EDELWEISS/RICOCHET

Joint project for Direct Dark Matter search and precision study of CEνNS with new cryogenic detectors

EDELWEISS:Direct search for dark matter particles, HPGe detectors at ~ 20 mK, low background conditions in the deep underground laboratory (LSM)

For the last 25 years EDELWEISS has been a leading experiment in the direct search of Dark Matter with HPGe bolometer detectors.

Unique proprietary detector technology. New generations of detectors with improved characteristics for each new phase of the experiment (lower background, lower energy threshold).

Thanks to the latest developments, the experiment remains competitive in regions inaccessible to large Ar / Xe experiments.

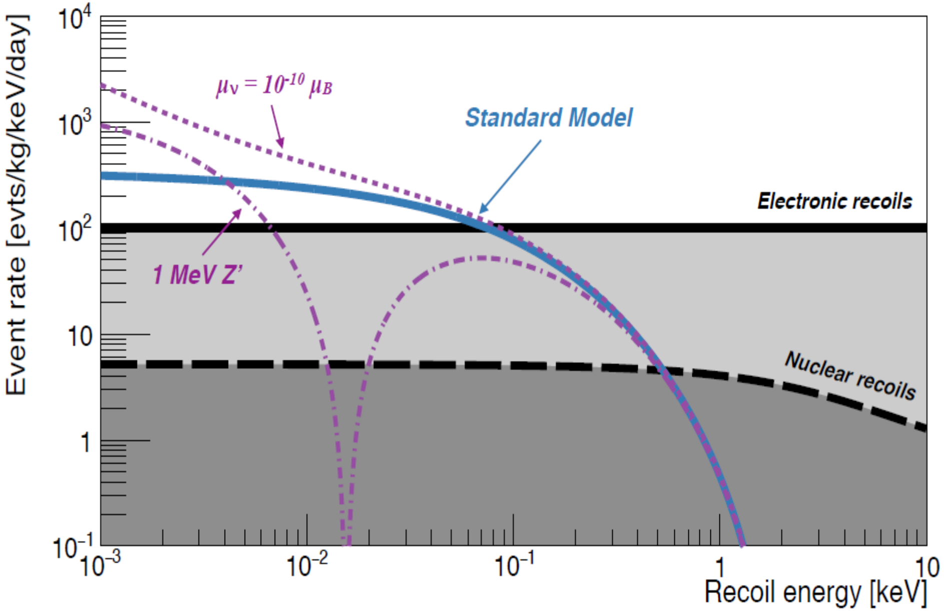
RICOCHET

New detector-bolometers developed by EDELWEISS have unique properties for detecting **low-energy nuclei recoils**.

It is expected that the influence of New Physics will lead to spectral distortions in the range of recoil nuclear energies induced by coherent neutrino scattering below 100 eV.

It is proposed to extend the use of the detectors developed by EDELWEISS to CEνNS studies in the region of full coherence (reactor antineutrinos). This part of the project was named **Ricochet**.

Due to direct energy reconstruction (heat signal) the main uncertainty arising due to not well known quenching in germanium will be avoided. The aim is a % level precision.

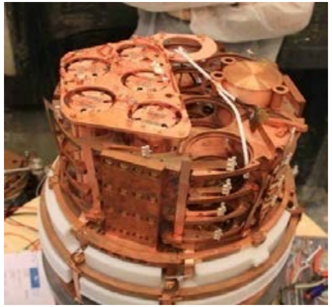


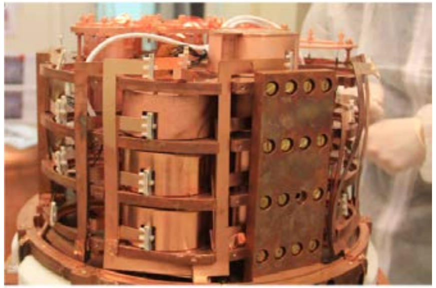
Edelweiss

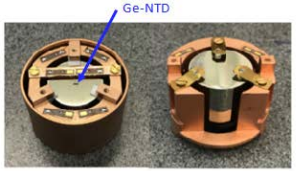
Expérience pour DEtecter Les WIMPs En Site Souterrain

The current phase results

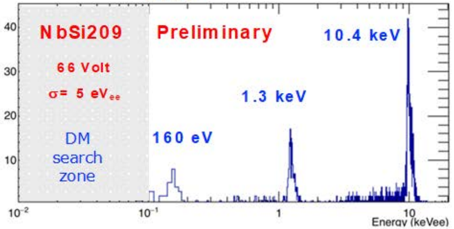
- Continuous data taking in the LSM underground laboratory from January 2019 – July 2020;
- Almost continuous data taking in the test dry cryostat in Lyon (R&D);
- 11 different Ge detectors;
  - Rest of the cryostat used for joint physics run with CUPID-Mo 0ν2β search
- Compare detector physics in 32 g, 200 g and 800 g detectors;
- Compare performance of NTD and NbSi-TES heat sensors;
- Obtaining near single-electron sensitivity on 33 and 200 g detectors: exploration of DM interactions with electrons and nuclei.
- Study of low-energy backgrounds in Ge detectors operated with large Neganov-Trofimov-Luke amplifications.



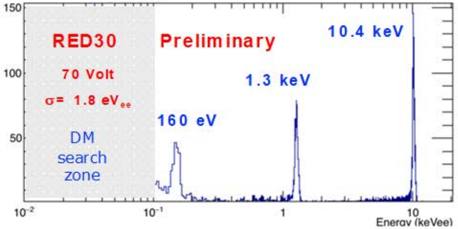




- NbSi209: 200g Ge with TES thermal sensor



- RED30 : 33 g Ge Al electrodes, NTD thermal sensor

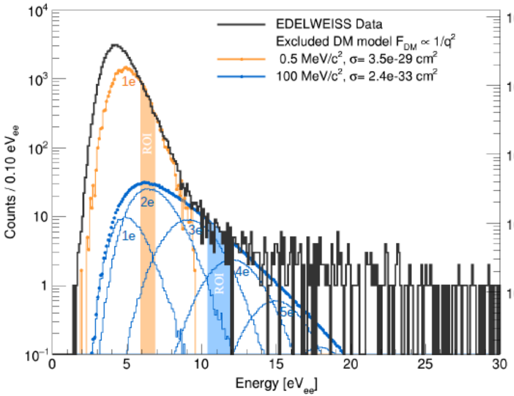


EDELWEISS has been able to obtain at the LSM run the lowest radioactive background levels below 10 keV in massive Ge detectors (~0.1 evt/kg/day/keV)

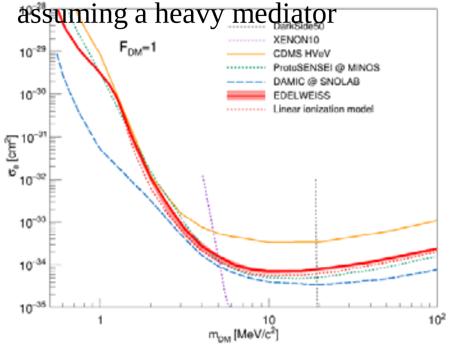
World leading results for DM search (a lot of data treatment is still in process)

New 2020 EDELWEISS results

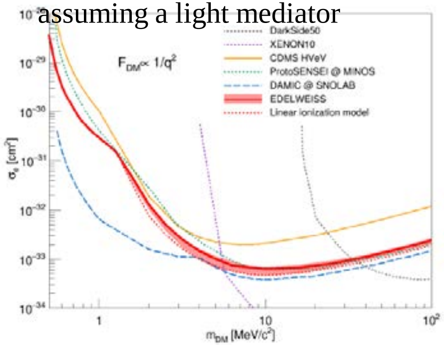
(PRL 125, 141301, 2020)



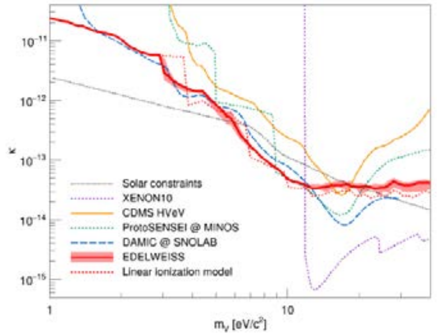
Scattering of DM particles on electrons assuming a heavy mediator



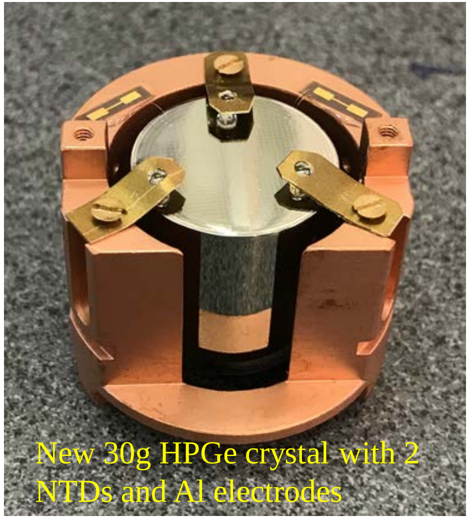
Scattering of DM particles on electrons assuming a light mediator



Kinetic mixing ***k*** of a dark photon



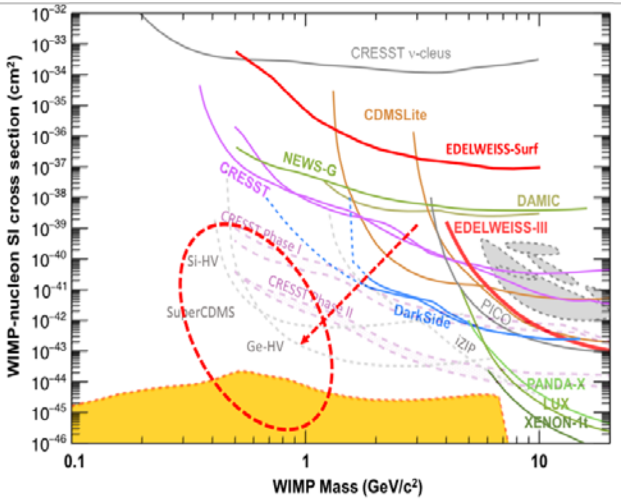
An unprecedented **charge resolution of 0.53 electron-hole pairs** (RMS) has been achieved using the Neganov-Trofimov-Luke internal amplification. We set the first Ge-based constraints on sub-MeV/c² DM particles interacting with electrons, as well as on dark photons down to 1 eV/c². These are competitive with other searches and demonstrate the high relevance of cryogenic Ge detectors for the search of DM interactions producing eV-scale electron signals.

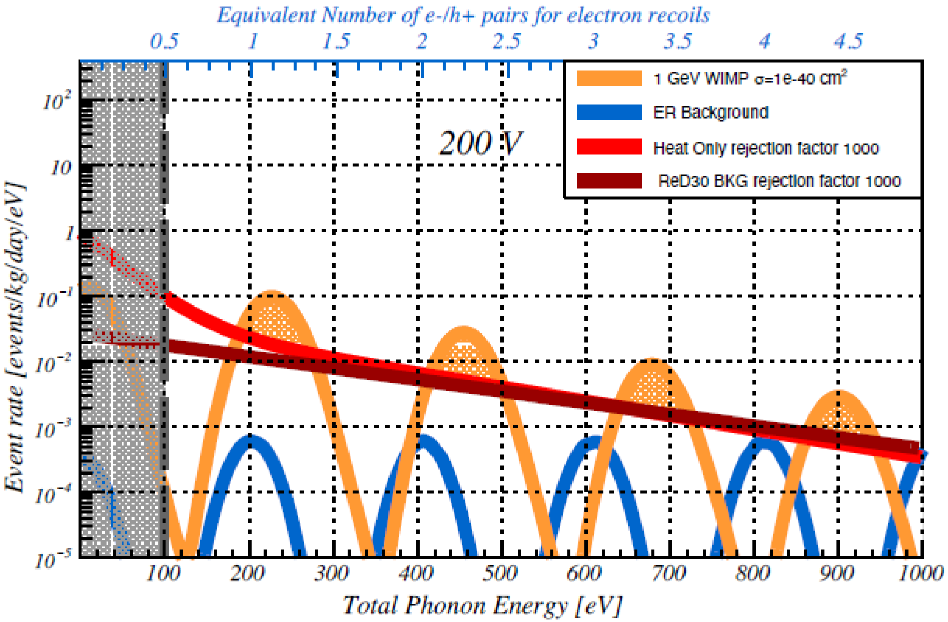


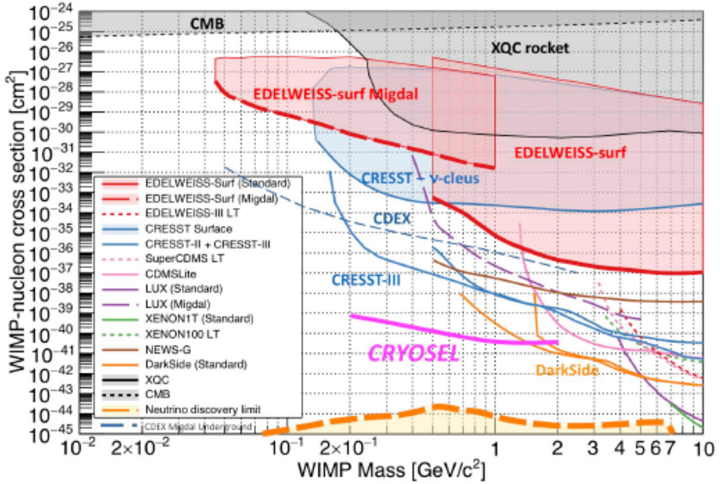
New 30g HPGe crystal with 2 NTDs and Al electrodes

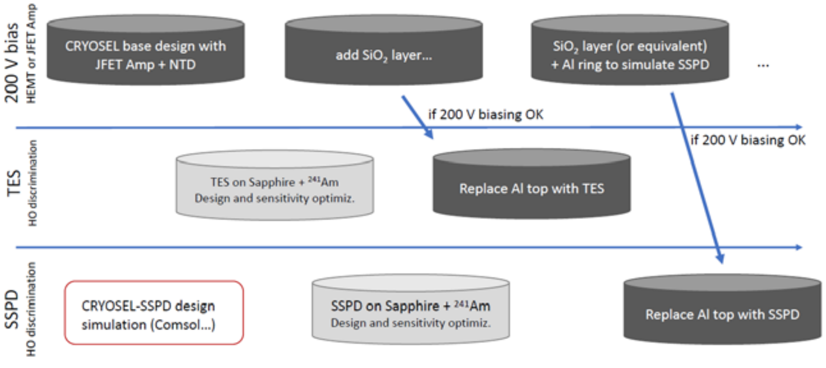
In new class of light DM models the interaction with normal matter comes from the coupling of a Dark Sector photon with the normal photon.

How to detect: DM-electron scattering
Theory predictions: complete coverage (10^{-40} cm²) possible with 1 kg year exposure of a detector sensitive to the single electron in the absence of any background









200 V bias
HEMT or JFET Amp

CRYOSEL base design with JFET Amp + NTD

add SiO_2 layer...

SiO_2 layer (or equivalent) + Al ring to simulate SSPD

...

if 200 V biasing OK

if 200 V biasing OK

TES
HO discrimination

TES on Sapphire + ^{241}Am
Design and sensitivity optimiz.

Replace Al top with TES

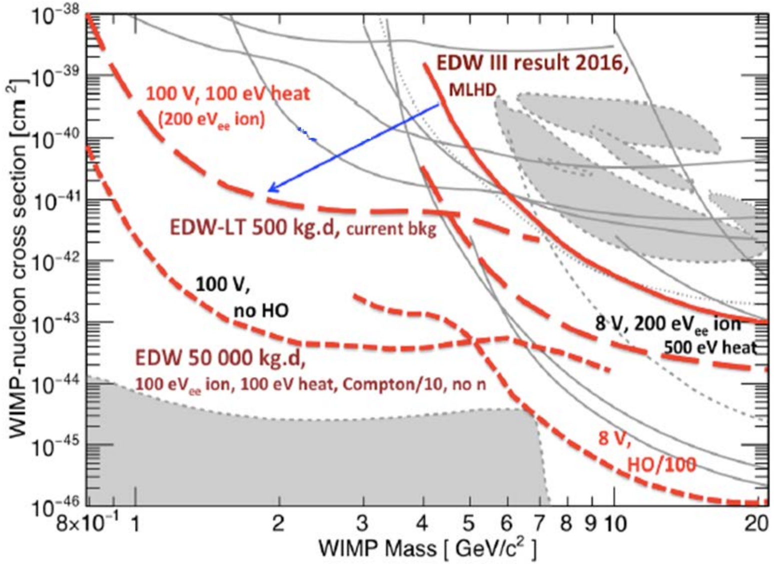
SSPD
HO discrimination

CRYOSEL-SSPD design simulation (Comsol...)

SSPD on Sapphire + ^{241}Am
Design and sensitivity optimiz.

Replace Al top with SSPD

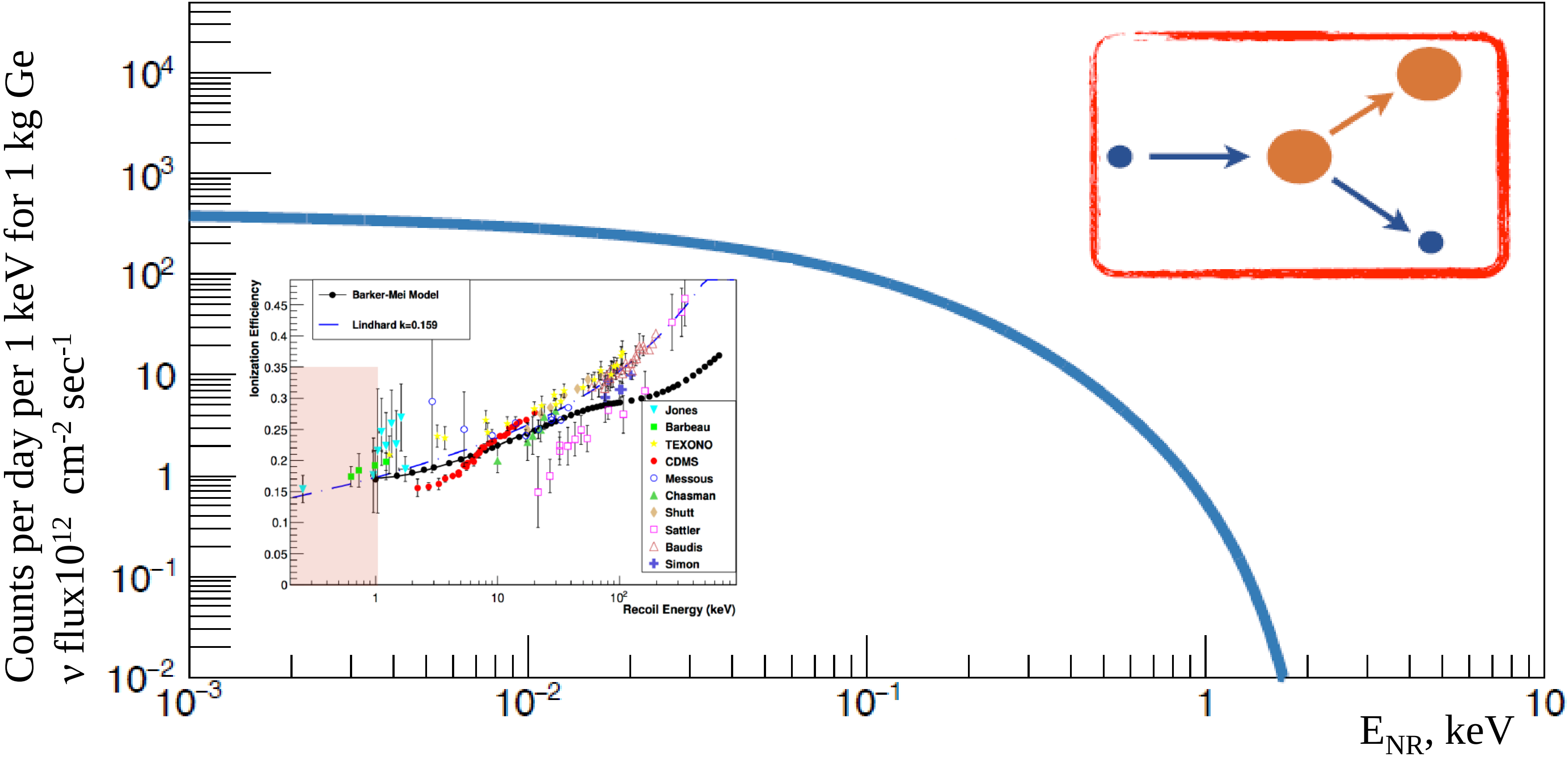
Lab and LSM physics runs to be planned upon R&D results



Coherent elastic neutrino-nucleus scattering (CEνNS)

The use of bolometers makes it possible to measure the energy of the nucleus directly (heat signal), in contrast to semiconductor detectors that measure ionization.

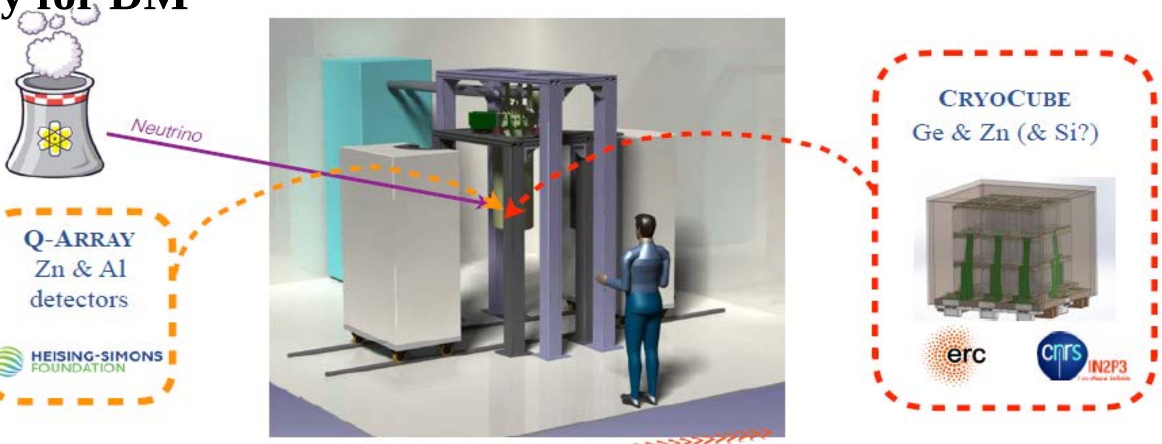
This it the way to the precision measurements.



J. Billard et al., JCAP 11 (2018) 016

EDELWEISS bolometers - not only for DM

RICOCHET aims at building the ultra low-energy **CEνNS neutrino observatory** dedicated to physics beyond the Standard Model



RICOCHET
A Coherent Neutrino Scattering Program

Northwestern University
LPSC Grenoble
CSNSM
IPNL
MIT
NÉEL
Wisconsin
UMASS AMHERST

50 eV energy threshold with a 10^3 background rejection down to the threshold

The first key feature of the RICOCHET program, compared to other planned or ongoing CEνNS projects, is to aim for a kg-scale experiment with significant background rejection down to the O(10) eV energy threshold.

The CRYOCUBE: a compact tabletop size setup

27 x 33 g detectors
8 x 8 x 8 cm^3
radio-pure infrared-tight copper box

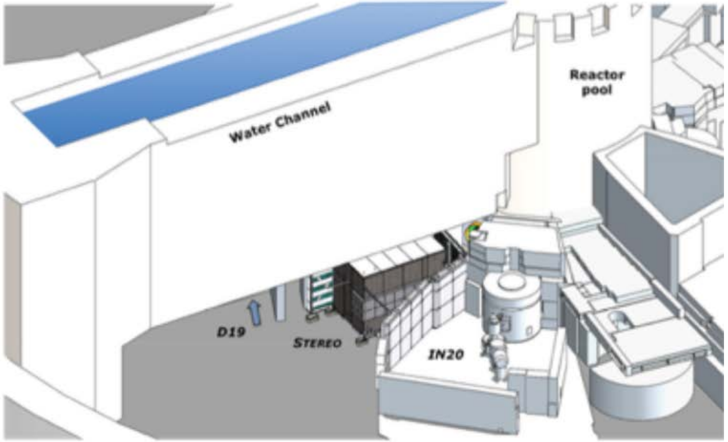
Neutrino source

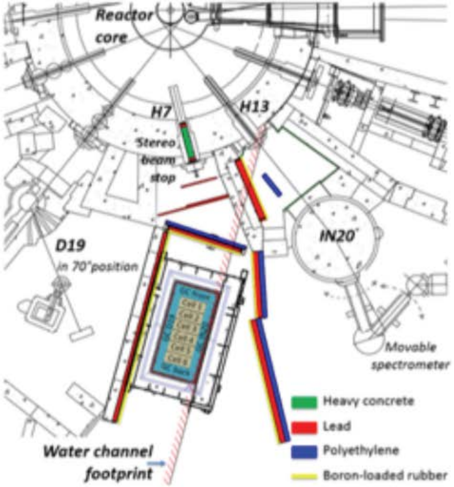
RICOCHET: first phase at ILL (Grenoble)

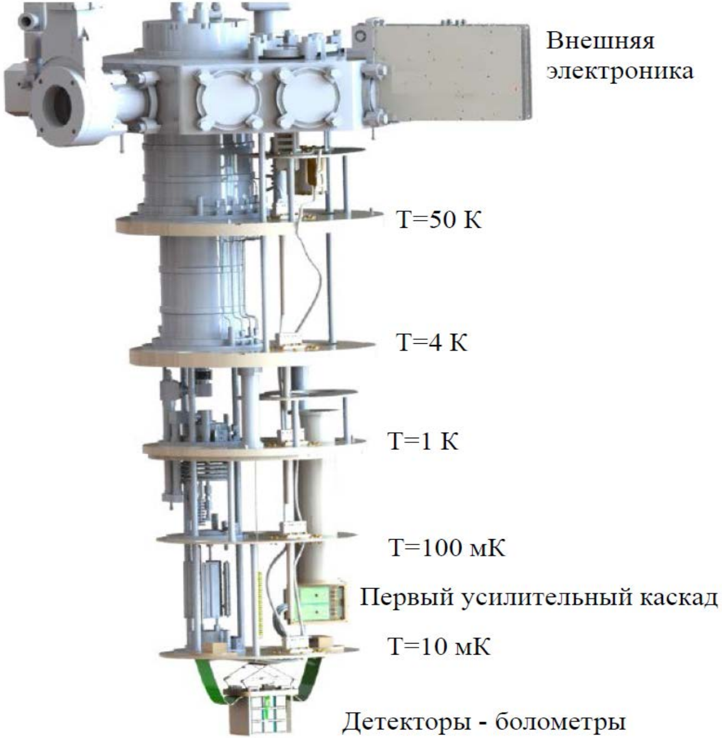
- 58 MW research reactor;
- Total neutrino flux: 1×10^{19} ν/sec;
- 20 events of CEνNS per day for RICOCHET (1 kg) for 7 m distance;
- 3-4 ON/OFF per year;
- Cosmic shield ~15 m.w.e.;
- STEREO data about neutrino spectrum and backgrounds.


December 2020: place for the RICOCHET at ILL

STEREO Coll., JINST 2018








CryoConcept

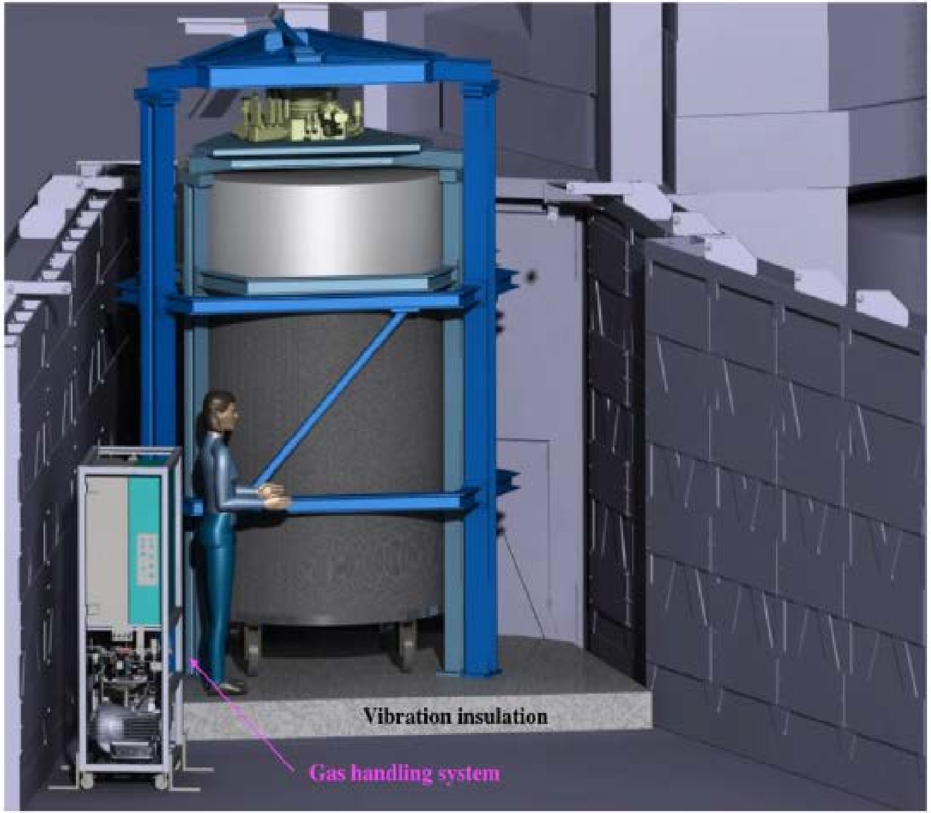
Description | Total Excl. VAT

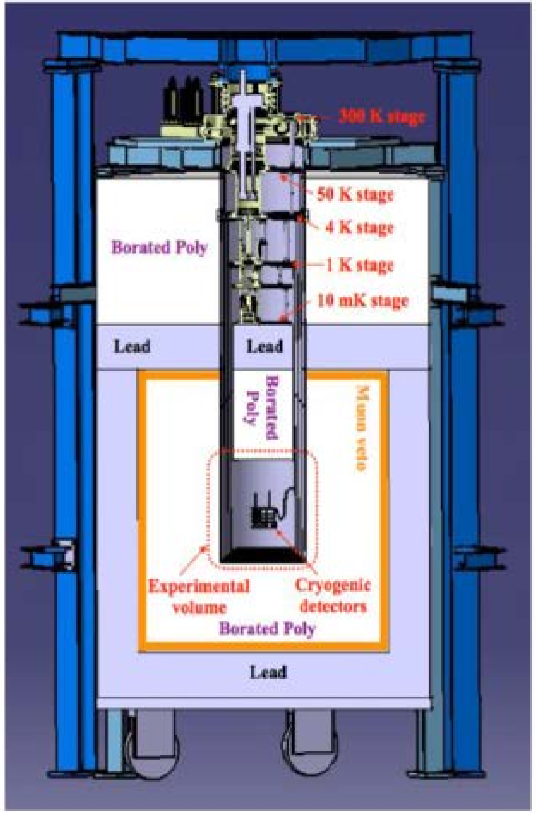
A **HEXA-DRY 200 – Cryogen Free Dilution Refrigerator**

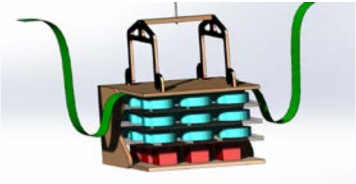
The HEXA-DRY 200 dilution refrigerator has been designed to achieve three main goals:

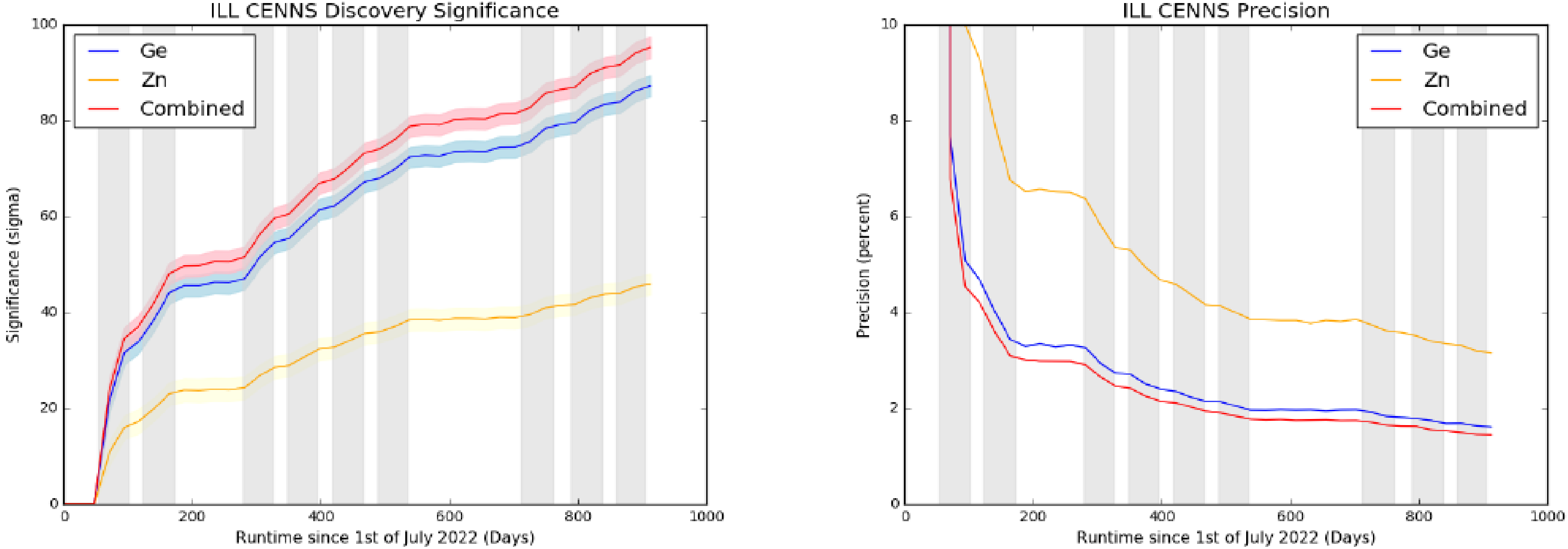
LARGE INSIDE: to give to the user the maximum available space to set up his experiment.

- Dilution unit off axis
- JT cooler parallel to dilution unit
- More than 50% of available volume for experimentation

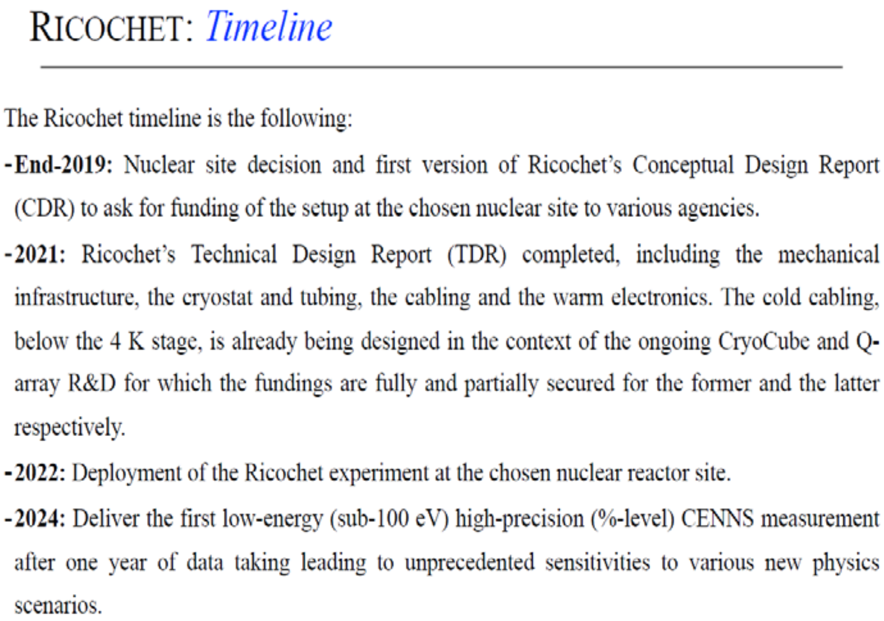

Vibration insulation
Gas handling system


300 K stage
50 K stage
4 K stage
1 K stage
10 mK stage
Borated Poly
Lead
Lead
Borated Poly
Muon veto
Experimental volume
Cryogenic detectors
Borated Poly
Lead





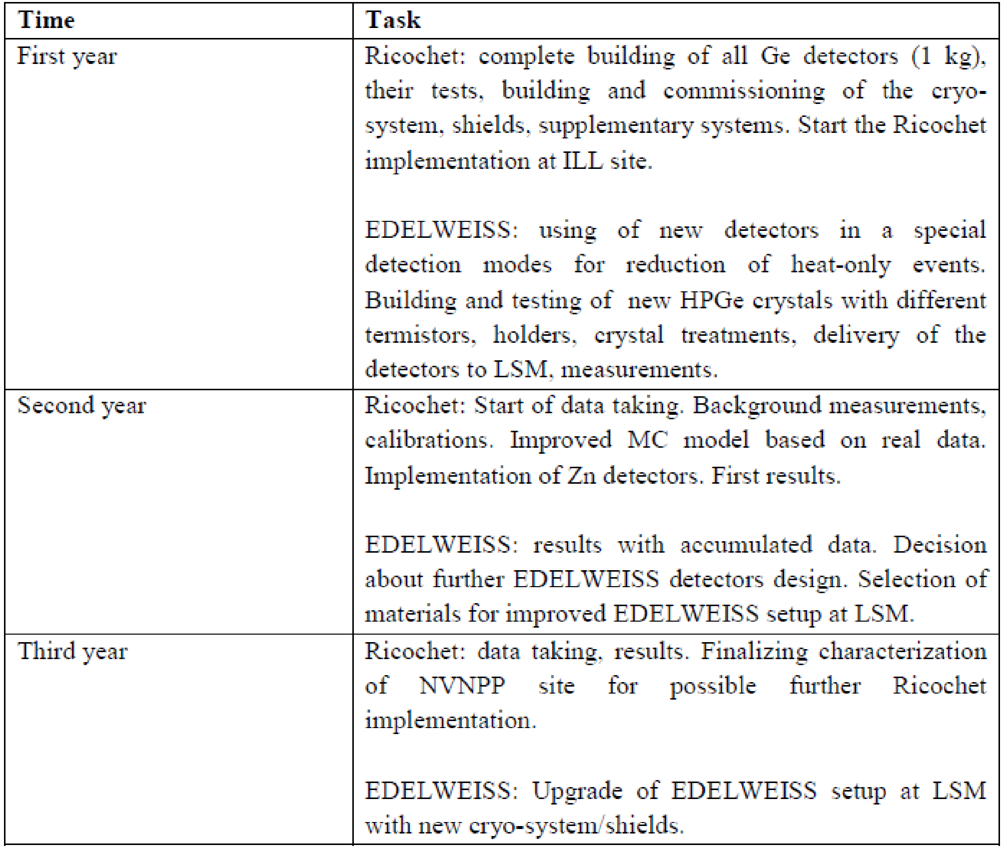
CEvNS discovery significance and precision as a function of exposure. Median significance and precision (and 95% confidence level bands) for the discovery of CEvNS using Ge (blue), Zn (yellow), and the combination of the two (red).



RICOCHET: *Timeline*

The Ricochet timeline is the following:

- **-End-2019:** Nuclear site decision and first version of Ricochet's Conceptual Design Report (CDR) to ask for funding of the setup at the chosen nuclear site to various agencies.
- **-2021:** Ricochet's Technical Design Report (TDR) completed, including the mechanical infrastructure, the cryostat and tubing, the cabling and the warm electronics. The cold cabling, below the 4 K stage, is already being designed in the context of the ongoing CryoCube and Q-array R&D for which the fundings are fully and partially secured for the former and the latter respectively.
- **-2022:** Deployment of the Ricochet experiment at the chosen nuclear reactor site.
- **-2024:** Deliver the first low-energy (sub-100 eV) high-precision (%-level) CENNS measurement after one year of data taking leading to unprecedented sensitivities to various new physics scenarios.



Time	**Task**
First year	Ricochet: complete building of all Ge detectors (1 kg), their tests, building and commissioning of the cryo-system, shields, supplementary systems. Start the Ricochet implementation at ILL site. EDELWEISS: using of new detectors in a special detection modes for reduction of heat-only events. Building and testing of new HPGe crystals with different termistors, holders, crystal treatments, delivery of the detectors to LSM, measurements.
Second year	Ricochet: Start of data taking. Background measurements, calibrations. Improved MC model based on real data. Implementation of Zn detectors. First results. EDELWEISS: results with accumulated data. Decision about further EDELWEISS detectors design. Selection of materials for improved EDELWEISS setup at LSM.
Third year	Ricochet: data taking, results. Finalizing characterization of NVNPP site for possible further Ricochet implementation. EDELWEISS: Upgrade of EDELWEISS setup at LSM with new cryo-system/shields.

ALL:

Assembly of the setup

Commissioning

Running and data taking

Calibrations

MC

Data analysis

Our responsibilities:

Neutron measurements

Radon measurements and control

Low radioactive materials selection

Performing of calibrations (work with radioactive materials, procedures, etc)

New detectors (detectors with low thresholds)

Ricochet cryosystem

Development of the Ricochet veto system

NVNPP site for further stages

We participates:

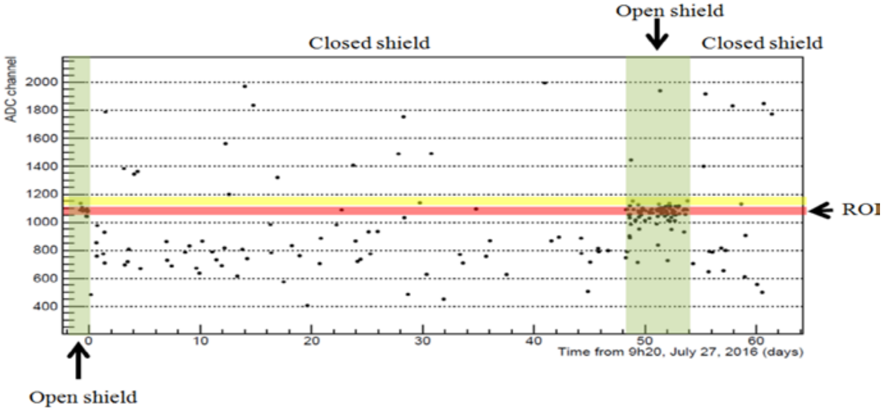
Measurements of neutrons in coincidence with muon veto (EDW)

Data base

Measurements of low neutron flux

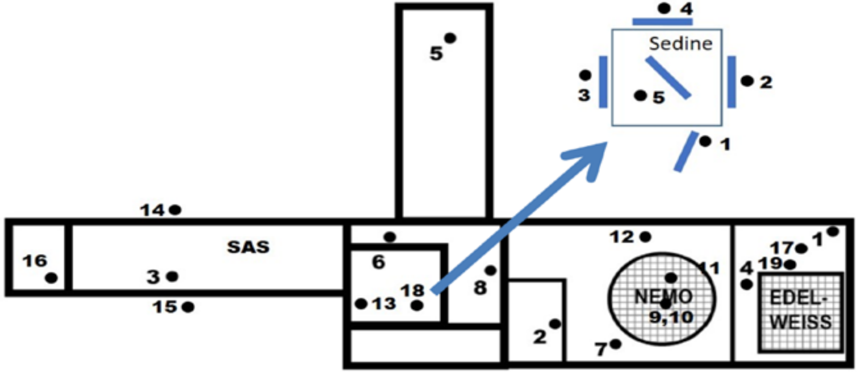
^{3}He low background detector on the top of the EDELWEISS cryostat

$< 10^{-8}$ n cm^{-2} sec^{-1}



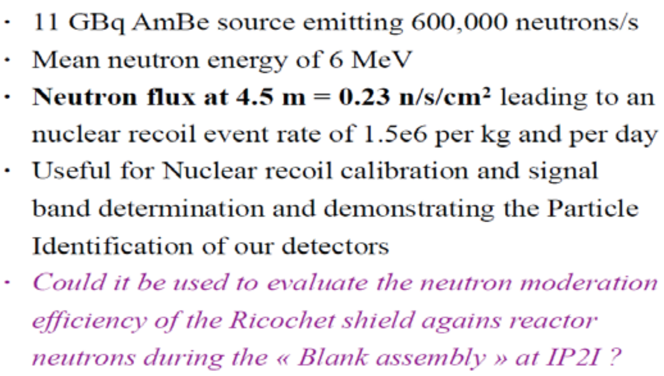
Continuous monitoring of LSM thremal neutron flux (new place from 2019)

3.05 ± 0.05 × 10^{-6} n cm^{-2} sec^{-1}



Neutron background for Ricochet

- Measurements at Lyon with HPGe detectors-bolometers for ambient background and with neutron source;
- Measurements fast and thermal neutrons in the same shield for ambient neutrons and for neutron source;
- Measurements with the same neutron detectors at ILL with reactor ON/OFF;
- Comparison of ILL data with Lyon one provides information about expected background in HPGe in the ROI;
- Design of the shield based on that input.



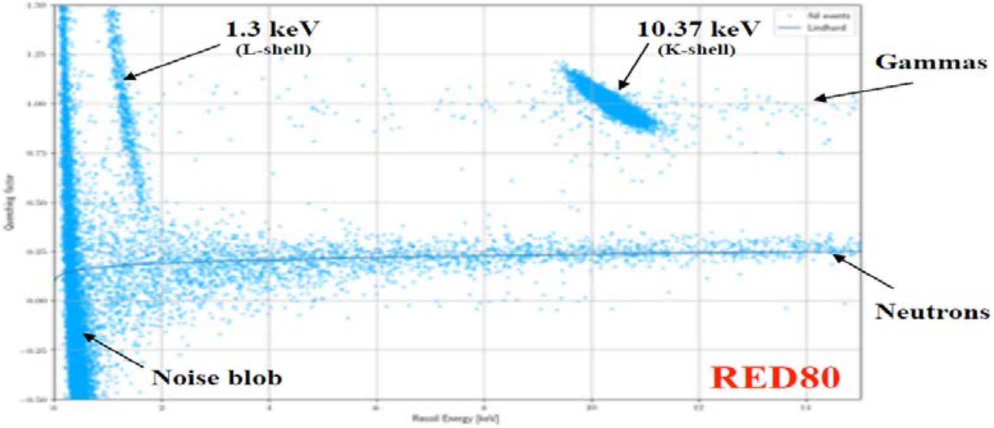
- 11 GBq AmBe source emitting 600,000 neutrons/s
- Mean neutron energy of 6 MeV
- **Neutron flux at 4.5 m = 0.23 n/s/cm²** leading to an nuclear recoil event rate of 1.5e6 per kg and per day
- Useful for Nuclear recoil calibration and signal band determination and demonstrating the Particle Identification of our detectors
- *Could it be used to evaluate the neutron moderation efficiency of the Ricochet shield agains reactor neutrons during the « Blank assembly » at IP2I ?*

Измерения в iP2i

(a) Back view

(b) Side view

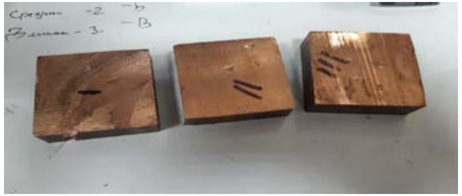
Figure 3.3: AmBe source shielding made of milk brick for safety issue and lead on the front to shield against gamma, when deployed at positions B and C.



Low radioactive materials

HPGe detectors (LSM)

Low radioactive materials
Infrastructure at JINR for sample preparation and preliminary tests



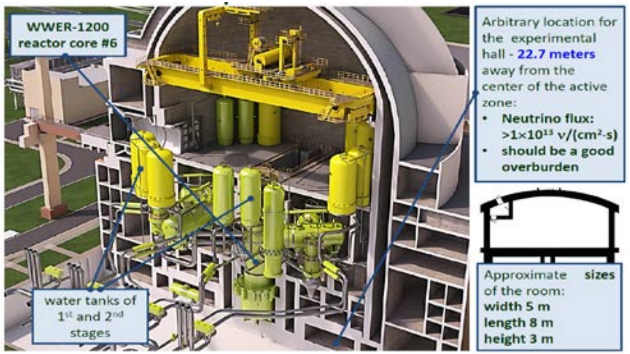
Solder (60% of Sn and 40% of archPb – (Talanta 192)

Low radioactive Flux (JINST 15 (05), T05004)

Unit #6 NovovoronezhNPP

Generation 3+ WWER-1200

Maximal thermal power 3212 MW

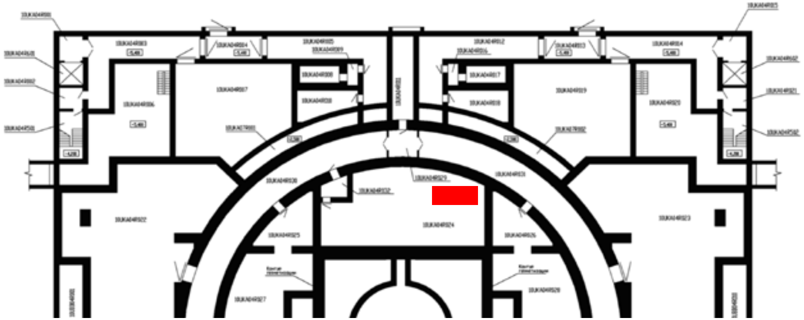


Arbitrary location for the experimental hall - **22.7 meters** away from the center of the active zone:

- **Neutrino flux: $>1\times10^{13}$ ν/(cm²·s)**
- **should be a good overburden**

Approximate **sizes** of the room:
width 5 m
length 8 m
height 3 m

Place investigated: -5.4 m



Maximal muon flux: 16.2 μ m^{-2} sr^{-1} sec^{-1},
~50 m.w.e.

Neutron flux: $<10^{-4}$ m^{-2} sec^{-1},
Factor 20 to the sea level.

SWOT analysis (main strengths)

- The one detector technology to study lowest energy part of the spectrum is in hands: HPGe detectors-bolometers (for both purposes EDELWEISS and Ricochet), another one Zn-bolometers is under development;
- The detector's performances (energy thresholds, energy resolution, efficiency, stability) were extensively tested in sea-level and underground laboratories;
- Similar dry dilution cryostat as one that will be used in the Ricochet is now used for 5 years; The low background/low noise cryostat for Ricochet will be ready in beginning of 2021;
- Place for first phase of the Ricochet is secured at ILL; The place has many advantages: known backgrounds, known neutrino spectrum, frequent reactor's ON/OFF cycles, relatively easy logistic, money for installation are available;
- The collaboration has many years experience in running direct DM search and neutrino from reactor experiments;

SWOT analysis (main challenges)

The main challenge for EDELWEISS and Ricochet rare-event search experiments is to distinguish DM and CEνNS signals from recoils induced by natural radioactivity, cosmic rays and other sources.

Reduction and understanding of backgrounds is the key to the success of the experiments. The EDELWEISS/Ricochet experiments together with traditional methods of background reduction uses several special methods for discrimination of backgrounds (heat/ionization measurements, FID detectors for discrimination of surface events, PSD for reduction of the noise).

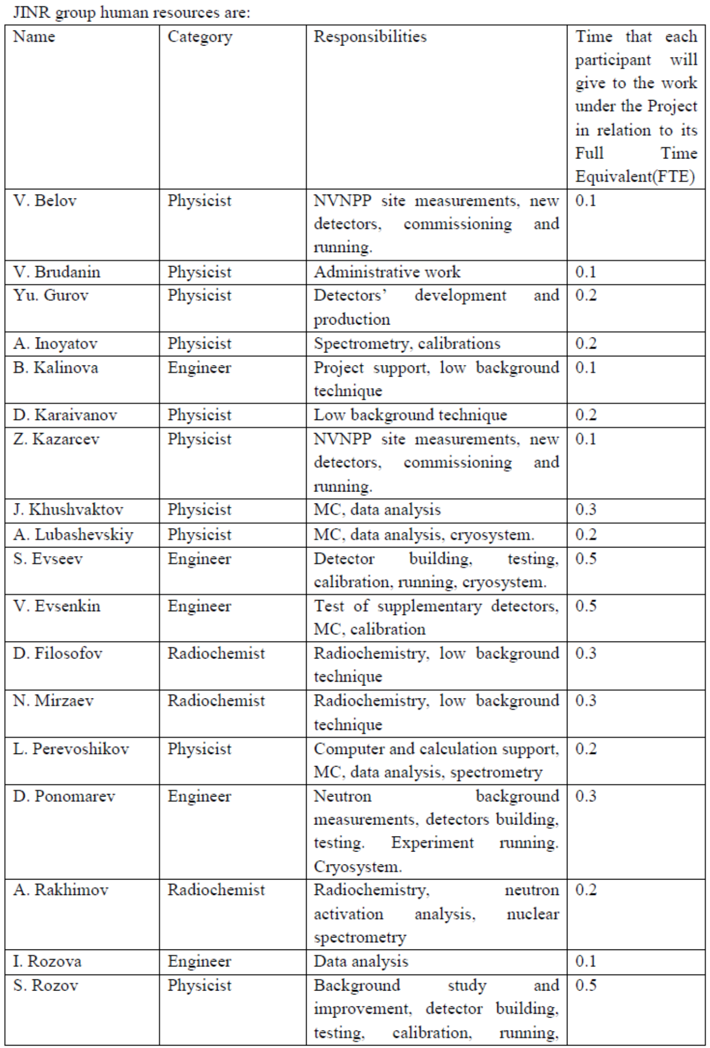
For the Ricochet experiment proper interpretation of results will be strongly depended on stability of **the neutron background**, especially for comparison of reactor ON/OFF runs. Analysis of this question is addressed in Appendix 4 of the project document provided to PAC.

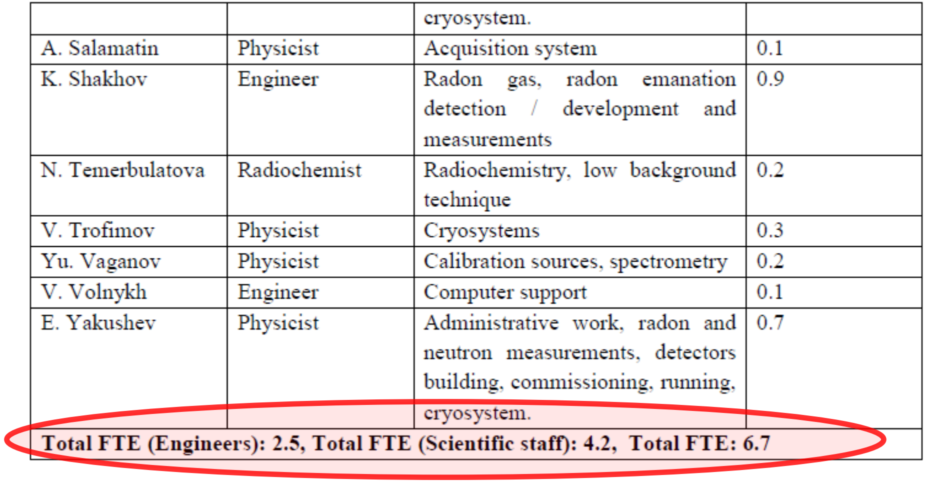
Another important point to worry about for the Ricochet is **vibrations** that could generate unwelcome low energy noises in the region of interest. Analysis of this question is addressed in Appendix 5 of the project document provided to PAC.

As the Ricochet experiment aim is **1% level precision measurements**, the questions about possible **systematic** become extremely important. Analysis of the Ricochet systematic is performed in Appendix 3 of the project document provided to PAC.

Some other issues: The schedule of the project can be significantly affected due to factors connected to **stability of running** of all components of the experiment including cryosystem with dilution cryostat and its stability, electronics, acquisition system, subsystems. Though **failure of different components** of the setups is difficult to predict, the collaboration already accumulated more than 20 years of running of the cryogenic setups, with accumulated **experience in fixing of arising problems including problems with the cryosystem in short time**.

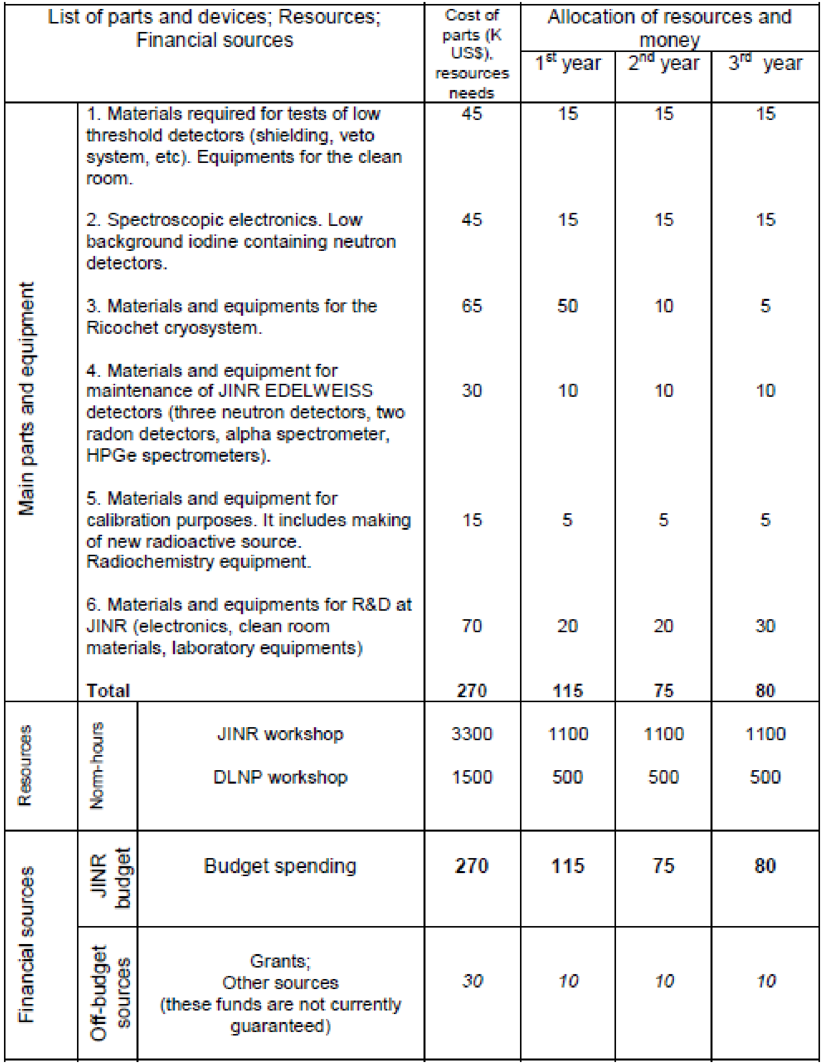
Critical part is avoiding of **contaminations**. The trace activities on unacceptable level can be accumulated due to calibrations with not properly tested (on radioactive leak and integrity) radioactive sources, due to radon and other radioactive gases in atmosphere, due to dust and dirt. To avoid these problems a **set of special procedures is in place during all stages of experiment** starting from the detector production to calibration measurements. Only specially certified materials can be entered into the clean room surrounding the setup. All works performed in the clean room are under continuous control of dust and radon level. Only double encapsulated and properly tested radioactive sources are used for calibrations. Minimal quantity of such sources is allowed. Special clean environment will be build for the Ricochet setup at ILL site.



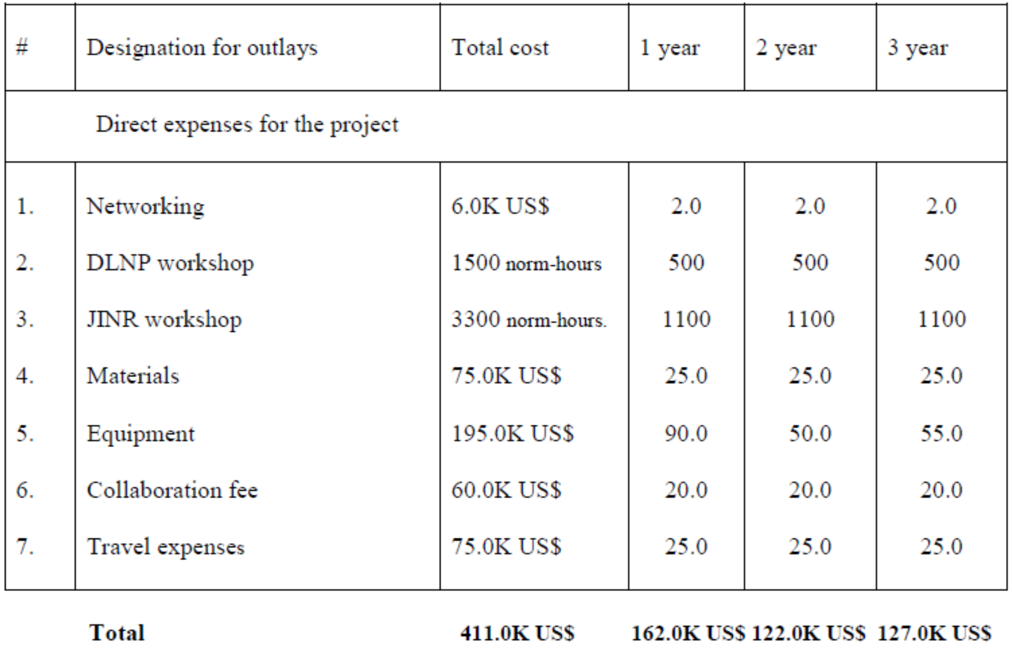


JINR group human resources are:

Name	Category	Responsibilities	Time that each participant will give to the work under the Project in relation to its Full Time Equivalent(FTE)
V. Belov	Physicist	NVNPP site measurements, new detectors, commissioning and running.	0.1
V. Brudanin	Physicist	Administrative work	0.1
Yu. Gurov	Physicist	Detectors' development and production	0.2
A. Inoyatov	Physicist	Spectrometry, calibrations	0.2
B. Kalinova	Engineer	Project support, low background technique	0.1
D. Karaivanov	Physicist	Low background technique	0.2
Z. Kazarcev	Physicist	NVNPP site measurements, new detectors, commissioning and running.	0.1
J. Khushvaktov	Physicist	MC, data analysis	0.3
A. Lubashevskiy	Physicist	MC, data analysis, cryosystem.	0.2
S. Evseev	Engineer	Detector building, testing, calibration, running, cryosystem.	0.5
V. Evsenkin	Engineer	Test of supplementary detectors, MC, calibration	0.5
D. Filosofov	Radiochemist	Radiochemistry, low background technique	0.3
N. Mirzaev	Radiochemist	Radiochemistry, low background technique	0.3
L. Perevoshikov	Physicist	Computer and calculation support, MC, data analysis, spectrometry	0.2
D. Ponomarev	Engineer	Neutron background measurements, detectors building, testing. Experiment running. Cryosystem.	0.3
A. Rakhimov	Radiochemist	Radiochemistry, neutron activation analysis, nuclear spectrometry	0.2
I. Rozova	Engineer	Data analysis	0.1
S. Rozov	Physicist	Background study and improvement, detector building, testing, calibration, running, cryosystem.	0.5
A. Salamatin	Physicist	Acquisition system	0.1
K. Shakhov	Engineer	Radon gas, radon emanation detection / development and measurements	0.9
N. Temerbulatova	Radiochemist	Radiochemistry, low background technique	0.2
V. Trofimov	Physicist	Cryosystems	0.3
Yu. Vaganov	Physicist	Calibration sources, spectrometry	0.2
V. Volnykh	Engineer	Computer support	0.1
E. Yakushev	Physicist	Administrative work, radon and neutron measurements, detectors building, commissioning, running, cryosystem.	0.7
Total FTE (Engineers): 2.5, Total FTE (Scientific staff): 4.2, Total FTE: 6.7			



List of parts and devices; Resources; Financial sources			Cost of parts (K US$), resources needs	Allocation of resources and money		
				1st year	2nd year	3rd year
Main parts and equipment		1. Materials required for tests of low threshold detectors (shielding, veto system, etc). Equipments for the clean room.	45	15	15	15
		2. Spectroscopic electronics. Low background iodine containing neutron detectors.	45	15	15	15
		3. Materials and equipments for the Ricochet cryosystem.	65	50	10	5
		4. Materials and equipment for maintenance of JINR EDELWEISS detectors (three neutron detectors, two radon detectors, alpha spectrometer, HPGe spectrometers).	30	10	10	10
		5. Materials and equipment for calibration purposes. It includes making of new radioactive source. Radiochemistry equipment.	15	5	5	5
		6. Materials and equipments for R&D at JINR (electronics, clean room materials, laboratory equipments)	70	20	20	30
		Total	**270**	**115**	**75**	**80**
Resources	Norm-hours	JINR workshop	3300	1100	1100	1100
		DLNP workshop	1500	500	500	500
Financial sources	JINR budget	Budget spending	**270**	**115**	**75**	**80**
	Off-budget sources	Grants; Other sources (these funds are not currently guaranteed)	*30*	*10*	*10*	*10*



#	Designation for outlays	Total cost	1 year	2 year	3 year
	Direct expenses for the project				
1.	Networking	6.0K US$	2.0	2.0	2.0
2.	DLNP workshop	1500 norm-hours	500	500	500
3.	JINR workshop	3300 norm-hours.	1100	1100	1100
4.	Materials	75.0K US$	25.0	25.0	25.0
5.	Equipment	195.0K US$	90.0	50.0	55.0
6.	Collaboration fee	60.0K US$	20.0	20.0	20.0
7.	Travel expenses	75.0K US$	25.0	25.0	25.0
	Total	**411.0K US$**	**162.0K US$**	**122.0K US$**	**127.0K US$**

Conclusion and outlooks

- JINR participates in modern world leading experiments dedicated to search and investigation of rear processes by means of nuclear physics methods (EDELWEISS/RICOCHET);

- In general, all modern methods of nuclear physics have to be applied to achieve the sensitivity levels that are interesting now for particle physics;

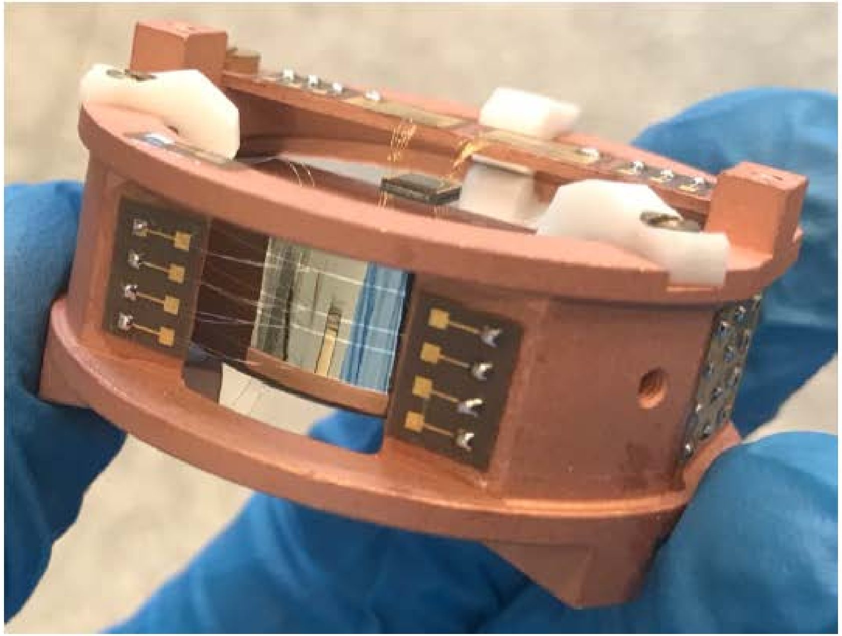
- JINR participates in direct DM search **EDELWEISS** programm, that started the new phase dedicated to investigation of low-mass DM region;

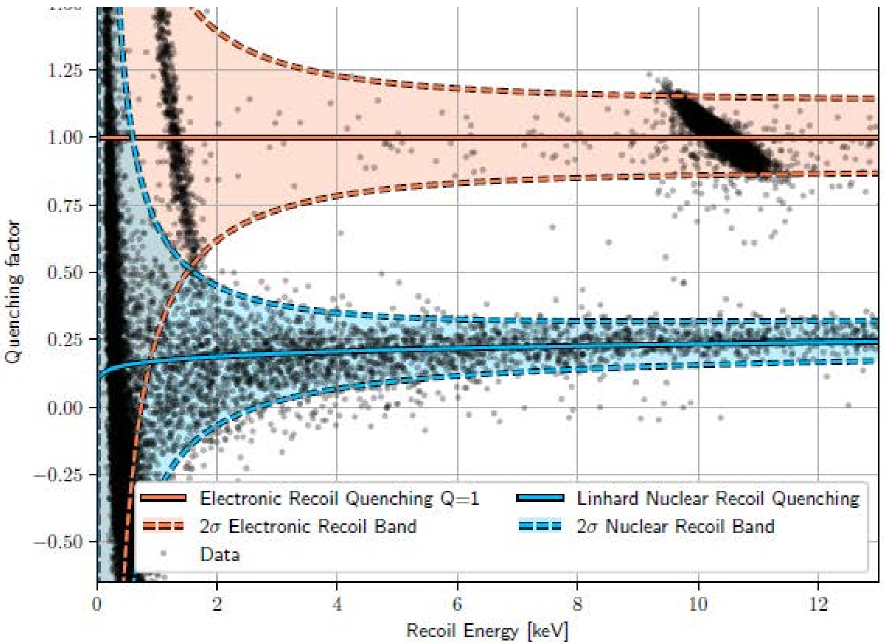
- Direct measurement of energy deposition and the excellent energy resolution provided by the bolometric technique are base for its further use for investigation of rear processes, in our case: investigation of neutrinos from reactor (**RICOCHET**).

- Precision level for **CEνNS in the region of full coherency** will be achieved with **RICOCHET** project already to 2025.

Supplementary materials

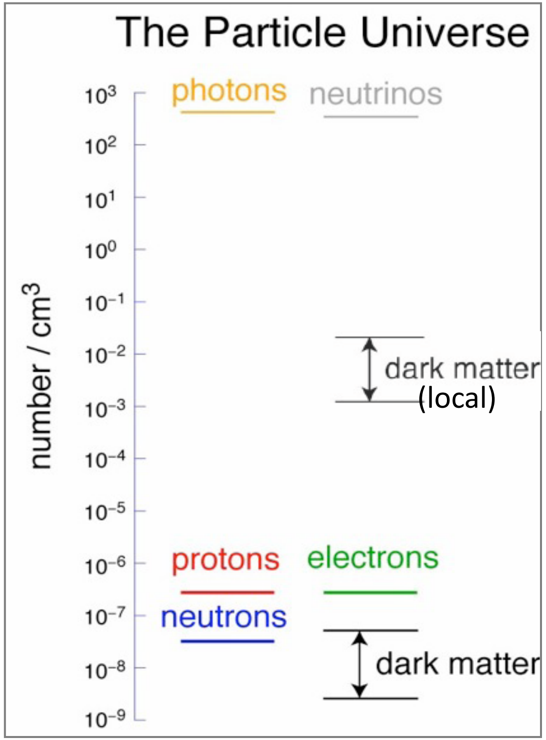
EDELWEISS detectors in new dry ^{3}He-^{4}He low radioactive, low noise dilution cryostat





Centre de Spectroscopie Nucleaire et de Spectroscopie de Masse, IN2P3-CNRS, Universite Paris XI, Orsay, France	EDELWEISS and Ricochet
Univ Lyon, Universite Lyon 1, CNRS/IN2P3, IP2I-Lyon, F-69622, Villeurbanne, France	EDELWEISS and Ricochet
Institut Neel, CNRS/UJF, Grenoble, France	EDELWEISS and Ricochet
CEA, Universite Paris-Saclay, Gif-sur-Yvette, France	EDELWEISS only
Karlsruhe Institute of Technology, Institut fur Kernphysik, Karlsruhe, Germany	EDELWEISS only (not yet approved for next stage)
Univ. Grenoble Alpes, CNRS, Grenoble INP, LPSC-IN2P3, 38000 Grenoble, France	Ricochet only
Laboratory of Nuclear Problems, JINR, Dubna, Russia	EDELWEISS and Ricochet
Institut Laue-Langevin, CS 20156, 38042 Grenoble Cedex 9, France	Ricochet only
Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA, USA	Ricochet only
Department of Physics \& Astronomy, Northwestern University, Evanston, IL 60208-3112, USA	Ricochet only
University of Massachusetts, Amherst, MA 01003, USA	Ricochet only
University of Wisconsin-Madison, Department of Physics, Madison, WI 53706-1390, USA	Ricochet only

Two huge challenges in modern physics: Neutrino properties and Dark Matter



Neutrinos: how neutrinos obtain their masses?
neutrino $\neq$ antineutrino?
connection with many astrophysics phenomena;
way to study early Universe, interior of stars, Earth
reactor monitoring;

Dark Matter: accounts for ~27% of total mass-energy.

?

Extremely interesting physics!
Experimental methods and approaches in many cases are similar.

Dark Matter puzzle

- Cosmology
  - non-baryonic DM in the early Universe *[WMAP, Planck, …]*
- Astrophysics
  - Gravitational probes at galactic/cluster sizes
  - WIMPs present in our Galaxy with density ~0.3 GeV/cm^3
- Particle Physics
- Indirect Searches
  - Annihilation decay products:

too many phenomena too be decisive (?), many experiments with different approaches

- **Direct Searches**:
  - background free measurements
  - winter/summer modulation measurements
  - **Is DM particles of the halo are those can be produced at LHC?**

- **Main experimental challenges for non accelerator cases are:**

  - ☐ **event rate is ultra small;**
  - ☐ **and (or) energy deposition is tiny**

  Thus main tasks for experiments are:

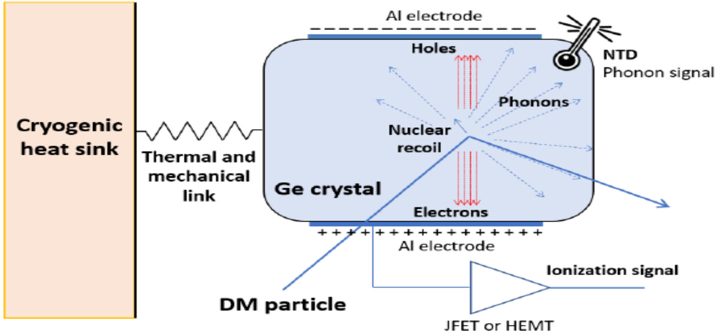
- **Detector mass + long stable data taking + stable predictable detector response**
- **Detectors' performance (low energy thresholds, good resolutions)**
- **Background reduction**

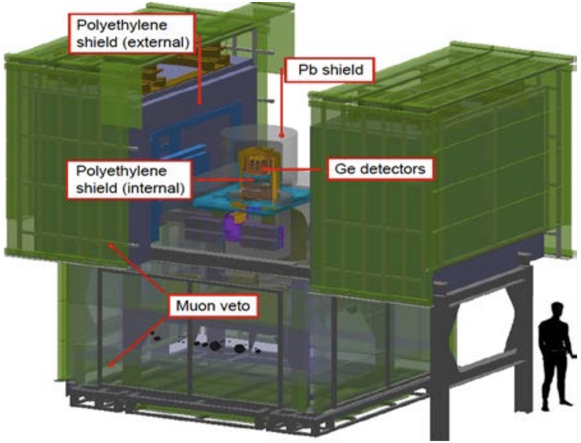
$E_R <$ ~100 keV → Very performant detector
Low threshold, good resolution

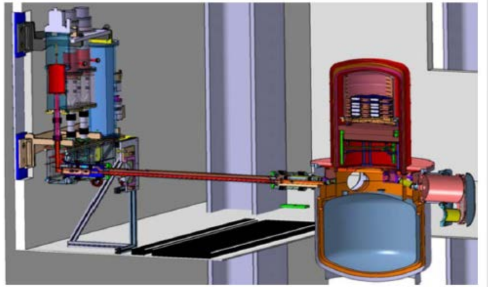
$R_{DM} <$ ~0.001 evt/kg/d → Large volume
10 kg – 1 ton

Background → 0 → Efficient shielding,
Underground lab,
material selection, …

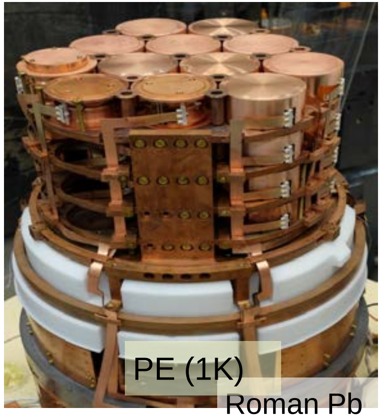
EDELWEISS (Heat and ionization HPGe bolometers)

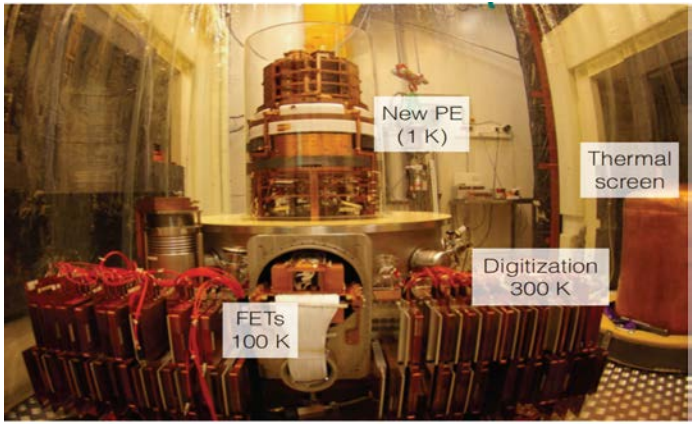






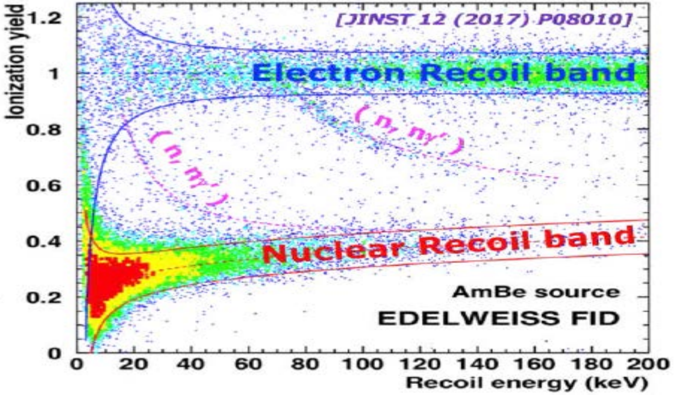
- LSM underground laboratory (France), 4800 mwe
- Clean room + deradonized air
  Rn monitoring down to few mBq/m^3
- Active muon veto (>98% coverage)
- External (50 cm) + internal polyethylene shielding
  Thermal neutron monitoring with ^{3}He detector
- Lead shielding (20 cm, incl. 2 cm Roman lead)
- Selection of radiopure material
- Cryostat can host up to 40 kg detector, at 18 mK





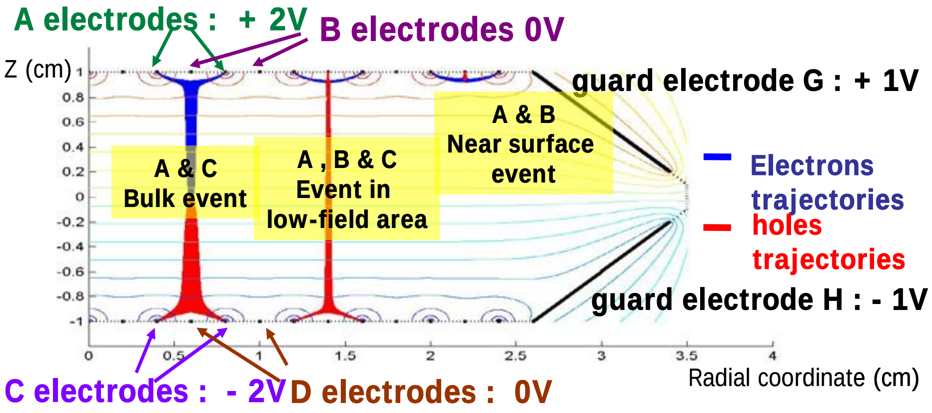
EDELWEISS (Heat and ionization Ge bolometers)

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


[JINST 12 (2017) P08010]

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

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


A electrodes : + 2V

B electrodes 0V

guard electrode G : + 1V

A & C
Bulk event

A , B & C
Event in
low-field area

A & B
Near surface
event

Electrons trajectories

holes trajectories

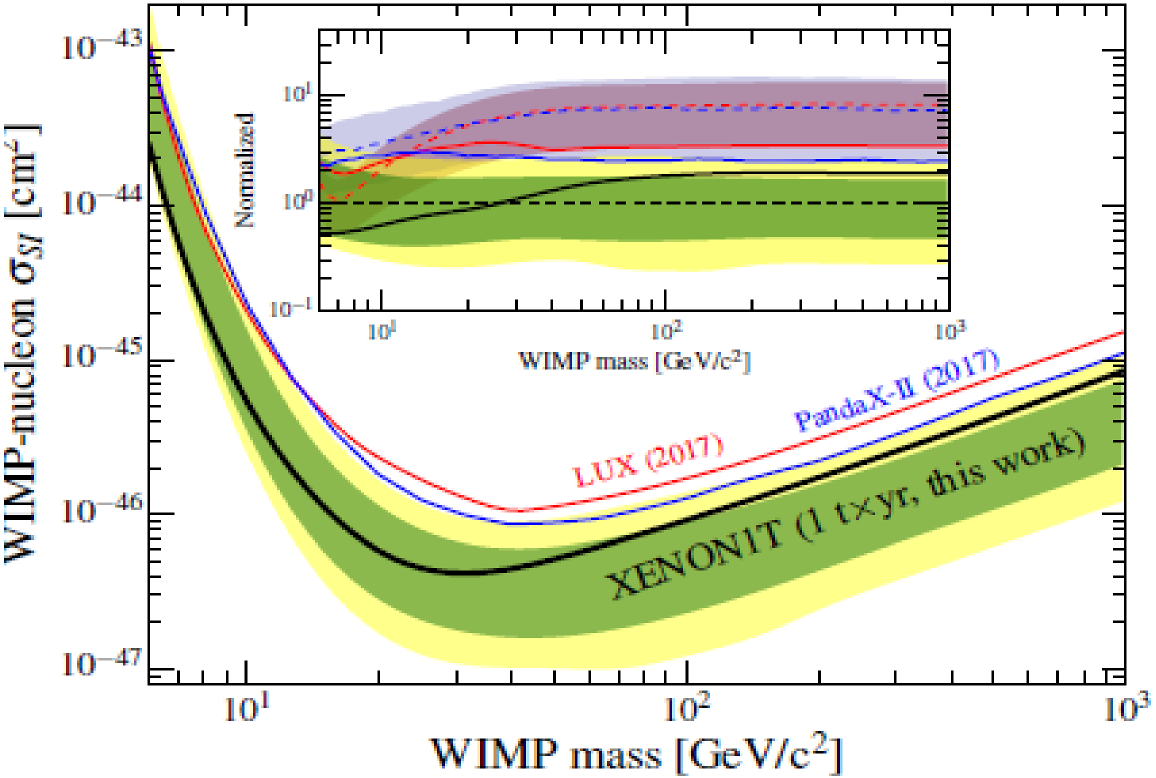
guard electrode H : - 1V

C electrodes : - 2V

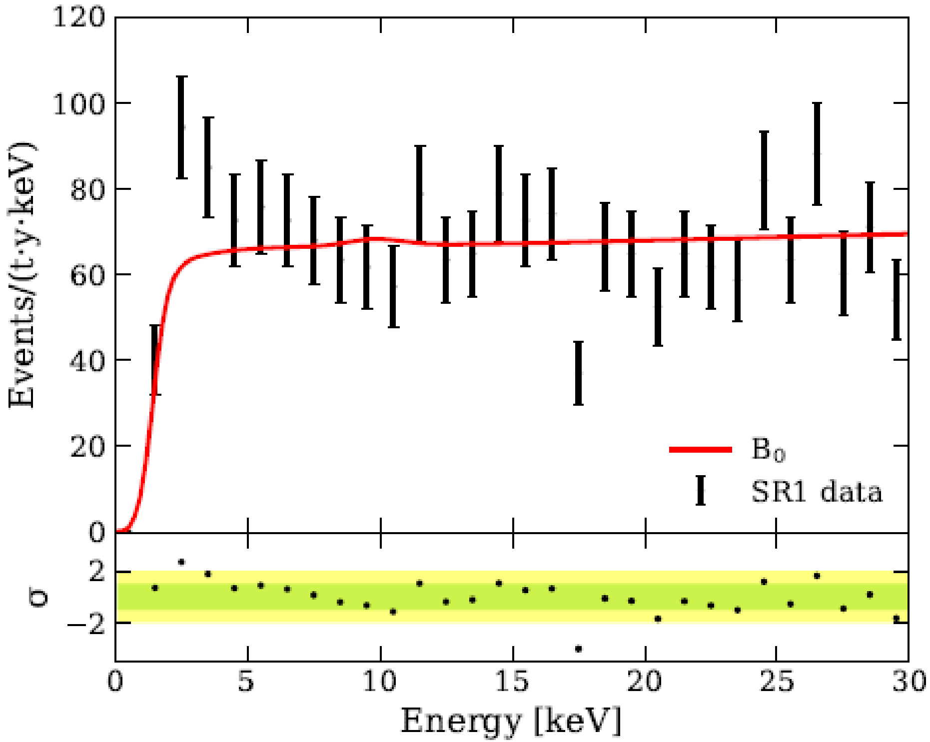
D electrodes : 0V

An increasing gain of interest for the search of low-mass, very-heavy WIMPs, other possible condidates

- Non evidence yet for SUSY at the LHC;
- New theoretical approaches favoring lighter candidates;
- No WIMP signals in the “expected” region;
- Controversial results in the region around and below of 10 GeV/c^2.



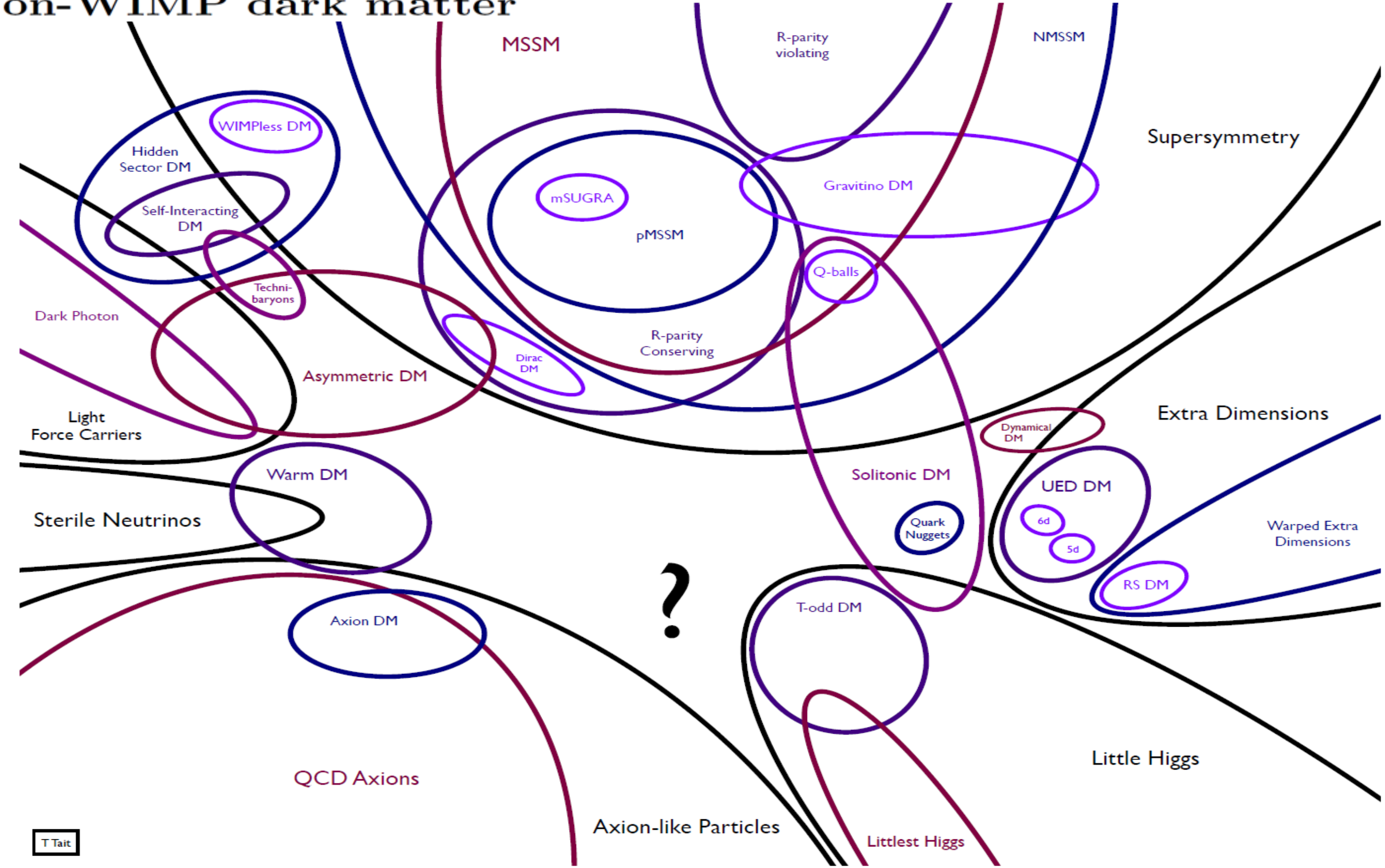
Observation of Excess Electronic Recoil Events in XENON1T



Snowmass-2013 Cosmic Frontier 3 (CF3) Working Group Summary: Non-WIMP dark matter

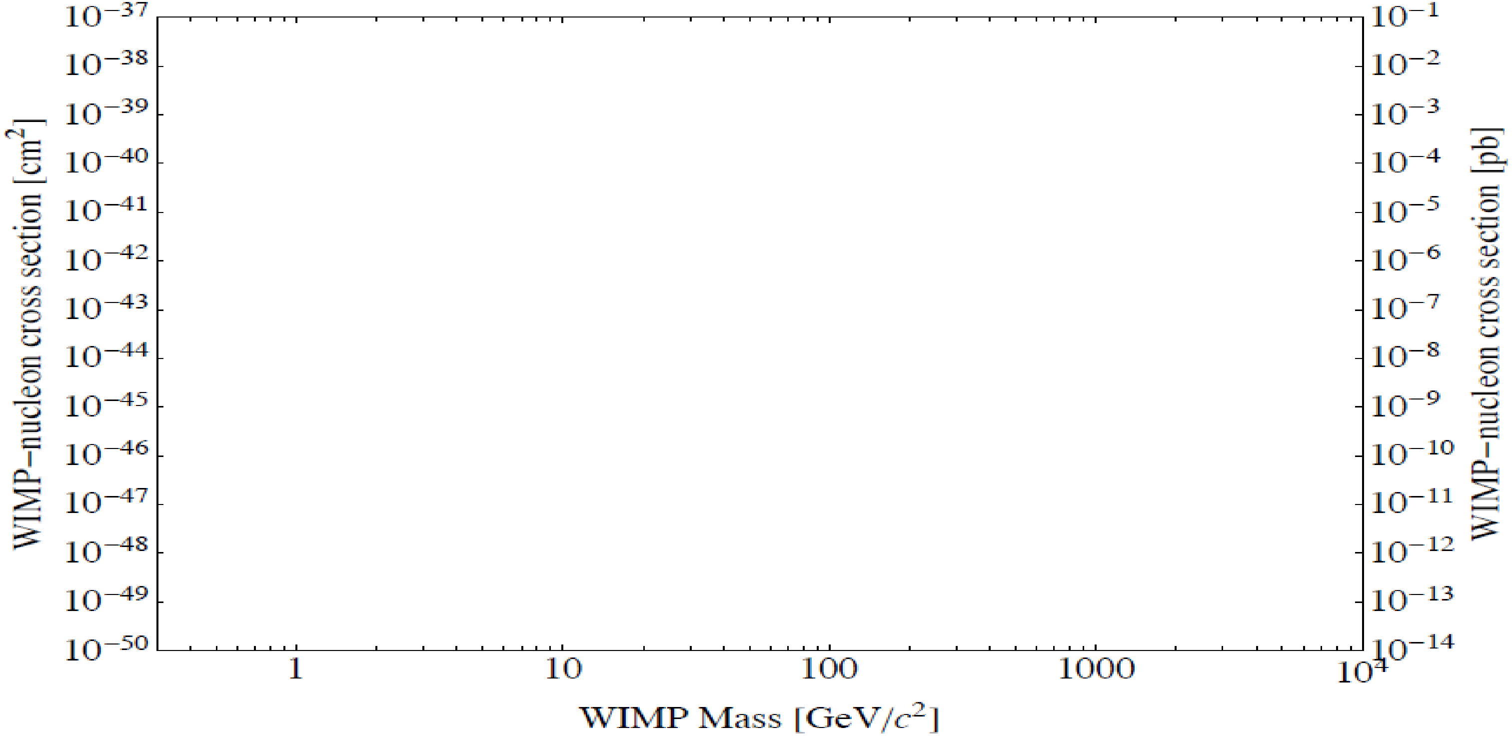
4 The (incomplete) landscape of candidates

The following sections of this report discuss some of dark matter candidates in more detail.



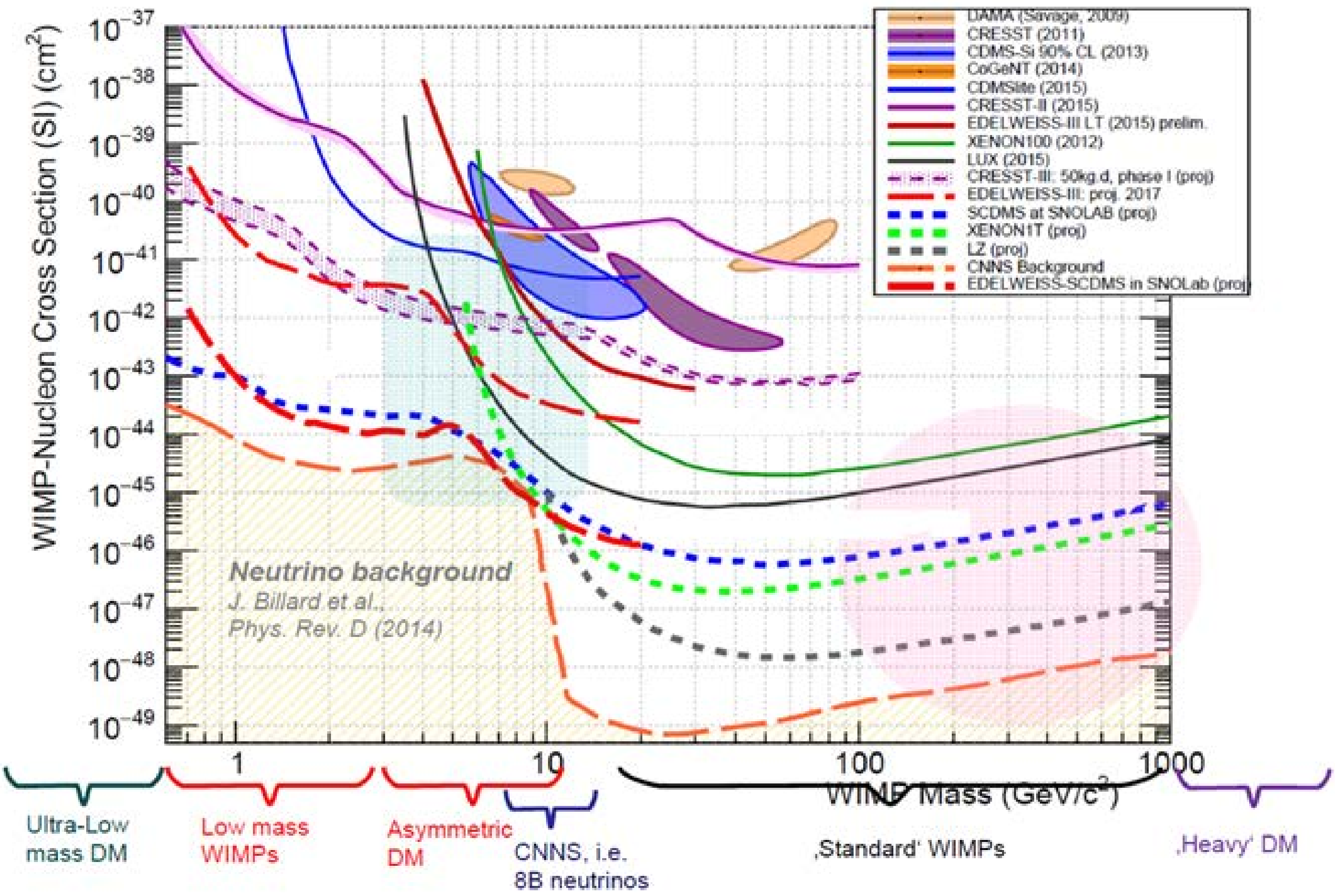
arXiv:1310.8642v1

A lot of space...

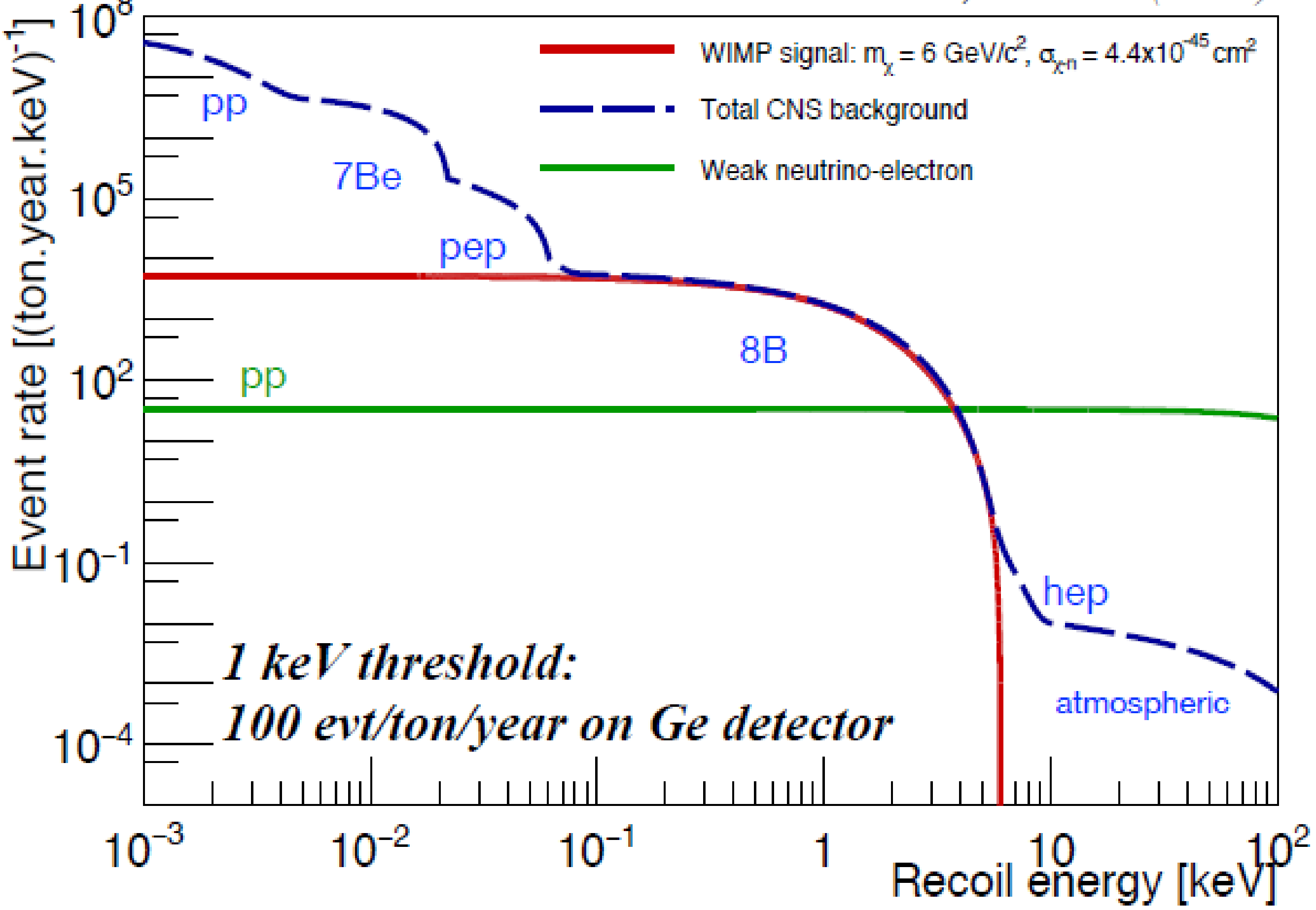


R. Hill 2016 Aspen Winter Conference

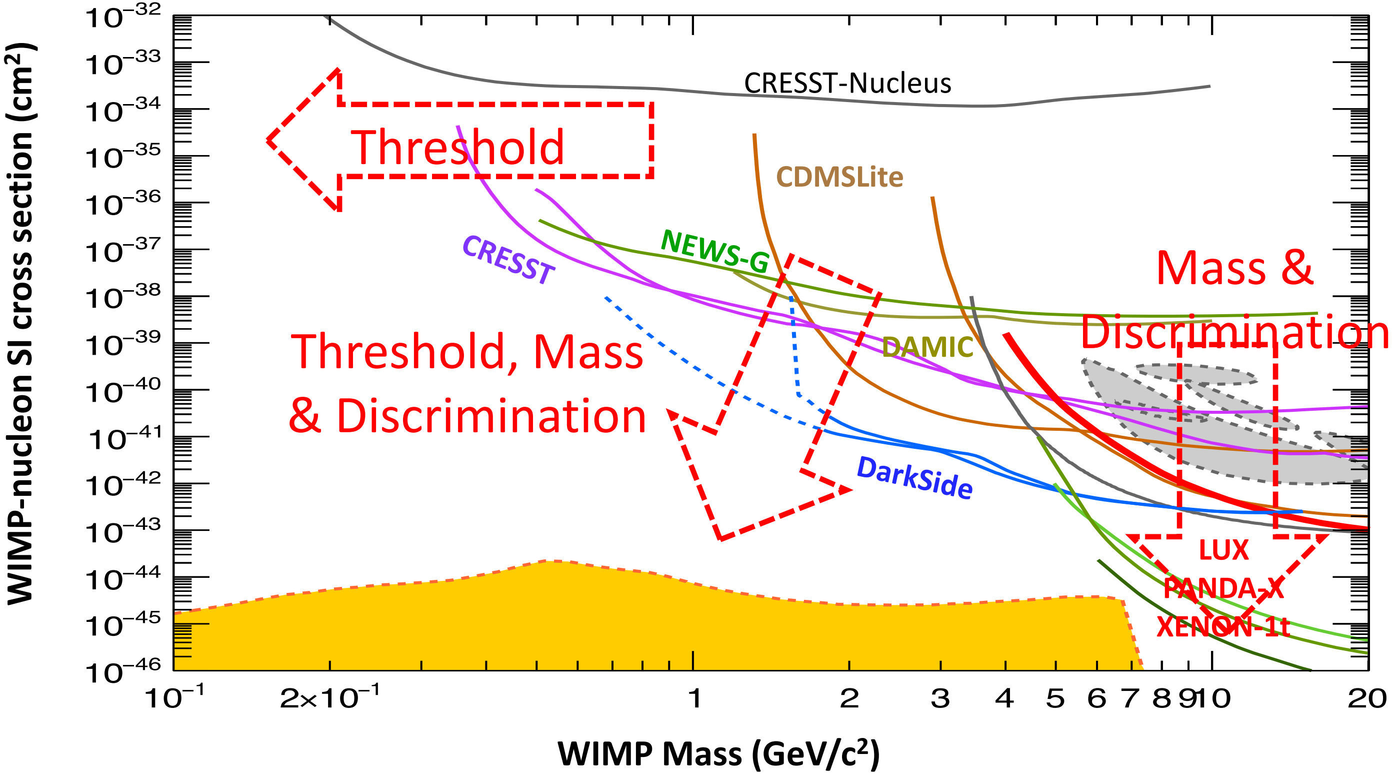
Model dependent interpretation: required many positive results + indirect search + accelerators!!!


WIMP-Nucleon Cross Section (SI) (cm^2)
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
1
10
100
1000
WIMP Mass (GeV/c^2)
DAMA (Savage, 2009)
CRESST (2011)
CDMS-Si 90% CL (2013)
CoGeNT (2014)
CDMSlite (2015)
CRESST-II (2015)
EDELWEISS-III LT (2015) prelim.
XENON100 (2012)
LUX (2015)
CRESST-III: 50kg.d, phase I (proj)
EDELWEISS-III: proj. 2017
SCDMS at SNOLAB (proj)
XENON1T (proj)
LZ (proj)
CNNS Background
EDELWEISS-SCDMS in SNOLab (proj)
Neutrino background
J. Billard et al.,
Phys. Rev. D (2014)
Ultra-Low
mass DM
Low mass
WIMPs
Asymmetric
DM
CNNS, i.e.
8B neutrinos
‚Standard' WIMPs
‚Heavy' DM

J. Billard et al., PRD 89 (2014)



1 keV threshold:
100 evt/ton/year on Ge detector



Threshold

Threshold, Mass & Discrimination

Mass & Discrimination

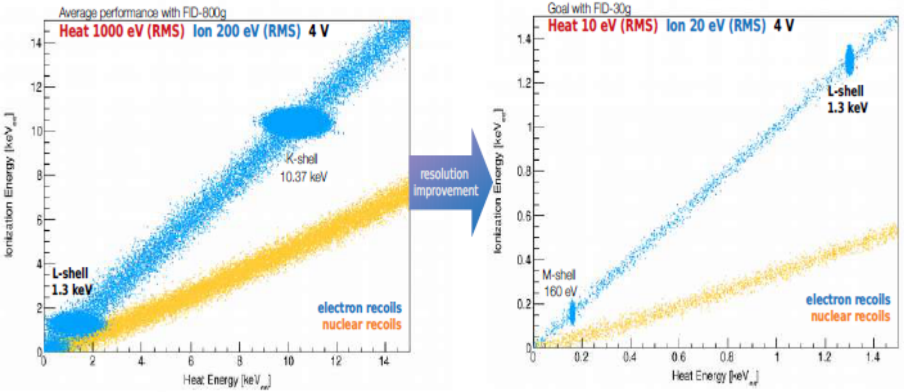
LUX
PANDA-X
XENON-1t

EDELWEISS SubGeV two modes

Low Voltage Objectives

- 10 eV (RMS) Heat energy resolution
- 20 eV (RMS) Ionization energy resolution

Particle identification & surface event rejection down to 50 eV



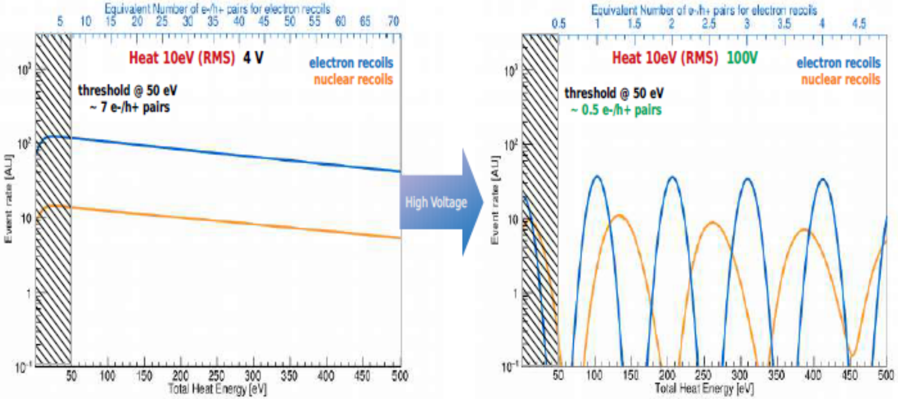
Low-voltage objectives are part of a common effort with the Ricochet collaboration, dedicated to studying CENNS at reactors supported by the ERC-CENNS Starting Grant (2019-2024)

High Voltage Objectives

- 10 eV (RMS) Heat energy resolution
- 100 V with signal amplification only

Single-e/h pair sensitivity with massive (~30g) bolometers

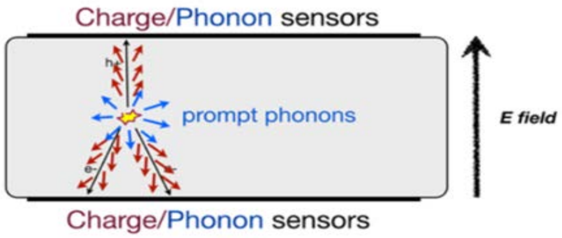
Single **ELE**ctron **N**uclear recoil **DIS**crimination
SELENDIS

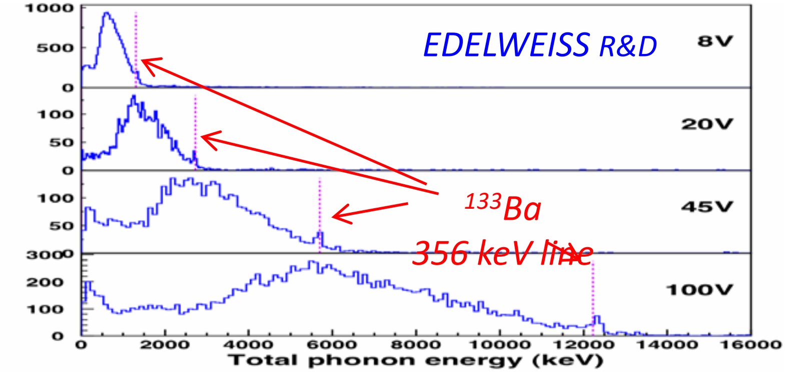


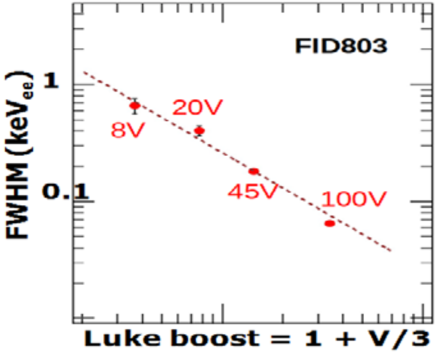
SELENDIS project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 838537

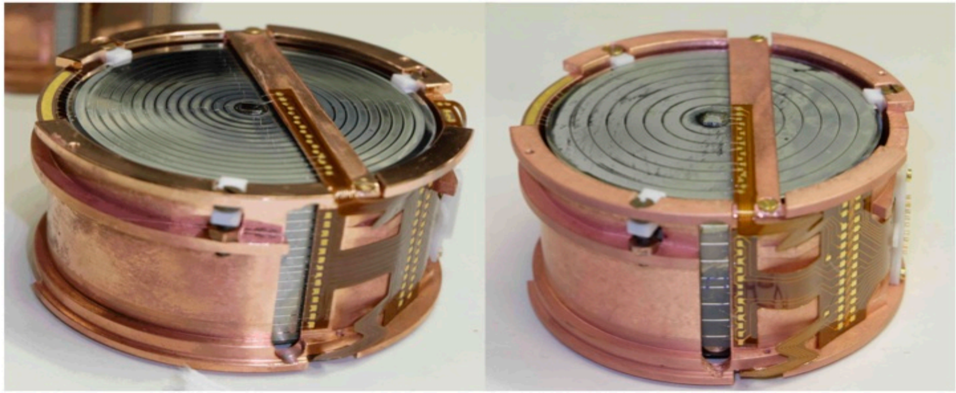
HV: Neganov-Trofomov-Luke effect for internal amplification of the heat signals.

$$E_t = E_r + \frac{1}{3\,eV} E_Q \Delta V$$



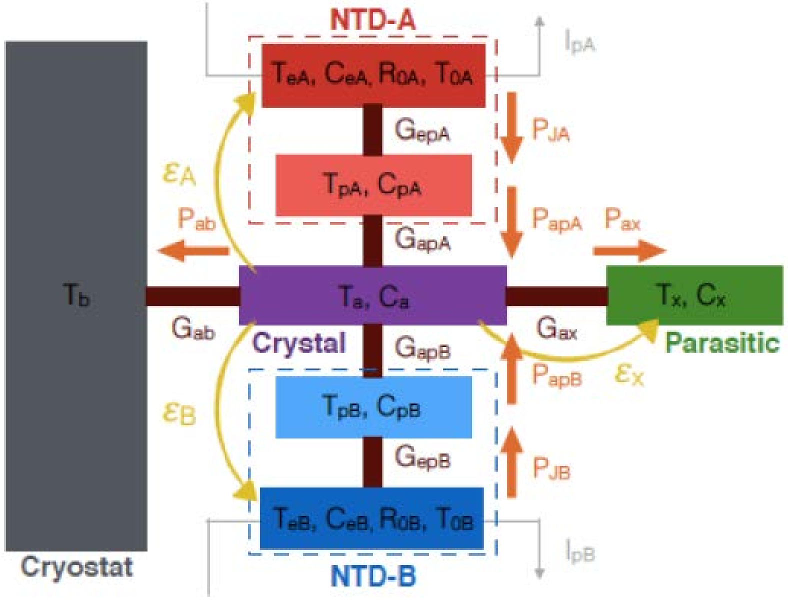






How to improve resolution (decrease noise)

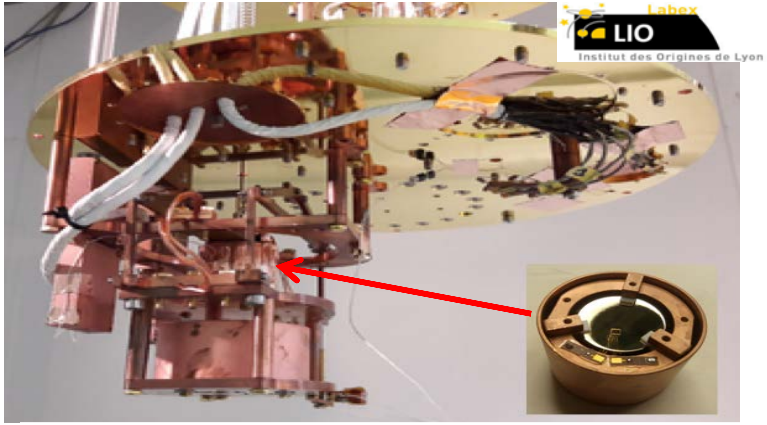
- Intense R&D on NTD sensors
- Detailed thermal model: optimization of the best configuration
- Test of different glues
- Alternative sensors: NbSi superconductive transition edge sensors
- First amplification: JFET at 100K to HEMTs at 4K

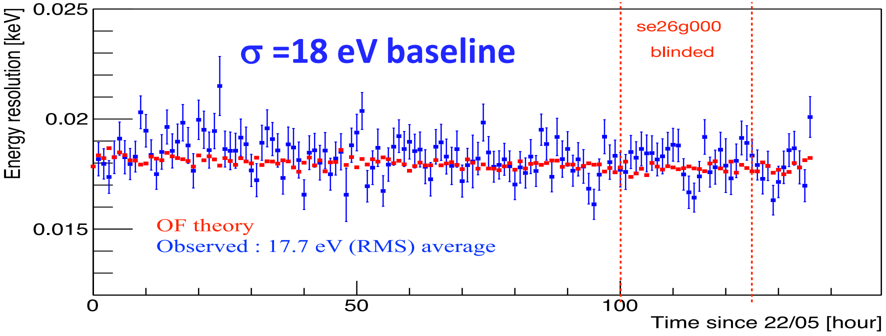


- **JFET to HEMT**
  - Lower intrinsic noise, low heat load
  - Works at 4K: shorter cables reduces capacitance and improves resolution
- ***Successful HEMT amplifier with sub-100 eV_{RMS} ion. resolution*** *[A. Phipps, arXiv:1611.09712, collaboration between SuperCDMS and EDELWEISS]*
- Step#1: Upgrade EDELWEISS ionization readout with this new design
- Step#2: Electrode design to reduce detector capacitance to reach 50 eV_{RM}

Resolution improvements on a 32g detector

- R&D with 32 g combined with the objective of testing the above-ground sensitivity to sub-GeV WIMPs
- *Optimized* NTD heat sensor on a 32g crystal, no electrodes
  (i.e. 1 keV = 1 keV_{NR})
- Kept at 17 mK in low-vibration dilution fridge
  [ArXiv:1803.03463]
- Stable σ = 18 eV baseline resolution
- DM search in [0-2] keV region

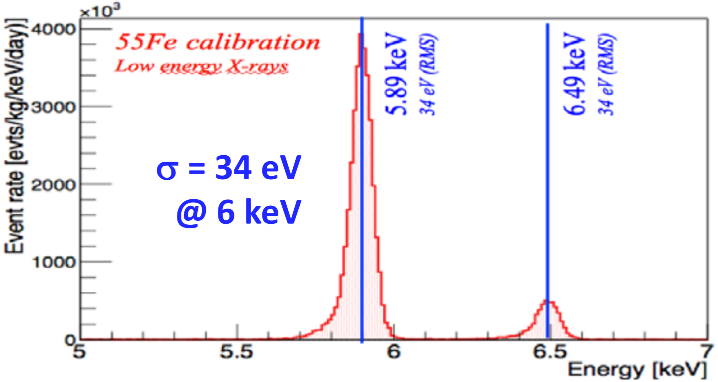



σ =18 eV baseline

se26g000 blinded

OF theory

Observed : 17.7 eV (RMS) average

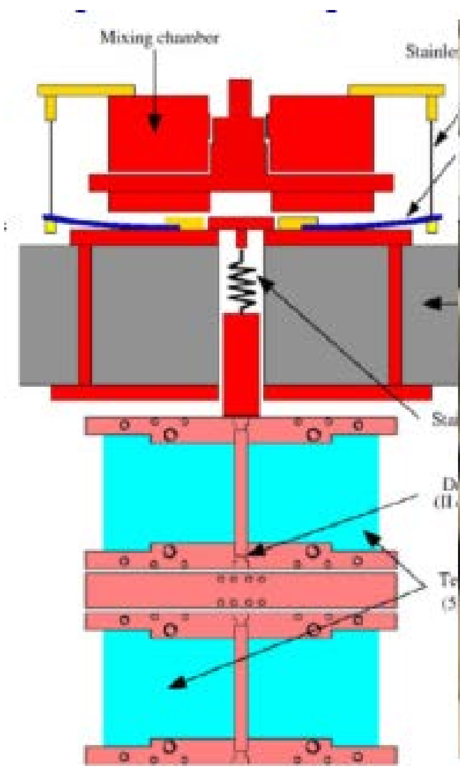

55Fe calibration

Low energy X-rays

σ = 34 eV @ 6 keV

5.89 keV 34 eV (RMS)

6.49 keV 34 eV (RMS)


Mixing chamber
Stainle
Sta
De
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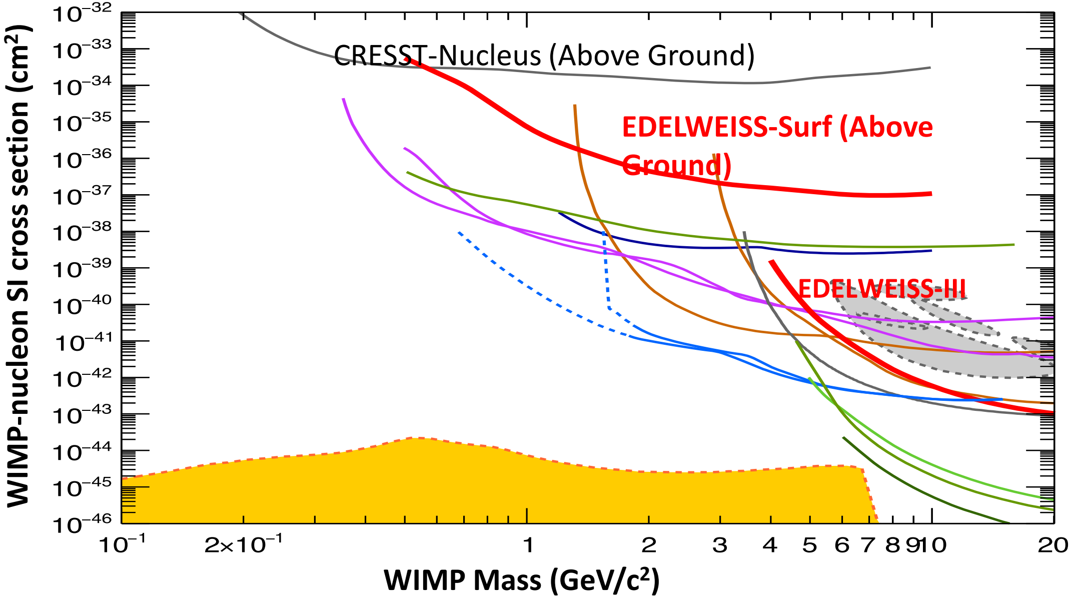
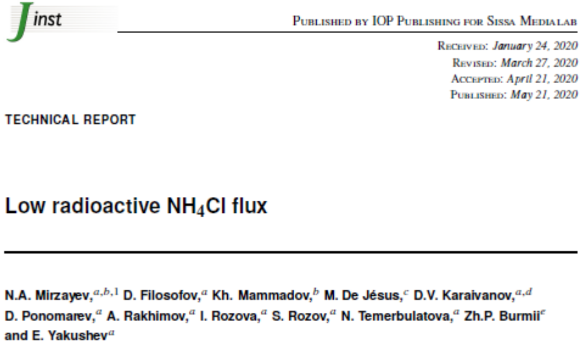
Te
(5

Surface limit (Physical Review D 99 (8), 2019)

- Achieved resolution on a smaller detector exceeds by x5 the original LT goal with 800 g detectors
- Best above-ground limit down to 600 MeV/c^2: SIMP
- First sub-GeV limit with Ge, down to 500 MeV/c^2
- Opens the way for the 0.1 – 1 GeV/c^2 range





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TECHNICAL REPORT

Low radioactive NH_4Cl flux

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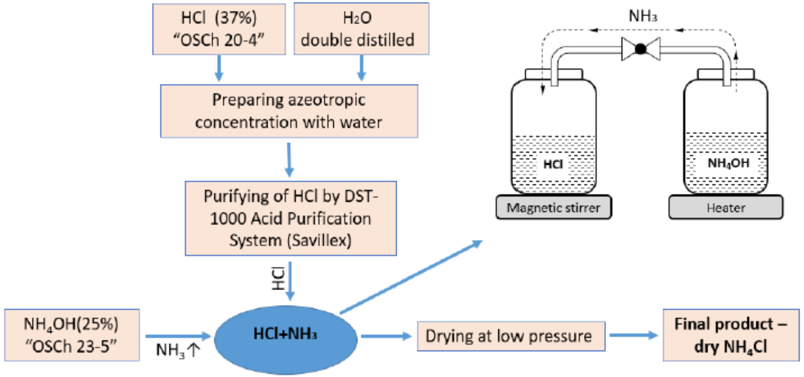
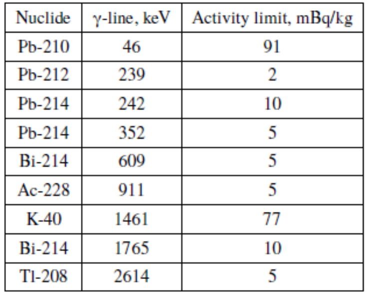
D. Ponomarev,[a] A. Rakhimov,[a] I. Rozova,[a] S. Rozov,[a] N. Temerbulatova,[a] Zh.P. Burmii[e]
and E. Yakushev[a]





Nuclide	γ-line, keV	Activity limit, mBq/kg
Pb-210	46	91
Pb-212	239	2
Pb-214	242	10
Pb-214	352	5
Bi-214	609	5
Ac-228	911	5
K-40	1461	77
Bi-214	1765	10
Tl-208	2614	5

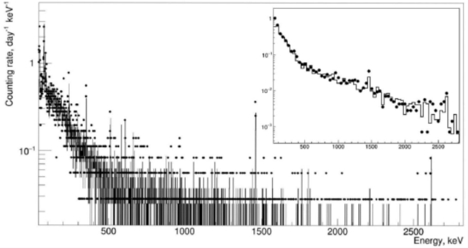
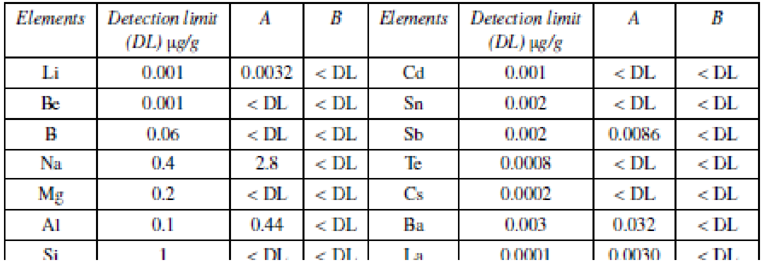


Figure 3. Comparison of experimental energy spectra for the sample of 50 g of custom-made NH_4Cl (dots accumulated during 34.6 days with detector's background (solid line). The same data with wider ~ 40 keV binning is shown in the insert.

Table 3. Results of ICP-MS elemental analysis of the NH_4Cl sample. A — "commercial" NH_4Cl-Reahin GOST-3773-60 and B — this work custom-made NH_4Cl.

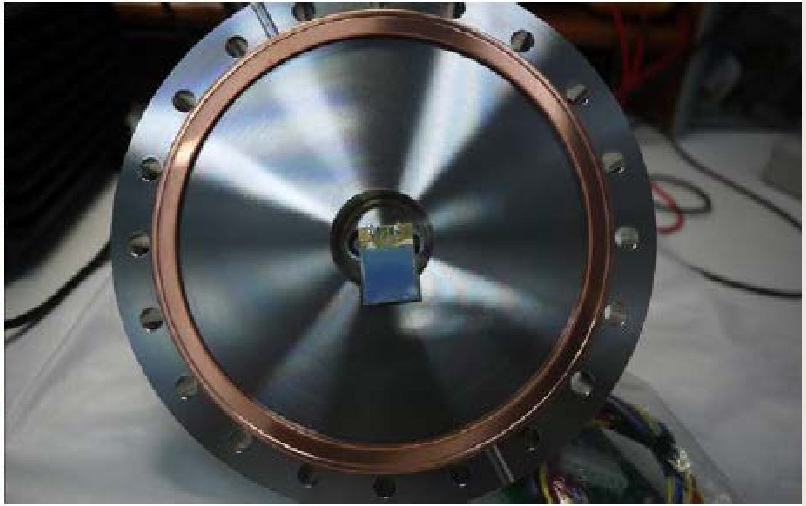


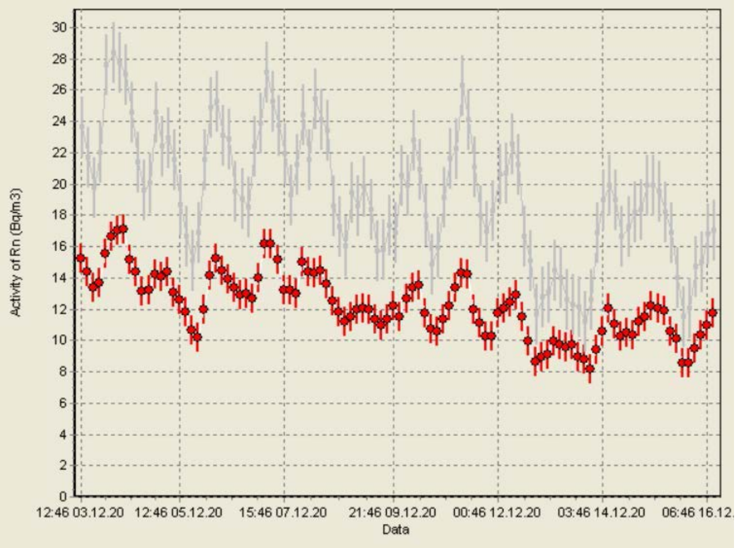
Elements	*Detection limit (DL) μg/g*	*A*	*B*	*Elements*	*Detection limit (DL) μg/g*	*A*	*B*
Li	0.001	0.0032	< DL	Cd	0.001	< DL	< DL
Be	0.001	< DL	< DL	Sn	0.002	< DL	< DL
B	0.06	< DL	< DL	Sb	0.002	0.0086	< DL
Na	0.4	2.8	< DL	Te	0.0008	< DL	< DL
Mg	0.2	< DL	< DL	Cs	0.0002	< DL	< DL
Al	0.1	0.44	< DL	Ba	0.003	0.032	< DL
Si	1	< DL	< DL	La	0.0001	0.0030	< DL

5 Conclusion

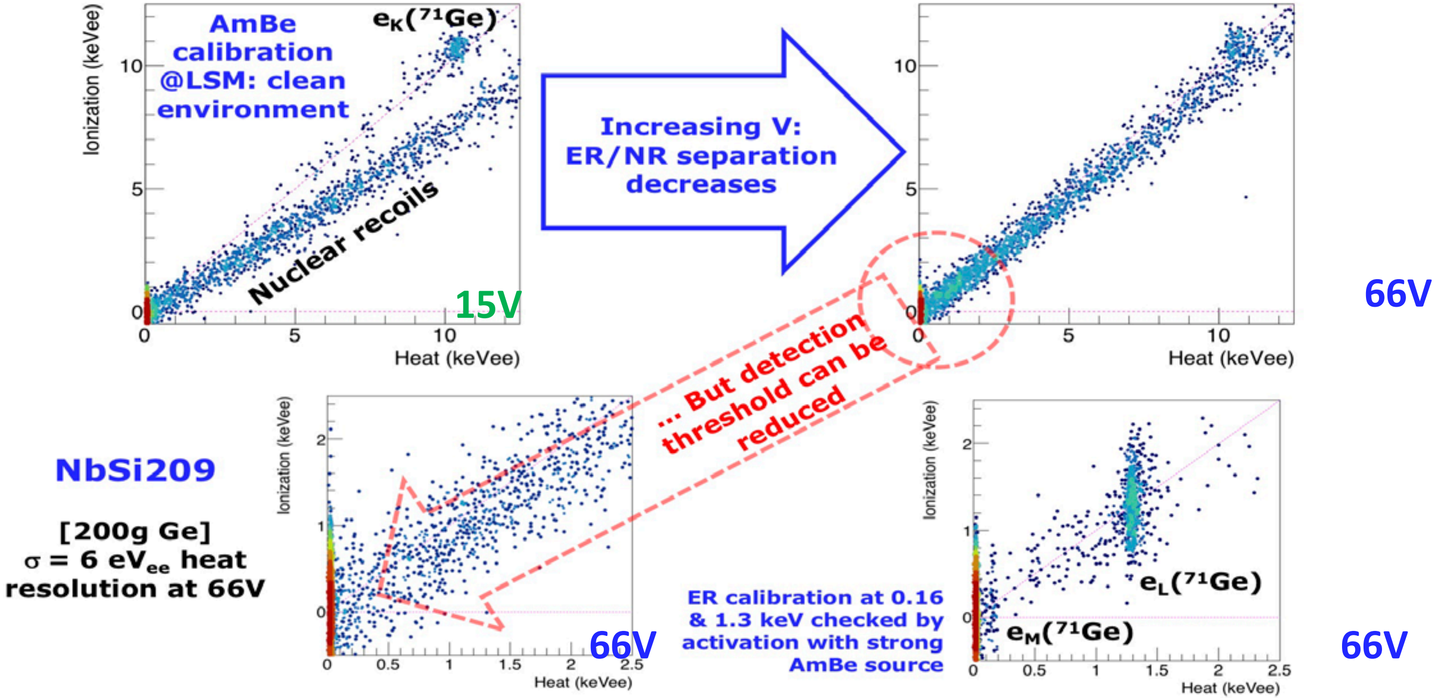
In this work we present a new simple method implemented to produce low radioactive NH_4Cl flux. Given the successful results on the tested solders made using the prepared ammonium chloride salt as the flux, the objective of creating a low-radioactive flux which fulfills the background level requirements for rare event search experiments is achieved.

Radon measurements





- Current run @ LSM : obtaining *near* single-electron sensitivity on 33 and 200 g detectors: *Calibration of nuclear recoils down to low thresholds*



AmBe calibration @LSM: clean environment

Increasing V: ER/NR separation decreases

... But detection threshold can be reduced

NbSi209

[200g Ge]
σ = 6 eV_{ee} heat resolution at 66V

ER calibration at 0.16 & 1.3 keV checked by activation with strong AmBe source

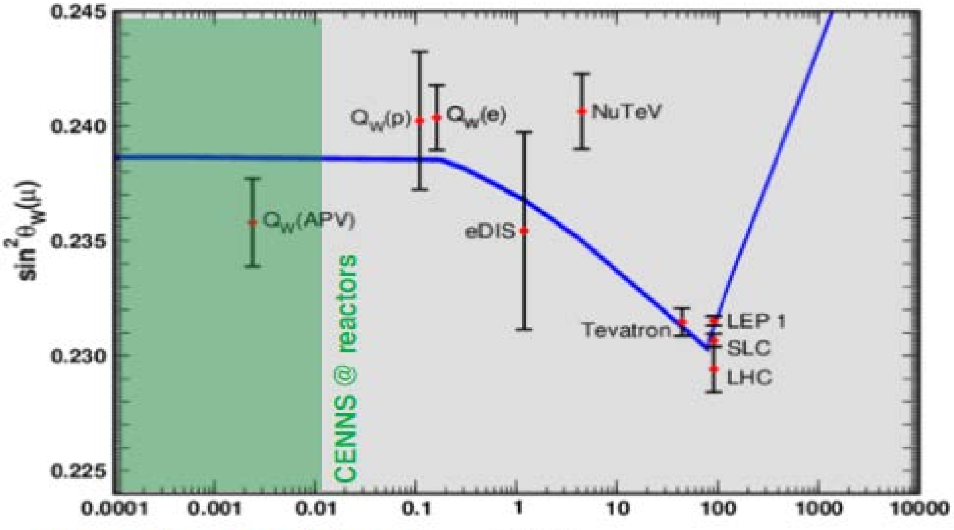
Ricochet

Dry cryostat

Why we want precision measurements?

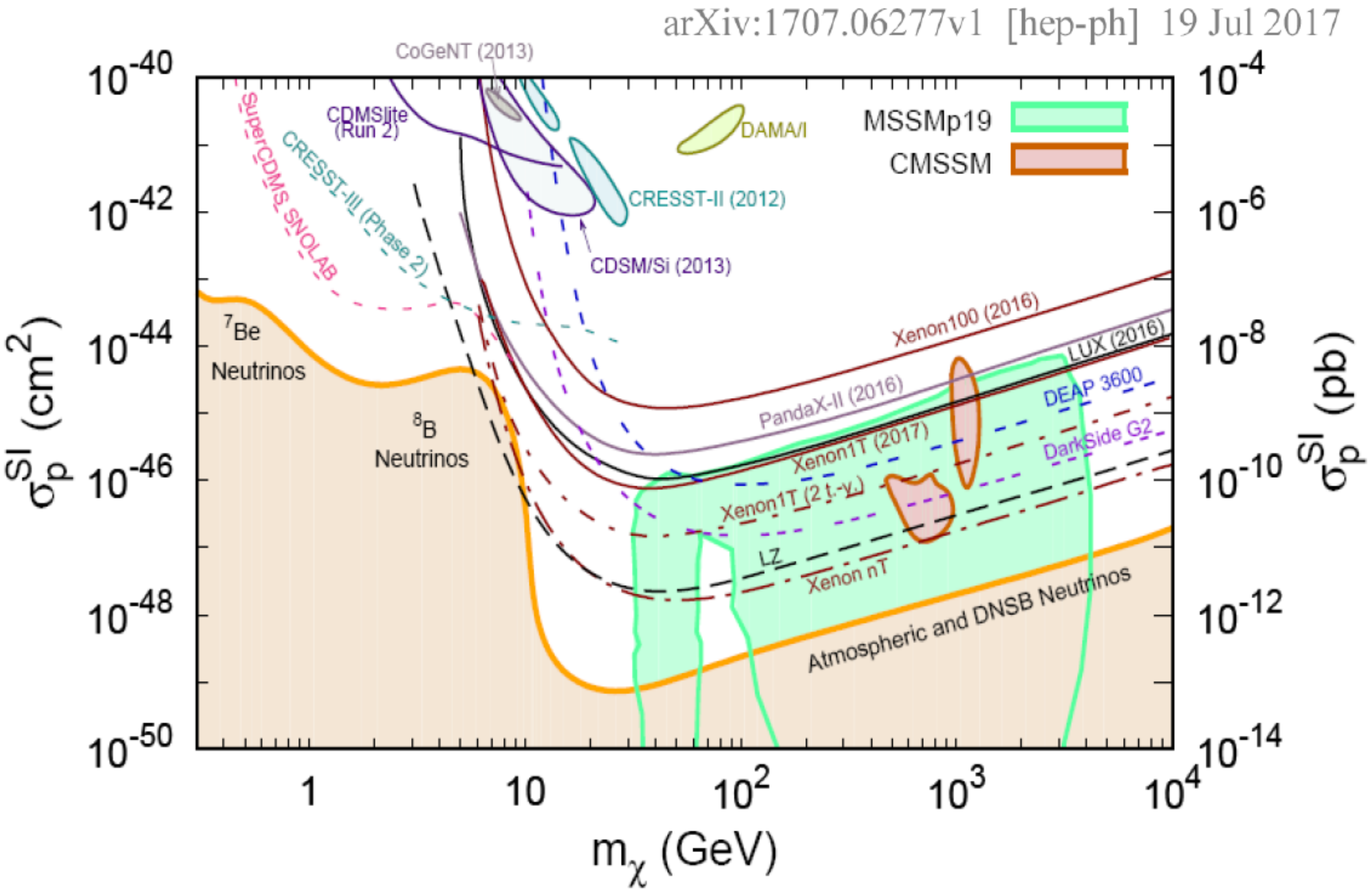
$$\frac{d\sigma(E_\nu, E_r)}{dE_r} = \frac{G_f^2}{4\pi} Q_w^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F^2(E_r)$$

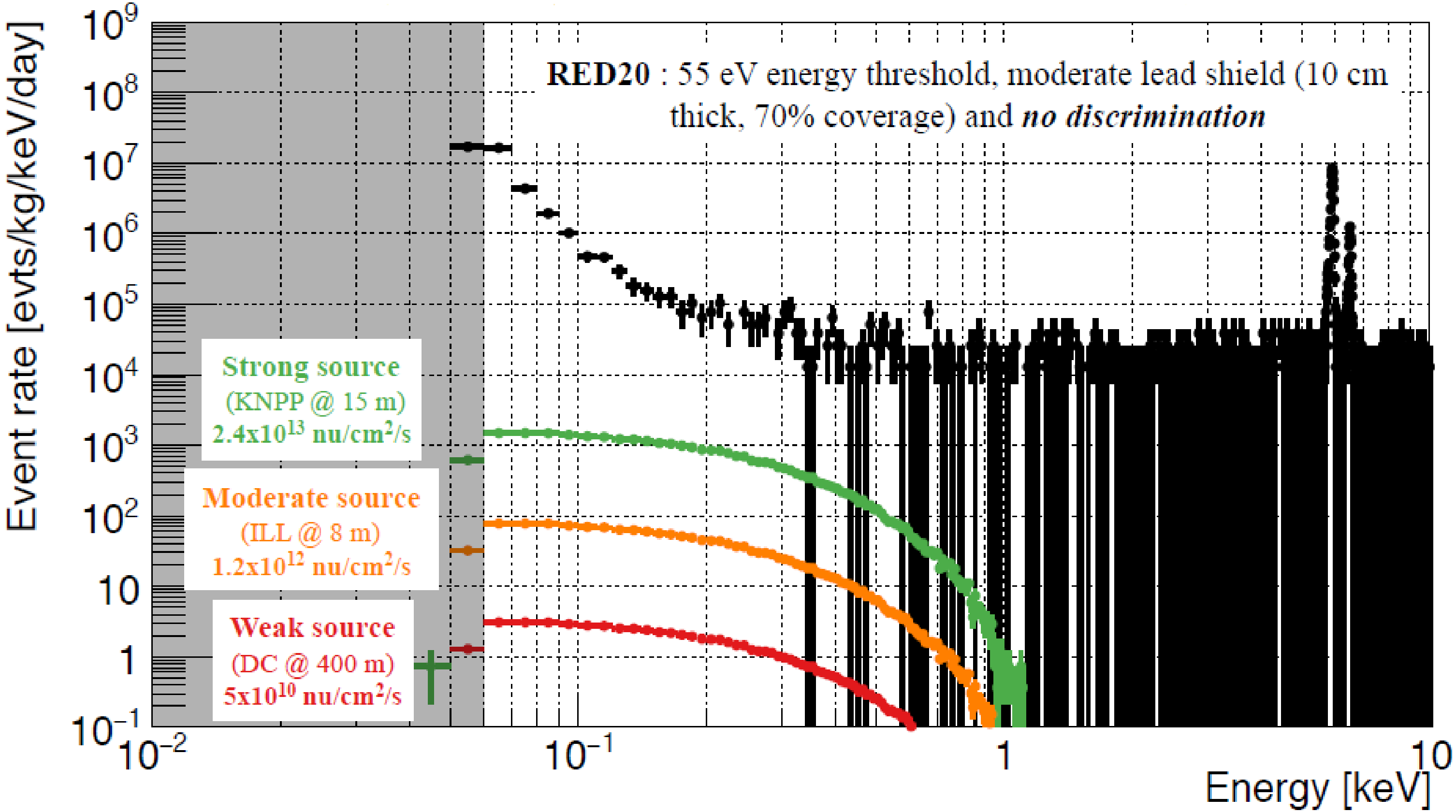
$$Q_w = N - Z(1 - 4\sin^2\theta_w)$$



PDG - electroweak (2016) μ [GeV]

Why we want precision measurements?



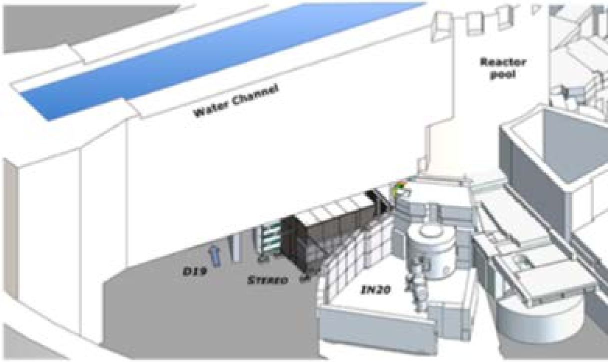

RED20 : 55 eV energy threshold, moderate lead shield (10 cm thick, 70% coverage) and ***no discrimination***
Strong source
(KNPP @ 15 m)
2.4x10^13 nu/cm^2/s
Moderate source
(ILL @ 8 m)
1.2x10^12 nu/cm^2/s
Weak source
(DC @ 400 m)
5x10^10 nu/cm^2/s
Event rate [evts/kg/keV/day]
Energy [keV]
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-1
1
10

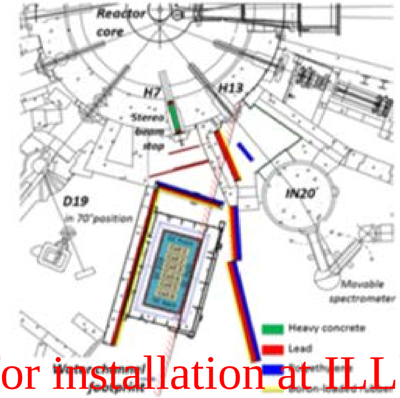
RICOCHET: *Searching for nuclear reactor site - ILL*

- 58 MW nominal thermal power
- Large neutrino flux: ~1×10^{19} ν/s
  - 5m from core: 40 evts/day/kg
  - 7m from core: 20 evts/day/kg
- 3 to 4 cycles per year: ***excellent ON/OFF modulation to subtract uncorrelated backgrounds***
- Significant overburden (~15 m.w.e)
- Ricochet could make use of STEREO casemate after its dismantling (2021 - 2022)
- Ricochet would benefit from the strong STEREO experience and background characterization
- Monte Carlo studies ongoing to estimate the expected backgrounds:
  - *reactogenic* and cosmogenic
- ***LoI submitted to ILL directors end-Feb***

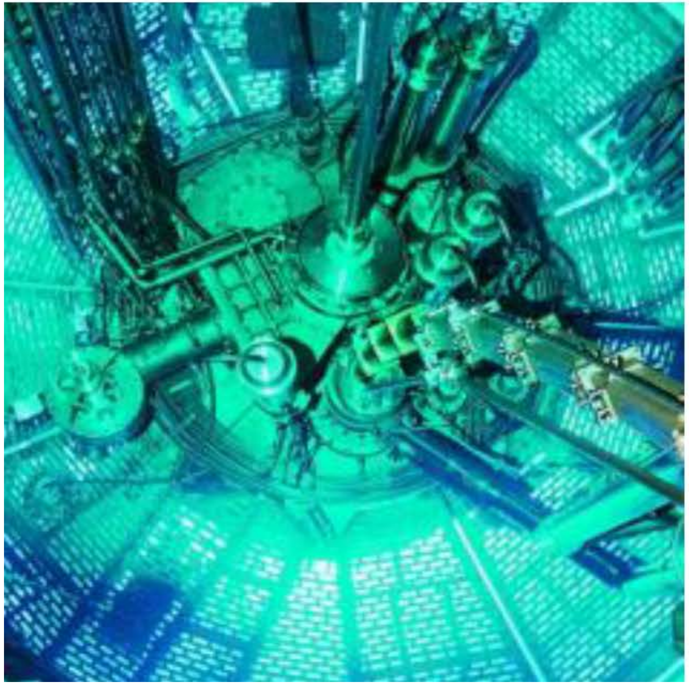
Approved at September 2020 (640 kEuro for installation at ILL)

STEREO Coll., JINST 2018





Optimised for extraction of intense neutron beams

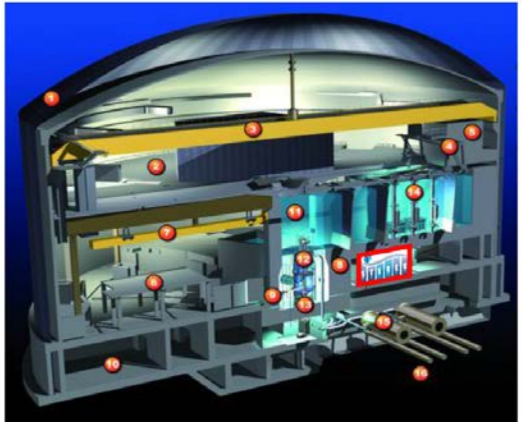


High-(neutron)flux reactor of the ILL

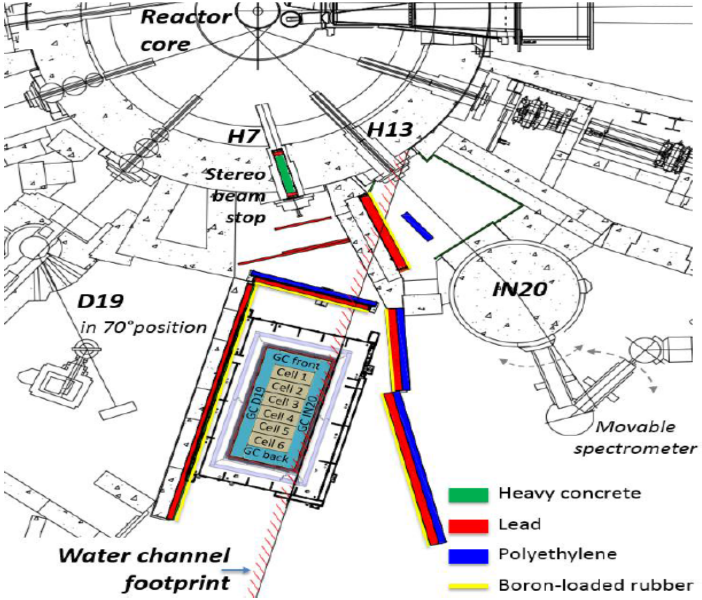
- 58.3 $\mathrm{MW}_{\mathrm{thermal}}$
- Single compact fuel element:
  - ◇ Ø40 cm × 80 cm
  - ◇ Highly enriched fuel: $^{235}\mathrm{U}$ (93%)
  - ◇ 1 cycle ~50 days
  - ◇ 3-4 cycles/year
- Heavy-water moderated
- Flux in moderator: 10^{15} n/cm^{2}s

Site H7

Antineutrino source and site



- Baseline: ≥ 8m
- Overburden: 15 m.w.e.
- Shielding improved for STEREO
- H6-H7 beam tube removed, or closed by plug



Advantages

- Pure ^{235}U spectrum, compact core
- Frequent on-off changes
- 15 m.w.e. overburden
- Profit from STEREO (site prep, reactor spectrum)
- Scientific environment and technical support

Disadvantages

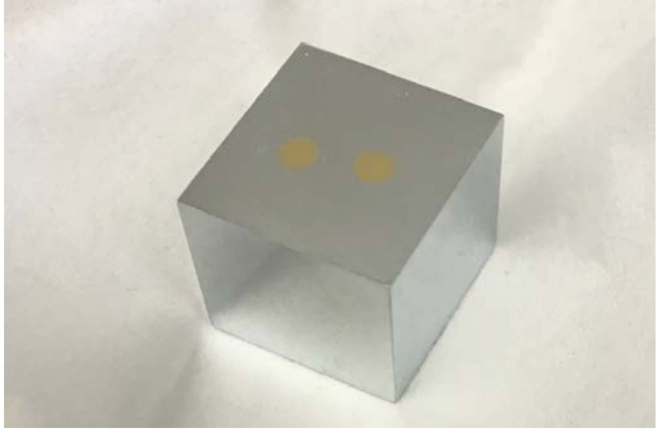
- Need to be close to core for high flux → Signal/ReactorBG?
- Backgrounds from neighbour instruments
- Limited crane access

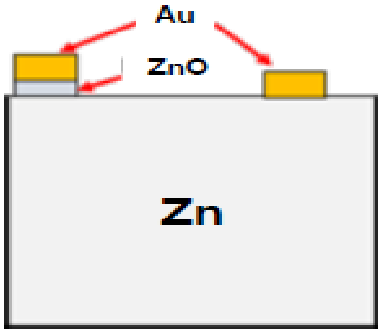
32 gram **zinc bolometer**

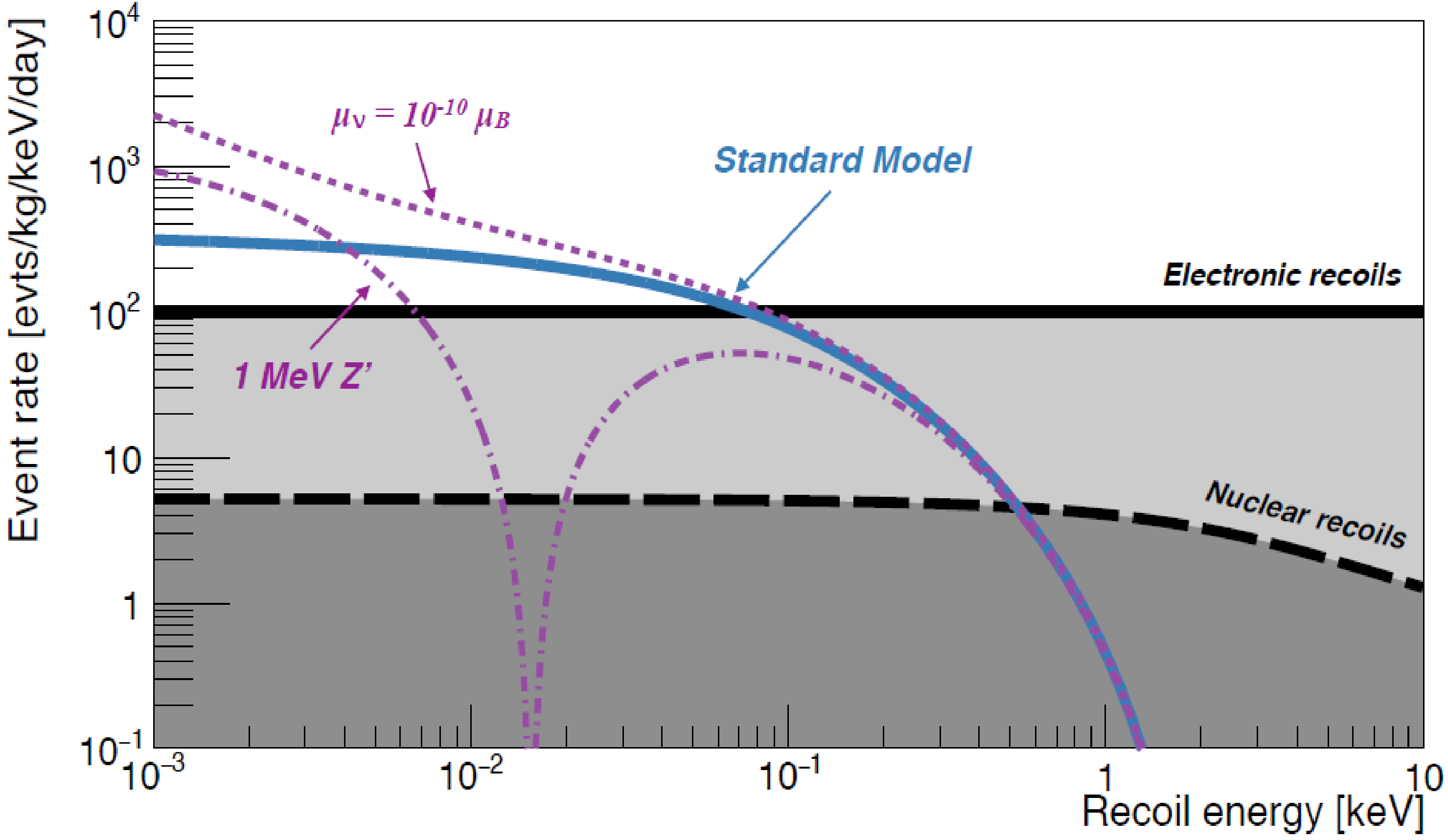
The zinc absorber was instrumented with an NTD thermal resistor and cooled to 15 mK.

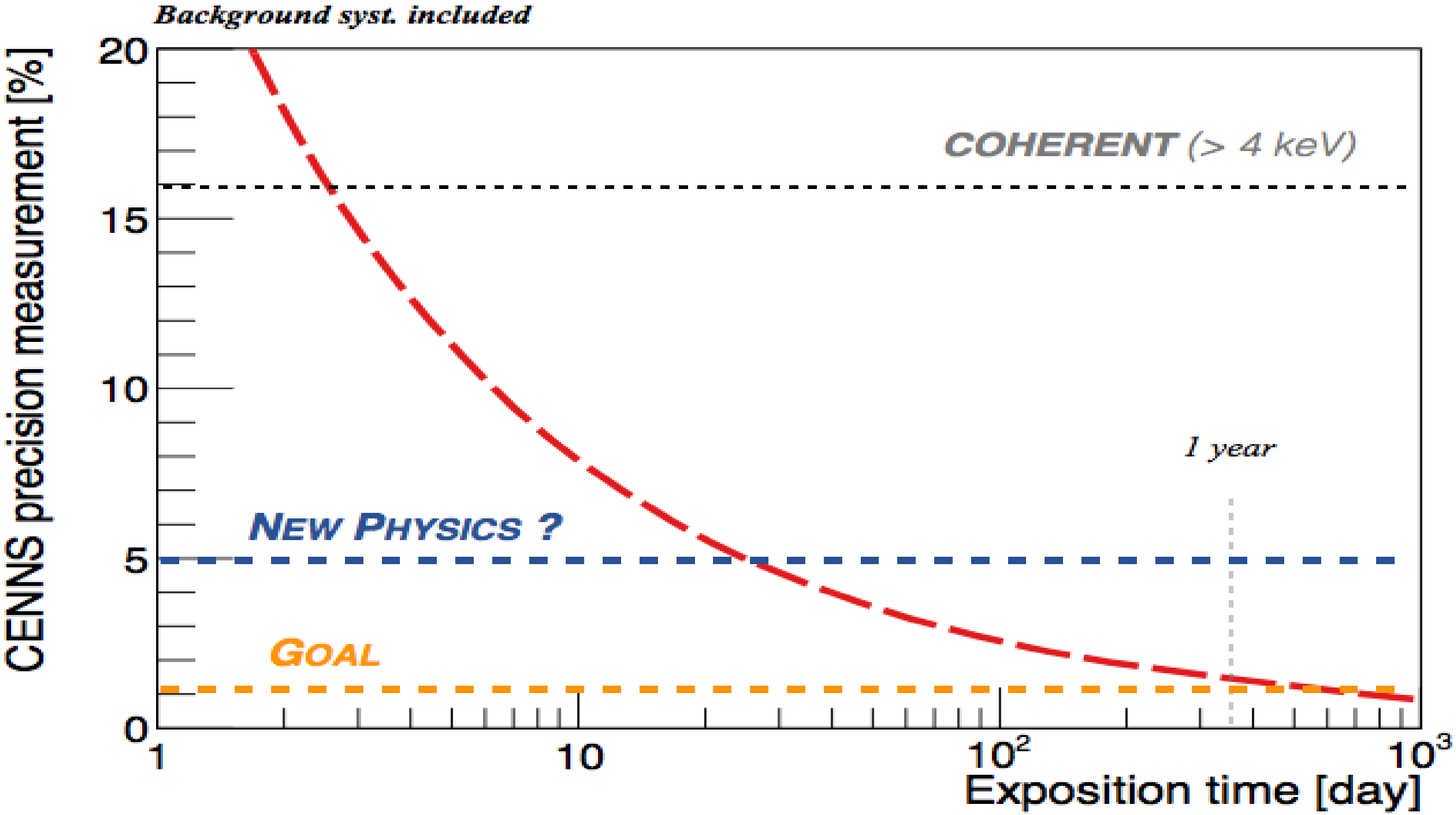
Each detector is instrumented with two gold pads, one in direct contact with the zinc absorber, the other having a 50-100 nm ZnO layer in between the two metals.

Such a configuration will allow one to simultaneously measure the phonon and the phonon+quasi-particle population from a given particle energy deposition.

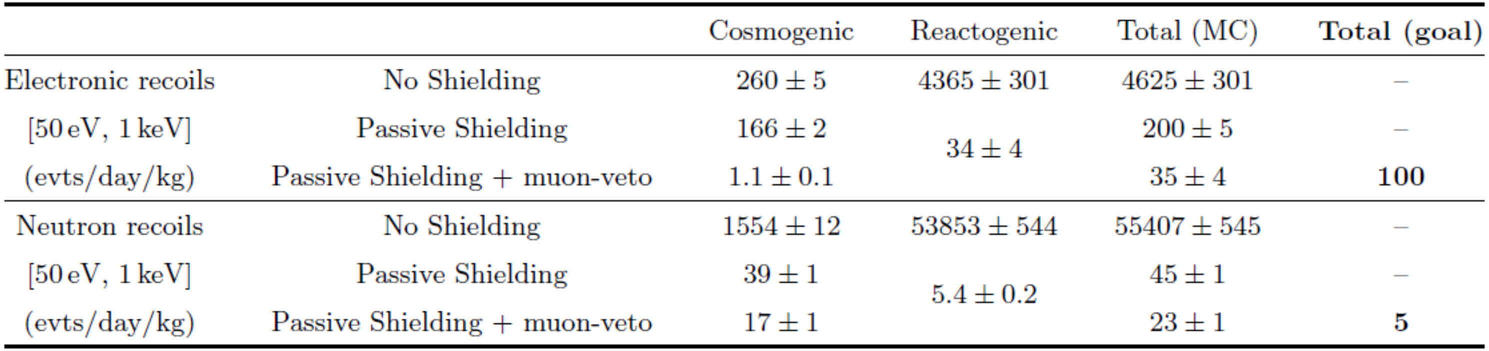




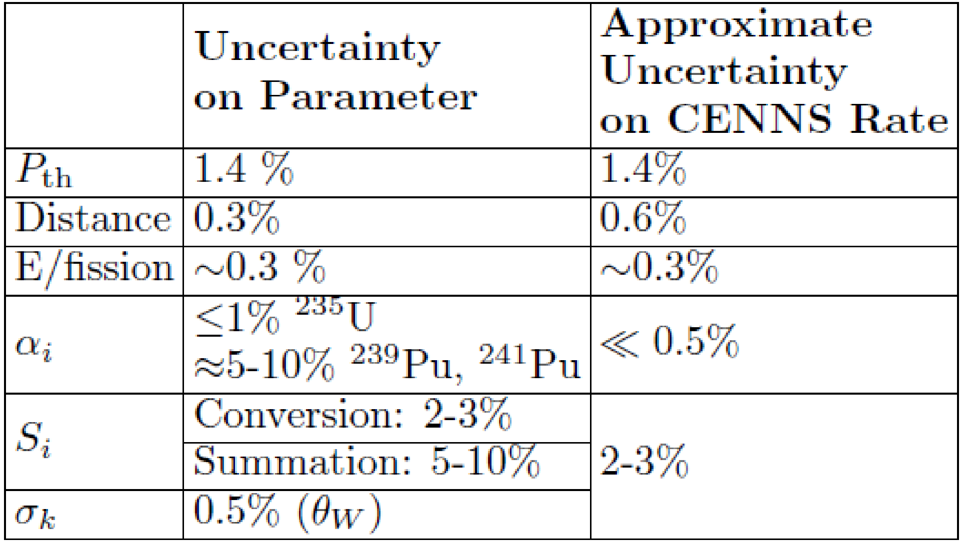

Event rate [evts/kg/keV/day]
10^4
10^3
10^2
10
1
10^{-1}
10^{-3}
10^{-2}
10^{-1}
1
10
Recoil energy [keV]
$\mu_\nu = 10^{-10}\,\mu_B$
Standard Model
Electronic recoils
1 MeV Z'
Nuclear recoils



Background syst. included
CENNS precision measurement [%]
20
15
10
5
0
COHERENT (> 4 keV)
1 year
NEW PHYSICS ?
GOAL
1
10
10^2
10^3
Exposition time [day]

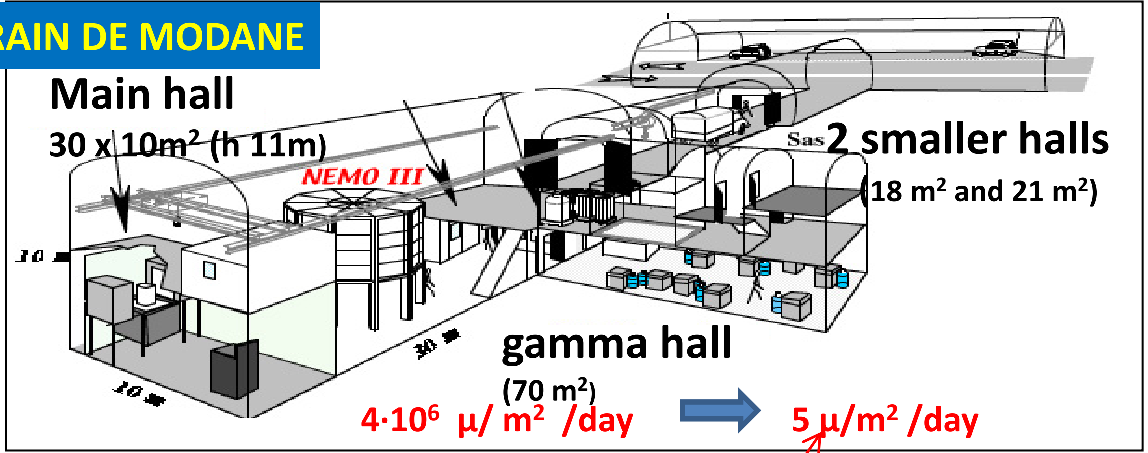


		Cosmogenic	Reactogenic	Total (MC)	**Total (goal)**
Electronic recoils	No Shielding	260 ± 5	4365 ± 301	4625 ± 301	–
[50 eV, 1 keV]	Passive Shielding	166 ± 2	34 ± 4	200 ± 5	–
(evts/day/kg)	Passive Shielding + muon-veto	1.1 ± 0.1		35 ± 4	**100**
Neutron recoils	No Shielding	1554 ± 12	53853 ± 544	55407 ± 545	–
[50 eV, 1 keV]	Passive Shielding	39 ± 1	5.4 ± 0.2	45 ± 1	–
(evts/day/kg)	Passive Shielding + muon-veto	17 ± 1		23 ± 1	**5**



	Uncertainty on Parameter	**Approximate Uncertainty on CENNS Rate**
P_{th}	1.4 %	1.4%
Distance	0.3%	0.6%
E/fission	~0.3 %	~0.3%
α_i	$\leq$1% ^{235}U $\approx$5-10% ^{239}Pu, ^{241}Pu	$\ll$ 0.5%
S_i	Conversion: 2-3%	2-3%
	Summation: 5-10%	
σ_k	0.5% (θ_W)	

LABORATOIRE SOUTERRAIN DE MODANE



Main hall

30 x 10m² (h 11m)

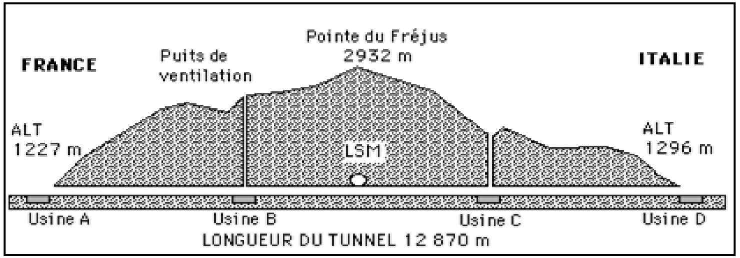
2 smaller halls

(18 m² and 21 m²)

gamma hall

(70 m²)

$4\cdot10^{6}\ \mu/\mathrm{m}^2\ /\mathrm{day}$ → $5\ \mu/\mathrm{m}^2\ /\mathrm{day}$



Operators	CEA/DSM & CNRS/IN2P3
Location	Fréjus Tunnel (Italian-French border)
Excavation	1983
Underground area	main hall (30x10x11 m) + γ-spectroscopy hall (70 m²) + 2 secondary halls of 18/21 m²
Depth	1700 m (4800 mwe)
Surface	> 400 m²
Permanent staff	10
Scientists users	100+

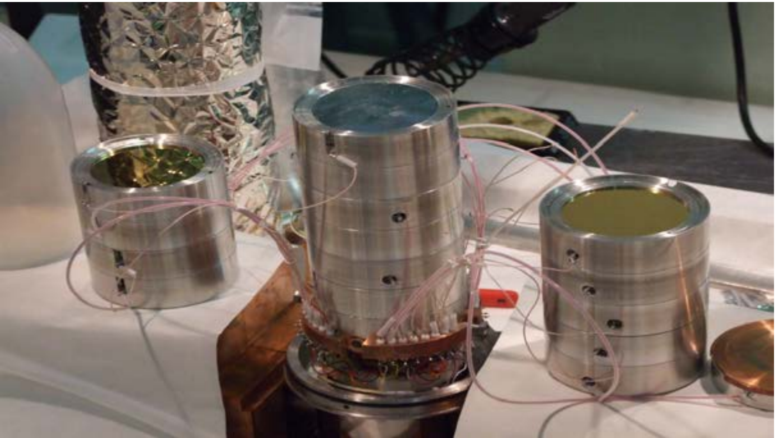
LSM / experiments

Direct DM search EDELWEISS

Doble beta decay with scintillating bolometers CUPID

Heavy elements in nature SHIN

Double EC TGV-II



World leading double beta decay identification NEMO

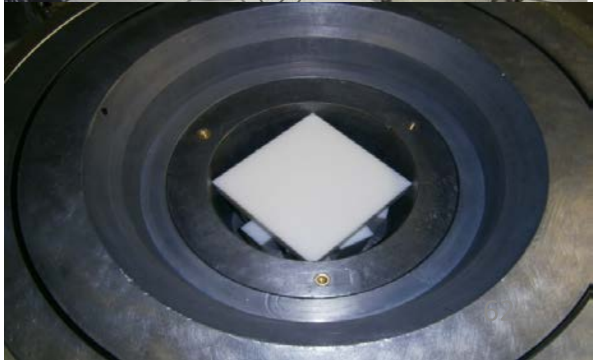
Underground material selection

- Low background detectors are required. Very often only limits of contaminations can be obtained

- Prototype of setup is required (has to tested in an underground lab)

- Impossible to make final phase without phase1, phase2, …,

HPGe detectors in the LSM underground laboratory

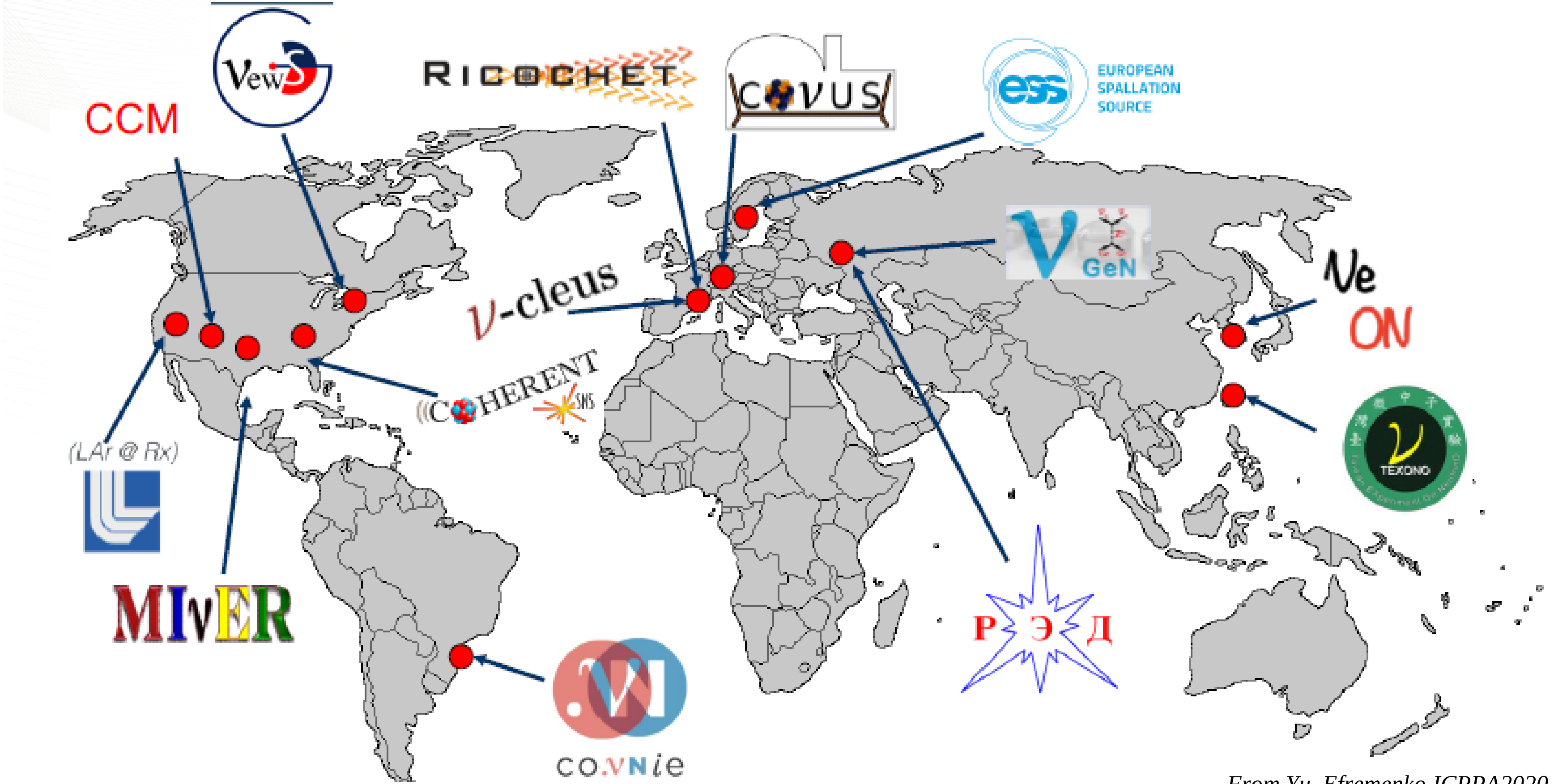


LSM :
HPGe detectors in the underground lab
Two from thems: Low background HPGe detectors with a sensitive volume of 600 cm^3; Relative efficiency: 160%;

NEMO, NEMO-2, NEMO-3, SuperNEMO
EDELWEISS-1, 2, 3, LT
with continuous increasing of mass target and reduction of backgrounds

LSM is used for tests of the νGeN / Ricochet setups

Worldwide Efforts to Measure CEvNS

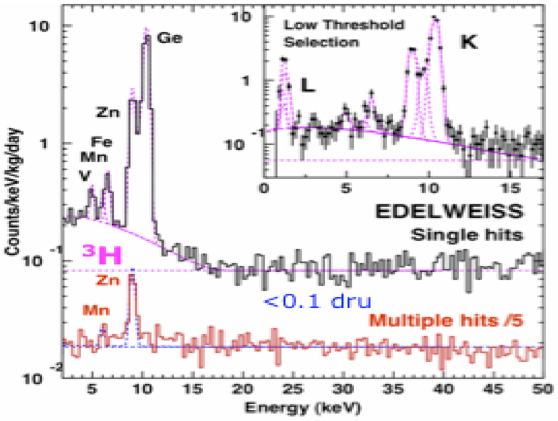


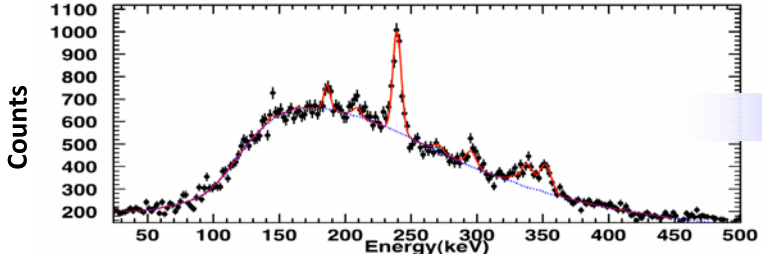
From Yu. Efremenko ICPPA2020 talk

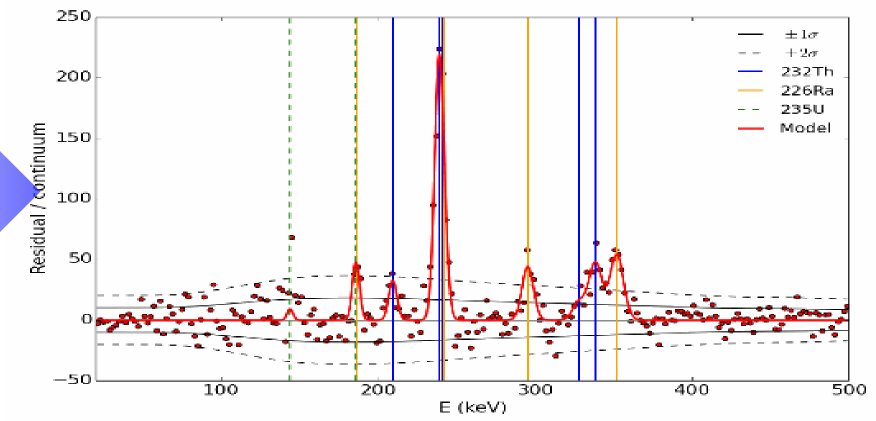
Axion-Like Particle searches

Physical Review D 98 (8), 082004 (2019)

- Starting point: study of electron recoil spectrum of tritium paper **[Astropart. 91 (2017) 51]**
  - 1149 kgd with 2 $\mathrm{keV_{ee}}$ threshold
  - 287 kgd with 0.8 $\mathrm{keV_{ee}}$ thresholds
- Analysis extended to higher energy for line search up to 500 $\mathrm{keV_{ee}}$
- Intensities of observed peaks consistent with known Th/U lines
- Resolution:
  - Baseline 0.19 $\mathrm{keV_{ee}}$
  - Proportional term = 1.2%







ALP & dark photons results

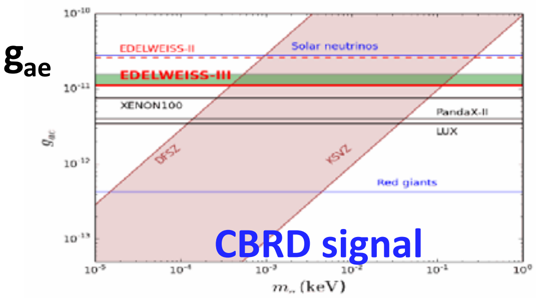
Physical Review D 98 (8), 082004 (2019)

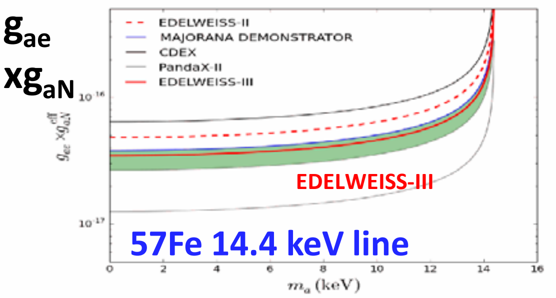
- Emission of axion/ALPs from the sun

keV-scale Bosonic DM:

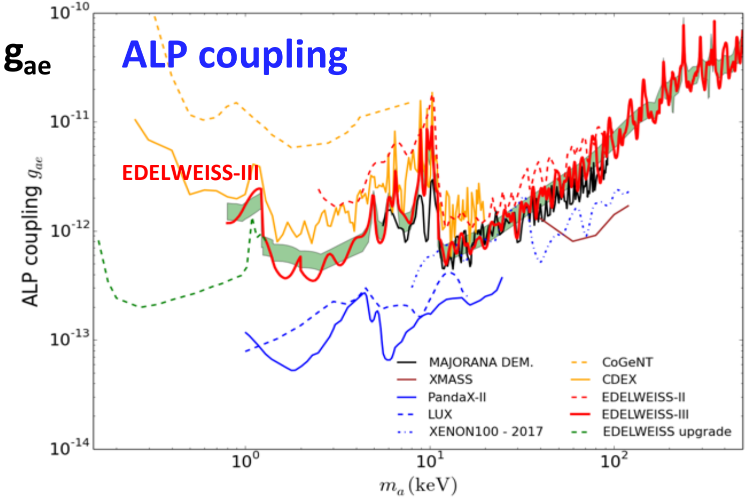
- Best Ge-based limits <6 keV (thanks to surface rejection)
- Start to explore <1 keV

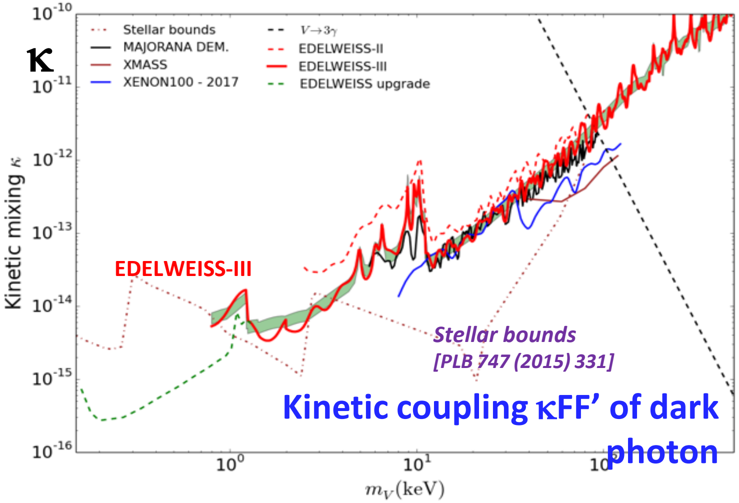
Emission of axions from the sun



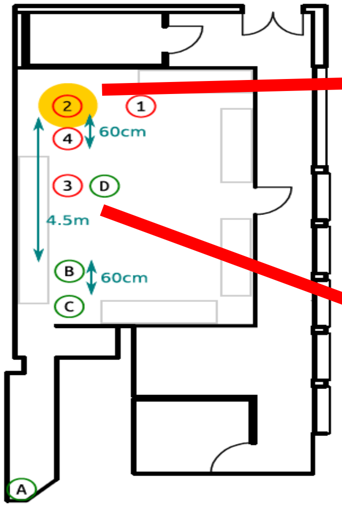


Bosonic DM





iP2i neutron measurements



● Cryostat

ⓧ He3 detector positions

ⓧ AmBe source positions

Ⓔ Outside laboratory

Figure 3.1: Plan of the cryogenic laboratory at IPNL

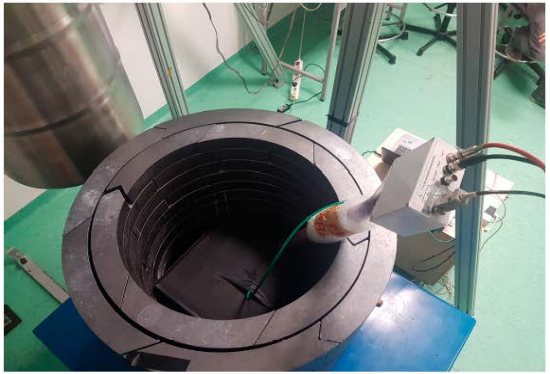
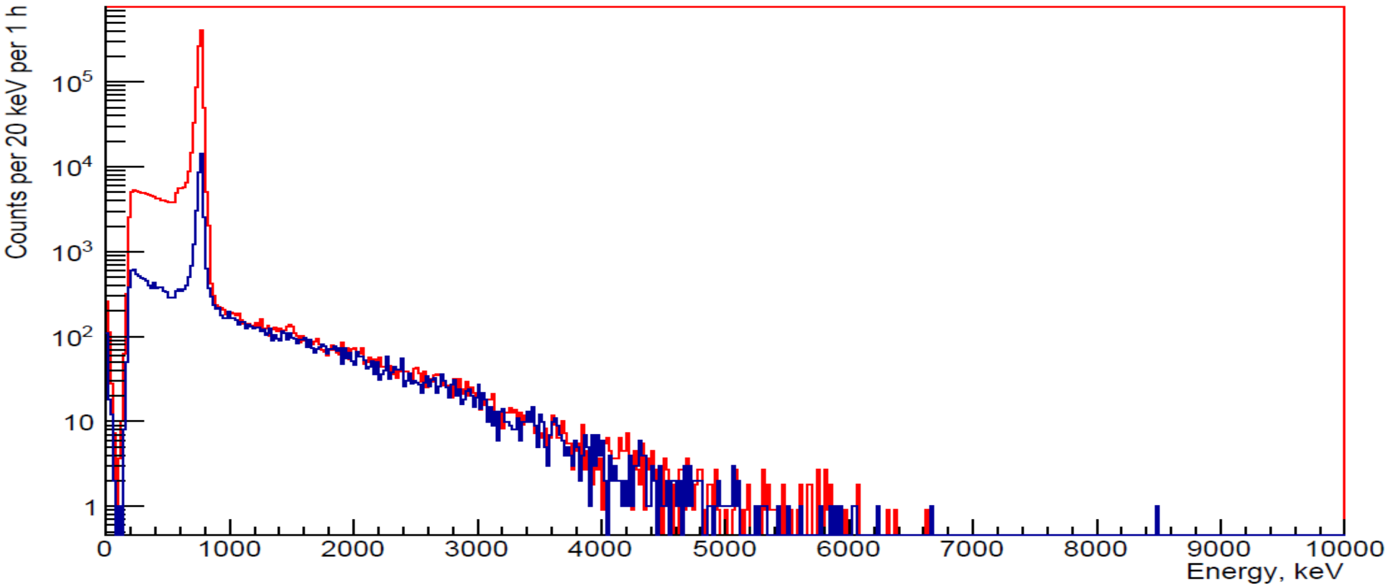


Figure 3.6: Photography of both He3 detectors in the lead shielding used for the cryostat.

iP2i neutron measurements



Blue: AmBe at 35 cm, detector is inside B4C,
red: AmBe at 35 cm

Interaction of Neutrons with He3
A. R. Sayres, K. W. Jones, and C. S. Wu
Phys. Rev. **122**, 1853 – Published 15 June 1961

ILL measurements

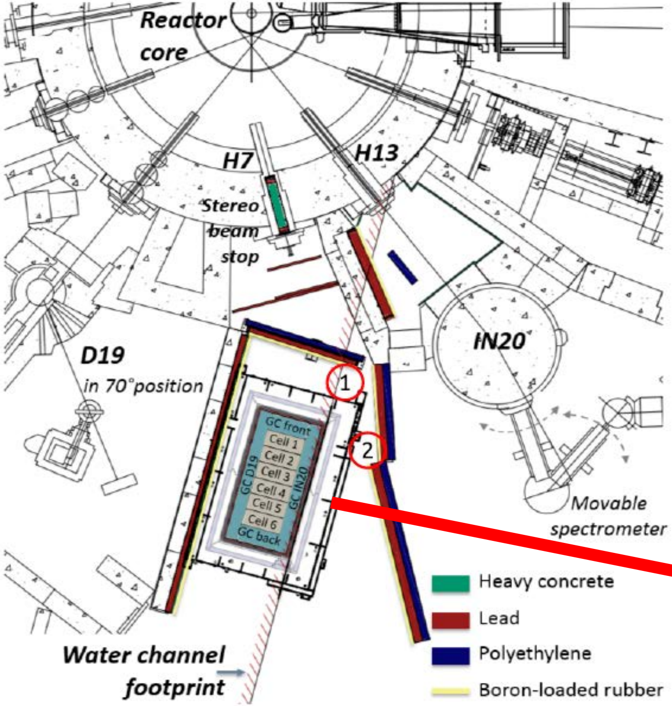
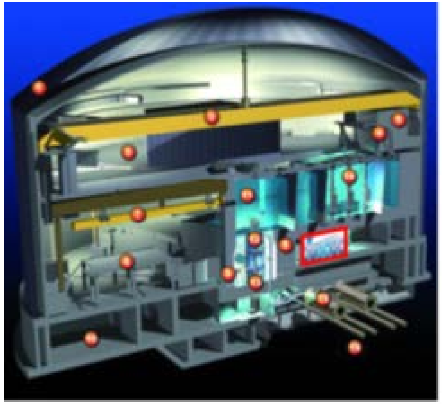
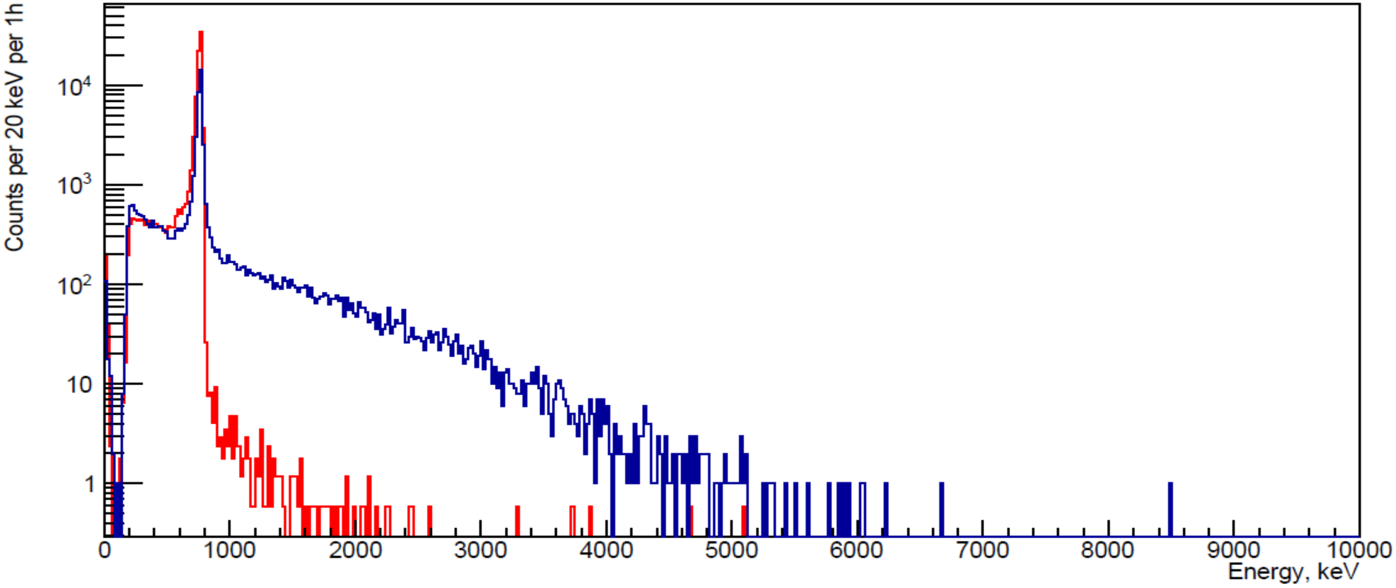
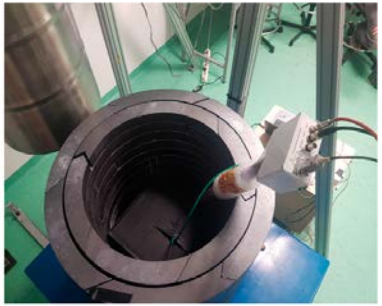


Figure 3.9: Plan of Stereo casemate at ILL



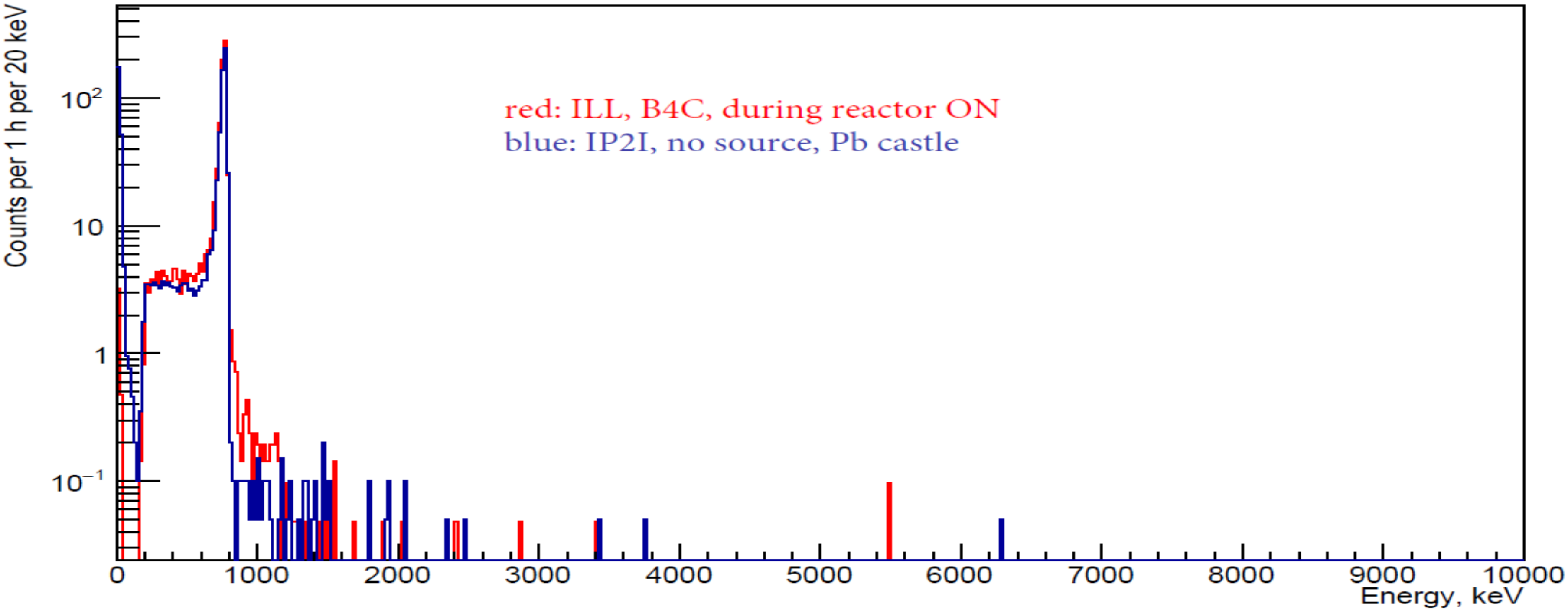
iP2i neutron measurements





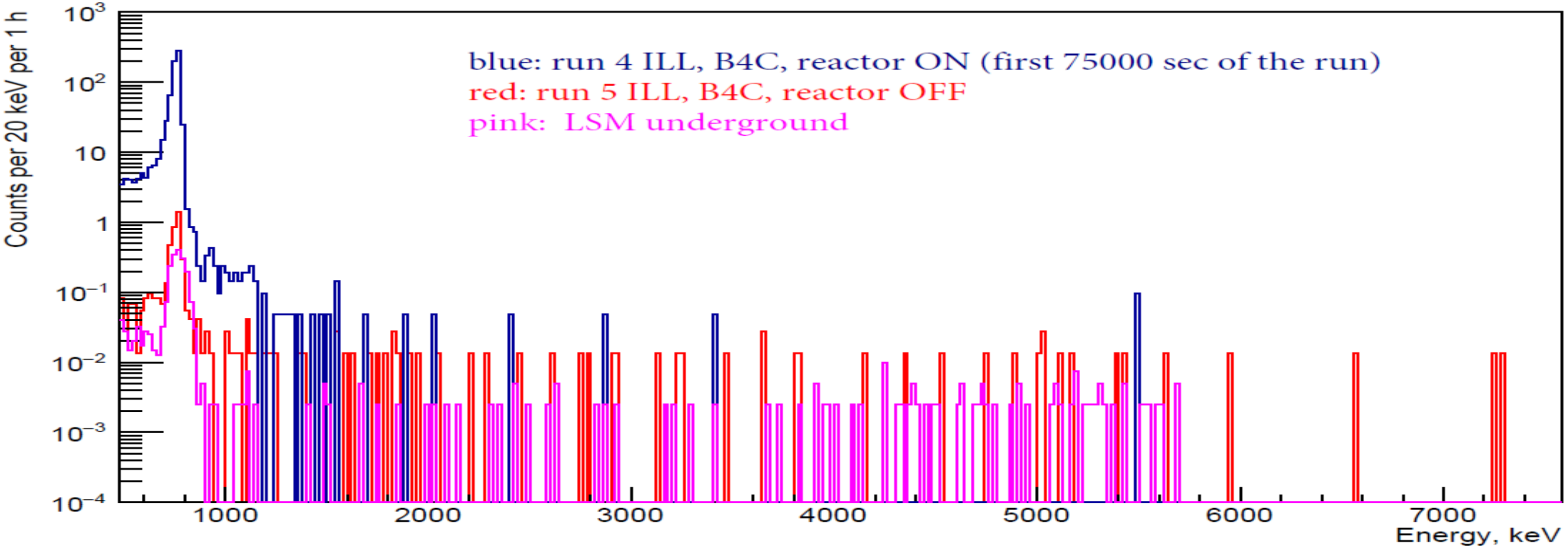
Blue: AmBe at 35 cm, detector is inside B4C,
red: detector inside Pb castle, AmBe is at 450 cm

ILL neutron measurements

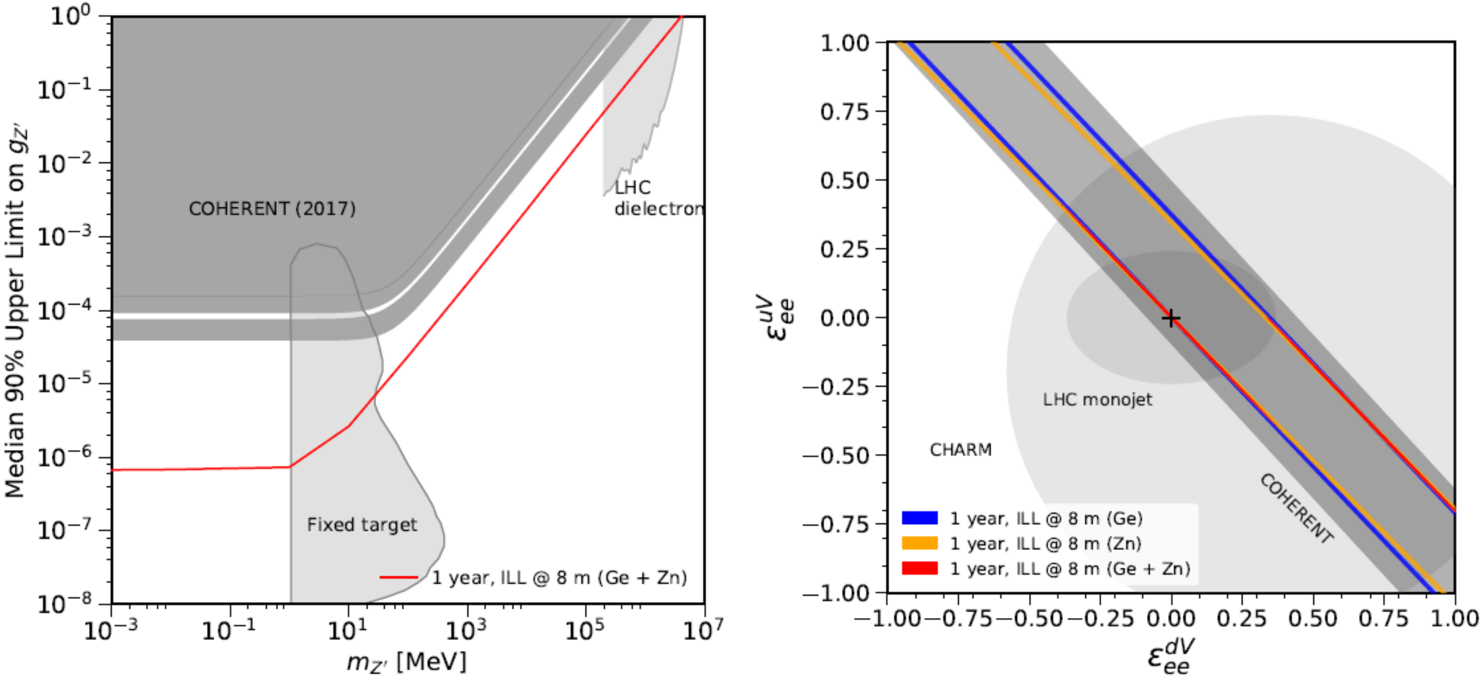


Comparison of spectra at IP2I at the Ricochet test Pb castle (this spectrum is slightly affected/underestimated due to presence of another neutron detector) and at ILL during reactor ON. For ILL measurements the detector was covered with B4C, for IP2I detector is bare

ILL neutron measurements



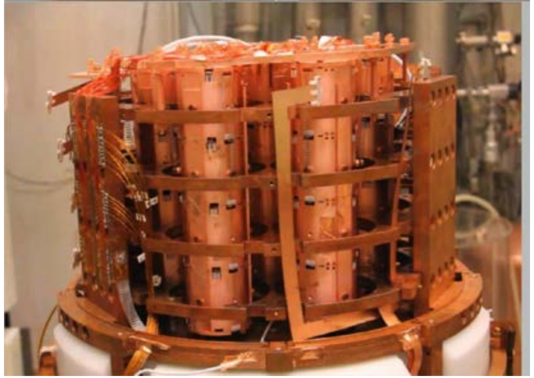
Comparison of energy spectra at ILL when reactor was ON and OFF and at LSM underground.



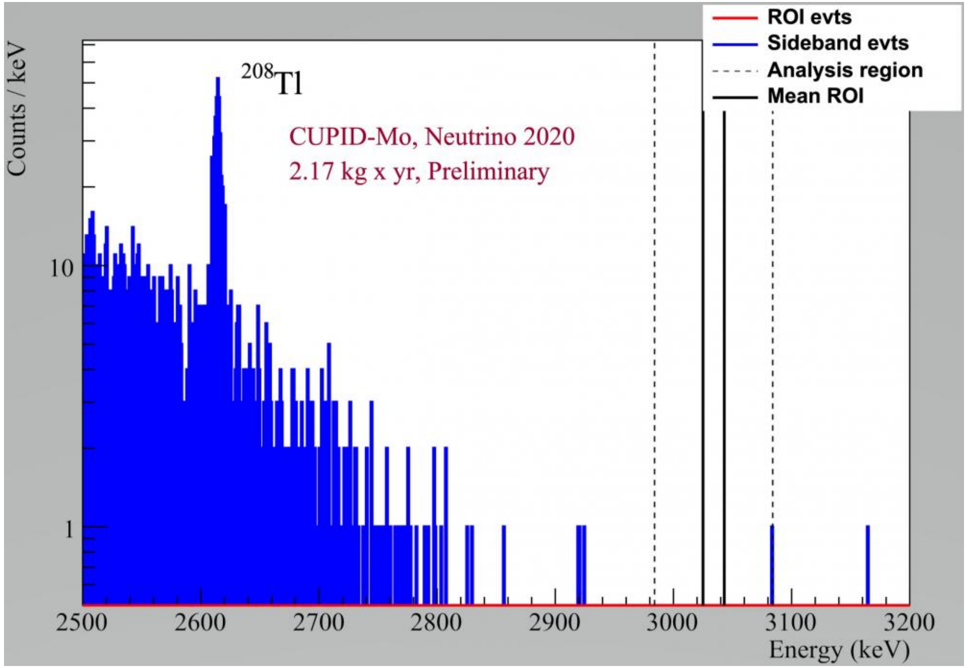
Projected sensitivities of the Ricochet experiment, located at 8 m from the ILL reactor core, to new physics searches in the low-energy CEνNS sector where a 50 eV energy threshold and an electromagnetic background rejection power of 10^3 was assumed. Left: constraints on Z' searches where we have assumed unified coupling to the quarks. The results are shown as 90% C.L. upper limits on the Z' coupling. Also presented are current leading constraints from the APEX fixed target experiment, LHC di-electron searches, and COHERENT. Right: constraints on Non-Standard neutrino-quark Interactions in the neutrino-electron sector. Results are shown as 90% C.L. allowed regions. Also shown are current experimental constraints from LHC mono-jet searches, CHARM, and COHERENT. The cross represents the Standard Model.

CUPID-Mo is a search for neutrinoless double-beta decay in ^{100}Mo which uses 20 Li_2MoO_4 scintillating crystal operated as bolometers. CUPID-Mo is co-located with the EDELWEISS experiment.

Li_2MoO_4 crystal coupled to its Ge light detector



CUPID-Mo detector installed inside the EDELWEISS cryostat at LSM



New world leading limit for 0νββ decay of ^{100}Mo of 1.4×10^{24} y, significantly better than the previous 1.1×10^{24} y, obtained by the NEMO3 collaboration, also at Modane.

Thanks to a very efficient alpha-to-beta/gamma separation and excellent radio-purity levels, the remaining backgrounds are:
significantly below the **10^{-2} counts/(keV kg year)** level in the 0νββ region of interest (around 3034 keV for ^{100}Mo).

This background level is already significantly better than that achieved in the leading bolometric experiment CUORE in the region of interest.