Simulation Studies on Supernova Neutrino Detections in JUNO

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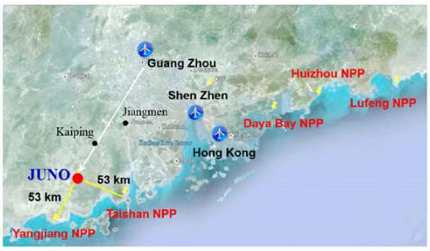
Supernova(SN) 1987A was the first detected neutrino burst in neutrino experiment. The Jiangmen Underground Neutrino Observatory(JUNO) is an upcoming large liquid scintillator detector experiment with an expected 3% energy resolution at 1 MeV and abundant light yield. These properties make JUNO a powerful SN neutrino detector. In this poster, we present our simulation studies on SN neutrino event selection efficiencies and purities for different detection channels involving different flavours of SN neutrinos. We demonstrate that pulse shape discrimination (PSD) technique is effective in JUNO detector for separating different SN neutrino detection channels.

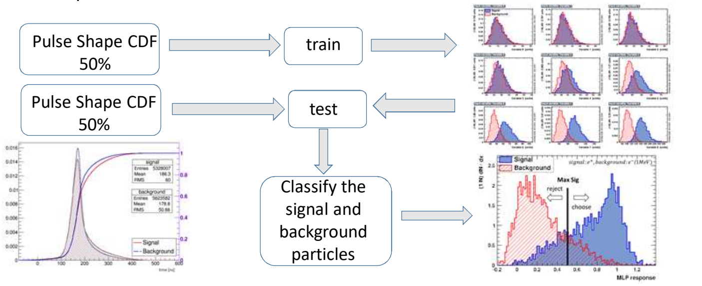
Introduction to JUNO

- **The Jiangmen Underground Neutrino Observatory(JUNO)** is an incoming reactor neutrino experiment with large liquid scintillator detector in southern China.
- The main purpose of JUNO is to **determine the neutrino mass hierarchy.**
- The detector energy resolution uncertainties are expected less than 3% at 1MeV.
- JUNO is expected to launch at 2020.



Multilayer Perceptron(MLP) Classifier

- To exploit the cumulative density function(CDF) of pulse shape as the input samples to train and test PSD method effectiveness.



Main Interactions for SN neutrino in LS

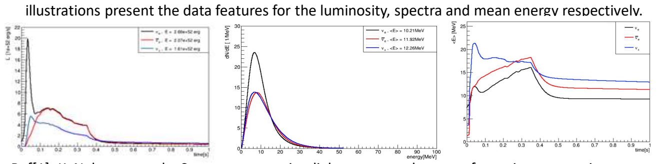
Channels	Type	
$\overline{\nu_e} + p \rightarrow e^+ + n$	CC	IBD
$\nu + p \rightarrow \nu + p$ $\nu + e^- \rightarrow \nu + e^-$	NC	ES
$\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N$ $\overline{\nu_e} + {}^{12}C \rightarrow e^+ + {}^{12}B$	CC	C12-CC
$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^*$	NC	C12-NC

- A typical galactic SN at 10kpc, JUNO can provide high statistics observation opportunity to probe SN neutrinos.
- For example, there are ~5000 neutrino events can be detected from IBD channel, and ~2000 from ES channel.

Simulation Procedure

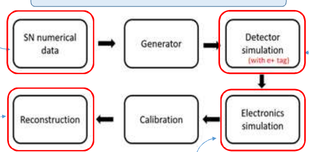
- ***Input numerical data***

The SN input data with the model Intp2013 are from Nakazato et al.[1]. The following illustrations present the data features for the luminosity, spectra and mean energy respectively.

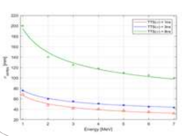


Ref[1]: K. Nakazato et al. , Supernova neutrino light curves and spectra for various progenitor stars: From core collapse to proto-neutron star cooling, Astrophys. J. Suppl. Ser. 205, 2 (2013).

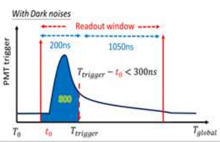
Simulation Flow Chart



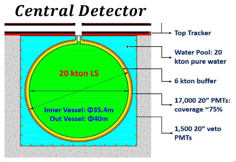
Rec.Vertex Resolution



Trigger System



Central Detector

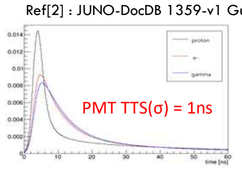


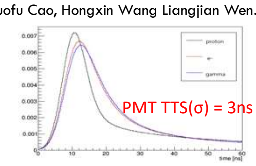
Pulse Shape Discrimination (PSD)

- For different kind of particle, the probability of light emission in LS can be express as $P(t) = \sum_{i=1}^{3} \frac{w_i}{\tau_i} \exp\left(\frac{-t}{\tau_i}\right)$

Particles	Fast(ns)/fraction	Slow(ns)/fraction	Slower(ns)/fraction
e^-, e^+, γ	4.93/79.9%	20.6/17.1%	190/3.0%
n, p	4.93/65%	34.0/23.1%	220/11.9%
α	4.93/65%	35.0/22.8%	220/12.2%

Ref[2] : JUNO-DocDB 1359-v1 Guofu Cao, Hongxin Wang Liangjian Wen.



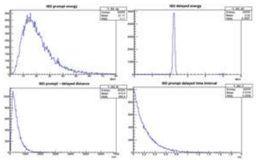


- The different shape of photon emission time for different particle offers a way to recognize what particle it is, but this distribution deeply depends on the PMT transition-time spread(TTS) and the reconstruction algorithm performance.

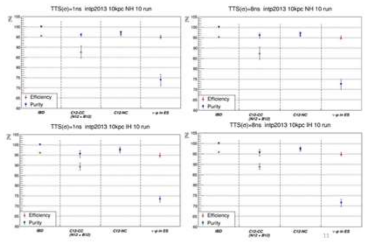
Results

- **Event Selection(w/o PSD)**

- A case to set these cuts for IBD events:
  - prompt energy: (1, 60)MeV
  - delayed energy: (1.9, 2.5)MeV
  - capture time: (0.1, 1.2)ms
  - distant cut: <1500mm



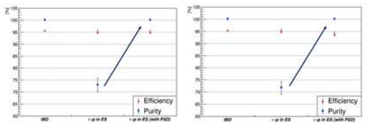
- **Event Selection results (w/o PSD)**



$$eff. \equiv \frac{selected\ true\ evts}{total\ evts} \qquad purity \equiv \frac{selected\ true\ evts}{selected\ evts}$$

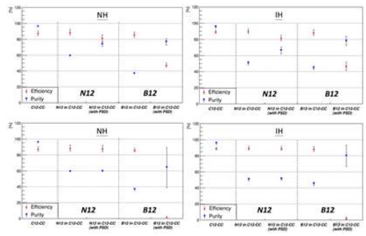
- Even without PSD, the IBD still can reach high purity(~100%) and efficiency(~95%).
- For ES, purity is just around 70% in event selection (ν-p + ν-p).
- ${}^{12}C$-CC channel can not be separated.

- **PSD on v-p ES channel**



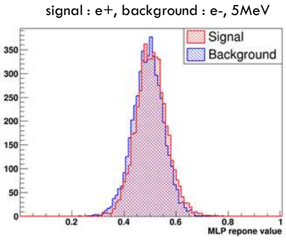
- For ES case, PSD is valid for increasing the purity significantly and just loses a little amount of efficiency.

- **PSD on C12-CC channel**



- PSD is of limited help.

signal : e+, background : e-, 5MeV



- Cannot recognize the difference between the two kind of pulse shape.

Summary

- IBD can reach high purity(~100%) and efficiency(~95%) by event selection.
- For proton vs. e− (ES channel), PSD can separate the two channels reasonable well.
- v-p ES events are mostly at low energy due to the quenching effect. Hence the energy trigger system should be considered carefully.
- For e+ vs. e- (C12-CC channel), PSD does not some advantage in improving the performance. By including electronics simulation and high PMT TTS, the two pulse shapes overlap completely.

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