XL International Meeting on Fundamental Physics

Benasque 24.5 – 30.6 2012

The Canfranc Underground Laboratory

A. Bettini

A bit of History

In 1985 Angel Morales and his group , set off the Canfranc Underground Laboratory

A main hall of about 120 m^2 (now Lab 2500) and two halls of about 18 m^2 (now Lab 780)

The construction of a road tunnel between Spain and France, parallel to the railway one, provided the unique opportunity to build a new larger laboratory (Now Lab 2400)

Total area 1560 m^2, total volume 10500 m^3

The facility was completed in 2006. In 2007 signs of rock instabilities started to appear and the laboratory was closed. Complete revision of the original project performed by the Saragossa University and the rock support structures necessary to guarantee the safety of the personnel and of the properties were installed

Underground Lab 2500 delivered to LSC Consortium on 30 June 2010

Surface facility building completed January 2011

Try building opportunities for inland world class research in Spain and attract scientists from abroad

Comité Científico Asesor

Frank T. Avignone (Chairman) - University of South Carolina (USA)

Elena Aprile - Columbia University, New York (USA)

Laura Baudis - University of Zurich (Switzerland)

Masayuki Nakahata - ICRR, University of Tokyo (Japan)

Ariella Cattai - CERN, Geneva (Switzerland)

Andres Gadea - Valencia University (Spain)

Francisco del Aguila - Universidad de Granada (Spain)

Maria Concepción Gonzáez-Garcia - Universidad de Barcelona (Spain); State University of Stonybrook (New York)

David Sinclair - Carleton University (Canada)

Budget

The Lab 2400 is run by a Consortium between the Spanish MINECO, the Government of Aragon and the University of Saragossa. Lab 2500 and Lab 780 are being integrated in the LSC according to a MoU with the Saragossa University

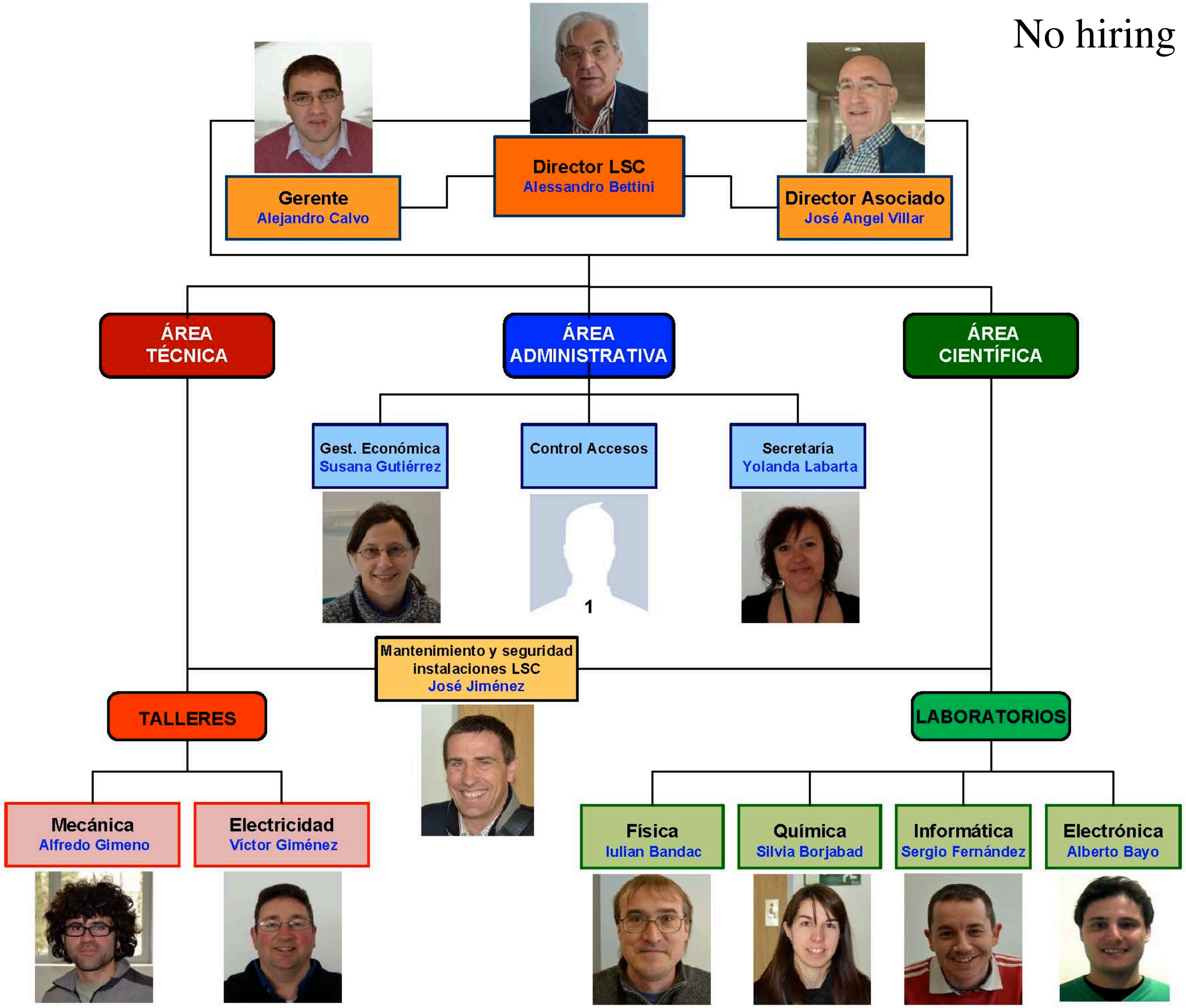
The Governing Bodies of the Consortium are: the **Consejo Rector** and the **Comision Ejecutiva** (which, amongst others, has the charge to approve the experiments)

The law of the Consortium foresees its funding in the period **2006-15** for a total of **19 301 925 €**

2012 budget **convenio 1918 k€** **actual 703 k€** **running exp. 1000 k€**

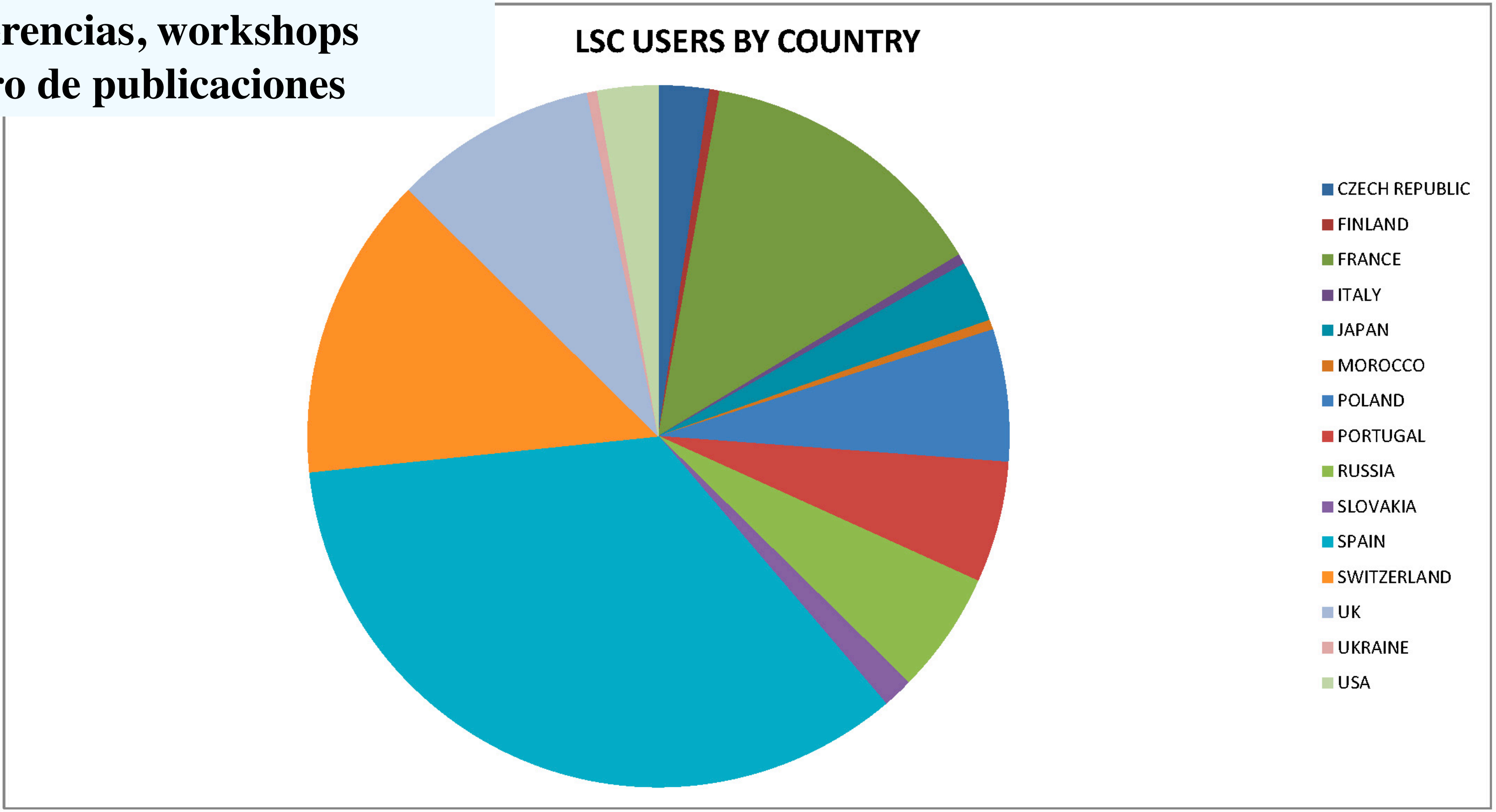
Personnel

No hiring in 2012



Usuarios = firmas su las propuestas aprobadas

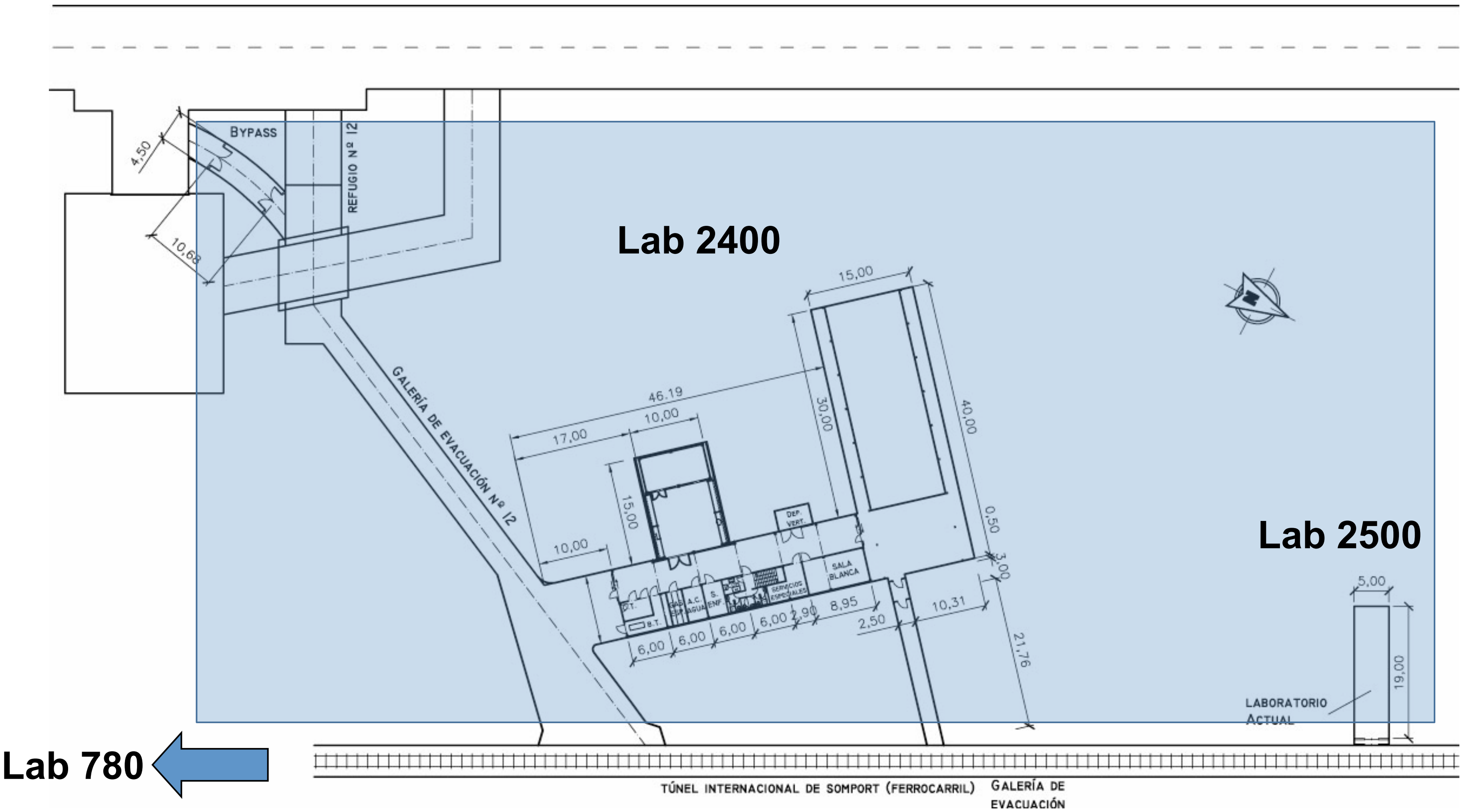
Registro de usuarios
214 registrados de 15 países
Registro de visitas
892 en 2011
4 conferencias, workshops
Registro de publicaciones



LSC. External building

Headquarters & Administration
Safety and Quality Assurance
16 offices for scientific users
7 offices for LSC personnel
4 specialised laboratories
Mechanical workshop & storage room
Meeting room & Library
Conference room& Exhibitions room
2 apartments

Map of LSC



BYPASS
REFUGIO Nº 12
4,50
10,68
Lab 2400
15,00
46.19
10,00
17,00
30,00
40,00
15,00
GALERÍA DE EVACUACIÓN Nº 12
10,00
DEP. VERT.
SALA BLANCA
0,50
3,00
Lab 2500
5,00
6,00
6,00
6,00
6,00
2,90
8,95
2,50
10,31
21,76
19,00
LABORATORIO ACTUAL
Lab 780
TÚNEL INTERNACIONAL DE SOMPORT (FERROCARRIL)
GALERÍA DE EVACUACIÓN

EoIs, LoIs, Eps, EXPs

- Approved experiments (3 years running)

✓ EXP-01-2008;LoI-2009 (ANAIS)	Dark Matter (NaI, Annual modulation)
✓ EXP-02-2008;LoI-2009 (ROSEBUD)	Dark Matter (Scintillating bolometers)
✓ EXP-03-2008;LoI-2009 (BiPo)	$0\nu2\beta$ decay (Ancillary to Super-NEMO)
✓ EXP-05-2008;LoI-2009 (NEXT)	$0\nu2\beta$ decay (Enriched ^{136}Xe TPC)
✓ EXP-06-2009 (SuperK-Gd)	Material screening for SuperK Gd
✓ EXP-08-2010 (ArDM)	Dark Matter (Liquid Argon TPC)
- Approved observatory	
✓ EXP-07-2009 (GEODYN)	Geodynamics (Underground & surface)
-Expressions of Interest	
✓ EoI-12-2009 (CUNA)	Nuclear astrophysics (New facility)

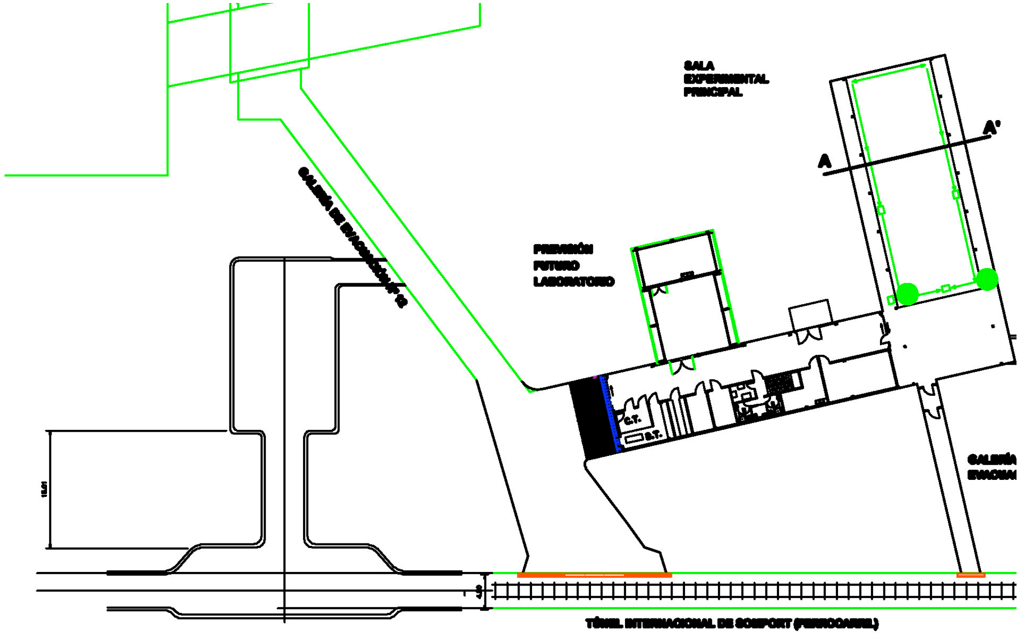
Hall CUNA. Preliminary project

Nuclear reactions in the stars and other astrophysical environments take place at very low energies, well below the Coulomb barrier
Cross sections extremely small, cannot be measured on the surface
Extrapolations done, but very risky
Underground Nuclear Astrophysics has started at LNGS with LUNA
e. g. LUNA showed that the “nuclear solution” of the solar neutrino puzzle did not work

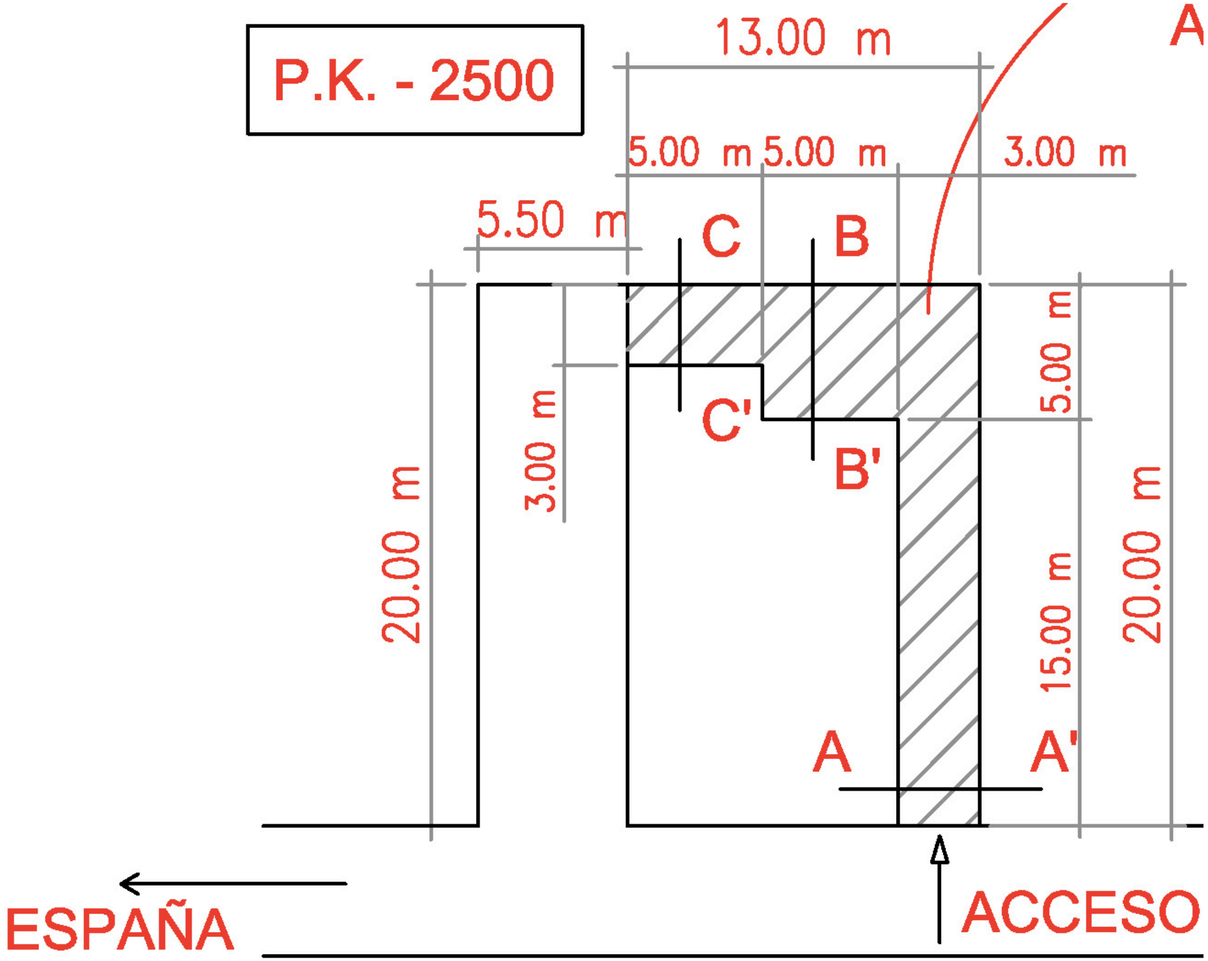
Much remain to be done (requiring modest investment)

Preliminary project completed by a specialised engineering company

Cost about 3 M€



Hall CUNA. Cheaper solutions?



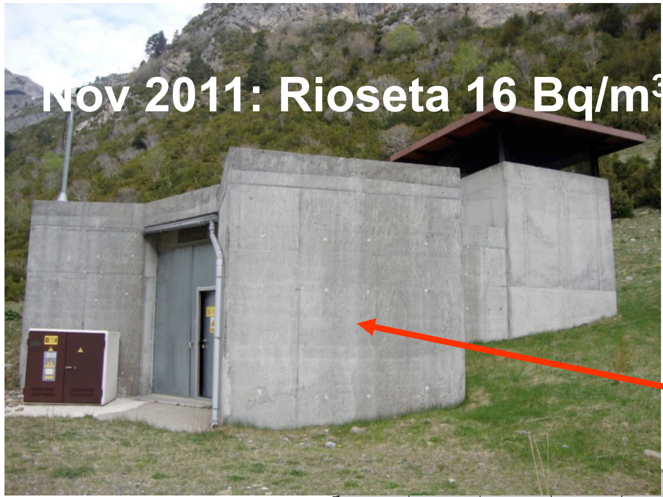

Underground clean room

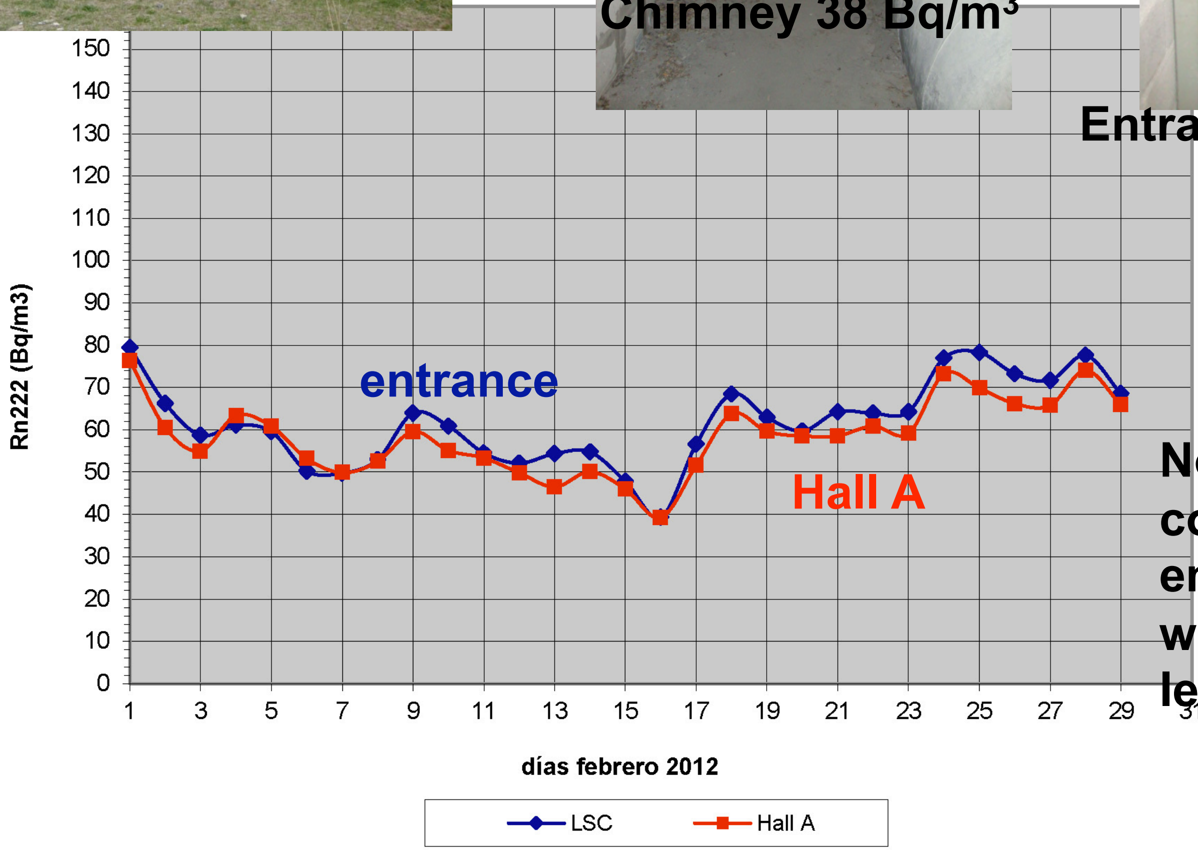
HP-Ge Counters. Hall C

<u>Seven</u> HP-Ge counters + shielding can fit

- 3 counters operational (GeOroel, GeTobazo, GeAnayet)
- 1 counter being installed
- 1 counter waiting for space
- 2 counters of the Saragossa Uni. Back after refurbished at Canberra (Lab 2500)
- Paco & Paquito in hall C, while Lab 2500 being restructured

^{222}Rn activity





No appreciable contribution of Rn emission from the Lab walls at the present level of input air flux

Gamma flux. Hall A

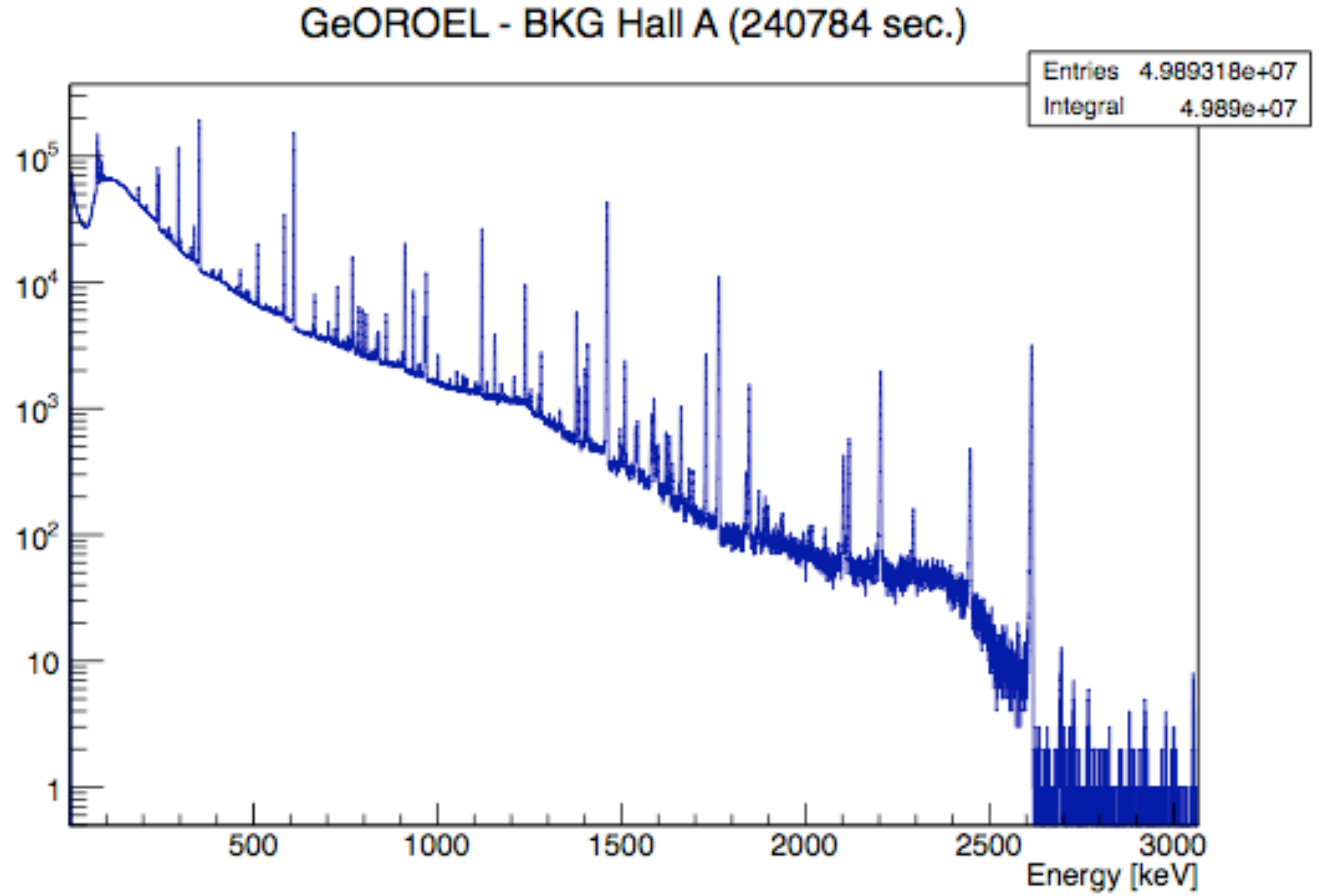
Iulian Bandac 2011 Hall A

^{40}K: 0.17±0.03 cm^{-2}s^{-1}

^{232}Th: 0.38 ±0.02 cm^{-2}s^{-1}

^{238}U: 0.68 ±0.17 cm^{-2}s^{-1}

Tot: 1.23±0.17 cm^{-2}s^{-1}



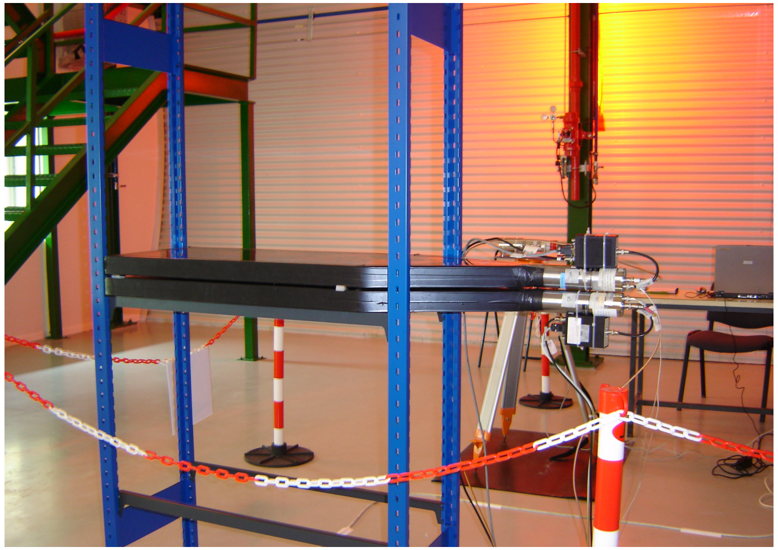
Muon flux

Measurements had been started in 2006 by Julio Morales

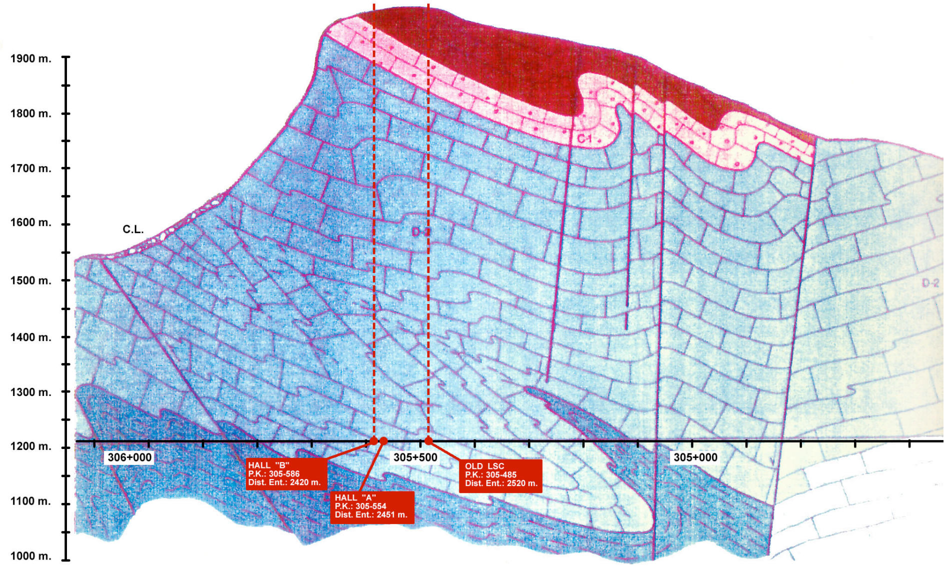
Preliminary results (1 month data in Hall B)

$$(5.04 \pm 0.25)\ 10^{-3}\ m^{-2}s^{-1}$$

About twice as in the Lab 2500

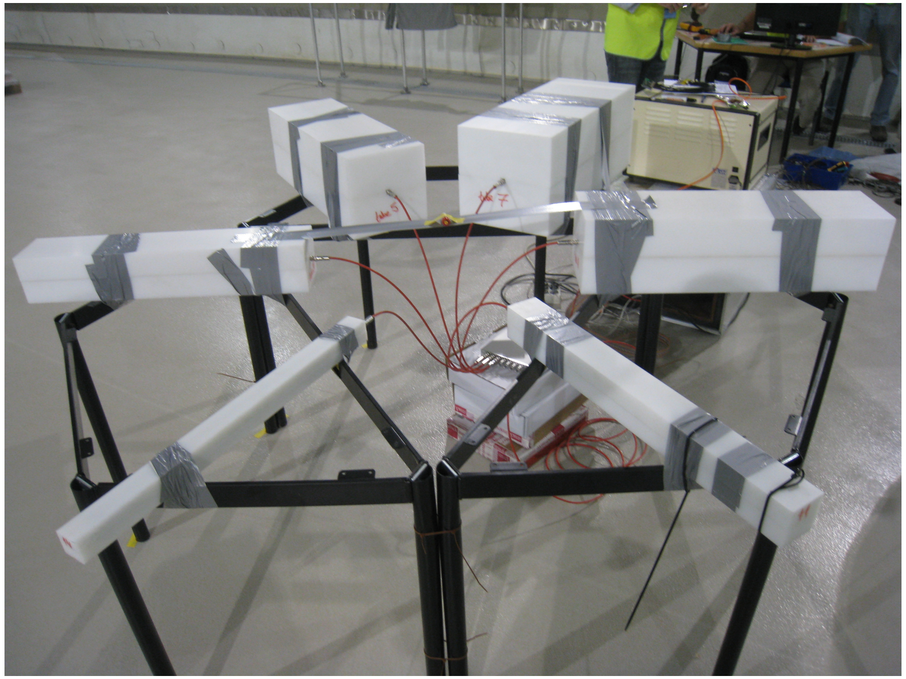


MoU signed with the Moscow Institute of Physics and Technology (Lev Inzhechik) for muon flux vs direction measurement

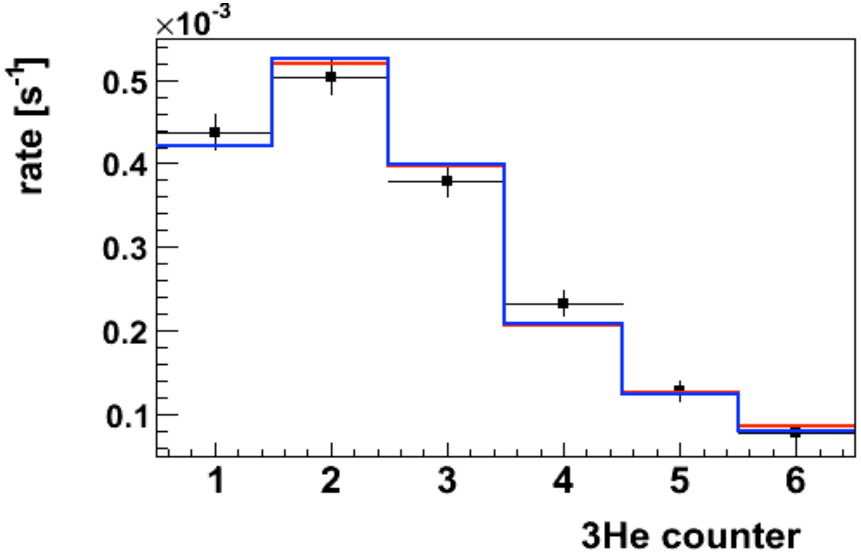


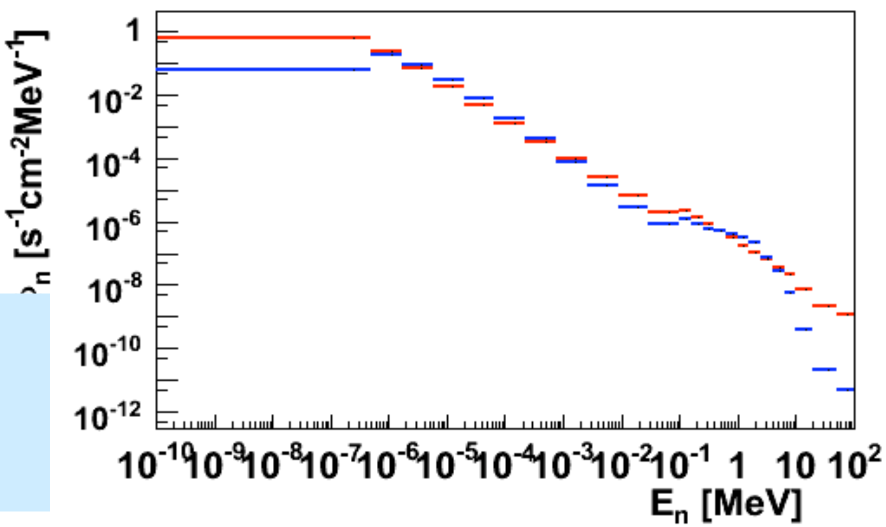
Neutron flux. Hall A

M.D. Jordan et al. . 2011 Hall A empty
Six ^{3}He counters with different thickness moderators



Measured rates



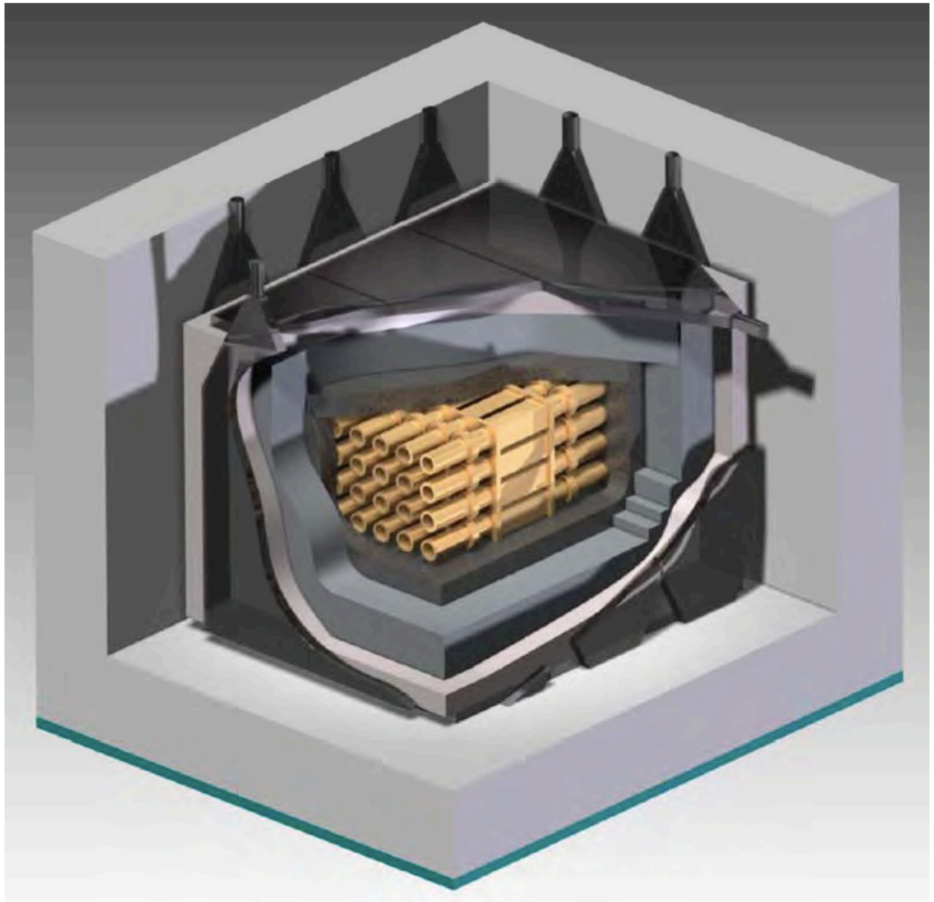


Deconvolving the spectrum (two different codes)

$\Phi_{Hall\text{-}A} = (3.47 \pm 0.35) \times 10^{-2}\ m^{-2}s^{-1}$

EXP-01-2008 ANAIS

- ANAIS: Direct search for WIMPs through annual modulation on NaI(Tl) scintillating crystals at LSC.
- Goal up to 250 kg
- ANAIS: uses same target as DAMA
- Purification of NaI powder done
    - Achieved <90 ppb (HPGe sensitivity)
- Goal: K in crystal <20 ppb
    - Two crystals produced. To be delivered from Colorado via surface transportation in May 2012



Internal Backgrounds

DAMA developed sophisticated techniques over the years for radio pure NaI (Tl) powders and protocols for crystal growing (St Gobin is not allowed use that for others!)

Activity of the major radioactive nuclides traces measured in the crystals (including cosmogenic ^{125}I, ^{129}I, ^{210}Pb, ^{22}Na, ^{24}Na) and

^{228}Th 2 - 30 μBq/kg

^{238}U several μBq/kg, may vary from crystal to crystal. Decay chain probably broken

^{nat}K 20 ppb (g/g) starting from < 100 ppb in NaI powder

^{40}K, abundance a_{40}=1.17×10^{-4}

89% beta decays to ^{40}Ca (maximum energy Q=1.31 MeV)

11% EC to ^{40}Ar (E=1.461 MeV), followed by X or Auger de-excitation E_X=3.2 keV

NIM A 592 (2008) 297

^{40}K

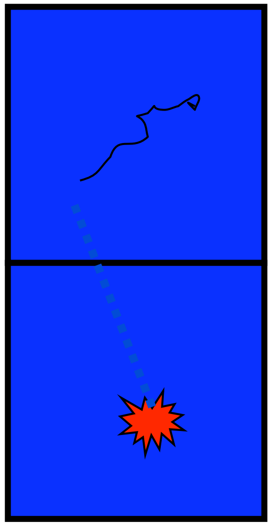
DAMA: protocols for extremely radio-clean NaI(Tl) crystals

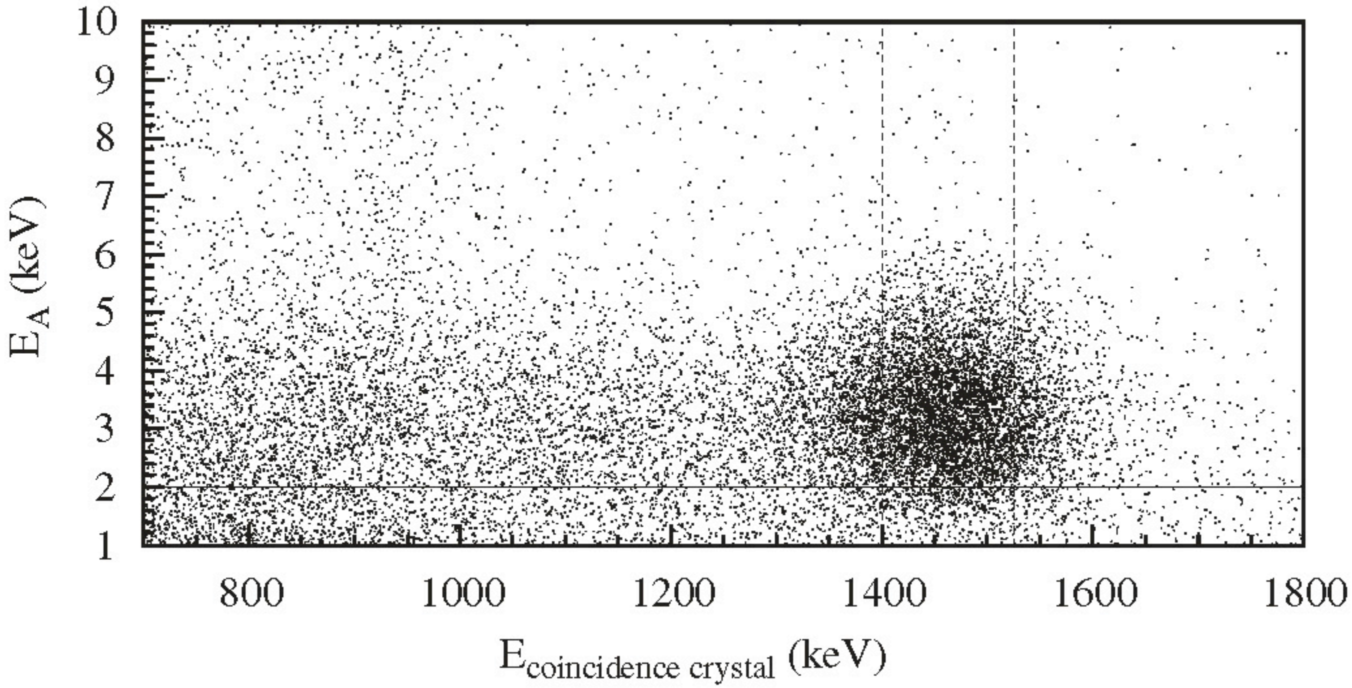
^{40}K in crystals = 20 ppb (g/g) ^{40}K decays

•89% beta to ^{40}Ca (Q=1.31 MeV). No severe background

•EC 11% EC to ^{39}Ar (E_γ=1.461 MeV)

+ X ray/Auger electron E_X=3.2 keV. BKGRND when γ escapes



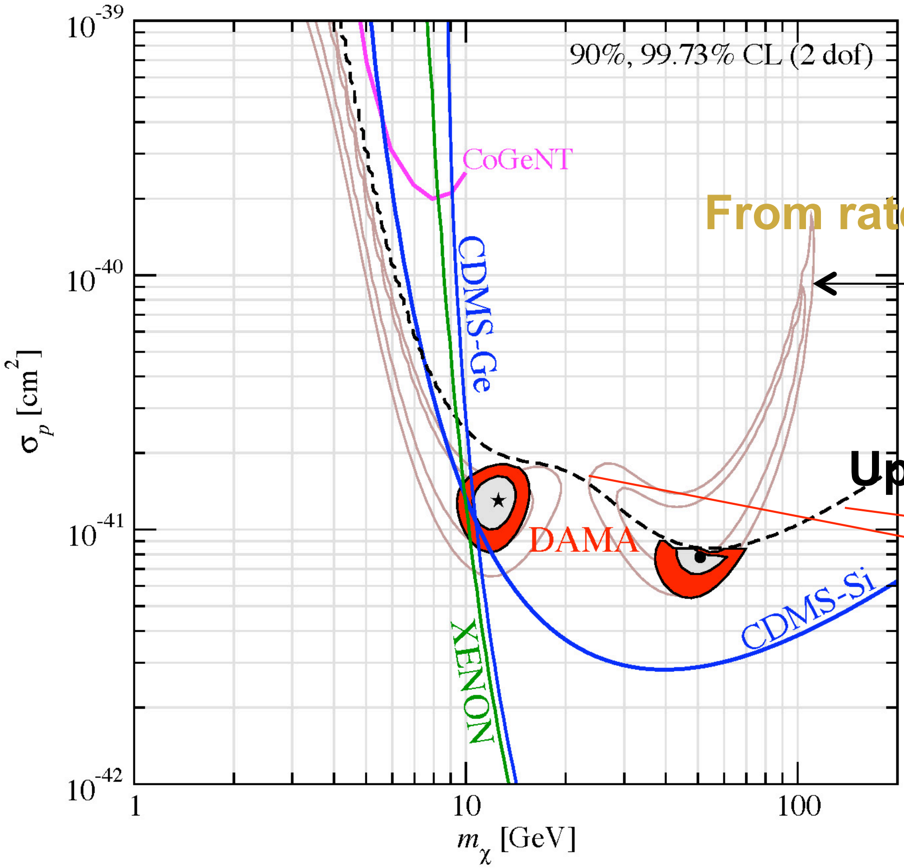


NIM A 592 (2008) 297

Fit W mass and SI cross section

Fairbairn & Schwetz
Arxiv 0808.0704

Model dependent. Spin independent coupling + “standard” halo model



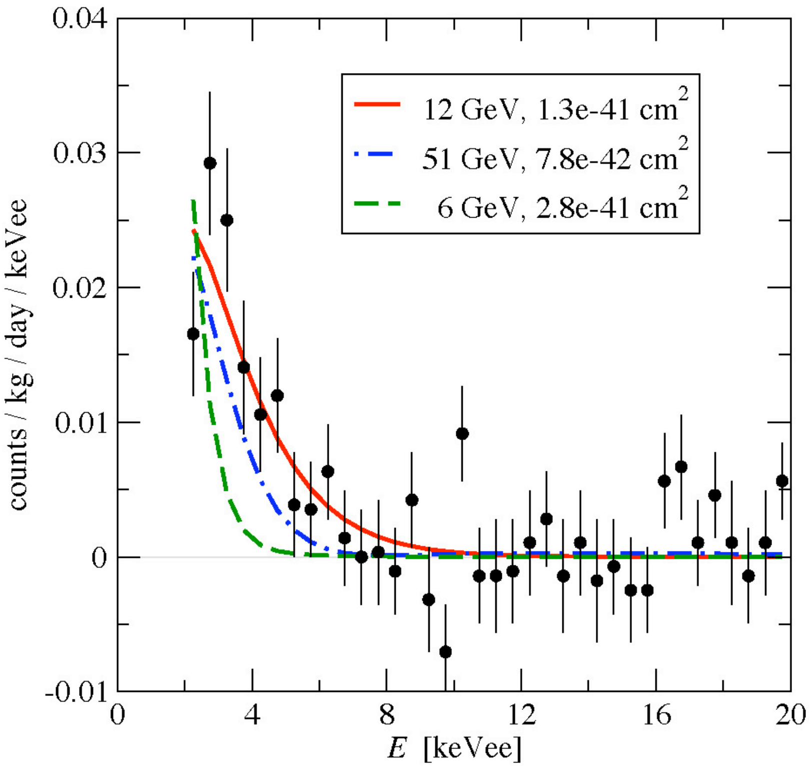
Large WIMP masses incompatible with time averaged rate

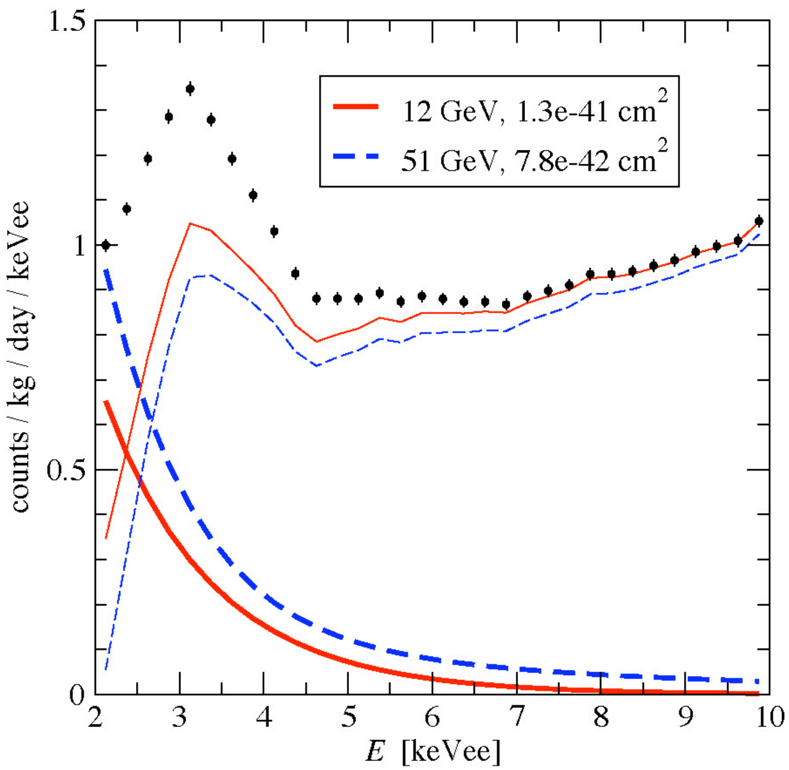
Upper limit (no background)

Rate & spectrum (allowing channelling)

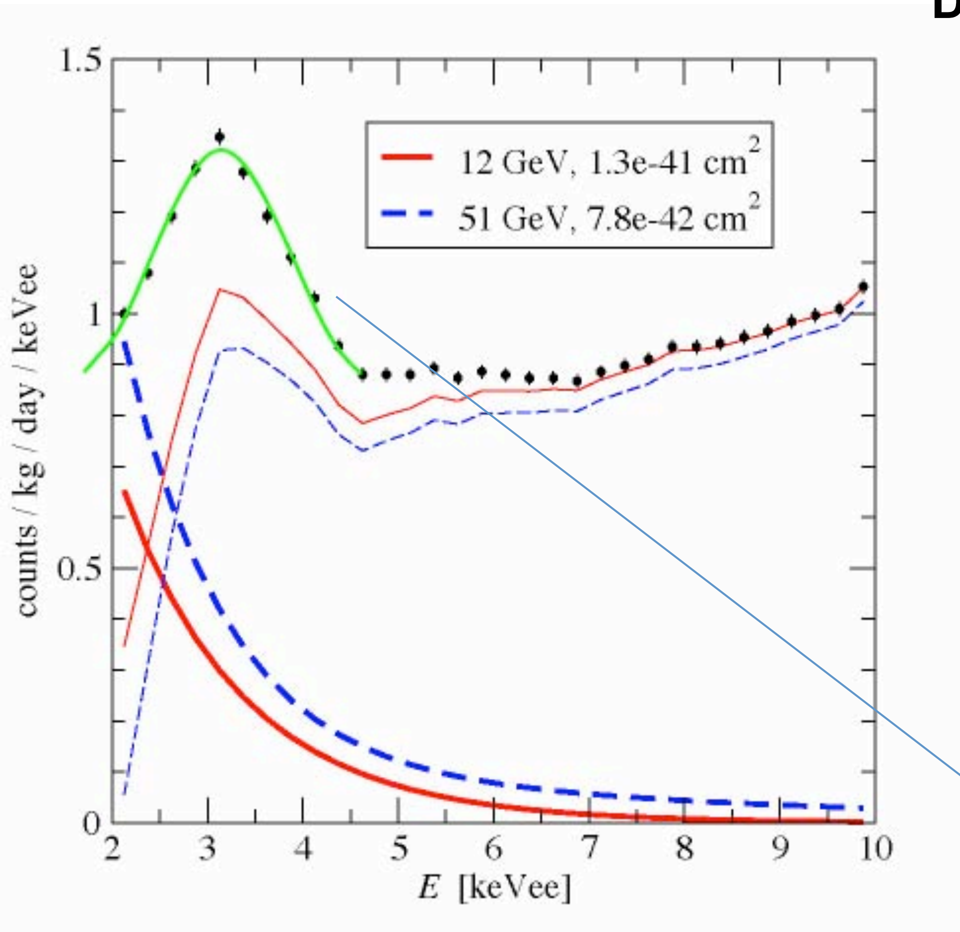
Fit W mass and cross section

ArXiv 0808.0704





^{40}K in the spectrum



DAMA/LIBRA measured ^{40}K = 20 ppb

$$\frac{\sigma}{E} = \frac{0.47}{\sqrt{E(\mathrm{keV})}}$$

σ/E=25% at 3.2 keV or σ=0.8 keV

Could not find DAMA in papers value of the 1.46 keV γ escape probability
Guess 20%

Calculation gives the 3.2 keV ^{40}K peak (green curve)

Alfa Spectra crystals for ANAIS

40K traces in the crystals to be measured with 1.45 MeV – 3.2 keV coincidence
Needs several months counting (if background small)

OFHC copper encapsulation

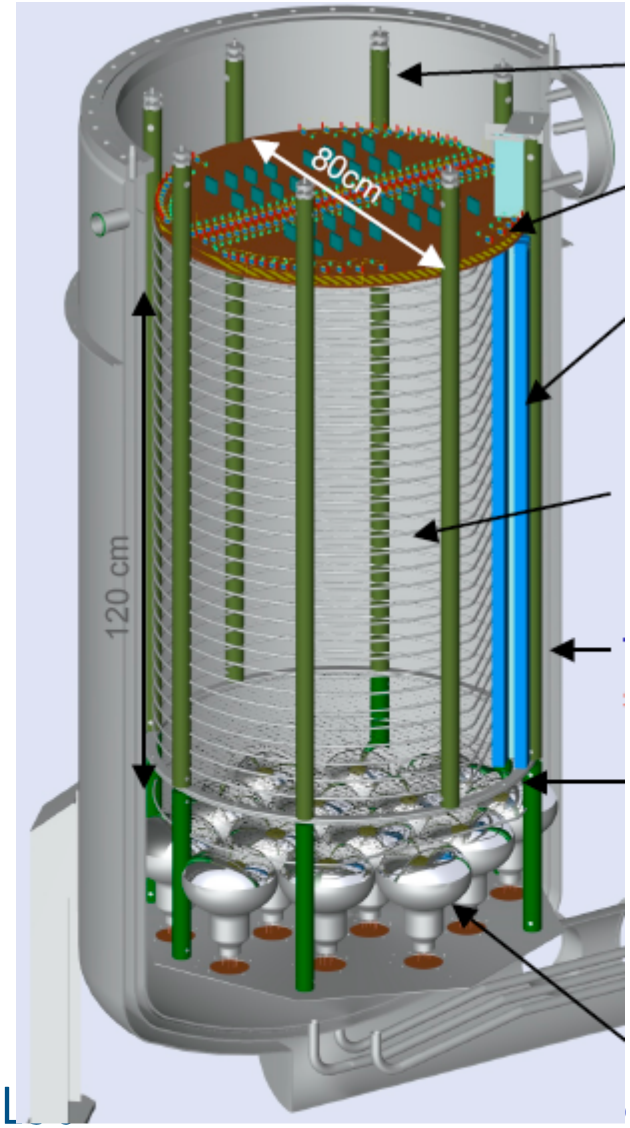
To be shipped by surface transportation

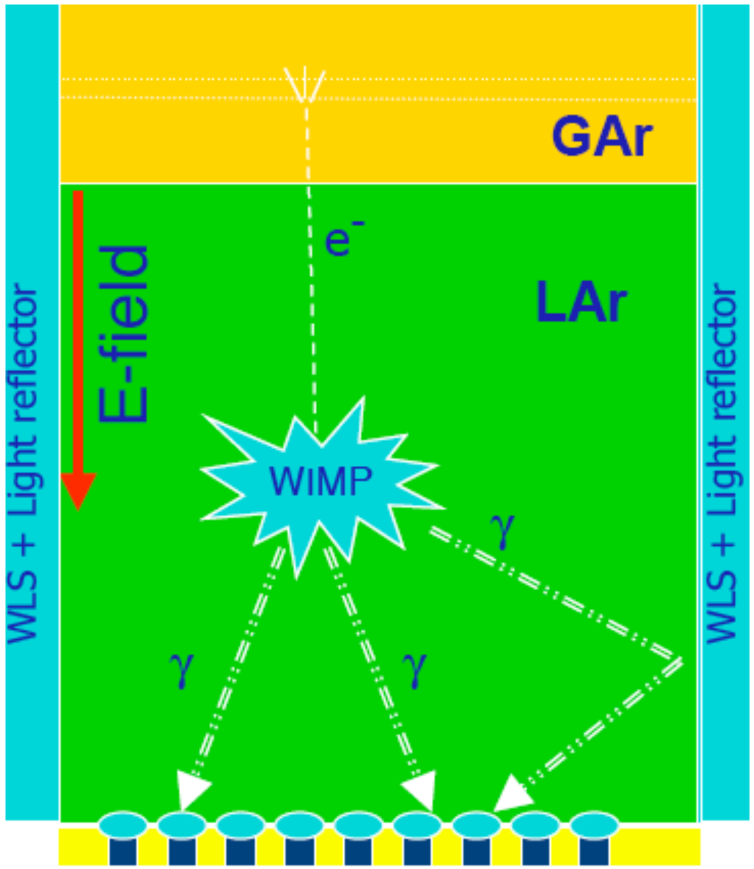
Ar two-phase TPC (800 kg)

Installed Feb 2012

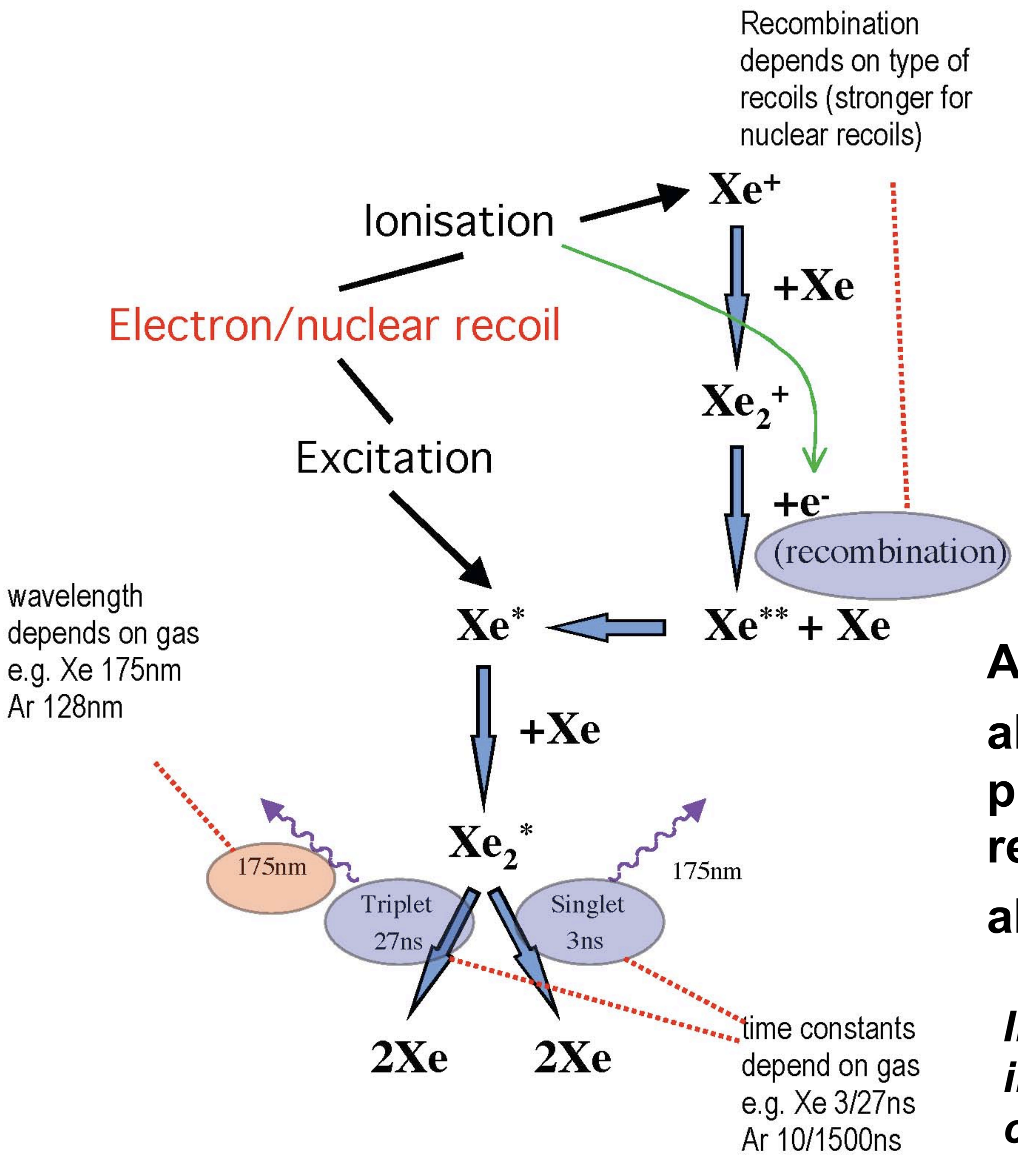
ArDM

Main background in Ar
cosmogenic ^{39}Ar 1Bq/m^3
Two ways to fight
- S1/S2
- long/short light pulse





S1/S2. Charge and light in Liquid Xe/Ar



Excited dimers (excimers) and molecular ions formed by double collisions with metastable atoms

$$Xe^* + Xe + Xe \rightarrow Xe_2^* + Xe \qquad Xe_2^* \rightarrow 2Xe + \gamma$$

etc.

At E=0 scintillation light in LAr and LXe

about 70% due to excited molecules produced by free electrons recombination

about 30% due to self trapped excitons

In a liquid (excited) atoms are not independent objects. The excitation of one can propagate to others. Exicton is the quantum wave of excitation

Excimer de-excitation. Singlet and triplet

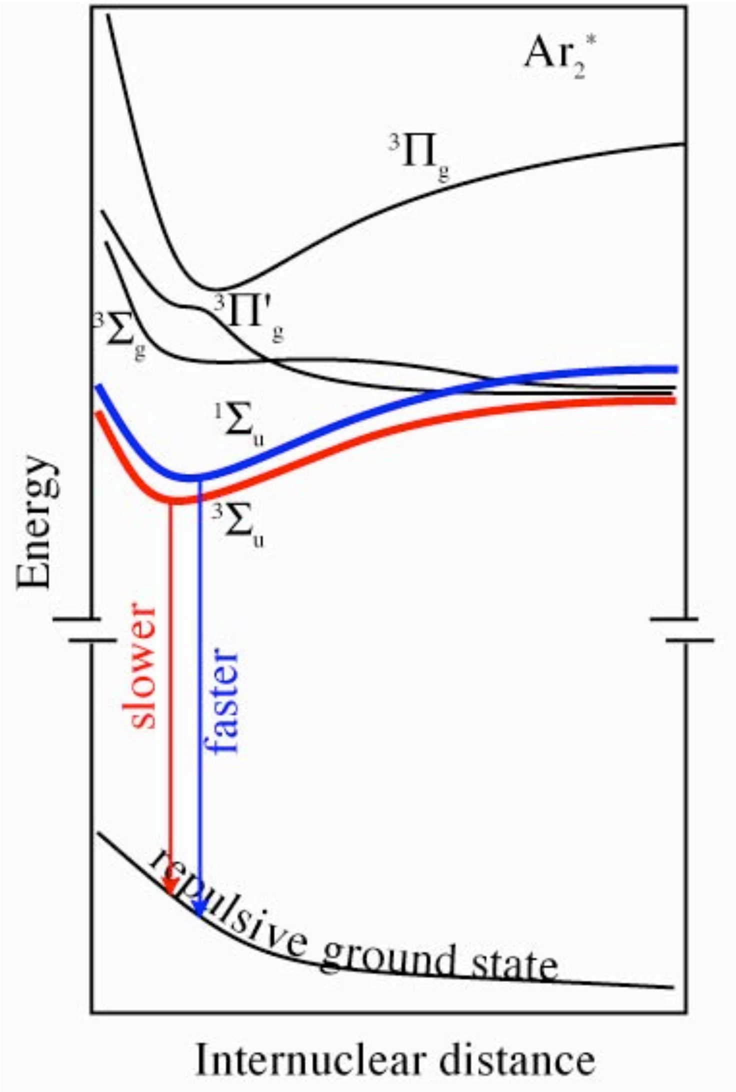
In liquid Ar the UV luminescence is due to the transitions to the ground level (two separate atoms) of the lowest molecular levels $^1\Sigma_u$ (Λ=0, total spin=0) and $^3\Sigma_u$ (Λ=0, total spin=1), within picoseconds

The singlet decay is strongly allowed (few ns lifetime) The triplet decay need to flip one electron spin (S=1→S=0) and cannot go emitting a photon. Need to wait for collisions

In Xe similar situation even if total Λ, total S scheme not appropriate

NB. Emitted radiation is not re-adsorbed because too low energy to excite atomic levels

Approximate and simplified



	T_1	T_3
Ne	5 ns	15.4 μs
Ar	7 ns	1.6 μs
Xe	4 ns	22 ns

ArDM. Sensitivity

We assume:

- 500 kg active mass after fiducialization.
- Background rejection: 10^7 (10^4 from PSD and 10^3 from S1/S2) for beta/gamma background
- Signal efficiency: 50%
- Neutrons from materials and neutron shield in place
- WIMP mass 100 GeV and xsec 10^{-44} cm^2
- Region of interest 30-100 keV

Ar39 [evt/day]	gamma [evt/day]	neutrons [evt/day]	background [evt/day]	WIMP rate [evt/day]
1.50E+06	47,500	0.07	0.22	0.25

Hall A. ArDM

Installed.February 2012

Risk analysis to be done before LAr filling

Double Beta Decay

Sensitivity of an experiment with background index *b*, sensitive mass *M*, live time *T* and energy resolution Δ*E*

$$\text{sensitivity to } \frac{1}{M_{ee}^{M}} \propto F_M = \left(\frac{MT}{b\Delta E}\right)^{1/4}$$

If *b*=0 during *T*, in an energy window of *ΔE* sensitivity to M_{ee}

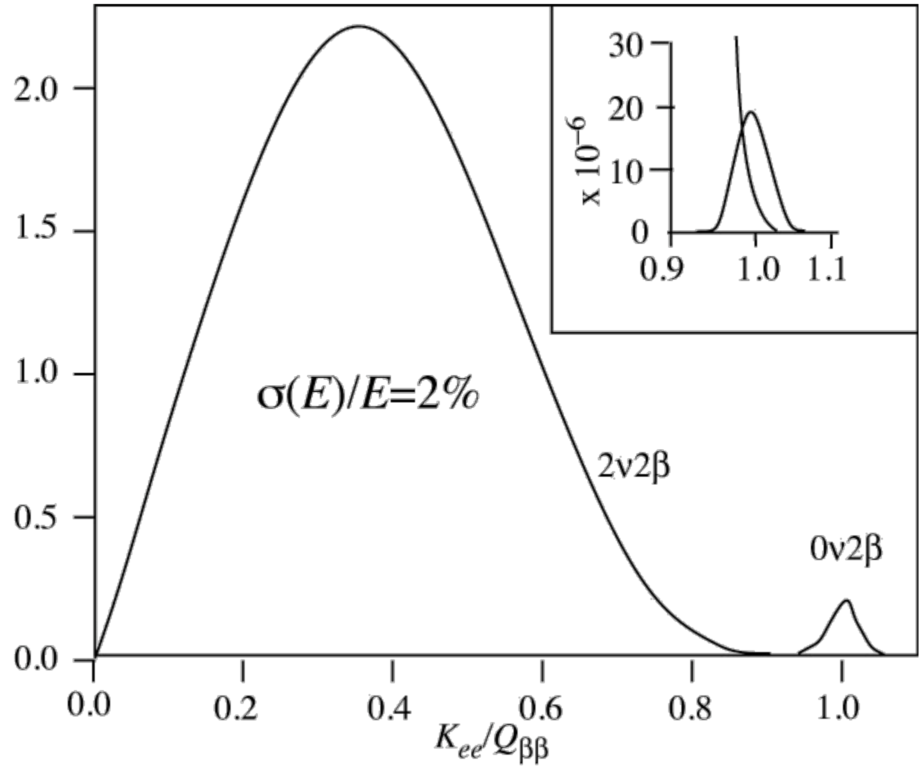
$$F_M \propto \sqrt[2]{MT}$$

The fraction of ββ2ν events in Δ*E* near end point is

$$F \simeq \frac{7\left(\Delta E\right)^6}{m_e Q_{\beta\beta}^5}$$

0ν2β signal/ 2ν2β background

$$\frac{S}{B} \simeq \frac{m_e Q_{\beta\beta}^5}{7\left(\Delta E\right)^6}\frac{T_{1/2}^{2\nu}}{T_{1/2}^{0\nu}}$$



Background free condition and and energy resolution are the key features

For M_{ee}≈ 10 meV need 1 t source mass <u>AND</u> $b\Delta E$≈10^{-4} cts/(kg keV yr)

Double Beta Decay

Energy of the signal known exactly $O(10^{-4})$

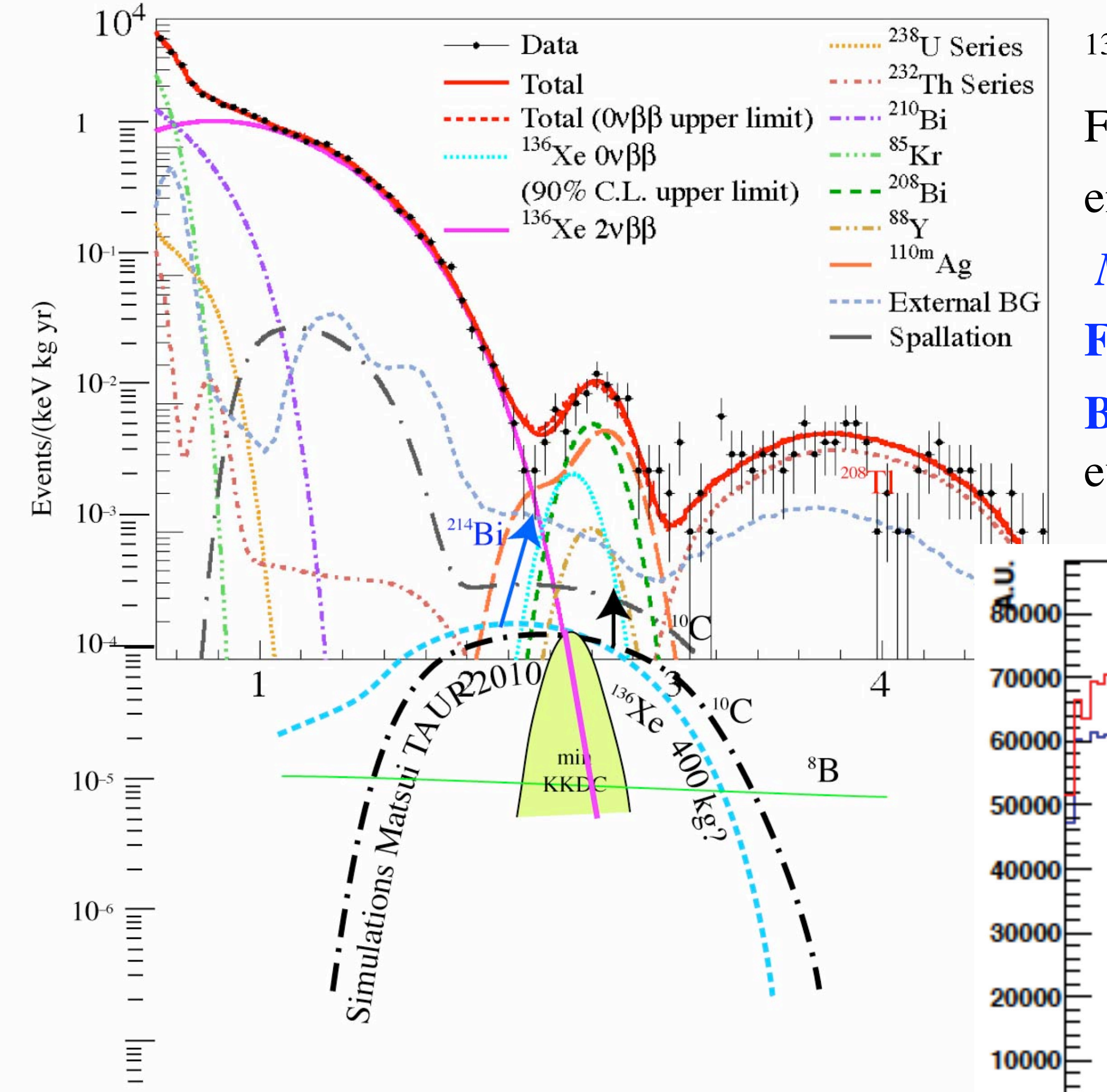
Need to explore different isotopes

Main experimental challenges

- **Energy resolution (<1% FWHM)**
- **Reduce background to "zero"**
- **Isotope fiducial mass**
- **"No" surface near fiducial mass**

EXPERIMENTS		**(BI in cts/(keV kg yr)**
GERDA	^{76}Ge	**Running (BI=1.7 10^{-2}, 14.6 kg, FWHM = 0.23%)**
EXO	^{136}Xe	**Running (see later)**
KmlZEN	^{136}Xe	**Running (see later)**
CUORE	^{130}Te	**commiss. 2015 (BI≤26 10^{-2}, 203 kg, FWHM = 0.2-0.4%)**

KamlandZEN – ^{enrich}Xe in scintillator



^{136}Xe doped liquid scintillator (Raghavan)

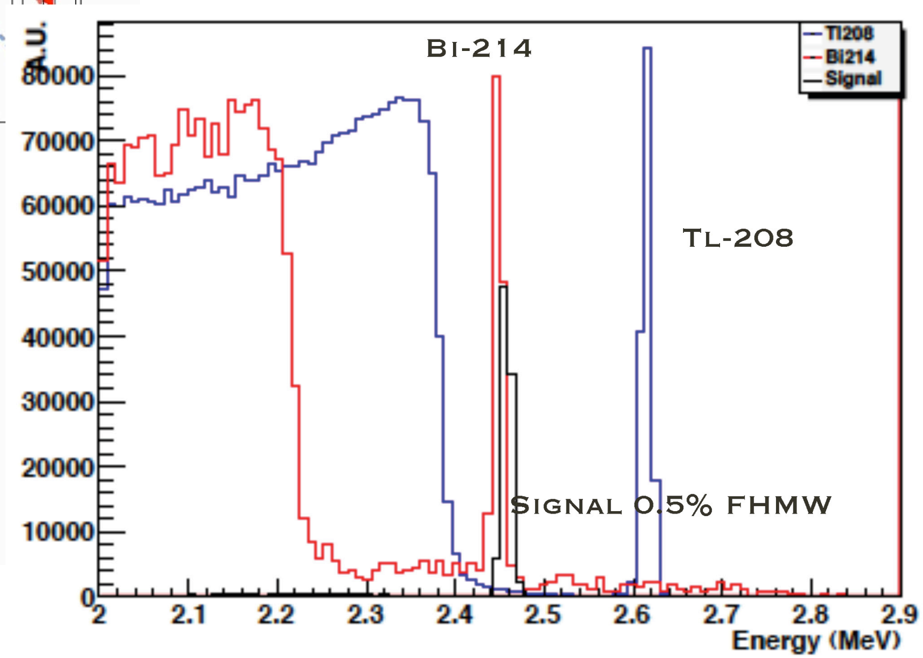
Fiducial volume by reconstructing event

enriched ^{136}Xe: **129 kg fid**/300 kg

***MT* = 27.4 kg yr**

FWHM = 10%

BI≈2 10^{-2}/(keV kg yr), originally under-evaluated



EXO 200: Liquid ^{enr}Xe TPC

Liquid enriched (80%) ^{136}Xe TPC

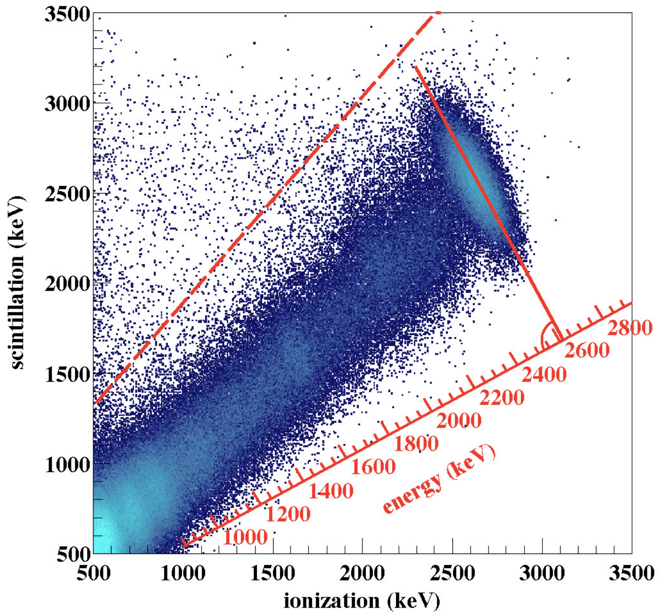
***M* = 79.4 kg fid**

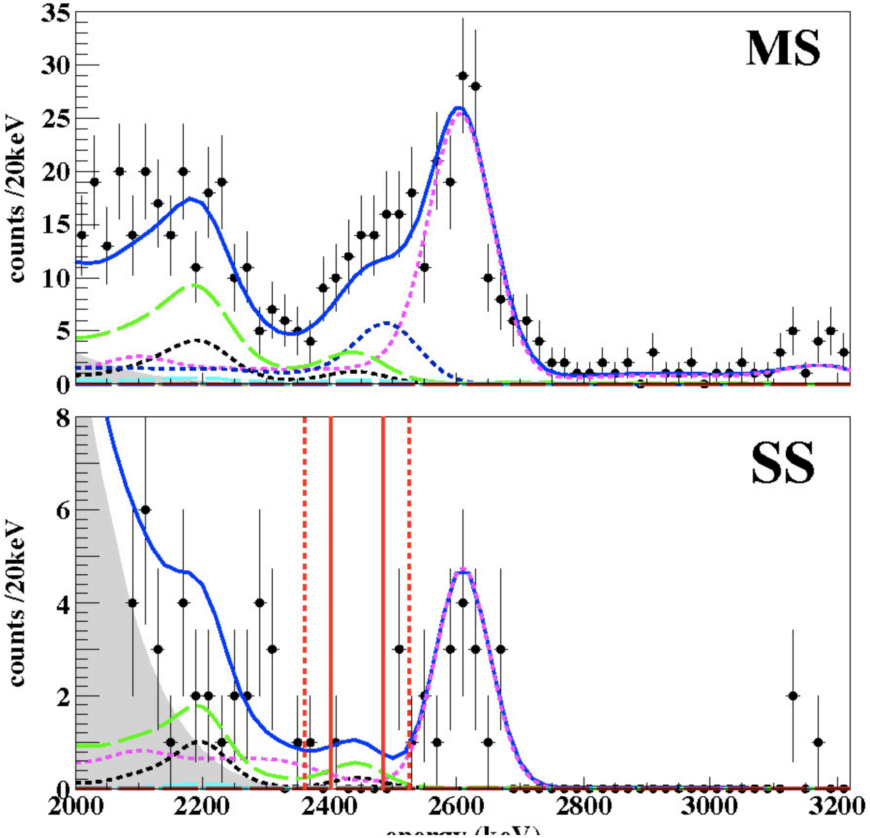
***MT* = 32.5 kg yr**

Energy measured from ionisation & scintillation:

FWHM = 4% @ $Q_{\beta\beta}$

BI= (1.5±0.1)10^{-3}/(keV kg yr)



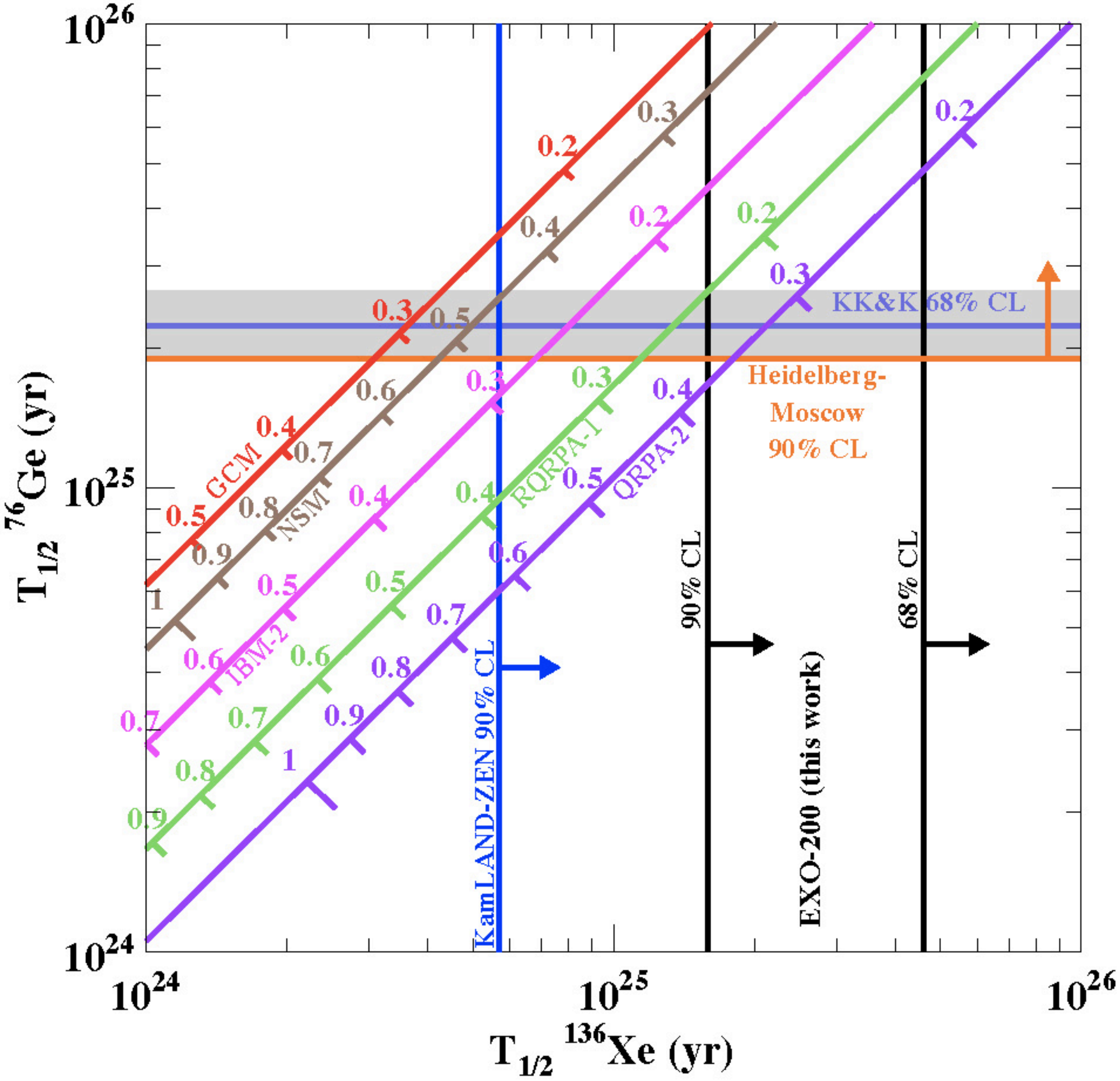


$T_{1/2} > 1.6\ 10^{25}$ yr (90%)

$M_{ee} > 150 - 380$ meV

arXiv 1205.560

76 GE VS 136 Xe



Energy resolution and Background index matter

NEXT Collaboration & Schedule

U. Girona • IFIC (Valencia) • U. Santiago de Compostela • U. Politécnica Valencia • U. Zaragoza• U. A. Madrid

LBNL • Texas A&M• John Hopkins

CEA (Saclay)

U. Coimbra • U. Aveiro

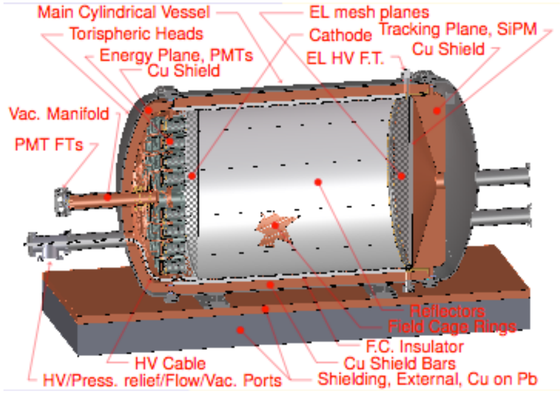
JINR (Dubna)

UAN (Bogotá)

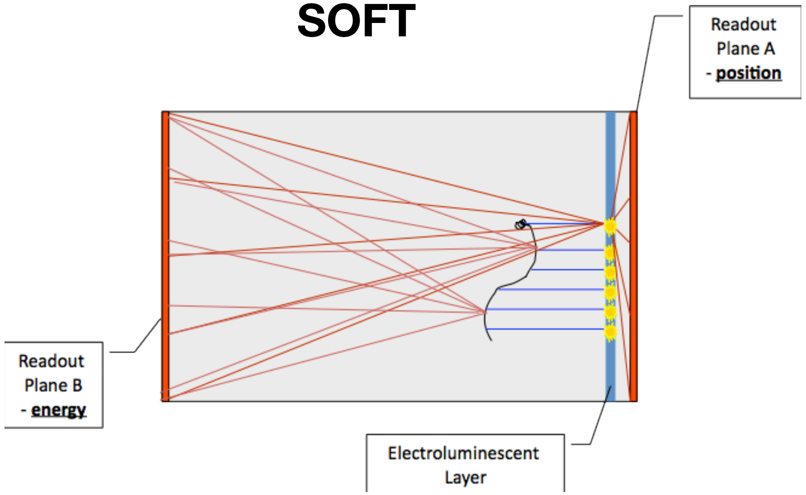
- CDR submitted in spring 2011
- TDR submitted in spring 2012
- Construction and commissioning 2012—2013.
- Running in 2014

NEXT Concept

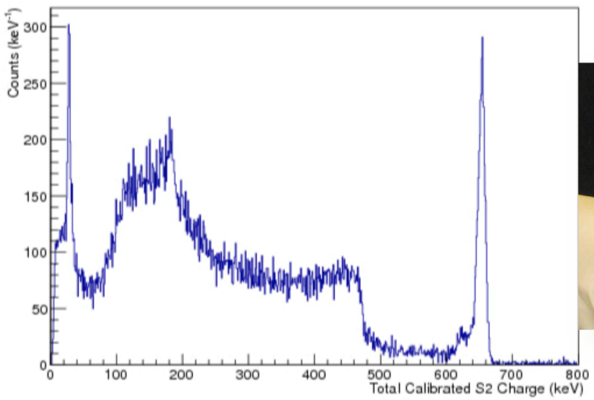
HPGXe

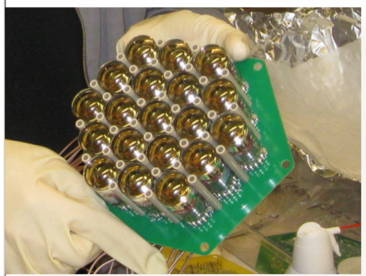


SOFT

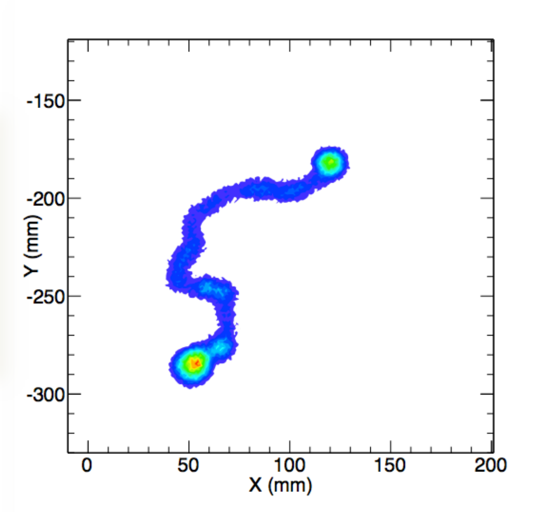


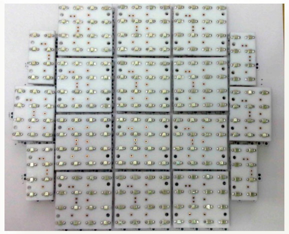
Energy resolution



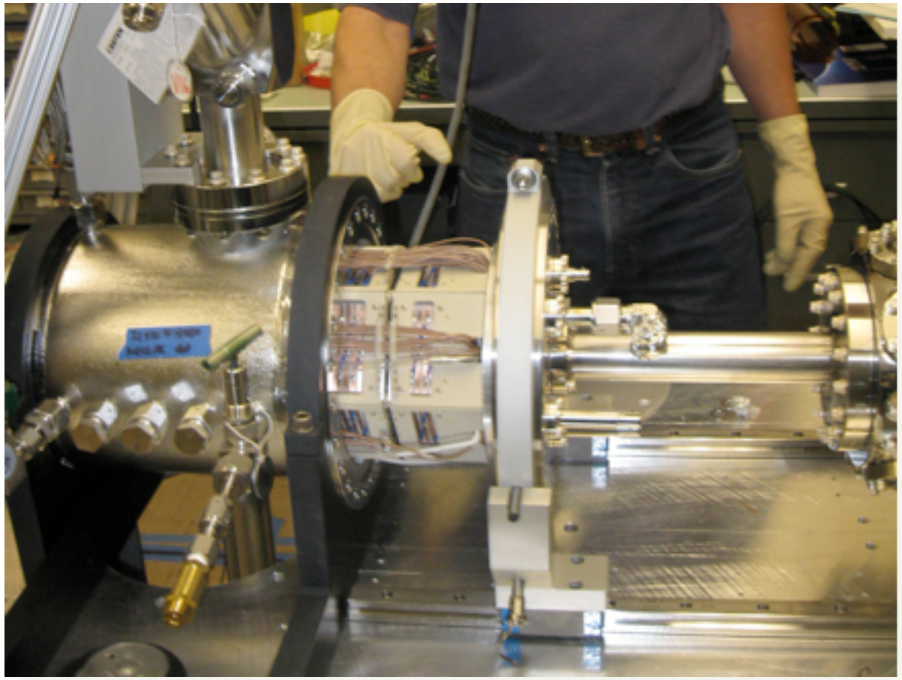


Topological signature





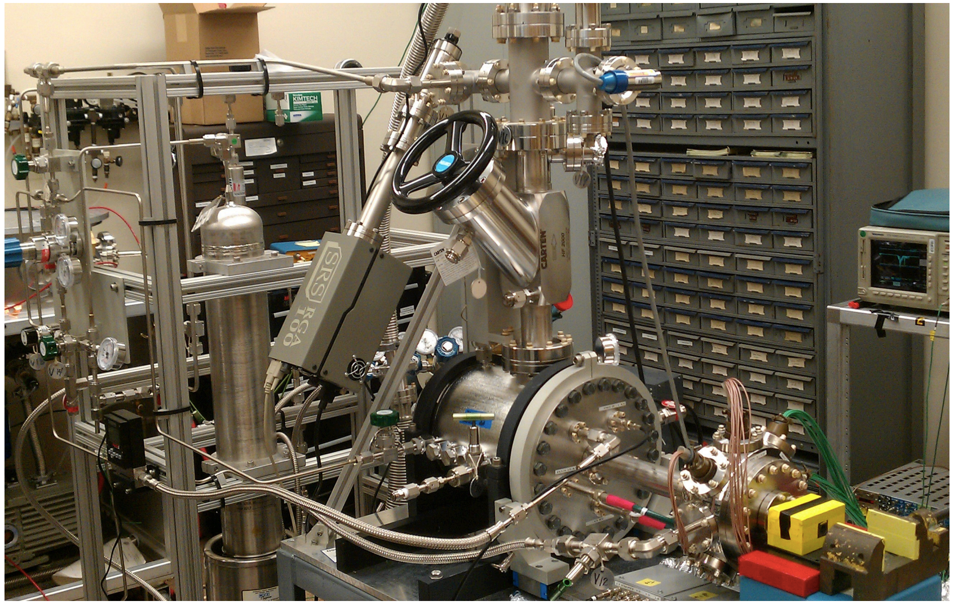
EL Prototypes

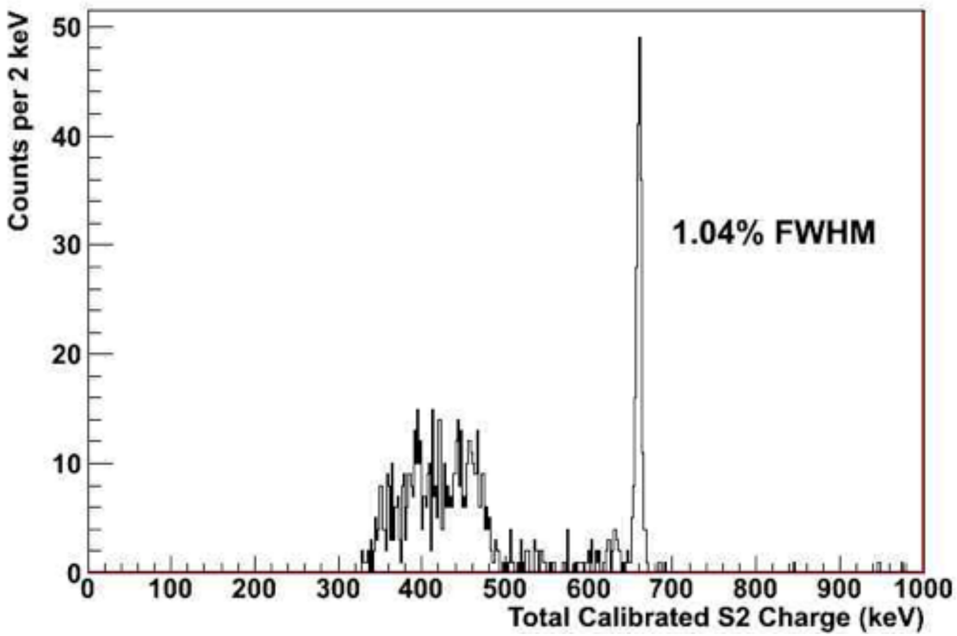


NEXT-DBDM

NEXT-DEMO

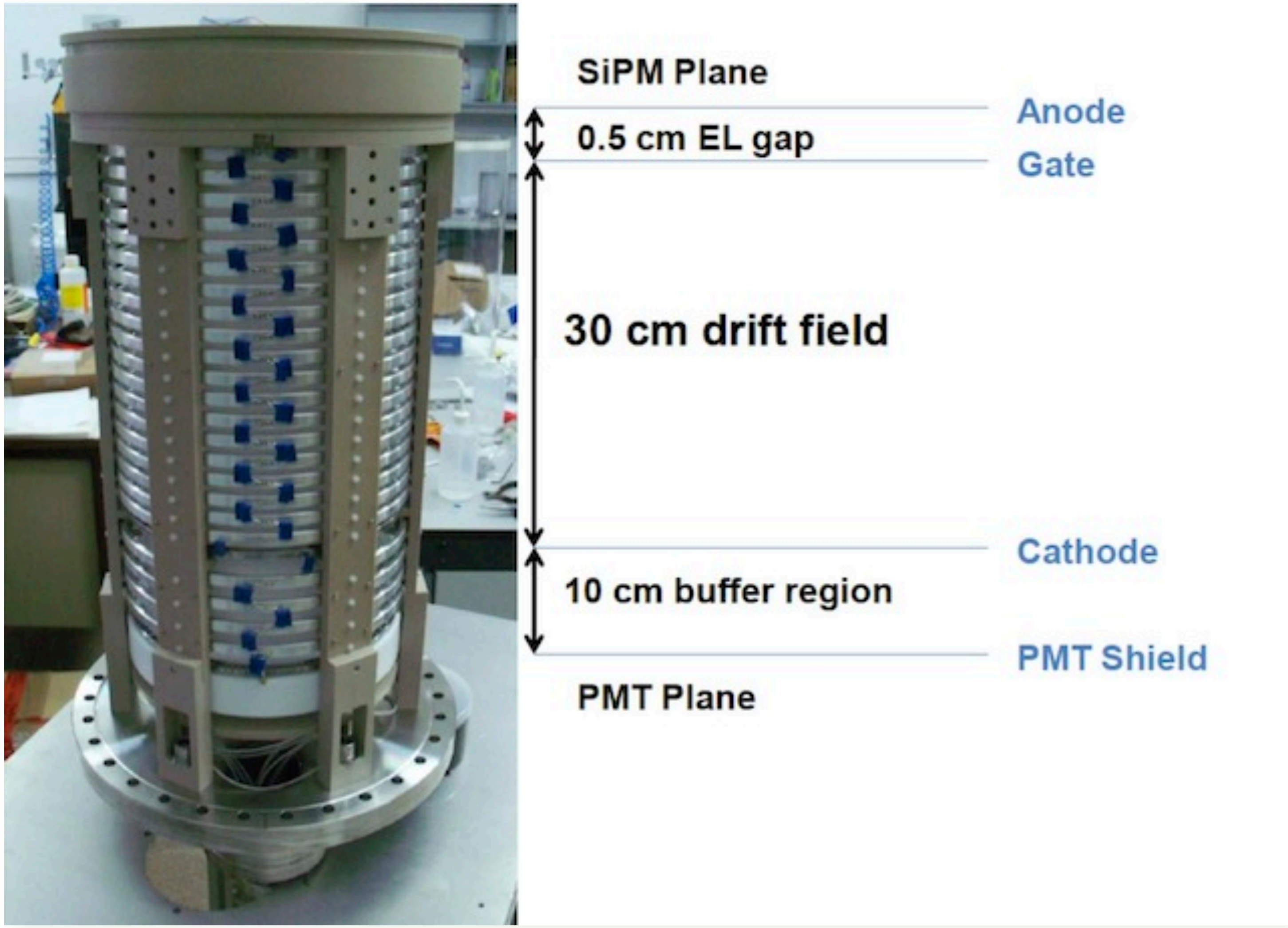
NEXT-DBDM. Energy resolution



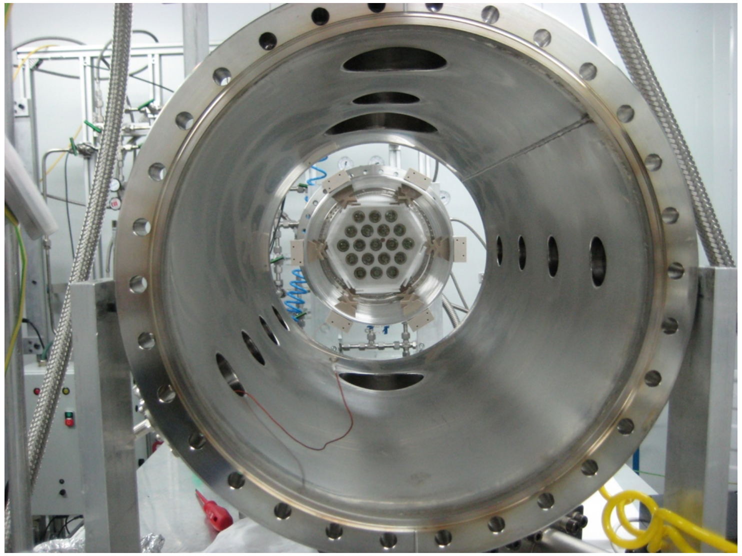


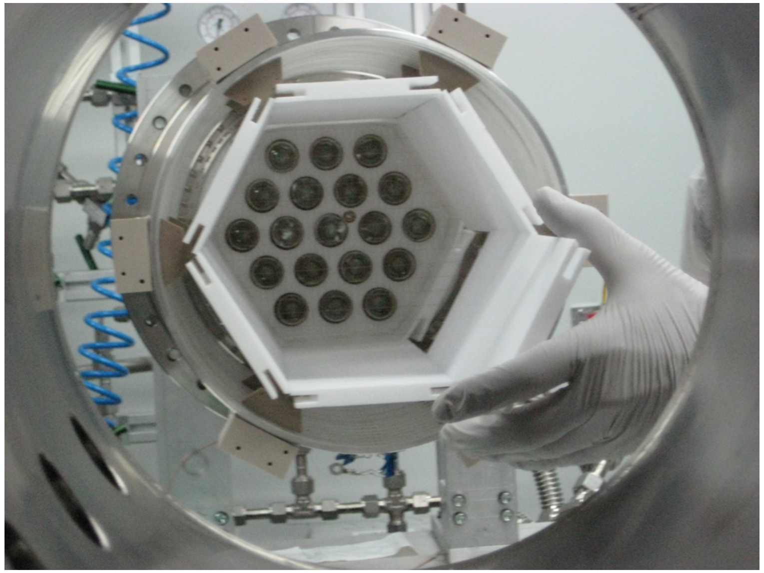
NEXT-DBDM obtains an extraordinary energy resolution: 1.04% at Cs-137 peak (about 0.53% @ Qbb)
No tracking yet. Impose hard fiducial cut which in practice selects only events in the center of the chamber.

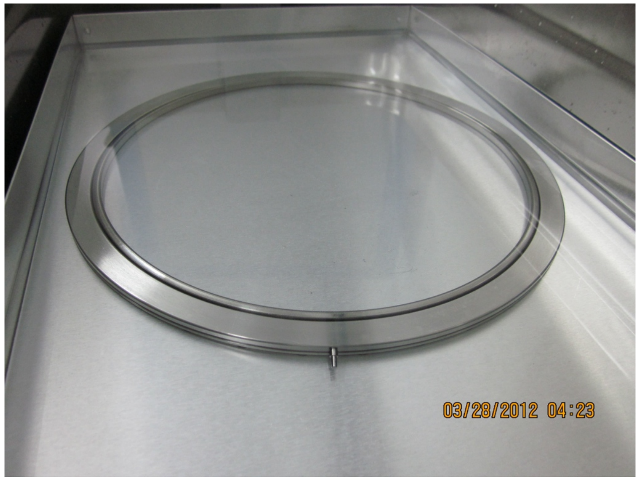
NEXT-Demo


SiPM Plane
Anode
0.5 cm EL gap
Gate
30 cm drift field
Cathode
10 cm buffer region
PMT Shield
PMT Plane

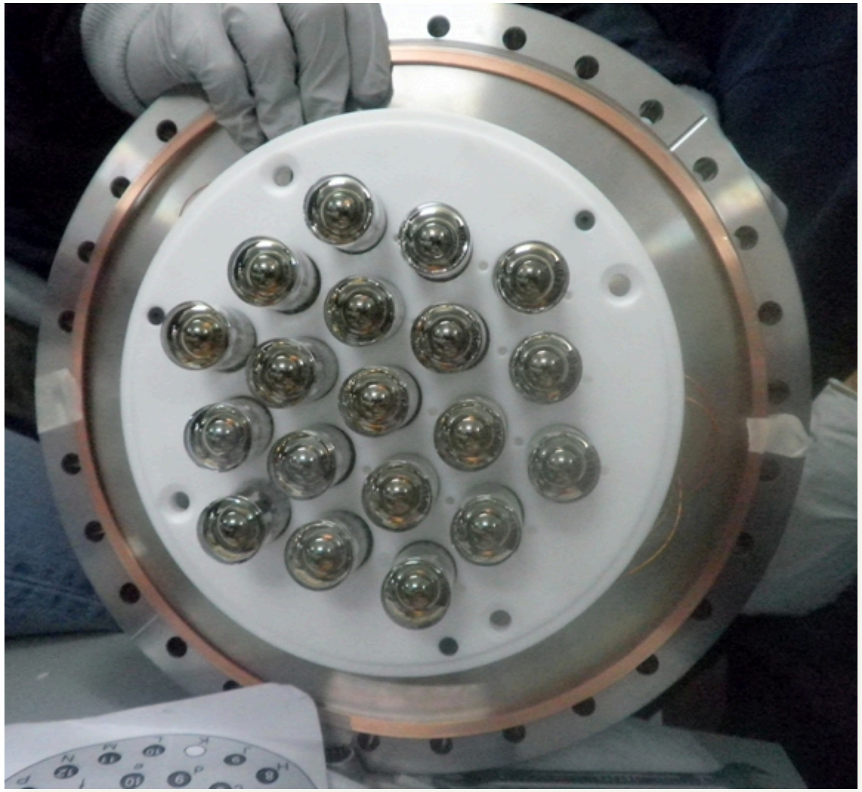
NEXT - Demo

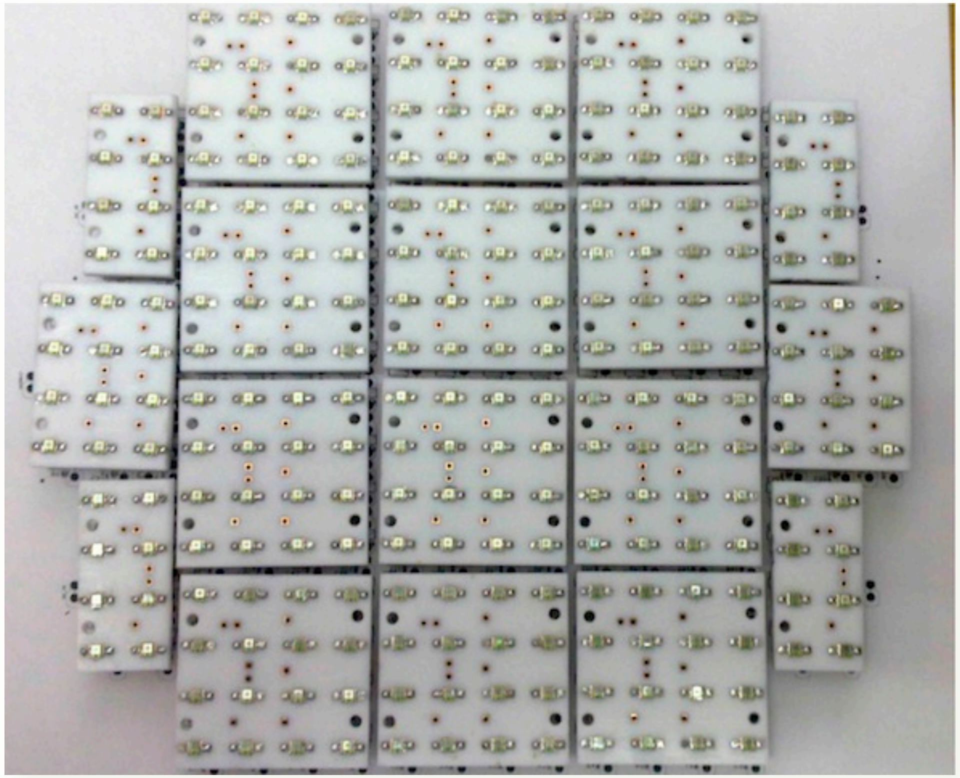




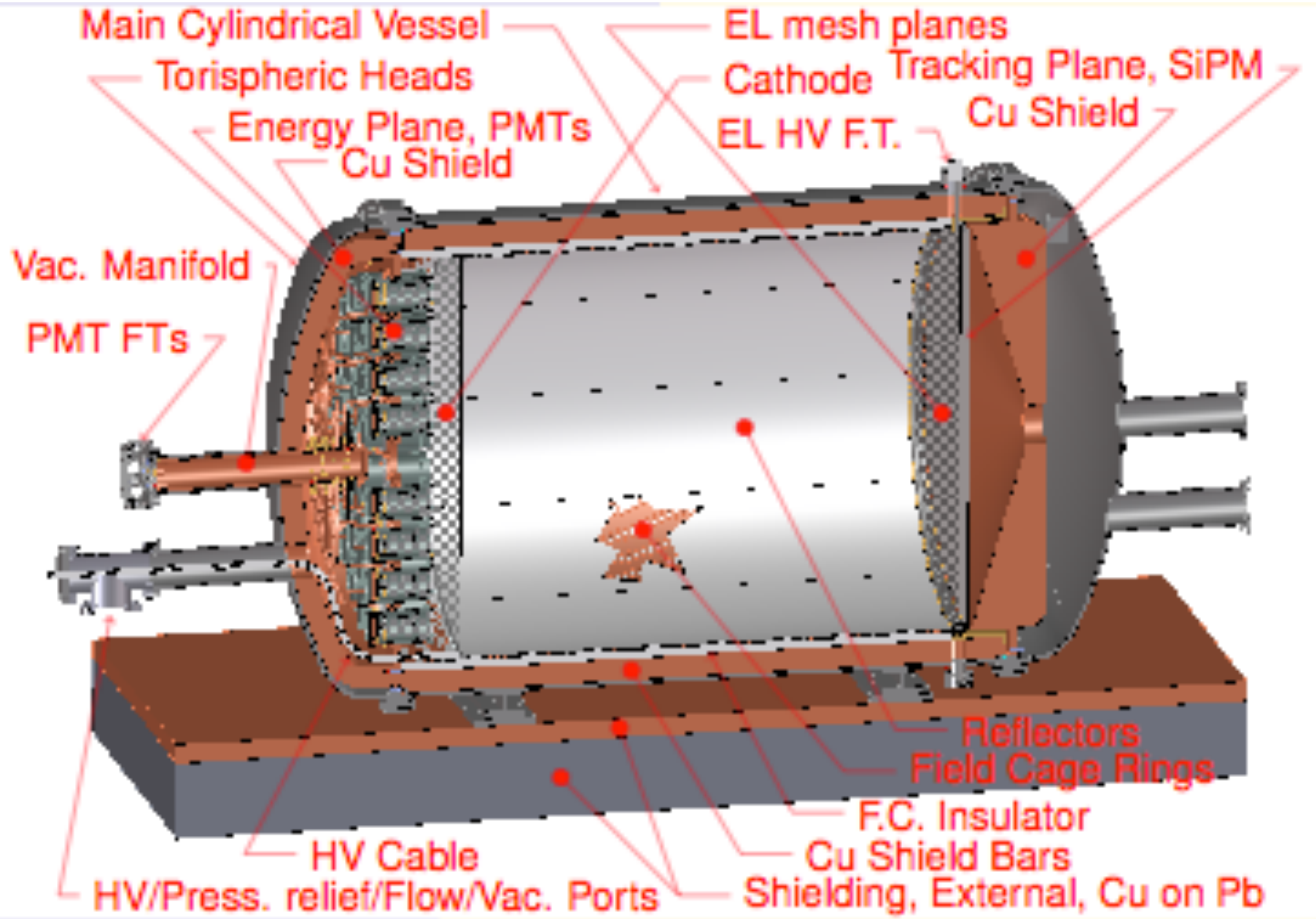


NEXT - Demo

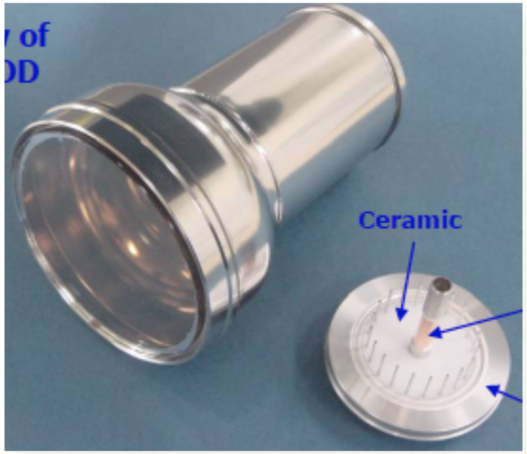




NEXT - 100

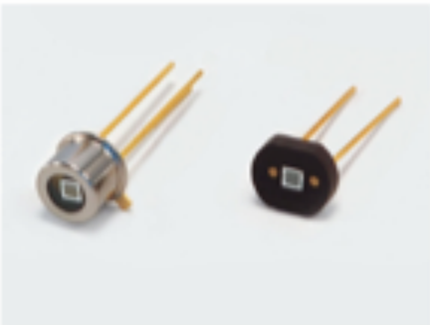

Main Cylindrical Vessel
Torispheric Heads
Energy Plane, PMTs
Cu Shield
Vac. Manifold
PMT FTs
EL mesh planes
Cathode
Tracking Plane, SiPM
Cu Shield
EL HV F.T.
Reflectors
Field Cage Rings
F.C. Insulator
Cu Shield Bars
Shielding, External, Cu on Pb
HV Cable
HV/Press. relief/Flow/Vac. Ports

NEXT Sensors



PMTs for calorimetry and start-of-event

- Excellent charge resolution and linearity, single-pe detection, large dynamic range, etc.
- Favorite candidate: Hamamatsu R1141MOD.
- No. channels ~60.



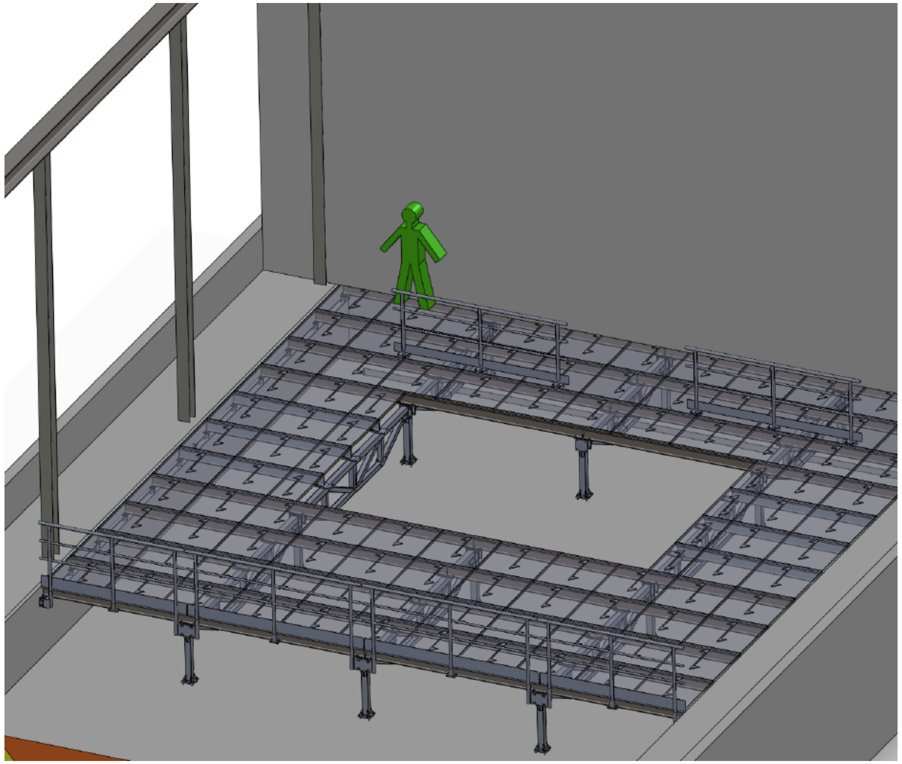
MPPCs for tracking:

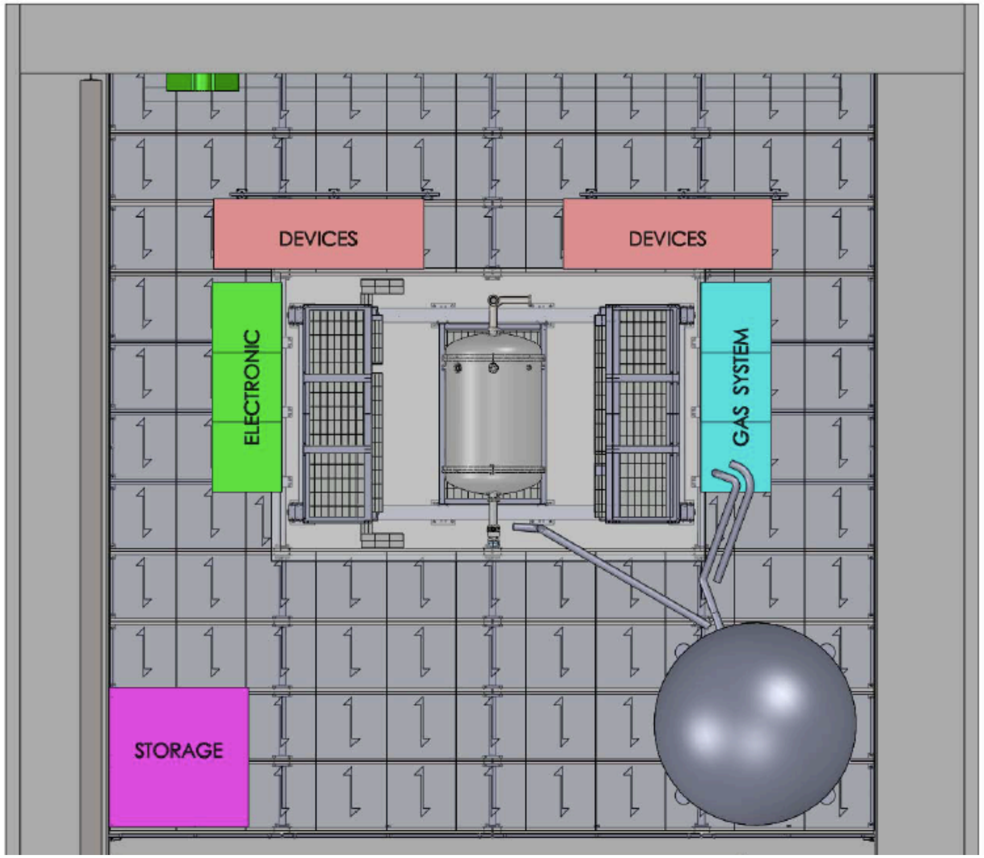
- Fine pixelization (~1cm pitch), low cost, some energy information.
- No. channels ~7500

Enriched ^{136}Xe (100kg) and depleted

Completely delivered in June 2011

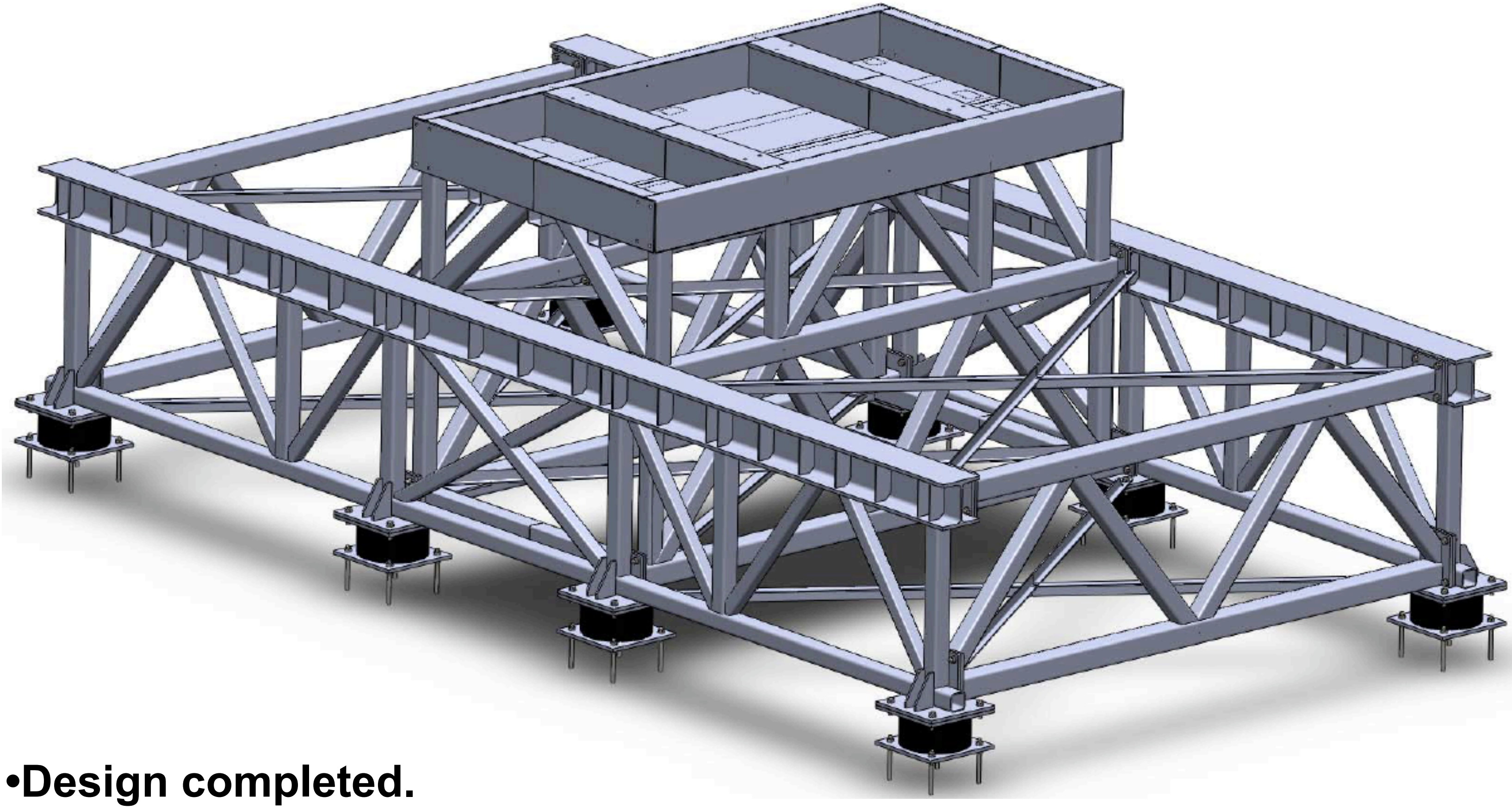
NEXT Infrastructures in hall A





- Platform under construction
- Gas system under construction
- Planning integration

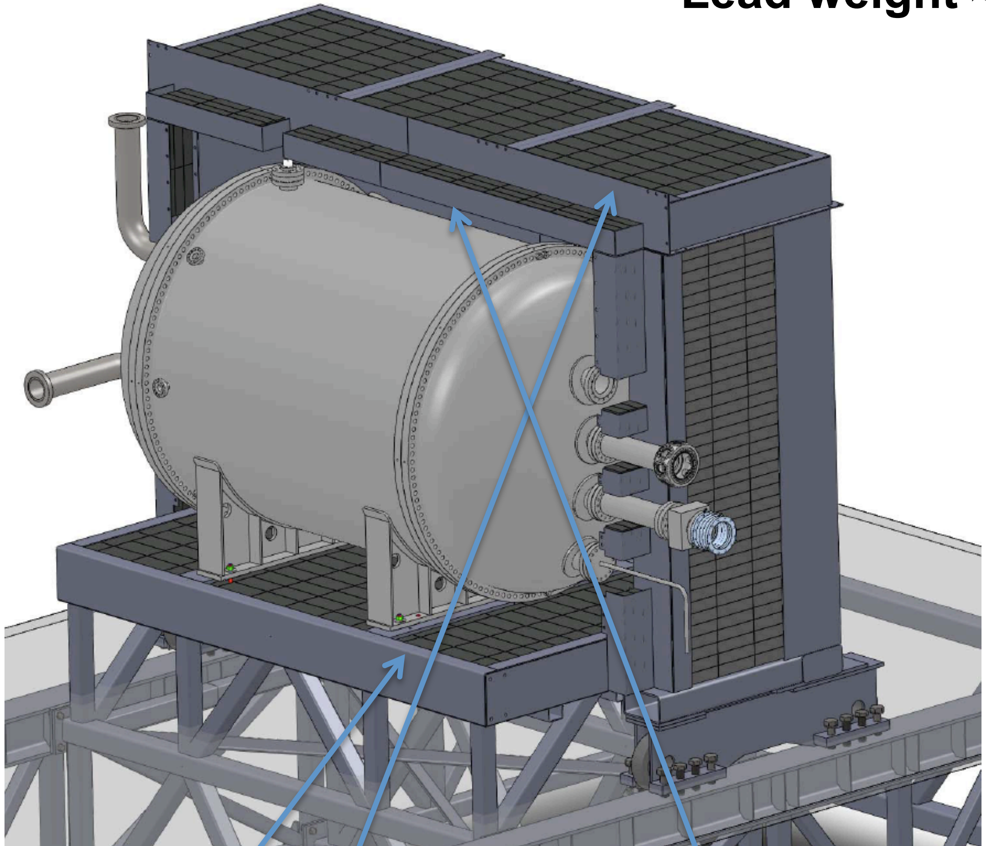
NEXT Seismic platform

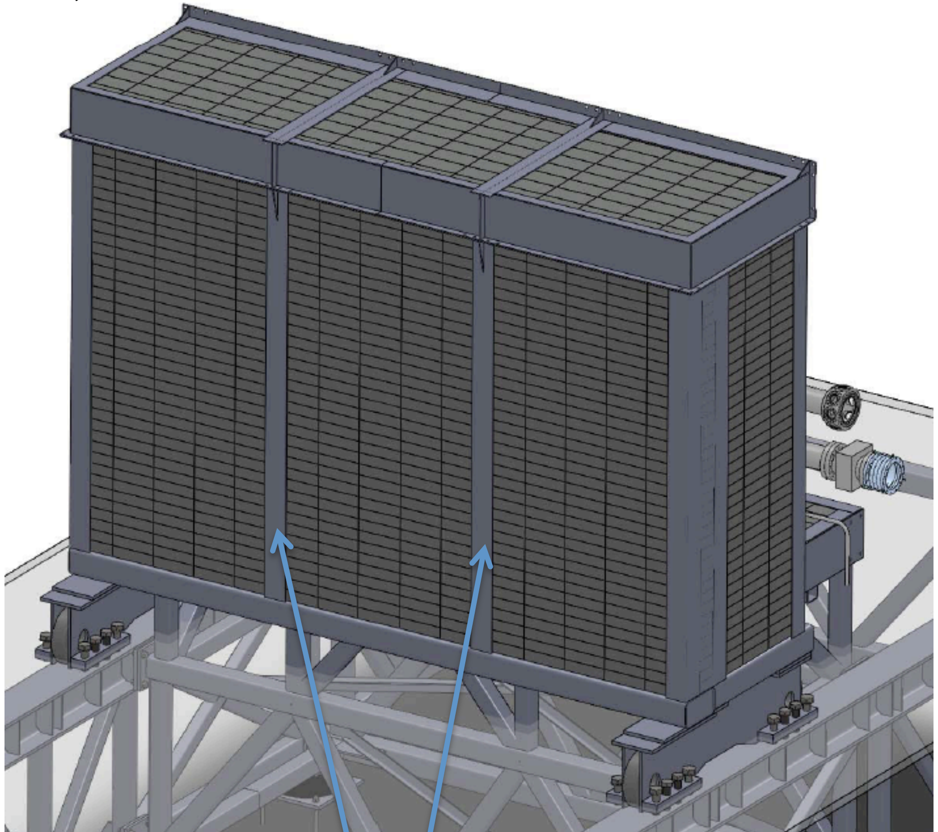


- Design completed.
- To be reviewed by LSC.
- Construction completed before the end of the year or early 2013

NEXT. Lead castle

Lead weight ≈ 58,2 t





Steel boxes for lead bricks

Structural steel shell inside the castle

Steel structures outside the castle

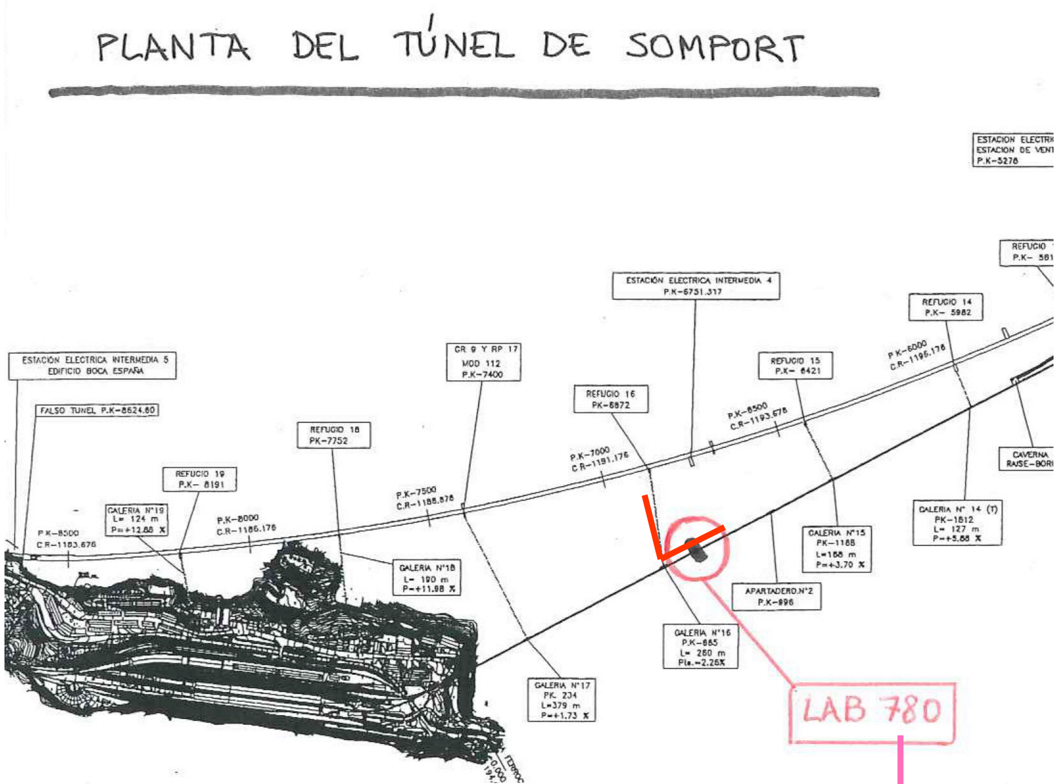
Risk analysis to be done

NEXT Performance

	Signal	^{214}Bi	^{208}Tl
1 track cut	0.48	6.0×10^{-5}	2.4×10^{-3}
ROI	0.33	2.2×10^{-6}	1.9×10^{-6}
Topological cut	0.25	1.9×10^{-7}	1.8×10^{-7}

Rejection Potential	$\sim 10^{-7}$
Background	2.0×10^{-4} counts/keV/kg/yr

GEODYN



Lab 780 L GEODYN

Accelerometers working

Interferometer working

Gallery 16

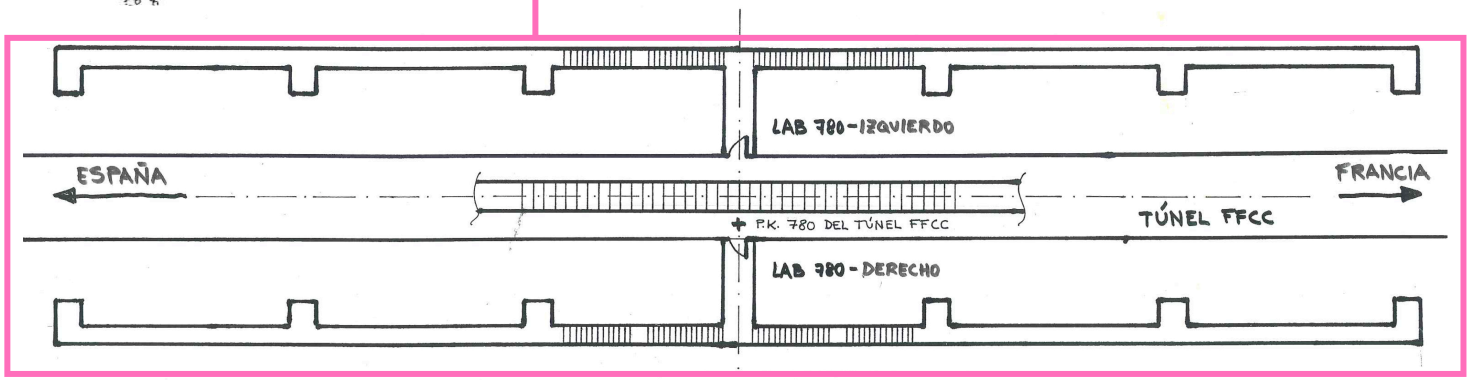
Interferometer working

GPS time

Installed

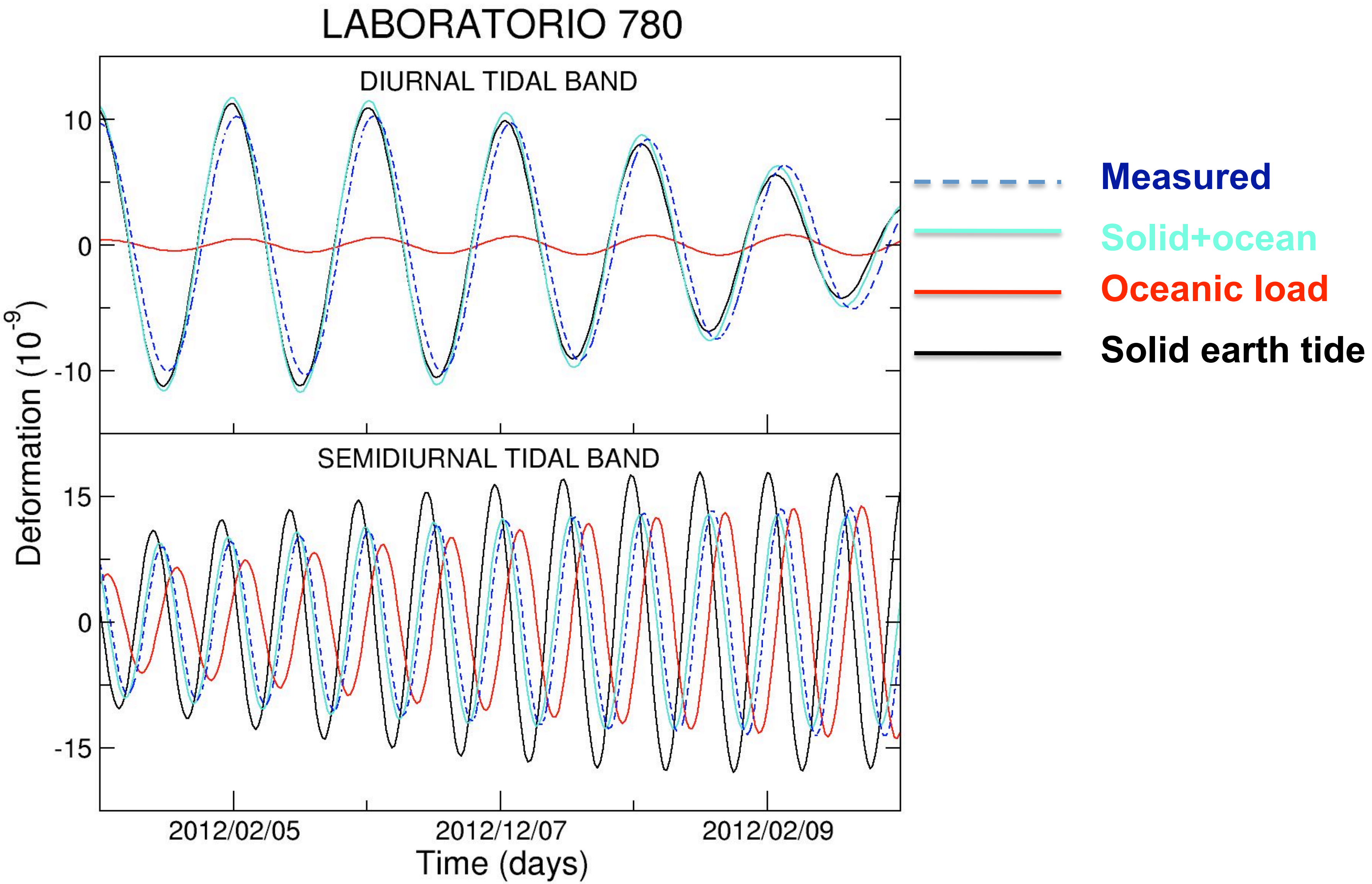
2 GPS position measurement stations

Surface sites identified. Permissions requested

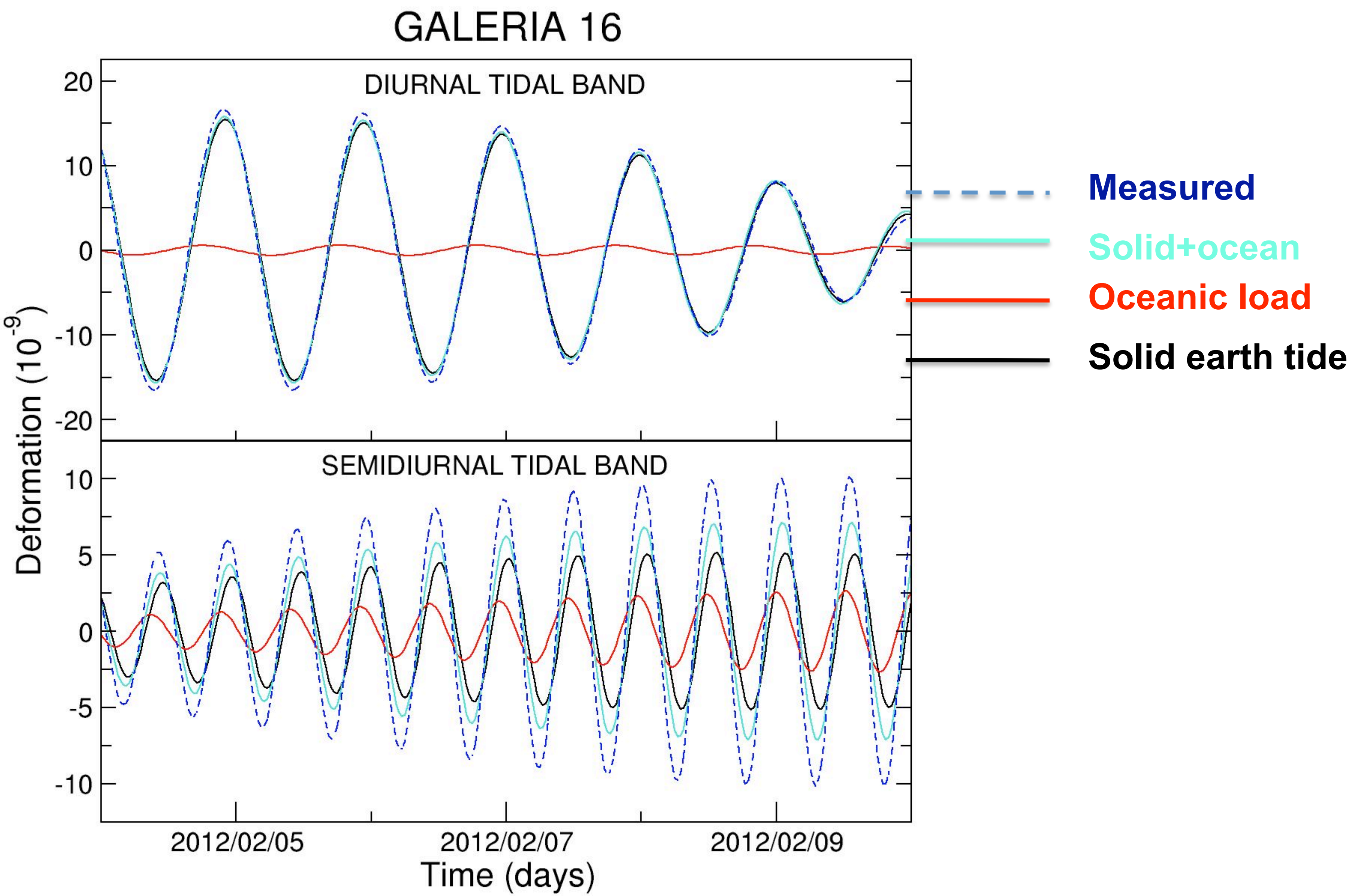


GEODYN Interferometers

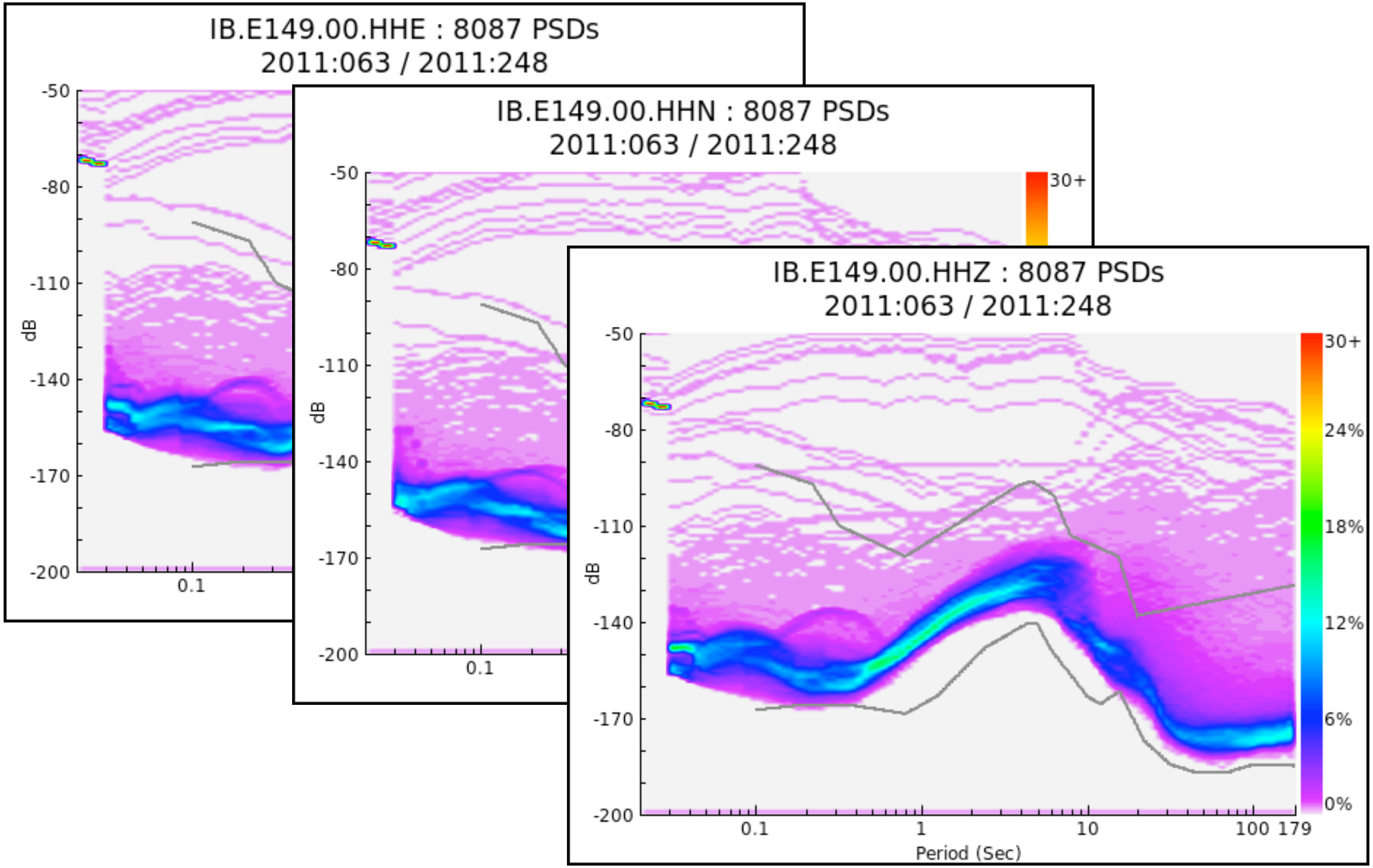
Tides


LABORATORIO 780
DIURNAL TIDAL BAND
SEMIDIURNAL TIDAL BAND
Deformation (10^{-9})
10
0
-10
15
0
-15
2012/02/05
2012/12/07
2012/02/09
Time (days)
Measured
Solid+ocean
Oceanic load
Solid earth tide

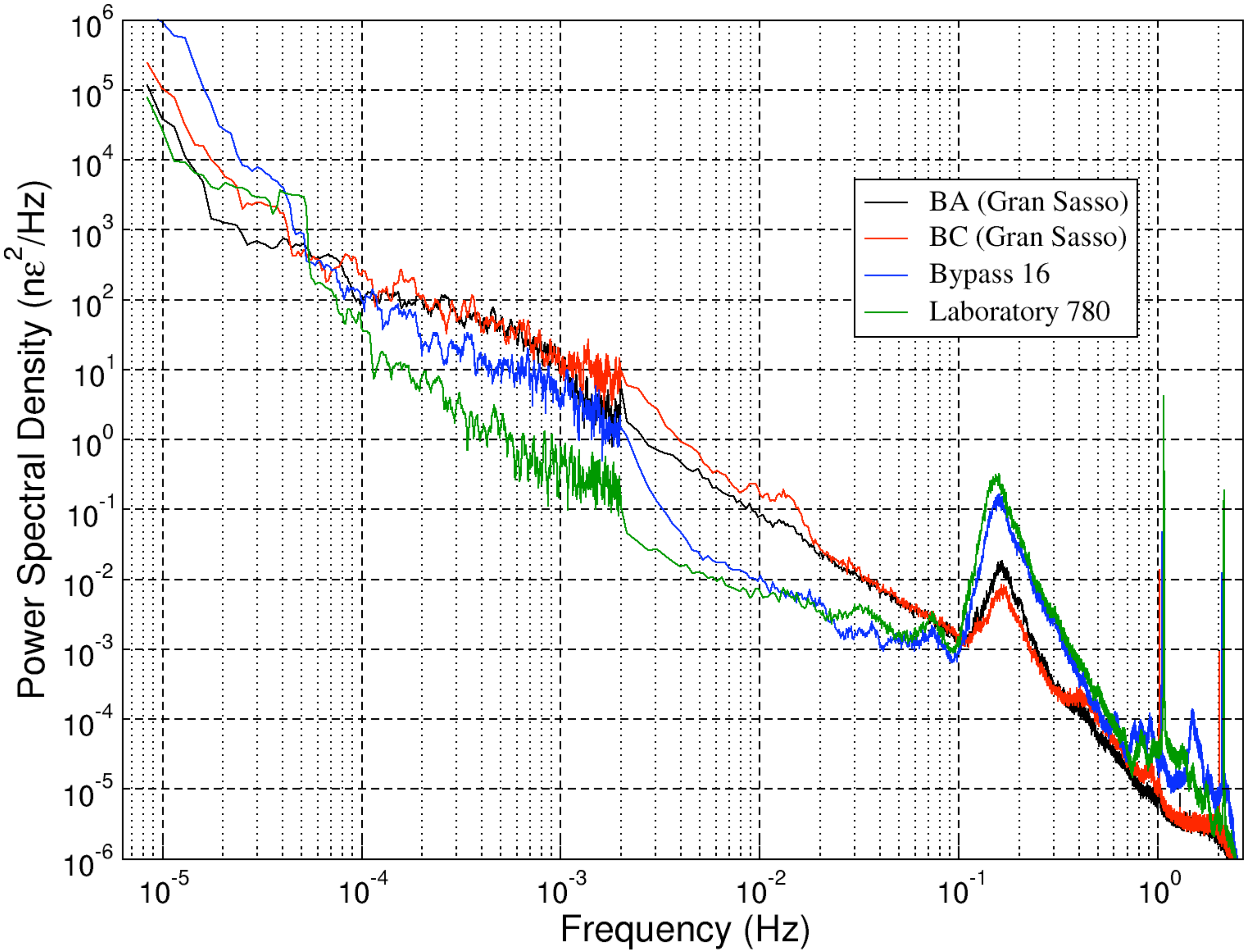
Tides


GALERIA 16
DIURNAL TIDAL BAND
SEMIDIURNAL TIDAL BAND
20
10
0
-10
-20
5
-5
Deformation (10^{-9})
2012/02/05
2012/02/07
2012/02/09
Time (days)
Measured
Solid+ocean
Oceanic load
Solid earth tide

Quality control of ambient noise
3-component BB sensor



Quality control of ambient noise
Interferometers




Thank you