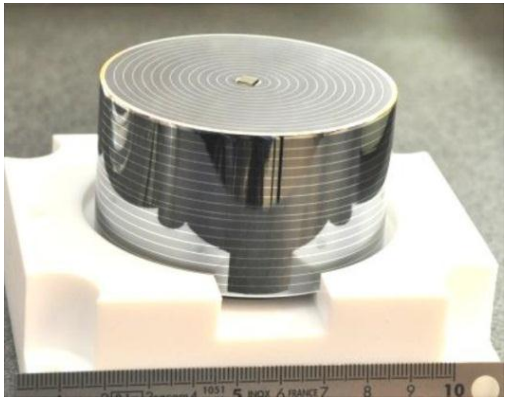
The EDELWEISS dark matter search: Latest results and future plans

- Dark matter – evidence – candidates
- Why use cryogenic detectors?
- Edelweiss – Interdigit detectors – latest results
- Other cryogenic experiments – CDMS/Edelweiss collaboration
- Future plans - EURECA



Sam Henry, University of Oxford

Collaboration

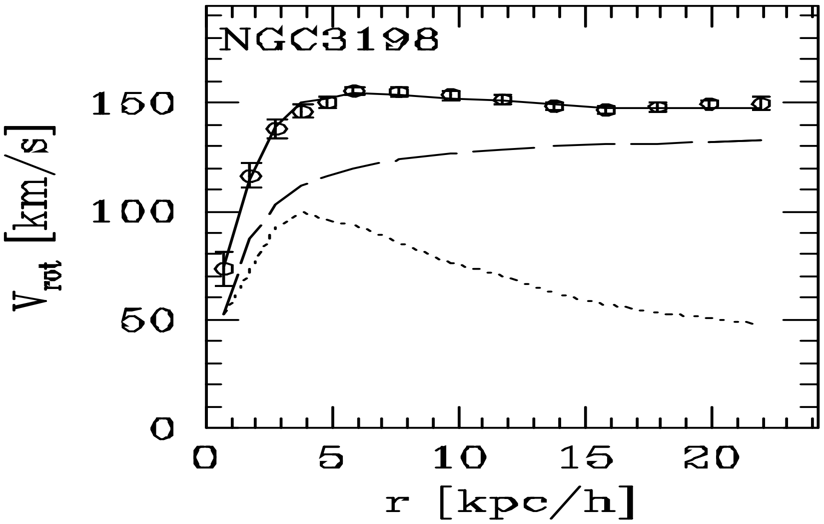
≈ 50 people:
30 senior researchers;
11 PhD students;
5 post-docs;
4 countries

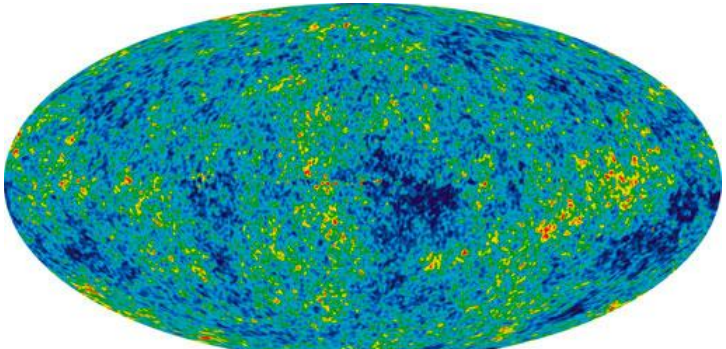
• CEA Saclay (DAPNIA & DRECAM)	• Detectors, electronics, aquistion, data handling, analysis
• CSNSM Orsay	• Detectors, cabling, cryogenics
• IPN Lyon	• Electronics, cabling, low radioactivity, analysis, detectors, cryo
• Institut Néel Grenoble	• Cryogenics, electronics
• KIT: IK, IEKP, IPE Karlsruhe	• Vetos, neutron detector, background, analysis, electronics
• JINR Dubna	• Background, neutron, radon monitors
• Oxford University	• Detectors, cabling, cryogenics, analysis
• Sheffield University	• MC simulations

Oxford group: Hans Kraus, Sam Henry, Mark Pipe, Philip Coulter, Xiaohe Zhang

Evidence for dark matter

- Rotation curves → dark matter density in galxy
- Gravitational lensing → map distribution on large scales
- CMBR → precision measurements of cosmological parameters
- Big bang nucleosynthesis → non baryonic dark matter

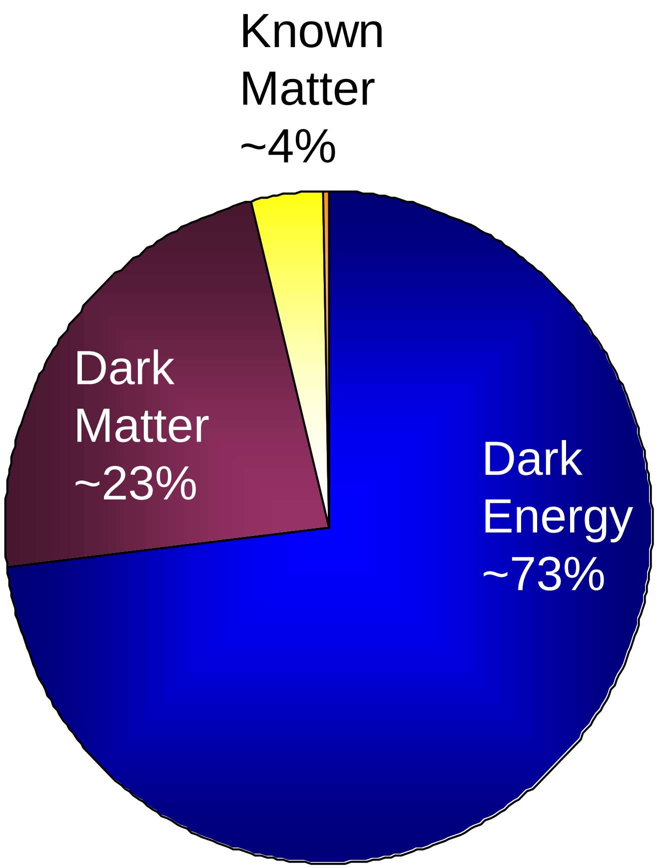


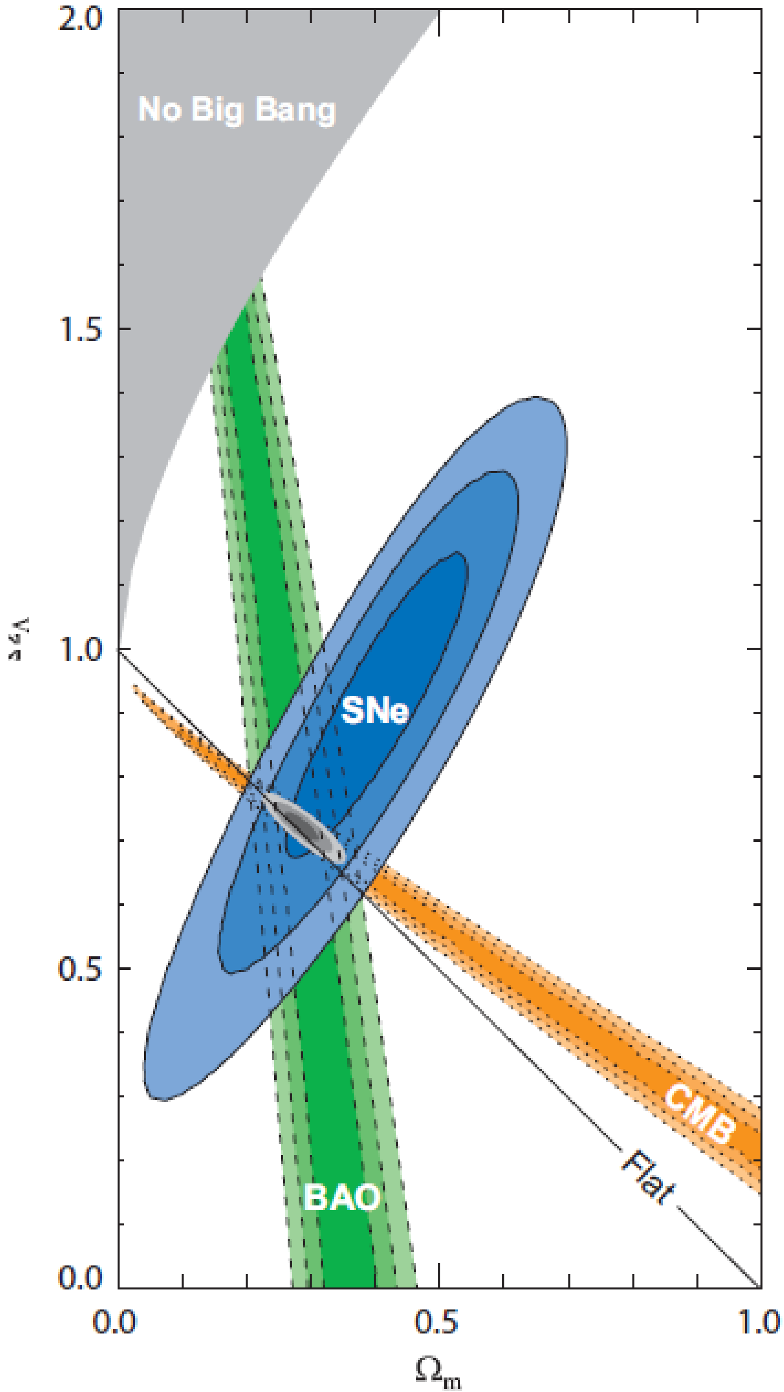


Conclusion:

$\Omega_\Lambda \sim 0.7$

$\Omega_M \sim 0.3$





The Bullet Cluster

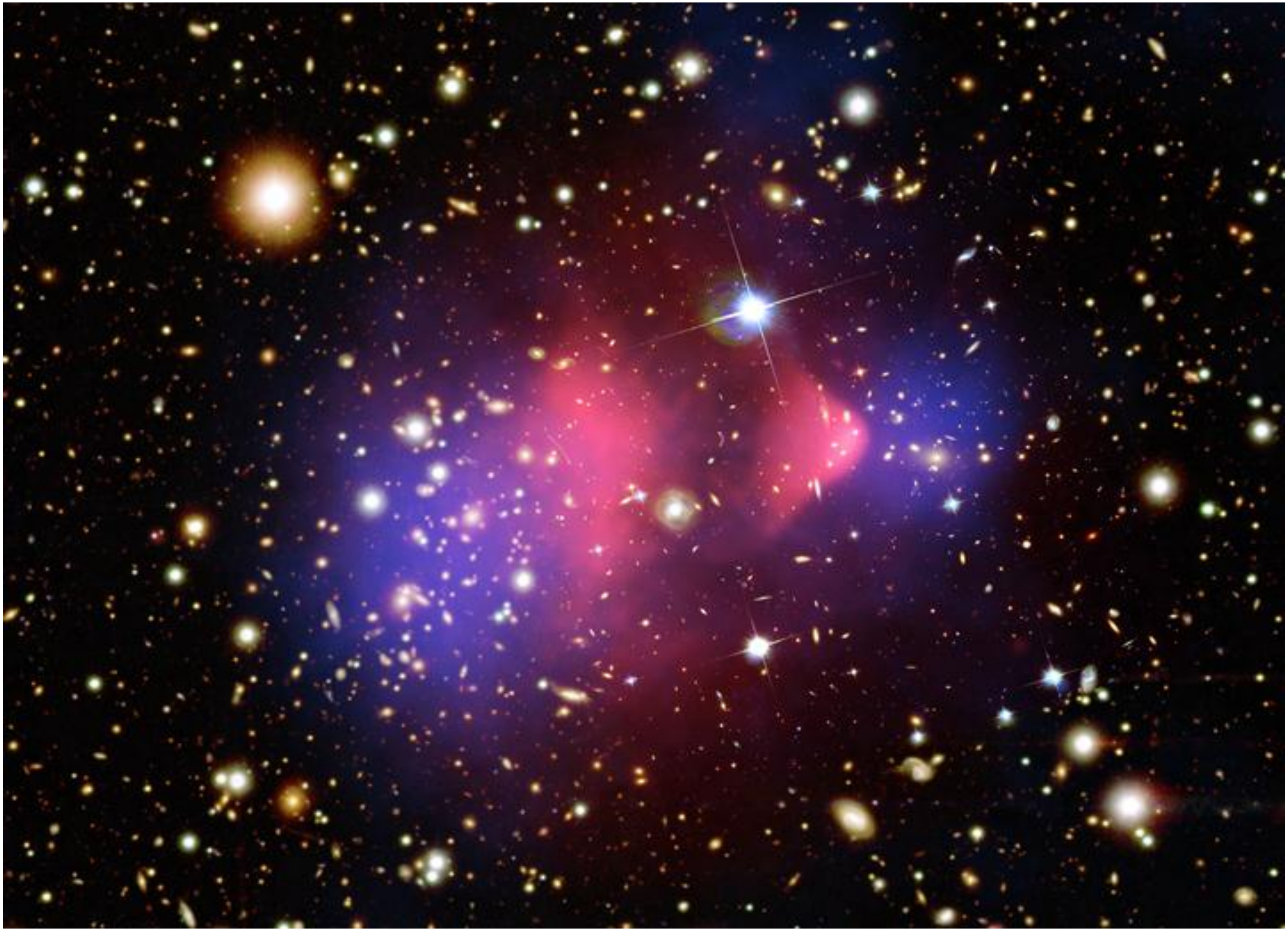
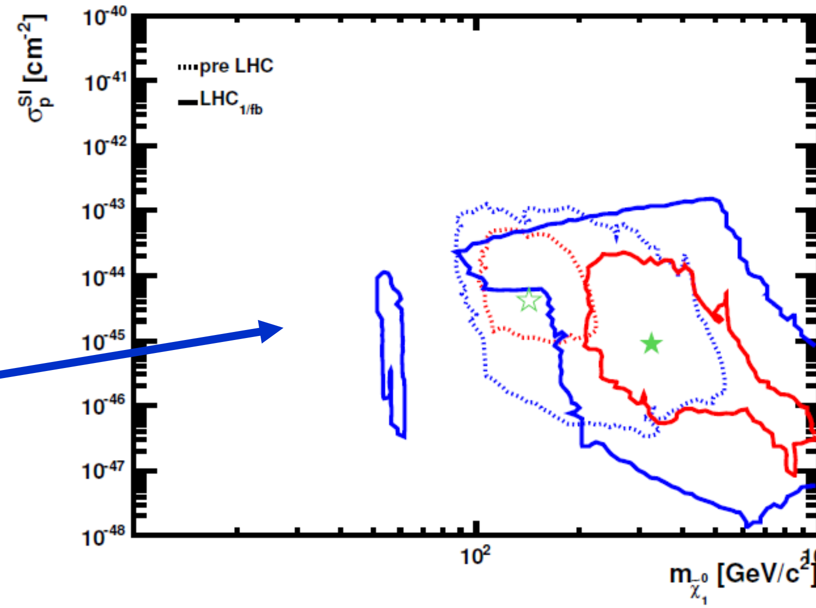


Image credit:NASA/CXC/M.Markevitch et al.
Optical: NASA/STScI; Magellan/U.Asizona/D.Clowe et al.
Lensing map: NASA/STSCI; ESOWFI; Magellan/U.Arizona/D.Clowe et al.

Dark matter - candidates

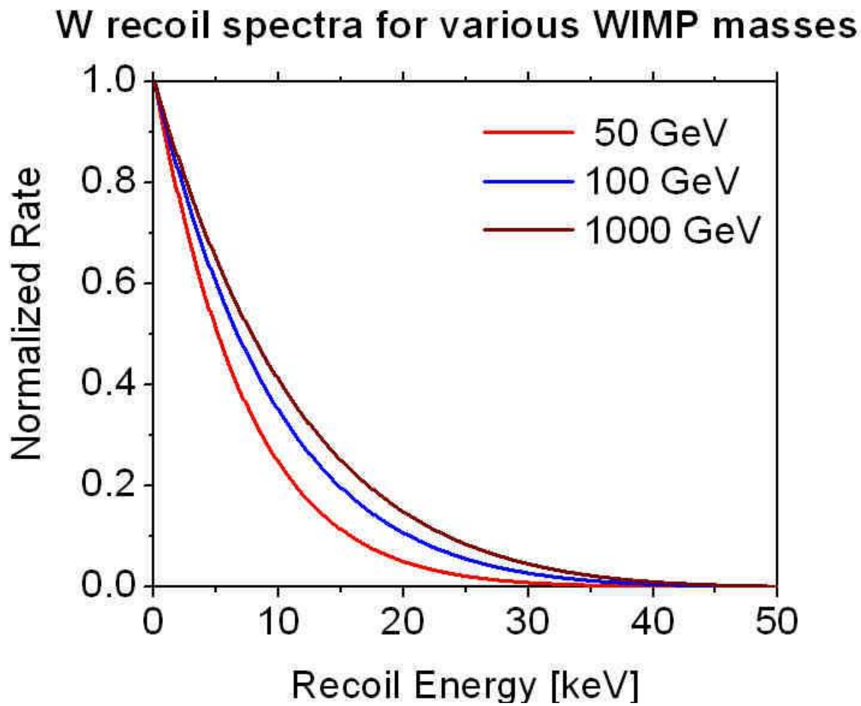
- Neutrinos
- Axions
- Gravitinos, axinos
- WIMPs - Weakly Interacting Massive Particles
  - Supersymmetric neutralinos
  - Kaluza Klein particles
  - Technibaryons
- Alternative gravity
  - MOND - TeVeS



Buchmueller et. al. arXiv:1110.3568

CMSSN Parameter space excluded by LHC data

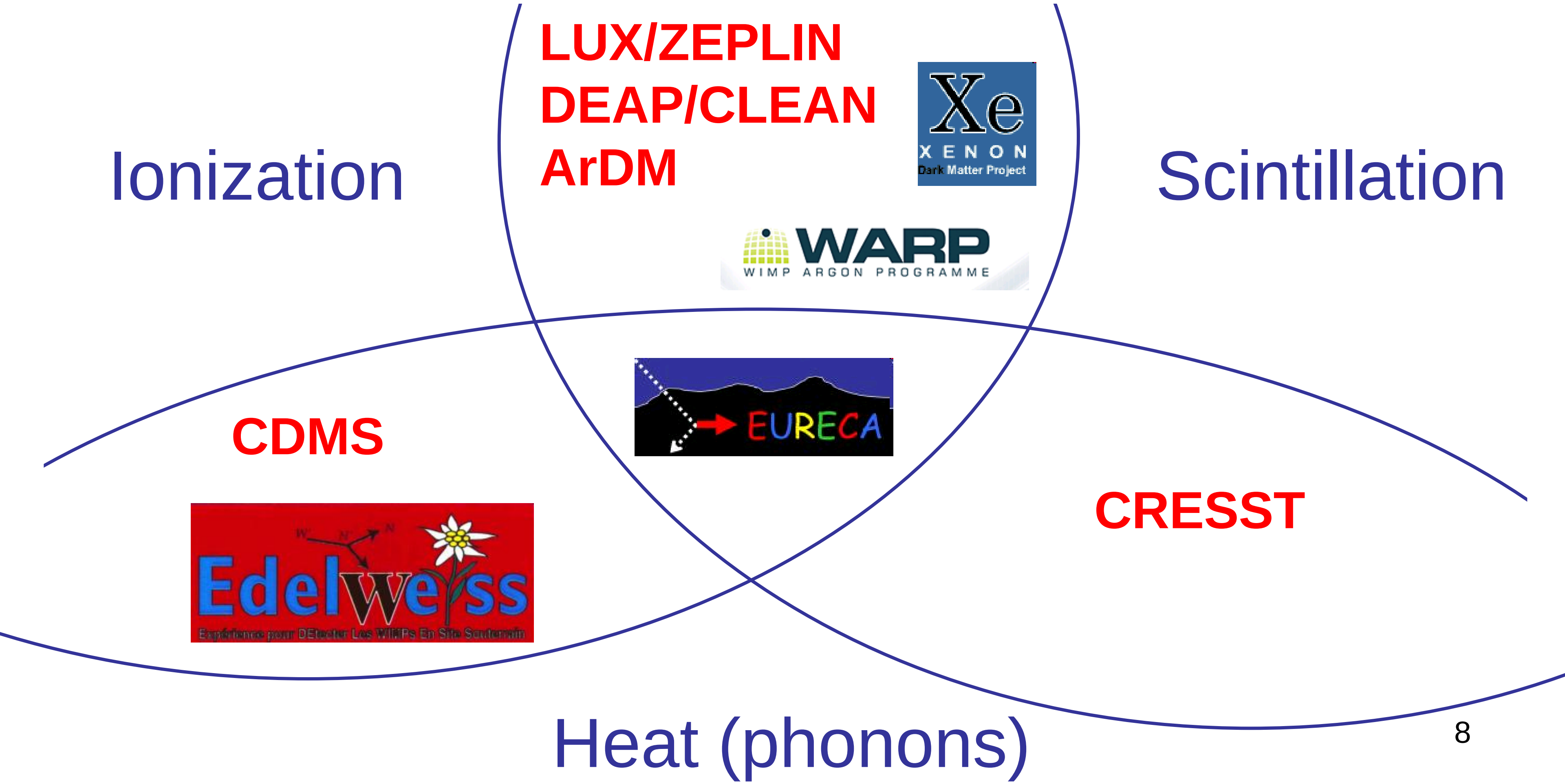
WIMP Direct Detection Requirements



- Search for elastic scattering of WIMPs off atomic nuclei
- Expected event rate 3 events/kg/year ($\sigma \sim 10^{-8}$pb)
- Sensitive detectors, large absorber mass, low threshold, background discrimination

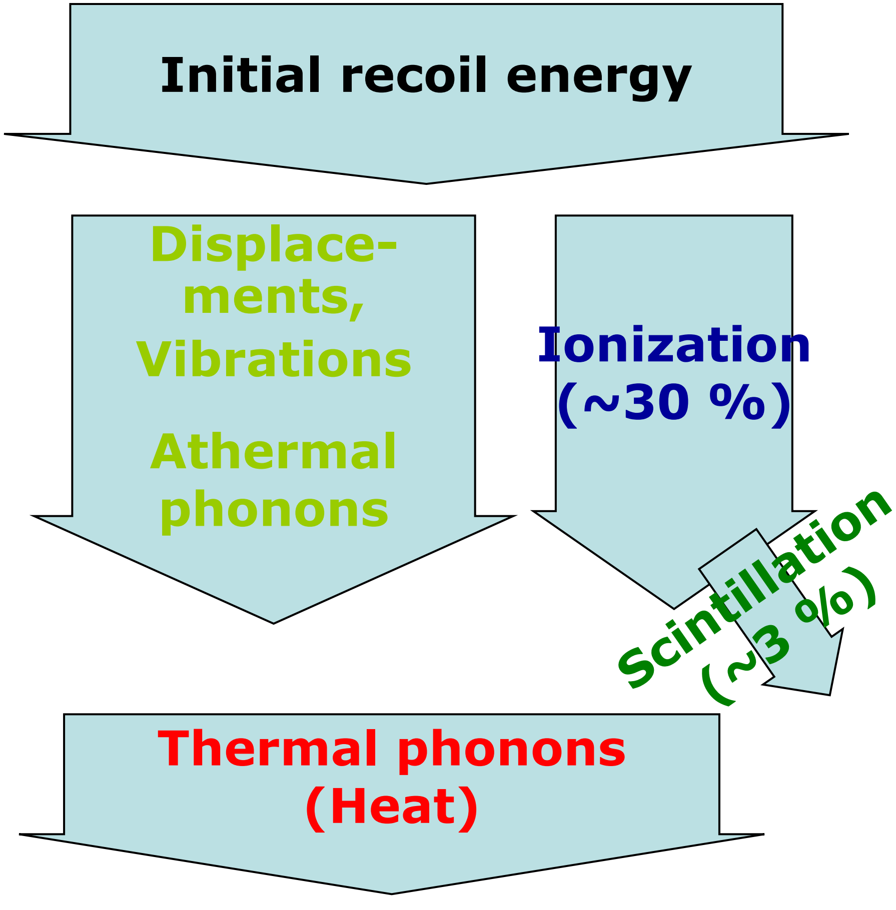
Direct dark matter detection

- Elastic WIMP scattering → Nuclear recoil
- Background rejection – discrimination electron recoils (α,β,γ) from nuclear recoils (n,WIMPs)



Cryogenic detectors

Phonon-ionization / phonon-scintillation



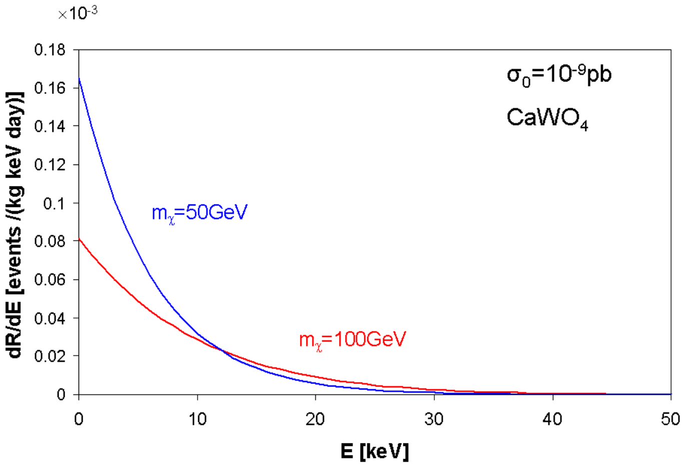
Phonon: most precise total energy measurement

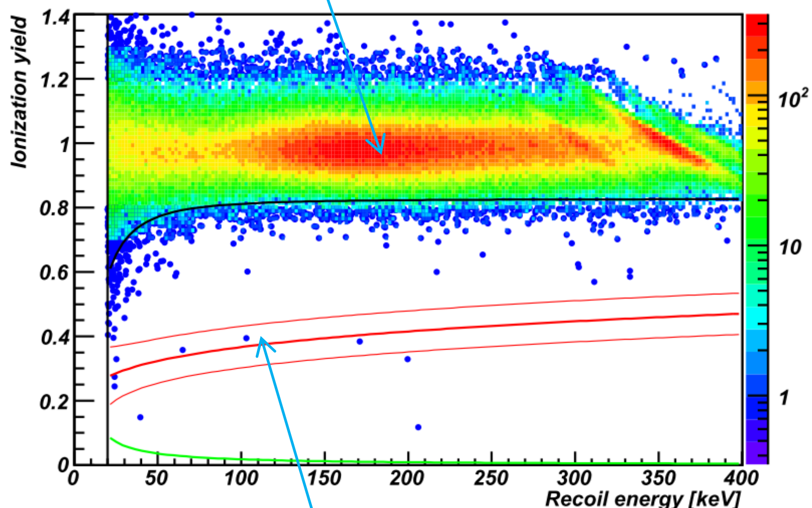
Ionization / Scintillation: yield depends on recoiling particle

Nuclear / electron recoil discrimination.

Why use cryodetectors?

- Low threshold
  - Event rate increases exponentially at low energy
- Excellent energy resolution
  - Useful to identify background
- Event by event background discrimination
  - Phonon/ionization or phonon/scintillation measurement
- Wide choice of absorber materials
  - Event rate scales with atomic mass





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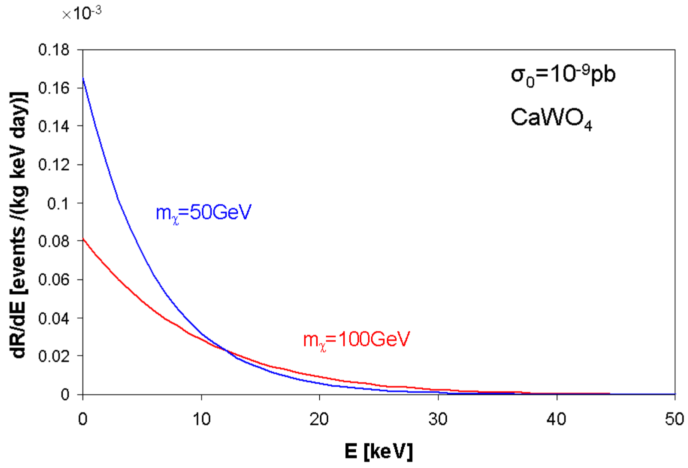
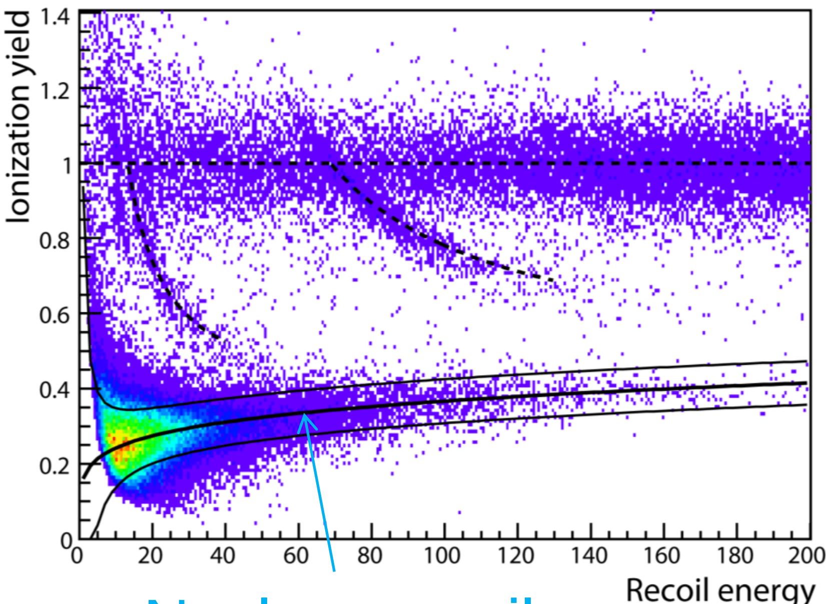


Neutron calibration



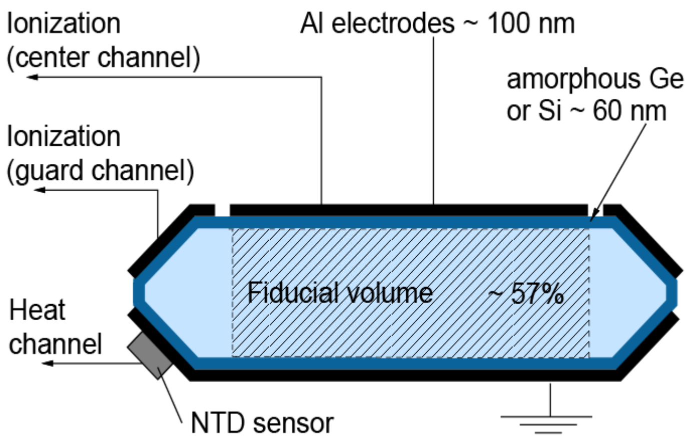
Nuclear recoil candidates

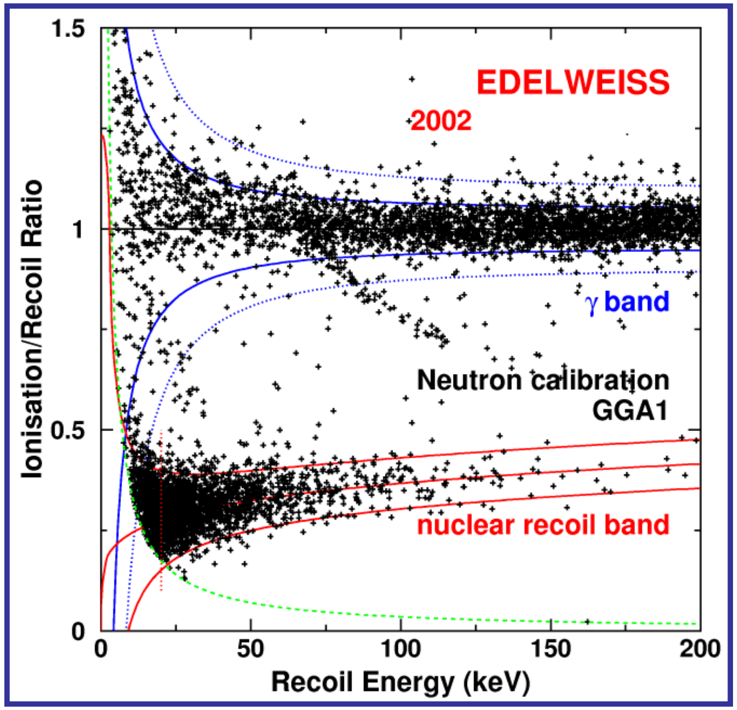
Expérience pour **DE**tecter
Les **W**imps **E**n **SI**te
Souterrain

EDELWEISS-II Dark matter search

- Search for scattering of WIMP dark matter
  ~10keV nuclear recoil
  <0.01 events/kg/day
- Need: Sensitive detectors with excellent discrimination. Low background
- Cryogenic germanium phonon-ionization detectors
- Laboratoire Souterrain de Modane

Edelweiss – Detectors

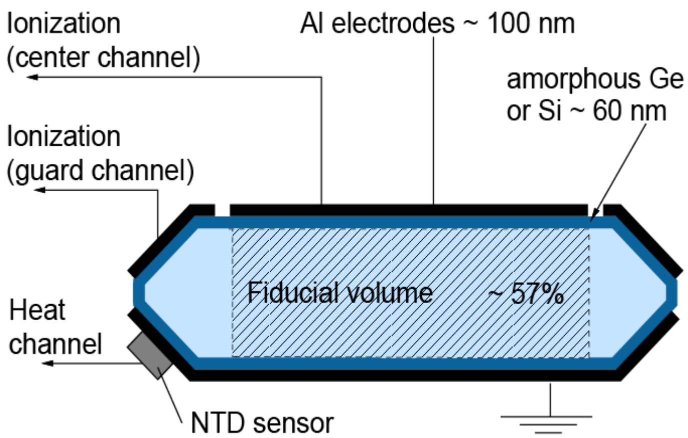


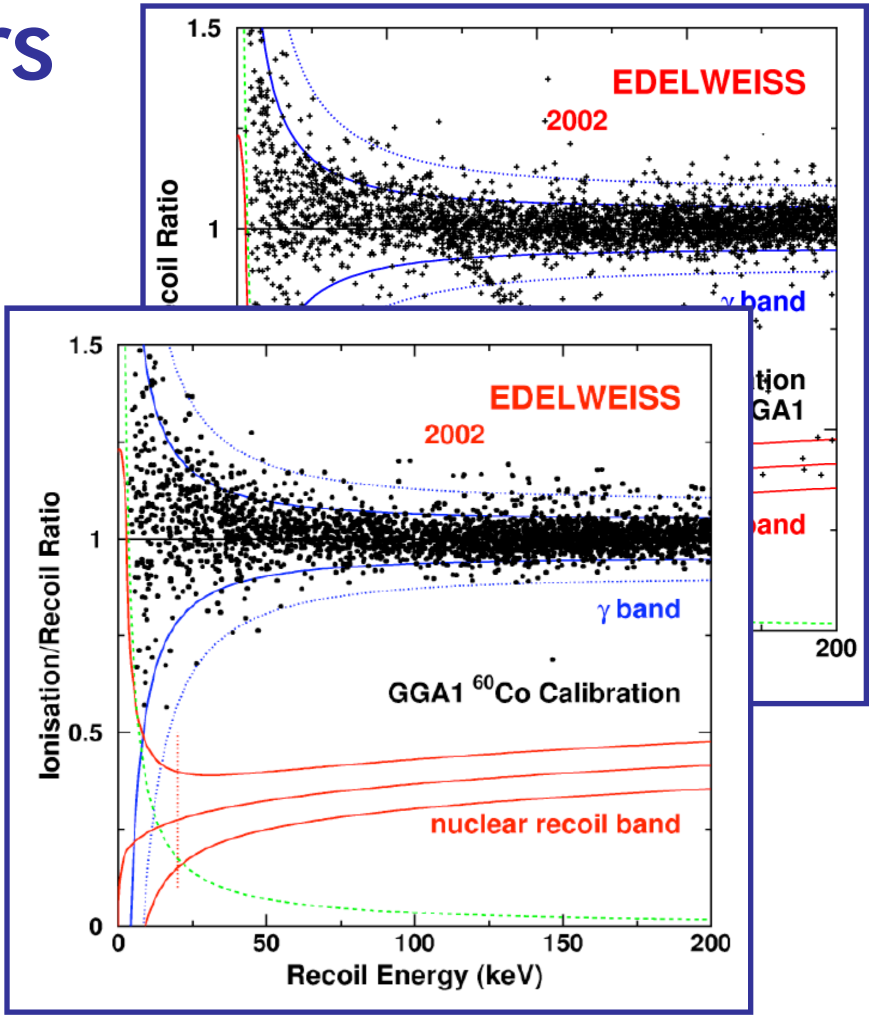


Target:
Ge crystal
Phonon - signal:
NTD-Ge (~ 20 mK)
Ionisation - signal:
Inner disc / outer guard ring
few V/cm
Event by event background discrimination

Limitation – surface events
(in detectors with plain electrodes)

Edelweiss – Detectors





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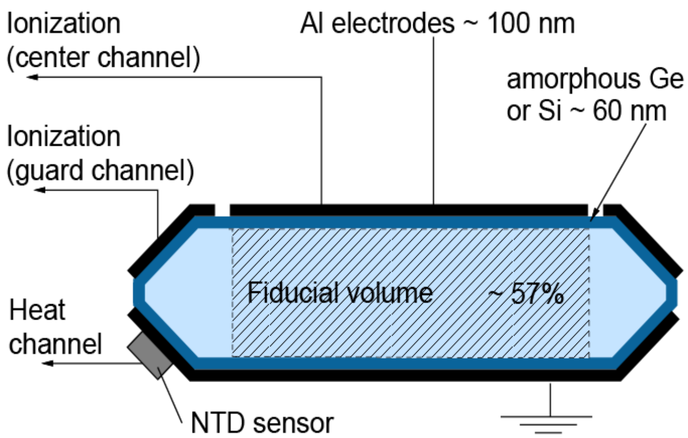

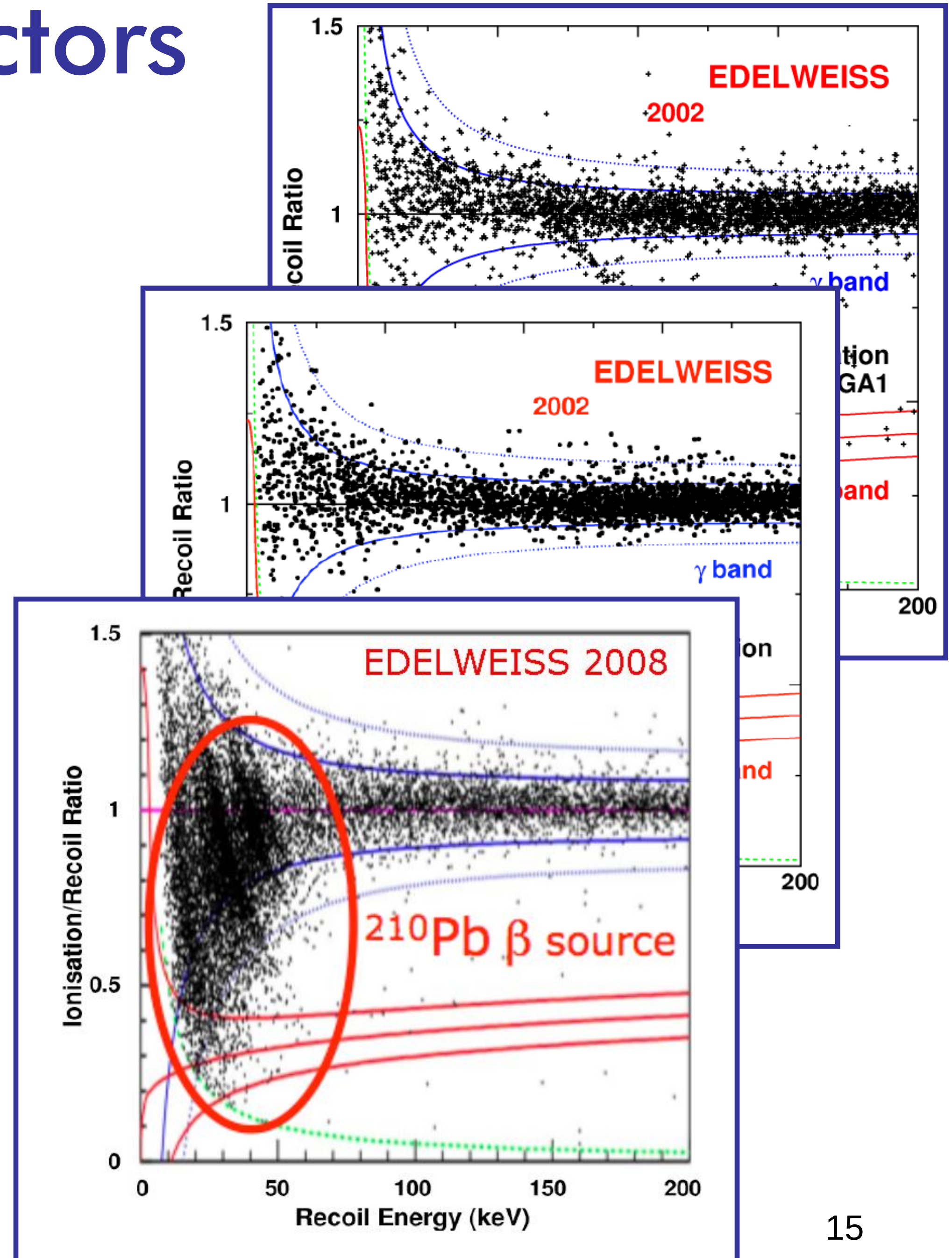

Target:
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Phonon - signal:
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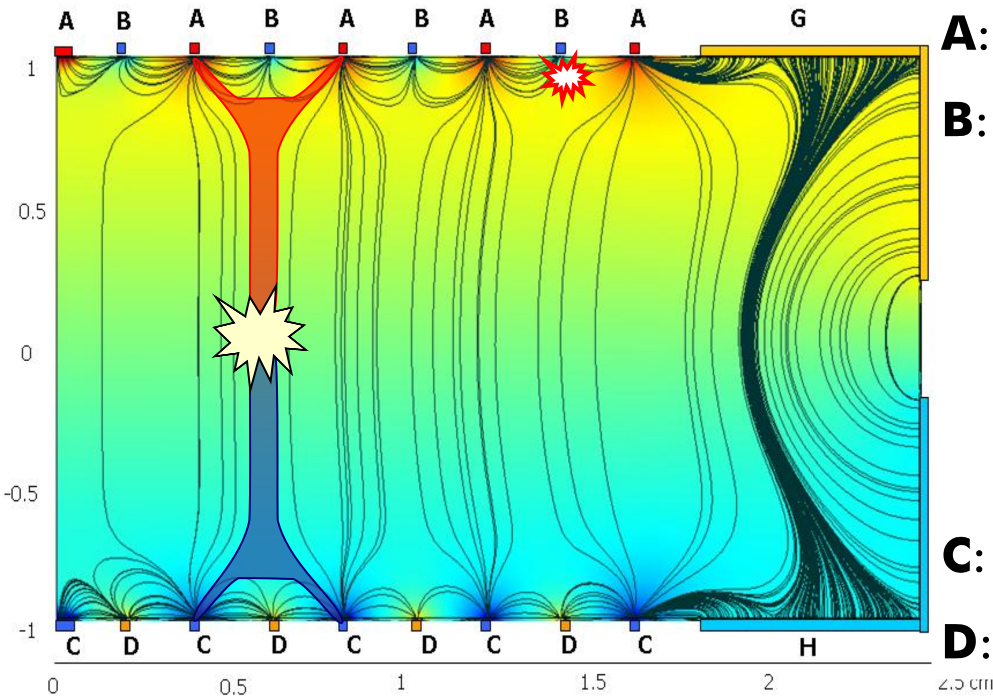
Ionisation - signal:
Inner disc / outer guard ring
few V/cm

Event by event background discrimination

Limitation – surface events
(in detectors with plain electrodes)

EDELWEISS InterDigit (ID) detectors

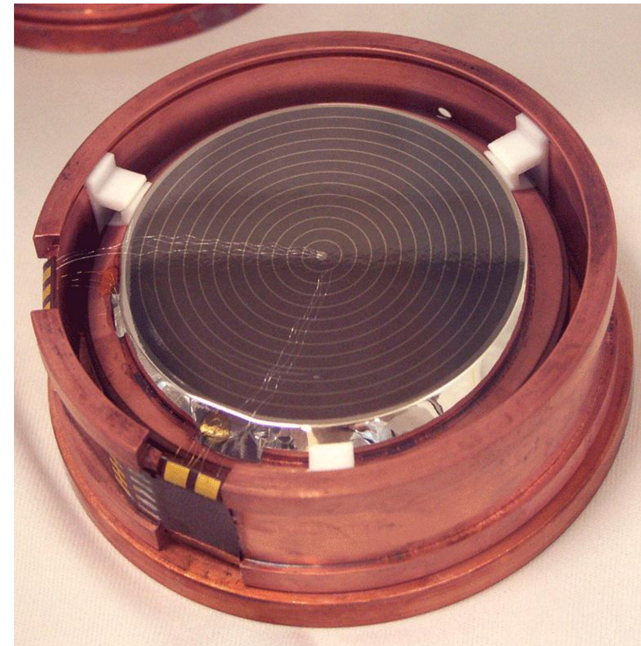


A: +4 V

B: –1.5V

C: –4 V

D: +1.5V



Surface event (β) rejection: 10^5

Bulk events:

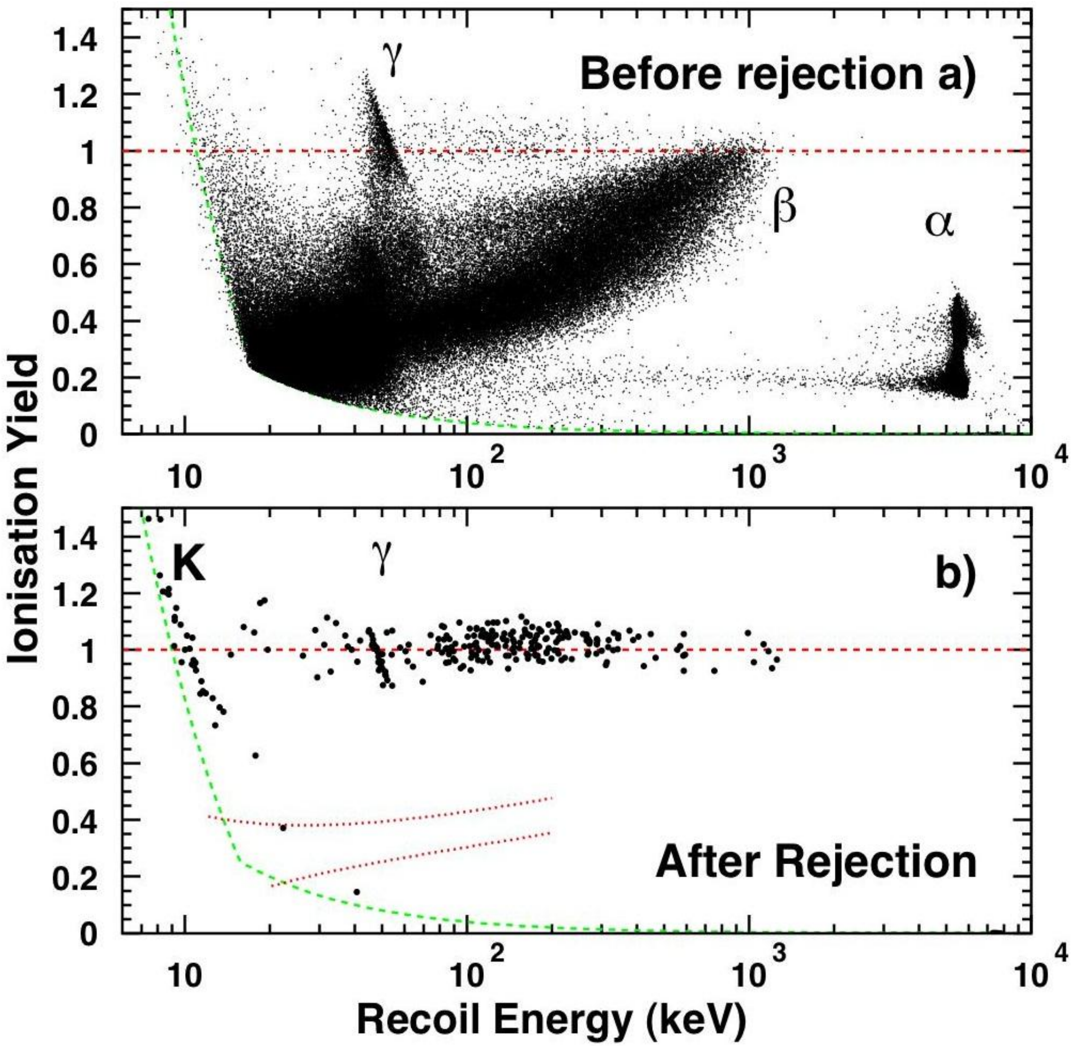
charge → AC (Fiducial electrodes)

Surface events:

charge → B,D, guard ring

A. Broniatowski et al **Phys Lett B 681 (2009) 305** [arXiv:0905.0753]

ID detectors – surface event rejection



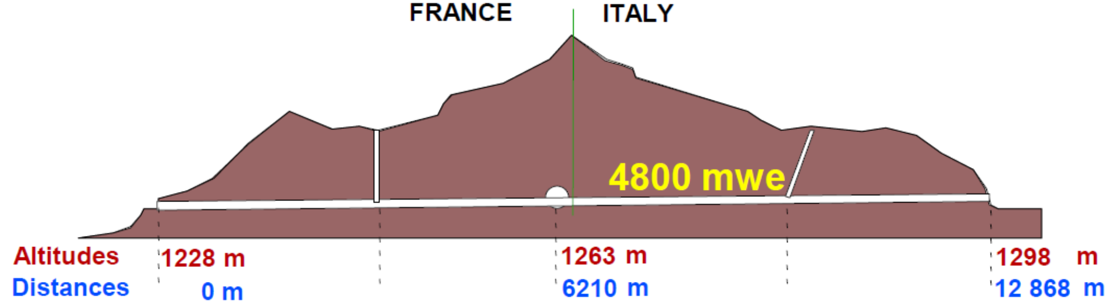
^{210}Pb Calibration

$6{\times}10^4$ β events

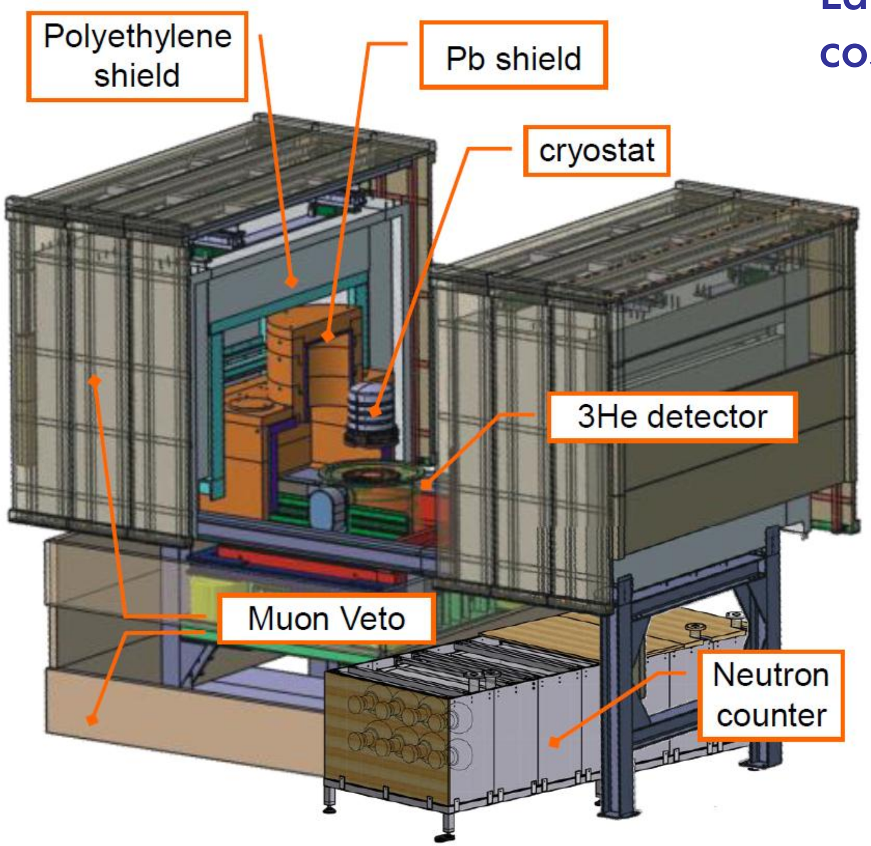
Surface event (β) rejection: $6{\times}10^{-5}$ (90% CL)

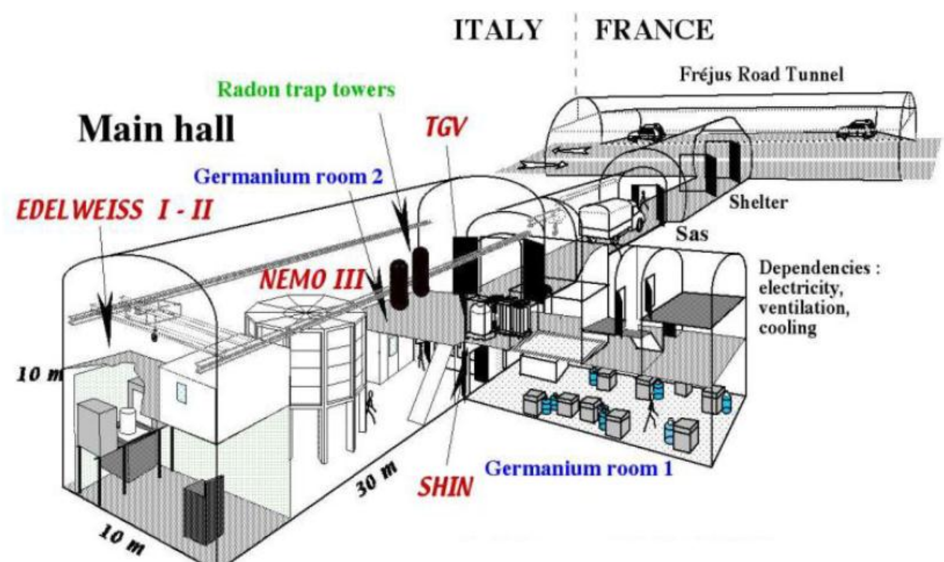
A. Broniatowski et al **Phys Lett B 681 (2009) 305** [arXiv:0905.0753]

Edelweiss



Laboratoire Souterrain de Modane:
cosmic muon flux 4 μ/m²/day



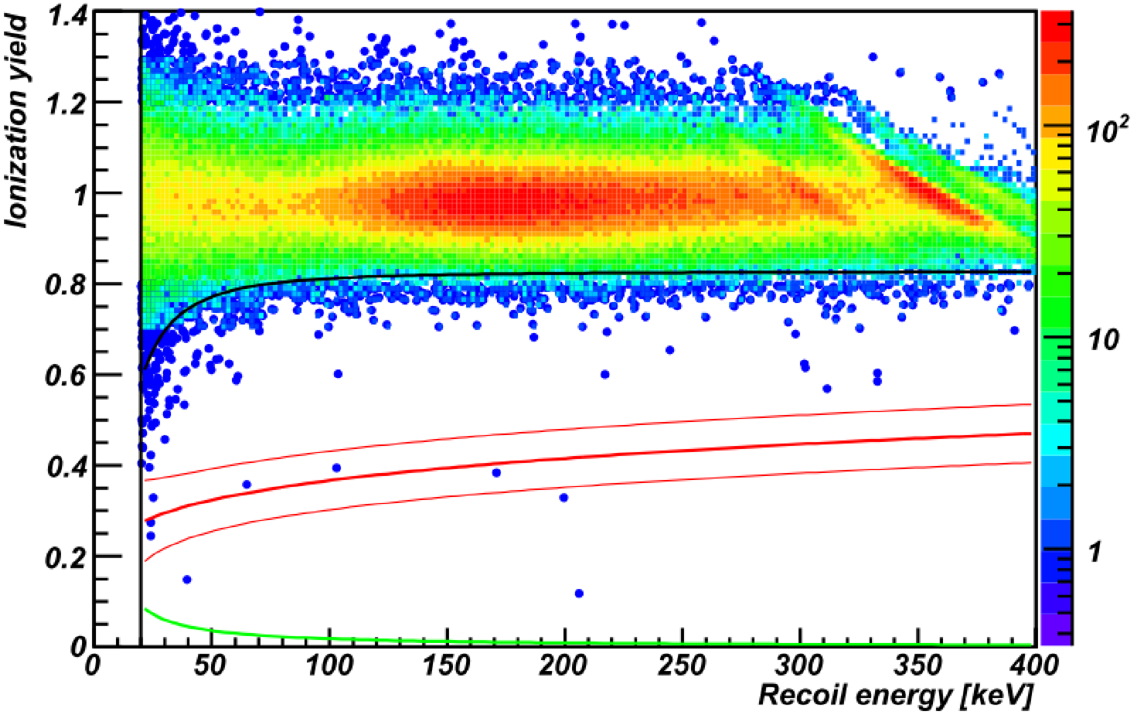


Shielding: 4800mwe rock; 20cm lead; 50cm polyethylene

LSM
Laboratoire Souterrain de Modane

Edelweiss II Run April 2009 - May 2010

- Ten 400g germanium ID detectors
  - ^{133}Ba gamma calibration



Gamma rejection 3×10^{-5}

Threshold set to 20keV for WIMP search

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- Ten 400g germanium ID detectors
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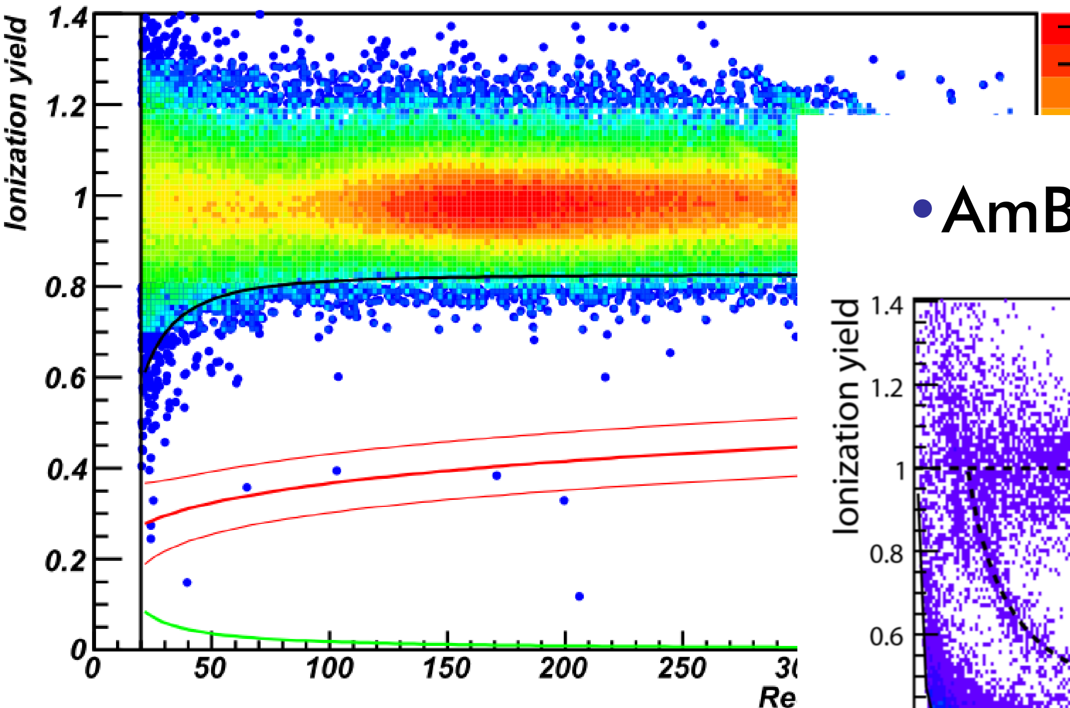
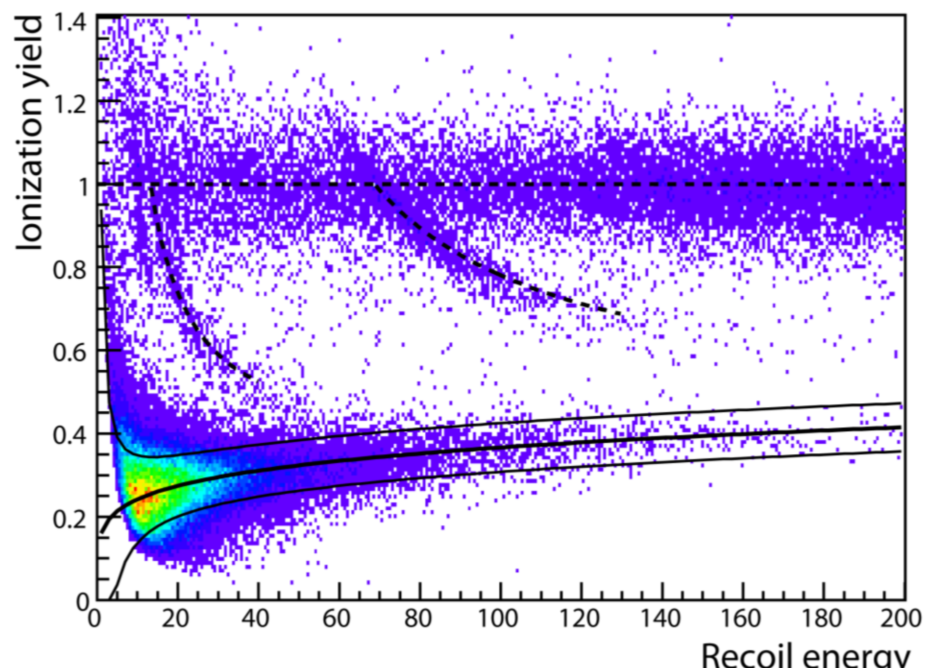


Gamma rejection 3×10^{-5}

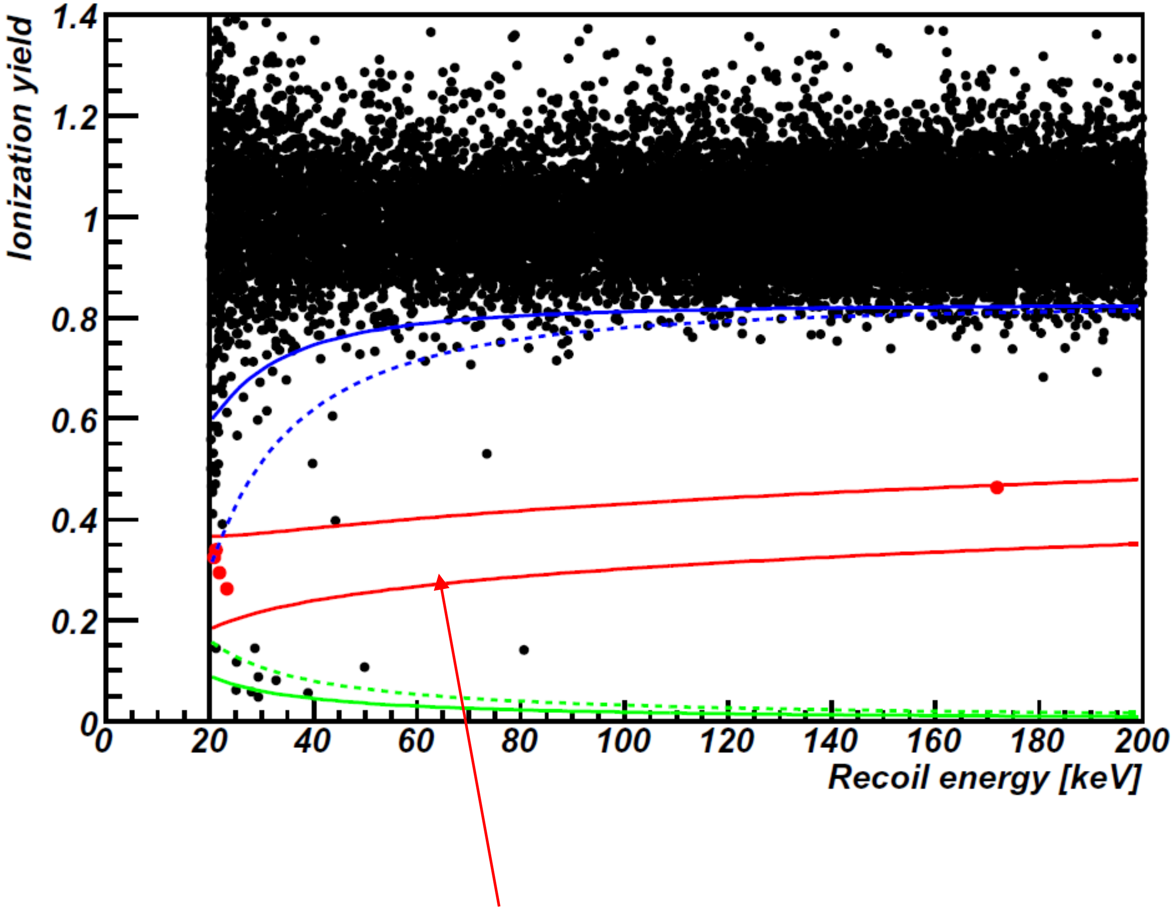
- AmBe neutron calibration



Threshold set to 20keV for WIMP search

Edelweiss II Results - 325 day WIMP search

- Ten 400g ID Ge detectors, 384kg day



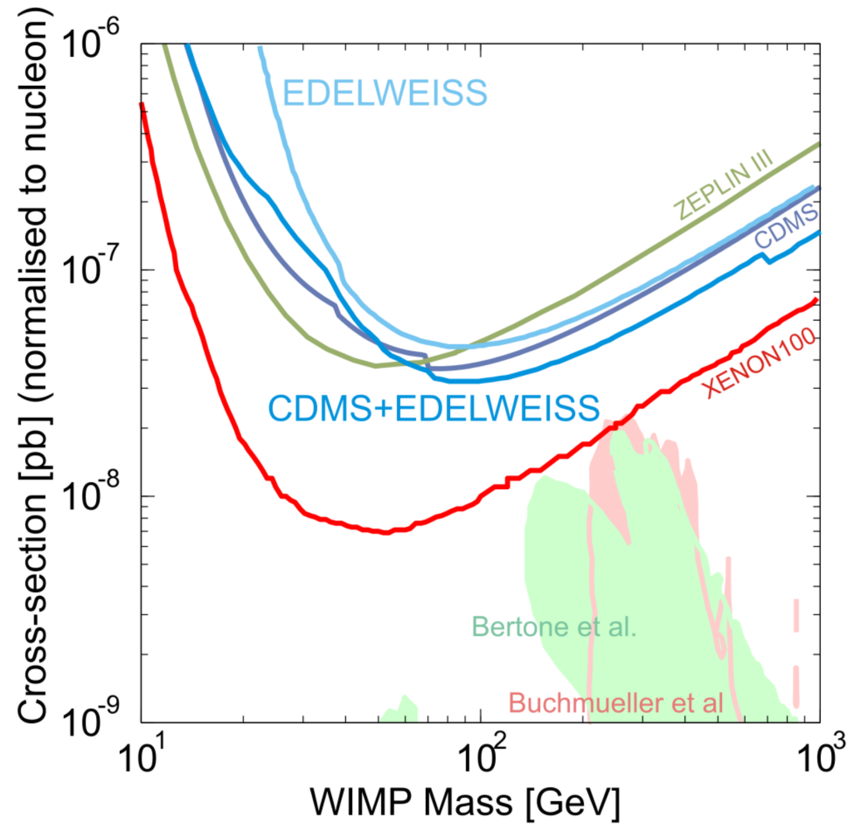
- Five nuclear recoil events (above 20keV)

EDELWEISS II Results – elastic scattering

EDELWEISS II Final result:

4.4×10^{-8}pb excluded for 85GeV WIMP

Physics Letters B.
702 (2011) 329-335
arXiv:1103.4070



CDMS December 2009 result: 3.8×10^{-8}pb,

Joint CDMS-EDELWEISS result:

3.3×10^{-8}pb excluded at 90GeV

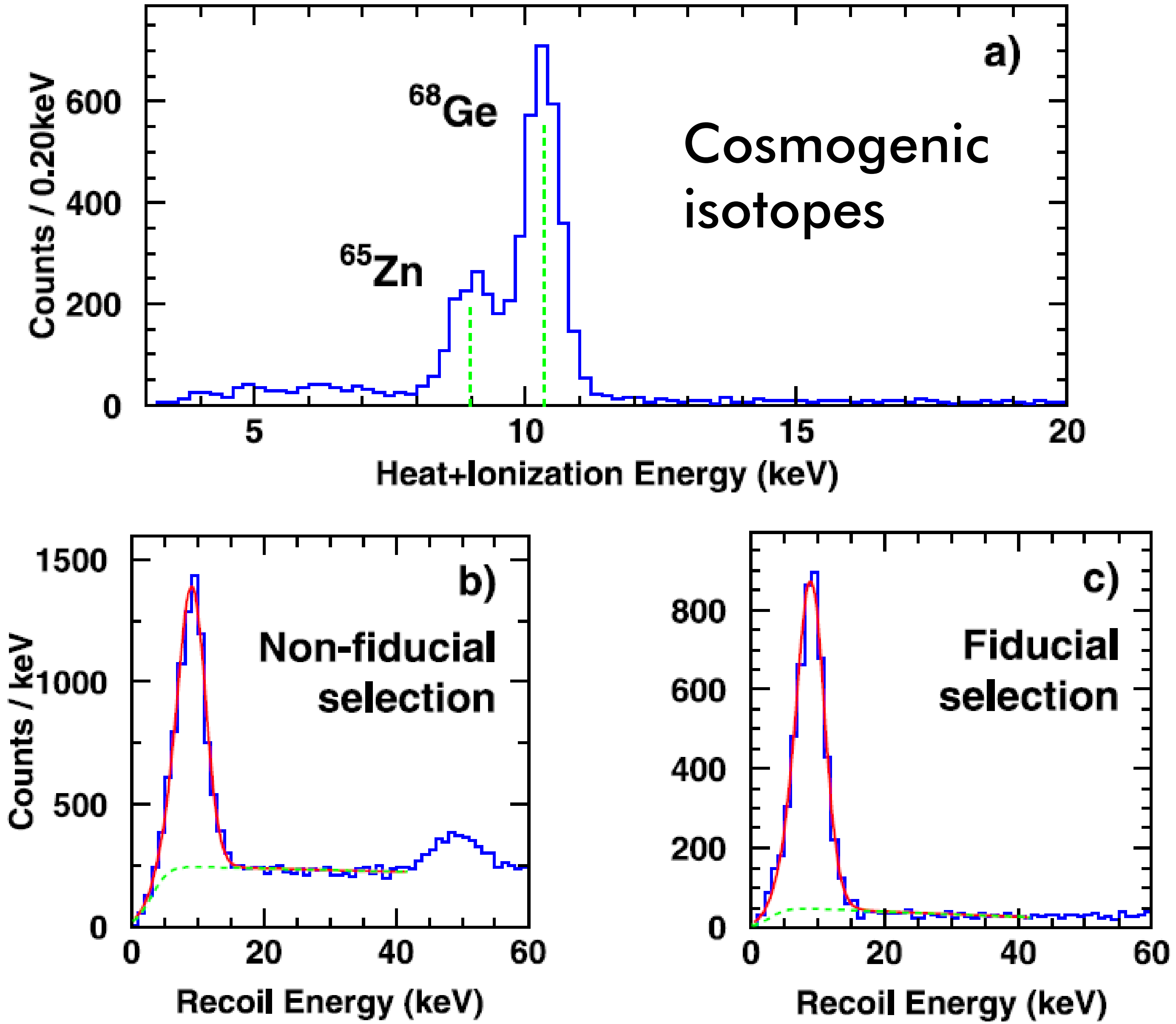
Phys, Rev. D 84 (2011) 011102(R), arXiv:1105.3377

Edelweiss II Background estimate

- Gamma background – 1.8×10^4 events (20-200keV)
  ^{133}Ba calibrations → 3×10^{-5} leakage into NR band
  → <0.9 events
- Surface events – 5000 events, rejection factor 6×10^{-5}
  → 0.3 events
- Muon induced events missed by veto → <0.4 events
- Neutrons from rock – GEANT4 simulations → 0.11 events
- Neutrons from contaminants in shield/cryostat → 0.21 events
- Neutrons from connectors / cabling in cryostat → 1.1 events

Total background estimate 3.0 events 90% CL

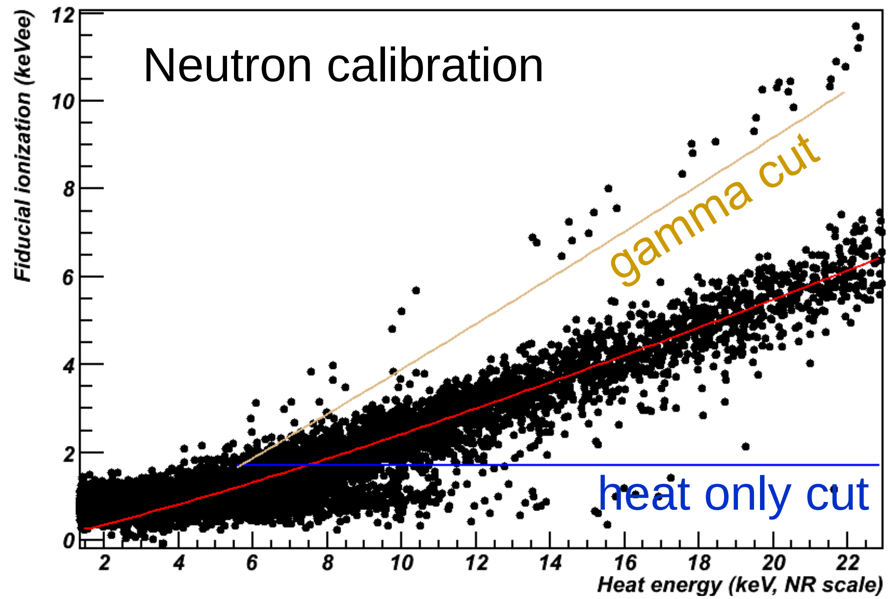
Edelweiss II Results – energy spectrum

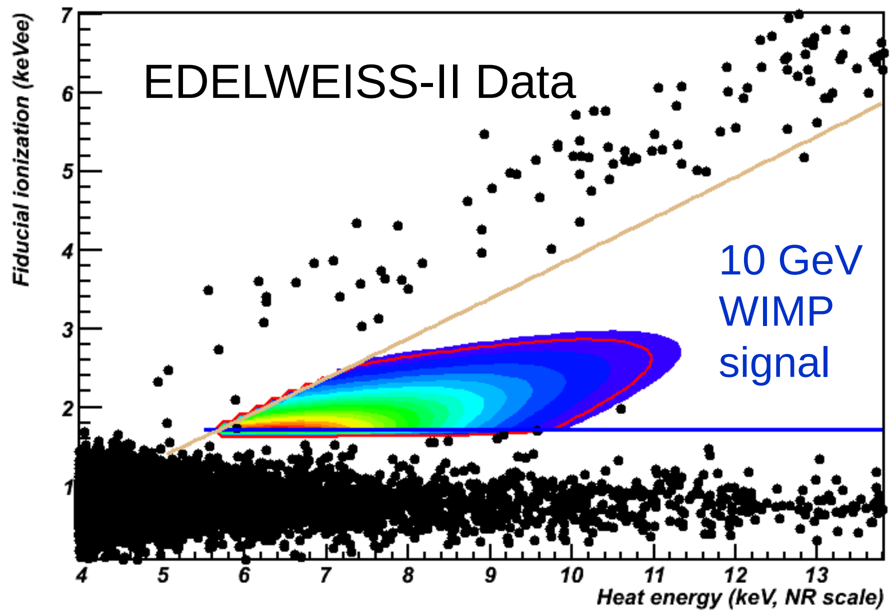


Energy spectra

EDELWEISS low energy analysis

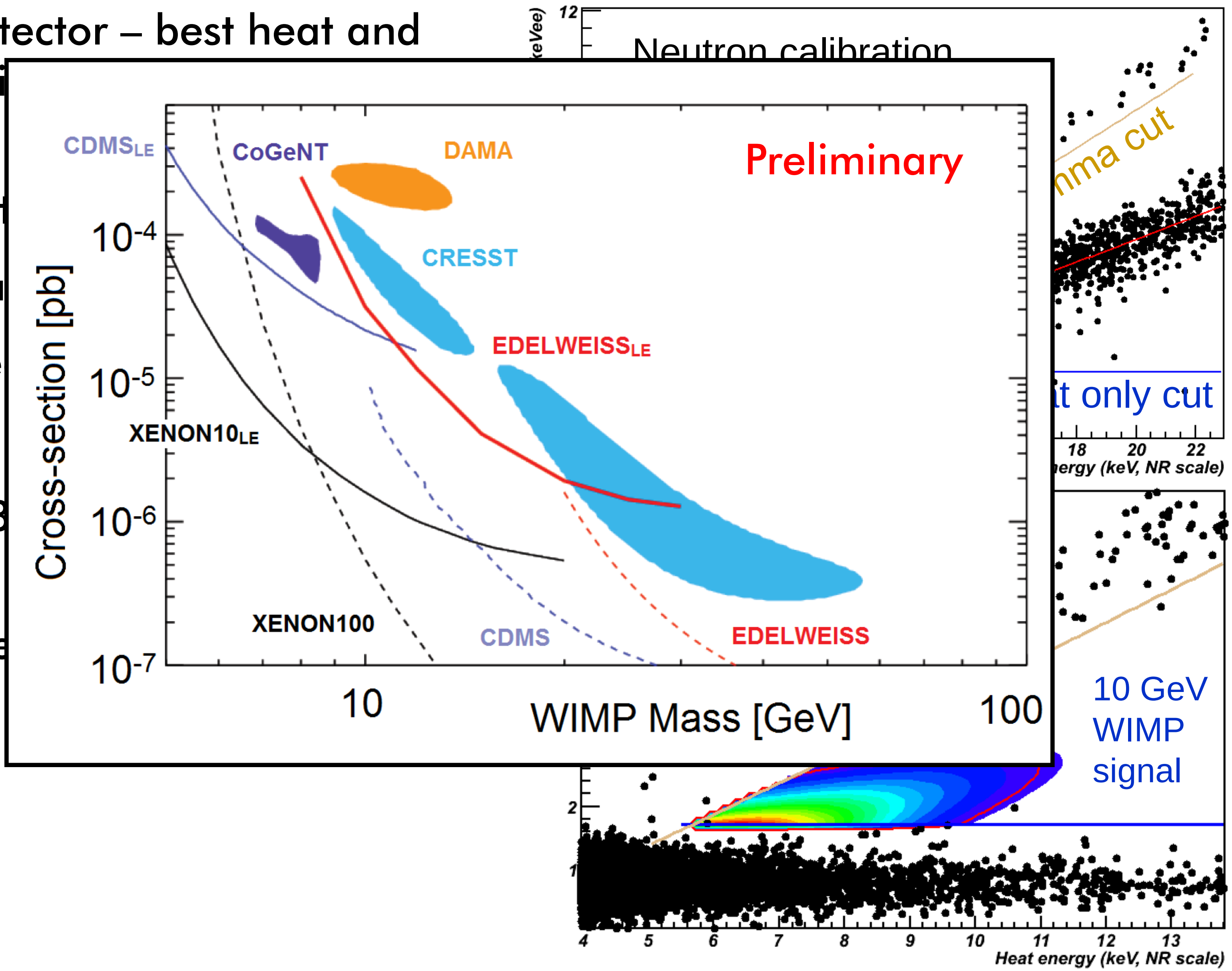
- ID3 detector – best heat and ionization resolution
- Define cuts in Fiducial ionization vs Heat energy plot
  - Gamma cut
  - Heat only pulse cut
- 31kg d
- For 8-30 GeV WIMP, we get 1-3 events in ROI
- Expected background ~1





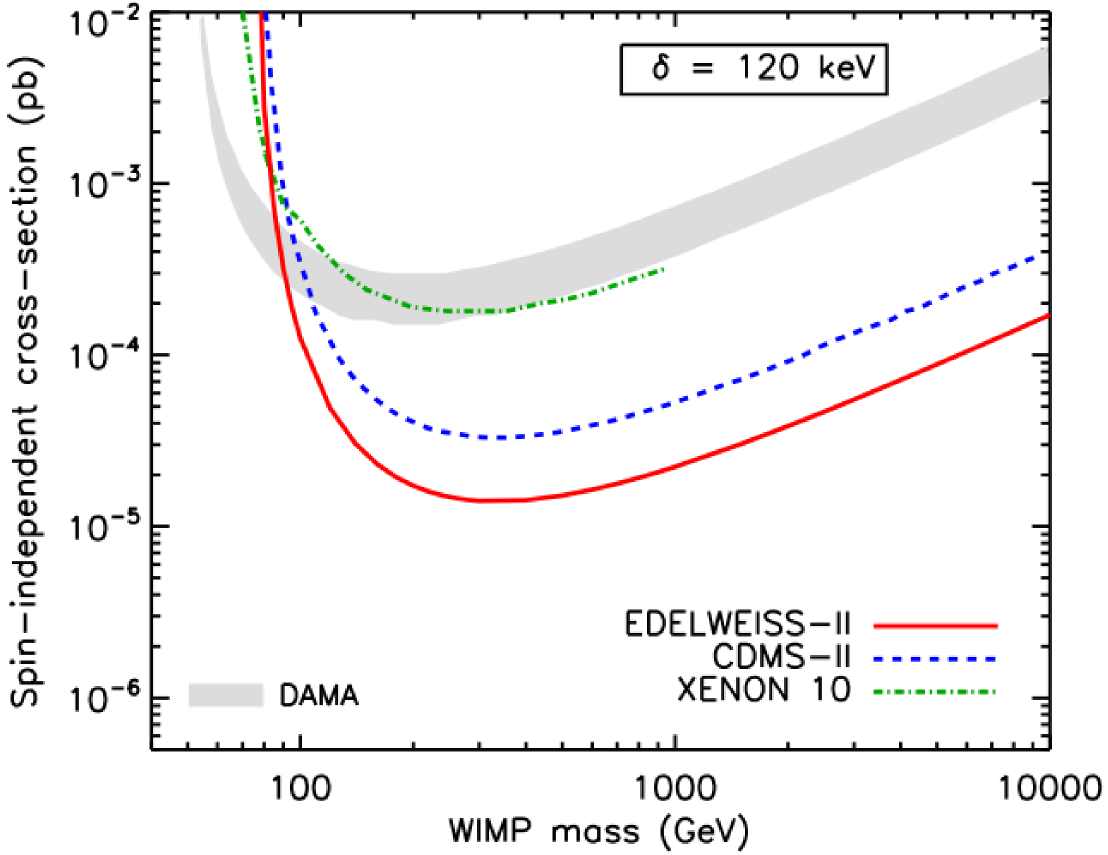
EDELWEISS low energy analysis

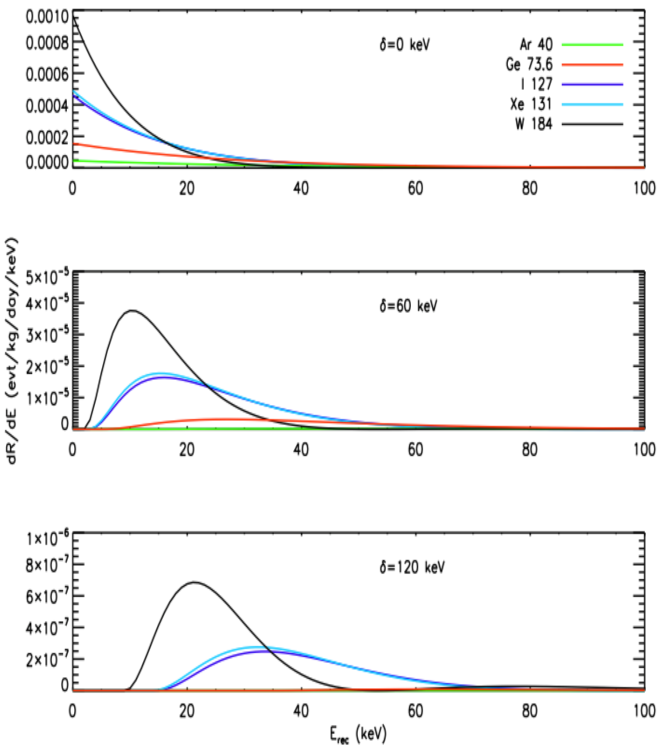
- ID3 detector – best heat and ionizati
- Define vs Heat
  - Ga
  - He
- 31kg d
- For 8-3 events
- Expecte



Results – inelastic scattering

- WIMP-nucleus scattering → excited state
- Mass splitting δ~120keV, DAMA region excluded above 90GeV

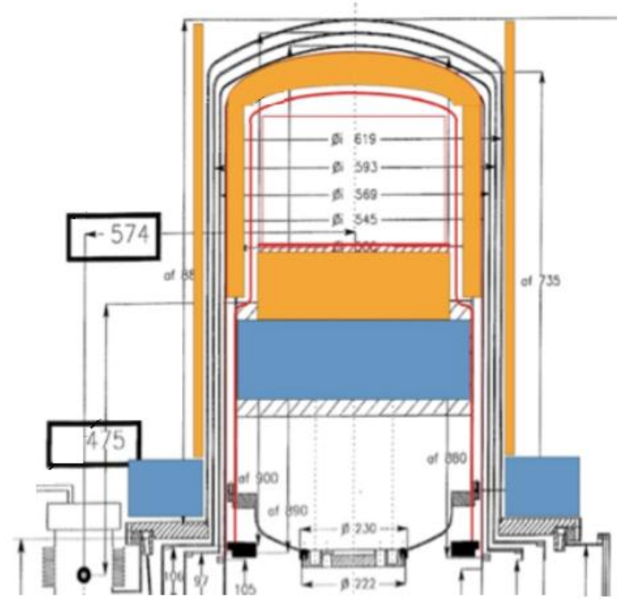


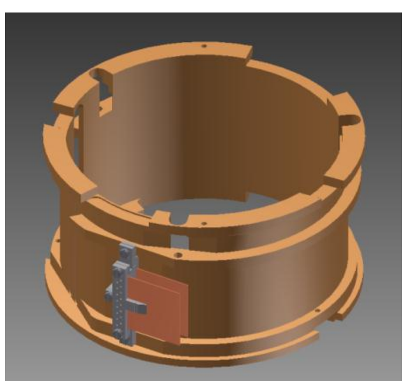


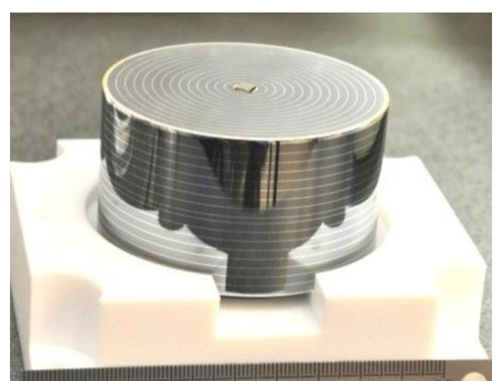
EDELWEISS III

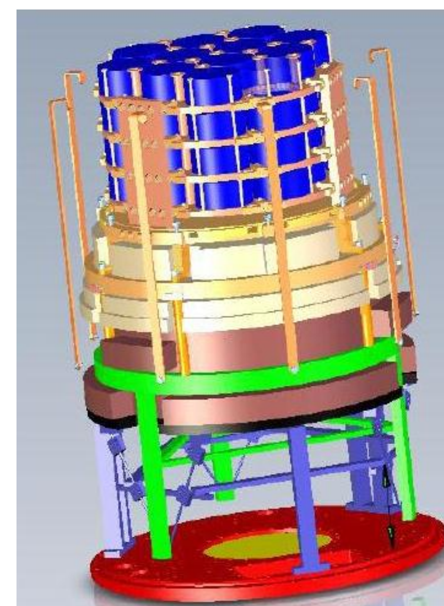
Increase detector mass
Decrease background

- Search for dark matter to 5×10^{-9}pb
- 40 FID-800 detectors installed 2012
- New Kapton cabling, connectors
- New cold electronics
- New cryostat design
- New internal PE shield
- New copper thermal shield



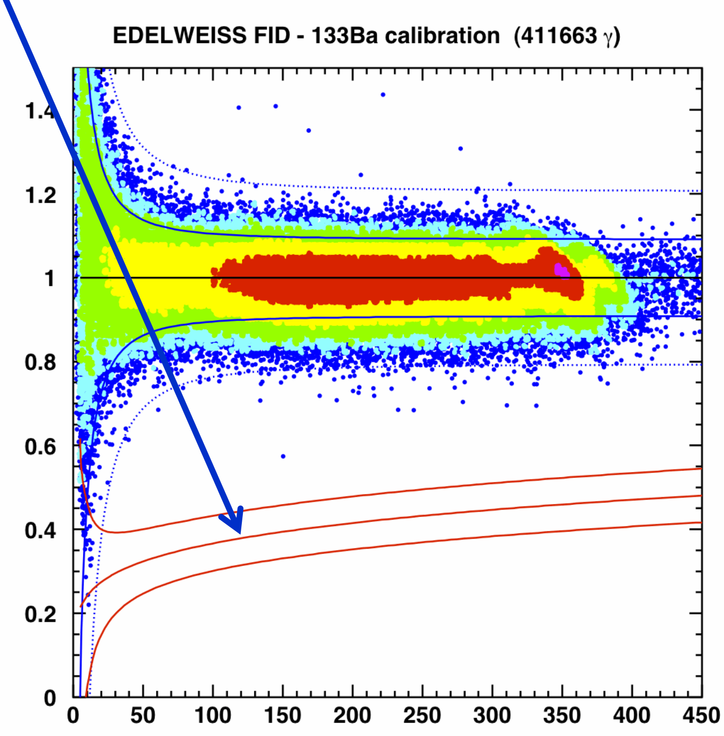


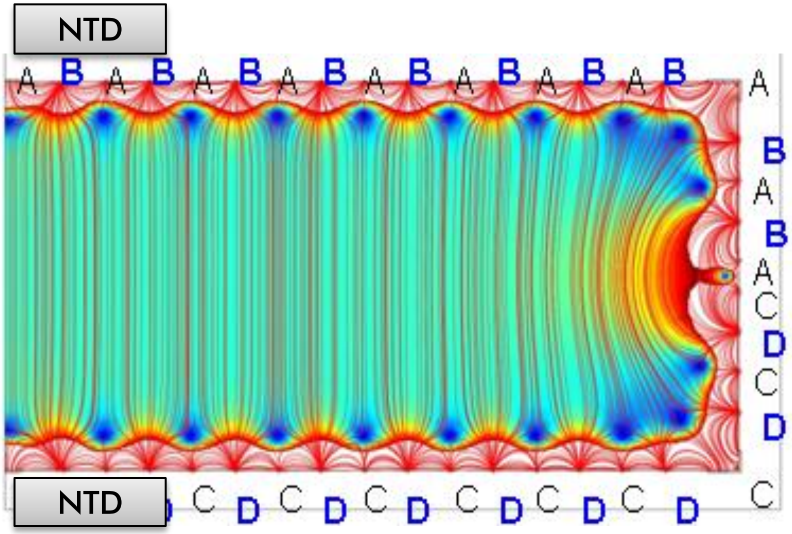




FID-800 detectors

- 800g crystals, fiducial mass >600g
- Improved background discrimination:
  0 NR events / 4×10^5 γ
  (ID detectors 6 NRs / 3×10^5 γ)





Other cryogenic dark matter searches

CDMS – Soudan mine, cryogenic phonon - ionization germanium detectors

Ongoing collaboration

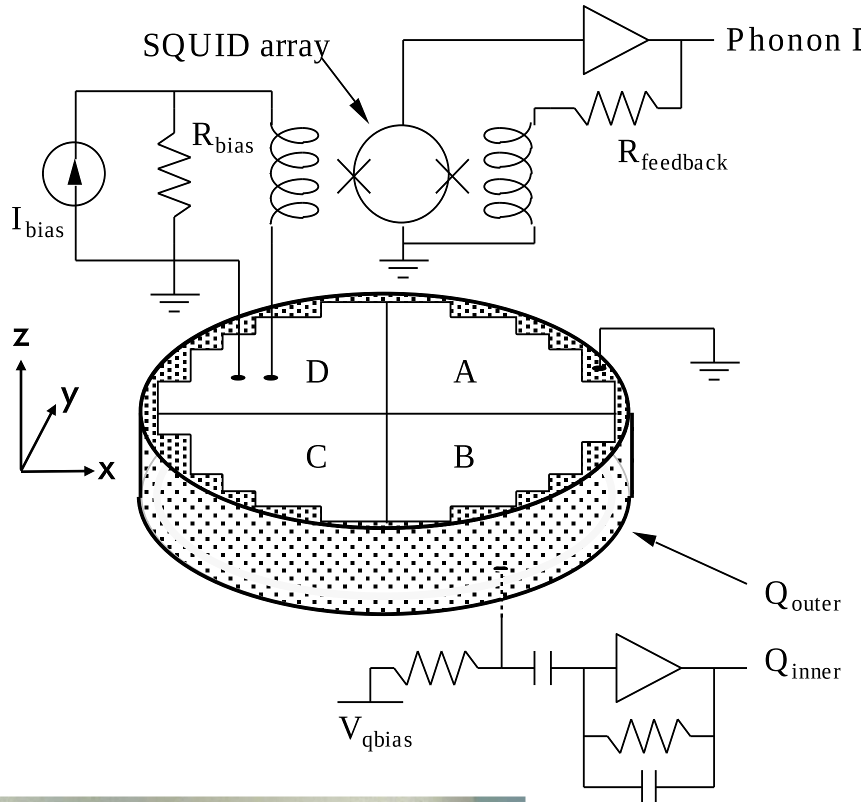
EDELWEISS

Will join forces to build EURECA

EURECA

CRESST – Gran Sasso, cryogenic phonon – scintillation detectors ($CaWO_4$)

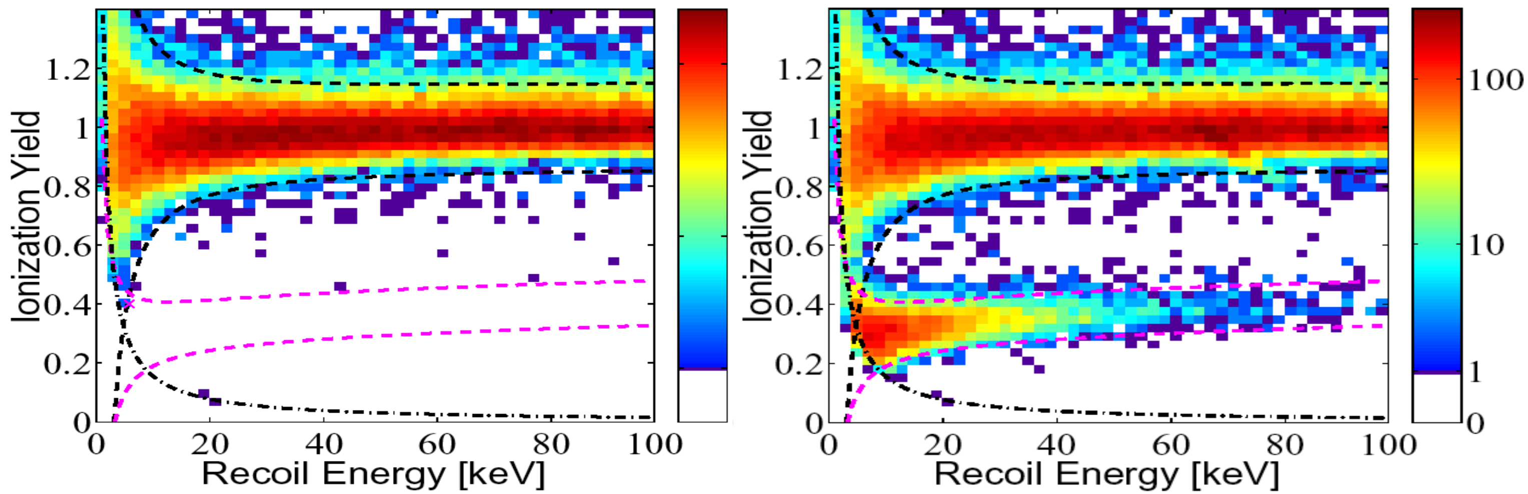
CDMS detectors

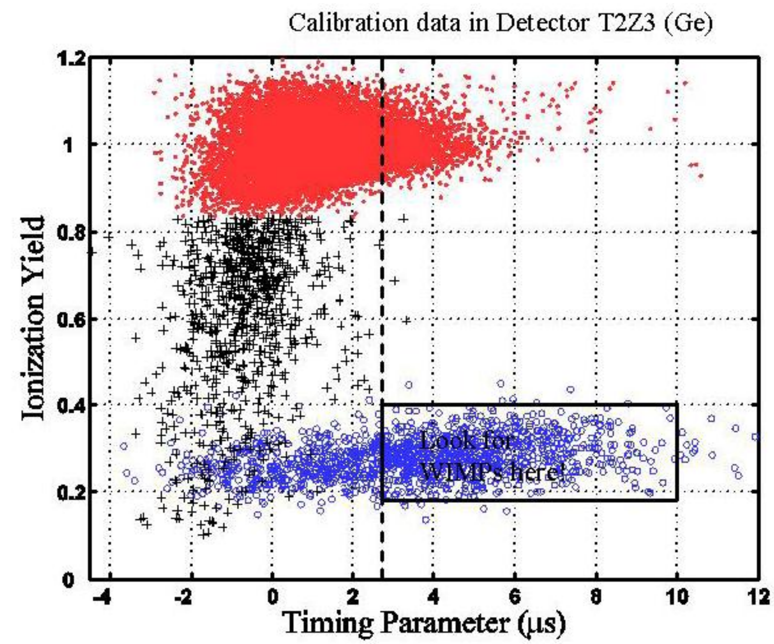


Z-sensitive
Ionization and
Phonon-
mediated©

- 250g Ge or 100g Si crystal 10mm x 75mm
- Athermal phonon sensors → position imaging
- Surface (Z) event veto based on pulse shape risetime
- Measure ionization with segmented contacts to allow rejection of events near outer edge

CDMS II: Background discrimination



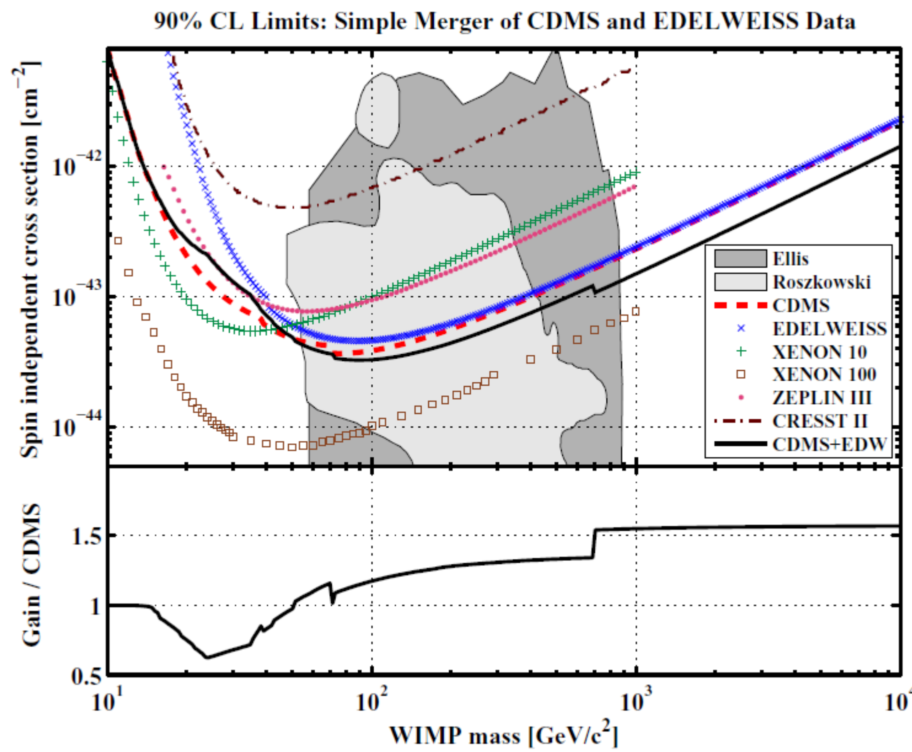


Identify surface events using timing information from phonon detectors

CDMS – EDELWEISS combined limit

Phys, Rev. D 84 (2011) 011102(R), arXiv:1105.3377

- Combined data from germanium detectors 614kg days
- 3.3×10^{-8}pb excluded at 90GeV
- Improved limit for high mass WIMPs



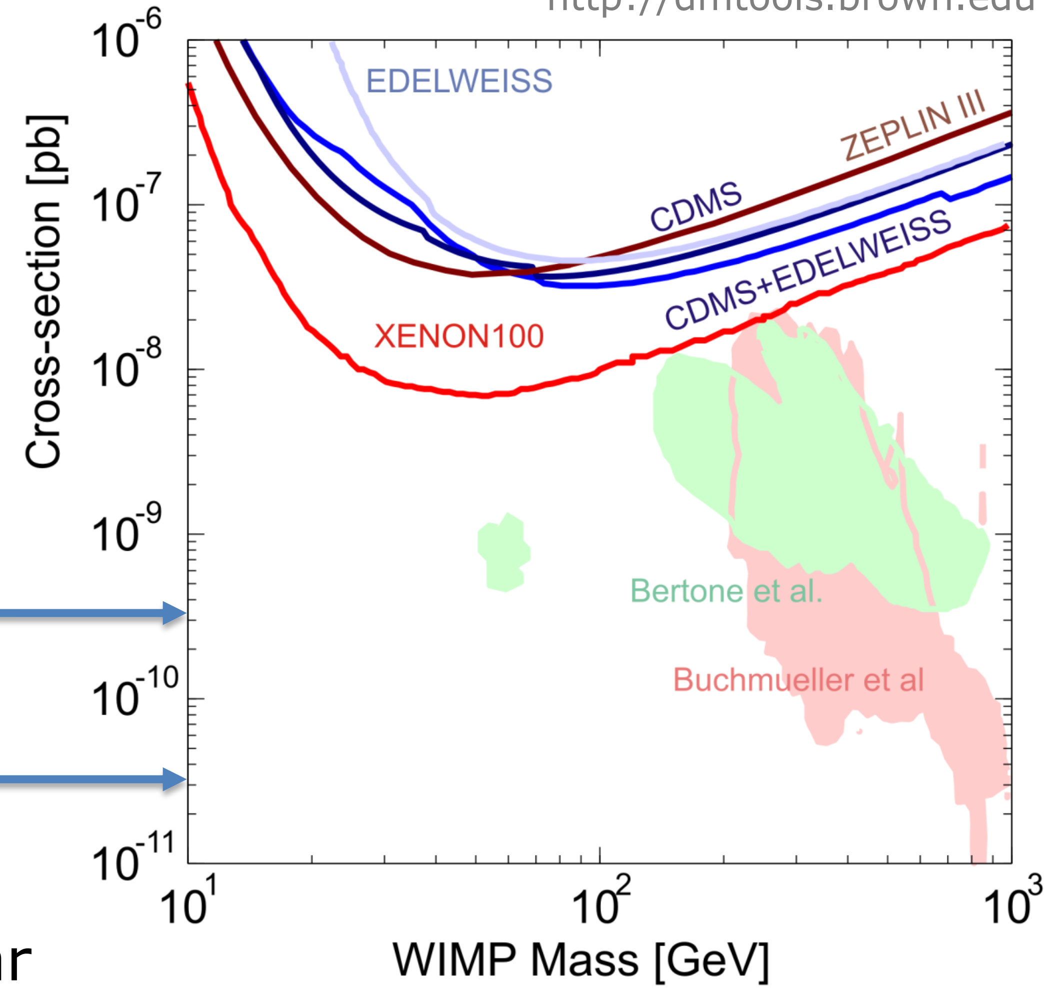
EURECA

European Underground Rare Event Calorimeter Array

EURECA phase I – 150kg
→ 3×10^{-10}pb

EURECA phase II – 1000kg
→ 3×10^{-11}pb

http://dmtools.brown.edu



Signal ~1event/tonne/year

Need 1-tonne cryogenic detector, radiopure environment, excellent background discrimination

To test a dark matter signal: Multi-target detector

EURECA Collaboration

EDELWEISS + CRESST + ROSEBUD collaborations + new members

France
- CEA: IRFU, IRAMIS
- CNRS: CSNSM, IPNL, Institut NÉEL, IAS, ICMCB

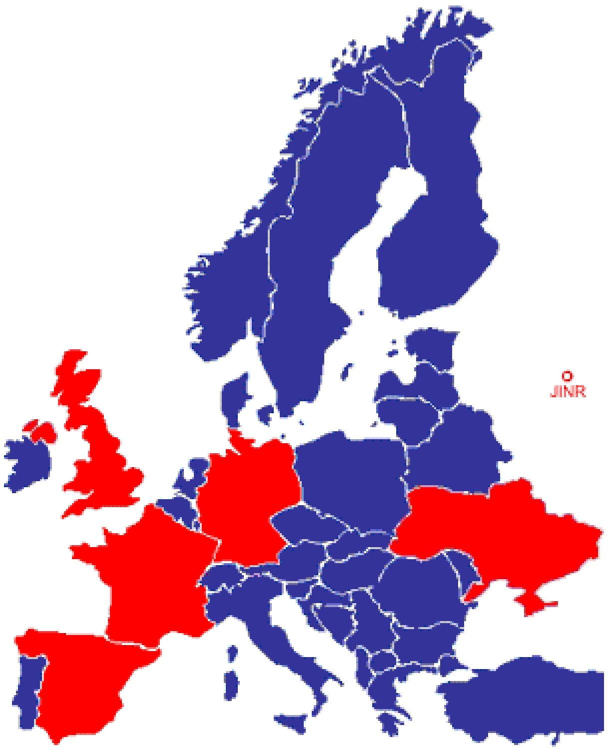
Germany
- MPI Munich
- TUM
- Universität Tübingen
- Karlsruhe Institute of Technology

Russia
- JINR Dubna

Spain
- Universidad de Zaragoza

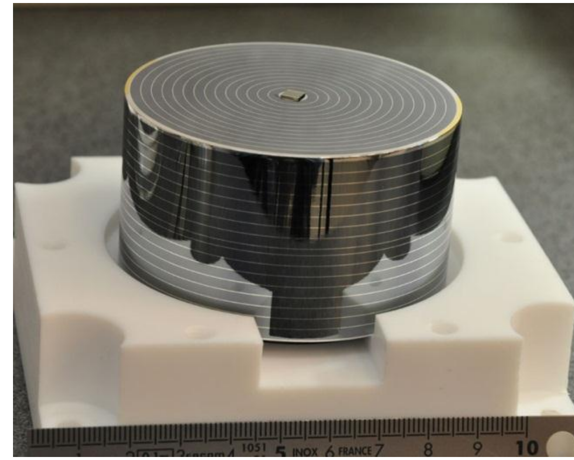
Ukraine
- INR Kiev

United Kingdom
- University of Oxford
- University of Sheffield



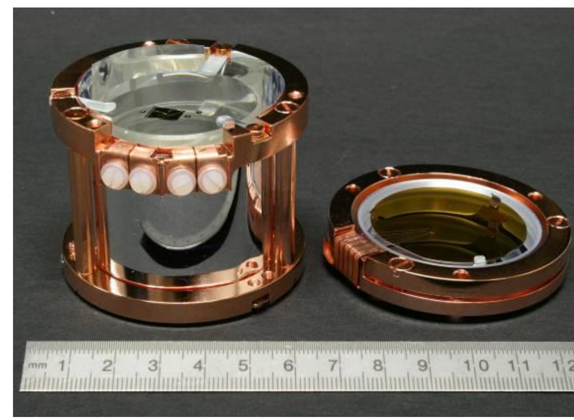
EURECA detectors – options:

EDELWEISS type: FID-800, 800g Ge phonon-ionization detectors with surface event rejection. NTD-Ge sensors

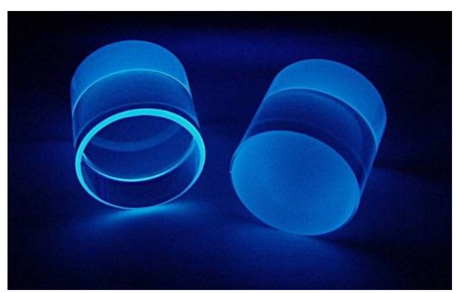


Further mass increase?

CRESST type: 300g $CaWO_4$ phonon-scintillation detectors. Tungsten TES sensors



New scintillator materials?



EURECA: 10^{-5} gamma rejection or better above 10keV threshold

Scaling up to 1-tonne

Larger crystals: 1.7kg? Need to increase diameter to 10cm, and maintain quality

Mass production: Seek industrial partner to produce ~300 detectors / year

Readout: 1000+ channels for all detector types (possible UK lead?)

Tower geometry: multiple detectors mounted in towers

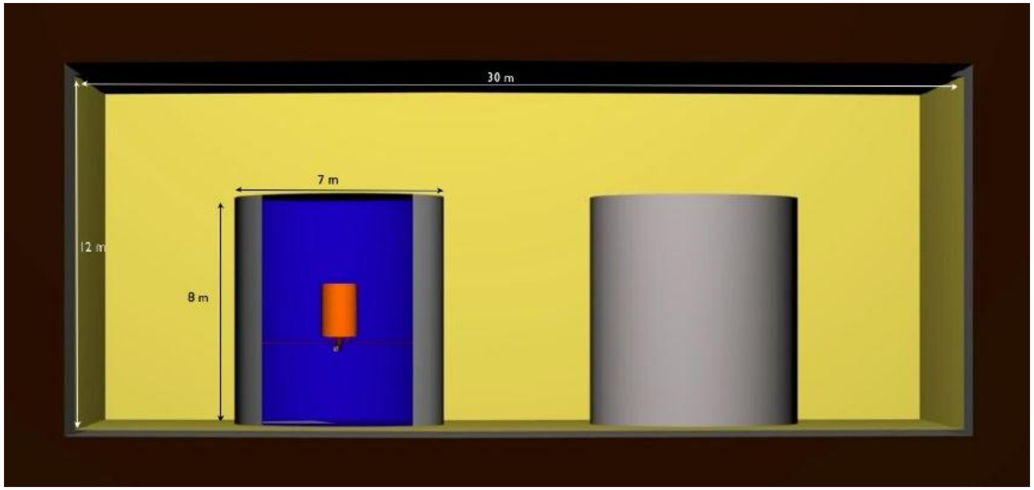
Radiopurity: Improve for all materials

Relative masses of scintillator and ionization detectors driven by background and physics reach

EURECA shielding

Target sensitivity: <few event/tonne/year
Gamma rejection: 10^{-5} in ROI

Shielding: 3m water, 15cm copper, 15cm CH_2
Radiopurity: <0.02 mBq/kg U/Th in Cu of cryostat
<10 mBq/kg U/Th materials inside inner shielding



Geant4 simulations

Astroparticle Physics 34 (2010) 70-79

Expected gamma rate: 0.02 events/kg/day/keV
Expected neutron rate: 1.3 events per year in 500kg

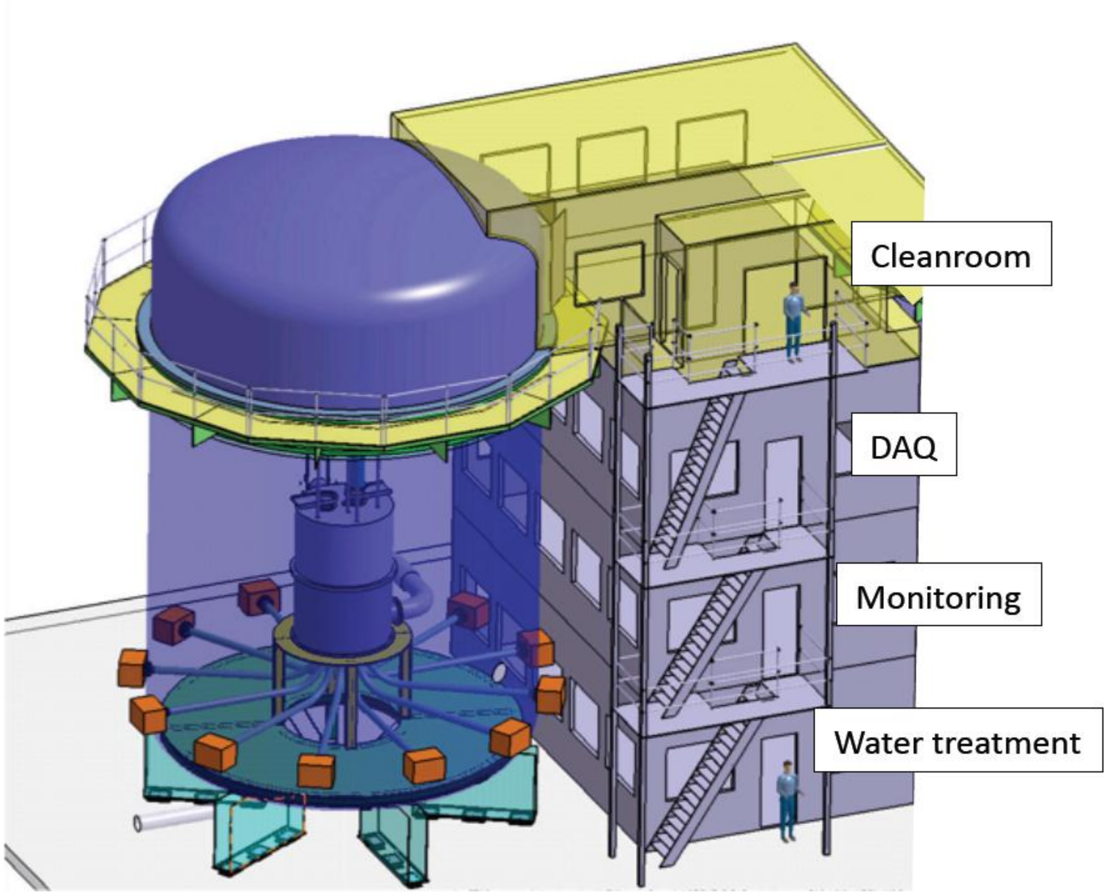
EURECA water tank

Passive shield

PMTs to detect Cherenkov light from cosmic muons

Veto events due to muon induced neutrons

Simulations: <0.3 NR events/year in 1012kg Ge



Radiopurity

LSM Ge detector lab

Screen materials using ultra low background HPGe detectors

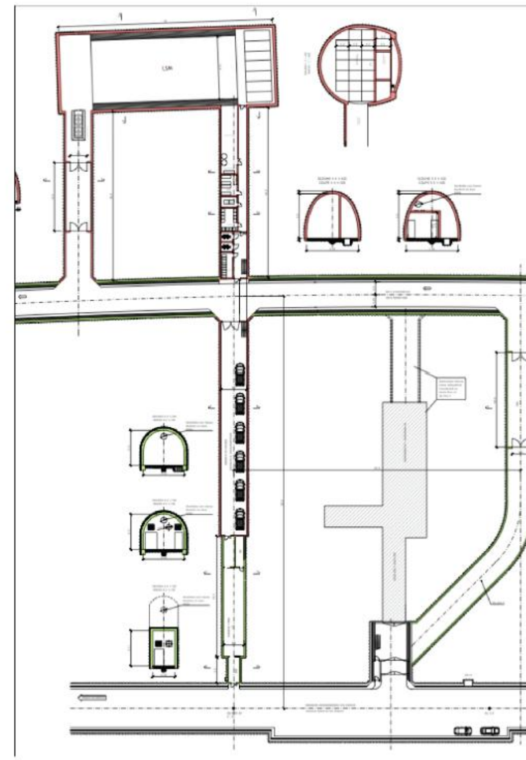
Store materials underground to minimise cosmogenic activation

Clean surfaces to remove contamination

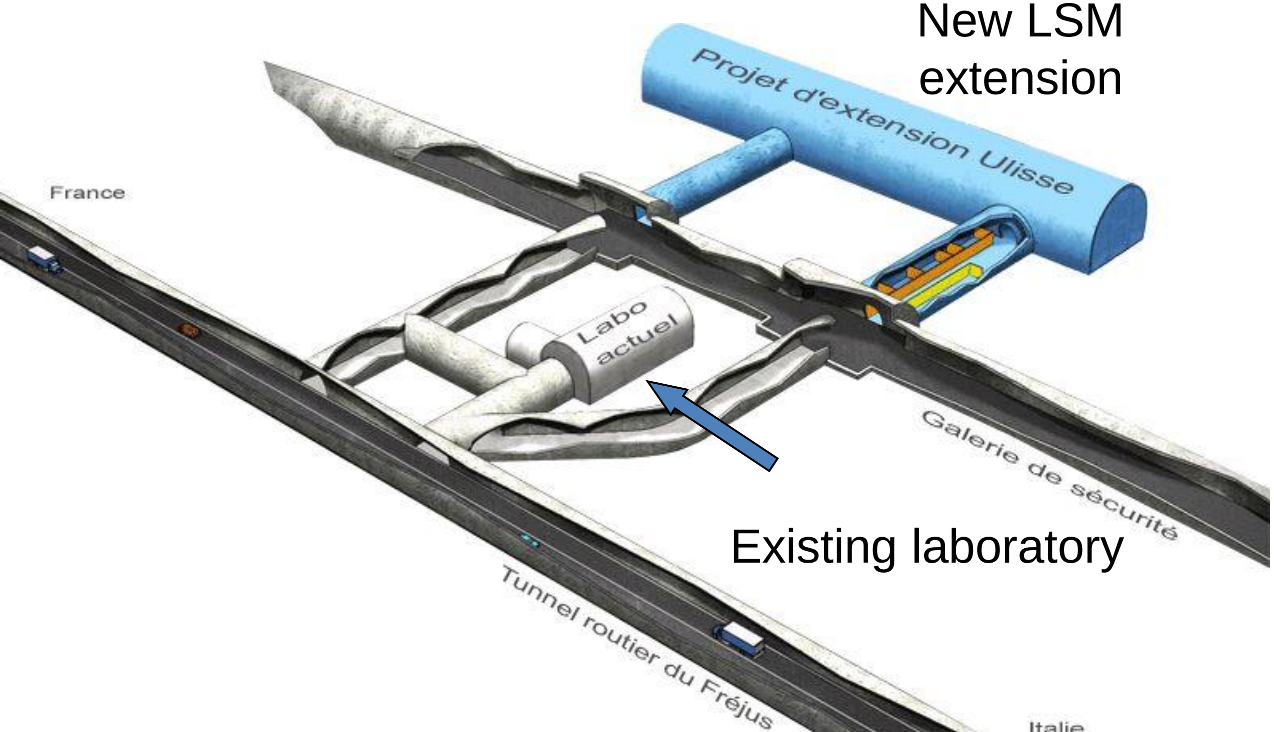
GEANT4 model → expected background event rates:

Source	Material	Mass kg	Contaminations U/Th, ppb	Gamma-rays events/kg/day/keV	Neutrons events/year
Screens, Cu parts	Cu	3000	0.005	0.005	0.03
Support rods	Cu-Ni alloy	100	0.1	0.002	0.5
Cables, 10 mK	Cu, Kapton	2	0.5	0.003	0.02
Holders	Kapton	0.2	1	0.0008	0.01
Holders	PTFE	0.5	0.1	0.0003	0.2
Screws	Cu, Zn	10	0.2	0.005	0.03
Electrodes	Al	0.0001	200	0.0002	0.05
Connectors	Cu, Delrin	1	1	0.0001	0.03
Cables	Cu, Kapton	5	0.5	0.0001	0.03
Neutron shielding	CH_2	500	0.1	0.001	0.4
Electronics (FET)	FR4	1	2000	0.002	0.03
Water shielding	Water	1 kt	0.001	0.001	0.003
Total				0.02	1.3

EURECA site:
Laboratoire Souterrain de Modane



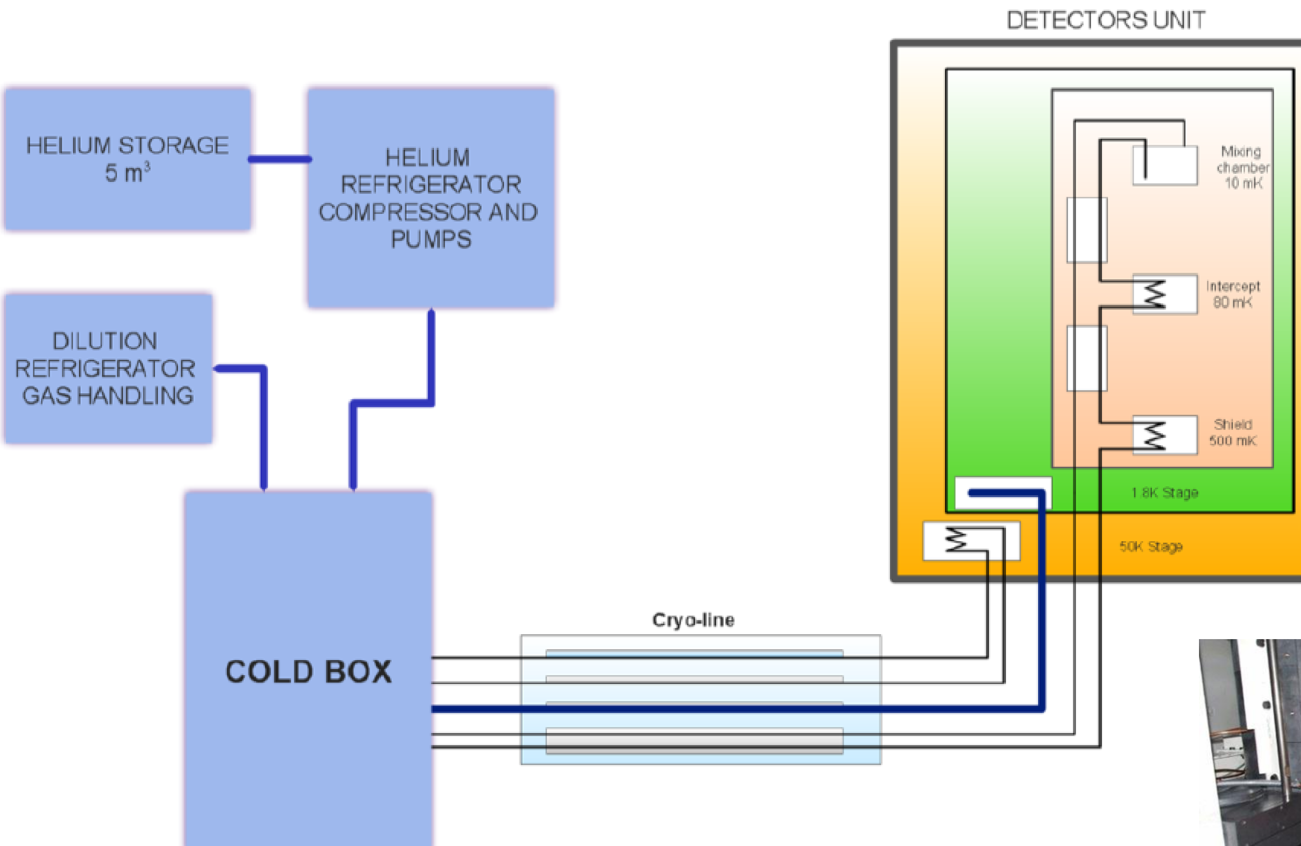
New LSM extension



Existing laboratory

EURECA Cryostat

How to cool a 1-tonne detector to 10mK



Inside water tank – radiopure materials

EDELWEISS cryostat

EURECA Timeline

2005: Collaboration formed (In Oxford)

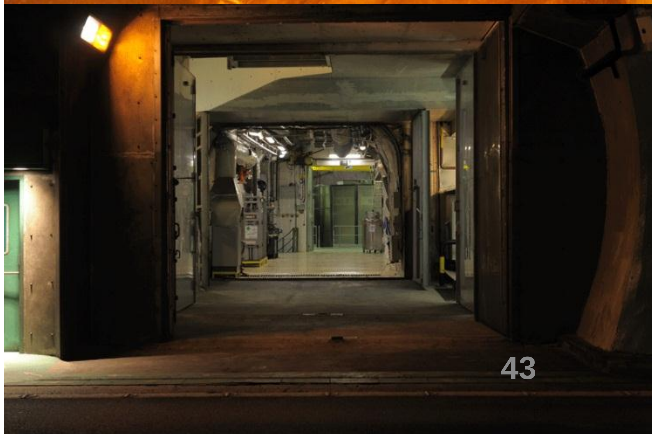
2010-12: Design Study → CDR

2012: TDR

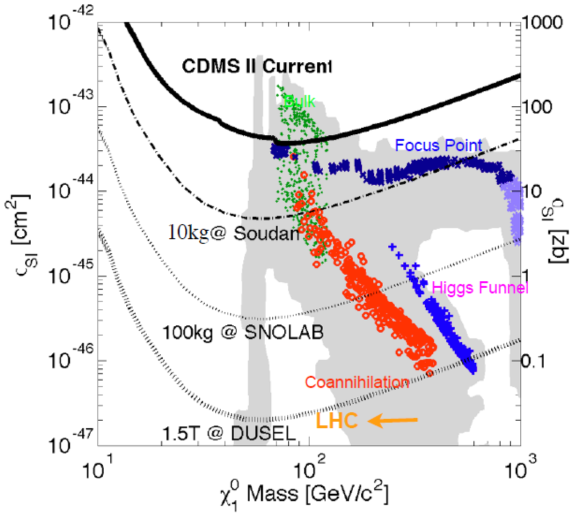
2013/14: Construction (depending on funding)

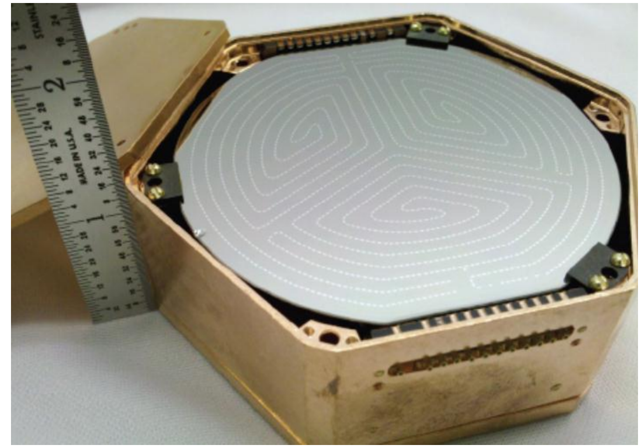
2015: Begin data taking and in parallel improve and upgrade.

2018: One tonne target installed.



EURECA and SuperCDMS/GEODM





iZIP Ge detectors

SuperCDMS Soudan	10kg
SuperCDMS SNOLAB	100kg
GEODM DUSEL	1500kg

CDMS-EDELWEISS combined limit: 3.3×10^{-8}pb excluded at 90GeV
Phys, Rev. D84 (2011)011102(R)

Collaborate on R&D on areas of common interest: detectors, radiopure materials

But we remain independent experiments...

Summary

- Edelweiss-II: Direct WIMP search with cryogenic germanium detectors
- Interleaved electrodes allow surface event rejection
- Ten 400g Ge-ID detectors – 384 kg day
- 4.4×10^{-8}pb excluded for 85GeV WIMP
- Edelweiss+CDMS 3.3×10^{-8}pb
- Edelweiss-III: Aim: 5×10^{-9}pb, FID-800 detectors
- EURECA: Aim: 10^{-10}pb, next generation European cryogenic dark matter experiment