Cryodetectors, CRESST and Background

A cryogenic detector for Dark Matter

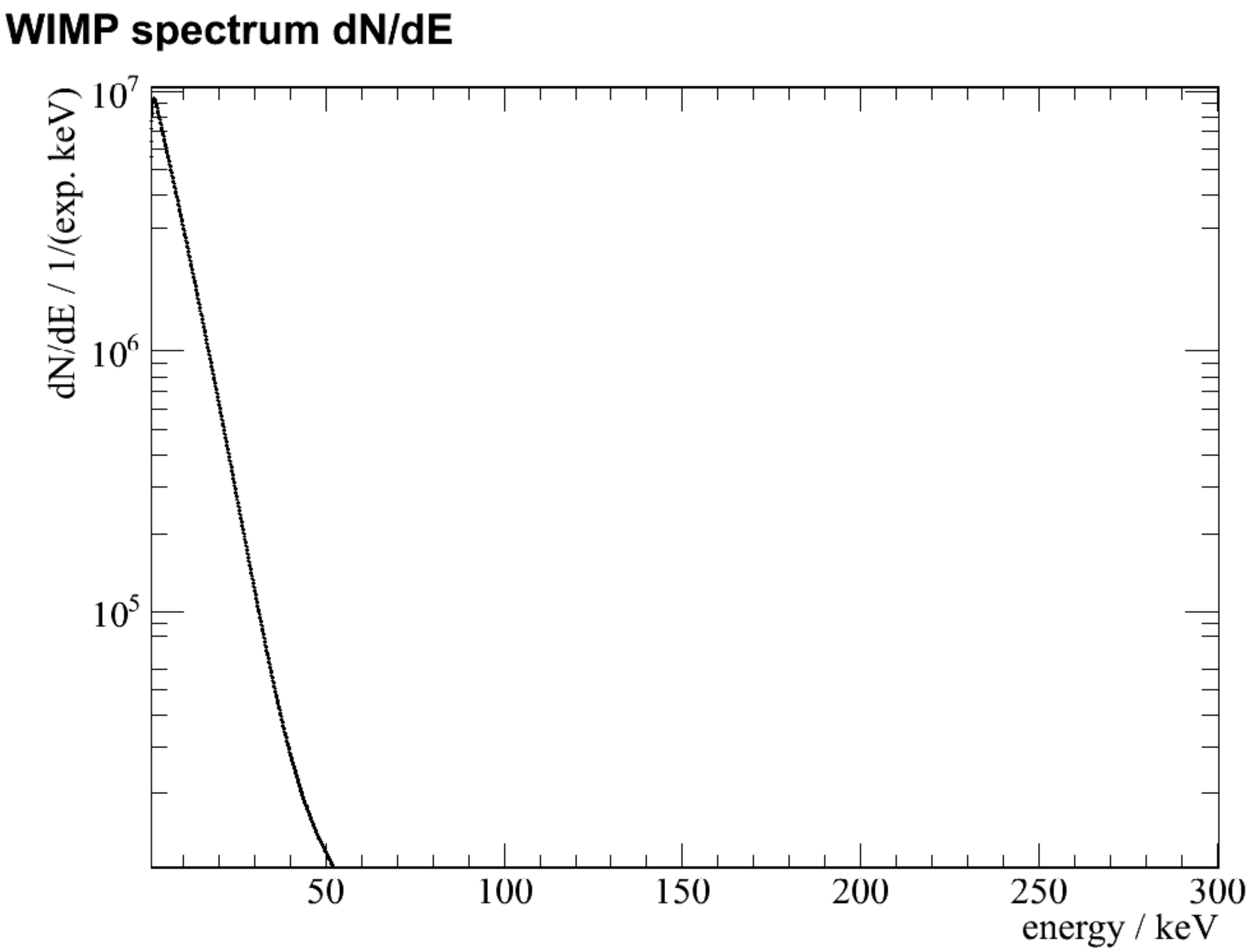
with heat (phonon) readout

and

light (scintillation) readout

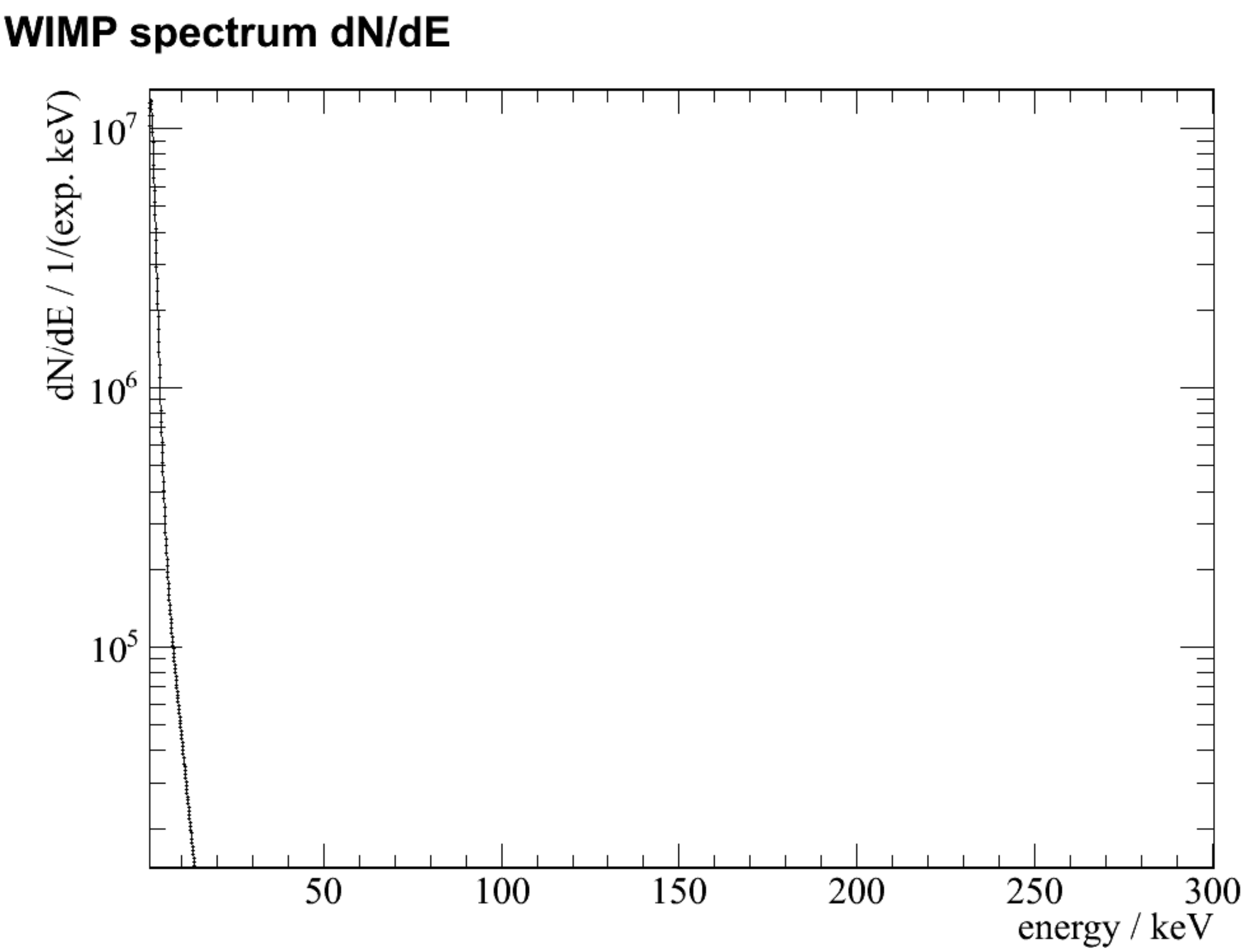
MPI, TUM, Oxford, Tübingen, LNGS

What we're looking for:



$M_{Wimp} = 50\,GeV$ in $CaWO_4$

Energy threshold and energy resolution
more difficult with lighter WIMPs



$M_{wimp} = 10$ GeV, $CaWO_4$

(almost all events below $\sim 5 keV$)

Low energy for WIMP because in the galaxy we talk about *velocity* (not energy).

$M_{wimp} = 10$ GeV, $v = 2 \times 10^{-3}$,

$E_{wimp} = \frac{1}{2} m v^2 \approx 20\, keV$

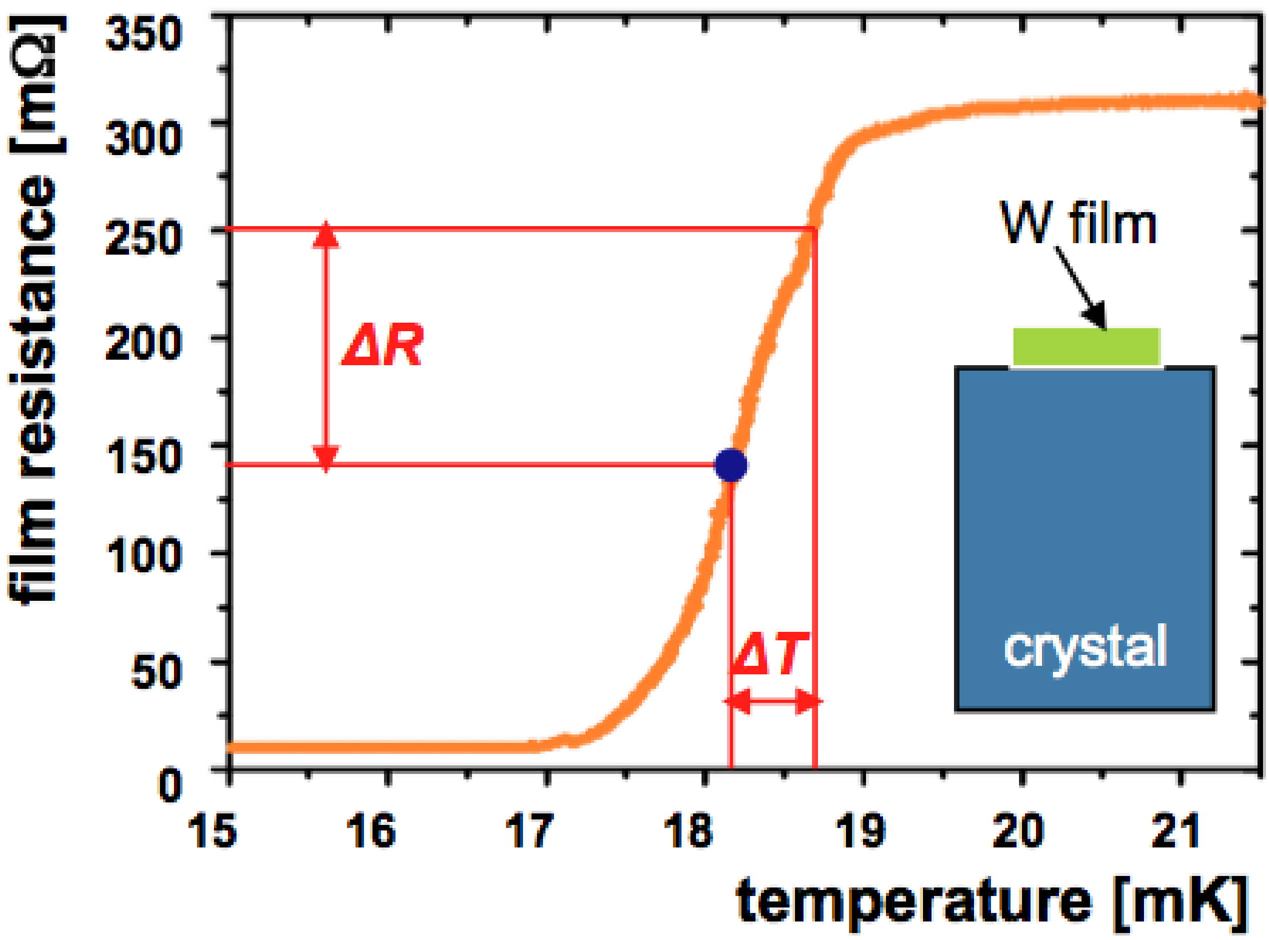
Want to detect small nuclear recoils, $E_{recoil} < 20keV$ or less –with good resolution

Solid state, liquid detectors: energy unit ≈ 1 eV

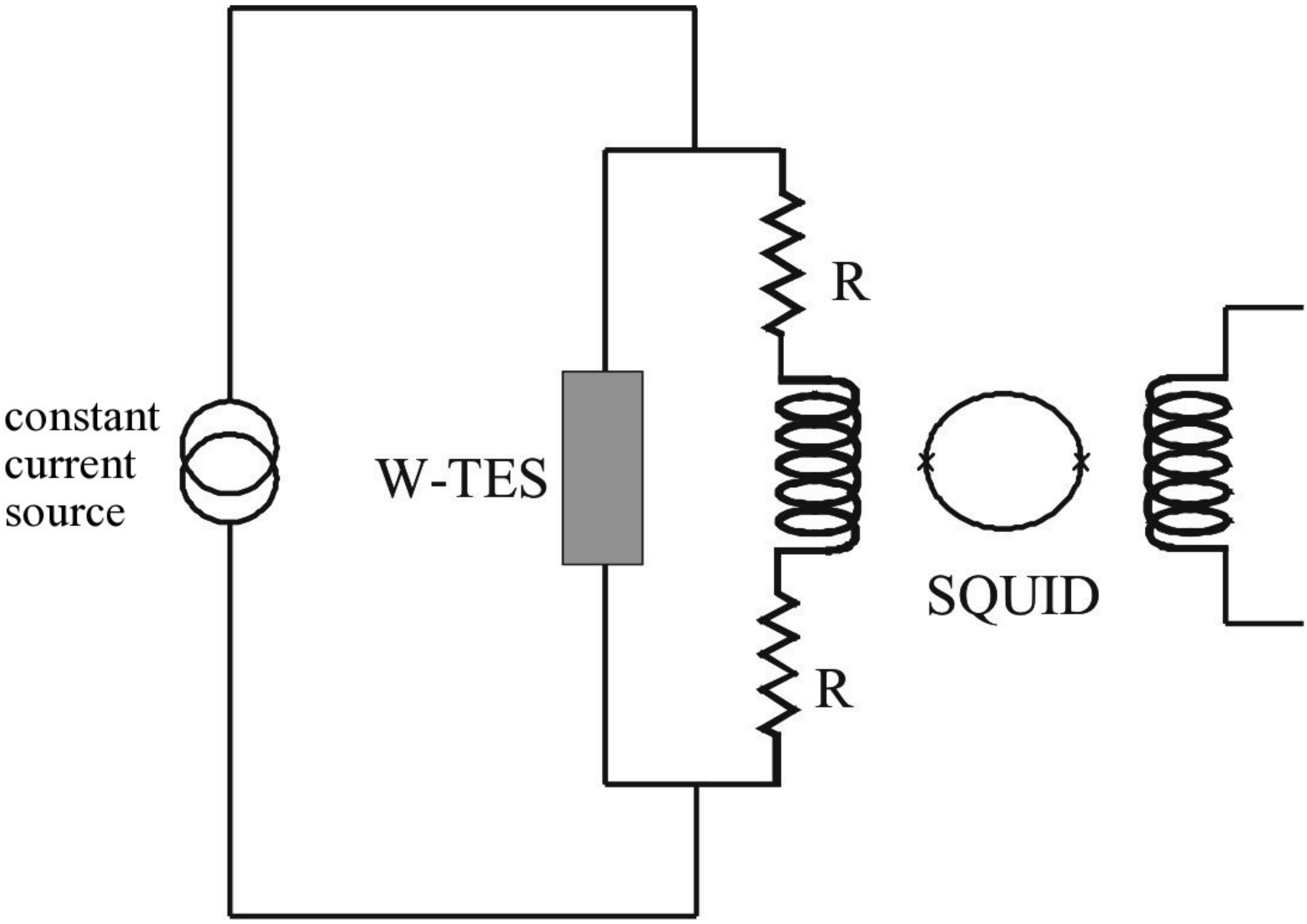
But cryo devices: e.g. superconductor, energy to break Cooper pair ≈ 10^{-4} eV

At LOW T a little energy can mean a lot!

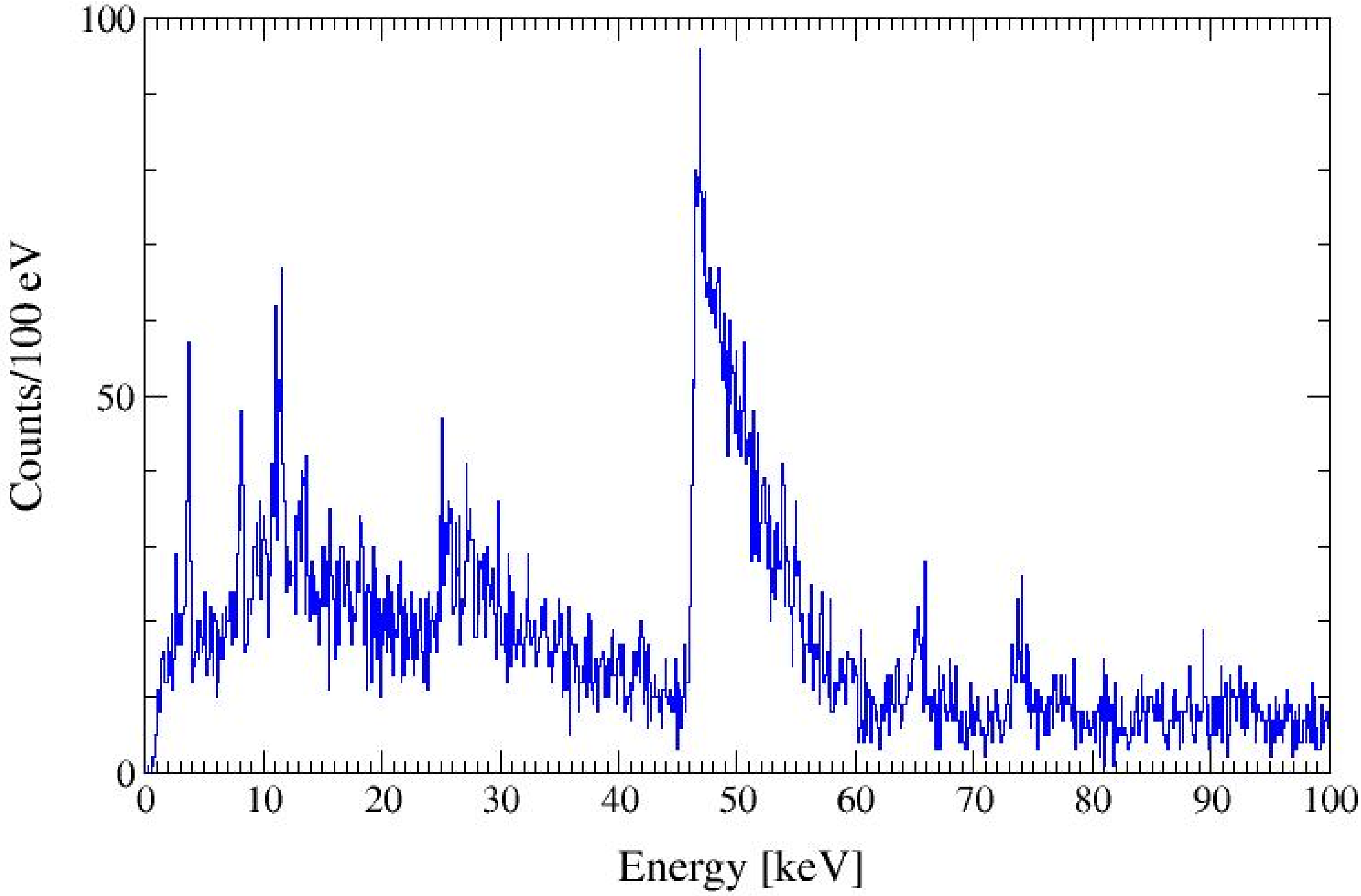
CRESST Transition temperature of Tungsten thermometer (TES) ≈ 14 mK.



Readout of resistance change:



Precise measurement of the energy
Low energy threshold



——Note: Sharpness of 46.5 keV feature (^{210}Pb)——-

Other structures down to ∼few keV understood

The LIGHT channel

In a scintillator the ratio (light output/energy) is large for low mass particles (fast), and small for heavy particles (slow).

CRESST II uses scintillating crystals ($CaWO_4$) for the main detector, plus a light detector

- A) Separates e/γ backgrounds from sought-for nuclear recoils

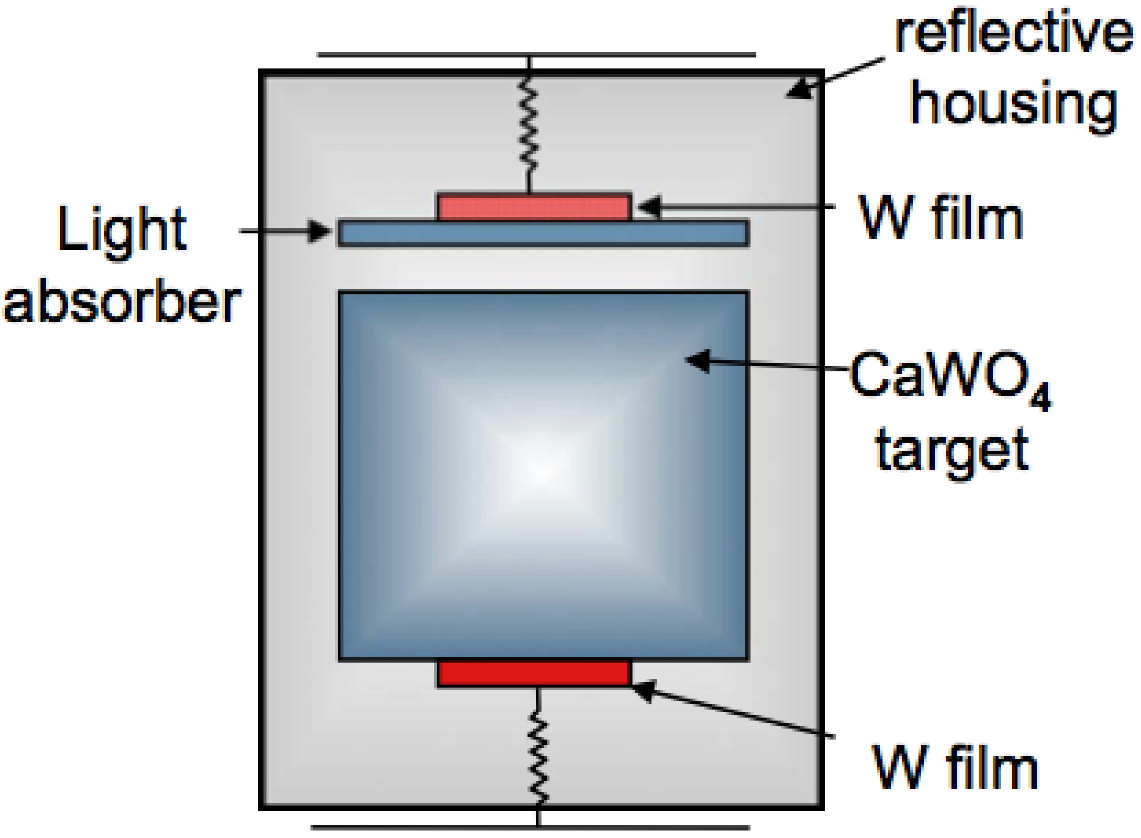
- B) Could determine which nucleus is recoiling

A) Is the main background– achieve $\sim 10^{-4}$ suppression

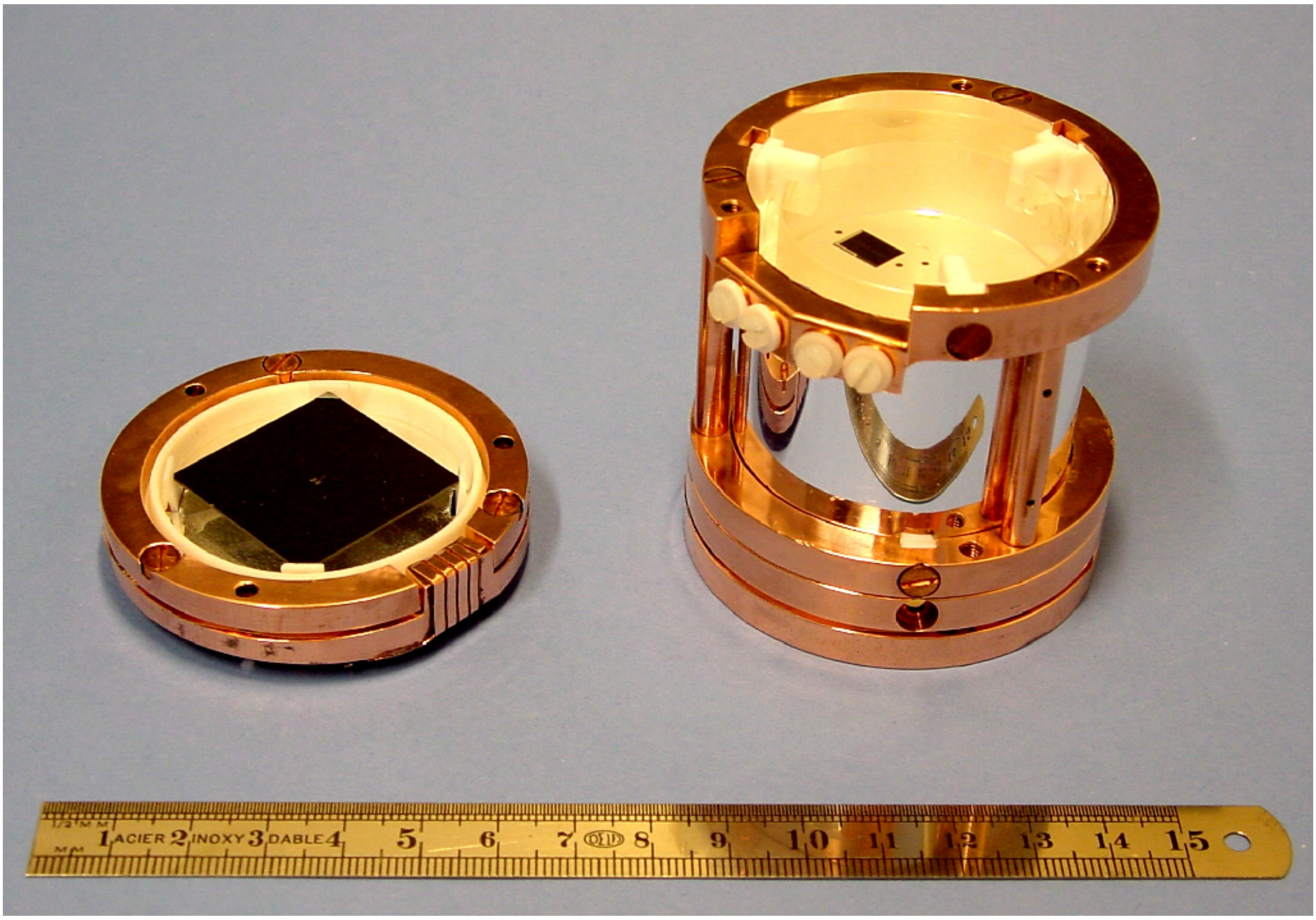
B) Potentially of great importance in unraveling a positive signal. (See later talk). At present works partially.

Presently about 2% of the energy appears in light

Energy and Light detectors make a 'Module'



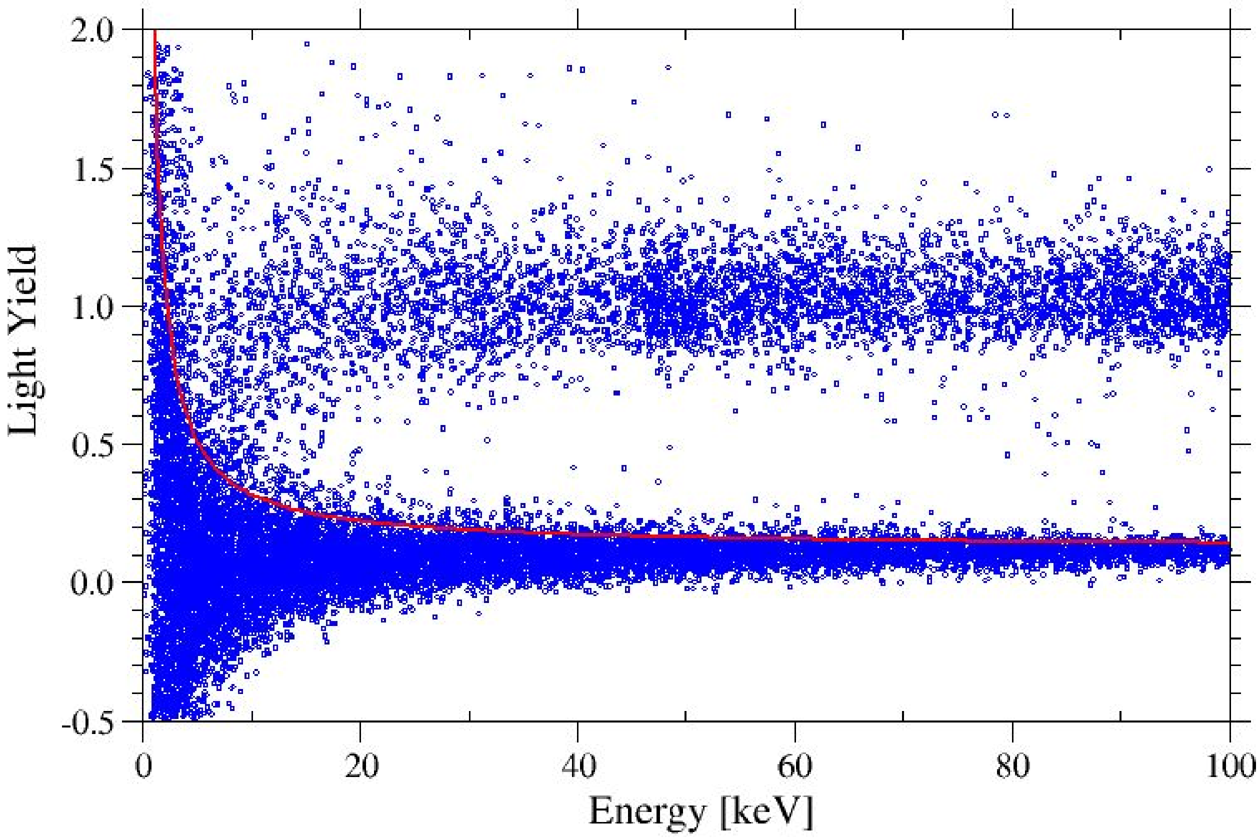
Really looks like



Plot events in light yield-energy plane

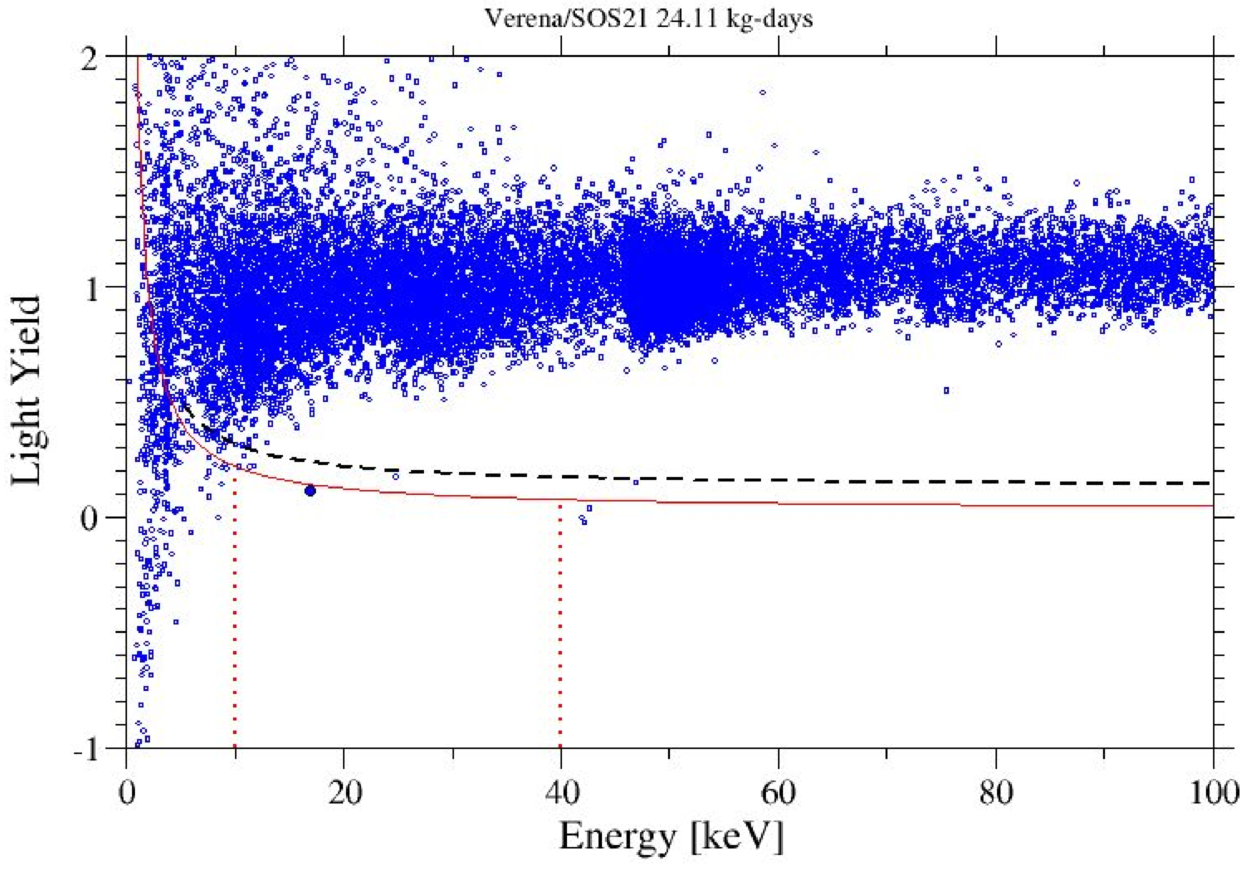
Light yield= (L/E)

With a γ and neutron source (makes nuclear recoils):



Neutron test run in Gran Sasso

And without neutron source:



WIMP Candidates: Low Energy, Low Light

To point B), distinguishing which nucleus,

Several studies by different techniques of 'quenching factors'

$QF_\alpha \approx 0.22$

$QF_O \approx 0.10$

$QF_{Ca} \approx 0.064$

$QF_W \approx 0.040$

(QF= light / light from electron of same energy)

With present light detector resolution, significant uncertainty, especially at low energy

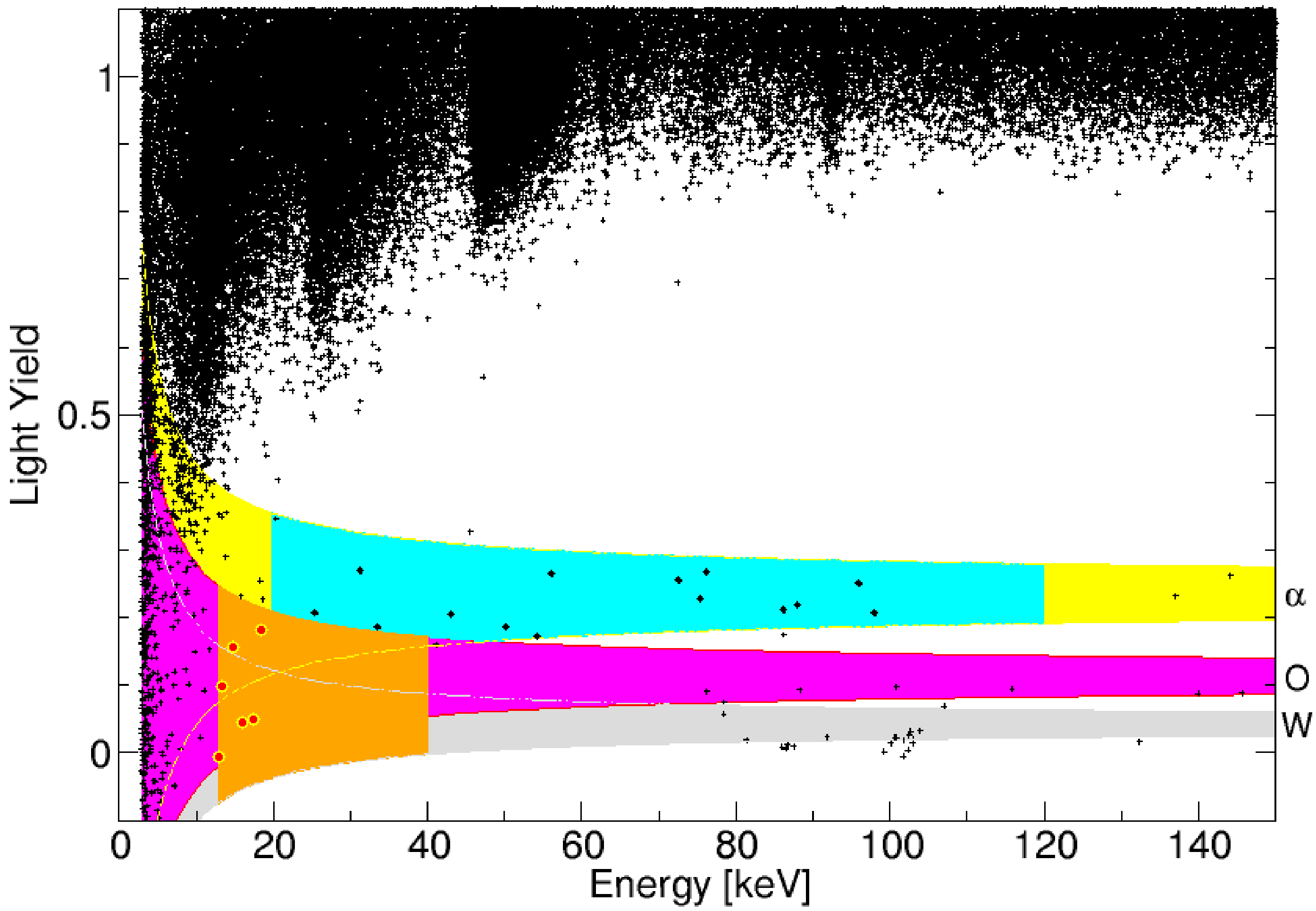
Ability to distinguish nucleus plays important role. Could be key in establishing positive signal

CRESST II

Analysis of a $>$ year-long run in GRAN SASSO

730 kg-days ($\sim$ 2.4 kg target mass of $CaWO_4$)

Some unexplained events in the acceptance region



All detectors (8 modules):

67 events

in the acceptance regions.

Backgrounds:

1) $\alpha's$: $(^{210}Po \rightarrow ^{206} Pb\,(103\,keV) + \alpha\,(5.3\,MeV))$

2) e/γ 'leakage'

3) W band (103 KeV Pb recoil)

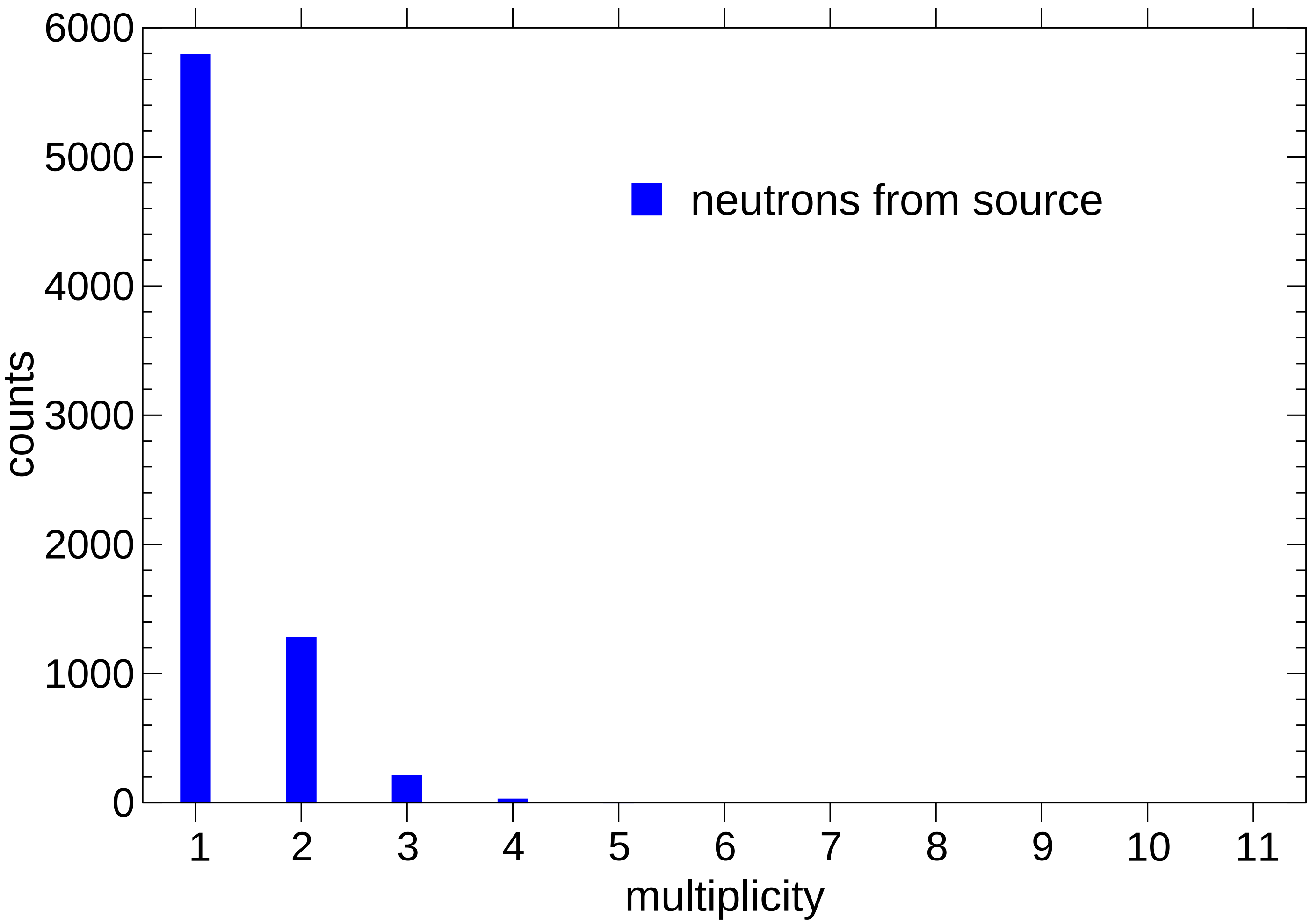
4) Neutrons

Estimates: 1 ,2, 3 extrapolate –for each module– events outside of acceptance region into acceptance region.

Neutrons

Neutrons (strongly interacting) can multiple scatter, WIMPS (weakly interacting) cannot

Establish ratio multiple hits/single hits with neutron test source. Use this ratio to scale up multiple hits to single hits



multiplicity= number of modules with events at same time

Observe 3 multiple events in Dark Matter data $\Rightarrow$11 neutron events. (If due to local radioactivity)

Similar argument for μ-induced neutrons $\Rightarrow$1.5 neutron events. (There is a muon veto.)

—- No Monte-Carlo involved—-

Backgrounds $1 + 2 + 3 + 4$

Do not appear to add up to all 67 events

Try adding a WIMP signal

Results of a maximum likelihood fit

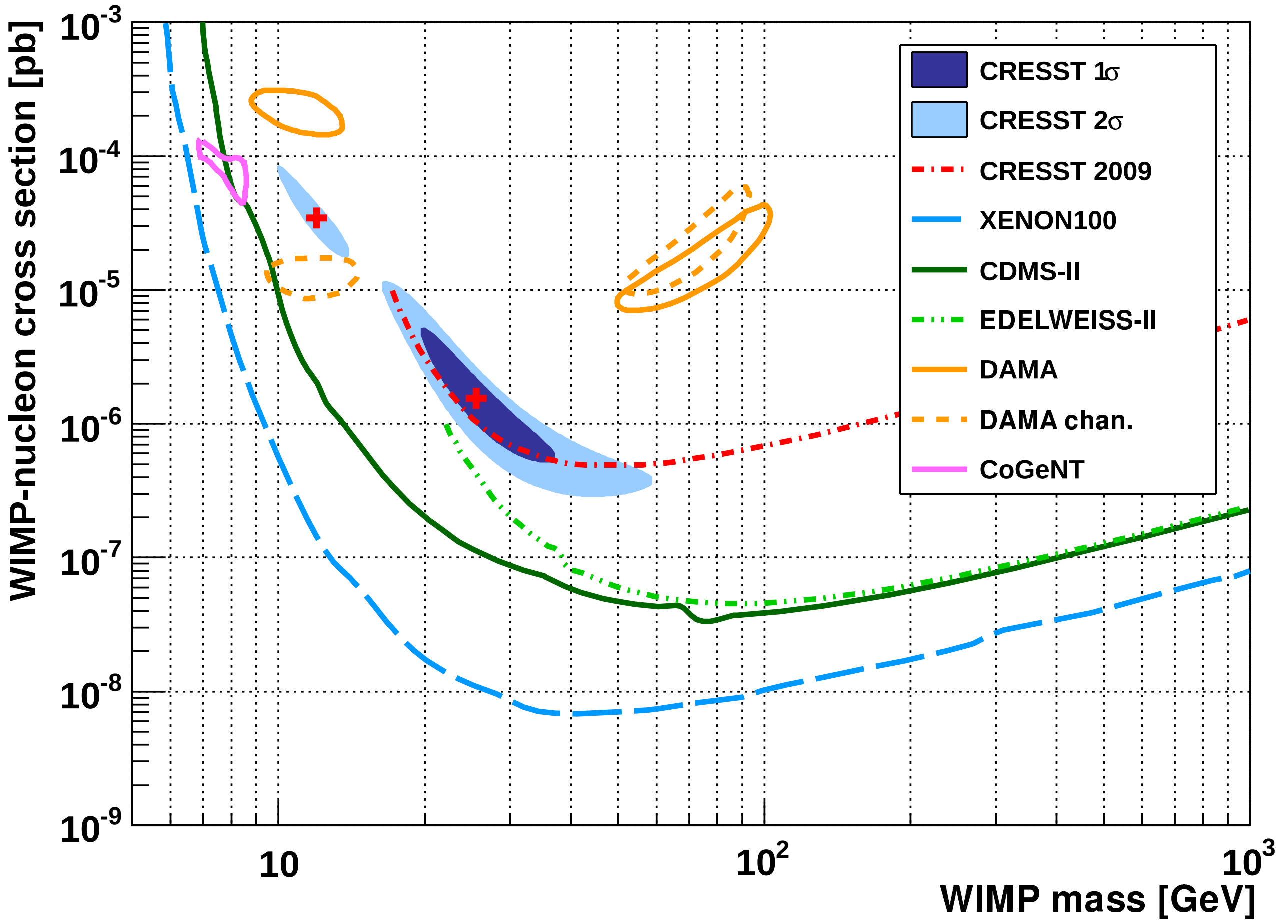
	M1	M2
e/γ-events	8.00 ± 0.05	8.00 ± 0.05
α-events	$11.5\,^{+2.6}_{-2.3}$	$11.2\,^{+2.5}_{-2.3}$
neutron events	$7.5\,^{+6.3}_{-5.5}$	$9.7\,^{+6.1}_{-5.1}$
Pb recoils	$15.0\,^{+5.2}_{-5.1}$	$18.7\,^{+4.9}_{-4.7}$
signal events	$29.4\,^{+8.6}_{-7.7}$	$24.2\,^{+8.1}_{-7.2}$
m_χ [GeV]	25.3	11.6
σ_{WN} [pb]	$1.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-5}$

Find two minima M1,M2 of about equal 'significance' for rejecting 'background only' 4.7σ, 4.2σ

Angloher et al. Eur. Phys. Jnl **C 72** 1971 (2012)

Comment on 'significance' in Max Liklhd method

So IF missing events are due to WIMP's



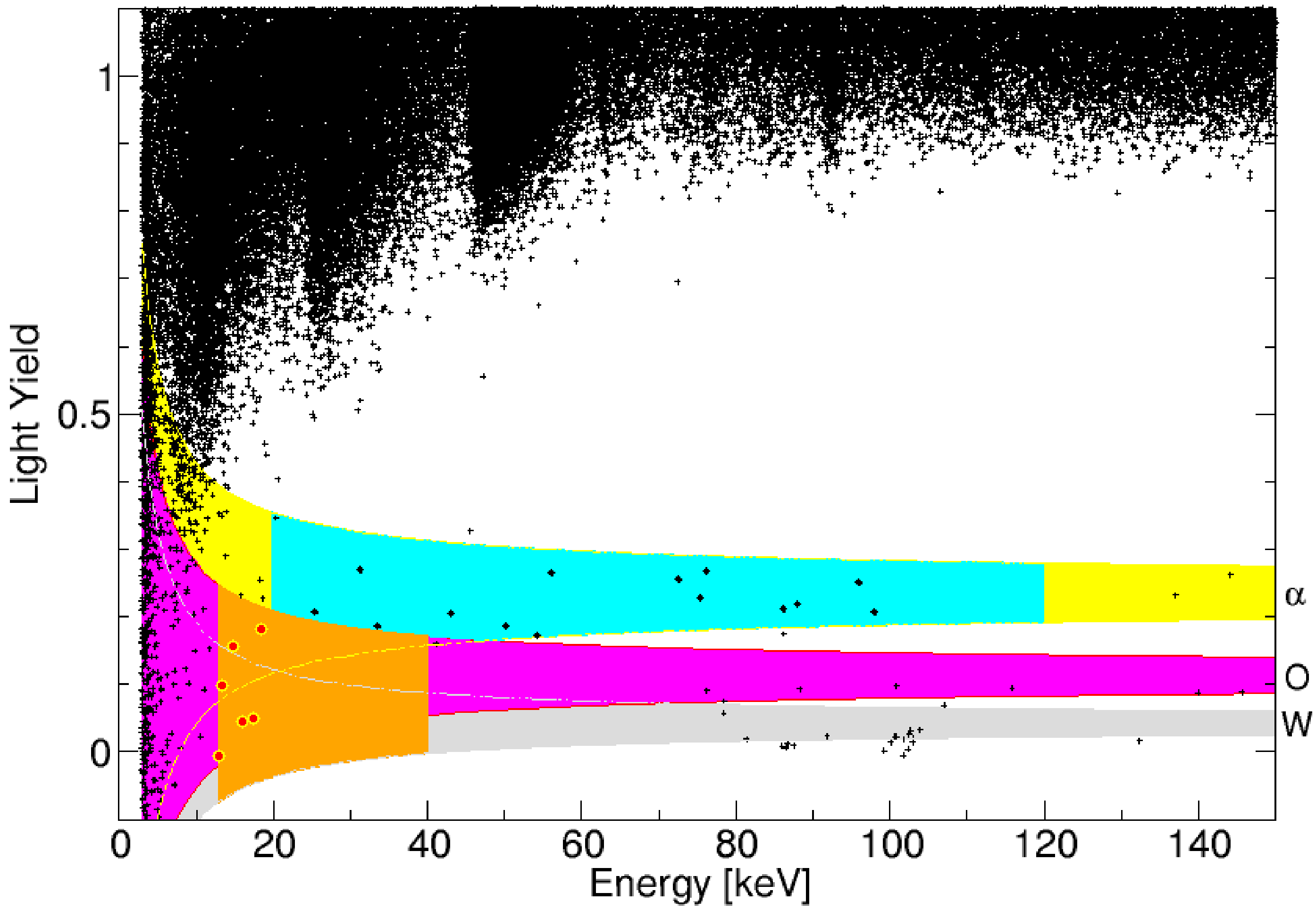
INTRIGUING

More work needed to clarify.

Issues

Most backgrounds seem to come from

$^{210}Po \rightarrow ^{206}Pb\,(103\,keV) + \alpha\,(5.3\,MeV)$

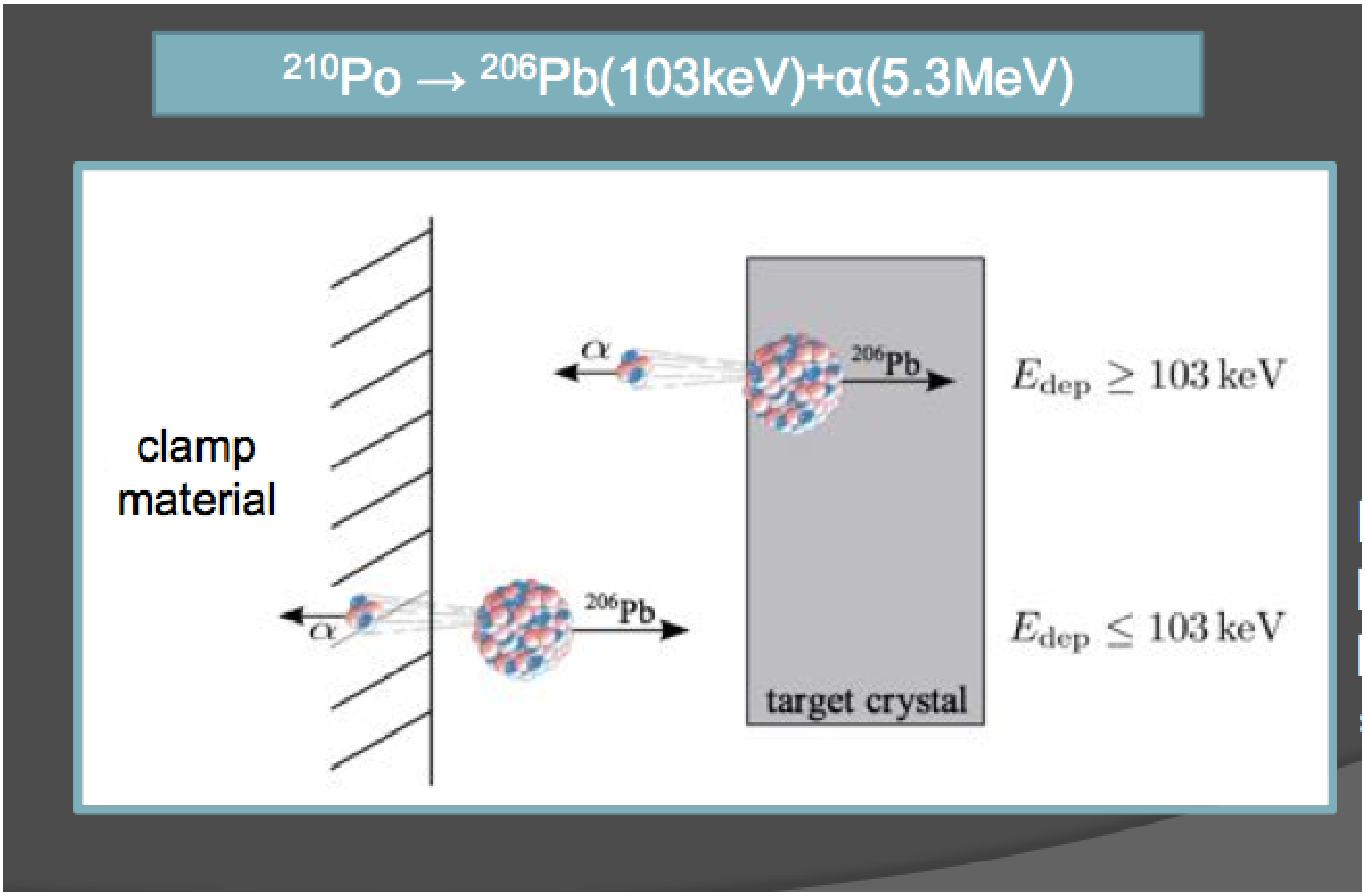


- originates from radon, so reduce radon
- more complete identification/rejection

Clamps issue

Usually α is caught: gives hi E, hi light

But if Po decay is in clamps holding crystal

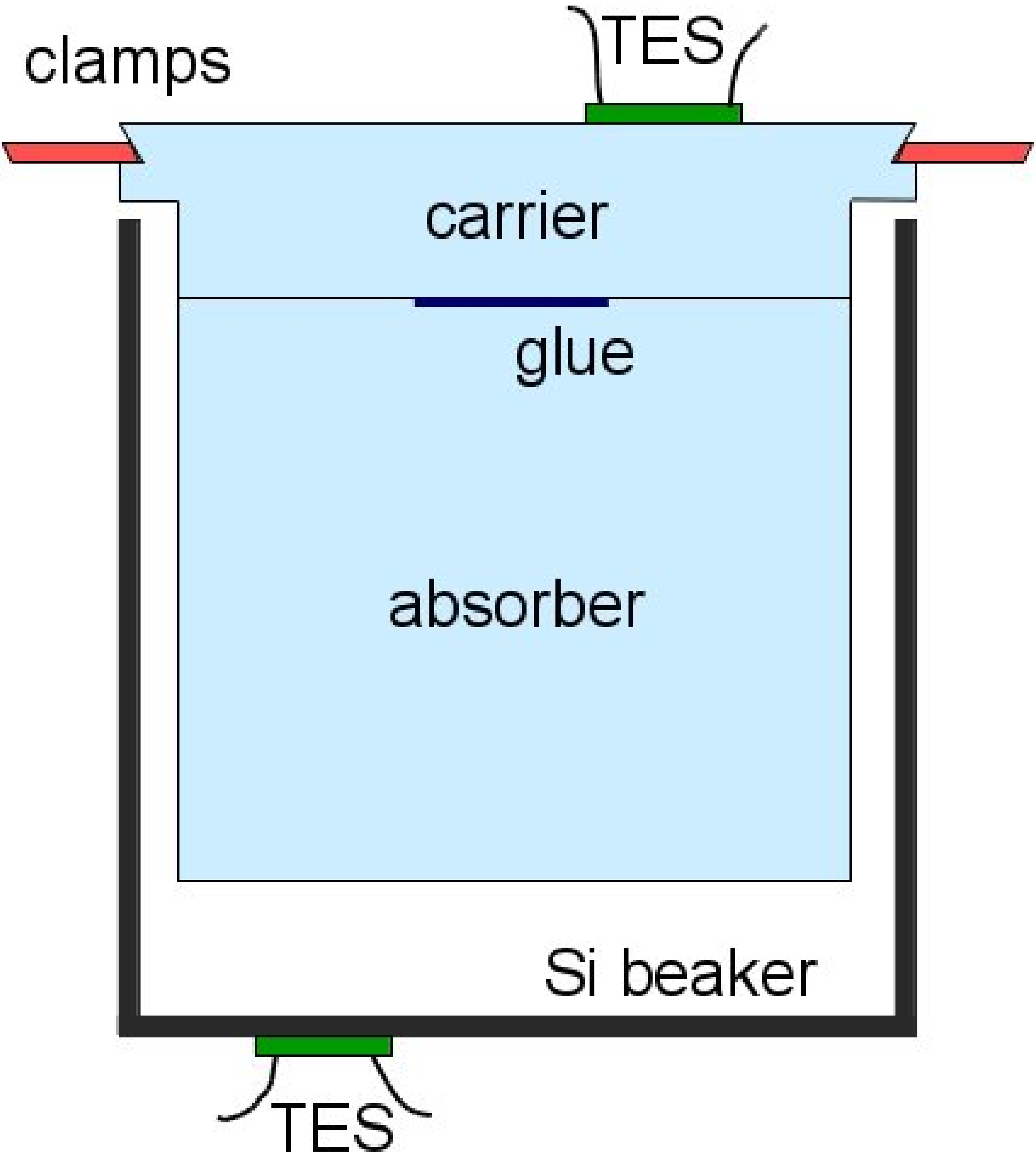


+ vice versa

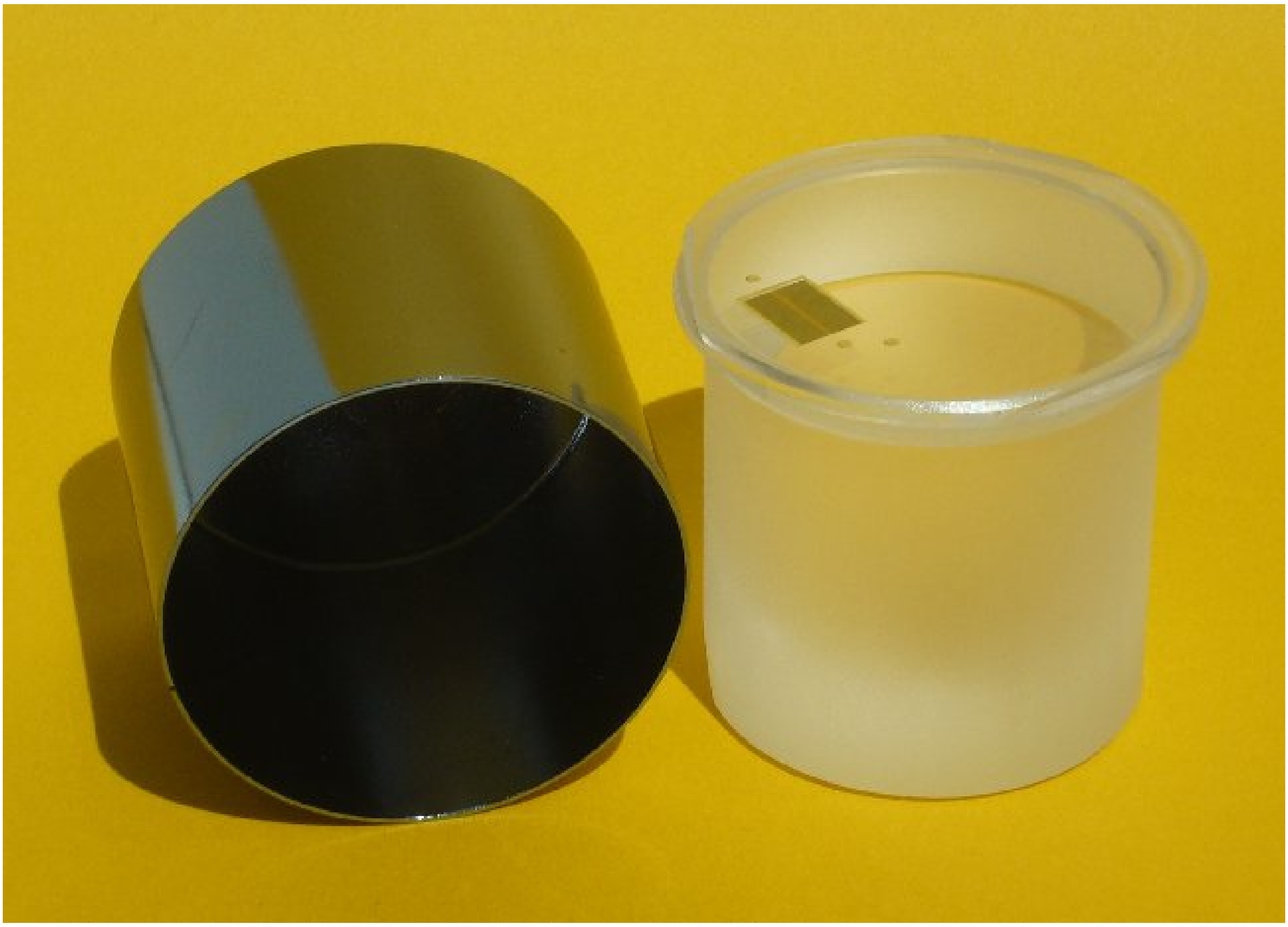
Interesting issue raised by Kuzniak et el. (arXiv 1203.1576):

Outgoing α from clamp sputters clamp material. Could lead to low E peak–if surface is rough (α stays in clamp, ejectiles are detected)

New Type of Light Detector (Gode Angloher) ‘Beaker’



- Higher light output/collection $\sim 4\%$



- Will catch all surface events
- No line of sight from outside, no clamp events
- Higher light output/collection $\sim 4\%$

New run, now being mounted:

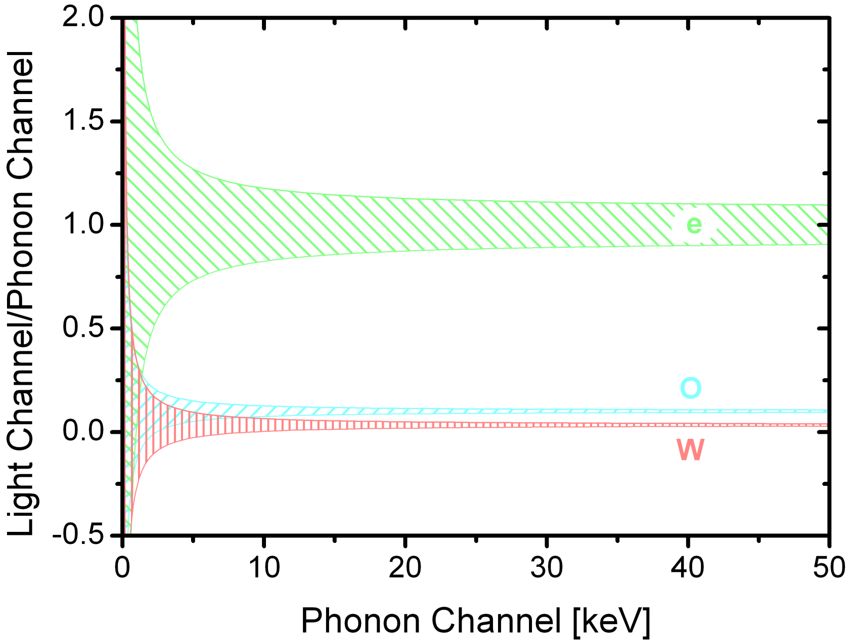
- 18 detector modules, 2 of which ‘beaker’ type
- 4 cm inner polyethlyene (being measured)
- new, high purity, clamps
- improved radon protection

My favorite for more distant future:

See which nucleus is recoiling—now works only very partially

Improve light detectors (resolution). Lower threshold, see Ca recoils separtely

Example: factor 5 improvement in light detector:



Ability to study different nuclei

e.g O, Ca, W *simultaneously*

Distinctive feature of CRESST

As our background suppression gets ever and ever more heroic....
(already practically unbelievable).

Any detector–at some level– will have *some* "unexplained" events.

Background....Noise,....Spirits...Alcoholic Spirits...
Wishful Thinking??

Desperate search for as yet unsuspected backgounds will ensue.

Will probably find some.

Or MAYBE indeed it is a WIMP!!!??

Would be VERY good to have some characteristic feature(s) of a WIMP signal

- Not also present for some background

- Not involving some a poriori assumptions like A^2,... details of WIMP spectrum,...

A further worry....

Many,– most– backgrounds peak at low energy

Look like WIMPs

Fast Neutrons

Elastic scattering diffraction peak
(nuclear optical model)

$\Delta R \sim 1$, so $E_{recoil} = \Delta^2/2M_A \approx (1/R)^2/2M_A$

Low recoil energy peak at energy

$E_R^o = \frac{1}{R^2} \times \frac{1}{2M_A} \approx \frac{10}{A^{5/3}} MeV$

Ranges 100 keV (oxygen) to 1.7 keV (tungsten)...right in the region of WIMP-induced recoils

$Element$	A	R(fermi)	$E_R^o(keV)$
O	16	3.5	98
F	19	3.7	74
Na	23	4.0	54
Si	28	4.2	39
Ar	40	4.8	21
Ca	40	4.8	21
Ge	74	5.9	7.7
I	127	7.0	3.1
Xe	132	7.1	2.9
W	184	7.9	1.7

But there is a way

Correct behavior when varying target nucleus

We can change the target but the 'beam' is the same

→ simple behavior wrt nucleus

A general background unlikely to behave this way.

NOTE:

Not absolute rate—this can vary w WIMP Q nos.

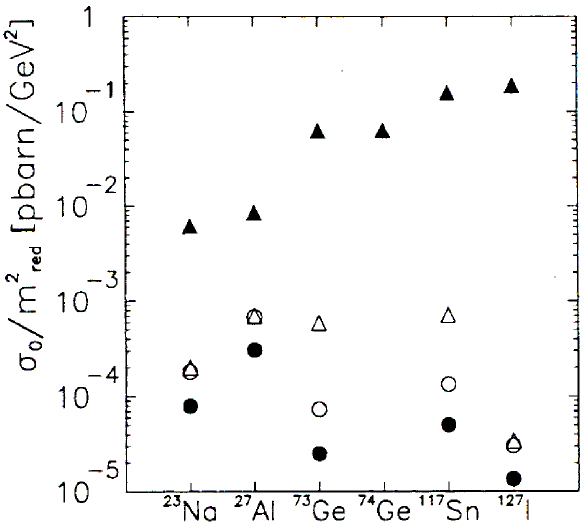


Figure 24: Cross section σ_0 (SI+SD) normalized to the reduced mass squared for different materials and neutralino compositions. Solid triangles: zino-higgsino mixture with 40% zino composition. Open triangles: pure higgsino. Solid circles: pure bino. Open circles: pure photino. The cross sections are calculated for set B with $\tan\beta=2$, $M_A=50$ GeV and $\alpha = -1.24$. As can be seen in Fig. 4, zino-higgsino mixtures and pure higgsinos are cosmologically relevant above ~20 GeV, while binos and photinos are cosmologically relevant above ~2 GeV (without grand unification constraints).

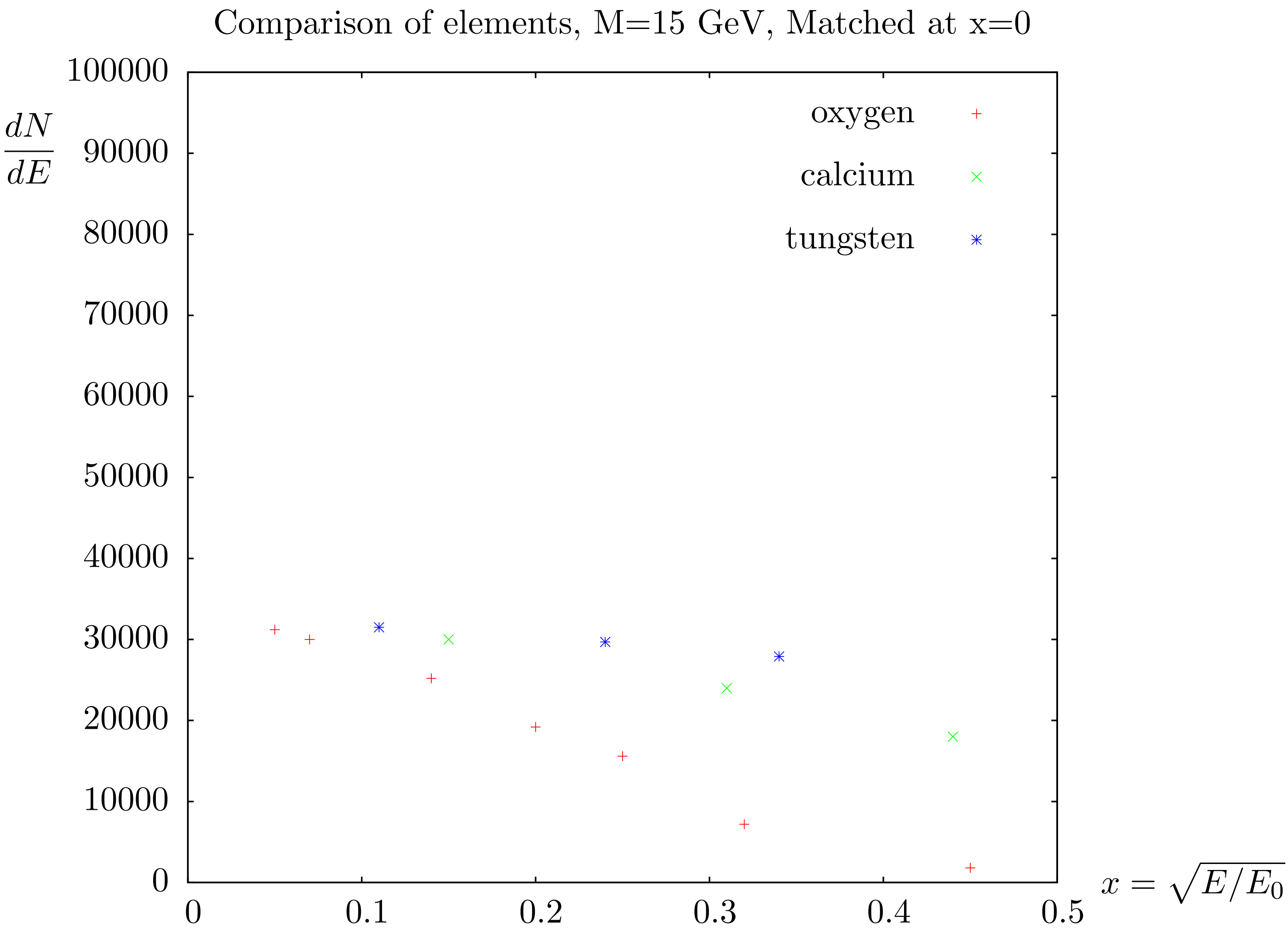
(Gabutti, et al. Astropart. Phys. **6**, 1,(1996))

(Indeed is a way of finding WIMP Q nos.)

Rather, *recoil spectrum*

Should see correct radius of nucleus.

All this illustrated in plot:



Variable $\sqrt{E/E_o}$ is ΔR
(E_o from table above)

Ca and W universal, Oxygen nucleus is light and so high recoil energy, comparable to WIMP energy

A data plot like this would be rather convincing

Also for neutron background

Diffraction scattering has characteristic A behavior
Different from WIMPs

Element	A	neutron E_R =20 keV	neutron E_R =30 keV	WIMP M=10 GeV	WIMP M=50 GeV
O	16	1	1	1	1
F	19	1.5	1.5	1.3	1.8
Na	23	2.2	2.2	1.6	3.3
Si	28	3.4	3.3	1.8	6.7
Ar	40	7.0	6.4	1.1	19
Ca	40	7.0	6.4	1.1	19
Ge	74	19	13	~ 0	93
I	127	20	5.1	~ 0	200
Xe	132	18	3.9	~ 0	240
W	184	2.6	1.6	~ 0	230

Table 3: Variation of the differential scattering rate per unit energy over various nuclei in the 'black disc' limit, Eq 11, at E_R =20 keV and E_R =30 keV. For comparison the same rate for a coherently scattering WIMP at $E_R = 20\,keV$ for masses 10 and 50 GeV is also shown. One notes different patterns of A behavior for neutrons and WIMPs. All values are per nucleus and normalized to that for oxygen.

(Leo, Astropart. Phys **35** 114 (2011))

Another reason to compare different nuclei

Convincing signal in direct detection

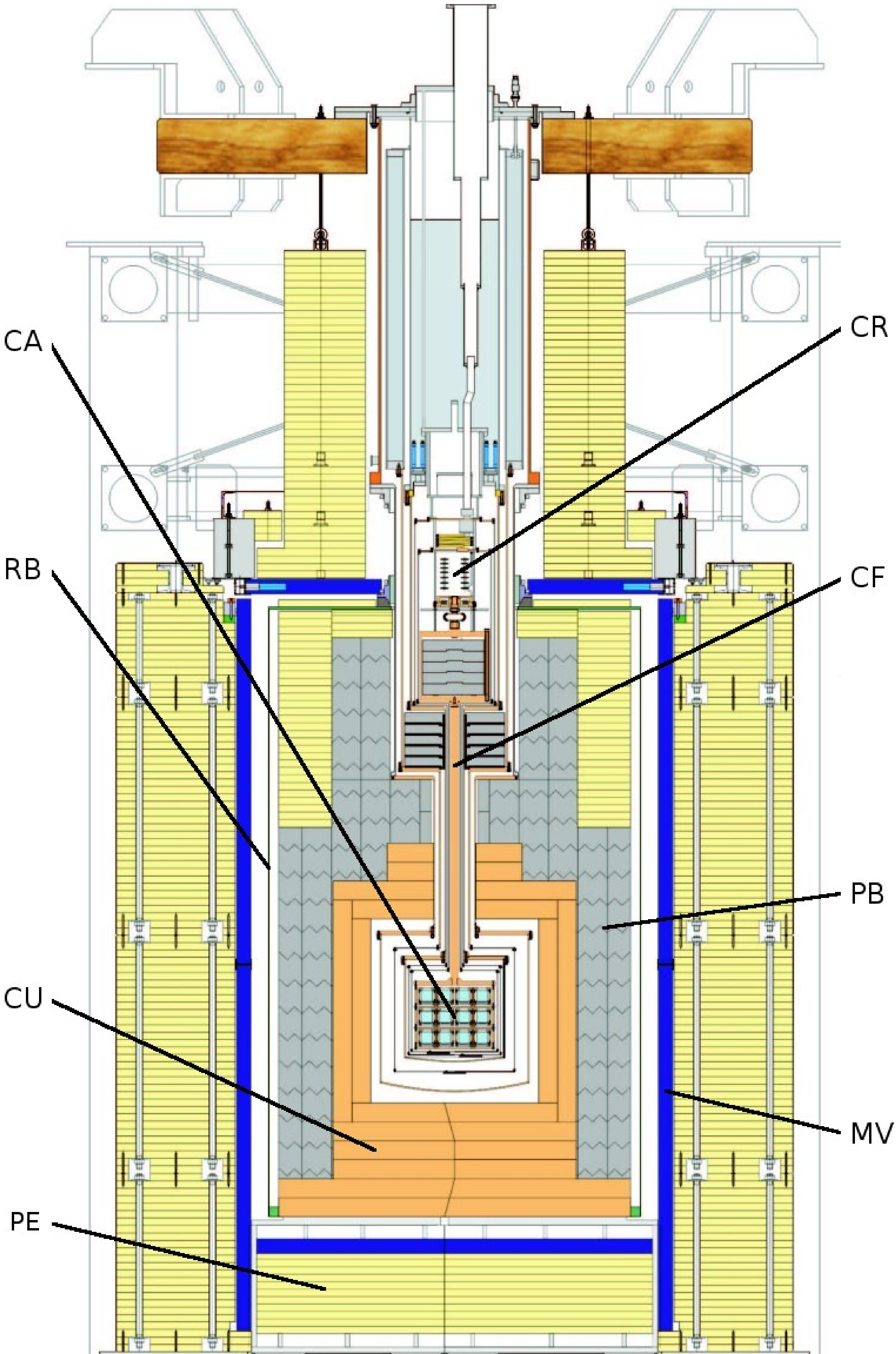
- Peaks at low recoil energy,

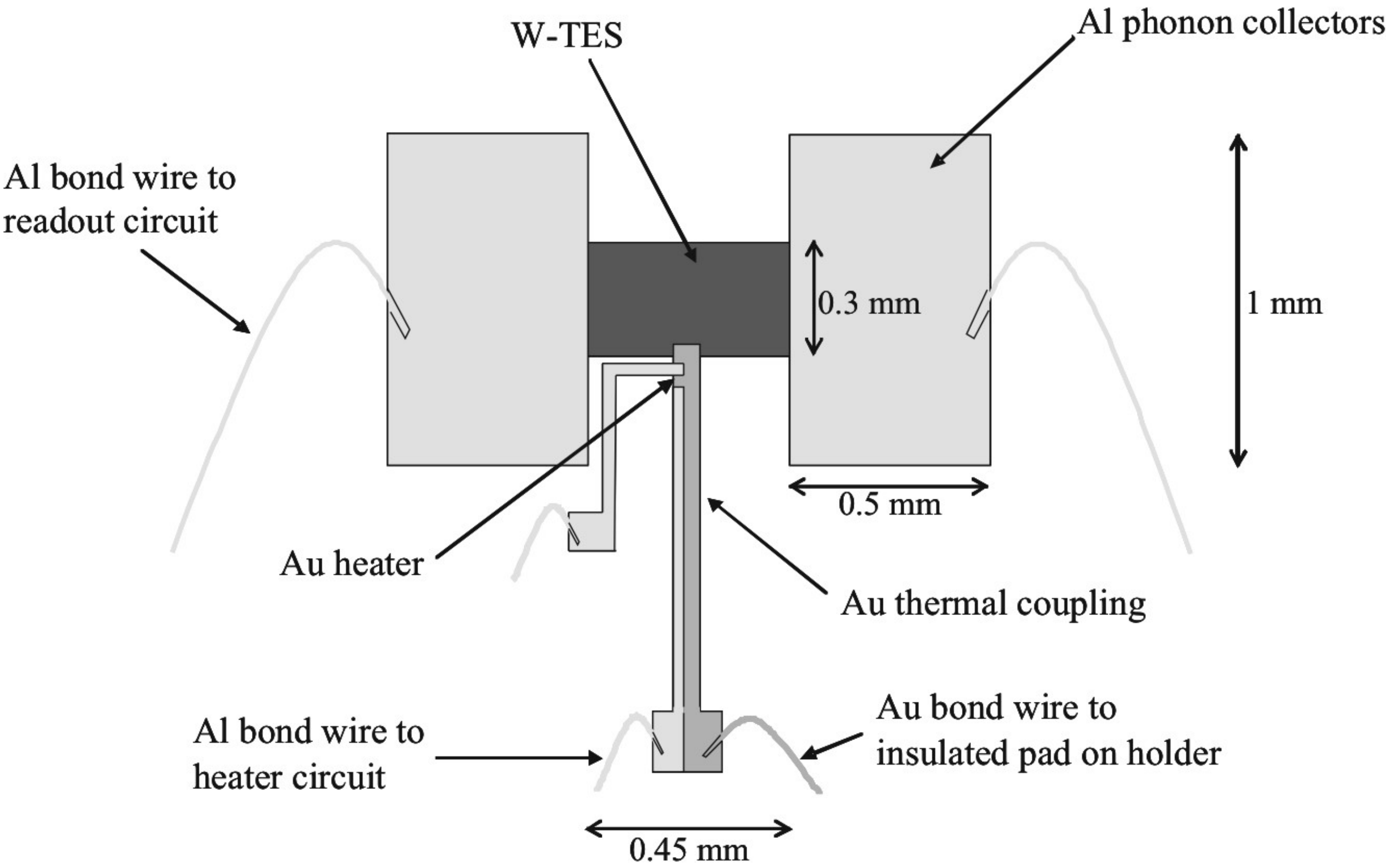
- Recoil spectrum varies correctly with nucleus

Additionally, nice if

- Varies with season correctly
(southern hemisphere detector?)

- Correct directional behavior
(if such detectors practical)


CA
CR
RB
CF
PB
CU
MV
PE



Layout of sensor (light detector)

Element	A	neutron E_R =20 keV	neutron E_R =30 keV	WIMP M=10 GeV	WIMP M=50 GeV
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(arXiv:1009.3791)