A NEXT-GENERATION NEUTRINO DETECTOR TO SOLVE THE SOLAR METALICITY PROBLEM

2015 SLAC Summer Institute — Universe of Neutrinos

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The Solar Metallicity Problem

Simulation

- Advances in quality have suggested lower metallicities than previously assumed.

Helioseismology

- Measurements consistent with higher metallicity solar composition.

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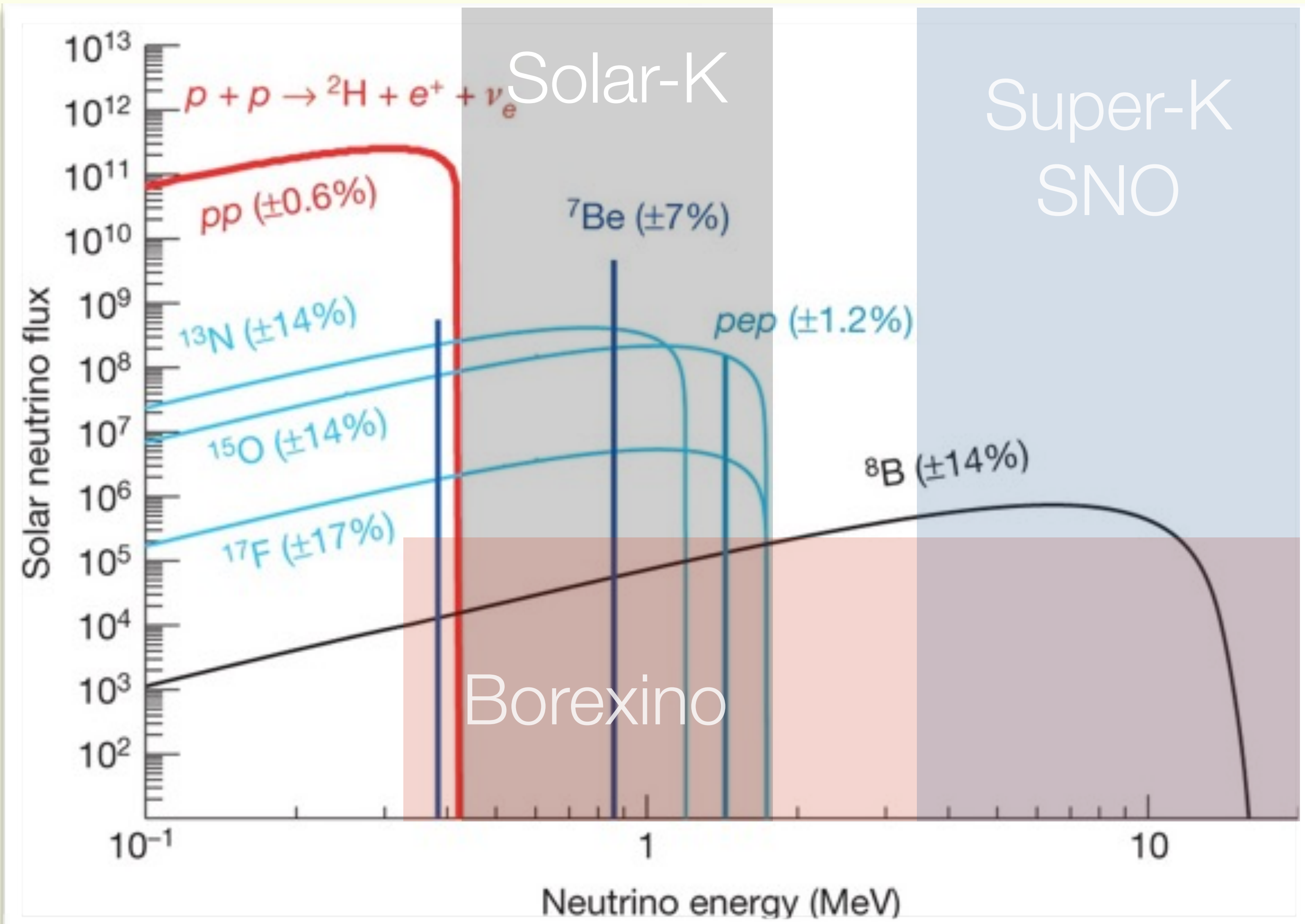
A MEASUREMENT OF THE CNO FLUX COULD HELP

But measuring the CNO flux is hard…



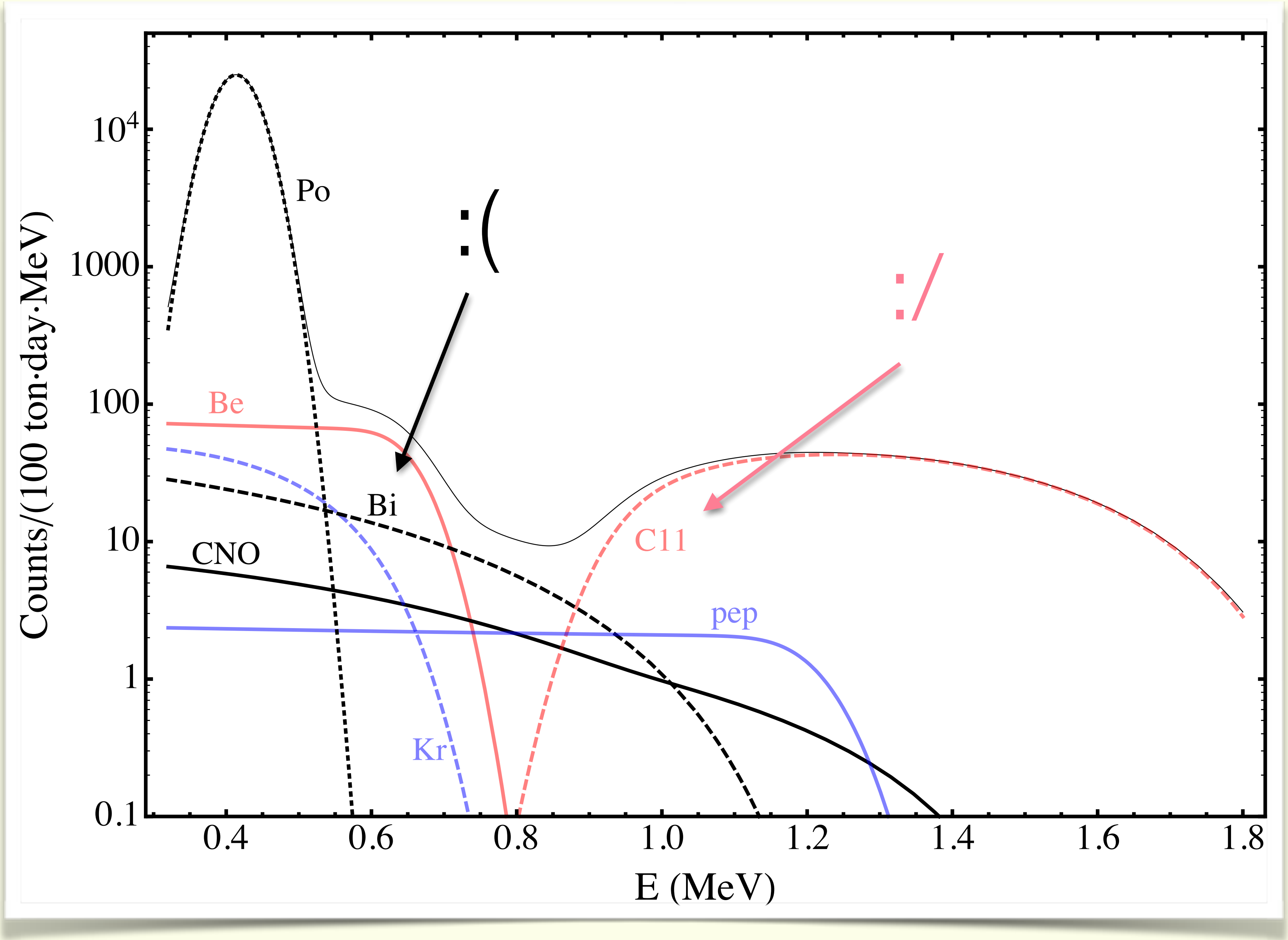
***Predicted solar neutrino energy spectrum from Standard Solar Model BS05(OP) –** Bachall, et al.*

Need to reliably measure energies < 2 MeV.

Looks like Borexino beat us to it. Time to pack up and go home?

Not quite…

The Solar Metallicity Problem



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Proposal

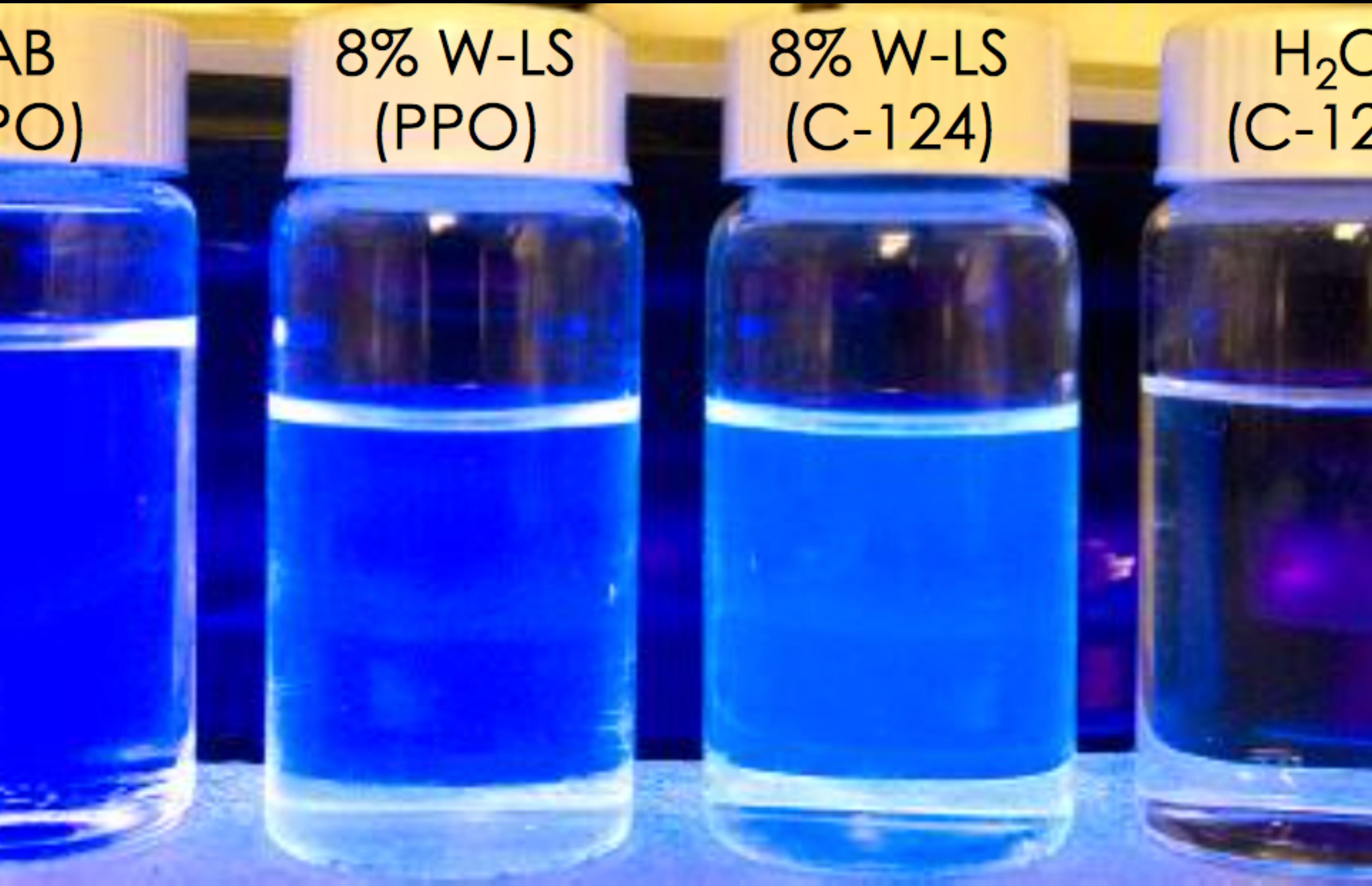
A ~50kt detector where Super-K currently lives
(should they decide to move out)

Target medium: – 79 – 89% H_20
– 10 – 20% LS
– 1% ^{7}Li

Detection: 850 8”x8” Large Area Picosecond Photodetectors

Benefits: – Shed light on the solar metallicity problem
– Designed to be highly economical
– Help usher in a new era of neutrino experiments

Water-based Liquid Scintillator (WbLS)



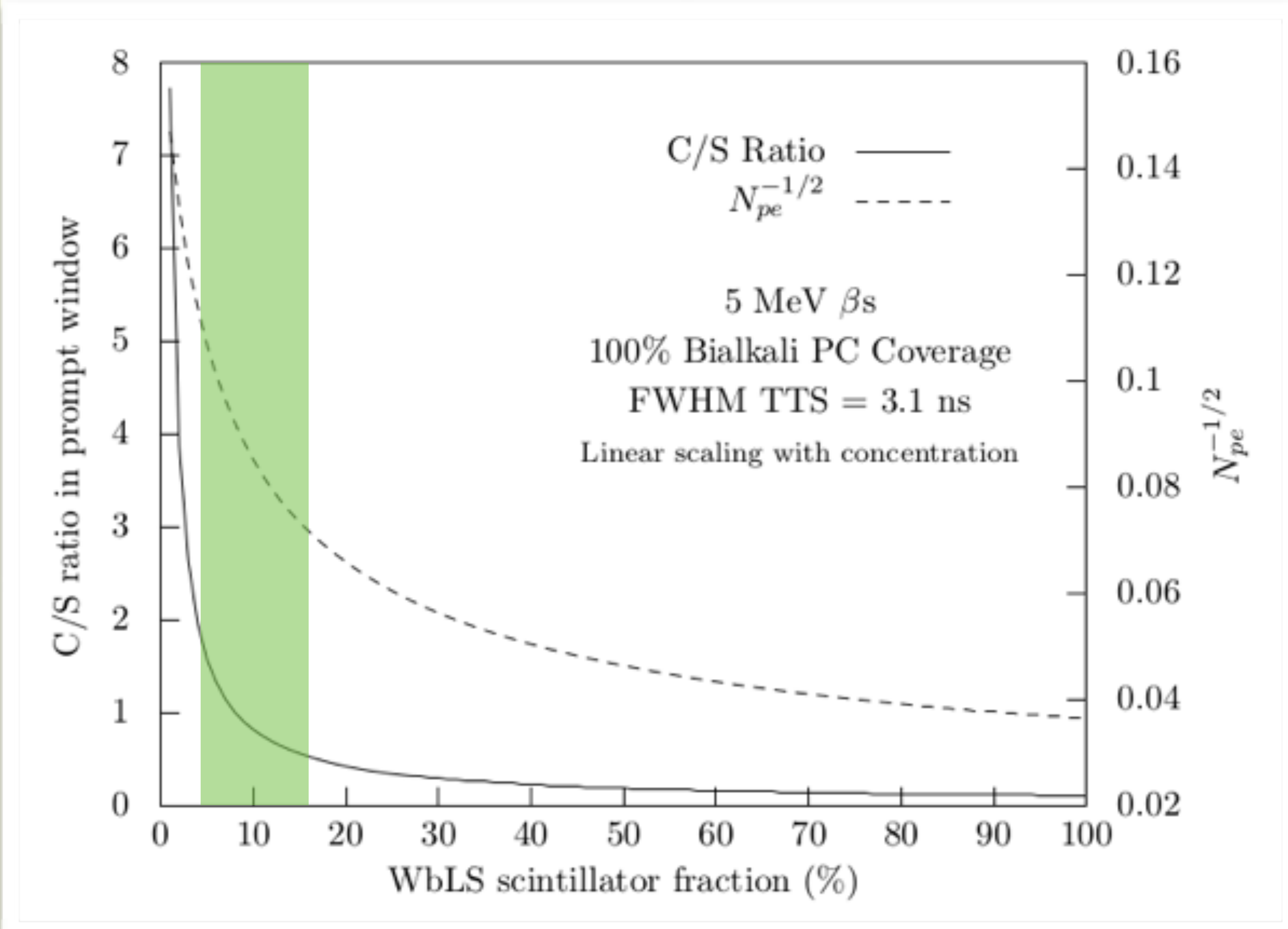
Water-based Liquid Scintillator (WbLS)

With WbLS, we can get the best of Water Cherenkov and Liquid Scintillator detection methods

Scalability
Directionality
Energy Resolution

One can tune the scintillator fraction and timing to optimize energy resolution and direction reconstruction for physics goals.

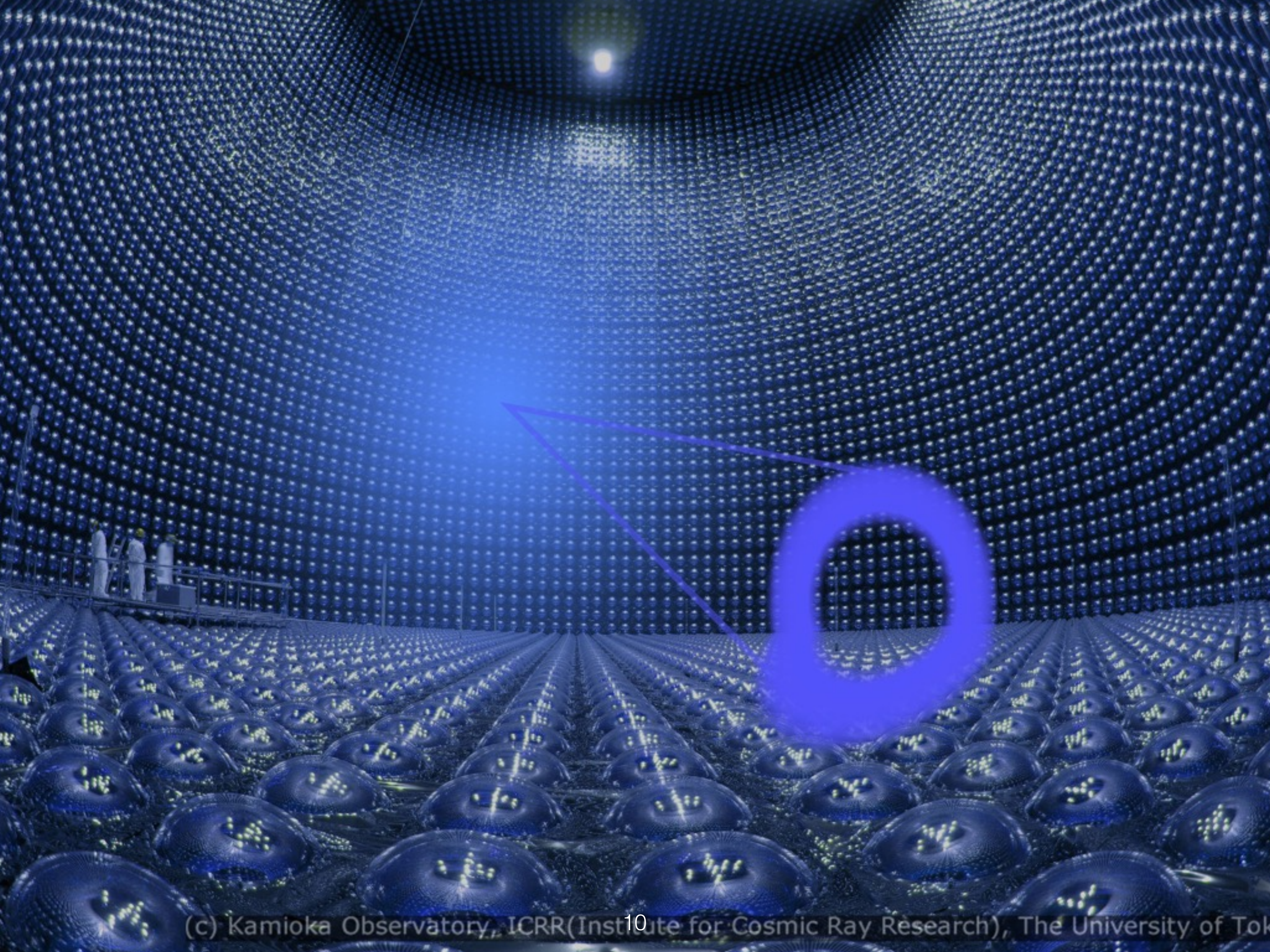
Water-based Liquid Scintillator (WbLS)

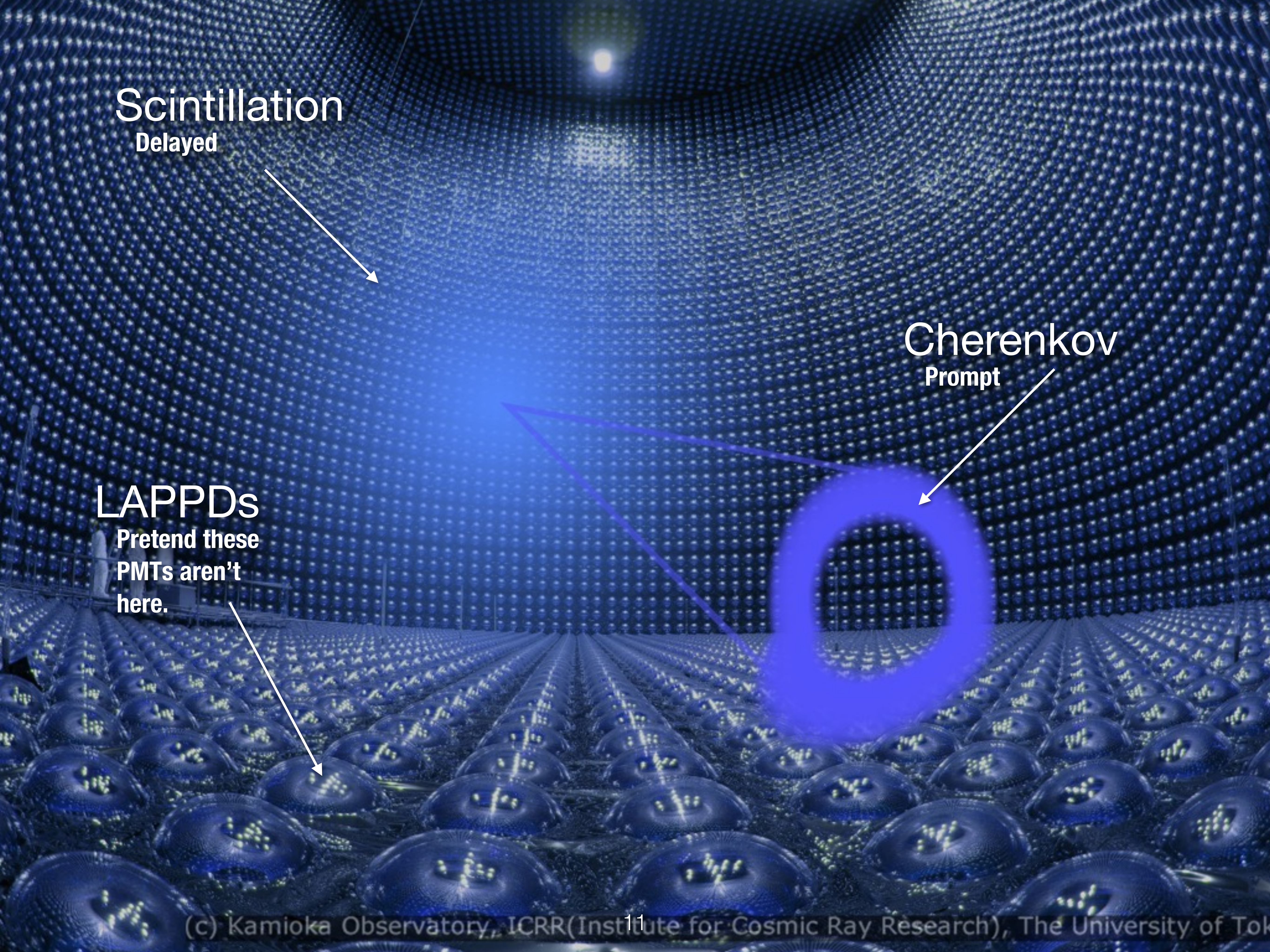


A. Mastbaum 2014

Light yield scales approximately linearly with LS concentration *(4% LS mixture ~= 4x light yield of pure water)*

A 1:5 S/C ratio is ideal, and should produce roughly 100 photons/ MeV.


(c) Kamioka Observatory, ICRR(Institute for Cosmic Ray Research), The University of Tok


Scintillation
Delayed
Cherenkov
Prompt
LAPPDs
Pretend these PMTs aren't here.
(c) Kamioka Observatory, ICRR(Institute for Cosmic Ray Research), The University of Tok

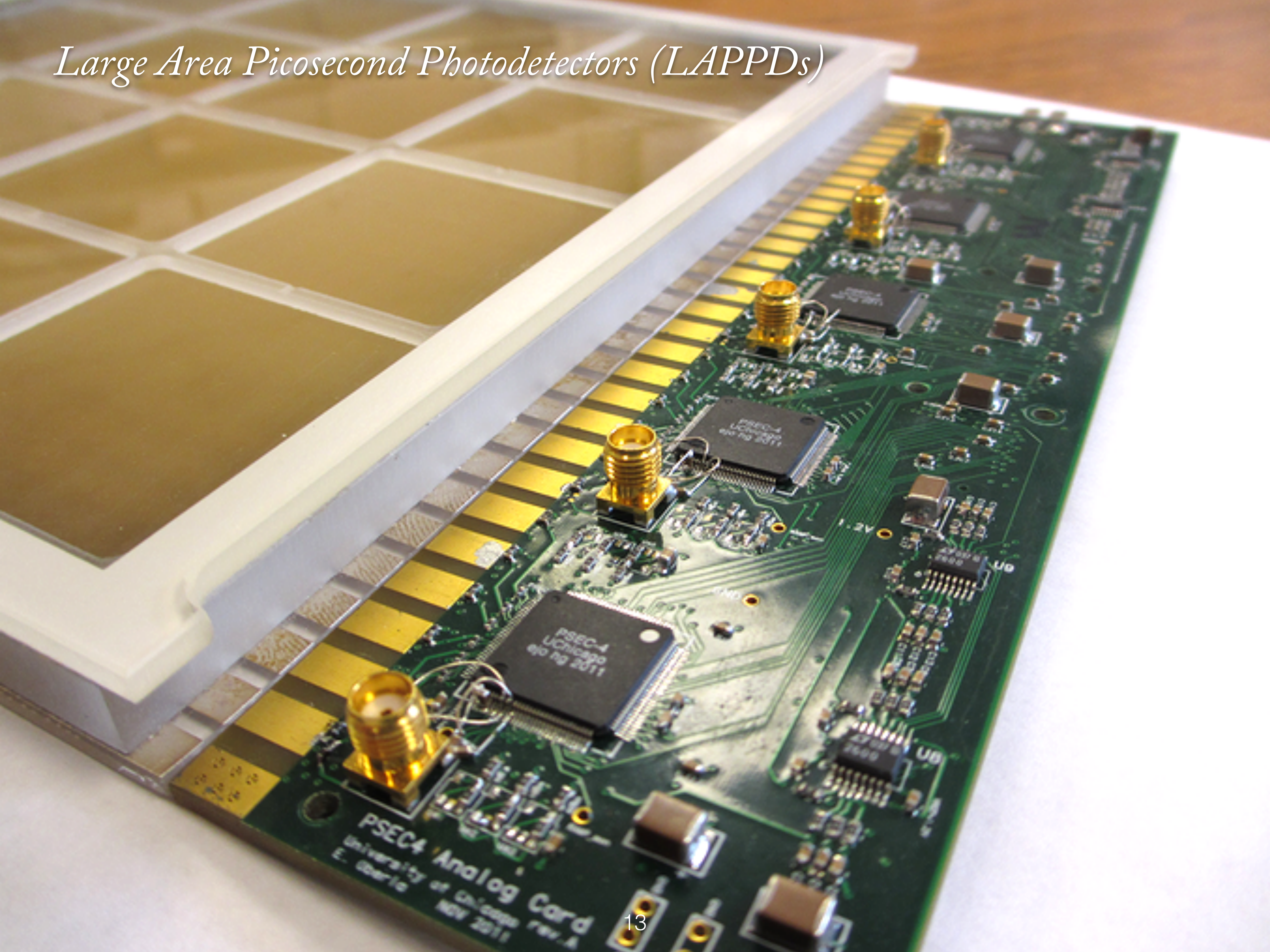
Loading WbLS with ^7Li

The ^{210}Bi background looks very similar to ES.

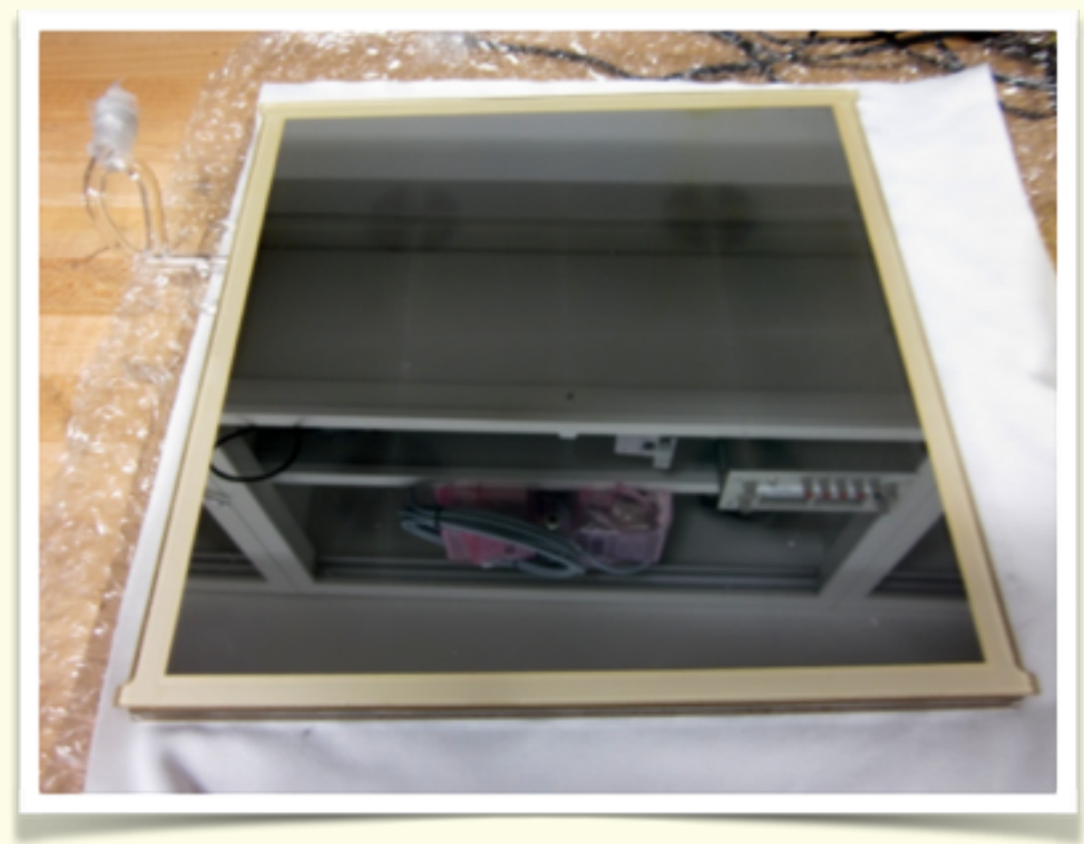
CC interactions can help to reject this background. CC is achieved via isotope loading (eg. ^7Li, ^{115}In).

$$^7Li + \nu_e \longrightarrow {}^7Be + e^- \quad (Q = 862\ keV)$$

Large Area Picosecond Photodetectors (LAPPDs)



The future…future…future…

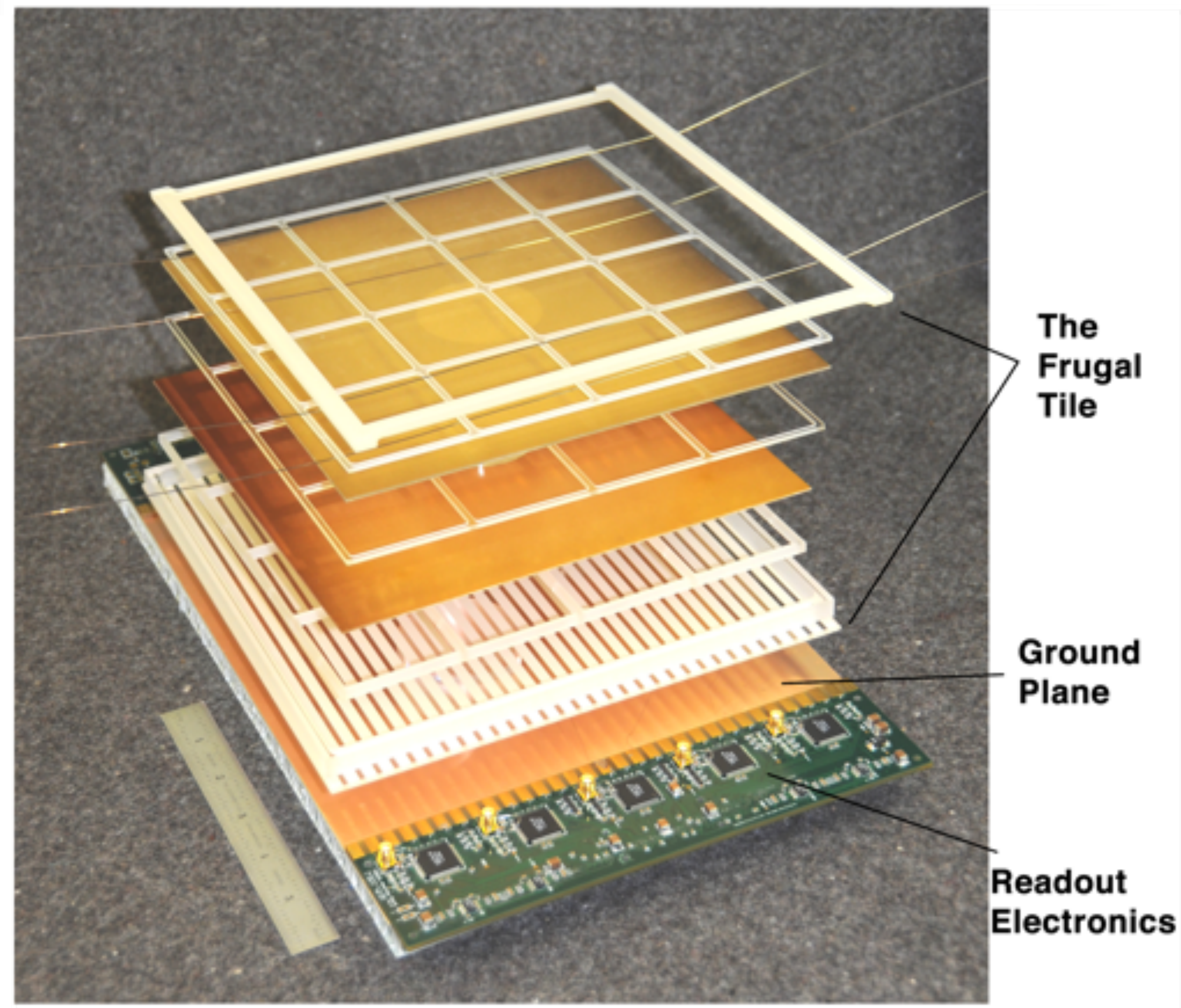


Large Area Picosecond Photodetectors (LAPPDs)

Being developed by a collaboration of universities and labs.

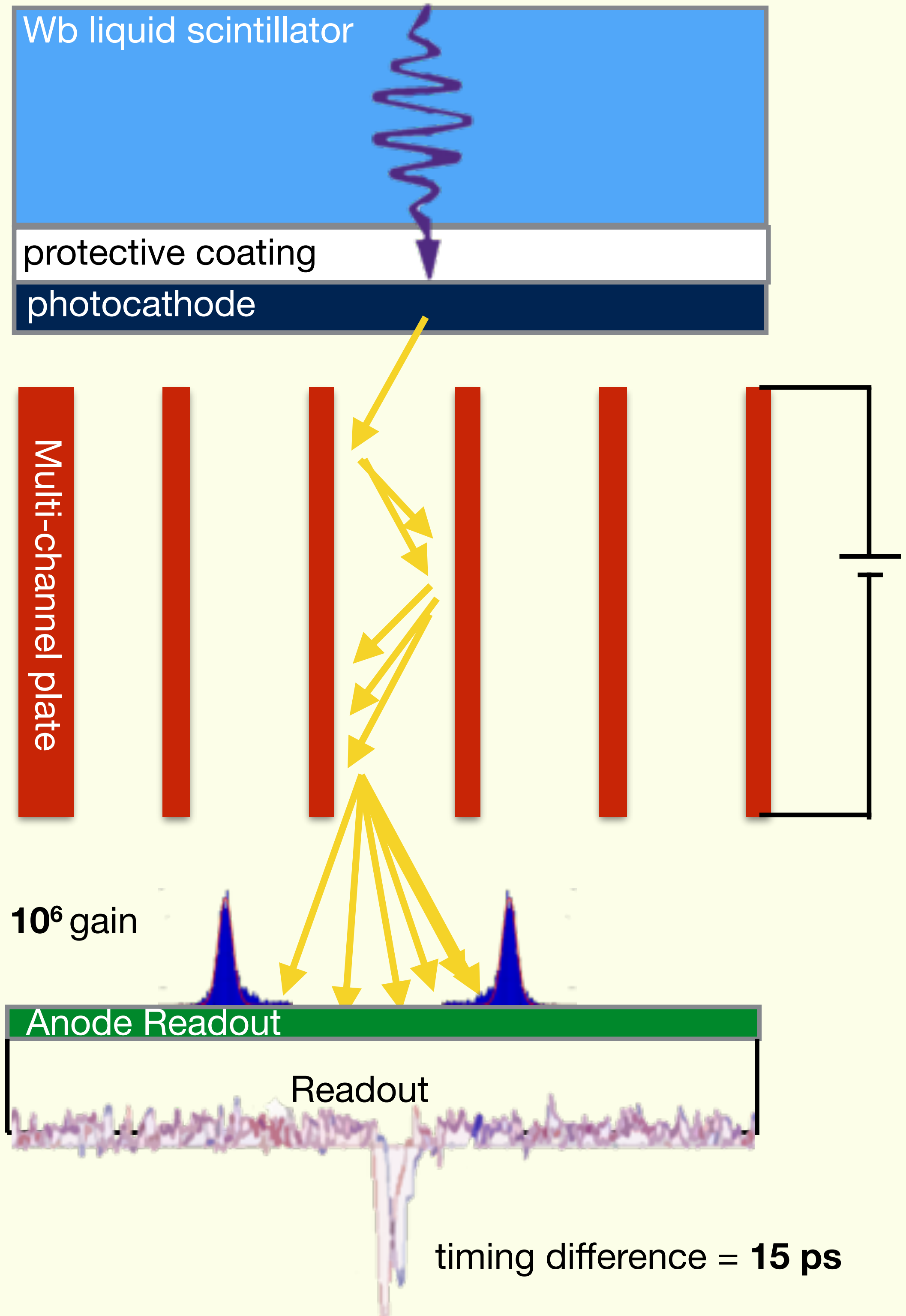
In commercialization phase by private companies.

Microchannel technology makes electron path very small –> quick timing.



The Frugal Tile - Detector Assembly

Large Area Picosecond Photodetectors (LAPPDs)



Pros

- 10's of ps time resolution (20-100 times improvement)
- economical
- could achieve sub-cm spatial resolution
- not susceptible to magnetic field
- improved timing and spatial resolution to help with background rejection
- $10^5 – 10^7$ gain
- atomic layer deposition reduces cost
- GaAsP photocathode QE = 35% at 434nm

Cons

- need water proof housing to protect agains pressure, and protect electronics

MC-based Event Reconstruction

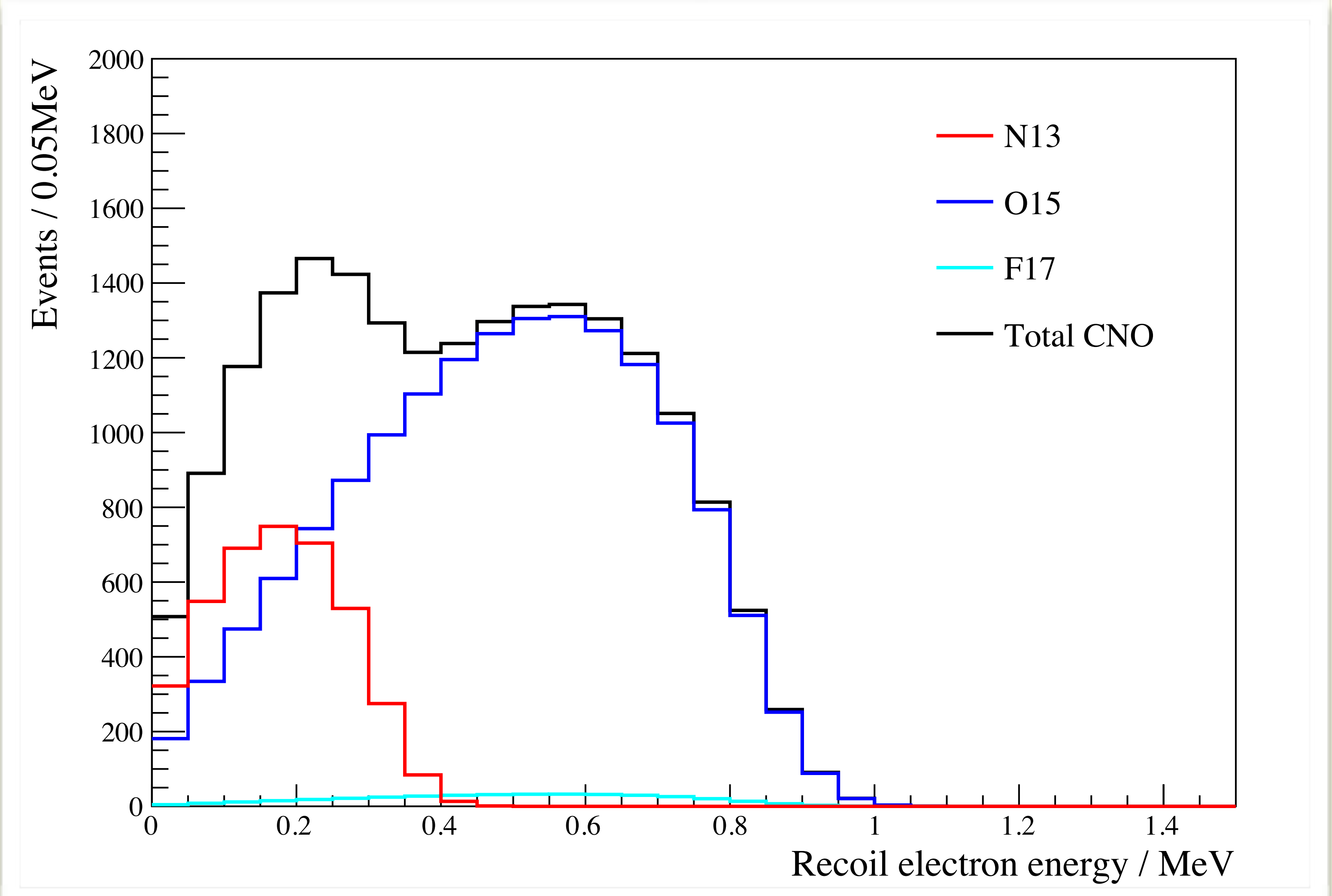
1. Run MC with initial hypothesis
2. Propagate photons over and over to build PDF
3. Evaluate likelihood given all available observables
4. Perturb initial state and try again until convergence (minimization)

This MC method can provide better vertex fitting, but is very CPU intensive.

There are tools available today that bring this into reach.

Chroma — With the right GPU, can propagate 2.5 million photons per second in a detector with 29,000 PMTs —> 200x faster than Geant4.

Measuring the CNO neutrino flux

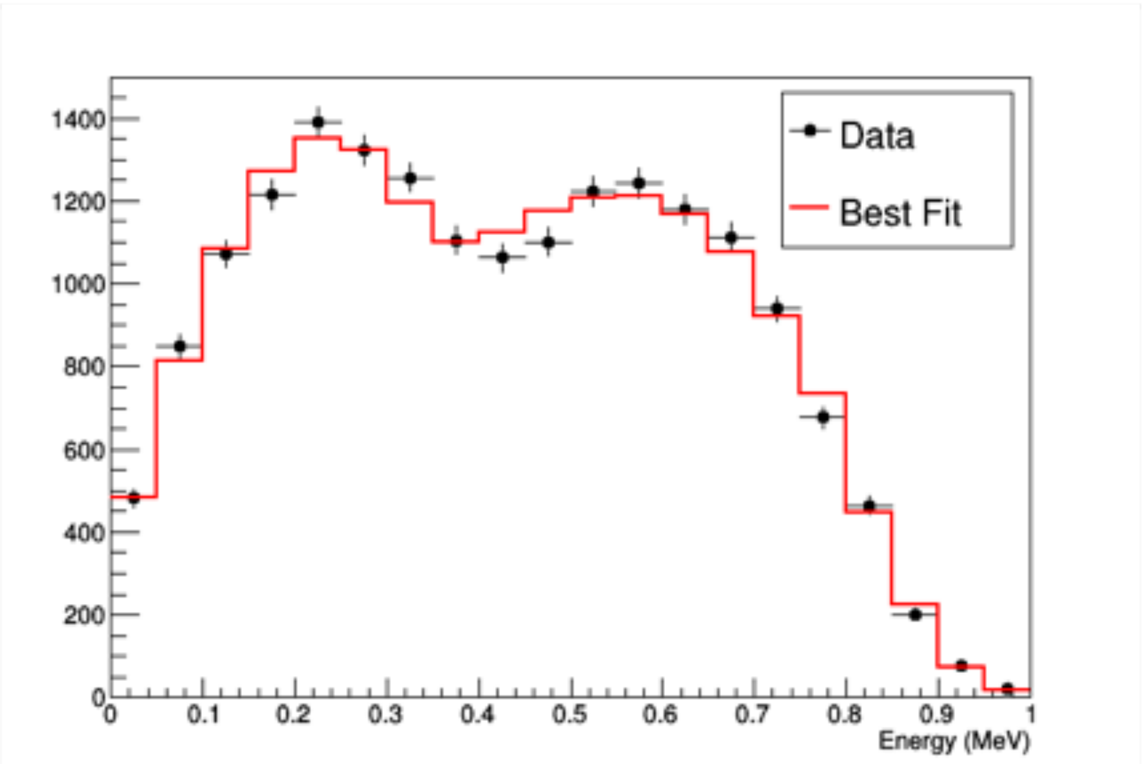


Predicted spectrum for the individual components of the CNO neutrino flux, and the total, in a WbLS detector. – G. D. Orebi, et al (2014).

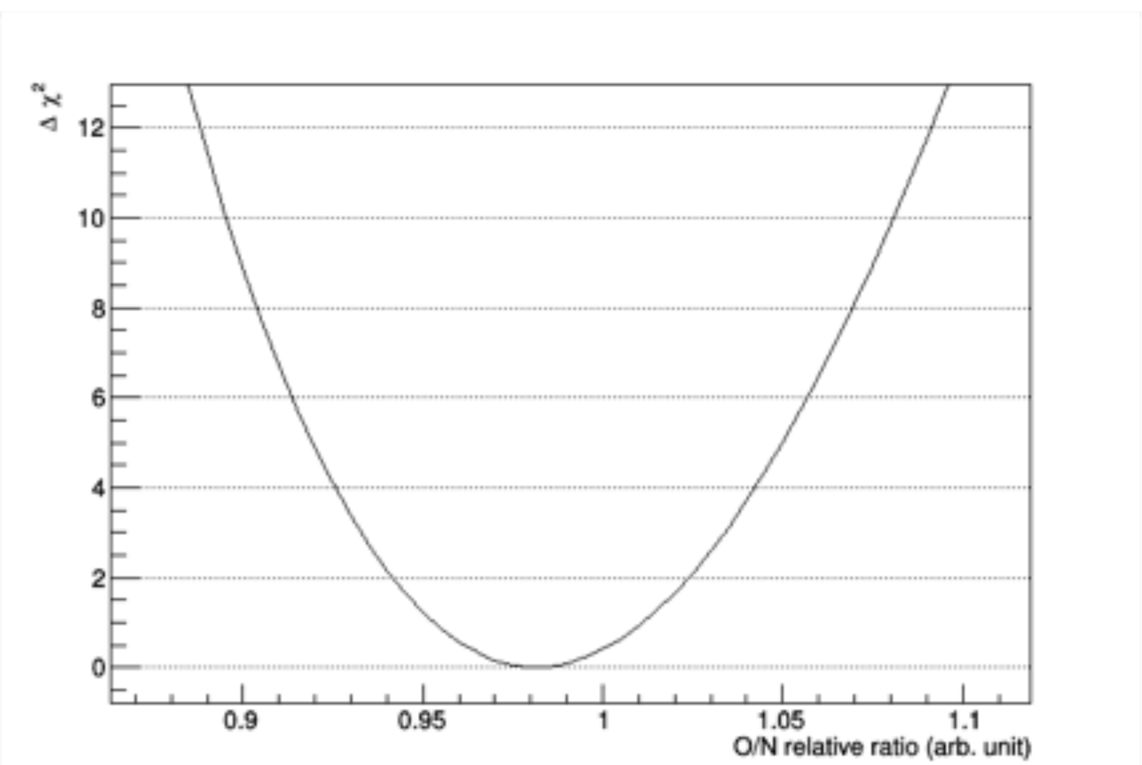
Increased spectral sensitivity from ^{7}Li allows the possibility of separating the constituents of the CNO flux.

Except for the ^{17}F flux, which is extremely small relative to ^{13}N, ^{15}O.

Measuring the CNO neutrino flux



Top: Best fit for 3 years of "mock data."



This detector can tease out the O:N ratio; not just the CNO flux!

O:N ratio can be determined with the following precisions:

- 10% after 3 months
- 5% after 1 year
- 2% after 3 years

This does not include other CC components or backgrounds — very rough, limited.

We're assuming that other components can be determined very precisely.

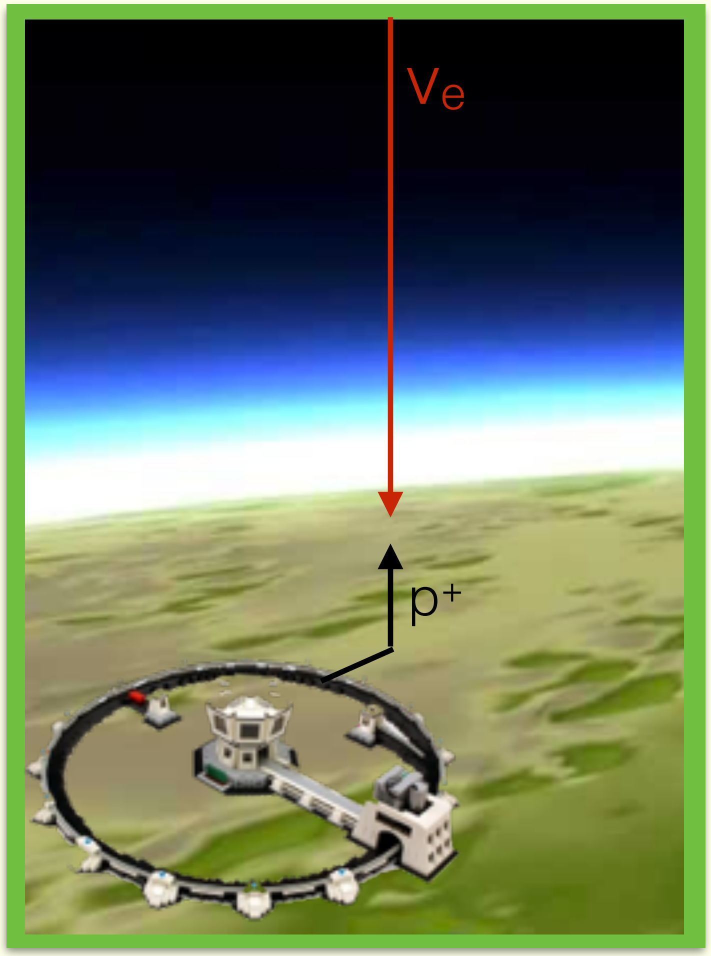

K
SOLAR
Shedding light on the sun

Epilogue: Some of our earlier ideas…

Neutrino detector on Halley's comet

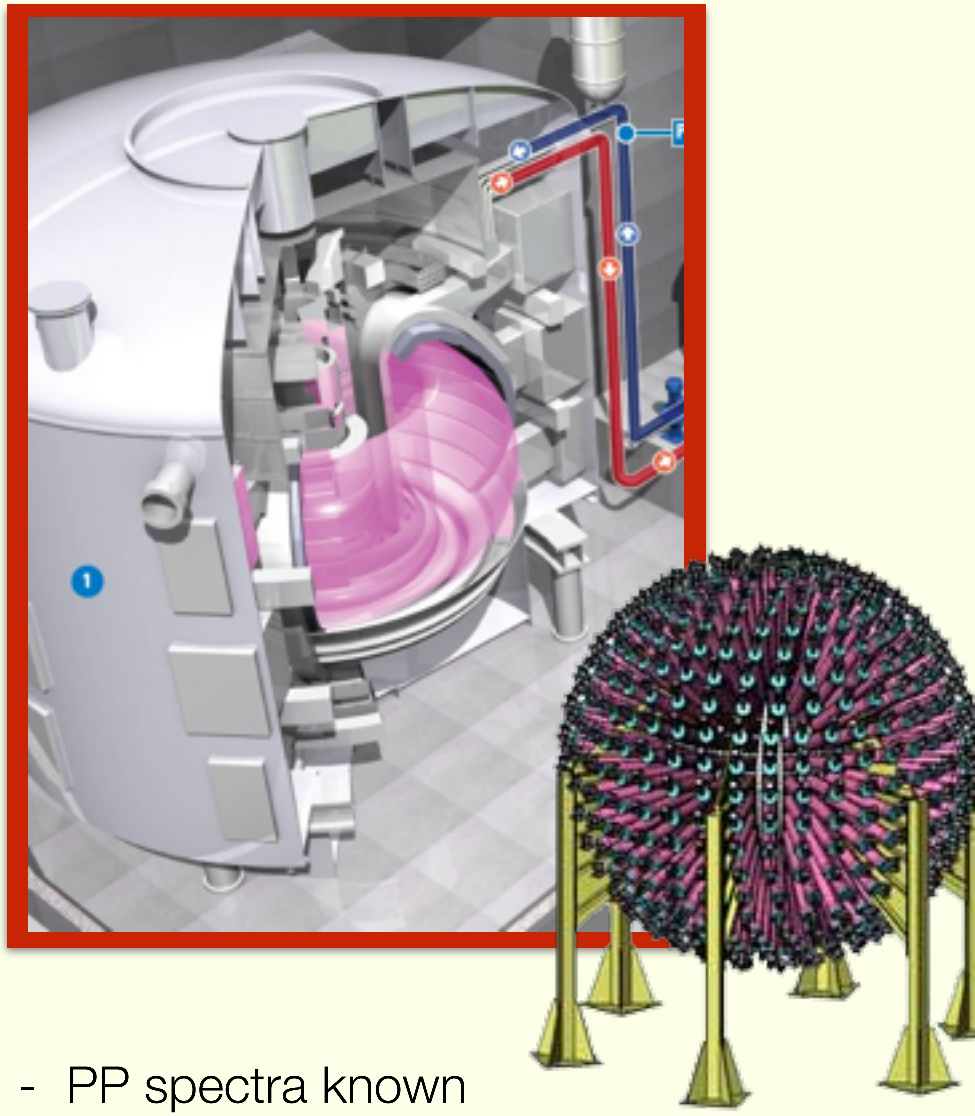
- Small increase in flux (9 times)
- Small increase in energy per interaction (25 eV)
- Dirty ice
- Expensive

Inducing neutrino interactions



- hard to detect scattered particle (very forward reaction)
- trillions of years for a single event
- small "interaction volume"

First fusion reactor neutrino detector



- PP spectra known
- Doesn't give information on sun
- DT or DD has higher energy output per interaction