HCERES evaluation of Laboratoires de la vallée d'Orsay

CSNSM
IMNC
IPNO
LAL
LPT

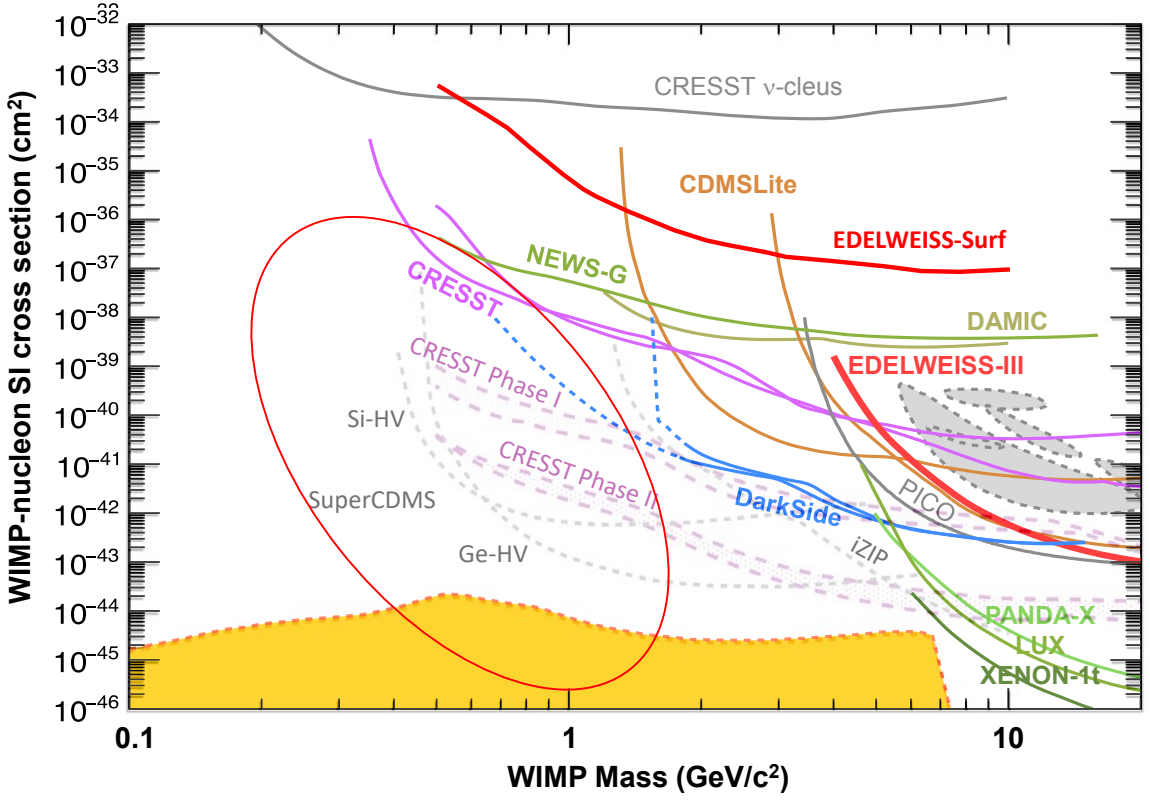
Dark Matter direct search

Speaker : C. Macolino on behalf of the dark matter group

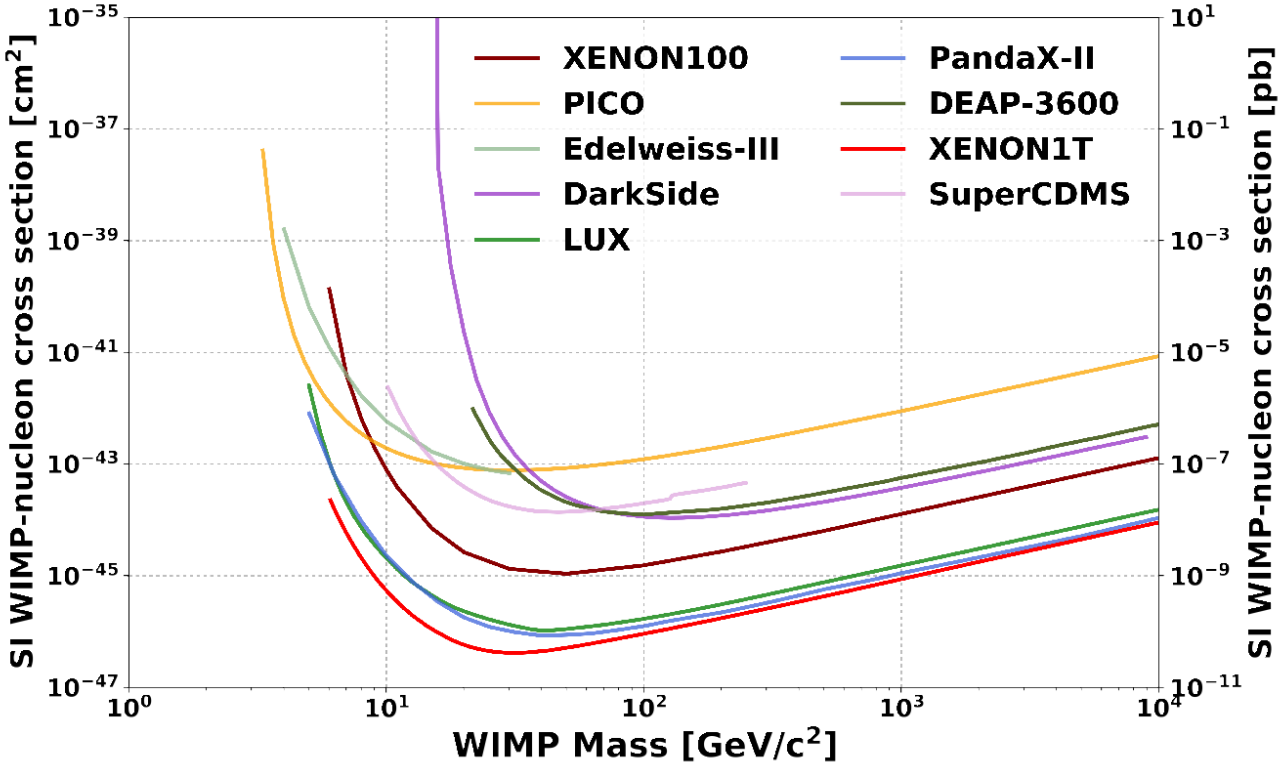
14-17 january 2019

Dark Matter direct search

The search for WIMPs (Weakly Interacting Massive Particles)



Light WIMPs



WIMPs: XENON

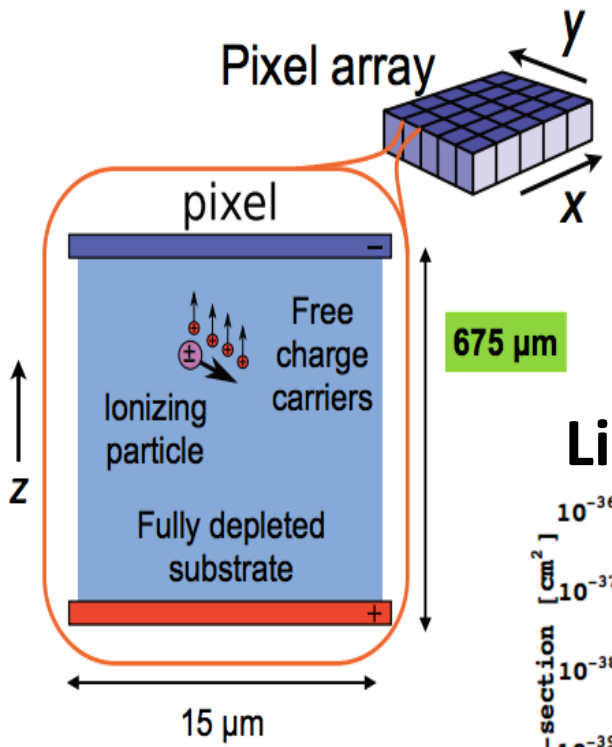
but also FIMPs, Axions, Axion Like Particles, Heavy Photon,…

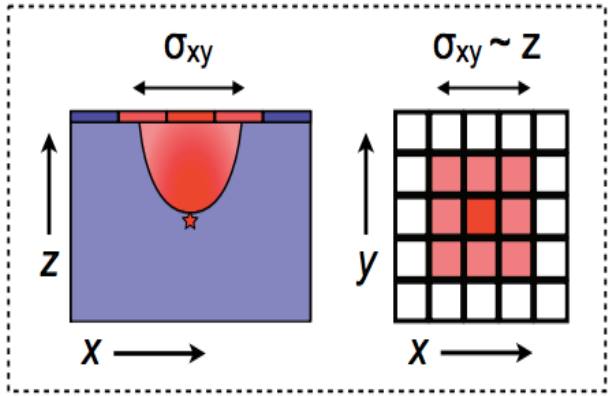
Competitive experiments with different detection techniques

List of experiments/activities and laboratories

- **DAMIC-M**: DArk Matter In CCDs. Direct search for low mass dark matter with CCD detectors.
  - Laboratories: IPN, LAL
- **EDELWEISS**: Direct search for low mass dark matter with bolometers
  - Laboratories: CSNSM
- **HPS**: Heavy photon search in the mass between 10-200 MeV
  - Laboratories: IPN
- **XENON/DARWIN**: Direct search for dark matter (>5 GeV/c^2) with a dual phase Xenon TPC
  - Laboratories: LAL

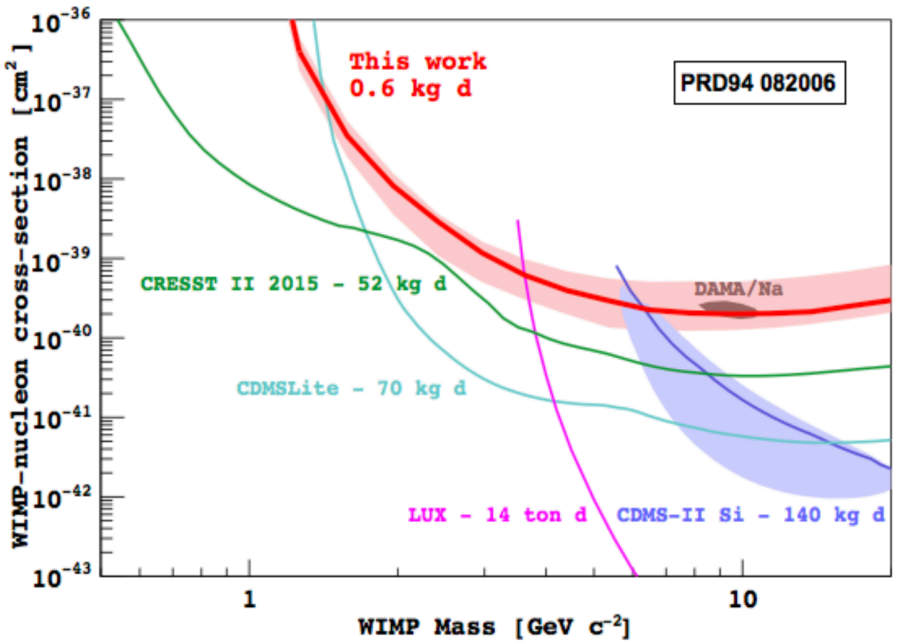
DAMIC@SNOLAB Scientific achievements



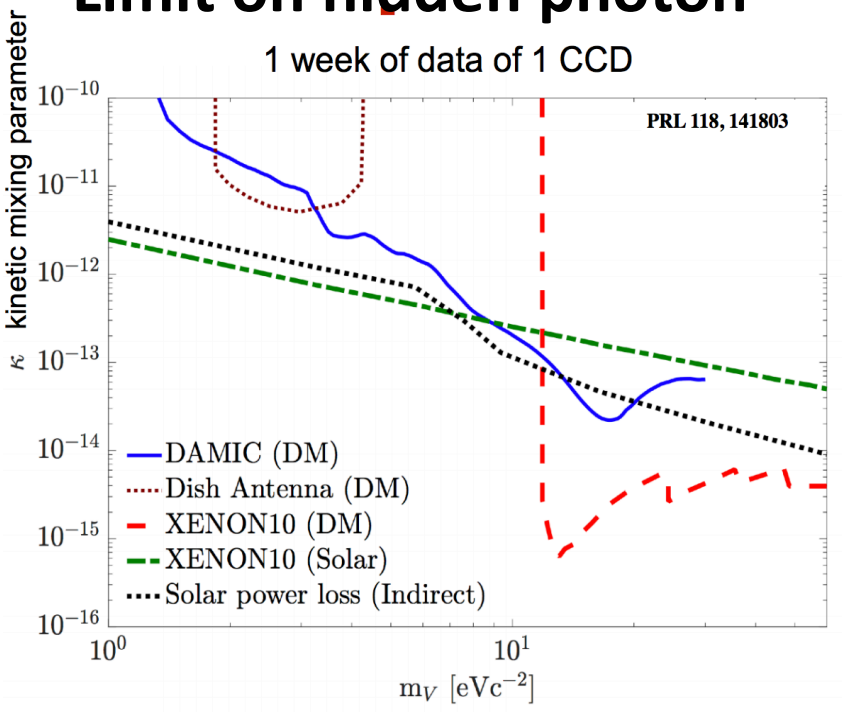


- Local deposit of energy from ionisation or nuclear recoil
- Spatial resolution 15x15 µm^2 in x,y, 50 to 100 µm in z
- Very low energy threshold: 3.6 eV for e$^-$/hole couple
- Energy resolution: <4% at 0.5 keV

Limit on SI WIMPs interactions

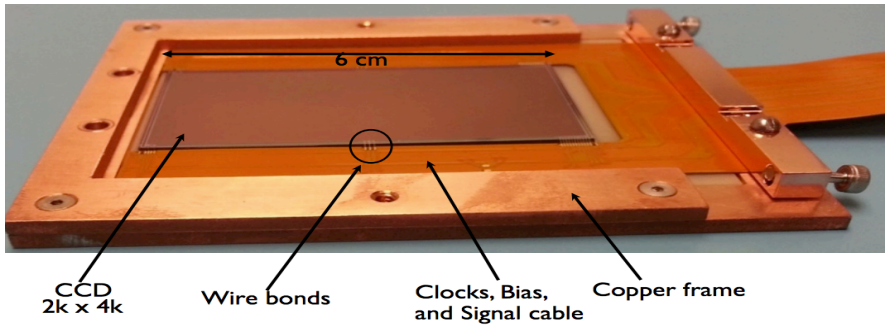


Limit on hidden photon

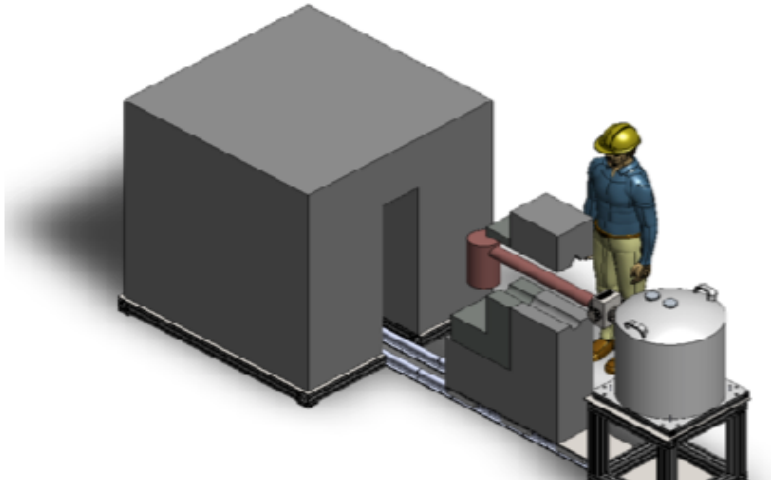


DAMIC-M Project at LSM

- **DAMIC-M at Modane: ERC Advanced funded project started last June 2018**



- 50 CCDs (cible de **1 kg**) at LSM
- CCD 6k x 6k x 1mm, 20 g
- Skipper readout, sub-eV background

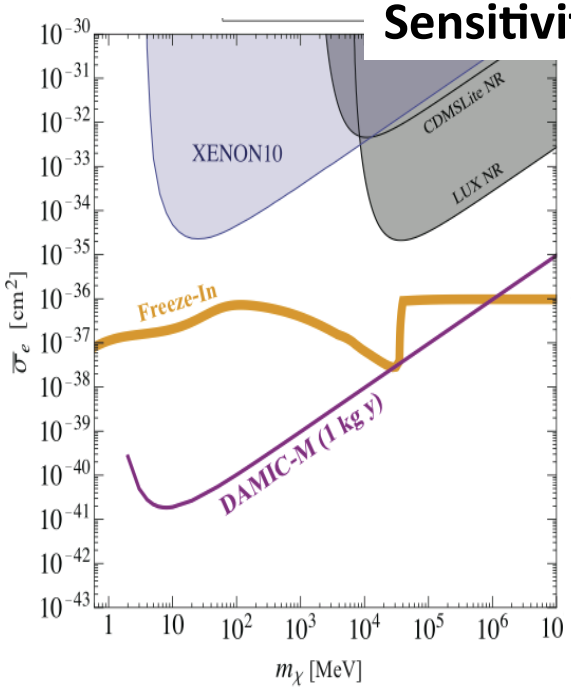


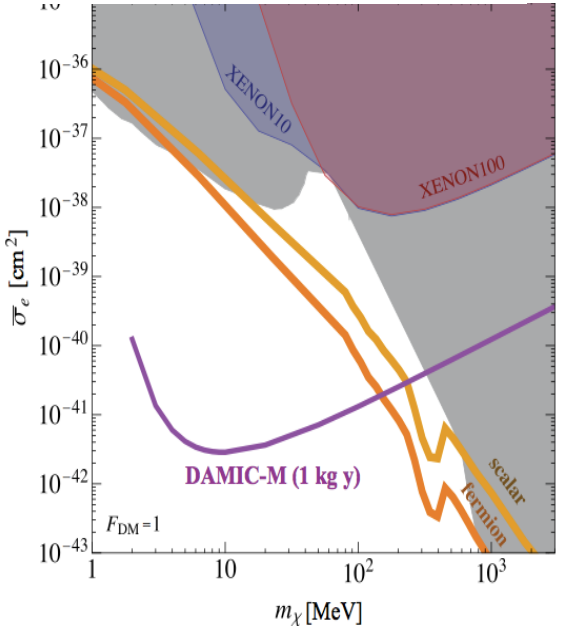
GOALS

- Background from few dru to a fraction of dru*
- External background : better design, materials (e.g. electroformed copper), better shielding and control (radon, surface contamination)
- Internal background :cosmogenic ^{32}Si et Tritium
- Pixels readout: resolution sub-eV
- Threshold at 2 eV
- Leakage current: 10^{-5} e^-/day/pixel

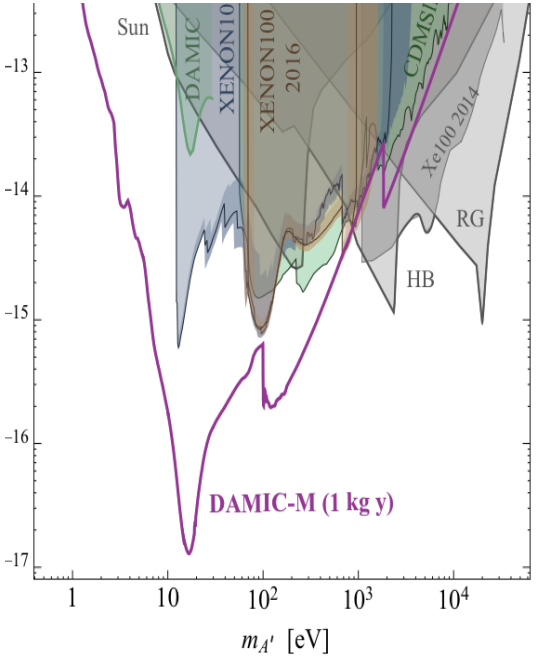
* 1 dru = 1 count/(keV kg day)

Sensitivity to FIMPs





Sensitivity to dark photon



DAMIC-M Project at LSM

Commitments of the group

1. **READOUT/CONTROL ASIC ELECTRONICS**
2. **BLINDING**
3. **LOW-BACKGROUND TECHNIQUES**
4. **DAQ SYSTEM AND DATA MANAGEMENT**

DAMIC-M Project at LSM

HUMAN RESSOURCES

- Electronics : 3 IR 0.8 FTE from LAL and IPN
- Background studies and blinding: 5 IR 0.75 FTE from LAL
- DAQ: 1 CR from IPN
- **HR EVOLUTION**:
  - PhD students and postdocs
  - contribution from other researchers

FINANCIAL SUPPORT

- ERC funding : 3,35 M€ (P. Privitera, May 2018)
  - 5 CCDs for 3 years: 0,7 M€
  - Budget for specific tasks: 1,1 M€ (CCD, electronics, test systems, …)
  - Infrastructures 0,45 M€ (clean room at Modane, electroformed copper)
  - General expenses 0,5 M€
- NSF (USA) : 4 M$ (P. Privitera, September 2018)
  - CCD, Cryostat, Kaptons
  - Missions

EVOLUTION: Need additional financial support to develop local test facilities and missions of the order of 10 or 20 keuros/year

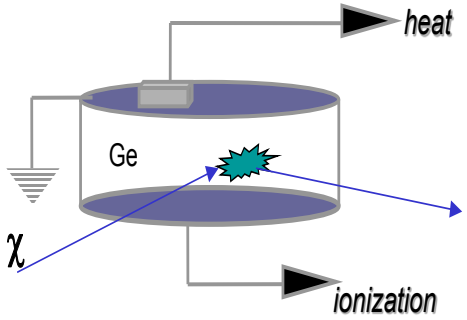
LINK WITH LOCAL/NATIONAL/INTERNATIONAL COMMUNITIES:

- Local: the project has been conceived as a collaborative effort of 2 laboratories of the Orsay campus (IPN and LAL)
- The project has been conceived thanks the presence of:
  - Expertise of mechanical engineering at LAL
  - Expertise on electronics at LAL and IPN
  - Expertise on DAQ

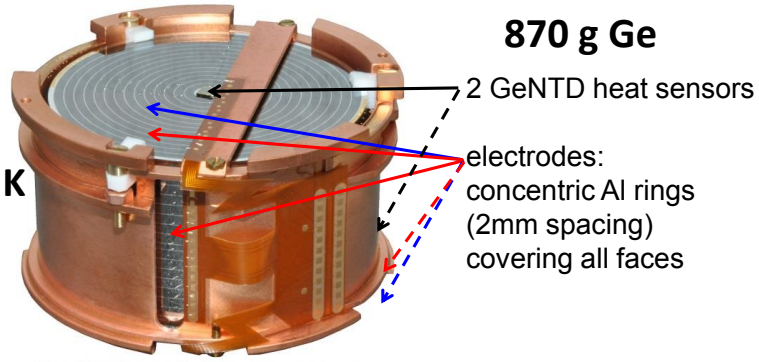
EDELWEISS Scientific Achievements

EDELWEISS-III detectors (CSNSM design)

Heat: $\Delta T = E/C_{cal}$



T = 18 mK



870 g Ge

2 GeNTD heat sensors

electrodes: concentric Al rings (2mm spacing) covering all faces

Ø=70mm, h=40 mm

J Low Temp Phys (2014)**176**:182
Phys.Lett.B **681** (2009) 305

Ionization:

ε_γ = 3 eV/(e-hole pair) for electron recoils (γ,β)

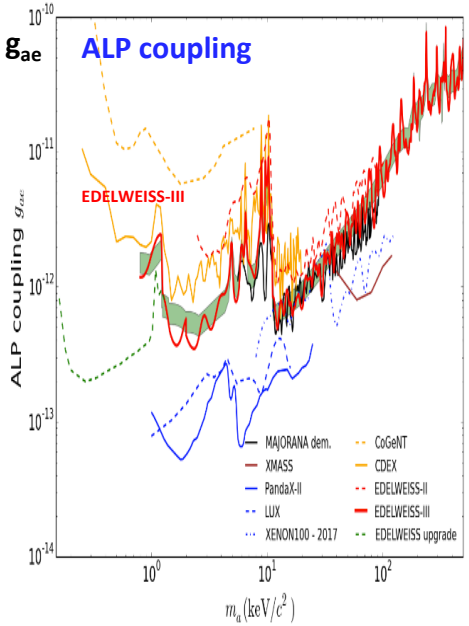
ε_n ~ 12 eV /(e-hole pair) for nuclear recoils (neutrons, WIMPs)

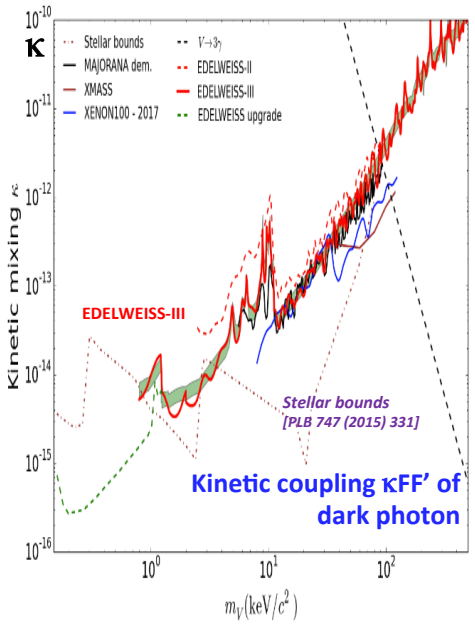
$\varepsilon_\gamma/\varepsilon_n$ = ionization quenching Q

→ $E_{ion} = Q\, E_{recoil}$ in keV_{ee}

Heat: direct measurement of ALL the energy, irrespective of particle ID

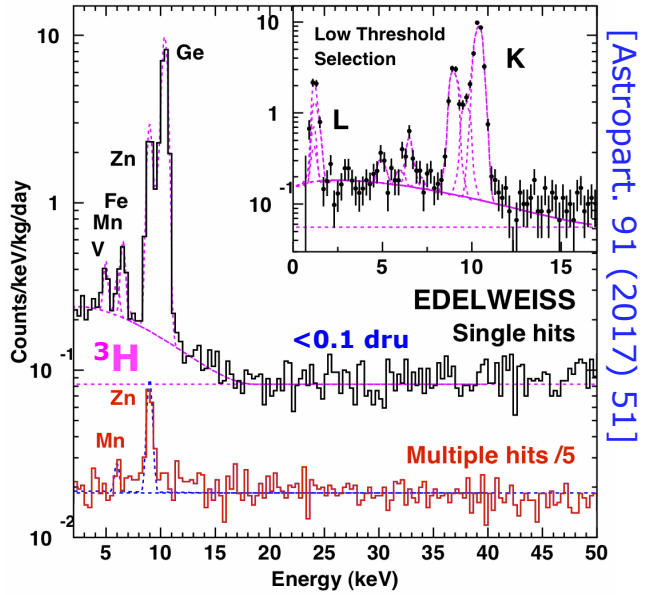
[PRD 98, 082004 (2018)]





Axion-Like Particles and dark photon results (best Ge-based limit)

Largest mass of cryogenic Ge (30 kg) for Dark Matter search



[Astropart. 91 (2017) 51]

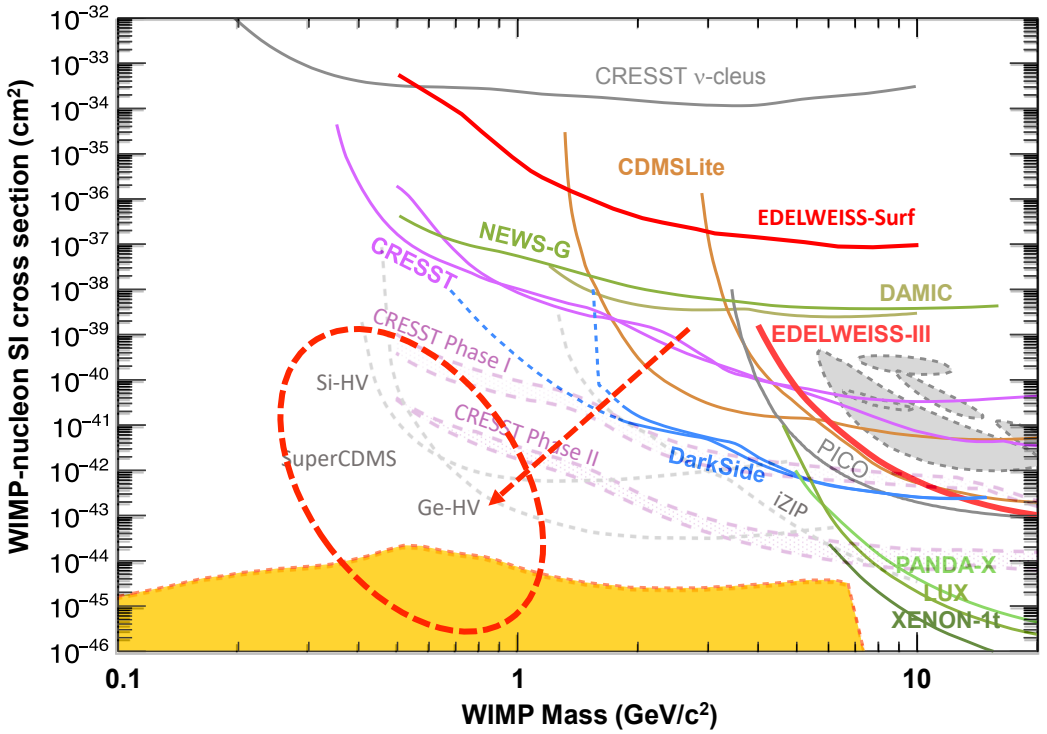
First precise Measurent of ^{3}H production in Ge

EDELWEISS Project

- The scientific objective of EDELWEISS is to reach WIMP-nucleon cross-section of 10^{-43} cm^2 at 1 GeV/c^2 using a new generation of detectors with event-by-event discrimination and < 100 eV_{ee} energy threshold.
- Cryogenic Ge-detectors with background discrimination are considered for coherent elastic neutrino-nucleus scattering physics. Cooperative actions inside the large laboratory will be investigated in the frame of this project.
- Reaching 10^{-43} cm^2 at 1 GeV/c^2 requires an exposure of 1 kg.y with a detector with s_{phonon} = 10 eV
- and s_{ion} = 20 eV_{ee}

➢ **3 tasks identified by the collaboration**
  ➢ **Heat resol.: σ_{phonon}= 10 eV**
  ➢ **Ionization resol.: σ_{ion}= 20 eV_{ee}**
  ➢ **adapted cryogenics**

➢ Demonstrator: operation at LSM of a kg-size array of detectors with σ_{phonon} = 10 eV and σ_{ion} = 20 eV_{ee}



EDELWEISS Project

HUMAN RESSOURCES

	2014	2015	2016	2017	2018
	3 CNRS (CR)			1 CNRS (CR)	
	1 Emeritus CNRS (DR)				
	2 Engineers				3 Engin.
	1 Postdoc				
				1 internship	

HR EVOLUTION: Involvement of a new researcher with experimental profile is crucial

PUBLICATIONS

More than 30 papers on TOP cited journals

In the last 5 years:

- 10 Reviews with referees
- 5 Conferences proceedings

FINANCIAL SUPPORT

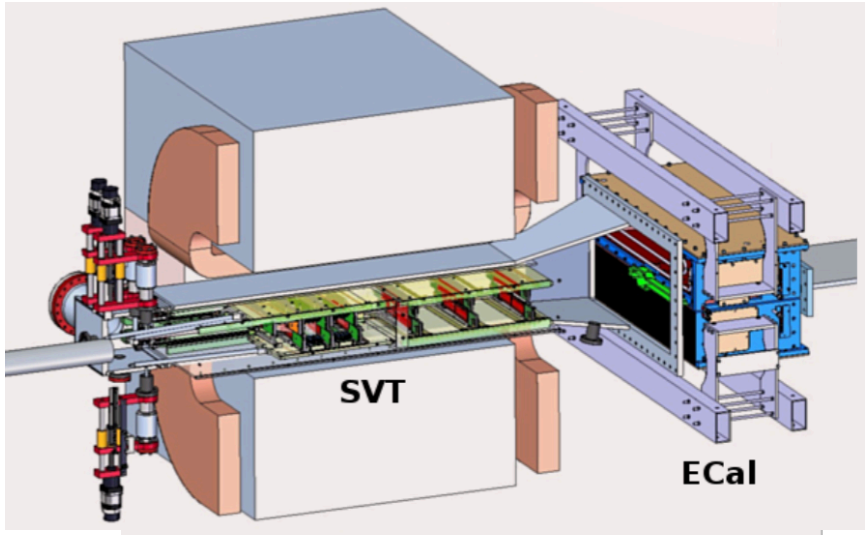
- Average IN2P3 contribution to EDELWEISS 2014-2018 running costs: 50 k€ /year
- Average cost of detector R&D : 50 k€ /year (IN2P3, CNRS, P2I)
- **EVOLUTION**: Expected support to R&D from IN2P3 : 50k€ /year + ANR, LabEx, PICS…

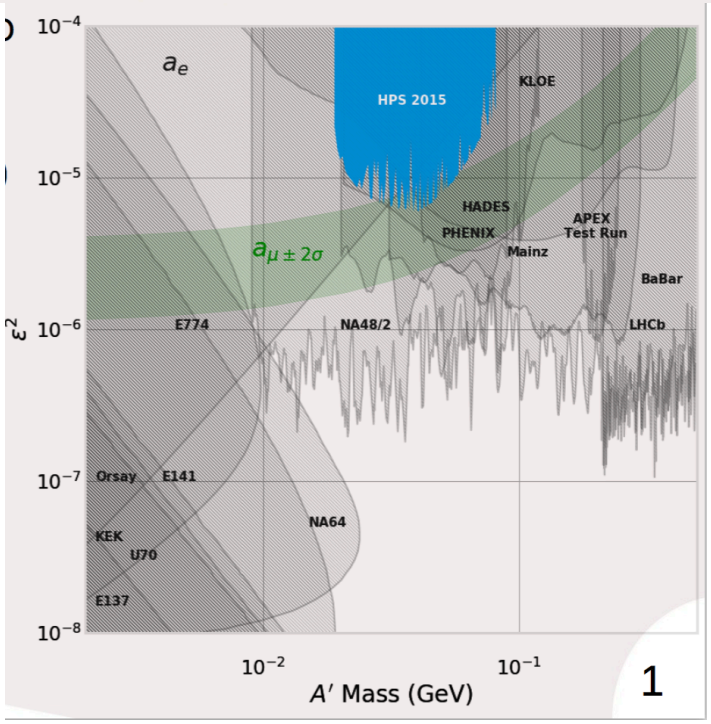
LINK WITH LOCAL/NATIONAL/INTERNATIONAL COMMUNITIES:

- Intensive R&D to achieve very low energy threshold and discrimination on cryogenic Ge detectors. The local community has great expertise on this domain.
- Active collaboration with INPL and CEA.
- Link with SNOLAB (Canada): opportunity to use SuperCDMS setup

HPS Scientific achievements and project

- **Heavy Photon Search (HPS@JLab)**
  - Search for a new massive vector boson (heavy photon) related to dark matter search in a dark sector
  - The heavy photon is produced via brehmsstralung from an electron beam on a tungsten target
  - The heavy photon decays into e^+e^-
- **Detection system**
  - The calorimeter (ECal) has been constructed in 2014 by the IPNO group
  - Funding ANR-JCJC and SESAME : 400 k€ (+ participation INFN)
  - **The calorimeter has demonstrated its capabilities *NIM A854, pp. 89-99***
  - Silicon tracker (SVT) installed in February 2015 (SLAC)
- **Data taking (180 days)**
  - Engineering run in 2015 with a 1.1 GeV beam for 1.5 days
  - **First published results *Phys.Rev. D98 (2018) no.9, 091101***
  - To be published soon : run of 2016 at à 2.3 GeV (4.5 days)
  - Next run in summer 2019 (~40 days)
- **Upgrade in 2019**
  - Hodoscope in front of the calorimeter
  - Design and construction at IPN finished in 2018





HPS project

HUMAN RESSOURCES

- The main goal of the group is to maintain its involvement in the HPS experiment and the heavy photon physics.
- 5 permanent people involved on the project, however the FTE in 2018 has dropped to ~0.5 FTE In the past 5 years.
- 3 years of postdoc (2012-2015) and a PhD student (2014-2017)

HR EVOLUTION:

- Hire a new PhD student to work on the 2019 and later data.

PUBLICATIONS

- Publication of the first physics result:

Phys.Rev. D98 (2018) no.9, 091101

- Other publications as technical papers

FINANCIAL SUPPORT

- Two grants have been obtained on the project:
  - one ANR-JCJC (257 k€)
  - a SESAME grant (200 k€) from the Ile-de-France

EVOLUTION: Support from IN2P3 to attend shifts and collaboration meetings. No major construction is planned

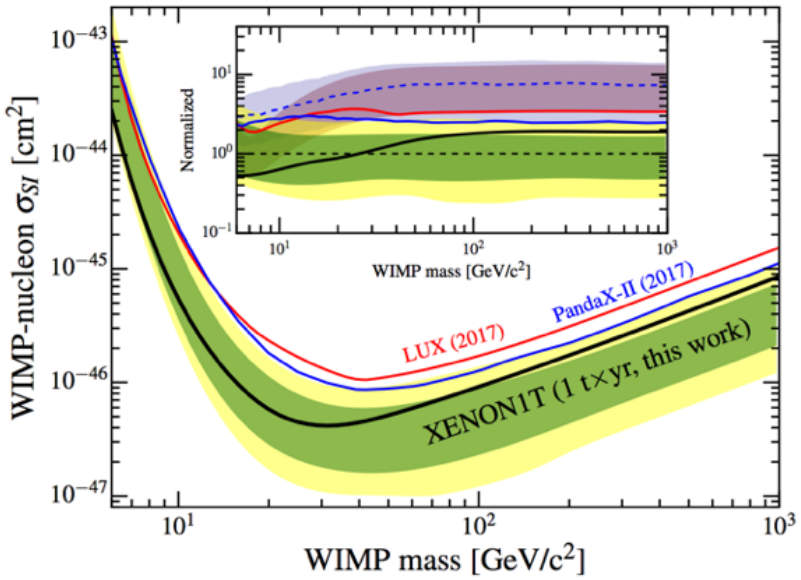
TEACHING

- Participated in the NPAC mini-stage for three years around the calorimeter project.

PROJECT EVOLUTION

- Strong expertise to start more activities in the domain of heavy photons but in the long term the activity will disappear if nothing new comes

XENON Scientific achievements



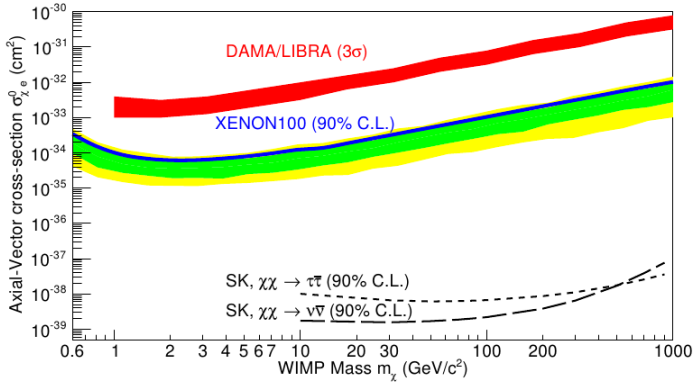
World best limit on WIMP search above 6 Gev/c^2

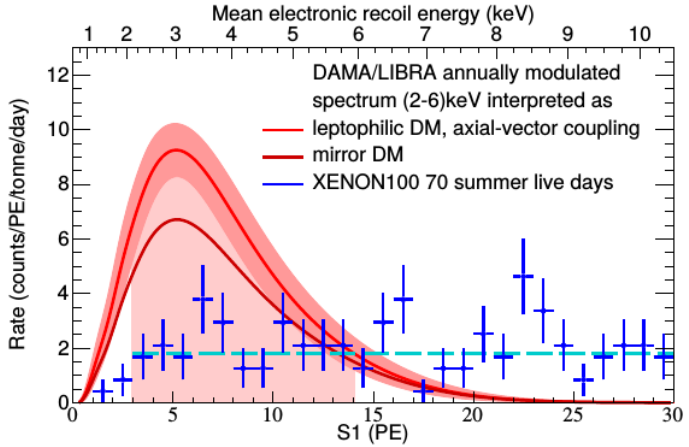
Factor 7 improvement wrt previous LXe experiment

And also with XENON100 data

- Spin dependent interaction
- Solar axions
- Galactic axion-like particles
- Magnetic inelastic dark matter
- …

Annual Modulation with XENON100

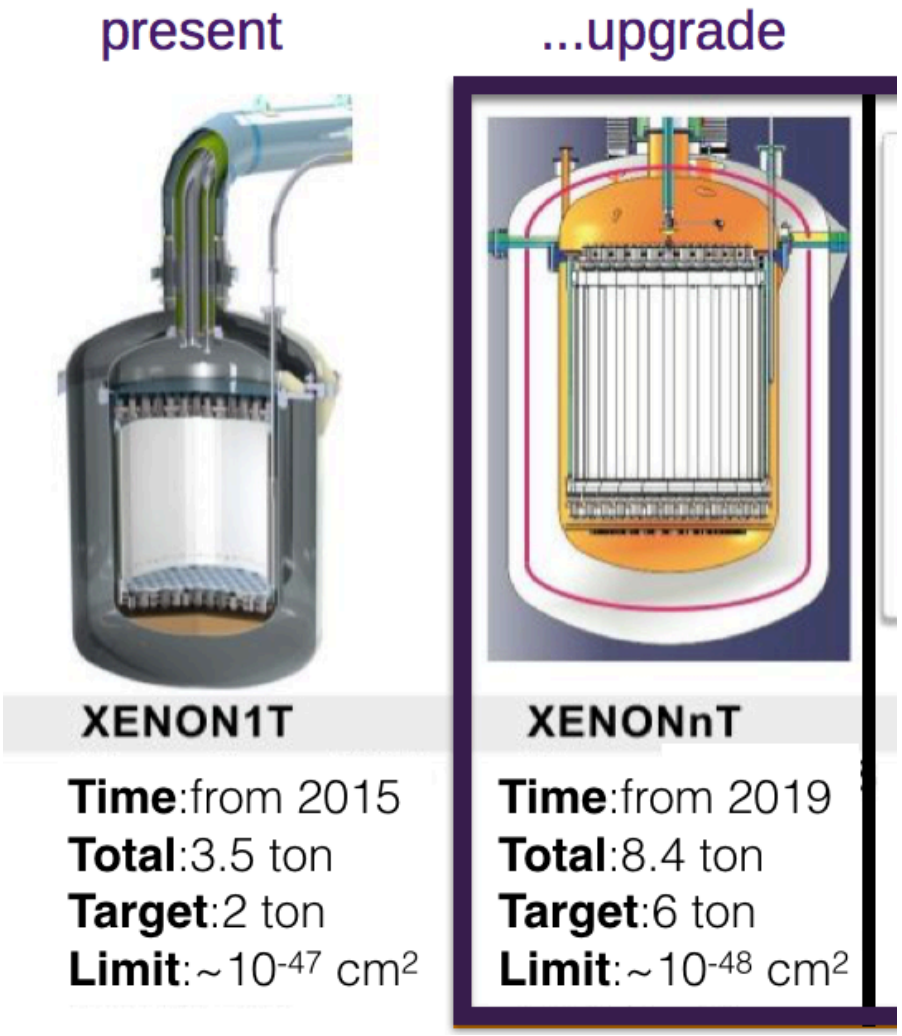




E. Aprile et al. (XENON), Science 2015 vol. 349 no. 6250 pp. 851-854

XENON Scientific achievements

nT detector operational in 2019: not just mass scale but also technical challenges and less background will be achieved!



LAL joined the XENON collaboration in 2017 with precise and important commitments for the XENONnT detector

LAL group is deeply involved in technical improvements for the XENONnT detector

- **ReStoX2**: Recovery and Stockage of Xenon under high purity conditions
- **Electrodes** for XENONnT: conception, realization and assembly of XENONnT electrodes for the TPC
- **Data analysis** and **Monte Carlo** simulations

The detector is currently in the installation phase and will start data taking end of 2019

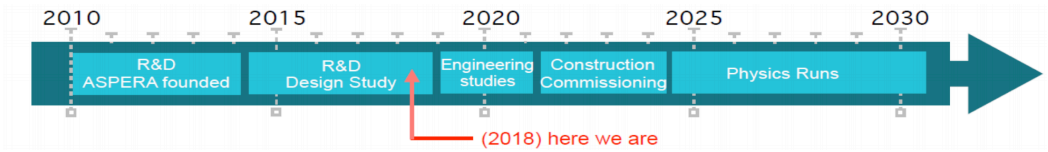
XENON/DARWIN Project

LAL joined the XENON collaboration in 2017 with precise and important commitments for the XENONnT detector.

The commitments for DARWIN will naturally follow the expertise acquired on the following topics

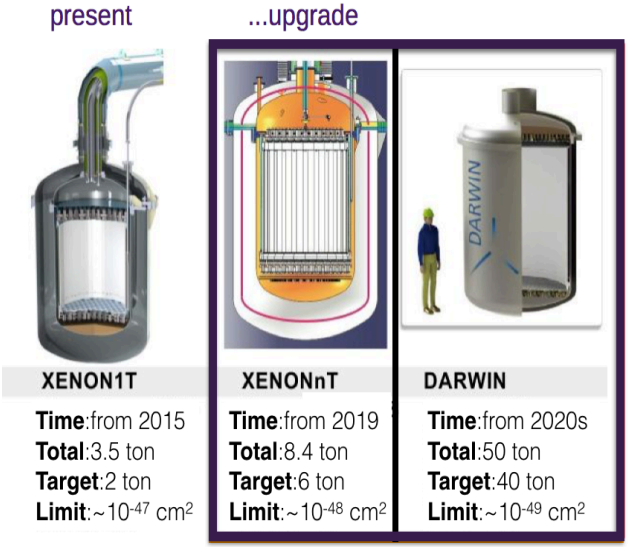
New technical challenges will have to be faced due to larger and more radio-pure detector

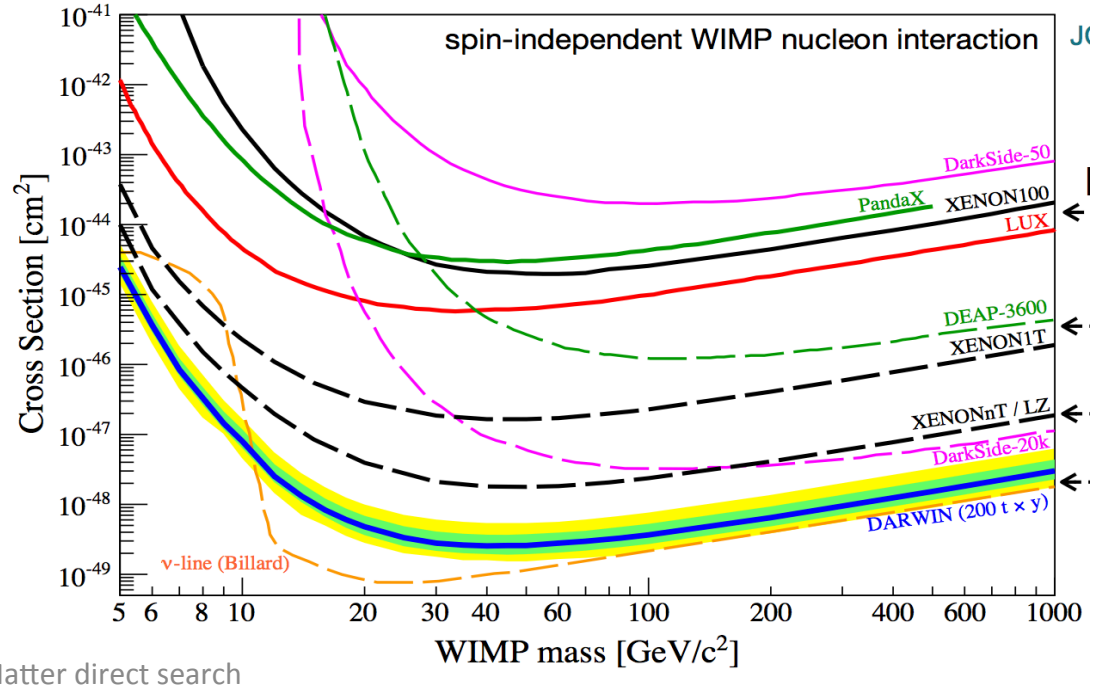
- **ReStoX2**: Recovery and Stockage of Xenon under high purity conditions
- **Electrodes** for XENONnT: conception, realization and assembly of XENONnT electrodes for the TPC
- **Data analysis** and **Monte Carlo** simulations



DARWIN is in the APPEC Roadmap

Best world sensitivity above 6 GeV/c²





XENON/DARWIN Project

HUMAN RESSOURCES

- 1 CR
- 4 IR from the mechanical division at LAL (0.5 FTE)
- **HR EVOLUTION**:
  - 2 other researchers involved in the activities for DARWIN
  - Reinforce number of engineers involved (currently 3 engineers), with at least 4 or 5 engineers.
  - At least 1 postdoc and 2 PhD students

FINANCIAL SUPPORT

IN2P3: in total 230 keuro from 2017 (80 keuro for nT electrodes) for the French contribution

Laboratories: 50 keuro from Subatech, 75 keuro from LPNHE, 56 keuro from LAL

EVOLUTION:

- Financial support from IN2P3 is necessary to support the technical commitments of LAL and of the other French groups
- Level of required financial support should be higher than the one obtained for the nT phase

XENON/DARWIN Project

PUBLICATIONS

XENON1T publications in TOP cited journals:

- **Dark Matter Search Results from a One Ton-Year Exposure of XENON1T**, PRL 121 (2018) – 528 citations so far
- and many other interesting phyiscs analyses to be published soon (low mass WIMPs, solar axions, ALPs, ….)

In the last 5 years XENON100 published more than 50 papers on TOP cited journals of which the most cited has 1490 citations

LINK WITH LOCAL/NATIONAL/INTERNATIONAL COMMUNITIES:

- Possibility to reinforce the technical commitments of the group in synergy with mechanical and electronics divisions of IPN and CSNSM
- Possibility to reinforce the data analysis effort with the support of the theoretical researchers from IPN
- Strong link with the other French groups involved in the XENON/DARWIN project
- Strong link with international communities
  - Strong collaboration with electrodes expert teams at University of Rice, Texas and University of California, San Diego
  - Strong link with team expert in wire properties measurement at Universitat Munster, Germany
  - Strong link with XENON local group at Laboratori Nazionali del Gran Sasso, Italy

Dark Matter perspectives on teaching/outreach/valorisation

TEACHING

- Internship of students (L3, M1, M2)
- PhD students

OUTREACH

- Fete de la Science, seminars in high-schools, etc..
- 31st of October: **Dark matter day**
  - Bar des sciences - Café du pont Neuf
  - Live on Twitter, Facebook

VALORISATION

- Journée des Jeunes Chercheurs
- Dark Matter summer school
- Meetings and international conferences

Dark Matter experiments SWOT analysis

STRENGHTS

- Among the most sensitive experiments for the search for dark matter
- Can test different dark matter hypotheses at both low and high mass
- Can rely on the high expertise of technical divisions in the Vallée campus (mechanics, electronics, daq systems,…)

WEAKNESSES

- Need to reinforce the number of physicists at short/middle term
- Need PhDs, postdocs

OPPORTUNITIES

- Strong potential of major discovery with huge impact in the scientific community
- Interaction with external companies and technical advancements for industry

THREADS

- Challenges related to technical aspects and to lower background level requirements

Conclusions

- There are intense activities for direct dark matter search in the Vallée laboratories:
  - **DAMIC-M** is a new project that will prove its technical and scientific goals in the next 5 years at Modane laboratory
  - **EDELWEISS** is a reliable technique for low-mass WIMP search with a defined future program to enhance its sensitivity
  - **HPS** is a well established detector searching for the heavy photon that could be connected to the light dark matter scenario
  - **XENON** is a well established technique for dark matter search with mass >6 GeV/c^2. A very clear program for the future will allow to cover the whole phase space until the « neutrino floor».
- The considered experiments have competitive sensitivity to the most reliable dark matter hypotheses and the role of the Vallee groups is crucial
- The activities in the Vallée laboratories cover important technical aspects of these experiments involving technical divisions (mechanics, electronics, computing, etc…)
- Collaboration among different Vallée laboratories is an important aspect of these projects

BACKUP SLIDES

Personnel involved

	Person	Position	Role	DAMIC-M	EDELWEISS	HPS	XENON	DM theory/phenom.	Other activity
CSNSM									
	L. Dumoulin	emeritus	Detector develop., data analysis		0,4				0,6
	A. Giuliani	DR	Detector develop., data analysis		0,4				0,6
	S. Marnieros	CR	Detector develop., data analysis		0,4				0,6
	C. Marrache	MdC	Detector develop., data analysis		0,07				0,93
	L. Bergé	IE	Detector instrumentation		0,4				0,6
	S. Hervé	T	Technical work		0,15				0,85
	E: Olivieri	IR	Detector instrumentation		0,2				0,8
	C: Oriol	IR	Detector instrumentation		0,4				0,6
	T. Redon	T	Technical work		0,15				0,85
	M. Chapellier	Volunteer	Detector development		0,5				0,5
LAL									
	Ch. Bourgeois	IR	Mechanics	0,05			0,02		0,93
	D. Douillet	IR	Mechanics	0,05			0,08		0,87
	E. Guerard	IR	Mechanics	0,05			0,02		0,93
	G. Iaquaniello	IR	Mechanics	0			0,3		0,7
	B. Leluan	IR	Mechanics	0			0,05		0,95
	P. Loaiza	IR	Background studies	0,2					0,8
	C. Macolino	CR	Detector R&D, data analysis, background	0			0,8		0,2
	Y. Peynaud	IR	Mechanics	0,4					0,6
	Ch. Syvia	IR	Electronics	0,3					0,7
	Ph. Vallerand	IR	Electronics	0,3					0,7
IPN									
	O. Deligny	CR	Data acquisition	0,2					0,8
	J.-J. Dormard	IR	Electronics	0,2					0,8
	R. Dupré	CR	Management, data analysis			0,2			
	M. Guidal	DR	Data analysis, phenomenology			0,05			
LPT									
	Yann Mambrini	DR	Relic + LHC + Supergravity + Inflation					1	0
	Adam Falkowski	CR	Relic + LHC + effective models					0,3	0,7
	Ulrich Ellwanger	Professor	Relic + LHC + Supersymmetry					0,3	0,7
	Asmaa Abada	Professor	Relic + neutrino					0,2	0,8
	Evgeny Babichev	CR	Gravity					0,2	0,8

Benefits and synergies

- **Are there potential benefits and synergies from the merging of the five Labs?**

Yes, most of the experiments will benefit by the merging of the five labs thanks to:

❖Common expertise in mechanics, cryogenics, low background techniques and electronics from the different labs will allow to play a major role for the technical contributions in DM experiments

❖Strengthening the role of the dark matter search in the Vallée laboratories with more researchers involved

❖Dynamic exchanges between theoreticians and experimentalists will improve the mutual knowledge. Possibility of joint papers with experimental constraints for specific theories.

Strategy for the next 5 years

- **What is the strategy for the next five years in the domains of Dark Matter?**

The physics strategy will be focused on the following actions:

❖Strengthen the technical and physics contributions for the starting activities of XENON/DARWIN and DAMIC-M experiments: Detector R&D and construction, electronics, DAQ system, low-background measurements

❖Achieve the technical challenges related to (DAMIC-M, EDELWEISS, DARWIN):

- ❖Lower background levels
- ❖Bigger detector setups
- ❖Detector properties pushed to the limits

❖Increase the number of researchers and technical staff involved in DM experiments to keep and even improve a major role in the collaborations

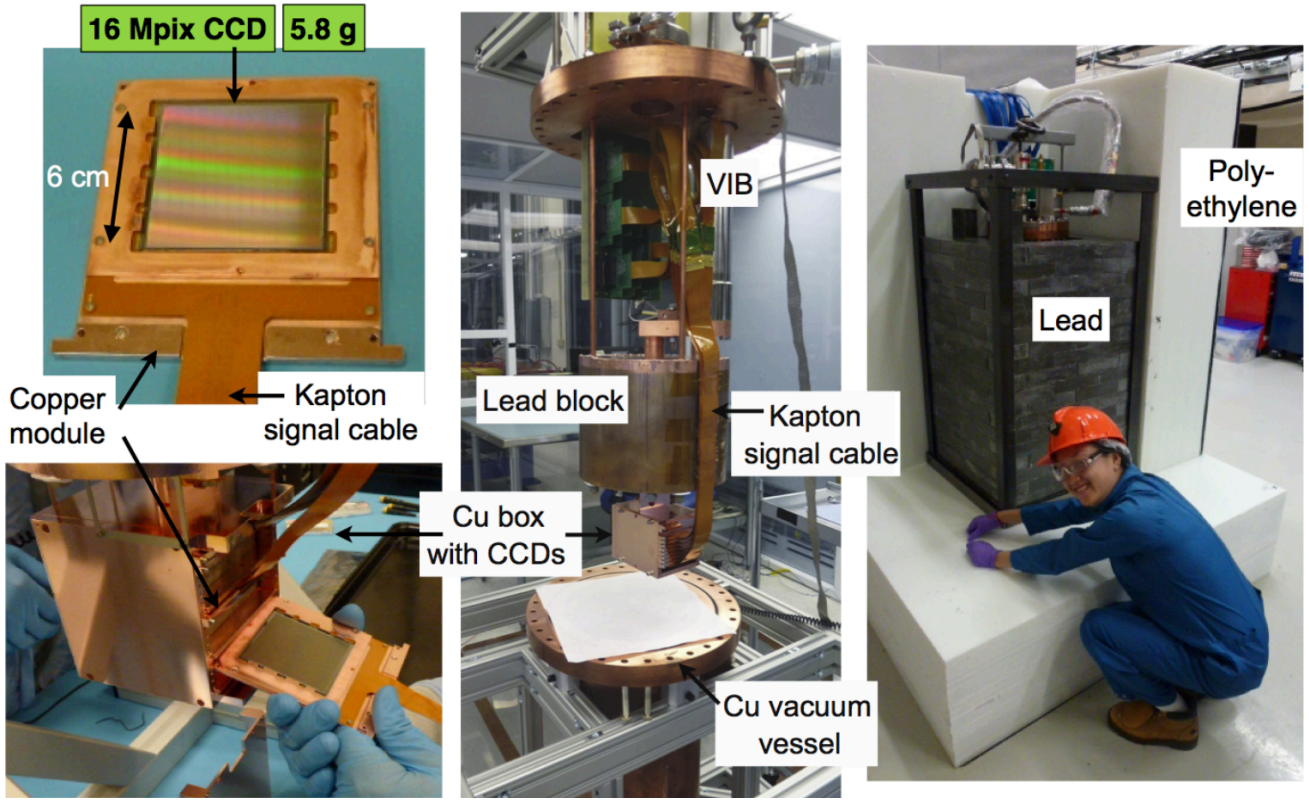
❖Exploit expected data from all the experiments (DAMIC-M, EDELWEISS, XENON, HPS) and establish the most sensitive constraints on direct dark matter search

Funding for 2019

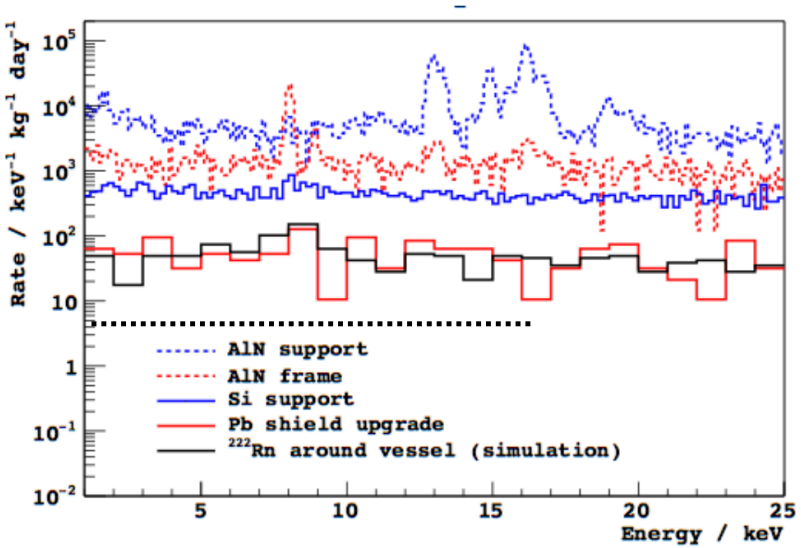
- **DAMIC-M**:
  - 5 CCDs for 3 years: 0,7 M€
  - Budget for specific tasks: 1,1 M€ (CCD, electronics, test systems, …)
  - Infrastructures 0,45 M€ (clean room at Modane, electroformed copper)
  - General expenses 0,5 M€
- **EDELWEISS**:
  - 50k€ to support the detector R&D program
  - Same level of funding expected for the future years
- **HPS**:
  - No construction foreseen, only funding for shifts and missions (about 10 k€)
- **XENON/DARWIN**:
  - 40 k€ for XENONnT electrodes design, tests and construction
  - 22 k€ for shifts, missions, common funds

DAMIC@SNOLAB Scientific achievements

DAMIC @ SNOLAB



DAMIC technology has already been proved at SNOLAB and interesting physics limits have been established

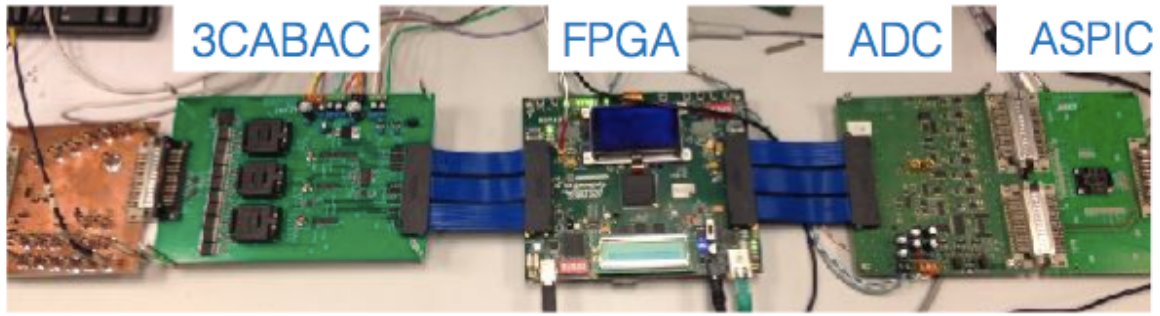


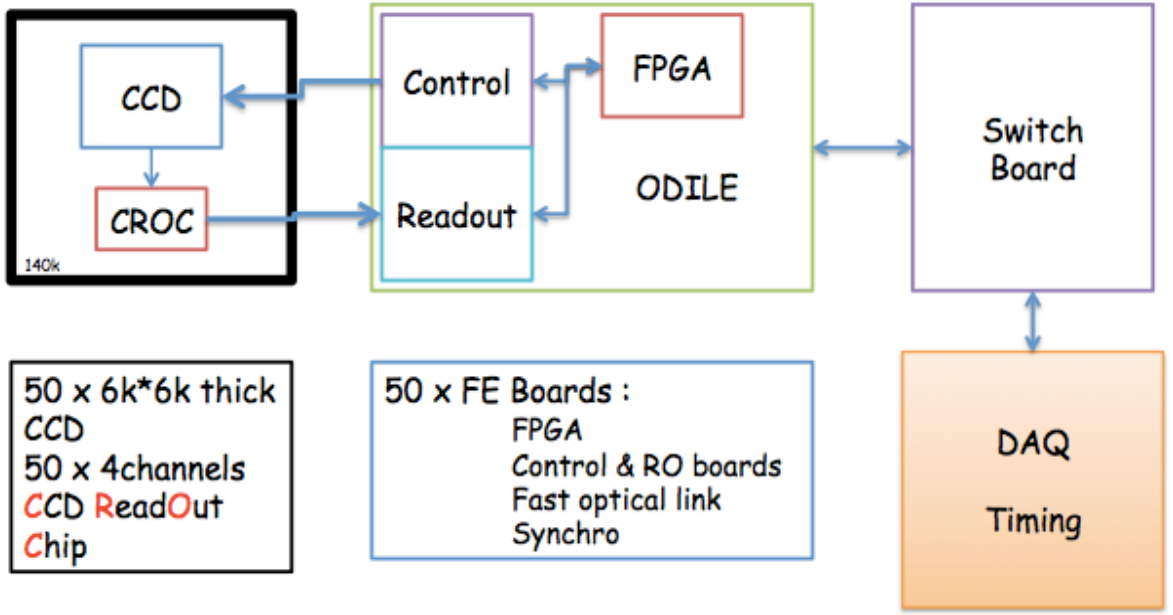
Background rate achieved at SNOLAB

DAMIC-M Project

Joint collaboration between LAL and IPN

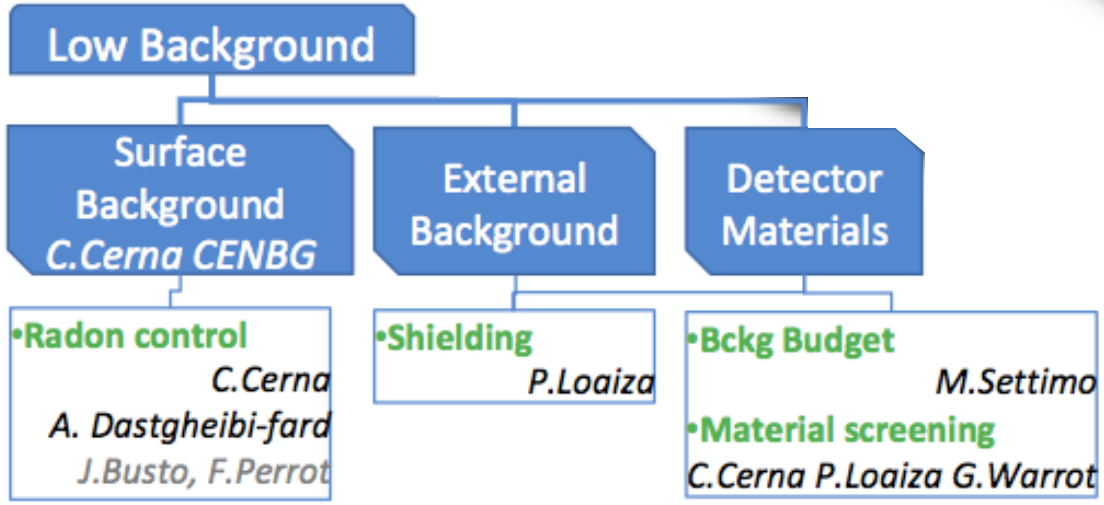
Readout/control ASIC electronics



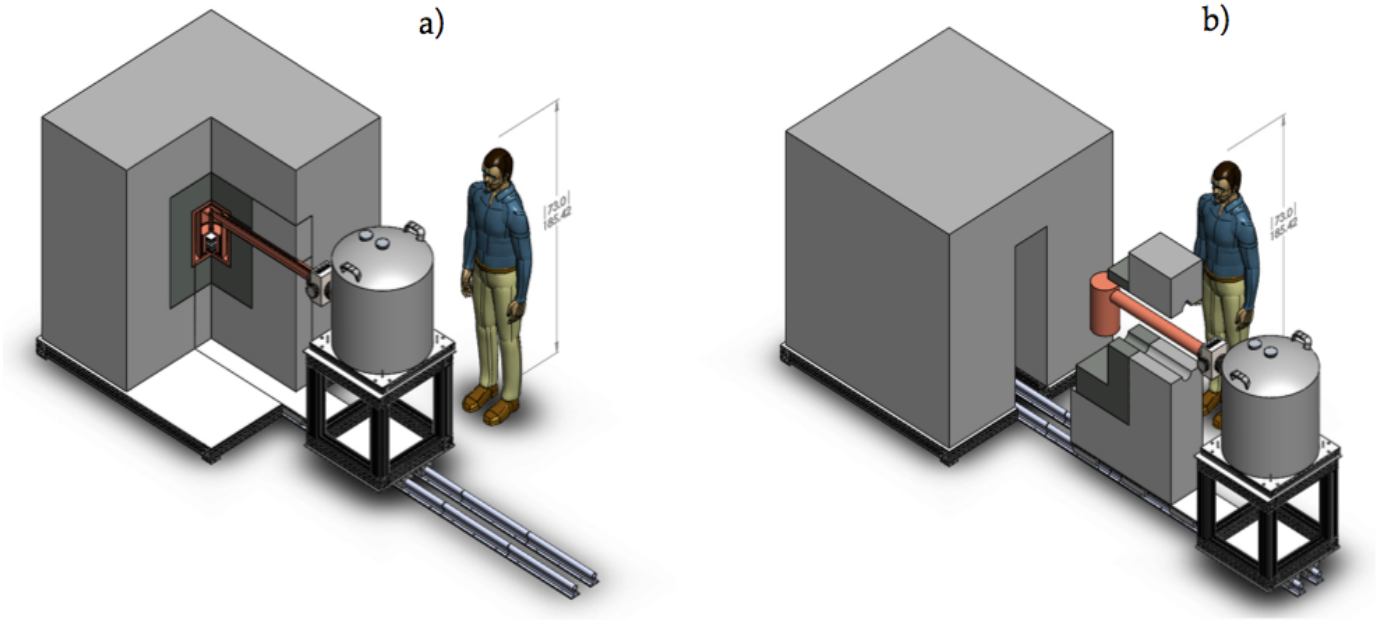


DAMIC-M Project

Low background techniques

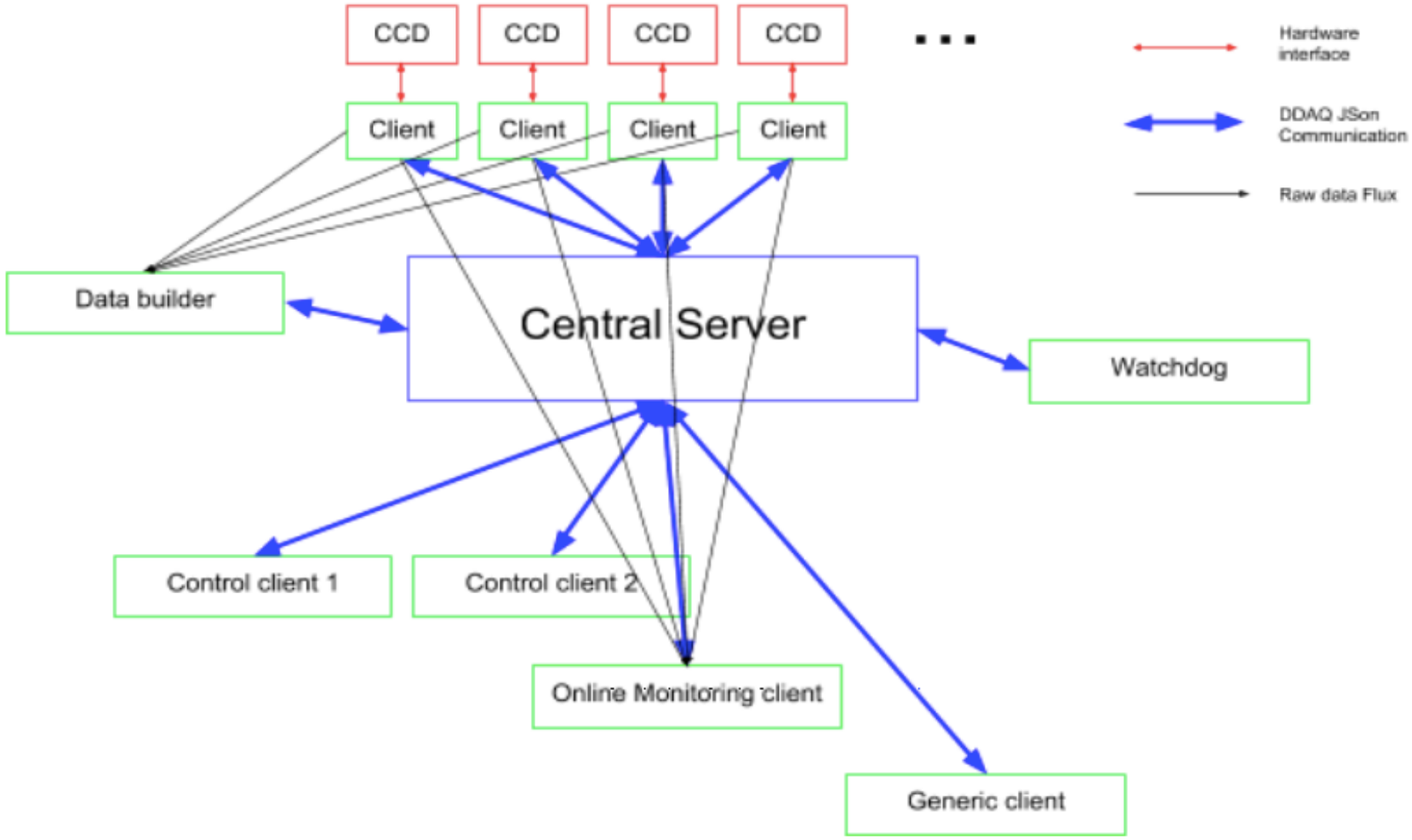


BLINDING



Blinding system design and realization

DAQ system and data management



DAMIC-M Human Ressources

- Electronics
  - Ph. Vallerand (LAL, 0.30),
  - Ch. Syvia (LAL, 0.30),
  - J.-J. Dormard (IPN, 0.20)

- Background studies and blinding
  - Ch. Bourgeois (LAL, 0.05),
  - D. Douillet (LAL, 0.05),
  - E. Guerard (LAL, 0.05),
  - Y. Peinaud (LAL, 0.40),
  - P. Loaiza (LAL, 0.20)

- DAQ
  - O. Deligny (IPN, 0.20)

EDELWEISS Project schedule

2019

- LSM: EDELWEISS R&D cryogenic run

2019 – 2020

- Development of a 32 g FID detector at CSNSM and IPNL.

  Objective: s_{phonon} = 10 eV and s_{ion} = 20 eV_{ee}

  → Collaboration with RICOCHET project
- Upgrade of cryogenics at LSM

  → Collaboration with CUPID-France and LSM platform
- French ANR 2019 proposal: Measure ionization yield <1keV @ LSM with 32g FID + HEMTs

2021 - 2022

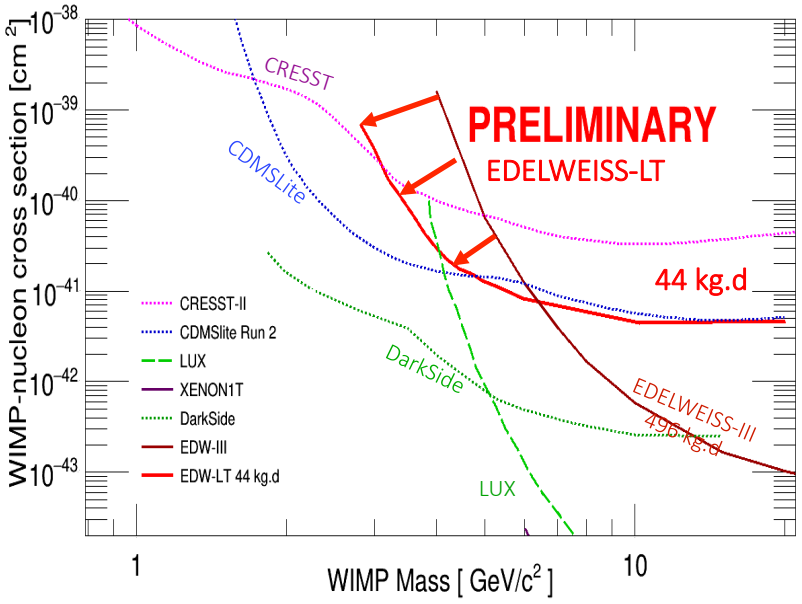
- Study of scaling to 200 g FID bolometers
- Operation of a 1 kg demonstrator of sub-GeV detectors at LSM, with goal 10^{-43} cm^2 below 1 GeV/c^2
- Definition of a high-impact contribution to the upgrade of SuperCDMS-SNOLAB

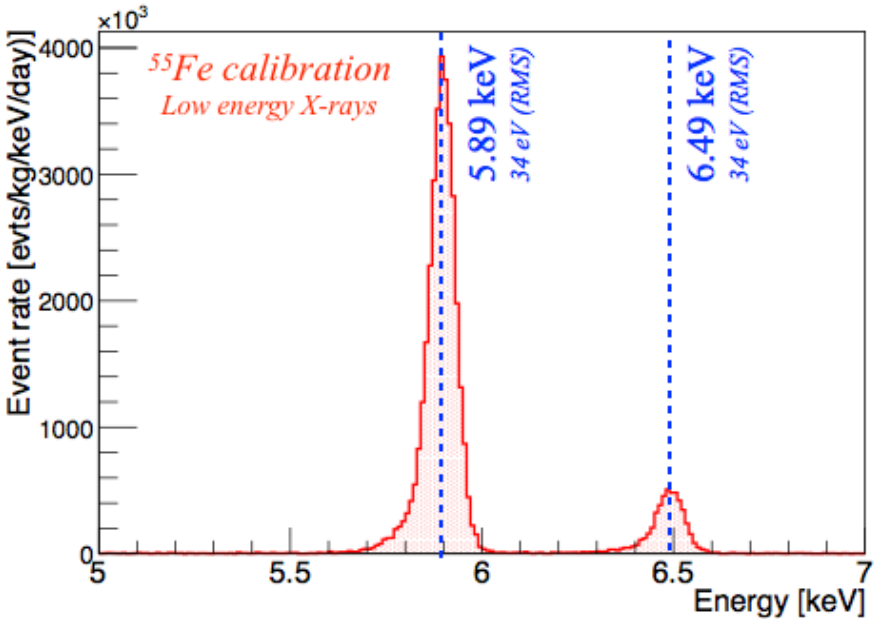
EDELWEISS Project

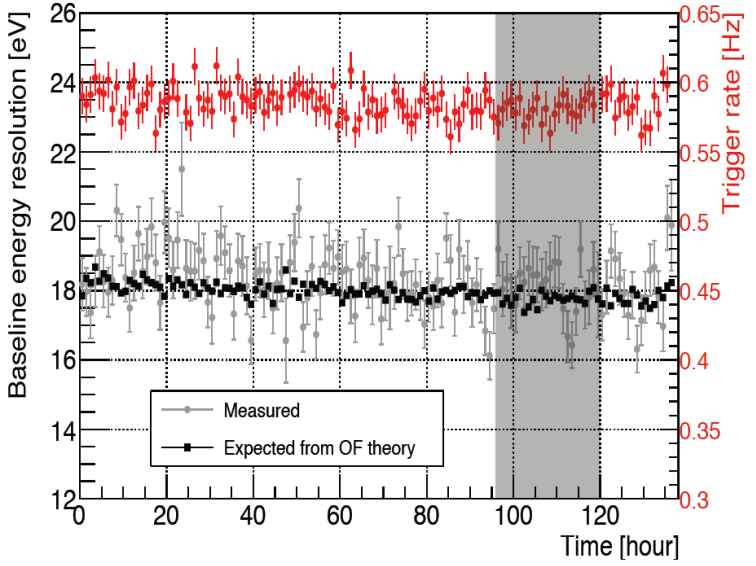
Neganov-Luke boost to amplify signal (and not noise) on existing FID800 detectors

2 FID detectors : σ_{phonon} = 1.0 & 0.35 keV, V_{bias} = 100V & 30V

- Better understanding of **heat sensor performance** + scaling with detector mass
- **Baseline resolution of s_{phonon} = 18 eV achieved on 32 g detector**
- Vibration control is the key to obtain stable resolution vs time **[NIMA 858 (2017) 73 & arXiv:1803.03463]**



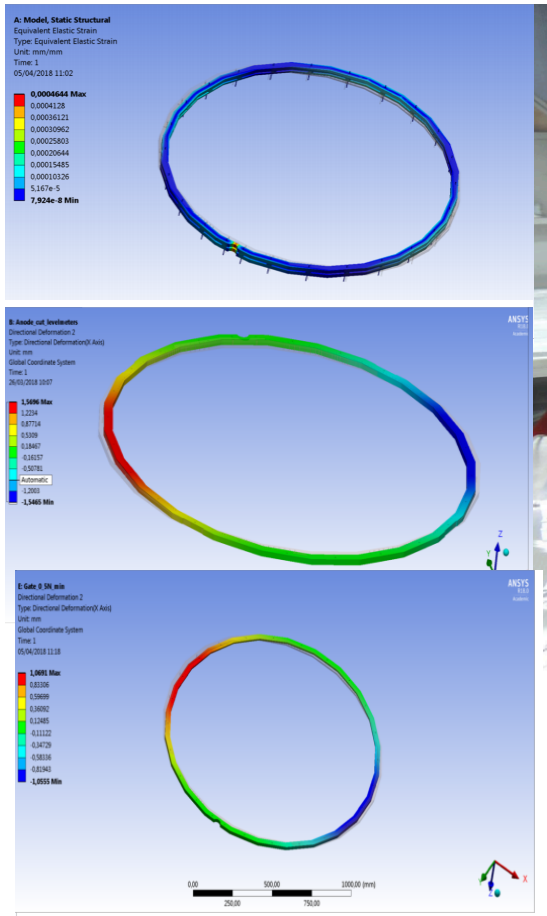




XENON Scientific achievements

ReStoX2
High Pressure auxiliary vessel X
enon storage capacity : 10 tons
Directly connected to ReStoX1 and TPC
Recovering : 1t/hour speed targeted
Working temperature : 77K to 20°C
Cooled with LN2

Totally funded by France (in2p3 + French labs including LAL)



Electrodes for the nT TPC
3 electrodes to ensure the correct potentials inside the scintillation and electroluminescence zone of the TPC
2 electrodes to screen the PMTs array from voltage inside the TPC

R&D completed
Full scale tests completed
In assembly phase now

C. Macolino is co-responsible of the Electrodes group in the collaboration

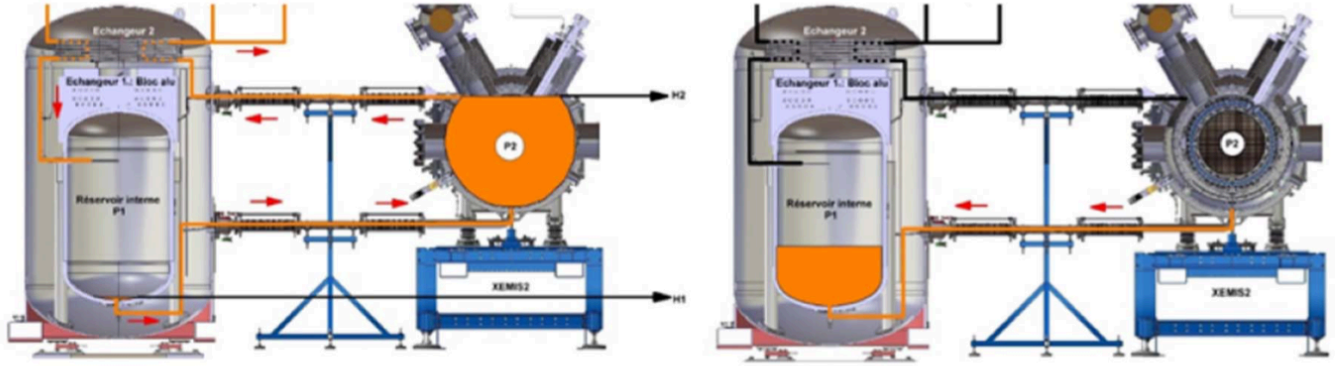
XENON/DARWIN Project

System for Xenon storage and recovery

Start of design studies and R&D tests in 2019

Studies to improve the recovering flow rate

R&D to assess best recovering strategy and mechanical feasibility



BEFORE

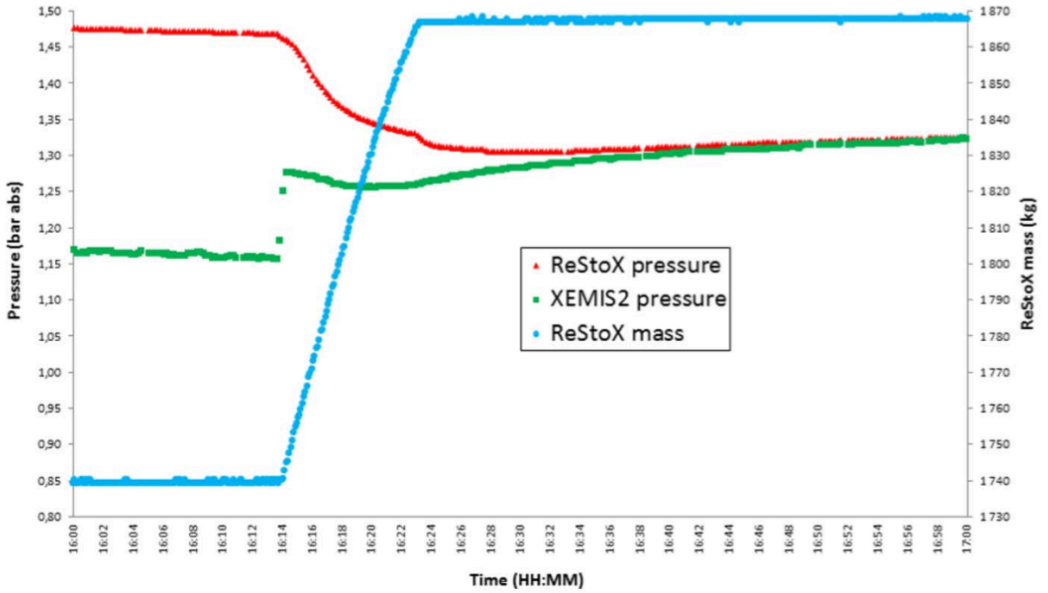
New ideas have been tested involving assisted gravity

Ton/hour passive recovering flow achieved

Very interesting and challenging topics for DARWIN. Studies and tests should be launched

Funding : InfraRed EC program ?

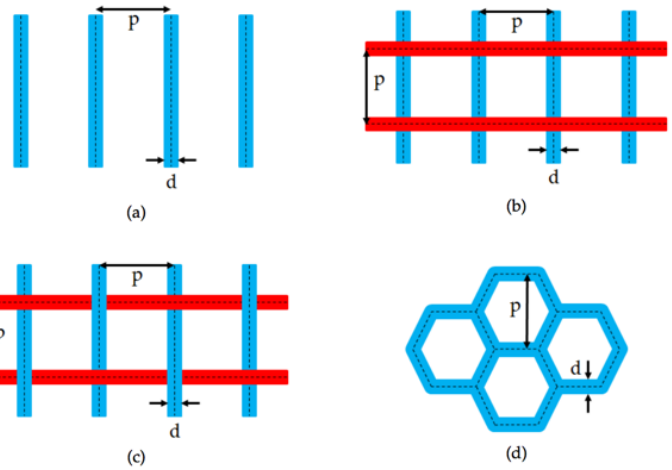
LXe recovery from XEMIS2 to ReStoX

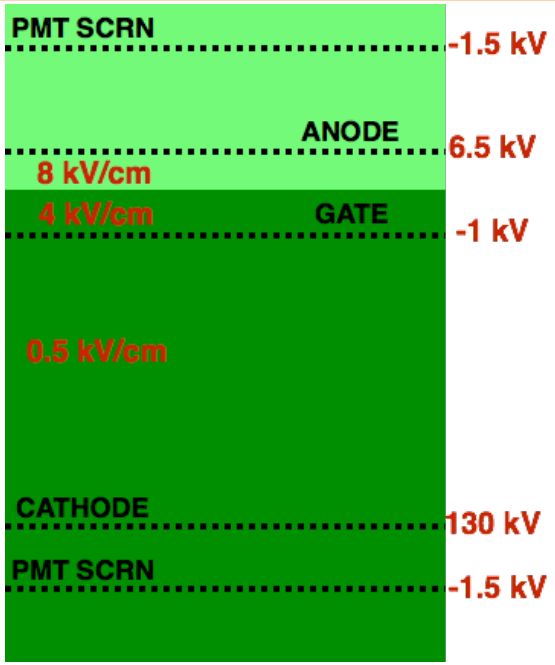


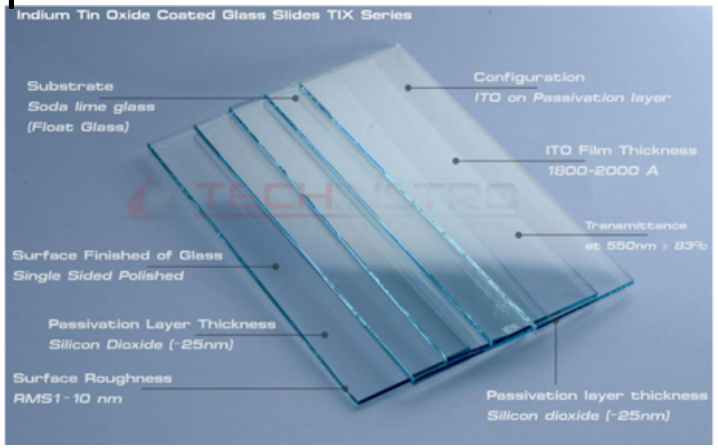
Electrodes for DARWIN

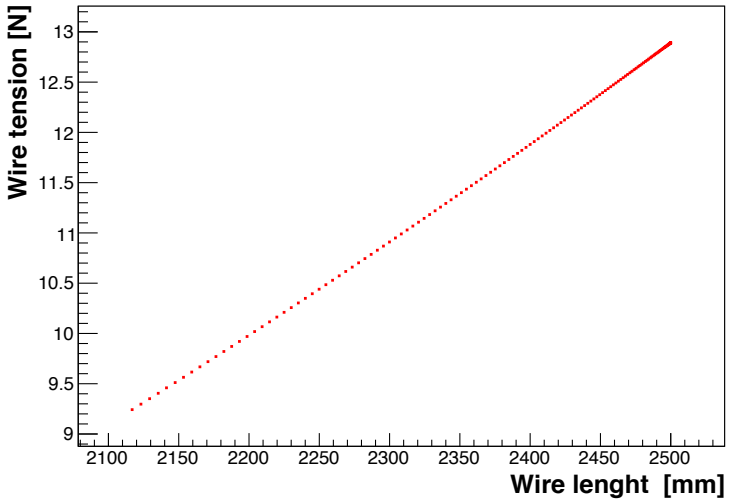
Technical challenges due to a much higher voltage on cathode electrode

- Studies for the mechanical stability conception
- Electric field simulations to understand best geometry configuration
- Fabrication
- Tests
- Assemby









Data analysis and Monte Carlo simulations

- Geant4 simulations for DARWIN:
  - Geometry implementation of TPC components
  - Contribution of intrinsic background due to atmospheric and solar neutrinos, neutrinoless double beta decay of ^{136}Xe

- Data analysis of 1T and nT data:
  - Search for low mass WIMPs with lone-S2 signals
    - Migdal effect
    - Bremsstrahlung effect
  - Search for neutrinoless double beta decay of ^{136}Xe
  - Search for annual modulation in the detected event rate