CEvNS for Nuclear Security

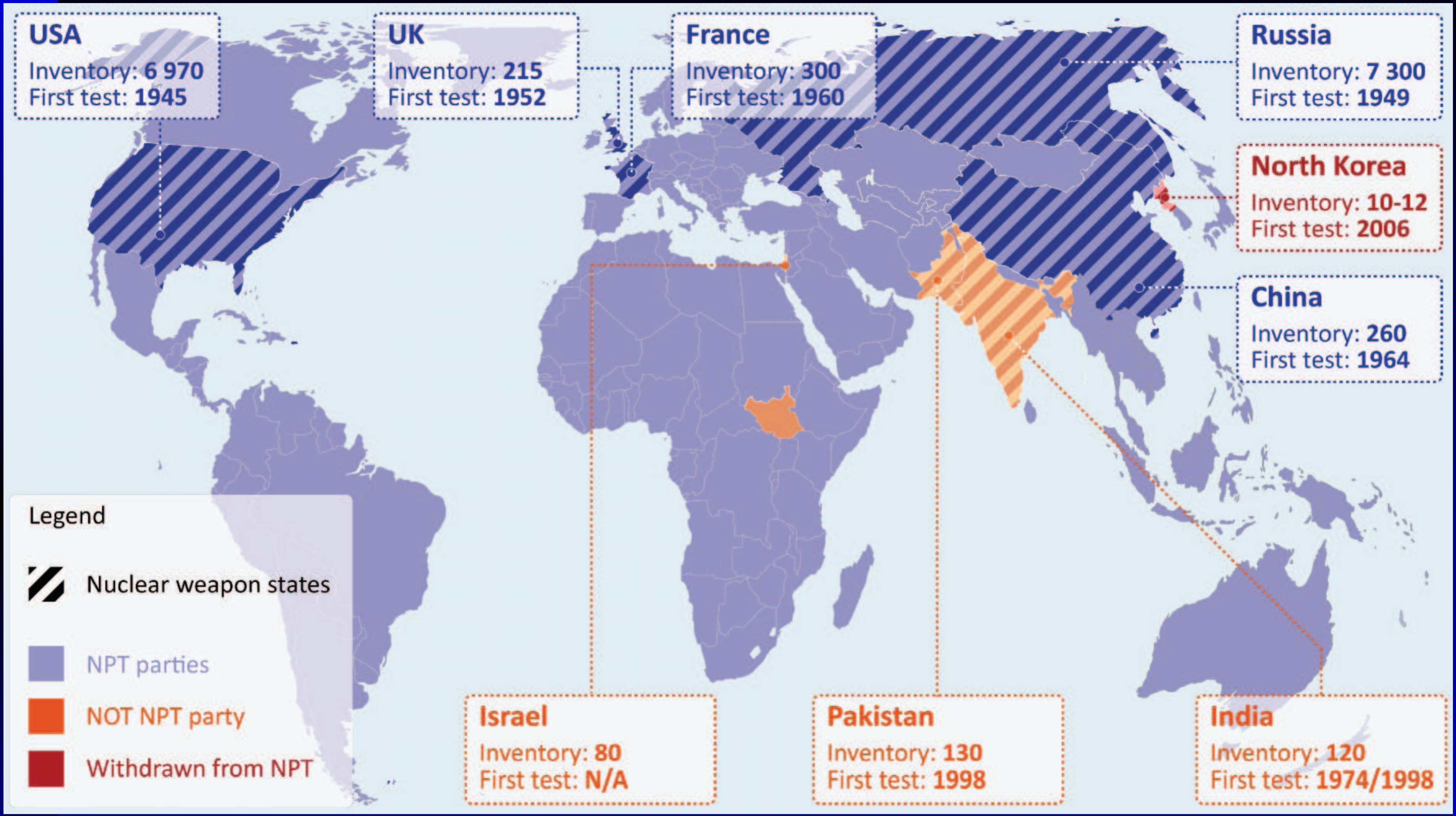
Patrick Huber

Center for Neutrino Physics – Virginia Tech

Magnificent CEvNS 2019

November 9-12, 2019

Duke University, Chapel Hill, NC

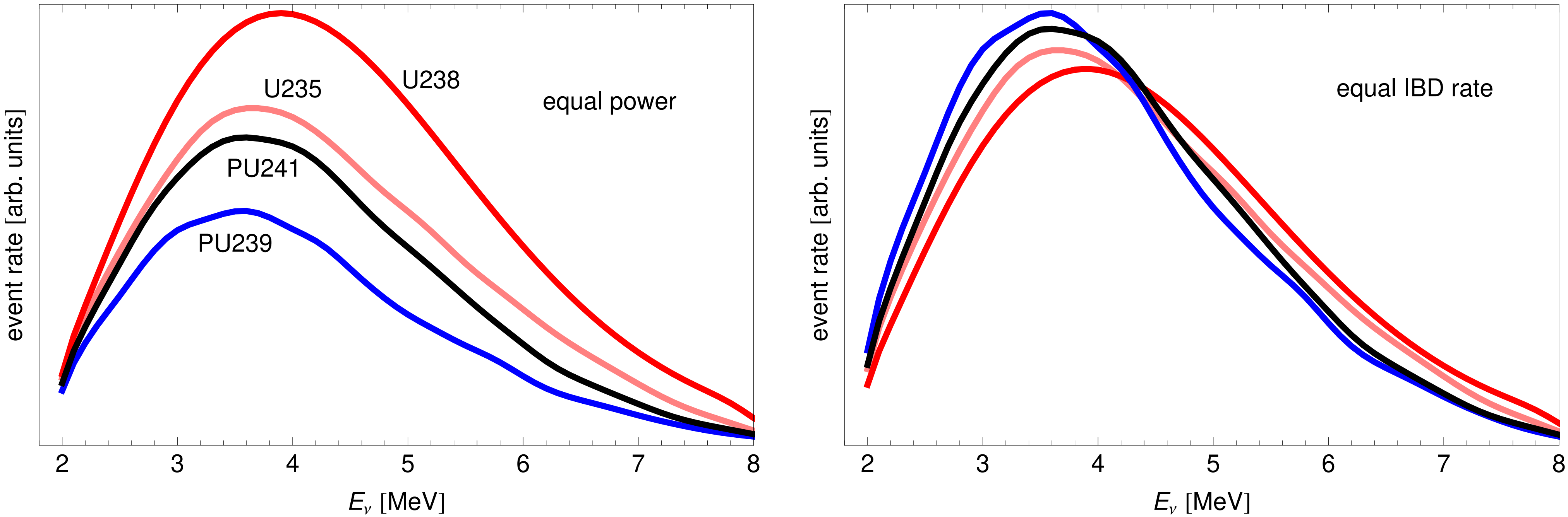


EPRS, 2016

NPT – Treaty for the Non-Proliferation for Nuclear Weapons

IAEA – International Atomic Energy Agency

IBD event spectrum



Pu239 has a softer neutrino spectrum than U235 – as a consequence the neutrino spectrum becomes softer for higher burn-up

Fuel evolution

In a reactor the breeding reactions take place:

$$
\begin{aligned}
{}^{238}\mathrm{U} + n &\longrightarrow {}^{239}\mathrm{U} \xrightarrow{\beta^-} {}^{239}\mathrm{Np} \xrightarrow{\beta^-} {}^{239}\mathrm{Pu} \\
{}^{239}\mathrm{Pu} + n &\longrightarrow {}^{240}\mathrm{Pu} \longrightarrow {}^{241}\mathrm{Pu}
\end{aligned}
$$

And thus except for reactor fueled with only ^{235}U, eventually four isotopes contribute to fission with a time dependent fraction:

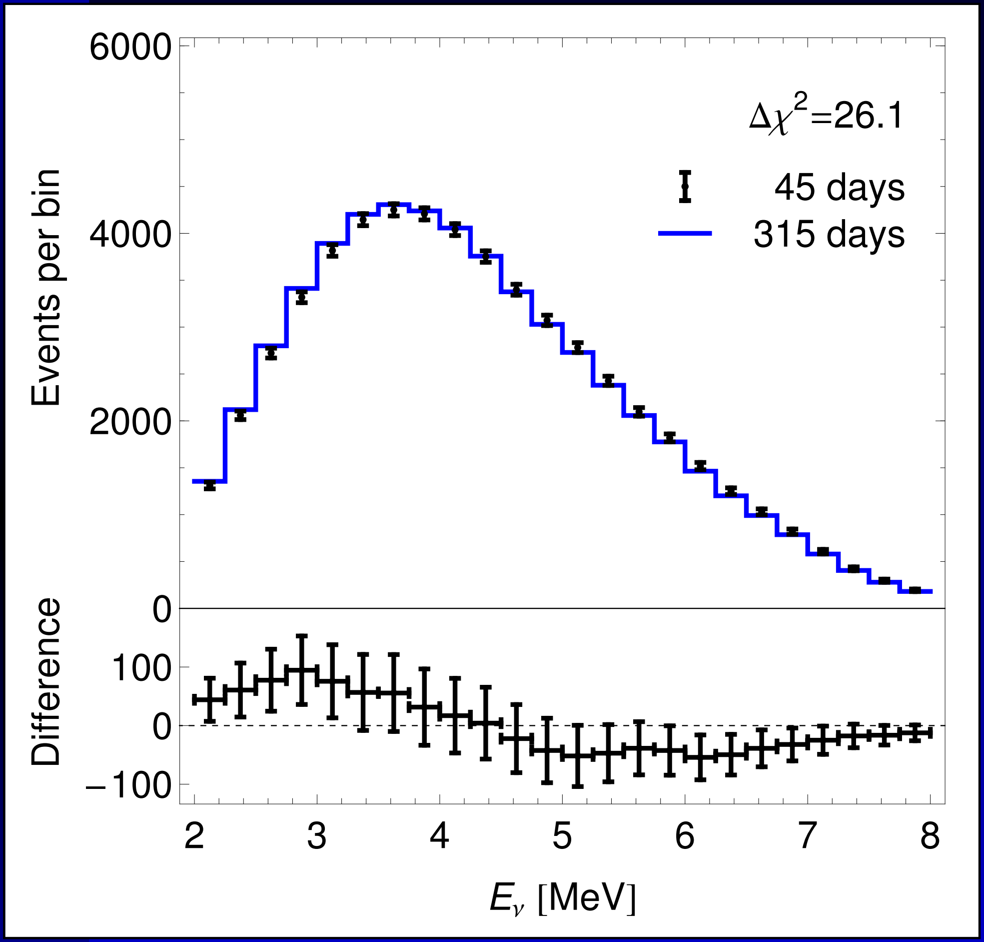
$${}^{235}\text{U},\ {}^{239}\text{Pu},\ {}^{238}\text{U},\ {}^{241}\text{Pu}$$

Application to safeguards

Neutrinos, due to their high penetration capability, offer unique safeguards opportunities:

- measure reactor power
- detect undeclared production of fissile material
- independent verification of fuel burn-up

Exploiting the energy spectrum

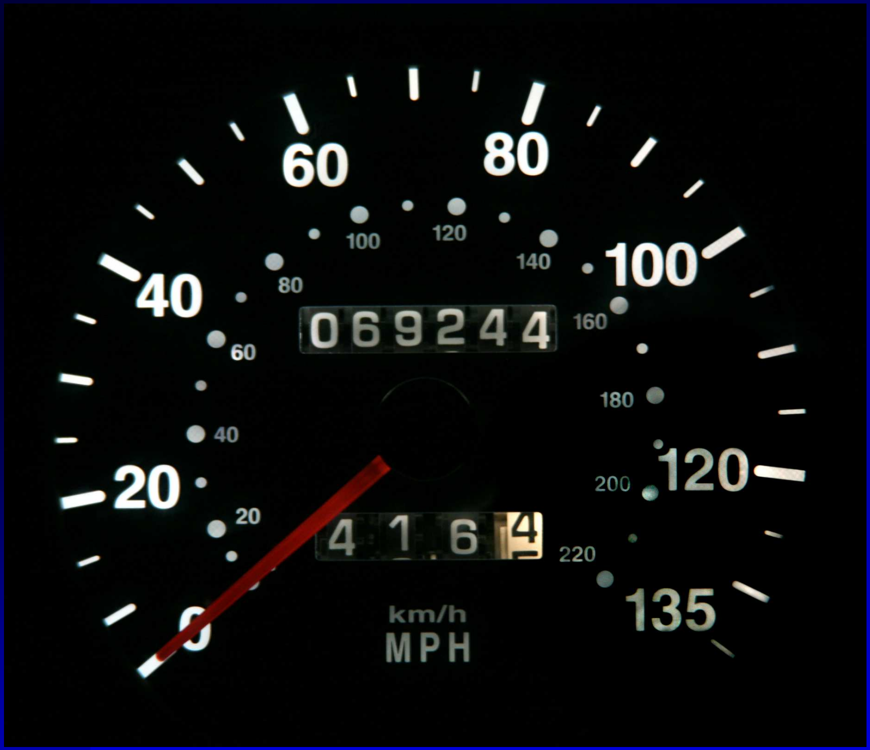


Comparing a reactor core at 45 days in the cycle to the same core at 315 days in the cycle

Corresponding to a difference in plutonium content of about 7 kg

Automobile analogy

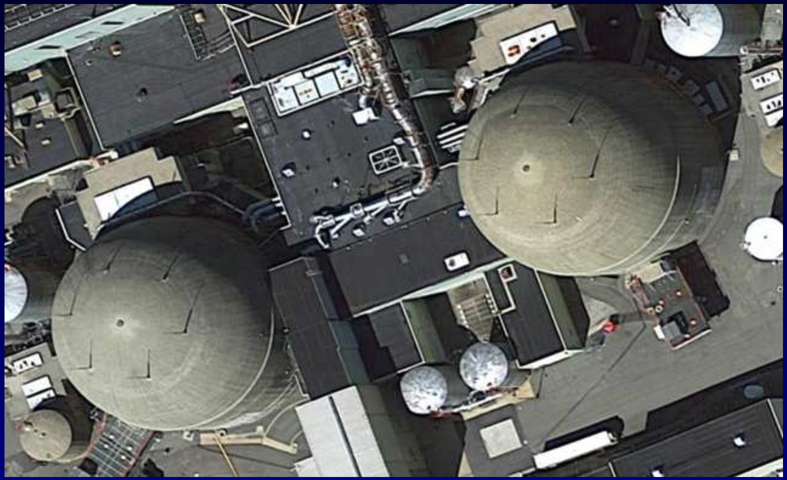
speed	thermal power
trip mileage	burn-up
used gas	produced plutonium

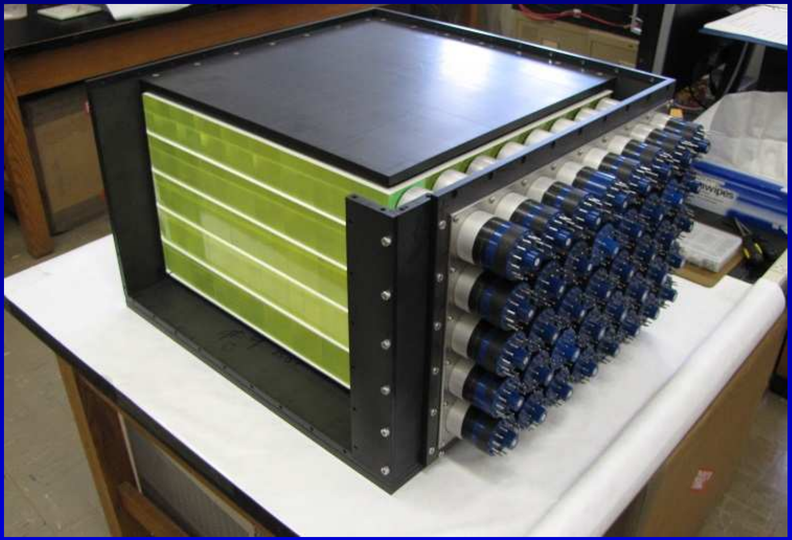


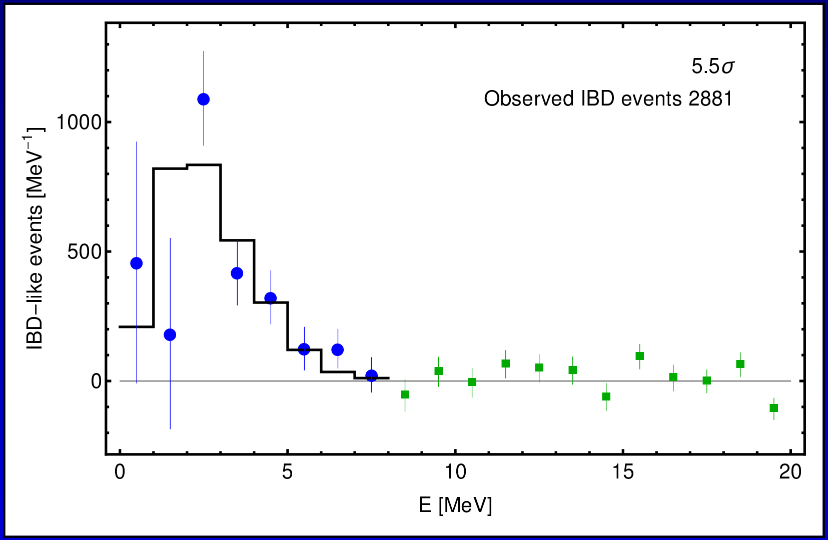
requires continuous speed measurement, discrepancies show up at refueling only

snapshot of used gas without prior record, discrepancies show up as you drive

IBD reality: CHANDLER





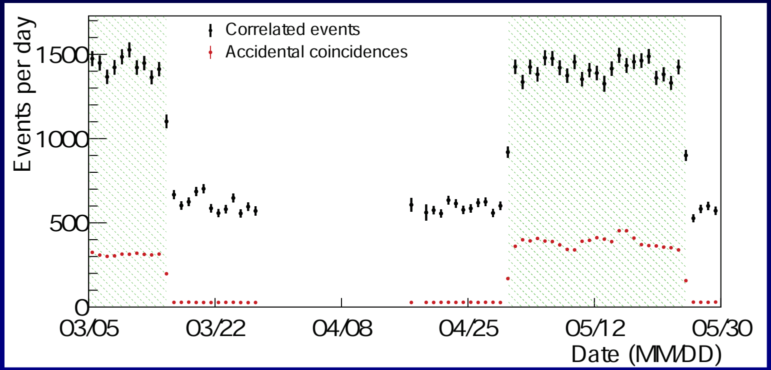


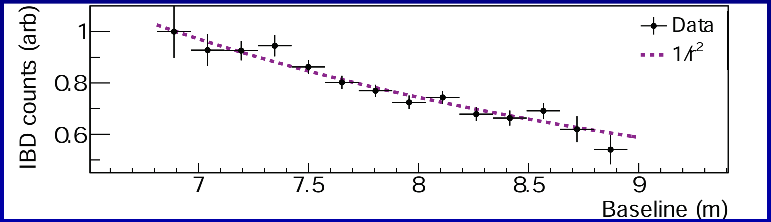
Haghighat *et al.*, 2018

US Pat. 10,429,526

IBD reality: PROSPECT

PROSPECT is a state-of-the-art neutrino detector, which works at the earth's surface.

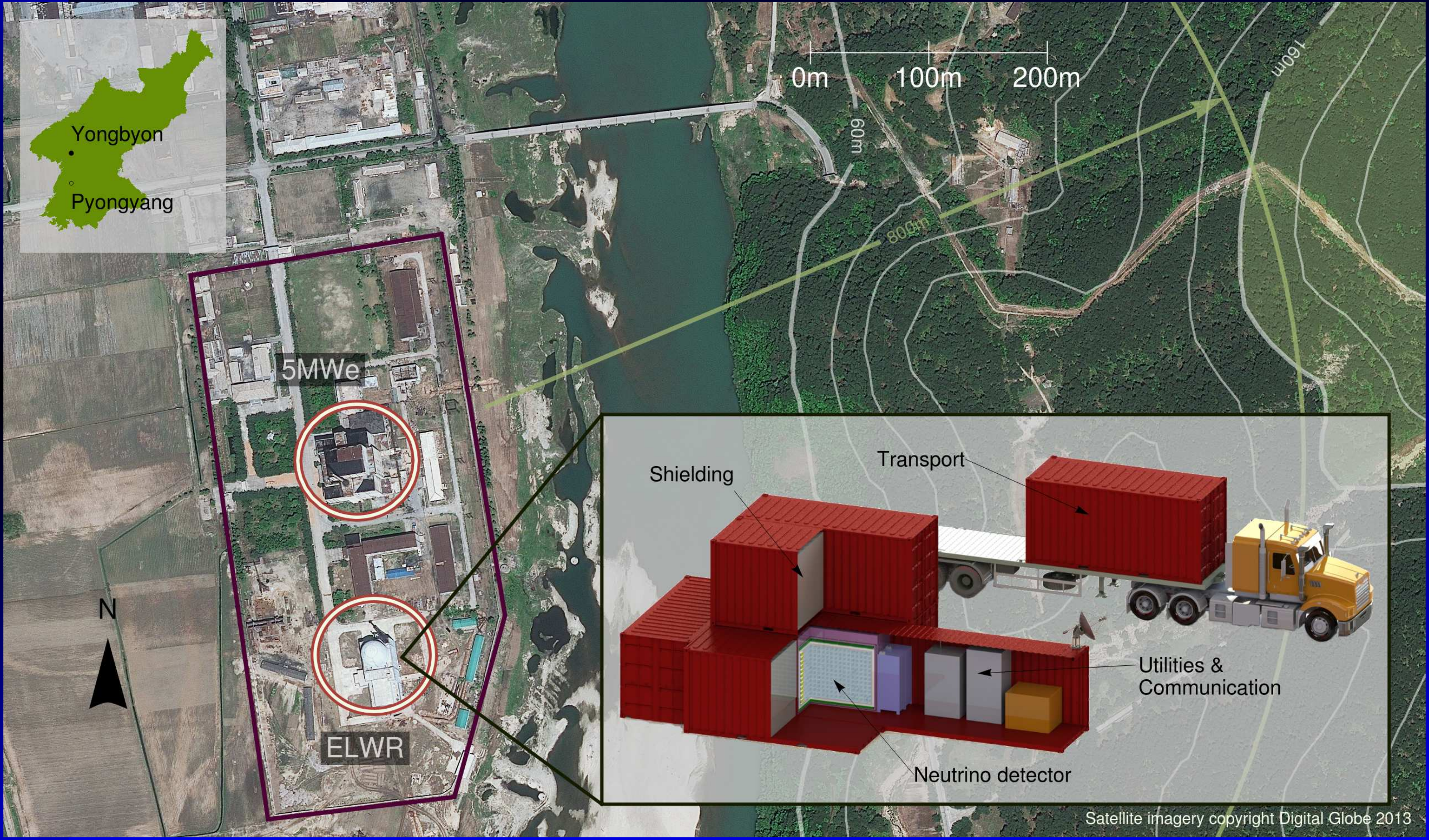




PROSPECT, 2018

We use it as yard stick in this talk for signal and background.

DPRK 2018



Carr *et al.*, 2019

Reactor status – near-field

Simplest thing to ask: Is the reactor on or off?

I use time to 95% C.L. detection based on a PROSPECT-sized detector with PROSPECT background, purely rate-based.

5MWe	IR40	ELWR
1.2d	8 h	1.5 h

Time to detection at 95% C.L.

$\Rightarrow$Can be done with a xerox copy of PROSPECT – 2 metric tons

Reactor core swap detection

6 times PROSPECT – 12 metric tons
BG level 1 corresponds to PROSPECT.

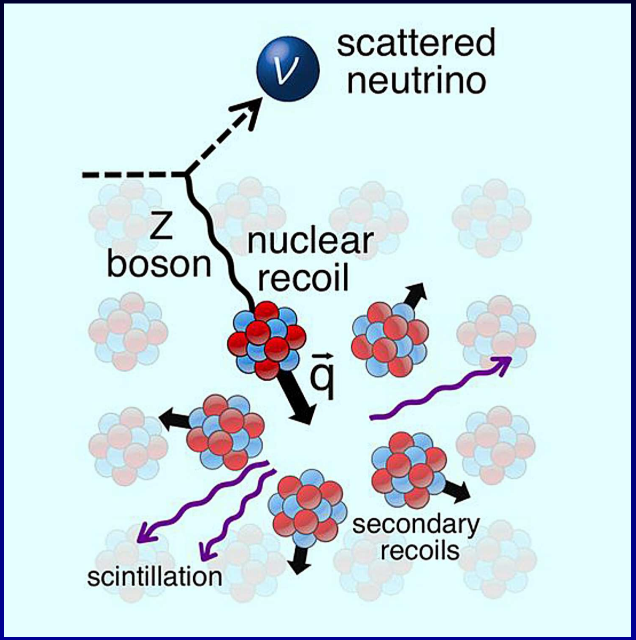
BG level	ELWR	IR40	5MWe
1	134	109	1154
0.5	83	59	830
0.2	56	30	637
0	45	16	527

Days to detection at 95% C.L.

Modest background reduction yields $t < 90\,\mathrm{d}$,
but not for the 5MWe.

Coherent Neutrino Scattering

Coherent neutrino nucleus scattering (CENNS) is threshold-less.



$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} N^2 M_N \left(1 - \frac{M_N T}{2E_\nu^2}\right)$$

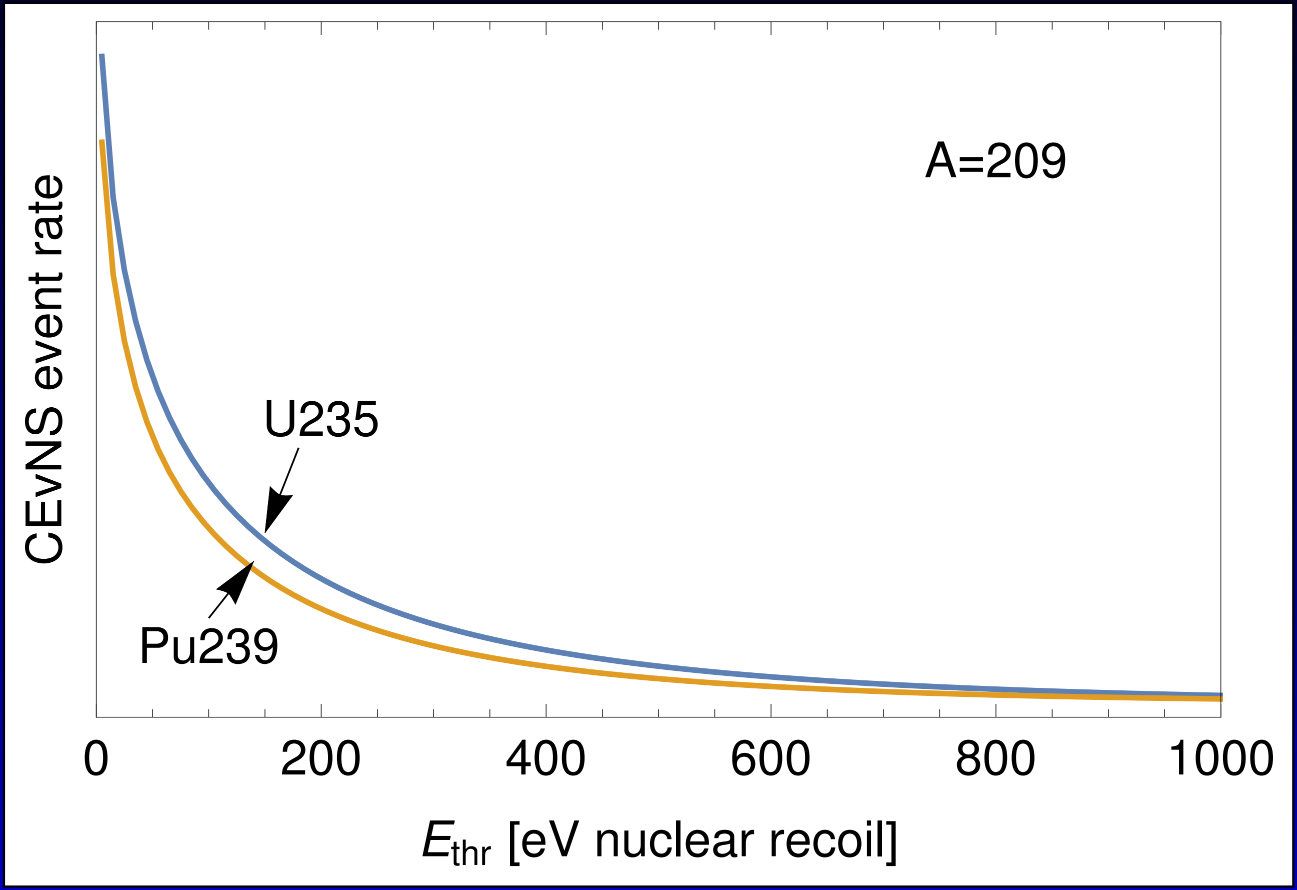
T recoil energy, N neutron number

Threshold in eV for parity in event rate per unit mass with IBD

^{12}C	^{20}Ne	^{28}Si	^{40}Ar	^{74}Ge	^{127}I	^{132}Xe	^{133}Cs
790	770	702	672	491	353	347	343

M. Bowen, PH, in preparation

CEvNS event spectrum



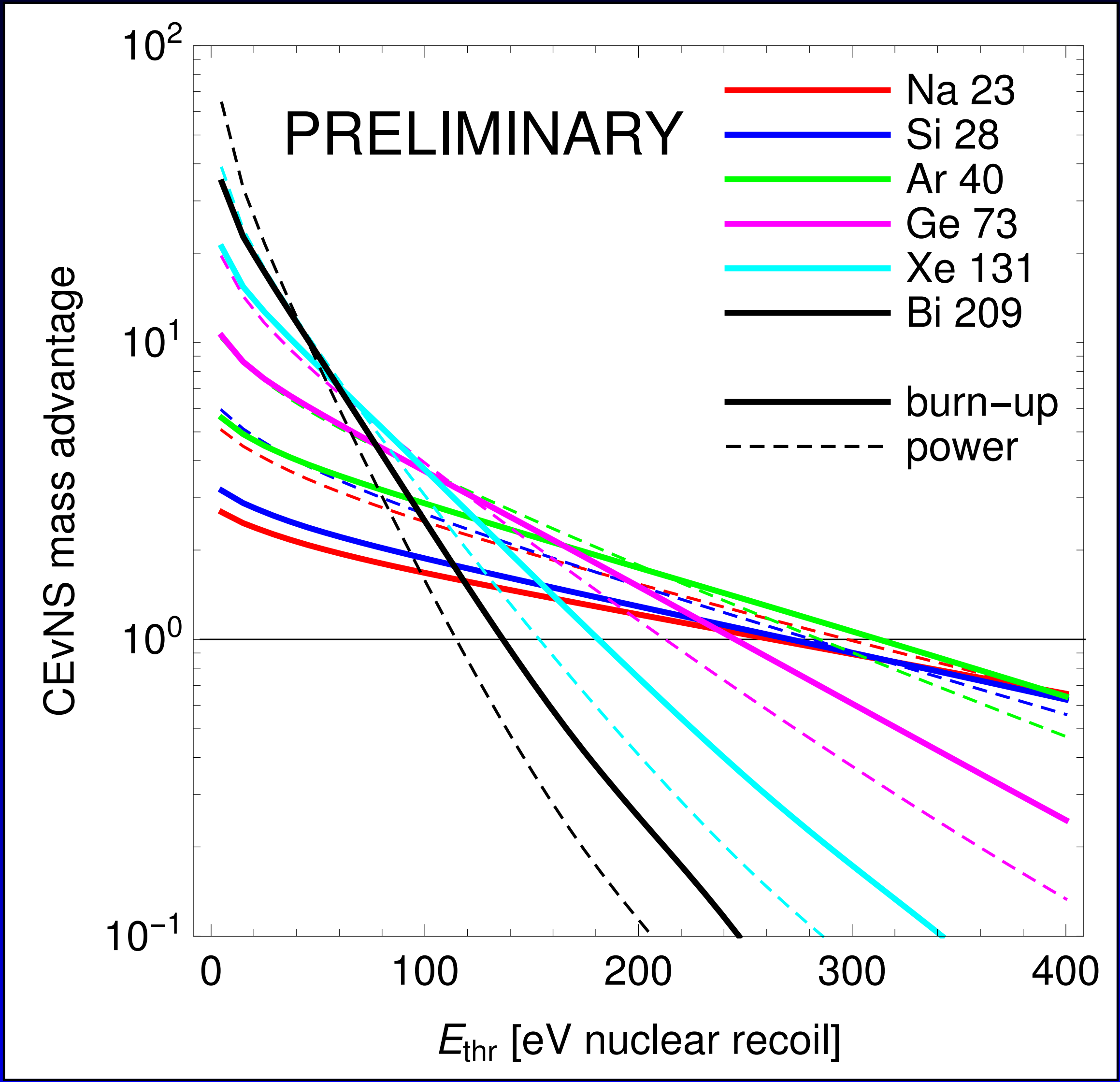
Pu239 has a softer neutrino spectrum than U235 – spectral difference persists in CEvNS, but less so than in IBD

CEvNS mass advantage

At 5 eV threshold:

0.6 tons Xe for burn-up
51 kg Xe for power

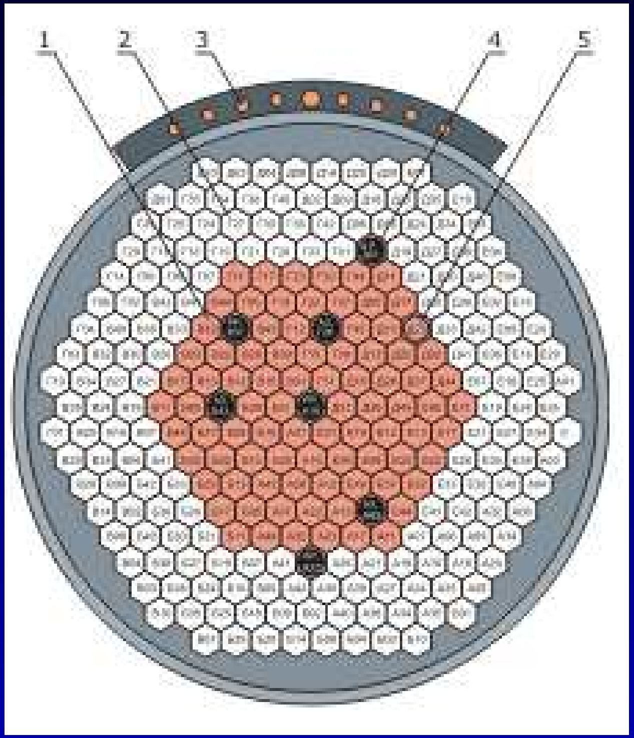
CAVEAT: no back-grounds



M. Bowen, PH, in preparation

Breeding blankets

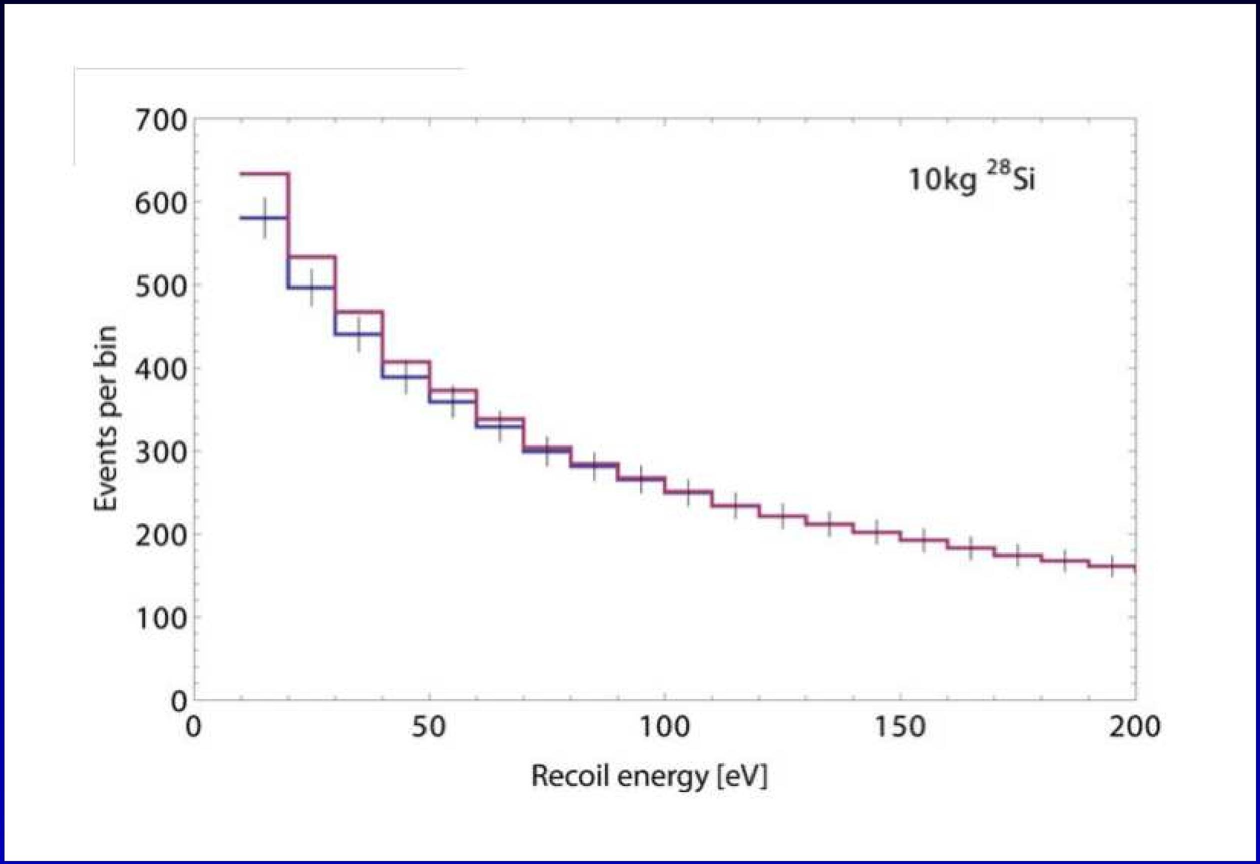
Breeder reactors generate more plutonium than they use fuel, but also can be used to burn weapons-grade plutonium.



The difference between making and destroying net plutonium stems from the presence/absence of a uranium-238 breeding blanket.

The problem is that the radiation from the fissions in the core outshine any radiation signature from the blanket.

CENNS and breeding blankets



Cogswell, Huber 2016

$10\,\mathrm{kg}$ background-free detector with $E_{\mathrm{thr}}^{\mathrm{nuc}} = 10\,\mathrm{eV}$

Summary

- Antineutrino monitoring is non-intrusive and can be performed *in situ* at a running reactor.
- CEvNS are reactors has not been demonstrated yet
- Breeding blankets require 10 kg detector with $E_{\rm thr}^{\rm nuc} = 10\,{\rm eV}$
- To gain advantage over IBD for power and burn-up measurement detectors with $A > 100$ in the 50 or 500 kg range with $E_{\rm thr}^{\rm nuc} = 5\,{\rm eV}$ needed.
- At $S/N \simeq 1$ expect a three-fold increase in detector mass

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Contact – pahuber@vt.edu