A Prototype Detector for Observation of Coherent Neutrino-Nucleus Scattering at a Nuclear Reactor

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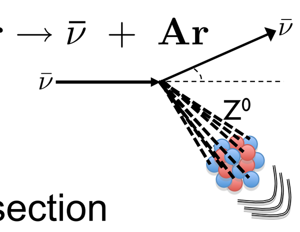
Coherent Neutrino-Nucleus Scattering

Coherent Neutrino Scattering is a neutral current process where an incoming neutrino elastically scatters on a nucleus

$$\bar{\nu} + \mathrm{Ar} \rightarrow \bar{\nu} + \mathrm{Ar}$$



Advantages:

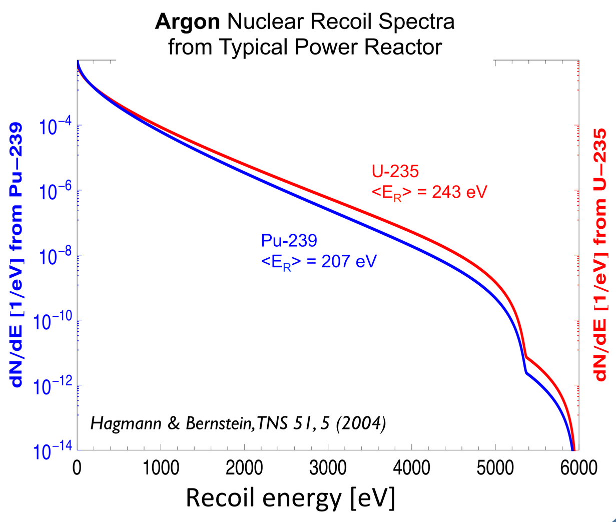
- larger cross section than inverse beta decay
- flavor-blind

Cross section:

$$\sigma_{cs} \simeq \frac{G^2 N^2}{4\pi} E_\nu^2$$

Average recoil energy:

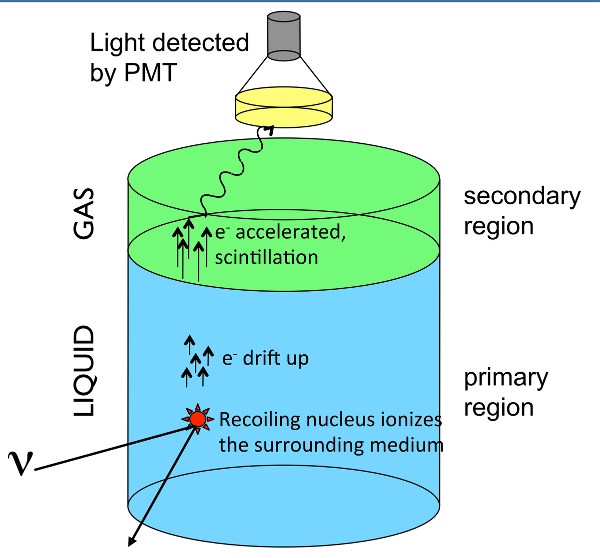
$$\langle E_r \rangle = 716\,\mathrm{eV}\,\frac{(E_\nu/\mathrm{MeV})^2}{A}$$



Detection Technique

- Noble-gas, two-phase (liquid/gas) ionization detector
  - large detector mass
  - low detection threshold
  - scalability
- Similar to those currently developed for WIMP searches

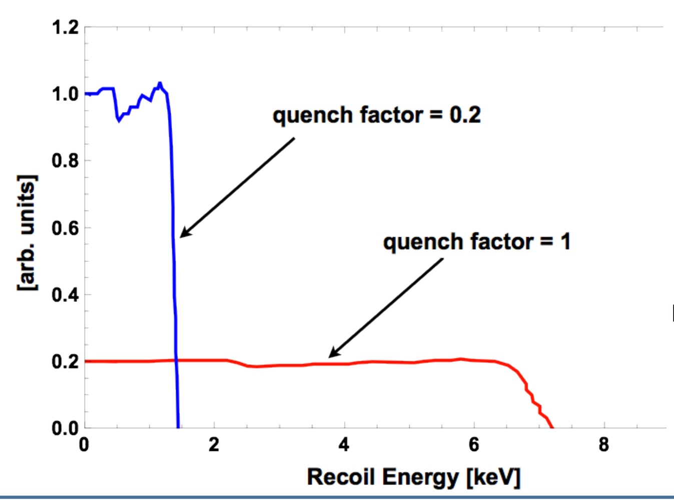
Basic operating principle:
The recoiling nucleus produces ionization in the liquid. The electrons are drifted toward the phase boundary and cross into the gas. The electric field in the gas is high enough so that the accelerated electrons excite the Ar atoms which then produce scintillation light that is then detected by PMTs

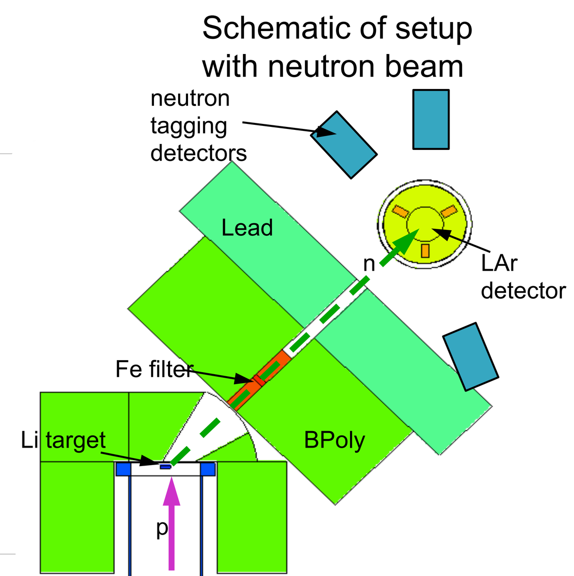


The Critical -Yet Unknown- Ionization Yield for Nuclear Recoils

Recoiling nuclei are less effective in producing primary ionization than electrons of the same energy

- No data for Ar at few keV and below, only MonteCarlo
- Use quasi-monoenergetic neutrons from $^{7}Li(p,n)^{7}Be$ reaction.
- End-point and tagged-neutron measurements planned for summer 2012



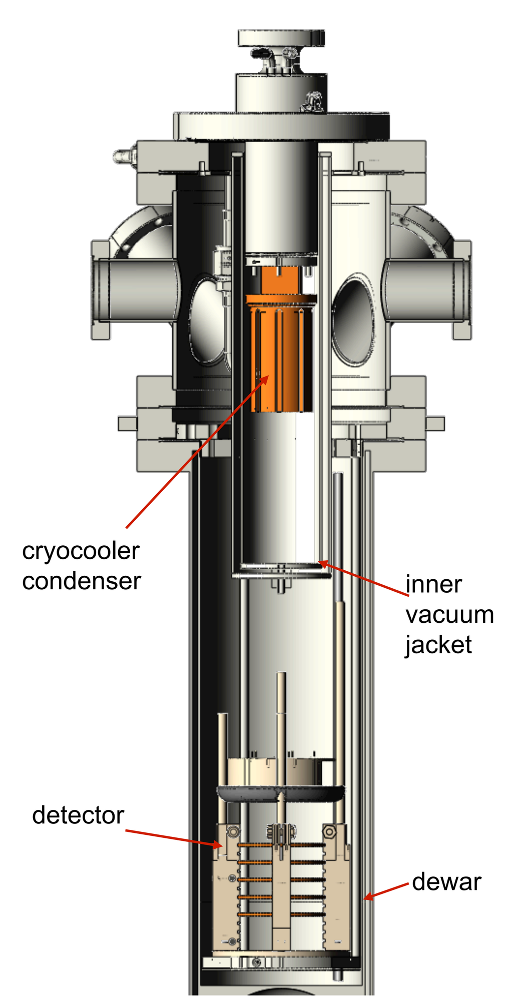


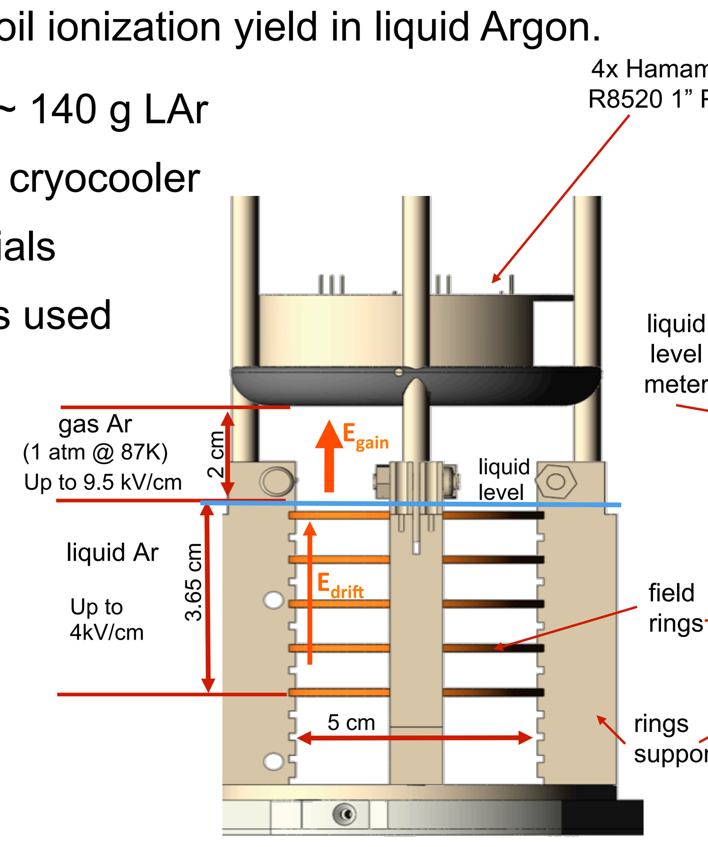
THE DETECTOR

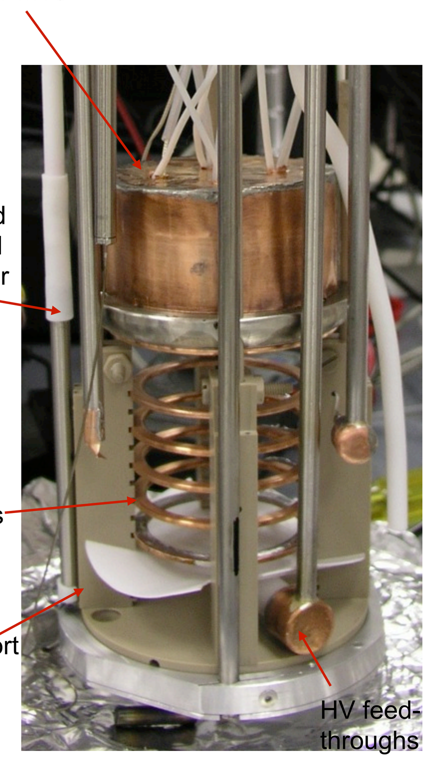
Dual-phase Argon Ionization Detector

Prototype detector for development/testing of necessary technologies and measurement of nuclear recoil ionization yield in liquid Argon.

- Primary active region volume: ~ 140 g LAr
- In-situ liquid Ar production with cryocooler
- Only Ultra High Vacuum materials
- TPB (Tetraphenyl-Butadiene) is used as a wavelenght shifter



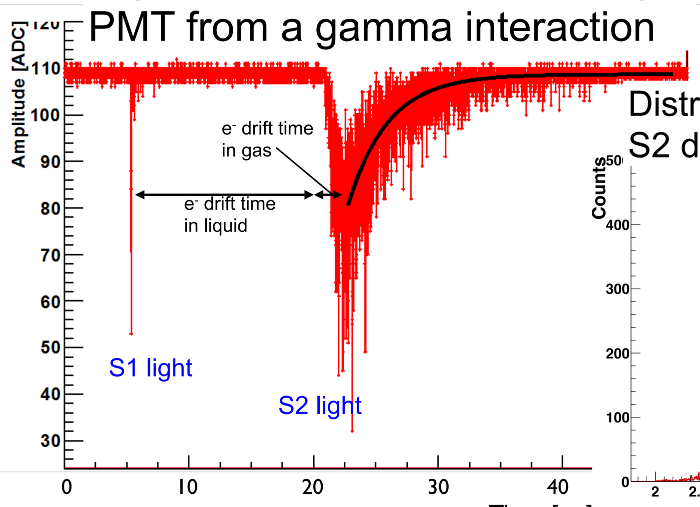




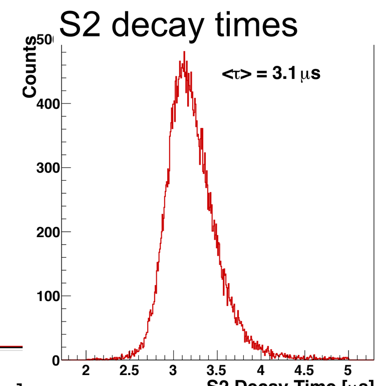
- Automatic overnight cool-down and liquefaction
- Liquid level measured with < mm accuracy
- Temperature stability ± 0.05 K
- Pressure stability ± 1 torr
- Continuous purification of Ar
- Wide range of achievable electric fields: up to 4kV/cm in liquid and 9.5kV/cm in gas
- Transportable setup

Detector Response

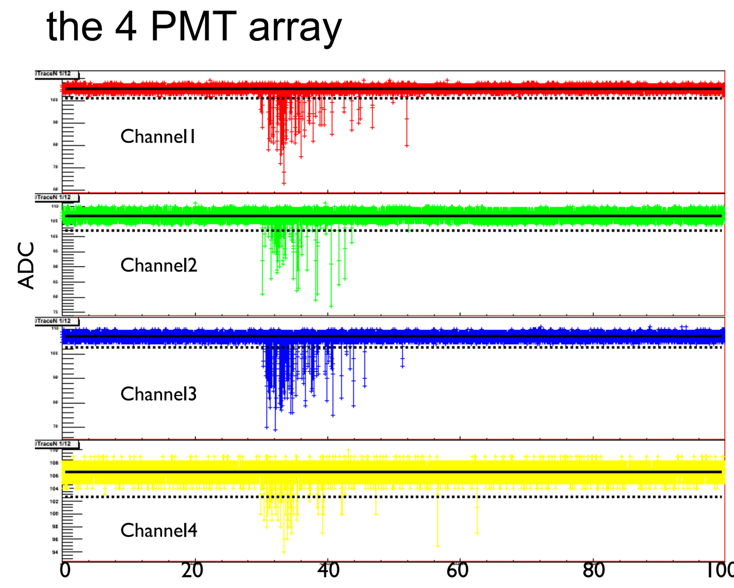
Digitized waveform from a single PMT from a gamma interaction

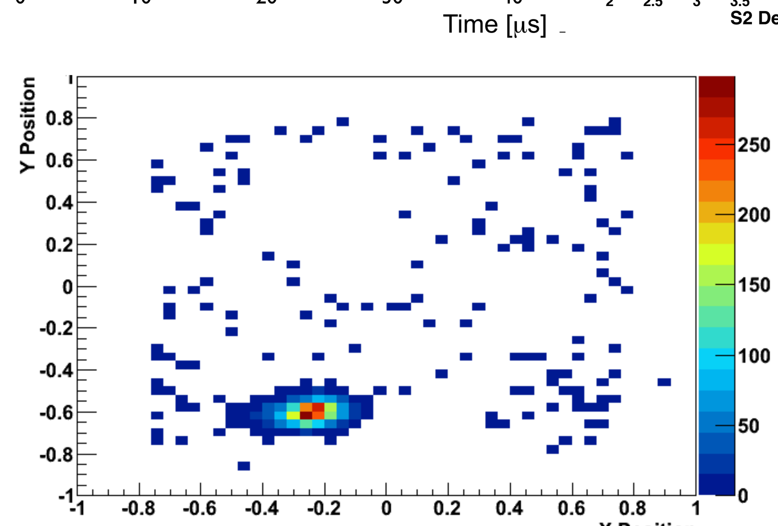


Distribution of fitted S2 decay times



Typical event from a 5.9 keV x-ray interaction in the detector as seen by the 4 PMT array





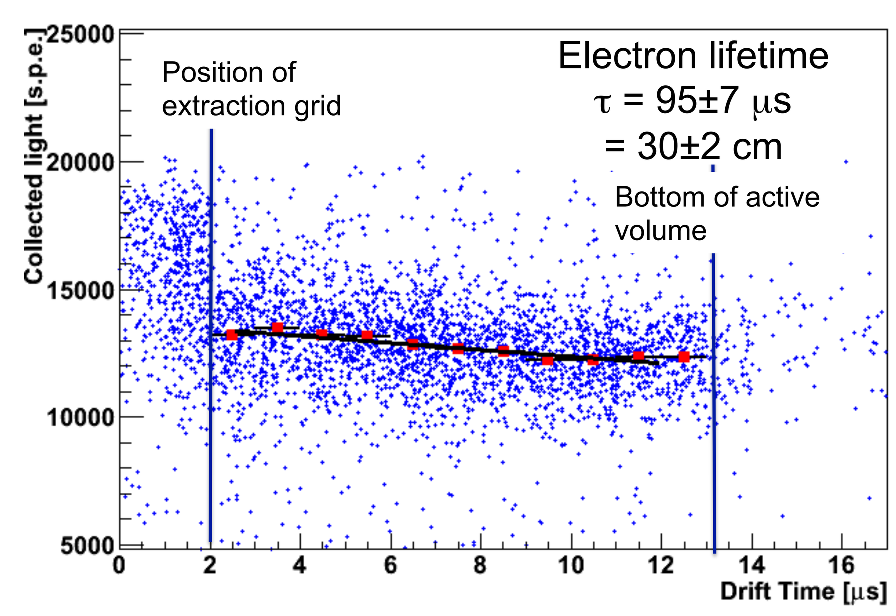
Fiducialization plot for the movable ^{55}Fe button source located inside the active volume. The (X,Y) position is computed using a center-of-mass algorithm among the 4 PMTs, based on the collected light.

References:
[1] D. Z. Freedman, *Physical Review D*, 9(5) (1974)
[2] A. Drukier, L. Stodolsky, *Phys. Rev. D*, 30 (1984)
[3] C. Hagmann, A. Bernstein, *Transactions on Nuclear Science*, 51(5) (2004)
[4] Mavrokoridis, K. *et al. Journal of Instrumentation* **6**, P08003 (2011).

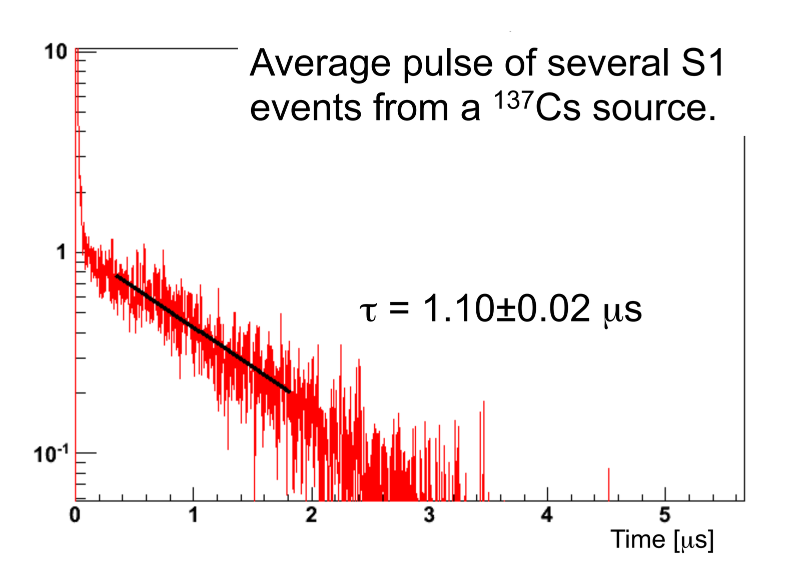
EXPERIMENTAL RESULTS

Argon Purity

The drift time from photopeak events (60keV) from an external ^{241}Am gamma source was used to measure the electron life-time in the liquid Ar.



The decay time of the S1 Argon scintillation light is also used to check for presence of impurities. The nominal life time for pure Ar is 1.1 – 1.6 μs (cfr reference [4])



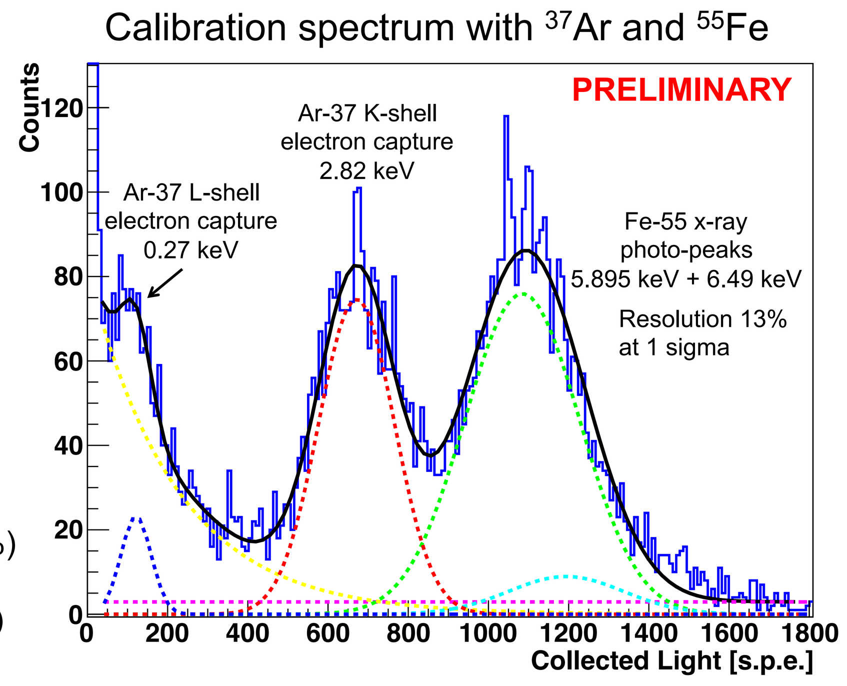
Calibration with ^{37}Ar and ^{55}Fe

- Electroplated movable ^{55}Fe X-ray source inside the active liquid volume
- Gaseous ^{37}Ar source:
  - produced by neutron irradiation of ^{nat}Ar
  - half-life of 35 days
  - provides a uniform calibration throughout the whole detector volume.

^{37}Ar Decay scheme
100% electron capture
$t_{1/2}$ = 35.04 d
Q(gs) = 813.5 keV

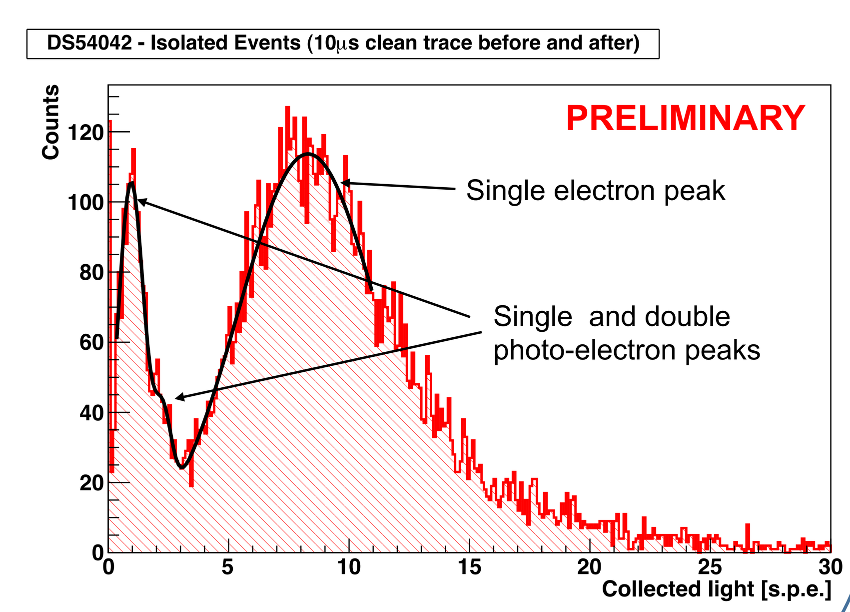
^{37}Ar Decay radiation
K-electron capture 2.82 keV (90.2%)
L-electron capture 0.27 keV (8.9%)
M-electron capture 0.02 keV (0.9%)

Calibration spectrum with ^{37}Ar and ^{55}Fe



Detection of Single Electrons

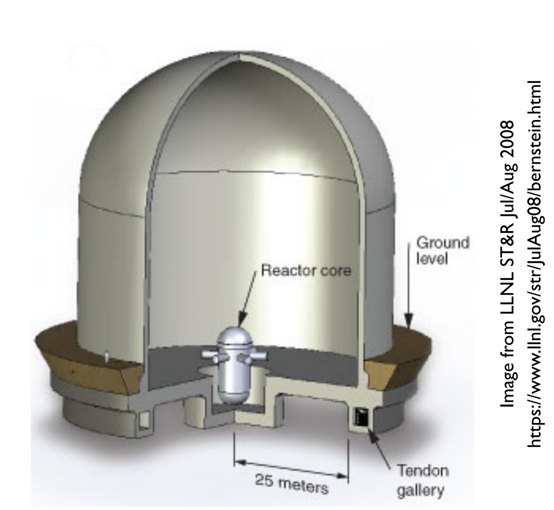
- **Ultimate detector sensitivity!**
- Observed appearance of a peak at ~8-10 s.p.e. in the measured spectrum
- Peak position moves linearly with gain field and is not affected by drift field
- The observed # of s.p.e. in the single e⁻ peak agrees with the s.p.e./i.e. extracted from the ^{55}Fe peak once recombination is taken into account



THE FUTURE

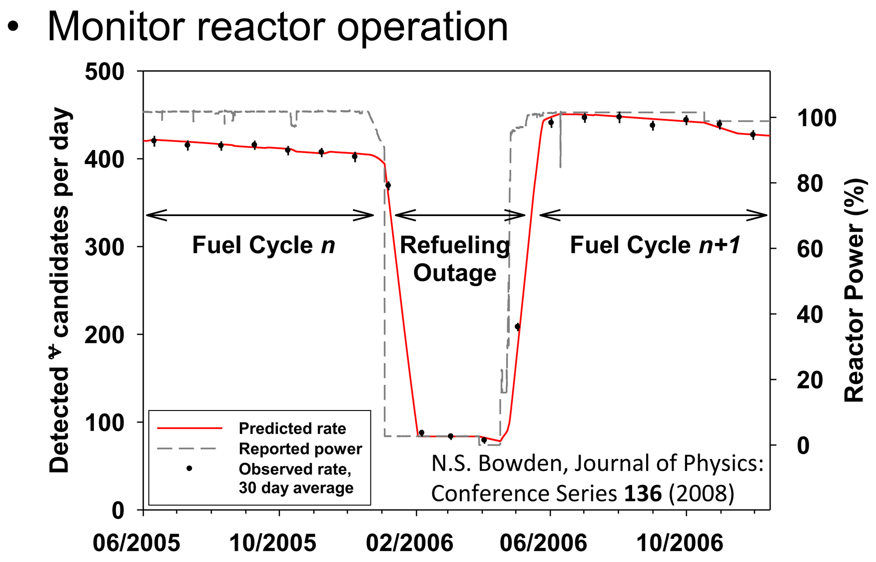
The 10-kg Detector

Once all systematic are understood and the detector technology well established, we plan to construct a dual-phase detector with a 10-kg primary region to be deployed at a nuclear power plant.



GOALS:

- Observe Coherent Neutrino-Nucleus Scattering!
- Monitor reactor operation



- Characterization of the background is performed when the power reactor is shut down for refueling

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