

Supernova and solar neutrinos: the present and the future

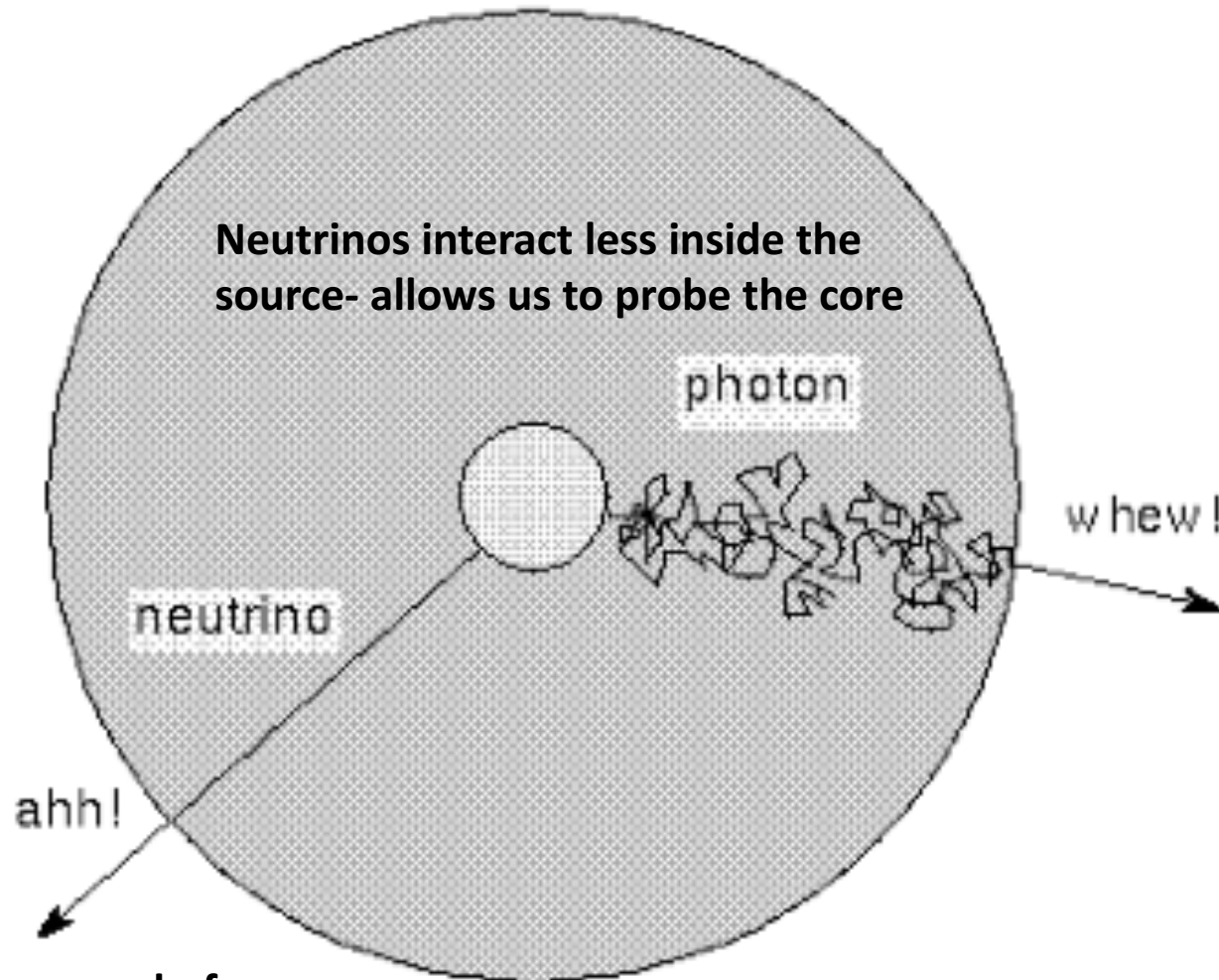
Erin O'Sullivan

Stockholm University, Oskar Klein Centre

NNN 2018 – Vancouver

With X-rays, which penetrate much more than ordinary light, you can see inside your hand. With neutrinos, which penetrate much more even than x-rays, you can look inside the Sun.

- Ray Davis Jr, Nobel Ceremony 2002



Neutrinos interact less inside the source- allows us to probe the core

photon

neutrino

ahh!

whew!

Neutrinos escape before photons – can provide early warning!

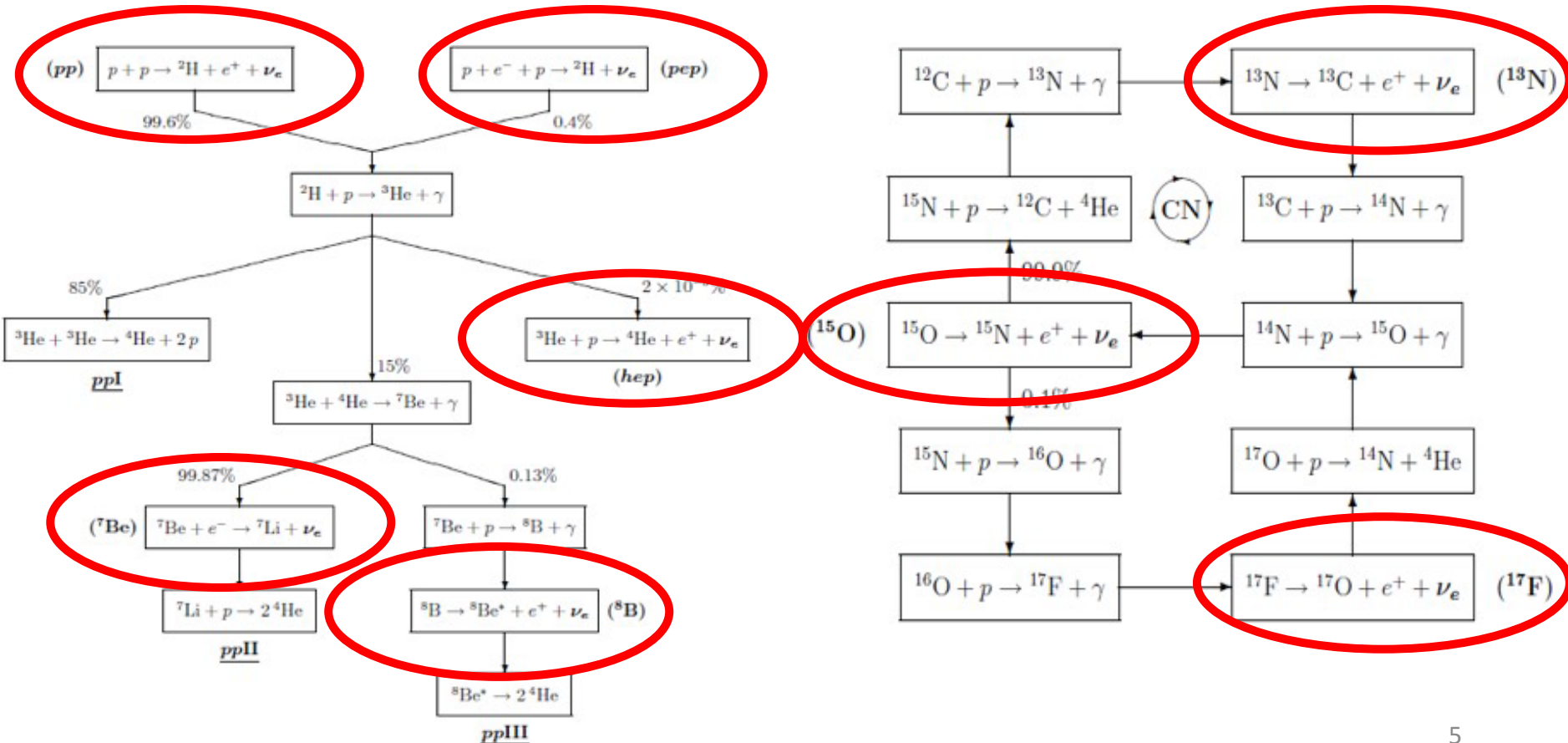


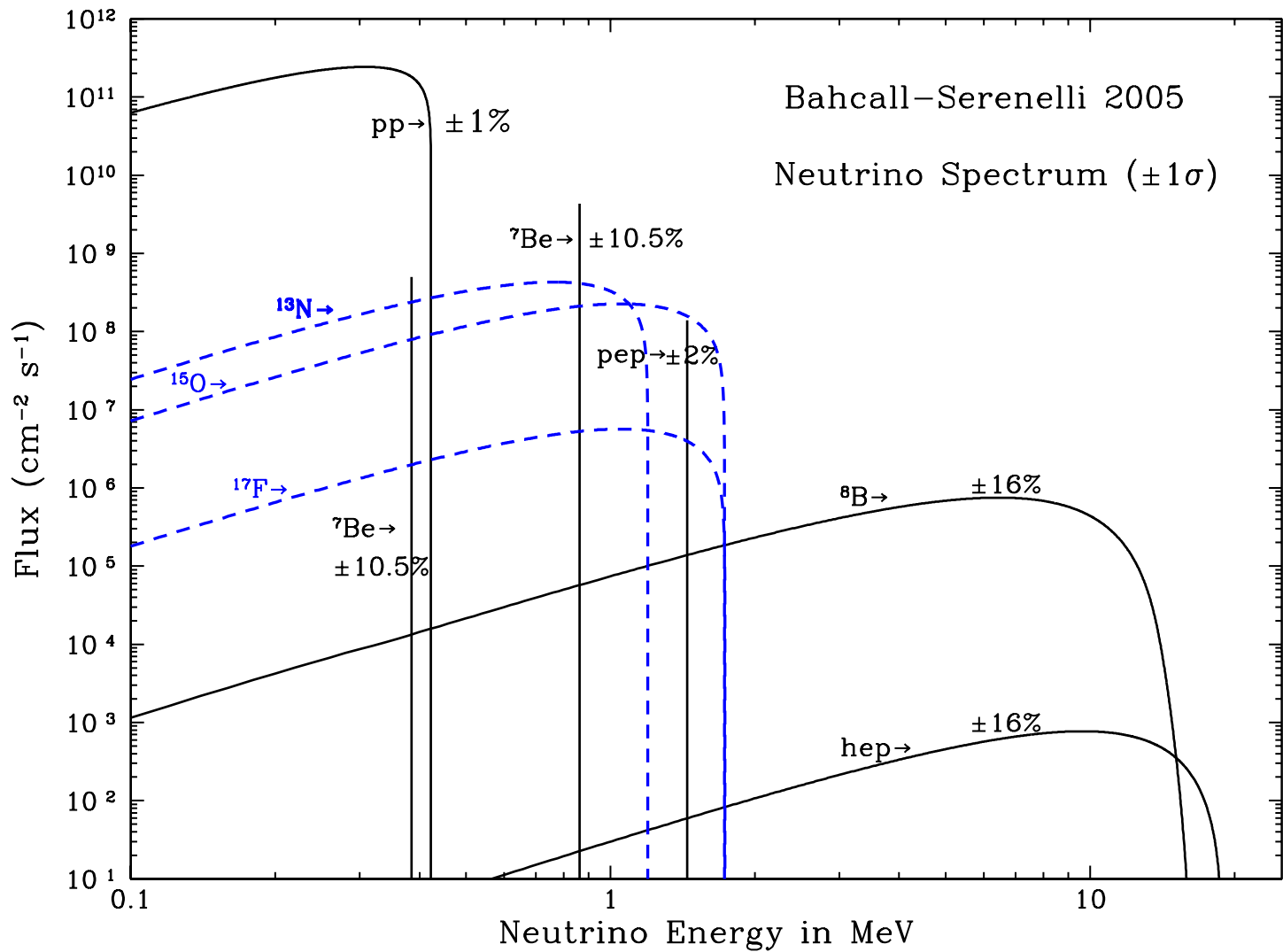
Solar neutrinos

Solar neutrinos are produced in thermonuclear reactions

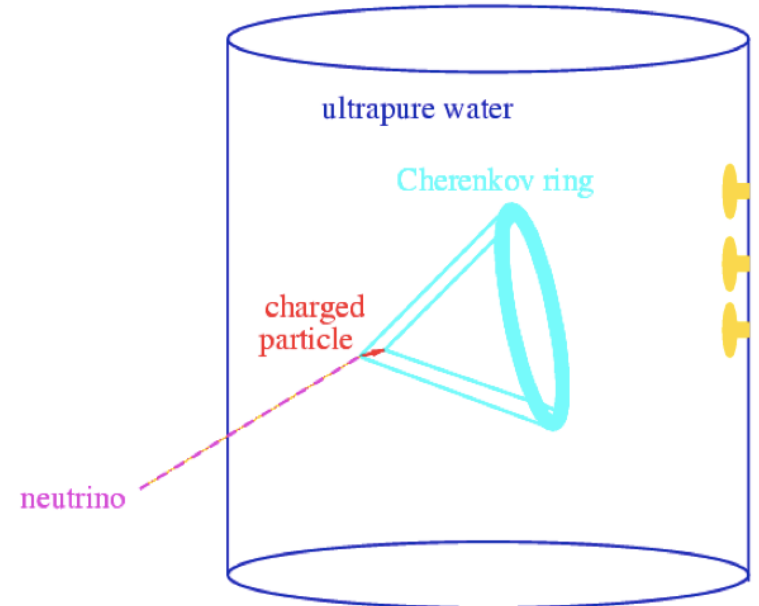
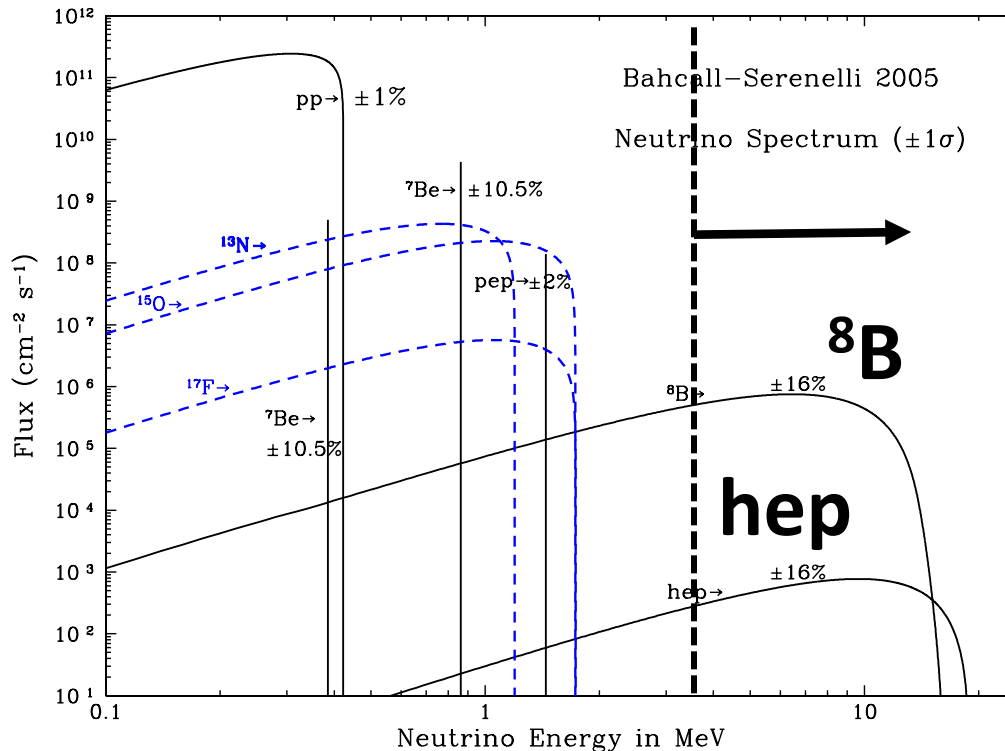
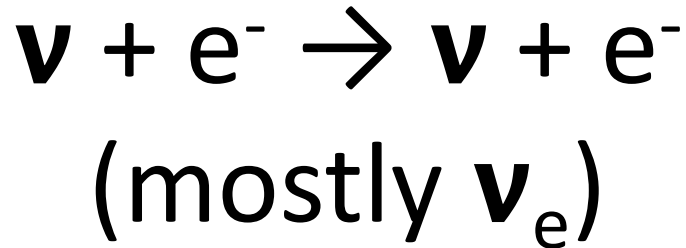
pp chain

CNO cycle





Water Cherenkov detectors make high stats measurements

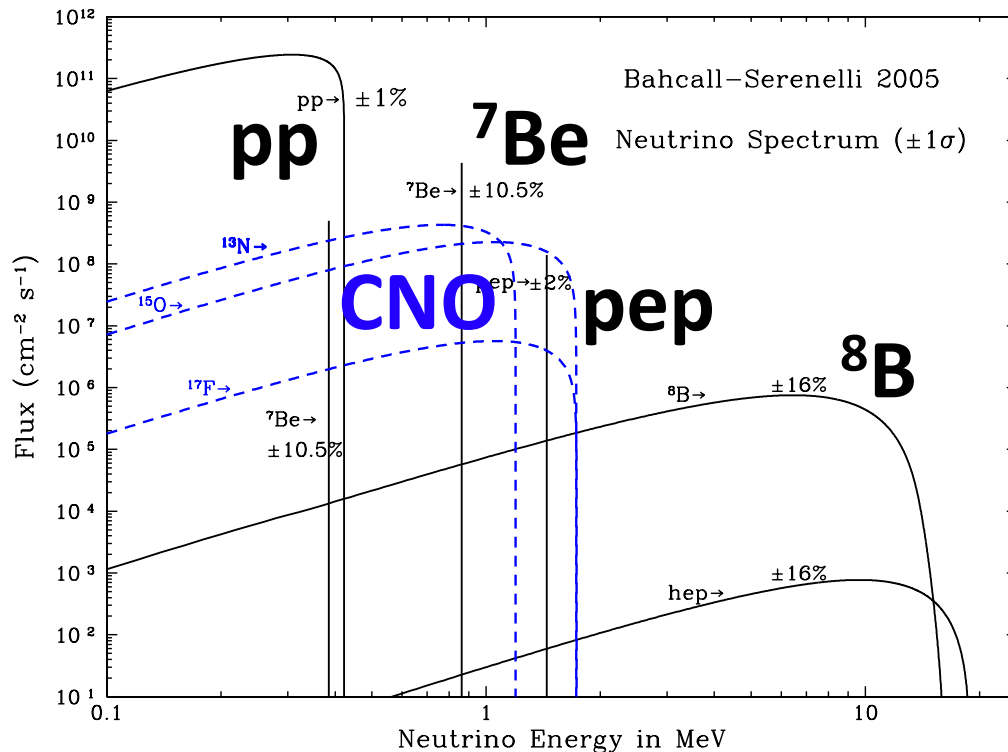
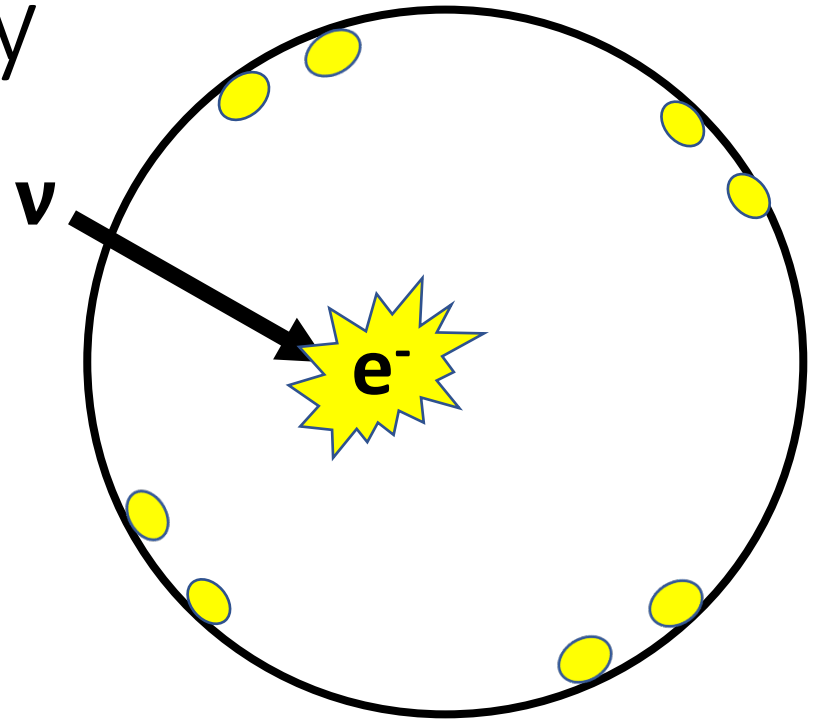


- High stats ✓
- Directionality ✓
- Low photon yield at low energies ✗

Liquid scintillator detectors measure low energy

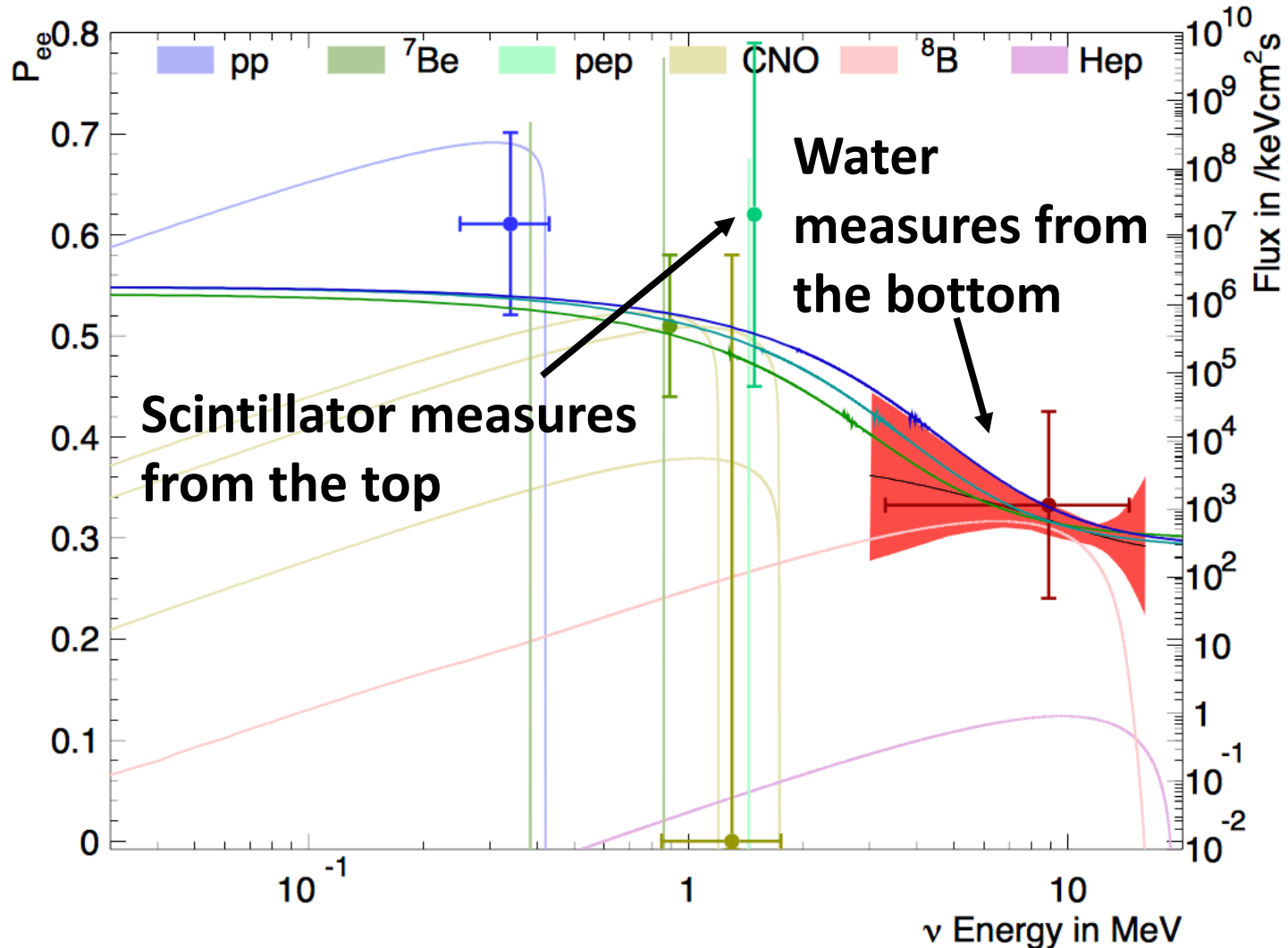
$$\nu + e^- \rightarrow \nu + e^-$$

(mostly ν_e)



- Lower stats ✘
- No directionality ✘
- High photon yield at low energies ✔

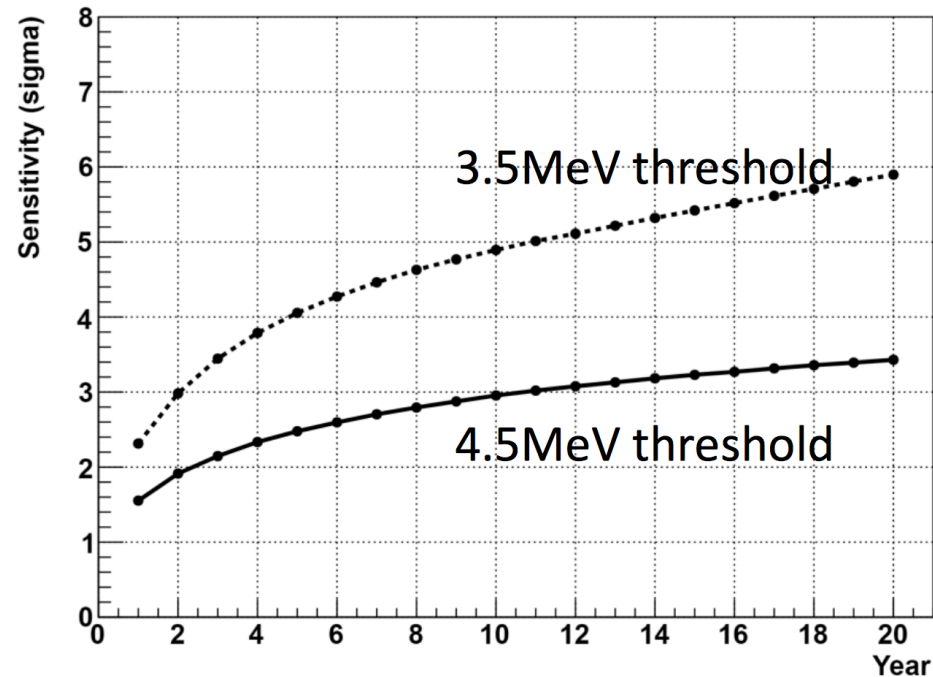
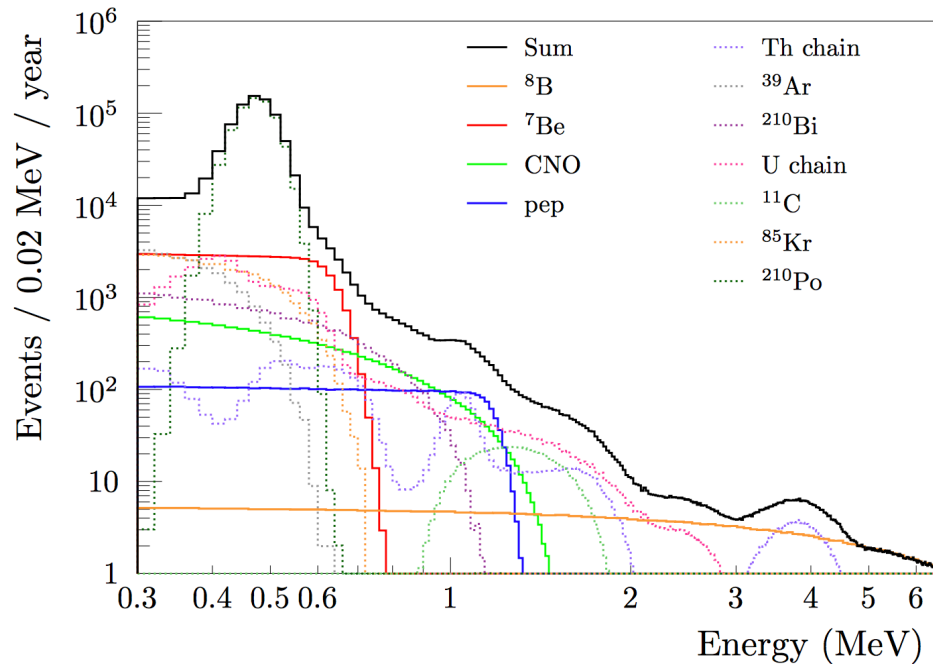
Complementary approaches to measuring the solar upturn/transition



Looking ahead: Transition region

Andringa+ 2016

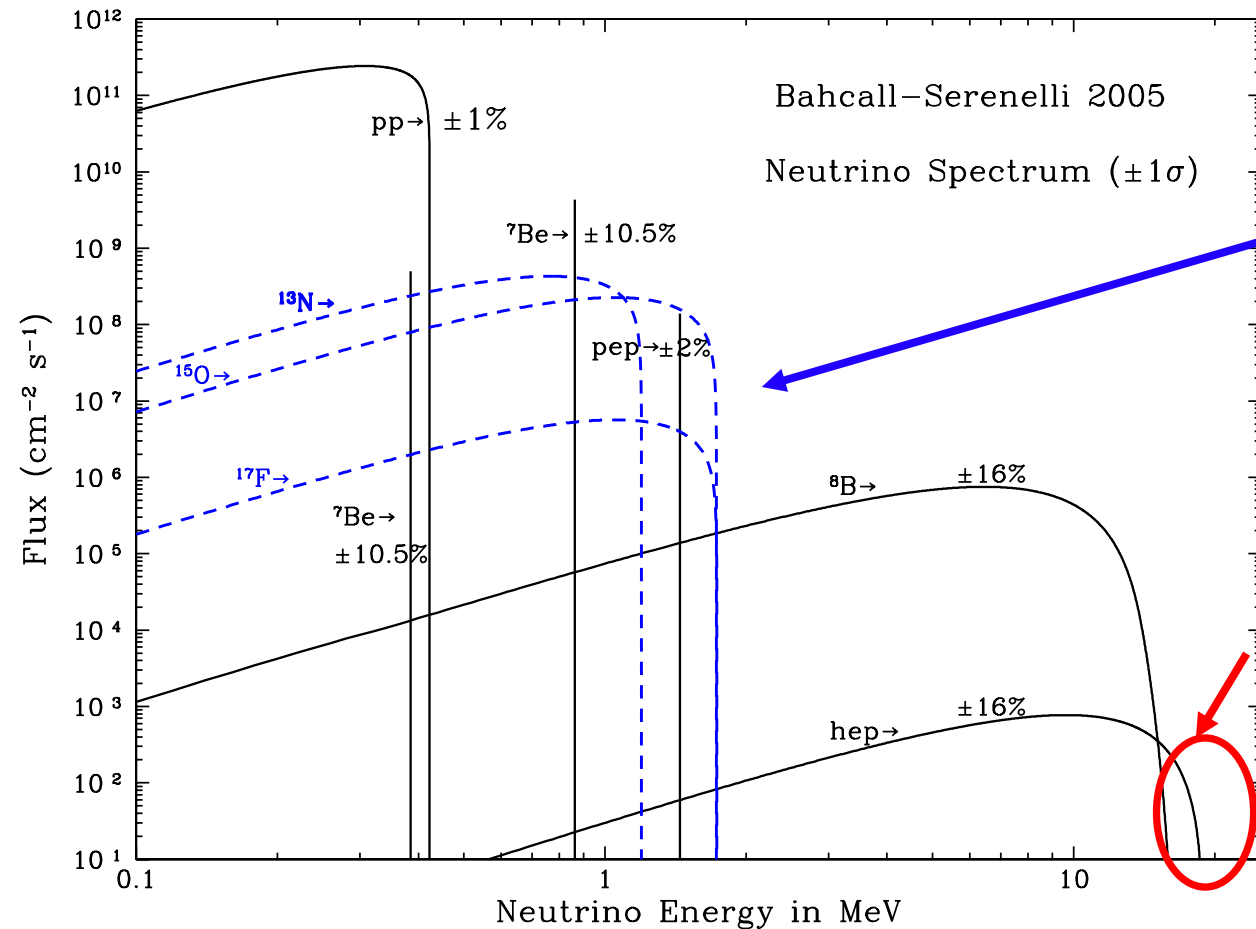
HK design report, arXiv: 1805.04163



SNO+ has the potential to measure pep neutrinos to 10% uncertainty in 1 year (depending on backgrounds)

Hyper-K will measure the upturn with 3-5 σ significance

Measuring the last unknowns of the solar neutrinos



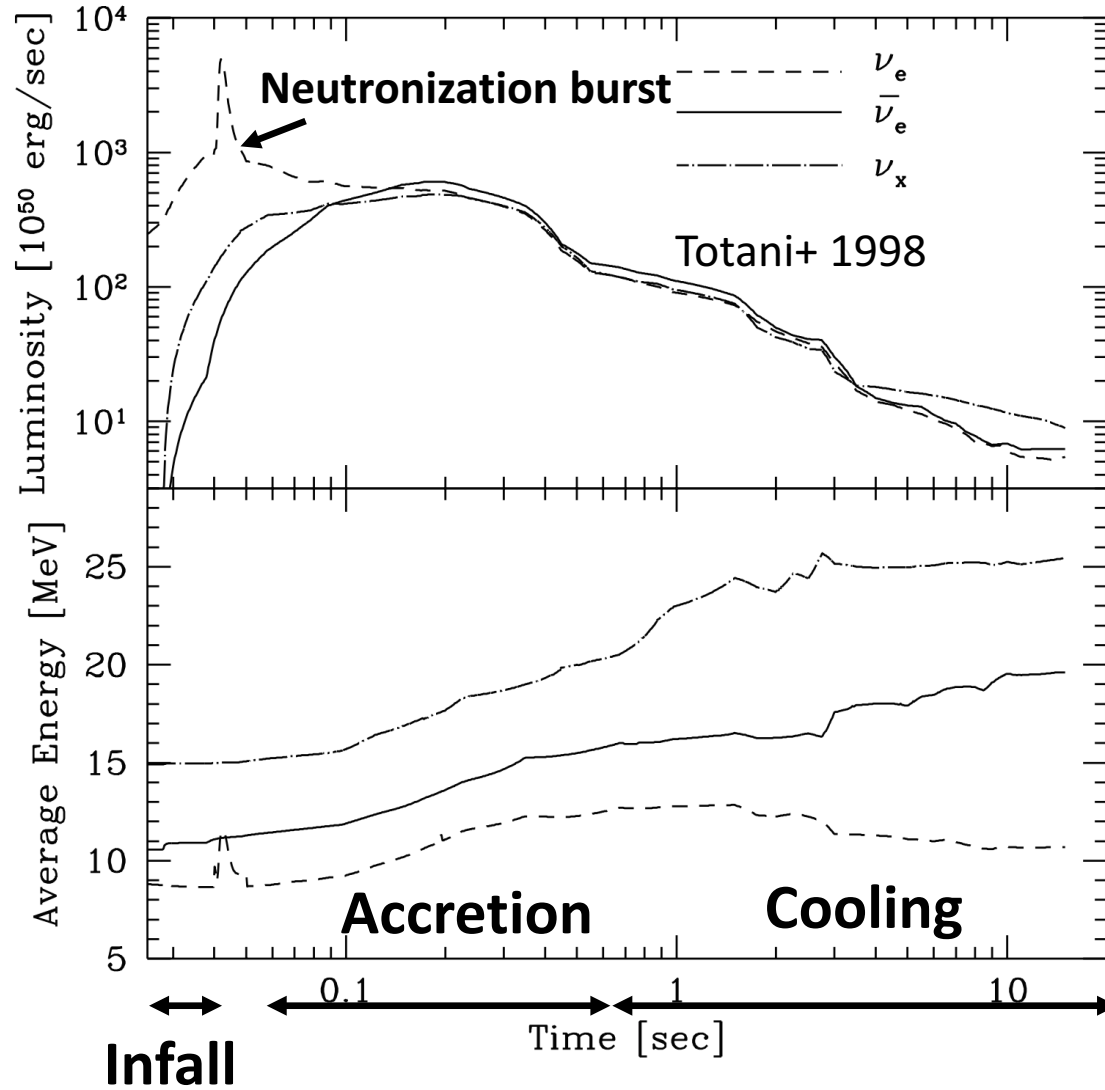
CNO: Low E, very dependent on backgrounds
SNO+ has potential to measure this (15% uncertainty after 1 year)

hep: Need high stats to see this bump
(potential to see this with Hyper-K $\sim 2\sigma$)



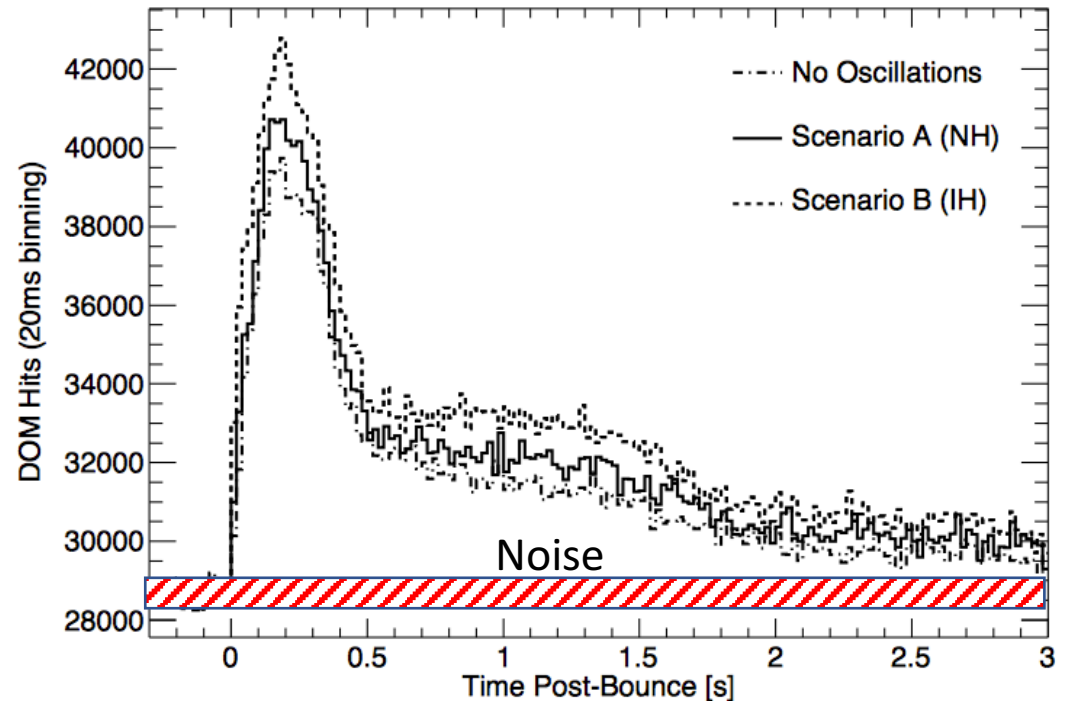
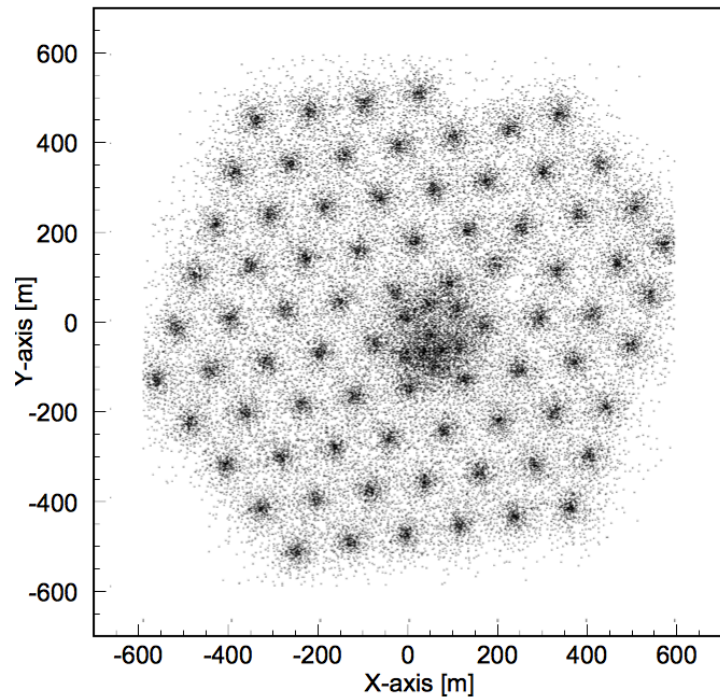
Supernova neutrinos

Thermodynamics imprinted on neutrinos



Detecting supernova neutrinos in IceCube

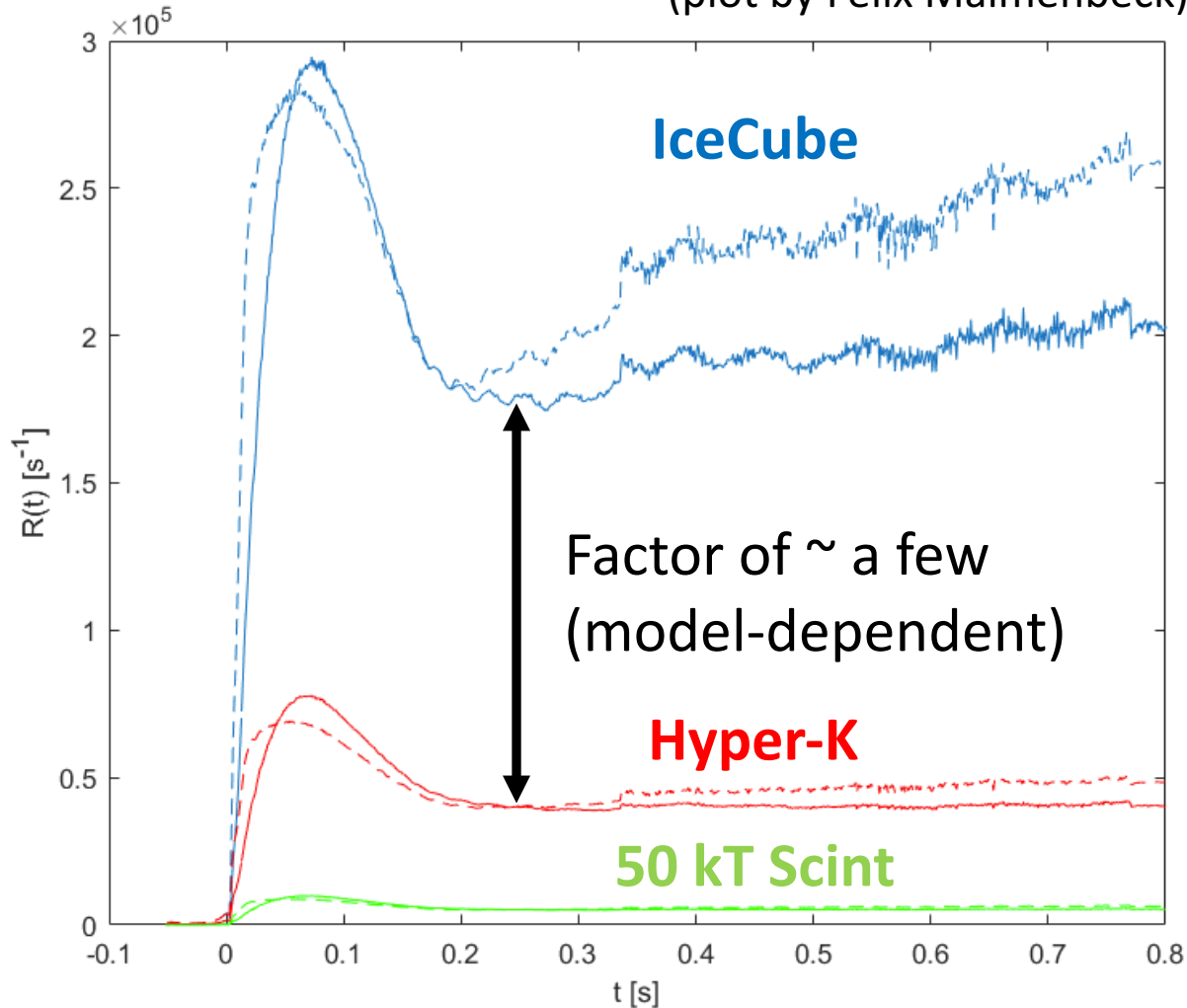
Abbasi+ 2011



Mainly inverse beta decay ($\bar{\nu}_e + p \rightarrow n + e^+$)

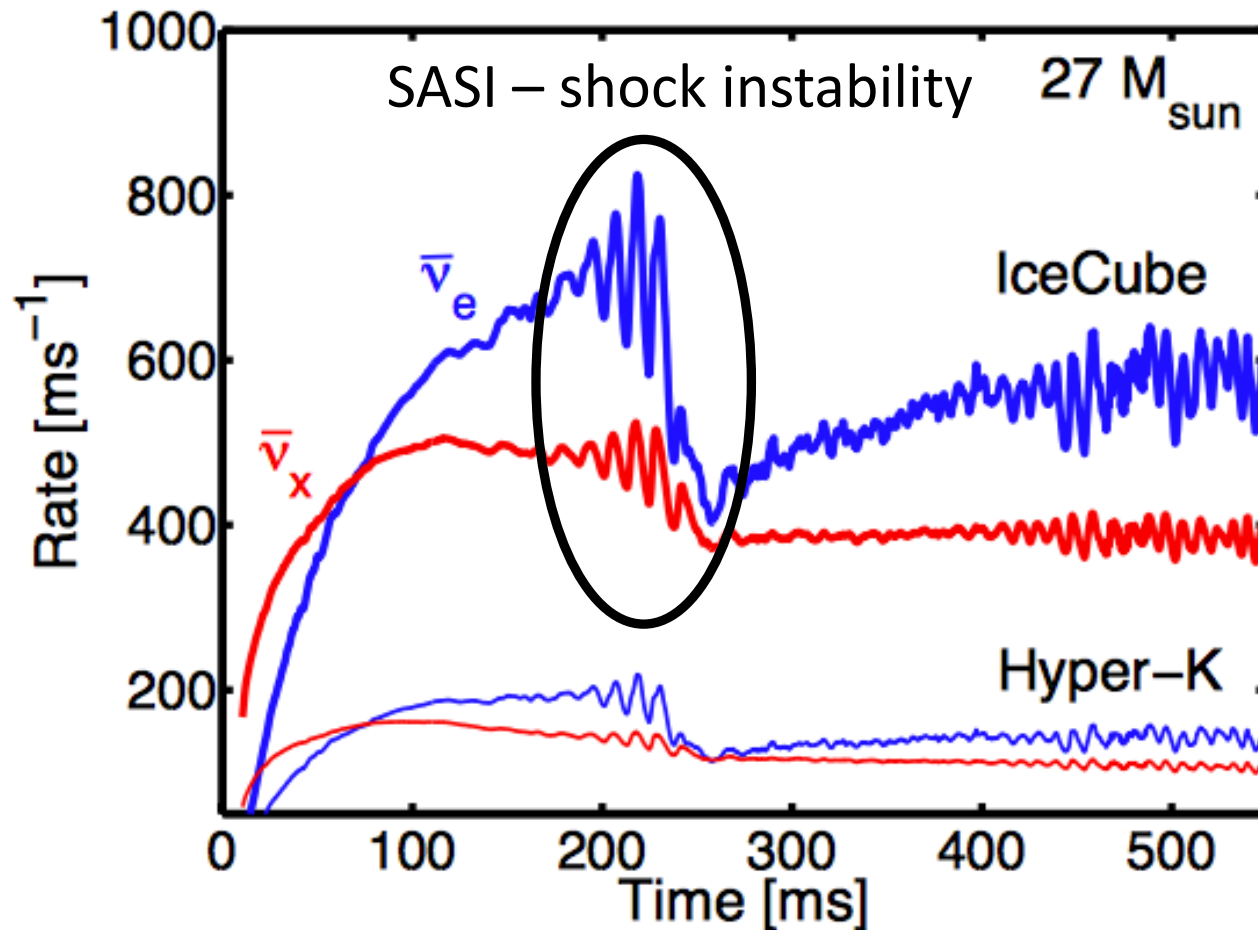
IceCube has the best neutrino rate measurement from nearby supernovae

(plot by Felix Malmenbeck)



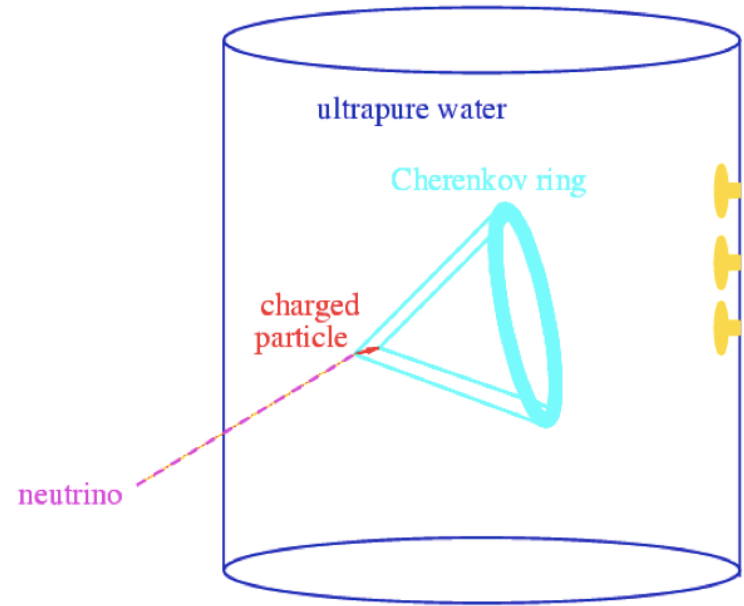
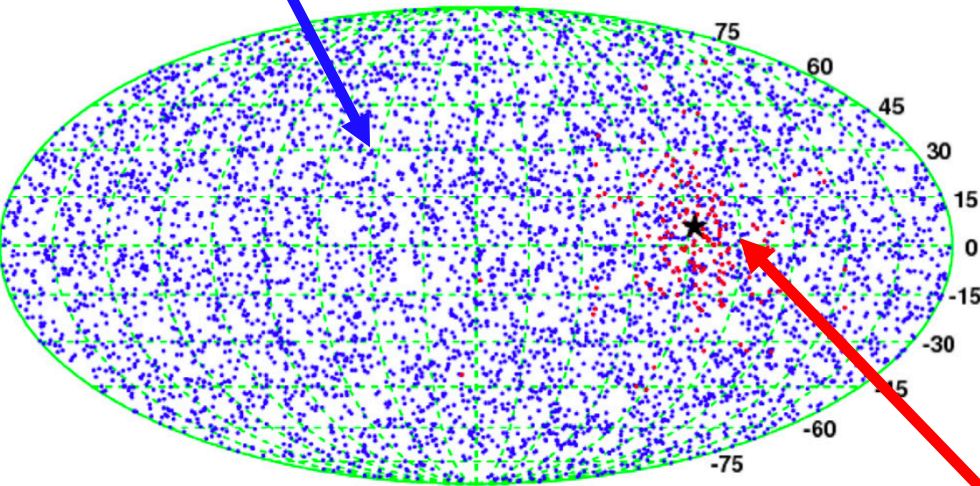
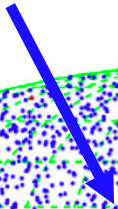
IceCube can measure features imprinted in the timing structure

Tamborra+ 14

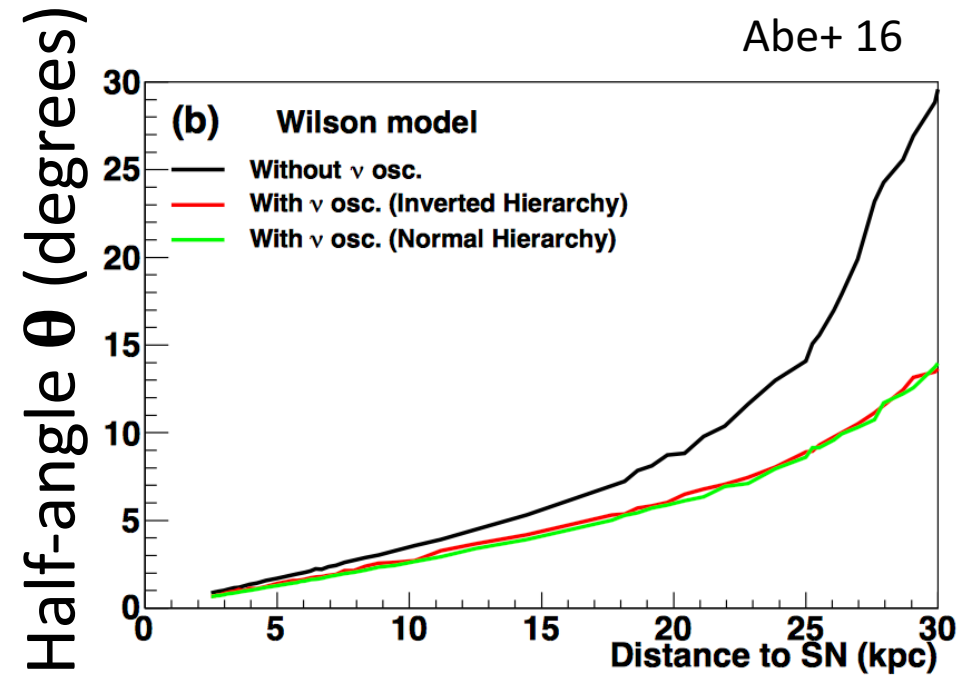


Detecting supernova neutrinos in water

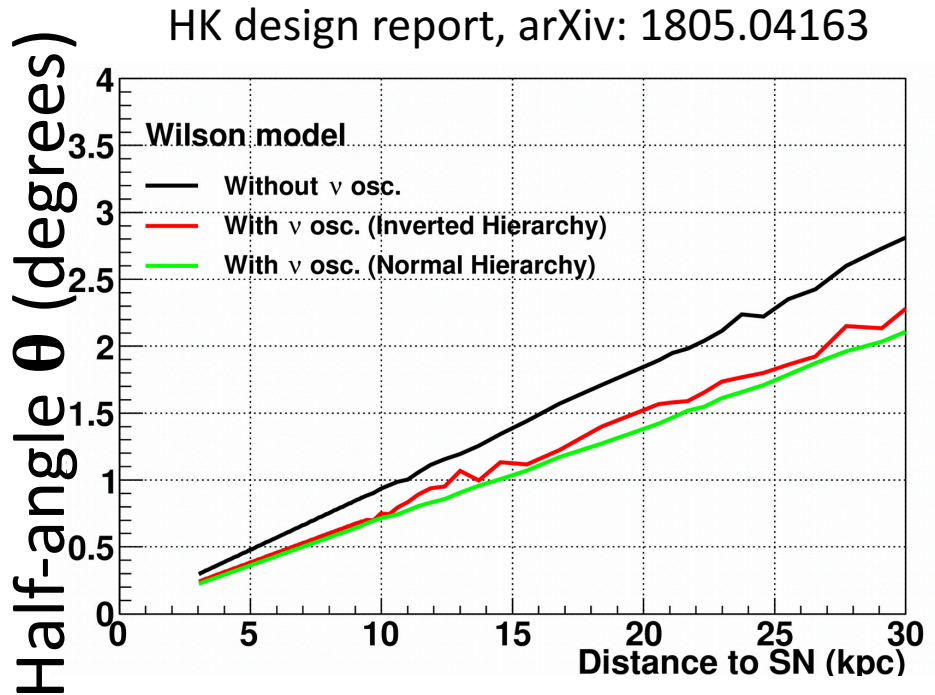
(Good stats for $\bar{\nu}_e$)



Measuring the supernova direction



Super-K can measure the direction of a SN with half angle of 3-5° @ 10 kpc (x2 times better with Gd)

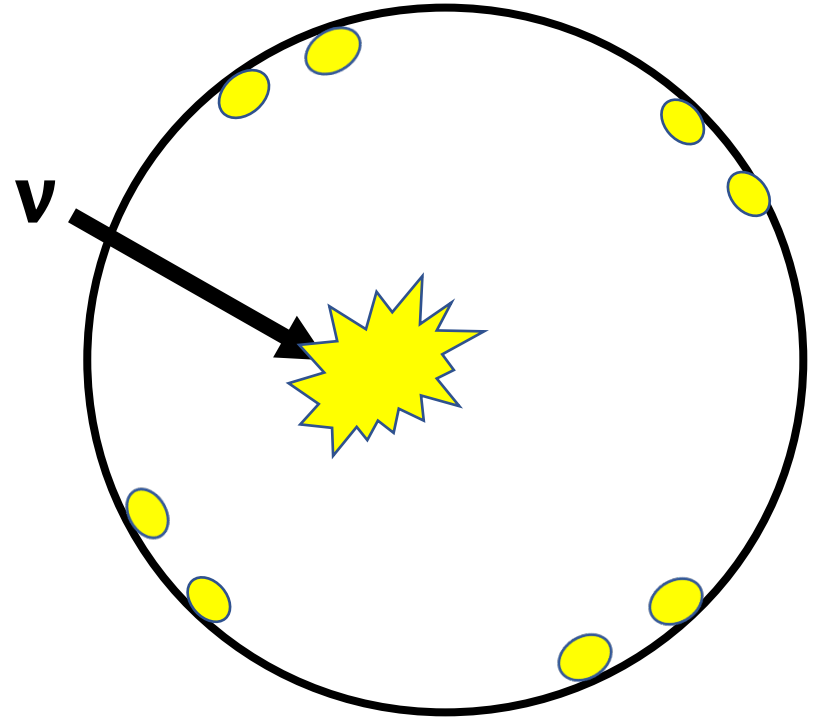
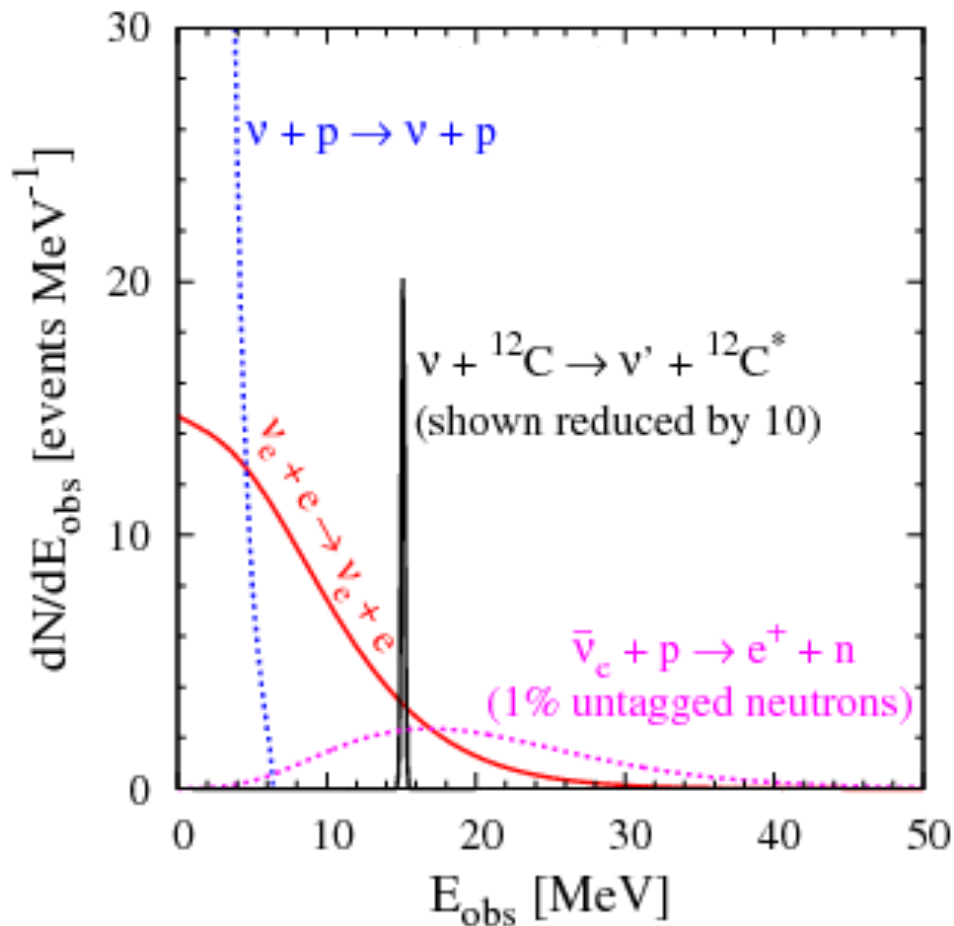


Hyper-K can measure the direction of a SN with half angle of 1-2° @ 10 kpc

Liquid scintillator detectors have unique NC channels

JUNO-like detector

Laha+ 14

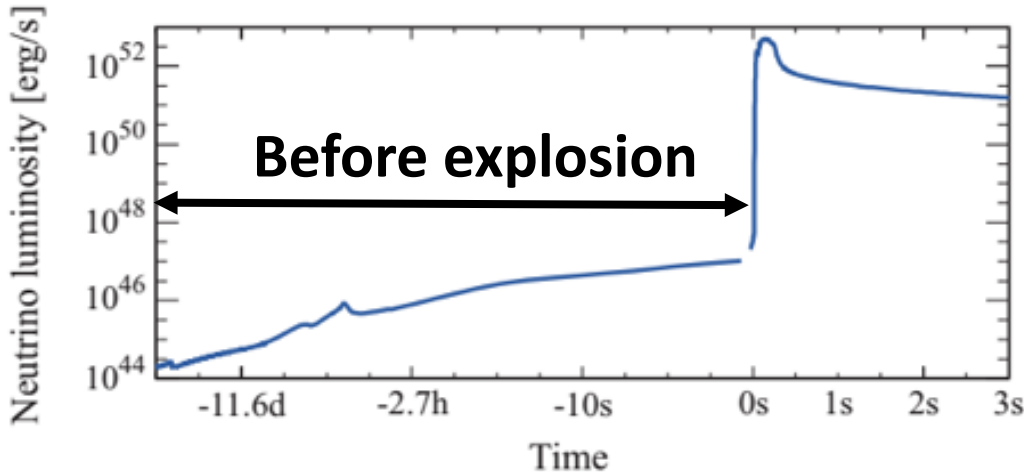


Lower stats ✘

No directionality ✘

High photon yield at low energies ✔

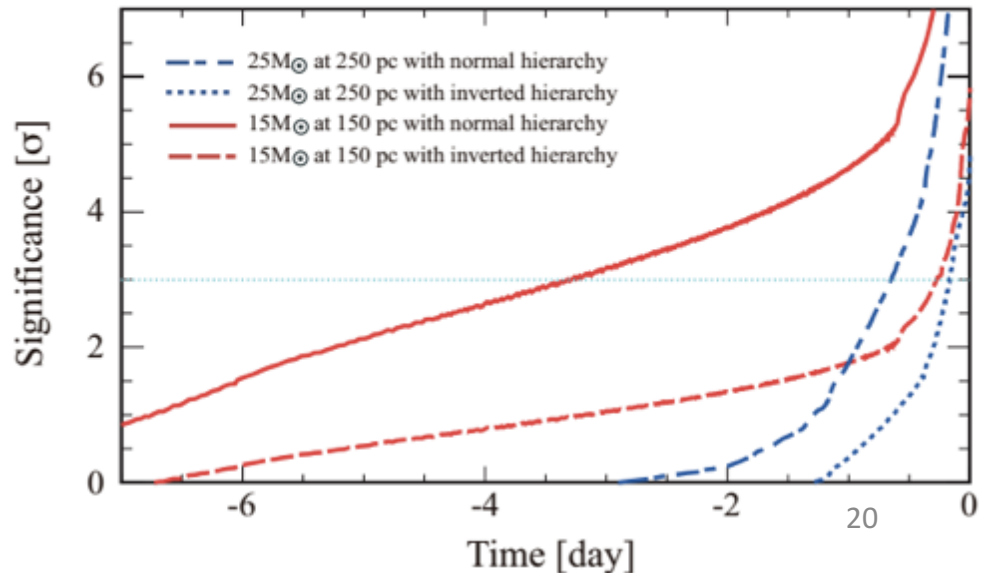
Liquid scintillator can provide an early-early warning for a supernova



Some models predict neutrino emission in the Silicon burning stage

This could give some advance warning of a (nearby) SN. Ex. for Betelgeuse in Kamland ~ 2 days

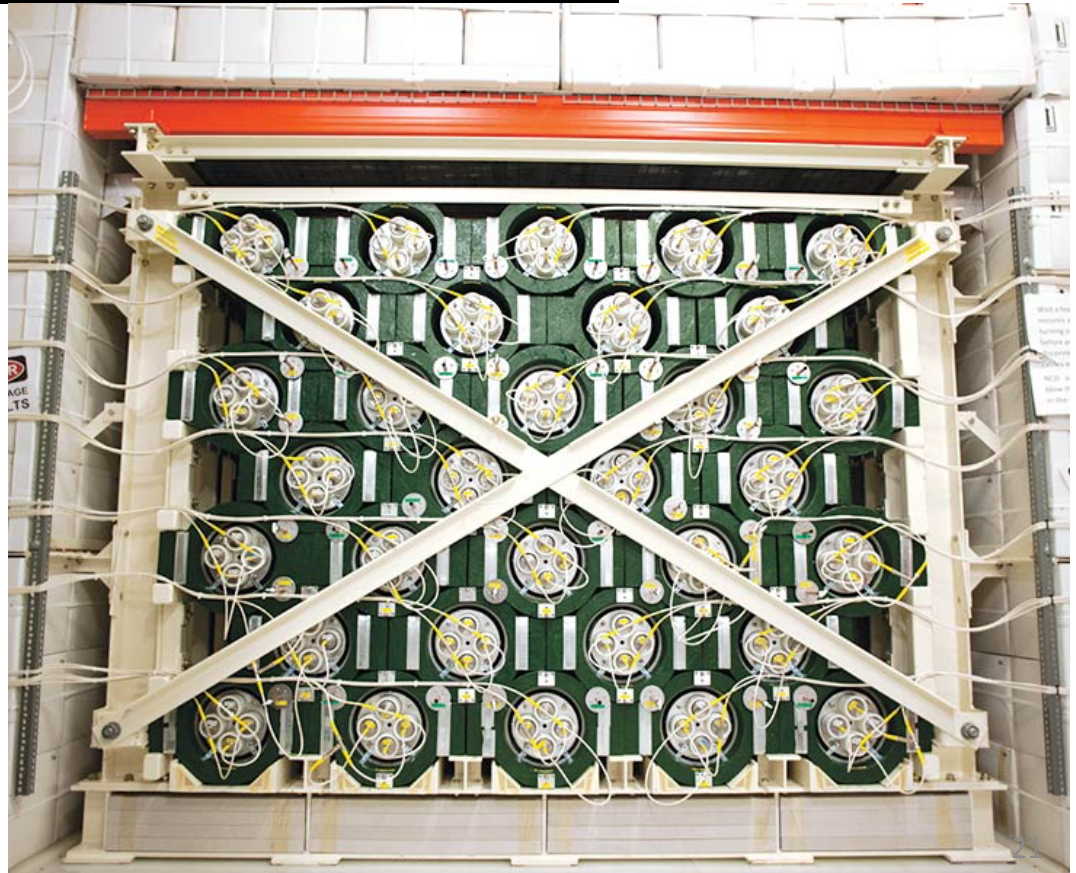
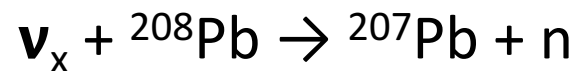
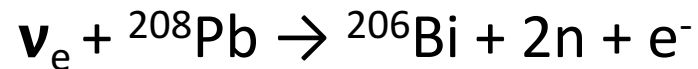
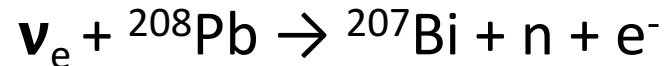
Asakura+ 2015



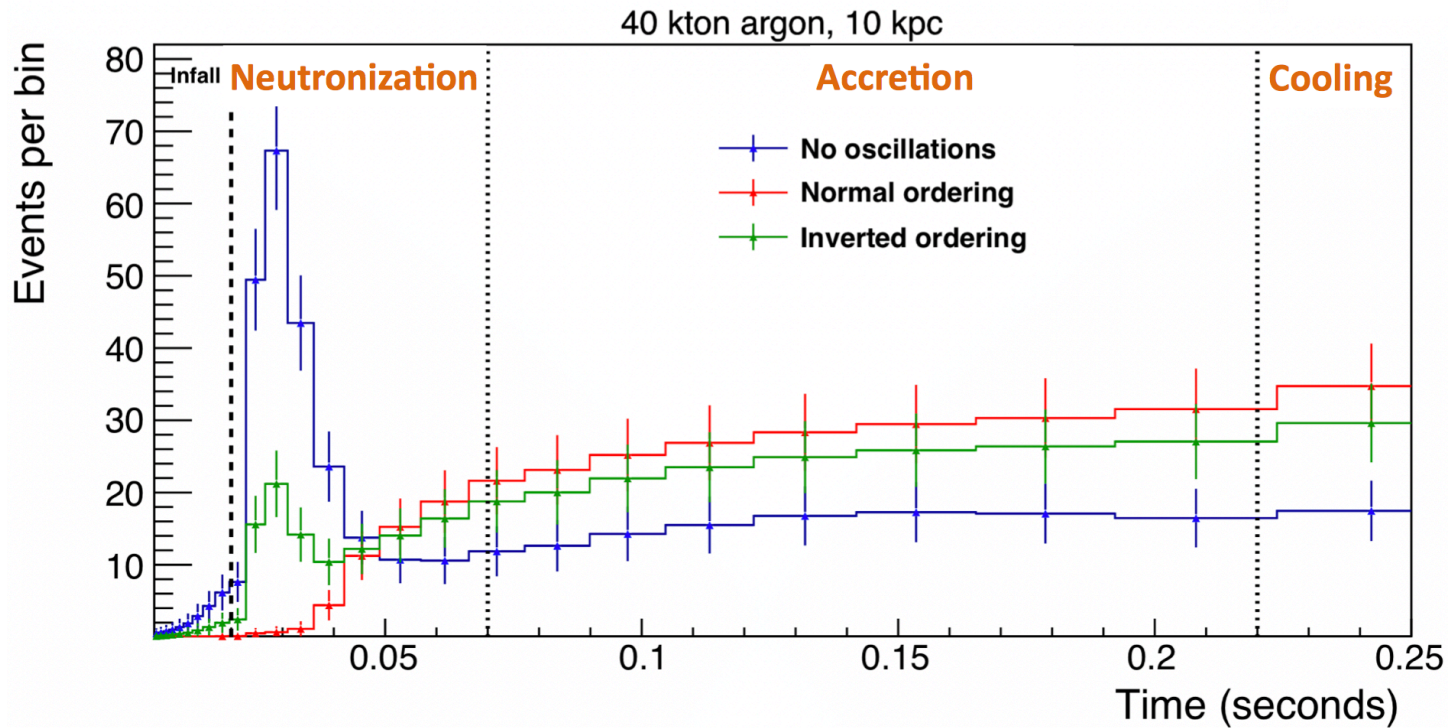
Lead measures non- $\bar{\nu}_e$ channels



Helium and Lead Observatory
Astronomically patient



Liquid argon: a ν_e measurement from nearby supernovae



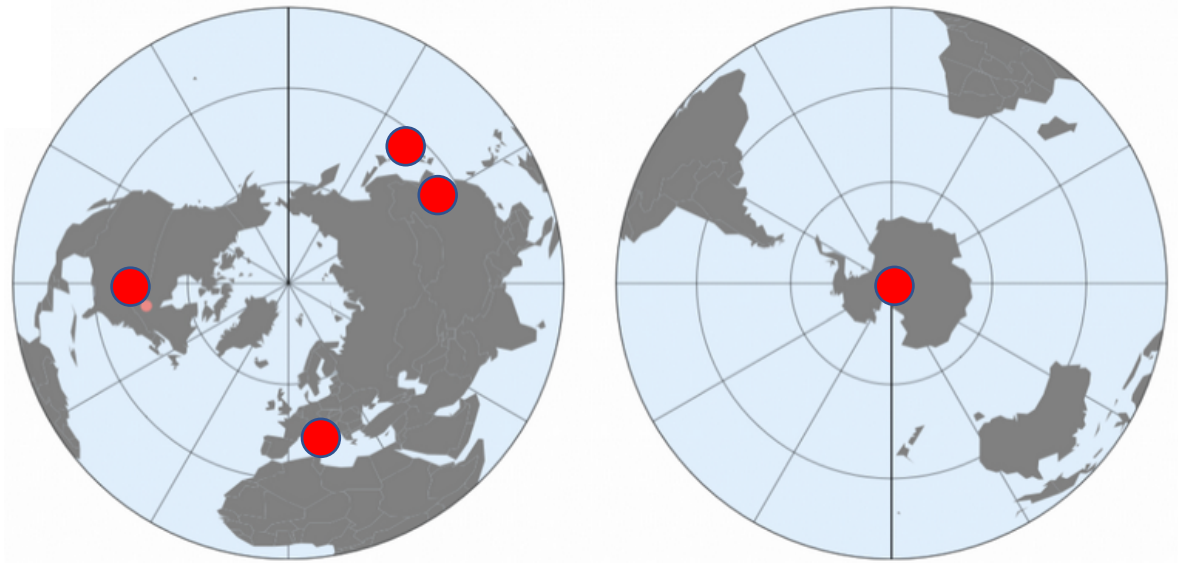
The technologies: complementarity

	Water	Ice	Argon	Lead	Scint
$\bar{\nu}_e$	✓	✓			✓
ν_e	(✓)		✓	✓	
ν_x				✓	✓
Low energy					✓
Pointing	✓				
Energy info	✓		✓		✓
How many events?	Super-K 10,000	IceCube 790,000	DUNE 3,000	HALO ~tens	SNO+ 7,000

Neutrino detectors work together to sound the alarm



Neutrino detectors connected to the SNEWS system

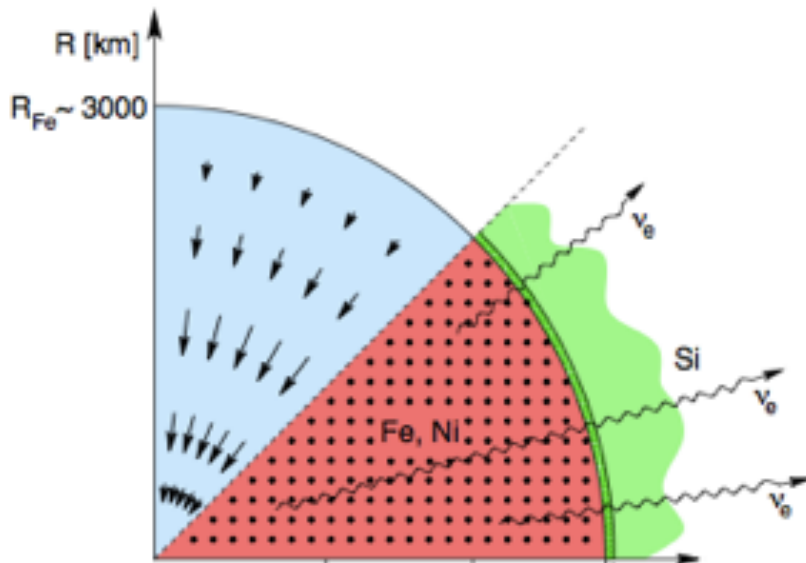


Summary

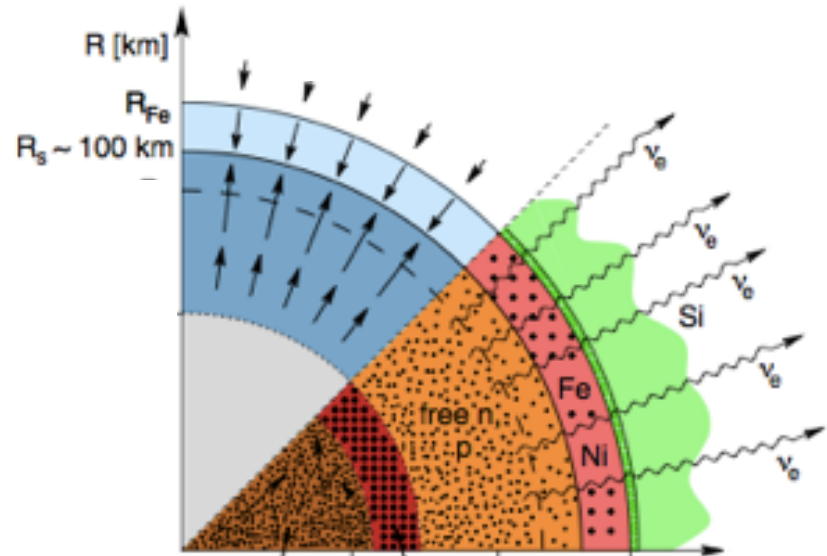
- New solar neutrino measurements with next-gen detectors will look for new physics, particularly in the vacuum-matter transition region, and will look for the remaining unmeasured solar neutrinos
- Using the entire suite of technologies available to measure supernova neutrinos will allow us to capitalize on this once-in-a-lifetime event

Early supernova explosion produces mostly ν_e

Infall



Neutronization

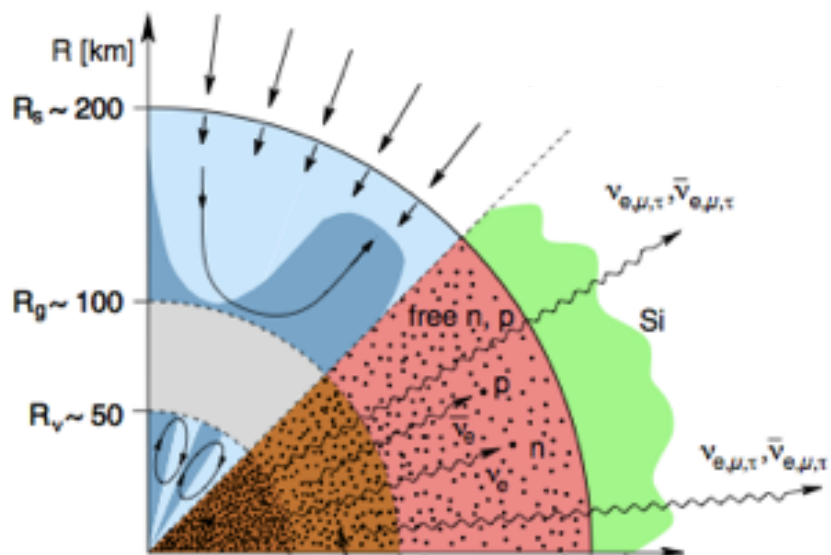


Janka+ 2007

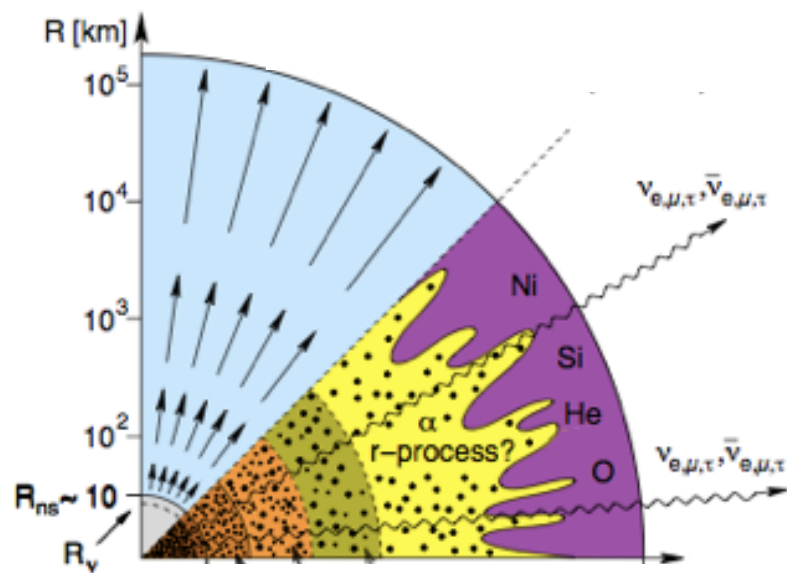


All flavours at late times

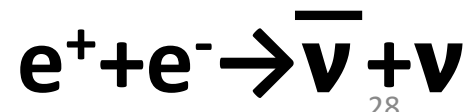
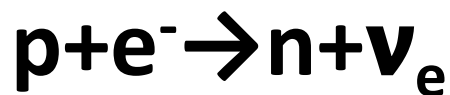
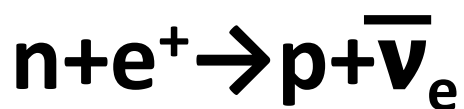
Accretion



Cooling



Janka+ 2007



hep discovery potential

