrino burst, which signified the event as a type II core-collapse supernova (SN), was retrospectively detected by several detectors.

51.4 kpc to the earth.

The first (and so far only) one to be detected by its neutrino emissions.





SN1987A Neutrino

arXiv:1702. 08713

- The first (and so far only) supernova detected by its neutrino emissions
- Neutrino events recorded by the Kamiokande, IMB and Baksan experiments.
- The 24 neutrino were recorded over a time interval of 13 seconds.
- Energy 10-50MeV

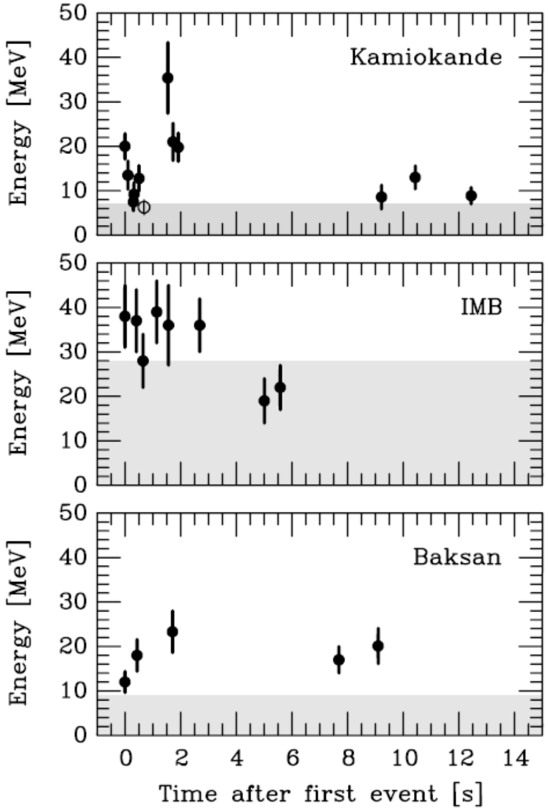


Figure 1.7 SN1987A neutrinos were observed at Kamiokande[29,30], IMB[31,32], and Baksan[33,34] experiments. The energies represent the detected energy of positrons from inverse beta decay reactions. The shaded area corresponds to a trigger efficiency less than 30%. (From Ref. [7])

Supernova Neutrino detection

Supernova neutrino is detected by the **inverse beta process(IBD)** in most experiments.

Positron carries almost all the energy from neutrino.

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

	Detection method	target	Target mass→ IBD events amount	backgr ound
1st class	IBD Event Reconstruction	Liquid scintillator/ water	Small	Low
2nd class	Collective rise in all events rates on top of the dark noise	water （ice）	Large	High

Compare LHAASO-MD with other experiments

	Experiment	Target	Target mass(kton)	IBD Events	Threshold(MeV)	Material coverage	Number and distance of detector units	background rate(Hz)
1st class	**KamLAND**	Liquid scintillator	1	300	0.35	underground 1000m	single	<1
	LVD	Liquid scintillator	1	300	4	underground 1400m	single	<1
	Borexino	Liquid scintillator	0.3	100	0.2	underground 1400m	single	<1
	Daya Bay	Liquid scintillator	0.33	110	0.7	underground 250-860m	8	<1
	JUNO	Liquid scintillator	20	6700	0.5	underground 700m	single	<1
	Super-K	water	32	7000	7	underground 1000m	single	<1
2nd class	**IceCube**	Ice	1000	134000	-	under ice 1450-2450m	5160DOMs, 7,72/42m	540->286
	LHAASO-WCDA	water	300	20000	-	on the ground	3120, Close to each other	>30K
	LHAASO-MD	water	51	12750	5	underground 2.5m	1171, 30m	8k->400?

The estimation based on calculations for the SK detector

SNEWS

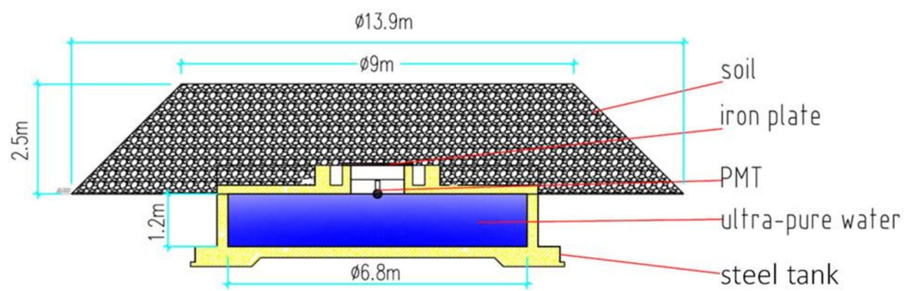
- SNEWS - SuperNova Early Warning System http://snews.bnl.gov/
- The goal is to provide a World-wide alert of the supernova neutrino signal
- 7 member experiments:

  Super-K (Japan), LVD (Italy), Ice Cube (South pole), KamLAND (Japan),

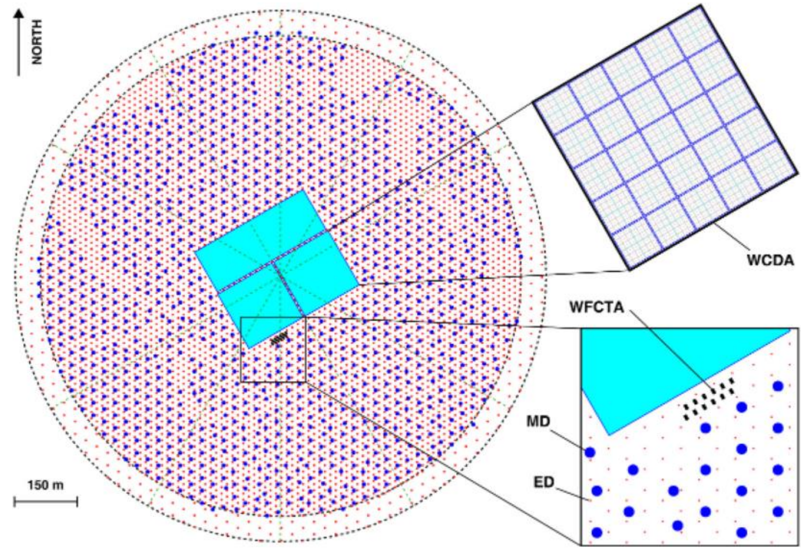
  Borexino (Italy), Daya Bay (China), HALO (Canada)

- Hope LHAASO could be the 8th experiments.

LHAASO-MD



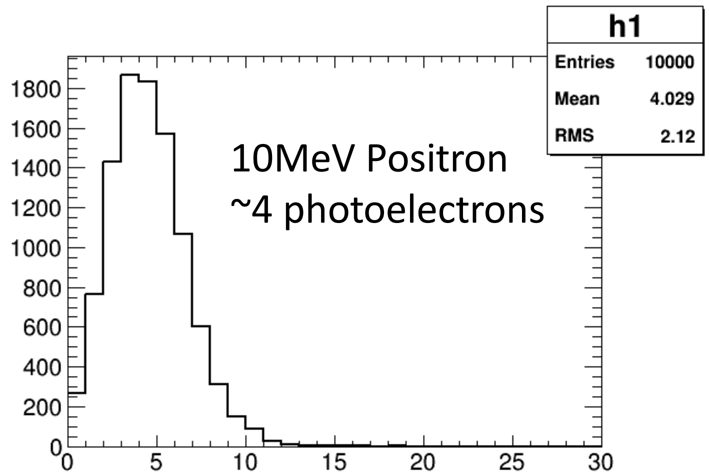
Schematic of LHAASO MD



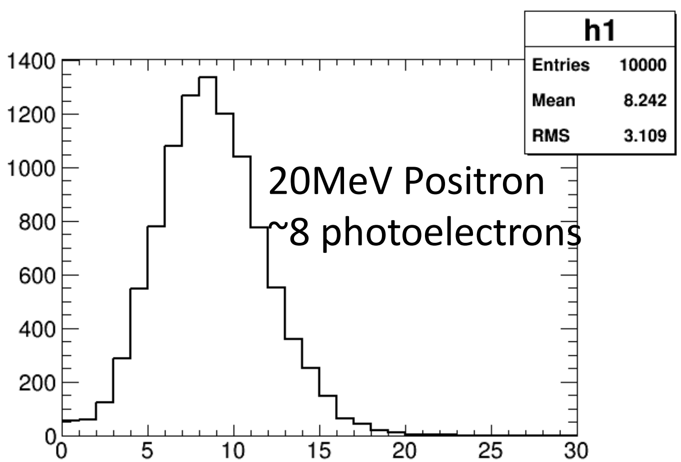
MD distribution

- Number of MD units: 1171; Distance 30m; water 0.044kton/PMT， total 51kton
- Scattered layout and spatial uniformity
- Good detection efficiency (> 95%) & good liner reflectivity (> 95%)
- PMT Threshold 5mV~1.7pe

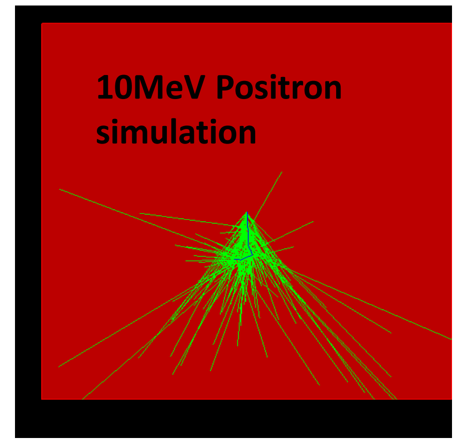
MD simulation



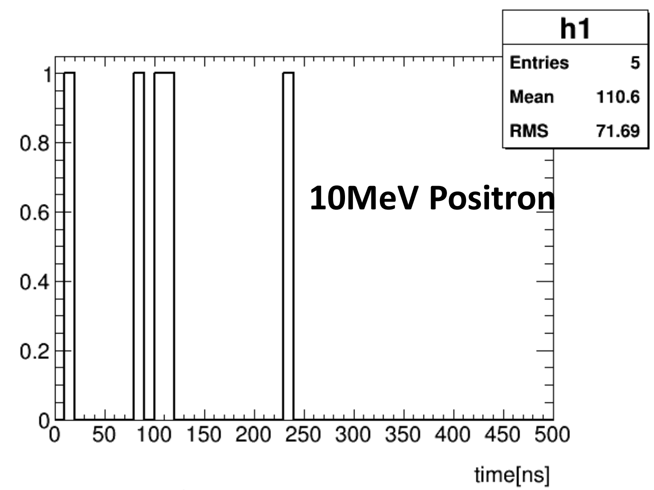
Distribution of Photoelectron Number



Distribution of Photoelectron Number



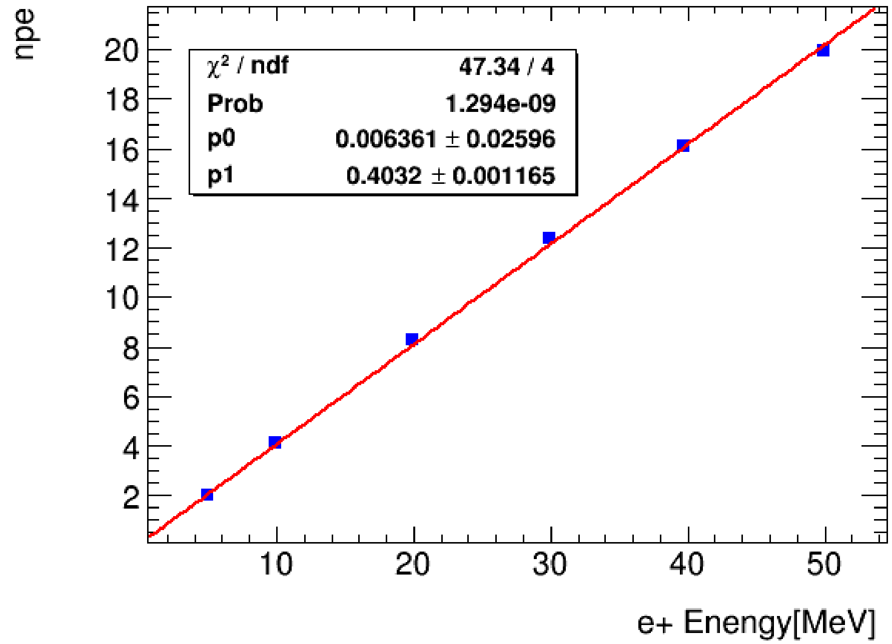
- Single Positron events



Time of Photoelectrons
0: positron injection time

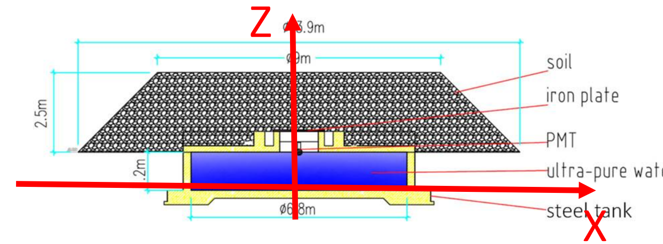
MD simulation

- Photoelectron Number ~ Positron Energy * 0.4



For each MD, ~ 4-20 Photoelectrons arrive in hundreds ns

Positron injection position X:Z

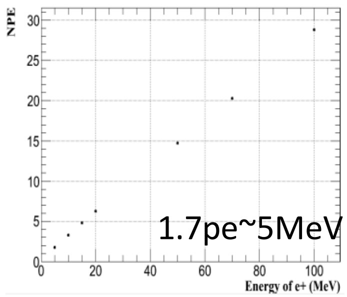


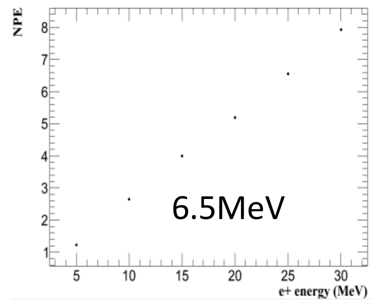
X =0 m

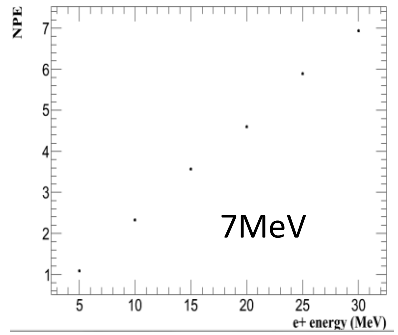
X =1 m

X =2 m

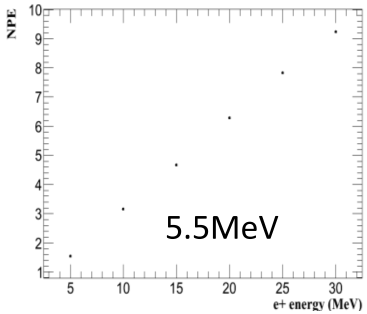
Z=1m

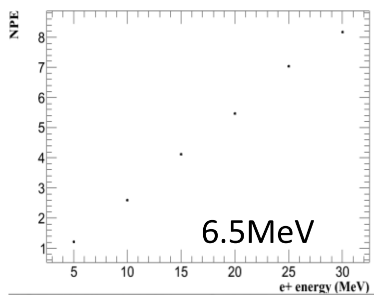


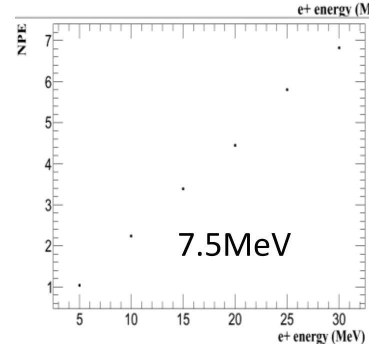




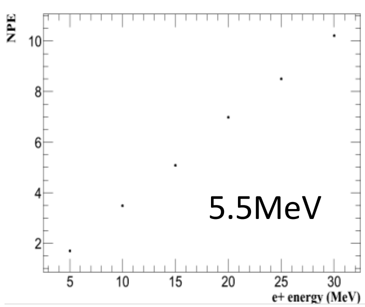
Z=0.7m

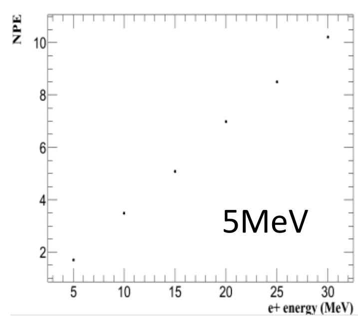


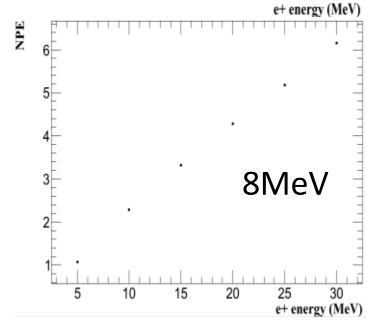




Z=0.2m





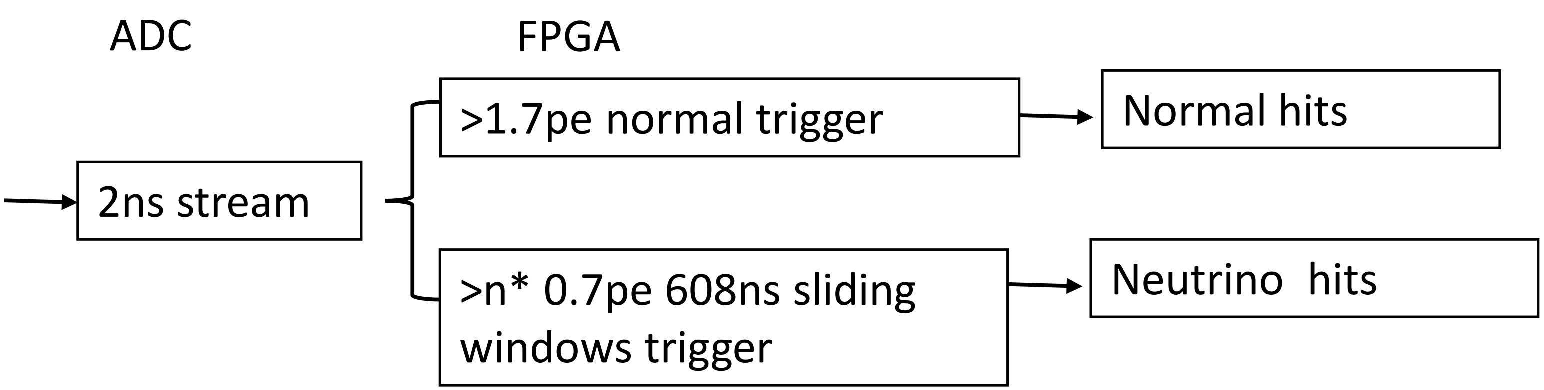


MD： 10MeV Positron 3.3pe

Threshold ~5MeV (1.7pe)

FPGA programming to be done

- For each MD, ~ 4-20 Photoelectrons arrive in 250 ns
- MD threshold is 1.7 pe
- Single photon will not be triggered by MD DAQ
- Need FPGA Level programming (sliding windows method) to trigger multi-photons in 608ns
- ---Studying by Xi Wang with help from Jinfan Chang



Noise estimation

Full MD record Data (Special trigger mode)：

/eos/lhaaso/raw/km2a/2020/0918/   140 files

- 10 minutes Full record Data
- Record all hits from MD before selection.

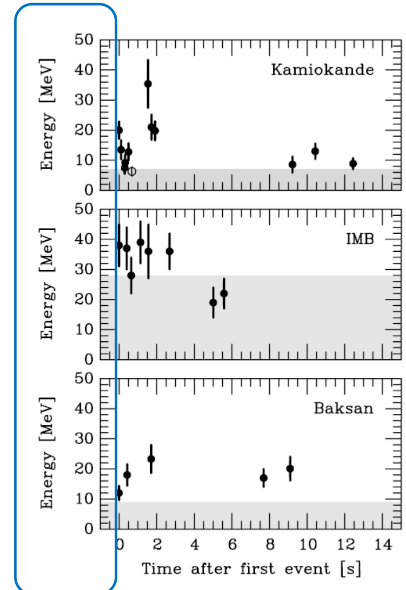
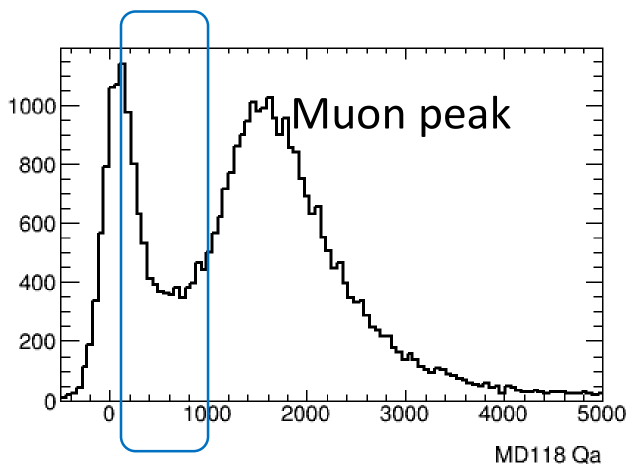


Figure 1.7 SN1987A neutrinos were observed at Kamiokande[29,30], IMB[31,32], and Baksan[33,34] experiments. The energies represent the detected energy of positrons from inverse beta decay reactions. The shaded area corresponds to a trigger efficiency less than 30%. (From Ref. [7])



MD rate ~8K Hz

Could remove the Muon by energy cut

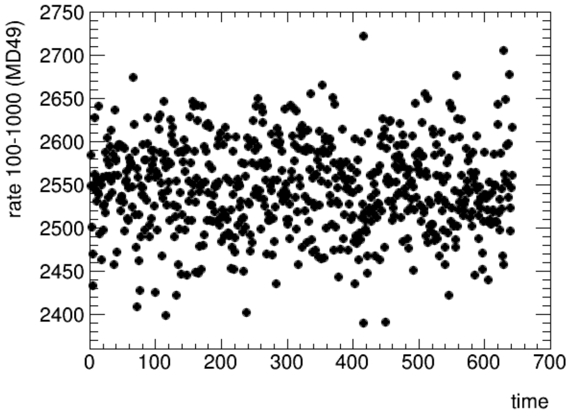
energy 10-100MeV

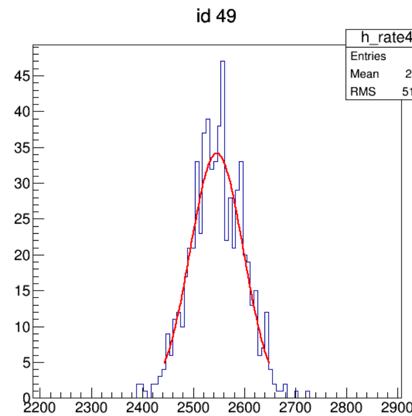
~ 100-1000ADC count

MD hits rate （100-1000 ADC count ）

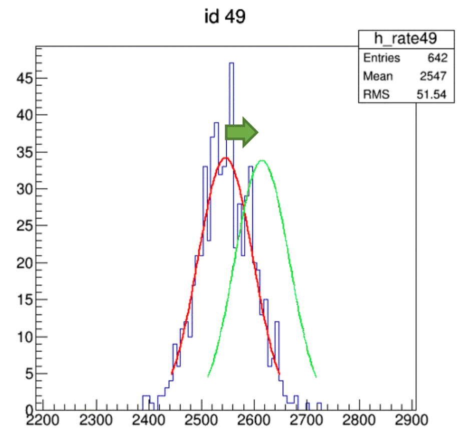
If Supernova arrives, could see a rise in hits rate

Single MD hits rate vs time



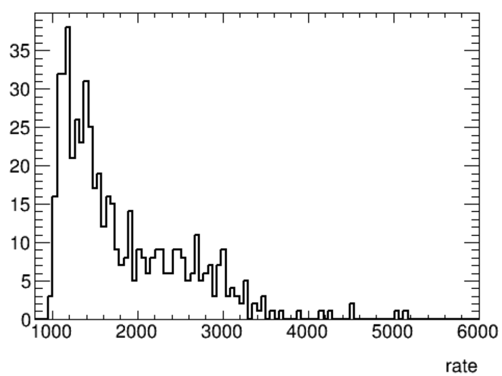


Single MD Rate

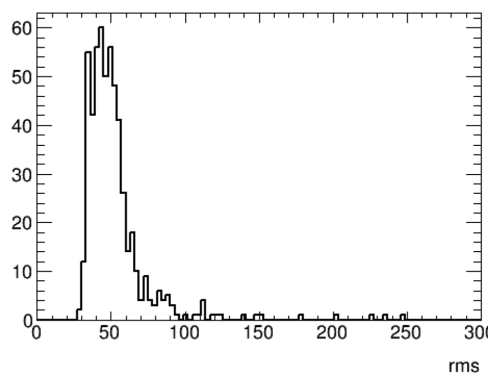


Single MD Rate

mean of 500 MDs hits rate



RMS of 500 MDs hits rate



Real-time analysis method

The most likely *collective rate deviation* μ of all single MD noise rates r_i from their individual $\langle r_i \rangle$ ’s, is obtained by maximizing the likelihood

$$\mathcal{L}(\Delta\mu) = \prod_{i=1}^{N_{\mathrm{MD}}} \frac{1}{\sqrt{2\pi}\,\langle\sigma_i\rangle} \exp\left(-\frac{(r_i - (\langle r_i\rangle + \epsilon_i\,\Delta\mu))^2}{2\langle\sigma_i\rangle^2}\right) .$$

i MD index

r rate

<r> rate expectation values

$\langle\sigma_i\rangle$ standard deviation expectation values

$\varepsilon_i \Delta\mu$ correction for each single MD

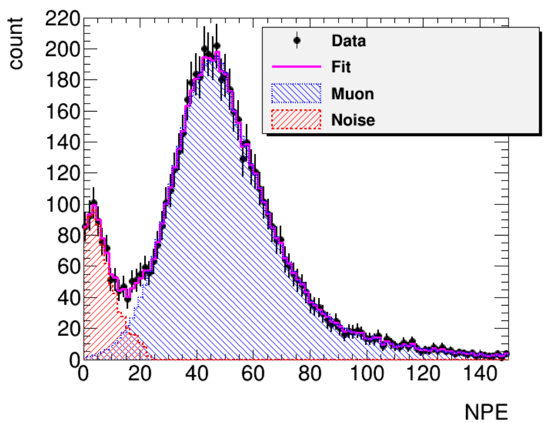
Significance estimation

- 10 second IBD events 12750
- First second positron 12750/2=6375
- Each MD positron 6375/1171=5
- Average noise rate 2000
- Significance of each single MD: 5/sqrt(2000)=0.11σ
- 1171 MDs: sqrt(1171) ⋆ 0.1σ=3.5 σ

- Important to lower the noise level

lower the noise level （to do）

1:Fit method to separate Muon and Noise



2:Artificial dead time (IceCube)，

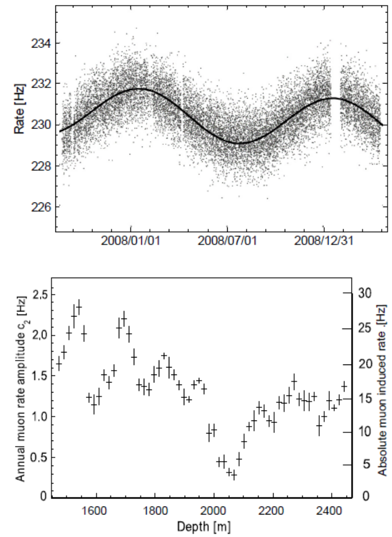


Fig. 7. *Top*: rate of a typical DOM as function of time covering 556 days of lifetime as measured in 0.5 s bins (baseline suppressed). The line corresponds to a rate fit according to Eq. (12). *Bottom*: parameter c_2 and estimated muon induced rate as function of depth. The variation with depth is mostly due to the optical properties of the ice and muons ranging out.

The data acquisition was designed to reduce the noise rate by
ninating the excess hits, while keeping the random arrivals.
e signal-to-noise ratio of the measurement can be improved
enforcing an artificial dead time τ after every count, config-
d to 250 μs by a field programmable gate array in the DOM.
s reduces the noise rate from 540 Hz to 286 Hz at the cost of
ne 13% dead time for signal. The choice of 250 μs optimizes
sitivity to the Lawrence-Livermore model (Totani et al. 1997)
distances up to 75 kpc, when neglecting the effect of after-
ses following the signal. A dead time $\tau > 110\ \mu$s guarantees

3:FPGA level study for Supernova Neutrino Detection is on going by Xi Wang and others.

4:Use 2 seconds’ hits rate

Summary

- Hope to detect Supernova neutrino by LHAASO-MD
- Need FPGA Level programming (sliding windows method) to trigger
- Important to lower the noise level
- Hope we could be member experiments of SNEWS in the future

Thank you!