New Ideas in Long Range Reactor Monitoring with Neutrinos

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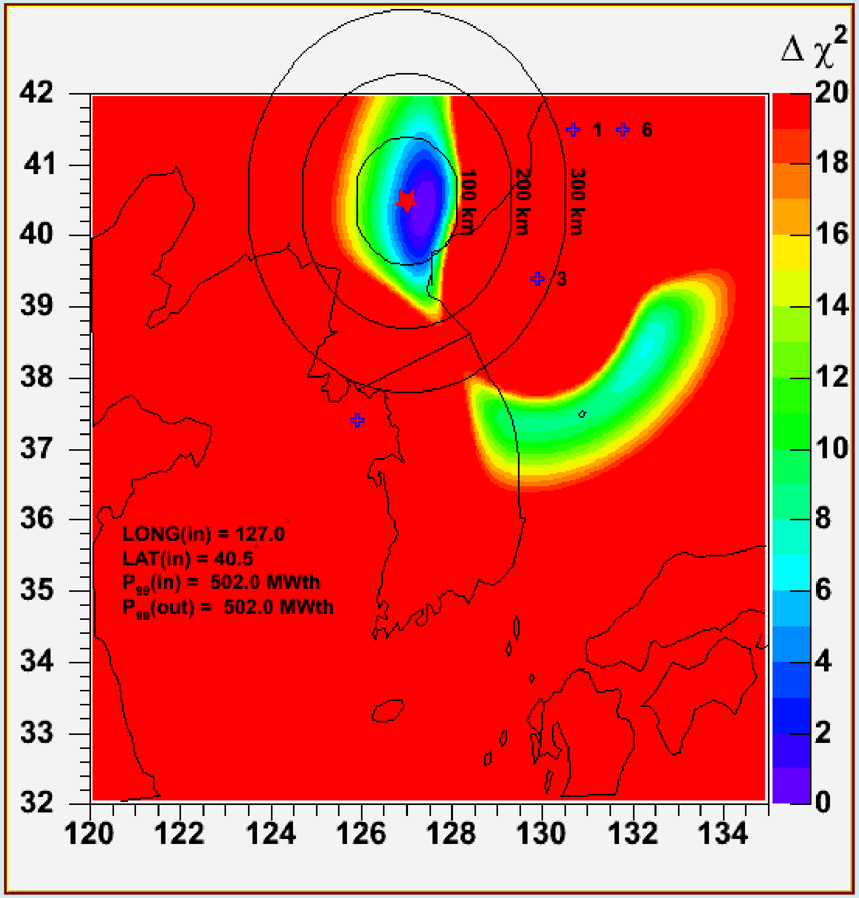
Introduction

- Previously we have used just neutrino rates to separate detectors.
- Can indeed be done.
- Requires multiple large detectors.
- Best if done far from other reactors.



3-ν Mixing: Reactor Neutrinos

$$P_{ee}=1-\{ \cos^4(\theta_{13}) \sin^2(2\theta_{12}) [1-\cos(\Delta m^2_{12}L/2E)]$$
$$+ \cos^2(\theta_{12}) \sin^2(2\theta_{13}) [1-\cos(\Delta m^2_{13}L/2E)]$$
$$+ \sin^2(\theta_{12}) \sin^2(2\theta_{13}) [1-\cos(\Delta m^2_{23}L/2E)]\}/2$$

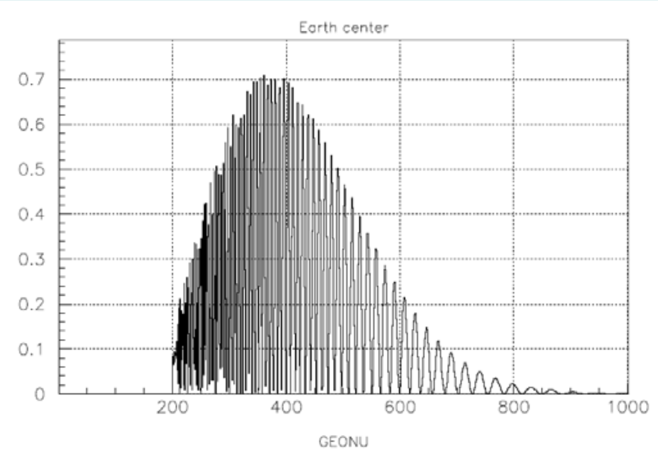
mixing angles

mass diffs

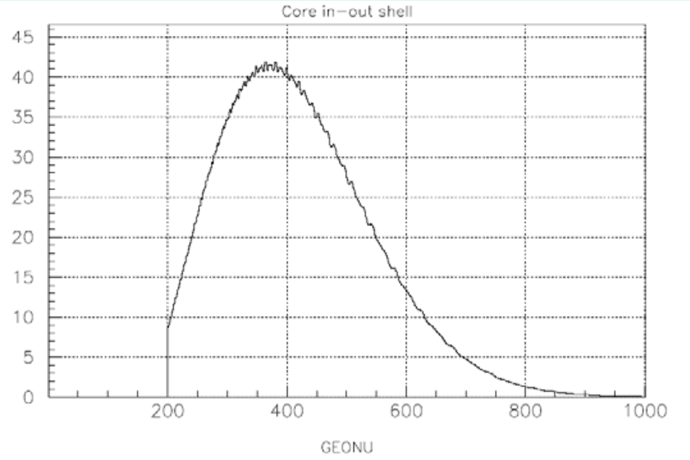
- Survival probability: 3 oscillating terms each cycling in L/E space (~t) with own "periodicity" ($\Delta m^2 \sim \omega$)
  - Amplitude ratios ~**13.5** : 2.5 : 1.0
  - Oscillation lengths ~**110 km** (Δm^2_{12}) and ~4 km ($\Delta m^2_{13} \sim \Delta m^2_{23}$) at reactor peak ~3.5 MeV
- In energy space it is like a **chirped signal**… very good for correlations.

Use Long Wave Nu Oscillations for Ranging Locations

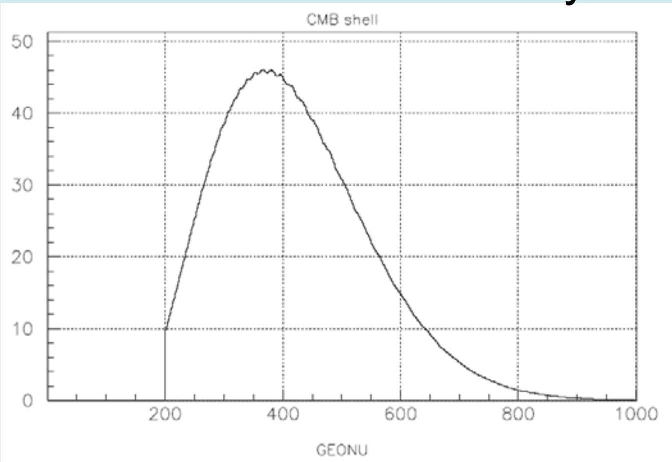
single geocentric reactor

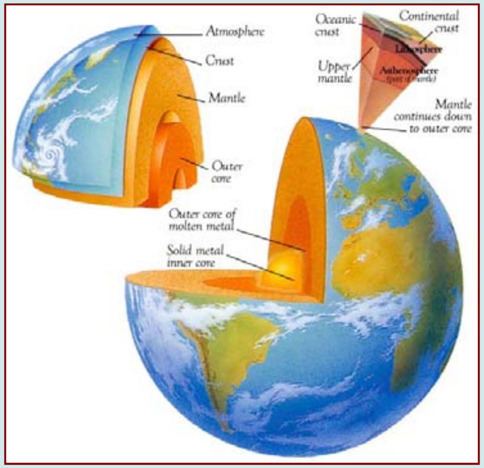


shell at solid core boundary



shell at core-mantle boundary

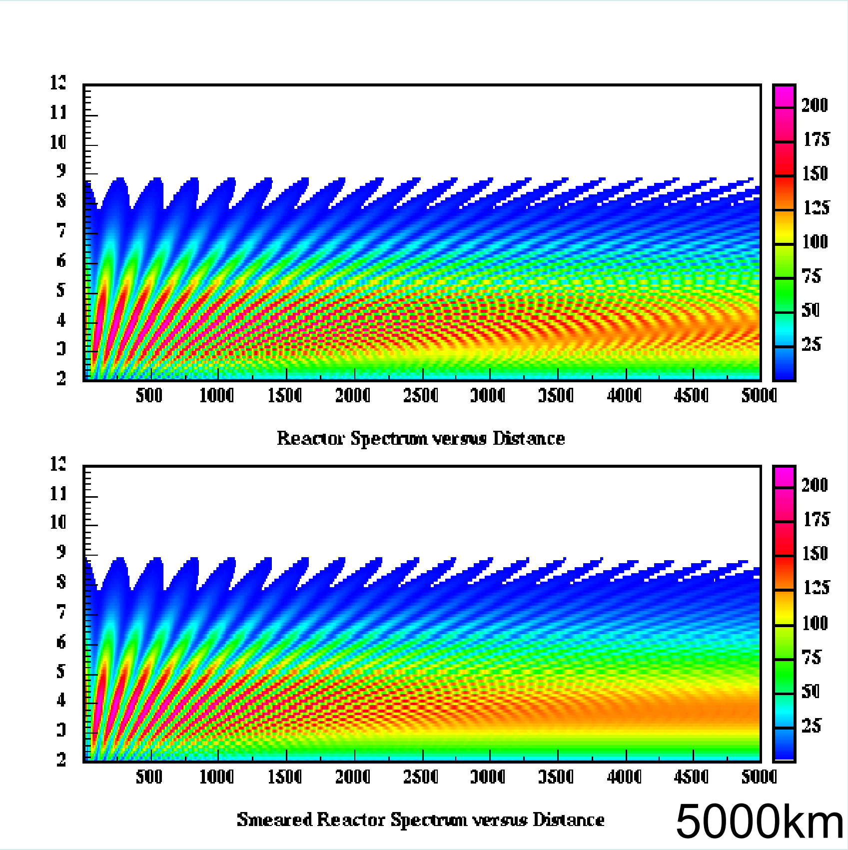


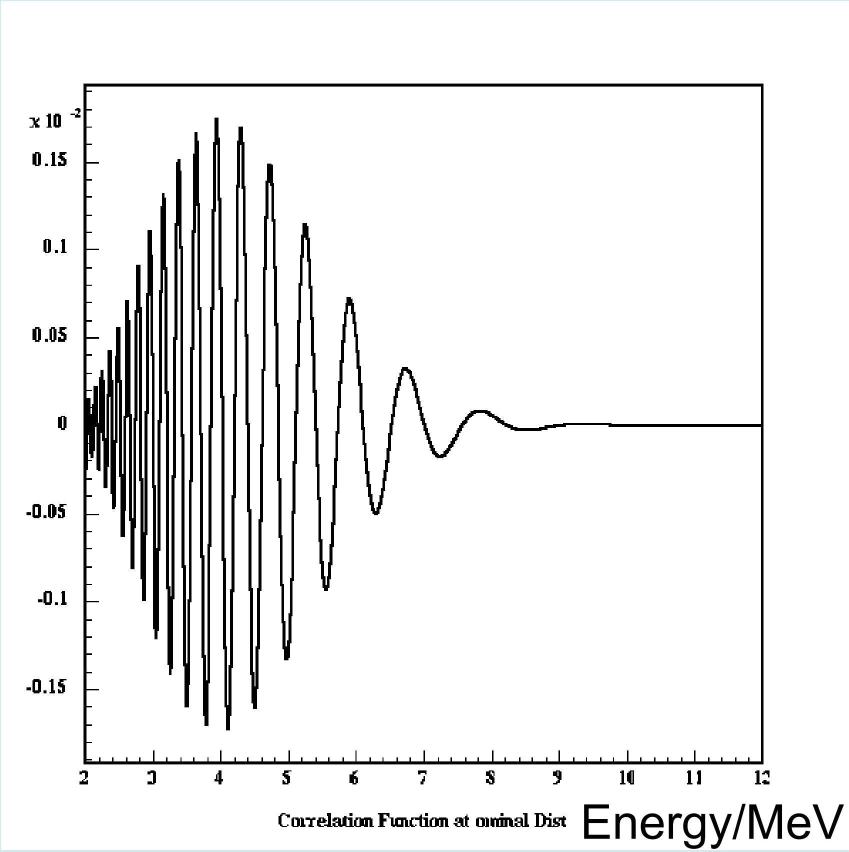


message... oscillations pattern not totally washed out -> possibility to extract

Can Use Matched Filter Techniques to Extract signal Range

Neutrino Energy / MeV



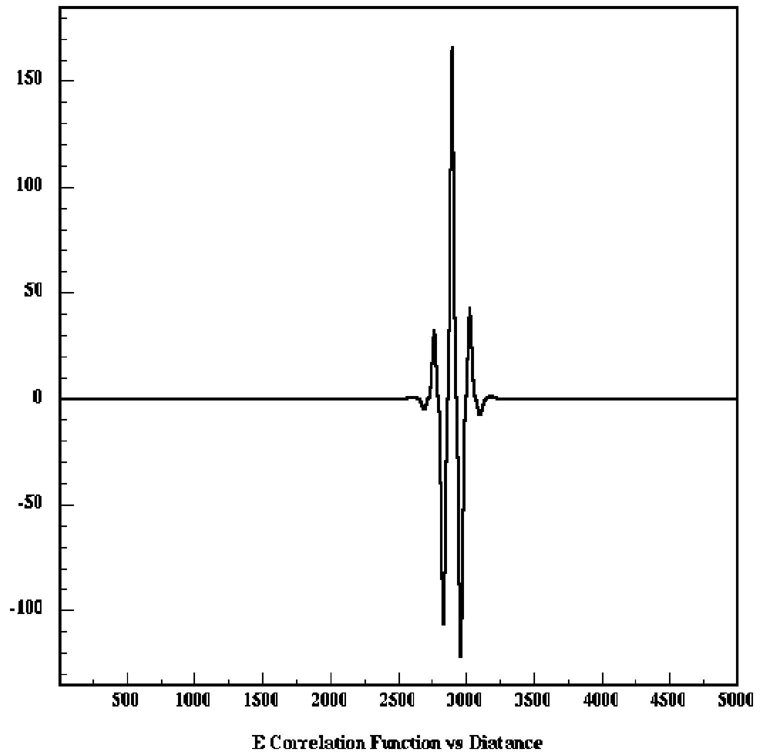


Distance / km

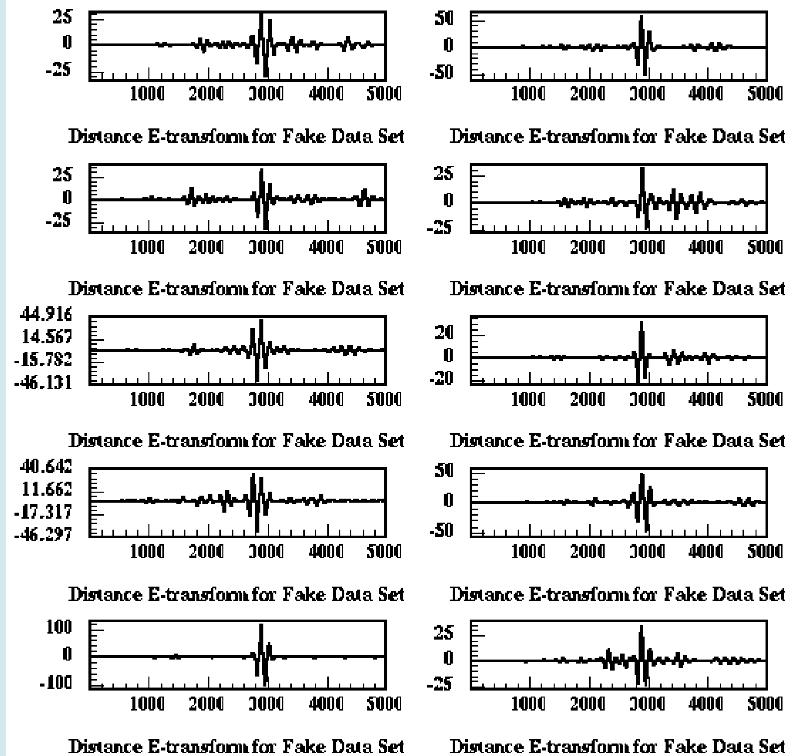
Correlation Function

Single Reactor Source at CMB

resolution to few km



10 sample simulated 1 yr runs



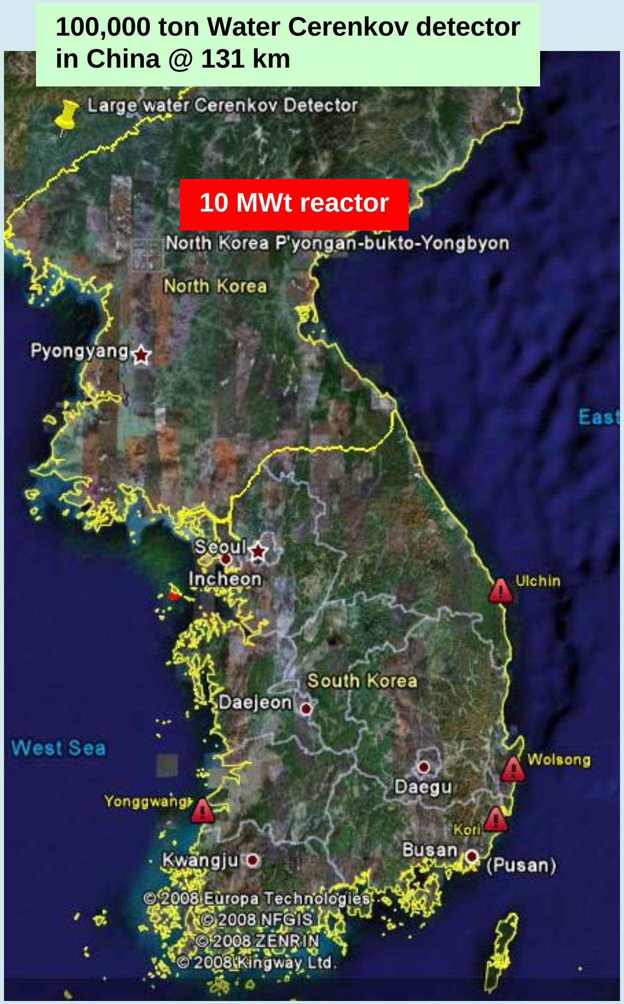
1 GW source observed by 100 kT detector

can be cleaned up

Conclusion for GEONUS

- We can make good measurements of any georeactors which exist, and find them accurately even with Hanohano.
- This information is needed for understanding backgrounds for long range reactor monitoring.
- Study needed to determine how well we can deconvolve distributions of natural sources in the presence of world power reactors (~1 TW total).

Hypothetical Monitoring Application



Take 10MT detector just inside China, 131 km from Yongbyon.

Can we detect a 10 MWt reactor?

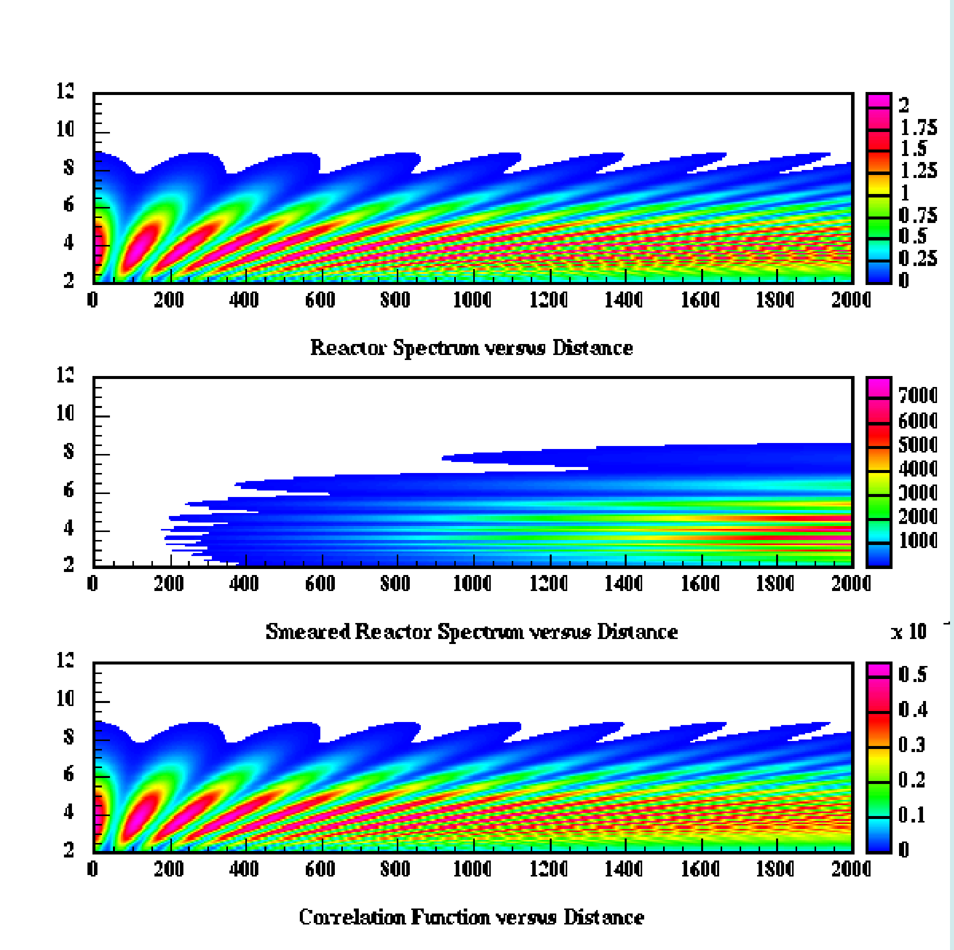
Answer **definitely yes** and know what we are seeing.

Spectra & Correlation Function

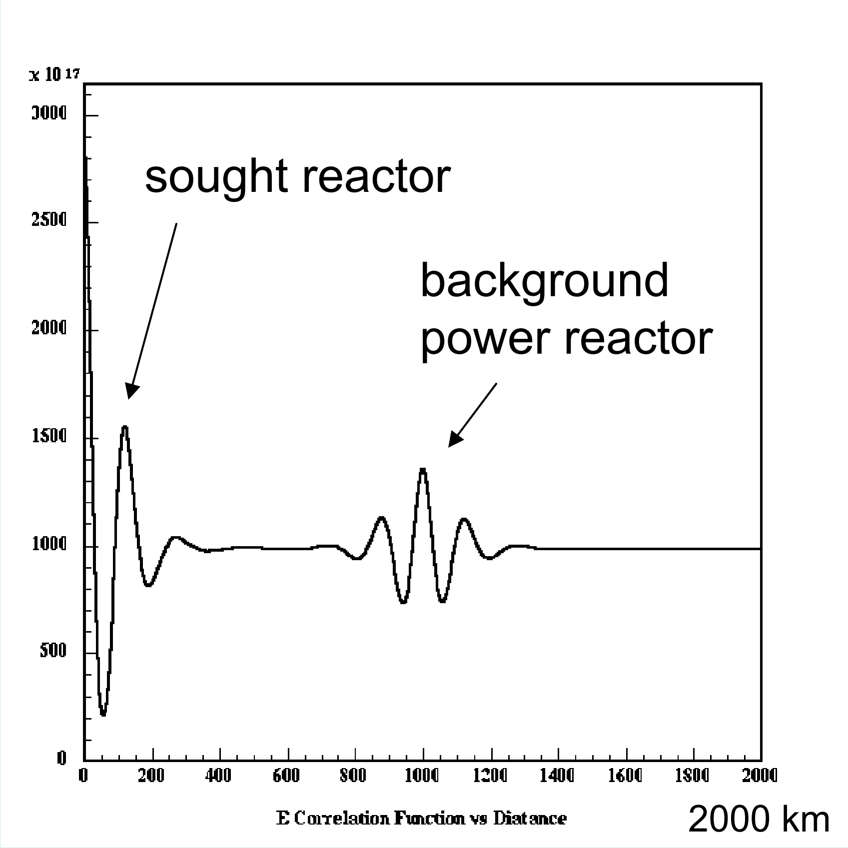
reactor spectra
at various distances

reactor spectra plus
1000 km bkgd

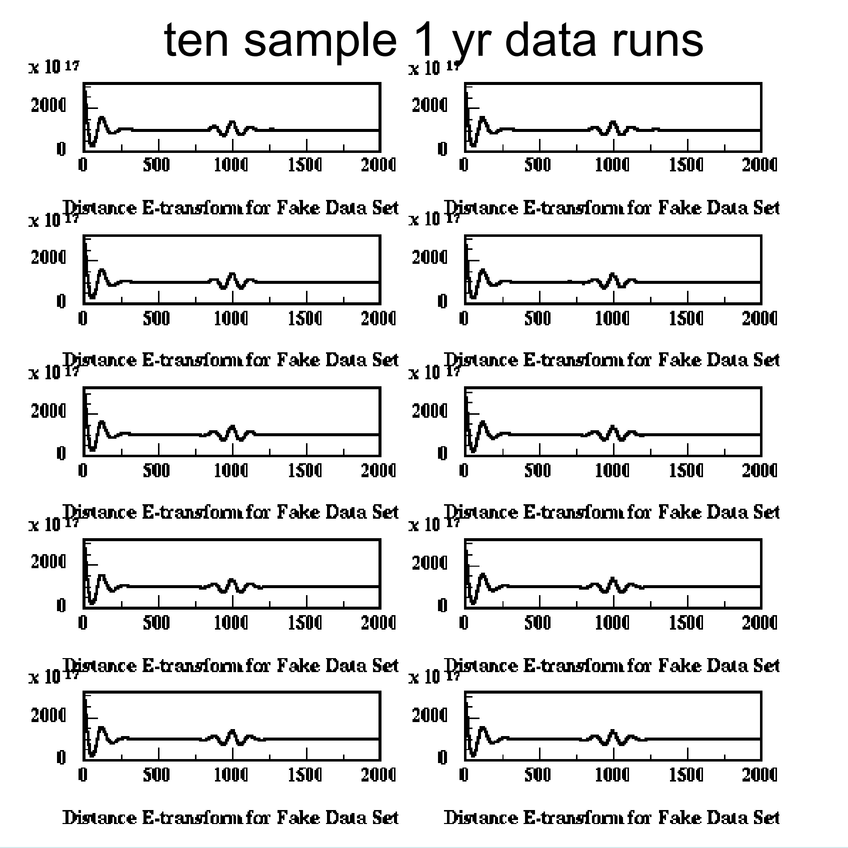
net correlation
function



After Sweep with Correlation Function



Distance / km

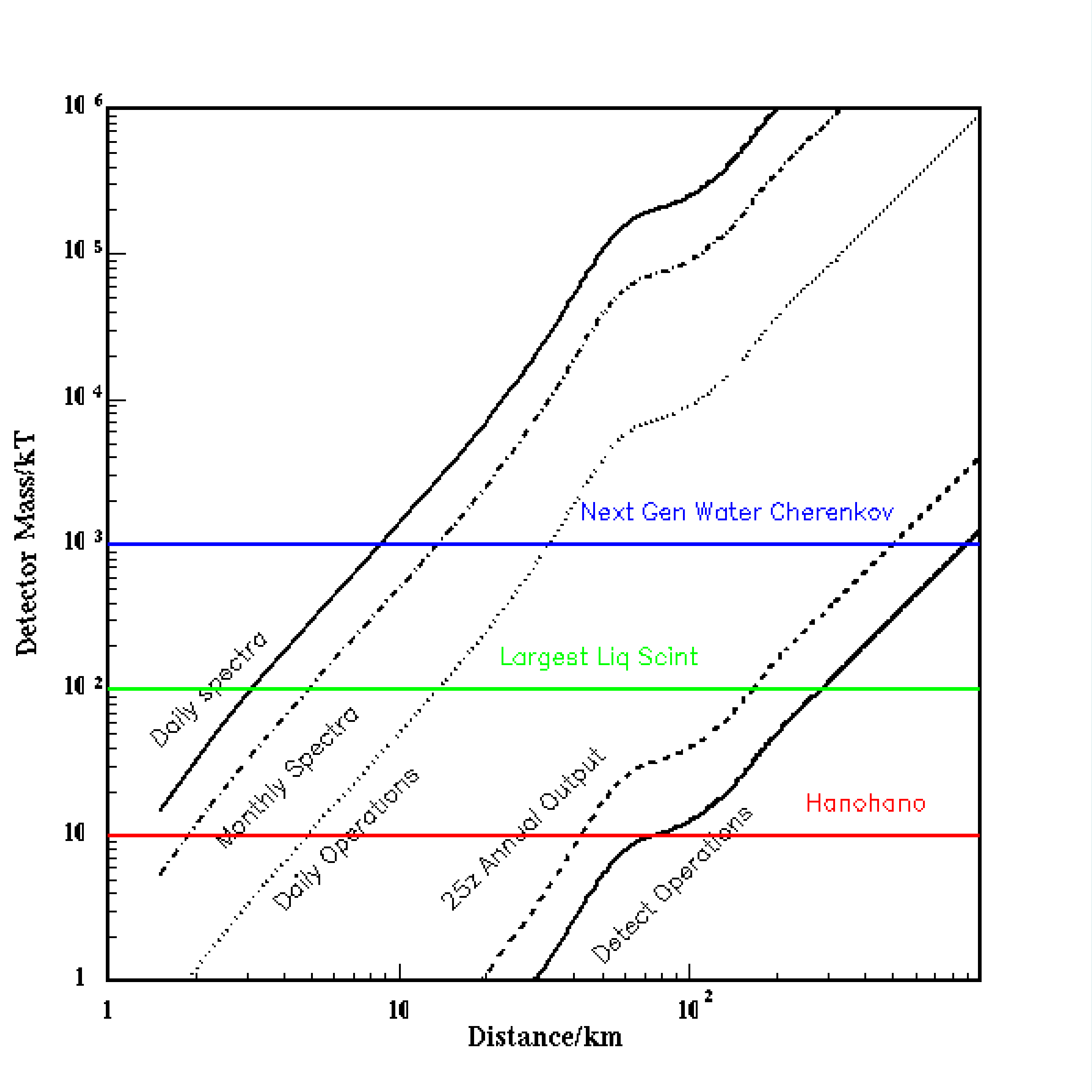


Monitored reactor easily seen.

Next Step: Use Sig. Proc. Techn. To Improve Resolution of Signal and Background

- Situation similar to that in radio astronomy and elsewhere, where one knows the point spread function.
- Can use MEM or CLEAN algorithms.
- Get much sharper distance and then power resolution.
- Limits will depend upon how many and disposition of background (distant power reactors) plus of course location and power of target reactor.
- Work needed with realistic sets of hypotheses.

Required Detector Size versus Reactor Range



Summary of Present Long Range Reactor Monitoring Abilities

- Scaled for a 10 MWt Reactor

Goal	Rate	#/Yr	Detector Size		
			10 KT	1MT	100 MT
Detect Operation ~1yr	~5 Events/yr	~5	70 km	800 km	>>1000 km
Total annual energy output with 25% accuracy	16 events/yr	16	35 km	400 km	>>1000 km
Daily operations, catch rod changes	> 10 events/day	3600	6 km	60 km	600 km
Monthly spectra, and hence fuel mix	> 3000 events per month	36K	2 km	20 km	350 km
Daily spectra, fuel evolution	> 3000 events/day	100K	1 km	12 km	120 km

Detect Clandestine Weapons Too

Goal for 100 MT instrument	Number of Events	Range
Detect explosion seen by other means	>1 evt in coincidence	1500 km
Estimate Yield to 30%	10 events	500 km
Detect otherwise undetected explosion	5 events in 4 sec	700 km
Estimate range for known yield, via number of events	10 events	+/- 15%
Precision range, via oscillations	100 - 1000 events	+/- 1 %
Location with 2 detectors	2 time >10 events	<250 km^2
Details of explosion (using time & spectrum)	1000 events	210 km

Summary of New Approaches

- Given knowledge of distant reactors, and location (few km) of reactor to be monitored, we can do better separation than had been thought previously.
- Sophisticated signal processing may be able to extract interesting information for both geoneutrinos and reactor monitoring.
- Some further cards to be played include direction and multiple detectors.