Simulation Updates From Experiments

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Version 1.0

AARM Collaboration Meeting

3/4/2013

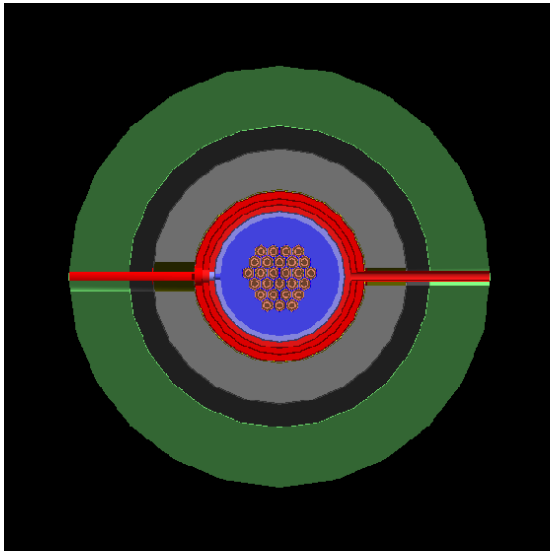
Outline

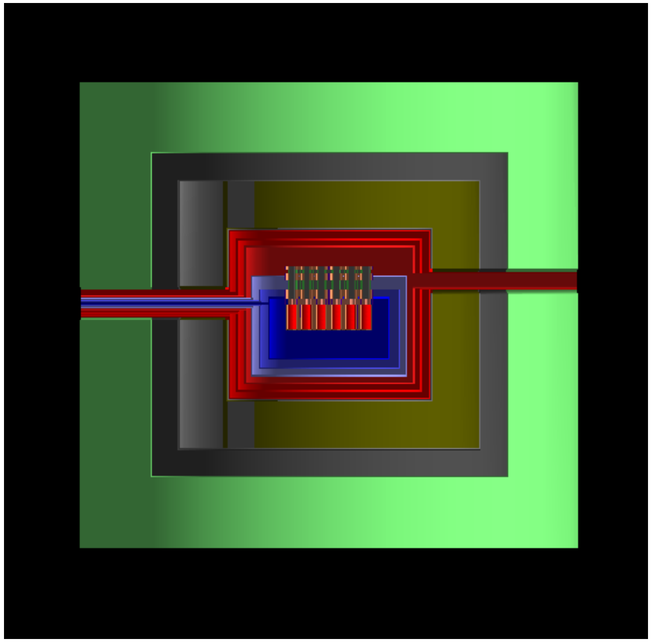
- SuperCDMS
- CoGeNT
- NEST (not an experiment. MC code like RAT.)
- DEAP-3600
- EXO
- XENON100
- LUX (and LUXSim)

- No time to cover future (LZ, XENON1T) except SuperCDMS (as I had no CDMS slides)
- Minimum talk of final results, like WIMP limits, present or projected. Focusing on the nitty-gritty
- If you sent me more >5 slides, I cut down…

SuperCDMS

- The SuperCDMS simulation includes a full modeling of the planned 200 kg active detector (27 towers of 6 each 100 mm x 33 mm Ge crystals), enclosed in a cryostat and shield large enough to expand to 400 kg (towers of 12).





Shielding Modeling

- The simulation includes a full-sized simplified model of the SNOLAB cavern, including 5 m thickness of the native norite rock and an optional layer of concrete on the walls.
- Several shielding models are supported:

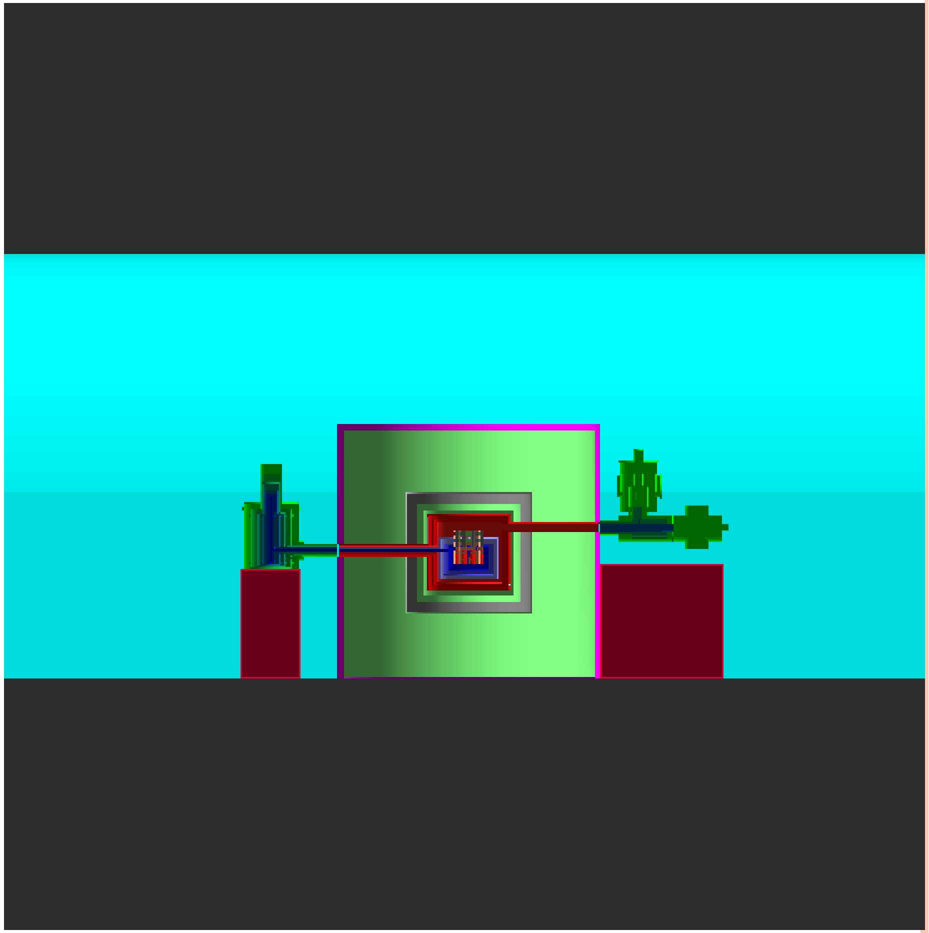
  -- passive shield (lead and polyethylene absorber layers)

  -- active external veto (plastic scintillator); as above with a scintillator can surround everything

  -- embedded veto (liquid scintillator surrounded by polyethylene)

  -- interleaved veto and shielding (lead/scintillator sandwich)

- Shielding configurations, apparatus dimensions, and detector layout are configurable through Geant4 macros at runtime.



BACKGROUNDS, BELLS, WHISTLES

- All existing (CDMS-II) calibration sources are supported, selected via runtime macro commands.

  -- High-intensity insertable plugs with Cf-252 and Ba-133
  -- Pre-installed silicon plates with Pb-210 layers
  -- Multisource plates with collimated Am-241 sources (used at test facilities)

  The SuperCDMS simulation has been validated against existing CDMS-II and test facility data, fitting the high-intensity sources' responses (as a global scale factor only) to match both line and continuum features.

  Contaminant and environmental backgrounds are supported.

  -- surface or bulk contamination of detector model volumes
  -- radiogenic gammas and neutrons from the cavern walls
  -- cosmogenic backgrounds from muons penetrating the overburden, modeled per Mei and Hime's prescription
  -- Neutron and gamma spectra for a wide variety of materials have been generated using SOURCES4, and then read into the Geant4 simulation

Signal Model, And Radioassay

- Modeling of the germanium detector signals, both phonons and charge collection (from electron-hole production), has been implemented in the Geant4 environment.

  -- crystal lattice parameters and orientation through a new "field" manager
  -- propagation of transverse and longitudinal phonons through an oriented crystal
  -- propagation of electrons through a lattice including the mass tensor
  -- physics processes including production of Luke phonons from propagating electrons, scattering, and down-conversion of phonons

  These developments were included as an "extended example" in the Geant4 9.6 release, and are expected to be included in the core Geant4 toolkit in a future release.

  Evaluation of radiopure materials is underway at several collaborating institutions, including Sothern Methodist University, the University of Minnesota, the Pacific Northwest Nuclear Laboratory, and other sites. We are leveraging the radioassay work of other dark matter experiments to evaluate materials for the neutron shielding and veto systems.

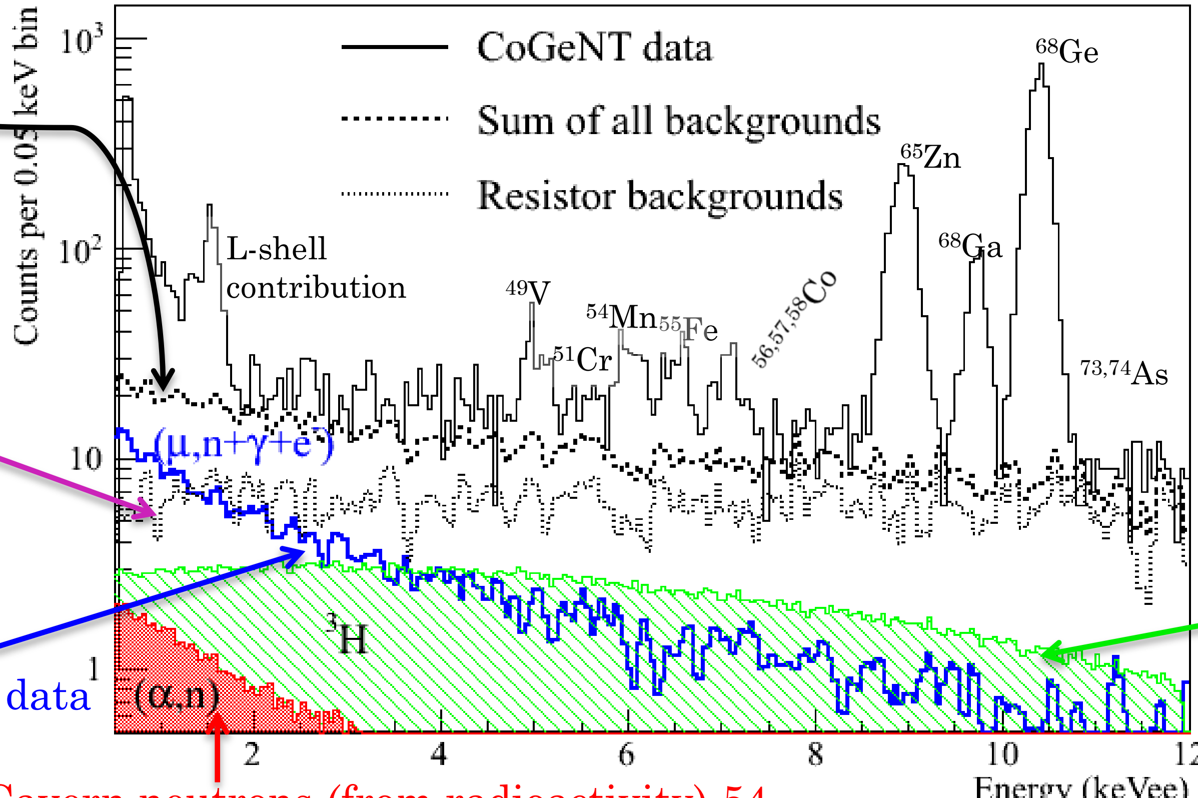
THE BACKGROUND PICTURE   CoGeNT

arXiv:1208.5737

Background sum

Resistor gammas ~324 events, ~16% of data

Muon-induced neutrons 339 events, 16% of data



Tritium β-decay 150 events, 7% of data

Cavern neutrons (from radioactivity) 54 events, 3% of data

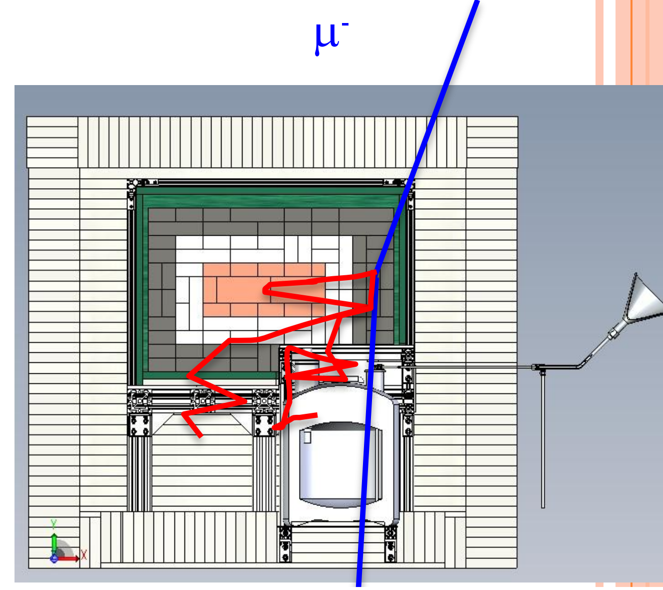
Other sources of background simulated:

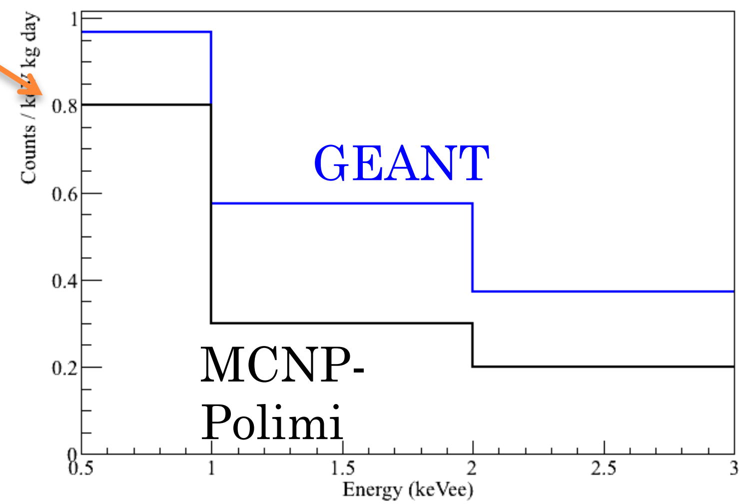
- U and Th chain backgrounds in surrounding material (copper)
- Muon-induced neutrons from the cavern
- U and Th chain backgrounds in lead shielding
- Spontaneous fission neutrons from shielding material
- (α,n) neutrons from shielding material

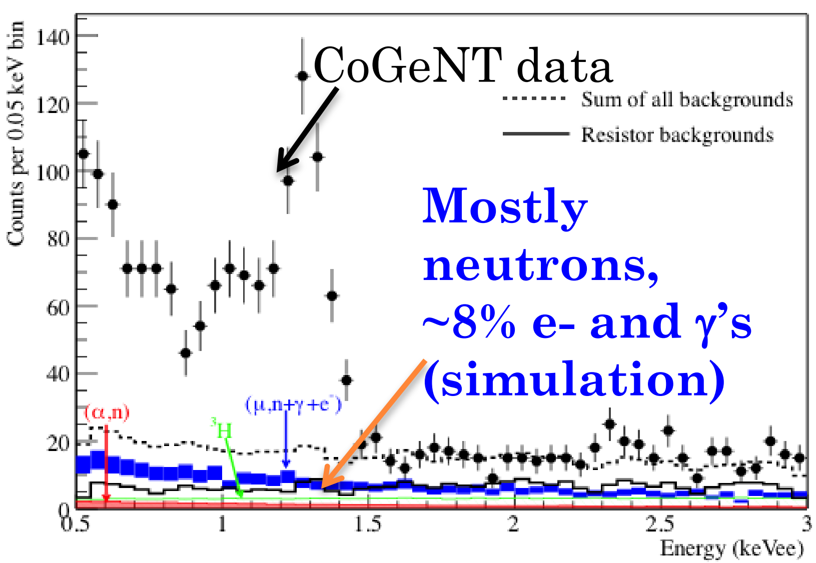
These BG are tiny

MUON-INDUCED NEUTRON SIM

- Two independent MC simulations used to assess neutron contributions
  - muon induced neutron
  - natural radioactivity in cavern
- #1: GEANT
  - Soudan muon flux, E, angular distribution to generate (μ,n) in full shield.
  - Includes e^- and γ (8% of neutron contribution)
- #2 MCNP-Polimi:
  - Neutron generation in lead shielding (largest contributor)
- Reasonable agreement between simulations (they use different inputs)
  339 +/- 68 events (GEANT)

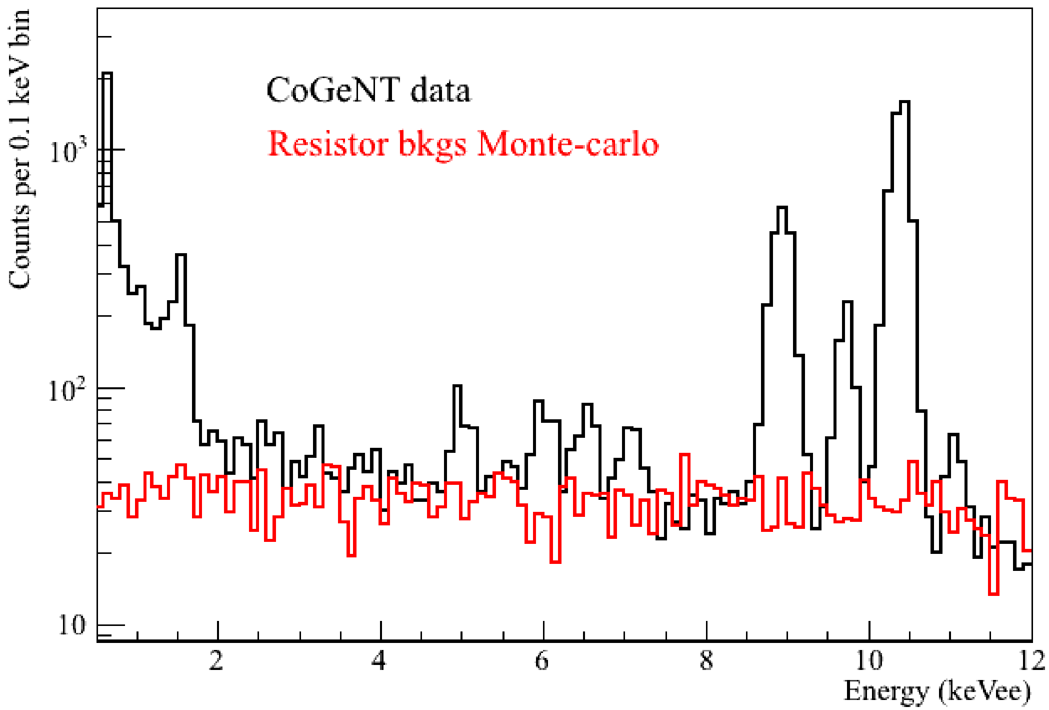






Less than a 16% neutron fraction in CoGeNT after L-shell subtractions

Most beta-spectra and gammas are a flat background in the CoGeNT analysis region



This is expected from Compton scattering of high-energy photons at these low energies

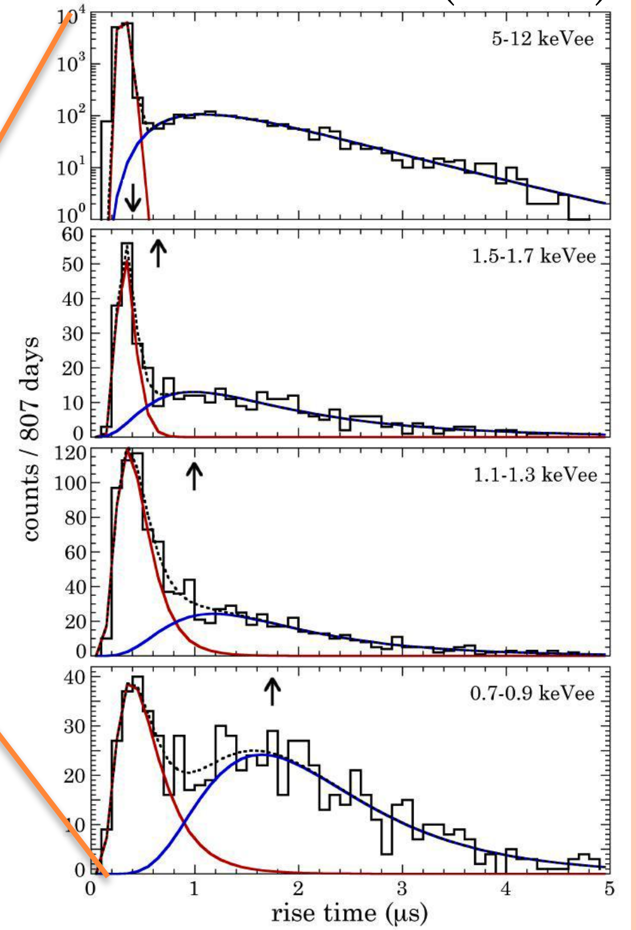
A background that can be reduced by having tightly packed detectors and rejecting multiples

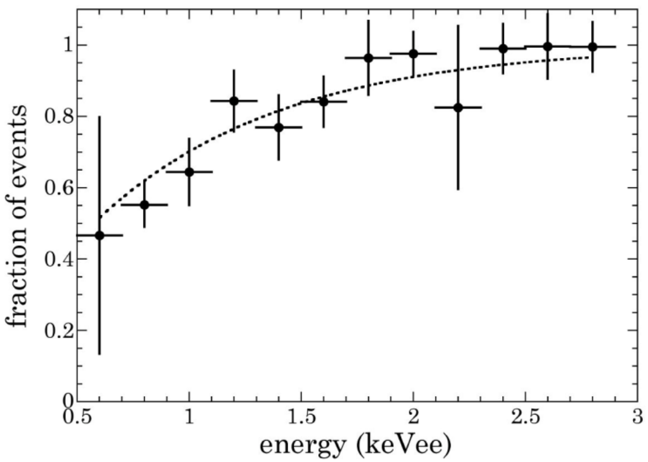
Without an assay we cannot be sure the flat background is from the resistors, but typical resistor backgrounds can plausibly explain most of the CoGeNT flat background

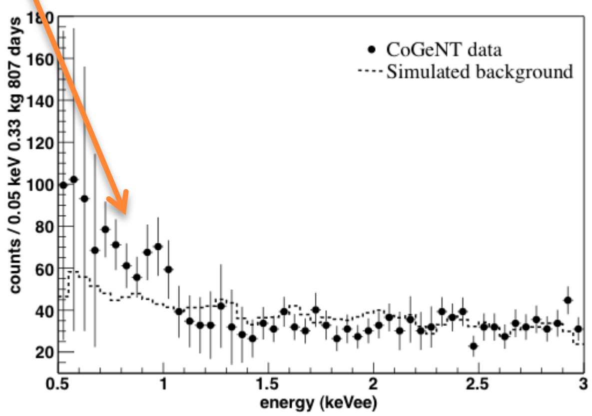
SURFACE EVENTS AND SLOW PULSES

Juan Collar (U of C)

- Surface events have degraded energy and pile up in the lowest energy bins (like WIMPs)
- Surface events (background dominated) on average have slower pulses than bulk events
- Rejection between bulk (fast pulses) and surface (slow pulses) gets worse at lower energies
- We can estimate the contribution of slow pulses in the data by fitting for the slow and fast pulse distributions
- Still looks like there is an excess of events above the expected background





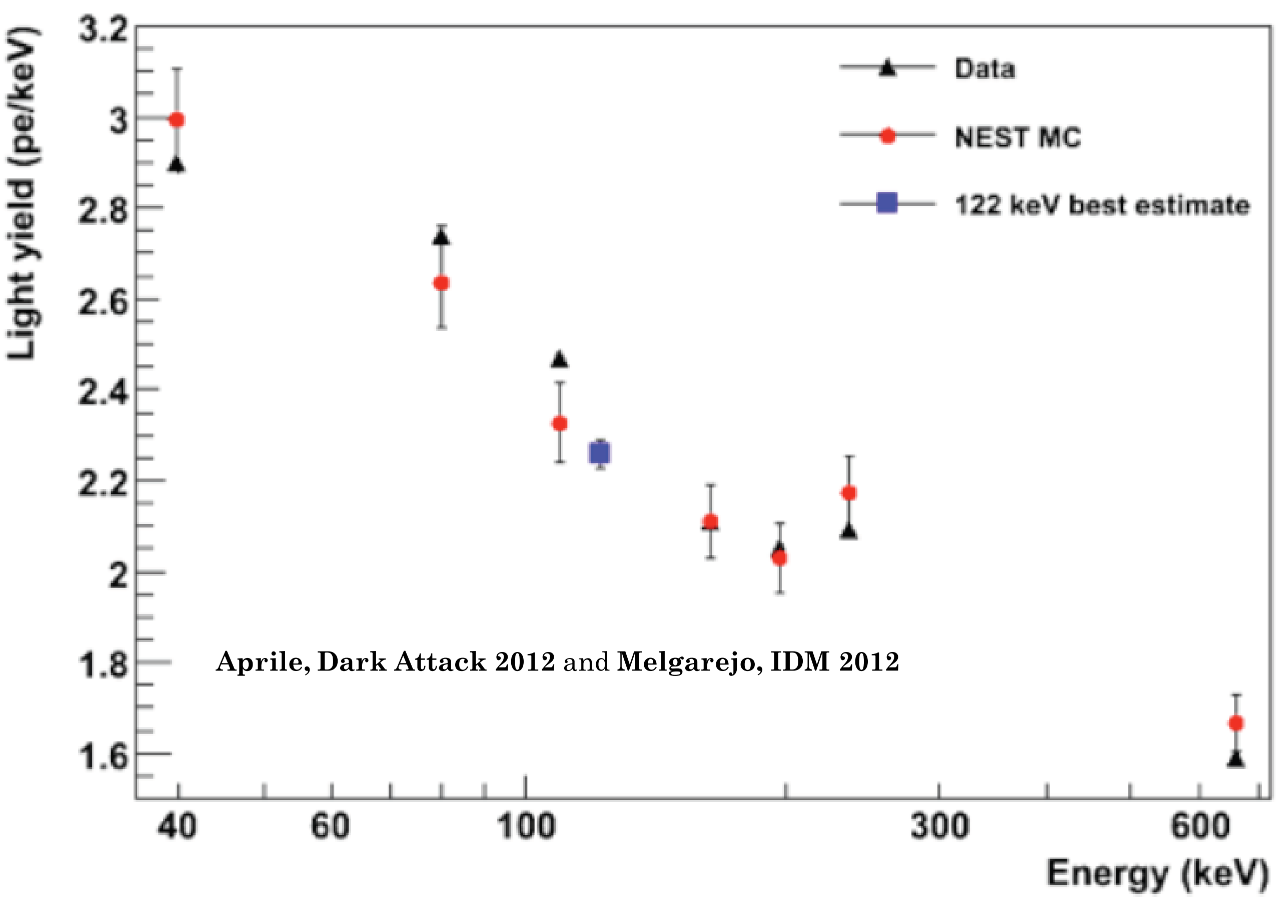


NEST: WORKS FOR NOBLES

nest.physics.ucdavis.edu (*)

Szydagis et al., **NEST: A Comprehensive Model for Scintillation Yield in Liquid Xenon**, 2011 JINST 6 P10002

- Noble Element Simulation Technique scintillation and ionization Monte Carlo code for G4
- NEST just has one success after another, sometimes making real **predictions**, and not just post-dictions
- Yield vs. energy (and field) well modeled

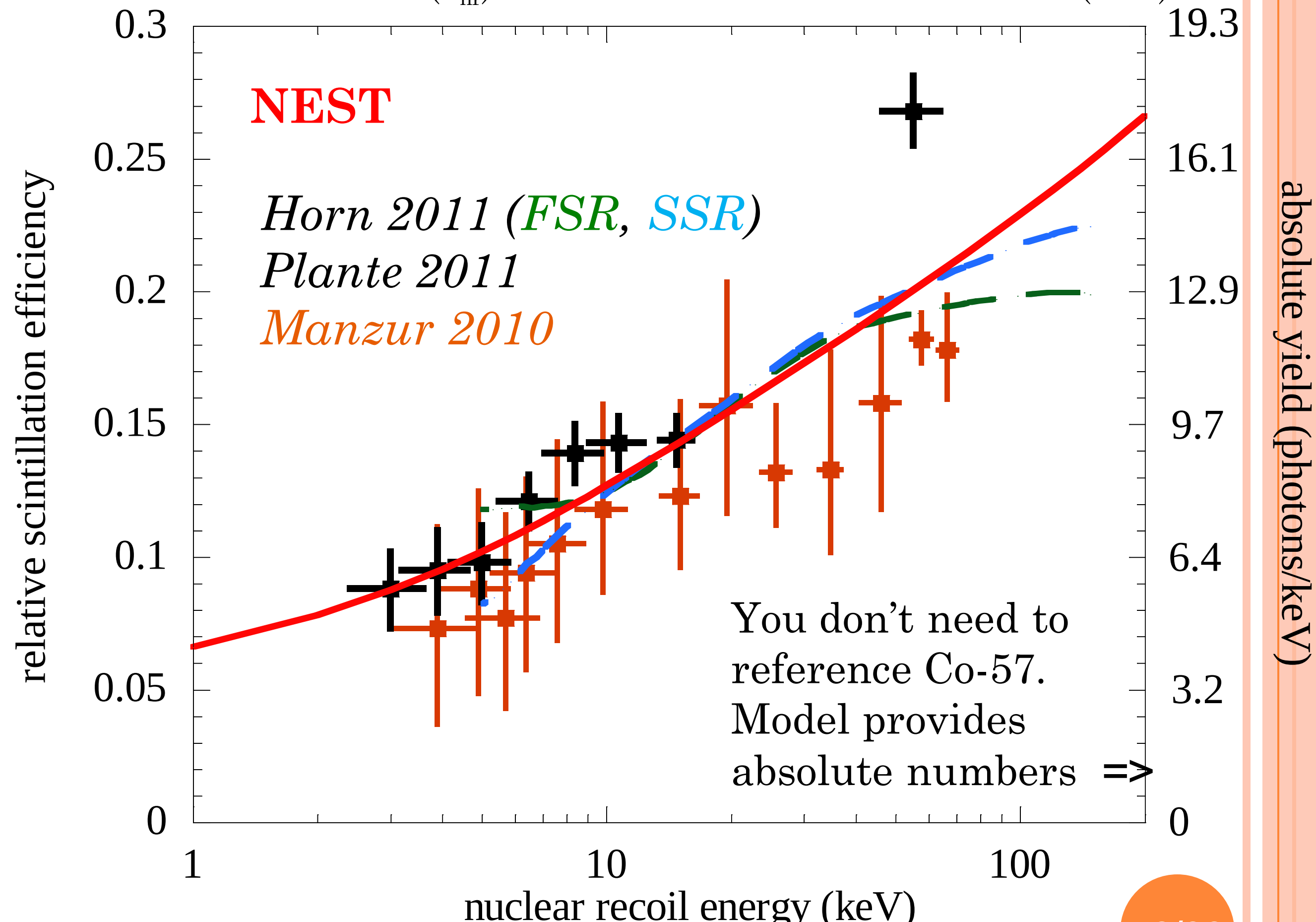


(*) contains links to all previous talks with WAY more detail than I can go into today, and post-publication code updates…

Even for Nuclear Recoil!

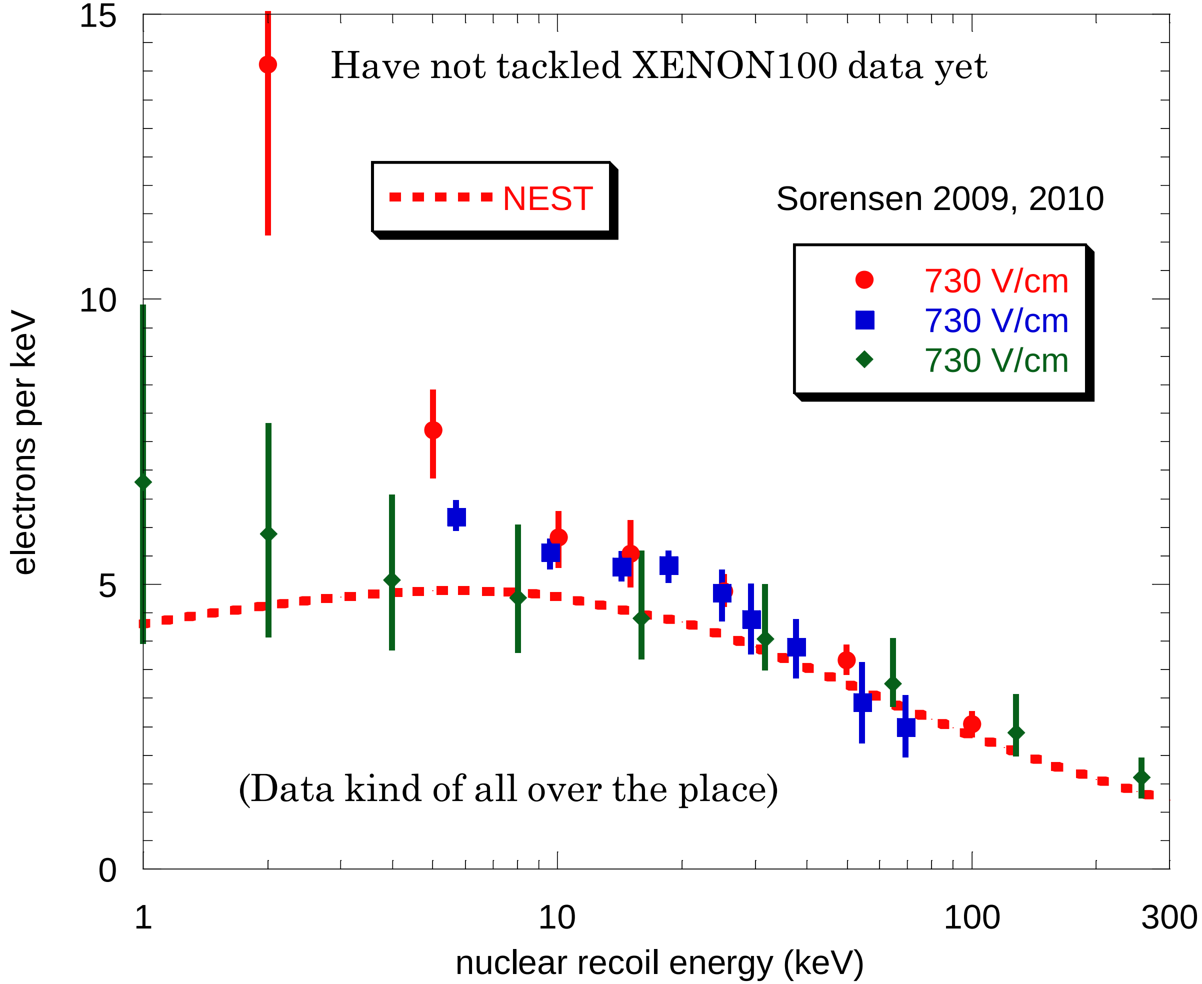
- ZEPLIN-III is matched near-perfectly (Horn)
- Where there is a low-energy discrepancy between science runs, the model splits the difference and hits Plante
- Is rarely more than 1-sigma above Manzur
- NOT A FIT, nor is there any interpolation or extrapolation
- Only model that is complete (ties together with ER) and does not directly need the NR data

This is for zero field. NEST also has an energy-dependent electric-field correction (S_{nr}) based on the Ph.D. thesis of C. E. Dahl (2009)



Absolutes scale assumes 63 photons/keV @ 122 keV (ZF), using NEST. Vetted against countless past experiments.

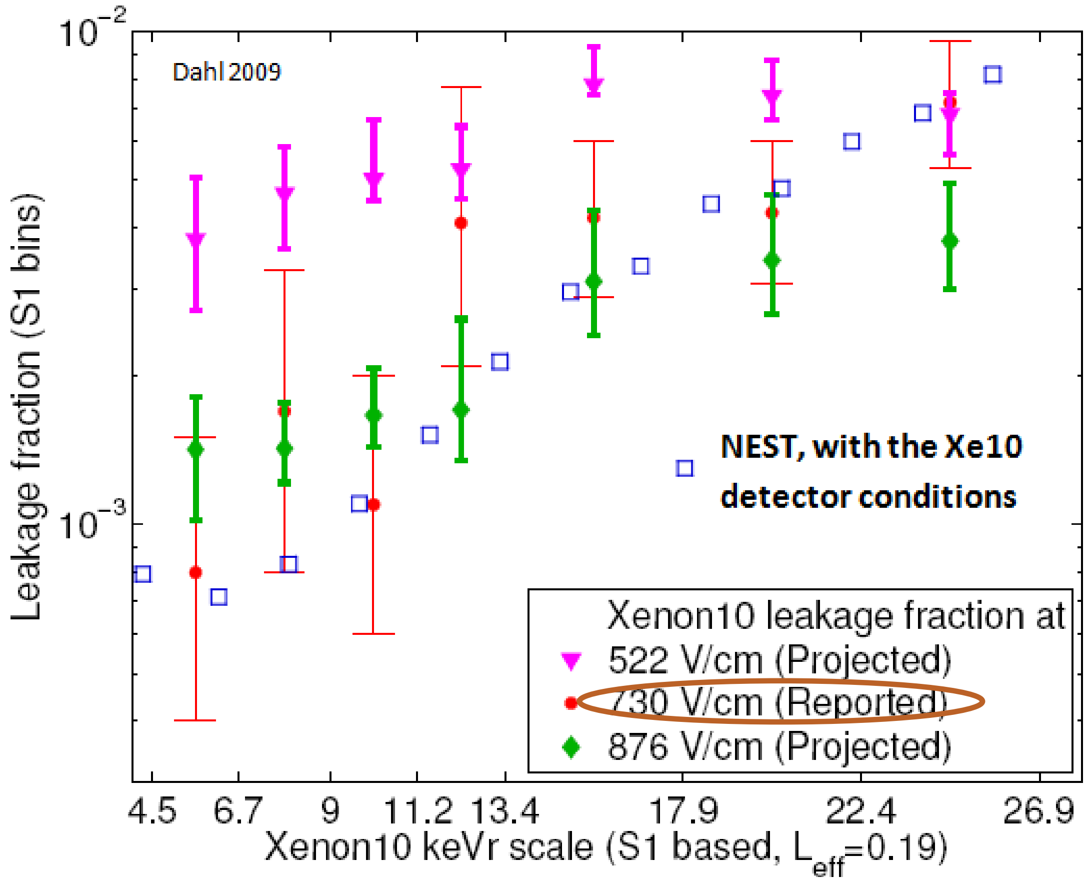
Charge Yield (Q_y)



P. Sorensen et al., Lowering the low-energy threshold of xenon detectors, PoS (IDM2010)017 [arXiv:1011.6439].

- Not fit to any data shown (all from XENON10), but a post-diction based on fits to Dahl data (Xed detector)
- Excellent description of at least one mode of understanding of these data (green), in the WIMP search region
- Conservative (low), but, more importantly, SELF-CONSISTENT with the light yield half of the same model
- Useful for establishing the combined energy scale

ER VS. NR DISCRIMINATION



Lebedenko et. al. arXiv:0812.1150v2 [astro-ph] 2 Sep 2009

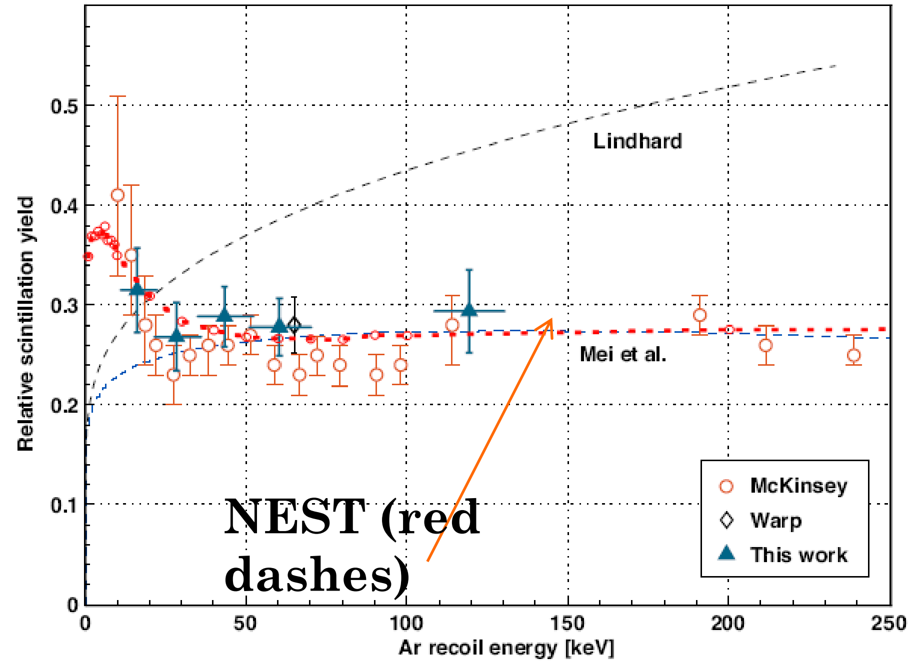
- After the improvements to the recombination model made to reflect non-Poissonian fluctuations, NEST exhibits the correct behavior for low-E discrimination!
- It should now be possible to use NEST in order to make general predictions for present and future detectors of differing light collection efficiencies and electric fields
- For Z3 FSR, NEST predicts 1:6700; 1:7800 leakage observed.

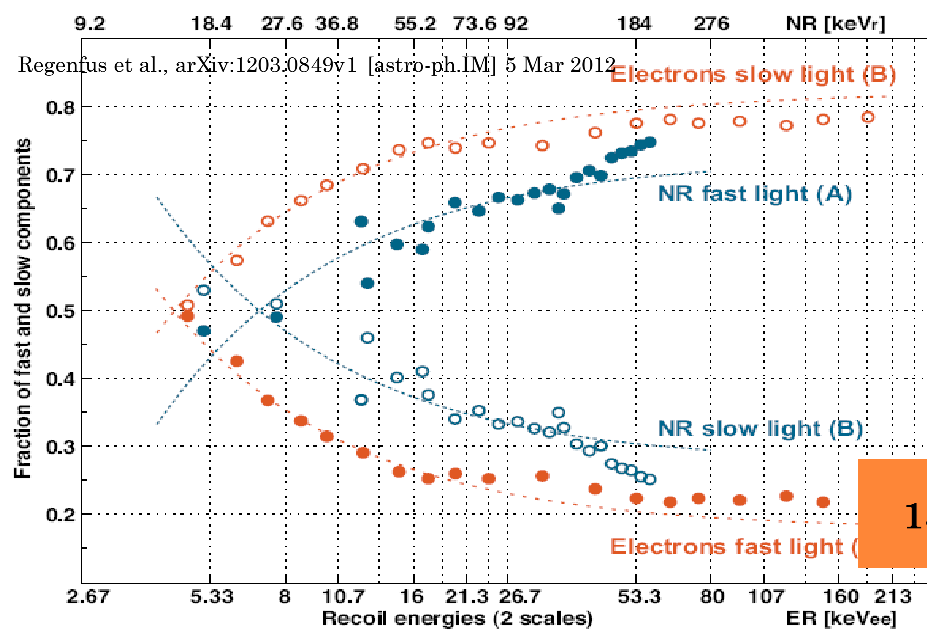
This plot is a culmination of all other NEST efforts. To get it right, mean light and charge yields for both NR and ER have to be correct, and the width of the ER band, too. This is the first time that publicly available code can do all of this successfully for you out of the box!

arXiv:1203.0849v1 [astro-ph.IM] 5 Mar 2012

Liquid Argon

- The NEST model is the only one that can explain the apparently higher nuclear recoil yield at lower energies, appealing to arXiv:1011.3990v2 [astro-ph.IM] 5 Jul 2011 (on LXe)
- For Xe and Ar, NEST handles pulse shapes too not just yields. It is meant to be a COMPLETE simulation. Example for Ar: plot at bottom right input into NEST to give correct fast/slow light ratio vs. dE/dx



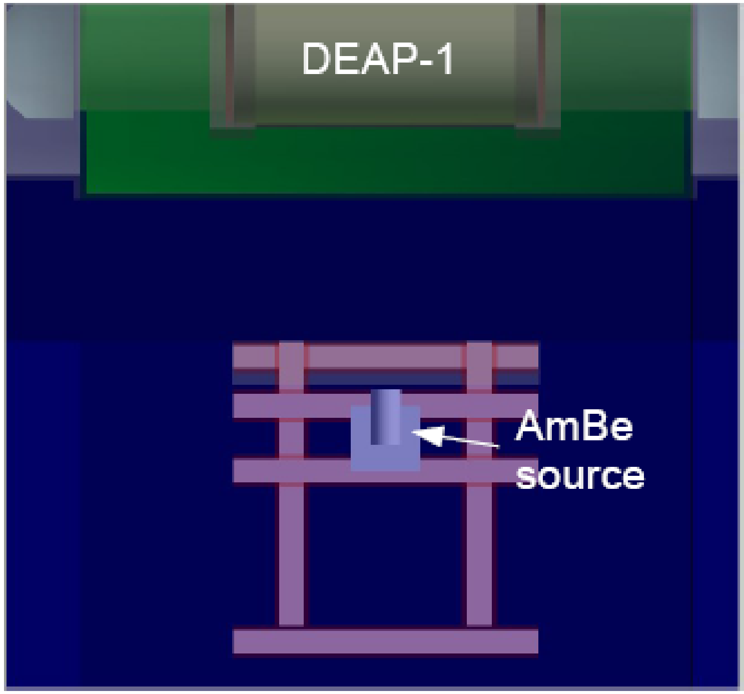


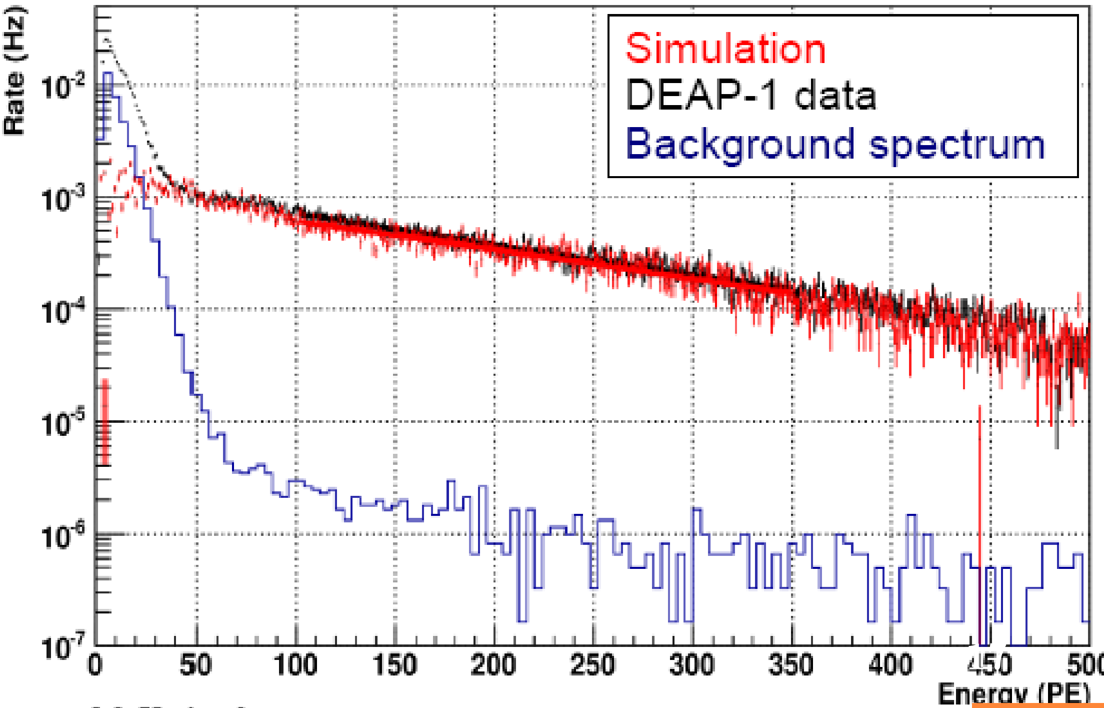
Simulations for DEAP

- Using 2 separate Monte Carlo packages:
  - deapmc (purely Geant4 based)
  - rat-deap (flavour of RAT, code shared between MiniCLEAN and DEAP)
    - Uses Geant4
    - Inherits code from GLG4sim: (http://neutrino.phys.ksu.edu/~GLG4sim/)
    - Scintillation model based on: D.M. Mei et al., Astrop. Phys. 30 (2008) 12
- We are exploring feasibility of NEST for our purposes
- DEAP-1 data and dedicated measurements used to validate the model:
  - Optics
  - Neutron transportation
  - Surface and wavelength-shifter related effects

DEAP-1 neutron calibration with AmBe source: good agreement between simulation and measurement

- Consistent simulated and measured spectra
- Good absolute agreement between simulated and measured detection efficiency: 0.069(1)% vs. 0.074(1)%.
- (Discrepancy at lowest energies caused by leakage gamma events)
- Completed extensive simulations of DEAP-3600 to define purity targets and assay program
- Pure materials identified and procured, **detector construction ends this year!**





Wavelength shifter effects must be taken into account for low energy background simulations

- We have measured alpha scintillation light yield in tetraphenyl butadiene (TPB): T. Pollmann et al., NIM A, 635 (2011) 127.
- (Currently studying this and the pulse shape as a function of temperature)
- Agreement demonstrated in DEAP-1 data (arxiv:1211.0909)

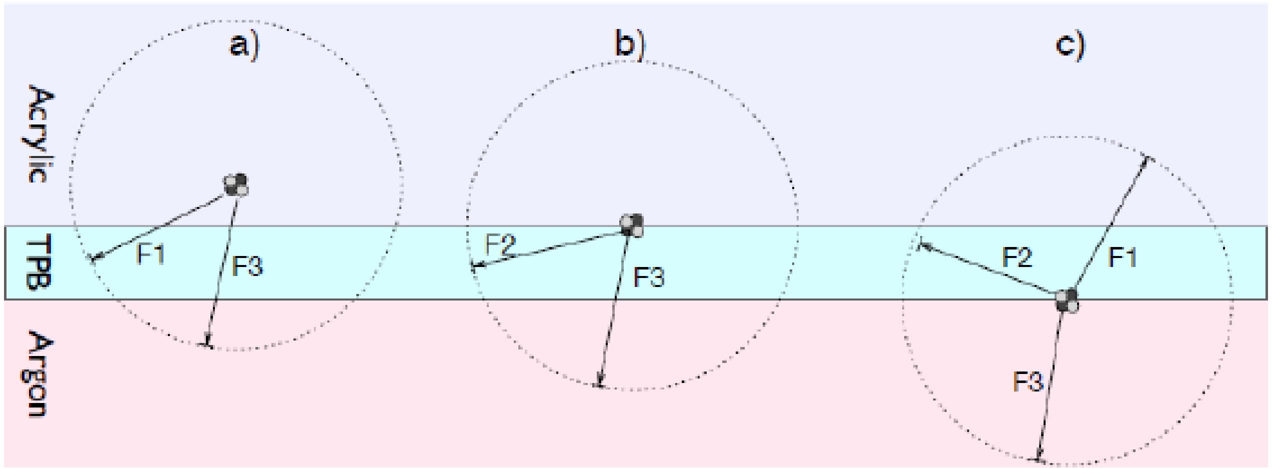
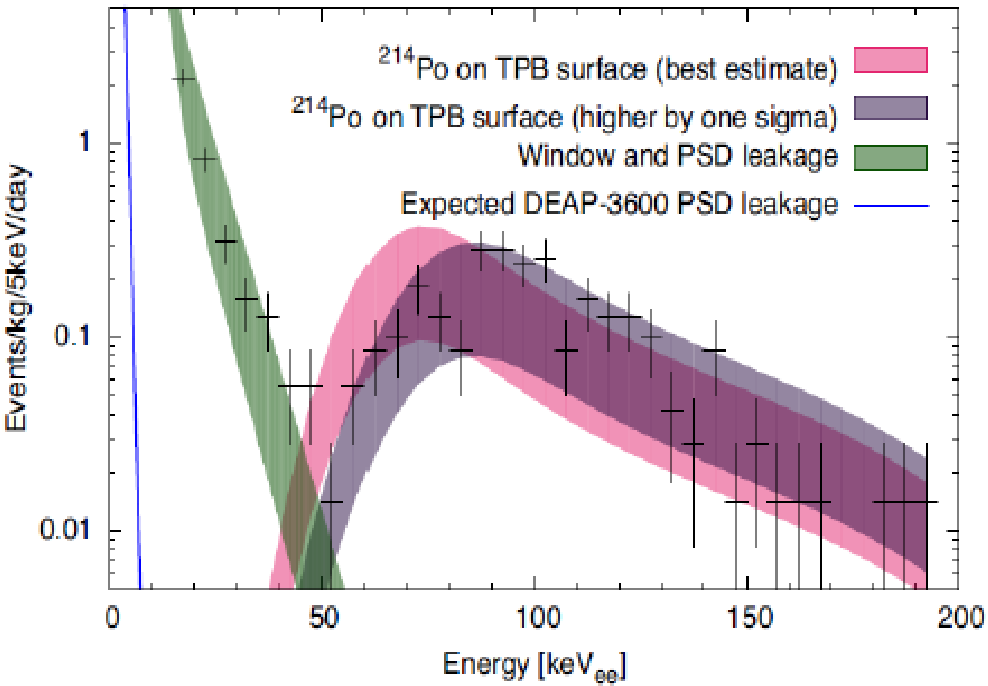


Figure 9: Sketch of possible paths that lead to light emission for an alpha particle emitted in the bulk acrylic (a), on the acrylic surface (b), and on the TPB inner surface (c).

The DEAP-1 low energy spectrum is well described by Rn-daughters decaying on a rough TPB surface.



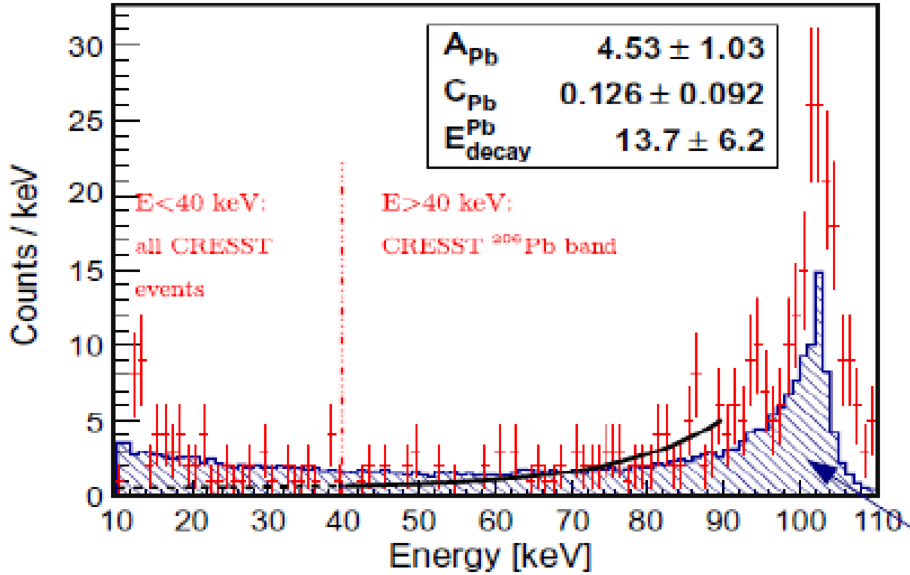
(T. Pollmann et al. arxiv:1211.0909)

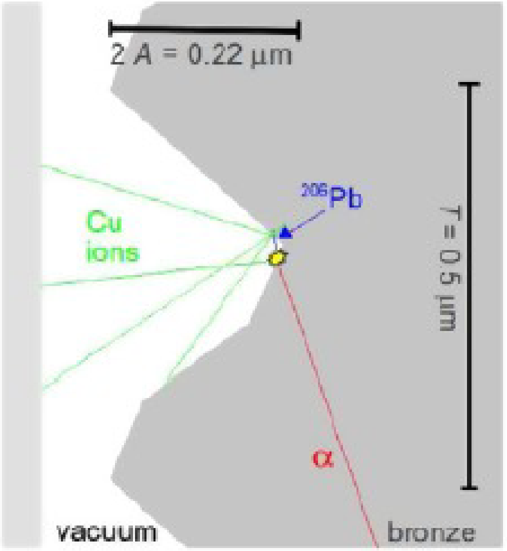
- Simulation including the TPB scintillation and a simple surface roughness model reproduces DEAP-1 data
- The combined visible energy from nuclear recoils and alphas from 214Po decays is above the upper bound of the energy region of interest relevant for the WIMP search
  => Rn from process systems is not a major concern for DEAP-3600
- Uncertainties dominated by TPB thickness and LY (in energy) and by counting statistics (in rate)
- TPB alpha scintillation light yield at 87 K is consistent with the room temperature value

Surface roughness leads to non-trivial effects

- Coupled with surface contamination it can lead to tails at low energies
- It is impossible to account for surface roughness using simple tools such as SRIM
- Can be properly simulated using Geant4 with one of its common extensions:
  => physics list from example "TestEm7" in the standard distribution

- Possible explanation of the CRESST-II event excess at low energies





M Kuźniak et al. Astropart. Phys. 36, (2012) 77

Geant4 + realistic surface + TestEm7

EXO-200

- First measurement of $2\nu\beta\beta$ in ^{136}Xe! New background for DM.

PRL **107,** 212501 (2011) PHYSICAL REVIEW LETTERS week ending 18 NOVEMBER 2011

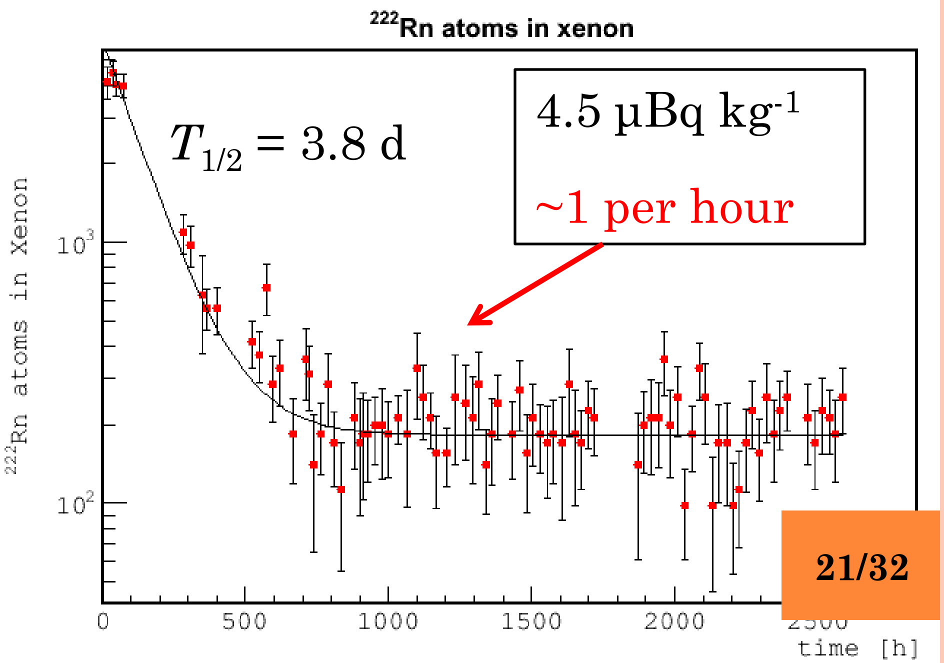
Observation of Two-Neutrino Double-Beta Decay in ^{136}Xe with the EXO-200 Detector

(EXO Collaboration) PRL 107, 212501 (2011)

- Extensive material screening campaign: successful!
- Background goals met: 40 cts/2 yrs / 2σ ROI / 140 kg

NIM A591, 490-509 (2008)
PRL 109, 032505 (2012)

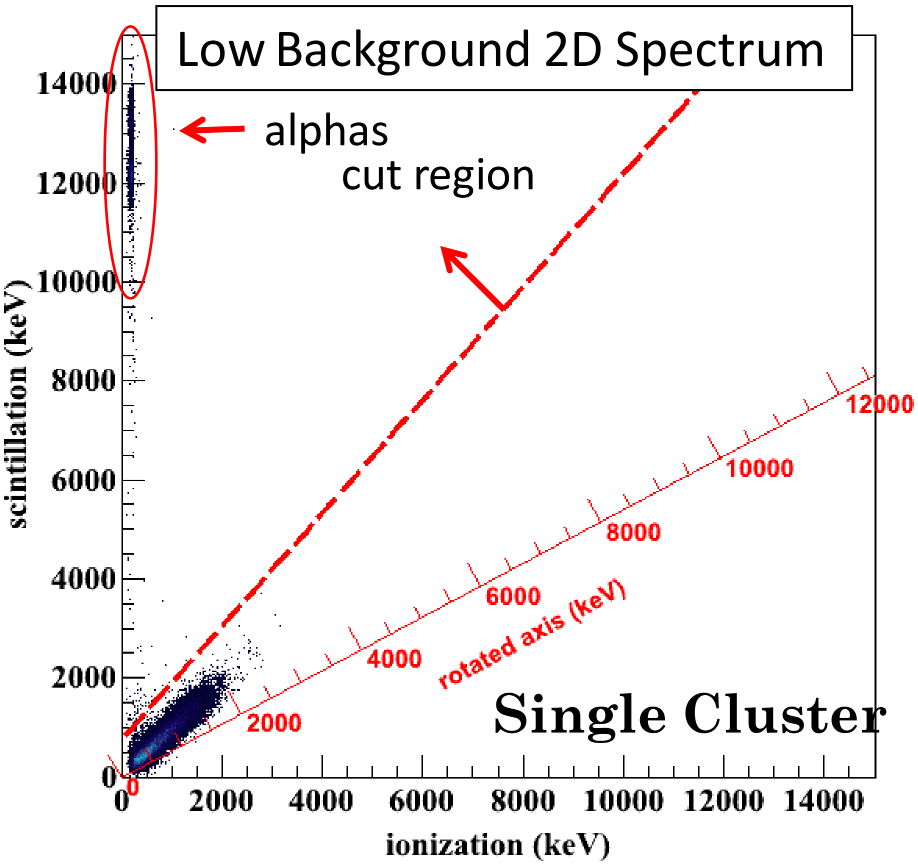
- Low radon contamination in Xe



EXO-200

- Alpha decay backgrounds rejected

PRL 109, 032505 (2012)



- New technique for measuring xenon contamination using a cold trap + mass spectrometry

NIM A675, 40-46 (2012)

- Sensitive Krypton in Xenon measurement: 25±3 ppt

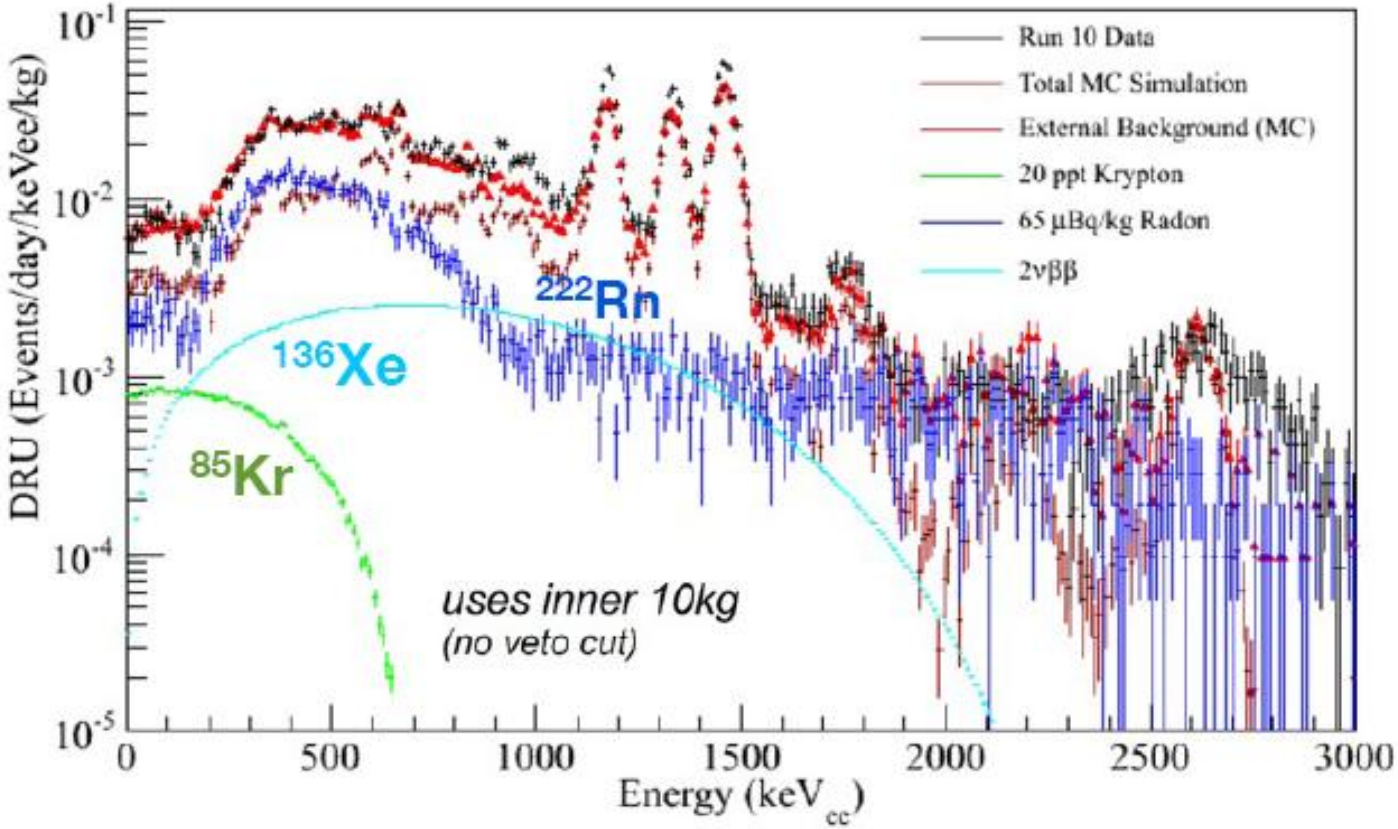
NIM A665, 1-6, (2011)

- All developments applicable to nEXO

The gamma background in Run10

XENON100

- Reached background level *before S2/S1-discrimination*: **5.3 x 10^{-3} events/(kg day keV)**

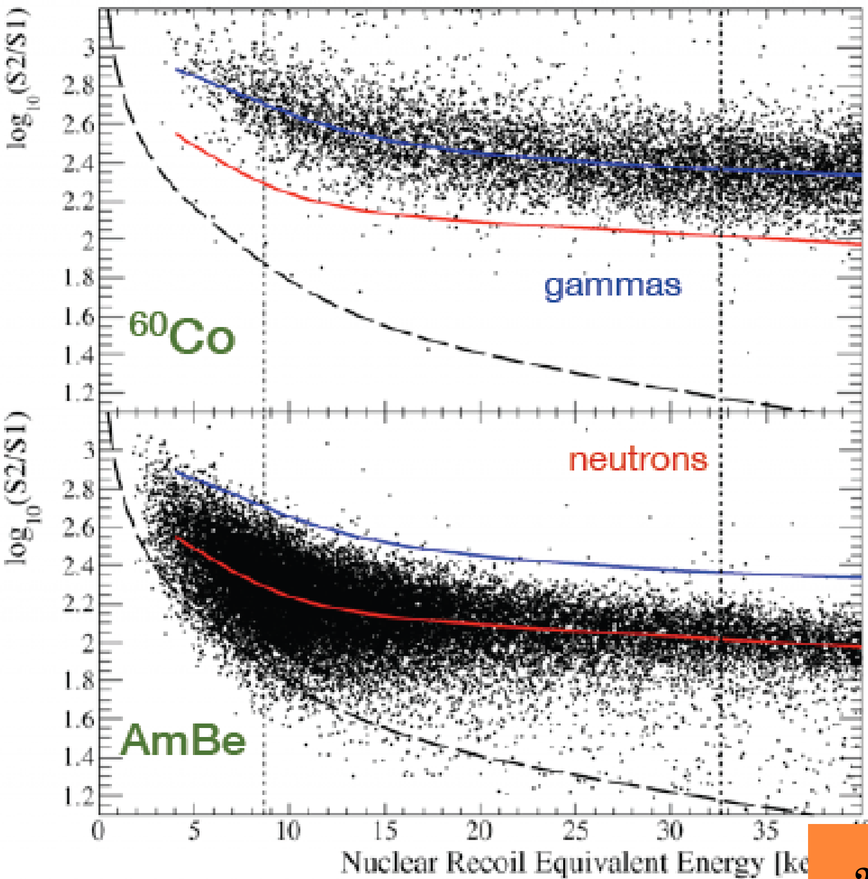


See also Aprile et al (XENON) PRD 83, 082001 (2011) for a detailed background description

Calibration of ER and NR bands

- The electronic recoil (ER) band is calibrated with high energy gammas from ^{60}Co and ^{232}Th sources
  - This data is also used to determine the background in the signal region due to low-energy Compton scatters
- The nuclear recoils band (NR) is calibrated with an AmBe neutron source
  - *Single scatters from elastic neutron-xenon collisions* are used to define the expected WIMP signal region

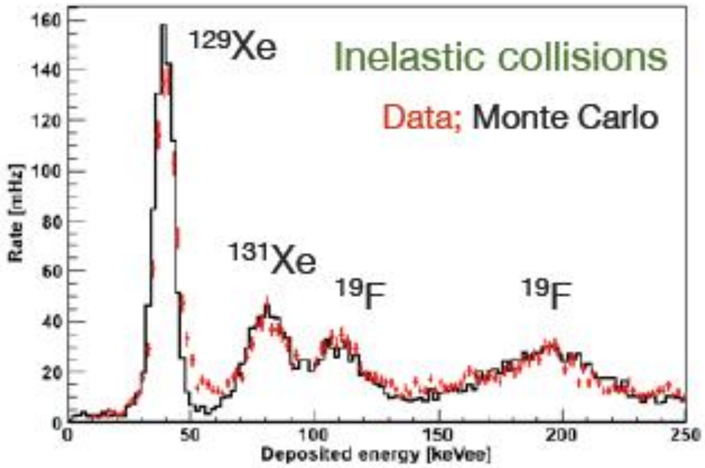
Electronic recoil (ER) band

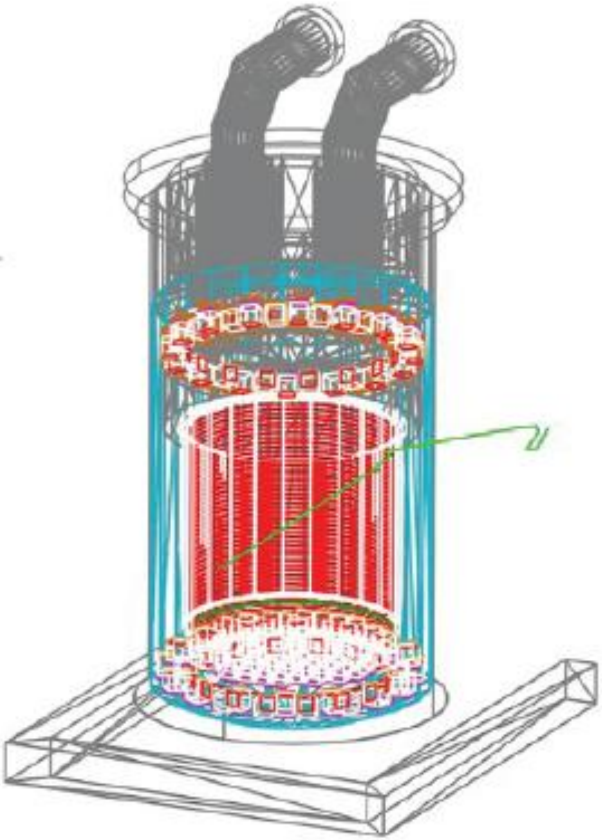


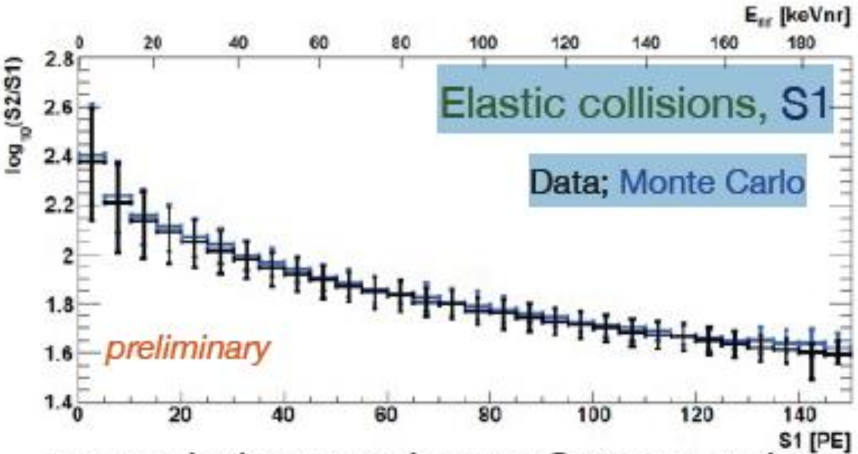
Nuclear recoil (NR) band

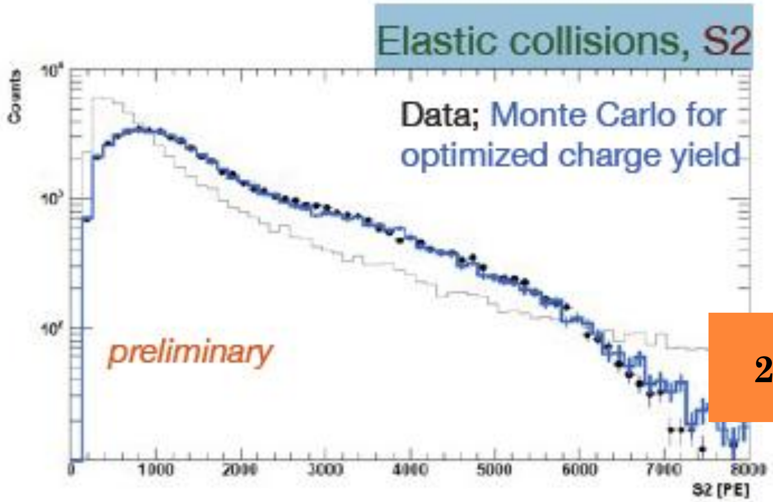
Nuclear recoils: data and MC

- Matching the AmBe data with MC simulations





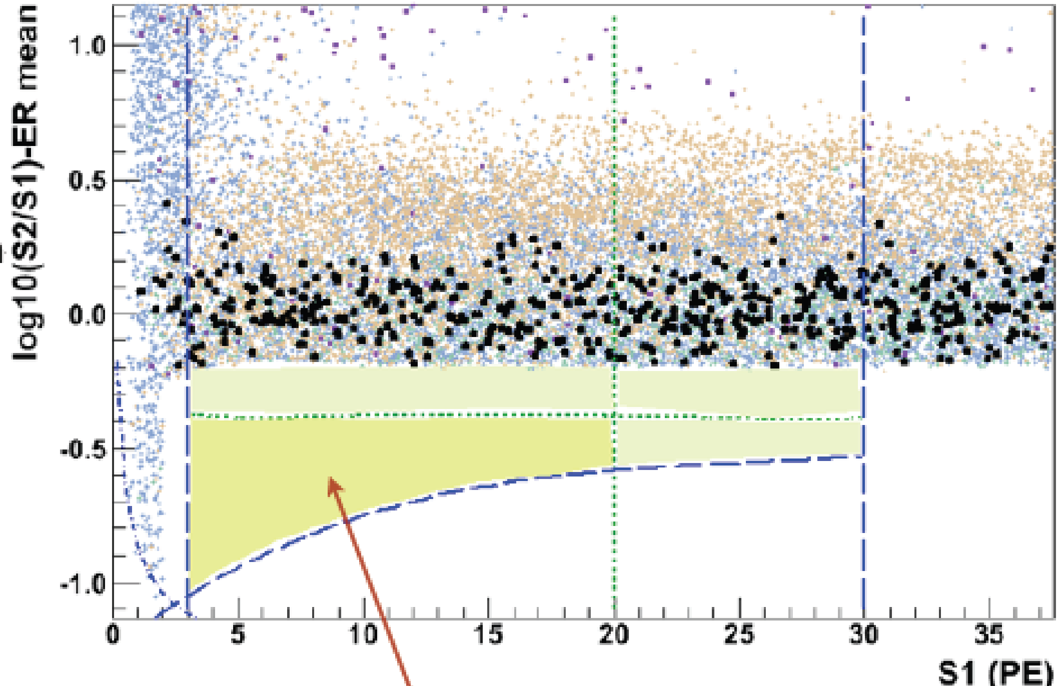




Manuscript in preparation: XENON collaboration

Background prediction for Run10

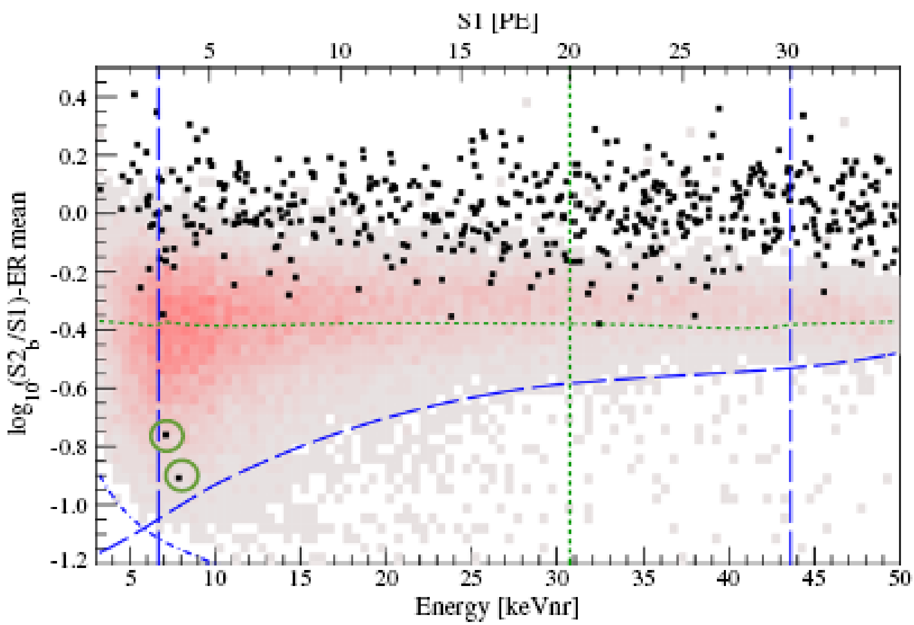
- Expected background in: 34 kg inner region, 224.6 live days, 99.75% rejection of electronic recoils
- Electronic recoil background:
  - 0.79±0.16 events
  - from ER calibration data, scaled to non blinded ER band background data
- Nuclear recoil background
  - 0.17+0.12-0.07 events
  - from cosmogenic and radiogenic neutrons
- Total: 1.0±0.2 events

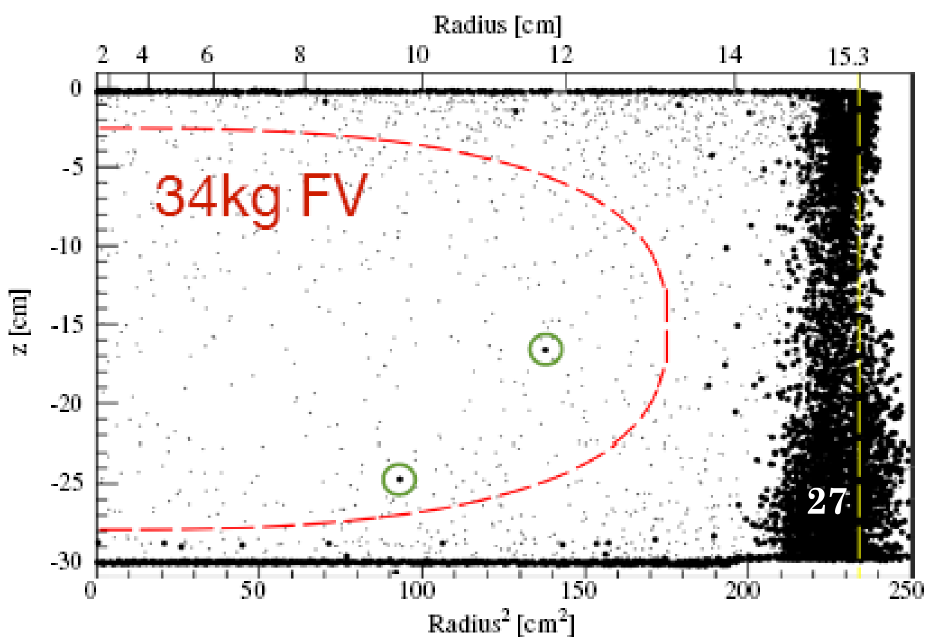


- *benchmark WIMP region (not used in PL analysis)*

After unblinding

- Two events observed in signal region (there is a 26.4 % chance for upward fluctuation): at 7.1 keV_{nr} (3.3 pe) and at 7.8 keV_{nr} (3.8 pe)
- Both events at low S2/S1 with respect to NR calibration data
- Visual inspection: waveforms of high quality
- New SD WIMP limit -- arXiv:1301.6620v2 [astro-ph.CO]

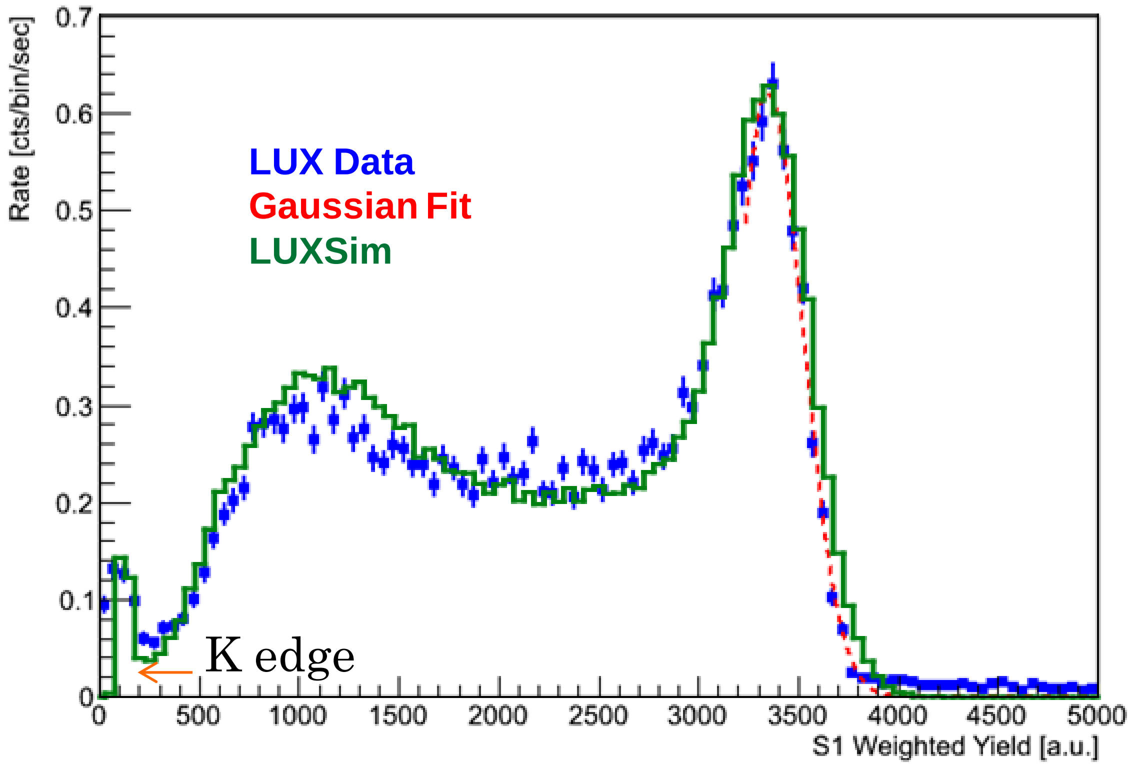




Cs-137 External Calibration

LUX

- LUXSim uses NEST, and was able to predict the energy resolution correctly as a result, possibly a first in the field of xenon
- First LUX results (technical):

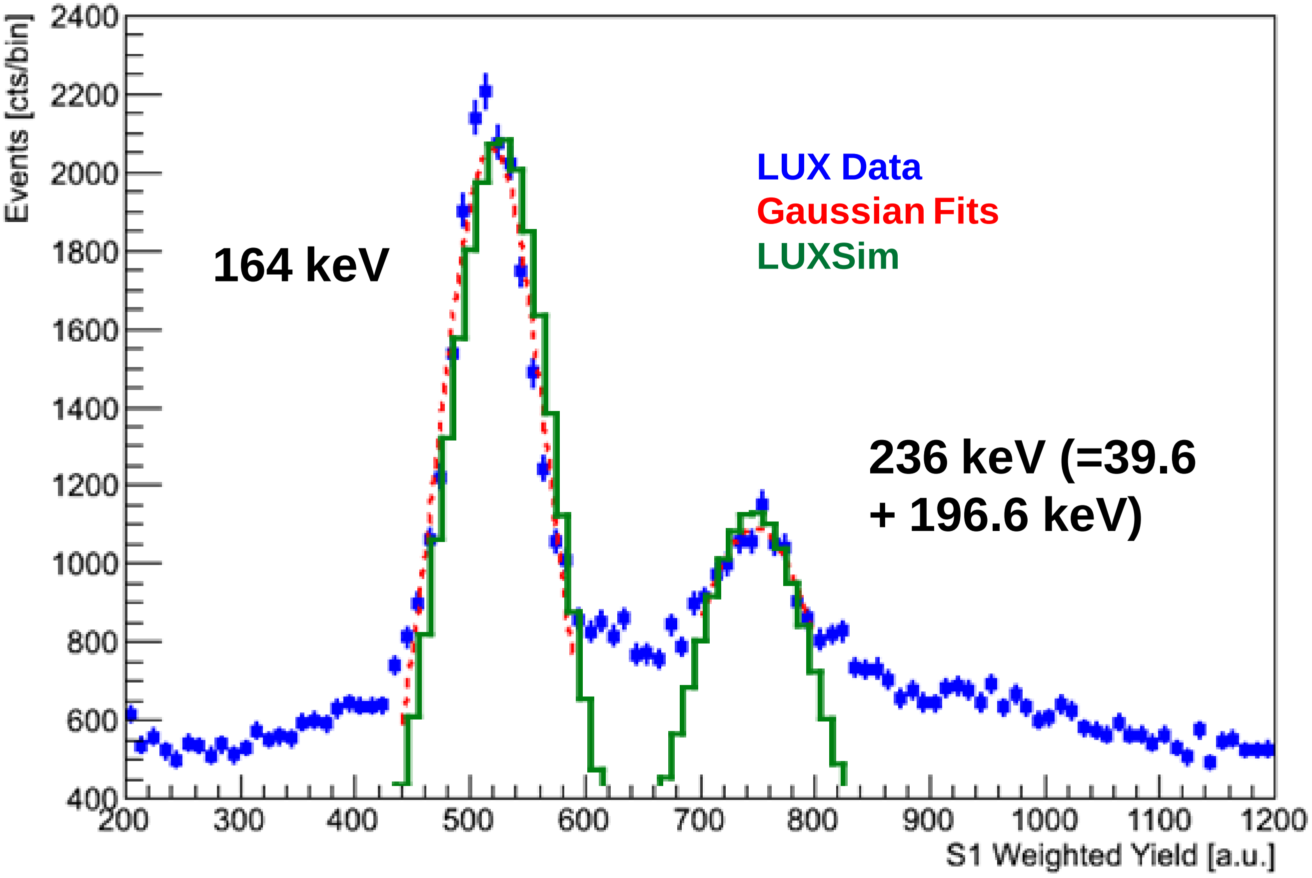


Simulation described in Akerib et al., "**LUXSim: A component-centric approach to low-background simulations**", Nuclear Instruments and Methods in Physics Research A (675) (2012) pp. 63-77.

Akerib et al., Astroparticle Physics, forthcoming (arXiv:1210.4569)

XENON ACTIVATION LINES

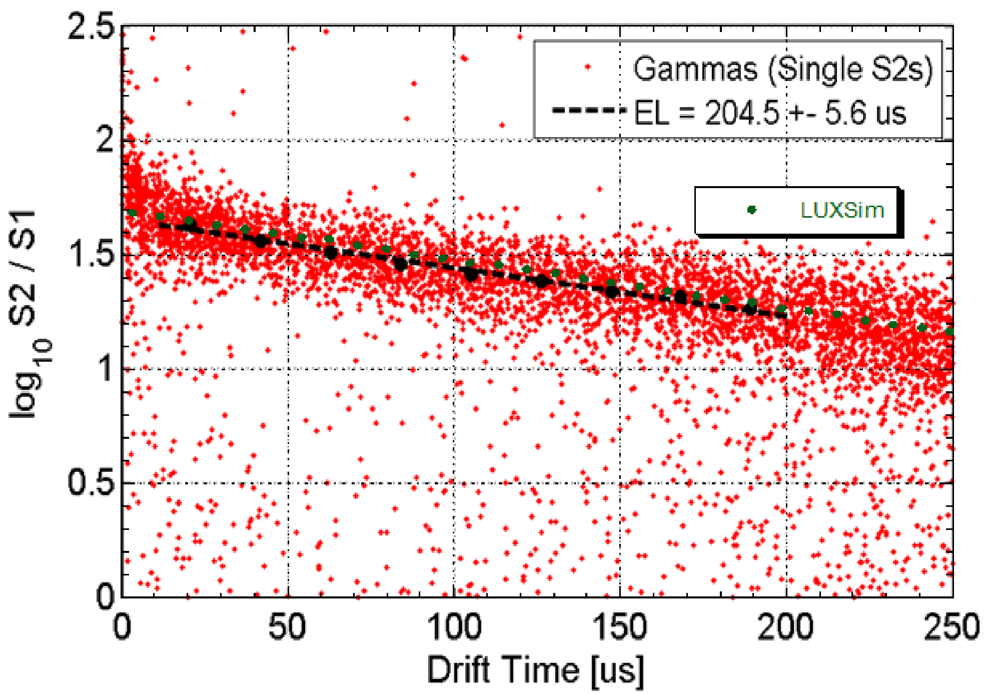
- "Weighted S1" optimizes weighting of top and bottom PMT light for best zero-field energy resolution
- Raw yield is ~8 phe/keVee (at 662 keV), roughly thrice XENON100 after accounting for different field and energy

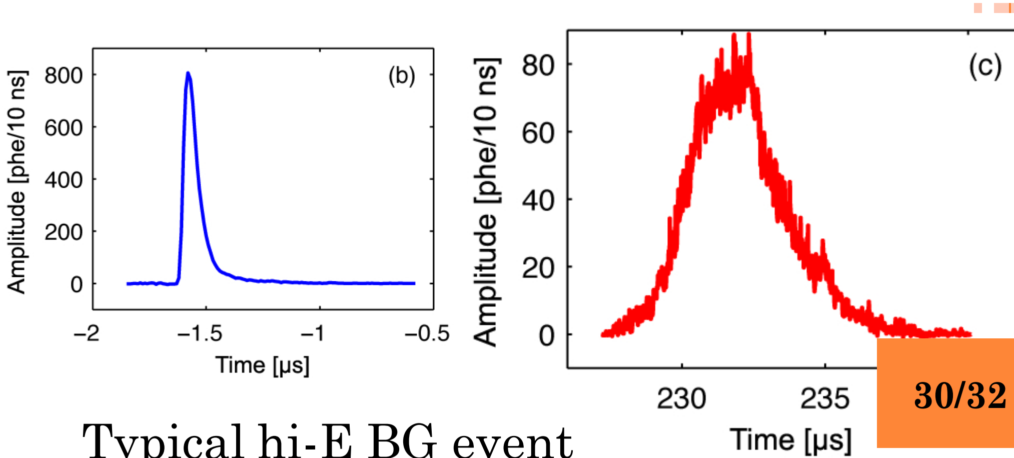


Pitfall: better comparison to data when simulating all components of a composite line individually with NEST, as each have unique dE/dx

Electron Lifetime

- Without purification complete, and with a (now-solved) plumbing issue: ~200 us
- Such a lifetime would nevertheless be adequate for seeing low-E events down to the bottom of detector
- Cf. XENON100: ~600 us, deep in Run10
- Absolute S2 yield predicted without even needing tweaking

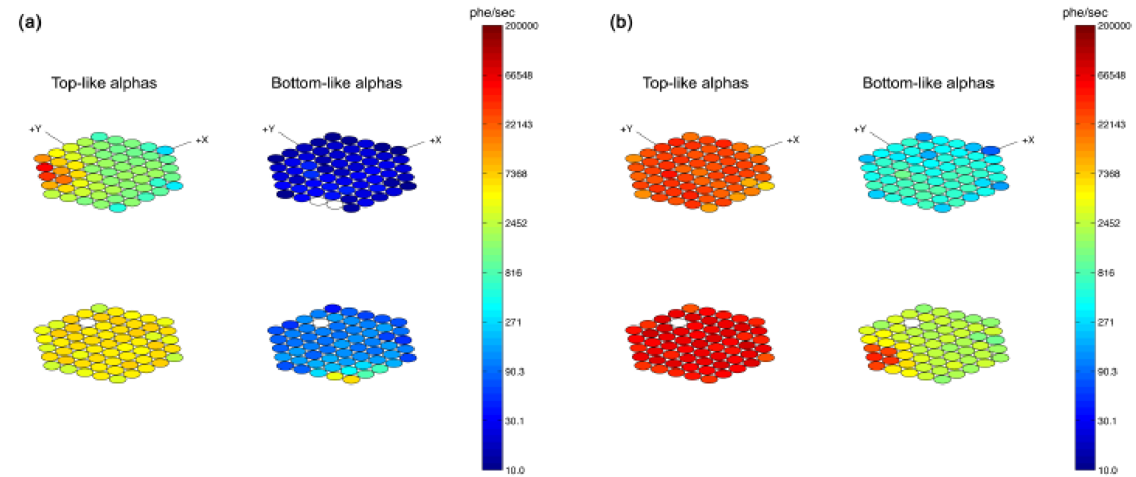


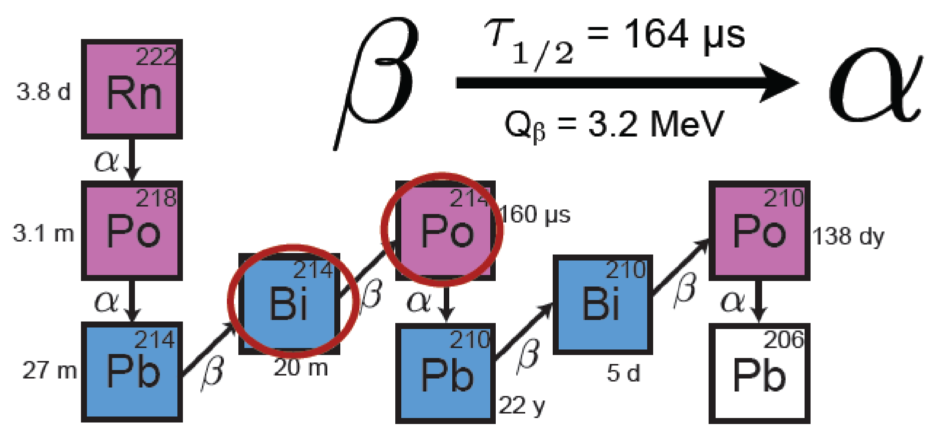


Typical hi-E BG event

Alpha Tomography

- Kr-83m was not ready yet during circulation problem, which got diagnosed with an injection of Rn-222
- Careful, conservative dose so that (alpha, n) <1% of PMT n contamination
- You could see the alphas "swimming" around in the Xe





Beta range (E_{mean} = 642 keV) in LXe is ~1.5 mm

Alpha range in LXe is ~50 μm

This coincidence event is highly localized in x,y,z

Position Reconstruction

- The Bi-Po alpha-beta coincident decay, plus grid wires, helped us determine at least the statistical component of the pos. resolution
- Result: Using the same iterative algorithm used in ZEPLIN (Mercury), better than 1 cm even at low energies (degraded alphas with degraded S2). Checked with MC