Monopoles, Edelweiss and Automated cryostats with Miguel

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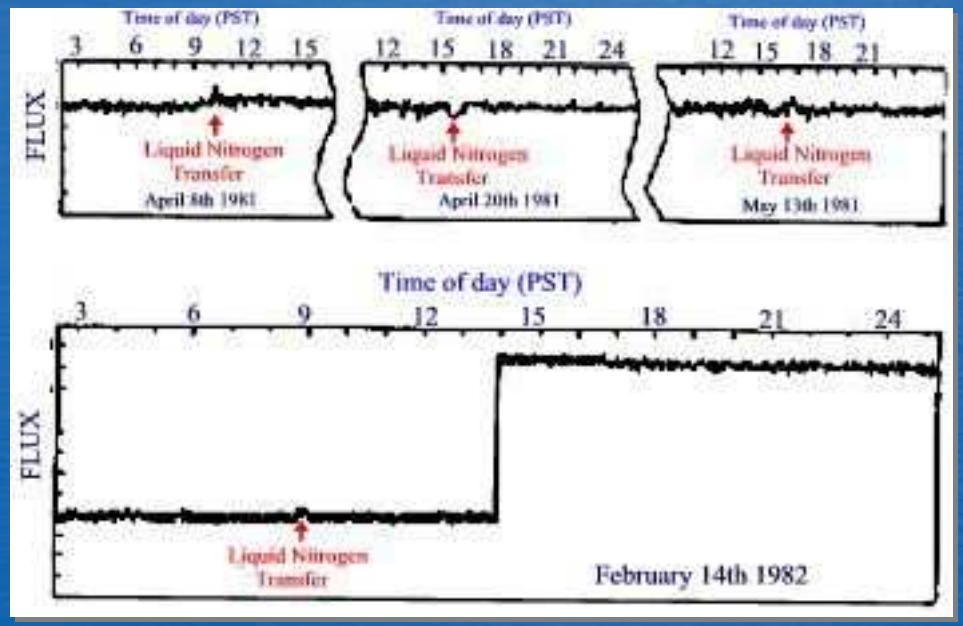
First discussions with Miguel 1982: the Cabrera monopole

- One super-conducting ring detector 20 cm^2
- Sign monopole by $2\Phi_0$ flux change
- One event had the exact characteristics of the signal expected for a monopole traversing the coil
- No obvious background factors could account for the signal observed
  Blas Cabrera, Phys. Rev. Lett. ***48*** *(1982) 1378*



1983: Miguel's gradiometer

- Strategy to improve the detection efficiency and background rejection of initial Cabrera experiment
- Miguel (together with J. Hammam) proposed to use a closed 6-face gradiometer
- A monopole should then cross exactly two phases with $2\Phi_0$ flux change
- Better rejection of spurious external flux changes
- IBM as a competitor (Fig.)

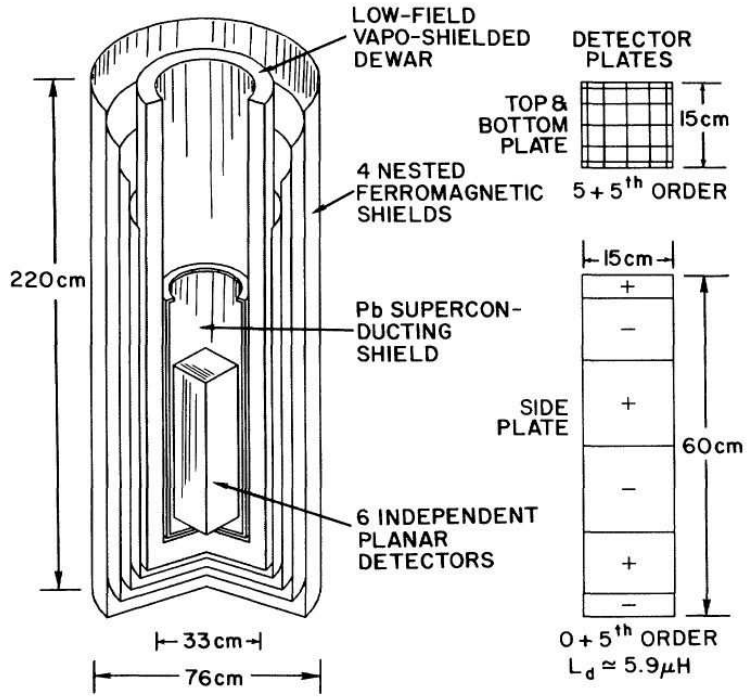
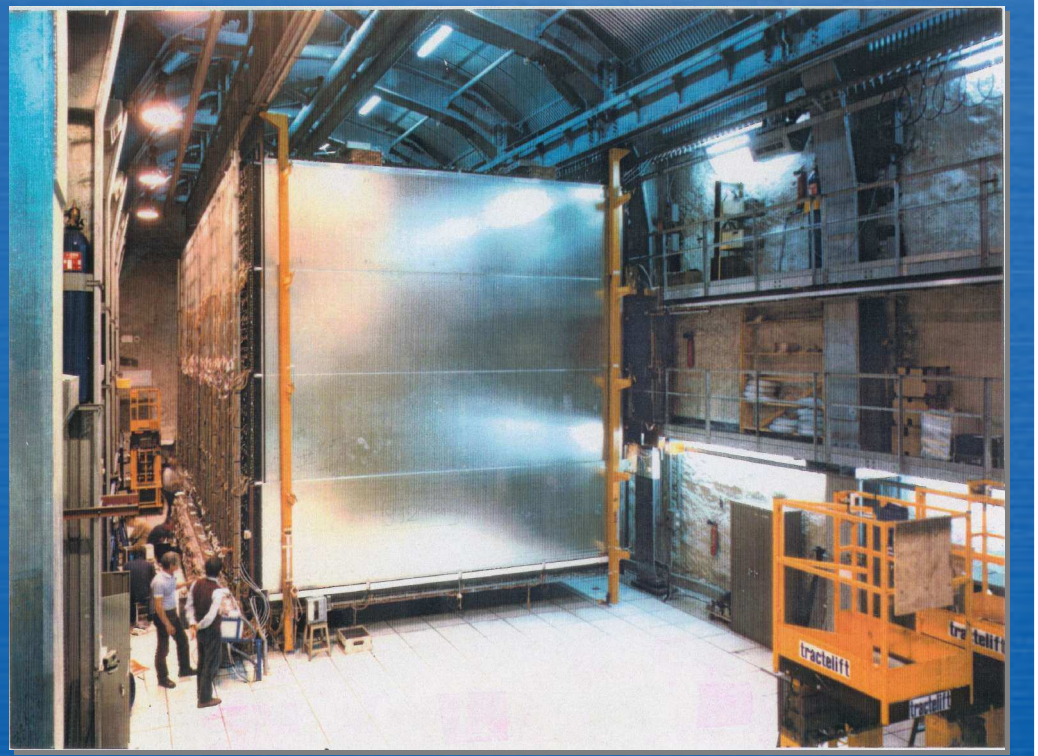


FIG. 1. Fully coincident 0.1-m^2 superconductive monopole detector consisting of six independent planar high-order gradiometer plates monitored by six separate SQUID's (not shown). An nth-order gradiometer is one which is insensitive to the $(n-1)$st spatial derivative of the field.

Use Frejus proton decay expt as a monopole detector

- The Frejus proton decay detector weighed ≈ 1000 tons and had about one million (!) electronic channels
- We used a subset of the Geiger cells to attempt a monopole detection
- Negative result
- Very large dedicated experiment, MACRO in the Gran Sasso underground laboratory: also a negative result, below the Parker limit (galactic B)



1930 : first evidence by F. Zwicky

In the early 1930's, **Fritz Zwicky** had noted that galaxies were often assembled in clusters.

In the Coma cluster on the right picture, he measured the velocity of individual galaxies…

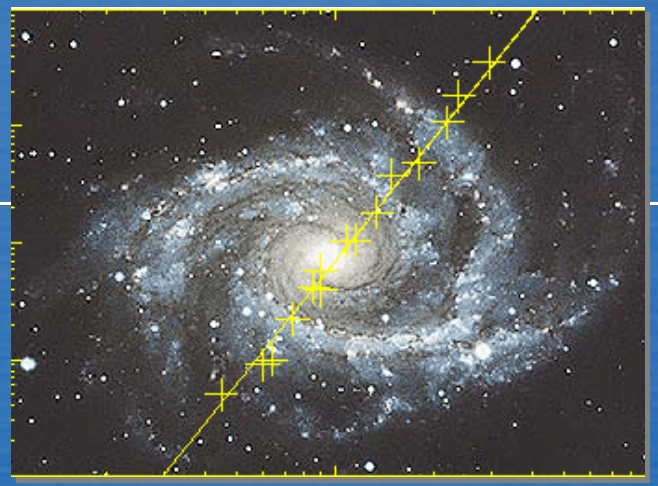
The speeds he measured were enormous.

$\Downarrow$

The galaxy cluster should have dispersed long ago, unless visible stars only represented ≈ 1% of the cluster mass.

Seventies : galaxy rotation curves

Spiral galaxies, such as our own Milky Way, are rotating.



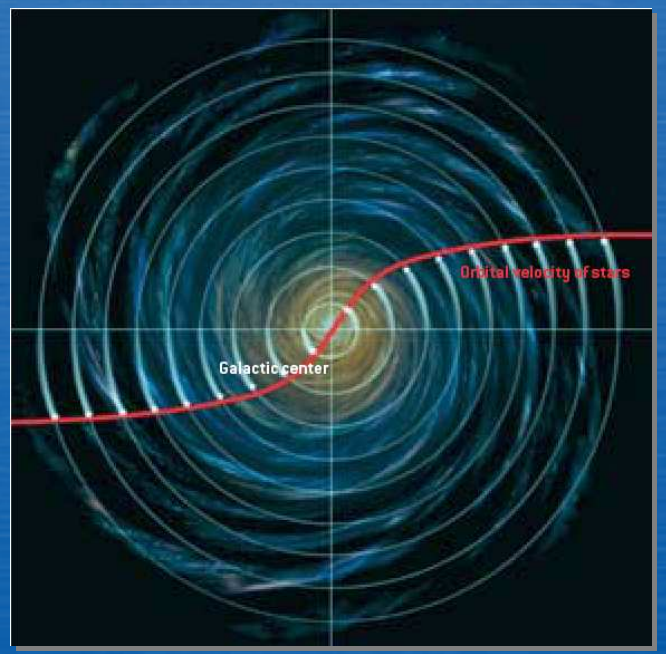
Surprise !

The rotation speed is not decreasing when the distance from the galactic center is increased, but keeps almost constant.

$\Downarrow$

Matter must extend far beyond the galactic visible part.

Speed of rotation

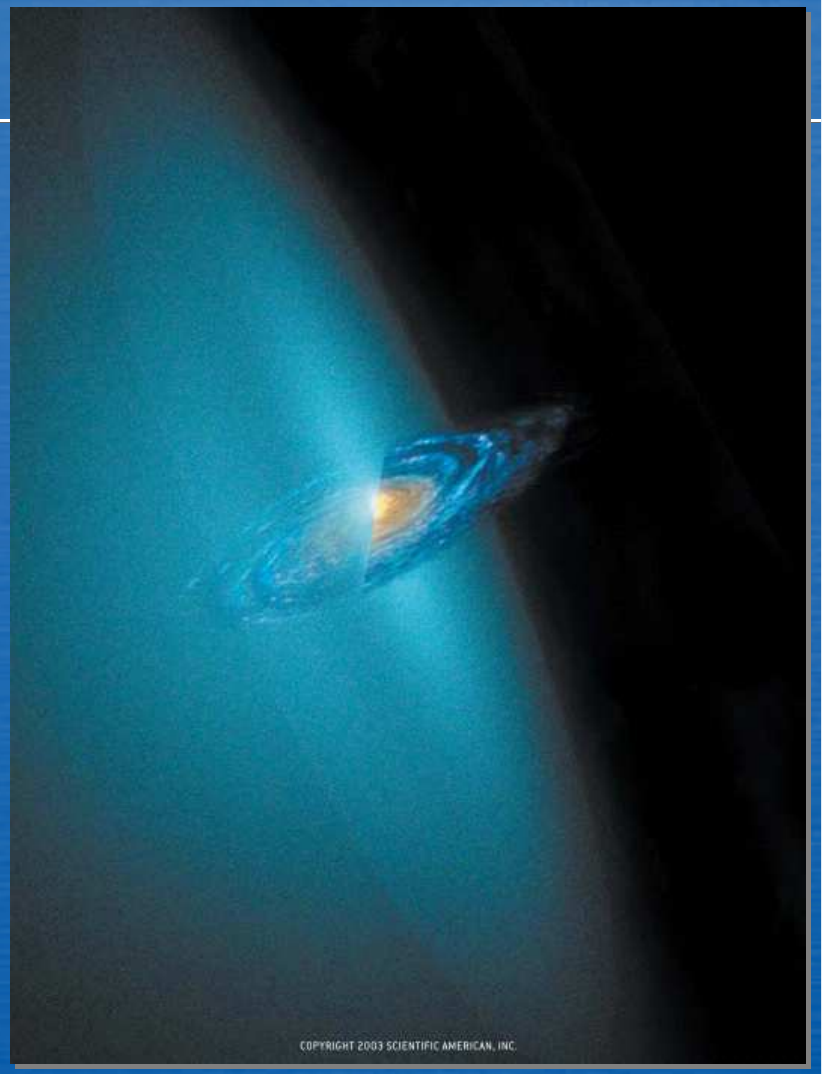


Galactic Dark Matter

Dark Matter could extend at radii 5 times larger than the observable (luminous) radius of a galaxy.

But what is it made of ? :

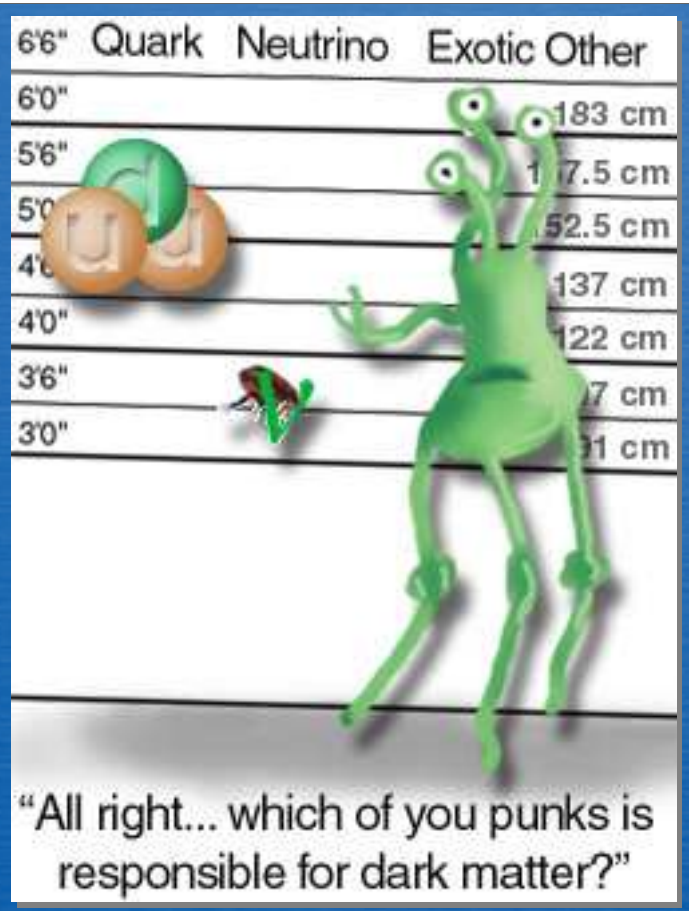
- gas ?
- dark stars (MACHOs) ?
- exotic particles ?



If not ordinary matter, then what ?

- **Neutrinos** ? No, far too light
- Would induce far too many interactions in our detectors
- New particles, **WIMPs**, predicted by particle theorists ?

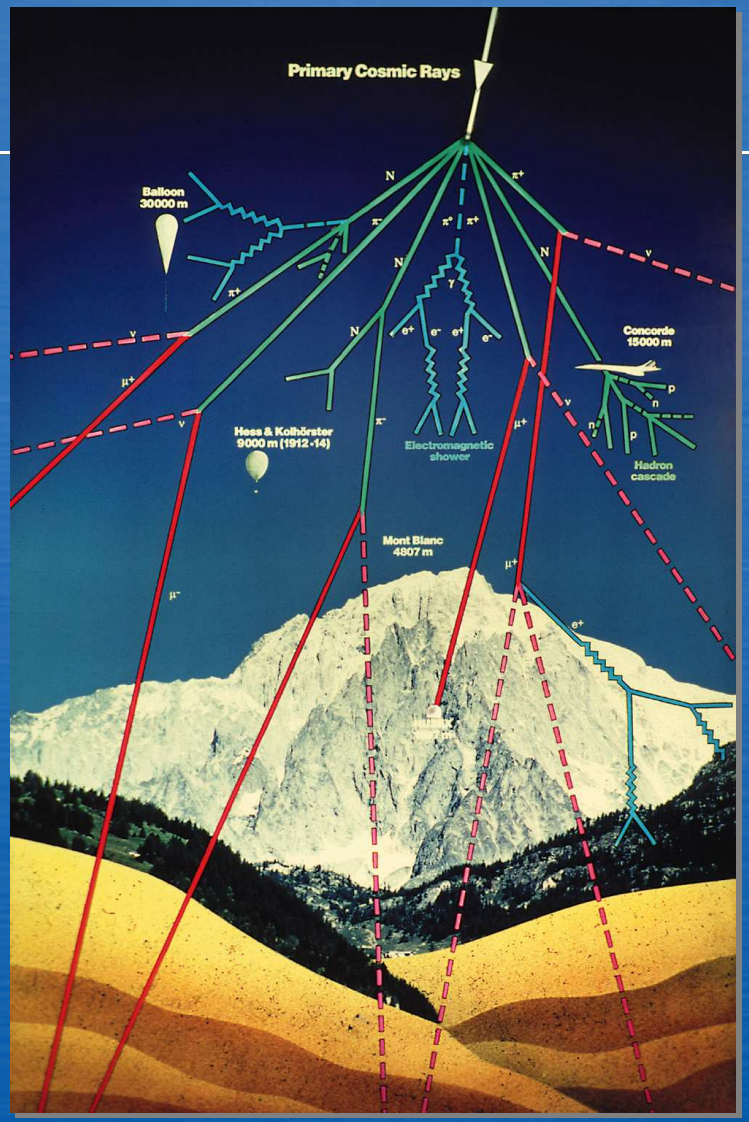
(WIMP = Weakly Interacting Massive Particle)



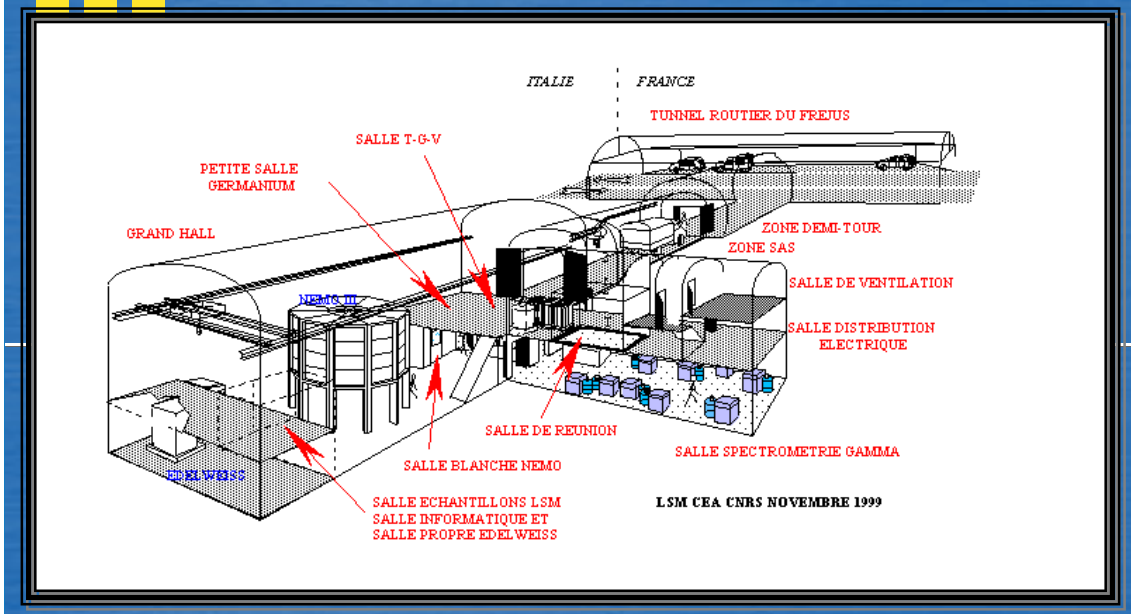
"All right... which of you punks is responsible for dark matter?"

Detecting WIMPs

To improve the sensitivity of experiments, it is mandatory :
- to hide underground to be protected from cosmic-rays (100 are crossing your body every second),
- to add a shield against rock natural radioactivity,
- to purify detector materials
- **to be able able to reject radioactive background**



CDMS, EDELWEISS and CRESST



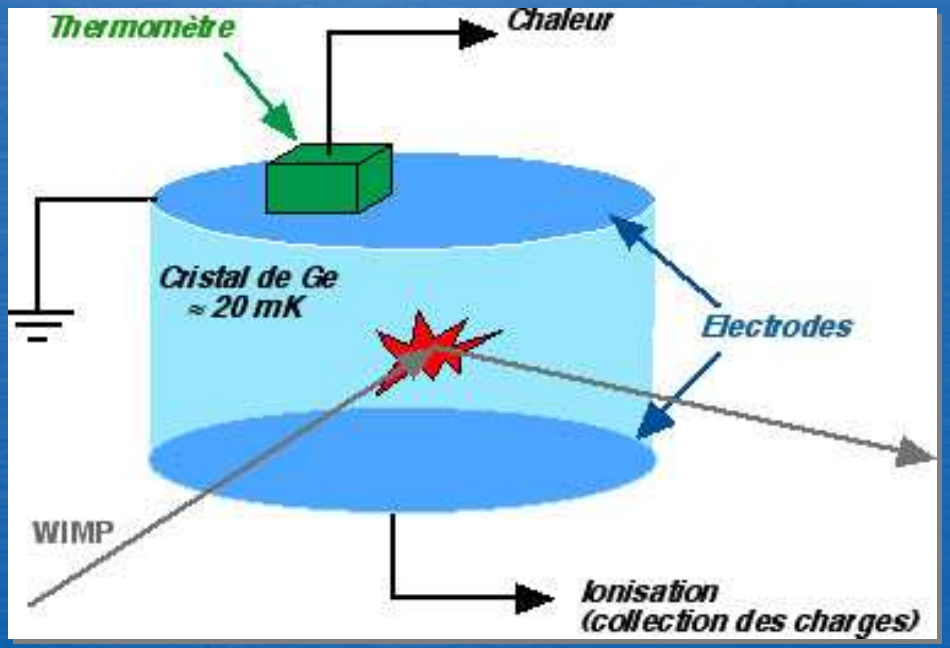
The Frejus underground laboratory. Less than 1 millionth of cosmic-rays manage to reach it.

The EDELWEISS experiment is shielded by more than 1600 m of rock, under the Alps.

CDMS (USA) and CRESST (Germany/UK) competitors are also shielded in underground labs.

An EDELWEISS detector

In an EDELWEISS detector, a WIMP collision :



An EDELWEISS detector

- leads to a **tiny temperature increase** (≈ 1 millionth of a degree !)

- generates an **electric signal of a few hundred electrons** three times **smaller than for natural radioactivity** (for the same energy transferred to the detector).

An EDELWEISS detector (2)

In the detector : Ge monocrystal, ultrapure material, a temperature increase of about one millionth of absolute degree.

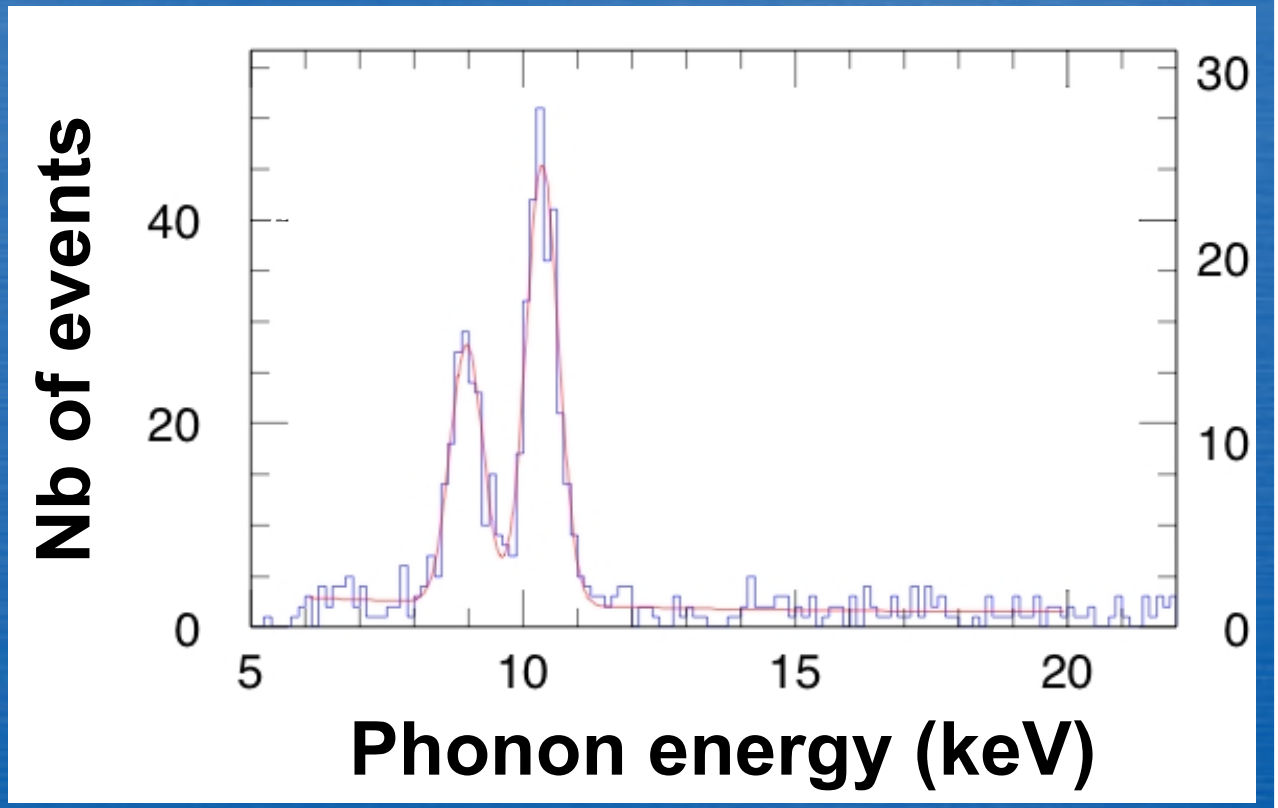
CDMS, CRESST and EDELWEISS are just starting to explore the domain of WIMPs and Supersymmetry…

Germanium detector of the EDELWEISS experiment.

EDELWEISS thermal detectors: excellent energy resolution

- Sub-keV energy resolution on phonon channels (down to 250 eV baseline, 350 eV FWHM at 10 keV)
- ≈1 keV FWHM on charge channels

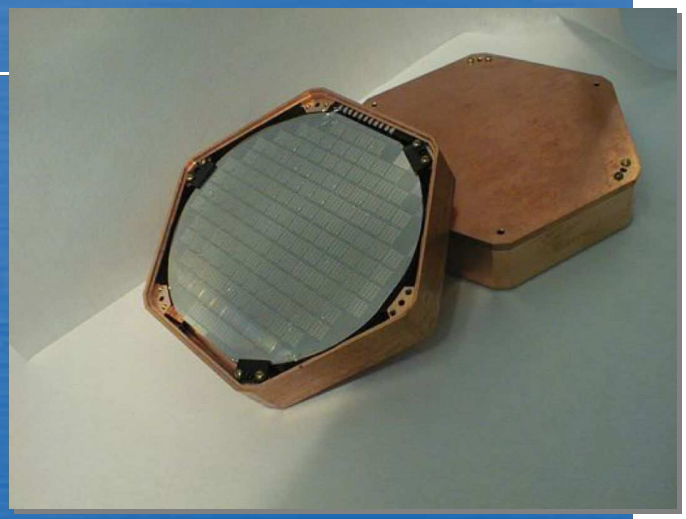
- **Background comprehension down to a few keV e.e.**

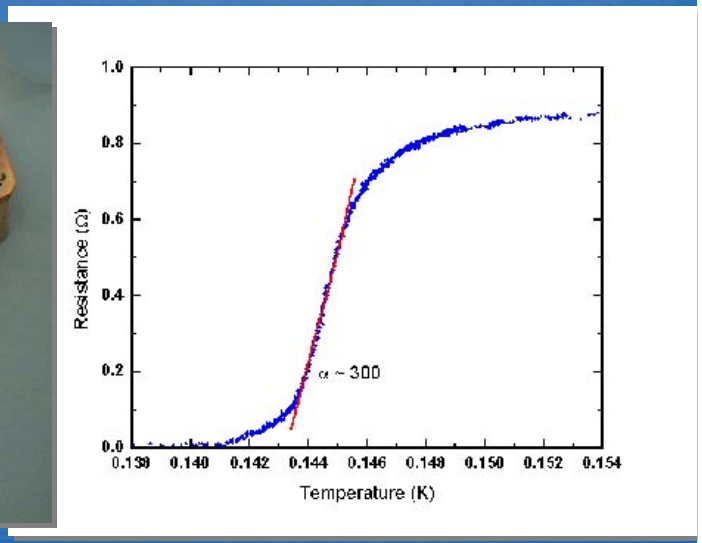


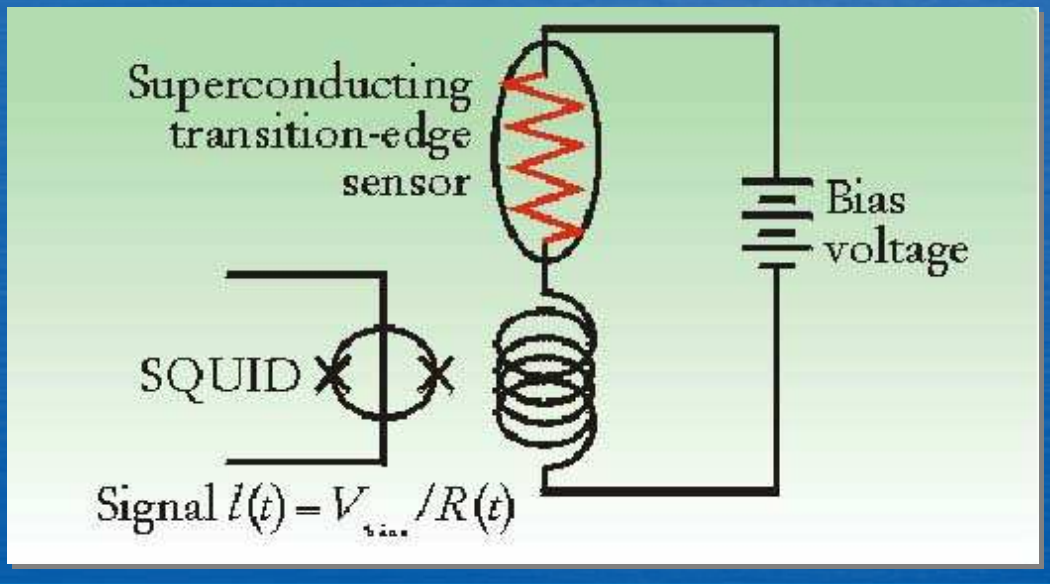
O. Martineau et al., astro-ph/0310657/

From MIT to TES sensors

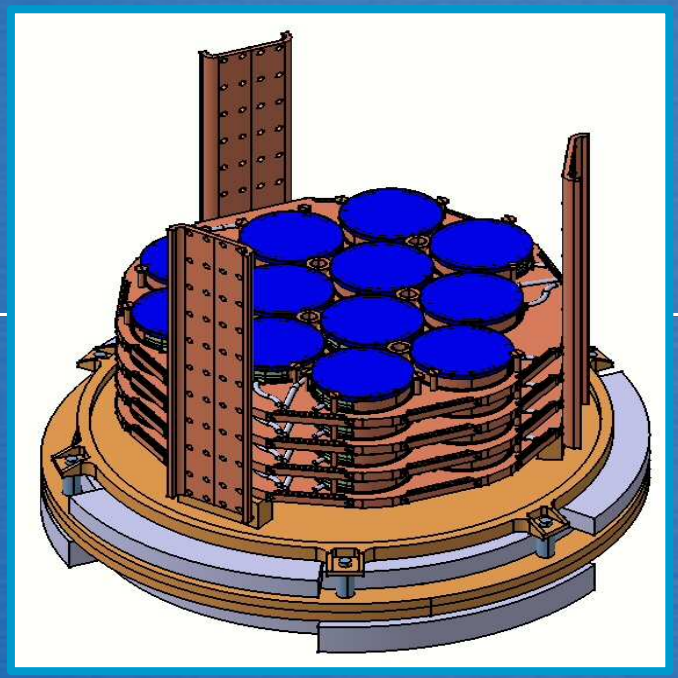
- alpha = T/R dR/dT of several hundreds (> 400 obtained by L. Dumoulin and M. Loidl in Edelweiss for AgAl samples)
- extreme sensitivity, but very low impedance => compulsory to use SQUIDs as readout







Edelweiss-II



March 2004: EDELWEISS-I ended

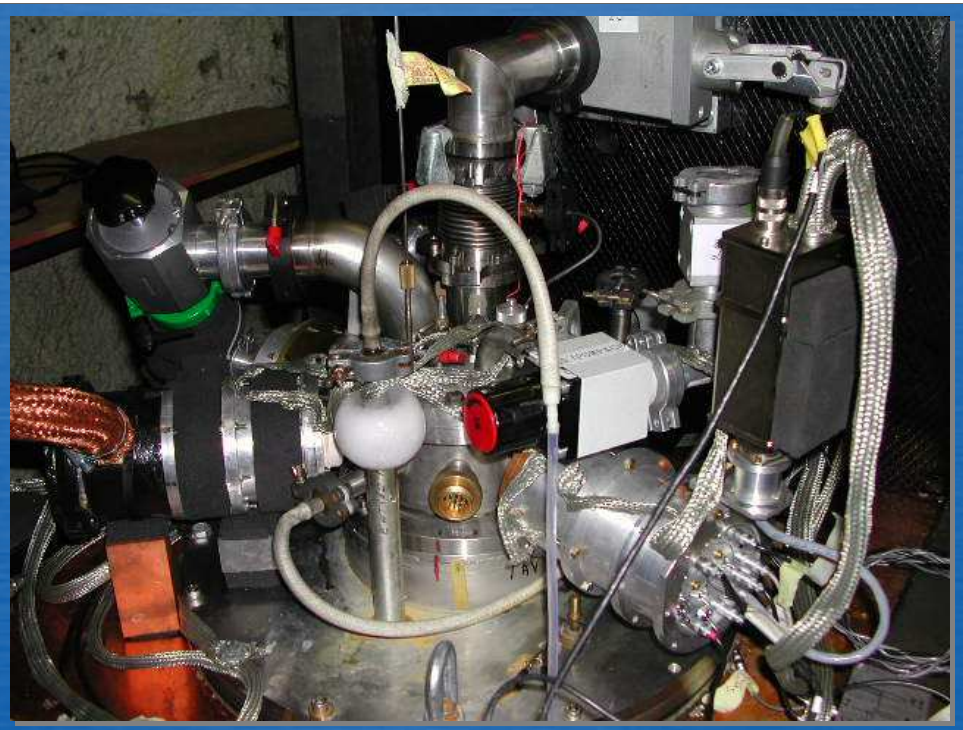
Install EDELWEISS-II with 21 x 320-g + 7 x 400-g Ge detectors

(≈ 10 kg germanium)

120 detector capacity (35 kg Ge)

Dilution : 8-10 mK 100-liter dilution cryostat, now installed in the Frejus laboratory

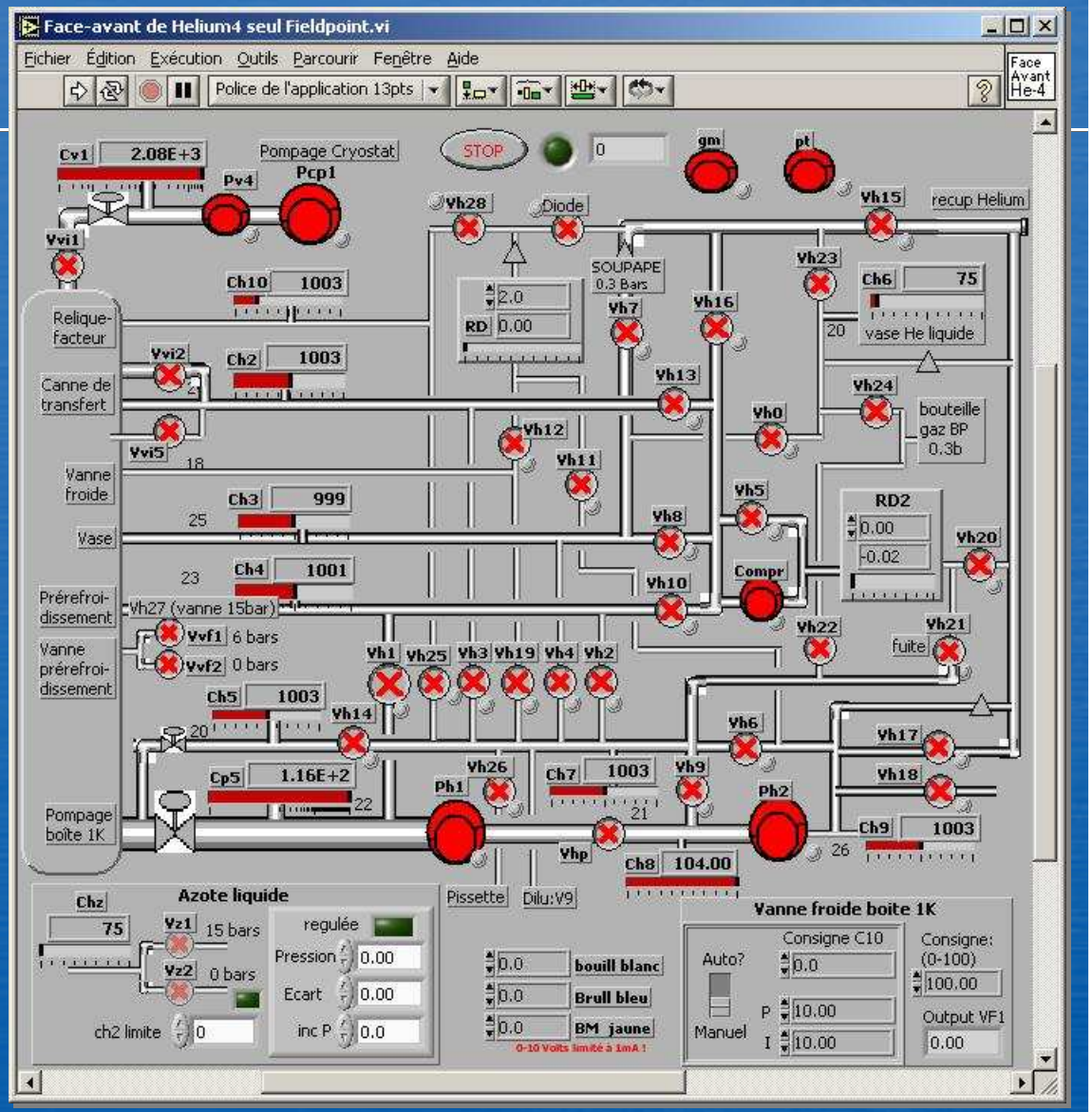
Automated cryostats (Patrick Pari, Edelweiss-I)



- Small and rather messy experiment, but best world sensitivity for WIMP search from 2001 to 2004 !

Automated cryostats

- From Edelweiss-I simple setup to Edelweiss-II much larger (100 liter) dilution cryostat
- Automated operation mandatory in remote site
- Links with Cryoconcepts



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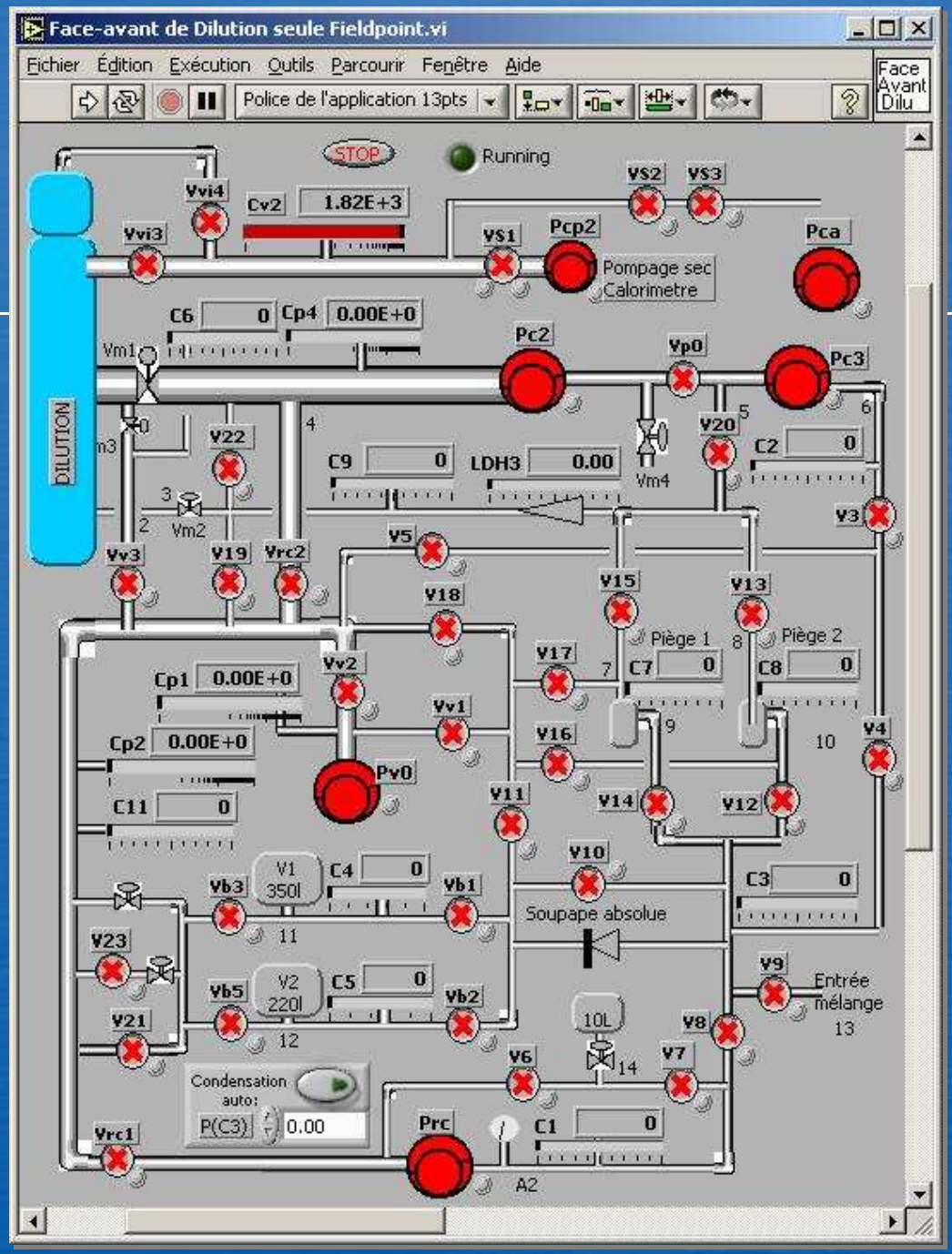
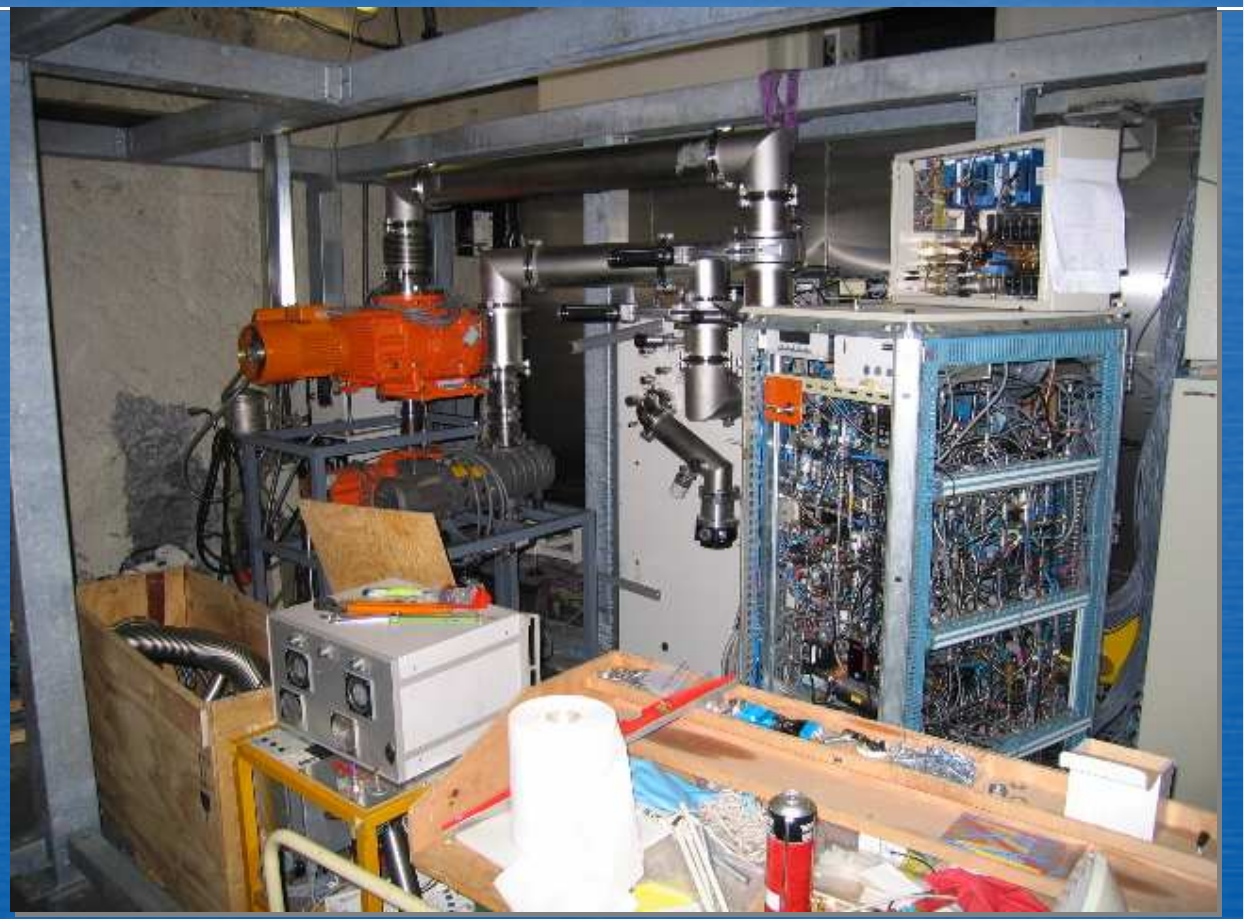


Automated cryostats

- The real stuff, installed in the Frejus underground laboratory
- New techniques developed: fully remote operation, pulsetubes, helium « caloduc », reversed cryostat



Automated cryostats

- Industrial solution also used by Miguel and Patrick in Cryoconcepts applications (LabVIEW, FieldPoint and Compact FieldPoint software and hardware)

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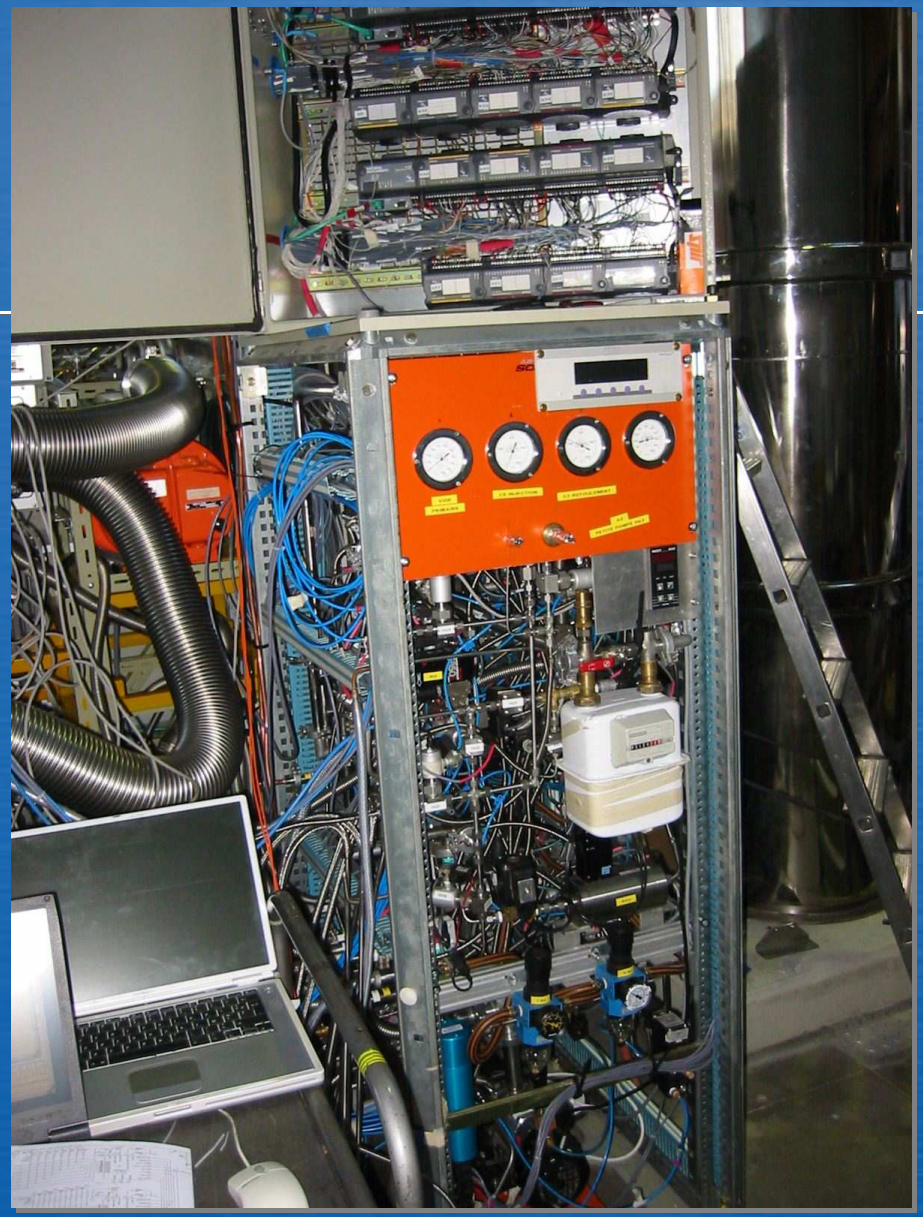

Automated R-T sample test bench with Miguel

- Automated test bench for magnetic samples from 300 K to 4K, and from 4K to 10-20 mK
- Completely automated, regulated and highly stabilized temperature controlled by a few thermometers (CERNOX, RuO_2, Ge)
- For example, temperature estimate: linear approximation not satisfying for Miguel
- Use instead Chebyshev polynomials
- Extreme care in the overlap region of different thermometers
- Control plateau and temperature fluctuations before accepting measurement
- Miguel soon controlled the whole programming system

Conclusion

- These are only a few examples of our interactions with Miguel
- Discussions with him were always enriching and opened new possibilities
- There was one drawback: we had to suffer his horrible tobacco, carefully manufactured by Miguel himself, and without any filter
- But we miss you very much, Miguel…