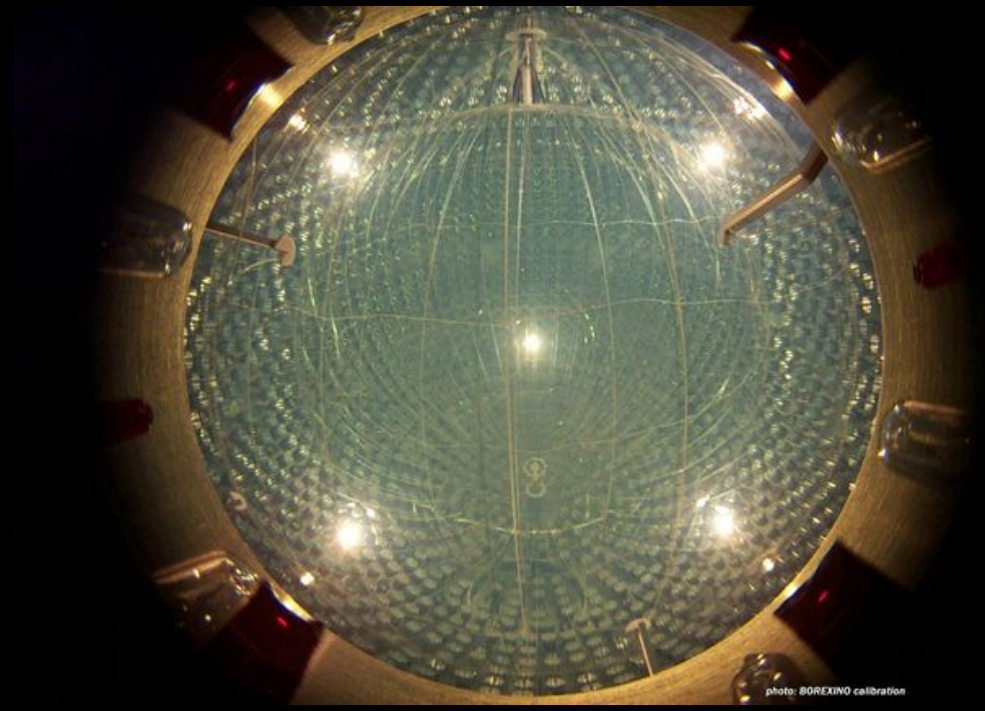
Scintillation detectors

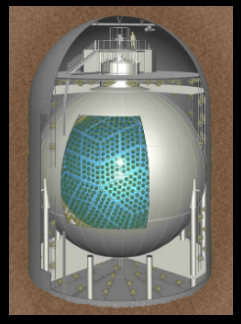


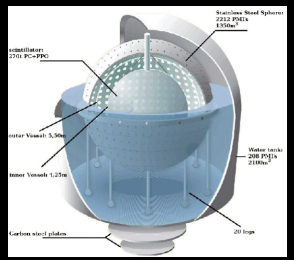
Liquid hydrocarbon (C_nH_{2n}) that emits (lots of) photons when charged particles lose energy in it

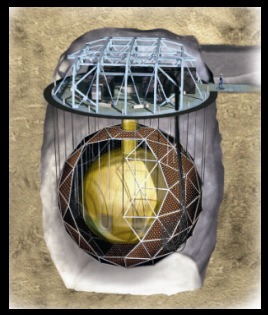
Will see supernova **electron antineutrinos**, with good energy resolution

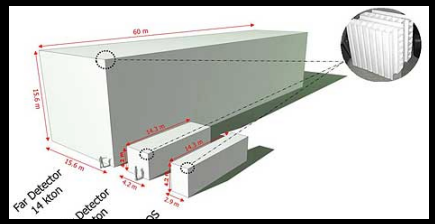
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

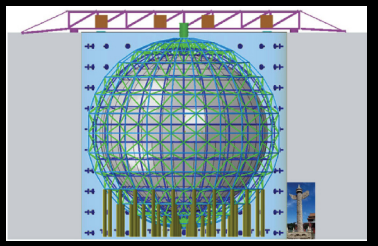
Many examples worldwide of current and future detectors



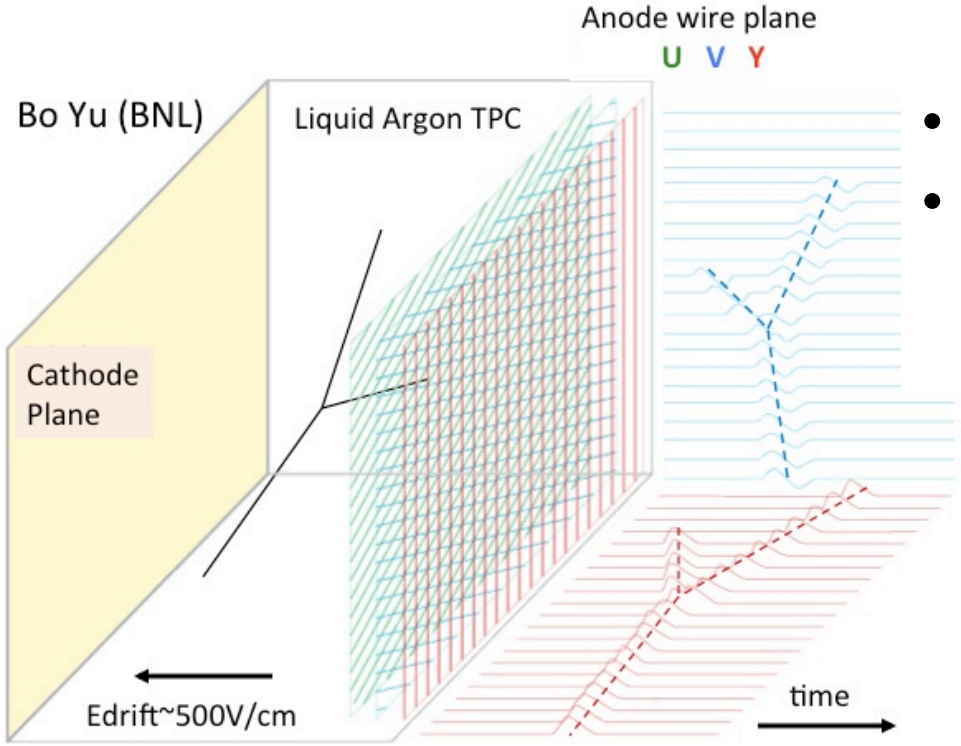








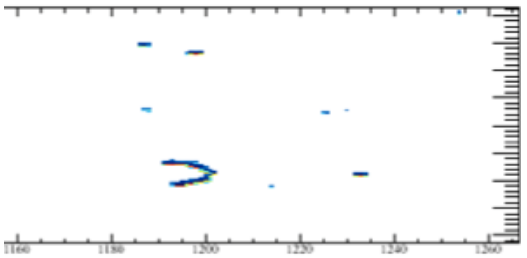
Liquid argon time projection chambers



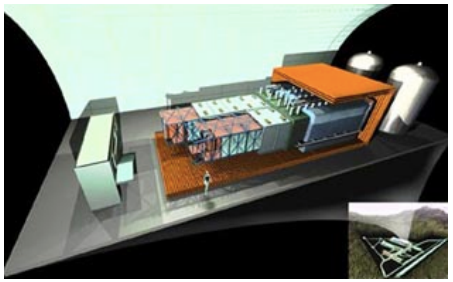
- fine-grained trackers
- sensitive to **electron neutrinos**

(as opposed to antineutrinos)

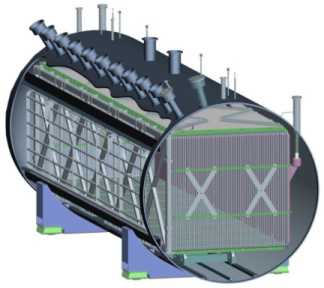
$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$



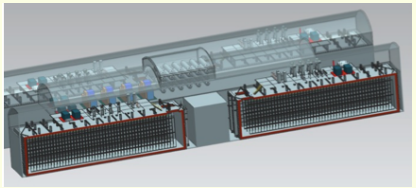
ICARUS
(Italy...)
0.6 kton



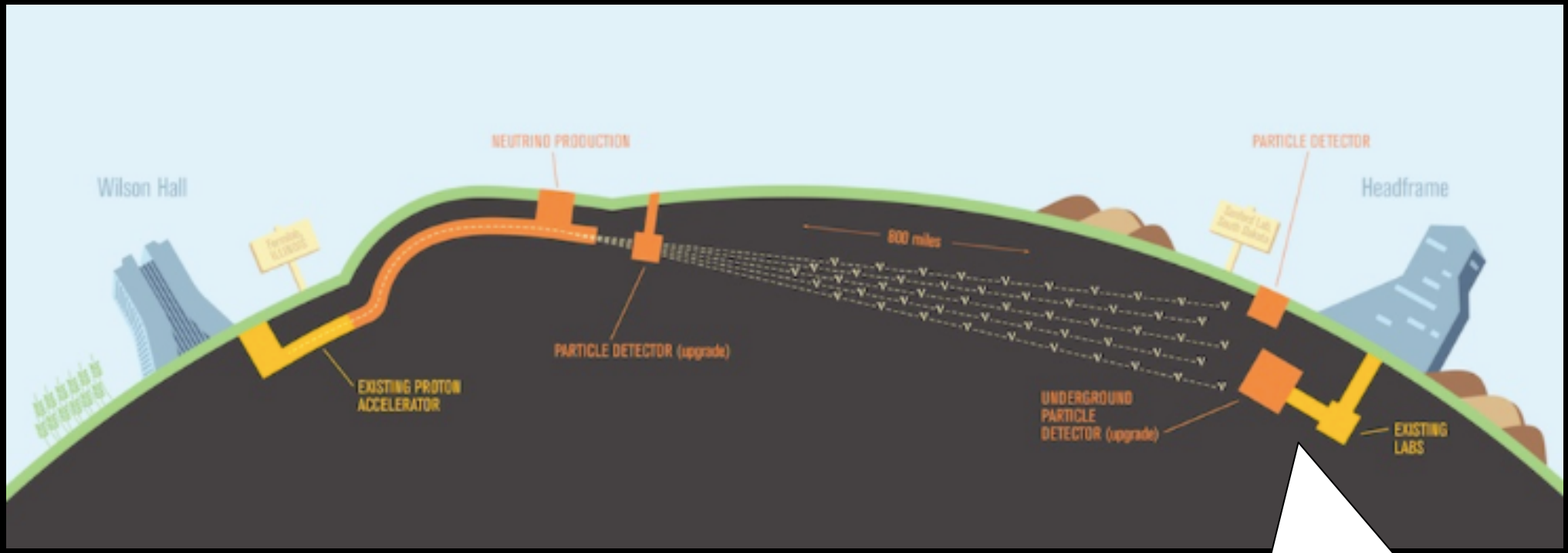
MicroBooNE
(USA)
0.2 kton



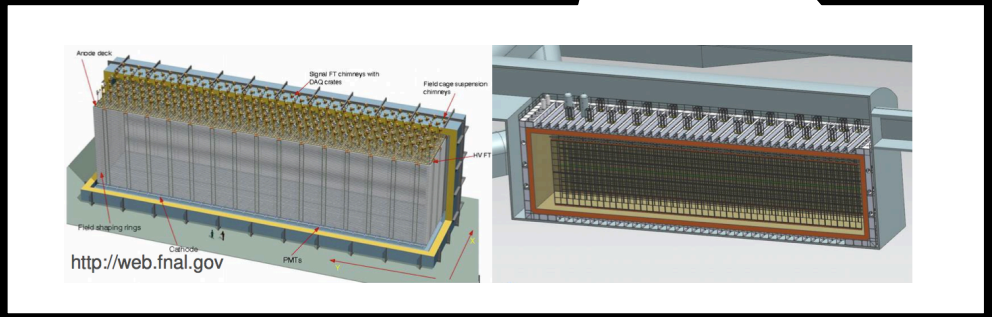
DUNE
(USA)
40 kton



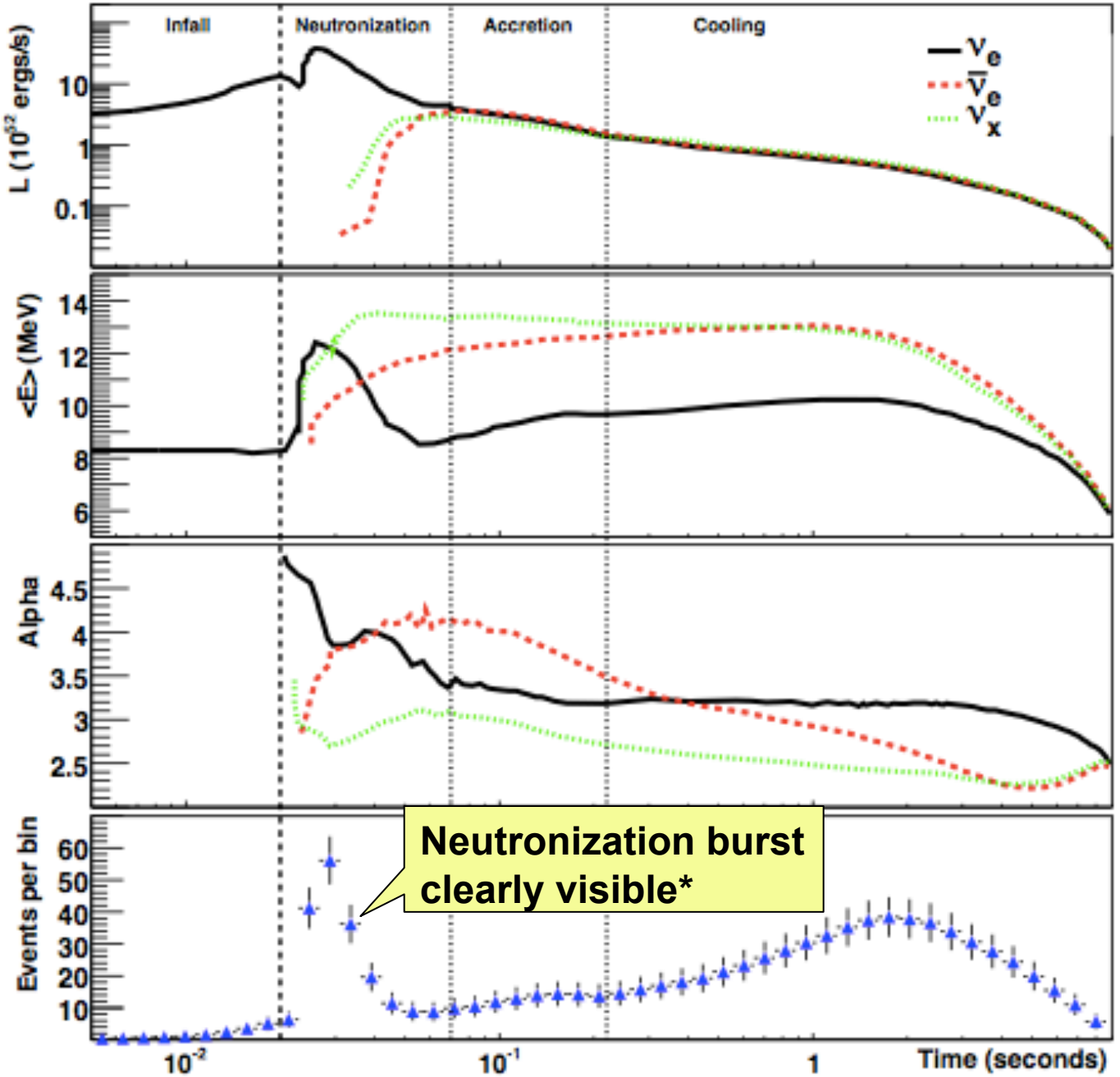
The far detector for the next international long-baseline neutrino program (beam from Fermilab to SD) will be an **underground liquid argon detector**



Expect ~1000's of **electron neutrinos** from a Milky Way supernova



Example of supernova burst signal in 40 kton of LAr



Flux from Huedepohl et al., PRL 104 (2010) 251101 ("Garching") @ 10 kpc

See the ν_e light curve!

*caveat: suppressed by oscillations

Summary of supernova neutrino detectors

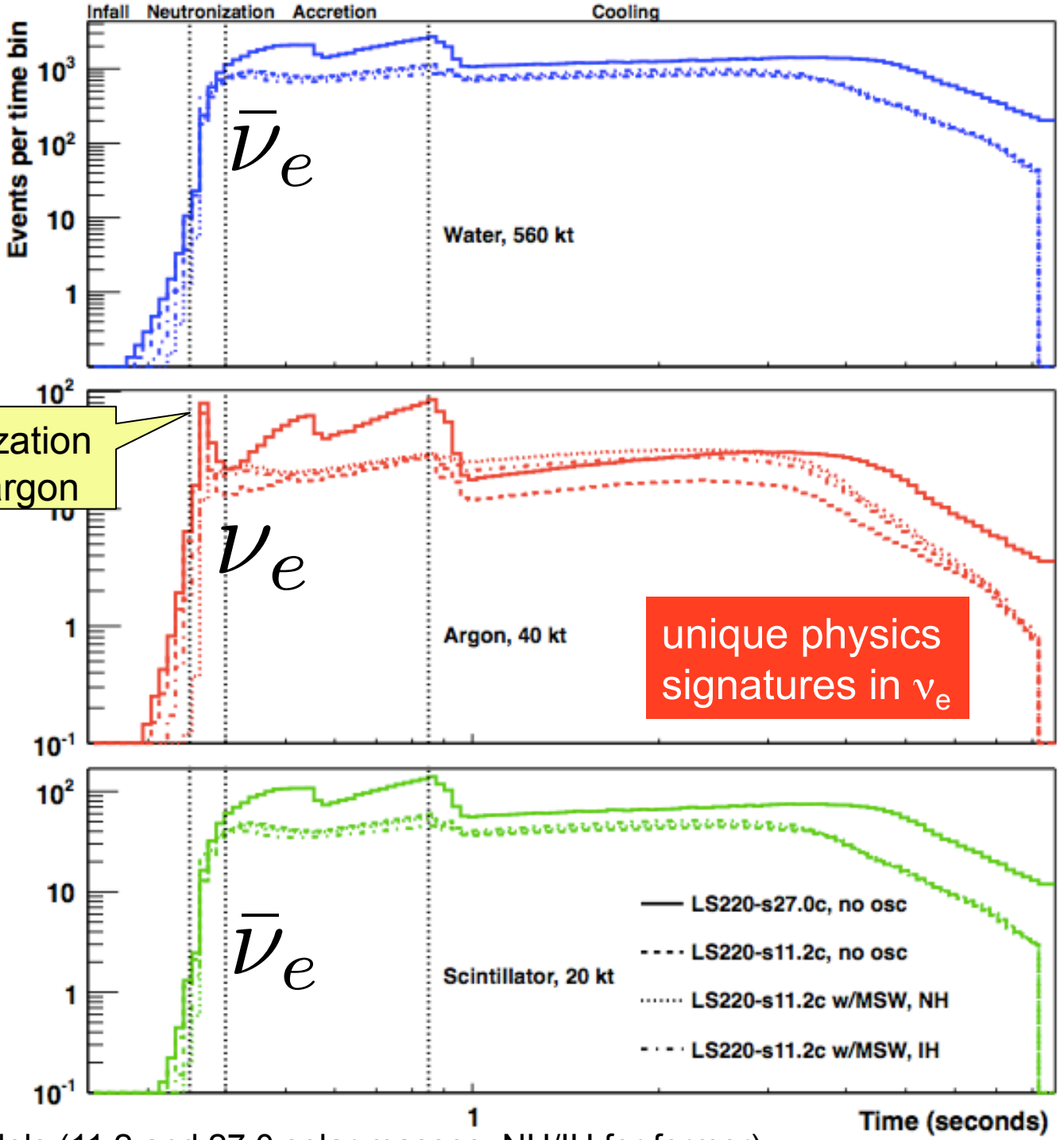
Galactic sensitivity

Extragalactic

Detector	Type	Location	Mass (kton)	Events @ 10 kpc	Status
Super-K	Water	Japan	32	8000	Running
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
HALO	Lead	Canada	0.079	20	Running
Daya Bay	Scintillator	China	0.33	100	Running
NOvA	Scintillator	USA	15	3000	Running
MicroBooNE	Liquid argon	USA	0.17	17	Running
SNO+	Scintillator	Canada	1	300	Under construction
DUNE	Liquid argon	USA	40	3000	Future
Hyper-K	Water	Japan	540	110,000	Future
JUNO	Scintillator	China	20	6000	Future
PINGU	Long string	South pole	(600)	(10^6)	Future

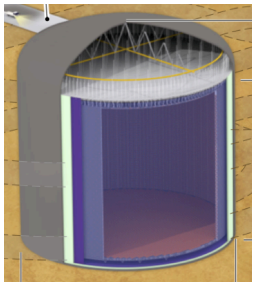
plus reactor experiments, DM experiments...

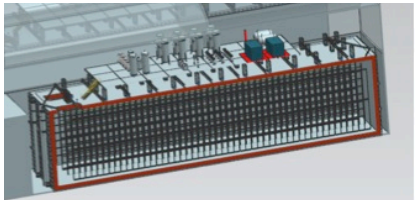
Example signals in future large detectors

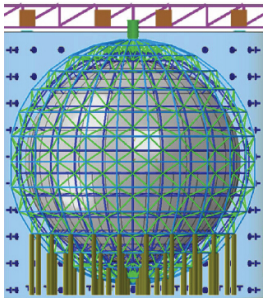


Neutronization burst in argon

unique physics signatures in ν_e



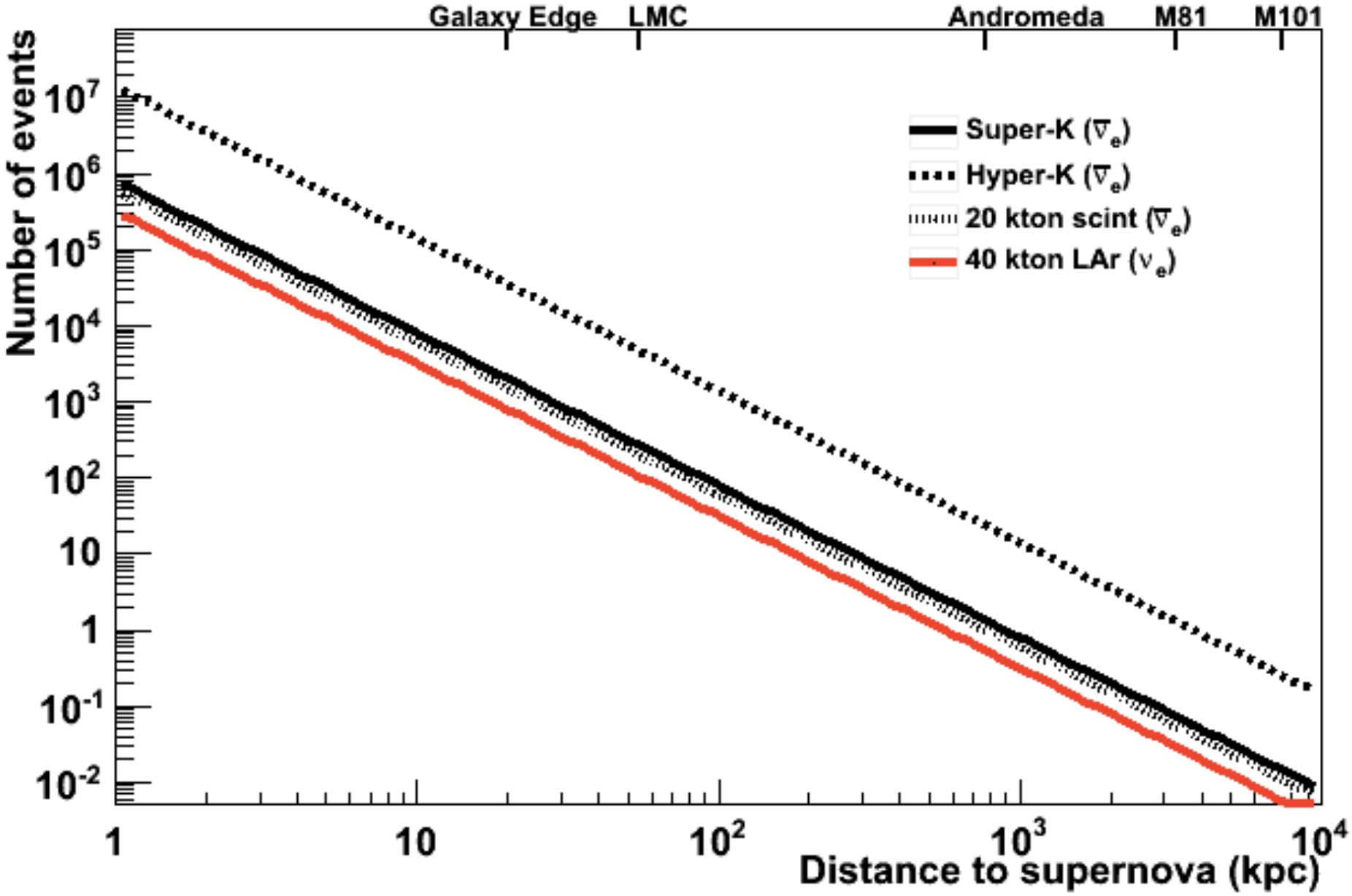




Two models (11.2 and 27.0 solar masses, NH/IH for former)

arXiv:1508.00785

Distance reach of detectors

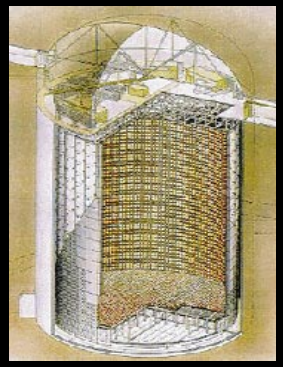


SK will see ~1 event from Andromeda; HK will get a ~dozen

SNEWS: SuperNova Early Warning System

- Neutrinos (and GW) precede em radiation by hours or even days
- For promptness, require ***coincidence*** to suppress false alerts

snews.bnl.gov

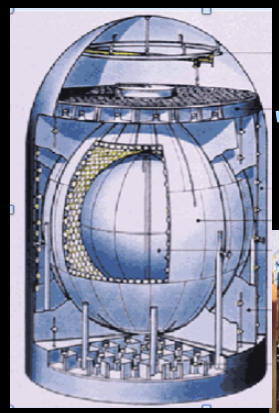


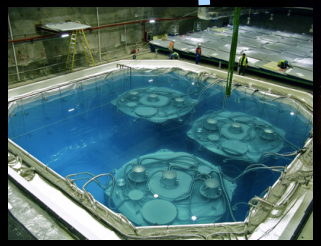
experiment
UT time
significance

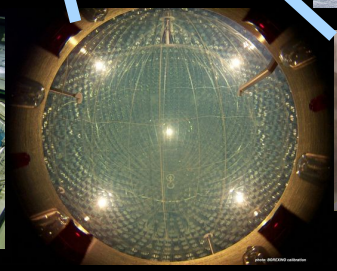
Coincidence Server at BNL

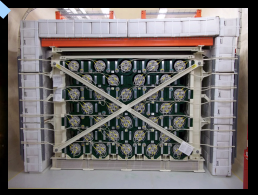
10 second coincidence by UT time stamp

alert to astronomers





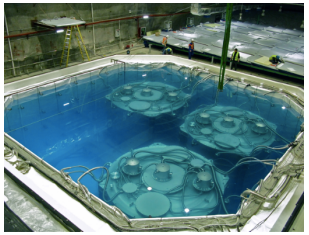




Running smoothly for more than 10 years, automated since 2005

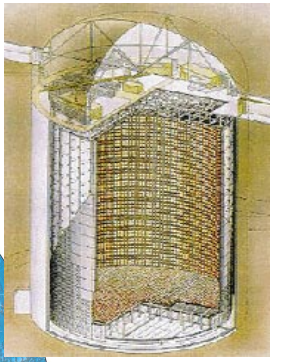
SNEWS: SuperNova Early Warning System

LVD

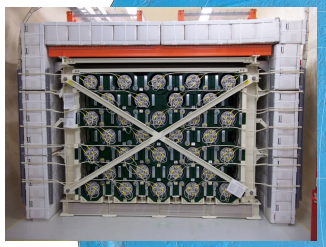


Daya Bay

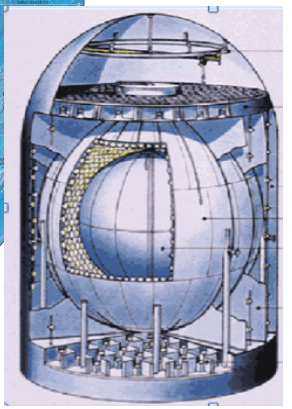
snews.bnl.gov



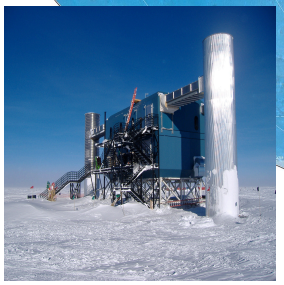
Super-K



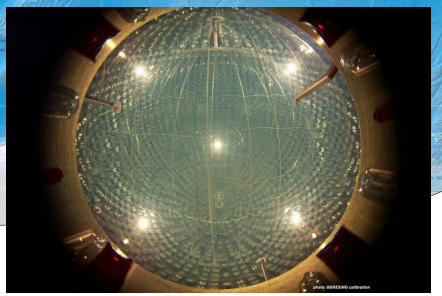
HALO



KamLAND



IceCube



Borexino

WUN2K (What You Need To Know) about the neutrino signal

Core-collapse neutrinos

- ~10 second prompt burst of all flavors, few tens of MeV

Current & near future detectors:

- ~Galactic sensitivity
  (SK reaches barely to Andromeda)
- sensitive mainly to the ν_e-bar component
- pointing: ~5^o from SK, may do better w/ SK-Gd
- ~ms timing from IceCube, neutronization burst
- SNEWS network is waiting

Future detectors

- huge statistics: extragalactic reach
- richer flavor sensitivity (e.g. ν_e in LAr!)
- multimessenger prospects

Neutrinos and Gravitational Wave Coincidences

Topics for discussion:

- improve sensitivity to sub-threshold bursts
  (in both directions...): realtime and offline
- joint alert?

- science from joint observation:
  - T_0 for neutrino-mass-induced kinematic delay
  - collapse and explosion phenomenology

Extras/backups

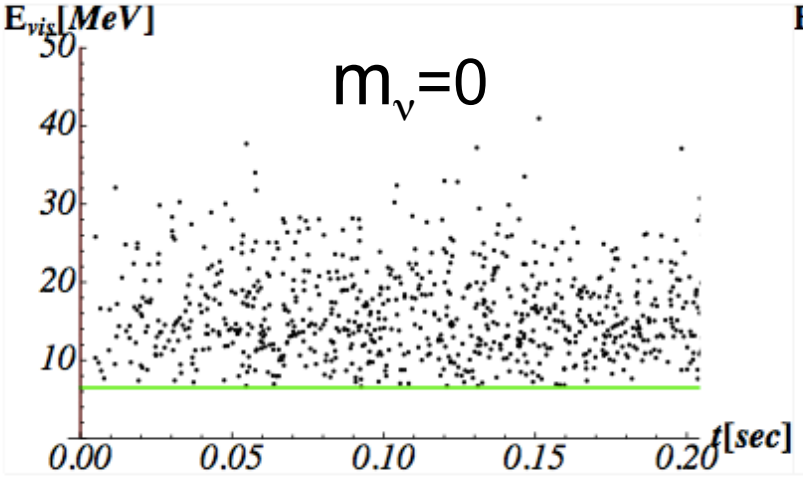
Neutrino Absolute Mass

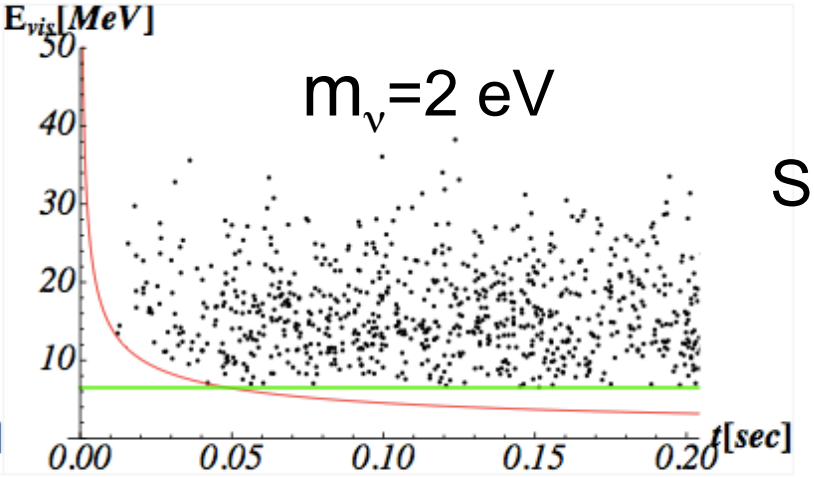
Expect time of flight delay for massive neutrinos

$$\Delta t(m_\nu, E_\nu) \simeq 5.14\,\mathrm{ms}\,\left(\frac{m_\nu}{\mathrm{eV}}\right)^2\left(\frac{10\,\mathrm{MeV}}{E_\nu}\right)^2\frac{D}{10\,\mathrm{kpc}}$$

Look for:

- energy-dependent time spread
- flavor-dependent delay





SK@10 kpc

$\bar{\nu}_e$

G. Pagliaroli et al., Astropart. Phys. 33, 287 (2010)