Direct Dark Matter search with the EDELWEISS experiment

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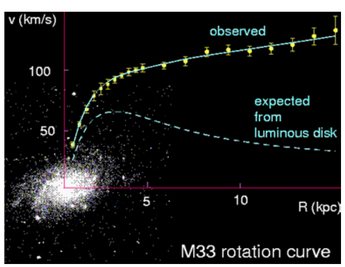
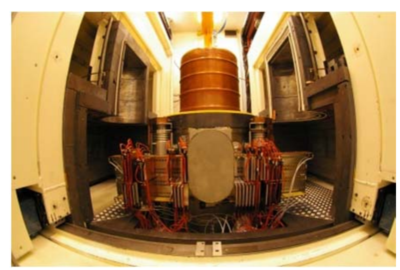
10th Patras Workshop on Axions, WIMPs and WISPs
CERN, Geneva, Switzerland, 30.6 – 4.7. 2014





Edelweiss: search for DM @ LSM (France)

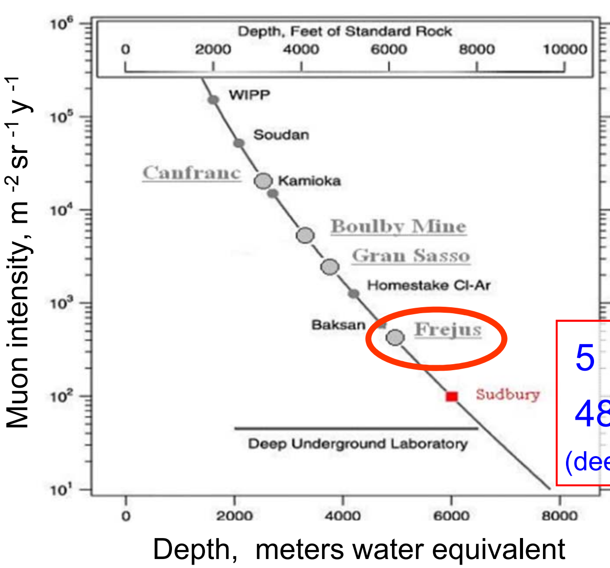
Collaboration


Collaboration meeting 9/2013 @Aussois (Fr)

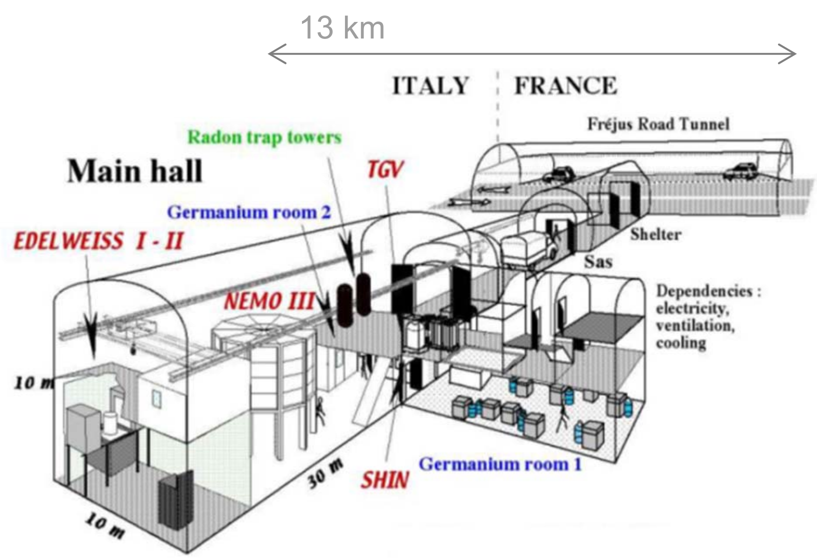
≈ 50 persons (30 FTE);
10 PhD students;
5 post-docs;
4 countries

Grenoble Lyon Orsay Saclay	Karlsruhe	Dubna	Oxford Sheffeld

LSM



5 μ/m^2/day
4800 mwe
(deepest in Europe)



Edelweiss-3 experimental set-up

Cryogenic installation (18 mK) :

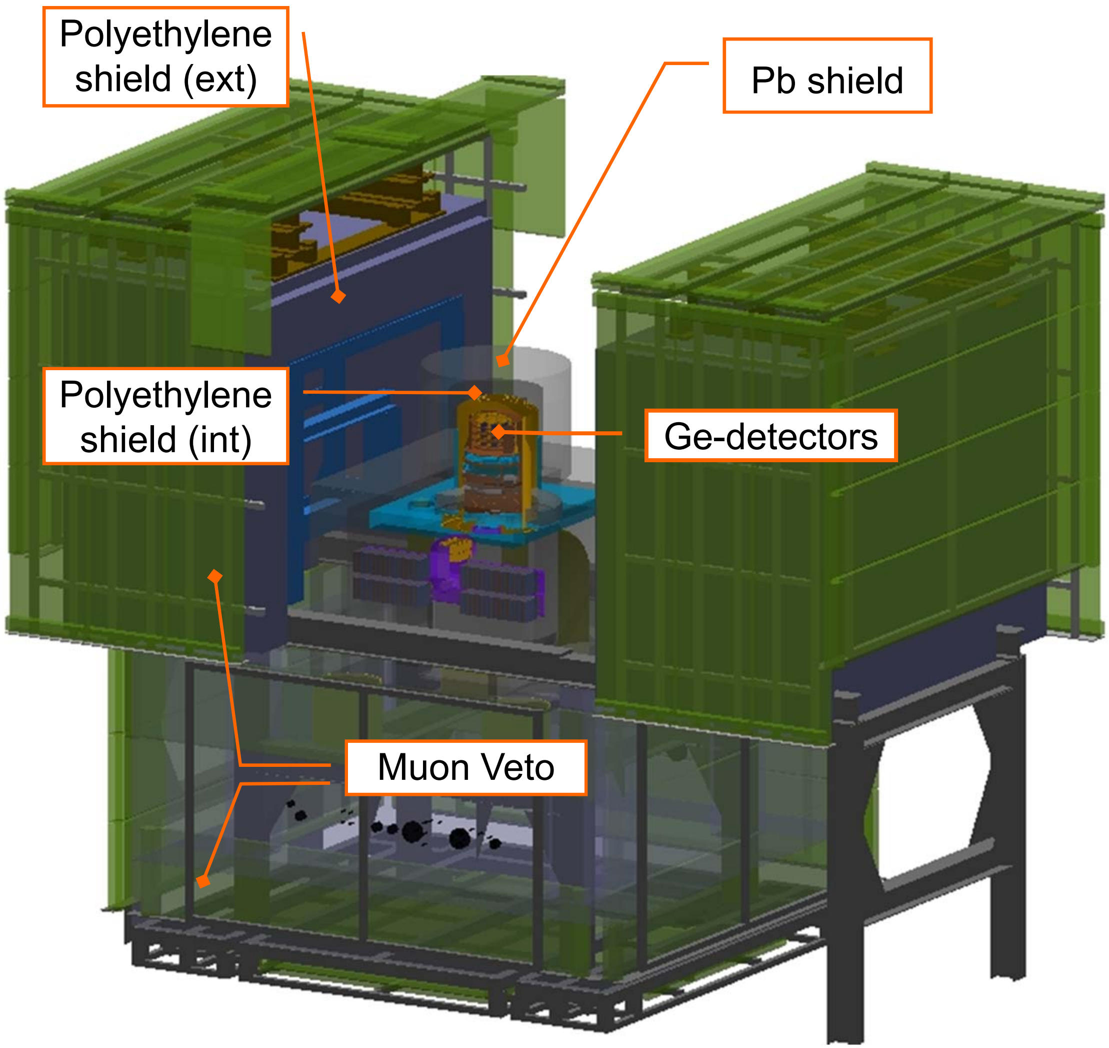
- Reversed geometry cryostat
- **Can host up to 40 kg of detectors**

Shieldings :

- Clean room + deradonized air
- Active muon veto (>98% coverage)
- **PE** shield internal + external (50cm)
- **Lead** shield **20 cm**

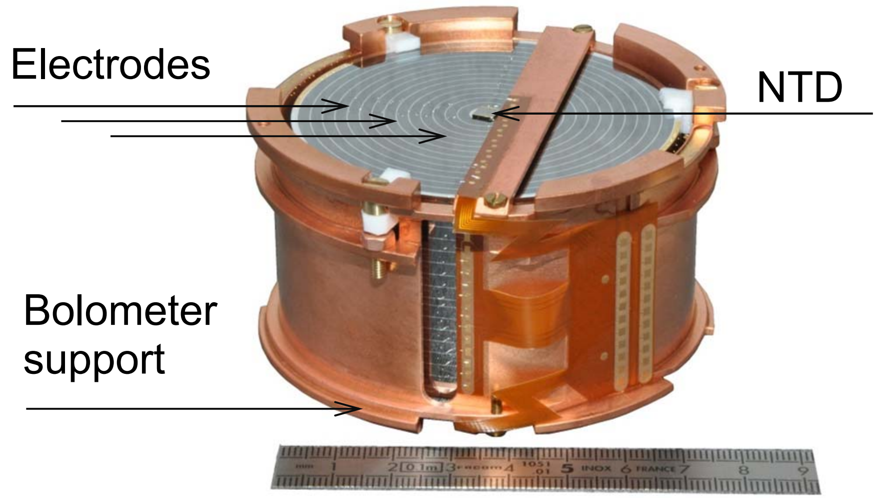
(Many) others :

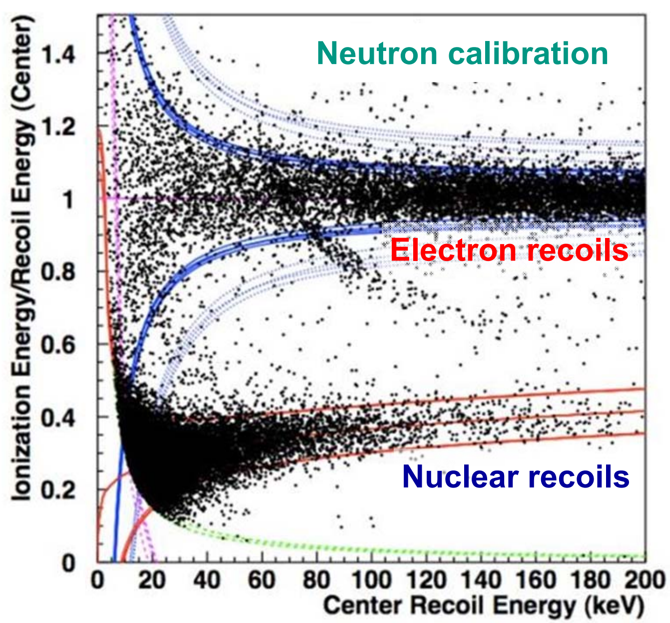
- Remotely controlled sources for calibrations + regenerations
- Radon detector down to few mBq/m^3
- thermal neutron monitoring (3He det.)
- study of muon induced neutrons (liquid scintillator 1 m^3 neutron counter)

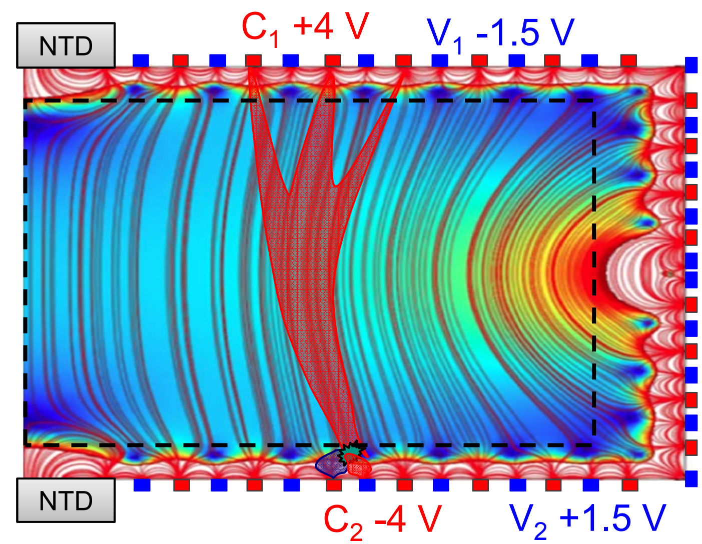


(F)ID Ge-bolometers: (Fully) InterDigitized design

- **Simultaneous measurement**
  - **Heat** @ **18 mK**
    with Ge/NTD thermometer
  - **Ionization** @ **few V/cm**
- **Evt by evt identification** of the recoil by ratio $Q=E_{ionization}/E_{recoil}$
  - **Q=1 for electron recoil**
  - **Q≈0.3 for nuclear recoil**
- **Vetoing surface events (ID electrodes)**







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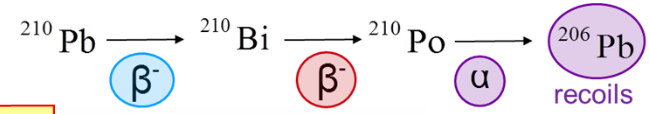
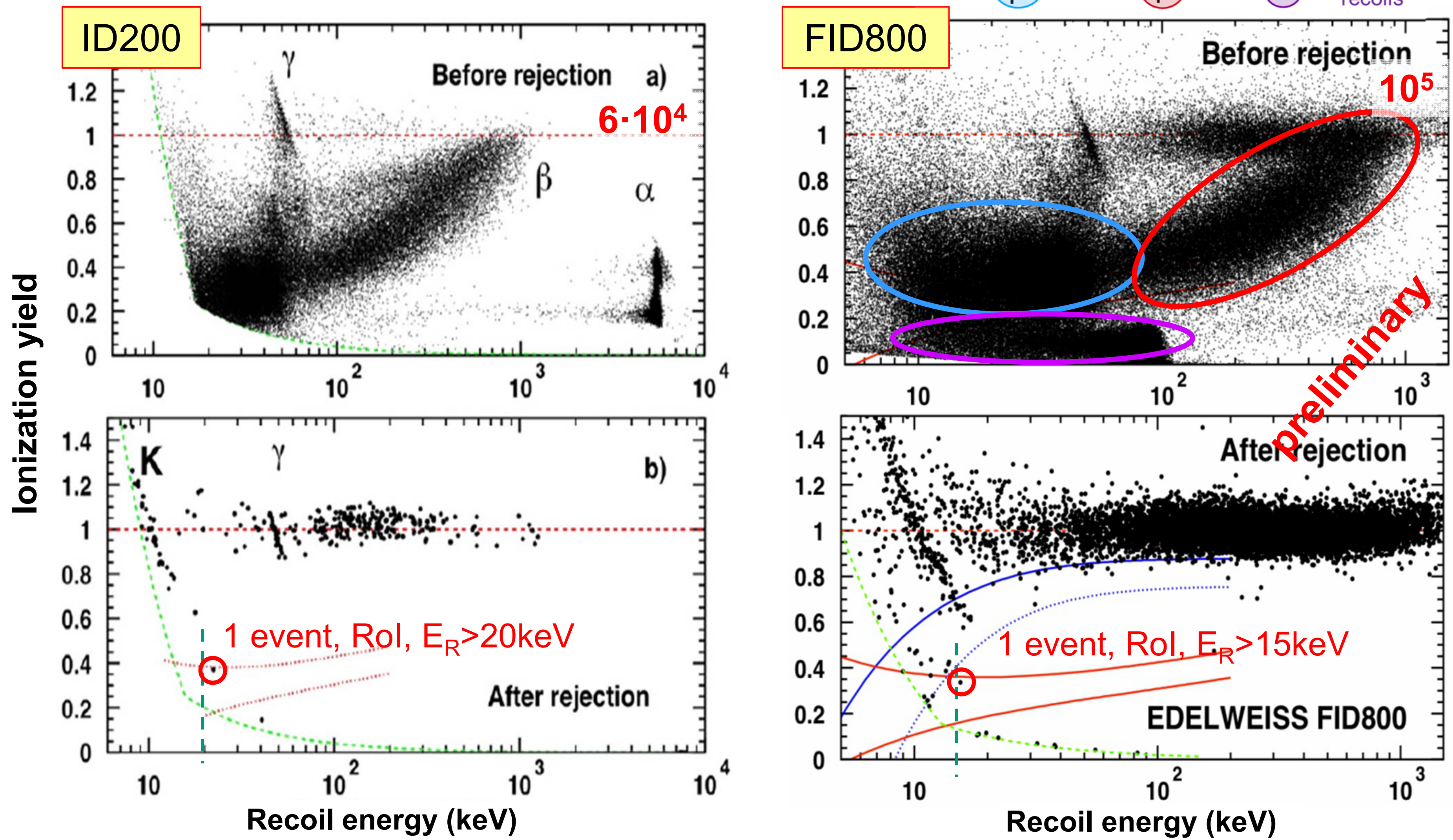
Edelweiss: surface-rejection





Surf. event rejection: ID200: $6 \cdot 10^{-5}$ (90% CL, >20 keV) → FID800: $4 \cdot 10^{-5}$ (90% CL, >15 keV)

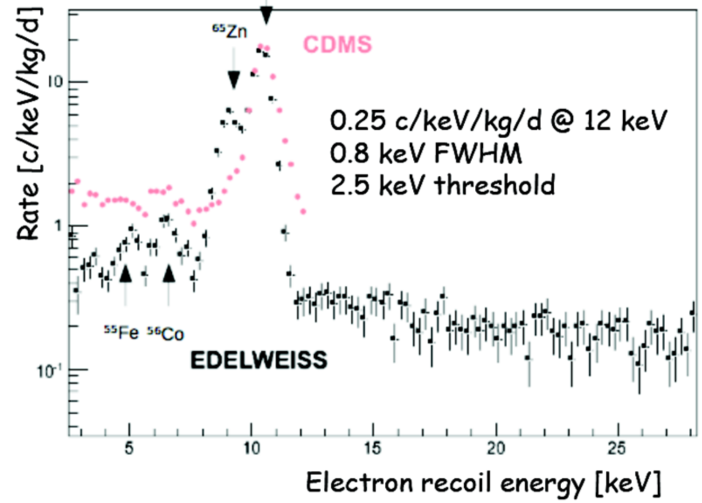
In case of no other background: $\sigma_{SI} \sim 4 \times 10^{-46}$ cm^2

Edelweiss-II reminder: Axion results

- **Axions** generate **electron recoils**
- Capability to **select electron recoils**
- **Reject Surface events**

→ **Good electron Background** down to **2.5 keV**

- Homogenous data set of **450 kg.d** with good baseline resolutions



Production in the Sun

(1) Primakoff effect

$$\gamma \rightarrow A$$

(2) ^{57}Fe NM transition

$$^{57}\mathrm{Fe}^{*} \rightarrow {}^{57}\mathrm{Fe} + A$$

(3) Axio-recombination

$$e^{-} + \mathrm{I} \rightarrow \mathrm{I}^{-} + A$$

Bremsstrahlung

$$e^{-} \rightarrow e^{-} + A$$

Compton

$$e^{-} + \gamma \rightarrow e^{-} + A$$

Axio-deexcitation

$$\mathrm{I}^{*} \rightarrow \mathrm{I} + A$$

(4) Dark Matter Galactic Halo

Source

$g_{A\gamma}$ | g_{AN}^{eff} | g_{Ae}

Detection

14.4keV

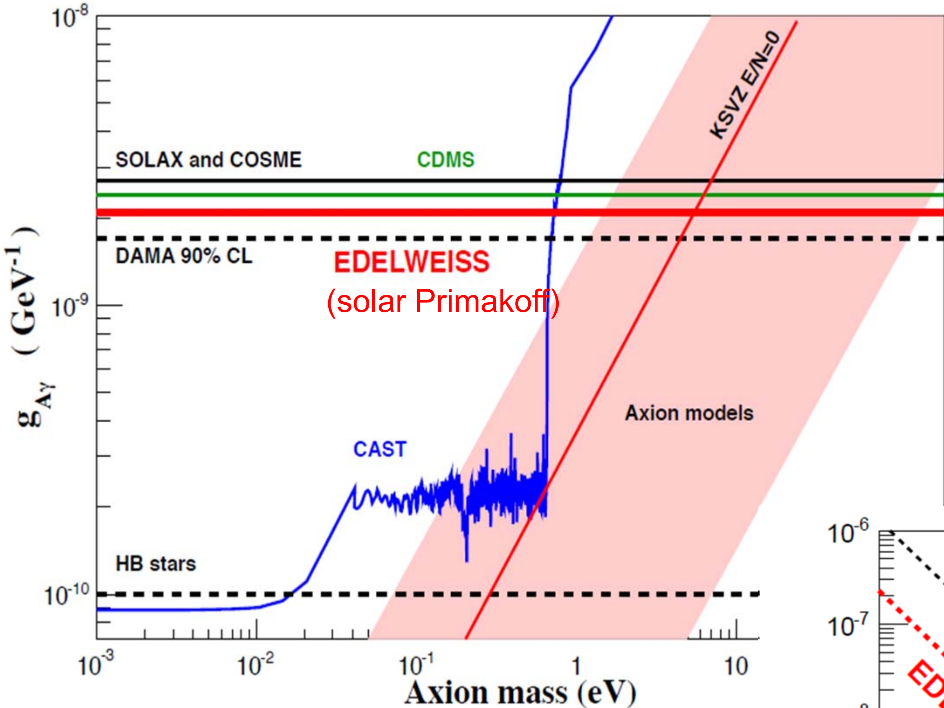
Primakoff effect — $g_{A\gamma}$

Axio-electric effect — g_{Ae}

Limits

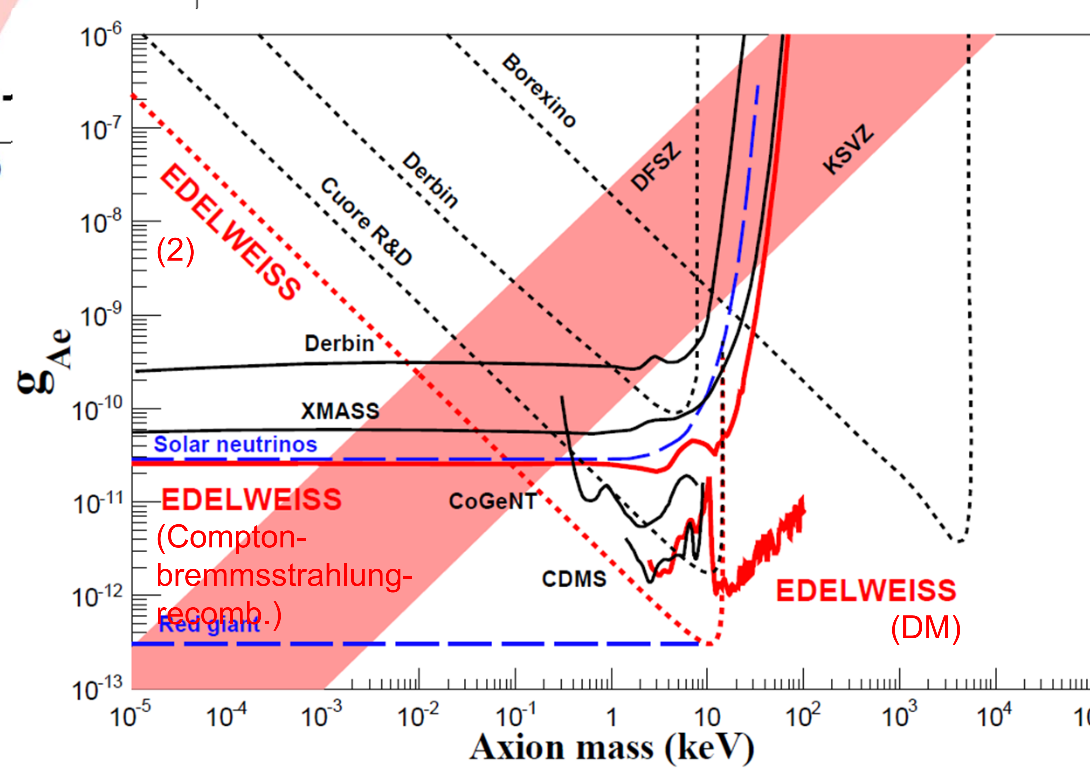
$g_{A\gamma}$	$g_{Ae} \times g_{AN}^{eff}$	g_{Ae}	g_{Ae}
$< 2.13\times10^{-9}$	$< 4.70\times10^{-17}$	$< 2.56\times10^{-11}$	$< 1.05\times10^{-12}\,\mathrm{GeV}^{-1}$
(95% CL)	(90% CL)	(90% CL)	(90% CL)

Edelweiss-II reminder: Axion results



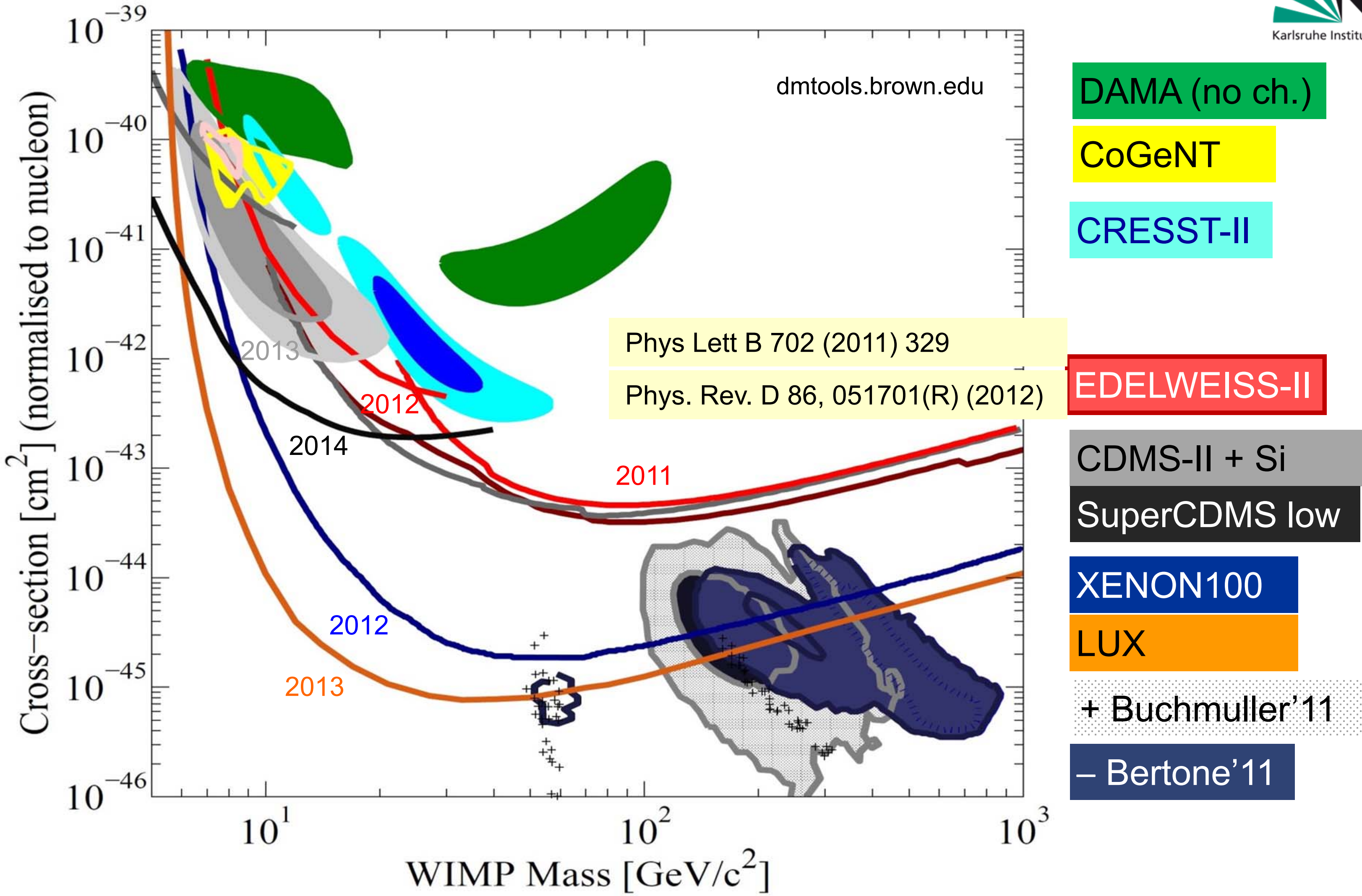
Competitive axion limits (Primakoff, axio-electric, solar or dark matter scenarios with axion like particles)

JCAP11 (2013) 067



(2) – from constraints on $g_{Ae} \times g^{eff}_{AN}$ by assuming that g^{eff}_{AN} follows DFSZ model

Edelweiss-II reminder: WIMP search 2009-2010



Edelweiss-II (384kg.d, 1.6 kg fid.mass) →

Mostly limited both by n's (<3.1)

And misidentified gammas (<0.9)

Edelweiss-III (22 kg fid.mass)

up to **x100** improve (material screening + internal PE)

ca. **x10** improve (material screening + new FID800)

Edelweiss-III: Goals and improvements

Karlsruhe Institute of Technology

Astropart. phys. 47 (2013) 1

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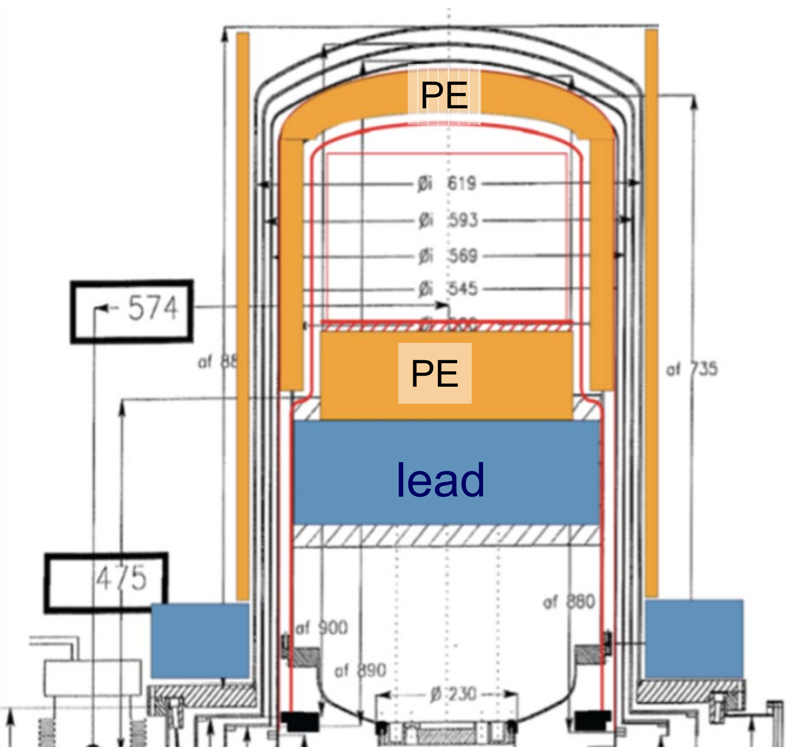
Simulations + measurements

Background (20 – 200 keV)	EDW-2 (evt / kg.d)	EDW-3 (evt / kg.d)	Improvement
Gamma rate	82	14 – 44	up to 6
Ambient neutrons	$< 8.1 \cdot 10^{-3}$	$(0.8 – 1.9) \cdot 10^{-4}$	up to 100
Muon-induced neutrons	$< 2 \cdot 10^{-3}$	$< 2 \cdot 10^{-4}$	up to 10



- Goal: 10^{-45} cm^2 with 36 FID800 (22 kg fiducial)
- Improved material selection
- Extra internal PE shield:
  - ca.10 cm below bolometers
  - ca. 5 cm on a side and top
- upgrades of muon veto, cabling, thermal screens
- Cryogenics (reduce microphonic noise)
- Modify electronics and DAQ (scalability): 240 channels + auxiliary detectors
- New event-based readout
- More analysis tools: Kdata: ROOT-based, multi-tier, db, …

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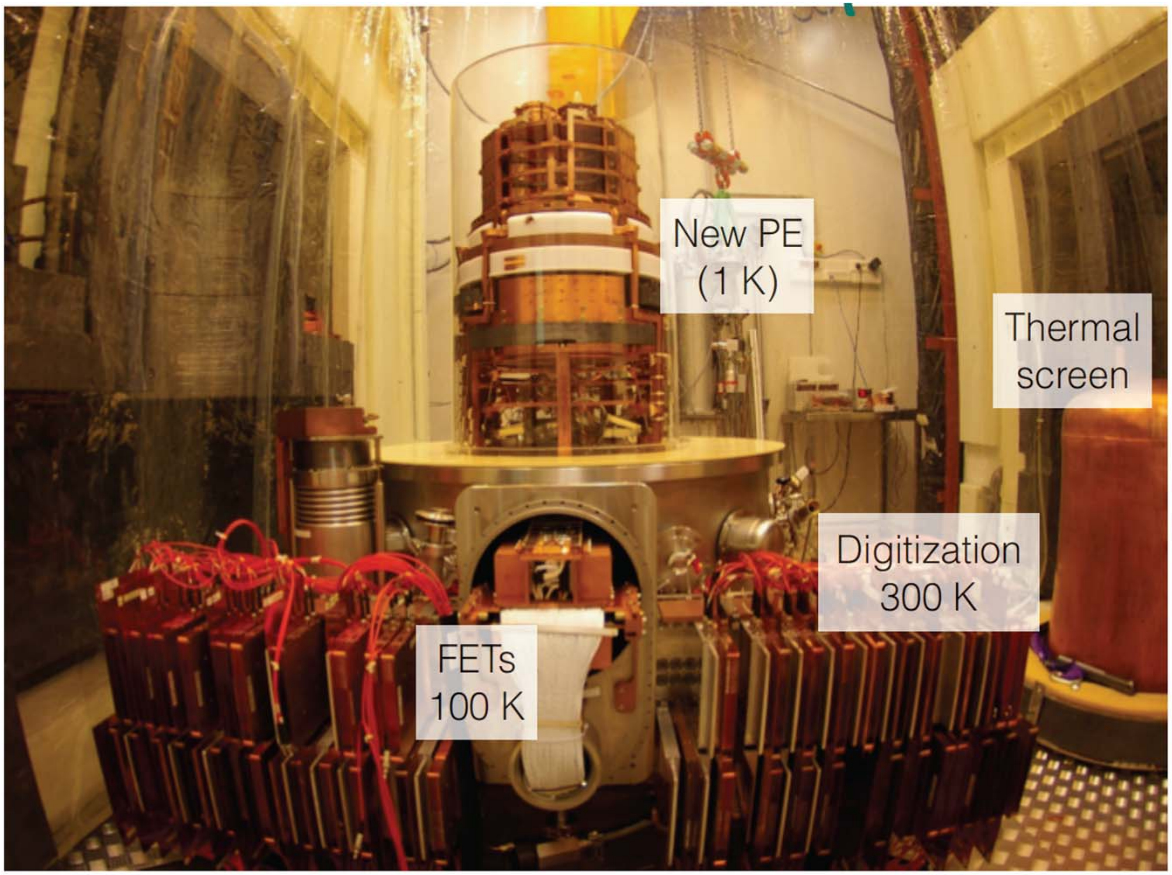
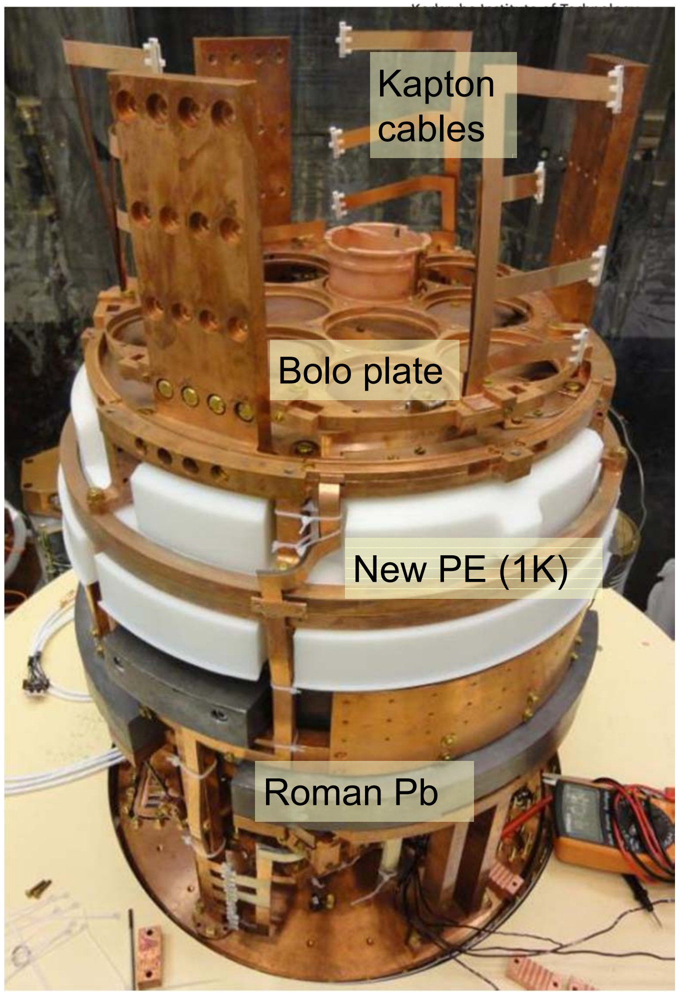
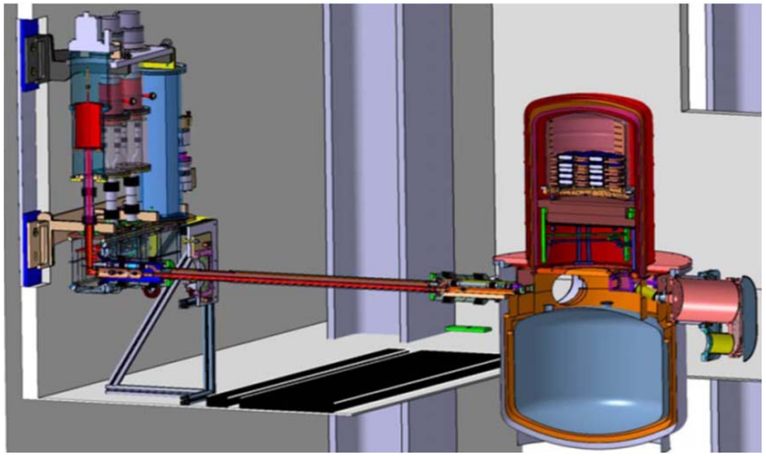
Edelweiss-III: new PE shield, screens, cables …





- ✓ Additional PE shield, new Cu thermal screens
- ✓ Kapton cables and connectors between 1K-10mK (Steel) and 10mK-10mK (Cu)
- ✓ ALL cold electronics at 100K, digitization at 300K

Edelweiss-III: new cryogenics & electronics



Cryogenics

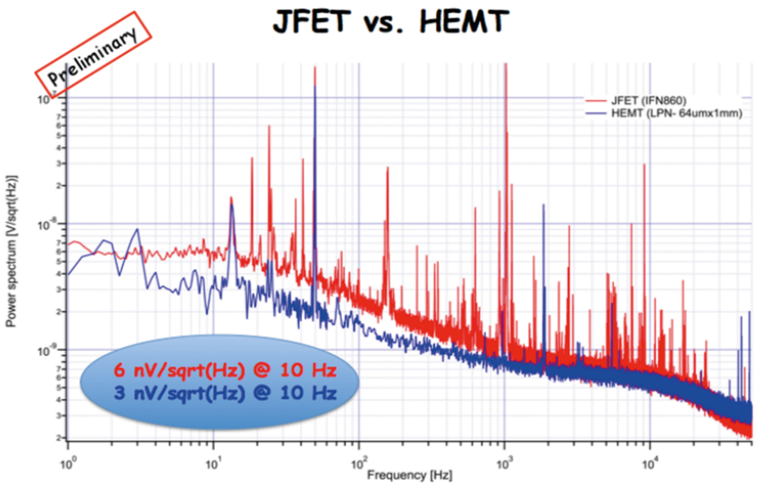
Pulse Tubes close to the cryostat replaced with GM thermal machines outside of shields (new cryoline)

→ microphonic noise reduced!

Electronics

ALL cold electronics at 100K : relay instead of resistances for FeedBack and detectors biases

J Low Temp Phys 167 (2012) 645



R&D with HEMTs (instead of FET)

- work at lower temperature
- lower noise

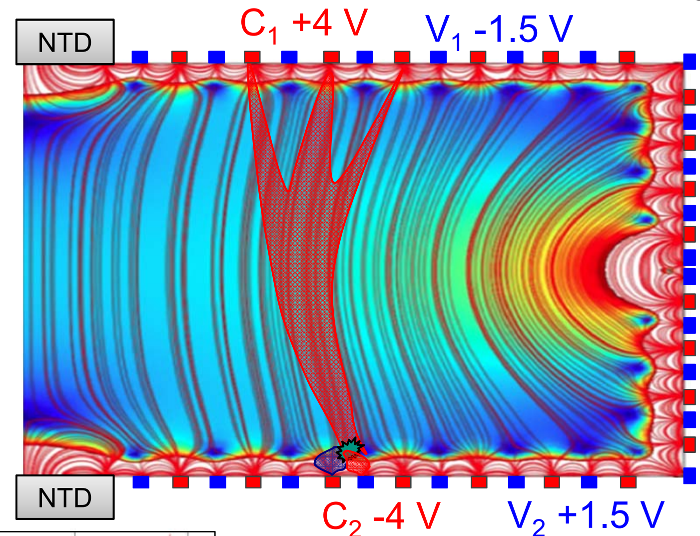
Baseline Resolution

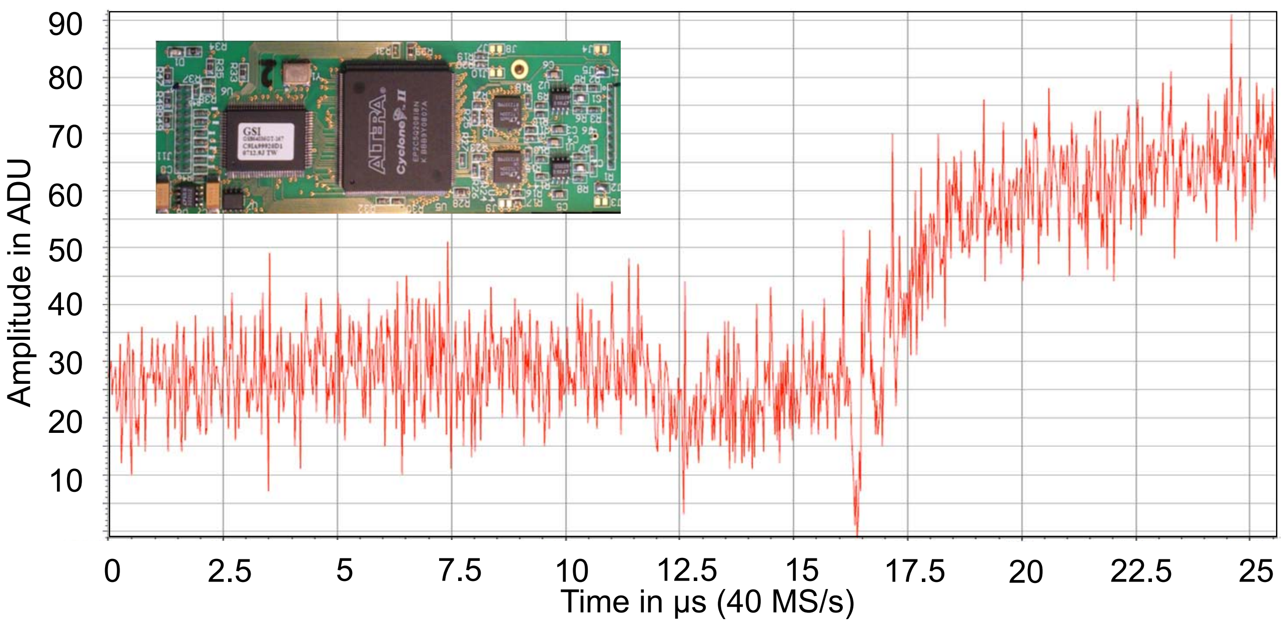
FWHM	Edelweiss-II		Edelweiss-III		R&D HEMT
Ionization	900 eV	→	600 eV	→	300 eV
Heat	1.2 keV	→	1.0 keV		

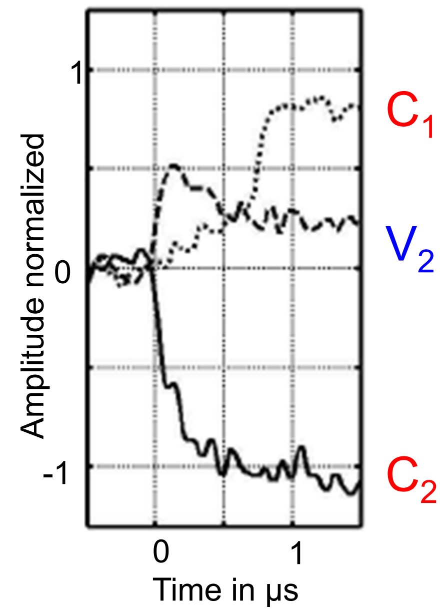
Time resolved ionization channel – 40 MHz

- Additional spatial information on z-axis of bolometer
- Improved understanding of charge migration
- Identifying double scatter events
- Surface event rejection

Event based readout needed for 40 MHz channel
→ Trigger on ionization channel







Edelweiss-III: 36 new FID800 produced …

Improved:		Fiducial mass	γ-rejection factor	
Edelweiss-II	ID400	160 g	$(3\pm1)\times10^{-5}$	
Edelweiss-III	FID800	600 g	$<6\times10^{-6}$	x5 better

Expected background from internal neutrons limits total exposure with <1 bkg event from 4.500 kg.d (σ_{SI}: 2.5x10^{-45} cm^2) to 12.000 kg.d (σ_{SI}: 10^{-45} cm^2)

Edelweiss-III: …and installed!

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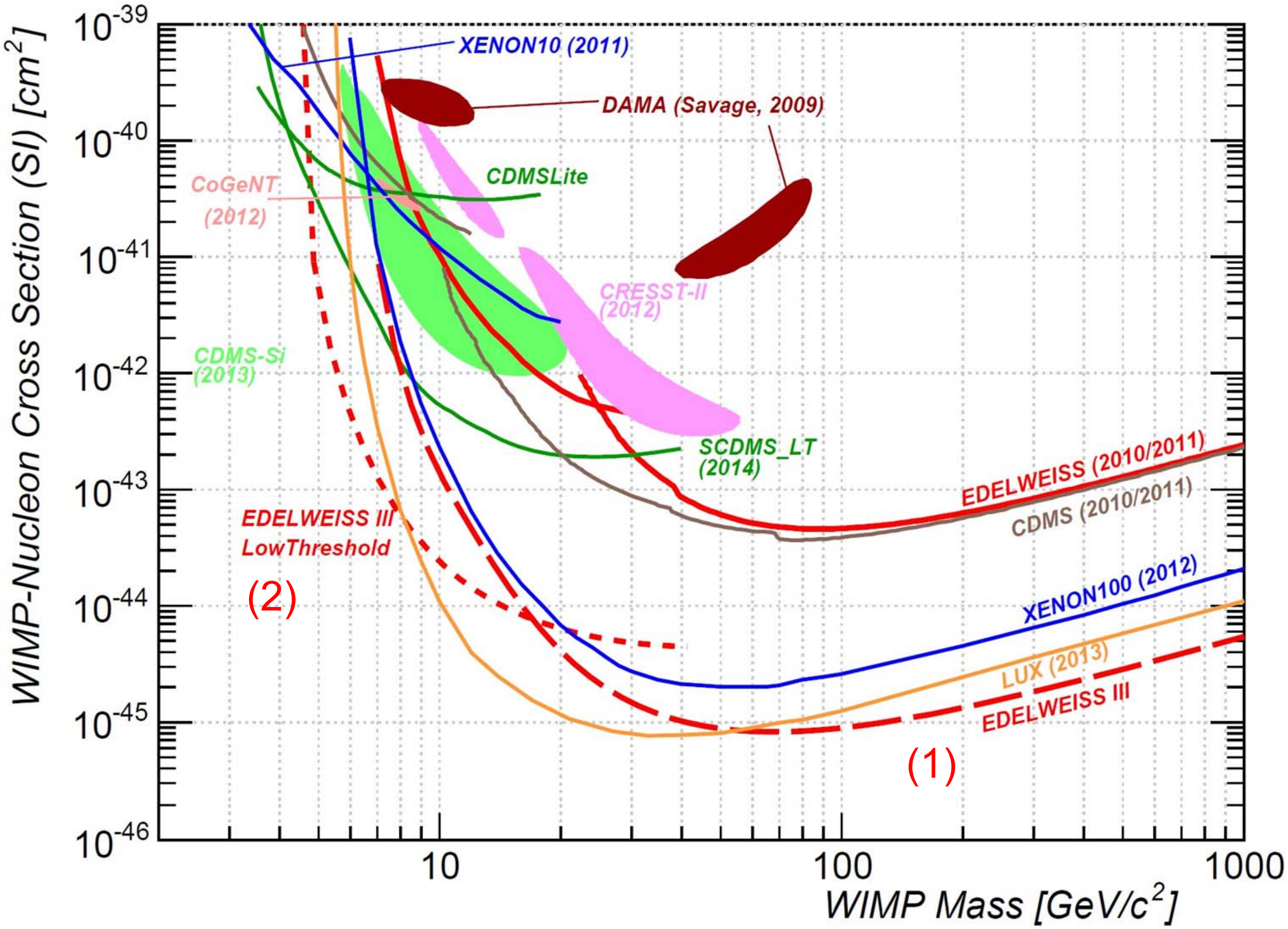
Edelweiss-III: Timeline

Now:
starting up with
36 FID800 installed
(***since 2 days: all @18mK***,
24 FID800 are read-out)

End 2014 / Early 2015:
reach 3000 kg.d
(125 live days)

2016:
reach 12000 kg.d
(500 live days)

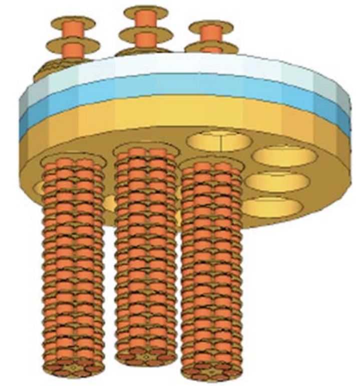


(1) ‚Standard' WIMP: 12000 kgd, E_R>15keV, no event

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

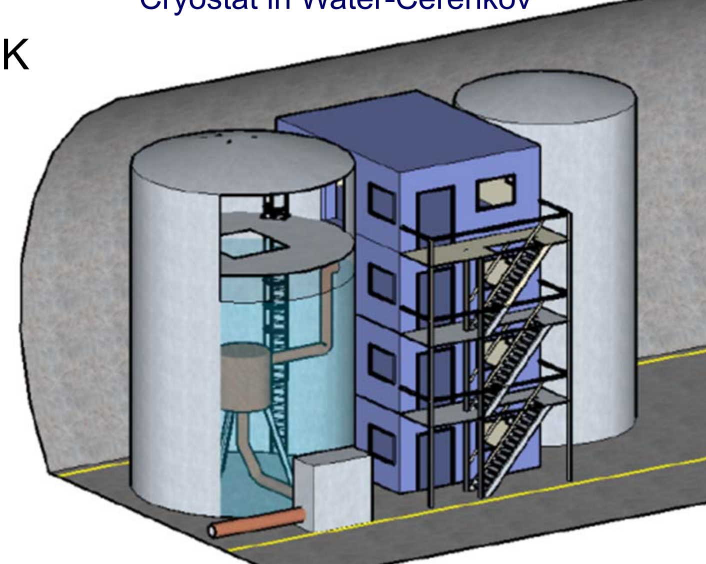
Next stage: EURECA

As in CDR Physics of the Dark Universe 3 (2014) 41

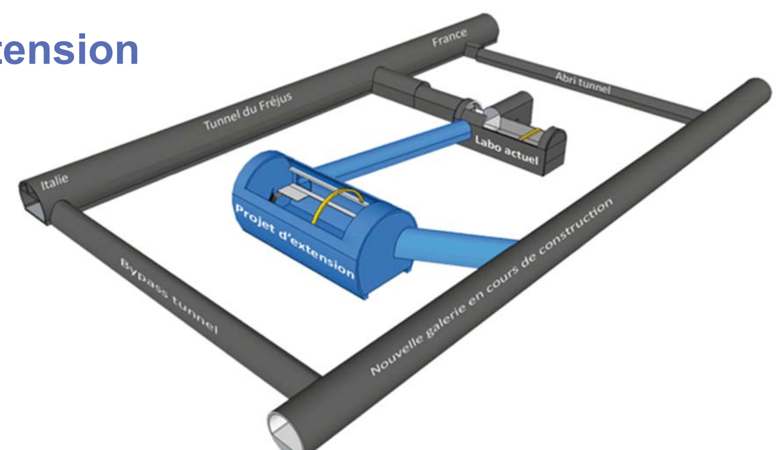


- # Personnel from 17 institutions from EDELWEISS, CRESST, ROSEBUD and others
- # To probe **$10^{-46} \div 10^{-47}$** cm^2
- # Two phase: 150 kg → 1 ton of Cryo detectors @15mK;
- # Multi-target (Ge, $CaWO_4$)
- # Basic features:
  - Large water tank as active shielding
  - Favorite site: new extension of LSM (approved)
  - 7 mK base temperature, „adjustable“
  - Flexible design, one tower : fully integrated, 7mK-300K

Cryostat in Water-Cerenkov

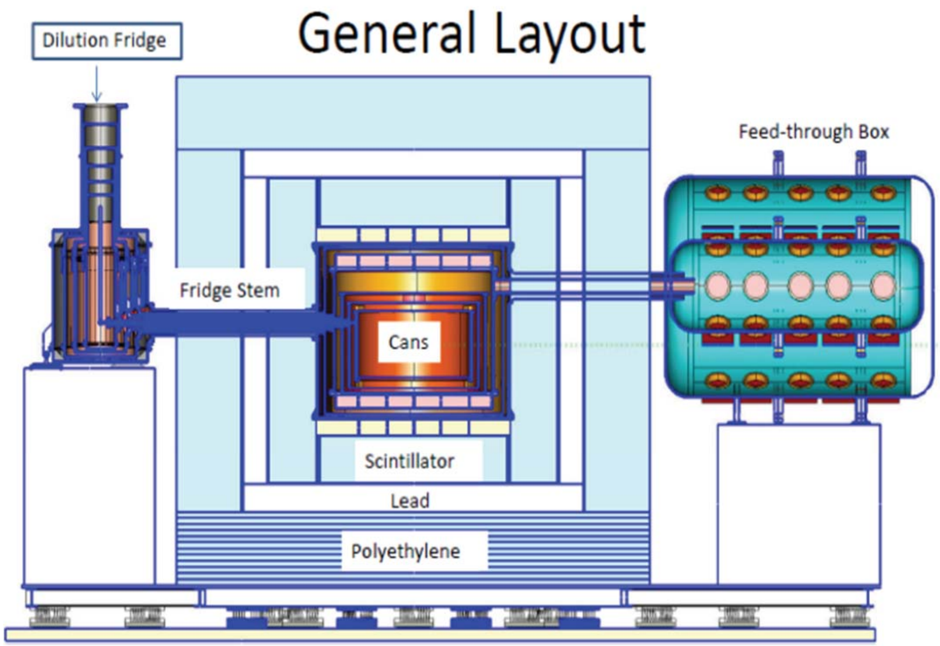


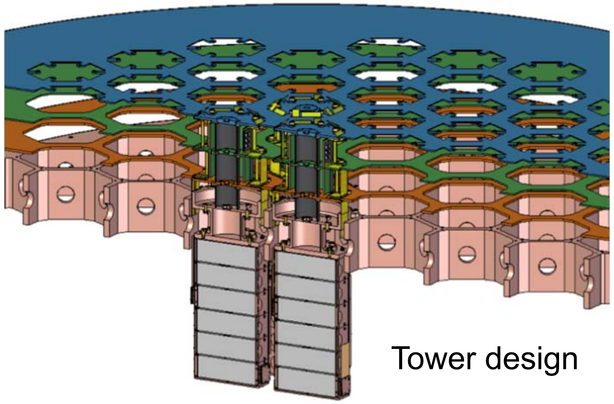
LSM extension



Agreed Cooperation with SuperCDMS

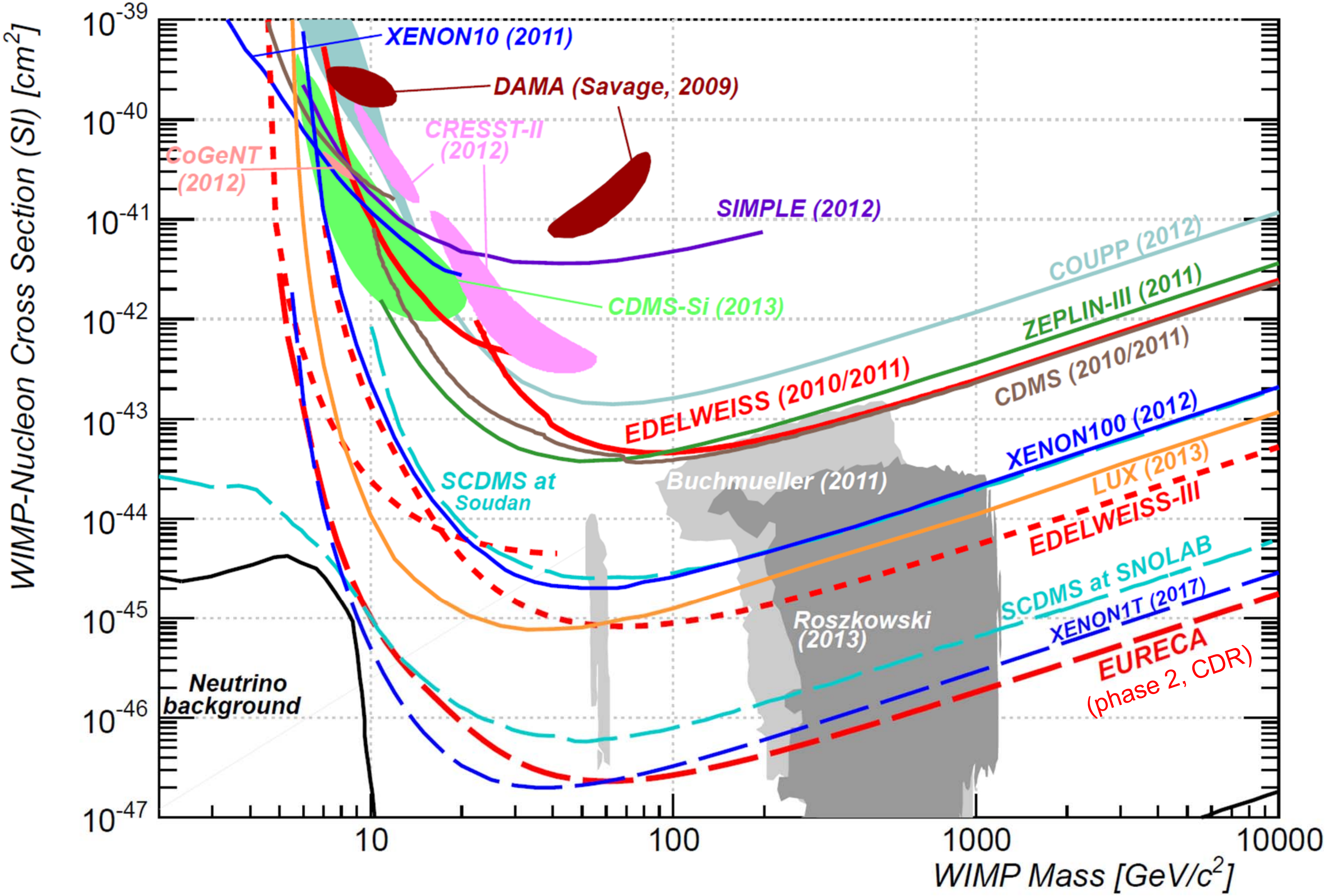
- US-based cryogenic dark matter search using Ge (and Si) detectors
- Currently running 10 kg of detectors in Soudan Underground Laboratory
- Builds on earlier collaborative work between EDELWEISS-II & CDMS
  → Joint publication in
  Phys. Rev. D 84, 011102(R) (2011)
- Plan to swap individual detectors and towers
  - 200 kg EDW Ge + $CaWO_4$
  - 100-200 kg SuperCDMS Ge at SNOLAB
  - Tonne-scale experiment at LSM (or SNOLAB) to follow





Tower design

Where we stand, where we go



Summary and outlook

Edelweiss-II (1.6kg fiducial):

‚Standard' WIMPs + Low-mass WIMPs + Axion search + Background studies

Edelweiss-III (22kg fiducial): 3000 kg.d end 2014/early 2015, 12000 kg.d by 2016

EURECA + SuperCDMS: potentially 400kg mass, better than $\sigma_{SI} \sim 10^{-46}$ cm^2

EURECA prospectives for 1 ton scale

"The moment of truth has come for WIMPs: either we will discover them in the next five to ten years, or we will witness their inevitable decline …"

G. Bertone, Nature 468, 389 (2010).

Backup slides

BACKUP SLIDES

Interaction rate

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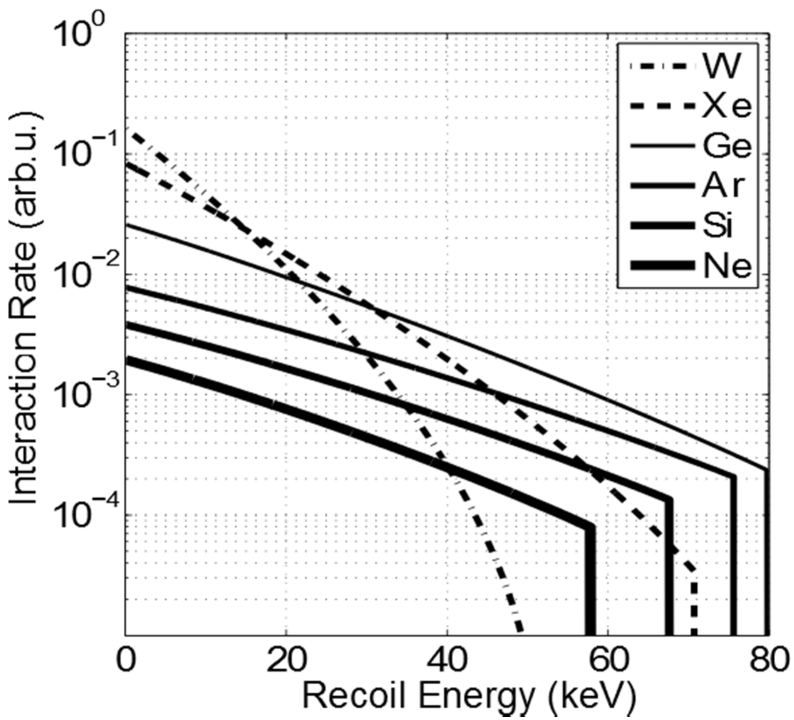
Particle physics	Nuclear structure	Local properties of DM halo

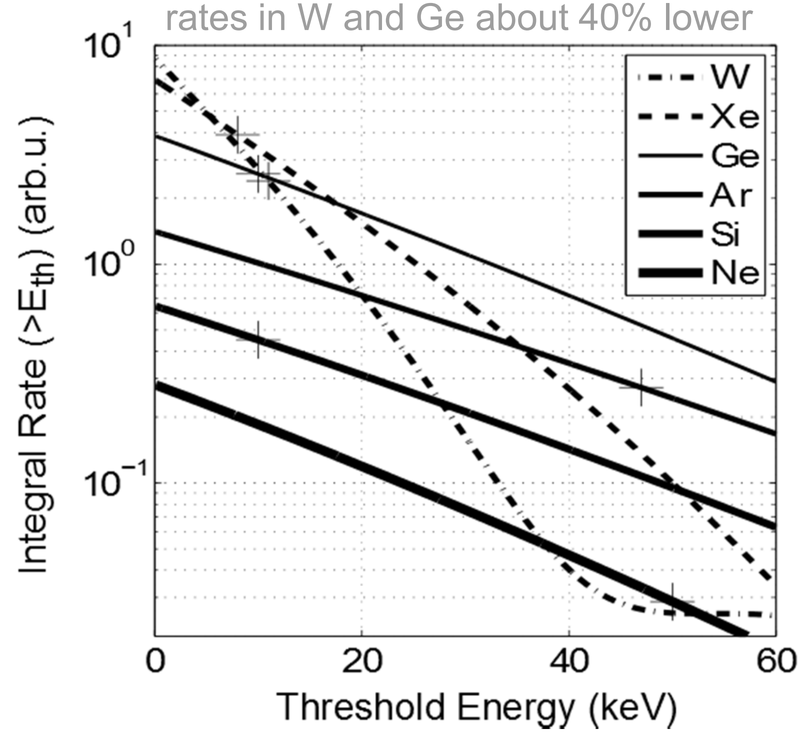
Interaction rate
event/keV/day/kg

$$\frac{dR}{dE_R} = \frac{\sigma_o}{m_\chi} \frac{F^2(E_R)}{m_r^2} \frac{\rho_o\, T(E_R)}{v_o \sqrt{\pi}}$$



$M\chi$ = 60GeV

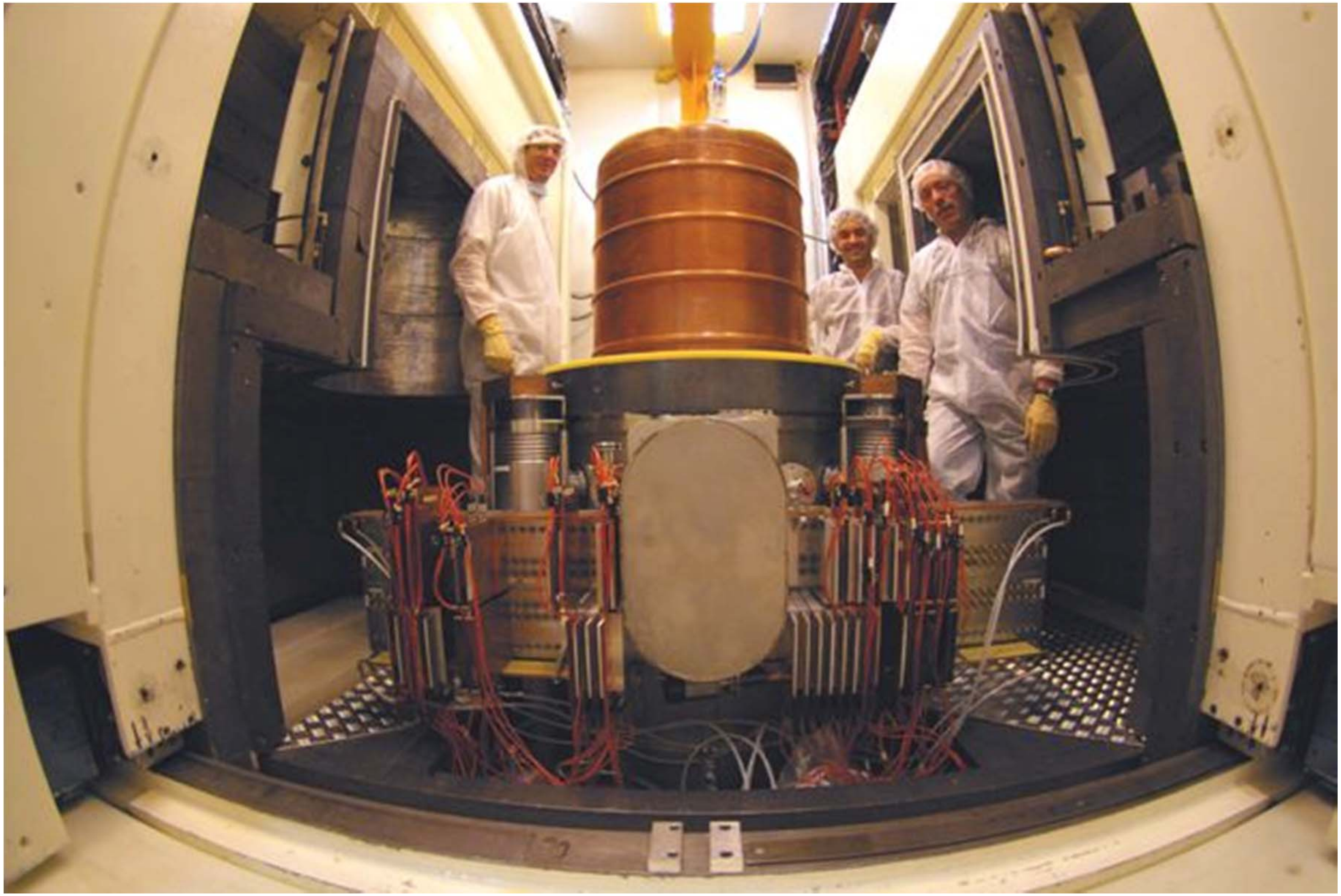
the highest signal rate in Xe, with rates in W and Ge about 40% lower



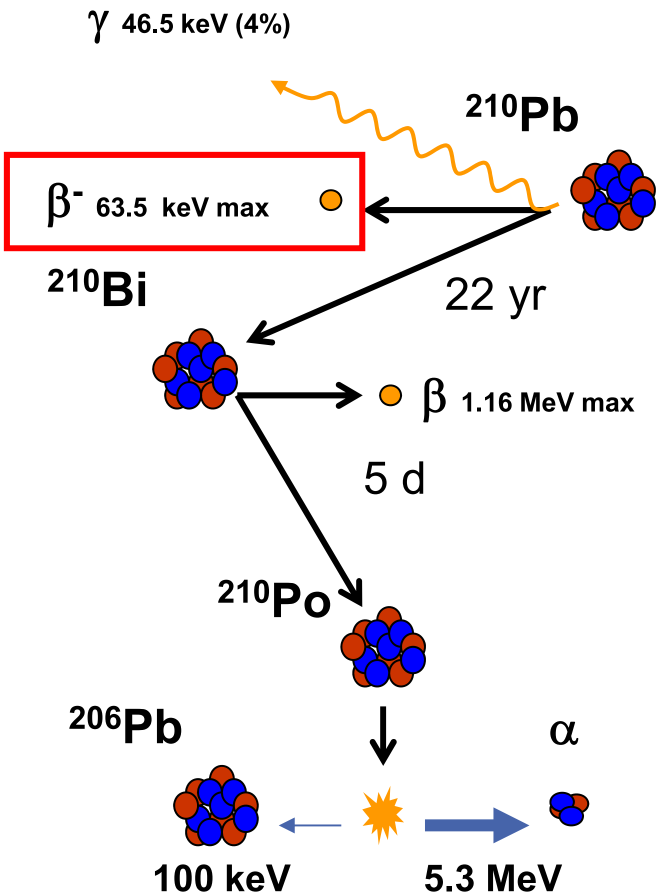
$M\chi$ = 100GeV

arXiv:1101.5205

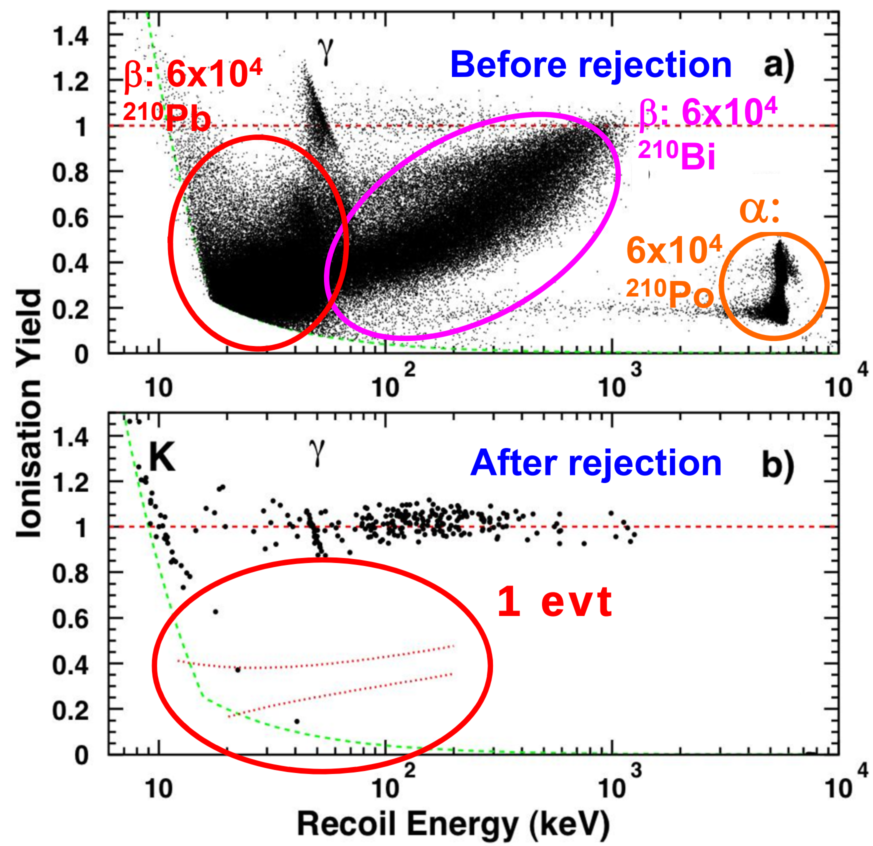
Edelweiss setup: View from ‚inside‘



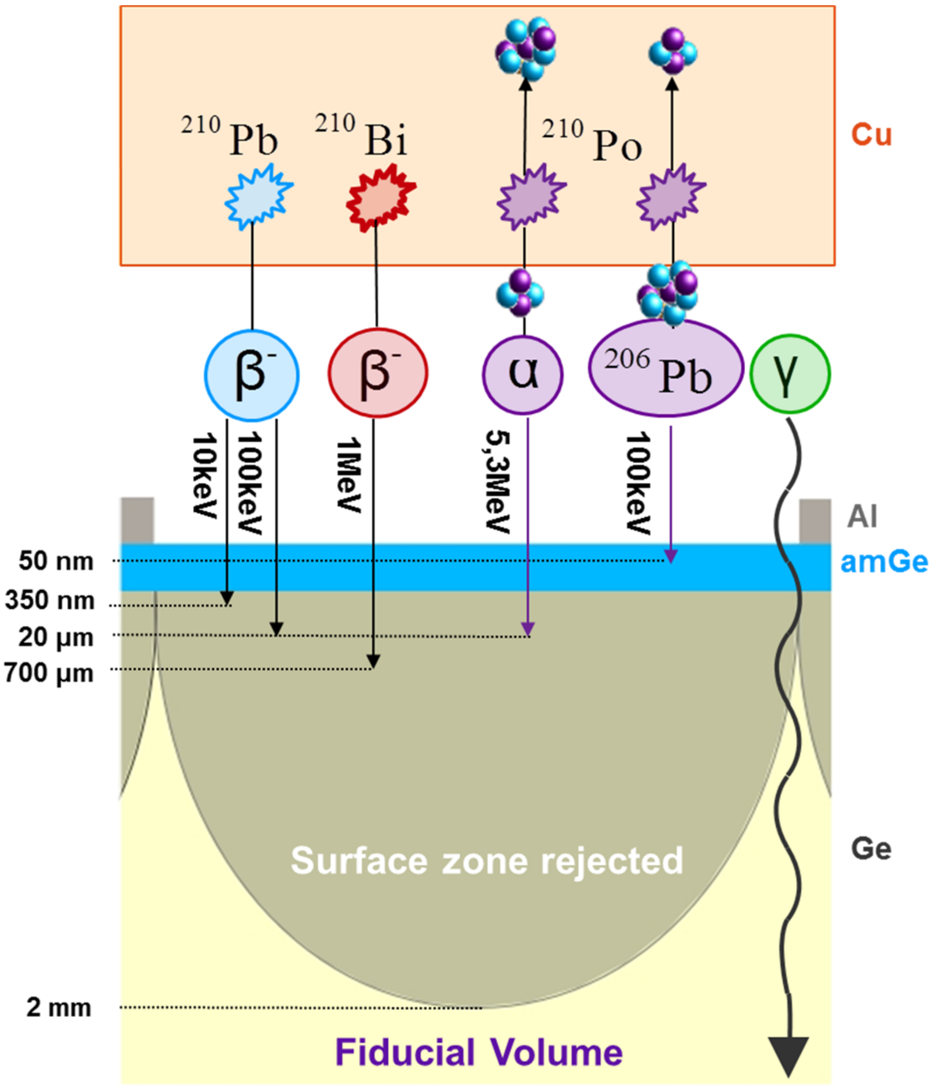
Background: beta surface events

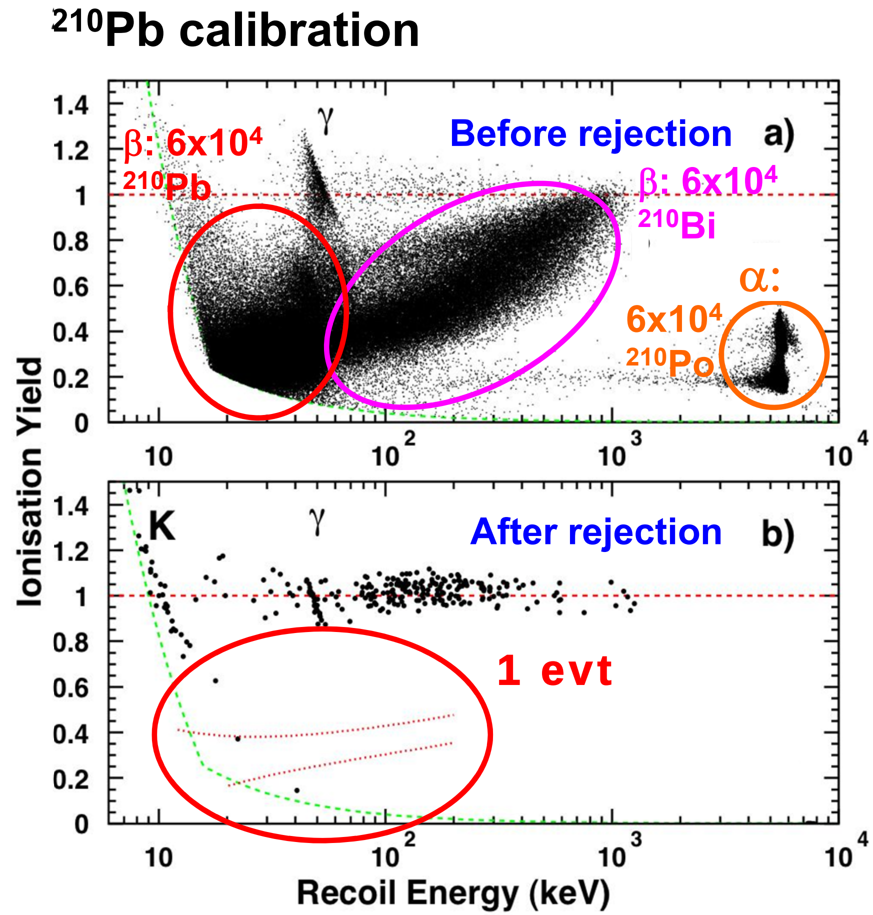


^{210}Pb calibration



Background: beta surface events





Background budget of Edelweiss-II, final

Background in RoI (20-200 keV)		Rate 90%CL (event / 384 kg.d)
γ-background	$1.8 \cdot 10^4$ events	
133Ba calibration:	$\times\ 3 \cdot 10^{-5}$ leakage into RoI	< 0.9
Surface events	5000	
210Pb source:	$\times\ 6 \cdot 10^{-5}$	< 0.3
Neutrons from all components		
Geant4 x measured radiopurity		< 3.1
μ-induced events	$\Gamma^{\mu-n} = 0.008^{+0.005}_{-0.004}$ (events/kg.d)	
veto efficiency (conservative):	>93.5%	< 0.72
Total		**< 5.02**

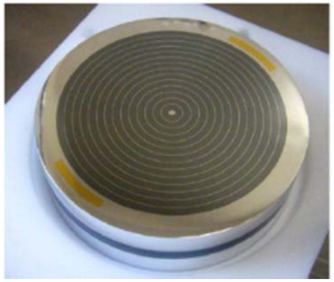
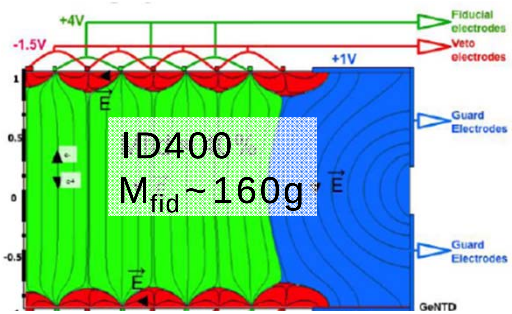
Result:

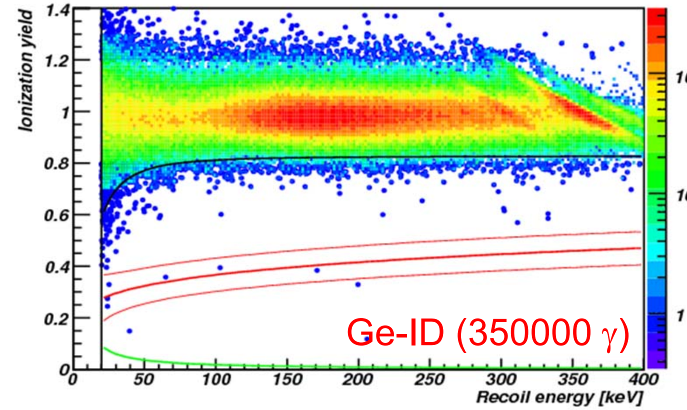
- Measured signal is interpreted as background
- Need better material purity (e.g. contribution from Cu parts @10mK and thermal screens)
- Need an additional neutron shield (neutrons from cables, connectors and electronics)

Edelweiss-III: new FID800, γ-rejection

ID400

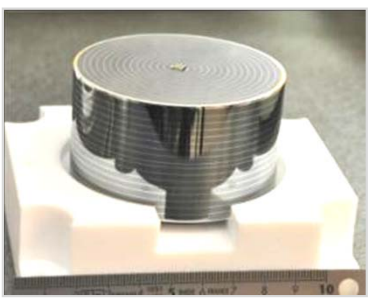
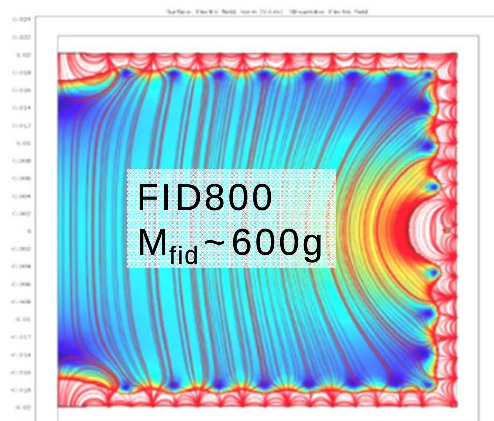
- ID400 (fid. 160g) => FID400 (300g) => FID800 (600g)

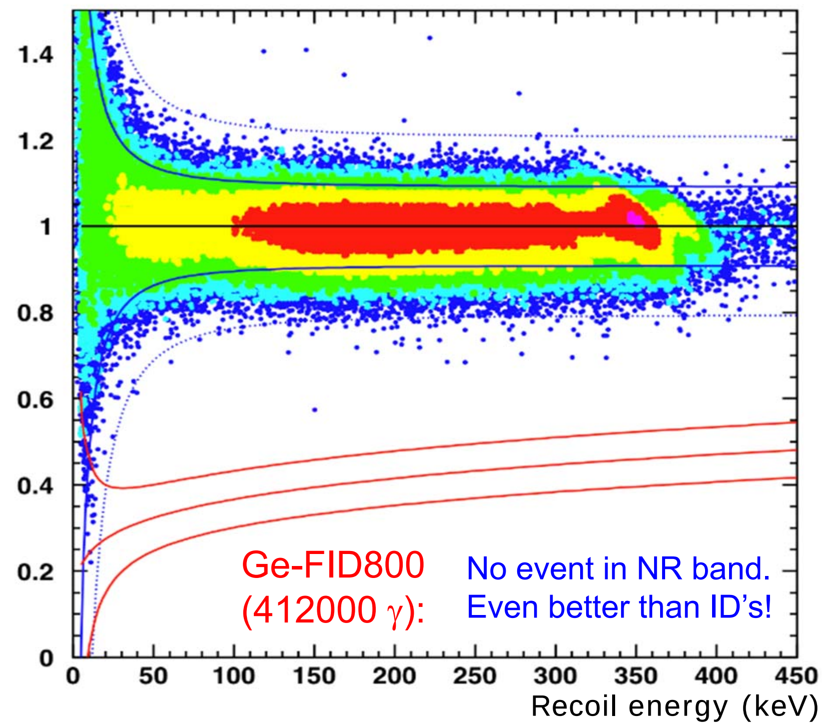





- 6 events in $3.5 \cdot 10^5$ γ's (^{133}Ba), rejection factor 3×10^{-5}

FID800



- Larger Fiducial volume (75% vs. 40%)
- No event in NR for $4 \cdot 10^5$ γ's (^{133}Ba)
  i.e. rejection factor < 5.75×10^{-6}