EDELWEISS

Expérience pour DEtecter Les WIMPs En Site Souterrain

- Short introduction
- The EDELWEISS-II
- Toward 5×10^{-45} cm^2
- Conclusion and outlooks

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Introduction

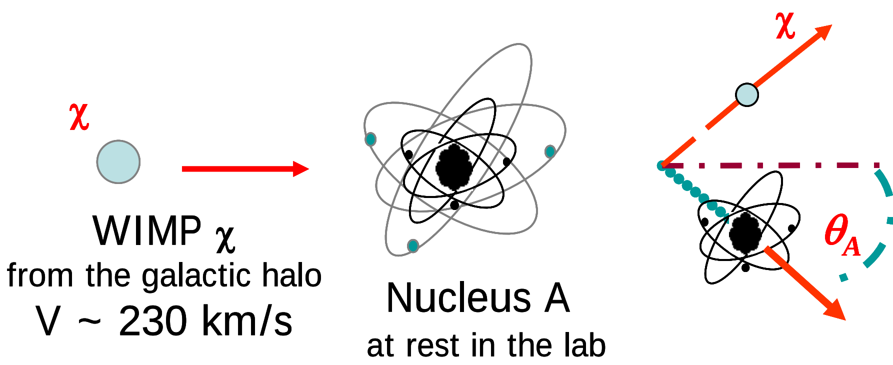
The EDELWEISS experiment is international quest for Non Baryonic Cold Dark Matter in form of WIMPs with Cryogenic HPGe Detectors

About 50 scientists from

- Centre de Recherche sur les Tres Basses Temperatures, SPM-CNRS, Grenoble, France
- Centre de Spectroscopie Nucleaire et de Spectroscopie de Masse, IN2P3-CNRS, Universite Paris XI, Orsay, France
- Department of Physics and Astronomy, University of Sheffield, UK
- DSM/DRECAM, CEA, Centre d'´Etudes Nucl´eaires de Saclay, France
- DSM/DAPNIA, CEA, Centre d'´Etudes Nucl´eaires de Saclay, France
- **DzLNP, Joint Institute for Nuclear Research, Dubna**
- Institut de Physique Nucleaire de Lyon-UCBL, IN2P3-CNRS, France
- KIT (IK / EKP/ IPE), Karlsruhe, Germany
- Laboratoire Souterrain de Modane, CEA-CNRS, Modane, France
- University of Oxford, Department of Physics, Oxford, UK.

The EDELWEISS experiment

EDELWEISS experiment search for rear events of WIMP-nucleon scattering with Ge as the target



$$E_R = E_\chi \frac{4 M_A M_\chi}{(M_A + M_\chi)^2} \cos^2\theta_A$$

Main experimental challenges are:
- event rate is ultra small (below of 1 per 100 kg of matter per day);
- energy deposition is tiny (below of 100 keV)

Thus main tasks for the experiment are:
- detector mass + long stable data taking
- detectors' performance (low threshold, good resolution)
- background reduction

Solutions of the background problem:

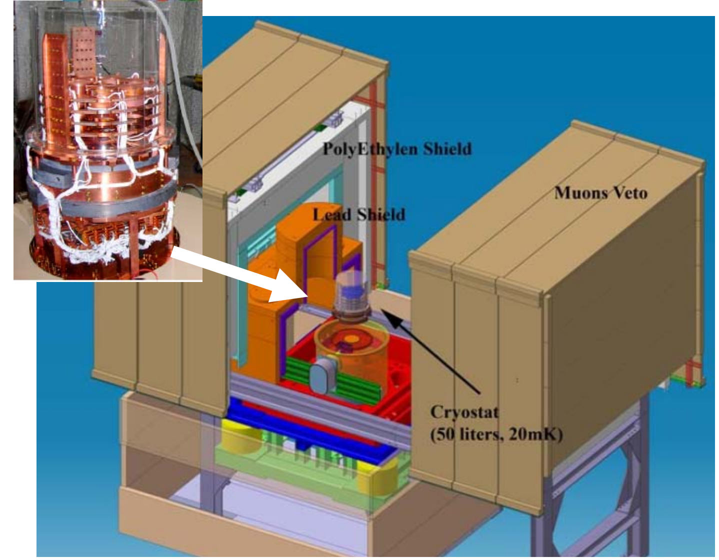
1. Traditional

Experiment is located in one of the deepest underground laboratory – Frejus – with muon flux only 4 $\mu/m^2/day$

Using of multi layer shielding + active veto system

Material selection

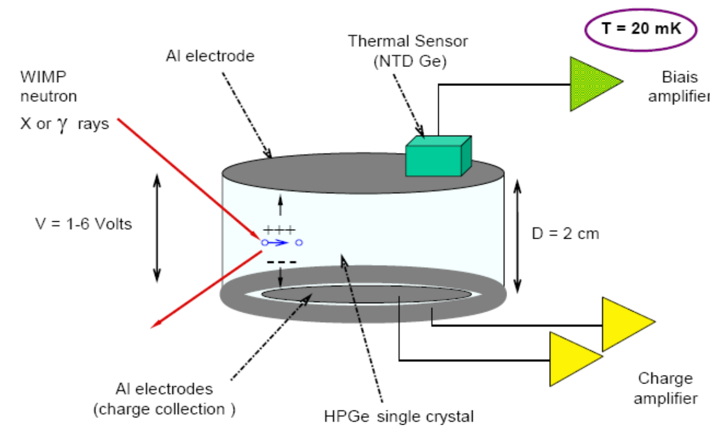
Continuous control of radon and neutron background



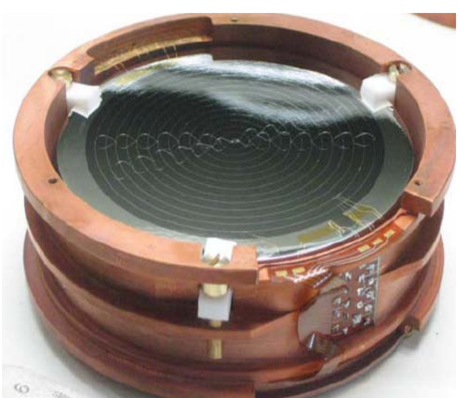
2. Special

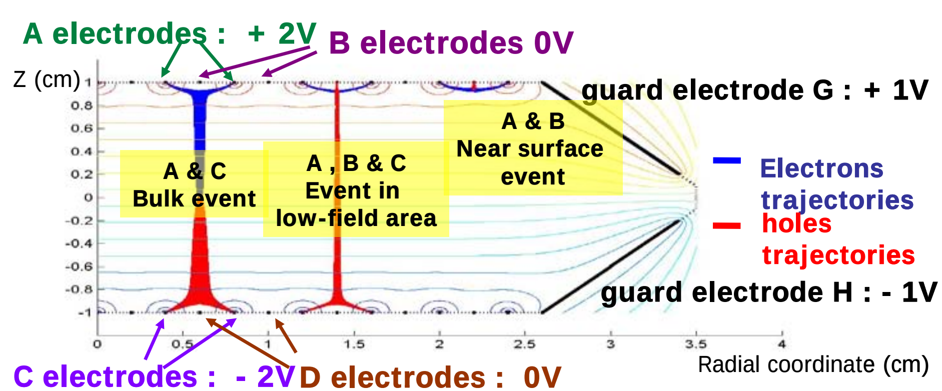
Using of *Heat* and *Ionization* HPGe detectors, running in ^3He-^4He dilution cryostat (<20 mK)

Ratio $E_{ionization}/E_{recoil}$ is
=1 for electronic recoil
≈0.3 for nuclear recoil
⇒Event by event identification of the recoil
⇒<u>Discrimination γ/n > 99.99%</u>



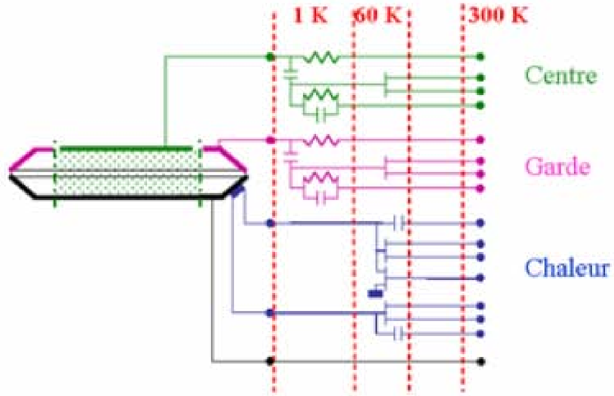
Detectors with special concentric planar electrodes for active rejection of surface events (miss-collected charge)





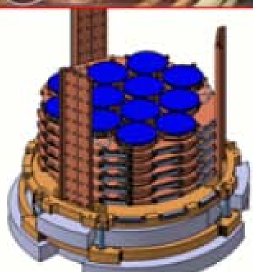
The EDELWEISS-II experiment

EDELWEISS-II *Signal measurement , stage 30*



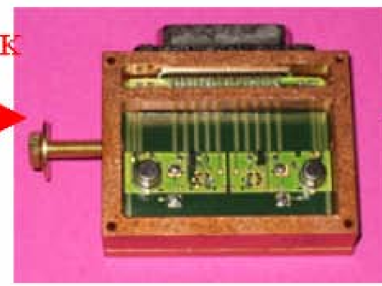
BBv1= Front end electronics + digitizers

- **-Heat square modulation ~ 1kHz**
- **- ionization and heat bias**
- **-Charge and heat amplifiers**
- **-digitization 14-16bit/100kHz**



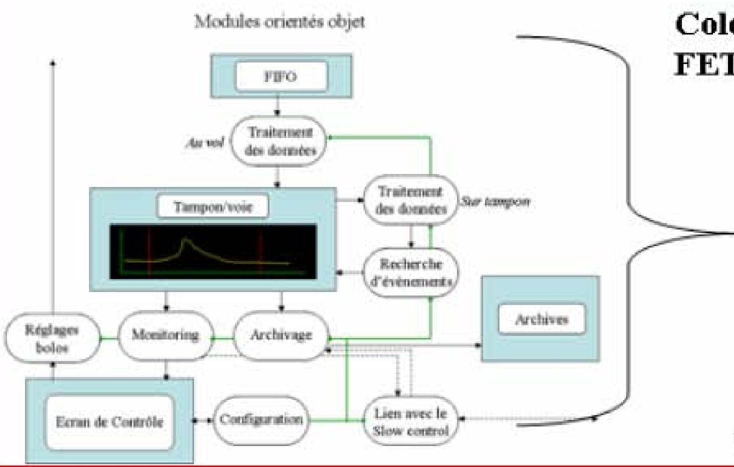
Detectors @ 20mK

Cryogenic Cabling
Thermalisation @ 100mK
1K, 10K



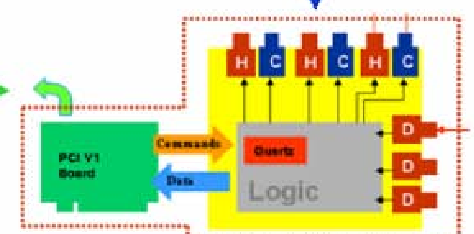
Cold Electronics100K
FETs

Optical fibers



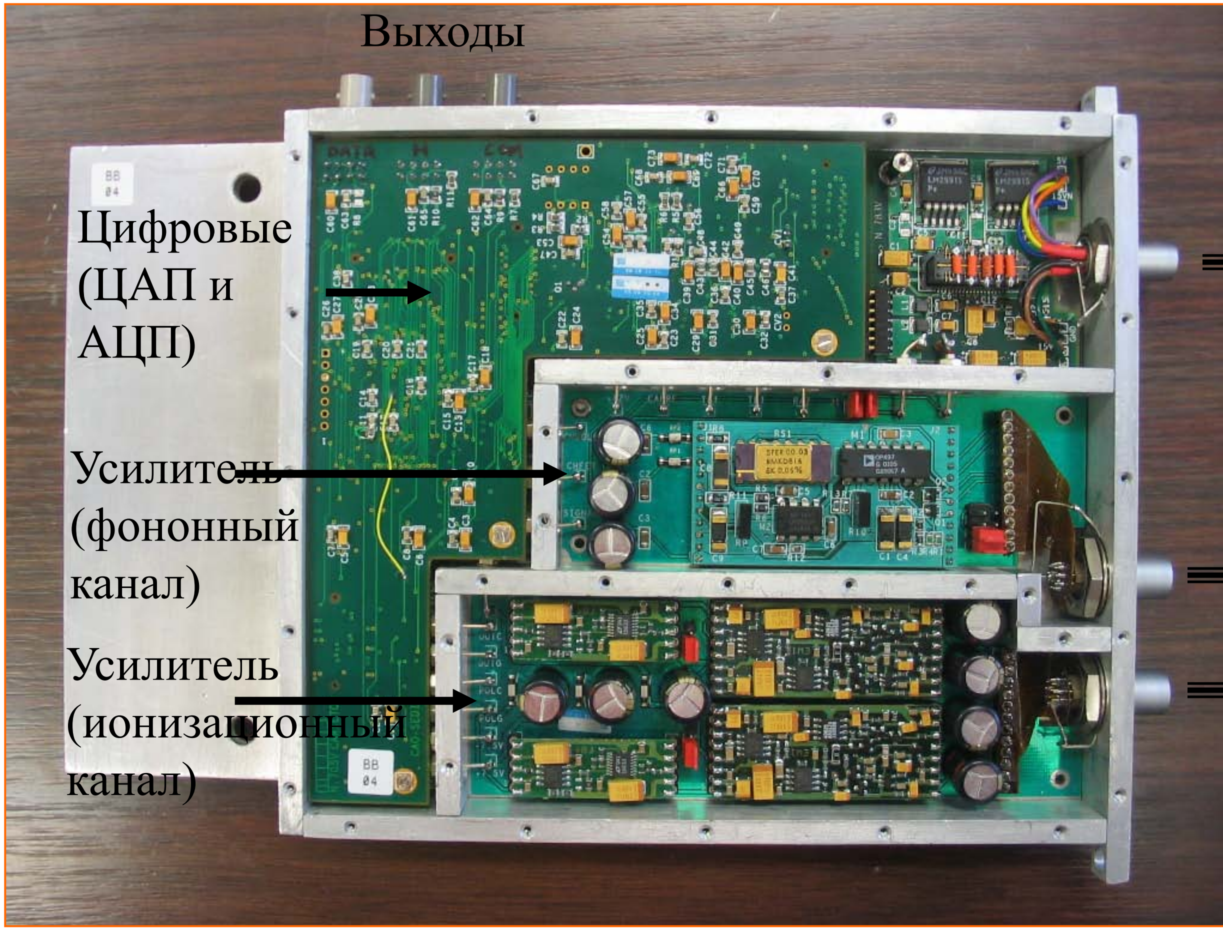
Mac for Acquisition

Bus PCI



Repartitor SuperCluzel (10BBs)

EDELWEISS-II - электроника

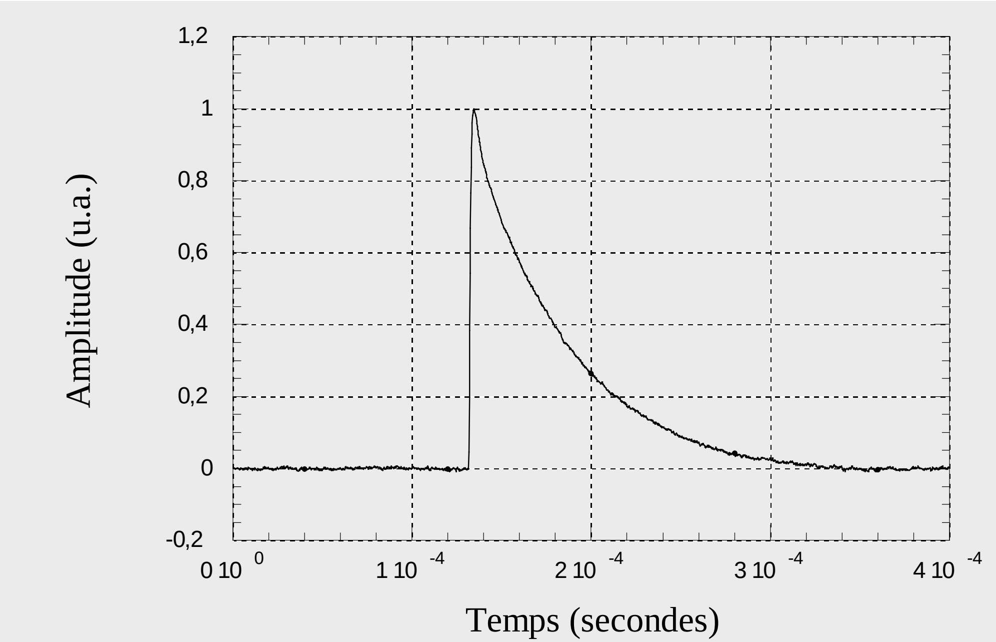


- Оцифровка сигнала с частотой 200 кГц

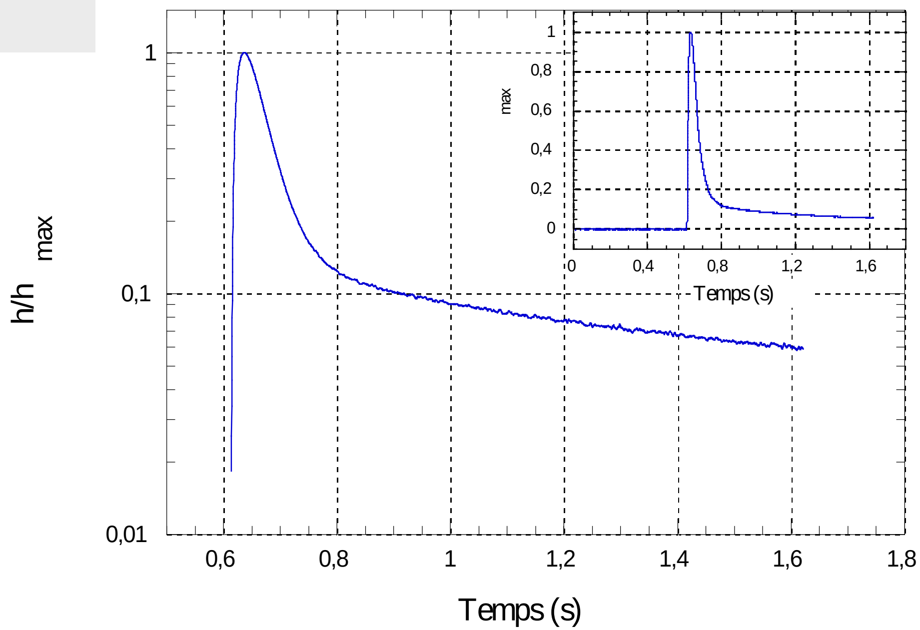
На выходе: форма импульса

Использование программируемого триггера

Ионизационный сигнал



Тепловой сигнал



Reduction and understanding of backgrounds

- Cosmic Rays and cosmic activation
- Natural radioactivity from rock and materials (γ and neutrons)
- Radioactive dust
- Radon in air from U-Th radioactive chains

…

<u>2 MAIN background problems for direct Dark Matter search:</u>

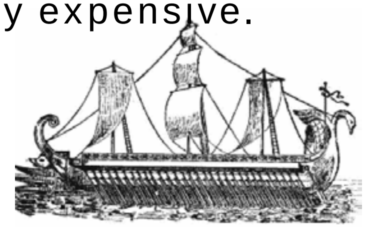
- Neutrons (produce similar signal as expected from WIMPs)

- Surface electrons (events with misscollected charge, mimic WIMP signature)

Shields / γ

Background requirement: <<0.01 event per kg per day
For example human body has: 100 Bq/kg
Need to reduce by 10^9 times (minimum)
All construction materials were selected by their low radioactivity

γ- need high Z, less-radioactive, easy for mechanical treatment, not very expensive.
Lead is good, but has problem with ^{210}Pb and it decay chain

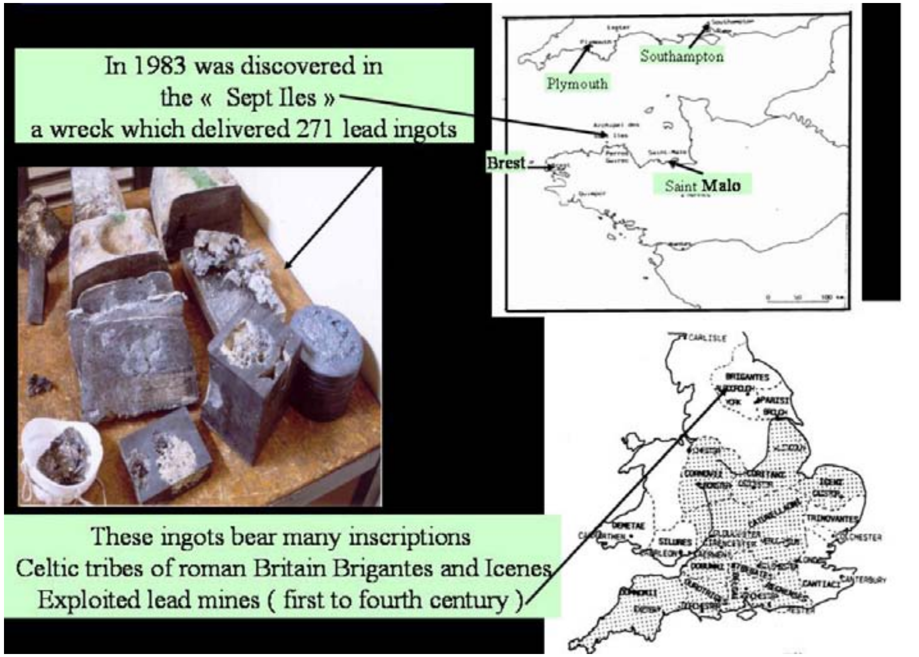


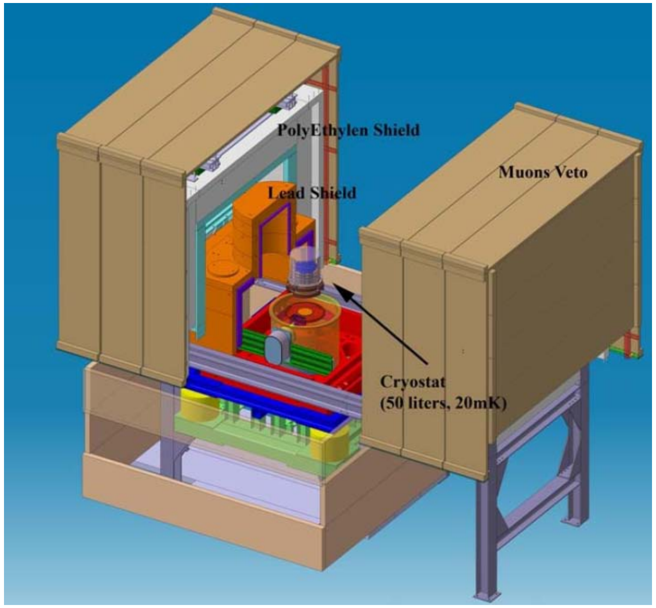
^{210}Pb 22.3 years and it daughters γ-lines:
4.25% 46 keV,
0.001% 803 keV (α-decay of ^{210}Po)

20-100 Bq/kg

Solution: archeological lead, 2 centuries reduce ^{210}Pb activity by 1000 times

EDELWEISS: internal layer of archeological lead(5 cm) +15 cm usual low activity lead





To shield from radioactive dust the setup is located in a clean room of class 1000

Protection from radon, radon free air supply, + continuous control

Background / neutrons

Neutron background sources underground:

Low energy neutrons induced by U/Th activities

- fission and (α,n) reactions in the surrounding rock/concrete
- fission reactions in detector shield

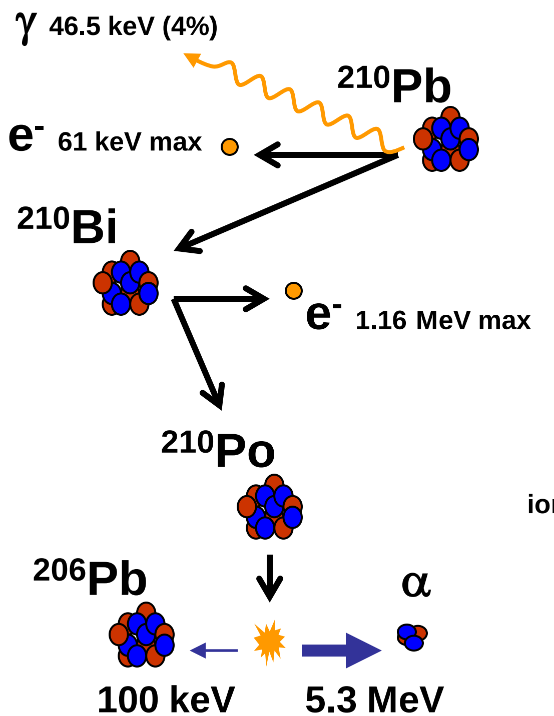
High energy neutrons induced by muons

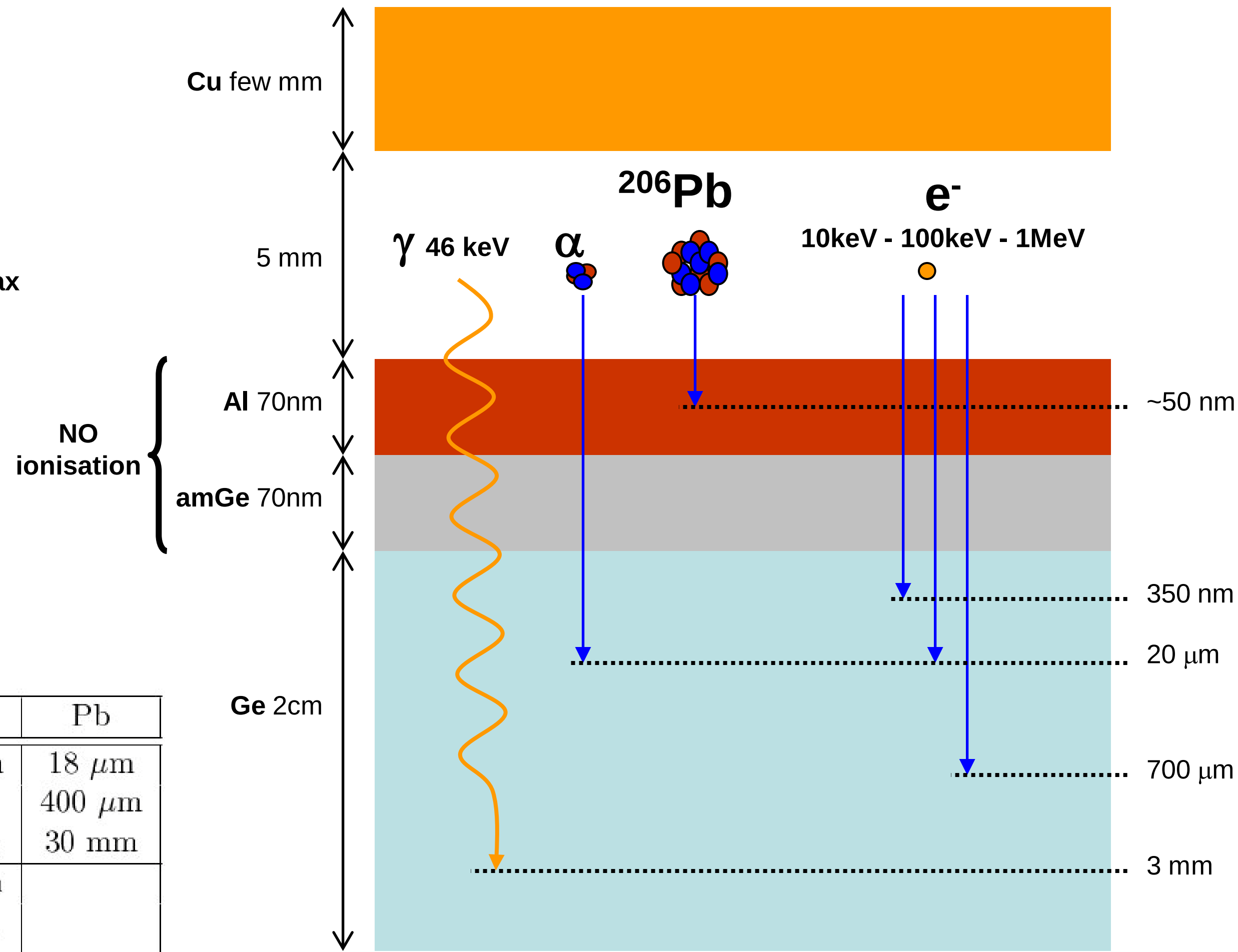
Fight with neutron background:

1) **Go underground laboratory / reduce neutron flux by ~4 orders**
2) **Muon veto system**
3) **Passive neutron shield (PE) / Control of shield performance**
4) **Multi-detector assembly**

Surface background events

Sources of such events: ^{210}Pb and ^{14}C



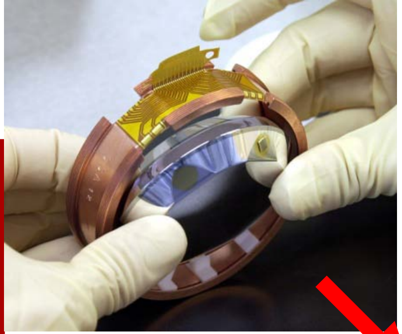


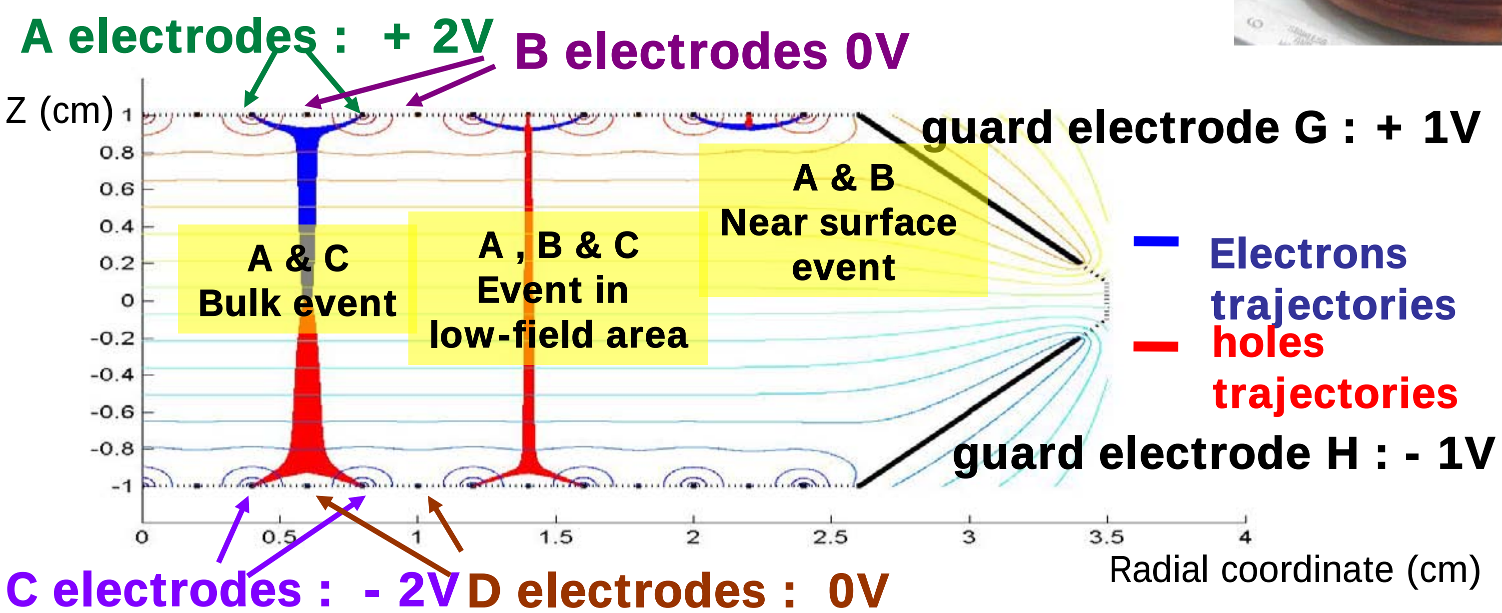
Particule	Energie	Cu	Ge	Pb
Gamma	10 keV	9 μm	170 μm	18 μm
	100 keV	6 mm	8 mm	400 μm
	1 MeV	40 mm	80 mm	30 mm
Electron	10 keV	200 nm	350 nm	
	100 keV	11 μm	20 μm	
	1 MeV	340 μm	700 μm	
Alpha	5.3 MeV	11 μm	19 μm	15 μm
Polonium	100 keV	40 nm	68 nm	

EDELWEISS-II New Detectors

“interdigit” Ge/NTD bolometers

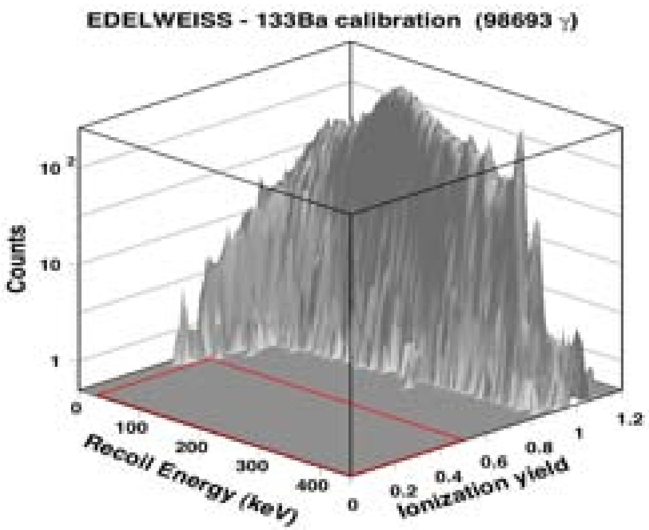
- central electrode changed to ring electrodes, that provides active surface rejection

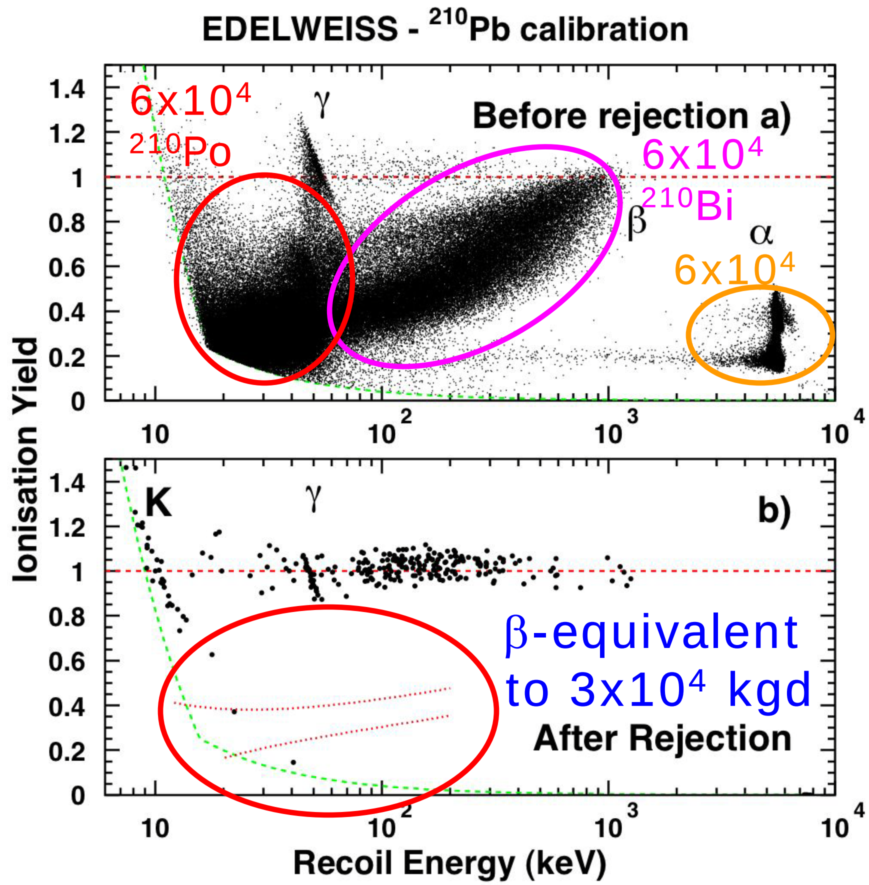




ID detectors and results

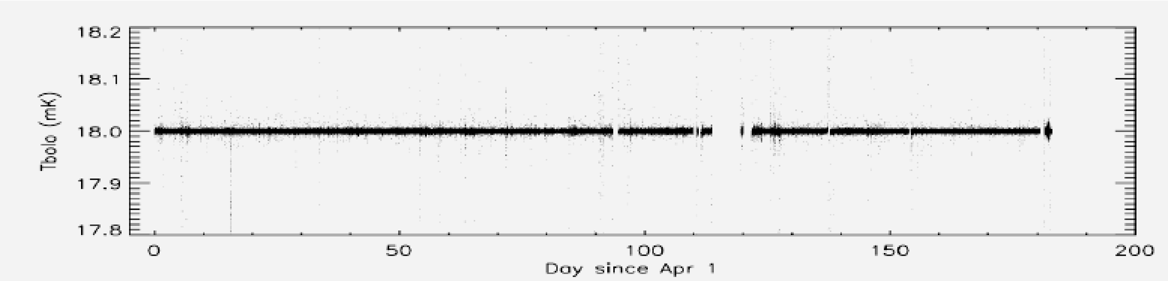
- **^{210}Pb source calibration at LSM**
- **Rejection ~ 1 in 2 10^4 !**
- Equivalent to exposure of 4000- 40 000 kgd !





- Gamma rejection better than 1 in 10^5
- Expected background ~0.1 per 3000 kg.d

ID detectors and results /WIMP data



10 ID detectors, 400 g each
1 detector with ^{210}Pb source
Performances of 2 ID detectors are not satisfactory to include in analysis
→ 7 ID detectors

~80% data taking time
~6% - calibrations

Fiducial volume of
each detector: 166±6 g (160 g was used in estimation)

Ambient Neutrons:

Source	Material	Mass (kg) or thickness (cm)	U/Th concentrations	# Events
Hall walls	Concrete	30 cm	1.9 / 1.4 ppm	< 0.10
Hall walls	Rock	300 cm	0.8 / 2.5 ppm	< 0.01
Shielding	Lead	20 cm (40 tonnes)	< 0.01 ppb U	< 0.08
Shielding	Polyethylene	50 cm	0.4 / < 0.5 ppb	< 0.05
Support	Stainless steel	0.6 cm (~200 kg)	0.4 / < 1 ppb	< 0.01
Support	Mild steel	8.6 tonnes	0.4 / < 1 ppb	< 0.04
Cryostat	Copper	~500 kg	< 0.3 / < 0.5 ppb	< 0.03
Electrodes	Aluminium	< 0.03 g	< 1000 ppb U/Th	< 0.01
Crystal holders	PTFE	~ 20 g	< 0.2 / < 0.5 ppb	< 0.01
Connectors	Al, plastics	0.32 kg	170 / 110 ppb	< 0.40
Cables	PTFE	≈ 1.35 kg	0.8 / < 1.5 ppb	< 0.66

Radiopurity measurements + GEANT4 Simulation of neutron background

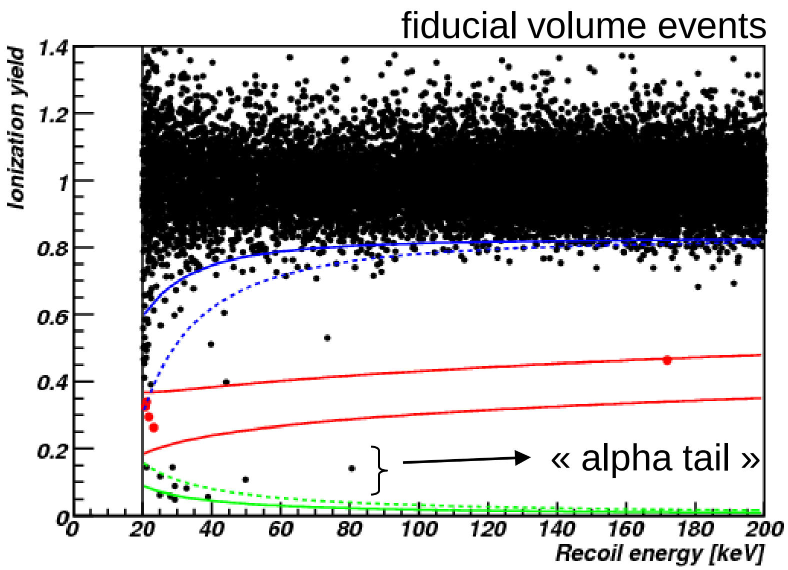
- Measured neutron spectrum

- SOURCES4A spectrum

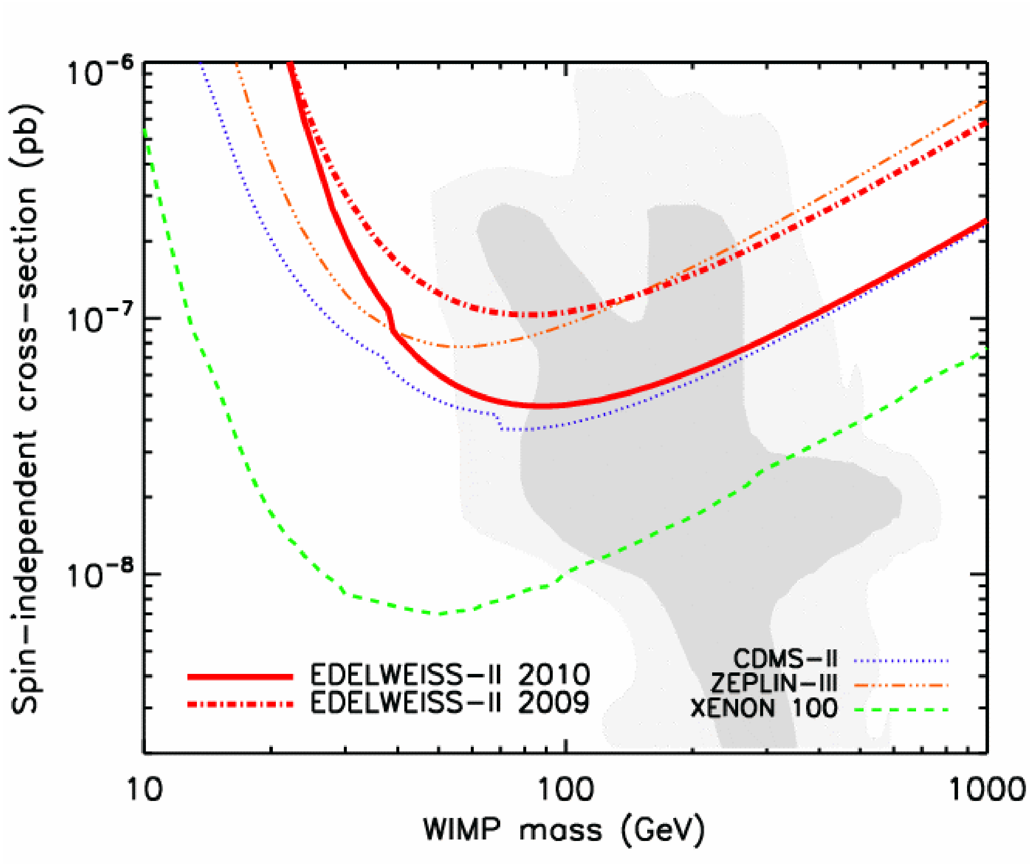
Muon-Induced Neutrons (not rejected by Muon Veto)	< 0.4	measured
Total Neutron Background	< 1.8	
Gamma Contamination of NR Band	< 0.9	measured
Surface Event Contamination NR Band	< 0.3	measured
Total Background Estimate in NR Band	**< 3.0**	Our Current Best Estimate

Results

Total rate in 20 - 50 keV region is 0.14 / (keV.kg.d)



Five WIMP candidates:
- four 20.8 < E < 23.2 keV
- one @ 172 keV
Expected bkg < 3 evt



- 384 kg.d

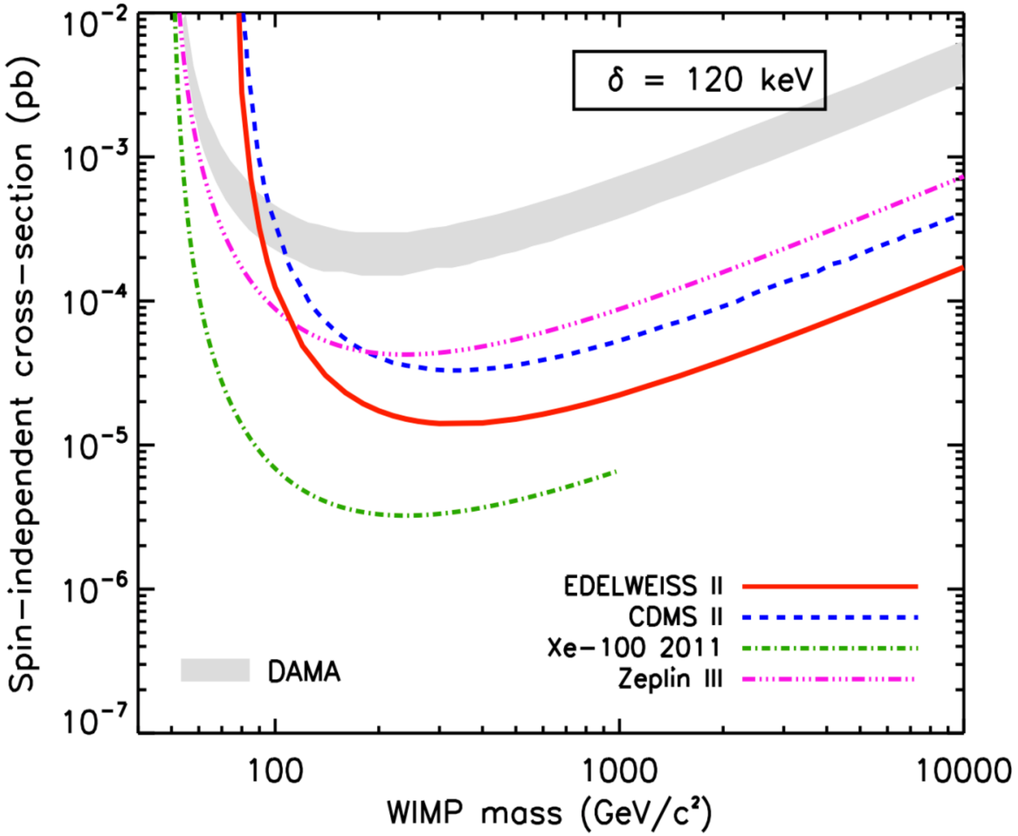
4.4 x 10^{-44} pb at Mχ=85 GeV

- Sensitivity limited at low mass due to background

Phys. Lett. B 702 (2011) 329-335

[first 6 month data: Phys. Lett. B687 (2010) 294-298]

Constraint on inelastic dark matter



<u>Inelastic dark matter :</u>

$\chi + m \rightarrow \chi^* + m$ (δ~100 keV)

Signal globally reduced and suppressed at low recoil energies

Depends on tail of WIMP velocity distribution (we use v_{esc}=544 km/s)

Modulation is enhanced (DAMA signal)

- same data & analysis as in the elastic case

Phys. Lett. B 702 (2011) 329-335

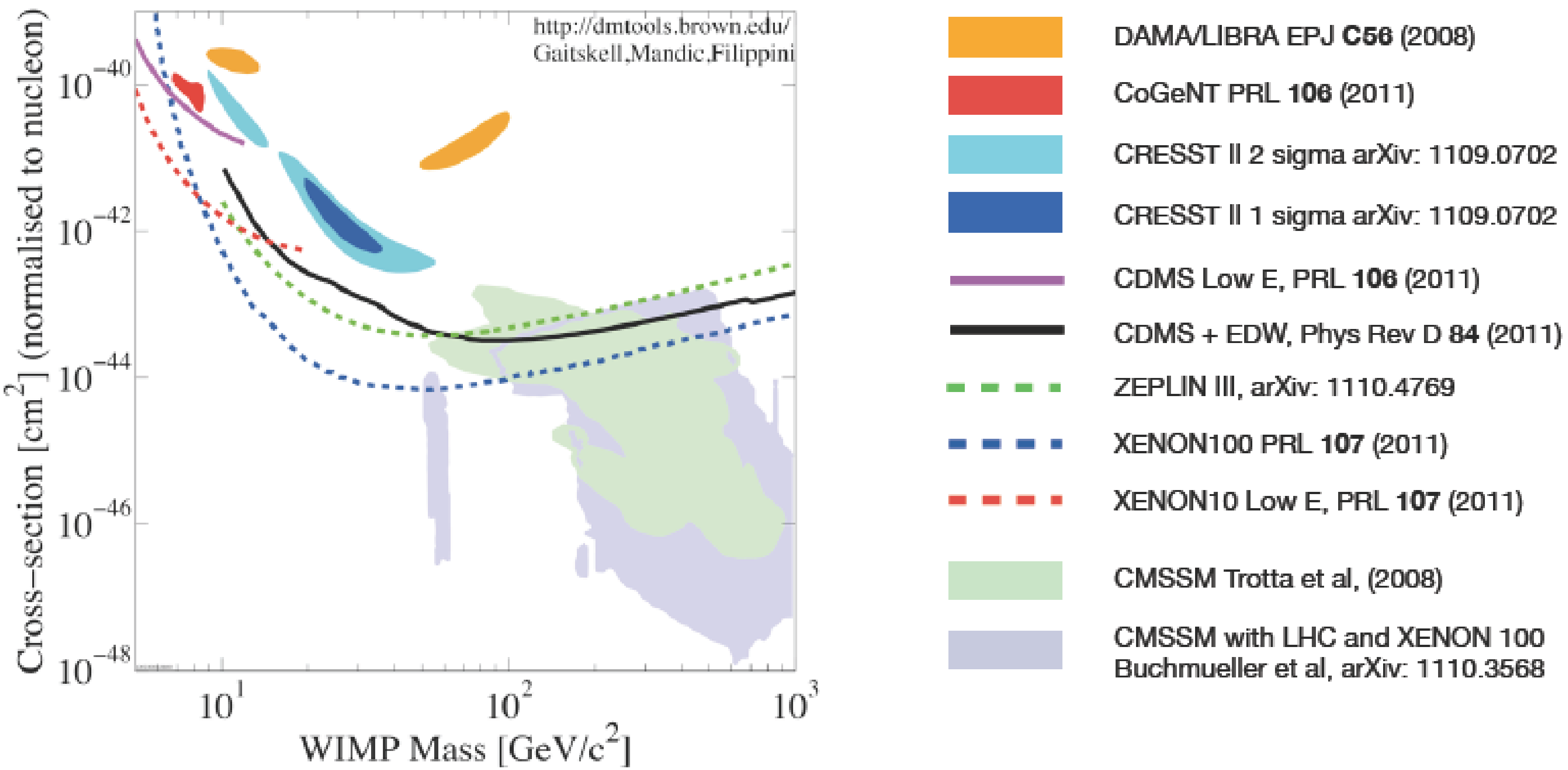
A remark about direct WIMP search by different technologies

An ideal scenario for WIMP discovery:

- **Observation of same spectra in 2 (let say EDELWEISS, CDMS) experiments with same nuclear but with sufficiently different background environments**

- **Observation of winter/summer modulation**

- **Observation of signal on a different nuclear**



http://dmtools.brown.edu/
Gaitskell,Mandic,Filippini
Cross−section [cm^2] (normalised to nucleon)
10^{-40}
10^{-42}
10^{-44}
10^{-46}
10^{-48}
10^1
10^2
10^3
WIMP Mass [GeV/c^2]
DAMA/LIBRA EPJ **C56** (2008)
CoGeNT PRL **106** (2011)
CRESST II 2 sigma arXiv: 1109.0702
CRESST II 1 sigma arXiv: 1109.0702
CDMS Low E, PRL **106** (2011)
CDMS + EDW, Phys Rev D **84** (2011)
ZEPLIN III, arXiv: 1110.4769
XENON100 PRL **107** (2011)
XENON10 Low E, PRL **107** (2011)
CMSSM Trotta et al, (2008)
CMSSM with LHC and XENON 100
Buchmueller et al, arXiv: 1110.3568

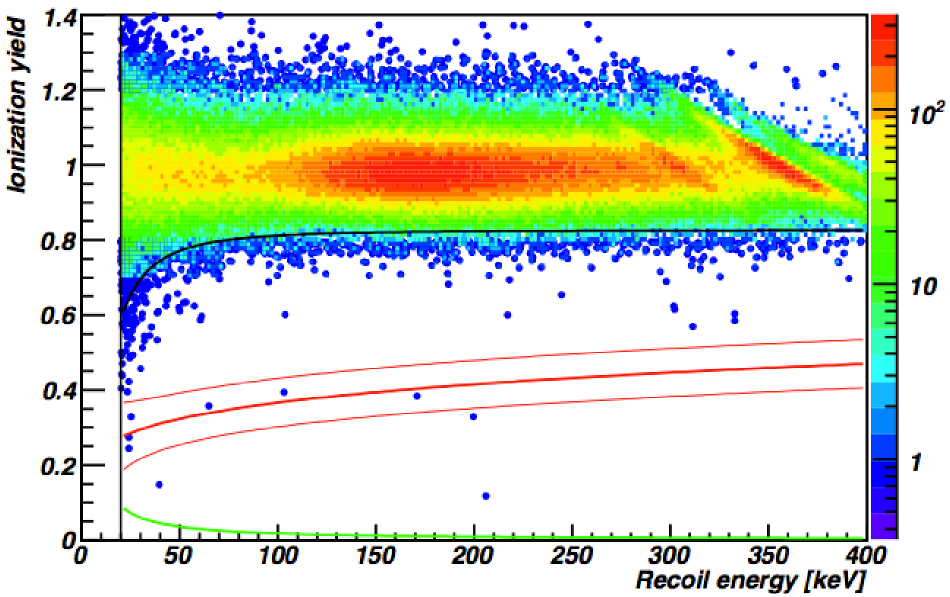
How to improve or what to do with background

<u>How to improve::</u>

- Low energy background

- Mass

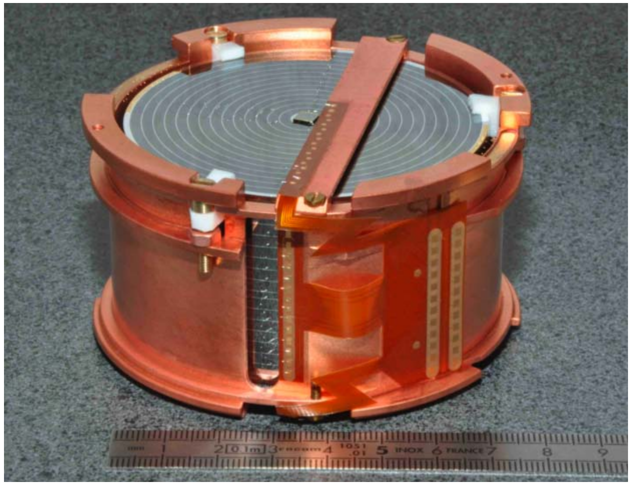
Both aims will be targeted with new FID800 detectors

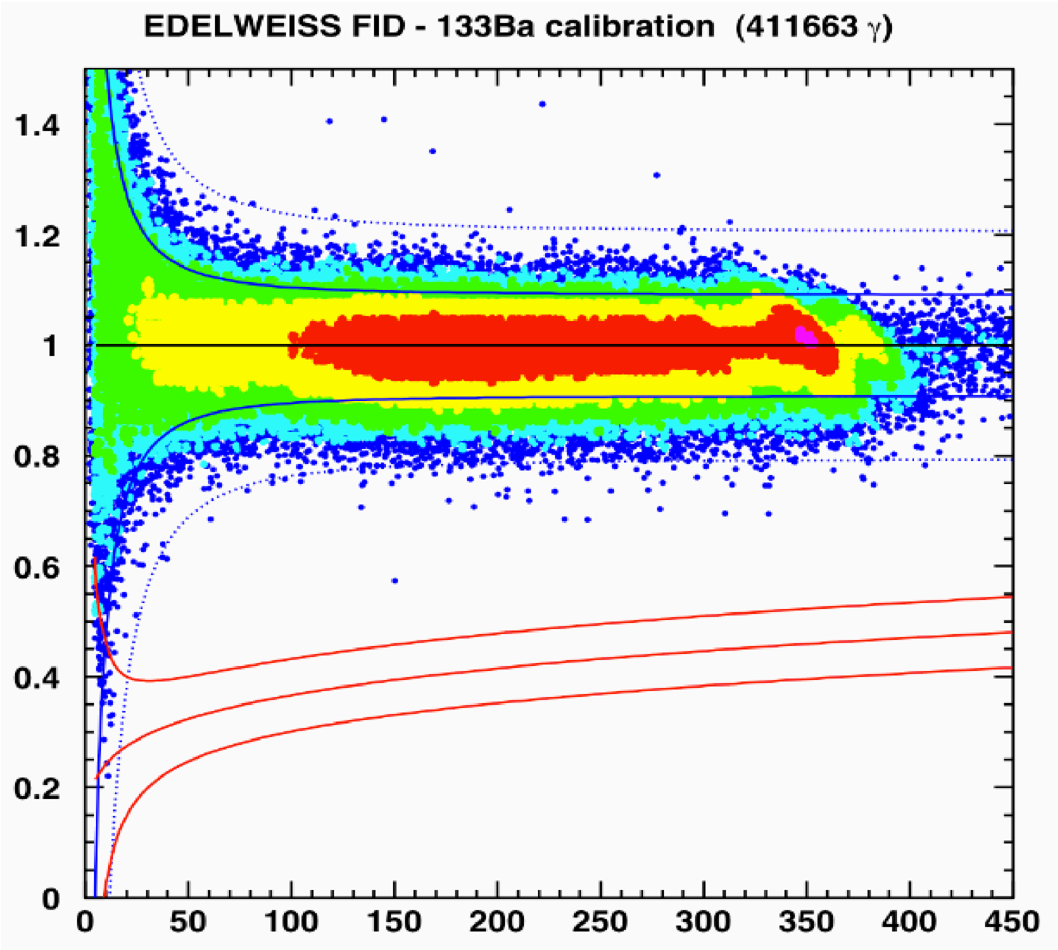


Calibration γ (^{133}Ba), ID400 detectors.

There is an excess of events between NR and γ bands

The FID800 detector





Strong improvement of the gamma-ray rejection over original ID detectors

Increase mass + sensitivity :

- 800g crystal
- two NTD sensors per detector
- interleaved electrodes on all the surface : no « guard » region anymore, ~ 75% fiducial volume

How to improve

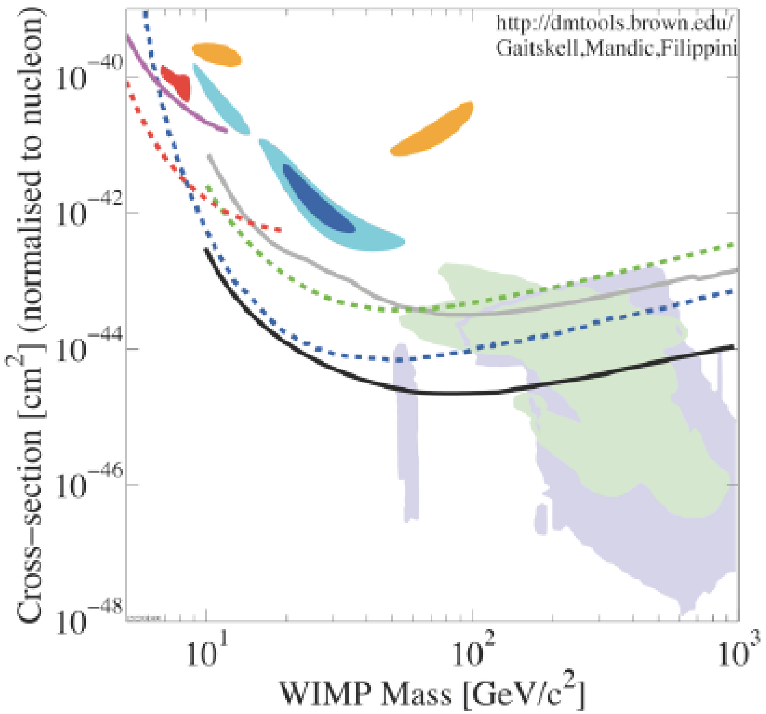
Towards 5x10^{-45} cm^2

- Program under way

- Infrastructure : Upgrades of cabling, cold electronics, cryogenics, acquisition and shielding **within the current EDW-II setup**
  - Lower thresholds due to reduced noises
  - Special care with neutrons : additionnal inner PE shield

- Detectors : ~ 40 FID800 bolometers installed 2012-2013 : **24 kg fiducial**

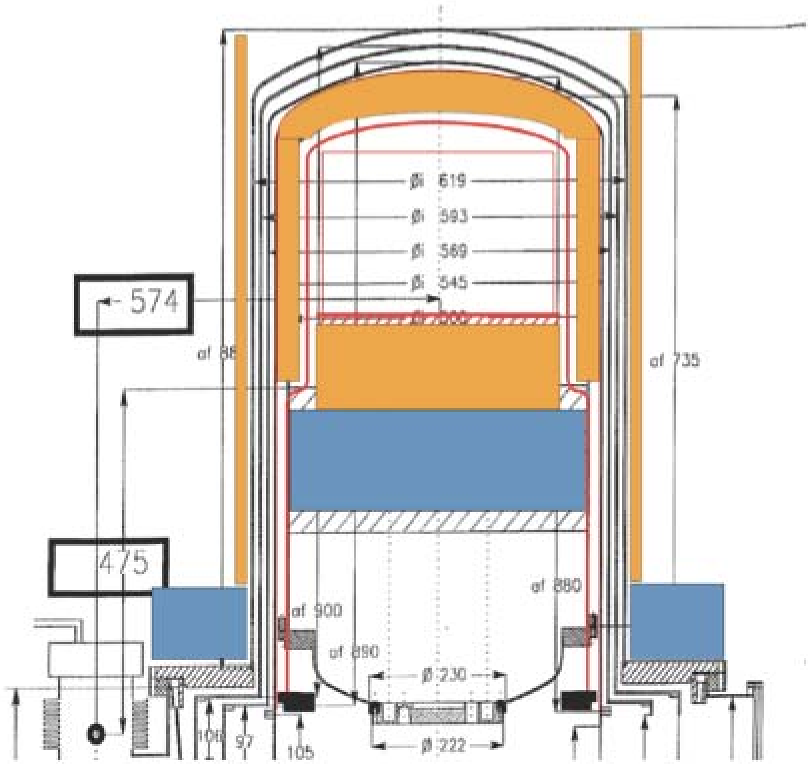
  $\Rightarrow$ 3000 kg.d



Potential for exploring 4x10^{-45} cm^2 level for SI WIMP-nucleon cross section (region of interest of SUSY models – discovery of WIMPs)

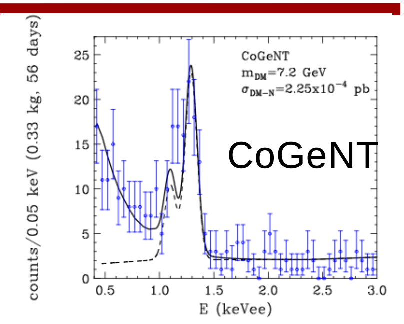
Neutron Shielding

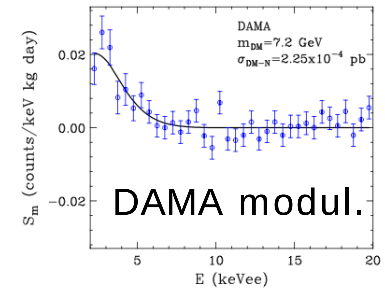
- Factor 6 reduction in neutrons
- Redesigned Cryostat, internal detector galette.
- Block neutrons from Pb Shield and cables/connectors
- Add Inner PE Shielding
- PE Radiopurity Measurement
- Material selection improvements for cables and connectors
- Cryostat design to be finalized in next month.

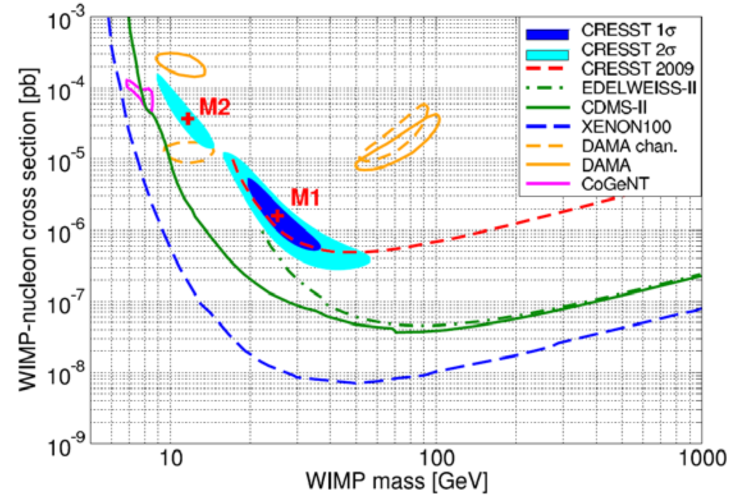


Low Mass WIMPs

- Observed excess at low energy, close to experimental thresholds, in DAMA/LIBRA (annual modulation in NaI) and CoGeNT (high-resolution Ge, ionization-only) [Aalseth et al, arXiv 1002.4703]
- Interpretation as M < 10 GeV WIMP? Inconsistent with XENON-100 [Aprile et al, subm. PRL, arXiv:1005.0380].
- New CRESST results
- Contradictory hints, require further investigations (& low thresholds)







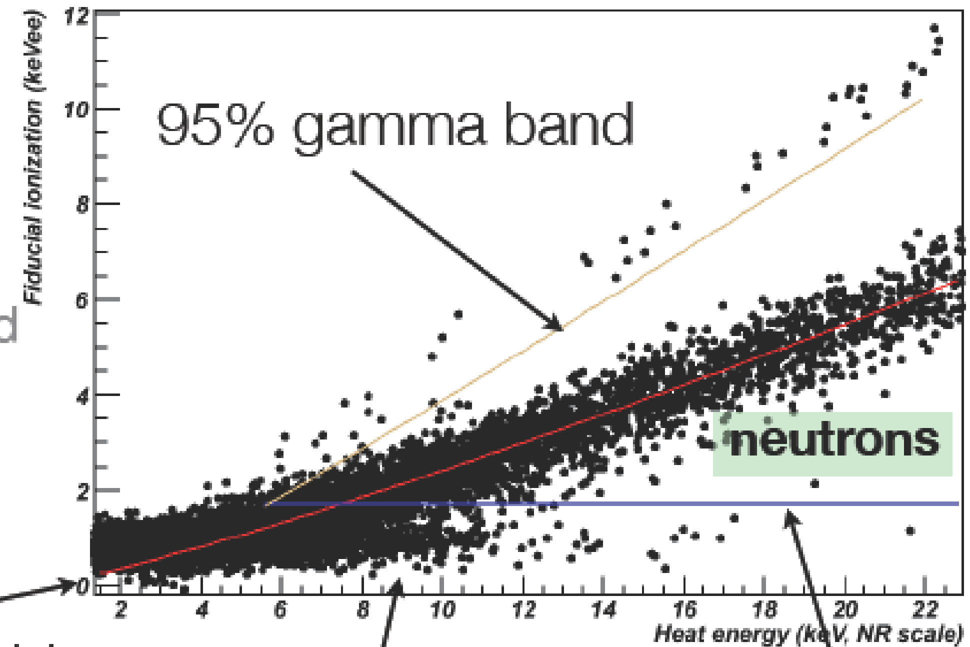
Preliminary Low Energy Analysis of ID3

- Search below 20 keV
- Neutrons to 5 keV
- Energy based on heat only

$$E_{\rm heat} = \frac{E_{\rm rec}}{1+V/3}\left(1+\frac{V}{3}0.16\,E_{\rm rec}{}^{0.18}\right)$$

- Chi2 cut on heat pulses
- Fiducial events (no veto/guard)
- Online trigger efficiency measured by calibration of ADU threshold value

Strong (10^5 n/s) AmBe neutron calibration 2010 placed outside of all shielding and muon veto



consistent with $0.16\ E_{rec}^{0.18}$

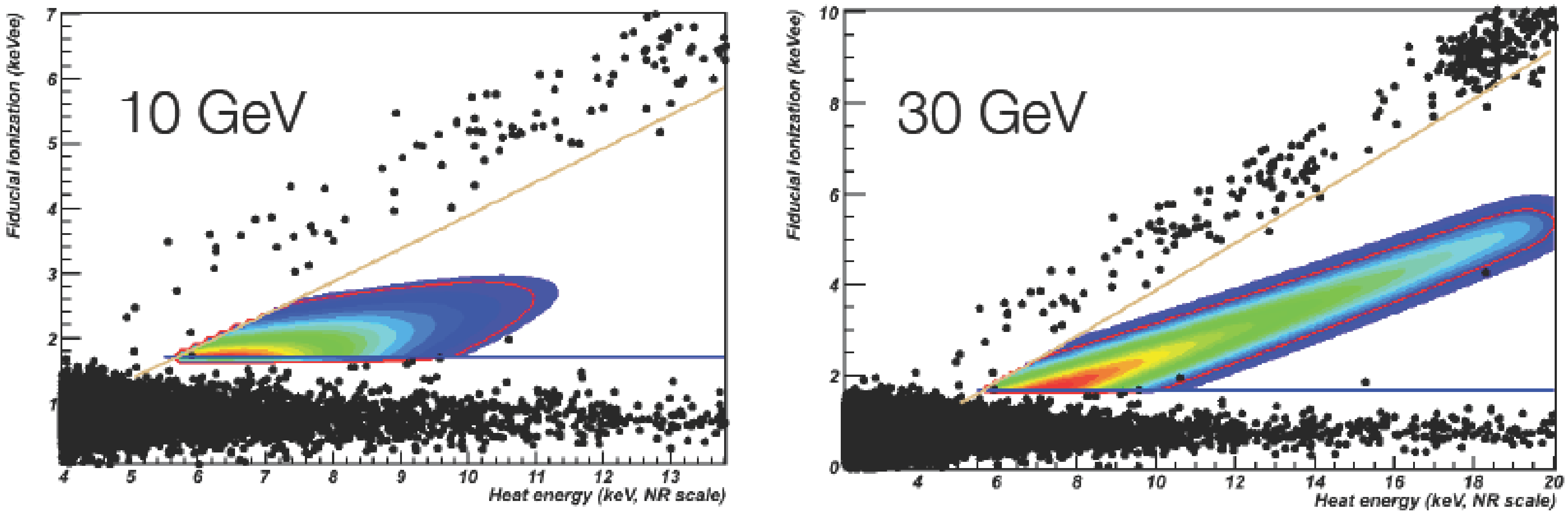
NR ionization yield (red line)

heat only events

Ionization threshold (1.7 keV)

WIMP search : ID3 low-energy background data

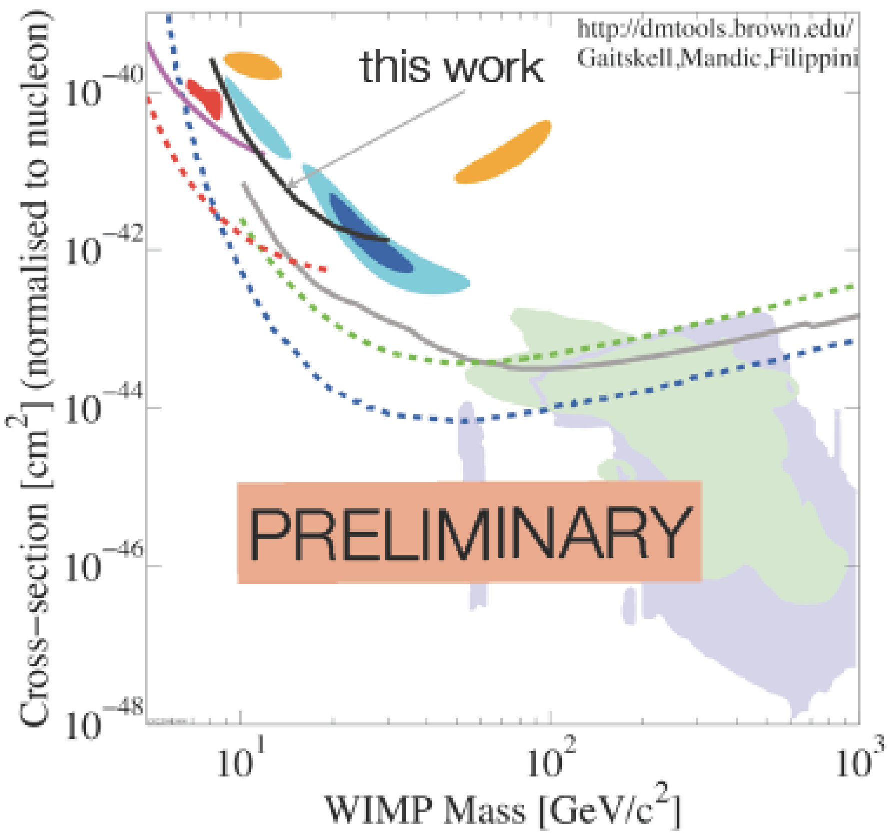
198 live days. Same data in both plots (different scale)



- Compute the density of a WIMP signal for a given mass (using measured resolutions and efficiencies) : colour contours
- Count the WIMP candidates within a ROI fixed to have 90% efficiency to the WIMP signal **(red contour)**
- No convincing signal (from 1 to 3 candidates depending on M_X); derive 90% CL limit on σ_{SI} from Poisson statistics
- Estimated backgrounds:
  - ~ 0.25 events from heat-only pulses (using a background model)
  - ~ 0.5 events from fiducial gamma-rays
  - ~0.5 neutrons

  No significant surface event background (compare to CDMS) !!!

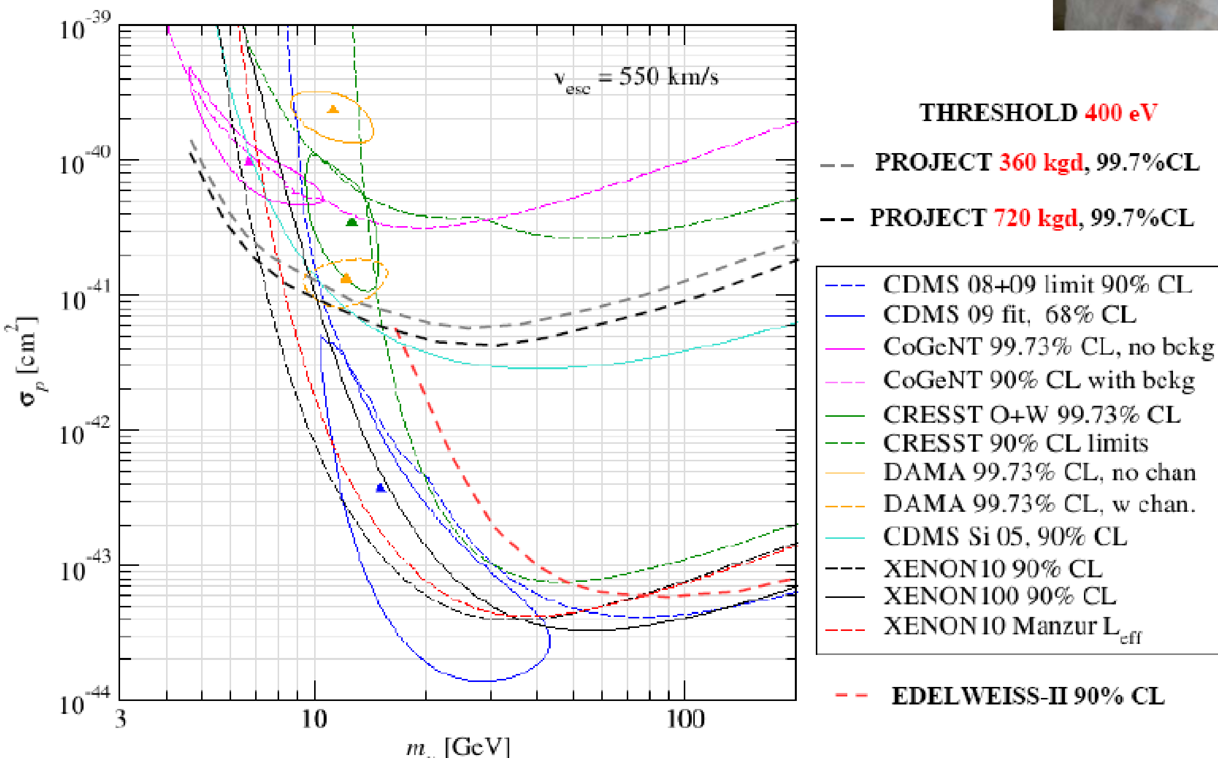
Preliminary low-mass WIMP limit ~ 30 kg.d



- Combination with detectors of equivalent performance (in progress)
- Limited by Heat Only events
- ID3 detector (this analysis) has best resolution
- Poisson limits (optimal interval to come)
- (2 NTDs per bolometer in EDW III)

Extend research area to low mass WIMPs with point contact HPGe detectors developed by JINR

Low Mass WIMPs



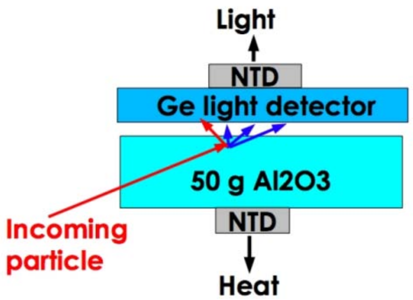
A possible results of using 1 or 2 point contact detectors in EDELWEISS for 1 year. CoGeNT positive WIMP detection will be directly verified.

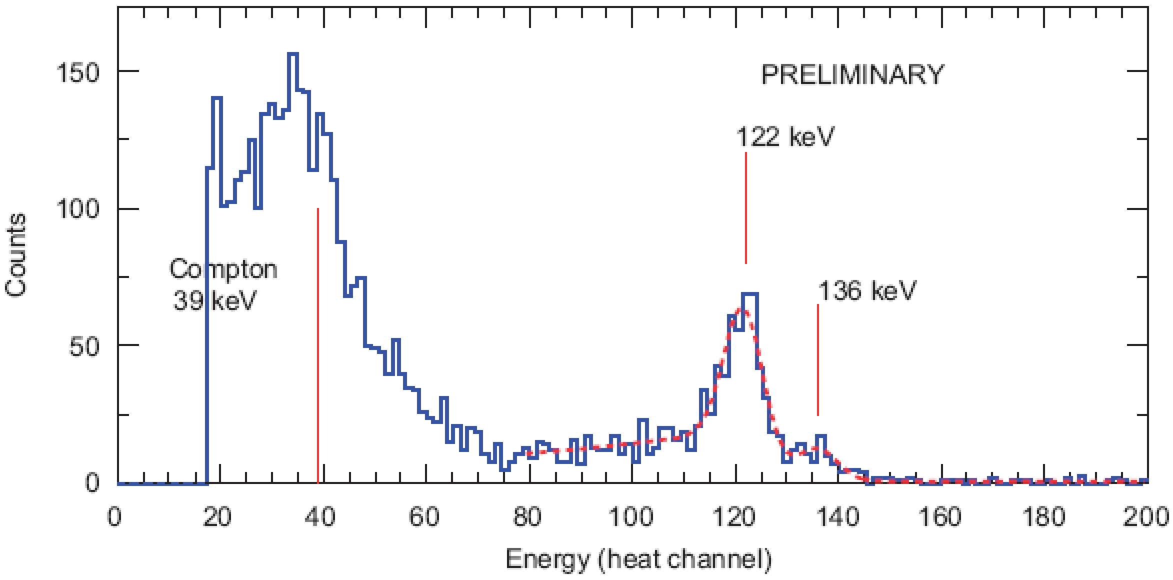
Some R&D for L&H detectors in EDELWEISS

During the commissioning runs (before 2009), EDELWEISS has integrated **sapphire** heat-scintillation bolometer for compatibility tests

The nominally pure sapphire crystal is a 50 g cylinder, *h = 25 mm and φ = 25 mm, c*ompletely polished, manufactured by SOREM. The light yield of this crystal is 1.3%. The light detector is made of germanium. It is a 195 mg disk, *h = 75 μm and φ = 25 mm.*

There are several differences between the IAS and the Ge NTD detectors: time constants of the order of 1ms for IAS and of 100 ms for the Ge, NTD resistance at 20mK of the order of 100MΩ for IAS and 10MΩ for Ge ent holders that may give a different response to microphonics.





Calibration of the heat signal of a sapphire heat-scintillation detector integrated in EDELWEISS II for compatibility tests

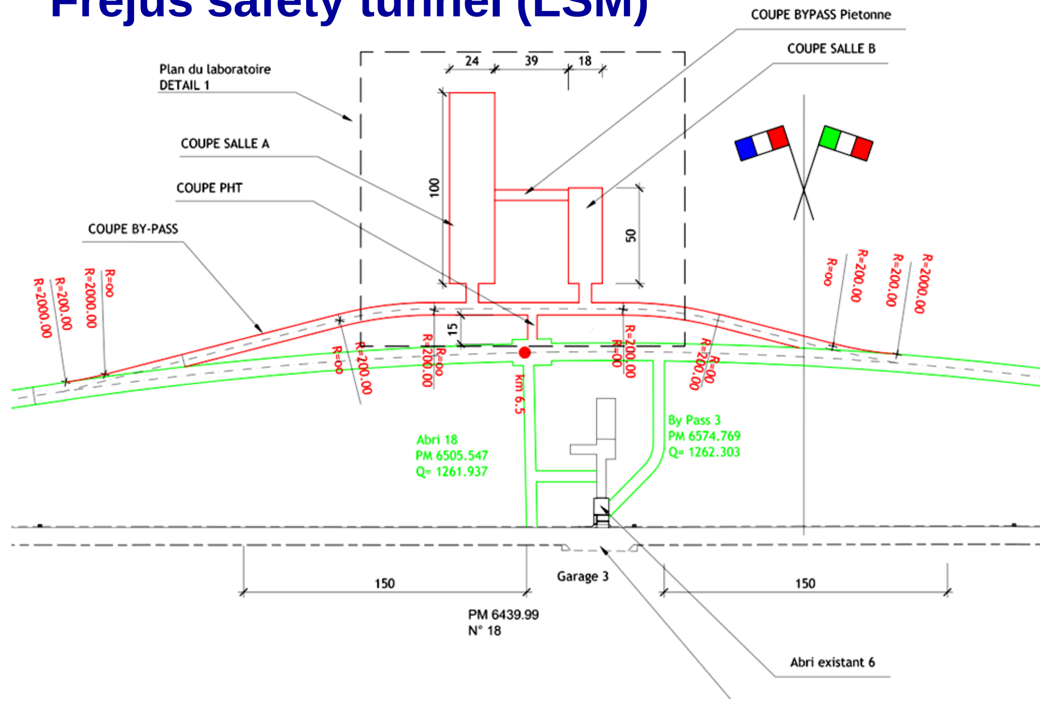
Conclusion and outlook

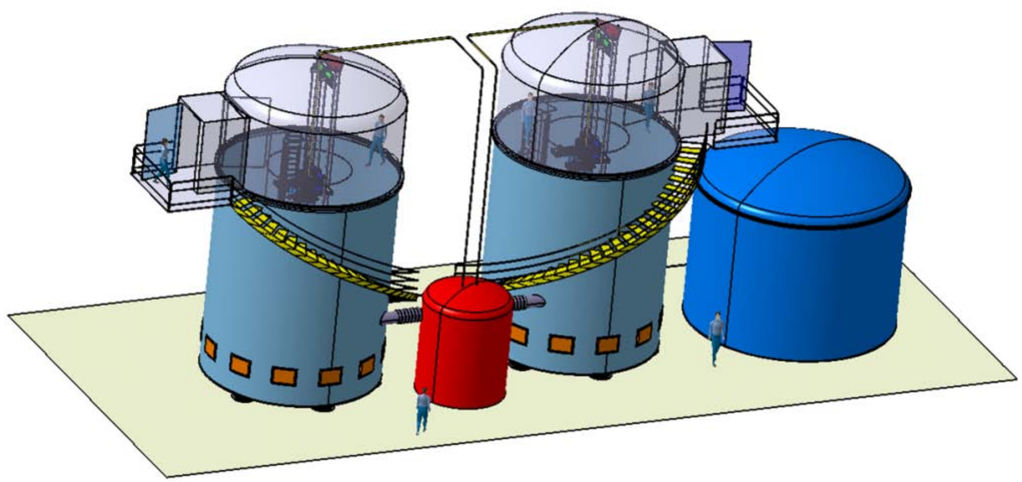
- **Dark Matter problem is important for both particle physics and astrophysics**
- **Many concurring state of the art experiments, good chance that we will find something soon**
- **EDELWEISS experiment aimed for direct WIMP observation in terrestrial laboratory with HPGe cryogenic detectors**
- **EDELWEISS has a potential for exploring $4x10^{-45}$ cm^2 level in next few years (region of interest of SUSY models – discovery of WIMPs)**

To probe 10^{-10} pb;
1 tonne Cryo detector;
$\sim 10^{-5}$ evts / (kg day)

Part of ILIAS/ASPERA European Roadmap

Fréjus safety tunnel (LSM)





EURECA short history

- Foundation date : 2005 : 1st meeting in Oxford : EDELWEISS and CRESST decided to put efforts together for next generation experiment : 1 ton cryogenic multitarget exp
- 2006 : CERN, ROSEBUD joined, collaboration agreement written, WP structure set up
- 2007-2010 : Bordeaux, Kiev, Sheffield joined

France

CEA/IRFU Saclay (G Gerbier coord)
CEA/IRAMIS Saclay
CNRS/Neel Grenoble
CNRS/CSNSM Orsay
CNRS/IPNL Lyon
CNRS/IAS Orsay
CNRS/ICMCB Bordeaux

Spain

Zaragoza

Ukraine

Kiev

United Kingdom

Oxford
Sheffield

Germany

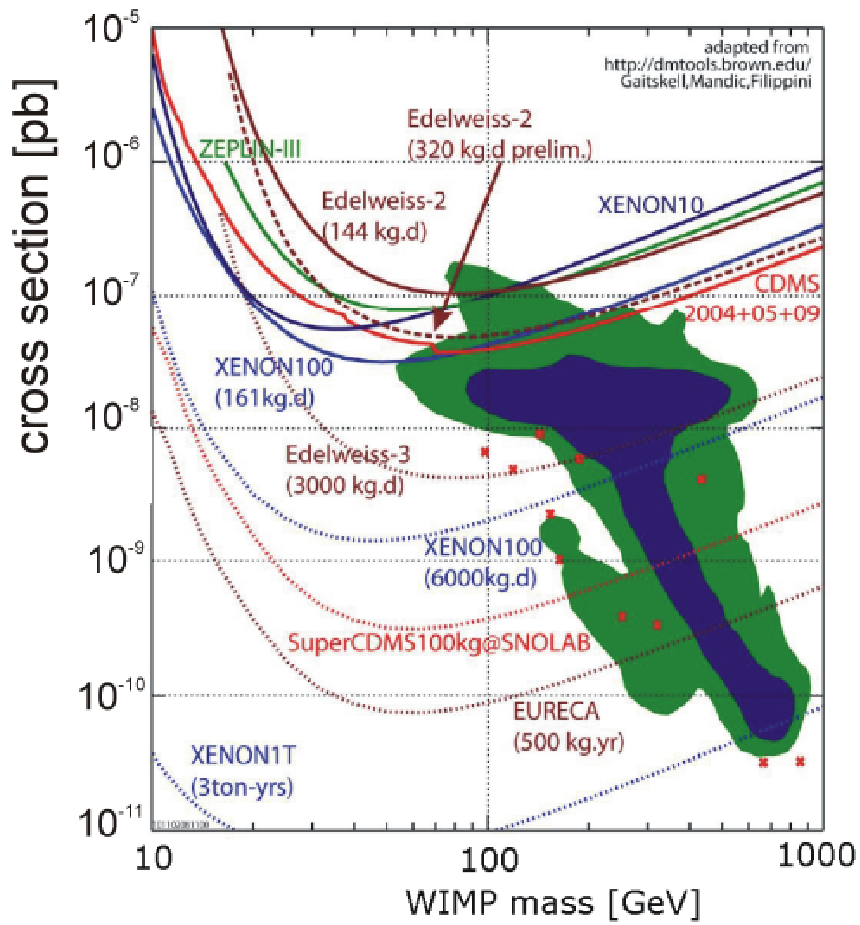
MPI für Physik, Munich
Technische Universität München
Universität Tübingen
Karlsruhe Institute of Technology

International

JINR Dubna
CERN

EURECA main features

- To reach low part of SUSY space need 20 years or **1t**
- Multitarget : Ge, scintillators : allows redondancy , A^2 dependence check
- Good resolution, low thresholds, high discrimination against background : EDWII, CRESST (300g to 800g unit)
- For Germanium : high intrinsic purity
- But to see **few evts/t.y**, need significant improvements in background
- Staged approach
  - EURECA 1 = 150 kg
  - EURECA 2 = 1t



EURECA in LSM

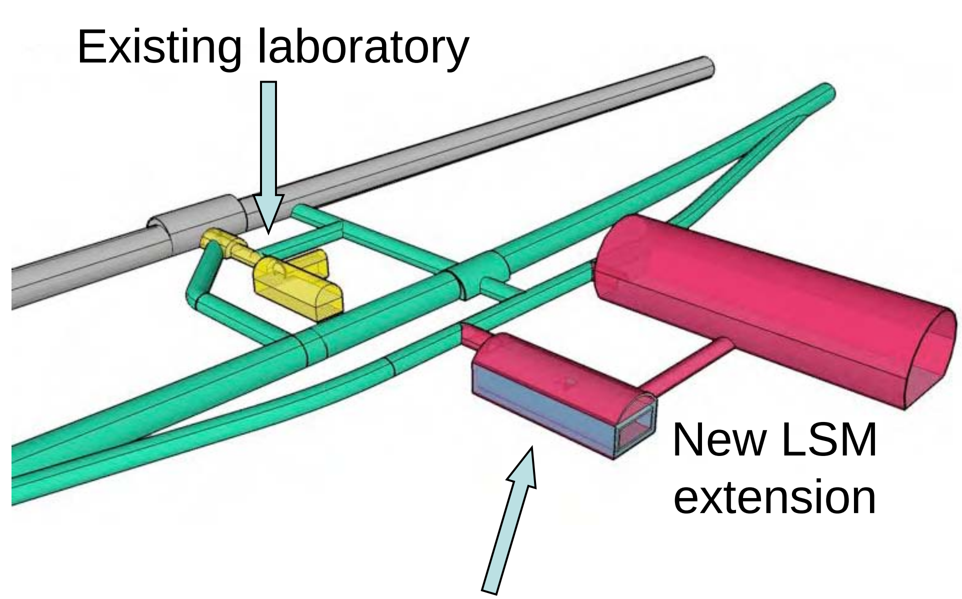
Timeline:

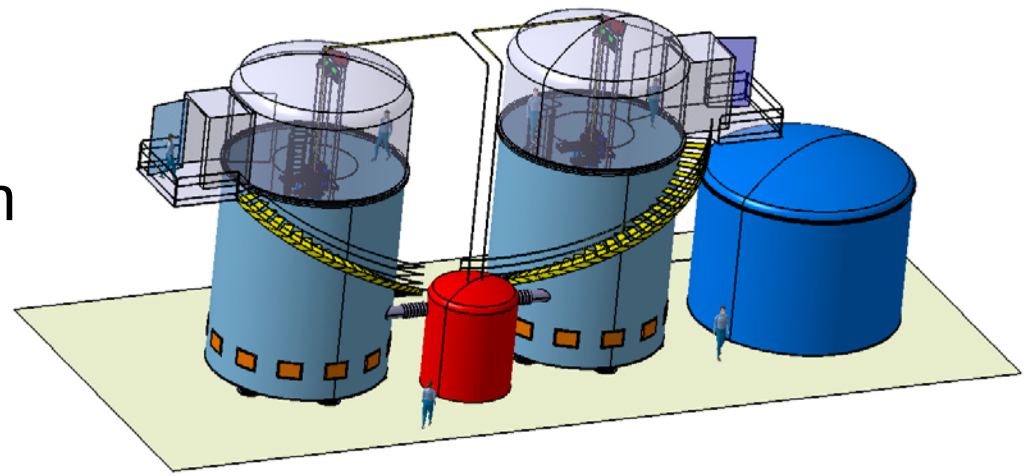
2011/12: In parallel to LSM excavation, begin R&D of EURECA components away from LSM. Aim for ~150kg stage (10^{-9} pb).

2014: LSM extension ready to receive EURECA.

2015: Begin data taking and in parallel improve and upgrade.

2018: One tonne target installed.

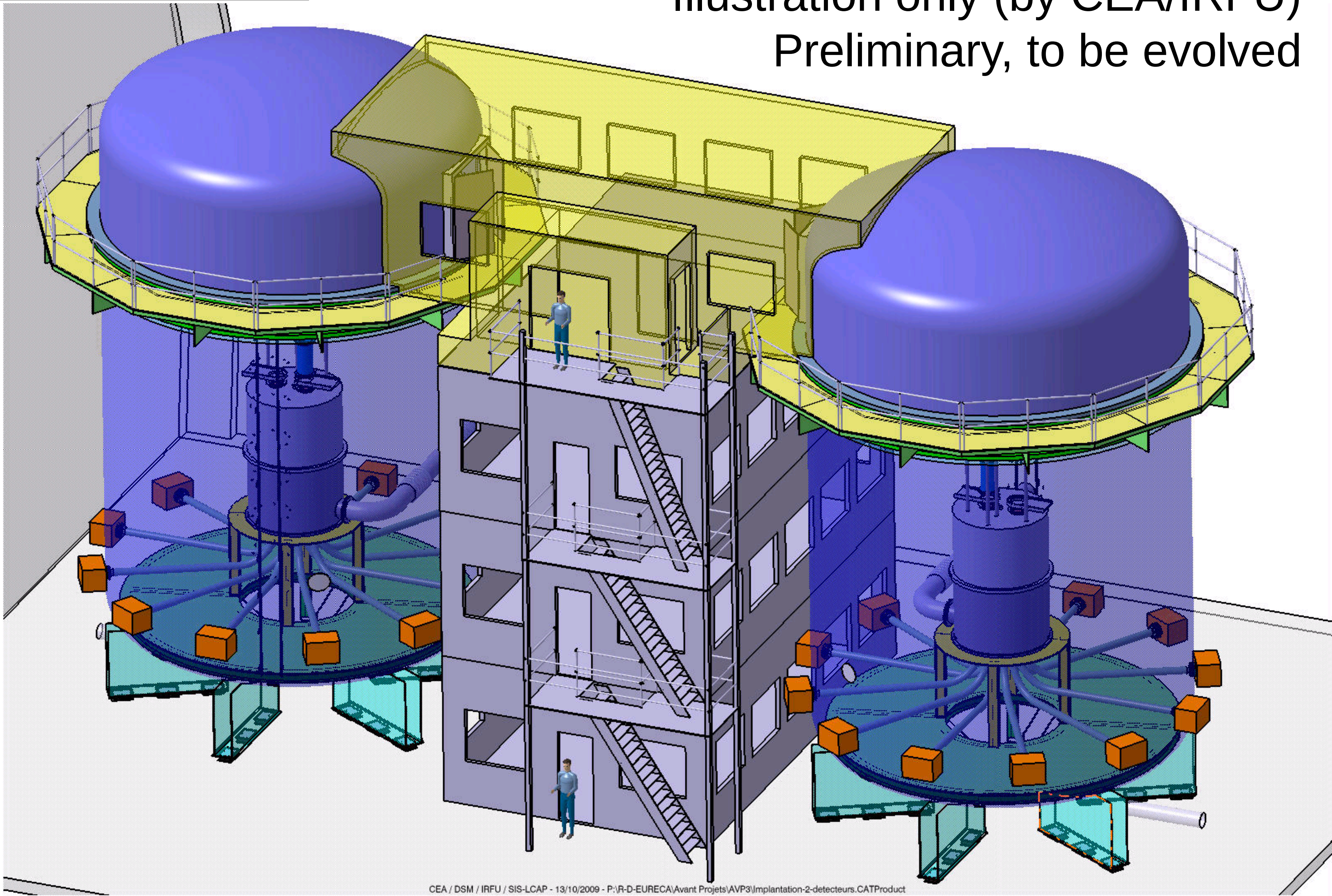




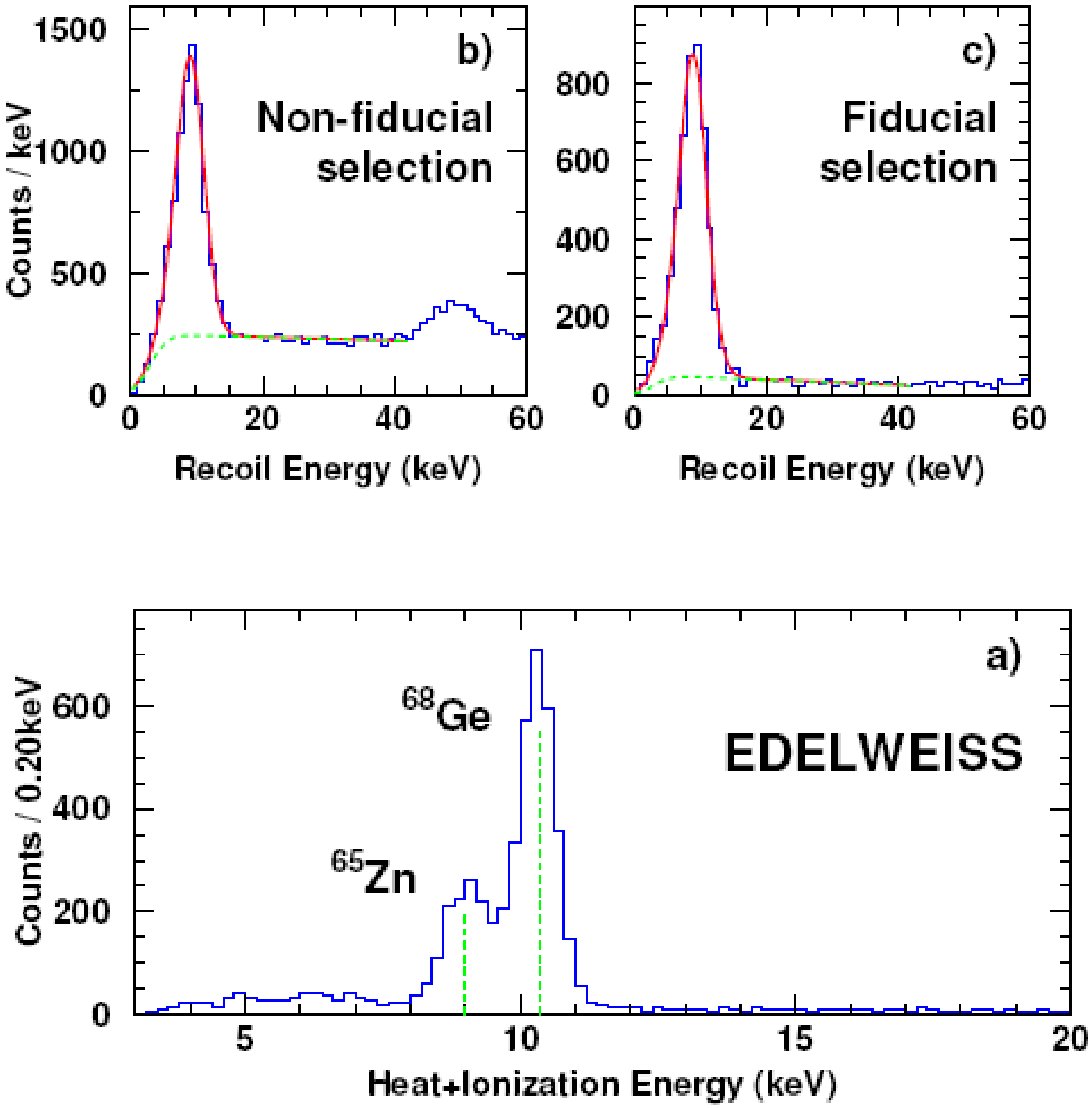
Possible EURECA Facility Layout

More Detailed View of EURECA

Illustration only (by CEA/IRFU)
Preliminary, to be evolved



ID detectors and results /WIMP data



Energy thresholds in heat and ionization channels are < 2 keV (important to get a good WIMP search threshold)

Background dominated by the cosmogenic lines at ~10 keV (help to defined fiducial volume)

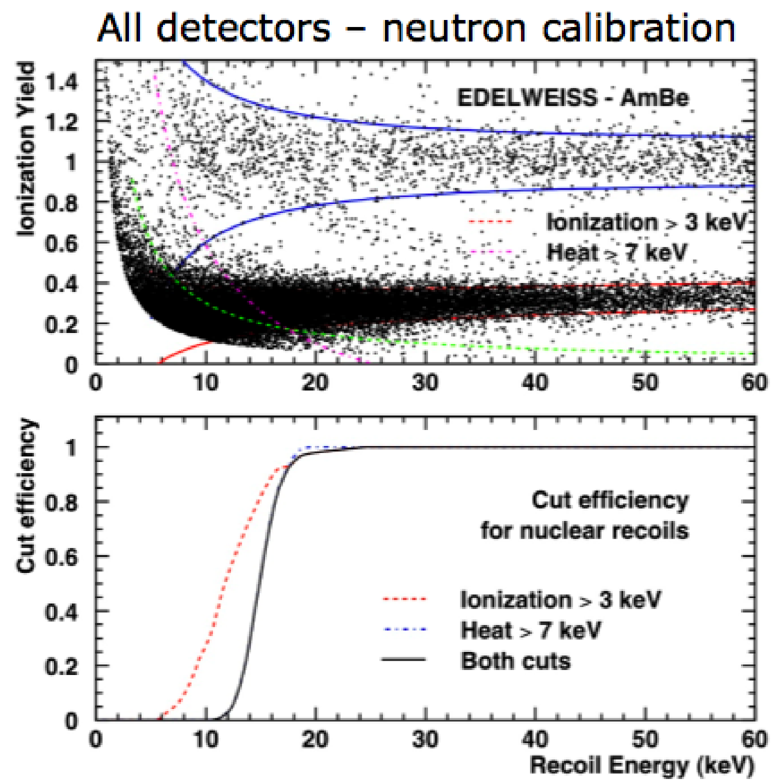
Good and stable energy resolution

46 keV peak associated with ^{210}Pb decays near the surface of the detectors is clearly visible outside and strongly suppressed inside of fiducial volume

The rate in the energy range from 20 to 50 keV is 0.14 evts/keV/kg/day

Data analysis

- 2 independent processing pipelines
- Period selection based on baseline noises
  - **80% efficiency**
- Pulse reconstruction quality (χ^2)
  - 97%
- Bolo-bolo & bolo-veto coincidence rejection (<1%)
- WIMP search threshold fixed a priori *Er > 20 keV* *(~100% acceptance)*



Description : schéma (Cryo froid)