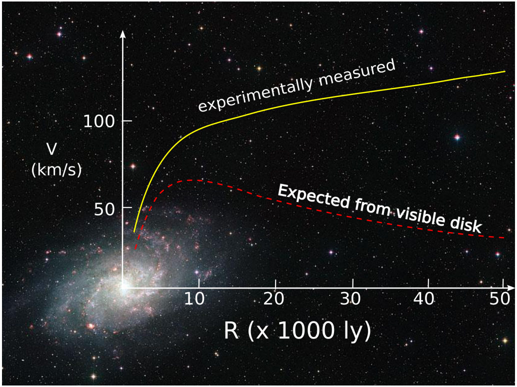
IMPRS Young Scientist Workshop
July 2015

The quest for Dark Matter

Nahuel Ferreiro Iachellini

Outline

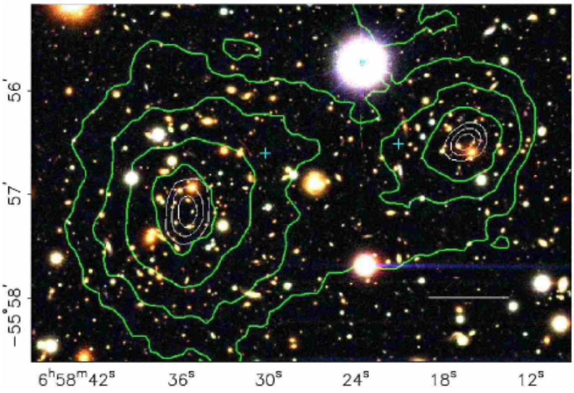
Motivation for Dark Matter - 33 Spiral Galaxy



The velocity distribution of visible matter does not follow the keplerian law $R^{-\frac{1}{2}}$. This mismatch can be solved accounting for additional (invisible) matter distributed in the galaxy.

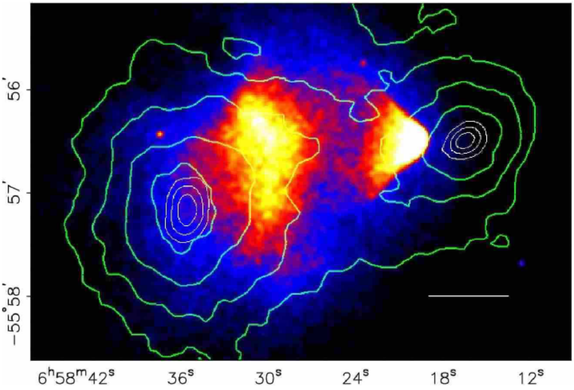
arXiv:astro-ph/9909252

Motivation for Dark Matter - The Bullet Cluster



Gravitational lensing is the light deflection caused by a mass distribution. This effect can be exploited to infer about the gravitational potential (green lines).

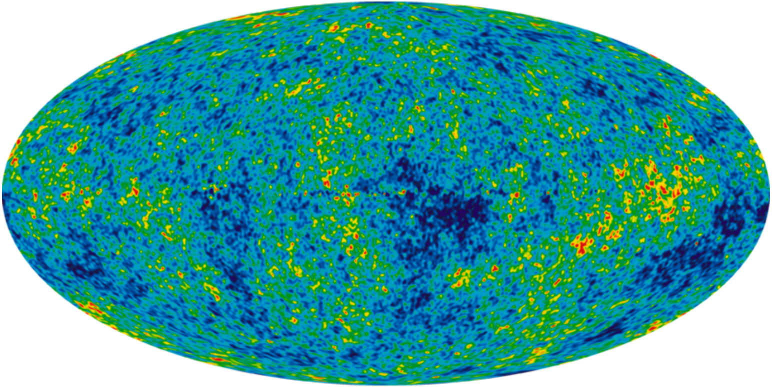
Motivation for Dark Matter - The Bullet Cluster



X-rays image shows the gaseous mass distribution, the dominant contribution among visible matter. Yet the two distributions overlay neither stars nor gravitational centers.

arXiv:astro-ph/0608407

Motivation for Dark Matter - CMB



The CMB appears as a black body at 2.728K. Fluctuations of the temperature are present in the order of $100\mu K$. These are originated by red-shift and probe the matter distribution some 13.7 billion years ago.

http://map.gsfc.nasa.gov

Dark Matter Candidates - WIMPs

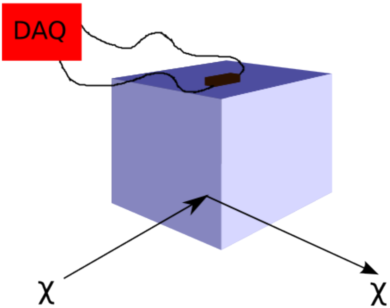
Starting (sad) point: we do not know dark matter!
Despite the evidences for its existence we have no knowledge about its nature.
What we know:

- Roughly 25% of the Universe is made out of dark matter
- Dark matter needs to be cold in order to participate to structures formation
- Dark matter particles need to be stable, or at least the lightest particles

WIMPs: the Weakly Interactive Massive Particles are a class of particles which do not interact any stronger than the weak force. Created right after the Big Bang, these particles are believed to be thermally created and, as the universe cooled, their number was "frozen out". Many theories predict WIMPs particles, i.e. Supersymmetry and its Lightest Super Partner.
There are many other theories which involve new exotic particles which could account for dark matter (Axions, WIMPzillas, gravitino...)

Direct Detection - Interaction rate

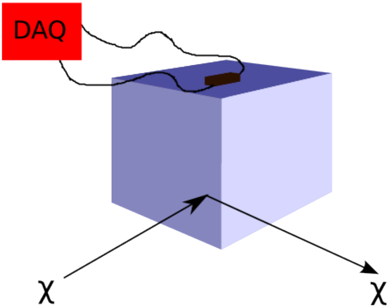
R total count rate
Φ_χ WIMPs flux
N_T number of target nuclei
σ cross-section



$$R = \Phi_\chi \cdot N_T \cdot \sigma$$

Direct Detection - Interaction rate

R total count rate
Φ_χ WIMPs flux
N_T number of target nuclei
σ cross-section
v WIMPs velocity
ρ_χ WIMPs density
m_χ WIMPs mass
E_R recoil energy
m_N target nuclear mass

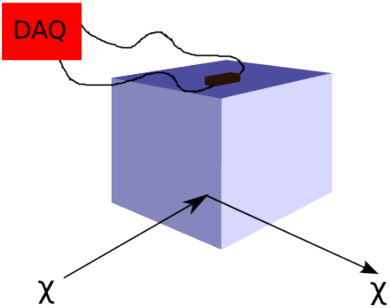


$$R = \Phi_\chi \cdot N_T \cdot \sigma$$

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

Direct Detection - Interaction rate

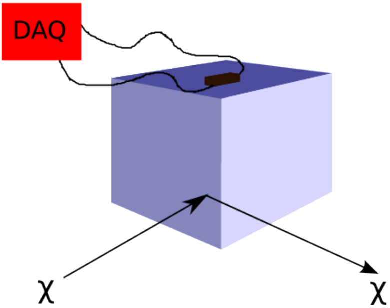
R total count rate
Φ_χ WIMPs flux
N_T number of target nuclei
σ cross-section
v WIMPs velocity
ρ_χ WIMPs density
m_χ WIMPs mass
E_R recoil energy
m_N target nuclear mass



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

$$\frac{d\sigma}{dE_R} \propto \sigma_0 F^2(E_R) \qquad \sigma_0 \propto A^2$$

R total count rate
Φ_χ WIMPs flux
N_T number of target nuclei
σ cross-section
v WIMPs velocity
ρ_χ WIMPs density
m_χ WIMPs mass
E_R recoil energy
m_N target nuclear mass

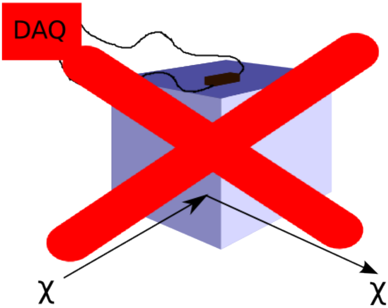


Let's put in some numbers

$$m_\chi = 100 GeV \qquad \rho_\chi = 0.3 GeV/cm^3 \qquad \sigma_0 = 10^{-42} cm^2$$

$$A = 131(Xe) \qquad E_{th} = 40 keV \Rightarrow R \simeq 10^{-1} counts/kg/day$$

R total count rate
Φ_χ WIMPs flux
N_T number of target nuclei
σ cross-section
v WIMPs velocity
ρ_χ WIMPs density
m_χ WIMPs mass
E_R recoil energy
m_N target nuclear mass

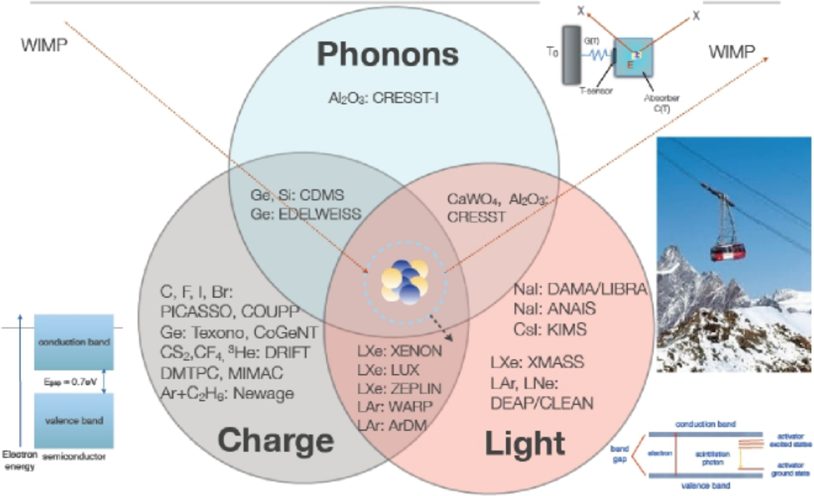


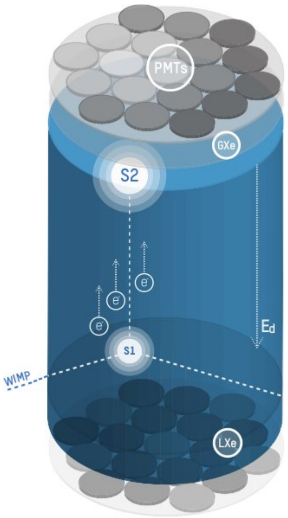
Let's put in some numbers

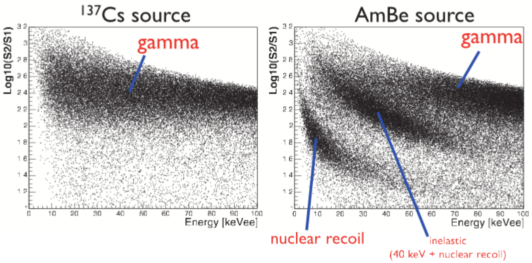
$$m_\chi = 100 GeV \qquad \rho_\chi = 0.3 GeV/cm^3 \qquad \sigma_0 = 10^{-42} cm^2$$

$$A = 131(Xe) \qquad E_{th} = 40 keV \Rightarrow R \simeq 10^{-1} counts/kg/day$$

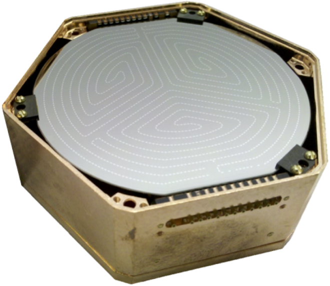
Experimental Techniques

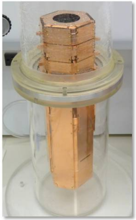


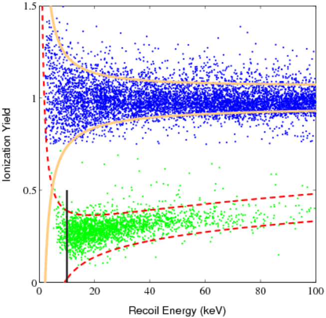




- Two arrays of PMTs are faced to the LXe tank
- Electric fields are applied across the liquid and gaseous phase
- Read-out of charge (S2) and light (S1)
- The ratio S2/S1 allows events identification

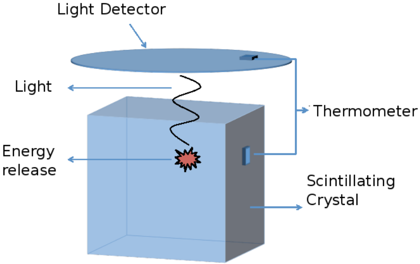






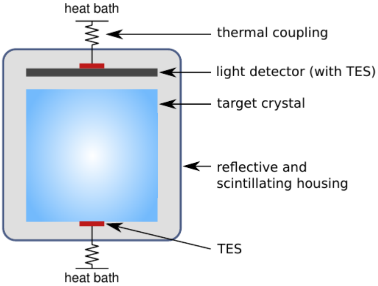
- Germanium crystals are equipped with phonon and charge-ionization sensors
- The phonon channel measures the event's energy
- The charge-to-phonon ratio allows events discrimination

Experimental Techniques - Phonon-light in CRESST



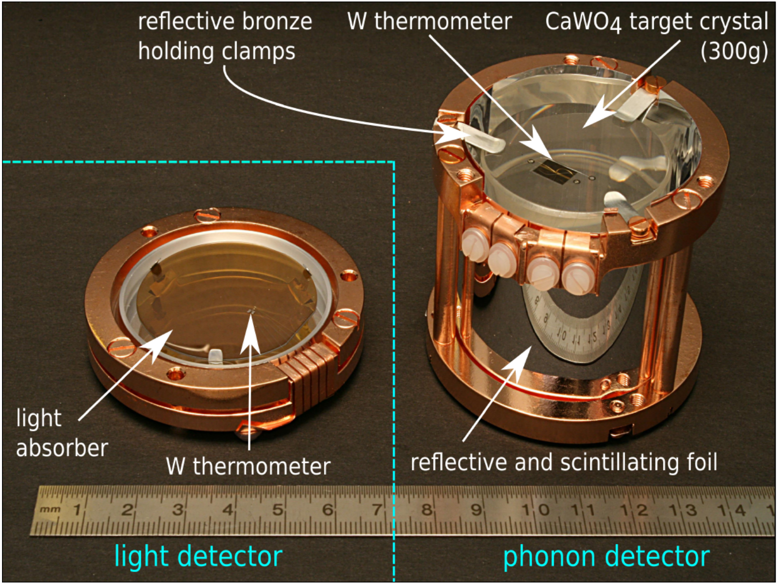
- A scintillating crystal (absorber) is operated at $\sim$15mK
- Energy release within the absorber causes a temperature raise AND scintillation light emission
- The temperature raise is measured via Transition Edge Sensor
- A second detector, operated the same way as the absorber, is dedicated to the light measurement

CRESST - Conventional design

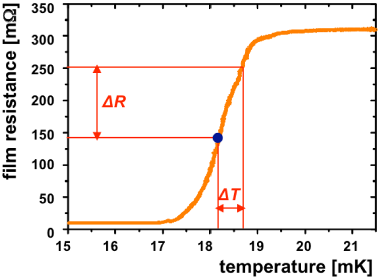


- $\sim$ 300g crystal made out of $CaWO_4$
- Reflecting and scintillating housing to increase light collection AND veto events
- Light detector made out of Si (or Silicon on Sapphire). Sensible down to 5eV energies (few photons of blue light)
- The light-to-phonon ratio provides an event-by-event discrimination

CRESST - Conventional design



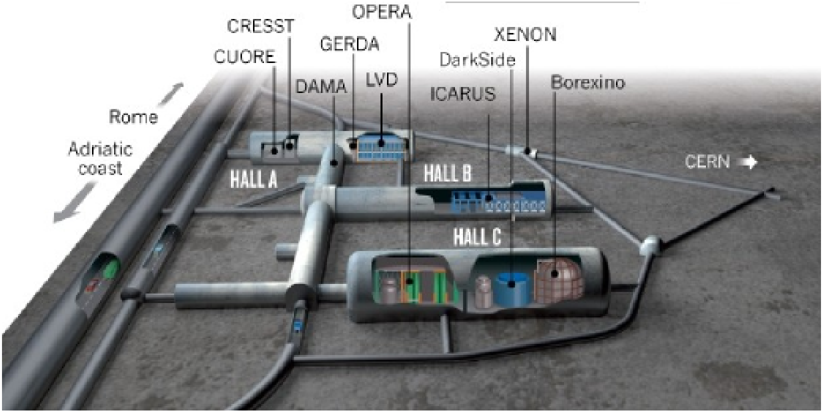
CRESST - Transition Edge Sensors



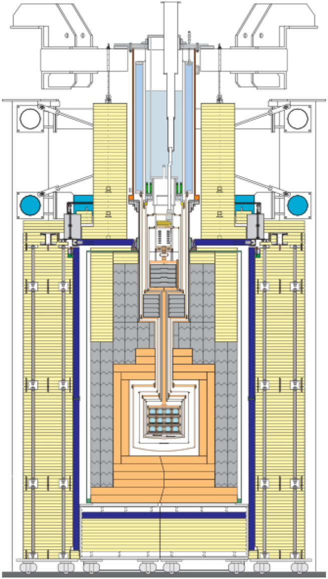
- TES in CRESST are thin tungsten films
- Their production is addressed to a transition temperature around 15mK
- A stability control system keeps the temperature of the films in the middle of the transition
- Particle events create phonons in the absorber, which are (partially) transmitted to the film
- The temperature raise ($\sim \mu$K) translates to a resistance variation

CRESST - The installation

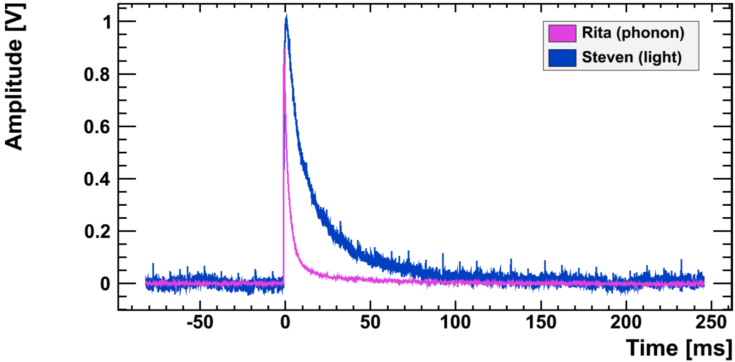
- CRESST is hosted at Laboratori Nazionali del Gran Sasso underground facility in Italy
- 3150m equivalent water of rocks shield against cosmic radiation
- The muon flux is reduced by six orders of magnitude



- CRESST detectors are accommodated in a dilution refrigerator whose base temperature is below 10mK
- Several shields provide isolation from the environmental radioactivity
- Muon veto surrounds the installation

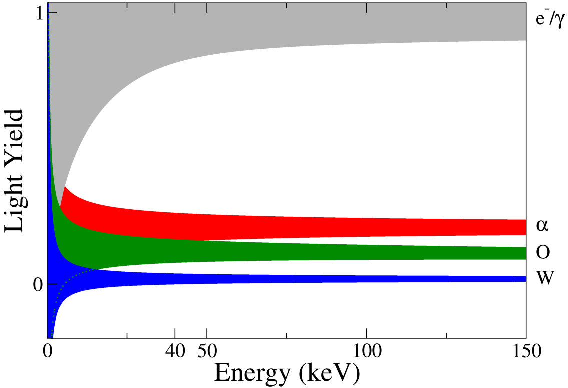


CRESST - Double read-out



When a particle event occurs most of the energy is converted into phonons (phonon channel). The part converted into photons is measured by the light detector (light channel). Pulses amplitudes are proportional to the respective deposited energies.

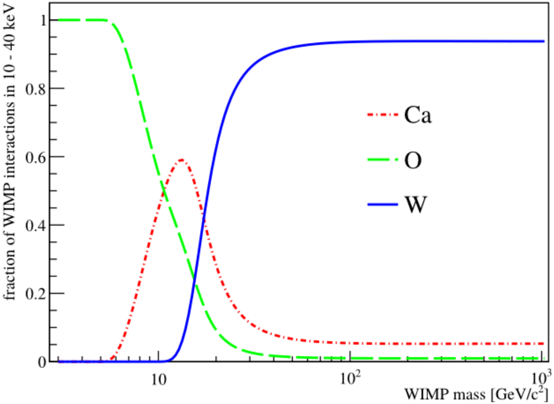
CRESST - Event discrimination



$$LY = \frac{E_{light}}{E_{phonon}}$$

The LY is a quantity specific for the kind of interaction happened in the absorber. It is convetionally set to 1 for e^{-}/γ events

CRESST



Because of multi-target absorbers, WIMPs are expected to interact differently with different nuclei

Thanks for your attention