Dominique Thers
Laboratoire SUBATECH
In2p3 Scientific Committee
25/10/2012

Direct Dark Matter search with the XENON1T experiment ?

Direct Dark Matter Search in the world

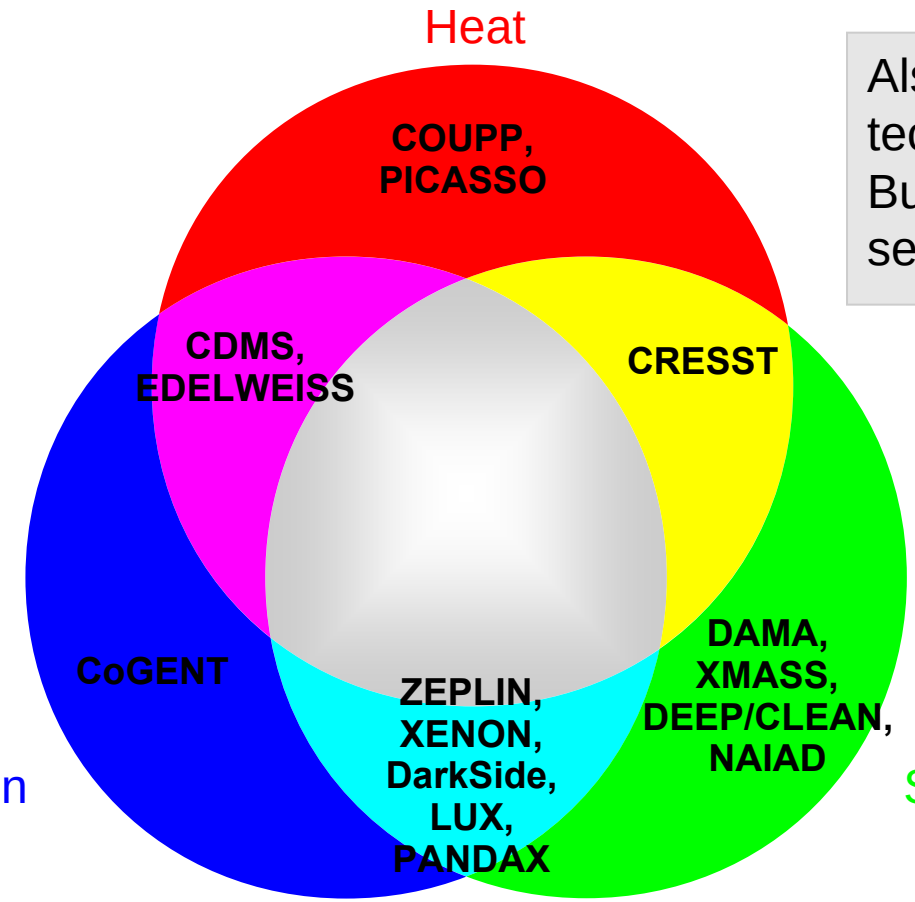
Using xenon

French participation

> 1000 Researchers in 2012 ?

Detection techniques

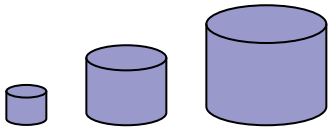
Various targets are used (Ge, Xe, Ar, Ne, . . .)
Energy recoil is transferred to three possible phenomena:
scintillation, **ionization**, **heat**
One (or two) among these three signals are used for particle detection.



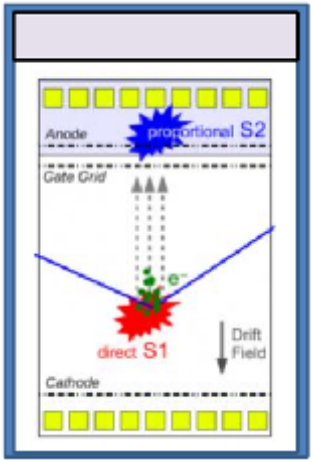
Also searched with indirect techniques and accelerators.
But direct search is the most sensitive method …

The XENON Dark Matter program

Science Objective : Explore WIMP Dark Matter with a sensitivity to Spin Independent cross section < $2 \cdot 10^{-47}$ cm^2



Strategy : Phased program with detectors of increasing target mass (from O(10), to O(100), to O(1000) kg) and parallel studies on increasing light detection sensitivity and decreasing the overall background

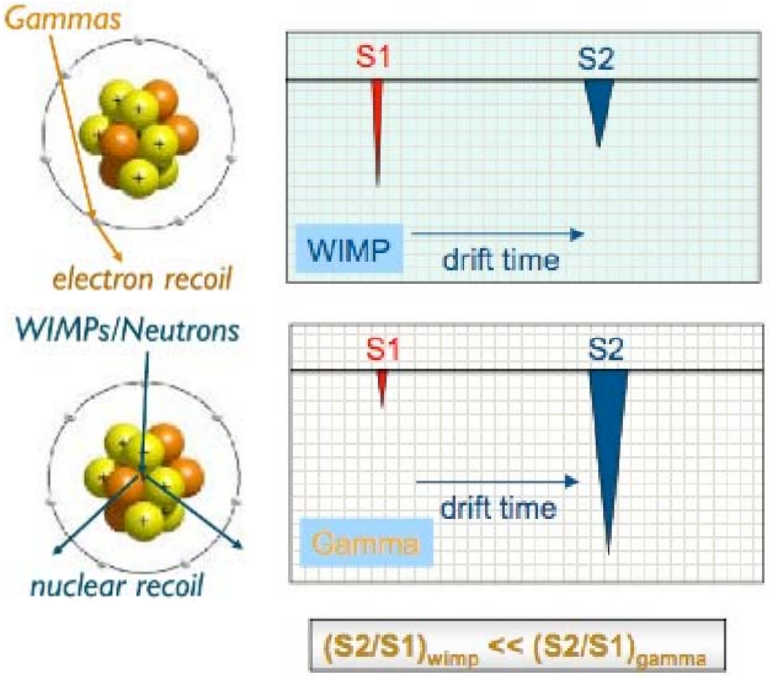


Detection technique : LXe (sensitive to both scalar and axial coupling) two-phase LXe TPC with simultaneous charge and light detection via PMTs with low radioactivity and QE > 30% at 178 nm.

Background Reduction and Signal Discrimination : LXe self-shielding; fiducial volume selection thanks to 3D reconstruction; ER/NR distinguished via charge/light ratio

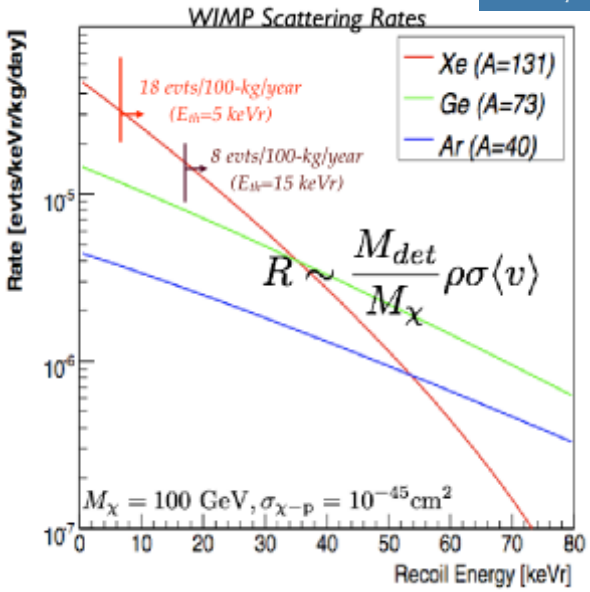
Advantages of two-phase xenon TPC principle

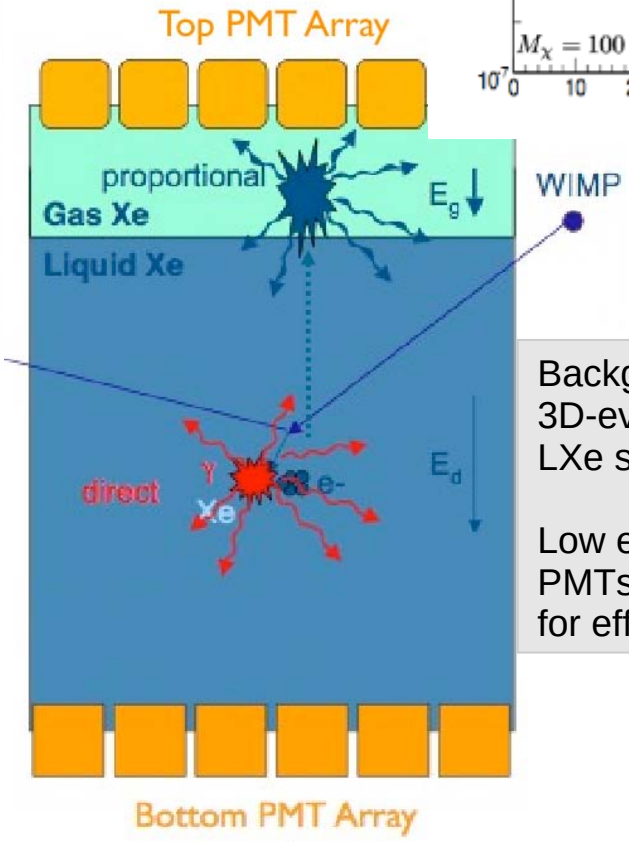
Background rejection: charge-to-light ratio



Charge & Light:
highest yield among noble liquids and best self-shielding

Big nucleus (A~131): good for SI + SD sensitivity





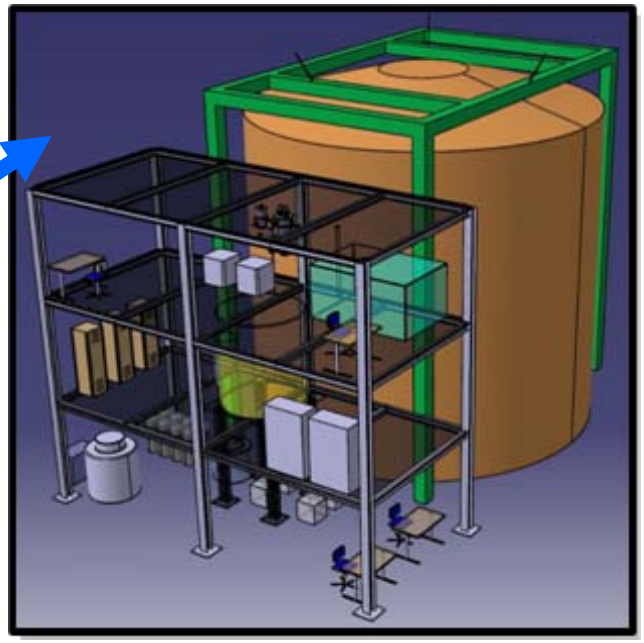
Background rejection:
3D-event imaging,
LXe self-shielding

Low energy threshold:
PMTs within liquid
for efficient light detection

Scalability: massive target at modest cost

Intrinsically pure: no long-lived radioactive isotopes

The XENON Dual Phase TPC scalability



XENON10
Achieved - 2007
$\sigma_{SI} = 8.8 \cdot 10^{-44}$ cm^2

XENON100
From 2008 until now

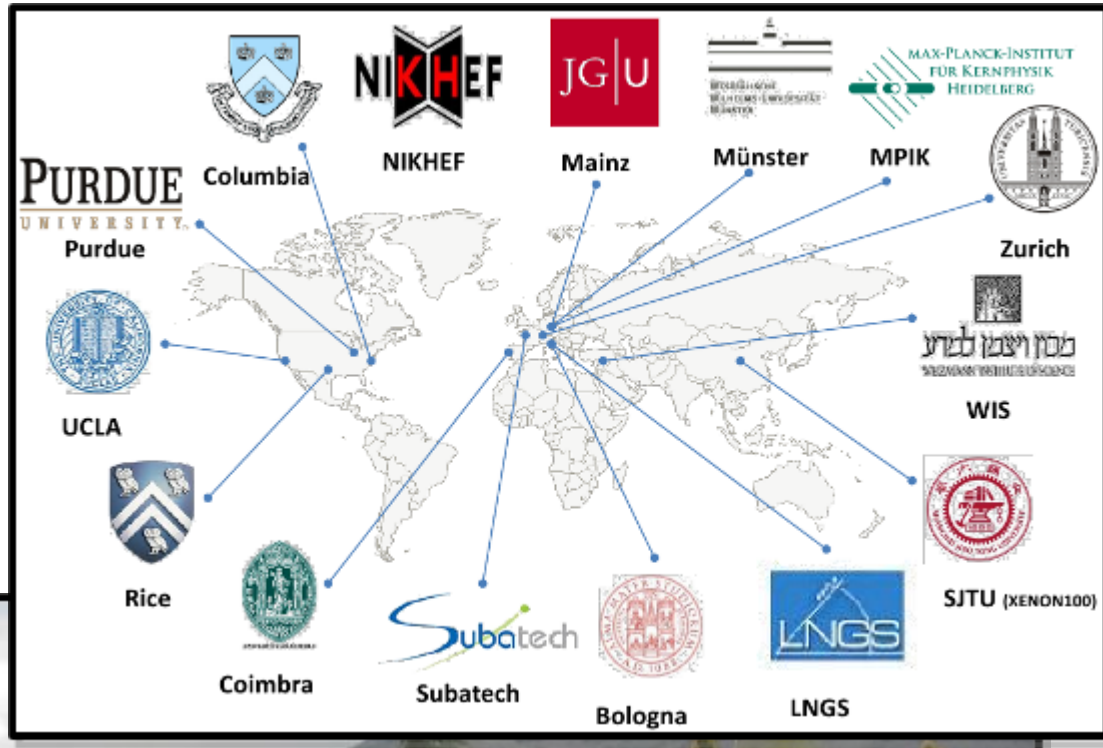
XENON1T
Projected - 2015

People

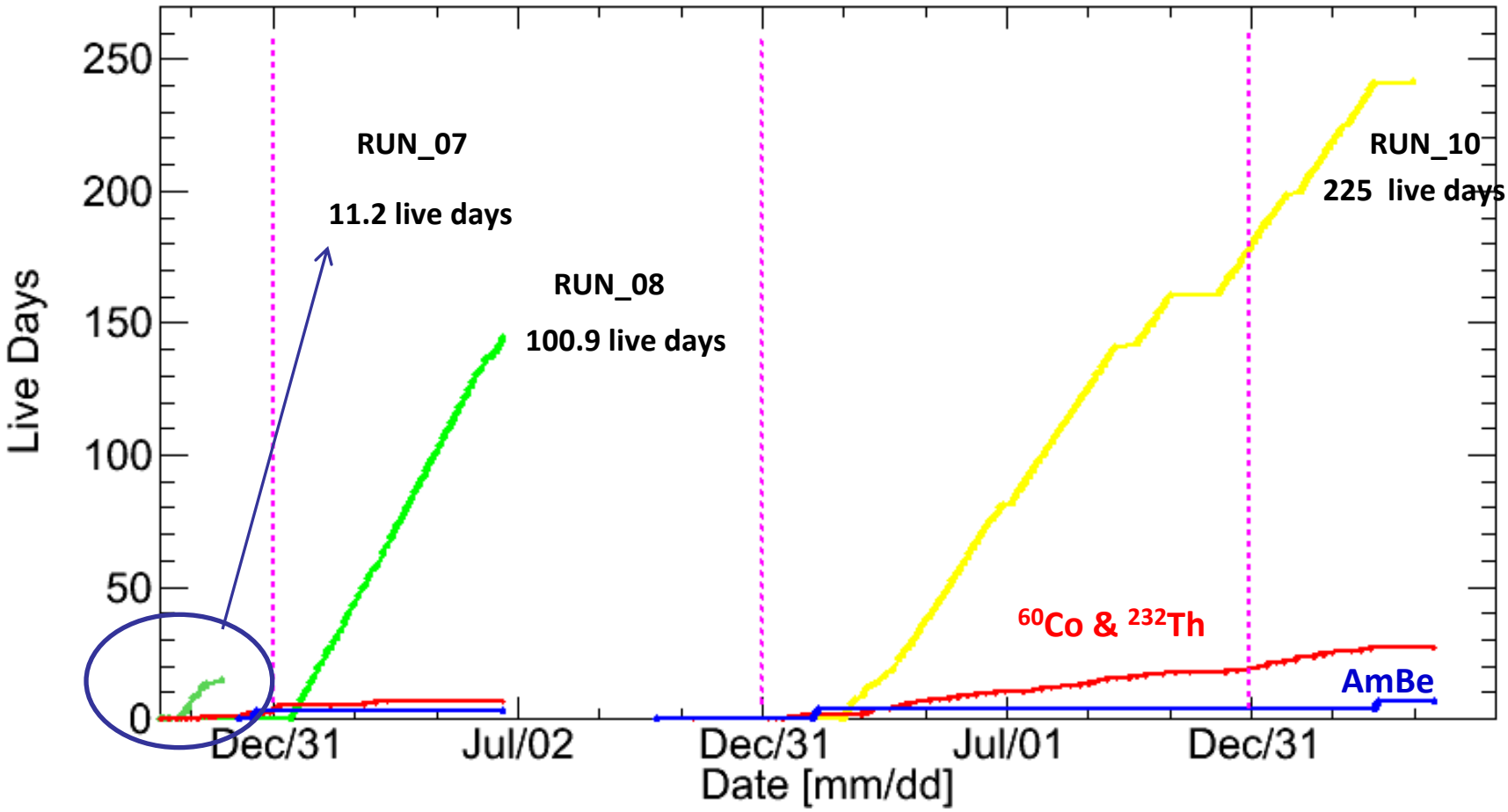
The XENON Collaboration

15 Institutes ~ 100 members today

Subatech joined in 2009 (XENON100 has been constructed in 2007-8)



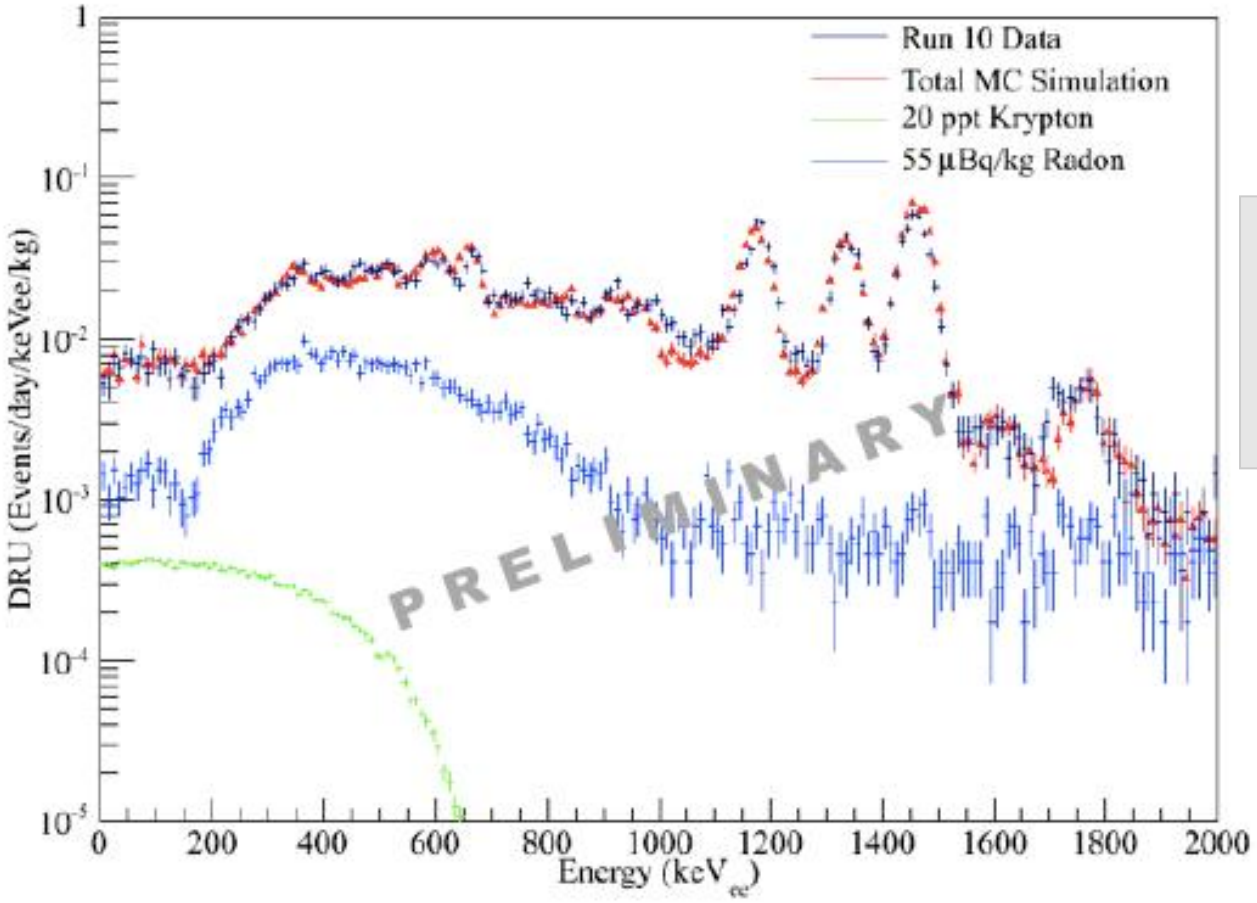
XENON100 run 10



Weekly γ calibration with ^{232}Th and ^{60}Co
n calibration with AmBe before and after the run10

Run 10 : from Feb. 28, 2011 to March 31, 2012
For 224.56 live days of DM data

Background in run 10

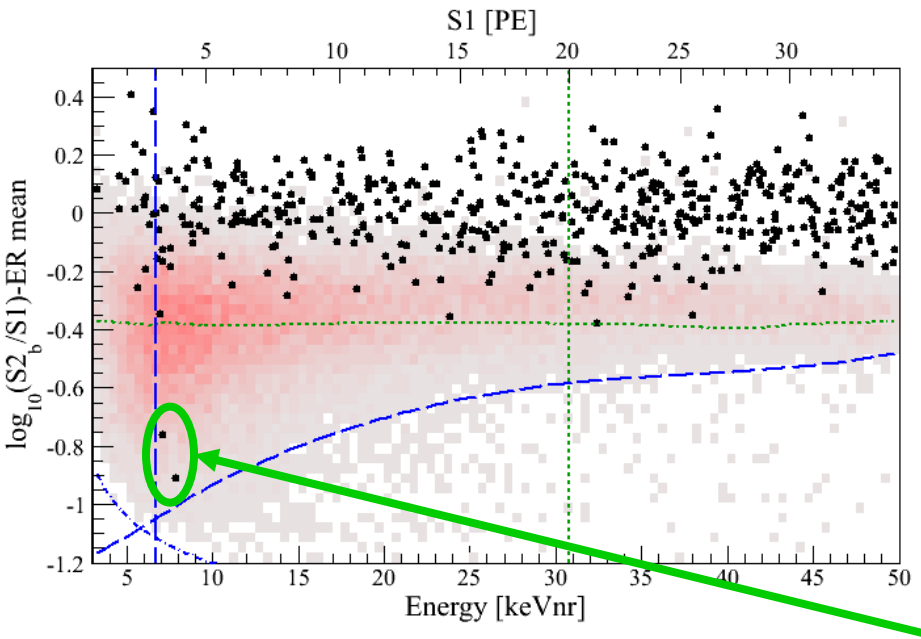


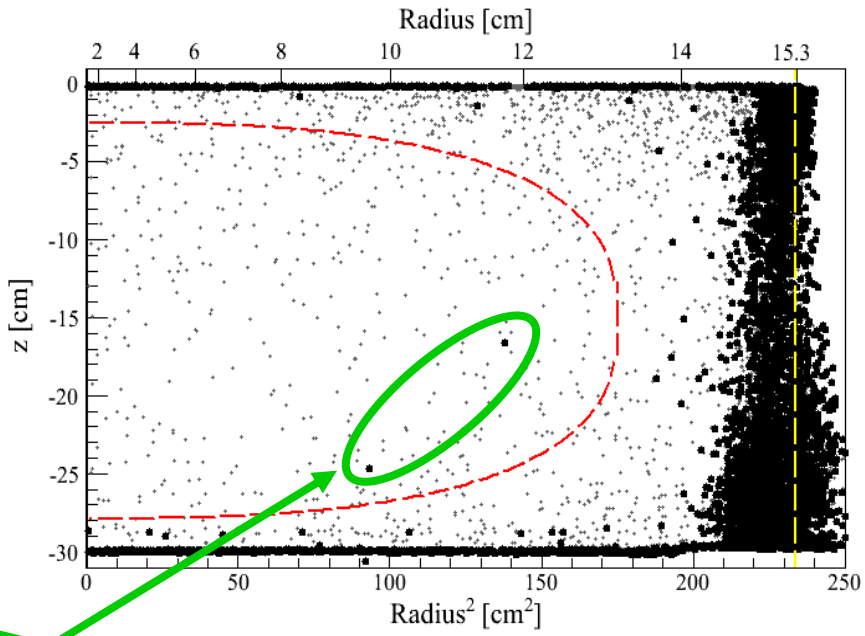
Run 10 data
Total MC simulation
^{222}Rn (α tagging and DC)
Reduced ^{85}Kr
19 +/- 1 (RGMS)
18 +/- 48 (DC)

Background level (34kg) : 5.3 +/- 0.6 dru with active veto and before S2/S1 discrimination.

Run 10 : Data unblinding

Expected background : 1.0 +/- 0.2 events





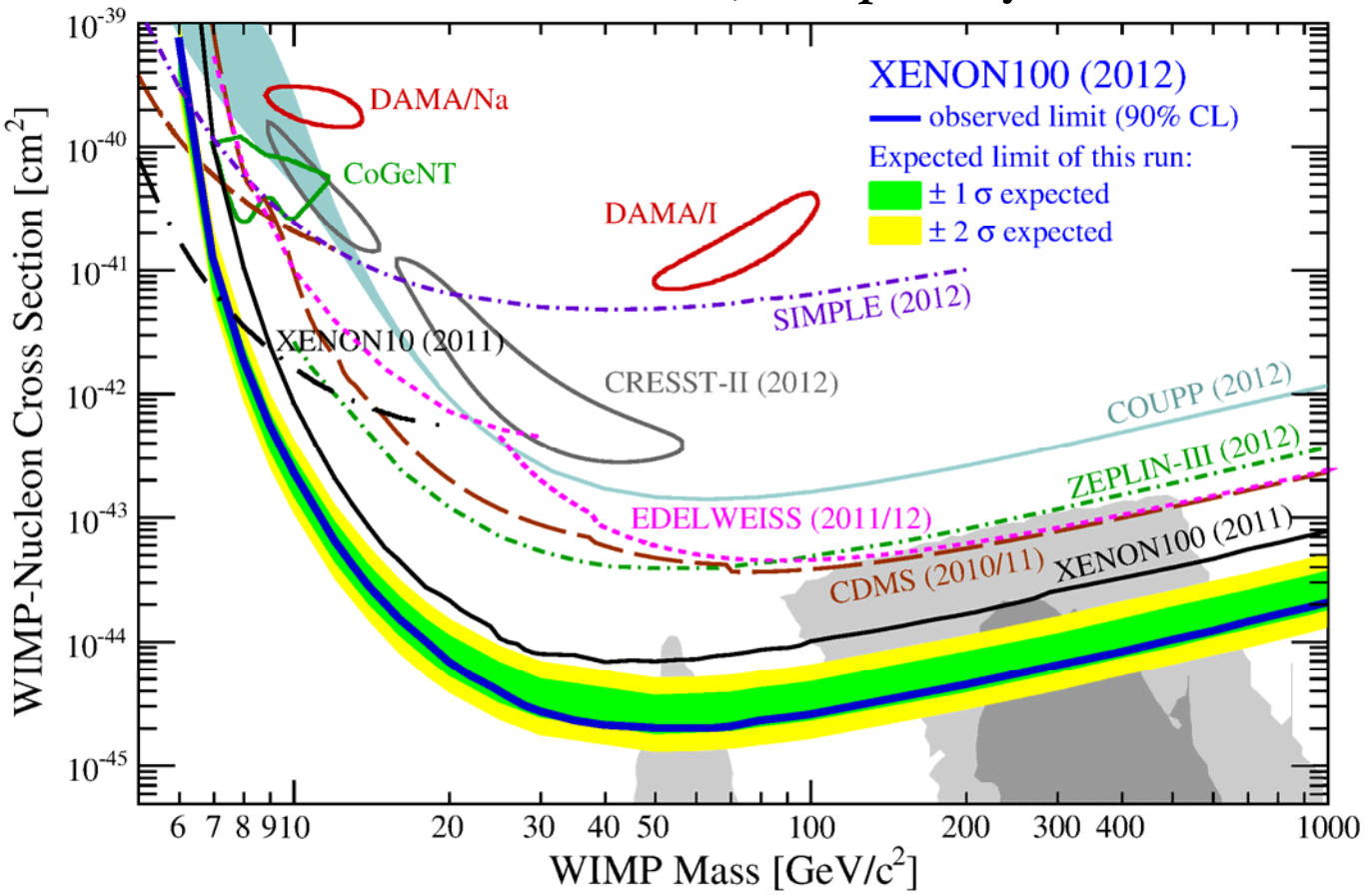
2 events observed

26.4 % probability that background fluctuated to 2 events
Profile Likelihood Analysis cannot reject the background, only hypothesis

No significant excess due a signal seen in XENON100 data

The new XENON100 limit

arXiv:1207.5988, accepted by PRL



Upper limit (90% CL) is 2×10^{-45} cm^2 for 55 GeV/c^2 WIMP

Our contribution to XENON100

Shifts:

- Regular on-site shifts contribution: 70 days per year
- Major contributor on shifts for Data Processing

Data Processing:

- Leading all the Data Processing activities of the experiment
- In charge for the following activities:
  - Database
  - Software management
  - Data quality
  - Computing system manager

Analysis:

- Study and monitoring of Light Yield, Charge Yield and of the presence of xenon electronegative impurities
- Major role on the study of the Single Electron detection (paper in progress)

Operations and slow control:

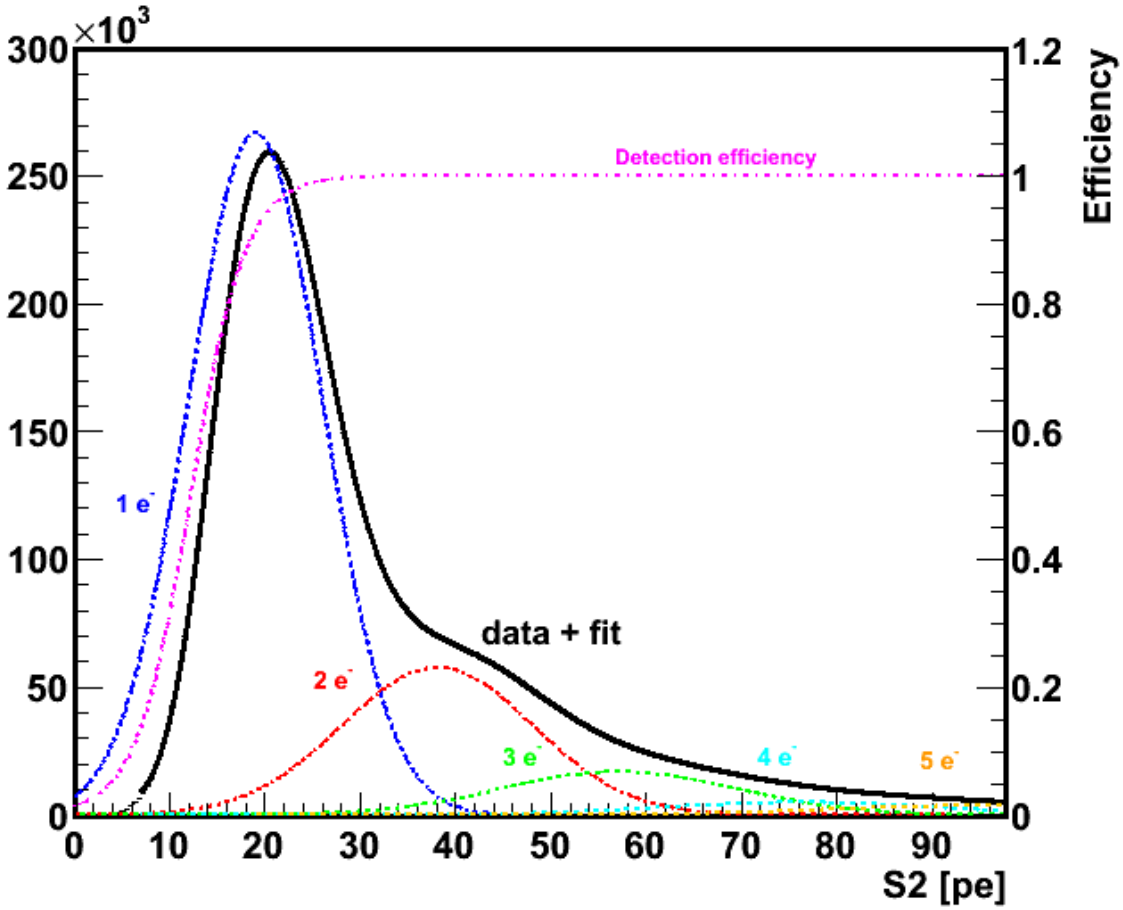
- Development, maintenance and monitoring of PMTs and anode High Voltage control

XENON100 analysis : Single Electron study

Responsibles : L. Scotto Lavina (Subatech), J. Lamblin (Subatech until 2011), G. Plante (Columbia)
PhD Student : M. Le Calloch (Subatech)

Aims:

- **Identify** single electrons
- **Extraction yield** at LXe/GXe interface
- Improve the **resolution** on the ionization signal
- Measure the **liquid level**
- **hotspot analysis**

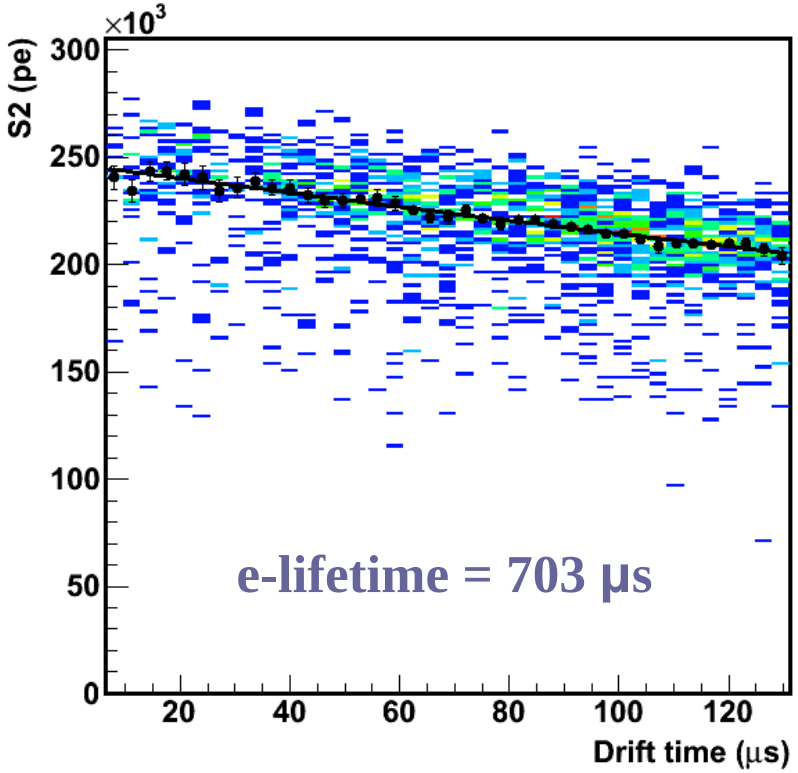


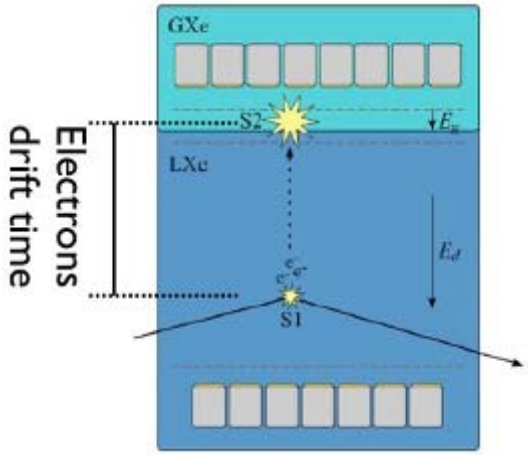
Paper in progress !

XENON100 analysis : Electron lifetime study

Responsible : L. Scotto-Lavina (Subatech), J. Lamblin (Subatech until 2011)

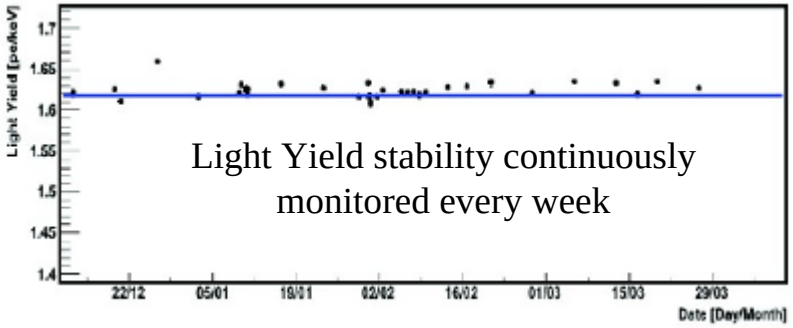
Amplitude of S2 signal vs Drift Time





Ultra high purity liquid xenon!

We reached 0.7 ppb O_2 - equivalent



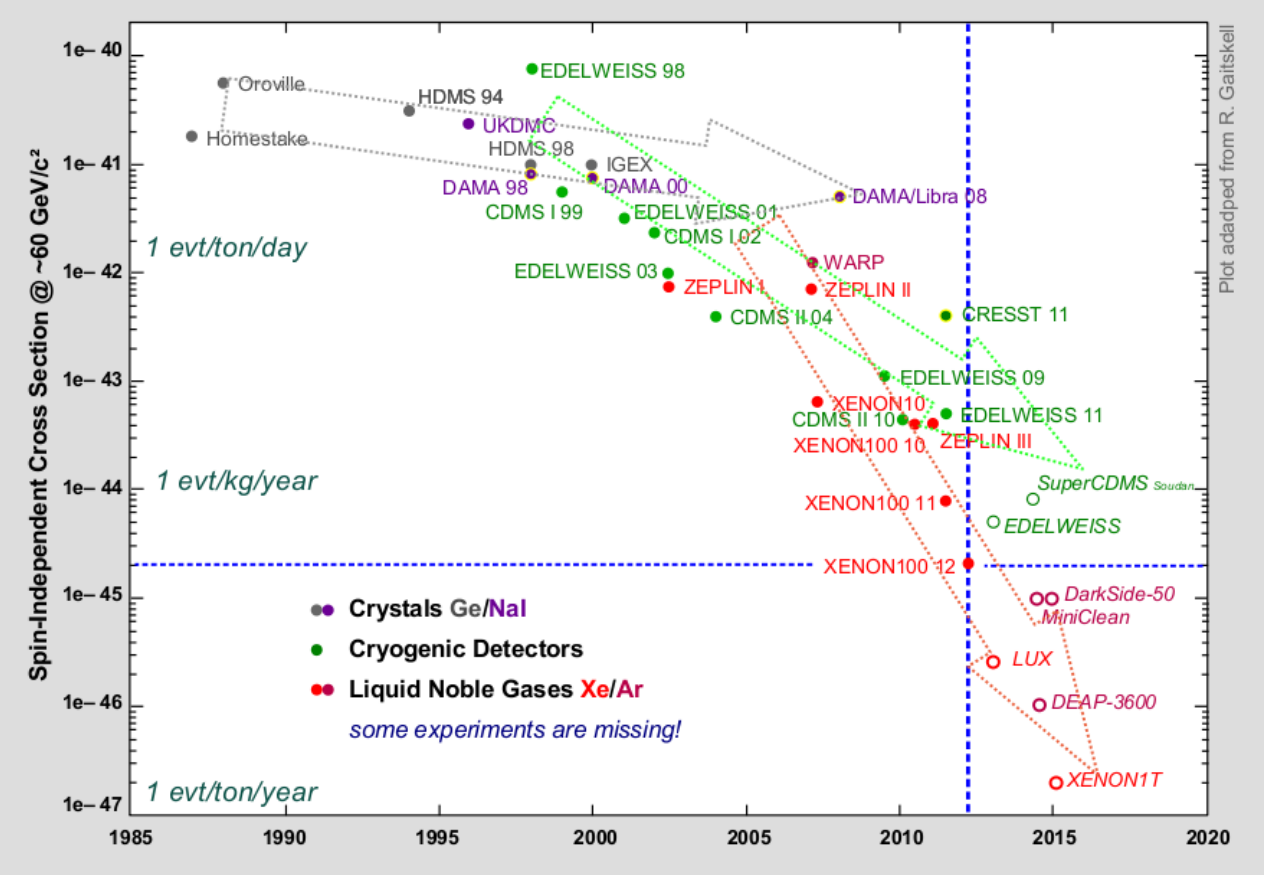
XENON status

XENON100

- **Dark Matter search run10 stopped**

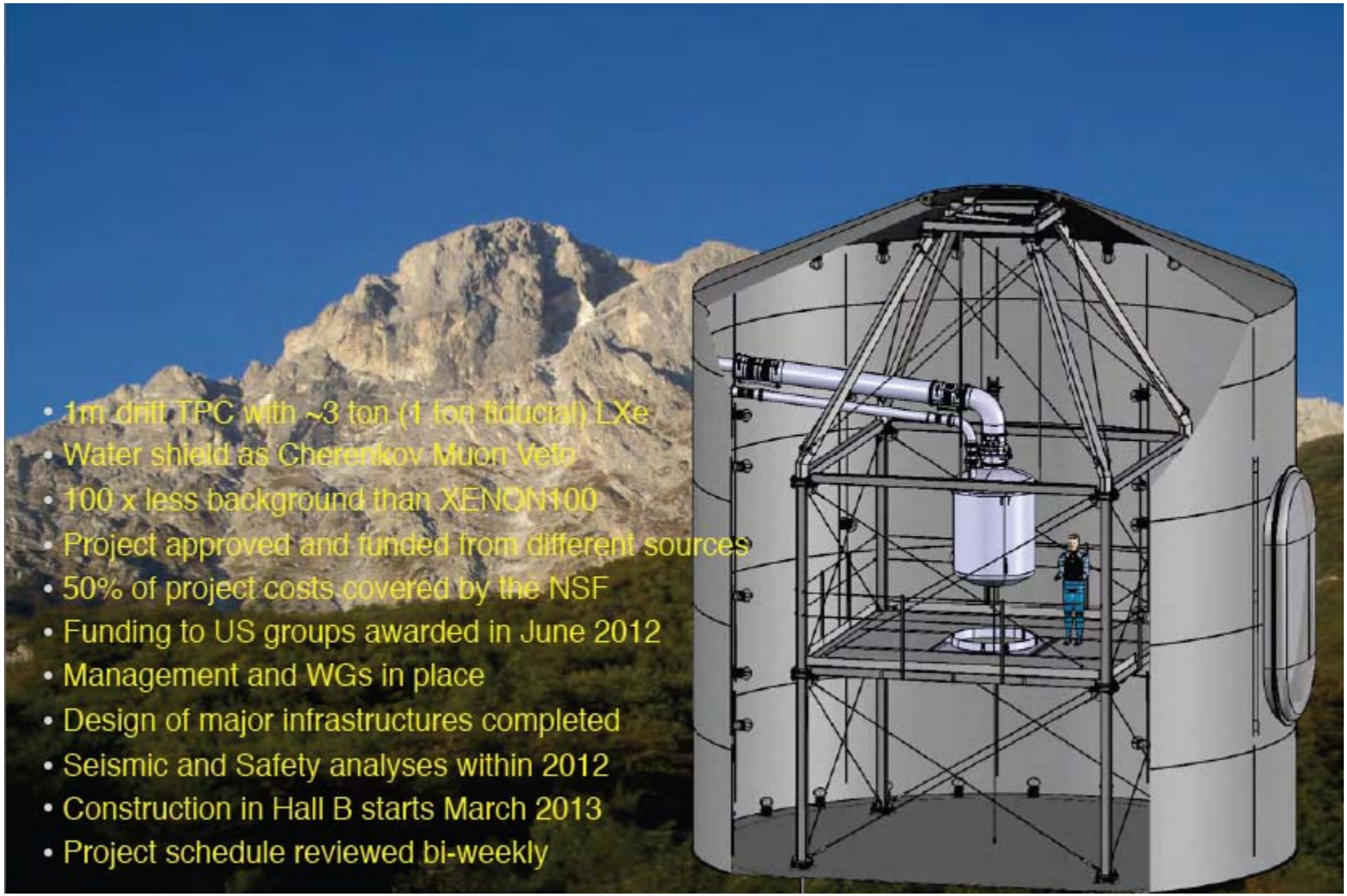
Data from March 1st 2011 up to 22nd May 2012

- **Run11 started**
- Measured Rn Emanation from empty detector and from gas system
- New Xe gas distillation to further reduce [Kr/Xe]



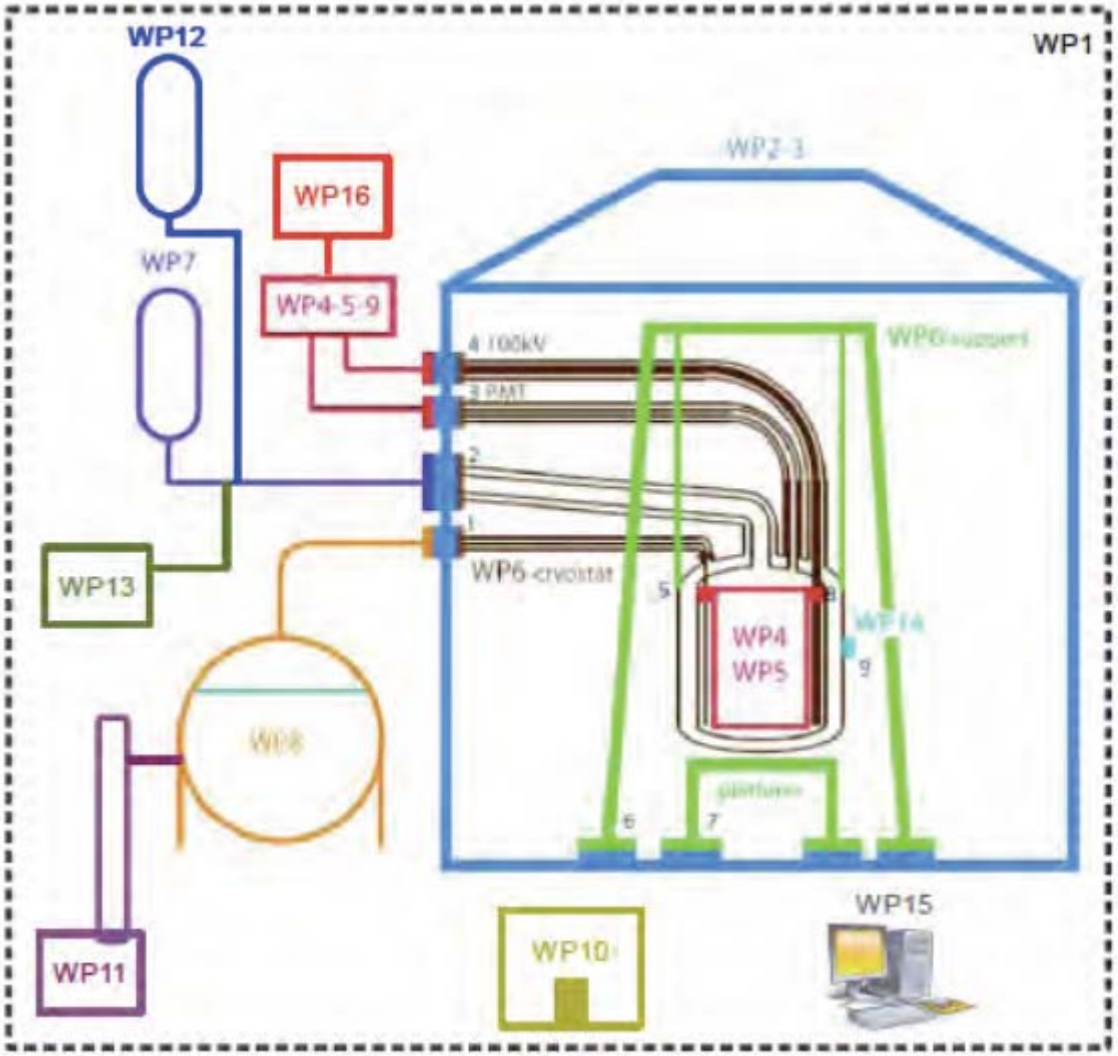
XENON1T construction will start in 2013

XENON1T : R&D started since 2010



XENON1T approved by INFN for installation in the LNGS hall B

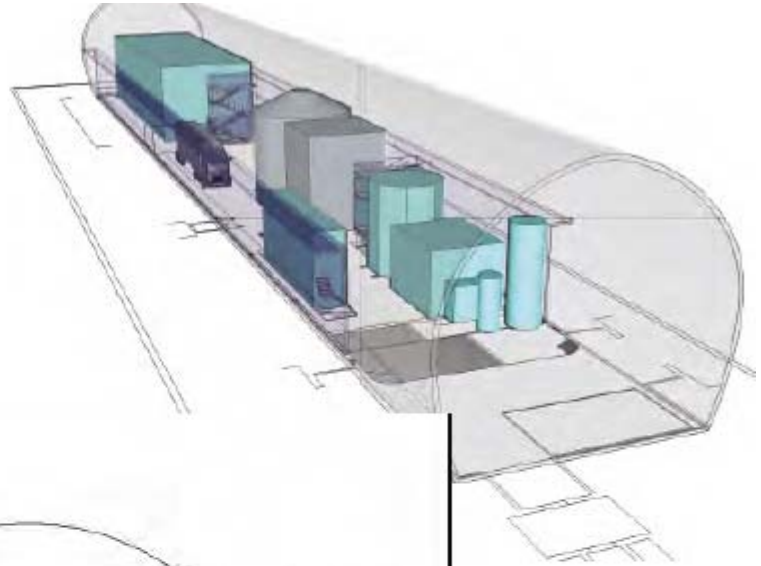
XENON1T : Working Groups

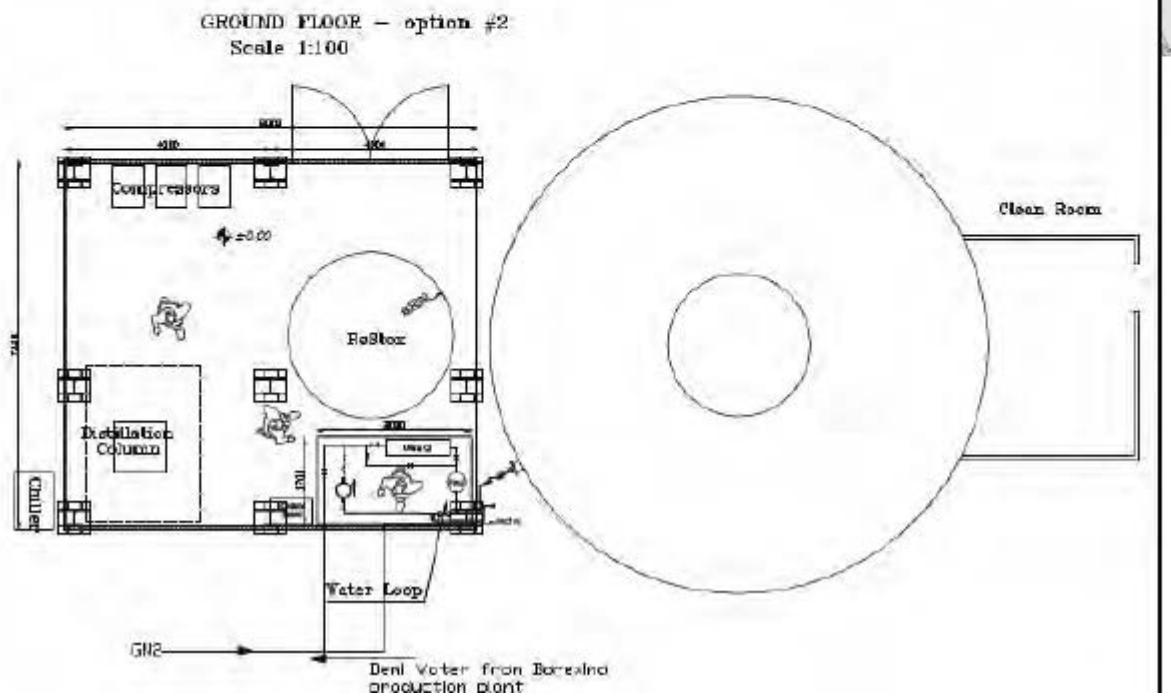


1. **Infrastructure**
   F. Arneodo (LNGS)
2. **Muon veto**
   W. Fulgione (INFN-Torino), S. Fattori (Mainz)
3. **Water tank**
   H. Landsman (WIS)
4. **Detector: TPC, Grids, HV**
   M. Messina (Columbia), M. Schumann (UZH)
5. **PMTs**
   K.Arisaka (UCLA), T. Marrodan (MPIK)
6. **Cryostat & Support Platform)**
   G. Tajiri (Columbia), A. Colijn (Nikhef)
7. **Cryogenics**
   G. Plante, R. Budnik (Columbia)
8. **Cryogenic storage vessel**
   L. Scotto Lavina (Subatech)
9. **Slow control**
   J. Cardoso (Coimbra), L. Levenson (WIS)
10. **Material screening and selection**
    A.D. Ferella (LNGS), J.Schreider (MPIK)
11. **Distillation column**
    C. Weinheimer (Munster)
12. **Xe Purification**
    E. Brown (Munster), A. Malgarejo (Columbia)
13. **Gas purity and analytics**
    H. Simgen (MPKI)
14. **Calibration**
    A. Kish (Zurich), R. Lang (Purdue)
15. **Monte Carlo simulation**
    M. Selvi (Bologna), A. Kish (UZH)
16. **DAQ and Trigger**
    M.Schumann (UZH), P.Decowski (Nikhef)

WG1 : Infrastructure

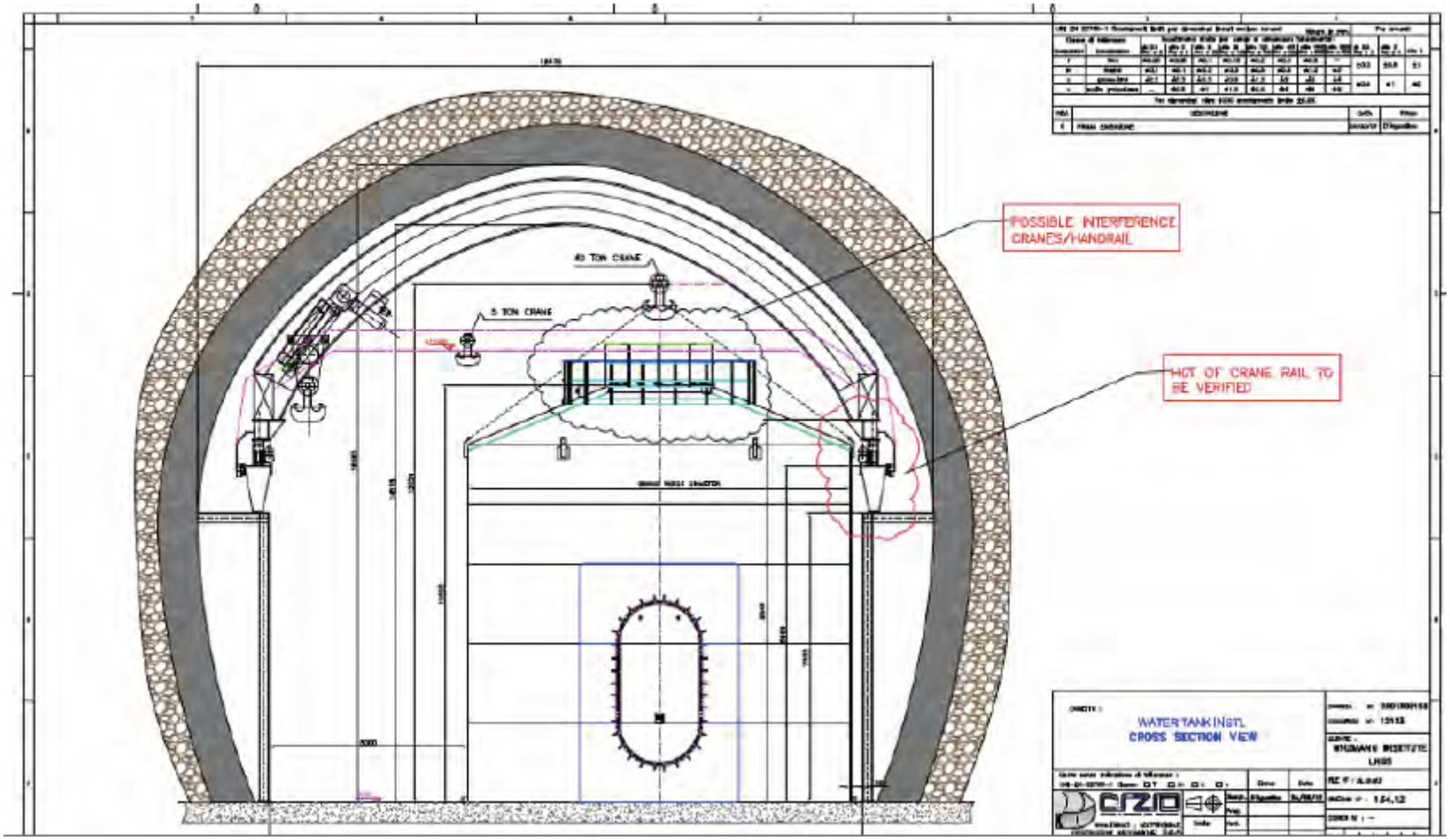
- building design completed by LNGS (C.Zarra): documents will be reviewed by INFN for approval and tender preparation



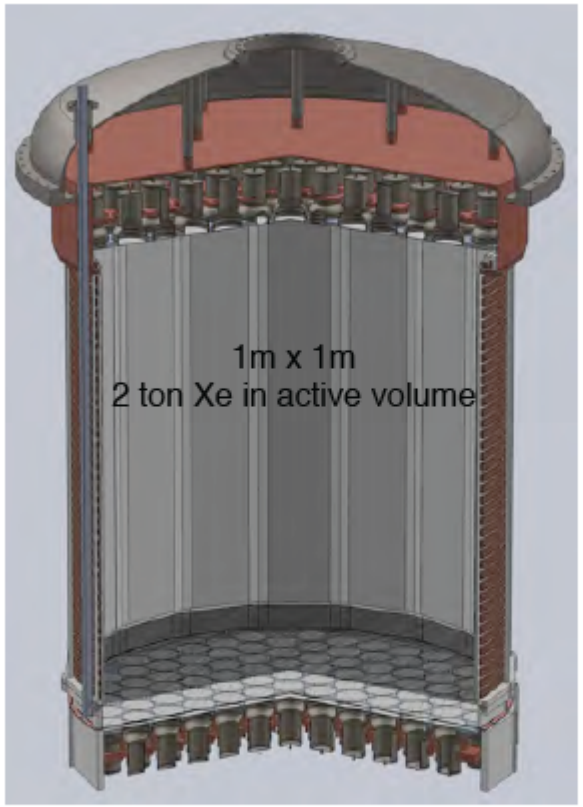


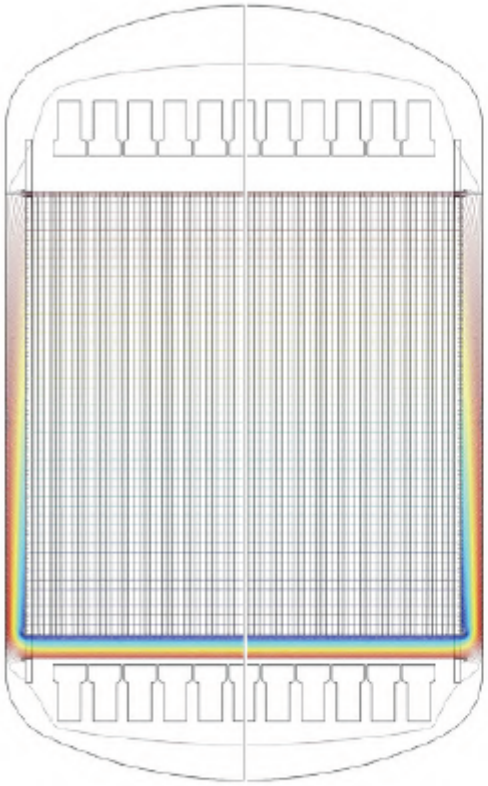
WG3 : Water Tank

- water tank (WIS) and water plant (LNGS) design completed: final review within collaboration prior to finalize order with contractor



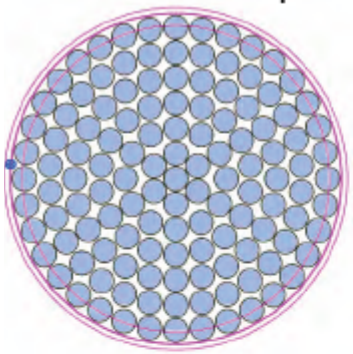
WG4 : Detector (TPC, Grids, HVs)

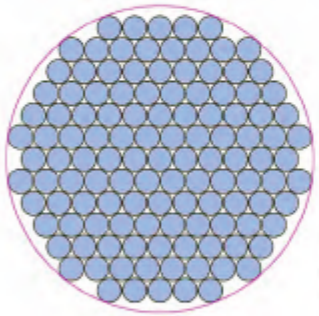




WG5 : Detector (PMTs)

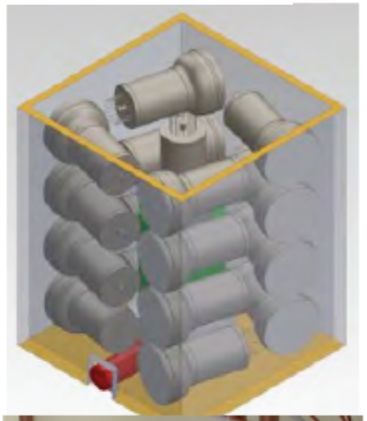
127 PMTs on top

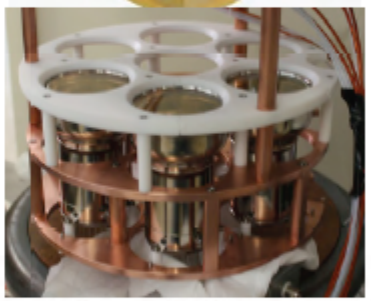


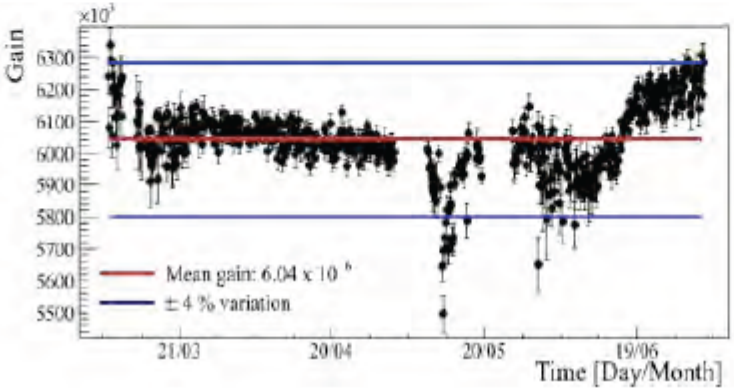


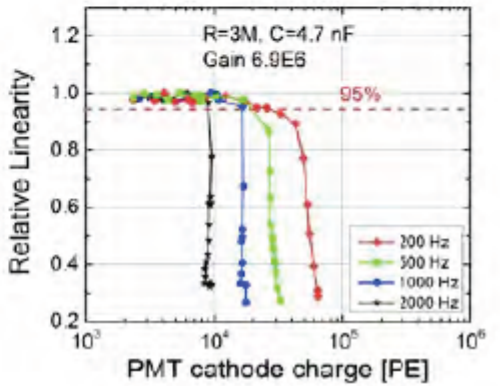
121 PMTs on bottom

- Hamamatsu R11410-21 chosen for XENON1T
- Orders for 300 PMTs placed by Columbia/MPIK and UZH
- materials selected for ultra-low radioactivity
- QE> 28% ; average of 300 tubes =32.5%
- All PMTs will be screened: 17 tubes fit in cavity of HPGe
- Gain stability in LXe tested over 5 months at UZH
- Base design & connectors/cables being tested at UZH
- Linearity and QE have been measured at UCLA
- 7-PMT array being assembled for testing at UCLA

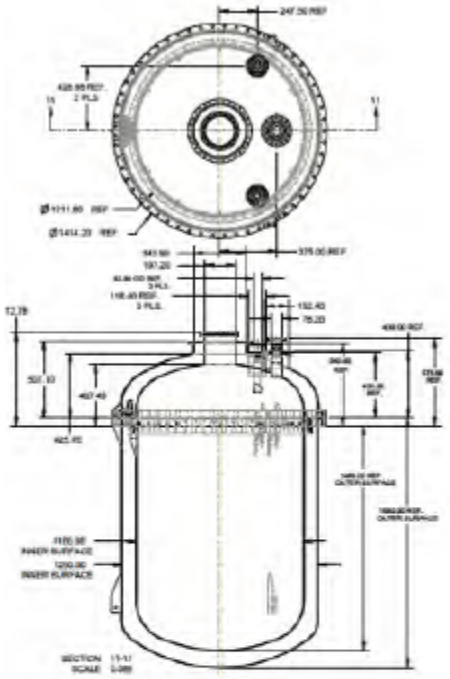


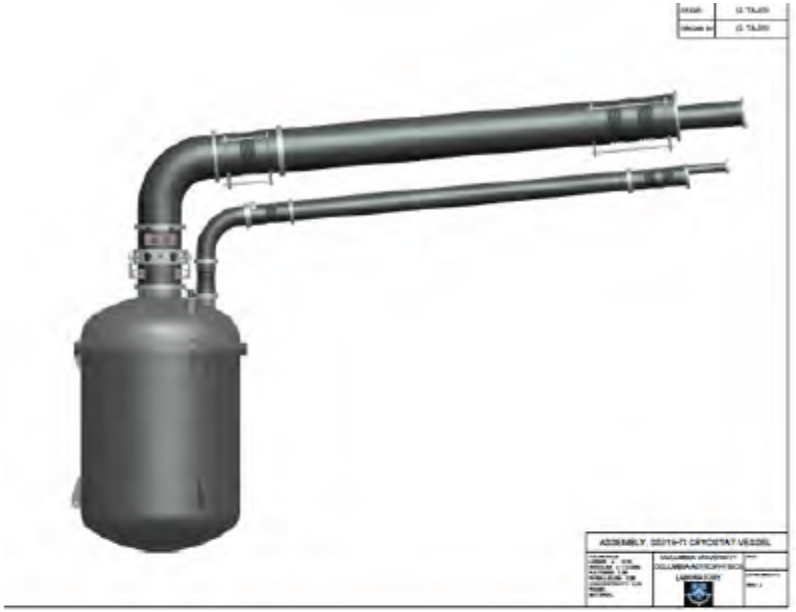






WG6 : Cryostat & Support





Double walled vacuum insulated vessel

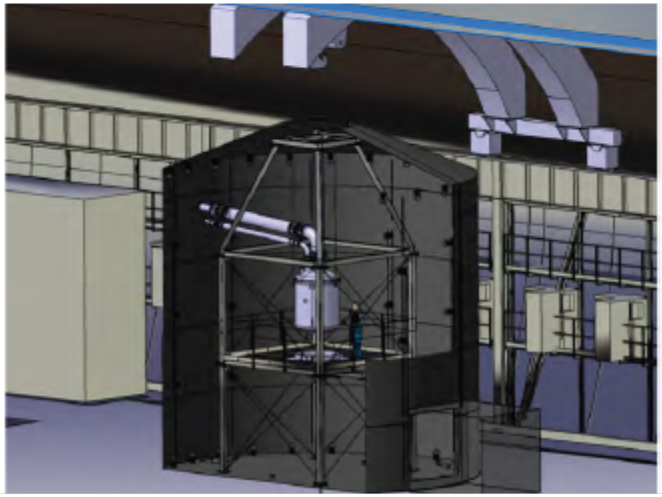
1.3 m diameter x 1.5 m height

Made of low-background SSTi

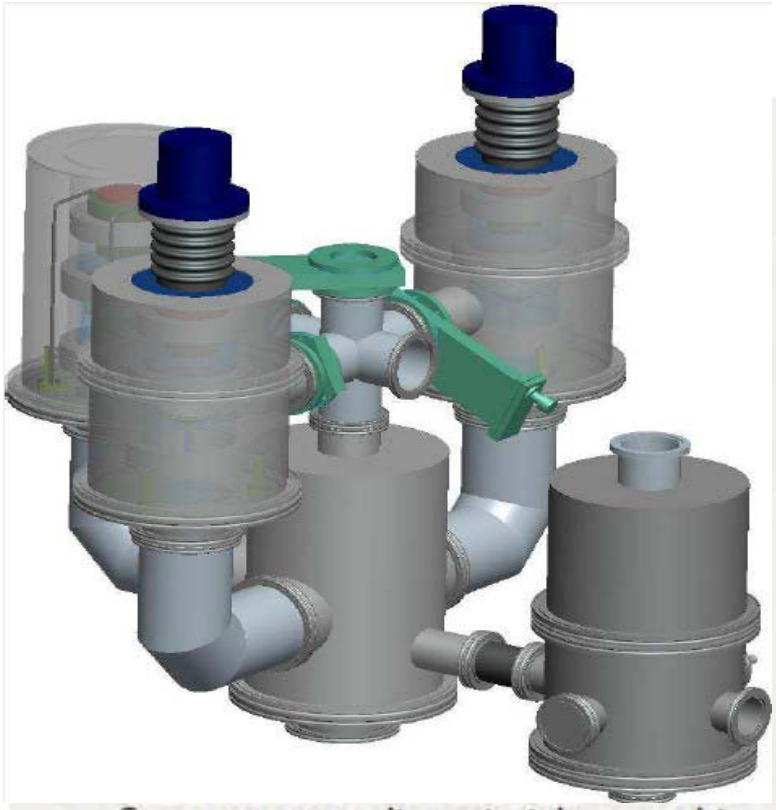
UHV compatible with low outgas rate

Heat load < 50W

Manufactured according to ASME code

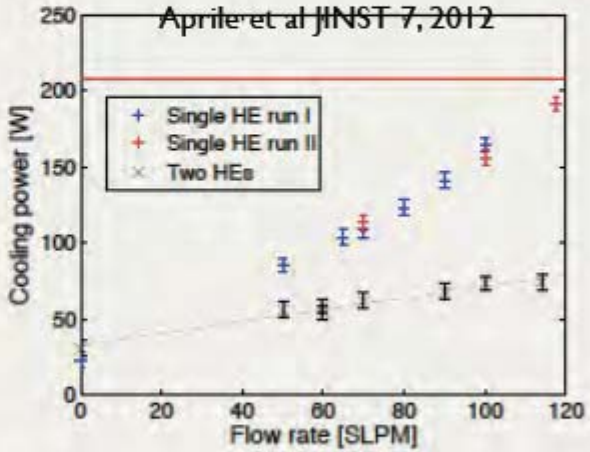


WP7 : Cryogenics



- Same remote cooling principle as used in XENON100. Cooling tower outside water tank, LXe flows back into detector vessel via gravity
- Design guided by knowledge acquired from XENON1T Demontrator program

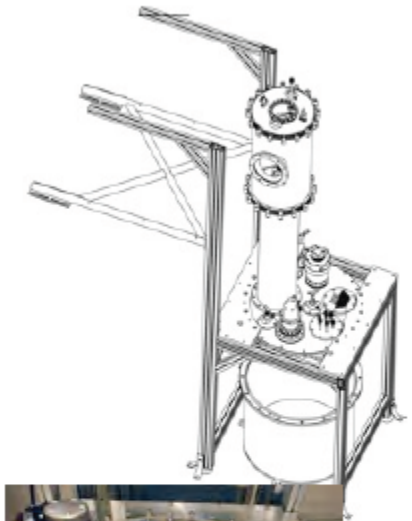
- 2 PC150 200 W Pulse Tube Refrigerators (PTRs) in 2 independent vacuum vessels
- One PTR can be serviced while the other is in operation, eliminates down time
- Dual heat exchangers will allow xenon circulation at speeds above 50 SLPM

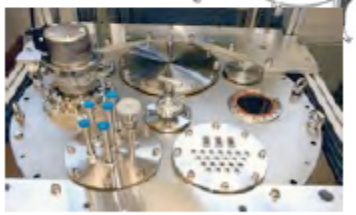


- Emergency liquid nitrogen system assures stable operation even in the event of a power failure

WP11 : Kr distillation column

Aim: sub-ppt concentration of Kr in Xe
Design values: 3 kg/h, factor 10000 separation
Status: all major components manufactured or purchased





Design is finished (together with Dr. Ion Cristescu, cryogenic distillation expert from KIT/ITER)

Two-phase setup: 3m test column (with major parts being the same) → 5m XENON1T column

All major equipment and components have been purchased or built

Setup of 3m phase I will be finished in 2012

Room temp. part of custom-made cold valve cold part

^{83m}Kr doping, $t_{1/2}$ = 1.83 hr

Sub-ppt rel. online measurement

RGA + cold trap, ATTA, RGMS → sub-ppt

WP8 : LXe storage and recovering

State of the art :

first XENON1T technical meeting organised at Subatech in Feb.2010

MEG / XMASS

2.4 t / 1 t of xenon

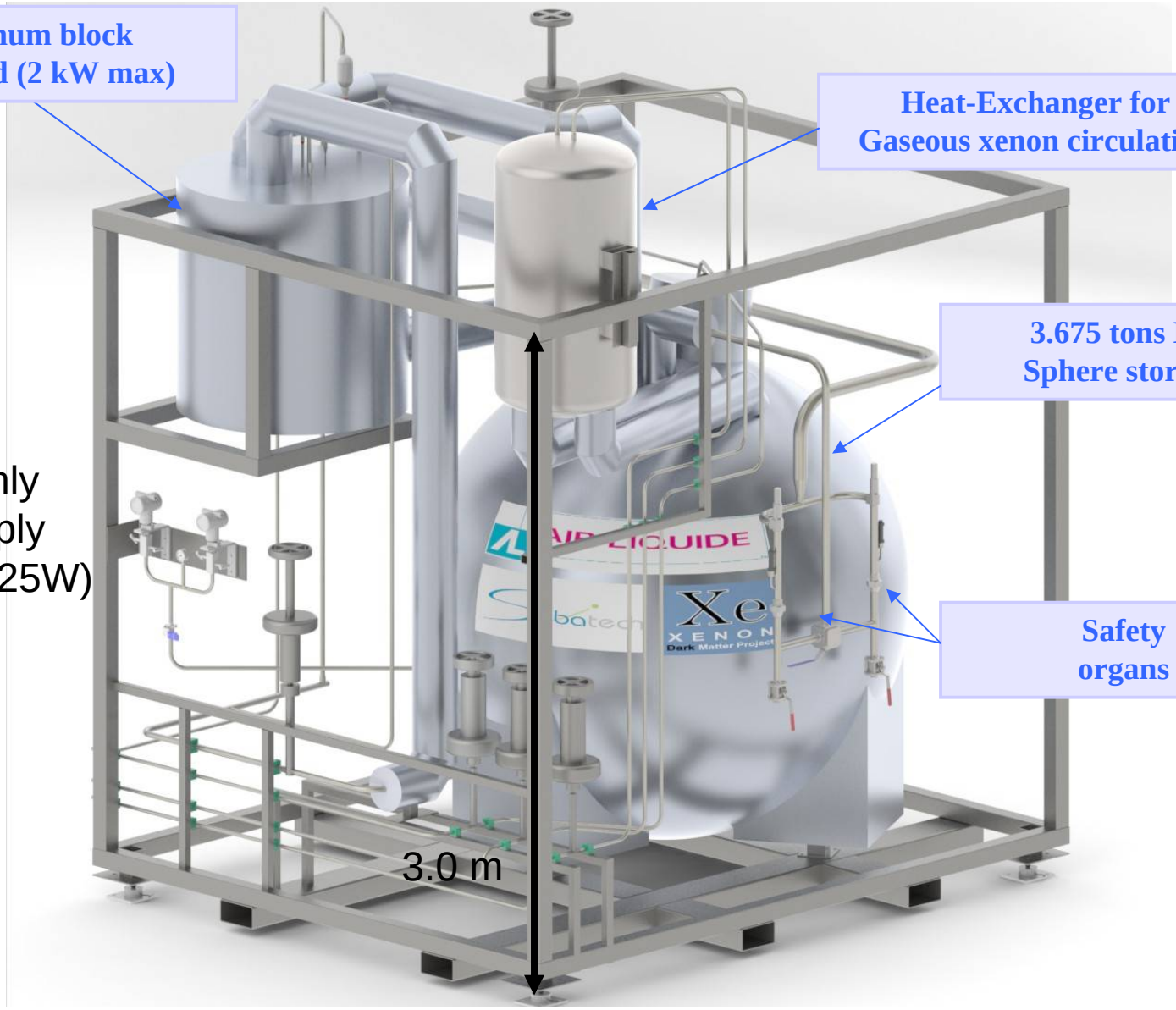
+

1st : low pressure LXe storage with liquid recovery/filling system for short shutdown

2nd : high pressure GXe storage with gaseous recovery system for long shutdown

It works very well ! For Xenon1T, we decided to keep the main functionalities and to do the system more compact by improving its operation

ReStoX : the Recovering and Storage System for XENON1T



Need only
LN_2 supply
(~ 1g/s = 225W)

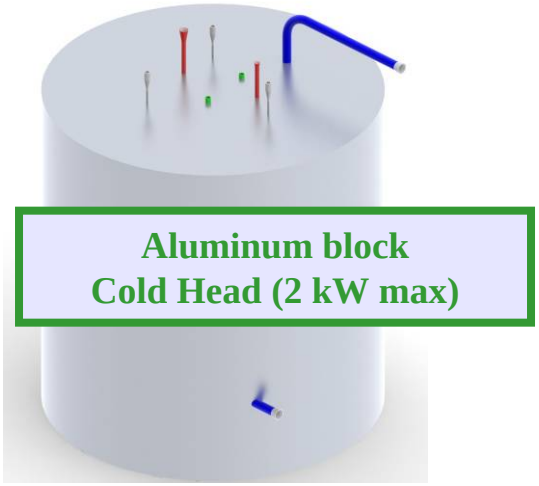
ReStoX - summary

R&D started in 2010 fully funded by the Region "Pays de la Loire" until the end of the design studies (2012):

- Choice of industriels
- Scientific exchanges and discussions with AL-AT
- Critical confrontation meeting (AL-AT/Subatech) to guide the development
- Continuous reporting in front of the XENON collaboration
- Real tests at Subatech to qualify the technical choice

Storage Sphere with internal nitrogen heater

The 4 main components



Aluminum block Cold Head (2 kW max)

Heat-Exchanger for xenon circulation (50 nl/mn)

ReStoX is approuved by the XENON collaboration
ReStoX is patented (CNRS/AL-AT since Jan.2012)
ReStoX has been presented to the international community (ICEC2012)

ReStoX – the sphere

Technical Data Sheet

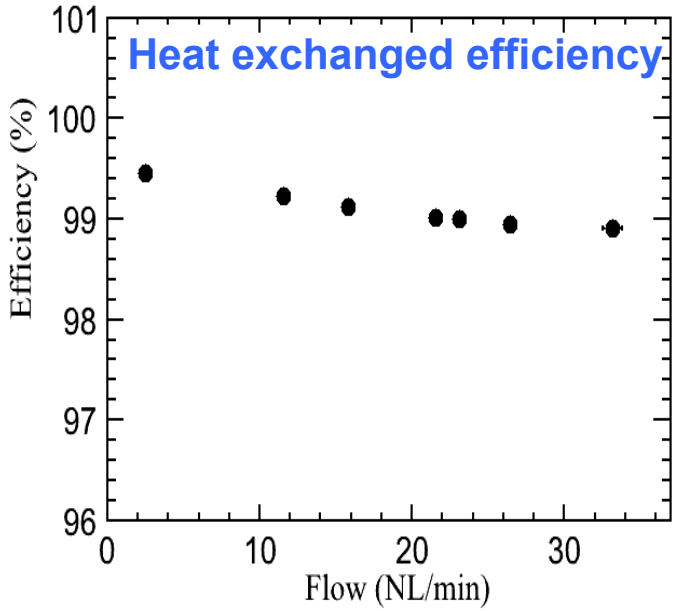
Inner Volume : 2.2 m^3
High Pressure vessel :
Design pressure : 6.5 MPa
Stainless Steel thickness : 26 mm
Capacity : 3.675 tons of xenon at 16°C
Insulation : 20 cm of polyurethane (vacuum insulation investigated but canceled for cost considerations)
Heat loss : 200 W expected
Fully electro polished
Equipped with weight sensors to control the charge of xenon (+/- 15 kg absolute expected)
Non measurable leak rate (< 10^{-7} mbar/l/s expected)
Certified by AL-AT (with 40% pressure safety coefficient)

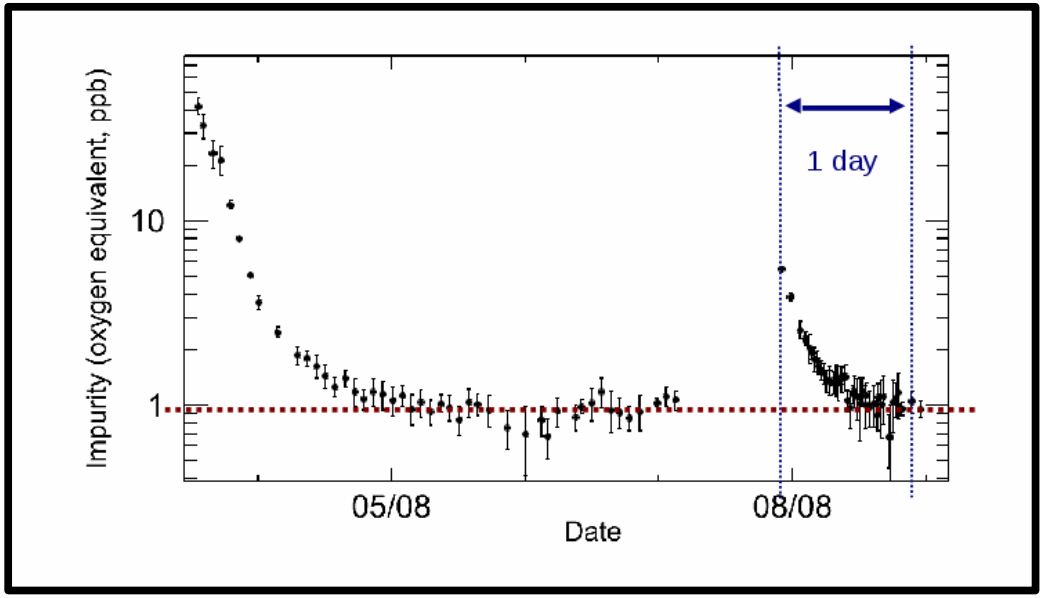
The most compact solution we can imagine to store xenon and to limit the quantity of matter in contact

ReStoX – the heat exchanger

Technical Data Sheet

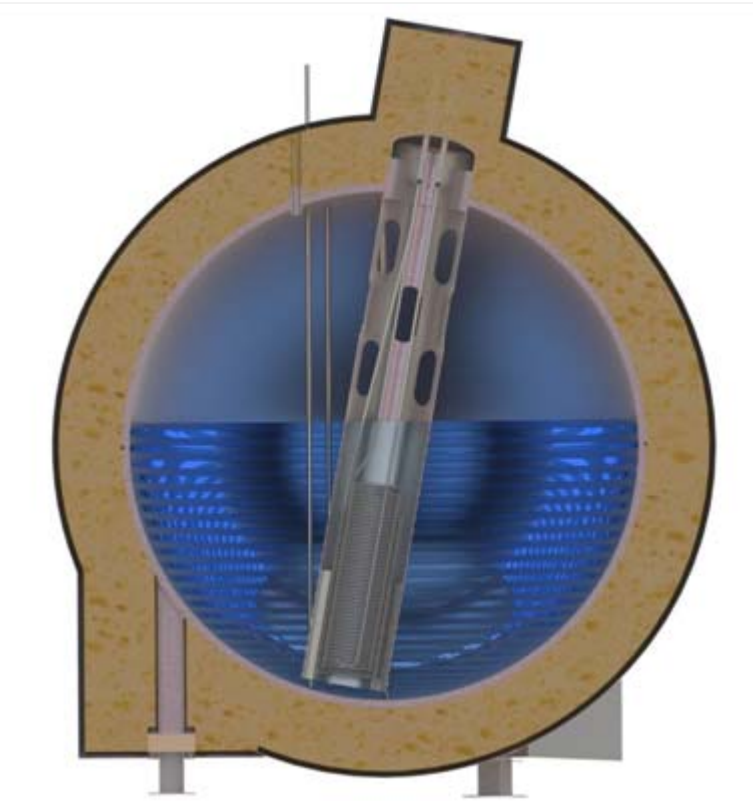
Exchange capacity : 50 nl/mn max with Xe vaporization/condensation
Pressure drop < 150 mbars
Maximum pressure > 100 bars
Insulation : vacuum and MLI
Heat loss < 10 W
Fully electro polished
Heat exchanged efficiency ~ 99%





Sub-ppb electronegative impurity concentration achieved in a few days
Fully characterized during the R&D done at Subatech in 2011 and 2012

ReStoX – the nitrogen internal heater

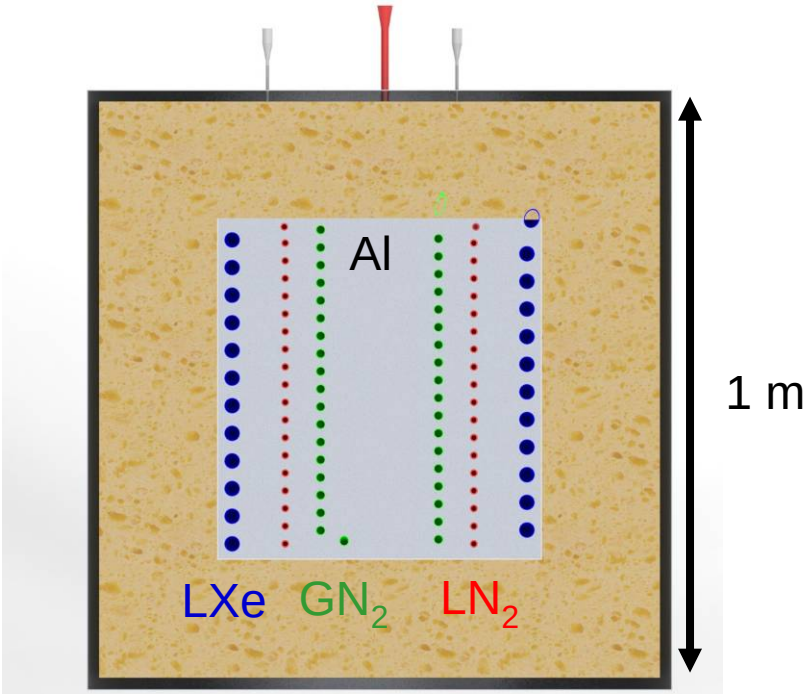


Technical Data Sheet

- **Until 1 kW of heating power with 30 g/s of RT GN2 flow**
- **Allow to pressurize the xenon in ReStoX without warming up the xenon during the liquid filling**
- **Will be the last component mounted on ReStoX to allow the electro polishing of all the other feedthroughs.**

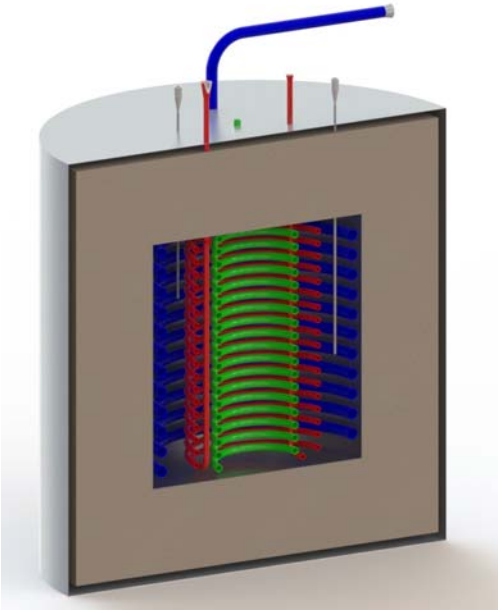
The nitrogen heater will be used only to increase the pressure during the filling phase.
It has been designed to allow the filling of the XENON1T cryostat with sub-cooled liquid xenon.

ReStoX – the aluminum cold head



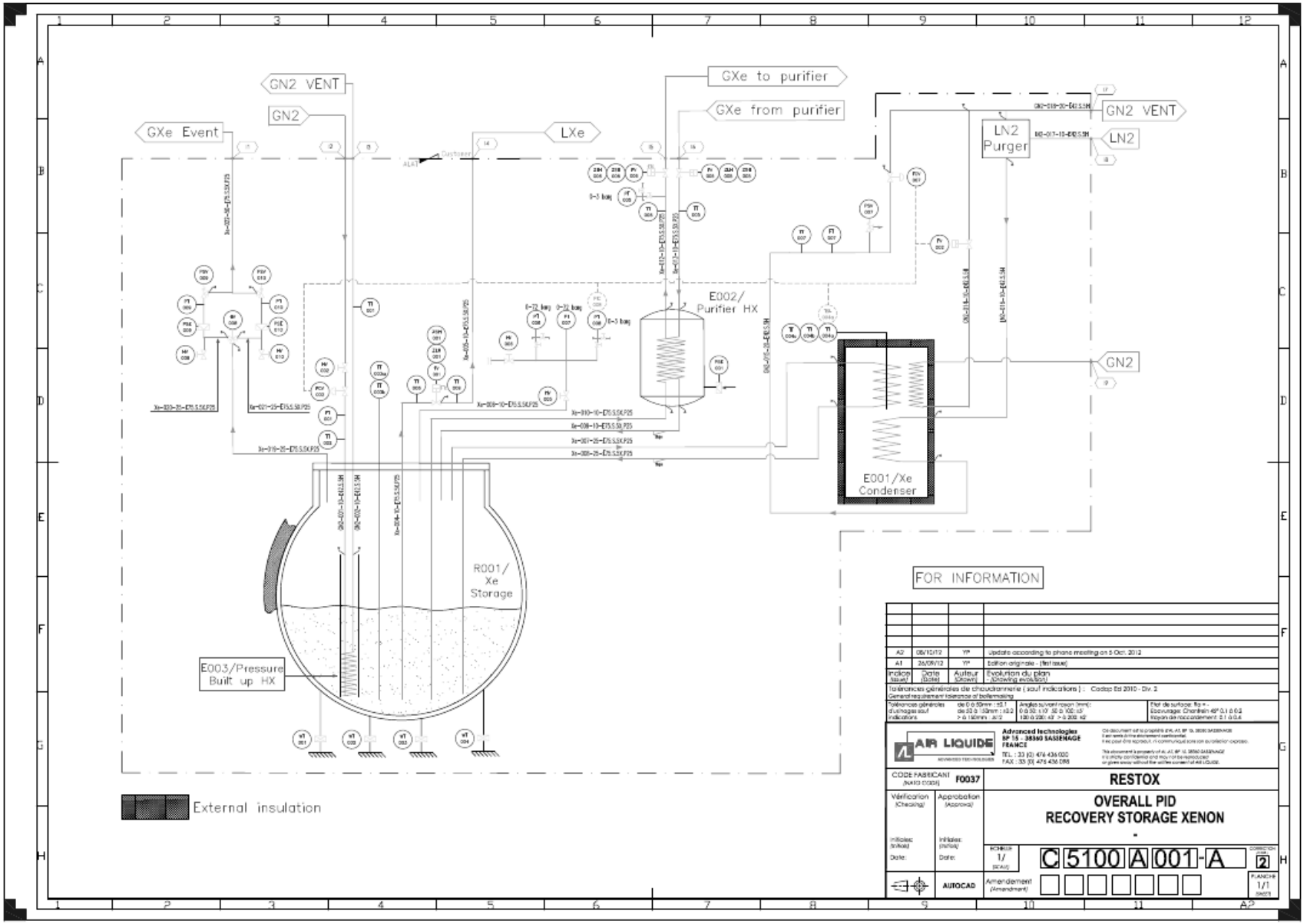
Technical Data Sheet

Exchange capacity : 2 kW @ 165 K
Aluminum mass : ~ 300 kg
Insulation : 20 cm of polyurethane
Maximum pressure > 65 bars
LN2 consummation : 1 g/s per 225W
Emergency GN2 circuit (500 W @165K) for fast warming up
Fully designed by AL-AT
Technology developed by AL-AT for other cryogenics liquid



Aluminum block is a well known technology for AL-AT
Aluminum block is a new technology for the "xenon community"
It is a major component for the ReStoX operations (Recovering)
It is a very promising solution for larger experiment like "DARWIN"

ReStoX – the final PID



ReStoX schedule

N° in the XENON1T general schedule

We are here

457	**ReStoX**	**507 days**	**11-Apr-12**	**20-Mar-14**	**20%**
458	**Design and Reviews**	**135 days**	**23-May-12**	**27-Nov-12**	**58%**
459	Preliminary Studies	58 days	11-Apr-12	29-Jun-12	100%
460	Preliminary Review	1 day	23-Aug-12	23-Aug-12	100%
461	Detailed Studies	67 days	24-Aug-12	26-Nov-12	50%
462	Critical Review	1 day	27-Nov-12	27-Nov-12	0%
463	**Procurement**	**146 days**	**28-Nov-12**	**19-Jun-13**	**0%**
464	Cryo Valve supply	83 days	28-Nov-12	22-Mar-13	0%
465	Other supplies (sphere and remaining components)	146 days	28-Nov-12	19-Jun-13	0%
466	**Fabrication**	**83 days**	**28-Nov-12**	**22-Mar-13**	**0%**
467	Fabrication of heat exchangers, tubes, frame	83 days	28-Nov-12	22-Mar-13	0%
468	**Assembly and Testing at AirLiquide**	**106 days**	**20-Jun-13**	**14-Nov-13**	**0%**
469	Assembly	68 days	20-Jun-13	23-Sep-13	0%
470	Bake test	15 days	24-Sep-13	14-Oct-13	0%
471	Insulation Vacuum	23 days	15-Oct-13	14-Nov-13	0%
472	Crating and Shipment to LNGS	10 days	15-Nov-13	28-Nov-13	0%
473	**Assembly and Testing at LNGS**	**110 days**	**29-Nov-13**	**01-May-14**	**0%**
474	Unpacking and Inspection	10 days	29-Nov-13	12-Dec-13	0%
475	Assembly and Testing	100 days	13-Dec-13	01-May-14	0%
476	Restox is installed and ready for integration	0 days	01-May-14	01-May-14	0%

Decision to start the construction of ReStoX should be taken at the end of 2012 or integration in XENON1T will be delayed

Our contribution to XENON1T until now

Life of the experiment :

- Organization of the 1st XENON1T technical meeting (Feb. 2010), participation to all meetings since the beginning
- Involved in all the steps related to the design of the experiment since the beginning, strongly concerned by all the choices done by the collaboration
- Strongly involved in the safety review (HAZOP, FMEA, Fault Tree analysis) of XENON1T

WGs :

- WG8 leader (storage and recovering)
- Contribution in WG7 (cryogenics), WG9 (slow control) and in WG15 (MC simulation)

R&D :

- Very active work to reach a completed, tested and approved ReStoX design
- Strongly linked to our contribution in the DARWIN project

Requests to the In2p3 SC :

We ask support to continue the work on XENON1T with the construction/installation/operation of ReStoX

We ask also support to continue the R&D effort for a next generation DM search with DARWIN (post-doc position)

XENON1T : Capital Costs

Item	Institution Responsability	Capital Costs
Calibration	Purdue	0.12
Cherenkov Muon Veto	Bologna, Mainz	0,50
Cryostat/Cryogenics Plant	Columbia, UCLA	0.85
Cryostat Support & Platform	Nikhef, Columbia	0.19
Electronics/DAQ/Computing	Zürich, Columbia	0,47
Internal TPC & PMT Support	UCLA, Rice, Columbia	0,46
LNGS Infrastructure	LNGS, Columbia, Rice, Purdue, UCLA	0,54
LXe ReStoX	Subatech	0,65
Material Screening	MPIK, Zürich, UCLA	0,26
Photomultiplier tubes	UCLA, Columbia, MPIK, Zürich	1.59
Purification & Distillation Plants	Muenster	0,54
Slow control	Coimbra, Weizmann	0,04
Xenon gas	All	3.15
Water Shield	Weizmann	0,39
	Total	**9,75 M€**

Request to the In2p3 SC :

We ask support to contribute technically in XENON1T with a Capital Cost of 0.65 M€ (cost of the ReStoX equipment)

XENON1T : simplified schedule

	Main contributors	Duration	Starting Date	Ending Date
Integration and Commissioning	All	458 days	03/22/13	12/24/14
Infrastructure	All	502 days	01/02/12	12/03/13
Muon Veto	Bologna,Torino,Mainz	1,041 days	10/01/10	09/26/14
Xenon1T Demonstrator R&D	Columbia,Rice,UCLA	521 days	10/01/10	09/28/12
Water Tank	Weizmann	283 days	03/26/12	04/24/13
Cryostat Support	Nikhef	336 days	04/02/12	07/15/13
Platform	All	140 days	08/28/12	03/11/13
Cryostat System	Columbia	431 days	01/16/12	09/09/13
Purification system	Munster	253 days	04/04/12	03/22/13
Calibration System	Purdue	441 days	04/03/12	12/10/13
Slow Control	Weizmann,Coimbra	472 days	04/11/12	01/30/14
Cryogenics	Columbia	478 days	06/01/12	04/01/14
ReStoX	Subatech	507 days	04/11/12	03/20/14
Distillation column	Munster	510 days	04/04/12	03/18/14
TPC & PMT system	Columbia,Zurich,Rice,UCLA	705 days	10/03/11	06/13/14
Screening	Zurich,MPIK	924 days	10/01/10	04/16/14
Radon Tower	MPIK	601 days	04/03/12	07/22/14
DAQ Project	Zurich,Nikhef	520 days	04/03/12	03/31/14
Monte Carlo Background predictions	All	585 days	01/03/12	03/31/14

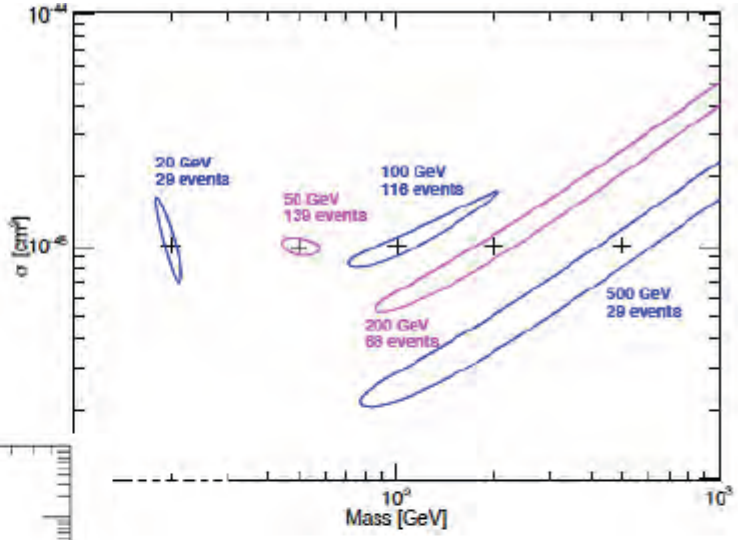
Request to the In2p3 SC :

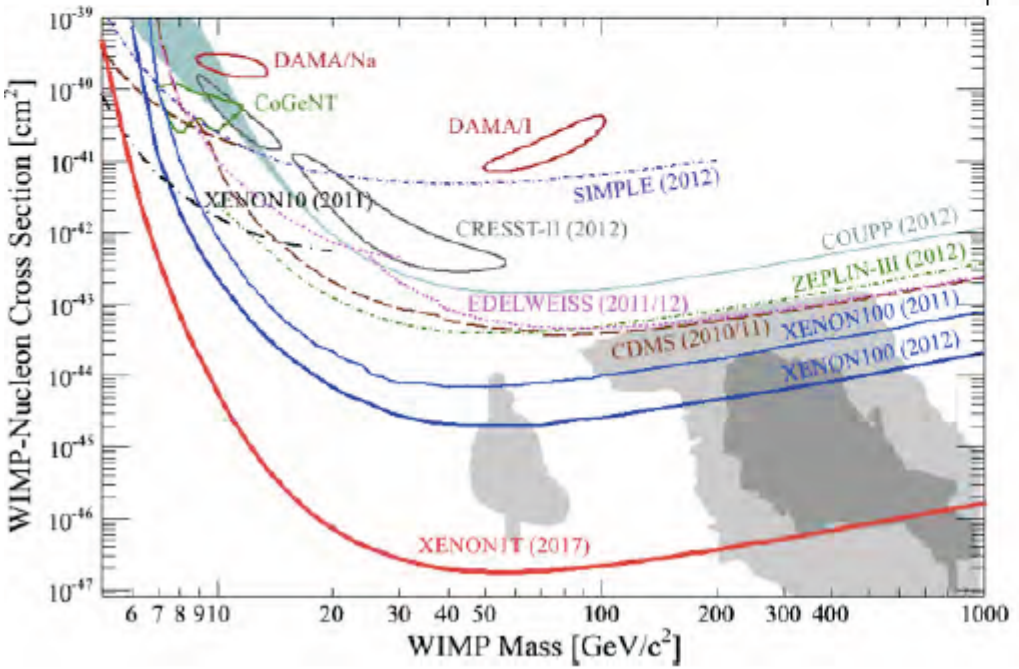
We ask support to be put in position to respect the ReStoX schedule

XENON1T : Physics case

a statistically significant WIMP signal after 2 ton-years of data

~100 events if cross section at 10^{-45} cm^2





2×10^{-47} cm^2 for 50 GeV WIMP in 2 ton-year

Two orders of magnitude improvement in SI cross-section sensitivity w/r to XENON100

Request to the In2p3 SC :

We ask support to contribute on being the first to discover DM

Conclusions

Motivations :

- The nature of DM stays an open question, its direct observation is one of the mission of the In2p3
- Direct Search with low background experiments is the most sensitive method
- A new worldwide community has been motivated in the last decade to develop new instruments with liquid xenon to observe DM particles. XENON1, XENON10 and now XENON100 experiments contributed actively to push the limits of the observations. The best limit is now at $2x10^{-45}$ cm^2 for the SI 55 GeV/c^2 WIMP, 3 magnitude orders of continuous increase in only one decade !
- XENON1T is now well advanced and construction will start in 2013. Discovery of DM particles is achievable with a limit increase of ~ 2 magnitudes expected in 2017.

Situation :

- We joined XENON100 in 2009, and since then, we actively contributed to its successful results
- We actively participated to XENON1T design since its first time
- We are strongly involved on the XENON1T recovering system (ReStoX), for which we complete the full studies and the design with the help of the AL-AT company.

Last and main request :

We ask support from the In2p3 Scientific Committee to open a new Research Program on Direct Dark Matter Search with XENON1T