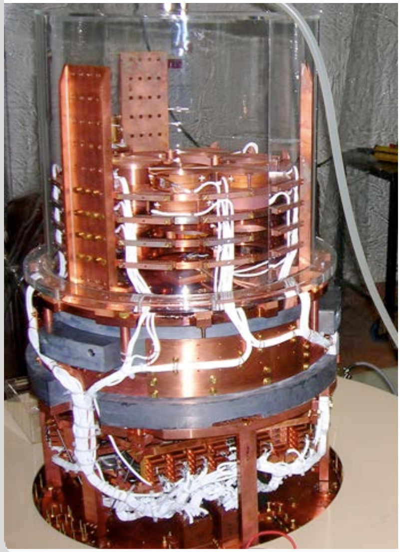
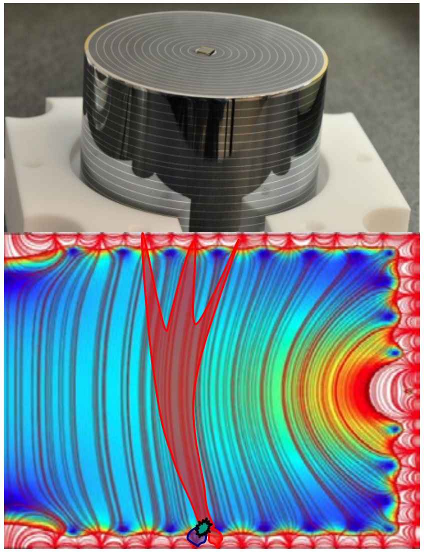
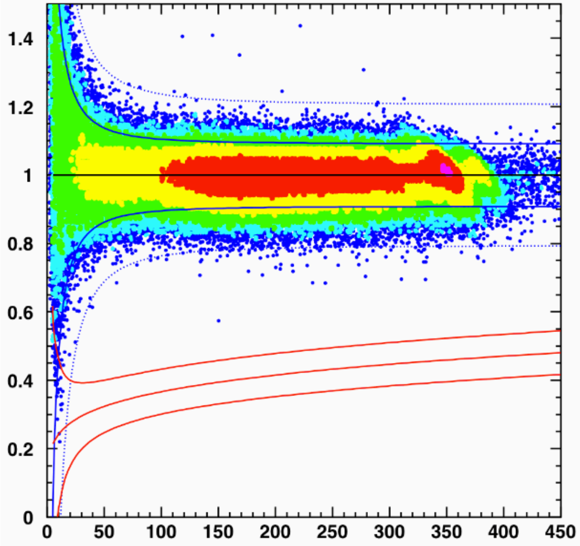
DM Searches with EDELWEISS and Plans for EURECA

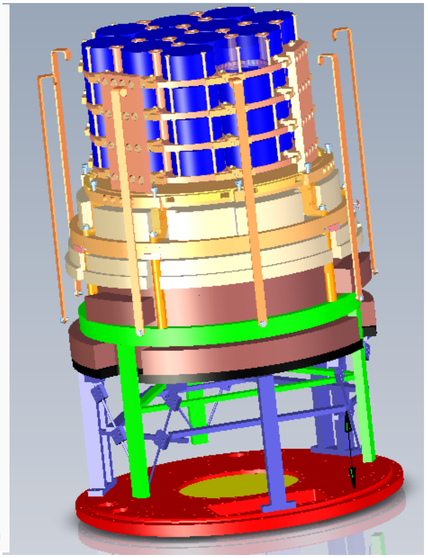
WS on future DM experiments

Klaus Eitel, KIT Center Elementary particle & Astroparticle Physics, KCETA





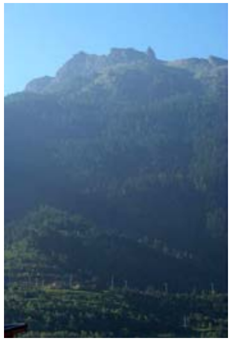


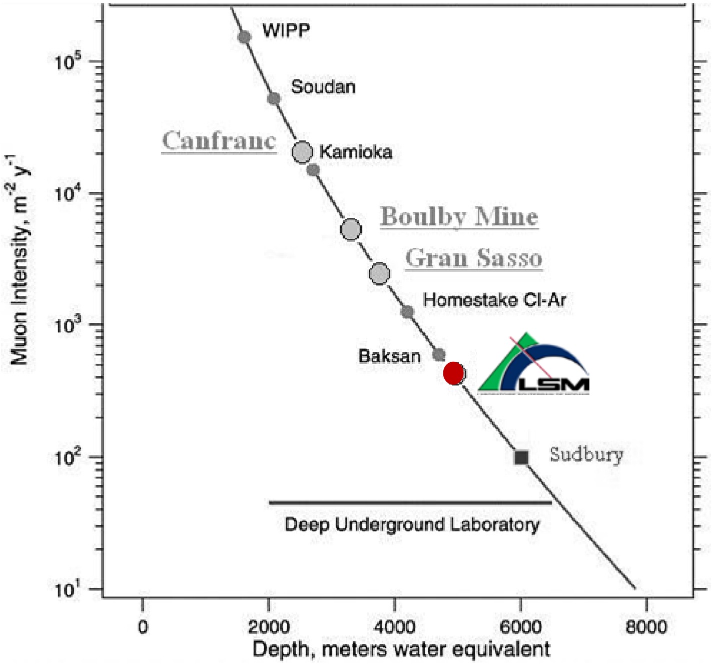


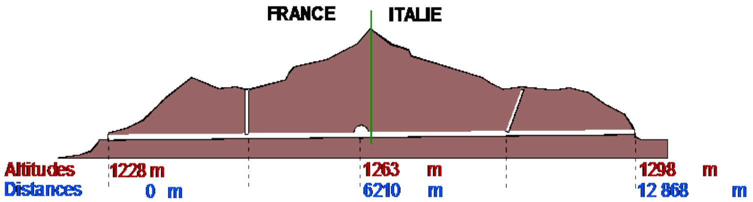
The EDELWEISS Collaboration

CEA Saclay (IRFU and IRAMIS)
CSNSM Orsay (CNRS/IN2P3 + Paris Sud)
IPNLyon (CNRS/IN2P3 + Univ. Lyon 1)
Néel Grenoble (CNRS/INP)
Karlsruhe Inst. of Technology (IKP, EKP, IPE)
JINR Dubna
Oxford University
University of Sheffield

Aussois 09/2013

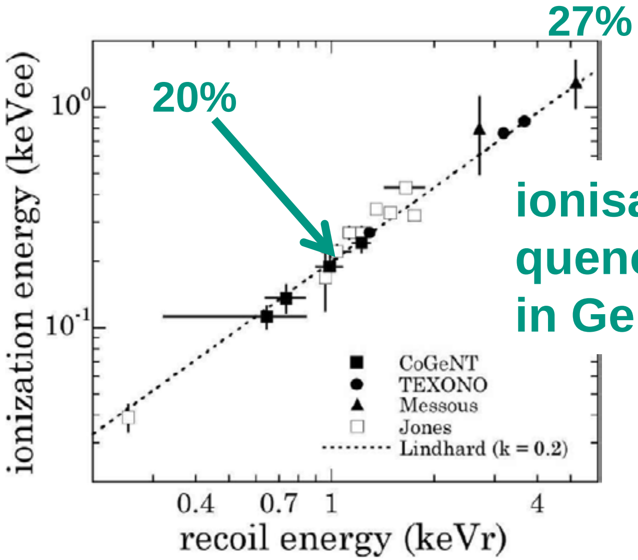




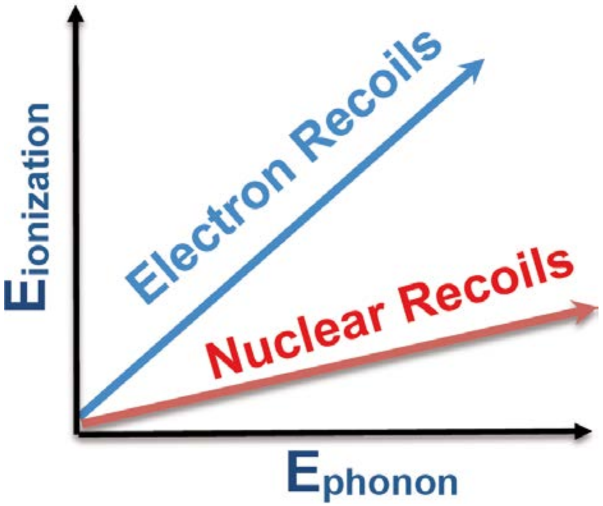


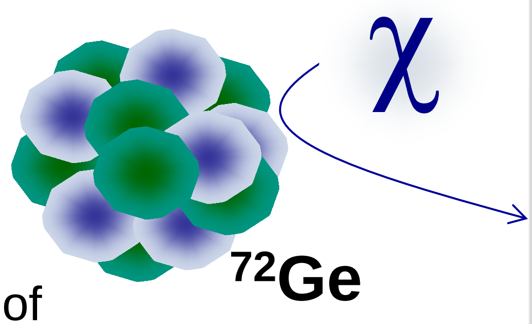
- Experimental site: *Laboratoire Souterrain de Modane (LSM)* in Fréjus Tunnel
- 4800 mwe depth: ~5 muon/day/m^2
- 10^{-6} neutrons/cm^2/s (>1MeV)
- Deradonized air supply
  (~10 Bq/m3 → ~30 mBq/m3)

DM search with cryogenic HPGe detectors



ionisation quenching in Ge





combination of

heat (phonons)
→ **energy measurement**

and

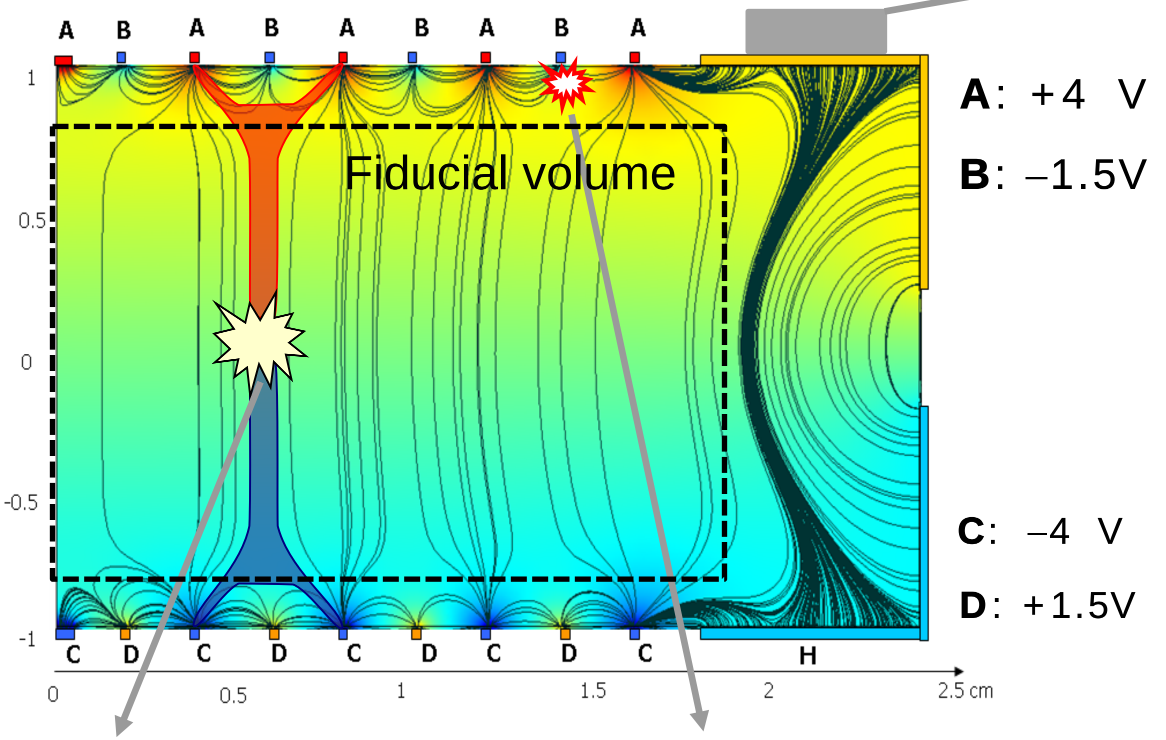
ionisation (charges)
→ **bgd discrimination**

requires T~10-50mK !

EDELWEISS Ge heat&ionisation detectors

Event discrimination via simultaneous charge and phonon measurement

Al electrodes ~100 nm



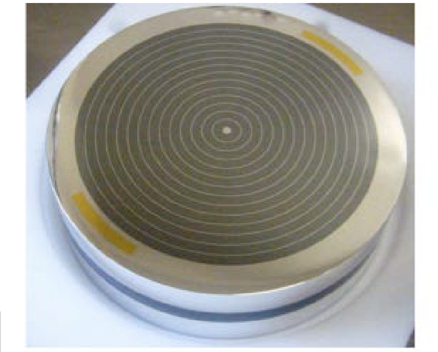
Bulk/Fiducial event
Charge collected on
electrodes A&C

Surface event
Charge collected on
electrodes A&B

NTD Phonon/Heat sensor
= calorimetric measurement of total energy ($T=18$ mK, $\Delta T \sim 0.1\ \mu K/keV$)

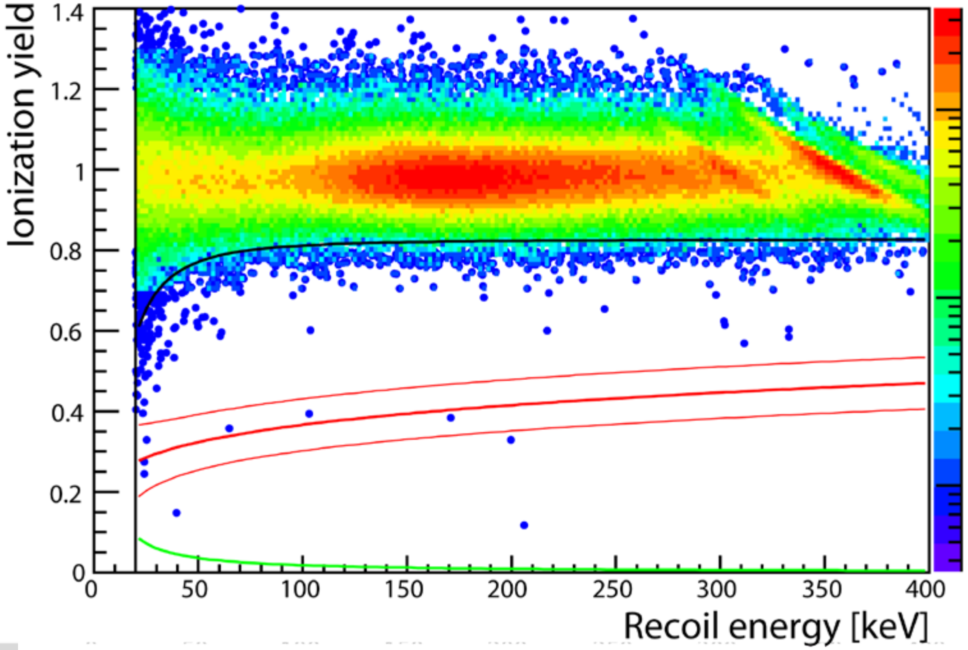
Al electrodes
Ionization measurement (sub-keV resolution)

Ionization yield
$Q = E_I/E_{Rec}$ nuclear recoils have ~1/3 Q of e-recoils

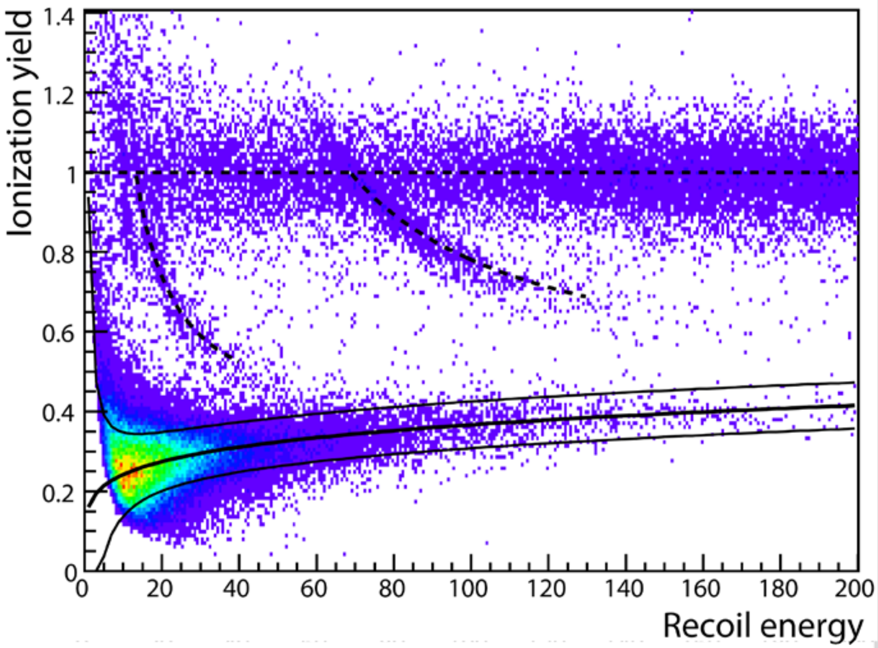


calibration with γ/n-sources

γ calibrations with ^{133}Ba



n calibrations with AmBe

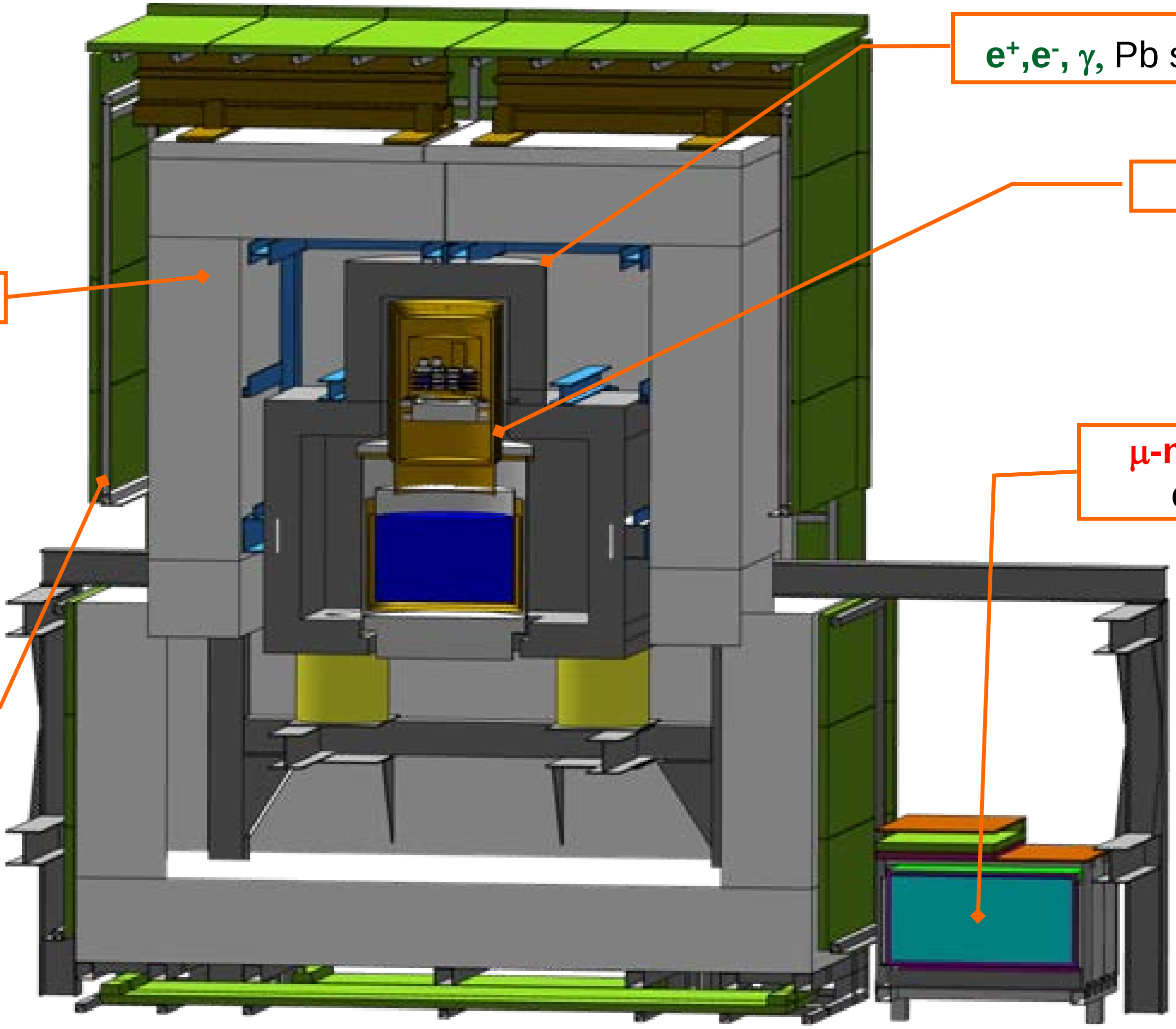


more than 350.000 γ´s
γ suppression factor 3x10^{-5}
1 ”NR” for every 30k γ´s (20-200keV)

90% CL signal region
$Q = 0.16\ E_r^{0.18}$ from <10 to 200keV
(detection efficiency below 20keV)

P. Di Stefano et al., ApP14 (2001) 329
O. Martineau et al., NIMA 530 (2004) 426
A. Broniatowski et al., PLB 681 (2009) 305

EDELWEISS setup



e^+,e^-, γ, Pb shield

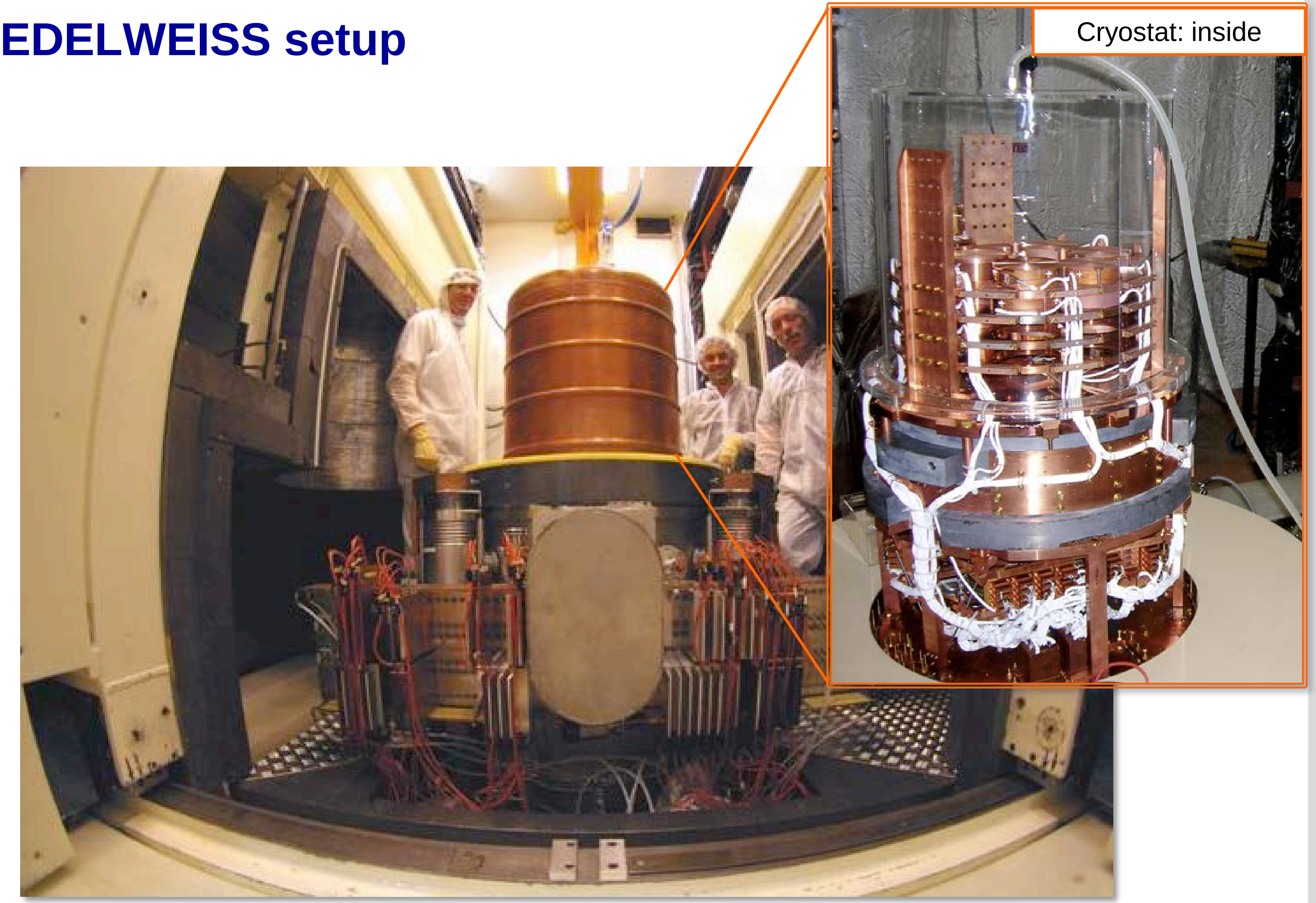
Cryostat

n, polyethylene shield

μ-n, Neutron counter

μ, Muon Veto

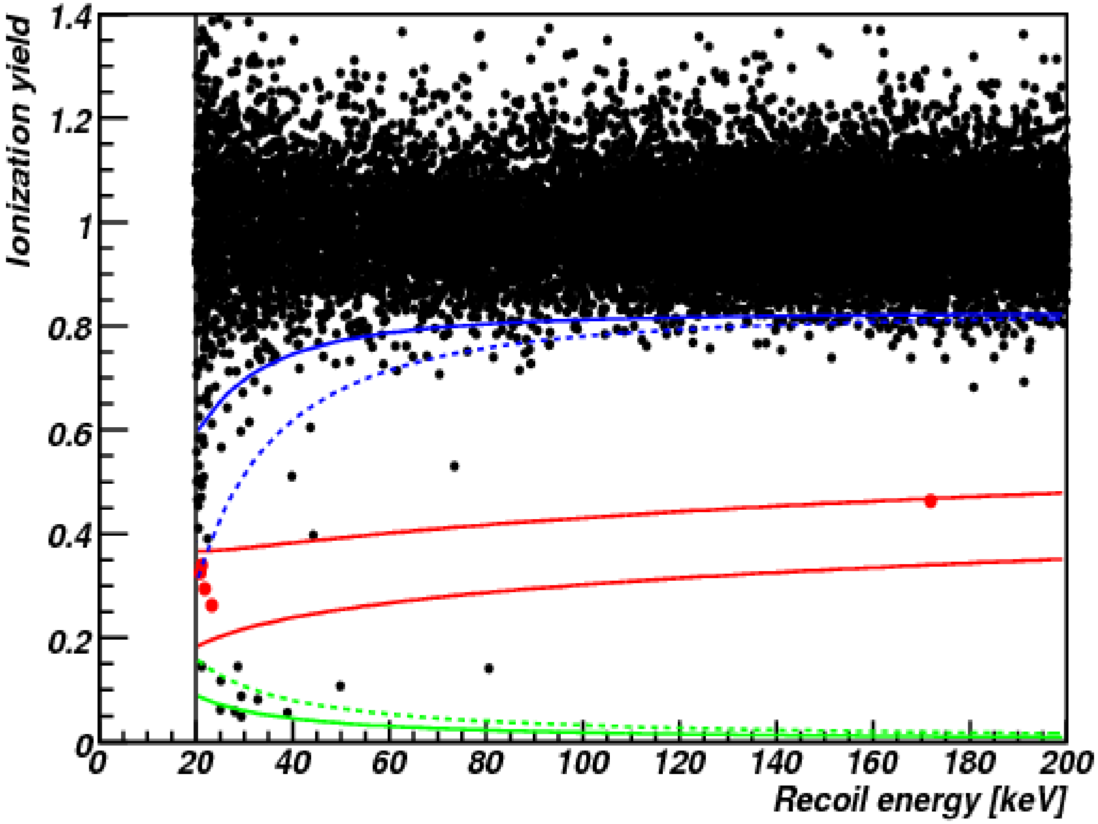
EDELWEISS setup



Results from EDELWEISS-II 2011 (384 kg.d)

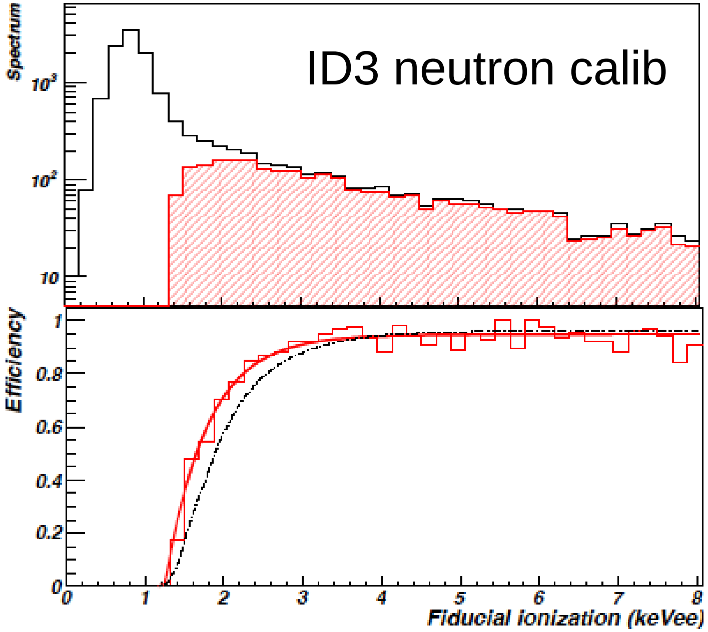
- Edw-II: semi-blind CDM analysis for ~100GeV WIMP mass
- 13 months / 384 kg.d of exposure
- 5 events observed
  3 background events expected
- $\sigma_{SI} < 4.4 \times 10^{-44}$ cm^2 (90% CL), Mχ=85GeV

EDELWEISS 2011:
PLB, 702(5), 329-335

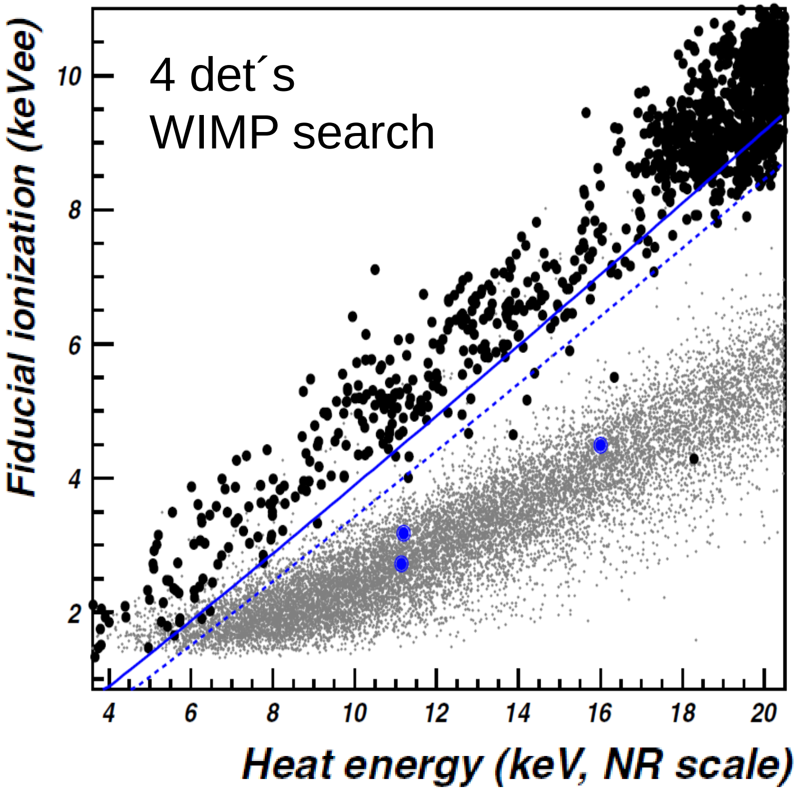


Avg ID FWHM baselines in 384 kgd sample:
0.9 keV ionization, 1.25 keV heat
(acceptable for >50 GeV WIMP search:
~100% eff. for 20 keV recoil threshold)

EDELWEISS-II
Low WIMP mass analysis



- ID det´s sensitive to NR´s down to 5 keV
- new independent analysis < 20 keV
- selection of data set :
  - keep 4 det´s with sub-keV resolutions
  - remove noisy periods
  - χ^2 based cut on signal shape
  - fiducial cut on ionization signal



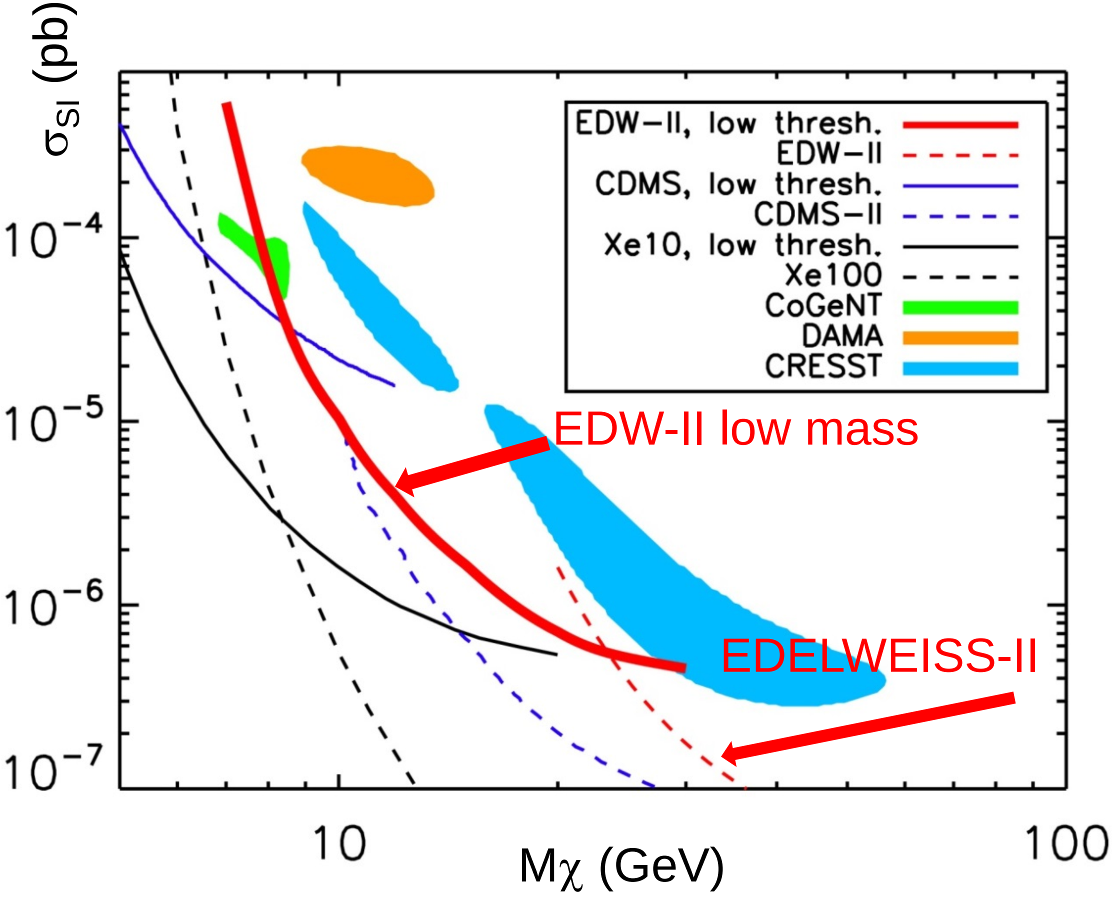
$$E_{\text{heat}} = \frac{E_{\text{rec}}}{1+V/3}\left(1+\frac{V}{3}0.16\,E_{\text{rec}}{}^{0.18}\right)$$

- define "WIMP box" for each mass m_χ

EDELWEISS-II
Low WIMP mass analysis

- 2009-2010 data (best ID detectors)

- 4/10 ID detectors (~113 kg.d)
- 1.4 – 1.9 keV Ionization threshold
- 95% C.L. gamma cut
- Background expect.: γ + ion. threshold + n: 2.9 evts / 1-3 observed



PRD, 86, 051701(R), (2012)

EDELWEISS-II
Low WIMP mass analysis results

- 2009-2010 data (best ID detectors)

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- 1.4 – 1.9 keV Ionization threshold
- 95% C.L. gamma cut
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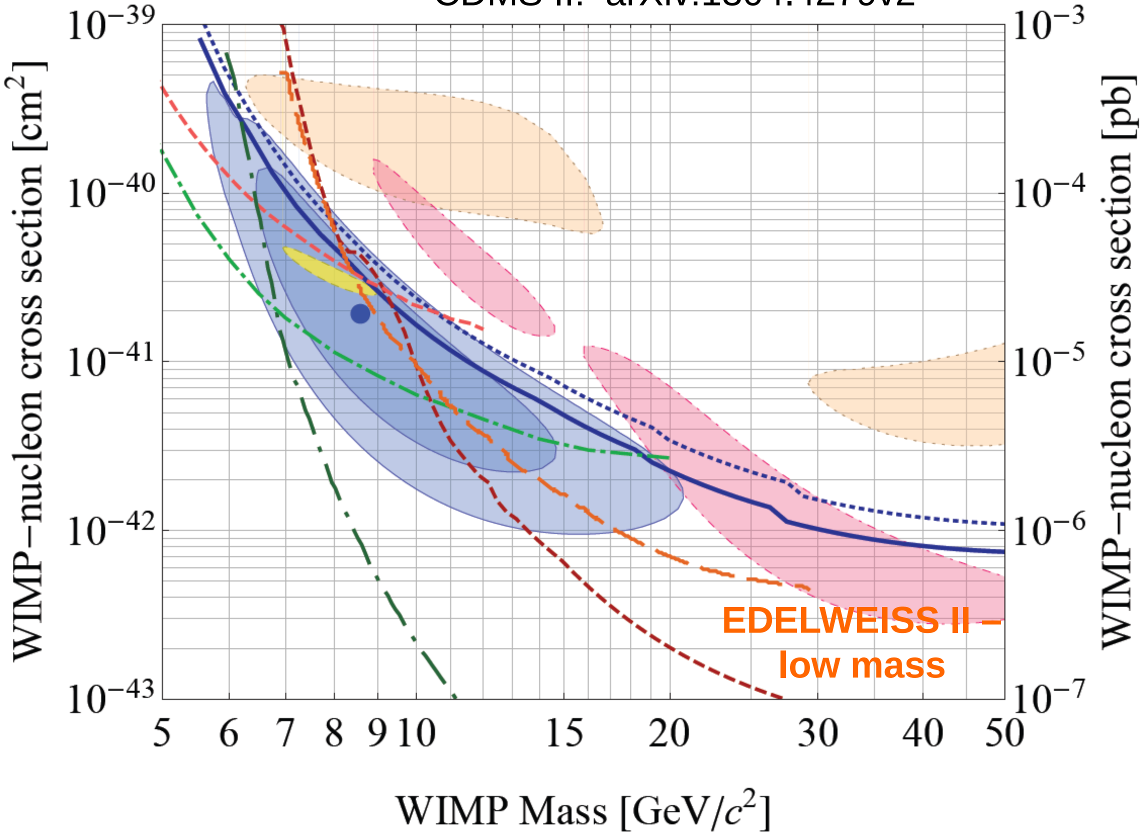
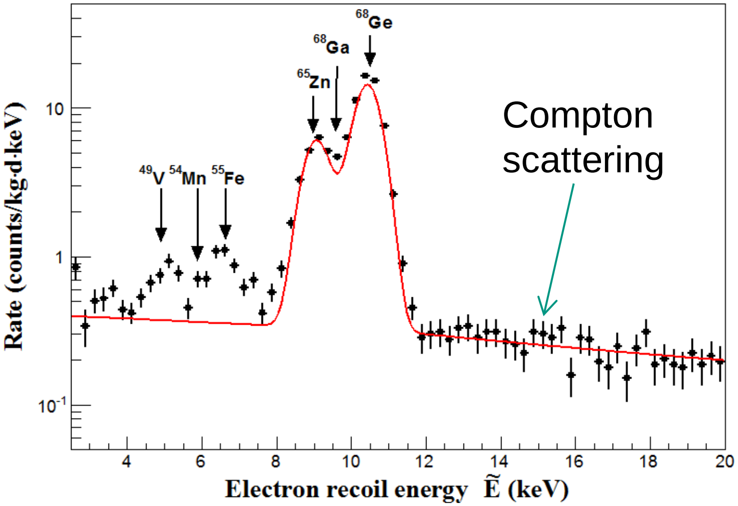
CDMS II: arXiv:1304.4279v2

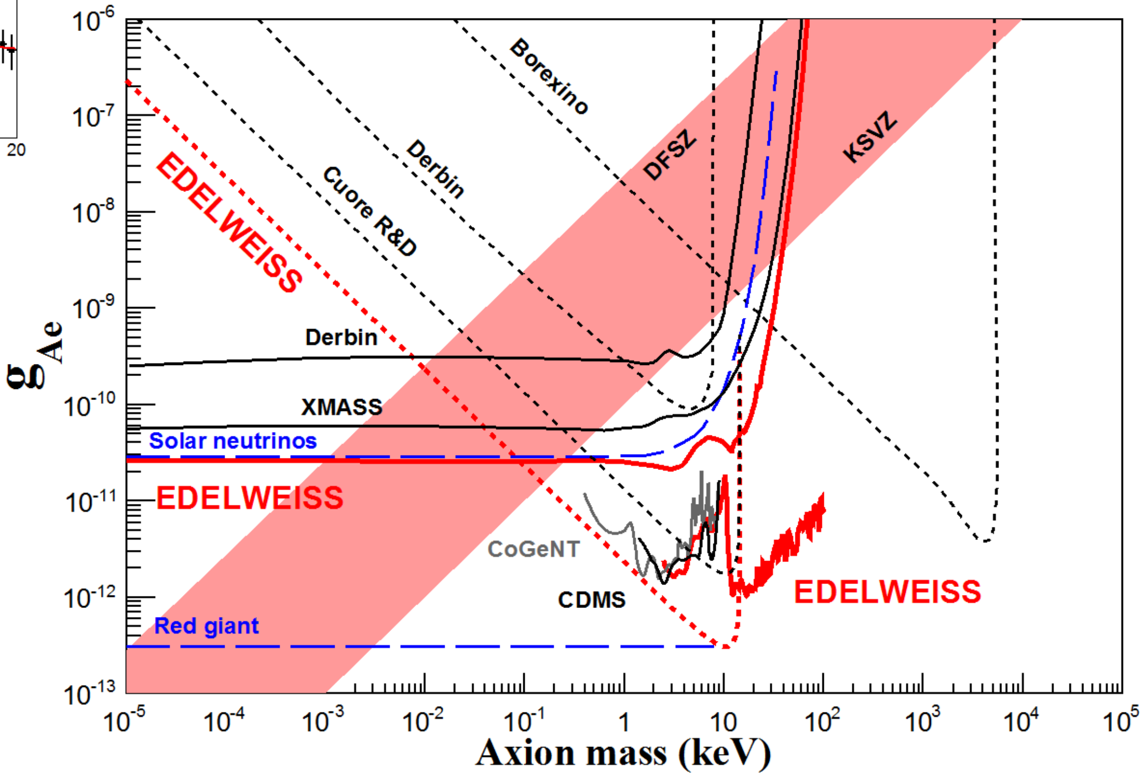


Axion results with EDELWEISS-II data



low-threshold and high resolution electron recoil spectrum used for axion search

very low background due to fiducial selection

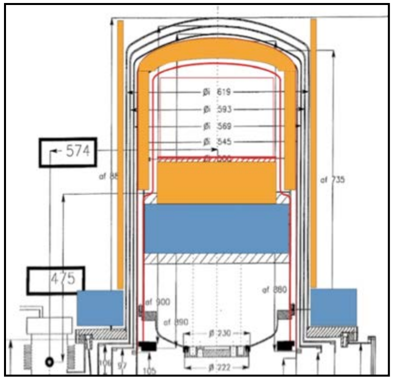


best/competitive axion limits (Primakoff, axio-electric, solar or dark matter scenarios with axion like particles)

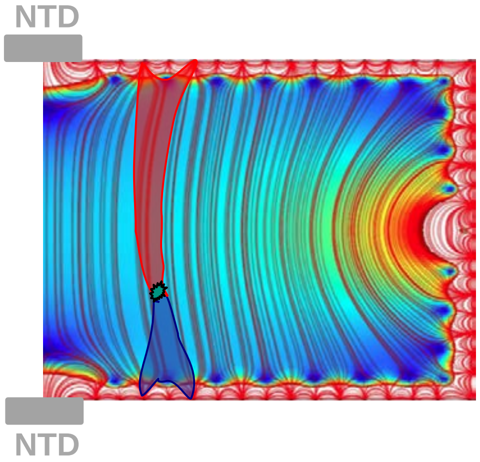
arXiv:1307.1488, acc. for publ. in JCAP

Upgrades → EDELWEISS-III

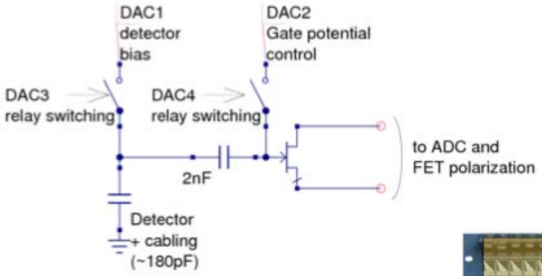
1. Suppression of background



2. Improvement of γ discrimination



3. Confirmation of β-rejection with new detectors and improved resolutions

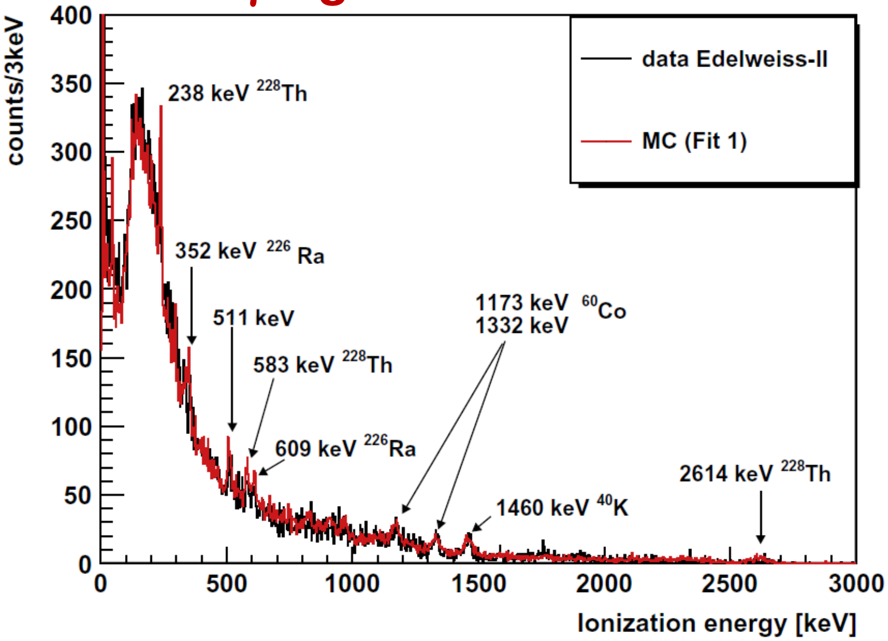


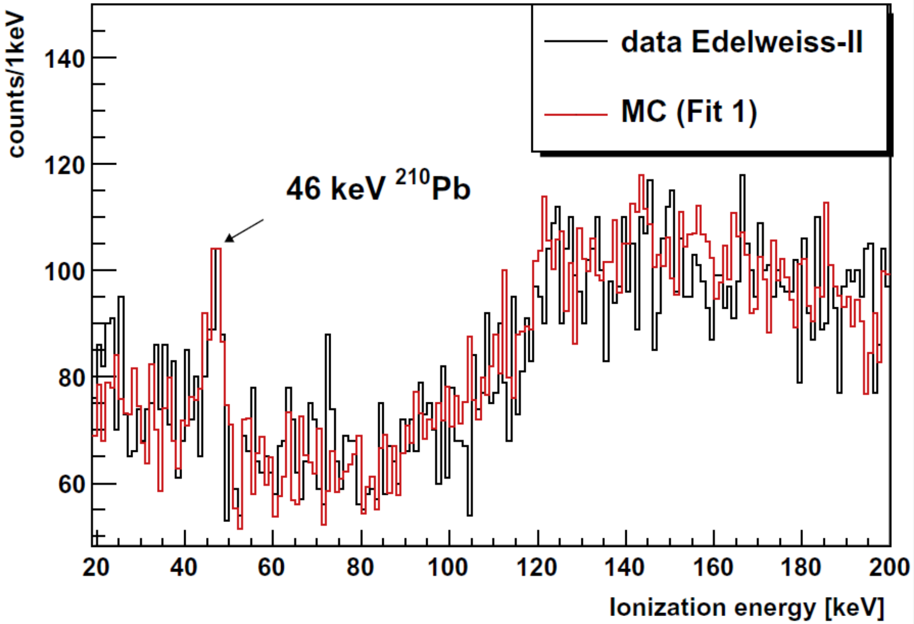
4. Enable upscaling towards 1ton-scale exp.

Upgrades towards EDELWEISS-III
1. Suppression of background

- detailed studies of remaining background

γ-bgd and ambient neutrons → arXiv:1305.3628, Astrop. Phys. **47** (2013) 1





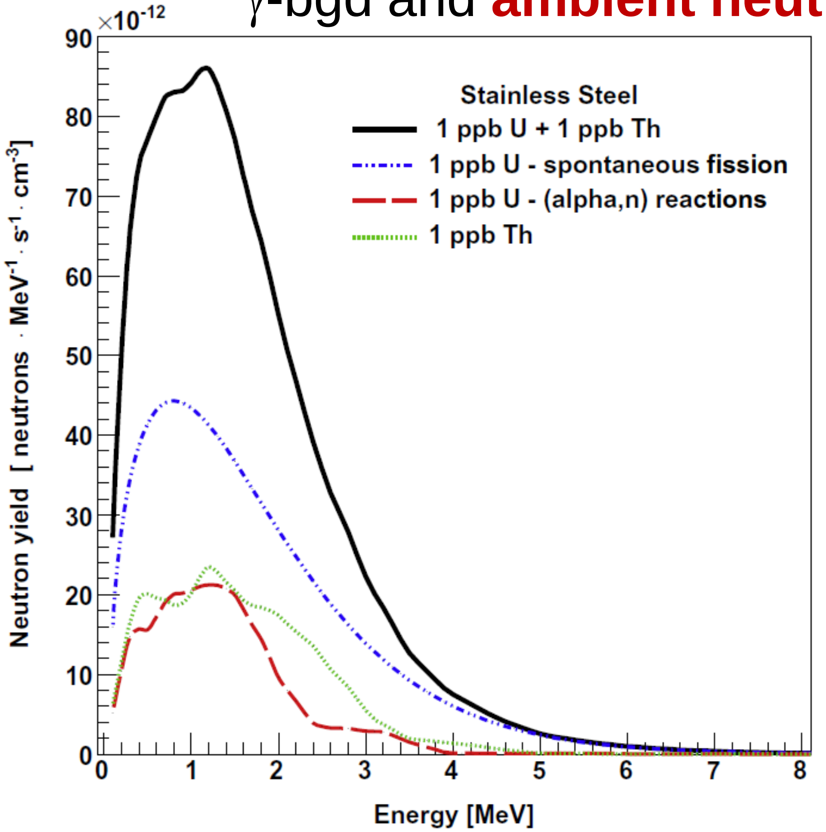
major sources only

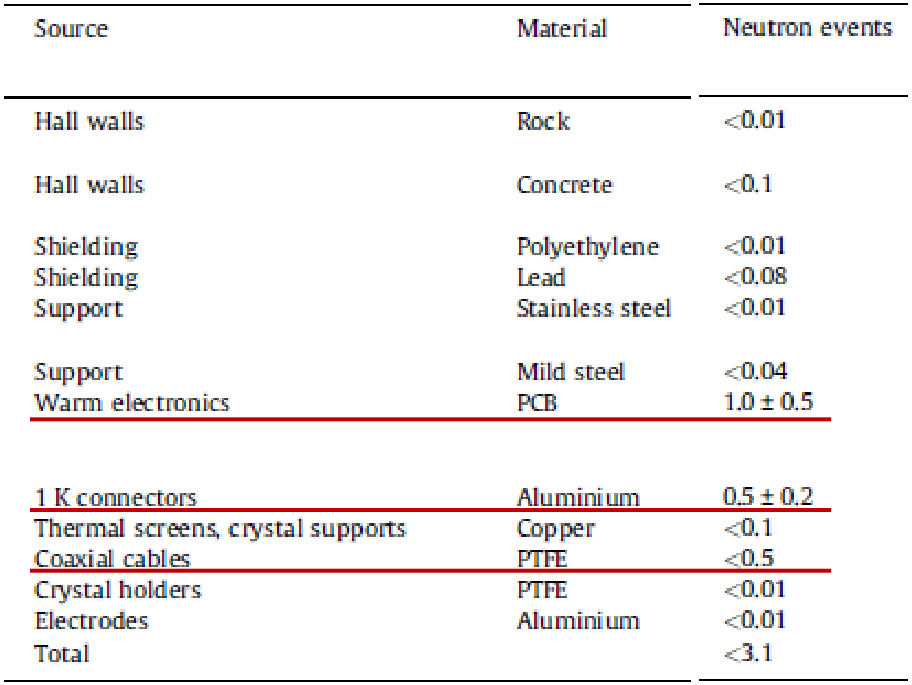
Material	γ rate (evts/kg/day) 20–200 keV	fraction (%)
Detector casings/CuC2 copper	14	17
Disks, bars, 10 mK chamber/ CuC1 copper	9.5	12
Screens 7–11/copper	**32.5**	**40**
Pollution 300 K	22	27
Total MC	82	
Total data	82	

Upgrades towards EDELWEISS-III
1. Suppression of background

- detailed studies of remaining background

  γ-bgd and **ambient neutrons** → arXiv:1305.3628, Astrop. Phys. **47** (2013) 1





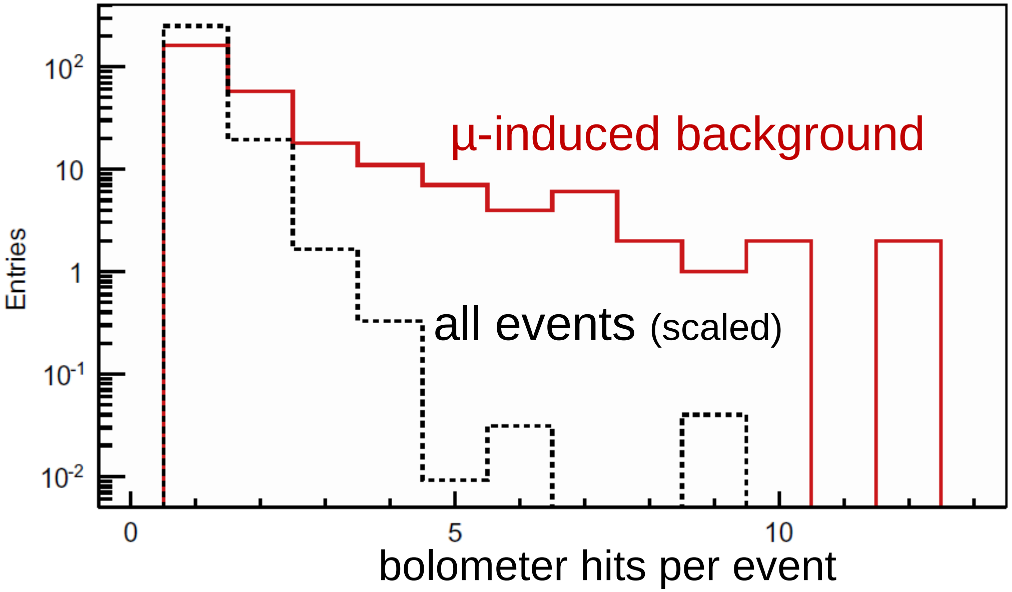
Source	Material	Neutron events
Hall walls	Rock	<0.01
Hall walls	Concrete	<0.1
Shielding	Polyethylene	<0.01
Shielding	Lead	<0.08
Support	Stainless steel	<0.01
Support	Mild steel	<0.04
Warm electronics	PCB	1.0 ± 0.5
1 K connectors	Aluminium	0.5 ± 0.2
Thermal screens, crystal supports	Copper	<0.1
Coaxial cables	PTFE	<0.5
Crystal holders	PTFE	<0.01
Electrodes	Aluminium	<0.01
Total		<3.1

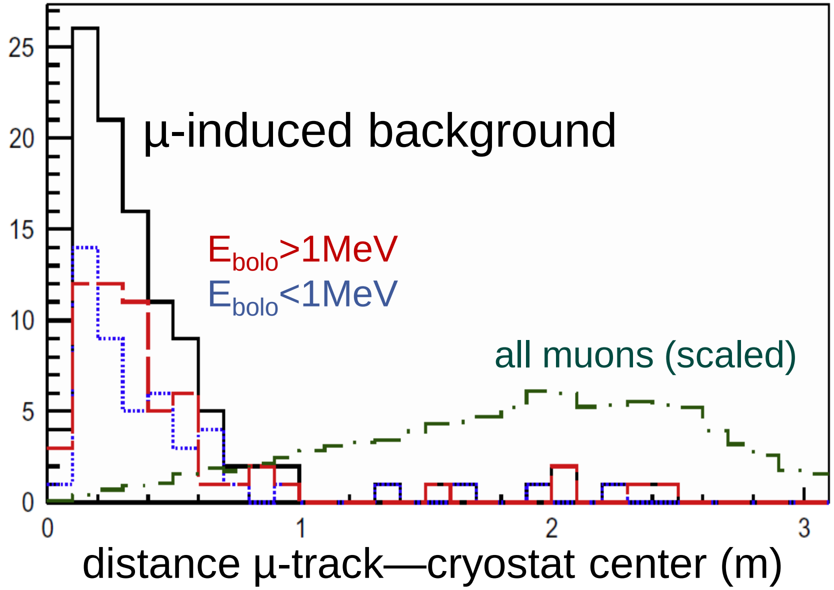
G4 neutron signatures/rates cross-checked via calibrations with AmBe sources inside(20n/s) & outside($2x10^5$n/s) passive shielding

Upgrades towards EDELWEISS-III
1. Suppression of background

- detailed studies of remaining background

μ-induced neutrons → arXiv:1302.7112, Astrop. Phys. **44** (2013) 28





$$\Gamma^{\mu-n} = (0.008^{+0.005}_{-0.004})\ \mathrm{evts}/(\mathrm{kg\ d})$$ before μ-veto cut

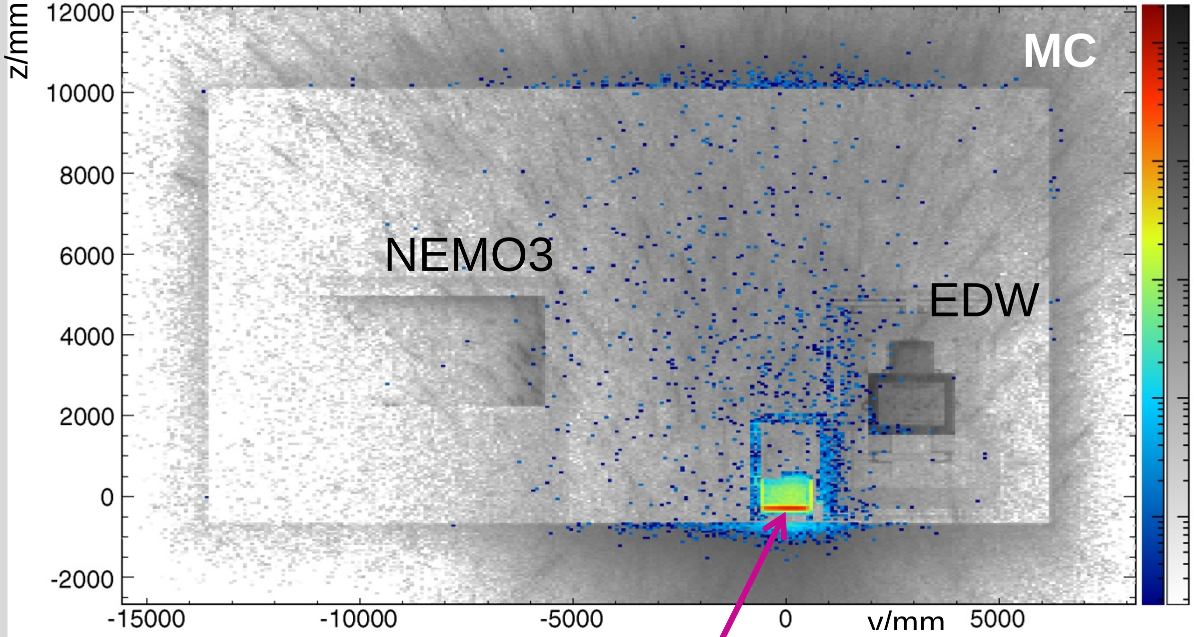
EDW-II: after μ-veto cut: $N^{\mu\text{-}n} < 0.72$ evts (90%CL)

EDW-III: after μ-veto cut: $N^{\mu\text{-}n} = 0.6^{+0.7}_{-0.6}$ evts (90%CL, 3000kg.d)

(not yet included: multiplicity enhancement, addtl. modules)

Upgrades towards EDELWEISS-III
1. Suppression of background

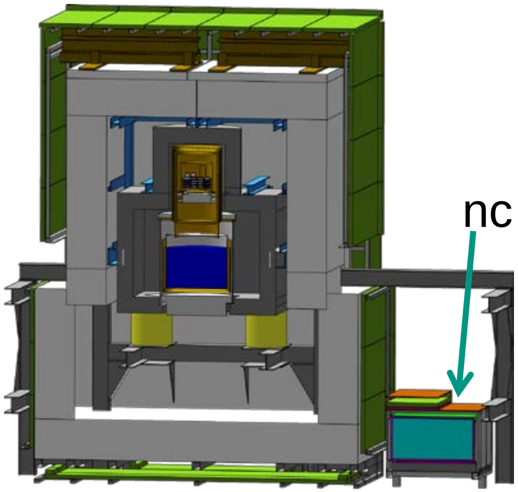
- Dedicated measurement of **μ-induced neutrons**

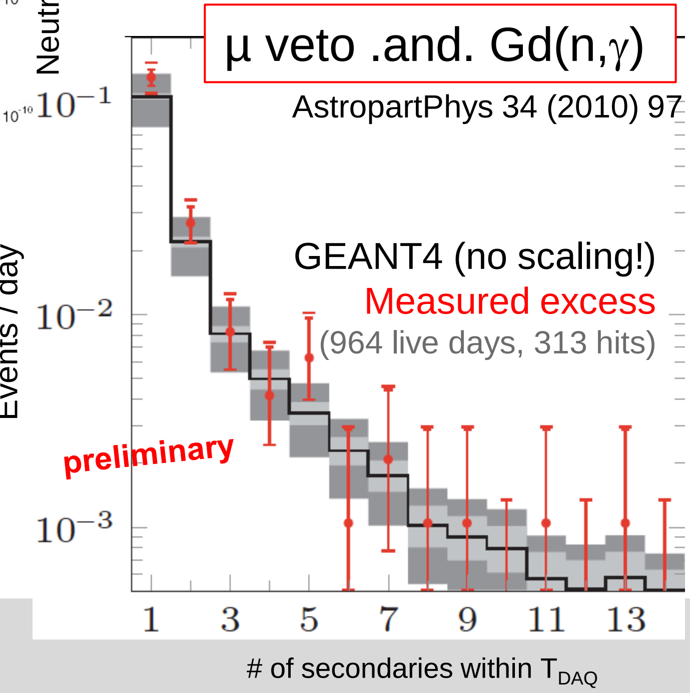


grey:
production vertices of
>4x10^5 μ-ind.neutrons
color:
prod. vertices of
detected n´s via Gd(n,γ)

neutron counter

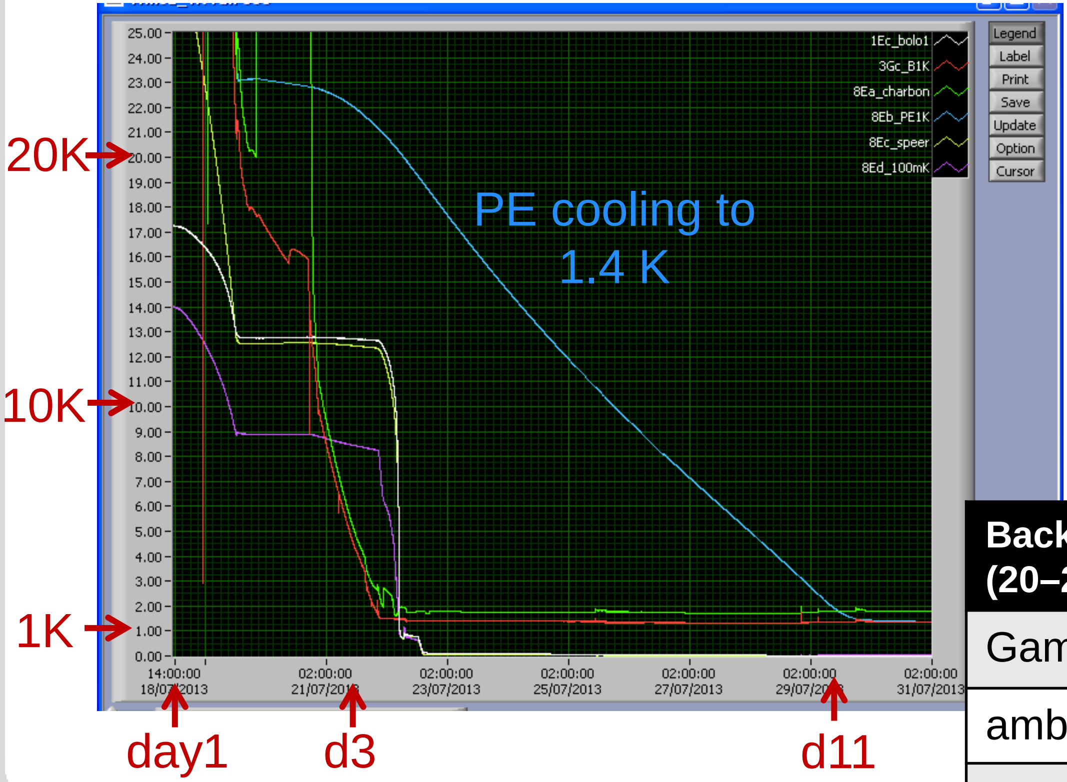
PhD thesis H. Kluck

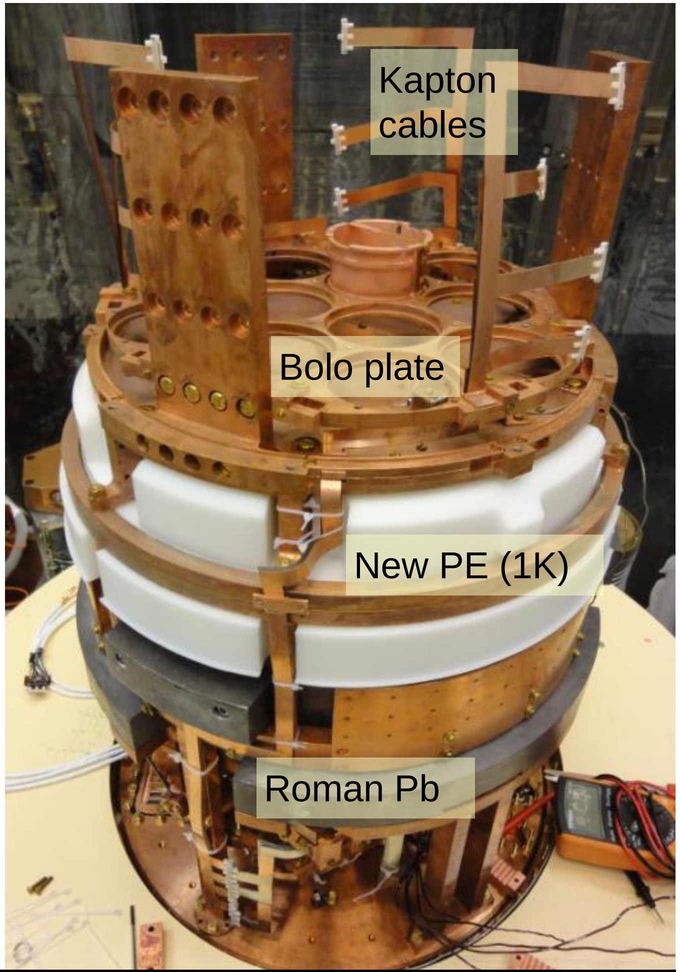




Upgrades towards EDELWEISS-III
1. actions against background

- additional cold PE shield
- new Kapton cabling
- better radiopure connectors
- redesign of NOSV copper shields



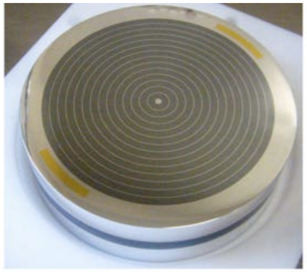


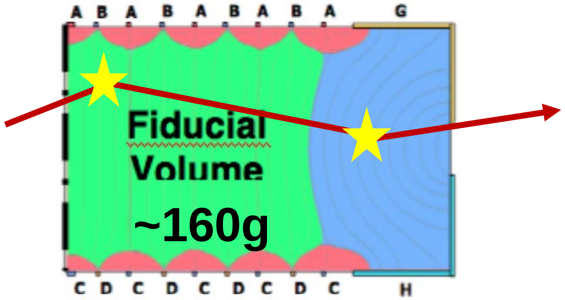
Background (20–200 keV)	**EDW-2 (evt / kg.d)**	**EDW-3 (evt / kg.d)**
Gamma rate	82	14 – 44
ambient n´s	$< 8.1 \cdot 10^{-3}$	$(0.8 – 1.9) \cdot 10^{-4}$
µ-induced n´s	$< 2 \cdot 10^{-3}$	$< 2 \cdot 10^{-4}$

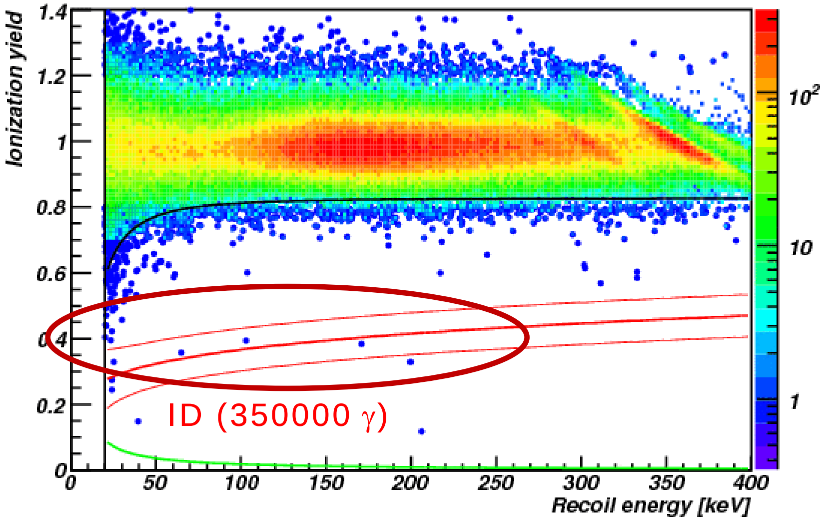
Upgrades towards EDELWEISS-III
2. Improvement of γ discrimination

EDELWEISS-II

ID 400g with 10x **160g** fiducial mass

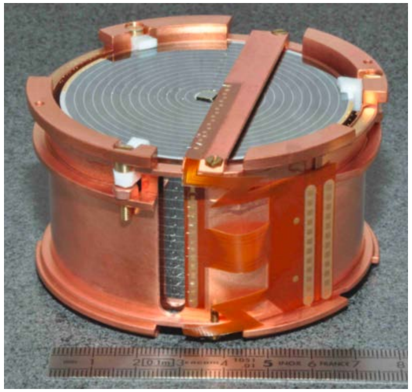


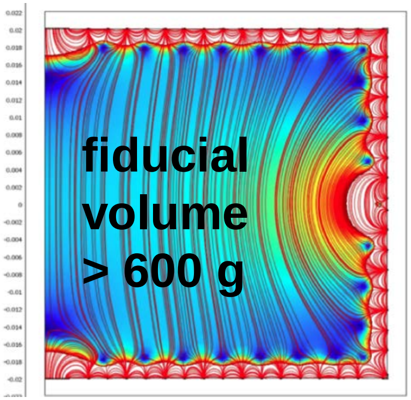


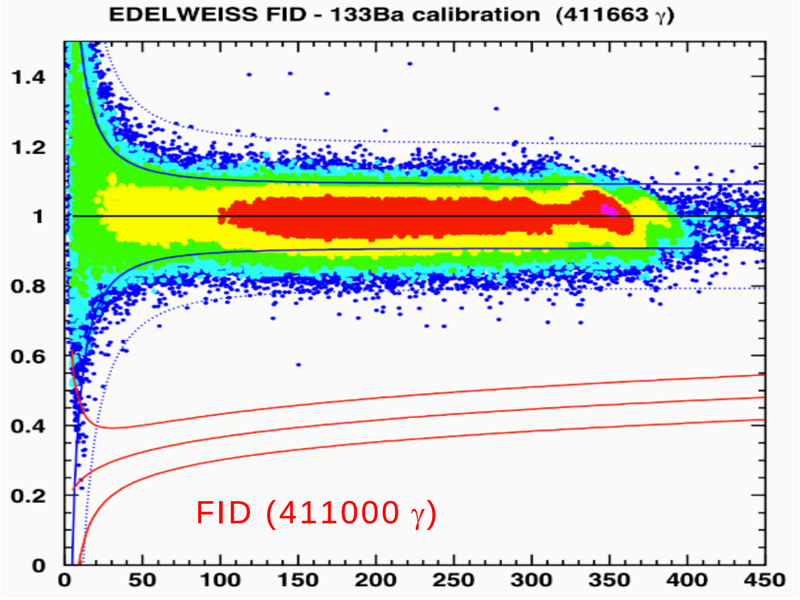


EDELWEISS-III

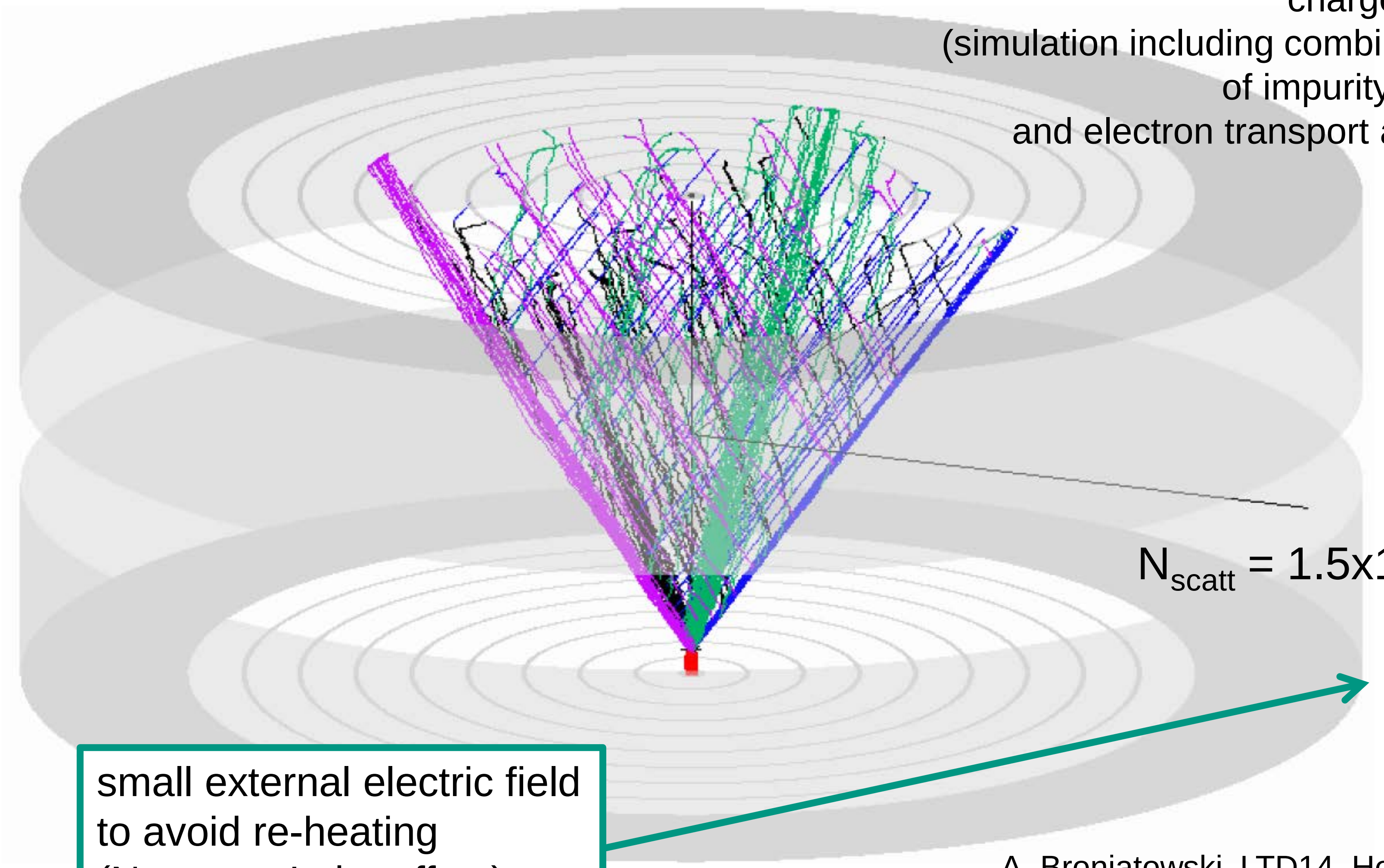
FID 800g with 40x ~**600g** fiducial mass







Upgrades towards EDELWEISS-III
2. detector developments & understanding



charge migration
(simulation including combined effects
of impurity scattering
and electron transport anisotropy)

$N_{scatt} = 1.5x10^{10}cm^{-3}$

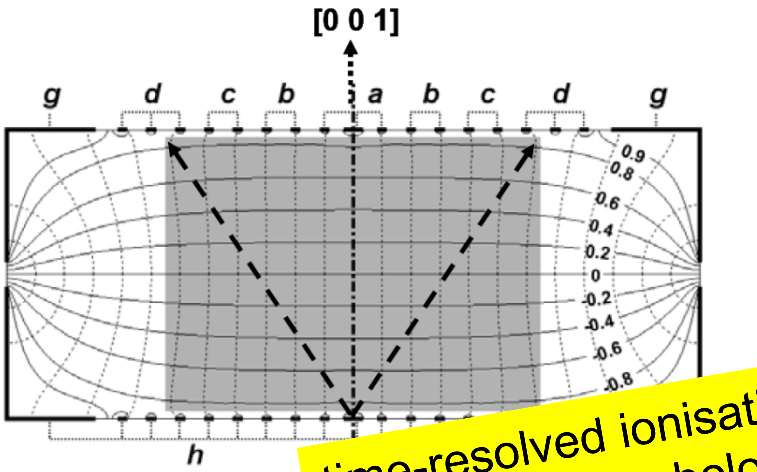
$V_a = 1V$

small external electric field
to avoid re-heating
(Neganov-Luke effect)

A. Broniatowski, LTD14, Heidelberg, 2011
E. Olivieri et al., J of Low Temp Phys (2012)

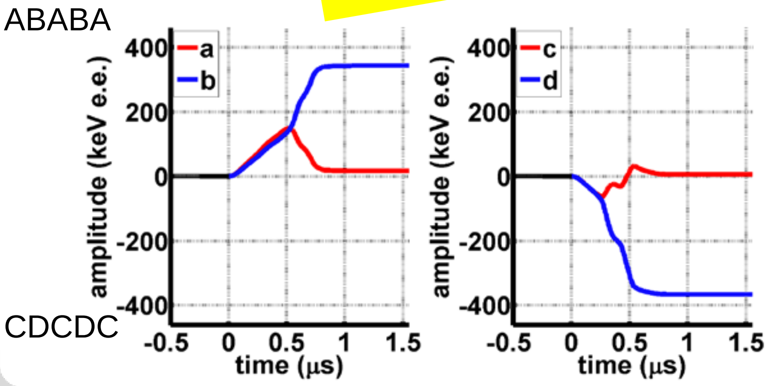
Upgrades towards EDELWEISS-III
2. detector developments & understanding

$+V_a = +V_b = +V_c = +V_d = +V_g = -V_h$

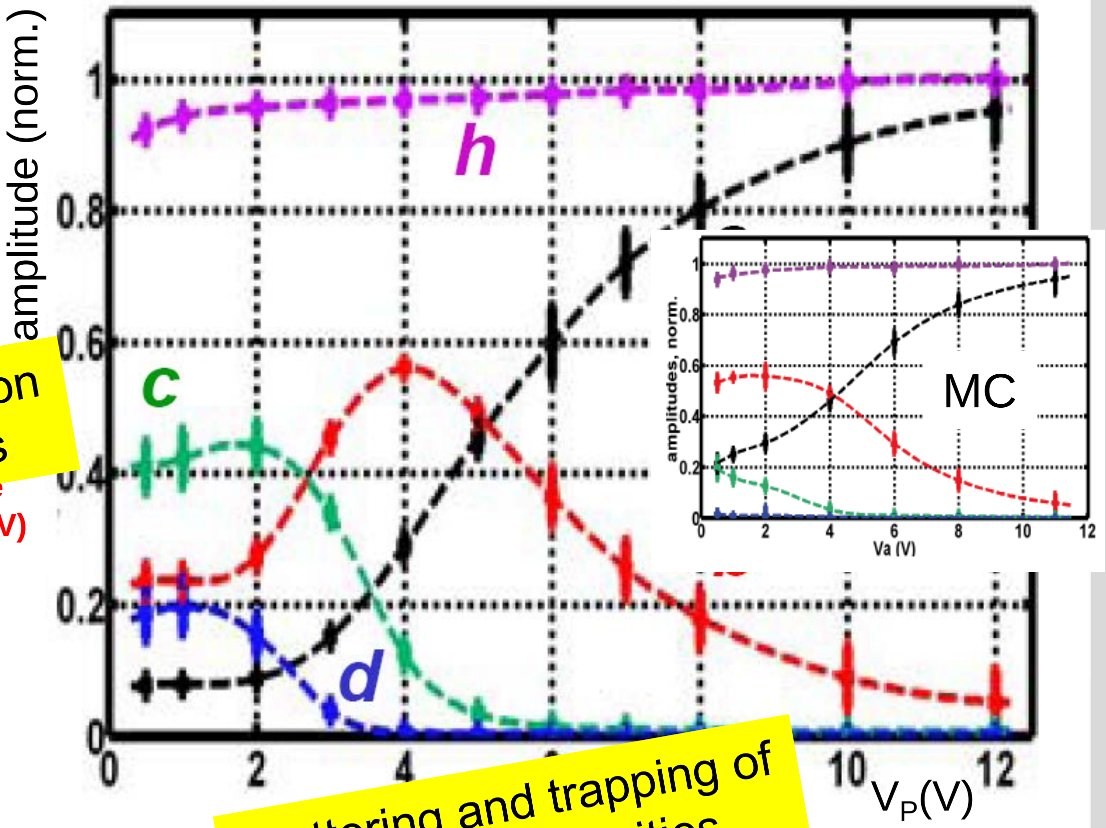


time-resolved ionisation
in cryogenic Ge bolos

urce
detector axis (60keV)



60keV electron collection pattern
n-type, $|N_d-N_a|<10^{10}/cm^3$
$|N_d-N_a|=10^{11}/cm^3$



scattering and trapping of
electrons on impurities

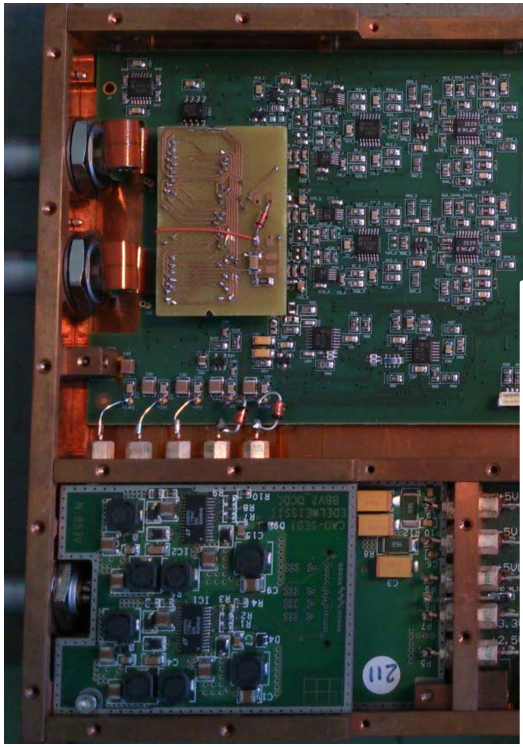
D14, Heidelberg, 2011
en et al., J of Low Temp Phys (2012)

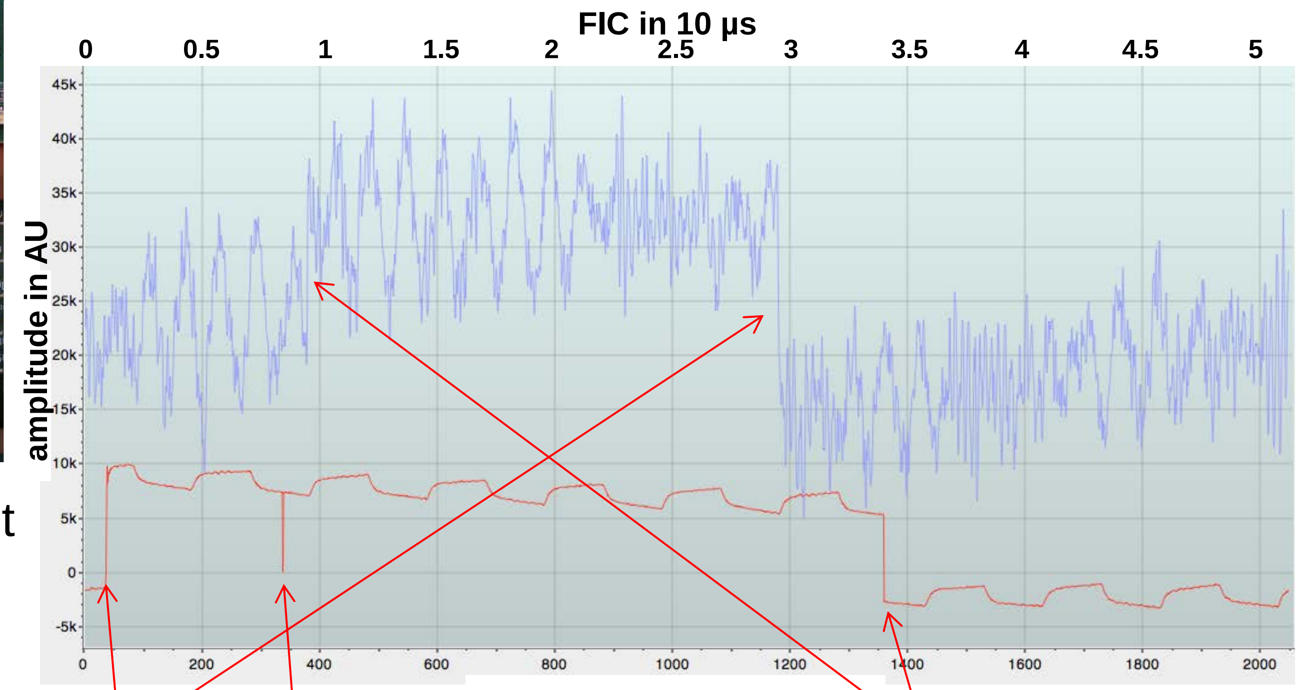
Upgrades towards EDELWEISS-III fast ionisation channel FIC

HELMHOLTZ | ASSOCIATION

Alliance for Astroparticle Physics

40MHz 16-bit ADC´s





100 kHz Ionization in 10 µs

transmission and readout of test pulses with new fast DAQ

Pulse

Trigger marker (300 S delay)

Memory page flip

3. Surface rejection measurements – improved discrimination

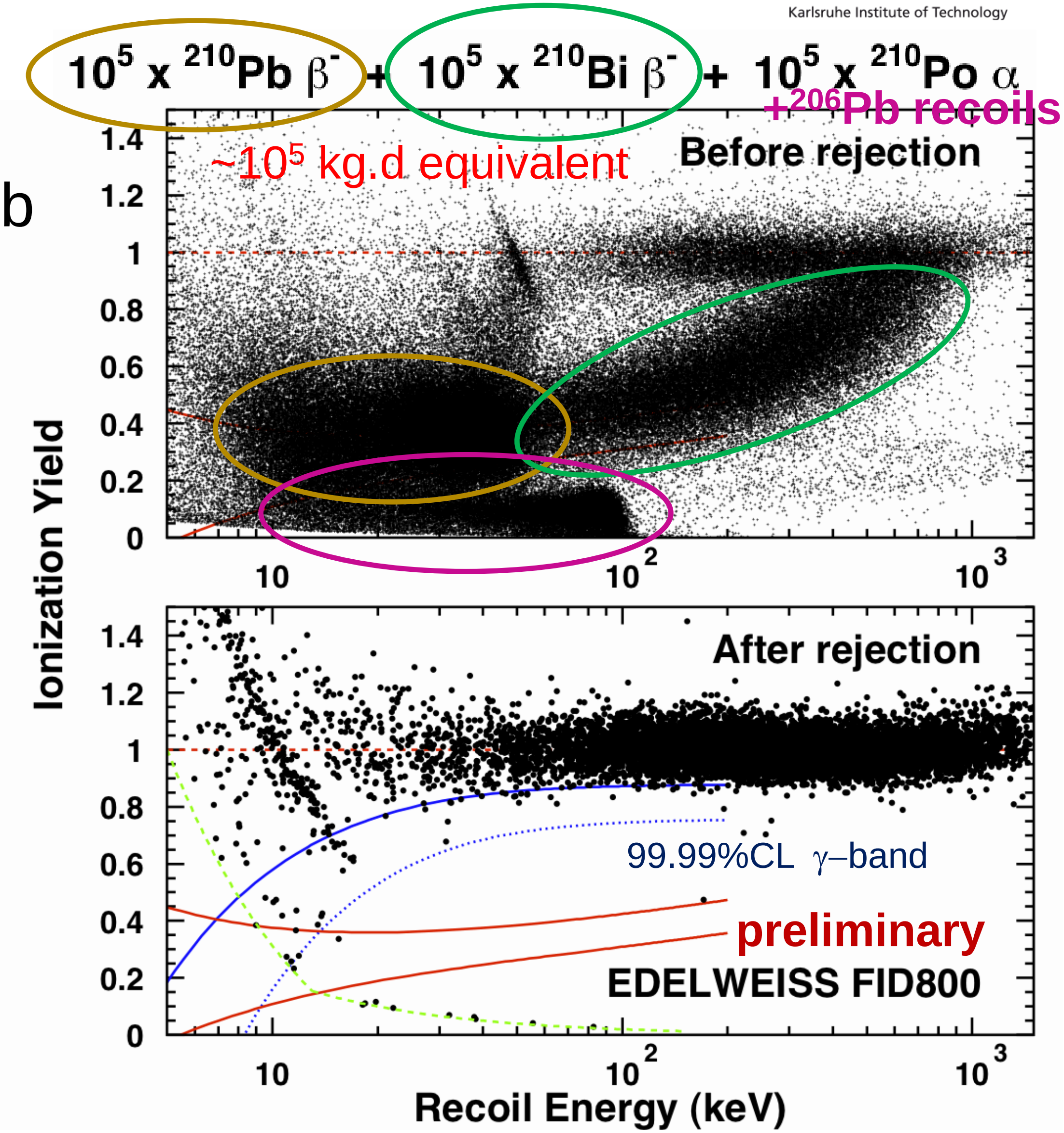
- measurement with ^{210}Pb β-source

- surface rejection:

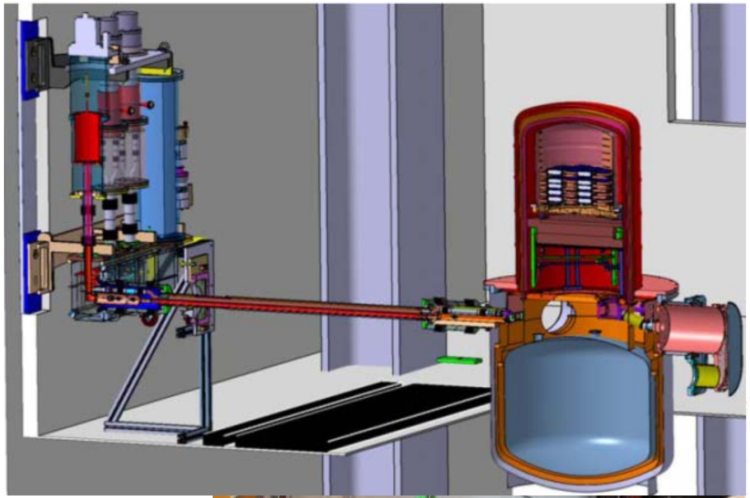
  < 4 x 10^{-5} misidentified events per kg.d (E_{rec}>15 keV)

better than previous EDELWEISS detectors

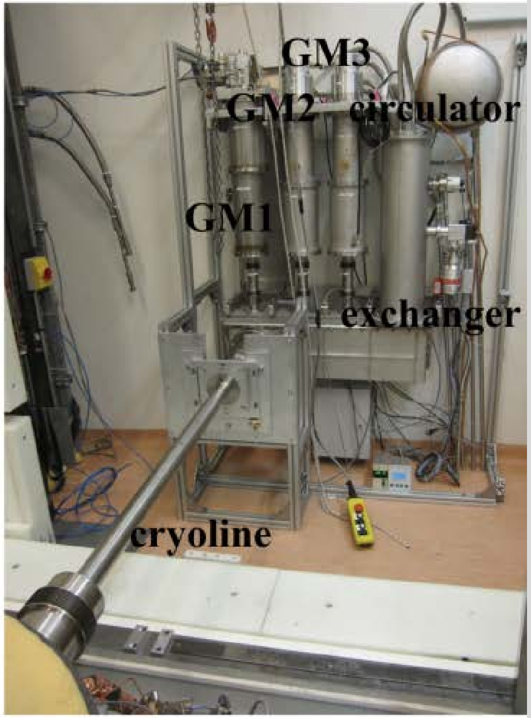
(< 6 x 10^{-5} misidentified events per kg.d, E_{rec}>20 keV)



3. Improvement on cryogenic system



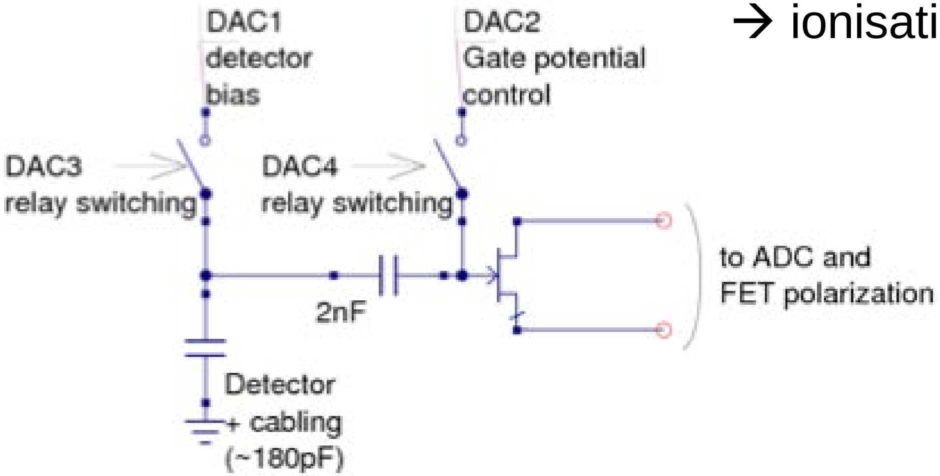
- remove pulse tubes close to cryostat to reduce noise due to microphonics
- replaced by thermal machines outside the Pb & PE shieldings
- cold distributed to thermal shields using cryogenic fluids (cryoline)



4. Improvement on electronics/DAQ

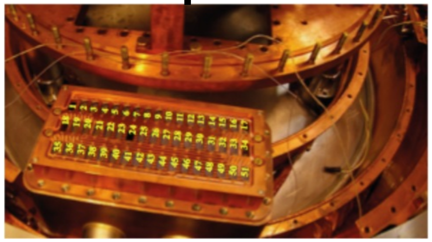
- new FE electronics

new FET boxes @100K:
no active feedback, but relays
→ lower noise level
→ ionisation signals: step fctn.

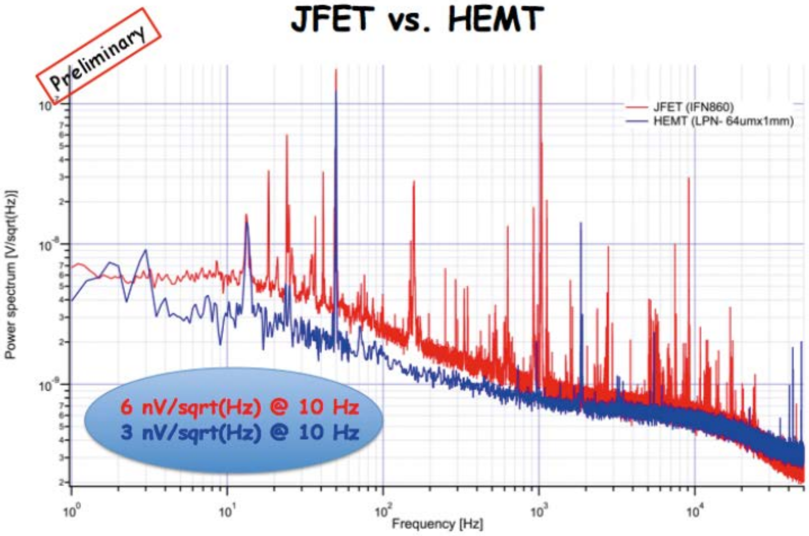


High Electron Mobility Transistor (HEMT)
→ low temperature
→ low noise, low power

HARD - **HEMT Amplifier Research & Development**
(funded @ CEA&CSNSM)

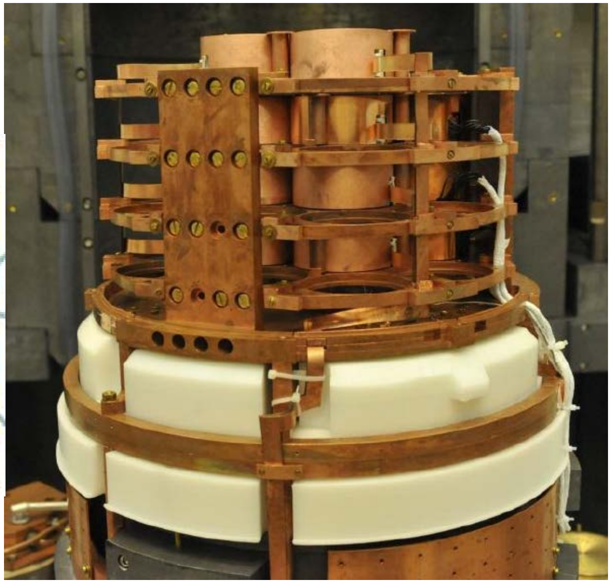


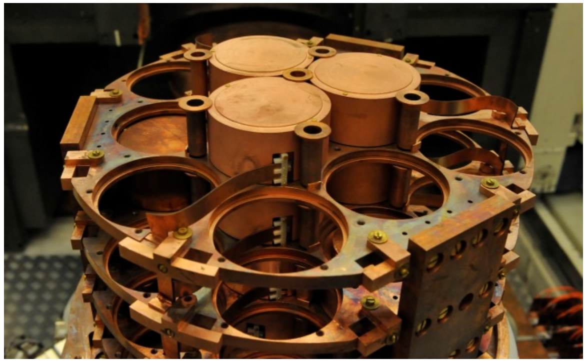
connector to HEMT @1K



4. Improvement on electronics/DAQ

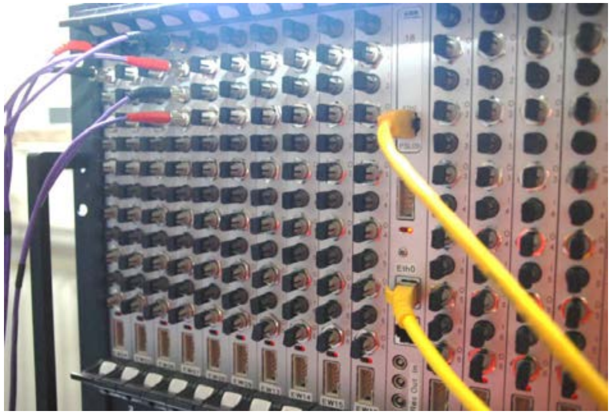
- new Kapton cables





10mK: Cu (18µm)
10mK→1K: stainl. steel (25µm)

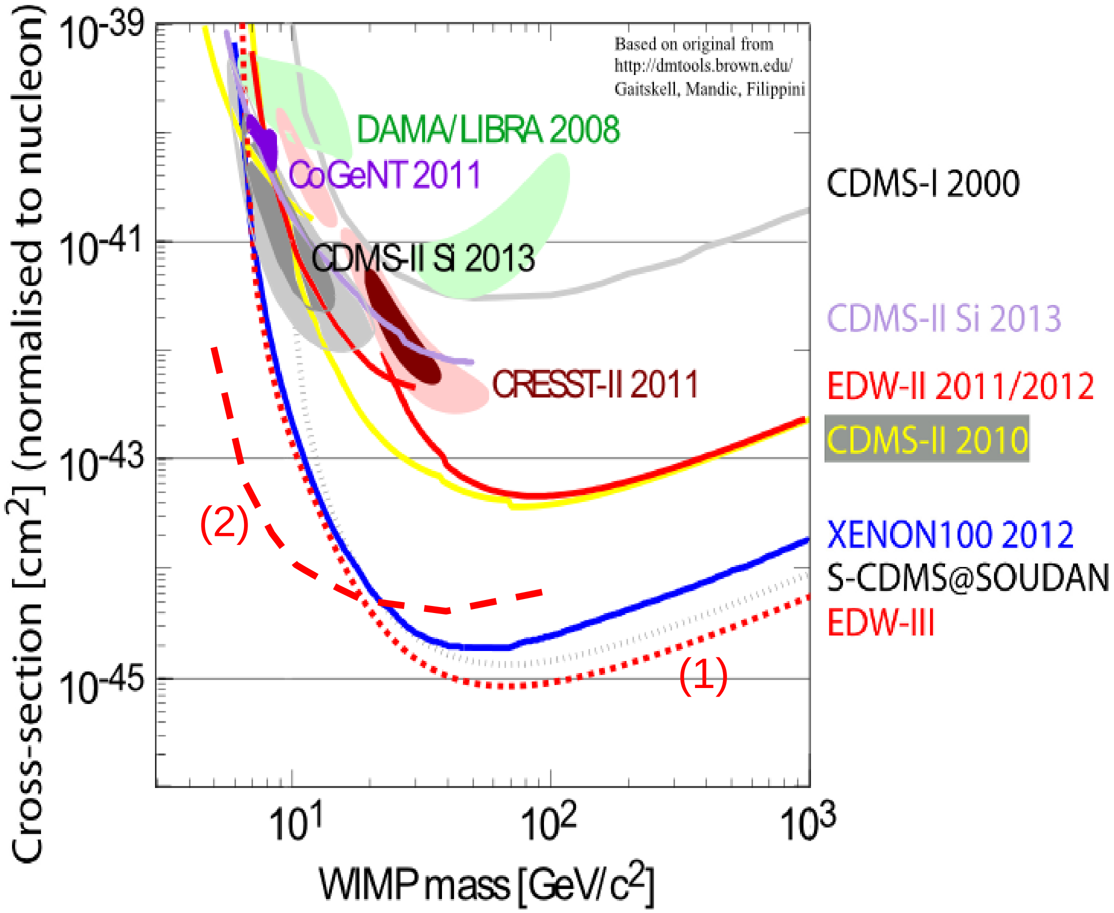
- new integrated DAQ system



- ➢ handling up to 60 bolometers
- ➢ integrates muon veto system
- ➢ FE trigger implemented
- ➢ control of FIC readout
- ➢ streaming or event mode
- ➢ controlled by SAMBA(EDW) or ORCA

Timeline/Projection EDELWEISS-III

- Oct. 2013 (now)
  - **EDELWEISS-III commissioning runs**
  - upgraded cryogenics
  - 15 FID 800g detectors
  - upgraded readout electr + Kapton cables
  - inner PE shield + new Cu screens
- early 2014
  - fully equipped cryostat with 40 FID 800g detectors



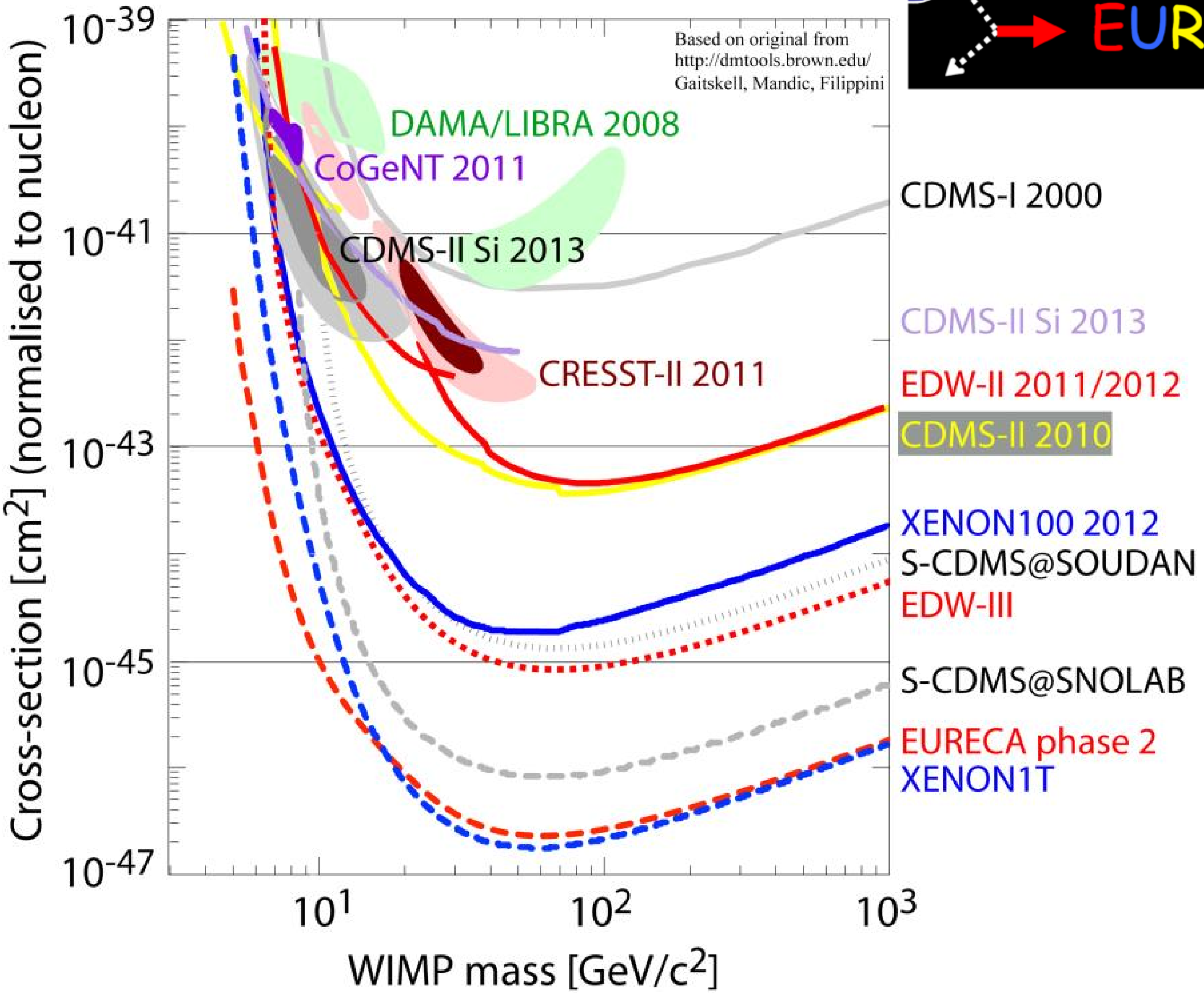
(1) ‚Standard' WIMP: 12000 kgd, E_R>15keV, no event

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

conclusion & outlook (I)

- EDW-I → EDW-II factor 20 improvement
- EDW-II: 10 ID Ge bolometers m_{det} = 400g; m_{fid} = 160g ➔ 1.6kg_{fid}
    - 20-200keV: 5 evts, <5.1 bgd (dominated by ambient n´s)
    - 5- 20keV: 1-3 evts, <3 bgd (1.7 n´s + 1.2 γ´s)
- EDW-III: 40 FID Ge bolometers m_{det} = 800g; m_{fid} = 600g ➔ 24kg_{fid}
    - upgrade of inner cryostat, new internal shield
    - upgrade of cabling and electronics
    - reduction of bgd (gammas: 2-6; neutrons >10)
- EDW-III 3.000 kgd_{fid} exposure in 6 months (no bgd expected)
- EDW-III ultimate goal: 12.000 kgd_{fid} exposure
- FID detector technology ready for 1-ton cryogenic array

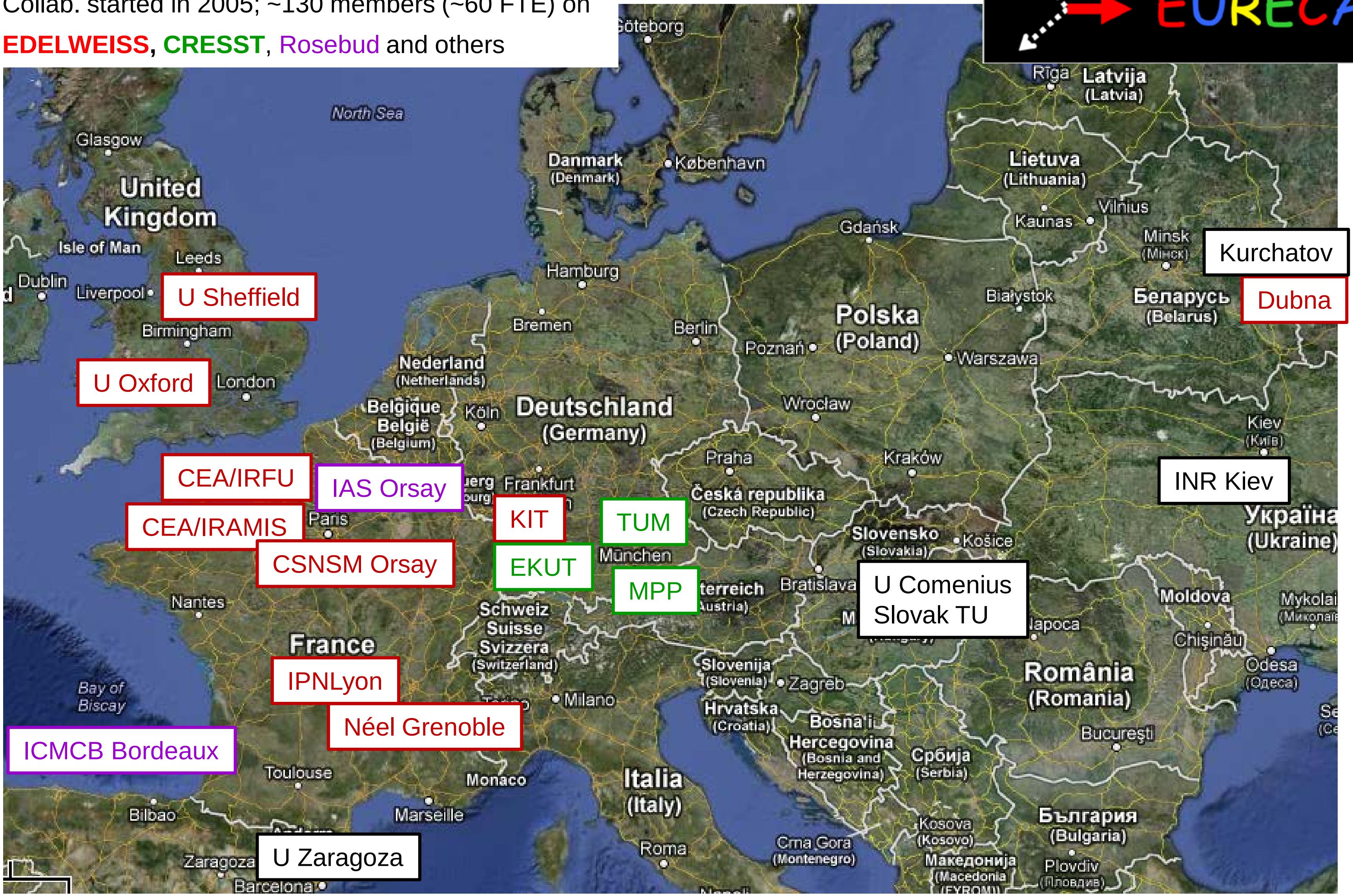
Beyond EDELWEISS-III → EUREKA



EURECA collaboration

Collab. started in 2005; ~130 members (~60 FTE) on

EDELWEISS, **CRESST**, Rosebud and others



EURECA Conceptual Design Report 2012

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https://dl.dropbox.com/u/58745013/EURECA-CDR-final.pdf

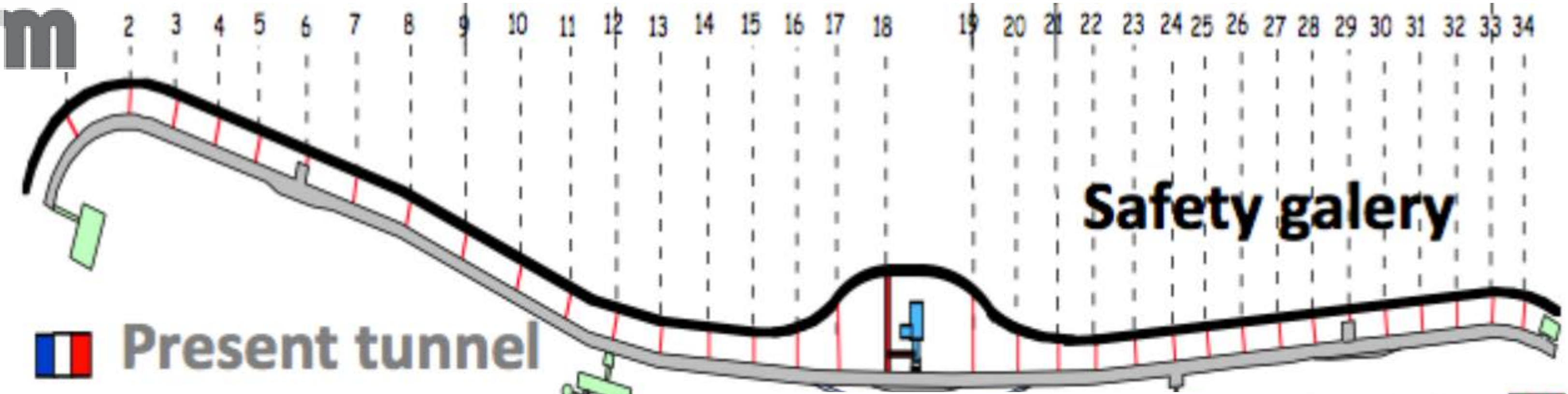
80+ pages document:

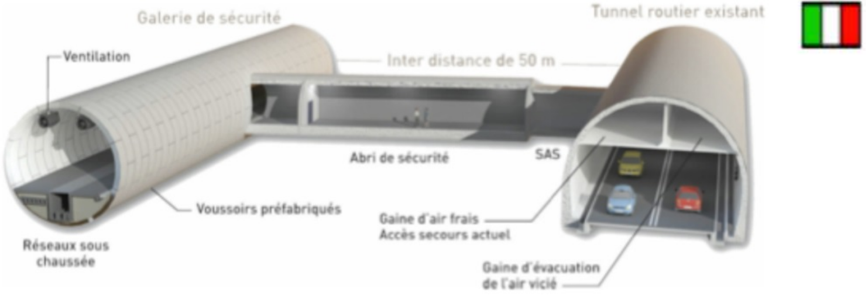
- summary of developed concept
- overview of key numbers
- sketch the line of developments

- consolidate knowhow
- form base for refinements
- 1st step towards TDR

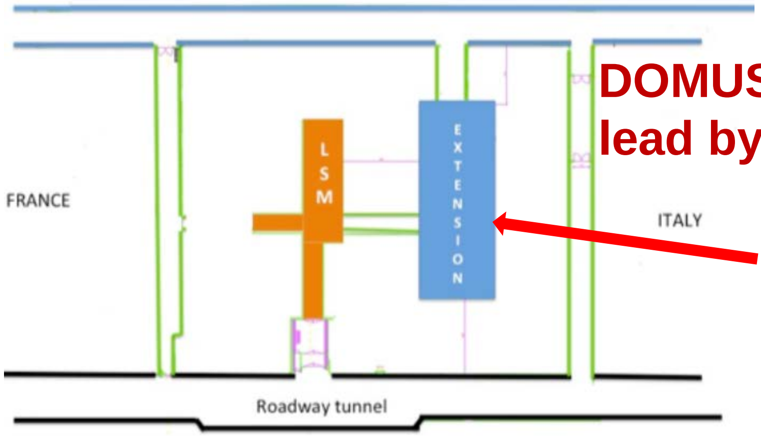
EURECA “baseline” site: DOMUS@LSM

Fréjus tunnel: 12870m; safety gallery decided in 2006





funded extension scheme

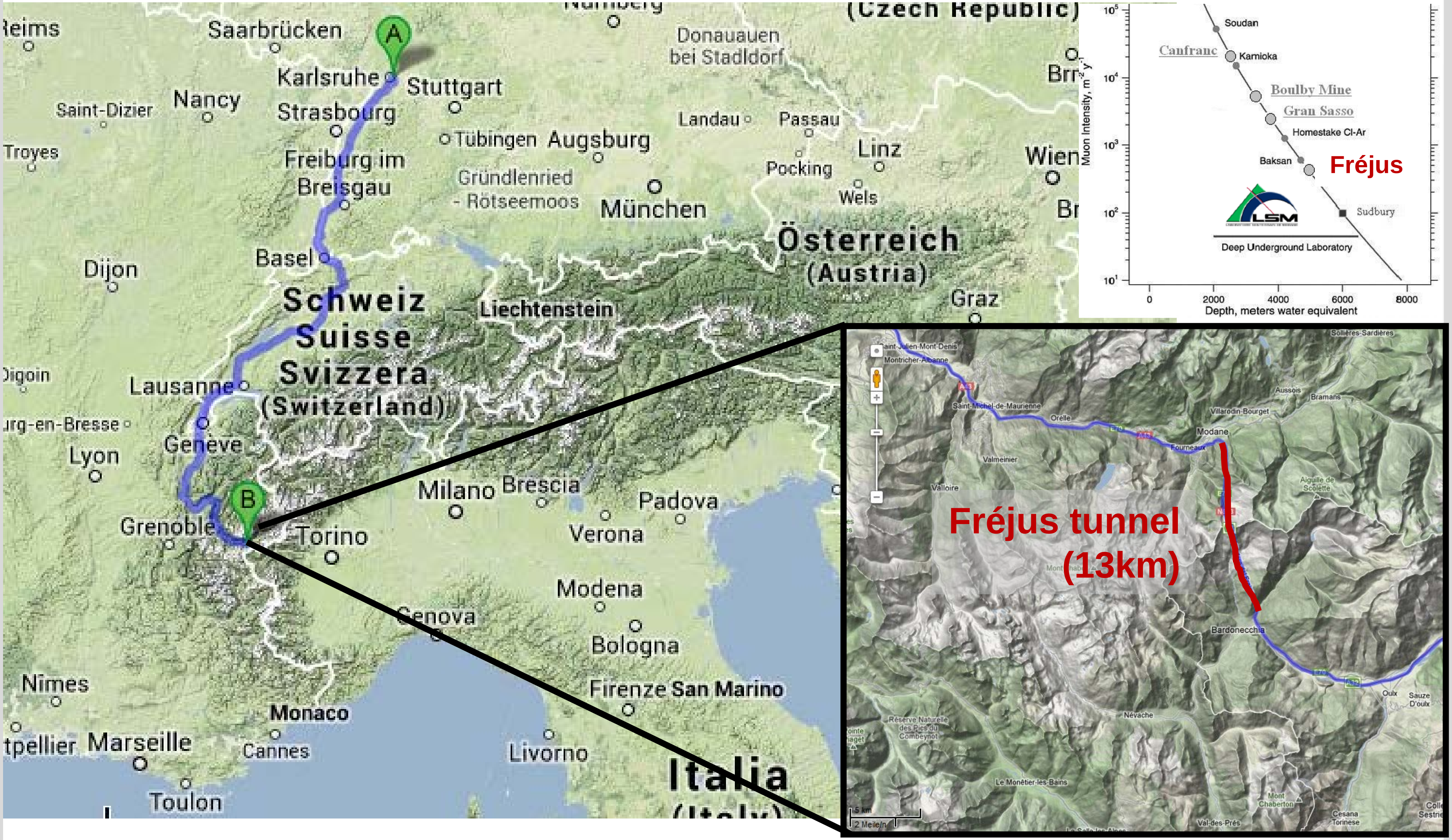


DOMUS project lead by CNRS

length: 40m
width: 19m
height: 16m
volume: 12.000 m^3

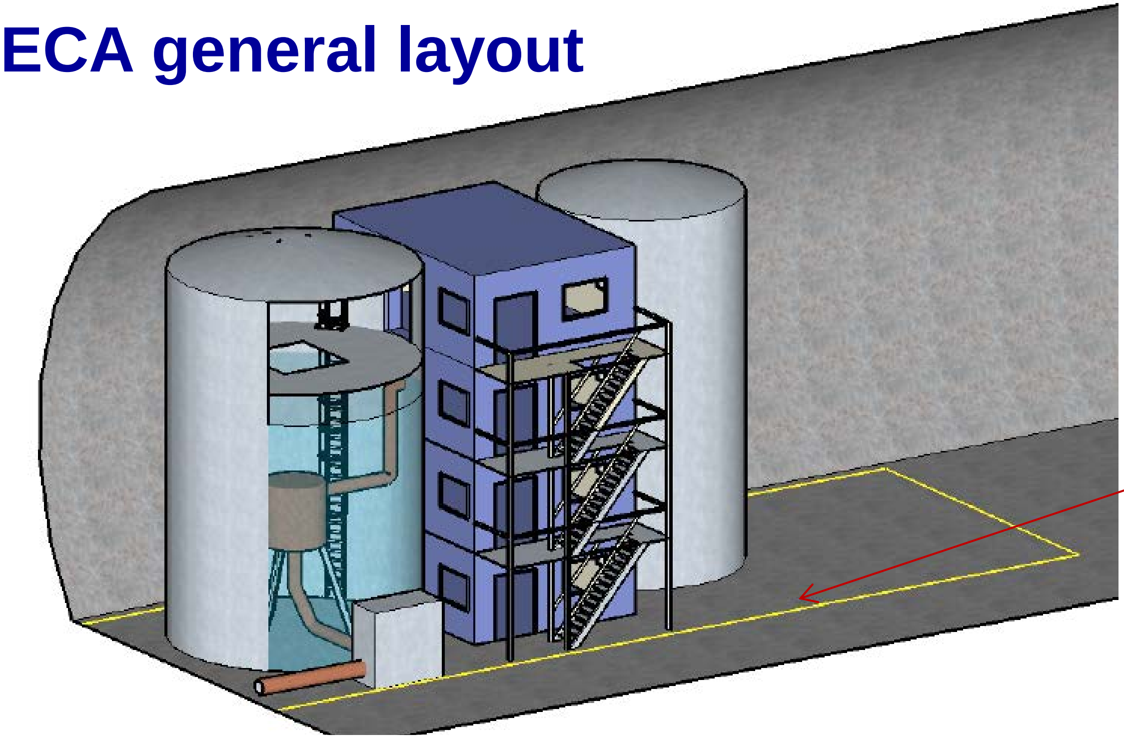
digging early 14 or end 15
6m excavation
10m outfitting
ready by 2016/2017
(F. Piquemal, TAUP13)

Laboratoire Souterrain de Modane (LSM)



4800 m.w.e.

EURECA general layout



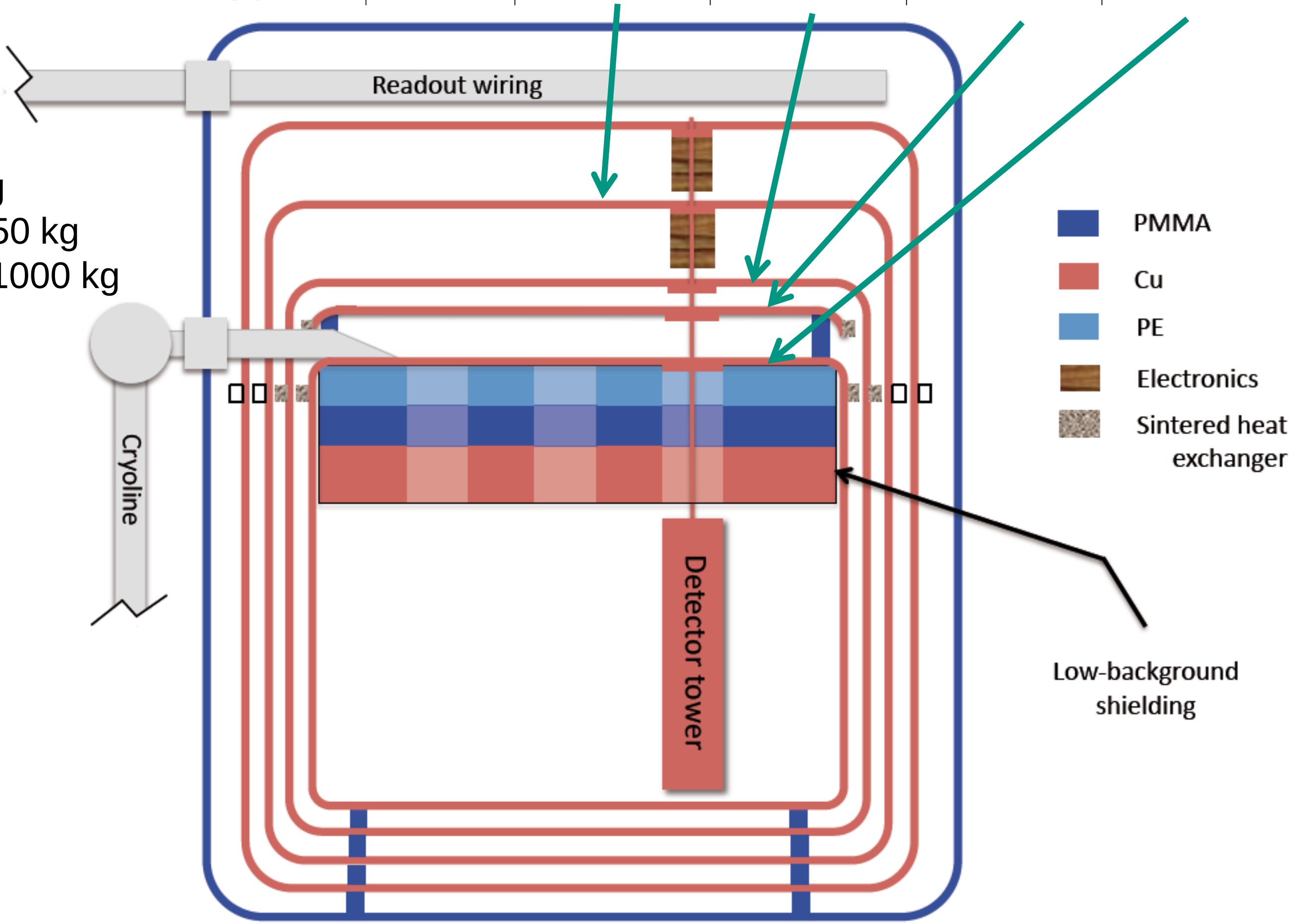
existing LSM surface

Infrastructure	Baseline option
	Space
EURECA volume	10×24-m footprint × 12-m height
Cryostat	2-m diameter × 2-m height
Water shield tank	8-m diameter × 12-m height
Water buffer	6.5-m diameter × 12-m height
Man tower	6×8-m footprint × 12-m height, 3 or 4 storeys
Cleanroom suite	48-m^2 footprint × 3-m height
Cryogenics	6×5-m footprint × 3-m height

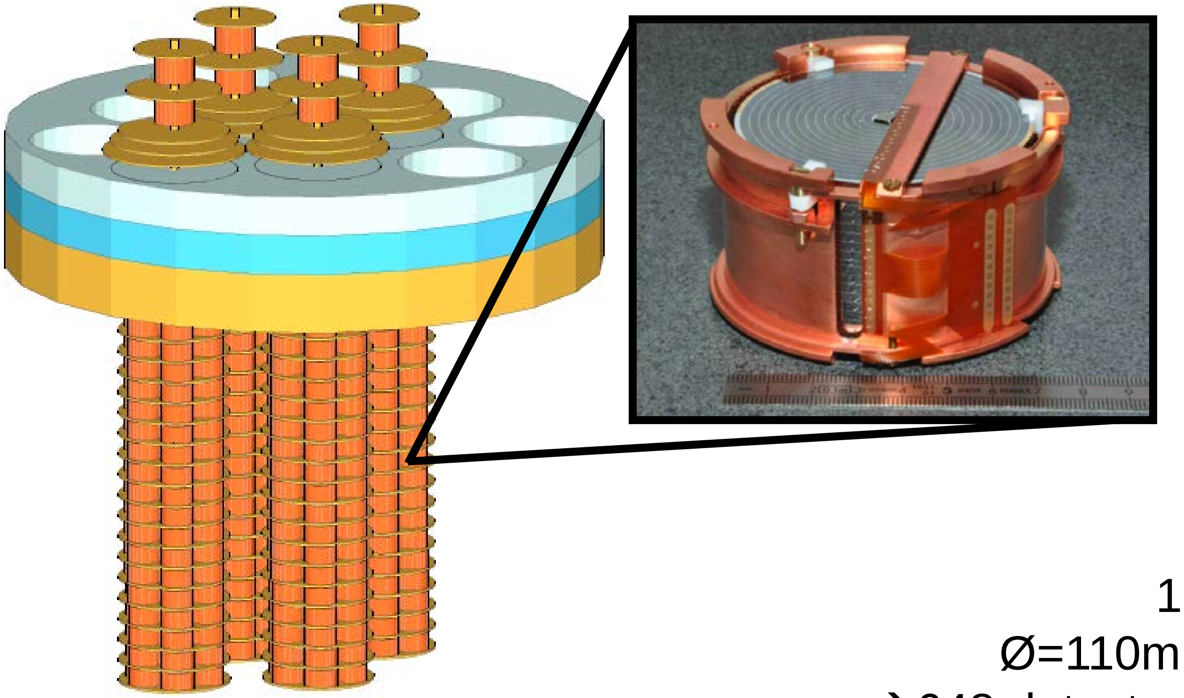
EURECA cryogenics

Stage	60 K	1.8 K	500 mK	50 mK	10 mK
Flow	5 mol/s ^{4}He	0.13 mol/s ^{4}He	10 mmol/s ^{3}He	10 mmol/s ^{3}He	10 mmol/s ^{3}He
Cooling power	2.2 kW	10 W	50 mW	600 μW	20 μW

- mass(Cu) ~ 2035 kg
- mass (PMMA) ~ 1650 kg
- mass (detectors) ~ 1000 kg



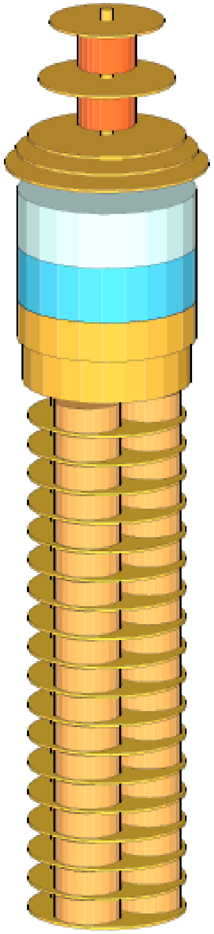
EURECA detector towers



12 towers with Ø=280mm tray
tower spacing: d=360mm

tower of 18x6 casings with
Ø=86mm; h=48mm
→1296 detectors **800g-Ge**

(or 2160 detectors **300g-CaWO$_4$**)

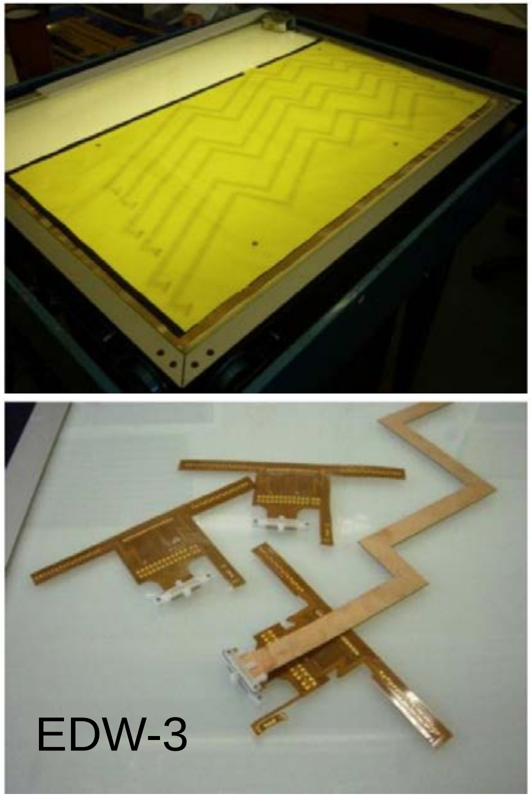


alternative:
tower of
18x3 casings
Ø=110mm; h=48mm
→648 detectors **1600g-Ge**

2013 ongoing study:

a) technical design of a tower
b) cabling & frontend electr.
c) thermal conductance tests

EURECA cabling (from EDW-3)



In-house made etched metal foil cabling

Advantages:

- can be used at <10mK
- with reliable connectors
- controlled materials
- can be made internally
- control over the process
- cheaper than external work
- low material and space budget
- individual design for each detector/module position

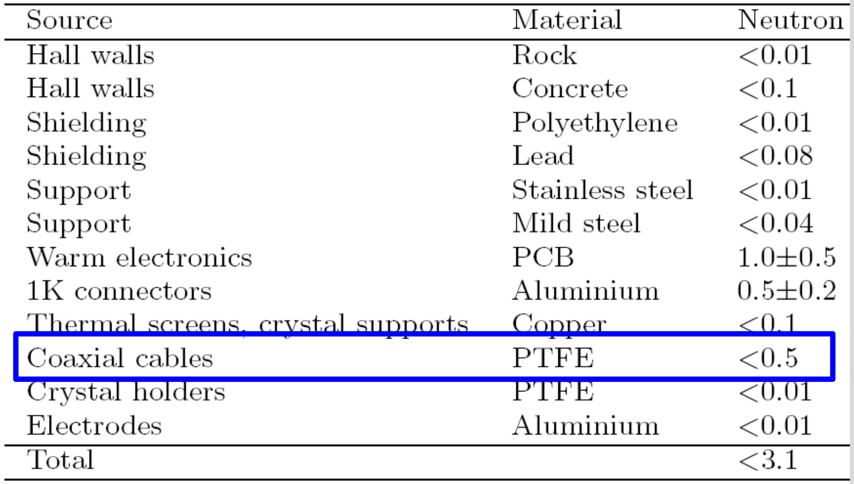
solution to requirements on

low-background

heatload

From	To	Length	’000 wires	Heatload
300 K	100 K	0.4 m	36	7.8 W
100 K	2 K	0.2 m	26	1.5 W
2 K	0.5 K	0.1 m	16	1.5 mW
0.5 K	0.05 K	0.2 m	16	29.0 μW
0.05 K	0.01 K	0.1 m	16	0.5 μW

CDR, table 15



Source	Material	Neutron
Hall walls	Rock	<0.01
Hall walls	Concrete	<0.1
Shielding	Polyethylene	<0.01
Shielding	Lead	<0.08
Support	Stainless steel	<0.01
Support	Mild steel	<0.04
Warm electronics	PCB	1.0±0.5
1K connectors	Aluminium	0.5±0.2
Thermal screens, crystal supports	Copper	<0.1
Coaxial cables	PTFE	<0.5
Crystal holders	PTFE	<0.01
Electrodes	Aluminium	<0.01
Total		<3.1

EDW-2 neutron bgd budget

EURECA ongoing studies

validation of the heat exchanger design

test Ag granulates (inframat advanced materials)

1. 47MR-21S, 0.4-1 µm average size
2. 47MR-10F flake, 2-4 µm average size
3. 47MR-32G w/ average particle size 20-50 µm

for HX in terms of

- handling/sintering → to be sintered at CEA Saclay
- porosity/Kapitza resistance → to be tested in Grenoble
- radioactivity → specimen measured at LSM:

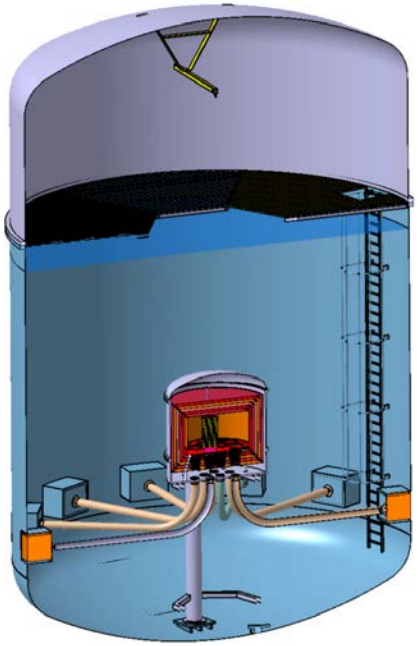
specimen	^{108}Ag	^{110}Ag	^{226}Ra	^{210}Pb	^{234}Th	^{228}Ra	^{228}Th	^{40}K	^{137}Cs	^{60}Co	others
47MR-21S	7.5 ± 2.1	26 ± 4	11 ± 4	<800	< 100	<10	5 ± 3	18 ± 10	< 5	<5	
47MR-10F	32 ± 2	29 ± 3	8 ± 3	< 600	< 100	< 10	11 ± 2	14 ± 10	< 5	< 5	^{235}U =49 ± 18
47MR-32G	34 ± 3	17 ± 3	13 ± 2	750 ± 565	< 60	< 10	4 ± 2	< 20	< 5	< 5	

mBq/kg

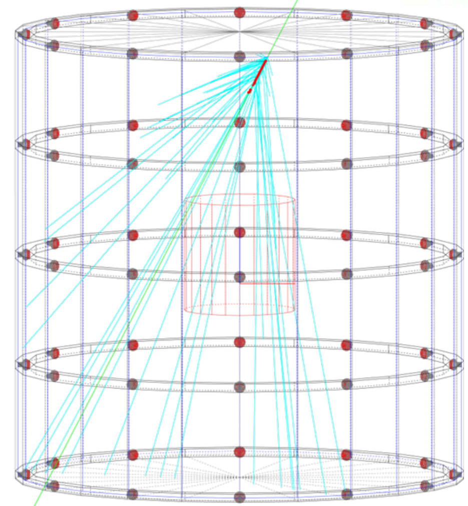
EURECA ongoing studies

Karlsruhe Institute of Technology

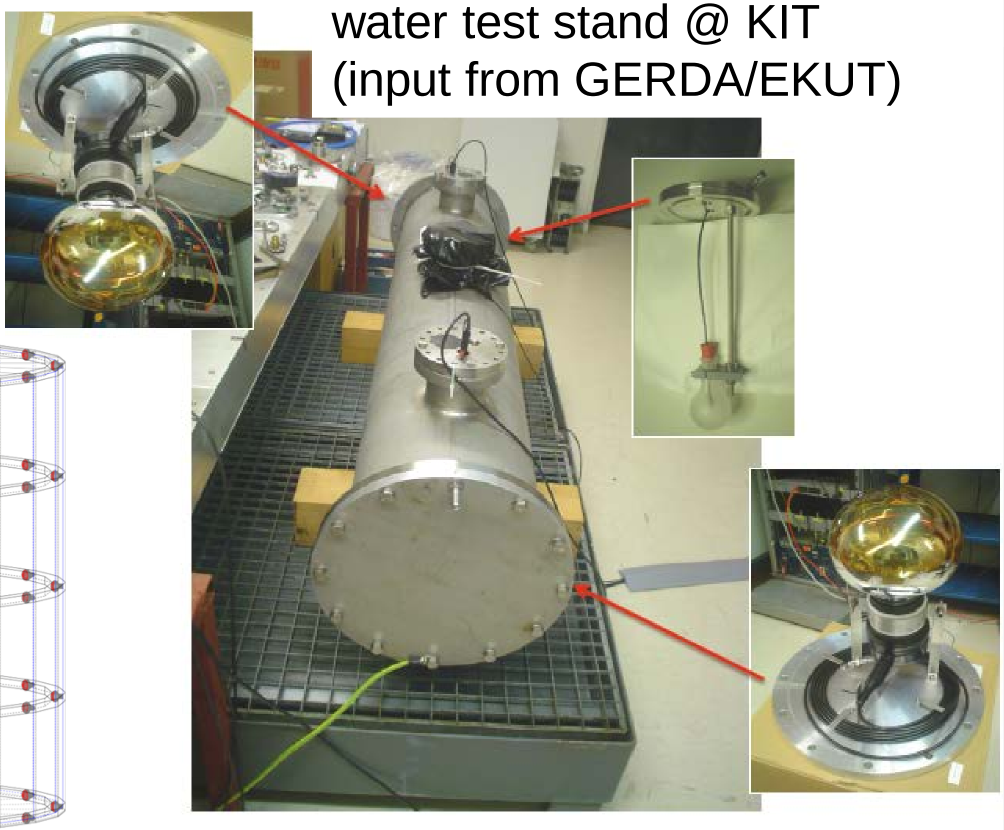
water tank as active Cerenkov veto

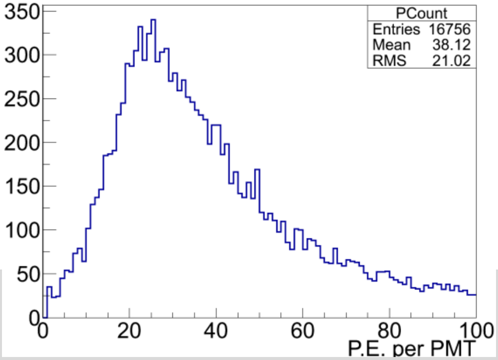


Hamamatsu R5912
8” PMTs encapsulated
(as used for Xenon1T)



water test stand @ KIT
(input from GERDA/EKUT)



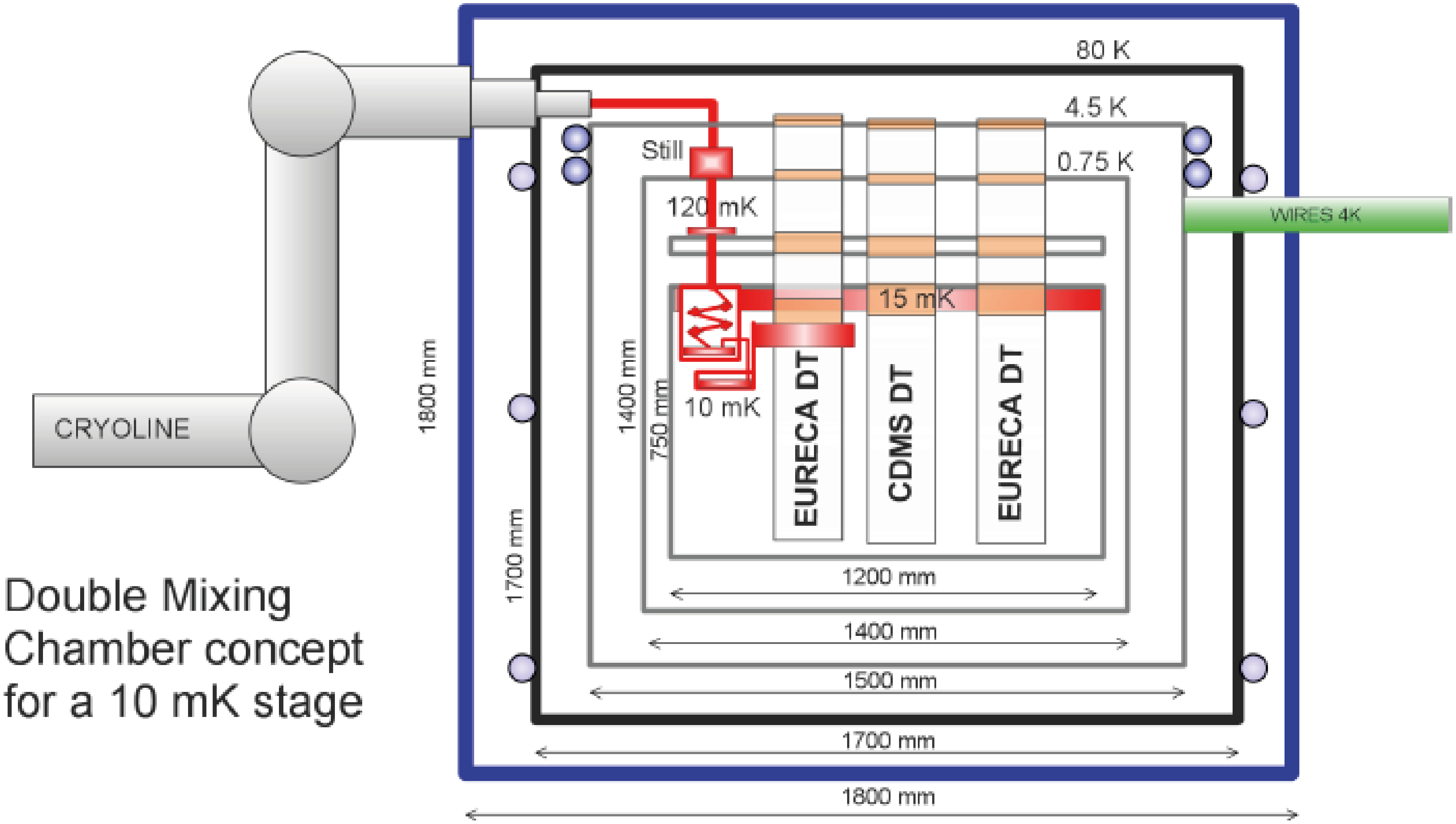


readout via
5GS/s switched capacitor
array (DRS4/PSI)
µTCA electronics

bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen
Grundlagenforschung

EURECA & SuperCDMS

cryo-design by Philippe Camus (Néel) based on mixing chambers inside shielding



Double Mixing Chamber concept for a 10 mK stage

EURECA & SuperCDMS

(in US terms: G2 DM experiment)

2011: Super-CDMS@Soudan: 10kg Ge

2012: CRESST@LNGS: 6kg CaWO4

2013: EDW-III@LSM: 30kg Ge

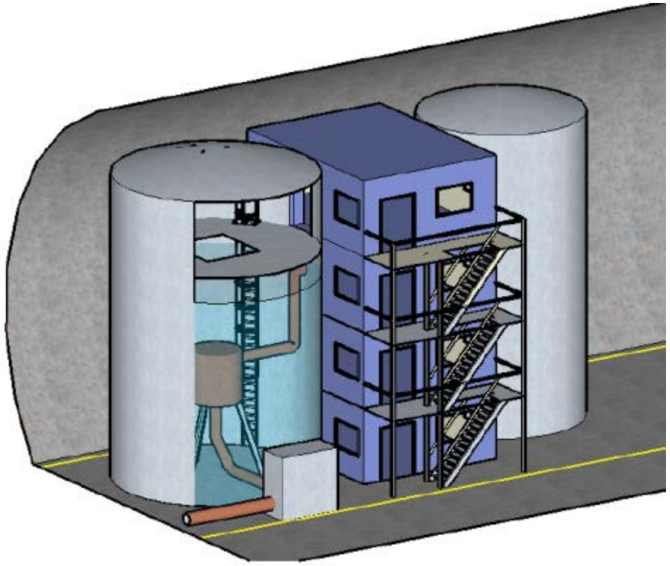
next steps: Super-CDMS@Snolab: 200kg Ge

EURECA phase 1: 150kg

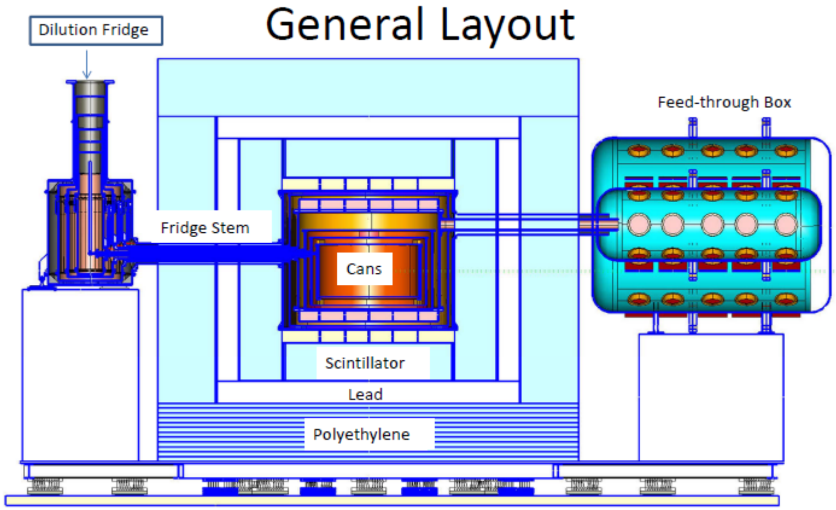
=400kg stage

EURECA phase 2: 1000kg

merge into a common next phase bolometer experiment with 2x200kg



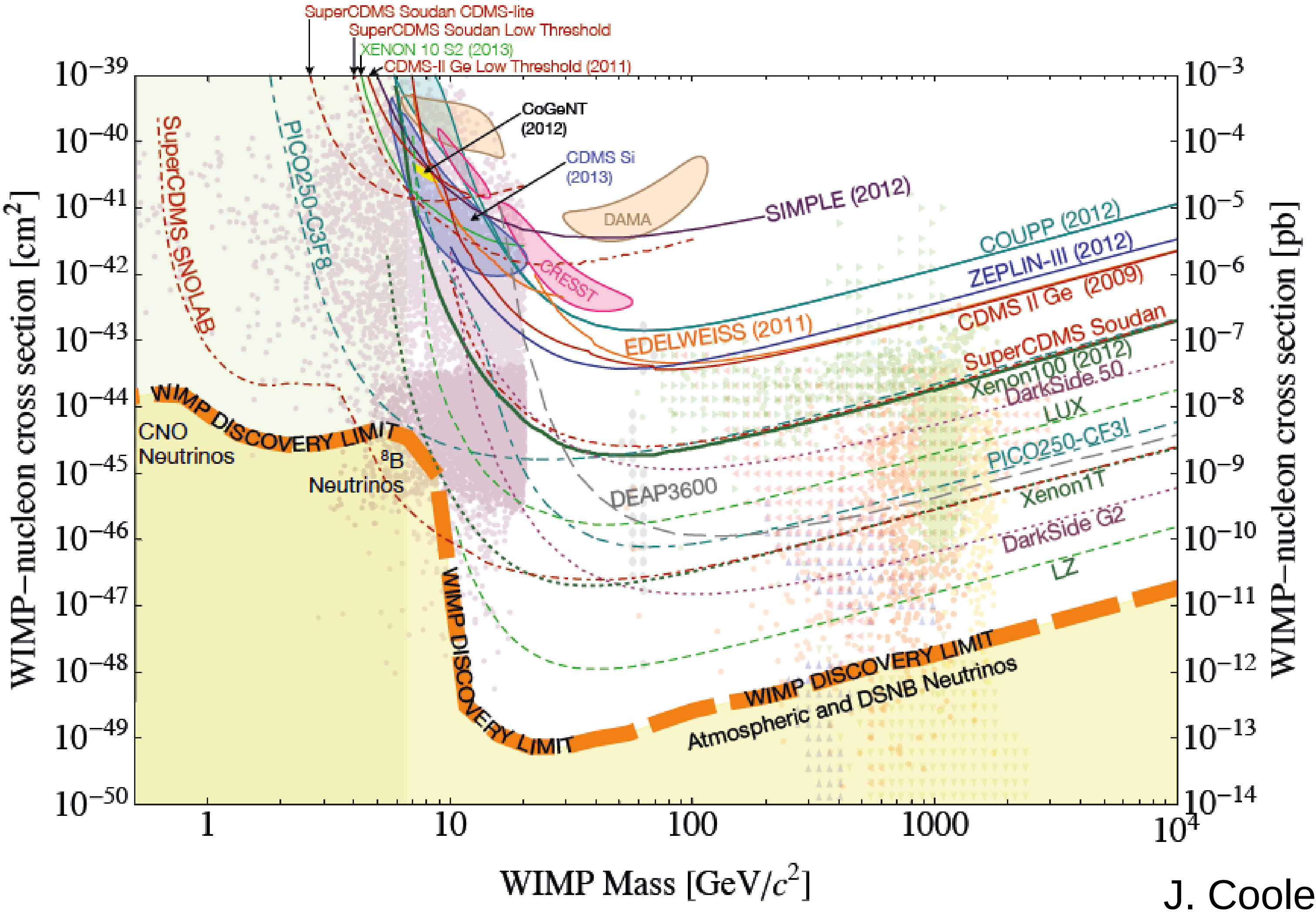
from EURECA conceptual design report (2013)



SuperCDMS design for SNOLAB

SNOWMASS 2013

Where Are We Going?



J. Cooley, TAUP13