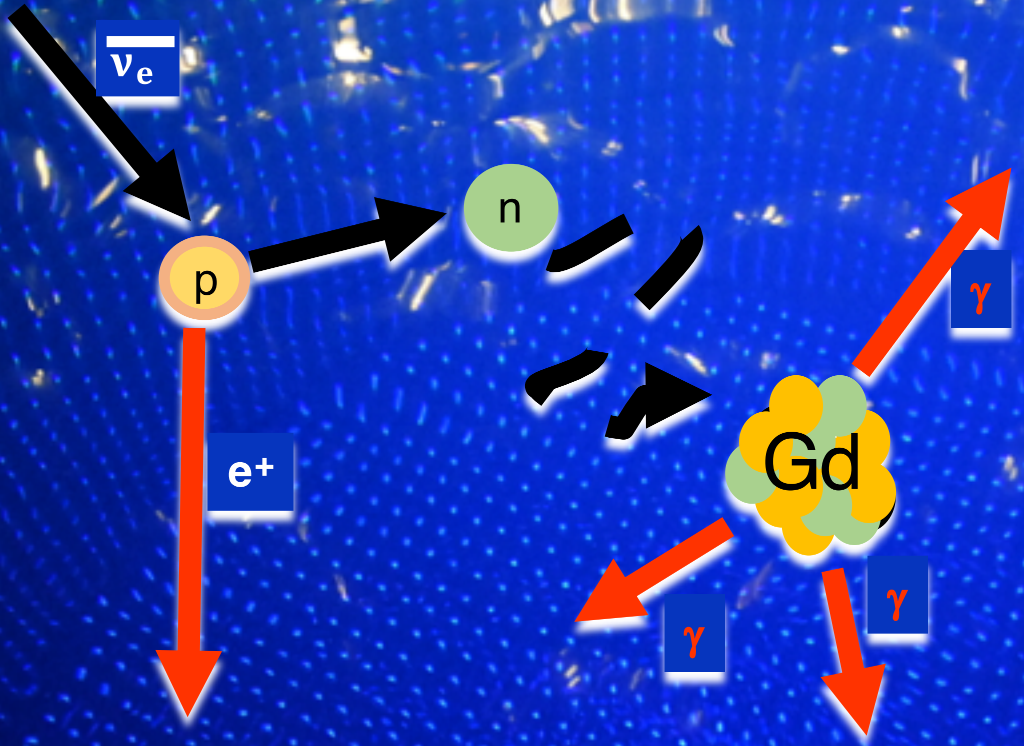
Physics Potential of Super-K Gd

Charles Simpson



スーパーカミオカンデ
Super-Kamiokande

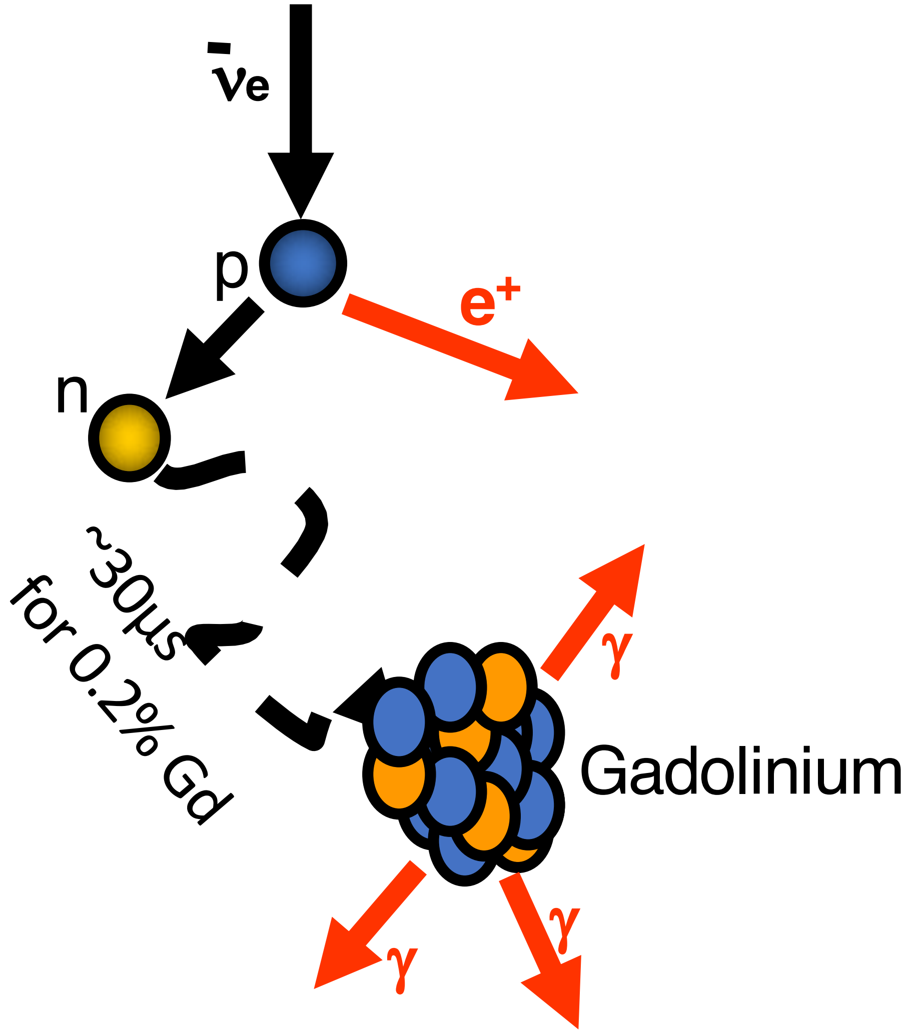
Inverse Beta Decay with Gadolinium

Highest cross section interaction for electron anti-neutrinos in Super-K

Gadolinium has a high **thermal neutron capture** cross section

High energy of gamma ray cascade gives highly efficient neutron tagging

Creates a **coincidence** event, which has much lower background



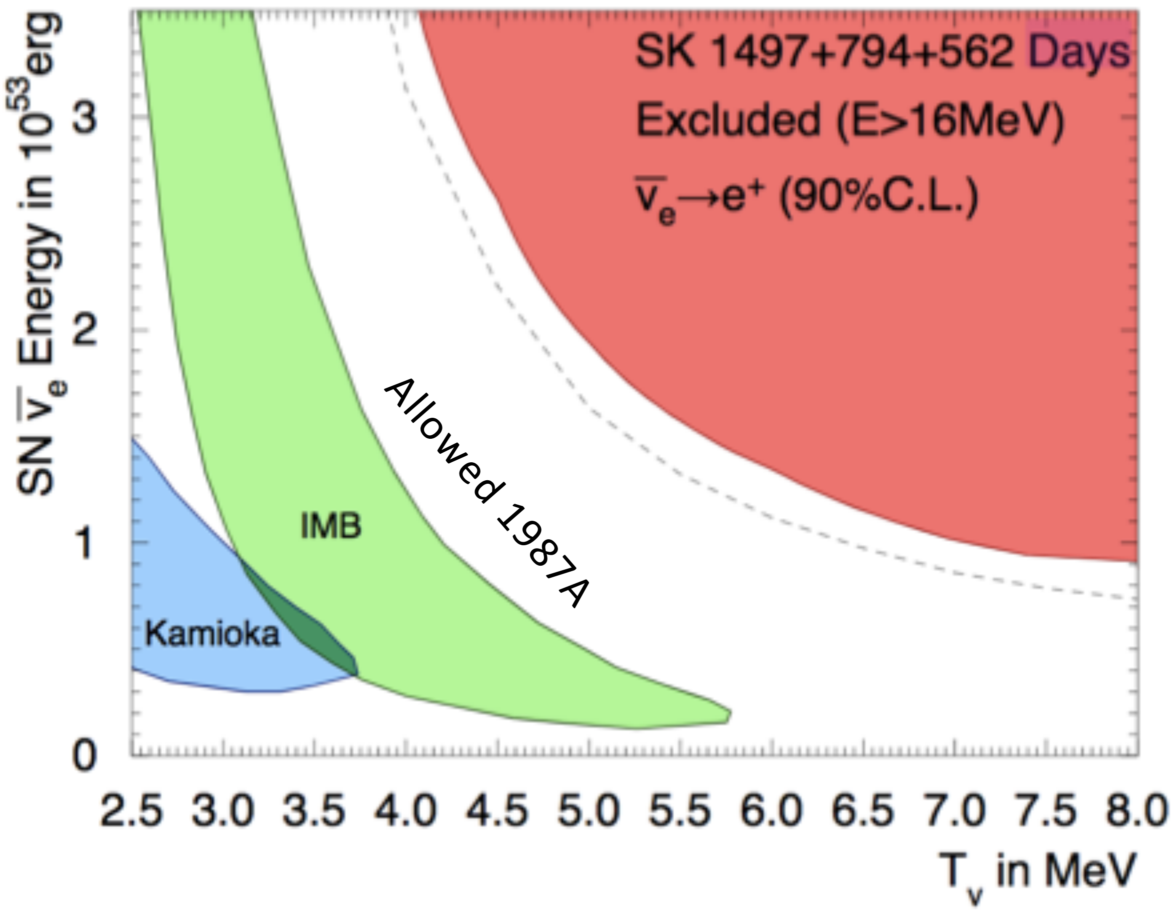
Diffuse Supernova Neutrino Background (DSNB)

The neutrinos from all distant and ancient supernova form an isotropic flux, which has never been detected.

Measurement of the rate would give information about the rate of star formation.
Was 1987A typical?

All neutrino flavours present, but detection is via $\bar{\nu}_e(p,n)e^+$

A.K.A. *Supernova Relic Neutrinos*

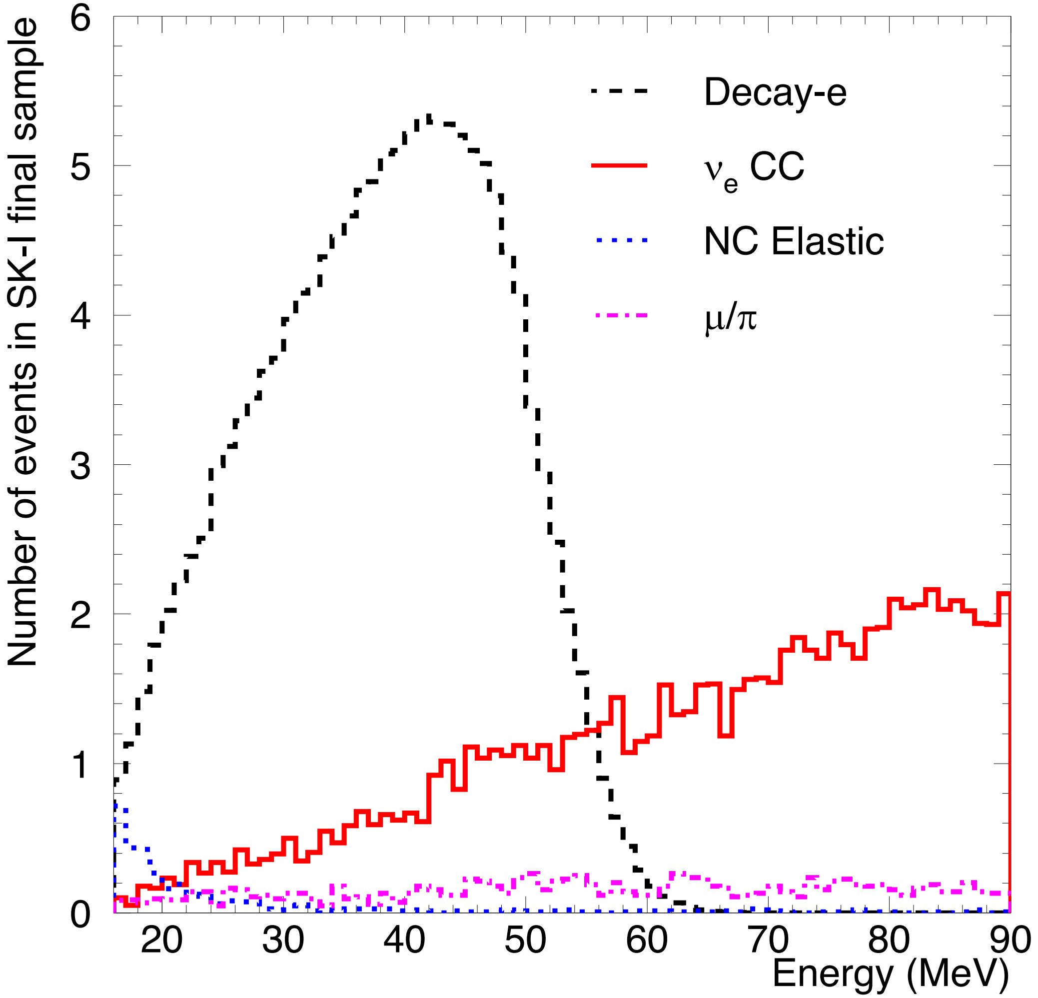


Super-K Collaboration 2011, arXiv:1111.5031

DSNB Backgrounds

Biggest backgrounds are:

- Decay electrons from muons below Cherenkov threshold, produced by neutrinos
- Atmospheric $\overline{\nu_e}$ and ν_μ
- Atmospheric ν NC elastic events (relevant at low energy)
- μ and π production by atmospheric ν

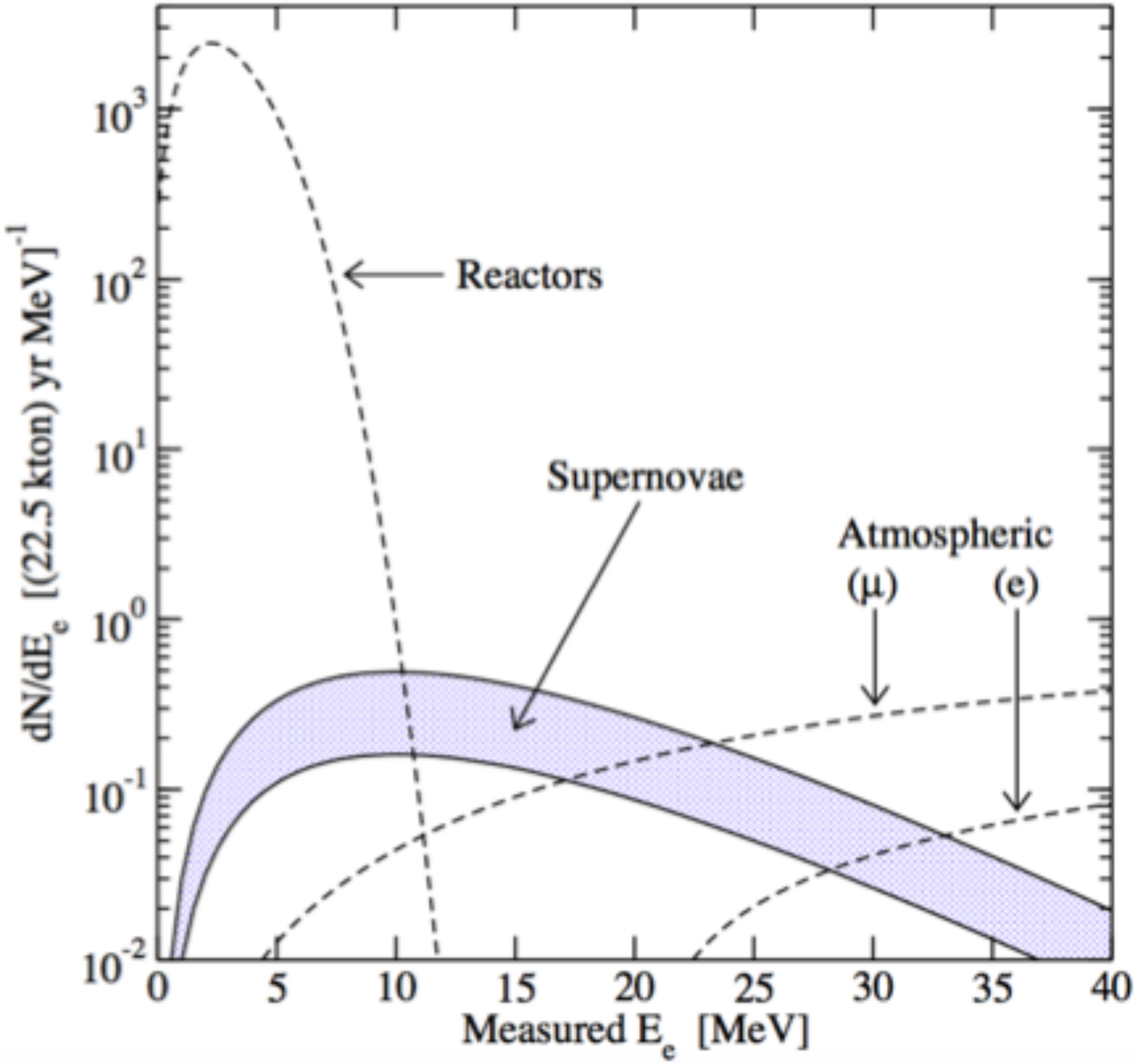


Backgrounds to DSNB at SK-IV

From arXiv:1111.5031

DSNB Backgrounds

- Neutron tagging with hydrogen is only ~18% efficient (see arXiv:1311.3738)
- Neutron tagging with gadolinium will be up to 80% efficient!

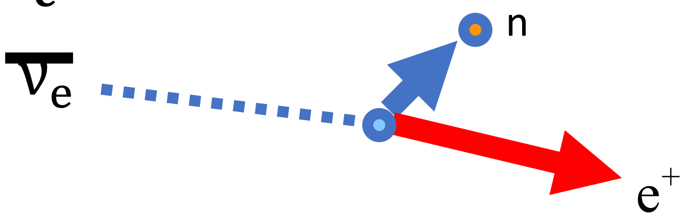


Beacom and Vagins, 2003, arXiv:hep-ph/0309300

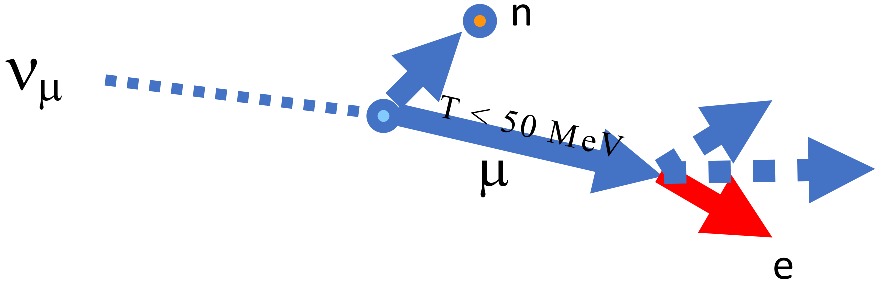
DSNB Backgrounds from Atmospheric Neutrinos

Charged Current:

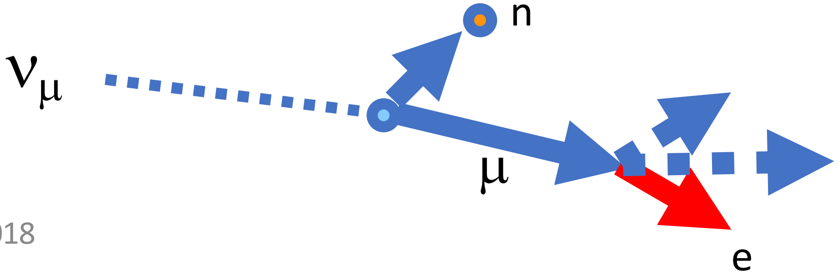
ν_e CC



Invisible μ:

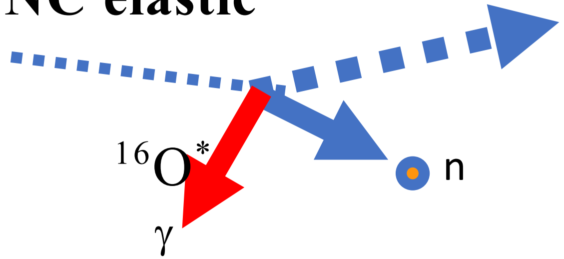


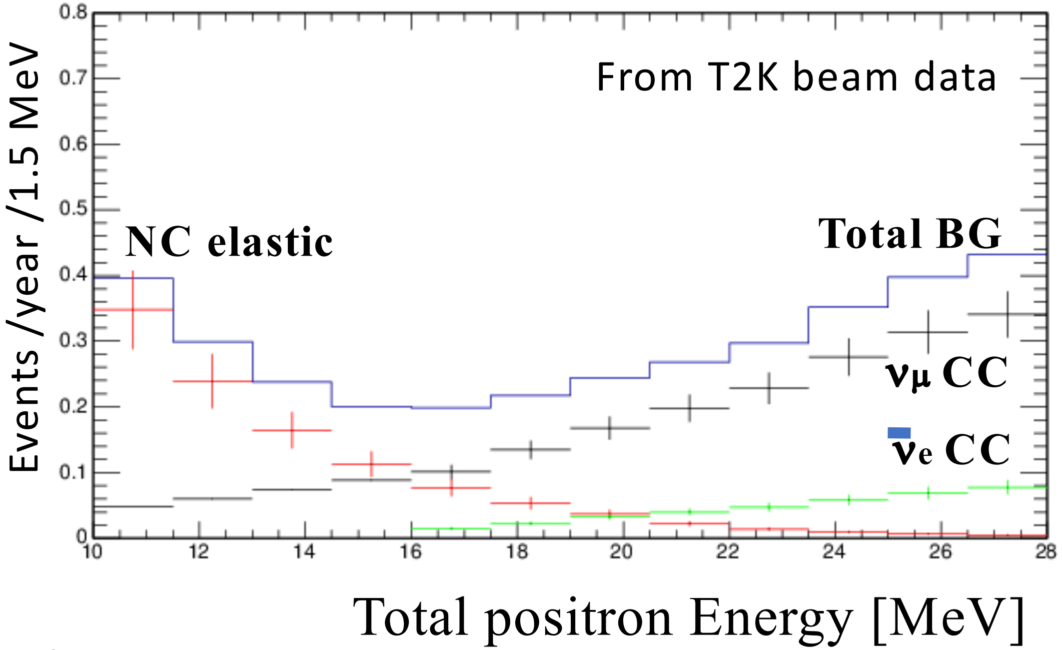
μ generation:



Neutral Current:

NC elastic





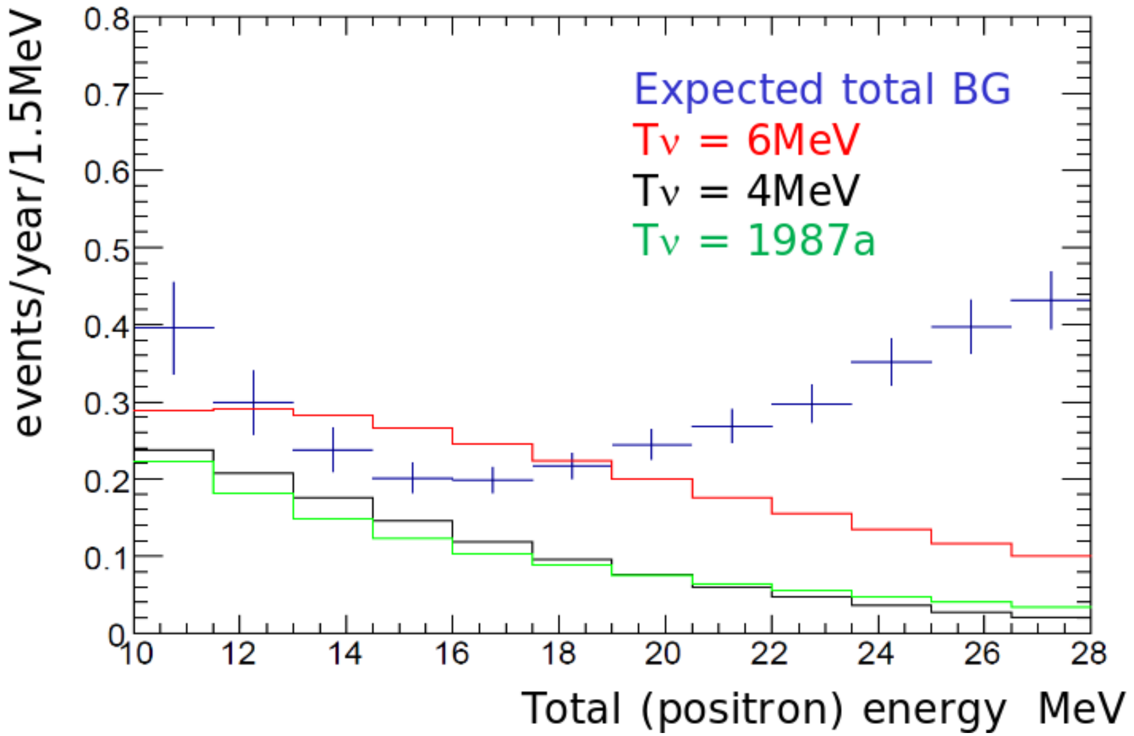
DSNB Detection

The detection of DSNB depends on the typical SN emission spectrum

$T_n \sim 5\,(M_{NS}/1.4M_{\odot})^{1/3}\,(R_{NS}/10km)^{-3/4}$

HBD models	10-16MeV (evts/10yrs)	16-28MeV (evts/10yrs)	Total (10-28MeV)	significance (2 energy bin)
T_{eff} 8MeV	11.3	19.9	31.2	5.3 σ
T_{eff} 6MeV	11.3	13.5	24.8	4.3 σ
T_{eff} 4MeV	7.7	4.8	12.5	2.5 σ
T_{eff} SN1987a	5.1	6.8	11.9	2.1 σ
BG	10	24	34	----

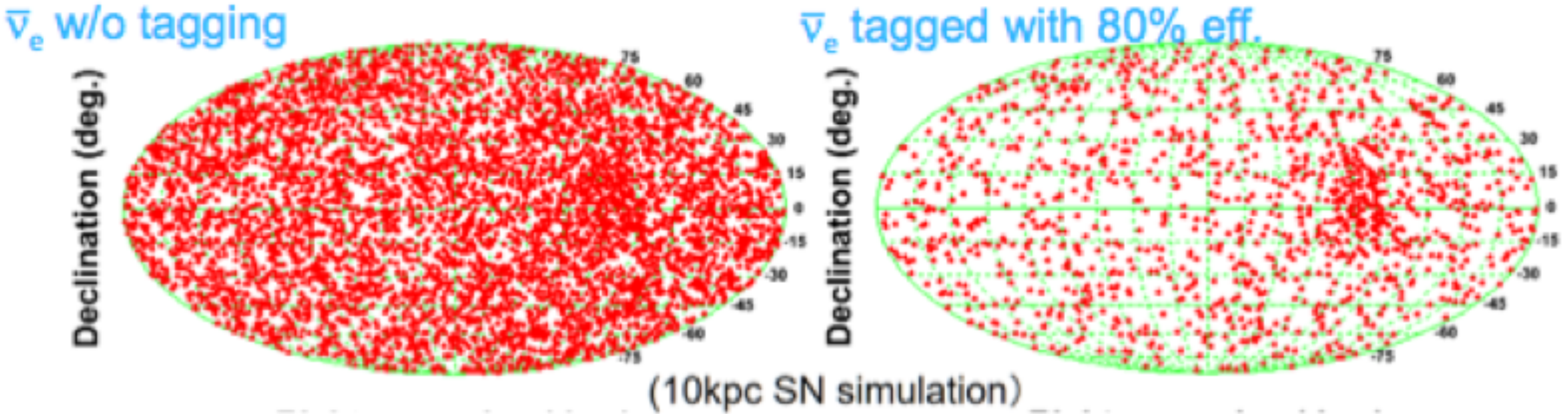
Expected DSNB events after 10 years of observation



With SuperK-Gd the first DSNB observation is within reach!

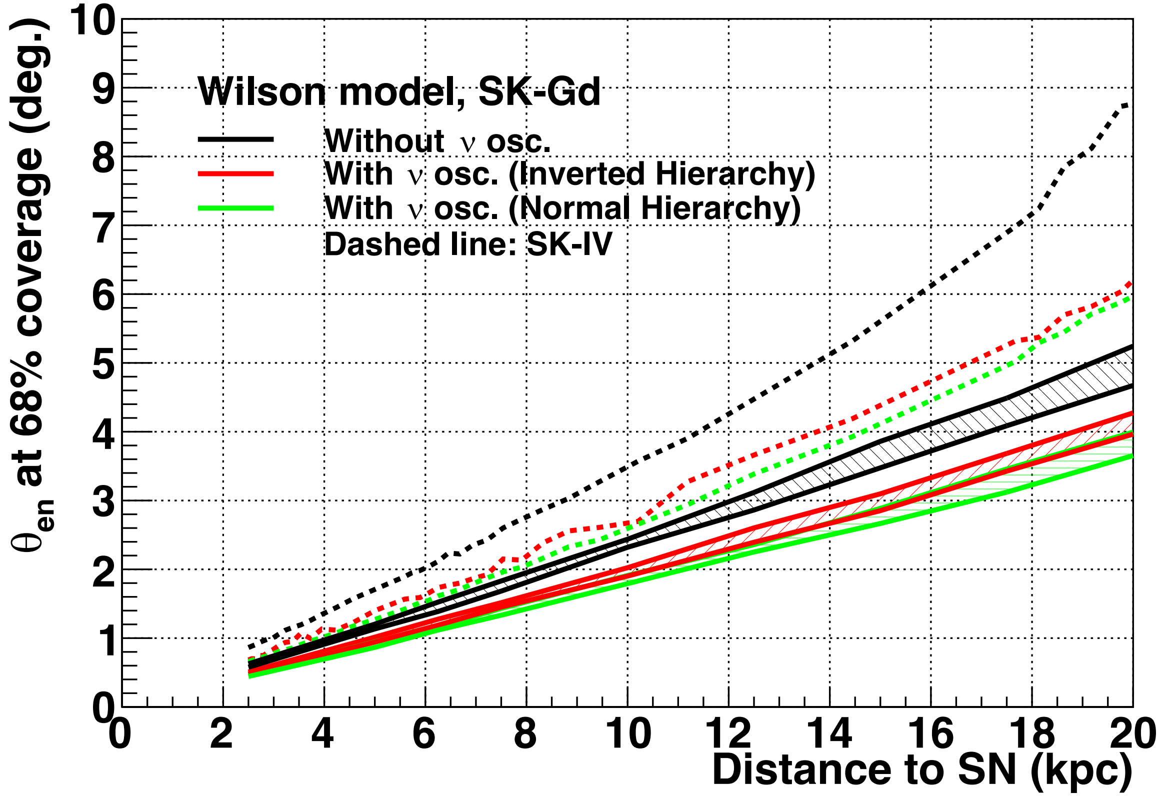
DSNB flux:
Horiuchi, Beacom, Dwek
PRD, 79, 083013 (2009)

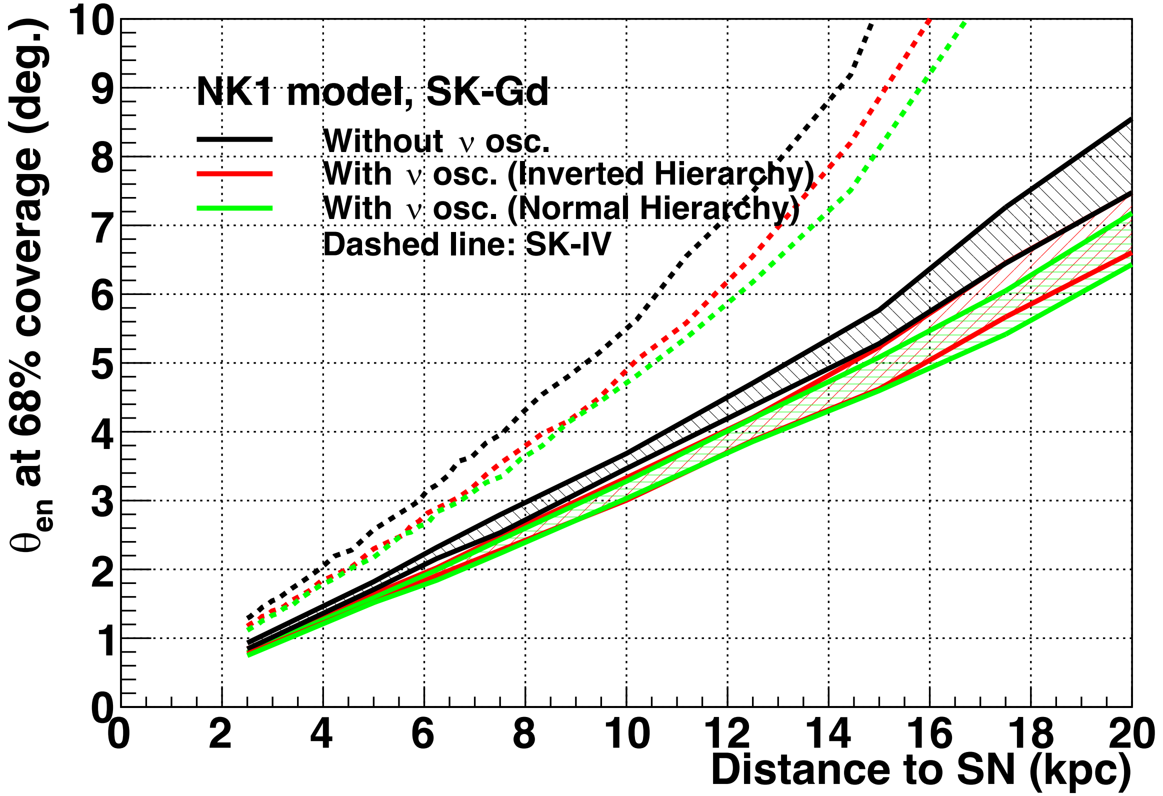
Supernova Burst Pointing



- SK can identify the direction of a nearby supernova
- 80% of events in SK from a supernova are inverse beta decay
- Pointing accuracy comes from elastic scattering, just 3% of events
- Neutron tagging can reject IBD events, improving accuracy

Supernova Burst Pointing





Based on arXiv:1601.04778, with unpublished improvements for SK-Gd

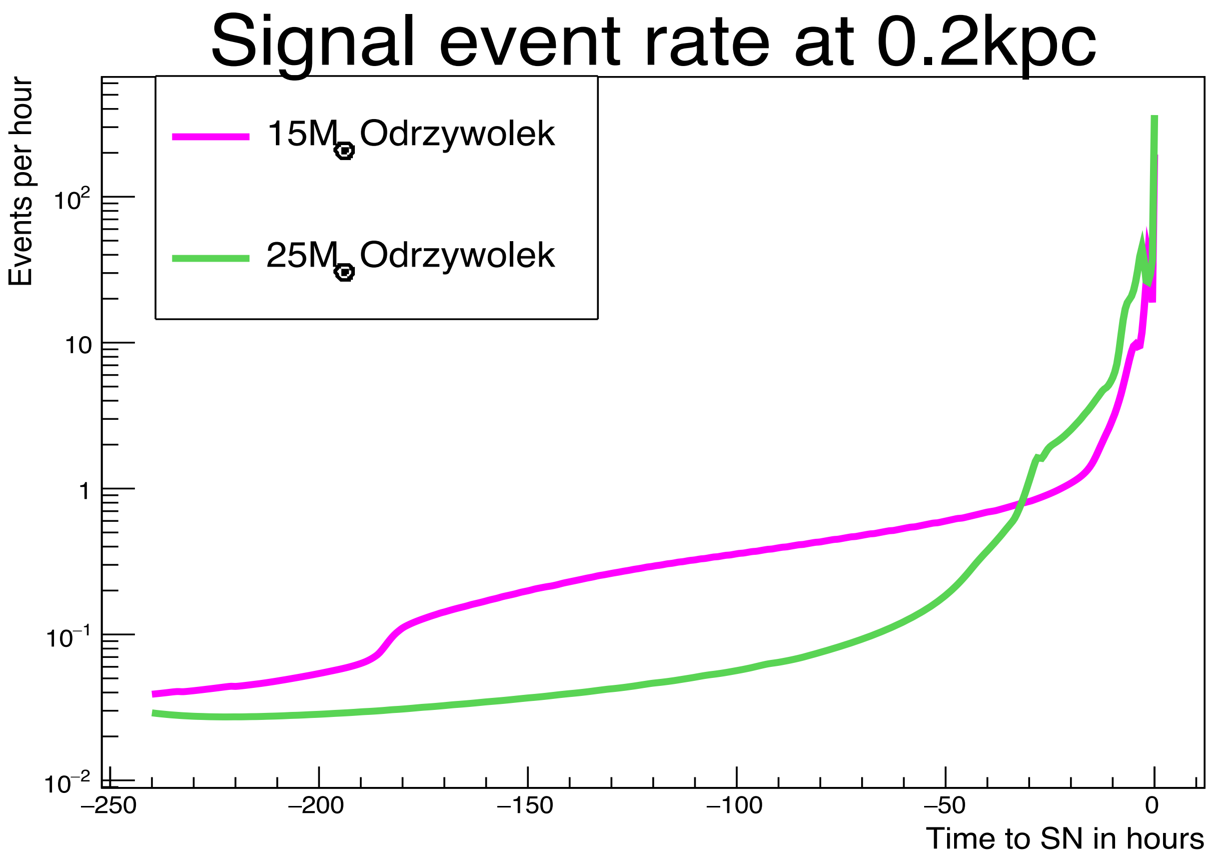
Other Supernova Benefits

Separation of non–IBD events also gives benefits for other aspects of SNe burst detection:

- Sensitivity to electron neutrino burst from neutronization over ~¼ of the galaxy
- Enhanced sensitivity to the burst temperature via charged current events
- Detect black hole formation through cut-off in IBD events

Silicon Burning Pre-supernova Neutrinos

- Core collapse supernova is preceded by heavy nuclei burning, up to Fe
- Temperature and density is rapidly increasing
- Increasing flux of low energy $\overline{\nu_e}$, which could be detected at SK-Gd for a *very* nearby supernova



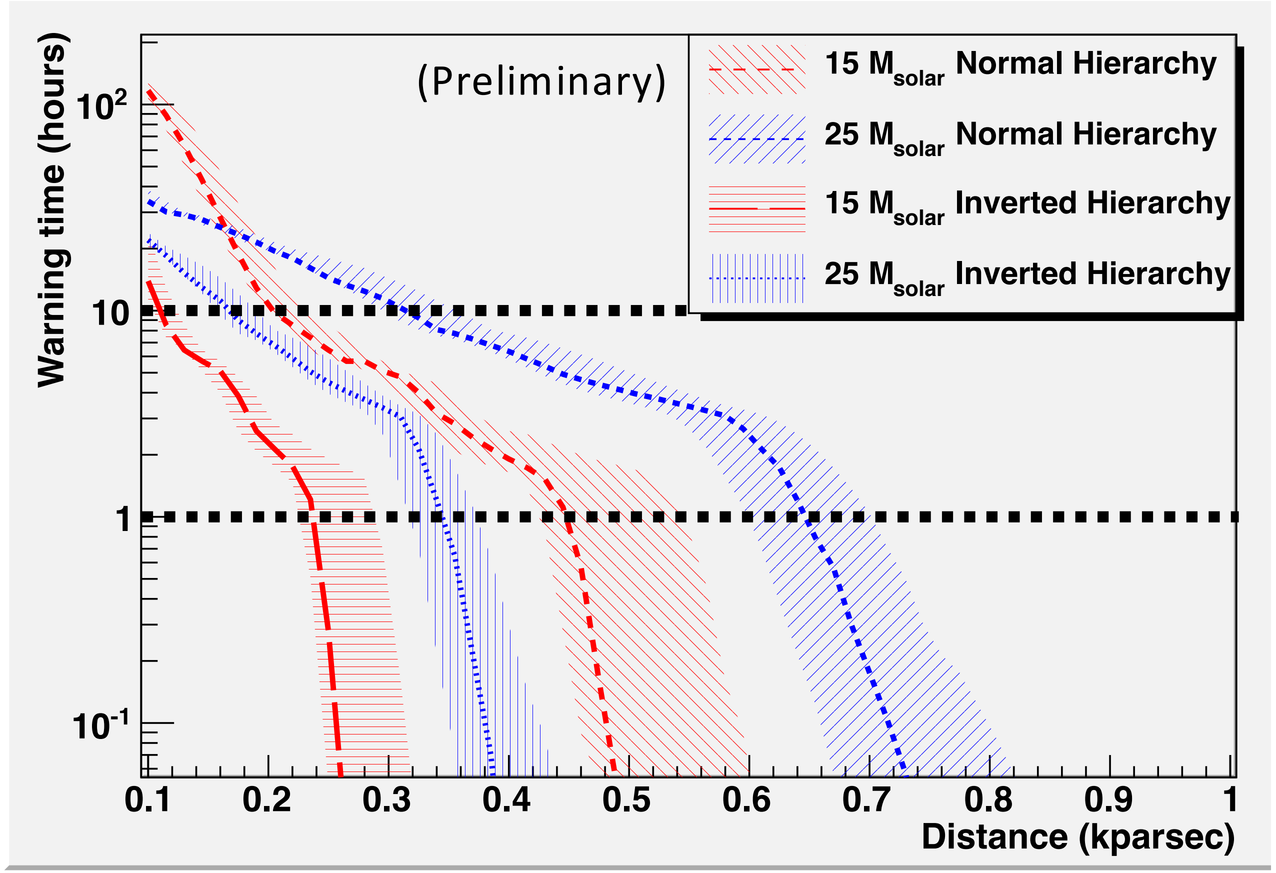
Silicon Burning Pre-supernova Neutrinos

Supernova Neutrinos	Silicon Burning Neutrinos
Mean Energy ~20 MeV	Mean Energy ~2 MeV
Hours before light from SN	Days before light from SN
Detected in 1987	Never detected before
1000s of events in seconds at SK at >10kpc	100s of events in a day at SK-Gd for stars at <1kpc

Silicon Burning Pre-supernova Warning

- Amount of warning depends on neutrino mass ordering, star mass, and Japanese nuclear reactor activity

- Max warning for Betelgeuse is ~60 hours (1 per 2 year type-II error rate assumed)
- Max range for 3σ discovery ~900 parsecs
- There are 41 red super giants in this range



Spallation

- Products of cosmic muon spallation are backgrounds to many SK analyses
- Currently removed with a cut around muon tracks – introduces ~10% dead time to solar neutrino analysis

- Most spallation products are made in hadronic showers, which produce bursts of neutrons
- Spallation background rejection can be improved by detecting bursts of neutrons around muons!

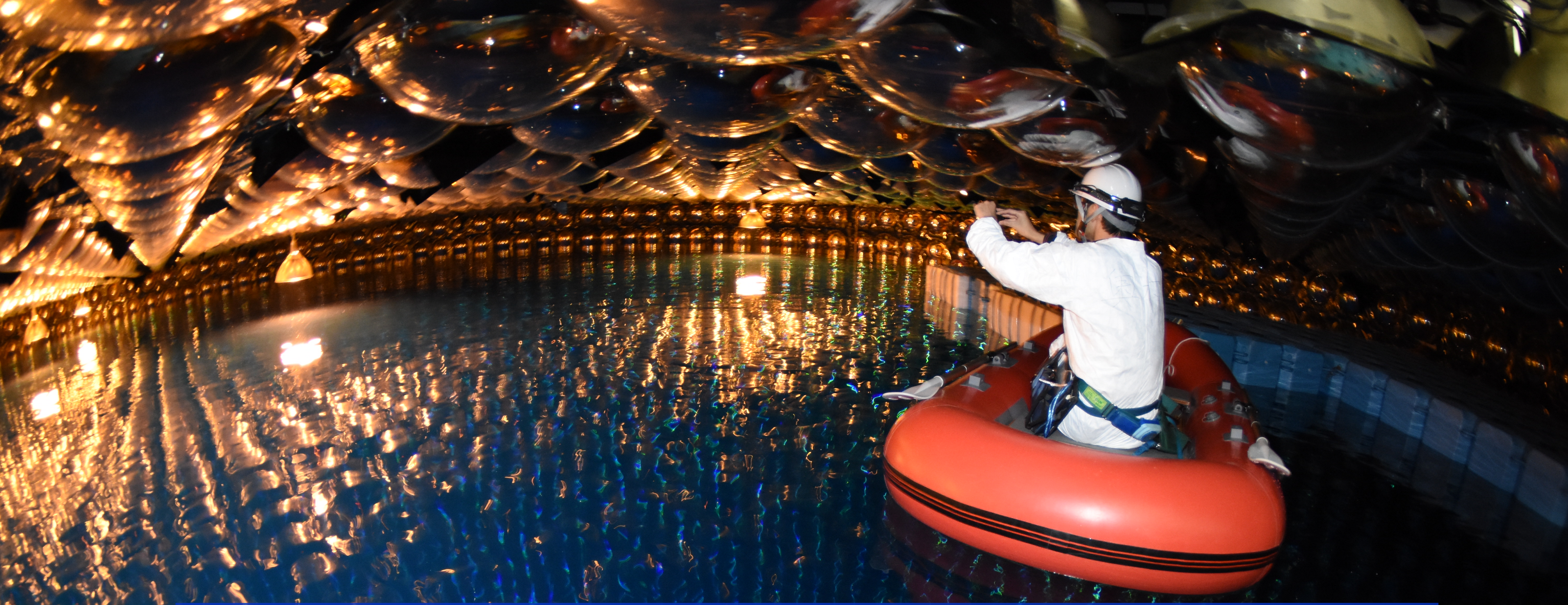
Other Benefits

- Discrimination between different interaction channels in SK atmospheric analysis, and for T2K
- Detection of 100s-1000s reactor neutrinos
- Reduced backgrounds for proton decay searches

Key Points

- Neutron tagging on gadolinium will reduce backgrounds for many SK analyses
- Spallation backgrounds will be reduced in general

- DSNB will be measured at SK-Gd within a few years of Gd loading
- SK-Gd will have improved ability to detect the direction of a galactic supernova burst
- Pre-supernova silicon burning neutrinos could be detected for a very nearby star



Learn more about the Super-K Gd upgrade in the next presentation

Lluís Martí-Magro: **The Road to Super-K Gd**