Progress towards Aboveground Detection by the AAP Community and the Challenges Ahead

N. Bowden

December 16, 2014

Lawrence Livermore National Laboratory

LLNL-PRES-665404

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

Outline

- My charge from the organisers: describe the *"challenges performing a rate+shape neutrino measurement with an above ground detector, applied to reactor safeguards"*

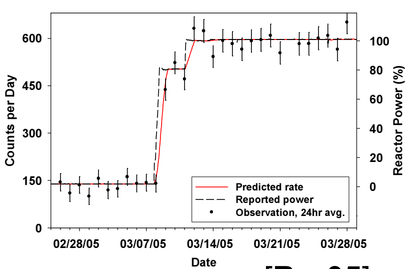
- The monitoring capabilities we seek to develop
- The primary challenge: cosmogenic background
- A brief review of aboveground detection concepts, some current projects, and the challenges they face
- Outlook and Conclusions

Monitoring Capabilities

- A wide range of monitoring capabilities are possible using reactor antineutrino detection
- With increasing capability comes greater system complexity and requirements on Signal:Background

Short-term rate

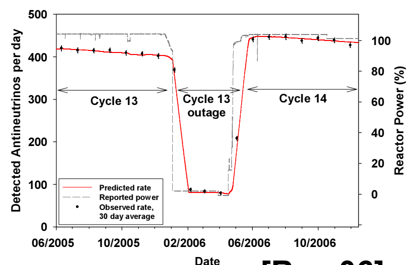
Verify Operational Status



[Ber05]

Long-term rate

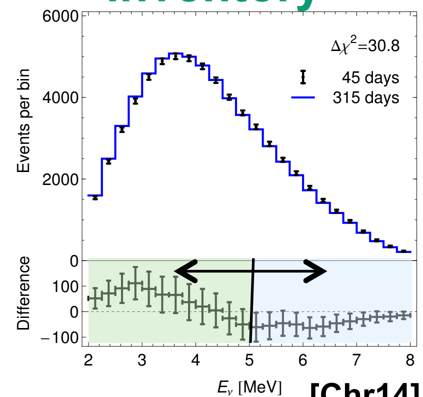
Constrain Operational Parameters



[Bow06]

Rate + shape ratio

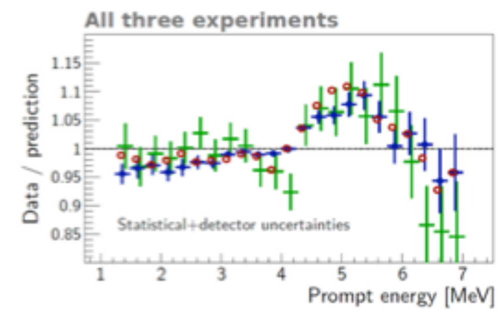
Estimate fissile inventory



[Chr14]

Rate + detailed shape

Improved fissile inventory estimate?



System complexity, Signal:Background, Capability

hours to weeks	weeks to months	months to years	months to years

Mode de Déploiement

- This community has long recognized that aboveground deployment would enable much greater portability and versatility. Important recent studies assume this mode.

6.2. Medium Term:

inspector needs in some specific areas of reactor safeguards. To further expand the utility of antineutrino detectors, several useful medium term (5-8 year timeframe) R&D and safeguards analysis goals are proposed.

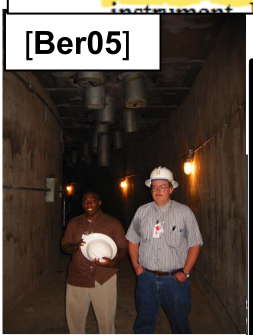
1. Above ground deployment. Above ground deployment will enable a wider set of operational concepts for IAEA and reactor operators, and will likely expand the base of reactors to which this technology can be applied;

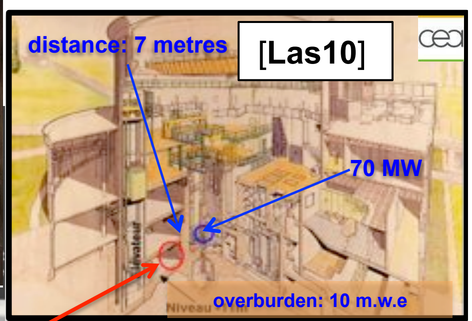
antineutrino detectors. .In this regard, a possible deployment scenario is envisaged where the component parts of the detector, shielding and all associated electronics are contained within a standard 12 metre ISO container facilitating ease of movement and providing physical protecti

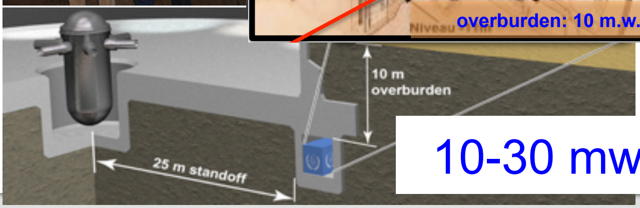
[IAE08]

composition are accounted for. We envisage a system where the whole detector with supporting electronics fits inside a standard 20′ shipping container. Smaller detectors would also work but the times required to achieve the performance we cite would be correspondingly longer. Furthermore, we assume sufficient background rejection capabilities to allow for surface deployment.

[Chr14]

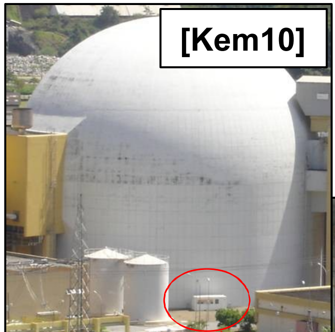


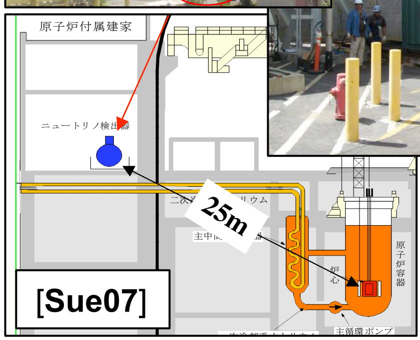




10-30 mwe

Much effort focused on developing an aboveground, or at least near-surface, capability



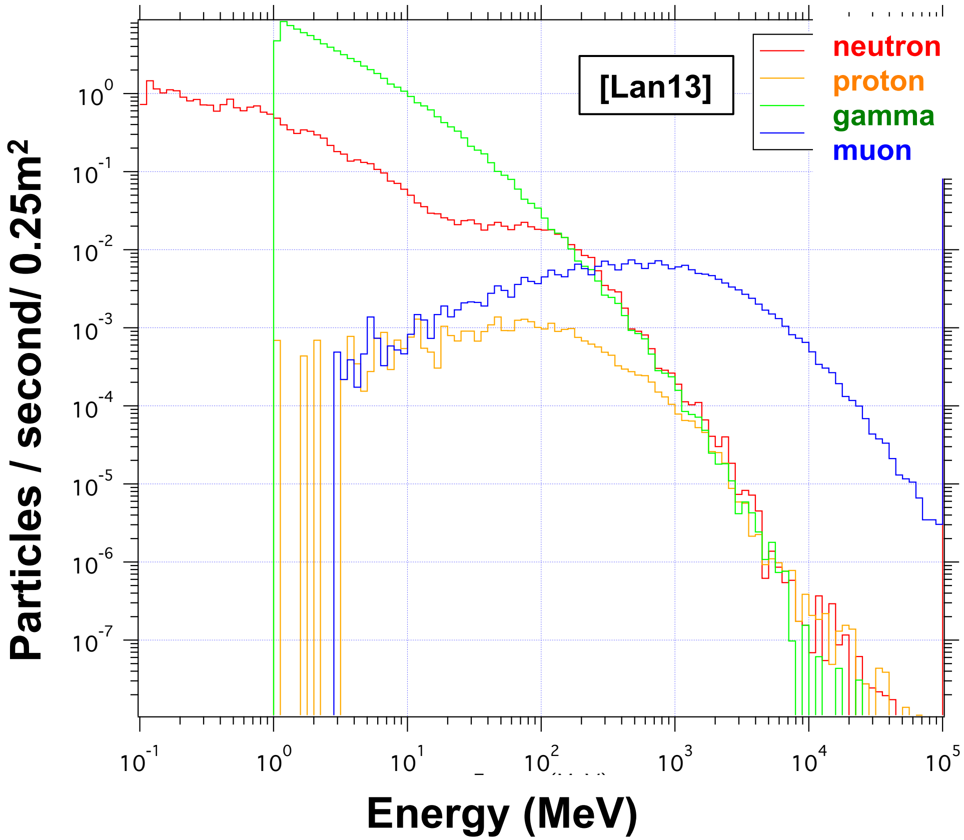


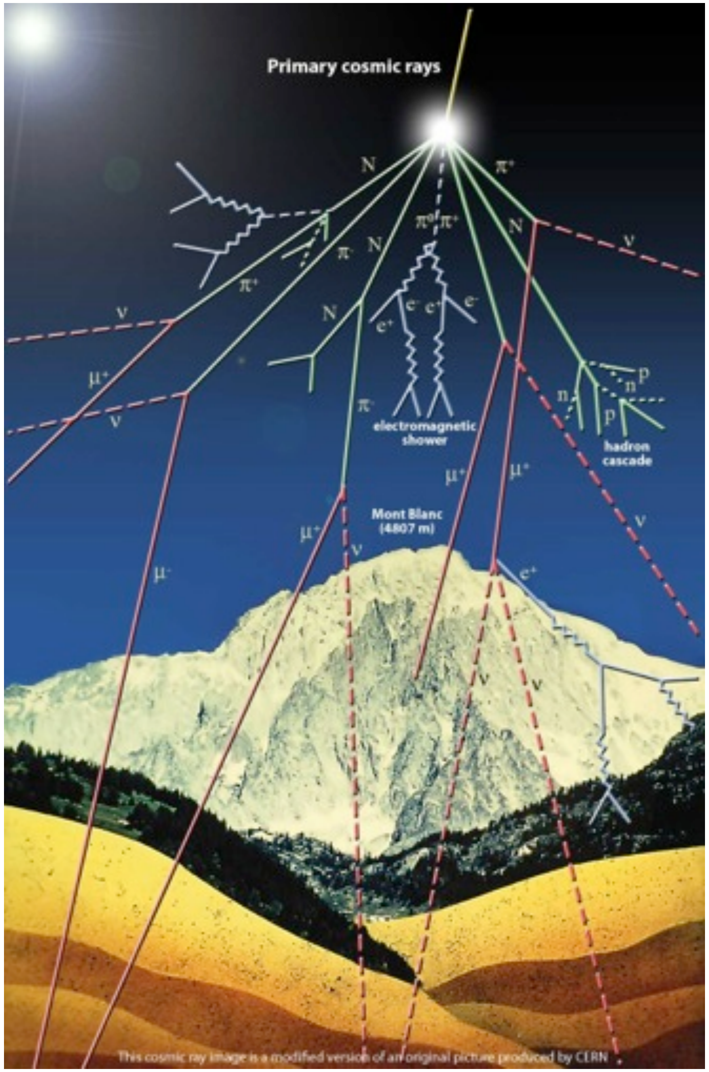
0-5 mwe

The great challenge: cosmogenic background

- At the surface detectors experience all components of the cosmic ray flux

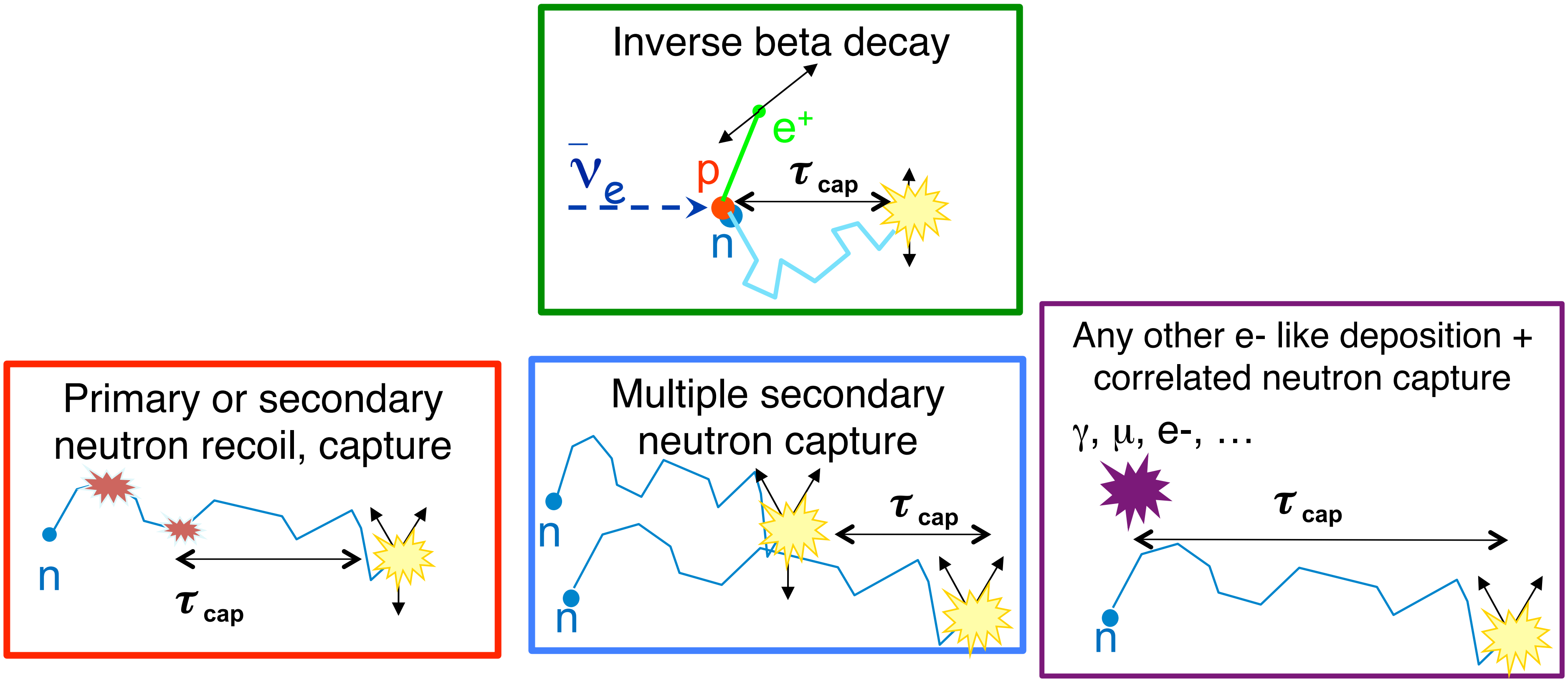
Surface flux prediction from CRY package





The great challenge: cosmogenic background

- In particular correlated background from:
  - Hadronic component of cosmic flux
  - Secondaries produced in the detector *and* its surroundings
  - Of course, accidentals must also be controlled



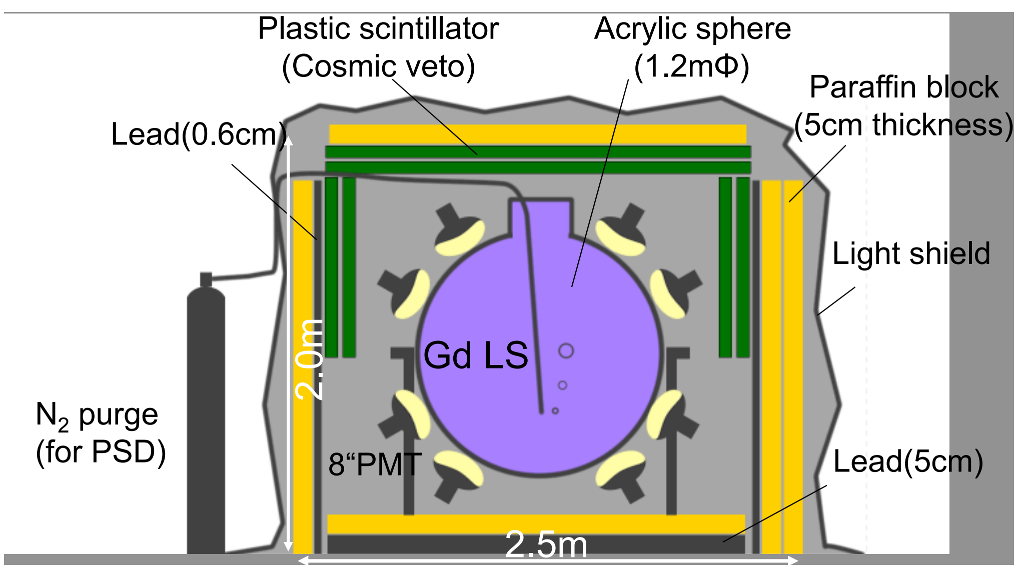
The great challenge: cosmogenic background

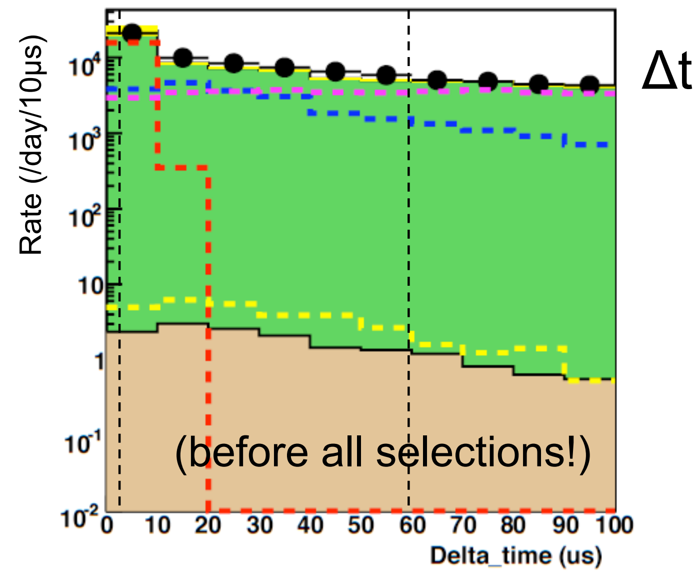
- Cosmogenic background rates simply overwhelm “conventional” detector designs

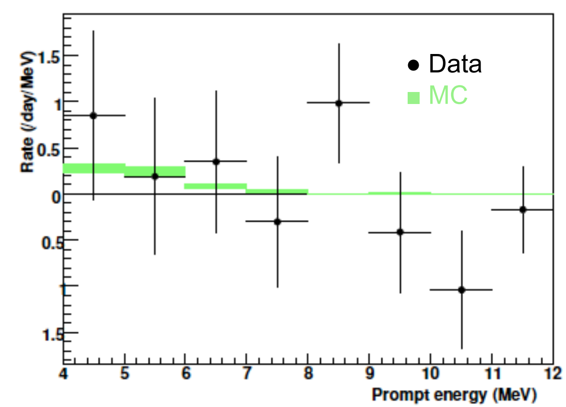
Joyo deployment data and MC prediction

- ● Data (OFF,sheld1)
- ■ Neutrino(MC)
- ■ Total BG(MC)
- - Accidental(data)
- - Michel e⁻
- - Fast n(from outside)
- - Fast n(from inside)

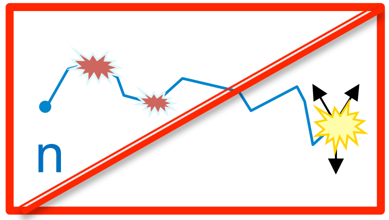
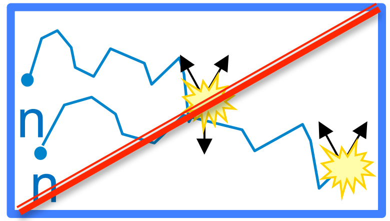
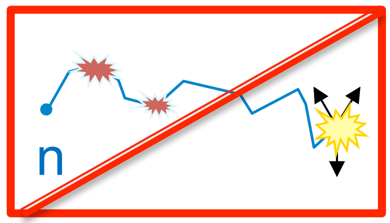
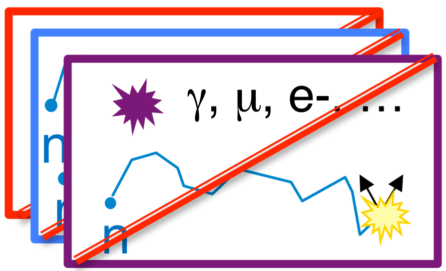
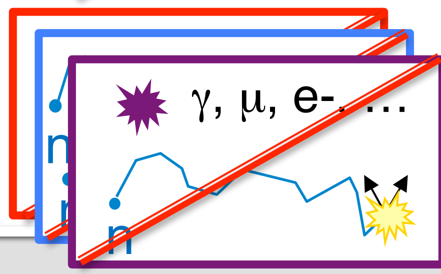
[Fur09]





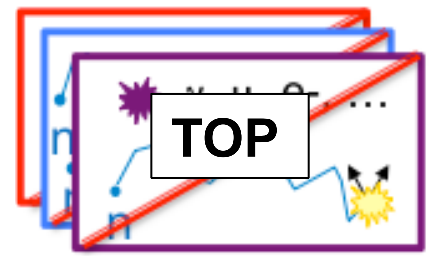


Correlated Background Reduction Techniques

	Pro	Con (*)
Insensitivity: exploit Cerenkov emission threshold dependence on particle mass 	Simple, Effective for bkg class	Narrow rejection capability
Neutron Capture Pulse Shape Discrimination (NC-PSD): explicitly reject multiple NC 	Effective for bkg class	Increased complexity; stronger rejection → reduced signal efficiency; constrains material selection
Fast Neutron PSD (FN-PSD): explicitly reject recoil, capture 		
Topological (TOP): Use spatial pattern of e+, NC, and/or IBD in position sensitive detector (**) (**) Ps detection is temporal variation 	Potentially broad capability	Increased complexity; stronger rejection → reduced signal efficiency
Veto/Fiducializaton (VETO): Use outer active layer(s) to isolate "signal" region 	Potentially broad capability	Increased deadtime, complexity; decreases active volume/footprint

(*) Broad generalisations

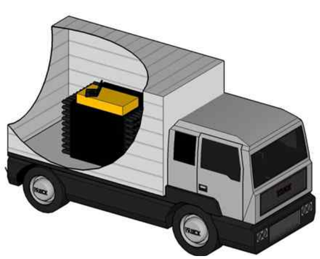
Realizations: Segmented Gd-doped

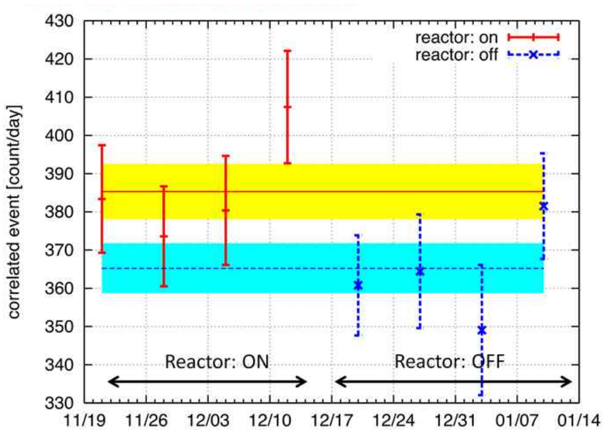


- Depend on topology of Gd shower and e+ annihilation gammas to distinguish signal from background
- In PANDA realization, this results in large efficiency penalty in aboveground environment
- Inhomogeneous geometries result in additional efficiency penalty
- Residual correlated backgrounds very troublesome in detailed reports currently available
- Finer segmentation may help, but at expense of reduced resolution

PANDA

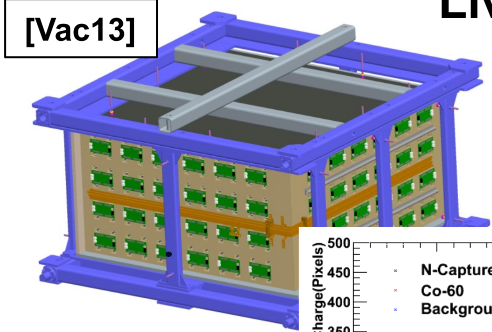
[Oug13]

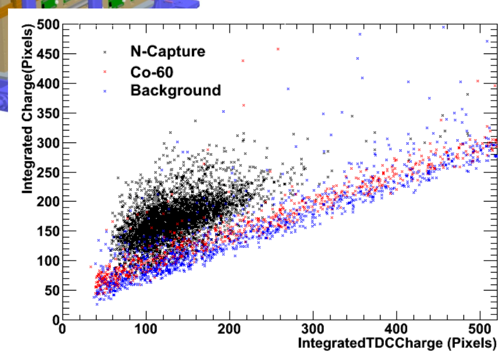




Liverpool

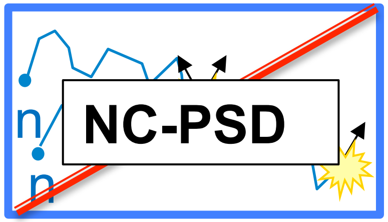
[Vac13]



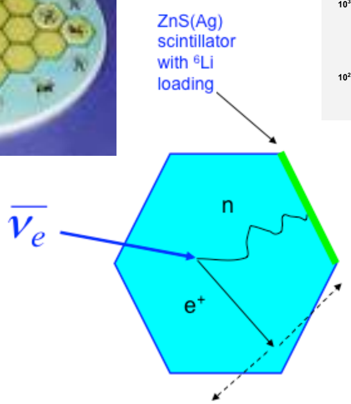


Realizations: Segmented LiZnS

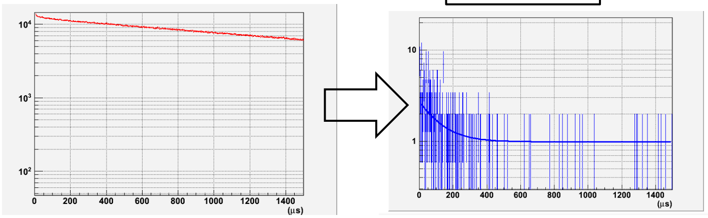
- Use LiZnS for NC-PID and topology for all other rejections
- Inhomogeneous geometries result in efficiency penalty; optical readout systems reduce resolution
- Need for topological selection reduces efficiency; finer 3D segmentation improves efficiency but further reduces resolution
- Good accidental & correlated reductions – next results on background rates awaited!

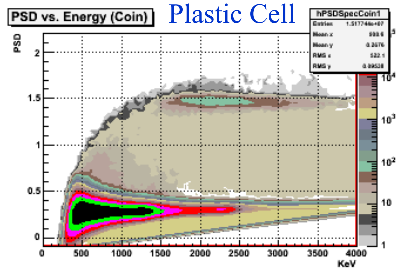


Beehive [Lun06]

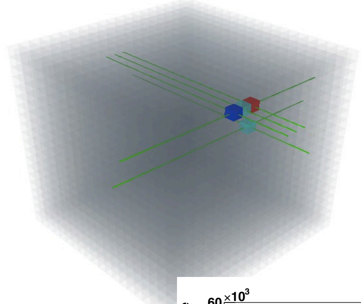


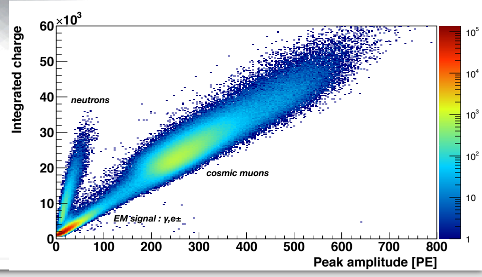
Segmented Scintillator Detector [Rey11]



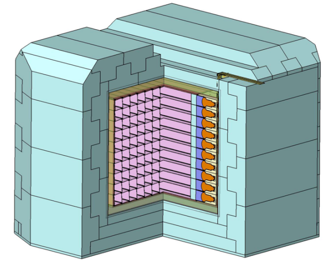


Solid/Mars [Vac13]

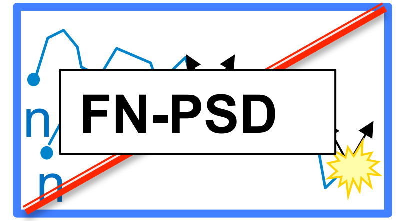


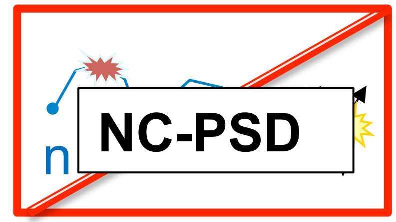


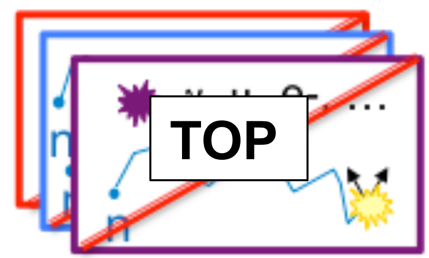
Realizations: PROSPECT

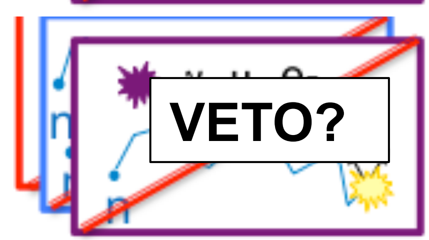


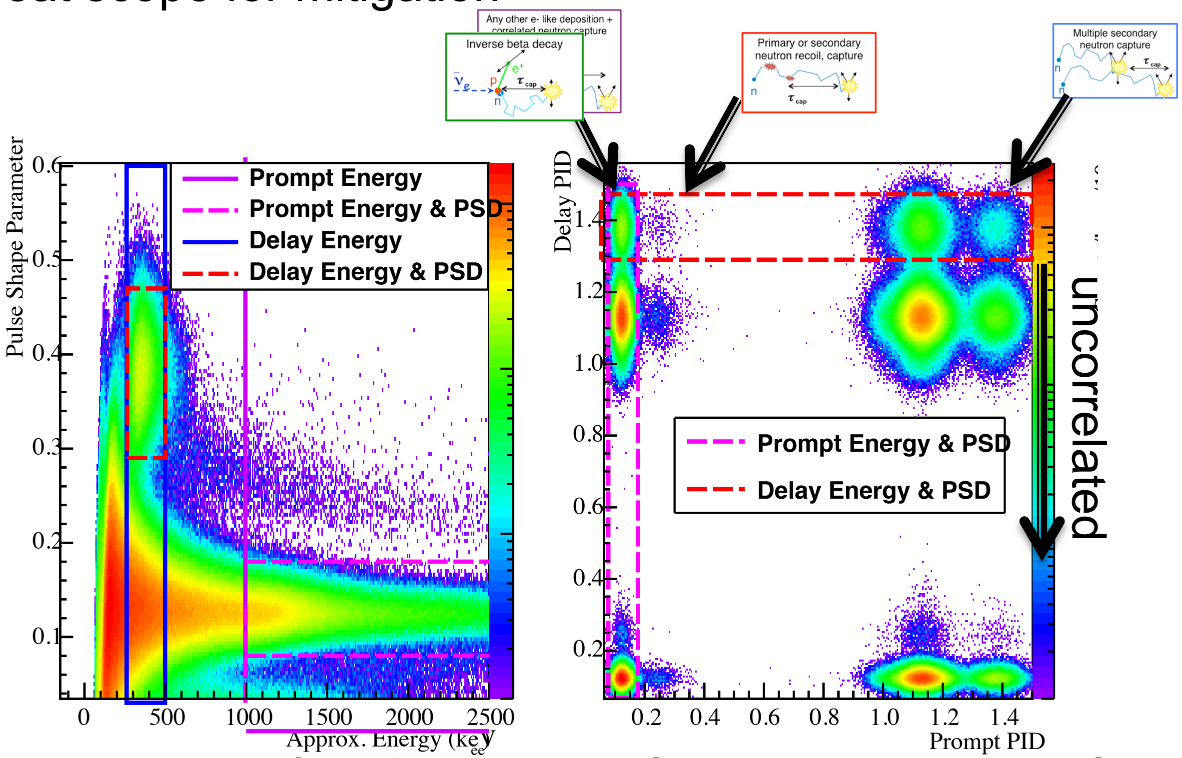
- Rely primarily on PSD selections
- Topology and perhaps veto/fidulization for residual EM correlated backgrounds
- This approach is relatively complex, but will provide detailed information about background generation mechanisms and great scope for mitigation





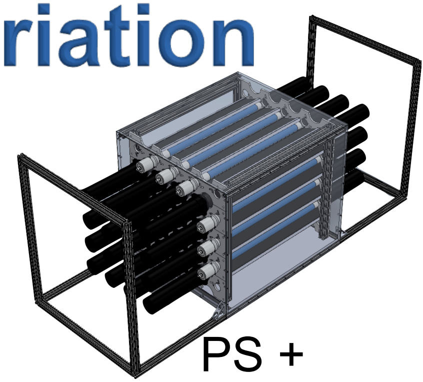






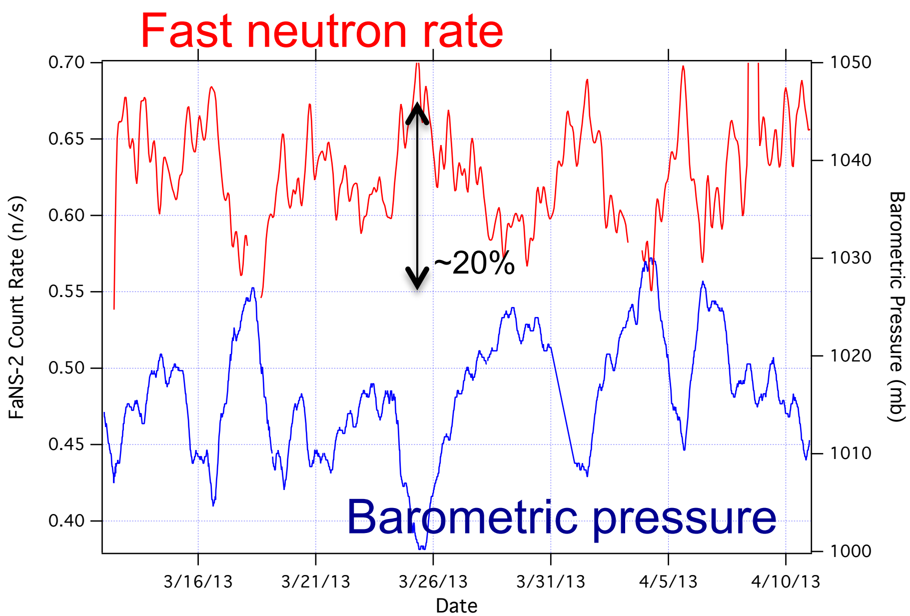
Background data from 3” Li-doped PSD plastic, courtesy A. Glenn

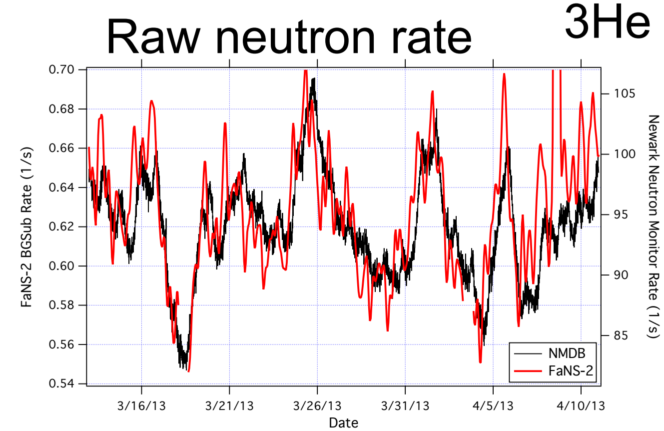
A challenge for all concepts: time variation

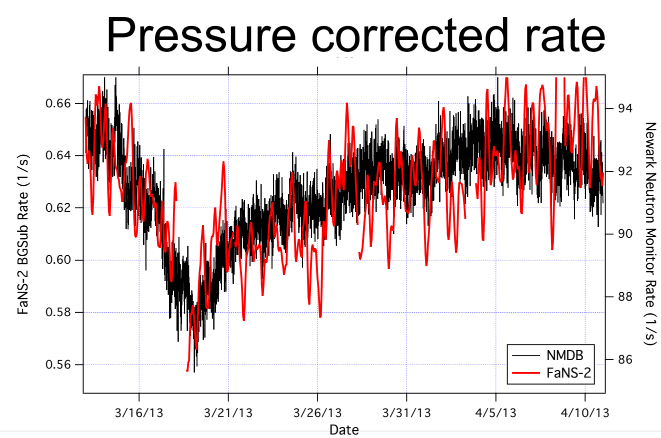


PS + 3He tubes

- Cosmic ray fluxes vary with atmospheric conditions (as noted yesterday) and with solar cycle:
- e.g. fast neutron data from FANS-2 capture gated spectrometer [Lan13]



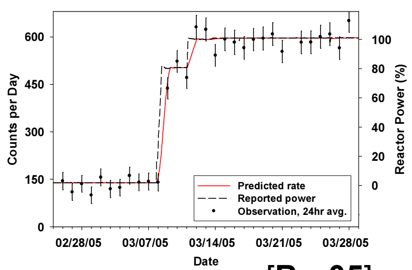




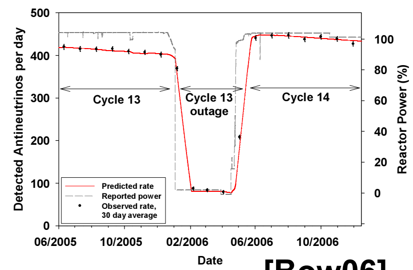
- Must understand relationship with correlated backgrounds and develop monitoring/ correction schemes
- Simple reactor-off subtraction not sufficient

Monitoring Capabilities?

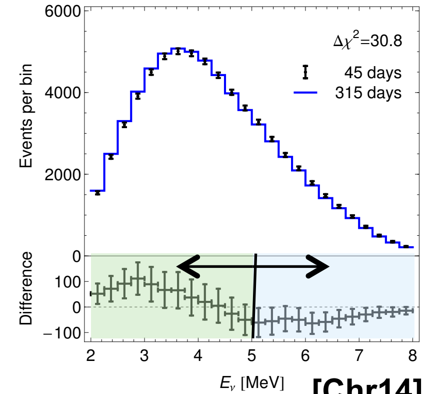
Short-term rate | **Long-term rate** | **Rate + shape ratio** | **Rate + detailed shape**



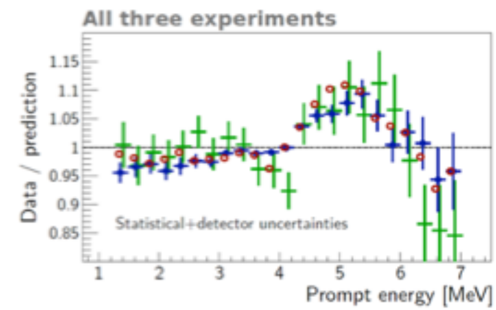
[Ber05]



[Bow06]



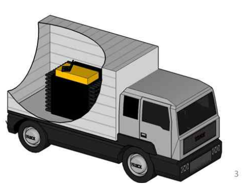
[Chr14]



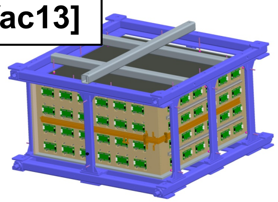
System complexity, Signal:Background, Capability

??

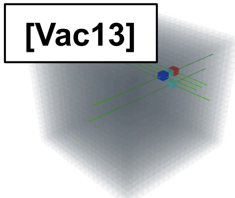
[Oug13]



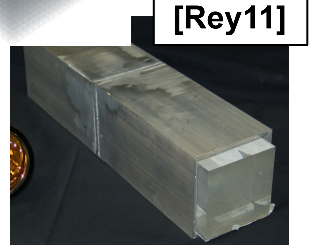
[Vac13]



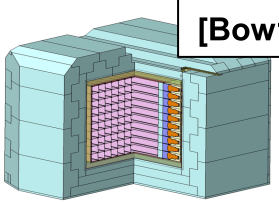
[Vac13]

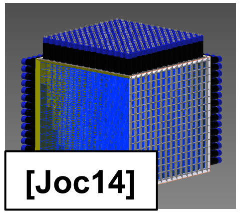


[Rey11]



[Bow14]





[Joc14]

The ***signal:background value*** and ***understanding*** that the various realizations achieve will ultimately determine their capability

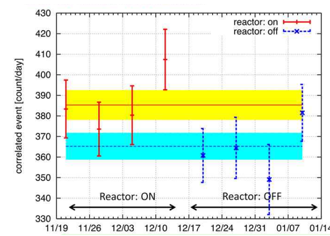
Outlook – data, forthcoming materials and technologies?

- Detailed interpretation of data from ongoing projects will inform design refinements

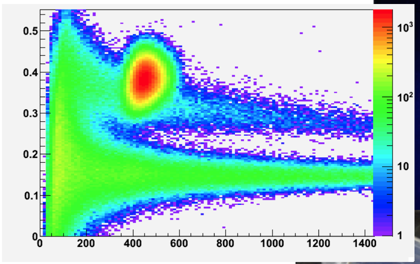
- PSD plastics, once available in large sizes and at reasonable cost, will be ideal for several of the concepts currently under development

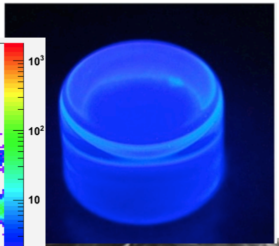
- Doped plastics (Gd and ^{6}Li) will offer increased neutron capture efficiency and reduce (γ,n-capture) correlated backgrounds

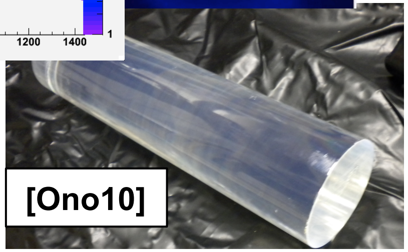
- ….looking to the far future, liquid organic TPCs would provide the ultimate in topological background reduction if realized…

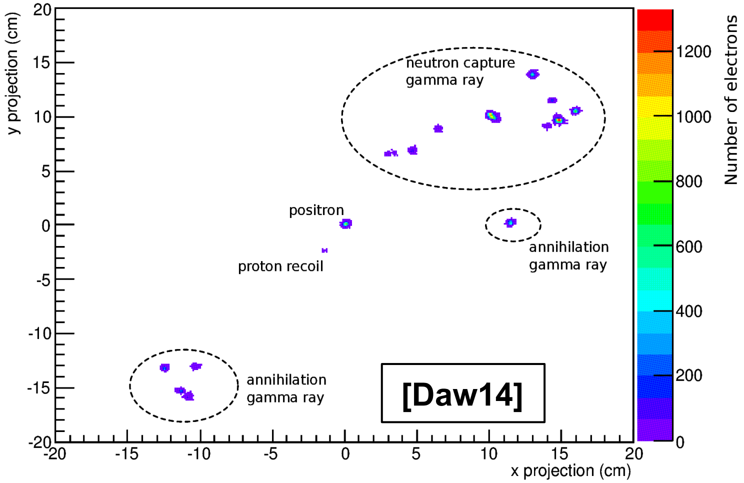


[Oug13]









Conclusions

- This community has long recognized the value of aboveground antineutrino detector deployment for reactor monitoring and there are many serious efforts underway to develop this capability

- The task is very difficult and is yet to be definitively realized

- The diverse range of technological approaches being pursed is a strength – we will learn a great deal from careful comparison of residual background sources in each

- In the near-to-medium term we can expect to learn the S/B that can be reasonably be achieved with existing approaches and to understand the monitoring capabilities that could therefore be provided

- *Everyone should keep up the good work!*

References (in order of appearance)

[Ber05] A. Bernstein, et al, “Nuclear monitoring: Near Field”, Neutrino Geophysics 2005
http://www.phys.hawaii.edu/~jelena/post/hnsc/bernsteinUH121605final.pdf

[Bow06] N. Bowden, et al, “The Safeguards Detector at SONGS”, AAP 2006
http://neutrinos.llnl.gov/workshop/presentations/06_Bowden.pdf

[Chr14] E. Christensen, et al, “Antineutrino monitoring for the Iranian heavy water reactor”, Phys. Rev. Lett. 113, 042503 (2014) http://http://arxiv.org/abs/1403.7065

[IAE08] “Final Report of the Focused Workshop on Antineutrino Detection for Safeguards Applications”, STR-361

[Las10] T. Lasserre, et al, “Nucifer”, AAP 2010
http://www.awa.tohoku.ac.jp/AAP2010/1stDay/lasserre.pdf

[Sue07] F. Suekane, et al, “KASKA and its Prototype ”, AAP 2007 http://www.apc.univ-paris7.fr/AAP2007/Talks/Suekane.pdf

[Kem10] E. Kemp, et al, “The Angra Cherenkov Detector”, AAP 2010,
http://www.awa.tohoku.ac.jp/AAP2010/2ndDay/AAP2010-Angra.pdf

[Rey10] D. Reyna, et al, “Current Attempts at Aboveground Antineutrino Monitoring at SONGS”, AAP 2010,
http://www.awa.tohoku.ac.jp/AAP2010/1stDay/Aboveground_Reyna.pdf

[Lan13] T. Langford, “MEASUREMENT OF THE SURFACE AND UNDERGROUND FAST NEUTRON SPECTRA WITH THE UMD/NIST FAST NEUTRON SPECTROMETERS”, PhD Thesis 2013, http://drum.lib.umd.edu/handle/1903/14895

[Fur09] H. Furata, et al, “JOYO measurement with KASKA prototype detector”, AAP 2009,
http://www.cbpf.br/~angra/files/AAP2009/JOYO%20measurement_H.Furuta.pdf

[Ogu13] S. Oguri, et al, “Reactor Monitoring with a Plastic Scintillator Array”, AAP 2013,
http://indico.cern.ch/event/245969/session/0/contribution/9

[Vac13] A. Vachert, et al, “Status of Developments in UK”, AAP 2013,
http://indico.cern.ch/event/245969/session/0/contribution/12

[Lun06] J. Lund, “An Alternative Design based on Inverse Beta Detection”, AAP 2006,

[Rey11] D. Reyna, et al, “Status of US effort at SONGS”, AAP 2011,
http://aap2011.in2p3.fr/Program_files/AAP_Reyna.pdf

[Daw14] J. Dawson, et al, “Organic Liquid TPCs”, ANT 2014,
http://neutrino.physics.ucdavis.edu/indico/contributionDisplay.py?sessionId=10&contribId=13&confId=7

[Ono10] H. Ono, et al, “Study of plastic scintillator based reactor neutrino detector”, AAP 2010,
http://indico.cern.ch/event/245969/session/0/contribution/12