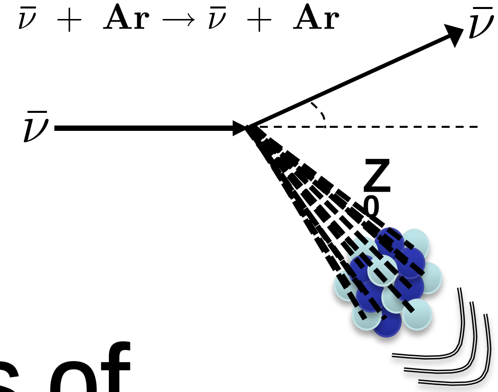
$$\bar{\nu} + \mathbf{Ar} \rightarrow \bar{\nu} + \mathbf{Ar}$$



Nonproliferation applications of coherent neutrino scatter detectors

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Meeting on Coherent Neutrino Scattering
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Talk Outline

0. What are IAEA reactor safeguards ?

1. How can antineutrino detection help safeguard reactors ?

2. What can/has be done with current inverse beta detectors

3. What improvement might come with coherent scatter detectors

4. What else can it do ?

First, what is the IAEA ?

- The International Atomic Energy Agency - IAEA - verifies nonproliferation in non-nuclear weapons states, and promotes nuclear power as part of the Treaty on the Nonproliferation of Nuclear Weapons

IAEA

International Atomic Energy Agency

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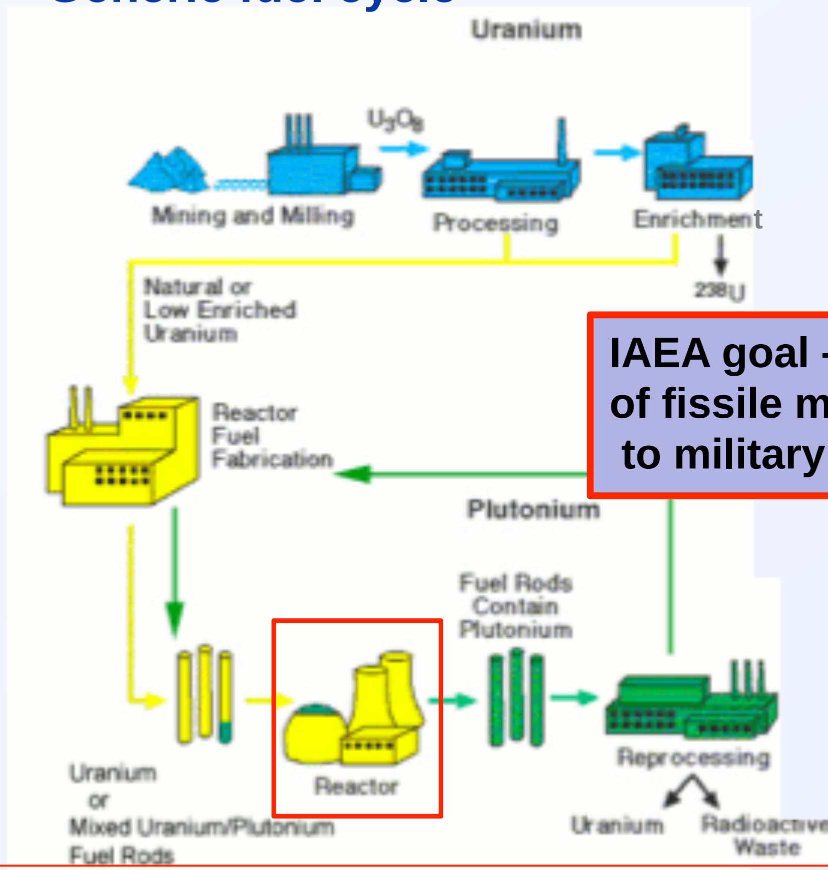
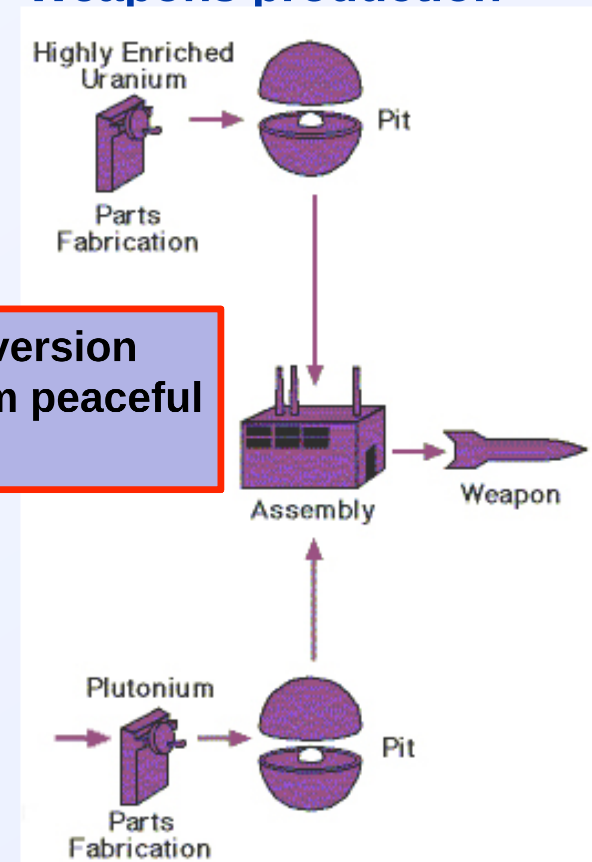
The IAEA ‘Safeguards’ regime monitors the flow of fissile material through the nuclear fuel cycle in 170 countries

Generic fuel cycle



Weapons production



IAEA goal – detect diversion of fissile material from peaceful to military programs

Goal for antineutrino measurements - track fissile inventories in operating reactors

Current IAEA attitudes towards 'ordinary' antineutrino detection

- Reactors are not the highest priority safeguards problem
- We are introducing a disruptive technology to an agency that demands stability, continuity, and economy
- IAEA sees no <u>immediate</u> utility in antineutrino detection – existing methods have worked, costs are modest, politics of changing are difficult

For coherent scatter detection to be adopted:

1. **IAEA will have to have seen demonstrations that any kind of antineutrino detector can benefit the safeguards regime**
2. **The CNS community will have to show some advantage compared with the reigning option, inverse beta detection**

Things the IAEA would like, ways CNNS could ***conceivably*** help

Application

1. Power monitoring for a subset of reactors under safeguards (usually research reactors)
2. Ensuring that certain reactor fuels (MOX) have achieved a desired level of burnup/ irradiation
3. Improve the level of precision and independence regarding fissile mass of discharged reactor fuel
4. Monitor multiple reactors with one detector
5. Long range monitoring or exclusion of reactors

Potential CNNS implementation

Smaller footprint counting detectors with competitive statistics
– 100s of cpd

Detectors capable of deconvolving the reactor energy spectrum
-1000s of cpd

Detectors with directional sensitivity
??

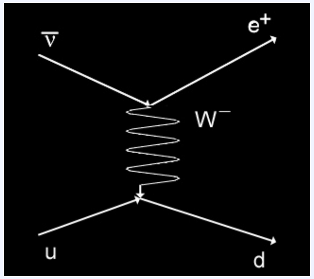
The field(s) of competition

1.Inverse beta decay

The gold standard for antineutrino detection

A robust time-coincident signal from positron and neutron
'*good old inverse beta*' - Petr Vogel
Neutrinos *are not* a background for this process

$$\bar{\nu} + p \to e^{+} + n$$



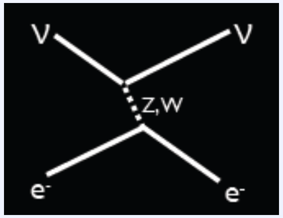
$$\sigma \sim 10^{-42}\,\mathrm{cm}^2\, E_{\bar{\nu}}{}^2$$

$$\bar{\nu} + e^{-} \to \bar{\nu} + e^{-}$$

$$\sigma \sim 10^{-44}\,\mathrm{cm}^2\, E_{\bar{\nu}}$$

2.Antineutrino-electron scattering

only the final state electron is detected
Neutrinos *are* a background for this process



3. Coherent antineutrino-nucleus scattering

(100-1000x **larger** cross section than inverse beta decay)

But - a very weak signal (10s-100s of eV nuclear recoils)

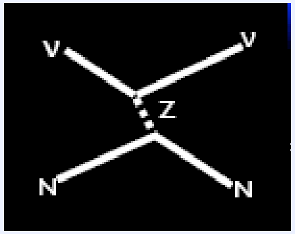
May be interesting for reactor monitoring out to a few km

Neutrinos *are* a background for this process

$$\bar{\nu} + N \to \bar{\nu} + N$$

$$\sigma_{\mathrm{coh.}} \approx 0.4 \times 10^{-44}\,\mathrm{cm}^2 N^2 E_{\bar{\nu}}{}^2$$

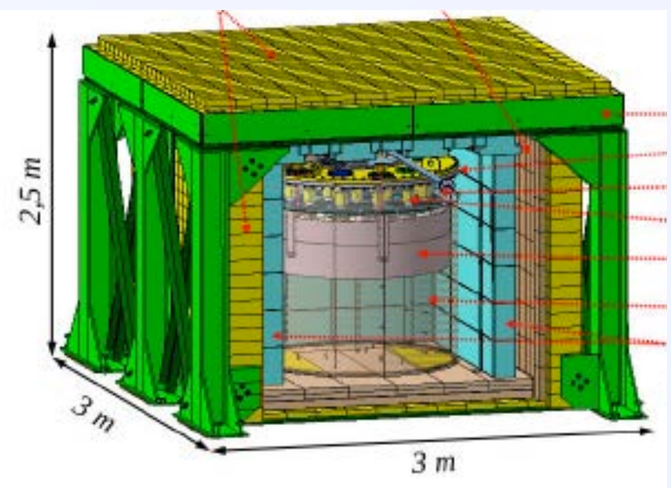
Enhanced by square of neutron number

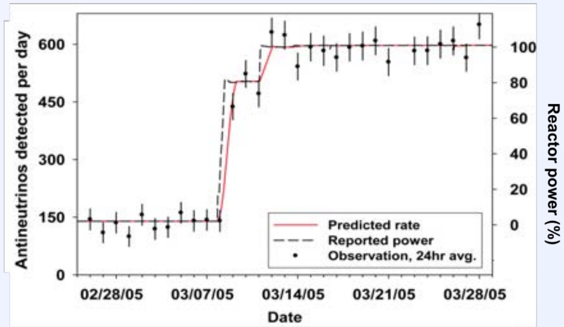


Counting with Inverse Beta Detectors: current and near term state of the art

Detector feature	Now	A little later
Total footprint with shield	(3 m)^3	(1.25 m)^3
Counts per day per ton @ 25 m, 3.4 GWt reactor, eff.=10-20%	600-1200	600-1200
Material/Form	Liquid/Homogenous	Plastic/Segmented
Cost	250K	100K

Nucifer, Saclay/APC, France

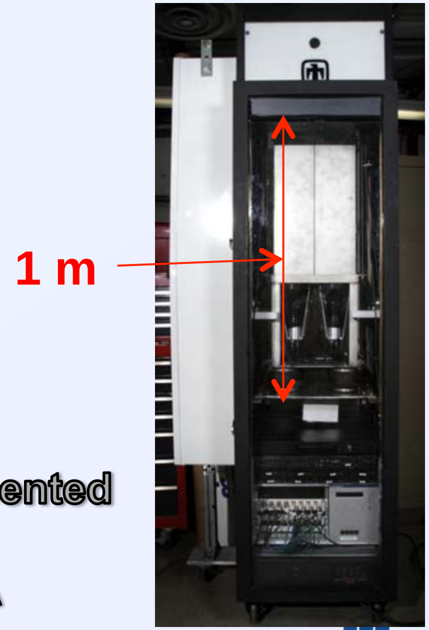




N. S. Bowden, Journal of Physics: Conference Series, **136** (2008).

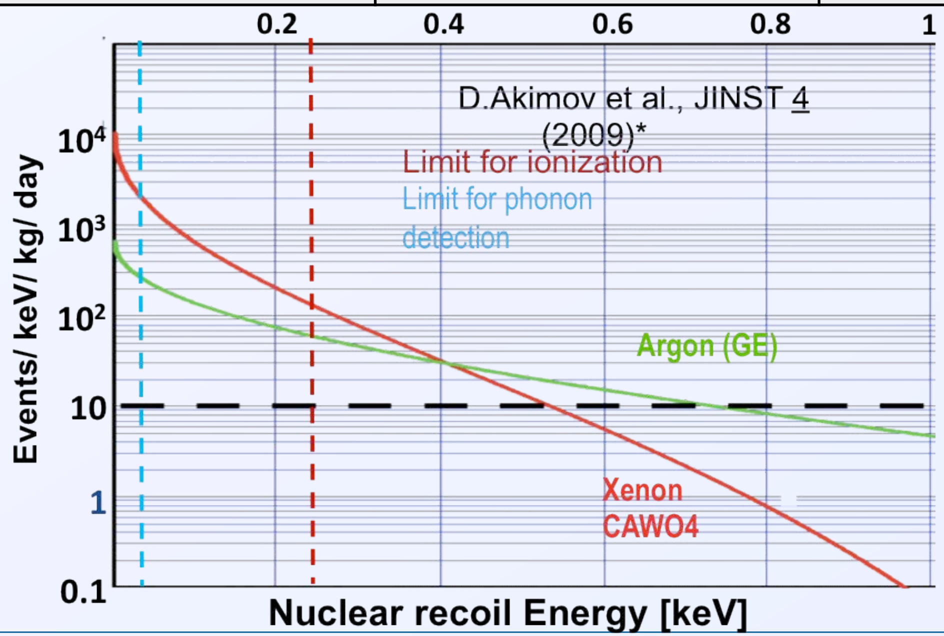
SONGS count rate data: USA

Prototype segmented detector, SNL-LLNL: USA



Coherent scatter antineutrino counting detectors

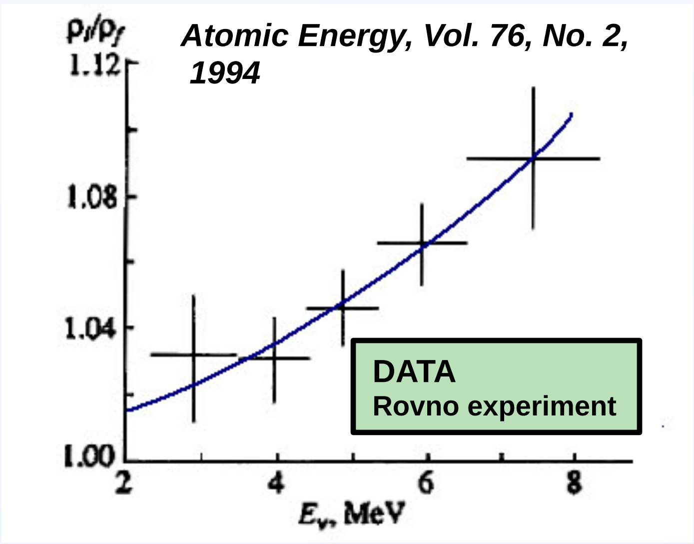
	Argon	Germanium	Phonon-counter
Footprint with cryo and shield	$(1.5\ m)^3$	$(1.5\ m)^3$??	$(0.5\ m)^3$??
Mass to get 100 cpd @ 25 m, 3.4 GWt	10-15 kg (> 2 e^- sensitivity, depends on quench factor)	4-5 kg (100 eV threshold)	50 gram (~50 eV threshold)
Cost	100-200K	?	?

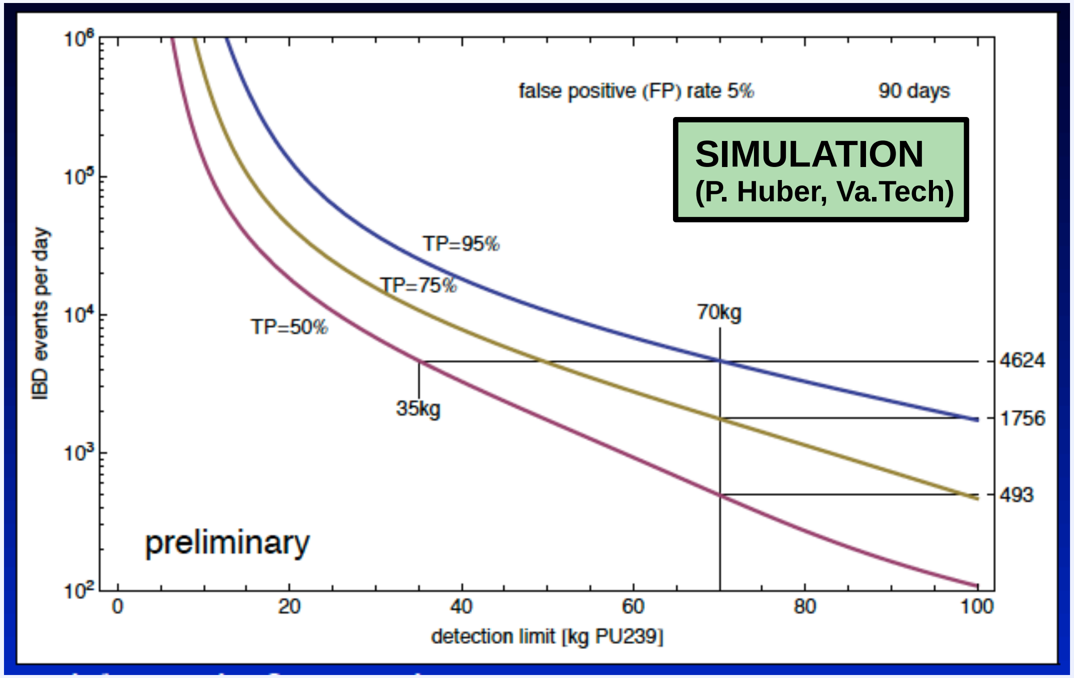


↑ Nice deployment feature: use local nitrogen generator to cool the detector

Spectroscopy with Inverse Beta detectors

$$N_{\bar{\nu}} = C \cdot (P_{th}(t) \cdot (1 + k(t))$$





Ratio of beginning and end of cycle spectra –
<u>spectrum 'softens' due to plutonium ingrowth.</u>

<u>No error on reconstructed Pu mass directly quoted</u>

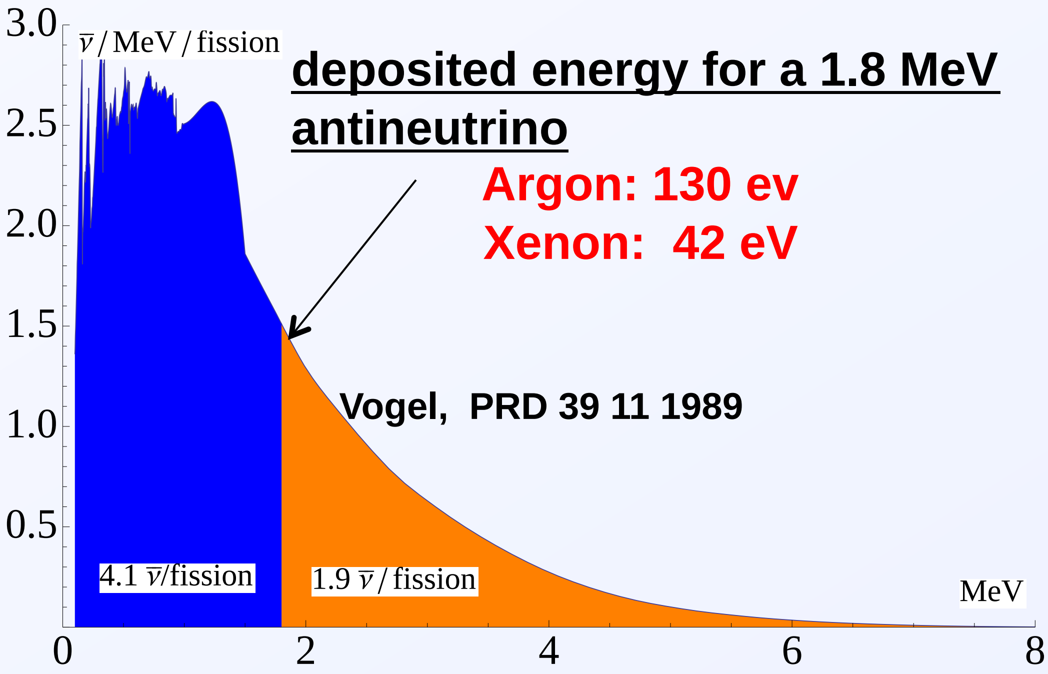
<u>An example spectral analysis from P.Huber</u>

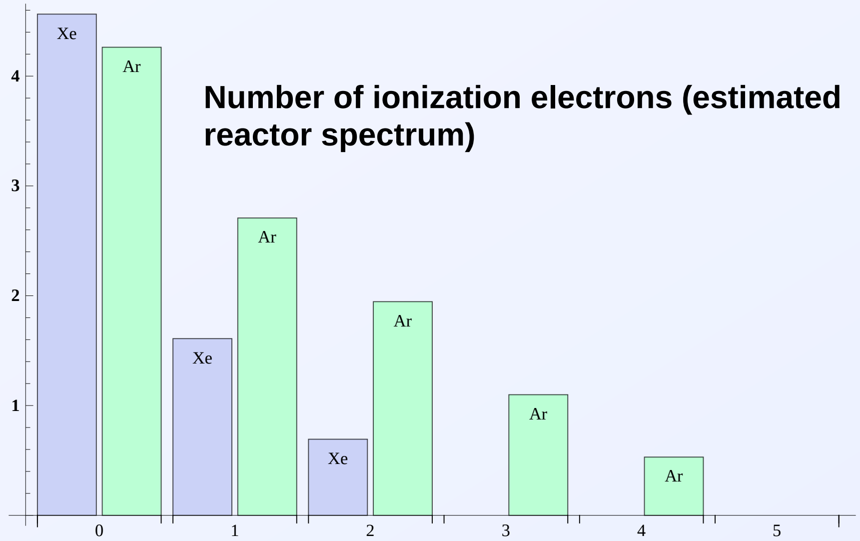
- 5% false positive, 95% true positive
- 4624 events per day
- 70 kg ^{239}Pu-^{235}U switch is detected in 90 days
- <u>Power not required as an input !</u>

18 years ago

Now or near term

Spectroscopy with CNNS (ionization methods)





Number of ionization electrons (estimated reactor spectrum)

1) Absence of threshold not a great advantage: only neutrinos above ~2 MeV are likely to be detectable via the ionization channel

2) Number of ionized electrons is small → Poisson and recombination fluctuations give poor energy resolution: 10x worse than IVB

3) Measured spectrum is stochastic and must be unfolded

$$E_{recoil} = \frac{2E_{\bar{\nu}}(1 - Cos(\theta))}{2A}$$

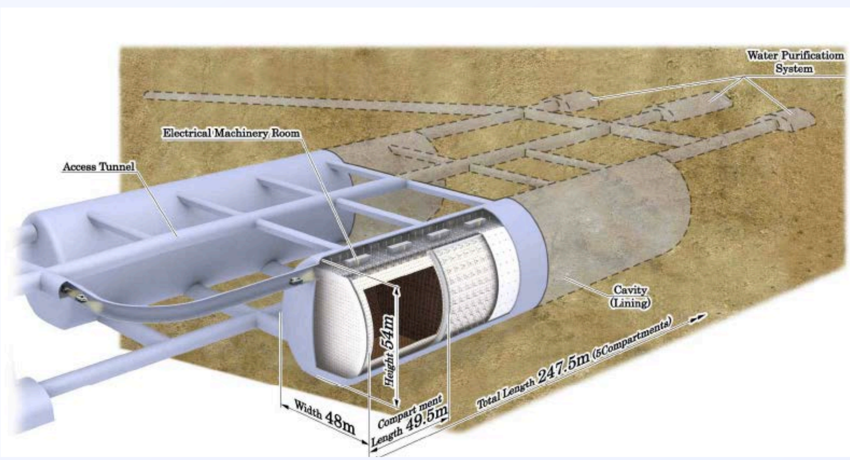
IVB spectrum is deterministic: event by event reconstruction

$$E_{'prompt'} = E_{\bar{\nu}} - 1.8MeV + 2 \cdot m_e$$

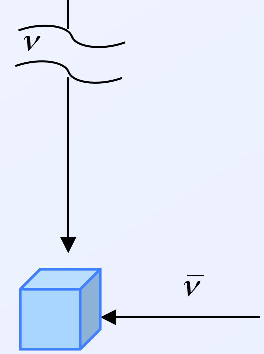
What about long distance monitoring/discovery ?

Speculative no matter the technology, but:

Goal	IVB in Gd-doped water	Argon	Phonon
16 events in 1 year from a 10 MWt reactor, 400 km standoff	1 Megaton	50 kton	5000 ton



B) Solar bg ~ reactor signal at >1.5 km from the reactor core – ultimate limit



Detector

A) IVB detector designs exist with prospect to achieve MeV thresholds

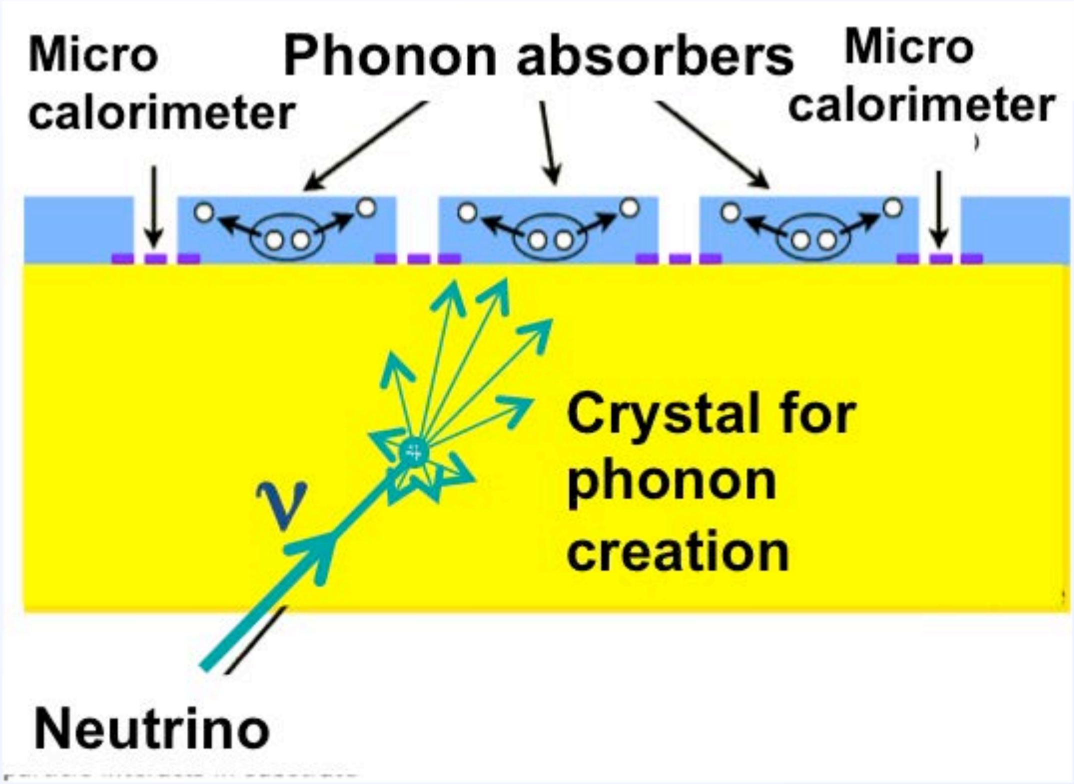
Directionality with Inverse Beta Detectors

	Now	A little later
Detector	Chooz	Double Chooz
Neutrino direction cone half-angle	18°	6° ?
Number of events	2500	~25000 (1 year)

Basic concept : in inverse beta, neutron is always forward of positron w.r.t. the incoming antineutrino direction

Averaging the vector between these two positions for a large number of events gives the average antineutrino direction

Directionality with phonon detectors



100s or 1000s of phonons per neutrino
Phonon cloud partially preserves antineutrino direction
Ratios of counts in phonon absorbers allow directional reconstruction

Conclusions

- Coherent Neutrino Scatter is a fascinating and tantalizing basic science prize, and advances the state of the art for neutral particle detection, including neutrons and gamma-rays
- It may also prove useful in the medium term for nuclear safeguards
- Early applications are likely to be ionization detectors in counting mode with improved statistics compared to IVB
- With much more work, spectral and directional information may be recoverable, likely with phonon detectors