Summary of the 15th Applied Antineutrino Physics Conference
Sun Yat-Sen University
December 5-7 2019

What We've Learned

Adam Bernstein

December 2019

LLNL-PRES-
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

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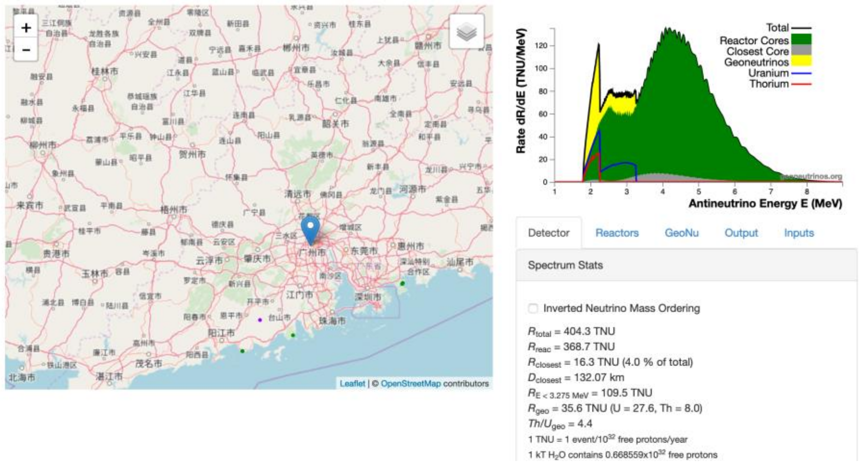
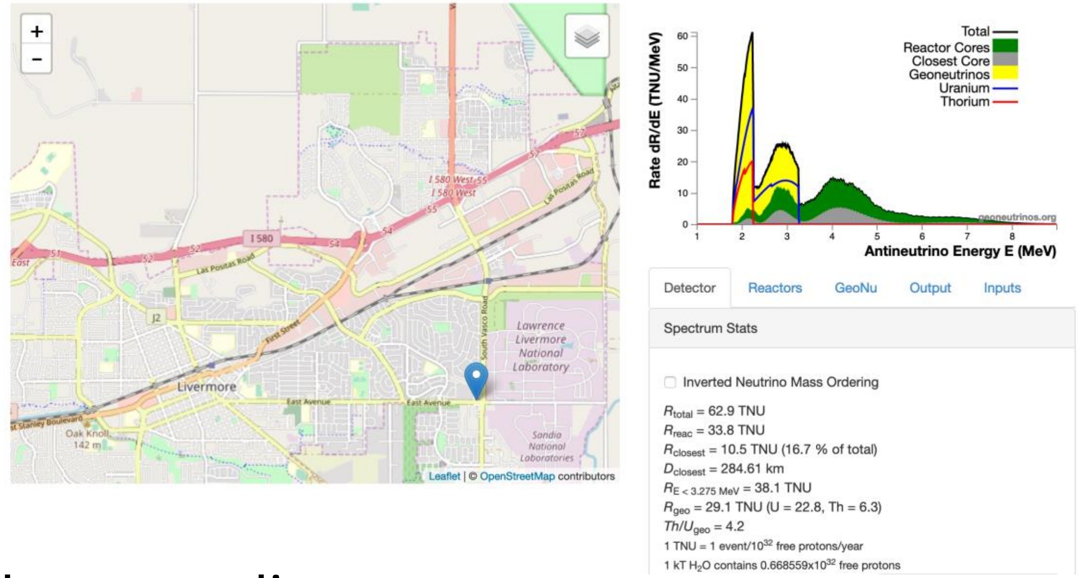
Day 1 – introduction to Guangzhou and Sun-Yat-Sen University

- SYSU, and the SYSU Physics Department, are growing at a rapid clip with ambitious hiring goals
- Guangzhou is awash in antineutrinos !





- JUNO the follow-on experiment to Daya Bay will come online rapidly in the next few years

John Iliopoulos – hadron and lepton flavo(u)r - from simplicity to relative complexity in 80 years

1932 THE WORLD IS SIMPLE!

- The complete Table of Elementary Particles the year 1932.

Matter particles : $\begin{pmatrix} p \\ n \end{pmatrix} \quad \begin{pmatrix} \nu \\ e \end{pmatrix}$

Radiation : γ

THE WORLD IS NOT SO SIMPLE!

- The complete Table of Elementary Particles today.

Matter particles : $\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix} \quad \begin{pmatrix} \nu_e \\ e \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$

Radiation : $\gamma \quad W^\pm, Z^0$ 8 QCD gluons

The BEH scalar : H

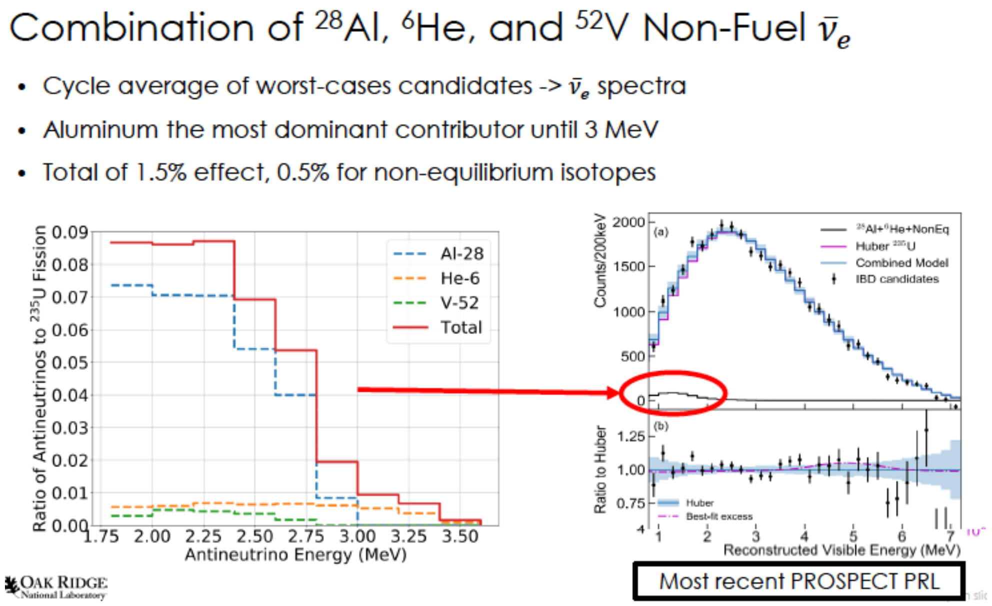
Some conclusions:

Experiment continues to lead the way in the field of neutrino physics

Without simple solutions like leptoquarks available, theorists must wait for either more data or more inspiration to better motivate and connect lepton and hadron flavours

Neutrinos and Safeguards

- Contributions of Non-Fuel Antineutrinos at the High Flux Isotope Reactor - Andrew Conant

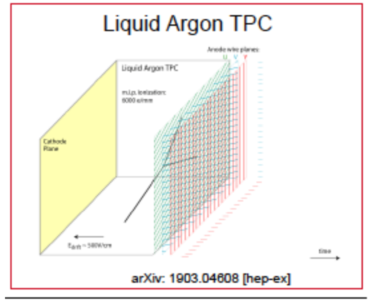


Research reactor core materials can influence antineutrino emisisons at the ~1 percent level dominated by low energy contributions

- Antineutrinos for Safeguarding Nuclear Waste - Madalina Wittel

Is there any chance of safeguarding spent fuel repositories ?

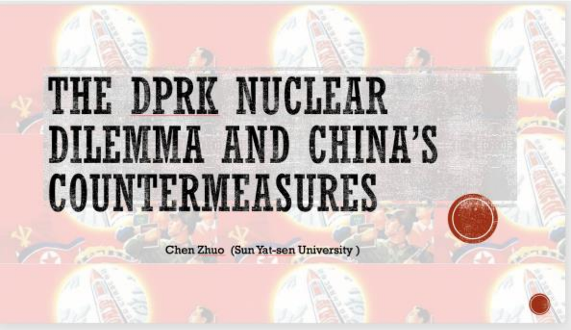
Answer after a first look –in theory yes, in practice quite difficult



80 tons Argon TPC would detect diversion of 20 out of 500 tons of 10 year old spent fuel at ~ 1 sigma
Electron scatter channel not IBD

The good news – there is a residual low energy flux
the bad news – repositories are large and contain widely distributed spent fuel – r-squared is a problem, and overburden is needed

Chen Zhuo



1990s led NK to go nuclear due to withdrawal of USSR support

2006 - 2017 - 6 nuclear tests

2012 – 2017 - numerous missile tests

Confrontation and cooperation depend on the actions of 6 key players – North Korea, South Korea, China, the US, and Japan - Chen Zhuo anticipates an intermediate kind of escalation, short of outright military confrontation

Denuclearization of the Korean Peninsula - or at least of North Korea - is sought by all other parties

North Korea seeks economic and security guarantees in exchange for denuclearization

Deployment of a neutrino detector could be a welcome distraction for all parties !

Science 09 Nov 2018: Vol. 362, Issue 6415, pp. 649-650

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LETTERS

Edited by Jennifer Sills

Denuclearizing North Korea requires trust

In their Policy Forum "Denuclearizing North Korea: A verified, phased approach" (7 September, p. 981) A. Glaser and Z. Mian describe a pathway for verified denuclearization of North Korea. I agree that such an approach is necessary and, equally importantly, technically feasible. However, Glaser and Mian only highlight the disarmament side of the denuclearization agreement, without a plan to develop the mutual trust and the assurances on which such a deal depends. Incentivizing North Korea to reduce nuclear weapons and fissile materials will require confidence-building measures, ease of sanctions, and security guarantees. These elements are strongly related to the disarmament questions and must be regulated with similar precision.

Coordinating with the proposed phased approach, the involved parties could pair North Korea's freeze on weapon-related activities with a freeze of new nuclear-related sanctions or military exercises in the region. Such commitments would lay the foundation for an interim agreement, paving the way for long-term denuclearization. In a final step, the facilitation of humanitarian trade in areas such as health and nutrition would initiate the ease of sanctions and the establishment of credible security guarantees.

These measures need control and verification mechanisms, too. In case of nonfulfillment of such an agreement, it must be possible to swiftly reinstate the United Nations Security Council's sanctions. The structure of this contingency could be similar to the snapback mechanism in Article 37 of the Joint Comprehensive Plan of Action with Iran (1). Likewise, North Korea will insist on similar guarantees if it dismantles its nuclear weapons. It is always a challenge to create mechanisms that can credibly assure such guarantees for both parties, and this has become even more difficult after the U.S. withdrawal from the Iran nuclear agreement.

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Email: tlangenegger@ethz.ch

REFERENCE
1. United Nations Security Council Resolution 2231 (2015); https://undocs.org/S/RES/2231(2015).

10.1126/science.aav4636

Neutrino physics for Korean diplomacy

Continued diplomatic progress with North Korea will be a journey of many steps, as A. Glaser and Z. Mian describe in their Policy Forum "Denuclearizing North Korea: A verified, phased approach" (7 September, p. 981). Leaders in North Korea, South Korea, and the United States agree that one step could be dismantlement or civilian repurposing of the nuclear reactors at Yongbyon. We propose a cooperative method for verifying reactor shutdown or conversion. The key tools are meter-scale, field-deployable detectors that track neutrino emissions from reactor cores.

Neutrino detectors can track power levels and fuel evolution in nuclear reactors, as experiments in South Korea, China, Russia, the United States, and Europe have demonstrated (1–7). At Yongbyon, neutrino detectors could be deployed to verify reactor shutdown or civilian operations without the need for operational records or access inside reactor buildings. Shutdown of North Korea's main plutonium production reactor could be verified with a detector in a standard freight container parked outside the reactor building.

Existing neutrino technology may be attractive to all parties in the ongoing talks. North Korea may value a tool for demonstrating treaty compliance while maintaining custody of the reactor buildings. Other parties may value the tamper resistance of the neutrino signal and resilience of neutrino detectors, which require minimal on-site access and can reconstruct reactor operational history even after a data-taking pause. Neutrino projects are also a natural opportunity to strengthen relations between North and South Korea and to build international scientific ties. South Korea has an active neutrino community and could choose to deploy a counterpart to a Yongbyon-based detector at one of its own reactors. Resulting scientific collaboration could benefit Korea and the world. We encourage policy-makers to consider neutrino detectors as one step toward stability and security on the Korean Peninsula.

Rachel Carr,* Jonathon Coleman, Giorgio Gratta, Karsten Heeger, Patrick Huber, YuenKeung Hor, Takeo Kawasaki, Soo-Bong Kim, Yeongduk Kim, John

A freeze in military exercises could help to establish trust during nuclear negotiations with North Korea

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Neutrino 4 discovers - but PROSPECT excludes - a sterile neutrino at 7.34 ev^2

Neutrino 4 - a claim for a heavy sterile neutrino !

SM-3 100 MWT 42 X 42 X 35 CM HEU fuel not well shielded from cosmics 3-5 mwe

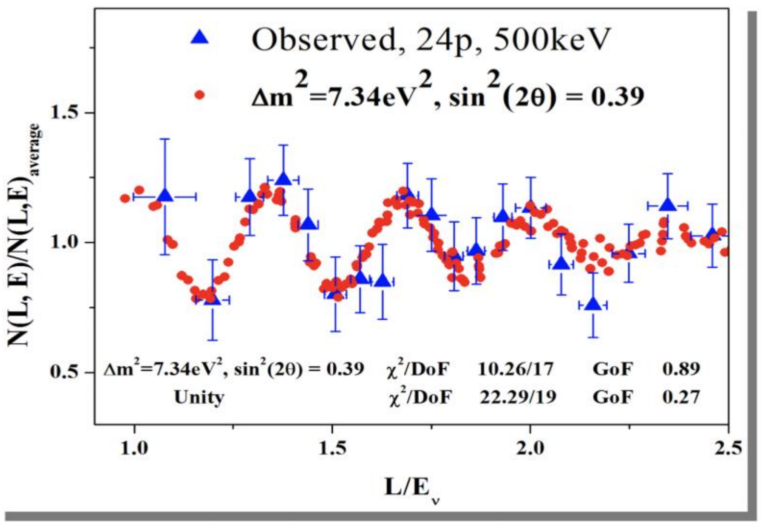
5 meter standoff to core - range from 6 to 12 meters

3 cubic meter detector 10” PMTs 50 cells

No dependence of backgrounds on reactor power or reactor distance

Upgrades planned for greater sensitivity- skipping Neutrino 5 and going straight for Neutrino 6

The first observation of oscillation of reactor antineutrino in sterile neutrino



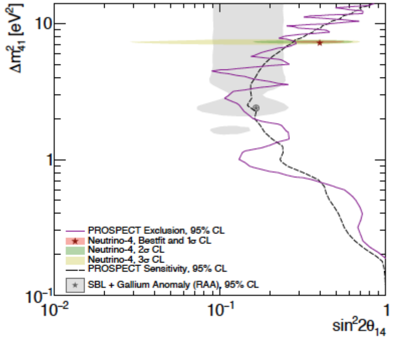
A.P.Serebrov, et al.
JETP Letters, Volume 109, Issue 4, pp 213–221.

https://doi.org/10.1134/S0021364019040040, arxiv:1809.10561

The period of oscillation for neutrino energy 4 MeV is 1.4 m

21

Not consistent with PROSPECT
PROSPECT notes that establishing meaningful confidence limits for high frequency and/or small amplitude oscillations requires a careful statistical treatment.



Jianrun Hu – reactor antineutrino measurement at Day bay

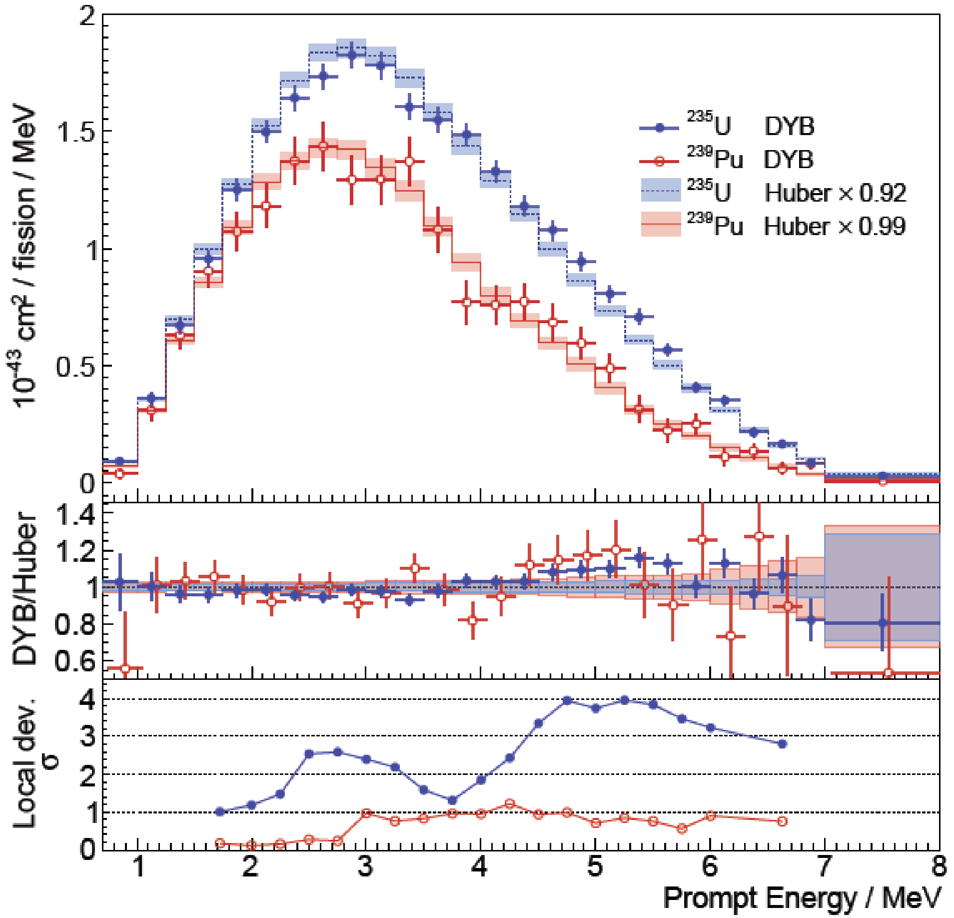
3.5 million events recorded !

Key results:

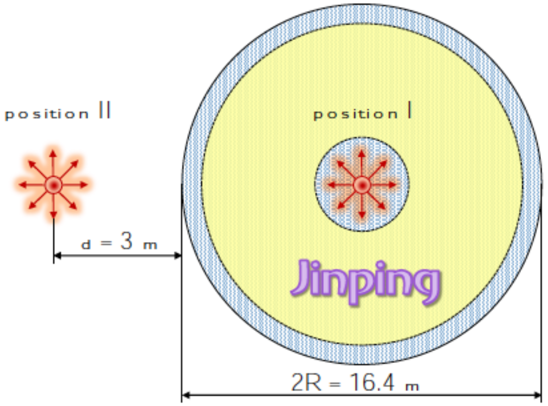
DB expt. expects **U235 t**o be mainly responsible for the reactor antineutrino anomaly

Rejects Pu only and all isotope hypotheses at ~ 3 sigma

Able to decompose U235 and Pu239 spectra using burnup – then plot two spectra separately

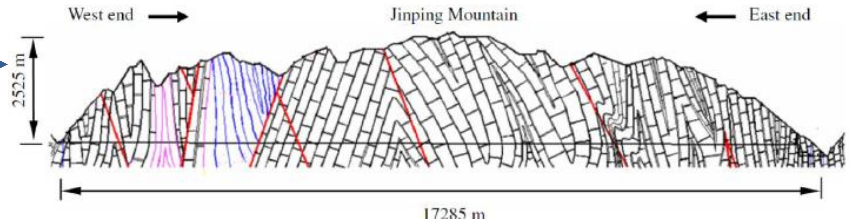


Sterile neutrino oscillometry at Jinping - Misha Smirnov



This

Jinping underground lab



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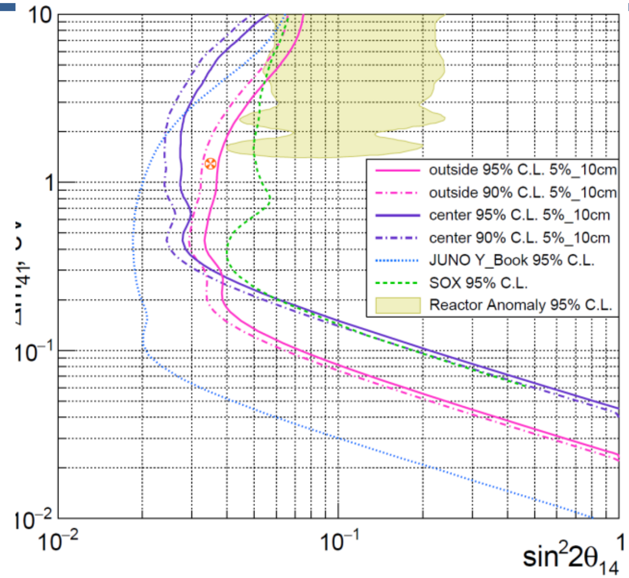
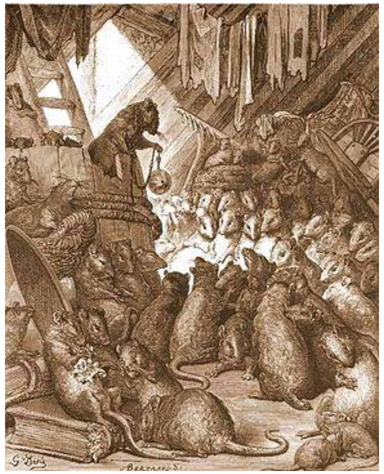


Would yield this good sensitivity to a sterile neutrino

However, a 50-100 kCI source is needed
And sources are hard to come by !

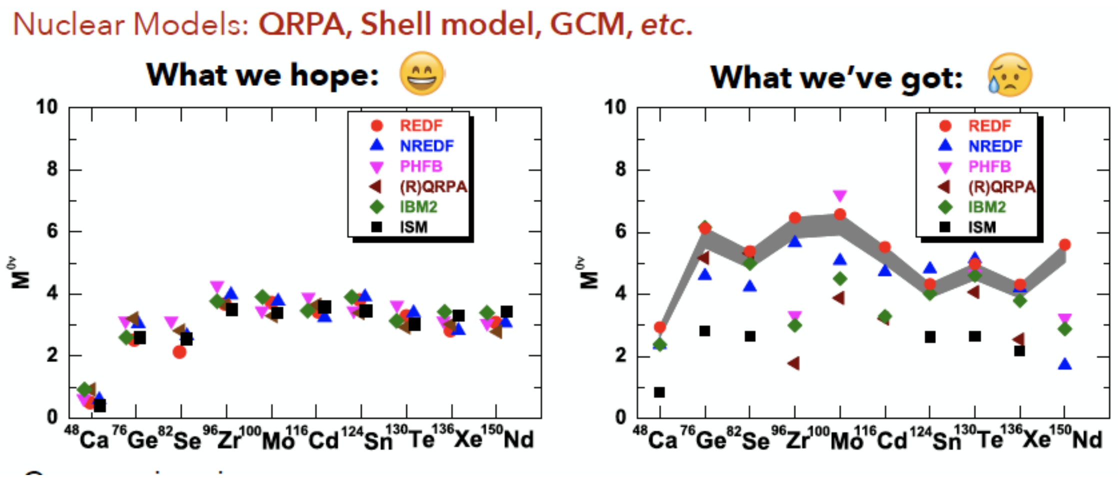
An analogous dilemma



"Belling the Cat" is a fable also known under the titles **"The Bell and the Cat"** and **"The Mice in Council"**. Although often attributed to Aesop, it was not recorded before the Middle Ages

Neutrinoless double beta decay and the challenge it poses for nuclear physics - Changfeng Jiao

Matric element calculations impose undesirable uncertainties on the conclusions that can be drawn from neutrinoless Double beta decay measurements



Professor Jiao advanced an *ab-initio* Generator Coordinate Method in order to include particle-particle correlations in nuclear ME calculations

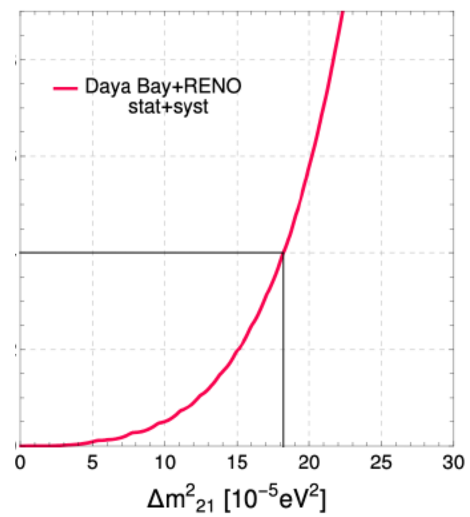
- Some basic confirmation of the method in surrogate systems
- More work to be done to demonstrate a real improvement in accuracy for DBD matrix elements

Sunny Seo - Constraint on the Solar Dm2 using 4,000 days of SBL reactor n data

Motivation –disagreement at 2 sigma between KamLAND and SuperK/SNO for **$dmsq_{21}$**

Dmsq21 helps control the level of CP violation through the Jarlsklog parameter - but could dmsq be different at different L/E ?

Another estimate may be extracted from Daya Bay and RENO data combination



$Dm2_{21}$ < 18x10-5 eV^2 (2.3x KL) at 95% C.L

using 4000 days of Daya Bay and RENO combined data
at L/E ~ 0.5 km/MeV

This result differs from KL (x2.5) and SK - a more precise measurement will come from JUNO

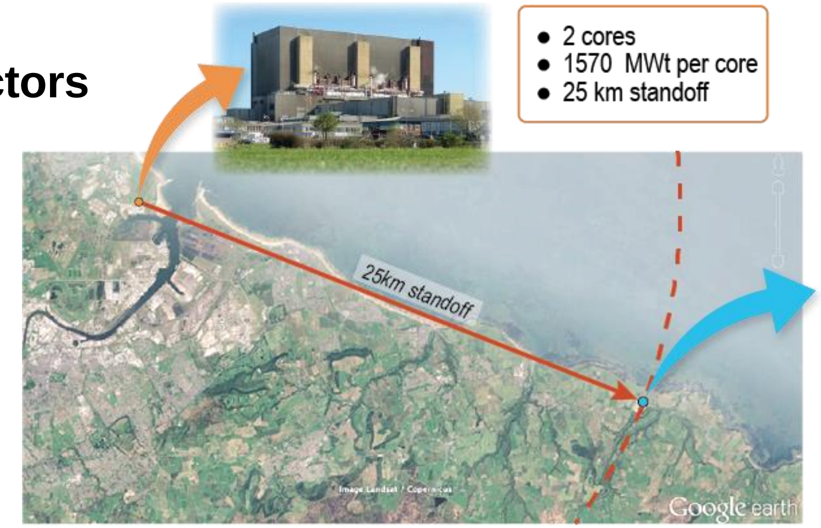
AIT-WATCHMAN and JUNO

AIT Project Goals:

1. demonstrate reactor discovery and exclusion
2. demonstrate verification of reactor operations
3. investigate the scalability and viability of detector concepts for far-field monitoring

HARTLEPOOL Reactors

- 2 cores
- 1.57 GWt per core
- 25 km standoff
- Relatively high power near an existing mine suits an initial demonstration

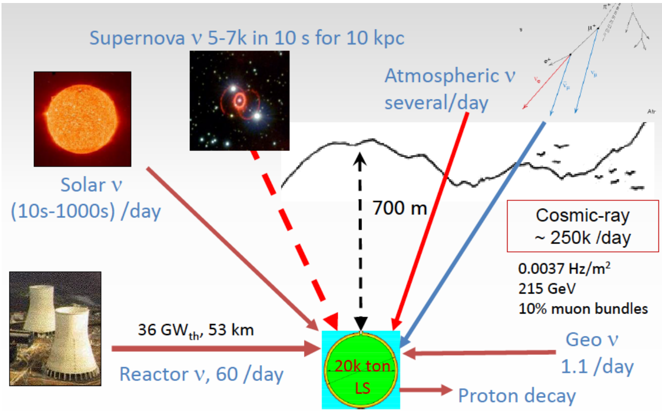


JUNO Project Goals:

1. Determine neutrino mass ordering (3 sigma sensitivity in 6 years)
2. Sensitivity to oscillation parameters, other physics

3% res for JUNO
77% photocoverage

1% res for TAO
(near-reactor)



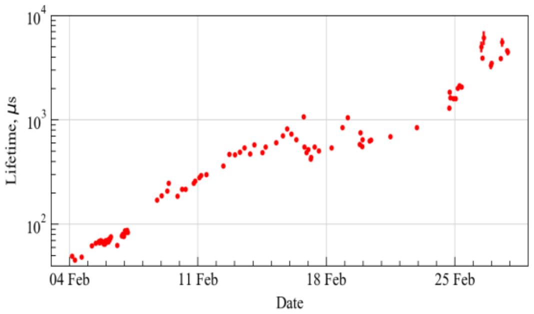
Project is moving fast toward 2021 goal of scintillator fill !

Main orientation is nonproliferation – non-contrast measurement physics (supernova,…) a desirable secondary goal

Main goal is neutrino mass ordering – a hard, important measurement - Great input for nonproliferation applications

Coherent neutrino scatter – experiment and extrapolation

- D. Akimov: Important strides in preparation for a reactor CNS measurement using dual-phase xenon



5 ms e- lifetime ! → no loss of electrons in drift
Record purity

1:1 S:B CNS measurement at Kaliningrad reactor for a 4 electron threshold !
Ethresh = a few hundred eV

- P. Huber: How long before safeguards can benefit
from CNS ? Answer – it will be a while

Thresholds are a key issue, and backgrounds are likely to be unfriendly at low threshold

- To gain advantage over IBD for power and burn-up measurement detectors with
A > 100
~500 kg
Ethresh – 5 eV !!

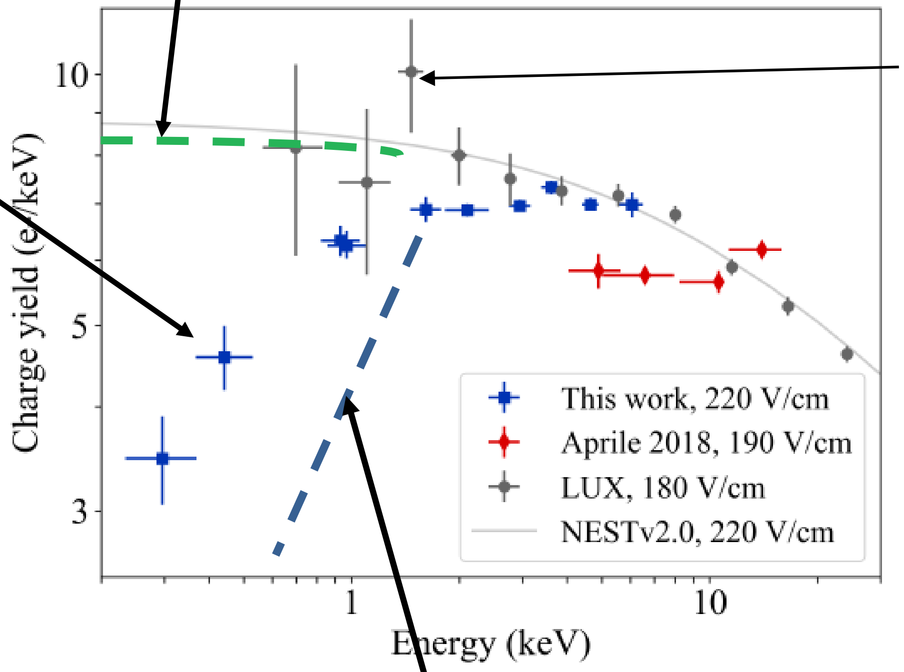
Russian and US species of optimism – the case of yield curves

NEST – Noble Element Simulation Technique

US optimism

New LLNL data

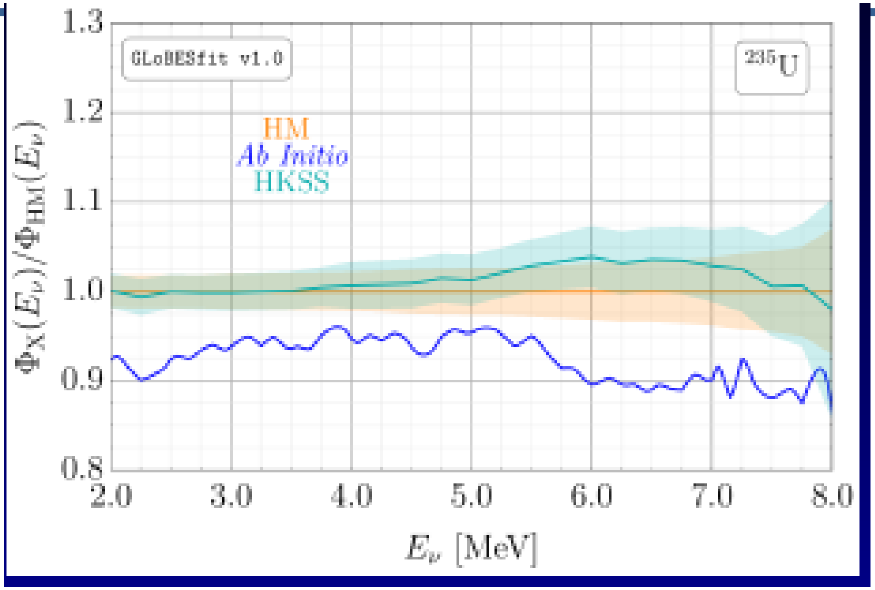
Russian Optimism



LUX data

Russian realism/pessimism

Talk II from Patrick



new reactor flux calculation HKSS tried to include non-unique forbidden decays quantitatively

For U235 Ab initio differs from both HM and HKSS –error bars don't explode for HKSS– so far

- Data favors a 235U rate offset

<u>If the Schreckenbach data where off by ~6%, the anomaly would disappear.</u>

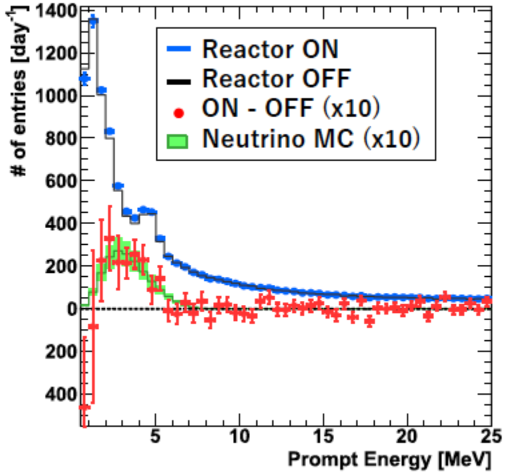
- **No calculation** produces a bump

  (but see Dwyer et. al ??)

CHANDLER, PANDA, SOLide, STEREO → LLNL and other R&D

- An impressive array of efforts efforts to improve near-surface sensitivity to reactor antineutrinos –all **near or above-ground measurement**
- Goals are improved safeguards, sterile neutrino search, or both

CHANDLER: plastic scintilator, Li6ZnS sheets
PANDA: segmentation with Gd doping
Solide: fiber readout of plastic cells, LI6-Z sulfide layer for N
STEREO – Gd-doped liquid scintillator, with segmentation



Results range from no clear evidence for antineutrino signal, to clear signals, to preliminary exclusion curves -

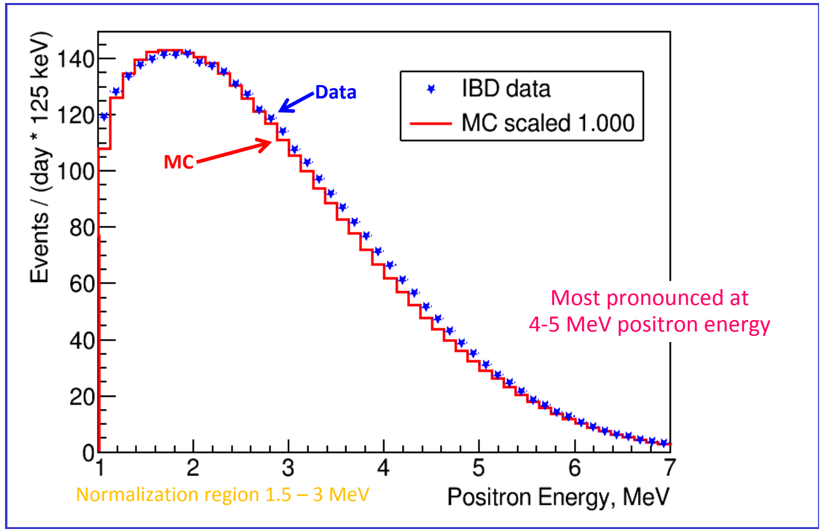
Example – PANDA
above-ground measurement

LLNL representative next effort --:> what is the 'best' detector for safeguards - mobile , spectral, efficient, aboveground

Key parameters that help with spectral sensitivity and background rejection are Li doping of **plastic**, PSD segmentation, good light collection and calibration

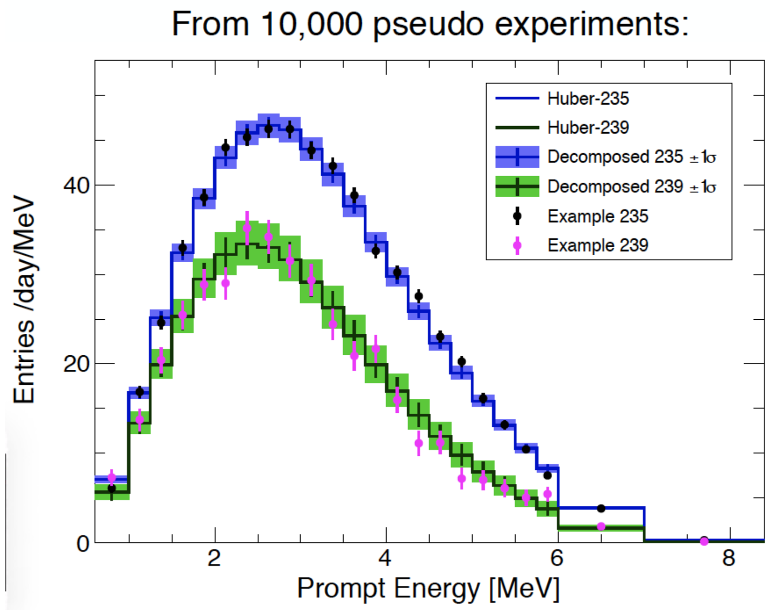
NEOS and DANNS – underground and high statistics acquisitions

- DANNS results



Impressively high statistics and
a preliminary exclusion curve

- NEOS



Also high statistics
another measurement of PU and U235 spectrum
Permitted by strong burnup effect

Recent results from RENO Hyunkwan Seo

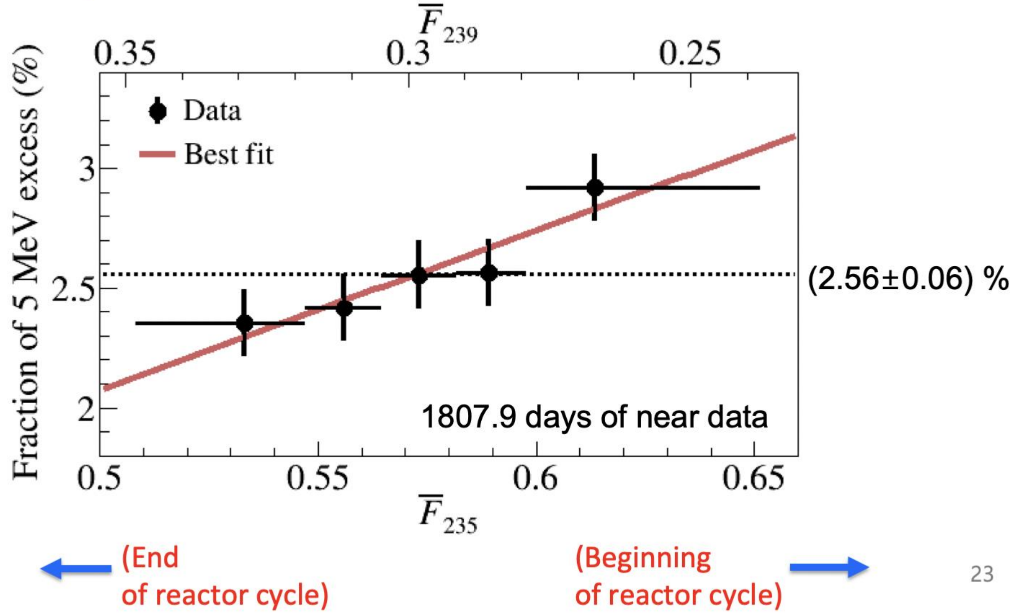
- Report updated results using ~2700 days of data

- More precise measurement of θ_{13} and $|\Delta m_{ee}^2|$ (2200 days)

- First hint for 2.9σ correlation between 5 MeV excess and ^{235}U fission fraction

- Obtained an excluded region from a sterile neutrino search

2.9σ indication of 5 MeV excess coming from ^{235}U fuel isotope fission !!



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Reactor projects & nuclear data

Alejandro Sonzogni: Development of realistic uncertainties in the summation method method for nuclear reactor antineutrino applications

- Xiaobao Wang (for A. Hayes): uncertainty study in analyzing the reactor neutrino anomaly based on nuclear structure physics

1) Including correlations in fission yields can help improve the summation method

2) More work to be done to realize the improvement – a few years effort ??

Conclusion: Hayes, Huber –

New experiments needed, especially Schreckenbach fission beta spectra to resolve the reactor antineutrino flux deficit

Final thoughts

Near-field experiments:

- **IBD:** Lots of variety and progress in ton-scale aboveground detectors – both safeguards and physics have provided the motivation and funding
- **CNS:** a reactor measurement is in the offing – 2-4 years ? -but practical application is a ways away
- **Short baseline oscillations:** a number of broadly consistent results, but Neutrino 4 must be considered and definitively rejected or embraced

Far-field experiments:

- **JUNO, WATCHMAN and Superk-Gd** cover the waterfront for far-field monitoring
- WATCHMAN – and others - benefit from convergence of individual efforts into a small set of projects

General remarks

- AAP remains comfortable with a primary focus on physics and technology – additional policy input would help focus and streamline our work – some policy studies underway in the US – use IUPAP and P5 to help ?
- What cycle is appropriate for these meetings ? 2 years may be appropriate based on progress, but we've had annual volunteers for some time