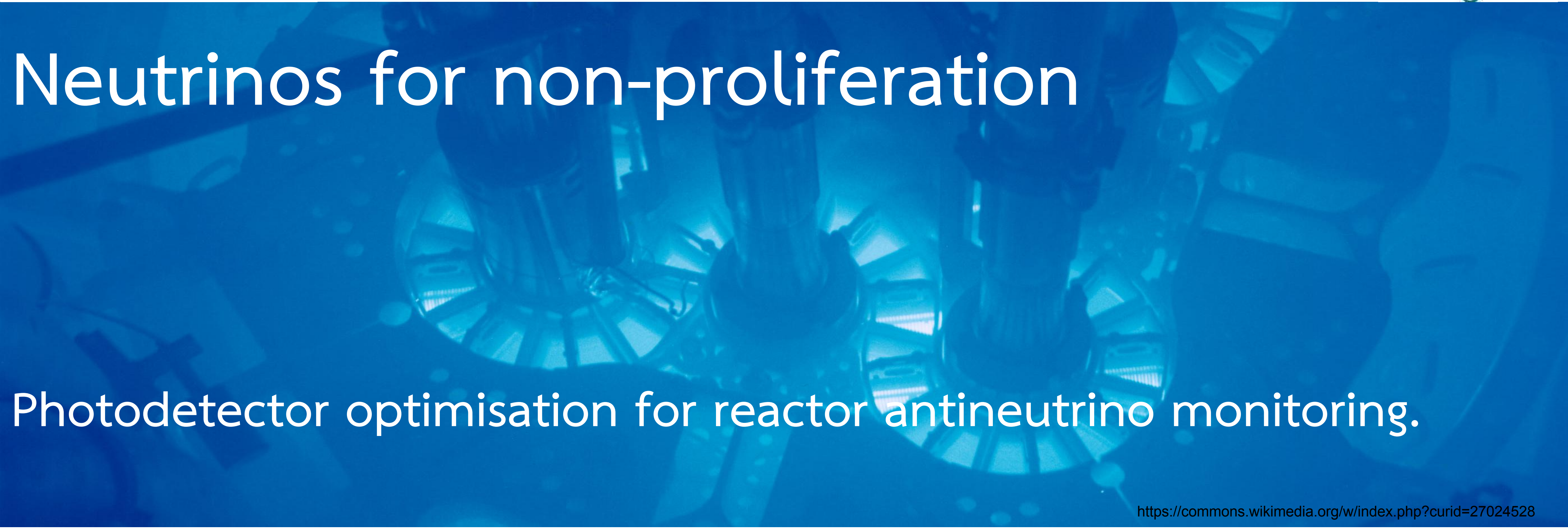
Neutrinos for non-proliferation

Photodetector optimisation for reactor antineutrino monitoring.



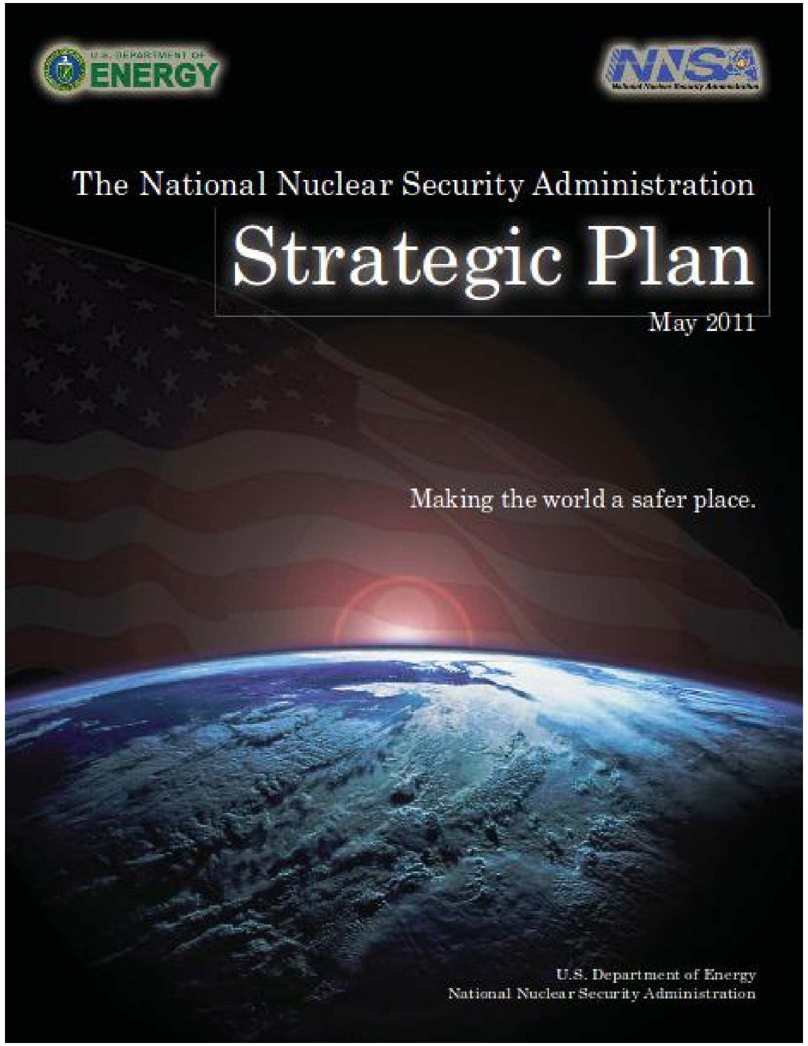
https://commons.wikimedia.org/w/index.php?curid=27024528

Liz Kneale

University of Sheffield

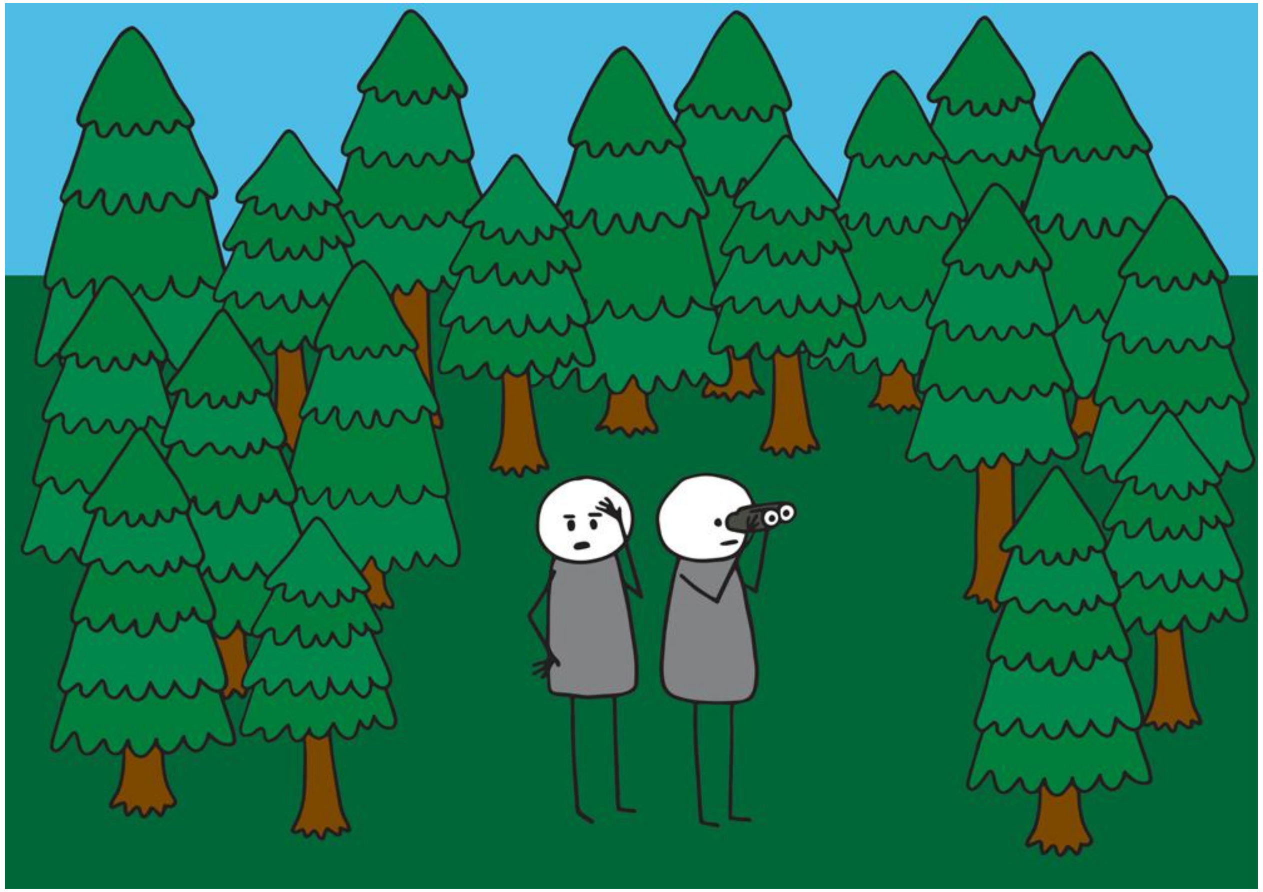
Defence & Security Doctoral Symposium 13-14 November 2018

Remote reactor monitoring



"By 2016, demonstrate remote monitoring capabilities for reactor operations."

Remote reactor monitoring



In a complex nuclear landscape we must be able to:

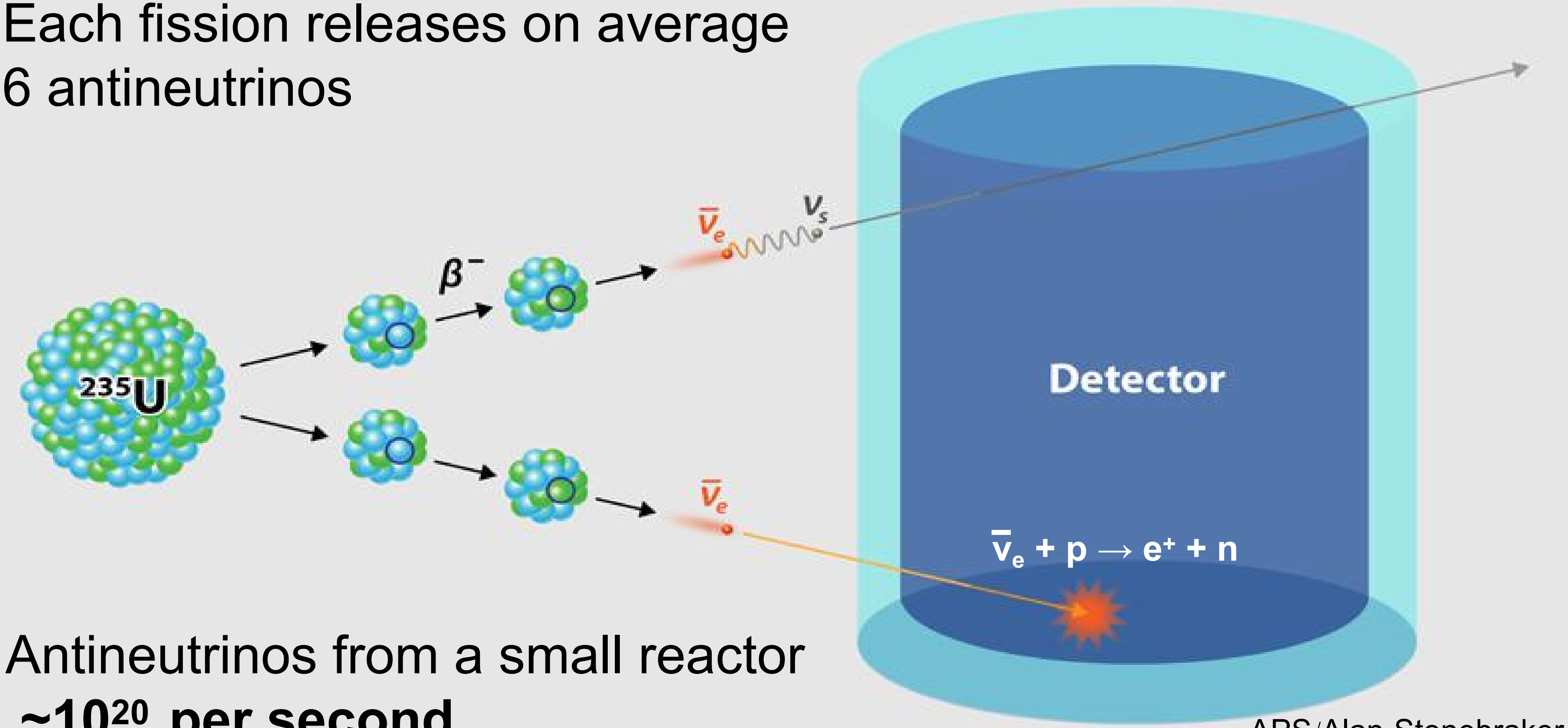
- Confirm the existence of a reactor,
- Separate a reactor's signal from other reactor backgrounds,
- Narrow down its location,
- Tell if a quantity of material is removed.

Neutrinos for non-proliferation

1. Reactor antineutrinos
2. Water Cherenkov detectors for reactor antineutrino detection
3. WATCHMAN & AIT
4. Maximising sensitivity

Reactor antineutrinos - unshieldable signal

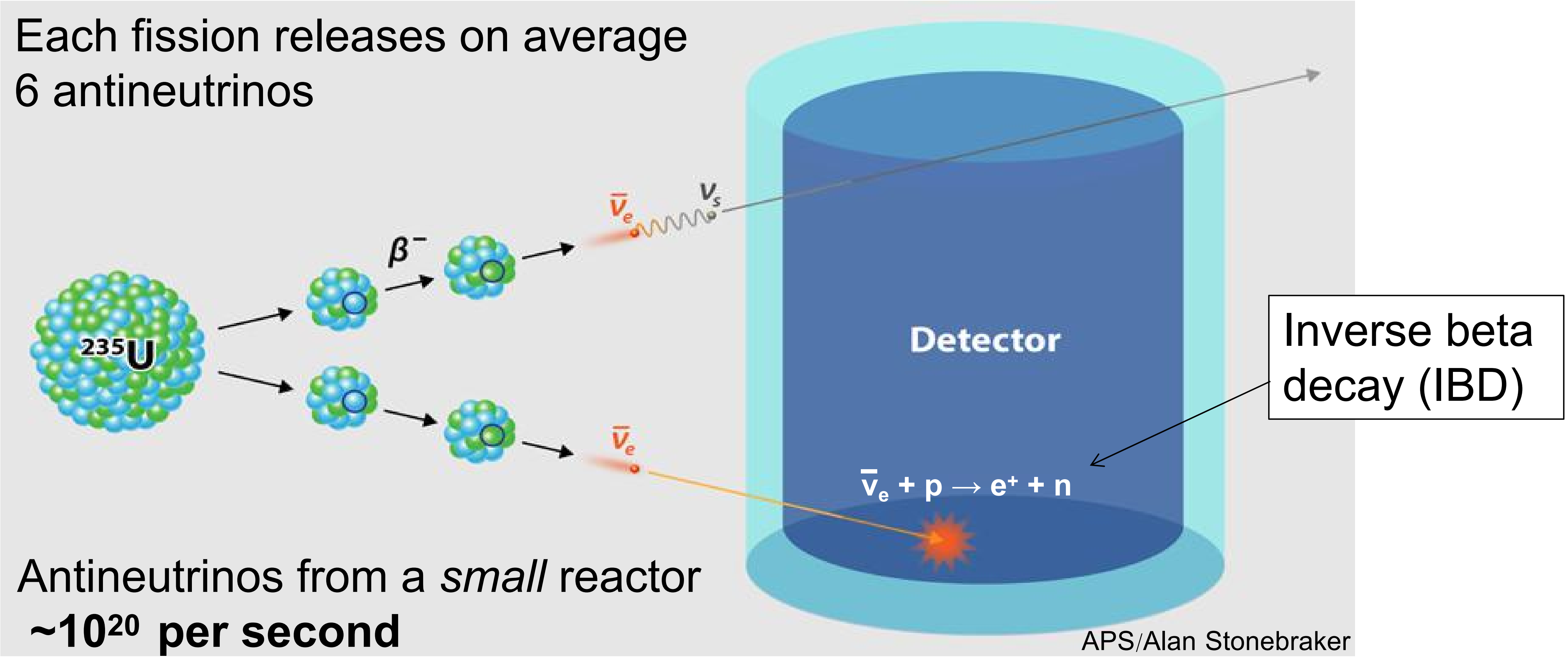
Each fission releases on average 6 antineutrinos



Antineutrinos from a small reactor
~10^{20} per second

APS/Alan Stonebraker

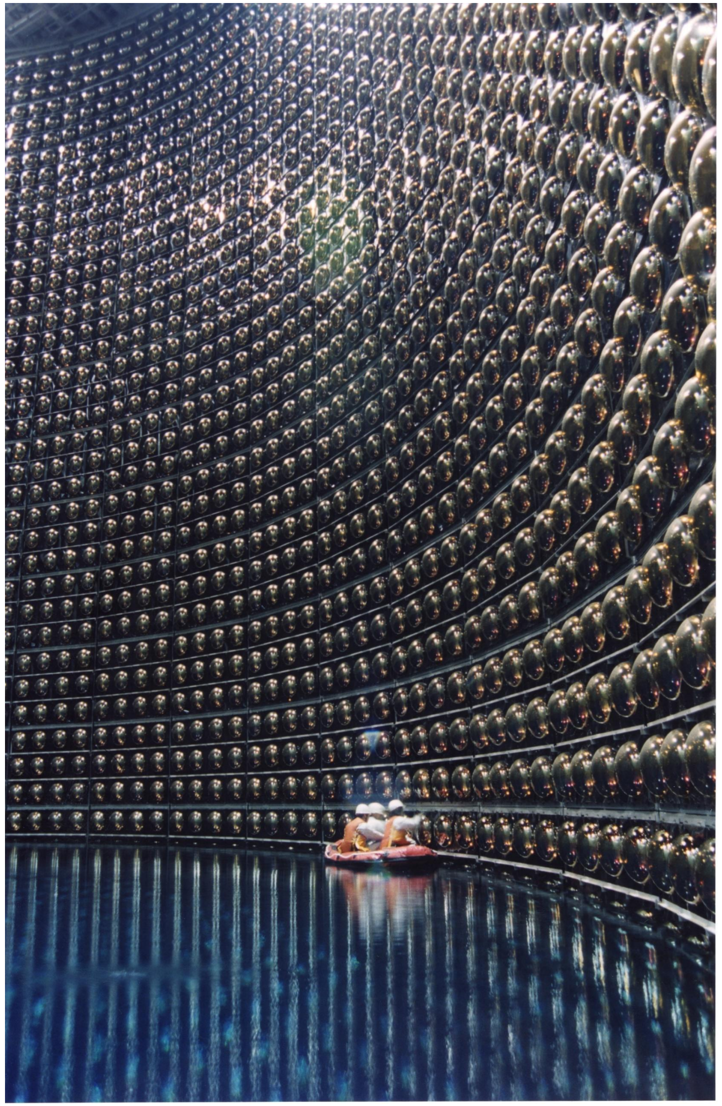
Reactor antineutrinos - unshieldable signal



Neutrinos for non-proliferation

1. Reactor antineutrinos
2. Water Cherenkov detectors for reactor antineutrino detection
3. WATCHMAN & AIT
4. Maximising sensitivity

Water Cherenkov detectors



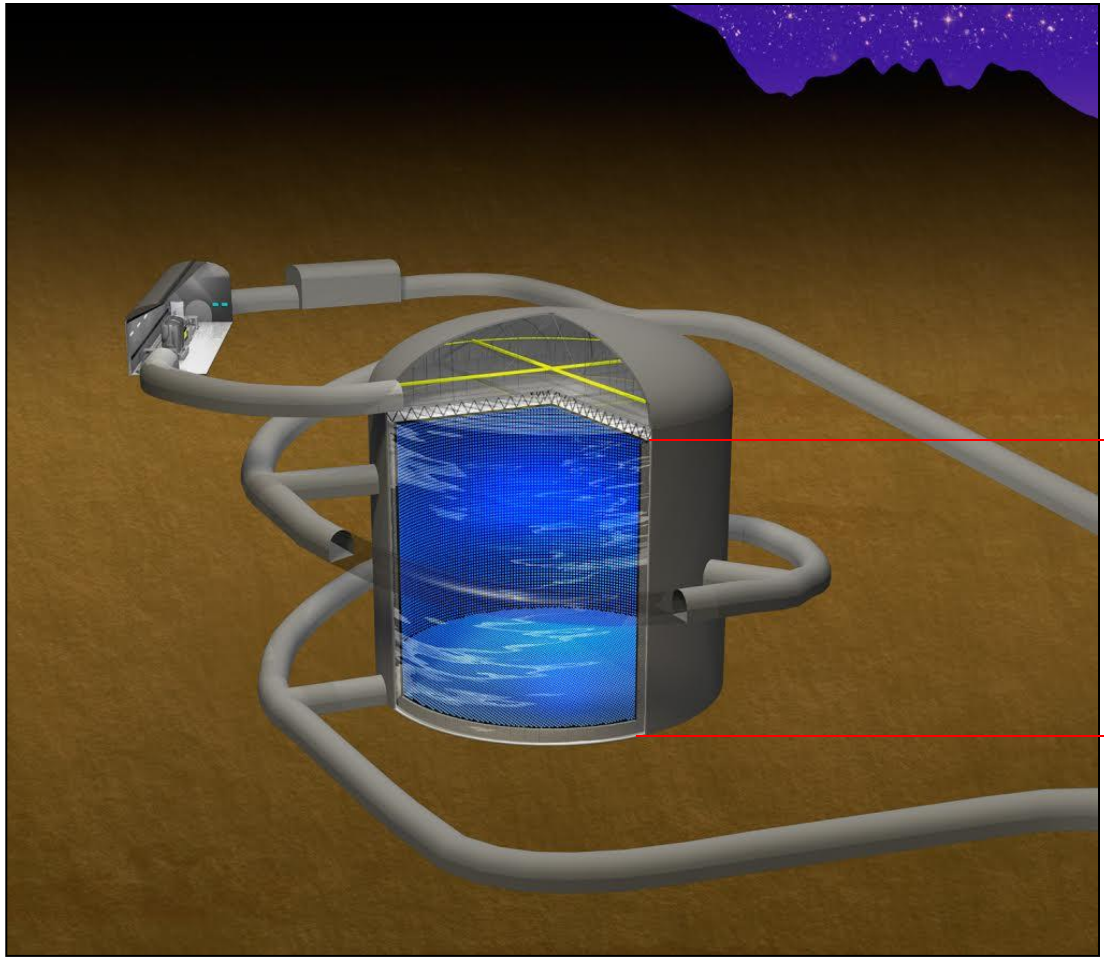
Water Cherenkov detector instrumented with photomultiplier tubes (PMTs).

© Kamioka Observatory, ICRR (Institute for Cosmic Ray Research), University of Tokyo

Water Cherenkov detectors

Antineutrinos interact rarely with matter - we need a very large tank to see many events.

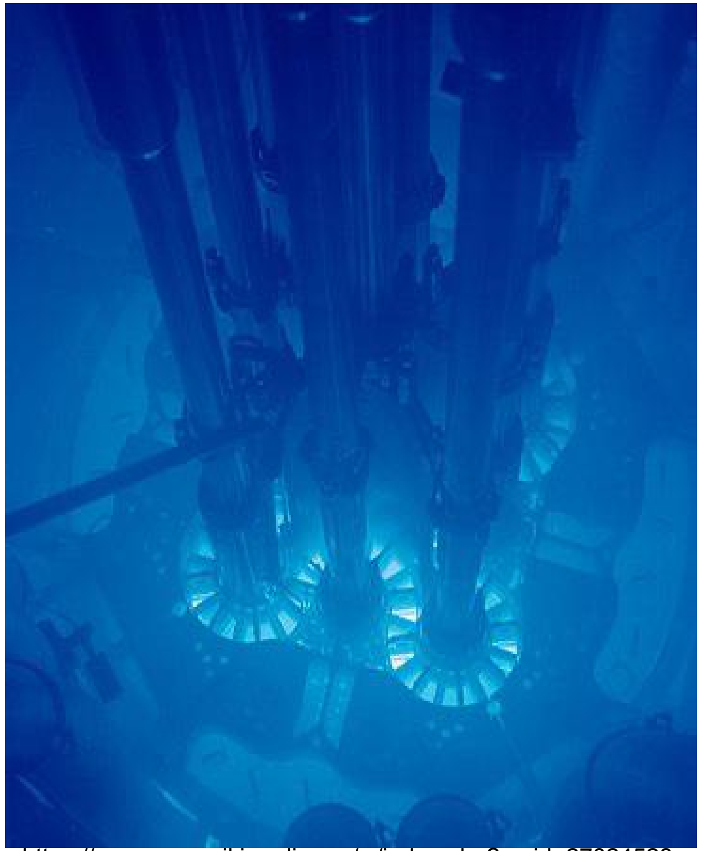
© Hyper-Kamiokande Collaboration



Light's 'sonic boom'

Sonic boom

https://commons.wikimedia.org/w/index.php?curid=1674474

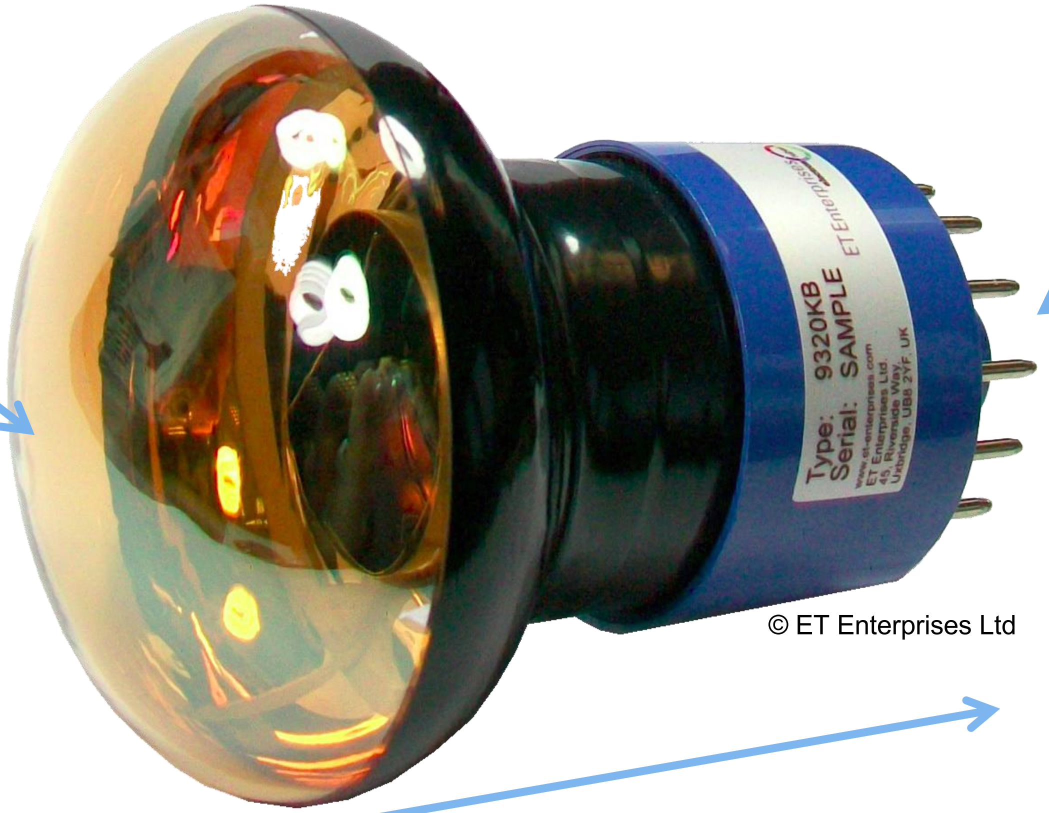


https://commons.wikimedia.org/w/index.php?curid=27024528

'Light' boom

Seeing the light

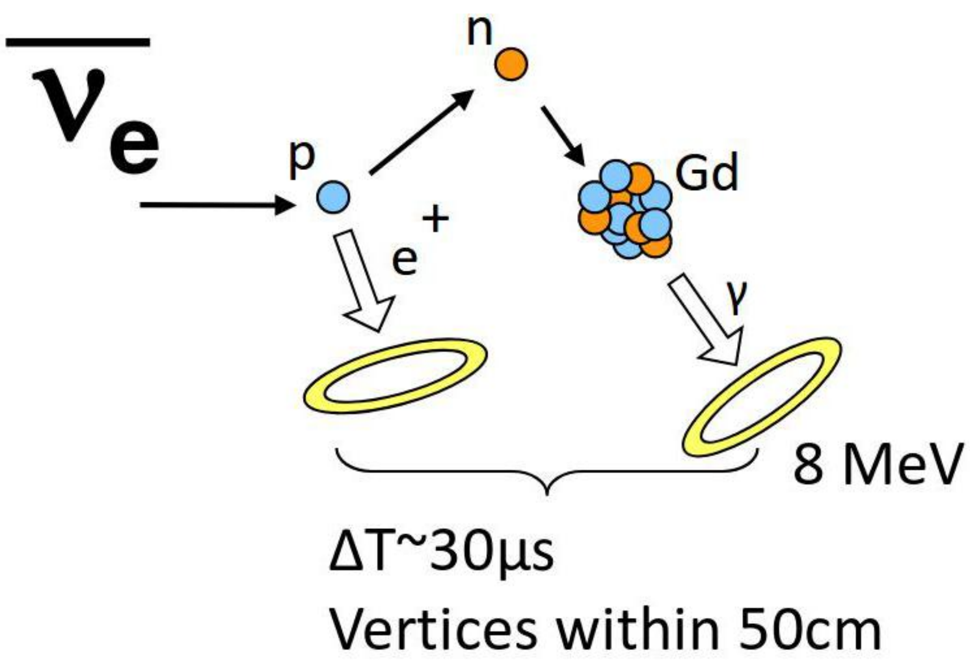
Cherenkov photon hits photocathode and is converted into an electron.



Pulsed signal output at the anode.

Electron 'multiplies' as it travels down the dynode chain.

Capturing low-energy antineutrinos

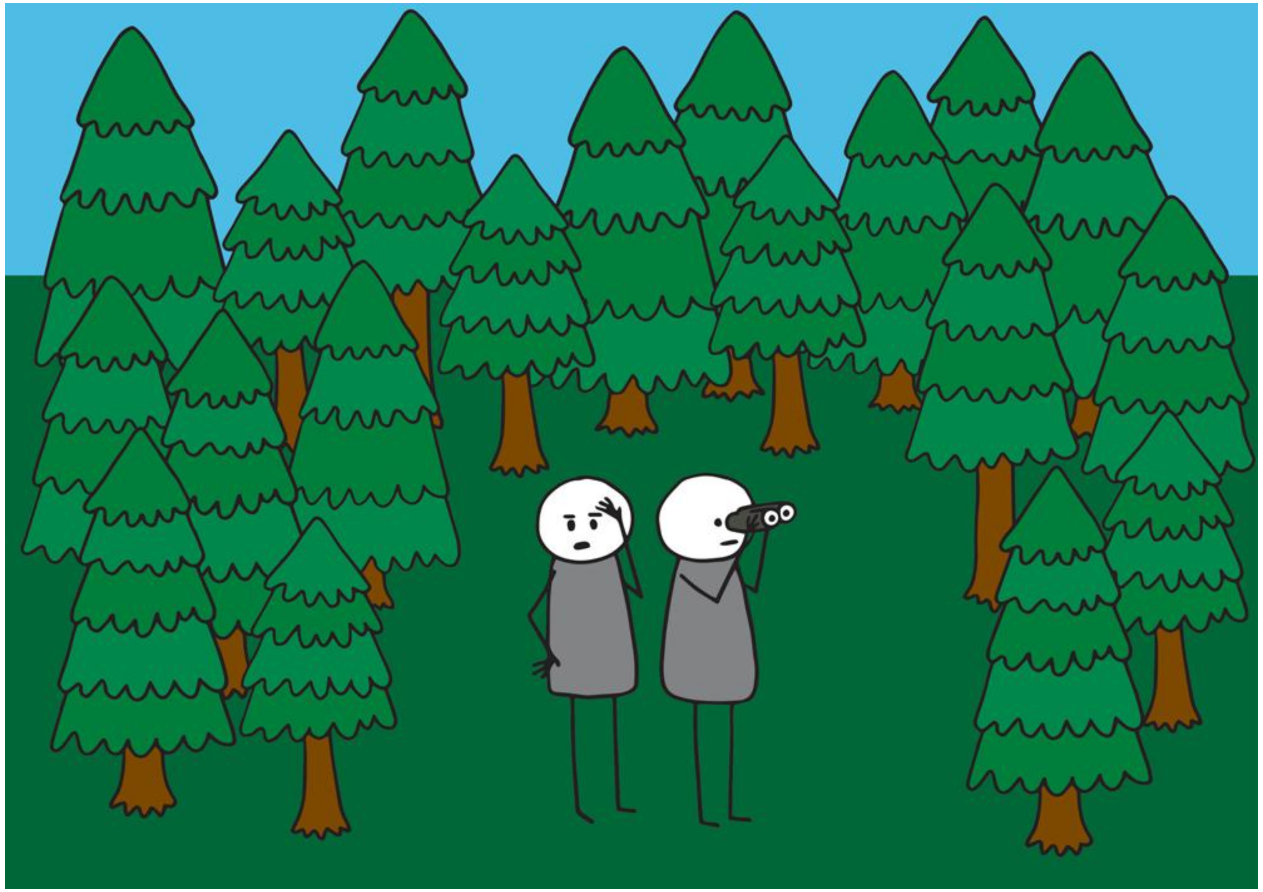


Inverse beta decay + neutron capture =
high-precision measurement of low-energy reactor antineutrinos for non-proliferation.

Neutrinos for non-proliferation

1. Reactor antineutrinos
2. Water Cherenkov detectors for reactor antineutrino detection
3. WATCHMAN & AIT
4. Maximising sensitivity

Remote reactor monitoring



In a complex nuclear landscape we must be able to:

- Confirm the existence of a reactor,
- Separate a reactor's signal from other reactor backgrounds,
- Narrow down its location,
- Tell if a quantity of material is removed.

UK location

WATCHMAN:
WATer CHerenkov Monitor for ANtineutrinos

Detect the on/off cycle of a reactor 25km away in the presence of other reactor cores.

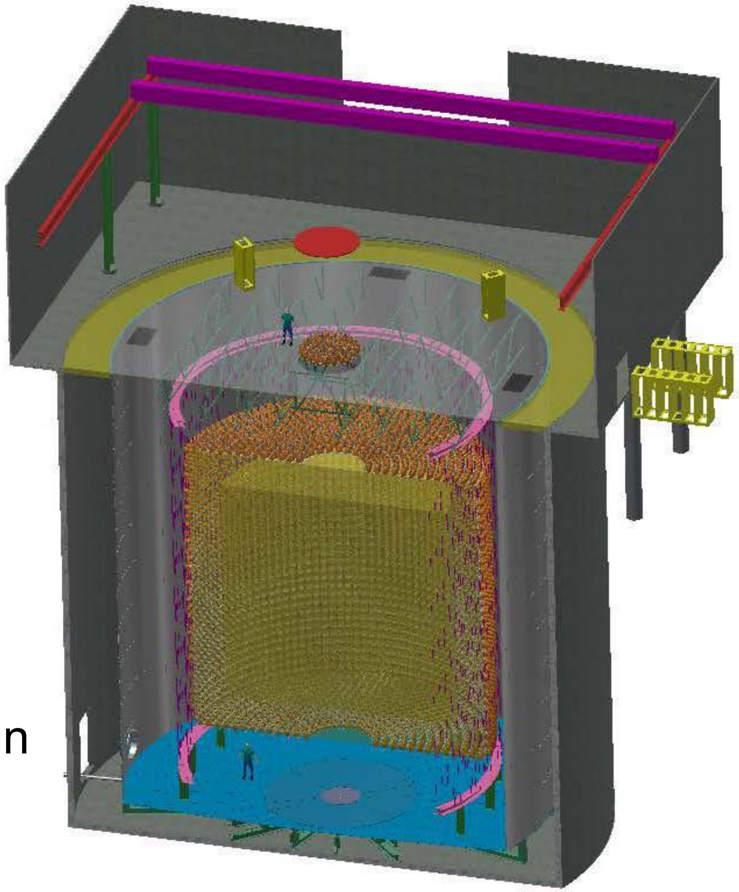
Boulby Mine

Working mine

Boulby Underground Laboratory

1km below ground

Large-scale neutrino detector in the UK

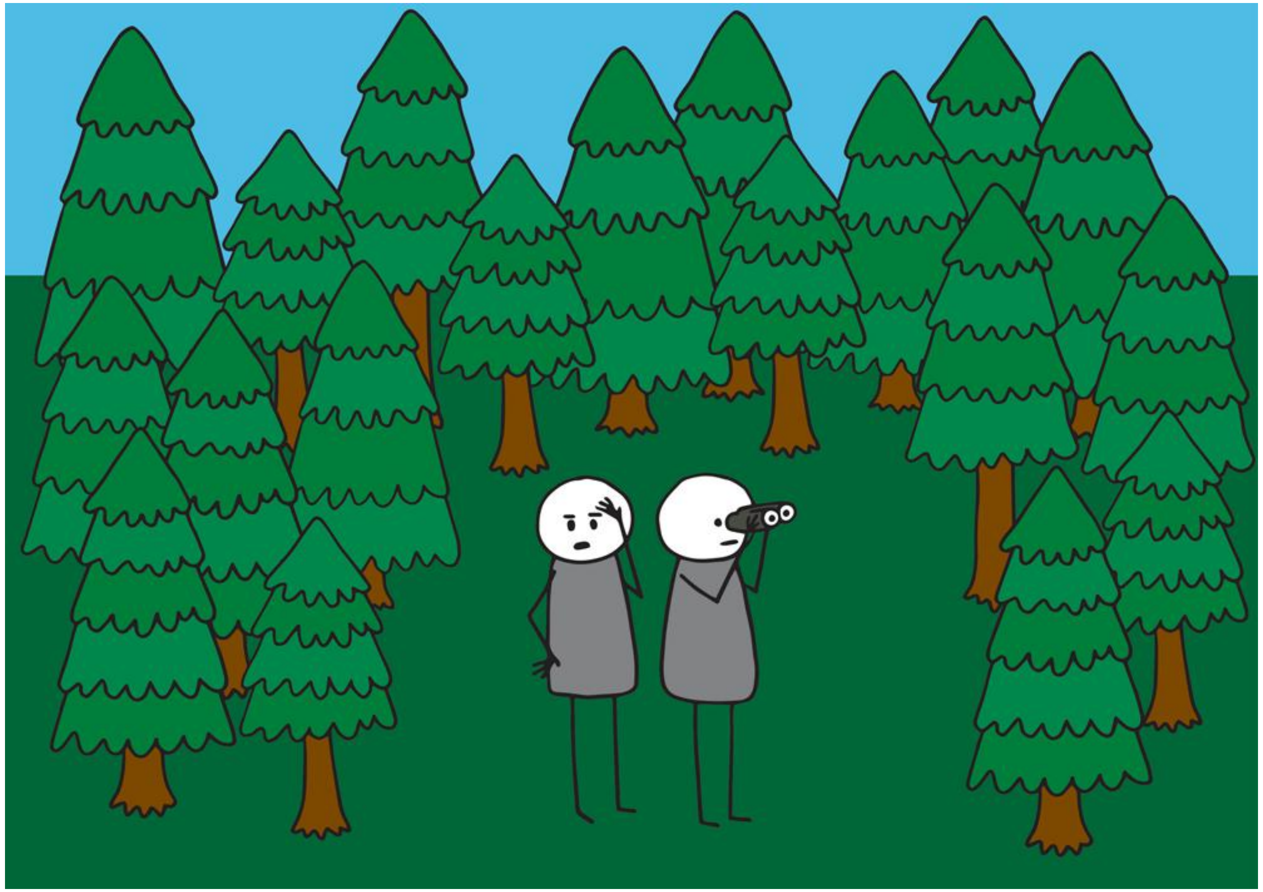


JG Boissevain
Design

One of the world's largest precision neutrino detectors

... to be built in the UK.

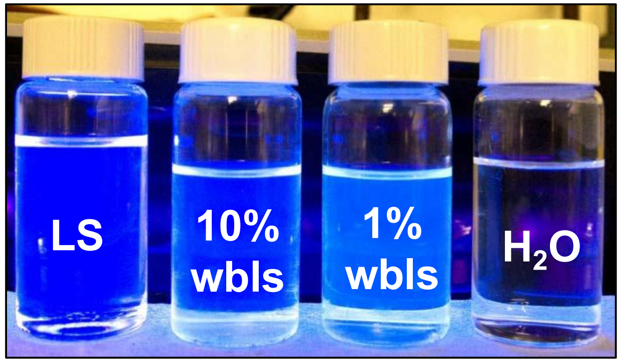
Remote reactor monitoring

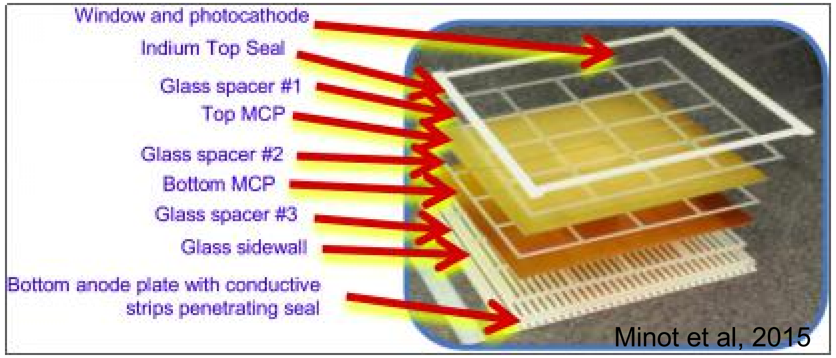


In a complex nuclear landscape we must be able to:

- Confirm the existence of a reactor,
- Separate a reactor's signal from other reactor backgrounds,
- Narrow down its location,
- Tell if a quantity of material is removed.

Advanced Instrumentation Testbed (AIT)





Minot et al, 2015

Ultimate non-proliferation goal

A megaton-scale detector with directionality to be deployed in the field to detect a small, clandestine plutonium production reactor within 1000km.

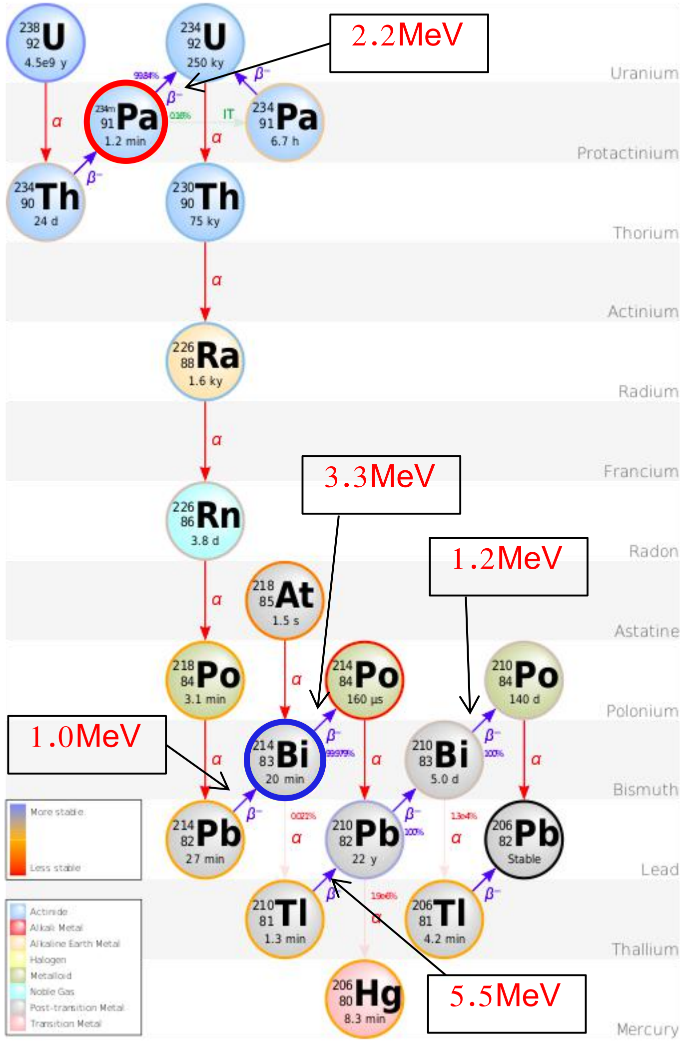
Neutrinos for non-proliferation

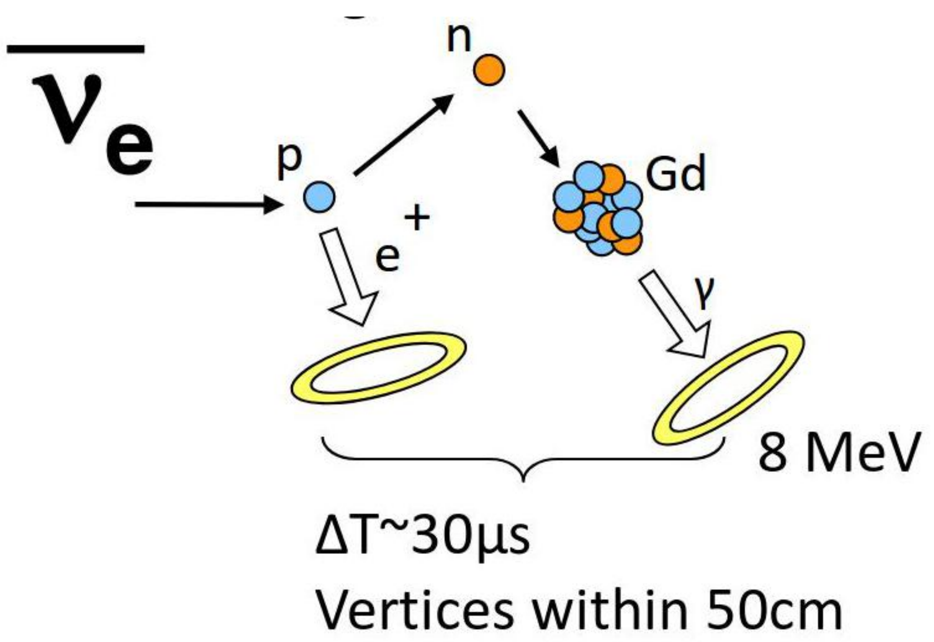
1. Reactor antineutrinos
2. Water Cherenkov detectors for reactor antineutrino detection
3. WATCHMAN & AIT
4. Maximising sensitivity

Minimising backgrounds

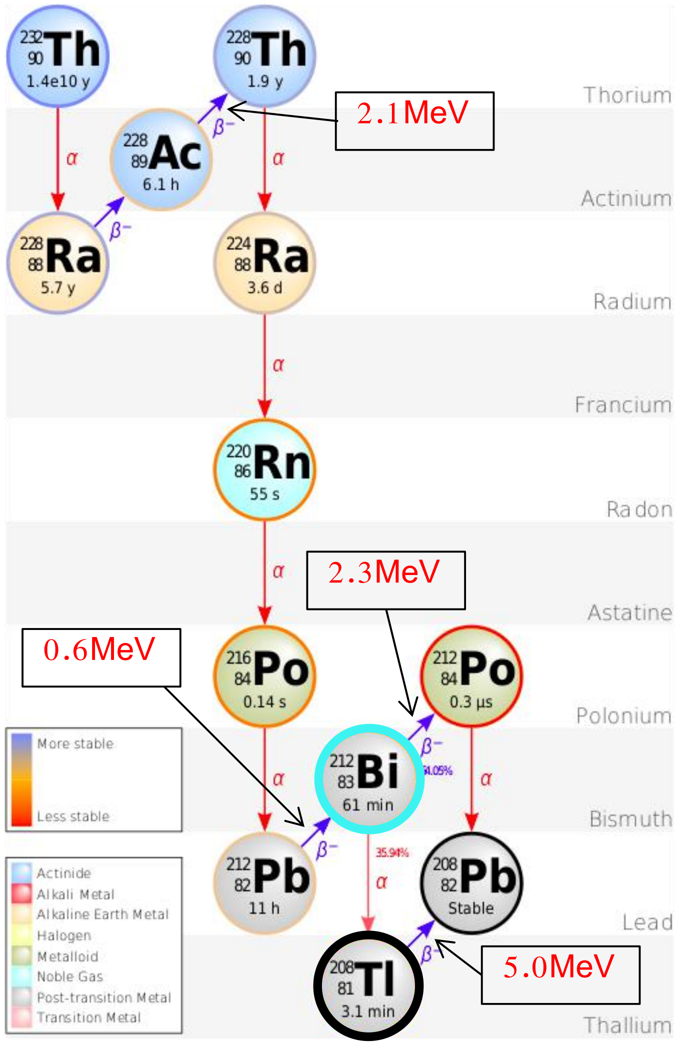
With just a handful of signal events per week, background discrimination is vital!

Backgrounds due to natural radioactivity

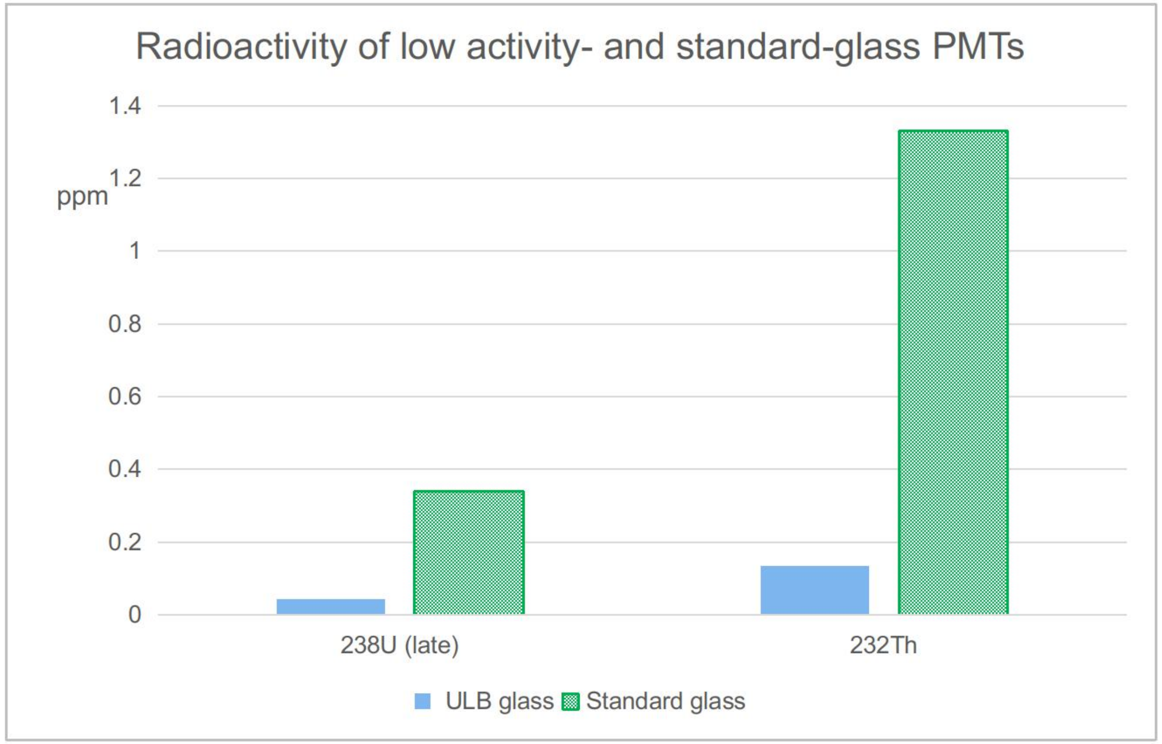




Radioactivity in photosensor (PMT) glass can mimic the correlated signal.

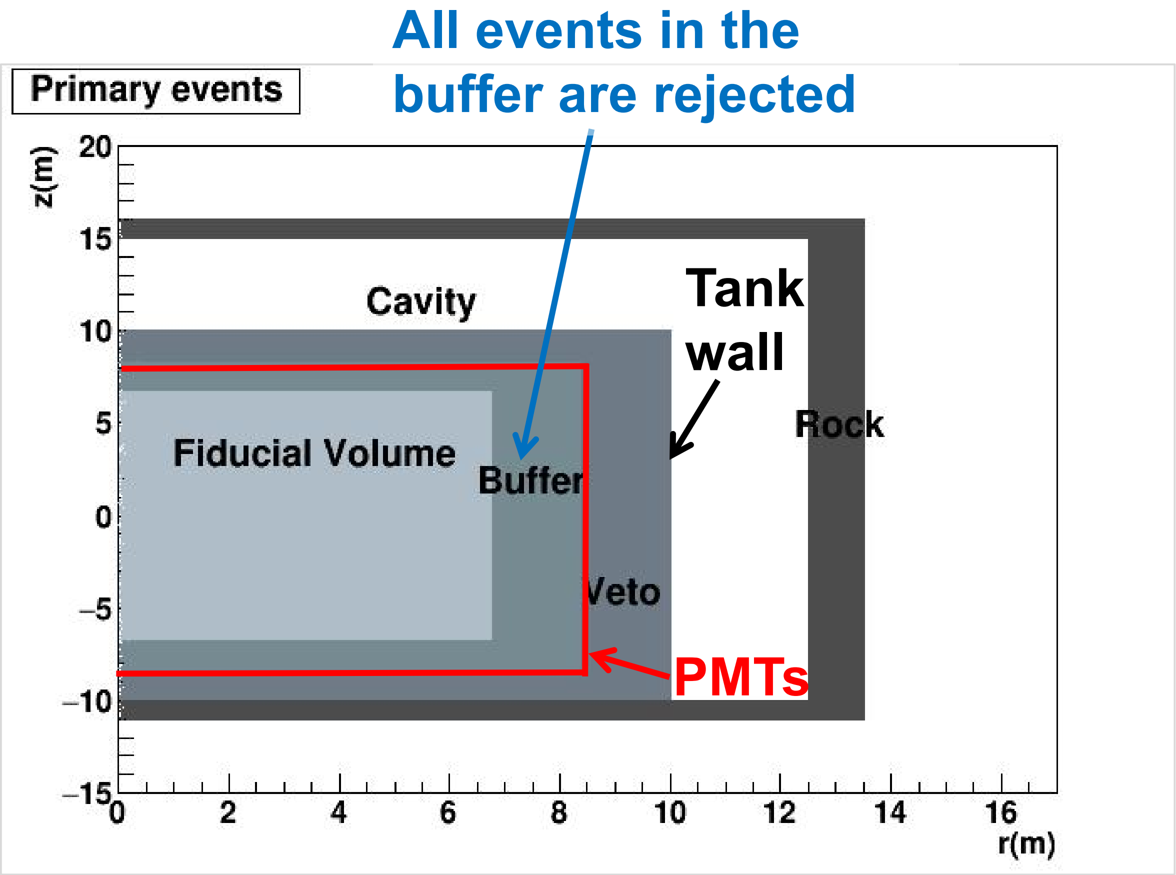


Minimising backgrounds - practical



Use low-activity glass in photosensors (PMTs) to reduce backgrounds from radioactivity.

Reducing backgrounds - analytical



20m diameter tank, PMTs at 8.4m from centre

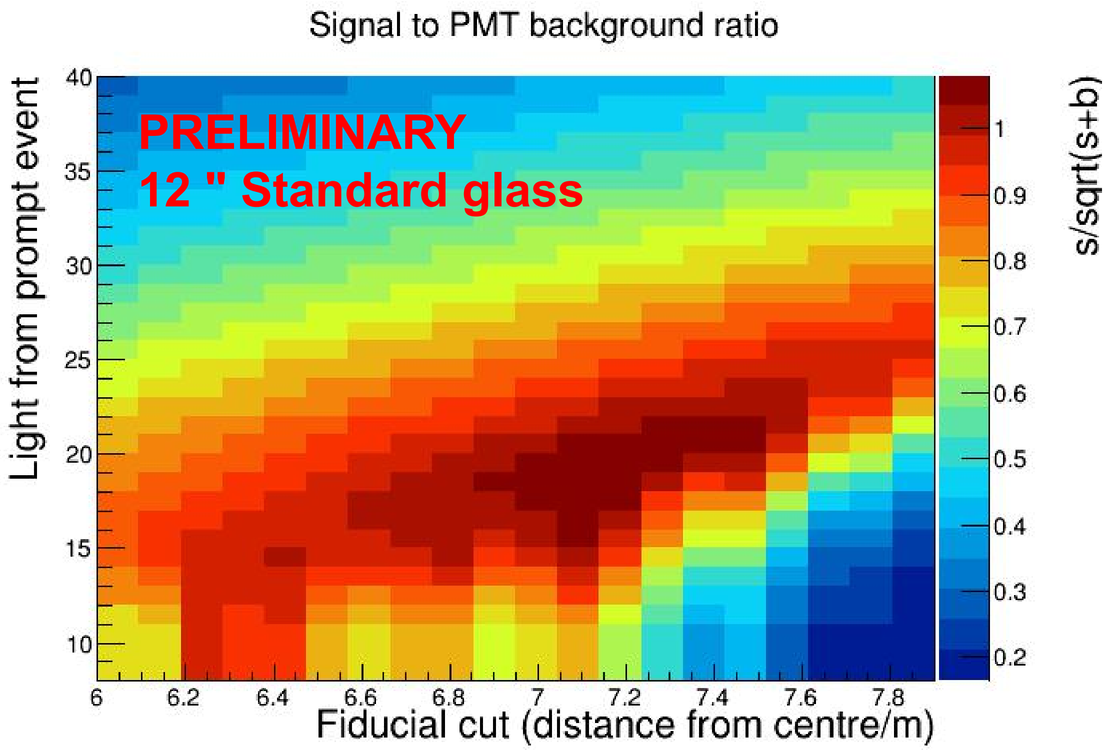
1. Upper limit on the time and distance between events -> 'accidentals' rate.

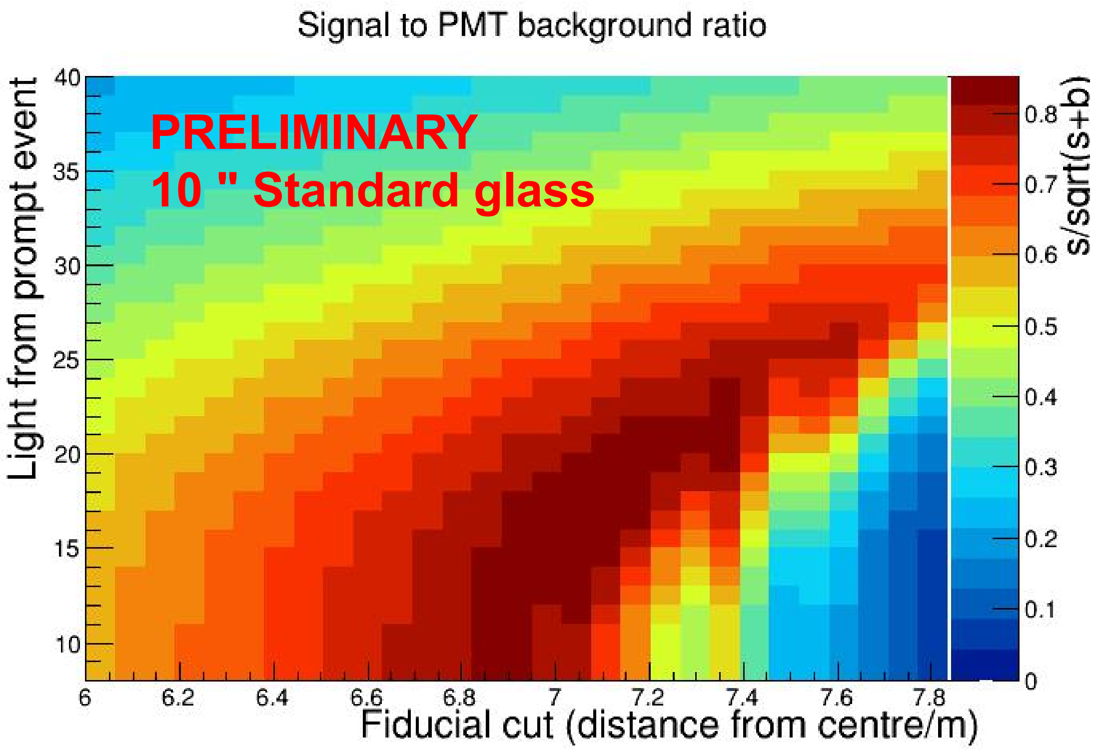
2. Define a 'buffer' region between the PMTs and fiducial volume.

Optimising signal to background - analytical

3. Set a lower limit on the light from the events.

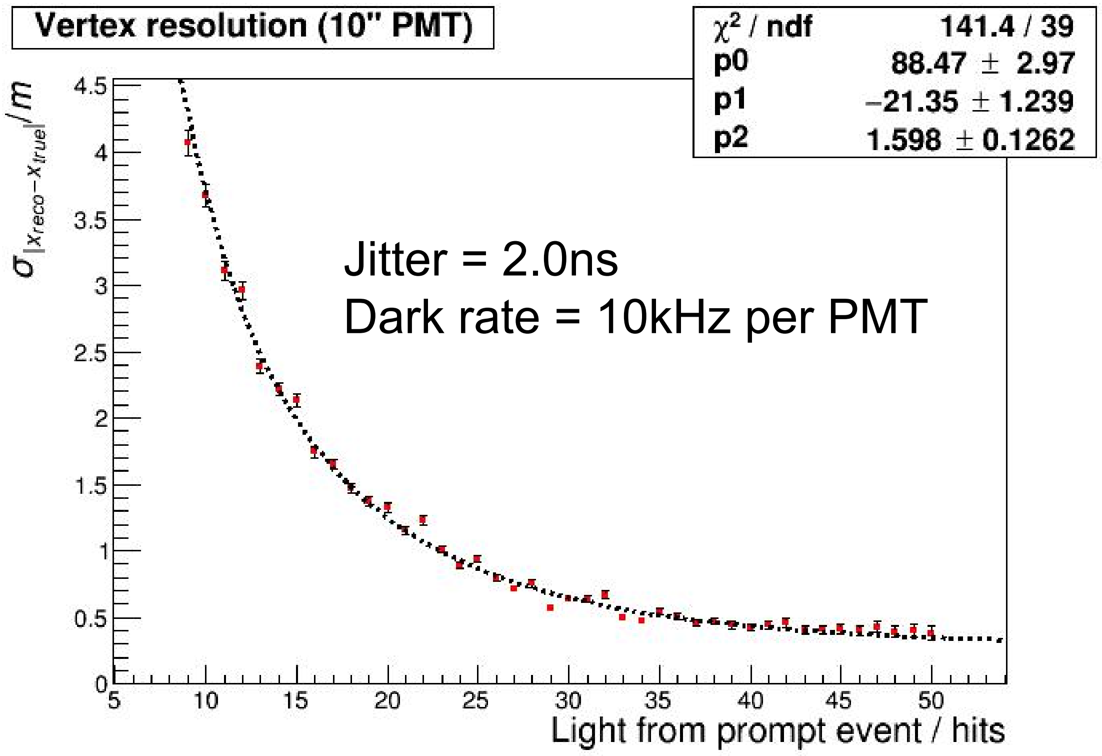
4. Optimise the signal-to-background ratio as a function of these cuts.

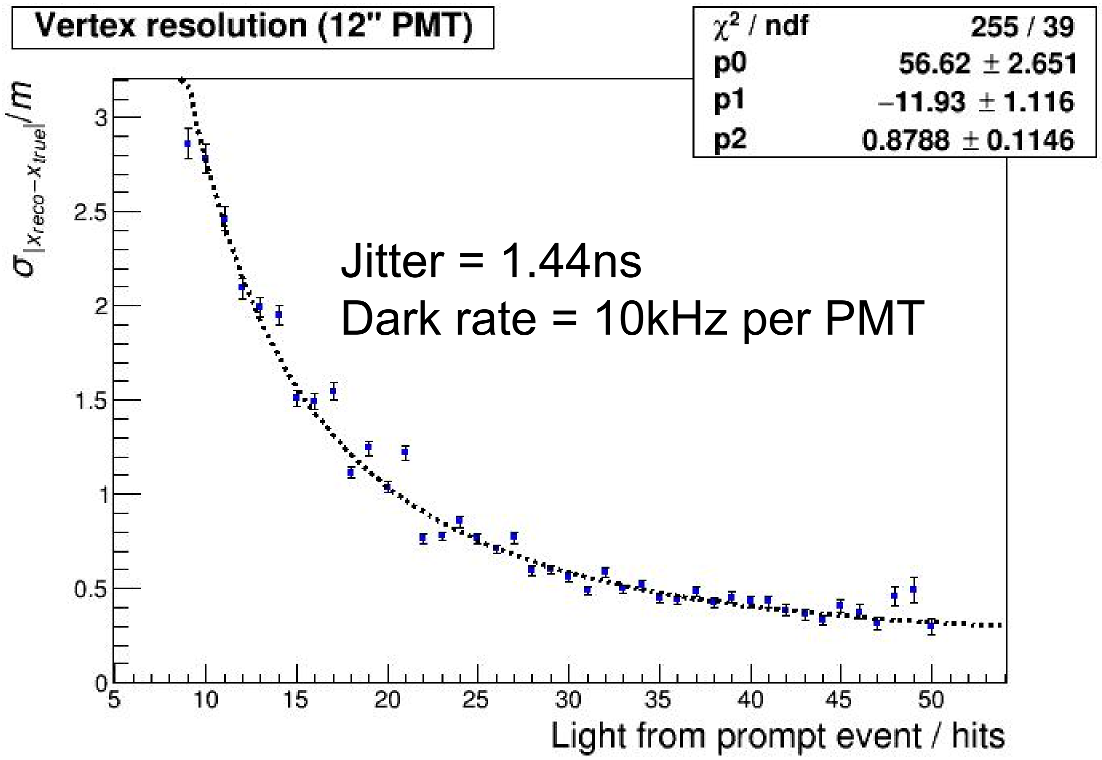




Example for 20m diameter tank, PMTs at 8.4m from centre

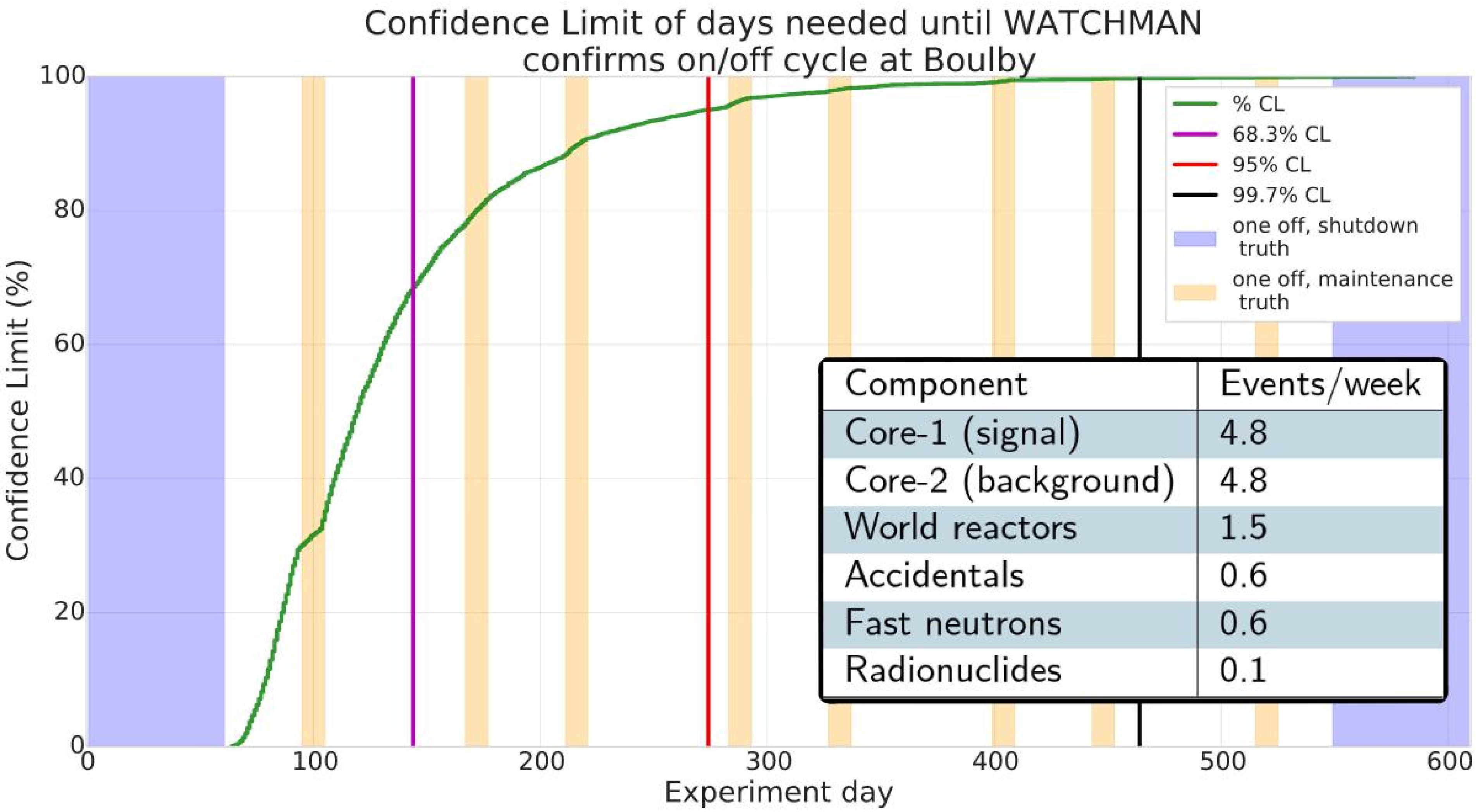
Improved reconstruction with 12" PMT





Smaller 'jitter' and higher signal-to-dark rate ratio → better reconstruction of location of antineutrino interactions, especially at lower energies.

How long to detect a reactor?



Component	Events/week
Core-1 (signal)	4.8
Core-2 (background)	4.8
World reactors	1.5
Accidentals	0.6
Fast neutrons	0.6
Radionuclides	0.1

'Particles for peace'

The signal-to-background ratio is expected to be low - optimisation of the detector *and* analysis is vital!

An emphasis on new analysis techniques and advanced technologies will further our non-proliferation aims.

Towards a megatonne-scale detector with directionality to locate an unknown reactor up to ~1000km away.

Thank you for listening! Any questions?

Acknowledgements:
Jon Burns (AWE), Matthew Malek (UofSheffield), Marc Bergevin (LLNL)

https://commons.wikimedia.org/w/index.php?curid=27024528

Liz Kneale
University of Sheffield

Defence & Security Doctoral Symposium 13-14 November 2018