DARK MATTER
Experimental Direct Detection

Status and perspectives in Spain

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Dark Matter in the Universe

- Cosmological evidences:

  CMB observations, data from Super-nova Ia, nucleosynthesis, large scale structures,…

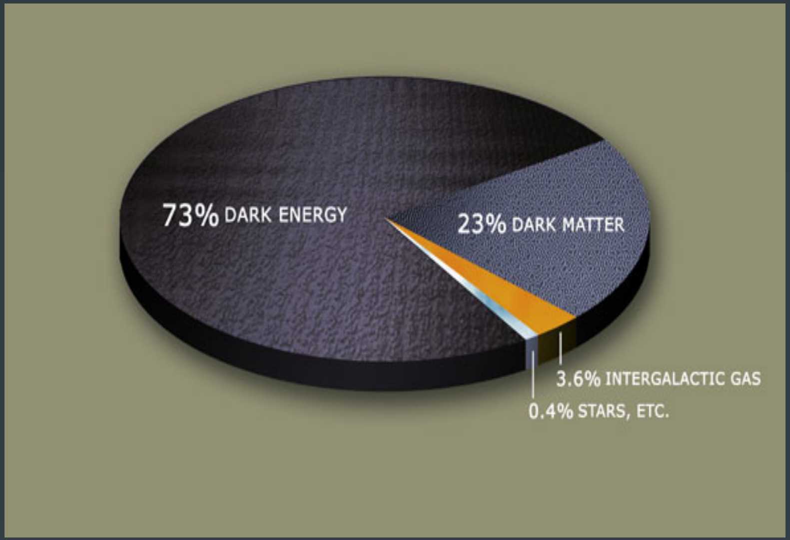
- Galactic evidences:

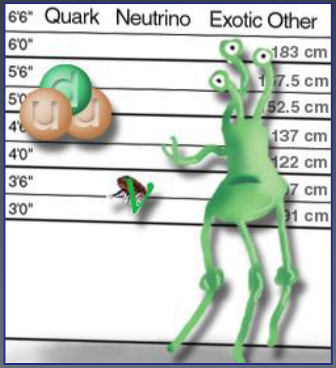
  Rotation curves, gravitational mass of galaxy clusters,…

- DM cannot be baryonic matter. We need to go beyond Standard Model

  Two main candidates:

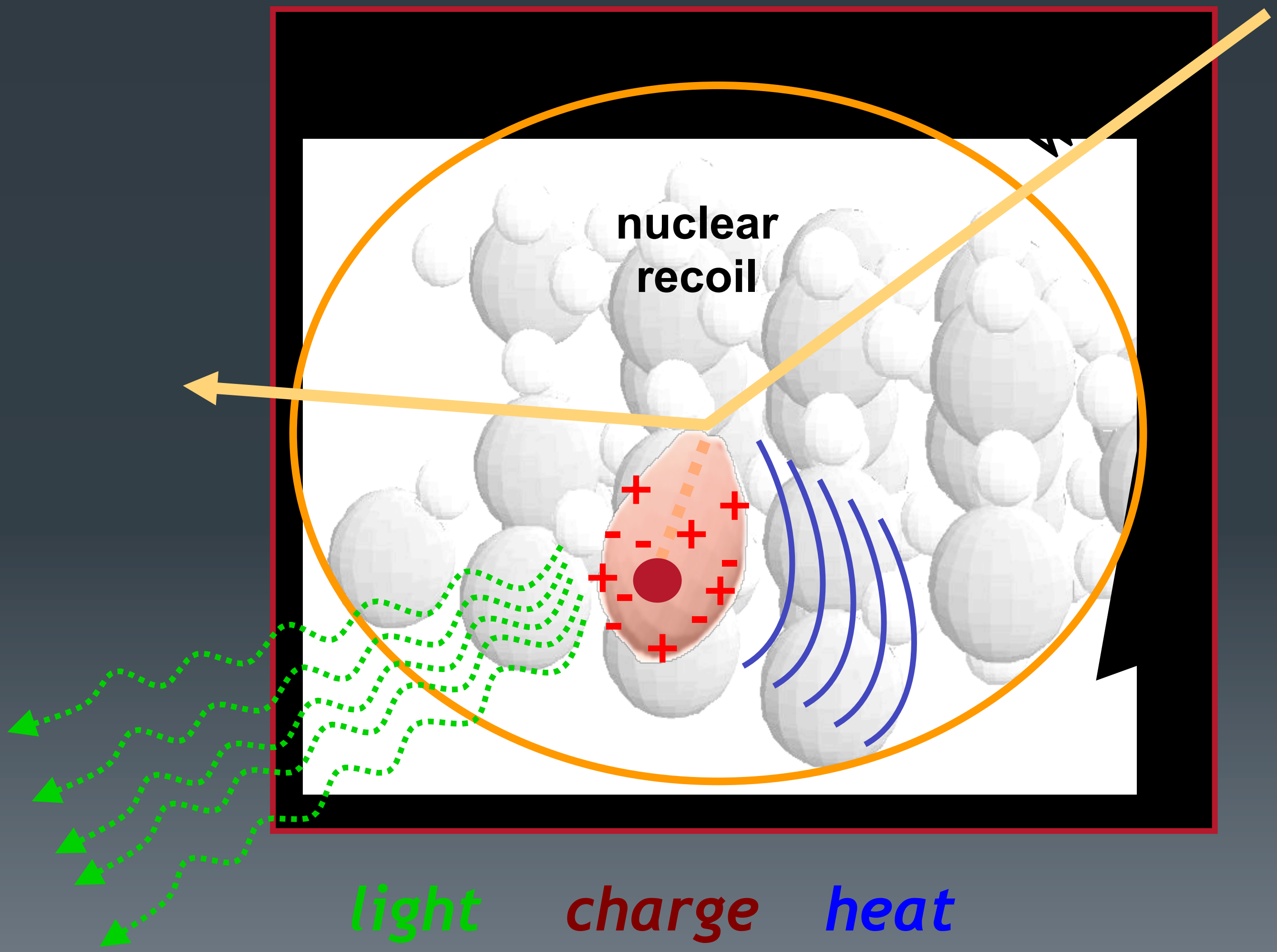
  WIMPs and Axions





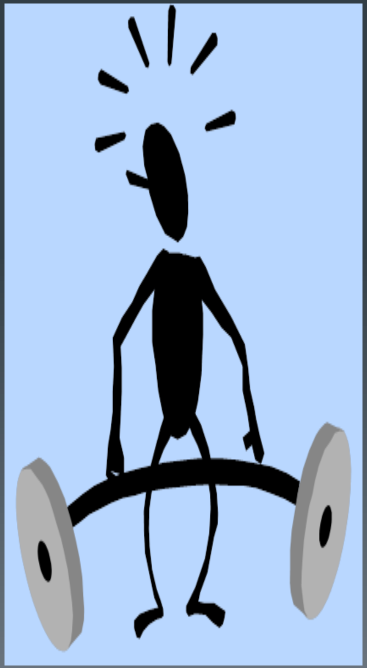
How do we detect a WIMP?

Searching for the elastic scattering of WIMP with the nuclei of our detector



BUT we have a problem

The expected a signal is very, very small and the background is very, very big ➡ We need to solve some no trivial challenges:

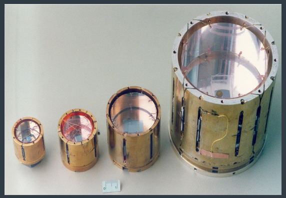


- Very low energy threshold (~keV)
- Good energy resolution
- Very, very low background (keV scale):
  - Radiopure materials & rejection techniques
  - Underground laboratories
- Large detector masses
- Great stability over the time

Techniques to distinguish DM signals

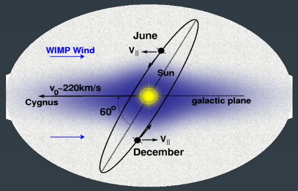
- Target material dependence

  Different WIMP-nuclei interaction mode depending of the target characteristics



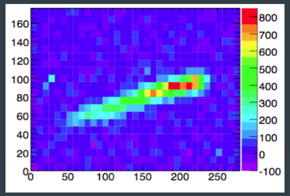
- Annual modulation

  Small modulation in the signal due to the relative movement of Earth around the Sun



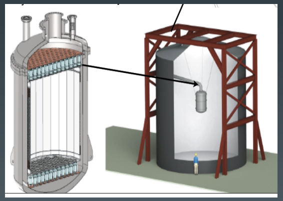
- Directional signal

  Measuring the direction of the nuclear recoil track as a clear signature of WIMP



- Detector characteristics

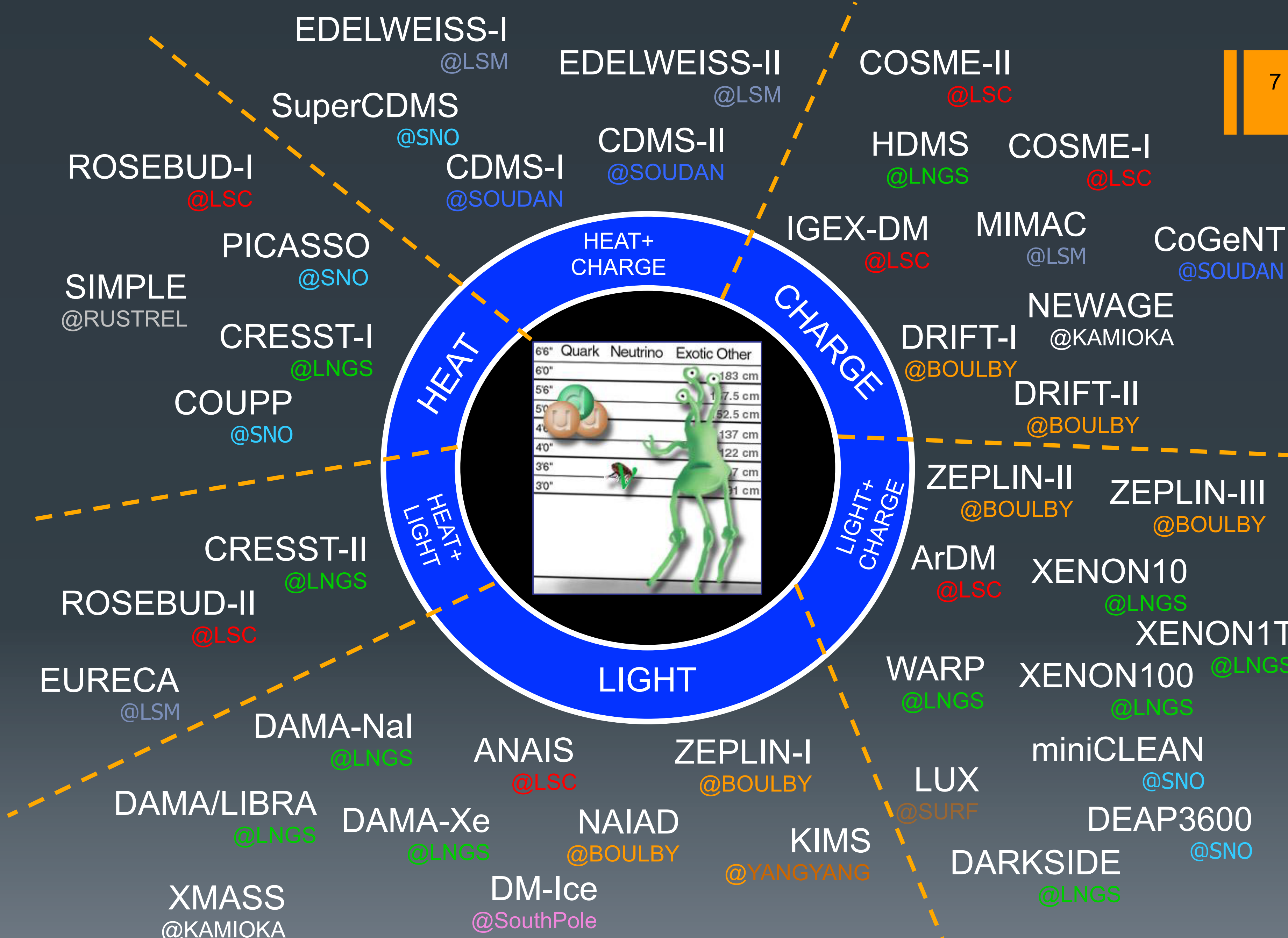
  Semiconductors, Scintillators, Bolometers, Noble liquids, gas TPCs, others,…



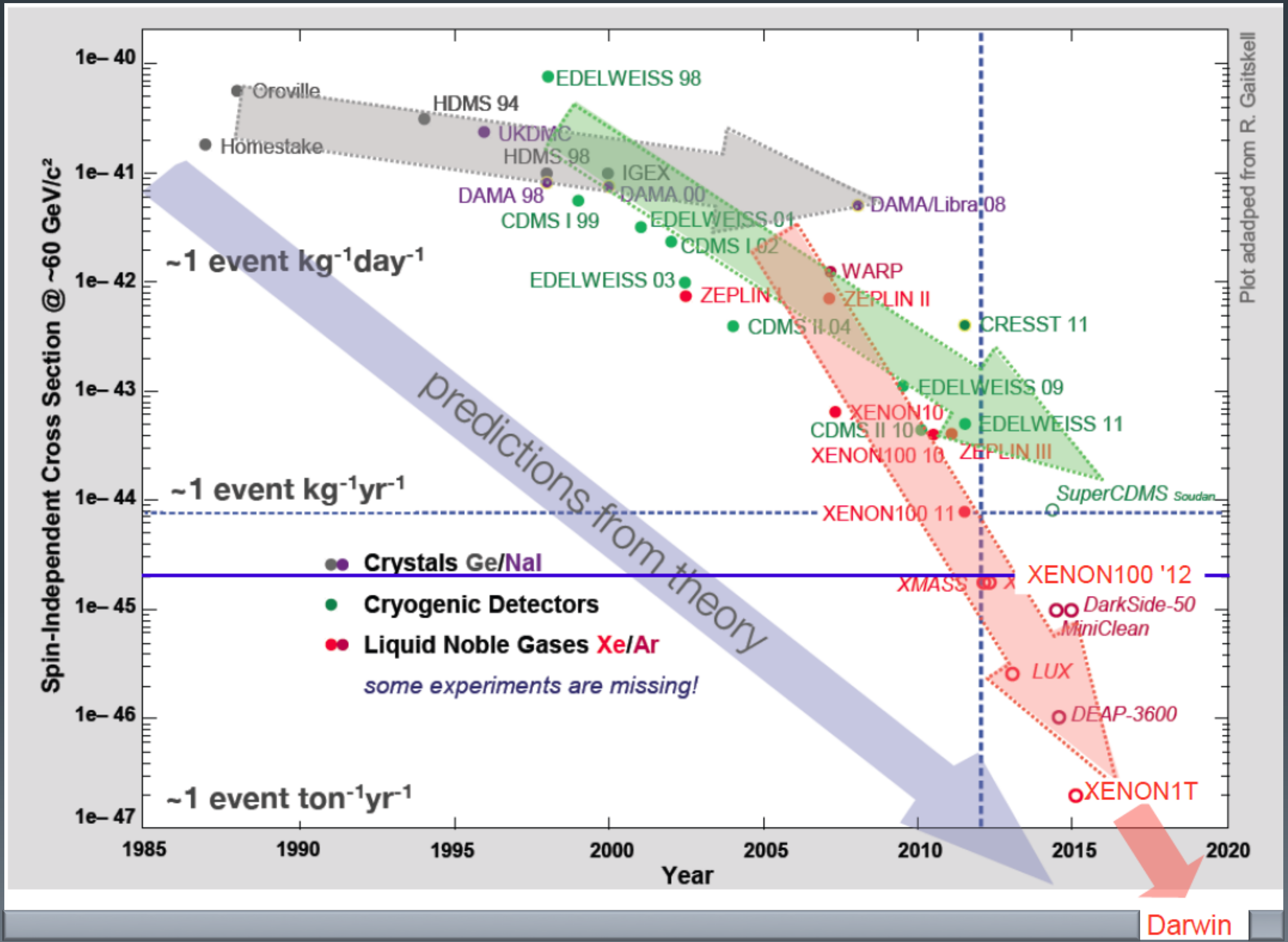
\+ Underground laboratory

If you mix all these possibilities…

the result is …


EDELWEISS-I
@LSM
EDELWEISS-II
@LSM
SuperCDMS
@SNO
CDMS-II
@SOUDAN
CDMS-I
@SOUDAN
ROSEBUD-I
@LSC
PICASSO
@SNO
SIMPLE
@RUSTREL
CRESST-I
@LNGS
COUPP
@SNO
CRESST-II
@LNGS
ROSEBUD-II
@LSC
EURECA
@LSM
DAMA-NaI
@LNGS
DAMA/LIBRA
@LNGS
DAMA-Xe
@LNGS
XMASS
@KAMIOKA
ANAIS
@LSC
NAIAD
@BOULBY
DM-Ice
@SouthPole
ZEPLIN-I
@BOULBY
KIMS
@YANGYANG
LUX
@SURF
DARKSIDE
@LNGS
miniCLEAN
@SNO
DEAP3600
@SNO
WARP
@LNGS
XENON100
@LNGS
XENON1T
@LNGS
ArDM
@LSC
XENON10
@LNGS
ZEPLIN-II
@BOULBY
ZEPLIN-III
@BOULBY
DRIFT-I
@BOULBY
DRIFT-II
@BOULBY
NEWAGE
@KAMIOKA
IGEX-DM
@LSC
MIMAC
@LSM
CoGeNT
@SOUDAN
HDMS
@LNGS
COSME-I
@LSC
COSME-II
@LSC
HEAT+
CHARGE
CHARGE
LIGHT+
CHARGE
LIGHT
HEAT+
LIGHT
HEAT
6'6" Quark Neutrino Exotic Other
6'0"
5'6"
4'0"
3'6"
3'0"
183 cm
137 cm
122 cm

Progress over time

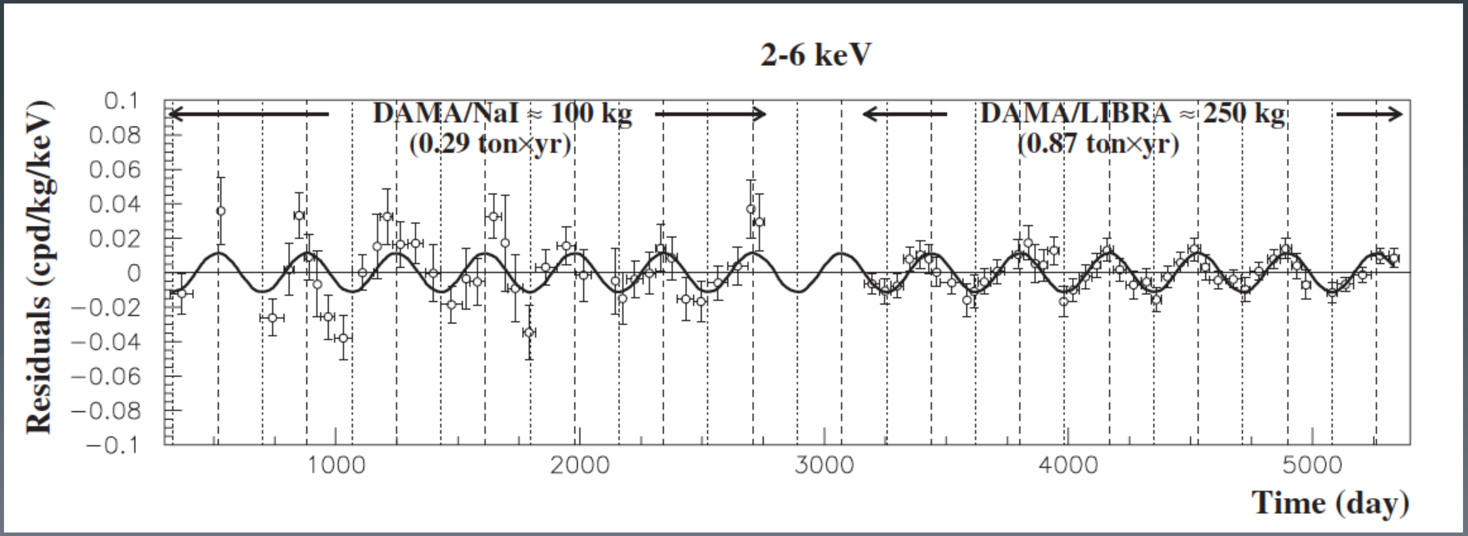


DAMA/LIBRA experiment (LNGS)

- Looking for annual modulation in the DM signal
- DAMA/NaI: 100 kg of NaI(Tl), 7 annual cycles
- DAMA/LIBRA: 250 kg of NaI(Tl), 6 annual cycles
- Total exposure: 1.17 ton year

POSITIVE CLAIM with a statistical significance of 8.9 σ

- No systematic effect found that can mimic the signal
- No modulation effect outside of the 2-6 keV interval

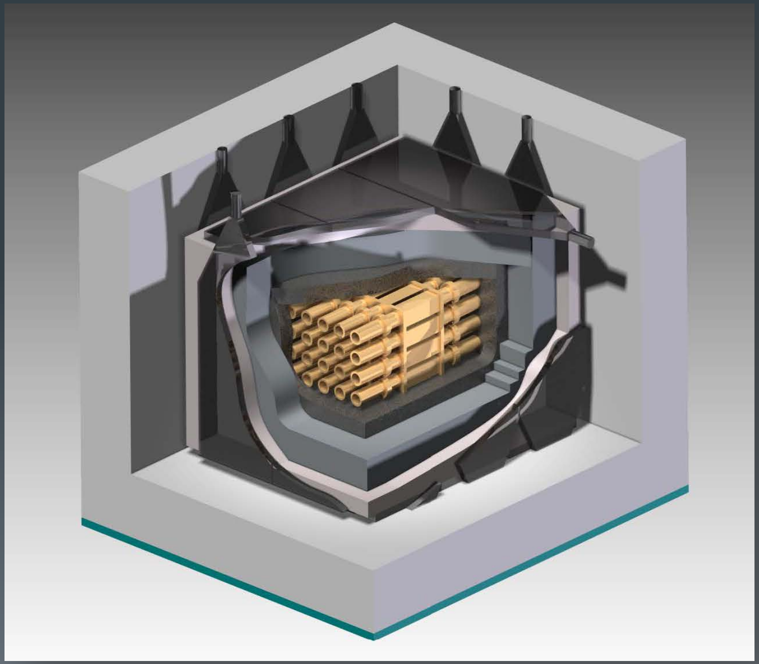


DAMA/LIBRA experiment (LNGS)

- No systematic effect can explain it satisfactorily (electronics, neutrons, temperature,…)
- Modulation effect is excluded by other experiments even with higher sensitivity (except a few options at low mass…)

New NaI experiments are needed to corroborate/refute the DAMA/LIBRA result

- **ANAIS** (LSC): under operation
  - Prototyping phase is concluded
  - 2 modules of 12.5 kg of ultrapure NaI (low content in ^{40}K) received
- **DM-Ice** (South Pole): proposal phase

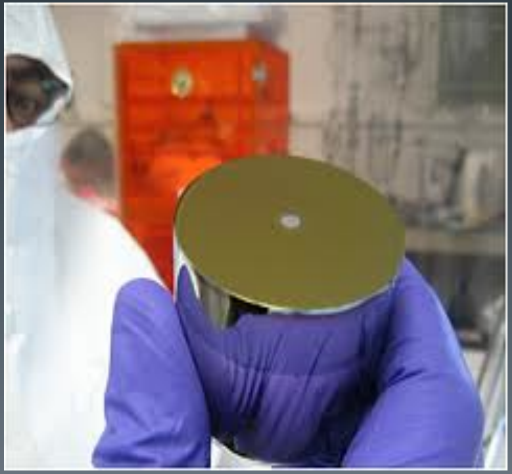


General view of the experimental WIMP direct detection

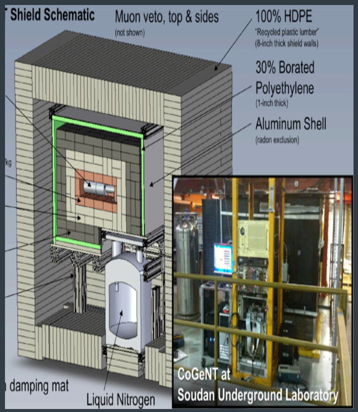
Past, present and future…

Semiconductors

- Ultrapure semiconductors used for 2β in the 90's → also used for DM search
- Excellent energy resolution and high purity material
- Possible PSA discrimination of signals coming from e/γ vs. nuclear recoils



DM exps. with semiconductors



COSME I,II
Ge
(LSC, UZ)

HDMS
Ge
(LNGS)

IGEX-DM
Ge
(LSC, UZ)

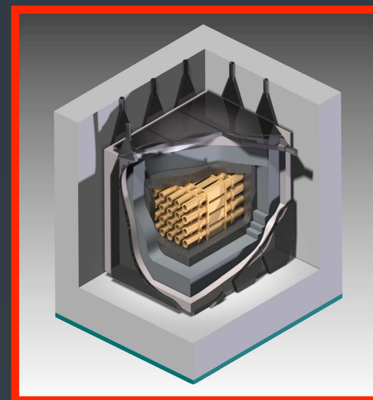
CoGeNT
Ge
(SOUDAN)

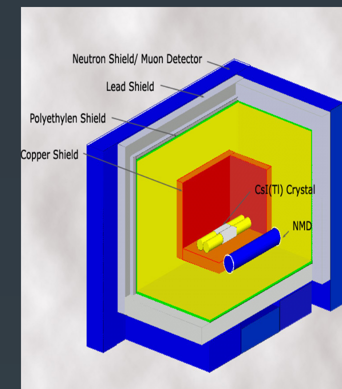
Scintillators

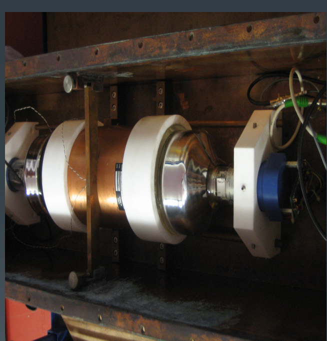
- Well known detection technique
- Good discrimination of signals coming from e/γ vs. nuclear recoils due to the different decay time
- Very easy scaling up to large masses

DM exps. with scintillators











NAIAD
NaI
(BOULBY)

DAMA/LIBRA
NaI
(LNGS)

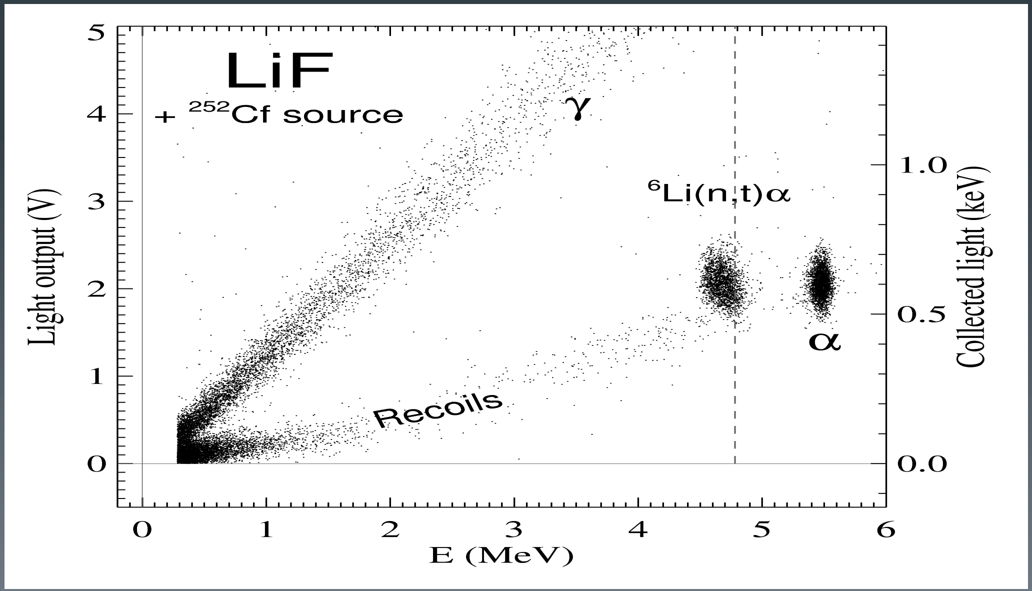
ANAIS
NaI
(LSC, UZ)

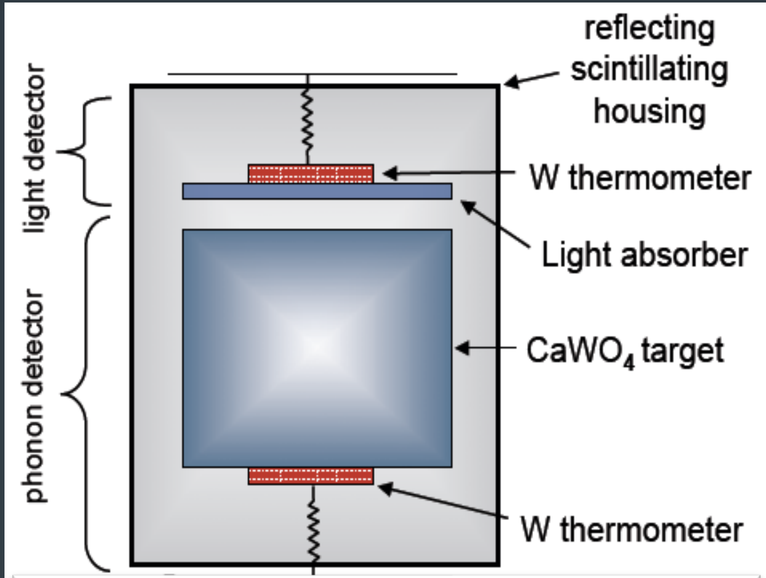
DM-Ice
NaI
(South Pole)

KIMS
CsI
(YANGYANG)

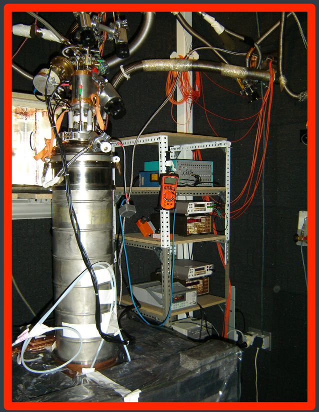
Hybrid bolometers

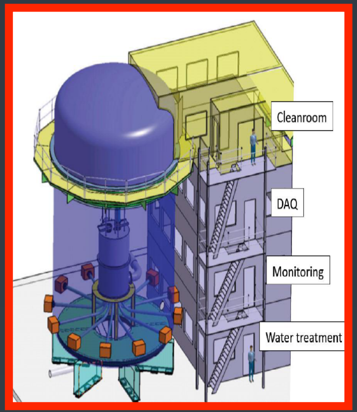
- Simultaneous measurement of heat-light or heat-charge allowing good discrimination
- Wide choice of target-absorbers
- Relative efficiency factors close to 1 and very low energy threshold & resolution

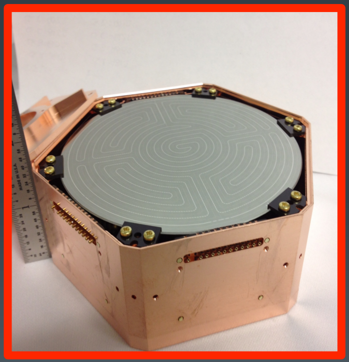


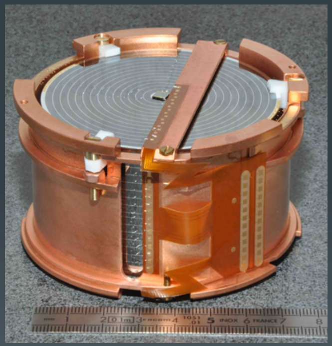


DM exps. with hybrid bolometers









CDMS-I,II, SuperCDMS
Ge (+Si)
(SOUDAN, UAM)

EDELWEISS-I,II
Ge
(LSM)

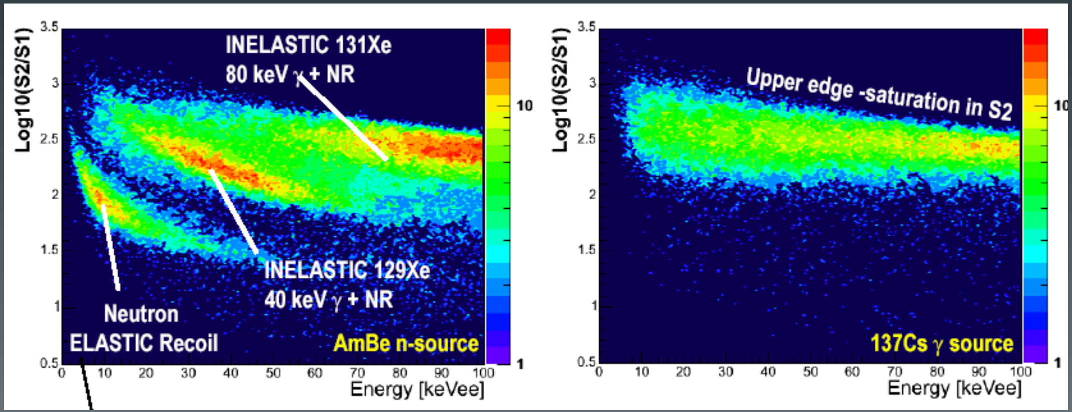
CRESST-I,II
$CaWO_2$
(LNGS)

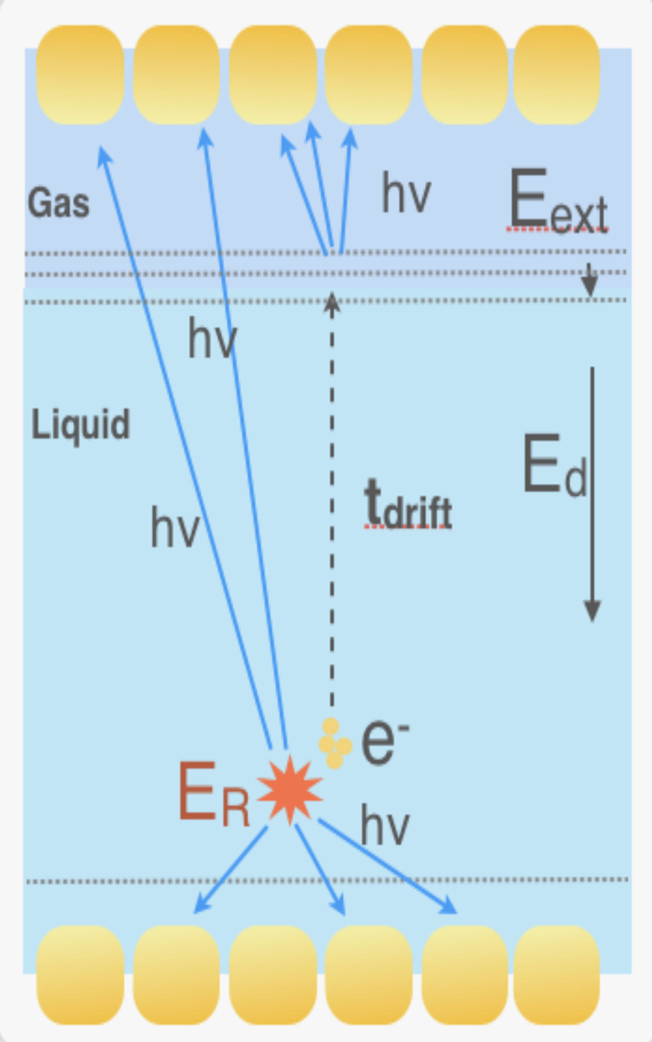
ROSEBUD-I,II
Ge, Al_2O_3, BGO,
LiF, $CaWO_4$,…
(LSC, UZ)

EURECA
Ge+ scint.bol.
(LSM, UZ)

Noble liquid detectors

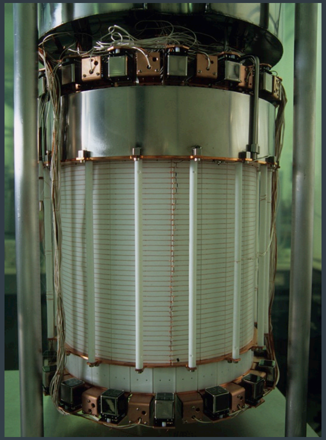
- Dual phase, liquid-gas, allows nuclear recoil discrimination using both primary scintillation and ionization of electrons drifted in liquid and amplified in gas
- Very clean media (purification by filtering) can be reached
- Relatively easy scaling up to large masses



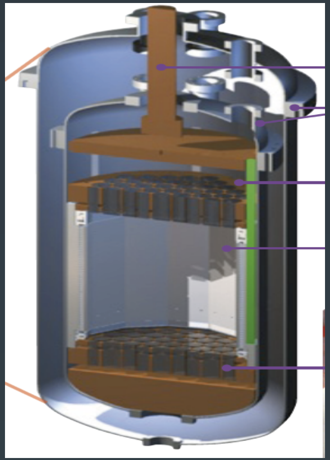


DM exps. with noble liquid detectors

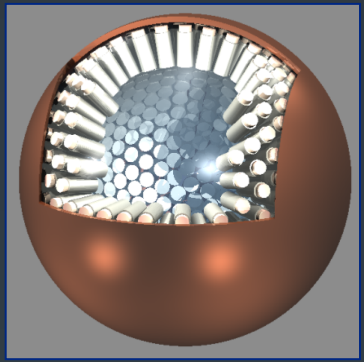
ZEPLIN I,II,III
Xe
(BOULBY)



XENON10,100,1T
Xe
(LNGS)

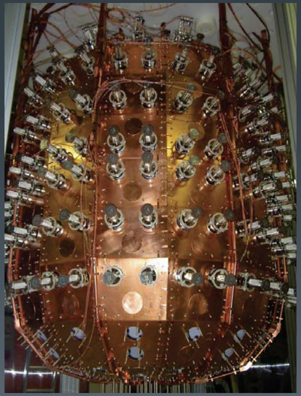


LUX
Xe
(SURF)



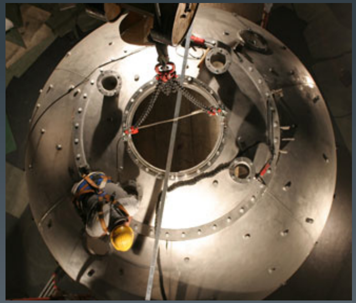
XMASS
Xe
(KAMIOKA)

DARWIN
Xe
(LNGS)



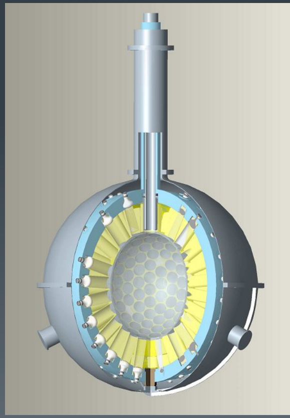
WARP
Ar
(LNGS)

ArDM
Ar
(LSC, CIEMAT)



DarkSide
Ar
(LNGS)

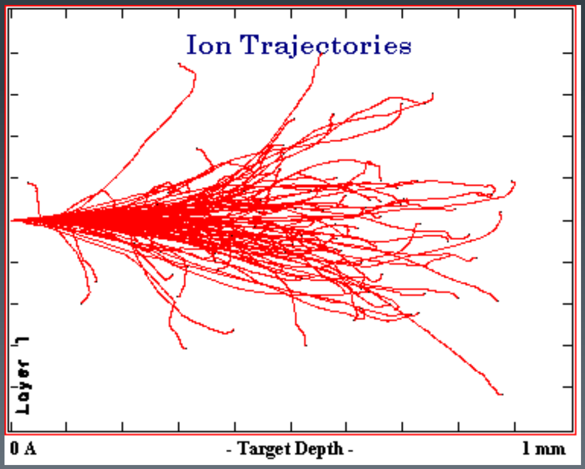
miniCLEAN
Ar/Ne
(SNO)

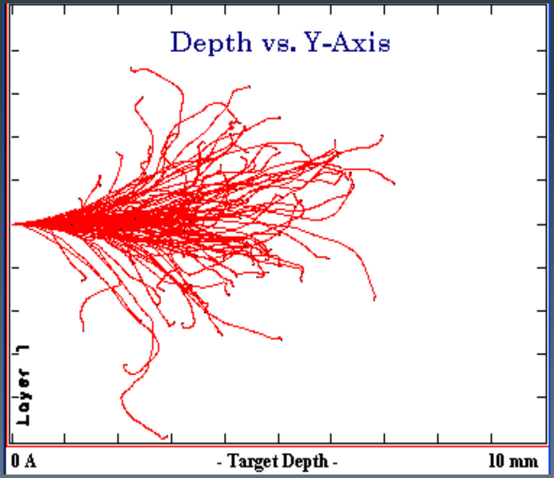


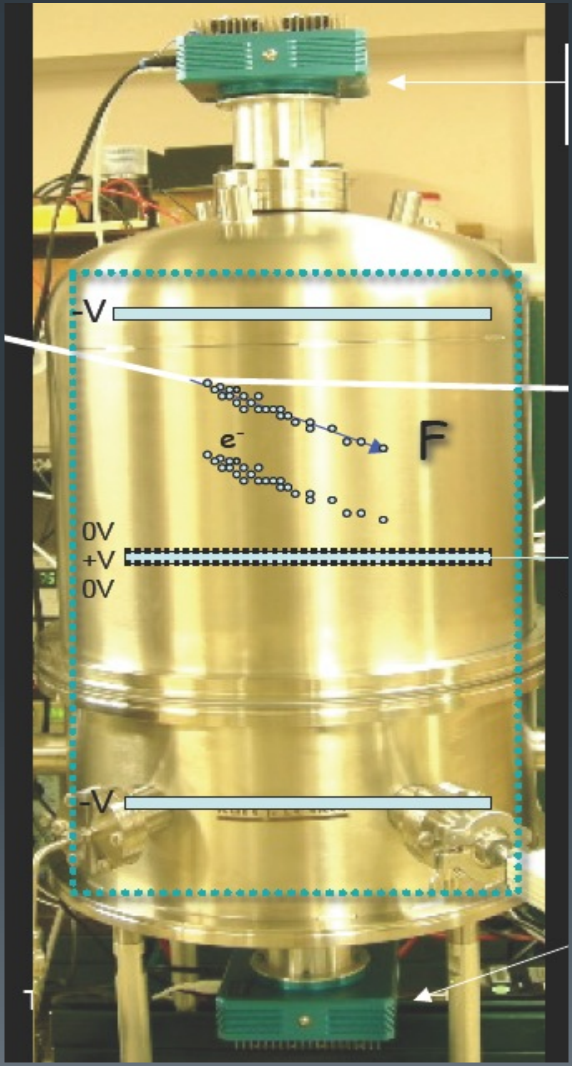
DEAP-3600
Ar
(SNO)

TPCs with gases

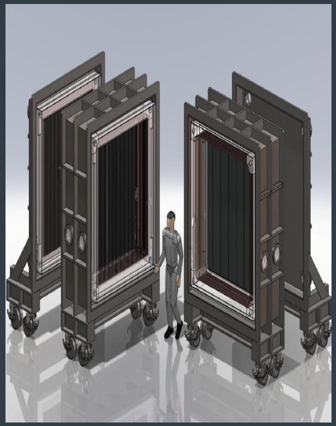
- Very good directional discrimination of nuclear recoils in gases
- However, it is still a very hard technological challenge
- Novel TPC concepts opening new perspectives

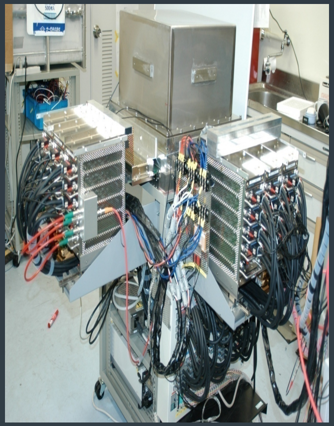


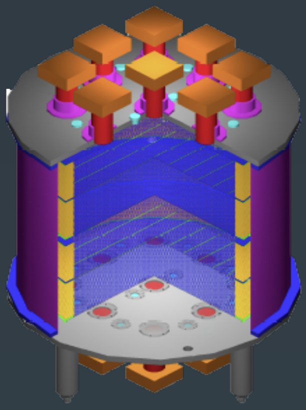


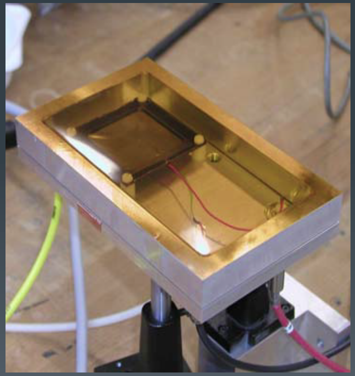


DM exps. with gaseous TPCs









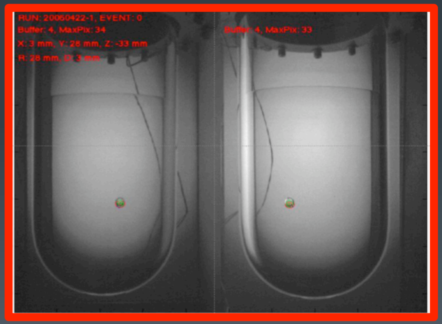
DRIFT
$CS_2 + CF_4$
(BOULBY)

NEWAGE
CF_4
(KAMIOKA)

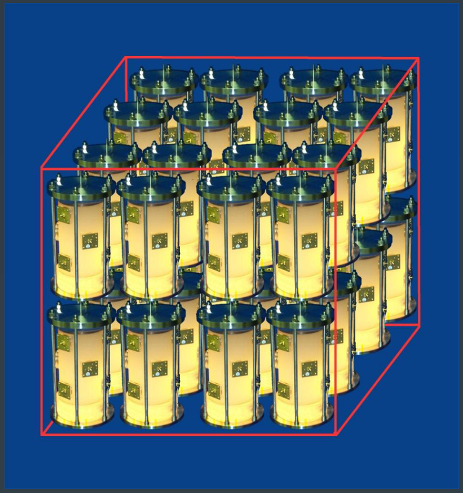
MIMAC
H_3 or CF_4
(LSM)

DMTPC
CF_4
(WIPP)

Unconventional detectors



COUPP
Bubble chamber CF_3Br
(SNO, UPV)

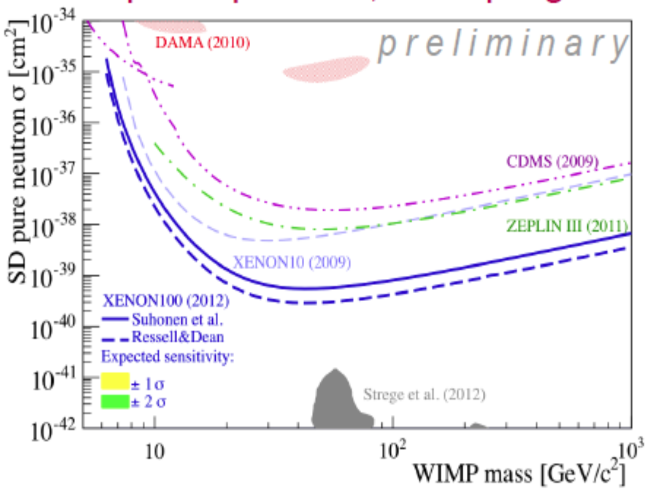


PICASSO
Freon droplets C_4F_{10}
(SNO)

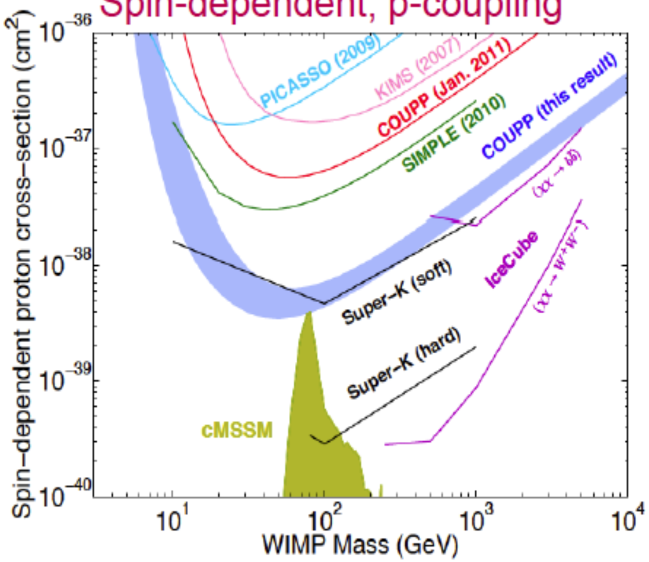
SIMPLE
Superheated droplets C_2ClF_5
(RUSTREL)

Status in WIMP DM sensitivities (2012)

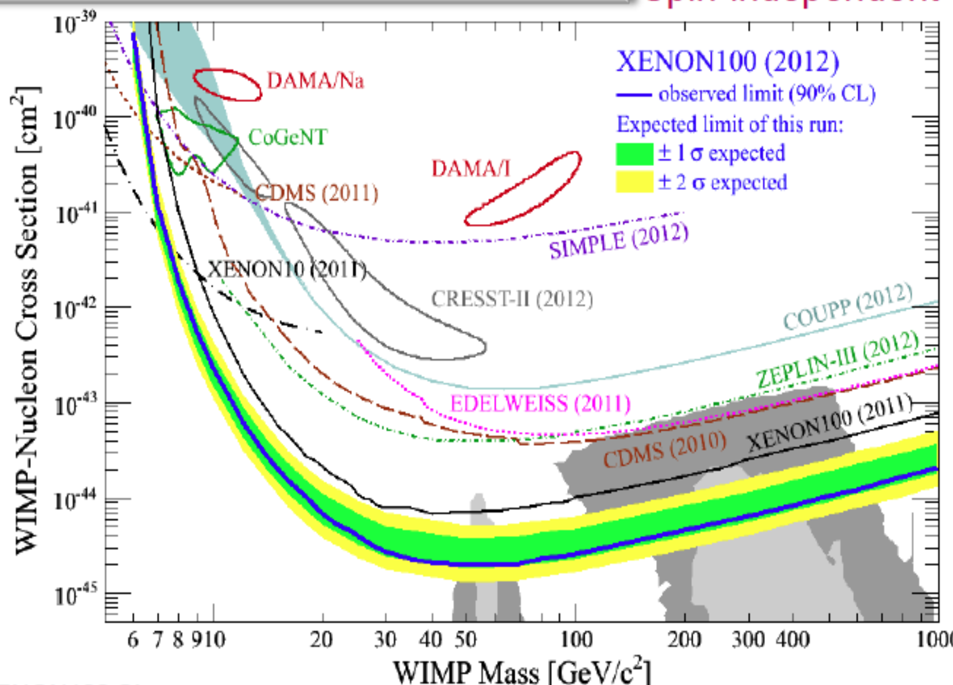
Spin-dependent, n-coupling



Spin-dependent, p-coupling



Spin-independent



XENON100 SI,
2010 PRL 105, 131302
2011 PRL 107, 131302

CDMS-II SI, 2010
Science 327, 1619

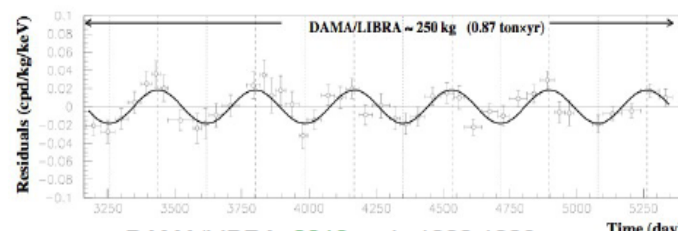
EDELWEISS-II SI, 2011
Phys. Lett. B 702, 329

CoGeNT SI,
PRL 106 (2011) 131301
2011b: arxiv:1106.0650

COUPP SD:
2012: arXiv:1204.3094

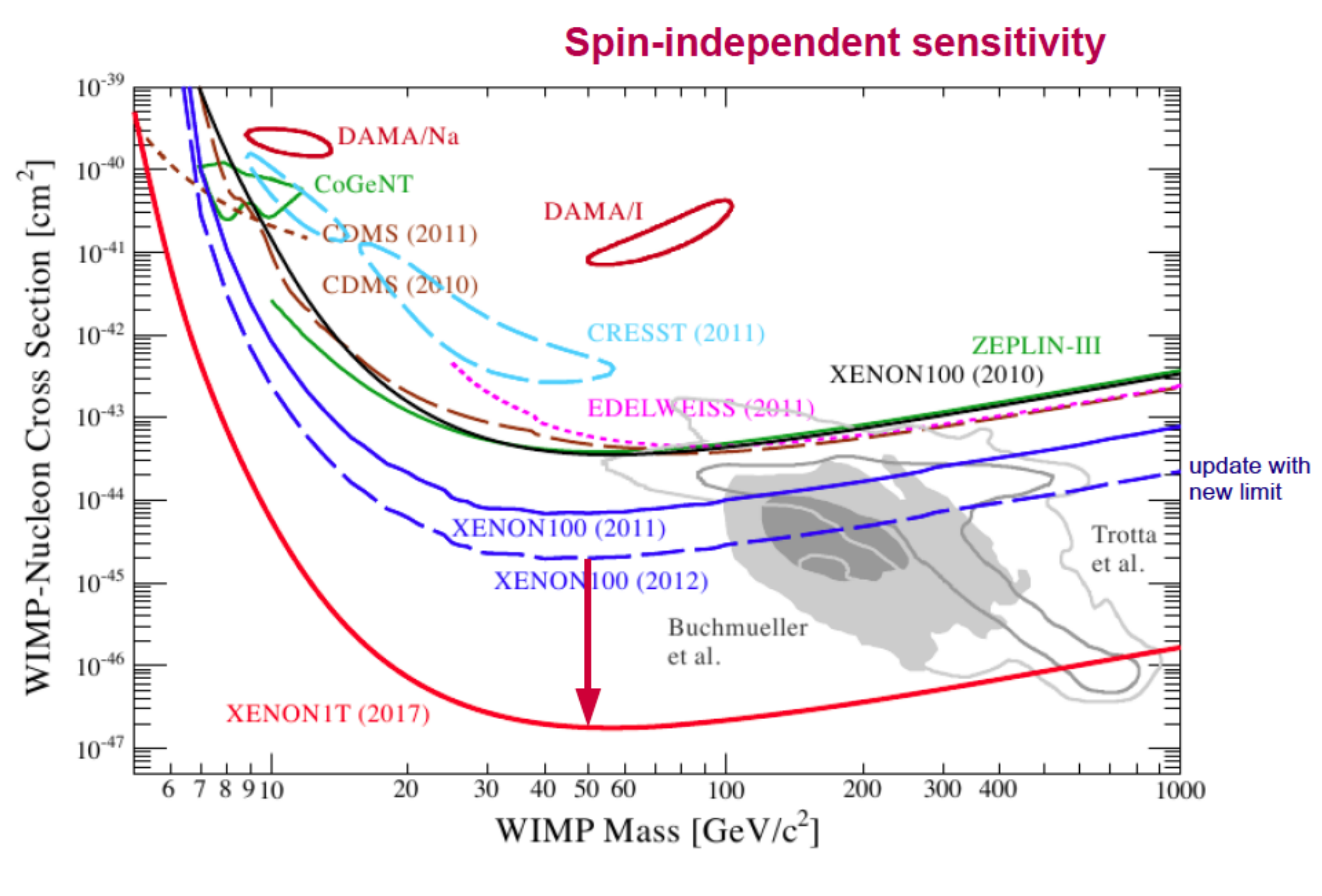
PICASSO SD, 2012
arxiv:1202.1240

Annual modulation – DM?



DAMA/LIBRA, 2010 arxiv:1002.1028

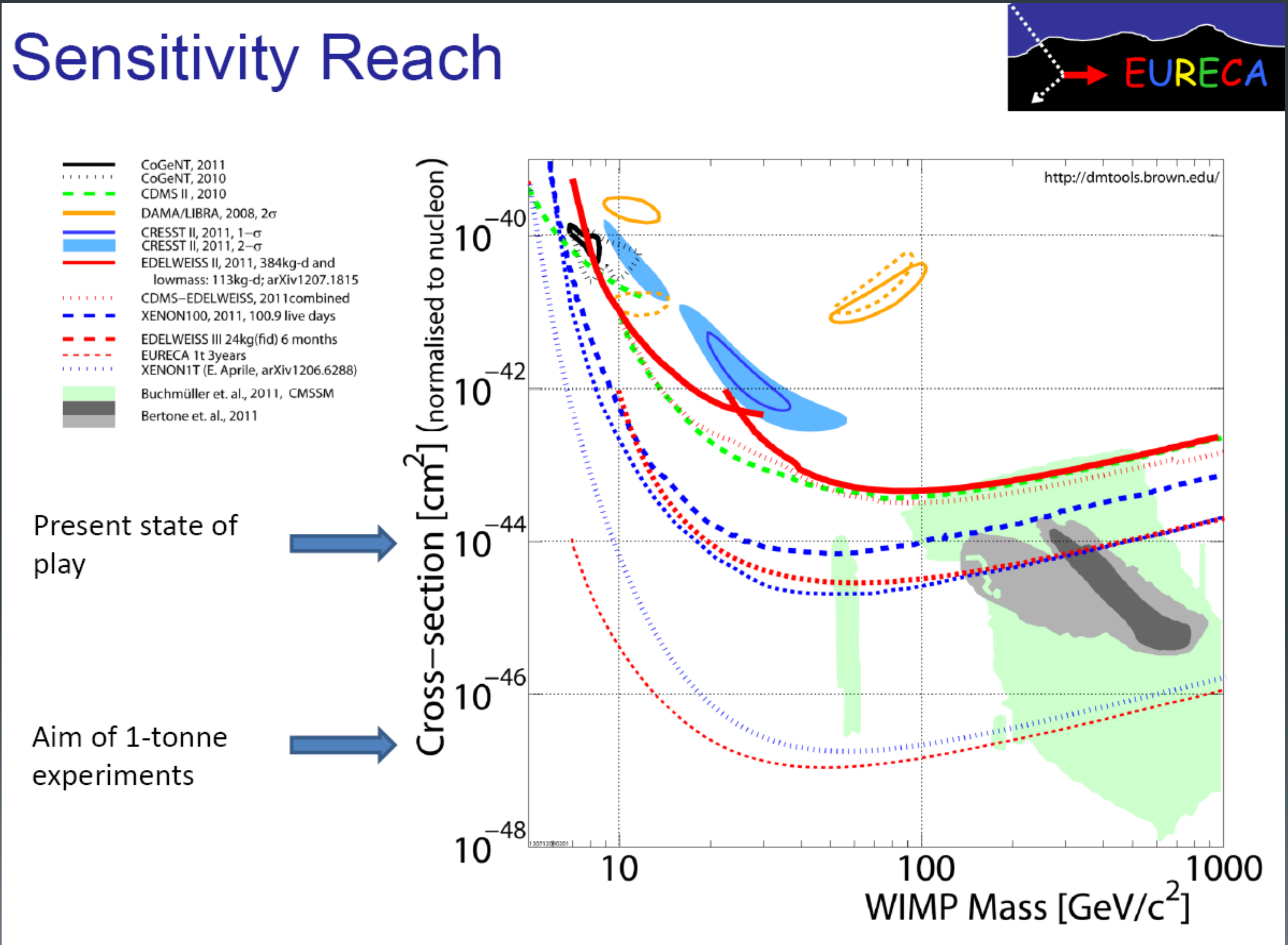
Near future …



Spin-independent sensitivity
WIMP-Nucleon Cross Section [cm^2]
10^-39
10^-40
10^-41
10^-42
10^-43
10^-44
10^-45
10^-46
10^-47
WIMP Mass [GeV/c^2]
6
7
8
9
10
20
30
40
50
60
100
200
300
400
1000
DAMA/Na
CoGeNT
DAMA/I
CDMS (2011)
CDMS (2010)
CRESST (2011)
ZEPLIN-III
XENON100 (2010)
EDELWEISS (2011)
XENON100 (2011)
XENON100 (2012)
Trotta
et al.
Buchmueller
et al.
XENON1T (2017)
update with
new limit

Near future …

Sensitivity Reach

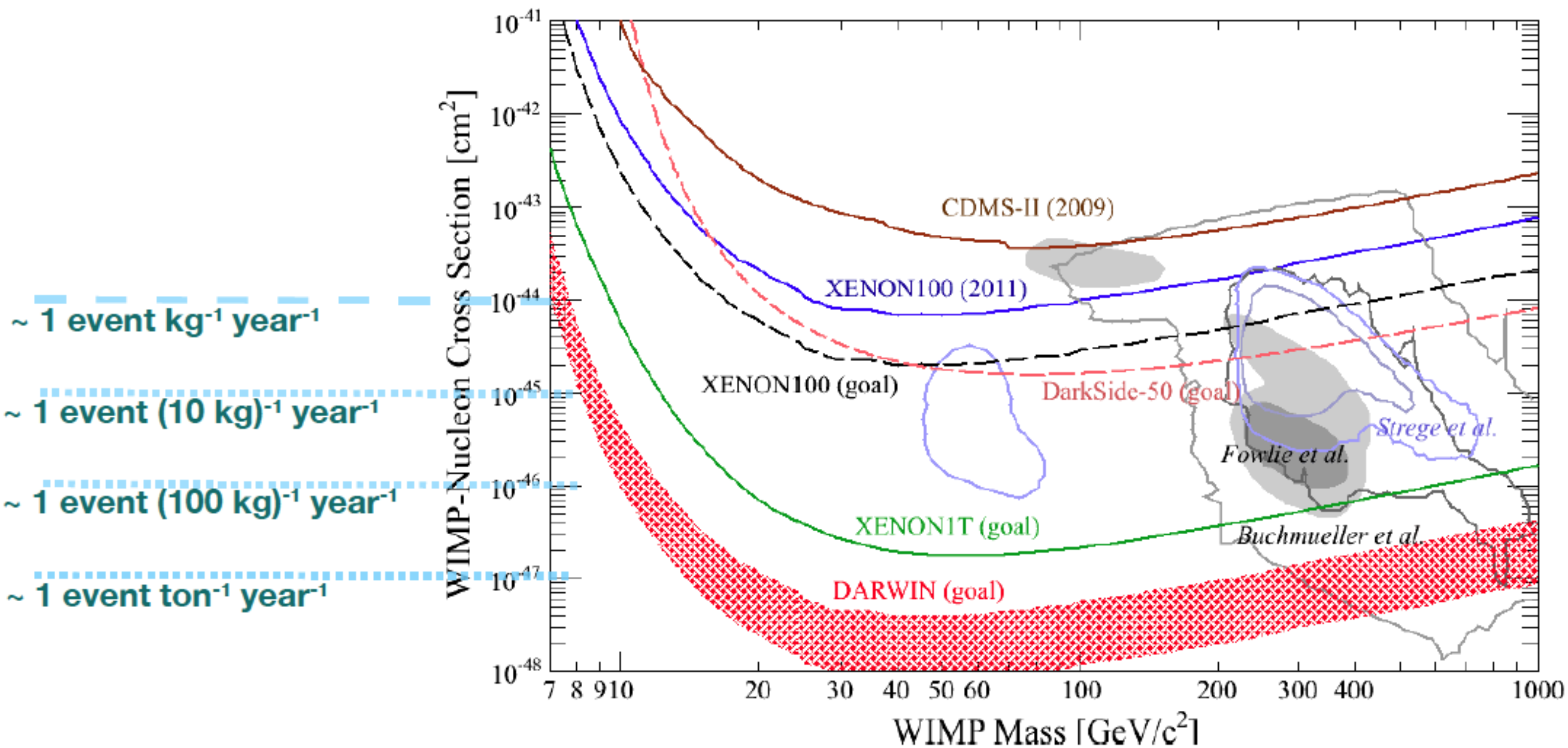


Not so near future …

DARWIN

Expected sensitivity

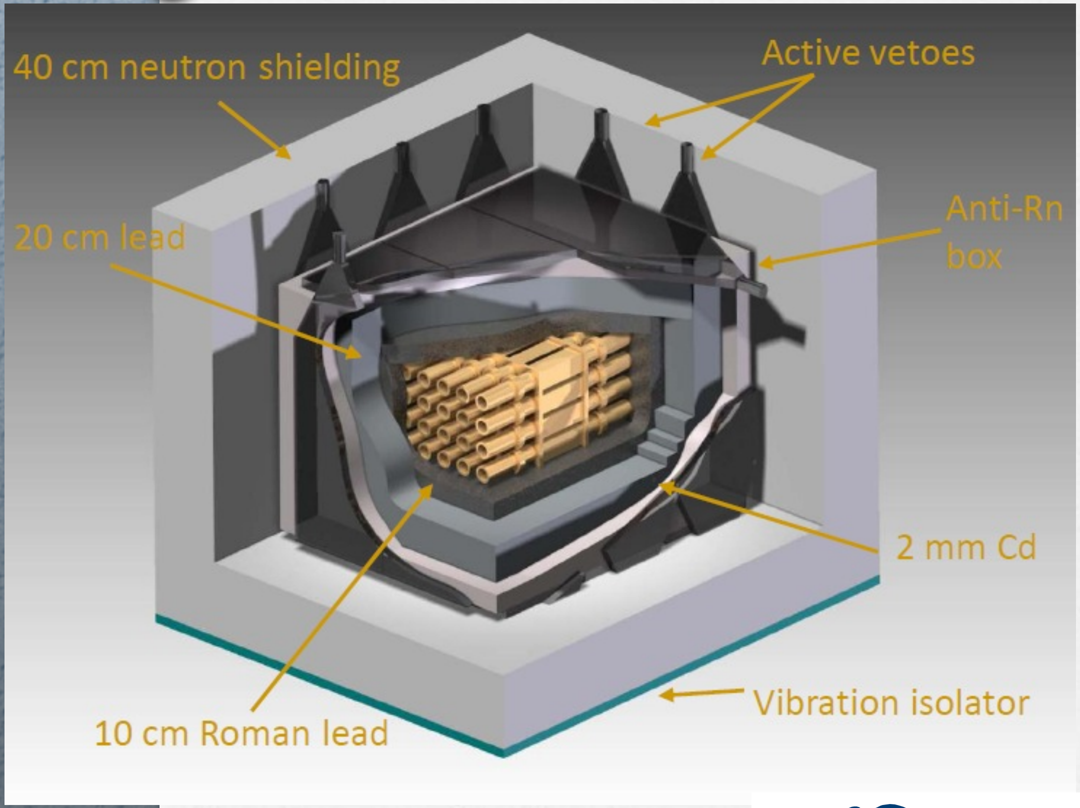
Goal is not exclusion limits, but WIMP detection!



Current Spanish contribution to direct detection of DM

ANAIS

The ANAIS Experiment



250 kg of ultrapure NaI(Tl) detectors at LSC

Goal: study the annual modulation in the dark matter signal

Universidad Zaragoza 1542

LSC Laboratorio Subterráneo de Canfranc

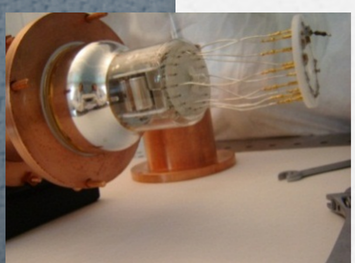
MultiDark Multimessenger Approach for Dark Matter Detection

SAME TARGET AND TECHNIQUE AS DAMA/LIBRA

The ANAIS Experiment

Long effort in R+D at the University of Zaragoza

- HPGe radiopurity test bench for material selection
- PMT Testing
- Background understanding
- Optimization of data analysis and readout



Progress in the NaI powder purification procedure

HPGe spectrometry screening of K content in NaI powder from different providers.

Two 12.5 kg cylindrical crystals have been grown with the best raw powder and are already encapsulated.

We require no more than 0.02 ppm Potassium.

	Potassium (ppm)
Merck – comercial	1.5 ± 0.7
Alfa-Aesar – commercial	1.59 ± 0.14
ESI – purified	0.32 ± 0.08
AS – selected	<0.09 (95% C.L.)

Status of the radiopure NaI(Tl) crystals growing and encapsulation

Protocols for low-background machining, selection of materials to be used, surface cleaning procedures, etc. were proposed by the UZ, discussed and agreed by AS.

The crystals are cylindrical in shape (dimensions of 4.75" diameter x 11.75" length) and have a mass of 12.5 kg each. They are encapsulated in OFHC copper, with an aluminized Mylar window to allow low energy calibrations.

PMT Testing

HP Ge spectrometry at LSC

Ham LB

Ham ULB

Ham VLB

Model	^{40}K (mBq/PMT)	^{232}Th (mBq/PMT)	^{2328}U (mBq/PMT)
HAM - R6233-100 HAM-LB	678 ± 42	68 ± 3	**100 ± 3**
HAM - R11065SEL HAM-ULB	12 ± 7	3.6 ± 1.2	**^{238}U: 47 ± 28** **^{226}Ra: 8.0 ± 1.2**
HAM - R6956MOD HAM-VLB	**97± 18**	**20 ± 2**	**^{238}U: 128 ± 38** **^{226}Ra: 8.4 ± 3**

PMTs for ANAIS

TECHNICAL INFORMATION

TENTATIVE
Nov. 2012

R6956 MOD SEL2 for ANAIS

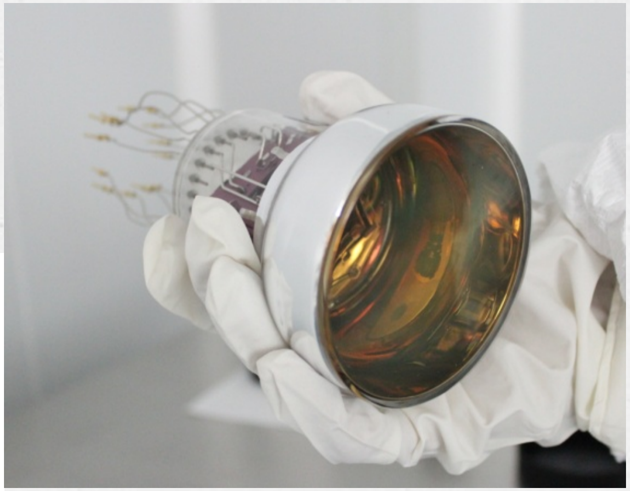
76 mm (3 inch) Diameter, Bialkali Photocathode, 10-stage, Head-On Type, Low Radioactivity, Short Profile

GENERAL

Parameter		Description / Value	Unit
Spectral Response		300 to 650	nm
Wavelength of Maximum Response		420	nm
Window Material		Borosilicate glass	-
Photocathode	Material	Bialkali	-
	Minimum Effective Area	70	mm dia
Dynode Structure / Number of Stages		Box and linear-focused / 10	-
Suitable Socket		E678-14W (supplied)	-
Operating Ambient Temperature		-30 to +50	°C
Storage Temperature		-80 to +50	°C

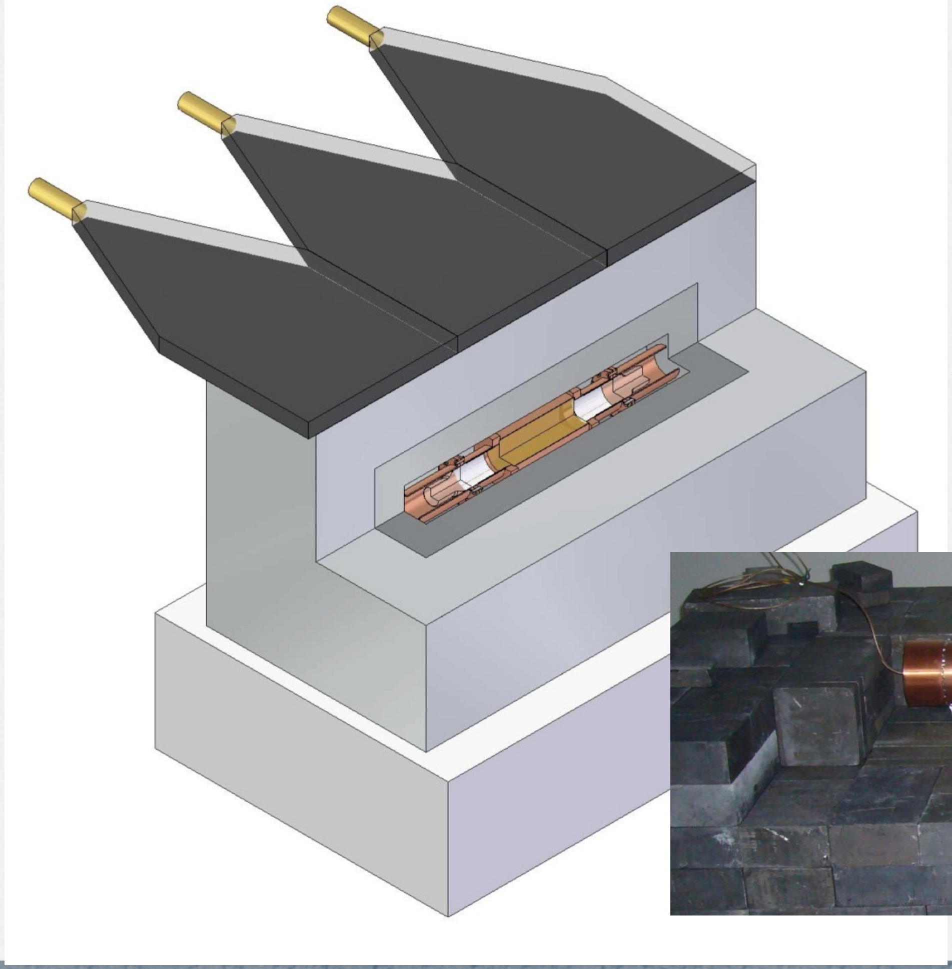
MAXIMUM RATINGS (Absolute Maximum Values)

Parameter	Value	Unit
Supply Voltage (Between Anode and Cathode)	1500	V
Average Anode Current	0.1	mA

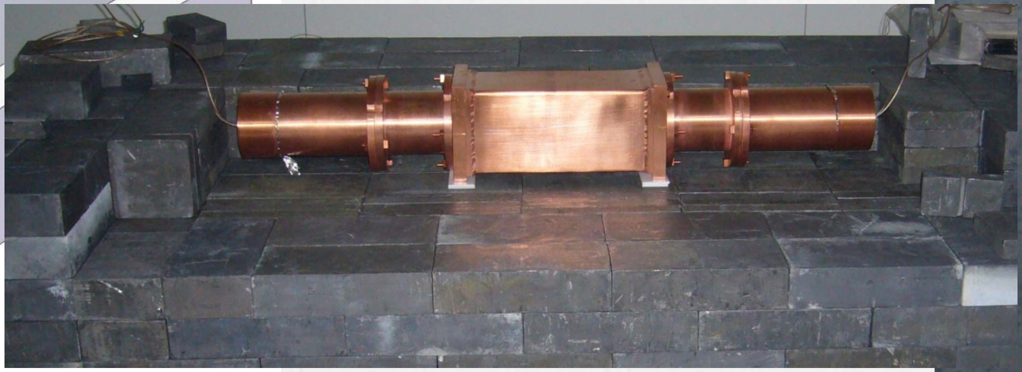


ANAIS-0: test bench for ANAIS

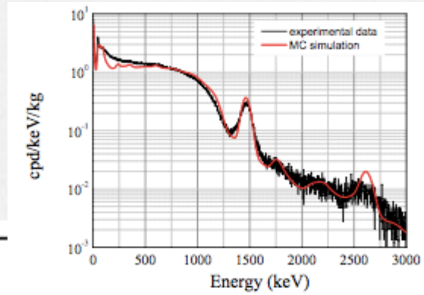
All the archaeological and low activity lead required for the whole ANAIS shielding is already available underground, at the LSC, ready for the mounting



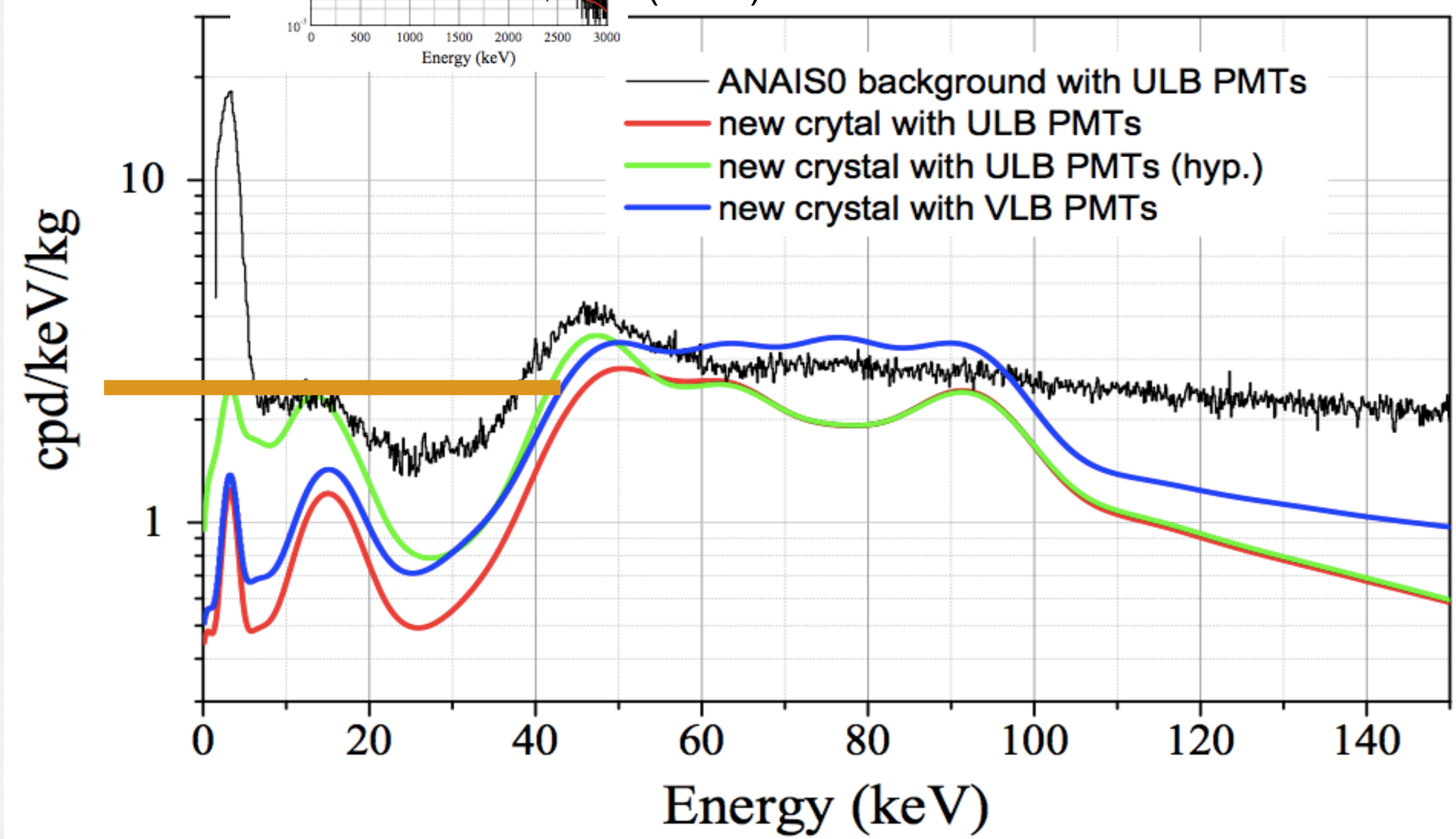
Tuning of the electronics, acquisition system, tests of PMTs, etc... has been done with ANAIS-0 prototype at LSC



Background Model for ANAIS: PROSPECTS



Background model for a NaI(Tl) detector devoted to dark matter searches,
S. Cebrián et al., Astroparticle Physics 37 (2012) 60.



Conclusions and Prospects

- Radiopure NaI powder (<90 ppb potassium) has been found and two 12.5 kg prototypes are almost ready to final background assessment at LSC
- **If potassium content is at or below 20 ppb, 250 kg NaI (20 x 12,5 kg) will be mounted at LSC along 2013**
- Electronic chain and readout is almost ready and the lead and polyethylene for the shielding are at LSC waiting to be mounted
- We understand quite well our present backgrounds: simulations and filtering protocols seem to work well

ROSEBUD-EURECA

ROSEBUD

http://www.unizar.es/lfnae/rosebud/

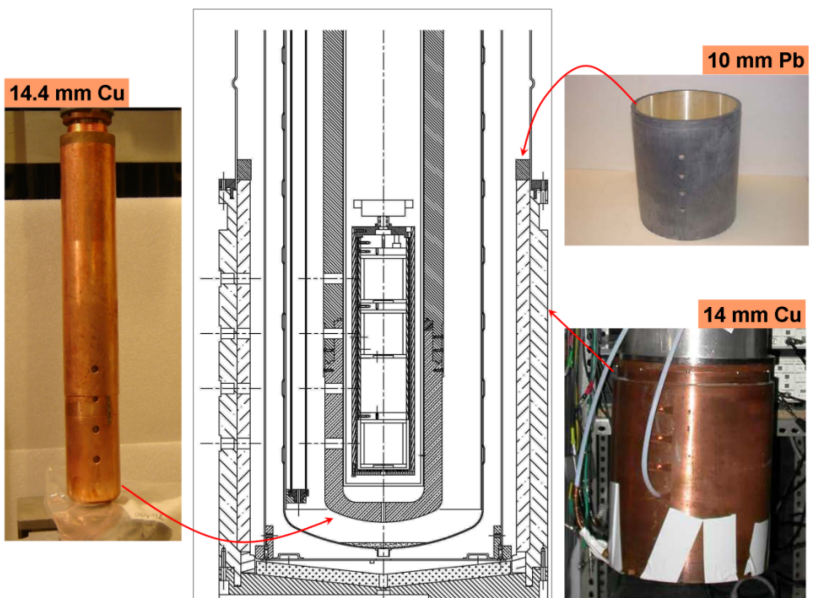
Institut d'Astrophysique Spatiale

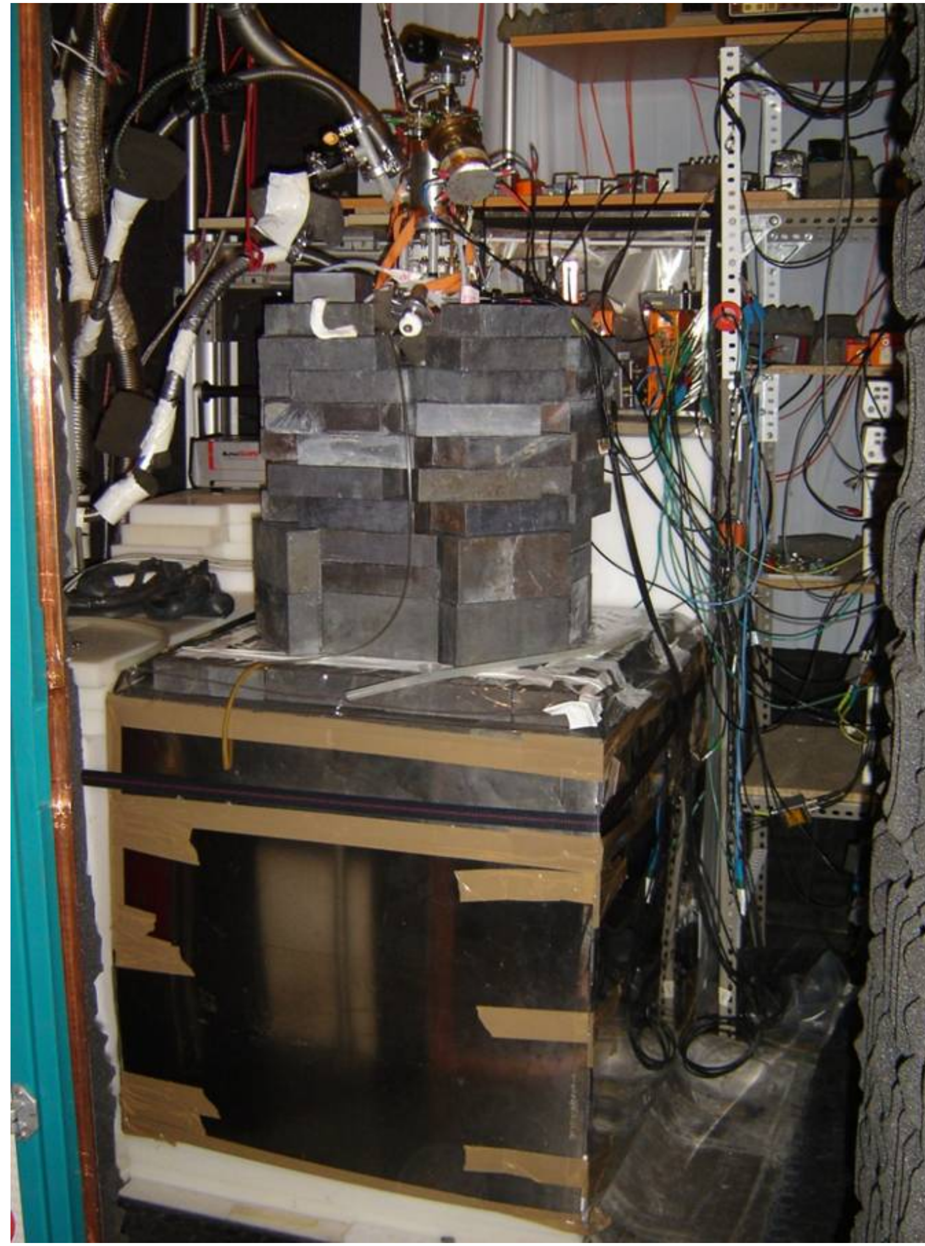
To develop and optimize scintillating bolometers of different materials and to use them in Nuclear and Particle Physics experiments

Integrated in EURECA

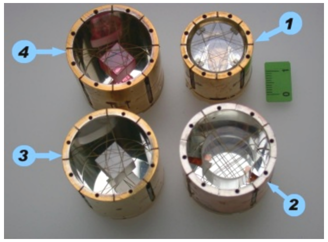
focus on DM search

ROSEBUD experimental set up in the old LSC (1999-2008)





ROSEBUD in the old LCS (1999-2008)



BOLOMETERS

Al_2O_3, Ge

Multiple target choice

Simultaneous use of several targets

SCINTILLATING BOLOMETERS

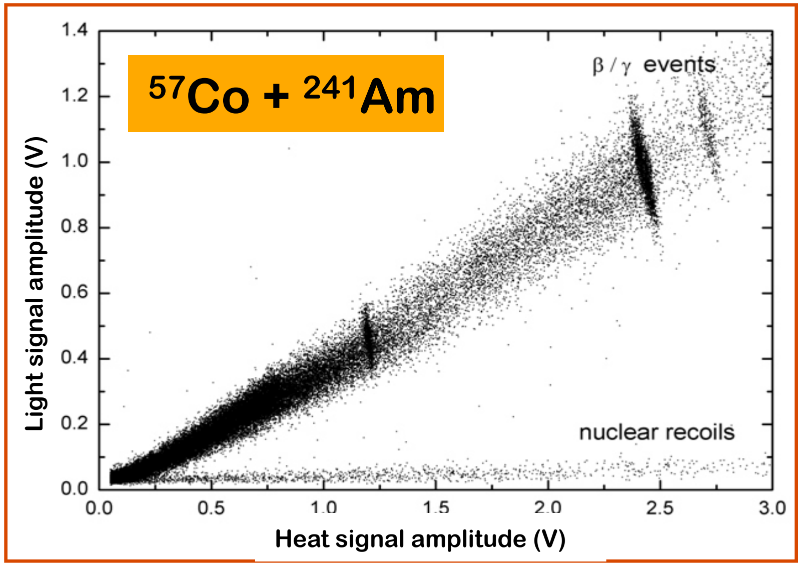
$CaWO_4$, LiF, TeO_2, Al_2O_3, SrF_2, BGO, CaF_2

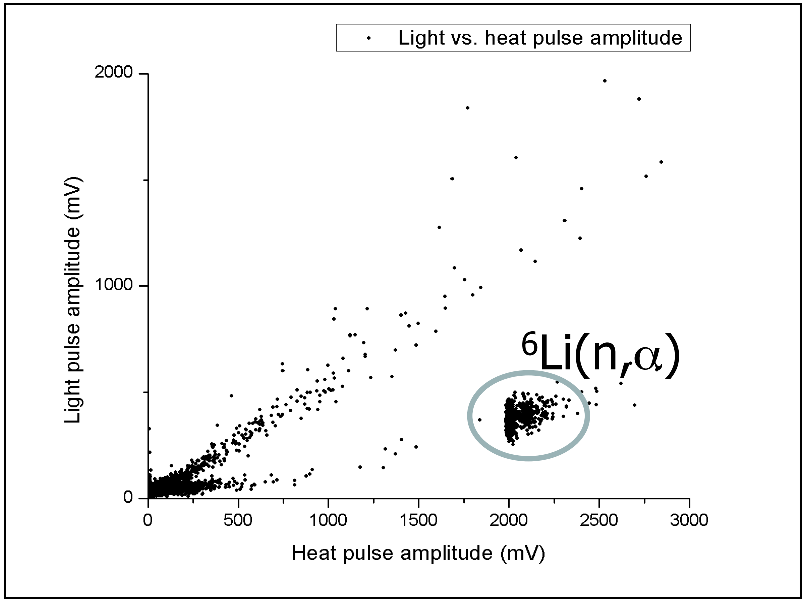
Particle discrimination capability

Increases sensitivity of experiments

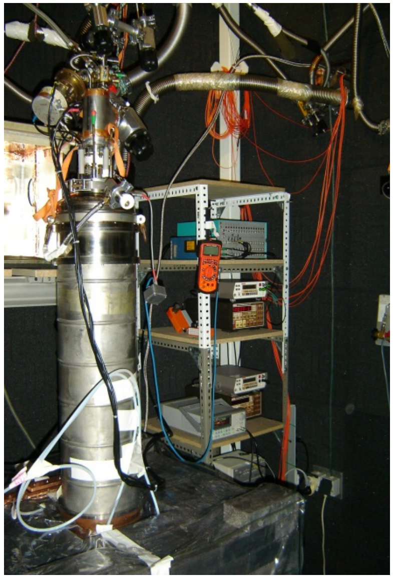
Excellent NR discrimination Al_2O_3

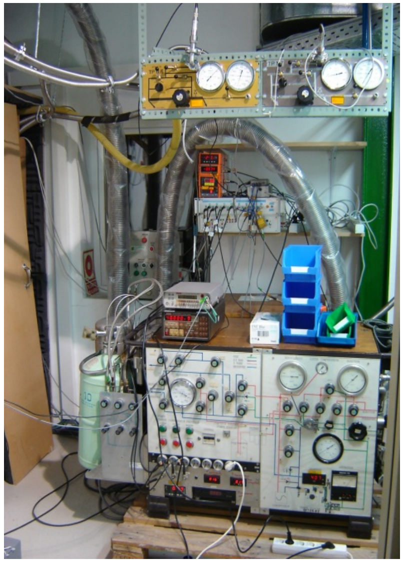
Neutron monitoring: LiF

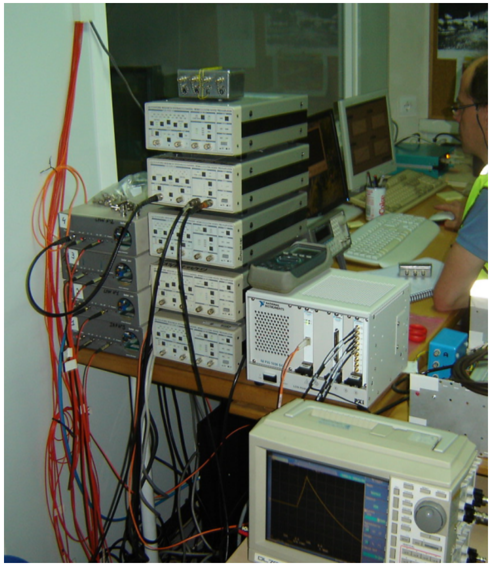


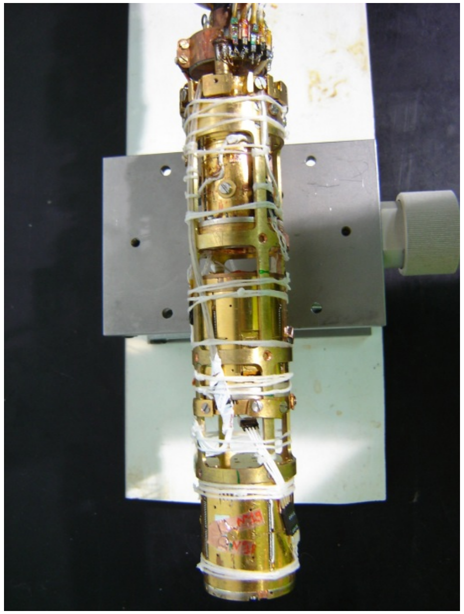


ROSEBUD in the new facilities of the LSC (2009- …)









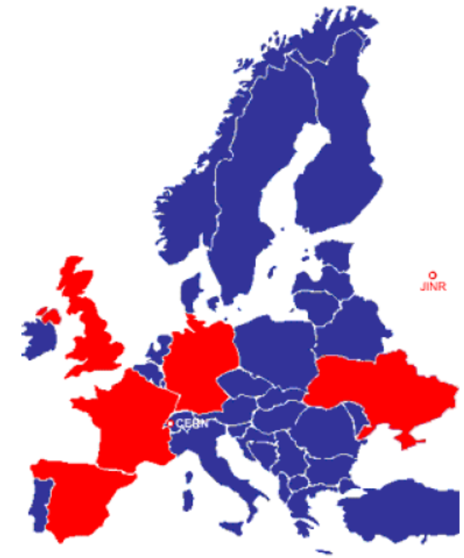
Scintillating bolometers being currently tested at LSC

46 g BGO $\Rightarrow$ γ background
self-calibrated (^{207}Bi internal contamination)

32 g ^{6}LiF $\Rightarrow$ fast (and thermal) n monitoring
(95% ^{6}Li) ^{241}Am source (α degraded by 25μm mylar)

50 g Al_2O_3 $\Rightarrow$ background in NR region
^{241}Am source (γ 60 keV)

EURECA-ROSEBUD

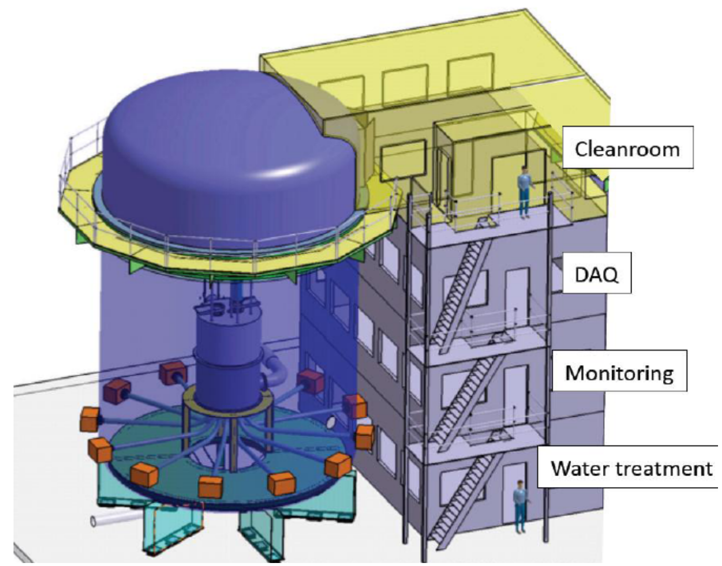


European **U**nderground **R**are **E**vent **C**alorimeter **A**rray
The future European 1-tonne cryogenic dark matter search
http://www.eureca.ox.ac.uk/

EDELWEISS + CRESST + ROSEBUD collaborations + new members

Detectors: Ge and scintillating bolometers
Laboratory: LSM
Shielding: radiopure Cu, polyethelene,
3m water tank with PMT's

Two-step approach (150 kg and 1 t)

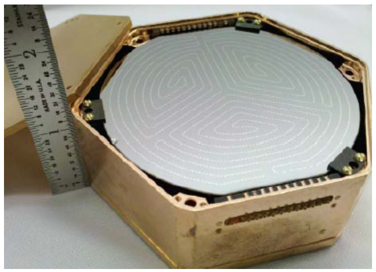


Status of EURECA

Coordinated cooperation with Super-CDMS

last meeting November 5th at Saclay

next meeting on January 18th at SLAC



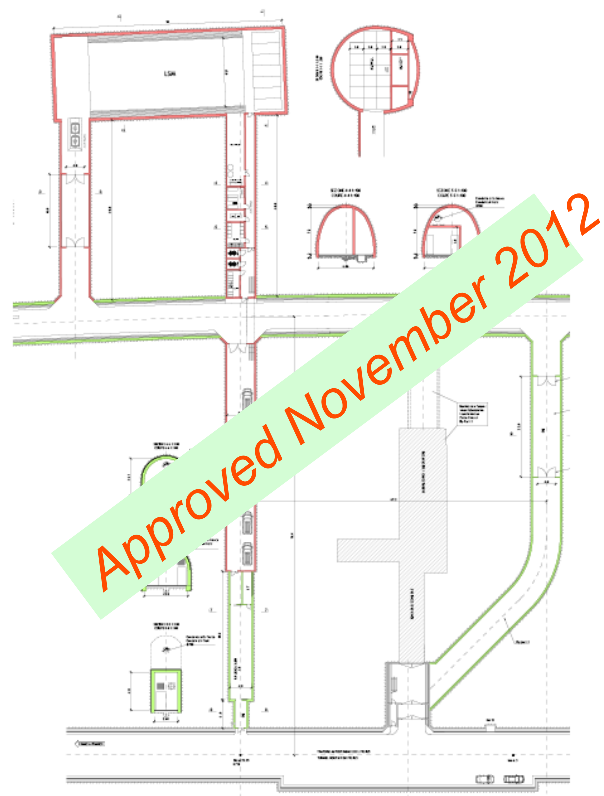
Construction of the LSM extension

confirmed by CNR on November 2012

full budget for digging obtained

civil work will start first semester 2013

new laboratory could be in operation ~ 2015



EURECA Conceptual Design Report (CDR)

EURECA Conceptual Design Report 2012

The EURECA Collaboration

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Radiopurity assessing for EURECA

Letter of Intent between MultiDark and HAP (Helmholtz Alliance for Astroparticle Physics) in Germany signed in January 2012

UZ cooperation with Munich group of CRESST: to obtain radiopure **$CaWO_4$** crystals that could be used as scintillating bolometers in EURECA

$CaWO_4$ is synthesized from **$CaCO_3$** and **WO_3**

We have measured 2 different batches of **$CaCO_3$** and other 2 batches of **WO_3**

Next months: another sample of **$CaCO_3$** and one sample of **$CaWO_4$** synthesized from measured powders

ArDM

The ArDM Collaboration
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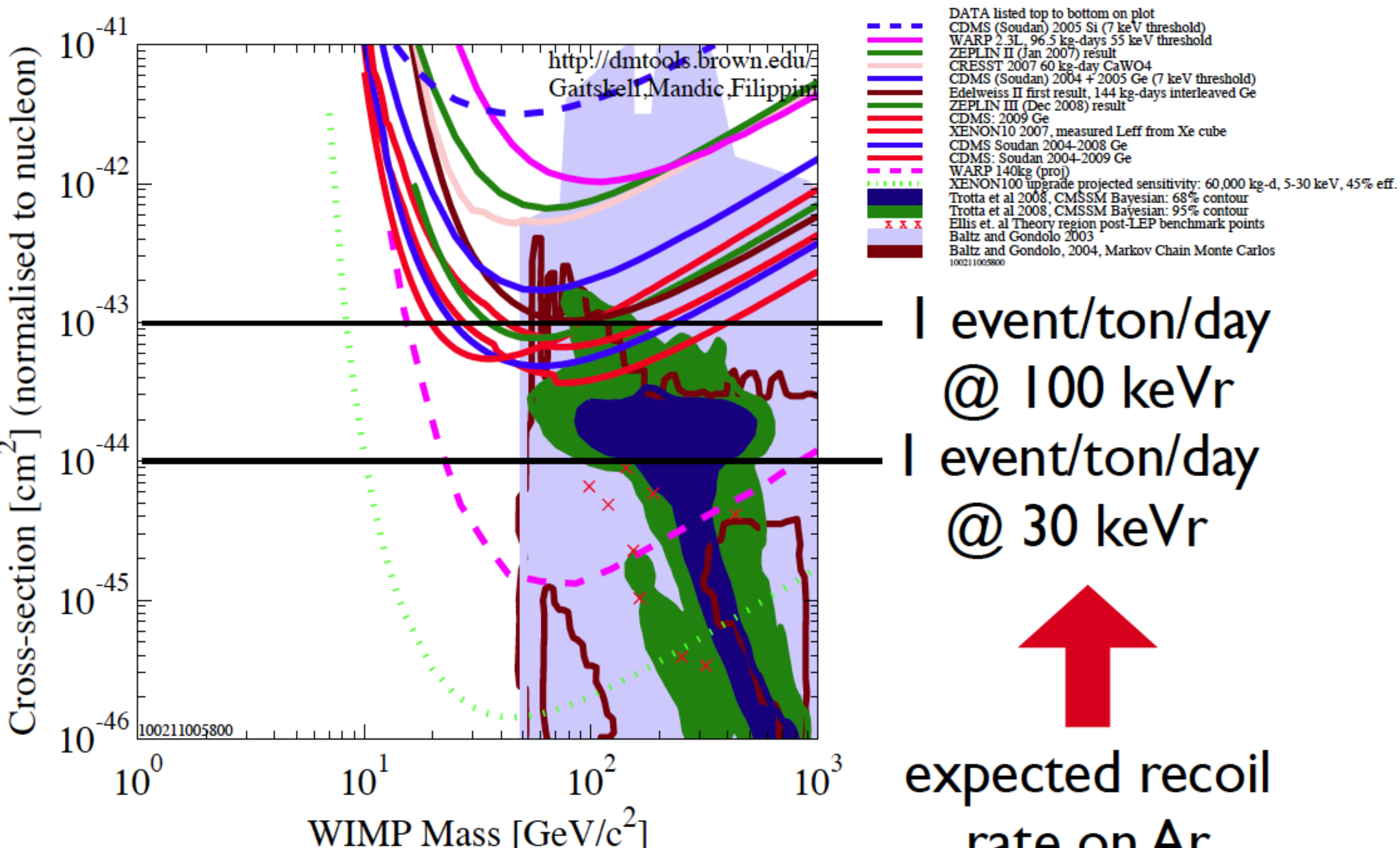
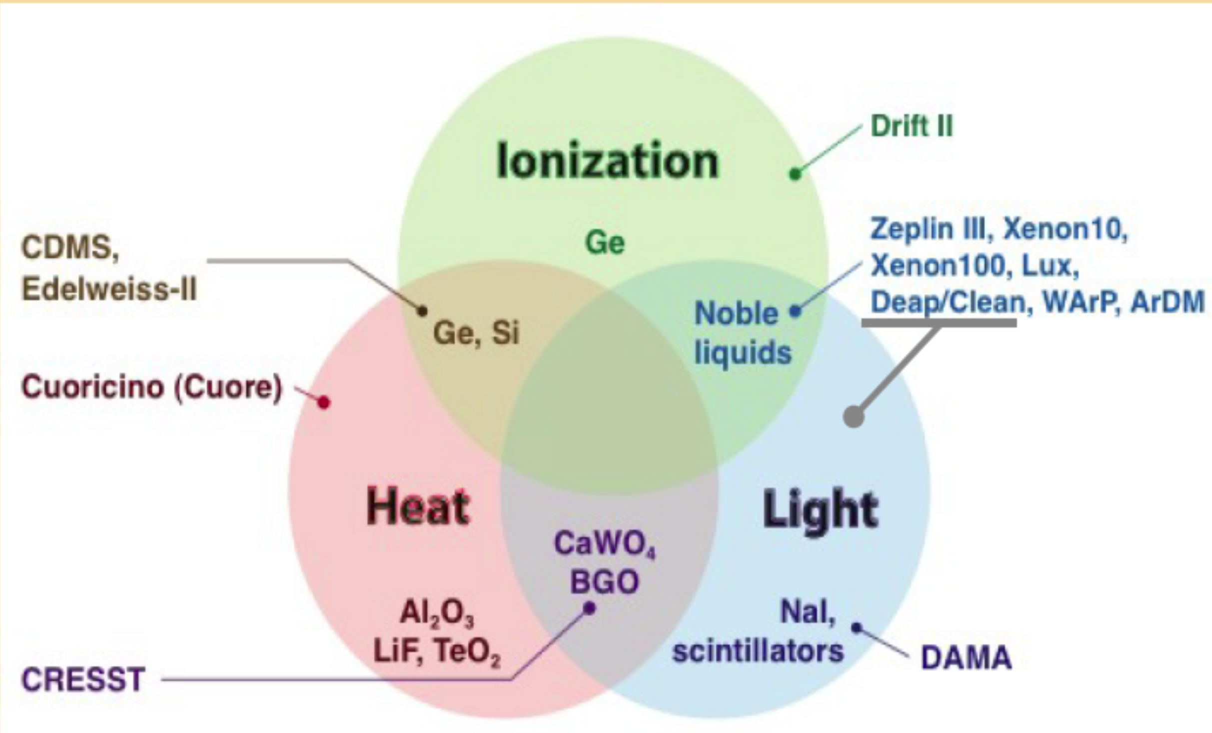
Why LAr for direct DM searches?

- Noble liquids as Ar & Xe offer the possibility to have large instrumented volumes to detect WIMP-induced nuclear recoils, with low energy threshold and excellent background rejection capabilities
- Event rate in Ar less sensitive to energy threshold than in Xe [nuclear form factors]: 30 keVr break-even point for equal masses
- LAr from liquid air industry is cheap, easy to handle and purify, ton scale detectors are routinely built for - e.g. - neutrino physics
- In case of positive DM detection, Ar and Xe provide complementary information because of different recoil spectra [kinematics]
- Charge/light ratio and pulse shape of scintillation provide powerful discrimination against gamma and beta background [pulse shape not available in Xe]
- Major drawback of atmospheric argon: traces of 39Ar [β emitter, τ=269 yrs, Q=565keV] gives ~1 Hz/kg of atmospheric Ar BUT:
    - Enough rejection power may be available [$\geq 10^8$?]
    - Possibility to have Ar depleted of 39Ar from underground wells

The physics goal



Choices / techniques



ArDM:
- 1 ton liquid argon
- double phase
- charge: LEM
- light: PMT

WArP:
- 100 liters liquid argon
- double phase

Deap/Clean
- single phase

➠ ArDM aimed at double phase & ton-scale LAr detector...

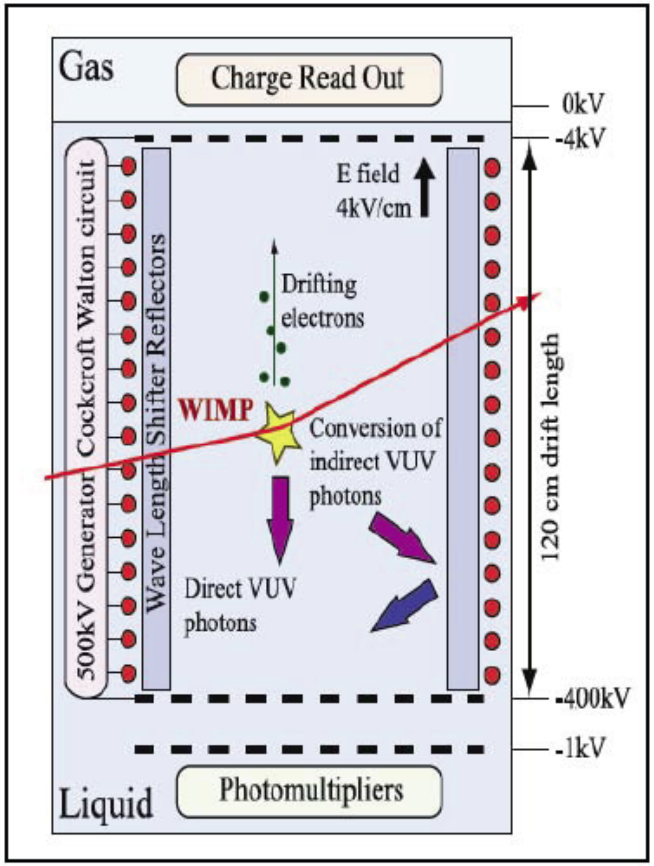
ArDM-1ton

ArDM goal: 1-ton two-phase (gas & liquid) LAr detector with *independent* charge and light readout optimized for direct DM searches [high discrimination power against background, few keV energy threshold, designed for stable underground operation]

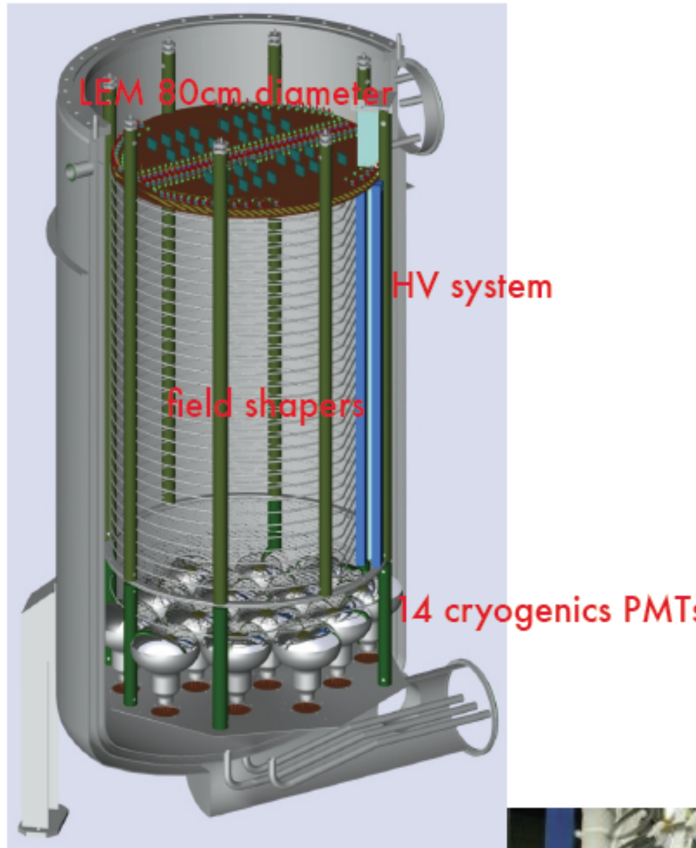
- Time projection chamber [TPC] readout for the charge produced by ionizing radiation, with sensitivity down to keV energy depositions and sub-millimeter position resolution using Large Electron Multipliers [LEM]. Fine segmentation helps background rejection through fiducial volume cuts, separate detection of multiple interactions within the same event.
- High voltage for drift field up to 3 kV/cm over 1.2 meter drift to detect ionization from highly quenched low energy nuclear recoils.
- Light readout of the prompt scintillation light using cryogenic photomultipliers immersed in LAr. Rejection of beta/gamma background from charge/light ratio and pulse shape discrimination.

ArDM-1ton

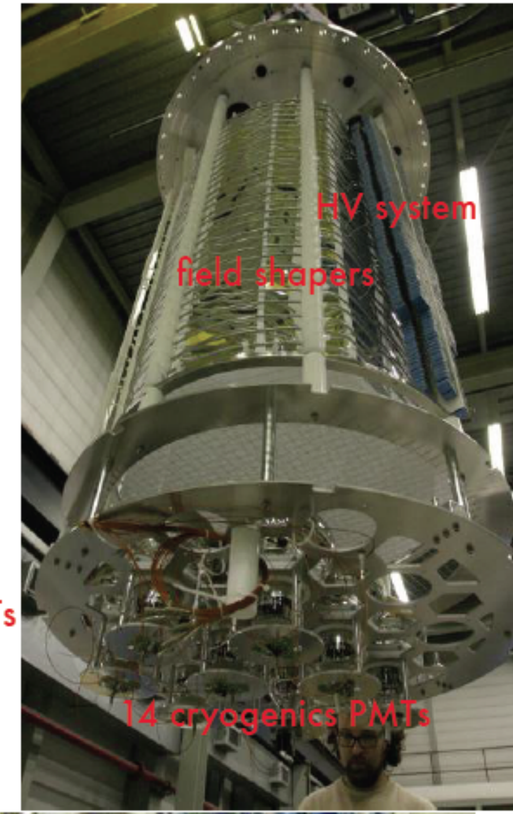
A.Rubbia, J.Phys.Conf.Ser.39 (2006) 129



Working principle



Inner detector



Polyethylene neutron shield

Installation of lateral shield structure at LSC

The first part of the installation took place on 1–5 October 2012.

Polyethylene lateral neutron shield has been installed up to the level of the first floor of the ArDM platform at LSC.

Polyethylene neutron shield

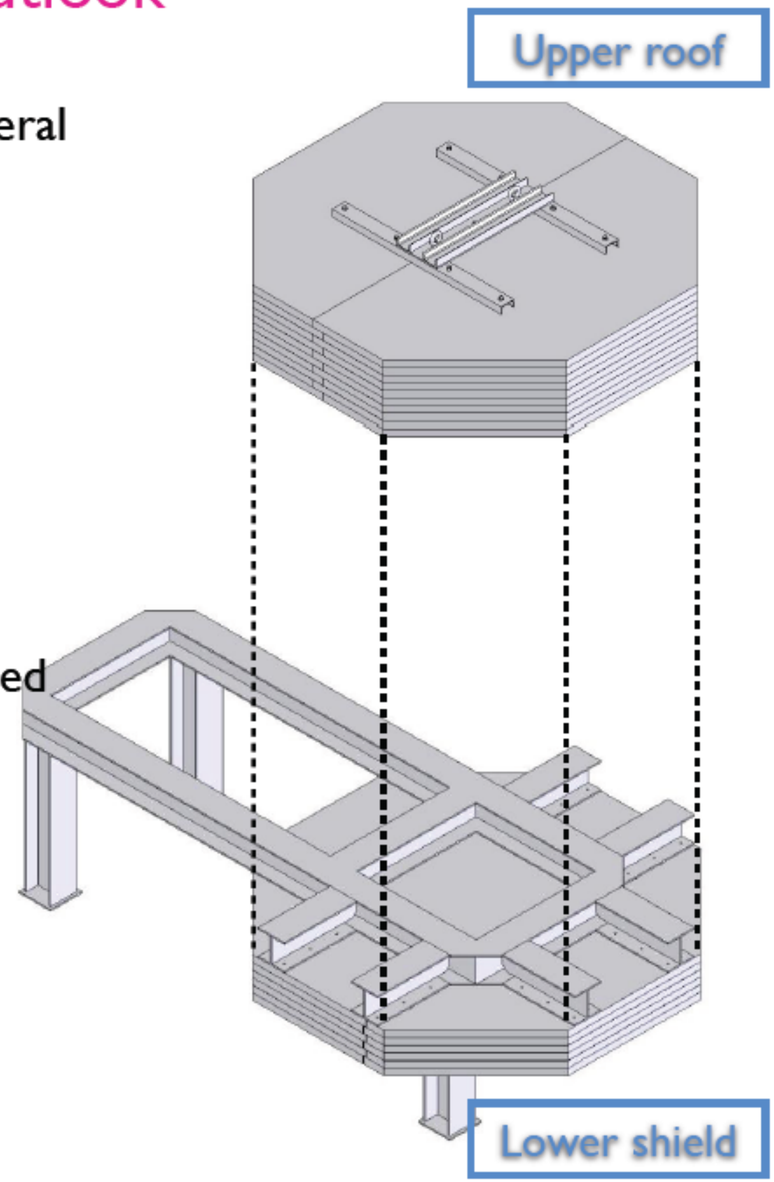
Summary and outlook

- The first phase of installation of the ArDM lateral neutron shield was successful

We are now ready to proceed

Next steps :

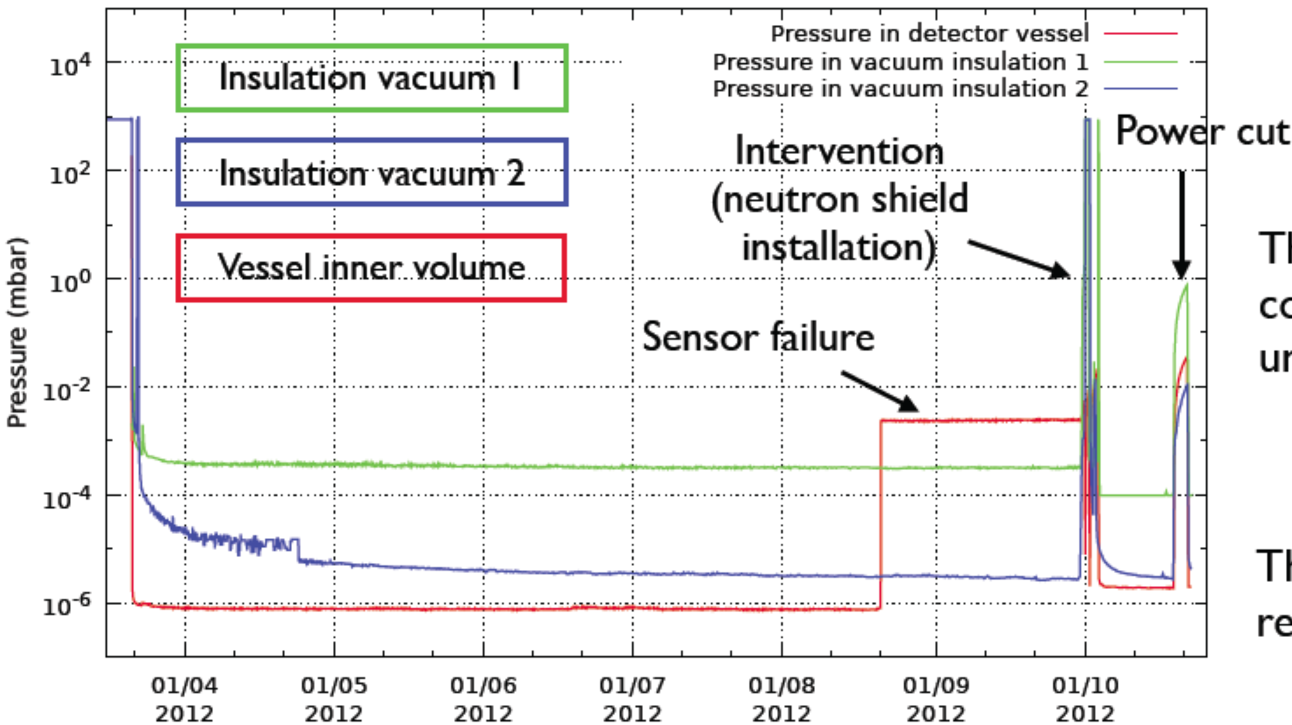
- Lower shield under the detector vessel
  - pieces in preparation at CIEMAT
- Upper half of the lateral shield – will be installed after the detector will have been installed
  - pieces ready for shipment
- Upper roof
  - CIEMAT group to purchase the pieces in January



ArDM vacuum system

Vacuum phase operation at LSC

Vacuum chart during the period March–October 2012



The PLC system reacted correctly in each of the unexpected events.

The vessel inner volume has reached <10^{-6} mbar

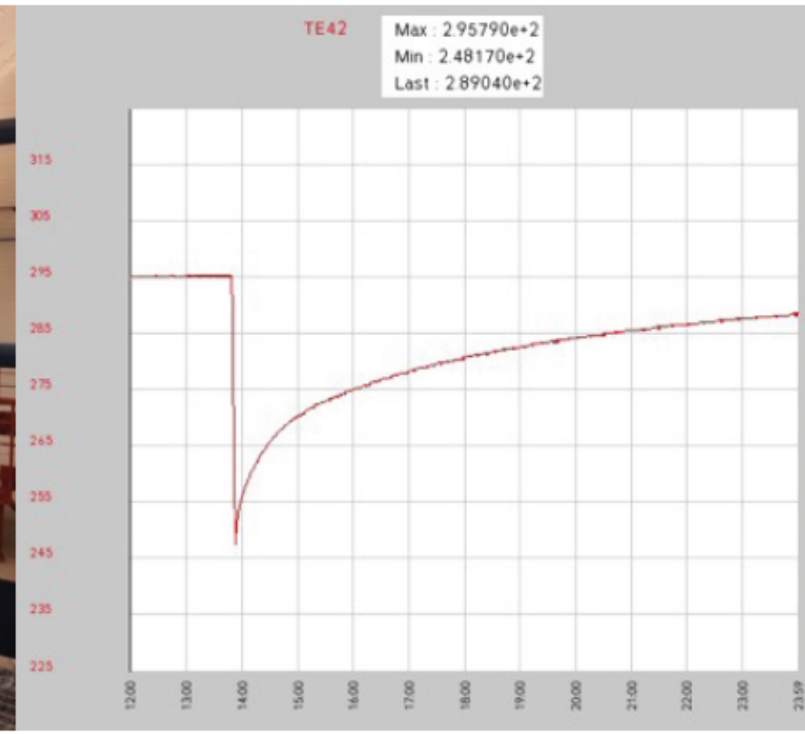
- We conclude that the ArDM vacuum system is fully commissioned and operational.
- We are operating the ArDM PLC system and have gained experience on the actual situation in the LSC underground Hall A.
- The vacuum phase operation of ArDM has gone very smoothly.

ArDM cryogenic system

Installation and the first test at LSC

Two compressors for the cryocoolers were shipped from CERN to Canfranc in September 2012.

Installation took place on 1–5 October.



The compressors are connected to the system.

Installation was successful

They were turned on for a couple of minutes. The cold head temperature went down immediately to –20°C.

Conclusions

- The first phase of installation of the lateral neutron shield took place at LSC on 1–5 October and was successful : We are ready to proceed. We are considering an in situ neutron measurement campaign in collaboration with the "Grupo de Innovación Nuclear del CIEMAT".
- We have started screening of the materials and plan to continue these measurements in order to collect as much information as possible. We count on the continued support of the Lab.
- Various improvements have been made on the inner detector design : two new arrays of 12 PMTs and a HV feedthrough for the drift field. Improvement in overall light yield is expected with improved coating of the PMTs and with the new design : the expected light yield is 1.75 p.e./keVee.
- For the full risk analysis we are in contact with Institute of Nuclear Technology-Radiation Protection "Demokritos". We need a dedicated Lab contact person.
- The ArDM cryogenic system is ready to start with a phased cryogenic operation. We ask permission to the Lab and would like the support from the SC to start planing the LAr bath cryogenic test.
- ¡¡ The ArDM Collaboration is committed to perform a first commissioning and physics run as early as possible !!

SuperCDMS

SuperCDMS Collaboration

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University of British Columbia
S. Oser, H. Tanaka

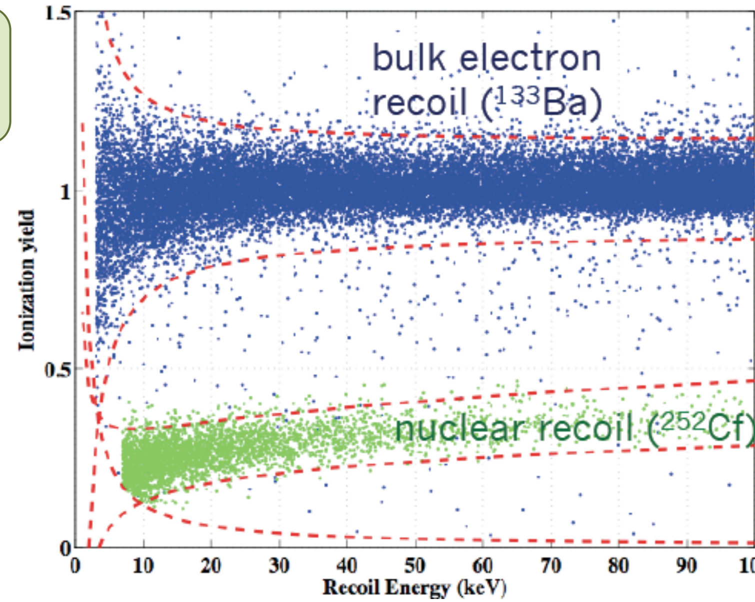
Cryogenic Dark Matter Search

- **CDMS II** (Oct 2006 – Sep 2008)
  5x6 Ge/Si ZIPs (4.5/1 kg)

Germanium and Silicon detectors (ZIPs) sensitive to ionization and phonons

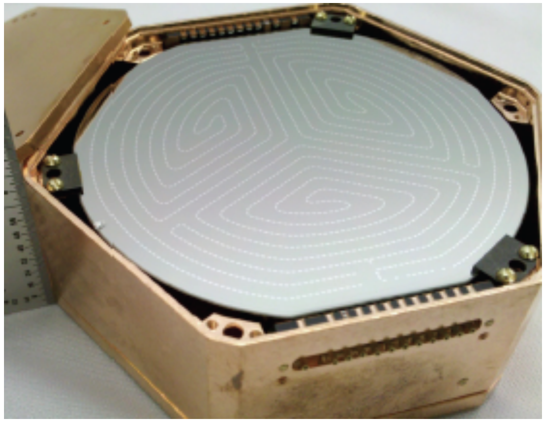
Rejection power for nuclear recoils and bulk electron recoils

Timing information to remove surface electron recoils



- **SuperCDMS-Soudan** (Mar 2012 – Mar 2015)
  5x3 Ge iZIPs (9 kg)

New interleaved detectors (iZIPs) for a better discrimination of surface events



- **SuperCDMS-SNOLAB** (Ongoing R&D)
  24x6 Ge iZIPs (~200 kg)

IFT-UAM group in SuperCDMS

- **David G. Cerdeño** (PI)
- Elías López-Asamar (Postdoc)
- Leyre Esteban (PhD student)

Active contribution to the following analyses:

- **CDMS II**

Reanalysis of Ge data: contributing with Monte Carlo simulations of the gamma background

Search for Fractional Charge Massive Particles: lead the study of radiogenic photons (nuclear gamma decays) as a background

- **SuperCDMS-Soudan**

Conventional WIMP search: participating in the study of the SuperCDMS gamma spectrum

Low-Threshold Analysis and CDMSlite: study of the spectrum of low-energy photons for the low-threshold analysis

- **SuperCDMS-SNOLAB**

Muon veto and cosmogenic muon background

COUPP

COUPP. The Collaboration

(And since August 2011)

- University of Chicago: Juan Collar (PI, spokesperson), C. Eric Dahl, Drew Fustin, Alan Robinson
- Indiana University South Bend Ed Behnke, Joshua Behnke, Tonya Benjamin, Austin Connor, Cale Harnish, Emily Grace Kuehnemund, Ilan Levine(PI), Timothy Moan, Thomas Nania
- Fermilab: Steve Brice, Dan Broemmelsiek, Peter Cooper, Mike Crisler, Jeter Hall, Martin Hu, Hugh Lippincott, Erik Ramberg, Andrew Sonnenschein, Fermilab Engineers and Technicians
- SNOLAB: Eric Vazquez Jauregui
- Virginia Tech: Shashank Priya

MultiDark
Multimessenger Approach for Dark Matter Detection

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Miguel Ardid
Manuel Bou-Cabo
Silvia Adrián-Martínez

COUPP. The technique

WIMP-Nucleus elastic scattering search
in a sea of background radiation
Detection technique: Bubble Chamber

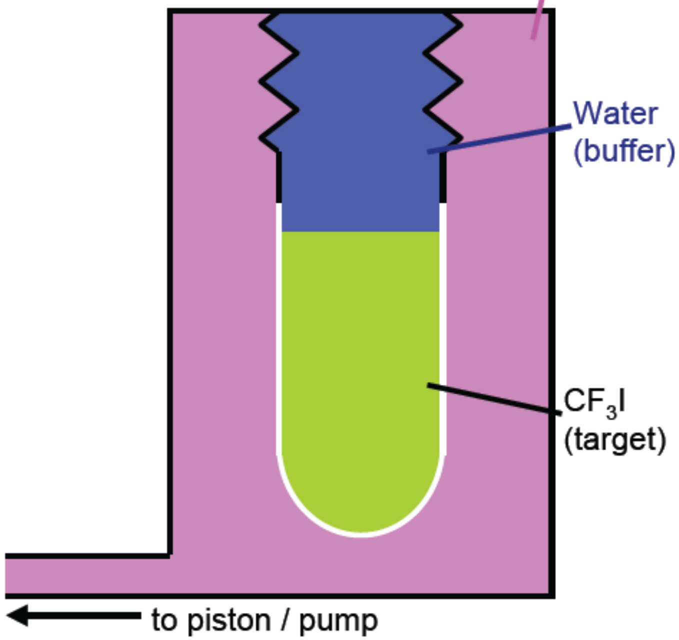
- WIMPs should exist locally!
  - Expected density 0.4 GeV/cm^3
  - rms velocity 230 km/s
- Coherent elastic scattering
  - Recoil energies *O*(10) keV
  - low background, low threshold detectors

Spin dependent

- Superheated CF_3I target

Spin independent

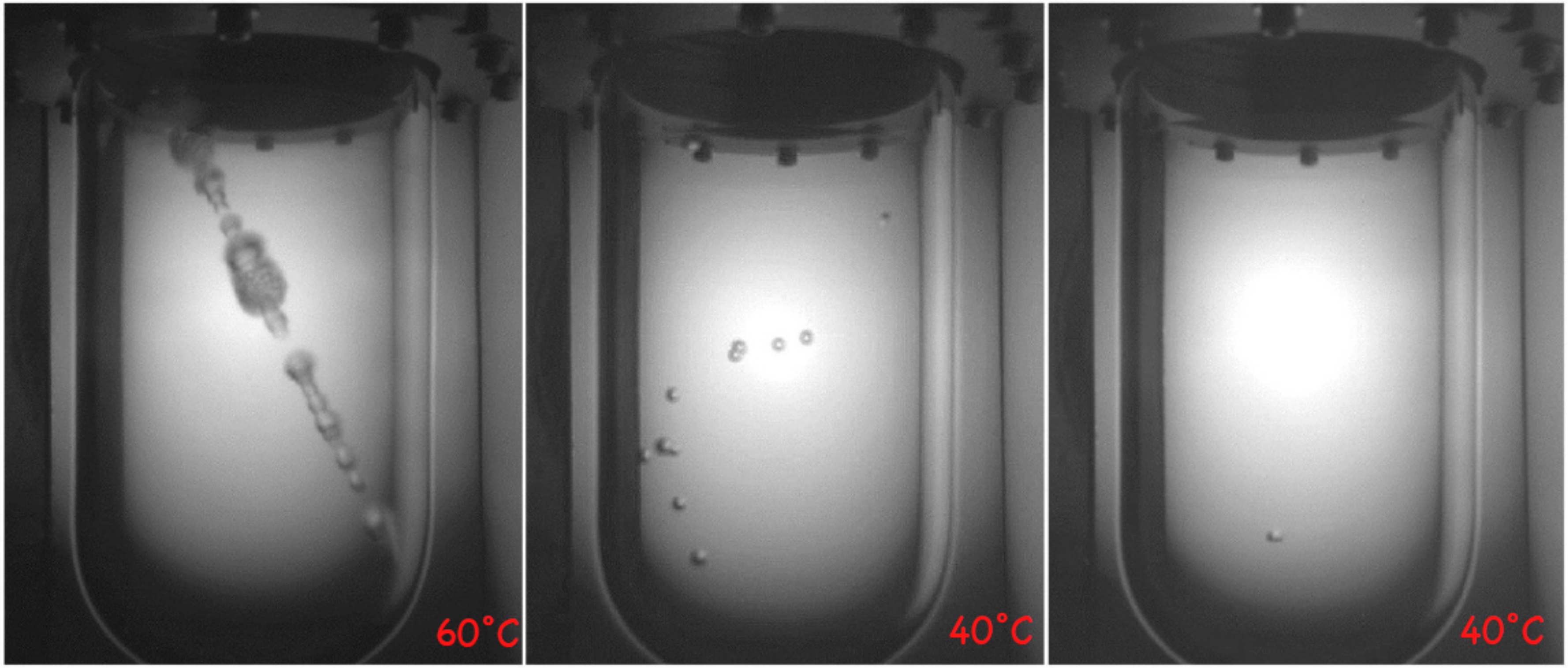
- Particle interactions nucleate bubbles.
- Cameras capture stereoscopic bubble images. Pressure and acoustic sensors offer additional information analizing the "acoustic signature".
- Chamber recompresses after each event.
- Pressure and temperature define the operating point (sensitive to nuclear recoils only)



Introduction to COUPP. The technique

Conventional BC operation
(high superheat, MIP sensitive)

Low degree of superheat, <u>sensitive to nuclear recoils only</u>

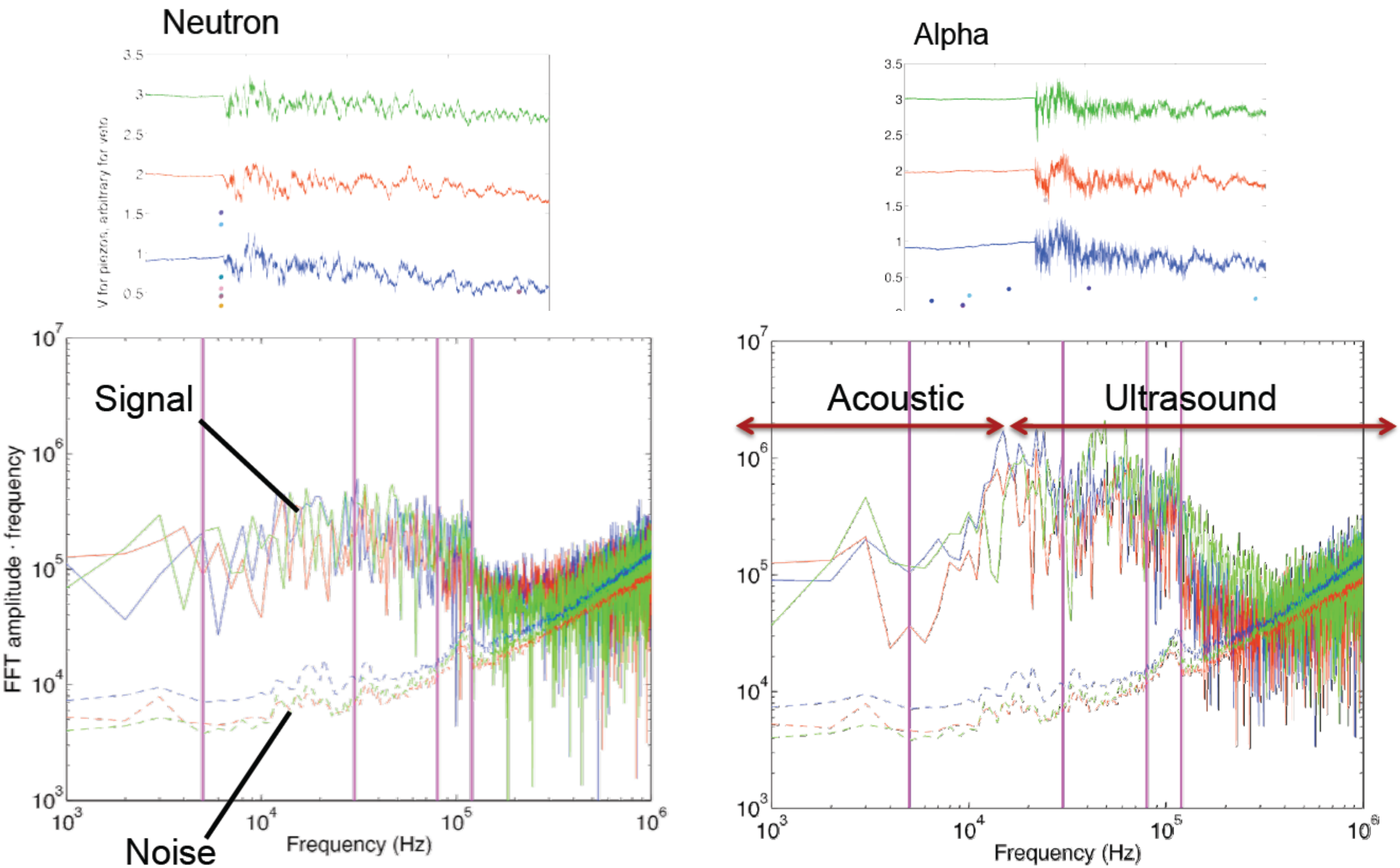


muon

Neutron

WIMP

4 kg bubble chamber (Acoustic analysis and discrimination)



Alphas are louder than neutrons. Discrimination better than 99%

However, piezo sensors have been found to be a source of background, through the α,n reaction (the technique should be used with care)

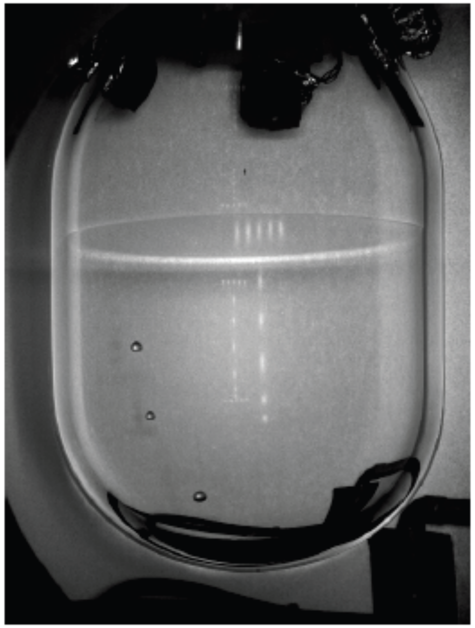
COUPP Bubble Chambers

- ✓ The ability **to reject electron and gamma backgrounds by** arranging the **chamber thermodynamics** such that these particles do not even trigger the detector
- ✓ Very good **alpha background discrimination using acoustics**
- ✓ The ability to **suppress neutron backgrounds** by having the radioactively impure detection elements far from the active volume and by using the **self-shielding of a large device** and the high granularity **to identify multiple bubbles**
- ✓ The ability to build **large chambers cheaply** and with a **choice of target fluids**
- ✓ **Sensitivity to spin-dependent and spin-independent WIMP couplings**

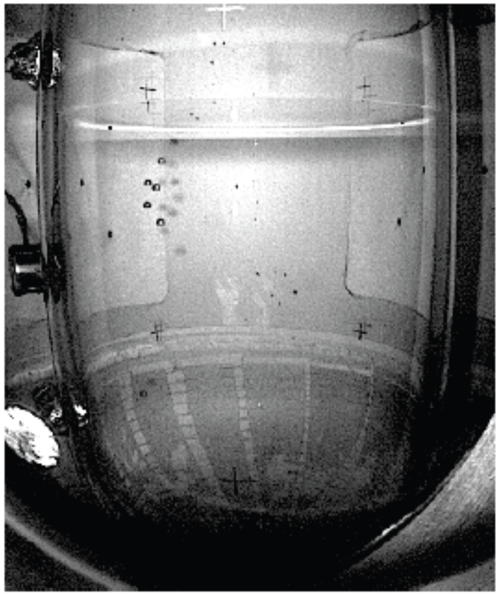
- **Not possible to measure the recoil energy** but **able to play** with the **threshold energy**

COUPP. The Program

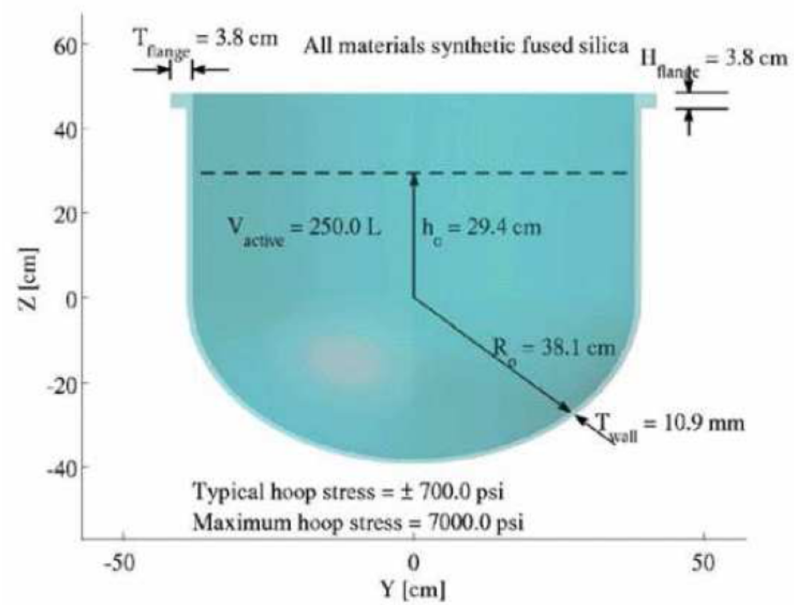
- COUPP-4: A 2-liter chamber, at SNOLAB since September 2010
- COUPP-60: A 30-liter chamber, commissioned at Fermilab and being installed at SNOLAB
- COUPP-500: 500 kg Chamber. Proposal accepted, R&D program funded by NSF



COUPP-4



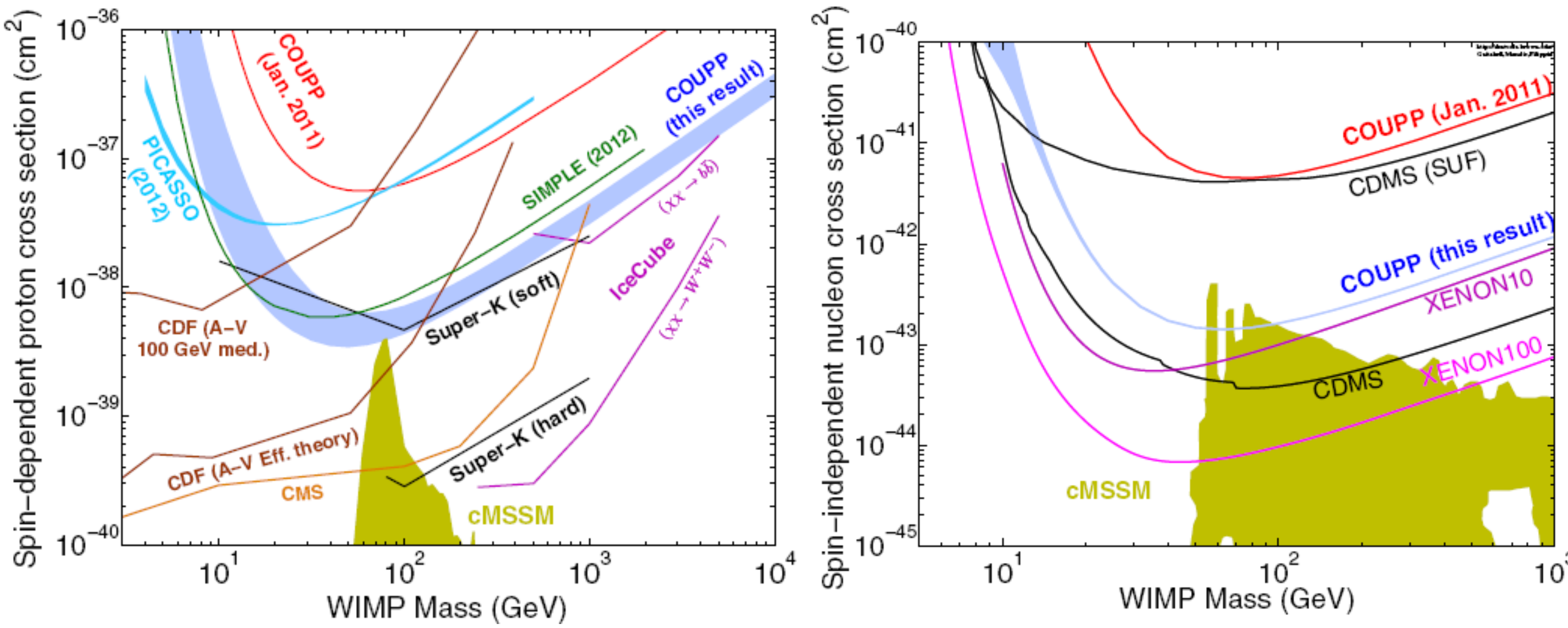
COUPP-60



COUPP-500

4 kg bubble chamber status and results

- Results published: "First dark matter search results from a 4-kg CF3I bubble chamber operated in a deep underground site", Physical Rev. D 86, 052001 (2012)
  - ➢ Leading Spin Dependent limits

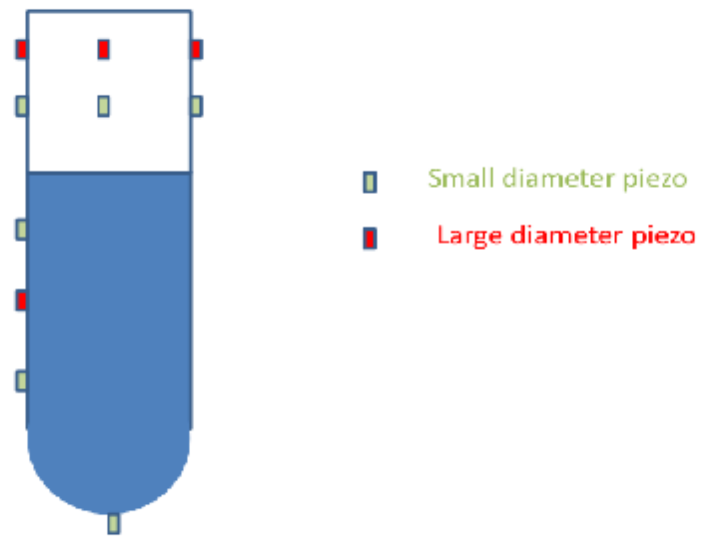


- Now: new SNOLAB run with an improved 4kg bubble chamber (low background piezo-transducers)

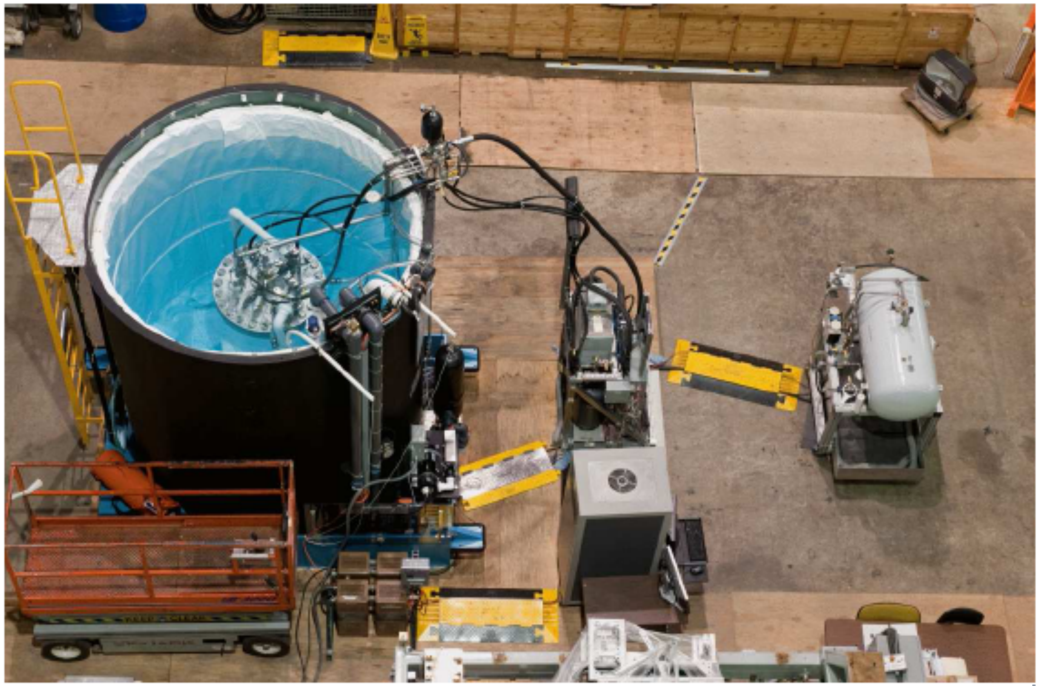
60 kg bubble chamber status

- Installation is going on at Snolab.
- Physics Runs to start in a few months
- New piezo transducers are being implemented.
- Piezo receivers with different radius installed in several places of the bubble chamber

Proposed locations for transducers on 60 kg device



UPV has studied the efficiency of the acoustic receiver depending on its location:
- Acoustic transmission between different layers fluid-fluid & fluid-solid interfaces



500 kg bubble chamber status

COUPP-500kg is the following target:

- a tonne scale detector
- spin-independent sensitivity: $9 \times 10^{-47}cm^2$ (background-free year running)
- inexpensive and versatile
- Funded by NSF
- Design: 2012-13, Construction: 2013-15, Ready for physics in 2016

UPV involved in the design and optimization of the acoustic system to be used in COUPP-500.

UPV (Multidark) participation in COUPP

UPV participates mainly in the **Acoustic Activities**

- **Understanding** of the acoustic signal generation, propagation in the chamber, and detection in the acoustic sensors
  - **Simulations** of the different processes: using finite elements methods (COMSOL), and transducer models
  - **4 kg Data** can be used **to validate** simulations
  - **Acoustic** Bubble Chamber **test bench** is being developed **in UPV**
  - From this, we hope to be able to optimize the acoustic technique, especially for larger chambers, hoping to **maintaining the quality in the alpha rejection, and using acoustics for triggering and WIMP detection**.
- **Optimization** of the acoustic setups:
  - **60 kg: short time** for decisions (a few months) **but critical decisions**: number of piezos and locations to have a very good discrimination and tolerable background. **We made some studies to deal with this.**
  - **500 kg: Full design** of the acoustic system (type of sensors, size, number and locations, signal processing, etc.)

CAST-IAXO

Axion motivation (conventional)

- Axions are the **most compelling solution to the Strong CP problem** (why strong interactions seem not to violate CP?)

- Axion-like particles (ALPs) **predicted by many extensions** of the SM.
- Axions, like WIMPs, may **solve the DM problem** *for free*. (i.e. not *ad hoc* solution to DM)
  - Axions are produced in the early Universe by a number of processes (both cold and hot DM)
- Relevany axion/ALP parameter space at **reach of current and near-future experiments!**
  - Haloscopes (ADMX in US). Helioscopes (CAST → IAXO)

Axion motivation (new/growing)

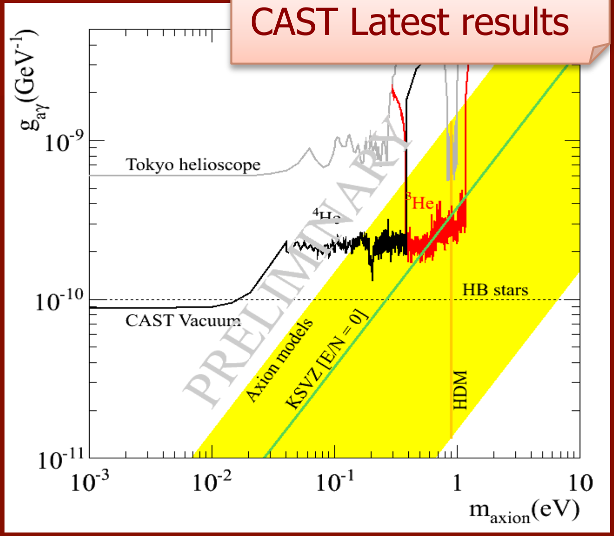
- New theory scenarios for axions/ALPS: (**string theory** predicts them with detectable parameters)
- **Astrophysical hints** for axion/ALPs?
  - Transparency of the Universe to UHE gammas
  - White dwarfs anomalous cooling → point to few meV axions
- Cosmological preference for axions vs. WIMPs (more speculative)
  - Axion DM would be a BEC → Caustic rings in the gal. halo

- **No sign of WIMPs in direct detection** experiment (after 4 orders of magnitude improvement in the last decate)
- **No signs of SUSY at LHC**
- Not justified experimental efforts unbalance towards WIMPs

CAST experiment @ CERN

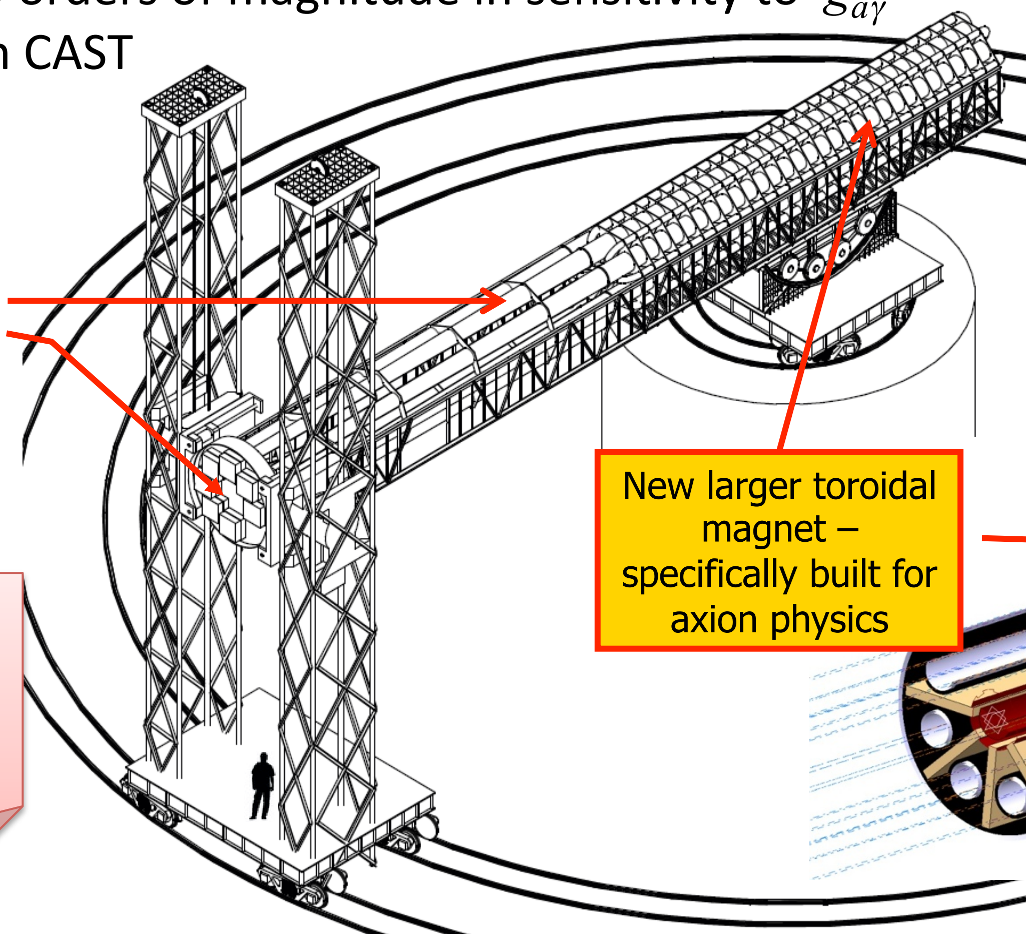
- CAST is the most powerful implementation of an axion helioscope
  - CAST phase II: inserting gas (^4He, ^3He) inside the magnet bores to gain sensitivity to high axion masses
- CAST is sensitive to QCD axions at the 0.1-1 eV scale
- Innovations: x-ray optics, low background techniques

CAST Latest results

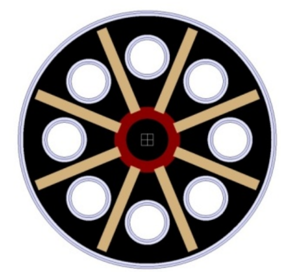


International Axion Observatory (IAXO)

- Towards a new generation axion helioscope
- Conceptual Design Report and **Letter of Intent** to CERN in preparation.
- **Goal**: 1-1.5 orders of magnitude in sensitivity to $g_{a\gamma}$ better than CAST

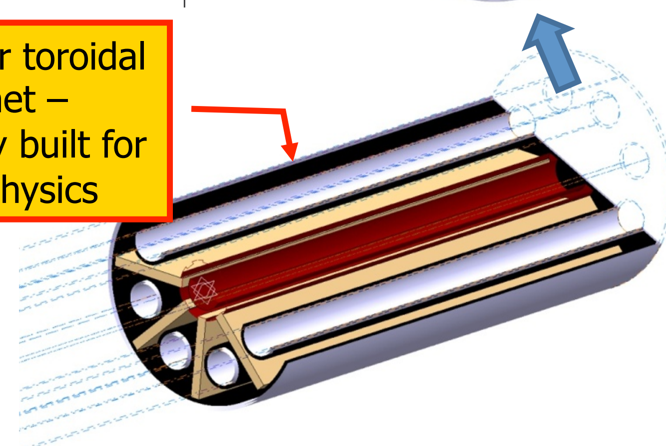


Each conversion bore (between coils) about 0.5-1 m diameter



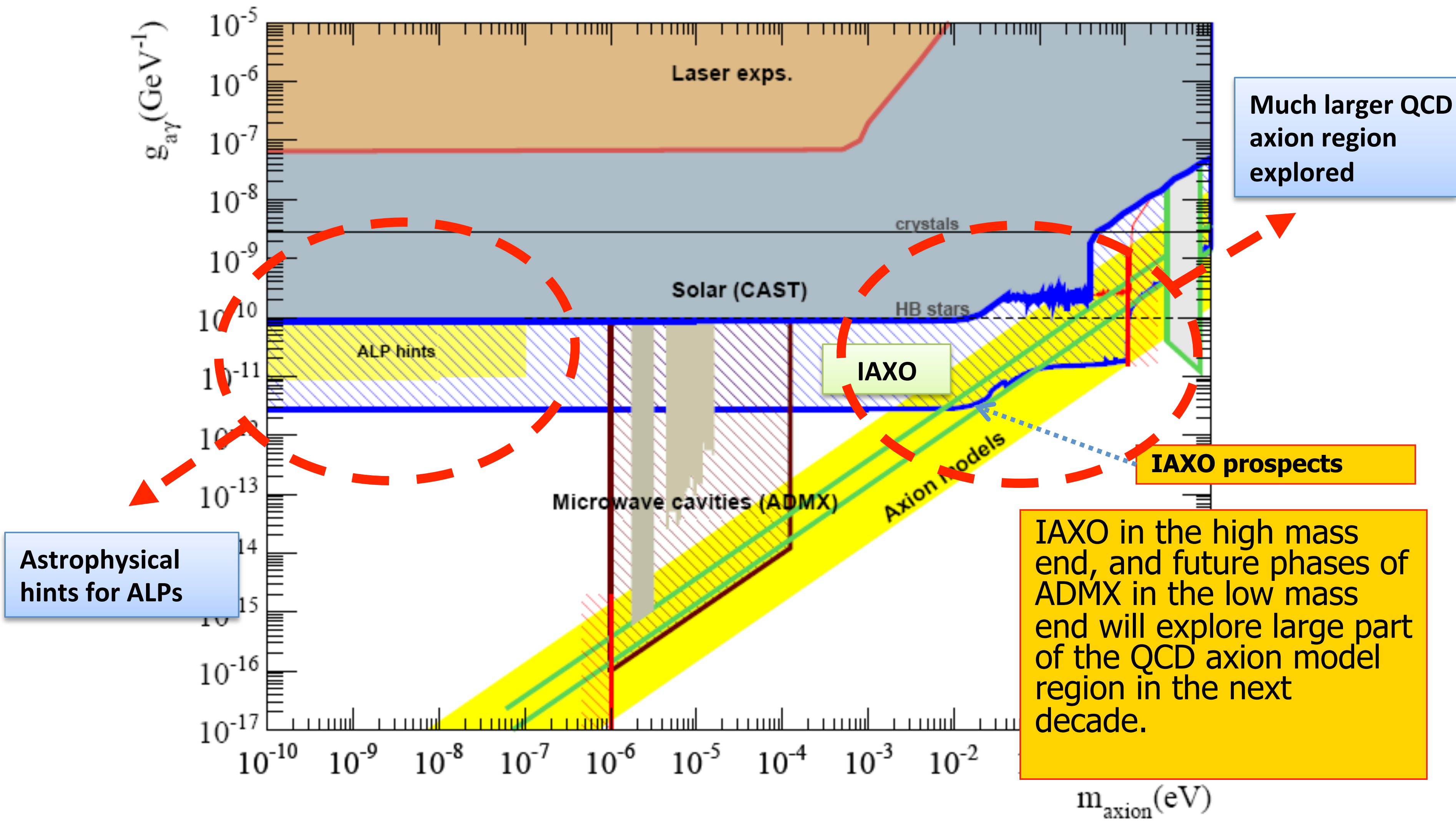
All bores equiped with x-ray focusing and low bkg detectors
-
Fully exploiting innovations of CAST

New larger toroidal magnet – specifically built for axion physics



First feasibility results and sensitivity prospects recently published:
JCAP 1106:013,2011
(arxiv:1103.5334)

Axion searches: mid-term prospects



Committees and Roadmaps

- **CAST** near term program (including pathfinder projects for IAXO) has been recently **approved** by CERN SPSC
- **IAXO LoI** towards CERN under preparation
- **ASPERA Roadmap** acknowledges axion physics, CAST, and **recommends** progress towards IAXO.

> "...A CAST follow-up is discussed as part of CERN's physics landscape (new magnets, new cryogenic and X-ray devices). The Science Advisory Committee **supports** R&D on this follow up, as well as smaller ongoing activities on the search for axions and axion-like particles."

C. Spiering, ESPP Krakow

- Growing presence of axion searches in the **European Strategy for Particle Physics** and in **US roadmappint exercises** (Intensity Frontier, Vistas on Axions)