Supernova Neutrino Signal Detection

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Statement of the Problem

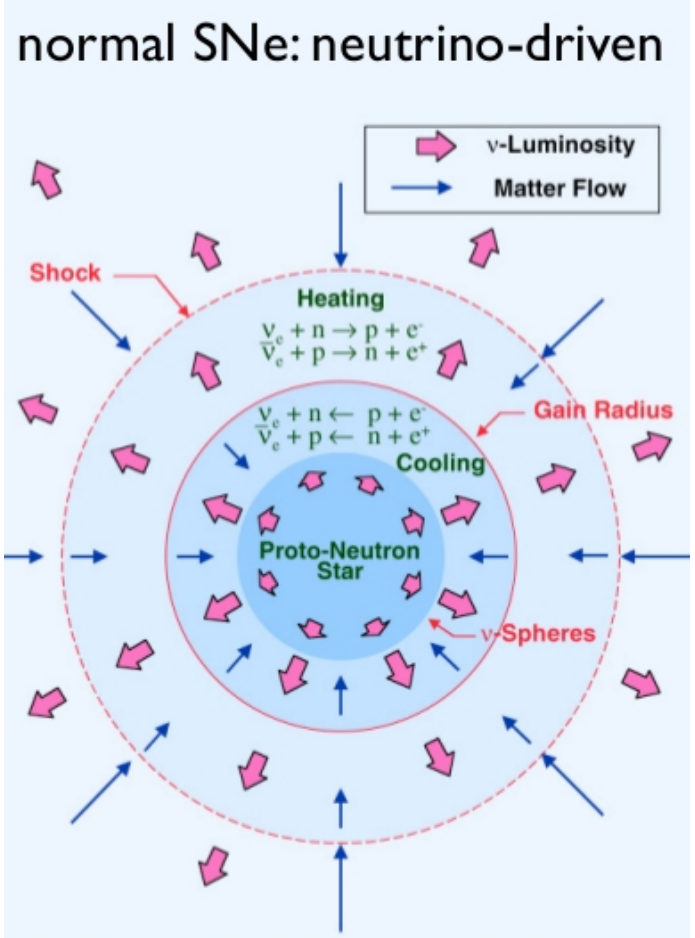
Detection of **neutrinos** from the core-collapse supernova blasts is a key goal of the current and next round of neutrino experiments.

This detection can be accomplished with a number of detector **technologies** (i.e. water-Cherenkov, liquid argon, scintillator, Icecube).

- Which **technology** is best suited for the task and why?
- What **detector** characteristics are desirable?
- What **considerations** are relevant for **designing** the **trigger** and data acquisition systems (**DAQ**)?
- Does it make sense to have **more than one** type of detector online?
- Does it help if the detectors are in **different** parts of the globe?

Supernova Basics

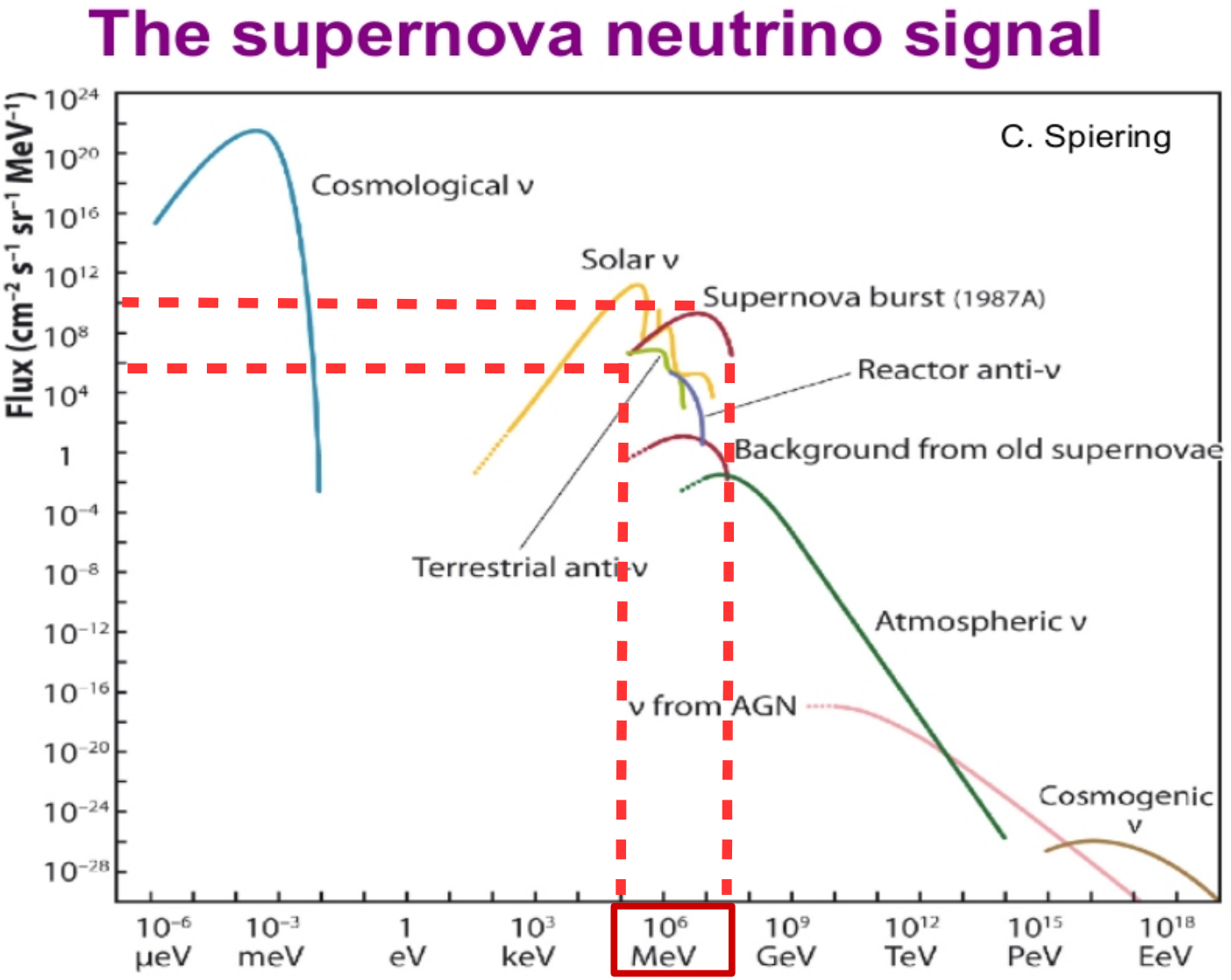
- As we learned from Alex Friedland lecture:
  - SN are very complex phenomenon, involving different kinds of stellar models to explain both evolution and burst



- What we want to focus on is:
  - Core-collapsing SN Type II
  - SN are gravity powered neutrino bombs!
  - Neutrinos carry away > 99 % of all released gravitational energy

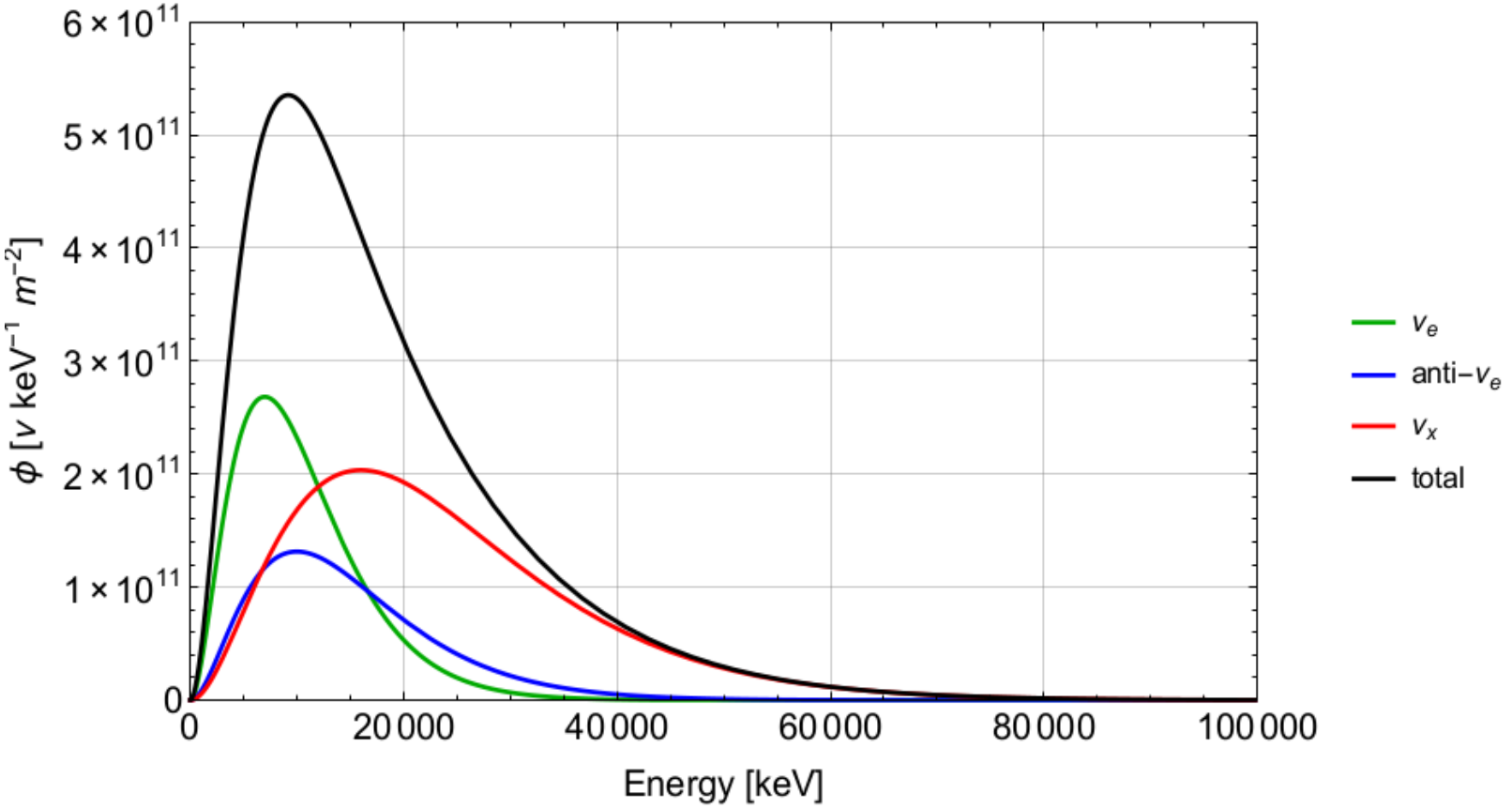
Neutrino flux I

- Neutrino signal is characterized in flux and energy distributions.



Neutrino flux II

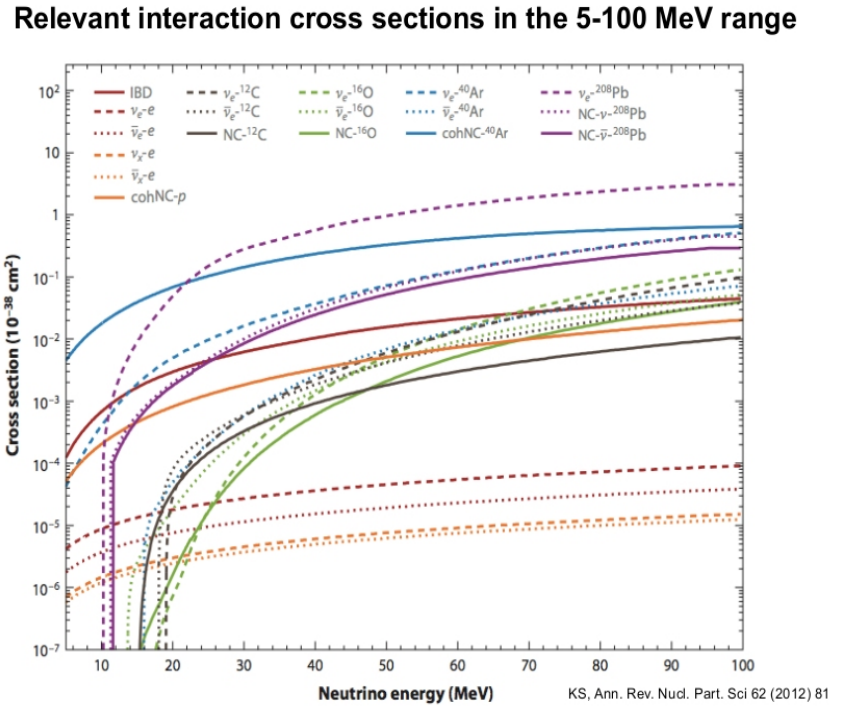
- The energy range is of the order of MeV.
- Flux of neutrinos arriving at earth (8.5 kpc) can be calculated for each neutrino species according to a predicted distribution.

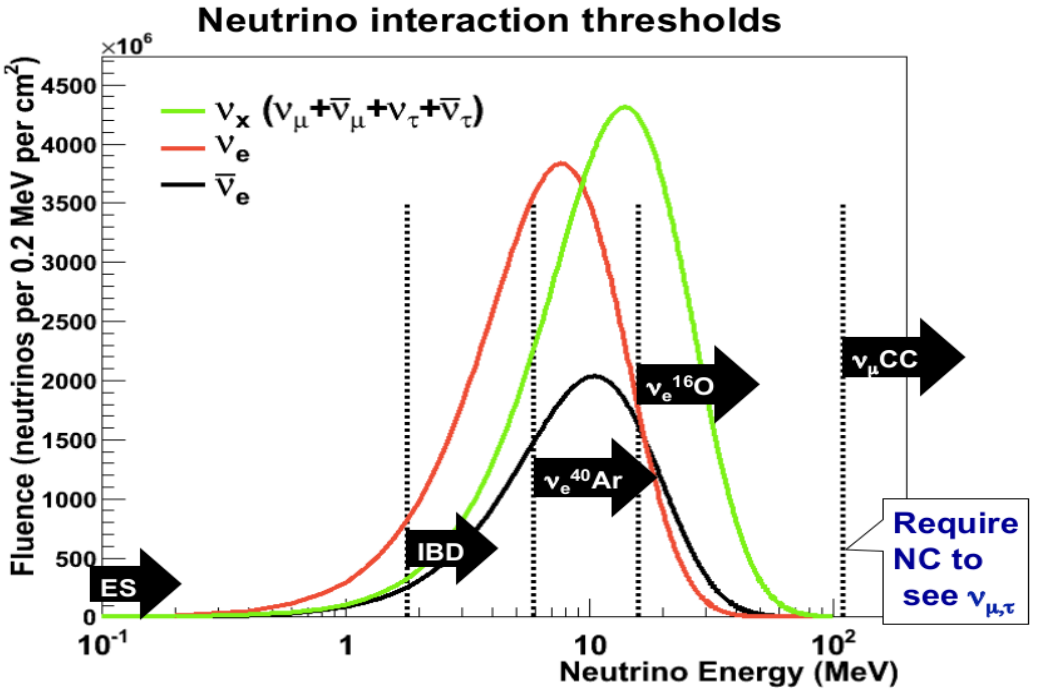


Detector technologies I

- For a given neutrino energy and flavor, we have to consider all the possible interactions for detection

- We need the cross sections and the threshold for each process we wish to exploit in our detectors





Channel	Observable(s)	Interactions
$\nu_x + e^- \rightarrow \nu_x + e^-$	C	17/10
$\bar{\nu}_e + p \rightarrow e^+ + n$	C, N, A	278/165
$\nu_x + p \rightarrow \nu_x + p$	C	682/351
$\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}^{(*)}$	C, N, G	3/9
$\bar{\nu}_e + {}^{12}\mathrm{C} \rightarrow e^+ + {}^{12}\mathrm{B}^{(*)}$	C, N, G, A	6/8
$\nu_x + {}^{12}\mathrm{C} \rightarrow \nu_x + {}^{12}\mathrm{C}^*$	G	68/25
$\nu_e + {}^{16}\mathrm{O} \rightarrow e^- + {}^{16}\mathrm{F}^{(*)}$	C, N, G	1/4
$\bar{\nu}_e + {}^{16}\mathrm{O} \rightarrow e^+ + {}^{16}\mathrm{N}^{(*)}$	C, N, G	7/5
$\nu_x + {}^{16}\mathrm{O} \rightarrow \nu_x + {}^{16}\mathrm{O}^*$	G	50/12
$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$	C, G	67/83
$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$	C, A, G	5/4
$\nu_e + {}^{208}\mathrm{Pb} \rightarrow e^- + {}^{208}\mathrm{Bi}^*$	N	144/228
$\nu_x + {}^{208}\mathrm{Pb} \rightarrow \nu_x + {}^{208}\mathrm{Pb}^*$	N	150/55
$\nu_x + A \rightarrow \nu_x + A$	C	9,408/4,974

Detector technologies II

Summary of supernova neutrino detectors

Galactic sensitivity

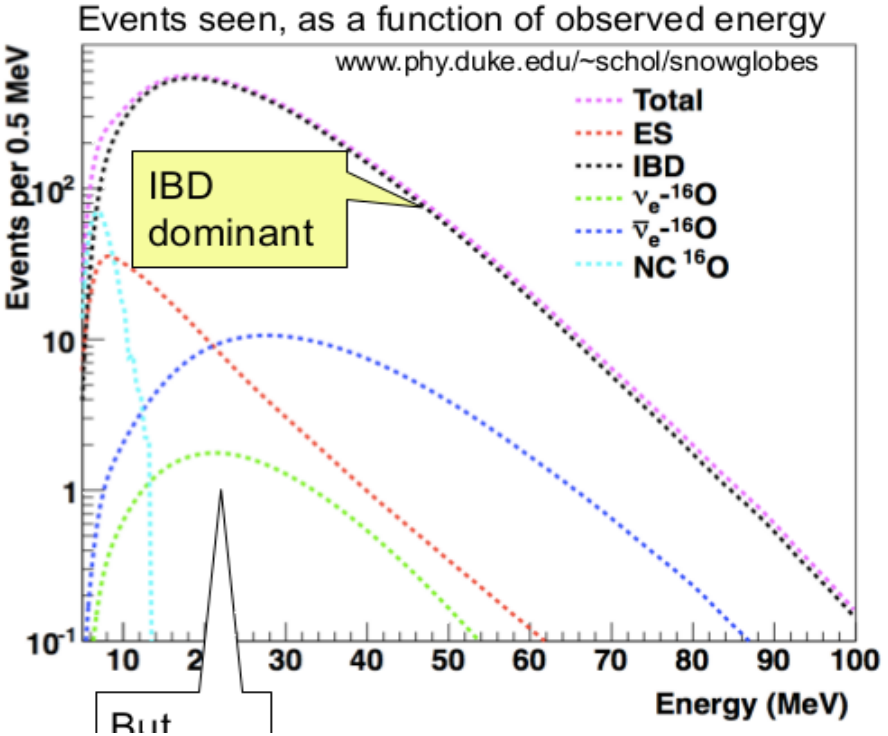
Extragalactic

Detector	Type	Location	Mass (kton)	Events @ 10 kpc	Status
Super-K	Water	Japan	32	8000	Running (SK IV)
LVD	Scintillator	Italy	1	300	Running
KamLAND	Scintillator	Japan	1	300	Running
Borexino	Scintillator	Italy	0.3	100	Running
IceCube	Long string	South Pole	(600)	(10^6)	Running
Baksan	Scintillator	Russia	0.33	50	Running
Mini-BooNE	Scintillator	USA	0.7	200	(Running)
HALO	Lead	Canada	0.079	20	Running
Daya Bay	Scintillator	China	0.33	100	Running
NOvA	Scintillator	USA	15	3000	Turning on
SNO+	Scintillator	Canada	1	300	Under construction
MicroBooNE	Liquid argon	USA	0.17	17	Under construction
LBNE	Liquid argon	USA	34	3000	Proposed
Hyper-K	Water	Japan	540	110,000	Proposed
JUNO	Scintillator	China	20	6000	Proposed
RENO-50	Scintillator	South Korea	18	5400	Proposed
PINGU	Long string	South pole	(600)	(10^6)	Proposed

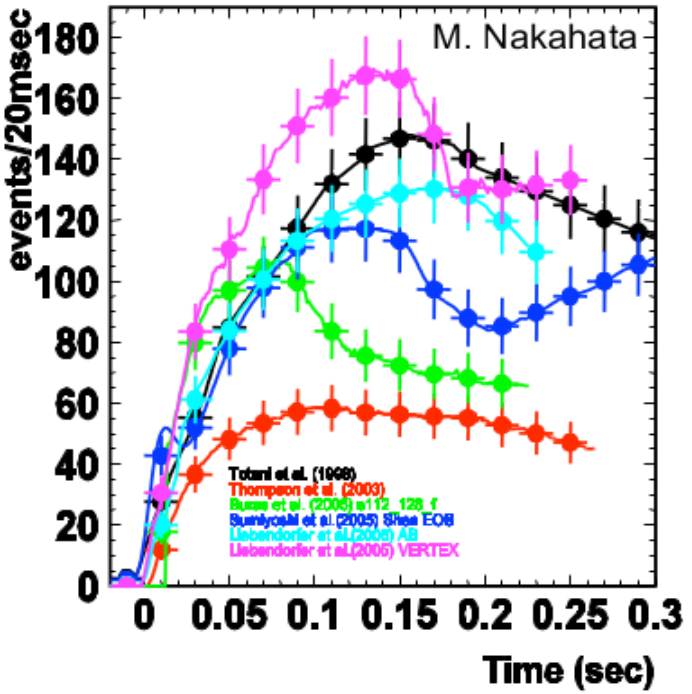
plus reactor experiments, DM experiments...

Cherenkov detector

Supernova signal in a water Cherenkov detector



Simulation for 100 kton @ 10 kpc

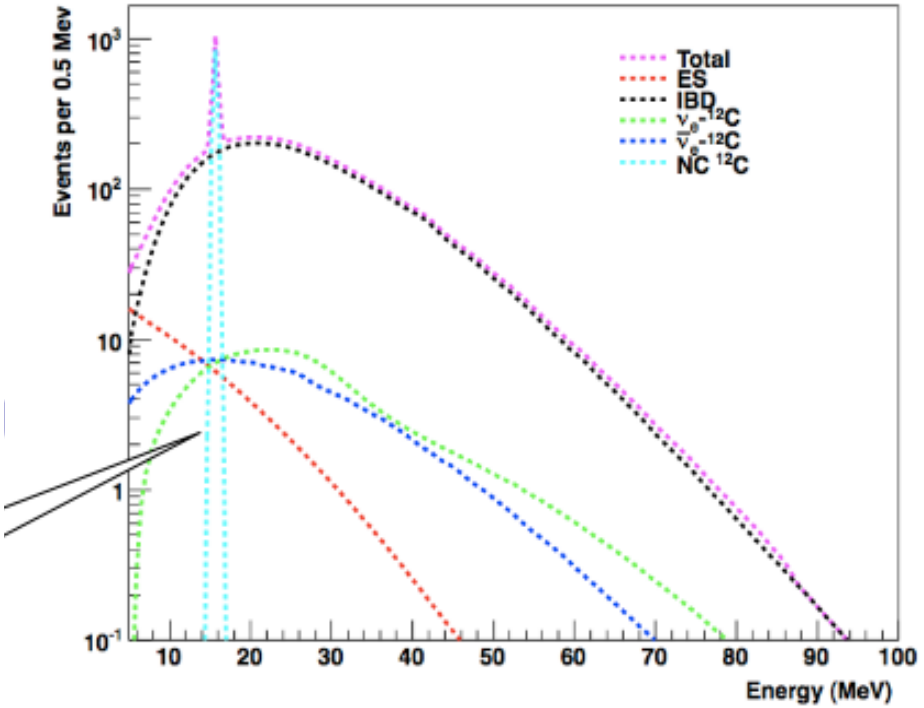


Events vs time for SK for different models

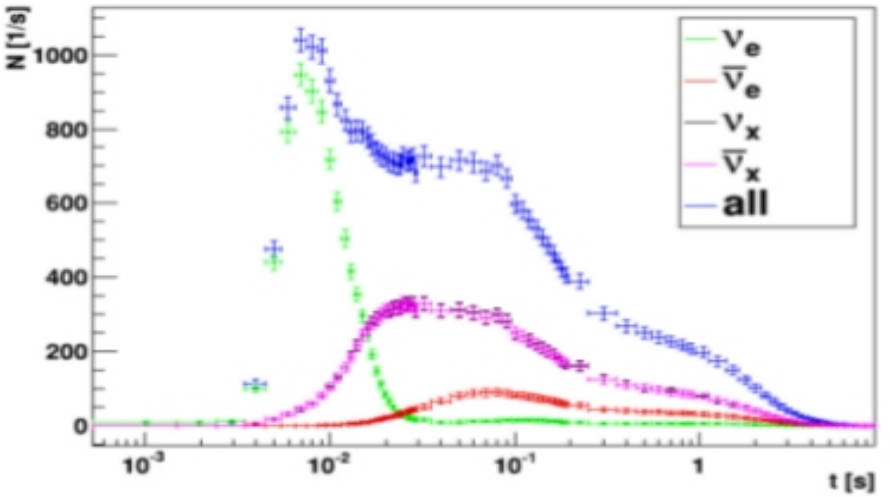
- Mainly sensitive to IBD (anti-nu).
- Optimized to point out to the source (from nue elastic scattering).
- Fast timing (ns), rough energy resolution.

Scintillator detector

- Low energy threshold with good energy resolution
- Good neutron tagging (when doped w/ Gd)
- Improvements in coherent elastic NC scattering sensitivity
- No good pointing capability
- Time signal (10 ms for nue)

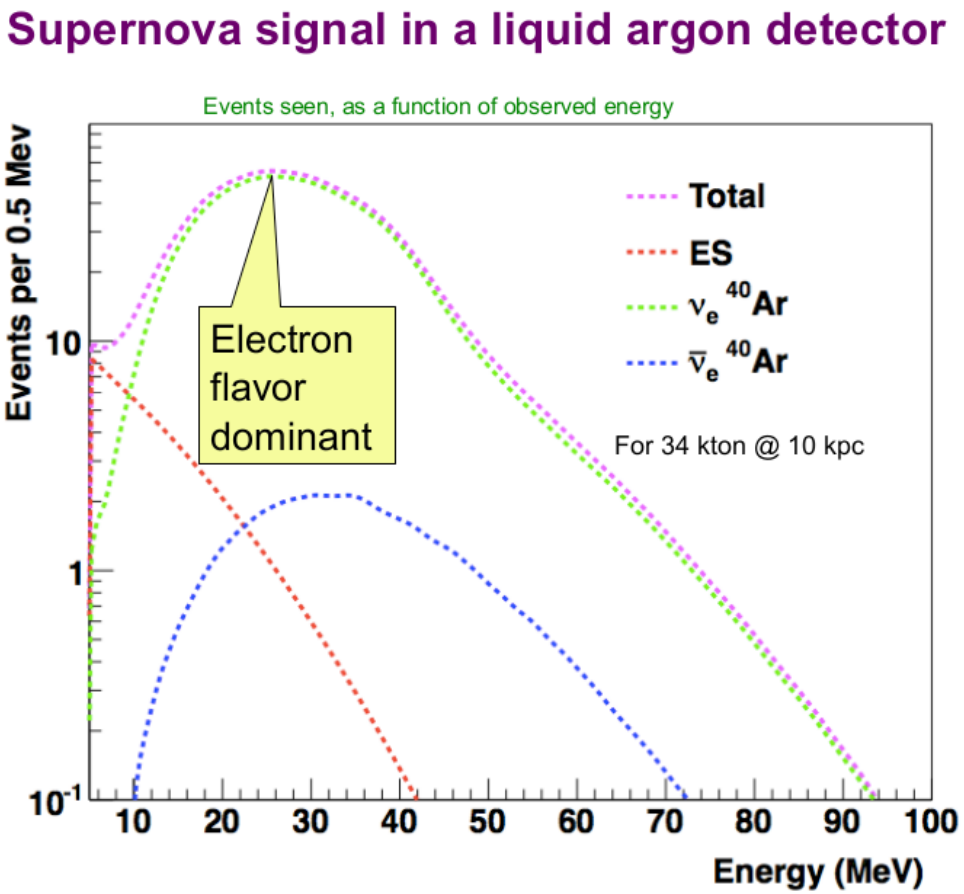


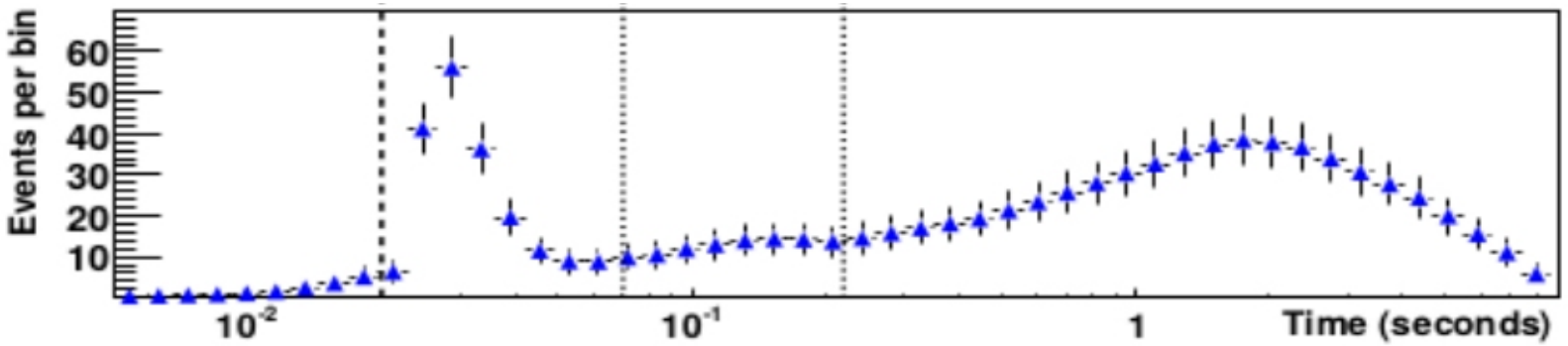
50 kt @ 10 kpc



Liquid Argon TPC

- Fine grained tracking
- High cross section for ν_e CC
- Sensitive to NC interactions of all ν flavors
- Slow (ms) timing
- Energy resolution (> 3 MeV)

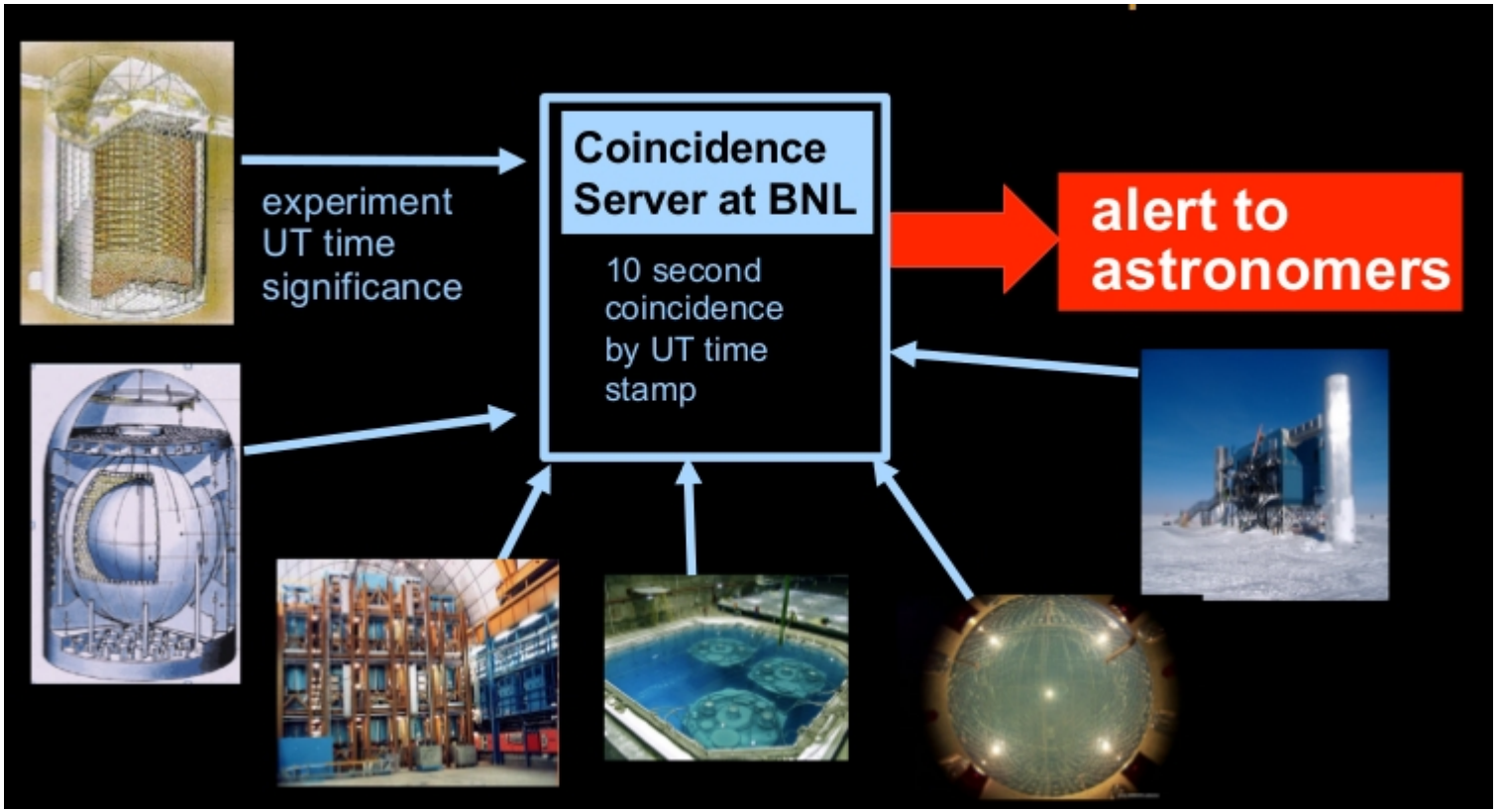




SNEWS: SuperNova Early Warning System

- Neutrinos come before photons by hours (or even days).
- Looking for ~ 1 SN/century.
- For promptness, require **coincidence** to suppress false alerts.

- A real SN neutrino front will show up in **more than more detector**, noise will not.
- Running smoothly for more than 10 yr, automated since 2005
- Amateur astronomy connection.

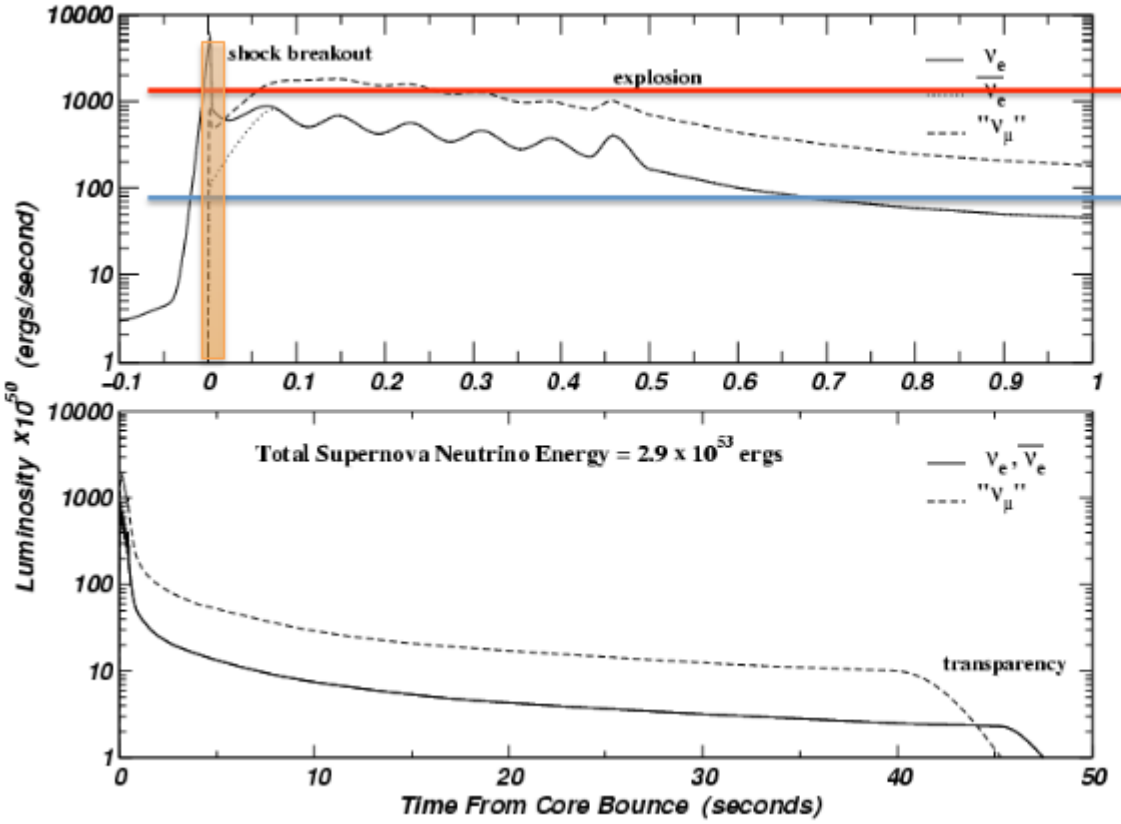


DDT : Data Driven Triggers

- *Save data based on characteristic neutrino signatures.*
- Simple activity triggers
  - Singleton, **double rates**, …
- Simple patt. rec.
  - Lines w/
    - Directionality
    - Timing
    - dE/dx
  - Simple “blobs” w/
    - ADC sums
- One idea for Supernova:
  - Look for unusual overall rates (doublets) to save data in case of exploding star
- Require:
  - Online (fast) analysis
  - Reliable and “simple”
  - Run on **buffer nodes**

Supernova triggers

- Double rates



peak rate threshold

tail rate threshold

peak time duration threshold (100TDC)

- Counting
  - Trigger counts number of neutrino interactions with energy cuts and send this info with timestamp

Conclusions

- Q: Which technology is best suited for the task and why?
  - A: There is **no best** technology, but a **gathering** of **technologies** in a detector for a single experiment, or several experiments using different technologies each.

- Q: What detector characteristics are desirable?
- A: Good **energy** and **timing resolution** in addition with a **big size**.

- Q: On trigger and DAQ?
- A: "second-by-second information about the emitted neutrinos, in different channels" requires **reliable** collection of data and **smart triggering** system (state of the art **computing**)

- Q: Global?
- A: **Yes!** it reduces **false alarms** and provide a sense of **community**.

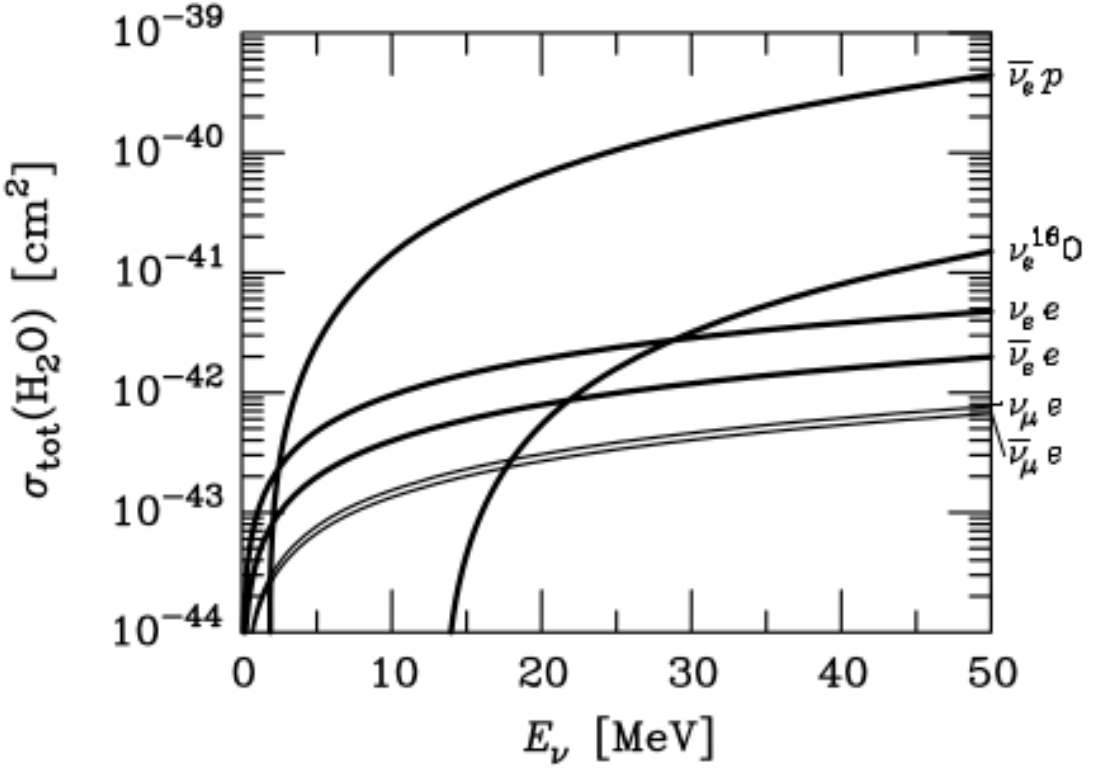
SNAP! team members:

Victor Basto
Akshay Katre
Andrea Mandarano
Daria Santone
Jose Sepulveda
Katherine Woodruff
Laura Zani

Back-Up

Cherenkov Technology

Neutrino cross section per water molecule in a Cherenkov detector



- A factor of 2 for protons and 10 for electrons is already included.
- A SN neutrino signal is primarily detected by inverse beta decay.

Neutrinos from SN 1987A

Energy release of neutrino signal in function of time, for different detectors

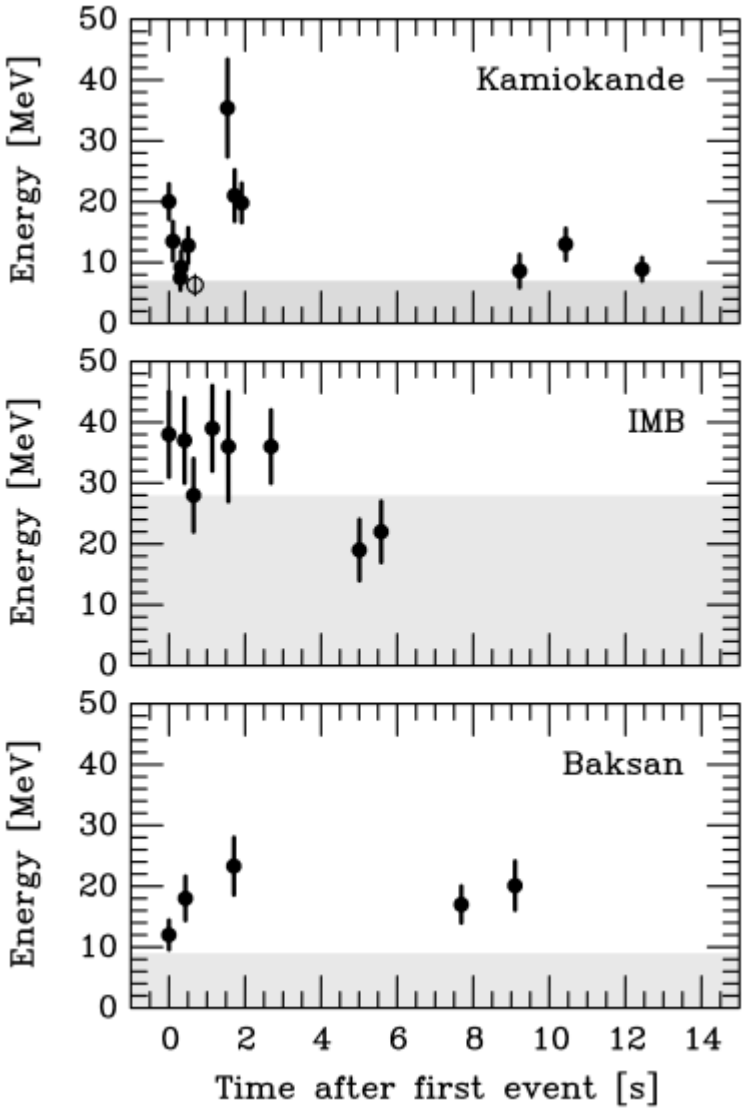
•SN 1987A neutrino observations at Kamiokande [155, 156], IMB [157, 158] and Baksa n[159, 160].

•The energies refer to the secondary positrons from IBD.

• In the shaded area the trigger efficiency is less than 30%. IMB was not optimized or low energy neutrinos detection

•The clock uncertainties are reported to be ±1 min in Kamiokande, ±50 ms in IMB, and +2/−54 s in BST; in each case the first event was shifted to t = 0.

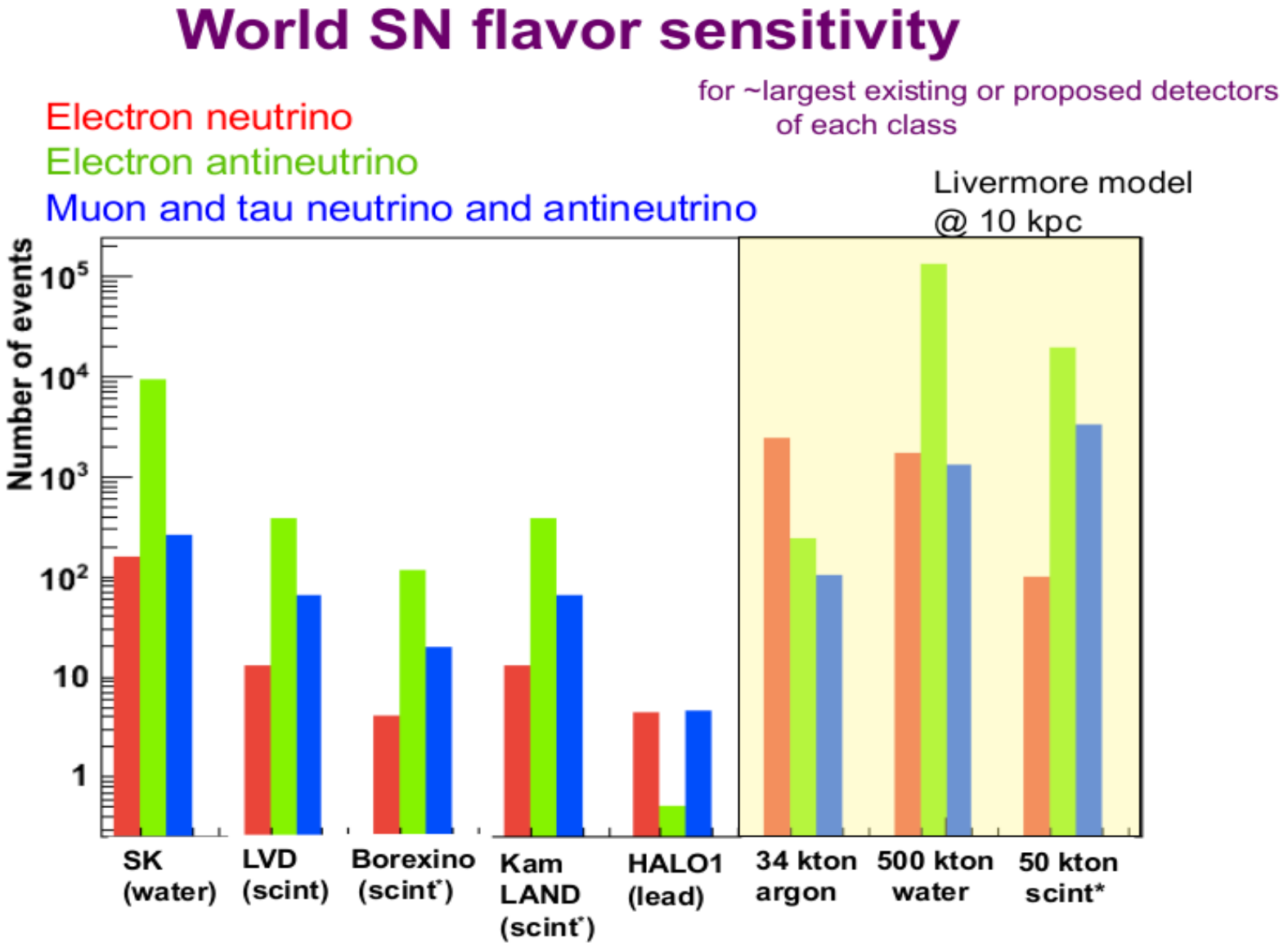
•In Kamiokande, the event marked as an open circle is attributed to background.



Summary technologies

- State of the art (as **2012**)

TABLE IX. – *Existing and near-future SN neutrino detectors and event rates for a SN at 10 kpc, emission of* 5×10^{52} erg *in* $\bar{\nu}_e$*, average energy 12 MeV, and thermal energy distribution. For HALO and ICARUS, the event rates depend on assumptions about the other species. For references and details see Ref. [173] .*

Detector	Type	Location	Mass [kt]	Events	Status
IceCube	Ice Cherenkov	South Pole	0.6/OM	10^6	Running
Super-K IV	Water	Japan	32	7000	Running
LVD	Scintillator	Italy	1	300	Running
KamLAND	Scintillator	Japan	1	300	Running
SNO+	Scintillator	Canada	1	300	Commissioning 2013
MiniBOONE	Scintillator	USA	0.7	200	Running
Borexino	Scintillator	Italy	0.3	80	Running
BST	Scintillator	Russia	0.2	50	Running
HALO	Lead	Canada	0.079	tens	Almost ready
ICARUS	Liquid argon	Italy	0.6	200	Running

Sensitivity by experiment