JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Find the Supernova!

Thomas Mettler, Giulio Settanta, Miao Yu

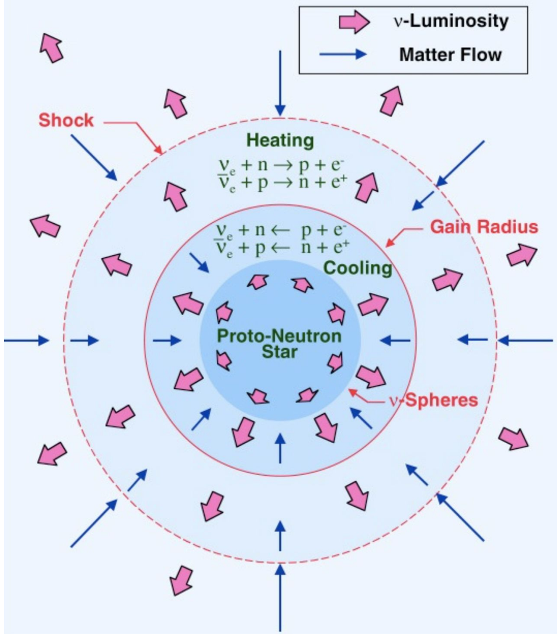
Group project seminar

11th International Neutrino Summer School, Schloss Waldthausen/Mainz
May 21 - June 1, 2018

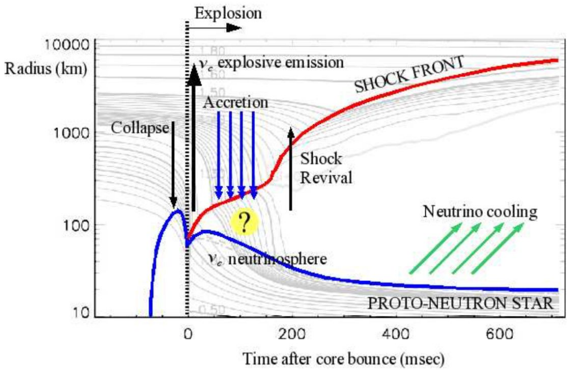
Tasks

- Find the direction of the Supernova
- Identify the physical process for directional information
- Generate a numerical simulation to evaluate the performances
    - Sk - like detector
- Improve event tagging efficiency

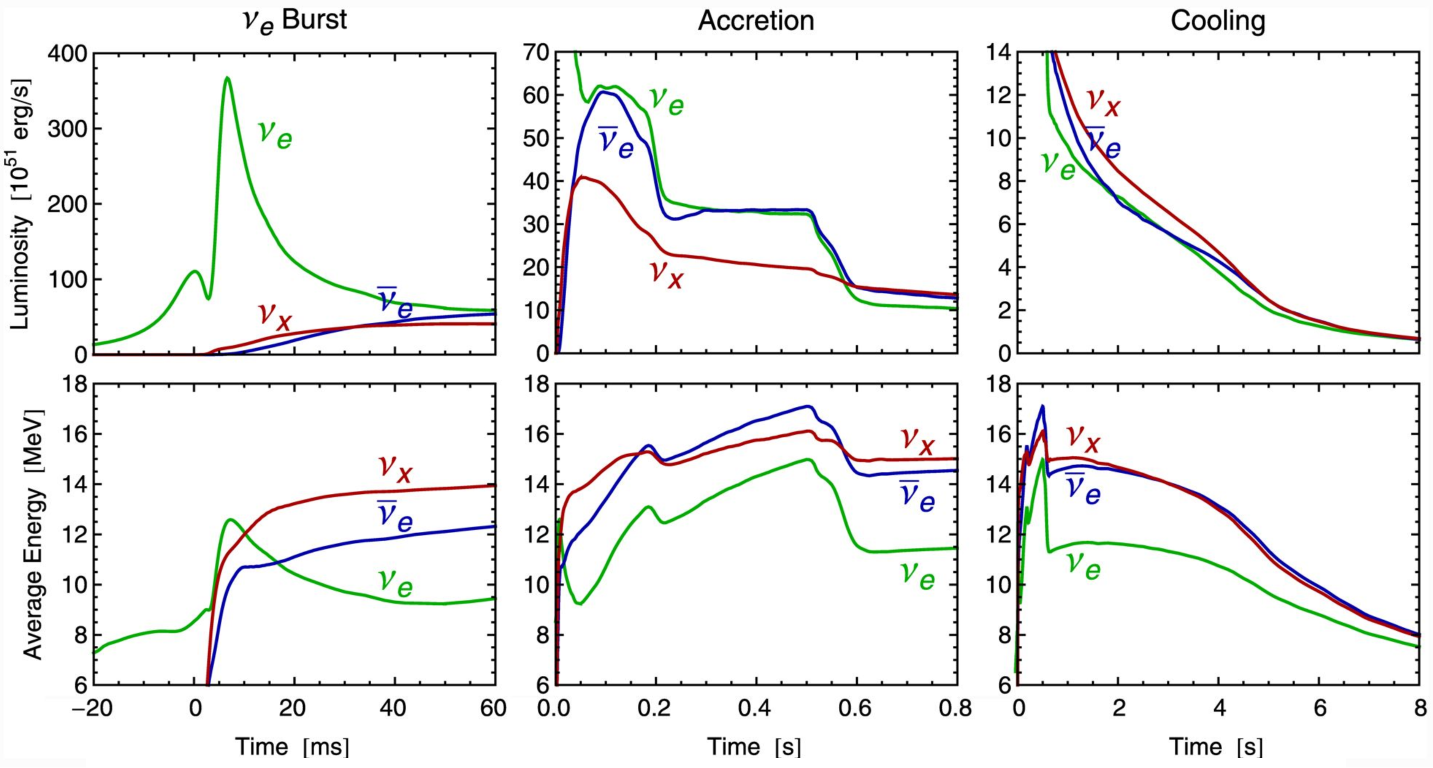
Supernova model(Type II)



- Stellar mass: $8M_{sun} < M < 40{\sim}50M_{sun}$
- Stages:
  - Nuclear reactions equilibrium(degenerate pressure of e^- v.s gravity)
  - Electron capture, photodisintegration reaction
- Core collapse
  - neutrino trapped, β-equilibrium → central density exceeds the nuclear density
- Shock wave form
  - Prevented by photodisintegration reaction and neutrino emission
- Neutrino driven



Supernova neutrino spectrum



$$\langle E_{\nu_e} \rangle \approx 11MeV, \langle E_{\bar{\nu}_e} \rangle \approx 16MeV, \langle E_{\nu_{\mu/\tau}} \rangle \approx 25MeV$$

SN Neutrino reactions in Super-K

K. Abe et al. (Super-Kamiokande), Astropart. Phys.81,39 (2016), 1601.04778.
Ando, S., & Sato, K. 2002, Prog. Theor. Phys., 107, 957

Table 1
Numbers of expected events at SK in the 22.5-kton fiducial volume with the 7 MeV total energy threshold for a SN burst with a distance of 10 kpc. We estimated these numbers using SK MC: we generate 3000 ensembles of the MC samples, reconstructed the events with the SK standard reconstruction tool, applied the selection criteria, and then calculated the average numbers.

	Wilson			NK1			NK2		
	No osc.	NH	IH	No osc.	NH	IH	No osc.	NH	IH
$\bar{\nu}_e + p \rightarrow e^+ + n$	4923	5667	7587	2076	2399	2745	1878	2252	2652
$\nu_e + e^- \rightarrow \nu_e + e^-$	74	130	114	43	56	56	39	54	54
$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$	25	29	37	10	12	14	9	11	13
$\nu_x + e^- \rightarrow \nu_x + e^-$	41	33	34	17	19	18	17	17	17
$\bar{\nu}_x + e^- \rightarrow \bar{\nu}_x + e^-$	34	33	29	14	14	14	13	13	14
$\nu_e +^{16}\mathrm{O} \rightarrow e^- + X$	8	662	479	22	78	74	16	72	68
$\bar{\nu}_e +^{16}\mathrm{O} \rightarrow e^+ + X$	64	196	531	27	48	70	20	41	64
Total	5169	6750	8811	2209	2626	2991	1992	2460	2882

SN Neutrino reactions in Super-K

K. Abe et al. (Super-Kamiokande), Astropart. Phys.81,39 (2016), 1601.04778.
Ando, S., & Sato, K. 2002, Prog. Theor. Phys., 107, 957

Table 1
Numbers of expected events at SK in the 22.5-kton fiducial volume with the 7 MeV total energy threshold for a SN burst with a distance of 10 kpc. We estimated these numbers using SK MC: we generate 3000 ensembles of the MC samples, reconstructed the events with the SK standard reconstruction tool, applied the selection criteria, and then calculated the average numbers.

	Wilson			NK1			NK2		
	No osc.	NH	IH	No osc.	NH	IH	No osc.	NH	IH
$\bar{\nu}_e + p \to e^+ + n$	4923	5667	7587	2076	2399	2745	1878	2252	2652
$\nu_e + e^- \to \nu_e + e^-$	74	130	114	43	56	56	39	54	54
$\bar{\nu}_e + e^- \to \bar{\nu}_e + e^-$	25	29	37	10	12	14	9	11	13
$\nu_x + e^- \to \nu_x + e^-$	41	33	34	17	19	18	17	17	17
$\bar{\nu}_x + e^- \to \bar{\nu}_x + e^-$	34	33	29	14	14	14	13	13	14
$\nu_e + ^{16}\mathrm{O} \to e^- + X$	8	662	479	22	78	74	16	72	68
$\bar{\nu}_e + ^{16}\mathrm{O} \to e^+ + X$	64	196	531	27	48	70	20	41	64
Total	5169	6750	8811	2209	2626	2991	1992	2460	2882

Elastic scattering is a good channel for neutrino direction!

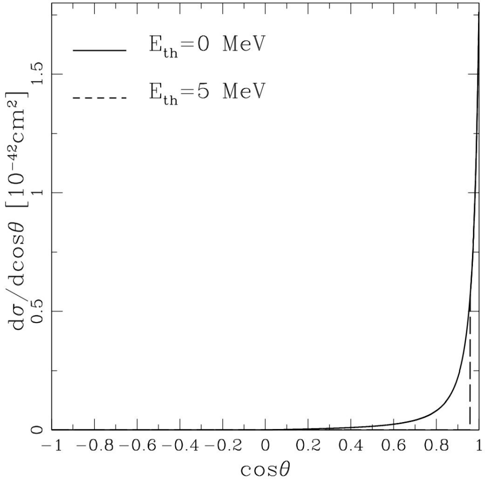
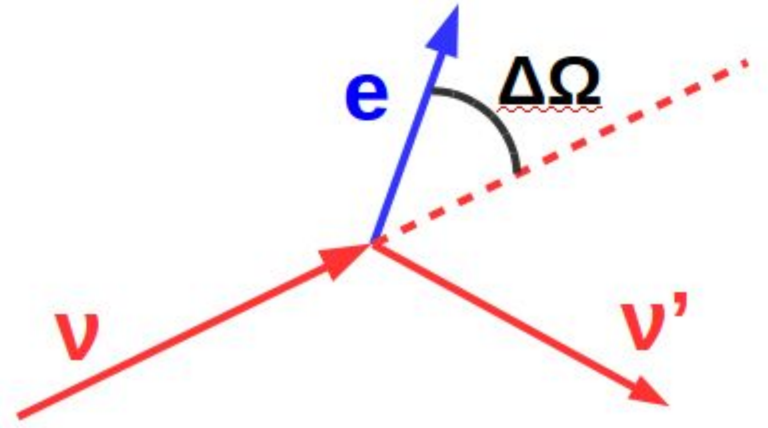


Fig. 3. Cross section for $\nu_e + e^- \to \nu_e + e^-$, with $E_\nu = 10$ MeV. The solid curve represents the cross section without an energy threshold. The dashed curve represents that with an energy threshold of 5 MeV, and that threshold is of SuperKamiokande detector. With the threshold, only the event of $\cos\theta > 0.95$ can be seen.

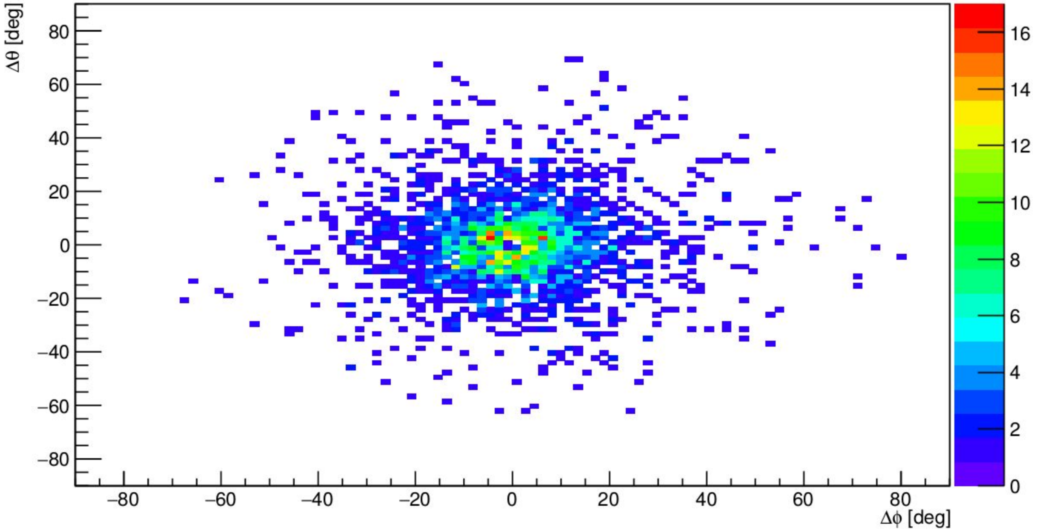
The simulation

- Events simulated with the GENIE Neutrino Monte Carlo generator, V_2.12.6
  - Pre-computed cross sections
- 5000 ν_e + 5000 ν_e(bar) on H_2O
  - Re-weighted to reproduce a realistic interaction rate
  - Expected much more ν_e(bar) interactions than ν_e
- Monochromatic 15 MeV flux
- Same direction (like a SN burst)
- Channels of interest:
  - ν – e elastic scattering
  - Inverse beta decay

The simulation

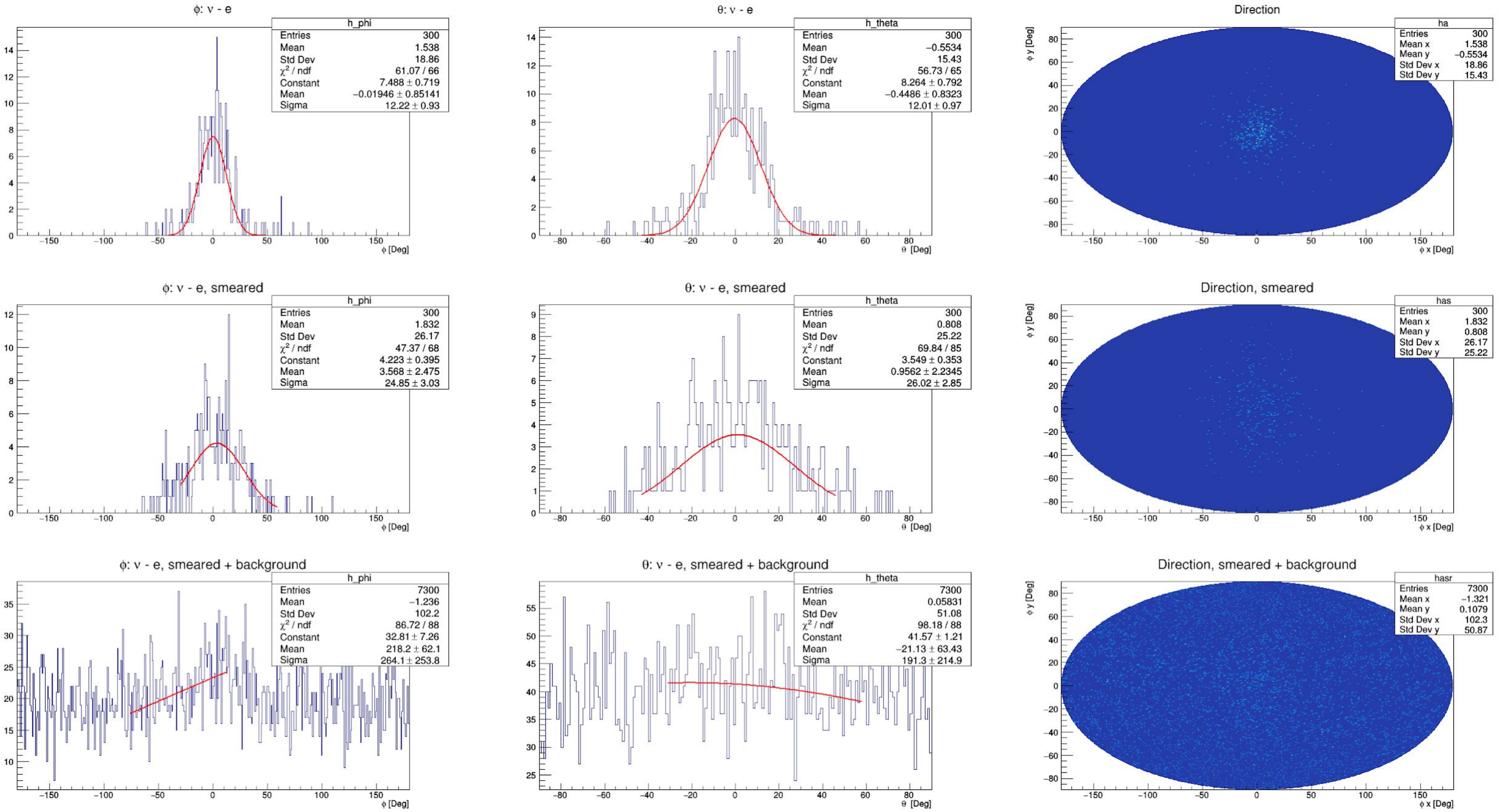


- Outputs of interest:
  - Neutrino direction
  - Final-state lepton direction
- Example: ν – e angular distance for ES on the ν direction orthogonal plane



The analysis

1. direction of the scattered electrons
2. added smearing for reco
3. added uniformly distributed background



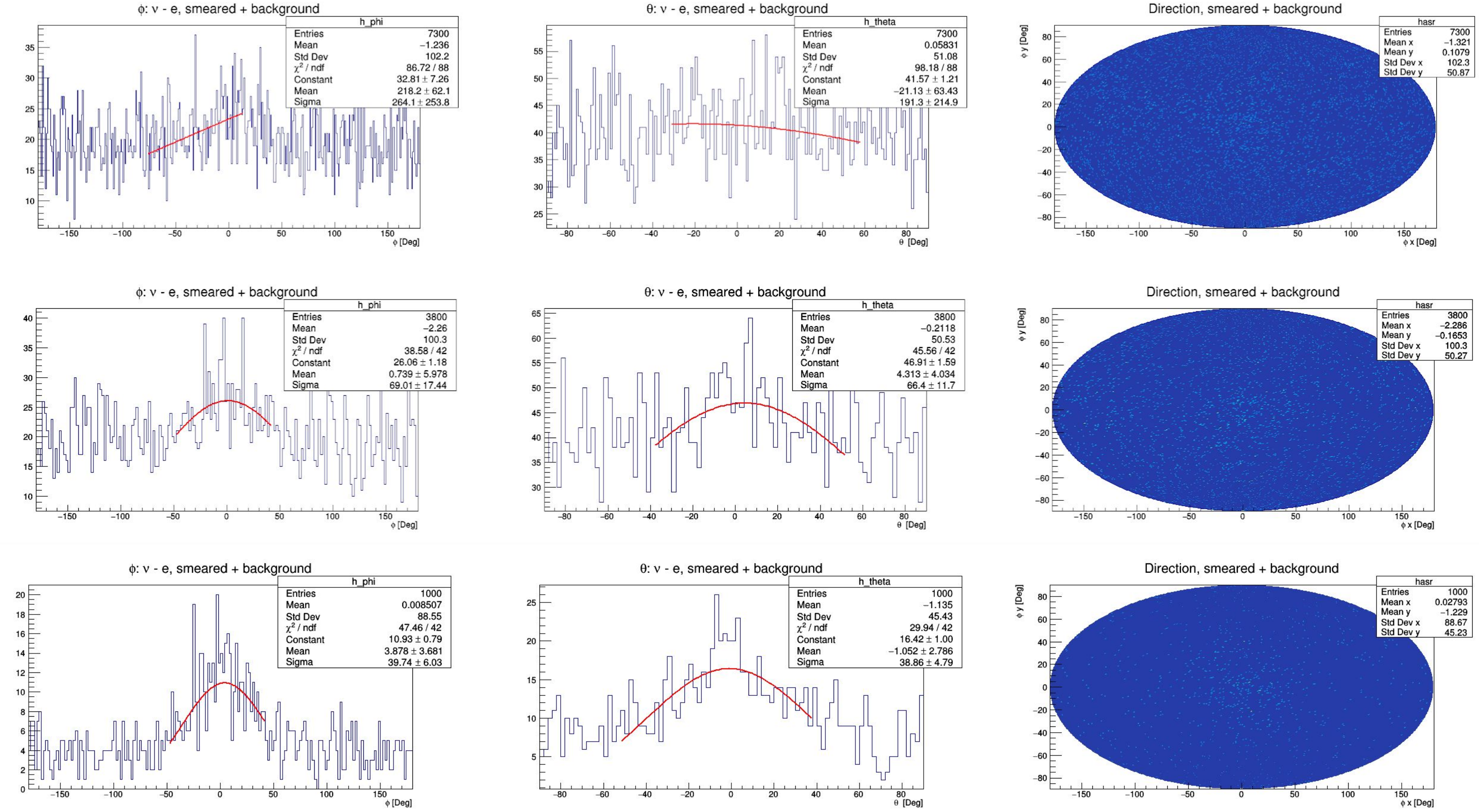
The analysis, identification of IBD

ES vs. # IBD

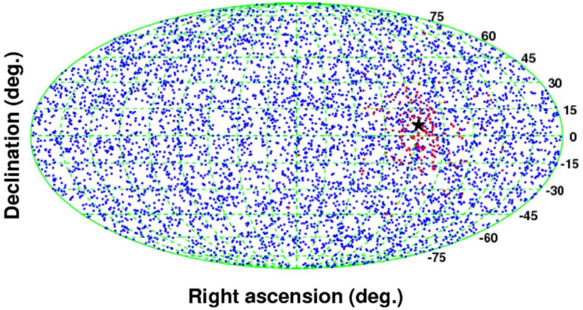
1. 300:7000
2. 300:3500
3. 300:700

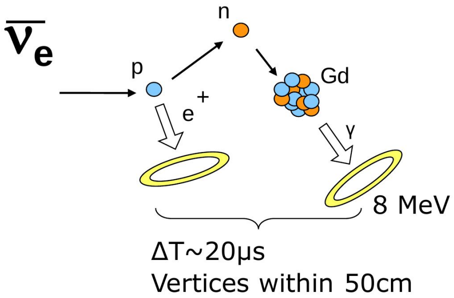
50% tagging efficiency

90% tagging efficiency



Comparison with papers





The SN direction pointing is of importance as it provides a chance for astronomers to observe the SN explosion from its onset with electromagnetic waves. SK is the only detector that enables us to reconstruct the SN direction using only neutrinos among the existing neutrino observatories. We have developed an algorithm to identify the SN direction and its error using a maximum likelihood method. The pointing accuracy estimated by the ensemble study is found to be 3.1–3.8°(4.3–5.9°) at 68.2% coverage for the Wilson (NK1) model at 10 kpc, where the range covers various neutrino oscillation scenarios.

Figure 5 shows the measured energy distribution of the gamma rays from the Gd, in good agreement with the MC prediction indicated as the hatched histogram. The mean energy is about 4.5 MeV, which is lower than the total emission energy of 8 MeV. This is because only part of the energy is translated into Cherenkov photons due to Compton scattering. The neutron tagging efficiency is estimated to be 66.7% with a 3 MeV energy threshold, taking into account the standard SK event reduction (80%) and the Gd capture efficiency (90%) in the solution. The accidental background rate is estimated to be 2×10^{-4} with an energy threshold of 10 MeV for the prompt $\bar{\nu}_e$ events. The time interval between the prompt and neutron capture events are measured, and we obtain the thermal neutron capture time constant of

SEARCH FOR SUPERNOVA NEUTRINO BURSTS AT SUPER-KAMIOKANDE; the Super-Kamiokande Collaboration; arXiv:0706.228.v1
Real-time supernova neutrino burst monitor at Super-Kamiokande, K. Abe et al. / Astroparticle Physics 81 (2016) 39–48

Conclusions

- It is possible to point back a Supernova burst
- The main interactions will be IBD with no direction information
- The challenge will be to identify the ES interactions among the others
    - Tagging the IBD interactions with the use of Gd