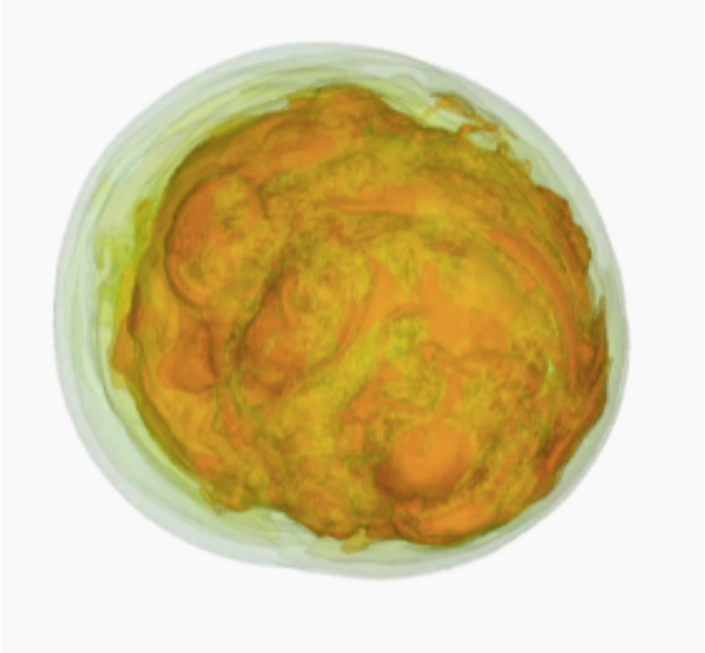
Supernova Burst Neutrino Physics

K. Scholberg, January 22, 2015
ELBNF meeting

- Supernova neutrino physics
- What will we see with 40 kton of LAr?
- What will we see with 10 kton of LAr?



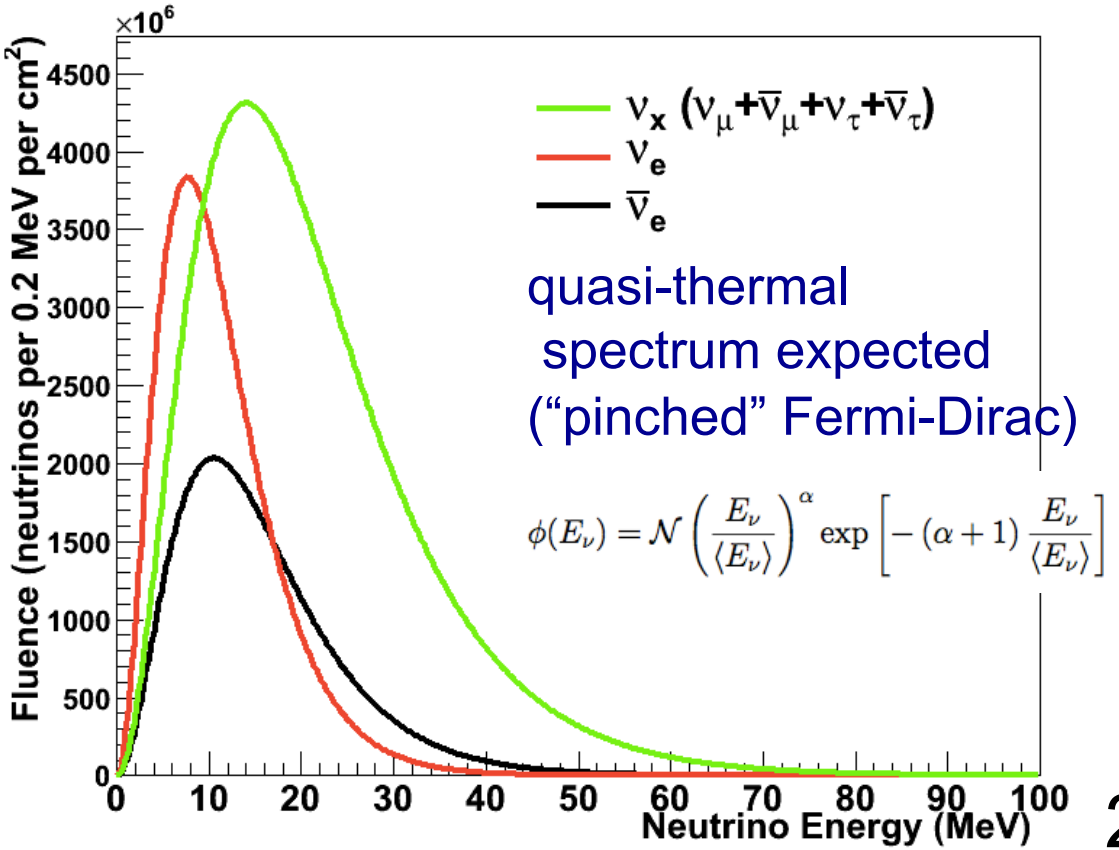
Neutrinos from core collapse

When a star's core collapses, ~99% of the gravitational binding energy of the proto-nstar goes into ν's of *all flavors* with ~tens-of-MeV energies

(Energy *can* escape via ν's)

Mostly ν-$\bar{\nu}$ pairs from proto-nstar cooling

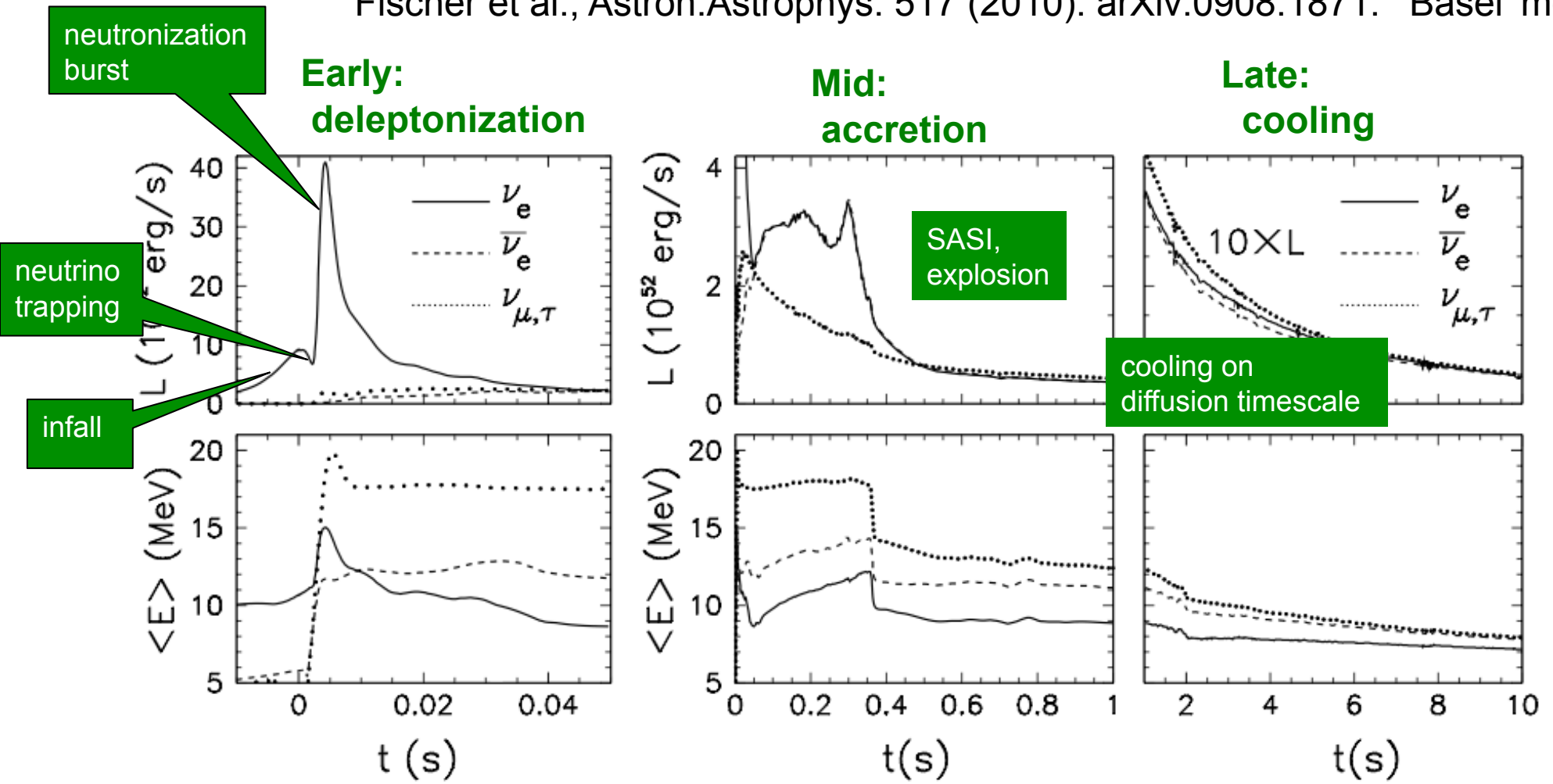
Timescale: *prompt* after core collapse, overall Δt~10's of seconds



Expected neutrino luminosity and average energy vs time

Vast information in the *flavor-energy-time profile*

Fischer et al., Astron.Astrophys. 517 (2010). arXiv:0908.1871: 'Basel' model

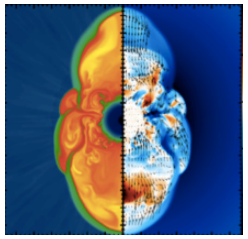


Generic feature:
(may or may not be robust)

$$\langle E_{\nu_e} \rangle < \langle E_{\bar{\nu}_e} \rangle < \langle E_{\nu_x} \rangle$$

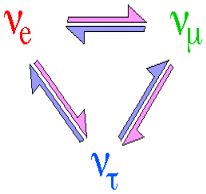
What can we learn from the next neutrino burst?

CORE COLLAPSE PHYSICS



explosion mechanism
proto nstar cooling,
quark matter
black hole formation
accretion, SASI
nucleosynthesis
....

input from neutrino experiments



from flavor, energy, time structure of burst

NEUTRINO and OTHER PARTICLE PHYSICS

ν absolute mass (not competitive)
ν mixing from spectra:
flavor conversion in SN/Earth,
collective effects
➔ **mass hierarchy**
other ν properties: sterile ν's,
magnetic moment,...
axions, extra dimensions,
FCNC, ...

input from photon (GW) observations

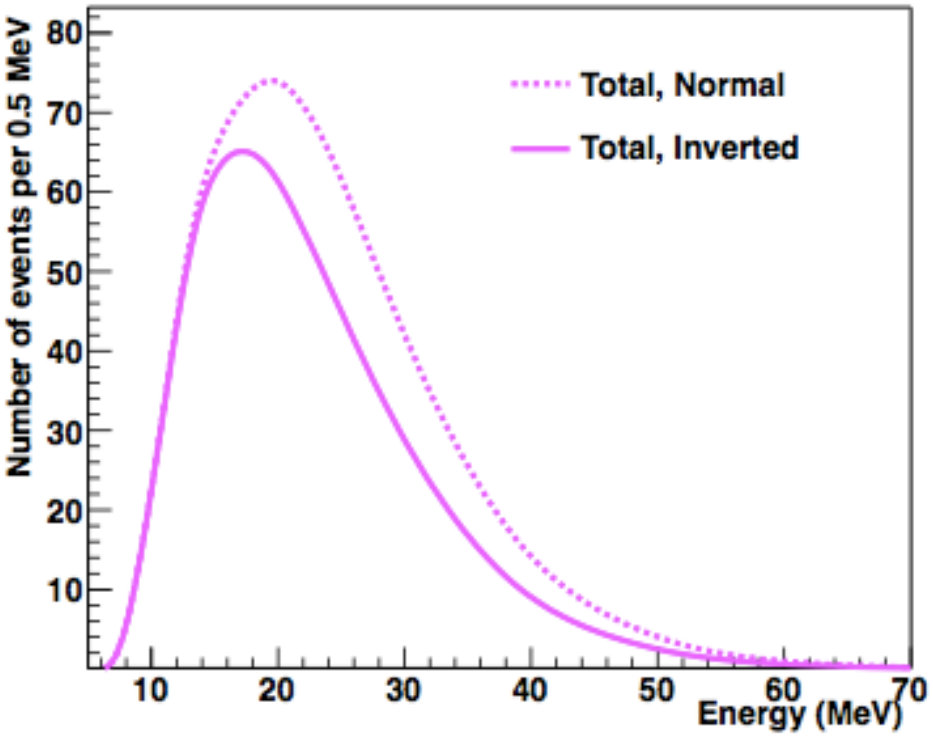
see Alex Friedland parallel talk

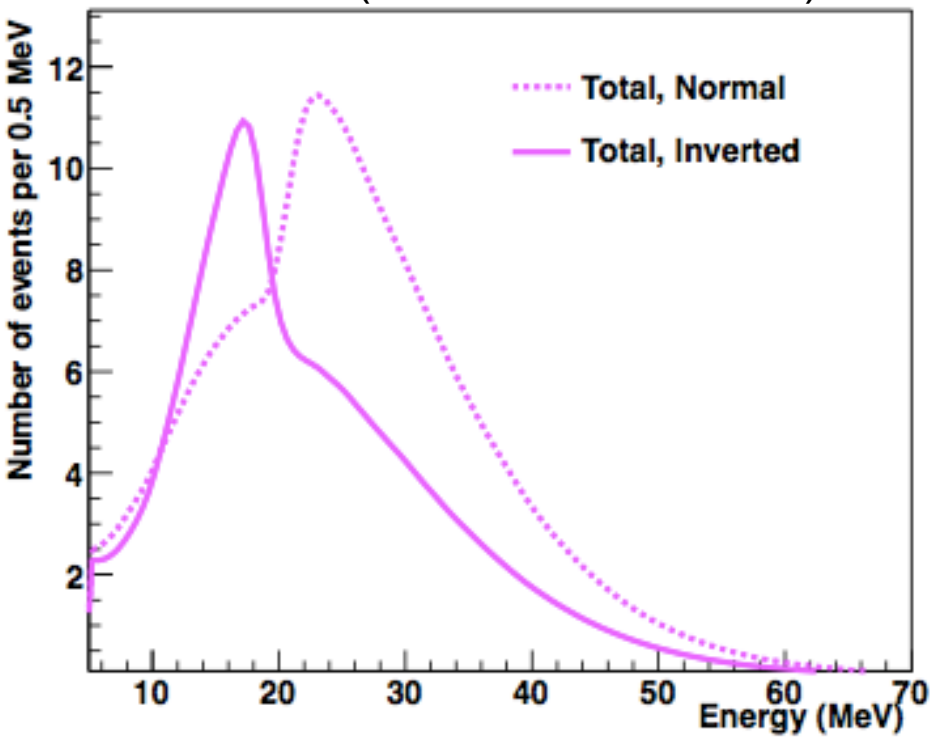
+ EARLY ALERT

Water

Argon

1-s time slice from Duan model; 100-kt water/ 34-kt LAr (caveat: an anecdote)





mostly $\bar{\nu}_e$

mostly ν_e

Different features in different flavors

Low energy neutrino interactions in argon

Charged-current absorption

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

Dominant

$$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$$

Neutral-current excitation

$$\nu_x + {}^{40}\mathrm{Ar} \rightarrow \nu_x + {}^{40}\mathrm{Ar}^*$$

Not much information in literature

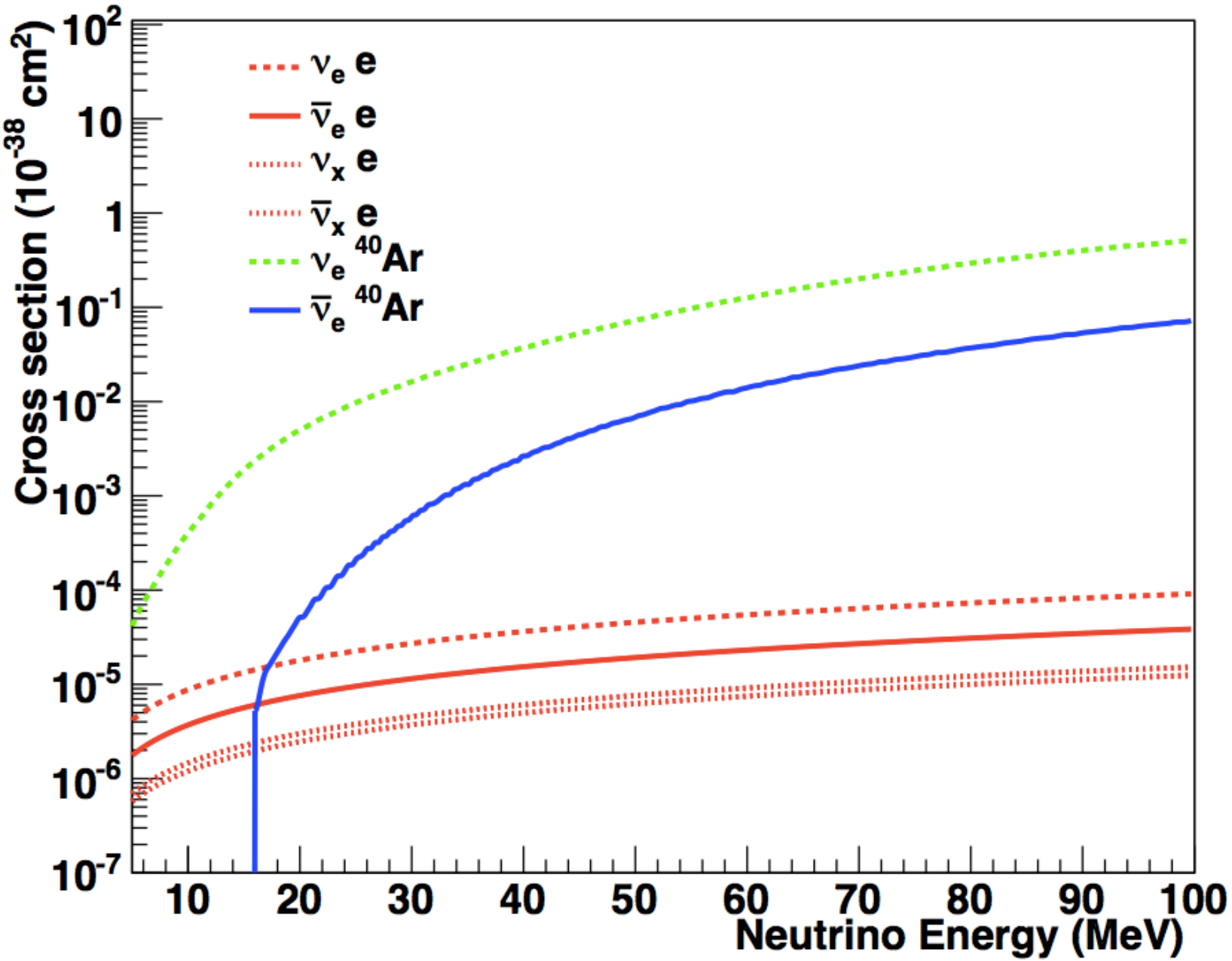
Elastic scattering

$$\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$$

Can use for pointing

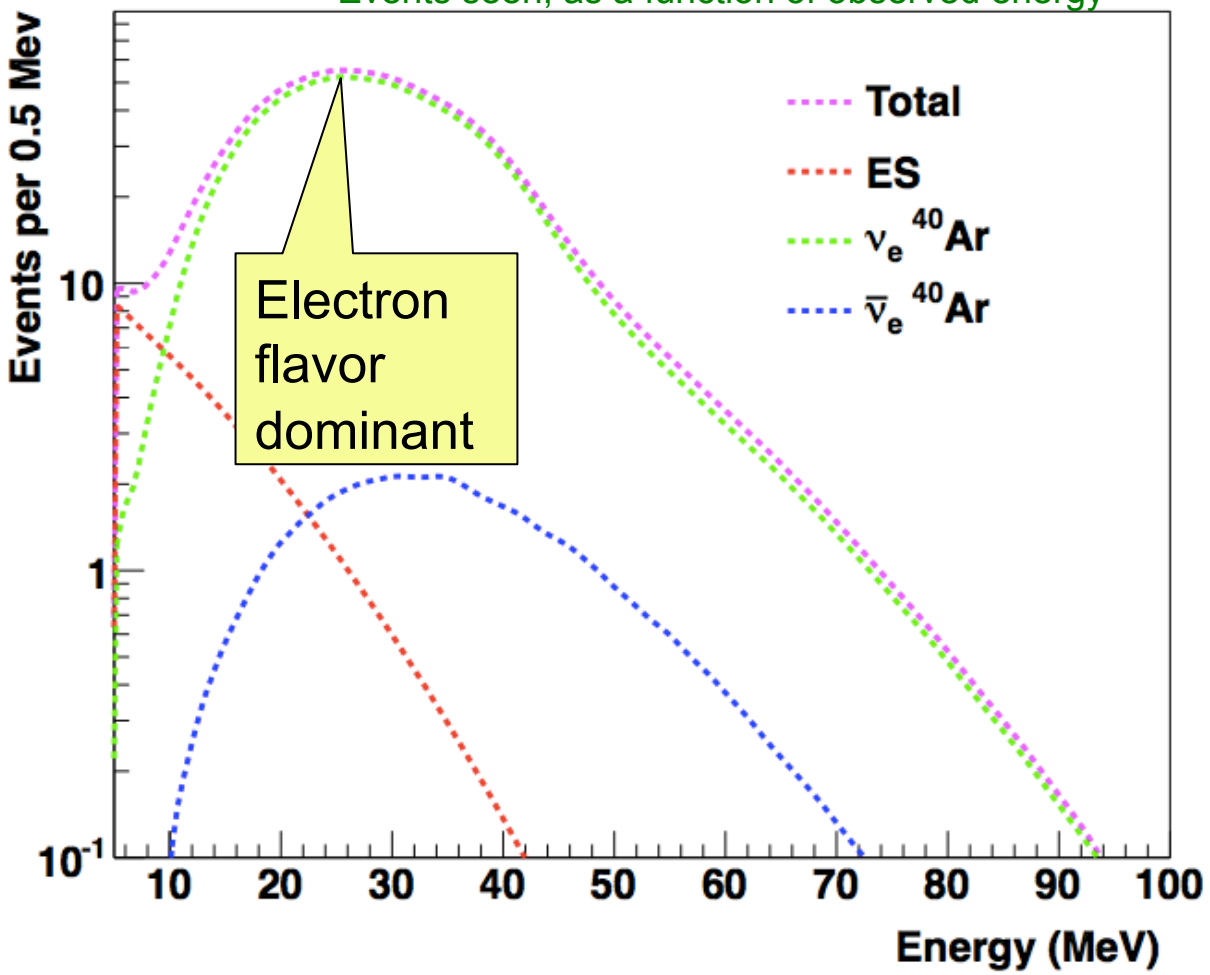
- In principle can tag modes with
- deexcitation gammas (or lack thereof)...

Cross sections in argon



Supernova signal in a liquid argon detector

Events seen, as a function of observed energy



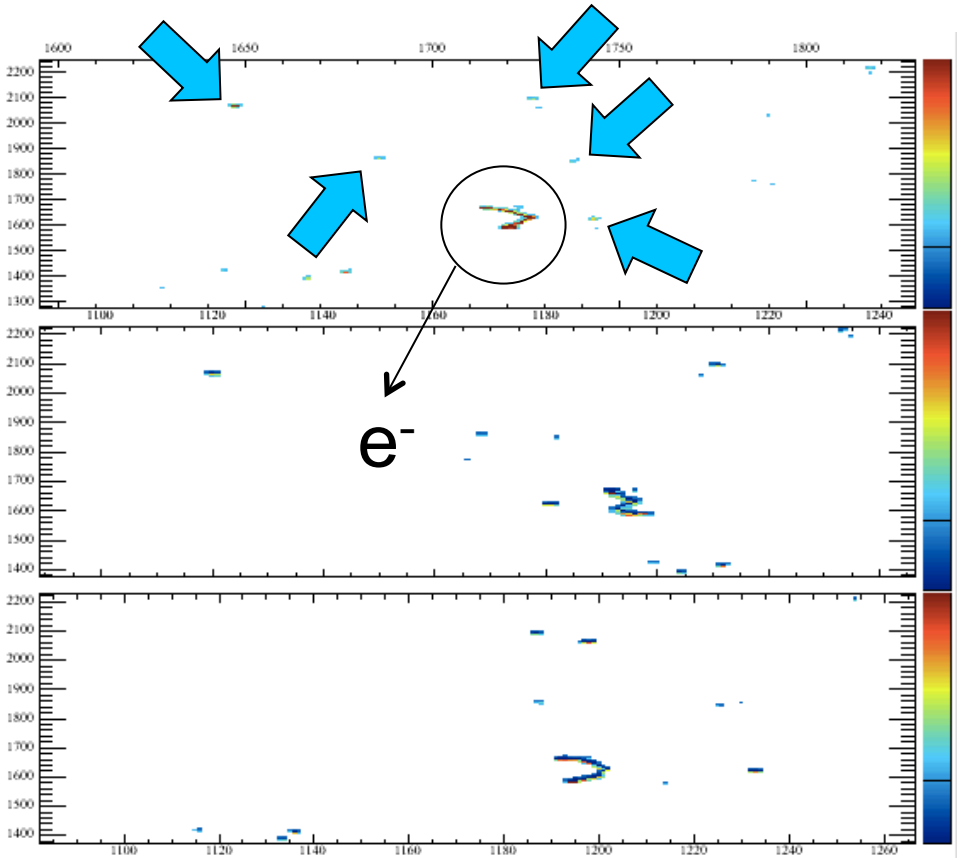
For 34 kton @ 10 kpc, GKVM model

Channel	Events "Livermore" model	Events "GKVM" model
$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$	2308	2848
$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$	194	134
$\nu_x + e^- \rightarrow \nu_x + e^-$	296	178
Total	**2794**	**3160**

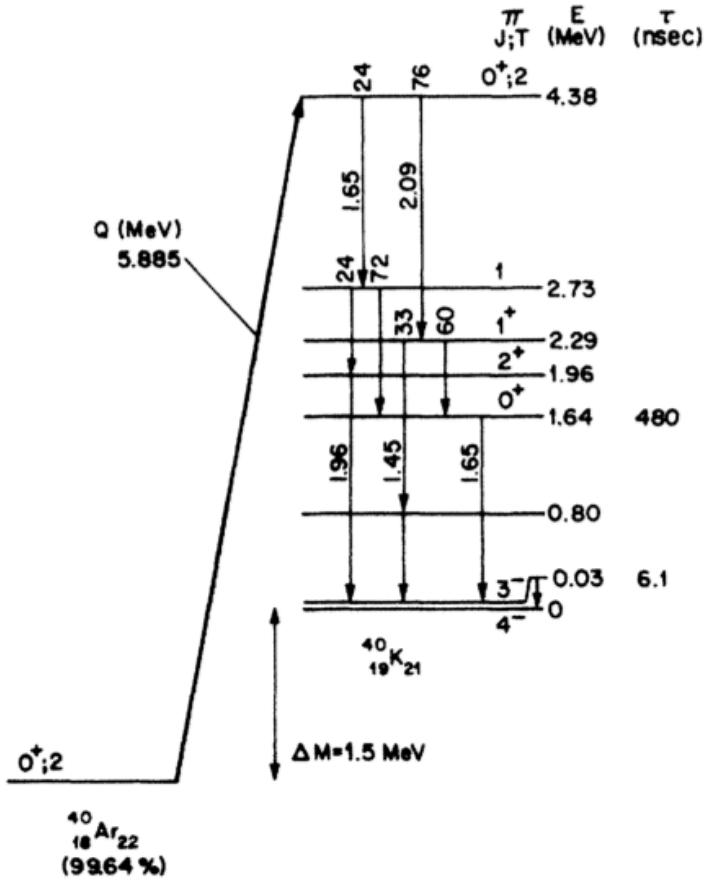
There is significant model variation

Can we tag ν_e CC interactions in argon using nuclear deexcitation γ's?

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



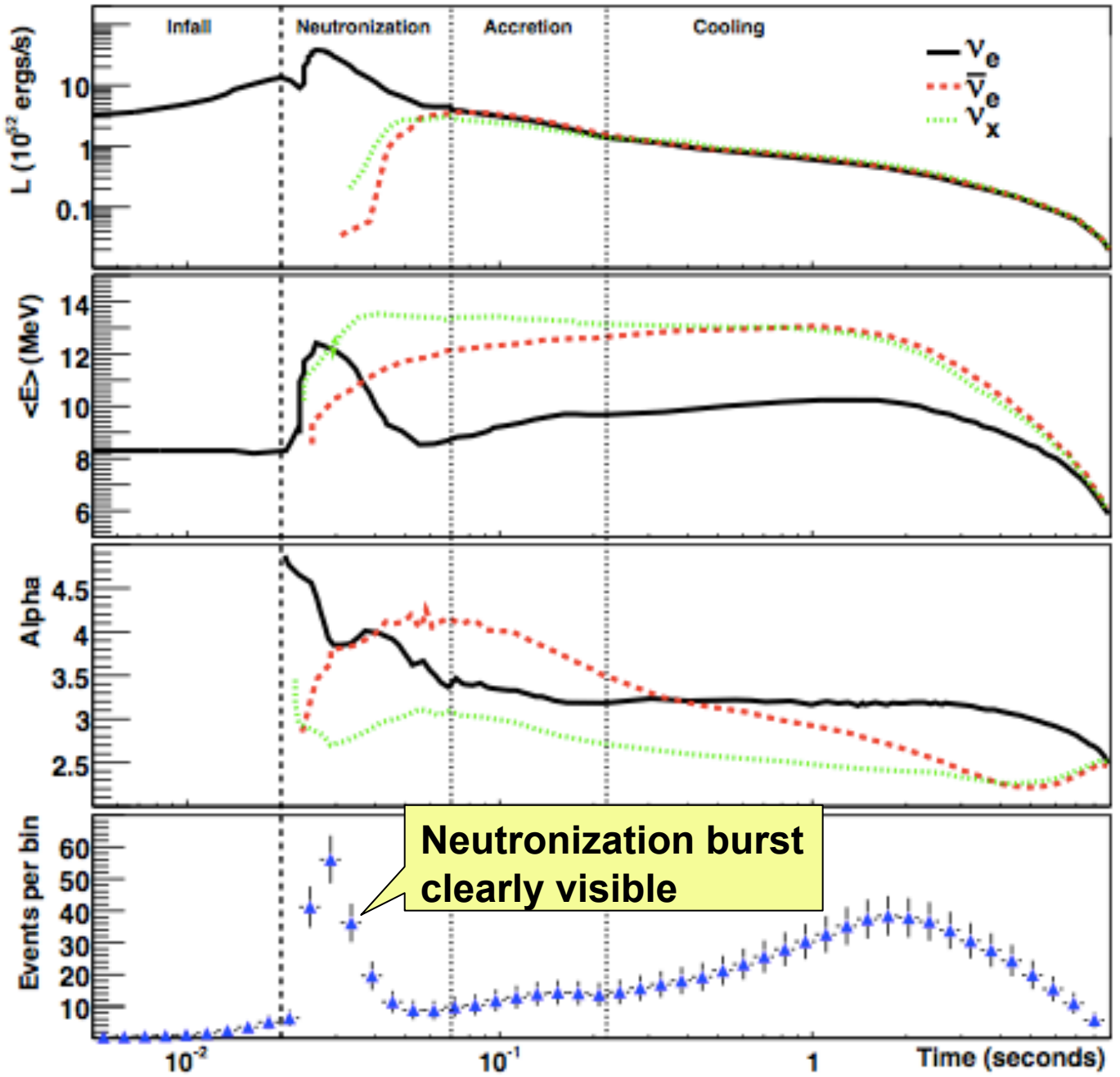
MicroBooNE geometry (LArSoft)



20 MeV ν_e , 14.1 MeV e^-, simple model based on R. Raghavan, PRD 34 (1986) 2088
Improved modeling based on ^{40}Ti (^{40}K mirror) β decay measurements possible
Direct measurements (and theory) needed!

Need to understand efficiency for given technology

Example of supernova burst signal in 34 kton of LAr



luminosity

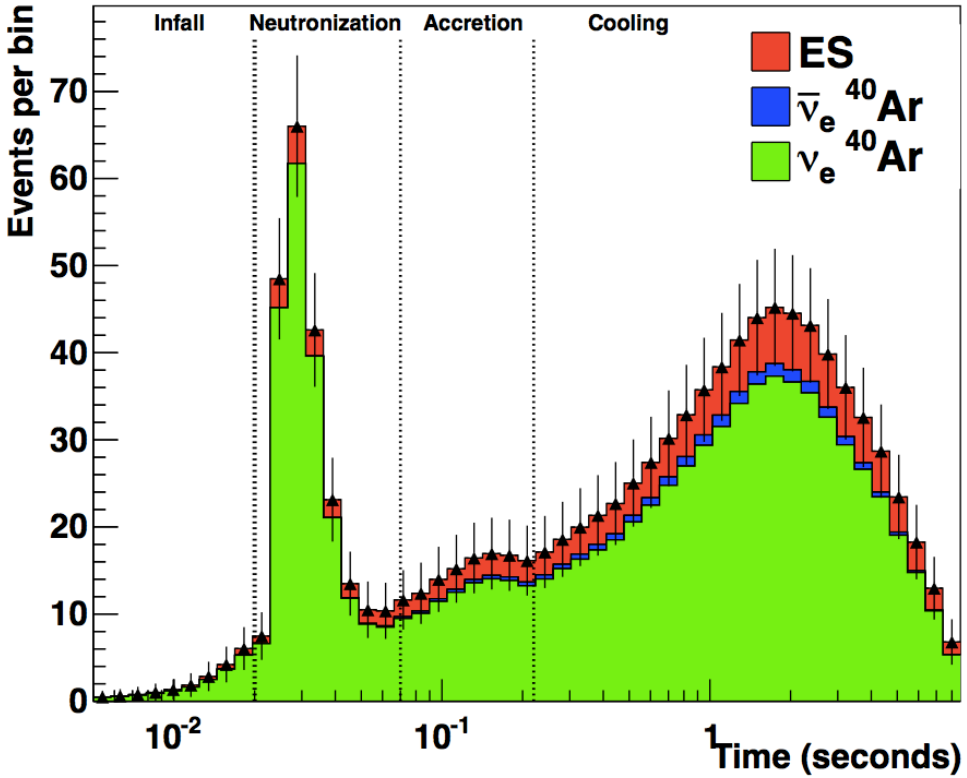
average ν energy

pinching
(large α ➔ suppressed tails)

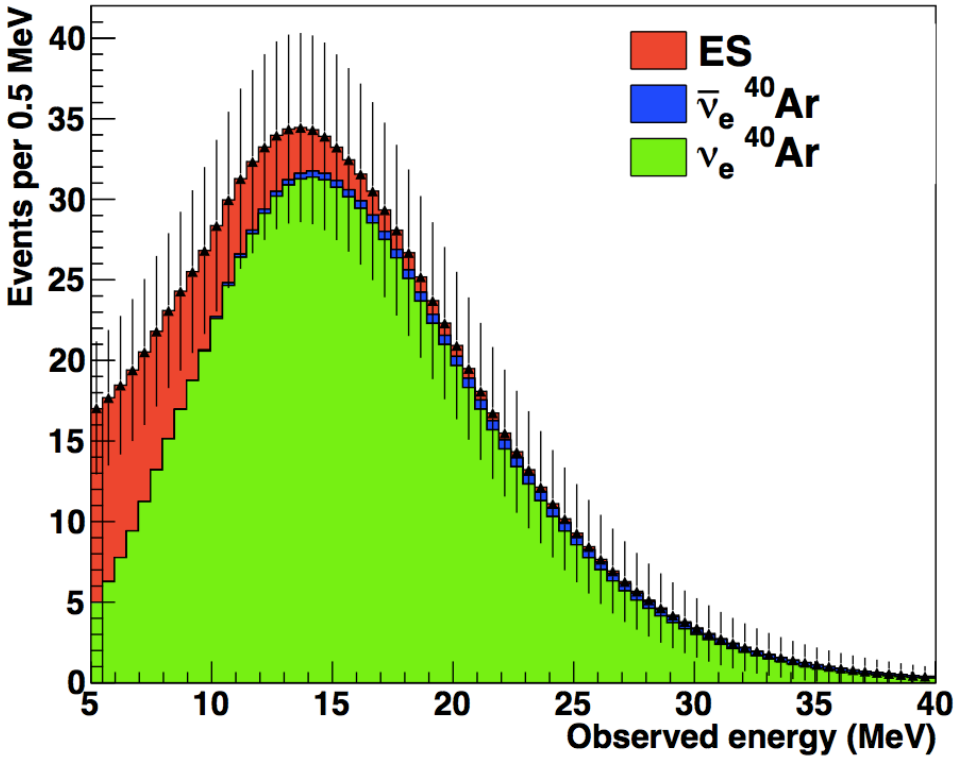
See the ν_e light curve!

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

Flavor composition as a function of time



Energy spectra integrated over time

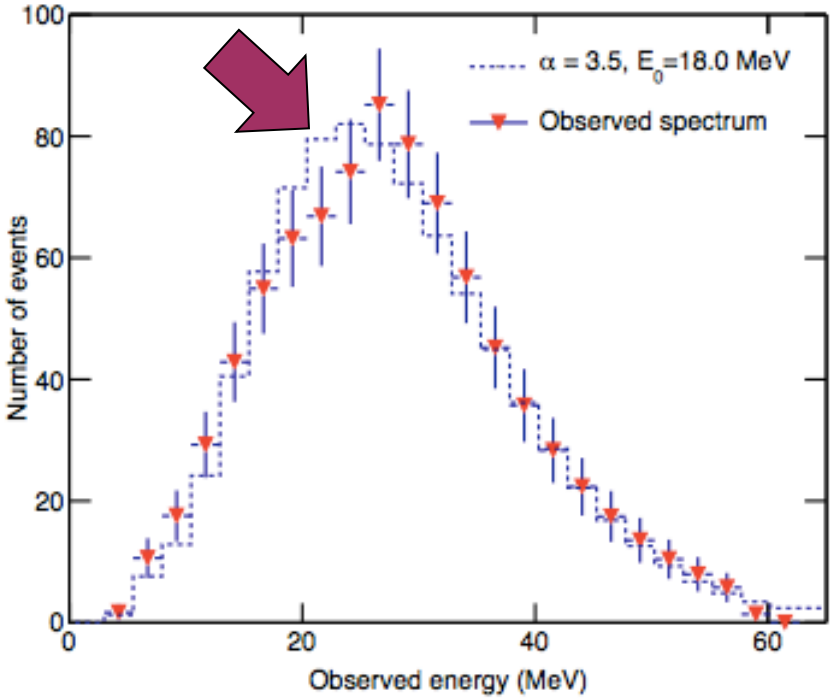


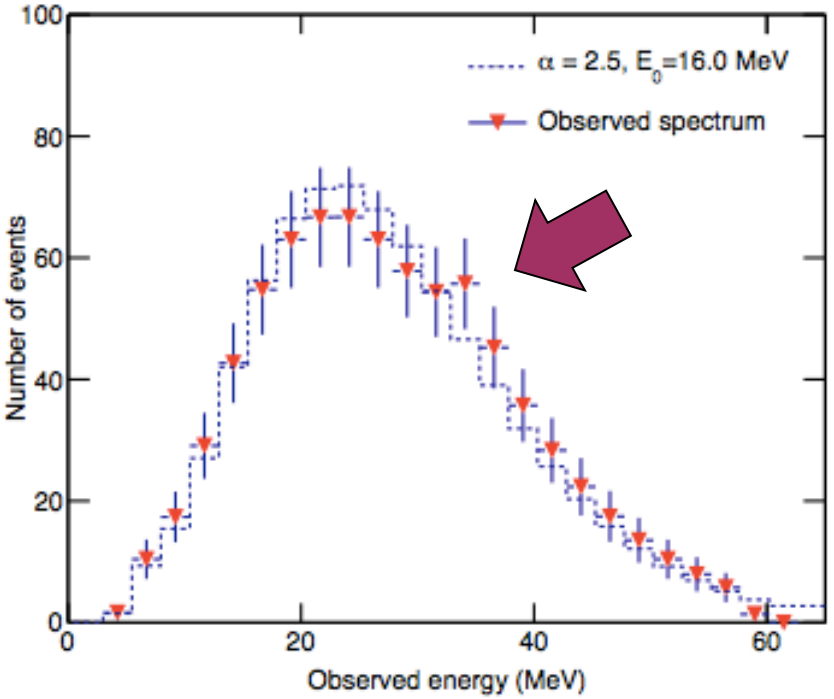
For 40 kton @ 10 kpc,
Garching model

Another anecdote:

A. Friedland, H. Duan, JJ Cherry, KS

1-sec integrated spectra in 34-kton LAr, few sec apart for 10-kpc SN, NMH

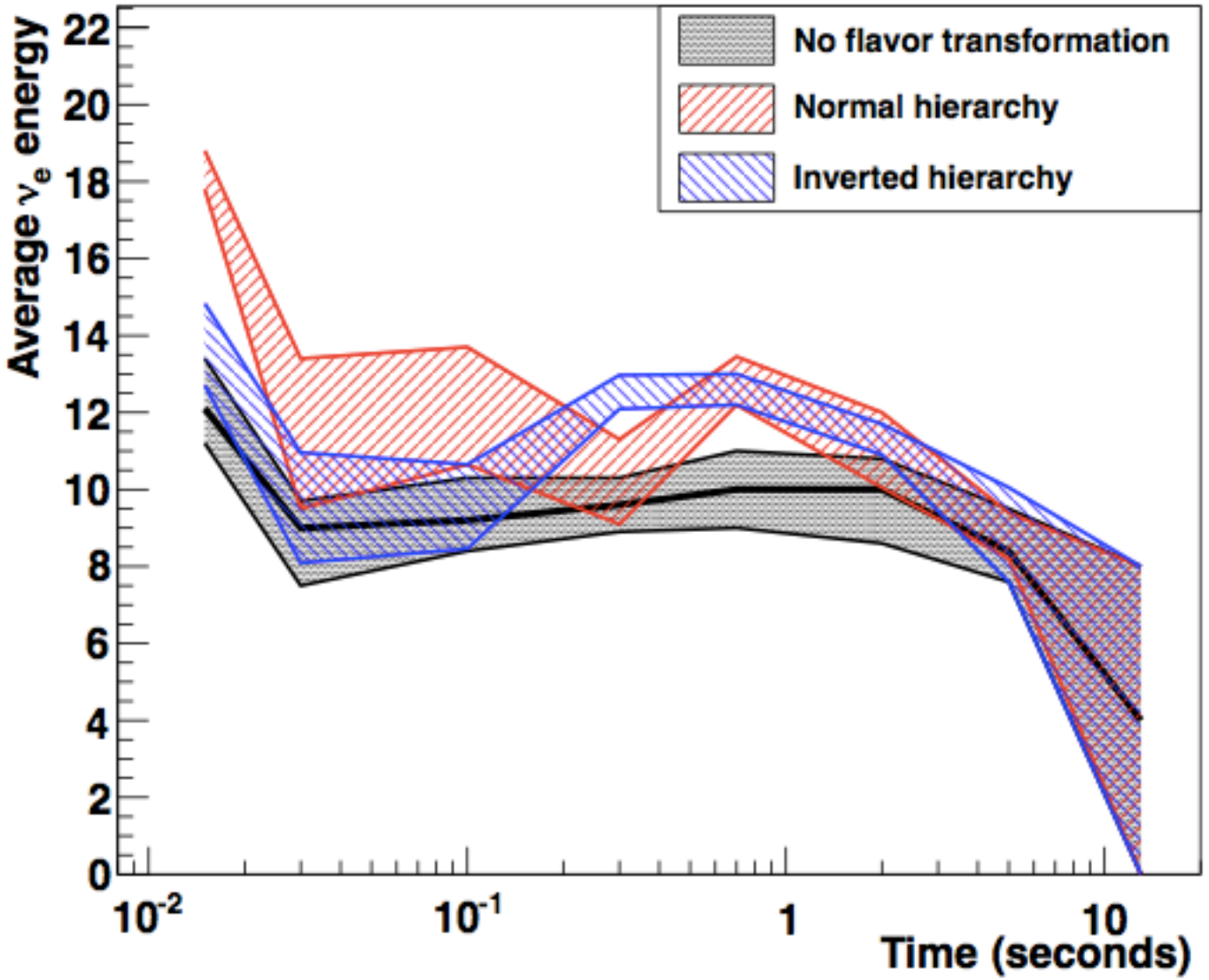




MH-dependent "non-thermal" features clearly visible as shock sweeps through the supernova

And another:

A. Friedland, H. Duan, JJ Cherry, KS



Average ν_e energy from fit to "pinched thermal",
34-kton LAr @ 10 kpc, including collective oscillations ➔
clearly, there's information in the spectral evolution

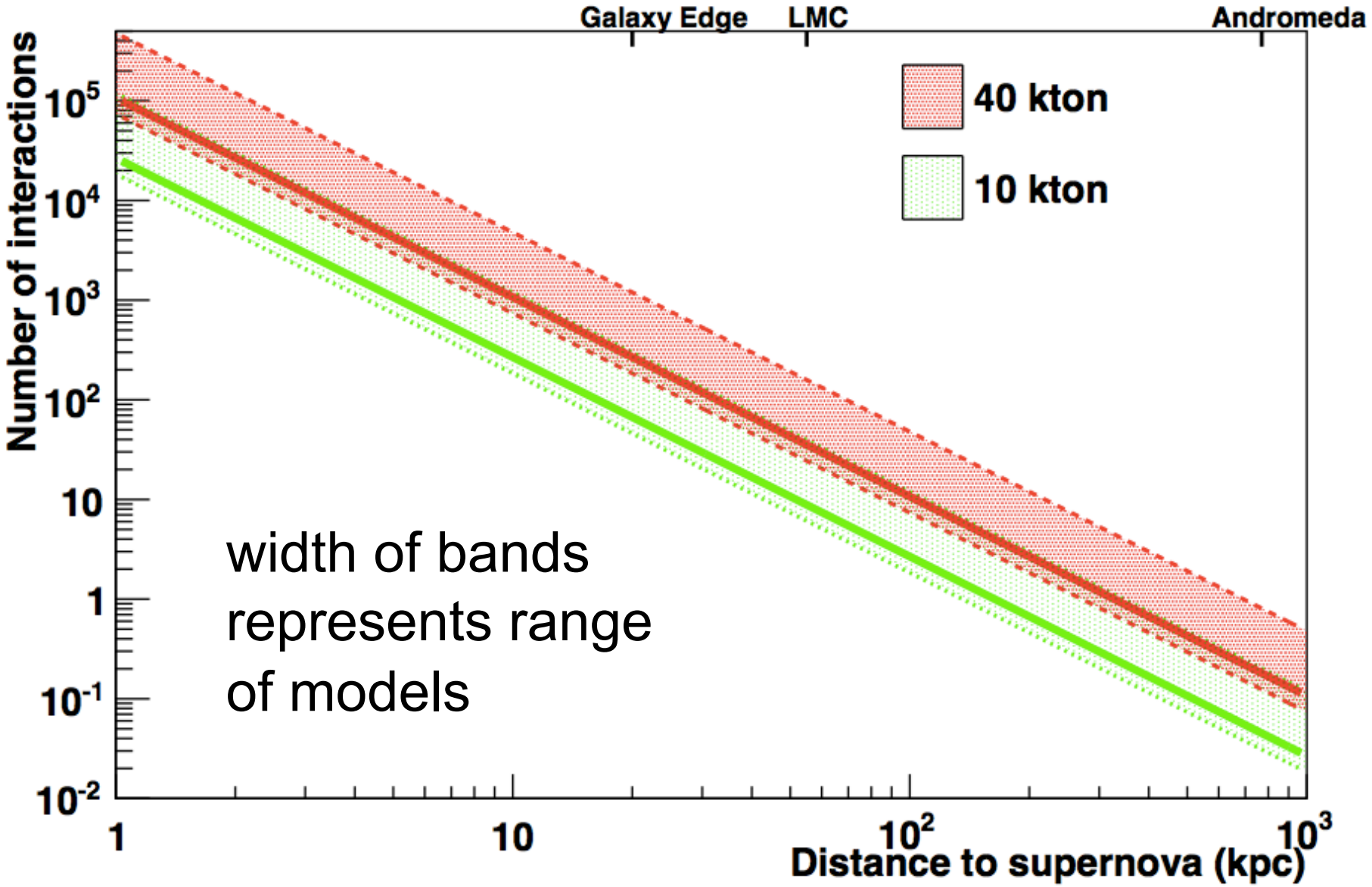
What if you “only” have 10 ktons?

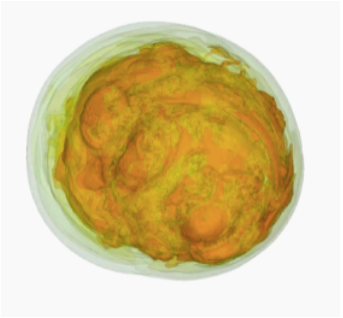
I’ll take it!!

We still get ~100’s to 1000’s of electron neutrinos...

(Remember that the current world supernova neutrino sample is ~2 dozen nuebars, and ~0 nues...)

Events in LAr vs distance





Take-Away Messages

- very rich information, both physics and astrophysics, in the **energy-flavor-time profile** of a core-collapse supernova ν burst
- liquid argon detectors have unique sensitivity to the **electron flavor component**, which has interesting features (e.g., neutronization)
- there is significant variation in models, and $1/D^2$ variation with distance
- **10 kton detector still has unprecedented capability**!
- we must understand detection and reconstruction efficiencies for ~5-50 MeV neutrinos, and **select detector parameters to ensure capability**

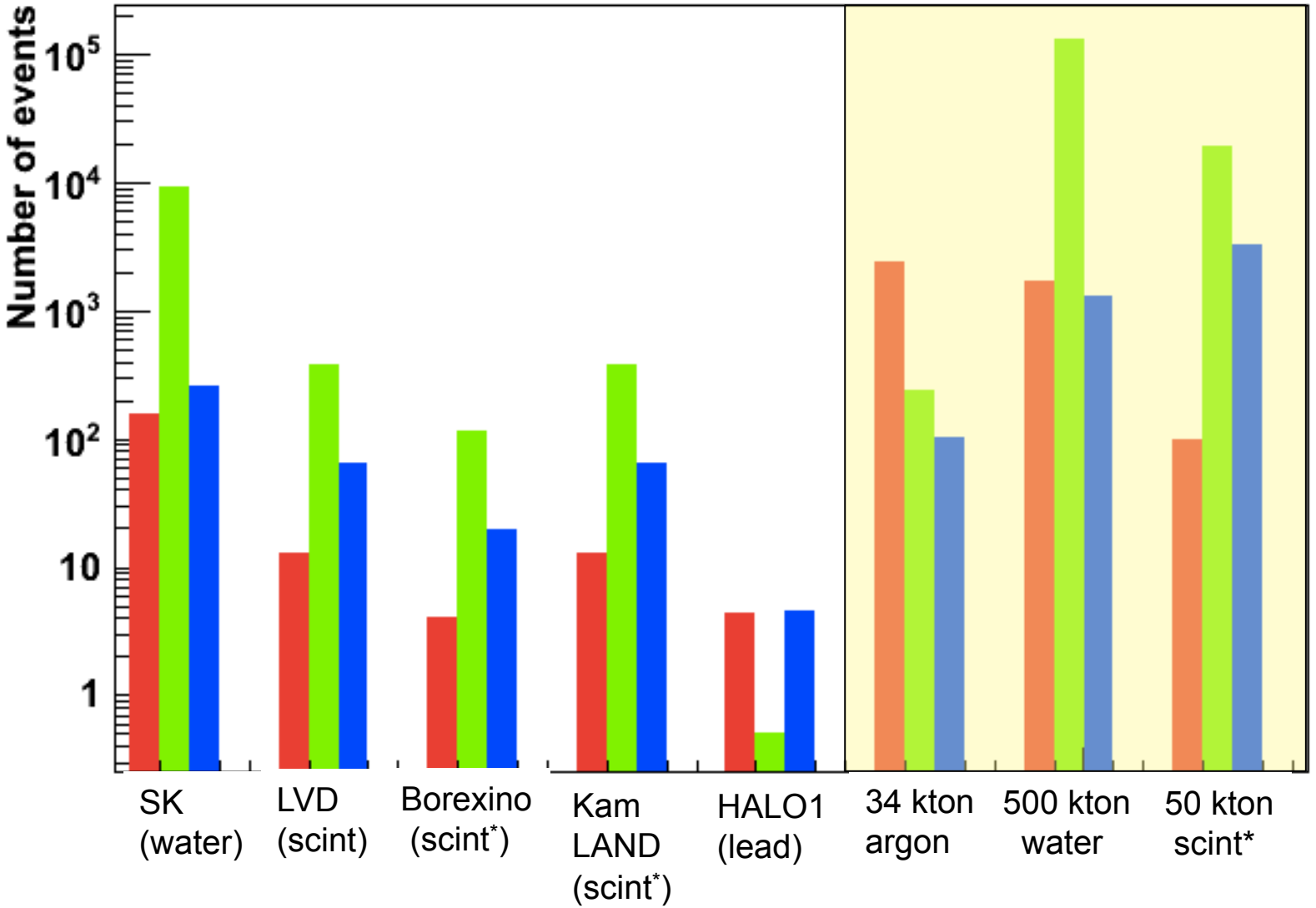
World SN flavor sensitivity

for ~largest existing or proposed detectors of each class

Electron neutrino ➔ dominate in LAr

Electron antineutrino ➔ dominate in water & scint

Muon and tau neutrino and antineutrino ➔ minor component



Livermore model @ 10 kpc

* plus NC ν-p scattering