



DE LA RECHERCHE À L'INDUSTRIE



Background suppression in the Edelweiss-III experiment

Experience pour DÉtecter Les Wimp En Site Souterrain

Workshop on Low Radioactive Techniques
Gran Sasso 2013
Xavier-François NAVICK

11 AVRIL 2012

OUTLINE

The EDELWEISS-II experiment

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The EDELWEISS-III experiment

Upgrade setup	P.20
Radioactivity measurements	P.24
Neutron and gamma backgrounds	P.25

THE EDELWEISS COLLABORATION

- CEA, SACLAY (IRFU, IRAMIS)
- CSNSM, ORSAY (CNRS/IN2P3, UNIV. PARIS SUD)
- IPN, LYON (CNRS/IN2P3, UNIV. LYON 1)
- INSTITUT NÉEL, GRENOBLE (CNRS/INP)
- LABORATOIRE SOUTERRAIN DE MODANE
- KARLSRUHE INSTITUTE OF TECHNOLOGY (IEKP, IKP, IPE)
- JINR, DUBNA
- UNIVERSITY OF OXFORD
- UNIVERSITY OF SHEFFIELD



KARLSRUHE MARCH 2013

EDELWEISS - II

EDELWEISS SETUP

- LSM - the deepest lab in Europe:

$\sim 5 \mu\text{m}^2/\text{day}$,

B. Schmidt et al., *Astropart. Phys.* 44 (2013) 28.

$\sim 10^{-6} \text{n/cm}^2/\text{s}$ ($E > 1 \text{ MeV}$),

S. Fiorucci et al. *Astropart. Phys.*, 28 (2007) 143.

- Radiopurity:

– Dedicated HPGe detectors for material selection;

– Clean room;

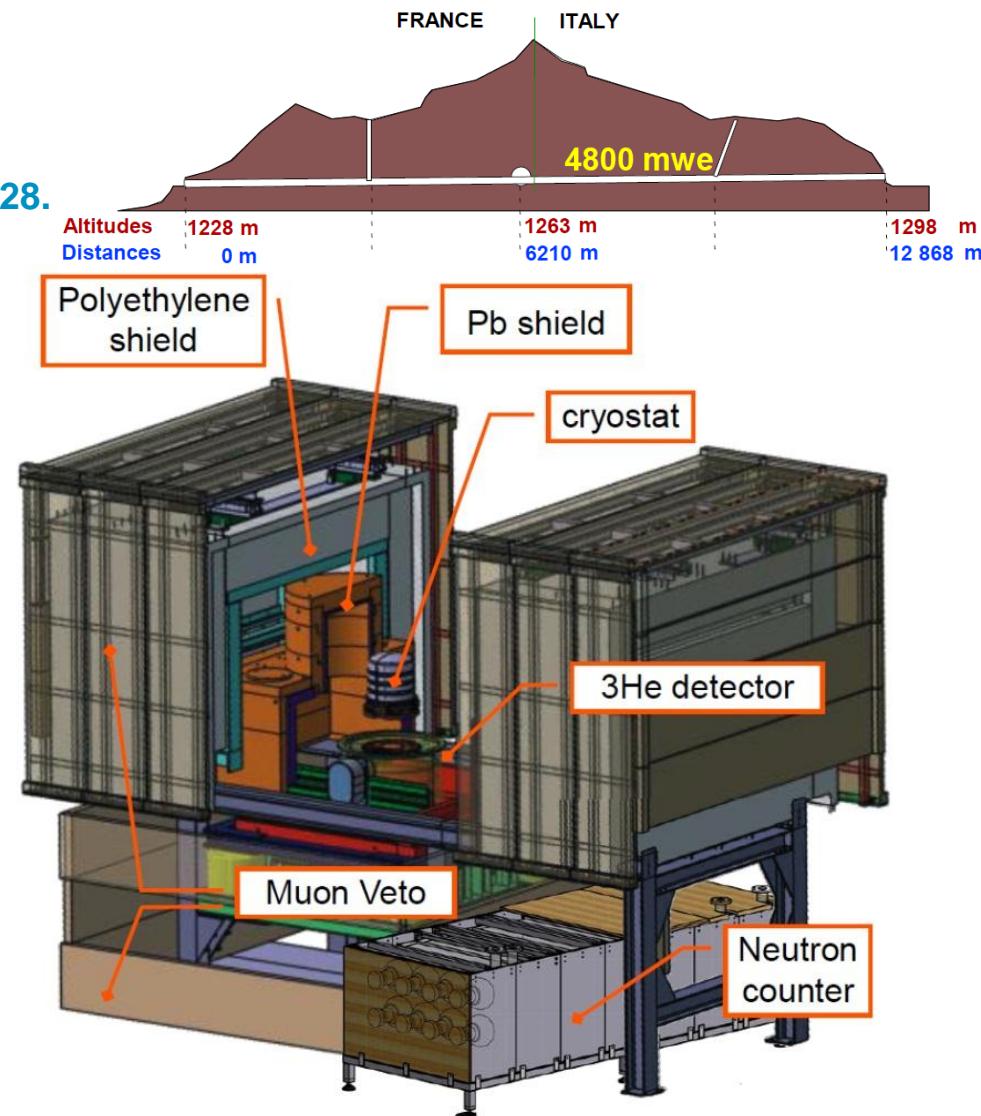
– De-radonised air (NEMO-3 radon trap): 10 Bq/m^3 to 0.1 Bq/m^3 .

• Gamma shielding - 20 cm Pb.

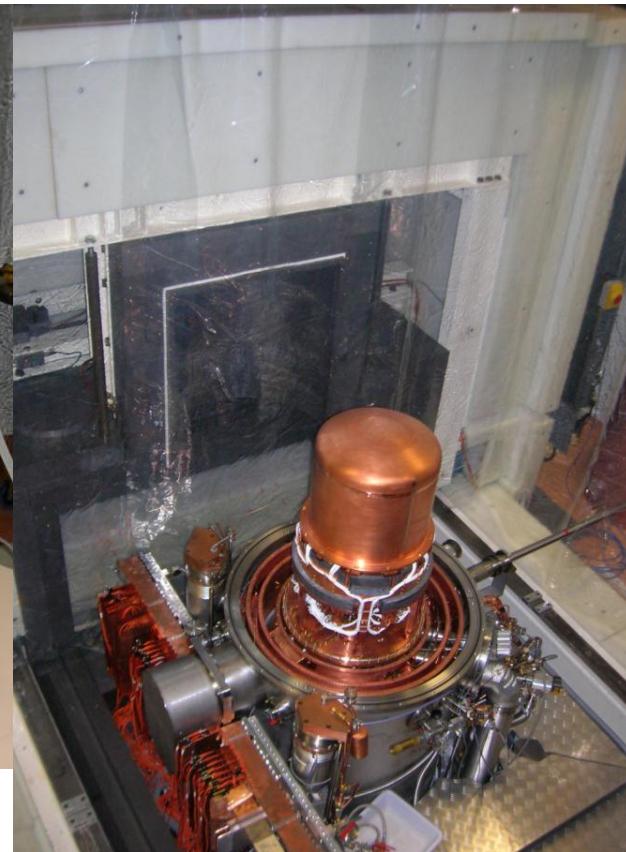
• Neutron shielding - 50 cm PE.

• Muon veto (>98% coverage).

• Neutron detectors.



EDELWEISS SETUP



**400g “Interleaved Detectors”(ID) detectors.
10 ID detectors used in the analysis:
E. Armengaud et al., Phys. Lett. B, 702 (2011) 329.**

EDELWEISS-II MODEL

GEANT4 geometry of detector and shielding:

Lead shielding
(inner 2 cm - casted
Roman lead)

Cryostat screens

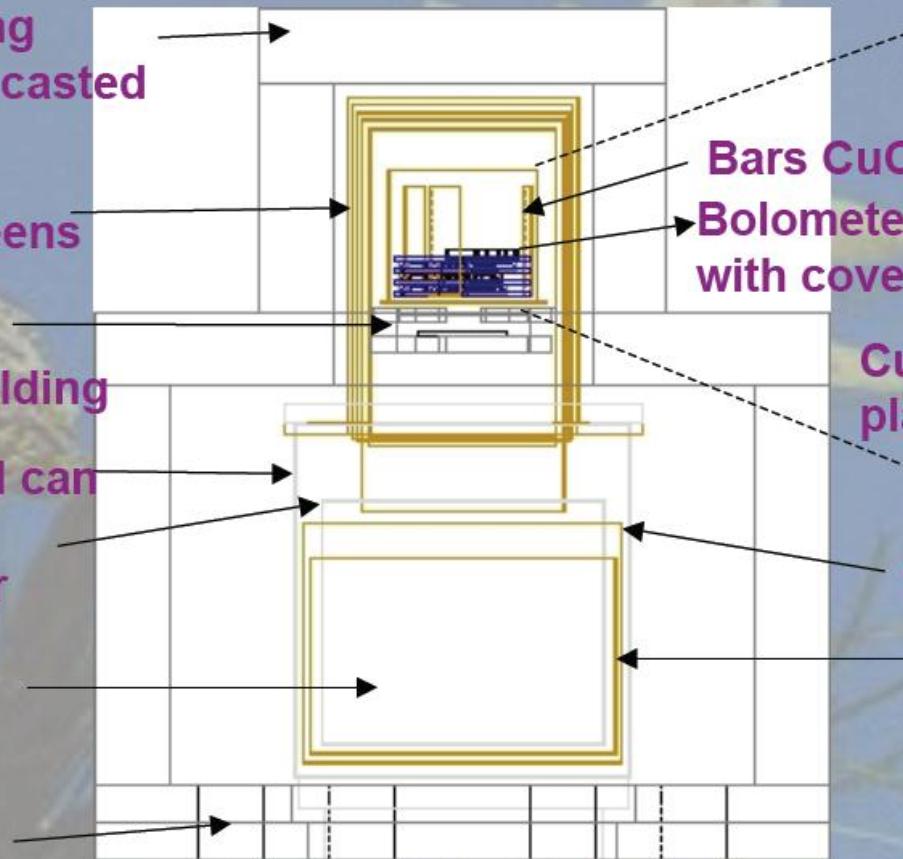
Roman lead
internal shielding

Stainless steel can

He reservoir

Liquid Helium

Mild steel
supports



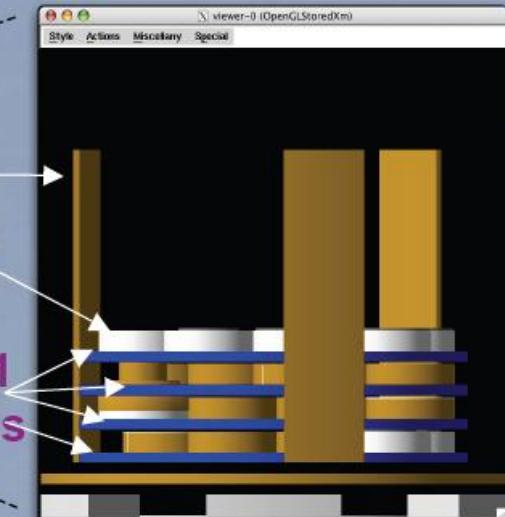
Bars CuC1
Bolometers
with covers

CuC1
plates

100K screen lower part

40K screen lower part

Polyethylene shielding not shown



RADIOACTIVITY MEASUREMENTS

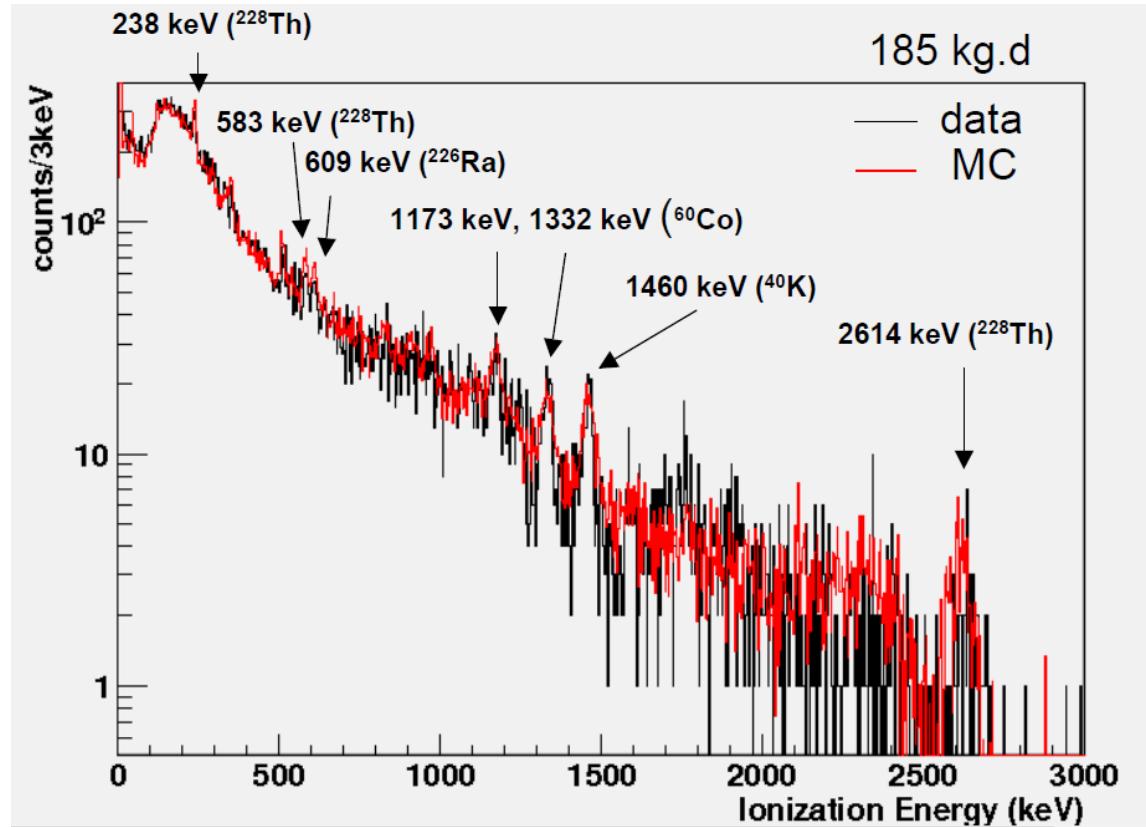
Component	Material	Mass, kg	$^{238}\text{U} / ^{232}\text{Th}$	^{226}Ra (mBq/kg)	^{228}Th (mBq/kg)	^{210}Pb (mBq/kg)
Shielding	Polyethylene	30000	1 / 0.1 ppb	< 2	< 2.5	< 28
Internal lead shielding	Roman lead	~120		< 0.3	< 0.3	< 120
Shielding	Boliden lead	40000	<0.01 ppb/ < 0.01 ppb	<3	<1	24000 ± 1000
Support	Mild steel	8600	<0.01 ppb/ < 0.01 ppb			
Warm electronics	PCB, electr. components	50 units	U: 134 mBq	331 ± 17	235 ± 13	1019 ± 56

$^{238}\text{U}/^{232}\text{Th}$ measured by neutron activation for PE, by ICPMS for lead and steel. All other results are from gamma-ray spectrometry.

RADIOACTIVITY MEASUREMENTS

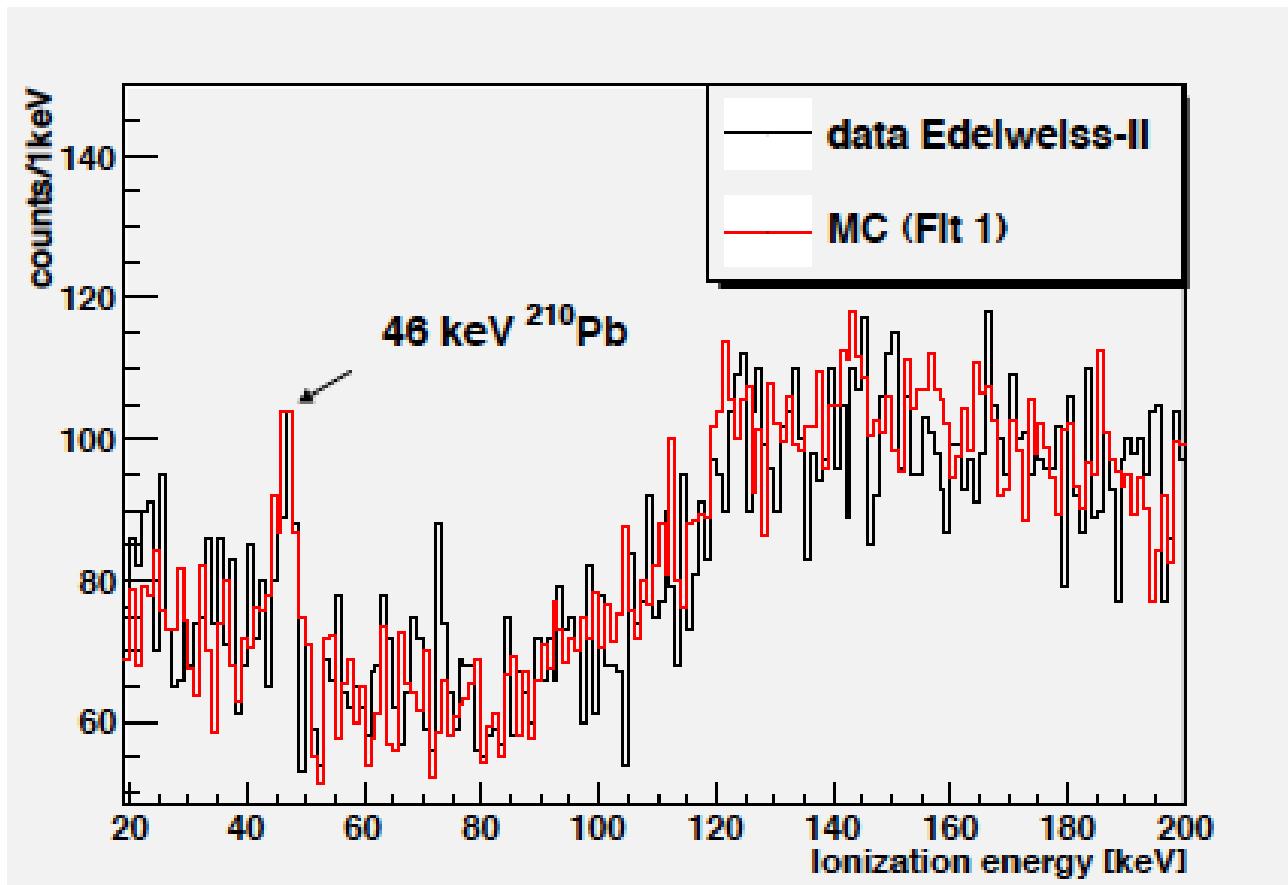
Component	Material	Mass (kg)	^{226}Ra (mBq/kg)	^{228}Th (mBq/kg)	^{60}Co (mBq/kg)	^{40}K (mBq/kg)
Crystal covers	Copper CuC2	~ 3	0.025 ± 0.015	0.033 ± 0.016	0.038 ± 0.010	< 0.39
Bars, plates, 10 mK screen	Copper CuC1	90	< 1	< 0.7	< 1	< 110
1K + 100K electronics (connectors)	Al, epoxy	0.32	644 ± 65 (^{238}U : 1994 ± 204)	1353 ± 138	< 25	1181 ± 197
Dilution parts, pipes, resistors	stainless steel, Cu-Ni, brass, silver	~1	< 20	< 20	< 20	< 100
Coaxial cables	PTFE, constantan	1.35	10 ± 7	< 6	< 8	120 ± 60
Cryostat screens	Copper	~500	< 3	< 2	< 2	< 25

GAMMA-INDUCED BACKGROUND



- The decays of ²²⁶Ra, ²²⁸Ra, ⁶⁰Co, ⁴⁰K, ⁵⁴Mn and ²¹⁰Pb were simulated in the detector casings, the copper plates at 10 mK, the bars supporting the plates, the screen and plate at 10 mK, cryostat, the dilution chamber, 1K connectors, the coaxial cables and the lead shielding.

GAMMA-INDUCED BACKGROUND



- Energy spectrum at low energies.

FITTING BACKGROUND SPECTRUM

	Event rate in fiducial volume (evts/kg day)	
	Fit 1	Fit 2
Ge (activation)	1.6 (2%)	1.7 (2%)
CuC2 Crystal covers and supports	14.0 (17%)	13.0 (17%)
CuC1 plates, Bars, 10 mK	9.5 (12%)	13.5 (17%)
Cu screens	32.5 (40%)	17.0 (21%)
Pollution at 300 K	22.0 (27%)	29.0 (35%)
Pb boliden	2.6 (3 %)	4 (5 %)
Total MC	82	78
TOTAL DATA	82	82

- Rock, concrete and shielding contribute a small fraction to the background event rate.
- Most components outside the external or internal shielding (some support structure, dilution parts, 1K-100K cables, connectors, electronics) contribute very little.
- The main contribution comes from copper parts at 10 mK and screens.
- There should also be an additional contamination (probably at 300K) to match the data.

NEUTRON BACKGROUND IN EDELWEISS-II

Source	Material	Neutron events (384 kg×days)
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

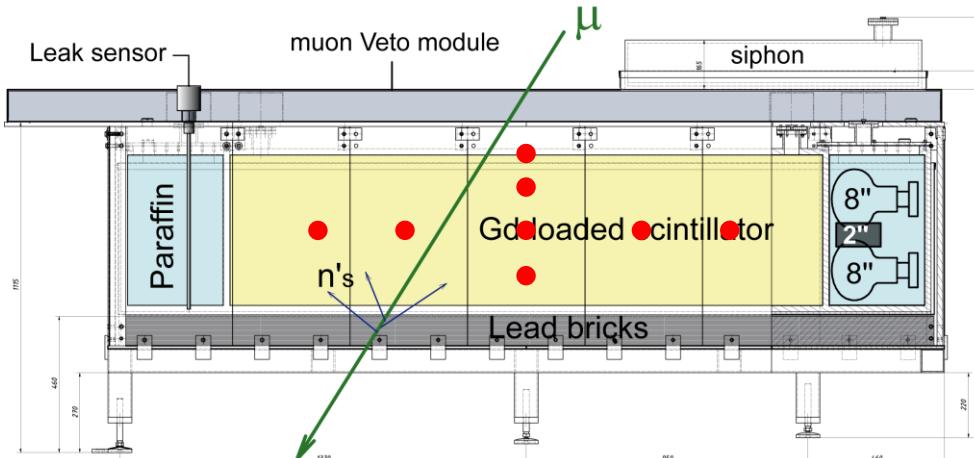
- Normalized to the statistics of 384 kg×days.
- The expected neutron rate is between 1.0 and 3.1 events in the above exposure.

MUONS-INDUCED NEUTRONS: V. KOZLOV

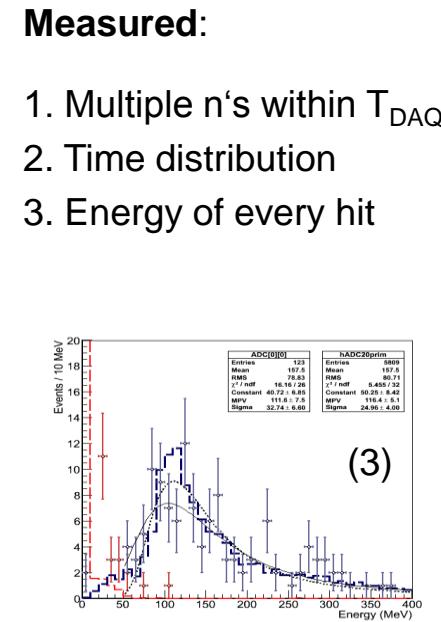
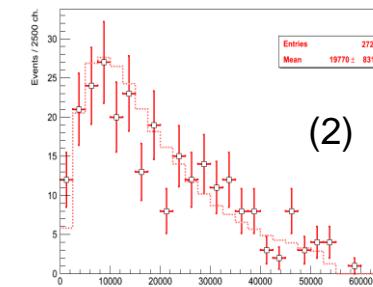
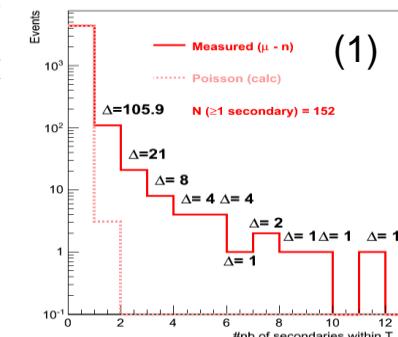
Muon-induced neutron background budget :

Goal	$4.4 \cdot 10^{-8} \text{ pb}$	a few 10^{-9} pb	$10^{-10} \dots 10^{-11} \text{ pb}$
Signal, ROI [20,200] keV	$< 10^{-2} / \text{kg.d}$	$< 10^{-3} / \text{kg.d}$	$< 10^{-5} / \text{kg.d}$
Irriducible muon-induced neutron background, ROI	<0.72 evt per 481 kg.d	<0.6 evt per 3000 kg.d	<0.3 evt per $3.65 \cdot 10^5 \text{ kg.d}$

Measurement of muon-neutron coincidences with a system of scintillators:



- 1m^3 of Gd-loaded scintillator + 10-cm Pb layer
- Muon telescope
- 8 LEDs to control scintillator transparency
- 3 years of data-taking



Measured:

1. Multiple n's within T_{DAQ}
2. Time distribution
3. Energy of every hit

MUONS-INDUCED NEUTRONS: V. KOZLOV

Monte-Carlo ‘end-to-end’ model:

- Geant4 9.2p01
- Muon-generator (99.9% of the local spectrum)
- Physics list is based on QGSP_BIC_HP but the composition is optimized depending on a particle and energy
- Detailed 3D geometry of the setup
- Custom Gd neutron capture spectrum
- Same cuts as in the measurement, ...

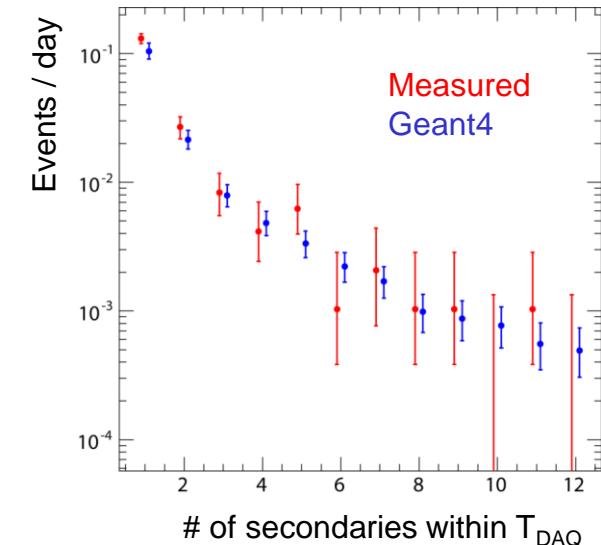
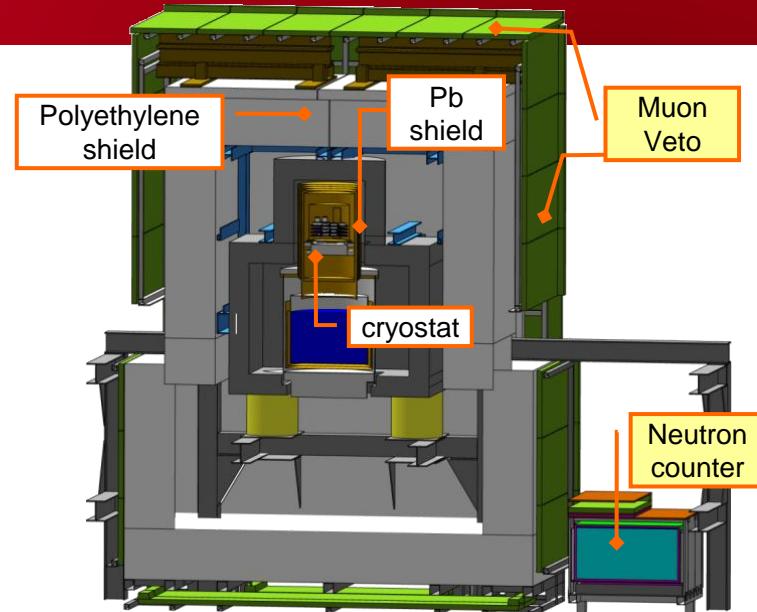
→ **details in H.Kluck, Ph.D. thesis**

Comparison between MC model and measurement:

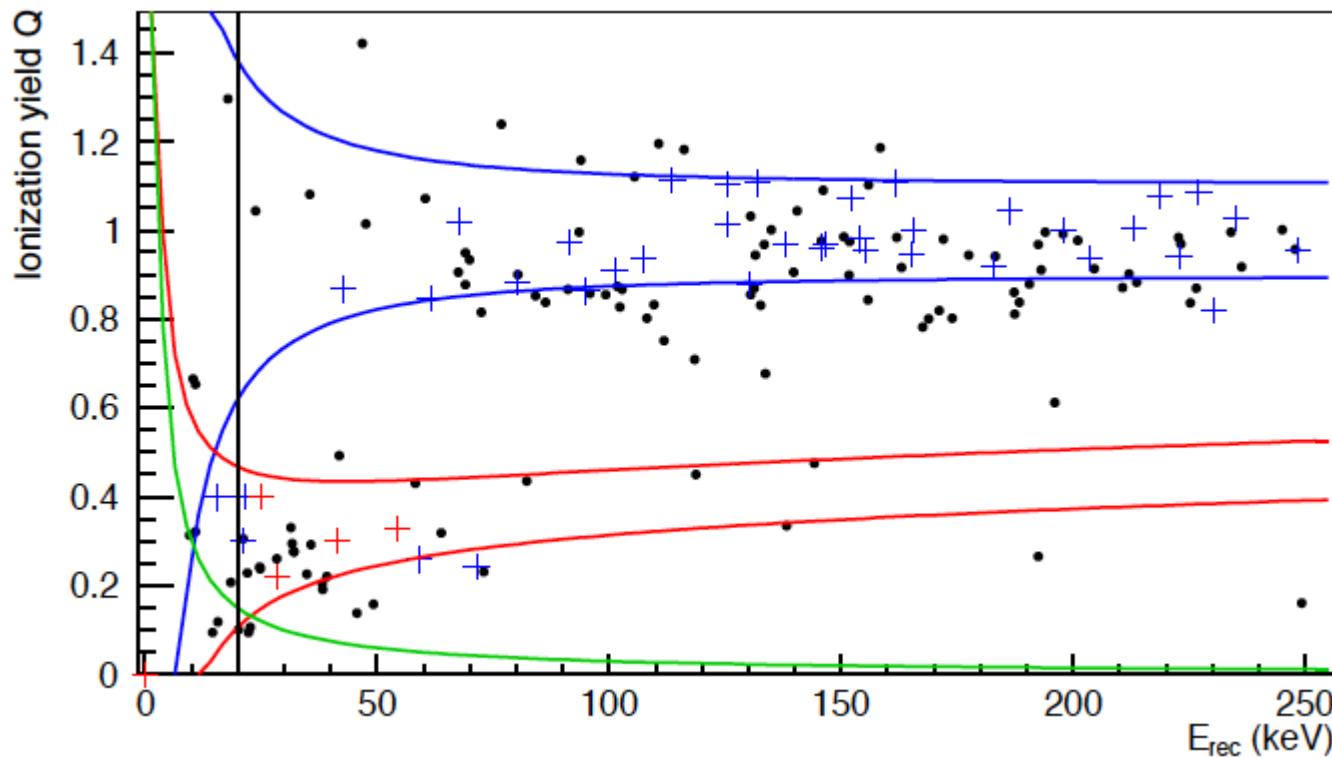
	Measurement	MC model ('end-to-end')
Muon rate, day ⁻¹	5.79 ± 0.08	$5.71 \pm 0.01 \pm 0.03 ^{+1.49}_{-0.47}$
Secondaries / muon	$(5.5 \pm 0.3) \cdot 10^{-2}$	$(6.57 \pm 0.04 \pm 0.12 ^{+1.49}_{-1.83}) \cdot 10^{-2}$

⇒ Agreement within 20%

⇒ $\eta_n = 2.2 \times 10^{-3} \text{ n}/\mu/(g/cm^2)$ (thin Pb target) , $E_\mu \sim 260 \text{ GeV}$
 $\eta_n = 4.9 \times 10^{-3} \text{ n}/\mu/(g/cm^2)$ (thick Pb target) , $E_\mu \sim 260 \text{ GeV}$



MUON-INDUCED NEUTRONS



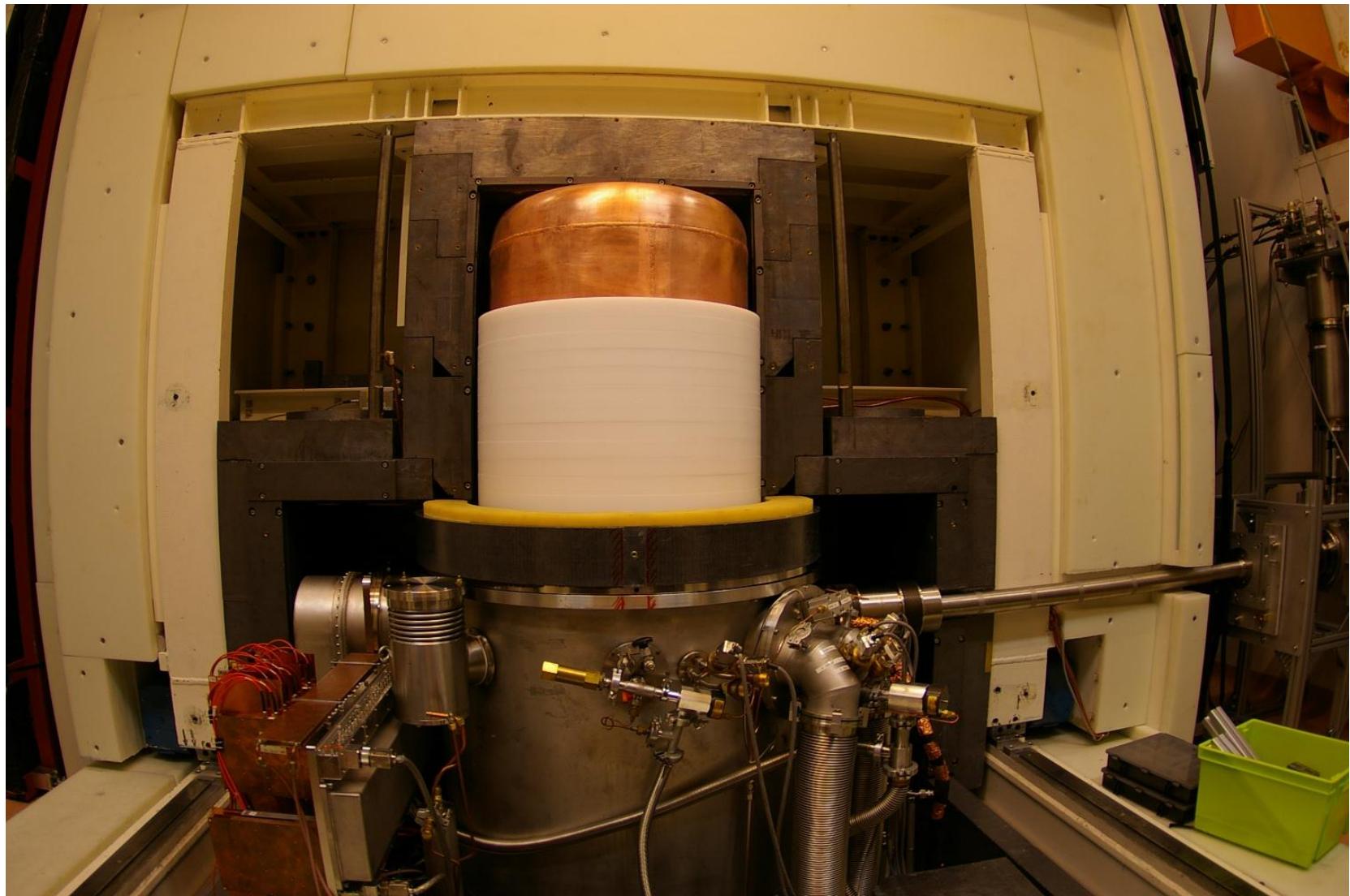
- Events recorded in coincidence with the veto system.
- B. Schmidt et al., Astroparticle Physics 44 (2013) 28 ,
ArXiv 1302 7112

BACKGROUND ESTIMATES

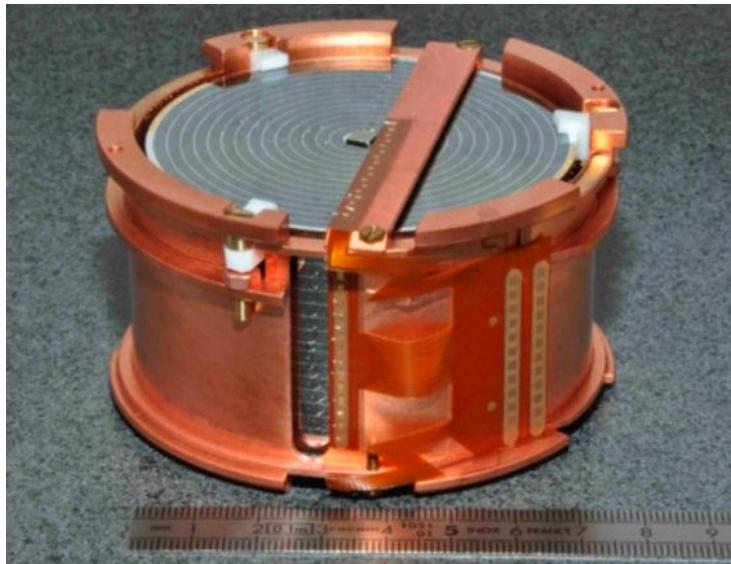
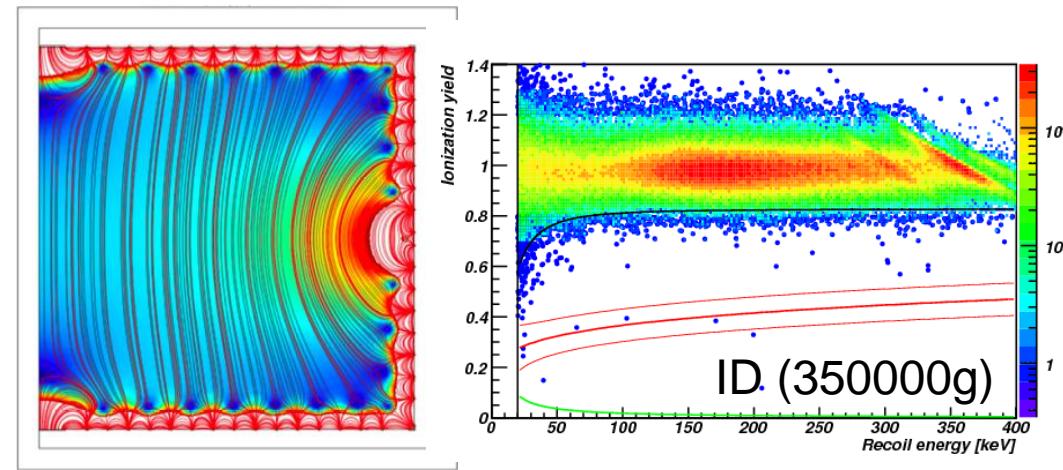
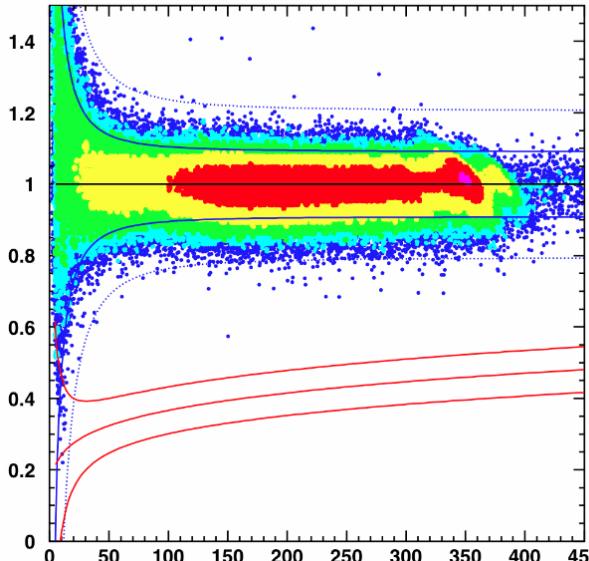
- Gamma background in data run – 1.8×10^4 events (20-200 keV).
- ^{133}Ba calibrations → 3×10^{-5} leakage into NR band
→ < 0.9 events at 90% CL.
- Surface events – 5000 events, rejection factor $< 6 \times 10^{-5}$
→ < 0.3 events.
- Neutrons from all components with identified contaminations
→ < 3.1 events.
- Muon induced events missed by veto – measurements of coincident events and veto efficiency; assuming a lower limit on muon veto efficiency of 93.5% → < 0.8 events.
- The sum of upper limits: < 5.1 events in $384 \text{ kg} \times \text{days}$.

EDELWEISS - III

EDELWEISS-III: NEW SETUP



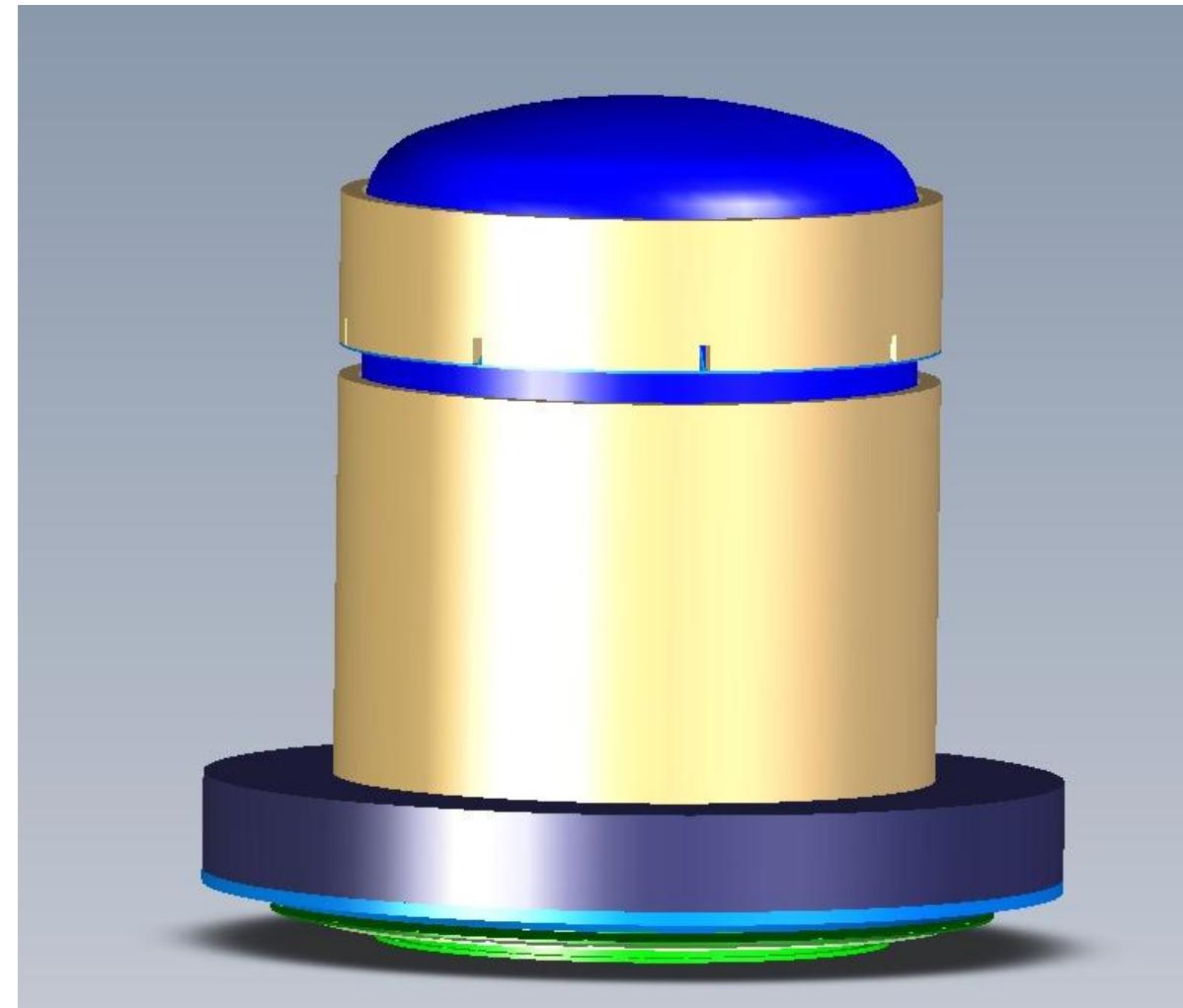
UPGRADE: EDELWEISS-III

EDELWEISS FID - ^{133}Ba calibration (411663 γ)

- **FID-800 - 800 g crystals with a fiducial mass of \sim 600 g.**
- **Rejection factor better than 10^{-5} (preliminary).**
- **Inner PE shield against neutrons.**
- **3000 kg \times days by the end of 2013, increased in 2014.**
- **Expected sensitivity $5 \times 10^{-9} \text{ pb}$ in 2013 and below later on.**

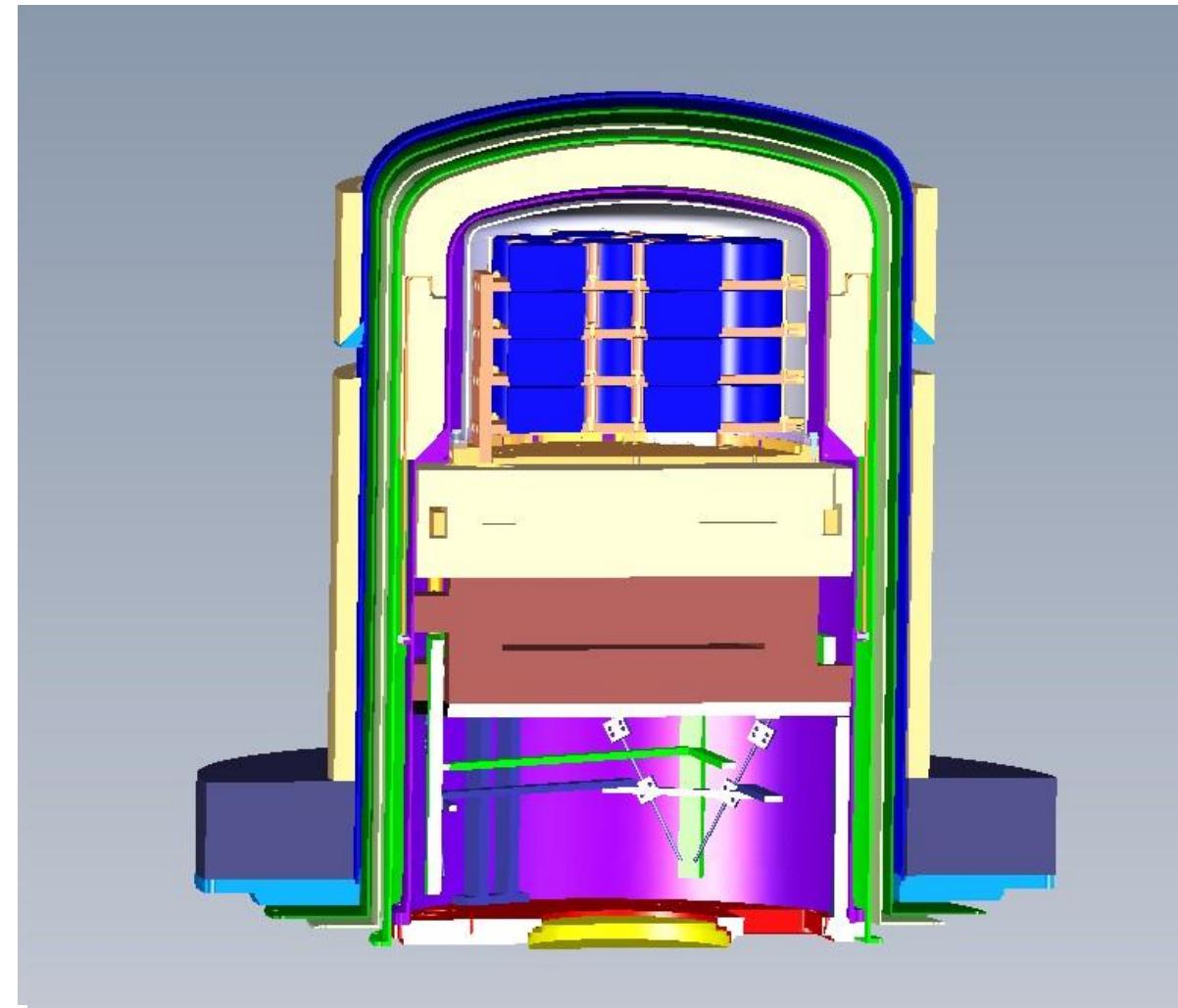
EDELWEISS-III: IMPROVED NEUTRON SHIELDING

- ~10 cm of polyethylene below detectors.
- ~6 cm of PE on the sides and top.
- Low-radioactive cables and connectors.
- New copper screens (cryostat), plates and bars.
- External shielding and veto as in EDELWEISS-II.



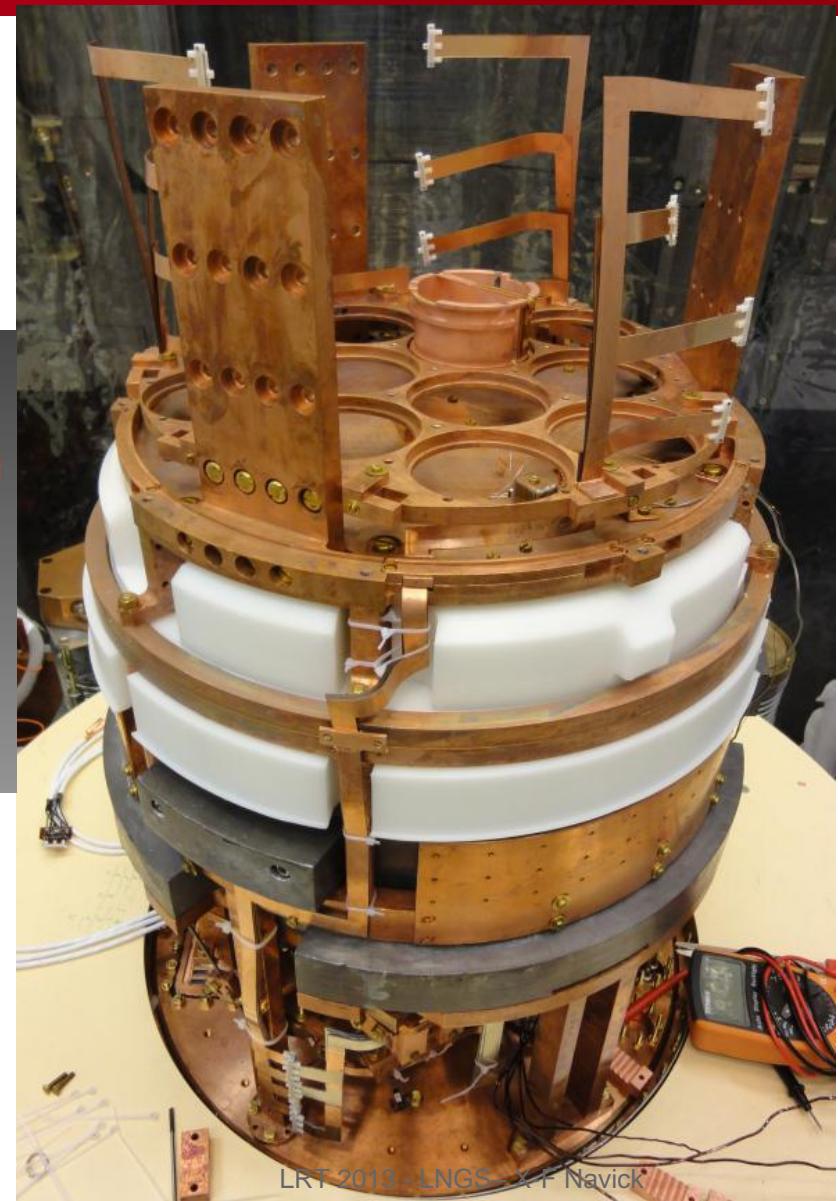
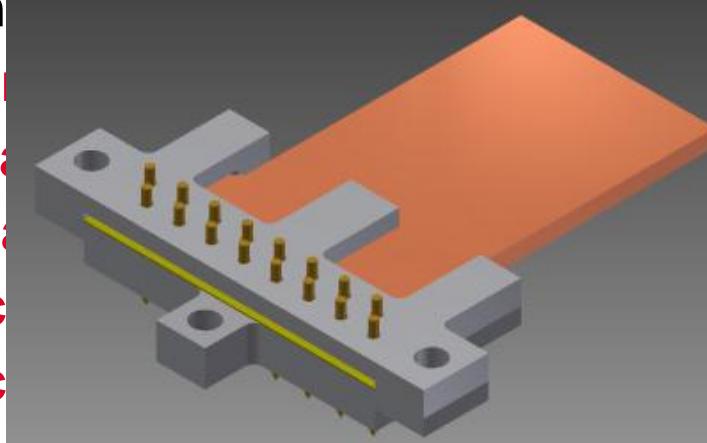
EDELWEISS-III: IMPROVED NEUTRON SHIELDING

- ~10 cm of polyethylene below detectors.
- ~6 cm of PE on the sides and top.
- Low-radioactive cables and connectors.
- New copper screens (cryostat), plates and bars.
- External shielding and veto as in EDELWEISS-II.



EDELWEISS-III: IMPROVED NEUTRON SHIELDING

- ~10 cm of polyethylene below detectors.
- ~6 cm of PE on the sides and top.
- Low-rate cables are connected.
- New cryostat screens (cryostat), plates and bars.
- External shielding and veto as in EDELWEISS-II.



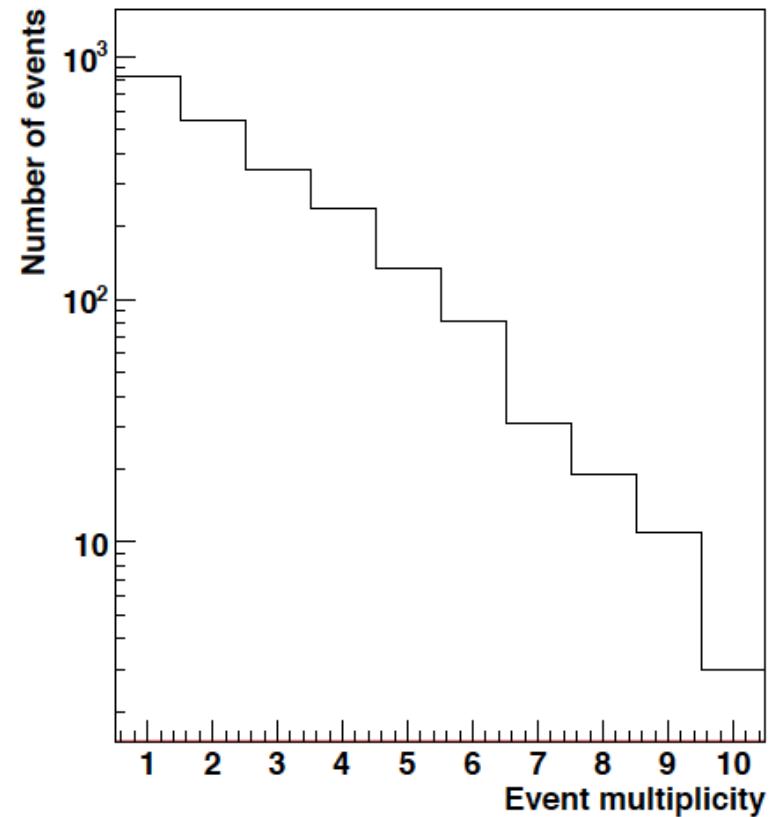
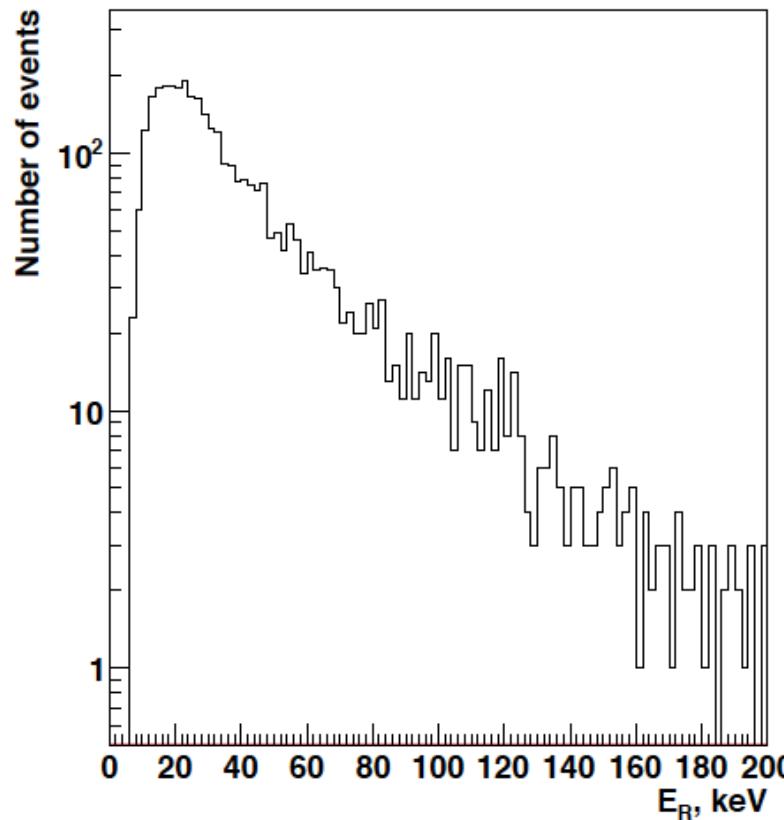
LRT 2013 - LNGS - X-F Navick

RADIOACTIVITY MEASUREMENTS FOR EDELWEISS-III

Component	Material	Mass (kg)	Radioactivity in materials (mBq/kg)				
			^{226}Ra	^{228}Th	^{210}Pb	^{40}K	^{60}Co
Cables	Apical, Cu	0.2	26 ± 15	<50	346 ± 110	167 ± 126	<25
Connectors	Delrin, brass	0.056	32 ± 20	<53	11000 ± 1000	680 ± 220	<36
Screws	Brass	0.1	4.9 ± 1.3	<3	<100	<40	<3
Screens, support	Cu	~500	<0.016	<0.012	—	<0.11	<0.018
Shielding	CH_2	~90	0.65 ± 0.08	0.30 ± 0.07	<3	<1	<0.06
Connectors	Al, resin	1.6	80 ± 9	158 ± 6	743 ± 48	129 ± 33	<4
Cables	PTFE	~1	<35	<28	190 ± 40	440 ± 110	<19
Cold electronics	PCB	0.23	7800 ± 500	12600 ± 1200	4500 ± 400	6500 ± 1200	<120
Warm electronics	PCB	-	$26500 \pm 1500^*$	19300 ± 1100	82000 ± 5000	27000 ± 3000	-

- Contamination for ‘warm electronics’ is given for the whole set.
- 40 crystals with the total fiducial mass of 24 kg.

NEUTRON BACKGROUND IN EDELWEISS-III



Assuming 1 year of running with a threshold of 20 keV

- Energy spectrum and multiplicity distribution for neutron events from the inner polyethylene shielding (U decay chain, 2.6×10^4 years of statistics).

BACKGROUND IN EDELWEISS-III

Component	Material	Mass (kg)	Gammas (kg×days) ⁻¹	Neutrons Events/year
Cables	Apical, Cu	0.2	5–11	0.03–0.07
Connectors	Delrin, brass	0.056	1–8	0.02–0.06
Screws	Brass	0.1	<1	<0.003
Screens, support	Cu	~500	<7	<0.01
Shielding	CH ₂	~90	7–14	0.03–0.06
Connectors	Al, resin	1.6	0.2–0.3	0.3–0.5
Cables	PTFE	~1	<1	<0.1
Cold electronics	PCB	0.23	1–2	0.04–0.06
Warm electronics	PCB	-	<1	0.3–0.5
Total			14–44	0.7–1.4

- Additional contribution from lead shielding and steel support structure will bring the total neutron rate to 0.7–1.7 events per year.
 - With a threshold of 15 keV the neutron rate will increase by 15–20%.
 - Muon-induced neutrons: < 3.8 events per year with a very conservative estimate of veto efficiency
- (B. Schmidt et al. Astropart. Phys. 44 (2013) 28).

SUMMARY

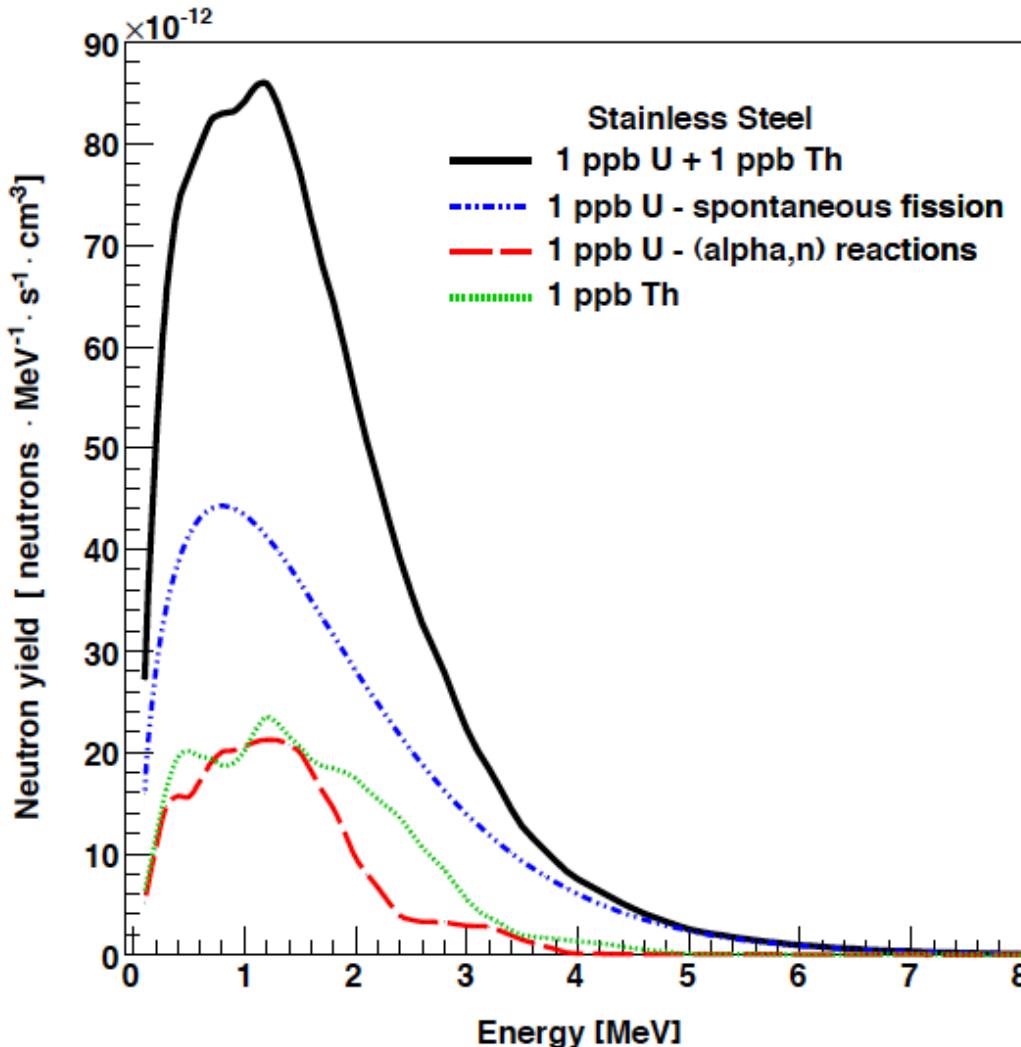
- Background in EDELWEISS-II is well understood.
- The detector and background models matches well the calibration data and gamma background.
- The total number of events in EDELWEISS-II exposure of $384 \text{ kg}\times\text{days}$ is < 5.1 events with 1.0-3.1 events expected from neutrons.
- EDELWEISS-III: 40 detectors, $\sim 24 \text{ kg}$ fiducial mass by the end 2013, $3000 \text{ kg}\times\text{days}$, $5\times 10^{-9} \text{ pb}$ in 2014.
- Additional PE shielding, purer materials and detectors with better discrimination power.
- An order of magnitude improvement in neutron event rate per unit mass and time compared to EDELWEISS-II.
- A factor of 2-6 improvement in gamma-ray event rate per unit mass and time.
- EURECA: $150 \text{ kg} \rightarrow 1 \text{ tonne}$, expected background: $\leq 1 \text{ tonne}^{-1} \text{ year}^{-1}$.

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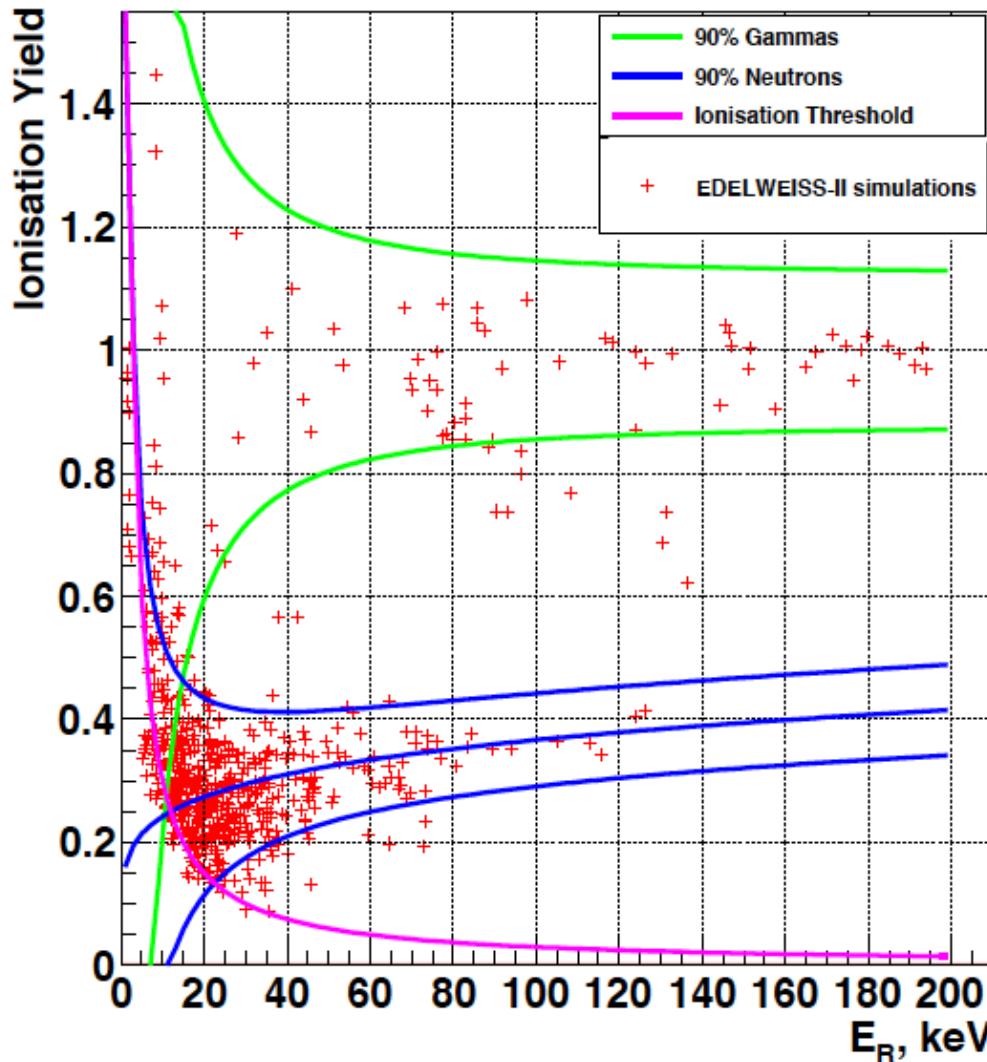
Direction DSM
Département IRFU
Service SEDI

NEUTRON SIMULATIONS



- Neutron yields and spectra - from SOURCES4.
 - (alpha,n) crosssections and excitation functions - from measurements or EMPIRE-2.19 calculations.
- V. Tomasello. NIMA
595 (2008) 431-438.

NEUTRON SIMULATIONS



- Neutrons from U decay chain in stainless steel of the support structure.
 - 4.5×10^4 years of statistics.
 - Full GEANT4 MC including detector response taken from calibrations (neutron and gamma sources).
- E. Armengaud et al.,
in preparation.