Supernova Neutrinos in a Surface Liquid Argon Detector

or,

"θ_{13} the lucky and patient way"

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- **Supernova ν's & Physics Potential**
- **Expected Signal in Liquid Argon**
- **Backgrounds in a Surface Detector**
- **Possible Ways to Estimate Backgrounds**

Supernova Neutrinos

Stellar core collapse in Galaxy: ~ few per century

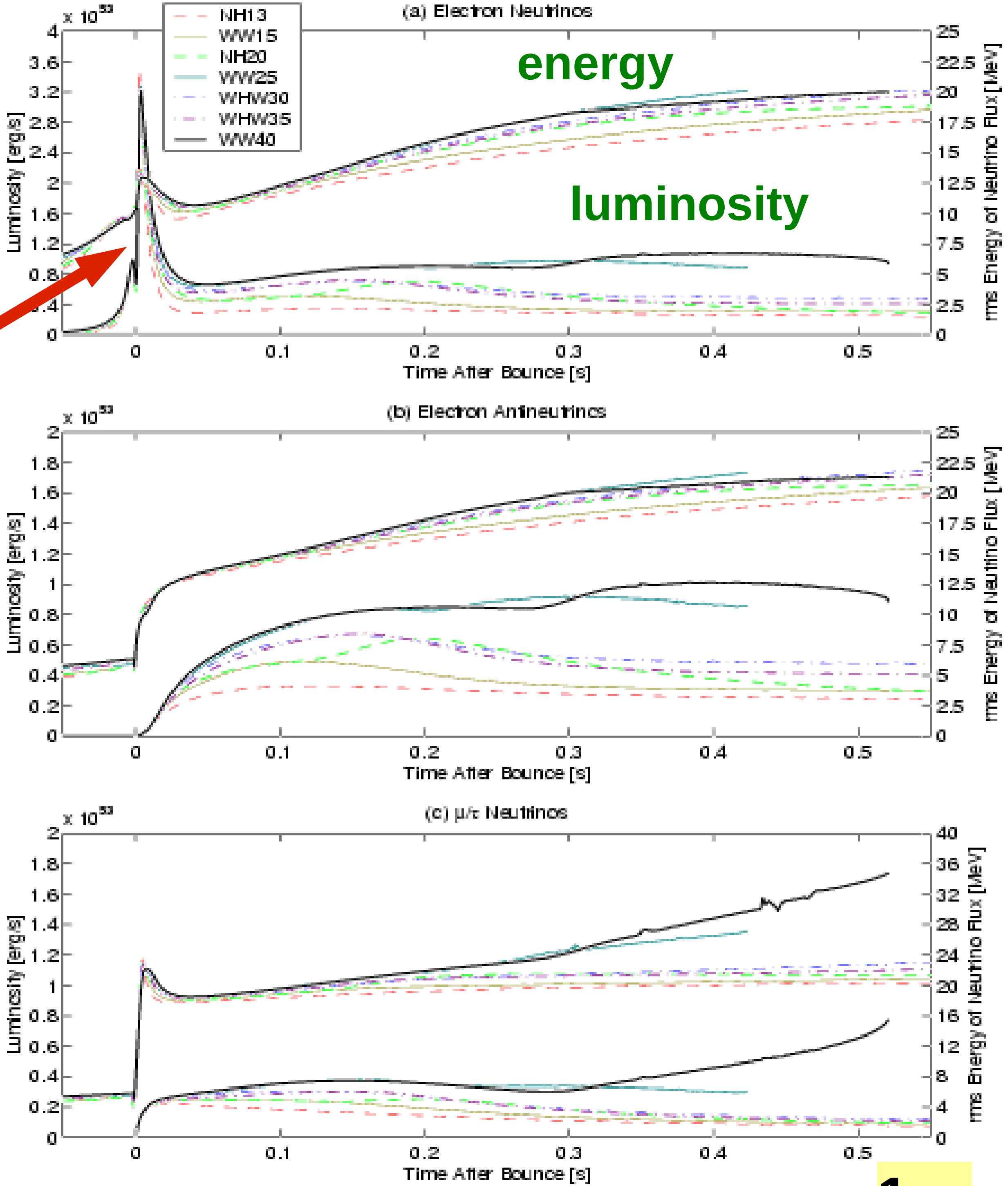
Gravitational binding energy of proto-nstar:

99% in ν's of all flavors

- **emitted over 10's of seconds**
- **energies 10's of MeV**

M. Liebendorfer et al.

"Breakout peak": 1% of total signal is ν_e at outset



ν_e

$\bar{\nu}_e$

$\nu_{\mu,\tau}$

1 s

What Can We Learn from a Galactic Supernova Neutrino Signal?

NEUTRINO PHYSICS

- ν absolute mass from time of flight delay
- MNS parameters from spectra (flavor conversion in supernova matter, in Earth)

CORE COLLAPSE PHYSICS

- explosion mechanism
- proto nstar cooling, quark matter
- black hole formation

from flavor, energy, time structure of burst

ASTRONOMY FROM EARLY ALERT

~hours of warning before visible SN, + some pointing with ν's

- progenitor and environment info
- unknown early effects?

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Neutrino Oscillations, Mass Hierarchy

e.g. Fuller et al. astro-ph/9809164, Dighe et al. hep-ph/9907423, Lunardini et al. hep-ph/0106149
Barger et al. hep-ph/0202158, Minakata et al. hep-ph/0010240 etc.

Energies: $\langle E_{\nu_e} \rangle \sim$ 12 MeV

$\langle E_{\bar{\nu}_e} \rangle \sim$ 15 MeV

$\langle E_{\overset{(-)}{\nu}_{\mu,\tau}} \rangle \sim$ 18 MeV

Flavor-energy hierarchy is robust (but may be only ~10%)

Flavor transformations in stellar matter

$\Rightarrow$ **spectral distortion**

e.g. expect **hot ν_e or $\bar{\nu}_e$**

Also: matter effects in Earth can modify signal

$\Rightarrow$ **compare NC, ν_e, $\bar{\nu}_e$ rates and spectra**

(Good to have geographically separated detectors!)

Some signatures (assuming LMA, $|U_{e3}|^2$ relatively large, 3-flavor picture)

- ν_e in neutronization peak completely transformed
- hard ν_e during cooling
- Earth matter effects for $\bar{\nu}_e$

} Normal hierarchy

- ν_e in neutronization peak partly transformed
- hard $\bar{\nu}_e$ during cooling
- Earth matter effects for ν_e

} Inverted hierarchy

Sensitivity to $|U_{e3}|^2$ as low as 10^{-4} to 10^{-5}

Some SN model-dependence...

The Supernova Signal in Liquid Argon

I. Gil-Botella & A. Rubbia, hep-ph/0404151

CC Interactions on Argon

$\nu_e + {}^{40}Ar \rightarrow e^- + A' + nN$ (${}^{40}K^*$ at low energy) E_{th}=1.5 MeV

$\bar{\nu}_e + {}^{40}Ar \rightarrow e^+ + A' + nN$ (${}^{40}Cl^*$ at low energy) E_{th}=7.5 MeV

see de-excitation γ's

NC Interactions on Argon

$\nu_x + {}^{40}Ar \rightarrow \nu_x + A' + nN$ (${}^{40}Ar^*$ at low energy) E_{th}=1.5 MeV

Elastic Scattering on Electrons

$\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$ (some pointing)

Expected Events in 50 kt at 10 kpc Based on Studies for Underground Detector

From hep-ph/0404151

	No osc	Normal hierarchy		Inverted hierarchy	
		Large θ_{13}	Small θ_{13}	Large θ_{13}	Small θ_{13}
Elastic	665	665	665	665	665
ν_e CC	3120	15660	11920	11920	11920
$\bar{\nu}_e$ CC	270	555	555	1219	555
NC	15220	15220	15220	15220	15220
		32100			

Some conclusions of this preprint:

For even 3kton detector, if SN ν energies are sufficiently 'hierarchical',

- -if θ_{13} is 'large' ($>3\times10^{-4}$), can distinguish mass hierarchy
- -if θ_{13} is 'small'($<2\times10^{-6}$), can set upper limits on θ_{13}
- -if θ_{13} is intermediate, can measure it
- -NC events important to disentangle from SN physics

This study apparently assumes:

- no background (maybe reasonable for underground detector)
- perfect tagging of interactions (reasonable ??)

Certainly no background is *not* likely to be a good assumption for a surface detector...

Backgrounds for a Surface Detector

Cosmic Ray Muons & Michel electrons

Cosmic Ray μ^- capture product ^{40}Cl
(t~100 s, E<~7 MeV)

'Spallation' products: radioactive isotopes created by spallation of argon (and impurities?), absorption of neutrons

some isotopes possibly long-lived;
mostly low energy, but some may not be
(NC signal is low energy)

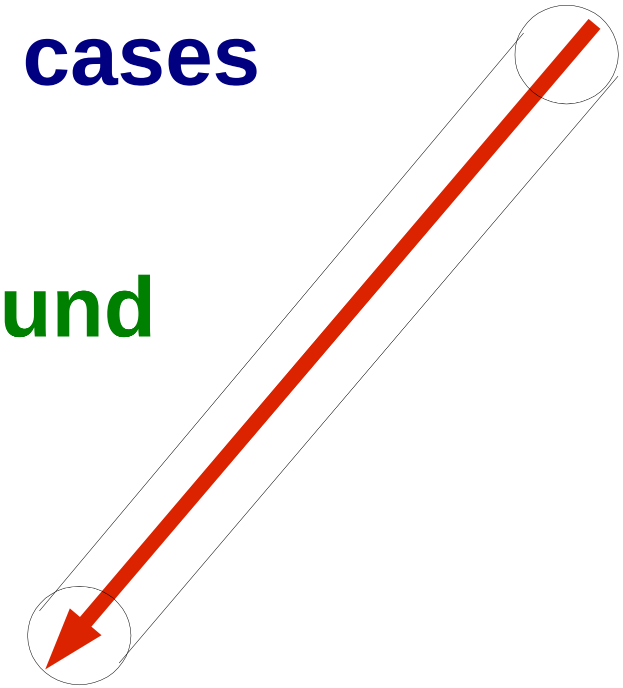
Radioactivity

Instrumental/reconstruction backgrounds??

General strategies for background rejection:

Require de-excitation signature and/or clean electron; can use directionality in some cases

Veto in space and time around muon tracks



- for long-lived isotopes, must track liquid flow (~7 cm/s)

Generic criterion:

(few kHz of CR μ) x ($\langle N \rangle$ bg events per μ)
x 50 s duration of signal = $\langle N \rangle * 10^7$ bg events

Total signal events $\sim 10^4$, so for
s/bg~1 must have rejection of $<\sim 10^{-3} / \langle N \rangle$

But to evaluate, must know:

What is $\langle N \rangle$, and the nature of the background? What time and space dimensions around muon to veto? (need to know dead volume/time)

How to estimate cosmogenic backgrounds?

I have not been able to find info in the literature on spallation products in argon

Calculate? (Hard nuclear physics problem..)

Possibly, use existing (or soon to exist) surface detector data?

Require roughly $M_{test}\ T_{test}$ ~ 50 kton * 50 s to characterize the background (0.1 ton- yr)

(need appropriate trigger)

Faster method (although not natural distribution):

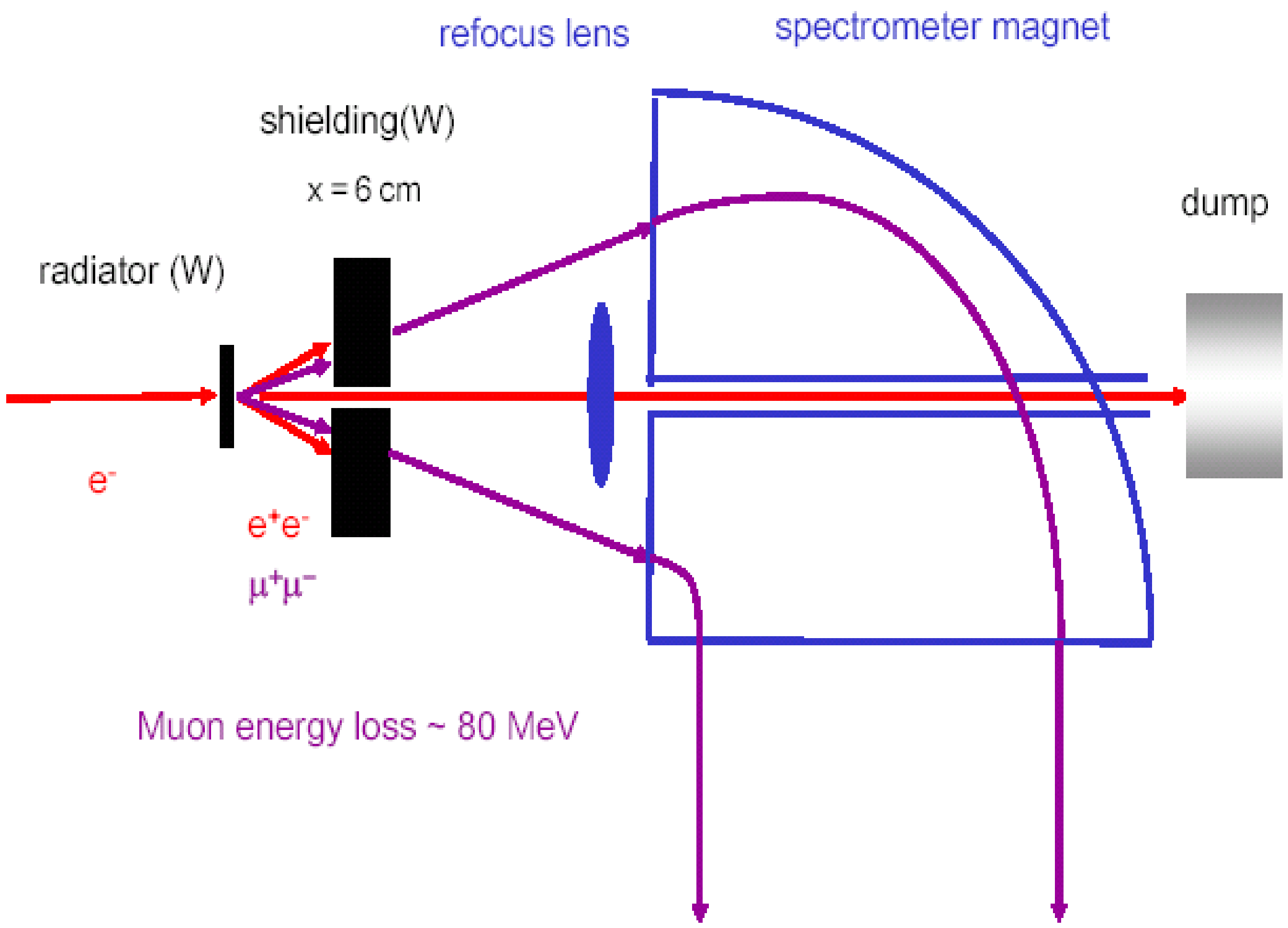
muon beam

with argon target to measure spallation isotopes as a function of muon momentum

(either LAr TPC or simpler detector(s); maybe could measure other targets, too)

One possibility: Alex Bogacz at JLab

e^+e^- shielding, momentum selection



Tunable muon beam, 10^6 μ/s, 0-5 GeV

Need higher energies?

Conclusions

Supernova neutrinos in a 50 kt LAr detector quite promising for getting at oscillation (and other) physics

Cosmogenic background in LAr is quite unknown! But possibly rejectable..

Need to characterize backgrounds:

surface detector? (slow)
muon beam test? (JLab? CERN?)

Other issues: instrumental backgrounds, reconstruction/tagging efficiency...