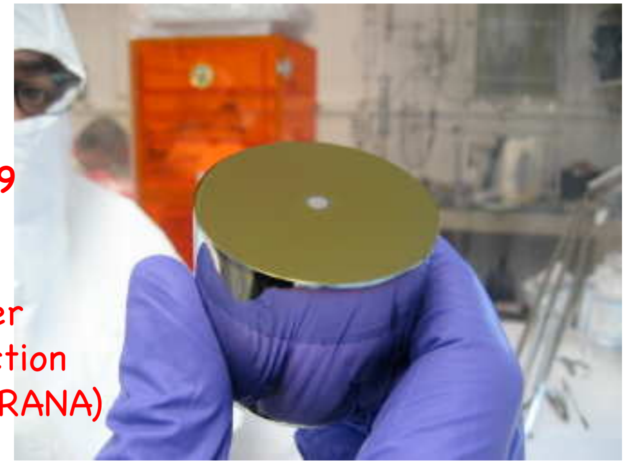
CoGeNT:

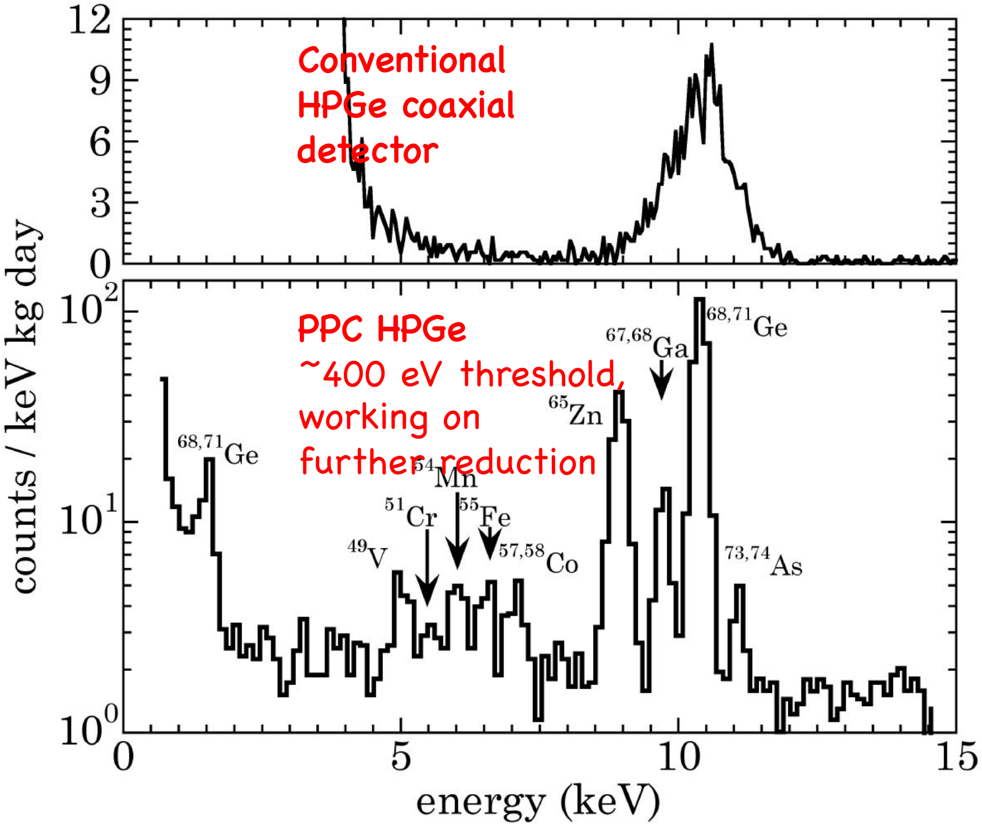
neutrino &
astroparticle physics
using large-mass,
ultra-low noise
germanium detectors
(CANBERRA, PNNL, ORNL, UC, UNC, UW)

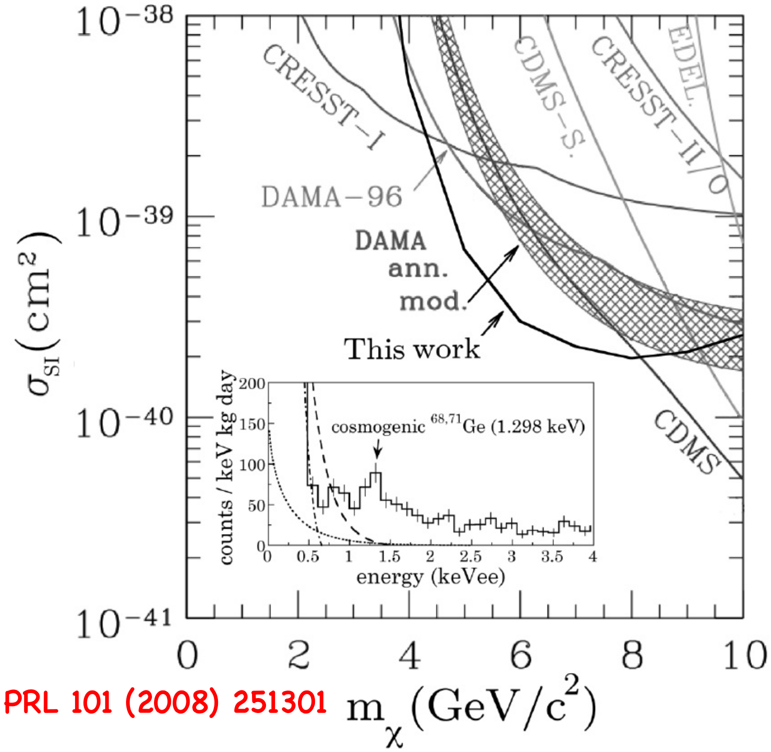
PPC HPGe

JCAP 09(2007)009

Applications:
- Light Dark Matter
- Coherent ν detection
- ββ decay (MAJORANA)





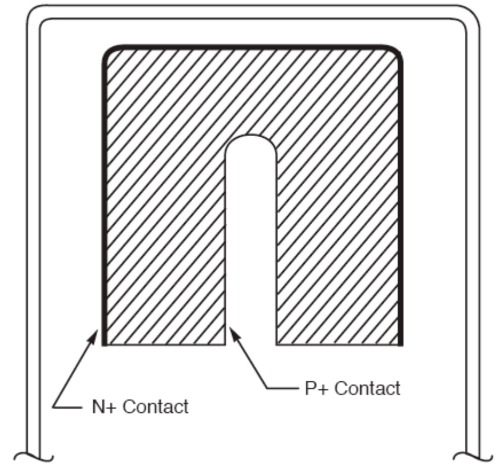


PRL 101 (2008) 251301

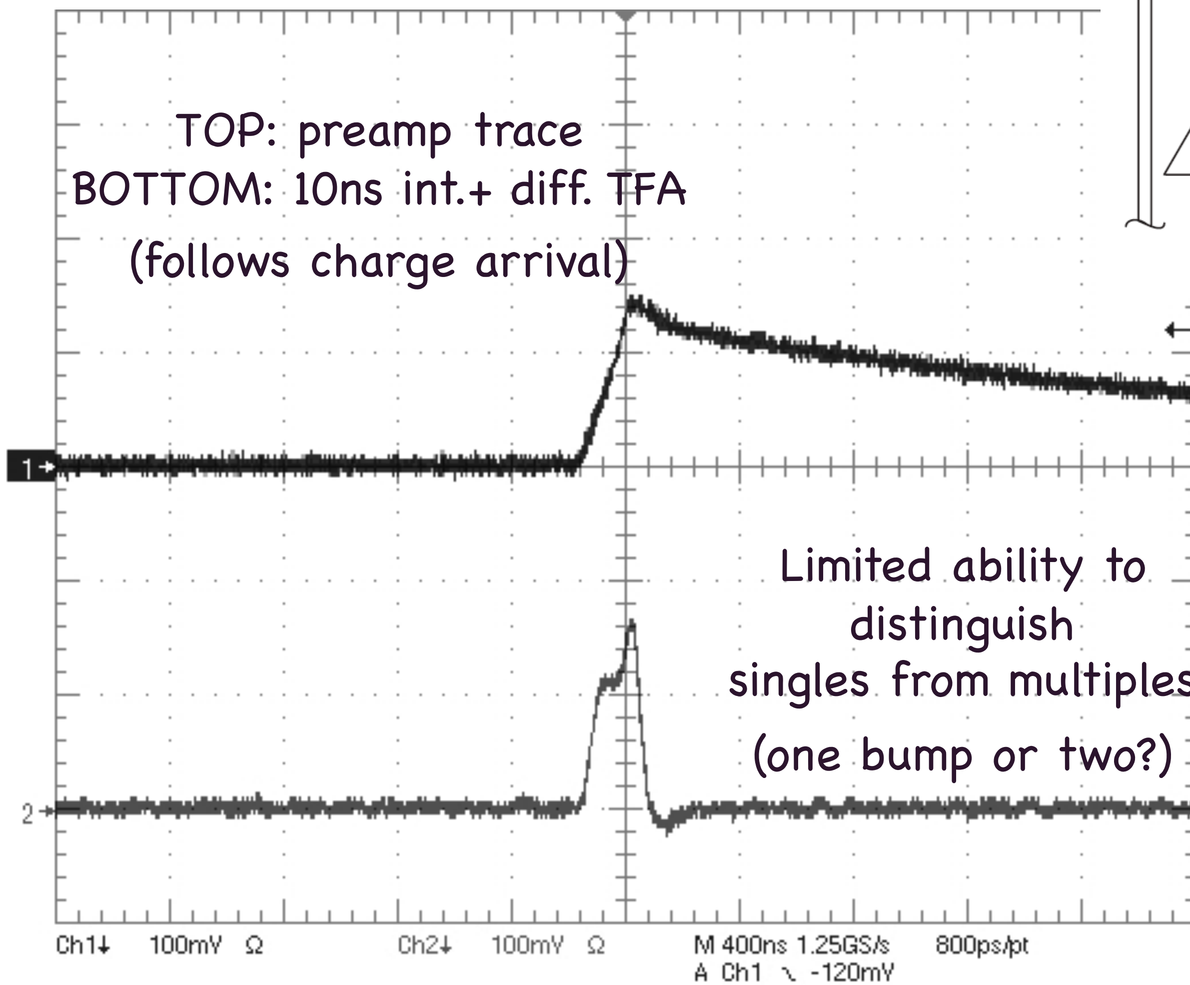
Extensive constraints on DAMA's claim:
- Light WIMPs
- Dark scalars
- Dark pseudoscalars

Other nice features brought by the point contact:

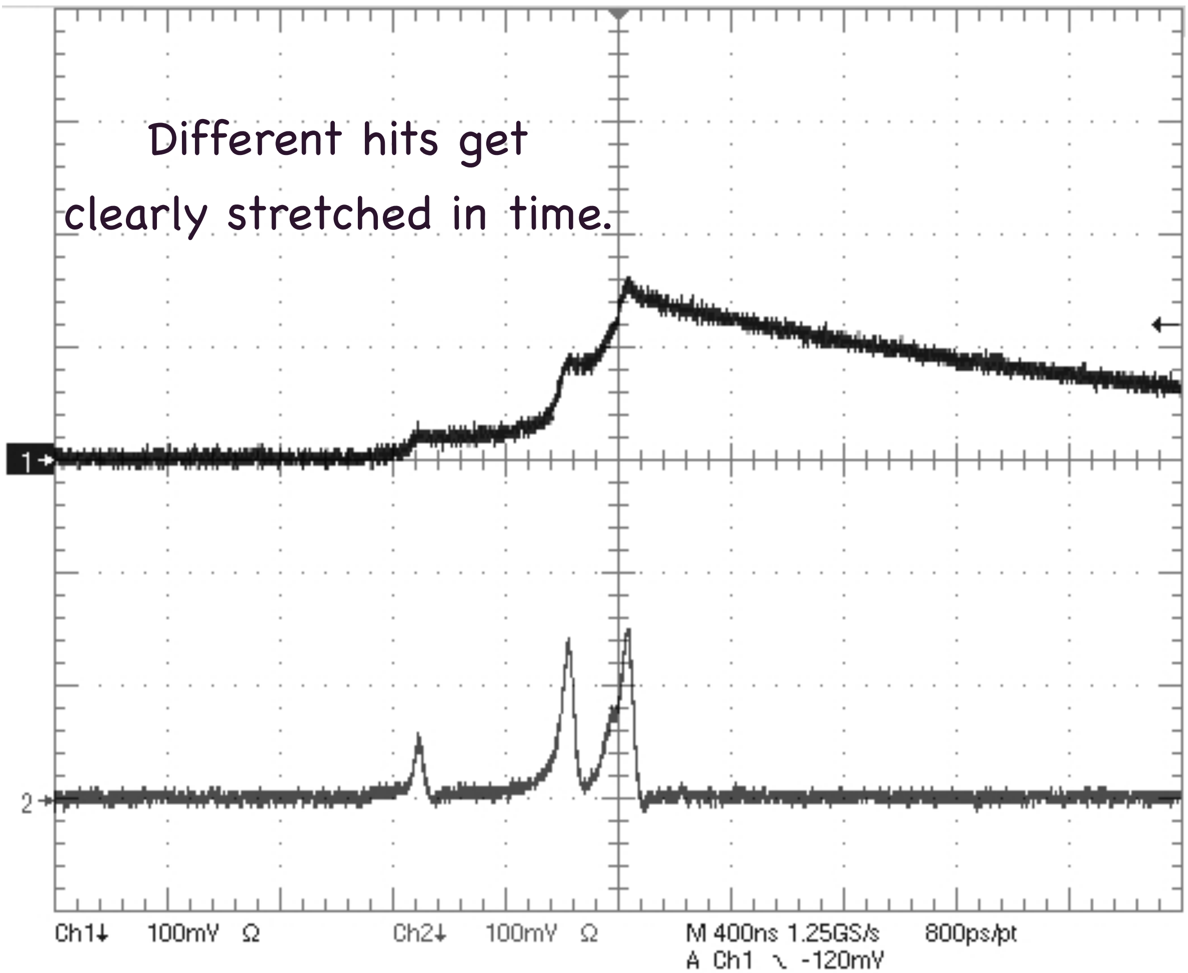
That was then...

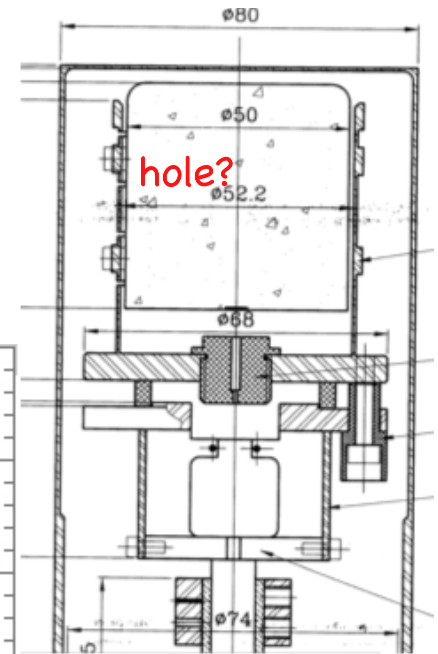


Coaxial Ge Detector Configuration



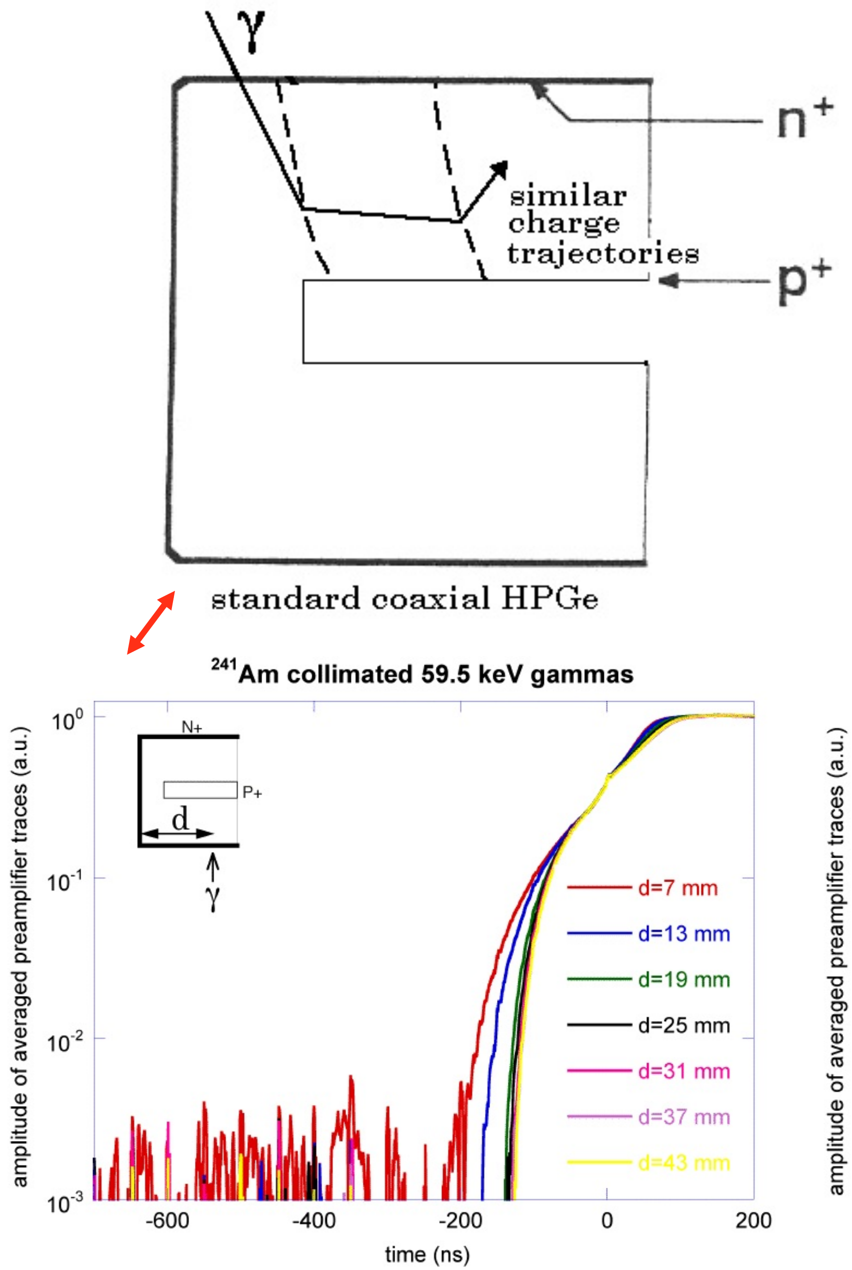
This is now.

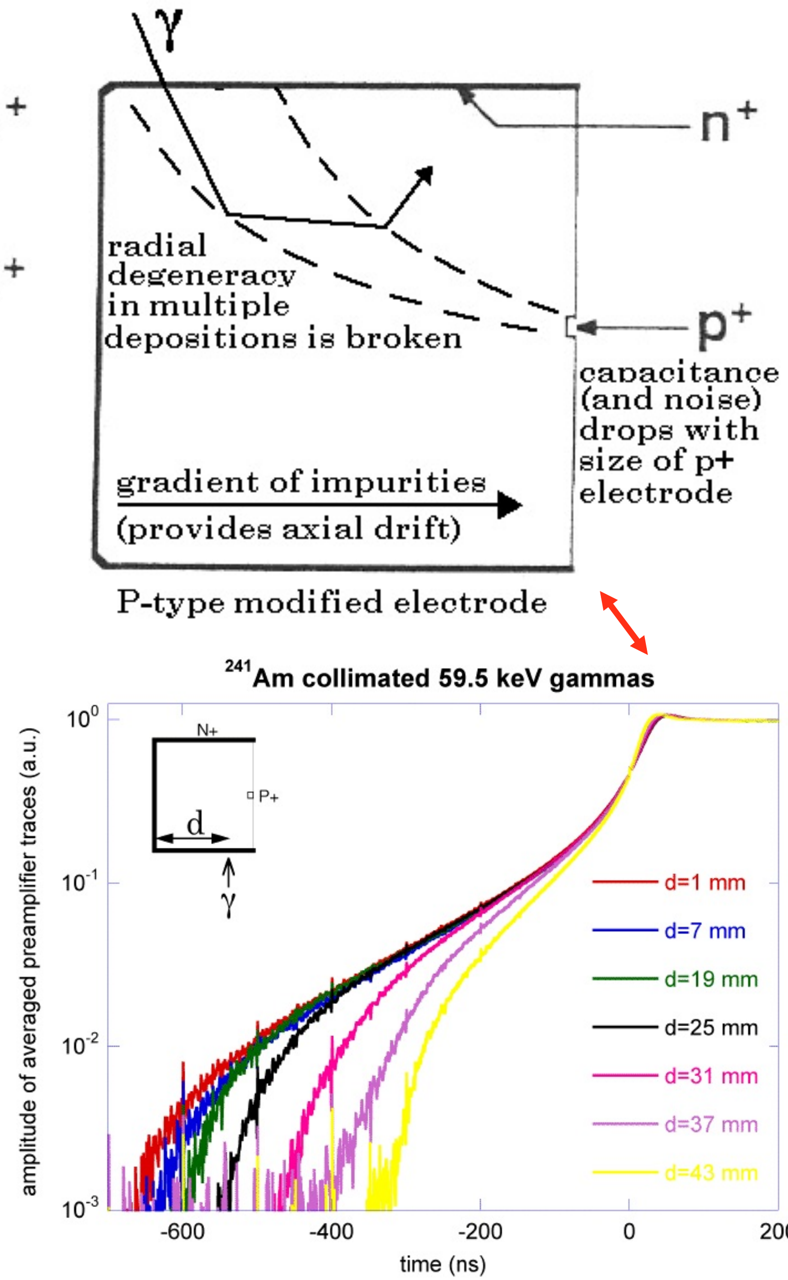




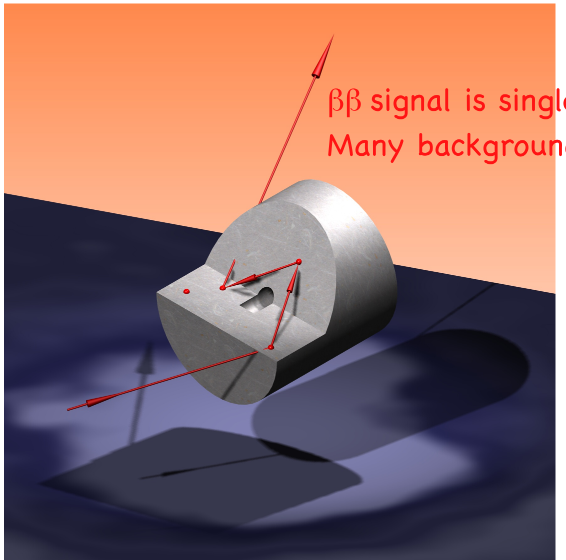
All this with optimal energy resolution and charge collection (<u>and one channel</u>)

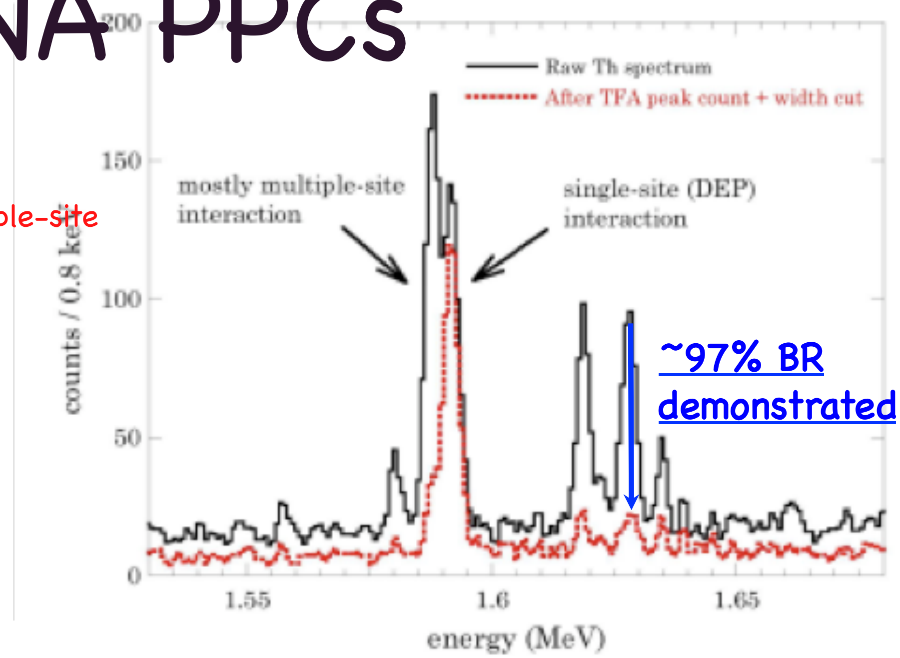
What is happening?





MAJORANA PPCs





Detectors studied / in hand:

(table actually missing a few)

Owner	Dimensions	Mass	Resolution (1.33 MeV)	Manufacturer
U. Chicago (PPCI)	50 mm Ø x 44 mm	460 g	1.82 keV	Canberra
PNNL (PPCII)	50 mm Ø x 50 mm	527 g	2.15 keV	Canberra
LBNL (SPPC)	62 mm Ø x 44 mm	800 g	2.11 keV	LBNL
LANL (MJ70)	72 mm Ø x 37 mm	800 g	2.15 keV	PHD's
ORNL (MJ60)	62 mm Ø x 46 mm	740 g	4-4.5 keV	PHD's
U. Chicago (BEGe)	"standard"	450 g	<2 keV	Canberra
LBNL (Mini-PPCs)	20 mm Ø x 10 mm	17 g		LBNL
ORNL (Big BEGe)	90 mm Ø x 25 mm	850 g	1.95 keV	Canberra

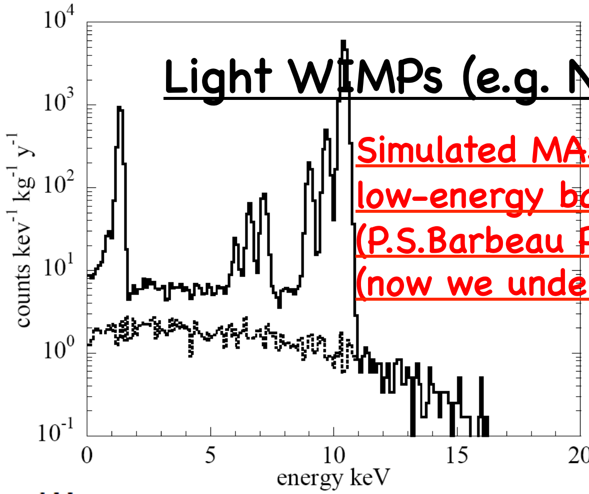
Move to modified commercial "BEGe" detectors (quasiplanar PPCs)

~30 PPCs already characterized and stored for 60kg MAJORANA demonstrator

Crystal storage underground

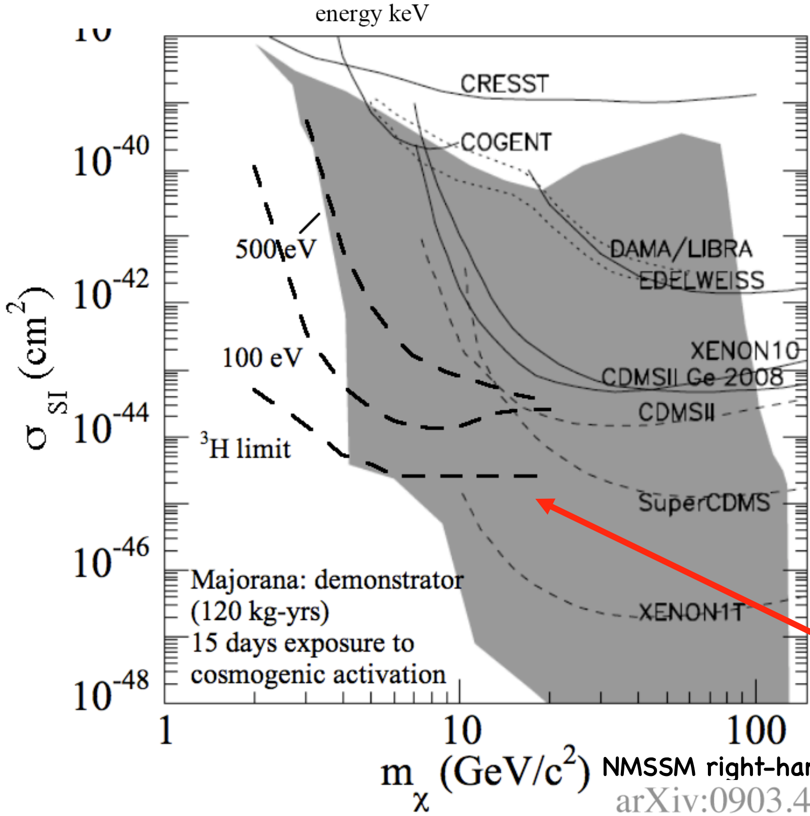
GERDA switching to PPCs for 2nd phase

MAJORANA as a DM detector



Light WIMPs (e.g. NMSSM)

Simulated MAJORANA-demonstrator low-energy backgrounds (P.S.Barbeau Ph.D. Diss.)
(now we understand these much better)

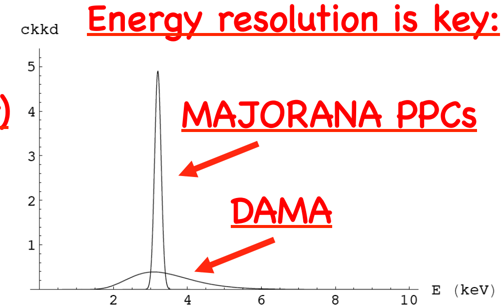


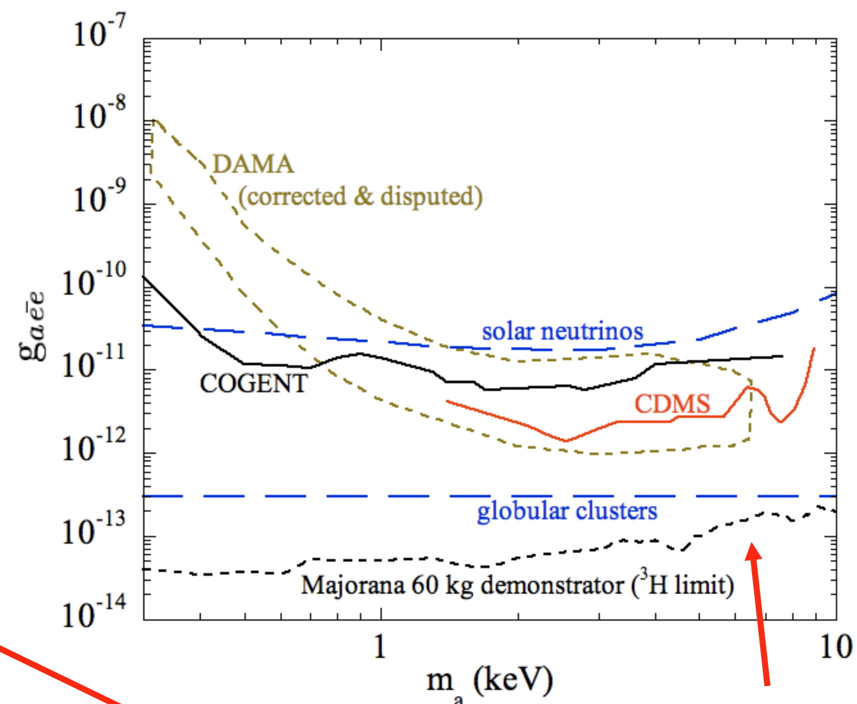
NMSSM right-handed sneutrino

arXiv:0903.4677v1

Pseudoscalars etc. (a.k.a."superWIMPs")

Energy resolution is key:



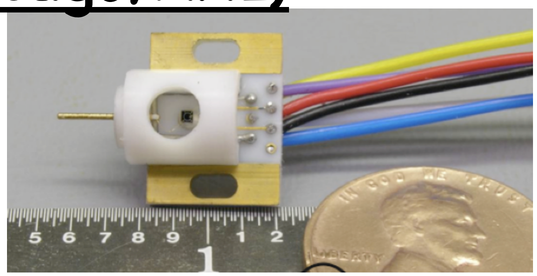


Possibility of reaching ^{3}H limit much nearer now with surface event rejection

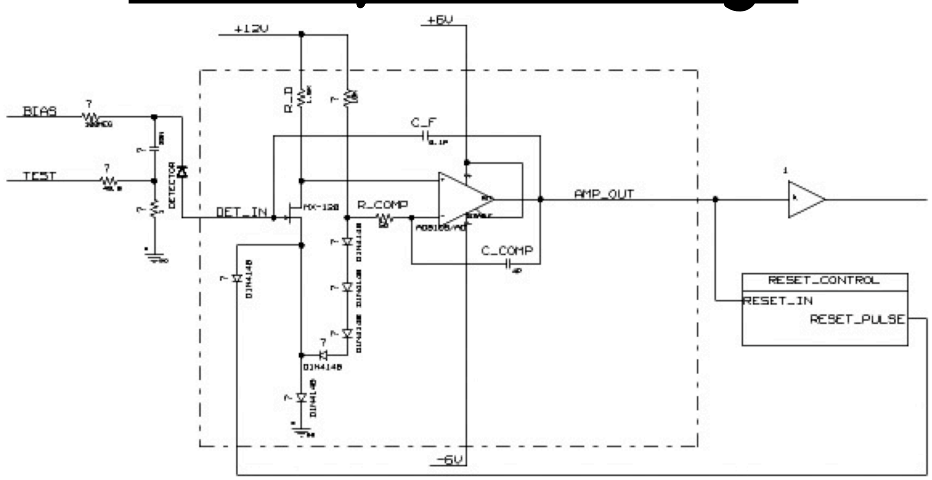
Front End Electronics (Majorana)

Pulse Reset

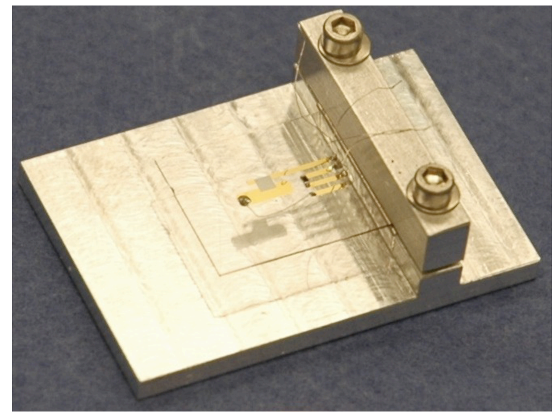
COGENT front ends (U Chicago/ANL)



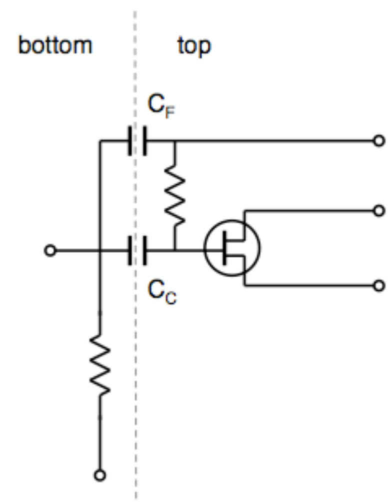
UW "Hybrid" Design



Resistive Feedback



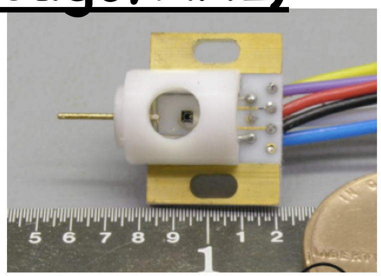
LBNL Design



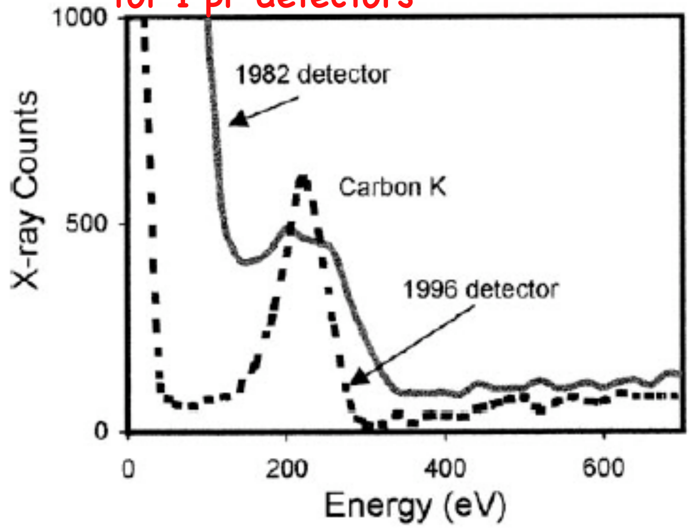
Front End Electronics (Majorana)

Pulse Rese

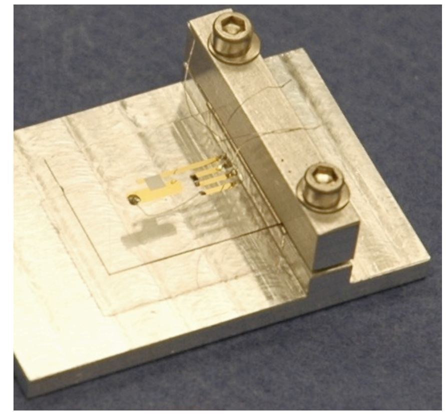
COGENT front ends
(U Chicago/ANL)

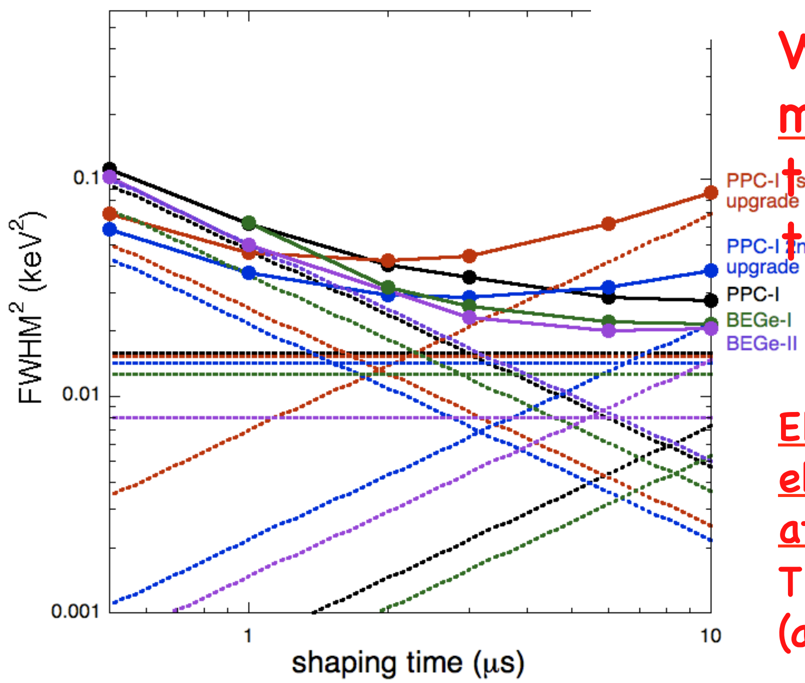


State-of-the-art
for 1 pF detectors



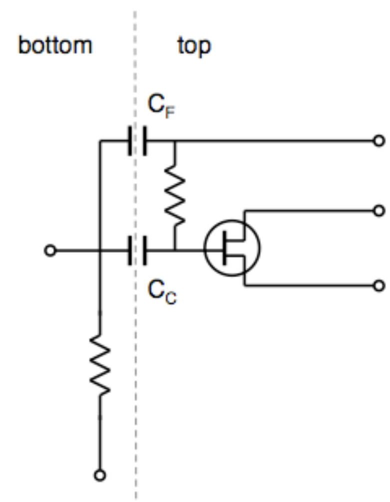
istive Feedback





We can do
much better
than 0.4 keV
thresholds

LBNL
Design

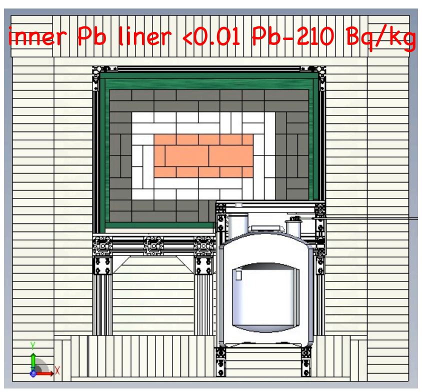


Electronic noise must be
eliminated
at the hardware level.
There is no other way around it
(arXiv:0806.1341)

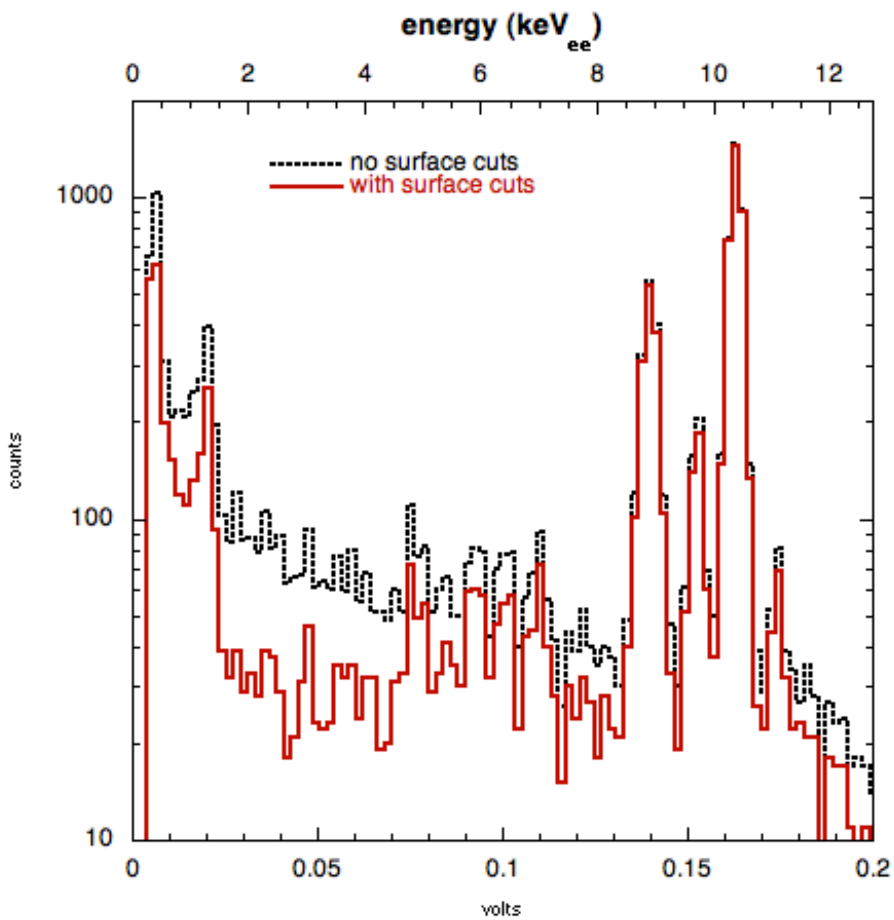
Making an excellent detector even better:
PPCs can reject surface events using rise time cuts

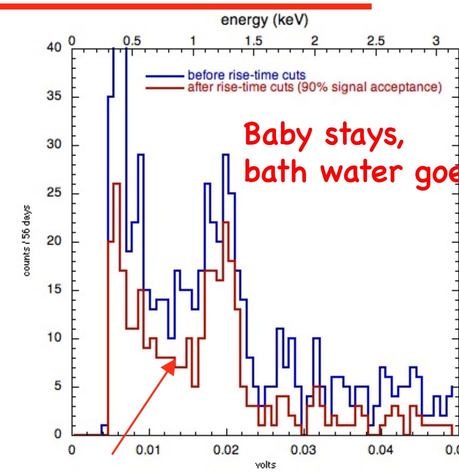
Based on a phenomenon ~40 years old (embarrasing!)

COGENT running
~20 m away from CDMS
(just to keep them honest… ;-)

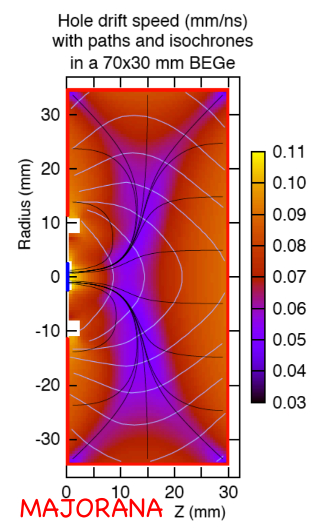


NOT nearly "best effort" yet.
MAJORANA Demonstrator
background goal is ~x1000 lower





Bulk signal acceptance
monitored down to 1 keVee
via L/K EC peak ratios and
pulser calibrations.
Working on characterizing
surface background rejection
(large exposure required).



MAJORANA
BEGe (ORNL simulation)

Charge
Collection
time
modelled
(small
100 ns
correction)

The "take-home message" transparency (pre-modulation)

• For m_χ ~7-11 GeV, a WIMP fits the data nicely (90% confidence interval on best-fit WIMP coupling incompatible with zero, good χ^2/dof).

• Red "island" tells you ~where to look (if you believe in WIMPs). Additional knowledge (e.g., more calibrations for fiducial volume and SA/BR) could wiggle it around some (so do the other regions shown, depending on who plots them).

• <u>Not a big deal on its own</u>, it simply means that our irreducible bulk-like bckg is ~exponential (the background model without a WIMP component fares just as well).

• We presently cannot find an obvious known source. <u>But we can fancy some unexplored possibilities</u>. It is not neutrons, and there is no evidence yet of detector contamination.

• The low-E excess is composed of asymptomatic <u>**bulk-like**</u> events (very different from electronic noise), coming in at a constant rate.

• <u>The possible subject of interest</u> is where we "got stuck" in phase space (a number of curious coincidences there), <u>for a spectrum where most (if not all) surface events are removed</u> (<- major contributors to low-energy spectrum). Caveat Emptor: without DAMA, would we have models there?

• We will attempt to strip the low-E data from known sources of background after a longer exposure, but all of them seem modest (see preprint). Planned additional calibrations will provide improved information on signal acceptance, background rejection and fiducial volume.

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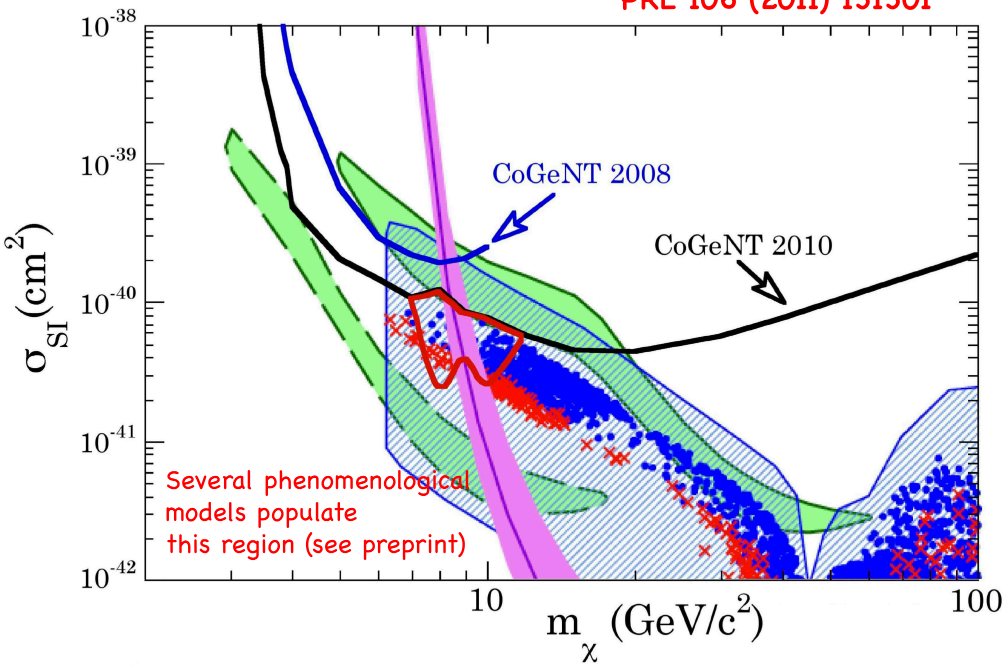
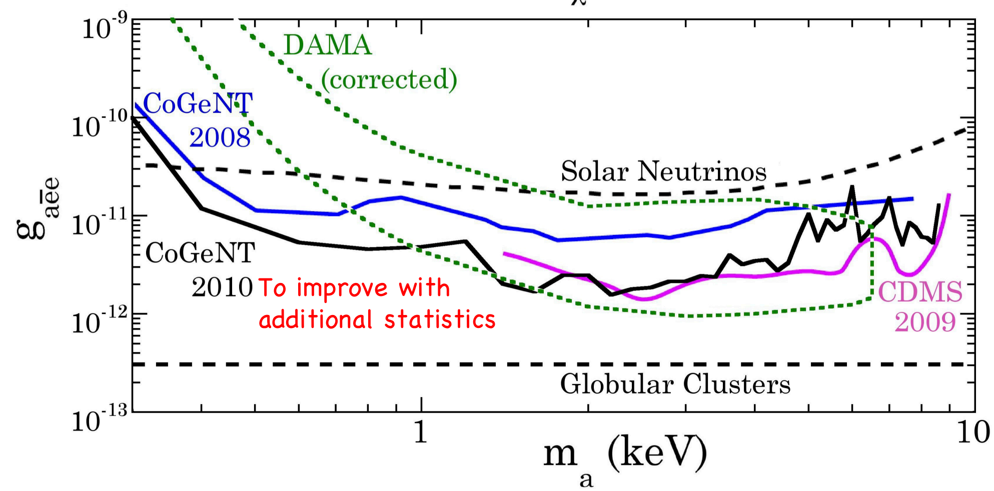
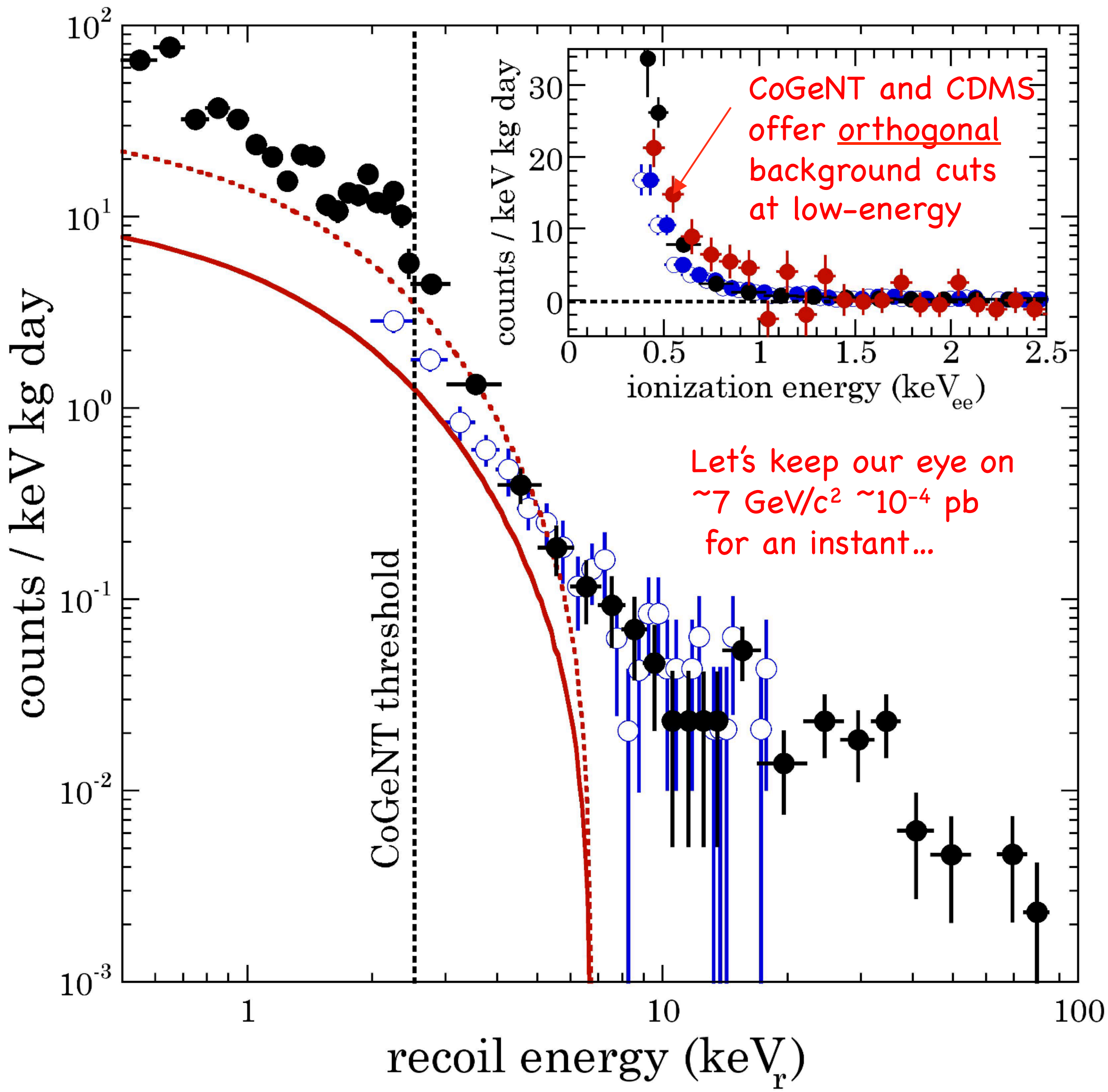




Can we make sense of the light-WIMP situation?

CDMS low-E recent results:



Critique (arXiv:1103.3481):

- Uncertainties in energy scale and method of calibration
- Uncertainties (and some clear WAGs) in background estimates
- Uncertainty in residual rate from cut selection: limits are mainly extracted from short exposure in a single detector (T1Z5). An alternative CDMS analysis during a different period in Soudan finds a ~70% larger irreducible rate for it, but not for a second detector.

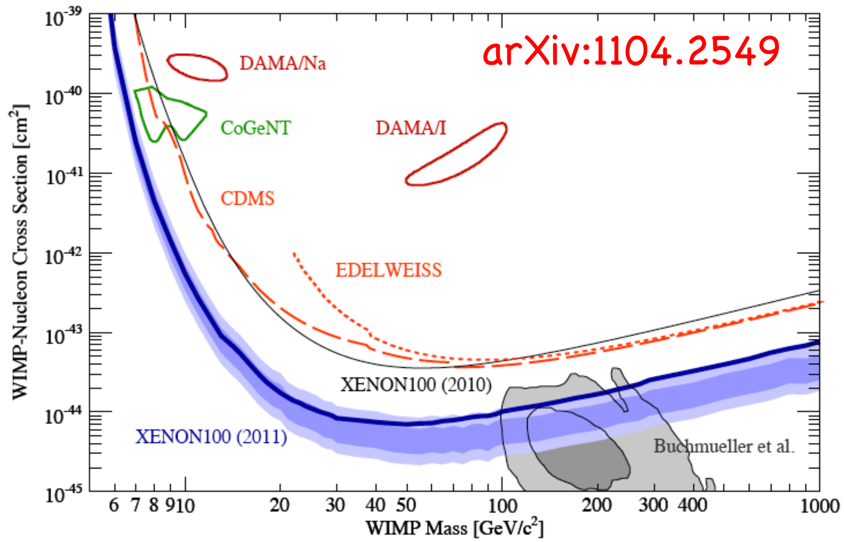
Is T1Z5 stable enough? What is the uncertainty in these limits from the choice of cuts?

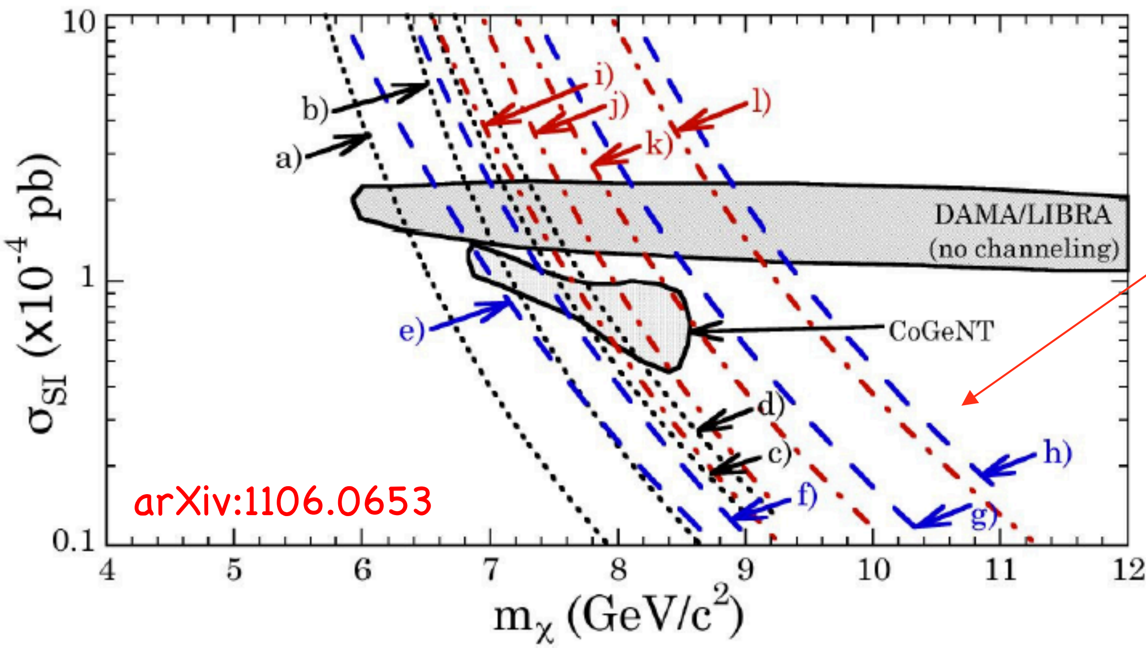
- Direct comparison of CoGeNT-CDMS irreducible spectra initially avoided (a much more straightforward indicator of relative sensitivity).

Can we make sense of the light-WIMP situation?

XENON-100 low-E recent results:

Compare these two figures:



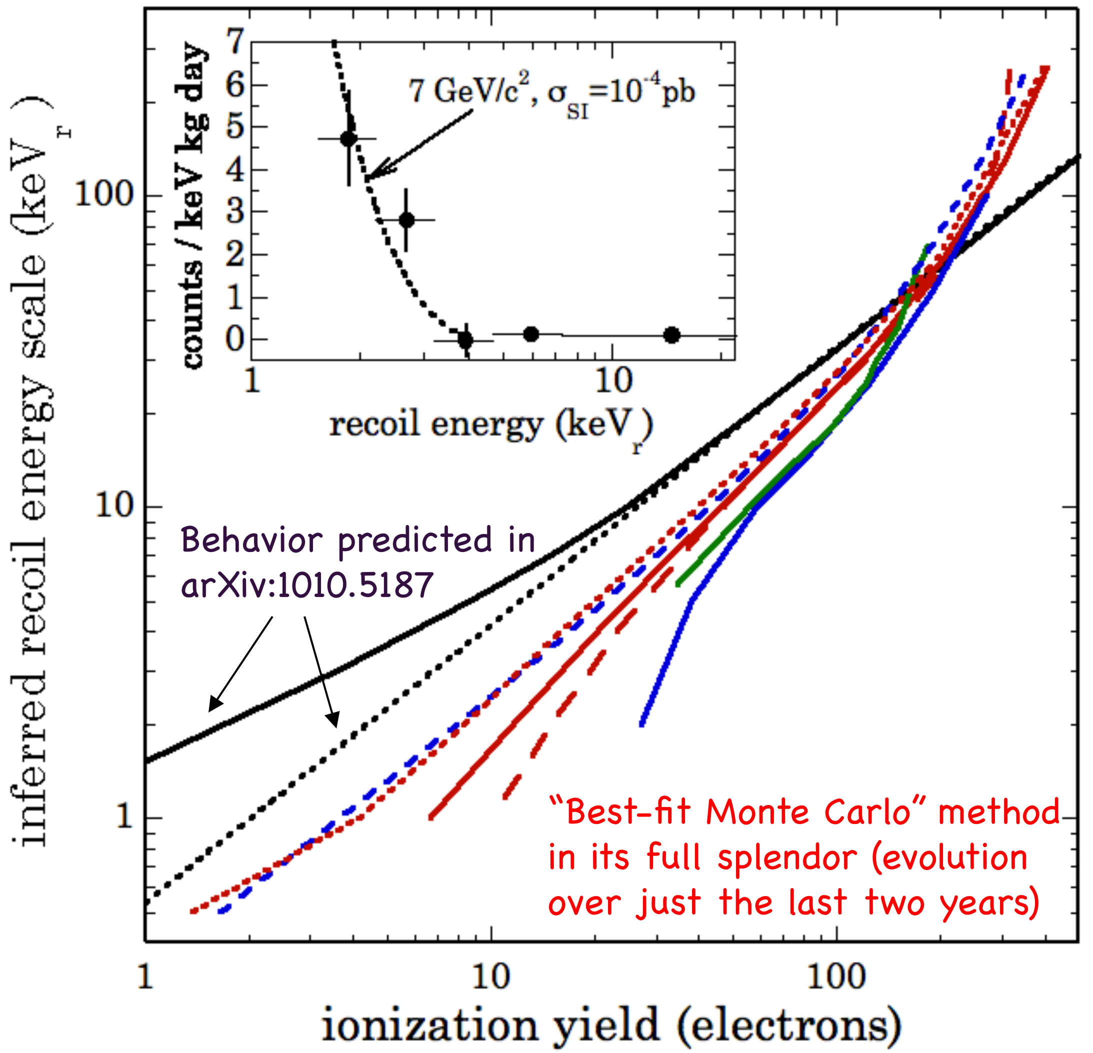


Critique (arXiv:1106.0653):

- Recent L_{eff} measurement represents progress, but still several important loose ends (energy resolution and L_{eff} **are not** independent magnitudes)
- Selective display of DAMA region (uncertainties not included)
- Issue with numerical calculation of uncertainties (does not pass self-consistency test –previous XENON100 results-)
- Discussion of uncertainties and strong assumptions made (Leff, second-guessed events, Poisson vs. sub-Poisson) broomed under the carpet.
- Most recent ZEPLIN-III L_{eff} (in situ measurement) still pointing at a vanishing value at few keV_r.

Can we make sense of the light-WIMP situation?

XENON-10 low-E recent results:

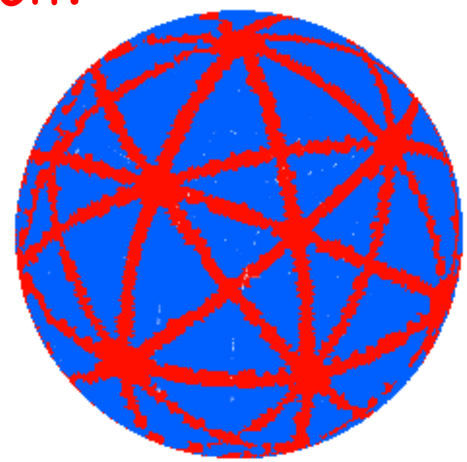


An additional ~1 keV shift in energy scale turns "robust exclusion" into "evidence" for a light-WIMP (hey, why stop now?)

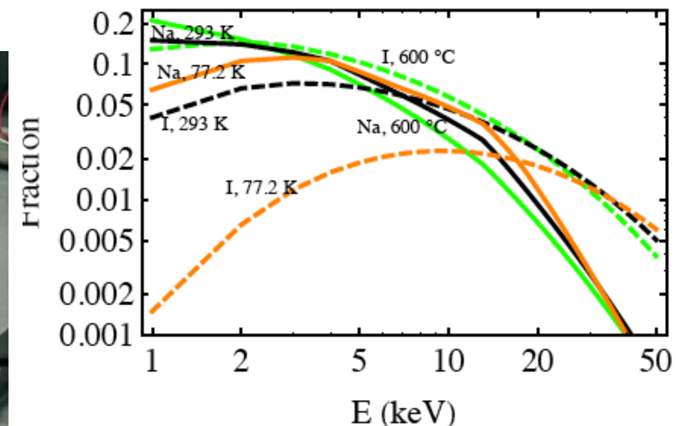
Critique (arXiv:1106.0653, 1010.5187):

- Very promising method.
- However, as is stands today: **pure drivel**
- Some entirely misleading statements about "interesting" population of low-energy events.
- Energy scale employed clashes (by ~three orders of magnitude) with existing measurements of ionization yield in very low-energy Xe ion-surface literature.
- Seems like some XENON10 authors do not mind contradicting themselves. Continuously.
- No excuse for this (this energy scale can be measured via (n_{th},γ) calibrations in the relevant range)

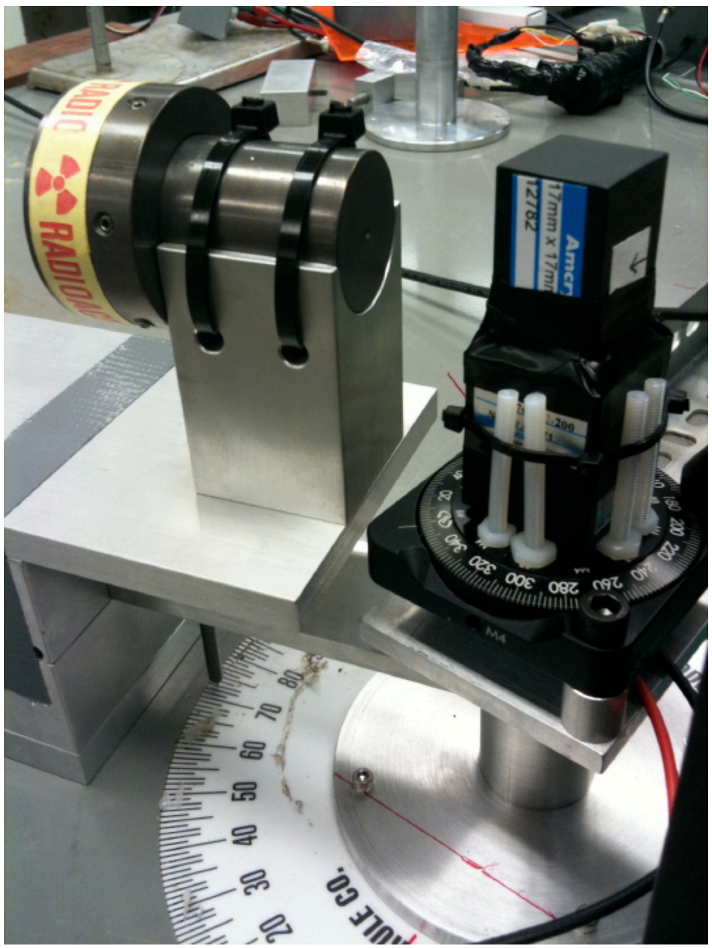
Can we make sense of the light-WIMP situation?



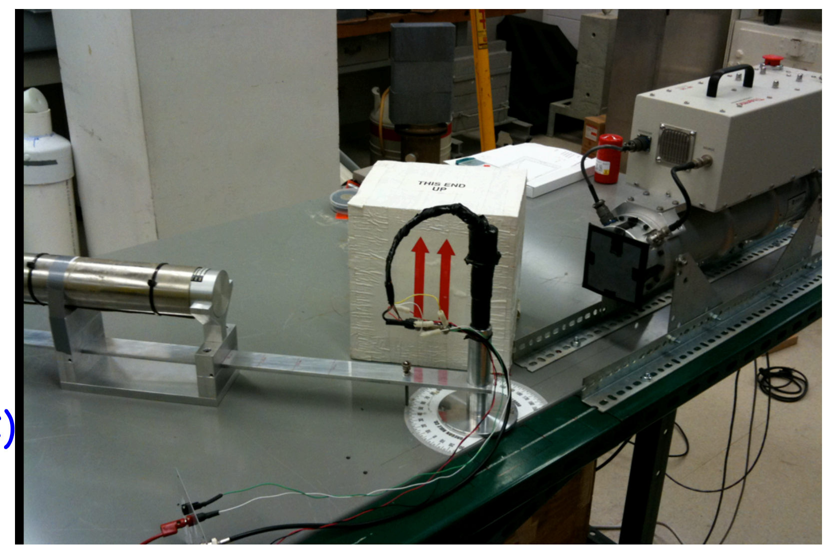
- Ongoing precision measurements of CsI[Na] and NaI[Tl] quenching factor and CHANNELING at UC to cast light on effects of methodology, kinematic cutoff, etc.



Bozorgnia, Gelmini & Gondolo
arXiv:1006.3110v1



Simultaneous measurements of electron (Compton) recoil energy and nuclear recoil energy for CsI[Na], and NaI[Tl] (ongoing work at UC)



Can we make sense of the light-WIMP situation?

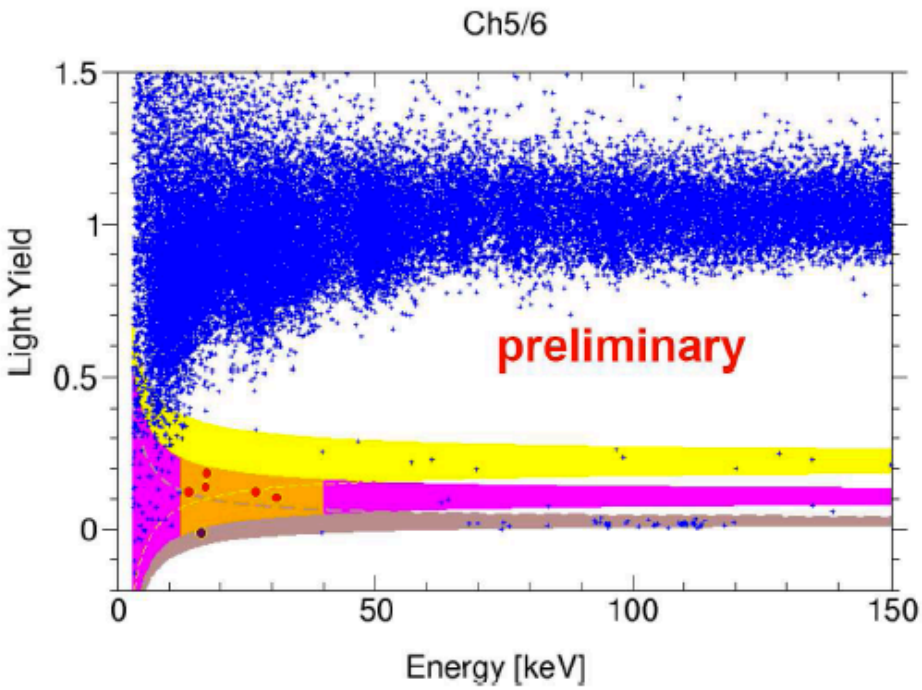
These figures ~1 year old,
Recent update: 20 irreducible recoils in excess over bckgs (after much studying of those), 4.6σ claim?
Word in the street: paper around time of TAUP2011.

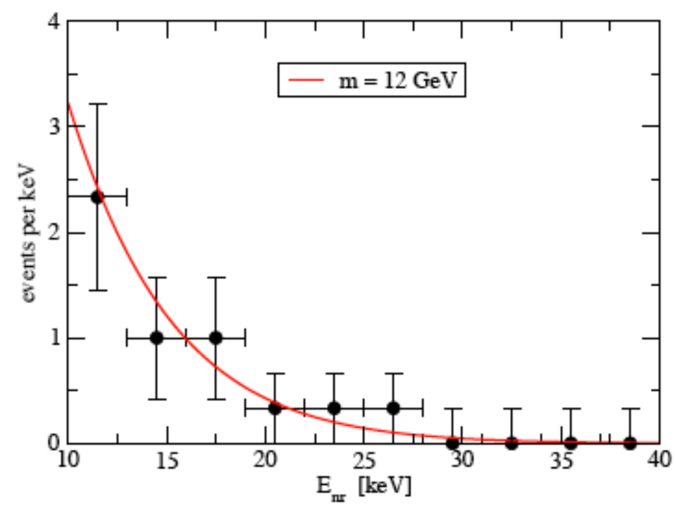
CRESST-II

Talk by W. Seidel @ WONDER 2010, March 22 to 23

$CaWO_4$ target, 9 detectors, about 400 kg d

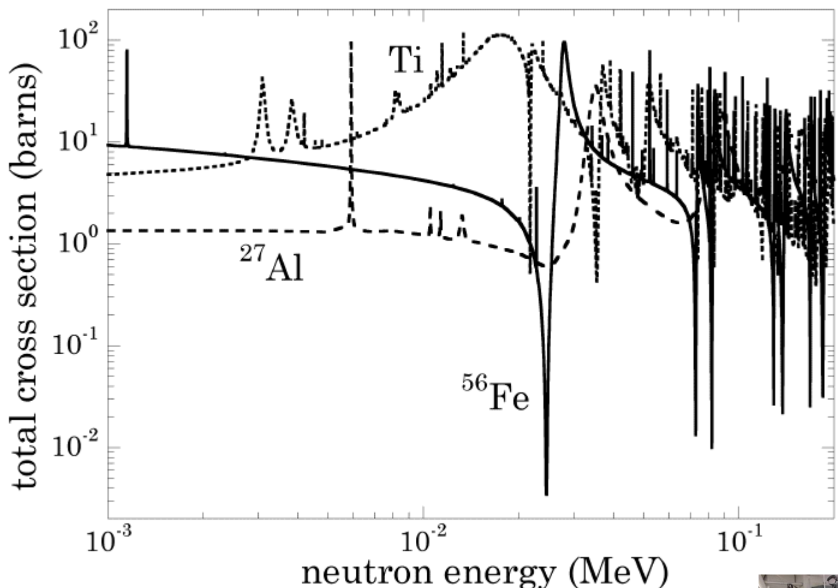
excess of single-scatter events in O-band (magenta)



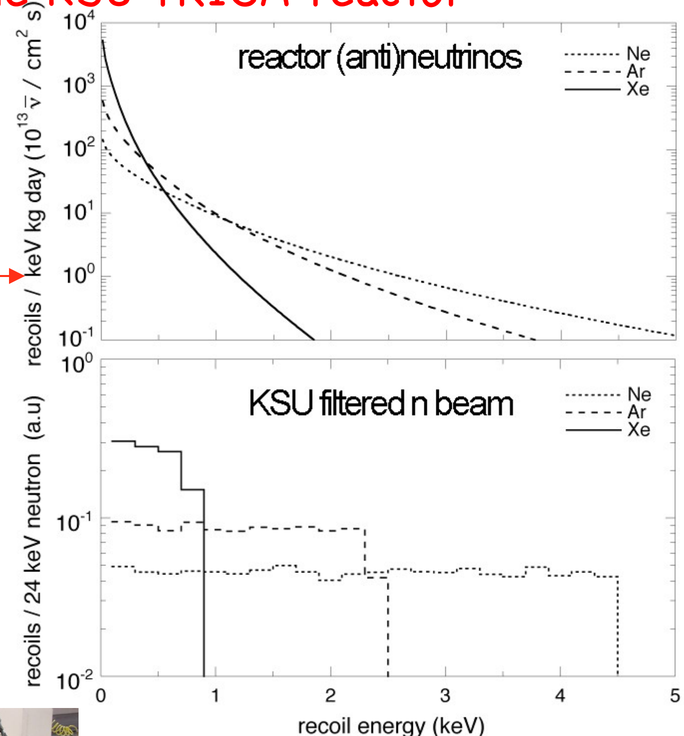


shape agrees with ∼ 10 GeV WIMP

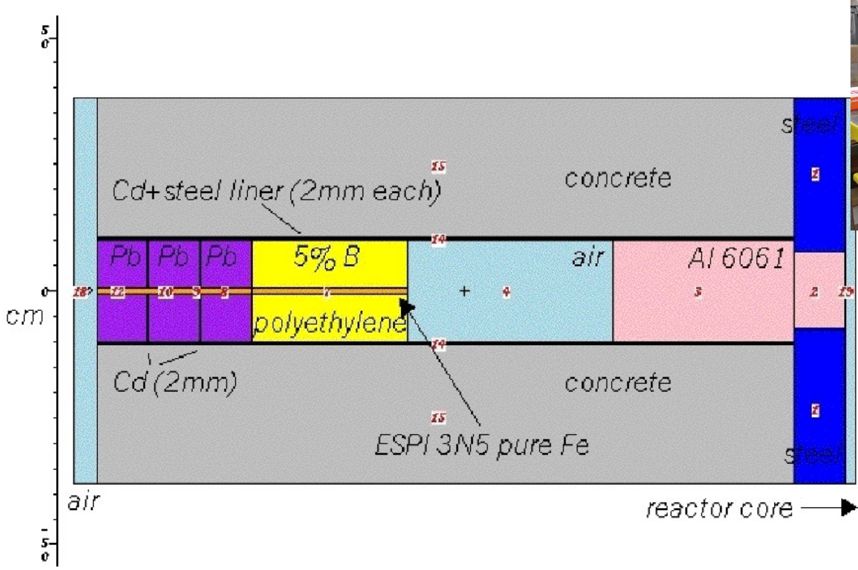
One should always start with the foundations: sub-keV recoil calibrations at the KSU TRIGA reactor



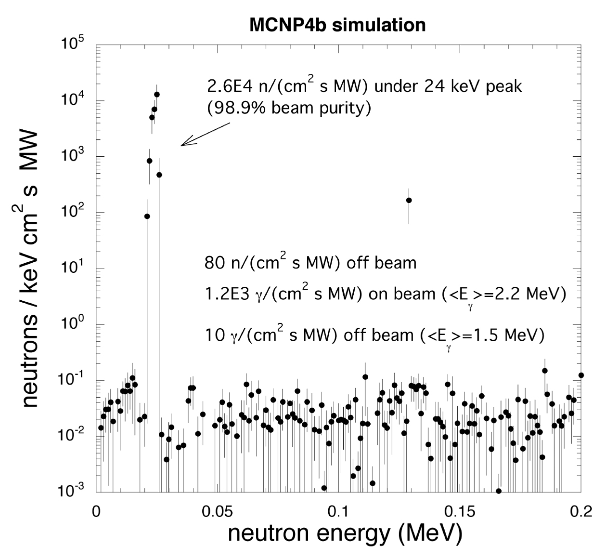
24 keV n's mimic reactor ν's →



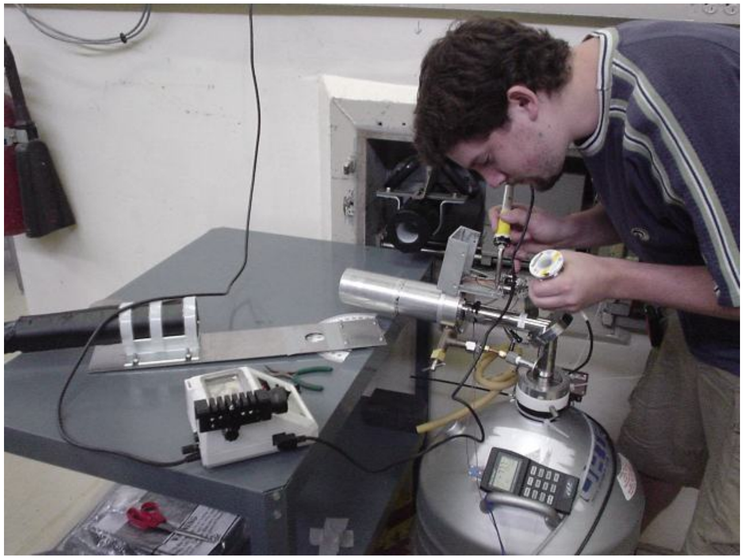
← Fe-Al filter + Ti post-filter

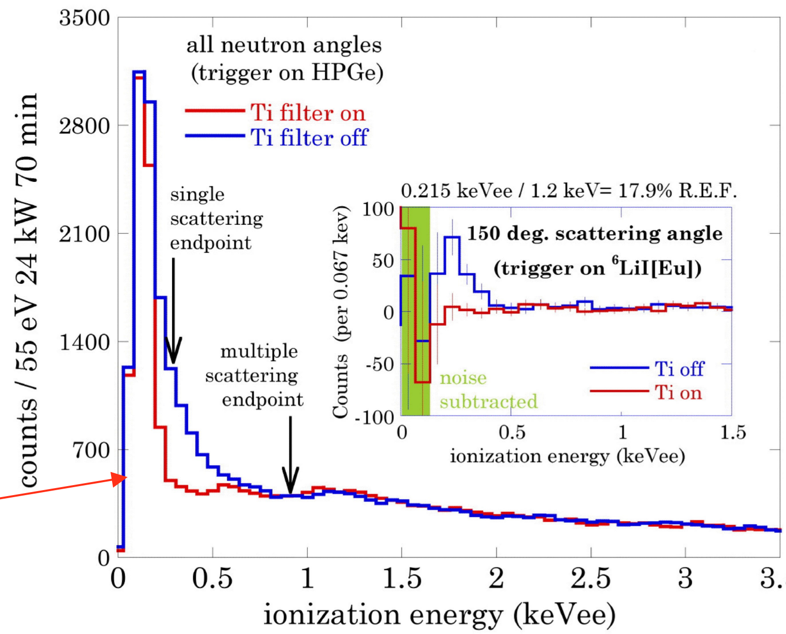


← MCNP filter design →

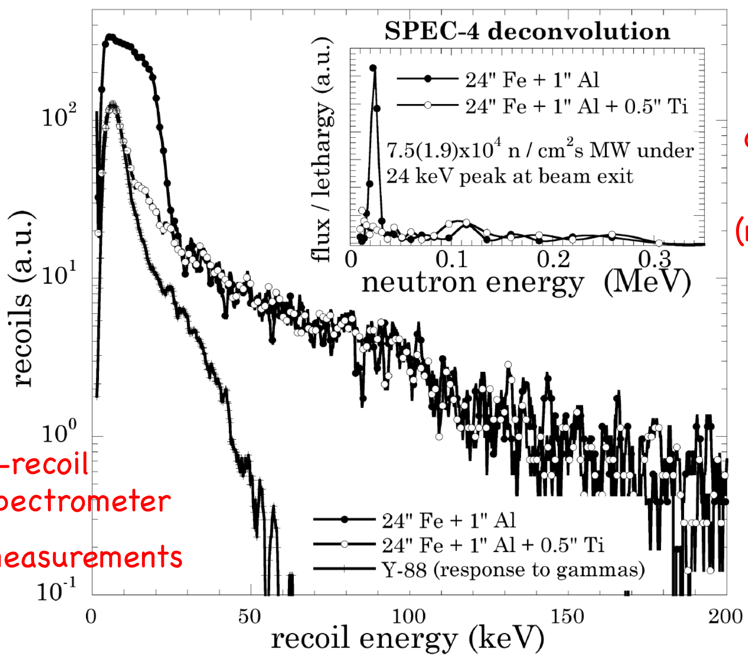


One should always start with the foundations:
sub-keV recoil calibrations at the KSU TRIGA reactor





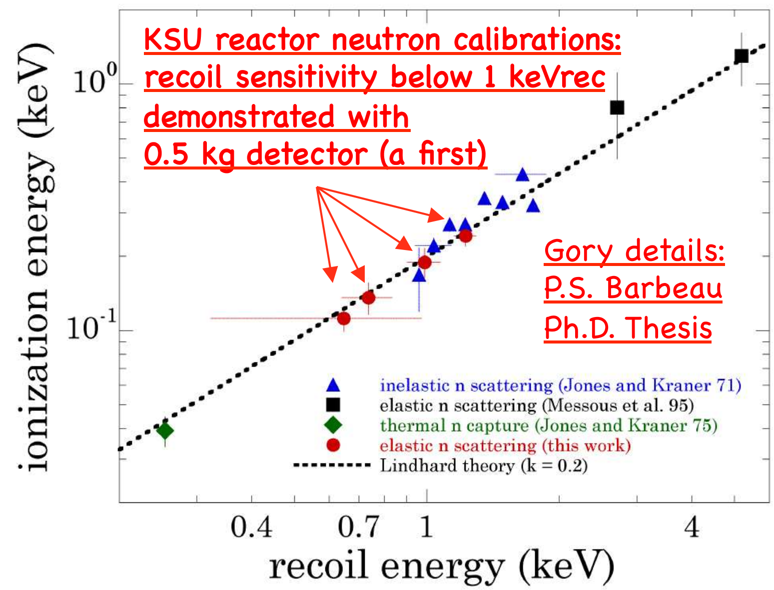
Ti post-filter "switches off" the recoils, leaving all backgrounds unaffected



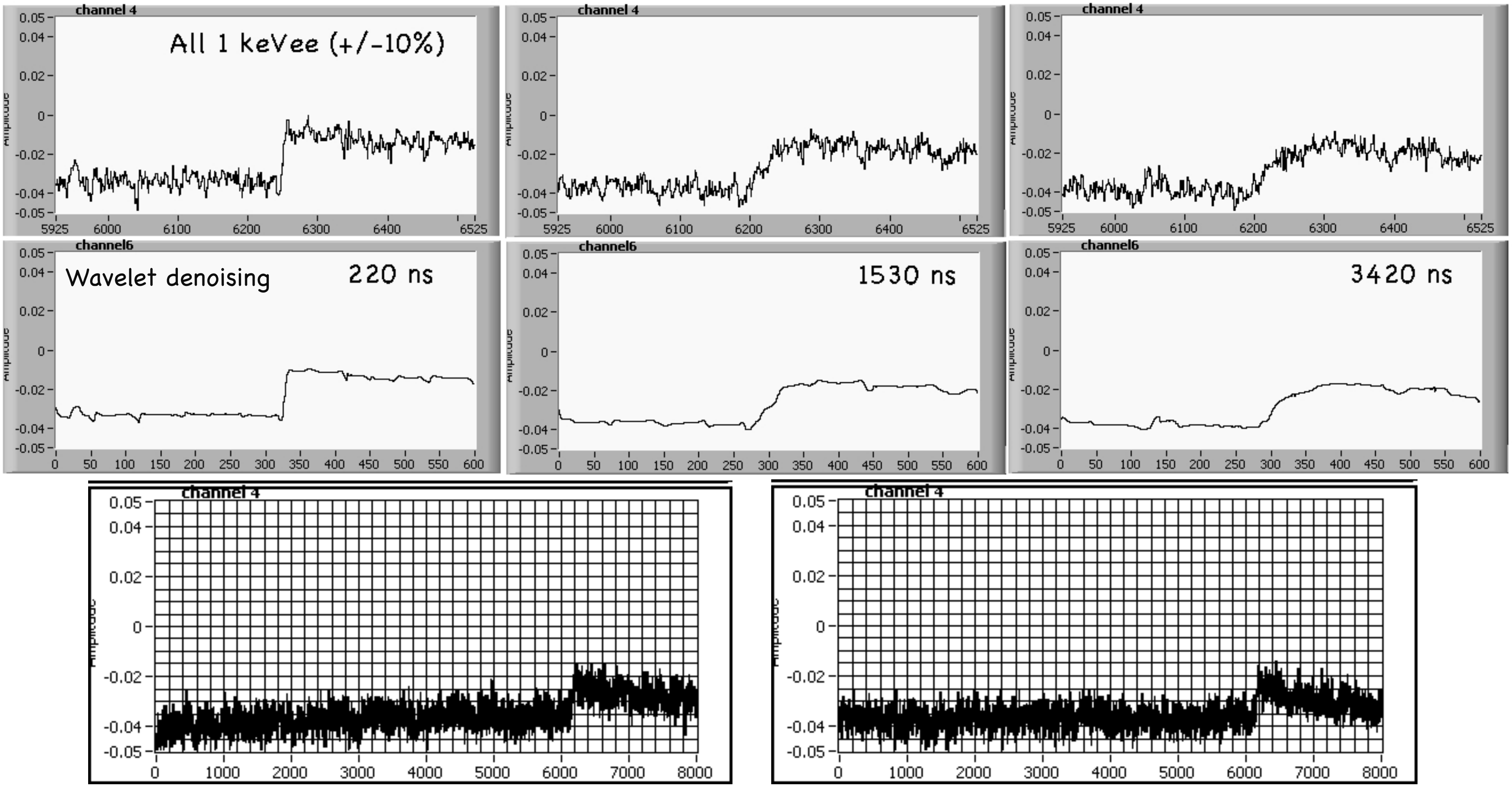
p-recoil spectrometer measurements

Beam characterization studies

(nucl-ex/0701011)



Healthy pulses, all the way down to 0.5 keVee threshold
(electronic noise = one thing the CoGeNT "excess" is not)



0.53 keVee before wavelet denoising

0.55 keVee before wavelet denoising

(full traces are 400 μs long, allowing baseline monitoring)

CoGeNT: must keep looking for non-exotic explanations

It is possible to come up with *MANY* natural explanations, however none yet satisfactory.

A PPC-based 60kg MAJORANA demonstrator would see annual mod. not just in rate, also in <E>.

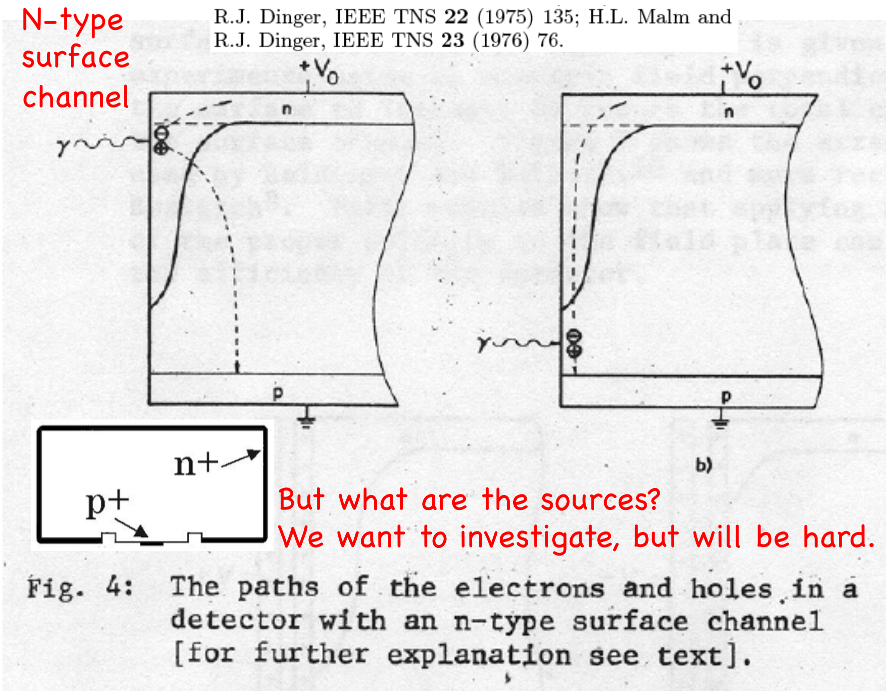
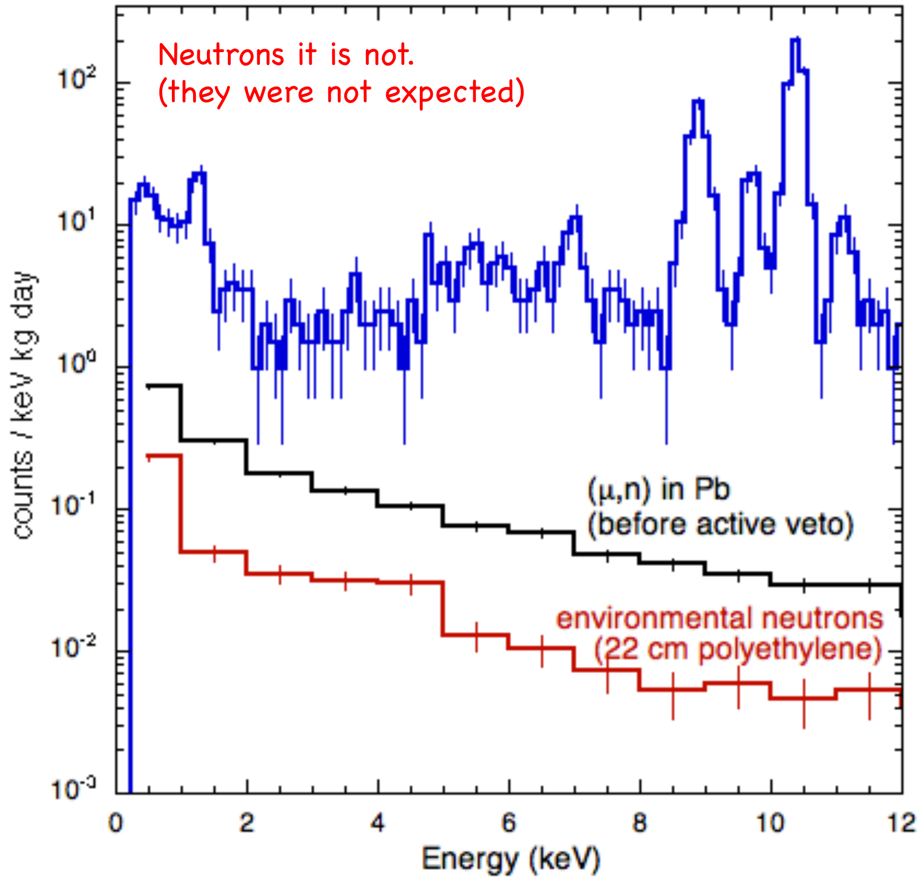
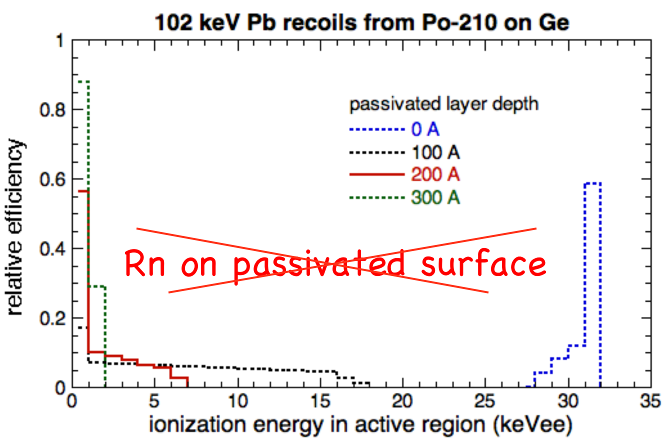


Fig. 4: The paths of the electrons and holes in a detector with an n-type surface channel [for further explanation see text].





~~Neutrons~~

~~Microphonics~~

~~Excess electronic noise~~

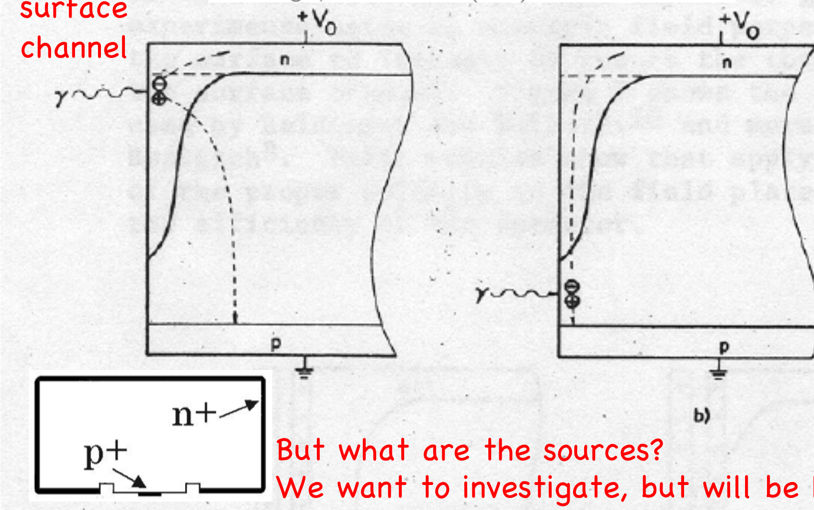
CoGeNT: must keep looking for non-exotic explanations

It is possible to come up with *MANY* natural explanations, however none yet satisfactory.

A PPC-based 60kg MAJORANA demonstrator would see annual mod. not just in rate, also in <E>.

N-type surface channel

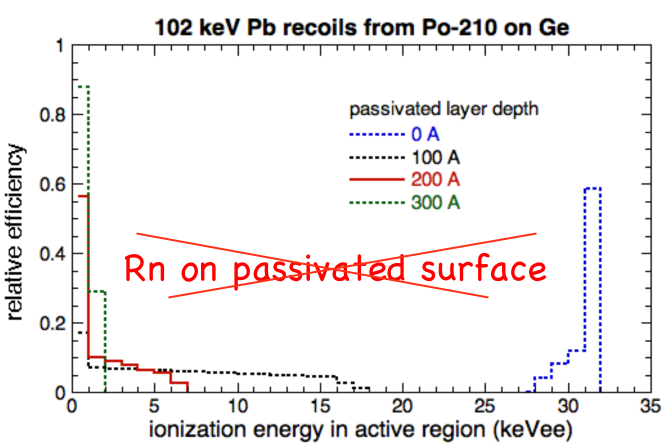
R.J. Dinger, IEEE TNS **22** (1975) 135; H.L. Malm and R.J. Dinger, IEEE TNS **23** (1976) 76.

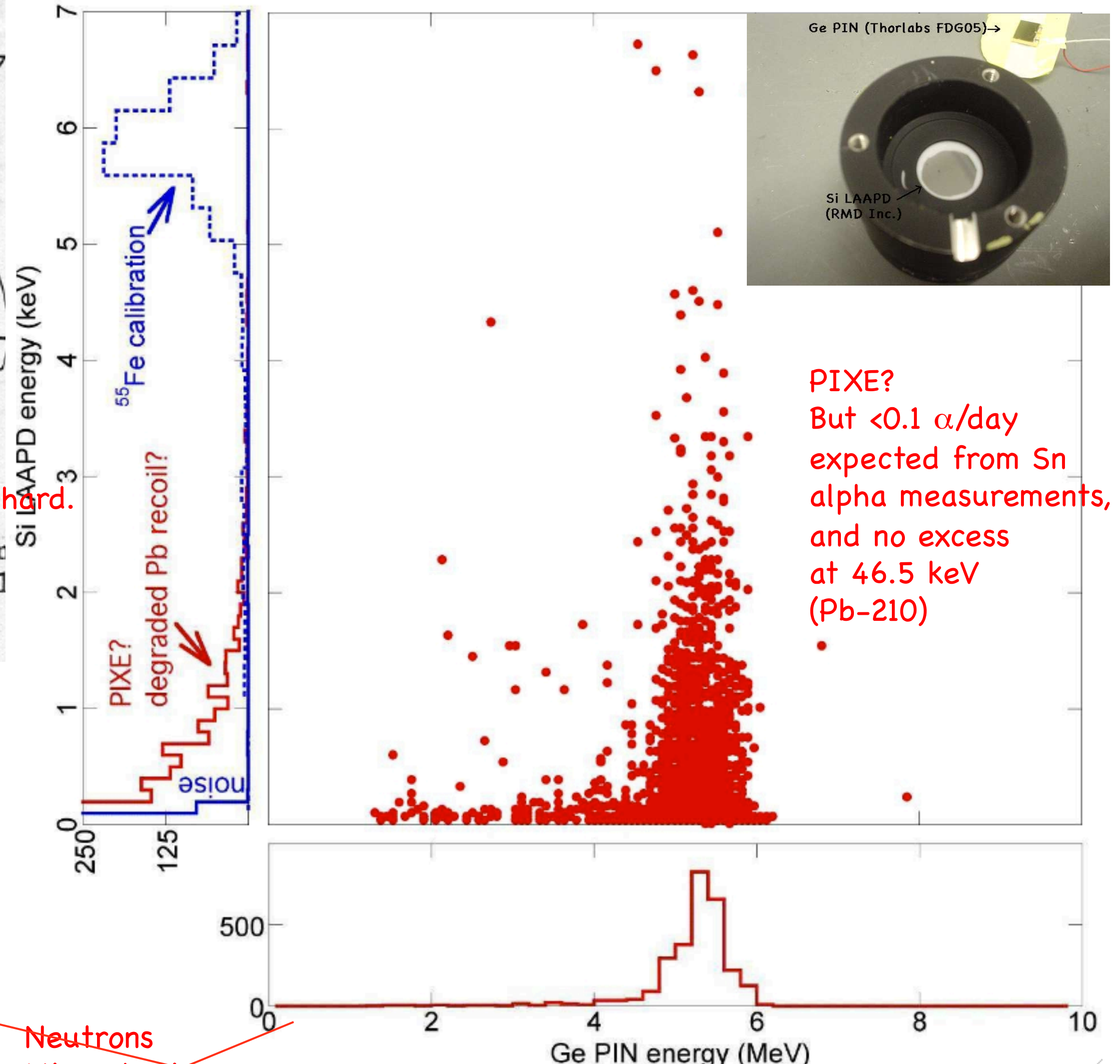


But what are the sources?

We want to investigate, but will be hard.

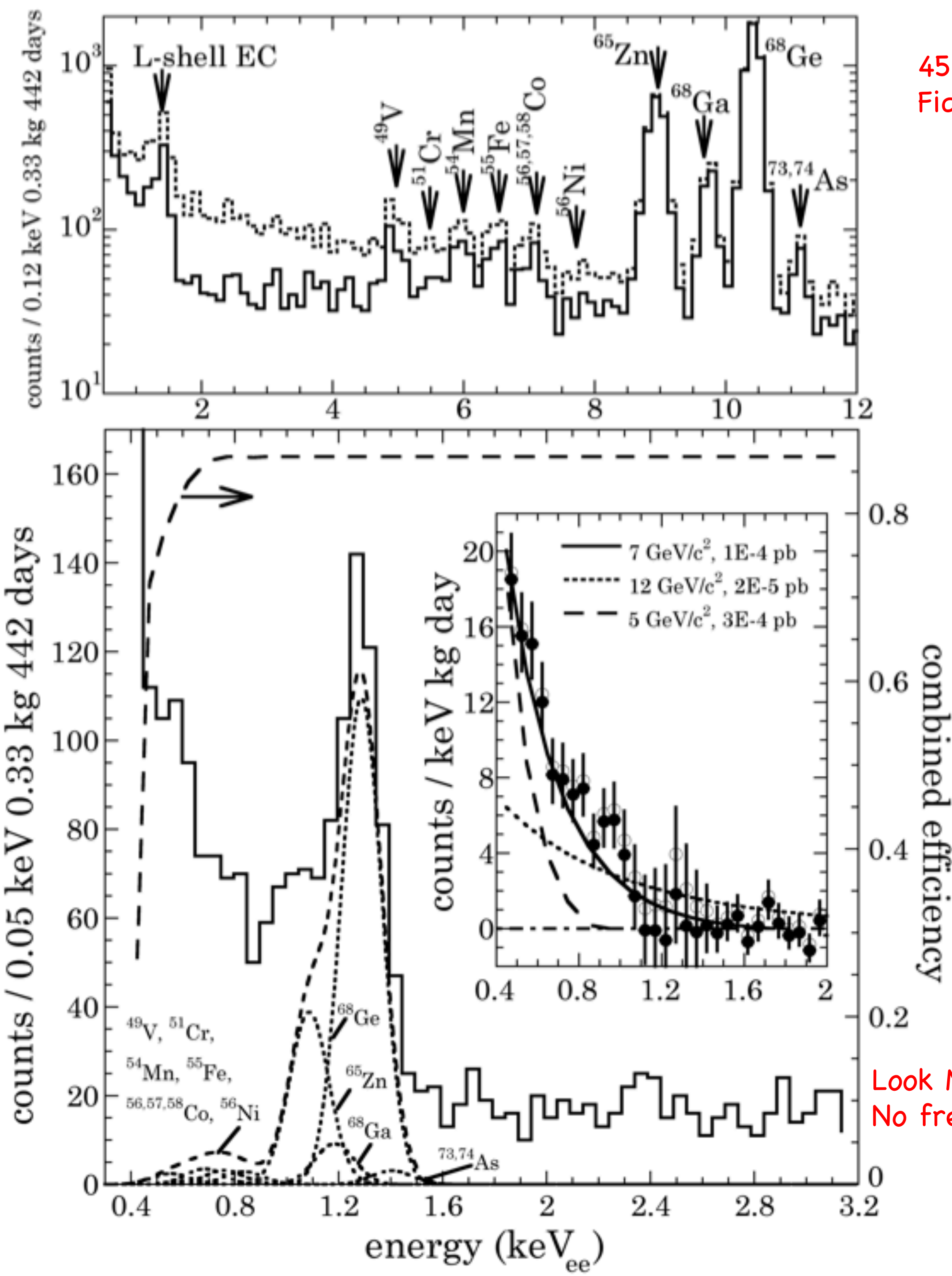
Fig. 4: The paths of the electrons and holes in detector with an n-type surface channel [for further explanation see text].





Neutrons
Microphonics
Excess electronic noise

Everything was going well until March 17th (Soudan fire)...



458 days collected (442d live)
Fiducial mass~330 grams

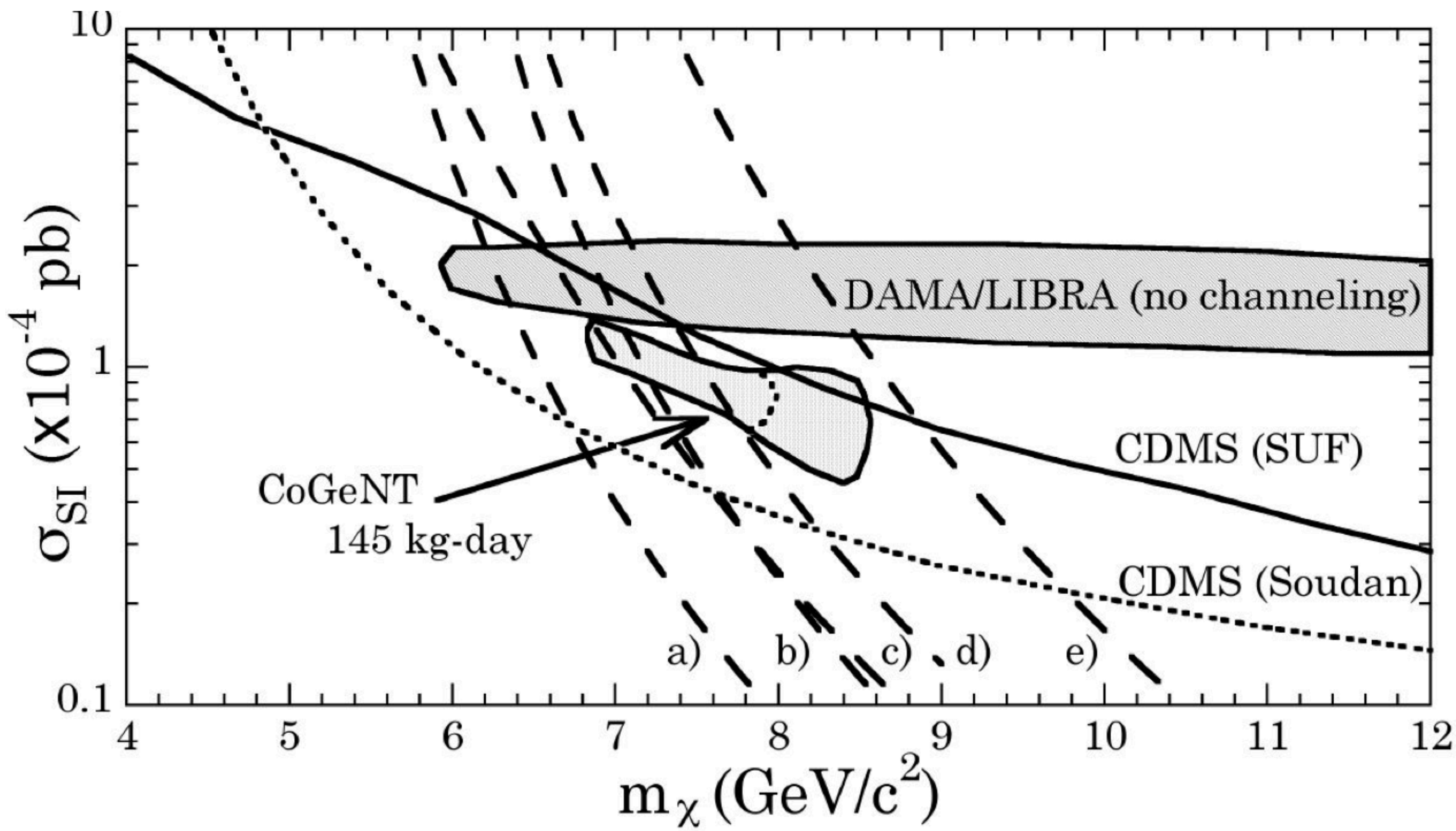
Look Ma!
No free-parameters!

JOHN N. BAHCALL PHYSICAL REVIEW VOLUME 132, 1963

TABLE IV. Comparison of theoretical and experimental L/K capture ratio.

Isotope	$\left(\frac{g(2s')}{g(1s')}\right)^2$	Usual theoretical ratio [Eq. (13)]	Exchange-corrected ratio [Eq. (4)]	Observed ratio	Number of precision experiments
Ar^{37}	1.006	0.0820	0.099	0.100 ±0.003	4
Cr^{51}	1.014[a]	0.0882	0.101	0.1026 ±0.0004	1
Mn^{54}	1.020	0.0898	0.102	0.098 ±0.006	1
Fe^{55}	1.051	0.0936	0.106	0.106 ±0.003	2
Co^{57}	1.017	0.0915	0.103	0.099 ±0.011	1
Co^{58}	1.008	0.0907	0.102	0.107 ±0.004	1
Zn^{65}	1.041[a]	0.0970	0.108	0.119 ±0.007	1
Ge^{71}	1.083	0.103	0.114	0.1175 ±0.002	2
Kr^{79}	1.021[a]	0.102	0.111	0.108 ±0.005	1

Everything was going well until March 17th (Soudan fire)...

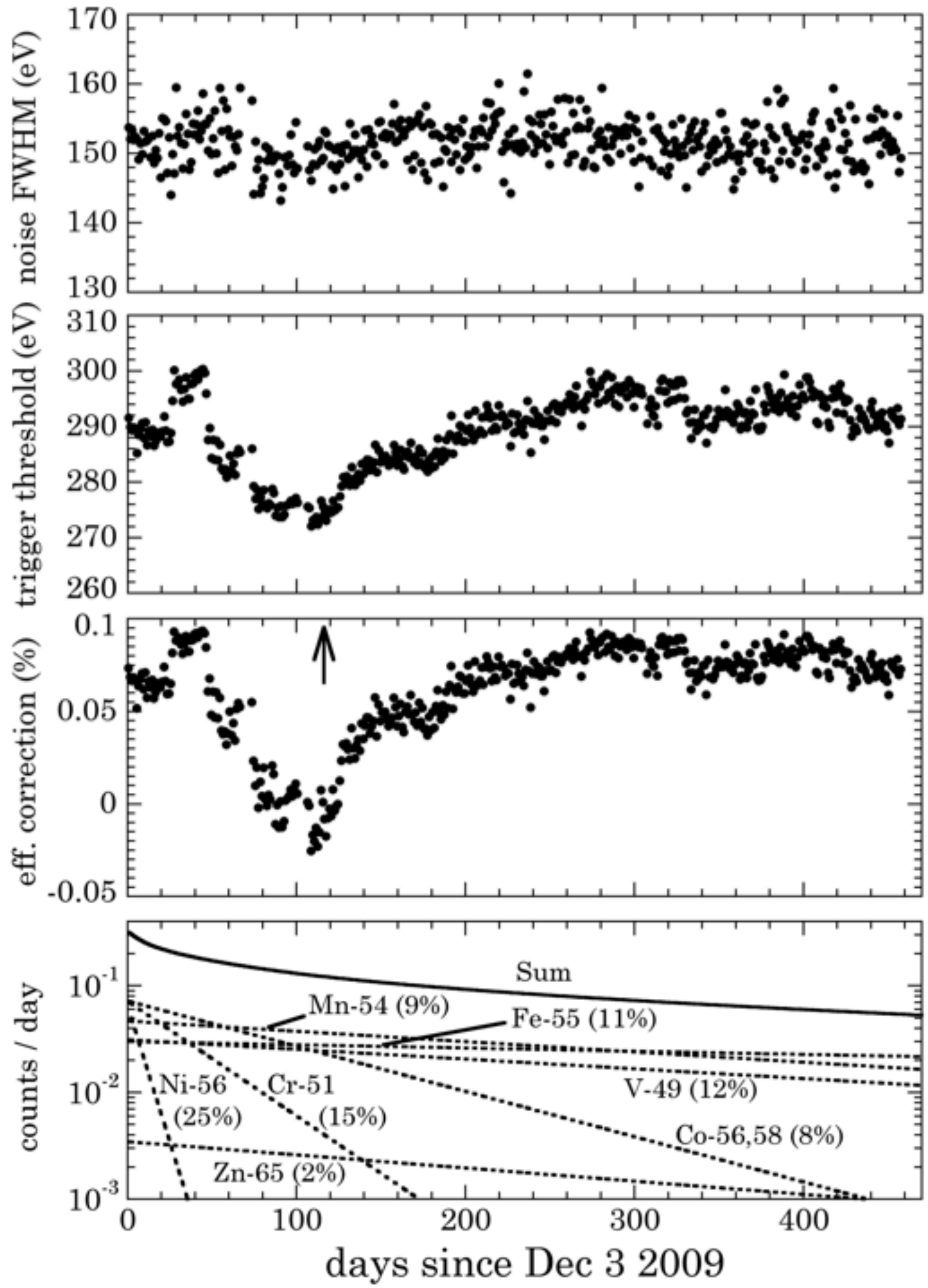


- CoGeNT region considerably smaller than before (but within previous ROI), next to DAMA.

- Most CoGeNT uncertainties not included in this figure

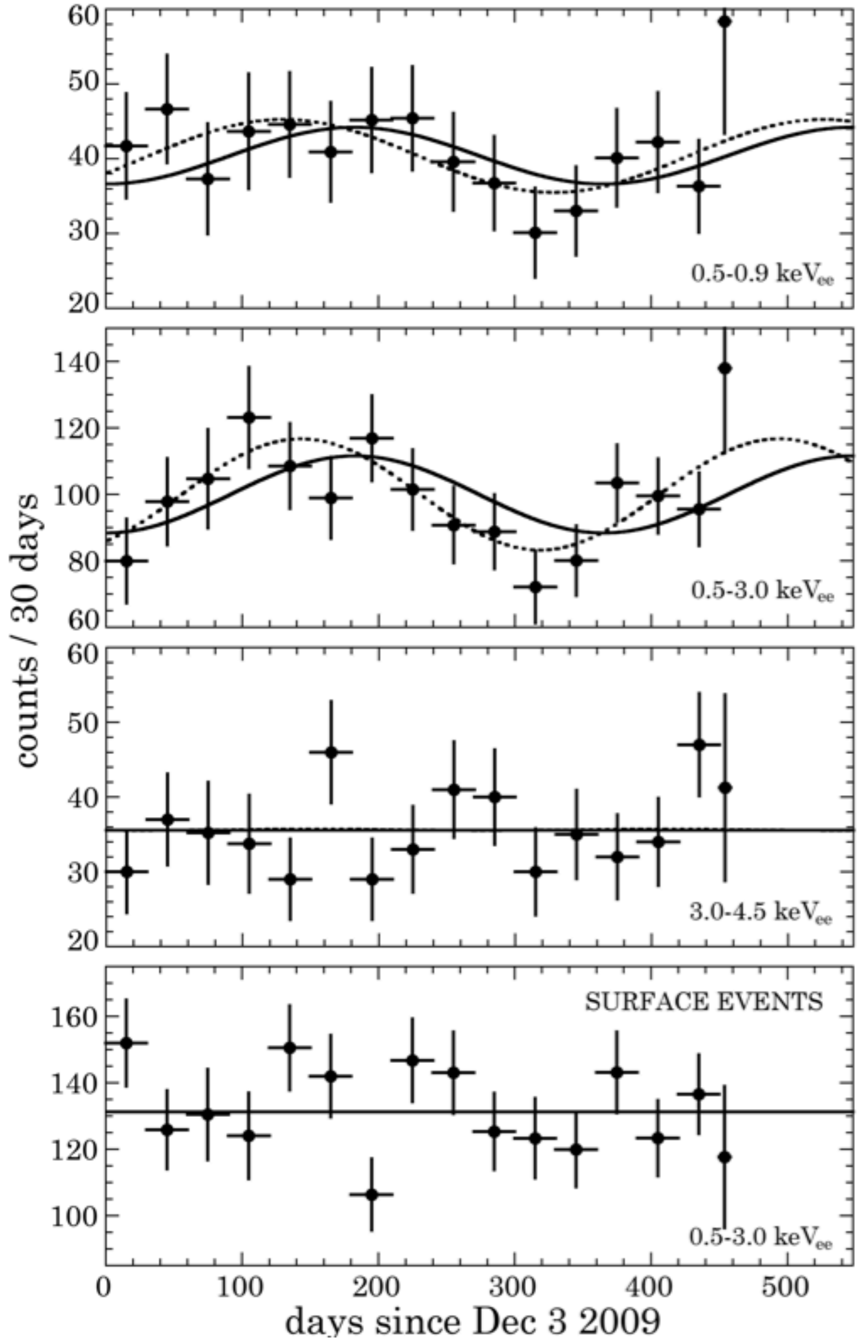
Remember that ~7 GeV/c^2, 10-4 cm^2 light WIMP we mentioned in discussing CDMS?

Everything was going well until March 17th (Soudan fire)...



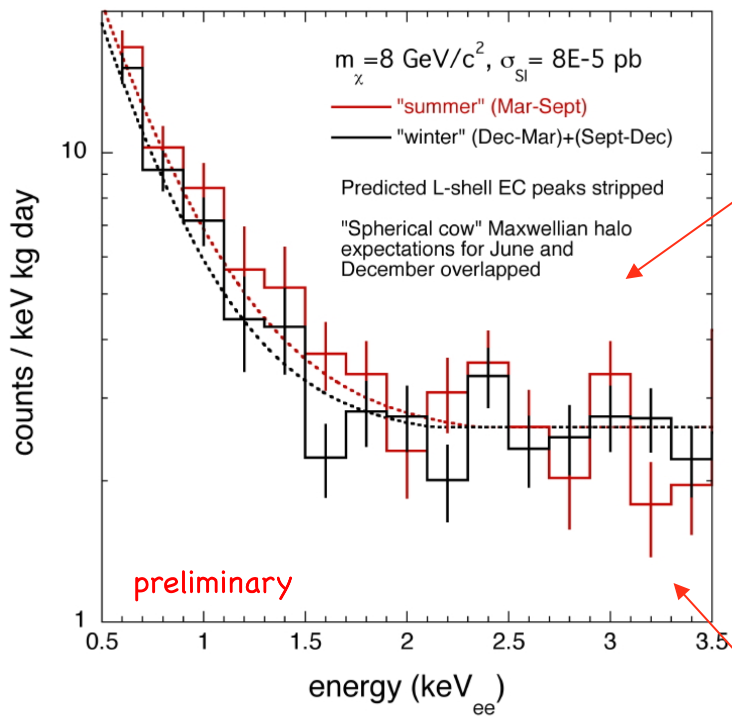
- Excellent stability in detector noise and trigger threshold allows search for annual modulation. Augurs well for other PPC-based searches.
- L-shell peak correction necessary, but prediction is very robust and uncertainties small.

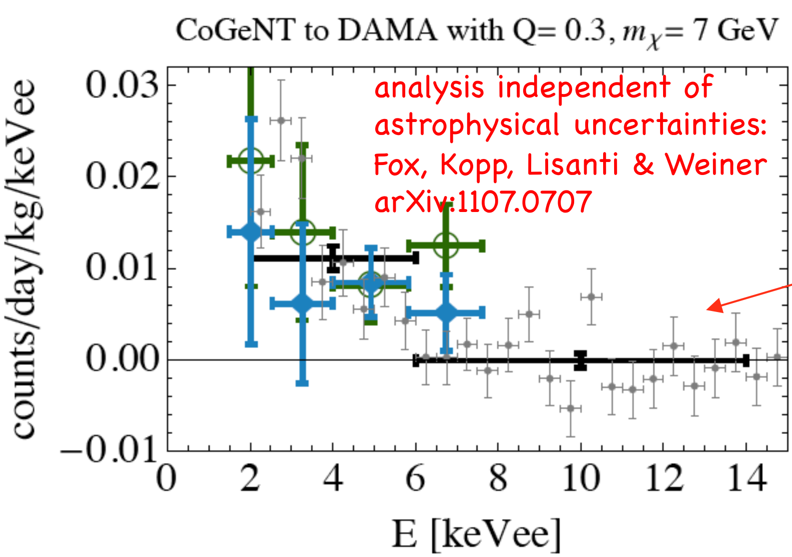
Everything was going well until March 17th (Soudan fire)...



- No fancy estimators tried (several available). Two basic unoptimized methods point at ~2.8σ preference of a modulated rate over the null hypothesis.
- Compatible with WIMP hypothesis expectations (amplitude, phase, period).
- Spectral and temporal analysis are *prima facie* congruent with a light-WIMP hypothesis.
- Modulation absent for surface events and also at higher energies.
- Lots of independent interpretations via data-sharing, but a few are forgetting some basics. Hint: there must be reasons for the experimentalists to include an exponential background in their models...

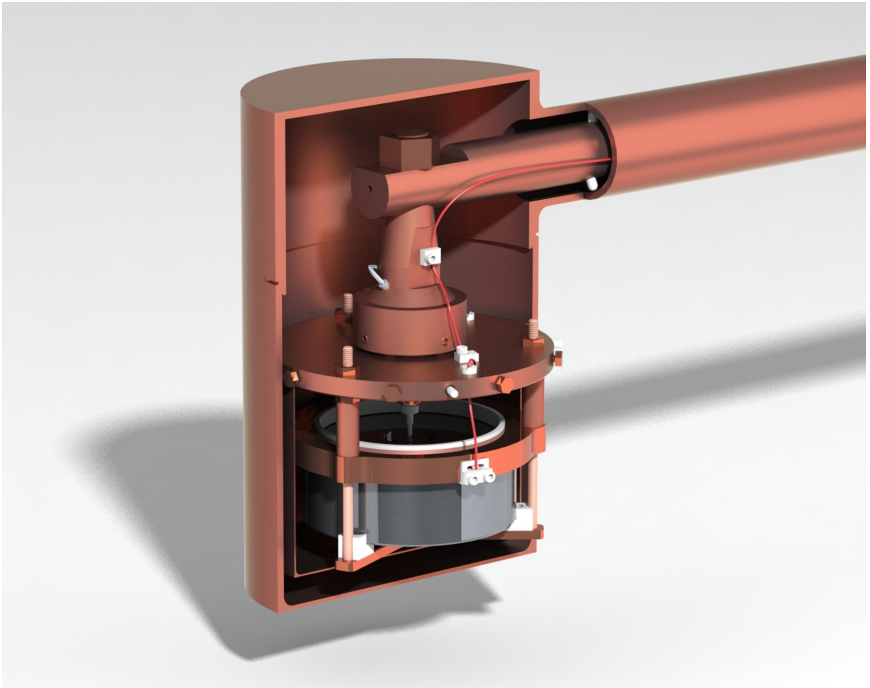
Are DAMA, CoGeNT and (rumored) CRESST in agreement or not?





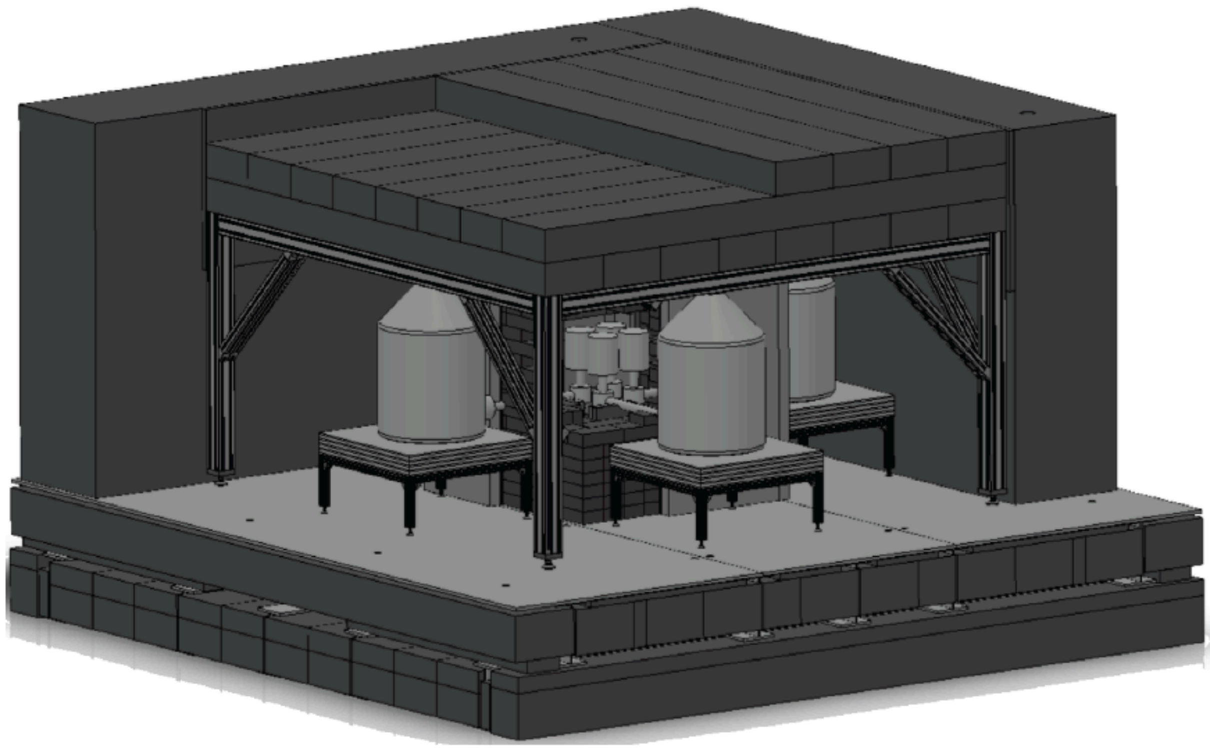
- What is the exact endpoint of the CoGeNT modulation (hard to tell w/ 15 mo)
- Some surface background contamination next to threshold? (analysis possible now with sufficient statistics) -> shifts CoGeNT ROI to lower coupling and larger mass.
- Channeling at few %? Contemplated by some models, if you read papers carefully. We'll know soon (experimentally). Idem for value of Q_{Na}.
- CoGeNT modulation larger than expected? (again, hard to tell after just 15 mo). If so, what happens to the DAMA ROI? Is a non-Maxwellian halo imperative?
- Most importantly, CoGeNT is now taking data again… (perhaps we should wait to see what happens next there before asking so many q's…)

UC/PNNL design CoGeNT-4 (C4)



Aiming to reduce parallel-f noise (and improving backgrounds).

Roughly 10 times present target mass (annual modulation)



Expected start summer 2011.

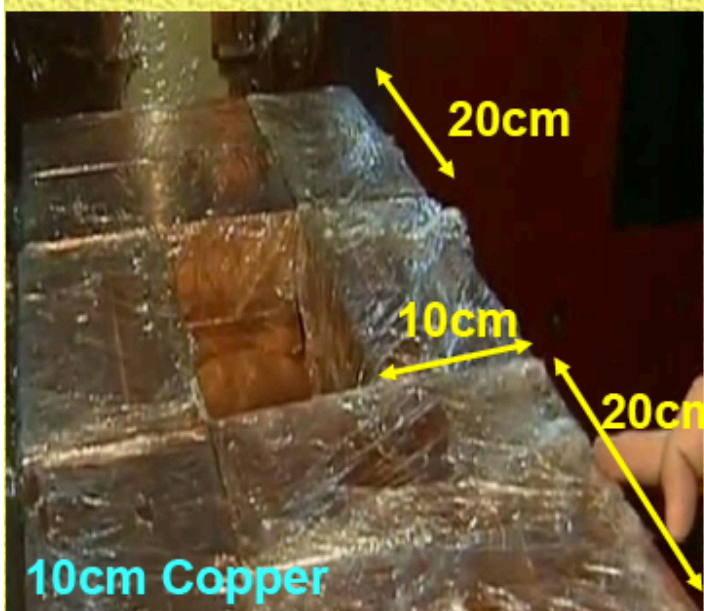
Jin-Ping Underground Lab

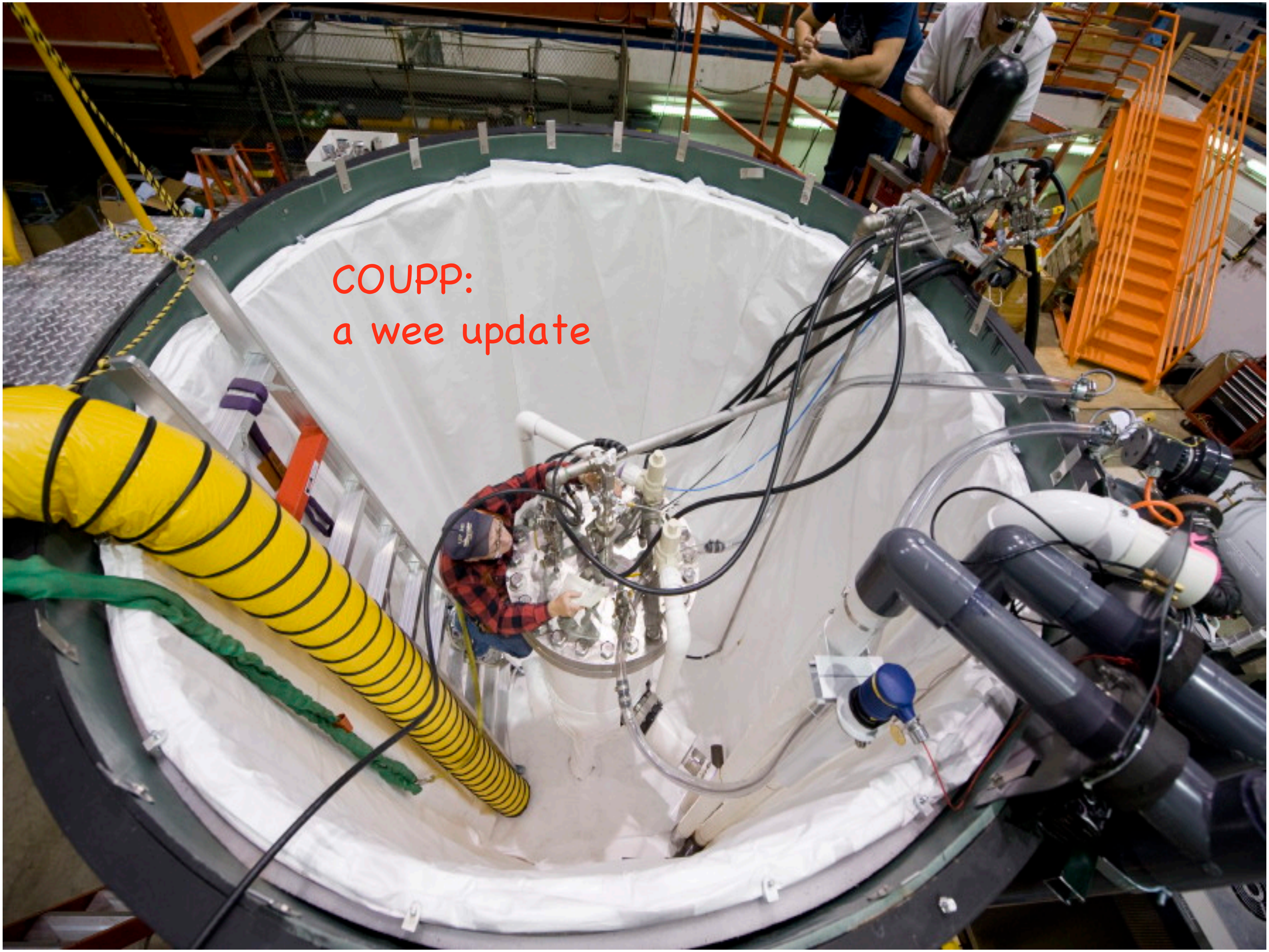
- Basic Infrastructures Completed,
- Research Started Sept 27, 2010.

polyethylene-room

inside polyethylene-room

Data Taking Configurations in CJPL - Feb 2011

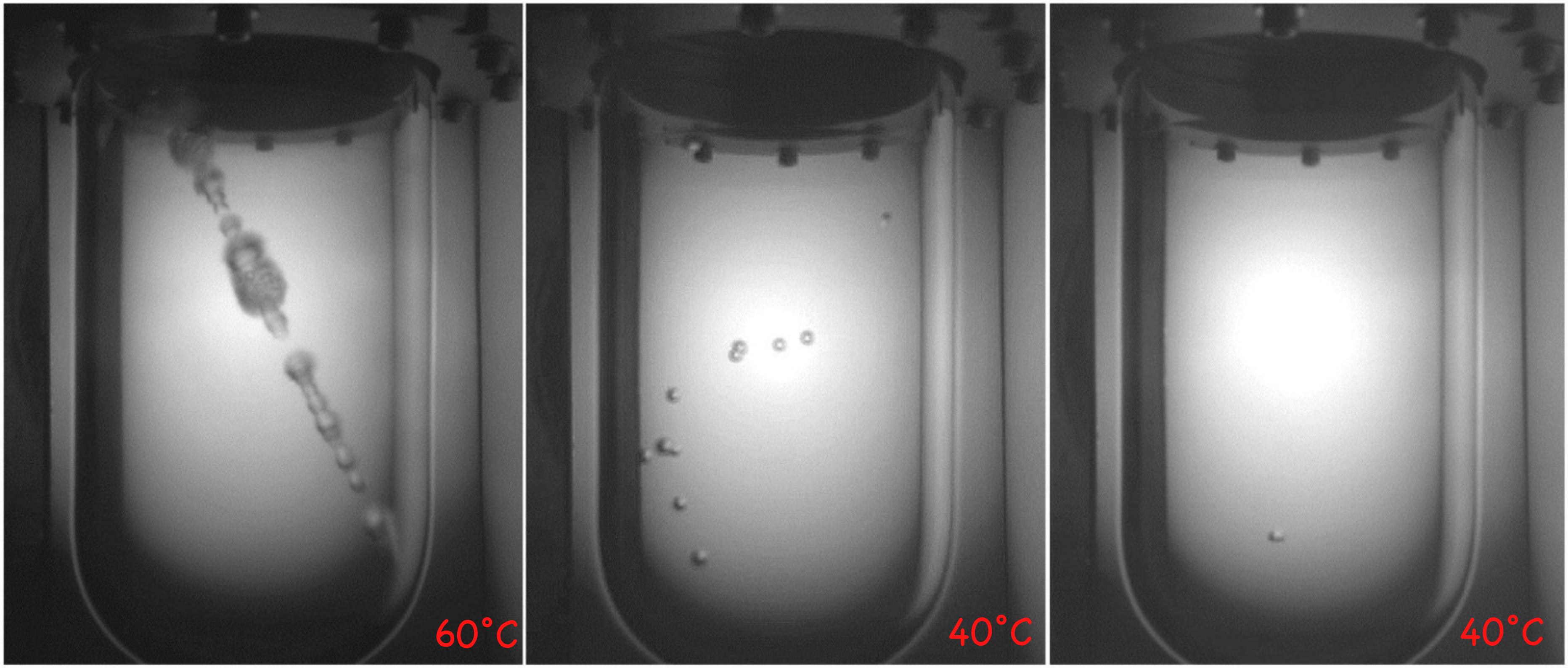



COUPP:
a wee update

COUPP: not your daddy's bubble chamber:

Conventional BC operation
(high superheat, MIP sensitive)

Low degree of superheat, <u>sensitive to nuclear recoils only</u>



muon   Neutron   WIMP (yeah, right)

ultra-clean BC: Bolte *et al.*, NIM A577 (2007) 569
Science 319 (2008) 933

COUPP approach to WIMP detection:

- Detection of single bubbles induced by high-dE/dx nuclear recoils in heavy liquid bubble chambers
- $<10^{-10}$ rejection factor for MIPs. *INTRINSIC* (no data cuts)
- Scalability: large masses easily monitored (built-in "amplification"). Choice of three triggers: pressure, acoustic, motion (video))
- Revisit an old detector technology with improvements leading to extended (unlimited?) stability (*ultra-clean* BC)
- Excellent sensitivity to both SD and SI couplings (CF_3I)
- Target fluid can be replaced (e.g., C_3F_8, C_4F_{10}, CF_3Br). Useful for separation between n- and WIMP-recoils and pinpointing WIMP in SUSY parameter space.
- High spatial granularity = additional n rejection mechanism
- Low cost, room temperature operation, safe chemistry (fire-extinguishing industrial refrigerants), moderate pressures (<200 psig)
- Single concentration: reducing or rejecting α-emitters in fluids to levels already achieved elsewhere (~10^{-17}) will lead to complete probing of SUSY models

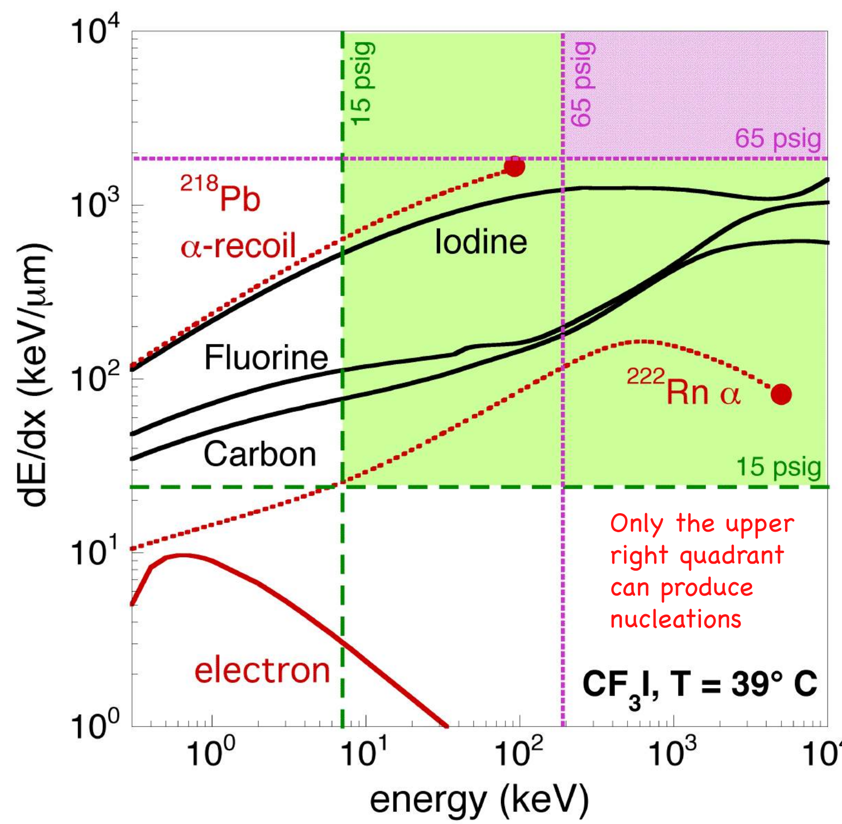
Seitz model of bubble nucleation (classical BC theory):

Threshold in deposited energy

$$E > E_c = 4\pi r_c^2\left(\gamma - T\frac{\partial\gamma}{\partial T}\right) + \frac{4}{3}\pi r_c^3 \rho_v \frac{h_{fg}}{M} + \frac{4}{3}\pi r_c^3 P \quad , \quad r_c = 2\gamma/\Delta P$$

$$\mathrm{d}E/\mathrm{d}x > E_c/(a r_c)$$

Threshold also in stopping power, allows for efficient INTRINSIC MIP background rejection



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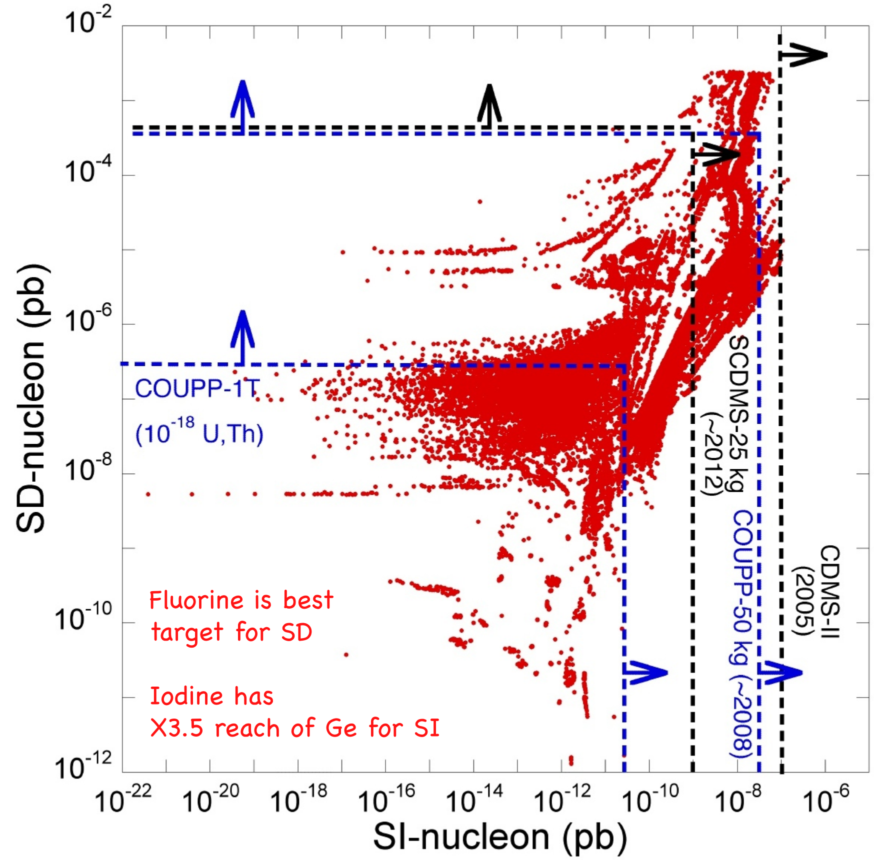
An old precept: attack on both fronts

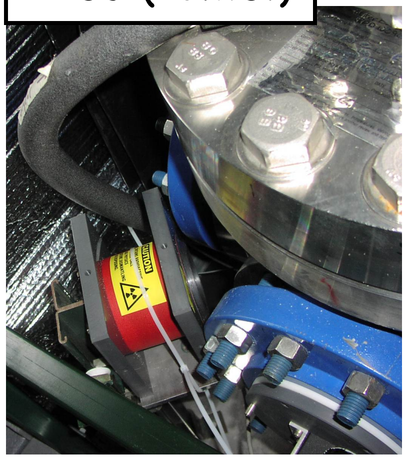


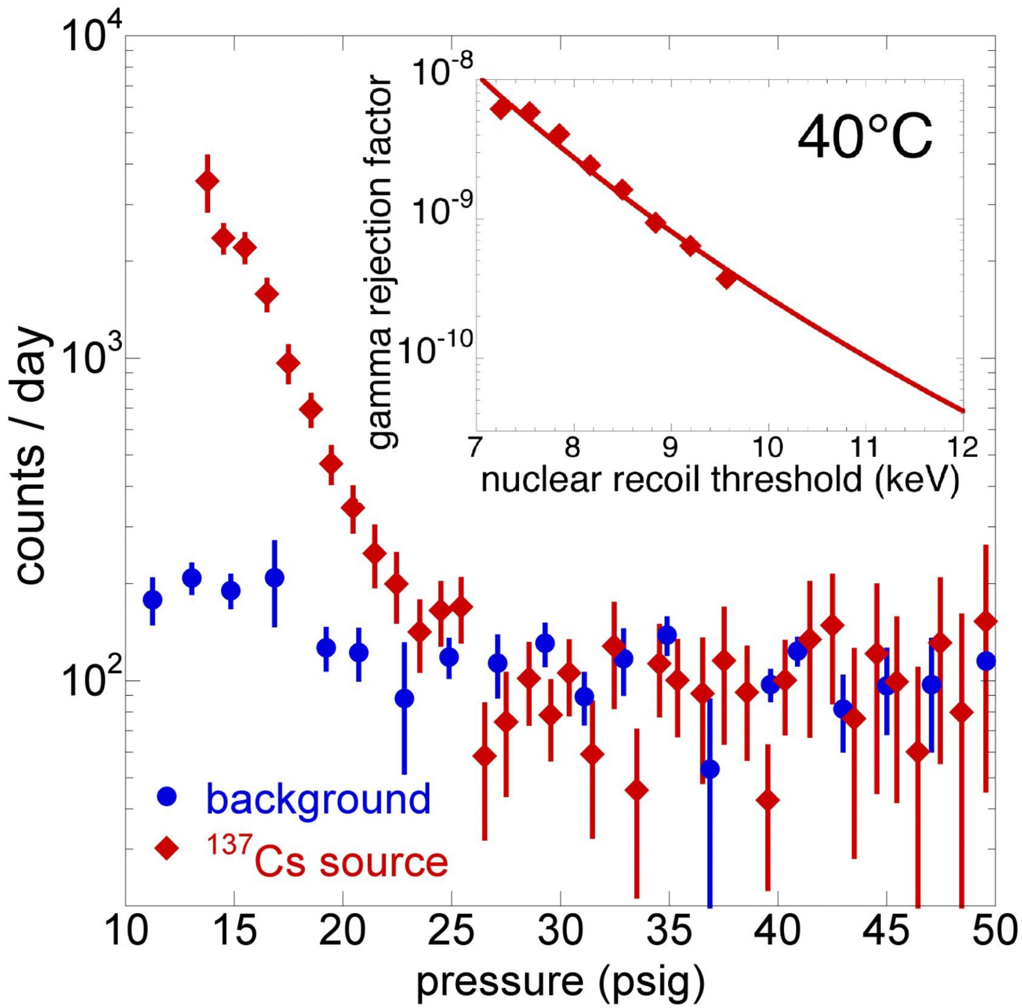
Baltz & Gondolo, JHEP 0410:052,2004. (WMAP-II update)

SD SUSY space harder to get to, but predictions are more robust and phase-space more compact. Worth the effort. (astro-ph/0001511, 0509269, and refs. therein)

E-961 progress: gamma and neutron calibrations

^{137}Cs (13mCi)





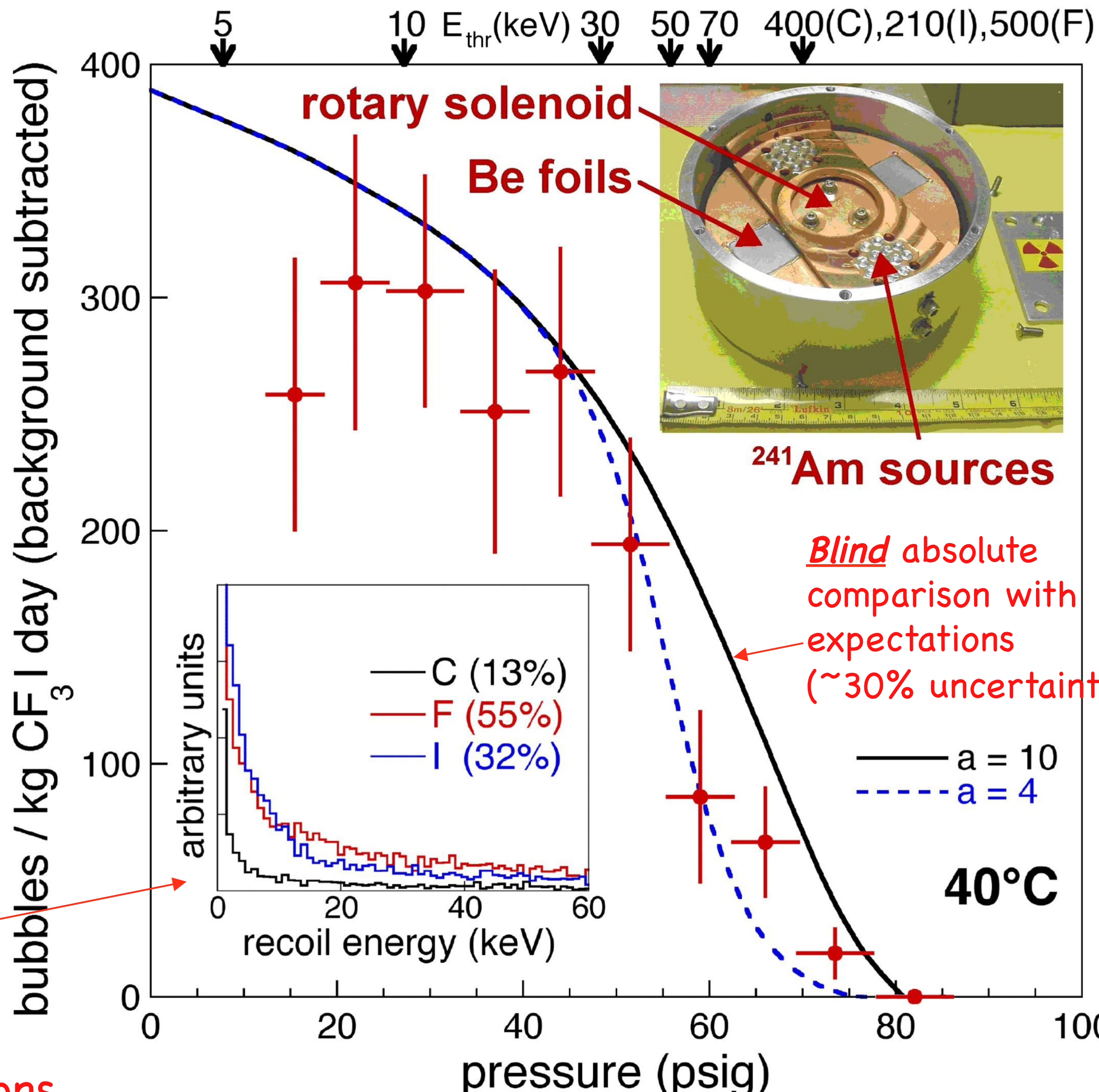
Best MIP rejection factor measured anywhere ($<10^{-10}$ INTRINSIC, no data cuts)

Other experiments as a reference:
XENON ~10^{-2}-10^{-3}
CDMS 10^{-4}-10^{-5}
WARP ~10^{-7}-10^{-8}

^{14}C betas not an issue for COUPP (typical O(100)/kg-day)
No need for high-Z shield
nor attention to chamber material selection
(...for the time being!)

E-961 progress: gamma and neutron calibrations

Switchable
Am/Be (5 n/s)

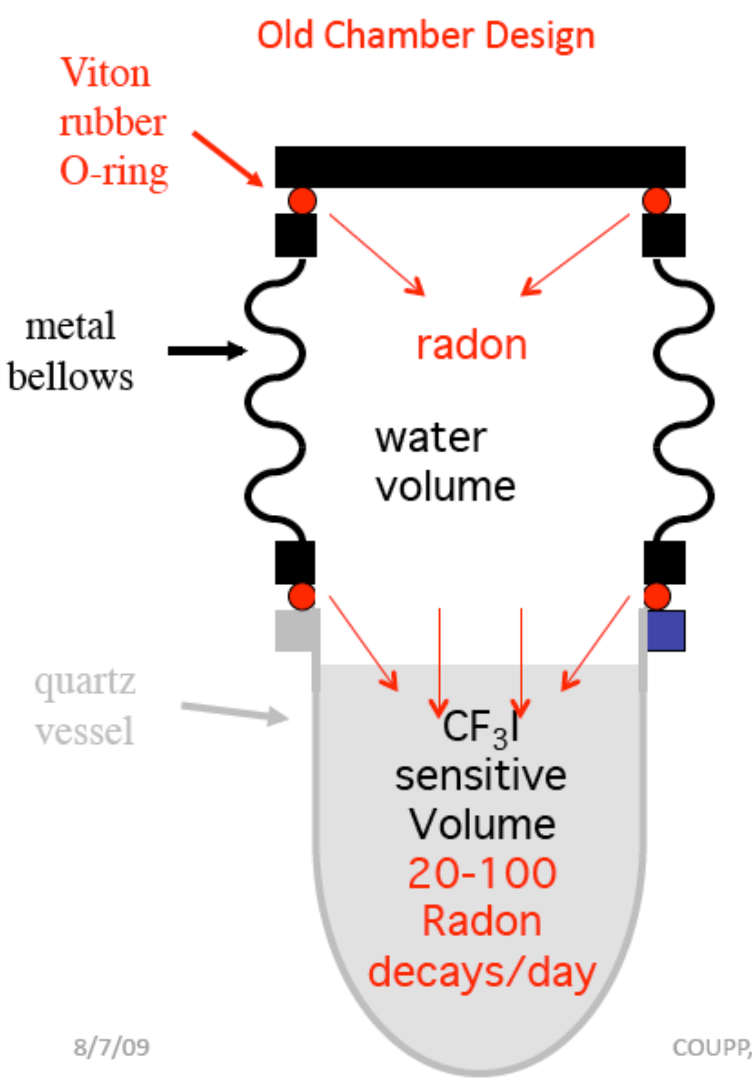


Blind absolute comparison with expectations (~30% uncertainty in those)

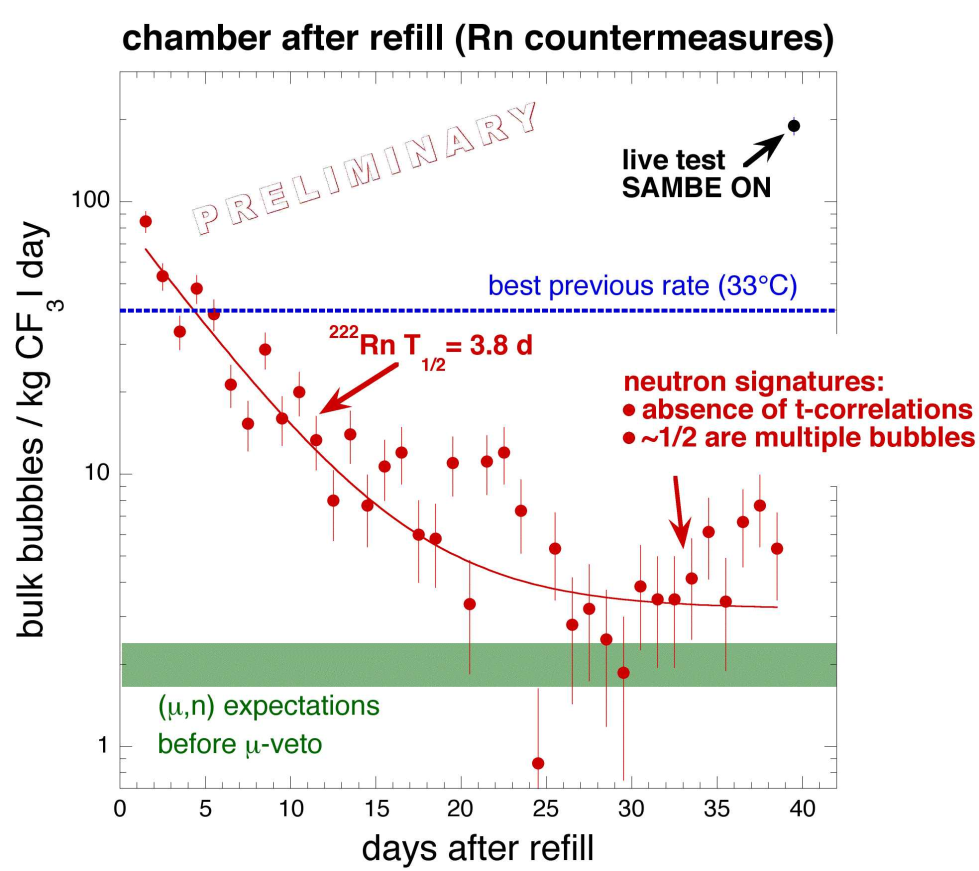
Low-energy WIMP-like recoil energy signal used in these calibrations

E-961 progress: Rn control

2-kg Chamber 2008 Data



- Radon greatly reduced by replacement of Viton O-rings with metal seals.
- We begin to see backgrounds from cosmic-ray coincident neutrons

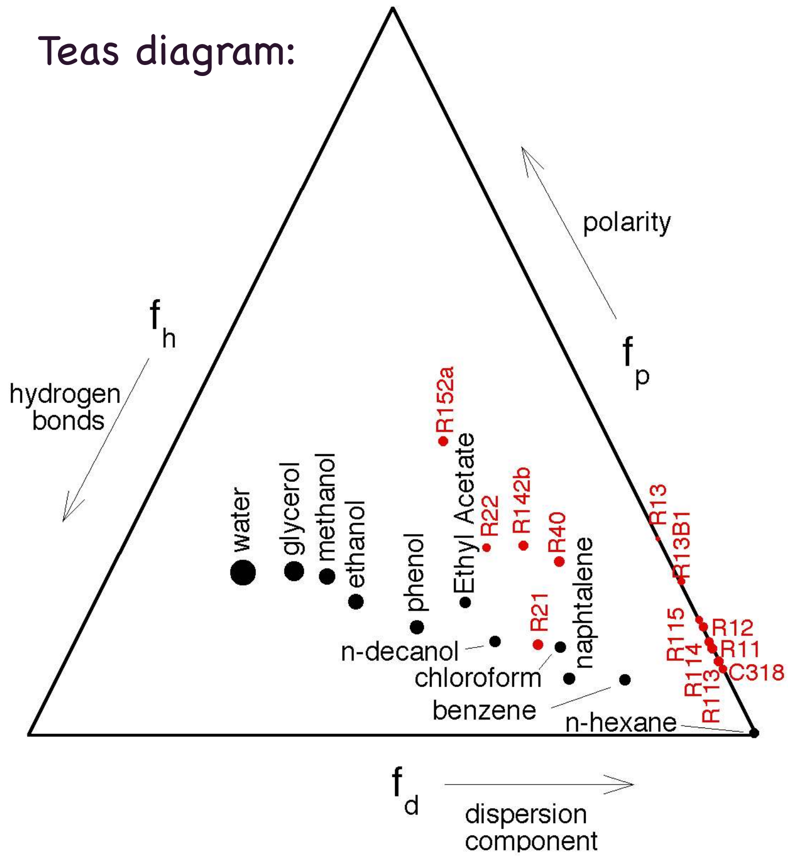


E-961 progress: fluid purification & handling

"like dissolves like"

U & Th salts readily dissolve in H_2O, refrigerants do not. **Solubility of U,Th in CF_3I expected to be very small** (a situation similar to mineral oil-based ν dets.)

Teas diagram:



Fractional cohesion parameters for refrigerants and common solvants (size of marker ~ δ_t)

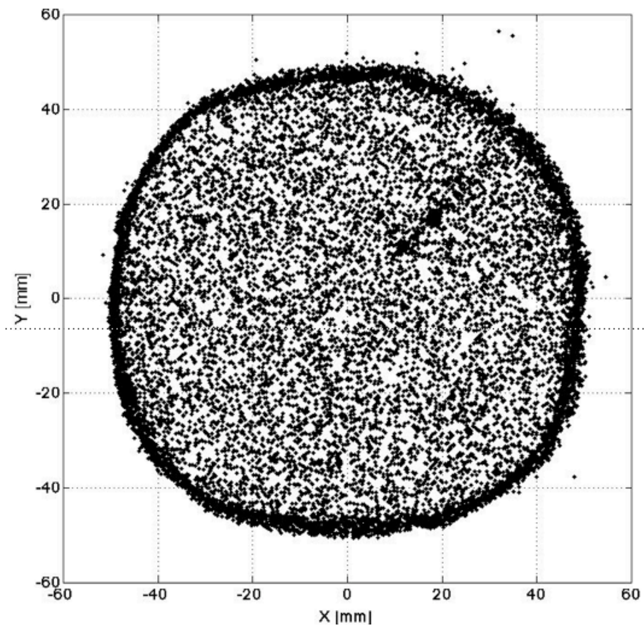
First serious attempt at fluid handling/purification, commissioned during NUMI 60-kg fill.

So far we have only profited from SNOlab water availability (to reach already <5 α-like ev/kg-day)

We foresee most future effort on H_2O purification.

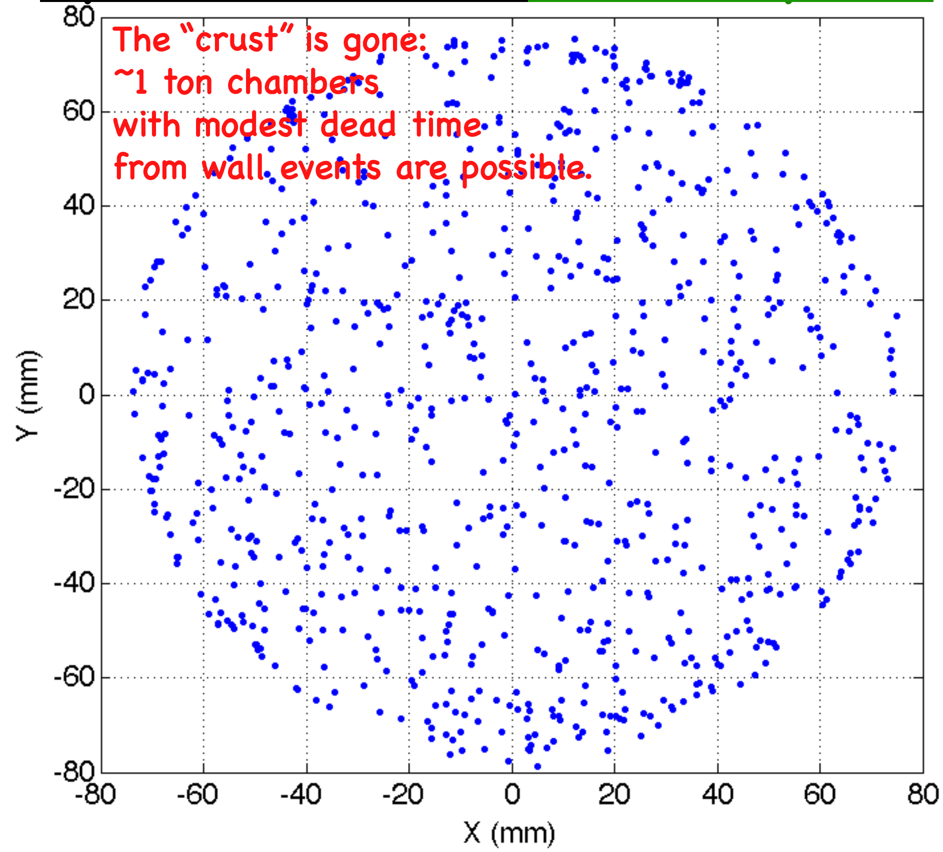
E-961 progress: wall events a thing of the past

Natural Quartz: 0.8/day/cm²



~40 live-days (2007-08)

Synthetic Silica: ≤1e-2/day/cm²



88 live-days (2009)

- We detected a ~50 ppb U,Th contamination in regular quartz used in early chambers.
- Alpha emission from surface was independently confirmed, at the same rate as wall evts.
- New chambers now featuring synthetic silica (~3 orders of magnitude lower U,Th content)
- New rate will allow us to reach 1 ton without any live-time penalty.
- Synthetic silica vessels available up to 250kg CF3I: extrapolation to ~500kg part of our DUSEL S4 charge. UPDATE: vessels up to >1 m^3 may be readily available.

Listening to particles (yes, listening)

Glaser (1955)

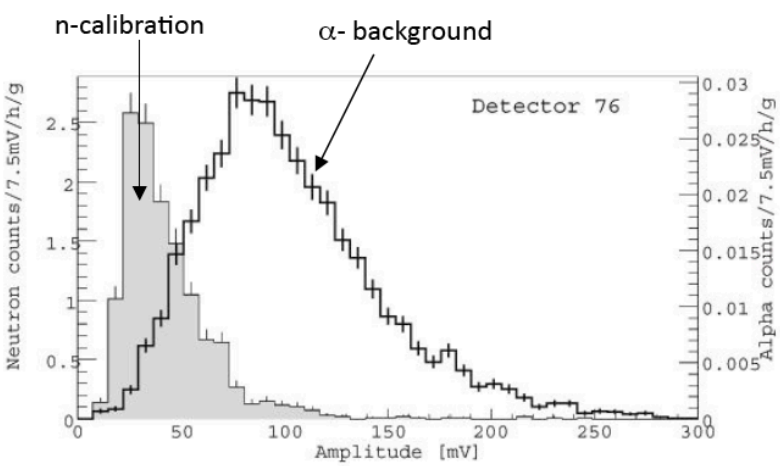
In order to see events more interesting than muons passing straight through the chamber, we took advantage of the violence of the eruption which produces an audible "plink" at each event. A General Electric variable-reluctance phonograph pickup was mounted with its stylus pressing against the wall of the chamber. Vibration signals occurring during the quiescent period after the expansion were allowed to trigger the lights and take pictures. In this way we saw tracks of particles passing through the chamber in various directions,

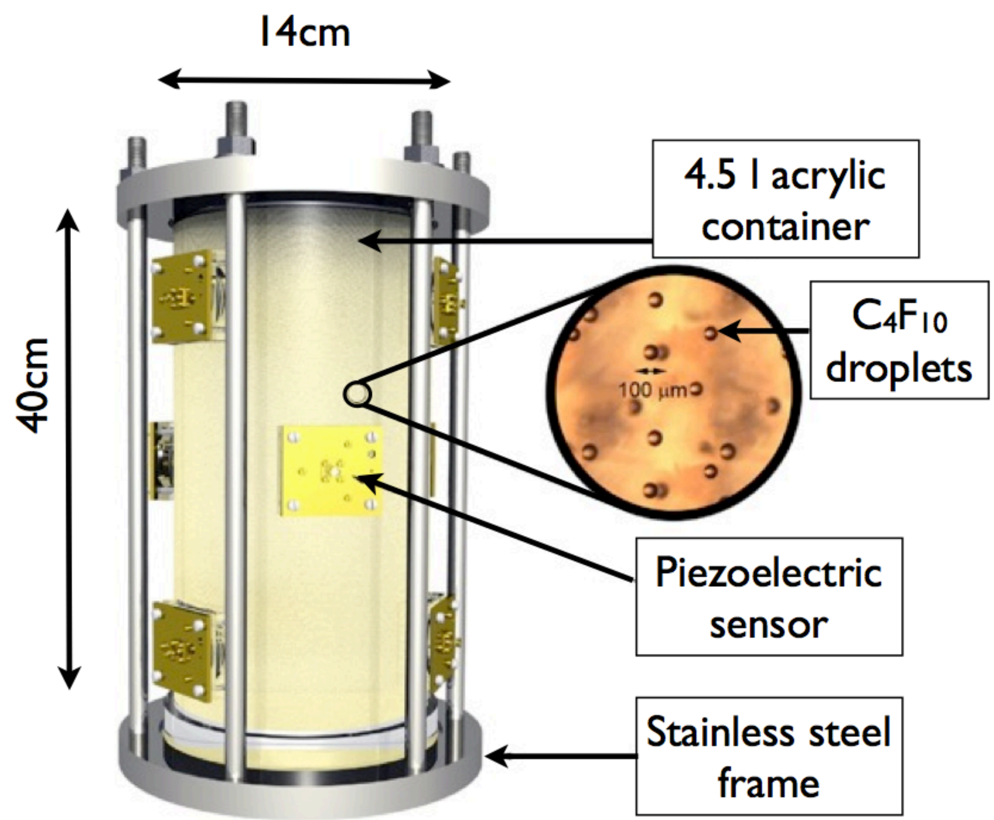
Martynyuk & Smirnova (1991)

The initial pressure in the volume *V* depends on the energy transmitted by the particle to that volume. Consequently, the characteristics of the acoustic pulse depend on the parameters of the particle responsible for formation of the bubble….

The parameters of these pulses must depend strongly on the characteristics of the particle.

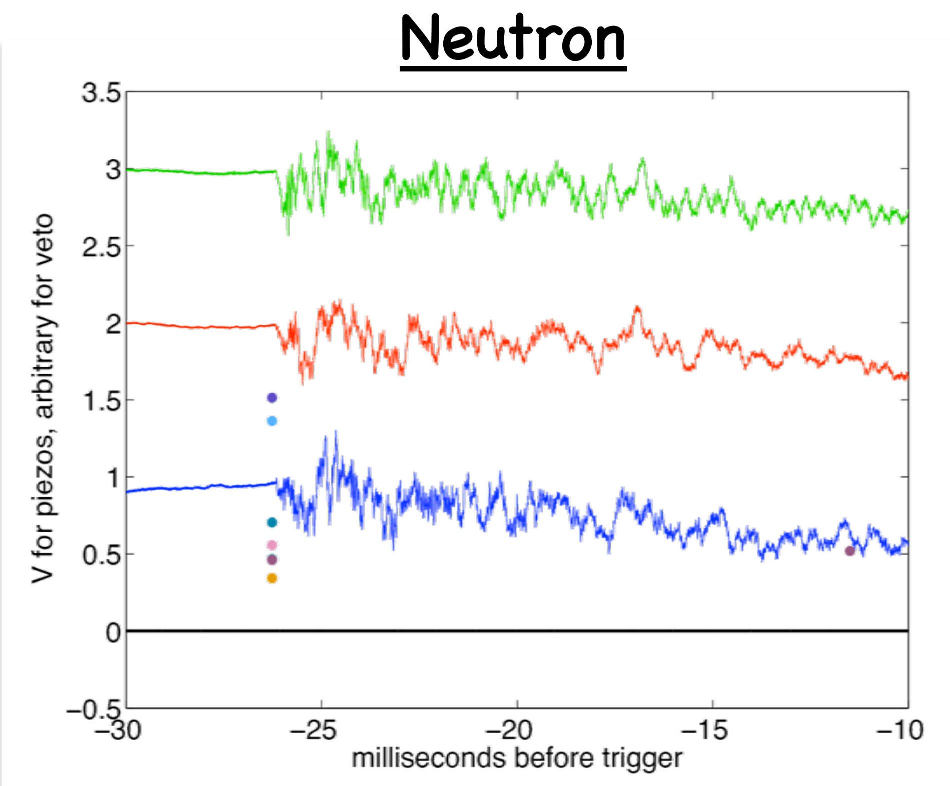
PICASSO collab. (2009)



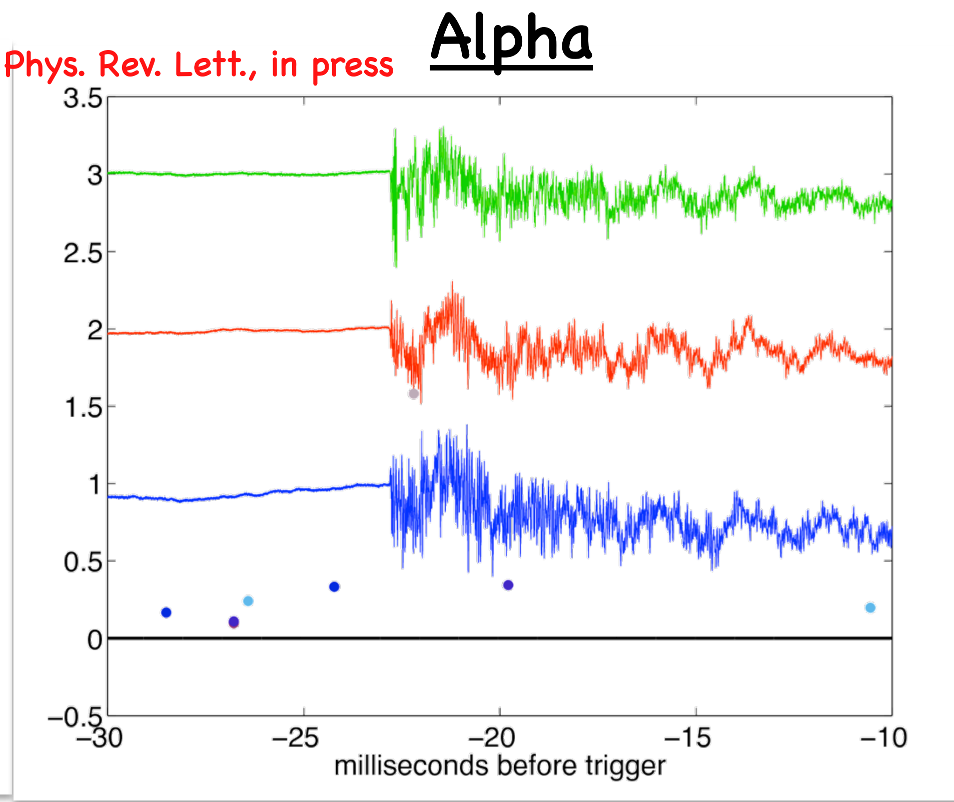


PICASSO demonstrates α – nuc. recoil acoustic discrimination in Superheated Droplet Detectors (SDDs)
F. Aubin *et al.*, New J. Phys 10 (2008) 103017

E-961 progress: acoustic alpha - nuclear recoil discrimination



Phys. Rev. Lett., in press



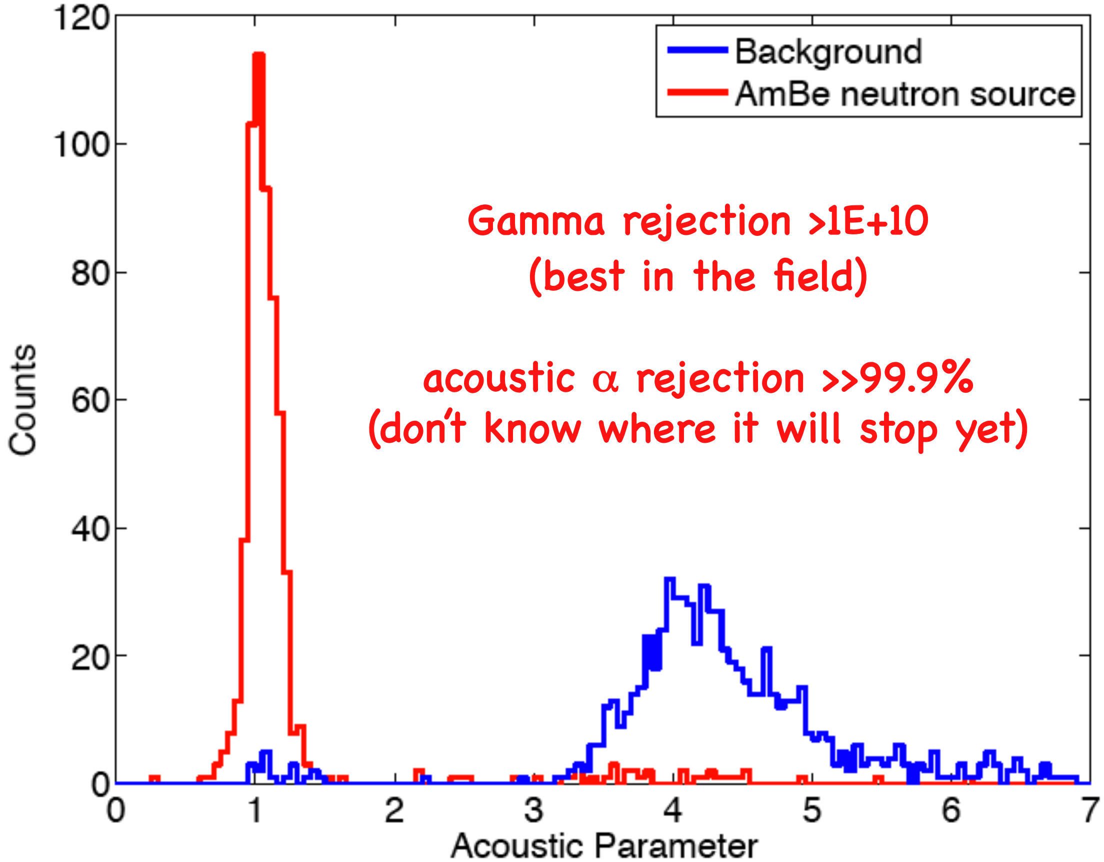
We observe two distinct families of single bubble bulk events in a 4 kg chamber:

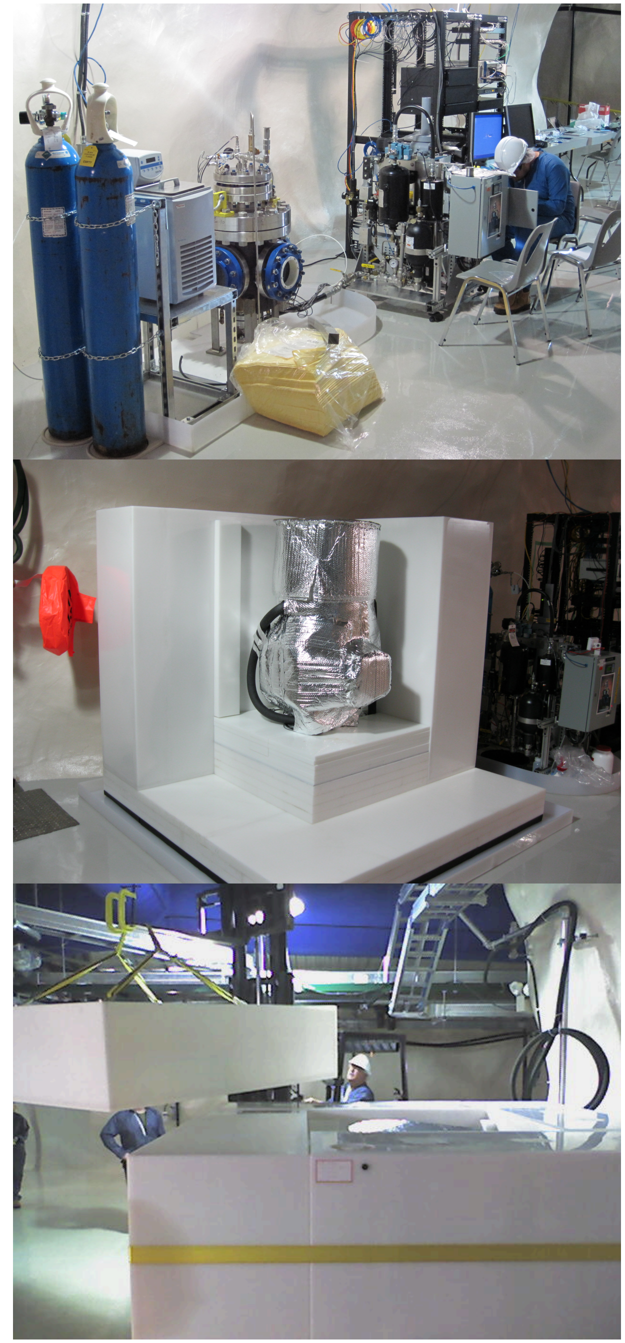
- Discrimination increases with frequency, as expected.
- We have a handle on which is which (Rn time-correlated pairs following injection, S-AmBe calibrations, NUMI-beam events).
- Polishing off the method, but potential for high discrimination against α's is clear.
- Challenge in obtaining same discrimination in the 60kg device: increasing sensors to 24, also their bandwidth (IUSB group)

A zero-background experiment soon?

COUPP progress: acoustic alpha - nuclear recoil discrimination

SNOlab COUPP-4kg data

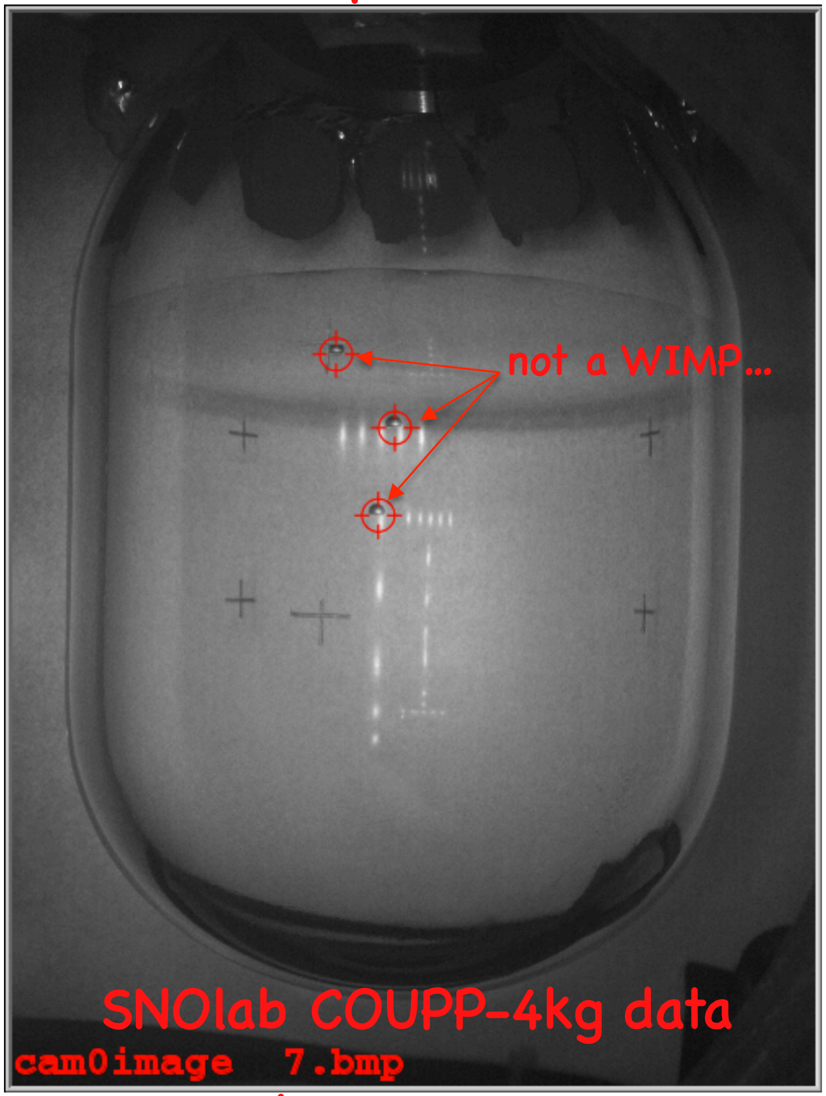


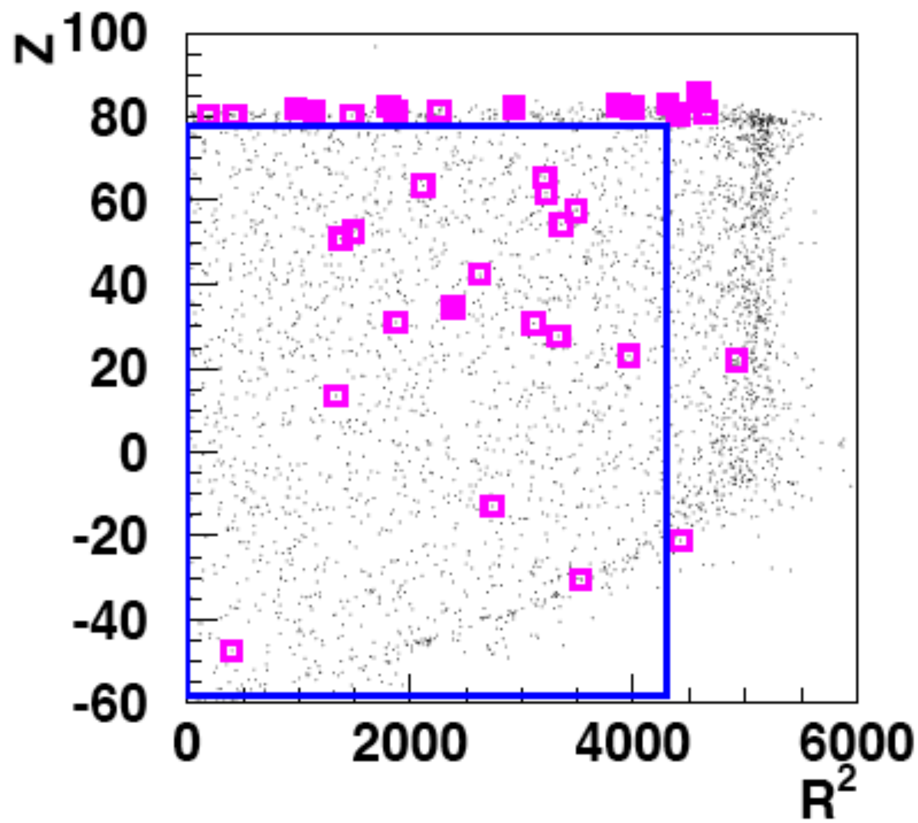


Light-WIMP sensitivity around the corner.

We have crossed the Rubicon:

Dark Matter experiments from now on to produce their own "WIMPs"



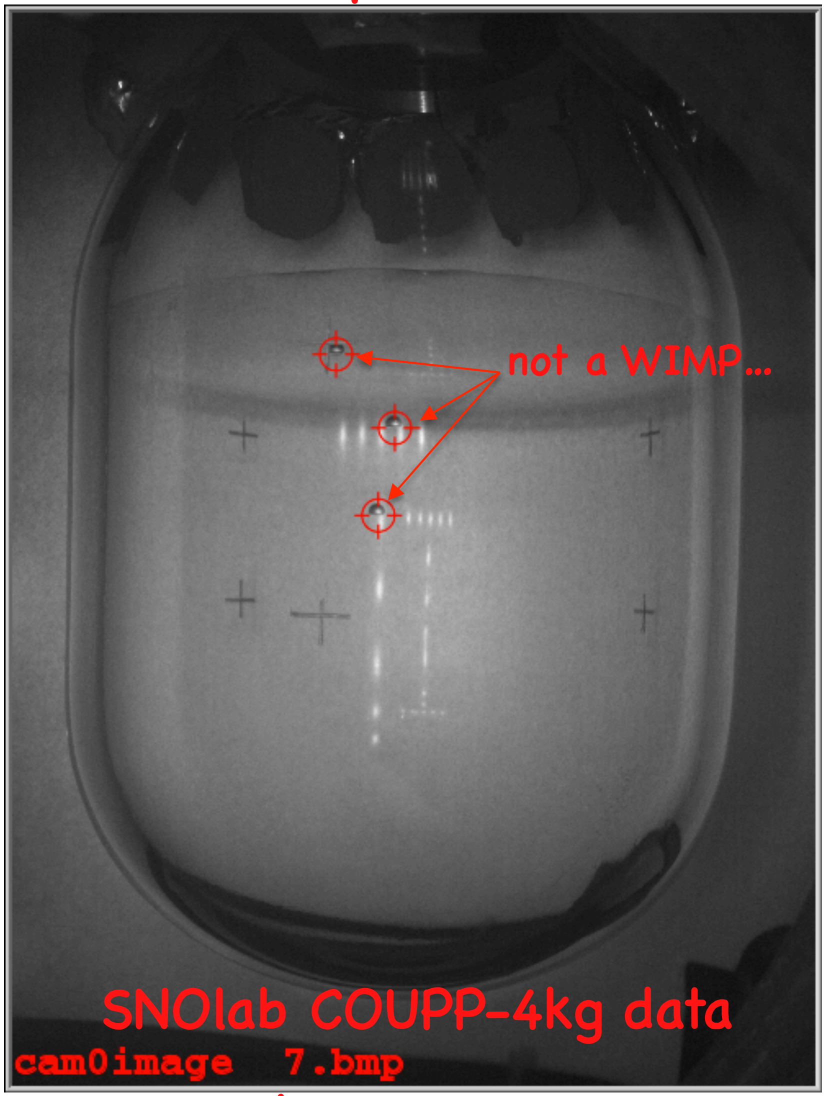


COUPP's dubious distinction:

first DM experiment to see (α,n) neutrons

In agreement with Po-210 and U, Th in PZT
and inspection windows. Replacement in progress.

We have crossed the Rubicon:
Dark Matter experiments from now on to produce their own "WIMPs"



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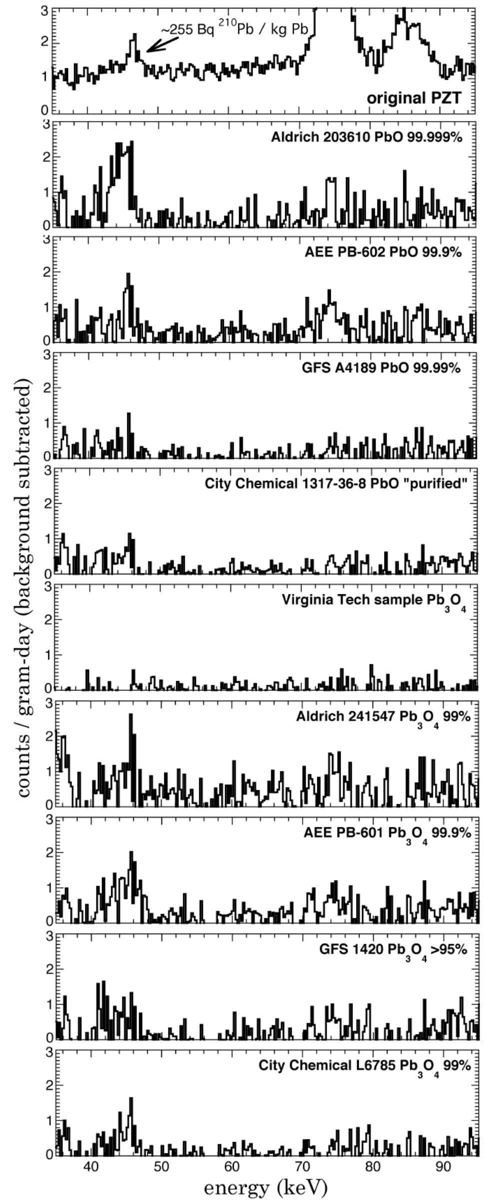


Piezo Salts Screening.

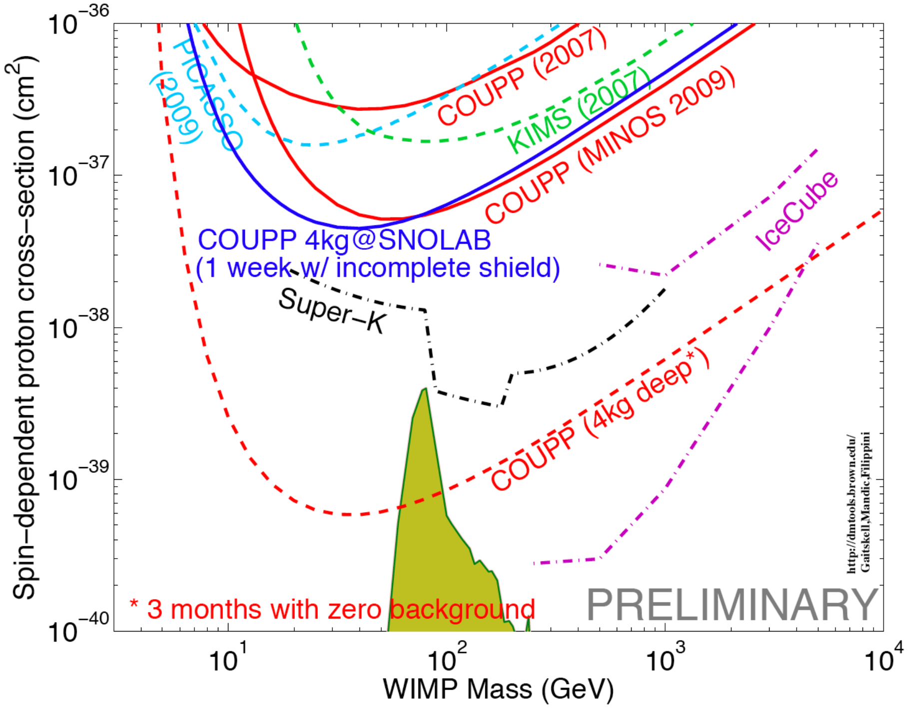
>x100 improvement within reach.

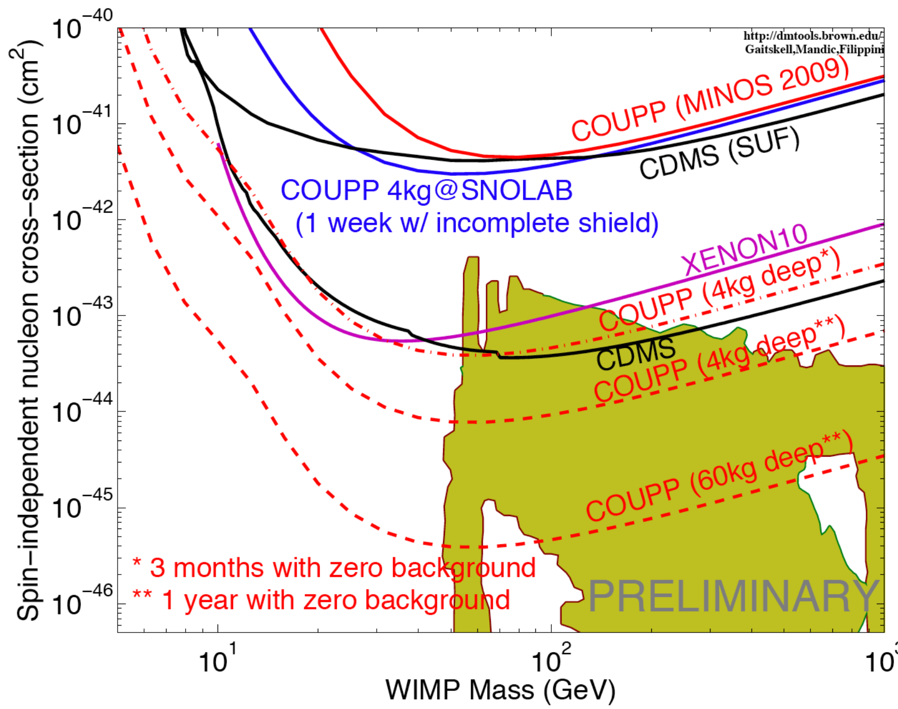
Virginia Tech producing low-bckg COUPP piezos.

The silver lining:

Following piezo replacement our modest next physics goal (World Domination) seems within grasp

(Plus we should be able to reliably explore the light-WIMP hypothesis)





- We expect COUPP to be at the forefront of *both* SD and SI WIMP searches during 2011.
- COUPP-500 design phase funded by NSF (DUSEL S4) and DOE/FNAL. Minimal extrapolations from 60 kg.

E-961 progress: 60kg chamber construction