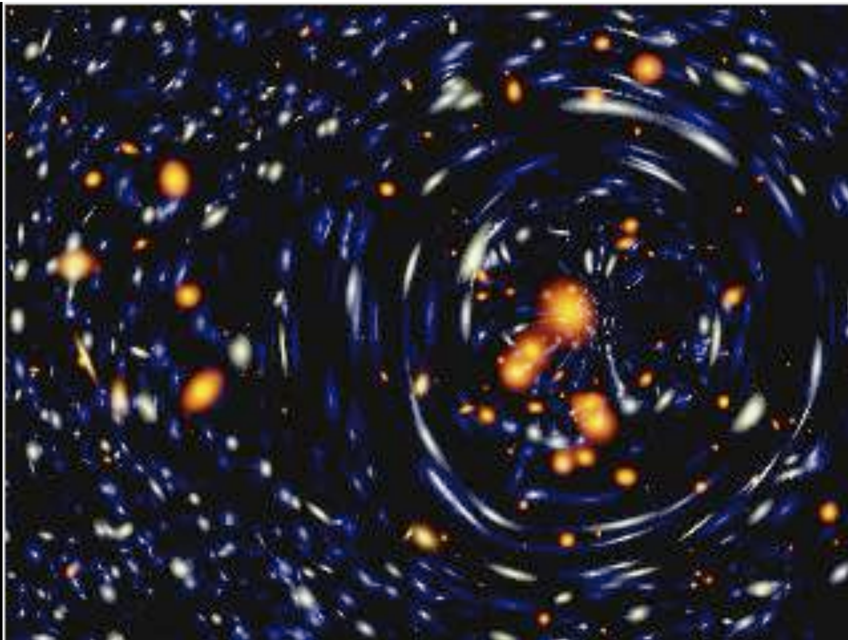
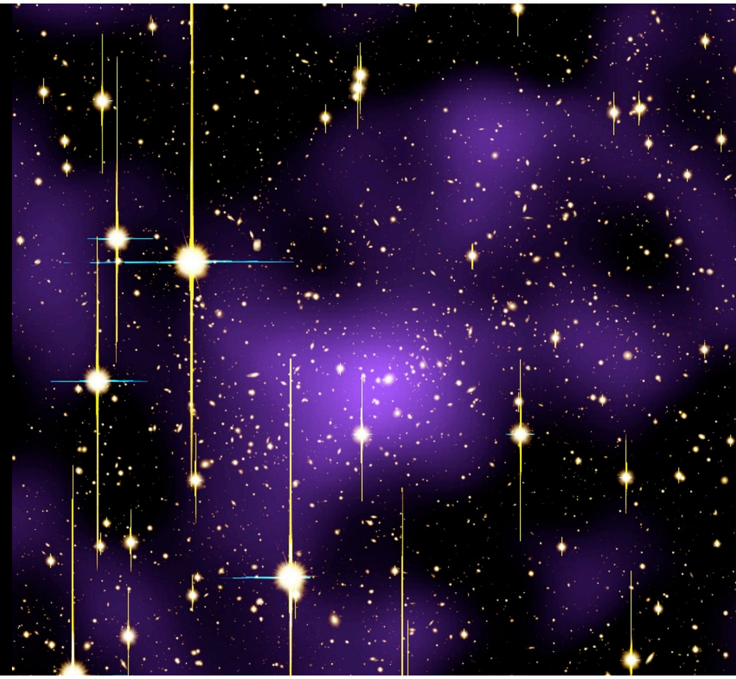
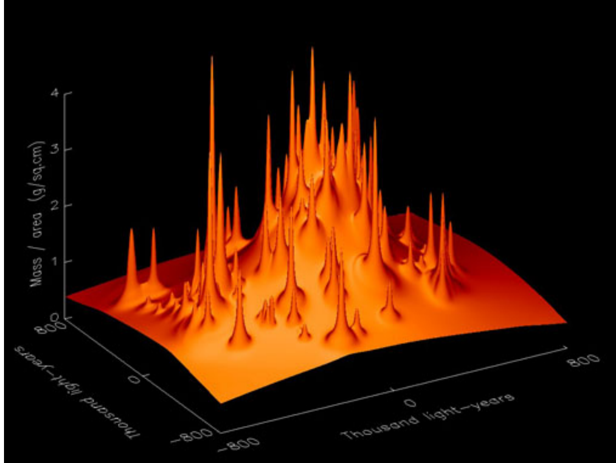
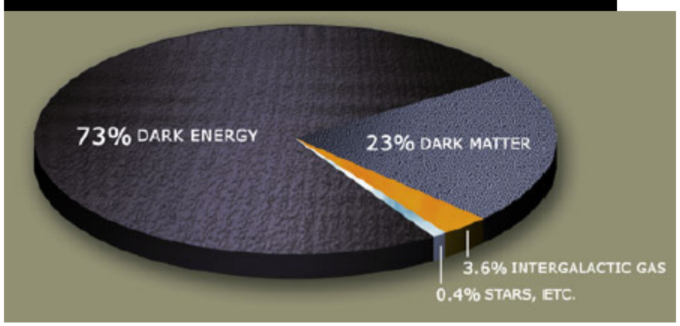
Certainty and uncertainty in dark matter searches



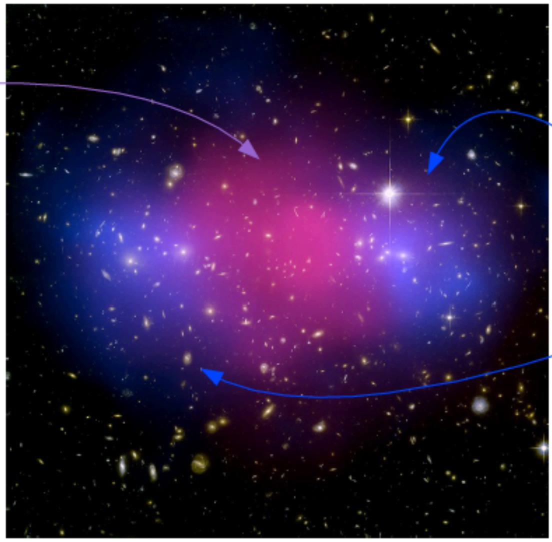




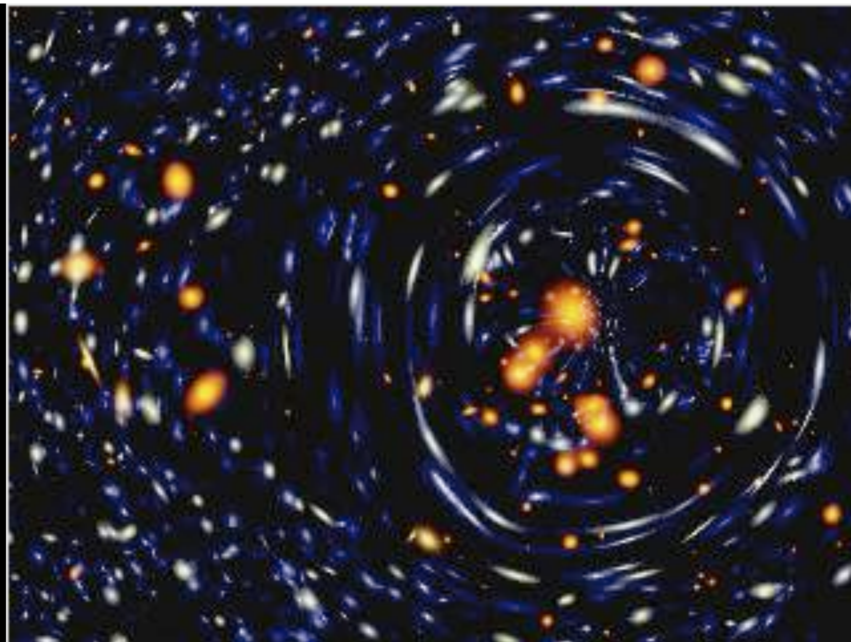


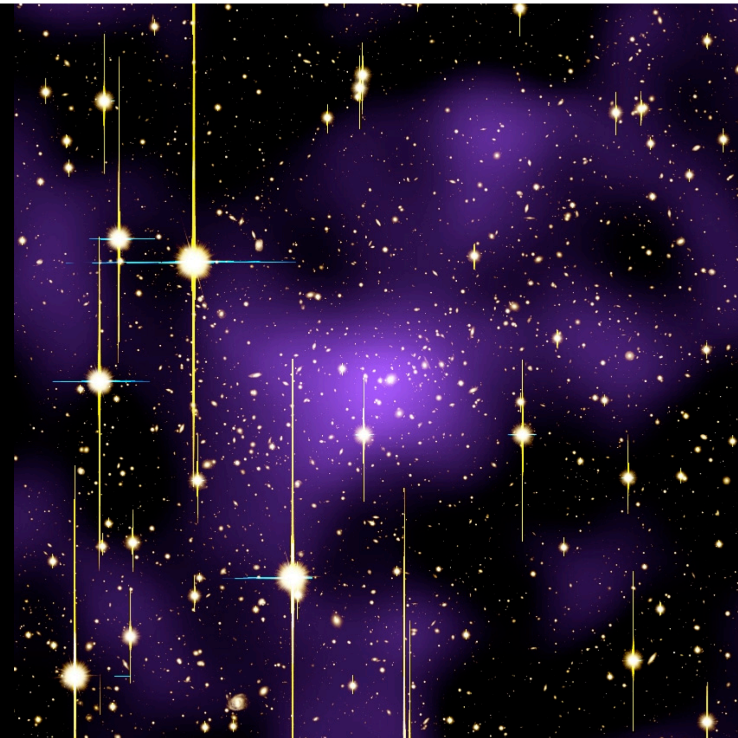
Most exciting observation (Bradac et al): The MACS J0025.4-1222 cluster collision

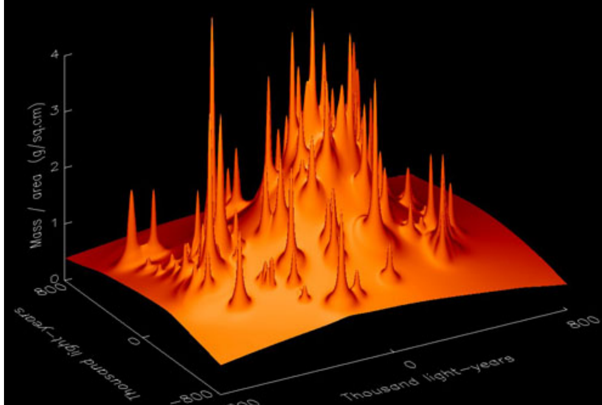
Luminous (X-ray-emitting) gas (stopped by collision)



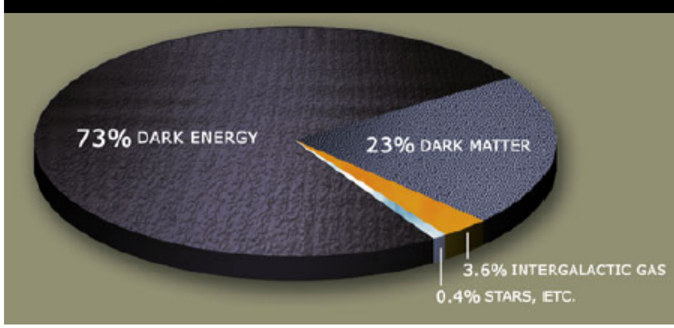
Dark matter (deduced by graviational lensing) (unaffected by collision)



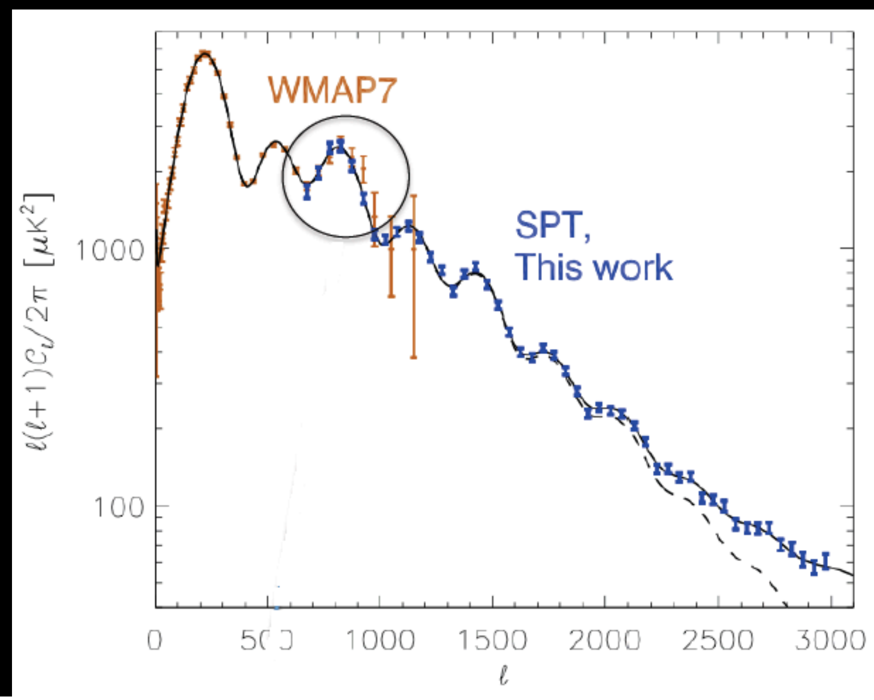




Mass / area (g/sq.cm)
Thousand light-years
Thousand light-years



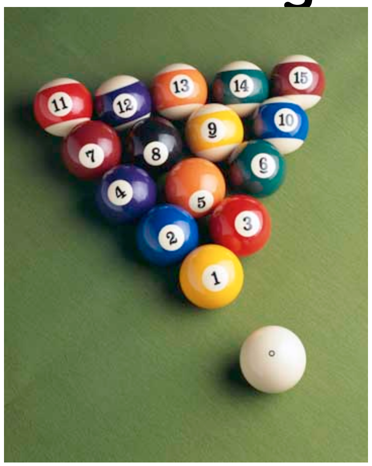
73% DARK ENERGY
23% DARK MATTER
3.6% INTERGALACTIC GAS
0.4% STARS, ETC.

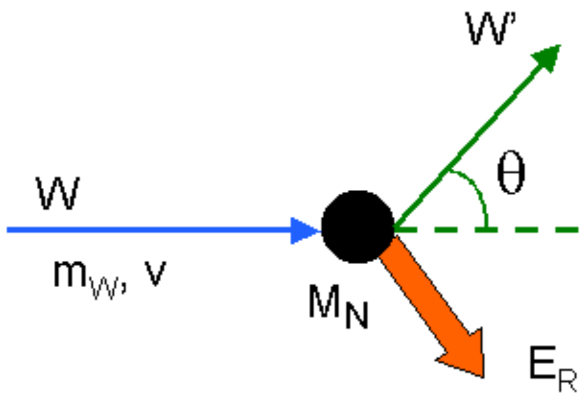


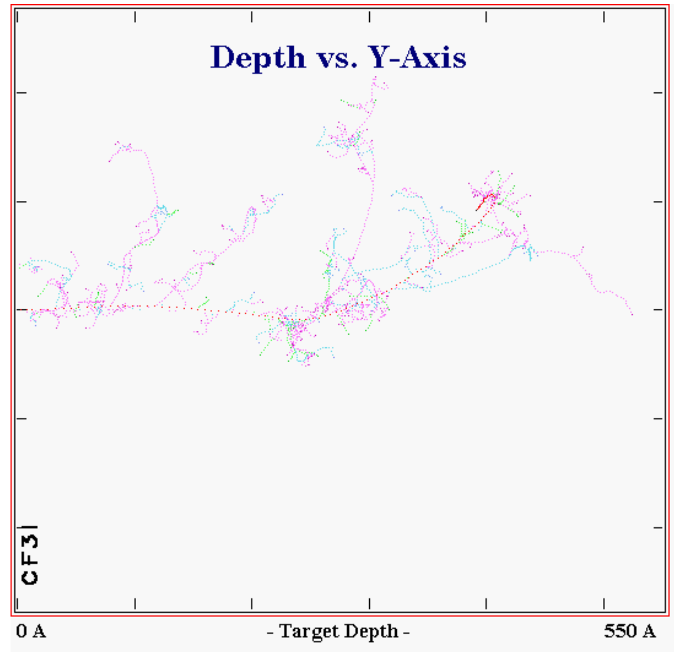
WMAP7
SPT,
This work
$\ell(\ell+1)C_\ell/2\pi\ [\mu K^2]$
1000
100
0
500
1000
1500
2000
2500
3000
ℓ

How do you look for Dark Matter in the lab?

It's all a game of billiards, really.



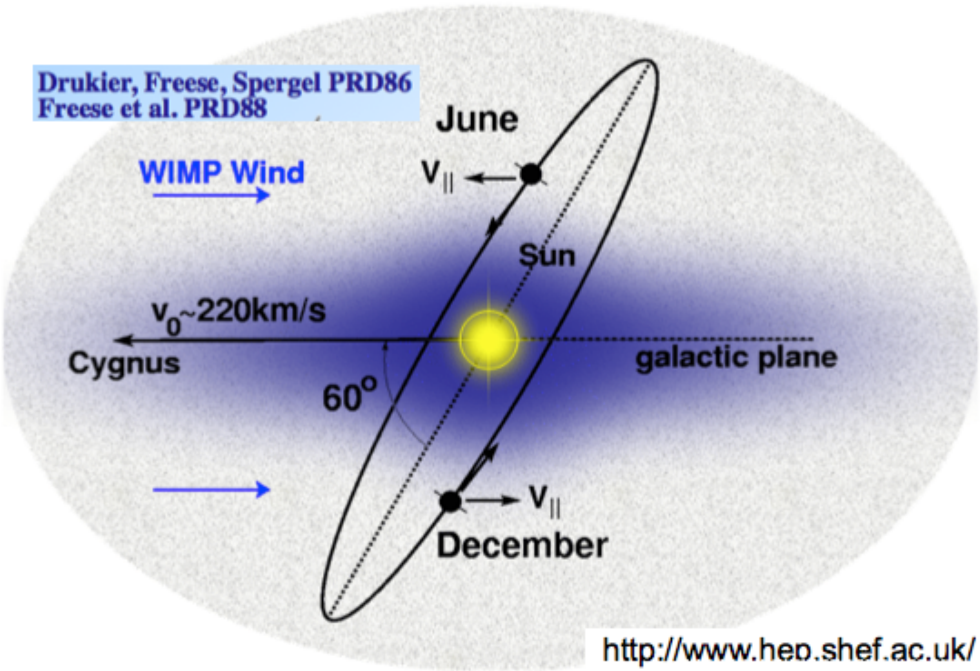




Location, location, location.

Plus a best effort at background abatement (shielding, radiopurity, and rejection), detector characterization, and positive signal identification.

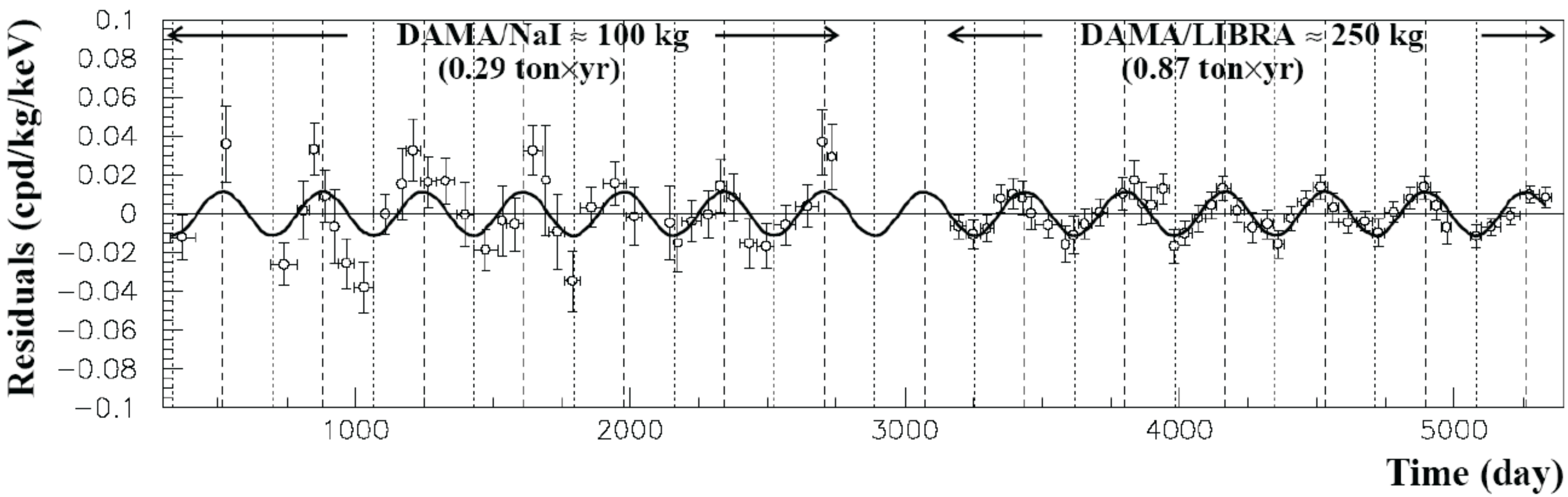
How do you look for Dark Matter in the lab?



Not the most fortunate phenomenology (from the point of view of number of things that could mimic this signature)

Also, expected recoil spectrum is a rather non-descript exponential distribution, similar to many low-energy backgrounds.

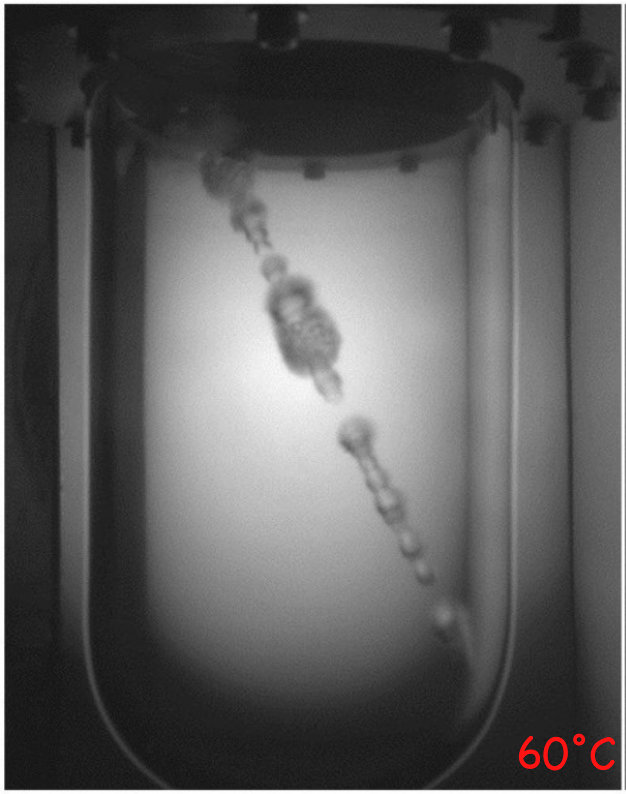
We make the best we can of this situation (e.g., through use of many complementary detection techniques)



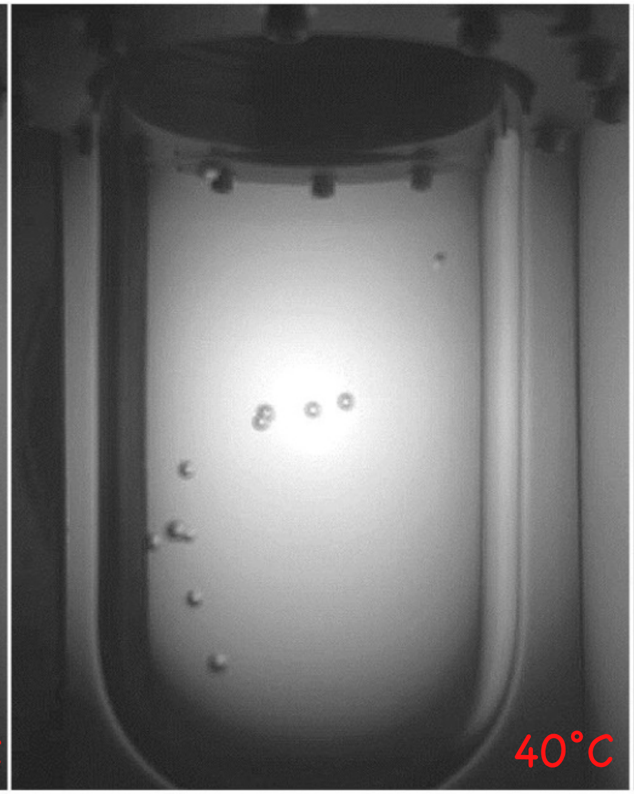
COUPP: not your daddy's bubble chamber:

Conventional BC operation
(high superheat, MIP sensitive)

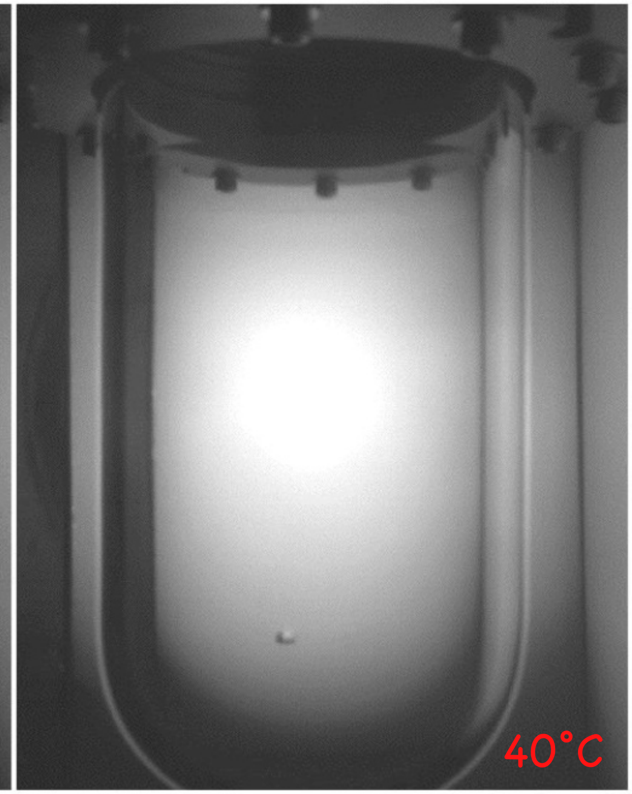
Low degree of superheat, <u>sensitive to nuclear recoils only</u>



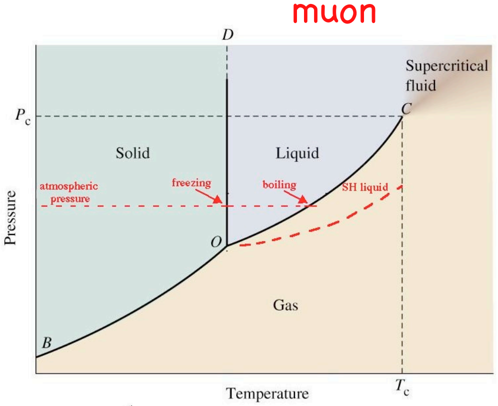
muon



Neutron



WIMP (yeah, right)



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

Science 319 (2008) 933, Phys. Rev. Lett. 106 (2011) 021303

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

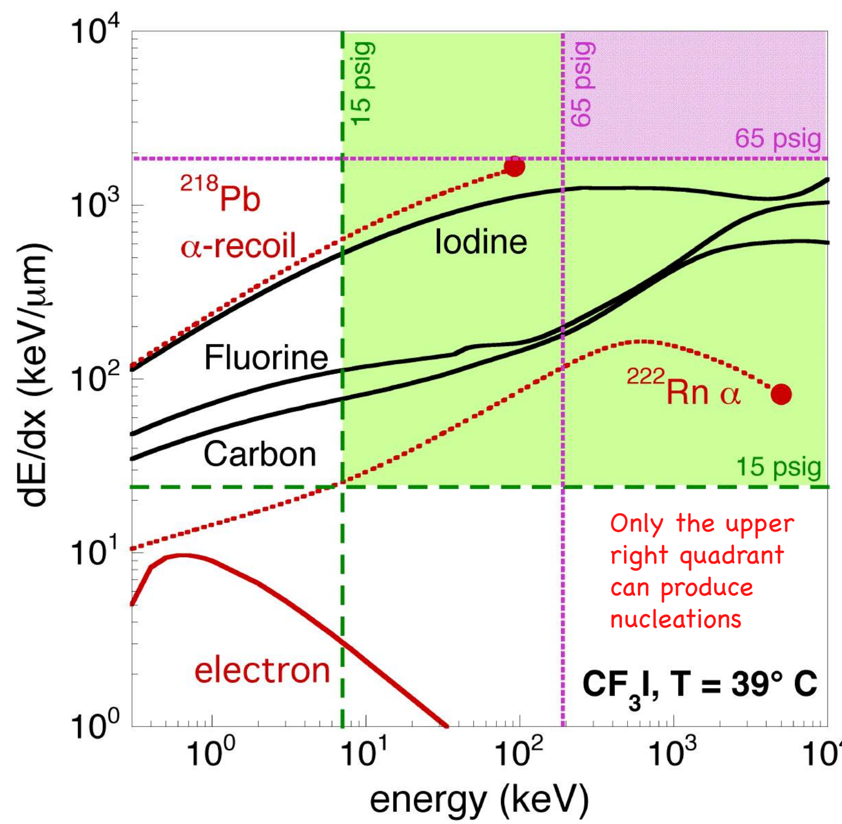
Seitz model of bubble nucleation (classical BC theory):

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



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)

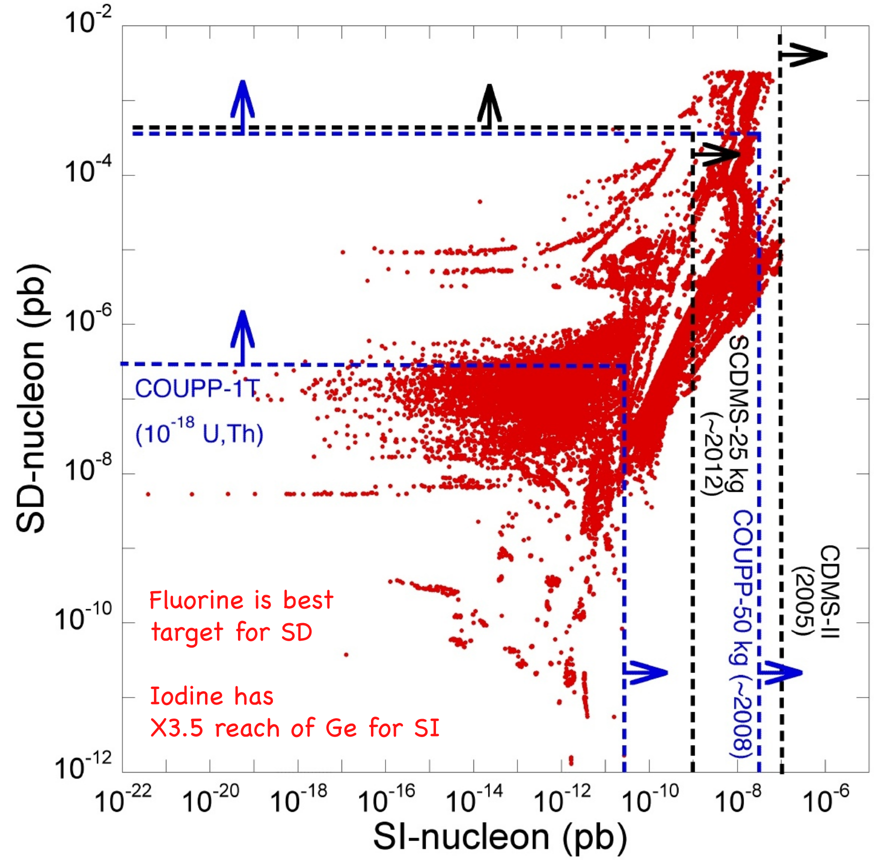
- Target fluid can be replaced (e.g., C_3F_8, C_4F_{10}, CF_3Br). Useful for separation between n- and WIMP-recoils and pinpointing WIMP in SUSY parameter space.

- 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

An old precept: attack on both fronts

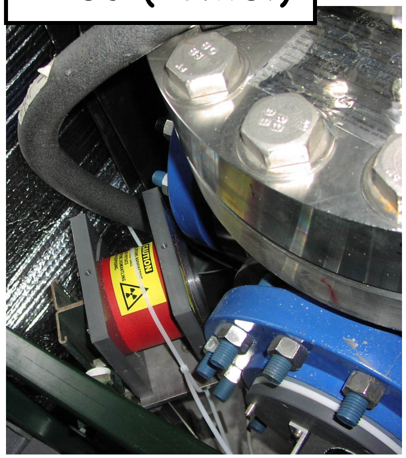


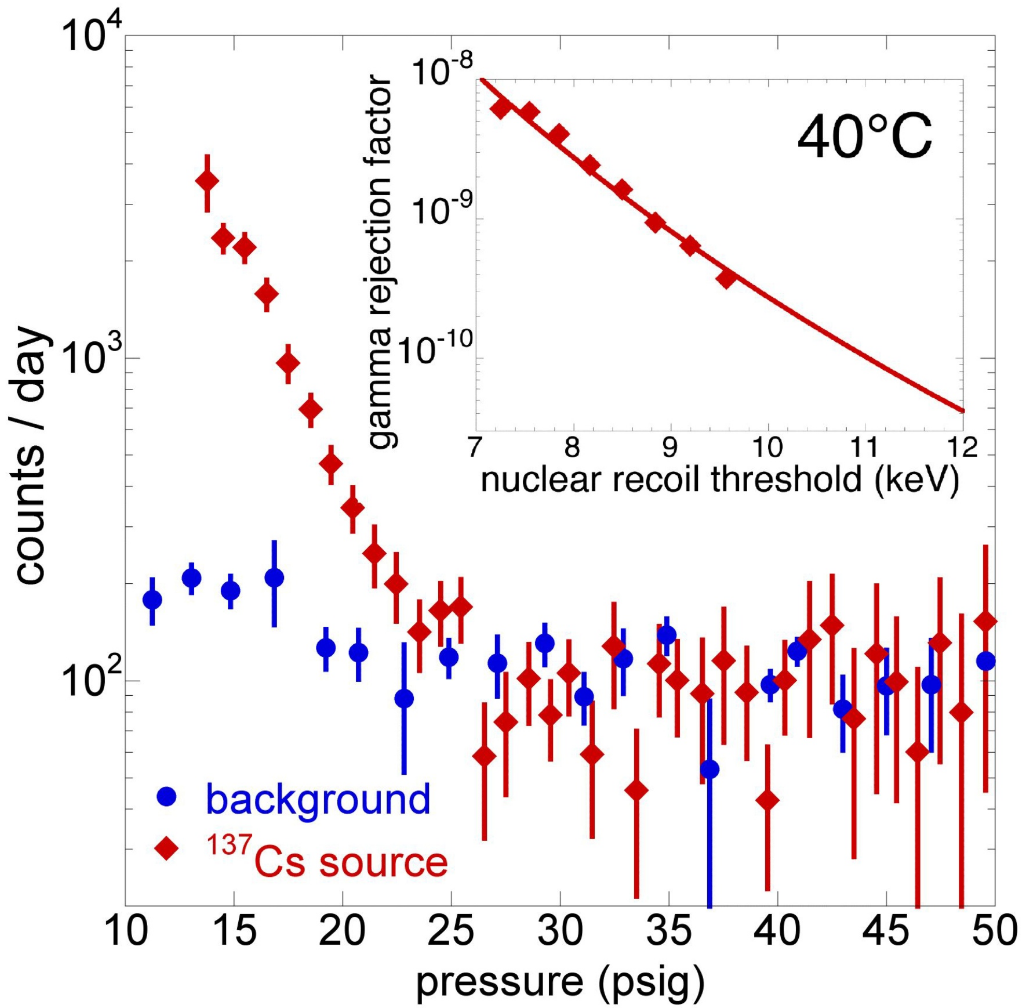
Baltz & Gondolo, JHEP 0410:052,2004. (WMAP-II update)

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)





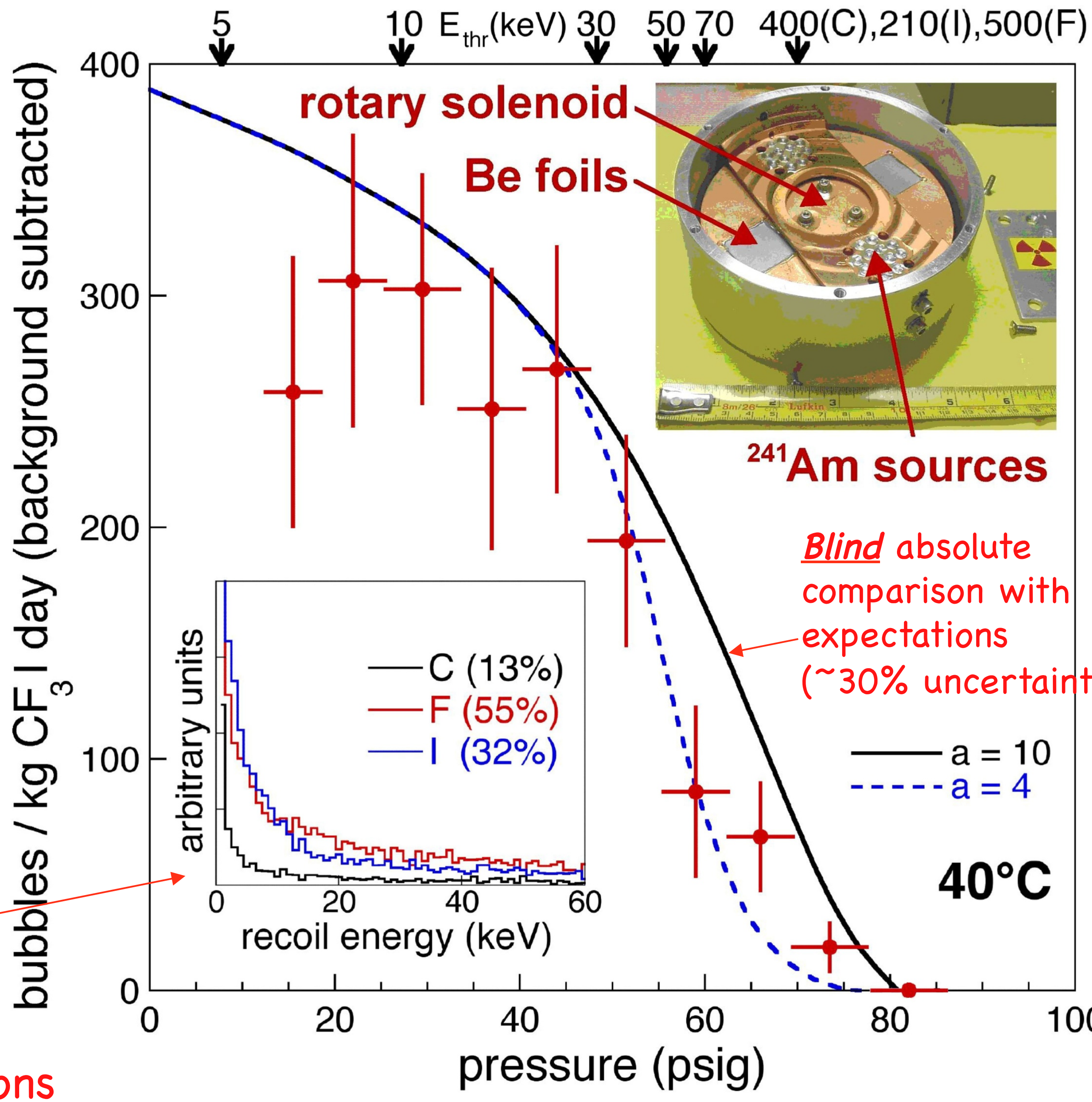
Best MIP rejection factor measured anywhere ($<10^{-10}$ INTRINSIC, no data cuts)

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

Listening to particles (yes, listening)

Glaser (1955)

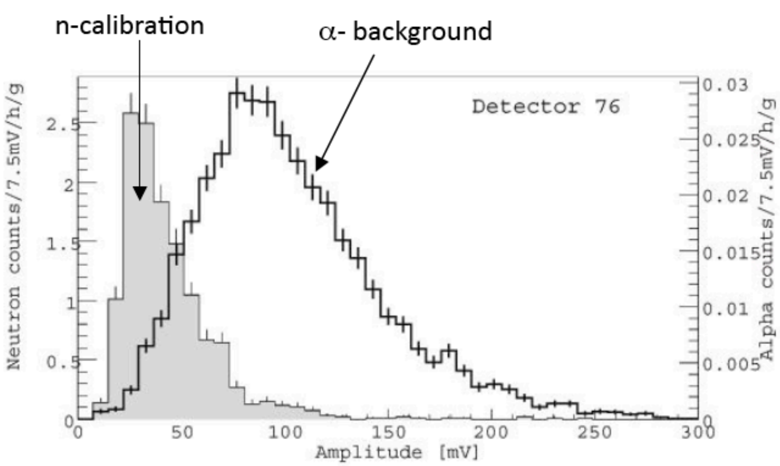
In order to see events more interesting than muons passing straight through the chamber, we took advantage of the violence of the eruption which produces an audible "plink" at each event. A General Electric variable-reluctance phonograph pickup was mounted with its stylus pressing against the wall of 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,

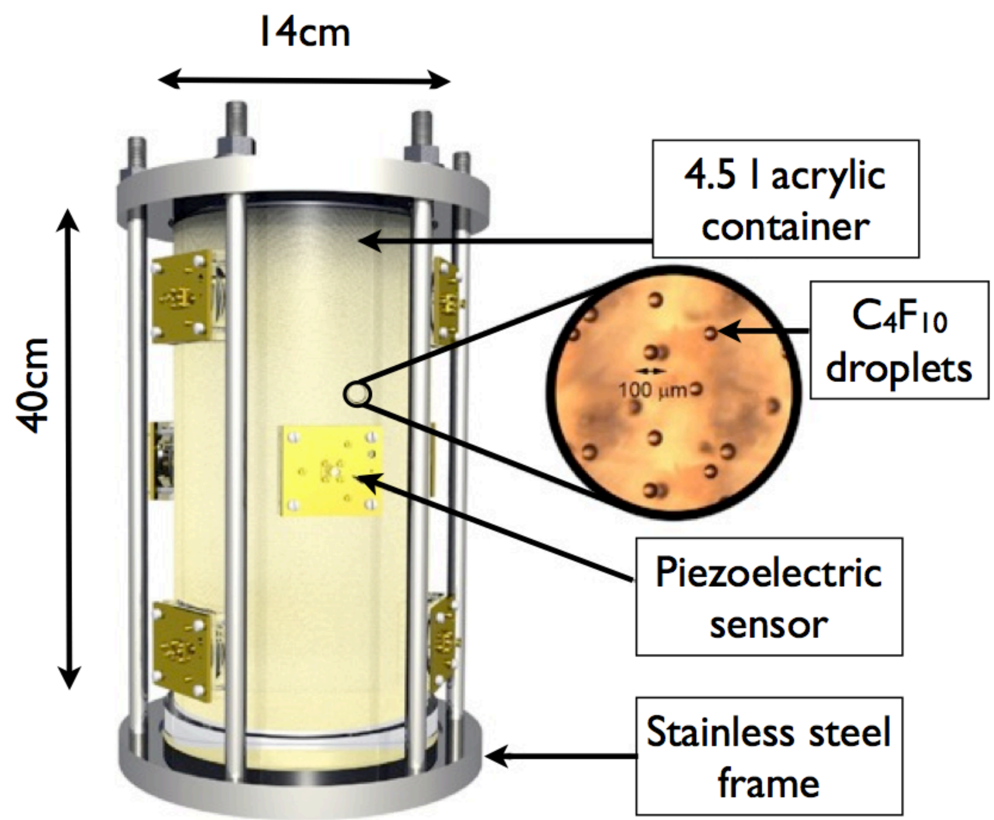
Martynyuk & Smirnova (1991)

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)



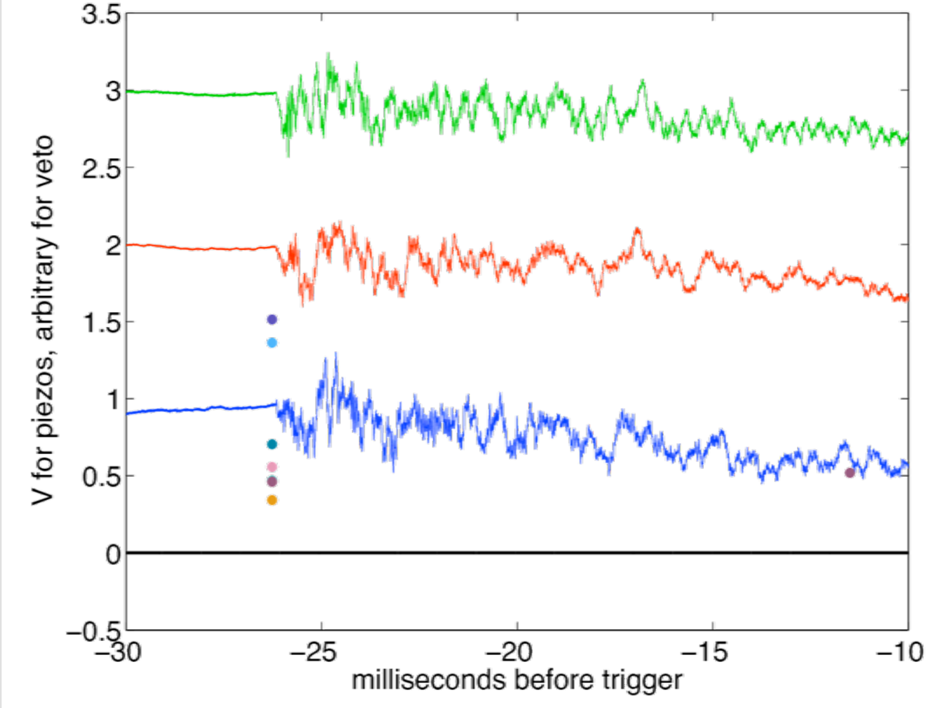


PICASSO demonstrates α – nuc. recoil acoustic discrimination in Superheated Droplet Detectors (SDDs)

F. Aubin *et al.*, New J. Phys 10 (2008) 103017

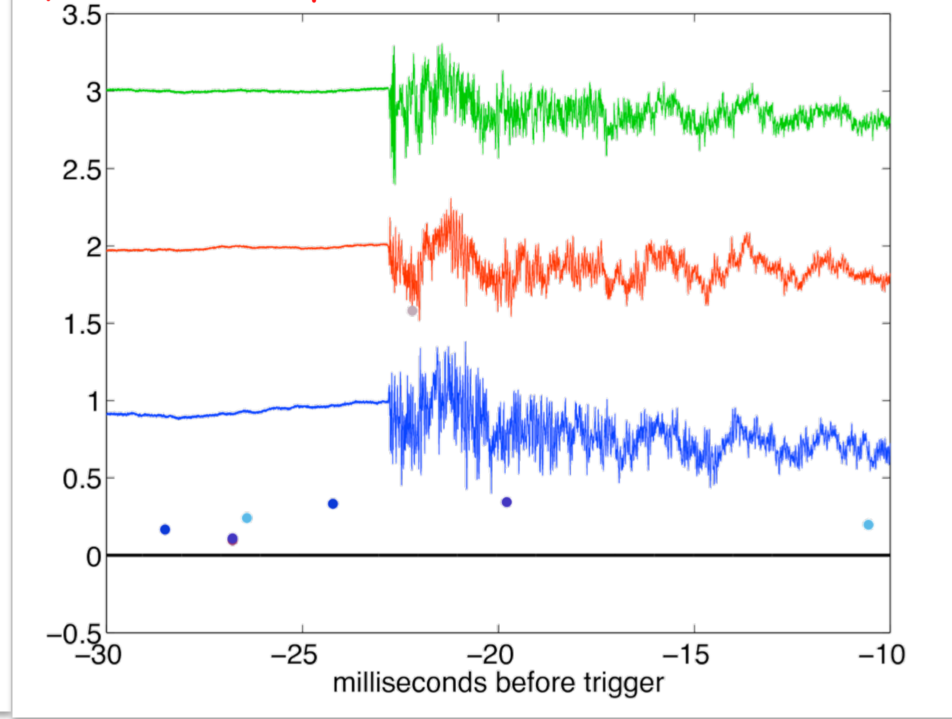
E-961 progress: acoustic alpha - nuclear recoil discrimination

Neutron



Phys. Rev. Lett., in press

Alpha



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)

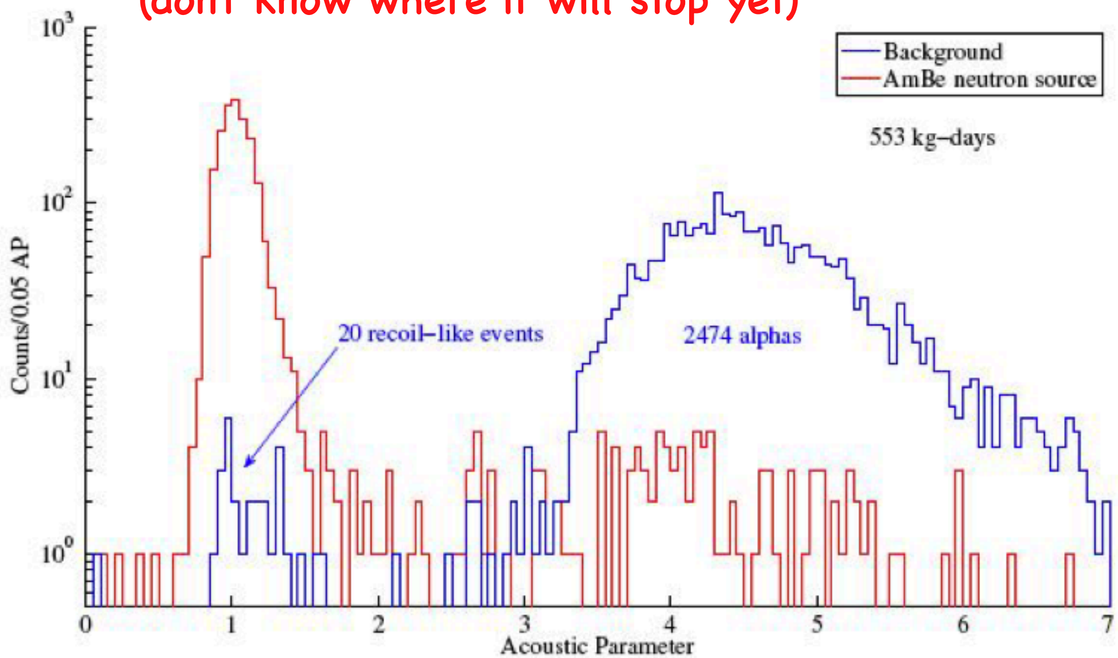
A zero-background experiment soon?

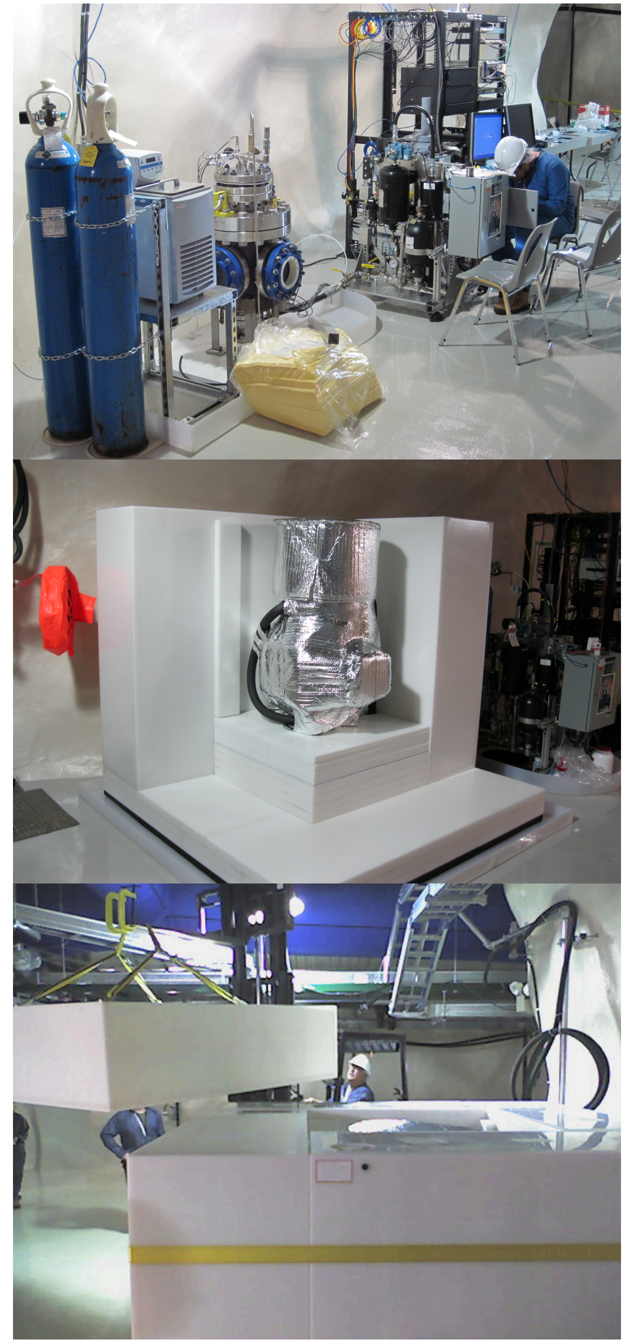
COUPP progress: acoustic alpha - nuclear recoil discrimination

SNOlab COUPP-4kg data

Gamma rejection >1E+10
(best in the field)

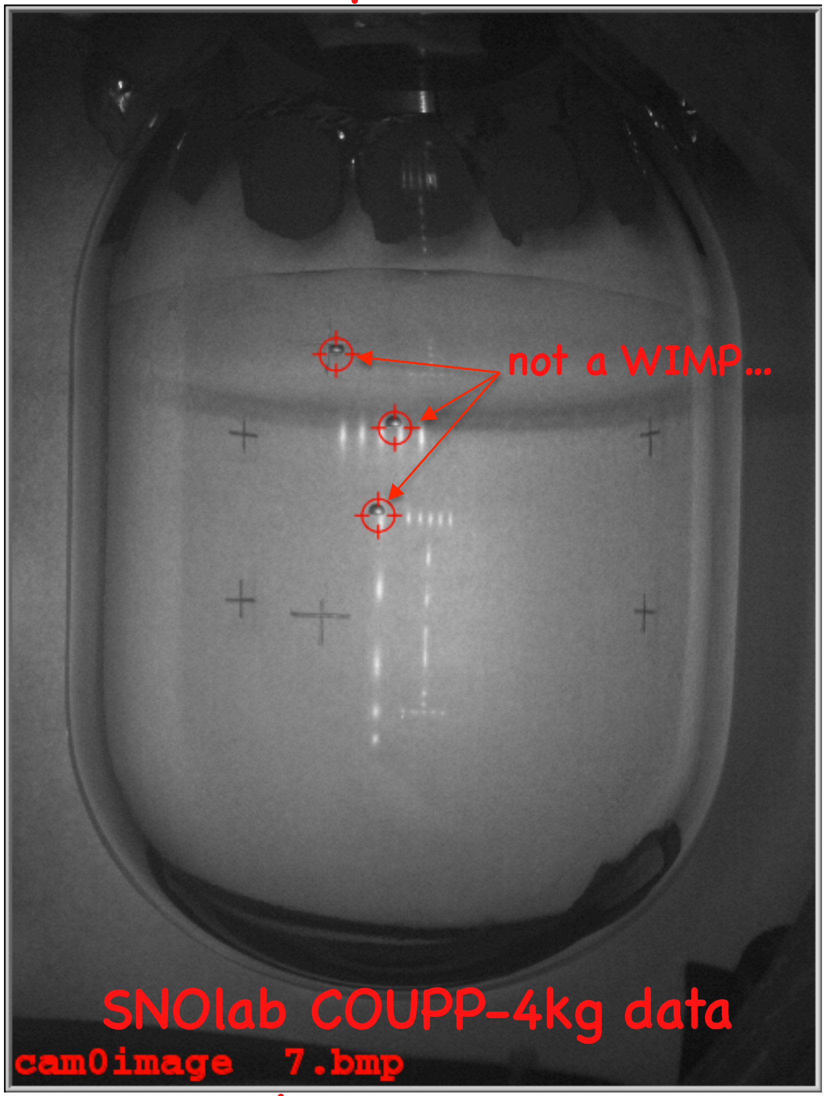
acoustic α rejection >>99.9%
(don't know where it will stop yet)

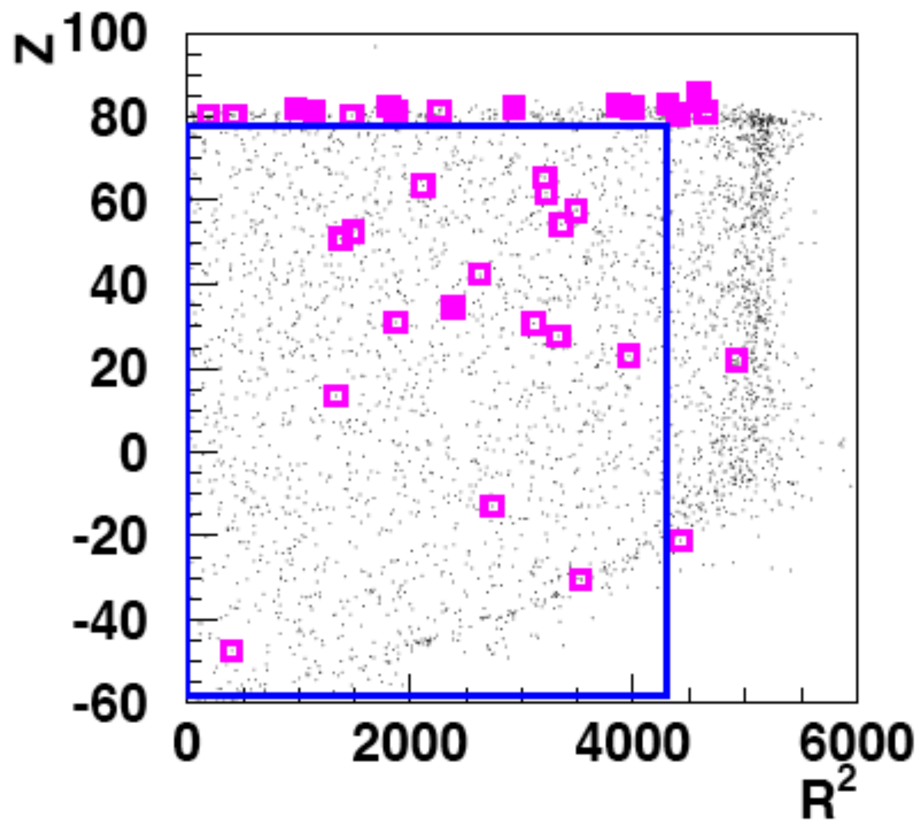




Light-WIMP sensitivity around the corner.

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



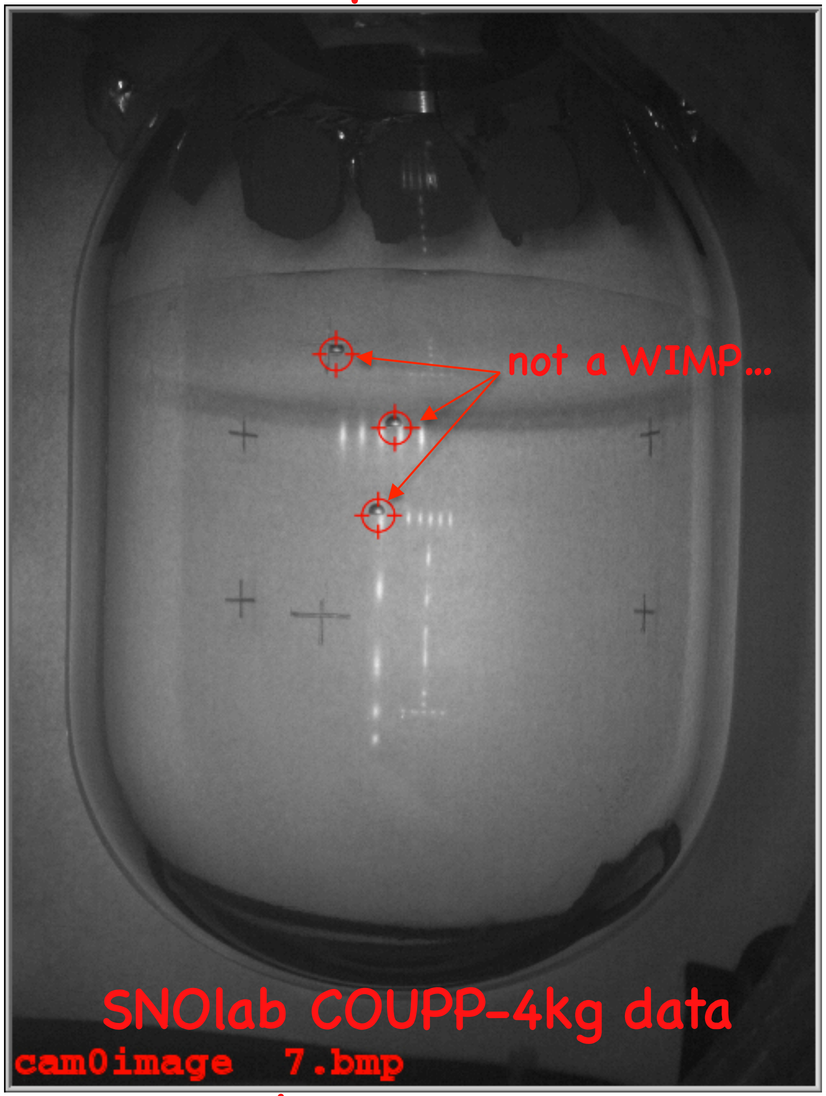


COUPP’s dubious distinction:
first DM experiment to see (α,n) neutrons

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"



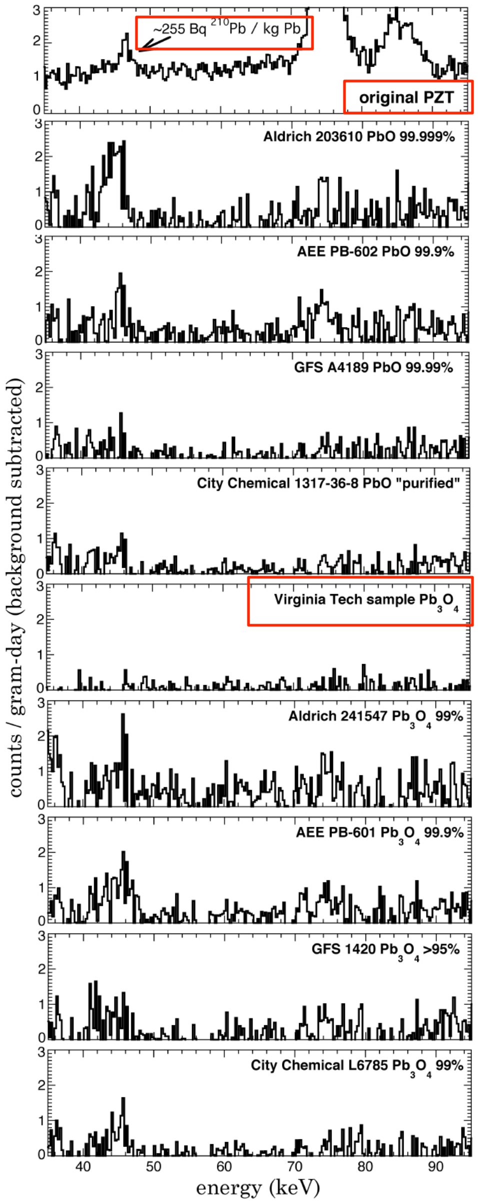
COUPP's dubious distinction:

first DM experiment to see (α,n) neutrons

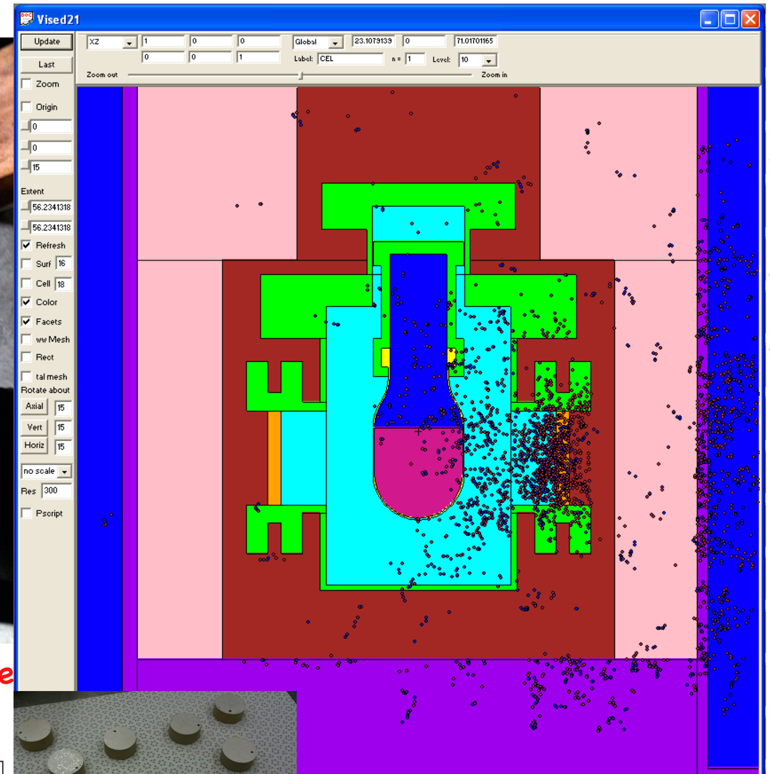
WIMP searches: a quixotic fight against backgrounds

Six-month screening & simulation campaign

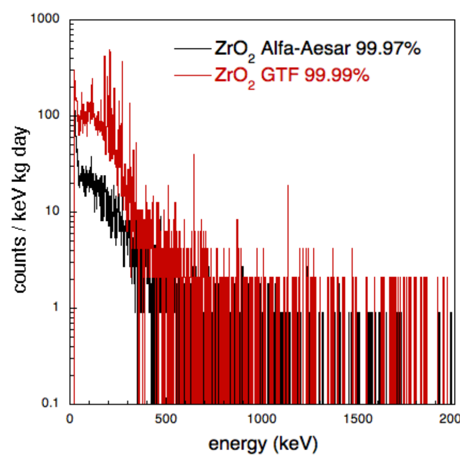
(leading to expected factor >200 improvement to present (α,n) activity)



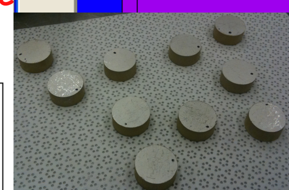
Pb-210 screening in PZT Pb oxide (low-bckg HPGe "well" detector)



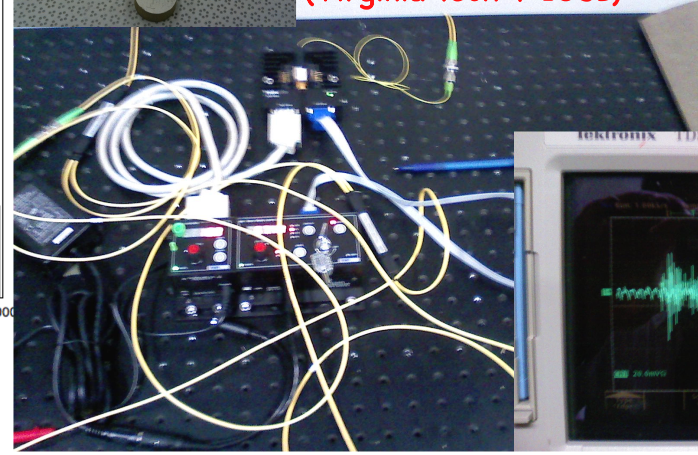
SOURCES + MCNP-Polimi (α,n) + fission simulations using screened activities



U, Th, Pb-210 screening (UC+SNOlab)



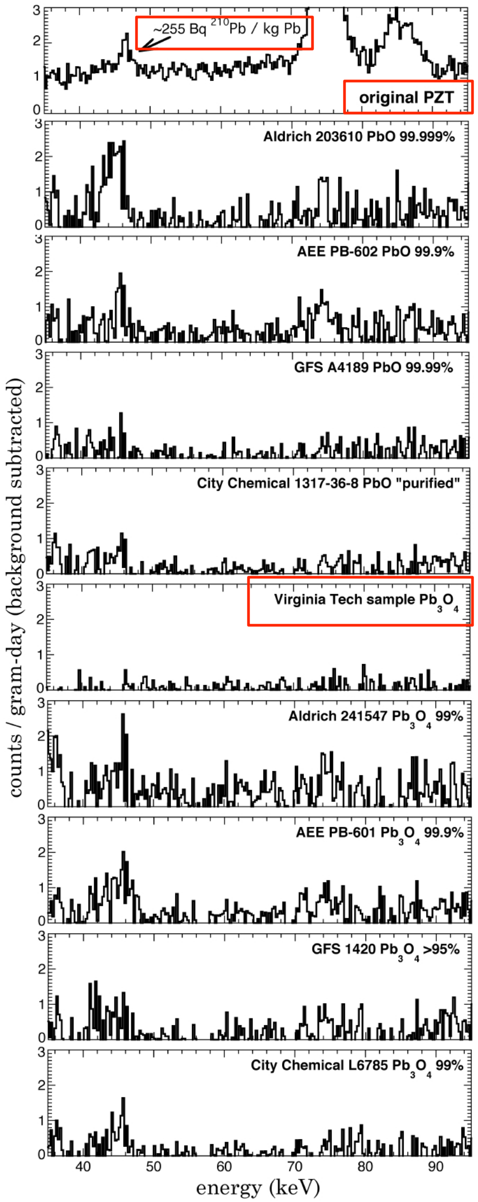
Radioclean PZT piezos (Virginia Tech + IUSB)



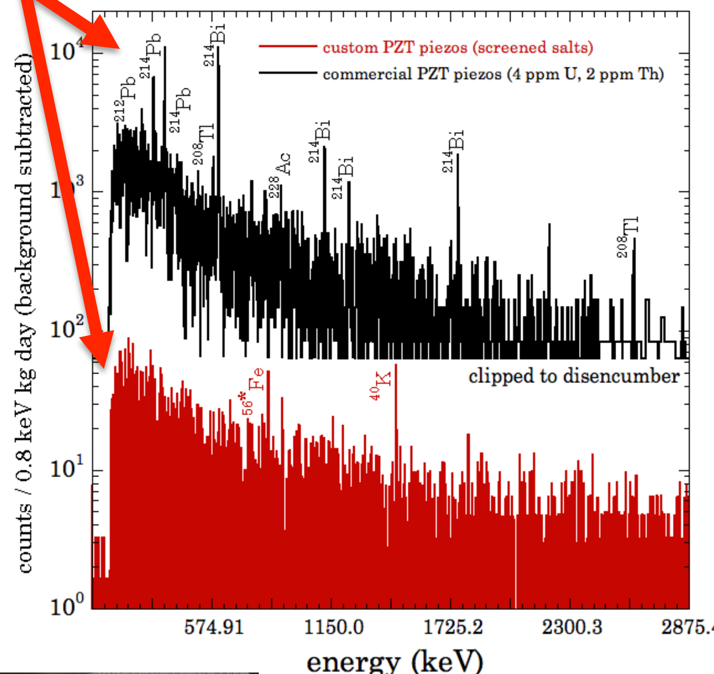
Remote acoustic sensing via Mach-Zender interferometry (FNAL)

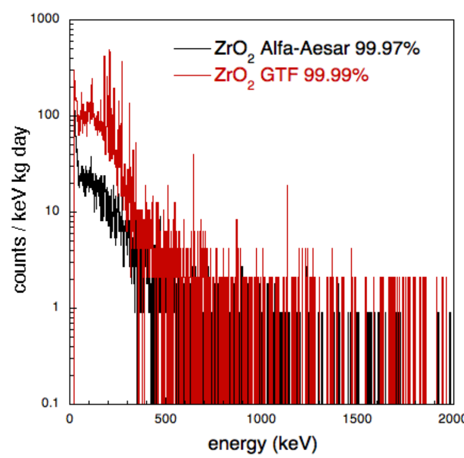
Six-month screening & simulation campaign

(leading to expected factor >200 improvement to present (α,n) activity)



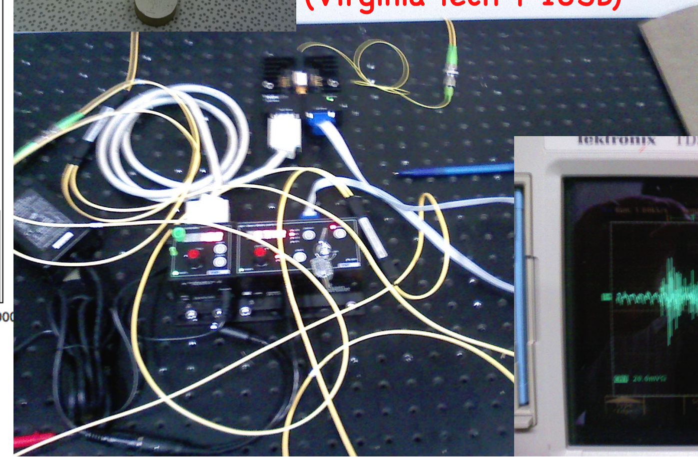
Pb-210 screening in PZT Pb oxide (low-bckg HPGe "well" detector)

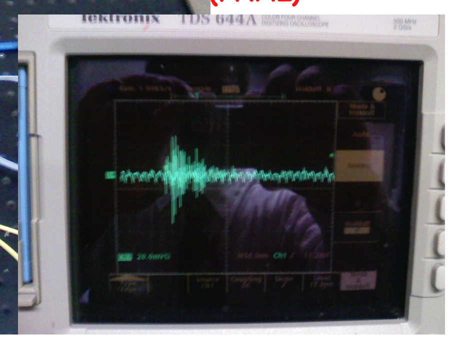




U, Th, Pb-210 screening (UC+SNOlab)

Radioclean PZT piezos (Virginia Tech + IUSB)



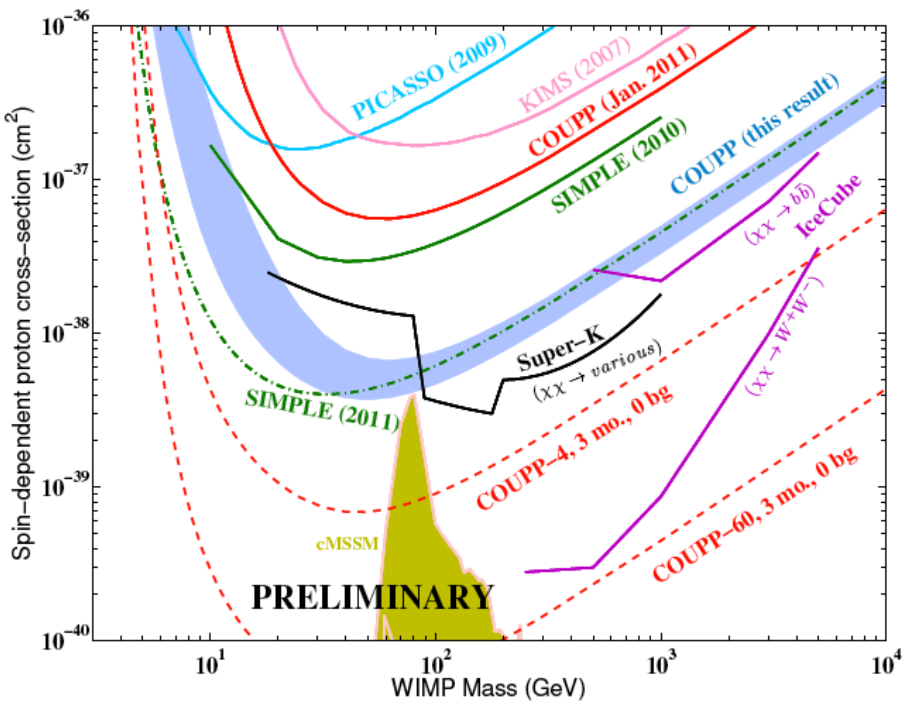


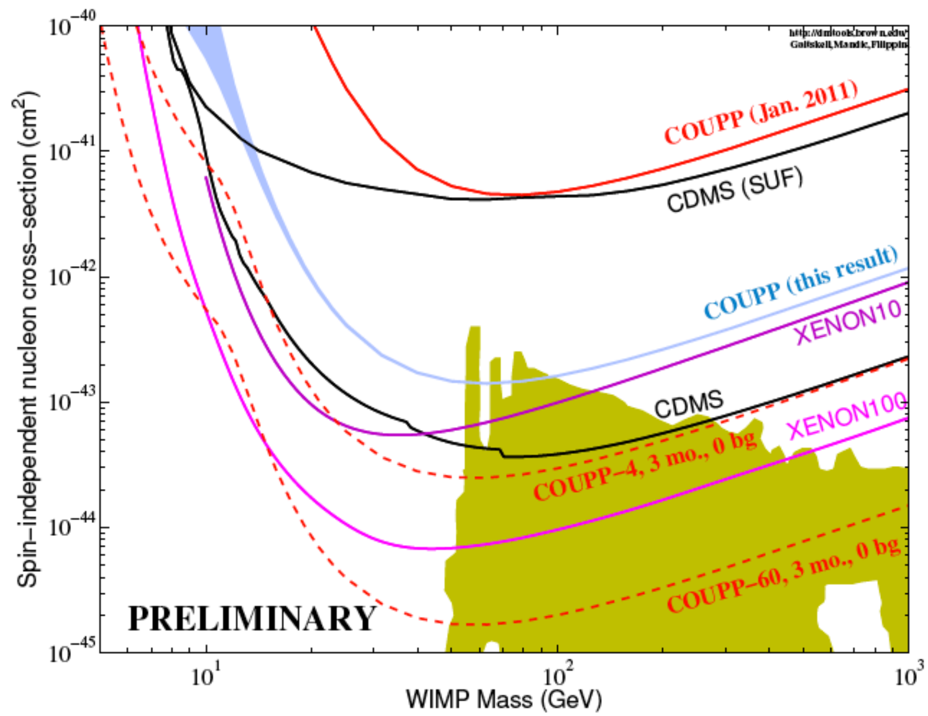
Remote acoustic sensing via Mach-Zender interferometry (FNAL)

Next physics goal:

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)

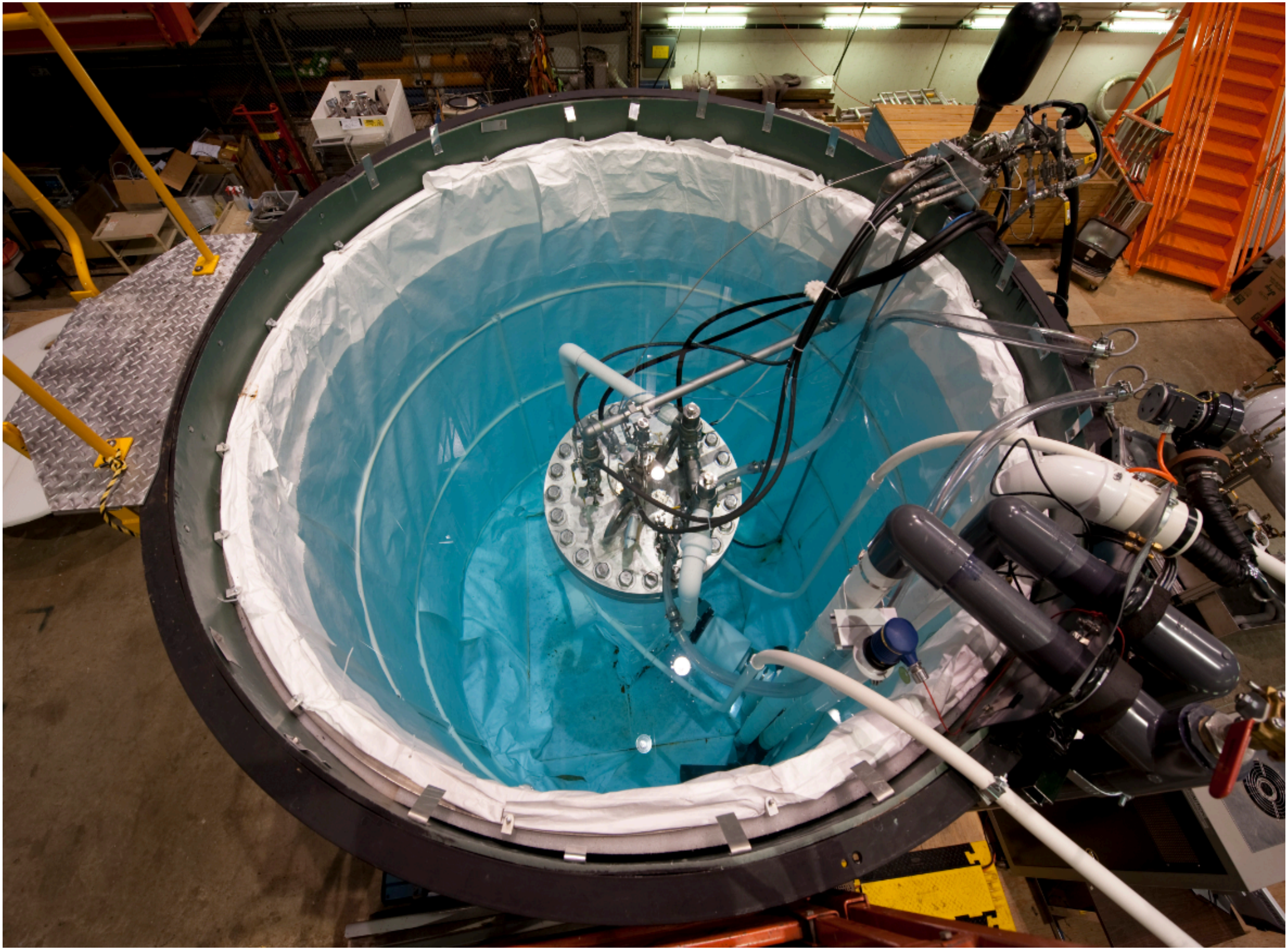


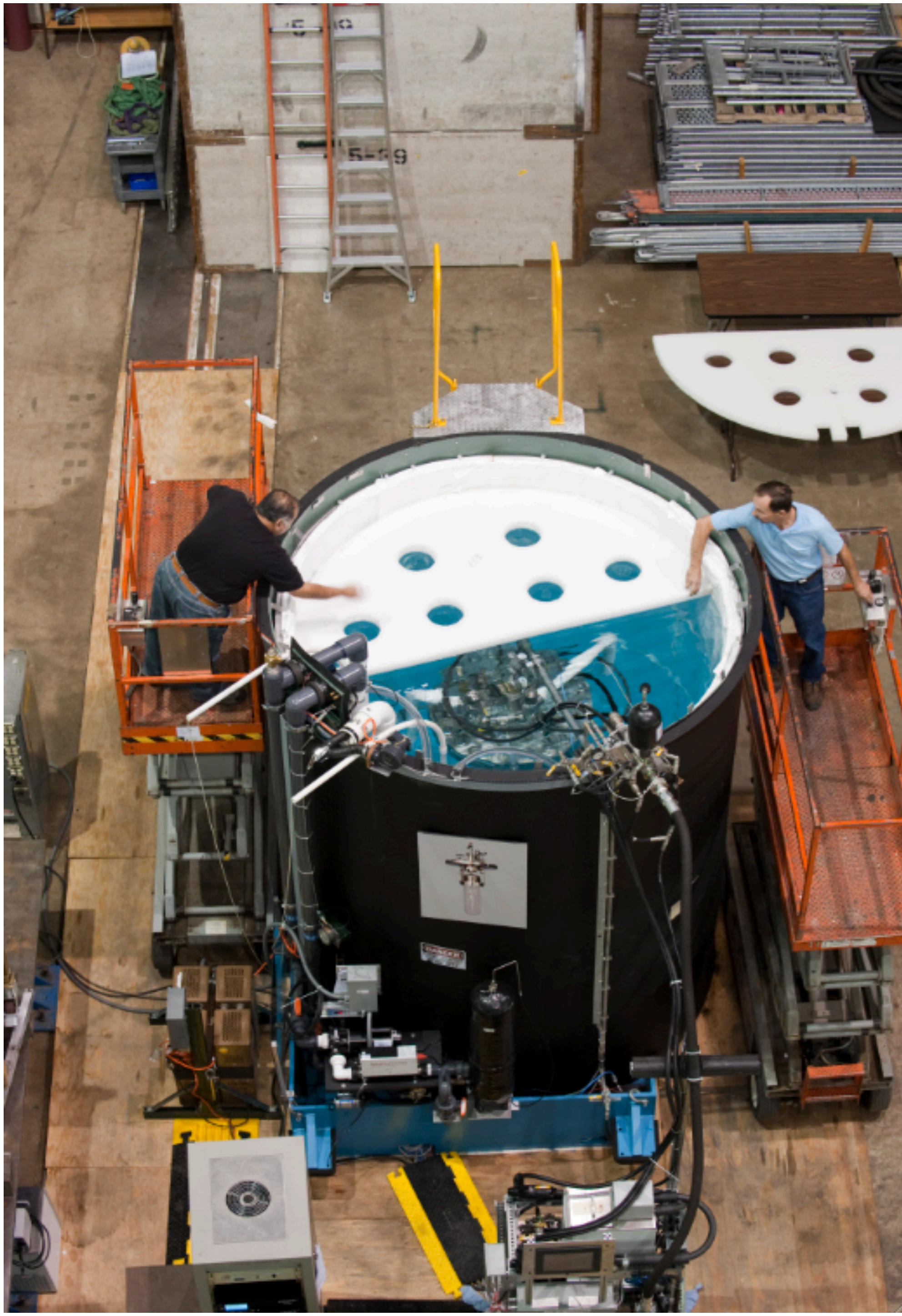


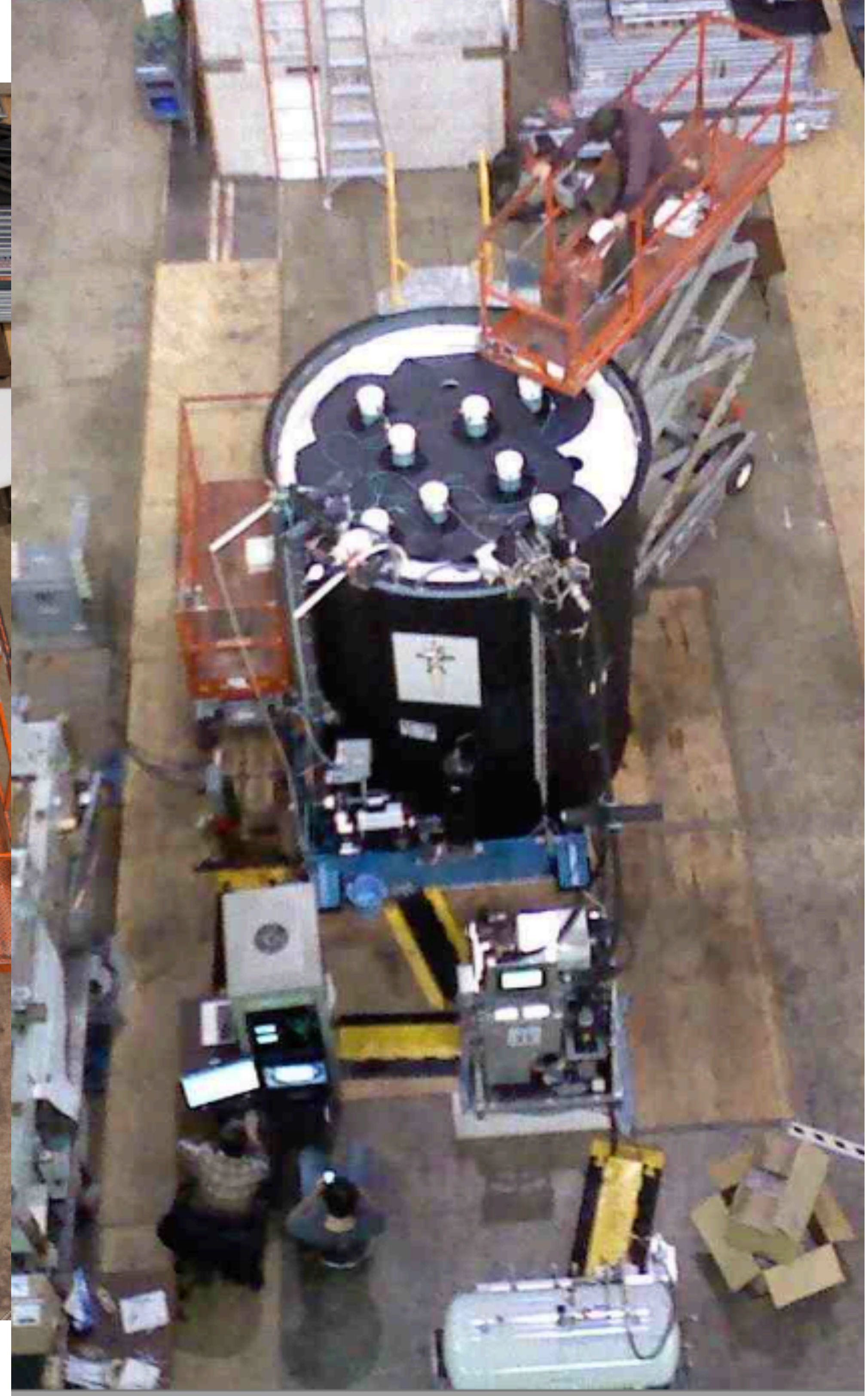
We expect COUPP to be at the forefront of *both* SD and SI WIMP searches during 2011/2012.

(New paper in preparation with new limits above and description of (α,n) abatement)

60kg chamber construction & testing







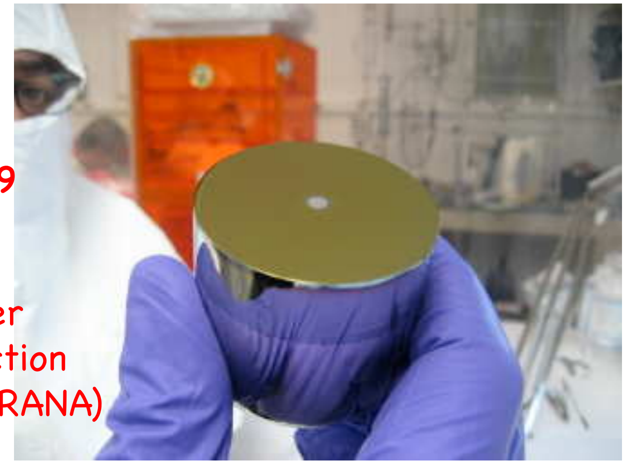
CoGeNT:

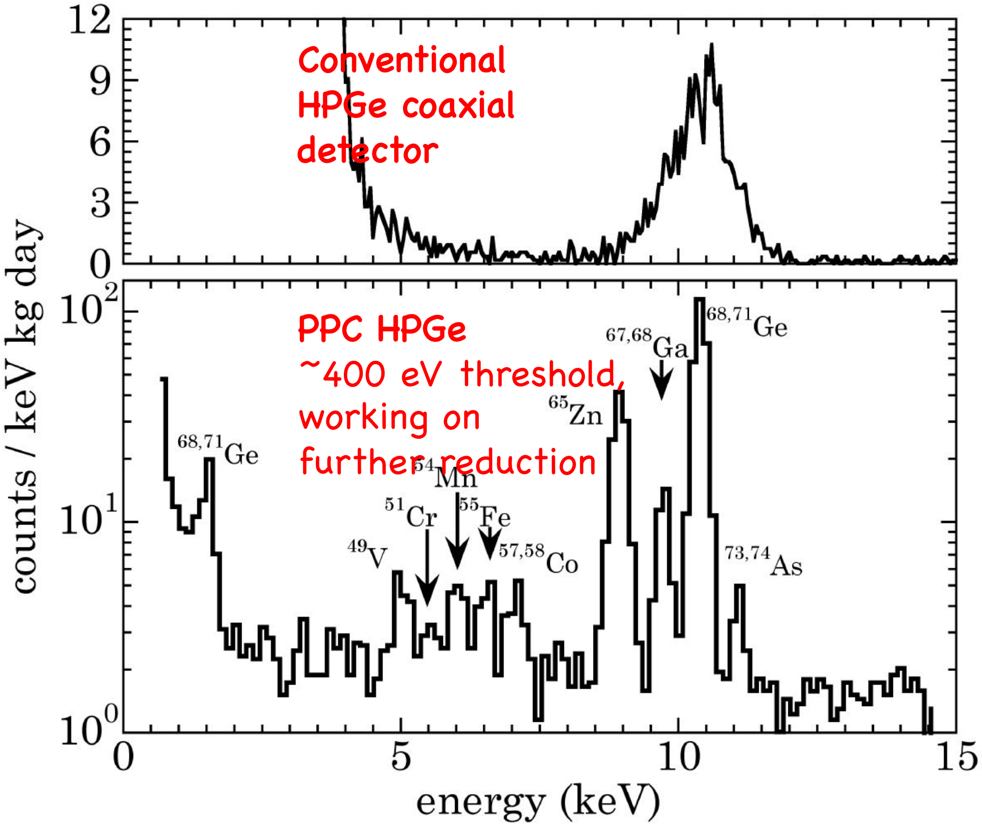
neutrino &
astroparticle physics
using large-mass,
ultra-low noise
germanium detectors
(CANBERRA, PNNL, ORNL, UC, UNC, UW)

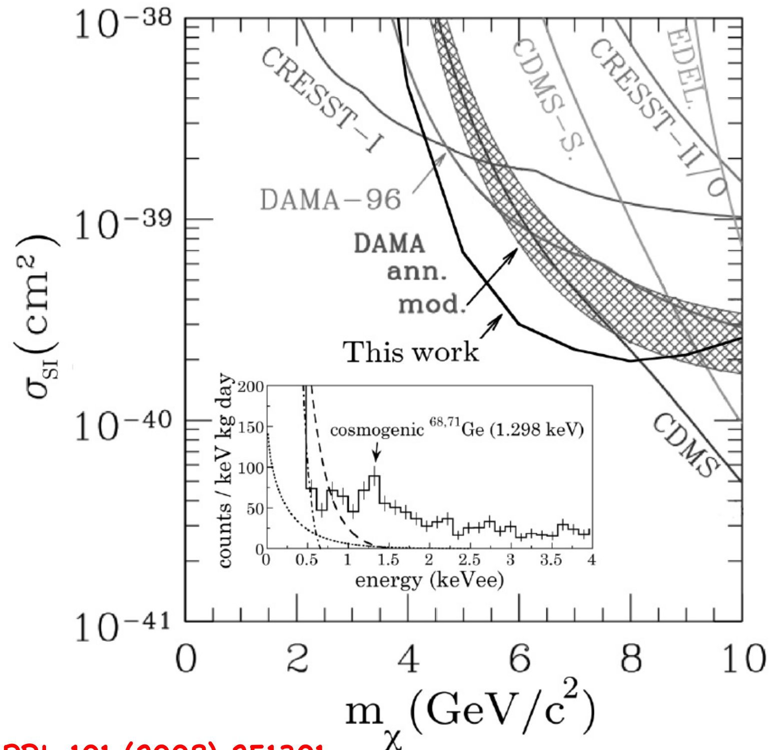
PPC HPGe

JCAP 09(2007)009

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







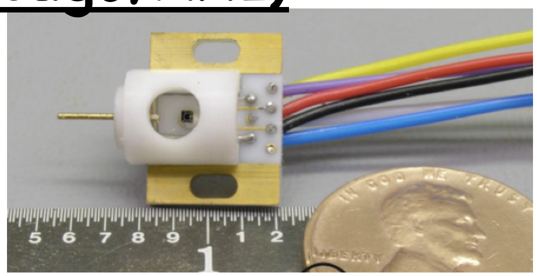
PRL 101 (2008) 251301

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

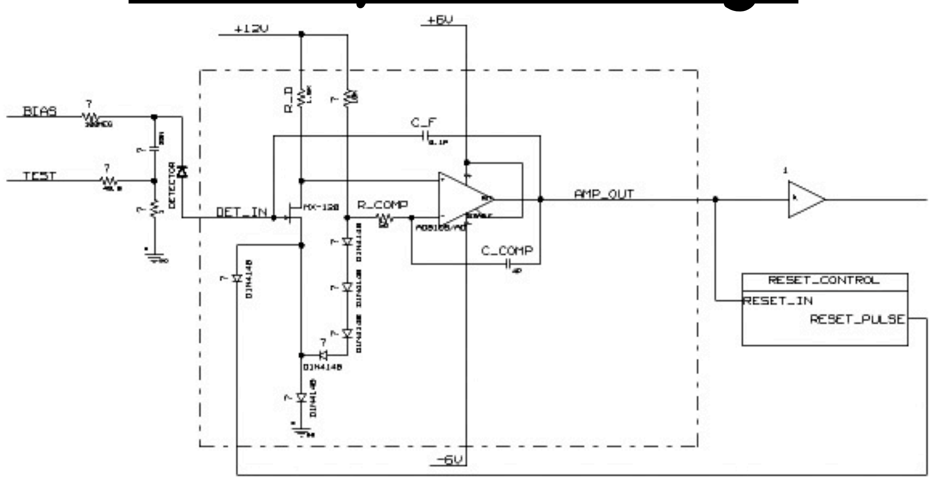
Front End Electronics (Majorana)

Pulse Reset

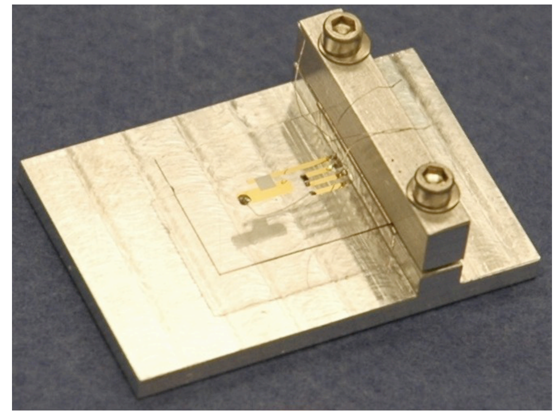
COGENT front ends (U Chicago/ANL)



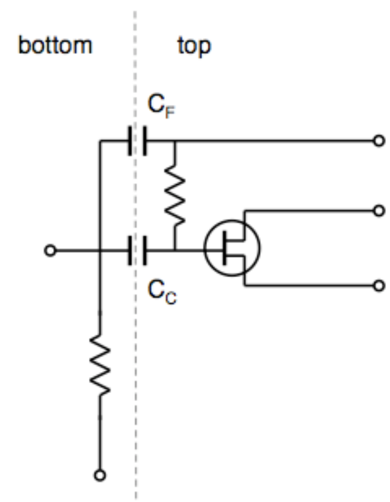
UW "Hybrid" Design



Resistive Feedback



LBNL Design

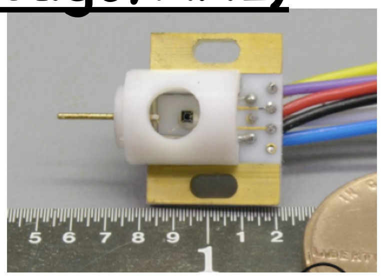


Front End Electronics (Majorana)

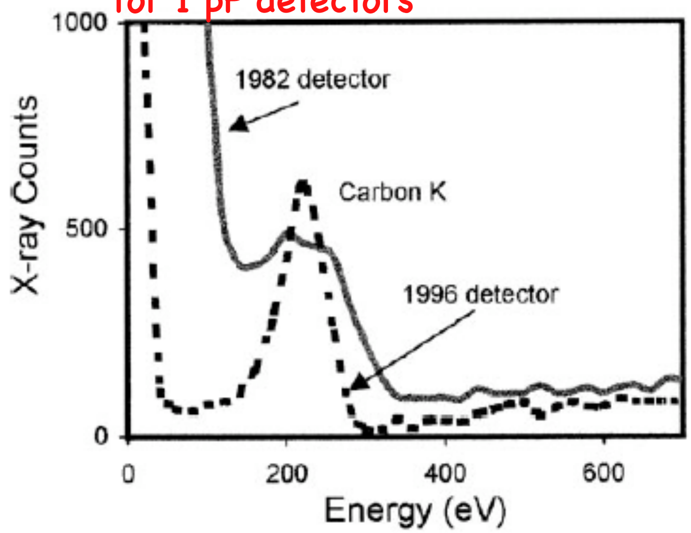
Pulse Rese

COGENT front ends

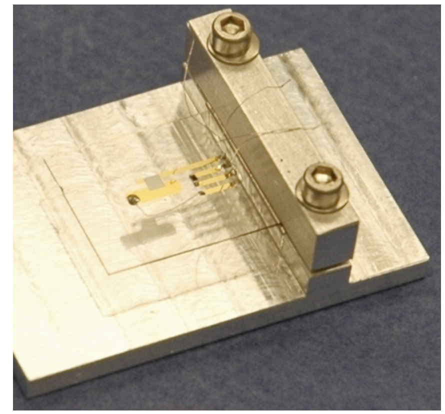
(U Chicago/ANL)

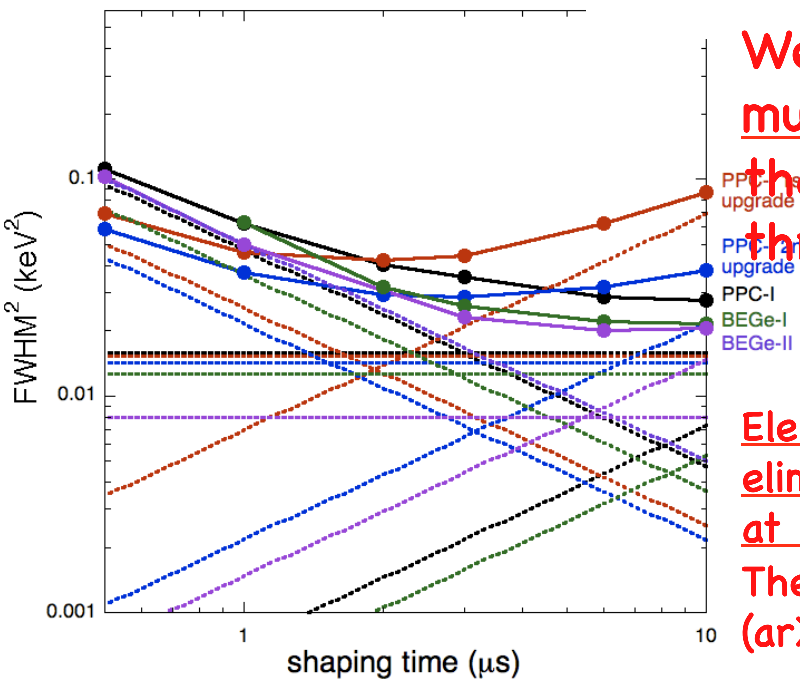


State-of-the-art
for 1 pF detectors



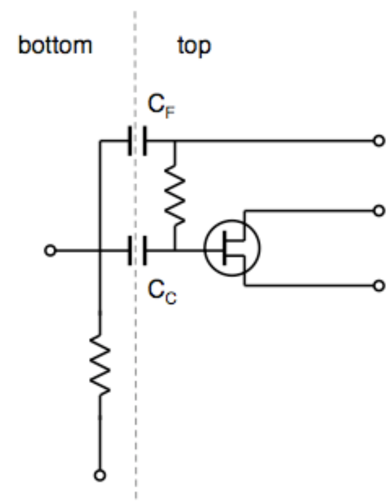
istive Feedback





We can do much better than 0.4 keV thresholds

LBNL Design

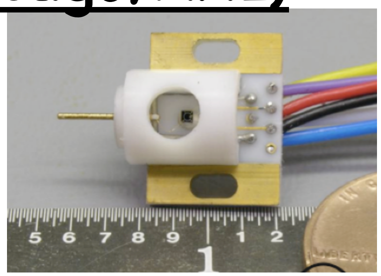


Electronic noise must be eliminated
at the hardware level.
There is no other way around it
(arXiv:0806.1341)

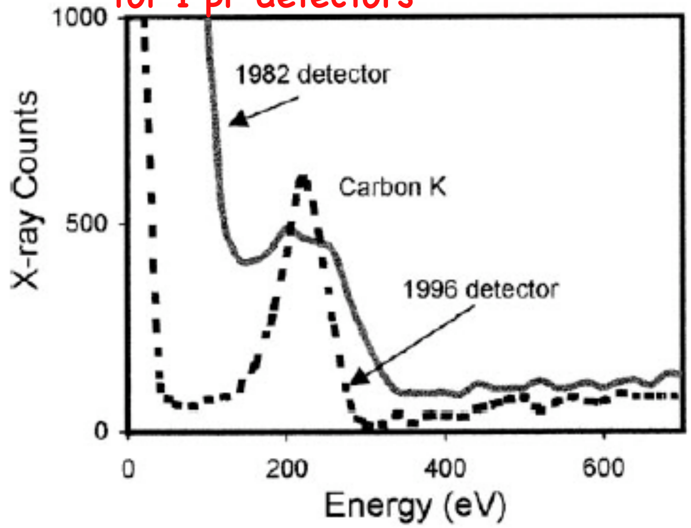
Front End Electronics (Majorana)

Pulse Rese

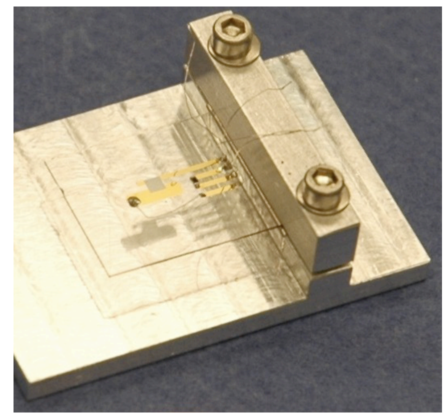
COGENT front ends
(U Chicago/ANL)

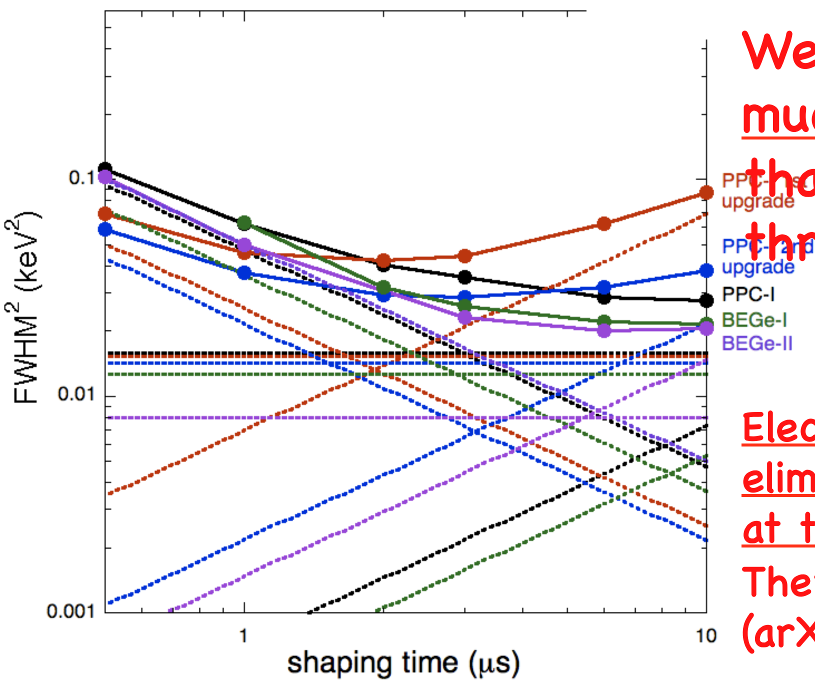


State-of-the-art
for 1 pF detectors



istive Feedback





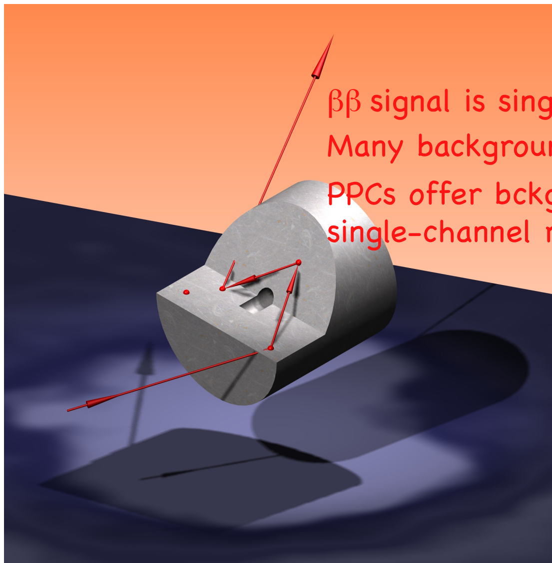
We can do
much better
than 0.4 keV
thresholds

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

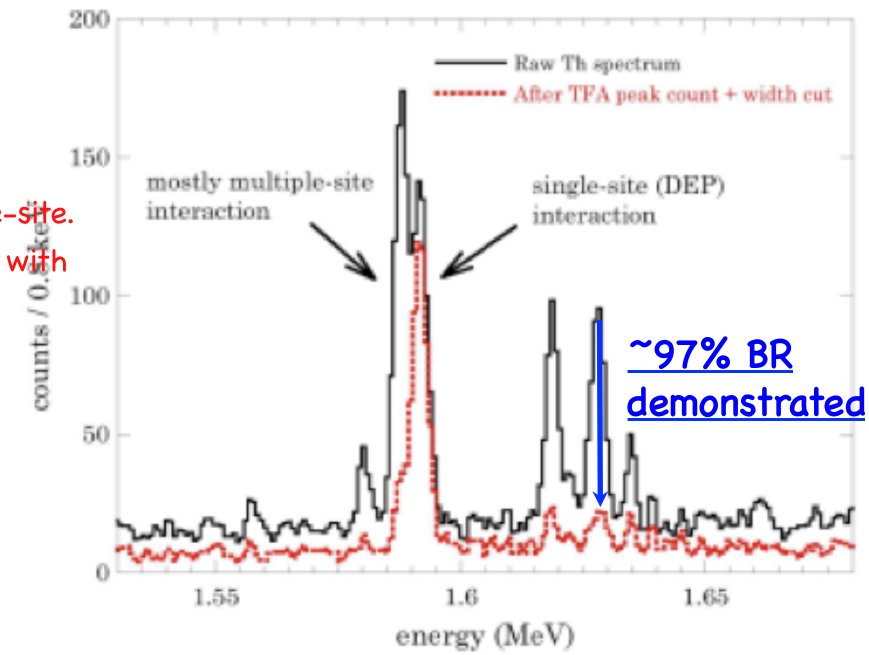
bottom | top

In case fighting backgrounds
wasn't enough...

MAJORANA PPCs



ββ signal is single-site.
Many backgrounds are multiple-site.
PPCs offer bckg discrimination with single-channel readout.



~97% BR demonstrated

Detectors studied / in hand:

(table actually missing quite 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)

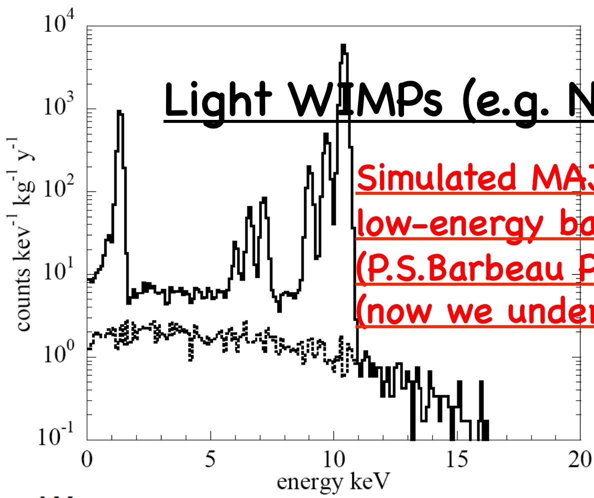
~30 PPCs already characterized and stored for 60kg MAJORANA demonstrator

Crystal storage underground

GERDA switching to PPCs for 2nd phase

MAJORANA as a DM detector

(see Monday talk by G. Giovanetti)

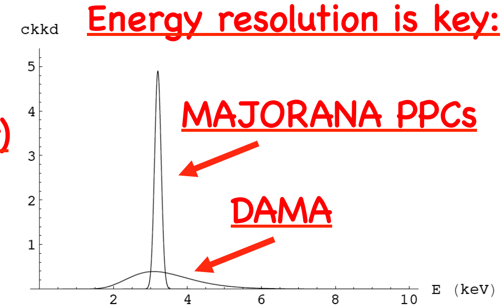


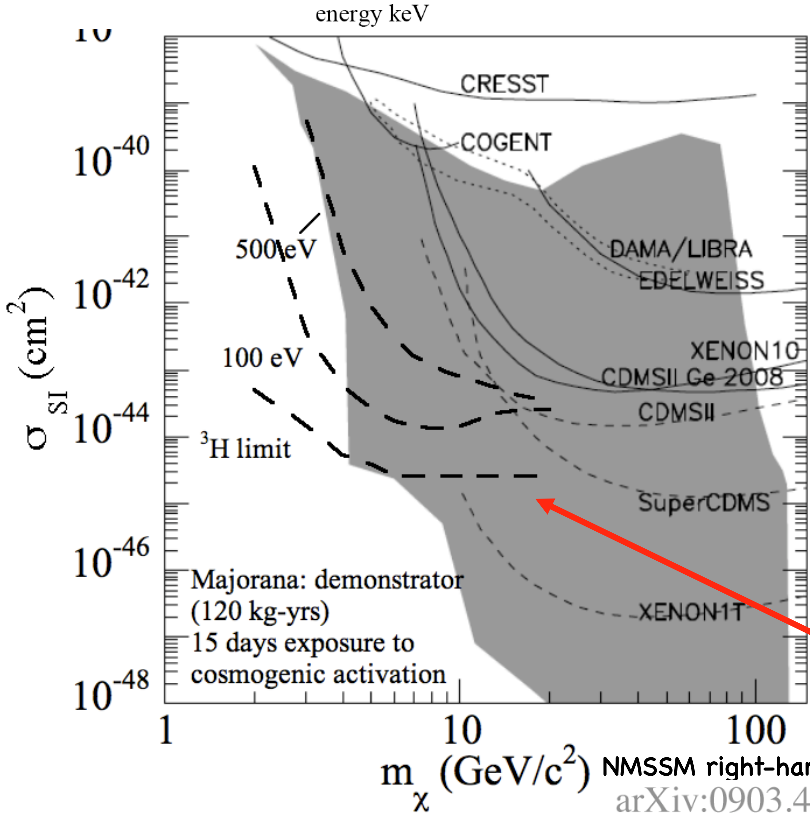
Light WIMPs (e.g. NMSSM)

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

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

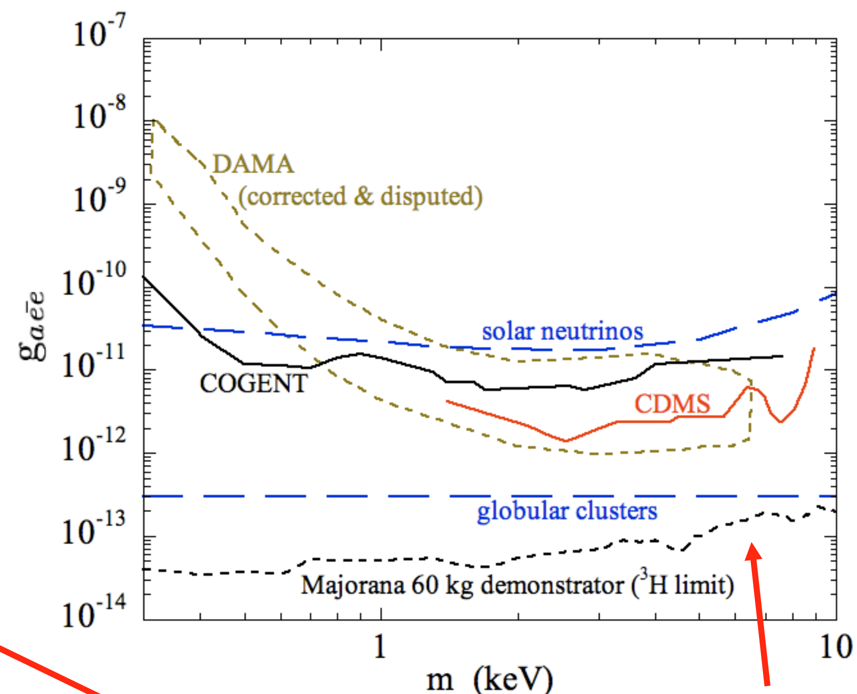
Energy resolution is key:





NMSSM right-handed sneutrino

arXiv:0903.4677v1



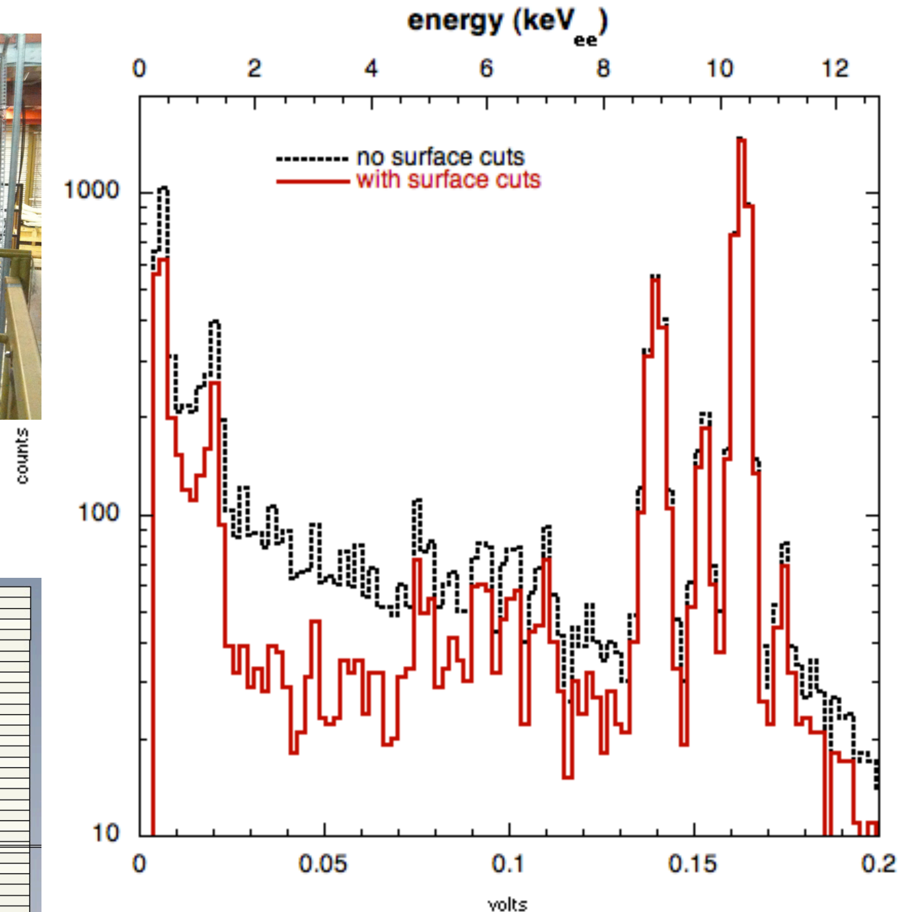
Possibility of reaching ³H limit much nearer now with surface event rejection

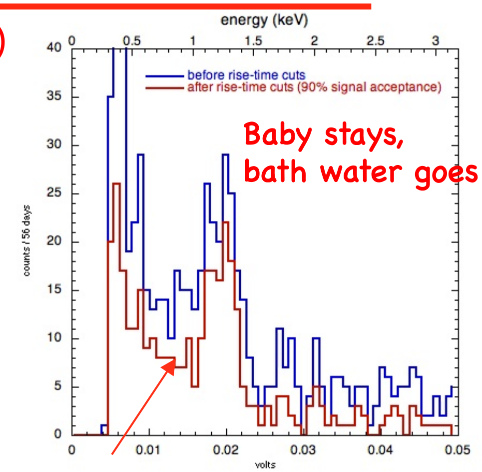
Making an excellent detector even better:

PPCs can reject surface events using rise-time cuts

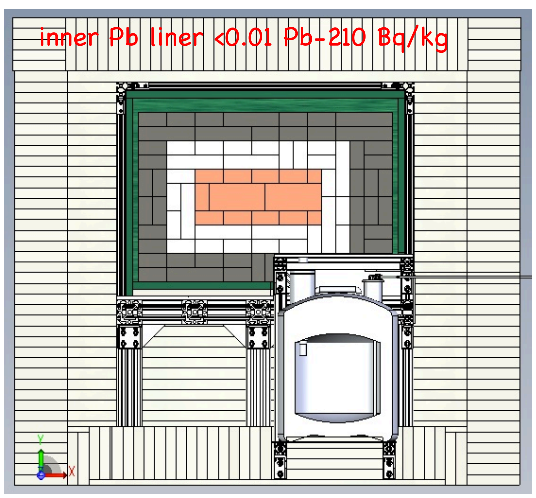
Based on a phenomenon ~40 years old (embarrasing!)

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

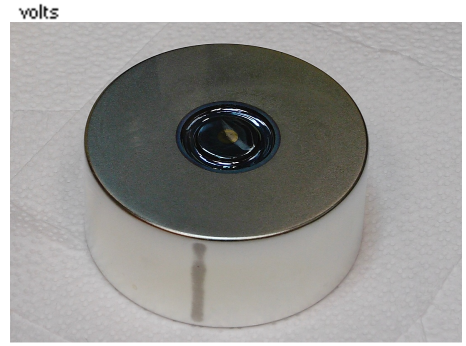


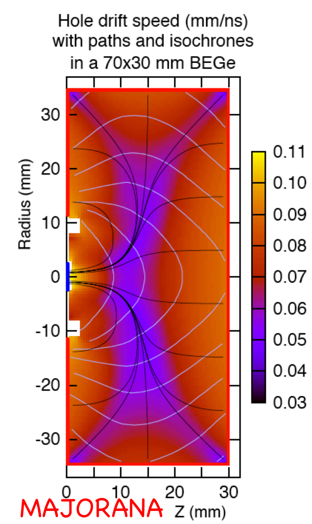


Bulk signal acceptance monitored down to 1 keVee via L/K EC peak ratios and pulser calibrations.
Working on characterizing surface background rejection (large exposure required).



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





Charge Collection time modelled (small 100 ns correction)

MAJORANA BEGe (ORNL simulation)

An old “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).

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

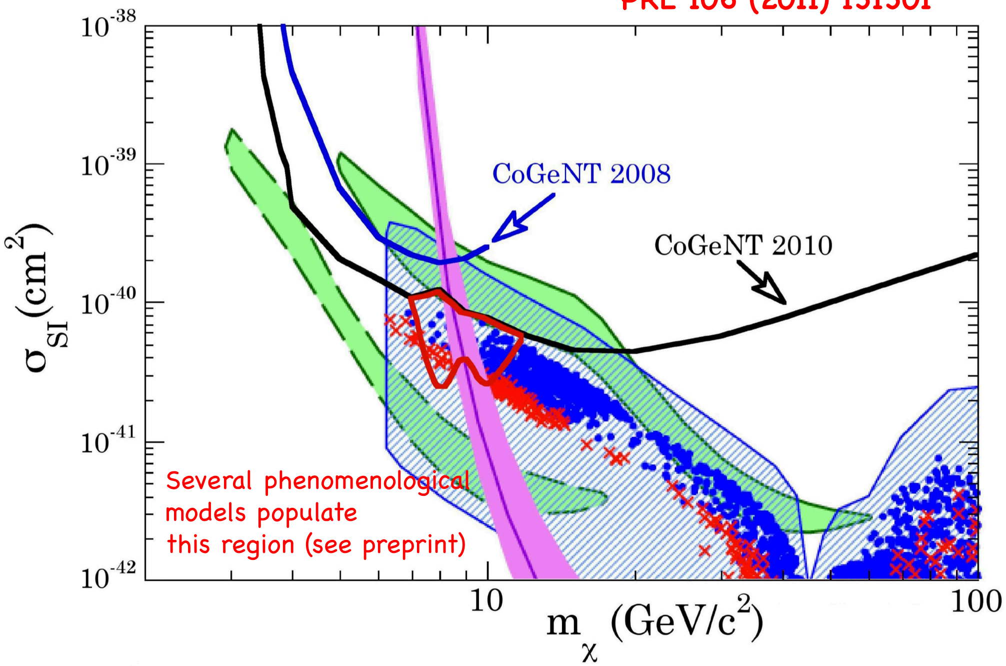
- We presently cannot find an obvious known source. But we can fancy some unexplored possibilities. It is not neutrons, and there is no evidence yet of detector contamination.

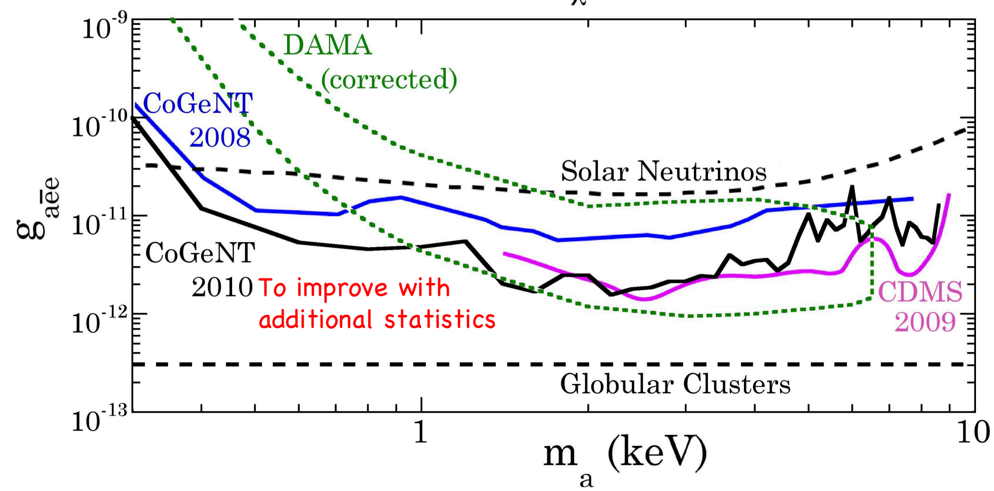
- The low-E excess is composed of asymptomatic **bulk-like** events (very different from electronic noise), coming in at a ~constant rate.

- The possible subject of interest is where we “got stuck” in phase space (a number of curious coincidences there), for a spectrum where most surface events are removed (<- major contributors to low-energy spectrum). Caveat Emptor: without DAMA, would we have models there?

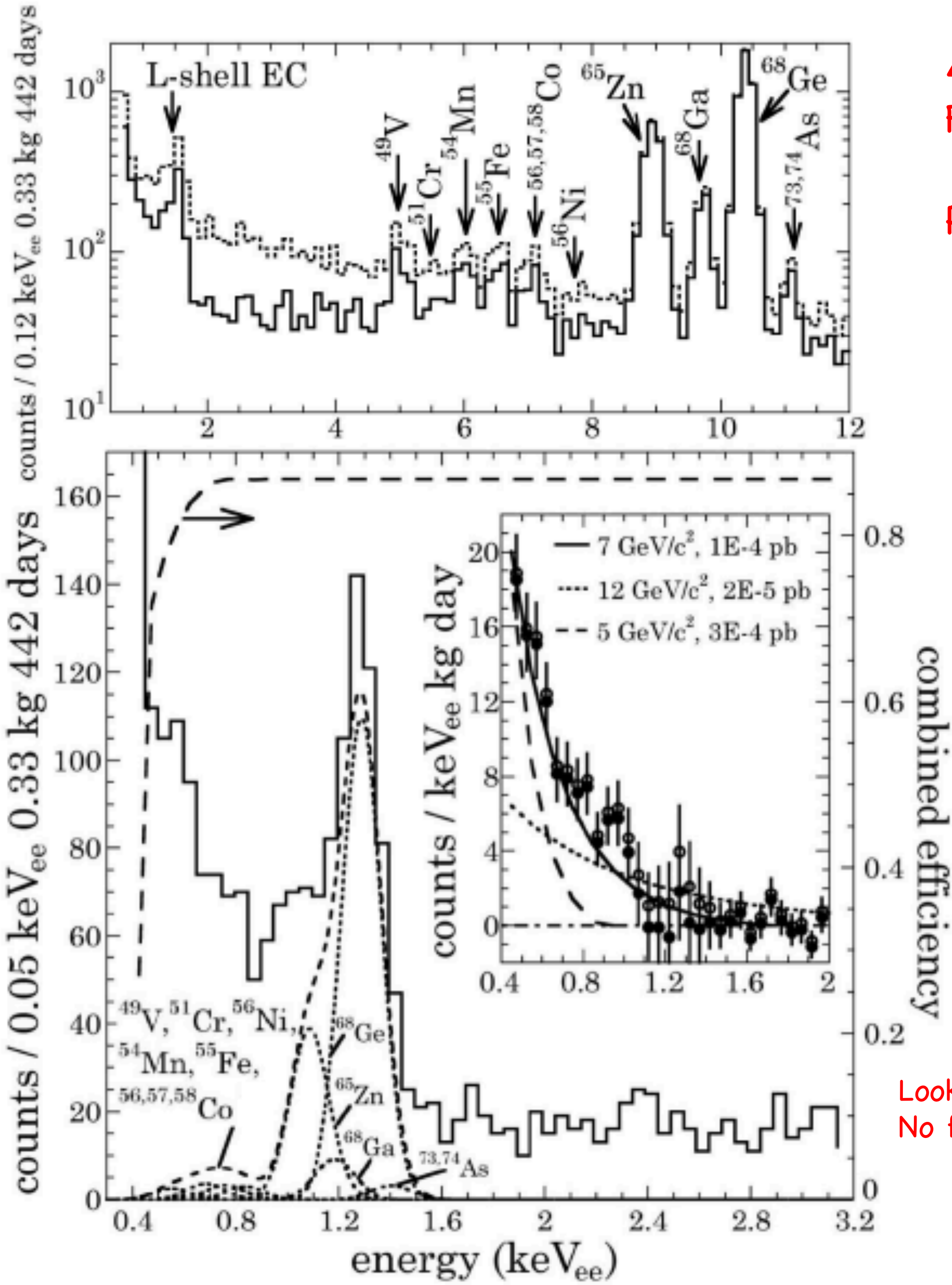
- We will attempt to strip the low-E data from known sources of background after a longer exposure, but all of them seem modest (see preprint). Planned additional calibrations will provide improved information on signal acceptance, background rejection and fiducial volume.

PRL 106 (2011) 131301





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



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

Phys. Rev. Lett. 107 (2011) 141301

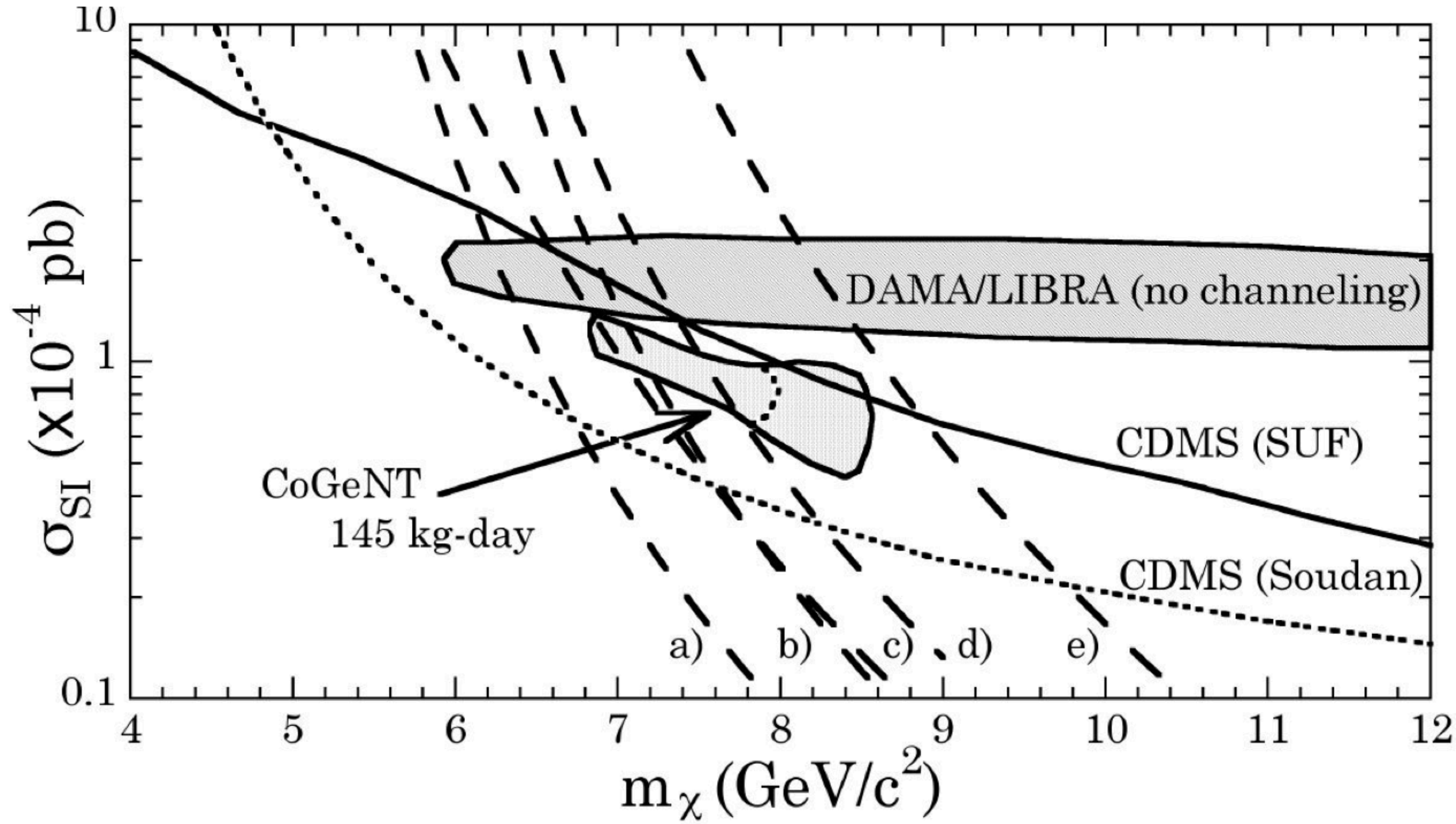
JOHN N. BAHCALL PHYSICAL REVIEW VOLUME 132, 1963

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

Look Ma!
No free-parameters!

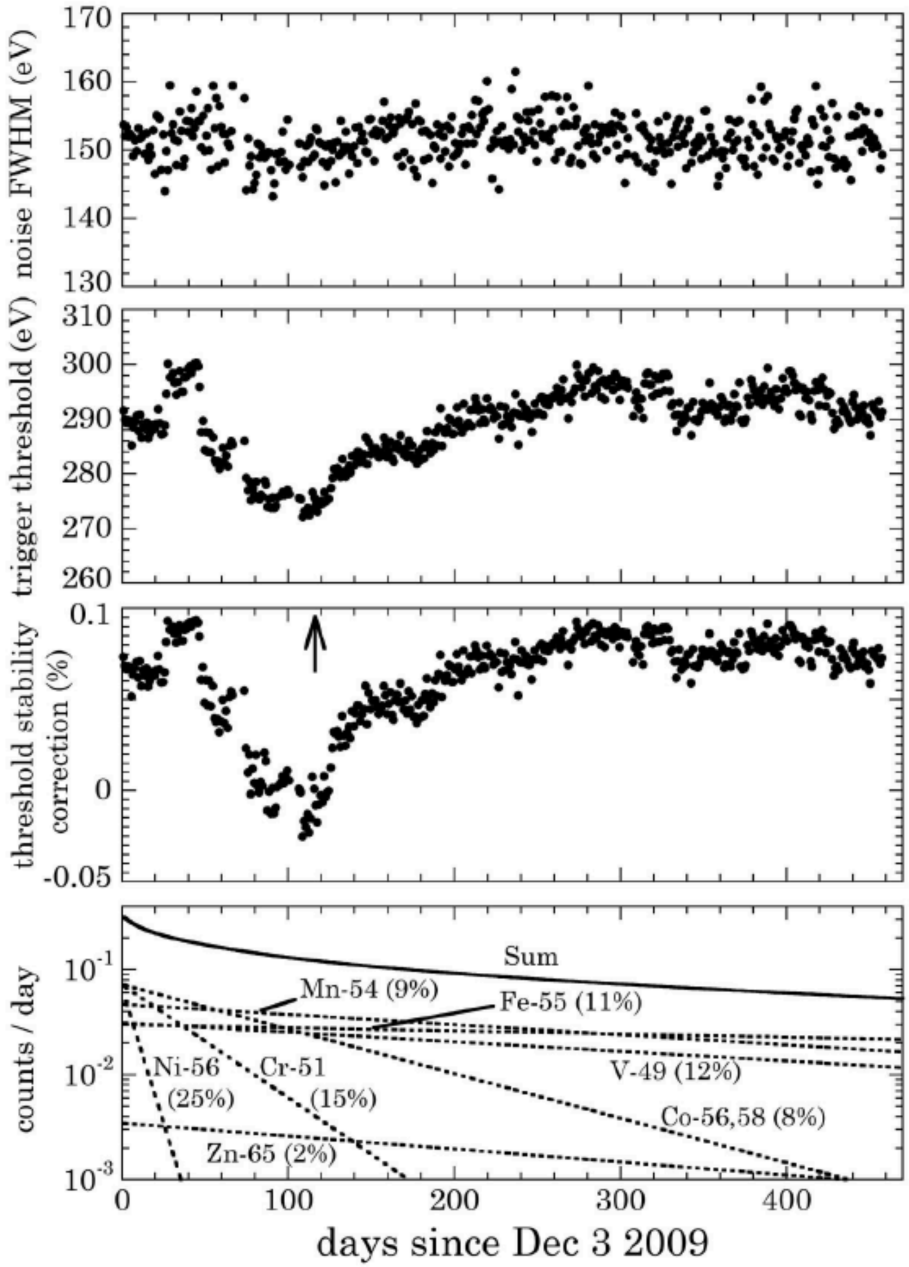
Everything was going well until March 17th (Soudan fire)…



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

- <u>Most CoGeNT uncertainties not included in this figure</u>

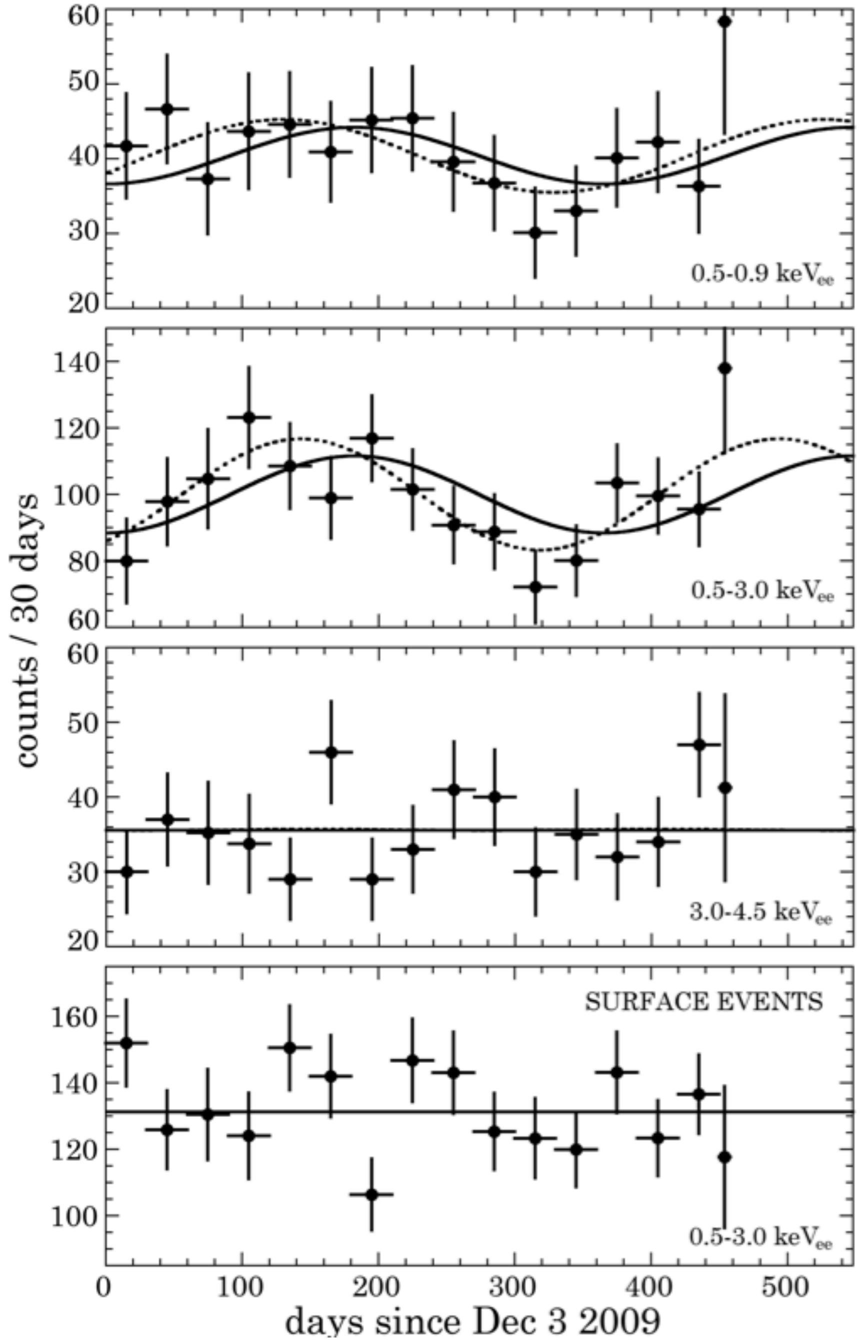
Everything was going well until March 17th (Soudan fire)…



- 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.

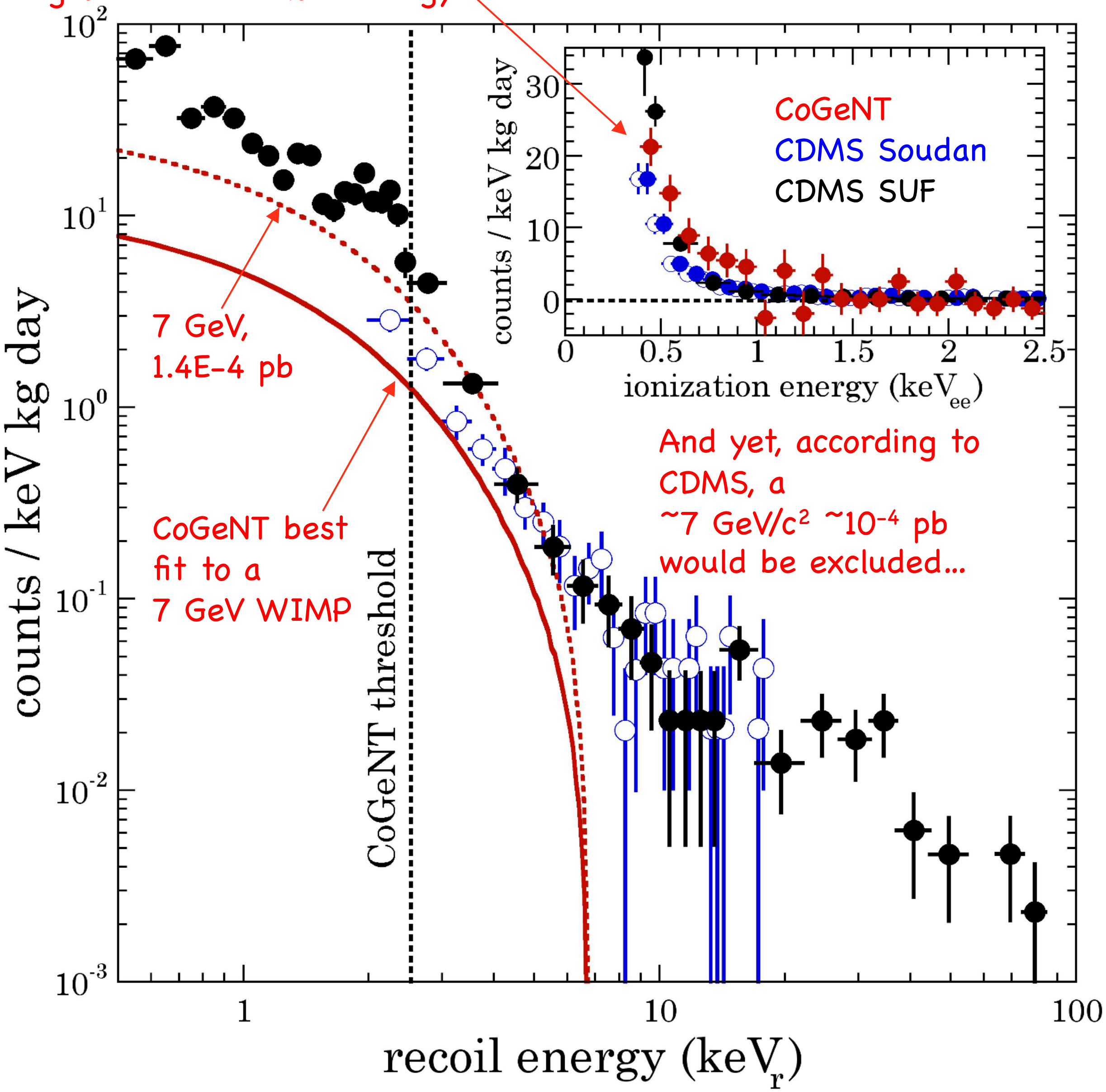
- Modulation absent for surface events and also at higher energies.

- Lots of independent interpretations via data-sharing, but a few are forgetting some basics. Hint: there must be reasons for the experimentalists to always include an exponential background in their models...

Can we make sense of the light-WIMP situation?

CoGeNT and CDMS arrive to similar irreducible spectra via <u>orthogonal</u> background cuts at low-energy

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 <u>in a single detector (T1Z5)</u>. An alternative CDMS analysis during a different period in Soudan finds a 70% larger irreducible low-E rate for it (!!), but this issue is absent for a second detector (T1Z2).

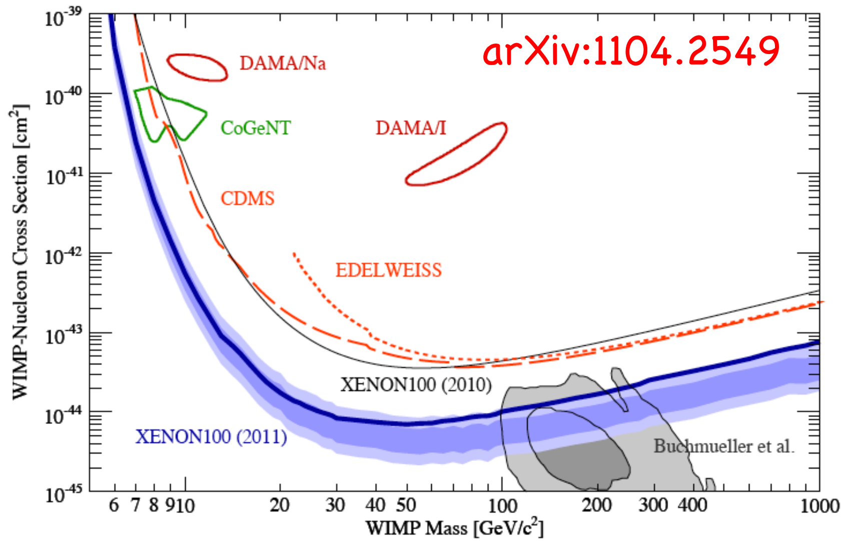
<u>Is T1Z5 stable enough? What is the uncertainty in these limits from the choice of cuts?</u>

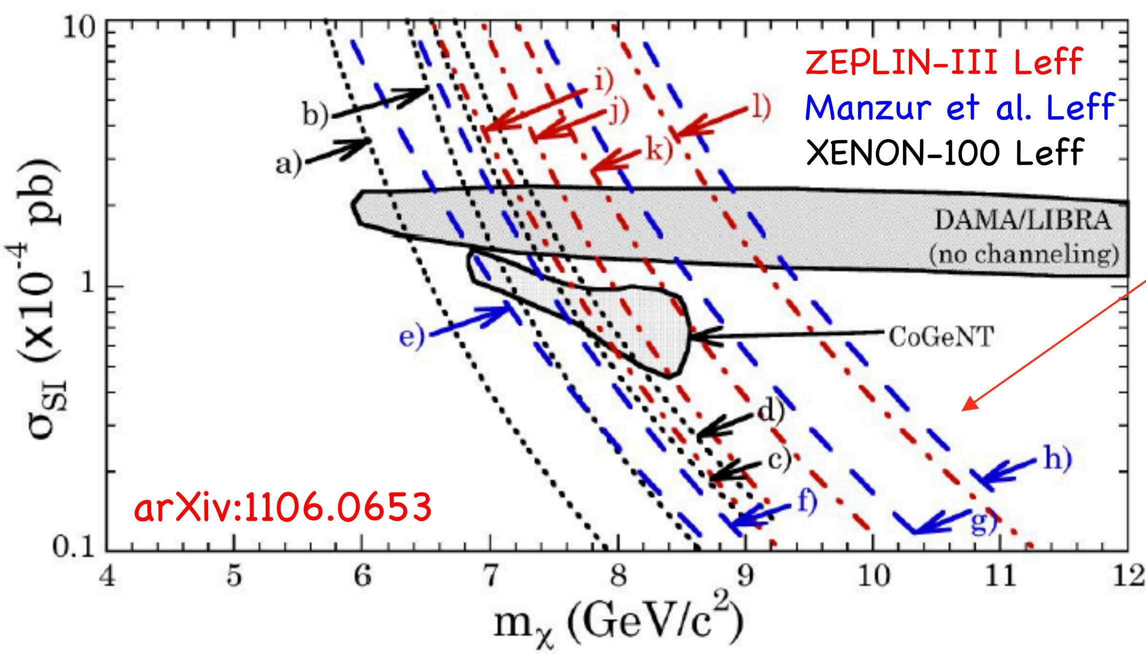
- Direct comparison of CoGeNT-CDMS irreducible spectra initially avoided (a much more straightforward indicator of relative sensitivity for experiments sharing a target).

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.
- Low-energy Am/Be rates: are they what is expected? Crucial for credibility of claimed sensitivity.

Can we make sense of the light-WIMP situation?

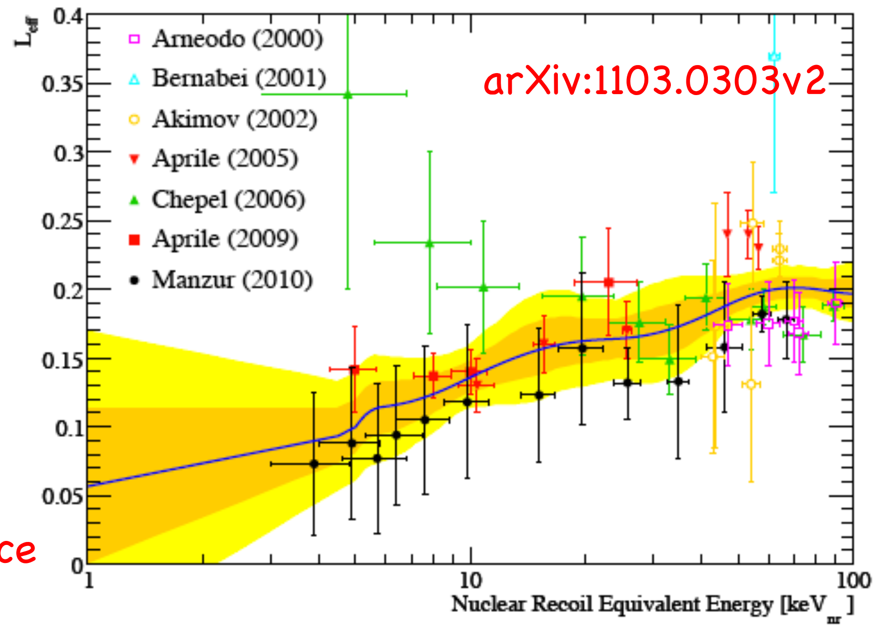
XENON-100 low-E recent results:

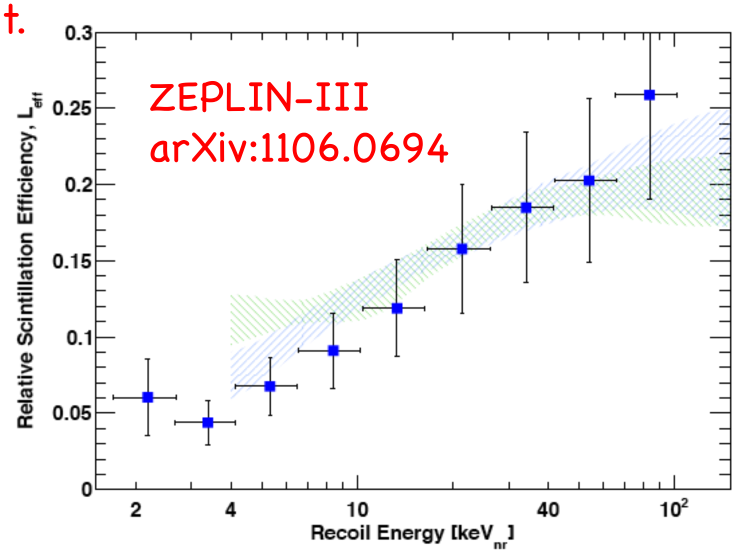
What is wrong with this picture?

* Preserves old results affected by threshold effects (e.g., Chepel)

* Does not include their own latest XENON100 Leff in the fit (similar to Manzur)

* Denies the existence of latest ZEPLIN-III Leff (in situ) measurement.





Low-mass exclusions are critically dependent on low-E Leff slope… Let's play fair.

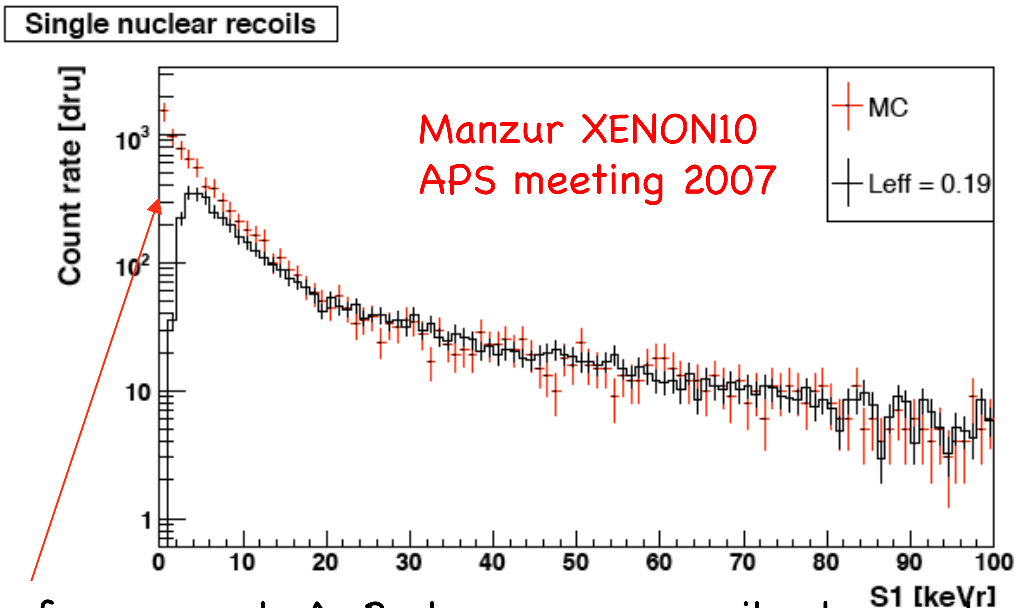
Critique (arXiv:1106.0653):

- Recent L_{eff} measurement represents progress, but still several important loose ends (energy resolution and L_{eff} **<u>are not</u>** 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 <u>strong assumptions</u> 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.
- Low-energy Am/Be rates: are they what is expected? Crucial for credibility of claimed sensitivity.

Can we make sense of the light-WIMP situation?

XENON-100 low-E recent results:

Calibrations come before exclusions:



* Large lack of response to AmBe low-energy recoils observed Below ~10 keV (a 7 GeV WIMP deposits a maximum of 4 keV in LXe), regardless of Leff adopted.

* Such data exist for XENON100, but have never been shown ("we are working on it").

* If a similar situation exists for XENON100, there are no low-mass limits to speak of.

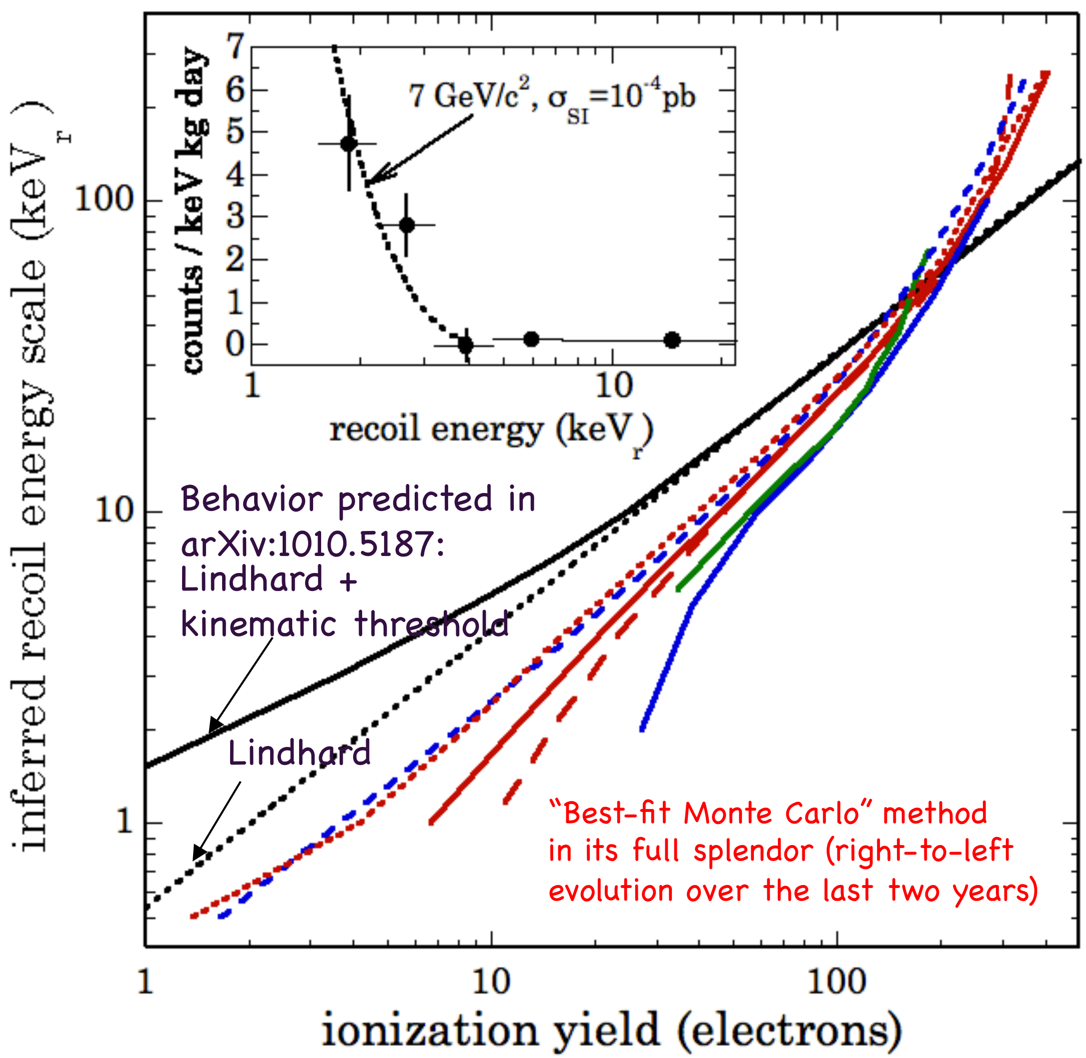
* Other DM searches adopt a sensitivity penalty even when comparatively minor disagreements between expectations and observations appear (e.g. COUPP). But not XENON100.

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.
- Low-energy Am/Be rates: are they what is expected? Crucial for credibility of claimed sensitivity.

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?

XENON-10 low-E recent results:

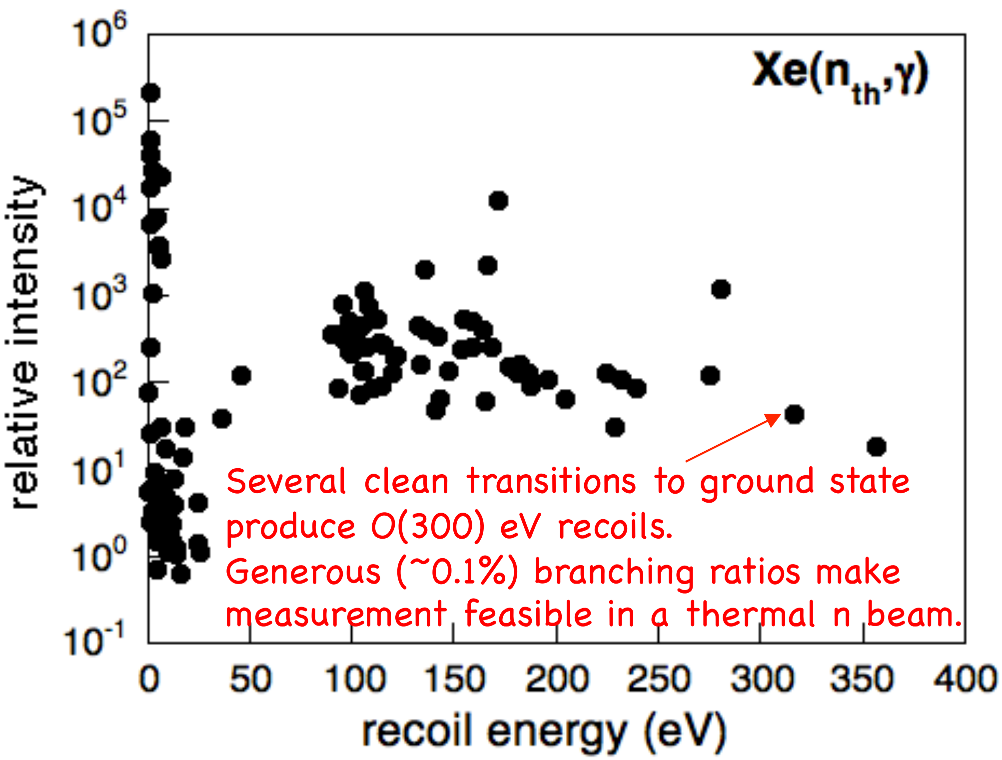
What an experimentalist would do: measure the energy scale (i.e., calibrate the S2 channel in the relevant energy range), THEN attempt to produce an exclusion.

Xenon is a target favorable to use of an old calibration method:

PHYSICAL REVIEW A VOLUME 11, NUMBER 4 APRIL 1975

Energy lost to ionization by 254-eV ^{73}Ge atoms stopping in Ge†

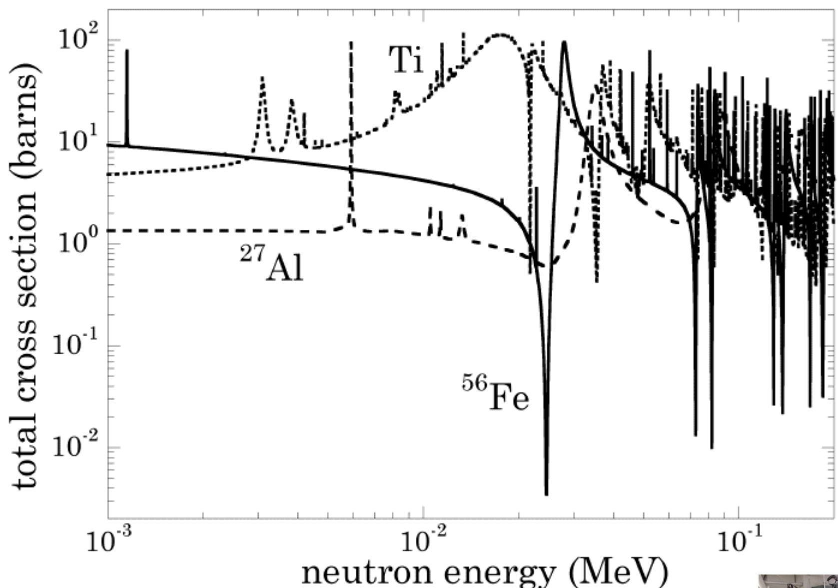
K. W. Jones and H. W. Kraner
Brookhaven National Laboratory, Upton, New York 11973
(Received 30 July 1974)



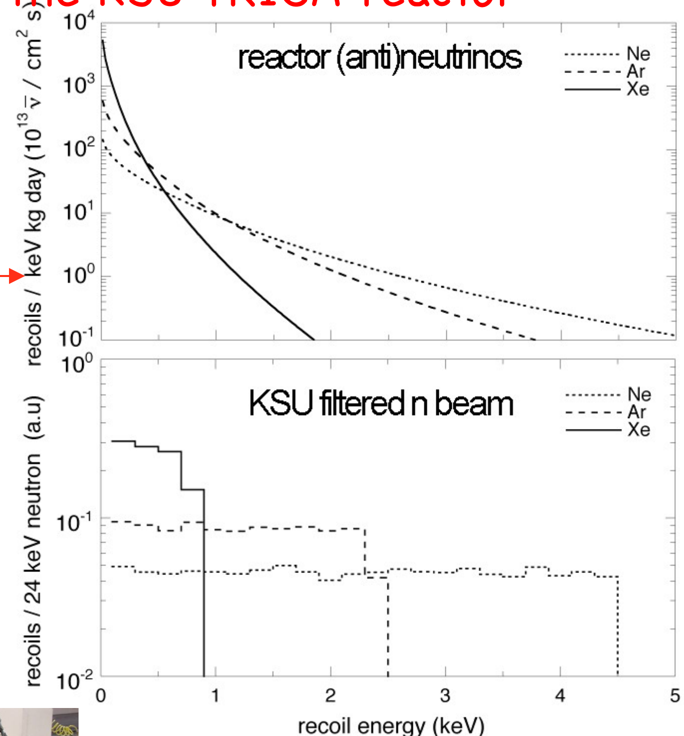
Critique (arXiv:1106.0653, 1010.5187):

- Very promising method.
- However, as is stands today: <u>**pure drivel**</u>
- Some entirely misleading statements about "interesting" population of low-energy events.
- Energy scale employed clashes (by ~<u>three orders of magnitude</u>) 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 <u>can be measured</u> via (n_{th},γ) calibrations in the relevant range)

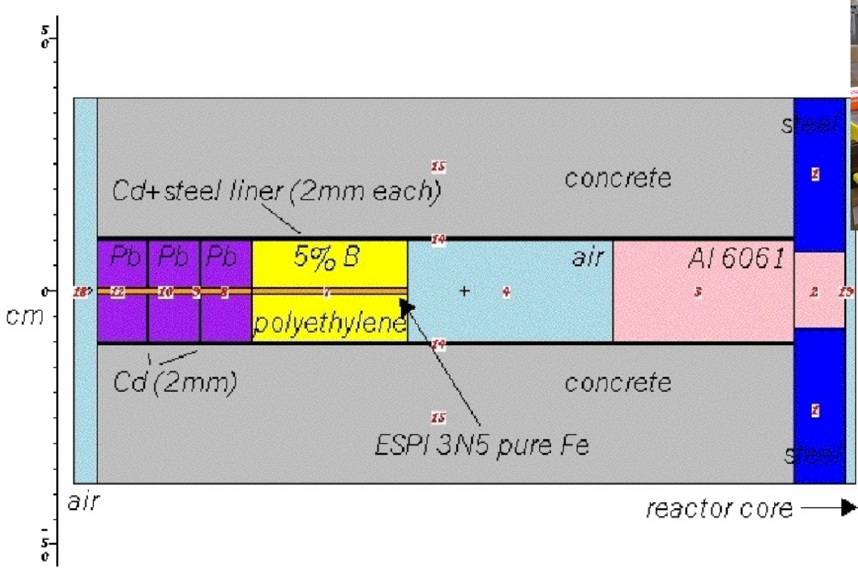
A dose of our own medicine:
PPC sub-keV recoil calibrations at the KSU TRIGA reactor



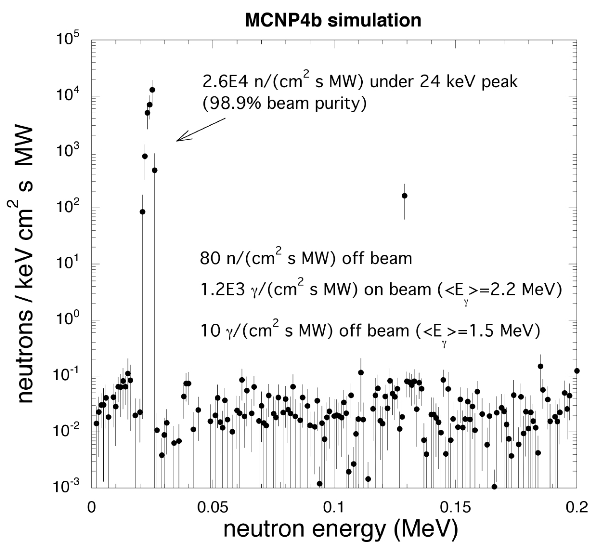
24 keV n's mimic reactor ν's →



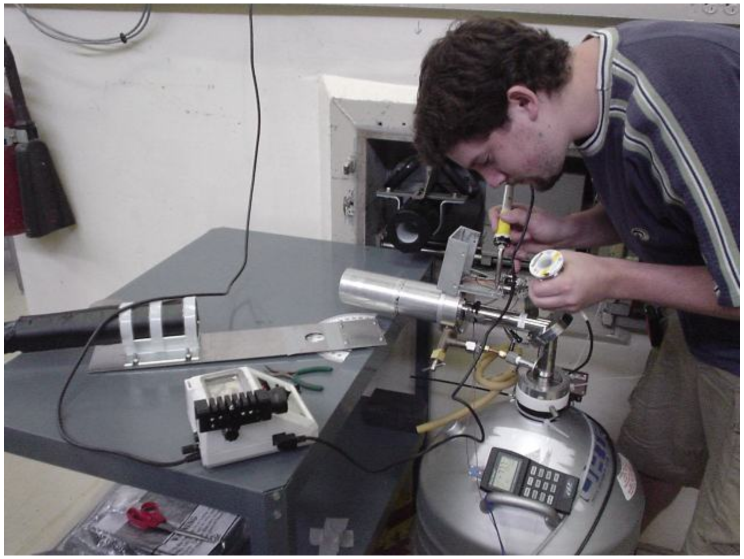
← Fe-Al filter + Ti post-filter

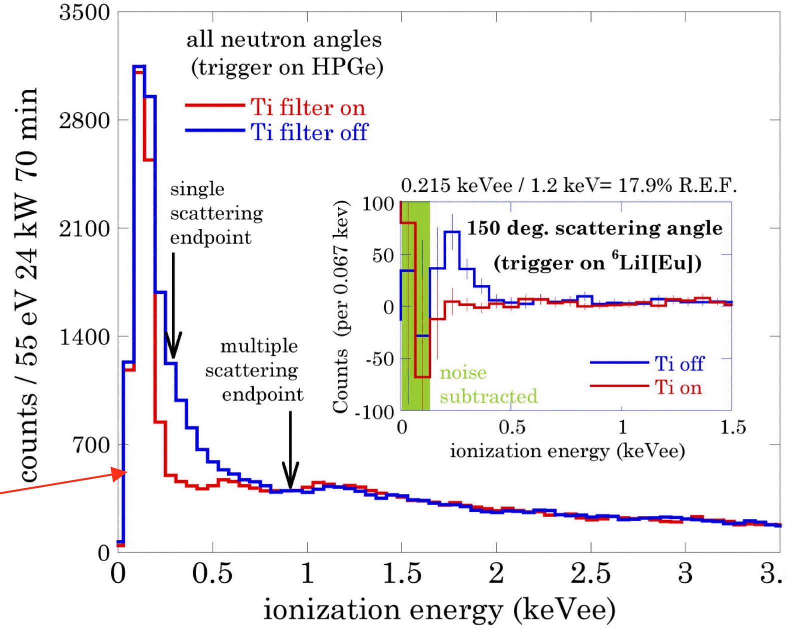


← MCNP filter design →

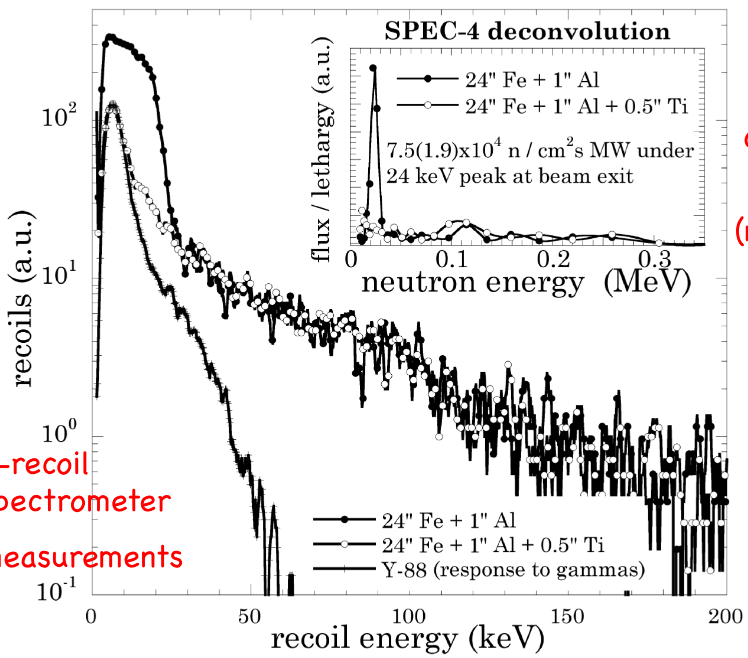


A dose of our own medicine:
PPC sub-keV recoil calibrations at the KSU TRIGA reactor





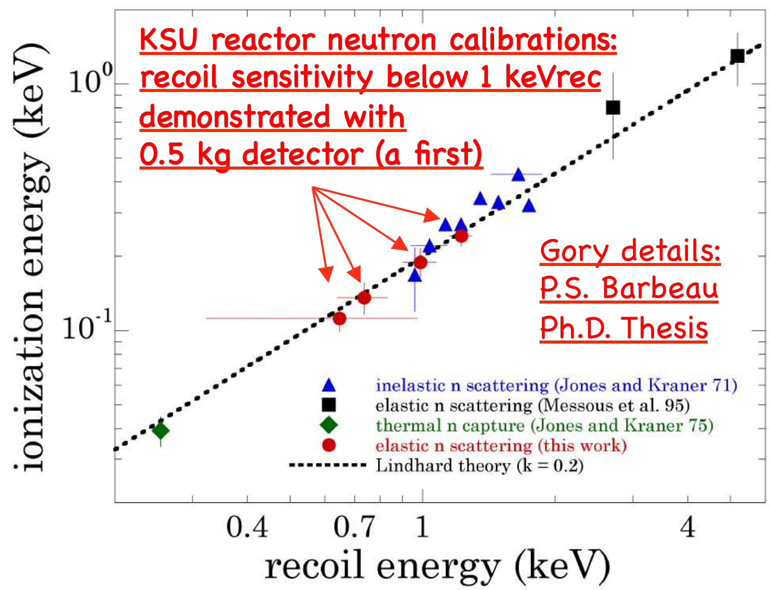
Ti post-filter "switches off" the recoils, leaving all backgrounds unaffected



p-recoil spectrometer measurements

Beam characterization studies

(nucl-ex/0701011)



KSU reactor neutron calibrations: recoil sensitivity below 1 keVrec demonstrated with 0.5 kg detector (a first)

Gory details: P.S. Barbeau Ph.D. Thesis

Can we make sense of the light-WIMP situation?

DAMA uncertainties (Q_{Na}, channeling)

• 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.

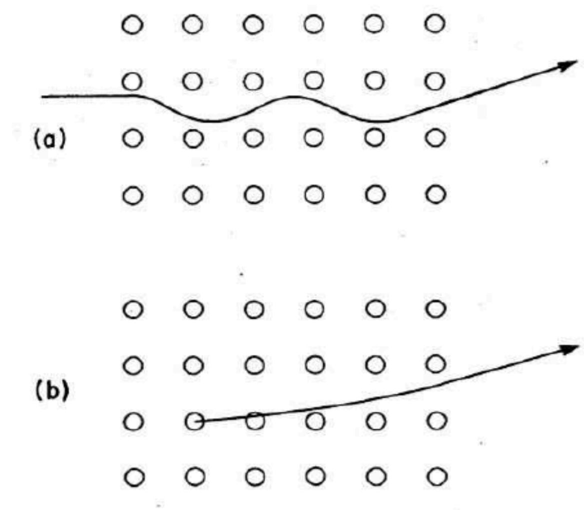
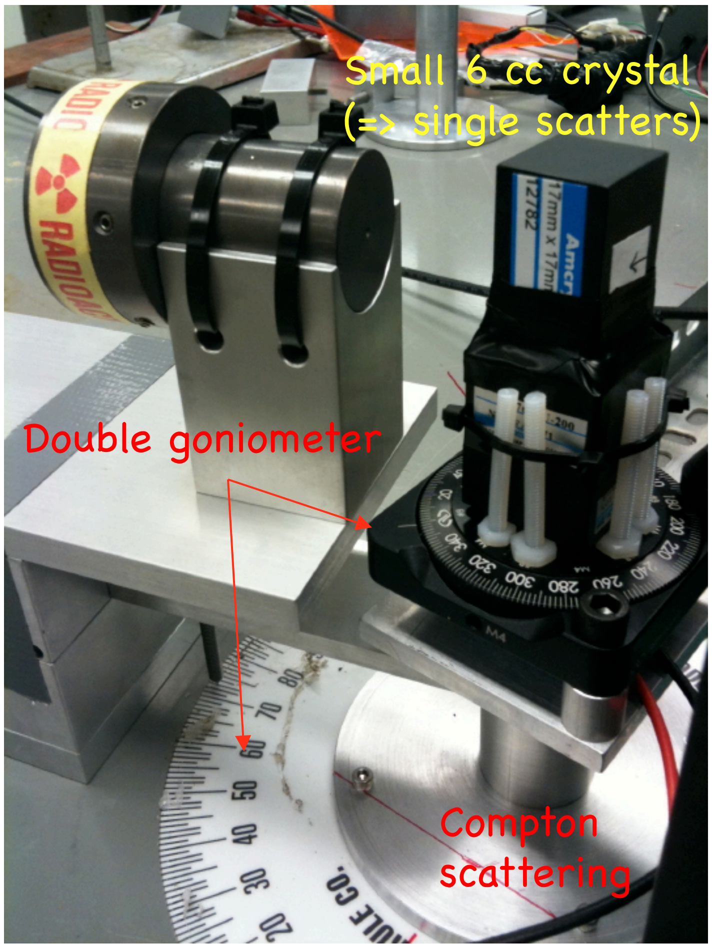
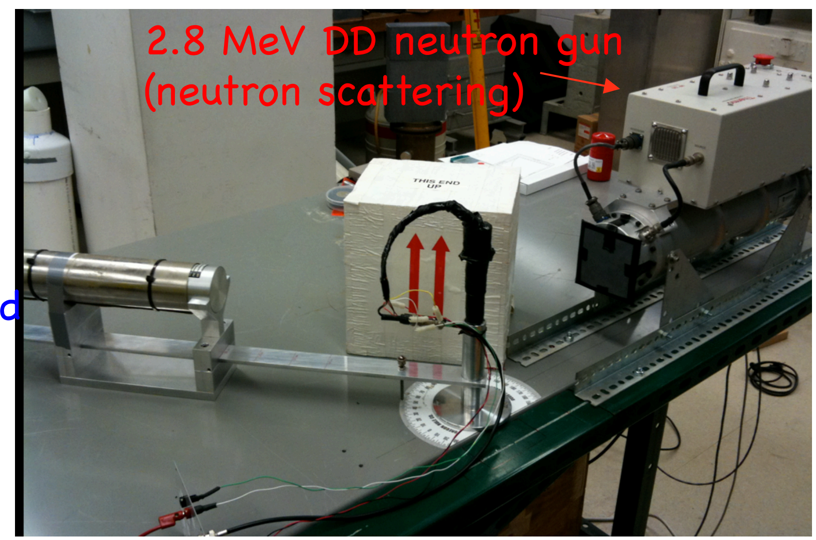


FIG. 1. Schematic illustration of (a) channeling and (b) blocking effects. The drawings are highly exaggerated. In reality, the oscillations of channeled trajectories occur with wavelengths typically several hundreds or thousands of lattice spacings.

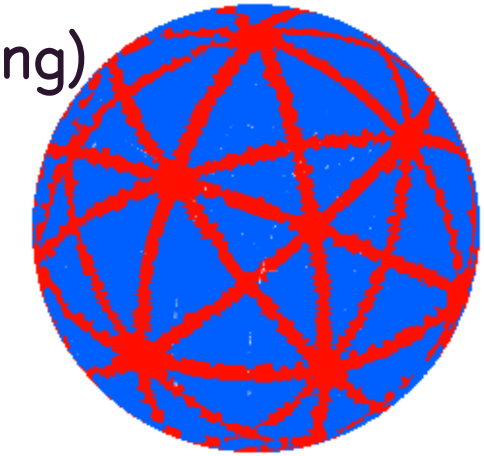


* Response to both electron and nuclear recoils measured.
*Use of ultra bialkali PMT (40% QE) to avoid threshold effects (x3 light yield of previous meas.)
*Crystal with known (growth) axis orientation.

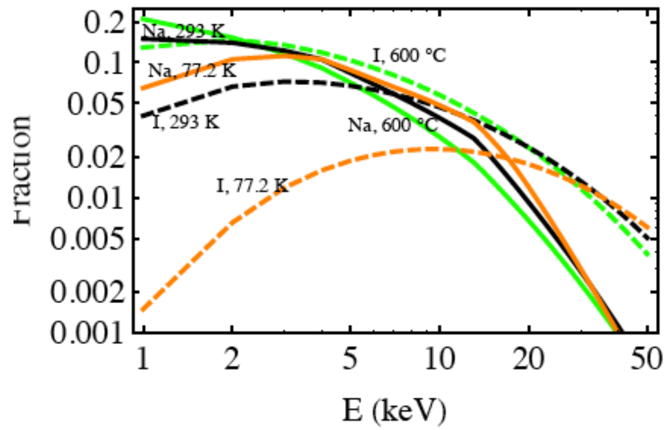


Can we make sense of the light-WIMP situation?

DAMA uncertainties (Q_{Na}, channeling)

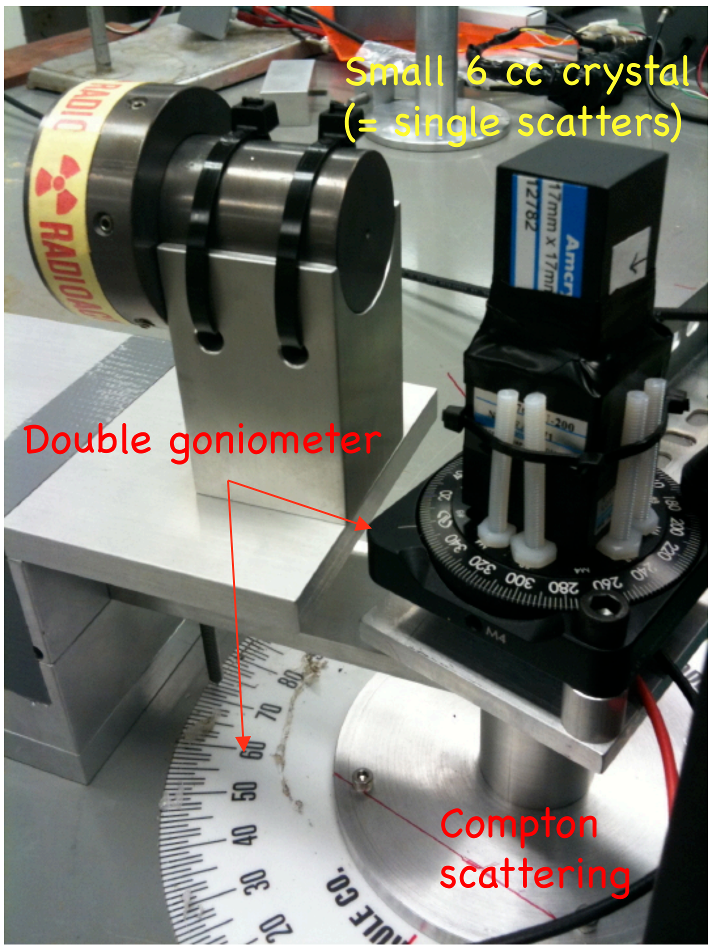


- Ongoing precision measurements of CsI[Na] and NaI[Tl] quenching factor and <u>**CHANNELING**</u> at UC to cast light on effects of methodology, kinematic cutoff, etc.

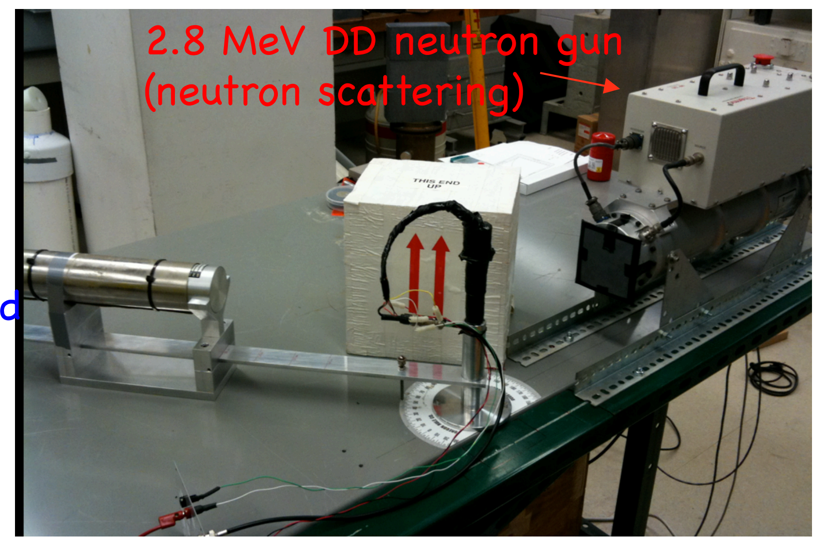


Bozorgnia, Gelmini & Gondolo
arXiv:1006.3110v1

Certain models predict non-negligible channeling: it <u>must be measured!!!</u>



* Response to both electron and nuclear recoils measured.
*Use of ultra bialkali PMT (40% QE) to avoid threshold effects (x3 light yield of previous meas.)
*Crystal with known (growth) axis orientation.



Can we make sense of the light-WIMP situation?

DAMA uncertainties (Q_{Na}, channeling)

- 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.

L. Miramonti / Radiation Physics and Chemistry 64 (2002) 337–342

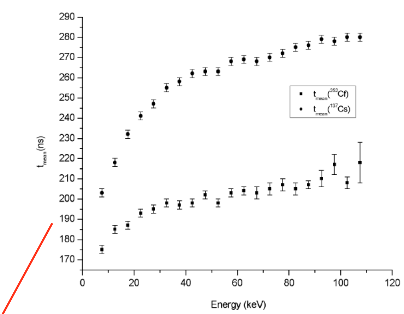
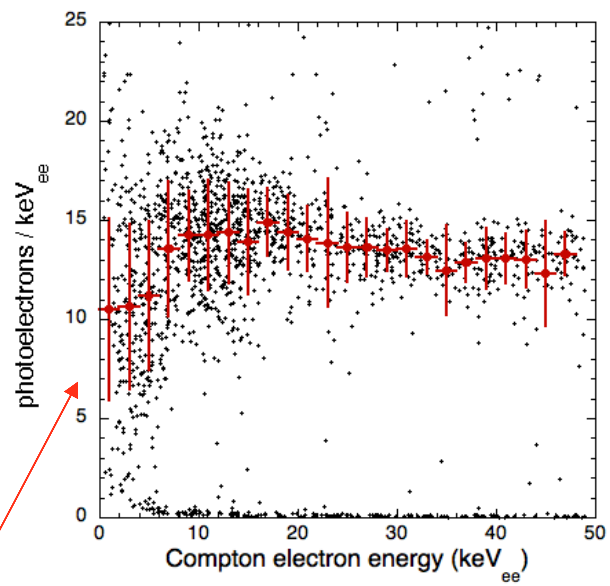
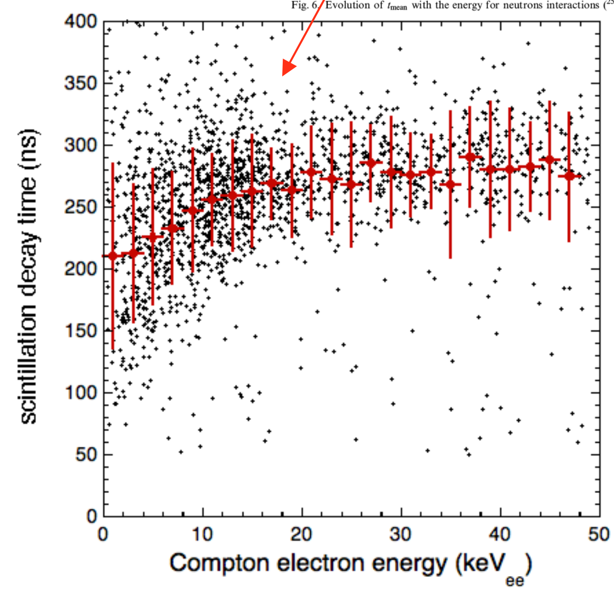


Fig. 6. Evolution of t_{mean} with the energy for neutrons interactions (^{252}Cf) and for gamma interactions (^{137}Cs).

PRELIMINARY DATA





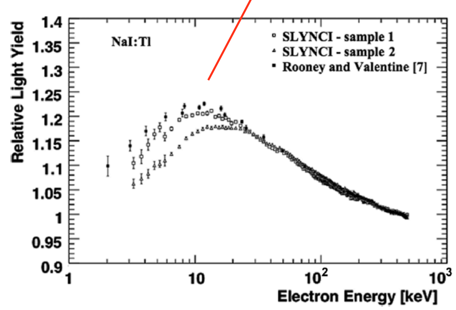


Fig. 8. Light yield response as a function of electron energy for NaI(Tl). Data are arbitrarily normalized to each other at 444 keV.

Compton scattering measurements reveal subtle low-E non-linearities expected for NaI[Tl], and excellent light yield via use of ultra-bialkali PMT (up to 15 PE/keV$_{ee}$, compare to 5 PE/keV$_{ee}$ in latest -Chagani 2008-)

Can we make sense of the light-WIMP situation?

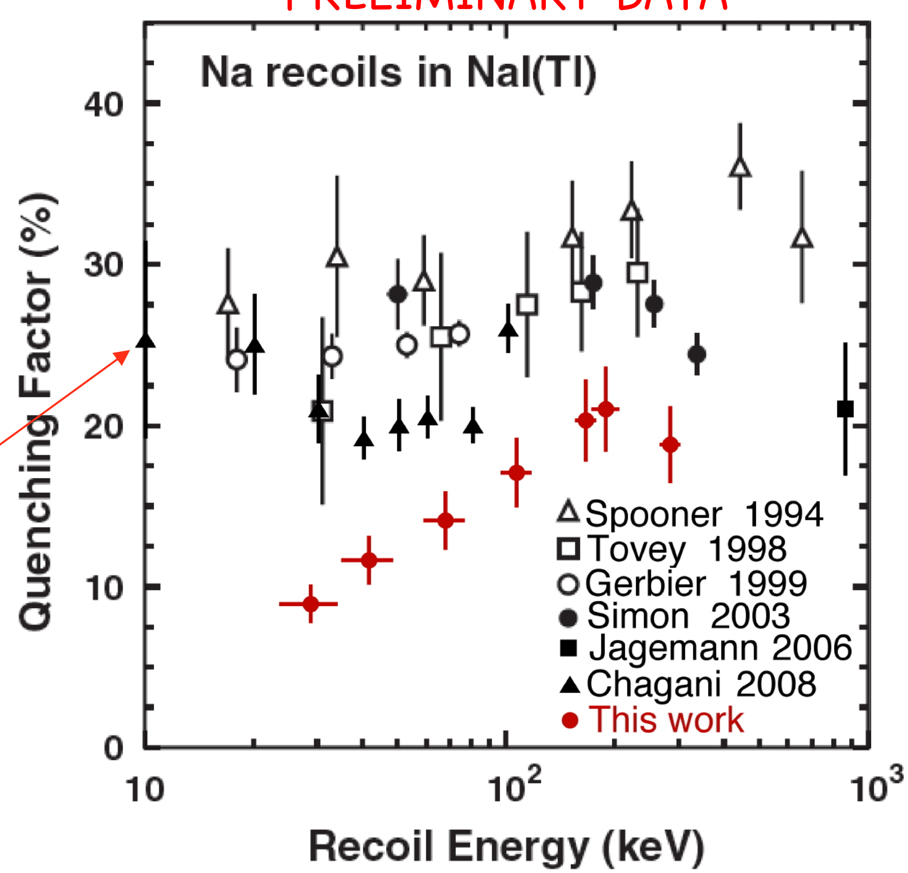
DAMA uncertainties (Q_{Na}, channeling)

- 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.

Discussion of threshold effects affecting quenching factor measurements: Collar, arXiv:1010.5187

(you cannot expect a proper measurement of Q at 10 keV_r with just 5 PE/keV_{ee} and a ~100 cc crystal...)

PRELIMINARY DATA



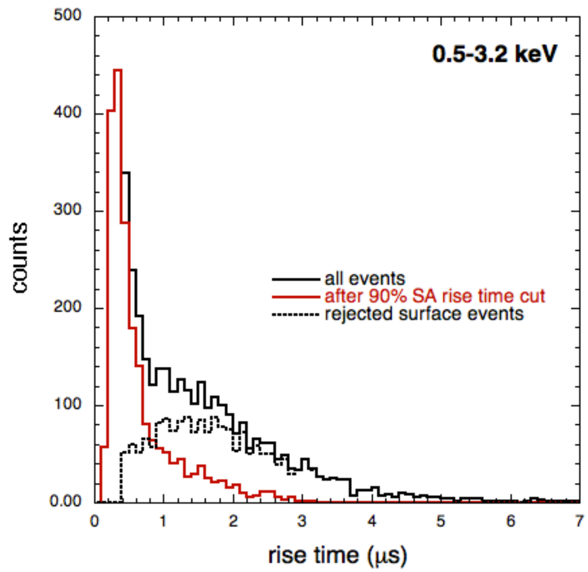
Surprisingly small quenching factor... (in a very clean measurement, away from threshold effects and with negligible multiple scattering).

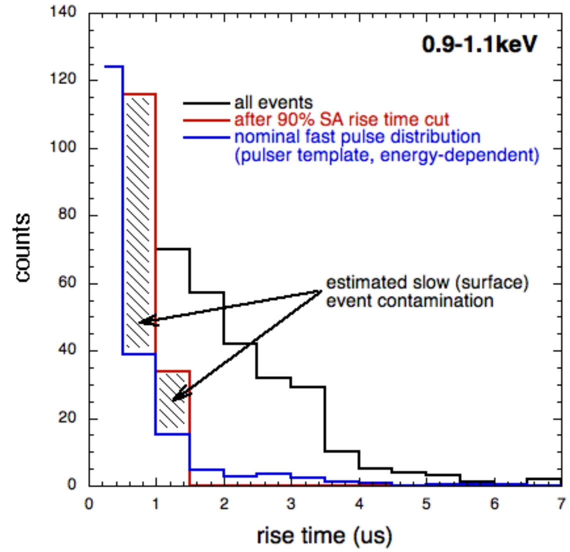
Several previous measurements do not account for NaI[Tl] non-linearity in electron recoil response.

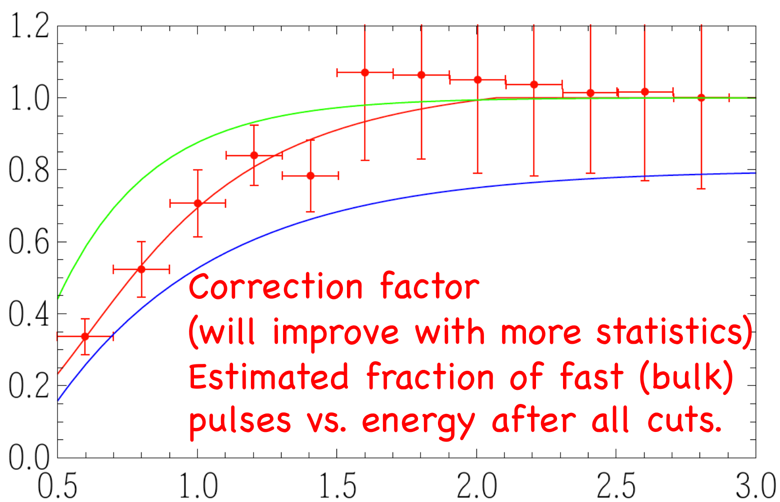
Can we make sense of the light-WIMP situation?

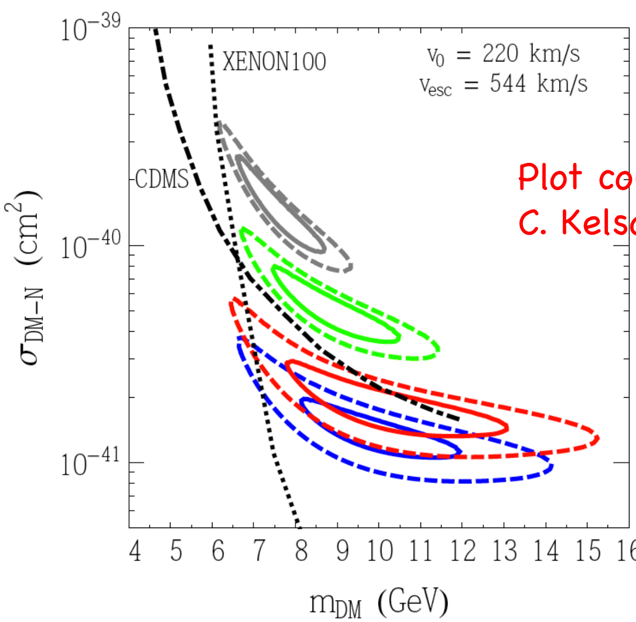
CoGeNT uncertainties (e.g., surface event rejection next to threshold)

PRELIMINARY (work in progress, not an exact science yet)







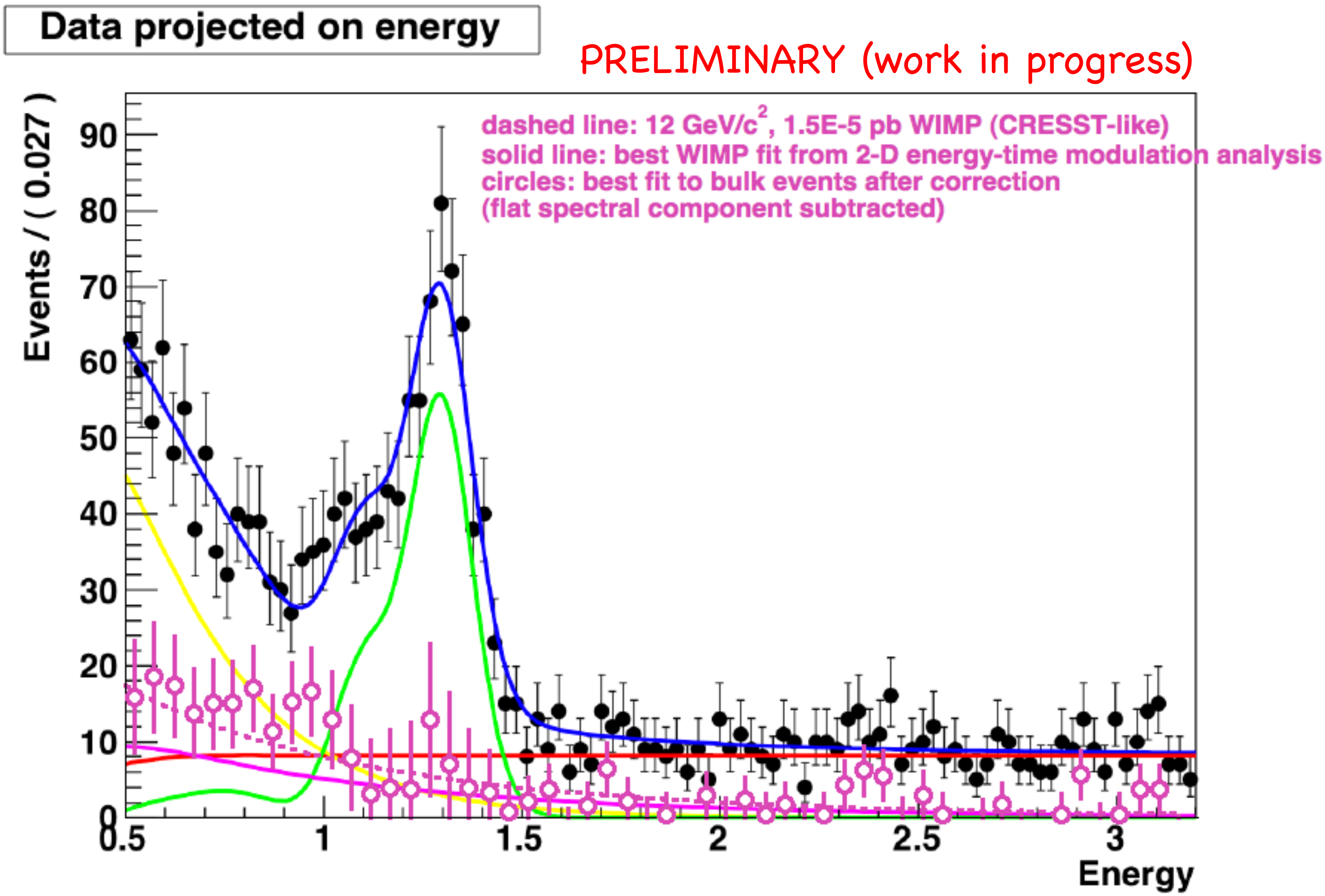


Plot courtesy
C. Kelso

Can we make sense of the light-WIMP situation?

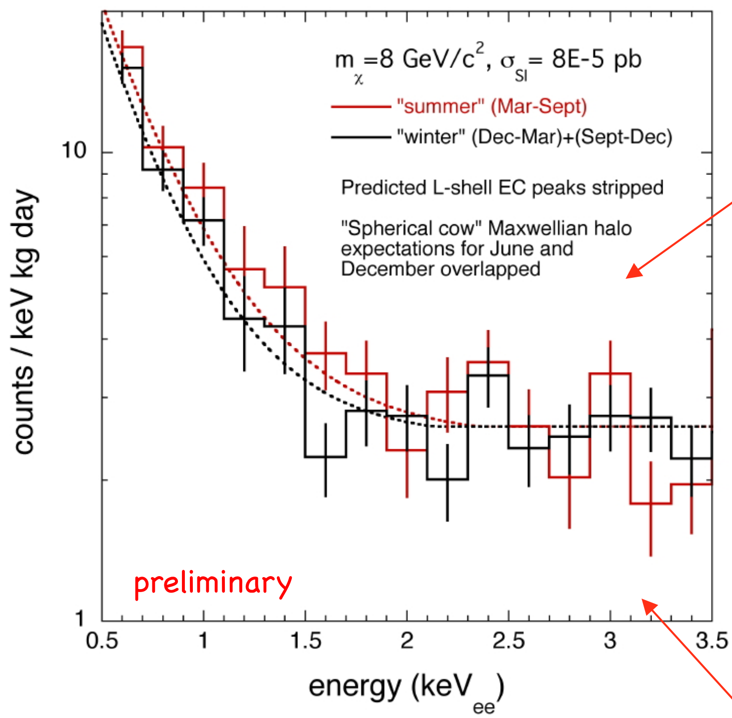
CoGeNT uncertainties (e.g., surface event rejection next to threshold)

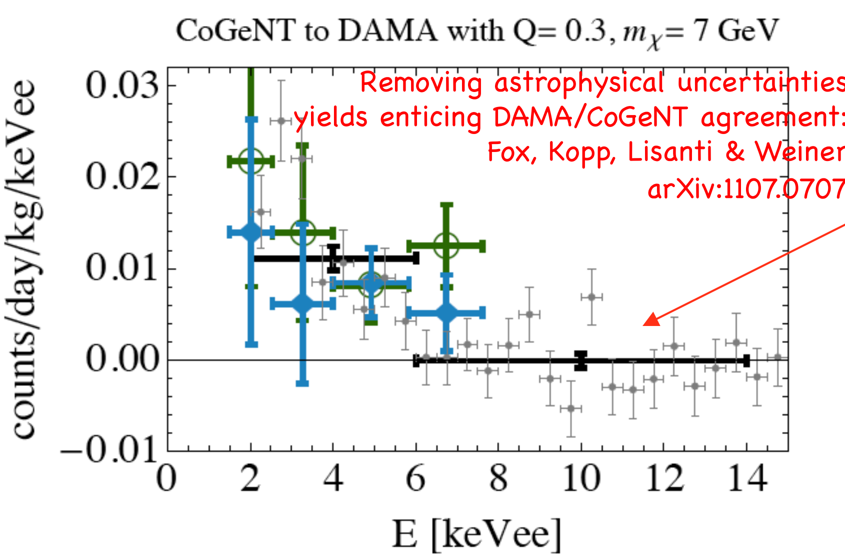
PRELIMINARY (work in progress)



Spectral and modulation analysis in CoGeNT seem to point to a similar WIMP mass & coupling,
BUT then modulated amplitude is <u>definitely not</u> what you would expect from a vanilla halo (is way too large).

Are DAMA, CoGeNT and CRESST in agreement, or not at all?

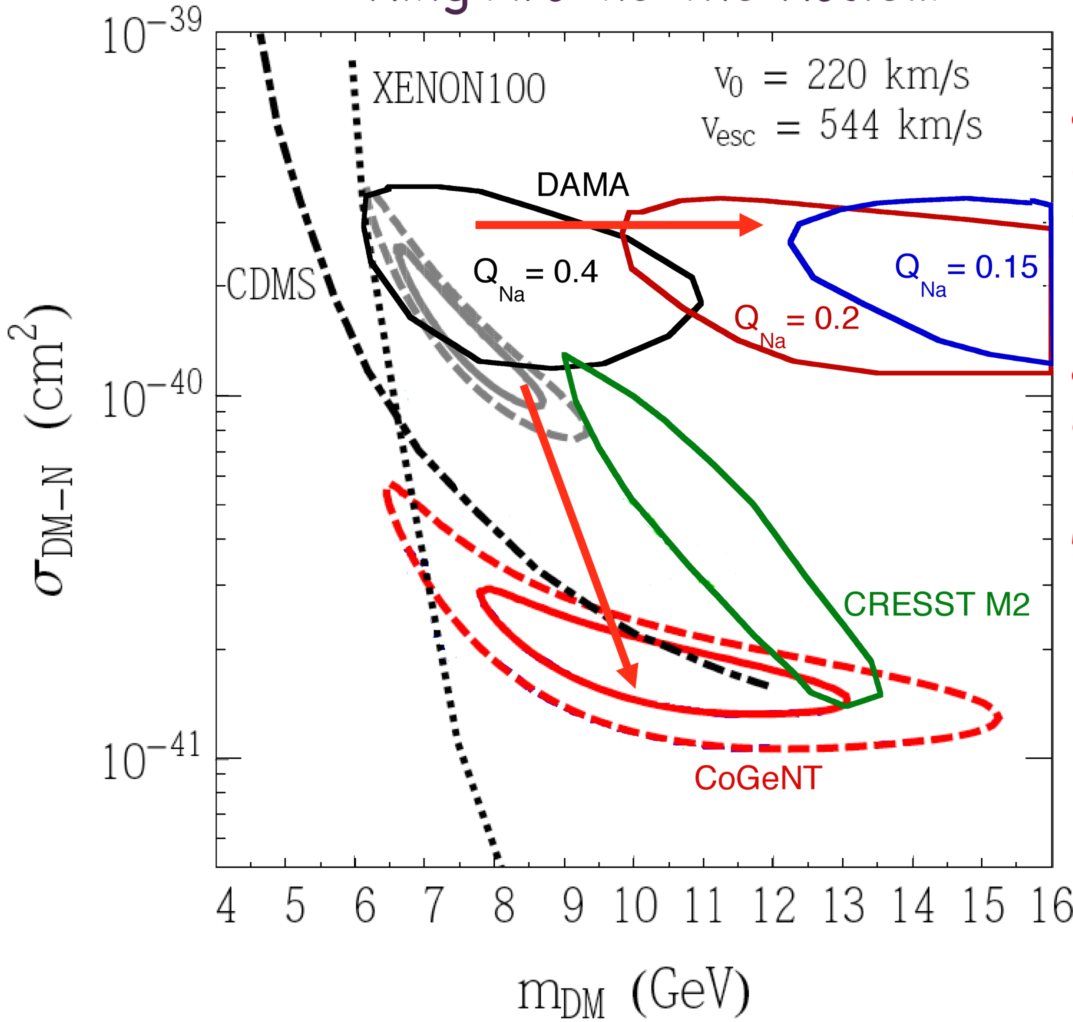




- What is the exact endpoint of the CoGeNT modulation? (hard to tell w/ just 15 mo)
- Surface background contamination next to threshold (analysis starting to be possible now with enough statistics) -> shifts CoGeNT ROI to lower coupling and larger mass (CRESST favored region?).
- Channeling at few %? Contemplated by some models, if you read papers carefully... What is the 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 questions... 3σ effects come and go)

Are DAMA, CoGeNT and CRESST in agreement, or not at all?

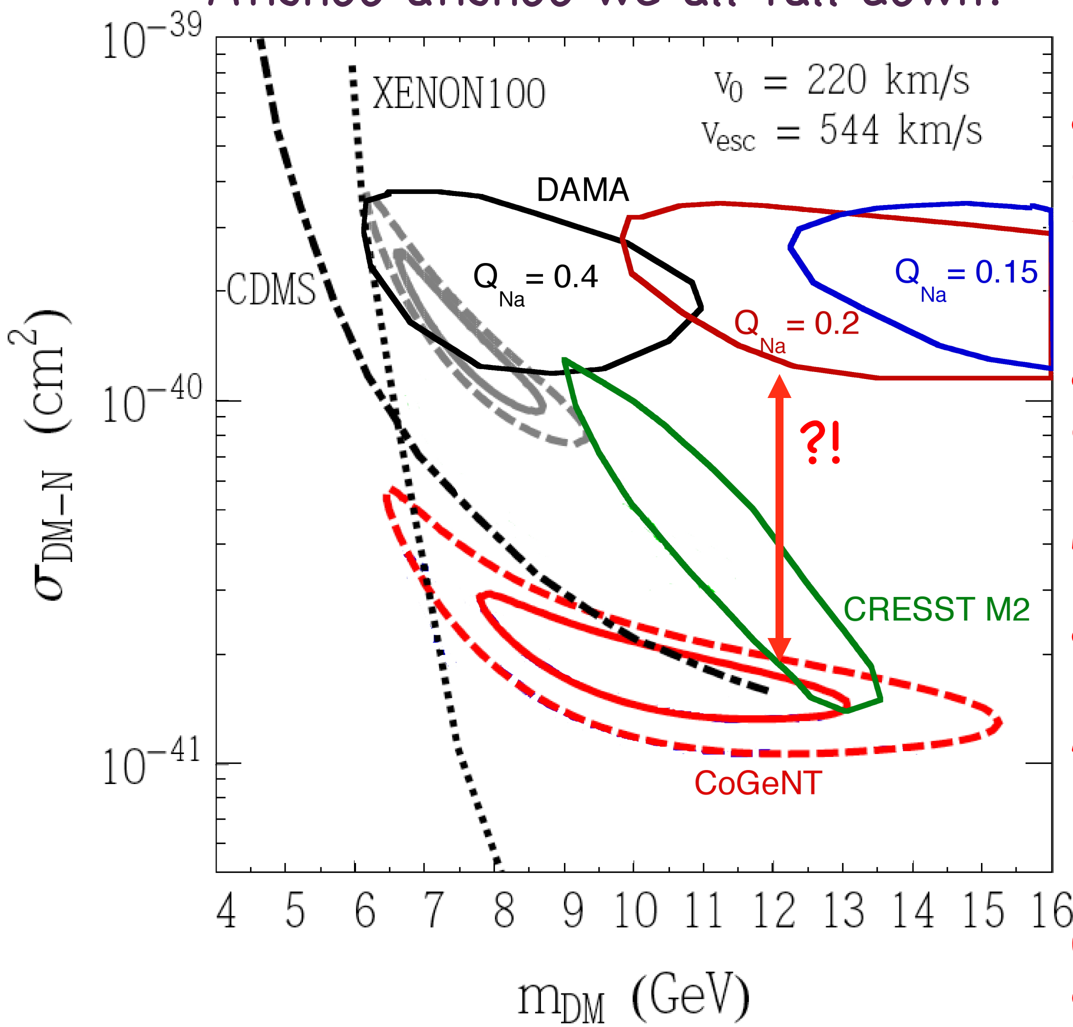
Ring Around the Rosie...



- Including surface event contamination next to threshold brings spectral and modulation CoGeNT analyses in close agreement at ~10-15 GeV.
- However, Q_{Na}~0.4 seems extremely unlikely after UC measurement, regardless of theoretical prejudice (see arXiv:1007.1005).
- ... and the modulation observed by CoGeNT would be order-of-magnitude larger than expected from a standard Maxwellian halo.

Are DAMA, CoGeNT and CRESST in agreement, or not at all?

Atishoo atishoo we all fall down?



- Including surface event contamination next to threshold brings spectral and modulation CoGeNT analyses in close agreement at ~10-15 GeV.

- However, Q_{Na}~0.4 seems extremely unlikely after UC measurement, regardless of theoretical prejudice (see arXiv:1007.1005).

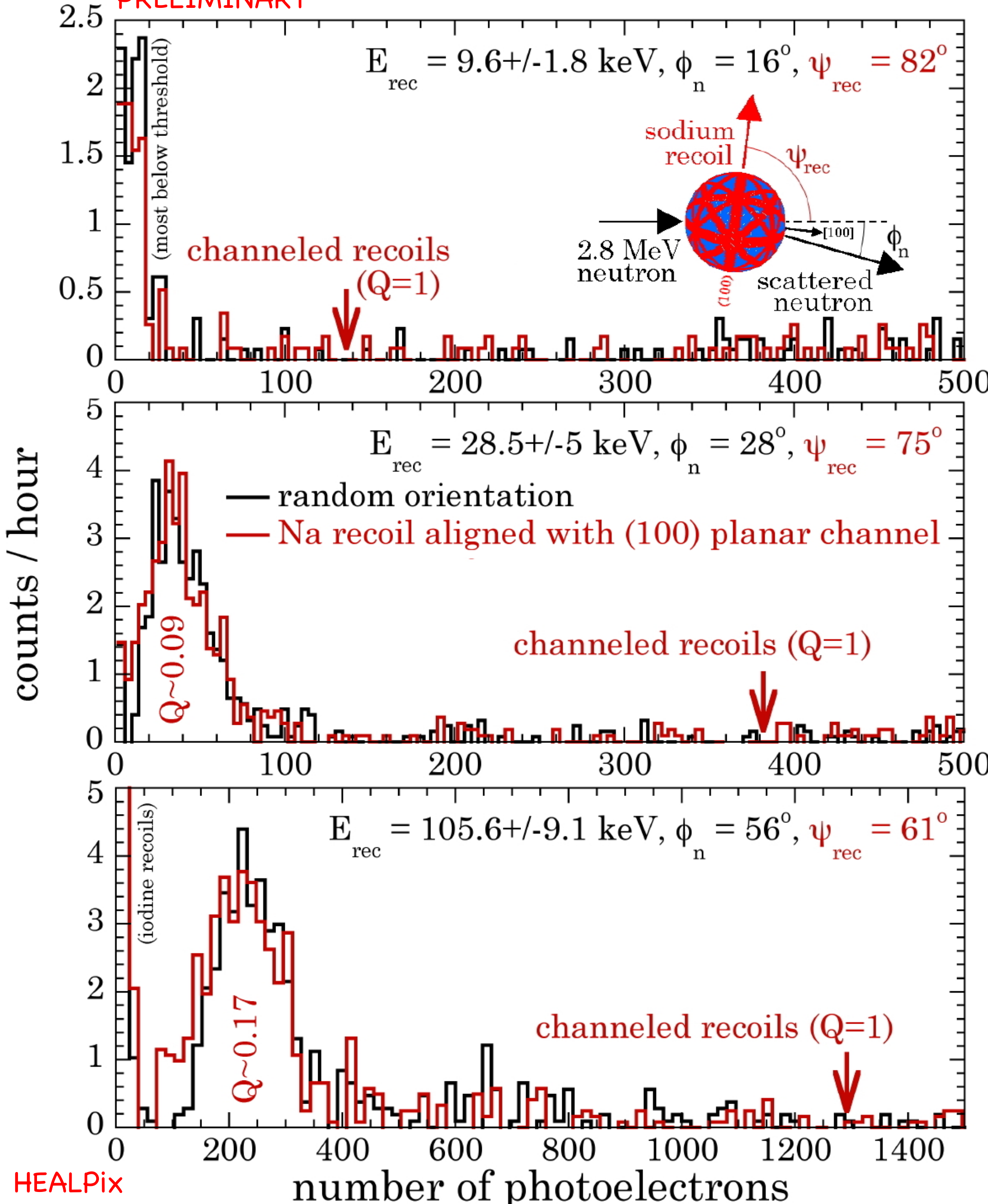
- … and the modulation observed by CoGeNT would be order-of-magnitude larger than expected from a standard Maxwellian halo.

- …DAMA floats an order of magnitude higher in coupling than COGeNT/CRESST. Are there ways to reconcile?:
    - * Channeling
    - * IVDM…
    - * streams, dark disk, debris, etc…

(let us remember that DAMA is placed in σ vs m_χ space via the assumption of a Maxwellian halo: if modulation is really much larger, DAMA's σ becomes smaller…)

Are DAMA, CoGeNT and CRESST in agreement, or not at all?

PRELIMINARY



HEALPix
Courtesy N. Bozorgnia

- Including surface event contamination next to threshold brings spectral and modulation CoGeNT analyses in close agreement at ~10-15 GeV.

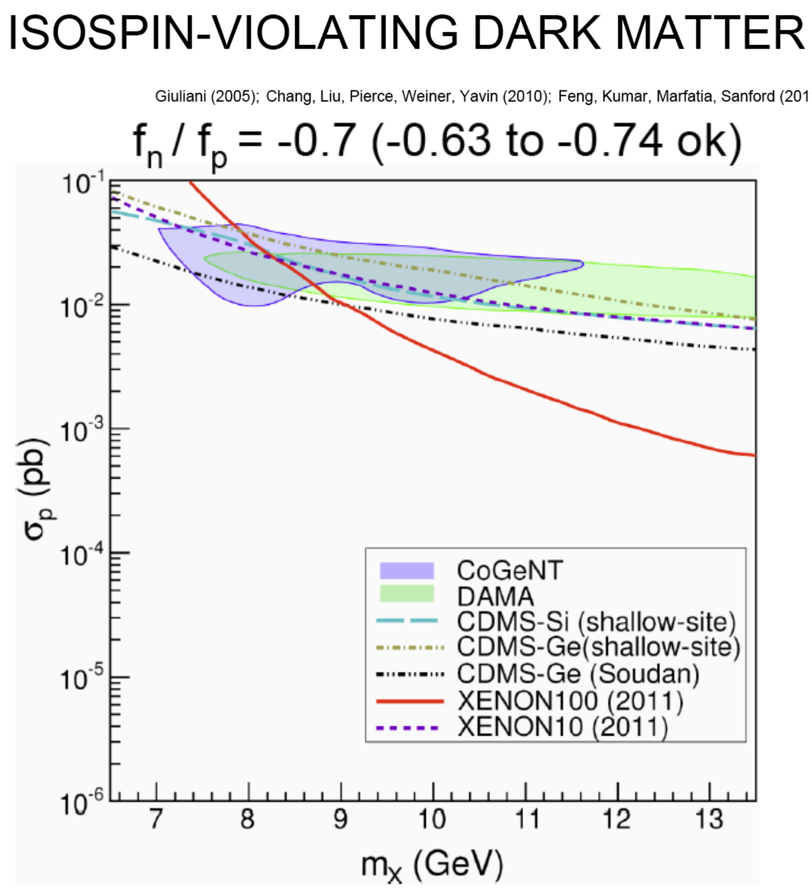
- However, Q_{Na}~0.4 seems extremely unlikely after UC measurement, regardless of theoretical prejudice (see arXiv:1007.1005).

- ... and the modulation observed by CoGeNT would be order-of-magnitude larger than expected from a standard Maxwellian halo.

- ...DAMA floats an order of magnitude higher in coupling than COGeNT/CRESST. Are there ways to reconcile?:
  - ~~Channeling~~ (UC measurement)
  - IVDM...
  - streams, dark disk, debris, etc...

(let us remember that DAMA is placed in σ vs m_χ space via the assumption of a Maxwellian halo: if modulation is really much larger, DAMA's σ becomes smaller...)

Are DAMA, CoGeNT and CRESST in agreement, or not at all?



Very intriguing possibility
(but let us hope XENON "tension" is not the motivation for such departures... we are not quite there yet)

- Including surface event contamination next to threshold brings spectral and modulation CoGeNT analyses in close agreement at ~10-15 GeV.

- However, Q_{Na}~0.4 seems extremely unlikely after UC measurement, regardless of theoretical prejudice (see arXiv:1007.1005).

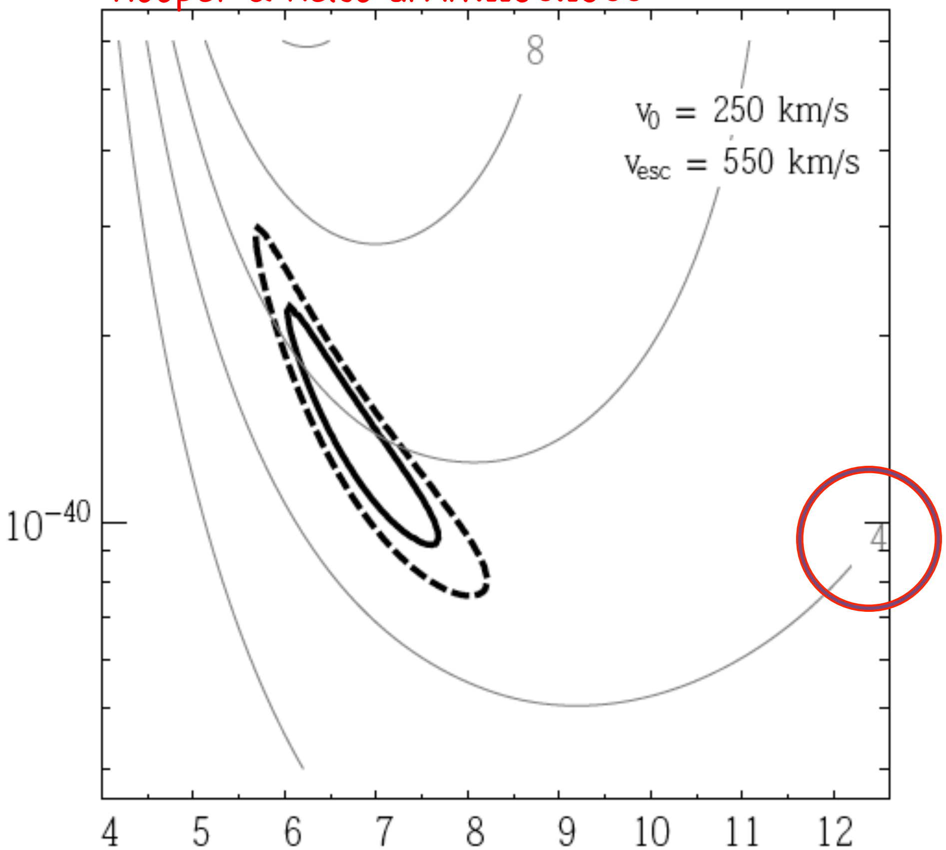
- ... and the modulation observed by CoGeNT would be order-of-magnitude larger than expected from a standard Maxwellian halo.

- ...DAMA floats an order of magnitude higher in coupling than COGeNT/CRESST. Are there ways to reconcile?:
  - * ~~Channeling~~ (UC measurement)
  - * IVDM...
  - * streams, dark disk, debris, etc...

(let us remember that DAMA is placed in σ vs m_χ space via the assumption of a Maxwellian halo: if modulation is really much larger, DAMA's σ becomes smaller...)

Are DAMA, CoGeNT and CRESST in agreement, or not at all?

Hooper & Kelso arXiv:1106.1066

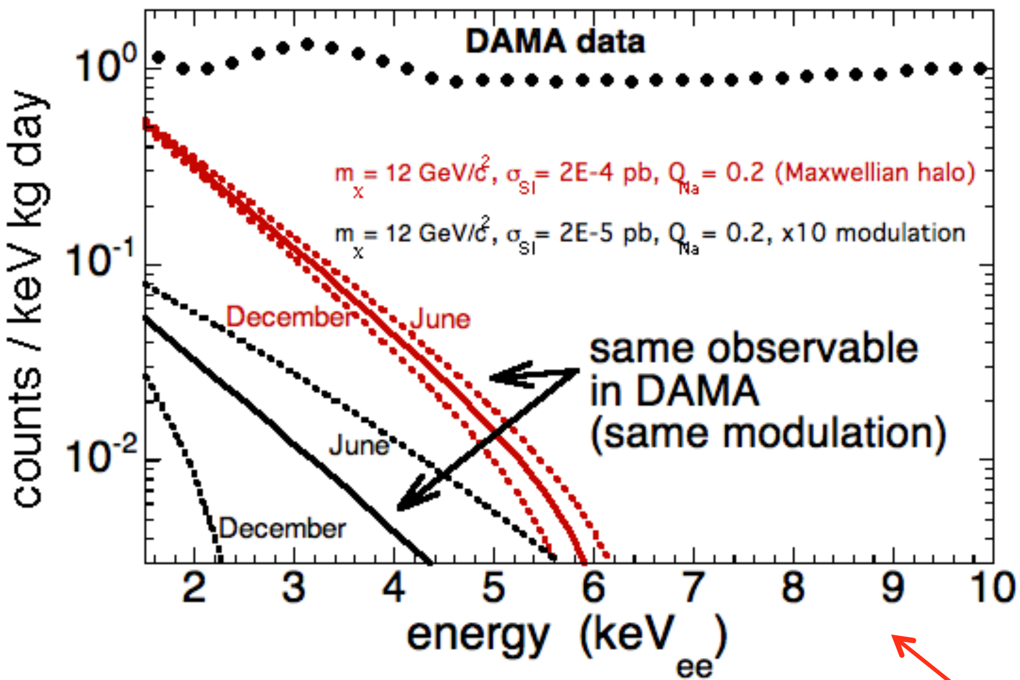


Some interesting incipient work:
A.M. Green: arXiv:1109.0916
Natajaran, Savage & Freese: arXiv:1109.0014

- Including surface event contamination next to threshold brings spectral and modulation CoGeNT analyses in close agreement at ~10-15 GeV.
- However, Q_{Na}~0.4 seems extremely unlikely after UC measurement, regardless of theoretical prejudice (see arXiv:1007.1005).
- ... and the modulation observed by CoGeNT would be order-of-magnitude larger than expected from a standard Maxwellian halo.
- ...DAMA floats an order of magnitude higher in coupling than COGeNT/CRESST. Are there ways to reconcile?:
  - * ~~Channeling~~ (UC measurement)
  - * IVDM...
  - * streams, dark disk, debris, etc...

(<u>let us remember that DAMA is placed in σ vs m_χ space via the assumption of a Maxwellian halo: if modulation is really much larger, DAMA's σ becomes smaller...</u>)

Are DAMA, CoGeNT and CRESST in agreement, or not at all?



- Including surface event contamination next to threshold brings spectral and modulation CoGeNT analyses in close agreement at ~10-15 GeV.

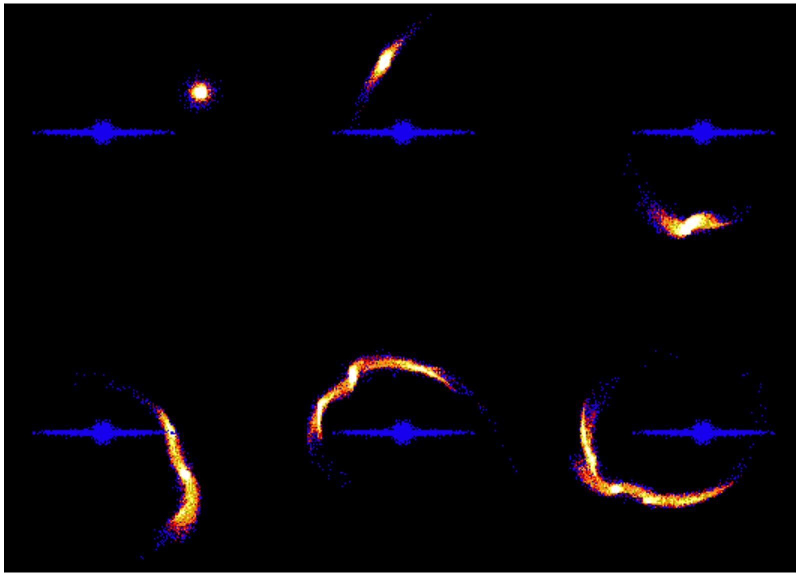
- However, Q_{Na}~0.4 seems extremely unlikely after UC measurement, regardless of theoretical prejudice (see arXiv:1007.1005).

- … and the modulation observed by CoGeNT would be order-of-magnitude larger than expected from a standard Maxwellian halo.

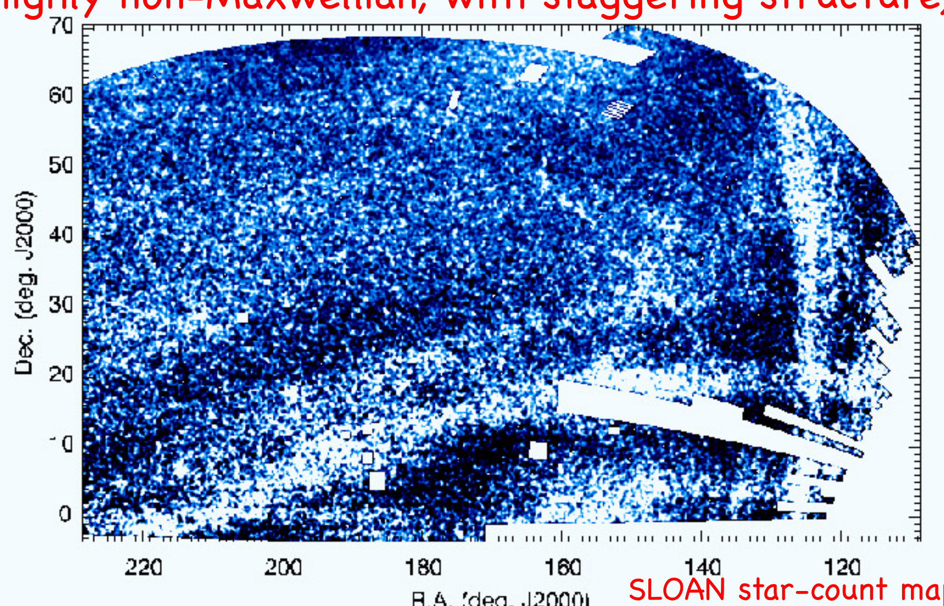
- …DAMA floats an order of magnitude higher in coupling than COGeNT/CRESST. Are there ways to reconcile?:
  - ~~Channeling~~ (UC measurement)
  - IVDM…
  - streams, dark disk, debris, etc…

(let us remember that DAMA is placed in σ vs m_χ space via the assumption of a Maxwellian halo: if modulation is really much larger, DAMA's σ becomes smaller…)

Are DAMA, CoGeNT and CRESST in agreement, or not at all?



Damn if I know much about this...
(...but word in the street is the local halo is highly non-Maxwellian, with staggering structure)



SLOAN star-count map showing Milky Way tidal streams

- Including surface event contamination next to threshold brings spectral and modulation CoGeNT analyses in close agreement at ~10-15 GeV.

- However, Q_{Na}~0.4 seems extremely unlikely after UC measurement, regardless of theoretical prejudice (see arXiv:1007.1005).

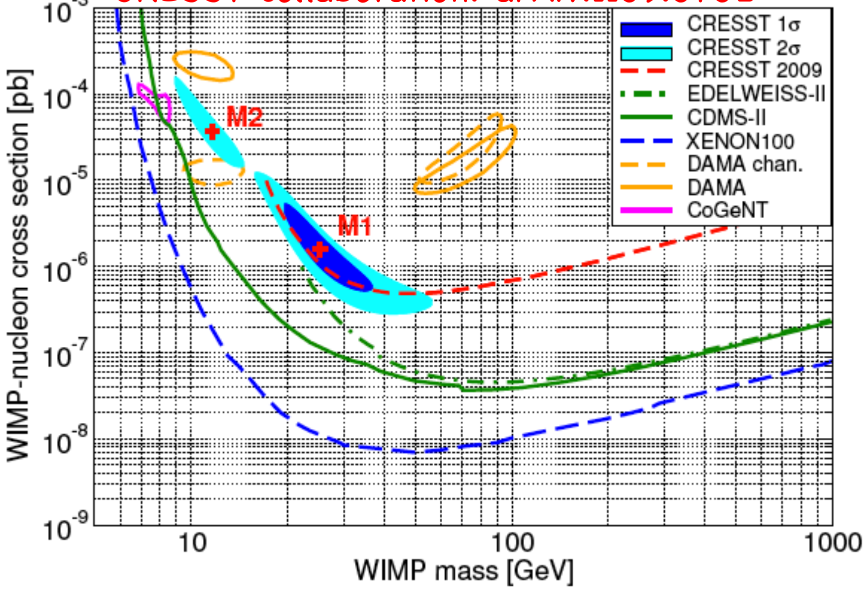
- ... and the modulation observed by CoGeNT would be order-of-magnitude larger than expected from a standard Maxwellian halo.

- ...DAMA floats an order of magnitude higher in coupling than COGeNT/CRESST. Are there ways to reconcile?:
  - ~~Channeling~~ (UC measurement)
  - IVDM...
  - streams, dark disk, debris, etc...

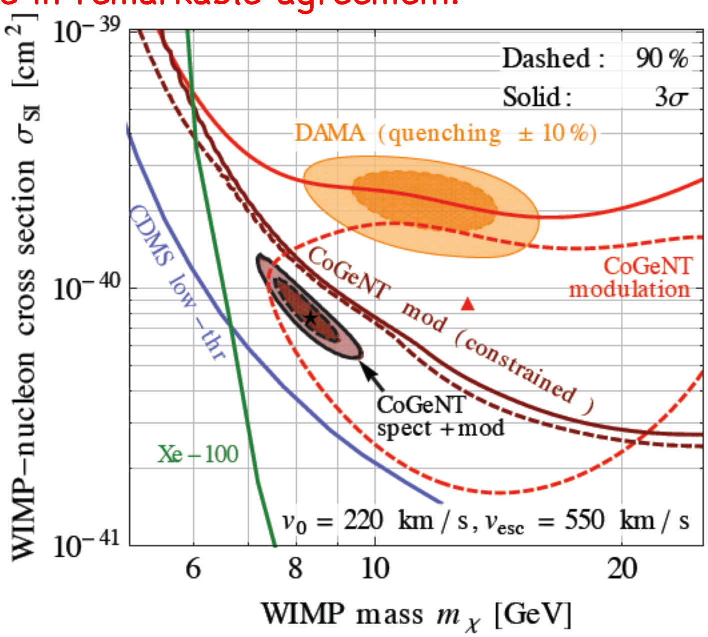
(<u>let us remember that DAMA is placed in σ vs m_χ space via the assumption of a Maxwellian halo: if modulation is really much larger, DAMA's σ becomes smaller...</u>)

Are DAMA, CoGeNT and CRESST in agreement, or not at all?

CRESST collaboration: arXiv:1109.0702



CoGeNT modulation ROI and CRESST M2 region seem to be in remarkable agreement.



P. Fox et al., arXiv: 1107.0717 See also Schwetz & Zupan arXiv: 1106.6241, P. Belli et al. arXiv: 1106.4667, etc.

- Including surface event contamination next to threshold brings spectral and modulation CoGeNT analyses in close agreement at ~10-15 GeV.
- However, Q_{Na}~0.4 seems extremely unlikely after UC measurement, regardless of theoretical prejudice (see arXiv:1007.1005).
- … and the modulation observed by CoGeNT would be order-of-magnitude larger than expected from a standard Maxwellian halo.
- …DAMA floats an order of magnitude higher in coupling than COGeNT/CRESST. Are there ways to reconcile?:
  - ~~Channeling~~ (UC measurement)
  - IVDM…
  - streams, dark disk, debris, etc…

(<u>let us remember that DAMA is placed in σ vs m_χ space via the assumption of a Maxwellian halo: if modulation is really much larger, DAMA's σ becomes smaller…</u>)

A few (personal) reflections:

* On a bad day: do we know enough about the local halo, DM coupling mechanisms, etc. to be playing this game? The last few transparencies follow very precisely the Popperian definition of pseudoscience... (and yet, a cynic would argue that this may be the beginning of "precision" DM work or "WIMP astronomy").

* On a good day: I am reminded of the Adams/Leverrier prediction for Neptune (i.e., maybe we are about to learn something new out of this royal mess). Also of how much fun we've been poking at the "spherical cow" halo model.

("bad day" and "good day" above are exchangeable)

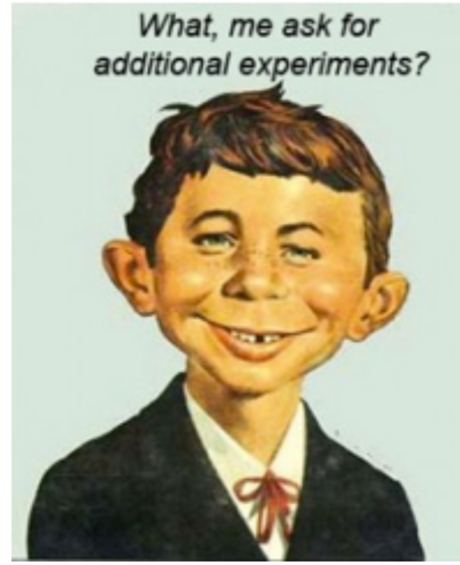
* On any given day: I look forward to more experimental data, and to an absence of bias in their interpretation.

And a brief desiderata:

* CDMS has collected ~10 times the low-E exposure of CoGeNT, spanning >4 annual cycles. Interest in light-WIMPs as a solution to the DAMA conundrum goes back to 2004 (Bottino *et al.*, later re-examined by Gelmini & Gondolo). This was one of the motivations for CoGeNT. For when a CDMS annual modulation analysis?

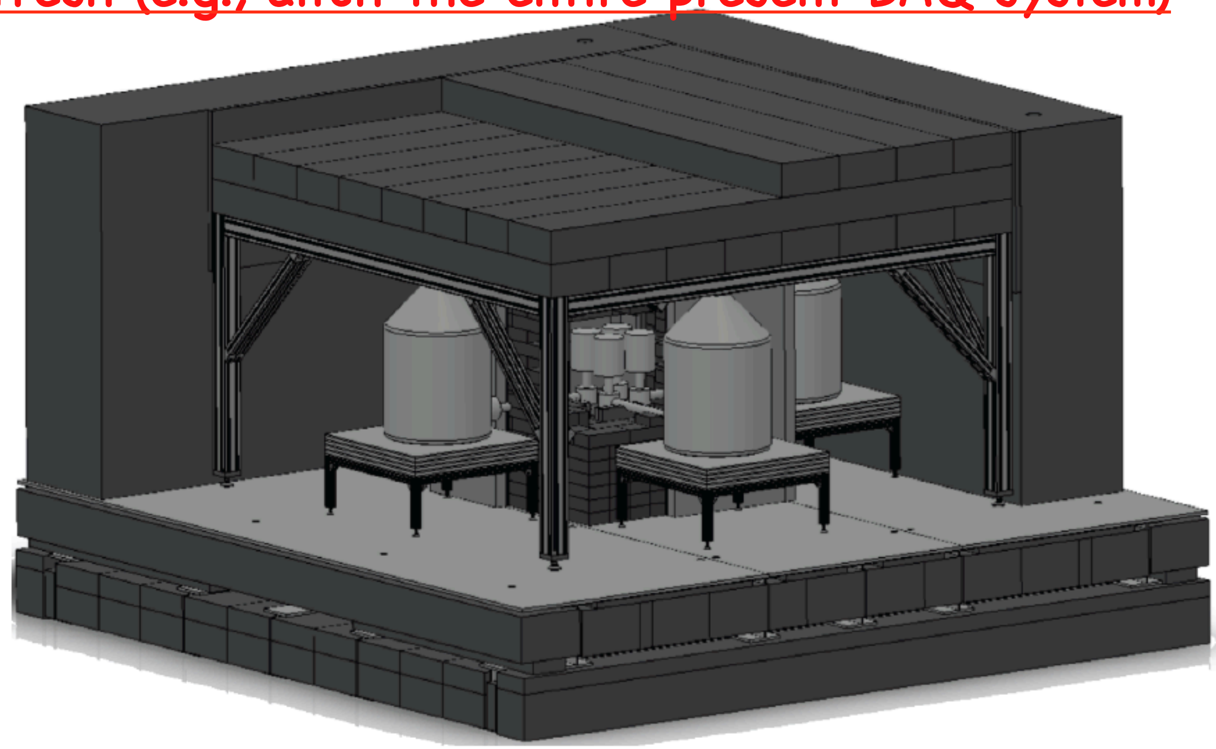
* Calibrations come before exclusions: the last time XENON presented a comparison between low-E neutron recoil rates and corresponding expectations was in 2007 (Manzur, APS meeting). It did not look good at all. Such data exist for XENON100. If the disagreement is as for XENON10, <u>there are no low-mass exclusions to speak of</u>.

UC/PNNL design CoGeNT-4 (C-4)



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

Start afresh (e.g., ditch the entire present DAQ system)



Roughly 10 times present target mass (annual modulation). Optimal light-WIMP detector, by design.

Expected start end of 2011.