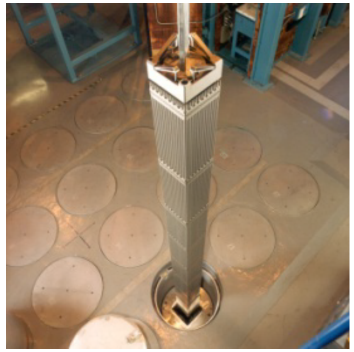
Highlights of Applied Antineutrino Physics Conference

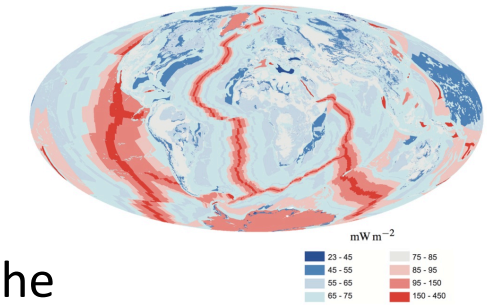
7th SYMPOSIUM ON LARGE TPCs FOR
LOW-ENERGY RARE EVENT DETECTION
Dec. 15-17, 2014

D. Lhuillier

Neutrinos, what for?



- Surveillance of nuclear reactors.
- Developments of new detection technics for compact detectors close to surface.
- Accurate measurements of ν fission spectra
- Search for a sterile neutrino at ~1 eV mass scale
- Coherent ν-scattering off nuclei
- Geoscience: measure the radiogenic contribution to the Earth's internal heat budget.
- Communication…



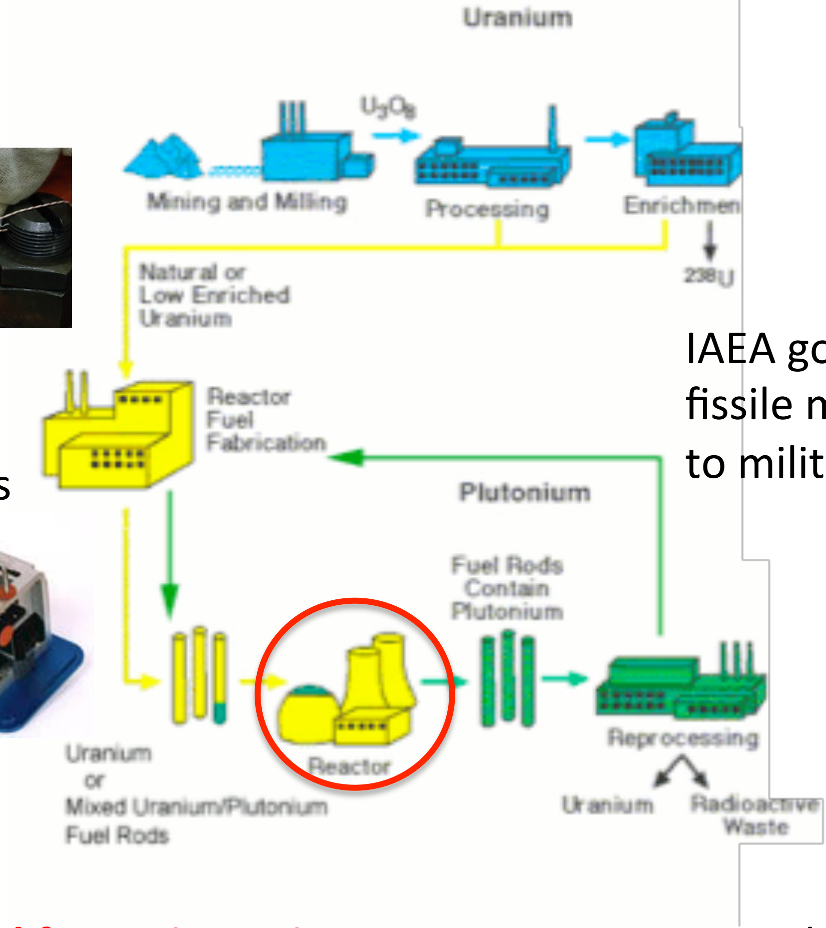
http://aap2014.in2p3.fr/index.html

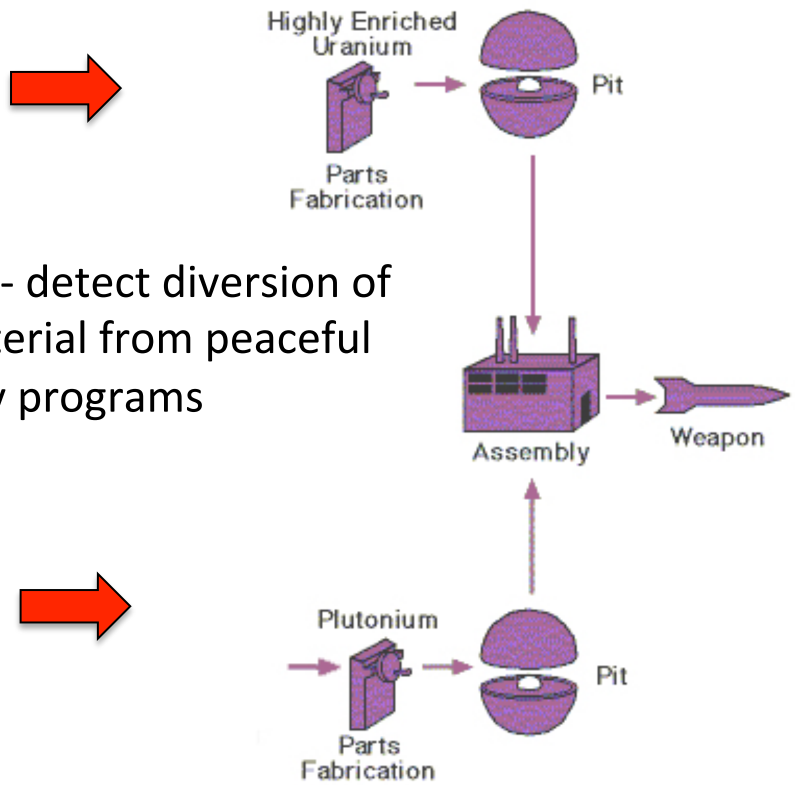
Non proliferation of Atomic Weapons

Monitoring of the nuclear fuel cycle by the IAEA

Seals

Cameras





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

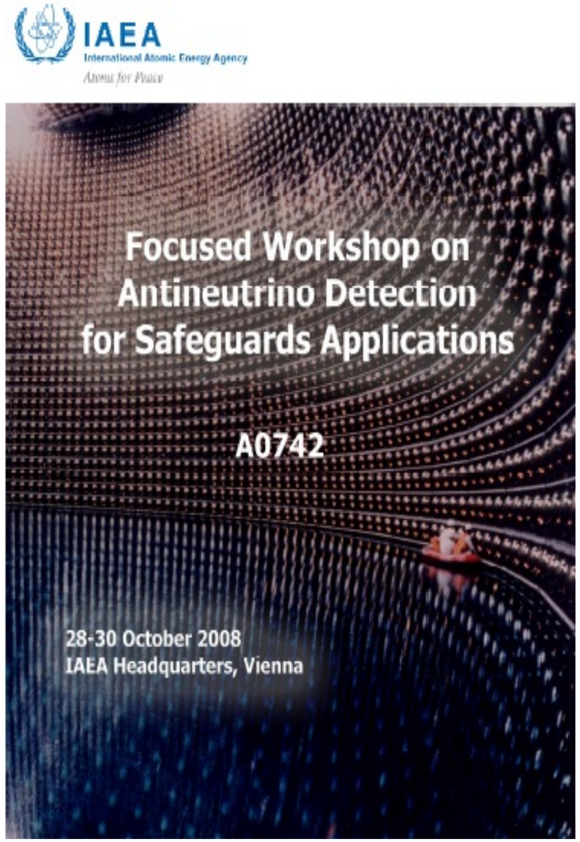
Goal for antineutrinos measurements – track fissile inventories in operating reactors
Unique probe directly connected to the production and consumption of fissile elements

Current IAEA Interest

- Agency is aware of the potential of the neutrino probe.
- But no immediate utility in reactors given the current safeguard tools available.
- Still, there are some areas of interest:

  1. Monitoring the irradiation of plutonium based 'MOX' fuel to ensure the material is hard to recover without reprocessing.
  2. Long range monitoring or exclusion of reactors.
  3. Improve knowledge of input plutonium mass at reprocessing facility or repository – currently no better than 5-10%.

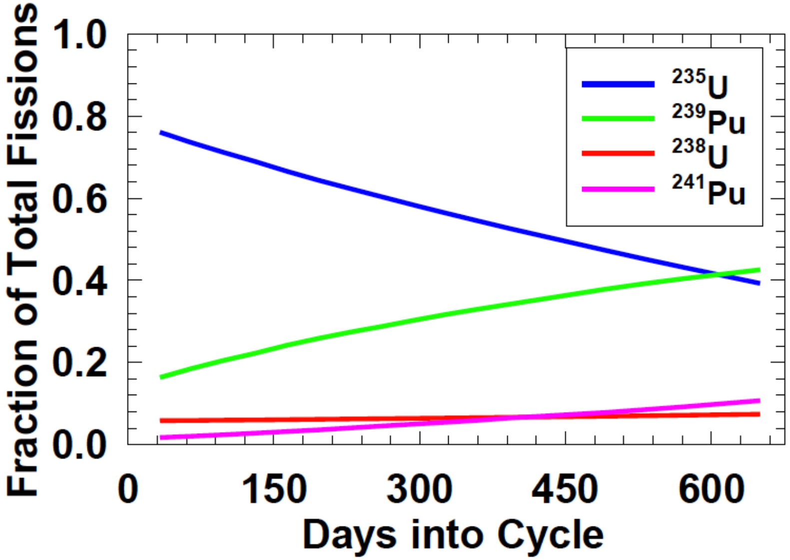
- IAEA remains interested in further R&D and ongoing demonstrations



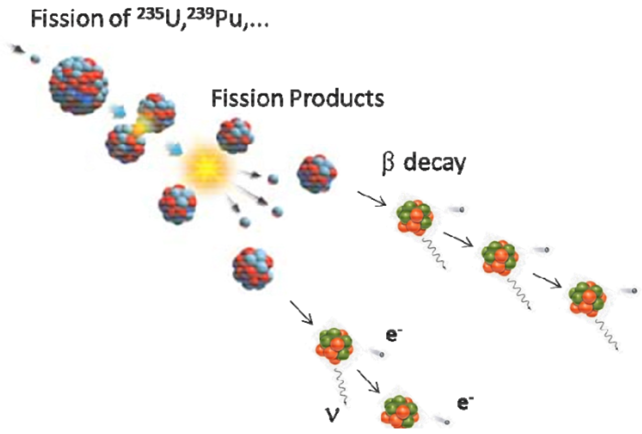
2012: official proceedings of antineutrino working group

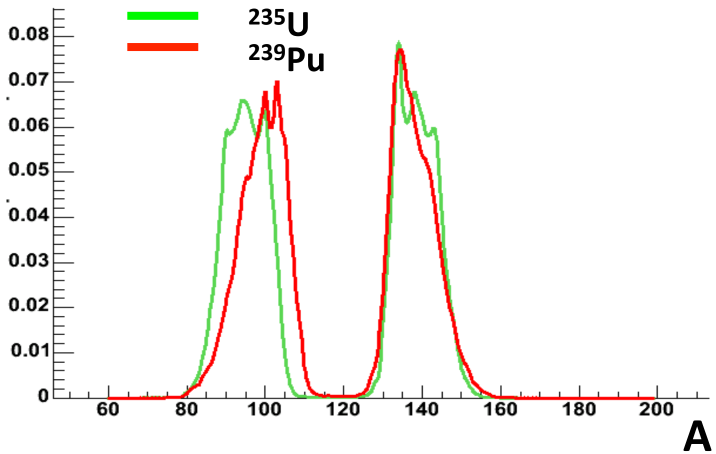
Principle of Reactor Surveillance with Neutrinos

When operating a nuclear reactor burns ^{235}U and accumulates ^{239}Pu



β-decay chains of FP → ~6 ν / fission



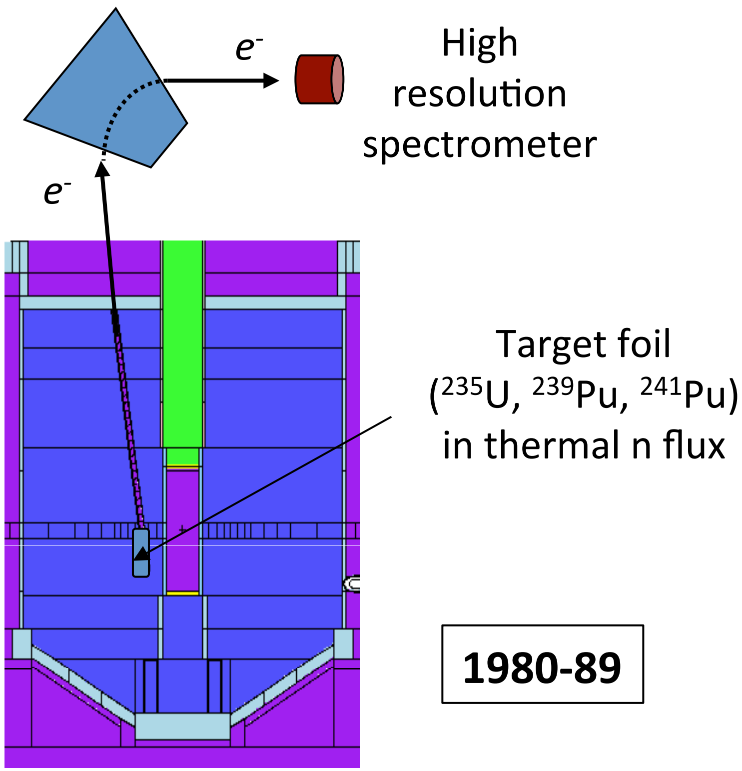


Different FP distributions lead to different ν spectra → **Sensitivity to Pu content.**

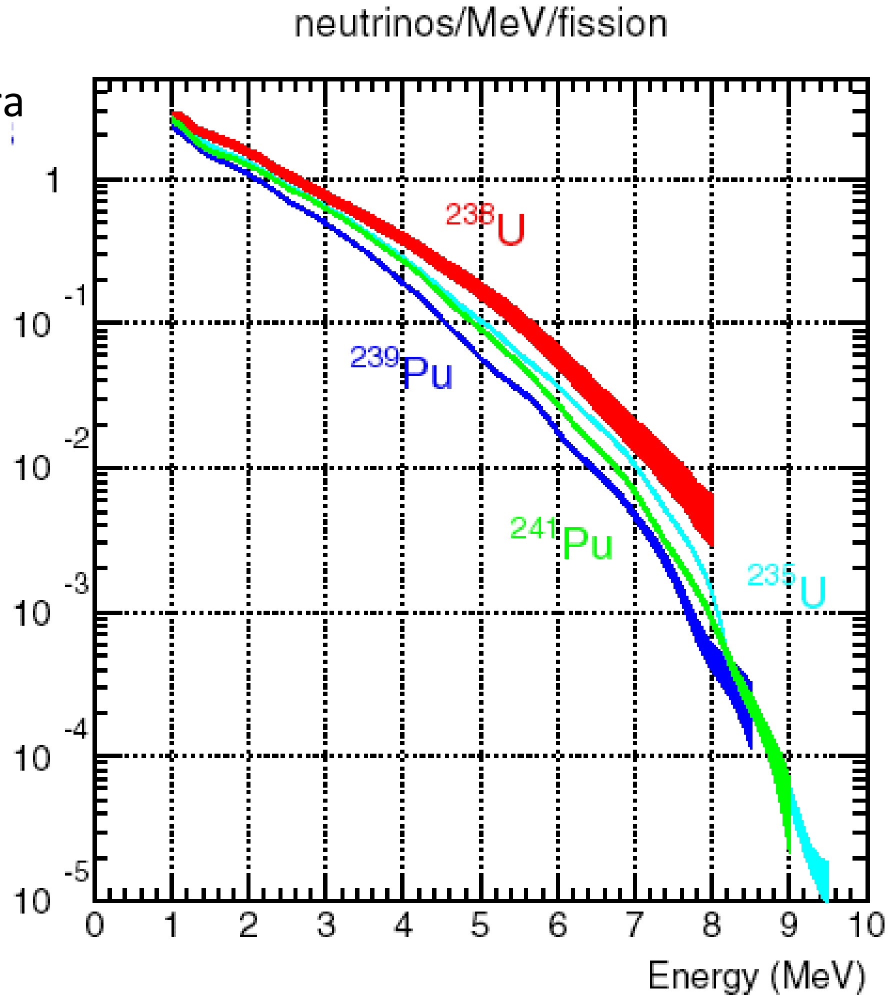
Reference Data

- Nuclear databases
- Accurate measurement of fission β spectra

+ Conversion procedure e→ν spectra

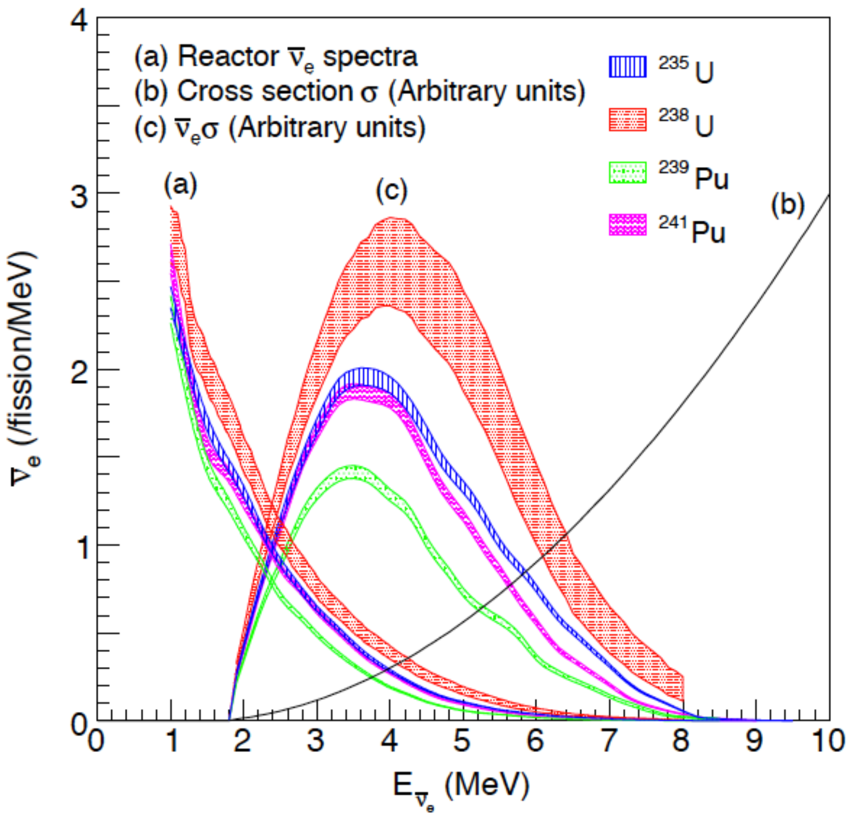


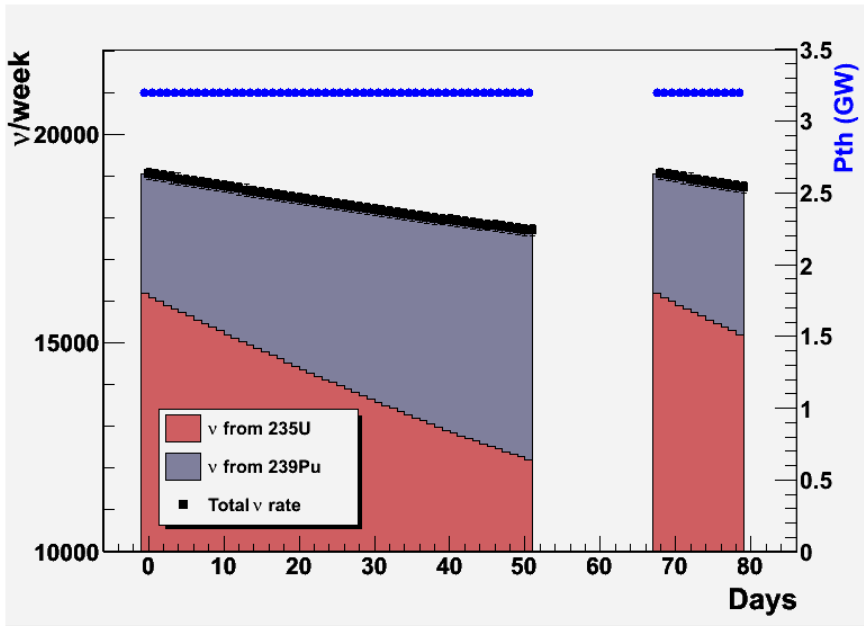
ILL research reactor (Grenoble, France)



Sensitivity to Pu content

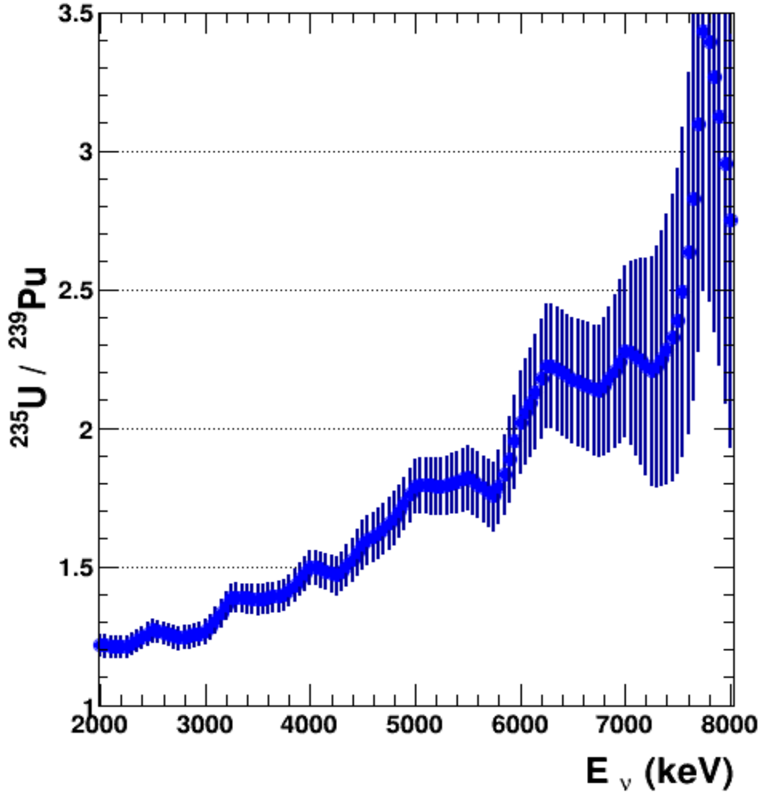
For the same released power, pure ^{235}U fissions emit 1.6 times more ν than pure ^{239}Pu

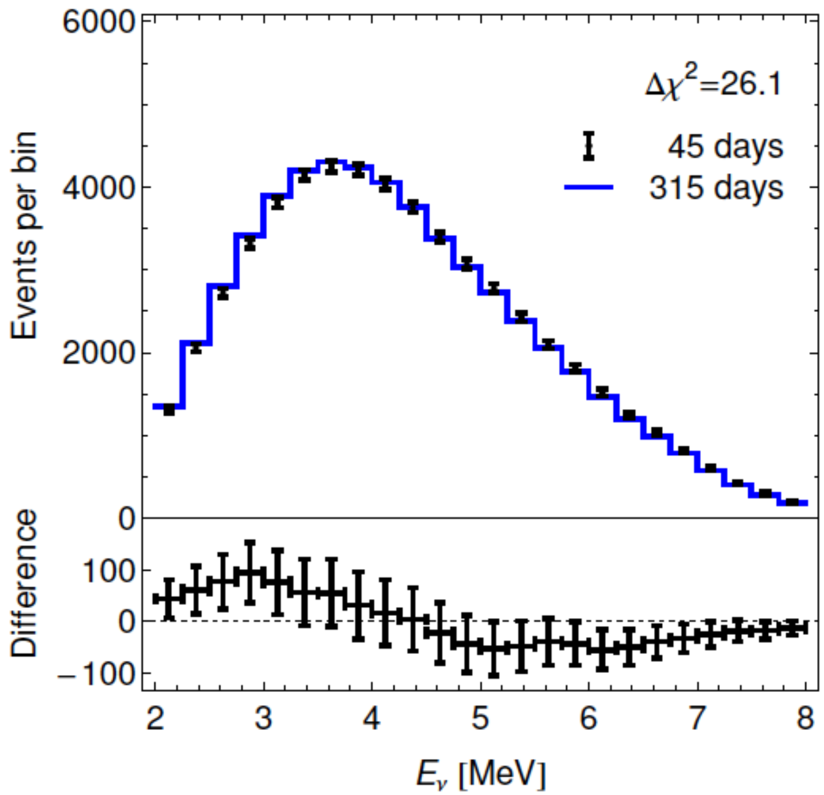




Considering typical reactor cycles, total lever arm is 5-10% relative change in the ν rate

Sensitivity to Pu content

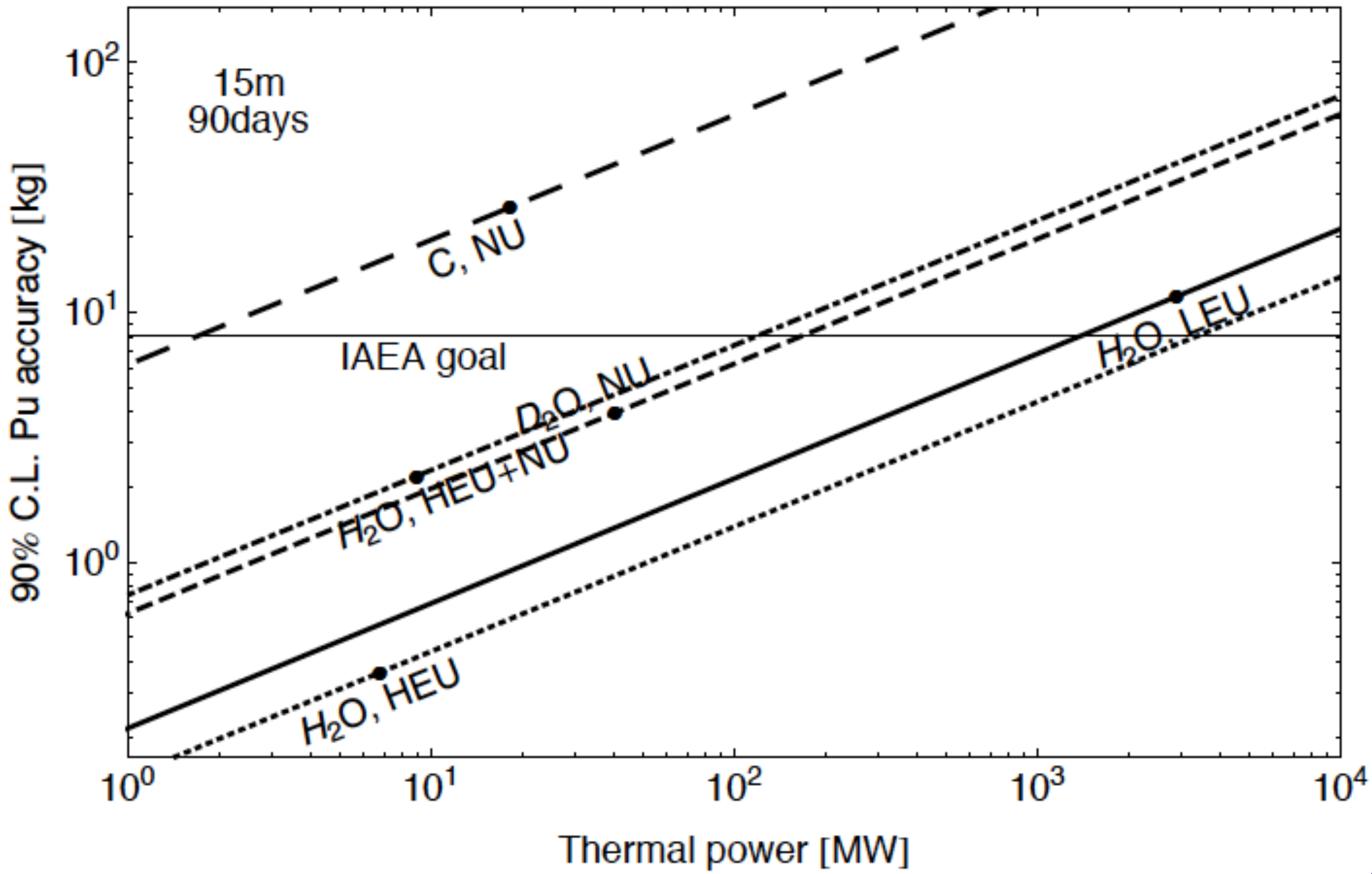




^{235}U spectrum is harder than ^{239}Pu

15-20% resolution @ 1 MeV is good enough to test the change in spectrum shape between beginning and end of a cycle.

Sensitivity to Pu content

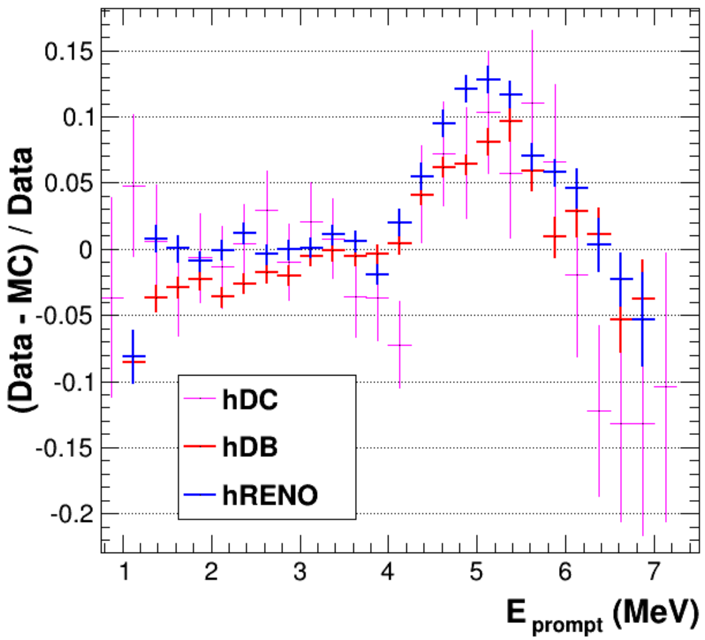


- Pure stat
- 10% E resolution
- No background

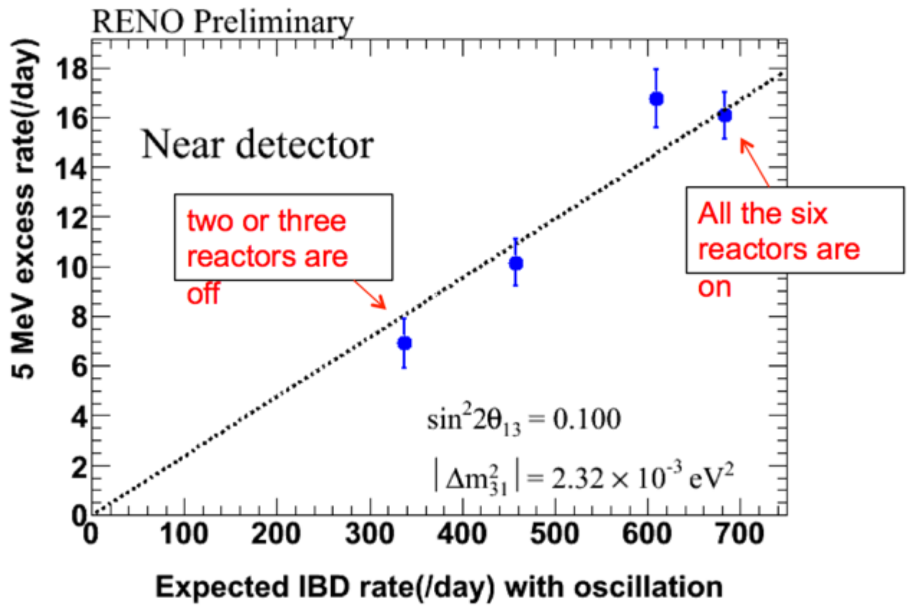
P. Huber

Reactor Spectrum Shape

Common deviation from predicted shape seen by 3 experiments



Scales with reactor power

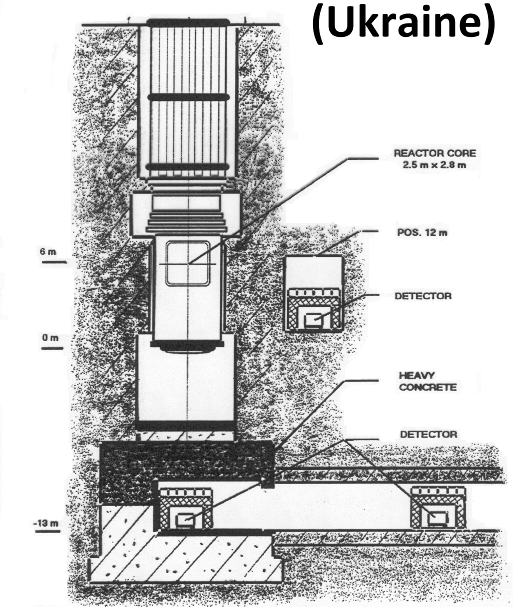


- Detection issue?
- Bias in prediction of reactor spectra?
- Upcoming measurements of HEU spectra at short baseline will clarify the picture

Evolution of Pu fission rate
Observed neutrino signatures

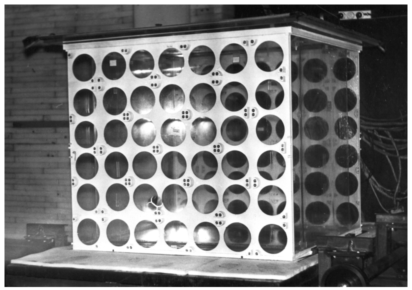
Rovno Experiment

1.3 GW_{th} PWR Rovno reactor (Ukraine)

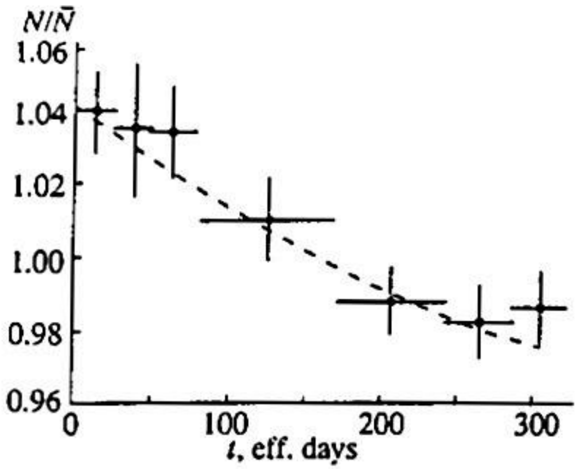


1986

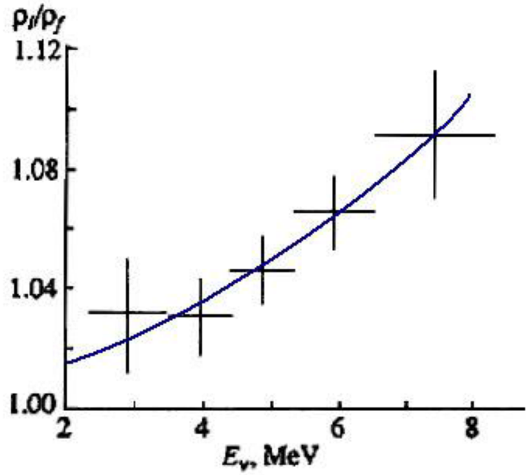
1m^3 of liquid scintillator



- Very favorable conditions:
  - 12 m from the core
  - High power
  - Well protected from cosmic rays
  - Low γ background
- 175 000 ν detected!
- **First evidence of Pu accumulation:**



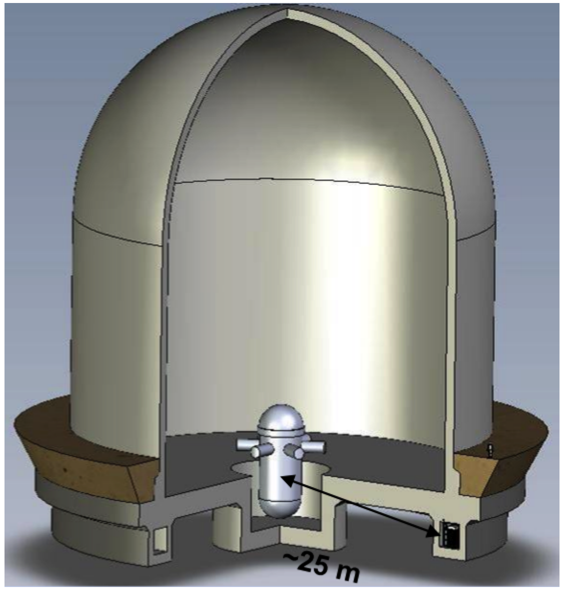
ν rate decreases

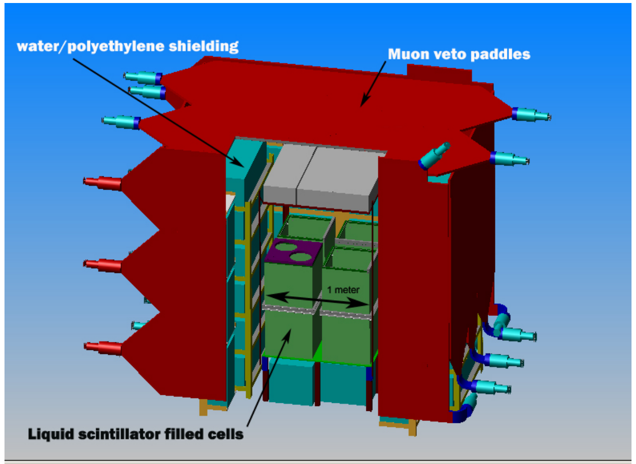


E Spectrum shape changes

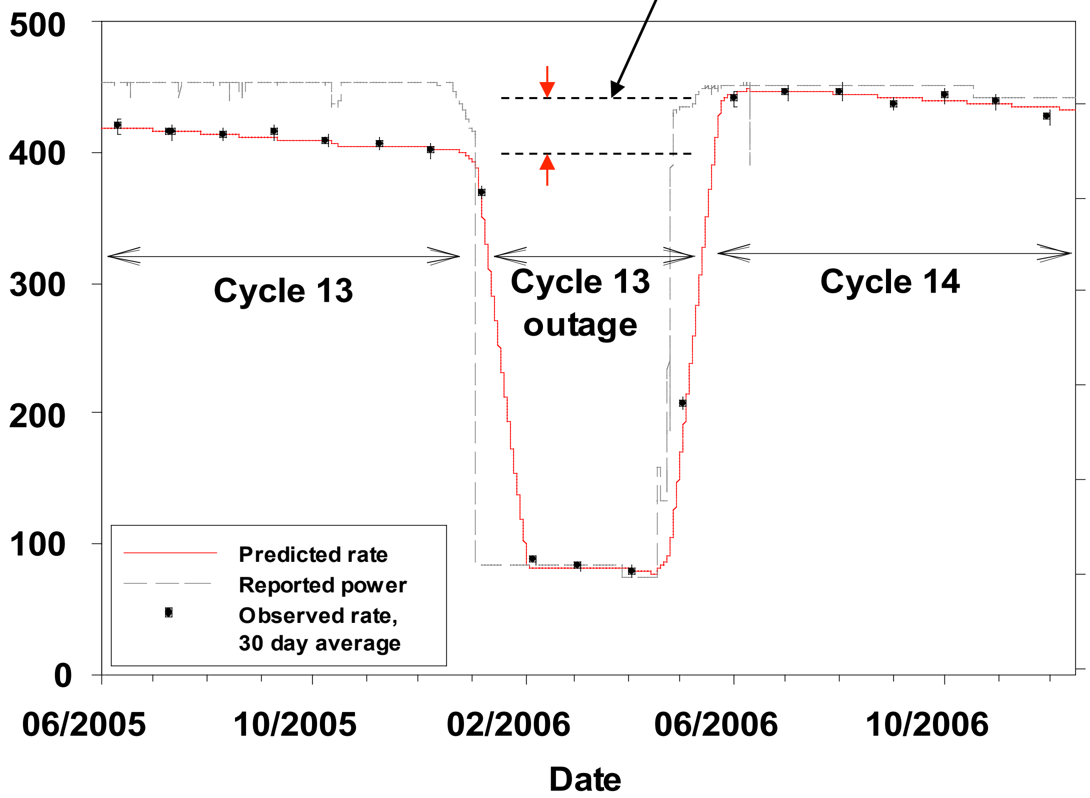
SONGS

San Onofre Reactor, CA



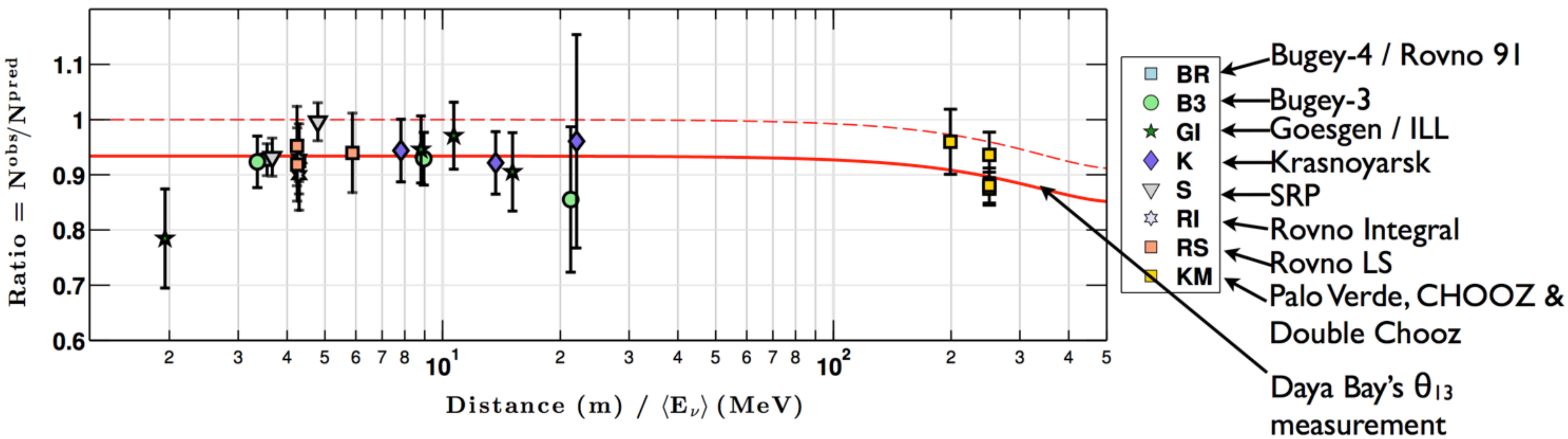


Removal of 250 kg ^{239}Pu, replacement with 1.5 tons of fresh ^{235}U fuel



Testing the 1 eV Sterile Neutrino Hypothesis

Reactor Anomaly



Updated result including :

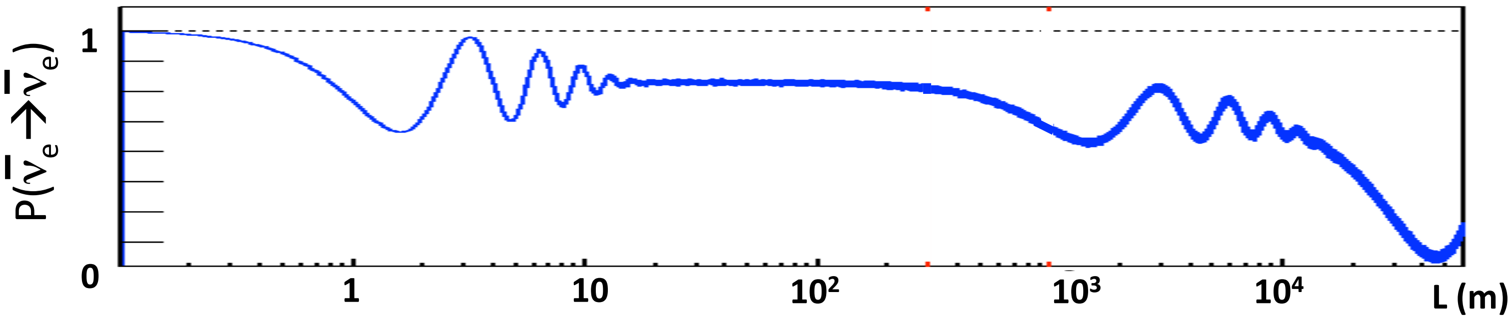
- Km baseline results
- Corrected statistical bias (1% shift)
- Neutron mean life (τ_n = 881.5 s)
- Refined treatment of experimental uncertainties and parameters

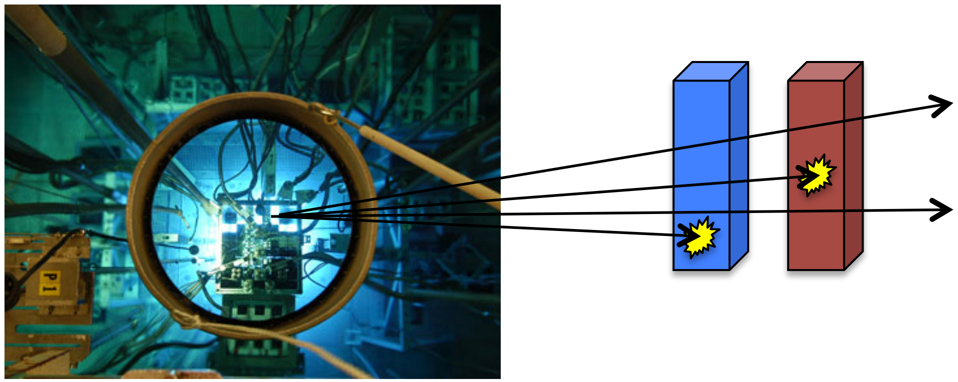
- 2013 result: μ = 0.936 ± 0.024, 2.7σ deviation from unity

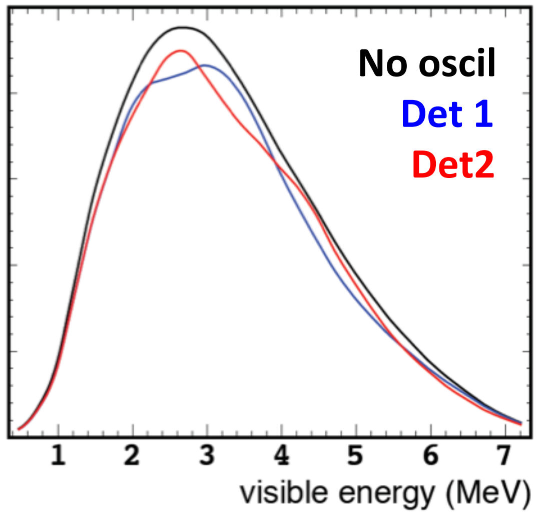
Testing the New Oscillation Hypothesis

Direct test of a new oscillation pattern in E & L

$\Delta m^2 > 0.1$, $\sin^2 2\theta > 0.05$ → L_{osc} = [1-10] m

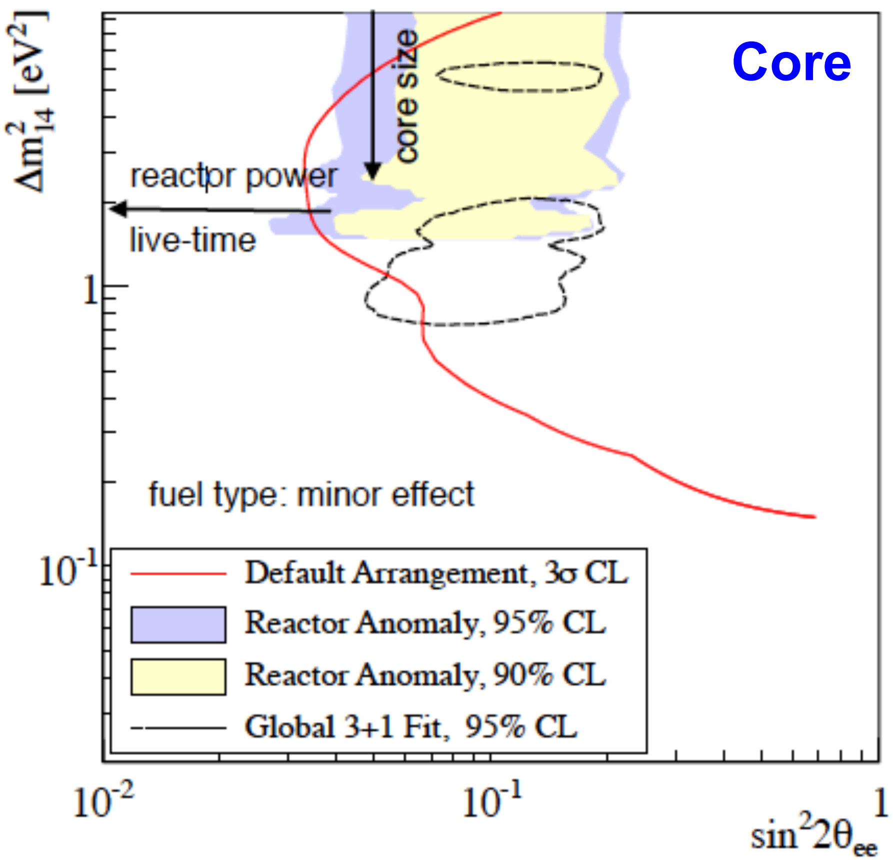


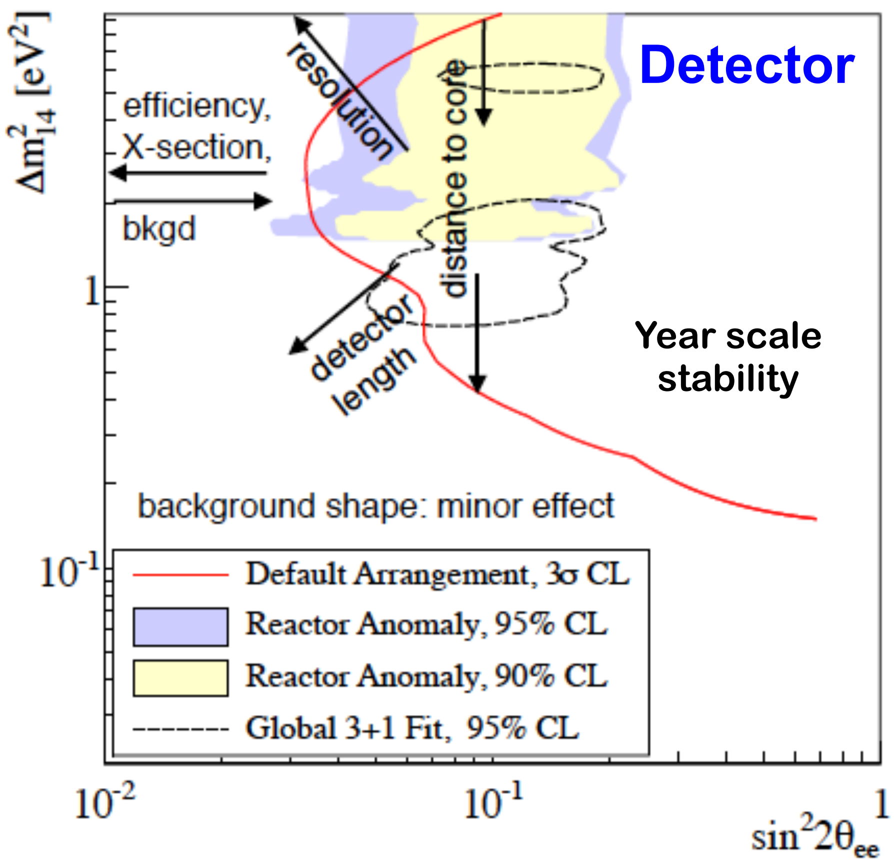




- <u>Relative</u> shape distortion in identical detector modules
- Complemented by rate info.

Contours and Key Experimental Parameters





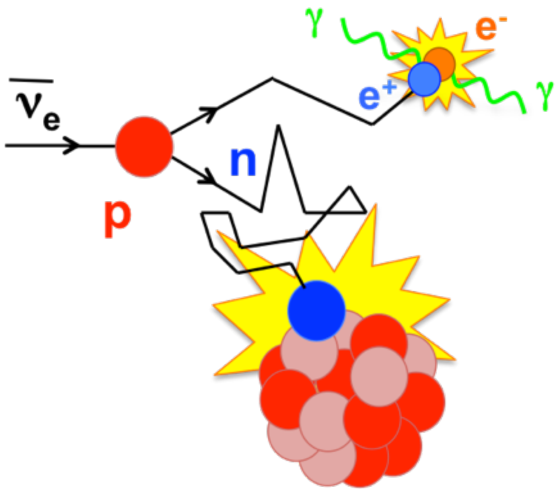
K.M. Heeger et al., arXiv:1212.2182v1

Background mitigation of very short baseline and shallow depth experiments

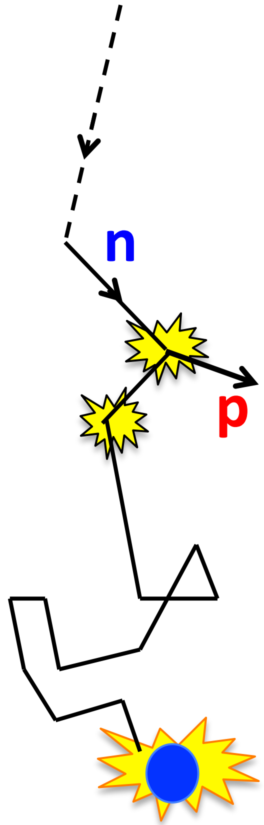
Detection Process and Backgrounds

Inverse Beta Decay

$$\overline{\nu}_e + p \rightarrow e^+ + n$$



Selective prompt-delayed signal sequence



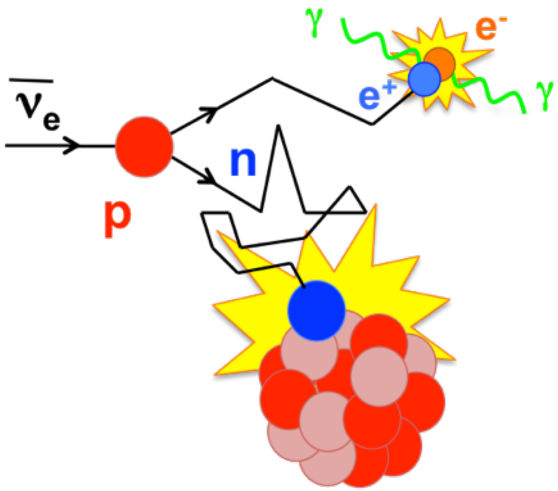
Correlated background from fast n

- Cosmic rays - induced
- Fast n from reactor is a killer
- **Online rejection:**
  - Minimal overburden
  - Active μ veto around target
  - PSD
- **Offline**:
  - Subtraction of reactor OFF data

Detection Process and Backgrounds

Inverse Beta Decay

$$\overline{\nu}_e + p \rightarrow e^+ + n$$



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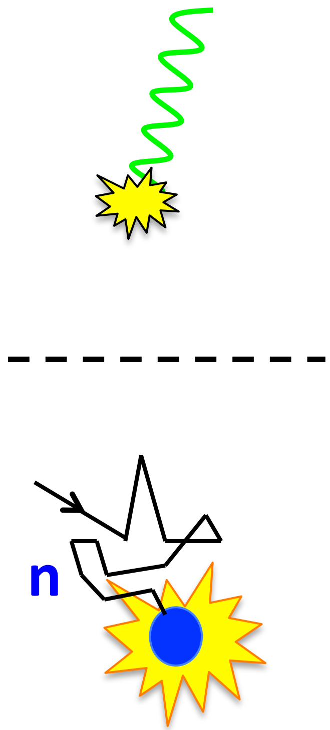
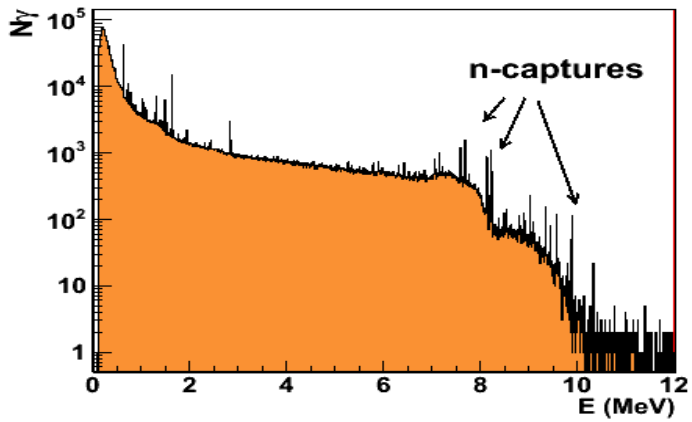


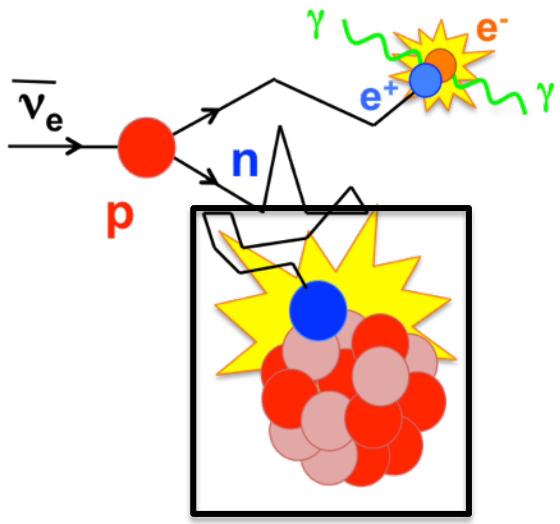
Accidental [γ-n_{th}] coinc

- Reactor dominated
- n_{th} leakage
- High E γ's from n-capture on metals, ^{16}N production in primary circuit, …



→ • On site measurements + heavy shielding design
• Online measurement and subtraction

Neutron Discrimination



Gd-loaded LS

$$n + Gd \rightarrow Gd + \gamma' s\ (8\, MeV)$$

- Mature technology with few years scale stability
- Short capture time
- PSD capability

But

- Sensitivity to high-E γ's
- Inefficiency from detector edge effects

n-capture on ^{6}Li

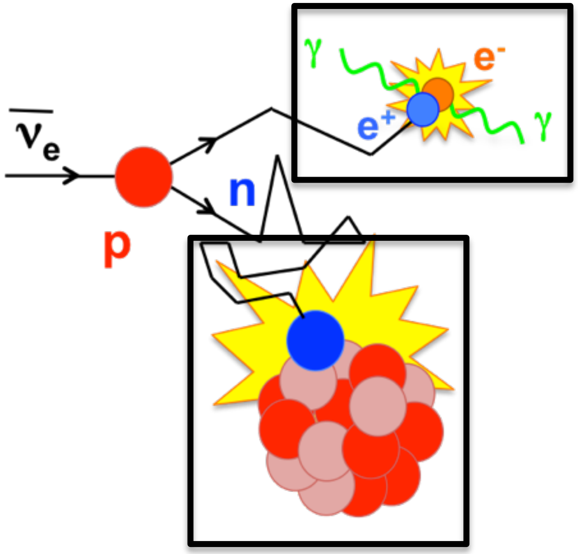
$$n + {}^6Li \rightarrow \alpha + t$$

- Very discriminant final state for online rejection of electromagn background
- High efficiency from localized E deposition
- Short capture time achievable

But

- Low energy signal in LS
- R&D for large target volume

Event Topology



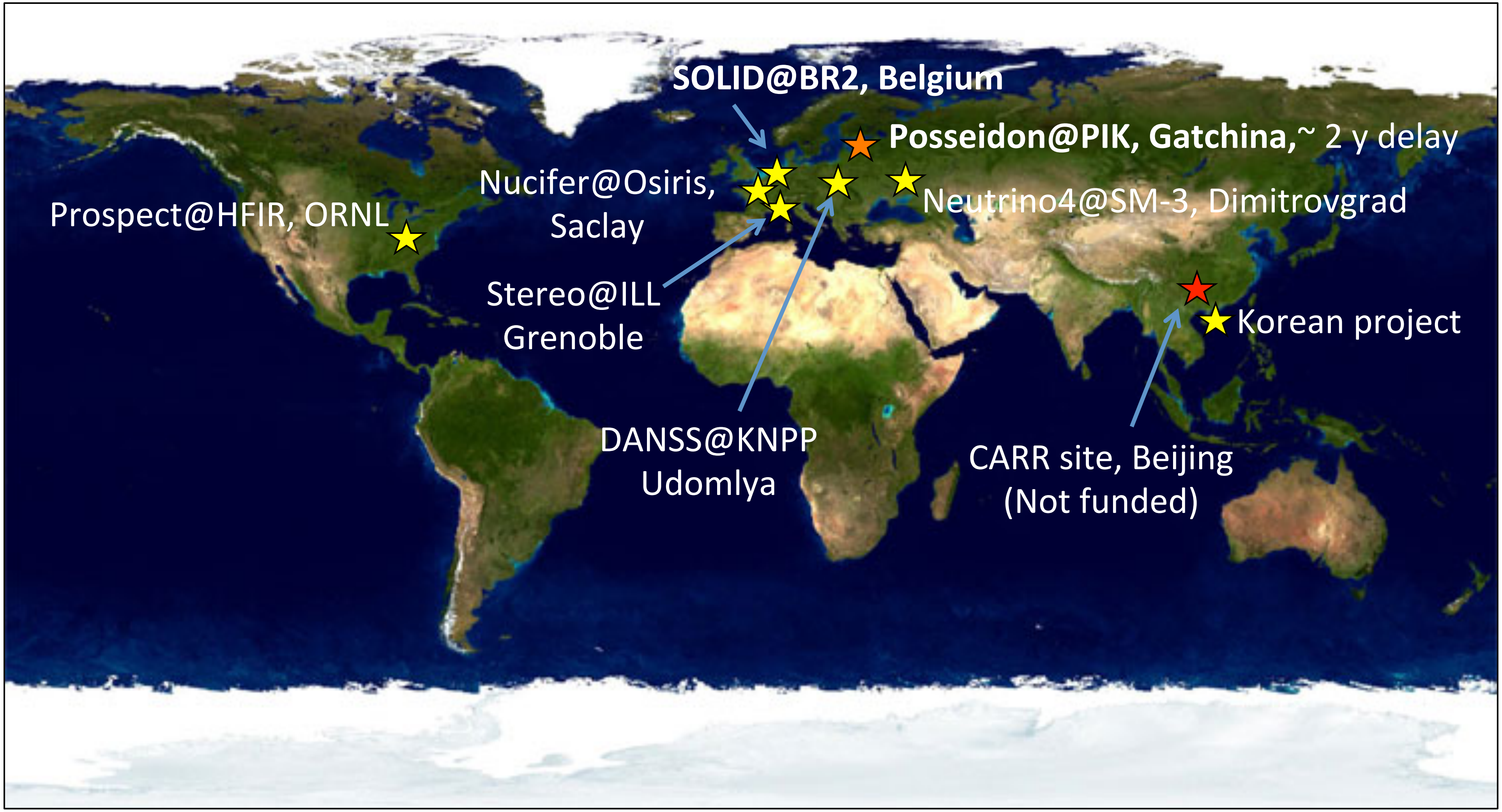
Highly segmented detector (10 cm scale) can help tagging the specific pattern of E deposition of the IBD process

- E depositions of e^+:
  e+ → compact track
  + annihilation γ's → longer int. length

- Space correlation between prompt and delayed vertices linked to n capture time.

Limitations: dead layer of the cell walls, light output, intercalibration

Worldwide Overview



Reactor Proposals

	Gd	^{6}Li	Highly Segmented	Moving detector	2 det.
Nucifer (FRA)	■				
Poseidon (RU)	■				
Stéréo (FRA)	■			■	
Neutrino 4 (RU)	■			■	
Hanaro (KO)	◣	◥	■	■	
DANSS (RU)	■		■		
Prospect (USA)	◣	◥	■	■	■
SoLid (UK)		■	■		

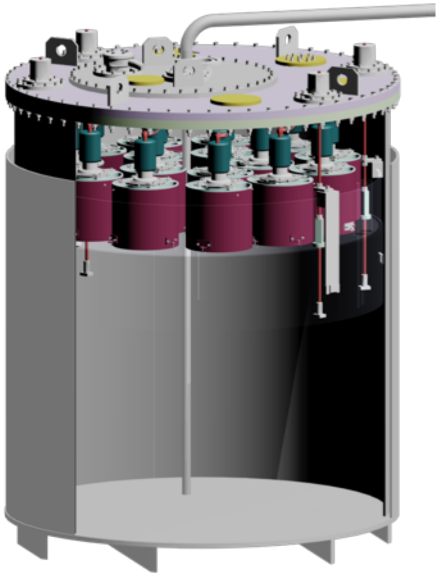
Reactor Proposals

	P_{th} (MW)	M_{target} (tons)	L (m)	Depth (m.w.e.)
Nucifer (FRA)	70	0.8	7	13
Poseidon (RU)	100	~ 3	5-8	~ 15
Stéréo (FRA)	57	1.75	8.8-11.2	18
Neutrino 4 (RU)	100	1.5	6-12	~ 10
Hanaro (KO)	30-2800	~ 1	6	few
DANSS (RU)	3000	0.9	9.7-12.2	50
Prospect (USA)	85	1 & 10	7-18	few
SoLid (UK)	45-80	2.9	6-8	10

Gd-Loaded Liquid Scintillators

Nucifer @ OSIRIS

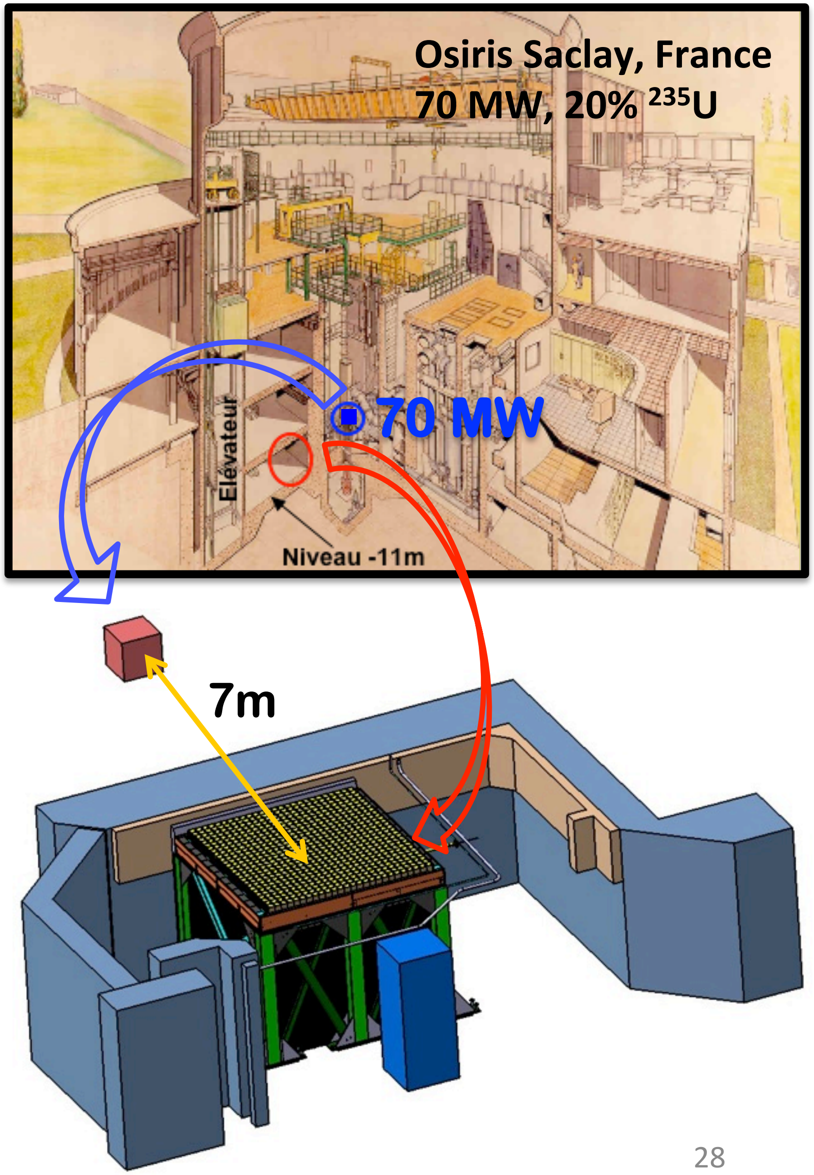
Simple design for reactor monitoring studies



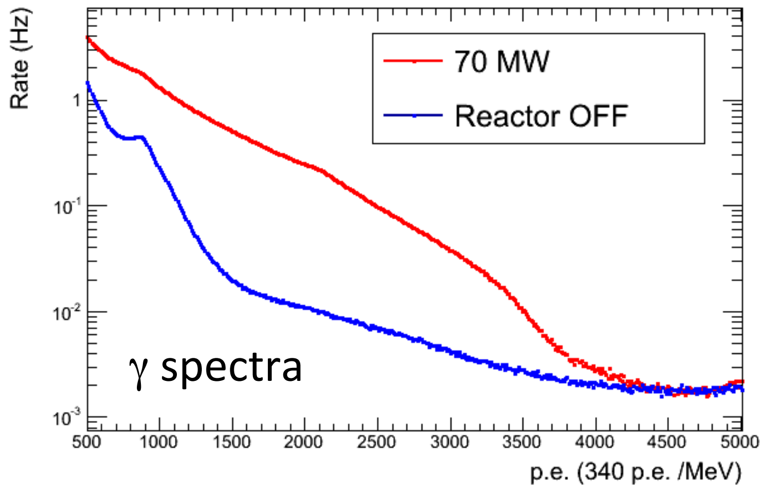
- 850 l Gd-loaded LS
- Compact core (60x60x60 cm^3)
- Short baseline: 7m
- 10 mwe overburden
- ~300 detected ν/day expected

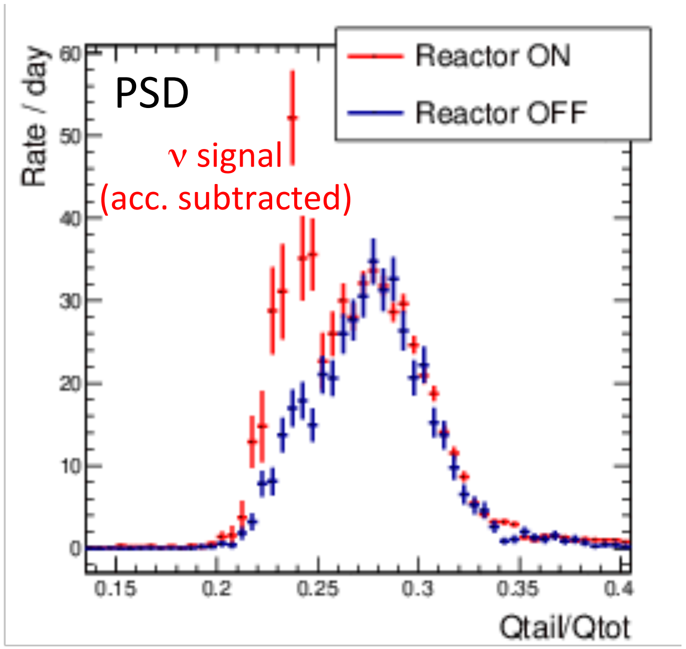
→ Some sensitivity to Sterile ν

But challenging reactor background



Nucifer @ OSIRIS

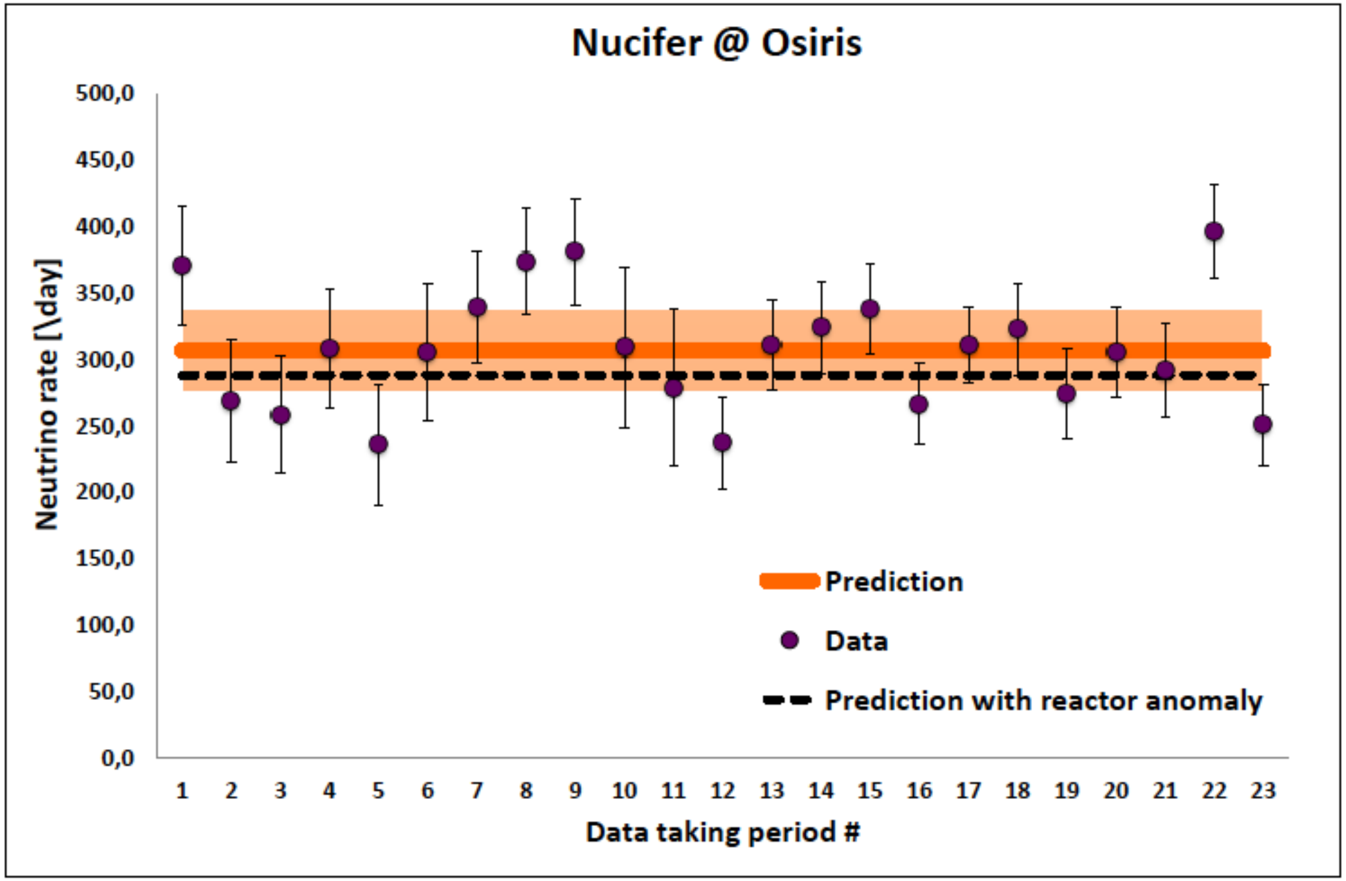




	Accidental rate	Correlated rate
Reactor OFF	(75 ± 1) /day	(1063 ± 10) /day
Reactor ON	(3793 ± 1) /day	(1384 ± 15) /day

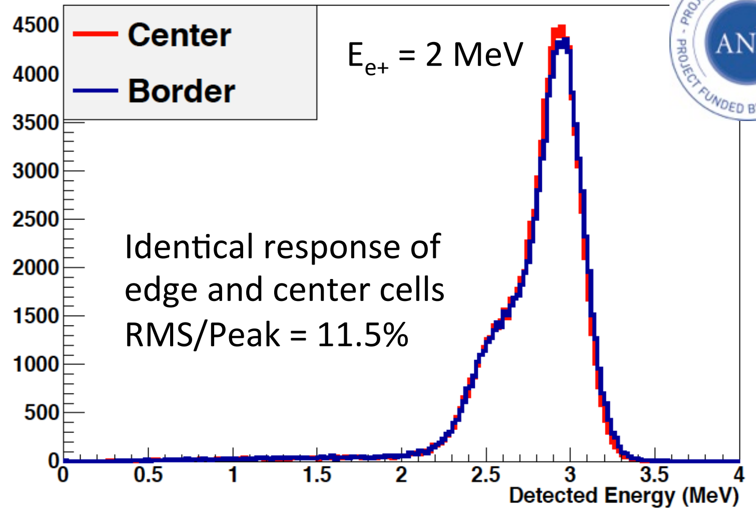
- Contamination of high E γ-rays in the n-capture energy range (5-9 MeV).
- S/B ~0.1 from accidentals
- Extra rejection of cosmic background using Pulse Shape Discrimination
- No reactor induced fast n @ 7m from core.

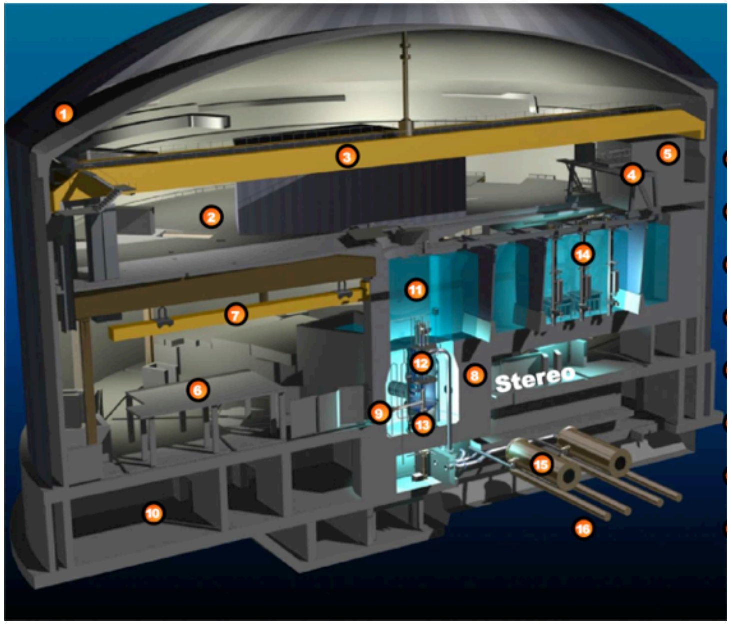
Nucifer @ OSIRIS



- Now in stable data taking mode until end of 2015.
- Analysis in progress with carefull background subtraction
- Might provide the first constraint on sterile neutrino

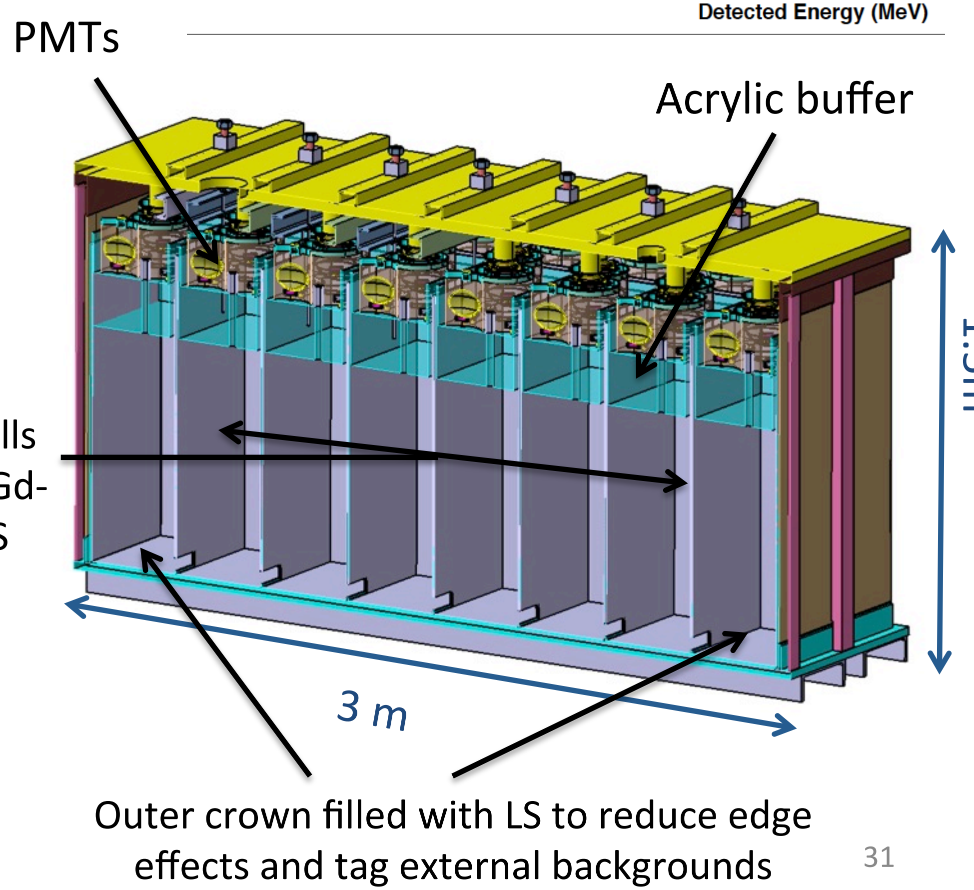
STEREO @ ILL





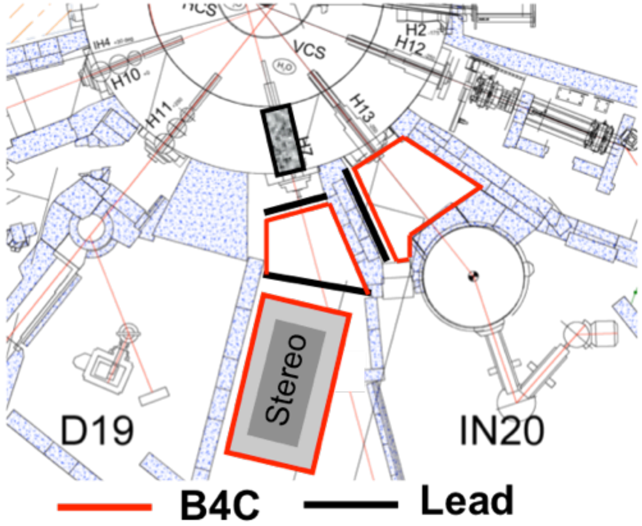
ILL site:

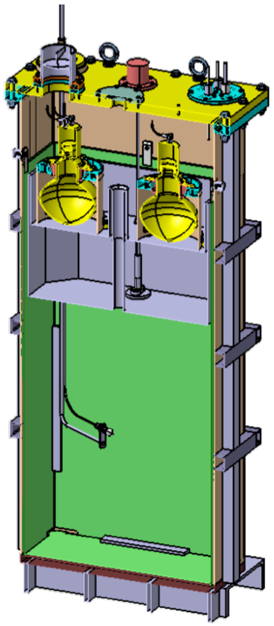
- 57 MW, compact core < 1m
- [8.9–11.1] m from core, possible extension to 12.3 m.
- 15 mwe overburden
- High level of reactor background



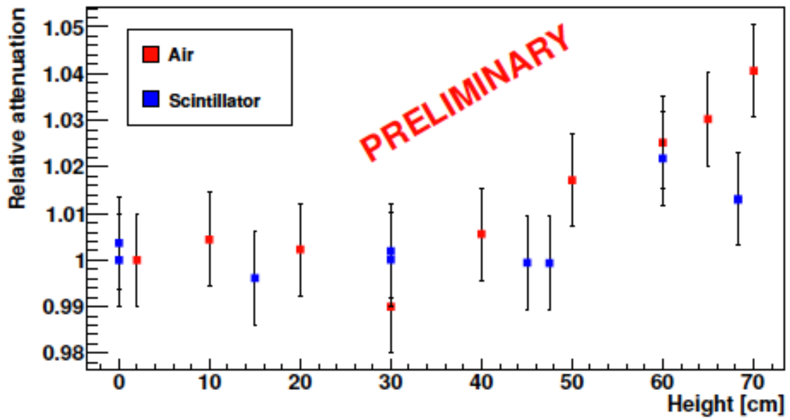
Background rejection

- Comprehensive on site measurements performed last year: μ, n and γ backgrounds.
- Sequential installation/validation of external shielding before detector installation early 2015.
- Muon induced background:
  - Overburden
  - Active outer-crown and μ-veto
  - PSD capability of the liquid scintillator

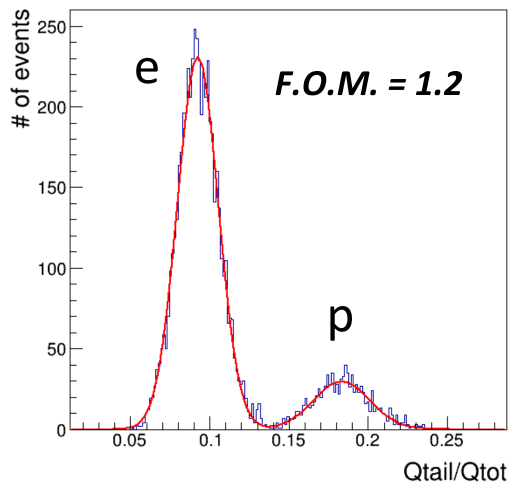




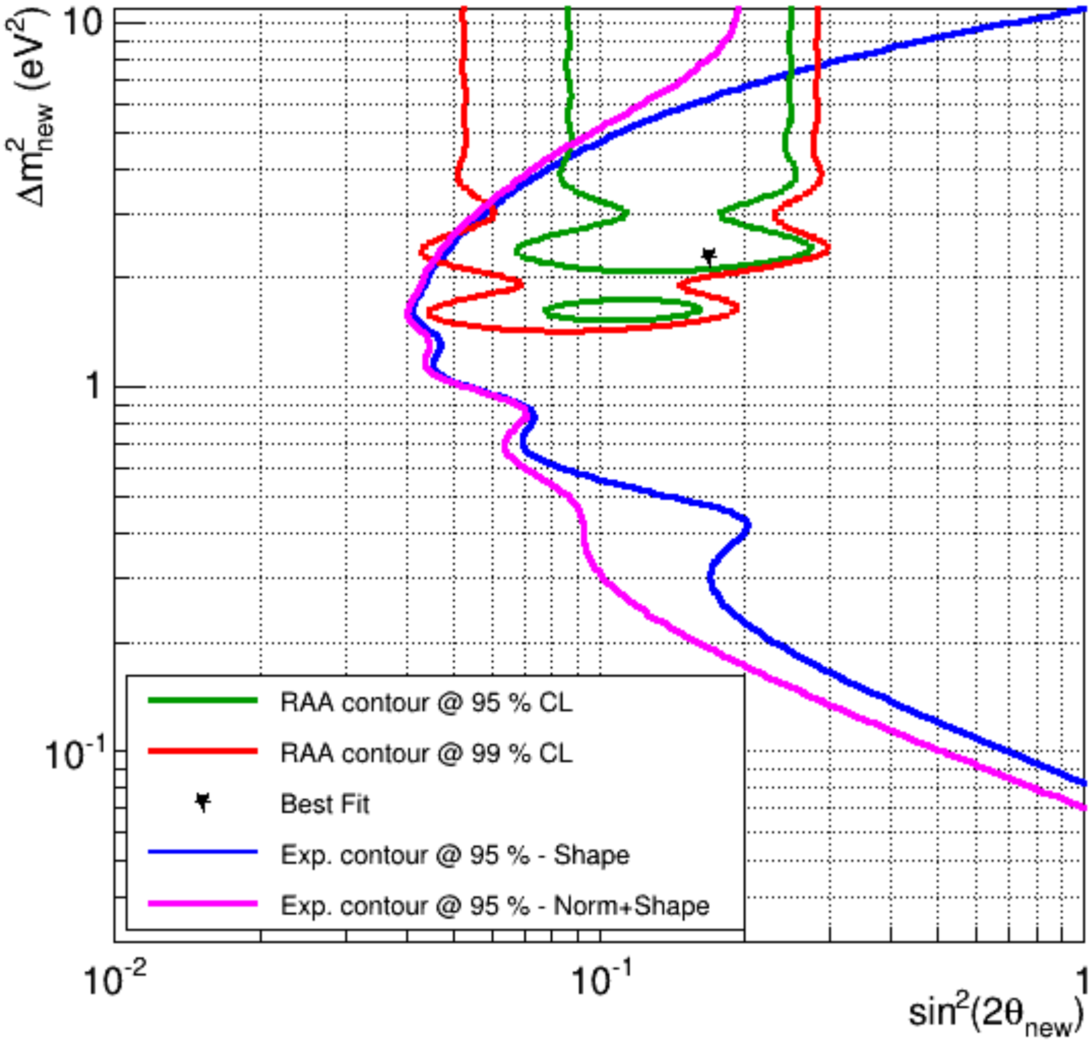
Validation of good light collection in prototype cell



PSD in small cell

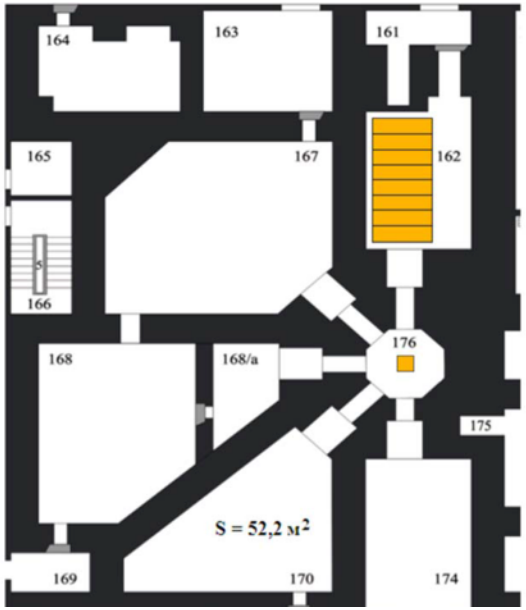


STEREO Sensitivity

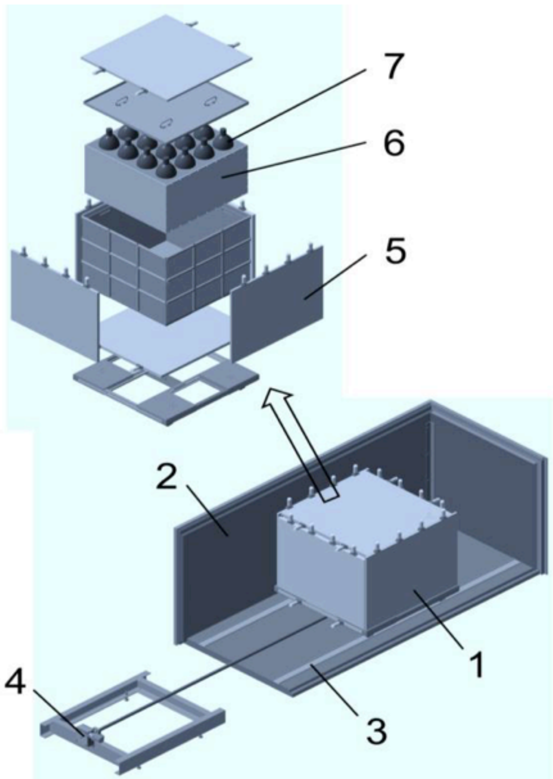


- 300 days, L_0 = 10 m
- E_{prompt}>2 MeV, $E_{delayed}$>5 MeV
- ~410ν_e/day
- δE_{scale} = 2%
- All syst. of predicted spectra
- S/B = 1.5, 1/E+flat model
- Norm 4%
- Start data taking in 2015

NEUTRINO-4 @ SM3



- Compact core
- 100 MW
- Few mwe



Prototype module

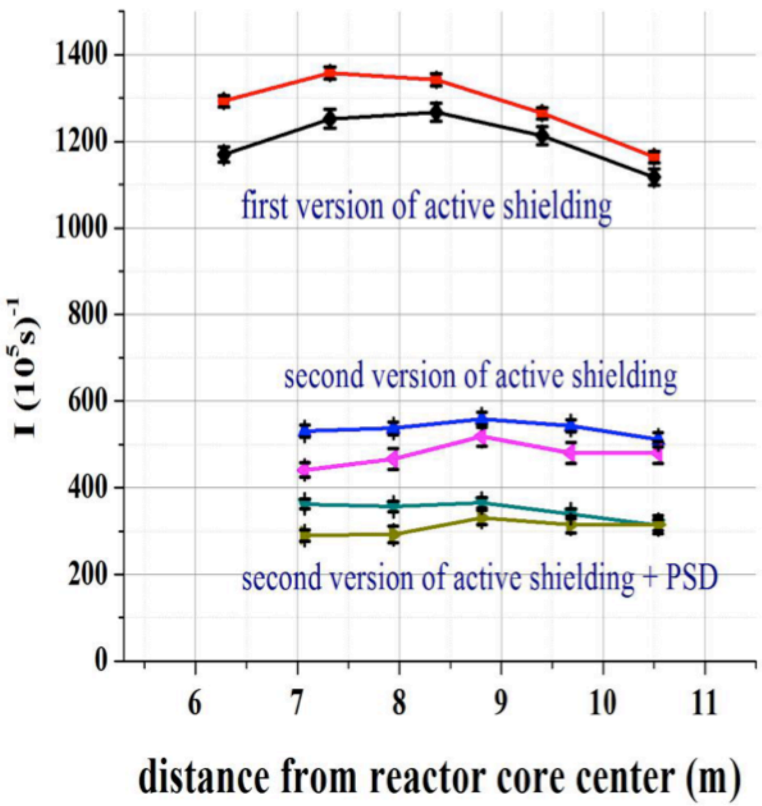
1 –detector module
2 –passive shielding
3 –rail
4 –motion system,
5 –muon veto,
6 –400 l Gd-loaded LS,
7 –Detector PMTs.

60 t shielding

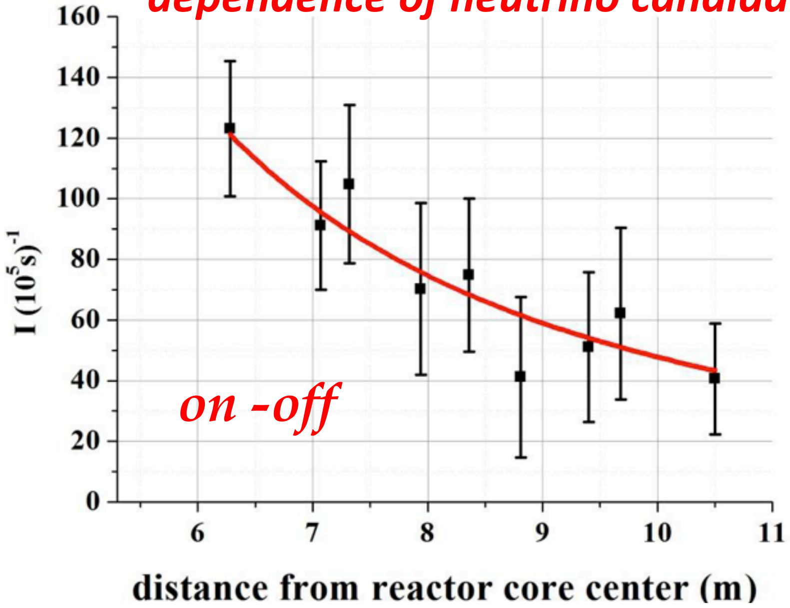
Movable det module
6-12 m baseline range

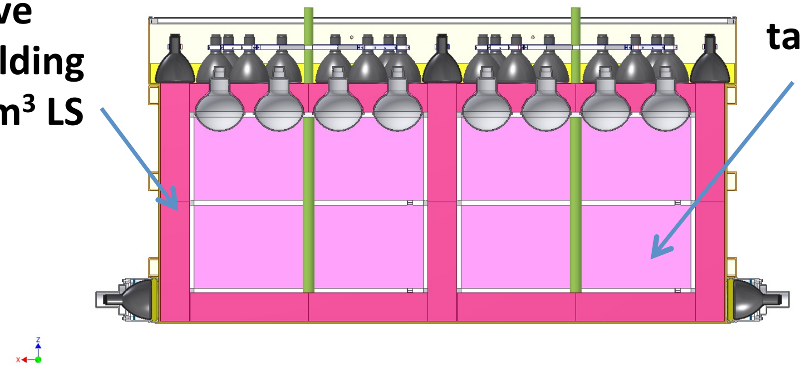
NEUTRINO-4 @ SM3

Cosmic background suppression



First measurement of 1/ R^2 dependence of neutrino candidates



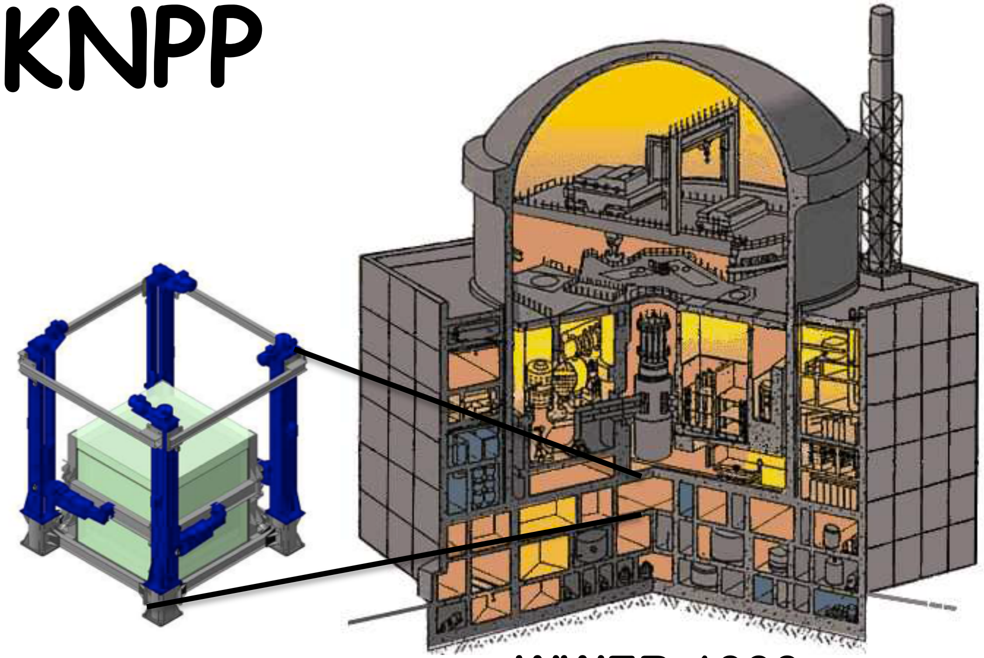


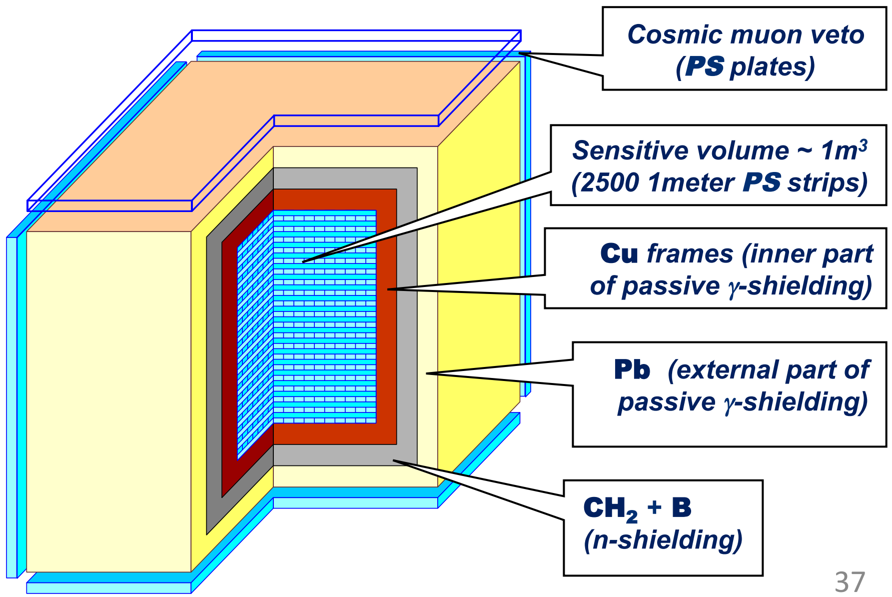
- Production of the full-scale NEUTRINO-4 detector
- Data taking in 2015.

Highly Segmented Detectors

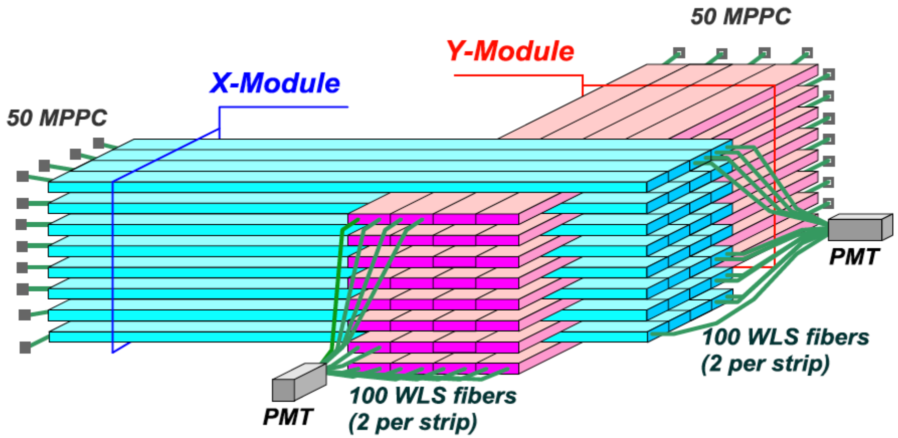
DANSS @ KNPP

- 1 GW extended core
- Good overburden, underneath the reactor.
- High statistics, ~ 10^4 evt/day expected
- Vertical motion of the detector (9.7-12.2 m)
- Highly segmented detector
  → background rejection



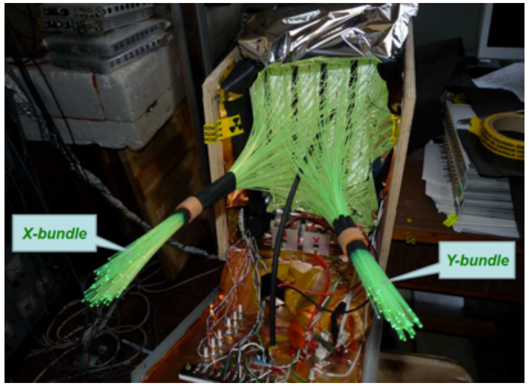


Detector Structure

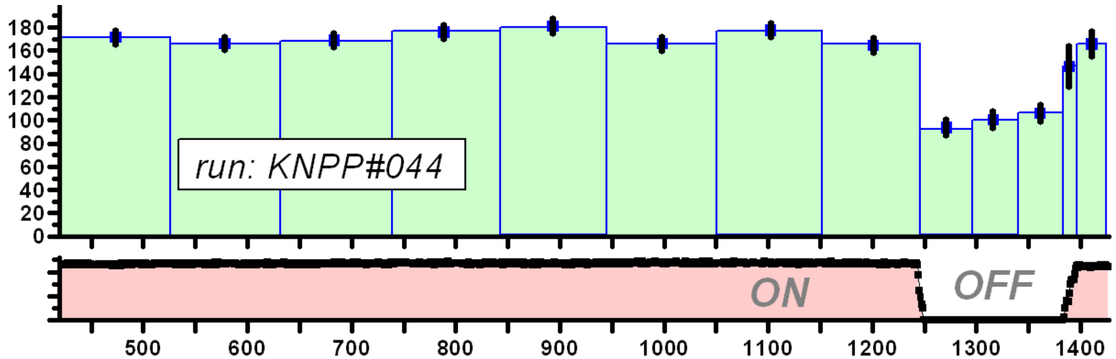


Plastic strips with Gd-loaded interlayer, WLS fibers readout, 15 pe/MeV expected.

1/25th prototype tested for 20 days @ KNPP



- First validation of the detector concept with the DANSSino prototype
- Antineutrino signal reported with S/B~1
- Final detector in 2015.

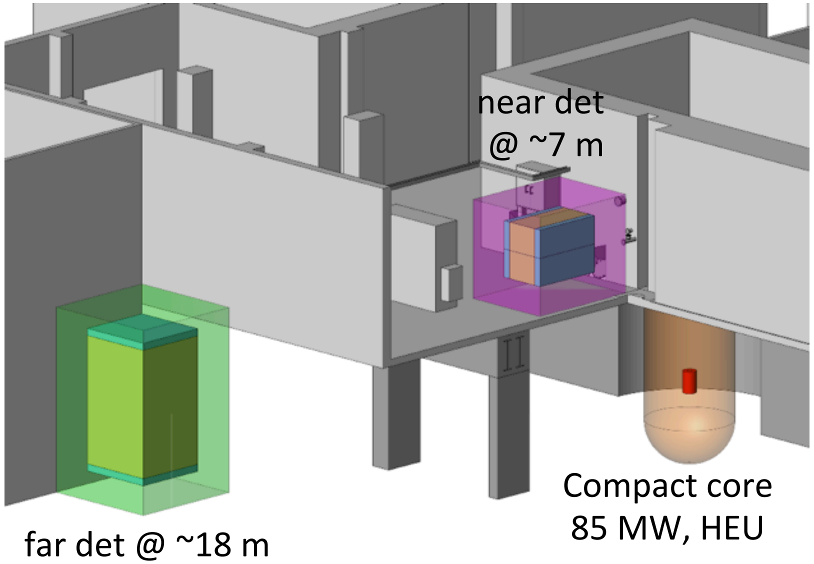


arXiv:1304.3696v2

Highly Segmented Detectors
+
^{6}Li-loaded Scintillators

PROSPECT

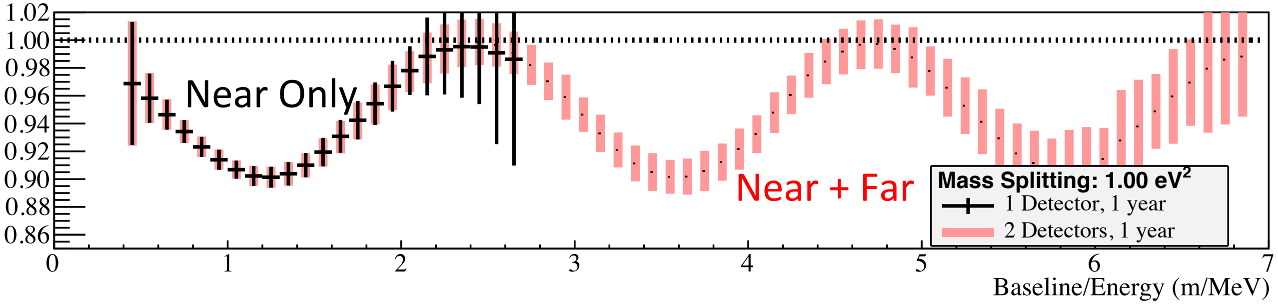
A Precision Reactor Neutrino Oscillation and Spectrum Experiment



Physics Goals

- Search for sterile ν_e oscillations at short-baseline.
- Probe and resolve "reactor anomaly".
- Precision measurement of reactor ν_e spectrum for physics and safeguards.

Map out L/E Oscillations

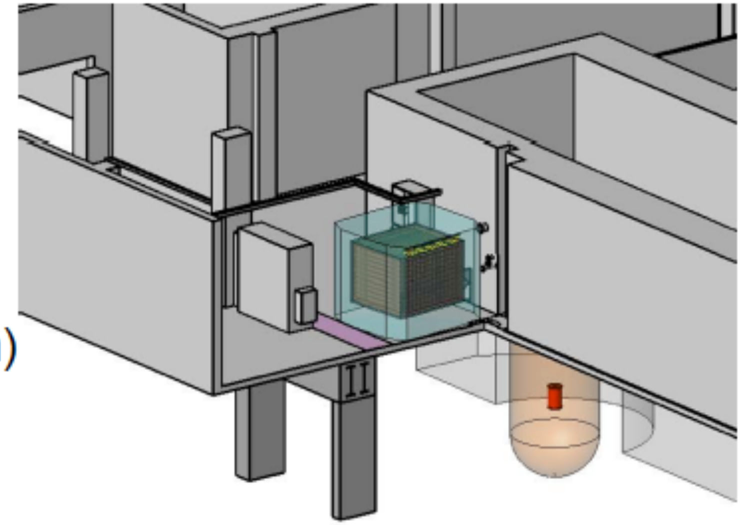


PROSPECT Phase 1 Detector Concept

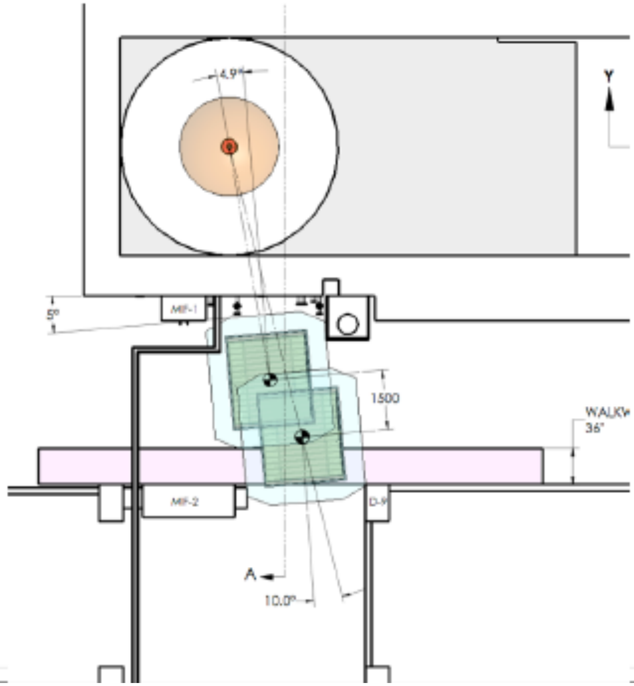
2.5 ton active target at < 8 m baseline
(140 segments, 280 channels)

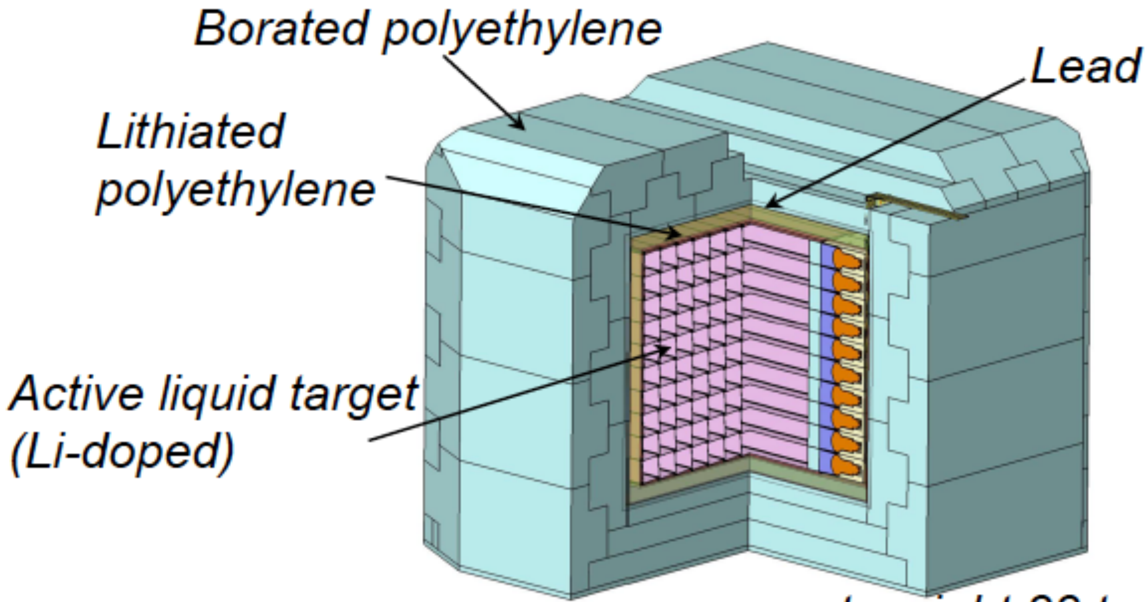
Single liquid tank containing full cell assemblies

Movable (airpads) to cover larger baseline (+1.5 m)
- Extends sensitivity to lower Δm_{14}^2
- Provides systematic checks



Veto system under consideration

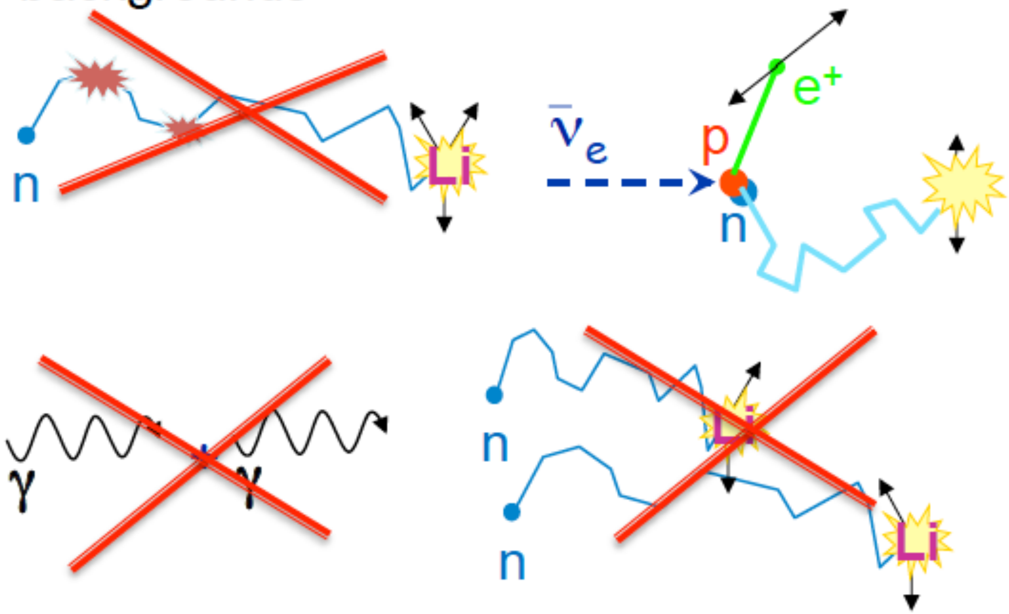




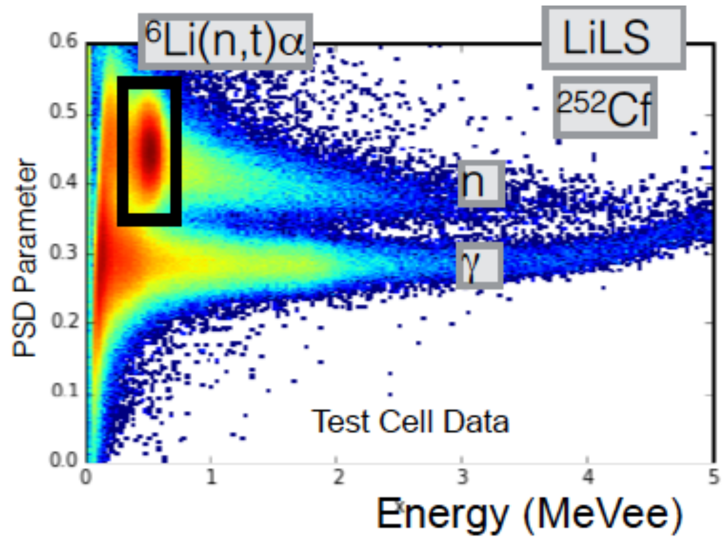
net weight 33 tons

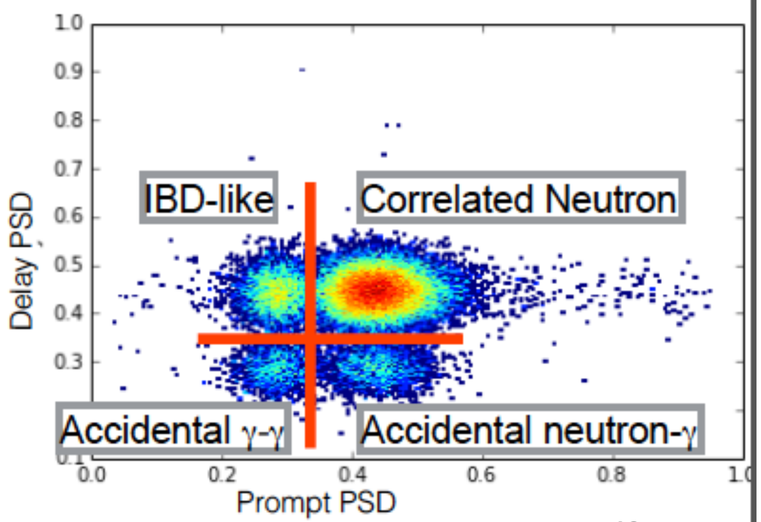
PROSPECT Background Rejection

- ^{6}Li-capture, Pulse Shape Discrimination, and topology from segmentation
- Strong rejection of accidental and correlated backgrounds

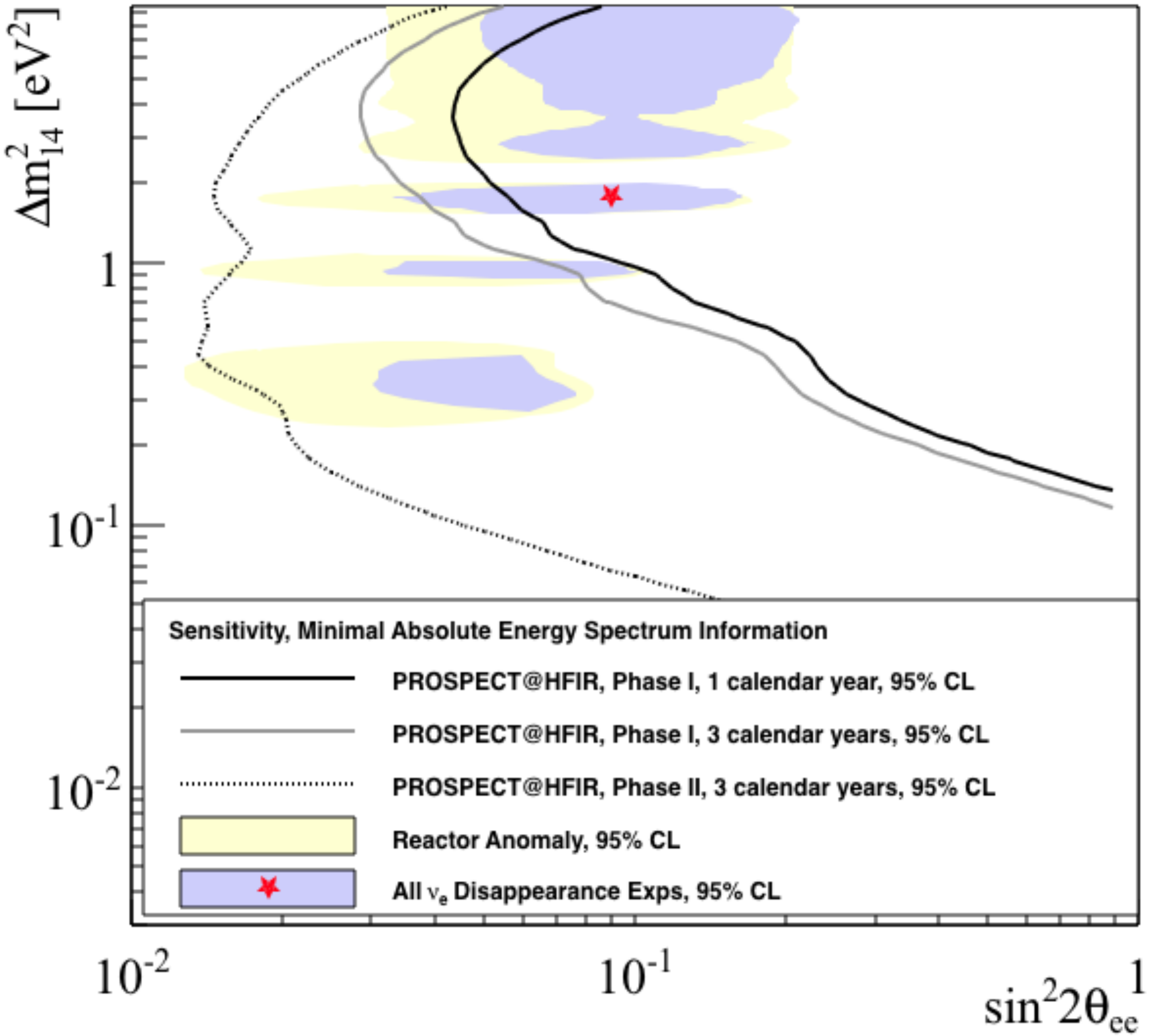


- Using simulation/deployment data to understand and mitigate electromagnetic-neutron capture correlated backgrounds





PROSPECT – Sensitivity



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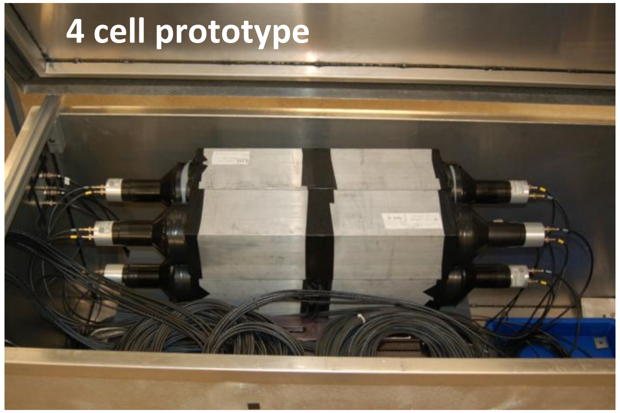
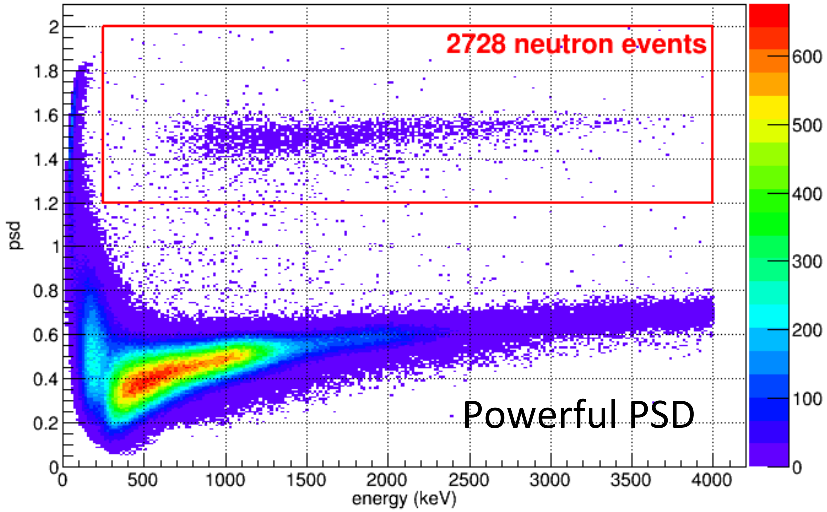
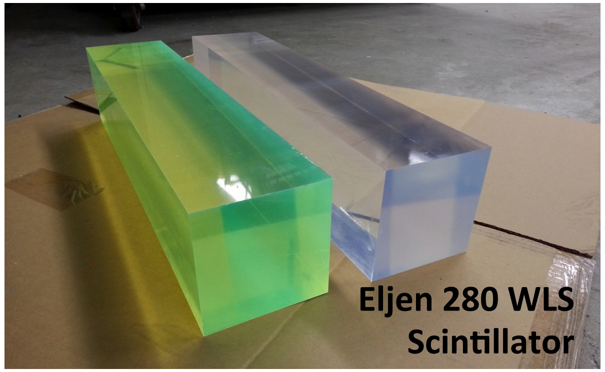
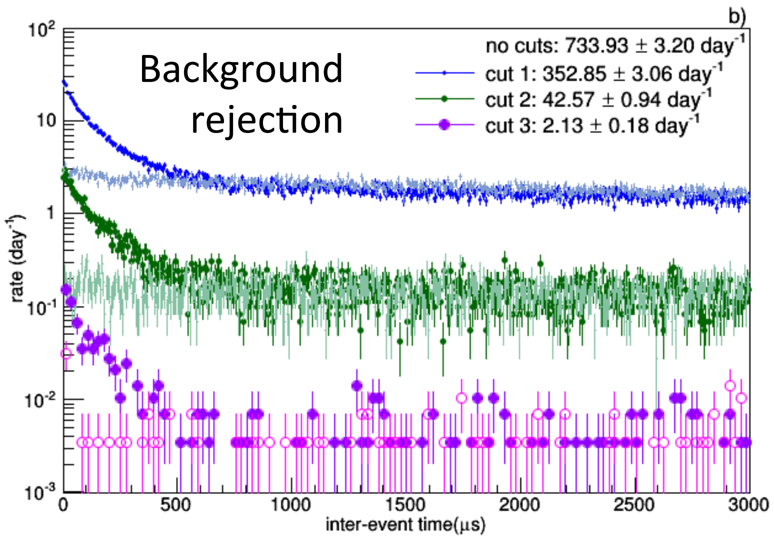
Development @ SANDIA





- Individual Segments contain organic scintillator with ZnS:Ag/^{6}LiF screens on outer surface
- Uniform response thanks to WLS scintillator





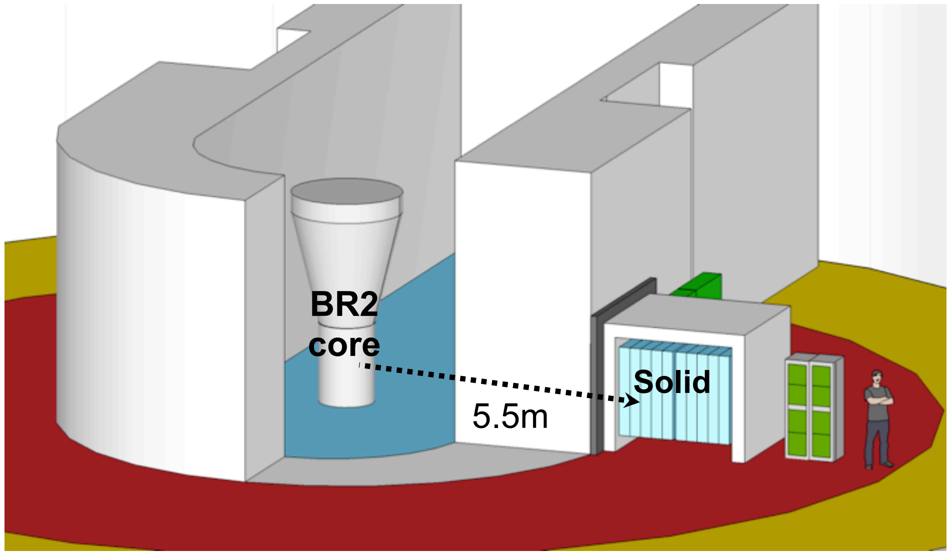
SoLid

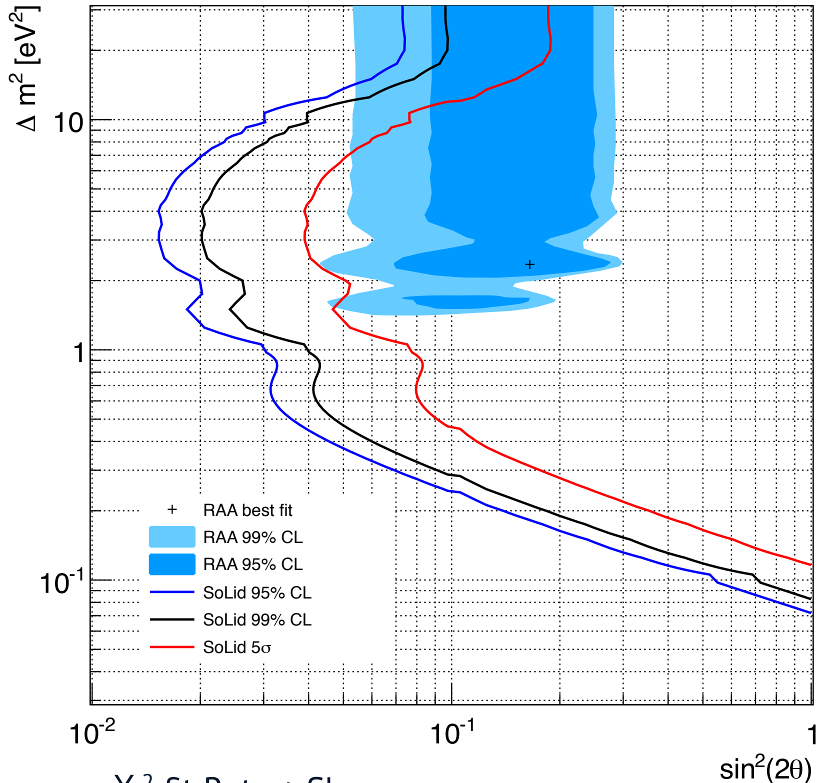
BR2 REACTOR, Mol, Belgium

- Core: 45-80 MW, HEU fuel
- Favorable reactor background level

DETECTOR

- **Novel type of composite solid scintillator detector** (PVT + ^{6}LiF:ZnS)
- 2.88t fiducial volume, highly segmented.





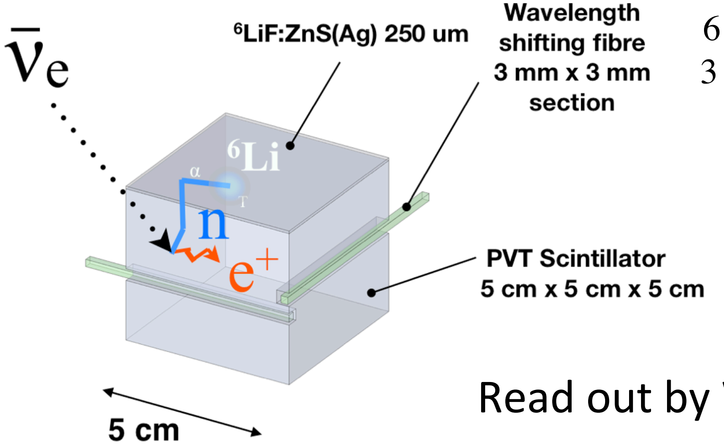
X^2 fit Rate + Shape

- IBD efficiency 41% (416nu/day/tonne)
- 300 days running at 6.8m baseline
- S/B ~ 6
- include flux normalisation (4.1%), detector efficiency (2%) systematics and backgrounds
- large bins to account for energy smearing effects

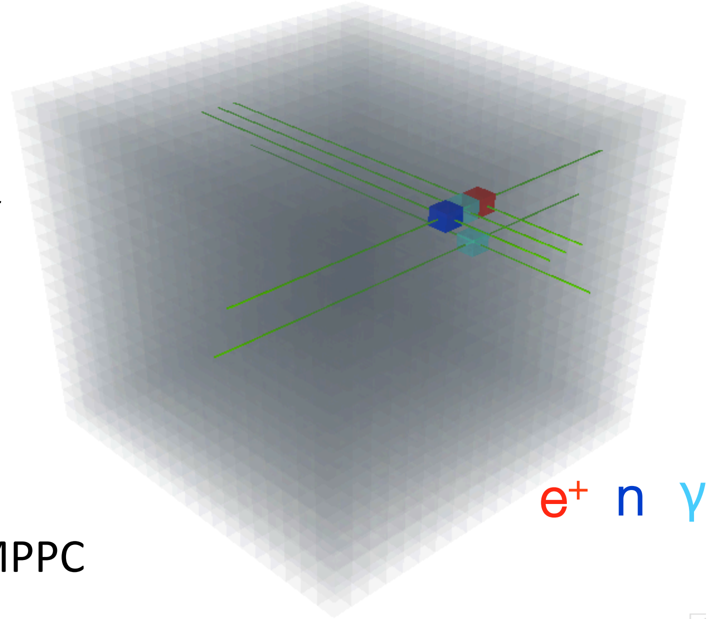
SoLid Detection Principle

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

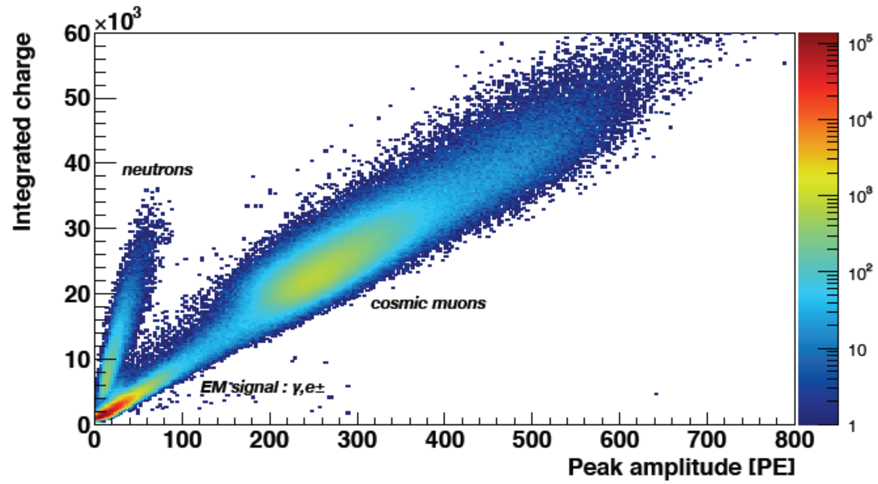
$${}^6_3Li + n \rightarrow \alpha + t$$



Read out by WLS fibers and MPPC



- Very **discriminant neutron signal** in ^{6}LiF:ZnS. High neutron-γ rejection factor
- 3D reconstruction close to interaction point : **high background rejection capability using topological information of IBD.**



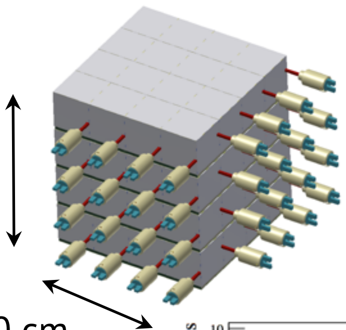
Status of experiment

NEMENIX prototype tested at BR2

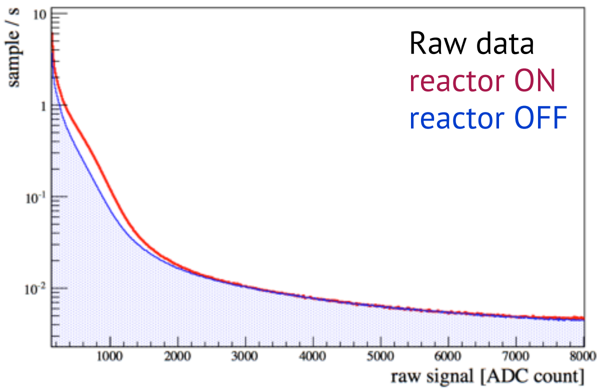
- New DAQ + muon veto
- Demonstrate expected response
- Study background rate and IBD analysis.
- Analysis of mars-may 2014 cycles in progess

8 kg, 64x cubes

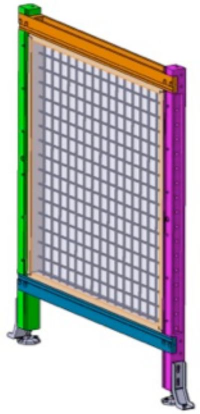
20 cm

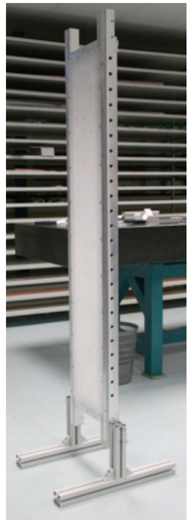


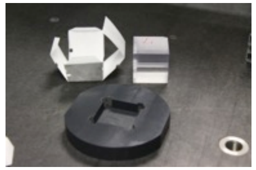
20 cm



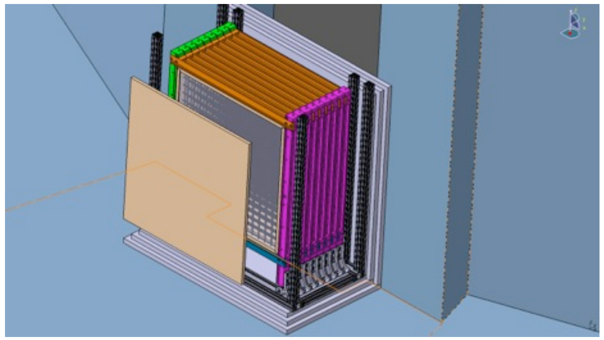
Larger scale prototype





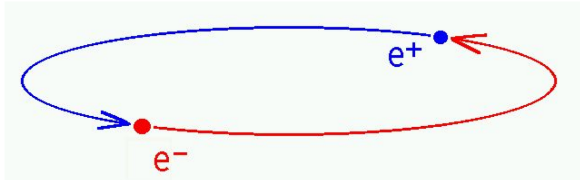


- 288 kg module (2304 cubes) deployment planned before end of year 2014 at BR2.
- **Data taking with full det early 2016.**



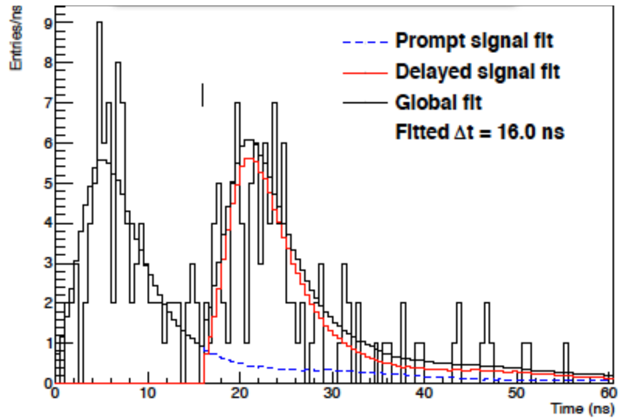
Positron tagging

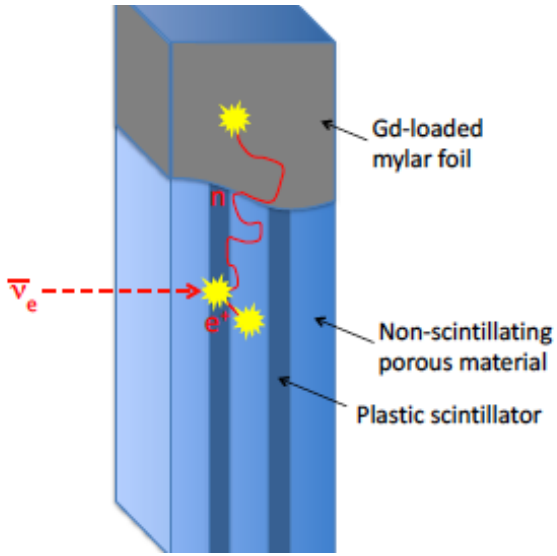
NuTops project



- Positron from an IBD event can form an ortho-positronium (o-Ps) state with increased lifetime (up to 142 ns in vaccum).
- Matter effects quench it to few ns in most liquid scintillators. Pulse shape distortions induced by o-Ps states have been observed by Borexino, Double Chooz although with very low efficiency.
- The formation of o-Ps and associated lifetime is enhanced by the insertion of porous material. But this is at the expense of the scintillator transparency.
- Ongoing study of a sandwich structure of porous material and scintillator

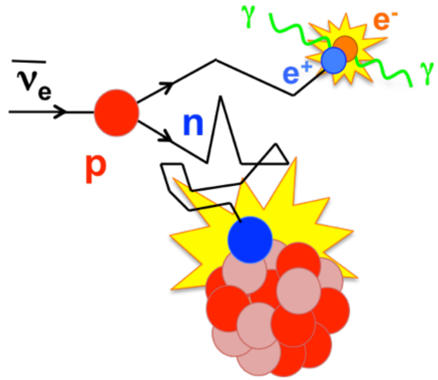
JHEP 1410 (2014) 32





→ **Potentially powerful rejection of background**
Limited by low intrinsic efficiency ~5%

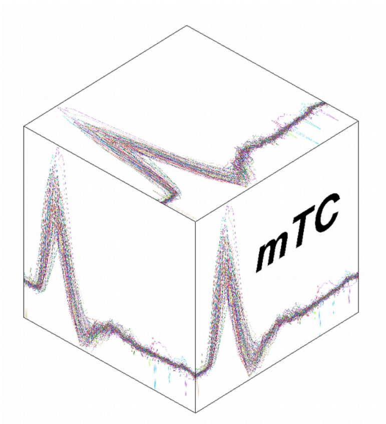
Directionality

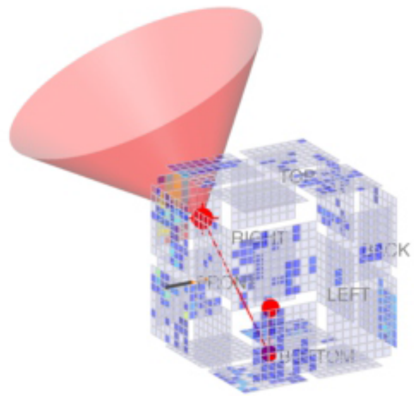


- In the Inverse Beta Decay process, the neutron is emitted preferentially in the direction of the incoming ν. But the diffusion before the capture prevent any event by event treatment (9° accuracy with 17000 ν in Double Chooz)

MiniTime cube project

- Read out by micro-channel plates with time resolution of 100 ps
- Time reversal imaging of the light created along the path of particle
- Capability of neutron path reconstruction to point the neutrino source
- To be tested at the NIST facility





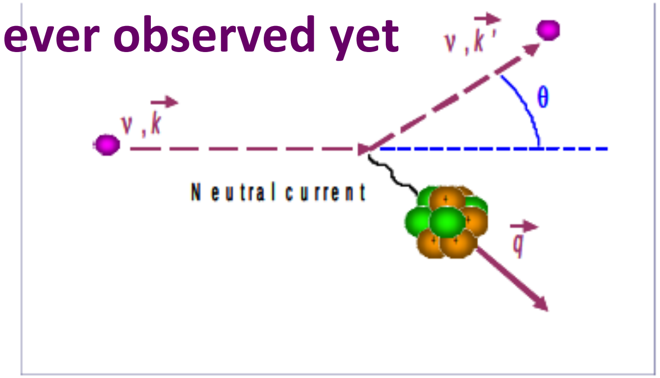
neutron event

Coherent ν Scattering off Nuclei

Coherent Scattering

- Highest interaction cross section
- Potential application in supernovae mechanics, test of SM at low energy, neutron radii of nuclei, ….
- Reactor monitoring with compact neutrino detectors
- Synergy with DM search

Never observed yet



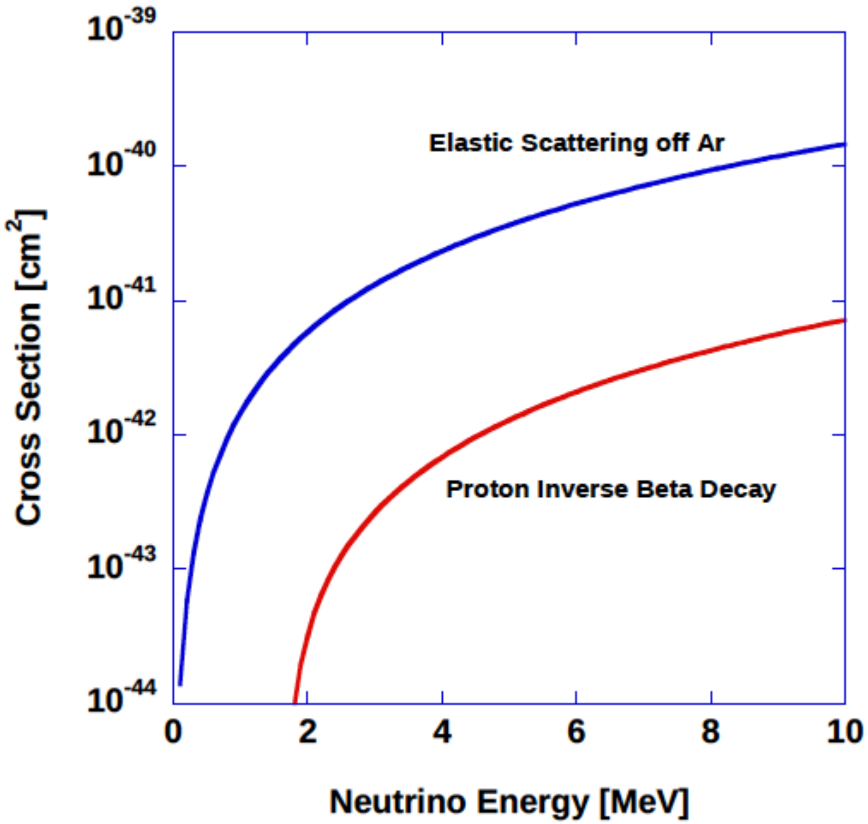
Large cross-section

$$\sigma_{\text{elastic}} = \frac{G_F^2}{4\pi} N^2 E_\nu^2$$

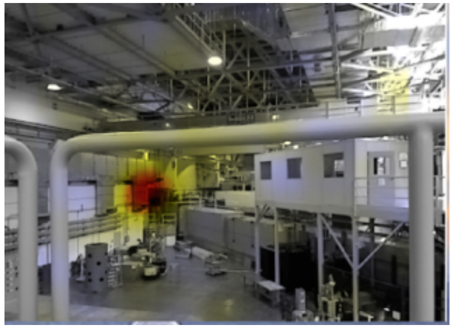
$$\approx 0.4 \times 10^{-44} \text{cm}^2 A^2 E_\nu (\text{MeV})^2$$

Small recoil energies

$$E_{\text{recoil}} \leqslant 716 \text{ eV} \frac{E_\nu^2 (\text{MeV})}{A}$$

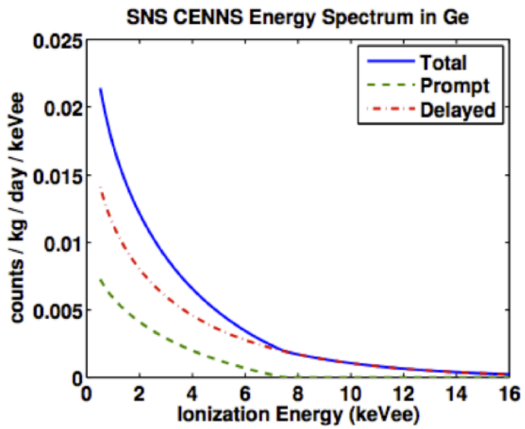


Coherent Scattering

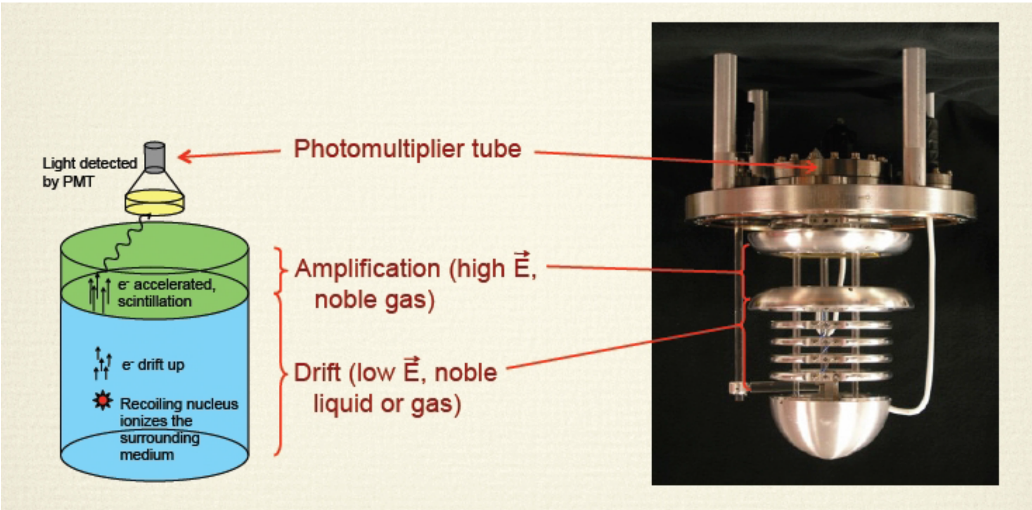


- New collaboration merging disparate groups

→ measure coherent nu scattering at the pulsed Spallation Neutron Source in Oak Ridge: 2e7 nu/cm^2/s @ 20 m from π decay at rest. Background from intra-pulse particles.



- Two-phase emission detector

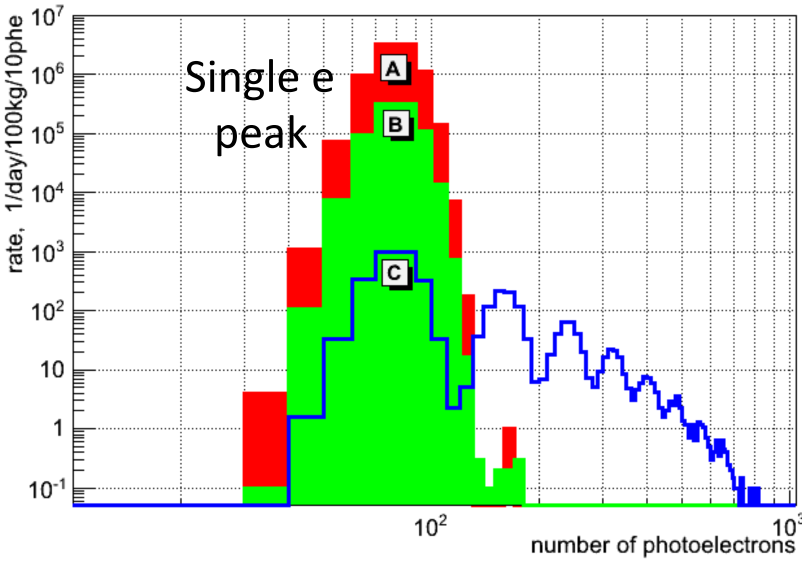


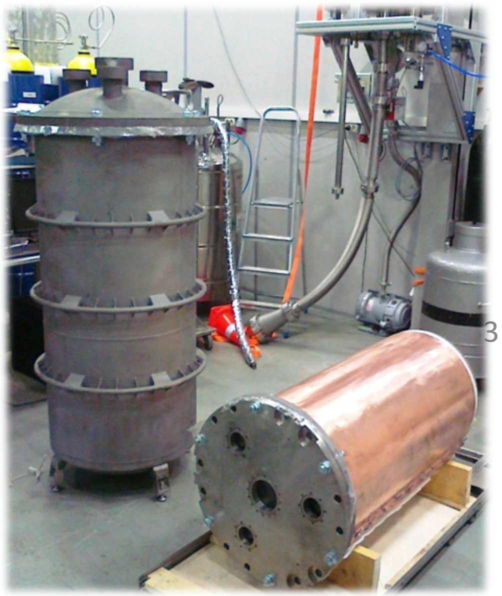
C.Hagmann and A. Bernstein, IEEE Trans. Nucl. Sci. 51(2004)2151-2155.

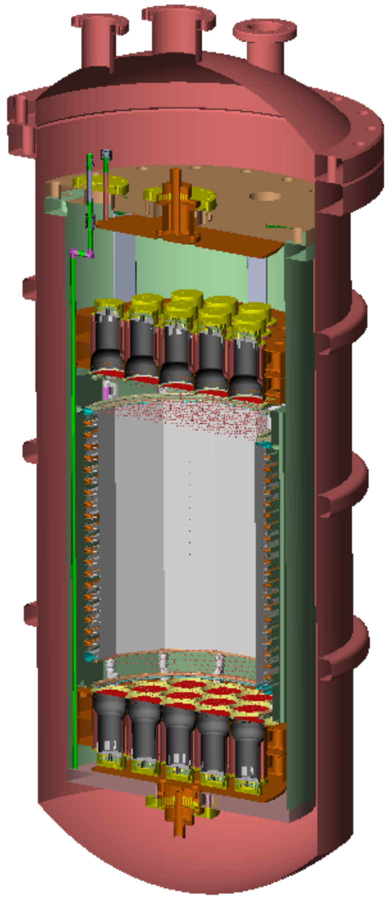
Coherent Scattering

Liquid Xe RED-100 detector

- To be installed at the Kalininskaya power reactor.
- Expected rate = 433 ν/day/100 kg with 2e threshold, equivalent to ~1 MeV neutrino threshold



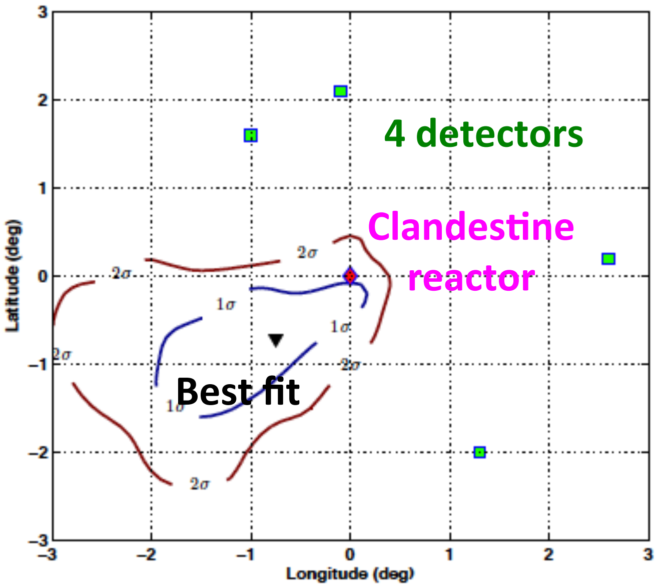




Large Detectors

Long Range Measurements

- Very large detector to be deployed 100-200 km away from international borders to detect **undeclared activities**.
- Target mass: 130 000 tons
- Overburden $\gtrsim$ 500 m.w.e



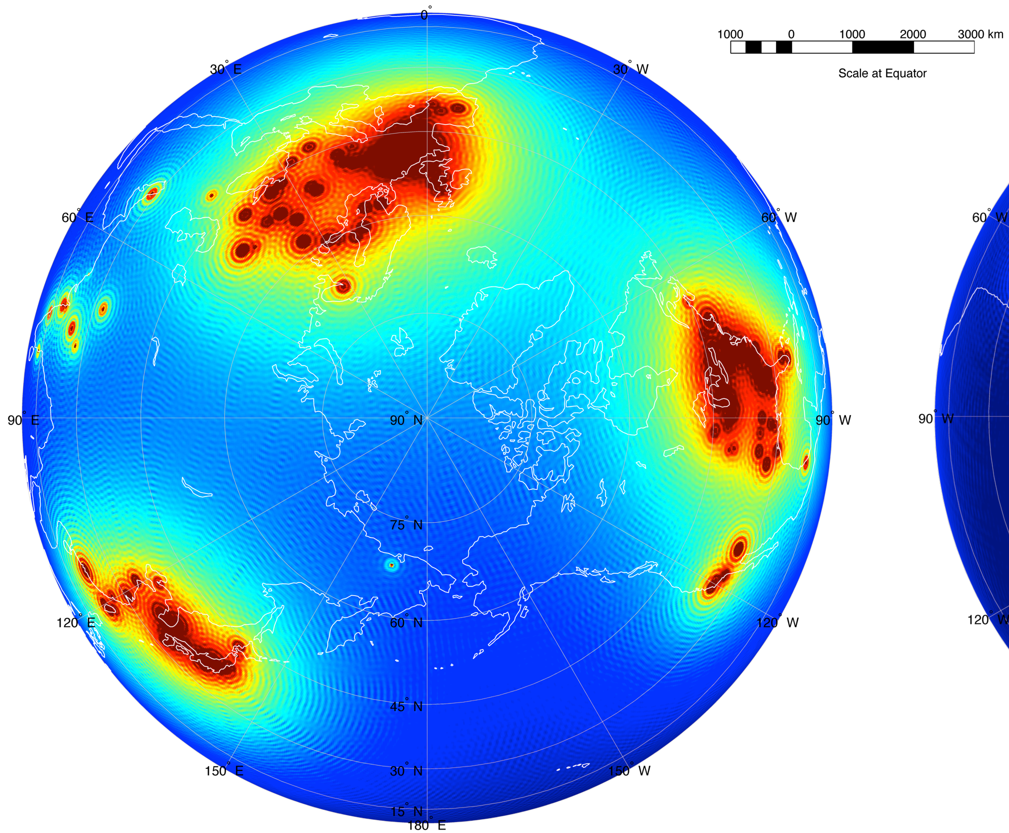
T. Lasserre et al, arXiv:1011.3850

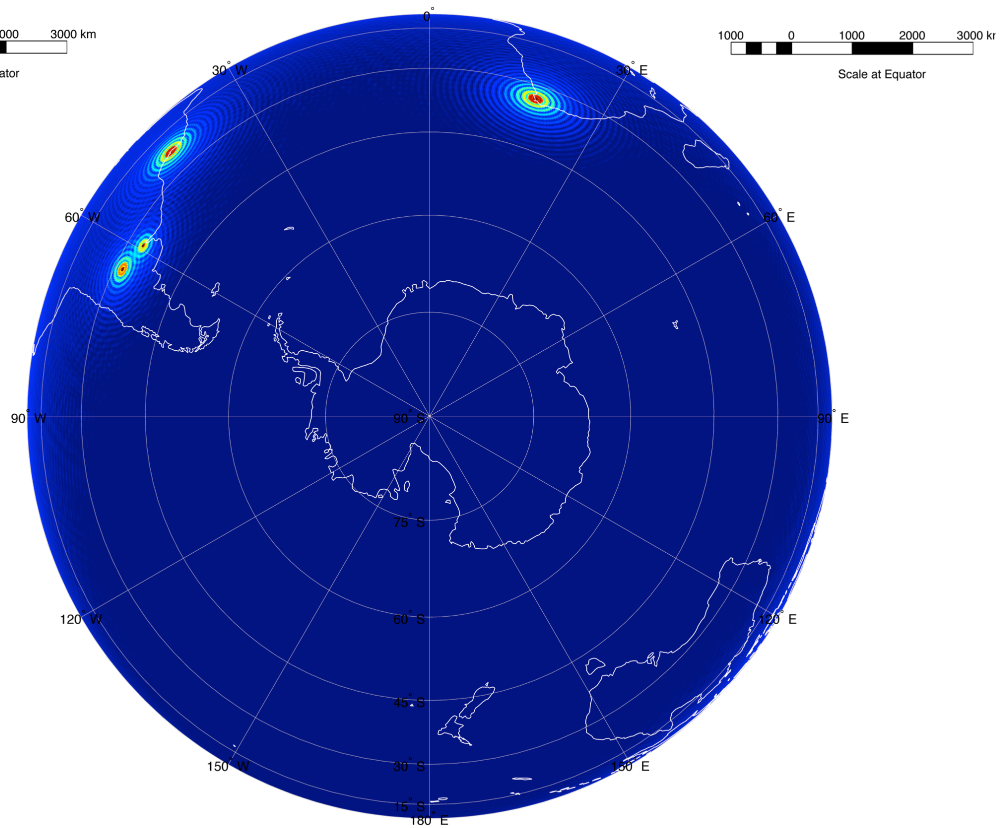
First "futuristic" study refined in light of recent technological developments

G. Jocher et al, Phys.Rept. 527 (2013) 131-204

Long Range Measurements

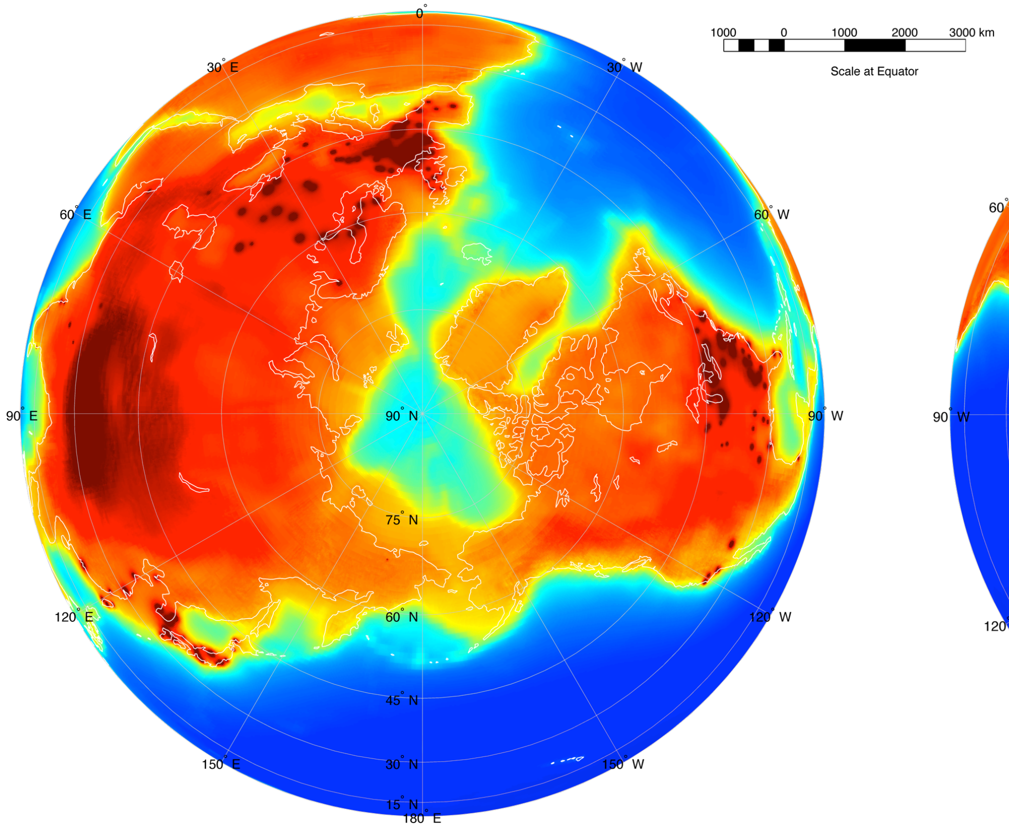
Detailed mapping of ν flux from declared reactors…

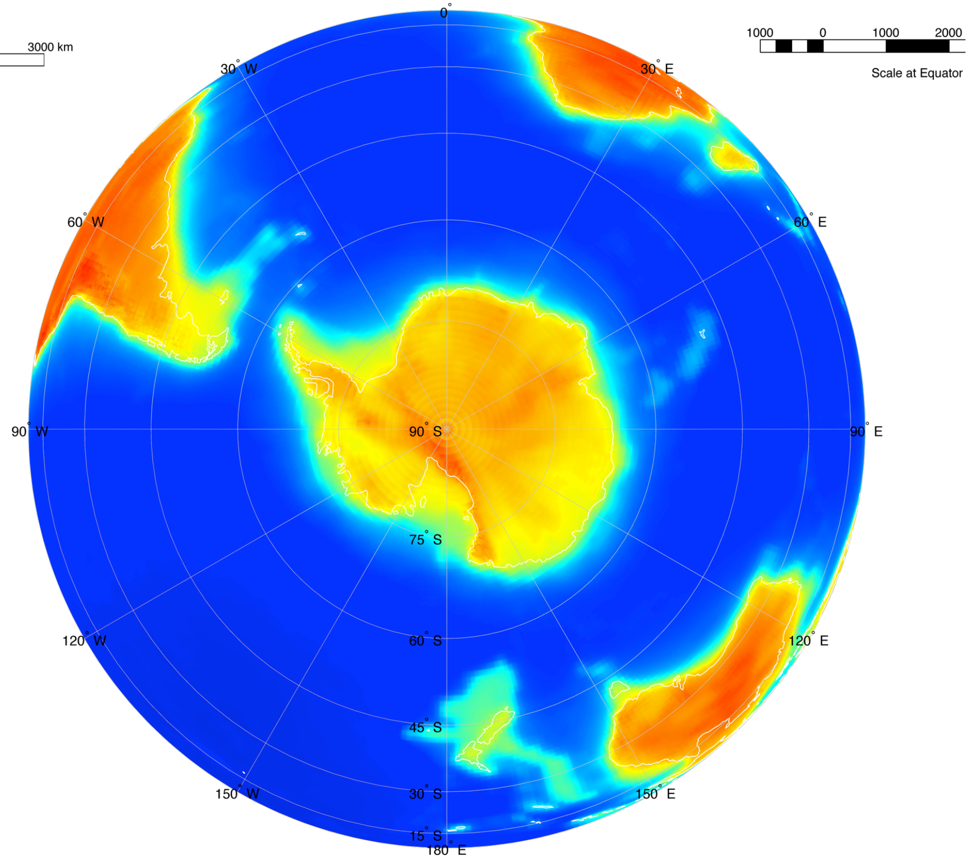




Long Range Measurements

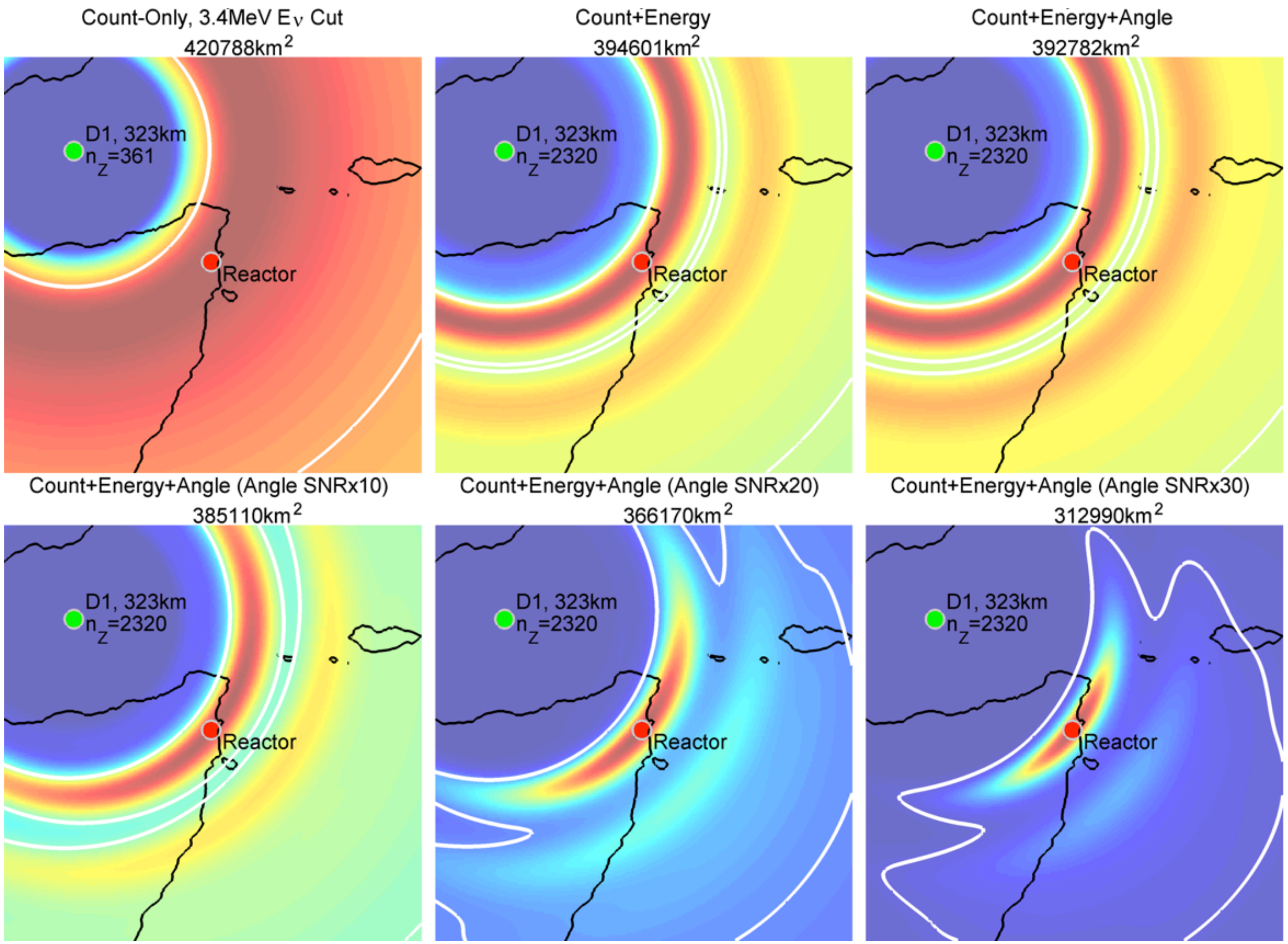
… and Geo-ν background





Long Range Measurements

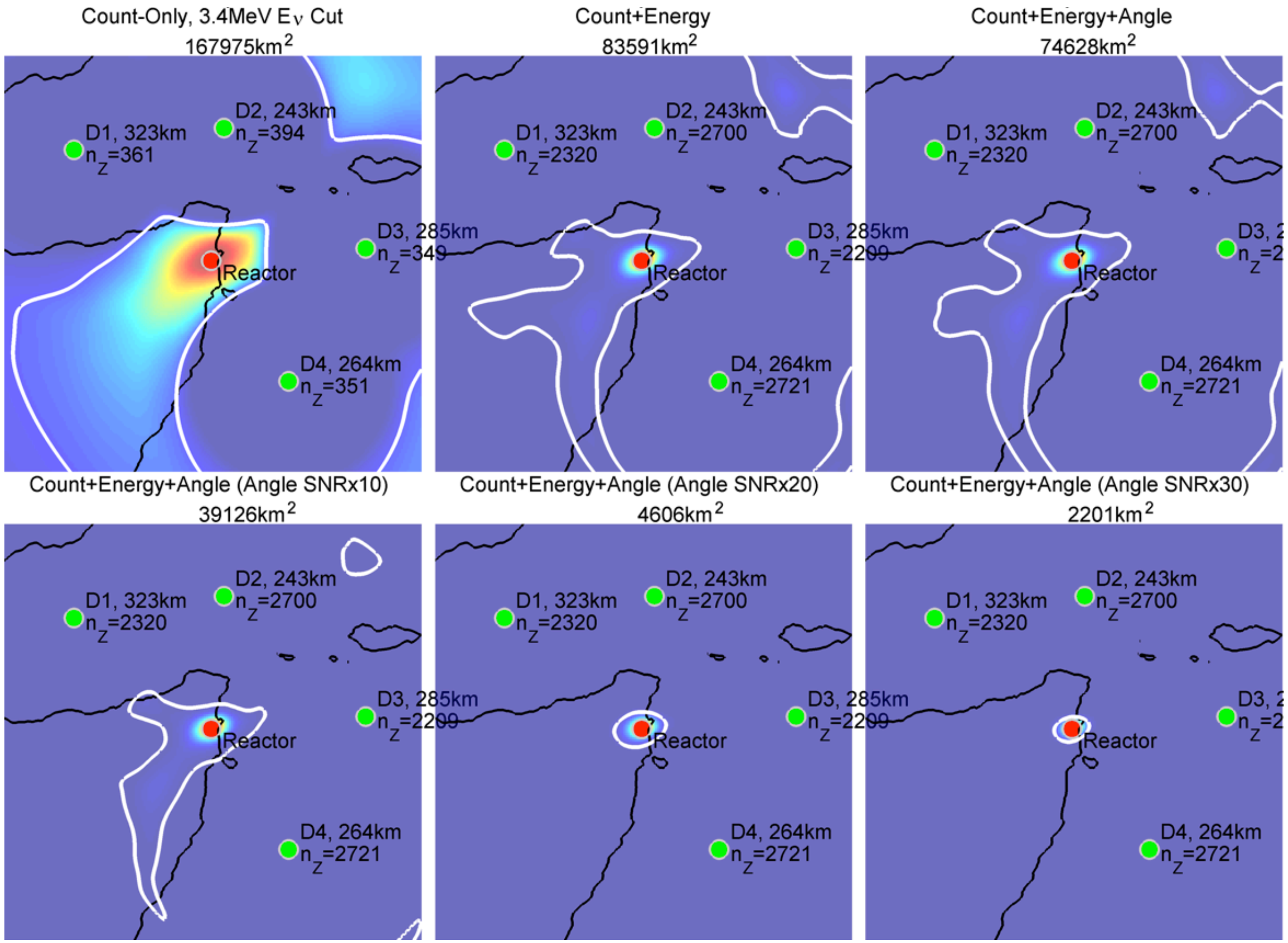
Localization with a single detector using rate + shape + directionality information



90% CL contours in white

Long Range Measurements

Triangulation

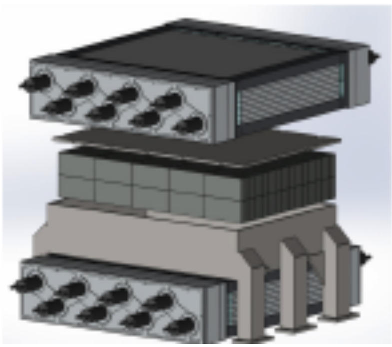


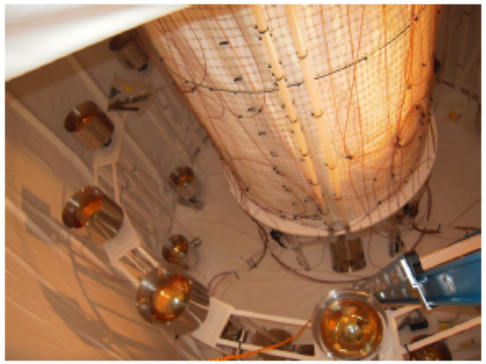
Watchman

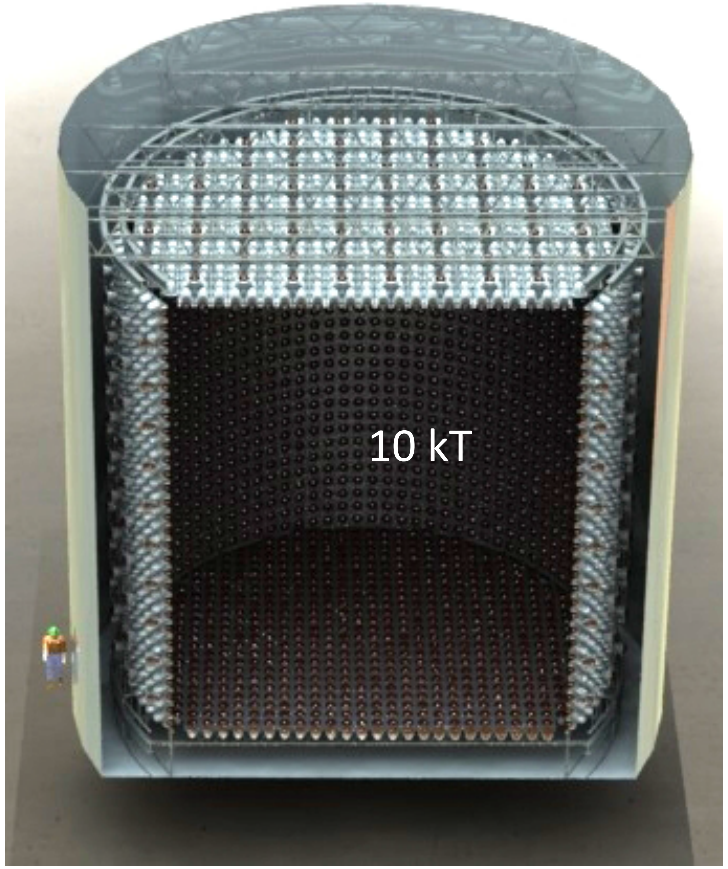
WATer CHerenkov Monitor for Antineutrinos

- Demonstrator for large water Cerenkov detector loaded with Gd.
- Morton salt mine, Ohio, identified as suitable site (old IMB experiment) to validate remote detection of the Perry reactor (13km away)

- Prototypes under test for background studies at the Kimballton mine.

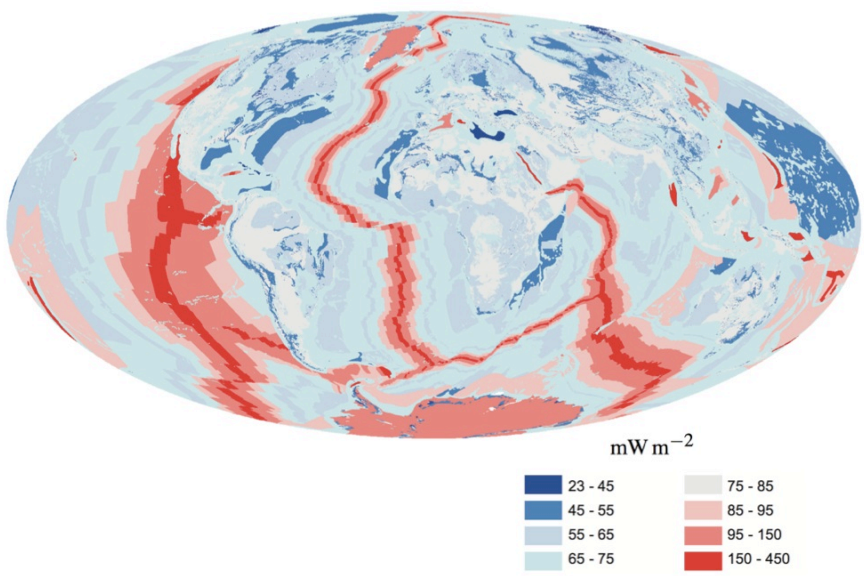


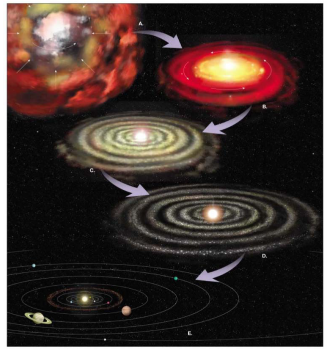


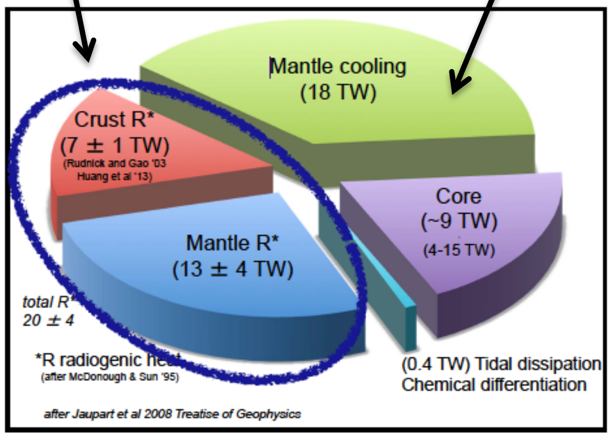


Geo-ν

Surface power loss well measured
47 ± 3 TW



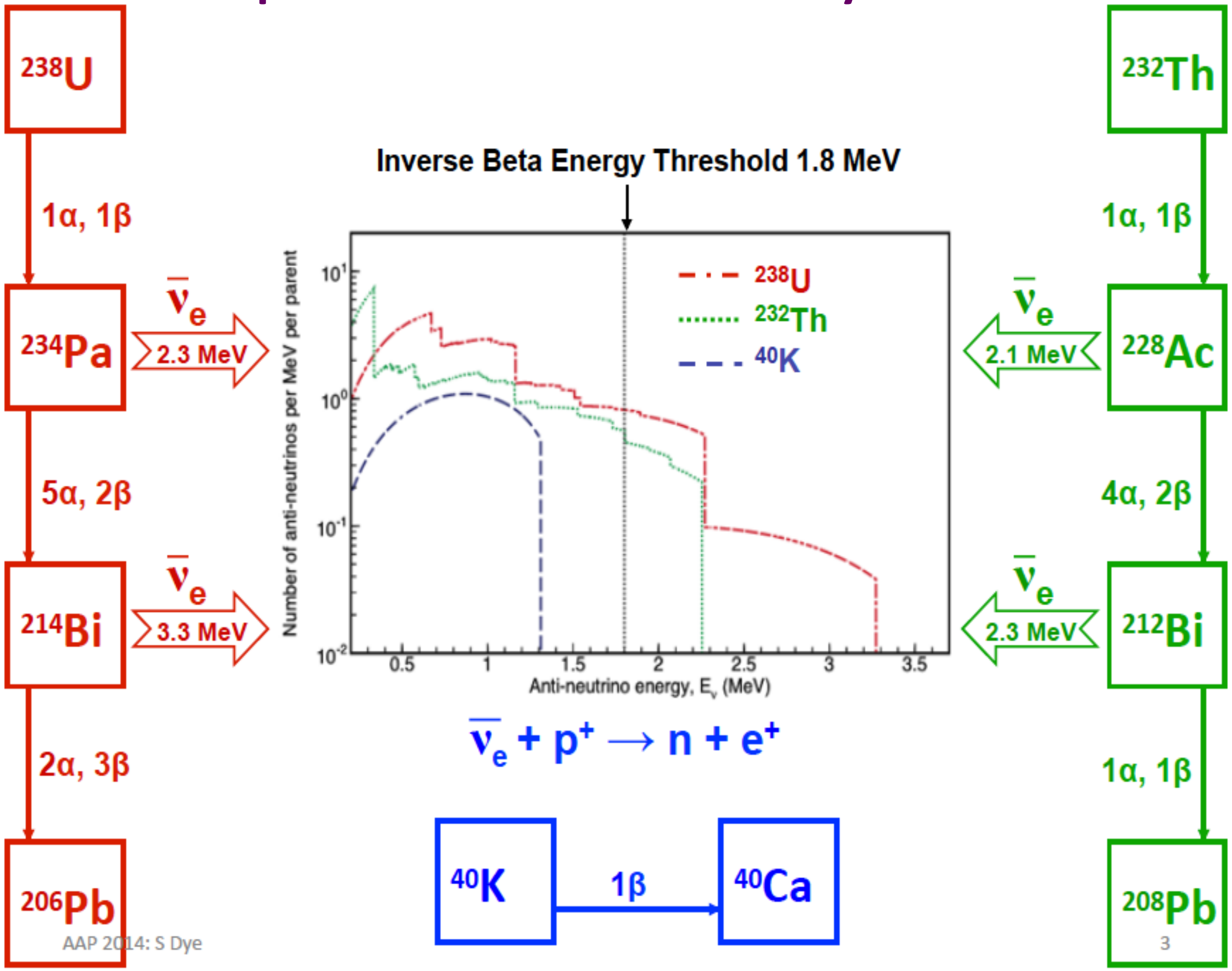




Almost half of radiated power comes from lithophile radioactive elements in mantle and crust

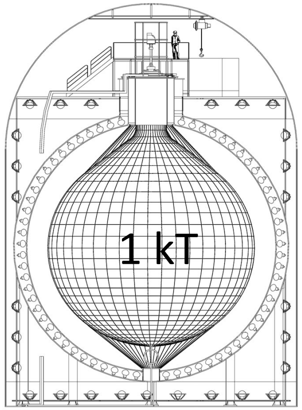
Geo-ν

ν spectra from U and Th decay chains

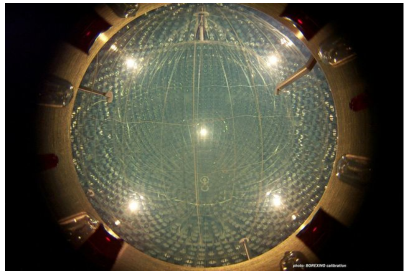


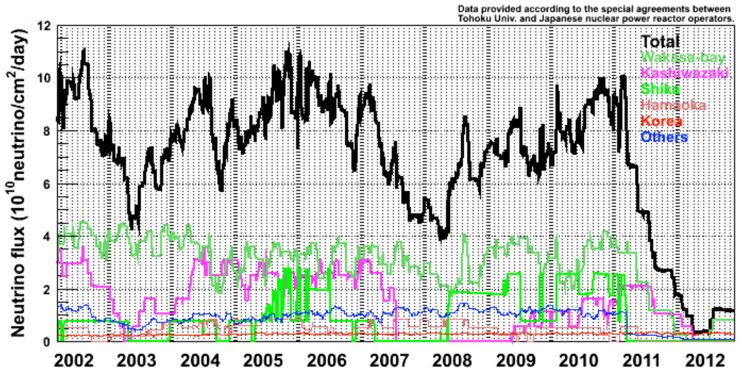
Geo-ν

KamLAND



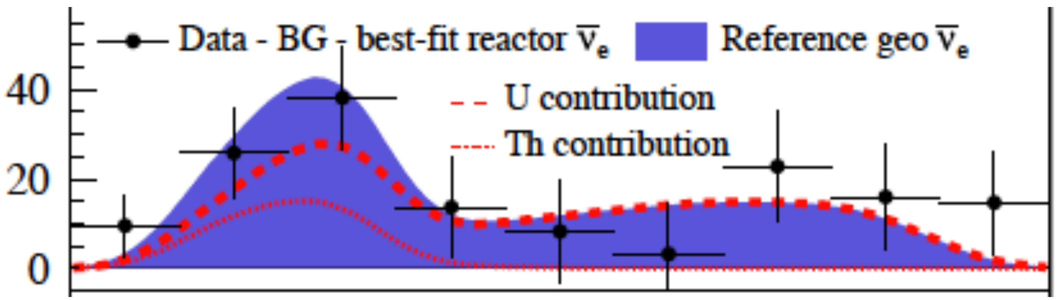
Borexino

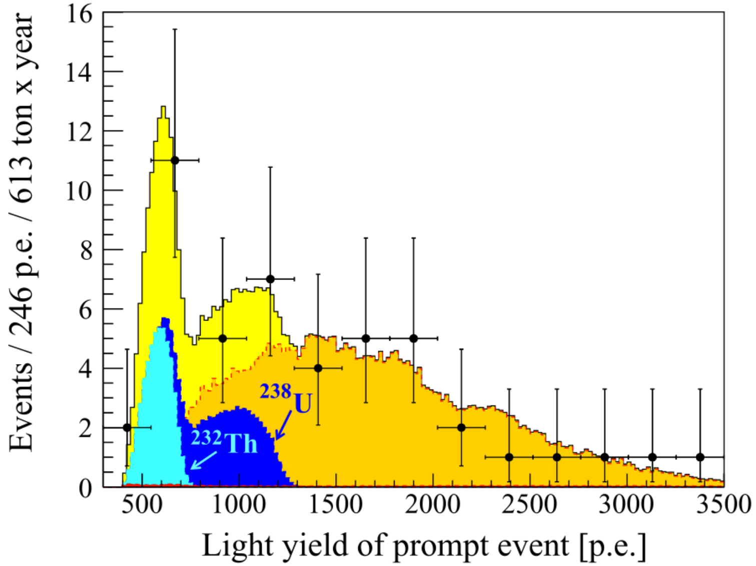




Signal significance > 4 σ

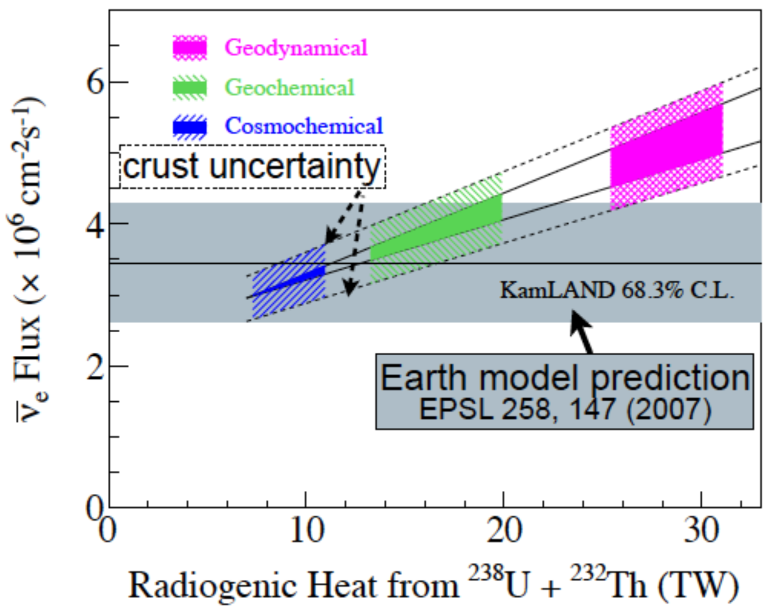
Background = accidentals, $^{13}C(\alpha,n)^{16}O$, ^{9}Li





Geo-ν

- 5 more years of data with KamLAND, Borexino, SNO+



[BSE composition models]

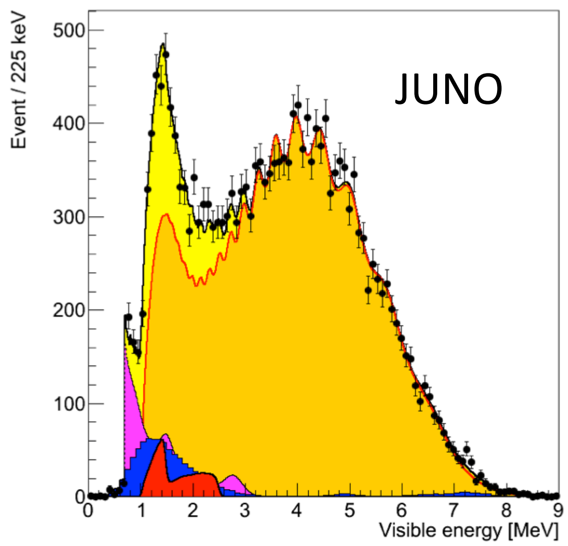
Geodynamical 30TW
based on balancing mantle viscosity and heat dissipation

Geochemical 20TW
based on mantle samples compared with chondrites

Cosmochemical 10TW
based on isotope constraints and chondritic models

- Starts selecting among earth composition models

- Upcoming very large detectors JUNO
  LENA, Hanohano,…



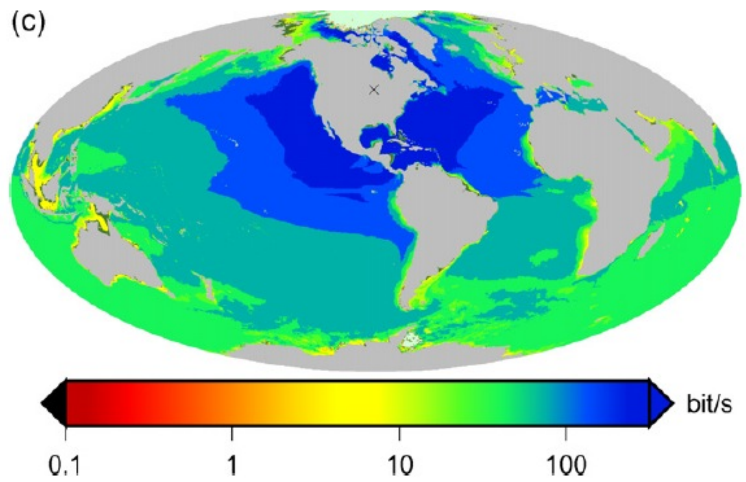
Future Secure Communication (?)

Communication

- May be useful when EM communication is not possible
  - Submarines (earliest proposal)
  - Point-to-point earth communications in the event of catastrophic failure of communications infrastructure
  - Communication with settlements on the back side of the moon in the event of relay satellite failure
- May be useful for secure communications

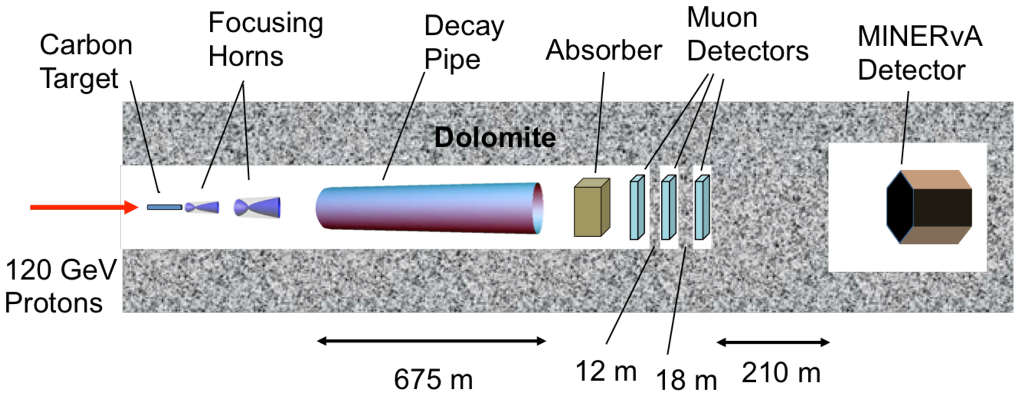
- Estimated data rate for neutrino communication with a submarine, using intense beam from a (future) muon storage ring and detection of Cerenkov light in sea water.

P. Huber, Phys.Lett. B692 (2010) 268-271



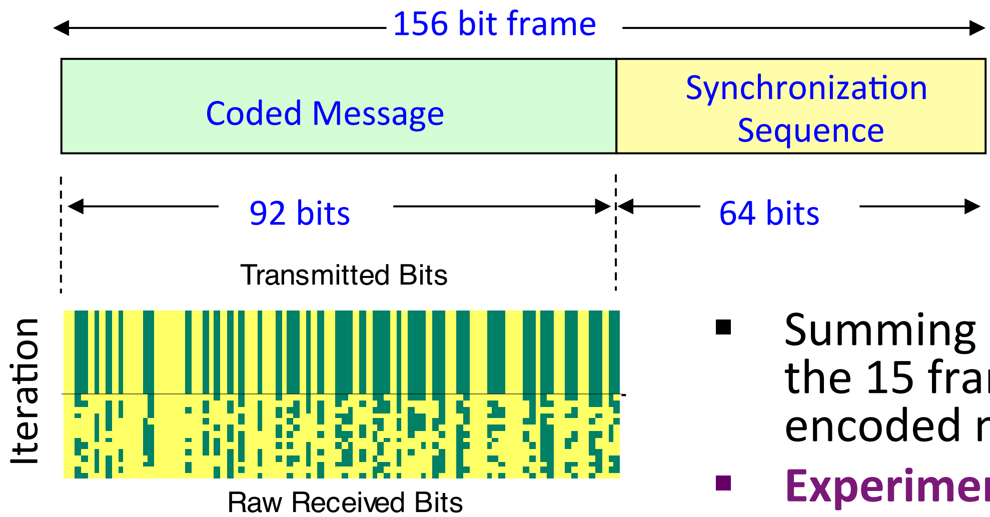
Communication

2010: First experimental demonstration with the NuMi beam at Fermilab



a

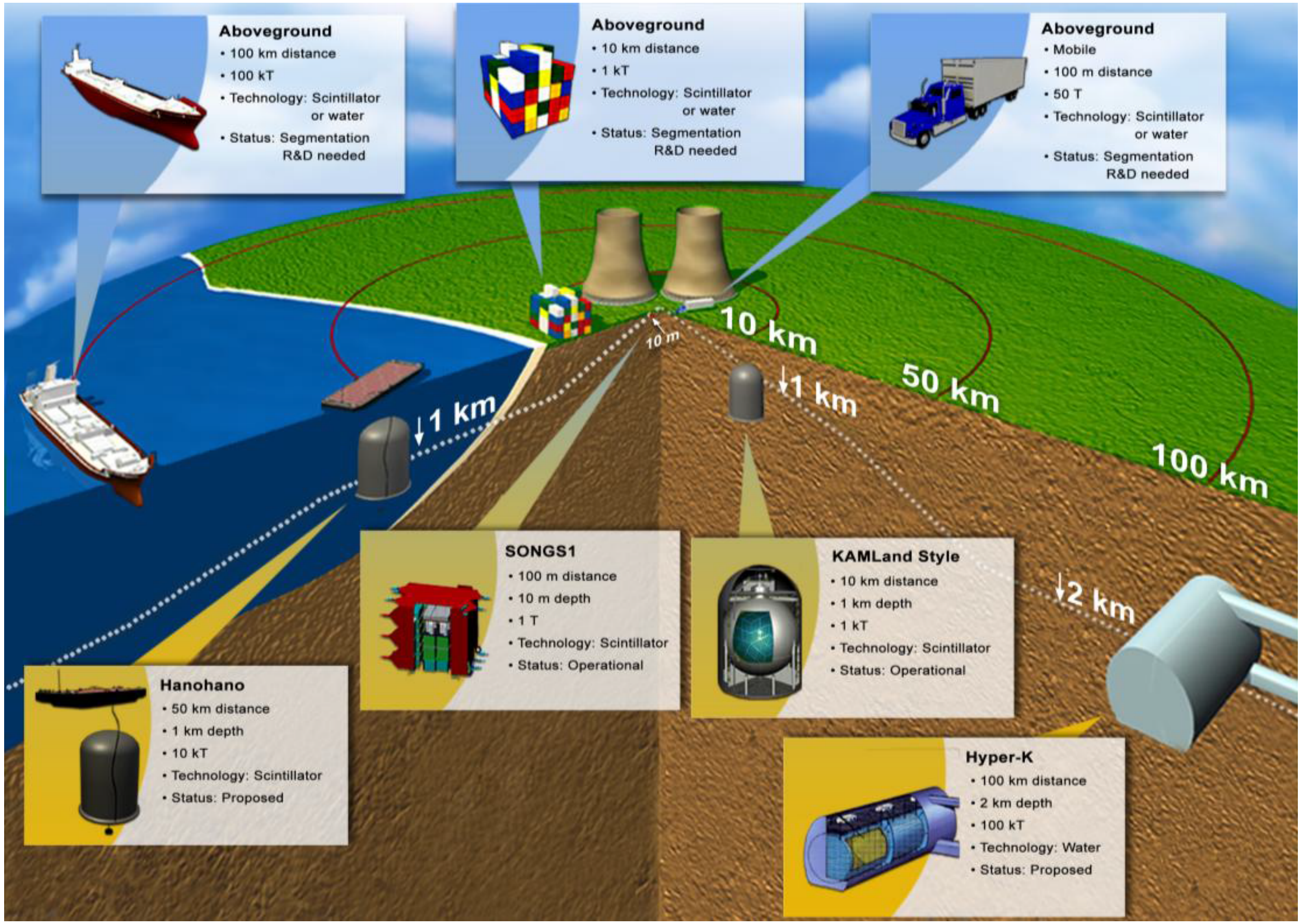
b



Message: “neutrino”

- Summing columns shows that combining the 15 frames correctly recovers 92 bit encoded message.
- **Experimental data rate : ~0.1 bit/sec**

Deployment Scenarios



A. Berstein et al., Sci. Global Secur. 18 (2010) 127-192

Conclusions

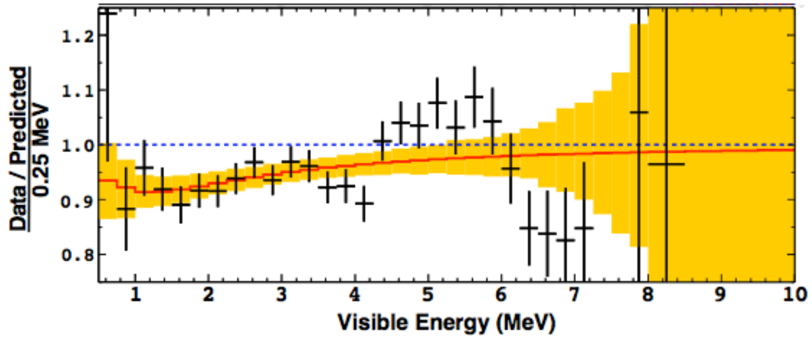
- Synergy between developments of compact neutrino detector at shallow depth for the non-proliferation and sterile neutrino searches at very short baseline.

- Many improved detection technics emerging. Reactor neutrino detection at surface seems within reach with segmented 6Li-doped detectors.

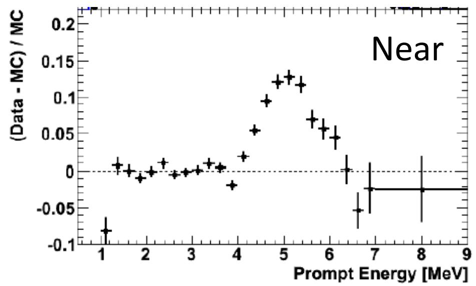
- Exciting next few years in terms of neutrino detection for applications and fundamental physics

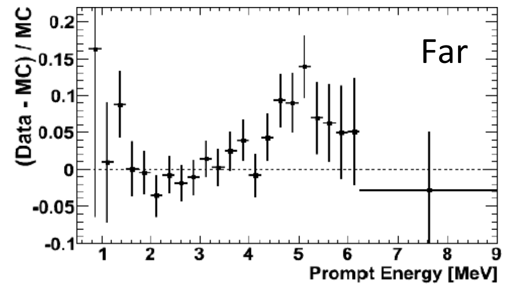
Convergent Signs of ν Excess at 5 MeV

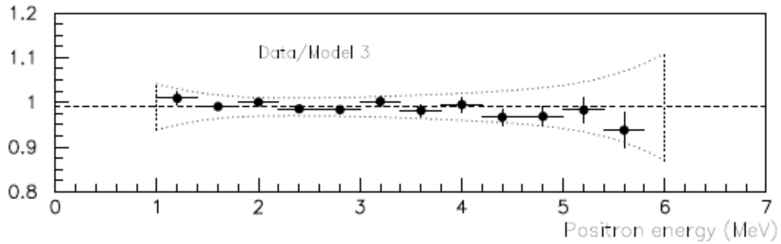
Double Chooz, this conference



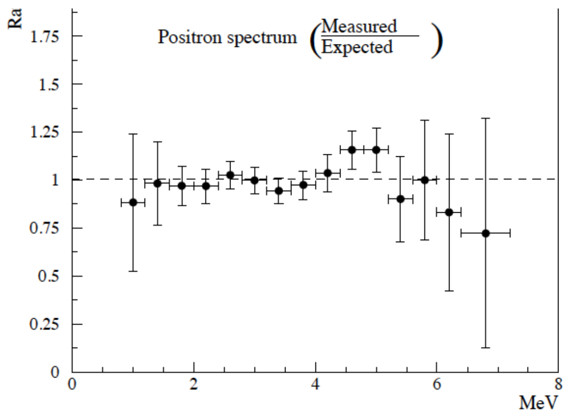
RENO, this conference



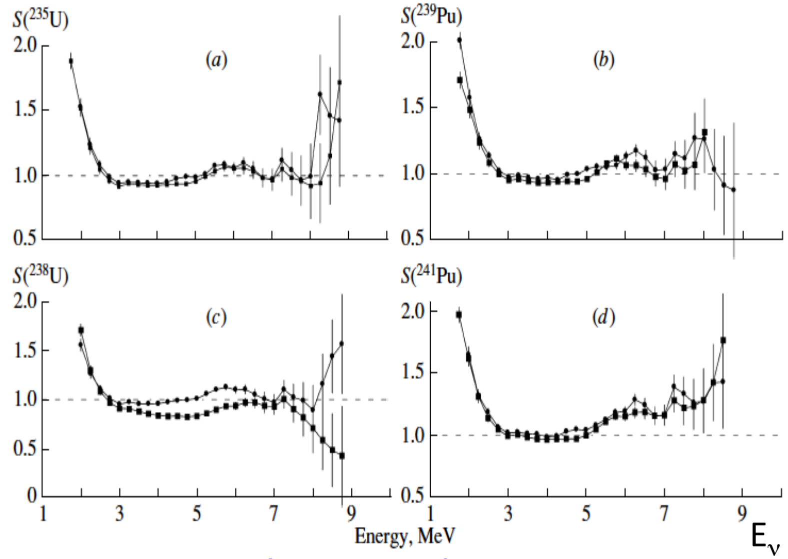




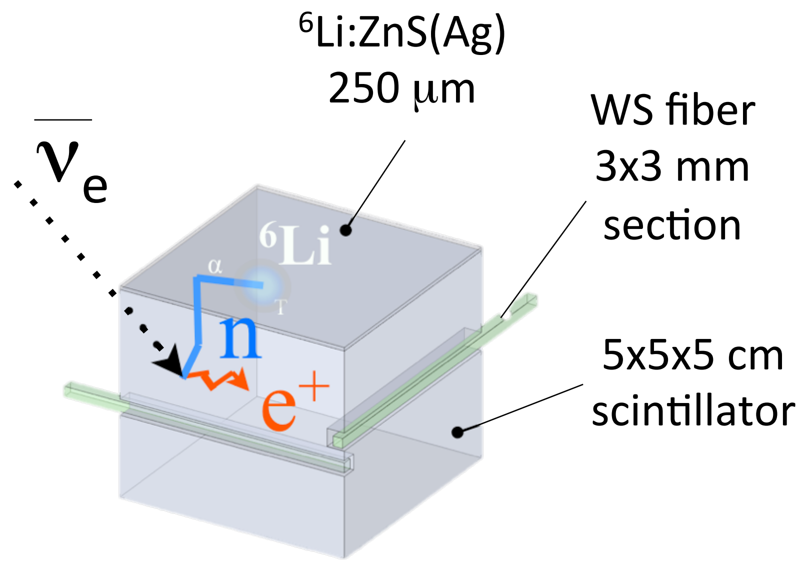
Bugey, Phys.Lett. B374 (1996) 243-248

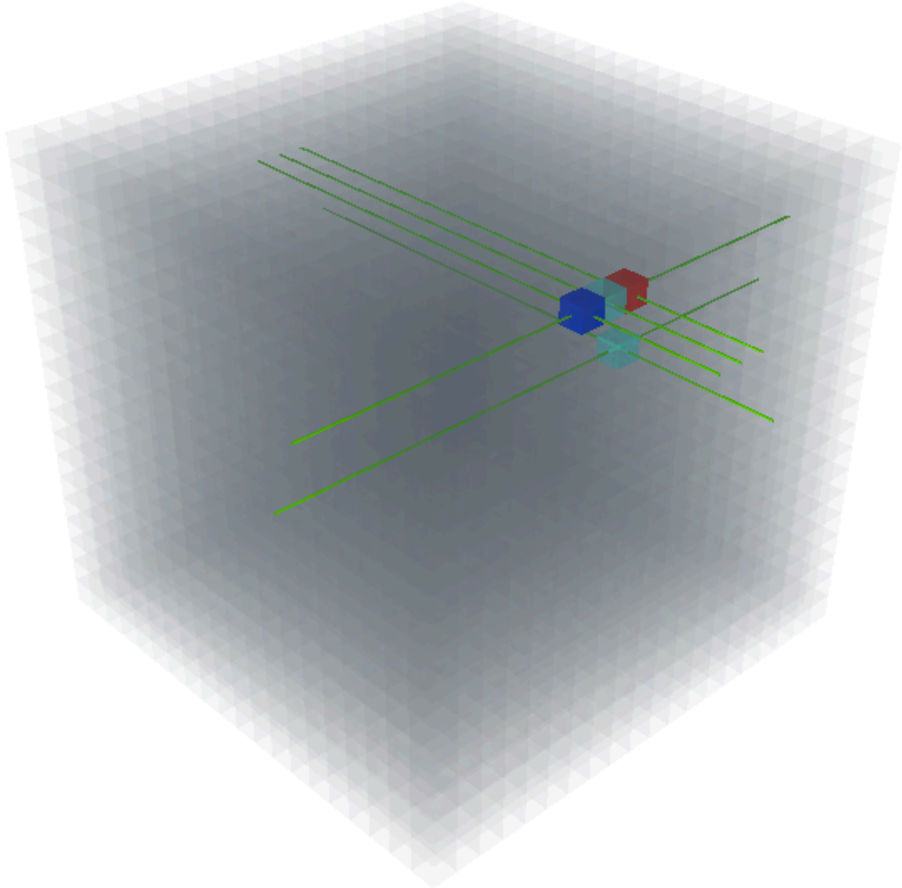


CHOOZ,
Phys.Lett. B466 (1999) 415-430



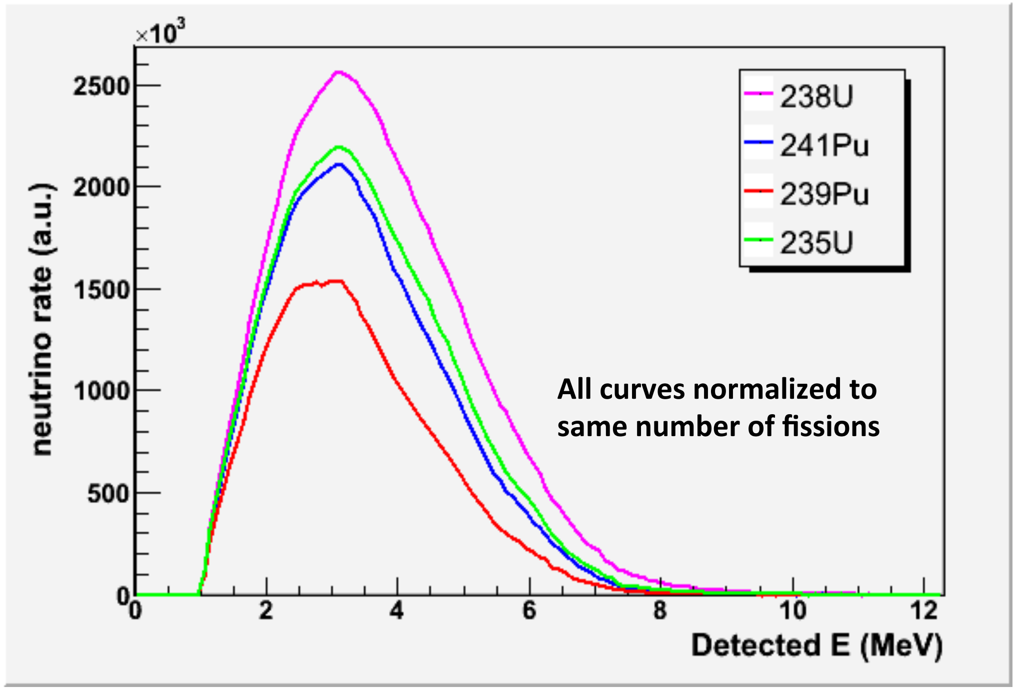
Rovno, V. Sinev, arXiv:1207.6956


$^6Li:ZnS(Ag)$
250 µm
WS fiber
3x3 mm
section
5x5x5 cm
scintillator
$\bar{\nu}_e$
^6Li
α
n
e^+



Principle of Reactor Surveillance with Neutrinos

	^{235}U	^{239}Pu
E / fission	201.7 MeV	210.0 MeV
$< E_\nu >$ (E_ν>1.8 MeV)	2.94 MeV	2.84 MeV
# ν / fission (E_ν>1.8 MeV)	1.92	1.45
$< \sigma_{\nu\ int} >$	≈ 3.2 10^{-43} cm^2	≈ 2.76 10^{-43} cm^2



For the same released power, pure ^{235}U fissions emit 1.6 times more ν than pure ^{239}Pu

$$\frac{\#\nu\ \text{int}\left(^{235}U\right)}{\#\nu\ \text{int}\left(^{239}Pu\right)} = \frac{210.0}{201.7} \times \frac{1.92}{1.45} \times \frac{3.2}{2.76} = 1.60$$

Few % Accuracy @ Reactors

- **High statistics**
  - Intense source
  - Very short baselines available

- **Variety of reactor sites**
  - Compact sources at research reactors vs powerful commercial reactors
  - Large range of E (1-8 MeV) and L (5-20 m) covered
  - 93% to 4% enriched nuclear fuel

- **Predicted reactor spectrum**
  - What shape?

- **Challenging background mitigation at shallow depths and very short baselines**

→ Review the detection technics of current projects

Korean Experiment

Reactor candidates

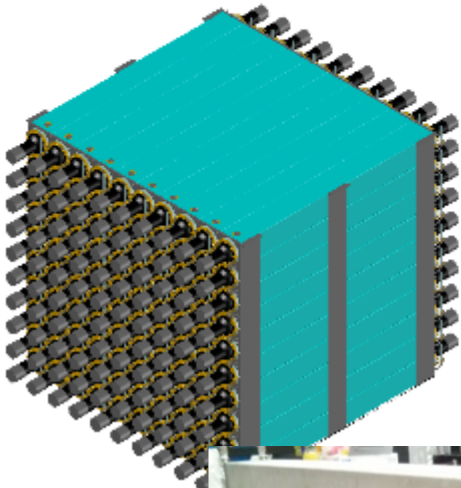
Reactor	Baseline [m]	Thermal Power [GW]	ν events / day	Overburden [m.w.e.]
Hanaro	6	0.03	179	-
Younggwang	24	2.8	1052	~ 10
Kijang (2017)	5	0.015	129	~ 20

Hanaro

Younggwang

Segmented detector

- 11x11x100 cm^3 cells
- Gd (or 6Li)-loaded LS
- 3” PMT
- 10x10 cells (~1 ton target)

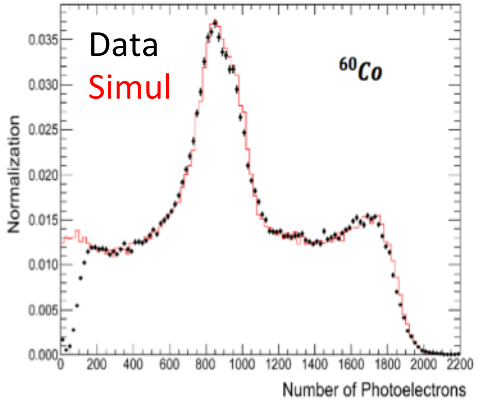


Korean Experiment

Prototype detector

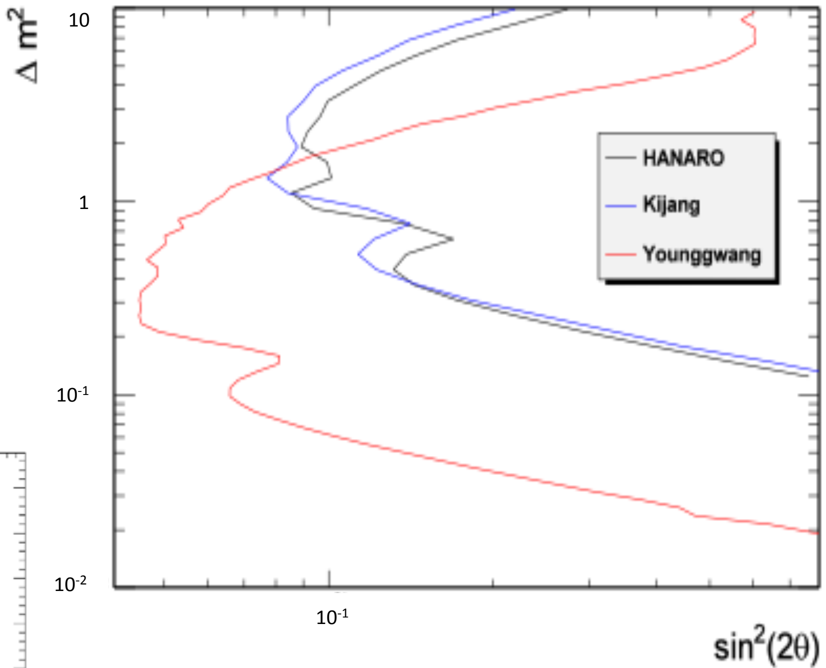
- 50 l of Gd-LS inTarget, 6 PMTs (8")
- 10 cm Thickness lead for passive shield
- 4π muon detector with liquid scintillator
- 670 pe/MeV

- R&D on ^{6}Li-loaded LS and PSD capability



Final installation and data taking in spring 2015

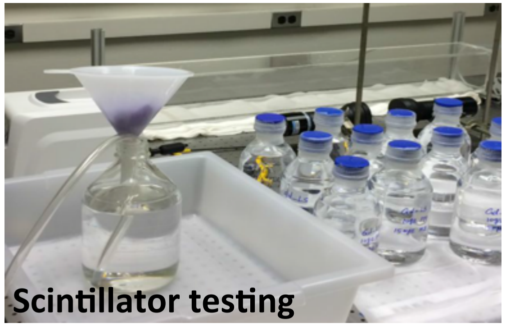
Sensitivity



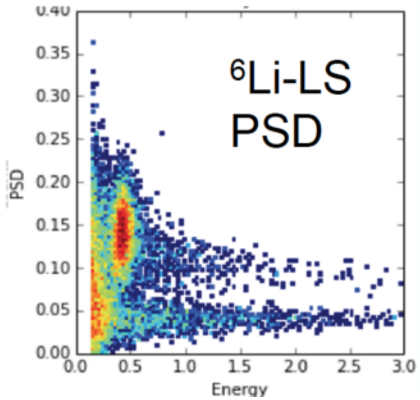
- **500 L of target**
- **1 year data taking**
- **S/B ~ 1: 1 @ Hanaro**
- **Detection and spectrum syst. included**

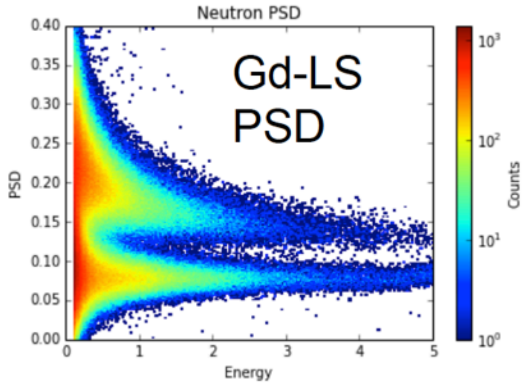
PROSPECT – Development and R&D

Scintillator Development



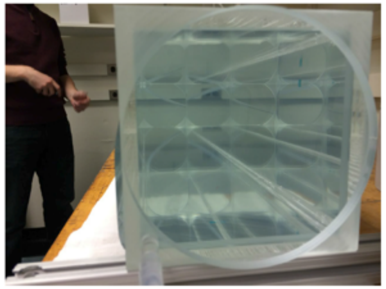
LS development

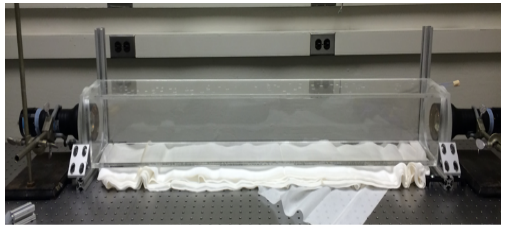




Prototype Detector Development

Large Cell PSD tests





Background Measurements at Reactor

Few mwe overburden

Detector and Background Simulations