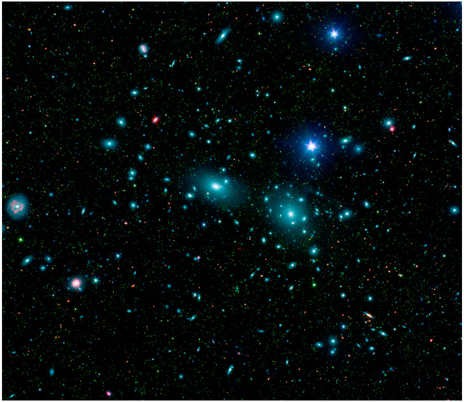
Direct Dark Matter Search with CRESST

Marc Wüstrich,
MPP (CRESST)

19.07.2014

First Hint for Dark Matter

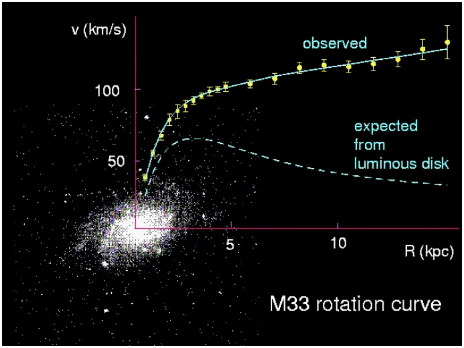
- first postulation of Dark Matter in 1933 by F. Zwicky



- kinematics of the Coma super cluster can only be explained by additional, not visible but gravitational interacting matter => Dark Matter
- todays observations suggest that 90% of the matter in the cluster is Dark Matter

Dark Matter in the Cosmos

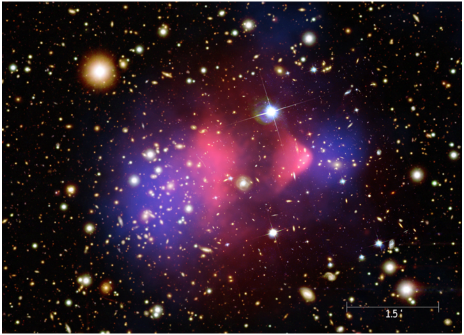
- today hints for the existence of Dark Matter on all cosmic scales
- rotation speed of spiral galaxies
- phenomenon of the Bullet cluster
- simulation of the evolution of the universe based on $\Lambda - CDM$



- => no experimental confirmation for the existence of Dark Matter

Dark Matter in the Cosmos

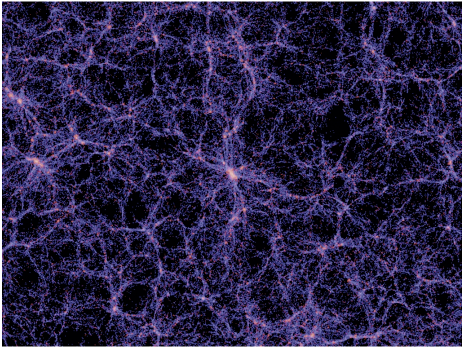
- today hints for the existence of Dark Matter on all cosmic scales
- rotation speed of spiral galaxies
- phenomenon of the Bullet cluster
- simulation of the evolution of the universe based on $\Lambda-$CDM



- => no experimental confirmation for the existence of Dark Matter

Dark Matter in the Cosmos

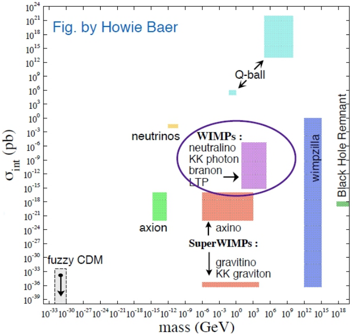
- today hints for the existence of Dark Matter on all cosmic scales
- rotation speed of spiral galaxies
- phenomenon of the Bullet cluster
- simulation of the evolution of the universe based on $\Lambda-$CDM

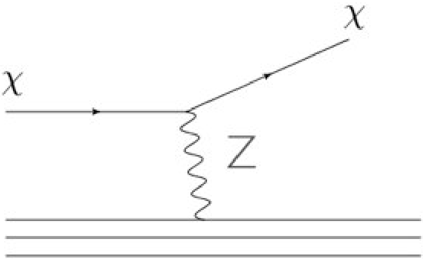


- $=>$ no experimental confirmation for the existence of Dark Matter

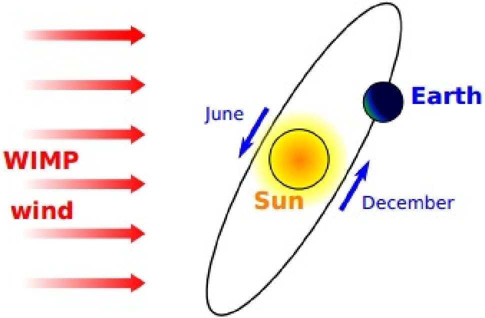
Approach for the direct detection of Dark Matter

- A well motivated candidate is the Lightest Supersymmetric Particle (LSP) also called WIMP (weakly interacting massive particle) (mass 1-100 GeV, cross section $< 10^{-44} cm^2$)
- Since the nature of DM is completely unknown, the most simple model is used for the direct detection => elastic scattering standard model particles





Smoking Gun Signature: Annual Modulation



- earth is moving with a speed of $\approx 220 \pm 30$ km/s through a Dark Matter halo
- due to the annual movement of the earth around the sun the average velocity has also an annual variation

WIMP nucleon interaction rate

Differential interaction rate

$$\frac{dR}{dE_R} = \frac{\rho_x}{m_\chi \cdot m_N} \int_{v_{min}}^{v_{esc}} |v| f(v) \frac{d\sigma}{dE_R} d^3 v \qquad (1)$$

WIMP nucleon interaction rate

Differential interaction rate

$$\frac{dR}{dE_R} = \frac{\rho_x}{m_\chi \cdot m_N} \int_{v_{min}}^{v_{esc}} |v| f(v) \frac{d\sigma}{dE_R} d^3 v \tag{1}$$

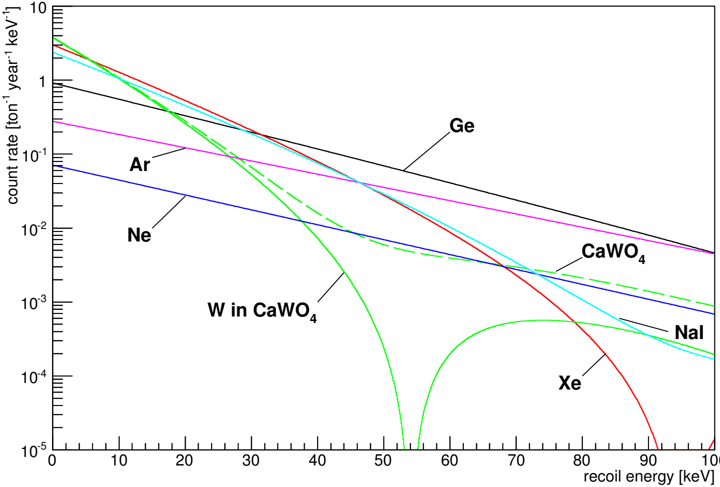
Particle Physics

$$\frac{d\sigma}{dE_R} = \frac{m_N}{2 \cdot v^2 \cdot \mu_{\chi,N}} \cdot \sigma_0 F^2(E_R) \tag{2}$$

$$\sigma_0 = \frac{4\mu_{\chi,N}}{\pi} [Z \cdot f_p + (A+Z) \cdot f_n]^2 \propto A^2 \tag{3}$$

- depending on the used target and the energy threshold, the expected rate is as low as 0.1 cnts/(kg days)

WIMP nucleon interaction rate for different nuclei



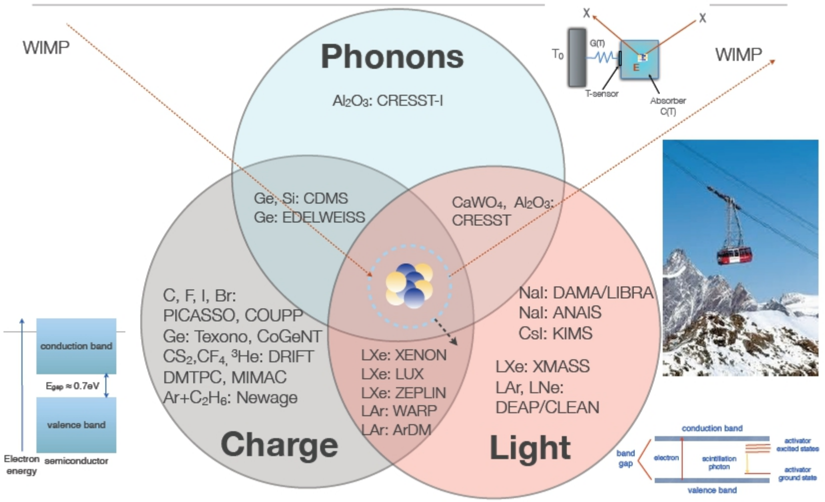
Experimental Constrains

- expected recoil energy is very tiny (< 10 keV)
- due to the low expected WIMP interaction rate, background reduction and identification is crucial for all experimental approaches
- event-by-event identification is necessary $=>$ all experiments are located in low background environments and introduced powerful event identification

Different Techniques

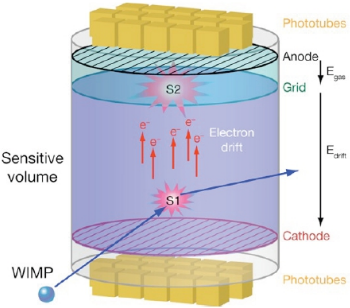
- different experimental techniques were developed and combined (phonon, scintillation, ionization)
- different target materials are used, all competitive limits and results are set by experiments using two channel readout detectors

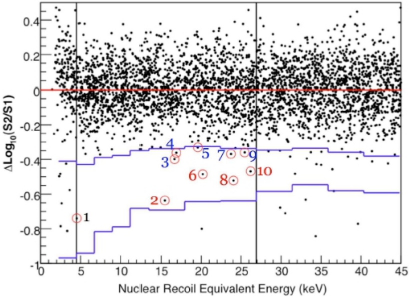
Experimental Techniques



Light-Charge Technique

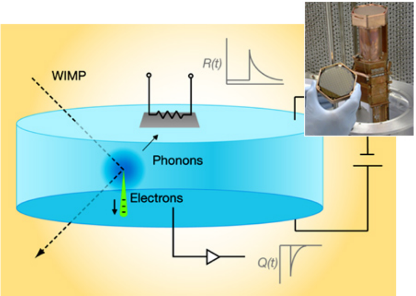
- simultaneous measurement of scintillation light and ionization in liquid noble gases
- suitable targets are Xe and Ar (high A number, high density)
- experiments using this technique set the best exclusion limits over a broad parameter space (LUX collaboration)

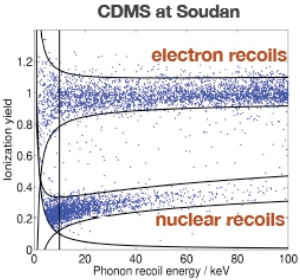




Phonon-Charge Technique

- simultaneous measurement of phonons and ionization in ultra pure semiconductors
- suitable target are Si and Ge (light and medium weight targets)=> more sensitive for light WIMPs

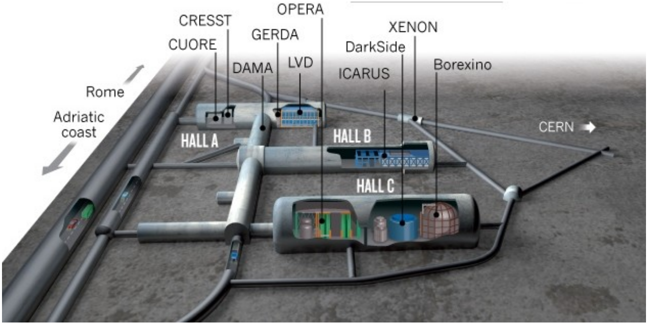




Phonon-Light: CRESST-II

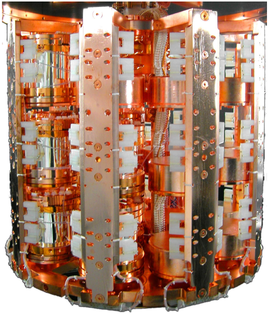
Experimental Setup

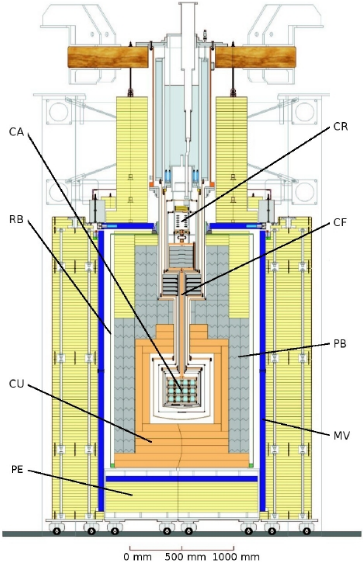
- The CRESST experiment is located at the Gran Sasso Underground Laboratory (3500 m w.e. of shielding)



Experimental Setup

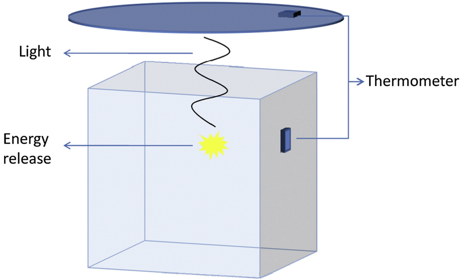
- Several additional layers of shielding surround the detectors to prevent the radiation of the surrounding rock to reach the detectors
- detectors are mounted in a cryostat operated in a base temperature of < 10 mK
- up to 33 detector modules can be mounted into the carousel



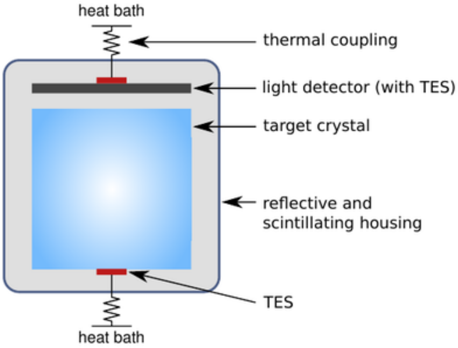


Scintillating Bolometers

- Energy deposition in a scintillating crystal produces phonons and light => Scintillating Bolometer
- Phonon channel provides a accurate determination of the deposited recoil energy
- Light channel is used for event identification => light emission is depending on the particle interaction

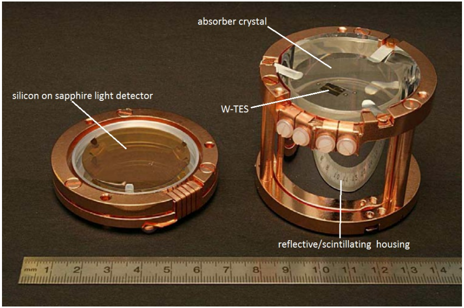


CRESST: Conventional Detector Module



- a scintillating absorber crystal ($CaWO_4$, 300 g)
- spatially separated light detector (Silicon on Sapphire, SOS)
- crystal is surrounded by scintillating and reflecting foil
- Signal readout is achieved with Transition Edge Sensors (TES)

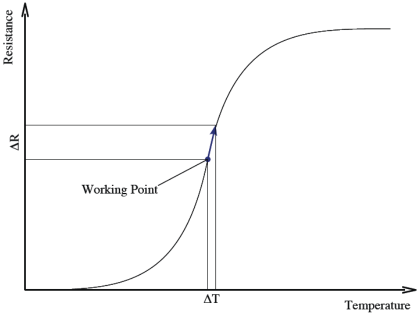
CRESST: Conventional Detector Module



- a scintillating absorber crystal ($CaWO_4$, 300 g)
- spatially separated light detector (Silicon on Sapphire, SOS)
- crystal is surrounded by scintillating and reflecting foil
- Signal readout is achieved with Transition Edge Sensors (TES)

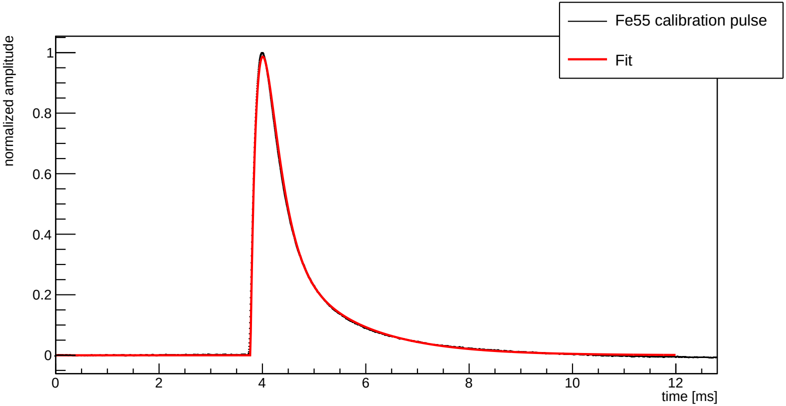
Signal readout

- TES are thin film systems (W in CRESST-II)
- operation in the step transition between the normal conducting state and the superconducting state
- temperature changes in μK scale can be measured as resistance change of the TES with a SQUID system



Signal readout

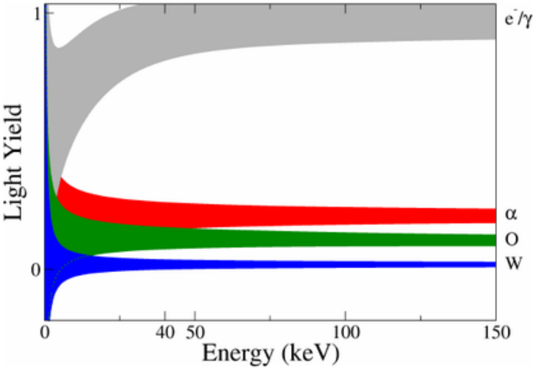
- TES are thin film systems (W in CRESST-II)
- operation in the step transition between the normal conducting state and the superconducting state
- temperature changes in μK scale can be measured as resistance change of the TES with a SQUID system



Event Discrimination

- Light emission depends on the interacting particle (α, β, γ or neutron/WIMP)
- event bands arise in the light yield vs. recoil energy scatterplot

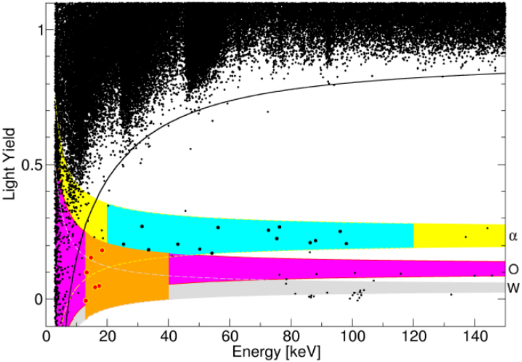
$$\text{Light Yield} = \frac{\text{Energy in the light channel}}{\text{Energy in the phonon channel}} \quad (4)$$



Event Discrimination

- Light emission depends on the interacting particle (α, β, γ or neutron/WIMP)
- event bands arise in the light yield vs. recoil energy scatterplot

$$\text{Light Yield} = \frac{\text{Energy in the light channel}}{\text{Energy in the phonon channel}} \quad (4)$$



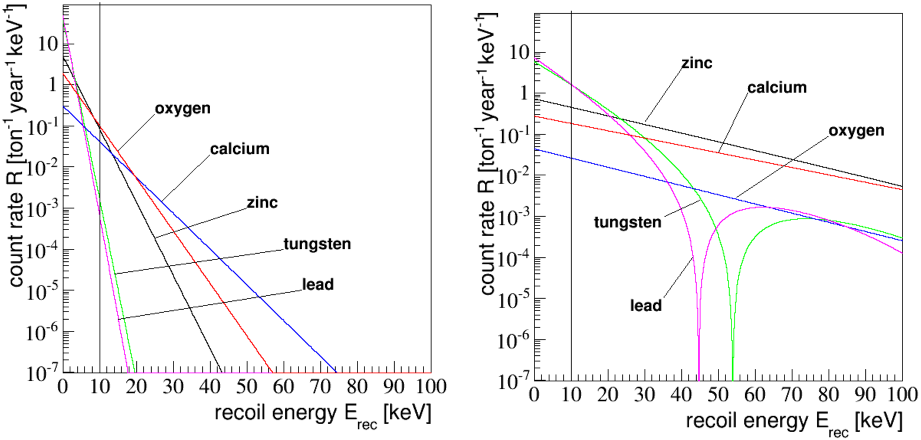
Summary

- located in a low background environment, scintillating bolometers can provide event-by event detection and identification
- all internal contaminations deposit their complete energy in the detector => distinct identification of every single event possible
- surface/external events that do not deposit their full energy in the detector can be misidentified and leak in the region of interest
- excess signal was measured in CRESST run33, may be explained by not identified surface contaminations

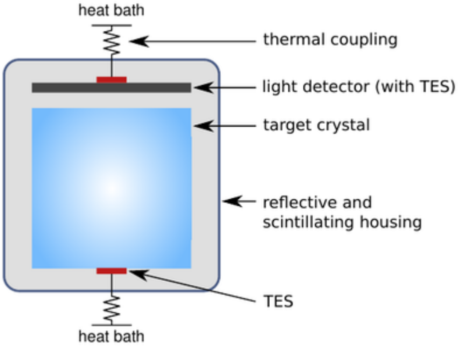
Thank you!

BACK UP

Expected Detection Rate

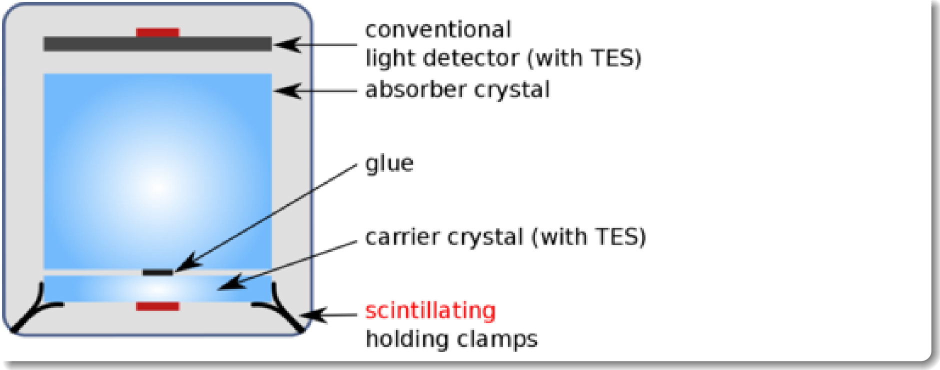


Conventional Detector Modules

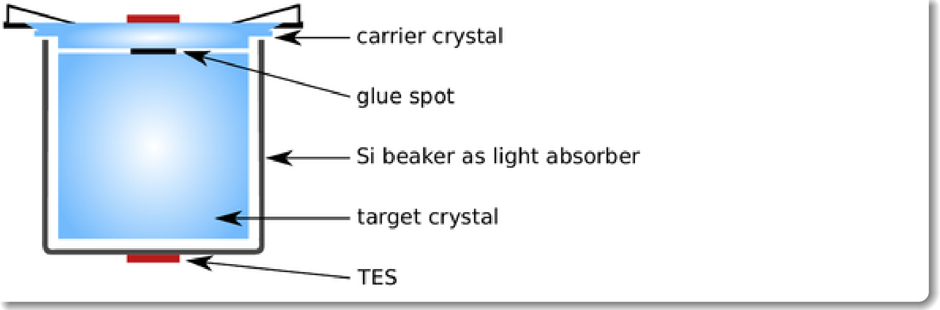


- A CRESST detector module consists of a scintillating absorber crystal ($CaWO_4$) and a spatially separated light detector (Silicon on Sapphire, SOS)
- Energy deposition in the absorbing scintillator crystal produces phonons and light => Scintillating Bolometer
- Transition Edge Sensors (TES) are used to measure the deposited energy as heat (both channels)

New Detector Modules



New Detector Modules



New Detector Modules