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UC Dark Matter Initiative

CDMS Technology and Coherent Neutrino Scattering

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CDMS: interest in lower thresholds

Improvements in phonon and ionization measurements

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Phonons (Matt Pyle)

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Phonons (Matt Pyle)

Ionization (Nader Mirabolfathi)

Speaking for

SuperCDMS Collaboration

Nader Mirabolfathi

Matt Pyle

Standard Model of Particle Physics

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Fantastic success of Standard Model but unstable

Why is H, W and Z at ≈100 M_p?

Need for new physics at that scale

supersymmetry

additional dimensions, global symmetries

In order to prevent the proton to decay, a new quantum number

=> Stable particles: Neutralino

Lowest Kaluza Klein excitation, little Higgs

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Bringing Cosmology and Particle Physics together: a remarkable concidence

Particles in thermal equilibrium

+ decoupling when nonrelativistic

Freeze out when annihilation rate ≈ expansion rate

$$\Rightarrow \Omega_x h^2 = \frac{3 \cdot 10^{-27} cm^3 / s}{\langle \sigma_A v \rangle} \Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2}$$

Cosmology points to W&Z scale

Inversely standard particle model requires new physics at this scale

=> significant amount of dark matter

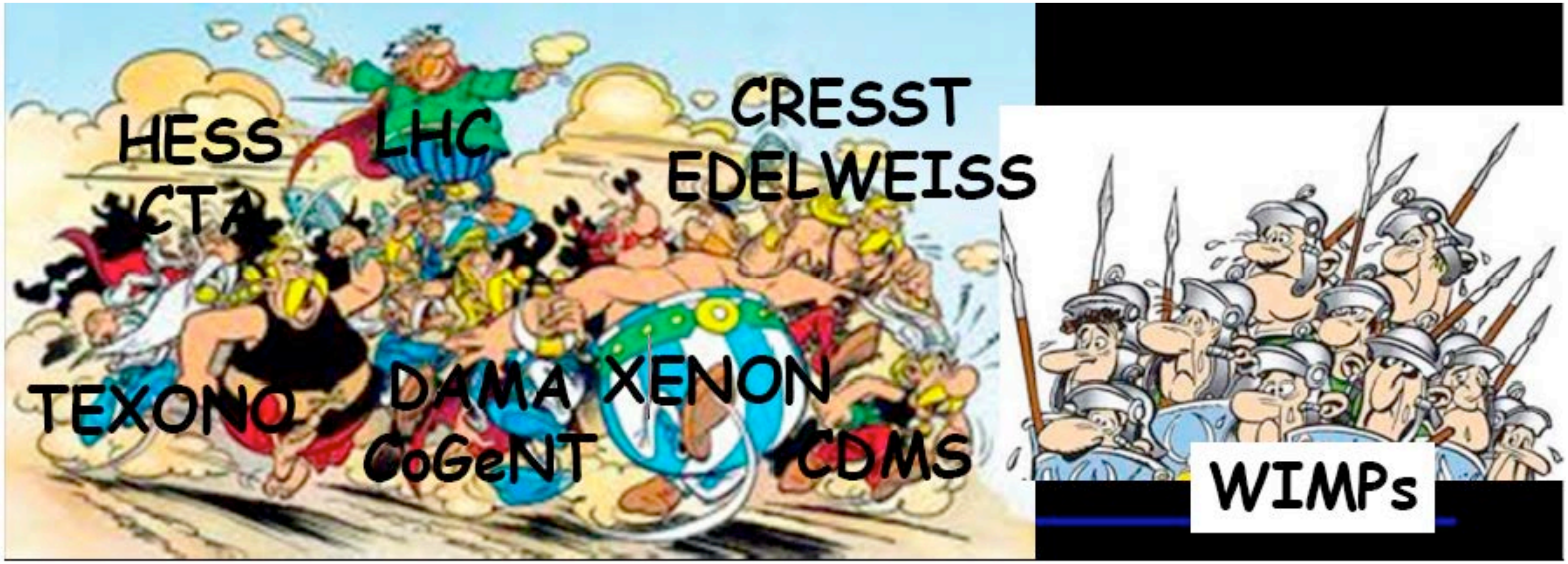
Weakly Interacting Massive Particles

Dark Matter could be due to TeV scale physics

Dark Matter: An Exciting Time!

Dark Matter: An Exciting Time!

Credit: Joerg Jaeckel



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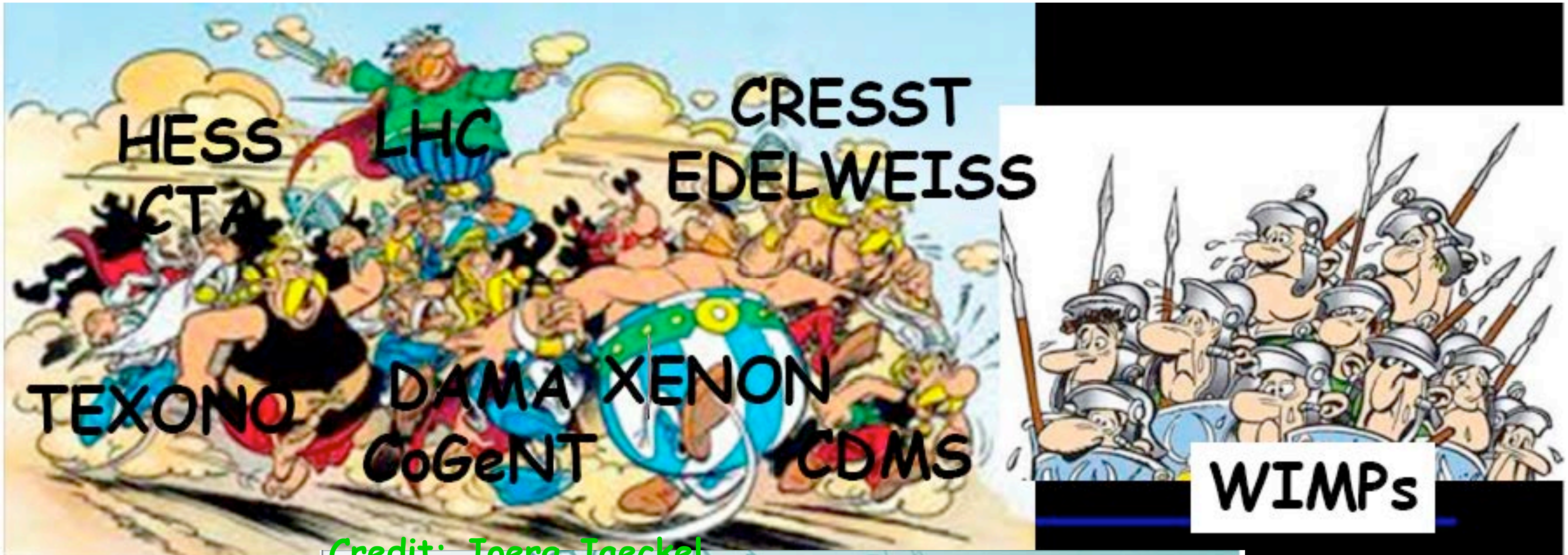

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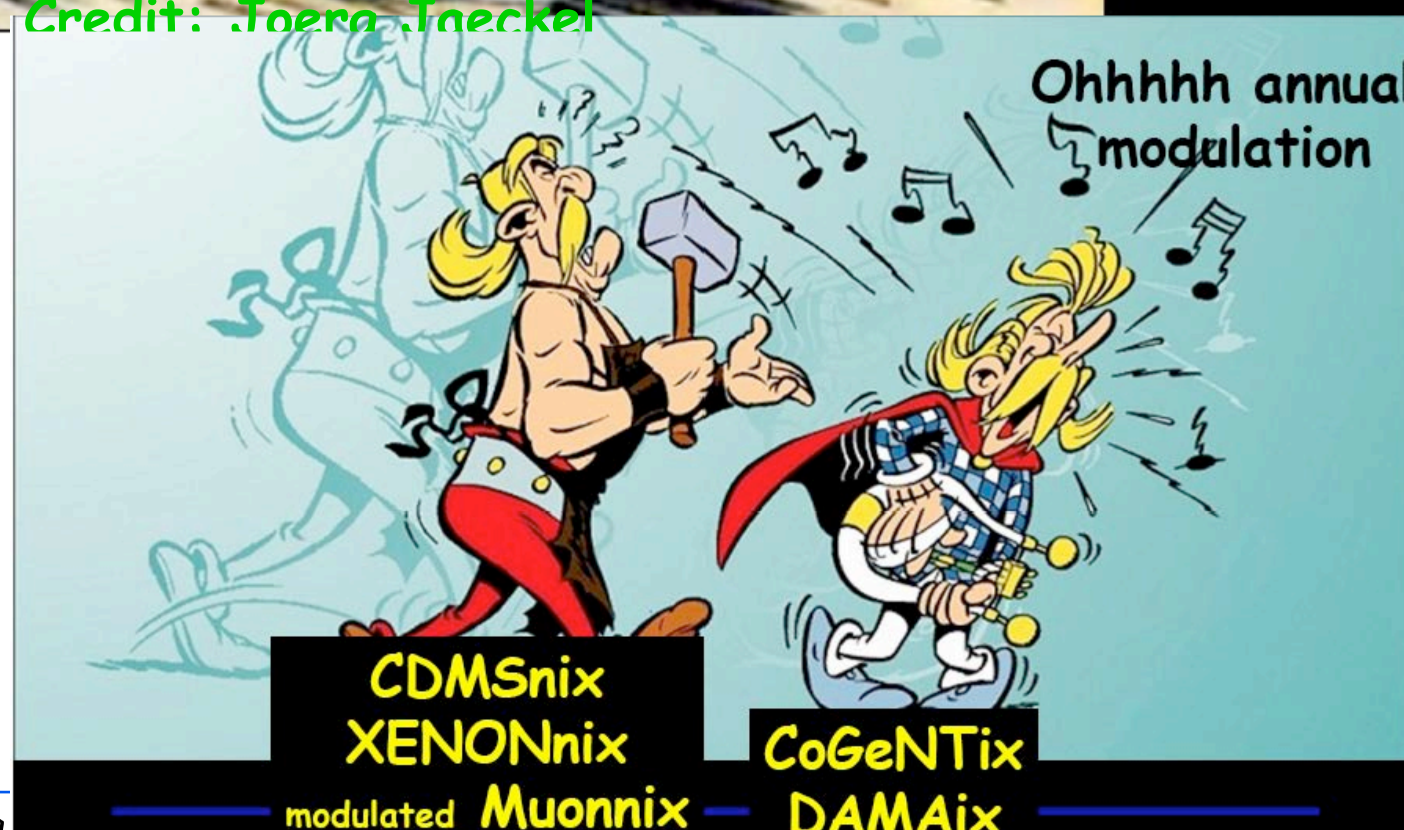
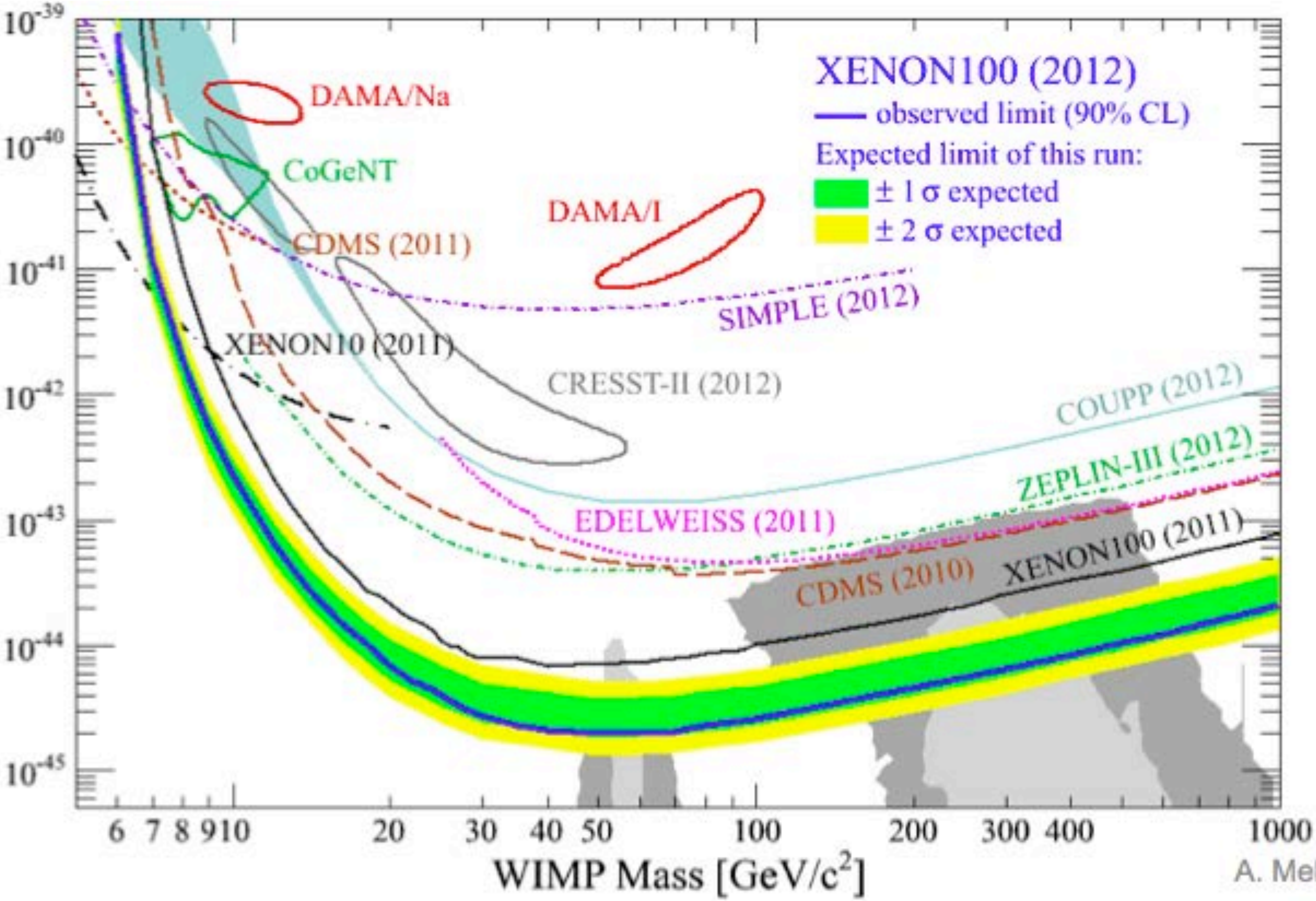
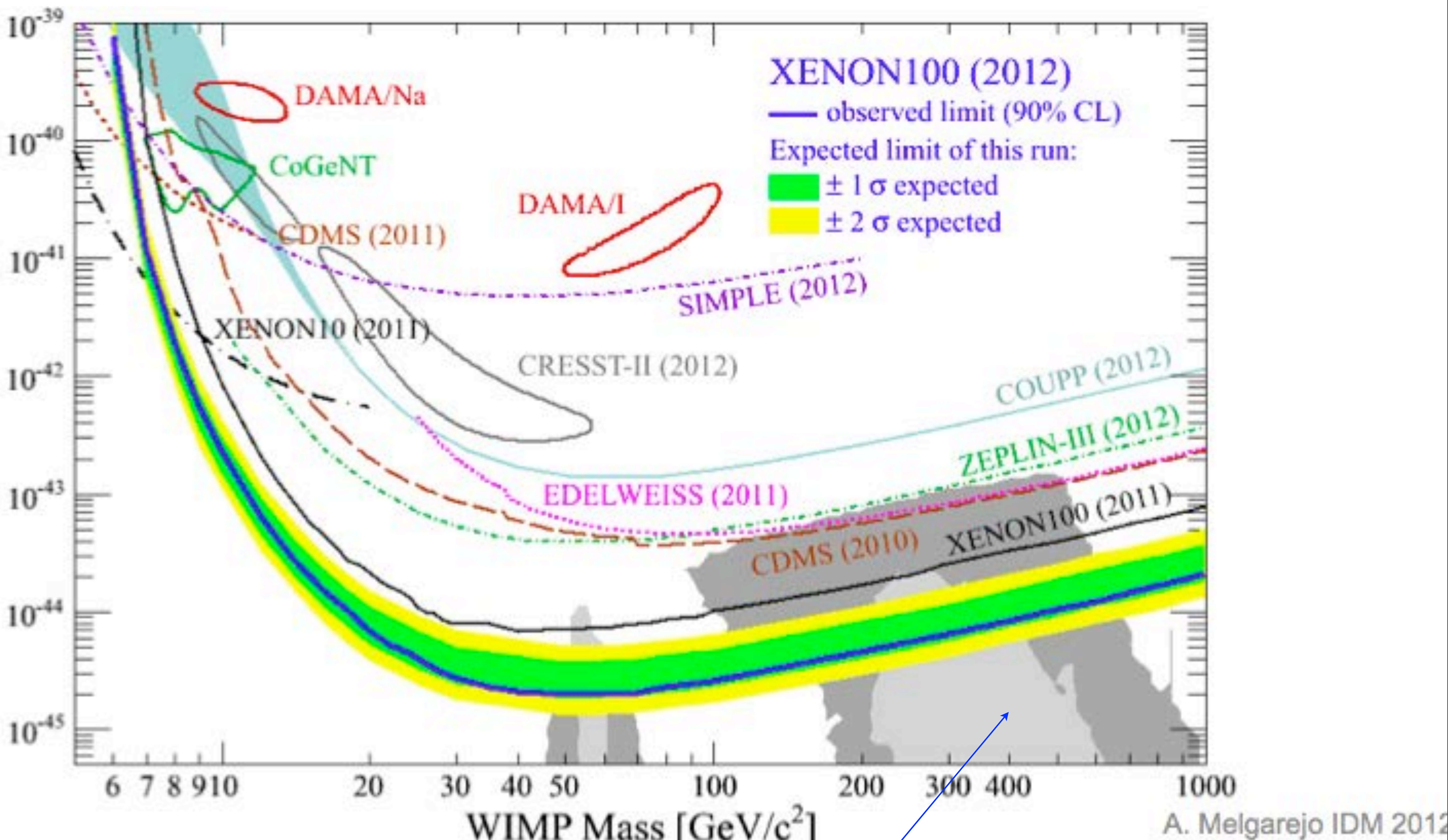


High Mass Region



A. Melgarejo IDM 2012

High Mass Region



CMSSM≈mSUGRA Focal point region

No threshold for Direct Detection

CDMS II December 2009
Ionization + Athermal Phonons

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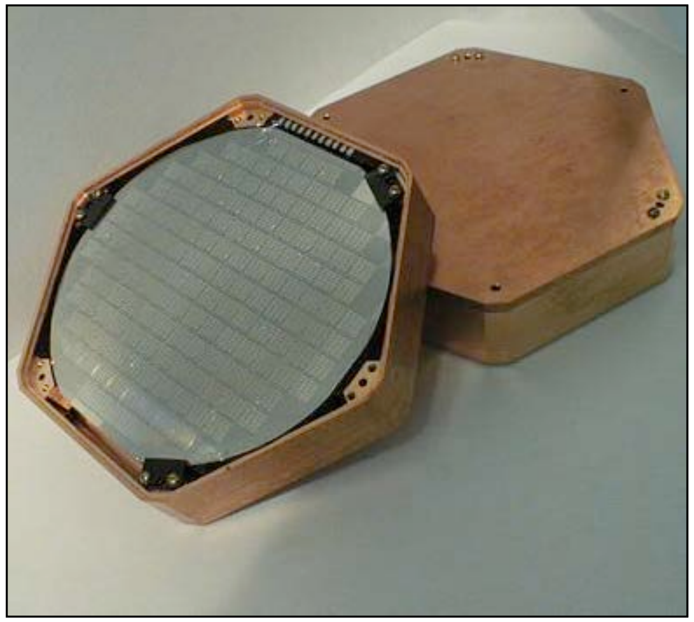
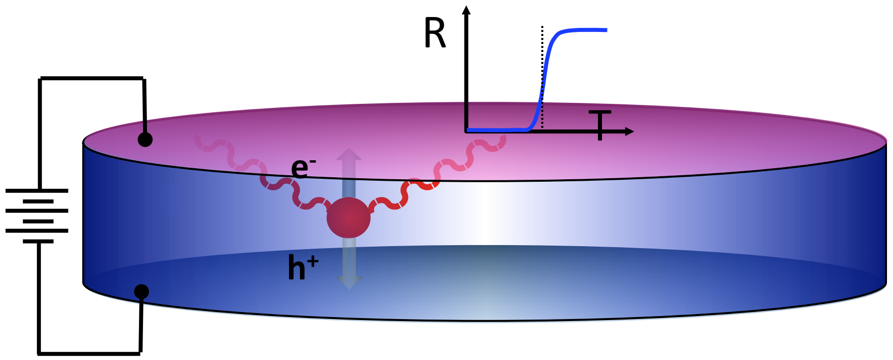
Ionization + Athermal Phonons

7.5 cmØ 1 cm thick ≈250g
4 phonon sensors on 1 face
2 ionization channel





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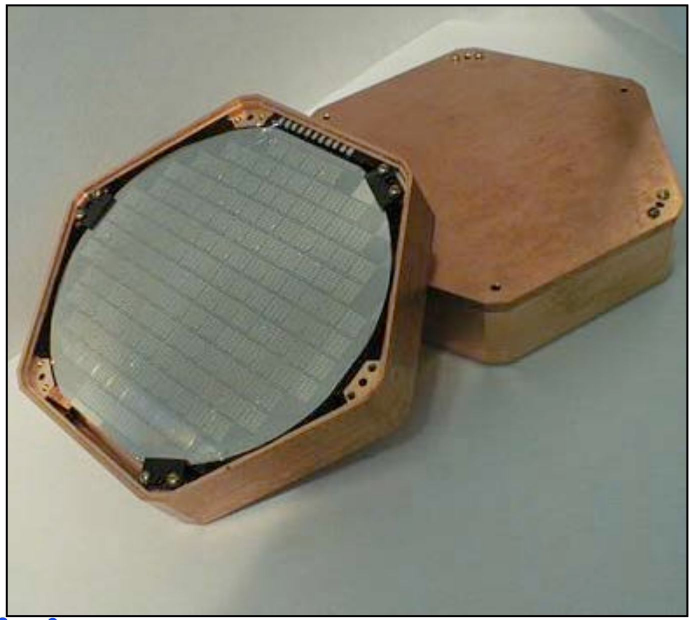
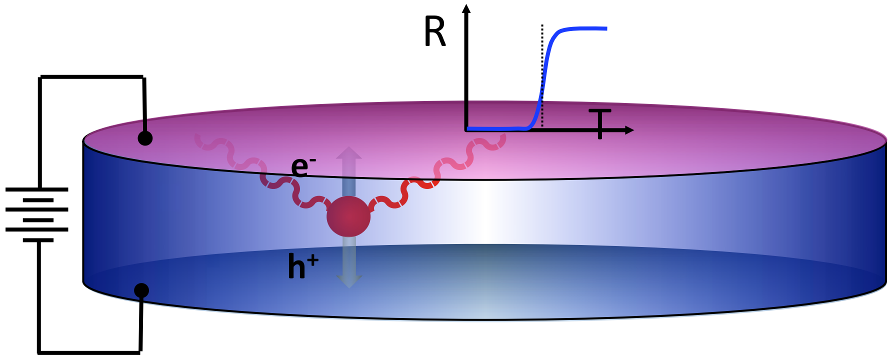
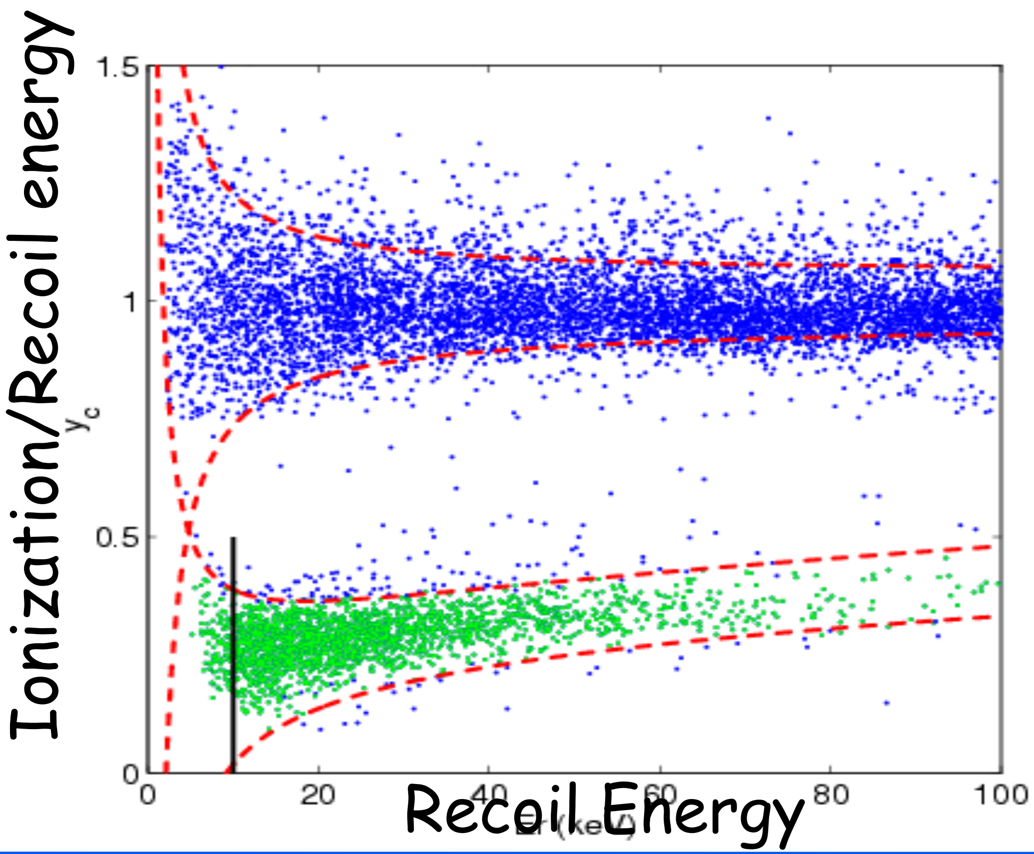




Ionization yield



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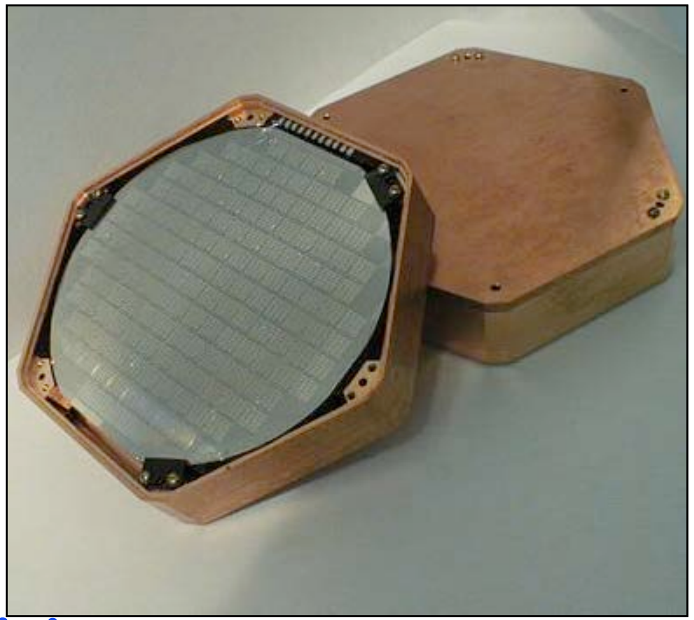

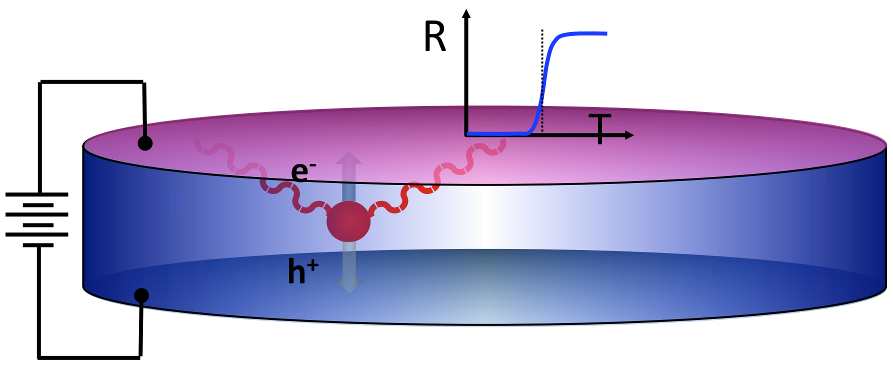

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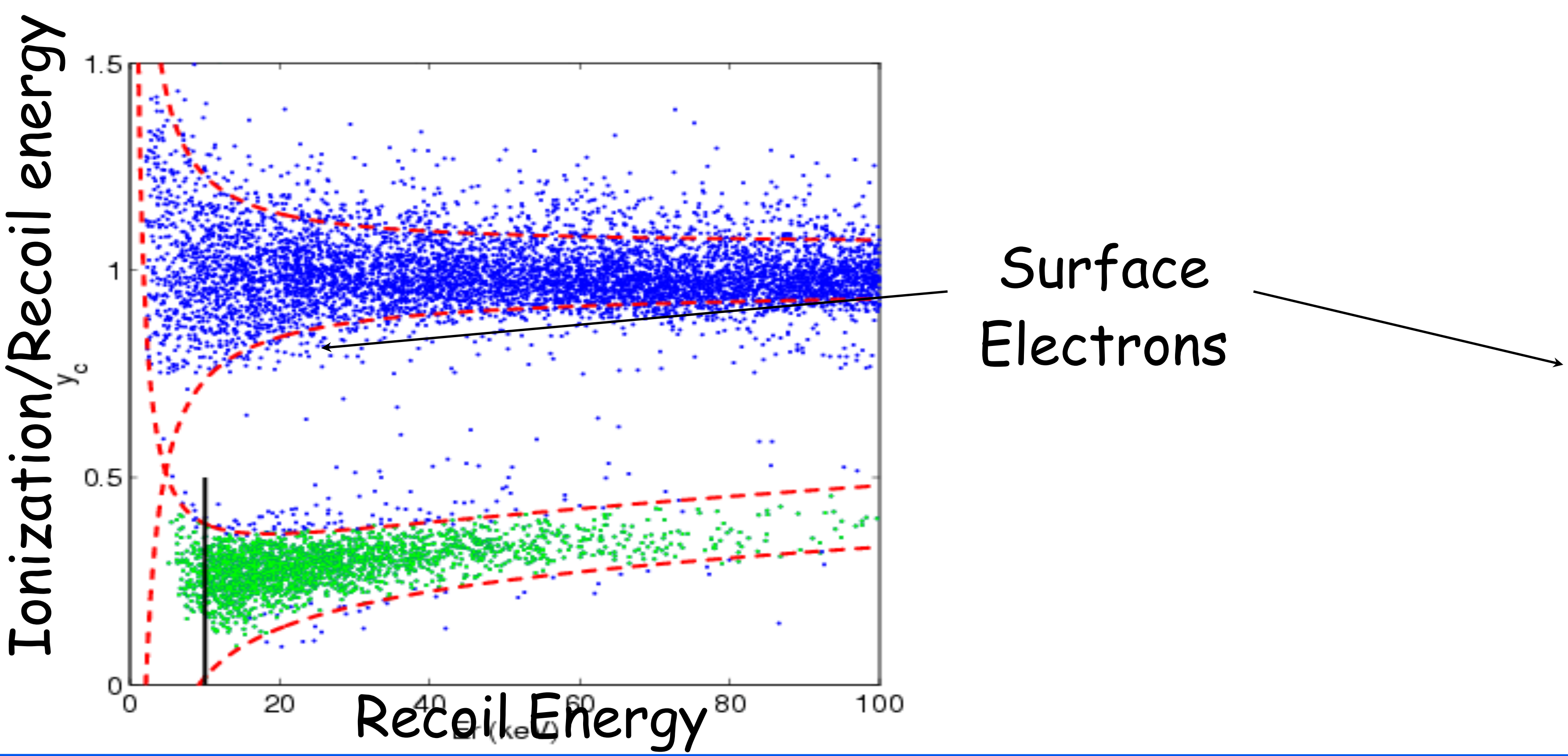

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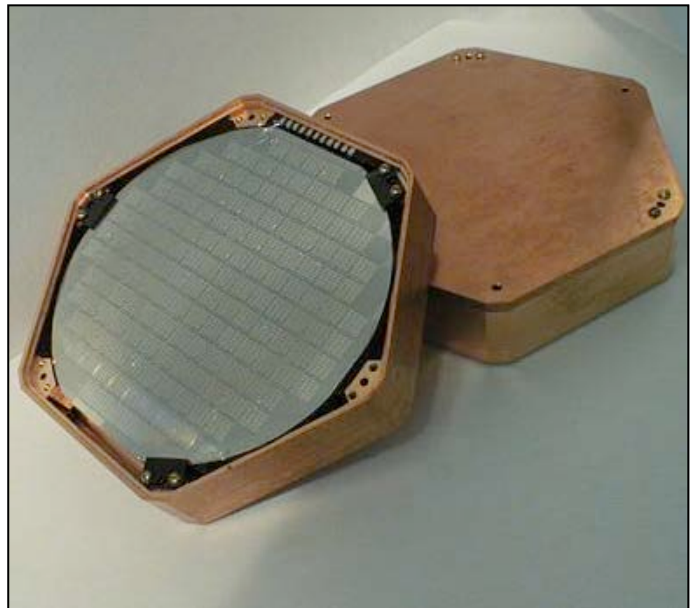

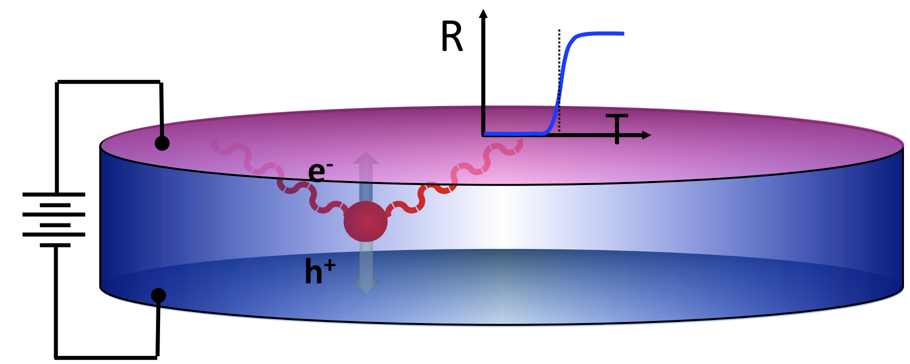

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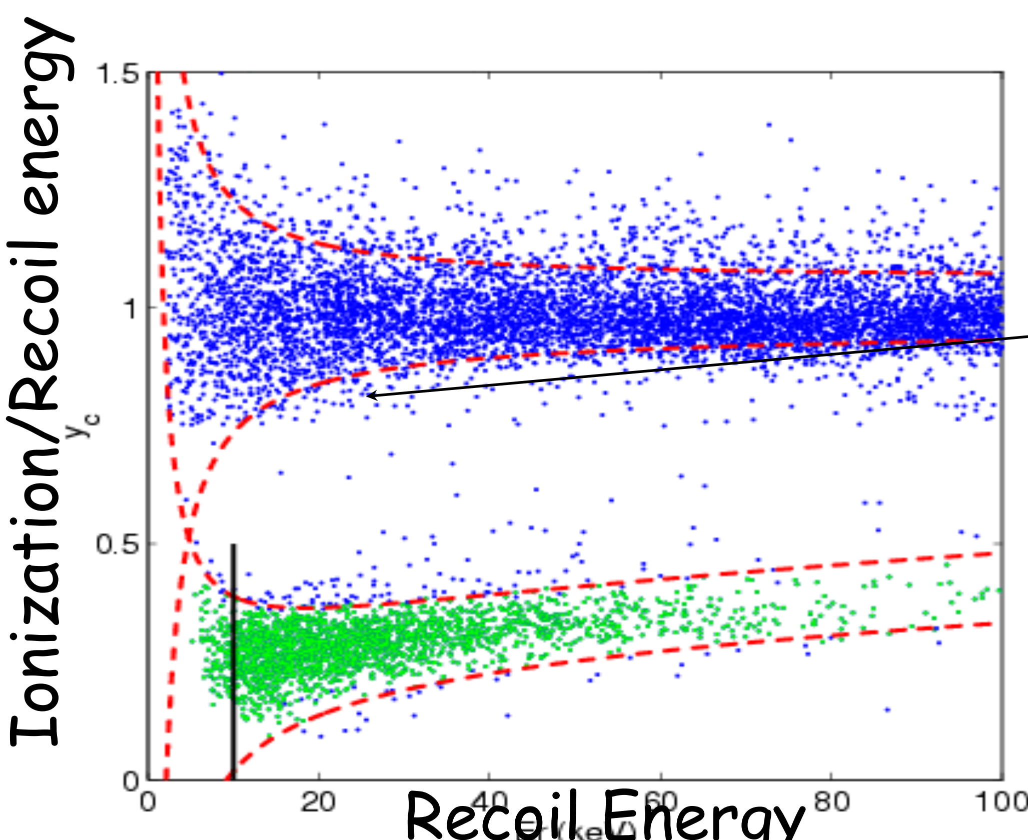
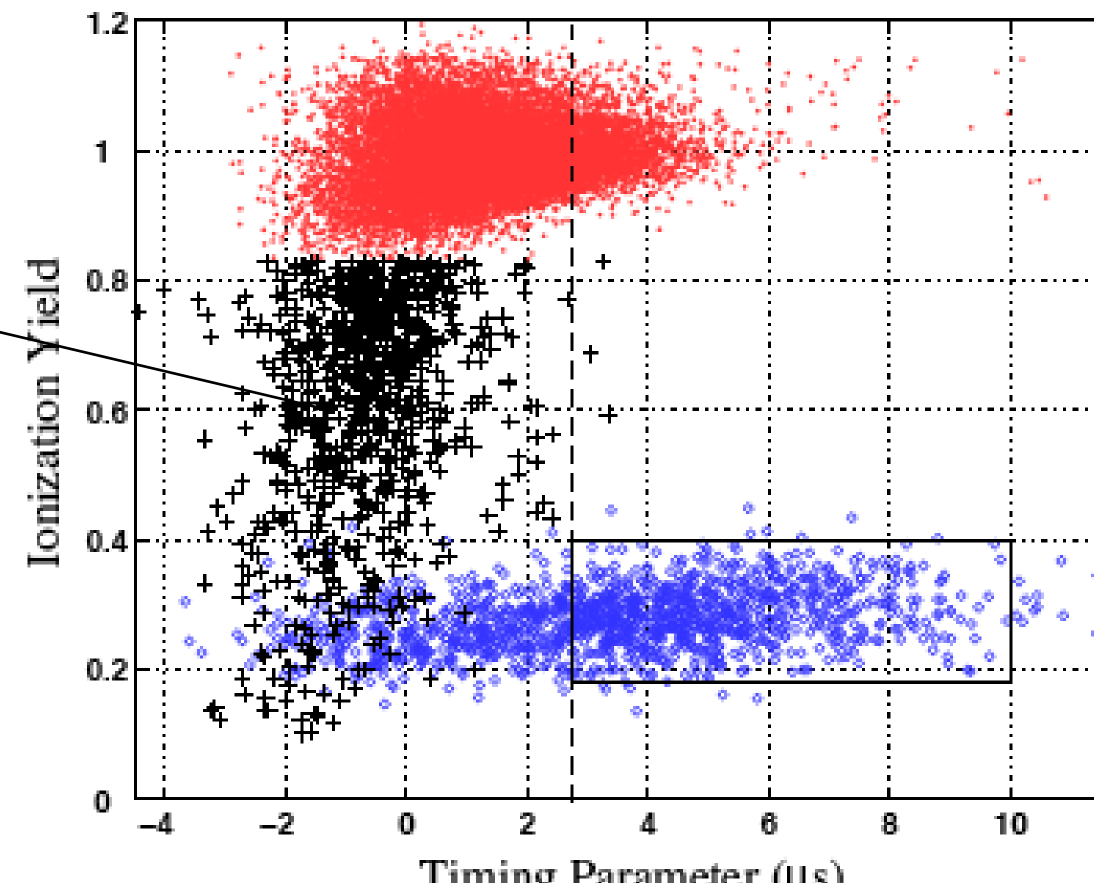


Surface
Electrons

Timing -> surface discrimination



Ge:Getting rid of the surfaces

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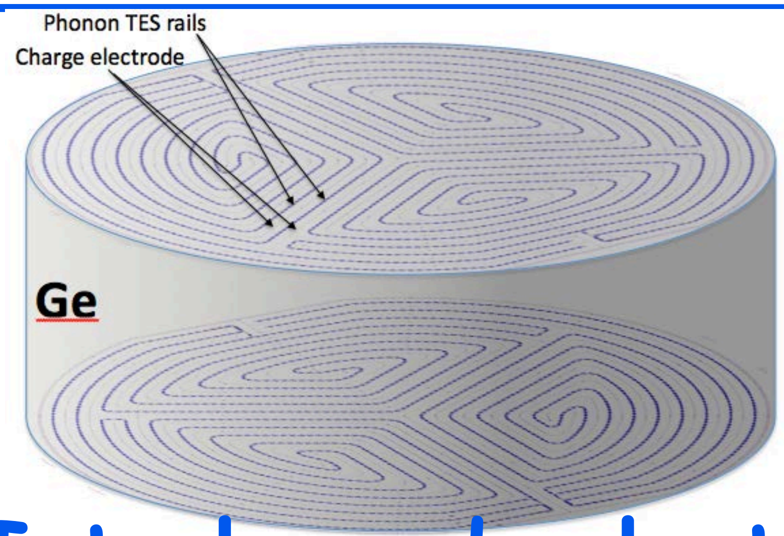

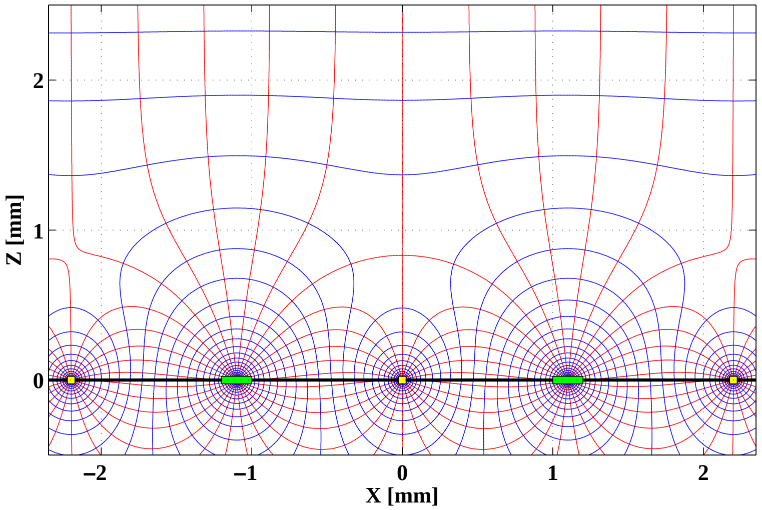

Interleaved electrodes

Reviving an idea of P. Luke (also used by EDELWEISS)

Events close to the surface seen on one side

≠Events in the bulk seen on both sides

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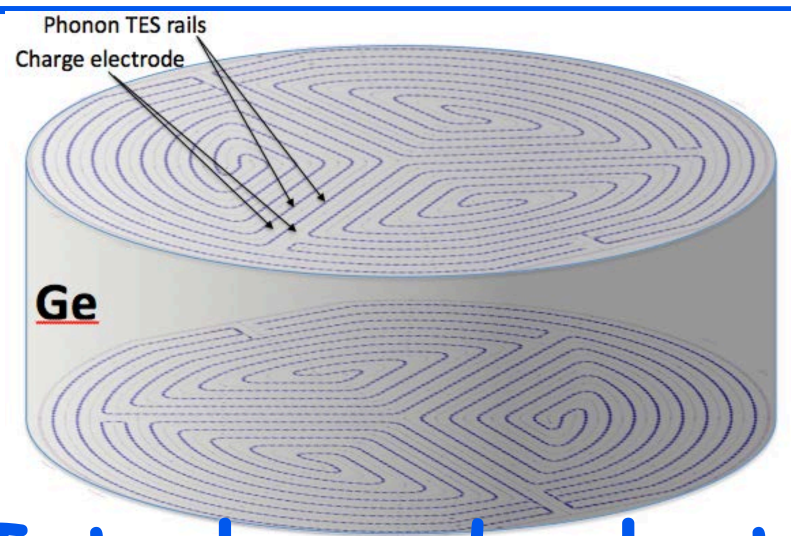

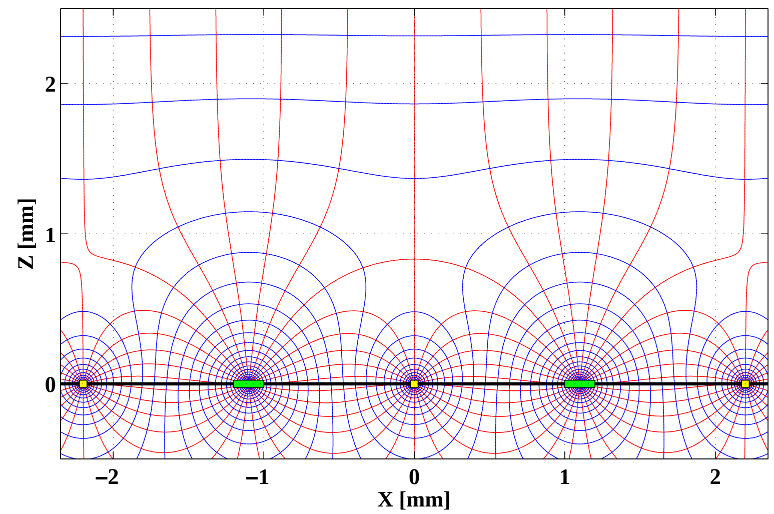

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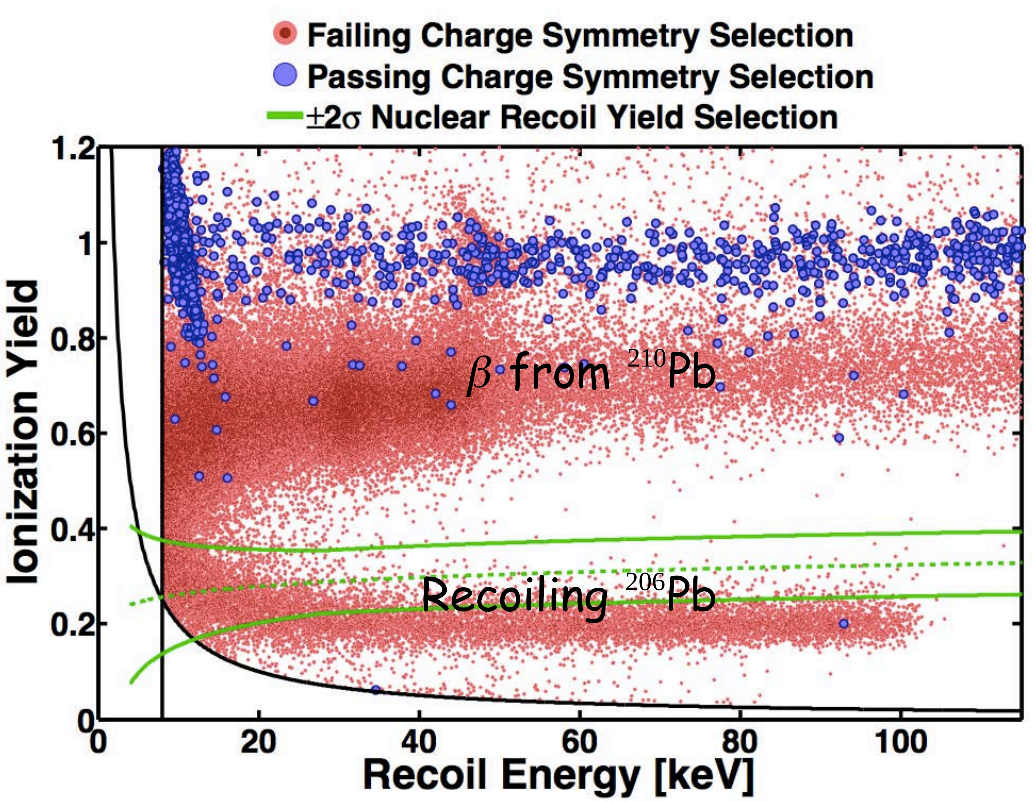
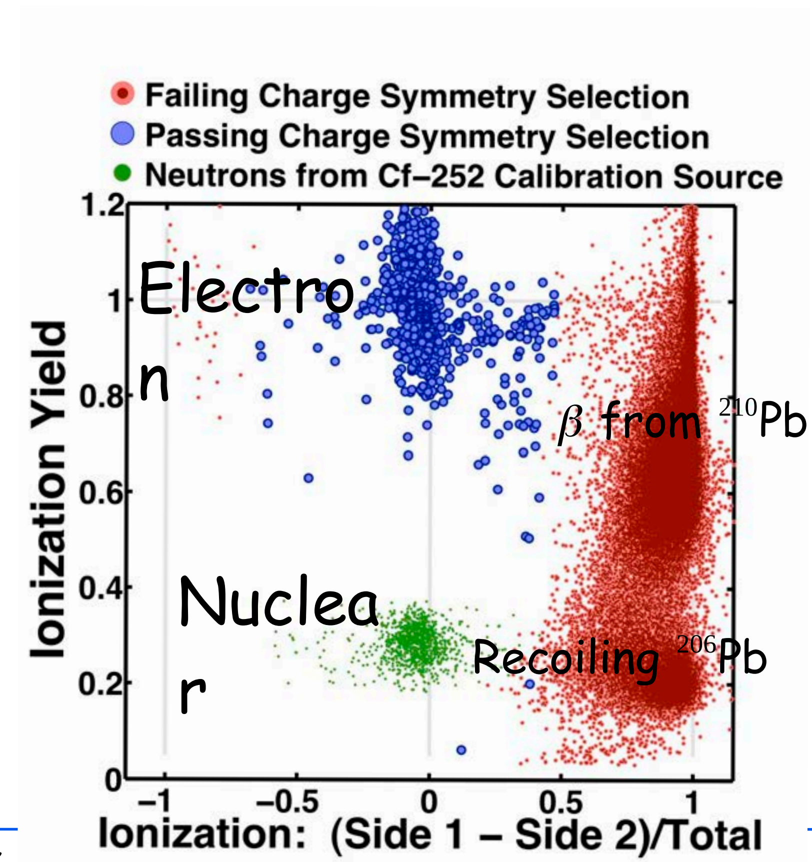
Test with ^{210}Pb in low background environment





0/65,000 betas

0/15,000 ^{206}Pb recoils

More than sufficient for 200kg for 3 years (SNOLAB)

SuperCDMS Soudan Large Mass Region

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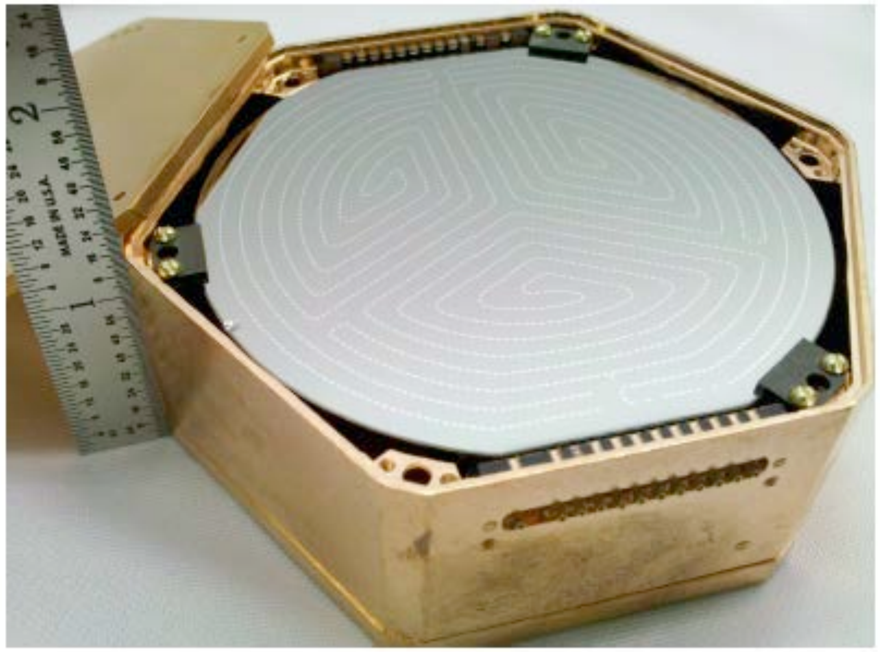
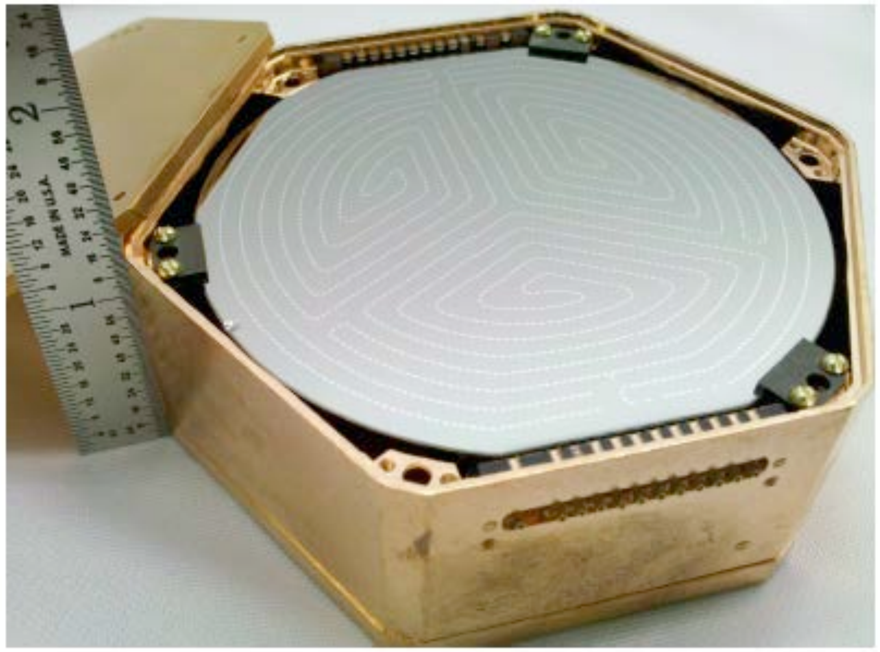


Ø 76mm thickness
25mm

Mass 630g

SuperCDMS Soudan Large Mass Region



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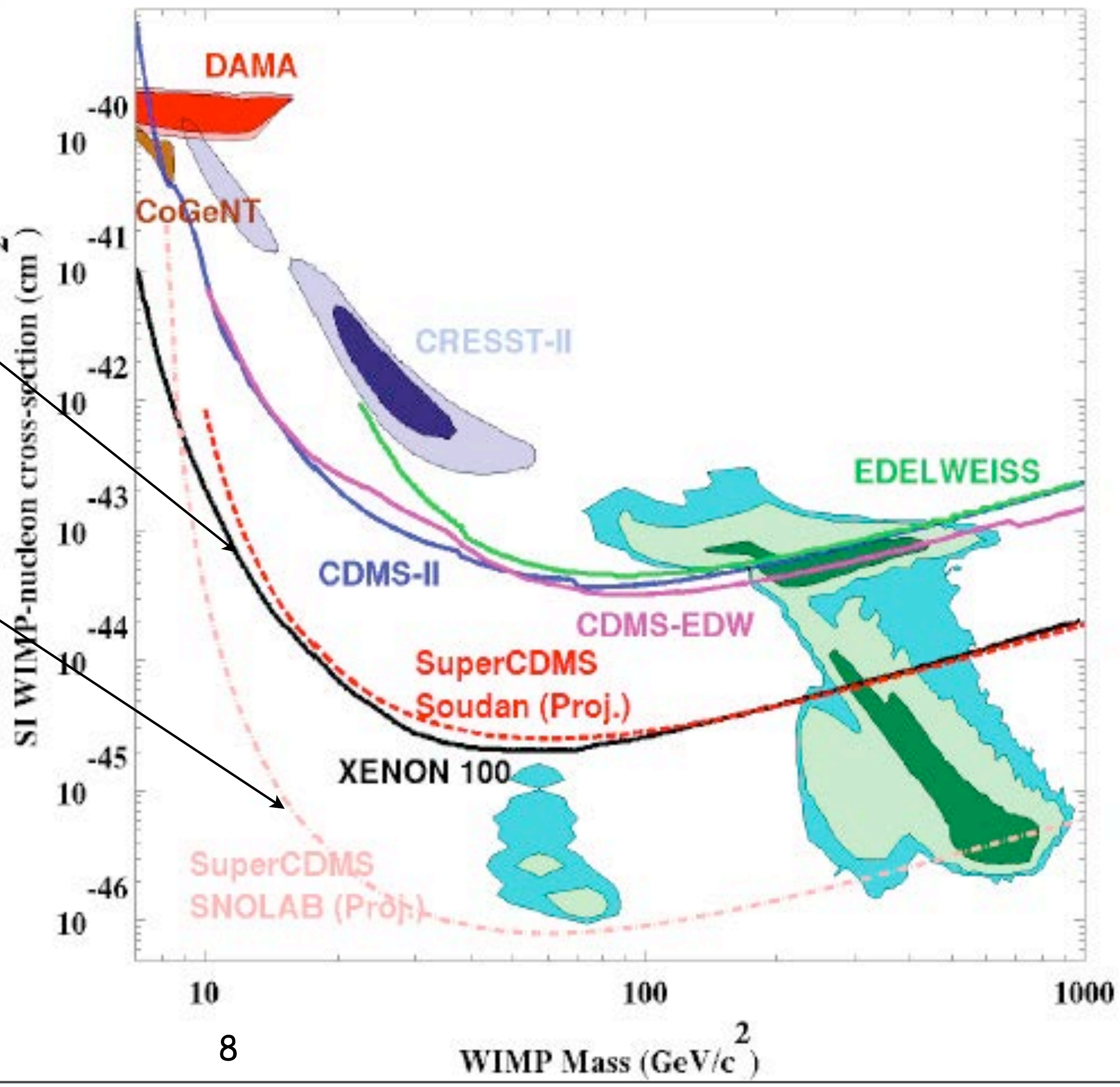
CDMS reach 2015

Somewhat dependent on cosmogenic neutrons + purity of our shield

CDMS reach 2019



Friday, December 28, 12

Low Mass Dark Matter

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Other possibilities! The Dark Matter sector could be complex or have different interactions e.g.,

Excited states

Weiner but now dead (CDMS, Xenon 10)

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A mirror dark matter sector

Maybe with matter-antimatter asymmetry

Would explain naturally why $\Omega_{DM} \approx 6\ \Omega_{baryon}$ if $M_{DM} \approx 6\ M_p$

Could even be the origin of baryogenesis!

High cross sections within the dark matter sector?

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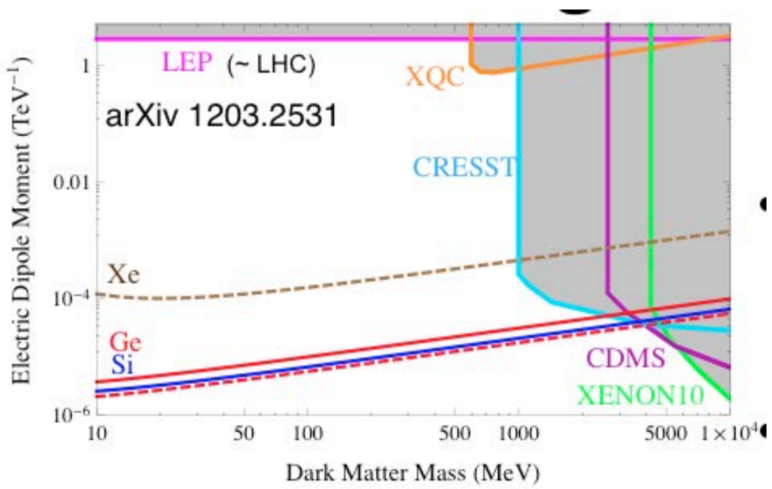


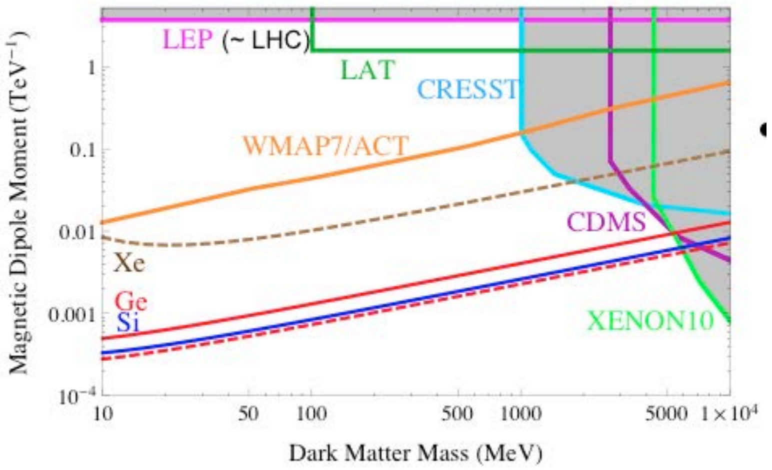
Sub GeV Dark Matter

Naturalness?

Electric/Dipole moment

Graham, Kaplan, Rajendran, & Walters (arXiv 1203.2531)

Claim: Pretty Natural



CDMS II

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Limited by ionization below 7 keVnr

To go down to 2 KeVnr; use phonon only and assume nr yield to compute Enr
Incompatible with original CoGeNT claim
CDMS not incompatible with 2 10^{-41} cm^2/nucleon signal
In latest paper, CoGeNT collaboration does not claim any WIMP signal

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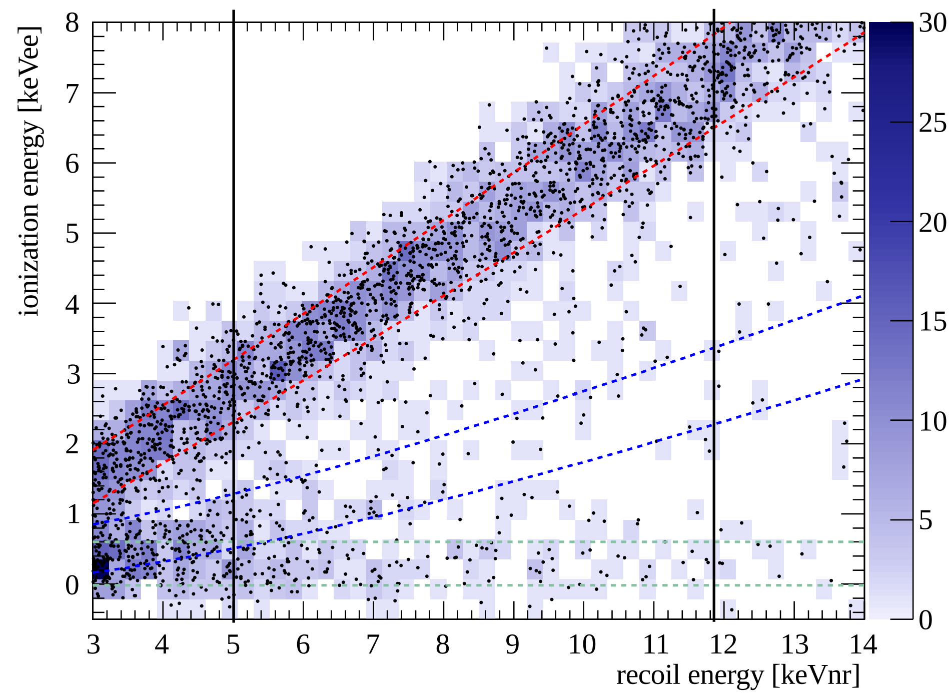
Collar& Fields: a signal in CDMS?

Maximum likelihood very sensitive to assumptions about background analytic shape
Doing our own analysis

No significant difference between singles and multiples



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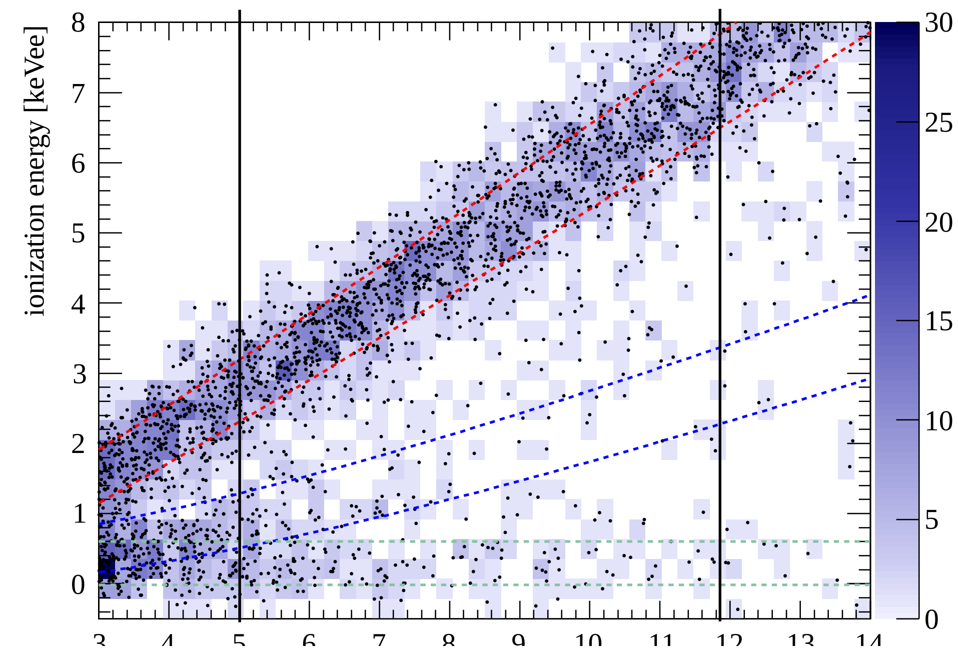

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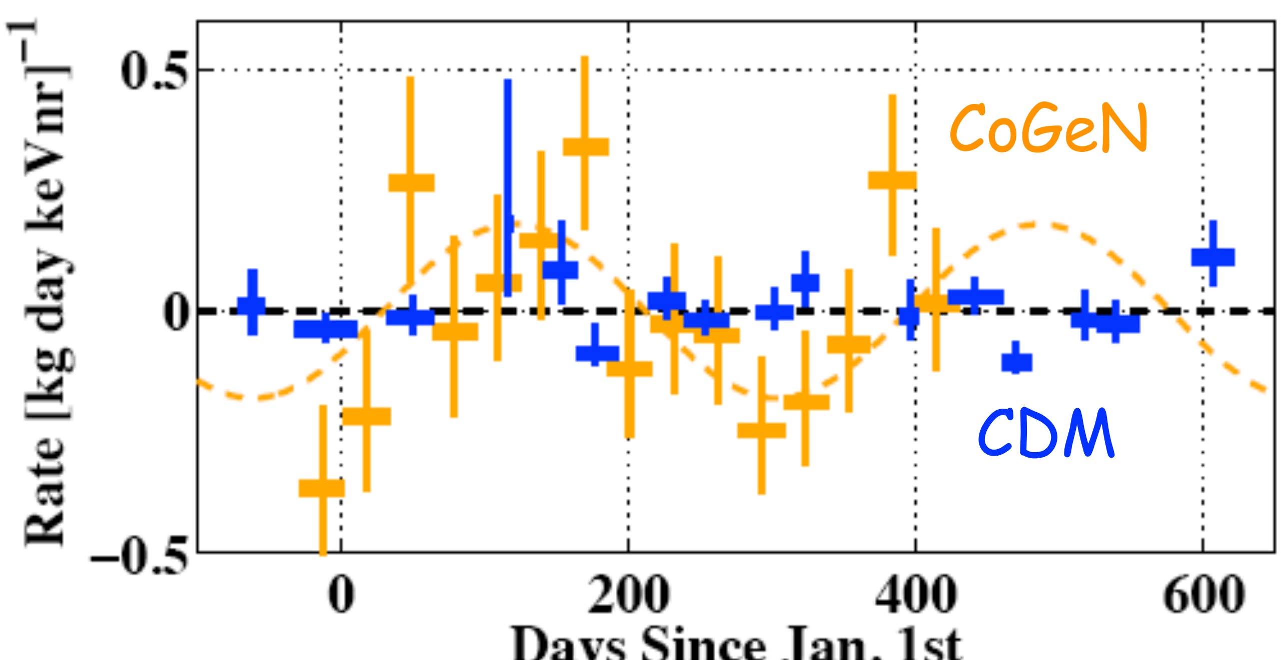
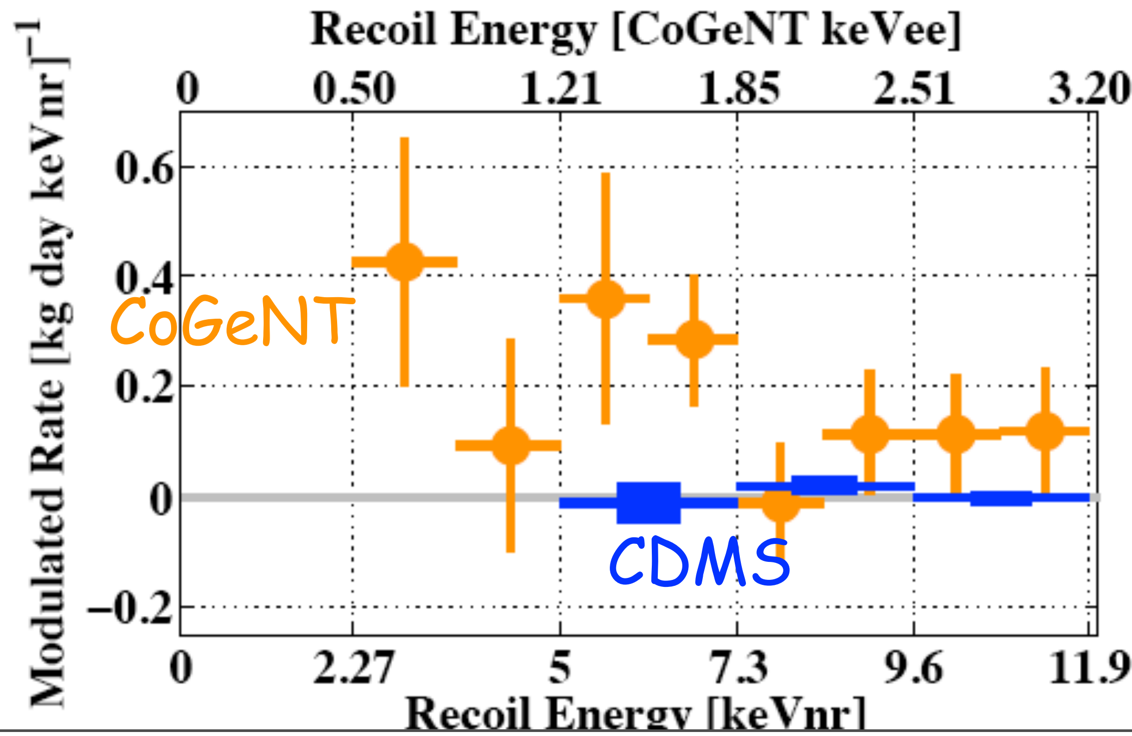
No Modulation 5 keV-11.9 keV nuclear recoil: arXiv:1203.1309





What we are doing for SuperCDMS Soudan

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2 modes

- "Low Threshold" : we measure the phonon energy and correct for the phonon emission from carrier drift in the electric field (Luke Neganov Effect) with the ionization yield of a nuclear recoil (15% correction)

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rapidly background limited

=> result in coming year

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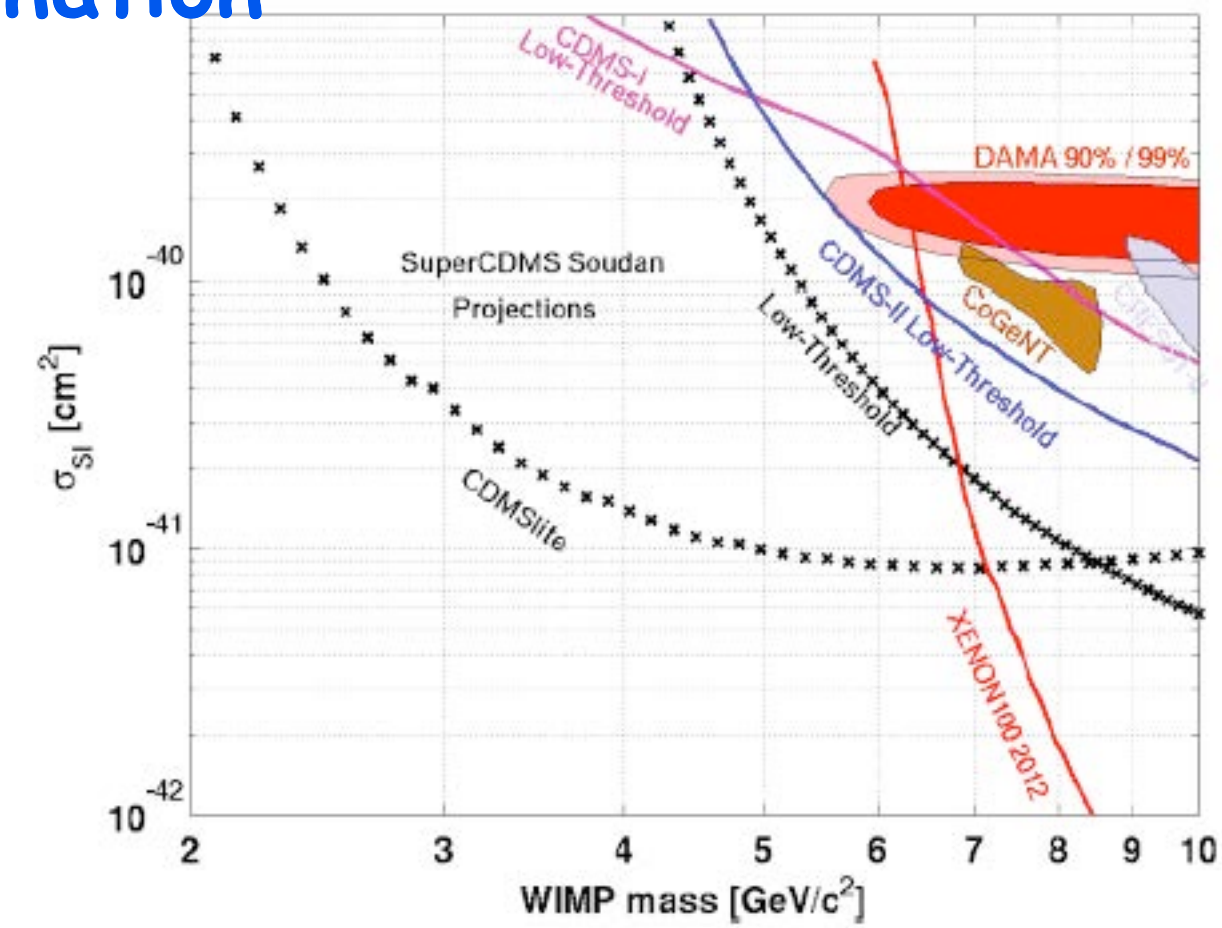

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Working on phonons

Optimization with new SQUIDS (lower L=> lower R_{TES})

Possibly working at lower Tc (sensitivity increase as T_c^3—See below)

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FET-> HEMT :4K instead of 100K, 100μW instead of 5mW

+ lower white and 1/f noise: theoretically could reach 200eV FWHM if detector leakage current is 10^{-13}

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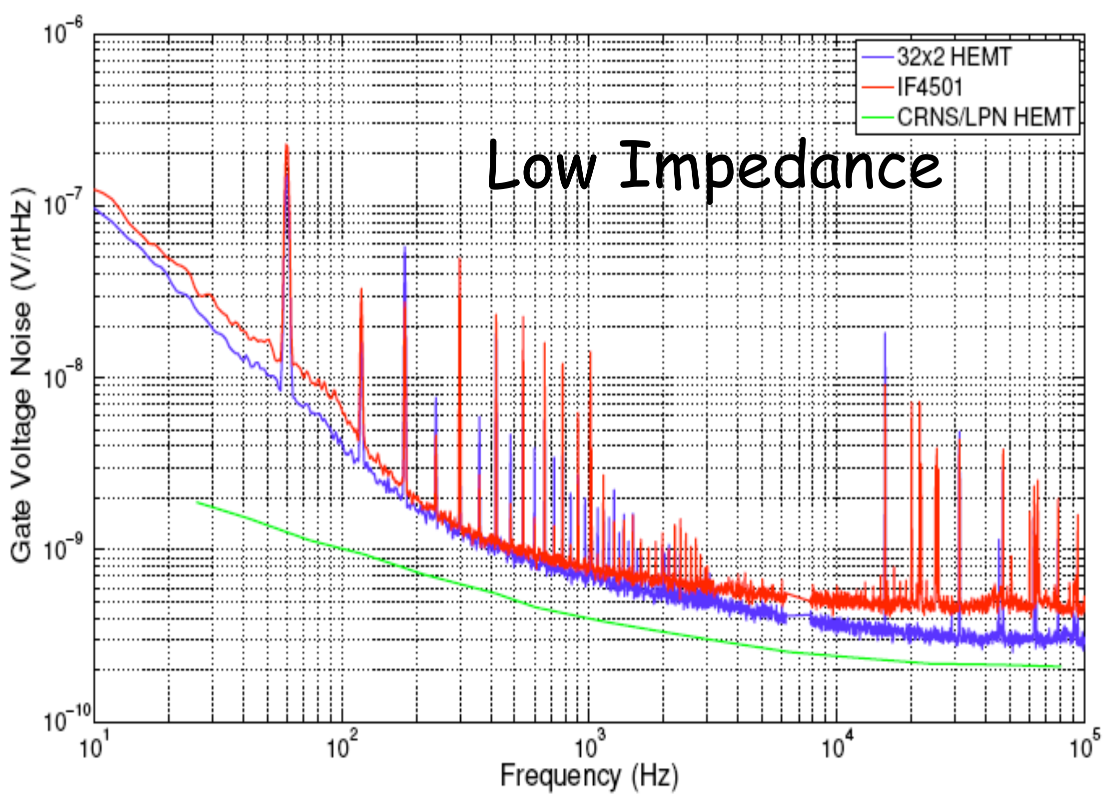
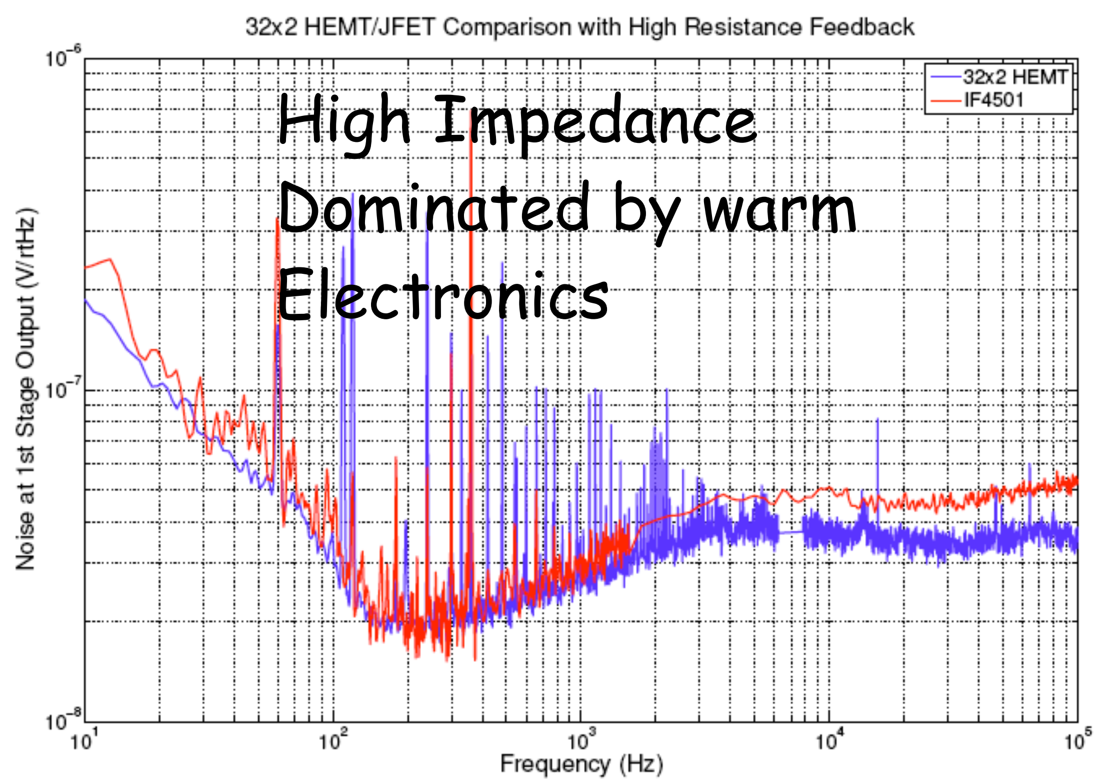




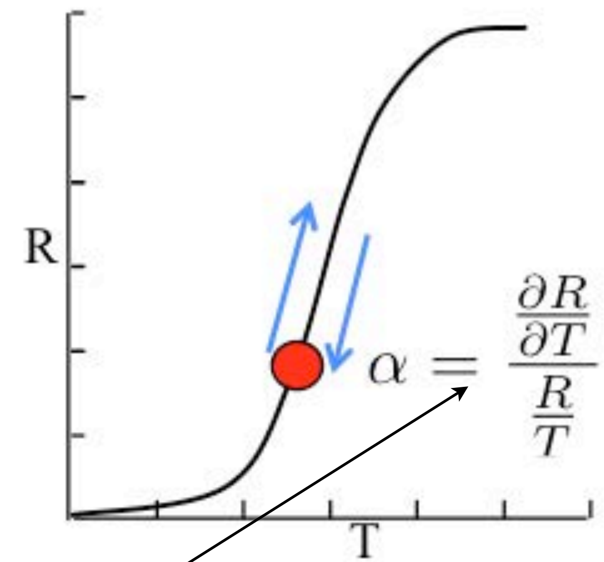
How to improve the phonons for coherent neutrino scattering?

Matt Pyle

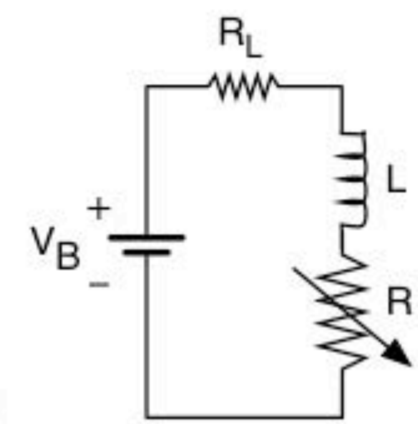
Transition Edge Sensor

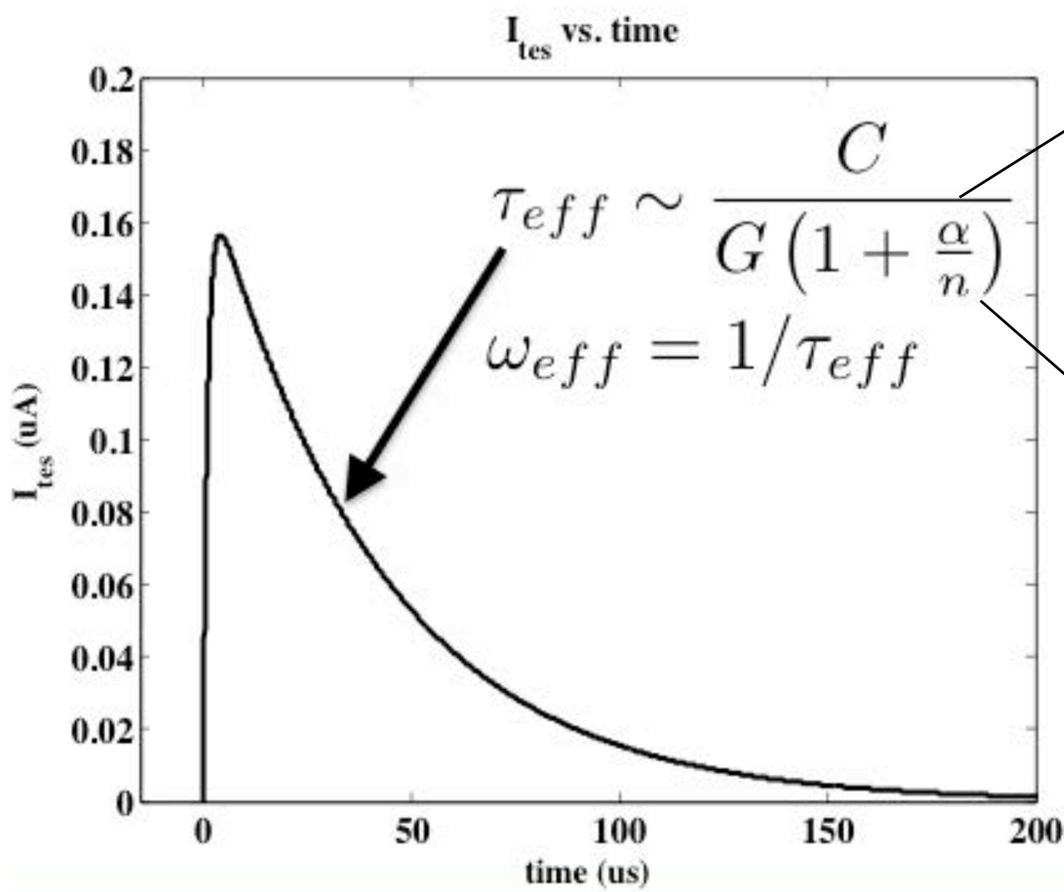
with electro thermal feedback

- Superconducting film artificially held within it's transition through voltage biasing
- Resistance incredibly sensitive to temperature change



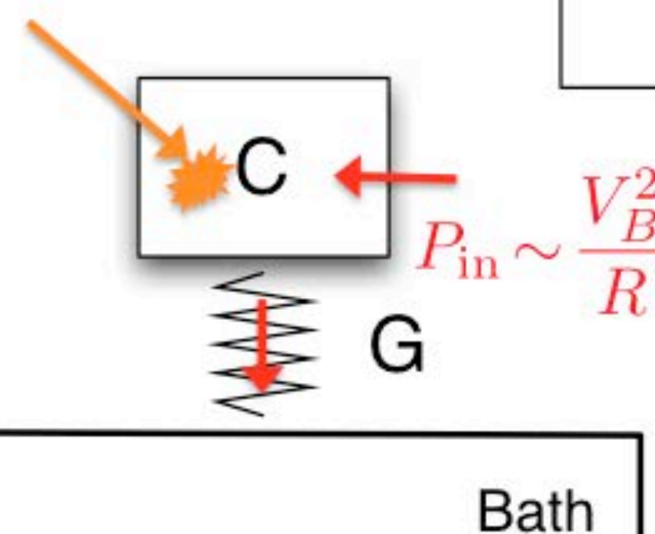
$$\alpha = \frac{\frac{\partial R}{\partial T}}{\frac{R}{T}}$$





$$\tau_{eff} \sim \frac{C}{G\left(1+\frac{\alpha}{n}\right)}$$

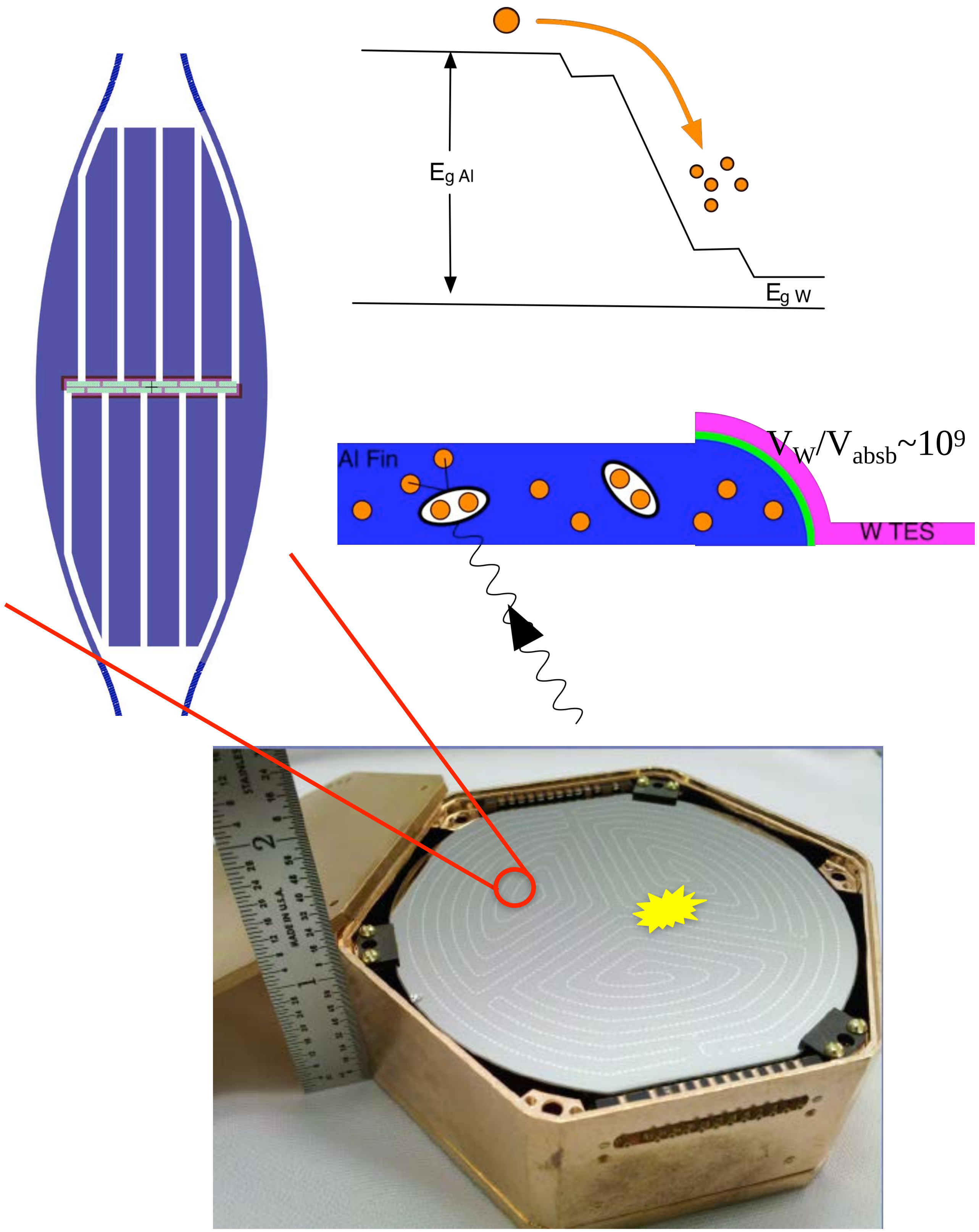
$$\omega_{eff} = 1/\tau_{eff}$$



$$P_{\text{in}} \sim \frac{V_B^2}{R}$$

$$P = \Sigma\left(T_{TES}^n - T_{bath}^n\right) \Rightarrow \frac{P}{GT} = \frac{1}{n}$$

Athermal Phonon Detection Principles



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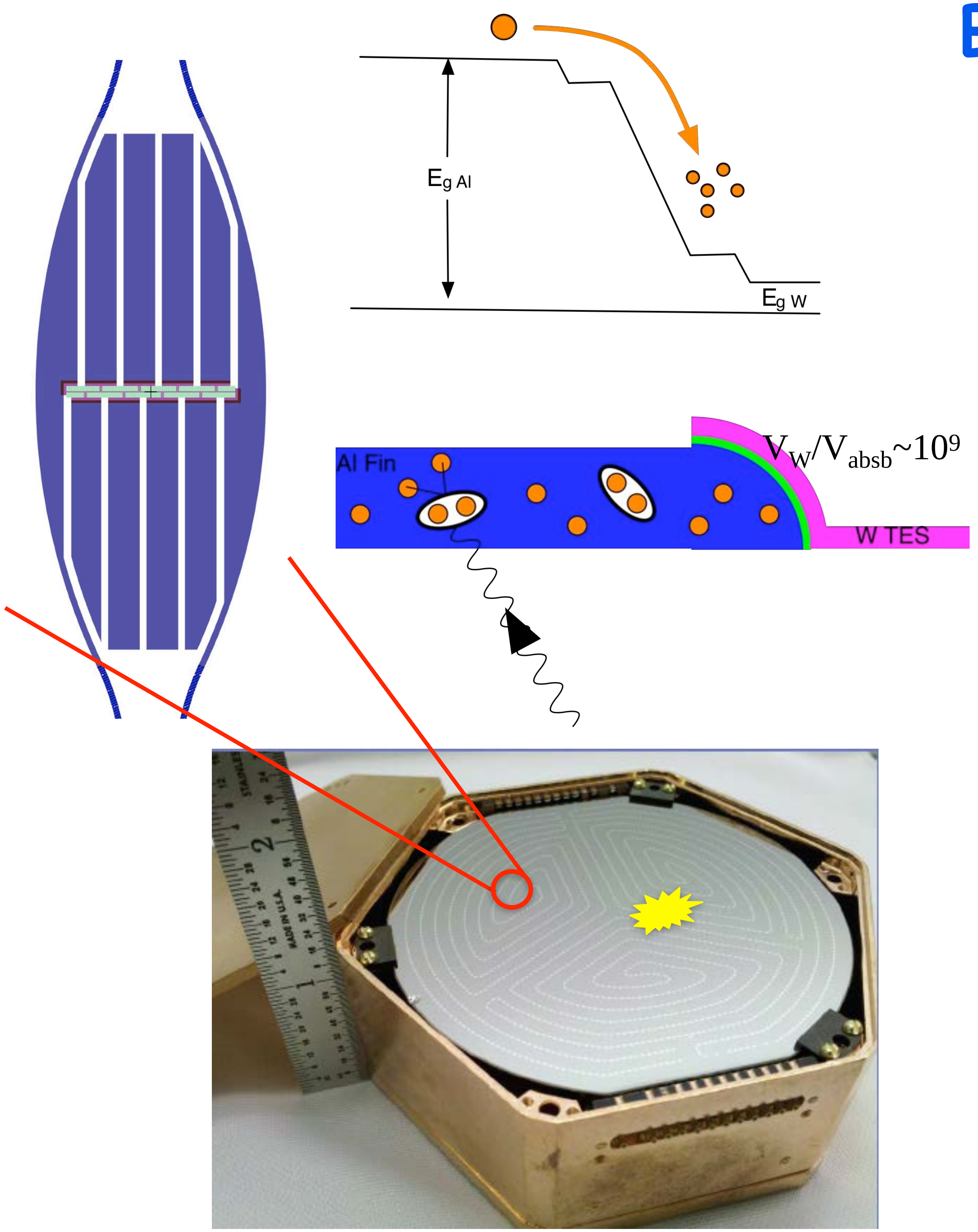

Become insensitive to $C_{absorber}$ by collection and concentration of Phonons

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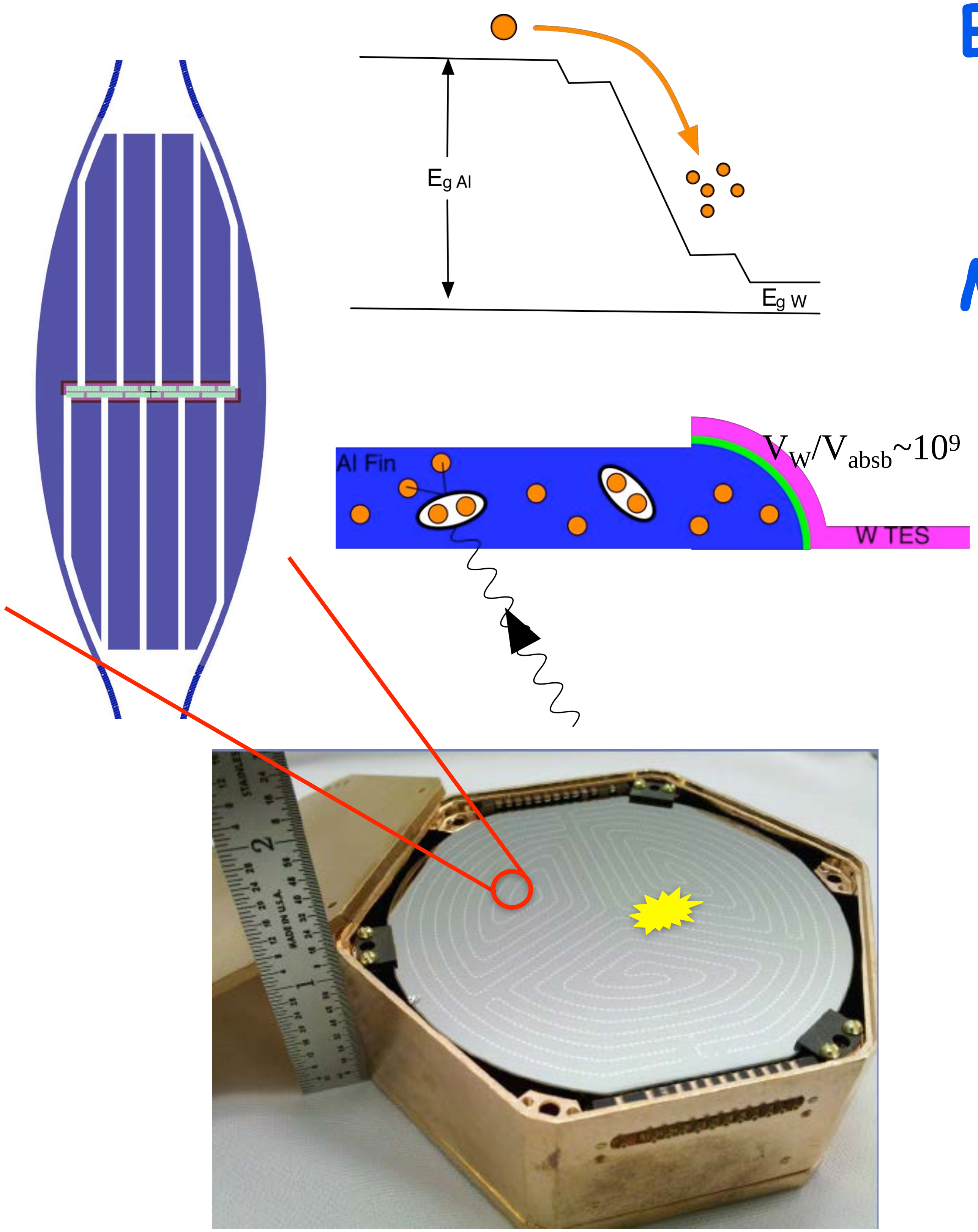

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More Complex

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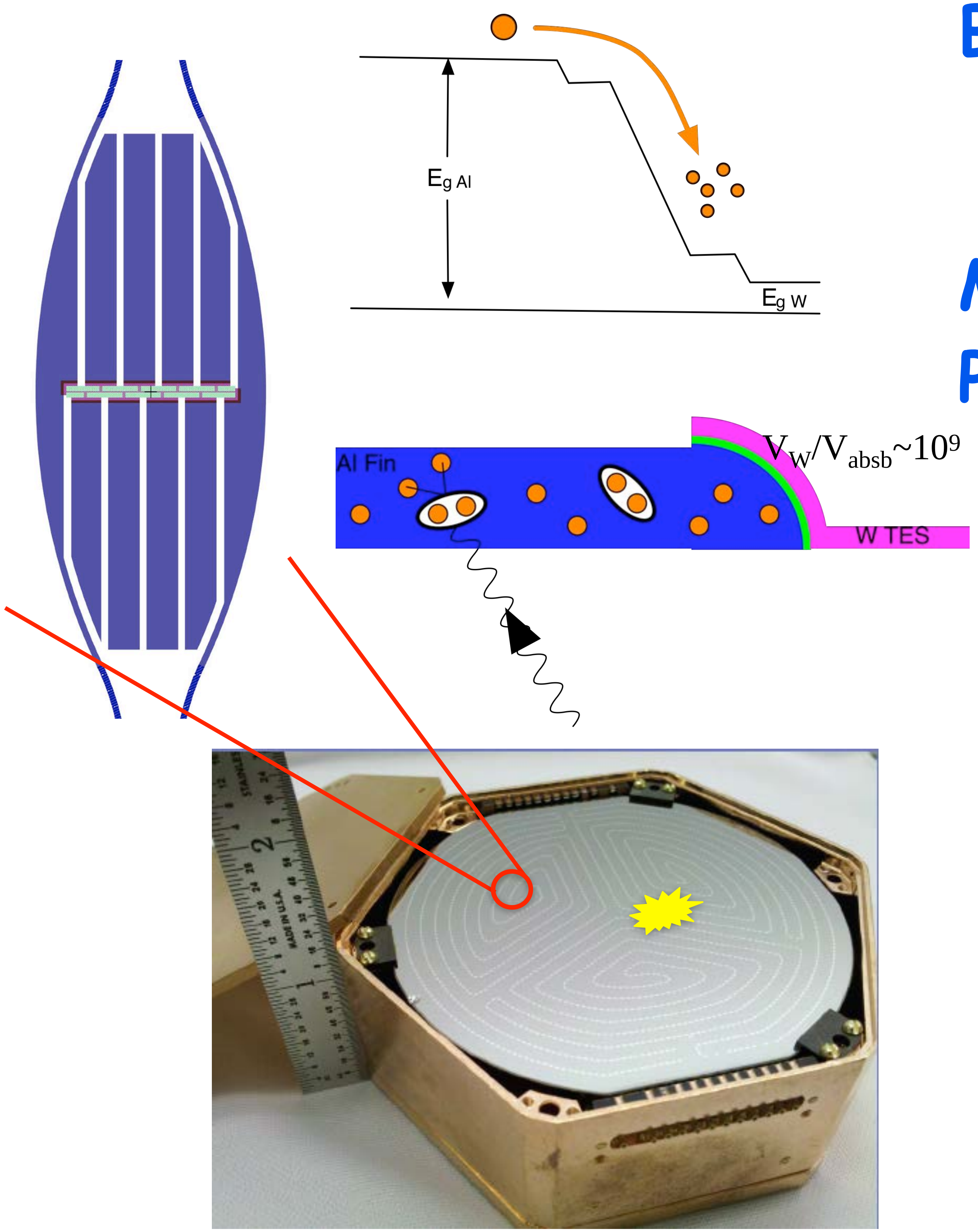

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Phonon Collection efficiencies (ε)

- Theoretical Max: ~40%
- Best Measured: 20±4%
- CDMS II: 1-4%
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- Active Research Area for Stanford SuperCDMS

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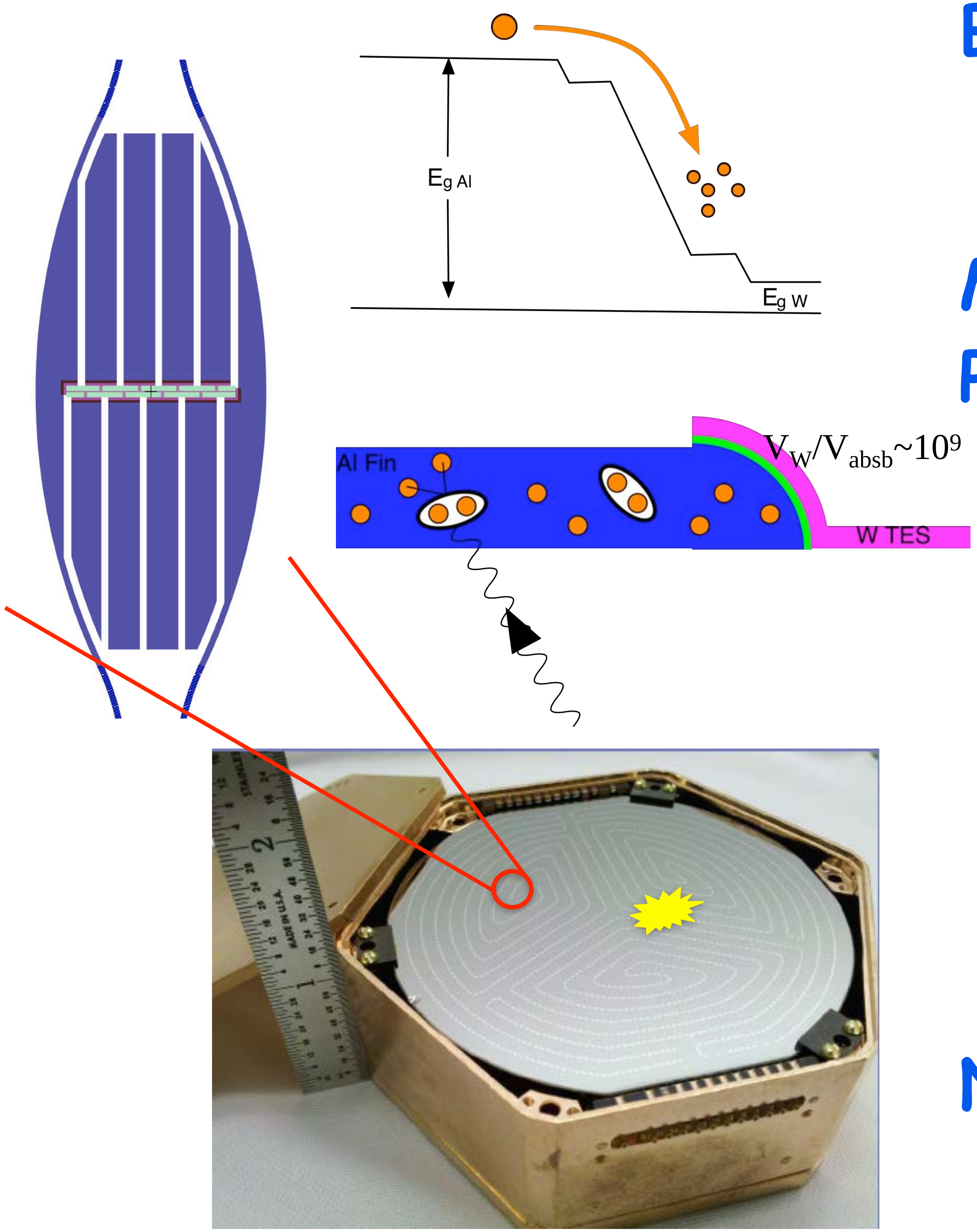

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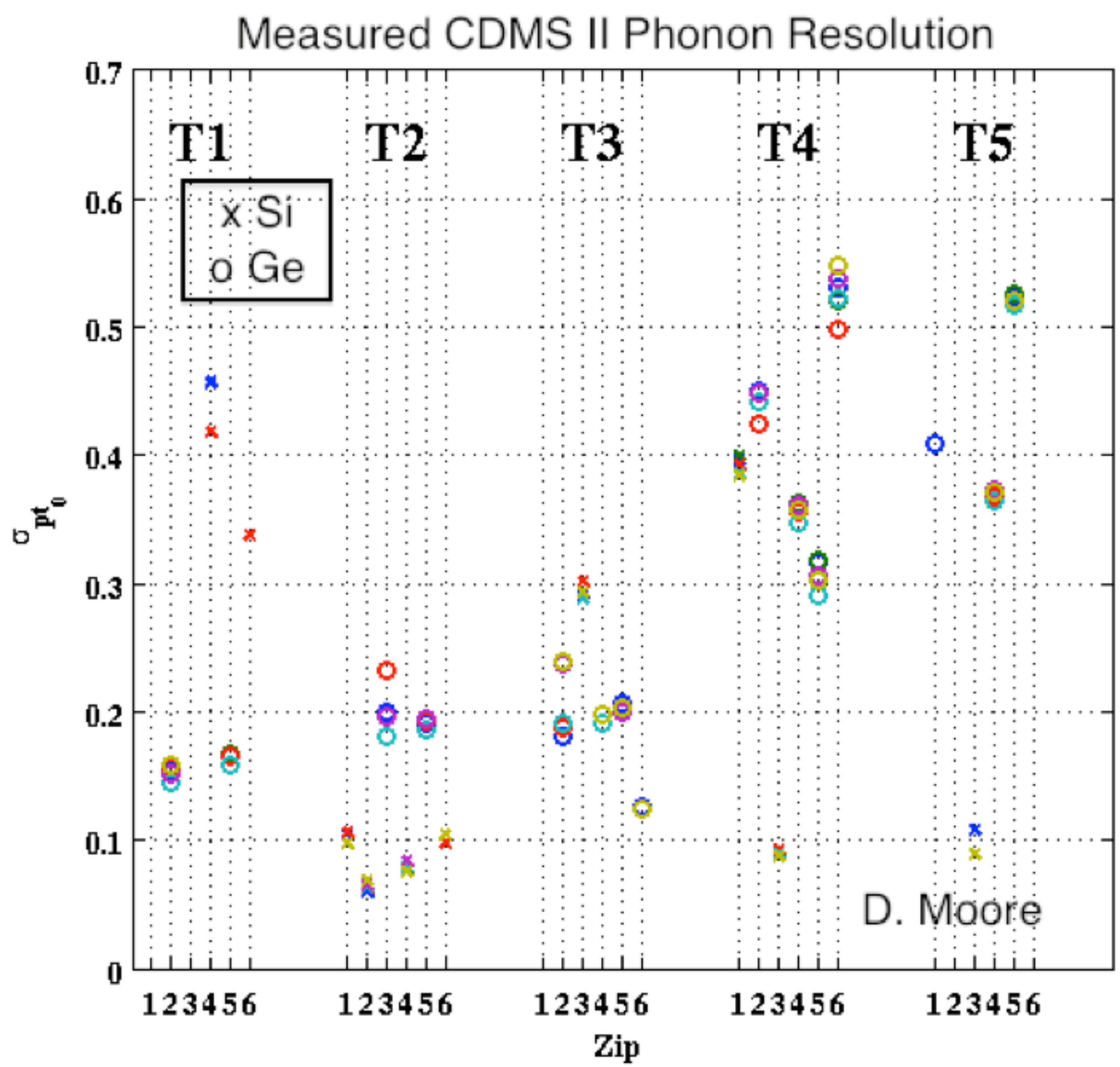
  - Active Research Area for Stanford SuperCDMS
- Not New -> CDMS technology (10+ yrs)

CDMSII resolution



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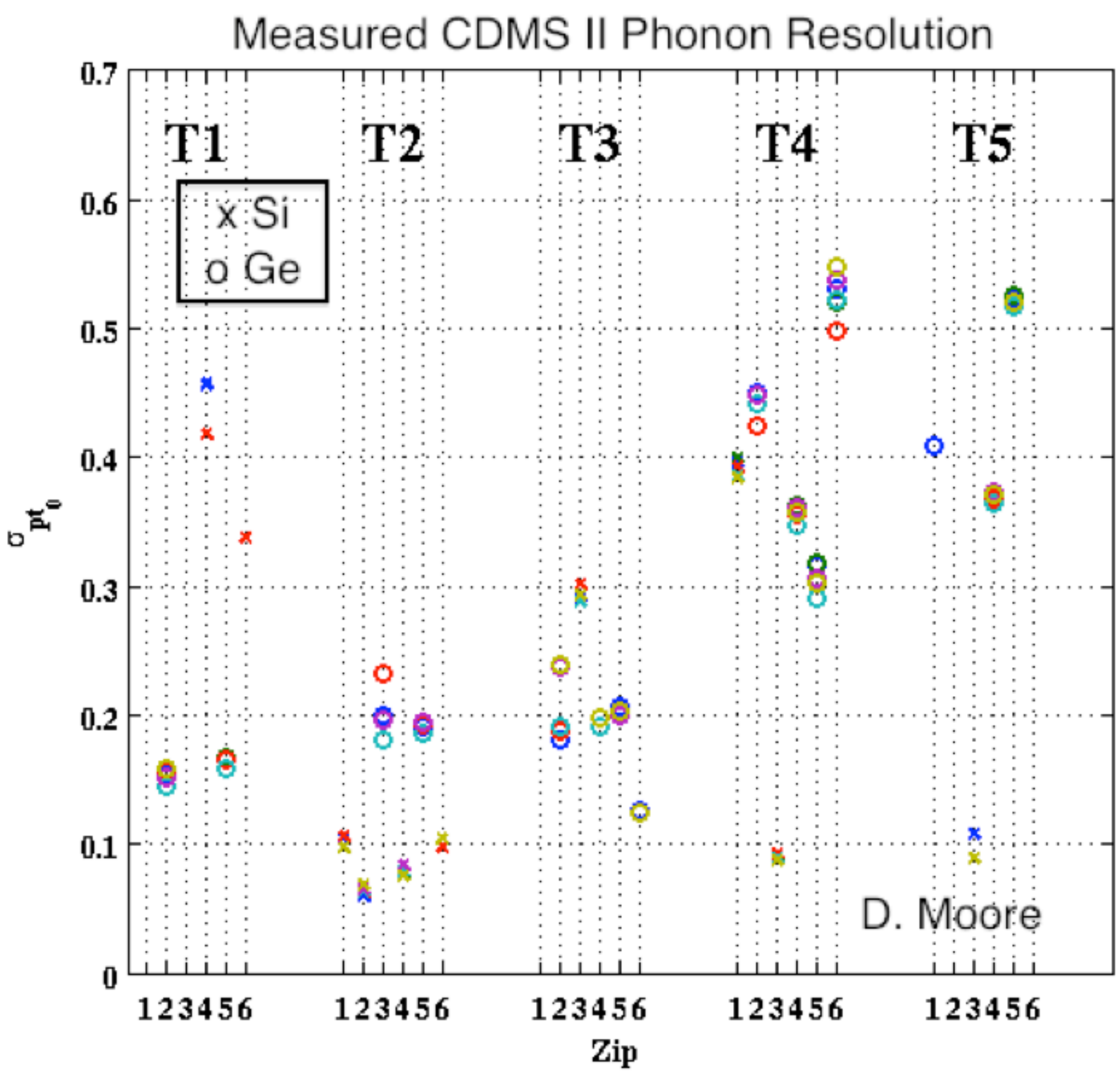
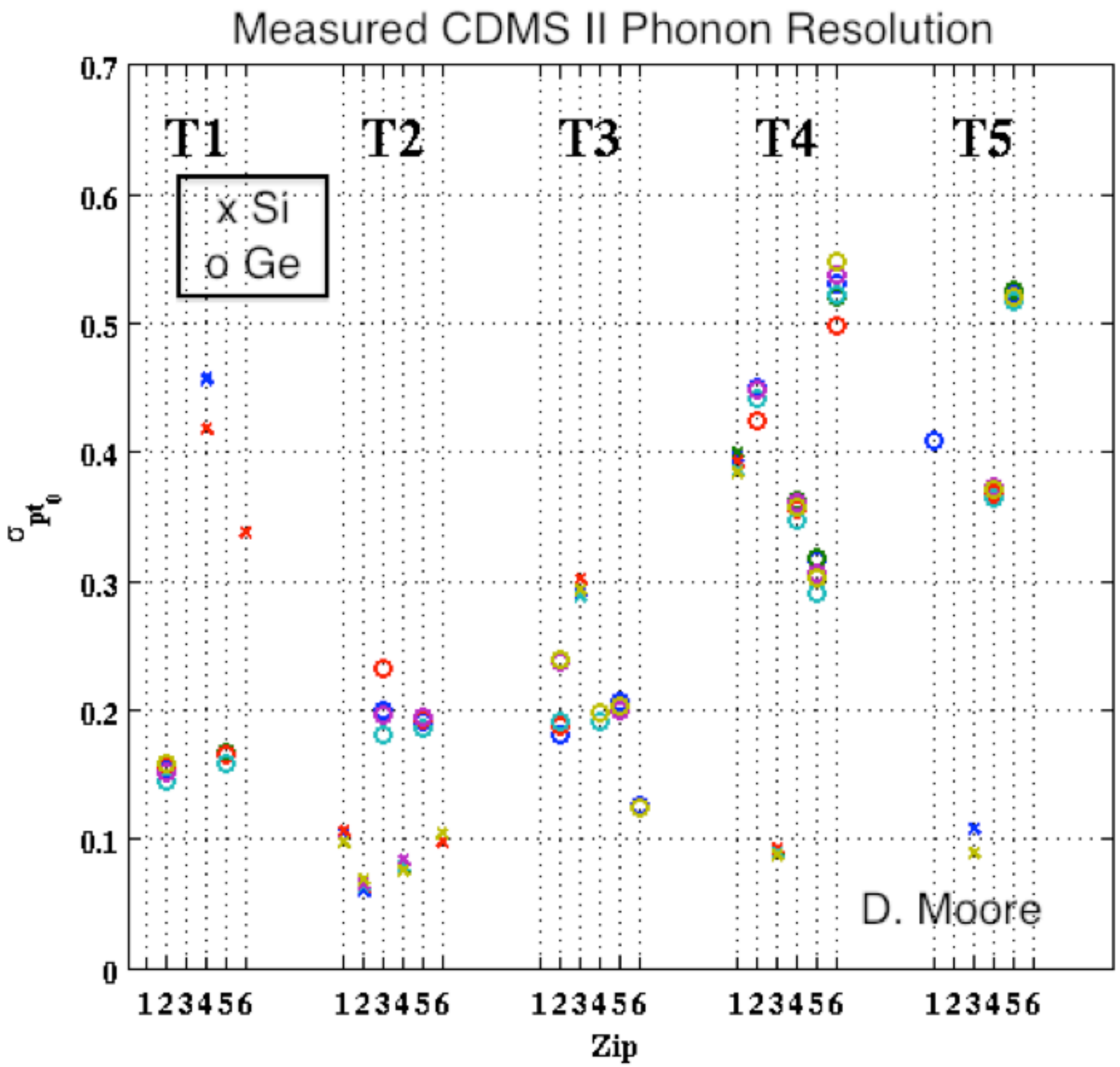


$E_{trigger}$~$6\sigma_E$: early CDMS II Si detectors good enough for reactor CNS ~12evt/kgday

0% < ε < 4%

CDMSII resolution



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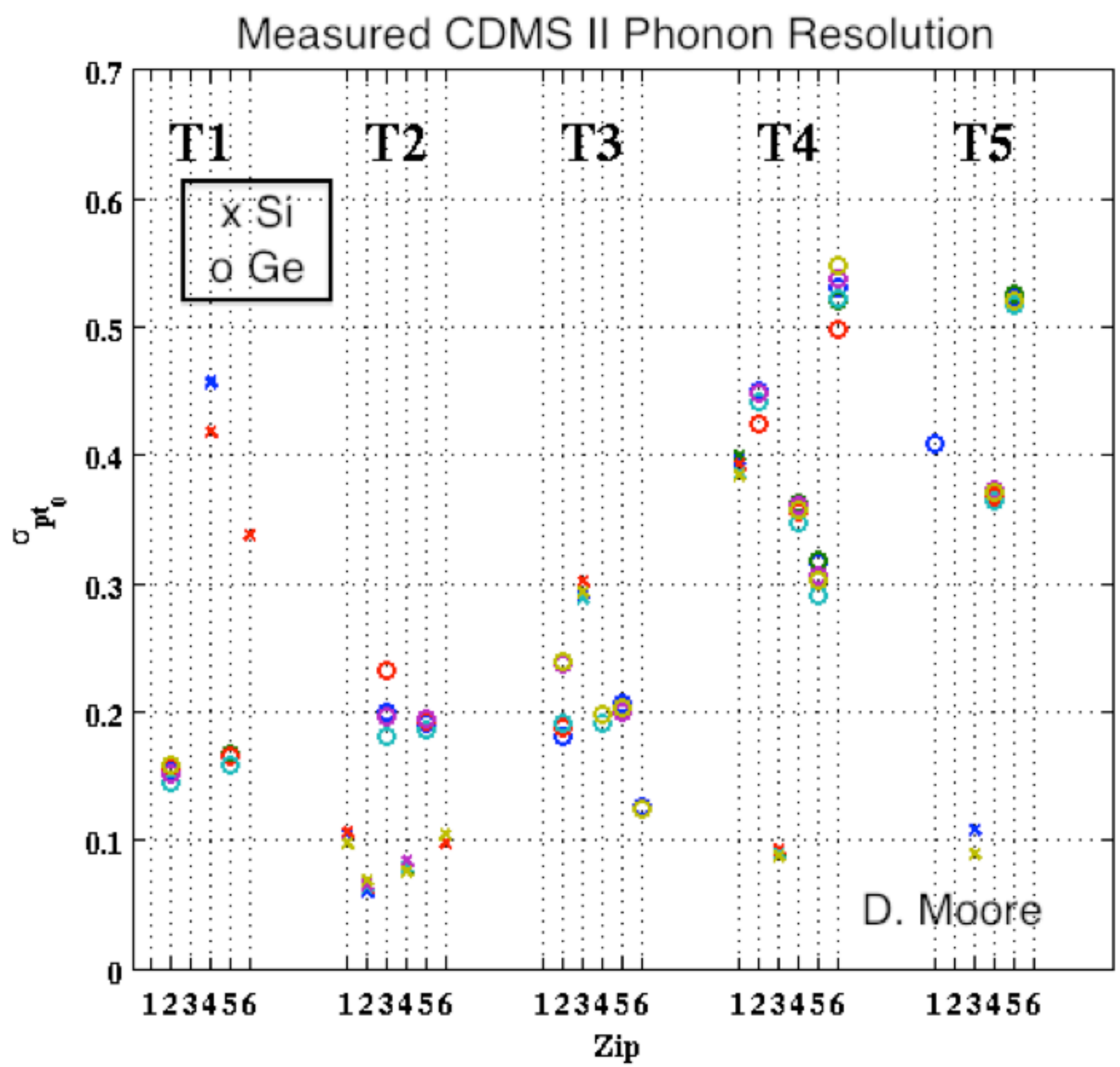

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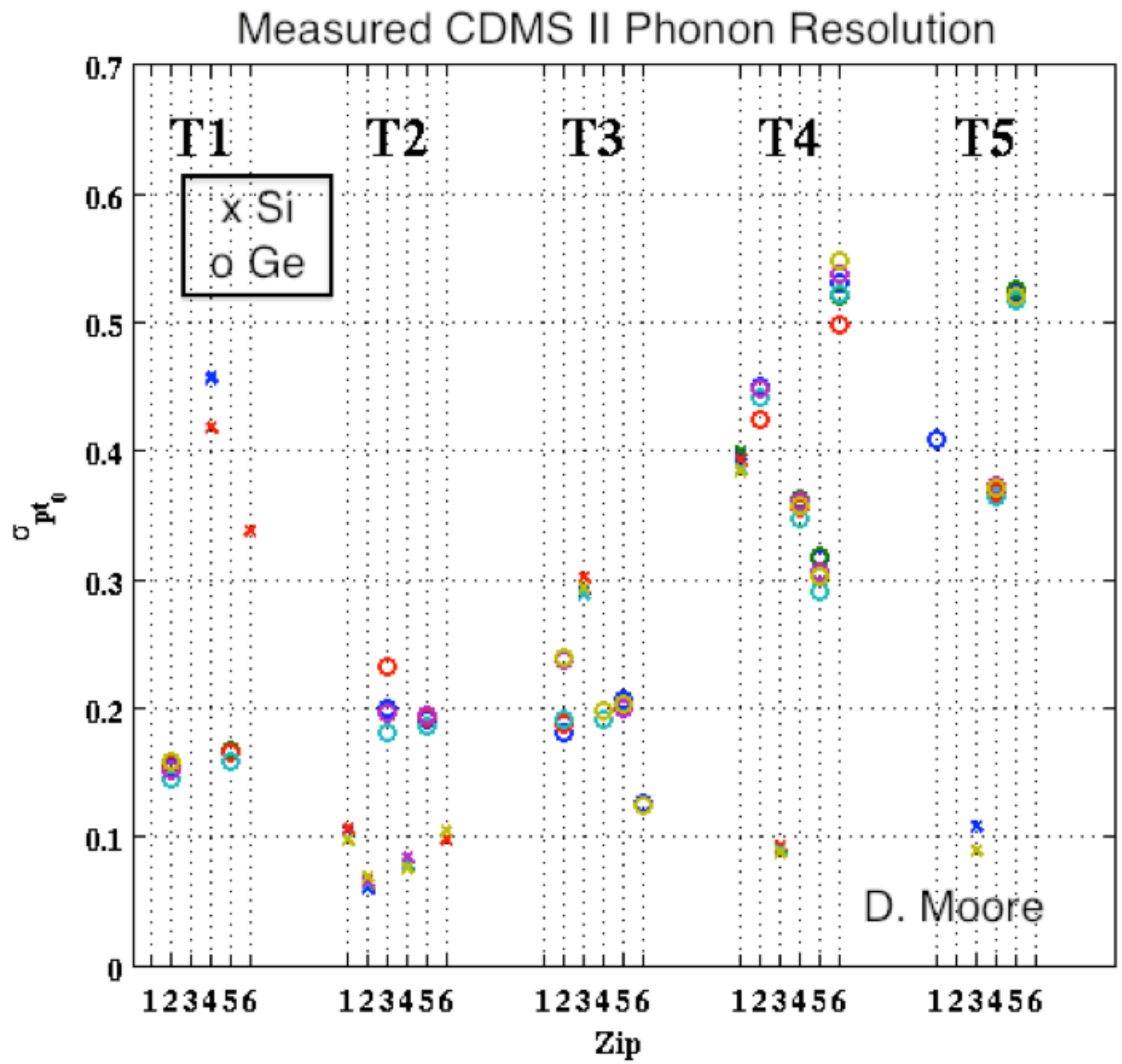

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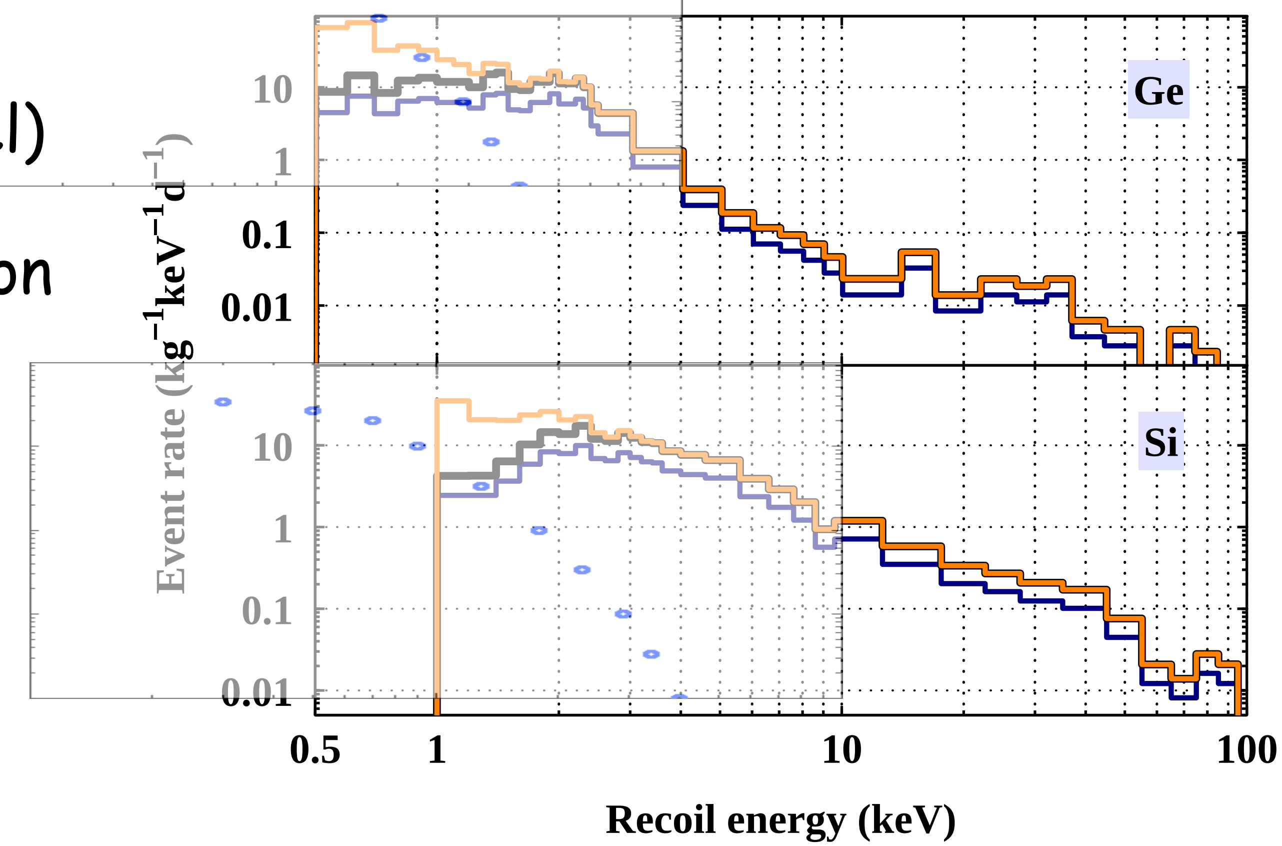
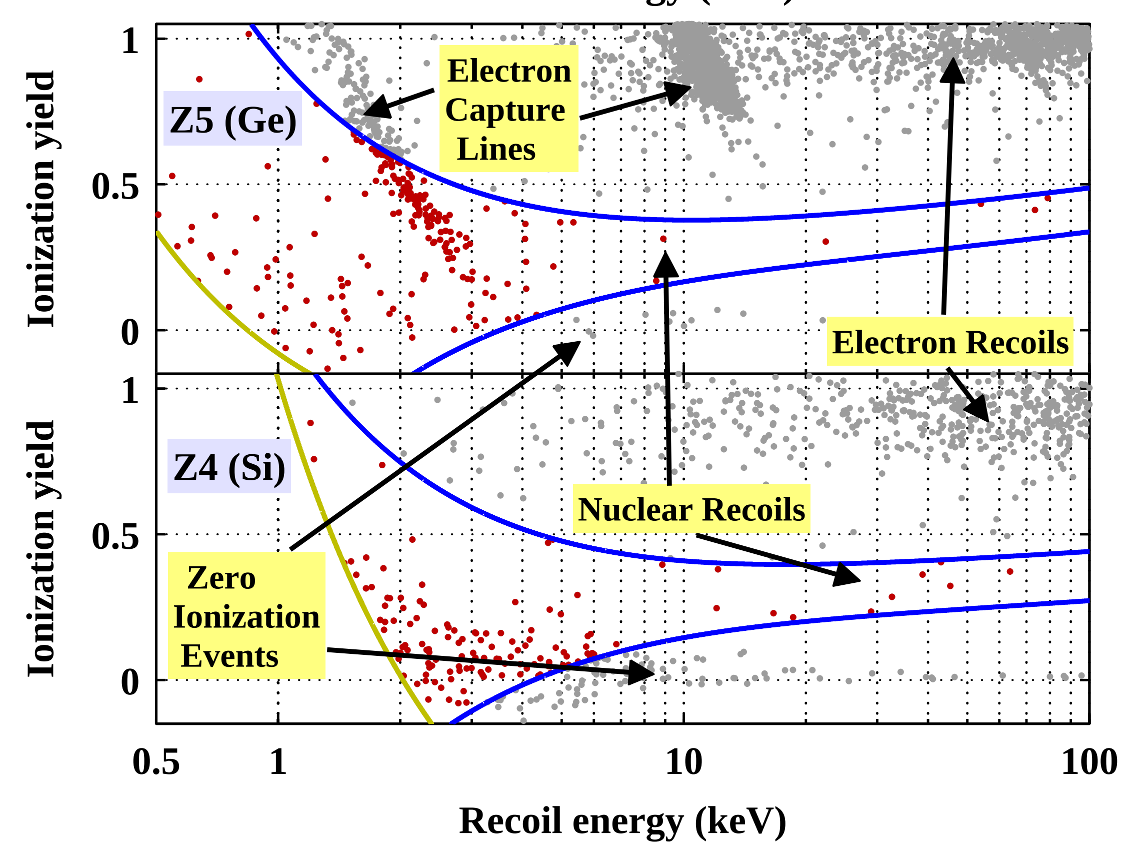
Detailed analysis of SUF data

Top plot is combined Ge (upper panel) and Si (bottom panel) WIMP candidate event rates as a function of recoil energy.



Bottom plot is ionization yield vs recoil energy for unvetoed single scatters for Ge (top panel, Z5 6 V) and Si (bottom panel, Z4 3 V) WIMP searches

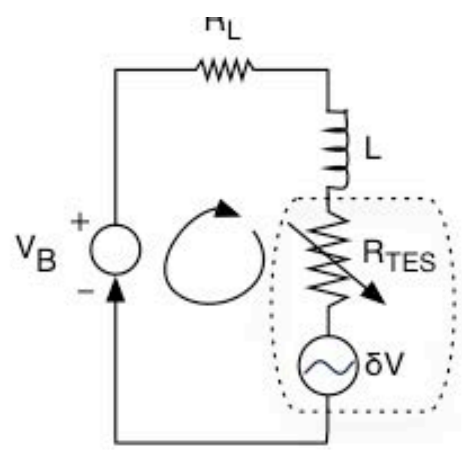
From PHYSICAL REVIEW D 82, 122004 (2010)

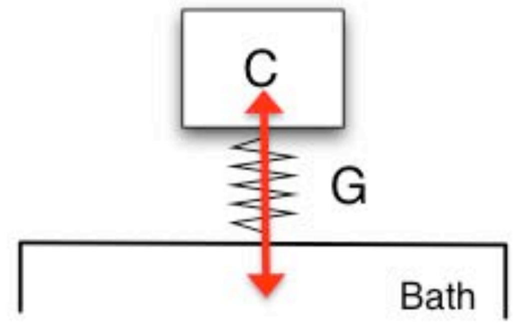


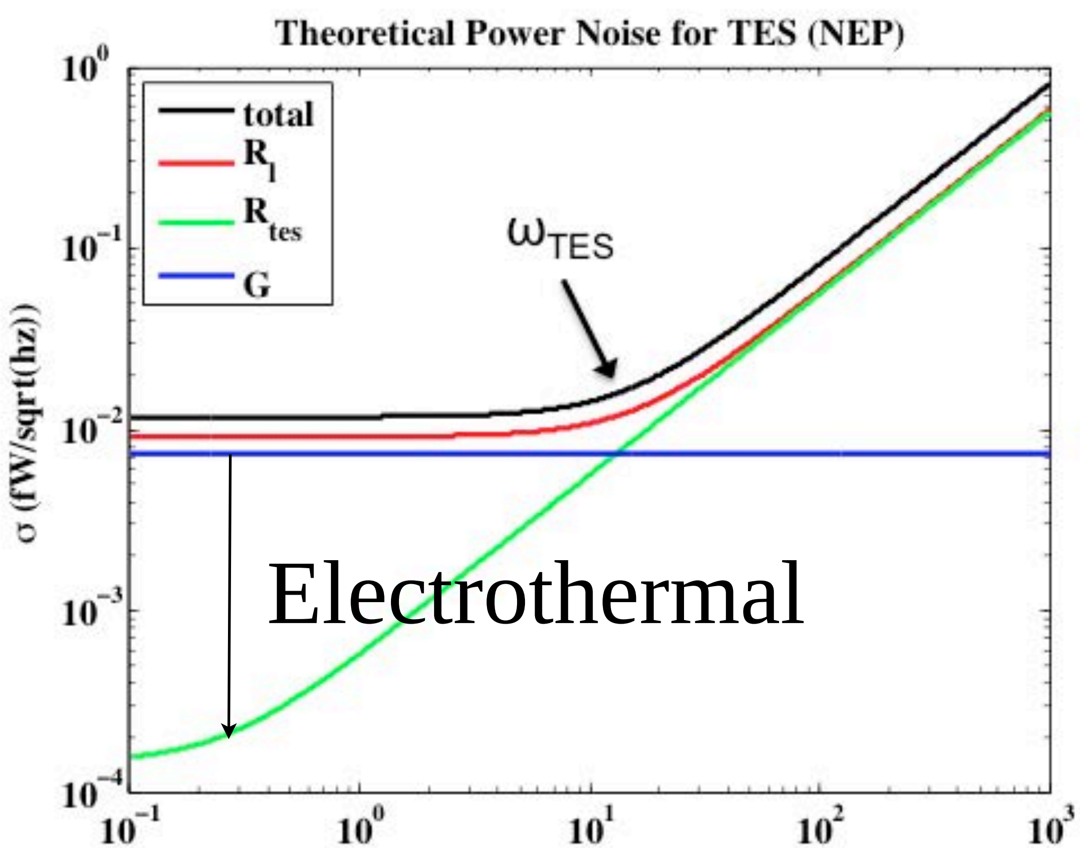
Nearly good enougH!
Background a bit high!

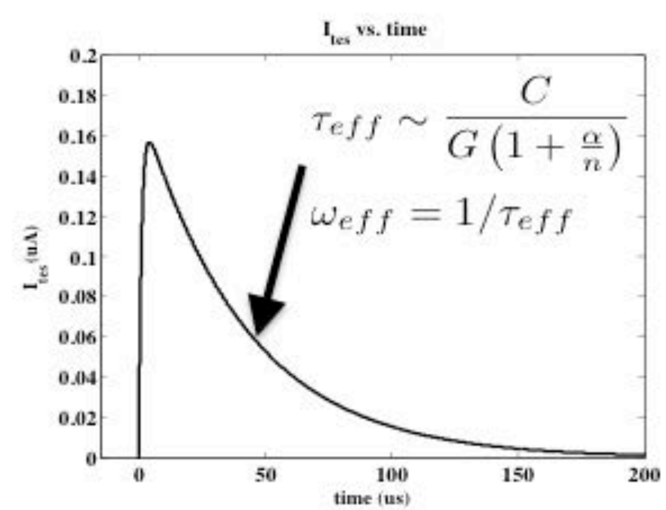
Can We Do Better?

- Johnson Noise
  - $4k_bTR$
- Thermal Fluctuation Noise
  - $4k_bT^2G$









Optimal Filter

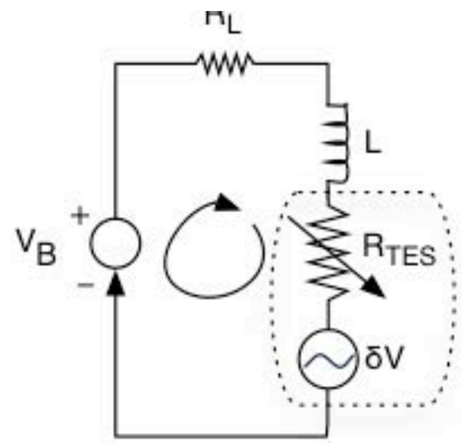
$$\sigma_E^2 = \frac{4kT^2C}{\alpha}\sqrt{n} \Rightarrow \sigma_E \propto T_c^{1.5}$$

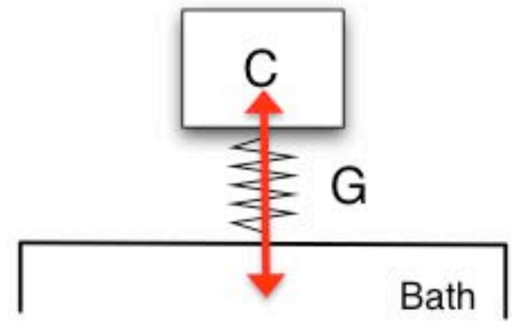
Can We Do Better?

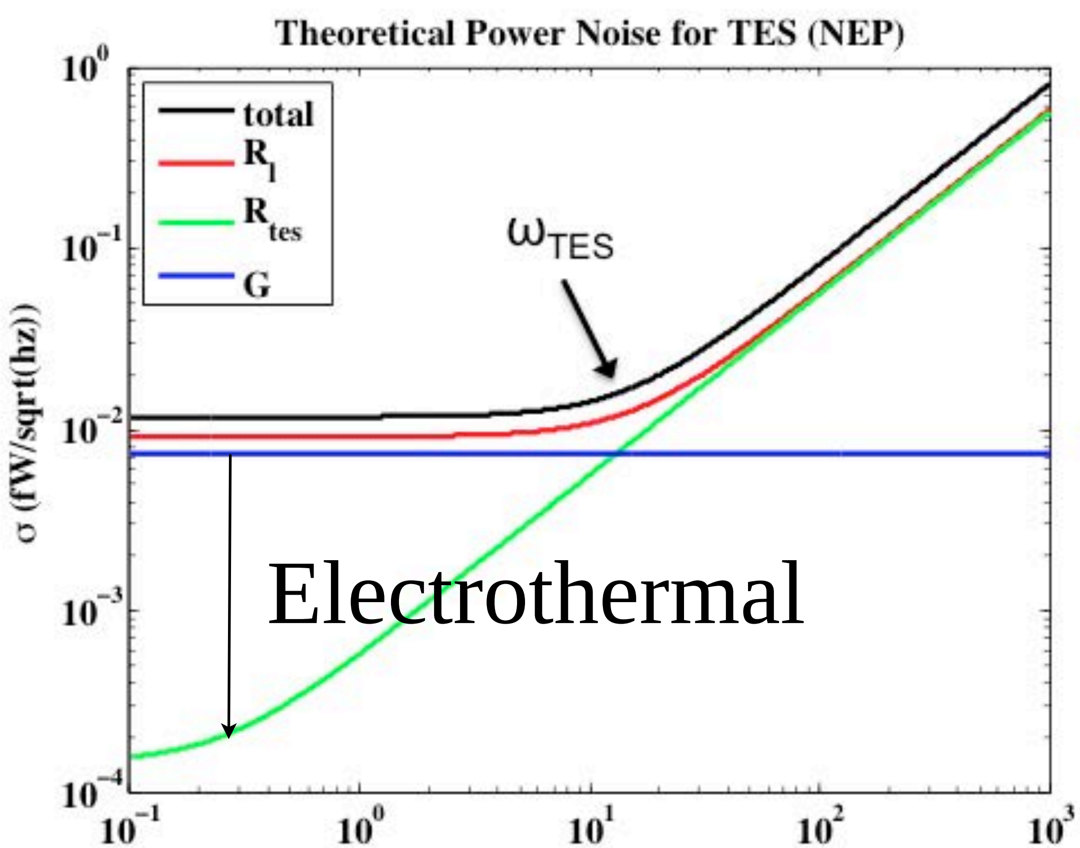
Matt: We can indeed!

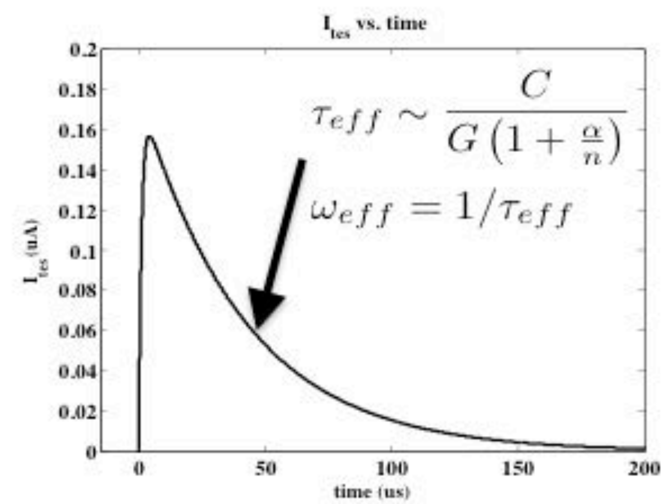
Increase raw sensitivity
Match better TES (ETF) bandwidth to collection bandwidth
Prevent phase separation (a big loss in CDMS II/ SuperCDMS Soudan)

- Johnson Noise
  - $4k_bTR$
- Thermal Fluctuation Noise
  - $4k_bT^2G$









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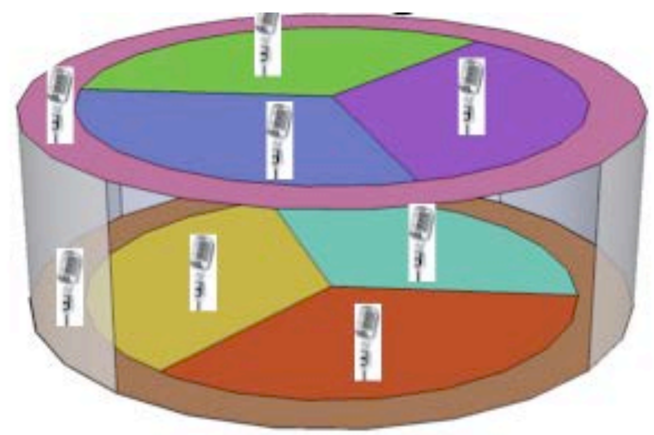
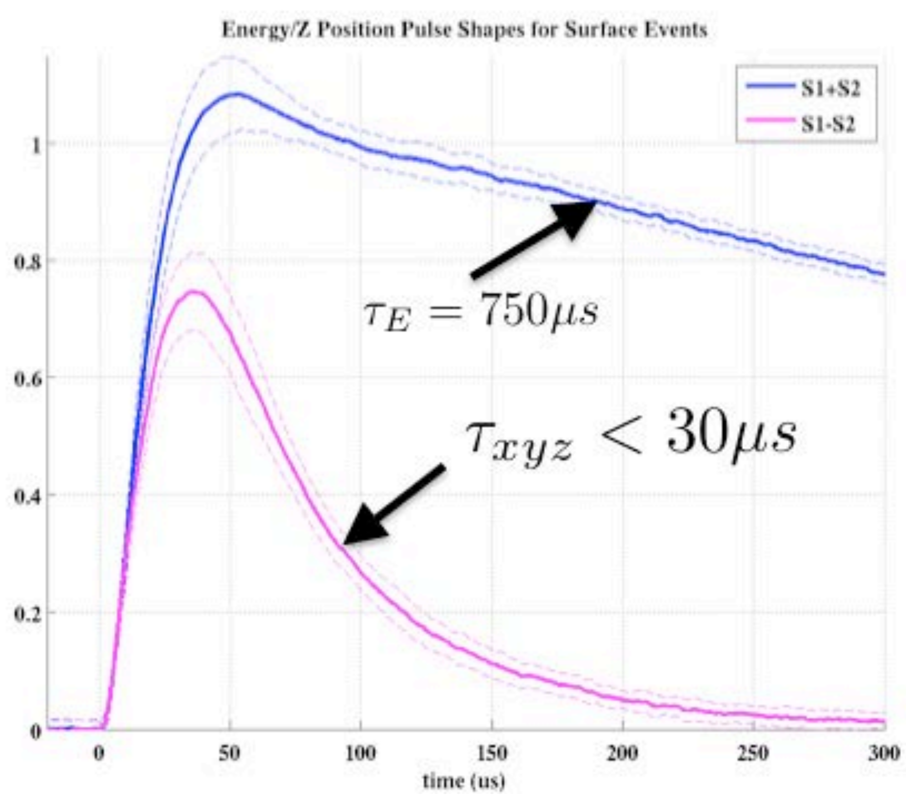
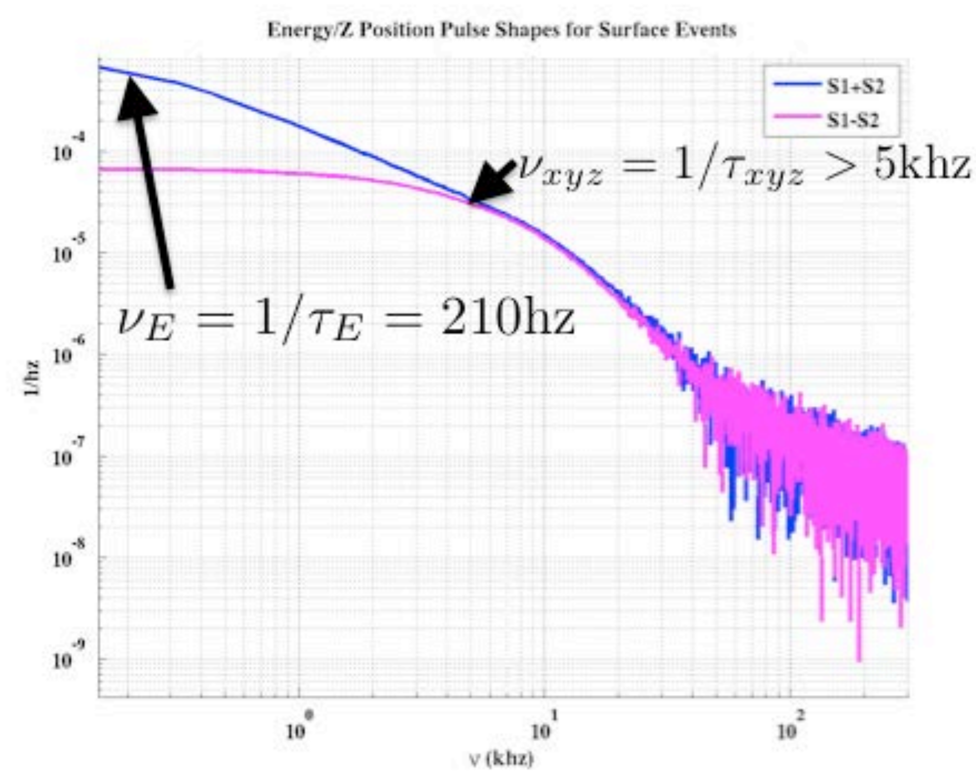
But large bandwith mismatch

- Position and Total Energy Signals have wildly different bandwidths
- Optimization for both Impossible
- SuperCDMS: Choose Position







But large bandwith mismatch

Phonon collection time>> TES time>> ETF time (phase separation)

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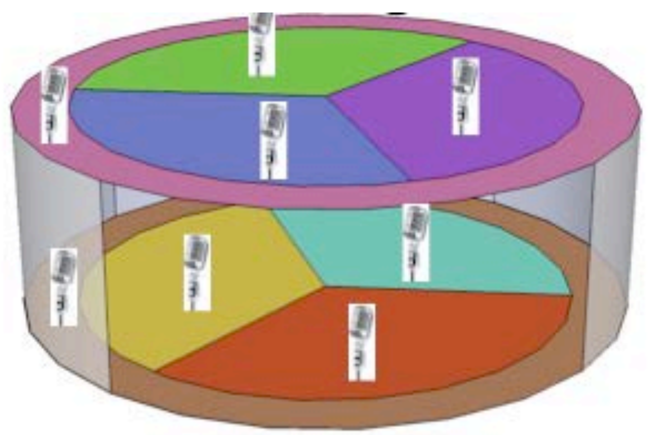

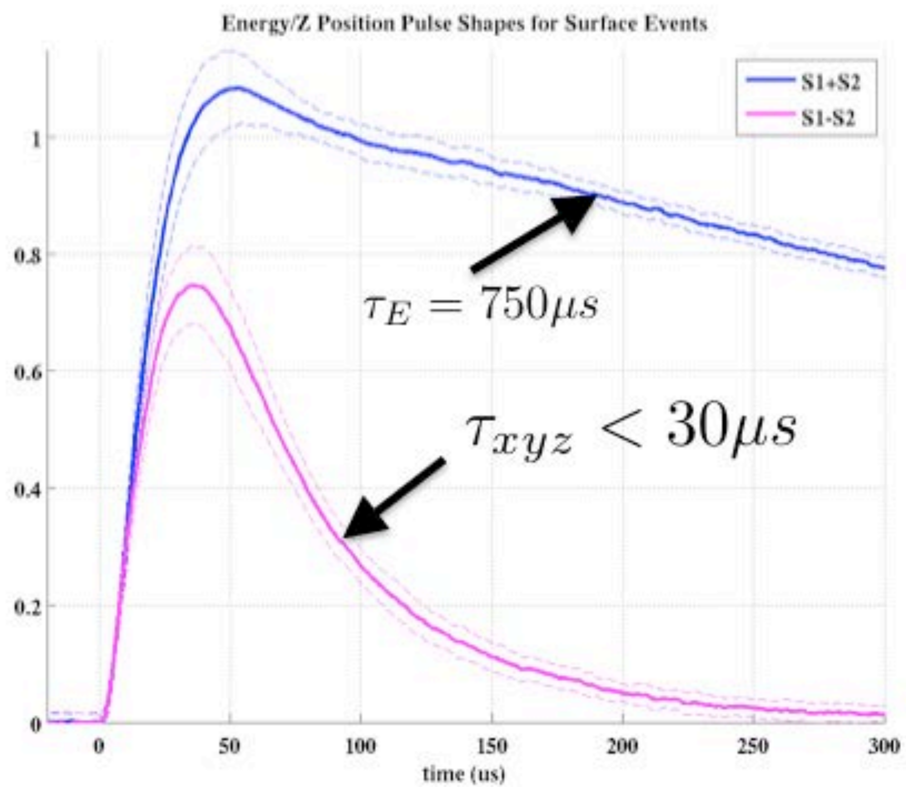

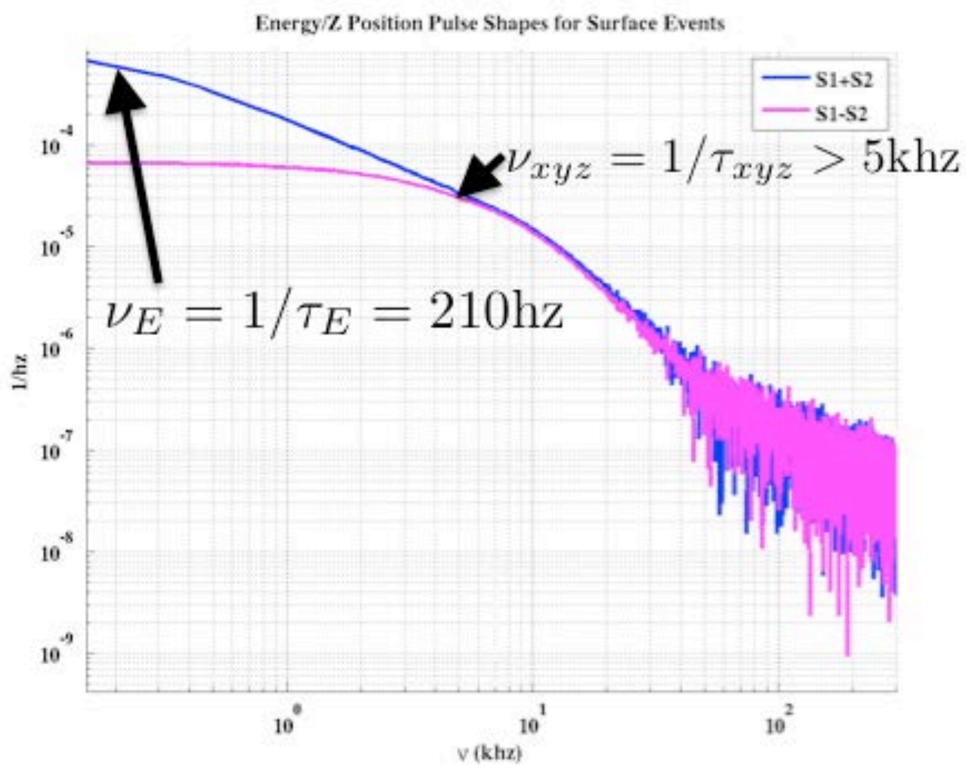

Consequence

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Noise^2 =power noise/ Collection bandwith

We gain as the cube of T_c!

$$\sigma_E^2 = \frac{4kT_c^2 G}{\tau_{coll}} \Rightarrow \sigma_E \propto T_c^3!$$

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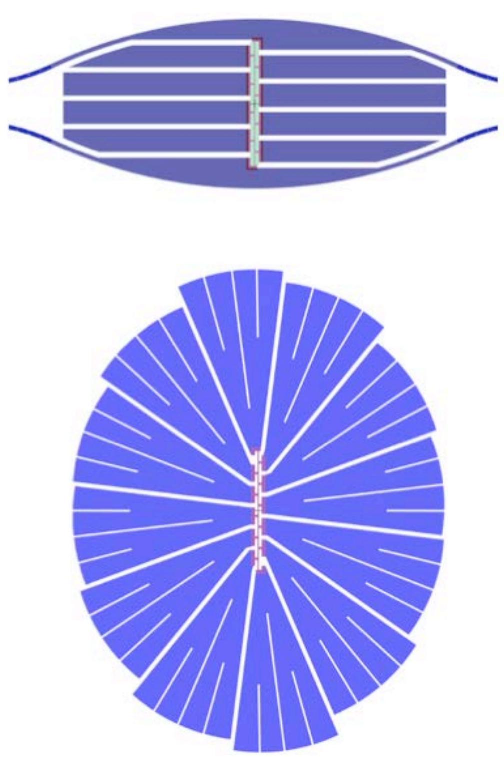
Furthermore: Lower Tc-> less phase separation!

In addition we can decrease G (and C) by decreasing length of the TES (we can accomodate lower R with lower L_{SQUID})



- QP trapping in Al antenna
  - L_{diff} ~ 180um
- Optimally use area near TES
- Not Possible in iZIP detectors charge signal capacitance constraints

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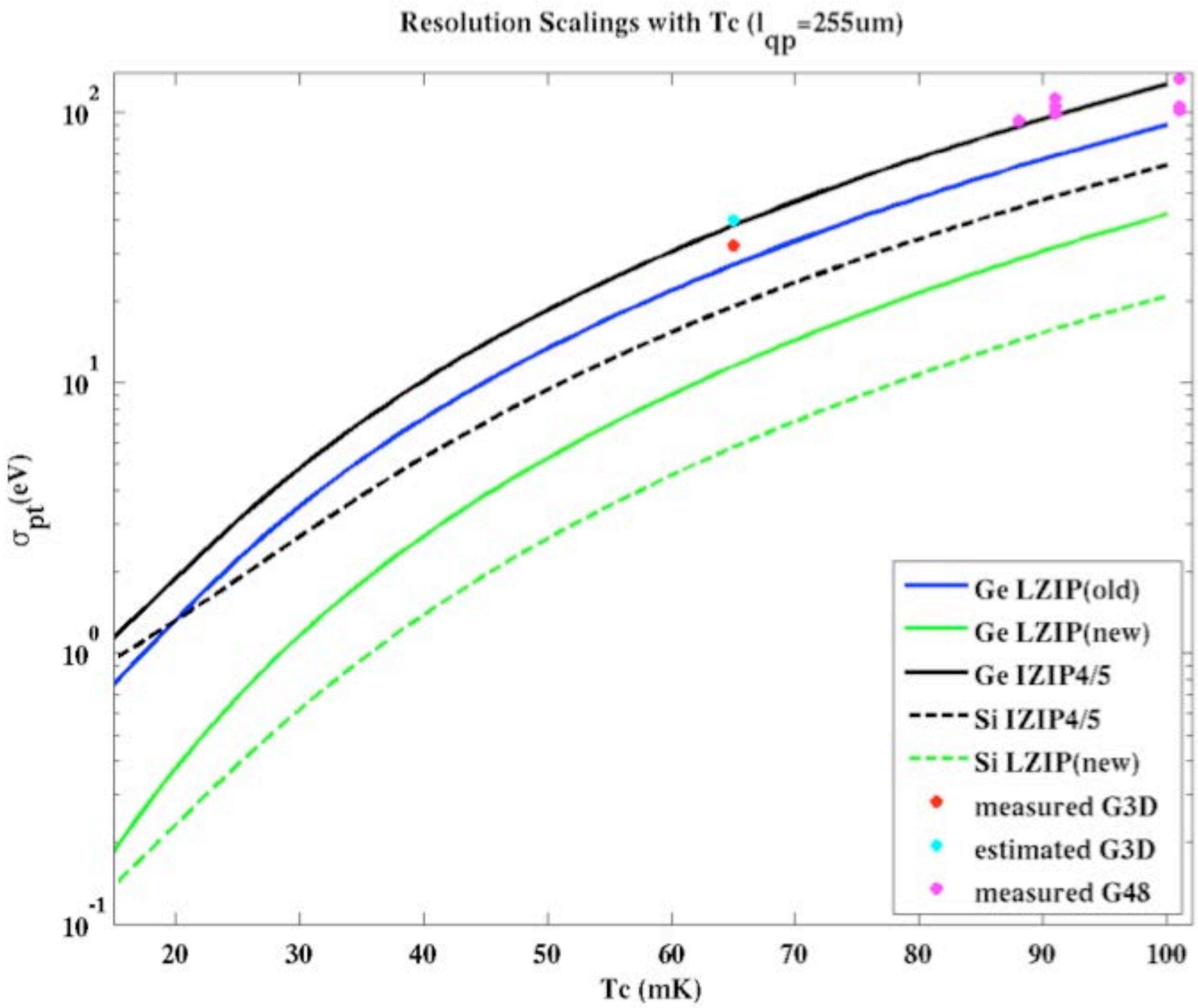
Baseline Energy Resolution Estimates



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- Baseline Resolution
- Position systematics ?
  - SuperCDMS 3%

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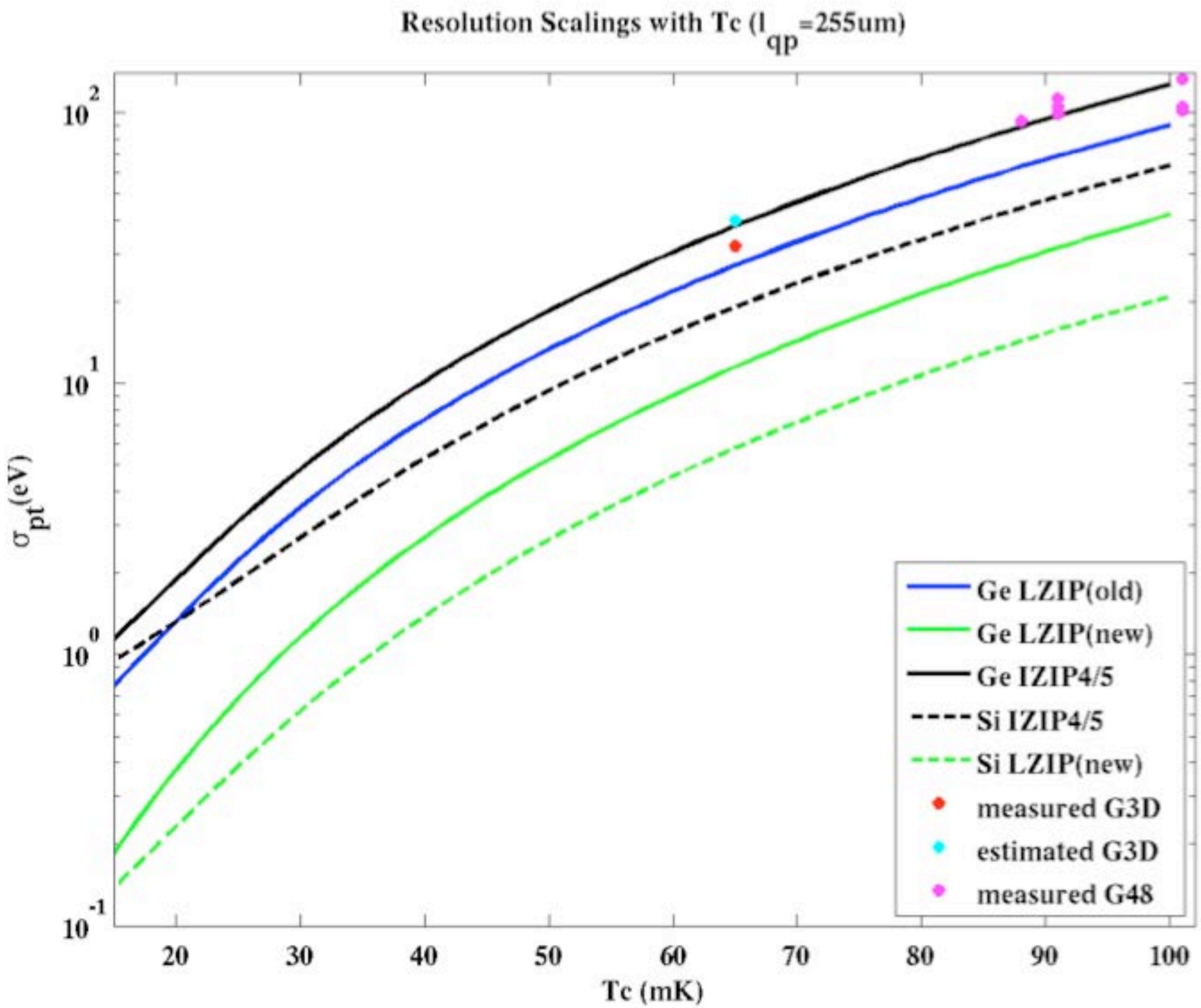

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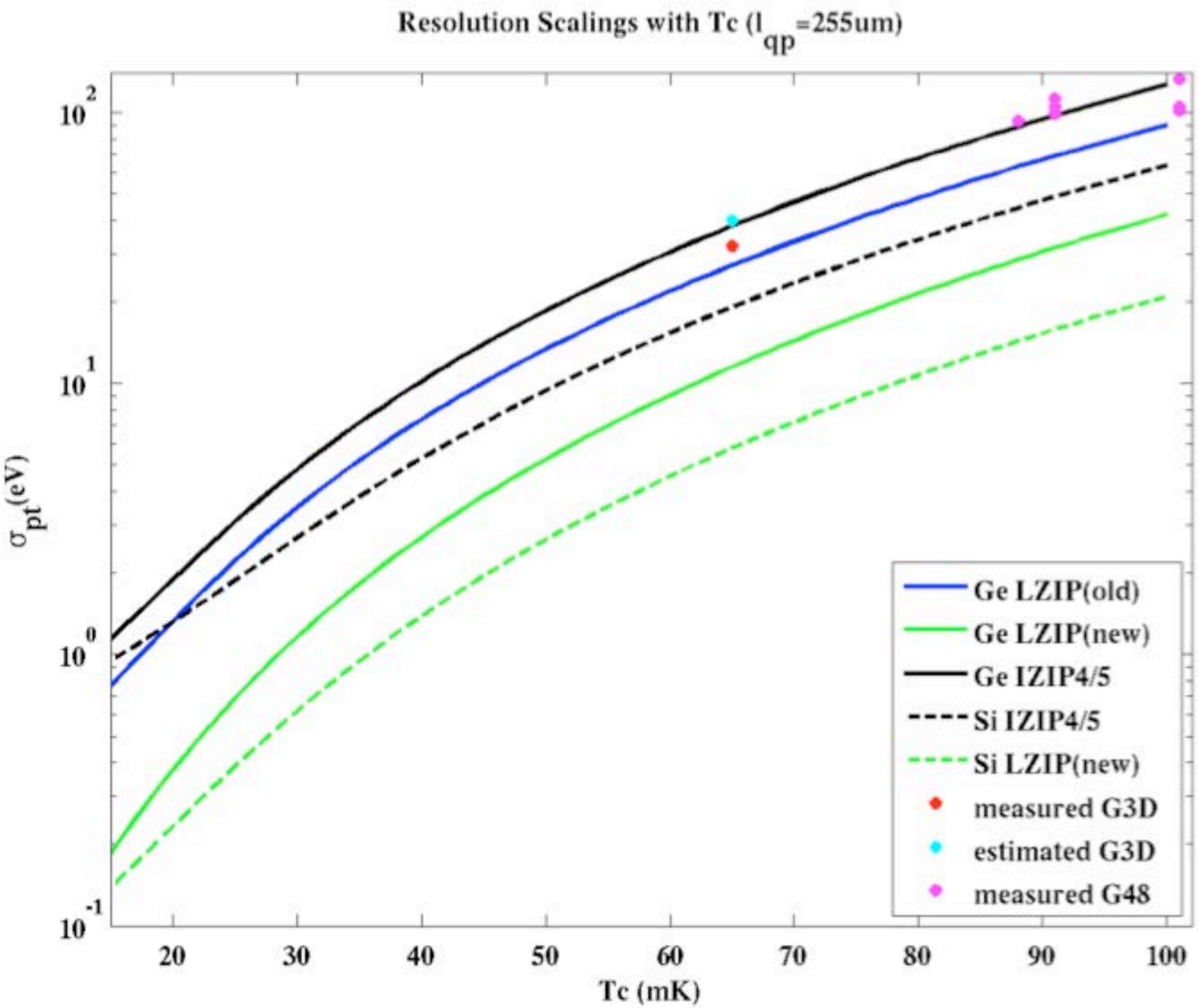

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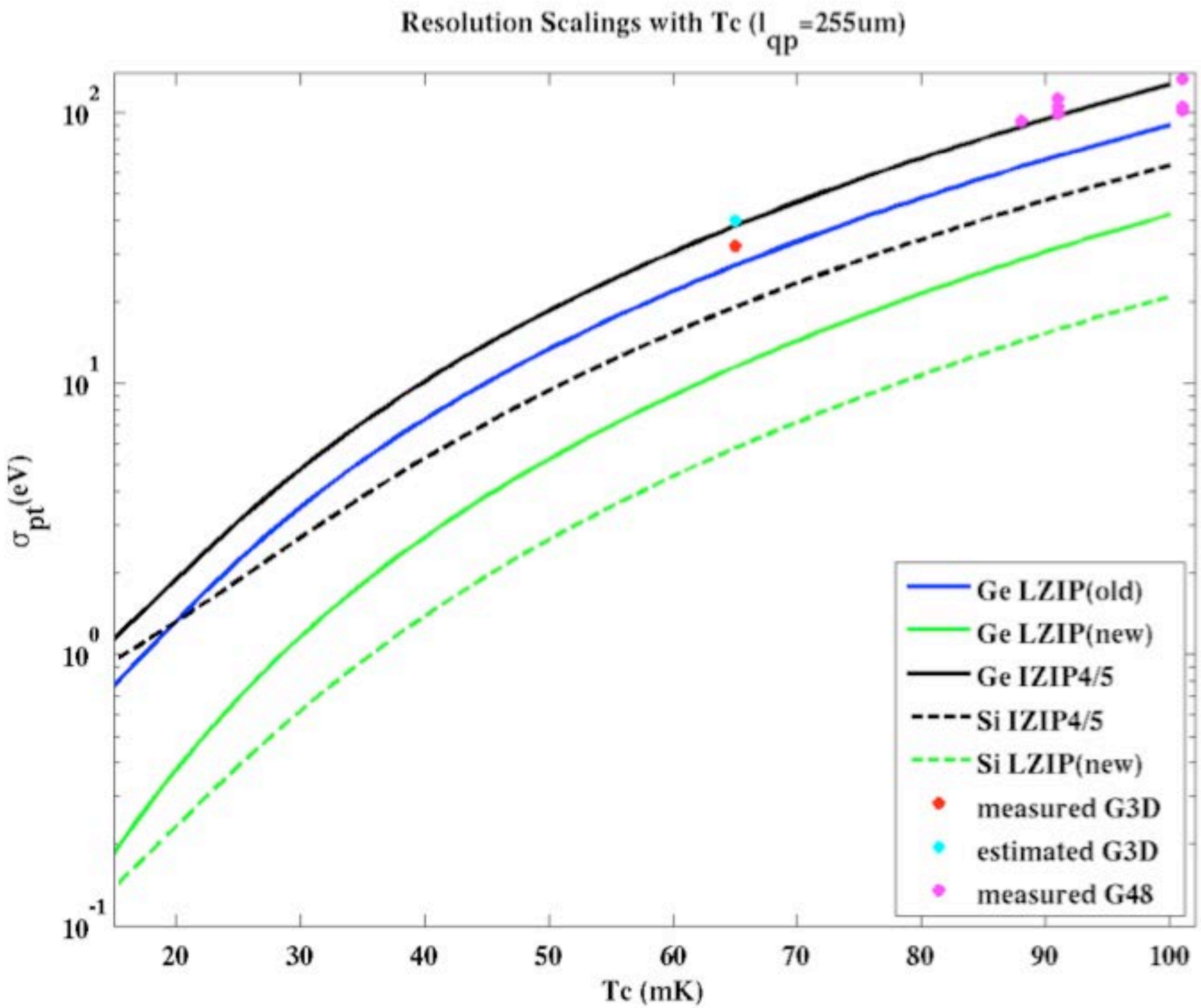

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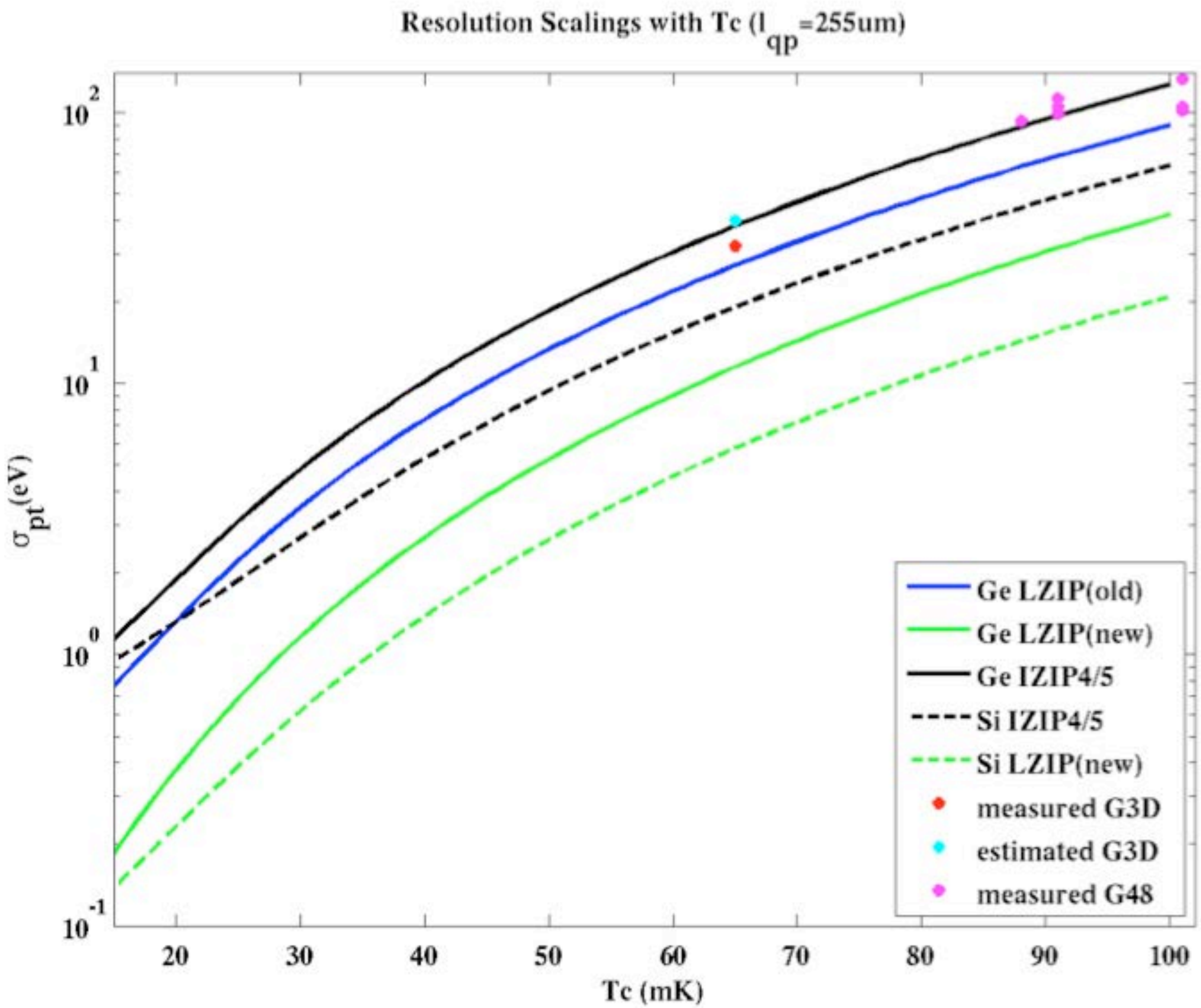

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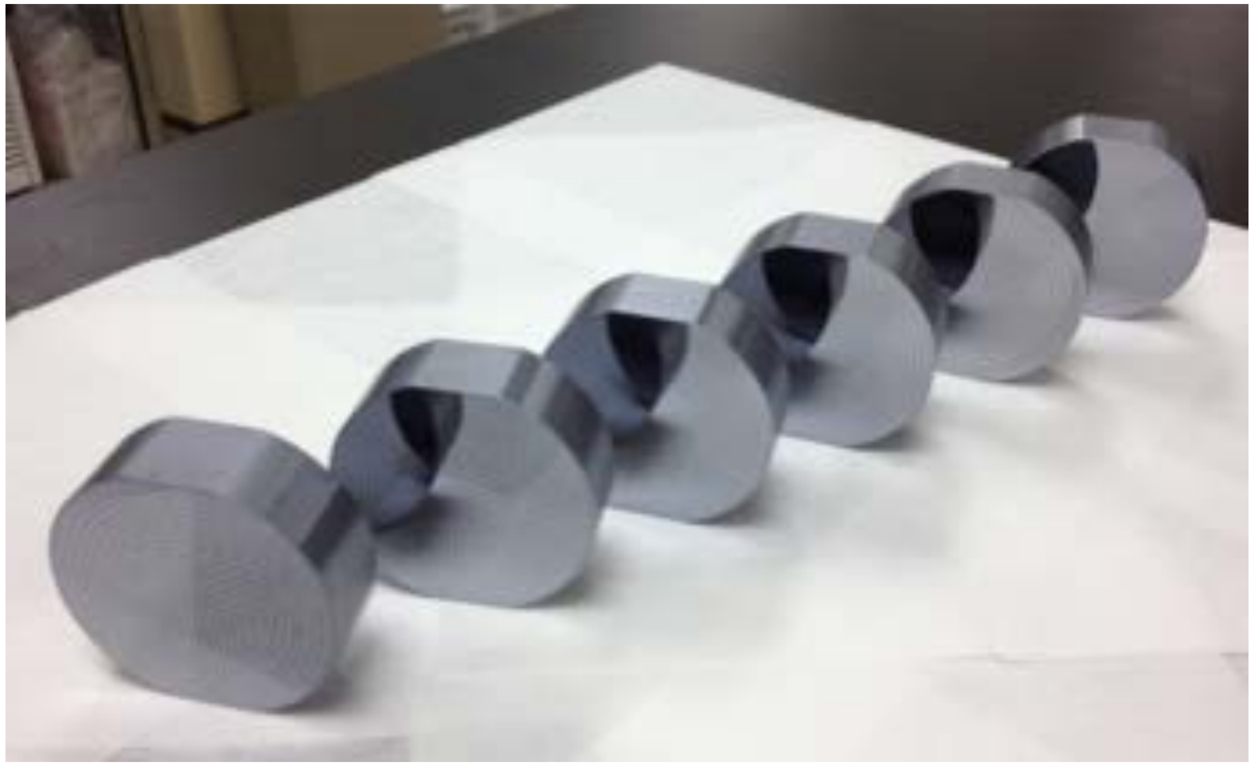
Possible stumbling blocks

- Film quality C if we decrease T_c
- Film uniformity (How does alpha evolve)
- Engineering : Fridge, low frequency noise, IR loading (goes as T^5)

Short Term Plans: Misfit Toys



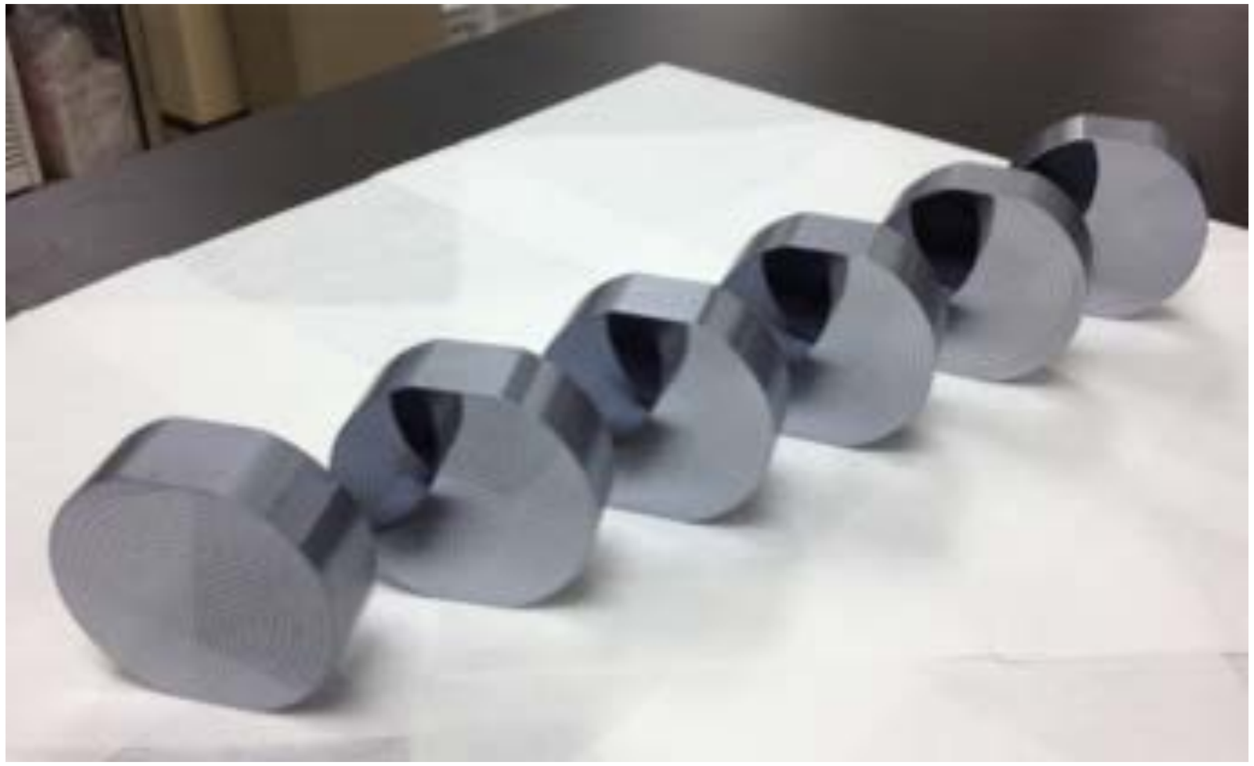
- Si: not interesting for standard high mass WIMP search
- Ion-Implant
  - LDM?
  - $\bar{\nu}N \rightarrow \bar{\nu}N$

Short Term Plans: Misfit Toys

SuperCDMS throughput study

6 x 1" Si detectors in 3 weeks with 3FTE fab team

IMPRESSIVE!



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  - LDM?
  - $\bar{\nu}N \to \bar{\nu}N$

Can We Improve the Ionization Measurement through Phonons?

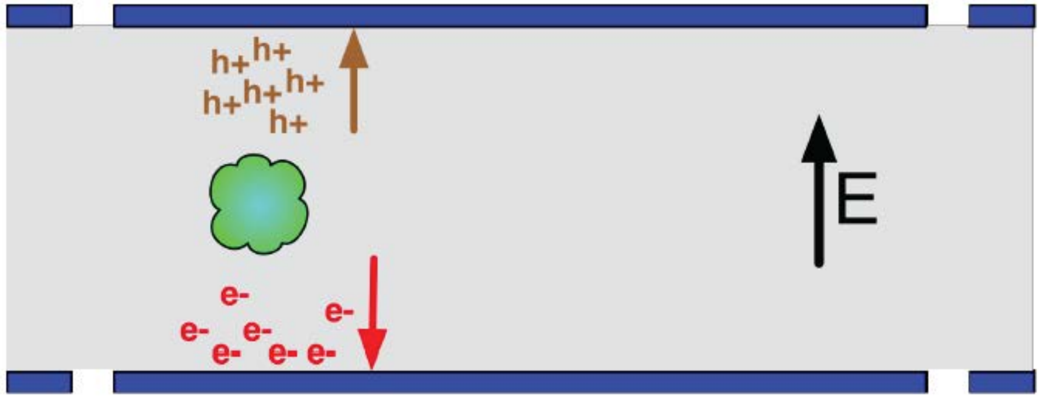
Nader Mirabolfathi for:

Enectali Figueroa-Feliciano (MIT), Matt Pyle (UCB), Kai Vetter (UCB, LBNL), Paul Luke (LBNL), Marc Amman (LBNL), Ryan Martin (LBNL), Bernard Sadoulet (UCB, LBNL)

Luke-Neganov amplification

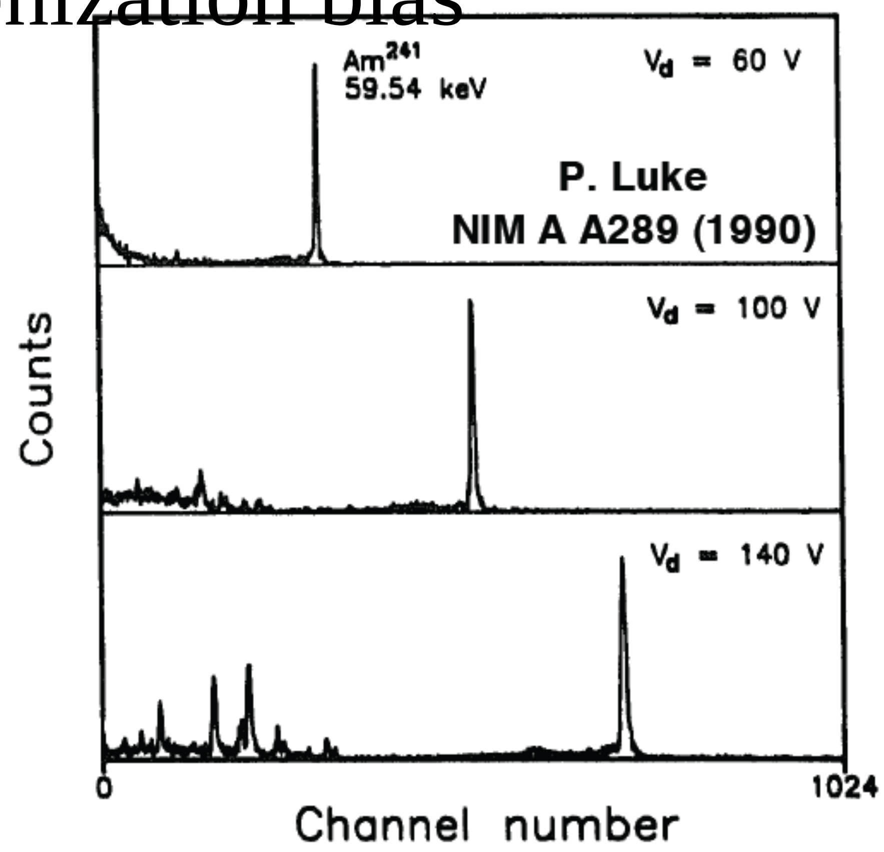
- **Luke**-Neganov Gain

$$E_{tot} = E_r + E_{luke}$$
$$= E_r + n_{eh} e V_b$$
$$= E_r \left(1 + \frac{eV_b}{\epsilon_{eh}}\right)$$



- Phonon noise doesn't scale with the ionization bias

=> **S/N** ⇧



In theory one can increase Bias to reach Poisson fluctuation limit: $\sqrt{F \varepsilon E}$

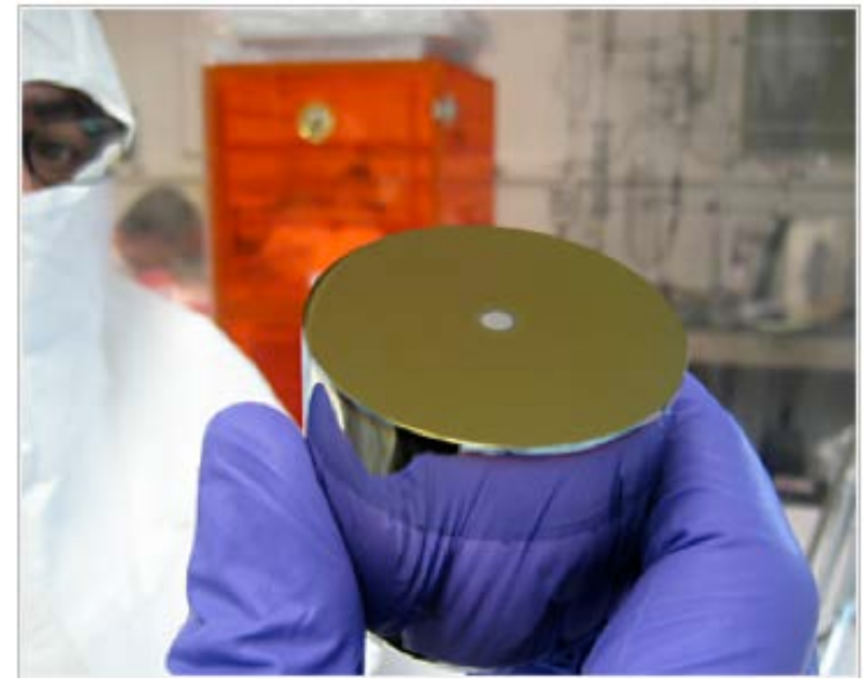
limitation: Ge Breakdown

Ionization breakdown with CDMSII

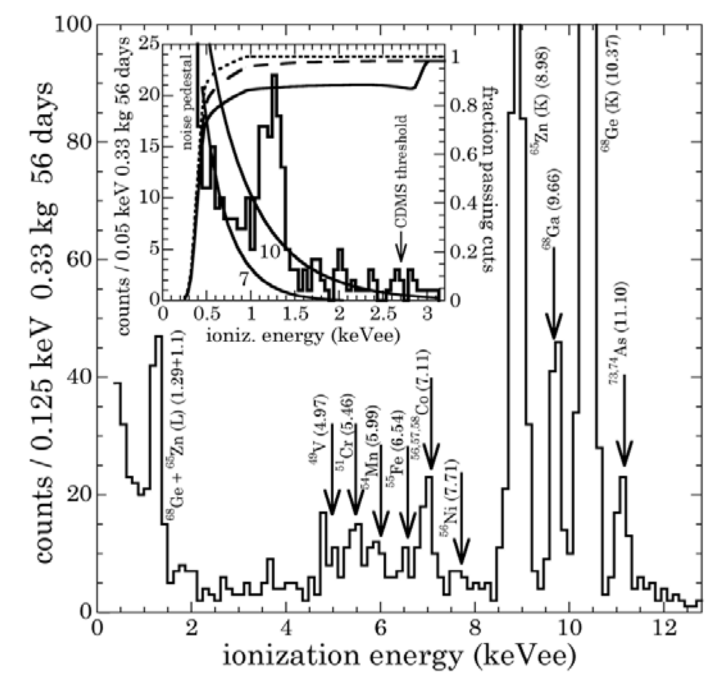
- CDMSII 1 cm thick Ge detectors can't handle much beyond 10 V/cm
- To keep ionization phonon discrimination CDMS limited to low collection fields anyways => no interest for field > V/cm
- Need to neutralize detector: All impurity levels (p or n) at neutral state to reduce trapping.
- Impact ionization on neutral states lead to breakdown?
- What if we charge all impurities like 77K depleted Ge gamma spectrometers.
- Results from latest UCB tests.

Point contact ionization detectors

• Main advantage low electrode capacitance i.e. threshold.
• CoGeNT 440g 5mm PPC, 1 pF gate capacitance
• $\sigma_n \sim 70$ eV
• Threshold 0.4 keVee



Idea:
• Transform Ionization to Phonons:
• Use very low threshold phonon detectors



Alternative: Point contact phonon

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Use the same principle as point contact but

- Very low temperature: No Carrier generation.
- < 4K the impurity charge status will freeze.
- Need to deplete the detectors at 77K and cool!
- Depleted => All impurities charged.

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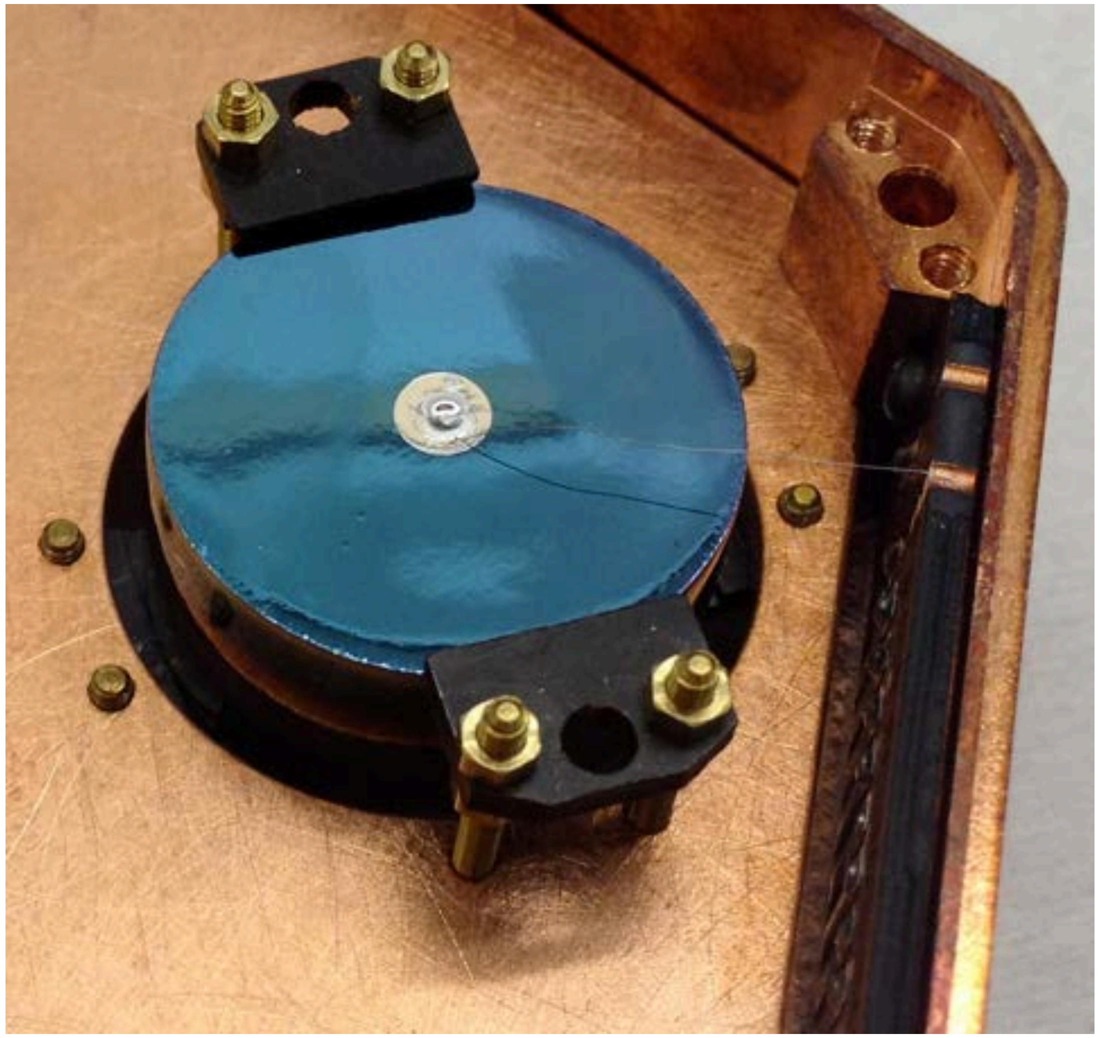


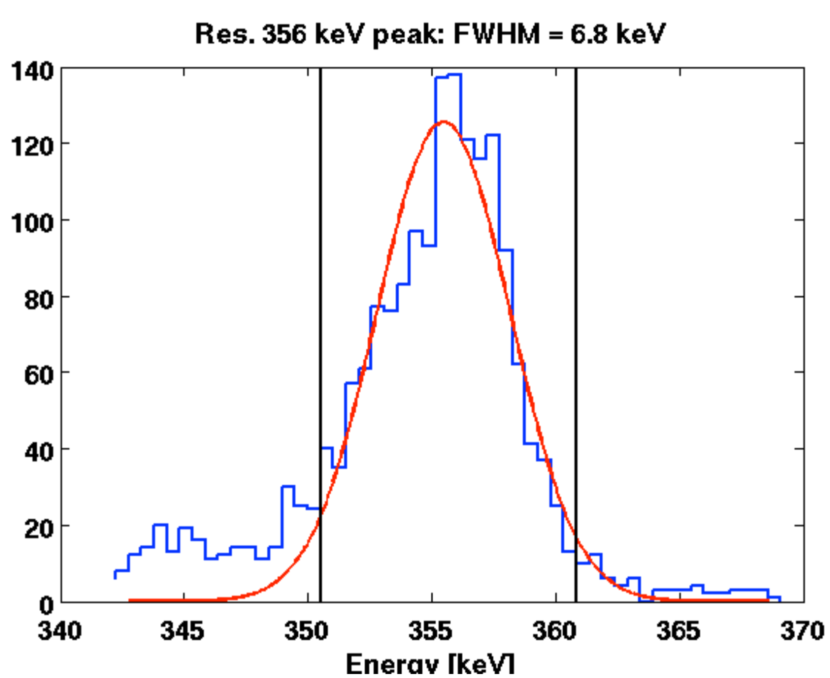
Recent tests at Berkeley

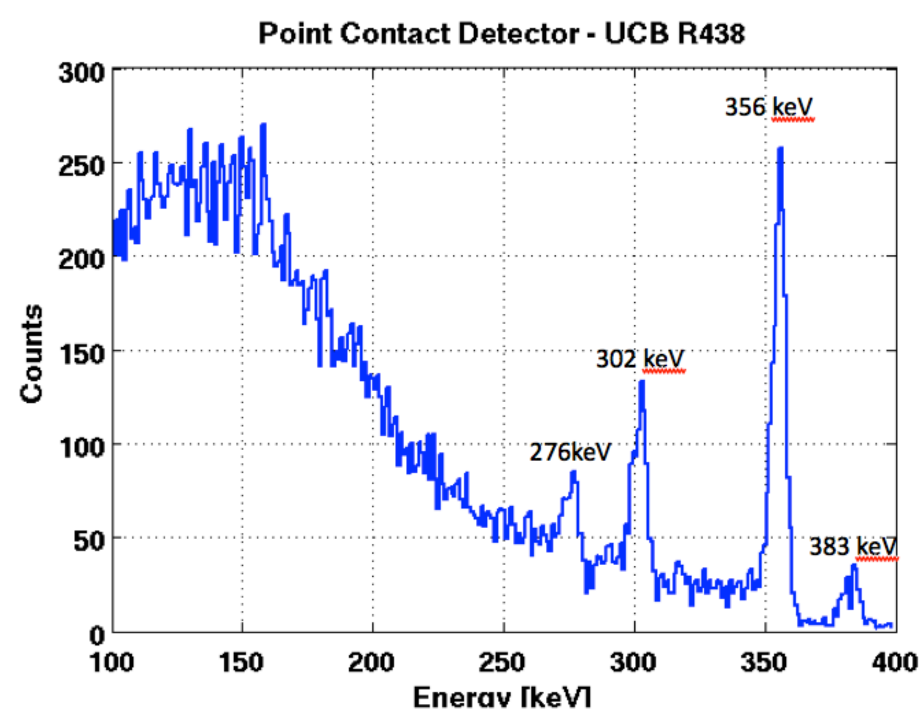
Φ=20 mm, h=10 mm p-type Ge: 10^{10} cm^{-3}

Could deplete at 180 Volts at 77K and cool to 0.05 K

Detector maintained depleted state down to 0.05 K

Ionization calibration with Ba-133 source





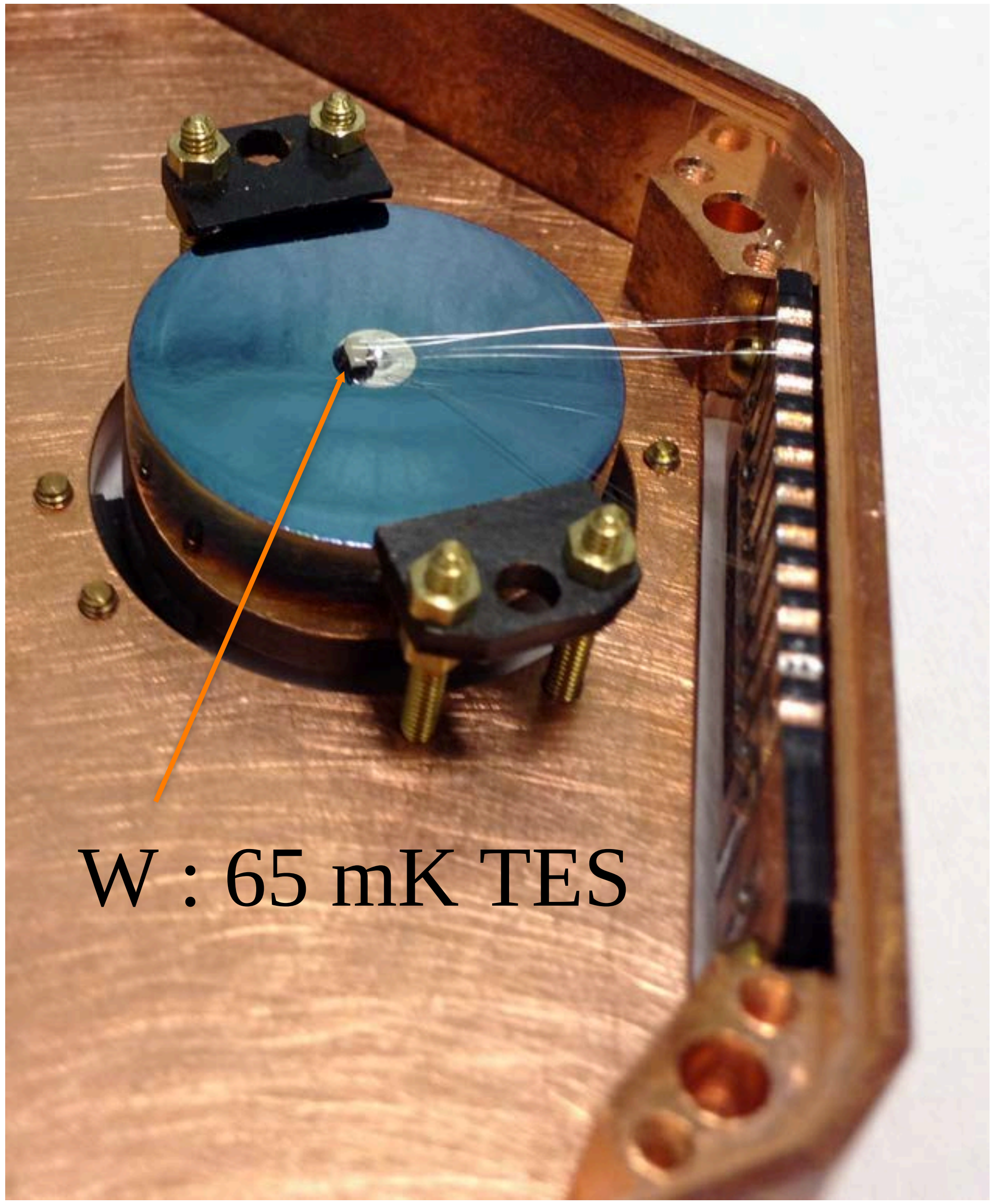
Not very good resolution

baseline= 1keV (badly adapted Cconnect+CFET)

lines: problem of collection close to surface?

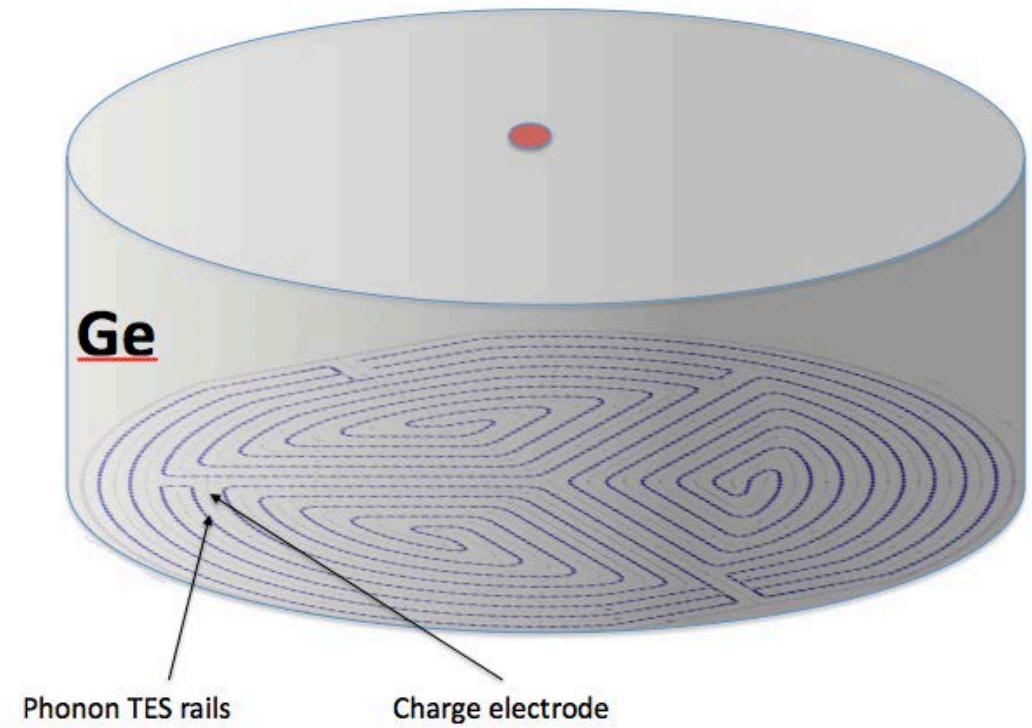
Next: Add phonon sensor

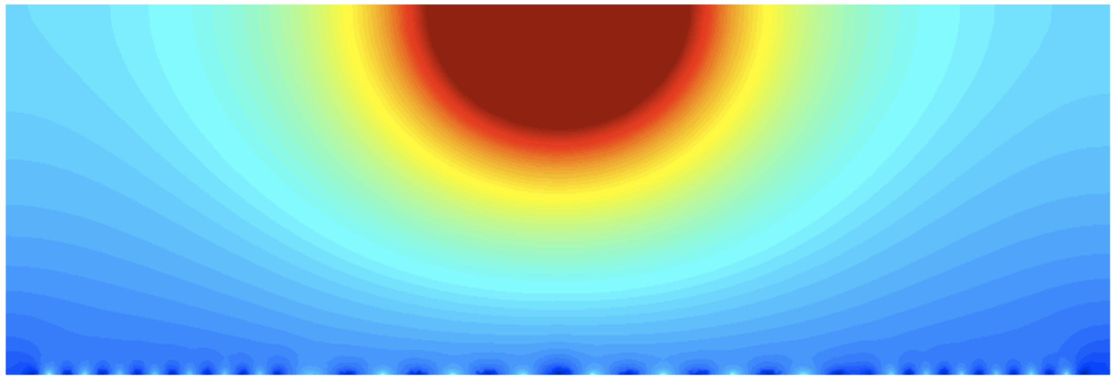
- A tungsten (T_c~65 mK) thermometer glued: Only sensitive to thermal phonons.
- Currently running with internal ^{241}Am source; 10 to 60 keV
- Study the Neganov-Luke gain
- Study near surface (dead layer)



Near surface events: Ionization dead-layer

- Near surface cause:
  - Back diffusion to the wrong electrode.
  - Self shielding of the initial e-h cloud
  - How bad for recoils <<1 keV ??
    - Need to be studied
    - Trapping on the surface states.
- One can engineer the size of the point contact such that:
  - Field near the phonon surface ~ Volts/cm.
  - Use the same concept as iZIP.
  - Majority of phonons released in the vicinity of the point contact.
  - Use Phonon partition to select only center events.
- Can also cover the cylindrical surface:
  - EDELWEISS FIDs.





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- **Majority of athermal phonon emitted from a small region around the point contact.**
  - Fiducial volume events: Most phonons from ~ 1 cm^3 around point contact where the field is strong.
  - The same principle can be used to identify deadlayer evenst.

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Disadvantage:

Basically ionization measurement.

Low ionization yield ~1/10 at the region of interest. But very good σ should compensate?

No event-by-event discrimination: Requires a very good understanding of the backgrounds.

Conclusions

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Noise improvement:

- 1-100eV $E_{trigger}$ seem technically possible
  - T_c^3 scaling for athermal phonon detectors
  - Improved cold/warm electronics
  - Optimize detector design
- R&D Challenges Remain
  - W FILM QUALITY
- 6 Si iZIPs -> hoping to be the first group to study CNS

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Signal improvement:

- Can deplete and operate Point contact Ge detectors at very low temperatures
- Phonon response improves linearly with collection potential while phonon noise is independent.
- Can reach ultimate Poisson fluctuation limit.
- R&D challenges:
  - Near surface events.
  - Larger detector and the regions of low electric field.