Towards Core Collapse Supernova detection with the 3-inch PMT system in JUNO

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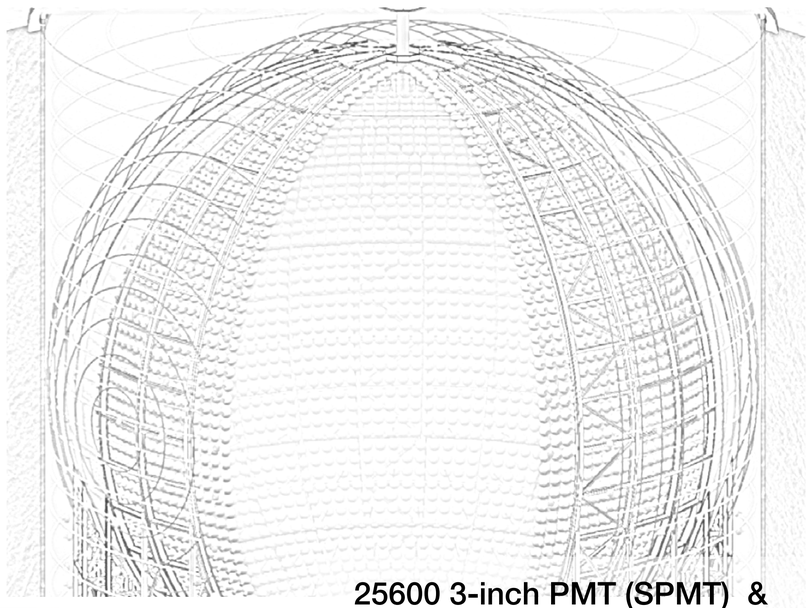
Neutrinos are unique messengers of the inner processes in Core Collapse Supernovae (CCSN). About 10000 interactions from neutrinos of all flavors are expected in JUNO from a CCSN at 10 kpc.

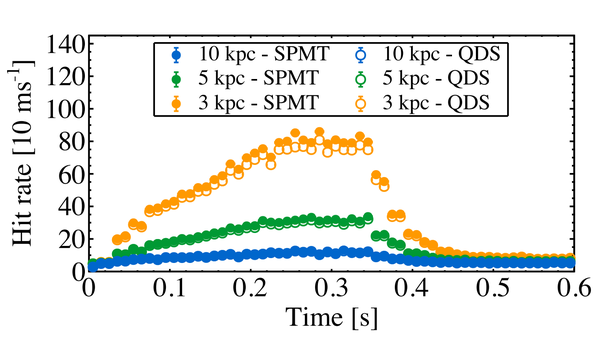
JUNO (Jiangmen Underground Neutrino Observatory): a 20 kiloton liquid scintillator experiment, under construction in Southern China, with 650 m of rock overburden. It features two independent photo-detection systems (20-inch and 3-inch PMTs) for a better control of systematics and recovery of saturated events [1]. Moreover, the 3-inch PMTs are less affected by signal pile-up in high-rate scenarios, such as under a nearby CCSN.

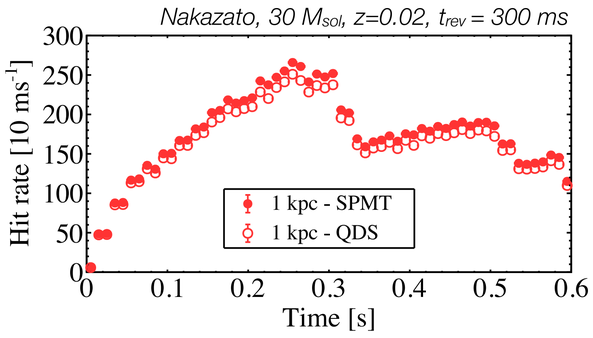


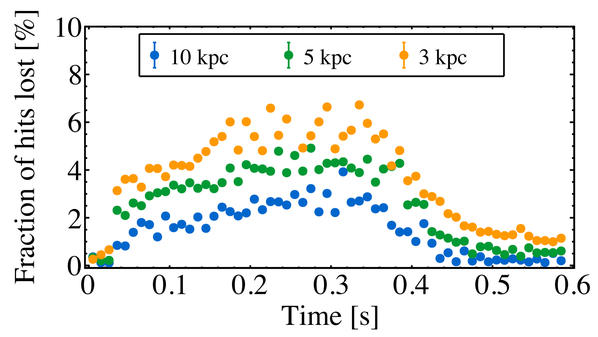
25600 3-inch PMT (SPMT) & 17612 20-inch PMTs (LPMT)

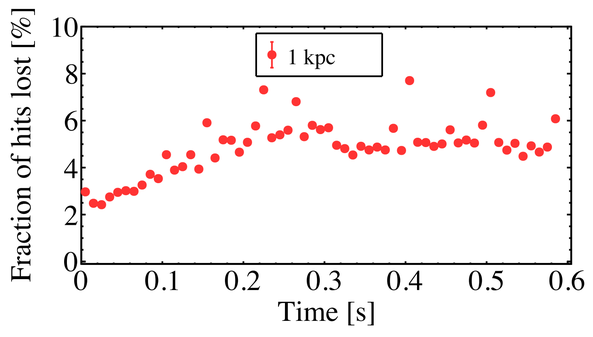
CCSN neutrino event rate with the 3-inch PMT system

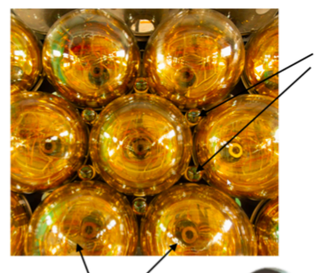
The 25600 3-inch PMTs (SPMTs) are connected to 200 front-end boards. Each board contains 8 CATIROC ASICS[2] for the charge & time measurement. The dead times due to trigger formation and signal digitization result in a relatively small loss of hits during high-rate CCSN detection.

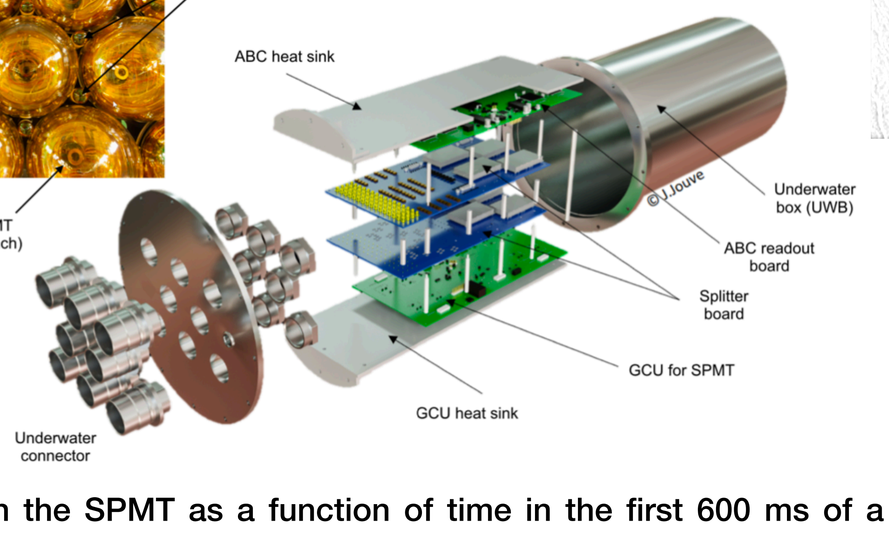








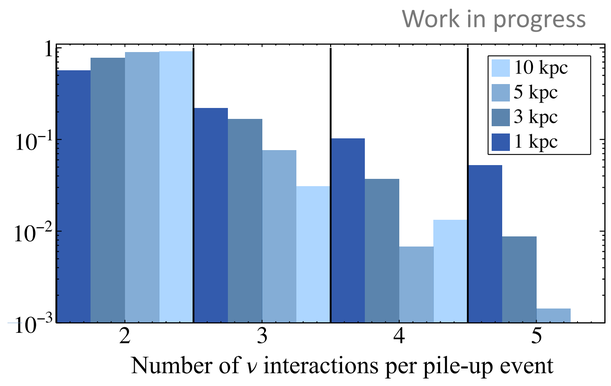




Hit rate on the SPMT as a function of time in the first 600 ms of a CCSN (filled markers). The electronics dead times induce a loss on the number of hits (Charge Data Stream, QDS, empty markers) of the order of few percent, even in the extreme case of a CCSN at 1kpc. The total measured charge is affected by less than 1% (10kpc) and 5% (1kpc) which is important for the energy reconstruction.

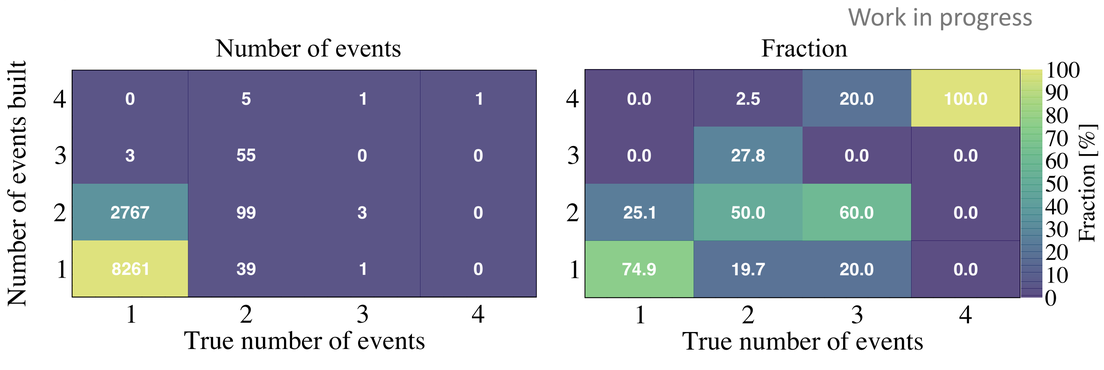
Event pileup for close-by CCSN

For a high neutrino event rate, the scintillation photons time distribution of two (or more) consecutive events can pile up, inducing a distortion of the measured signal and neutrino energy spectrum.



Normalized histogram of the number of events in case of pileup for different distances to the CCSN. The number of events affected by pileup signals increases from 2.5% (at 10kpc) to 45.3% (at 1kpc)

A dedicated event builder, using optimized signal time length and PMT multiplicity thresholds over background can retrieve most of the events.



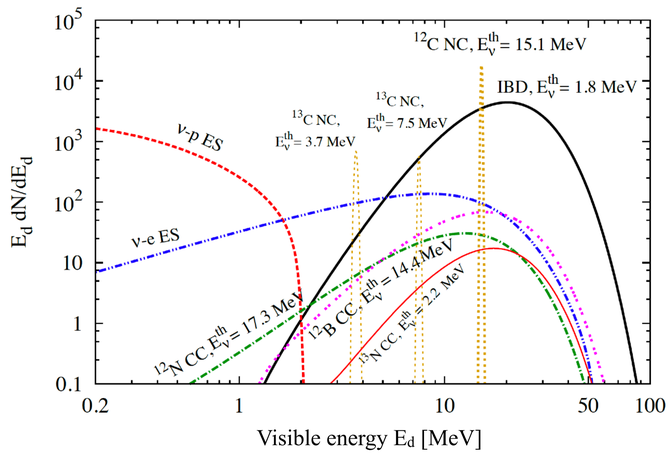
Confusion matrix between the number of events per pile-up event and the number of events built with a dedicated event builder for a 10 kpc away CCSN. Number of events (left) and fraction (right) are indicated. More than 50% of the 2 pileup events can be recovered.

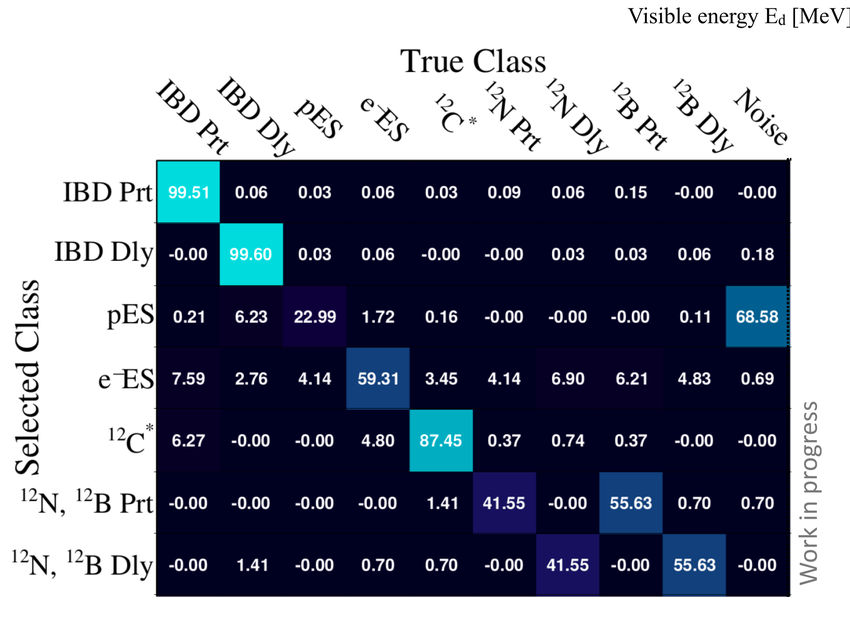
Multi-flavor neutrino detection

Most interesting channels with the 3-inch PMTs : IBD and νeES.

Steps in the selection strategy

IBD (time/space correl.)
↓
CC ^{12}C (time/space correl.)
↓
NC ^{12}C (E, gamma peak)
↓
νeES (E, low statistics)
↓
νpES (energy, low energy)





Confusion matrix of the different interaction channels with the selection strategy applied to a CCSN at 10 kpc, after full processing of the events (detector & electronics simulations, event builder, vertex and energy reconstruction). Remaining pileup events (<1%) are not removed.

[1] JUNO Collaboration, "JUNO Physics and Status", PPNP, 123 (2022), 103927
[2] S. Conforti, et al., CATIROC: an integrated chip for neutrino experiments using photomultiplier tubes, JINST, 16 P05010