Dark Matter Search:
Very low temperature techniques

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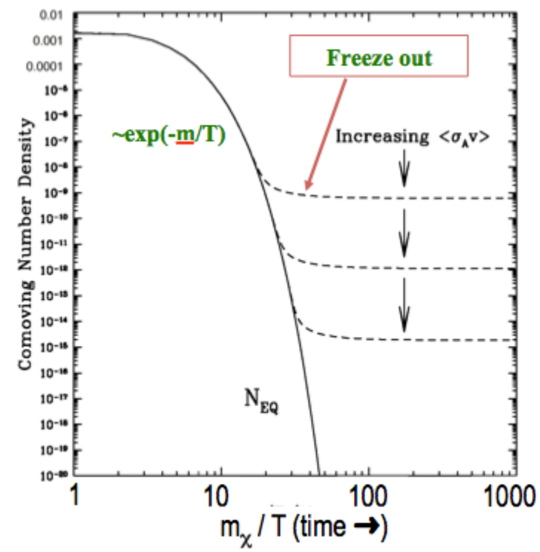
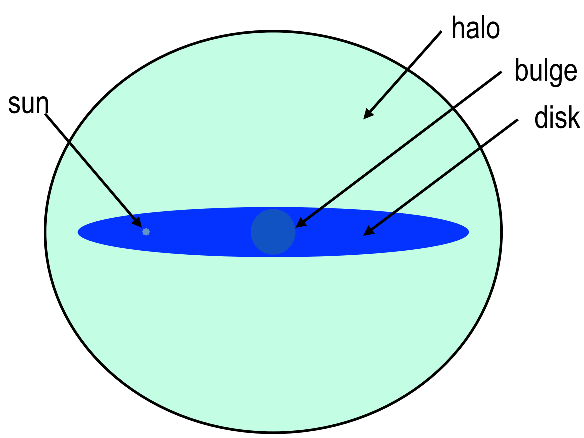
Rencontre de Moriond EW, La Thuile March 2013

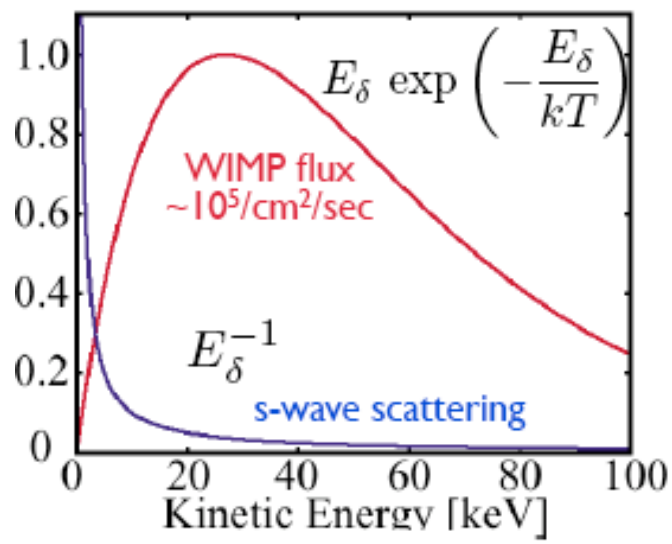
- WIMP detection Challenges.
- Why low temperatures?
- CDMS, EDELWEISS and CRESST
- Lowering thresholds
- Future and perspective

What are we trying to detect?

- WIMPs 10-100 GeV/c^2, 1-10 GeV/c^2 or even lighter.
  - High mass range Standard WIMP freeze-out scenario.
  - Low Mass range e.g. Asymmetric Dark Matter.
- Expected **cross section** at the **Weak Scale**.
- Isothermal distribution with V_0=230 Km/s, ρ~0.3 GeV/cm^3.
- Expected recoil **~<15> keV** and falling exponentially.
- Much Lower for lower WIMPs masses.
- **Rate ~ N n_χ $\langle\sigma_\chi\rangle$ << 1 event /kg/day**







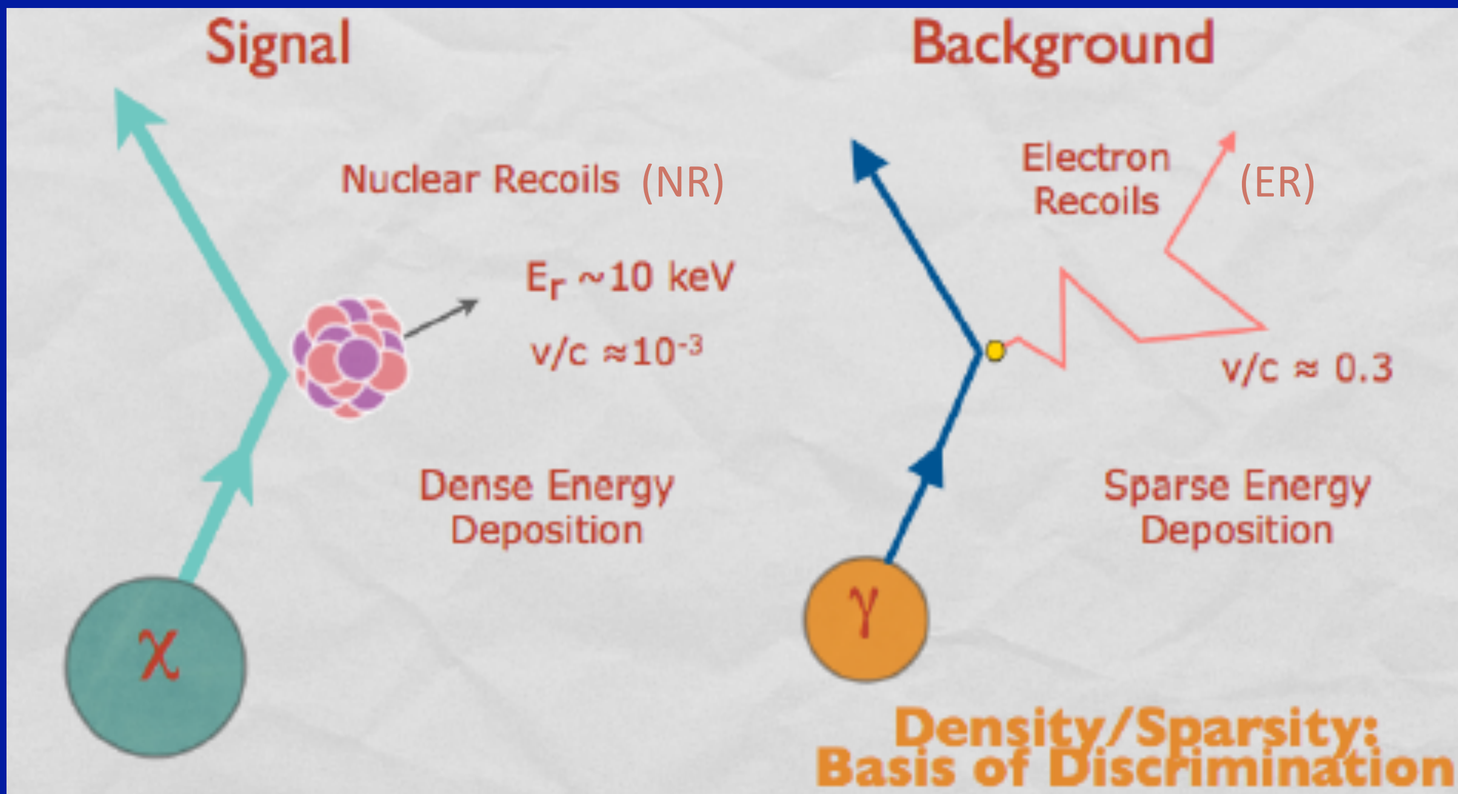
Direct detection challenges:

Backgrounds, Backgrounds and again Backgrounds

- Search sensitivity (low energy region <<100 keV)
  - **Current Exp Limit ~1 evt/100 kg/ month**
  - **Goal < 1 evt/tonne/year, ~< 10^{-5} evt/kg/day**
- Activity of typical Human
  - **~10 kBq (10^4 decays per second, 10^9 decays per day)**
- Environmental Gamma Activity in unshielded detector
  - **10^7 evt/kg/day (all values integrated 0–100 keV)**
  - **This can be reduced to ~10^2 evt/kg/day using 25 cm of Pb**

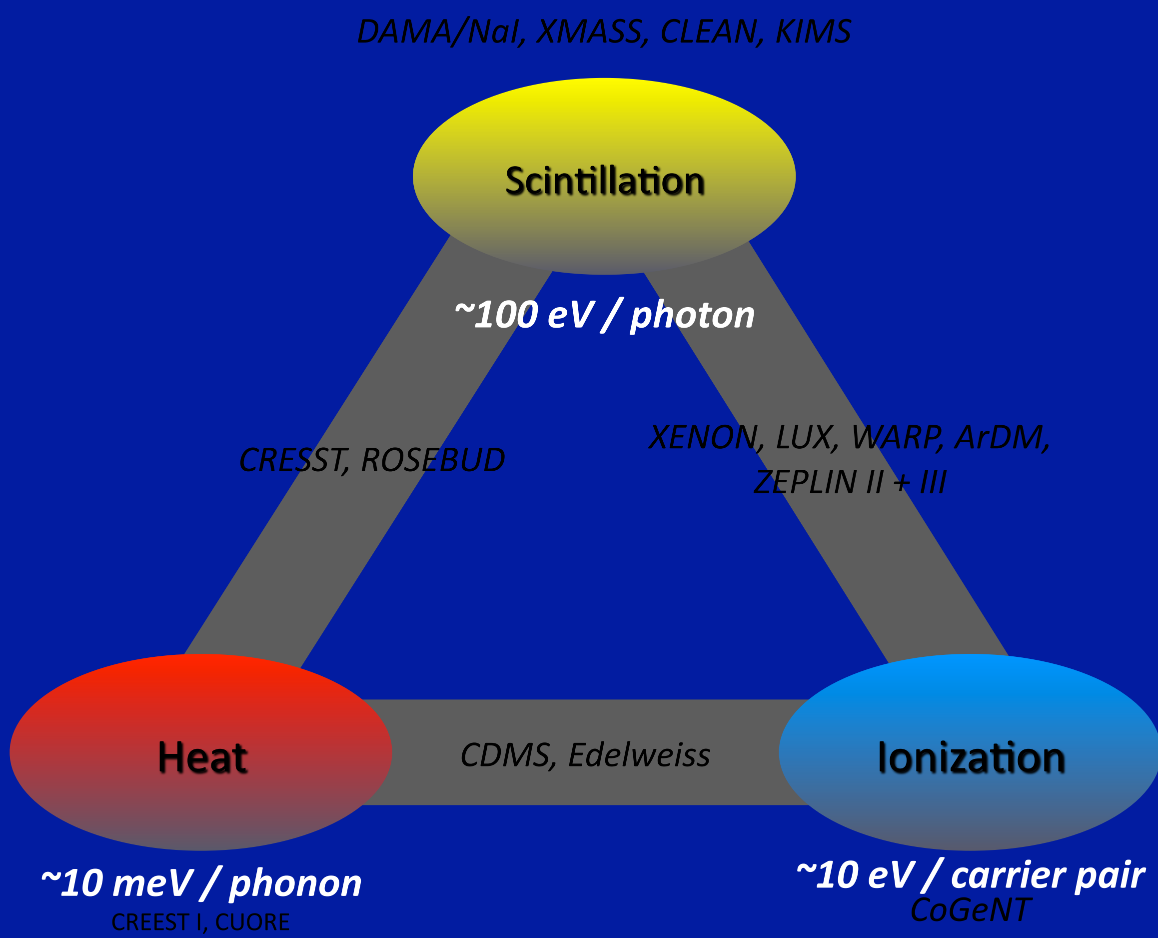
An event-by-event discrimination based on Nuclear recoil (WIMP interaction) versus Electron recoil (radioactive background) is therefore inevitable!

Event-by-event discrimination



Event-by-event discrimination:

Low T detector advantages



How does it work?

$C_V \propto (T/\Theta_D)^3$

Germanium at T= 300 K C_V=*3200 J/kg·K* and Θ_D=*374 K*
$\Rightarrow C_V$ at T=0.02 K = *5e-10 J/kg·K*
=*3e6 keV/kg·K*

Therefore for a 1kg Ge absorber cooled down to 0.02 K, ΔT caused by a 10 keV interaction will be: ~3.3e-6 K

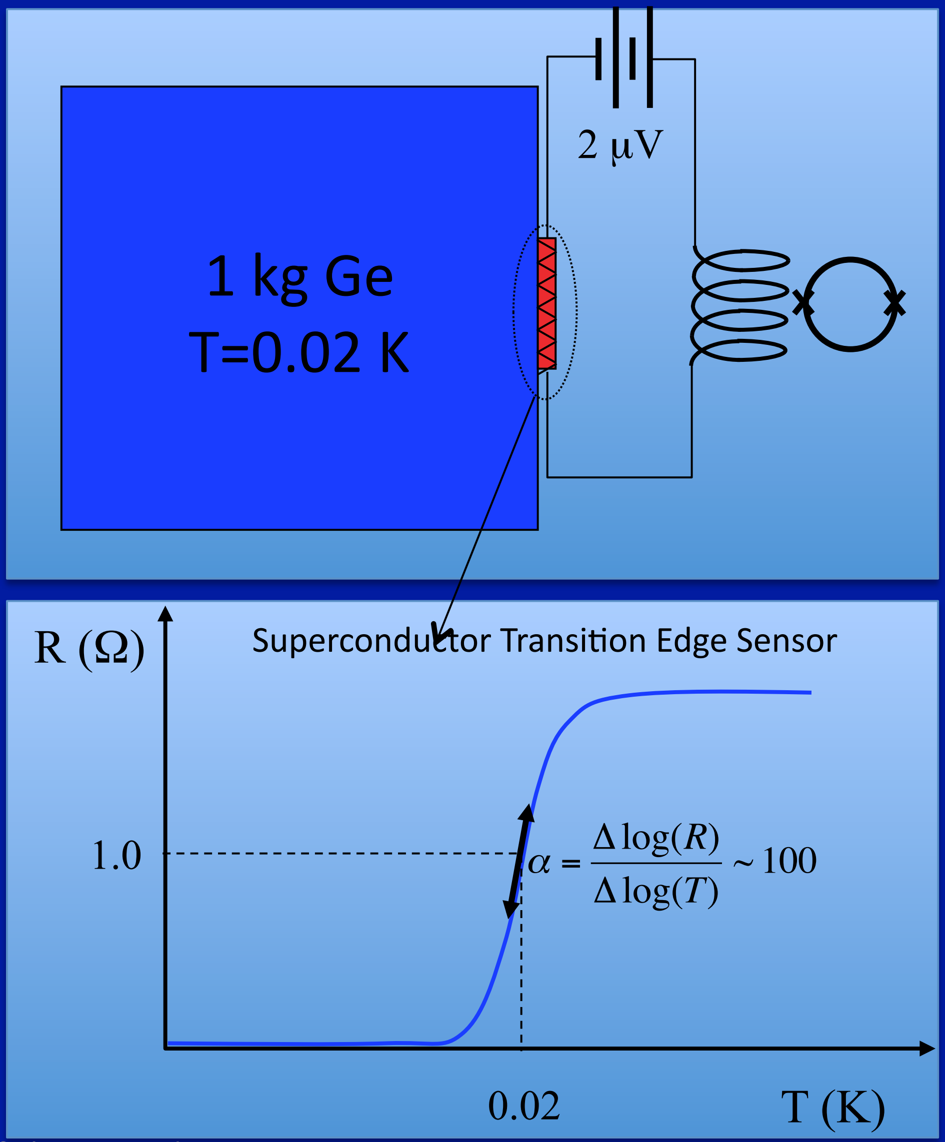
A thermometer attached to the absorber with α ~100:

Signal ∝ΔI~ 40 nA

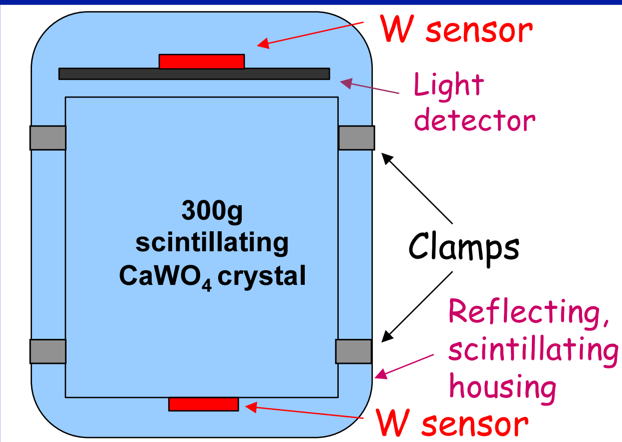
Noise~1pA/(Hz)^1/2

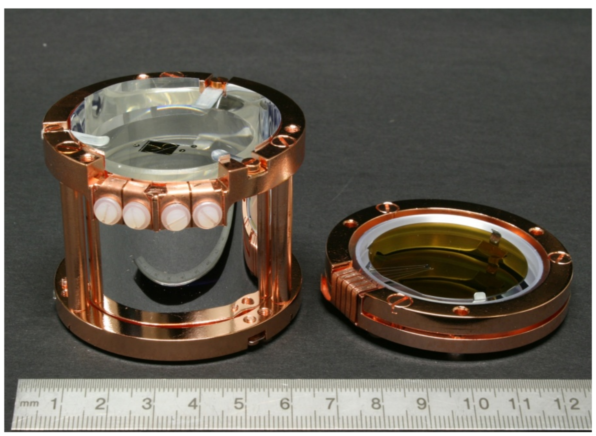
Typical for SQUID Amplifiers

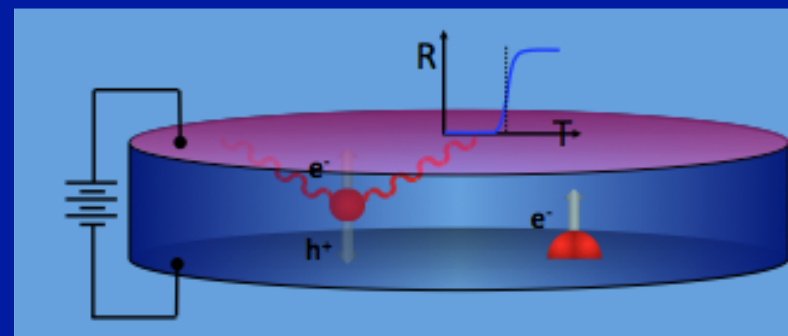
Very good resolution

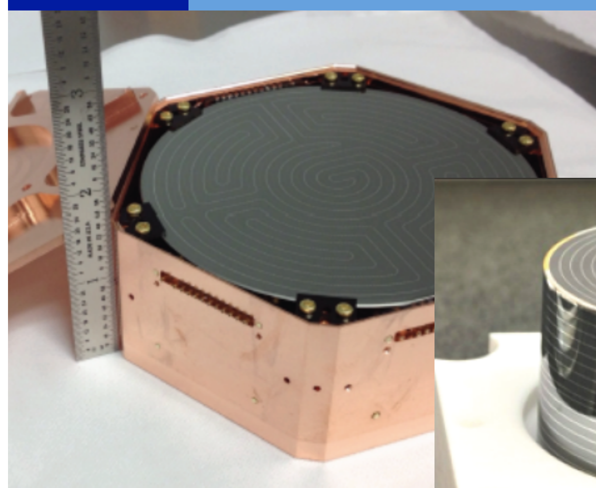


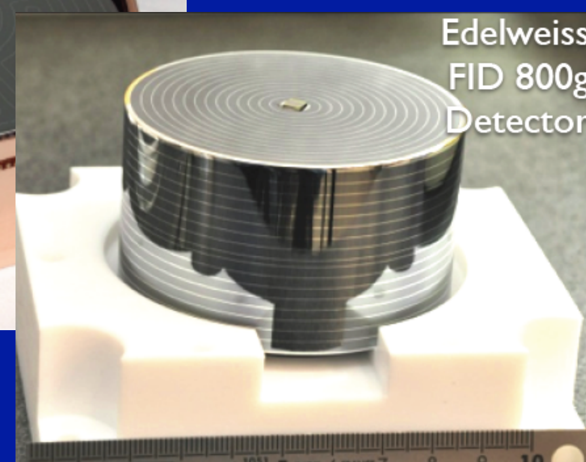
Detection techniques





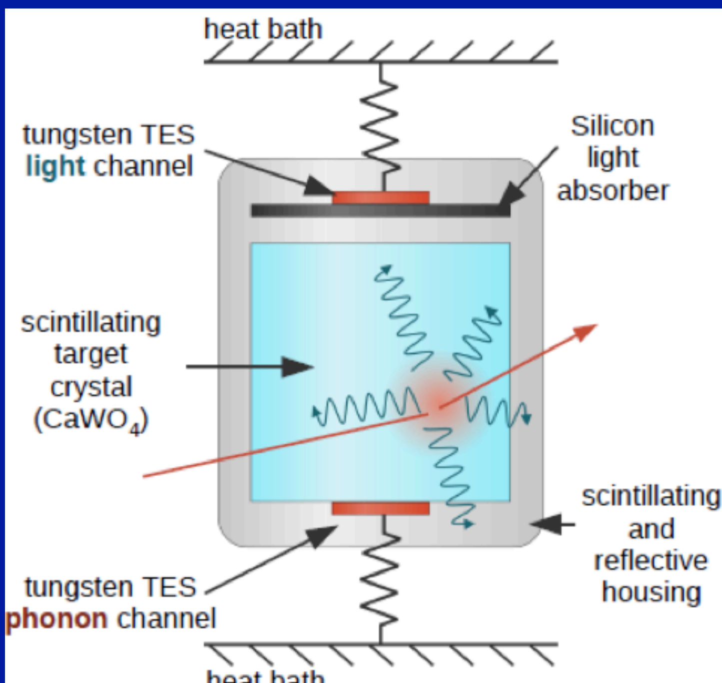


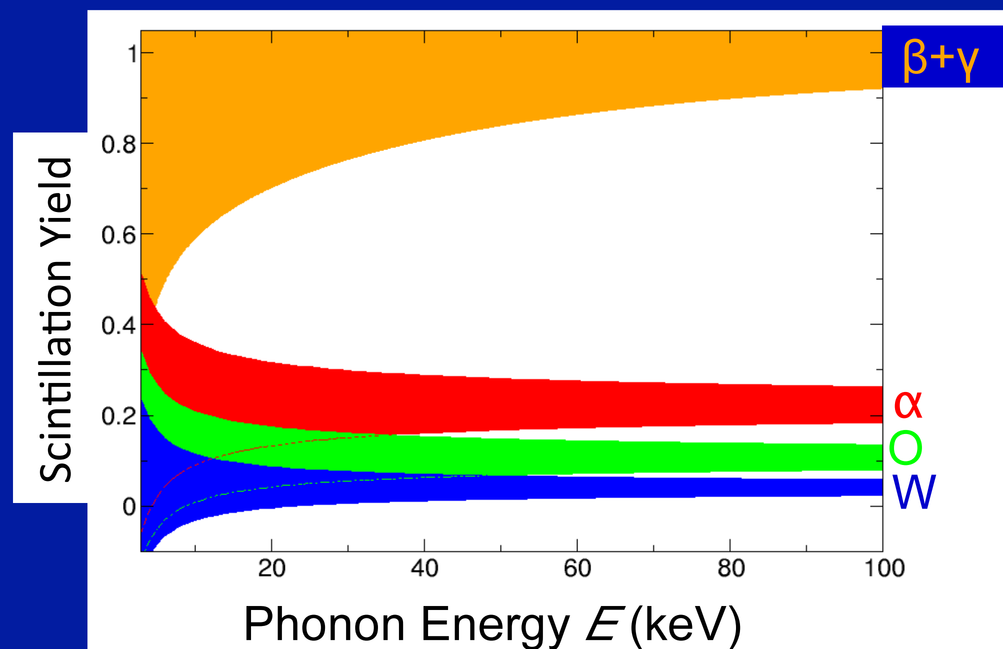




CRESST II

- Uses **Scintillation yield** differences for **NR versus ER** in **$CaWO_4$** crystals to detect WIMPs.
- To some extent probes WIMPs interactions with multiple target nucleus.
- Very small yield for NR: Susceptibility to the events that make phonons but no photons:
  - Cracks by the detector holder clamps, 210Po α-decay on clamp surfaces.

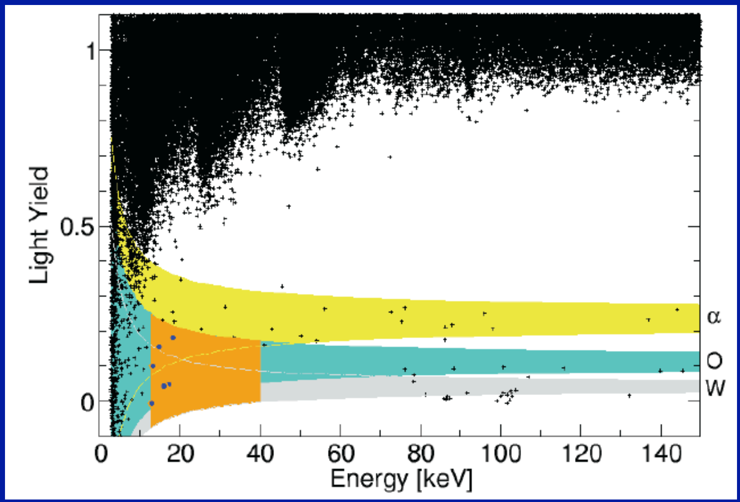


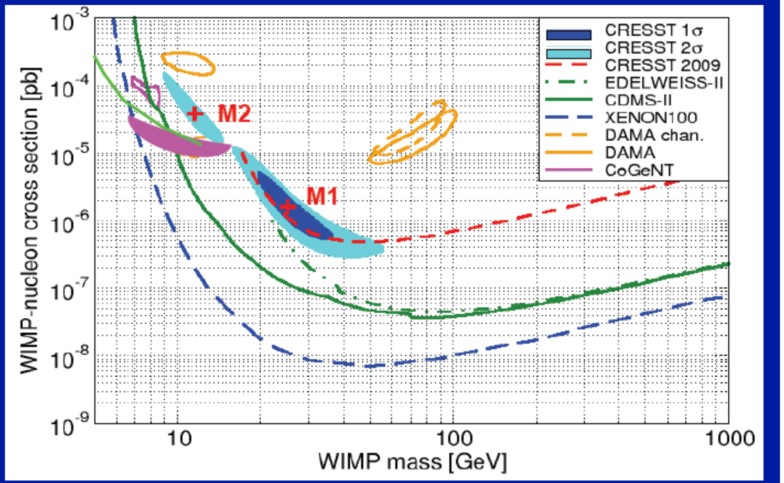


CRESST Results

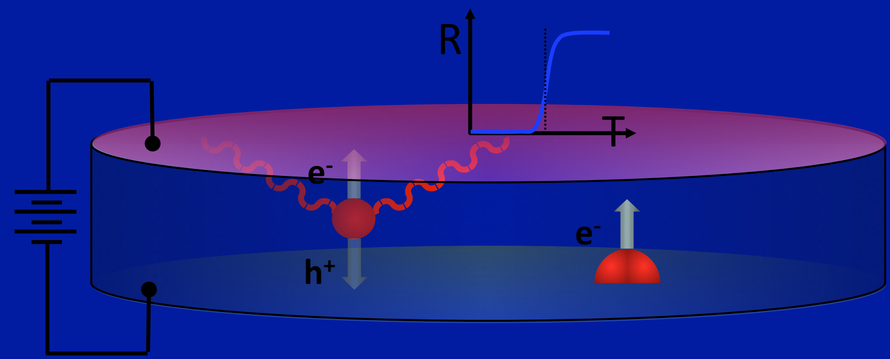
- 8x300g modules run: June 2009- April 2011.
  - •730 kg.days
- Known background (~40) unable to explain 67 events in NR :
  - •Large systematics on α-Pb decay recoils over clamps. *Astropart. Phys.* ***36****, 1, 77-82.*

- New physics run in preparation (Spring 2013) with reduced backgrounds:
  - Modification of Clamps to reduce α-Pb background.
  - Additional internal neutron shield.
  - Should confirm or rule out WIMPs hypothesis.
  - Unclear re background for future Ton scale experiment.

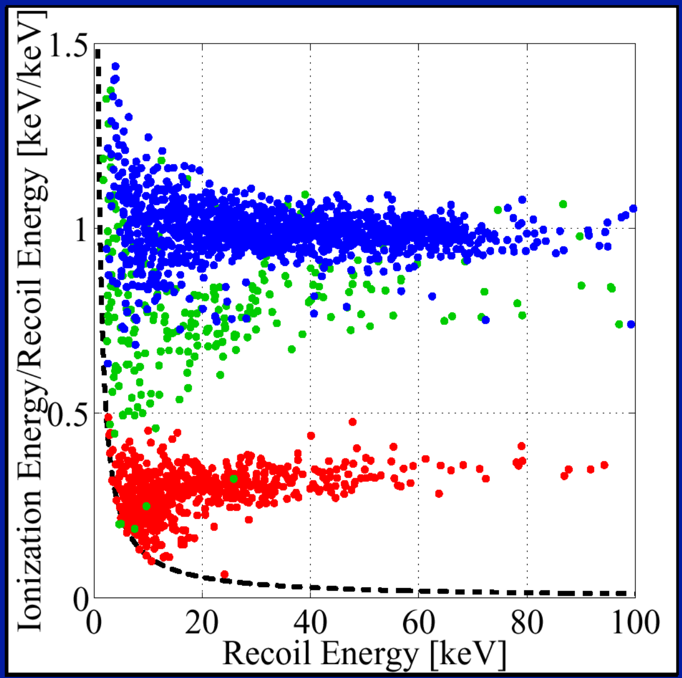




Ionization phonon technique

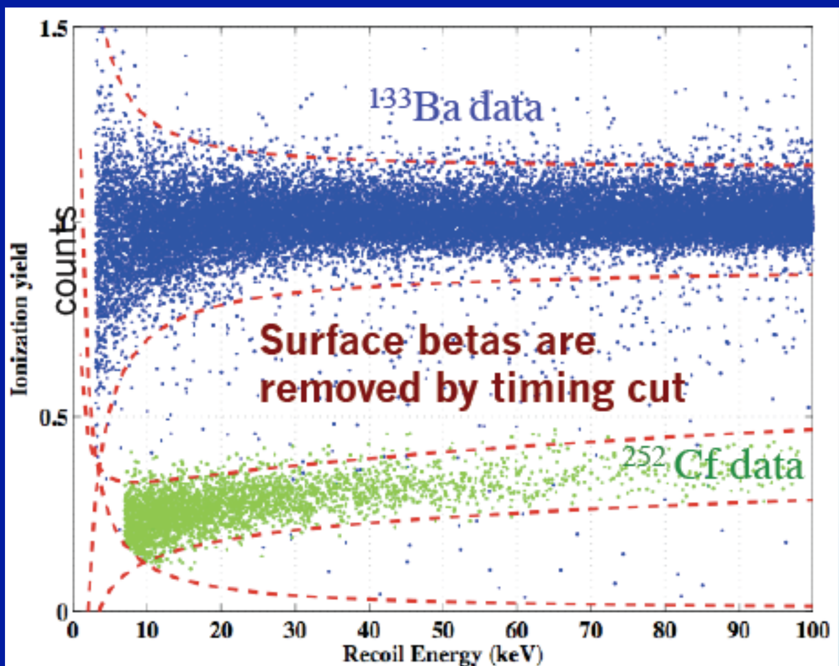


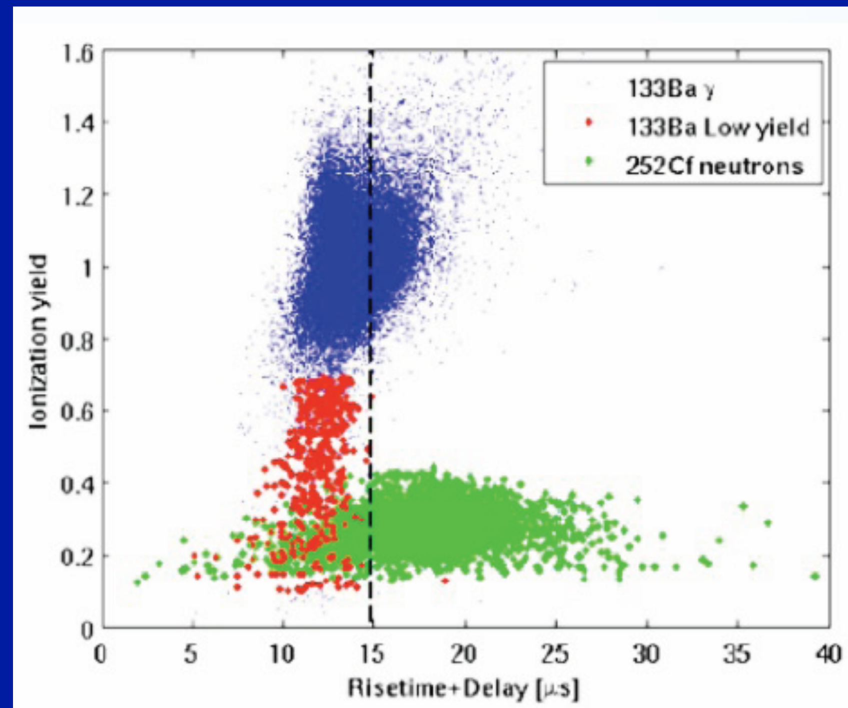
- Measure recoil energy via Lattice vibrations (phonons) in Ge or Si:
  - Very sensitive superconducting Transition Edge Sensors : Tc~0.08 K
- Measure the Ionization.
- Ionizing power (Ionization yield:Y)
  - $Y_{ER} > Y_{NR}$
  - Event-by-event discrimination
- Near surface events
  - Electron recoil but poor charge collection
  - Near geometrical boundaries



CDMS athermal phonon solution

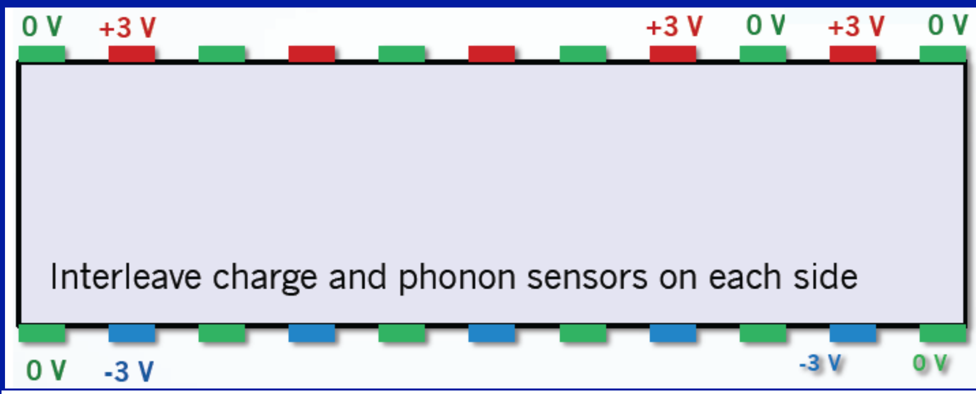
- Detect phonons before reaching equilibrium i.e before ΔT=E/C.
- Athermal phonons: Carry information about the event transients including location.
- In particular the phonon signal rise time and delay faster for near surface events.

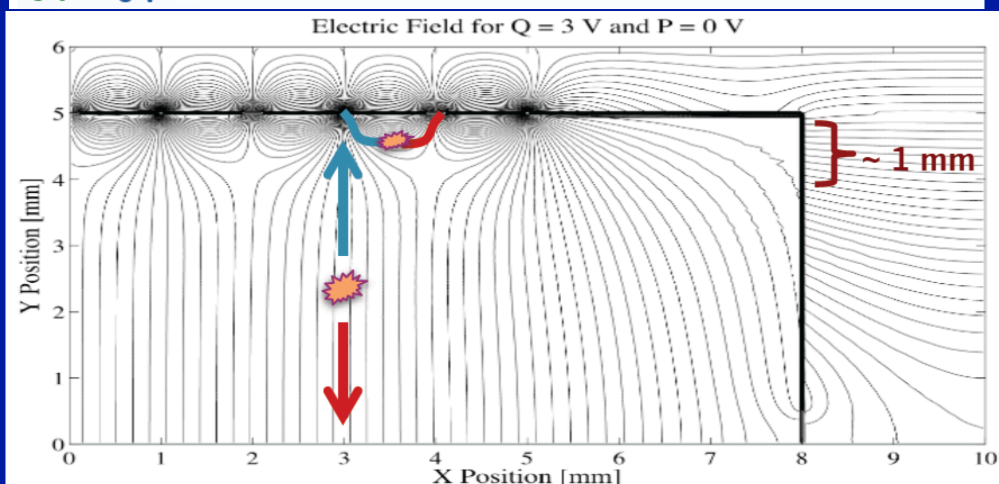


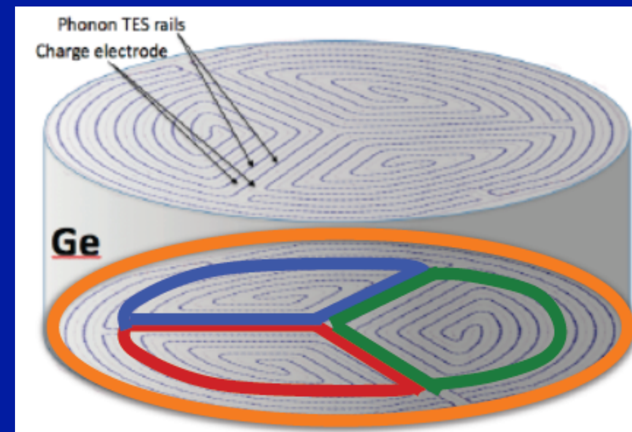


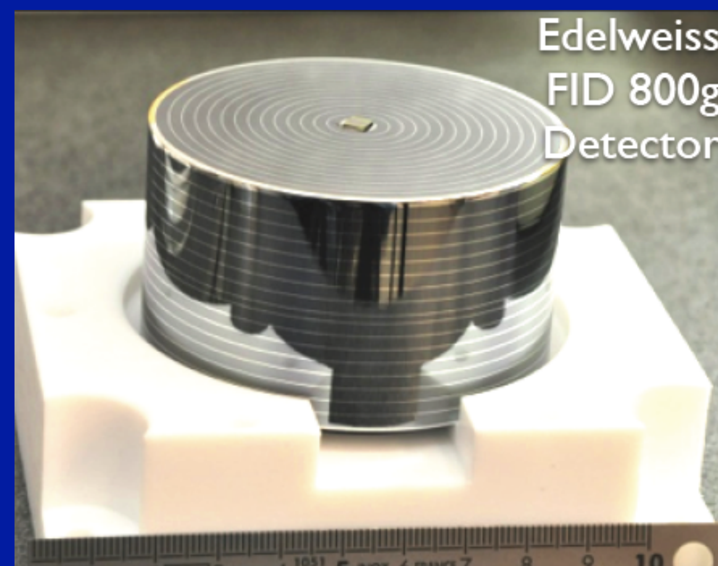
CDMS/EDELWEISS New solution

- Use Ionization to identify near-surface events
- Interdigit Ionization electrodes
  - E-Field Non-unifrom on the surfaces

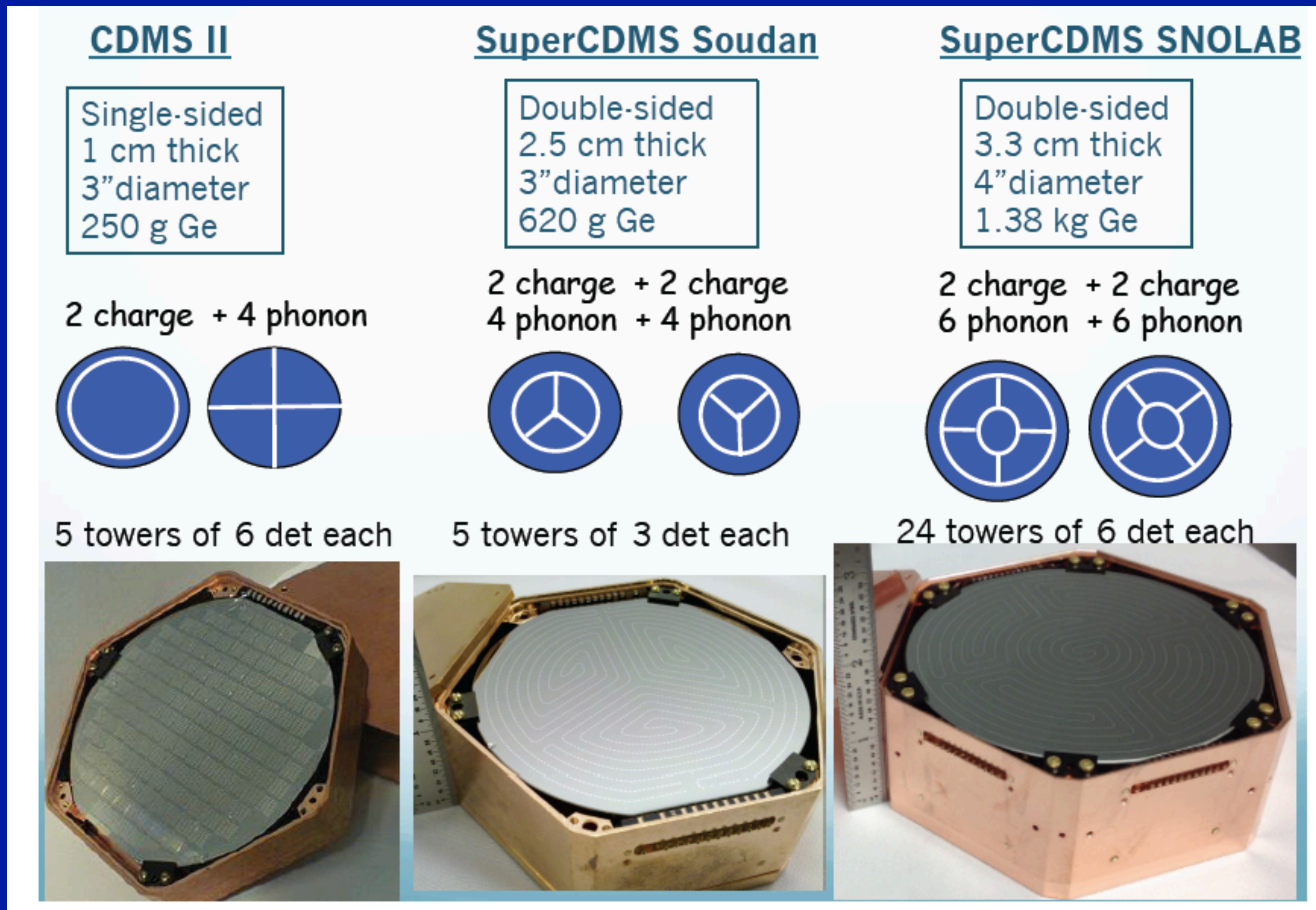








CDMS Detector evolution



CDMS II

Papers Published

WIMP search 10<E<100keV
CDMS-Edelweiss Combined
Limits on Inelastic DM
Axion limits
Low threshold Ge
Annual Modulation

Papers in process

Reanalysis: improved pulse-finding at low E_r with 4 analysis techniques

Silicon data from Reanalysis

Nuclear Recoil Energy Scale

SuperCDMS Soudan

Engineering run 2011
Physics run in progress

Demonstrate new interleaved technology

Establish excellent Background Rejection

$\sigma_{SI} \sim 5 \times 10^{-45}$ cm^2 for 60 GeV/c^2 WIMP

Concentrate on a competitive limit of $\sigma_{SI} \sim 10^{-41}$ for 5 GeV/c^2

Explore Luke phonon amplification mode $\sigma_{SI} \sim 10^{-41}$ for 3 GeV/c^2 (80 keV$_{ee}$ threshold)

SuperCDMS SNOLAB

Ongoing R&D

100 mm detector
- procurement
- fabrication
- testing
- production (6 det/mo)

Readout improvements
- Tower engineering
- new SQUID arrays
- JFET → HEMT

Installation @ SNOLAB
- Shielding design
- Cryogenic System
- Neutron Veto

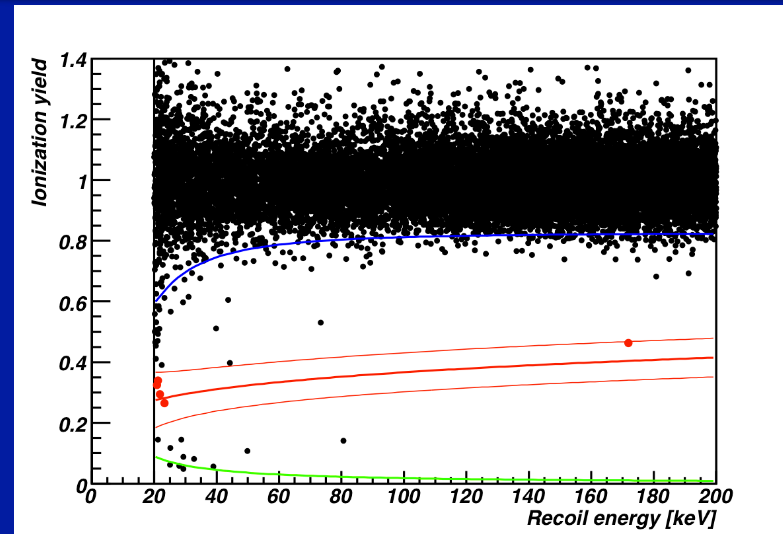
Run 200 kg for 4 years
$\sigma_{SI} < 8 \times 10^{-47}$ cm^2
for 60 GeV/c^2 WIMP

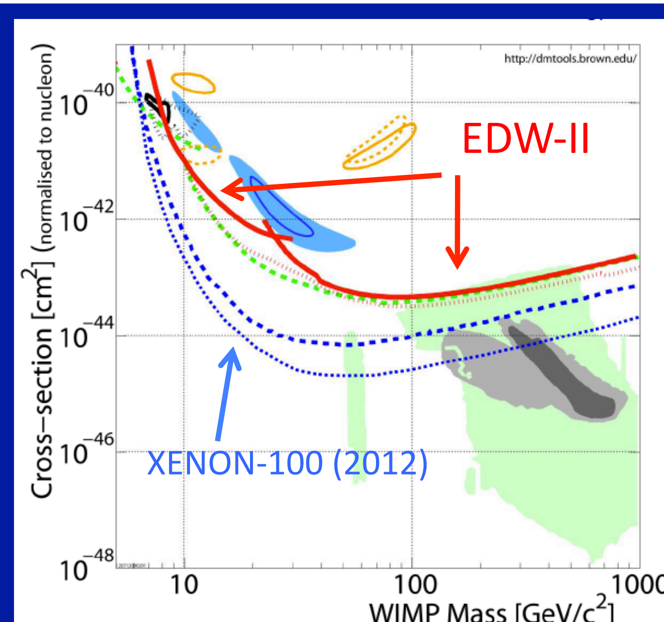
Edelweiss II Status

- Data from 2008 – 2010.
- 10 Interdigit Detectors (ID) detectors 400g each.
- 384 kg.days exposure.
- Energy range of [20,200] keV
  - Observed 5 events in NR.
  - 3 evts bg expected!

- Low-E investigation [5-20 keV] using 113 kg-day exposure (3 evts obs, <3 bgd)

- *Phys. Lett. B 702 (2011) 335–329.*
- *arXiv:1207.1815v1 (Low E)*





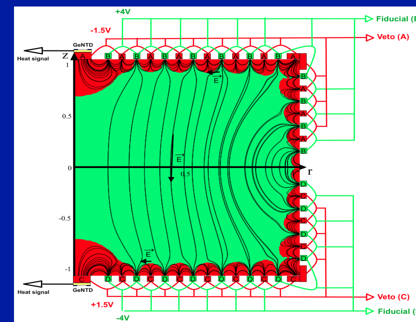
EDELWEISS-III

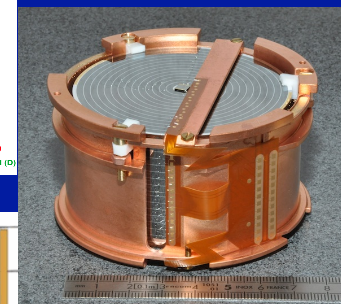
- **40 x FID800** Ge detectors (fiducial mass X4)
  - All surfaces covered with interleaved electrodes.
  - **Improved γ-rejection** wrt EDWII ID detectors.
  - FID surface rejection: confirmed as good as ID.

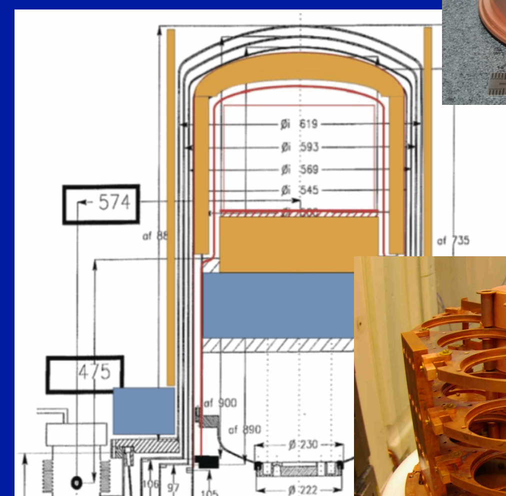
- **Internal PE shield:** Neutron rejection x10.

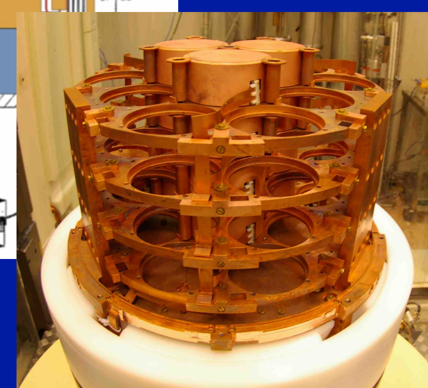
- Ionization and heat resolution improved by >30%
  - Upgrade of **cabling**, **electronics** and **cryogenics**
  - Full efficiency near 10 keV,
  - Significant sensitivity below 5 keV
- Feb 2013 instalation with 15 FID800
- **Summer 2013 Full installation with 40 FID800**
- Toward the end of 2013: Start WIMP search data

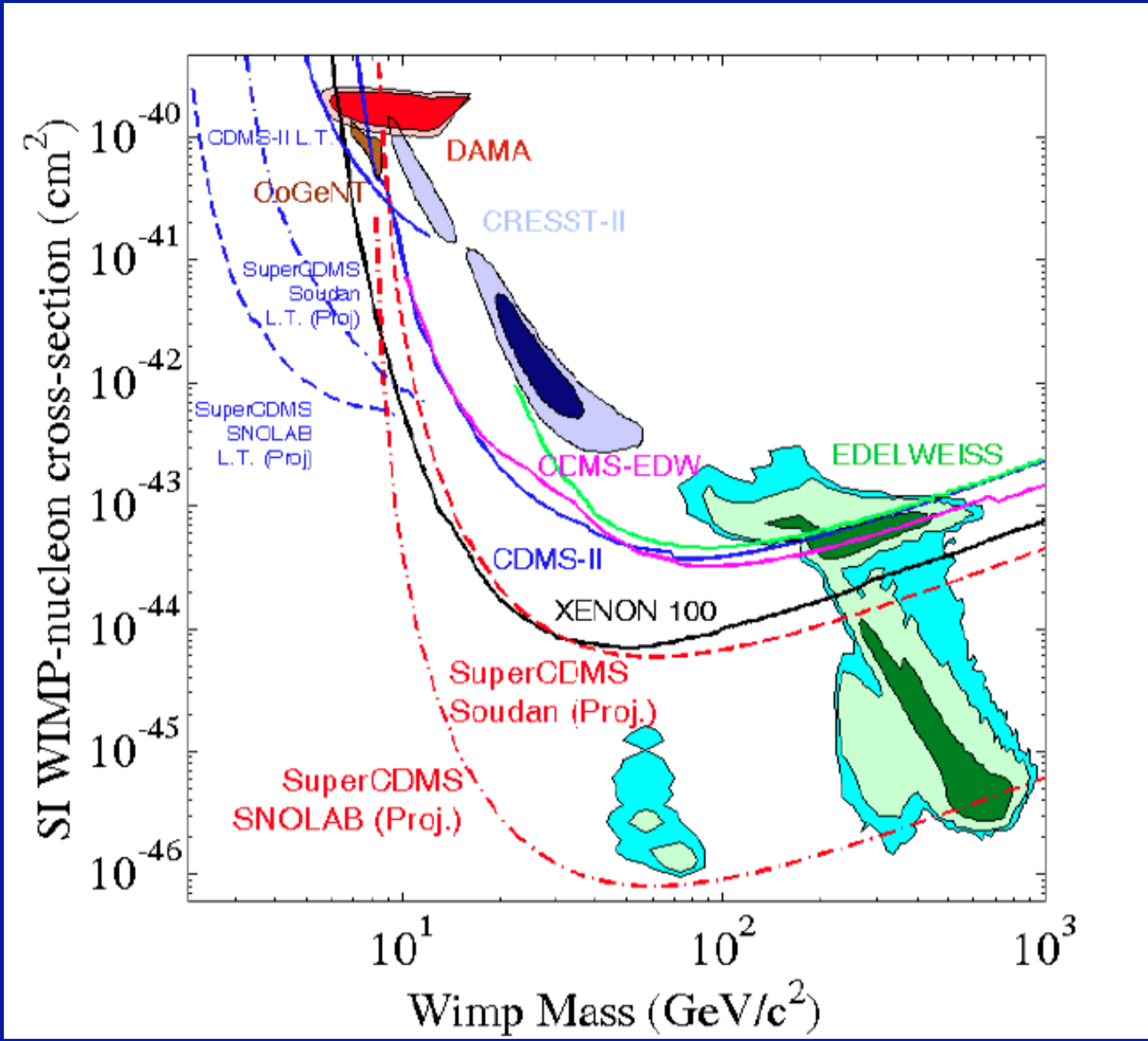
  → **Reach 10^{-9} pb in 2years operations**










DAMA
CDMS-II L.T.
CoGeNT
CRESST-II
SuperCDMS Soudan L.T. (Proj)
SuperCDMS SNOLAB L.T. (Proj)
CDMS-EDW
EDELWEISS
CDMS-II
XENON 100
SuperCDMS Soudan (Proj.)
SuperCDMS SNOLAB (Proj.)
SI WIMP-nucleon cross-section (cm^2)
Wimp Mass (GeV/c^2)

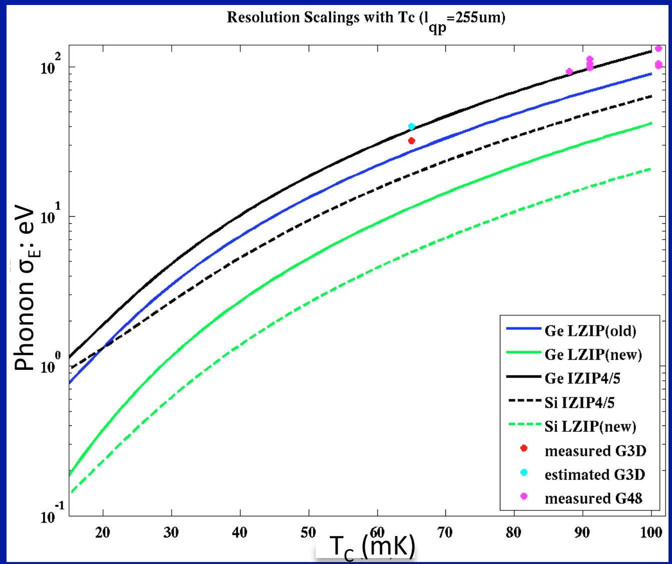
Very low threshold: New ideas

- Not much efforts toward CDMS phonon S/N optimization so far.
  - Phonon S/N was more than enough for Standard WIMP (10-100 GeV/c^2).

What about Low mass WIMPs?

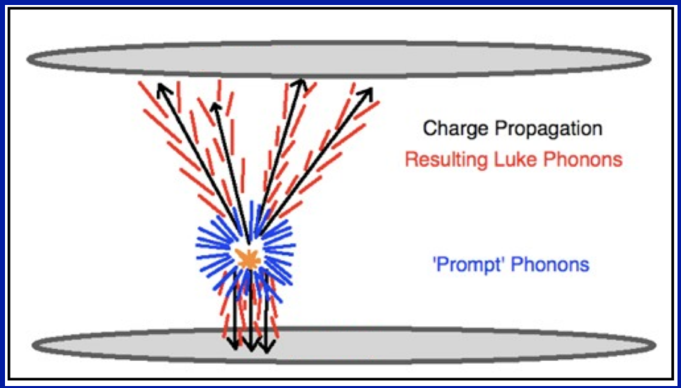
- Phonon sensitivity scales with T_C^3:
  - => For 20 mK x 125 better resolution i.e. <1eV
- Suitable even for DM+e^-→DM+e^- detection: MeV DM.

M.Pyle Stanford Dissertation 2009



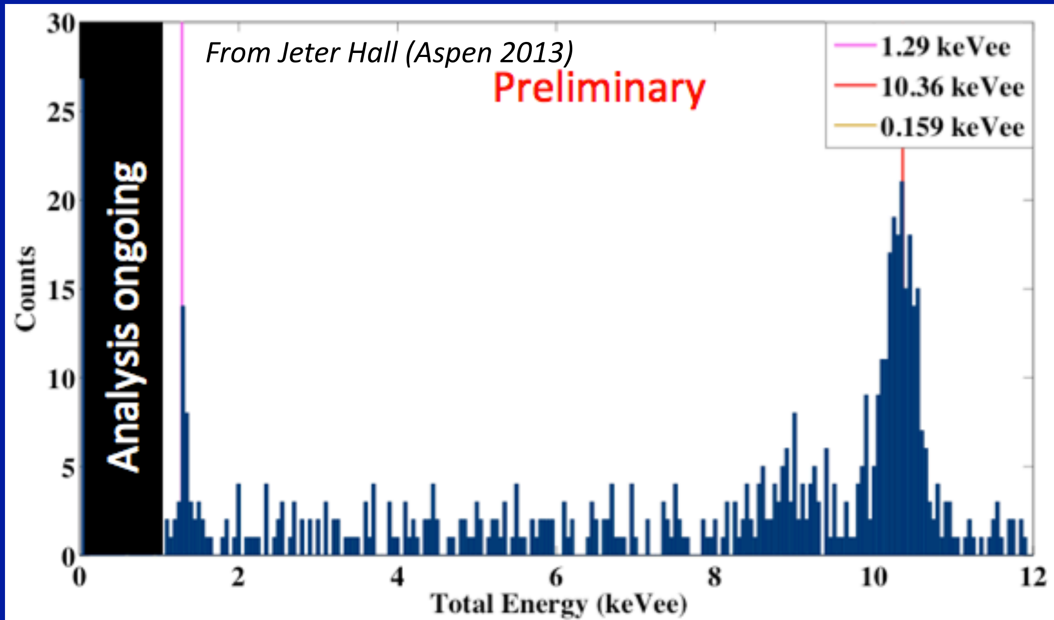
- Electron holes drifting through Ge produce more phonons:
  - Neganov-Luke inherent phonon amplification.
  - Amplification proportional to bias Voltage.
  - But Phonon noise is independent.
- At 300V bias: **Single electron detection threshold.**
  - CDMS detectors breakdown <100 V
  - New design in progress to avoid break down

Luke et al., Nucl. Inst. Meth. Phys. Res.A 289, 406 (1990)



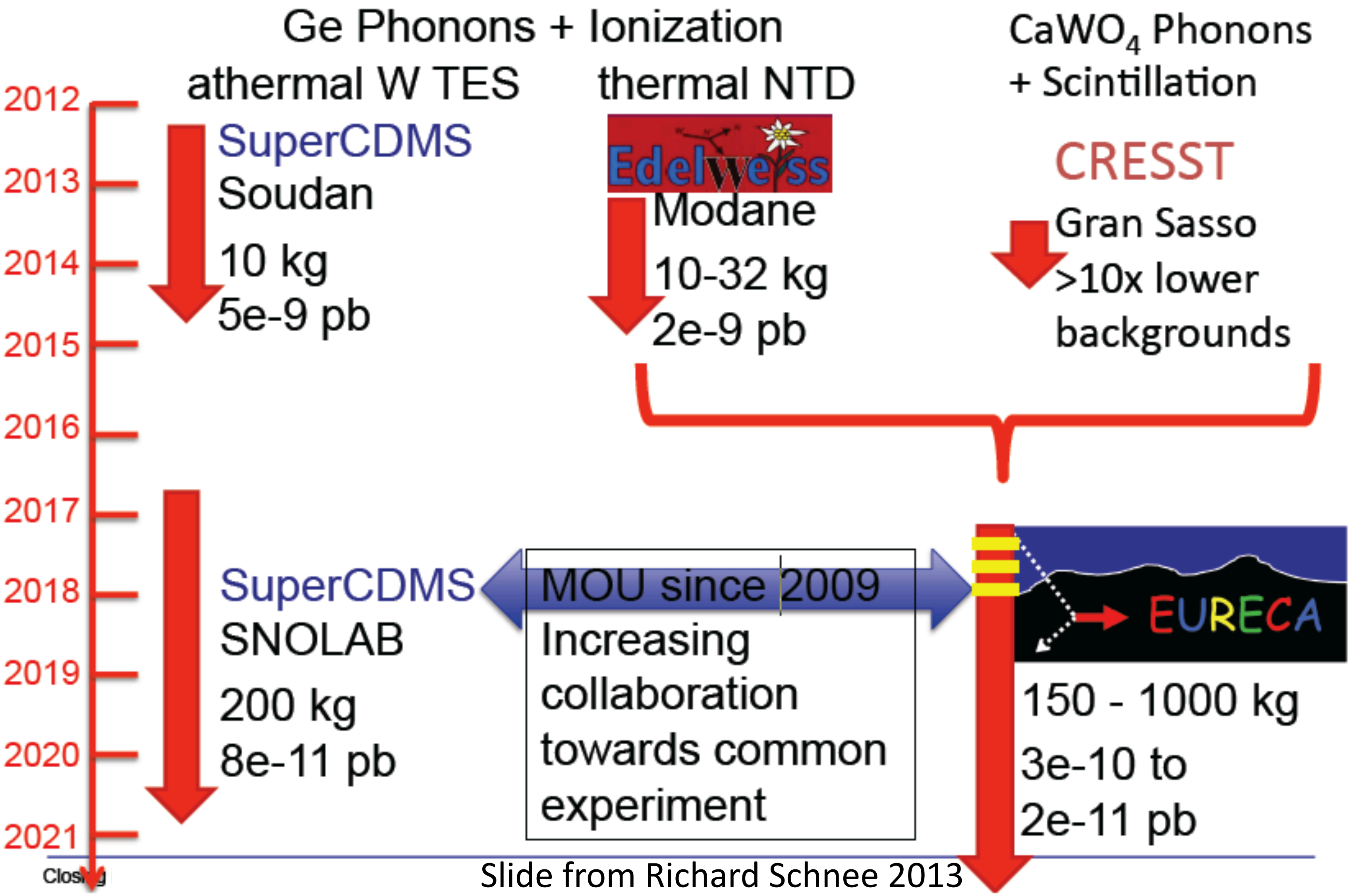
CDMS Low Ionization Threshold Experiment (CDMSlite)

- Using Phonon amplification to realize low threshold with SuperCDMS detectors
- Low Background data since Fall 2012
- First results Spring 2013



This spectrum shows the low-energy performance of SuperCDMS detectors with increased voltage. The applied bias was 69V corresponding to an order of magnitude gain in the signal. The energy resolution for the 1.29 keV gallium L-shell line is ~24 eV, the Fano limited resolution is ~20 eV. The increase at 9 keV is due to cosmic ray activation of ^{65}Zn. Note that the efficiency of the cuts used to produce this preliminary spectrum has not been applied.

Future



Slide from Richard Schnee 2013

Conclusion

- Low Temperature (LT) detectors have fundamentally and practically better energy resolution than any other WIMP direct detection technique.
- Although more sophisticated in technology, LT detectors provide direct Recoil energy measurement and thus much easier interpretation of data.
- With the new handle on the near-surface events, both SuperCDMS and EDELWEISS provide robust and low risk means to maximize sensitivity at the ton scale.
- By lowering the T_C or (and) using inherent phonon amplification via Neganov-Luke effect LT Ge detectors can reach detection threshold ~ 1 eV revolutionizing low mass DM search.
- At the minimum two different technologies for DM detection with very different systematics are needed to claim a discovery. Discussions on combining CDMS/ EDELWEISS/CRESST efforts into a unique LT experiment at the ton scale with wide range of WIMPs masses accessible: 1 MeV-100 GeV.