Dark Matter direct search with EDELWEISS and other experimental efforts at DPHPE/DAPNIA/IRFU

Gilles Gerbier

5ème Rencontre de l'IRFU

Saclay – may 14th 2014

European Underground Rare Event Calorimeter Array

Expérience pour DEtecter Les Wimps En SIte Souterrain

What do we look for ?

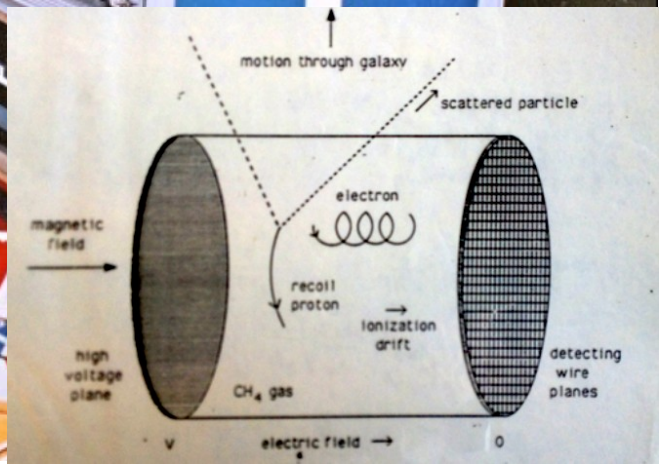
- Interactions with matter of low velocity (200 km/s) massive (>1 GeV) particles = WIMP's
- => dominant channel = elastic scattering off nuclei
- Low energy < 100 keV, the lower is M_W the lower is the mean recoil energy
- Low count rate < 1 evt / 100kg.d => need to
  - Go underground to avoid CR muon induced background
  - Shield against local radioactivity
  - Discriminate electron recoils from nuclear recoils

Short historical overview 1

- The story starts around 1986-1987
- Cold dark matter as elementary particles was exotic concept attracting exotic people
- What was best detector ?
  - First hunt was for « cosmions » = low mass high X sections particles captured in sun (Spiro, Rich,Tao, GG)
    - TPC with Hydrogen with mag field for 1 keV tracks

PHD student OB

Few liters prototype TPC by A Breskin filled with Hydrogen

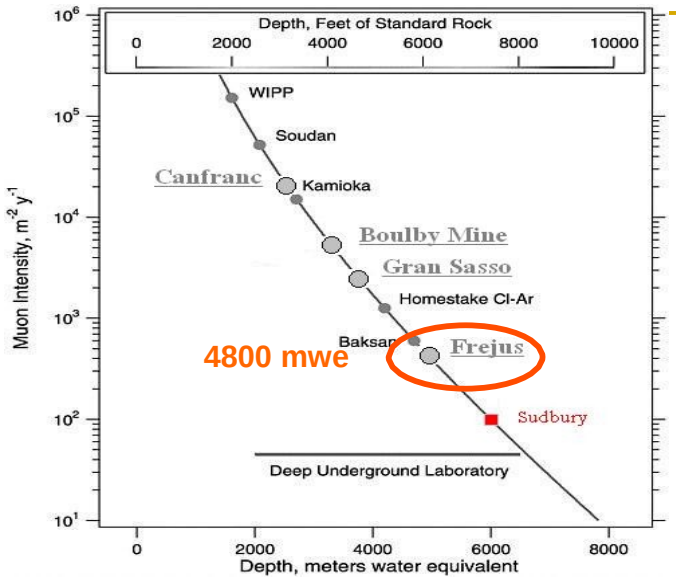


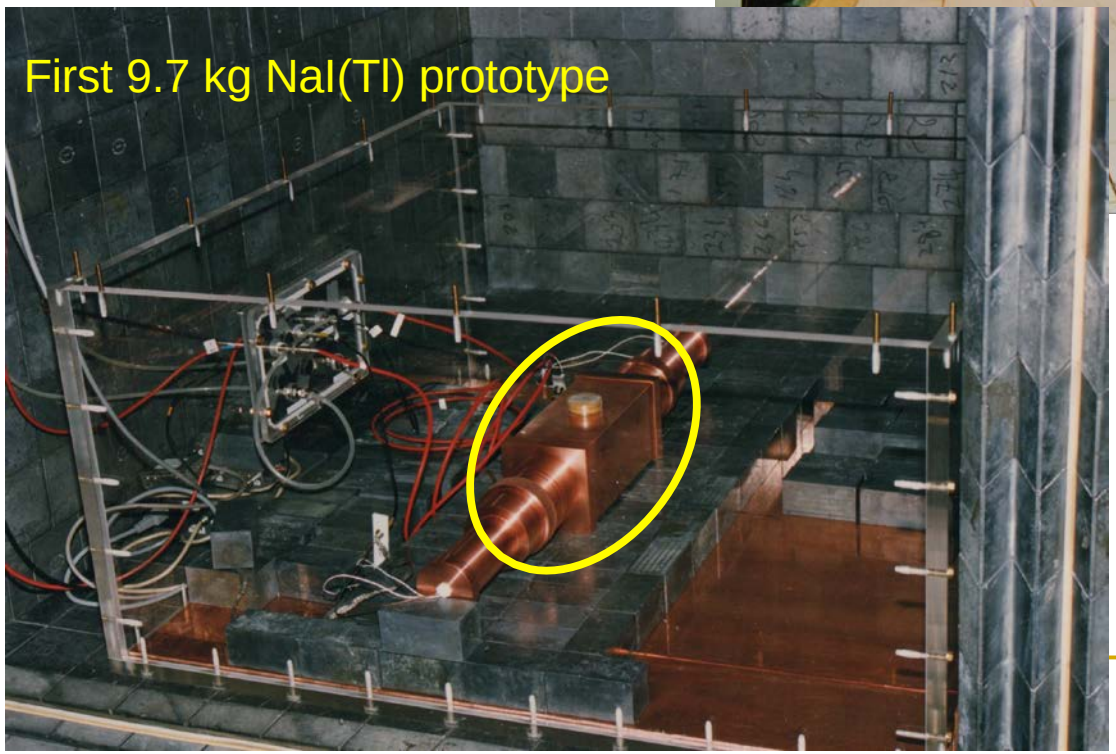
Short historical overview 1

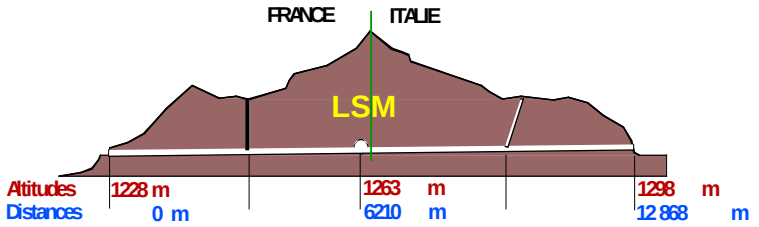
- The story starts around 1986-1987
- Cold dark matter as elementary particles was exotic concept attracting exotic people
- What was best detector ?
  - First hunt was for « cosmions » = low mass high X sections particles captured in sun (Spiro, Rich,Tao, GG)
    - TPC with Hydrogen with mag field for 1 keV tracks
    - Silicon detector : first collaboration with US, calibration of QF at Bruyères

Short historical overview 1

- The story starts around 1986-1987
- Cold dark matter as elementary particles was exotic concept attracting exotic people
- What was best detector ?
  - First hunt was for « cosmions » = low mass high X sections particles captured in sun (Spiro, Rich,Tao, GG)
    - TPC with Hydrogen with mag field for 1 keV tracks :
    - Silicon detector : first collaboration with US, calibration of QF at Bruyères
  - Scintillator NaI(Tl) (Tao, Mosca, GG)
    - Calibrations of Quenching Factor and Pulse Shape Discrimination at Bruyères
    - First underground measurements at LSM



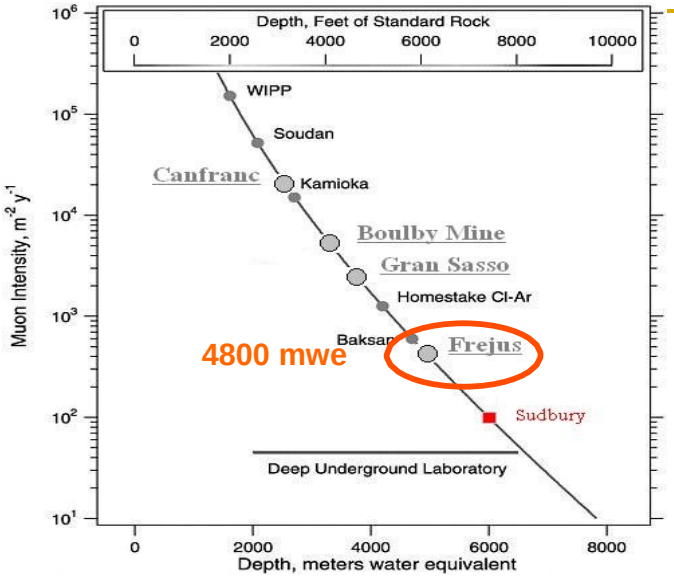


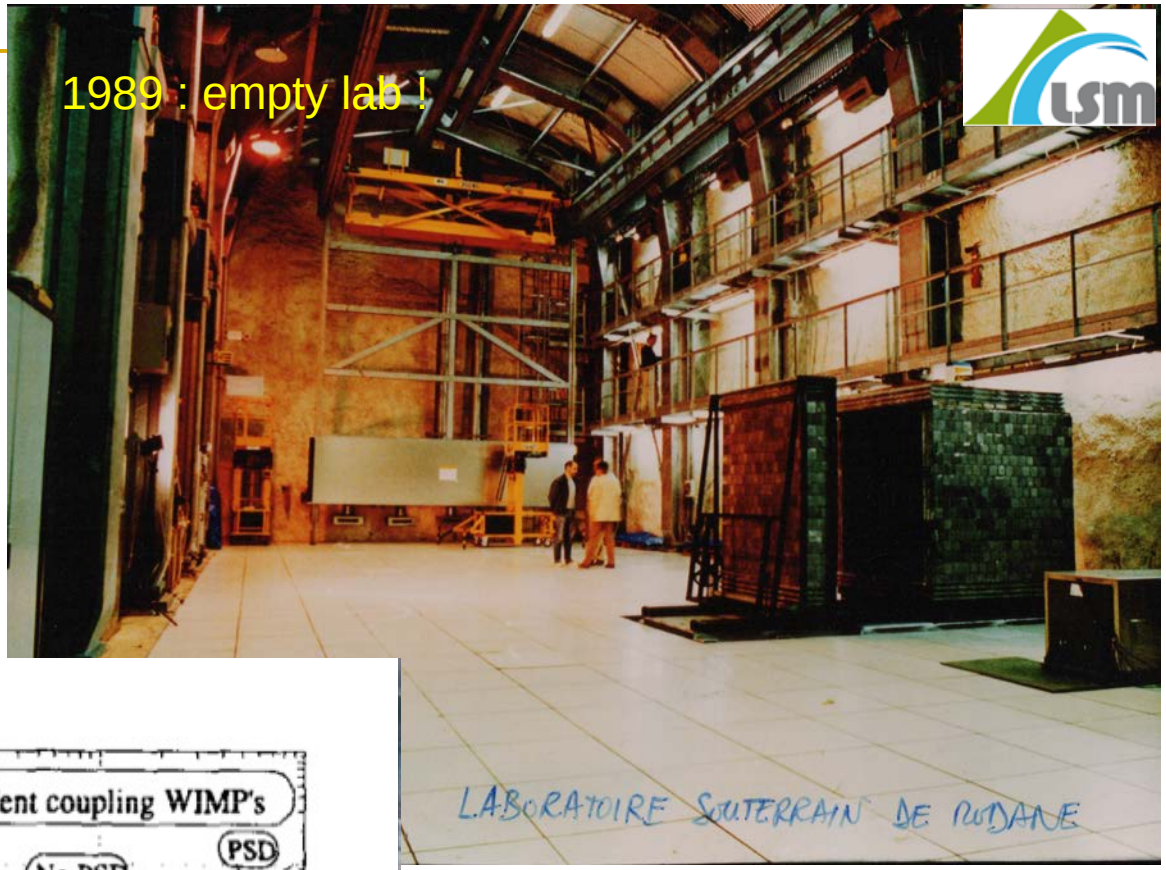


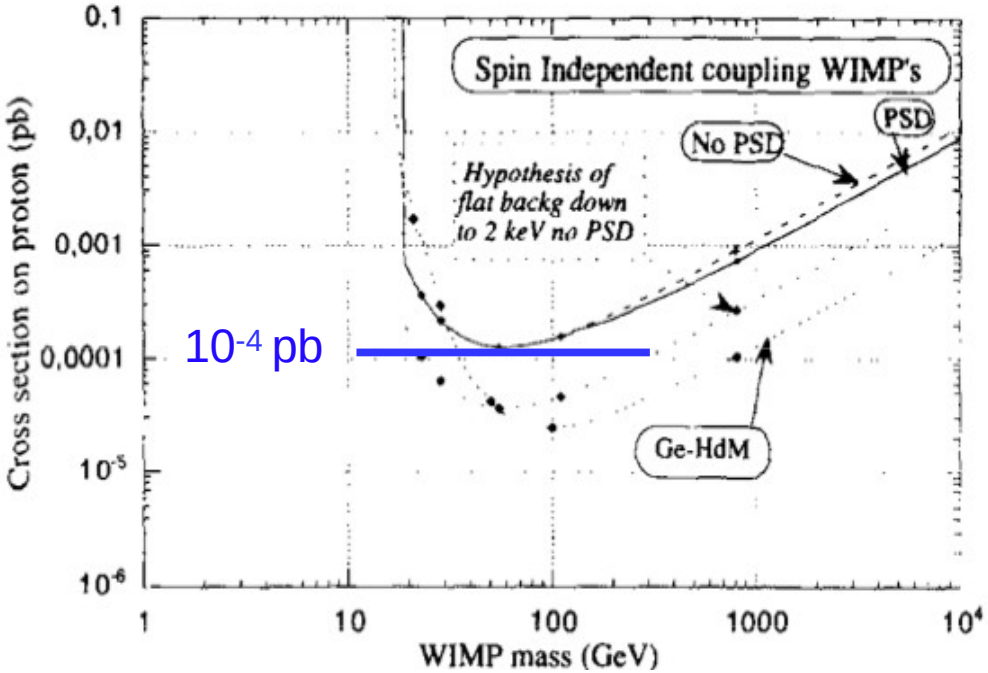
Frejus tunnel in Alps

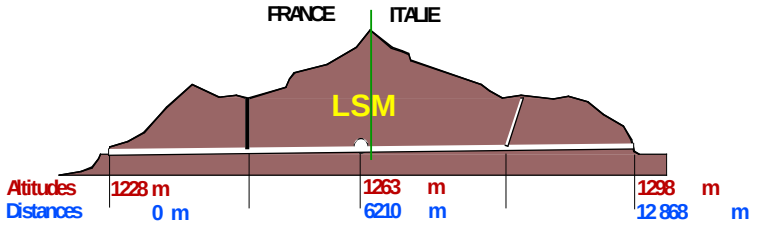
Short historical overview 1

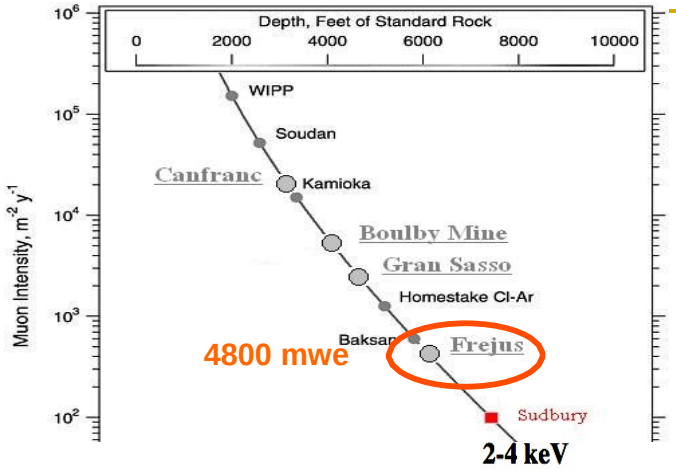
- The story starts started around 1986-1987
- Cold dark matter as elementary particles was exotic concept attracting exotic people
- What was best detector ?
  - First hunt was for « cosmions » = low mass high X sections particles captured in sun (Spiro, Rich,Tao, GG)
    - TPC with Hydrogen with mag field for 1 keV tracks :
    - Silicon detector : first collaboration with US, calibration of QF at Bruyères
  - Scintillator NaI (Tao, Mosca, GG)
    - Calibrations of Quenching Factor and Pulse Shape Discrimination at Bruyères
    - First underground measurements at LSM
    - 1990 collaboration started with Roma group => and stopped end 1995 / 1999


Depth, Feet of Standard Rock
0
2000
4000
6000
8000
10000
WIPP
Soudan
Canfranc
Kamioka
Boulby Mine
Gran Sasso
Homestake Cl-Ar
Baksan
Frejus
Sudbury
Deep Underground Laboratory
Muon Intensity, m-2 y-1
Depth, meters water equivalent
4800 mwe

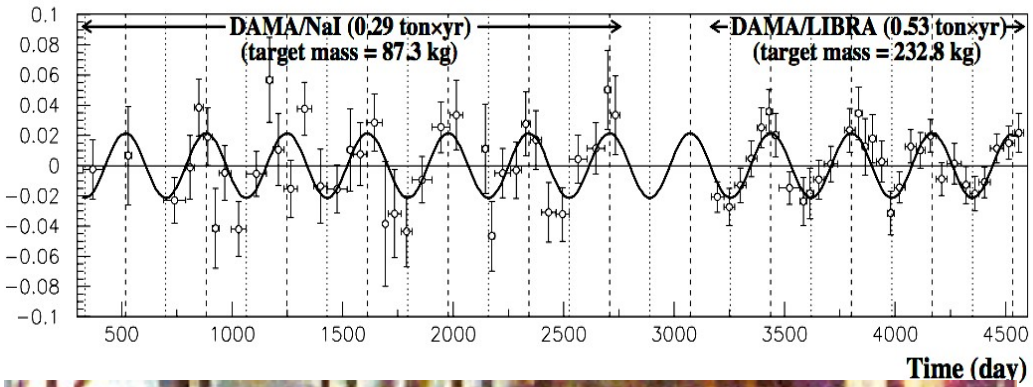

1989 : empty lab !
LABORATOIRE SOUTERRAIN DE MODANE


Spin Independent coupling WIMP's
PSD
No PSD
Hypothesis of
flat backg down
to 2 keV no PSD
10-4 pb
Ge-HdM
Cross section on proton (pb)
WIMP mass (GeV)

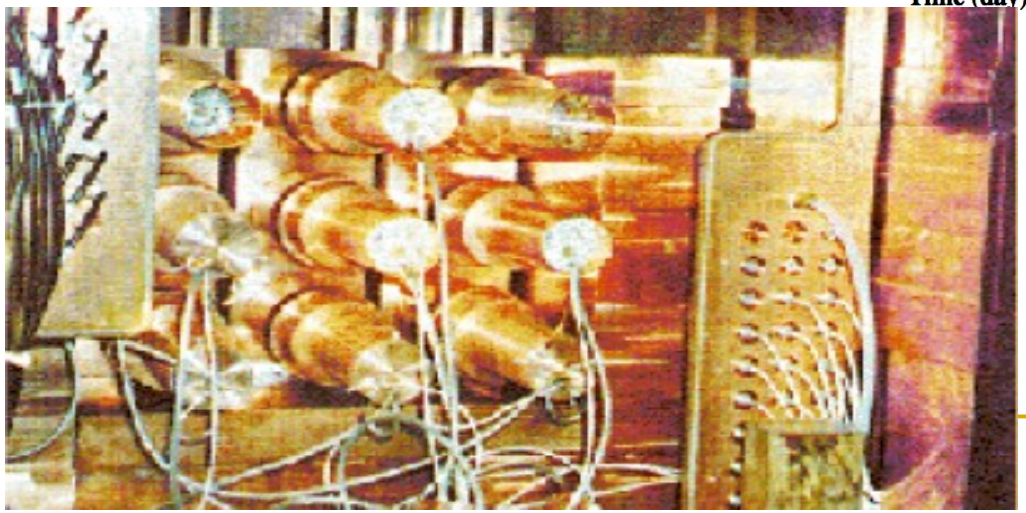

FRANCE
ITALIE
LSM
Altitudes
Distances
1228 m
0 m
1263 m
6210 m
1298 m
12 868 m

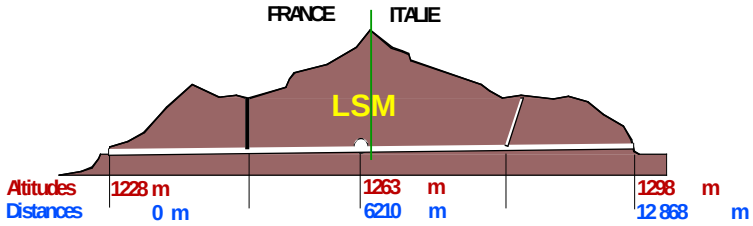

Depth, Feet of Standard Rock
0
2000
4000
6000
8000
10000
WIPP
Soudan
Canfranc
Kamioka
Boulby Mine
Gran Sasso
Homestake Cl-Ar
Baksan
Frejus
Sudbury
Muon Intensity, m-2 y-1
4800 mwe
2-4 keV


Good old times : empty lab


DAMA/NaI (0.29 ton×yr)
(target mass = 87.3 kg)
DAMA/LIBRA (0.53 ton×yr)
(target mass = 232.8 kg)
Time (day)


LABORATOIRE SOUTERRAIN DE MODANE

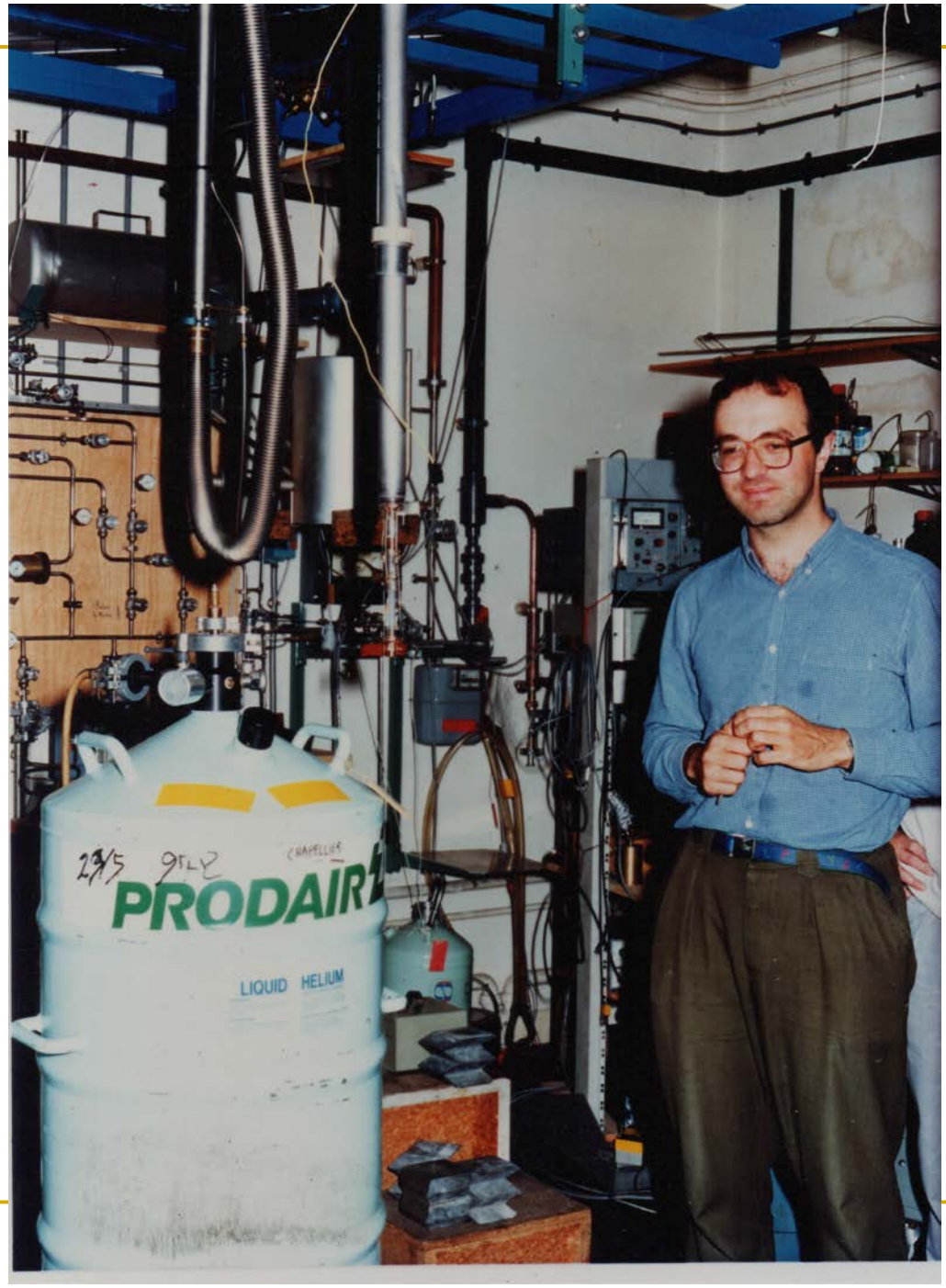



FRANCE
ITALIE
LSM
Altitudes
Distances
1228 m
0 m
1263 m
6210 m
1298 m
12 868 m

Short historical overview 1

- The story starts around 1986-1987
- Cold dark matter as elementary particles was exotic concept attracting exotic people
- What was best detector ?
  - First hunt was for « cosmions » = low mass high X sections particles captured in sun (Spiro, Rich,Tao, GG)
    - TPC with Hydrogen with mag field for 1 keV tracks :
    - Silicon detector : first collaboration with US, calibration of QF at Bruyères
  - Scintillator NaI (Tao, Mosca, GG)
    - First calibrations of QF and Pulse Shape Discrimination done at Bruyères
    - First underground measurements at LSM
    - 1990 collaboration started with Roma group => and stopped end 1995
  - Cryogenic detectors (Chardin,Chapellier) started 1986

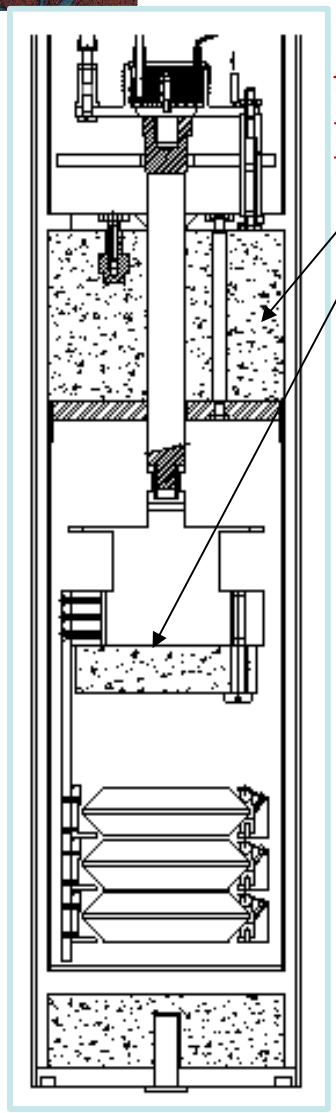
- First tests at CSNSM of cryogenics (10th of mK) installation to use « bolometers », the ultimate low threshold detector
- At that time few gram bolometers were used
- Crazy people wanted to make kg detectors !



Short historical overview 2

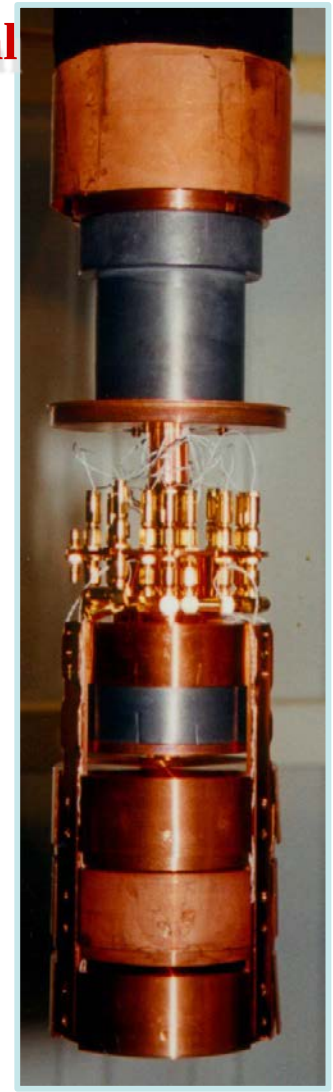
- Edelweiss I : 3 detectors : 1 kg total ! fid mass : 0.5 Kg
  - 1988-2002
- Edelweiss II : 10 detectors : fid mass : 1.6 Kg
  - 2002-2009
- Edelweiss III : 36 detectors : fid mass : 24 Kg
  - 2009-2016
- EURECA : Edelweiss + CRESST + others : 18 groups
  - 2016-2020 : build large cryostat with 200 kg for 5-15 GeV
- Spherical gaseous detector (Giomataris, GG)
  - Going to very low mass 0.2-5 GeV with Ne/He/H : 2016-2020

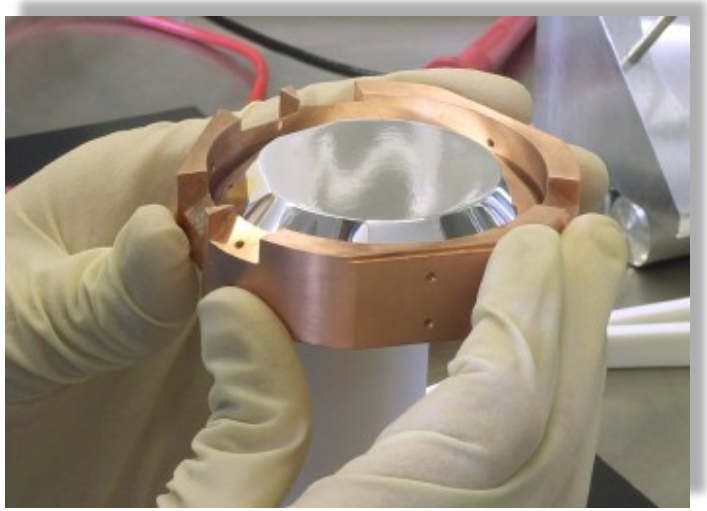
EDELWEISS-I “1kg” stage



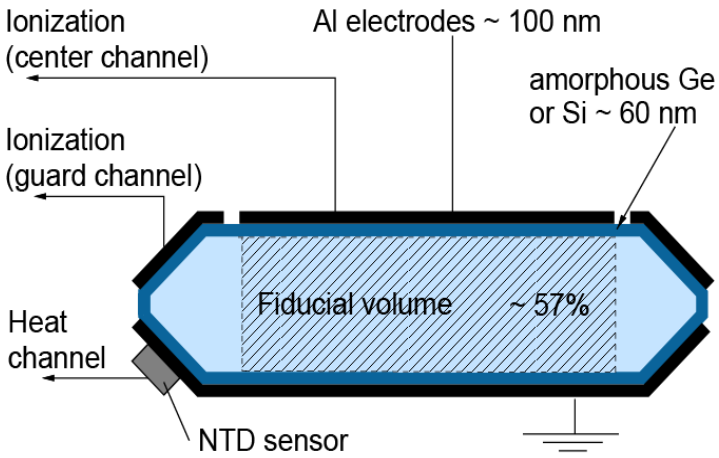
Archeological lead

3 * 320 g Ge detectors





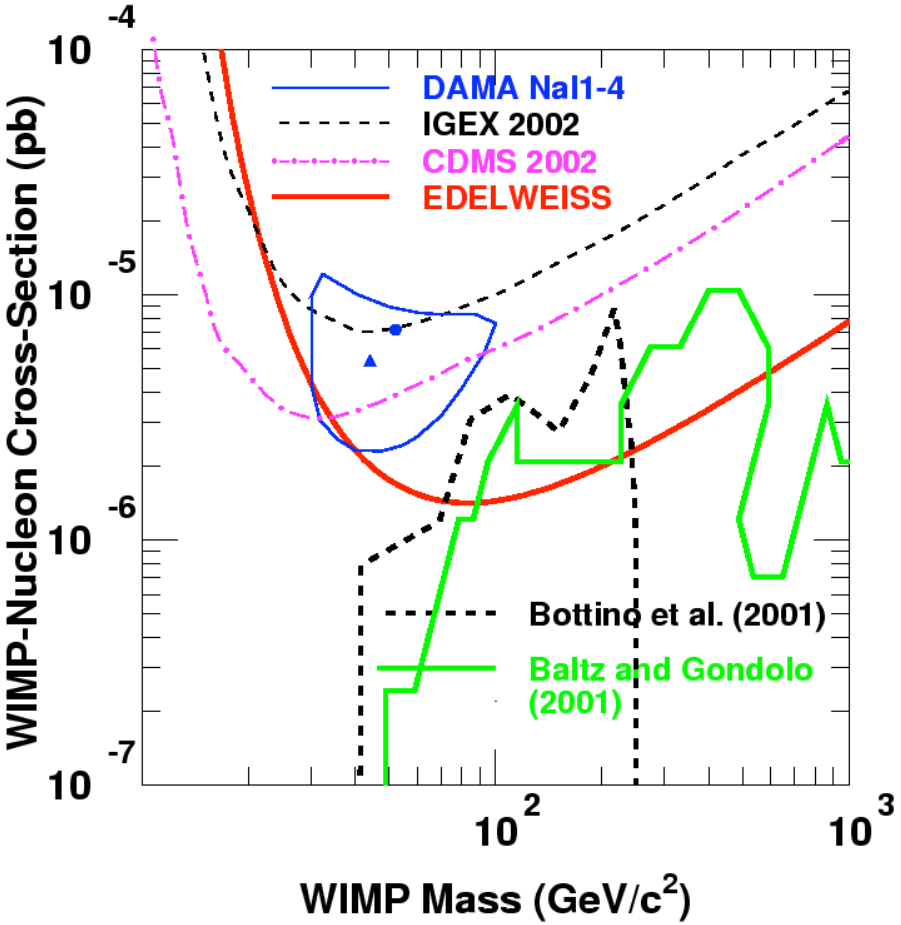
20 mK

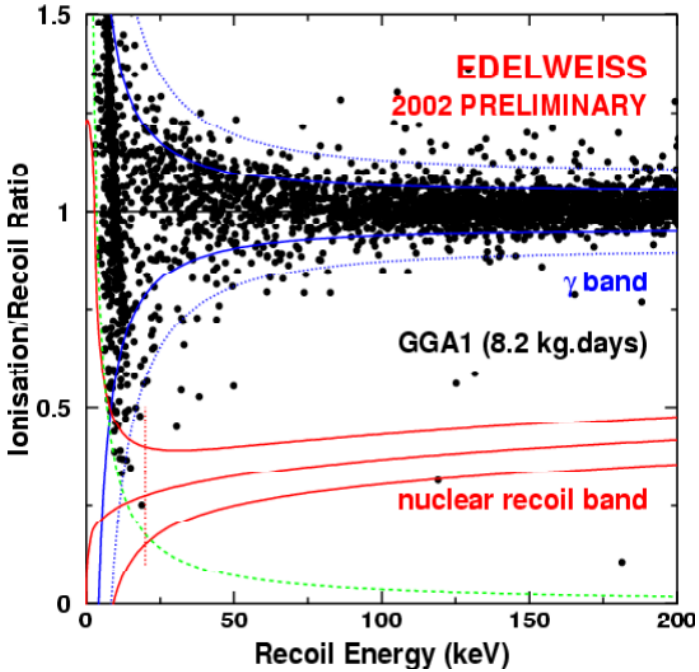


Measure « heat » and ionisation

EDELWEISS-I 05/2002

Present sensitivity for spin independent WIMPs



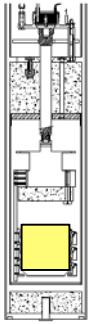


- M_W = 52 GeV, s = 7.2×10^{-6} pb : Prediction = 9.8 evts, P(0) = 0.006%
- M_W = 44 GeV, s = 5.4×10^{-6} pb : Prediction = 6.2 evts, P(0) = 0.2%

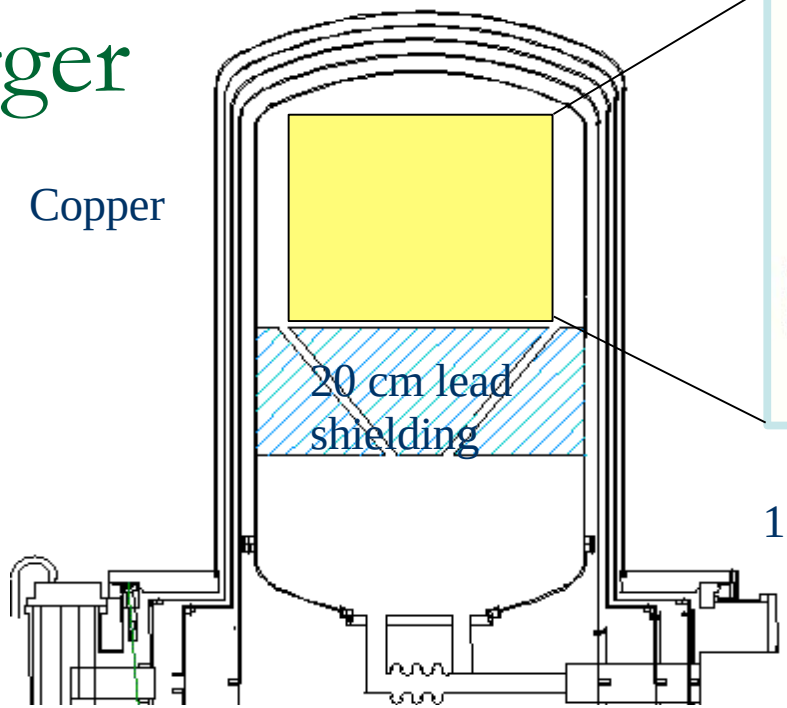
- **Exploration of first sample of SUSY models compatible with accelerator constraints.**

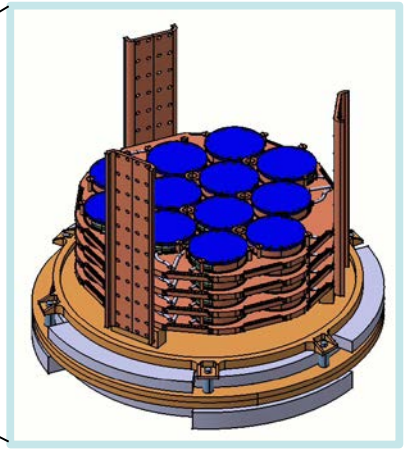
Getting bigger

from EDELWEISS I 1kg …



3 detectors of 320 g



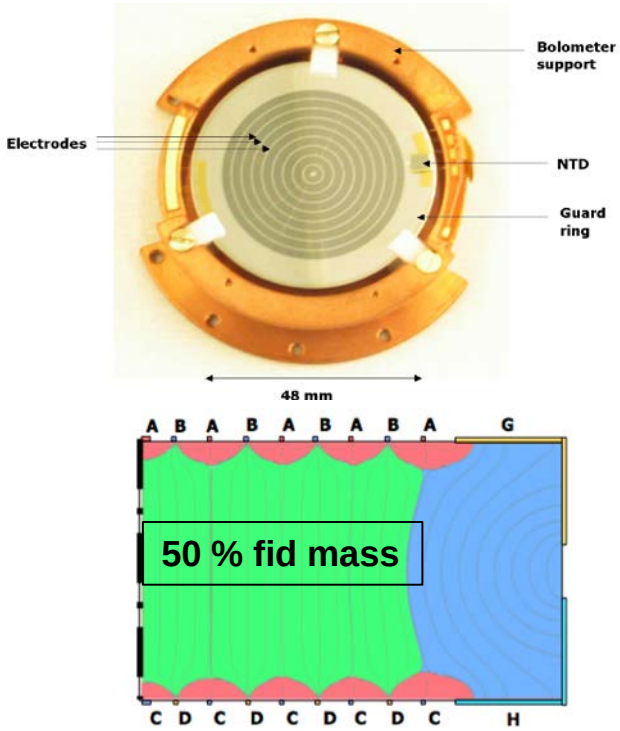


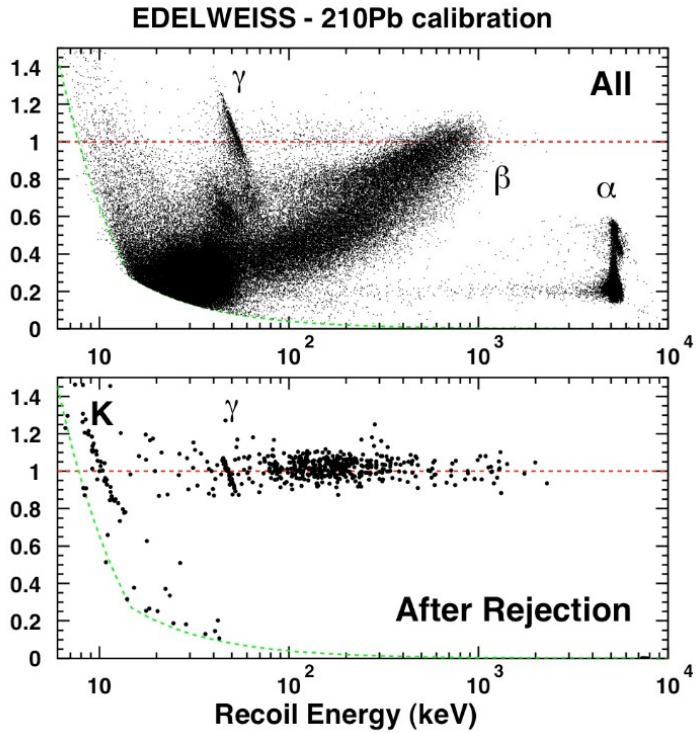
10 layers of
12 detectors of 320 g

…to EDELWEISS II – 40 kg

An instrumental issue : surface events

- 2 major approaches
  - NbSi films : heat channel : use of ballistic phonons : considerable R&D
  - Interdigitised electrodes : alternate potential on ionisation channels
- Unexpected breakthrough : the interdigitised electrodes



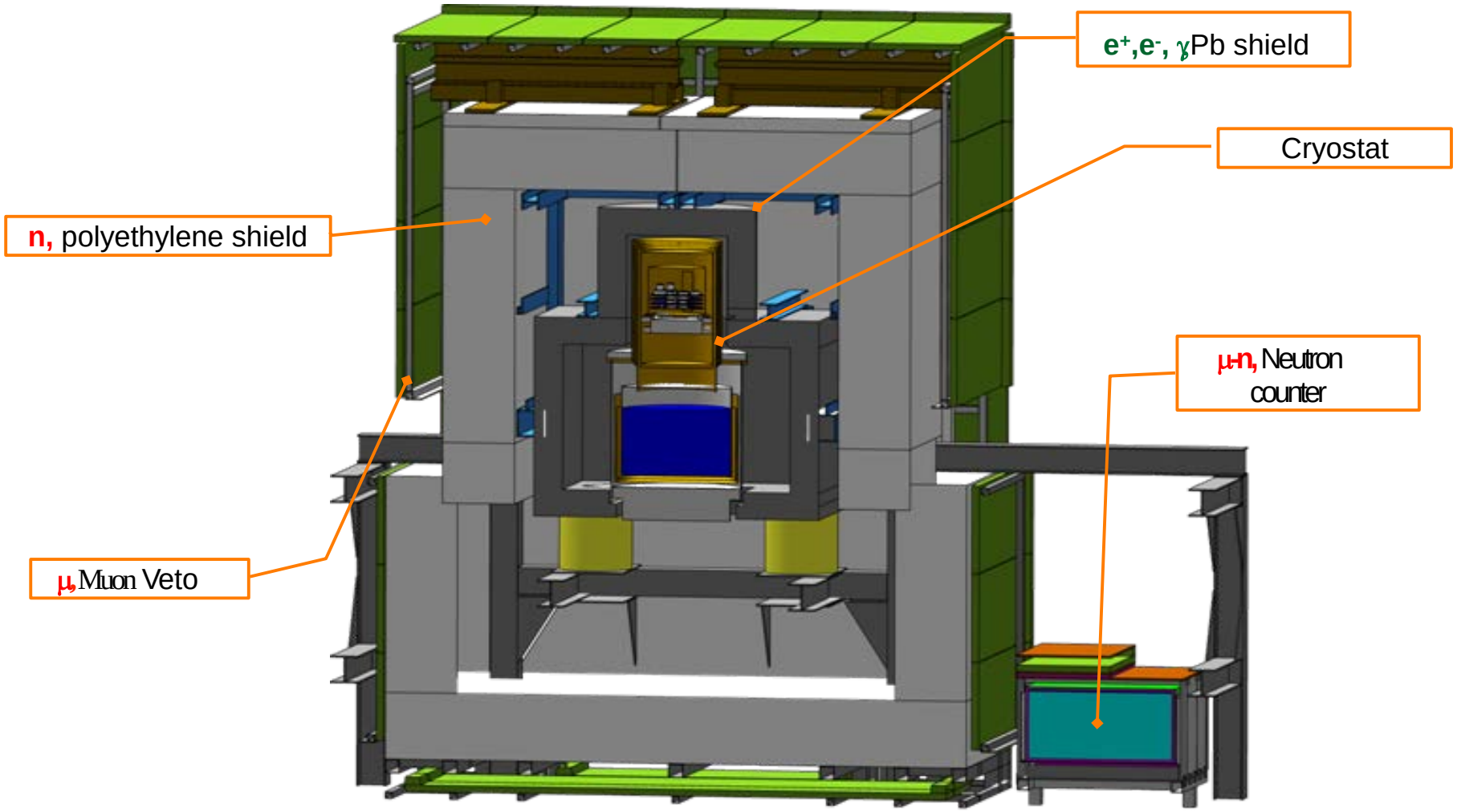


The EDELWEISS collaboration grew up

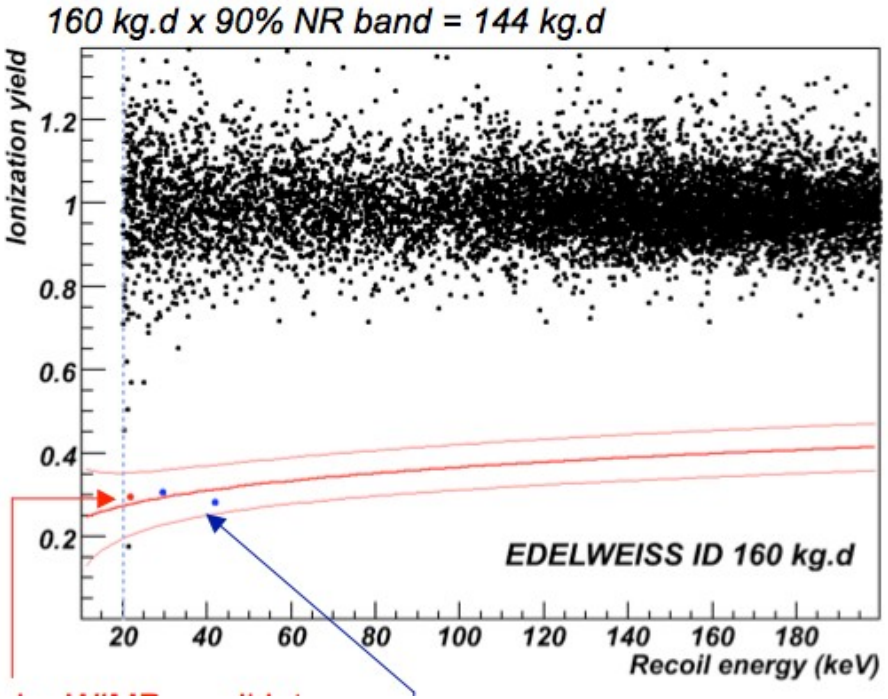
Karlsruhe

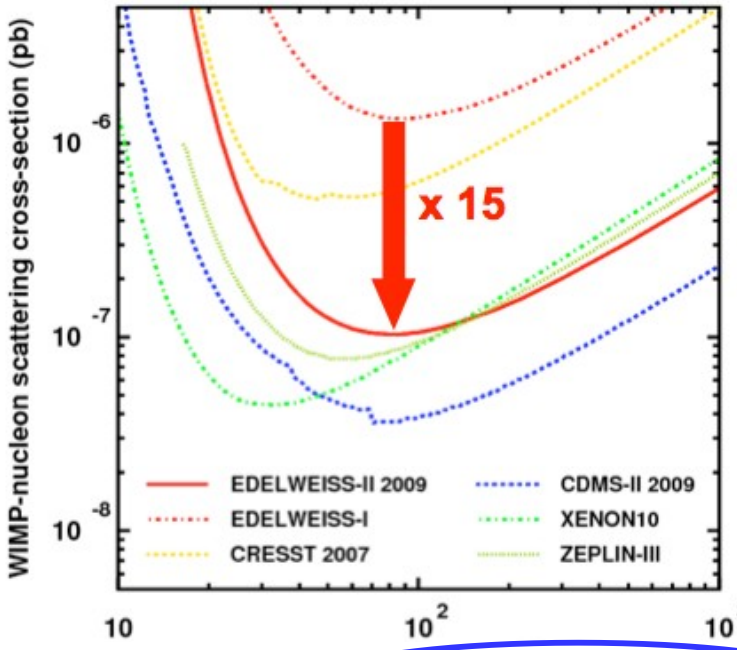
- CEA **Saclay** (IRFU and IRAMIS)
- CSNSM **Orsay** (CNRS/IN2P3 + Univ. Paris Sud)
- IPN **Lyon** (CNRS/IN2P3 + Univ. Lyon 1)
- Institut Néel **Grenoble** (CNRS/INP)
- LPN **Marcoussis** (CNRS)
- **Karlsruhe** Institute of Technology
- JINR **Dubna**
- **Oxford** University
- **Sheffield** University

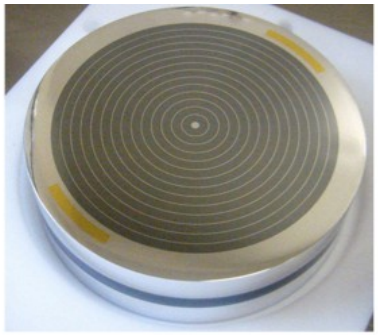
EDELWEISS II setup



WIMP search : first result EDELWEISS-II 2010

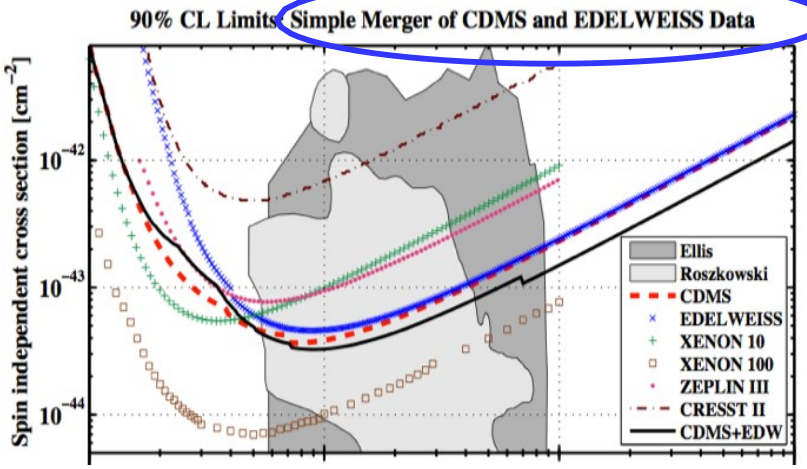






ID401 to 405:
Φ 70mm, H 20mm, 410g

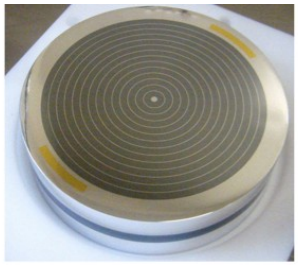
ID2 to ID5:
Φ 70mm, H 20mm, 410g

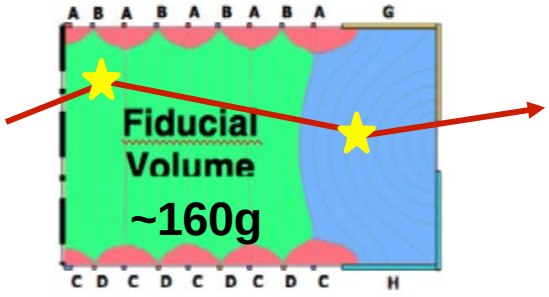


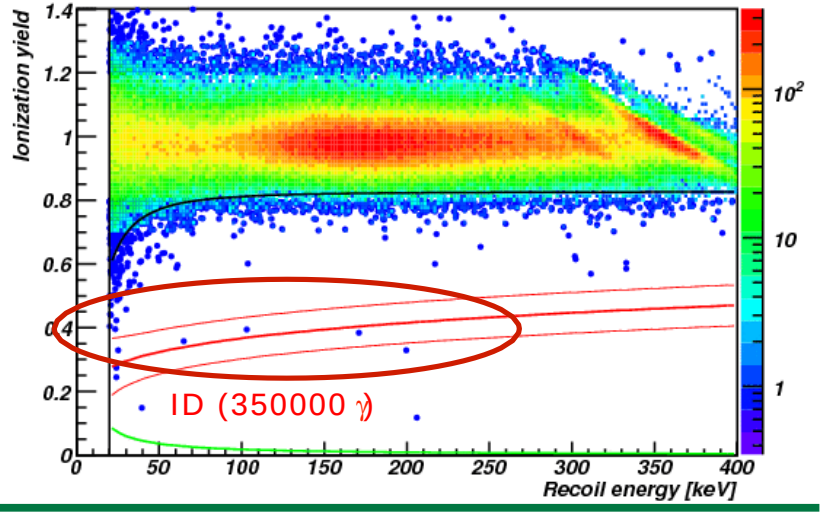
10 detectors

EDELWEISS-III: from ID to FID

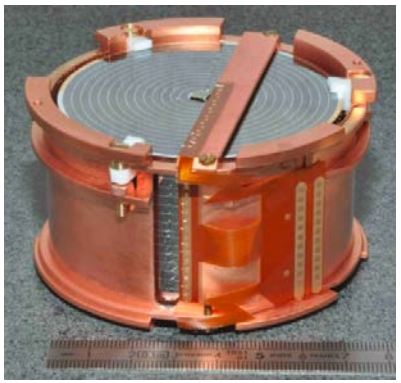
EDELWEISS-II
ID 400g with 10x **160g** fiducial mass

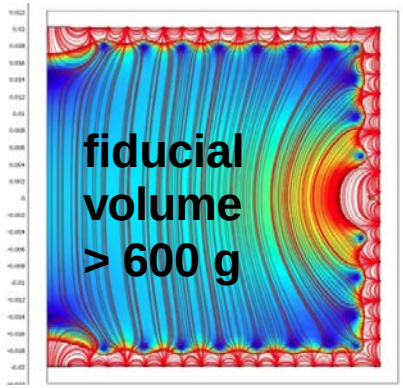




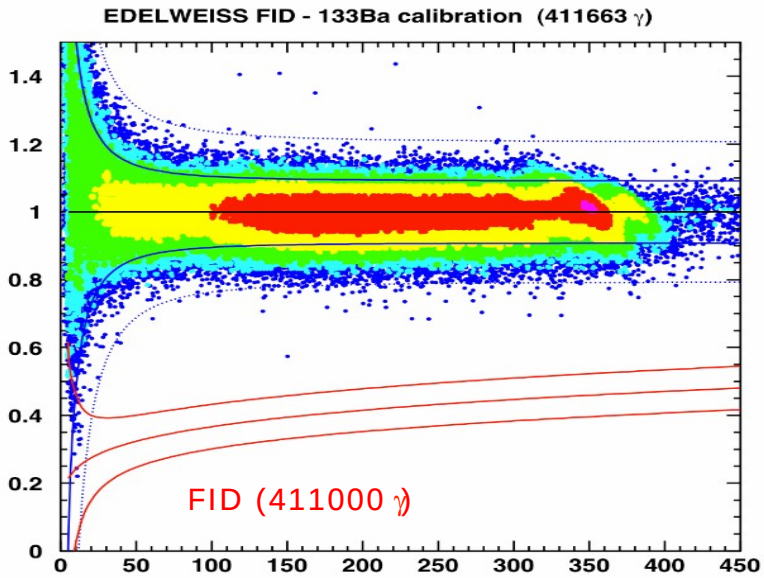


EDELWEISS-III
FID 800g with 40x ~**600g** fiducial mass





« **F**ull **I**nter**D**igitised »



EDELWEISS-III status

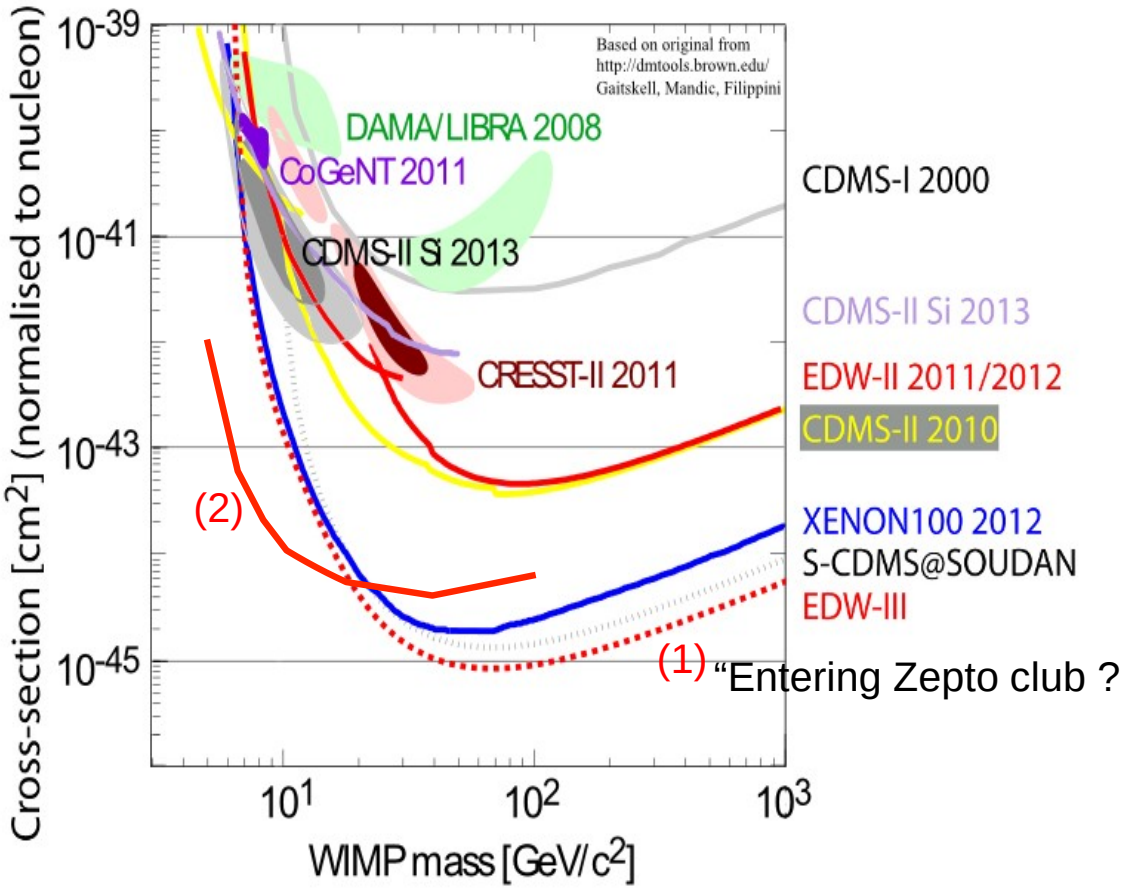
- February 2014: **36** x 800 g detectors installed in cryostat
  - ***Set up upgraded vs internal Pb shield, cryogenics …***
  - ***More than 20 kg of fiducial mass in germanium***

- Facility able to acquire 3000 kgd per 6 months
- Expected background from internal neutrons limits total exposure with <1 bkg event from 4 500 kgd (2.5×10^{-9} pb) to **12 000 kgd** (10^{-9} pb)
- April 2014 : some technical issues with cabling
- Run starts in May with 20 detectors

EDELWEISS update

EDELWEISS-III timeline

- Summer 2014
  - starting with 36 detectors
- End 2014
  - reach 3.000 kg.d
    (125 days of data taking)
- End 2016
  - reach 12.000 kg.d
    (500 days of data taking)

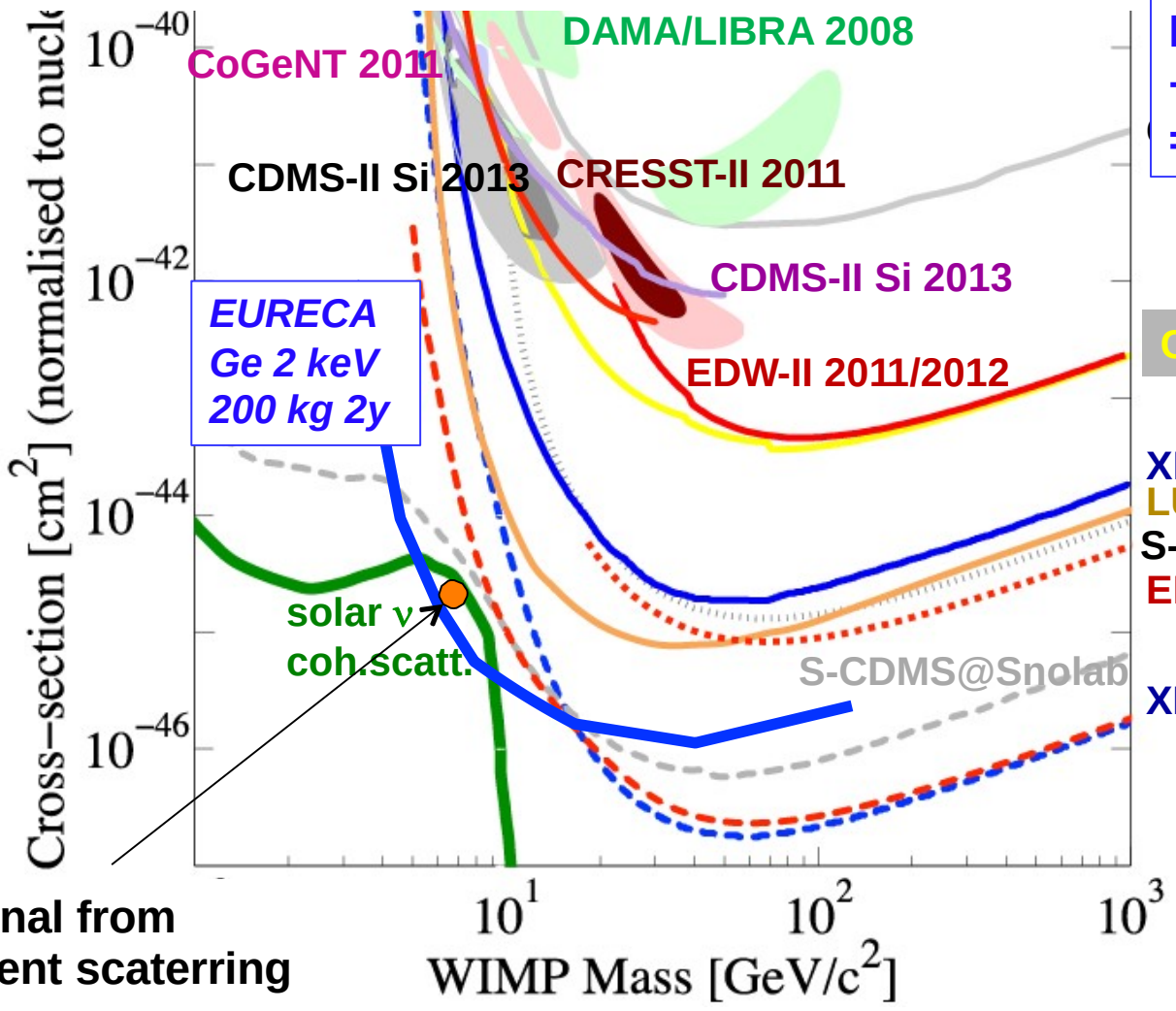


(1) ‚Standard' WIMP: 12000 kgd, **E_R>15keV**, no event

(2)Low-mass WIMP: 1200 kgd (4 FID800 with HEMT) 300eV FWHM, **E_R>3keV**

Beyond EDELWEISS-III → EURECA with SCDSM ?

The new strategy 2014



EURECA = Edelweiss+CRESST + 6 EU labs = 18 groups

CDMS-II 2010

XENON100 2012
LUX 2013
S-CDMS@Soudan
EDELWEISS-III

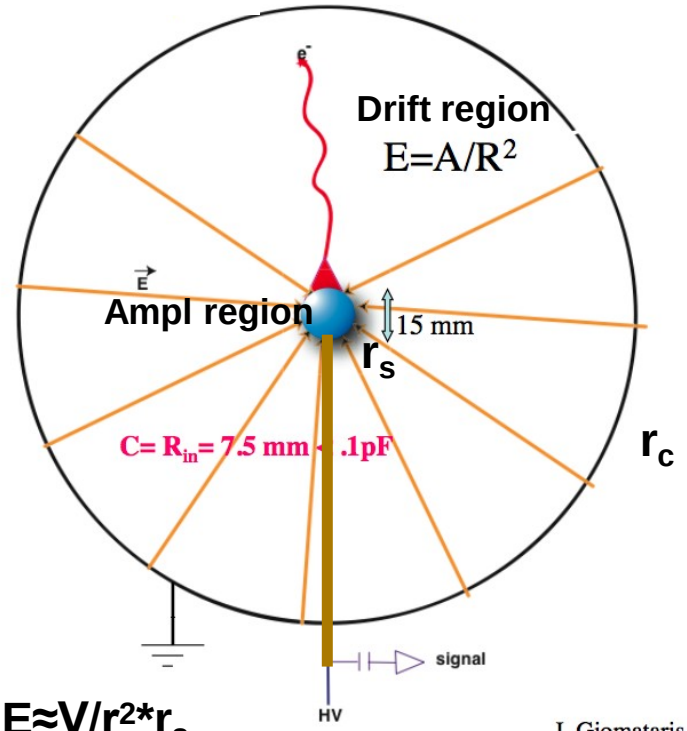
XENON1T

^{8}B signal from coherent scaterring

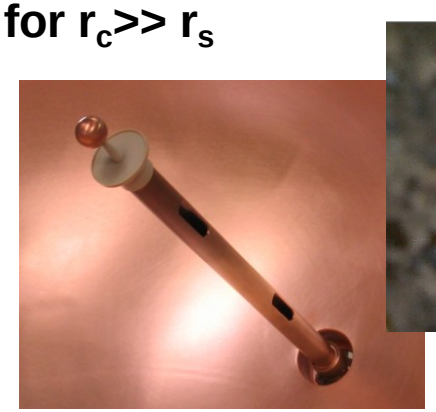
Short historical overview 2

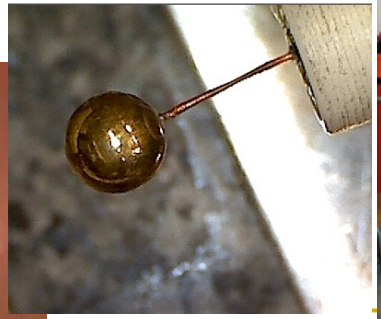
- Edelweiss I : 3 detectors : 1 kg total ! fid mass : 0.6 Kg
  - 1988-2002
- Edelweiss II : 10 detectors : fid mass : 1.6 Kg
  - 2002-2009
- Edelweiss III : 36 detectors : fid mass : 24 Kg
  - 2009-2016
- EURECA : Edelweiss + CRESST + others : 18 groups
  - 2016-2020 : build large cryostat with 200 kg for 5-15 GeV
- Spherical gaseous detector (Giomataris, GG)
  - Going to very low mass 0.2-5 GeV with Ne/He/H : 2016-2020

Spherical Proportional Counters



$E \approx V/r^2 * r_s$
for $r_c >> r_s$

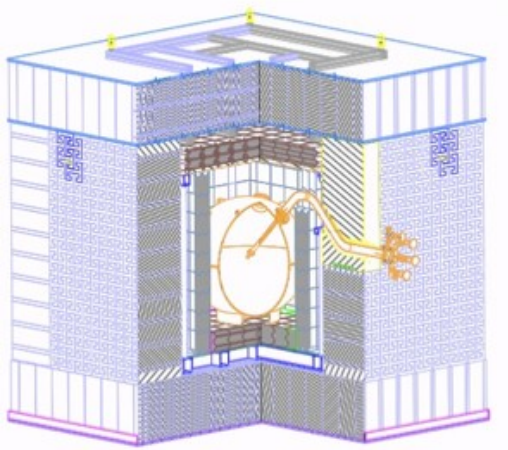


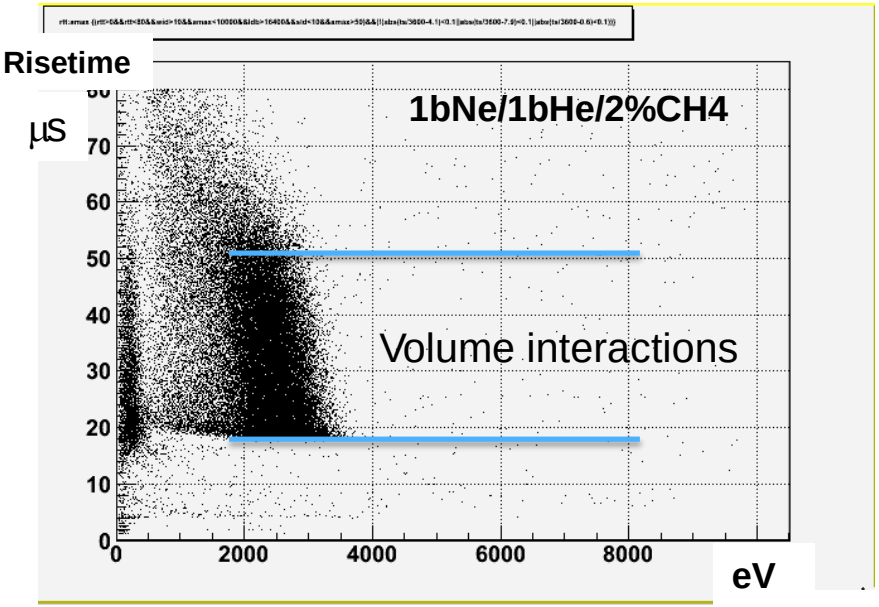


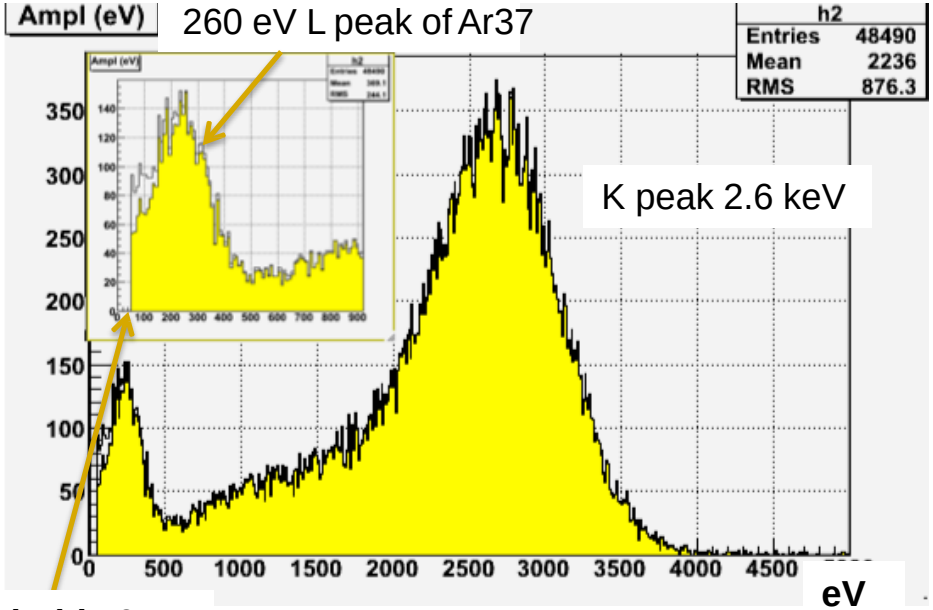
- Sphere cavity + spherical sensor + HT
- => Low threshold (low C), does not depend on size
- Fiducial volume selection by pulse risetime
- Flexible (P, gaz)
- Works in sealed mode
- Large volume => 10's kg possible
- 2 LEP cavity 130 cm Ø tested
- Digitisation at 2 MHz + soft trigger

Light dark matter search : low activity
60 cm Ø prototype @ LSM

- 50 eV threshold reached
- Fiducialisation measured
- Reduction of RA contaminants ongoing
- Preparing 2m diameter project planned to be installed in SNOlab (Canada)
- => 0.1 – 5 GeV WIMP
- Many other applications







Threshold 50 eV

Summary

- … of 27 years of research at IRFU ?
  - Witness 5 orders of magnitude increase in sensitivity
  - No serious hint showed up
  - SuperSymetry disfavored by LHC , not eliminated
  - Dark Matter is main of few hints of new physics
- Edelweiss / EURECA
  - Exemplary team work and use of resources
  - One of world leading experiments
  - Window of opportunity is below M_w=15 GeV
- Tremendous increase in public interest in dark matter question
  - « Le Mystère de la Matière Noire » documentary Arte
  - LSM in « Guide du Routard »
- How many years more to identify Dark Matter … ?

Around 60 people worked, work on Dark Matter direct detection at « IRFU »

- M Spiro, J Rich, C Tao, G Chardin, M Chapellier, J Mallet, L Mosca, O Besida, E Lecanu, D Yvon, L Miramonti, P di Stefano, A Juillard, S Fiorucci, M Hannewald, M Loidl, XF Navick, E Armengaud, J Poinsignon, P Charvin, I Prostakov, S Hervé, AS Torrento, S Pichard, B Paul, M Gros, E Gremion, R Lemrani, H Deschamps, M Fesquet, M Karolak, N Fourches, F Nizery, S Launay, A Chantelauze, R Walker, L Schoefel, S Hassani, J Domange, F Senée, A de Lesquen, I Giomataris, P Magnier, T Papaevangelou, G Tsiledakis, P Mols, E Bougamont, R Granelli, J Galan, MC Piro, T de Boissière…