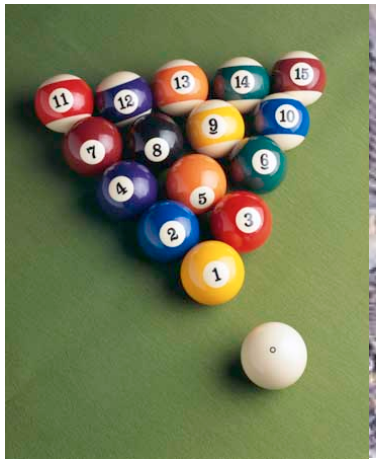
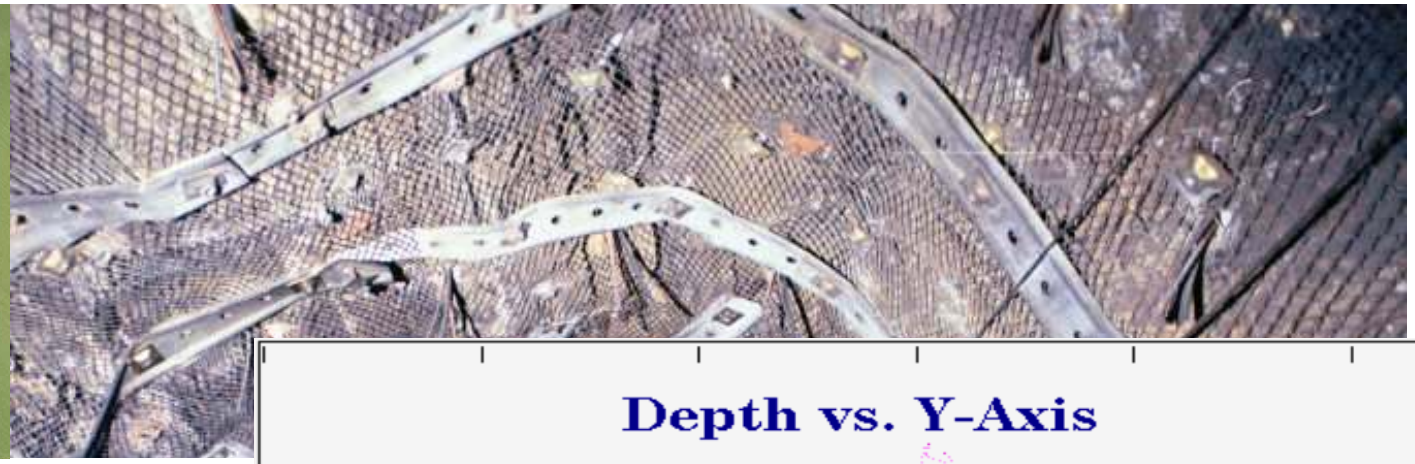
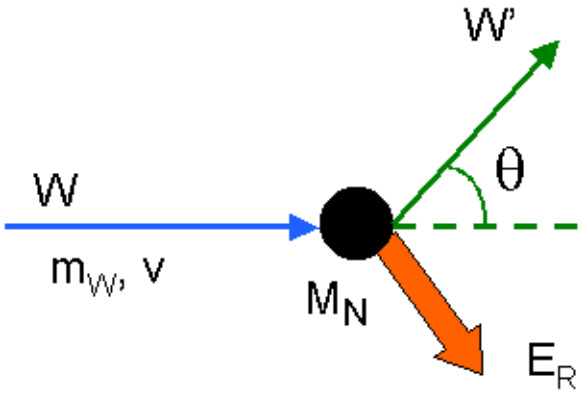
How do you look for WIMPs in the lab?

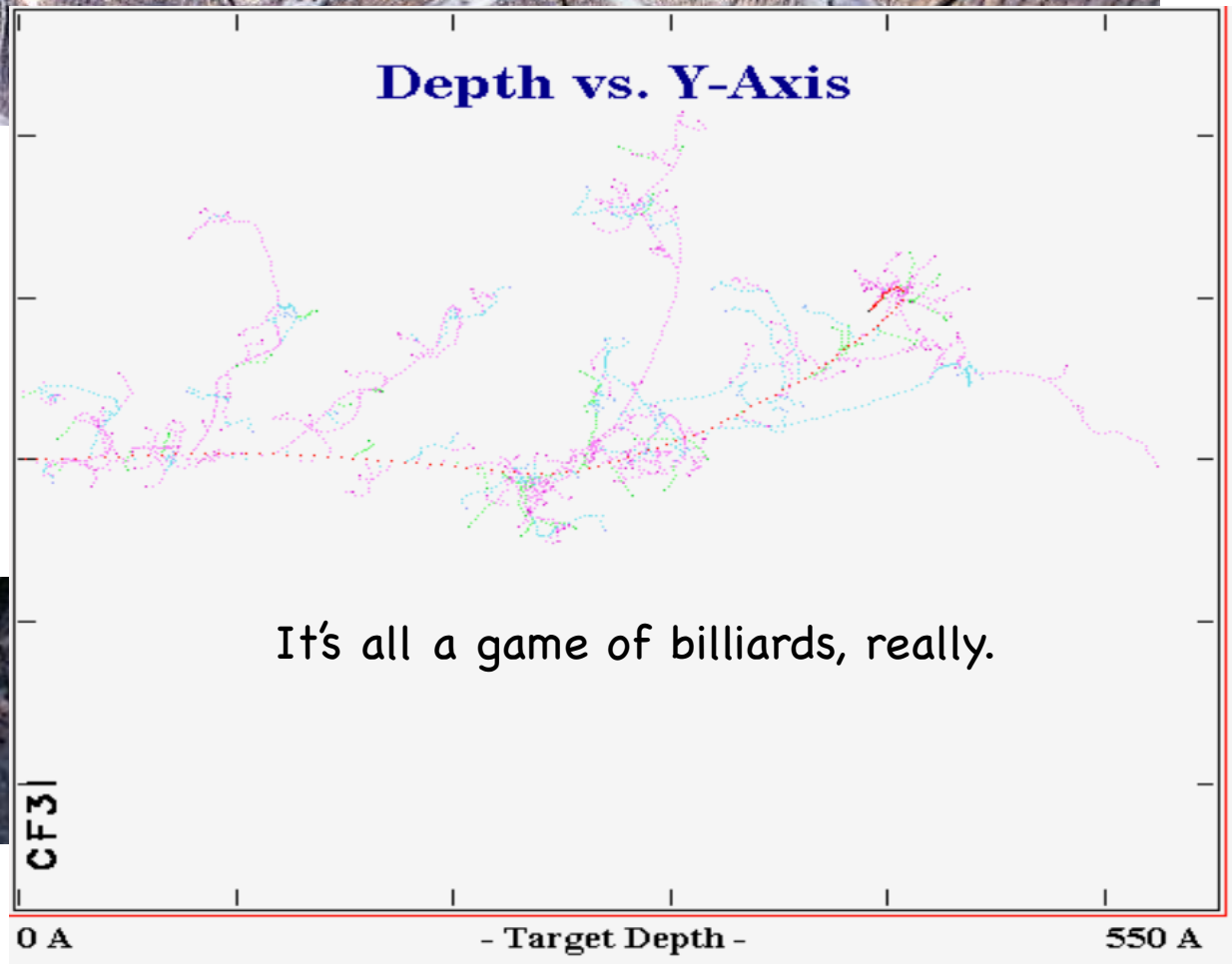
Location, location, location.

How do you look for WIMPs in the lab?



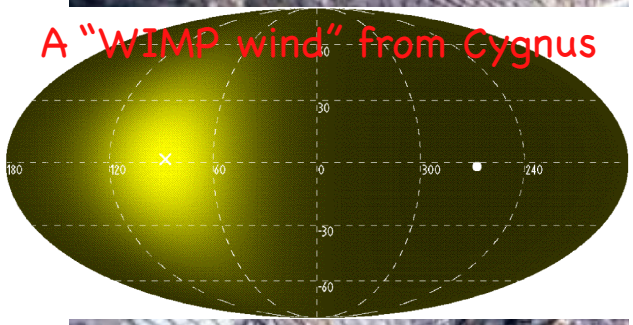


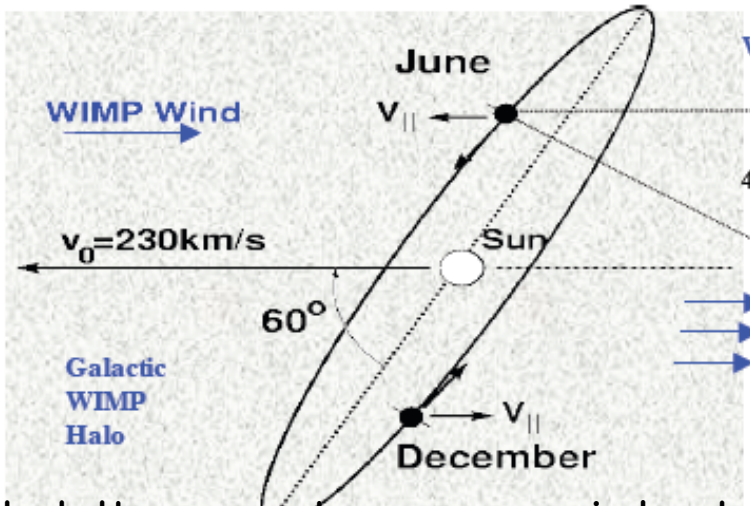


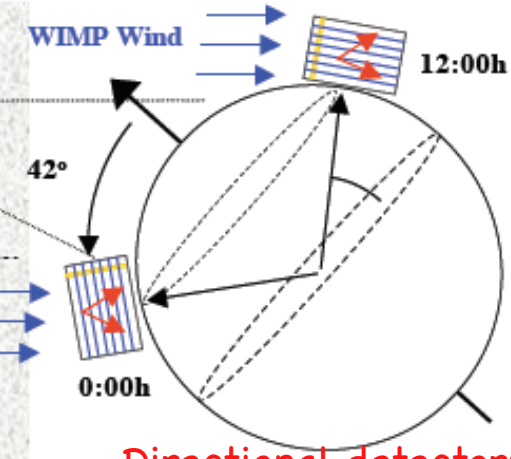


It's all a game of billiards, really.

How do you look for WIMPs in the lab?

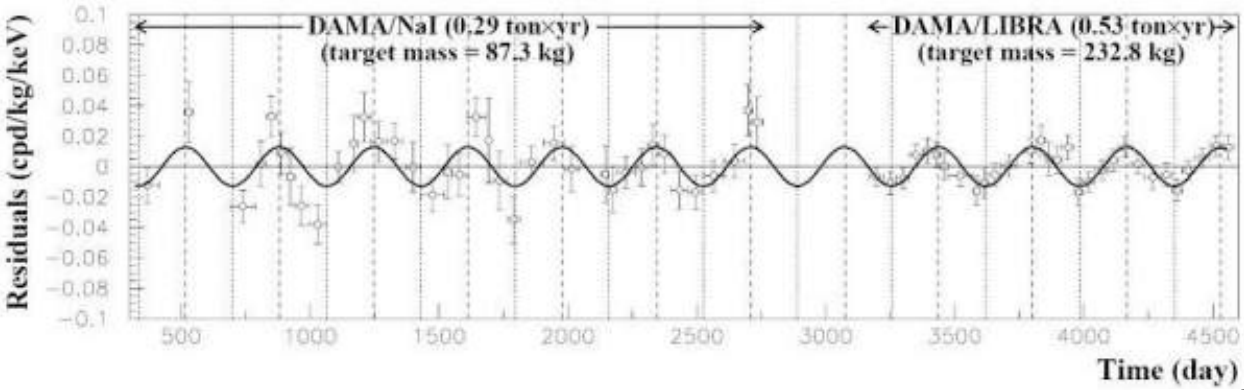


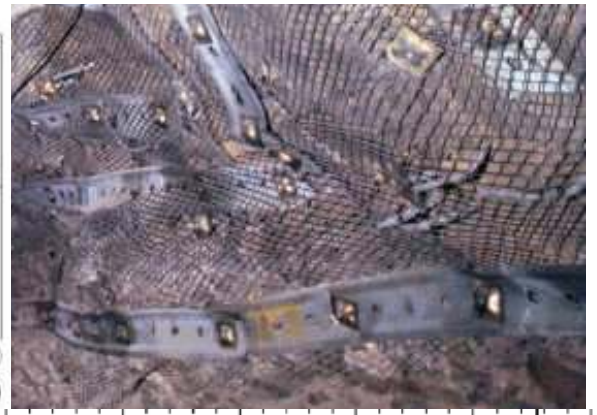


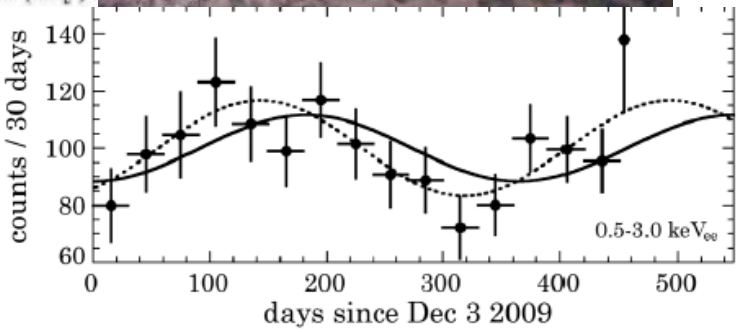


Directional detectors, our holy grail

(but the game has some weird rules)







We live in a radioactive medium

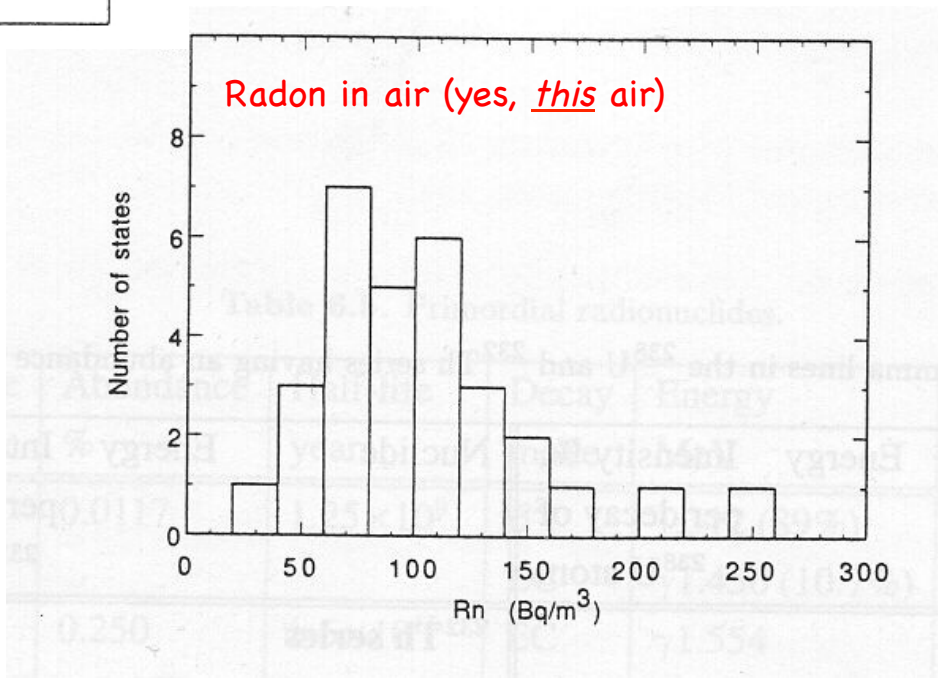
(and one day, "dark matter" will be regarded as just another form of radiation)

Many sources:

- Primordial (U, Th, K)
- Cosmogenic
- Man-made

	Half-life, years	Activity Bq/kg	γ/dis (>50 keV)
Potassium, ^{40}K	1.25×10^9	2.98×10^4	0.11
Thorium, ^{232}Th	14.0×10^9	4.02×10^6	2.08*
Uranium, ^{238}U	4.5×10^9	12.3×10^6	1.80*

Rule-of-thumb: ~1 ppm U and Th in Earth's crust.
You are what you eat...



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Don't look up now...

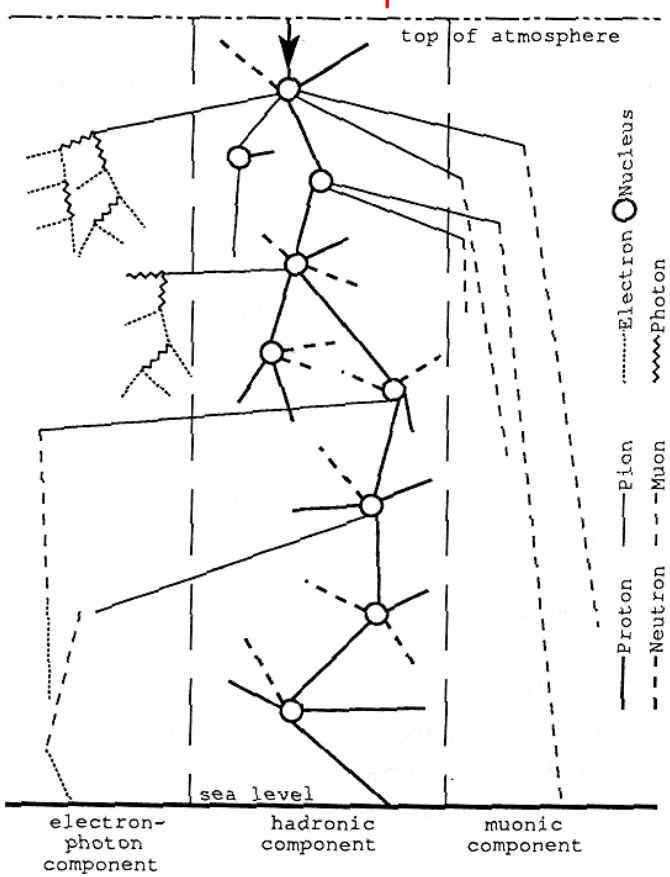
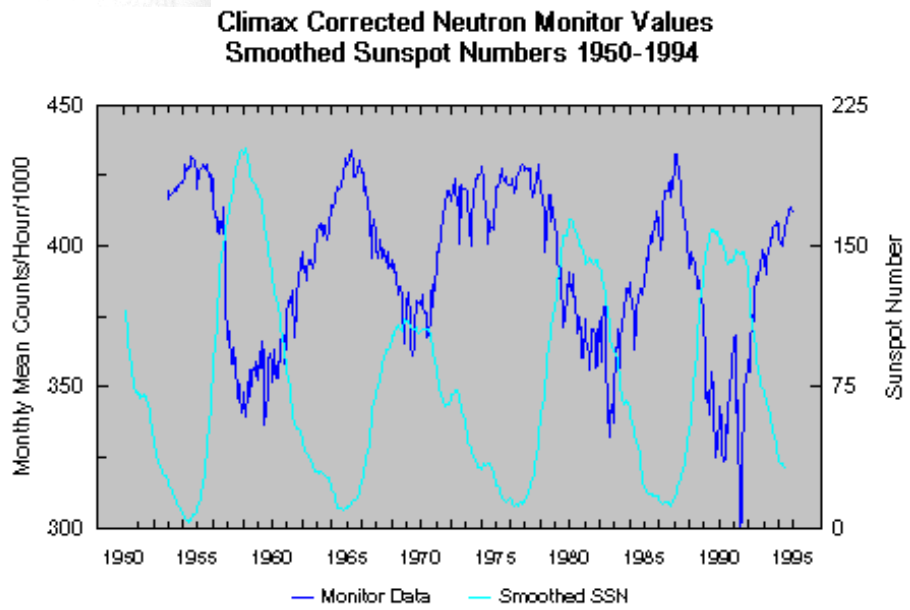


Fig. 7.3. A schematic description of the production and fate of cosmic ray particles in the atmosphere and upper layer of the Earth.

The Sun, doing its bit to help



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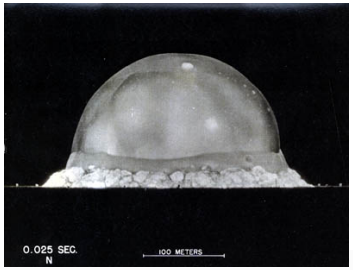
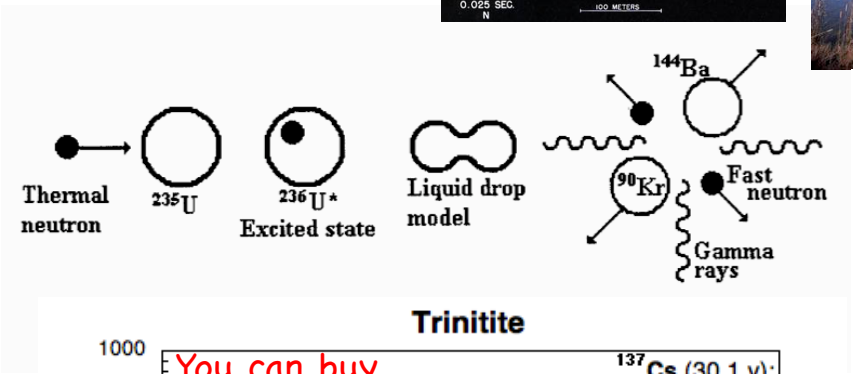
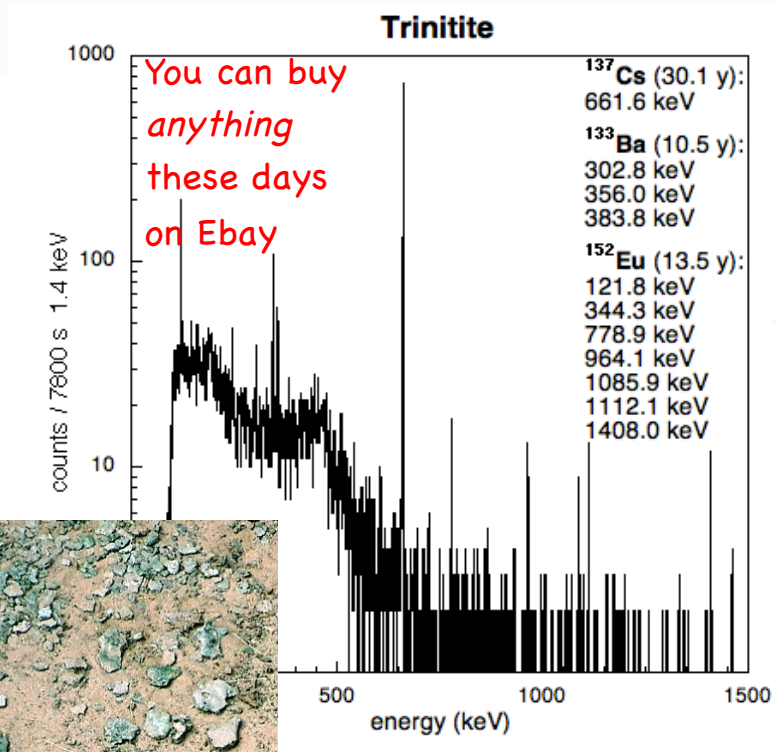
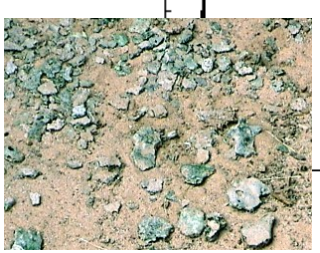








Man-made isotopes limiting sensitivity of KIMS Dark Matter detector

Chemical affinity: a real pain in the tuckus

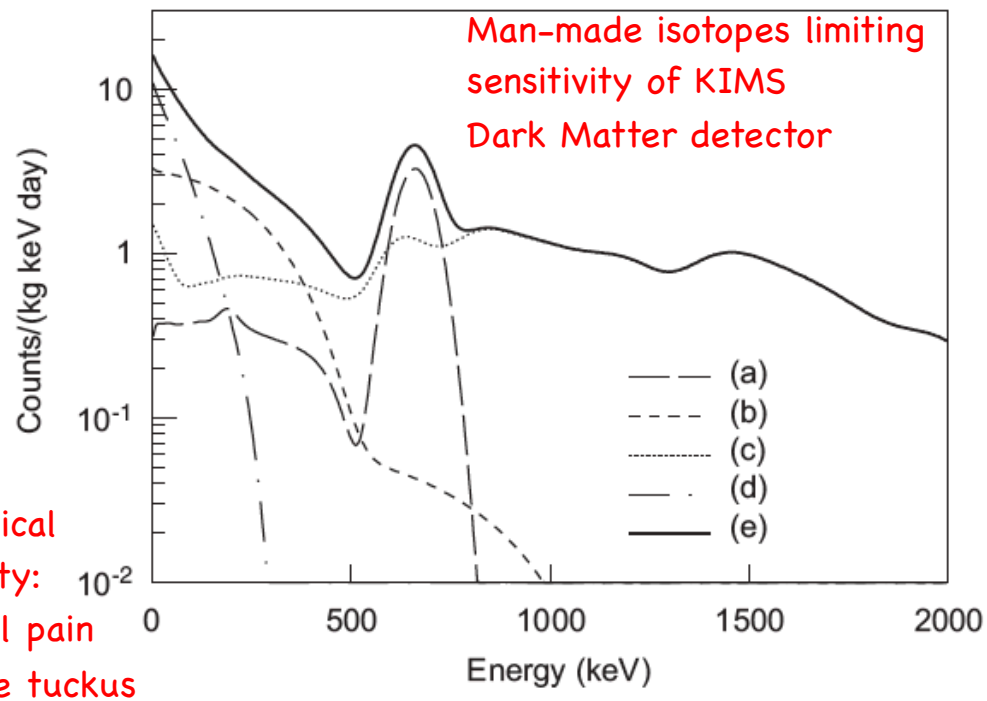
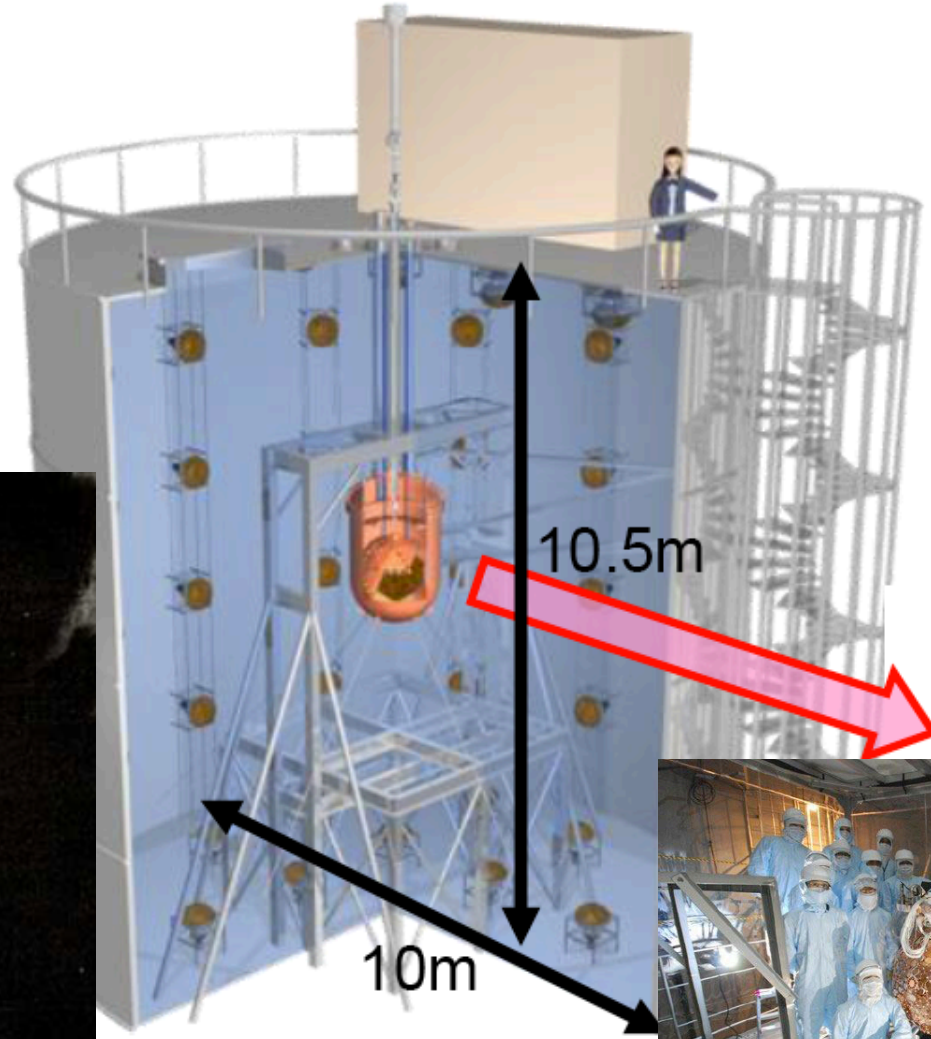


Fig. 3. Background spectra obtained using GEANT4 simulation for the $8 \times 8 \times 30\,\mathrm{cm}^3$ CsI(Tℓ) crystal with 10 mBq/kg ^{137}Cs contamination, 30 mBq/kg ^{134}Cs contamination, and 10 ppb ^{87}Rb contamination: (a) spectrum of ^{137}Ba*; (b) beta-ray spectrum of ^{137}Cs; (c) ^{134}Cs spectrum; (d) ^{87}Rb spectrum; and (e) total summed spectrum.

Remember that "W" in "WIMP"?

The challenge: to go from a few hundred radiation events per kg of detector mass per second...



...to a few per ton per year (and they have to look like billiard ball collisions)

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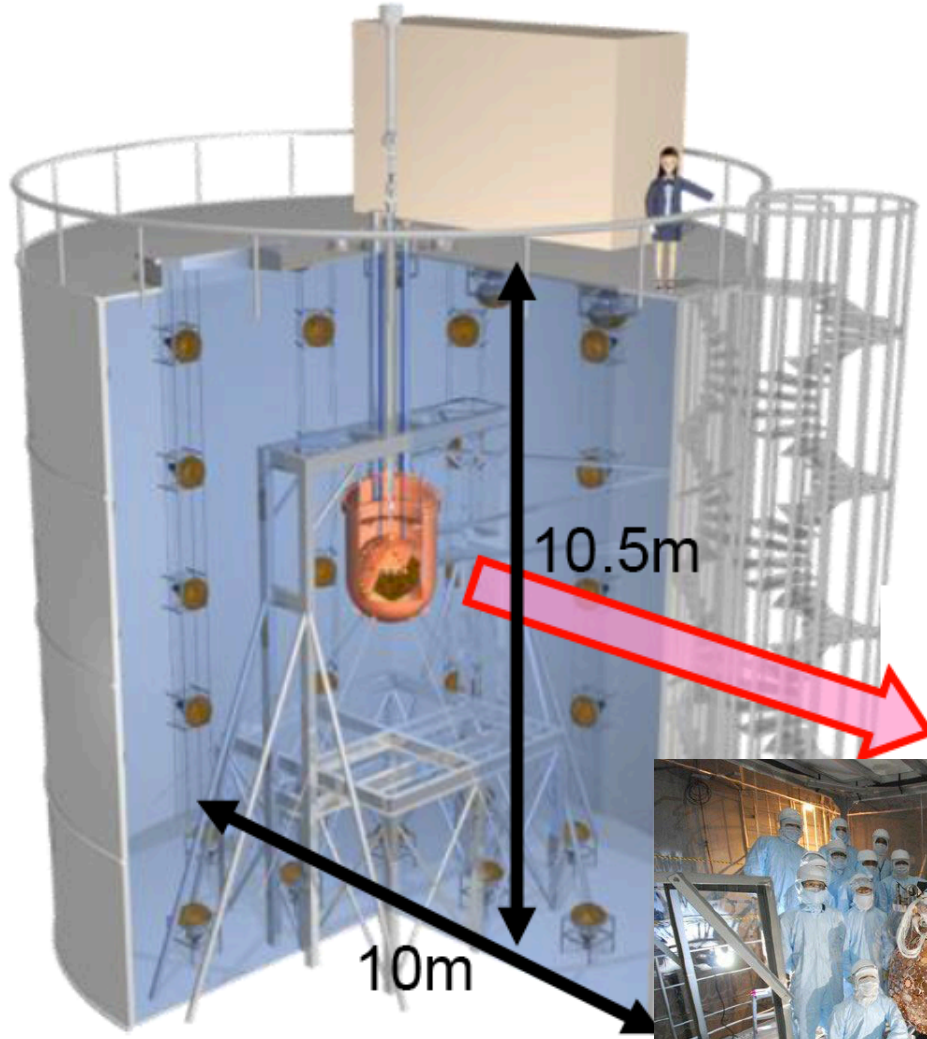
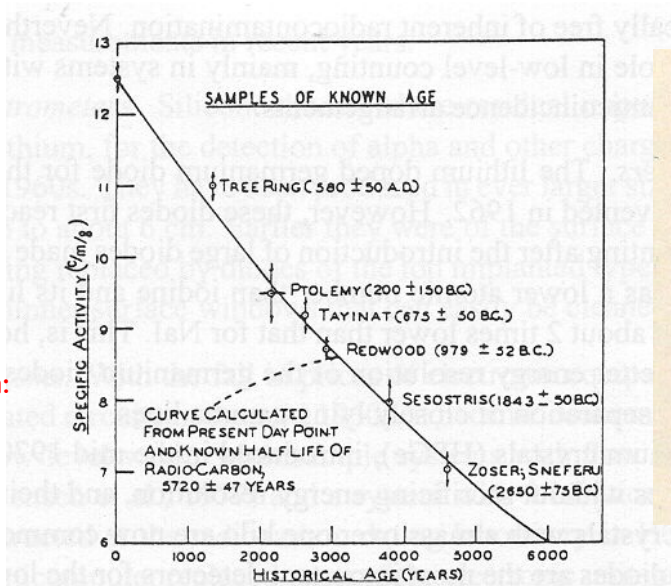


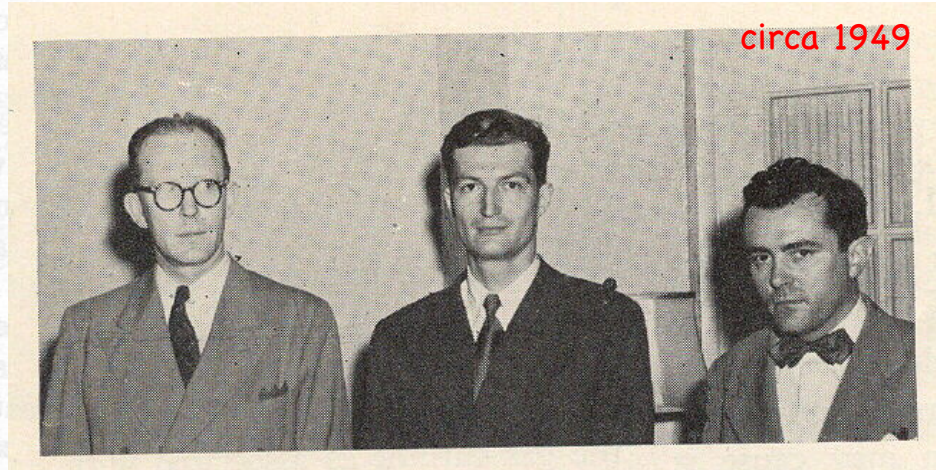
...to a few per ton per year (and they have to look like billiard ball collisions)

Enter low-background techniques

Problem for Early ^{14}C counters:

Background rates ~100c/min regardless of shielding, largest ^{14}C signal ~14c/g/m: Birth of the anticoincidence veto

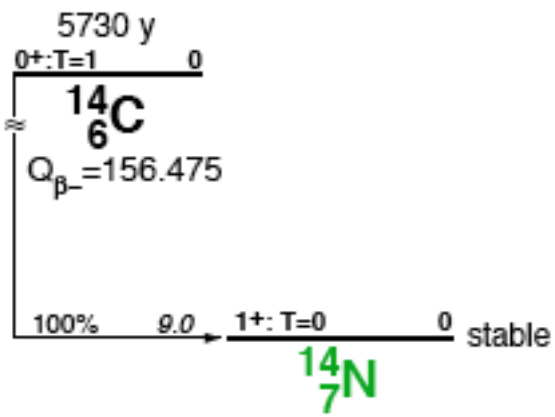




Pioneered at University of Chicago by W. Libby (tradition continued by J. Simpson, T. Turkevich, etc.)

Cosmogenic origin: $n_{th} + {}^{14}N \rightarrow {}^{14}C + H$

Fixed by plants via photosynthesis



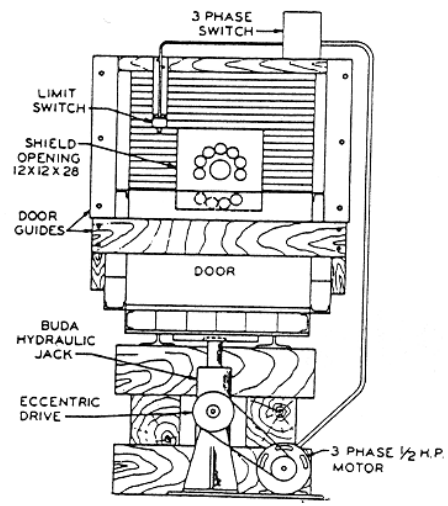


Fig. 1.1. Low-level counting started with this system. Libby's radiocarbon system with which he and his co-workers established the radiocarbon dating technique in 1947–1949.

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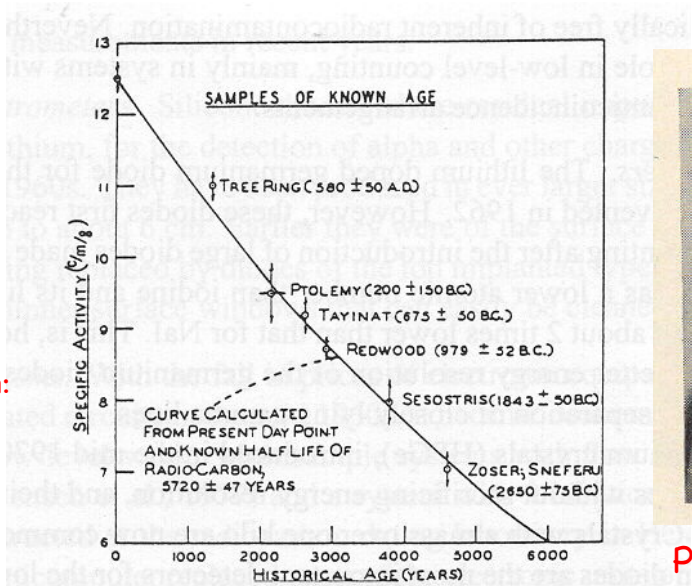

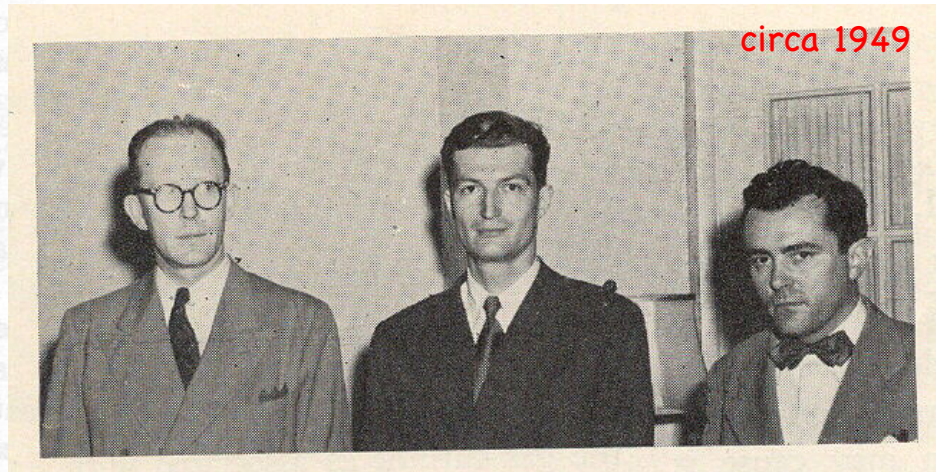

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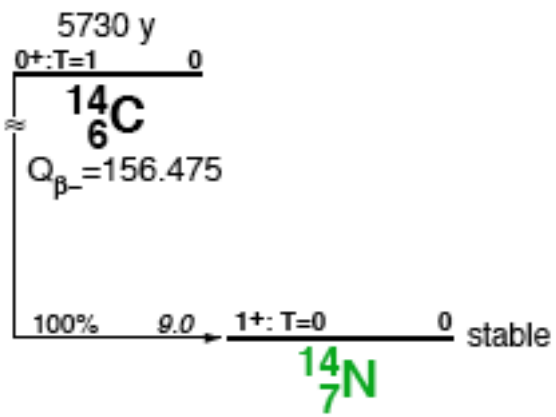
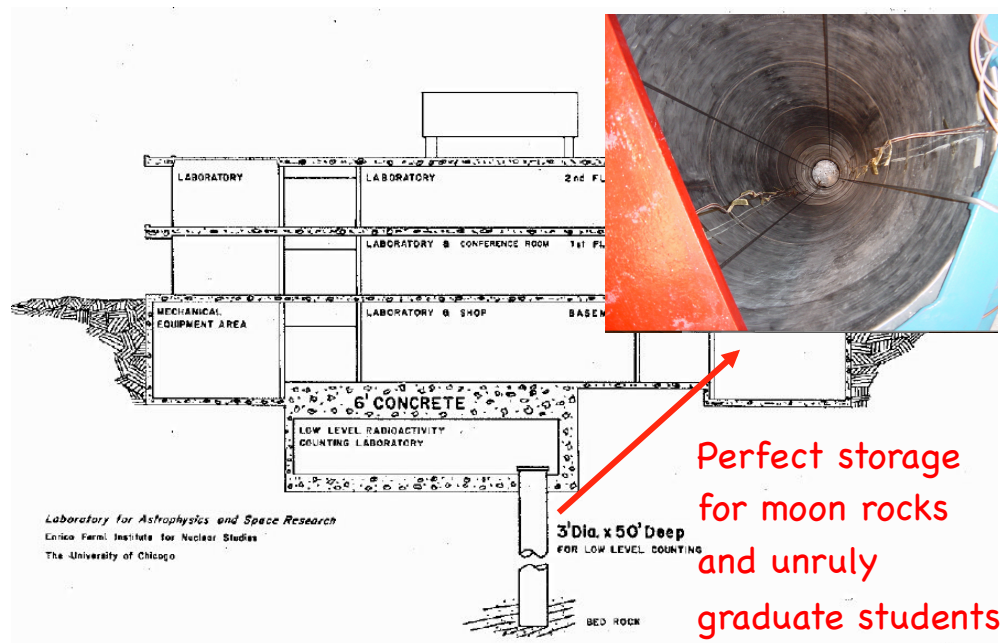


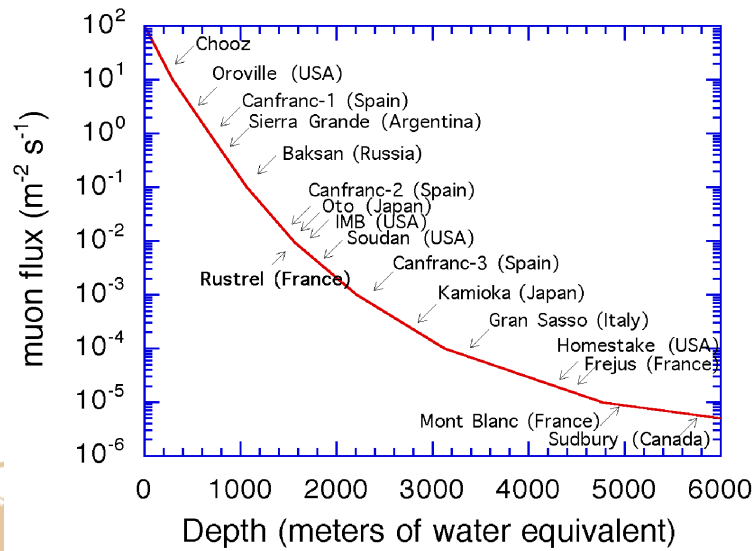


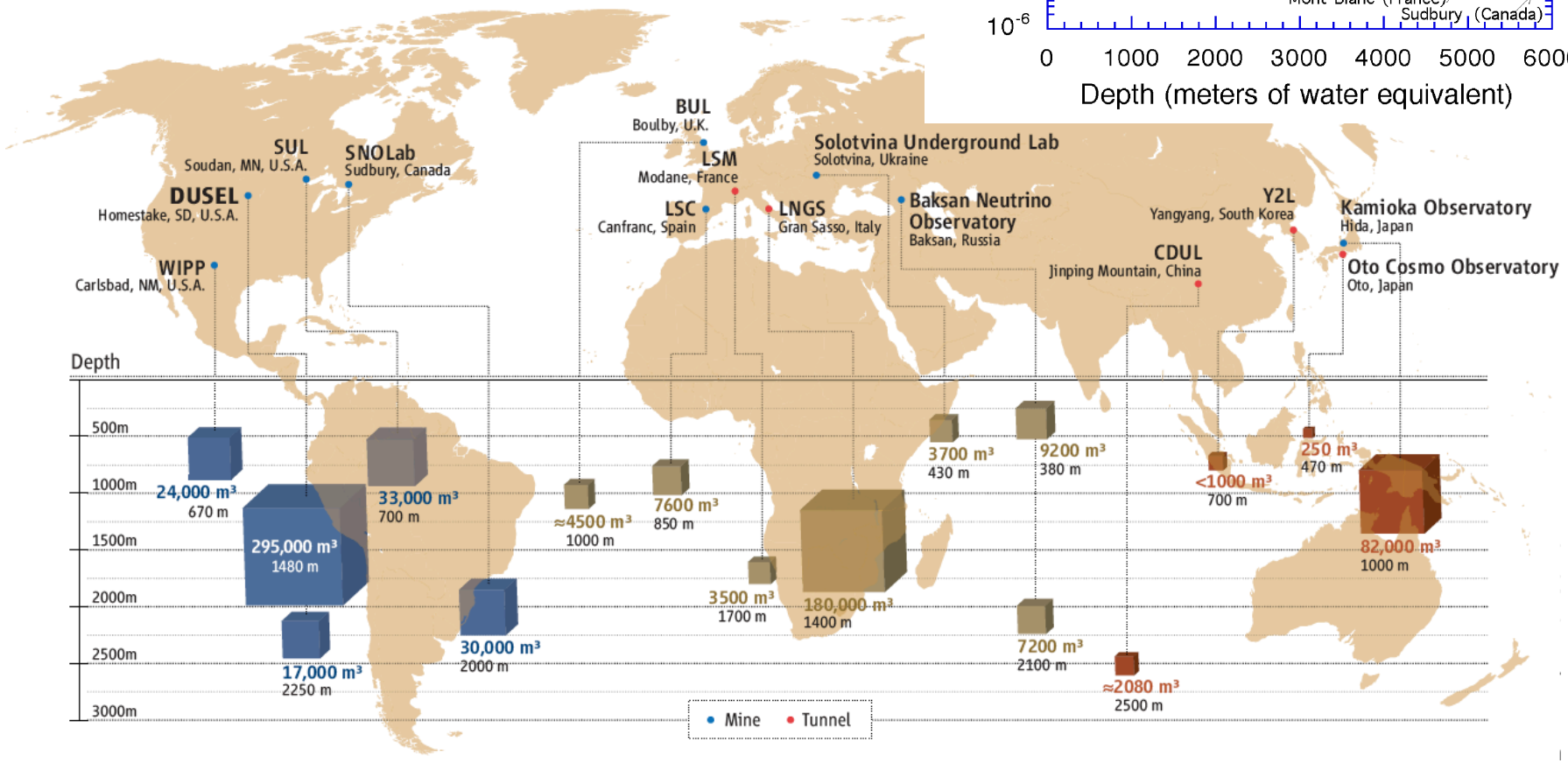
Perfect storage for moon rocks and unruly graduate students

Low-background techniques
(as applied to DM searches)

Bag-of-tricks:

- Depth
- Shielding (active & passive)
- Radiopurity
- Background rejection
- Special detector properties





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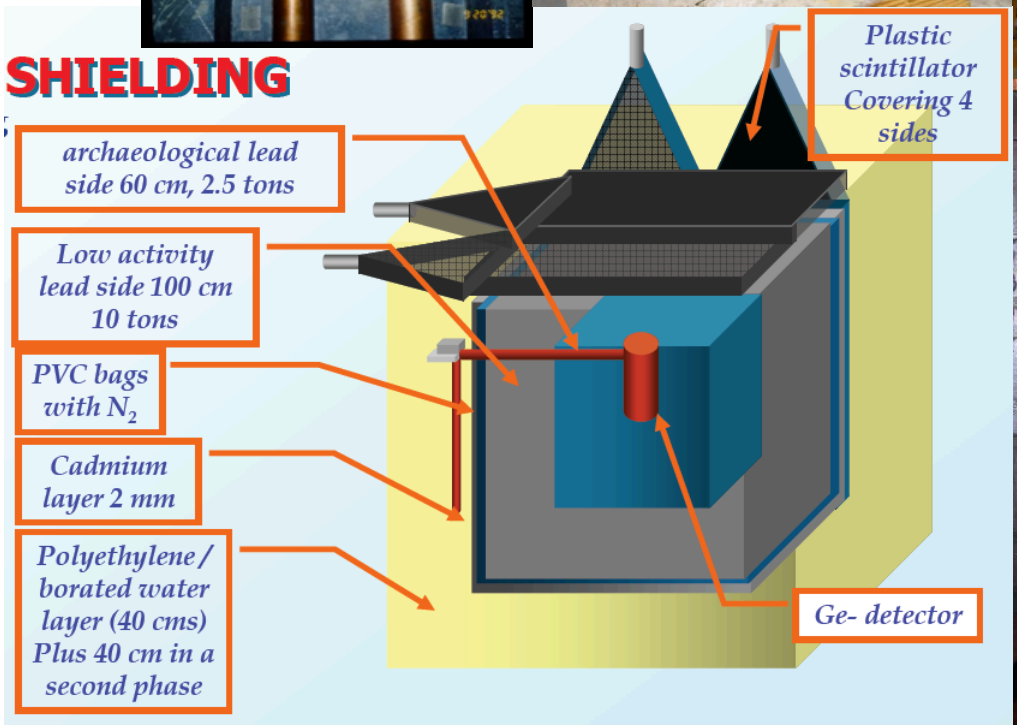

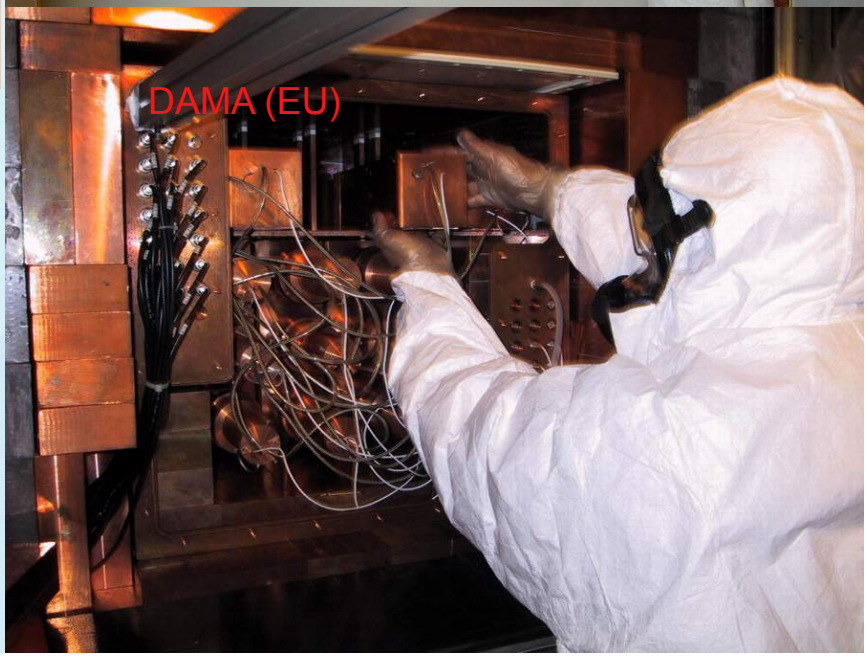

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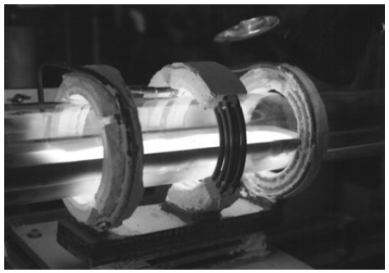
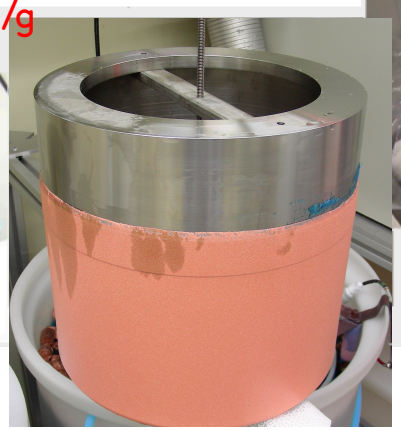


Fig. 2. A 3-Coil Zone Refiner.

Fig. 3. A Zone-Refined Ingot.

Ge zone refinement

impurities ~1E-13 g/g



Electroformed
Cu cryostat

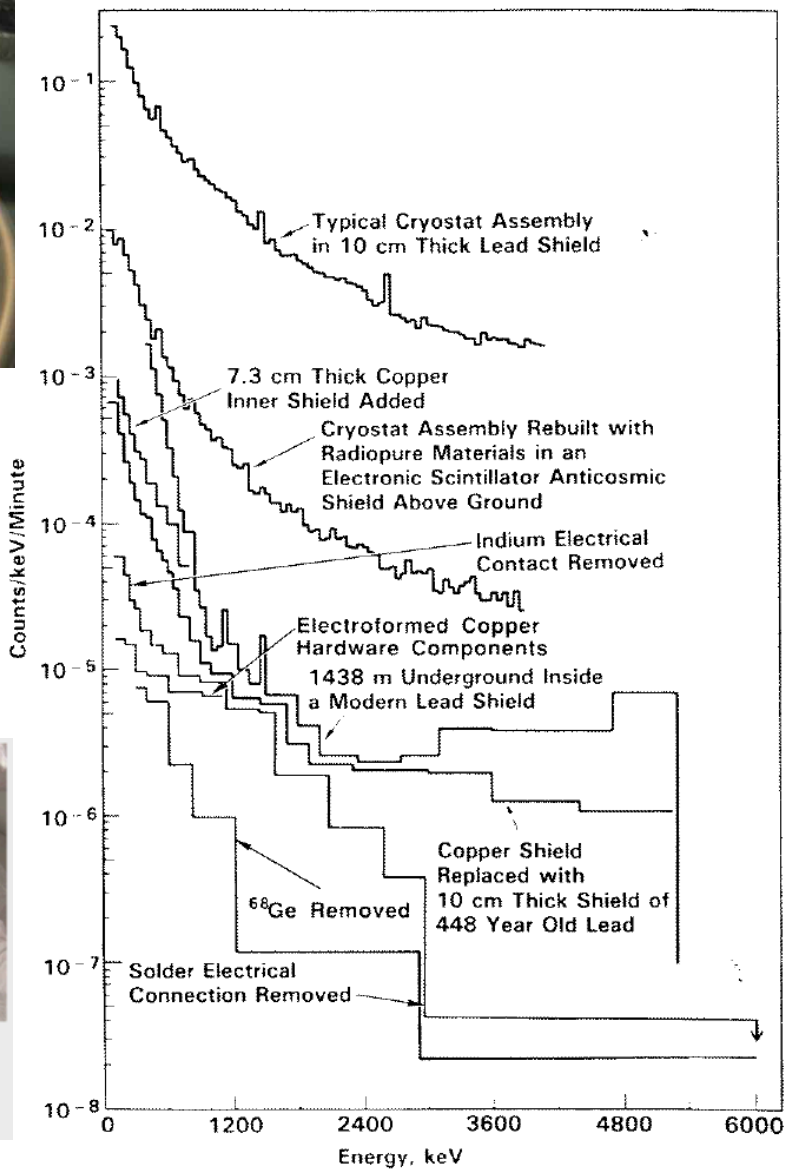


Fig. 1. Improvements in low-background technology.

...and yet not enough *per se* to catch a WIMP...

Low-background techniques
(as applied to DM searches)

Bag-of-tricks:

- Depth
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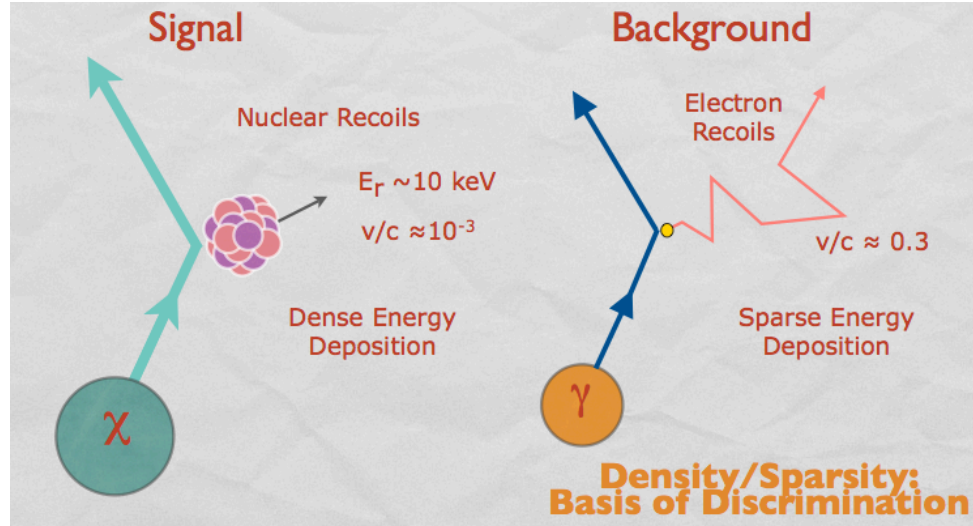
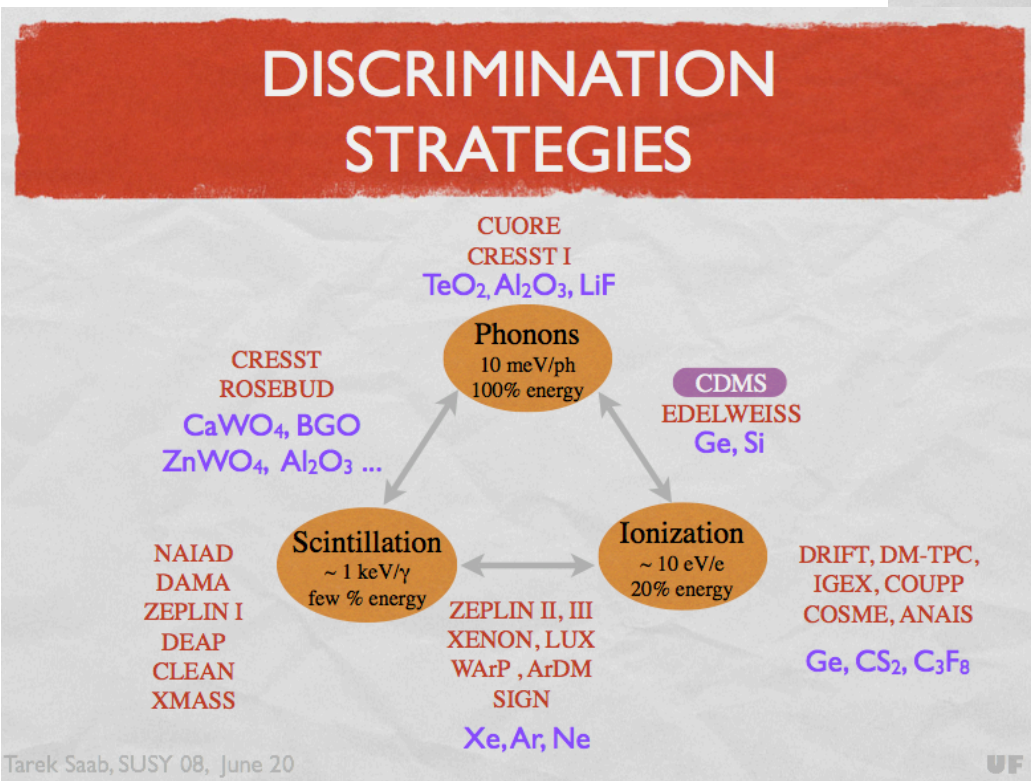
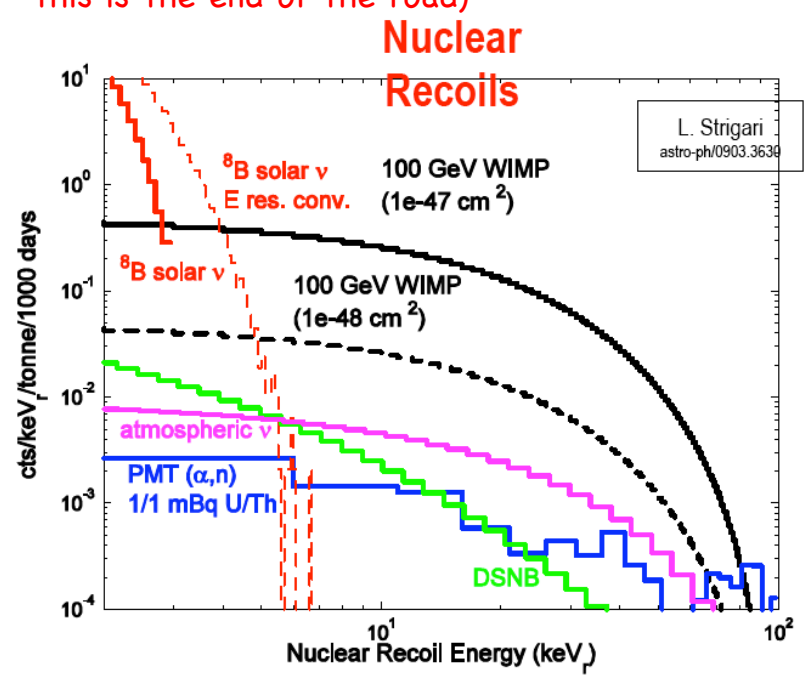




Ridiculous or sublime? (one way or another, this is the end of the road)



L

Particle dark matter? The number of candidates is comparable to the ~30 experiments out to detect it.

- Standard model neutrinos
- Sterile neutrinos
- Axions
- Supersymmetric dark matter (neutralinos, sneutrinos, gravitinos, axinos)
- Light scalar dark matter
- Little Higgs dark matter
- Kaluza-Klein dark matter
- Superheavy dark matter (wimpzillas)
- Q-balls
- CHArged massive particles (CHAMPS)
- Self-interacting dark matter
- D-matter
- Cryptons
- Superweakly interacting dark matter (SWIMPS)
- Brane-world dark matter
- Heavy 4th generation neutrinos
- Mirror particles
- Etc., etc.

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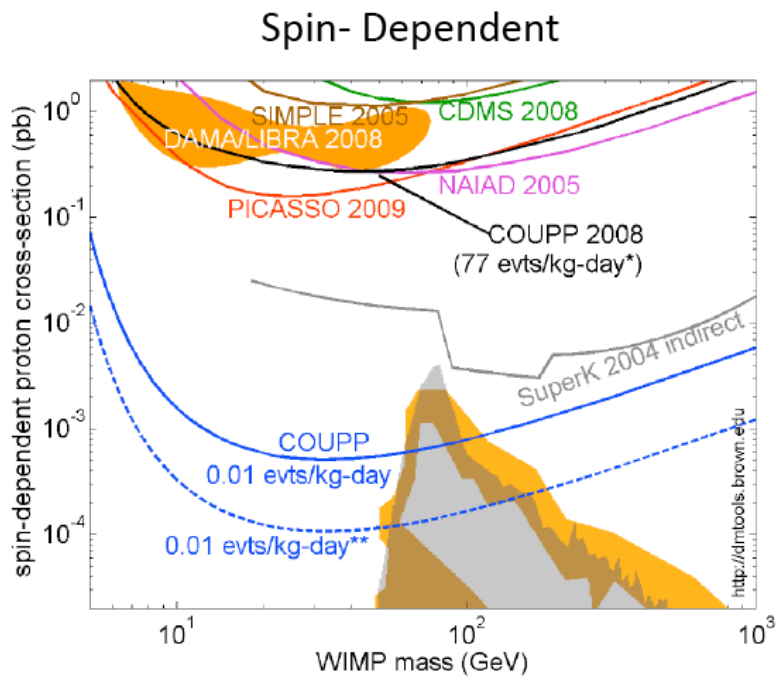
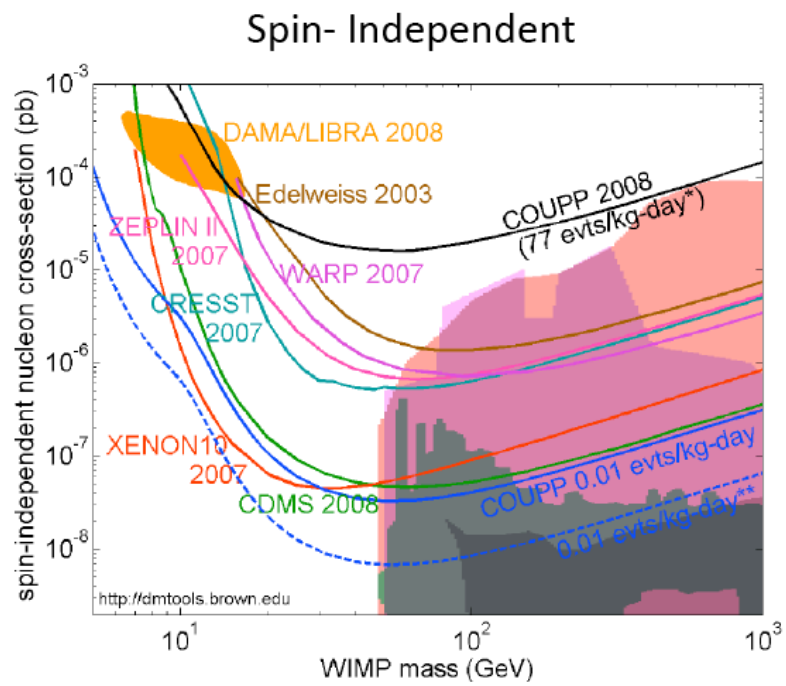
(theory types come up with the funny names, we get to do the rest of the job)

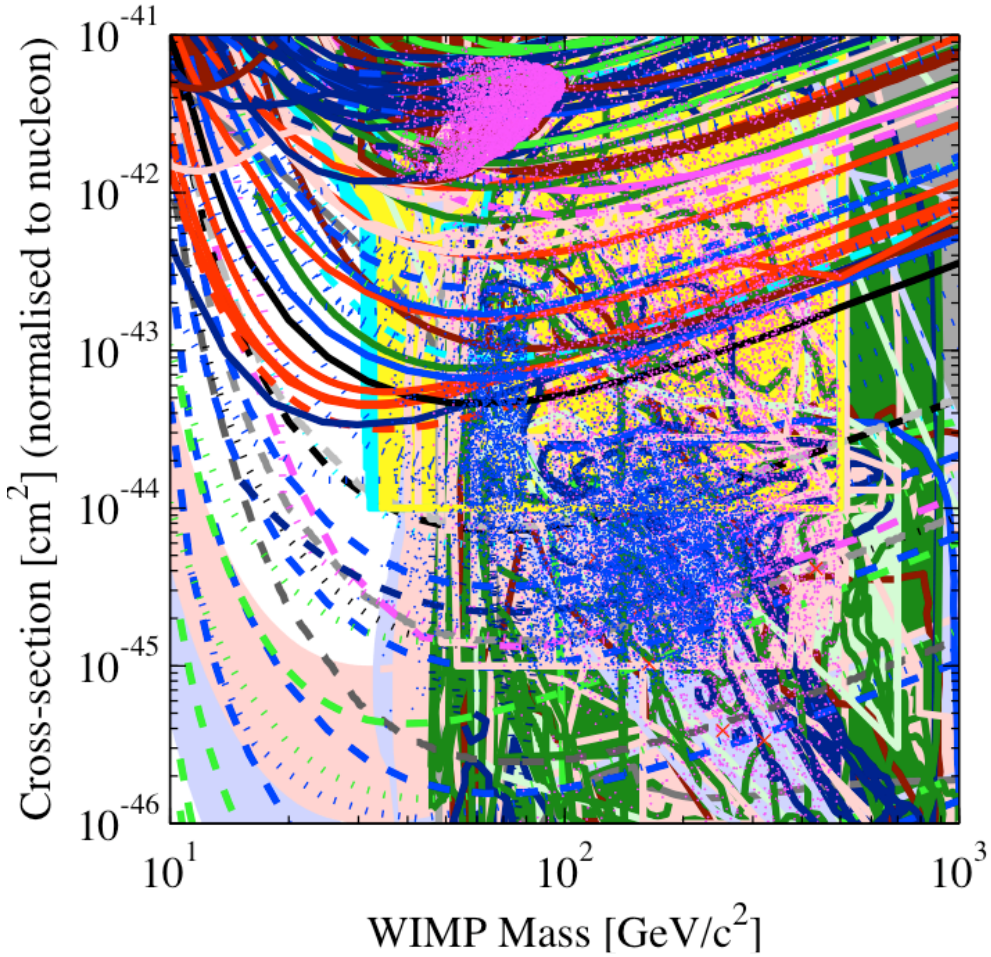
The sociology of this field:





Q: What do you get if everyone is right?

The sociology of this field:



A: ART

What will it take to call it "Dark matter"?

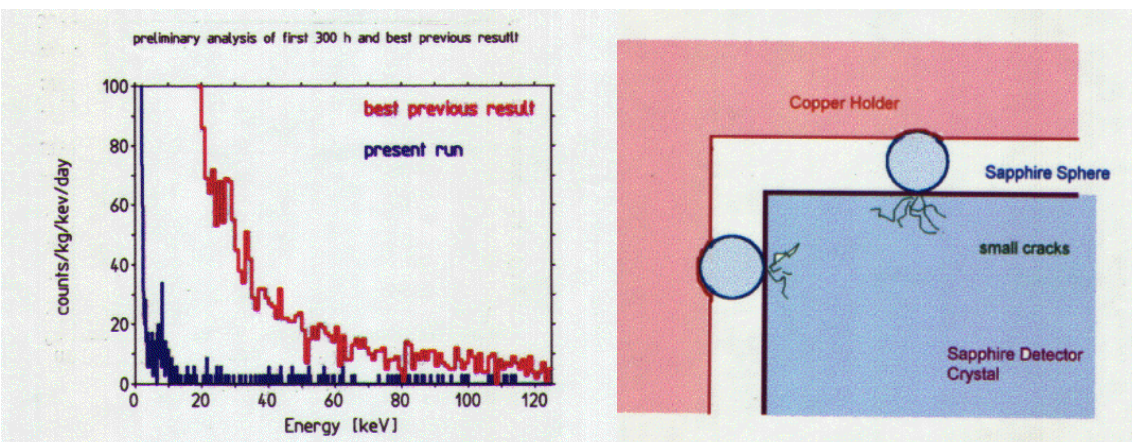
- A number of "hints" of discovery already available. But it takes just one finger on the Ouija board to set it into motion...

  The LHC should offer some help soon (man-made Dark Matter!)

- In a few years (decades?) we will regard Dark Matter as just another form of natural radiation (and a background to other experiments).

- Along the way we will bump into many manifestations of natural radioactivity that we have not yet realized are there...

  ... and many mundane artifacts:

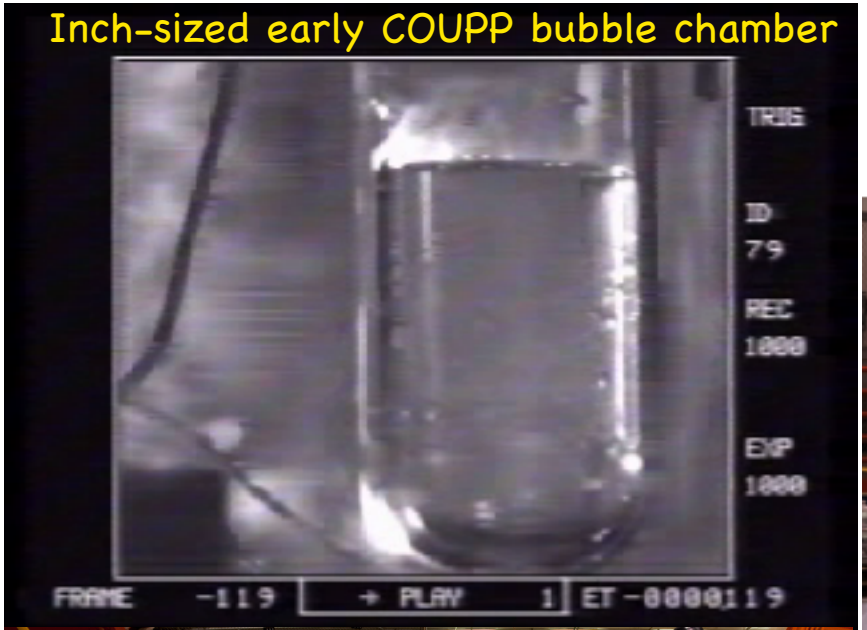


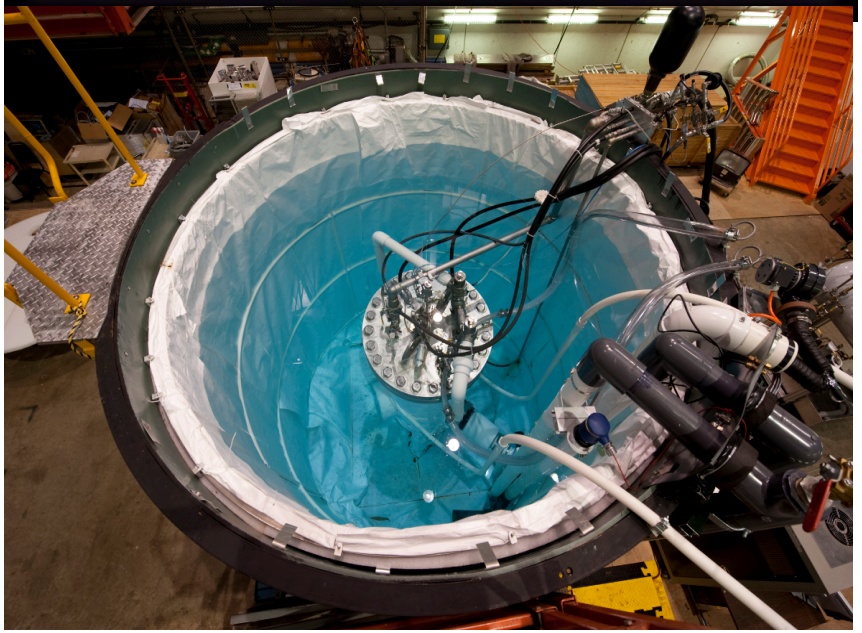
- No degree of enthusiasm (impatience?) from us will hasten this process.

WIMp searches: a quixotic fight against backgrounds.

Some of the fun toys we are going
to play with in the lab:

You have to start small before you grow BIG

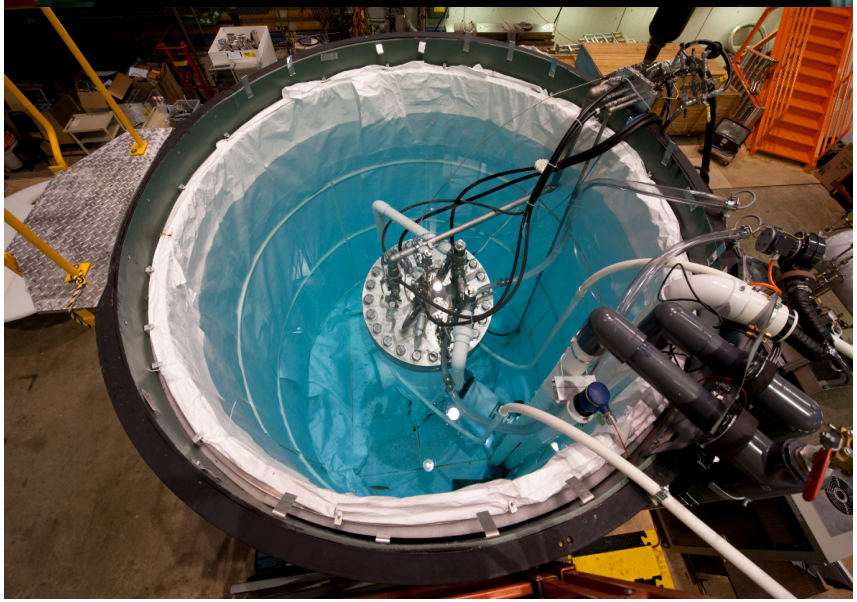




COUPP 60kg at Fermilab (500kg in preparation)

You have to start small before you grow BIG

Pretty much the same, "Mythbusters" version



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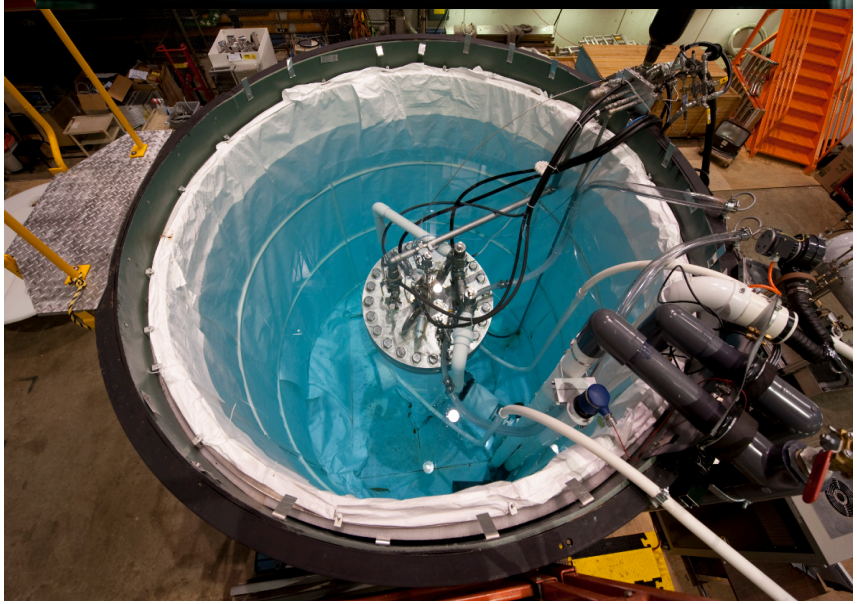


COUPP 60kg at SNOLAB

Rejecting alphas: listening to particles (yes, listening)

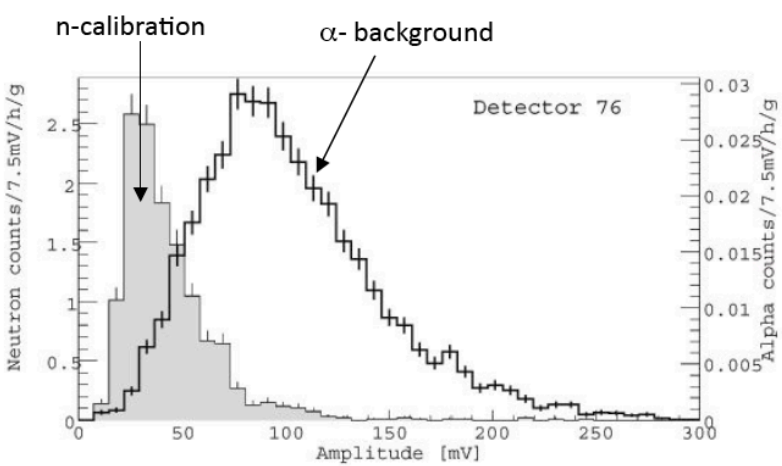
Glaser (1955)

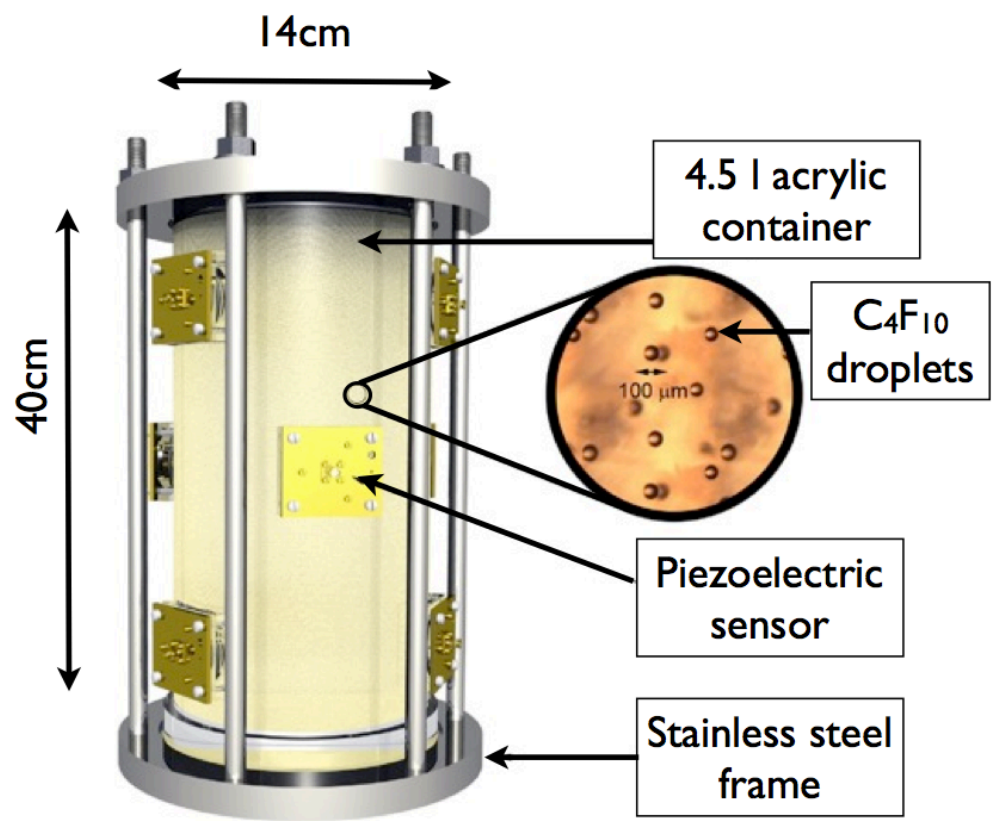
In order to see events more interesting than muons passing straight through the chamber, we took advantage of the violence of the eruption which produces an audible "plink" at each event. A General Electric variable-reluctance phonograph pickup was mounted with its stylus pressing against the wall of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

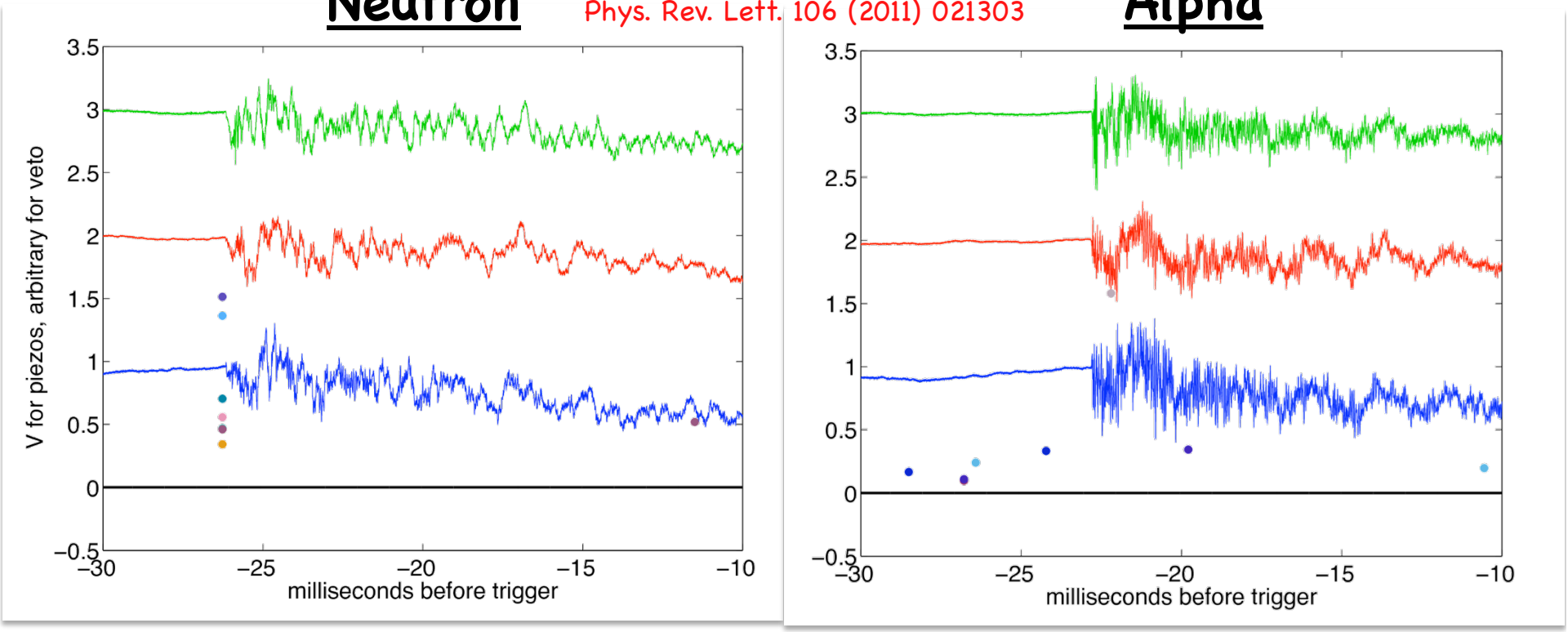




PICASSO demonstrates α – nuc. recoil acoustic discrimination in Superheated Droplet Detectors (SDDs)
F. Aubin *et al.*, New J. Phys 10 (2008) 103017

E-961 progress: acoustic alpha - nuclear recoil discrimination

Neutron Phys. Rev. Lett. 106 (2011) 021303 **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).
- Very high discrimination against α's is clear (~1E-5 rejection factor, we don't have enough statistics yet to determine this)
- Discrimination is considerably better than in PICASSO's droplet detectors (multiple reasons for this).
- Challenge in obtaining same discrimination in the larger devices: increasing number of sensors while reducing (α,n).

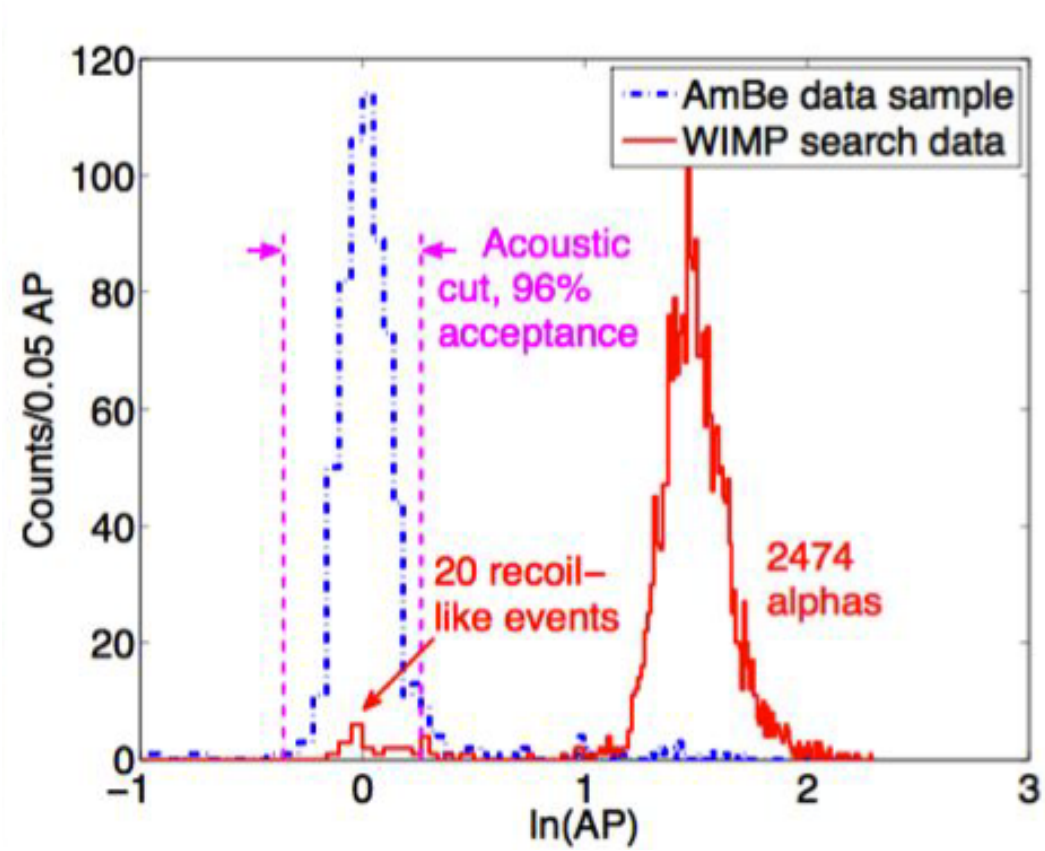
Relaxes internal radiopurity goals by 4-5 orders of magnitude

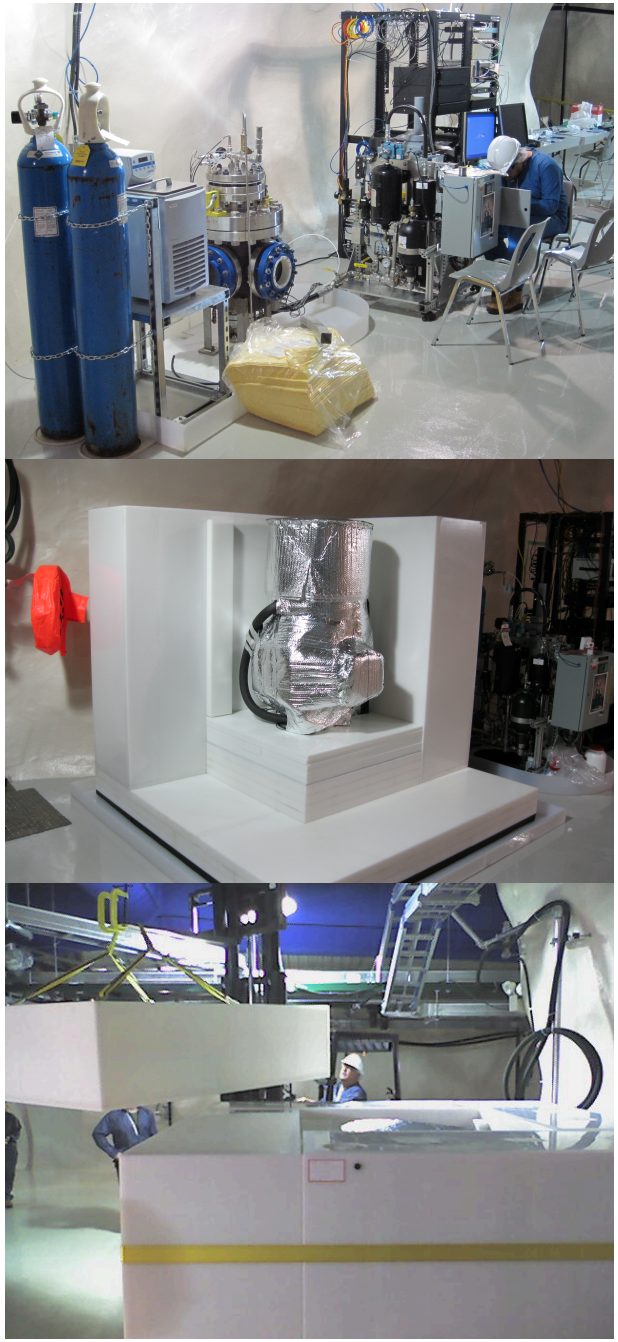
COUPP progress: acoustic alpha - nuclear recoil discrimination

SNOlab COUPP-4kg data

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

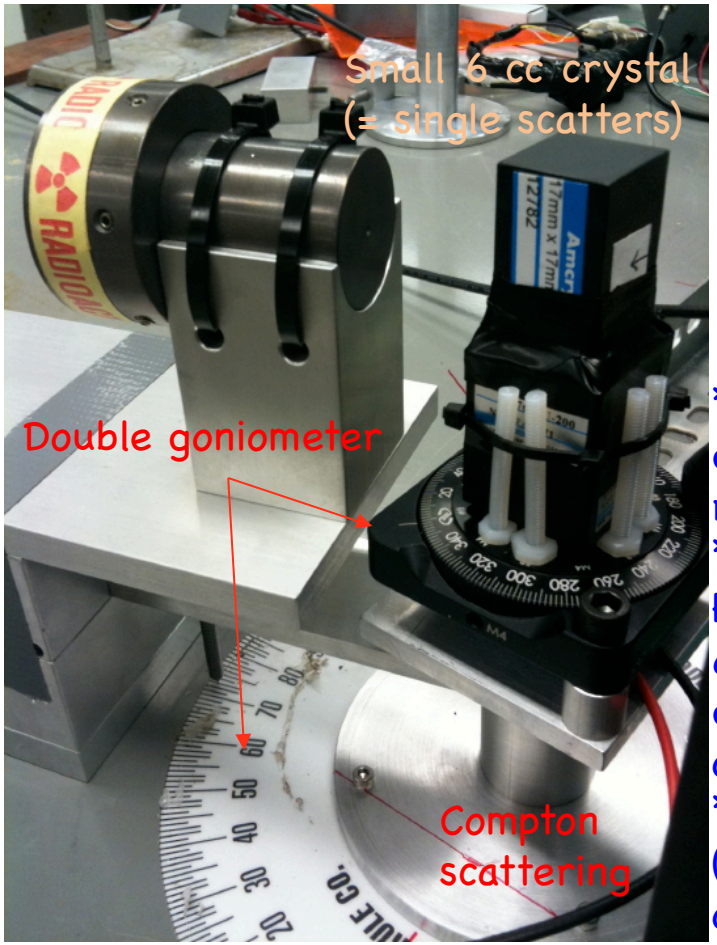
acoustic α rejection >>99.9%
(don't know where it will stop yet)

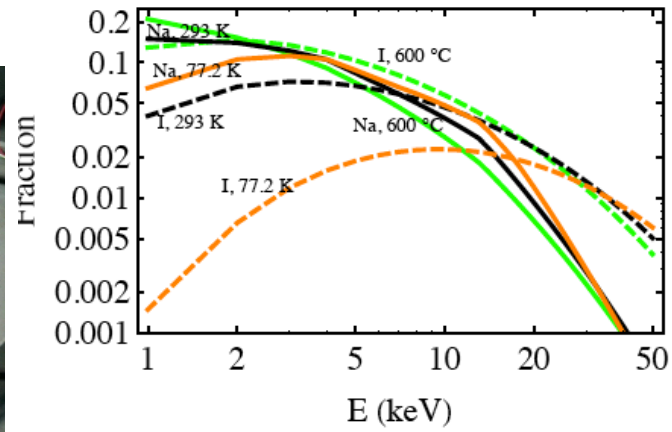


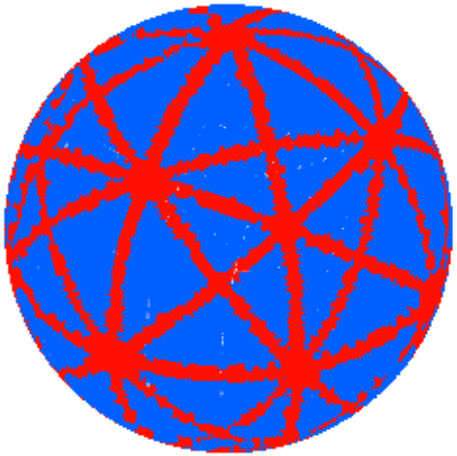


The devil is in the details (quenching factors, channeling)

- 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.





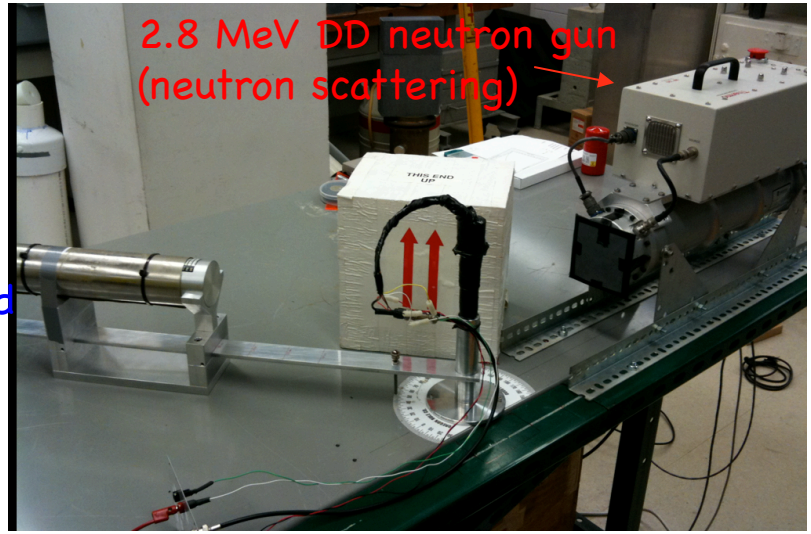


Bozorgnia, Gelmini & Gondolo

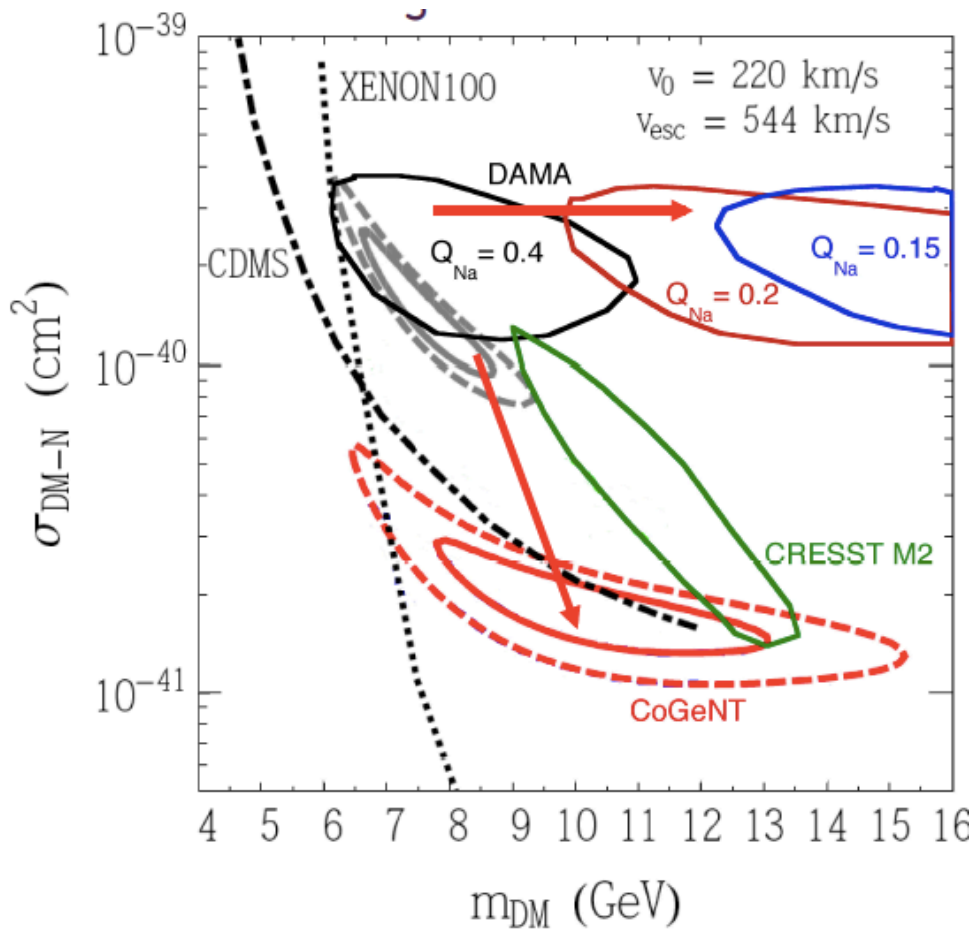
arXiv:1006.3110v1

Certain models predict non-negligible channeling: it must be measured!!!

* 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.



Age of anomalies:
are DAMA, CoGeNT and CRESST in agreement, or not at all?



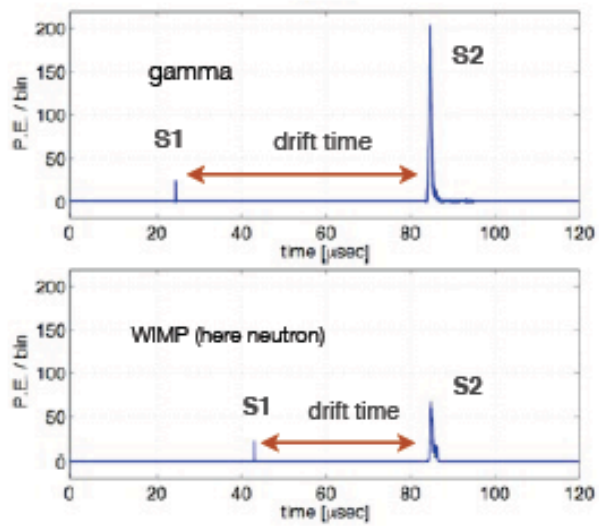
...and these are detector aspects only
(throw in a dash of particle physics and astrophysical uncertainties for a total chaos)

More on particle identification:

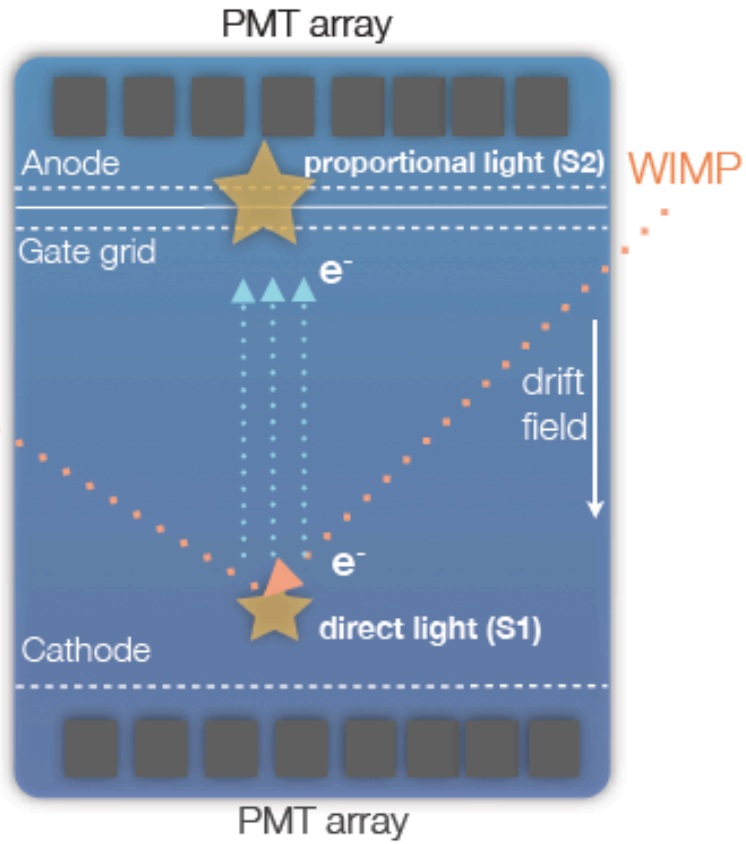
The Detection Method: a Liquid Xenon TPC

- XENON100: a large, homogeneous, scalable detector
- Particle interaction in the active volume produces prompt scintillation light (S1) and ionization electrons
- Electrons drift to interface (E= 0.5 kV/cm) where they are extracted and amplified in the gas. Detected as proportional scintillation light (S2)
- $(S2/S1)_{WIMP} << S2/S1)_{Gamma}$

➡ 3-D position sensitive detector with particle ID



Xe (A=131); λ = 178 nm



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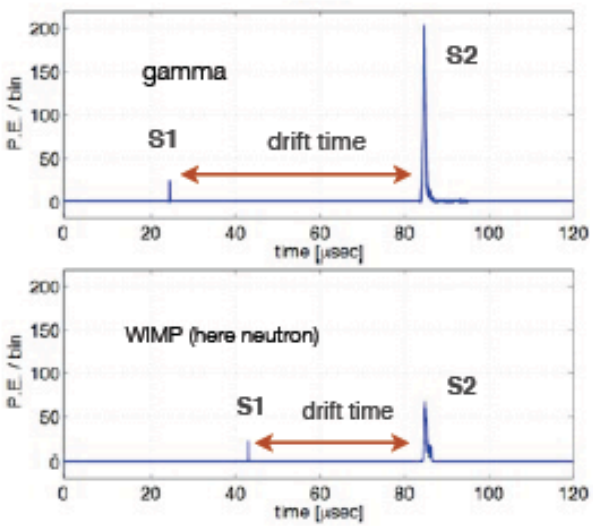
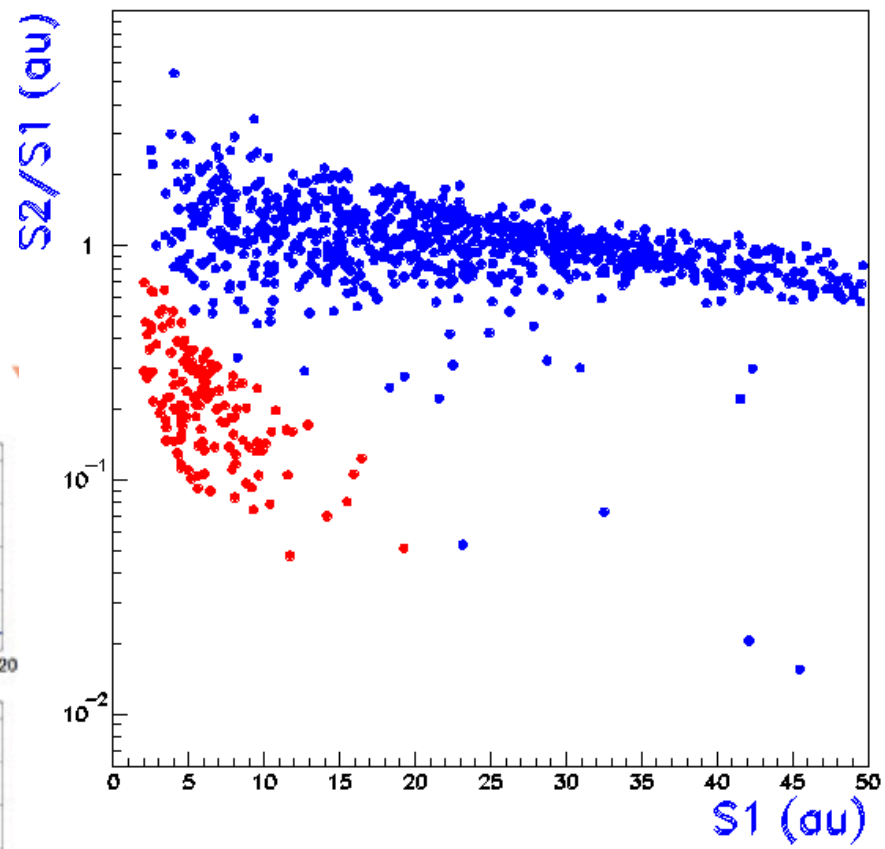




More on particle identification:

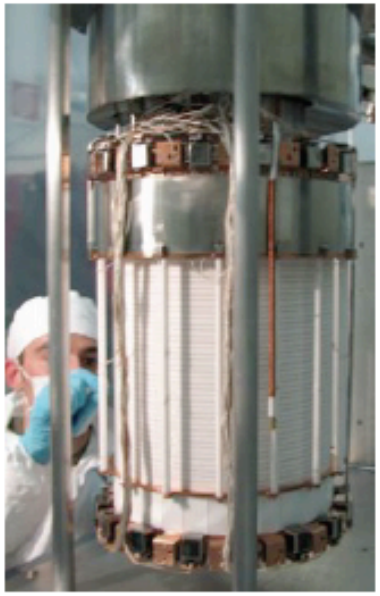
The XENON Roadmap

XENON10

2005-2007

PRL100
PRL101
PRL 107
PRD 80
NIM A 601

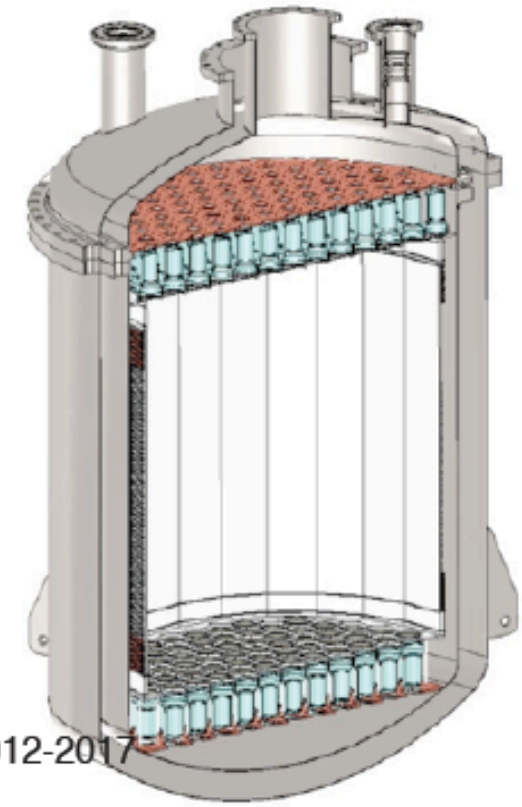
XENON100



2007-2013

first results:
PRL105, PRL107, PRD84

XENON1T



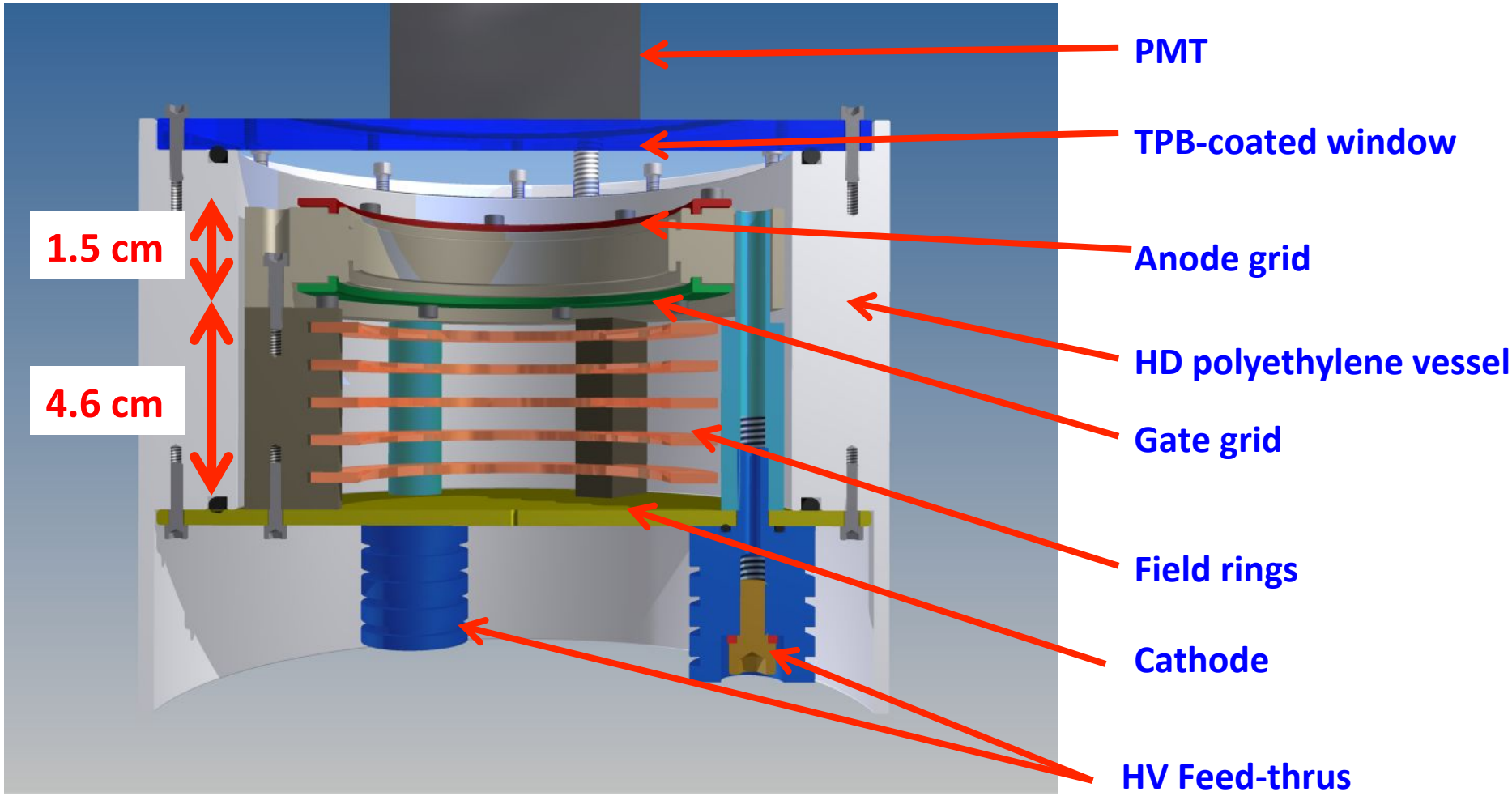
2012-2017

approved at LNGS, Hall B
construction starts in fall 2012

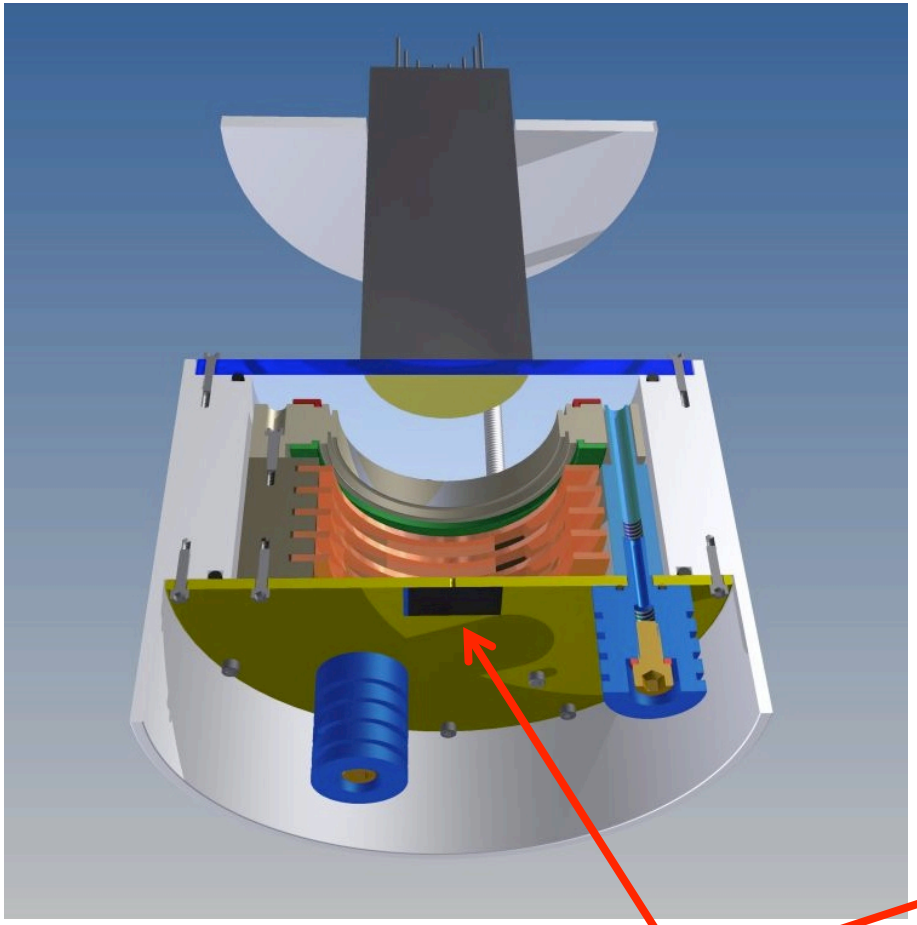
- Gradually increasing the WIMP target mass while decreasing the background level

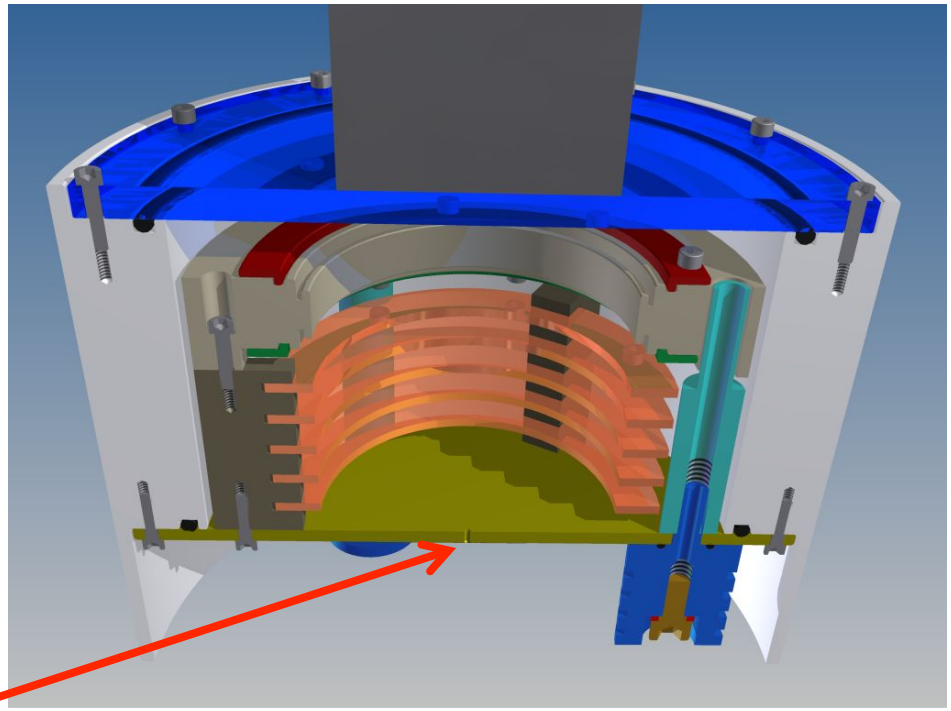
EL TPCito

(a wonderful educational dark matter toy by J.T. White, Texas A&M)



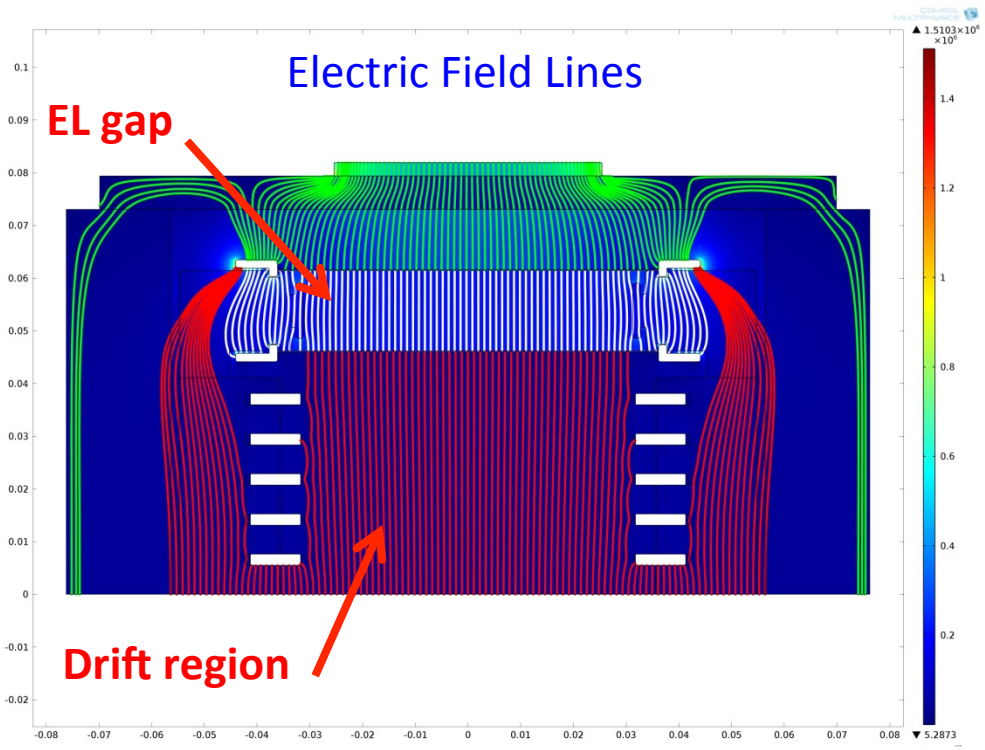
EL TPCito (cont)

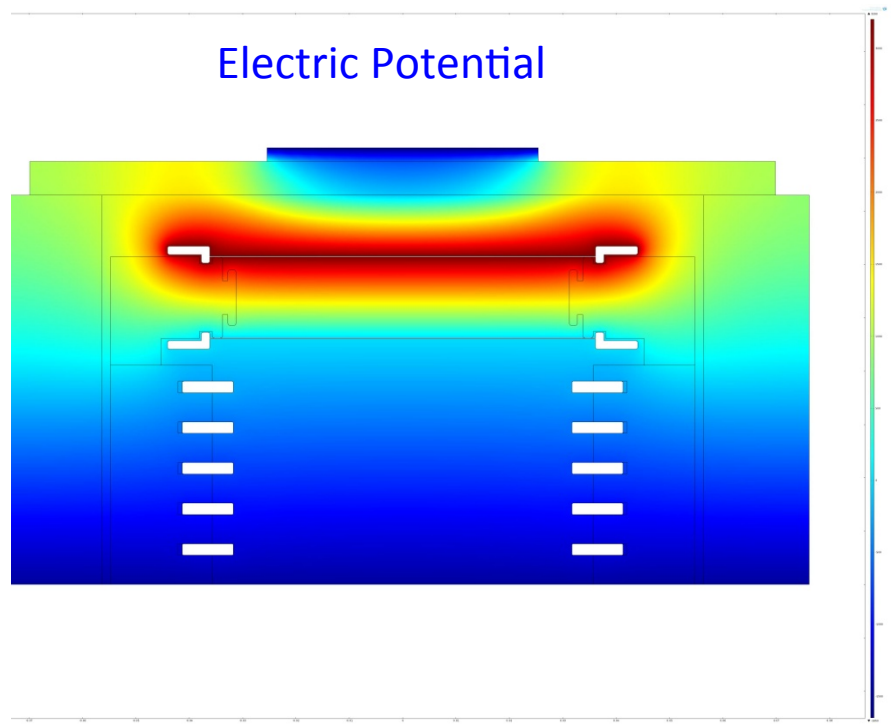


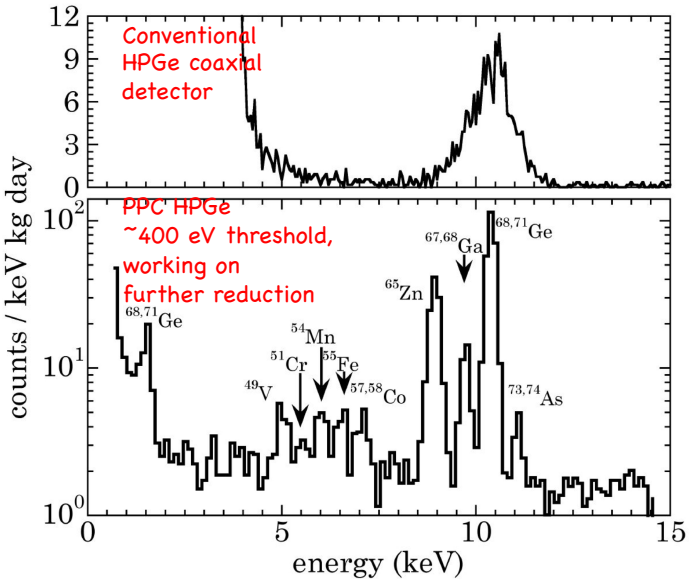


source location

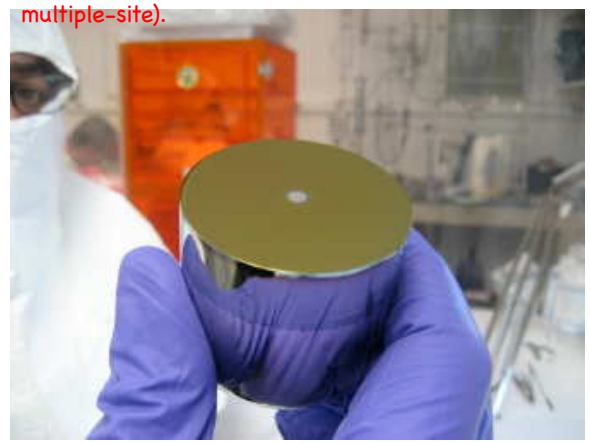
Electro-statics





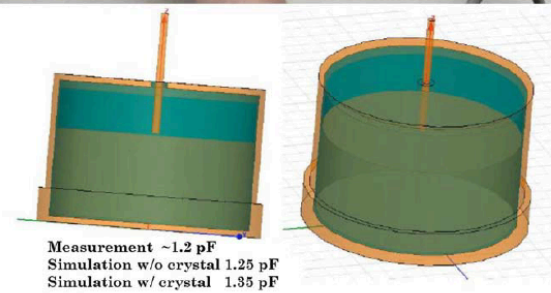


PPCs: reducing capacitance and noise, exploiting charge collection features for background reduction (surface & multiple-site).

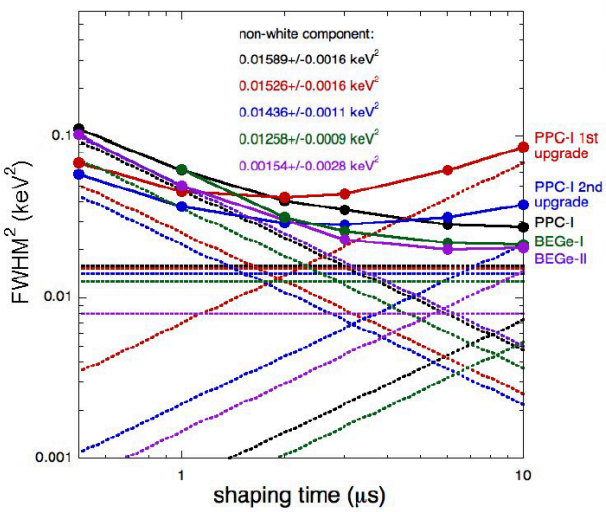


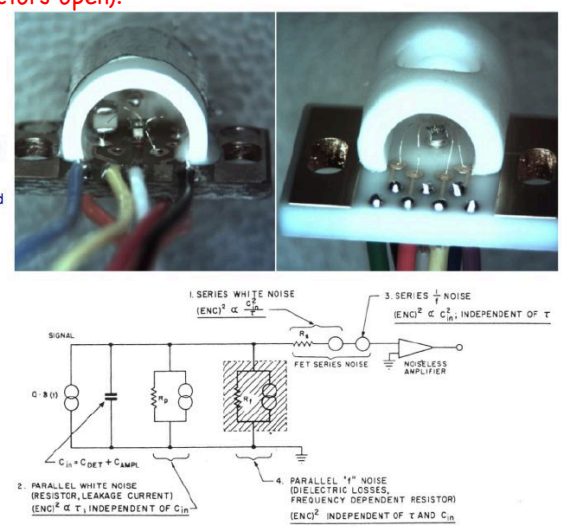
Why bother: few keV signals expected from WIMPs, esp. at low mass. Quenching factor does not help.

Present PPCs dominated by parallel-f noise:



Noise identification detective work (approximately ~2 years of cracking detectors open):





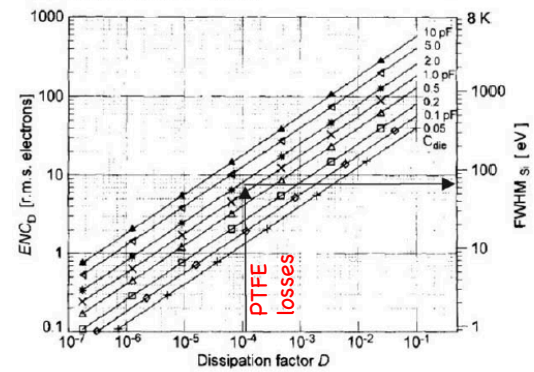


Fig. 4. Equivalent noise charge contribution due to the lossy dielectrics.

(all of this noise mumbo-jumbo actually checks)

Noise abatement not dissimilar to background reduction: one layer of crap hides the next one (noise terms add in quadrature!).

FIG. 2: *Left:* Electronic noise contributions measured with a pulser, for a number of PPC detectors and their upgrades. The (flat) non-white component remained invariable up to the last attempt (BEGE-II, see text). *Right:* Top left, commercial FET package employing a sub-optimal boron nitride and PCB package, and a surface-mount feedback capacitor. The improved package on the right uses a vacuum feedback capacitor, PTFE as the single dielectric, and improved mounting of the heating resistor. This package features not only the best available measures against non-white electronic noise, but is also constructed out of radioclean materials. Bottom: schematic illustrating the origin and characteristics of several sources of electronic noise in detector systems, with "parallel-f" highlighted [12].