The Canfranc Laboratory: a multidisciplinary underground facility and the search for Dark Matter and Double Beta Decay

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Outline

- Introduction
  - Underground Laboratories
  - Canfranc Laboratory

- Dark Matter search at Canfranc

- Double Beta Decay search at Canfranc
  (by JJ Gomez-Cadenas)

Early History of Underground Laboratories

- In **1965** first atmospheric neutrinos observed (horizontal muon induced) in very deep locations (mines) in India (2700m) and South Africa (3200m)
- **1966** Baksan Neutrino Observatory with first horizontal access in the Caucasus
- **1968** Homestake, USA, first solar neutrino observation
- **1983** Kamioka Underground Laboratory with horizontal access
- **1987** LNGS with horizontal access. Largest underground facility in this framework

Characterizing an underground laboratory [1]

We are referring to **D**eep **U**nderground **L**aboratories

- **Access**
  - Horizontal (LNGS, Kamika, Canfranc) or vertical (SNOlab, SURF)
- **Muons flux**
  - Depends on depth at present change between 10^{-3} $m^{-2}s^{-1}$ at LNGS, Kamioka, Canfranc to 10^{-6} $m^{-2}s^{-1}$ at SNOlab and CJPL (China)
- **Radiogenic neutrons**
  - For DULs does not depend on depth but on local geology and concrete or other material used for lining, usually of order 10^{-2} $m^{-2}s^{-1}$
  - Energy range < 10 MeV

Characterizing an underground laboratory [2]

- **High energy neutrons (cosmogenic)**
  - Induced by muons, flux depends on depth
  - high energy >> 10 MeV
  - Flux is usually a factor of 10 or larger smaller than for radiogenic neutrons

- **Gamma background**
  - Flux depends on local geology and underground environment (radon level …)
  - Usually in DULs of order 10^4 $m^{-2}s^{-1}$

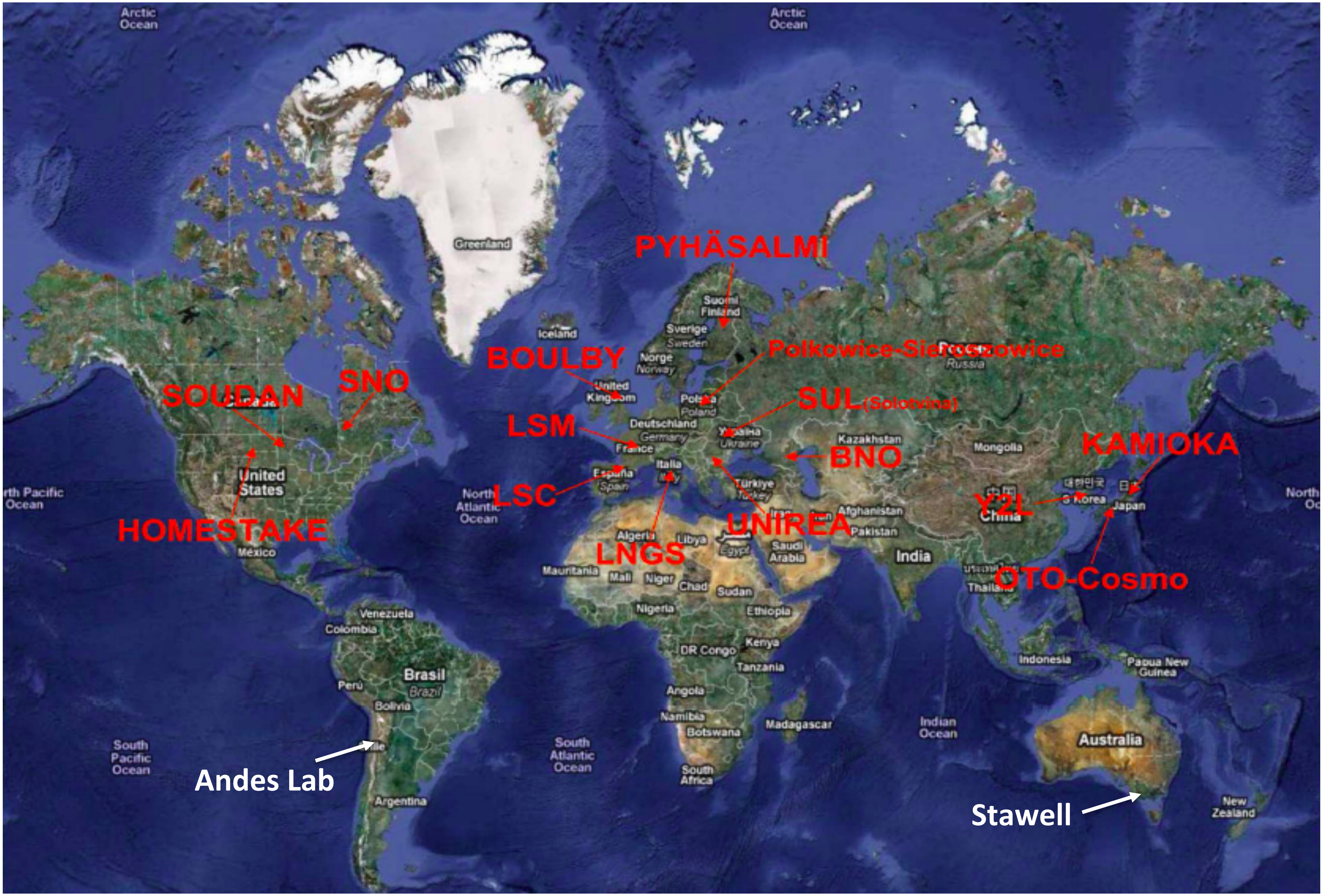
Characterizing an underground laboratory [3]

- **Radon**
  - Does not depends on depth but on local geology and underground infrastructure
  - In DULs of order 50 - 100 Bq/m^3
  - Possible seasonal dependence
  - In specific equipment can be very much reduced
- **Stability of underground environment**
  - Monitoring convergence in underground excavated area
  - Usually not done

Research activities in DULs

- **Neutrinos**: atmospheric, solar, geo, supernova, reactor, beam
- **Dark Matter**: direct detection
- **Double beta decay**
- **Rare processes** (nucleon decay, e-decay, …)
- **Geophysics** (monitoring local and teleseismic events)
- **Biology**: Life in extreme environment

Most Known DULs

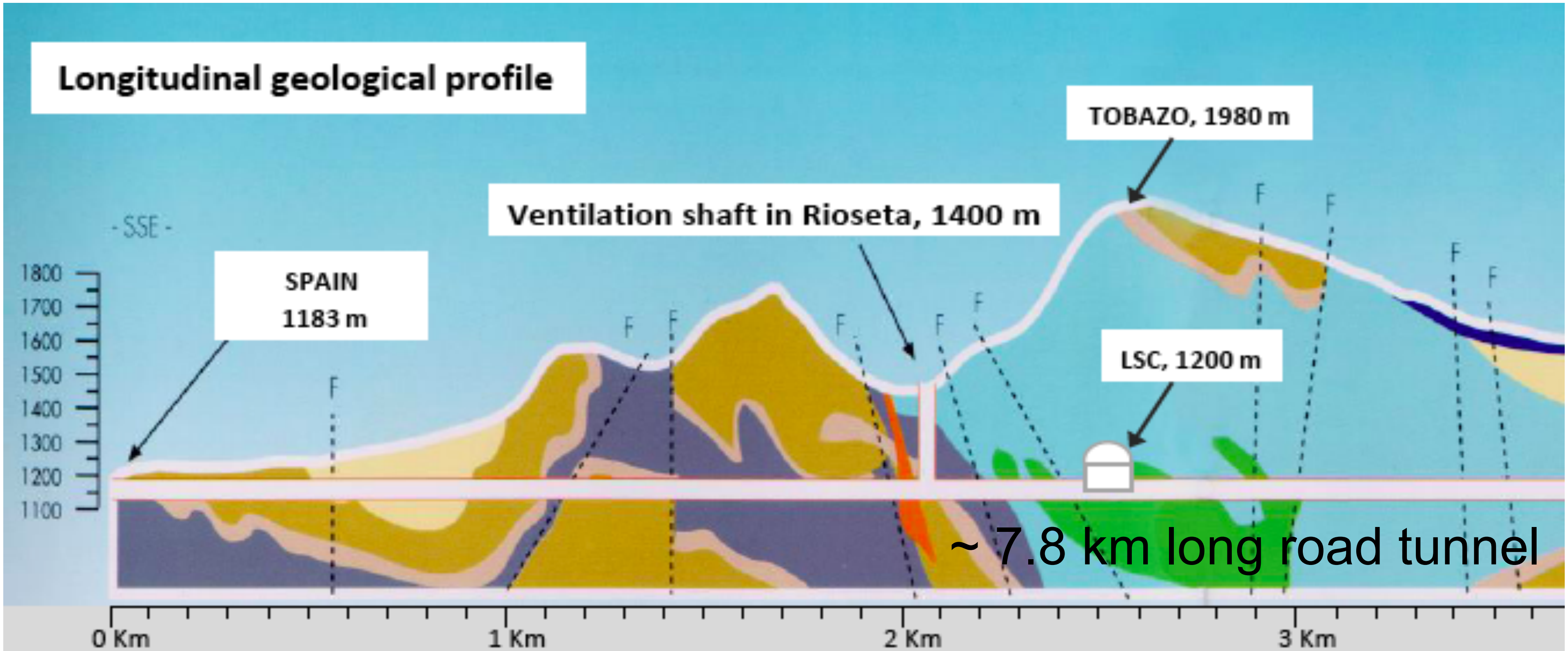


European DULs geography

Canfranc Laboratory

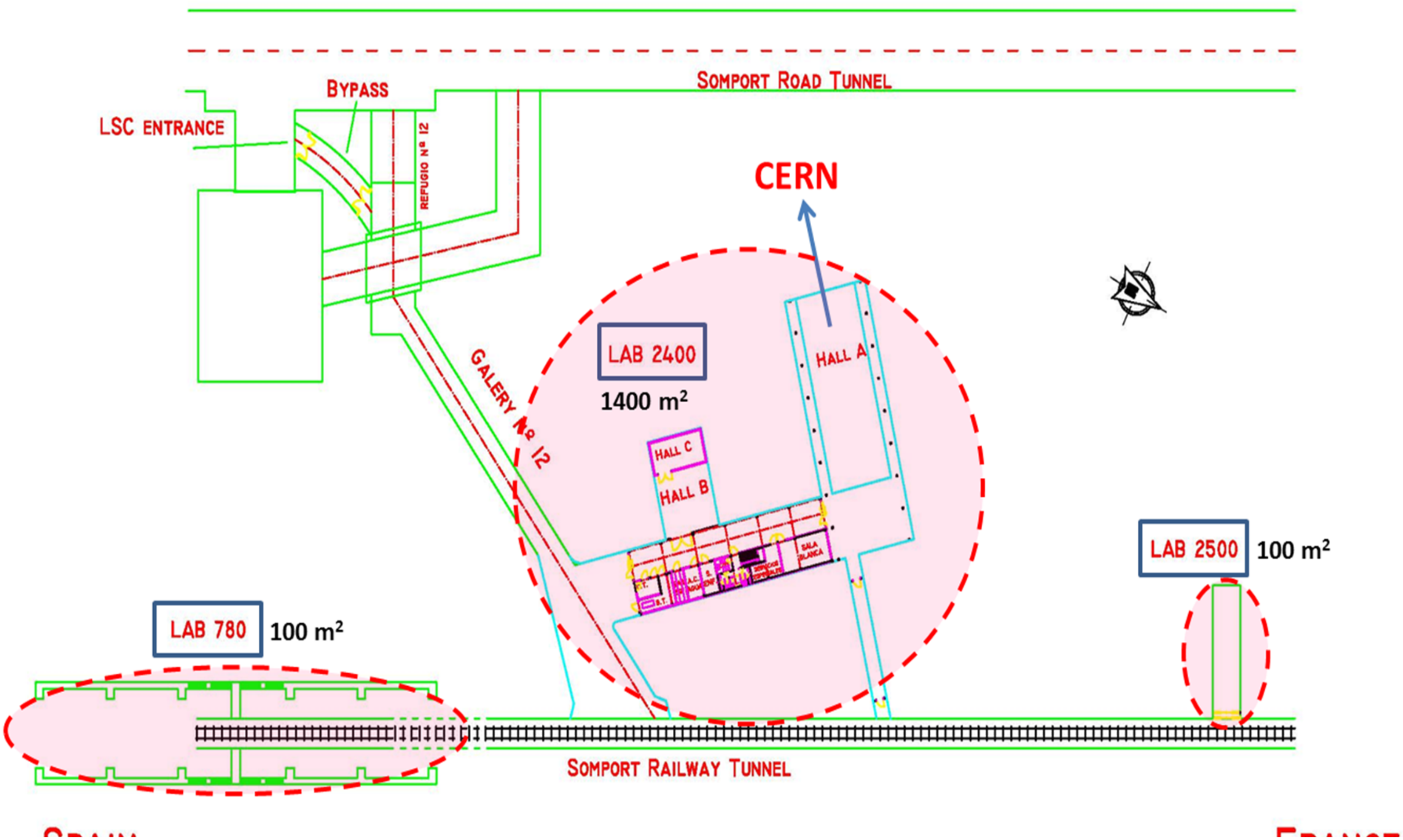
- **1985**, Angel Morales and collaborators from the University of Zaragoza started using abandoned space in the train tunnel
- **1994**, during the excavation of the road tunnel a cavity of 118 m^2 was made for research activities: LAB2500
- **2006**, a large excavation of 1600 m^2 is done: LAB2400. **Canfranc becomes an international research infrastructure**

LSC Mountain Profile



850 m under mount Tobazo (~ 2500 m.w.e)
Muon flux ~ 4×10^{-3} m^{-2} s^{-1}
Inlet air flux ~ 20000 m^3/h
Radon level 50 - 80 Bq/m^3
Neutron (<10 MeV) ~ 3.5×10^{-6} n/(cm^2 s)
Gamma rays flux ~ 2/(cm^2 s)

LSC Underground Layout



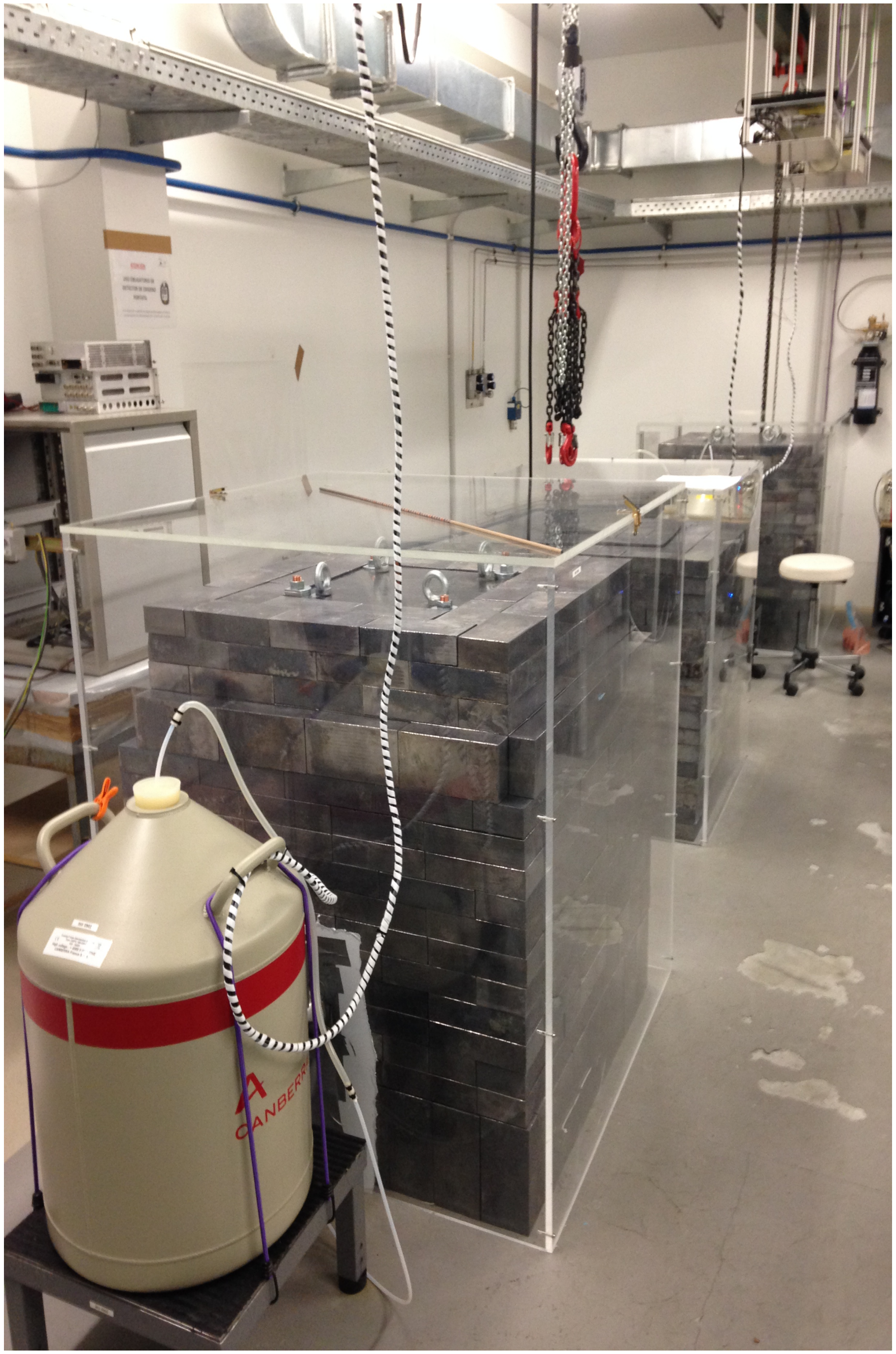
LSC Service Facilities

- **Screening** HpGe underground laboratory
  - high purity germanium γ-spectrometers
  - Integral sensitivity of counters < 3 MeV ~ mBq/kg
  - SAGe well detector being installed
  - This facility used by SuperKGd to select Gd salt for SuperKamiokande with $Gd_2(SO_4)_3$
- **Underground Clean room**
- **Radon abatement system** (being installed)
- **Chemistry laboratory**
  - Electroforming of copper, support for sample preparation, ICP-MS (in 2016)
- **Workshop (on surface and underground)**
- **Computing**

Low radioactivity facility @ LSC

- Equipped with 7 HpGe (p-type), 1 SAGe well
- Proportional counter α/β
- Alpha spectrometer (2016)
- NaI 3” x 3”
- 4 AlphaGuard for Rn monitoring
- Rn detector at mBq/m^3 (2016)
- Screening of materials for experiments at LSC and for external users (request reviewed by an internal Committee)

Detector	100-2700 keV background	583 keV	609 keV	1460 keV
GeOroel	148±1 cpd	0.553 ±0.016	2.385±0.063	0.418±0.029
GeTobazo	436±2	3.941±0.004	2.816±0.044	0.545±0.010
GeLatuca	314±2	4.175±0.008	3.916±0.085	0.973±0.020
GeAspe	433±1	4.191±0.005	3.316±0.051	0.760±0.017




INDUSTRIAS AJUSCAL, S.L.
Tlfno 976 790 610
10 Tm

Experiments @ LSC

✓ **ANAIS**	DarkMater (NaI(Tl), Annual modulation -	operational)
✓ ROSEBUD	DarkMatter (Scintill. Bolometers –	stopped)
✓ **ArDM**	DarkMatter (2phase LAr TPC –	operational)
✓ **NEXT**	$0\nu2\beta$ (Enr ^{136}Xe gas TPC – demonstrator	commissioning)
✓ BiPo	$0\nu2\beta$ (specialized facility for SuperNEMO –	operational)
✓ Muons	cosmic rays monitoring underground	operational)
✓ SuperK-Gd	screening for SuperKamiokande-Gd –	operational)
✓ GEODYN	Geodynamics –	operational)

Expressions of Interest under review

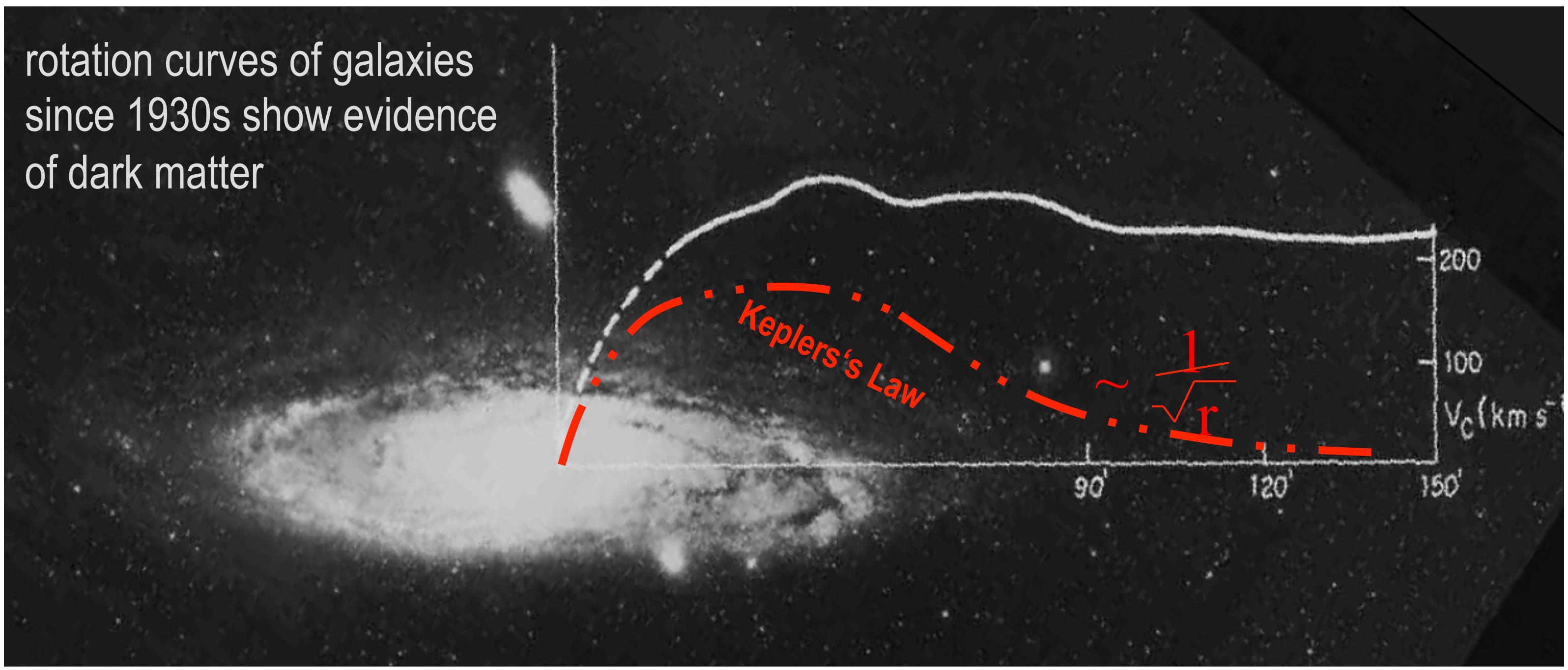
✓CUNA Nuclear astrophysics

✓New 300 m^2 facility feasibility study

✓GOLLUM deep-life: characterising subterranean bacterial

The Search for Dark Matter in DULs

Dark Matter in Galaxies



Energy density associated to dark matter in galaxies:

$$\Omega_{Mat} > \Omega_{Lum} \approx 0.01$$

Evidence of Dark Matter

- Galaxies **rotation curves**: $\Omega_{halo} \sim 10\Omega_{stars}$ **(Ω_{matter}>0.1)**
- **Clusters**: galaxy motion, gravitational lensing: **Ω_{matter}~0.2-0.3**
- **CMB anisotropy**: **Ω_{matter}~0.27**, $\Omega_{baryons}$~0.04
  - ~84% of mass in the Universe dark and non-baryonic
  - $<\rho_{DM}> \sim 0.23\rho_{crit} \sim 10^{-6}$ GeV/cm^3
  - around our Sun: $\rho_{DM} \sim 0.3\text{-}0.4$ GeV/cm^3
- Using early universe nucleosynthesis: $\Omega_{baryons}$~0.04
- **Large Scale Structures**:
  - Formation of structures by gravitational clustering
  - Comparison of observations with non-relativistic (cold) dark matter clustering agree well

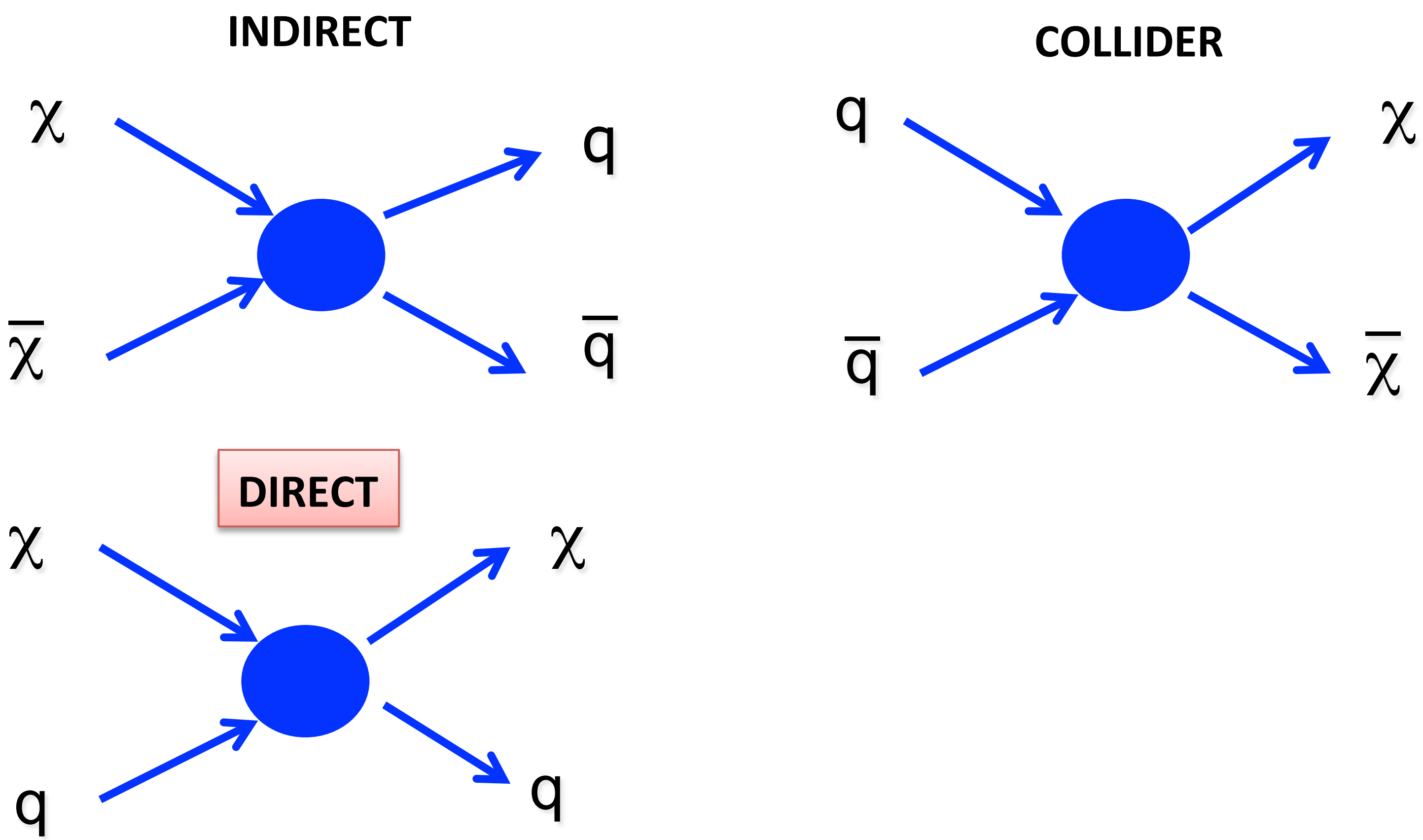
What Dark Matter is made of?

- One possible scenario: dark matter made of Weakly Interacting Massive Particles (WIMPs)

- WIMPs are a general class of weakly interacting massive (1GeV – 10 TeV) particles not from the Standard Model

- Assuming thermal equilibrium in the early Universe and non-relativistic decoupling, the energy density for these relic particles is predicted to be:
  - **$\Omega_\chi \sim 0.2$ for $\sigma \sim 10^{-36} cm^2$**

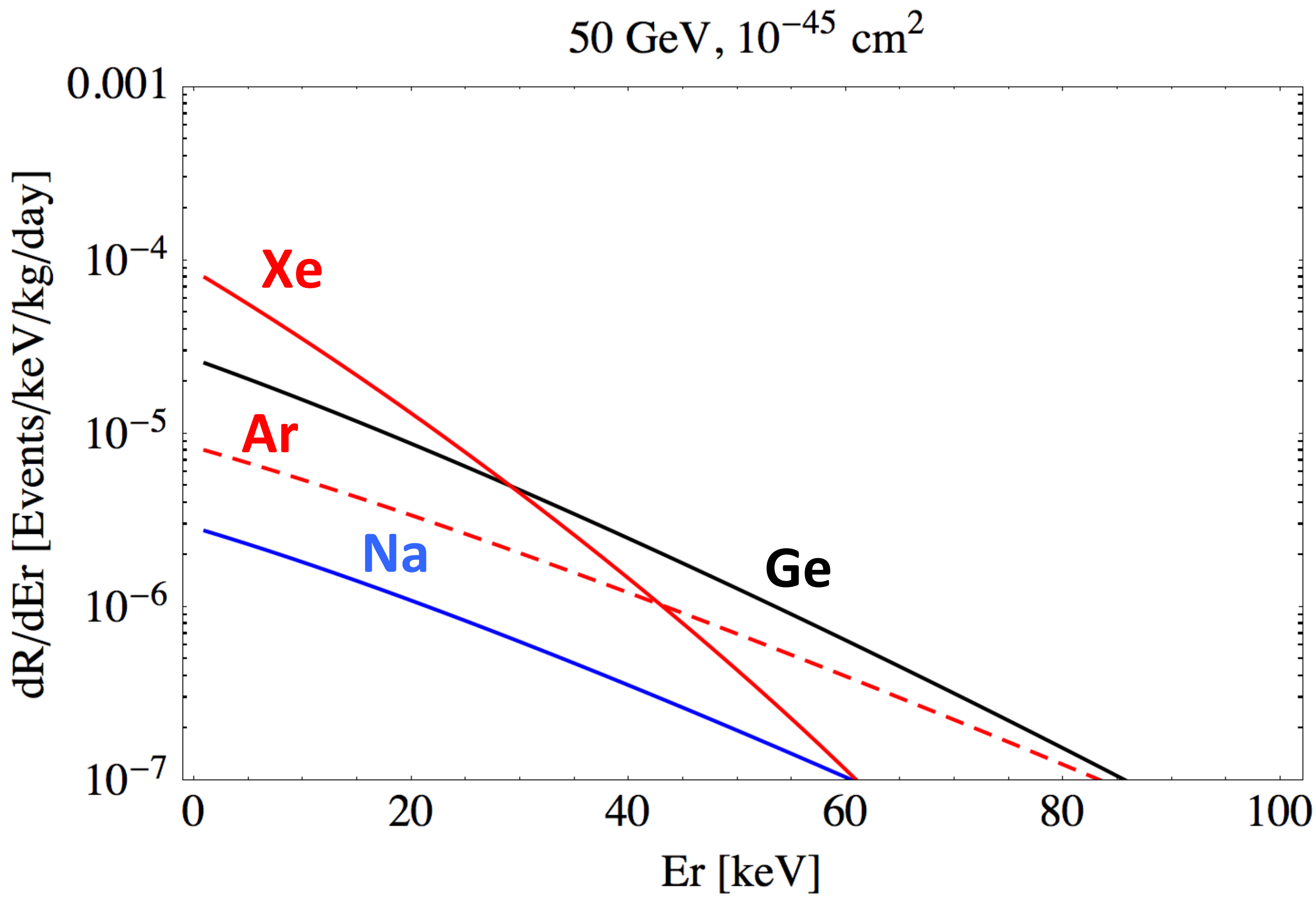
Dark Matter Searches



Remarks on expected WIMP signal

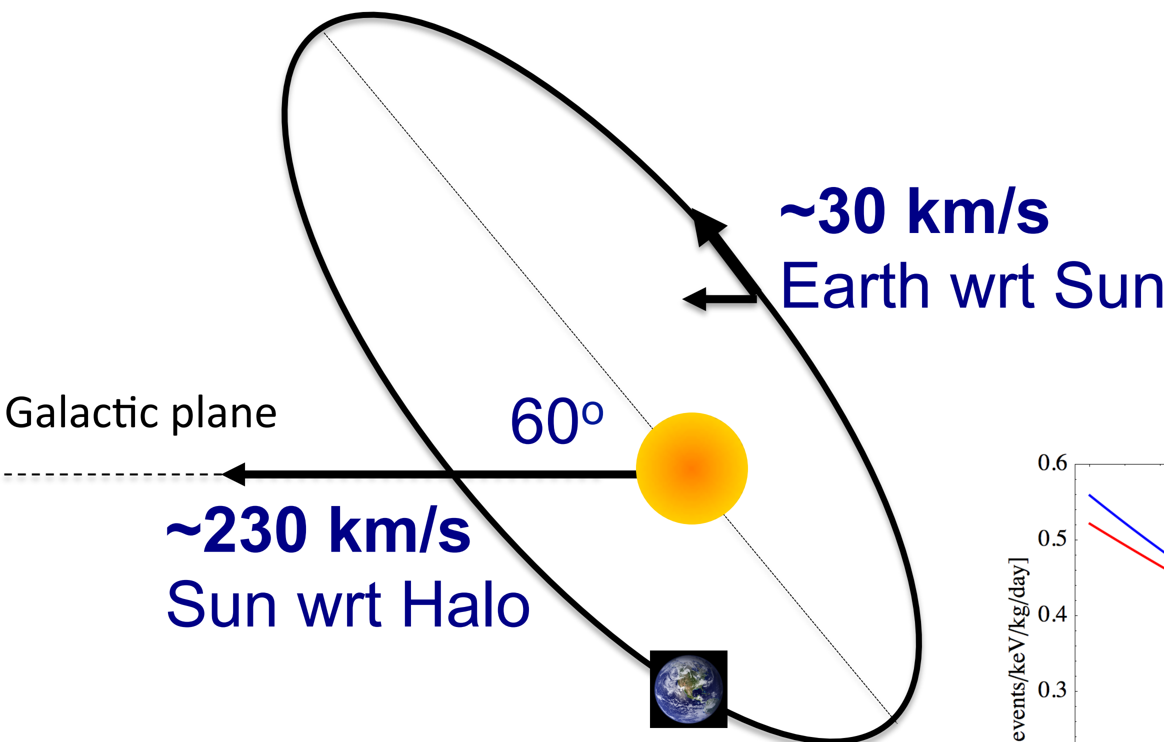
- No specific feature
- Low nuclear recoil energy (< 100 keV)
- few events for 1 ton-year exposure at 10^{-47} cm^2
- **GOAL of WIMPs search**:
  - If Dark Matter is made of WIMPs we need:
    - Strong background suppression (below WIMPs interaction rate)
    - As low as possible sensitivity to WIMP-nucleon cross section

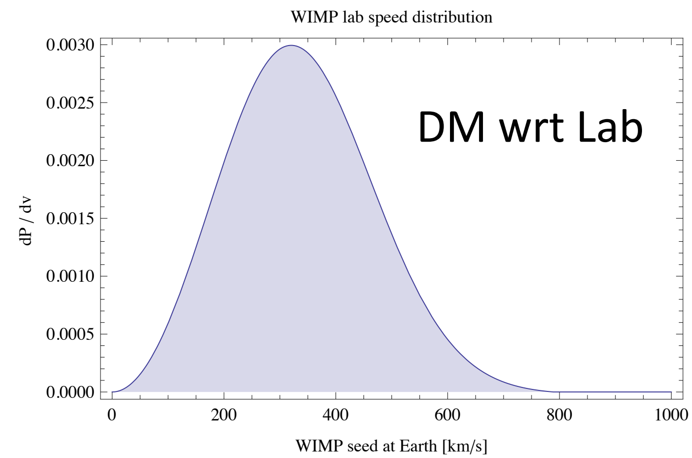
Recoil Spectrum

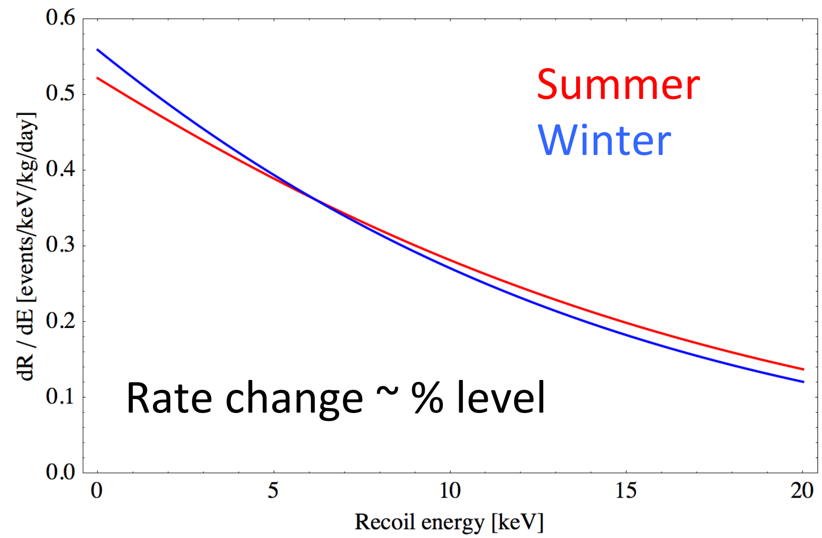


0.3 events/kg/year in Xe for 10^{-45} cm^2 and 50 GeV/c^2

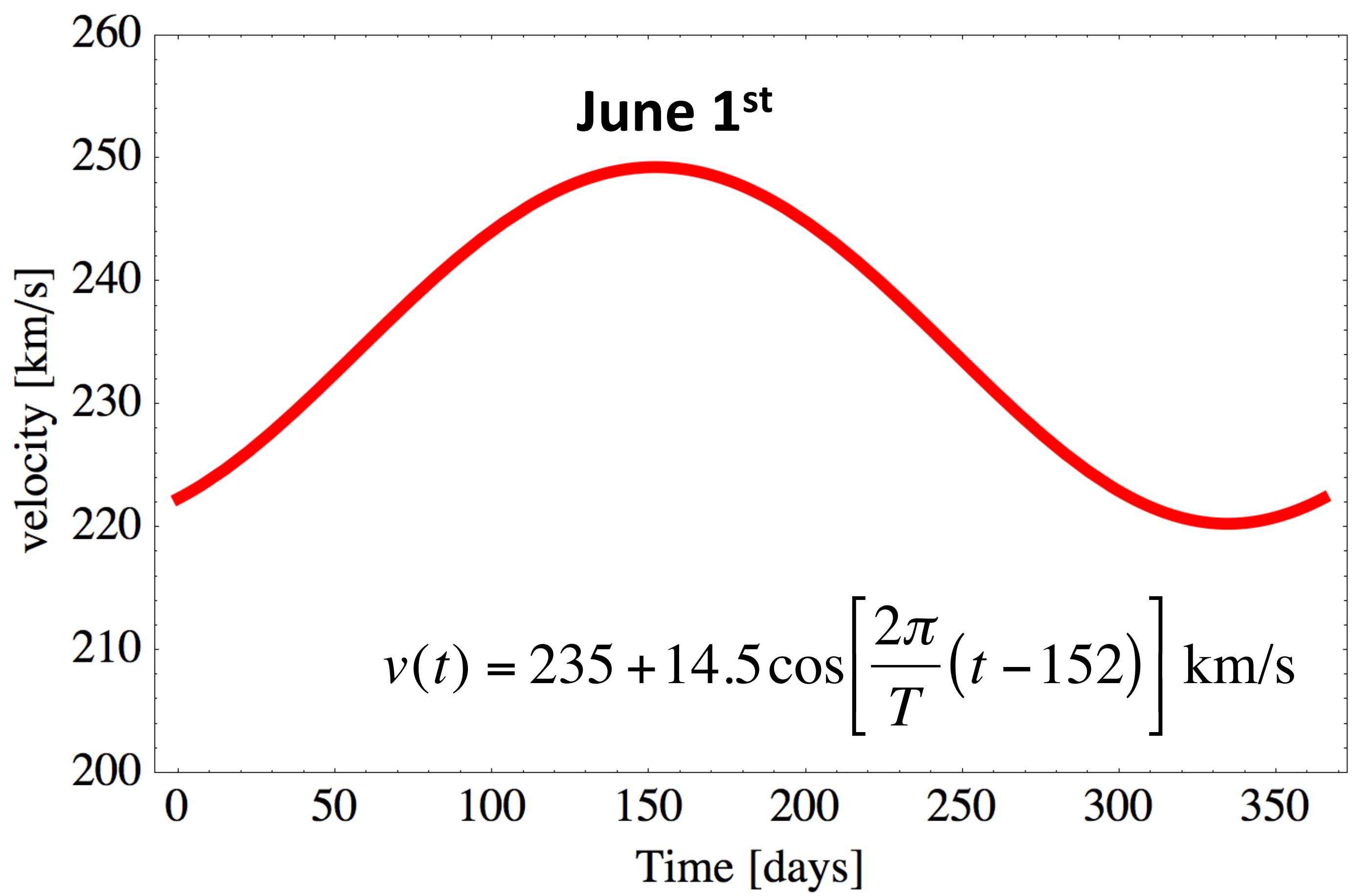
Dark Matter
Annual Modulation Signature







WIMPs Velocity relative to Earth

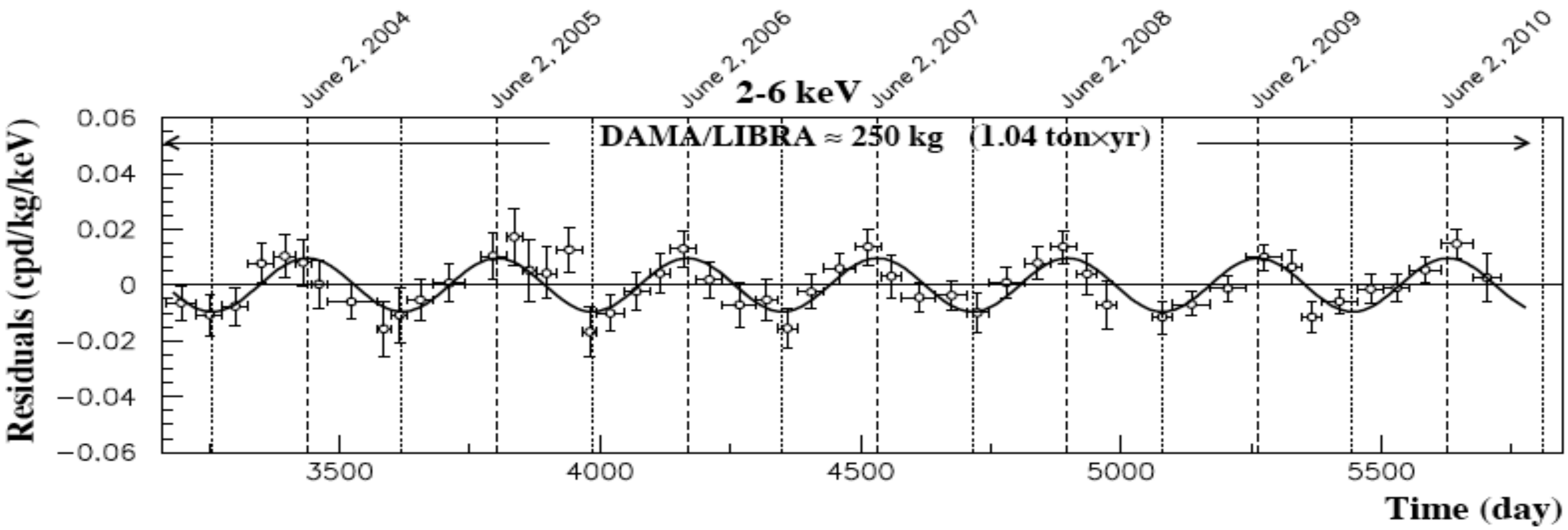


Flux of 100 GeV/c^2 WIMPs on Earth ~ 7×10^4 $cm^{-2}s^{-1}$

DAMA/LIBRA

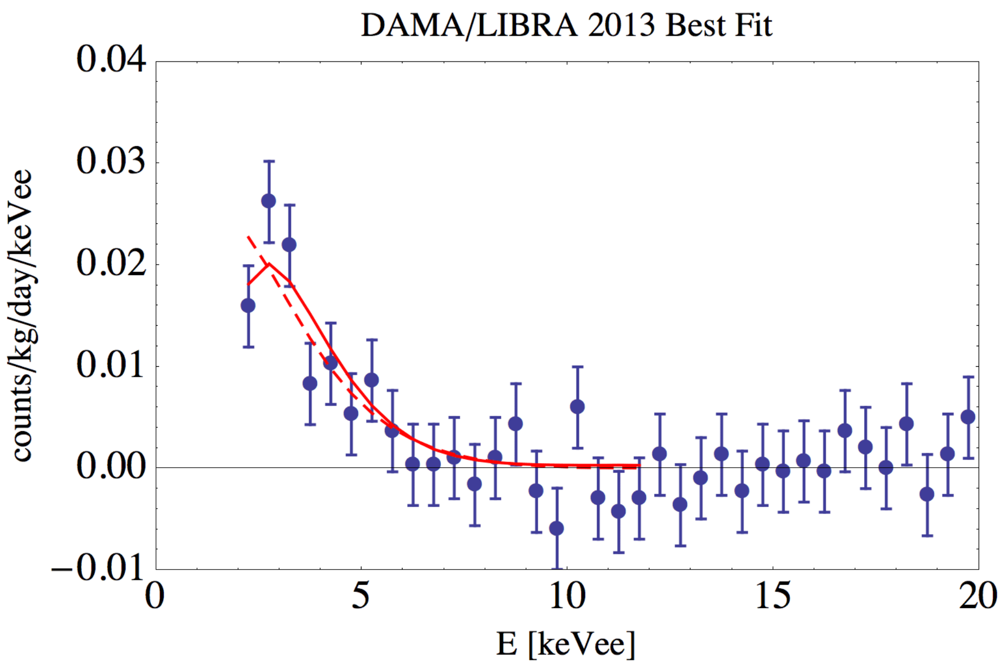
- **DAMA**
  - Low radioactivity 100 kg NaI array operated from 1996 to 2002 at Gran Sasso
  - Measures scintillation in crystal
  - No discrimination between ER and NR
  - 0.29 ton-year
  - Positive signal for annual modulation
- **LIBRA**
  - 250 kg NaI array operated since 2003
  - 1.04 ton-year
  - Positive signal for annual modulation

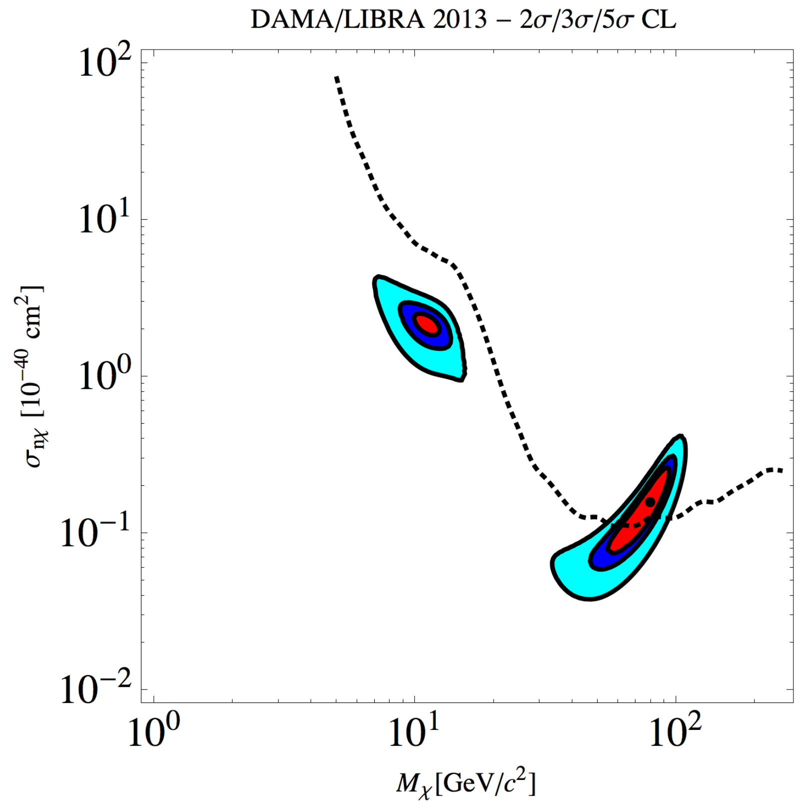
DAMA/LIBRA: results



- Modulation observed over **14 cycles**
- Cumulative exposure = **1.33 ton-year**
- Significance of modulation signal is **9.3σ**
- Modulation amplitude in [2,6]keV = 0.0112±0.0012 cpd/kg/keV
- Phase = 144±7 days
- Period = 0.998 ± 0.002 year

DAMA/LIBRA: WIMPs fit





Target	LY [pe/keV]	Threshold ER [pe/keV]	Threshold NR [keVr]	σ/E
NaI	5.5-7.5	2	6.7(Na) 22(I)	~7% at 60keV

The Challenge of DAMA/LIBRA

- It could be a model independent Dark Matter signal
  - MUST be tested by another experiment
- DAMA/LIBRA crystals have very low radioactivity
  - ^{40}K ~ 20 ppb
  - $^{210}Pb < 30\ \mu Bq/kg$
- "Standard" WIMP scenario does not fit DAMA/LIBRA together with other direct Dark Matter experiments (see later)
  - Is there an unknown systematics/background?
  - Are we missing something fundamental in the "standard" WIMP scenario?

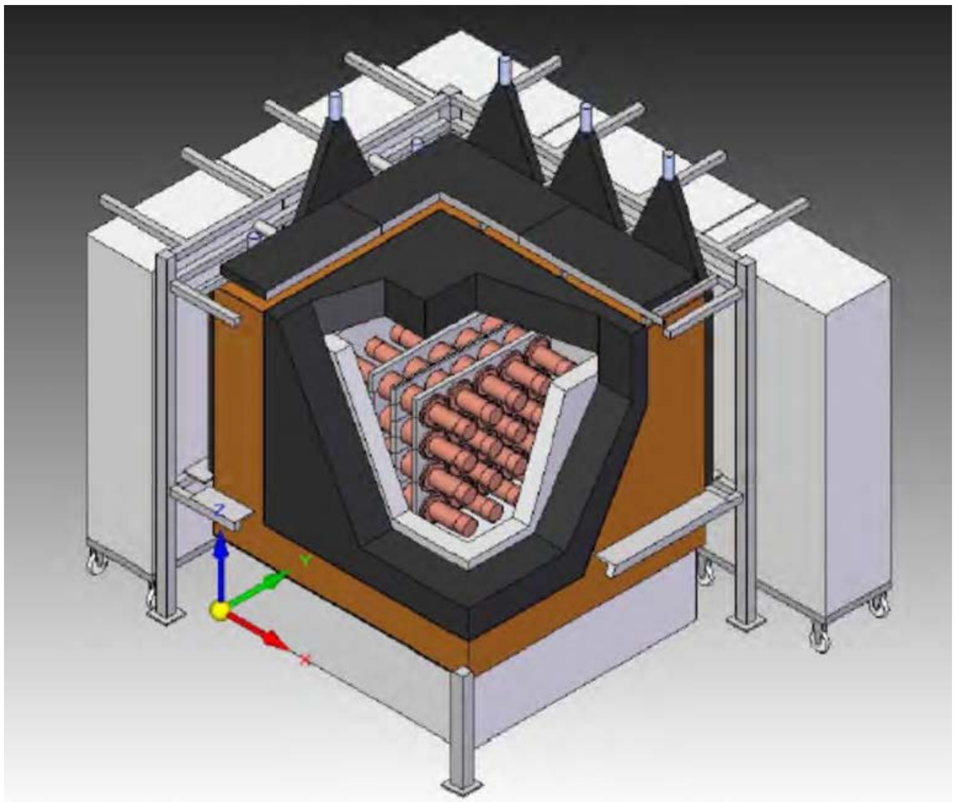
Direct Dark Matter Search at Canfranc

- **ANAIS**: array of high purity NaI(Tl) crystals to search for Dark Matter annual modulation (like in DAMA/LIBRA)
  - New 12.5 kg high purity crystal under measurement: **16.3±0.6 p.e./keV**
    - **1 keVee detection threshold feasible**
    - In 2016 will take data with 112 kg target mass

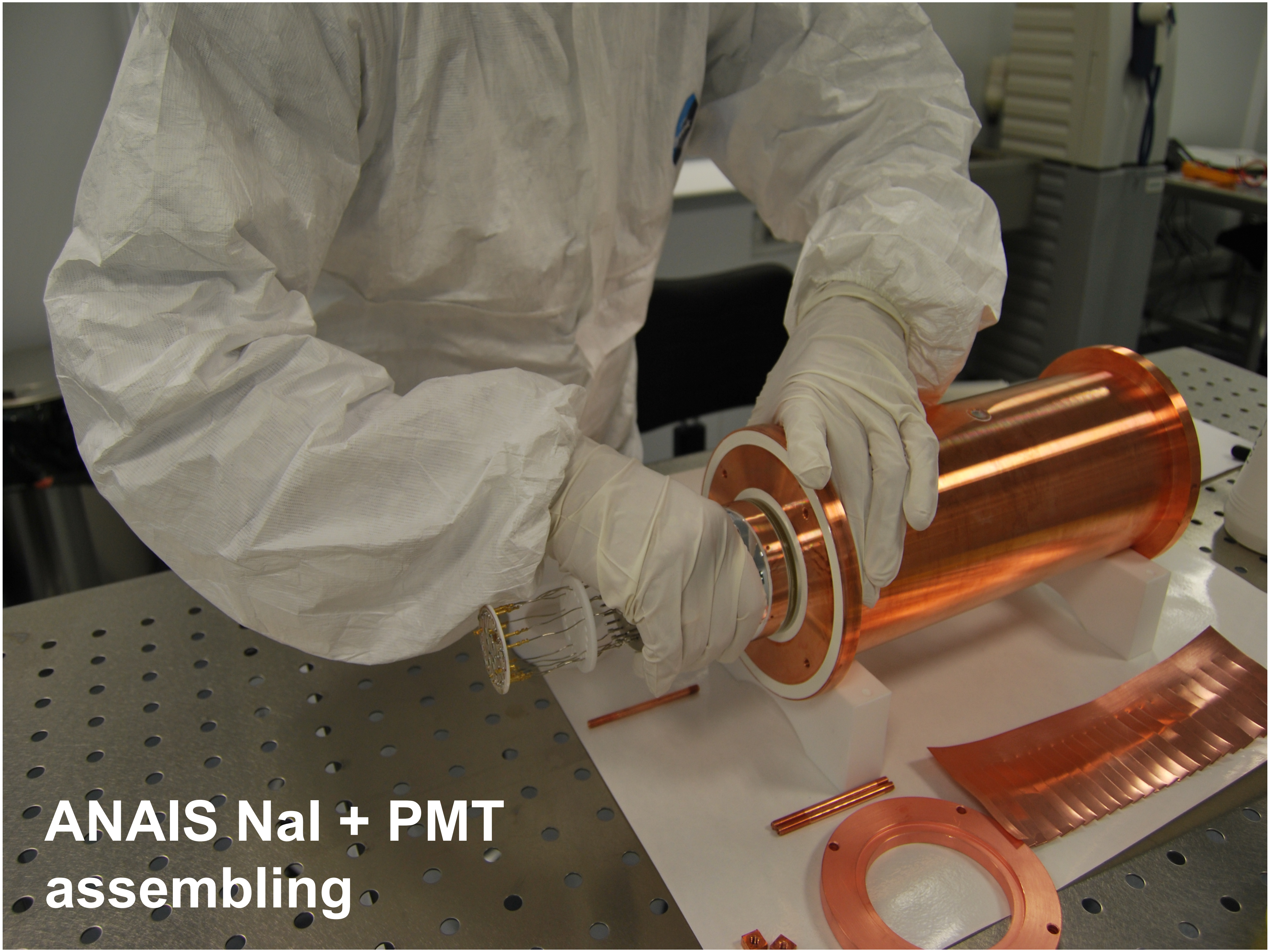
- **ArDM**: 2 tons of liquid argon for WIMPs detection in a two-phase TPC.
    - It has been in operation in single phase
    - At present upgrade to start two-phase operation mode

Direct Dark Matter Searches @ LSC

ANAIS NaI(Tl) crystals array
for annual modulation measurement



ArDM liquid argon TPC to
measure dark matter
induced nuclear recoils
(technology similar to DarkSide)

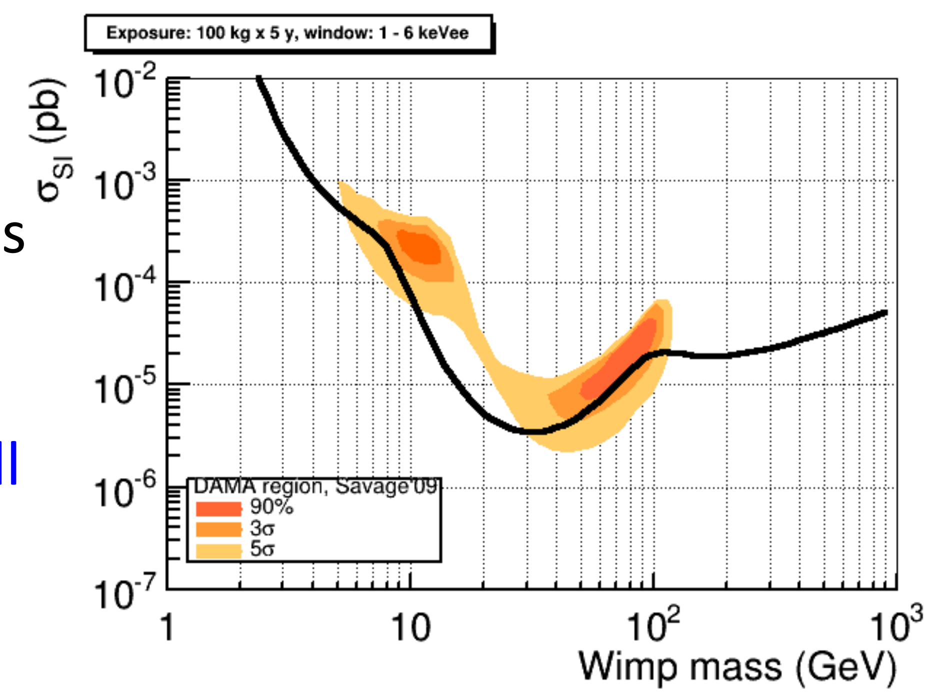

ANAIS NaI + PMT
assembling

ANAIS

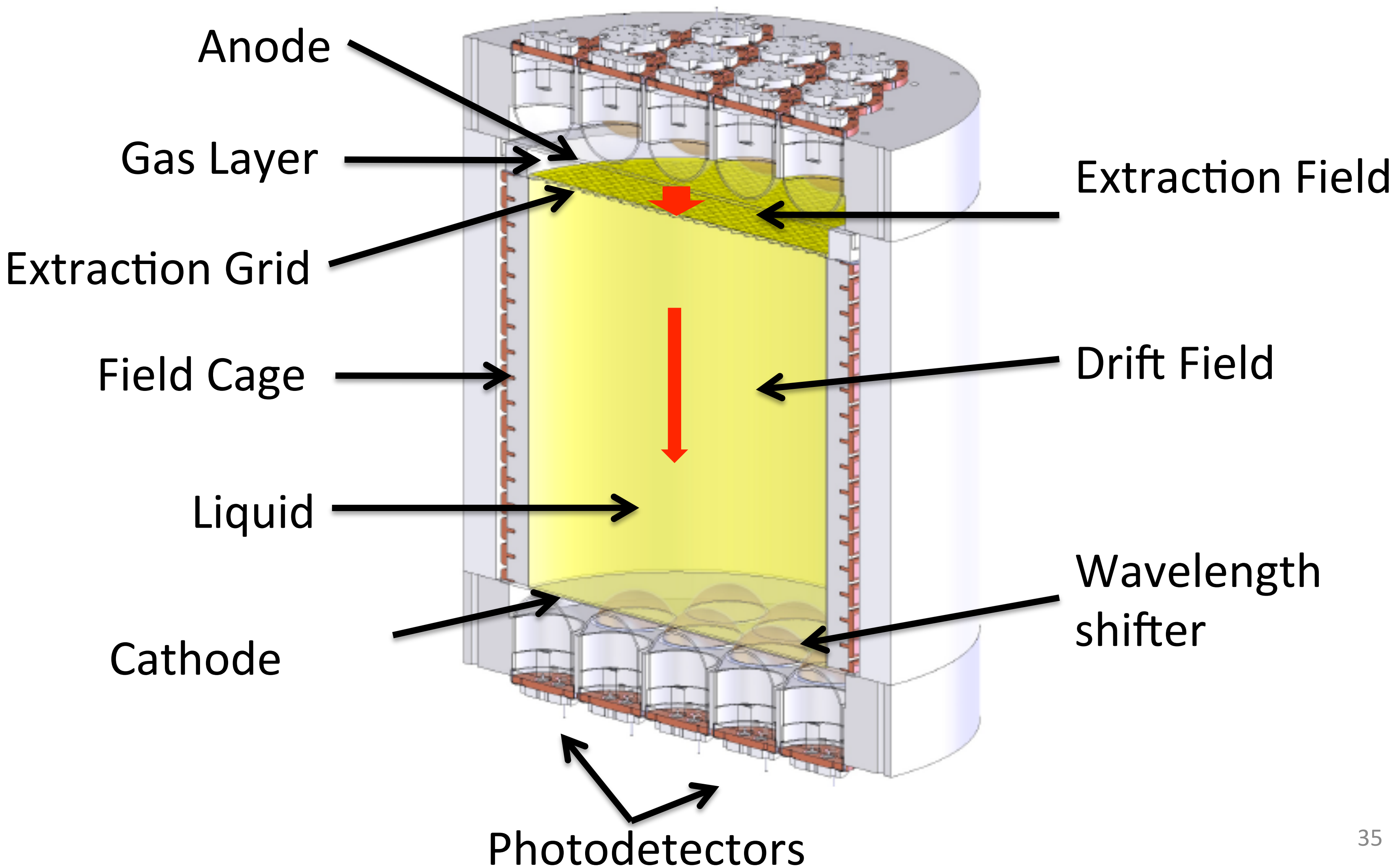
- DAMA/LIBRA signal must be tested by another set-up
- ANAIS will have 112kg of new NaI(Tl) crystals in 2016 in operation at LSC
- New crystals can operate from 1 keVe with 16 p.e./keVe

Expected sensitivity
vs DAMA/LIBRA allowed regions
in WIMPs hypothesis

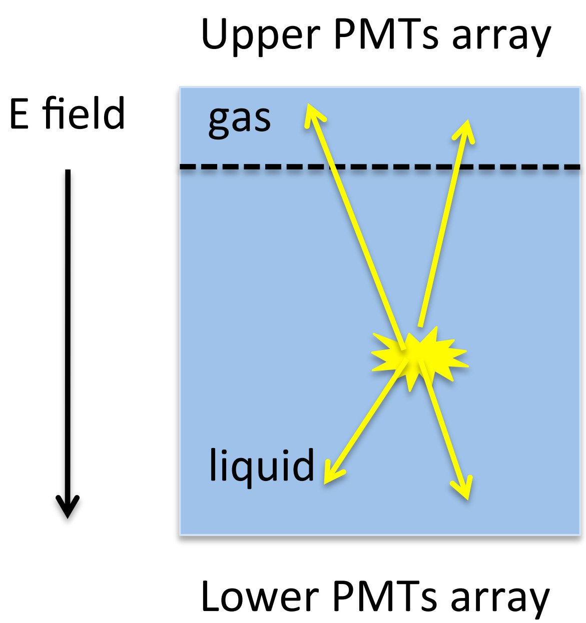
Total background in crystals still to be properly understood



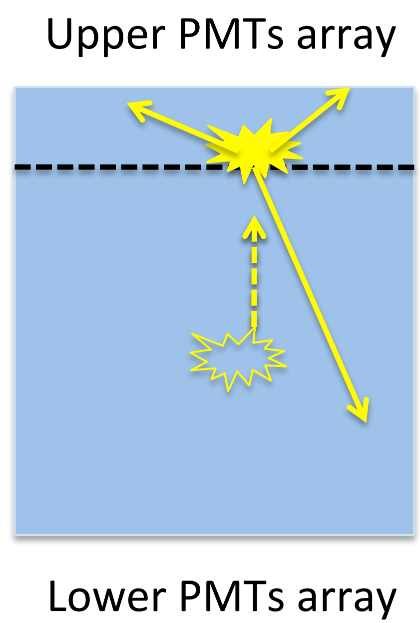
Double-Phase TPC



Two-phase TPC at Work: basic



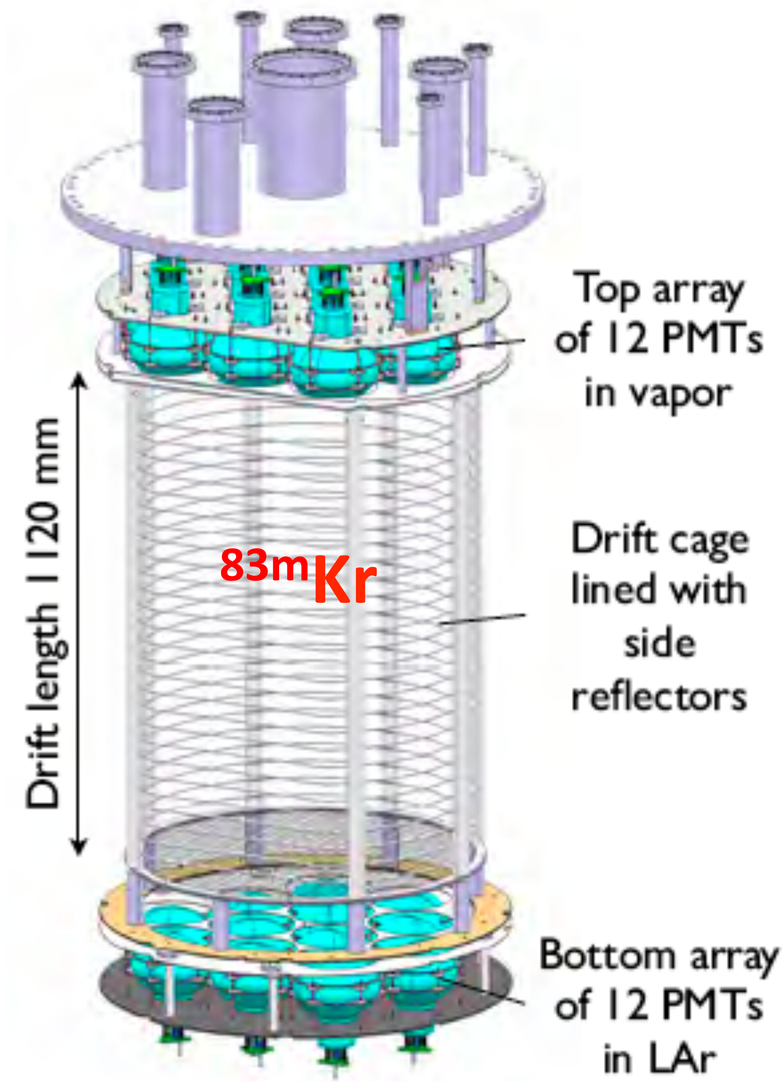
S1 prompt signal
from LAr



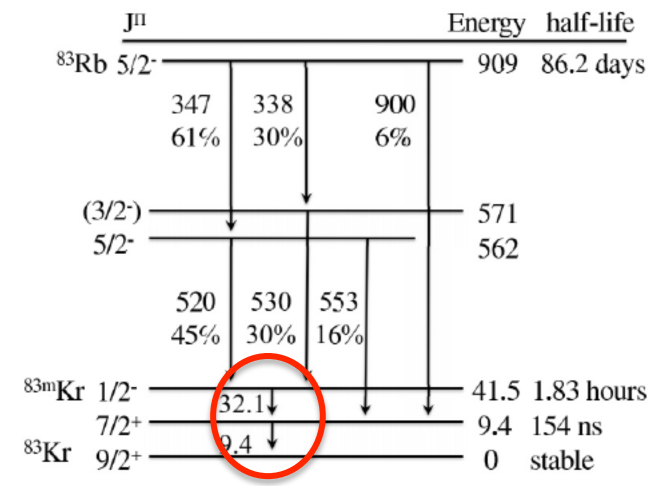
Drift of free e^-
and delayed
signal in gas S2

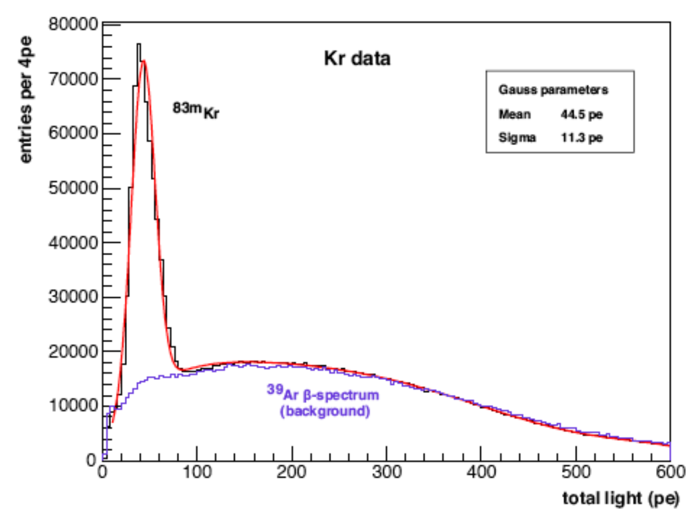
S1 measures energy and time of event
S2 measures position of event in LAr and is proportional to the fraction of charge that escapes recombination (this fraction depends on the drift field)

ArDM calibration with internal source

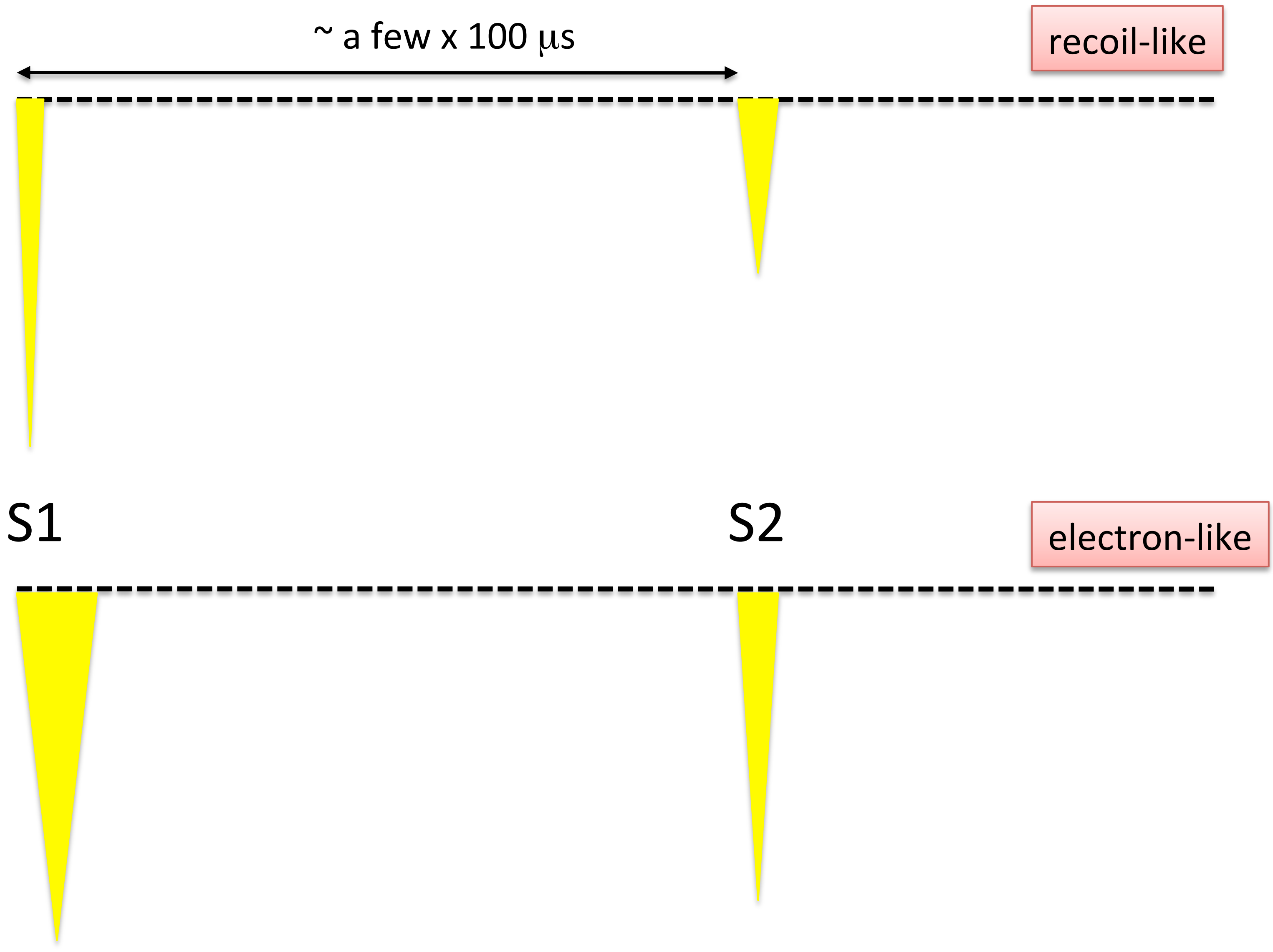


^{83}Rb->^{83m}Kr





LAr two-phase TPC at Work: signals

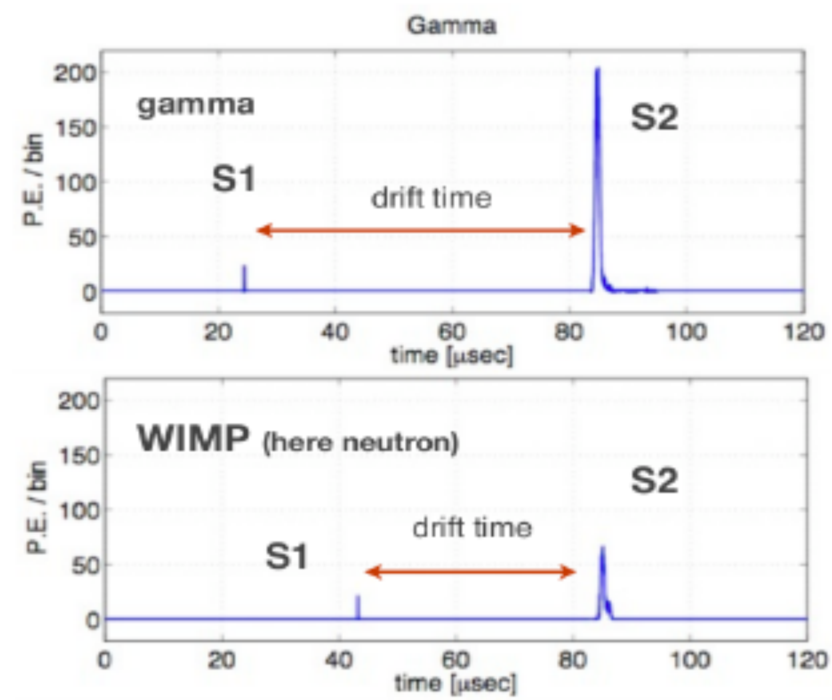


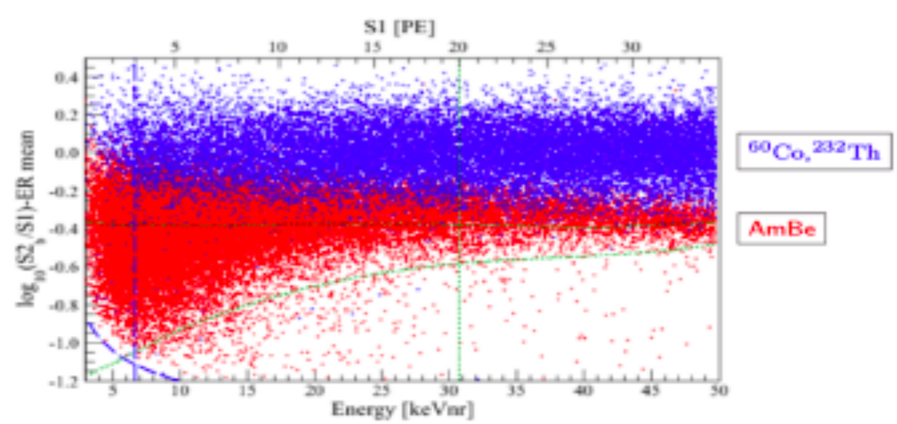
NR vs ER discrimination and Fiducial Volume definition

S2 / S1 used to discriminate Electron Recoils vs Nuclear Recoils

Drift time to measure z coordinate at very high prevision (<<1mm)

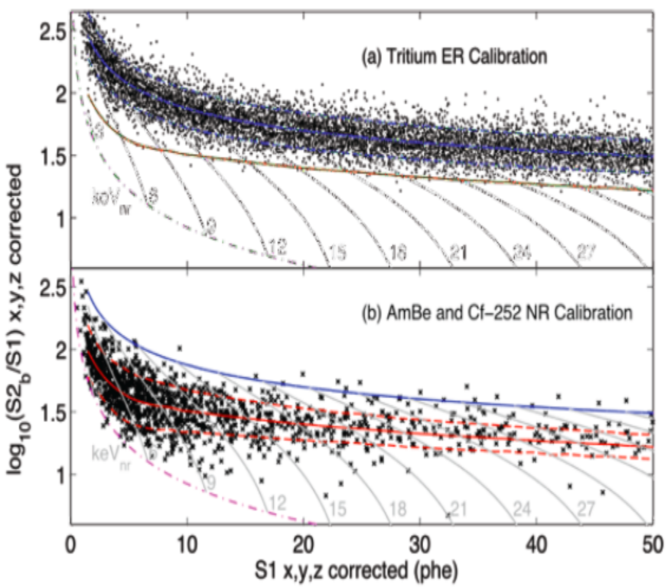
S2 pattern on upper array light sensors to measure x, y coordinates (< 1cm)

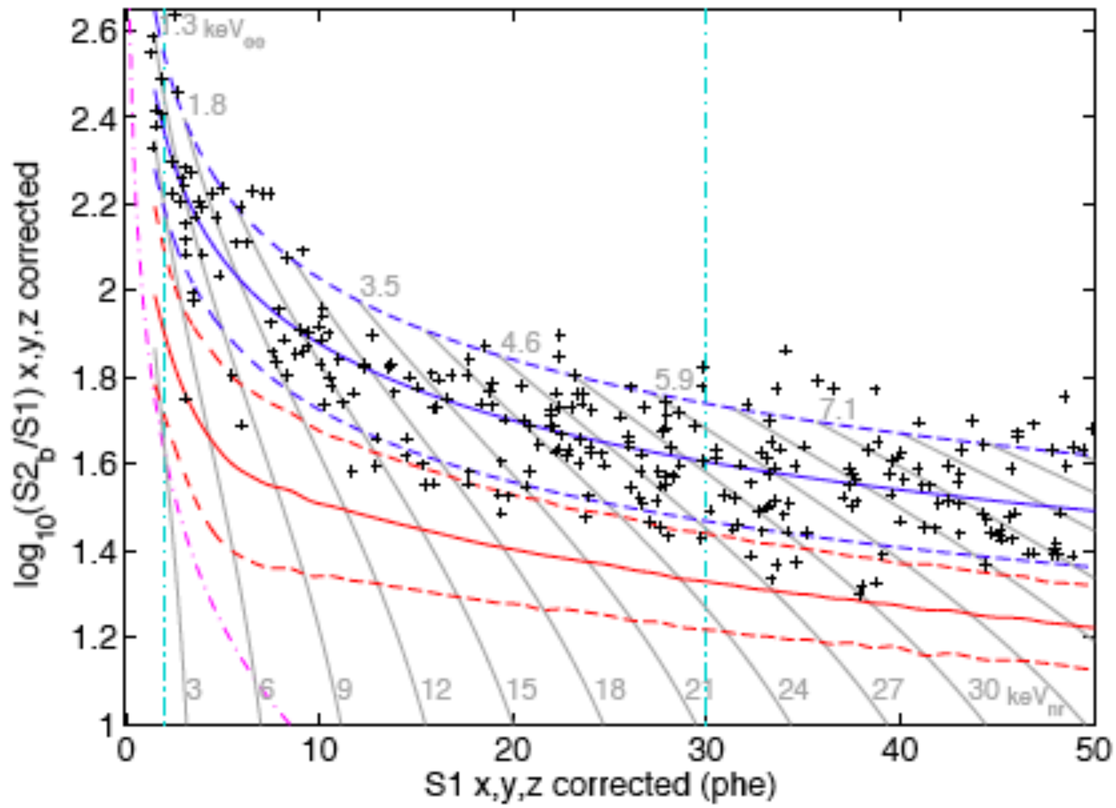




LUX 2013 results

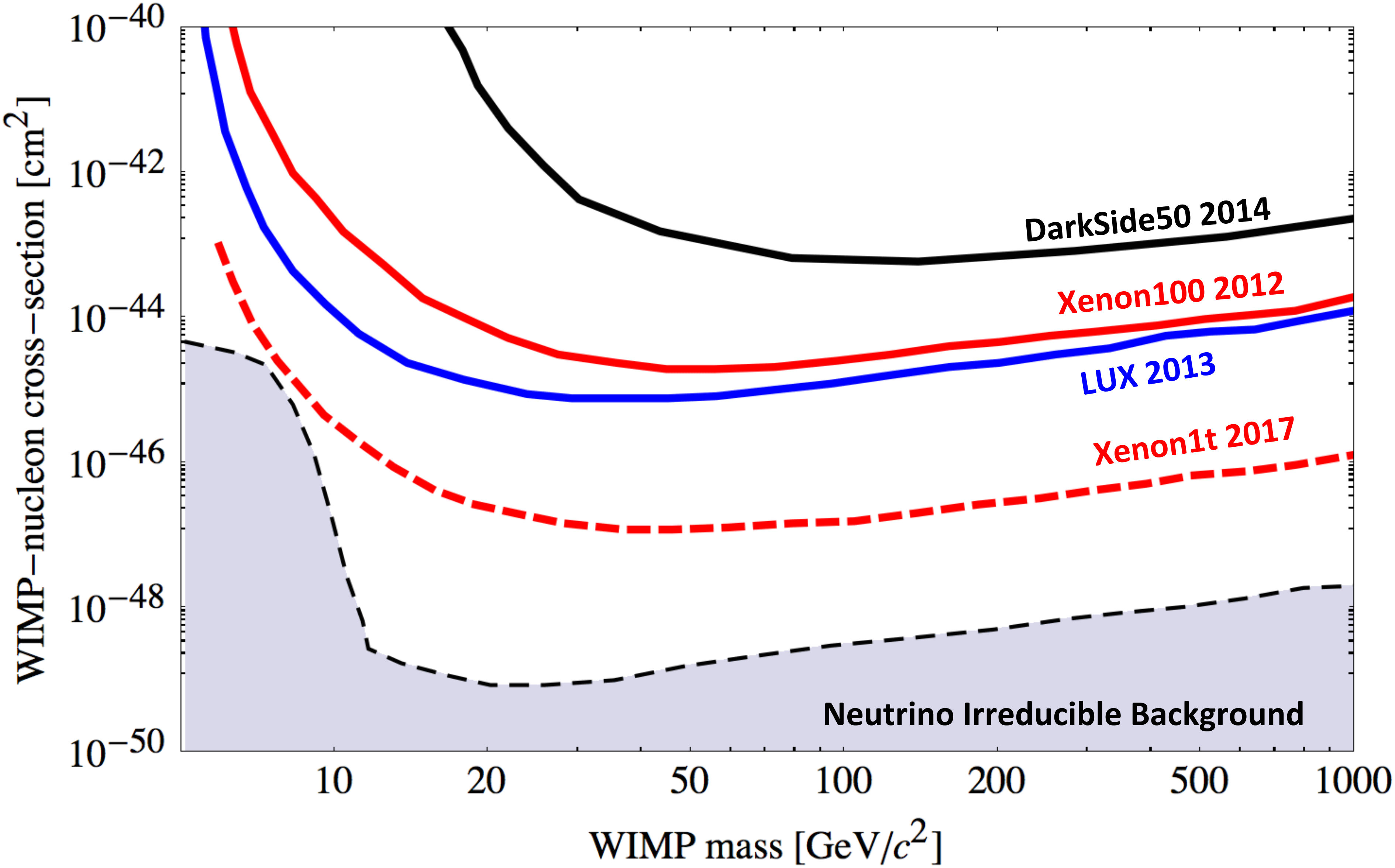
- 118 kg and 85.3 days





No events observed with 50% NR acceptance and 0.64±0.16 events of ER background

DM WIMP SI limits



Direct Dark Matter Search in DULs

- Challenge the DAMA/LIBRA result
  - ANAIS at Canfranc
  - Competition with KIMS, DM-Ice, SABRE
- Push the "standard" WIMP search to limiting sensitivity
  - ArDM at Canfranc
  - Competition with Dark-Side and Deap

Nuclear Astrophysics: CUNA

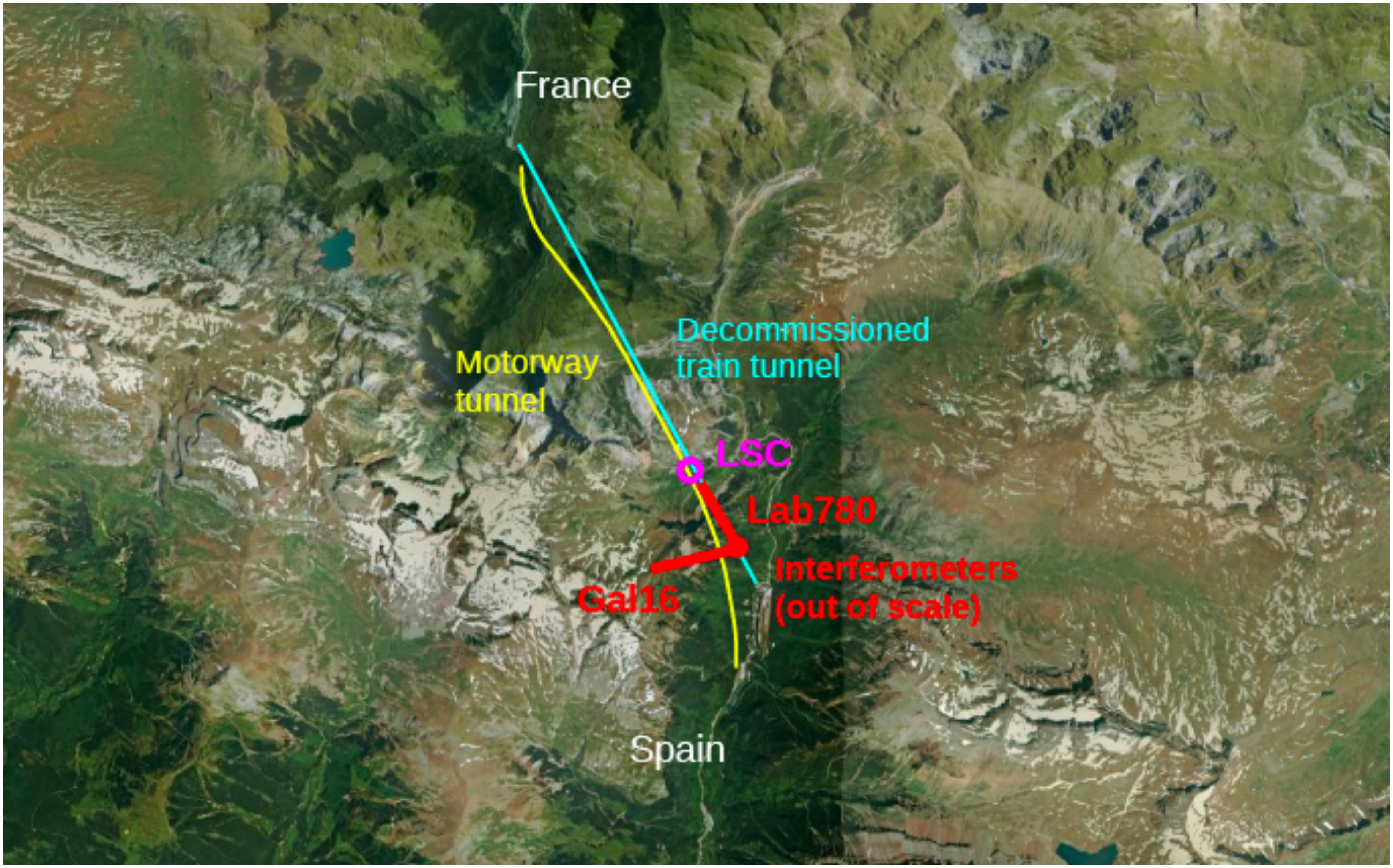
- CUNA @ LSC is a project to develop a facility to measure cross sections of interest in nuclear astrophysics for the s-process nucleosynthesis:

  - **$^{22}Ne(\alpha,n)^{25}Mg$** and **$^{13}C(\alpha,n)^{16}O$**

- A new and independent excavation is needed
- Goal of CUNA is to measure these cross sections at lowest possible energy
- Measurement to characterize the neutron background underground have been performed

Geophysics

- LSC is equipped with a geodynamic facility which aims to study local and global events
- The facility consists of
  - A broadband seismometer and accelerometer
  - Two 70 m long laser strainmeters with exceptional low background at the LSC site
    - One in LAB780
    - One in by-pass 16
  - Two GPS stations on surface



L=70m, $\Delta L/L<10^{-12}$, bandwidth: 0 Hz to 200 Hz
for $\Delta L/L=10^{-9}$ $\Delta L=0.07\mu m$

Laser strainmeter in LAB780

Life in extreme environments

Life on Earth extends into the deep subsurface and extreme environments

Canfranc railway tunnel offers a unique opportunity to study microorganism communities

The **GOLLUM** project, at present being proposed and under review, aims to characterize microbial communities by extraction of DNA in rock samples

Conclusions

- LSC is one of the four **deep underground laboratories** in Europe; second in available space for research activities

- LSC has some 280 users from international collaborations

- LSC is a **multidisciplinary infrastructure**
  - **astroparticle, geophysics, biology**

- LSC well equipped to support existing experimental activities and external users interested in some service assistance

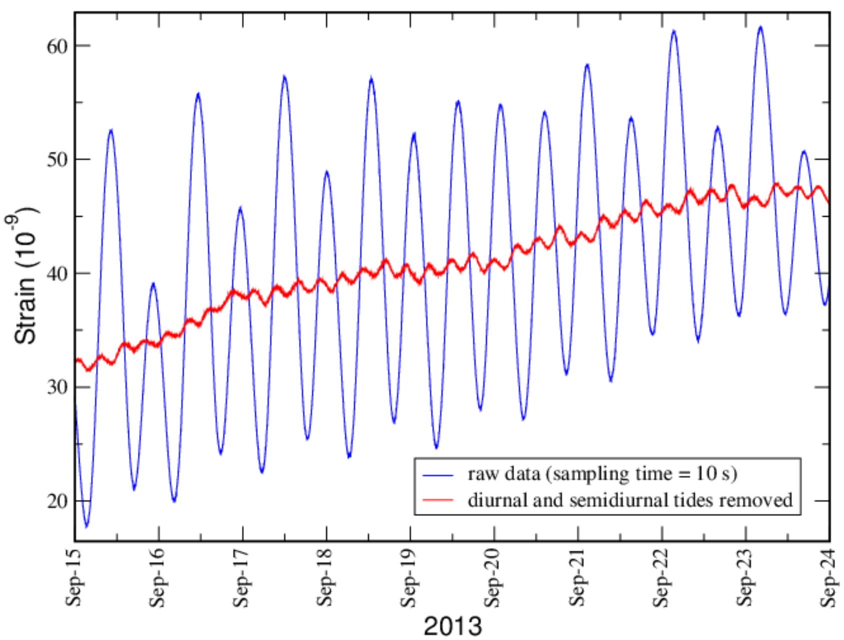
- LSC facilities can give support to new R&D and activities carried out in other laboratories

Spares

LSC Underground Facility

- LSC underground total volume ~10000 m^3 for a total surface of 1600 m^2.
- Underground space divided as:
  - **LAB780**(L and R) since 1985:
    - two small halls 12 m^2 each and two 70 m long small tunnels
    - early installation in service space for railway tunnel
  - **LAB2500**:
    - 118 m^2 hall in operation since 1994
  - **LAB2400**:
    - Hall A has dimensions $40\times15\times12(h)$ m^3 and Hall B has dimensions $15\times10\times8(h)$ m^3
    - 45 m^2 clean room and 215 m^2 service space
    - In operation since 2006
- Protocol to enter underground area:
  - Entrance through road tunnel
  - Independent exit through the railway tunnel

Tides from set-up in LAB780

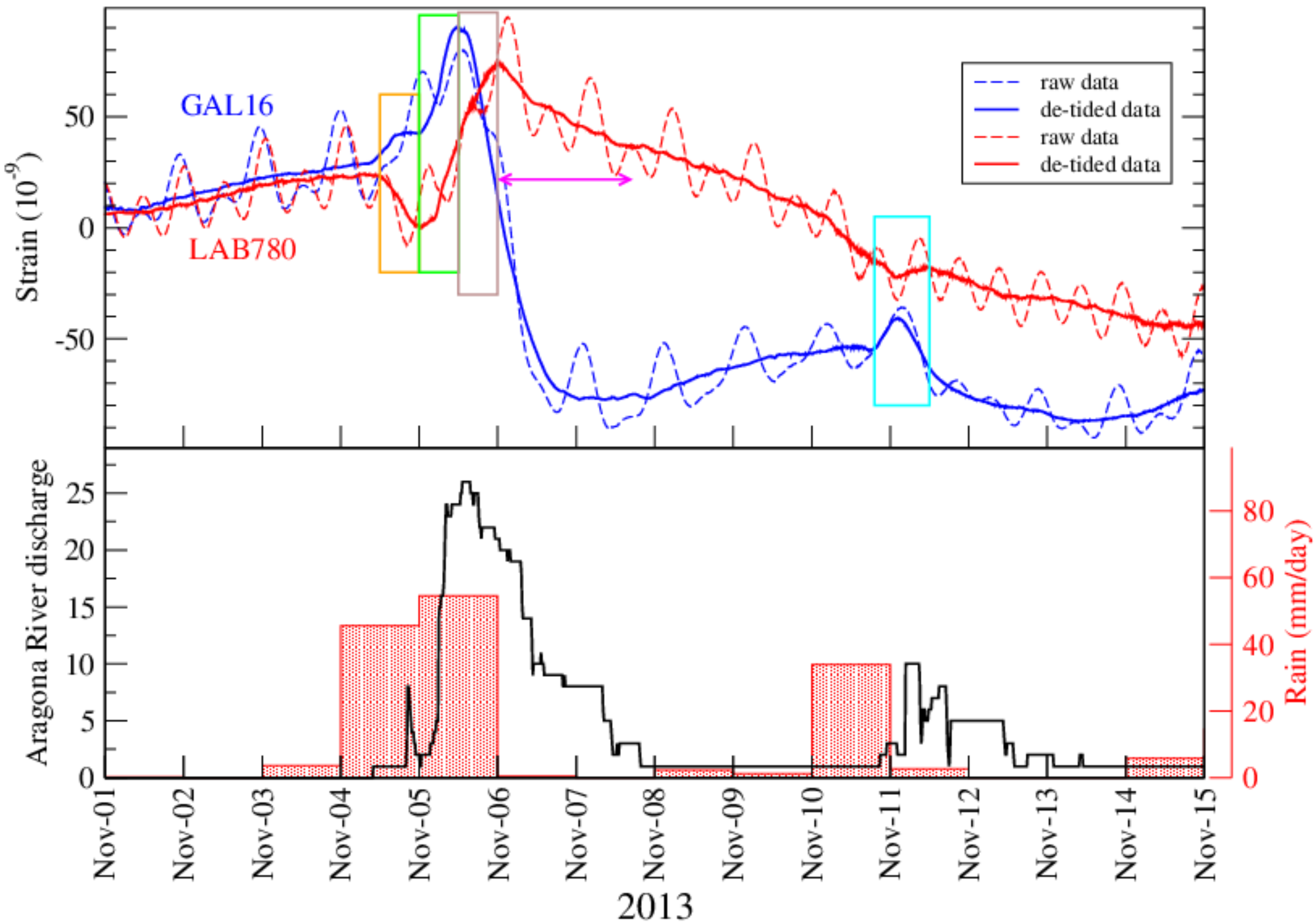


Nine-day-long record, sampled at 10s. Residual oscillations, after removing diurnal and semidiurnal tides, are due to quater-diurnal nonlinear ocean tides in the Gulf of Biscay.

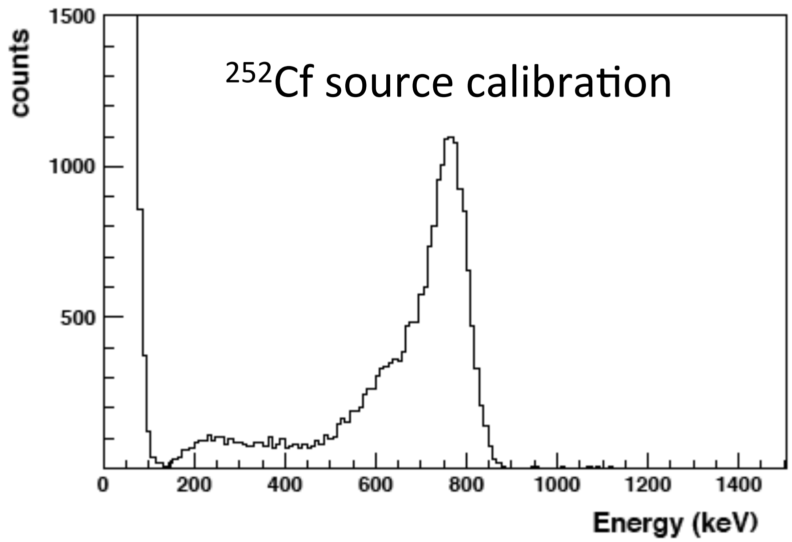
At 120km distance non linear ocean load tides observed

Amplitude and phase in agreement with computations

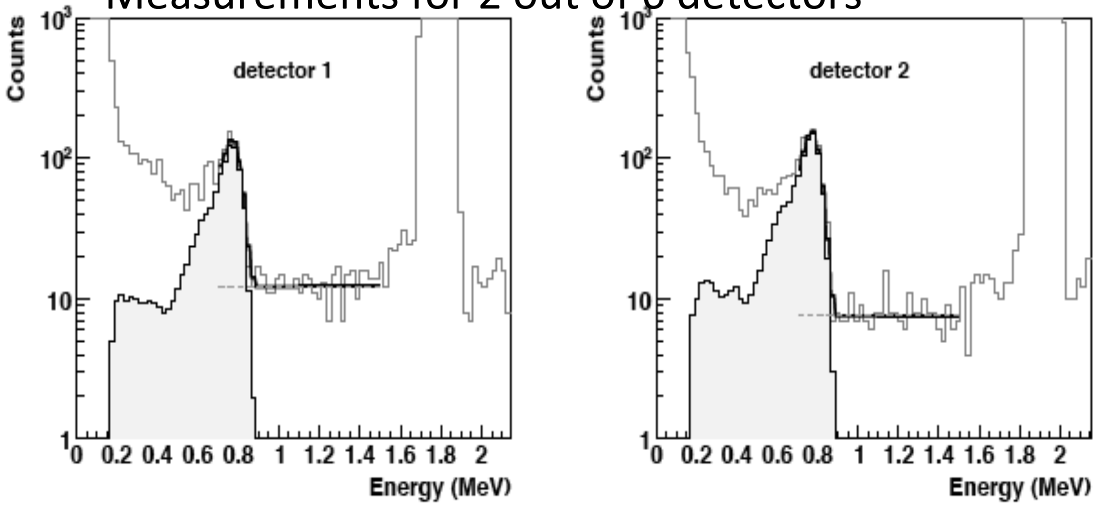
Hydrological signature from strainmeter

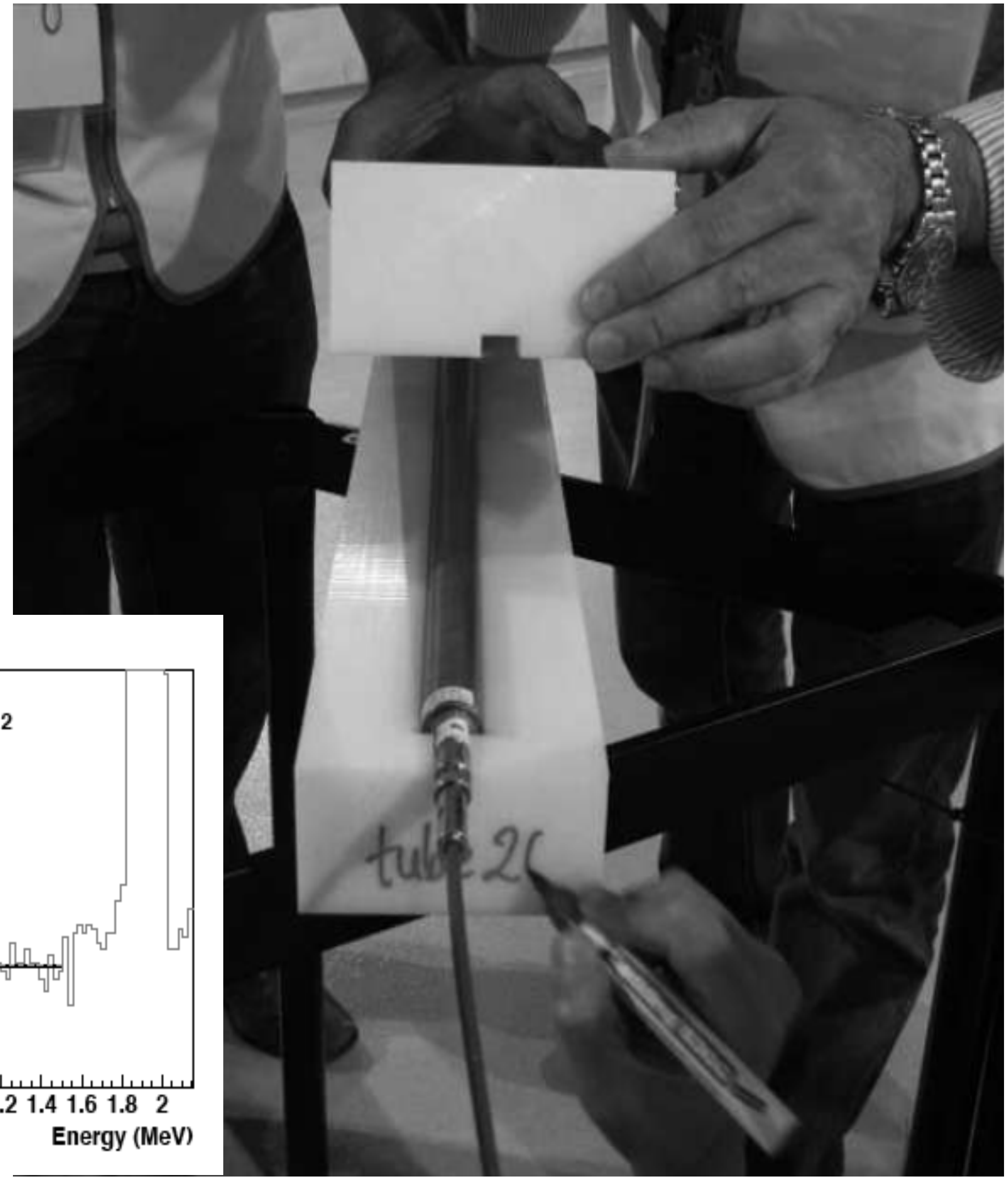


Neutron background measurement in Hall A with ^{3}He counters



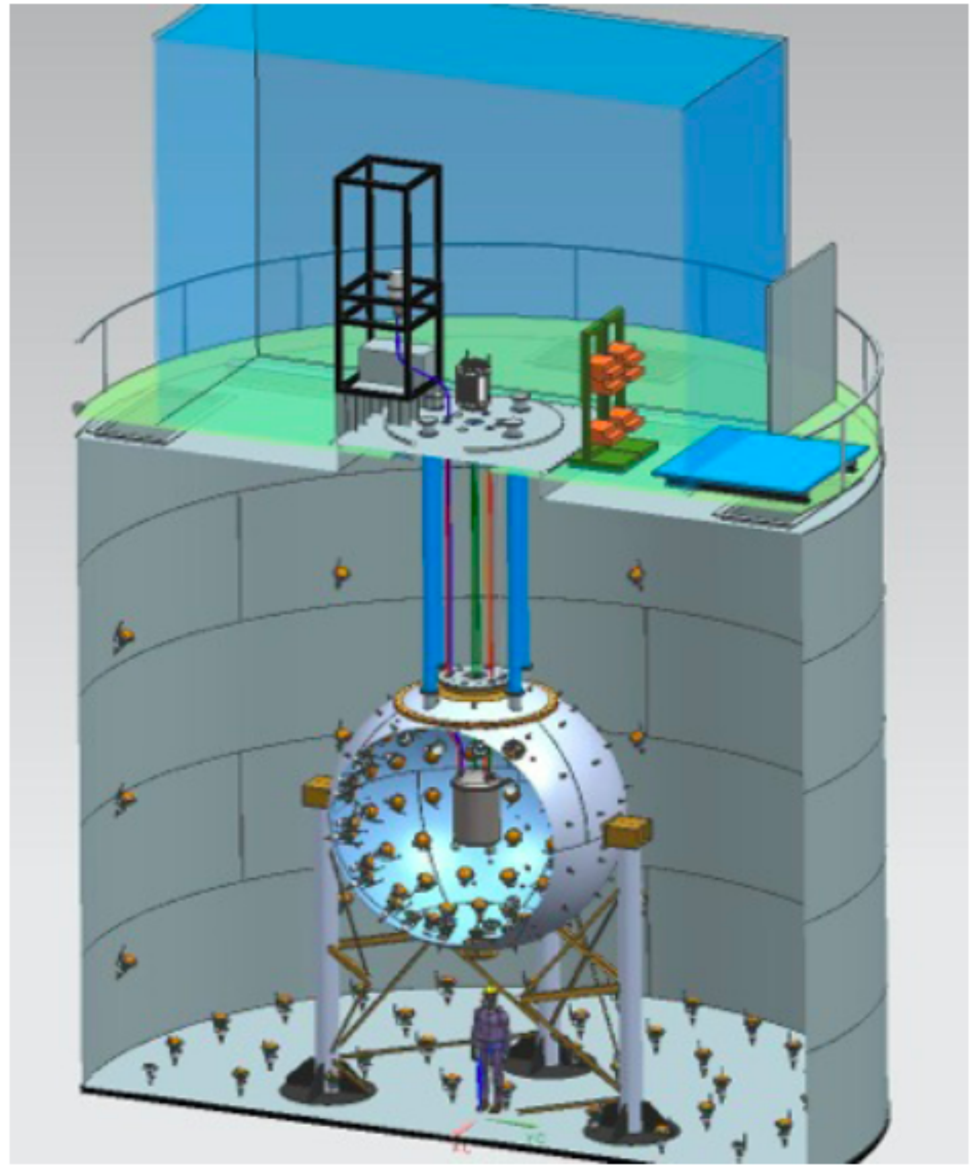
Measurements for 2 out of 6 detectors





DarkSide-50

- **Cryostat**
  Double wall low background Stainless Steel vessel; the Internal Cryostat has the capacity of 150L;
- **Neutron Vito**
  Stainless Steel Sphere with d = 4m filled with 30t of 50%PC +50%TMB+PPO mixture.
  ***1.5m** of shielding*.
  Viewed by **110 8" PMTs**;
- **Water Tank**
  Stainless Steel cylindrical Tank (h=10m, d=11m) filled with 1000t of HPWater
  ***3m** of shielding*.
  Viewed by **80 8" PMTs**;




Water Cherenkov