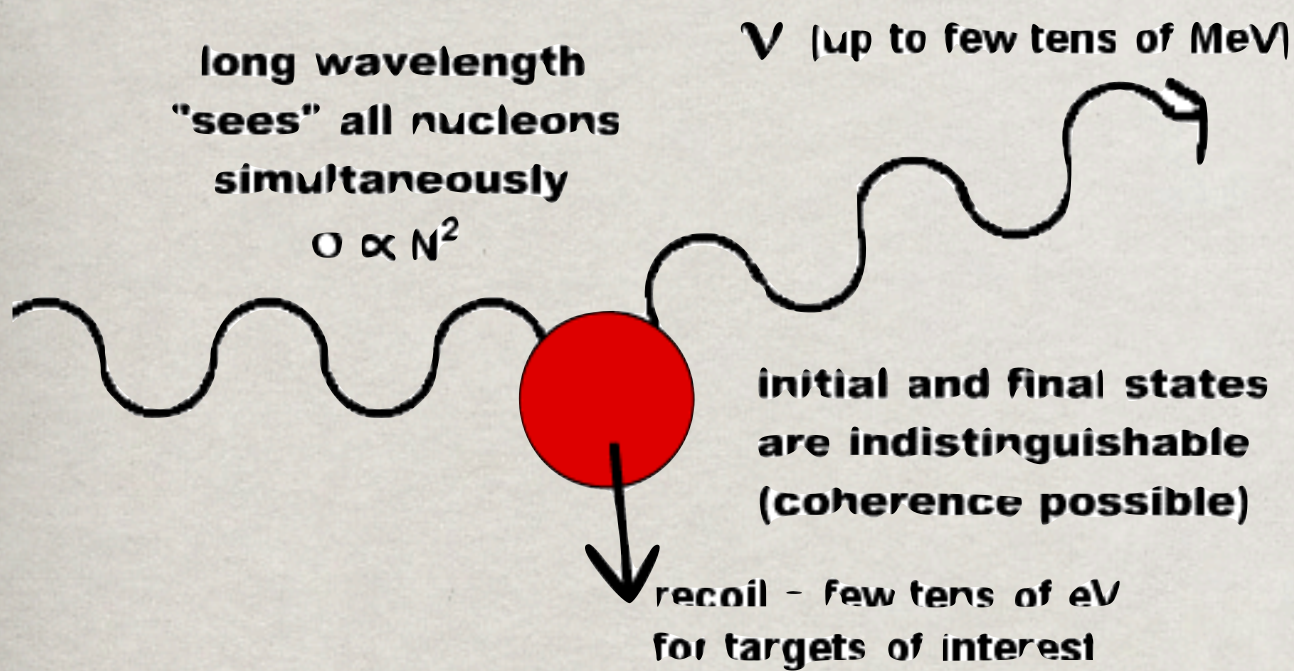
CoGeNT: Neutrino and Astro-particle Physics Program

Phil Barbeau
Stanford University

Initial Motivation: coherent neutrino-nucleus scattering



- non-controversial SM process
- $\sigma \sim N^2$ for neutral currents, $E_\nu <$ few MeV
- need sub-keV threshold
- and low backgrounds (~ c $\text{keV}^{-1}\ \text{kg}^{-1}\ \text{day}^{-1}$)
- and large mass (~ kg)
- Has been tried before, without success:
  Cabrera, Krauss & Wilczek, PRL 55 (1985), 25-28

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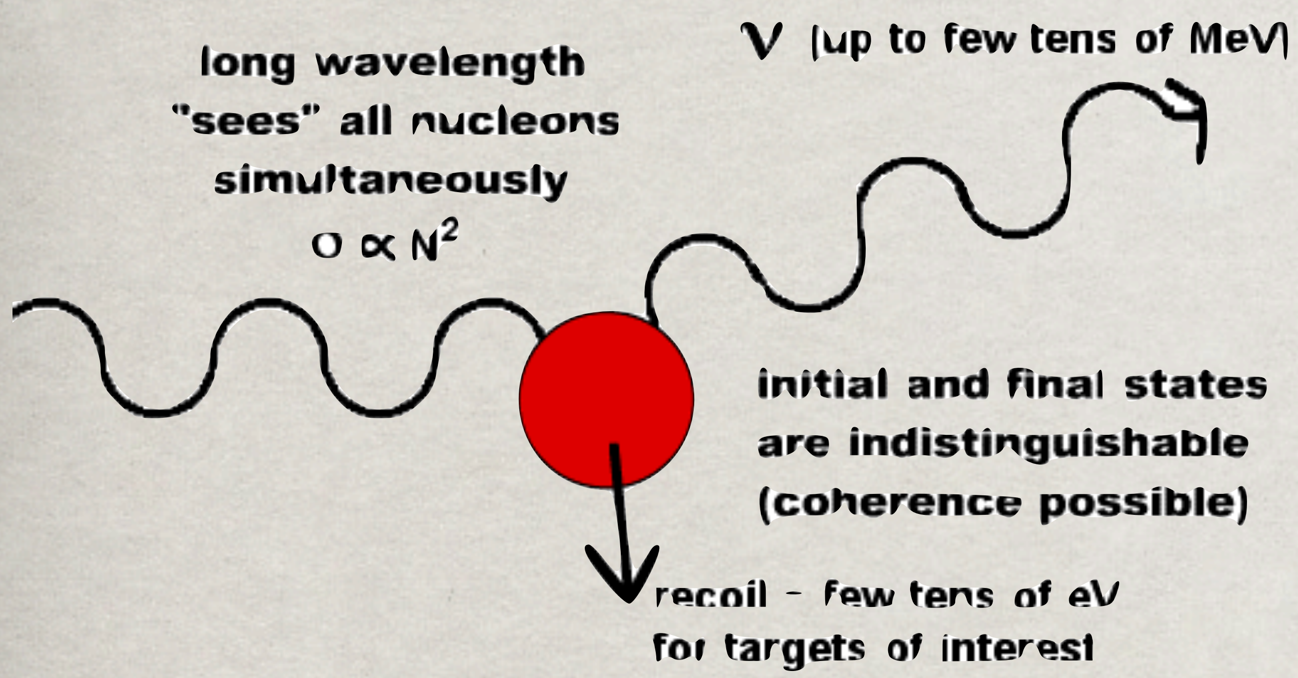

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- Largest σ in SN dynamics: measurements validates models. J.R. Wilson, PRL 32 (74) 849
- Large detector can measure total E and T of nearby SN, ν_μ ν_τ measurement allows determination of oscillation pattern. (J.F. Beacom, W.M. Far & P. Vogel, PRD 66 (02) 033011)
- Search for sterile neutrinos (A. Drukier & L. Stodolsky, PRD 30 (84) 2295)
- Sensitive probe of weak nuclear charge (L.M. Krauss, PLB 269, 407)
- NSI and effective ν charge radius tests (J. Barranco et. al, hep-ph/0508299, hep-ph/0512029)
- σ critically dependent on μ_ν (A.C. Dodd et. al, PLB 266 (91) 434)
- Neutrino Technology: Reactor Monitoring
- Also: light WIMP searches
- Solar Bound WIMPS

P-Type Point contact HPGe detectors

- Resurrected an old detector concept...and made it work. (P. S. Barbeau, J. I Collar, O. Tench, J. Cosmol. Astrop. Phys. 09 (2007) 009.)
- improvements after ~ 20 year wait
  - P-Type detector with proper charge collection and less sensitivity to Low-E backgrounds
  - Modern FET Technology = lower noise (140 eV FWHM Pulser)

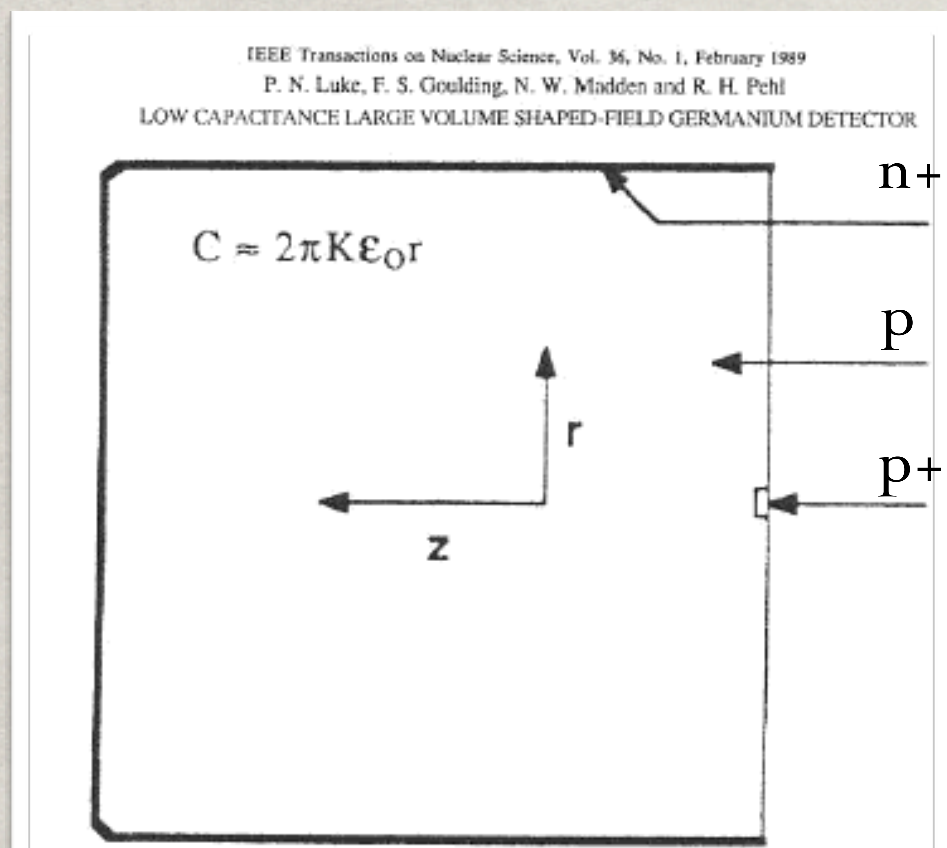

Fig. 3. Structure of the shaped-field detector.

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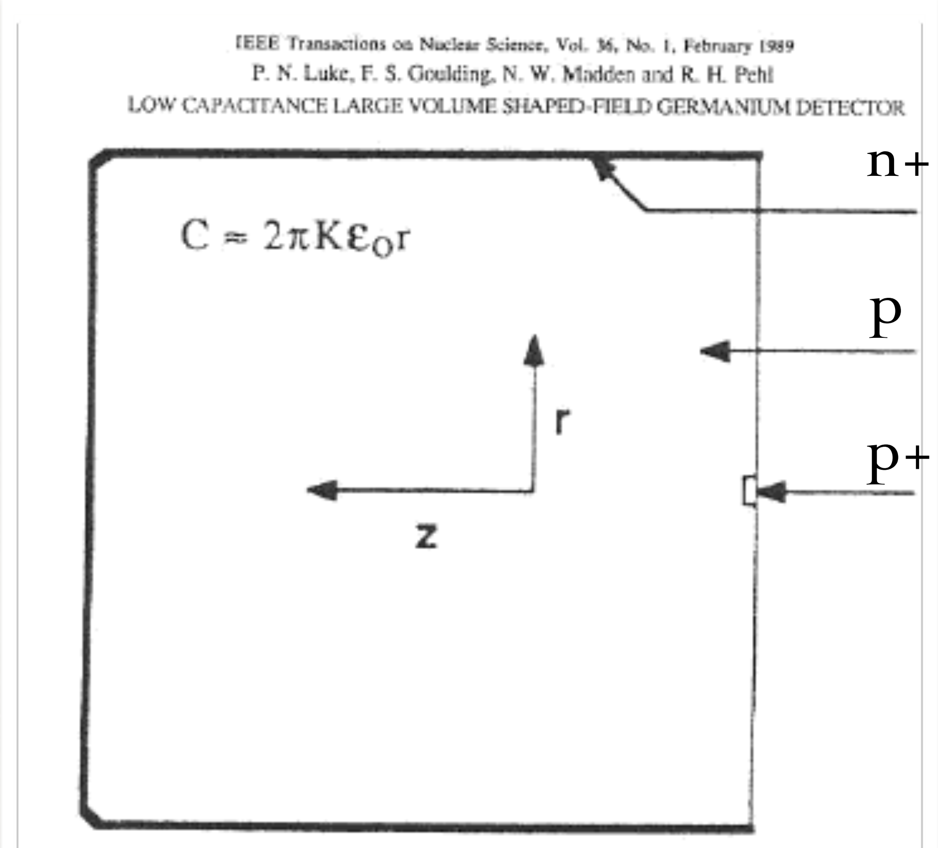

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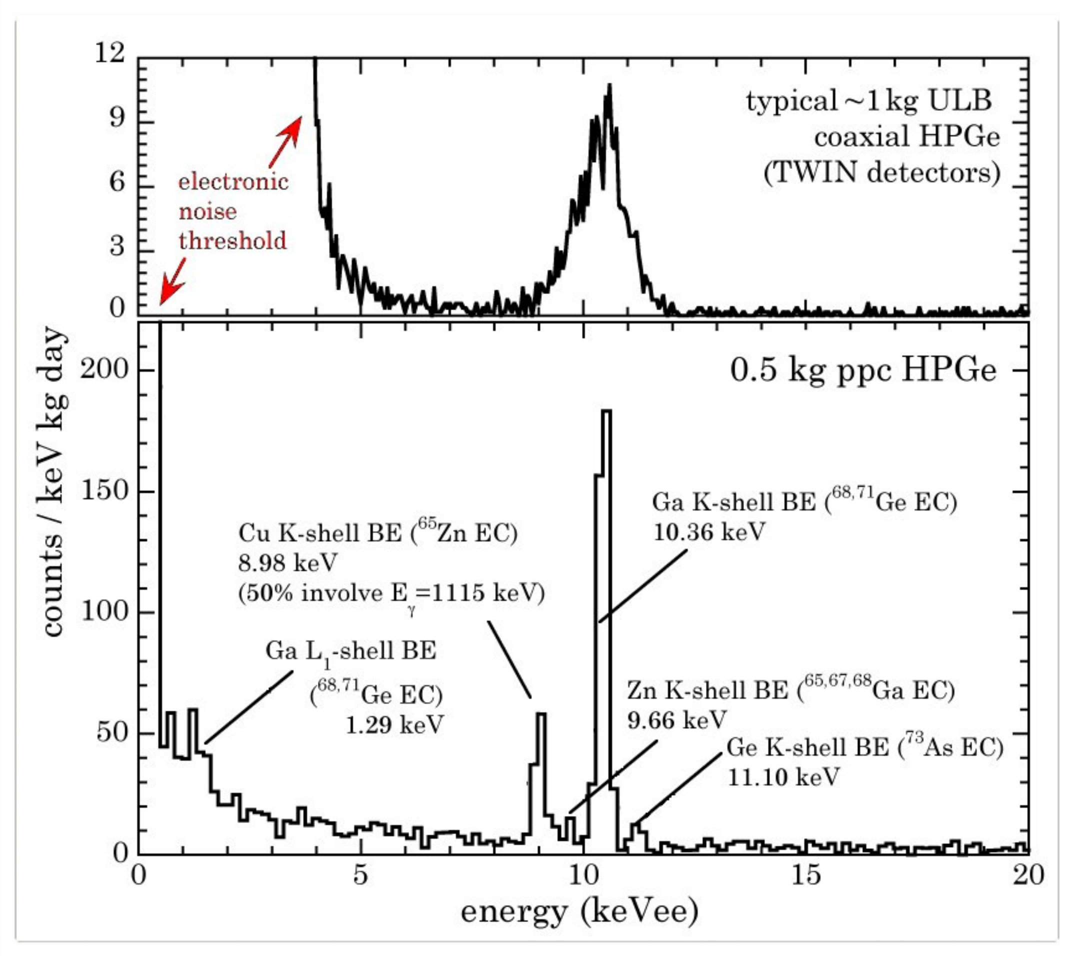
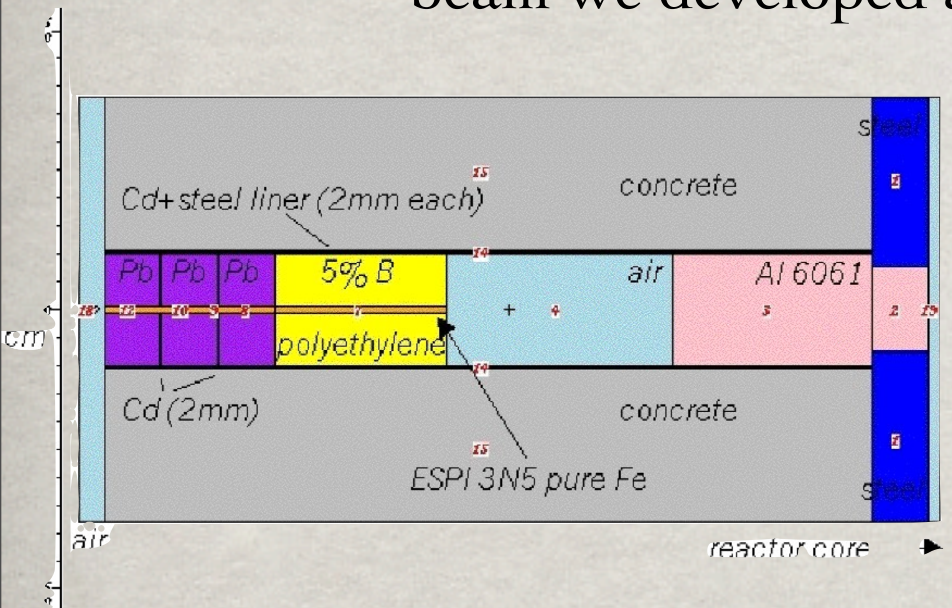
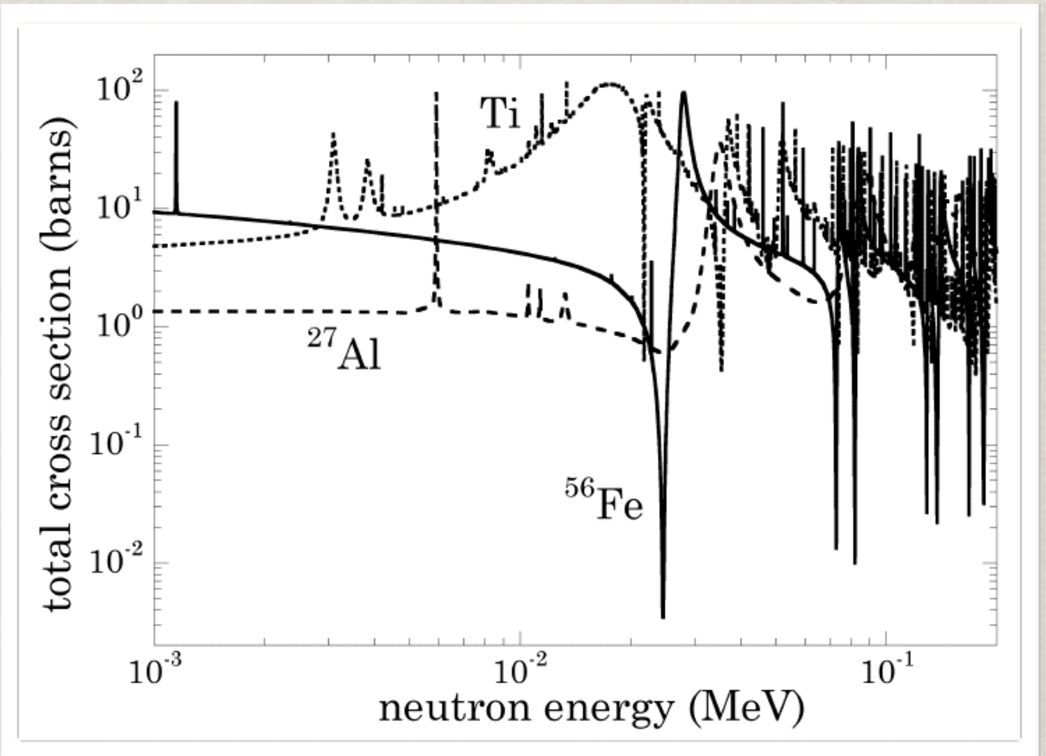
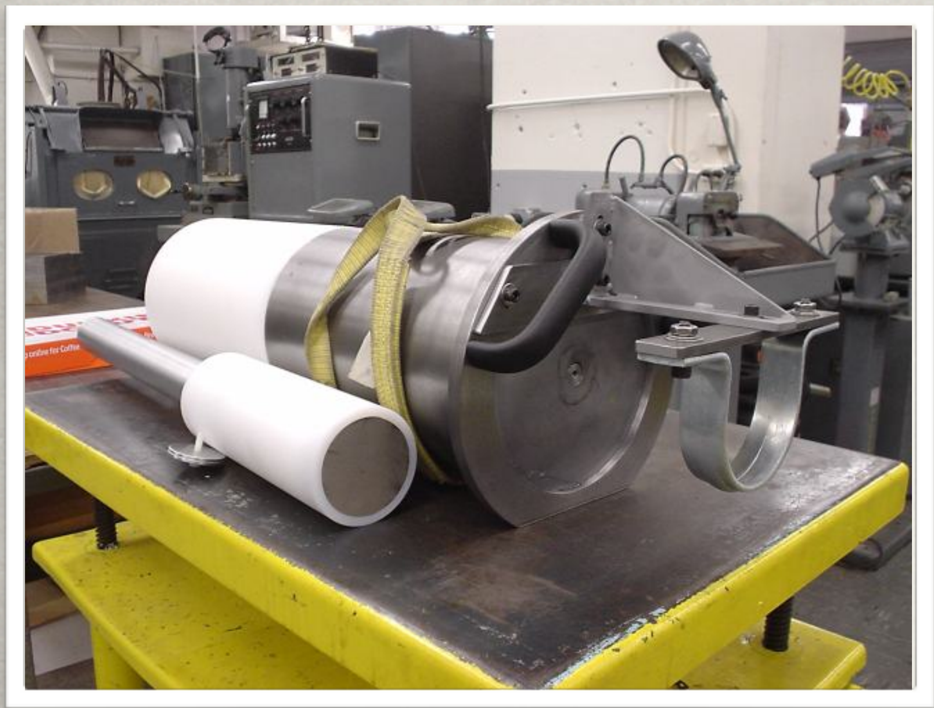


Quenching Factor Measurement

- Quenching factor: the fraction of the nuclear recoil energy that goes into ionization.
  - ~20% in HPGe semiconductor detectors
  - with PPC: measured QF for low energy nuclear recoils using 24 keV neutron beam we developed at KSU TRIGA research reactor







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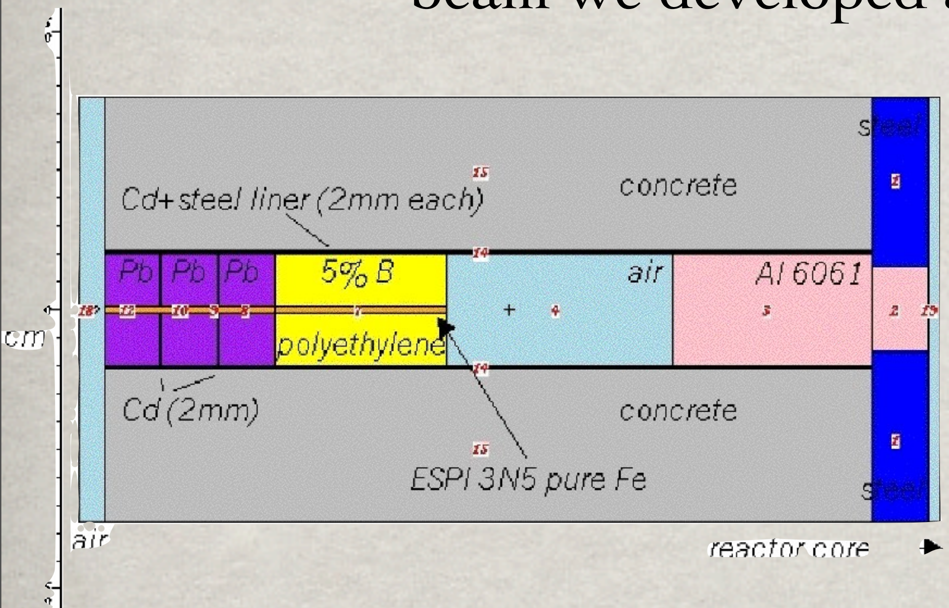

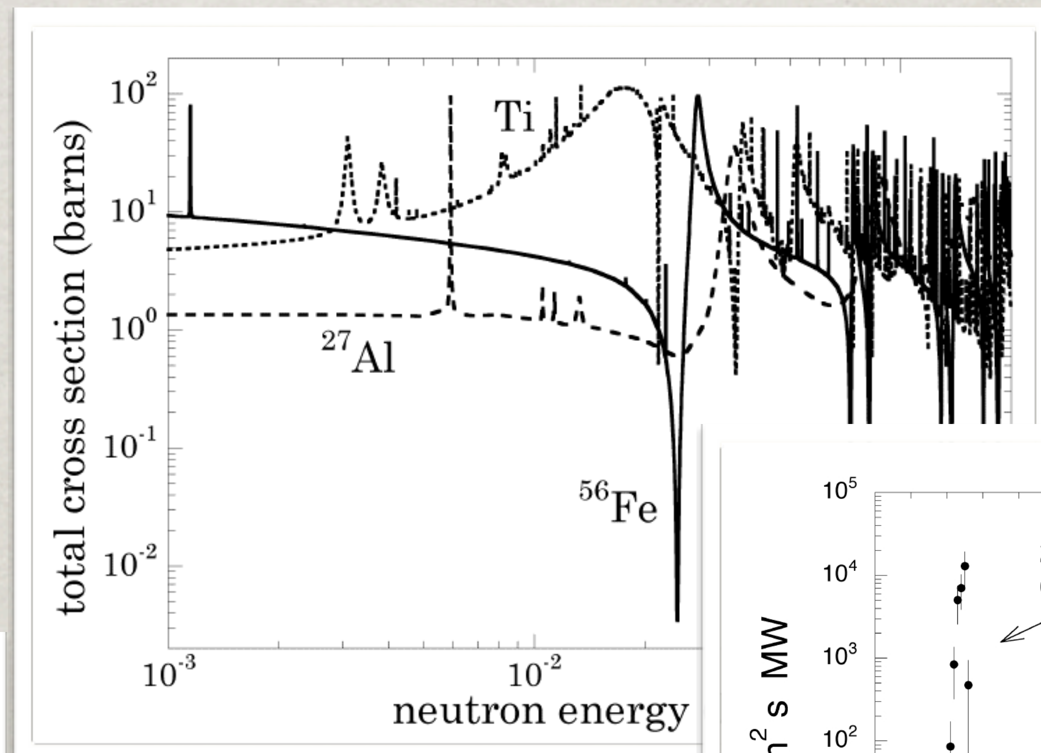

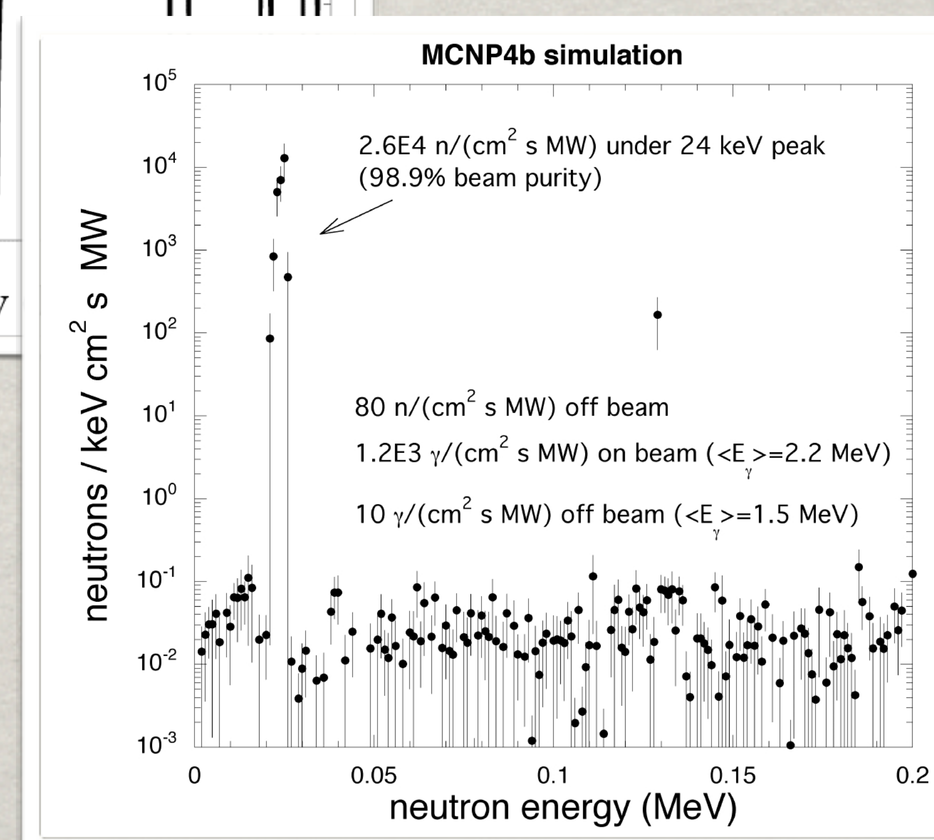

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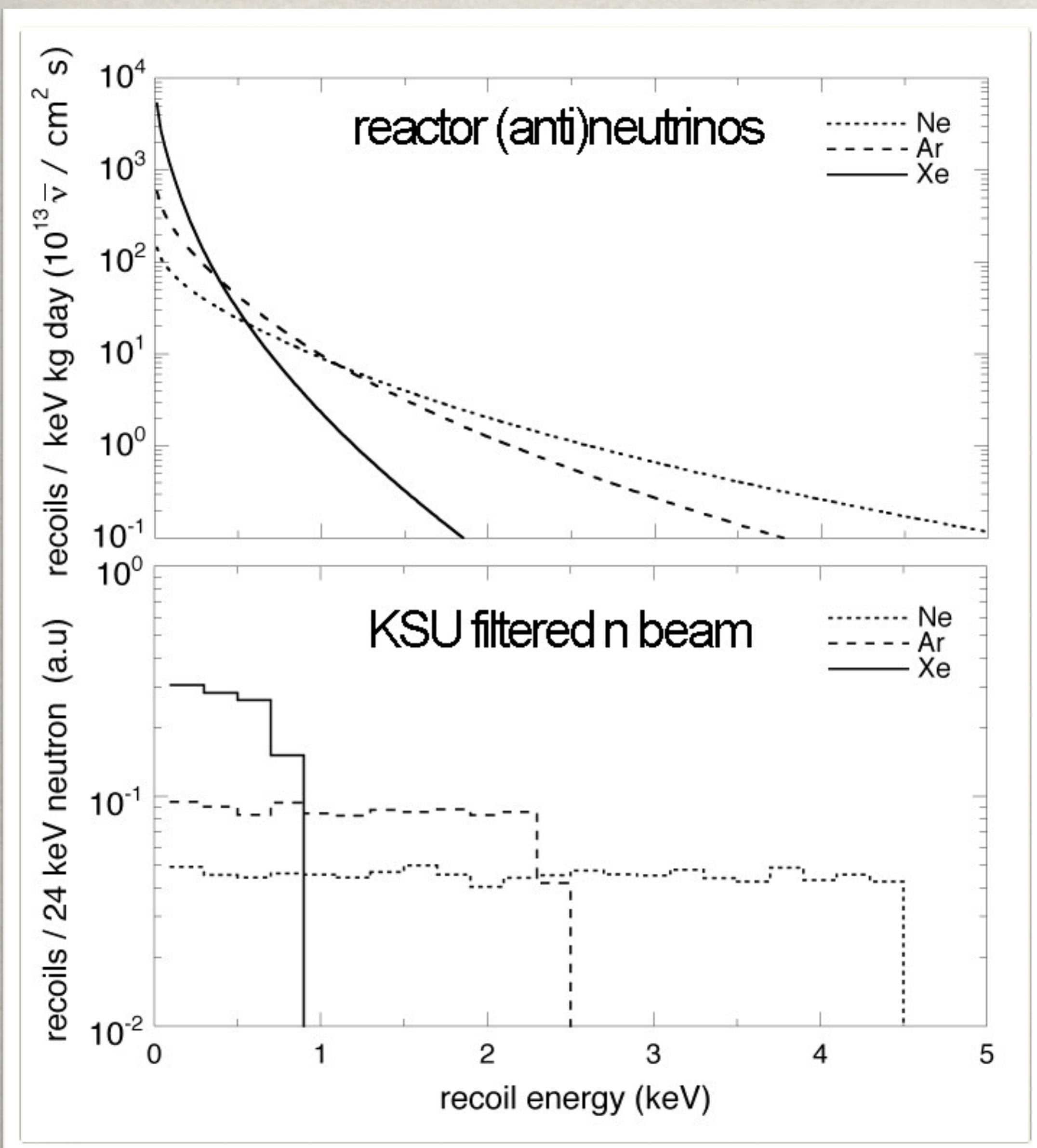

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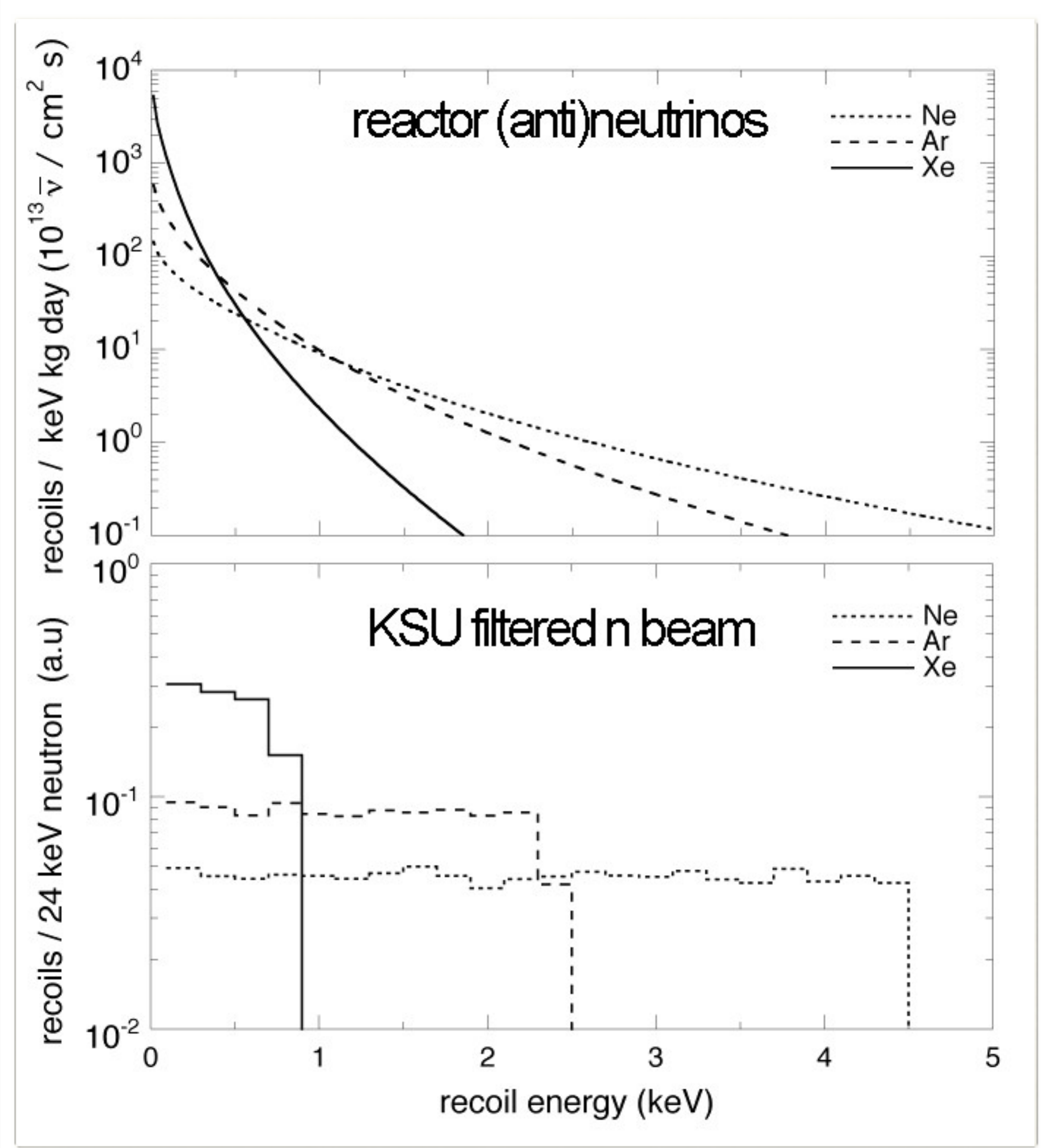
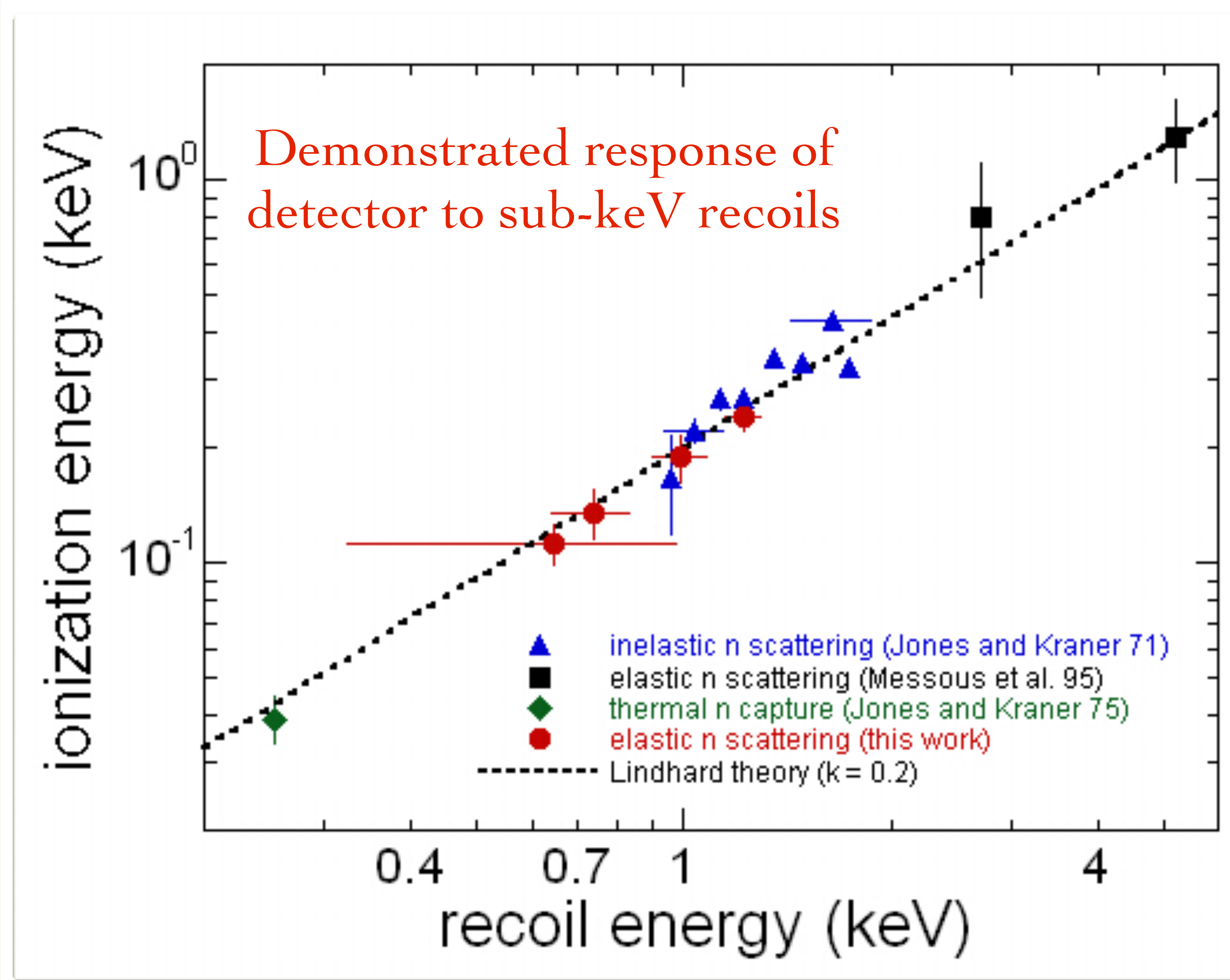
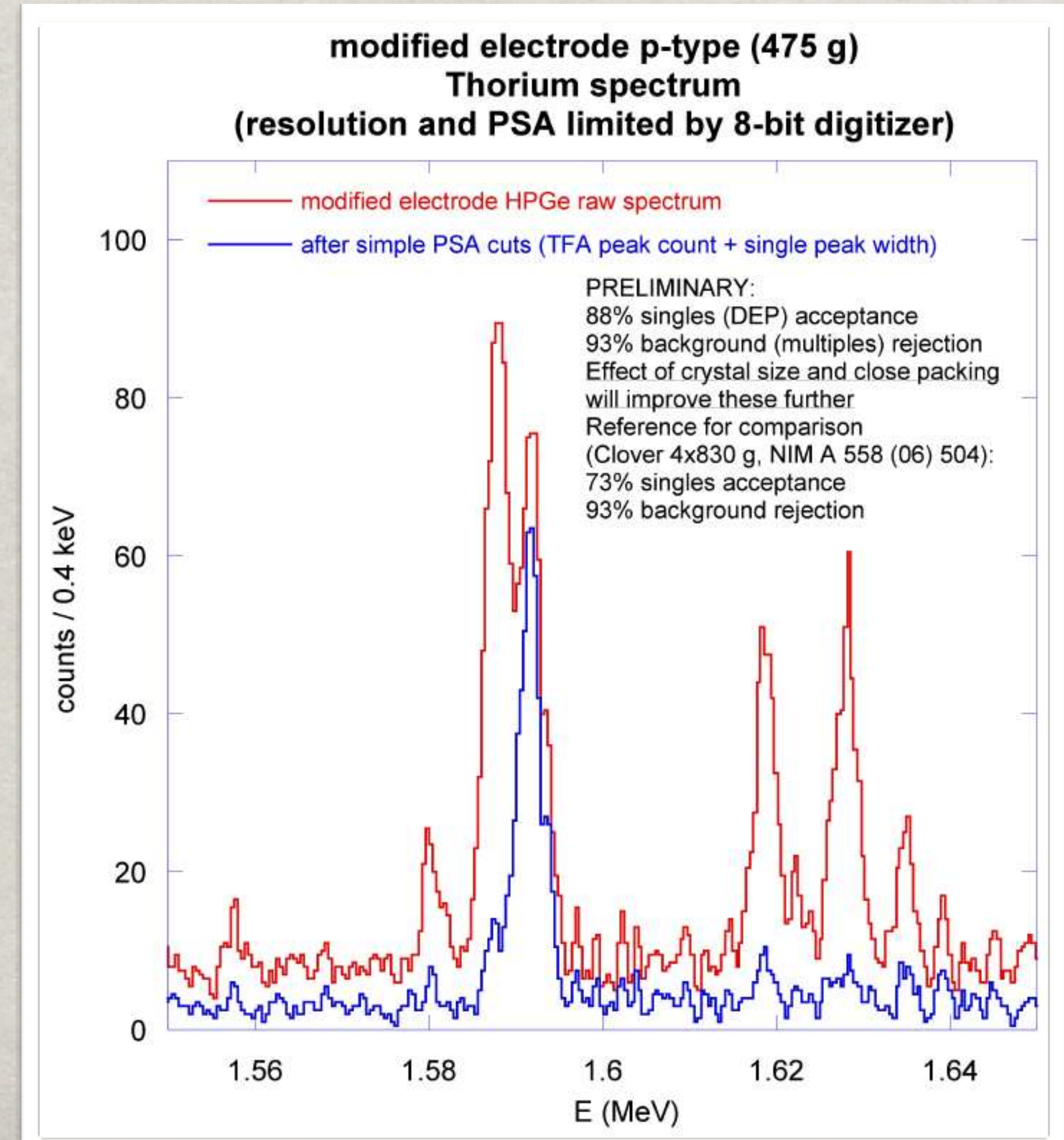


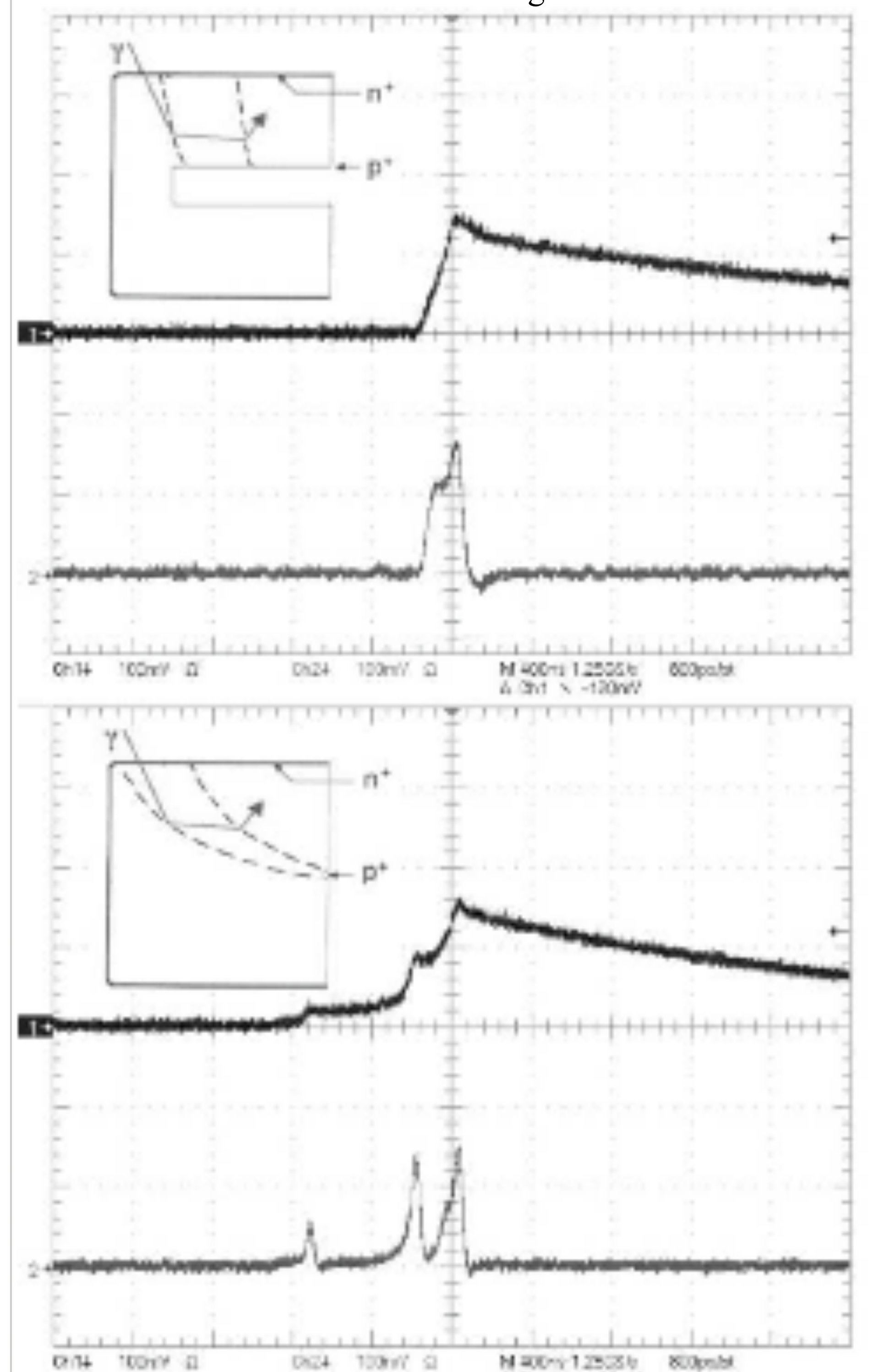


A Surprise: Pulse shape discrimination for high energy gammas

- Arrival time of charge spread out in PPC
- Pulse Shape Disc. is far superior & simpler than with other detector technologies (highly segmented N-type, Clover, standard Coax)



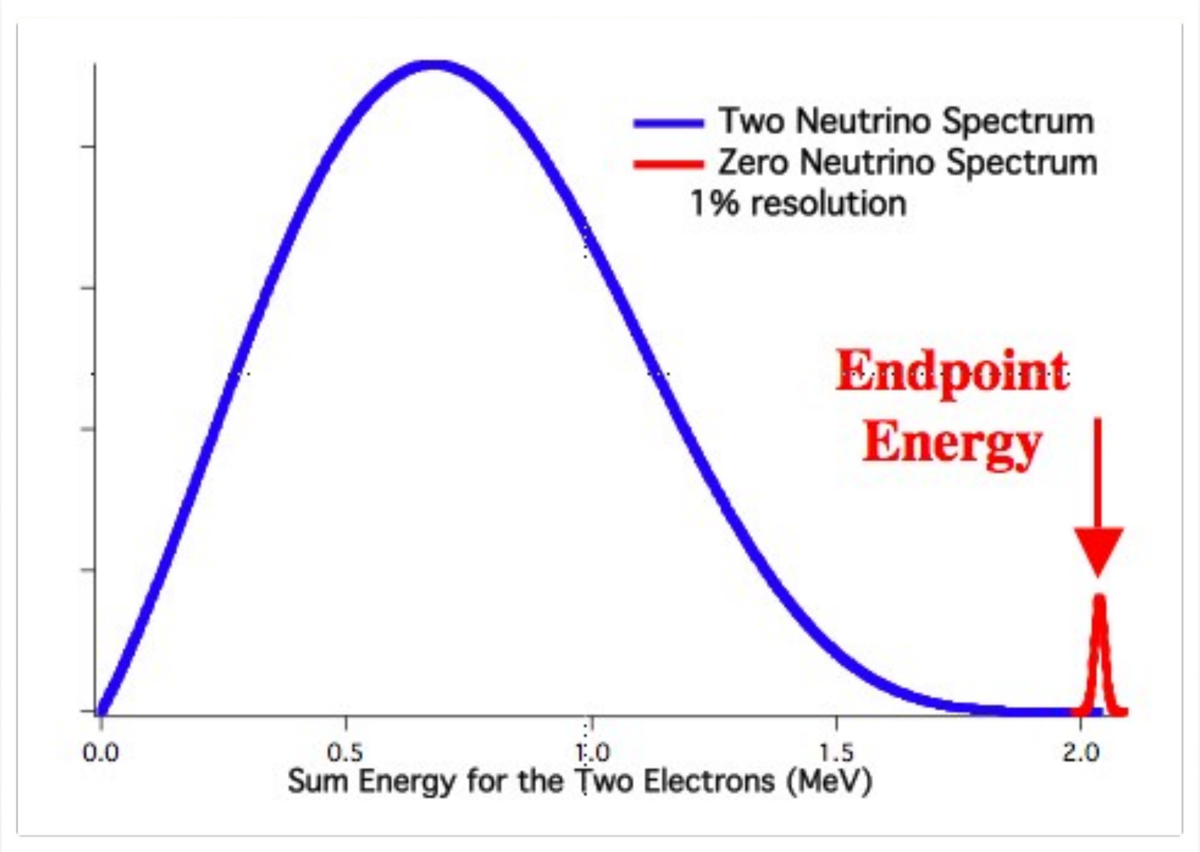
Standard Coax HPGE digitized event

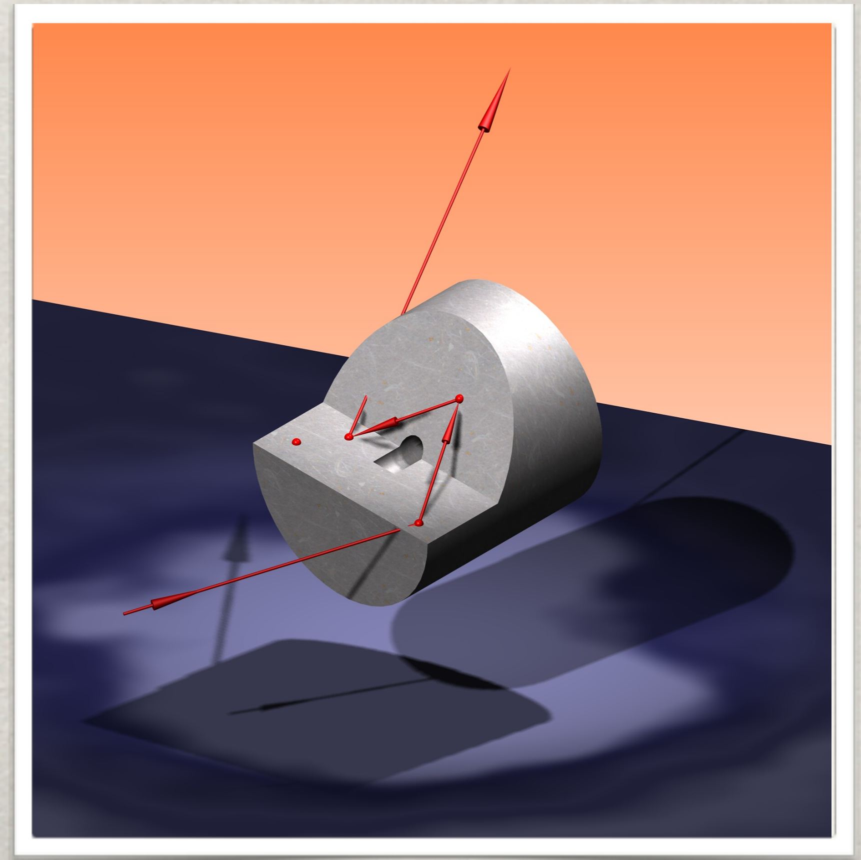


P-PC HPGe digitized event

A brief Parenthesis: the role of PPC detectors in the Majorana $0\nu\beta\beta$ experiment

- Source and target are the same…enriched ^{76}Ge HPGe
  - Signal peak at 2039 MeV single site $0\nu\beta\beta$ interaction
- The name of the game is background suppression
  - ΔE of Ge detectors limits ROI (0.16%)
  - clean materials (HPGe, underground electroforming of Cu, etc.)
  - reject Compton-scattered photon backgrounds: >1 crystal interaction (Granular cut)
  - PSD rejects multiple site depositions within a single (~ 1kg) crystal





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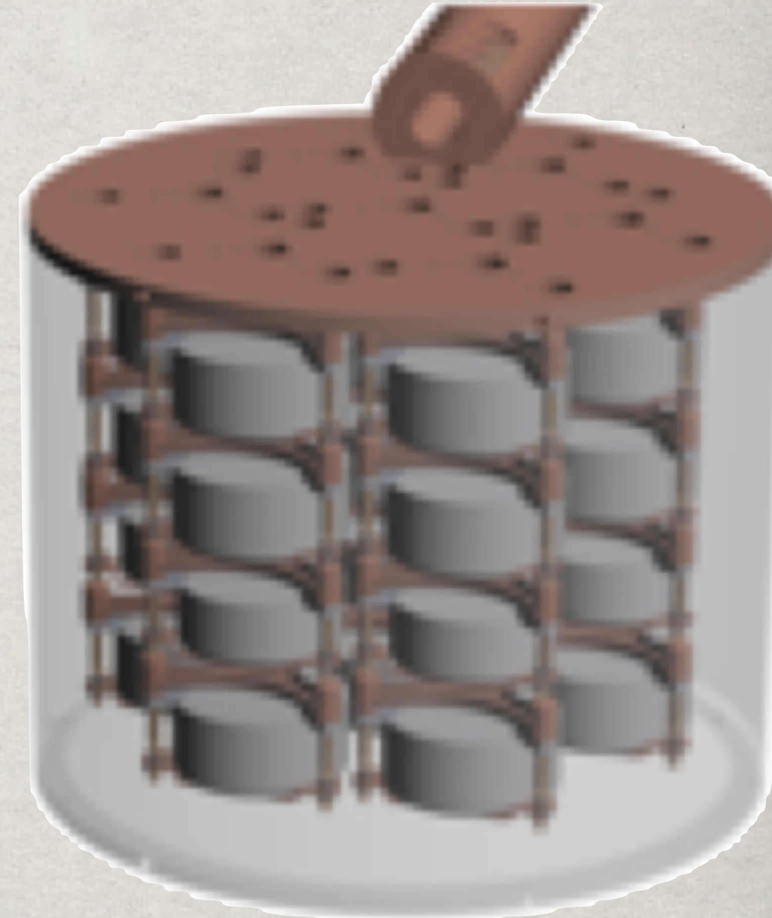


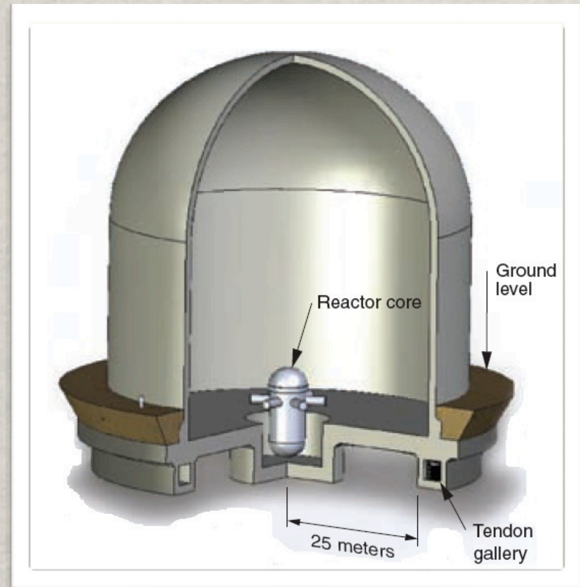
- PPC's enrich the Physics program of Majorana
  - Light WIMP searches
  - Dark Pseudoscalar searches
  - Enhanced sensitivity to electron decay
  - Simpler detectors & easier characterization
  - less background (cabling, dead layer)
  - less $/kg

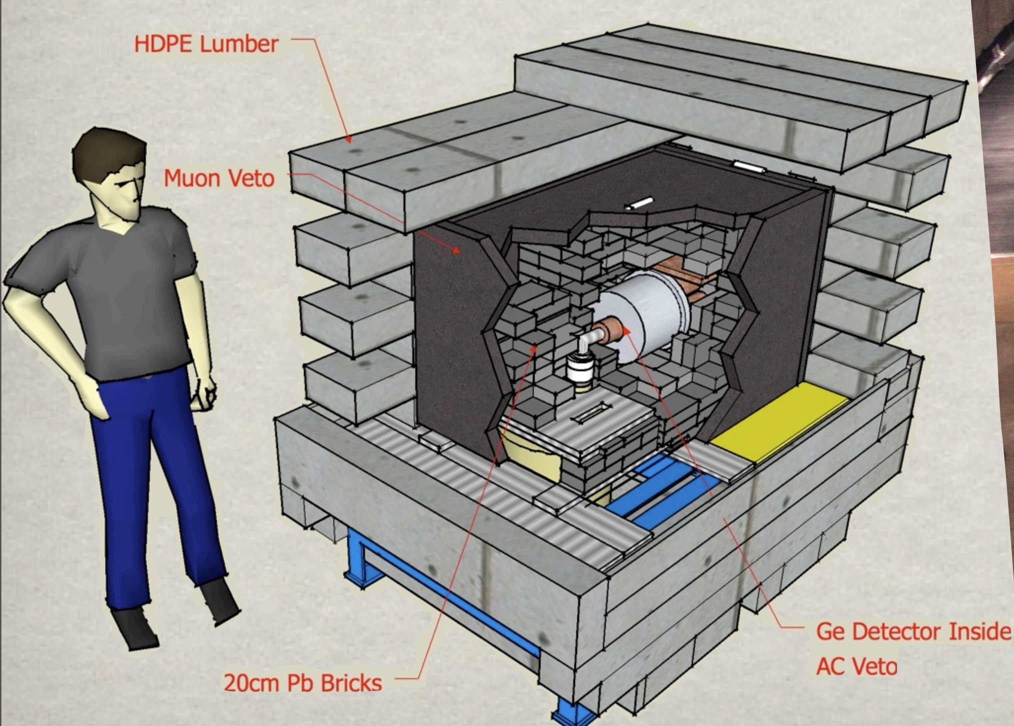
Previewed in this talk

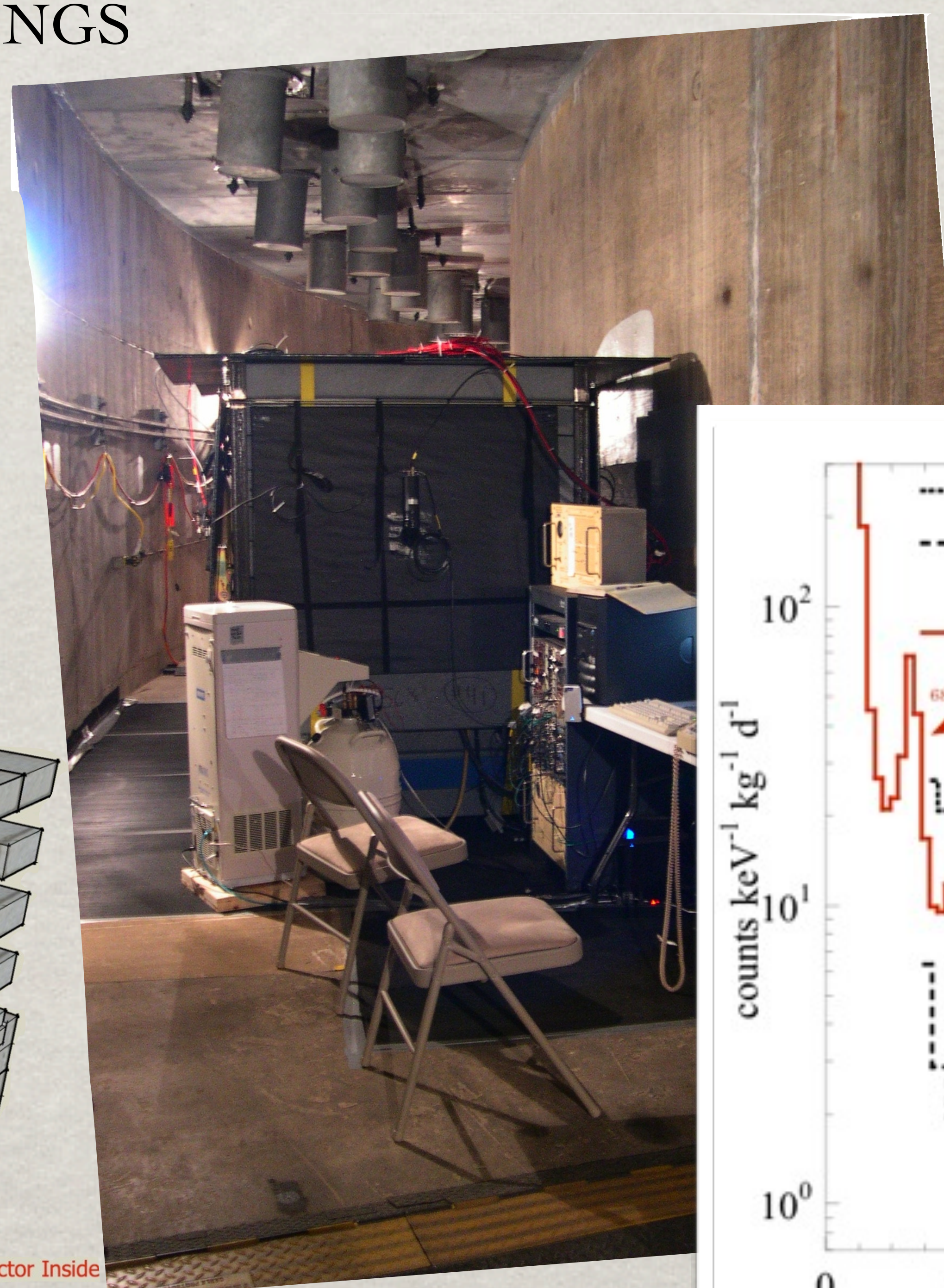
- 18+ P-PCs now exist within the Majorana collaboration
  - now BEGe (quasi-planar PPC) crystals from CANBERRA
  - 60 kg of Majorana demonstrator module to be PPCs
- Gerda Switching to PPCs (in the BEGe style) for phase II

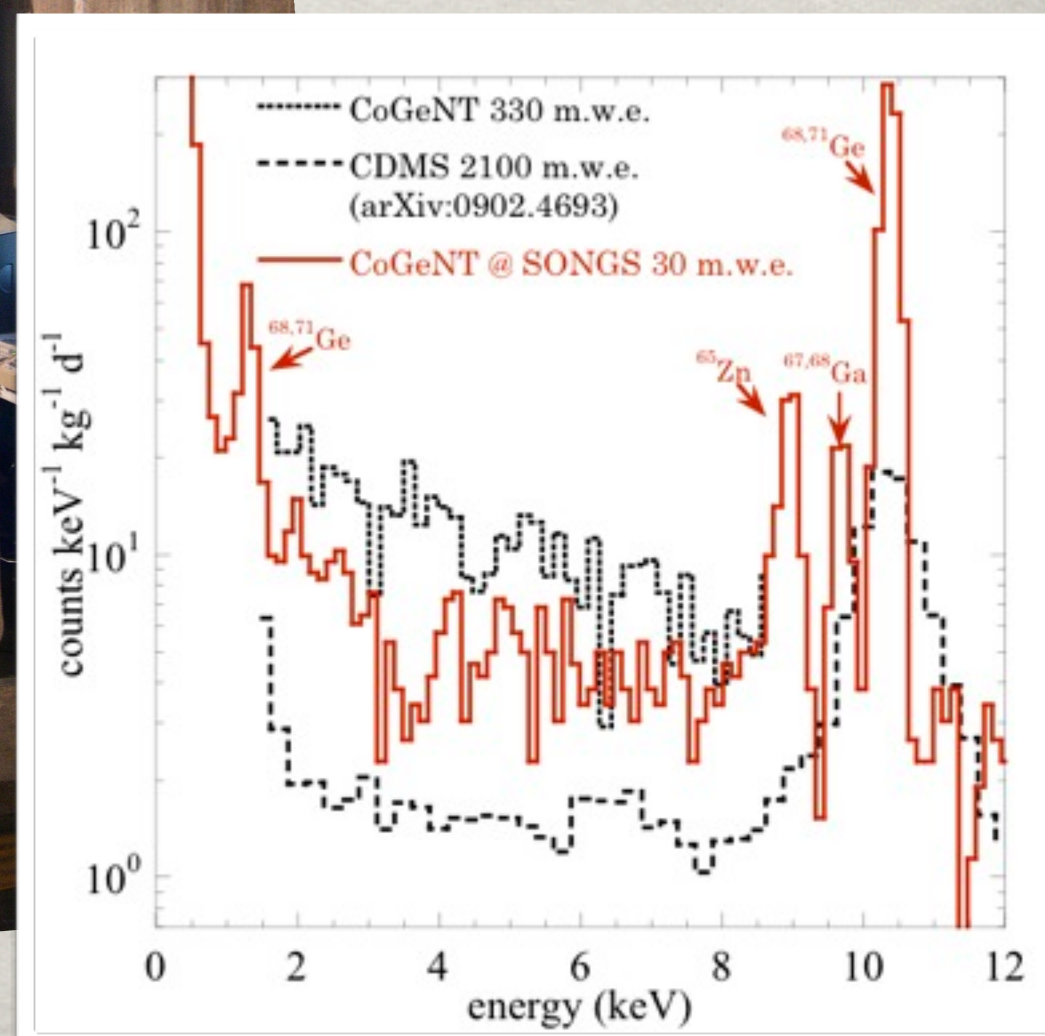
Back to the show: Coherent ν-N scattering At the SONGS nuclear reactor

- After quick deployment to 300 m.w.e (DM limits C.E. Aalseth *et. al,* Phys.Rev.Lett.101:251301,2008), moved detector and shielding to SONGS



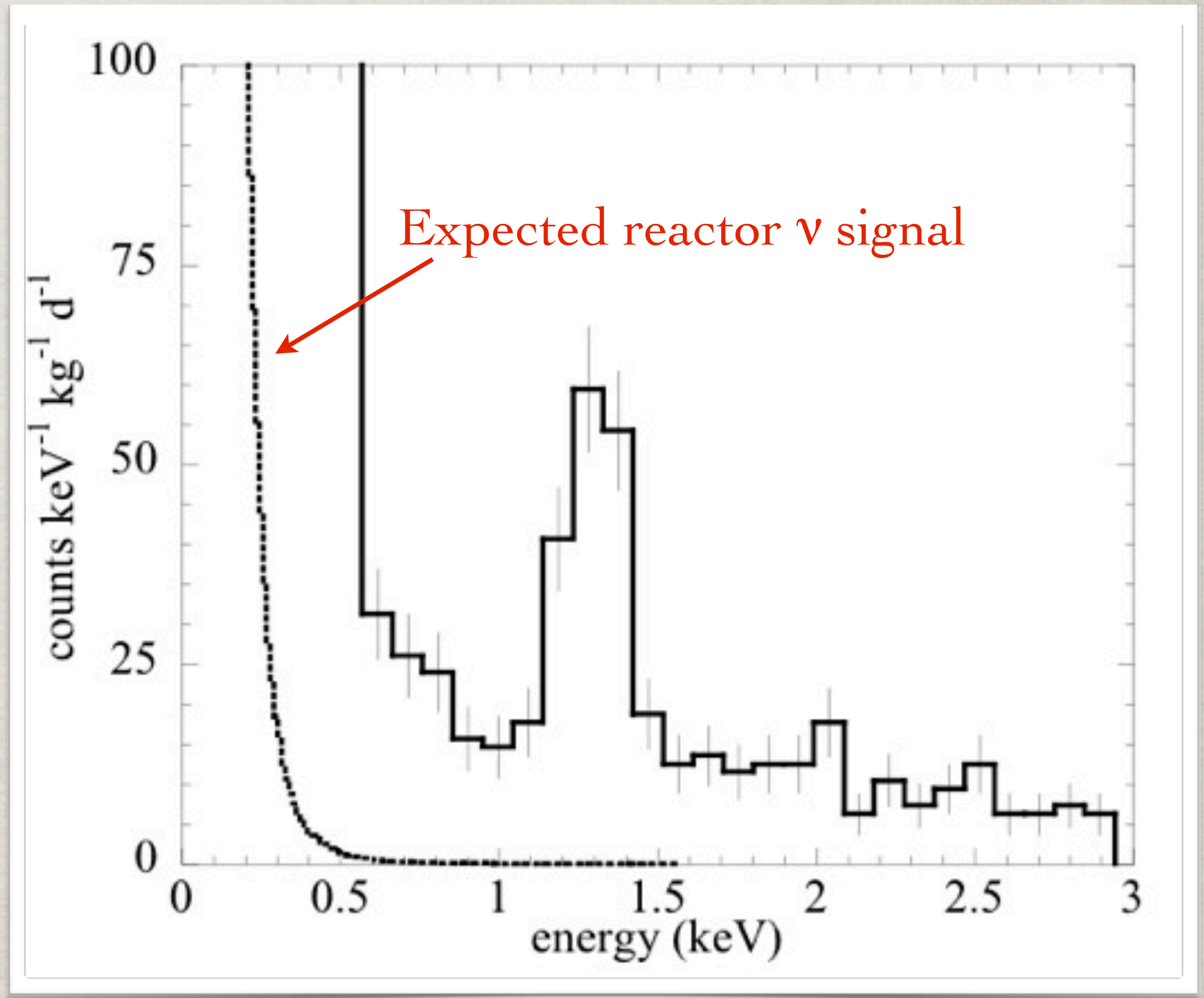






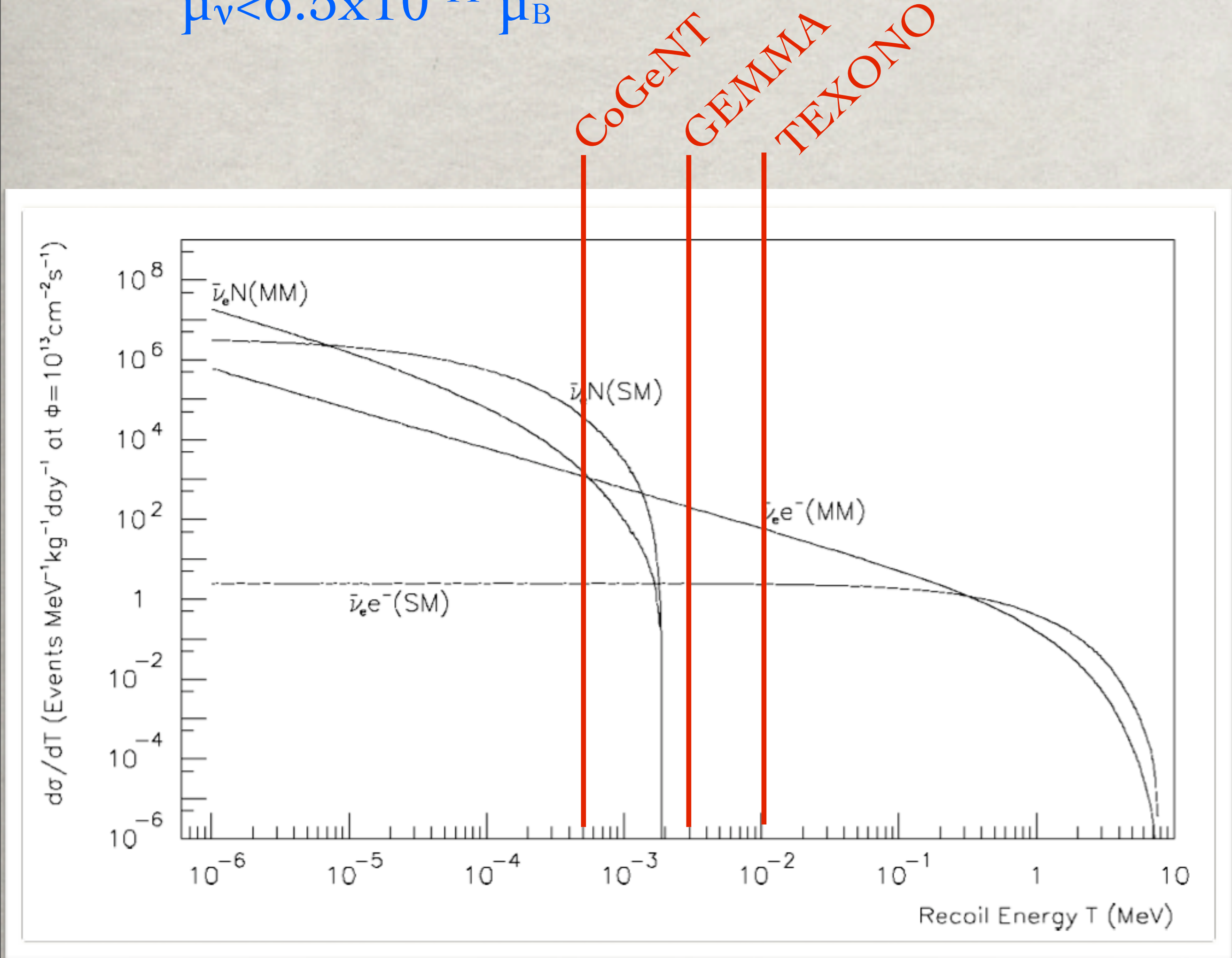
Status of Coherent ν-N scattering measurement

- Need to reduce threshold further
- Address still some μ induced neutron backgrounds
- Move detector to Soudan to further characterize backgrounds and perform light WIMP searches



While we are at the reactor... μ_ν search

- Sensitivity from 1/T spectral shape
- $\mu_\nu < 4\times10^{-10}\ \mu_B$ without Rx-off subtraction
- TEXONO $\mu_\nu < 7.4\times10^{-11}\ \mu_B$
- GEMMA $\mu_\nu < 3.2\times10^{-11}\ \mu_B$
- CoGeNT: 6.5 yr projection (5 cycles and background @ 2009 and 400 g detector) $\mu_\nu < 6.5\times10^{-11}\ \mu_B$



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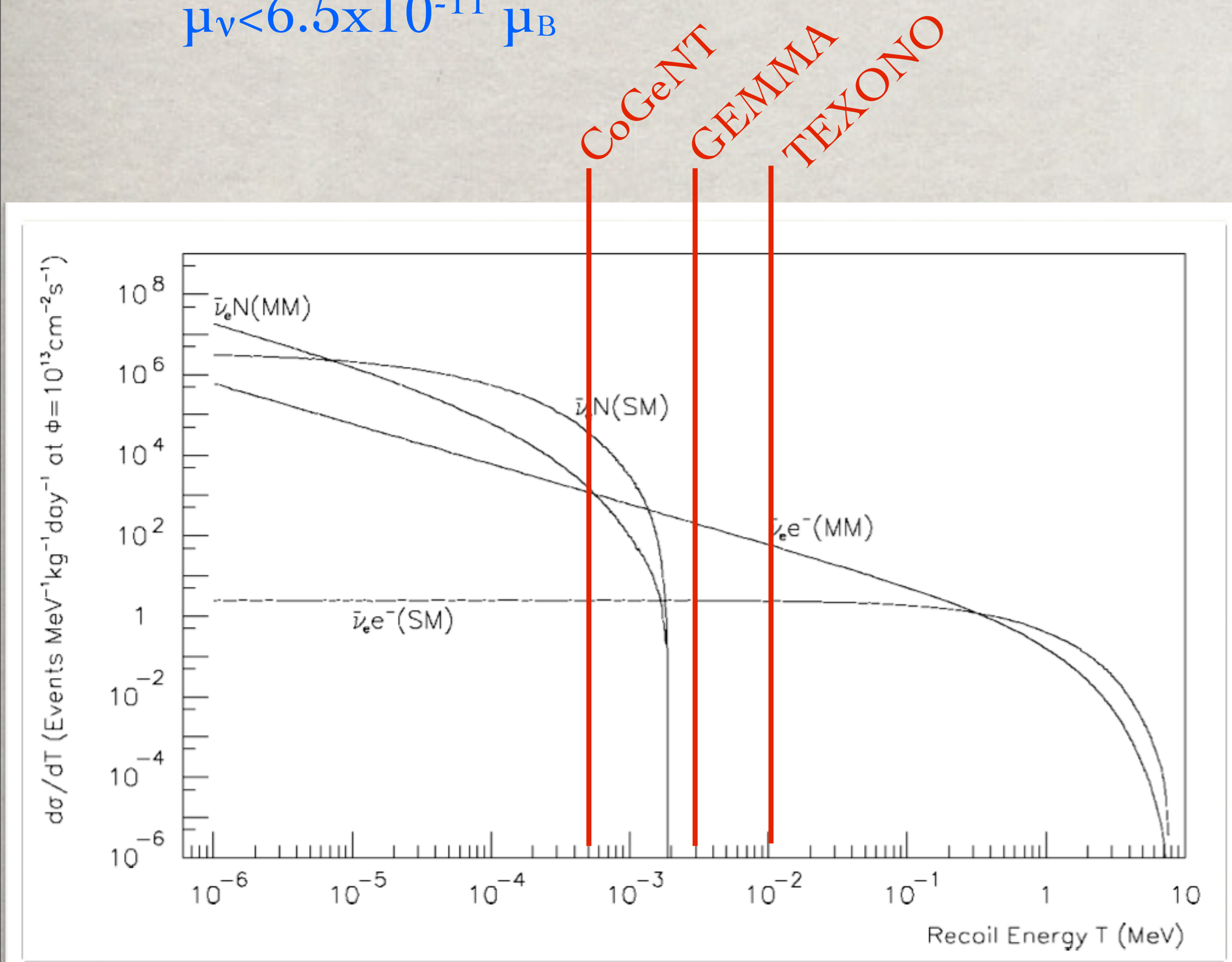
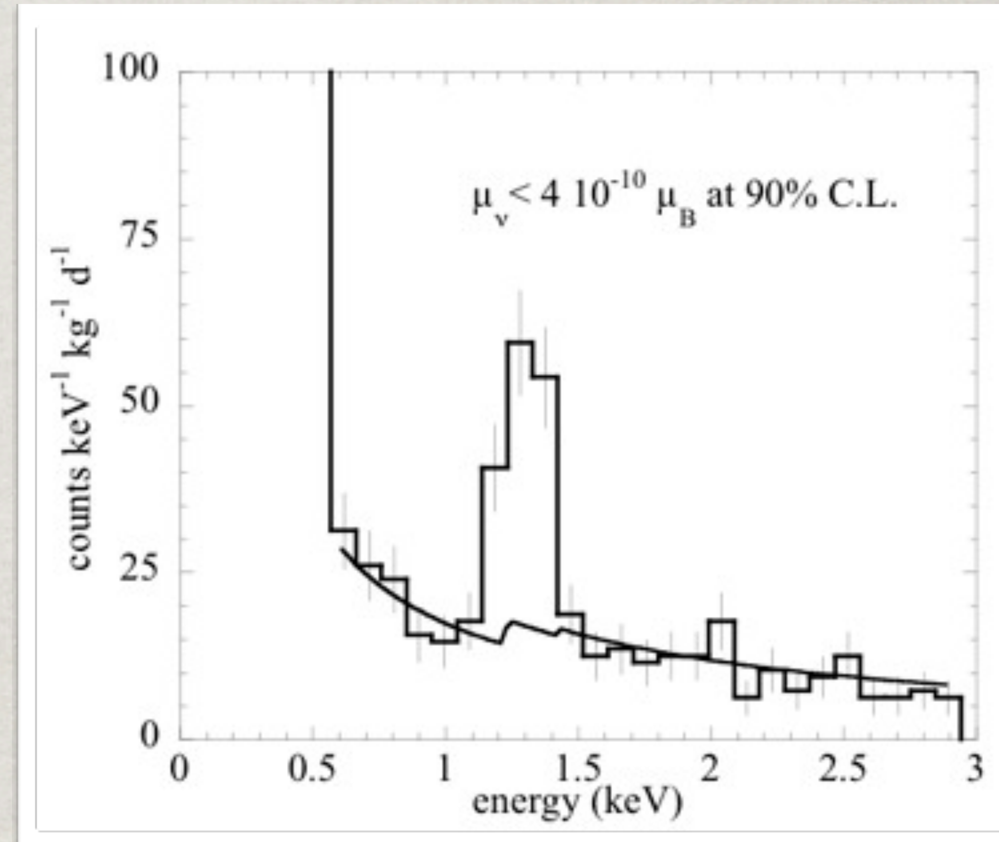
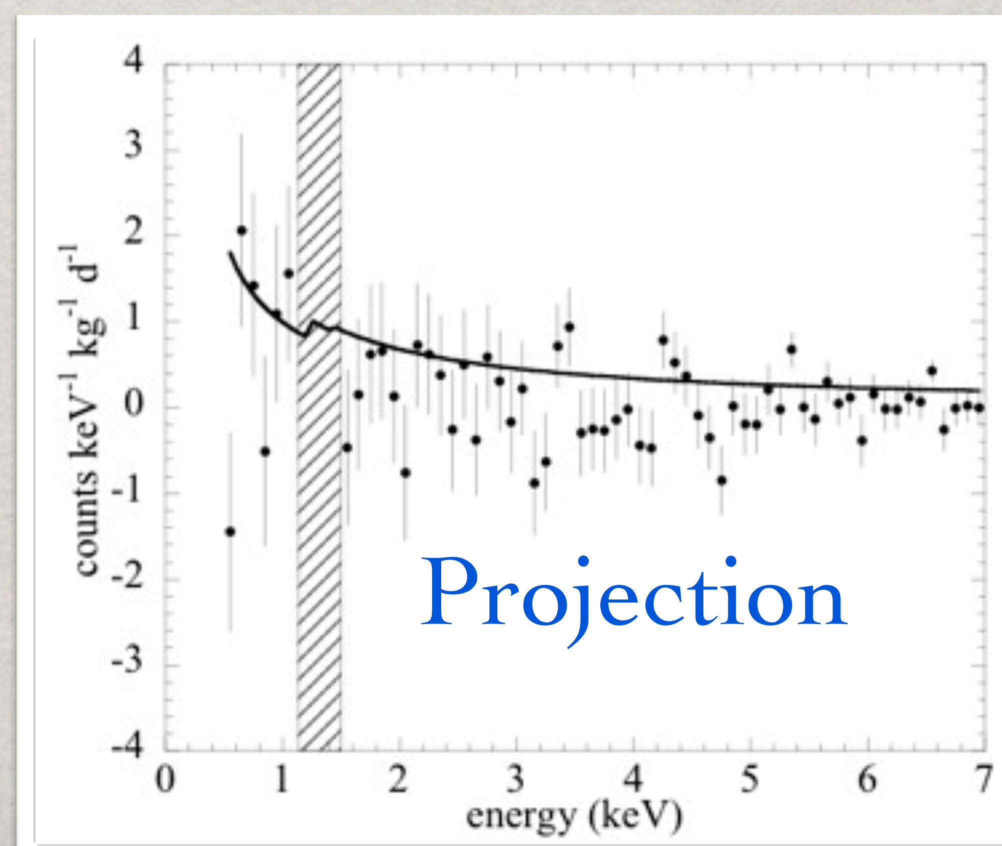






While we are at the reactor...
ν dE/dx

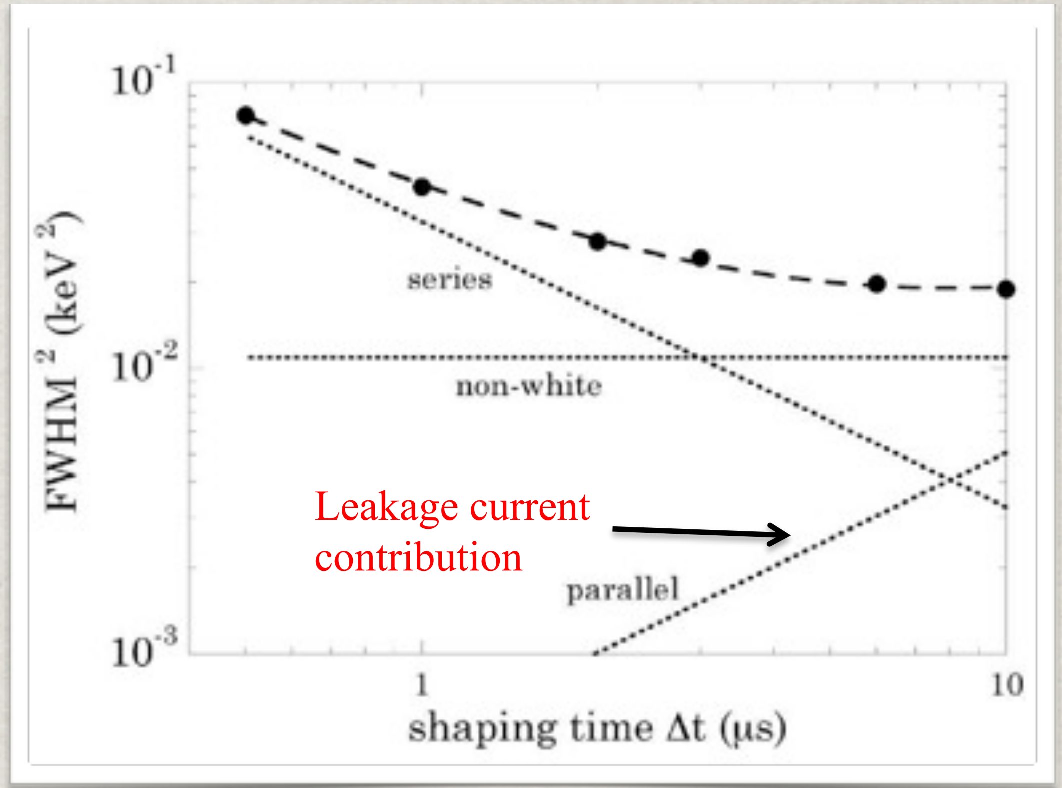
- continuous energy deposition from EM interaction F. Vanucci , Nucl Phys. B 70 (1999) 199-200; A. Castera *et al., Phys. Lett. B 452 (1999) 150-154*

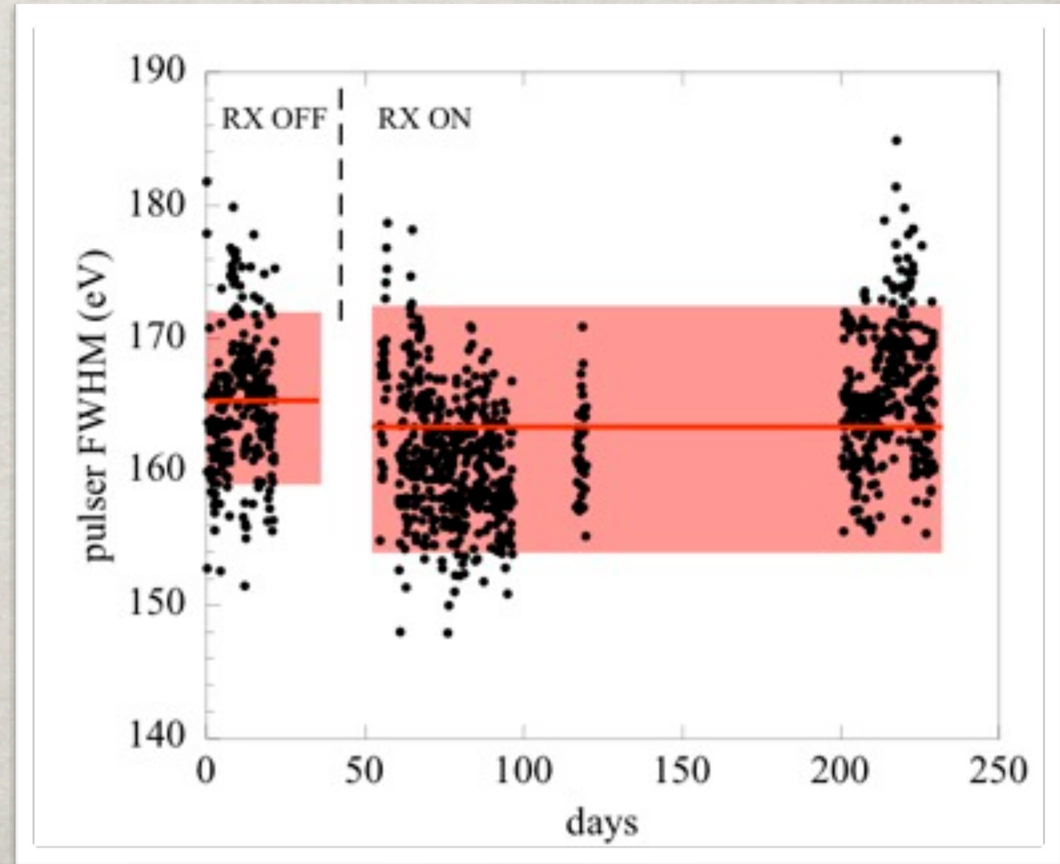
- signature = increased leakage current with Rx operation

$$I_L = \frac{ENC^2}{0.67 \times q\tau}$$

- $I_L < 1.63$ pA at 90% C.L. from reactor

- dE/dx < 4.6 x 10^{-8} eV cm^{-1}

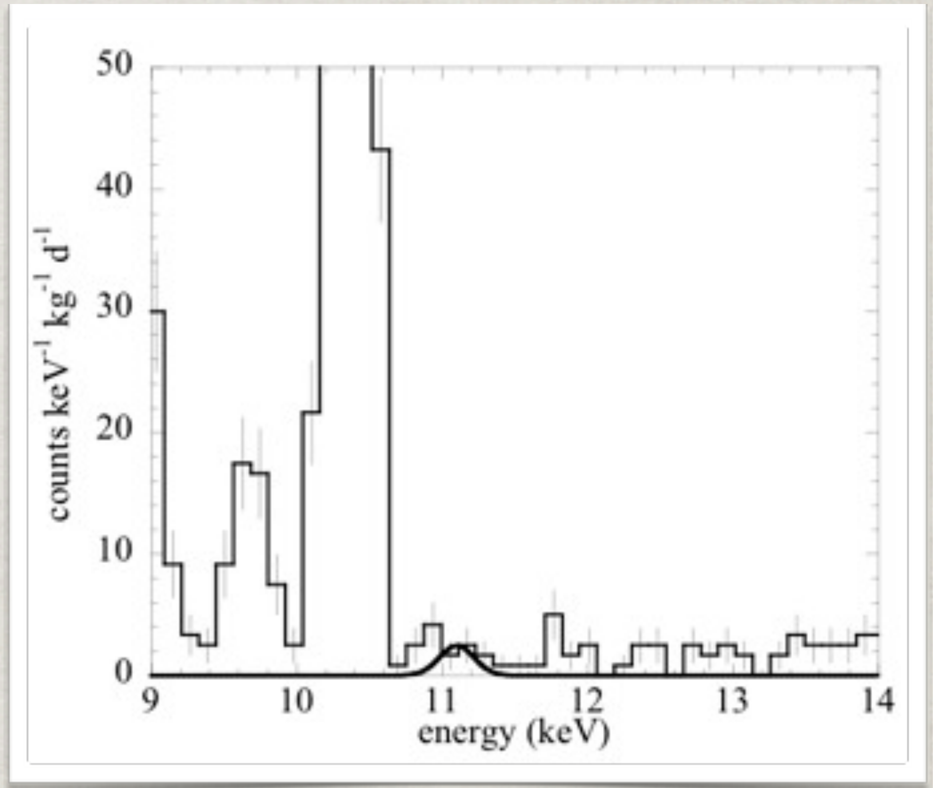


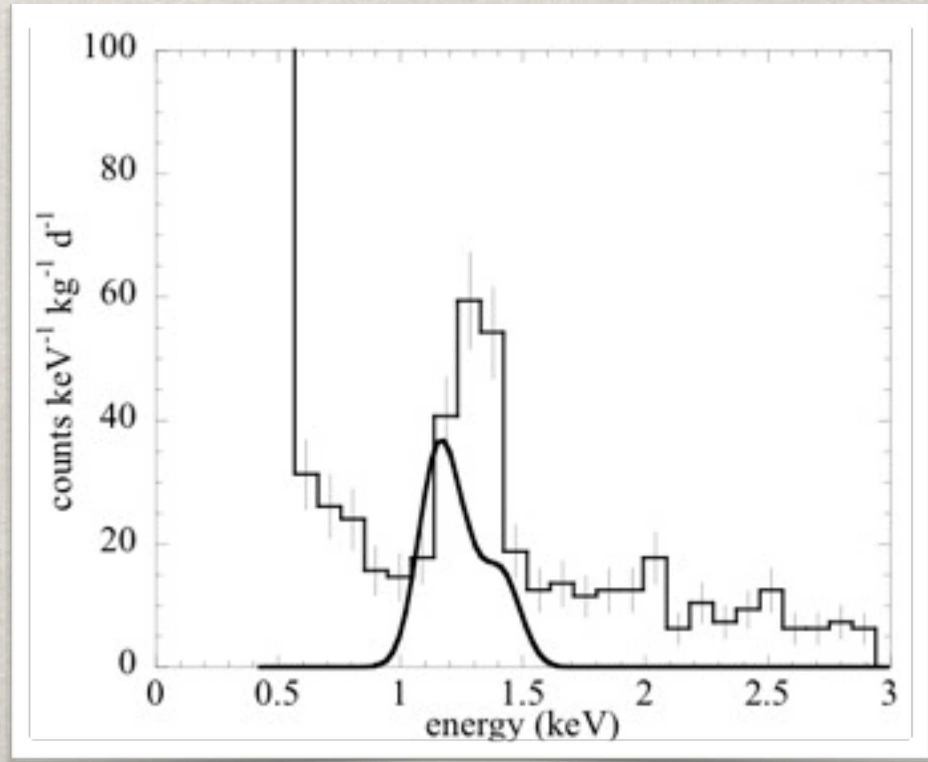


While we are low background... e^- decay

$$e^- \longrightarrow \nu_e \nu_e \bar{\nu}_e$$

- "invisible" decay
- cascade of x-rays and auger e^-'s
- K-shell (11.1 keV)
- L-shell's (1.14, 1.25, 1.41 keV)
- $\tau > 8.6 \times 10^{22}$ yr (90 % C.L.)
- DAMA –NaI(Tl) $\tau > 2.4 \times 10^{24}$ yr
- COSME –HPGe $\tau > 2.6 \times 10^{23}$ yr
- Majorana Projection:
  - $\tau > 1.8 \times 10^{26}$ yr

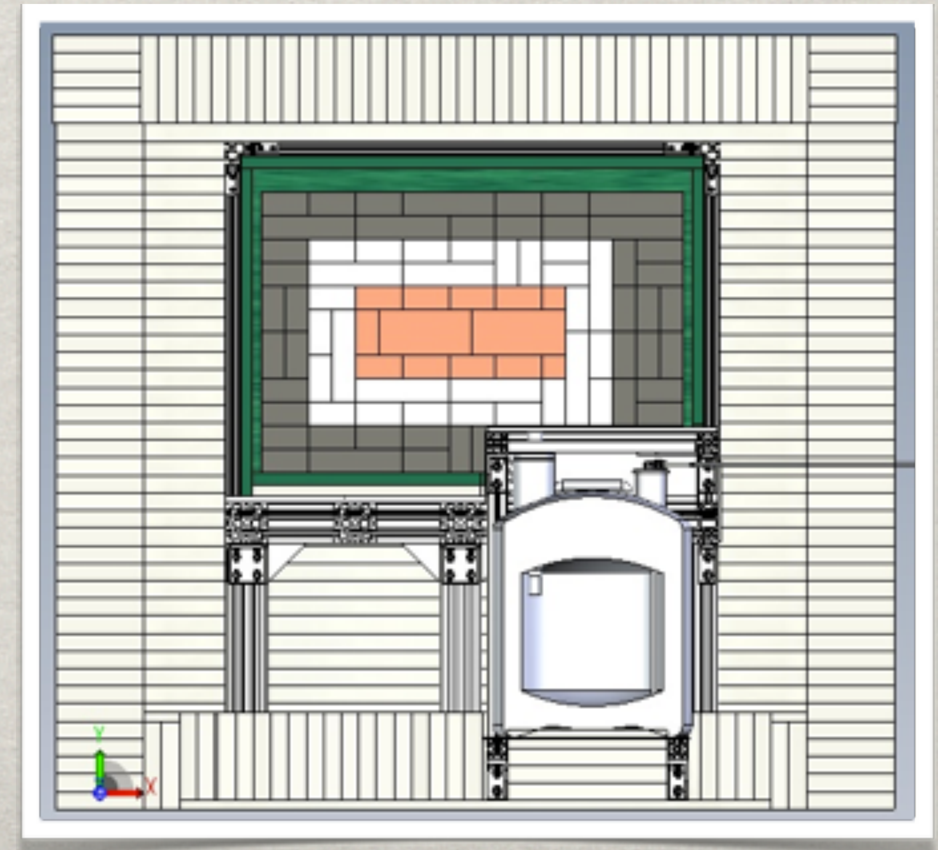




Monday, September 12, 2011

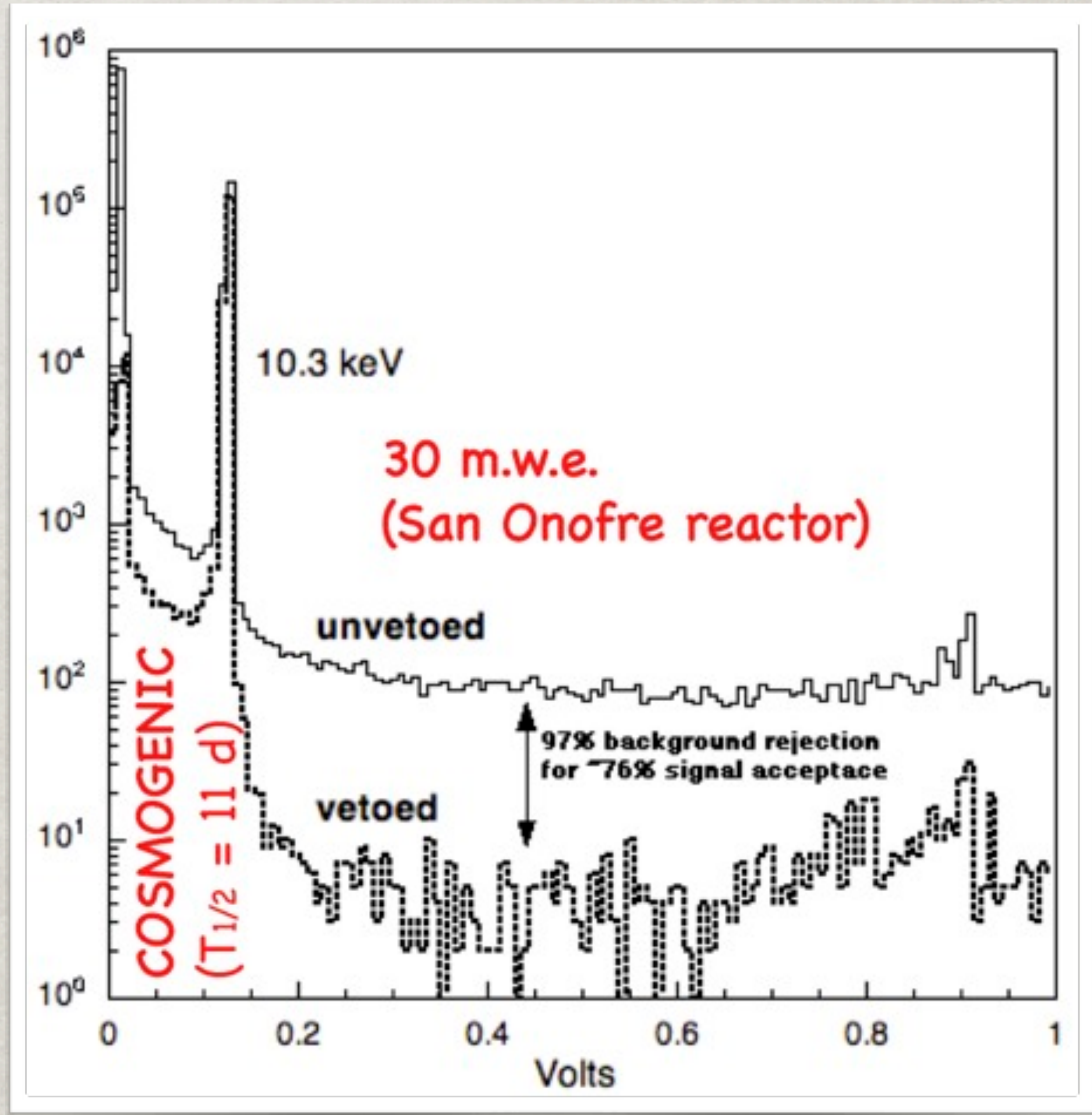
While we are low background... Dark Matter searches

- SuperWIMPS (Dark Pseudoscalars, Scalars)
- Light WIMPS
- This would be interesting if we didn't run to Soudan right away.
  - SONGS had high cosmogenic activation.
  - Also difficult to get LN2 to detector



Trying to get lower background

- At SONGS observed partial charge collection signals from ^{71}Ge K-shell
- At Soudan: discovered “slow” pulses
- At Chicago: Figured out that these are surface events



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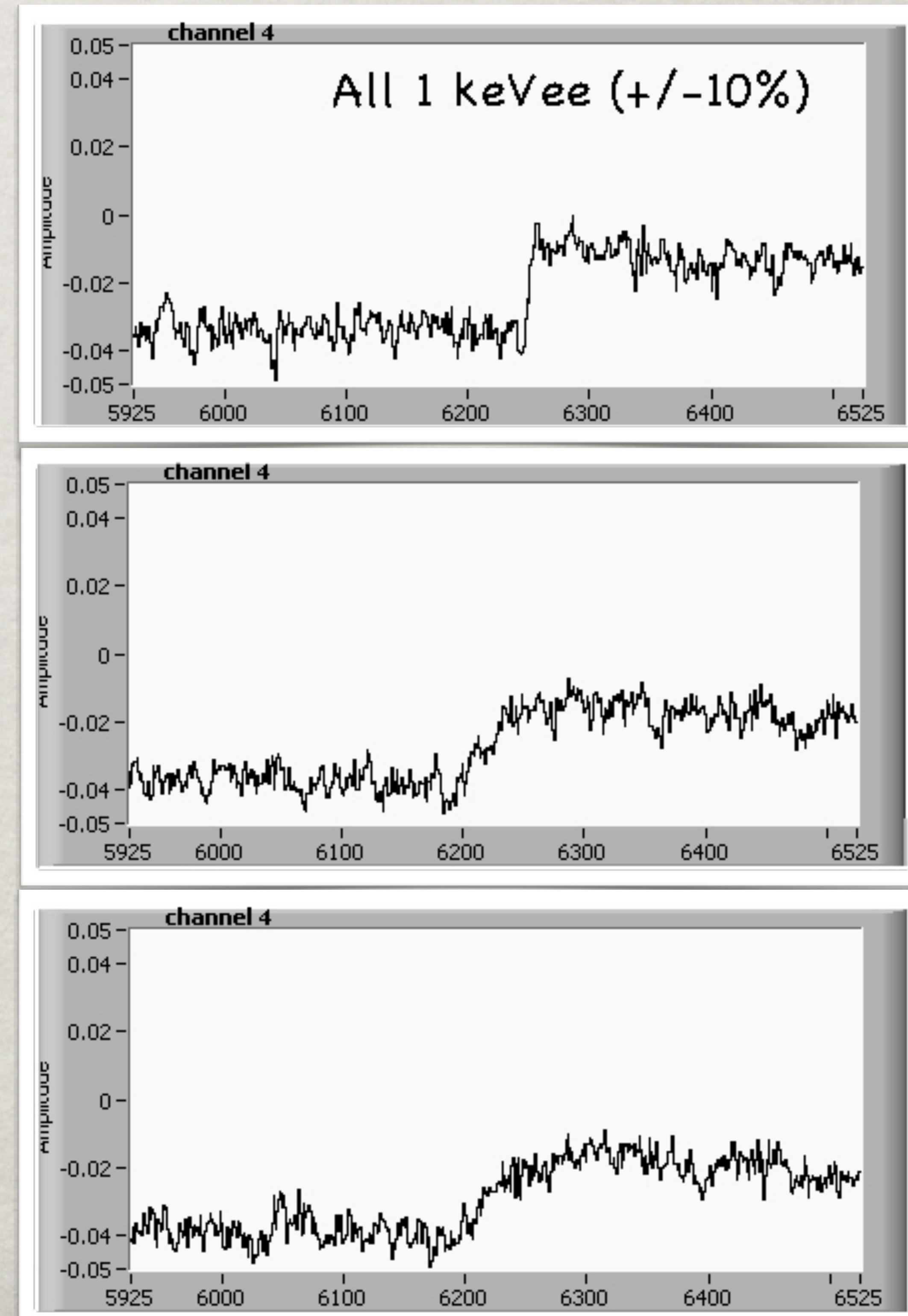

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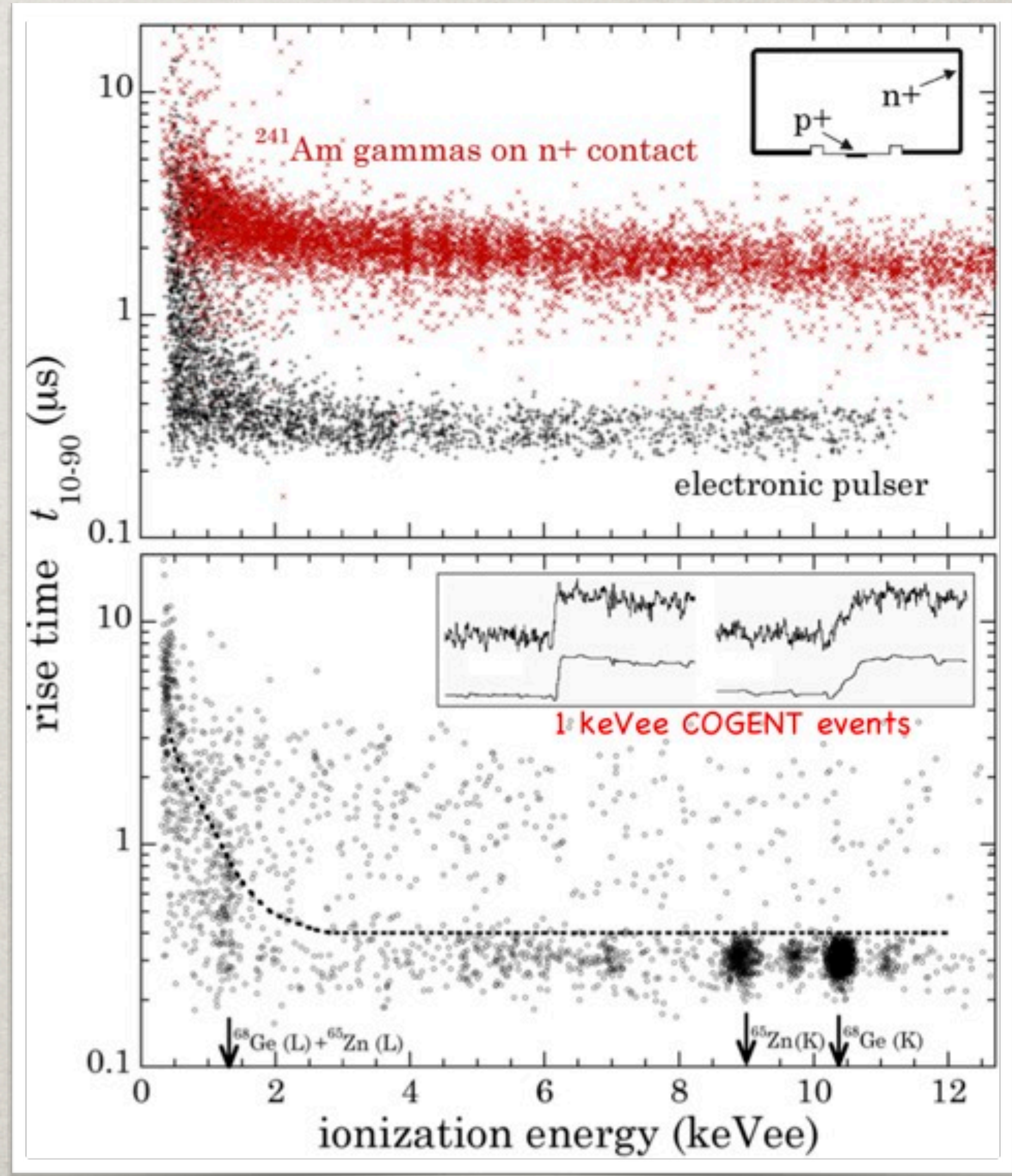
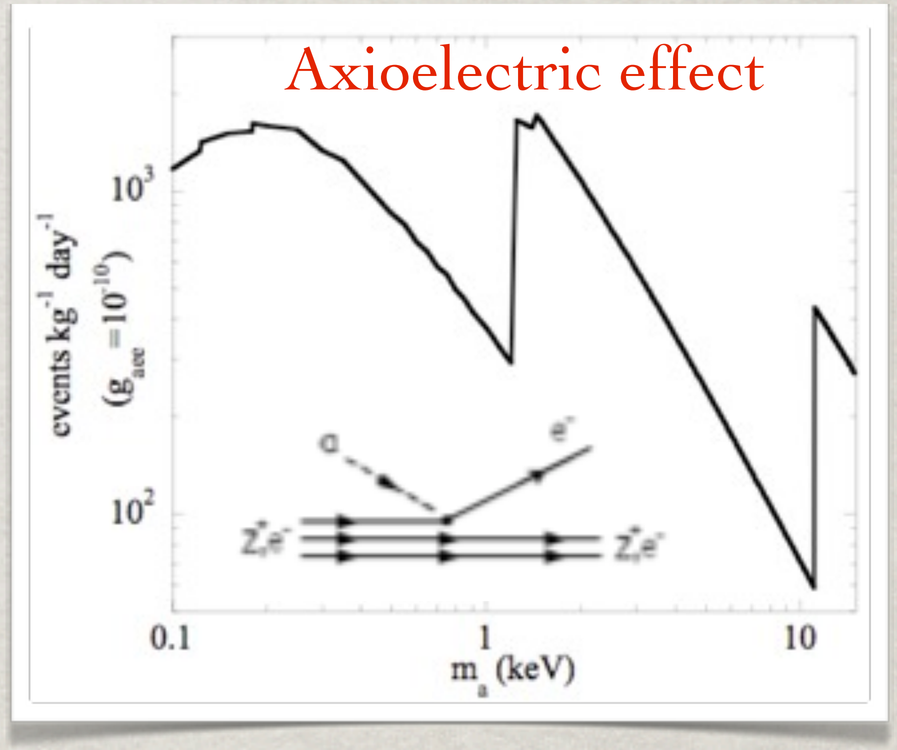
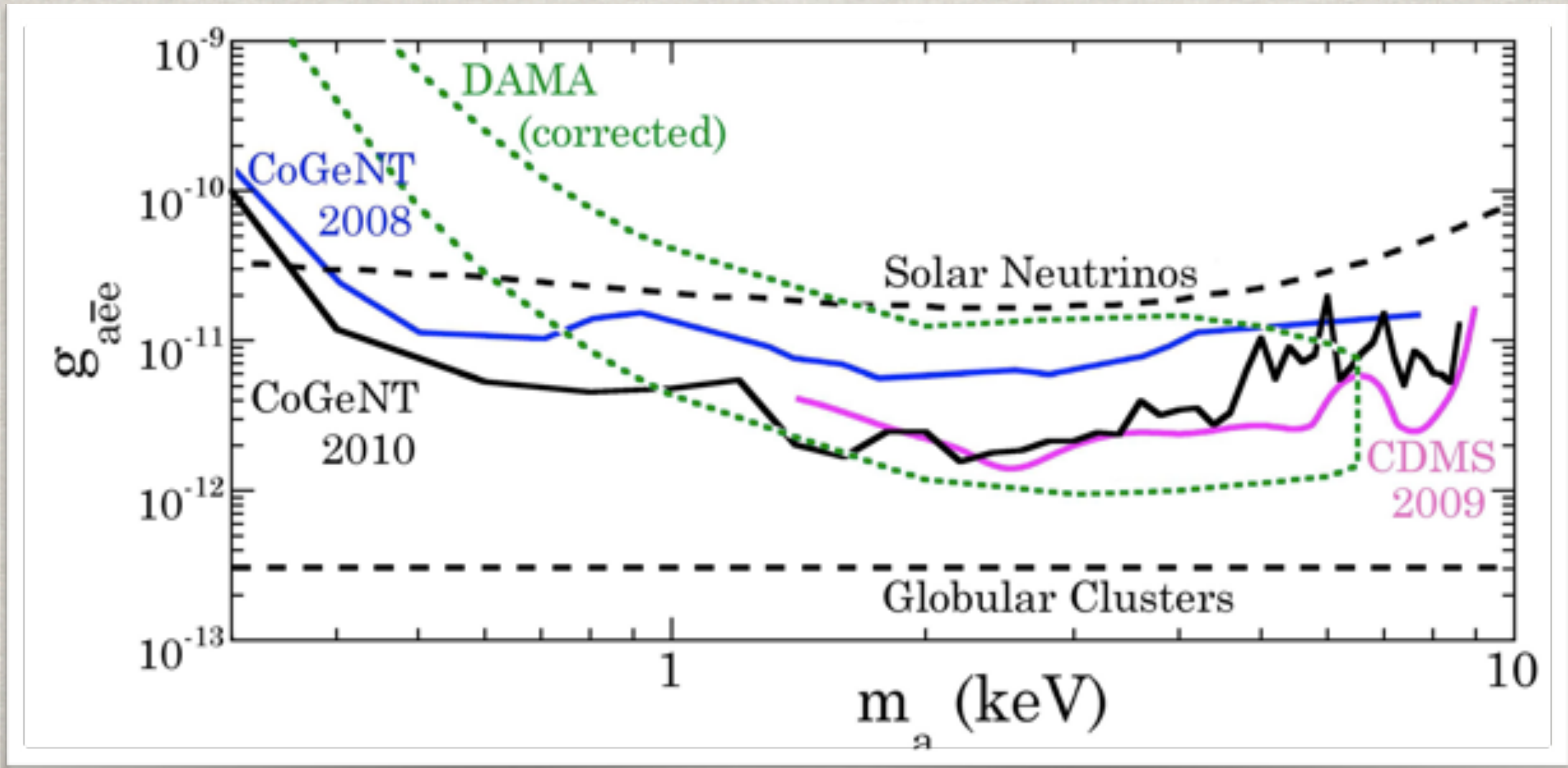
- At Chicago: Figured out that these are surface events
- And so we apply a cut (based, in part, on weighting field simulation of crystal



Search for Super-WIMPS (axion-like)

- Correct spectra for Trigger, Microphonics, Rise-time rejection efficiency
- Fit spectrum to background:
  - cosmogenic peaks
  - exponential
  - flat component
- Plus Pseudoscalar signal:





WIMPS: Observation of "an excess"

- Correct spectra for Trigger, Microphonics, Rise-time rejection efficiency
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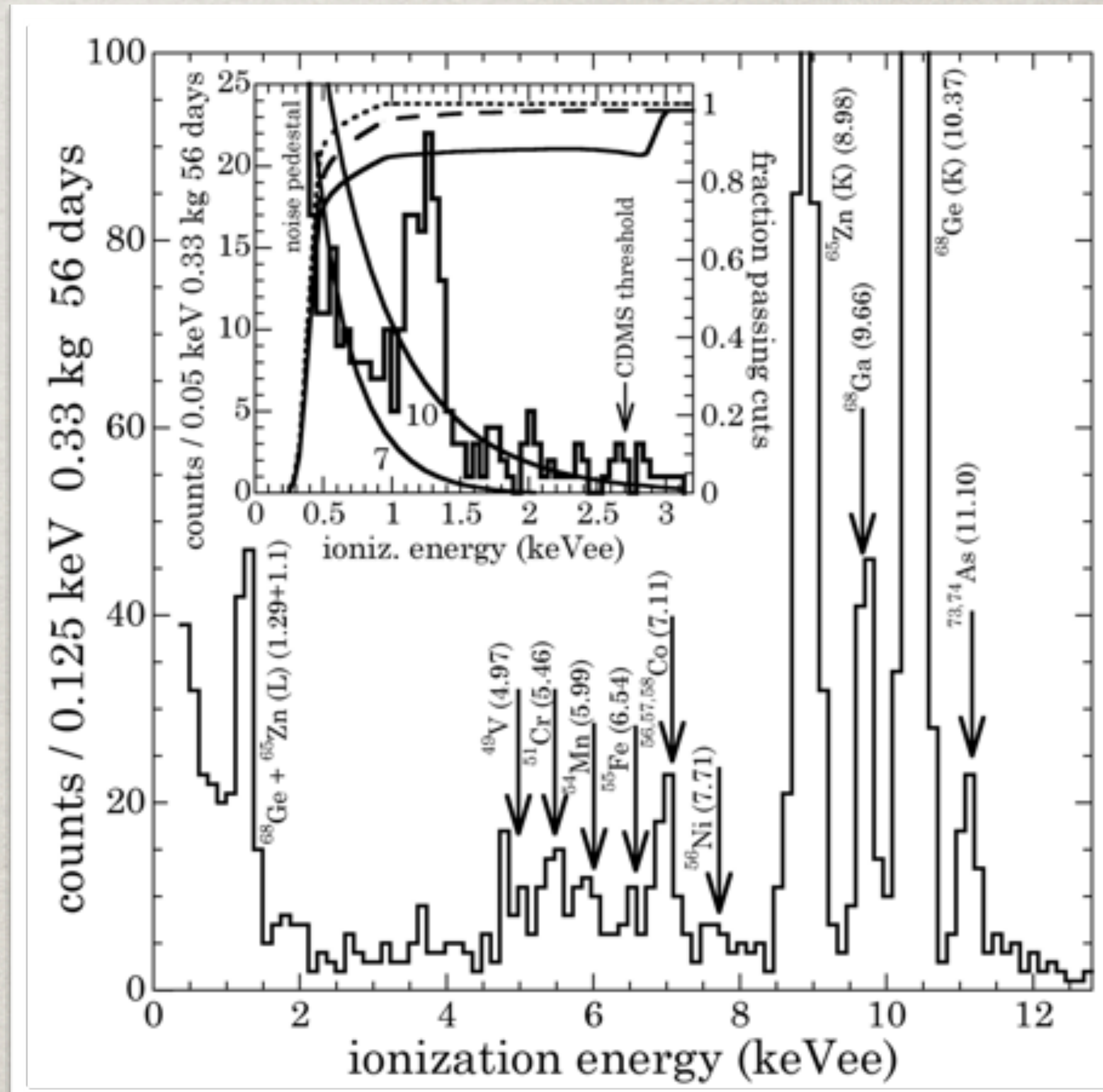
- Plus WIMP signal:
  - Exponential with escape velocity cut-off

- observe non-zero excess in fit though it does not exclude the null hypothesis of no-signal



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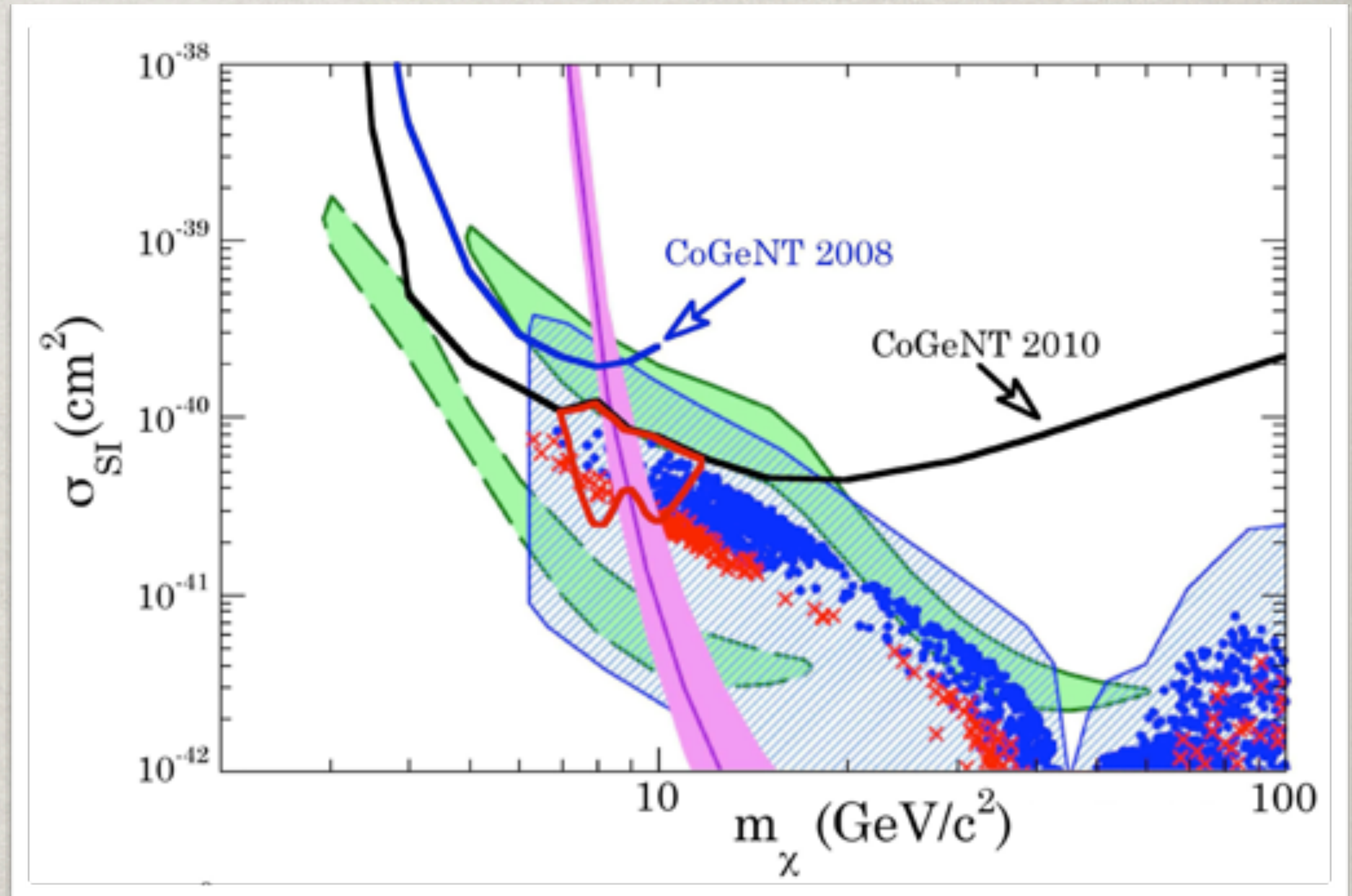

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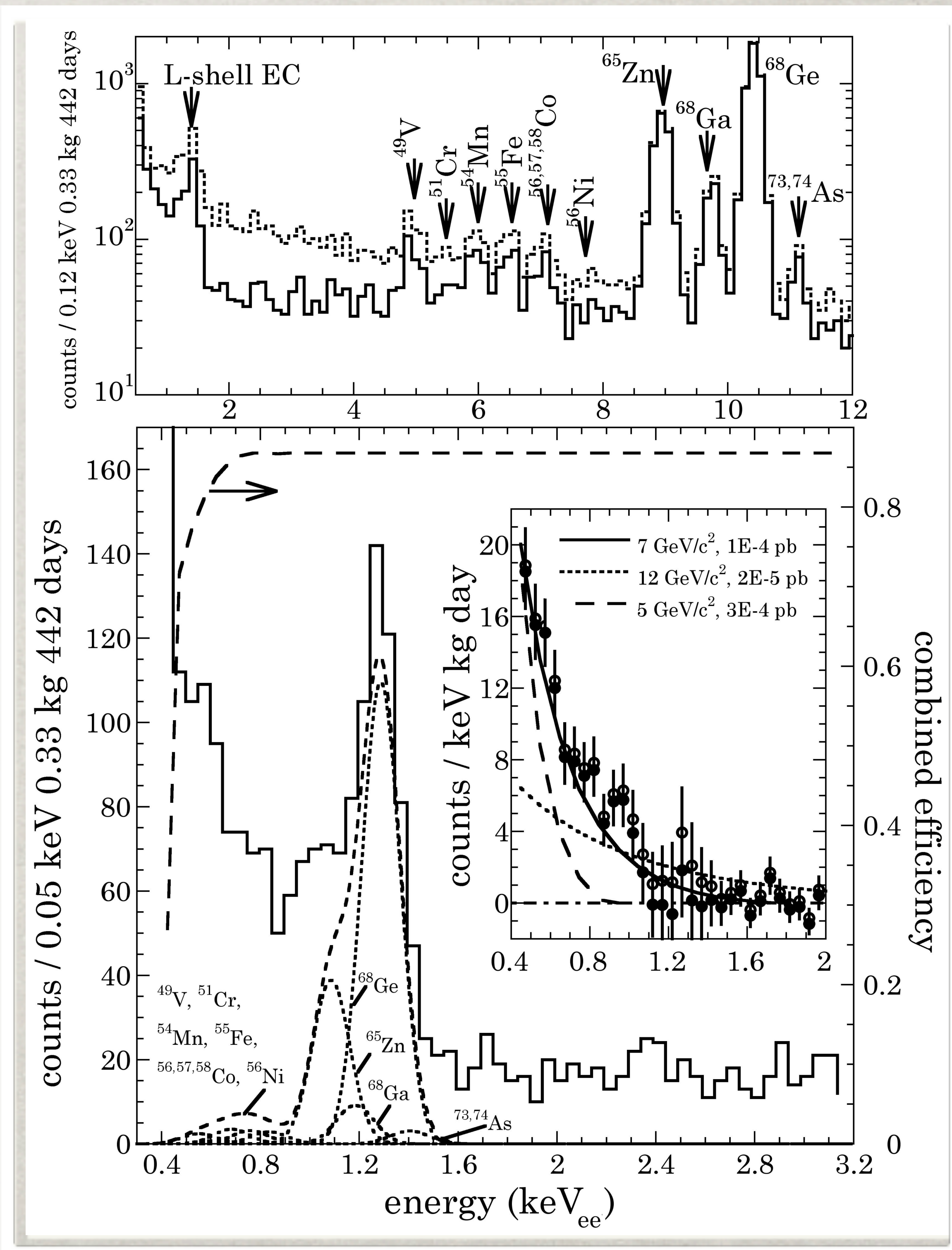
A FIRE AND A 2.8σ HINT OF A MODULATION

- Fire in Soudan Lab March 17th of this year
- Everything survived
- incident triggered data analysis...just in case
- 458 days (442 live)
- Strip low-E Spectrum of L-Shell peaks (using assiciated K-Shell peaks)



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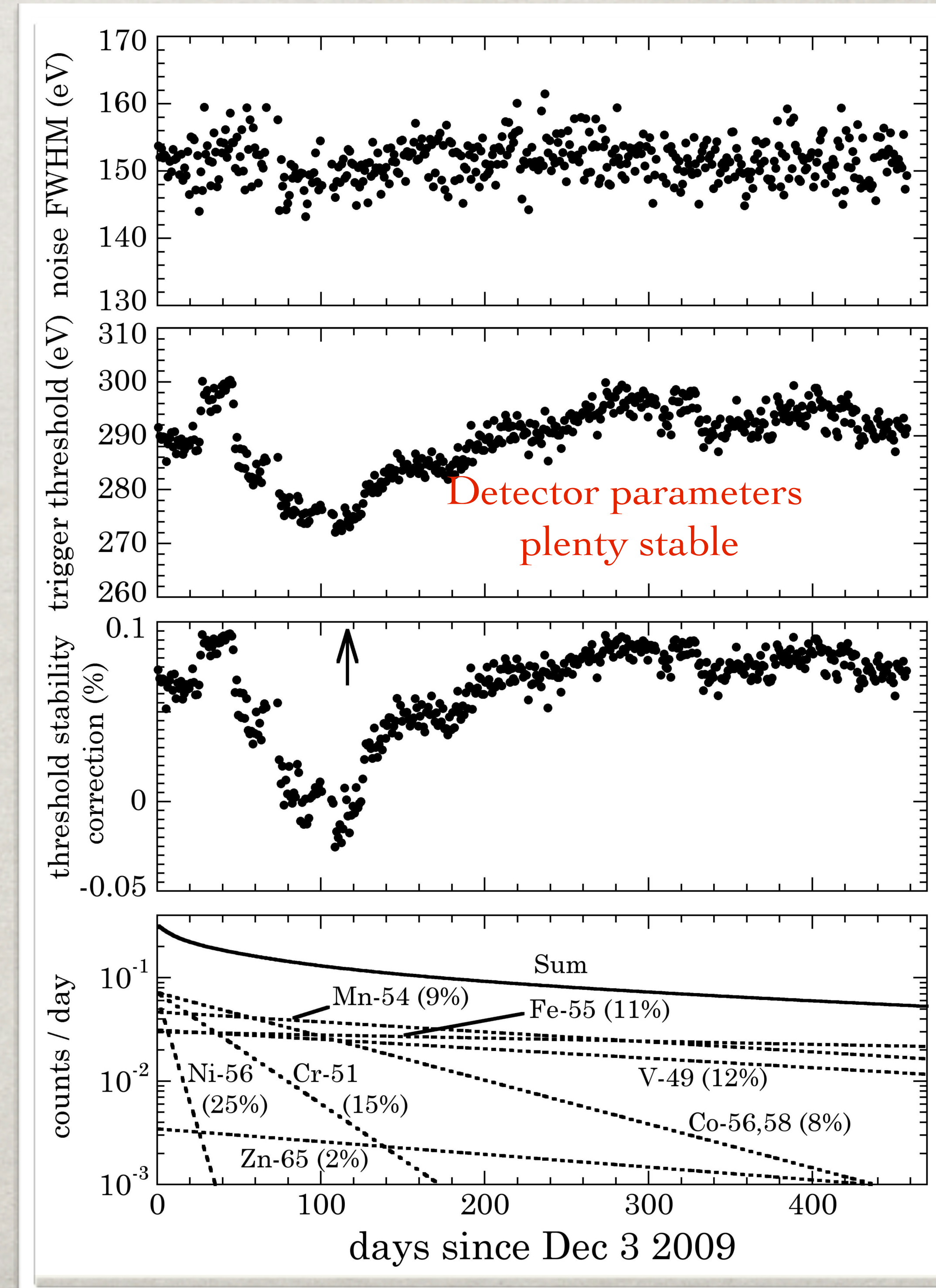

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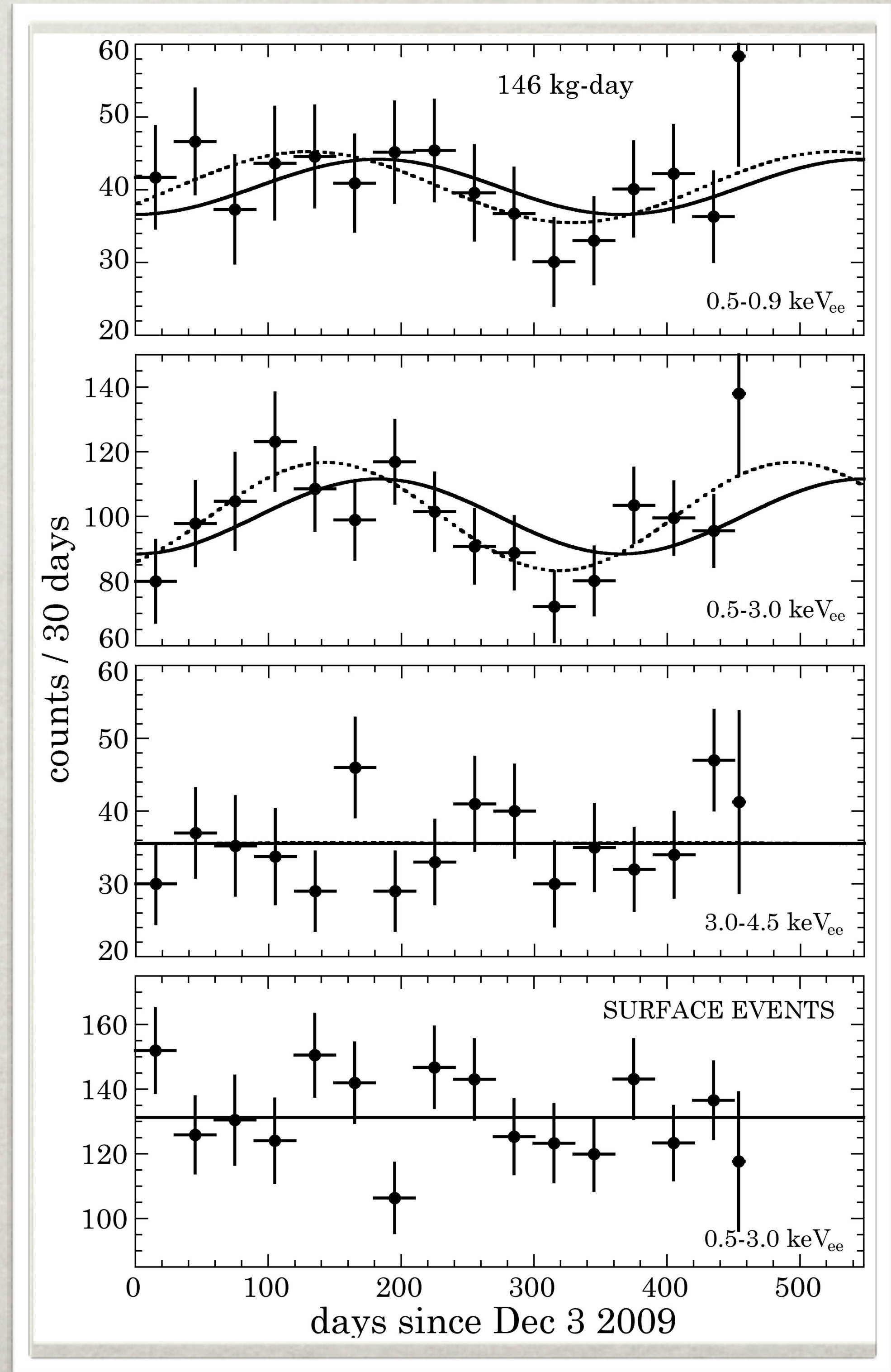
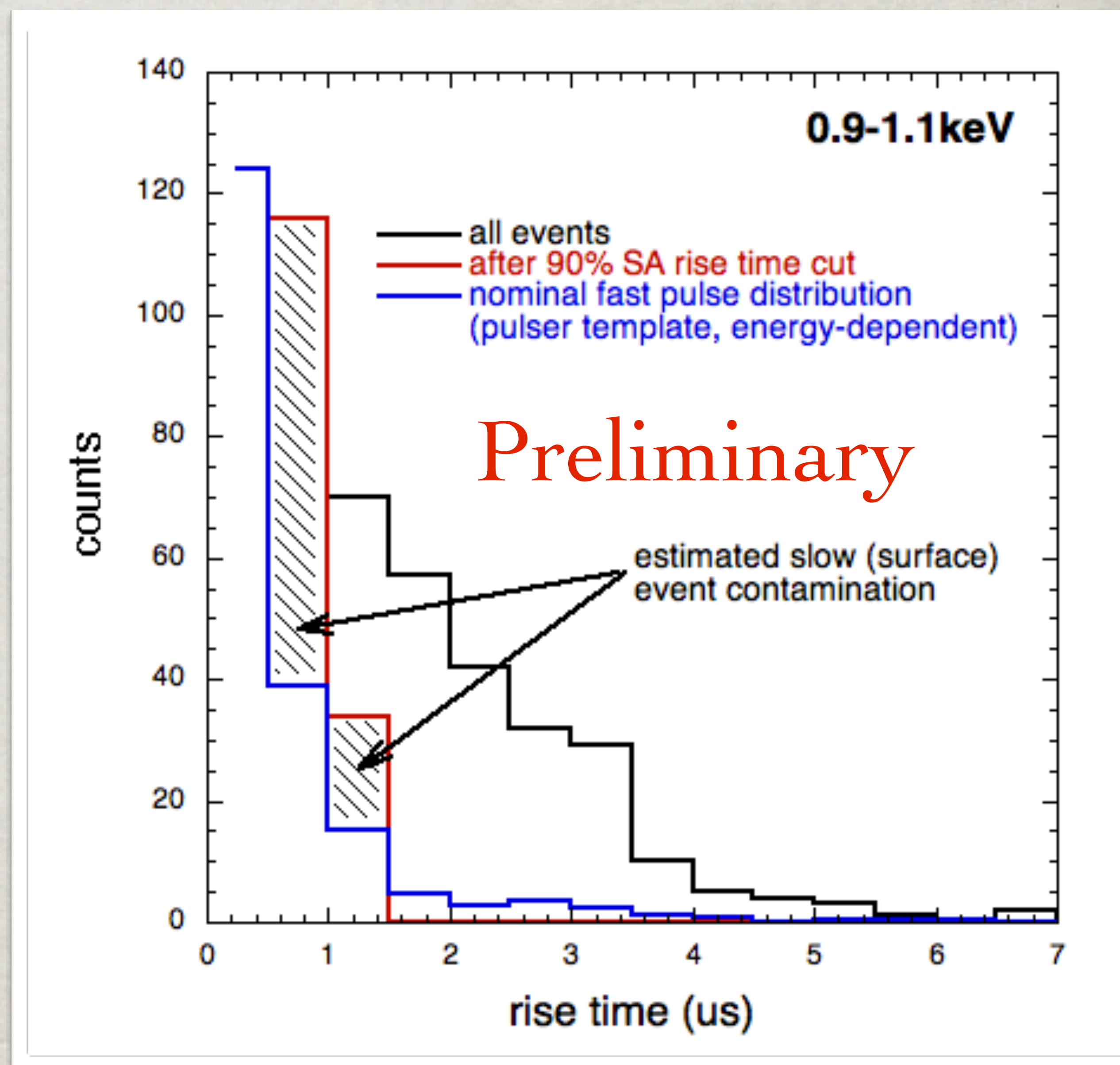
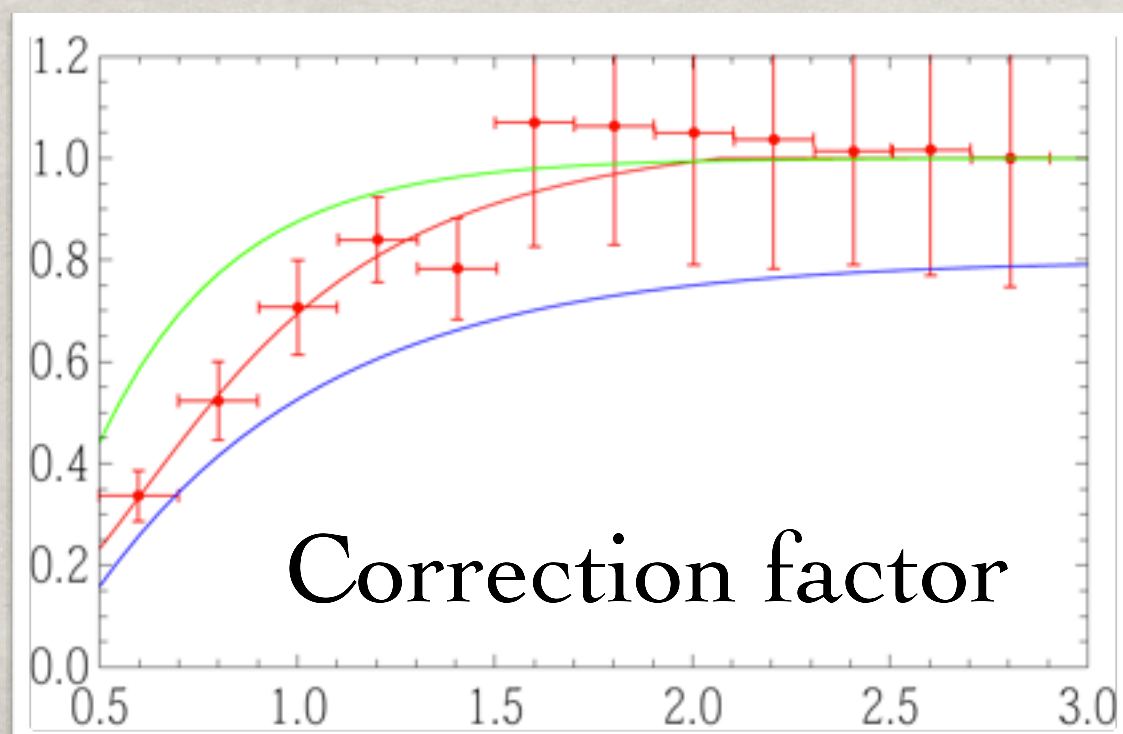
- Strip low-E Spectrum of L-Shell peaks (using assiciated K-Shell peaks)
- Account for decays of cosmogenically activated peaks
- Modulation signal at 2.8σ (cross-checked by many others after data shared)



Update: More statistics

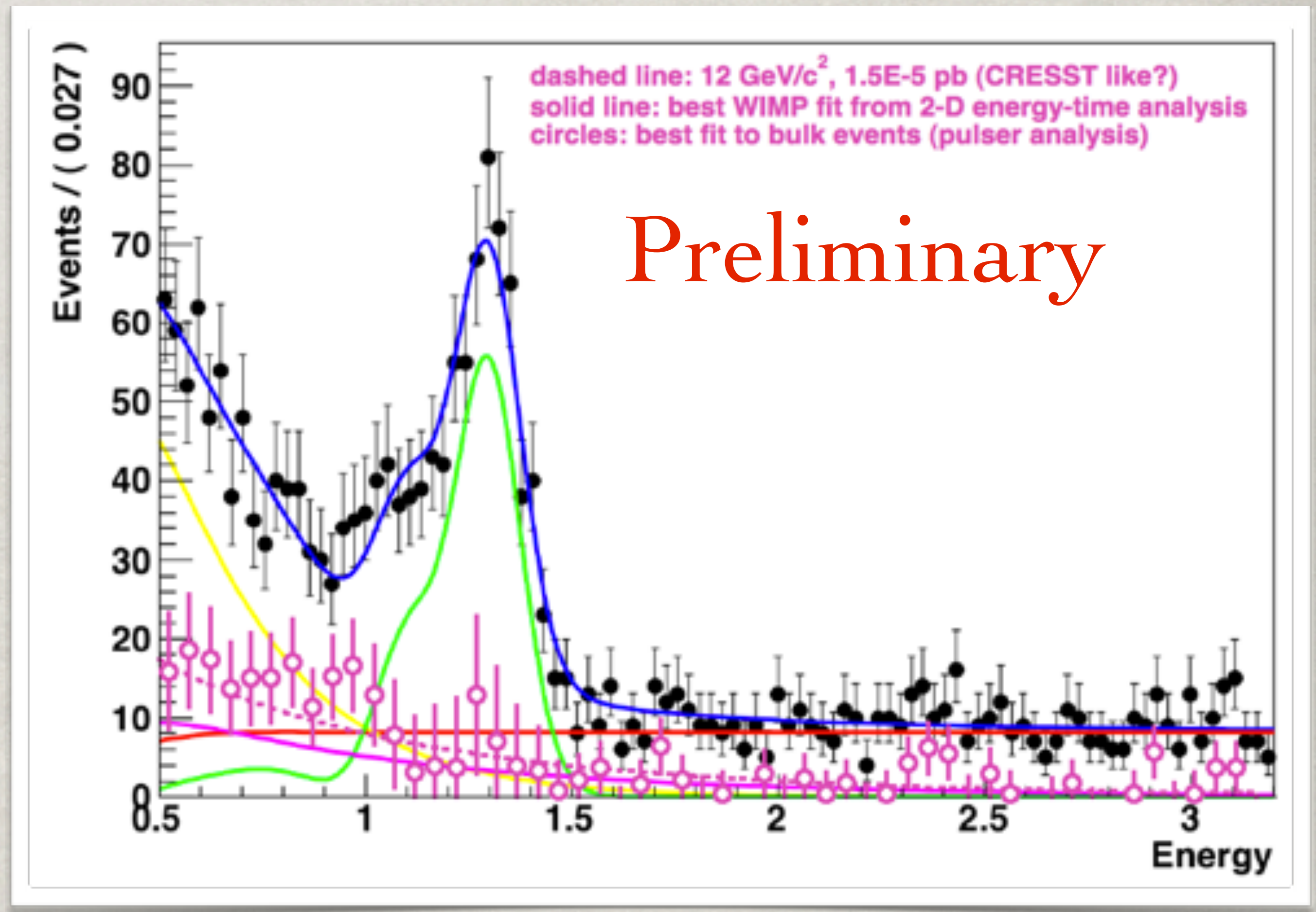
- Some indications of leakage of surface events past rise-time cut (Preliminary)
- The data on this is only now becoming available





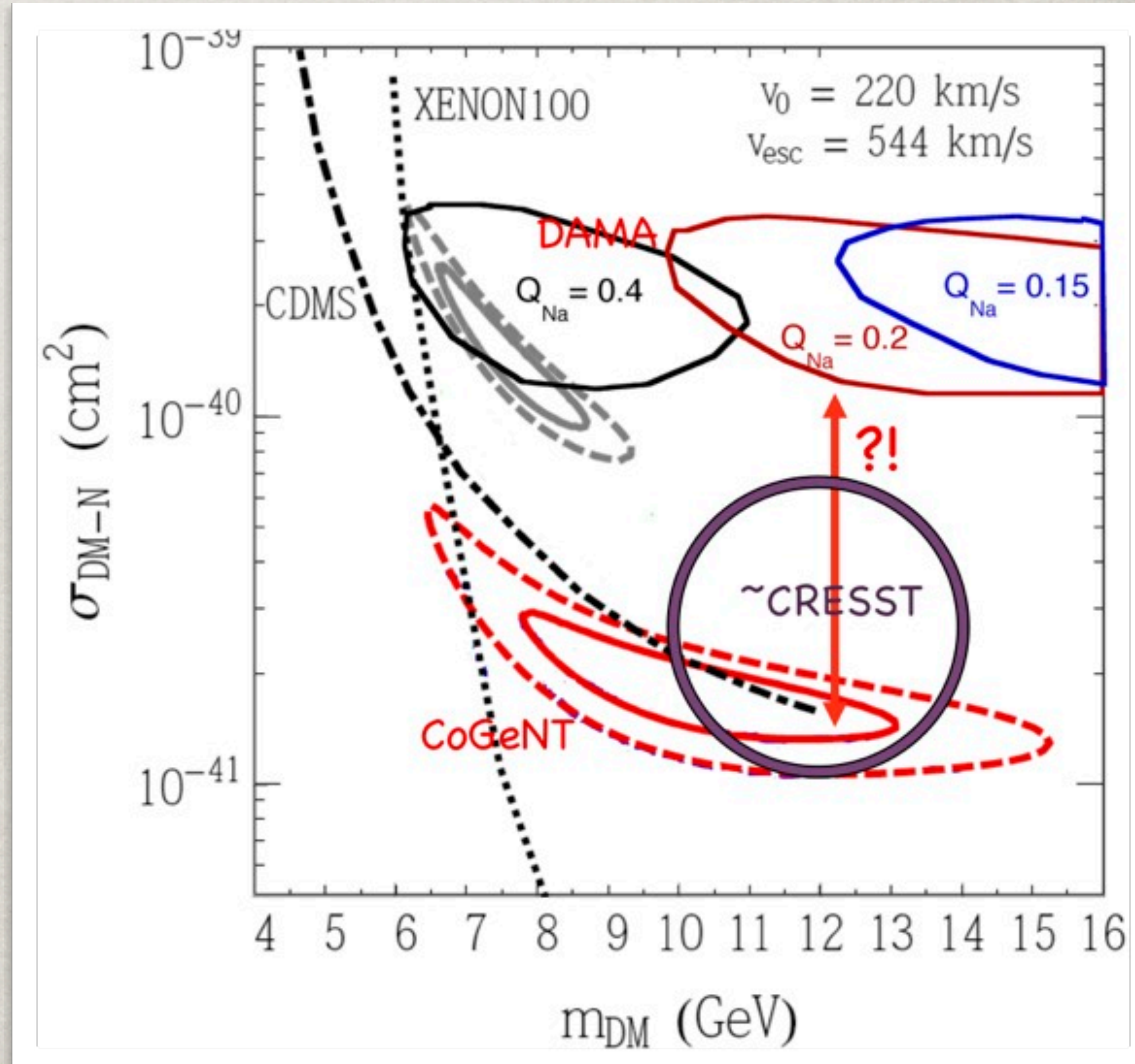
Update: More statistics

- Some indications of leakage of surface events past rise-time cut (Preliminary)
- The data on this is only now becoming available
- These leaked surface events seem to have biased earlier fit results
- Now combined energy-time modulation analysis and spectral-only analysis seem to point to similar σ and M_χ
- But! It needs to be pointed out that the modulation amplitude is too large (x10) for a simple isotropic halo model for WIMPS



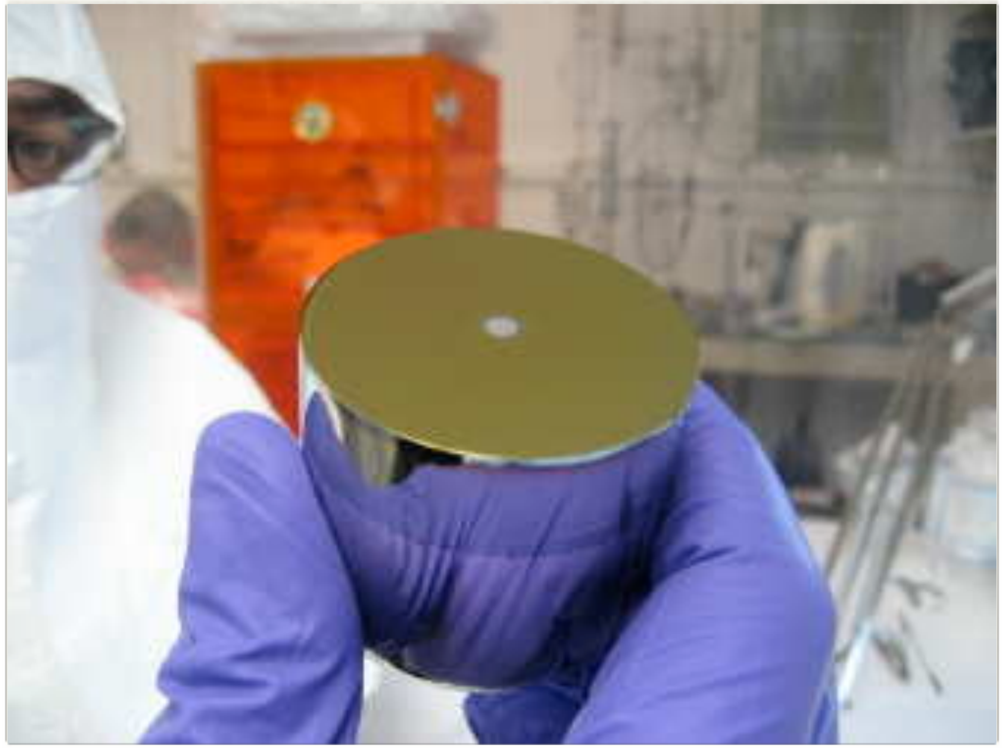
Vanilla WIMP halo model

- Movement of CoGeNT region with better understanding of backgrounds
- This whole region is a mess: There are too many models and too many possible observations to make clear sense of things
- Lets not forget that the modulation is too large for the Vanilla WIMP Halo Model
- Could be many physics explanations...or could be backgrounds. (Isospin Violating DM, Streams...etc.)
- Only time will tell.



What next?

- Continue to take modulation data at Soudan for a bit of a cycle (> 2.8 σ)
- Calibrate low energies by activating with thermal neutrons? (^{71}Ge)
- Perform detailed x-ray scan over surface with this detector
- bring to surface to create more cosmogenics?
- Compton-scatter scan of bulk and surfaces?
- Build bigger/smaller detectors to test surface/volume effects
- Change point-contact size to test noise effects
- Attempt to lower threshold/noise to improve peak resolution (and go back and measure Coherent neutrino-nucleus scattering)
- Building CoGeNT-4 (4 detectors...check relative modulations if any); maybe can measure/see WIMP escape velocity?
- Majorana Demonstrator by the Majorana Collaboration



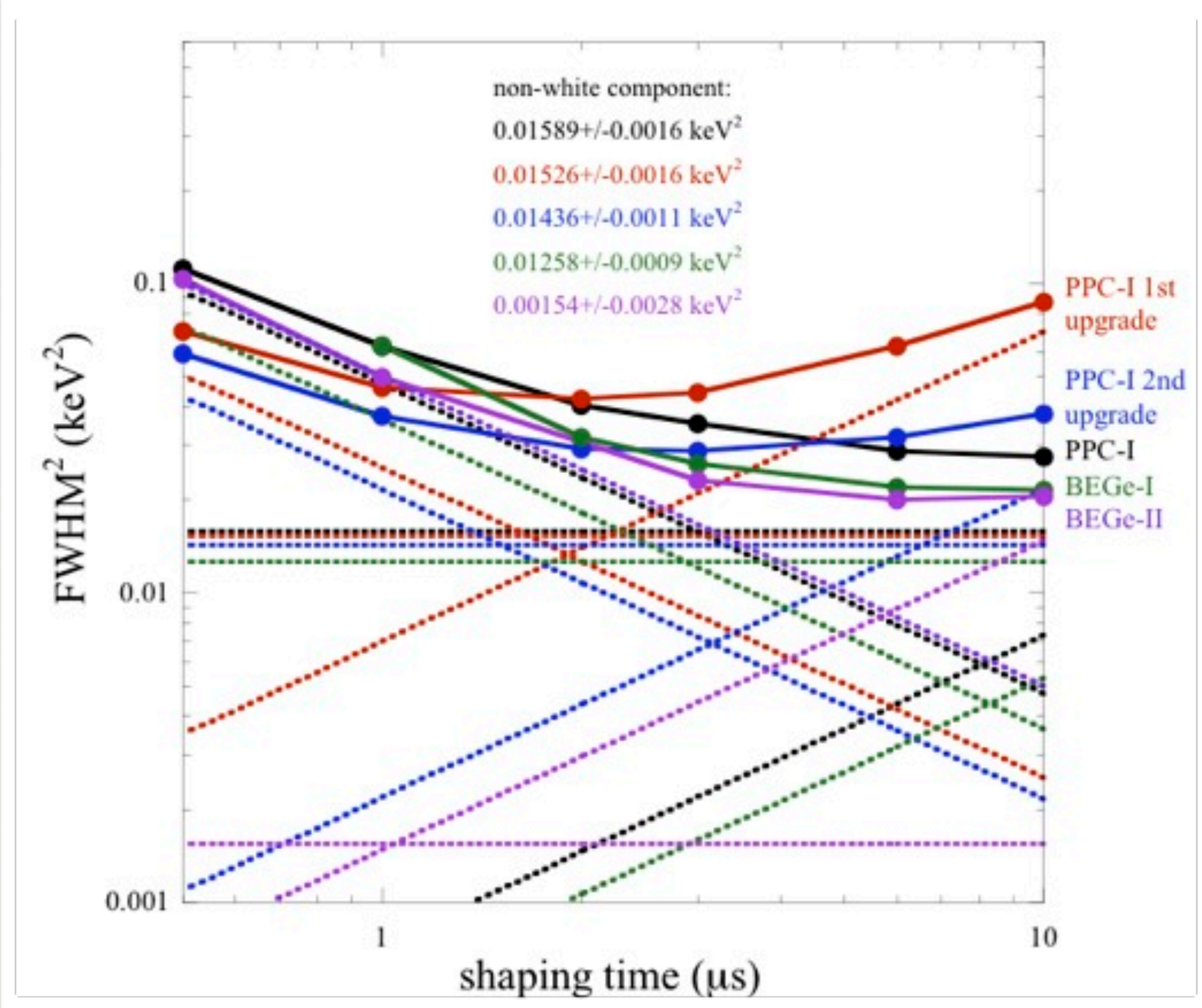
CoGeNT Team

ANL: Pat de Lurgio
CANBERRA Industries: Jim Colaresi, Orren Tench, Mike Yocum
LLNL: Nathaniel Bowden, Steven Dazeley
ORNL: David Radford
PNNL: Craig Aalseth, Jim Fast, Todd Hossbach, Martin Keillor, Jeremy Kephart, Harry Miley, John Orrell
SNL: Belkis Cabrera-Palmer, David Reyna
UC: Phil Barbeau, Juan Collar, Nicole Fields, Charles Greenberg
UNC: John Wilkerson
UW: Mike Marino, Mike Miller, Tim Van Wechel

Backup Slides

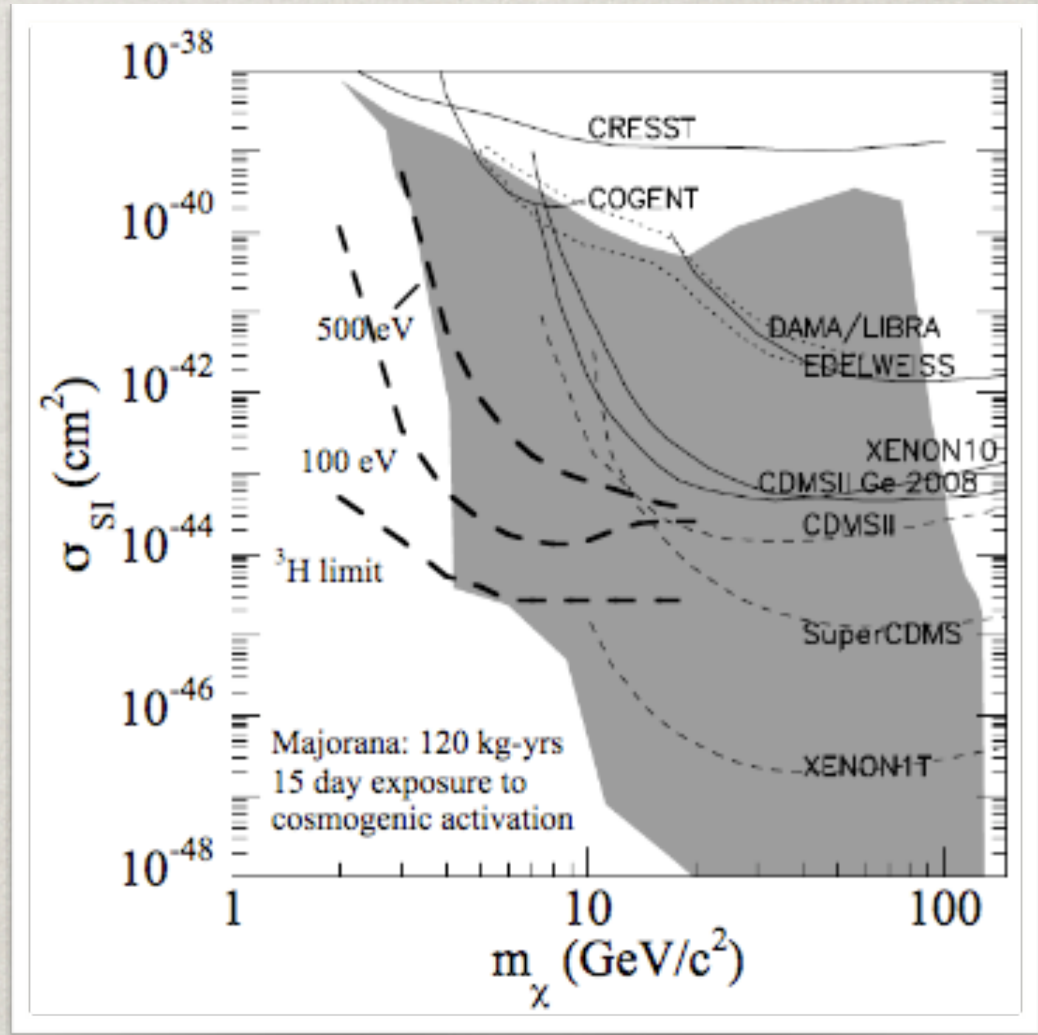
Status of Coherent ν-N scattering measurement

- Need to reduce threshold further
- Address still some μ induced neutron backgrounds
- Move detector to Soudan to further characterize backgrounds and perform light WIMP searches



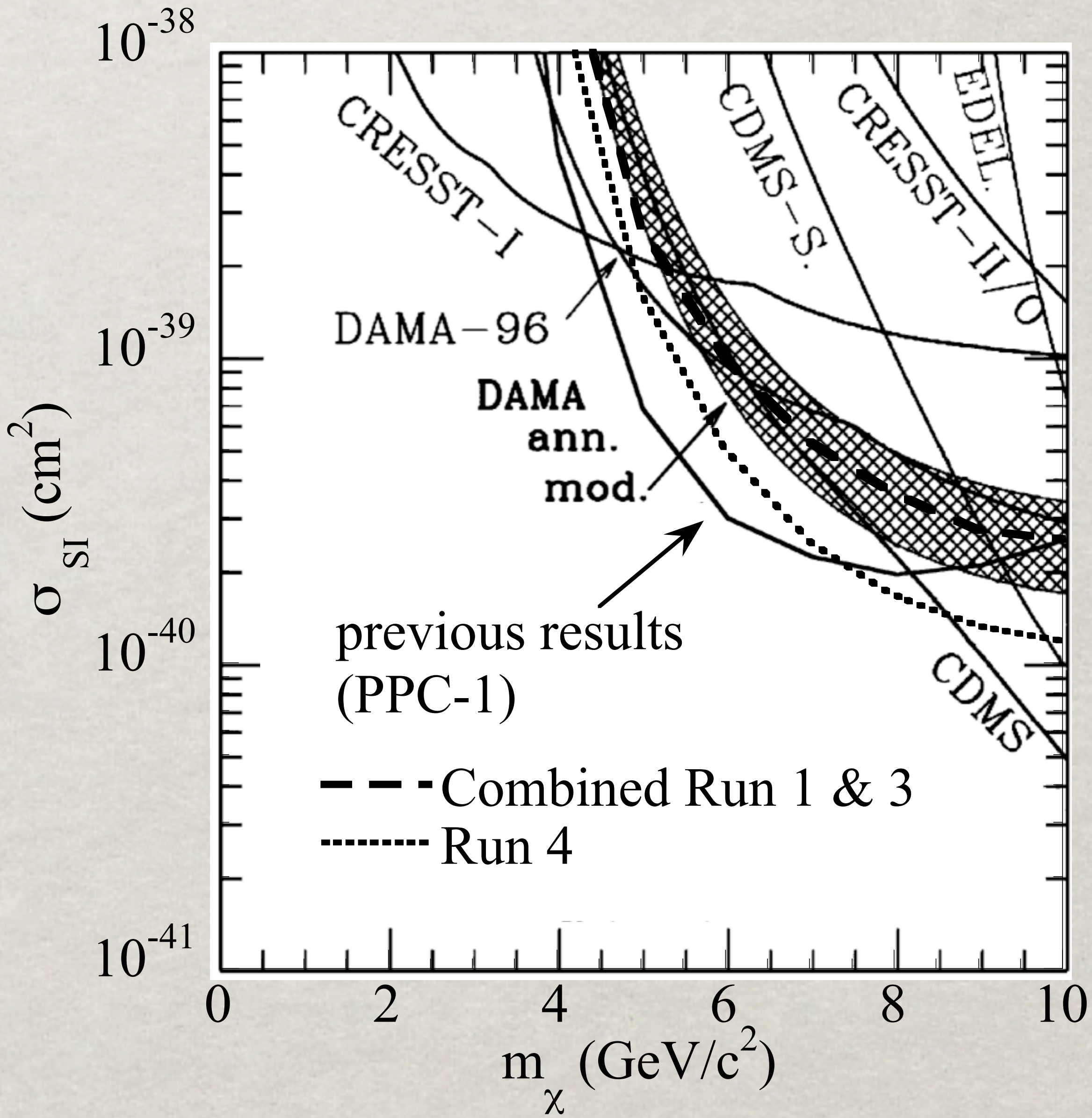
Majorana Demonstrator WIMP Projections

- 15 days of exposure on the surface for 30 kg of unenriched detectors
- Dominated by ^3H

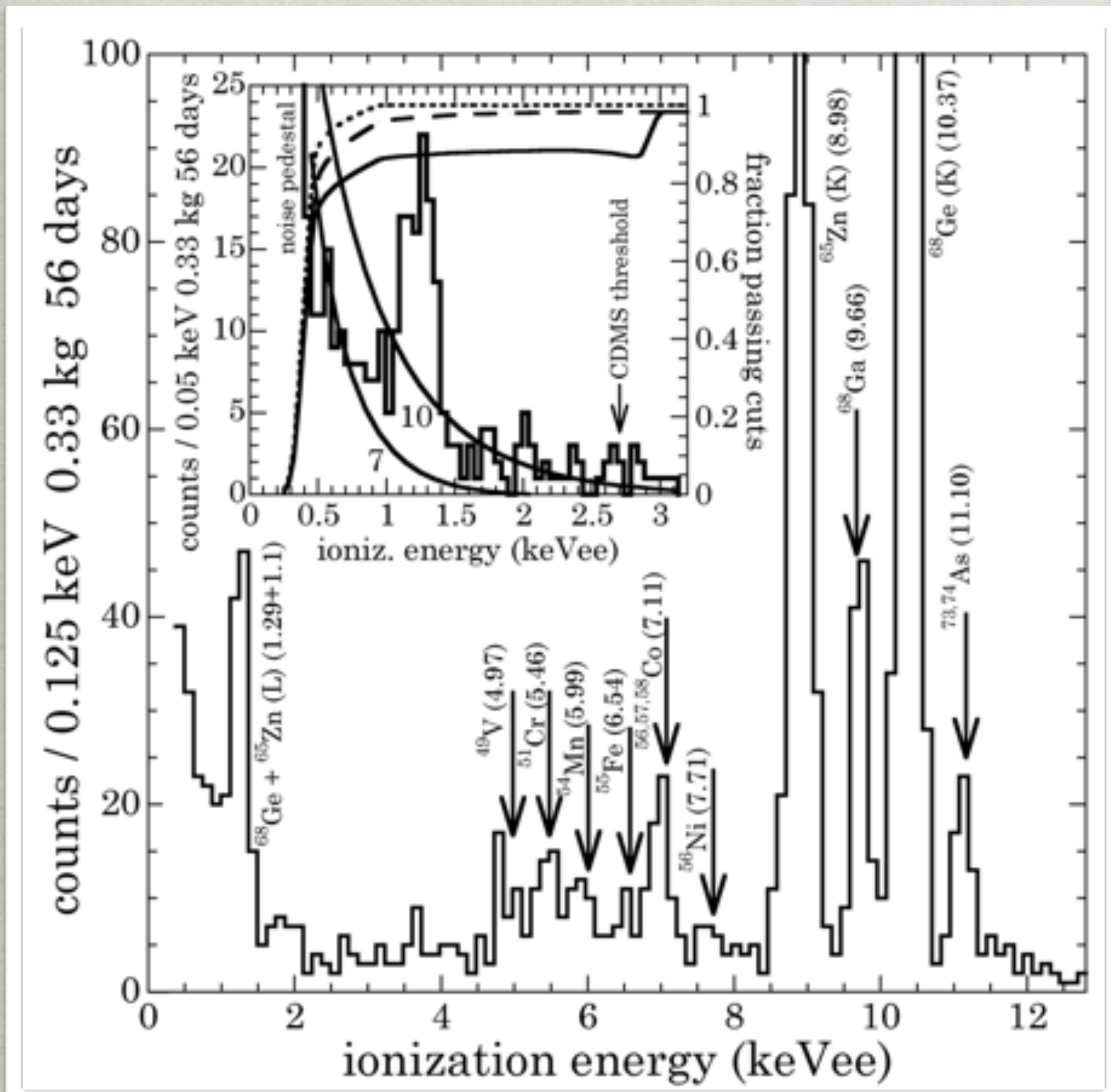


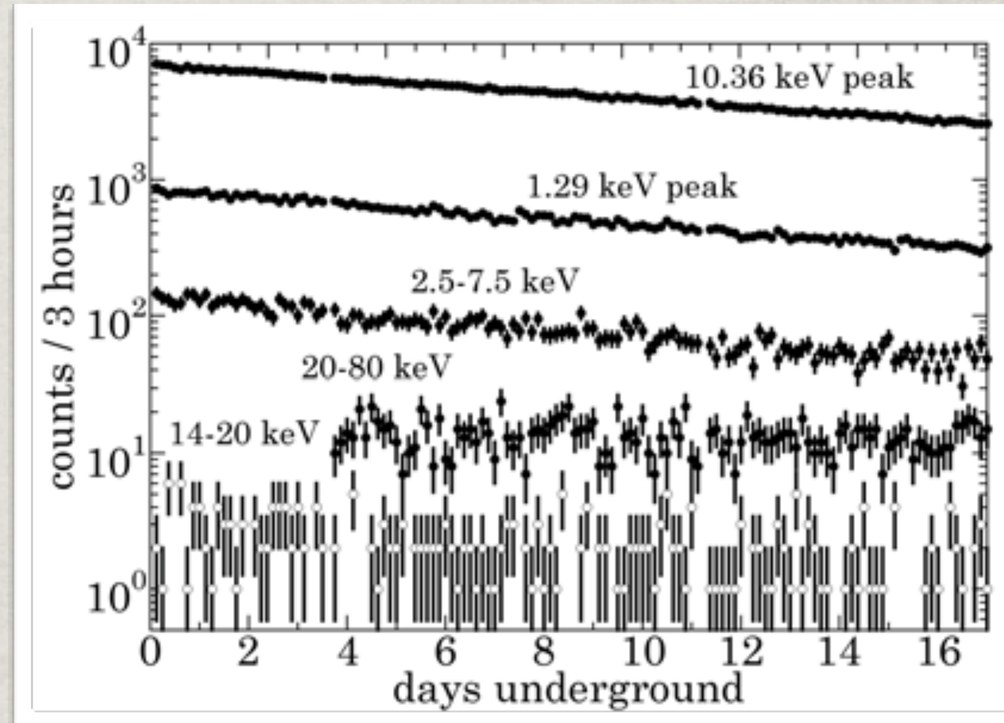
SONGS Light WIMP Limits

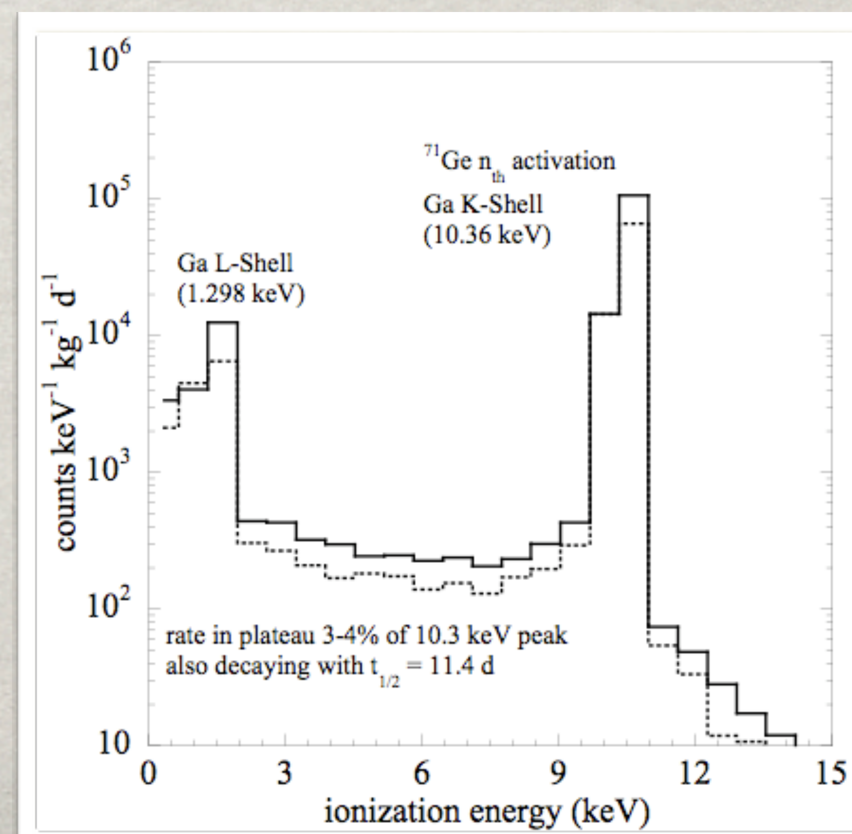
- SONGS limits degraded due to high levels (and rapidly changing) cosmogenic activation, limited exposure and Low LN2 levels



EARLY DECAY OF CONTINUUM REGIONS SUGGESTING CHARGE LOSSES

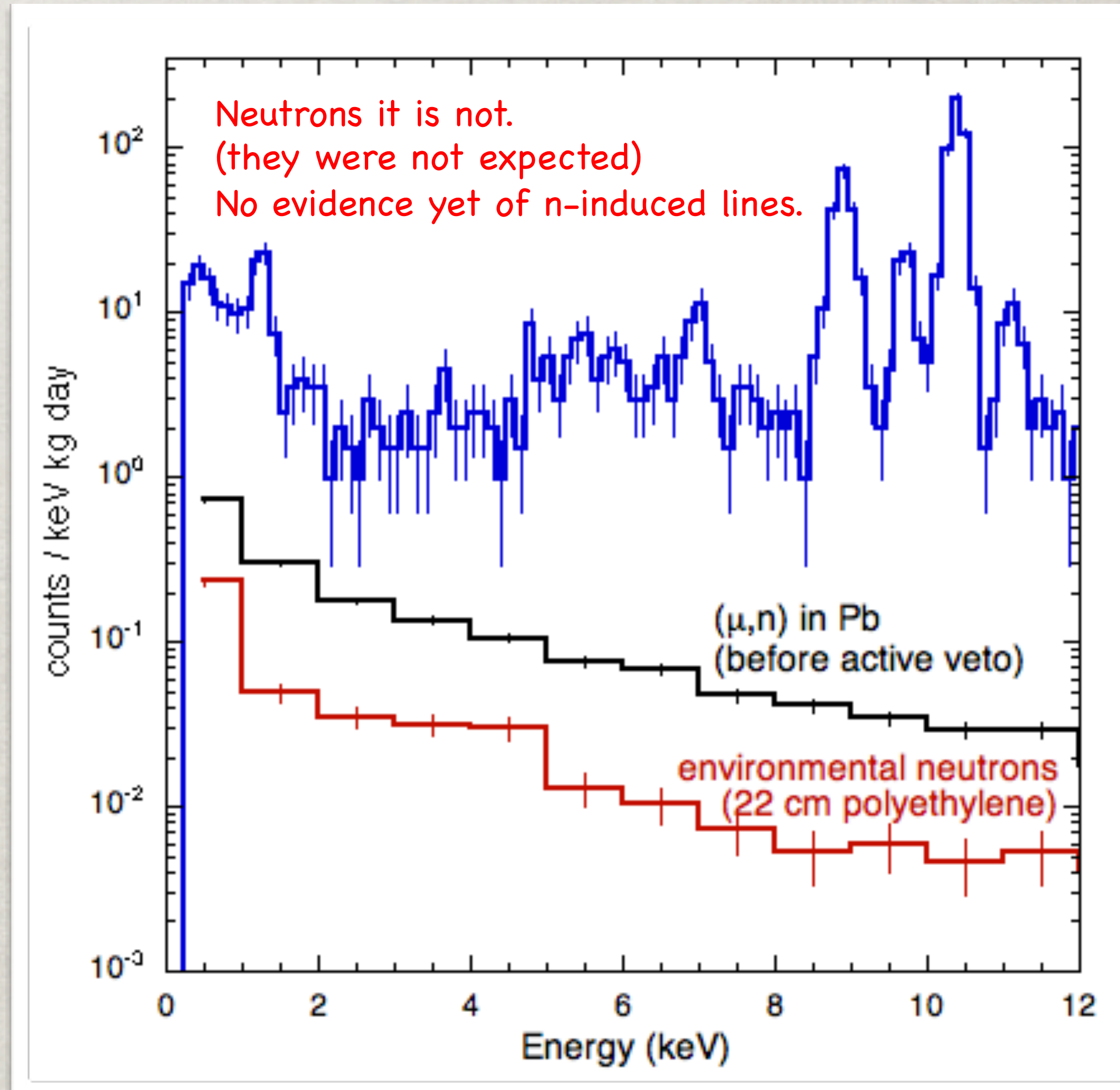






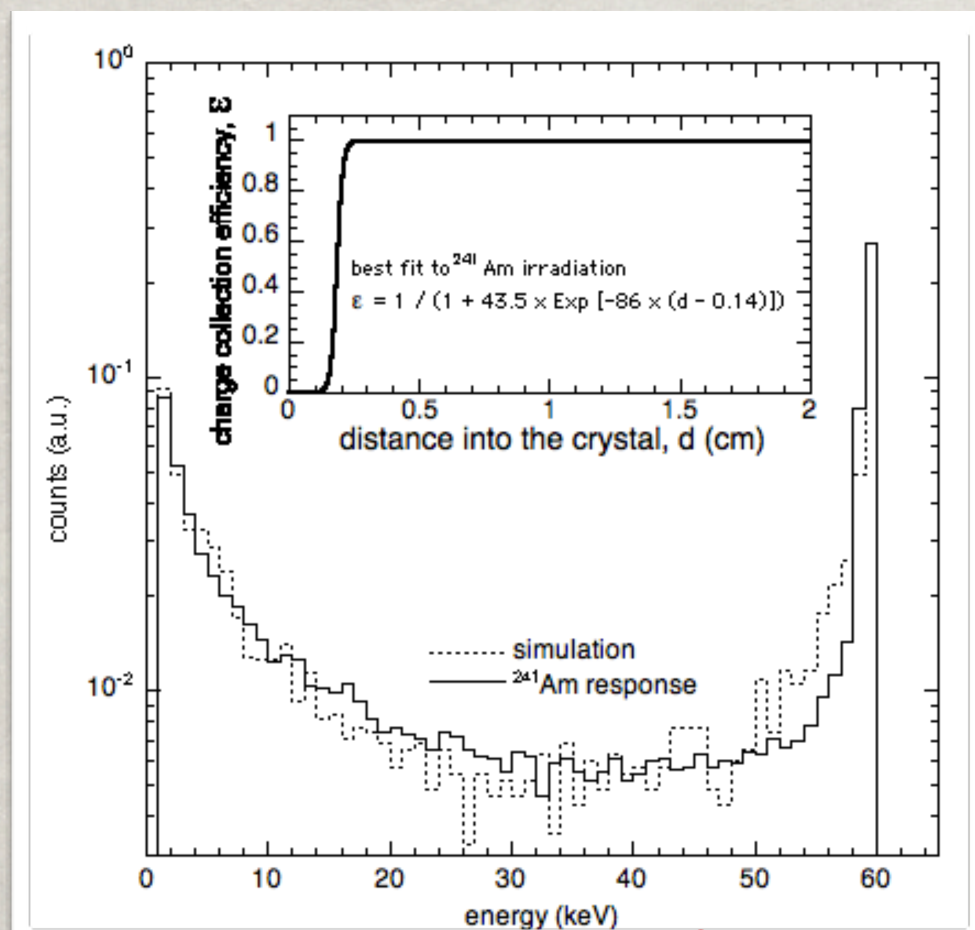
Expected neutron backgrounds at Soudan

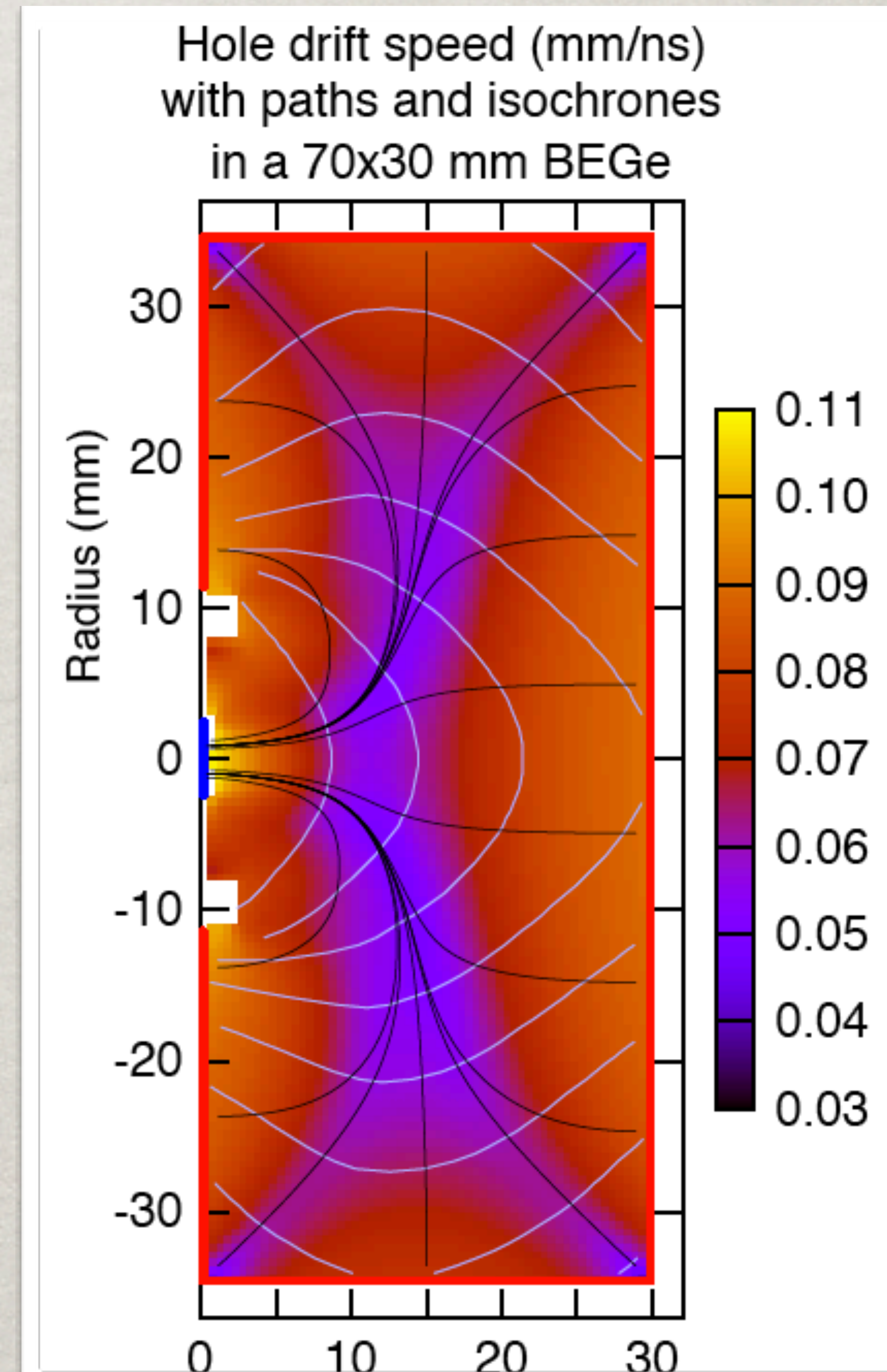
- MCNP simulation of muon-induced neutrons in Pb (and poly shield)
- Also of environmental neutrons in rock
- Still too low to explain excess & strength of modulation amplitude



Surface event simulation

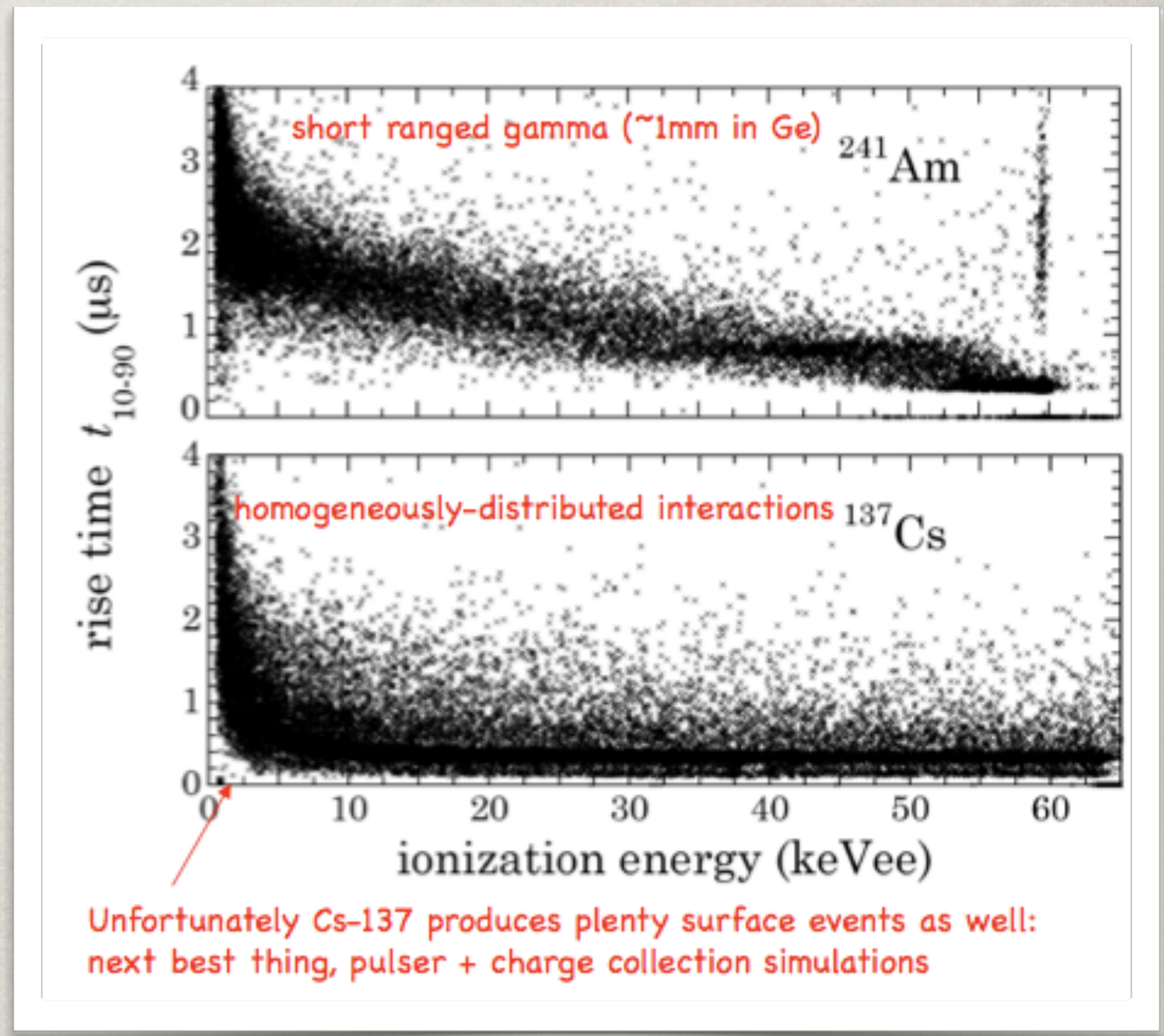
- Charge collection offset time modeled resulting in 100 ns correction
- Theoretical sensitivity curve agrees with source scan





Surface event characterization

- Use external sources to scan and characterize surface events
- Difficulty: Penetrating high E sources have plenty of interactions on the surface
- Solution 1: use many different energies, as well as bulk-like sources from activation
- Solution 2: use collimated source and second detector(s) to produce Compton (pair-production) events at well characterized locations



Microphonics PSD

- Reject microphonics using standard technique from Morales: (ratio of amplitude of two shaped pulses with different characteristics times)
- Bunching (in time)
- LN2 refills