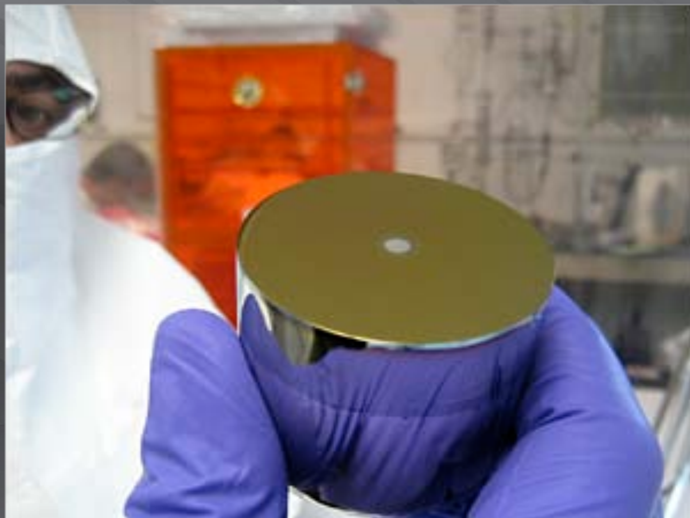

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Analysis of 3.4 years of CoGeNT Data

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Rencontres de Moriond EW 2014

Overview

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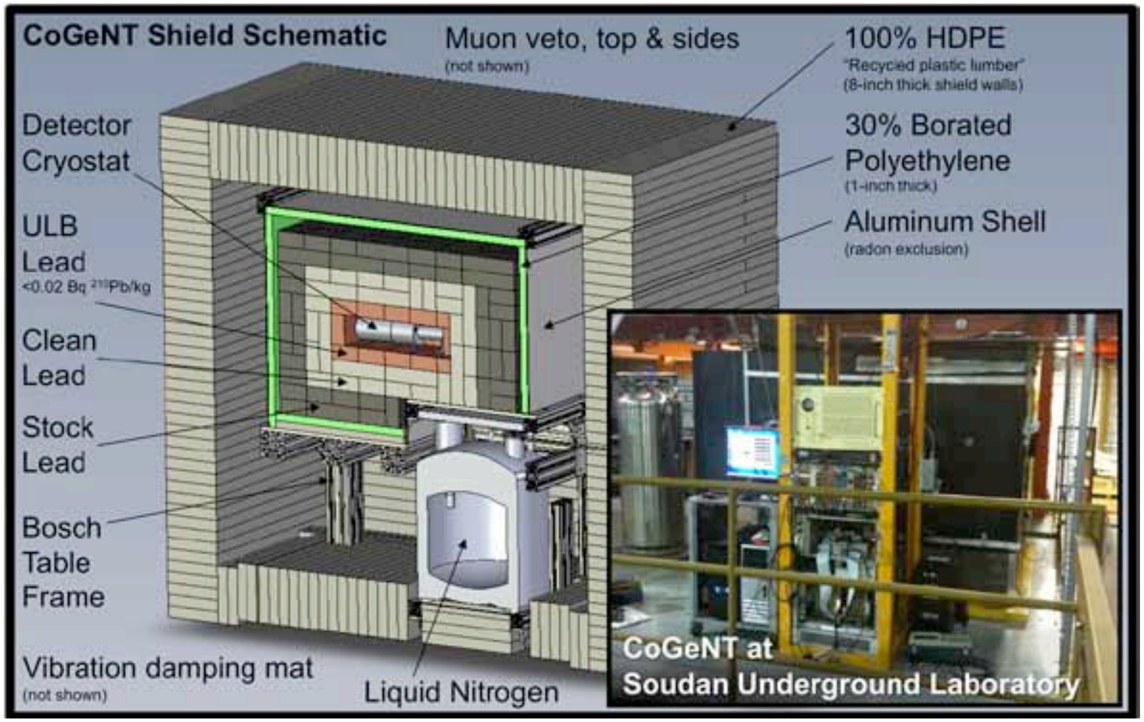
- Description of detector and history of recent results
- The CoGeNT background model
  - Backgrounds with a similar spectral shape to WIMPs
  - Backgrounds that modulate
  - Surface events (slow pulses)
- Search for an annual modulation in CoGeNT
  - Results from the modulation search
- Maximum likelihood signal extraction applied to 3.4 years of CoGeNT data
  - PDFs for background and signal
  - Signal extraction results
- Future low-mass WIMP searches

A Little CoGeNT History

- CoGeNT: 1 Ge crystal (440 g) at the Soudan mine (data taking since Dec 2009)
- CoGeNT employs PPCs (JCAP 09 (2007) 009) to search for low-mass WIMPs, specifically aiming to test the DAMA/LIBRA claim. PPCs offer required stability, low threshold, and rejection of surface events. At higher energies, rejection of gamma backgrounds (MAJORANA and GERDA, $0\nu\ \beta\beta$-decay searches).
- Irreducible low-energy exponential excess found following surface event rejection (PRL 106 (2011) 131301). Larger exposure has allowed for better surface event rejection, also, a lot of work in understanding and simulating backgrounds (PRD 88 (2013) 012002).



The background picture

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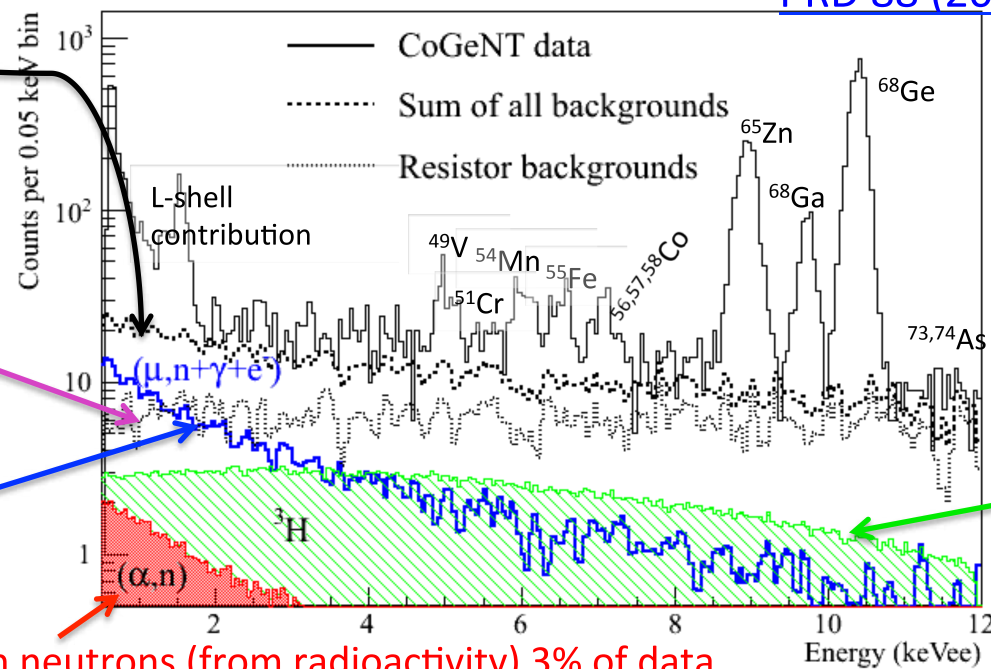
PRD 88 (2013) 012002

Background sum

Resistor gammas ~16% of data

Muon-induced neutrons 16% of data



Tritium β-decay 7% of data

Cavern neutrons (from radioactivity) 3% of data

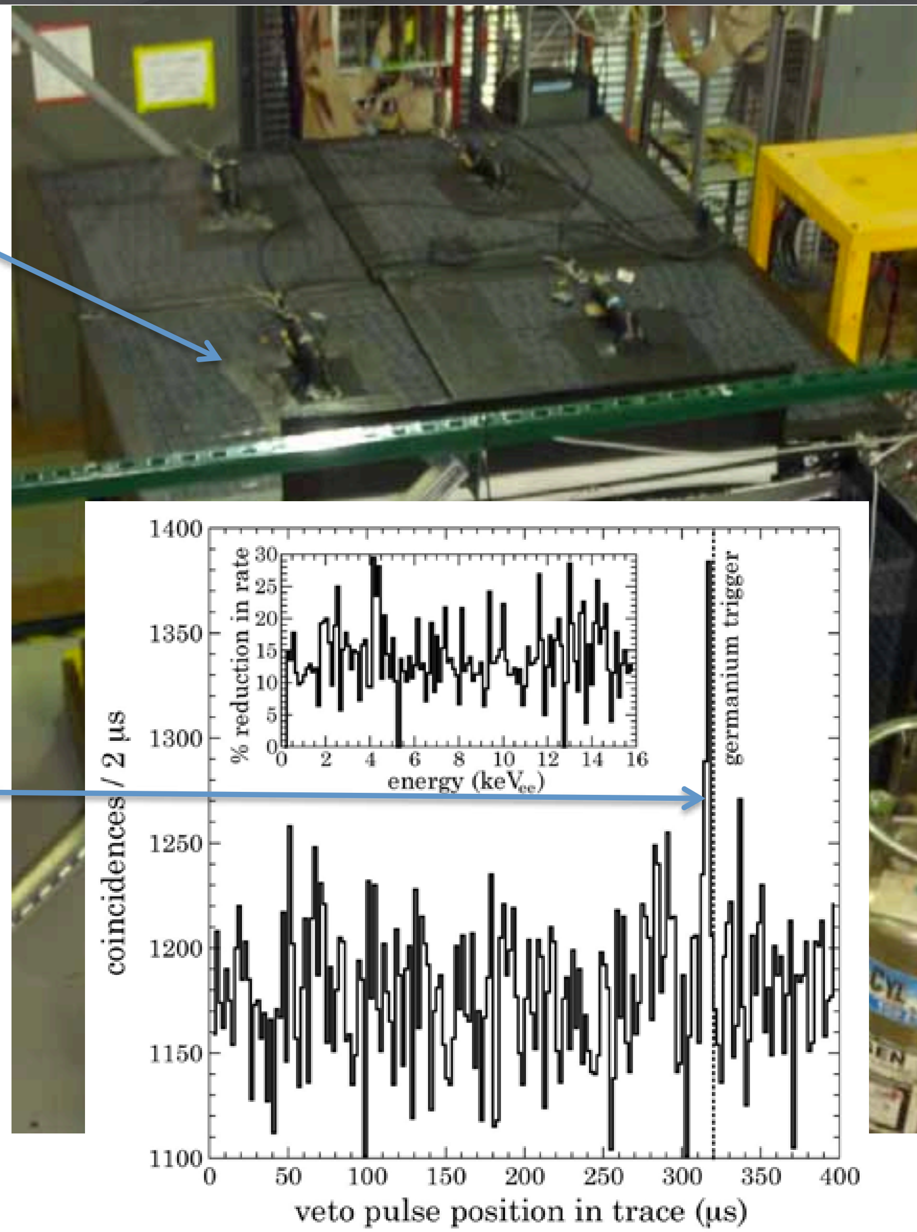
Other sources of background simulated:

- 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 backgrounds are tiny

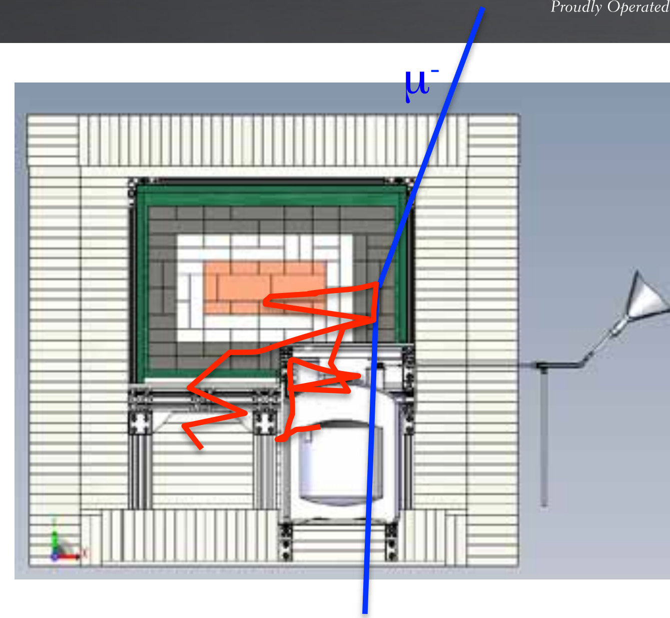
Muon-induced neutrons (largest background)

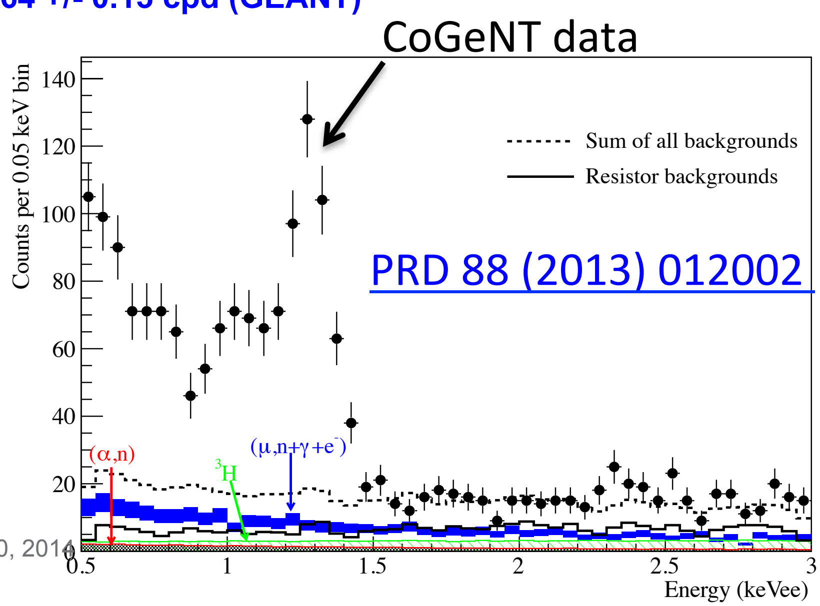
- 1 cm panels do not allow muon-gamma separation
  - Veto operated at single photo-electron sensitivity
  - Generate ~12% dead time from spurious germanium detector-veto coincidences.
- True coincidences are however observable and rate is in good agreement with Monte-carlo (next slide)

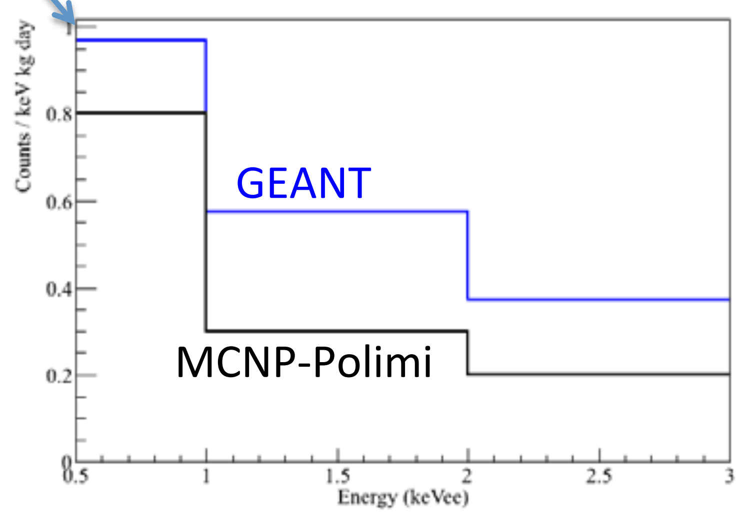


Muon-induced neutron simulation

- 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)
  0.64 +/- 0.13 cpd (GEANT)







Backgrounds from the front-end electronics (2nd largest background)

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- RESISTORS ARE HOT!

ILIAS database

SNOLAB

Description	U-238 (Bq/kg)	Th-232 (Bq/kg)	K-40 (Bq/kg)	Events in CoGeNT
Carbon film resistor	4.3	12.7	21.9	972 +/- 120
Metal film resistor 1	4.3	0.5	37.5	324 +/- 164
Metal film resistor 2	5.1	16.1	24.7	1208 +/- 160
Ceramic core resistor	5.9	4.6	34.3	644 +/- 131
Metal on ceramic resistor	28	40.7	25.7	4509 +/- 352
Ceramic	15.5	0.2	13.8	993 +/- 200

Tritium production in Ge (3rd largest background)

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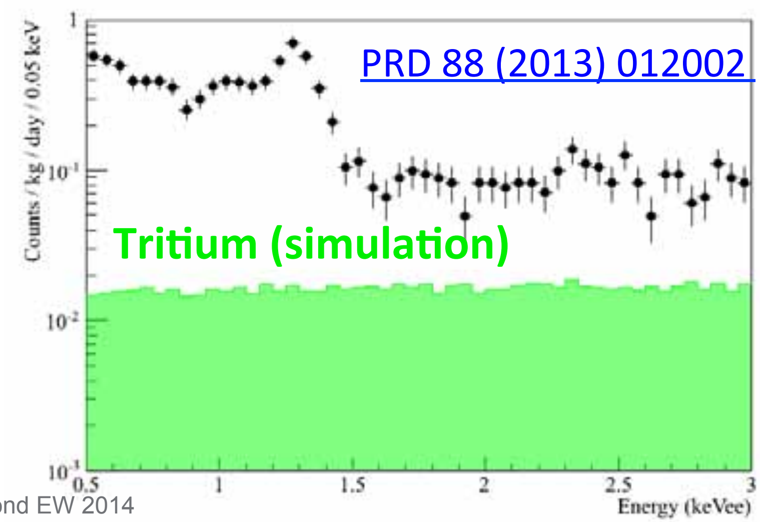
- Cosmogenic production of tritium in Ge while detector at surface
- Tritium β-decay endpoint at 18.6 keV
  - Half-life of 12.33 yrs
- Tritium production rate:
  - 27.7 /kg-day
    Astroparticle phys, **31**, 417 (2009)
  - Based on IGEX data
    Phys Lett**, B432**, 8 (2002)
- Assuming a surface exposure of CoGeNT detector of 2 yrs:
  - **0.34 events/day in 0.5 – 3.0 keVee**
    (Geant4 simulation of ^{3}H in CoGeNT)

Years of surface exposure	Tritium decays underground
1	299
2	583
3	850
4	1103
5	1342
6	1568
7	1782
8	1983
9	2174
10	2355



Backgrounds that modulate

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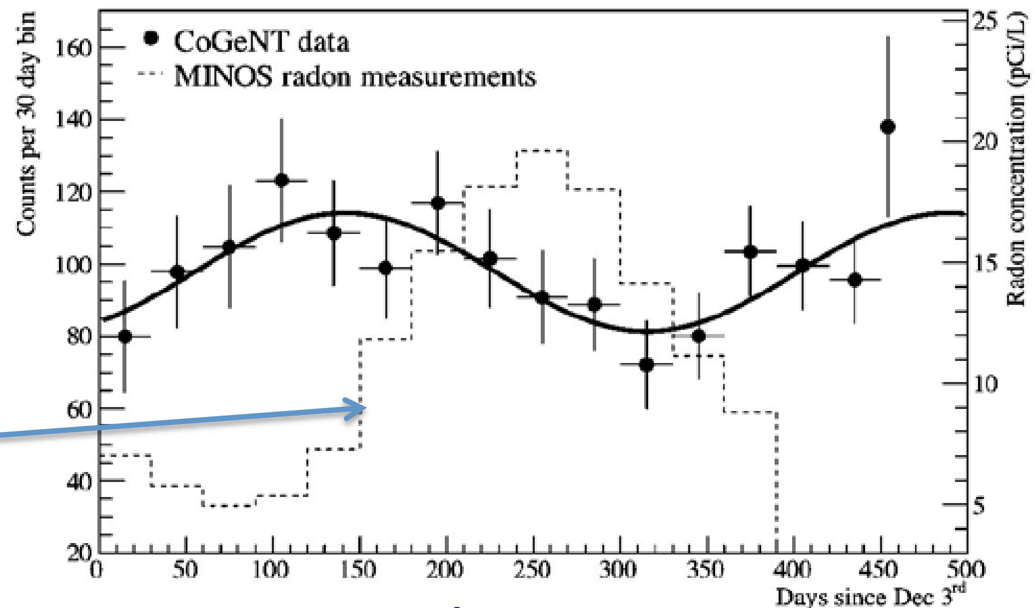
- Radon levels modulate underground – Measured
  - Modulation out of phase!
  - Inner shield is inside a sealed nitrogen purged box
  - So far it doesn't look like radon

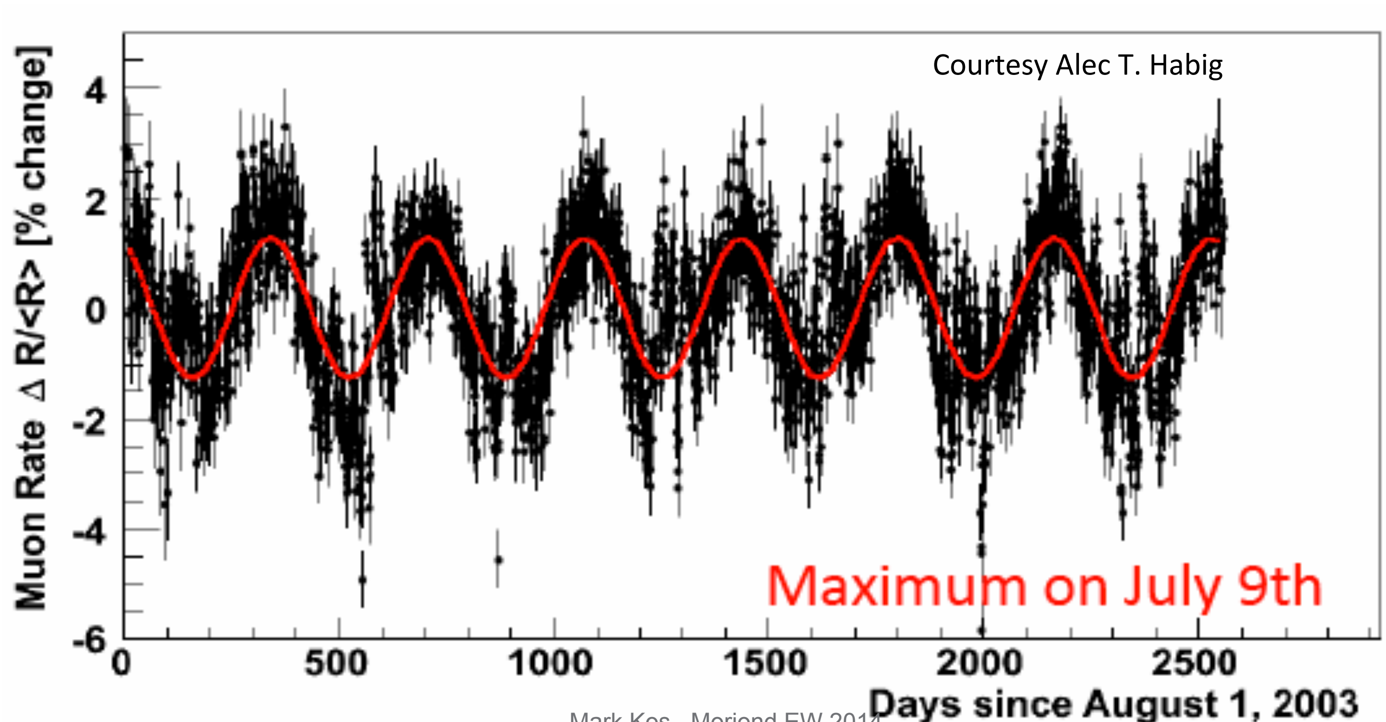
PRD 88 (2013) 012002



CoGeNT data: Dec 3 2009 - March 6 2011
MINOS data: Averaged 2007-2011

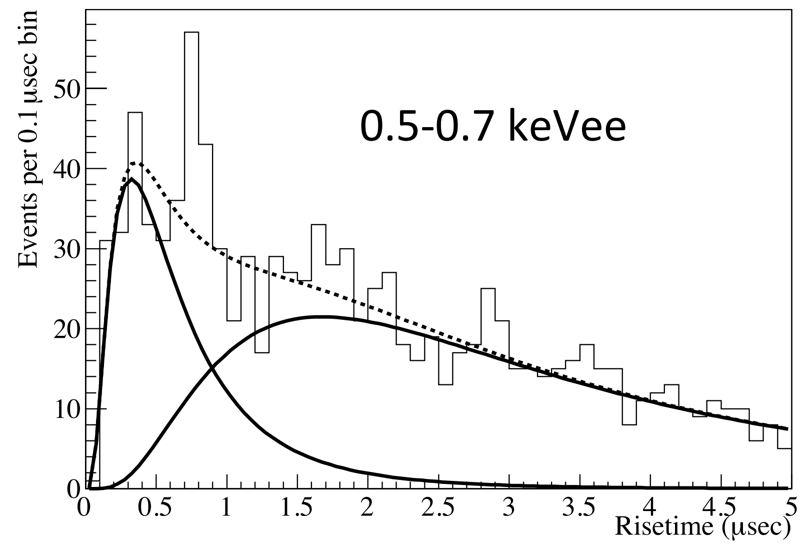
Backgrounds that modulate: muons

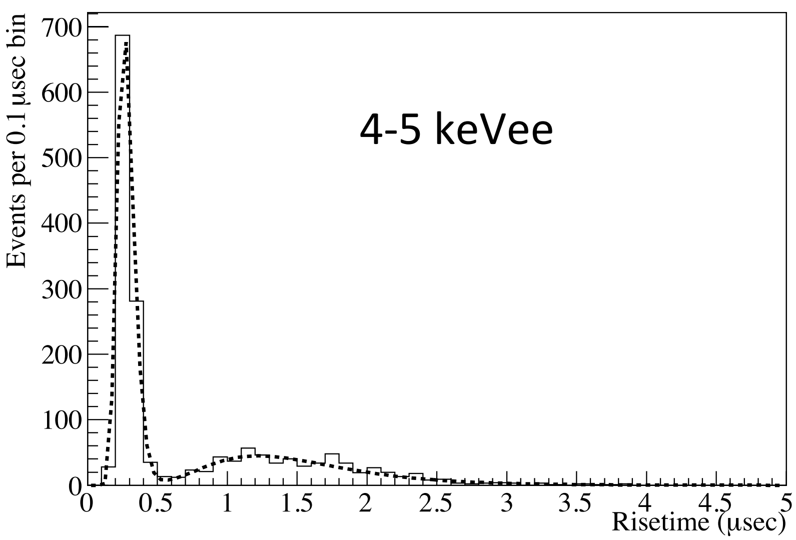
- MINOS muon flux modulation measured in Soudan
  - Approximately +/-1.5%
  - Peaks three months after best fit to present CoGeNT data
  - The CoGeNT event rate is 4.8 cpd in the 0.5-3 keVee energy range. **A 1.5 % modulation of muon induced events could only produce a 0.2% modulation effect in the CoGeNT data set.**

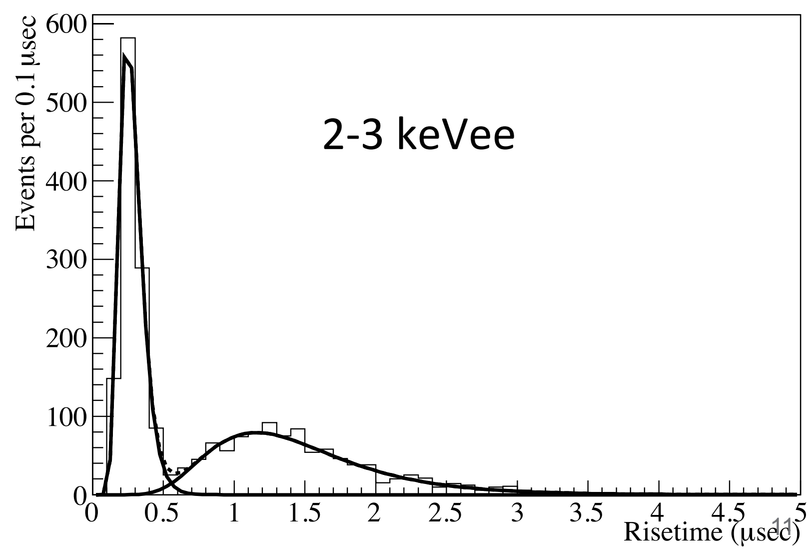


Surface events and slow pulses

- 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 distribution
- Log-normal functions seem to be good approximations for these distributions







New: Modulation analysis of 3.4 years of data

- Detector recovered from 3 month post-fire outage w/o significant changes in performance. It has been continuously taking data ever since.

- Make use of the rise-time analysis developed in (PRD 88 (2013) 012002). Rise-time bulk event selection:

  rt < 0.7 μs (0.5 - 2.0 keV),

  rt < 0.6 μs (2.0 - 4.5 keV)

- Paper available: arXiv:1401.3295. Data released in energy, time-stamp, and rise-time format.

Search for an annual modulation

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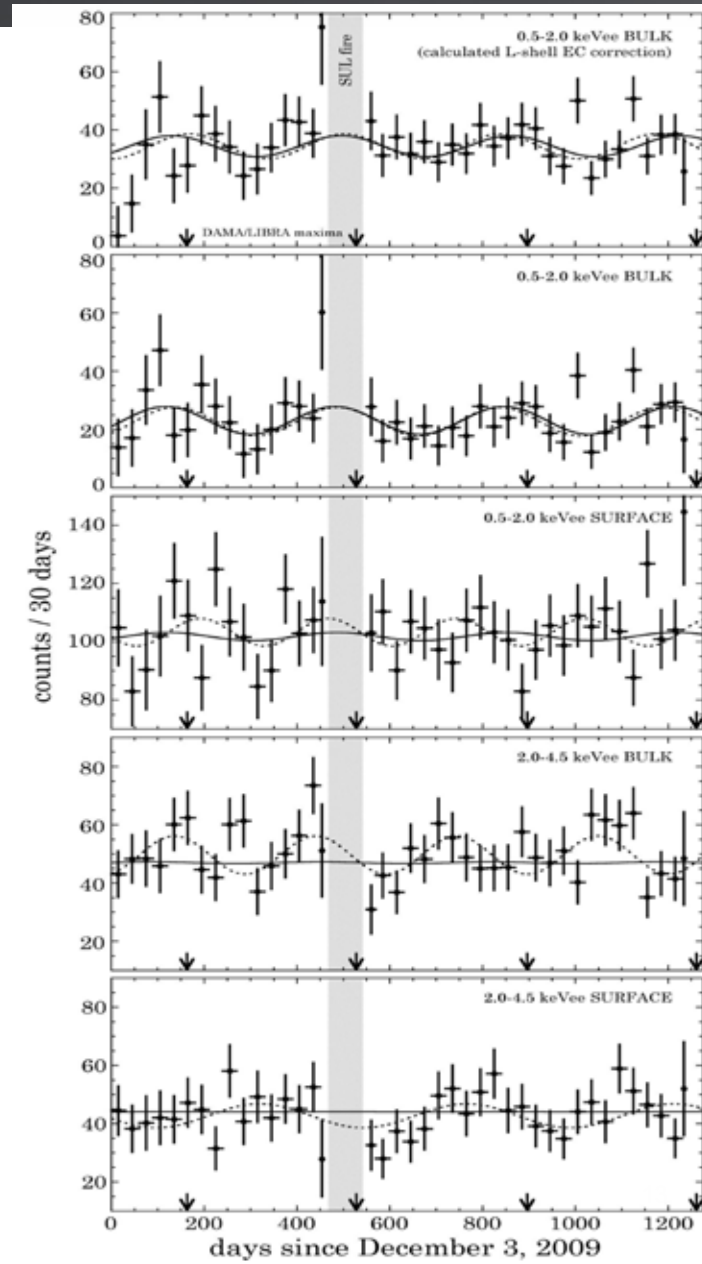
	L-shell subtracted	Floating $T_{1/2}$
T	336 +/- 24 days	350 +/- 20 days
t_{max}	102 +/- 47 days	137 +/- 7 days
S	(12 +/- 5) %	(22 +/- 15) %

Fits were done both with L-shell contributions subtracted and a floating $T_{1/2}$ for the L-shell contribution



- The actual WIMP “signal” modulation would be 35 -65% !
- The modulation is only favored over the null hypothesis at 2.2 σ

Maximum likelihood signal extraction applied to CoGeNT data

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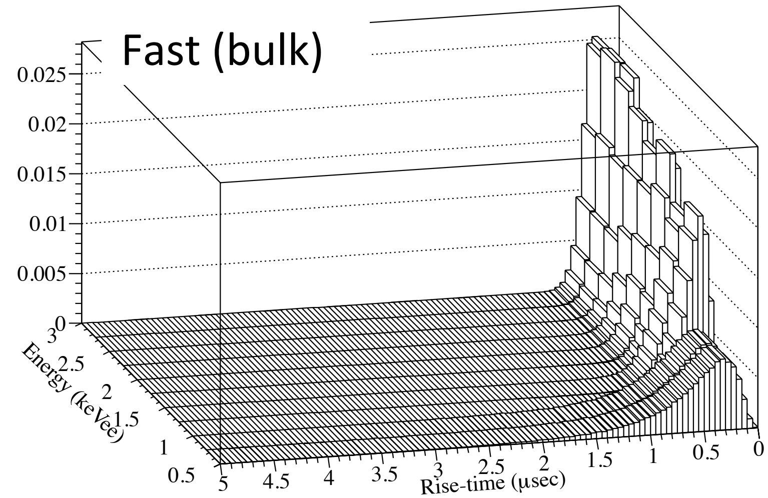
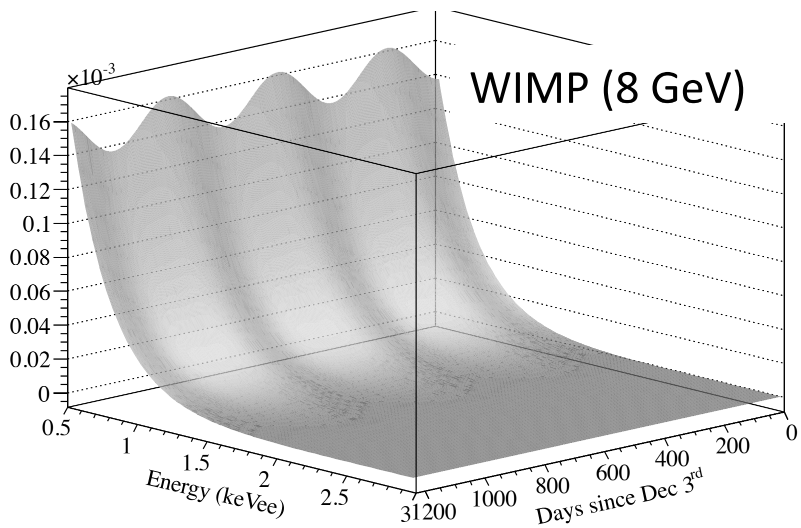
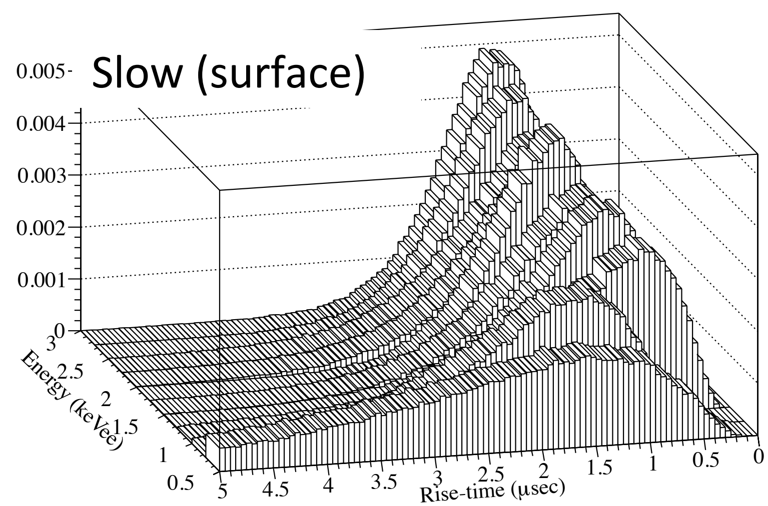
- We know a lot about are backgrounds: use Probability Density Functions (PDFs) for the backgrounds and signal in a maximum likelihood signal extraction
- 2-D PDFs in energy AND time AND rise-time:



$$P_\chi(E,rt,t) = P(E,t) \times P(rt,E).$$

$$P_{bkg}(E,rt,t) = P(E) \times P(rt,E) \times P(t),$$





Surface event background

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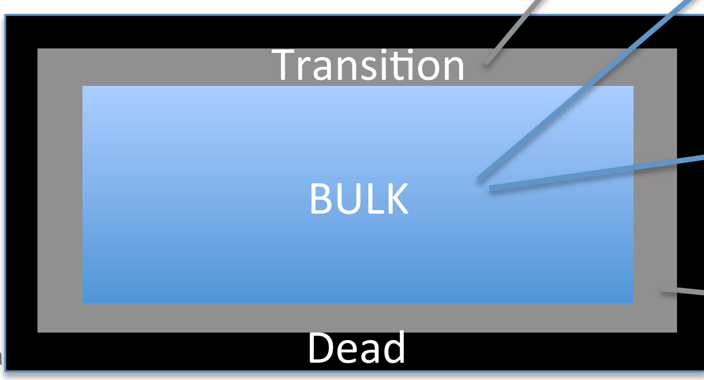
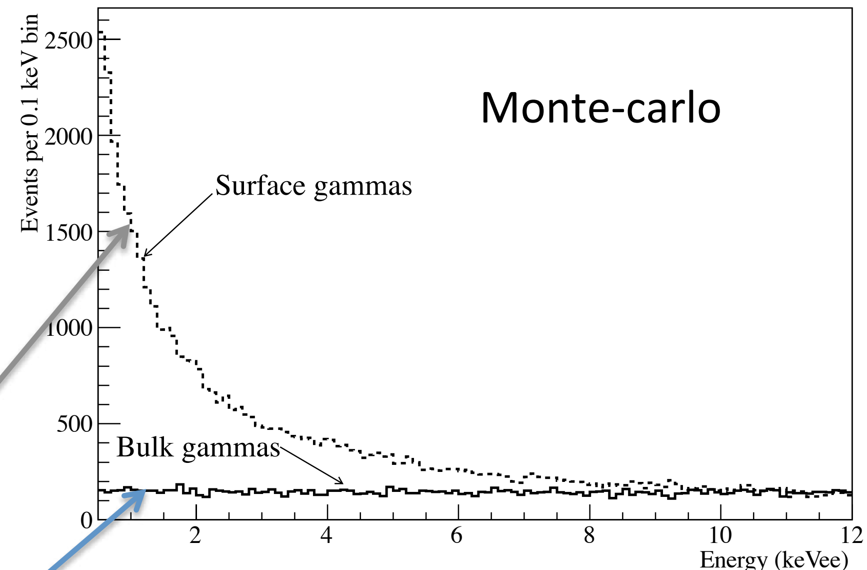
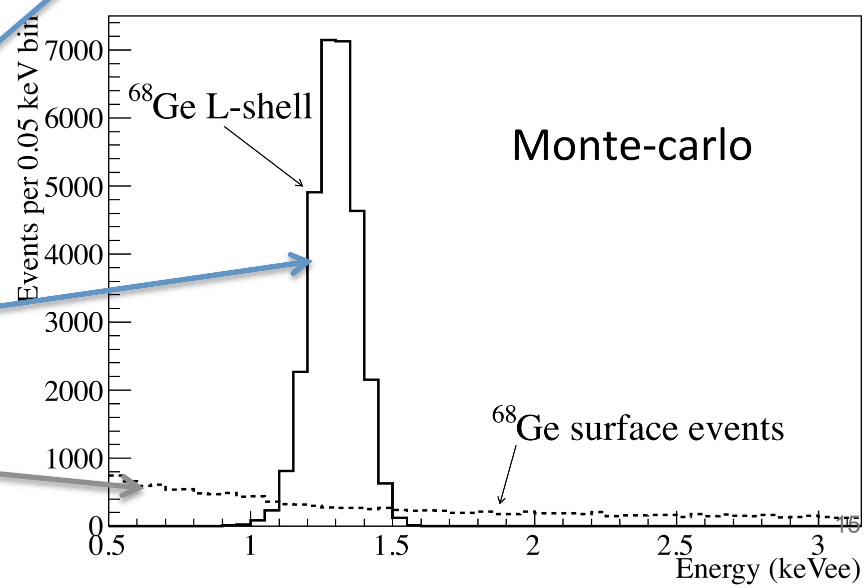
- The largest unknown in this analysis are the surface event distributions
- The Monte-carlo background simulations include the surface dead and transition layers
- We believe most of the slow pulse events in the 0.5 – 3.0 keV region are from external gammas depositing energy in the transition region

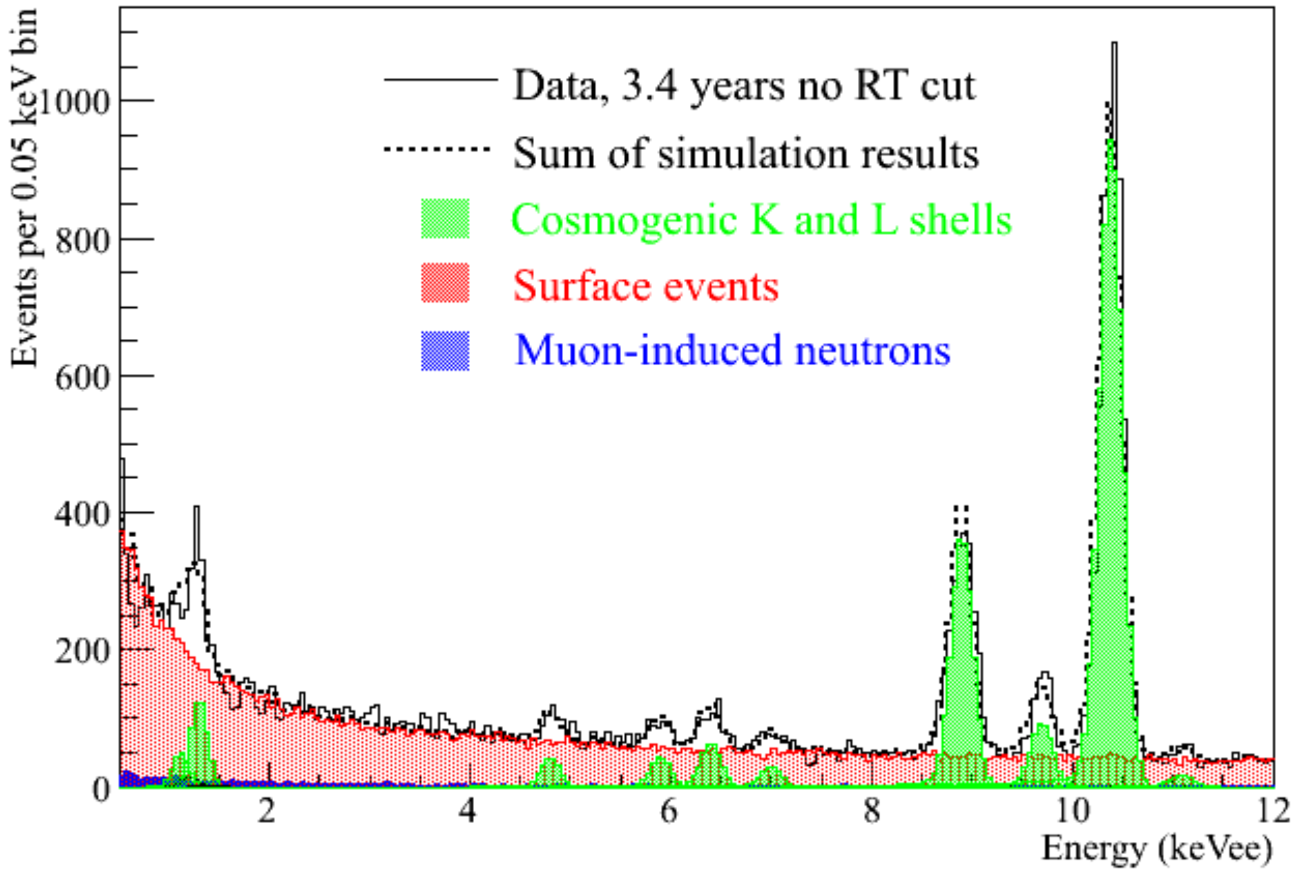






Comparisons of simulations with data

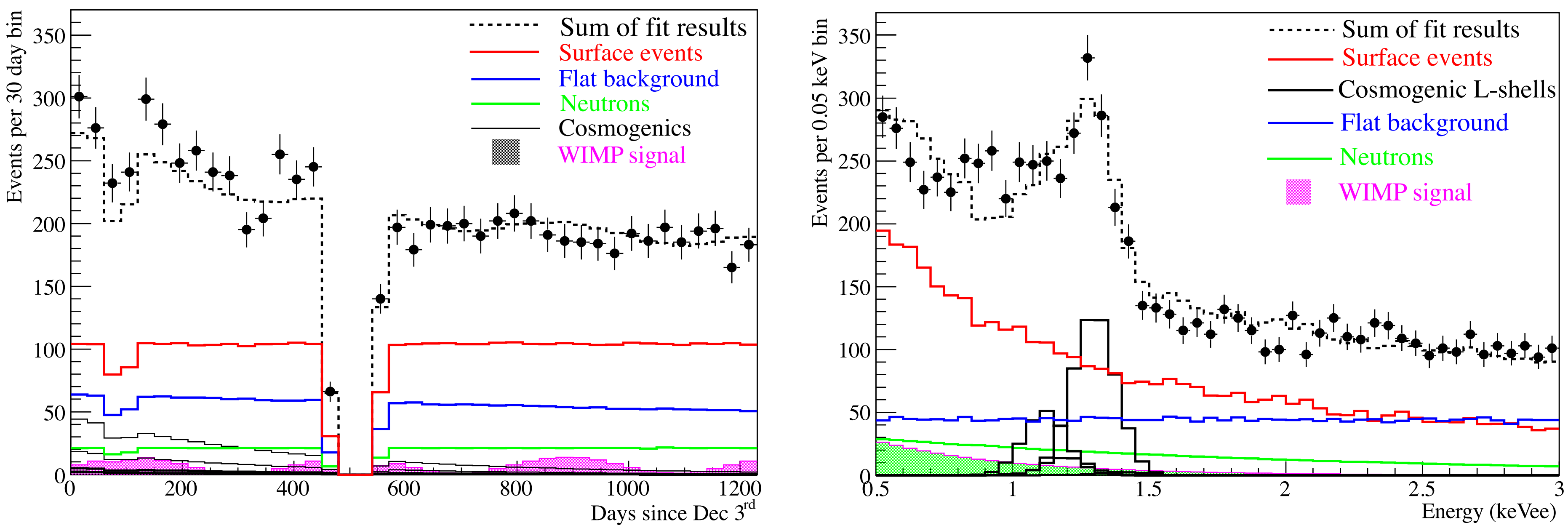
- Good agreement between simulations and the data even after including the surface transition region
- No rise-time cuts applied to data in this figure!



Signal extraction results

- We performed the signal extraction with both the Standard Halo Model and free oscillation parameters
- The free oscillation parameter fit is favored at 2.7 σ
- The flat background and surface events were allowed to have a floating $T_{1/2}$

arXiv:1401.6234



Results cont'd

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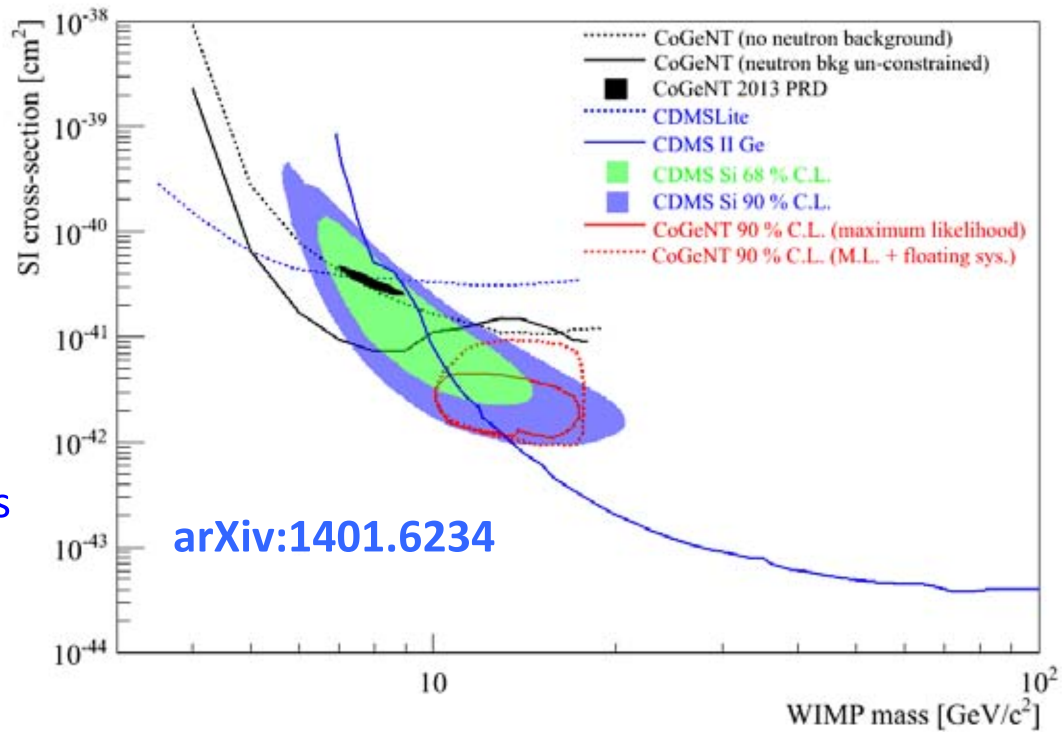
T:	388 +/- 18 days
t_{max}:	106 +/- 24 days
S (amp):	(84 +/- 32) %
Mass and cross-section:	(12.8 +/- 2.7) GeV, 2.8 X 10^{-42} cm^2

$T_{1/2}$ flat background: 4143 +/- 1812 days (Tritium: 4500 days)

$T_{1/2}$ surface events: 6424 +/- 5140 days (Pb-210: 8140 days)



- The NULL result is only excluded at 1.9 σ (we are not claiming anything)
- This method can provide better sensitivity to WIMPs when backgrounds cannot be avoided, particularly if the background distributions are well understood)

First CoGeNT-4 (C4) detector coming very soon

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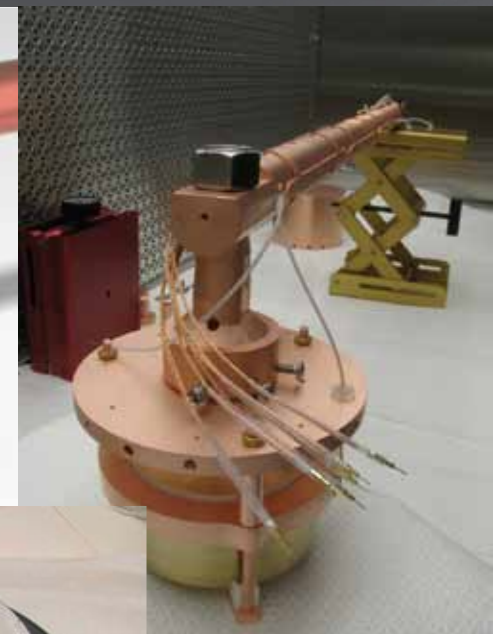
- First C-4 detector features ~1/3 of the noise of the existing GoGeNT detector, at ~x3 its mass (1.3 kg)
- Not a one-off: its noise characteristics are now reproducible (CANBERRA R&D supported by NSF award PHY-1003940). Second detector expected to reach the same noise figure at 2 kg, the realistic PPC maximum.



Design and assembly of ULB cryostat at PNNL

CANBERRA's proprietary modifications to point contact

Low-mass dark matter search with C4

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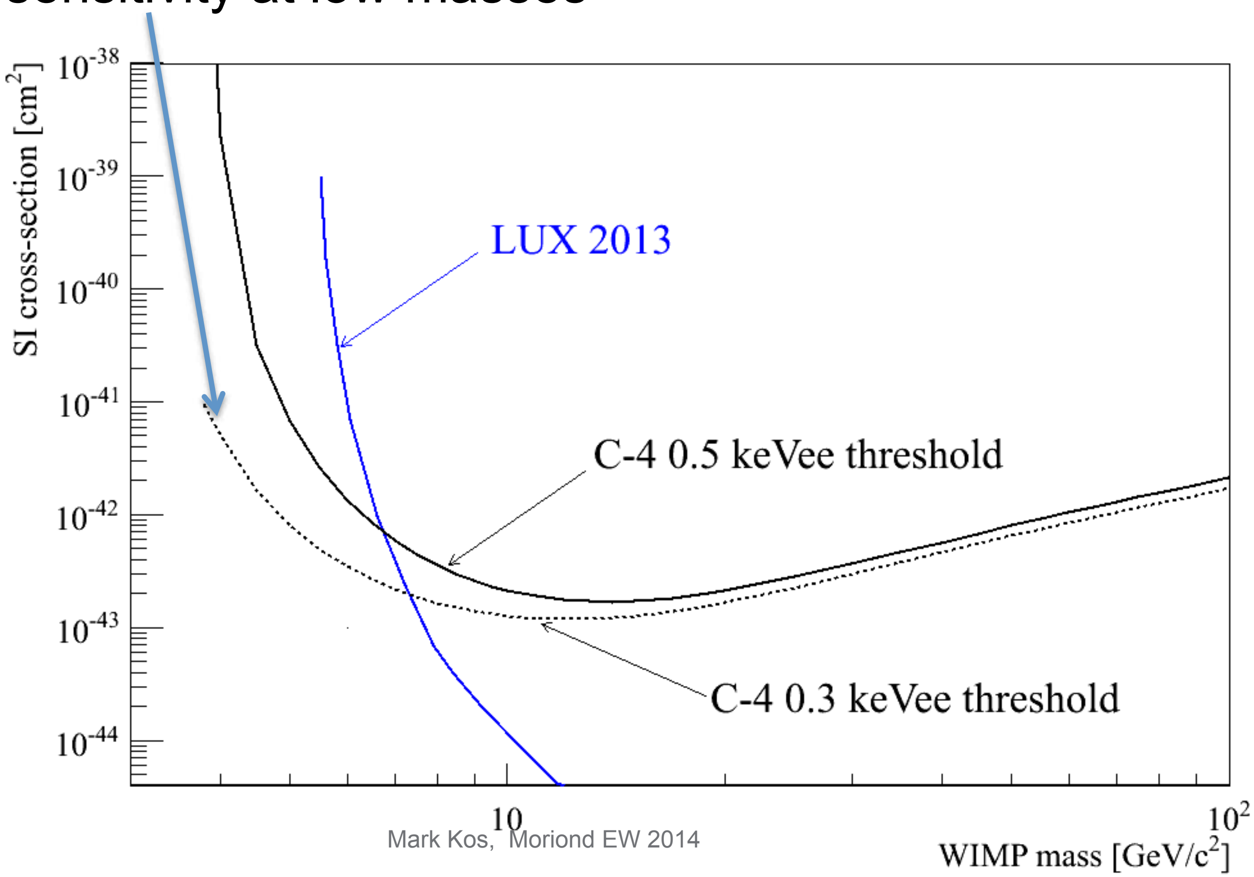
- C4 WIMP sensitivity will be competitive in the low-mass region and complement other experiments in excluding WIMP parameter space
- Even a modest lowering of the energy threshold can give a large increase in sensitivity at low masses



Summary

- We have a very good understanding of the backgrounds in the CoGeNT detector PRD 88 (2013) 012002
- There has been a lot of work on understanding the slow-pulses (surface events), which is a background that is very similar to a possible WIMP signal
- A modulation analysis has been performed arXiv:1401.3295 on 3.4 years of data. A modulating event rate is preferred (at 2.2 σ)
- Using our Monte-carlo simulations of backgrounds and our ability to separate bulk from surface events we perform a maximum likelihood signal extraction on the data, **arXiv:1401.6234** – using this method we have can better separate backgrounds from a potential WIMP signal, thus improving the sensitivity to WIMP interactions
- C4 will be able to push the limit of sensitivity in the low-mass WIMP parameter space NIM A 712 (2013) 27

Systematic studies of surface event distributions

- Can select high purity surface events by choosing events with long rise-time

- Determine how the energy distribution of these events changes as the rise-time threshold is decreased, and then extrapolate to determine the surface event energy distribution for all pulses – reasonable agreement with Monte-carlo!