Dark Matter search with liquid xenon: from XENON100 to next generation experiments

Presented by
Samuel DUVAL

Direct detection of Dark Matter

- the XENON100 experiment
- XENON100 results

Toward large scale detectors

- XENON1T
- DARWIN

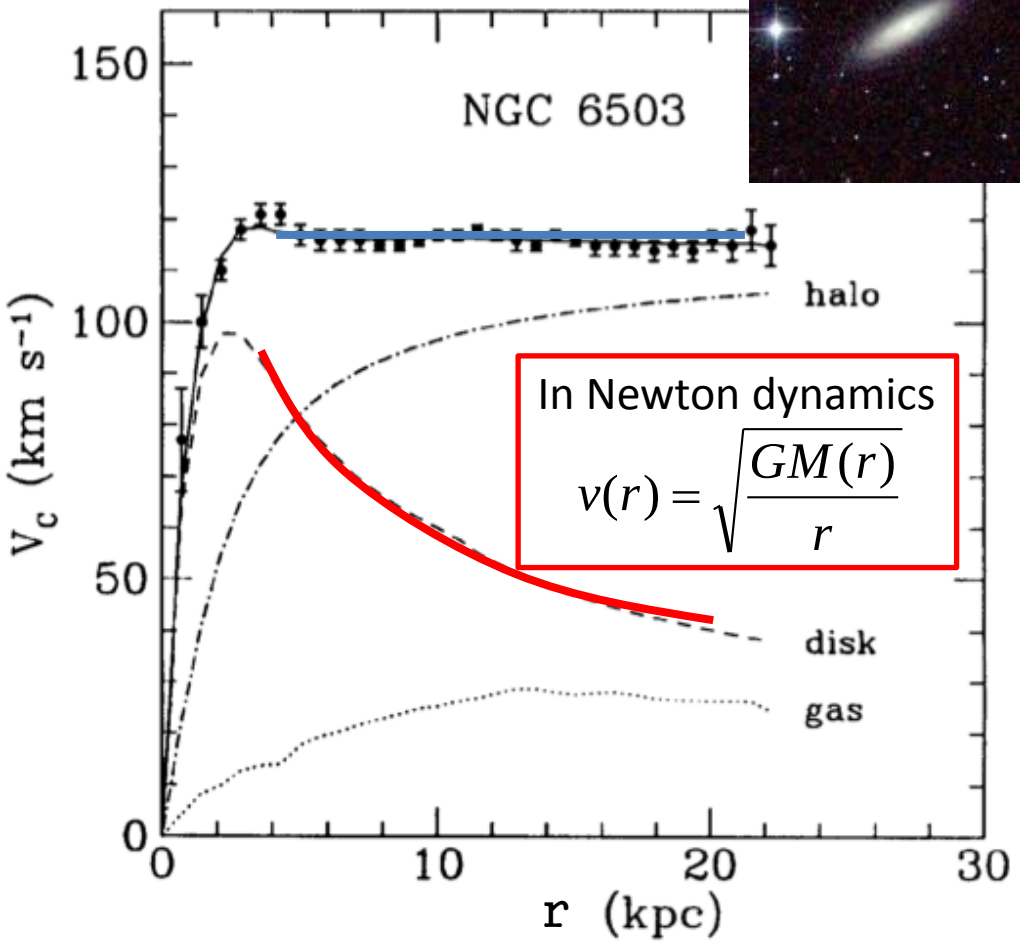
Photodetection in liquid xenon

- a large-area GPM

Something is missing…

Rotational curves of stars in galaxies

NGC 1309 : NASA, ESA, The Hubble Heritage Team, (STScI/AURA) and A.Riess (STScI)



In Newton dynamics

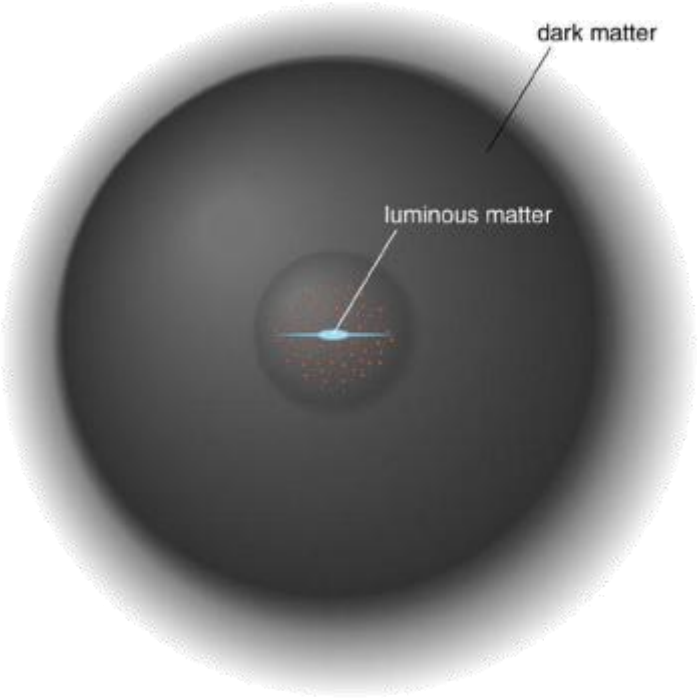
$$v(r) = \sqrt{\frac{GM(r)}{r}}$$

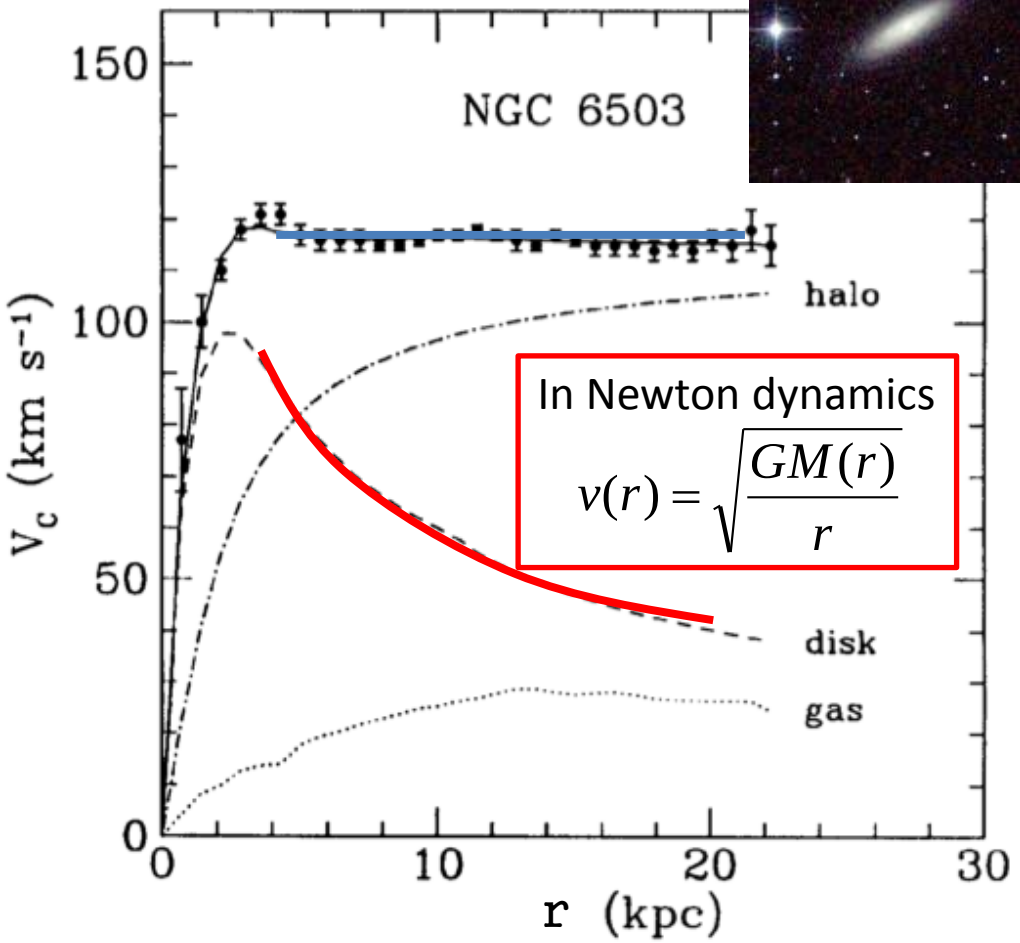
Z. Frei et al., Astrono. J 111 (1996) 174 and K.G. Begeman, A.H. Broeils, R.H. Sanders, MNRAS 249 (1991) 523

Something is missing…

Rotational curves of stars in galaxies

… a halo of Dark Matter surrounding visible one

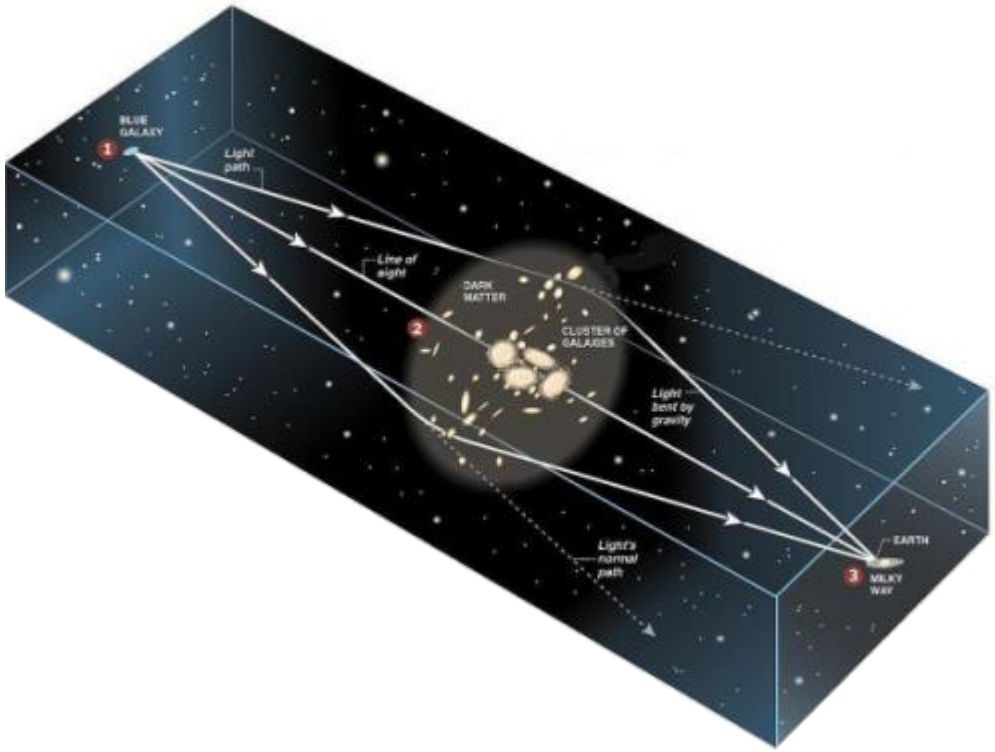


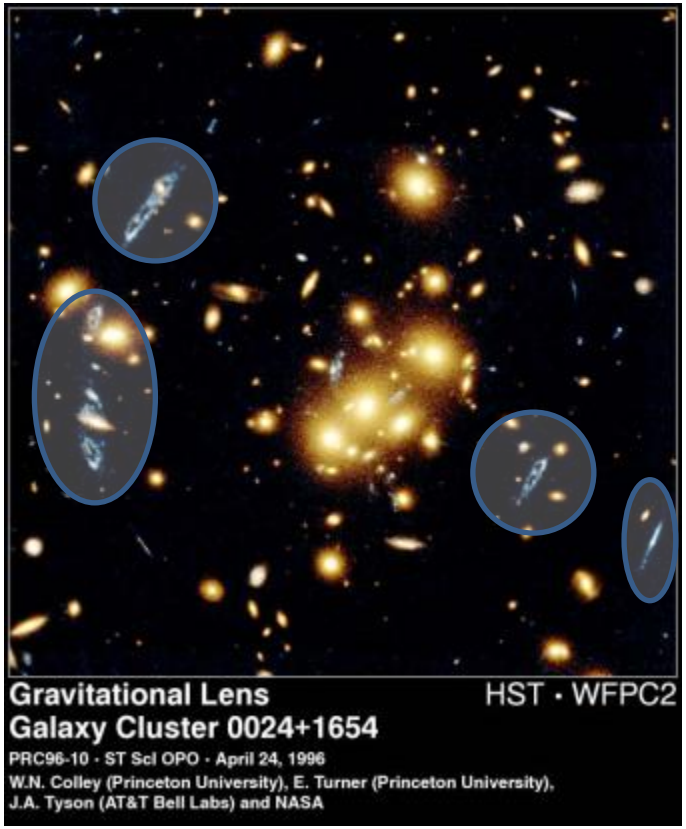


Z. Frei et al., Astrono. J 111 (1996) 174 and K.G. Begeman, A.H. Broeils, R.H. Sanders, MNRAS 249 (1991) 523

One can see it by gravitational effects…

Gravitational lensing

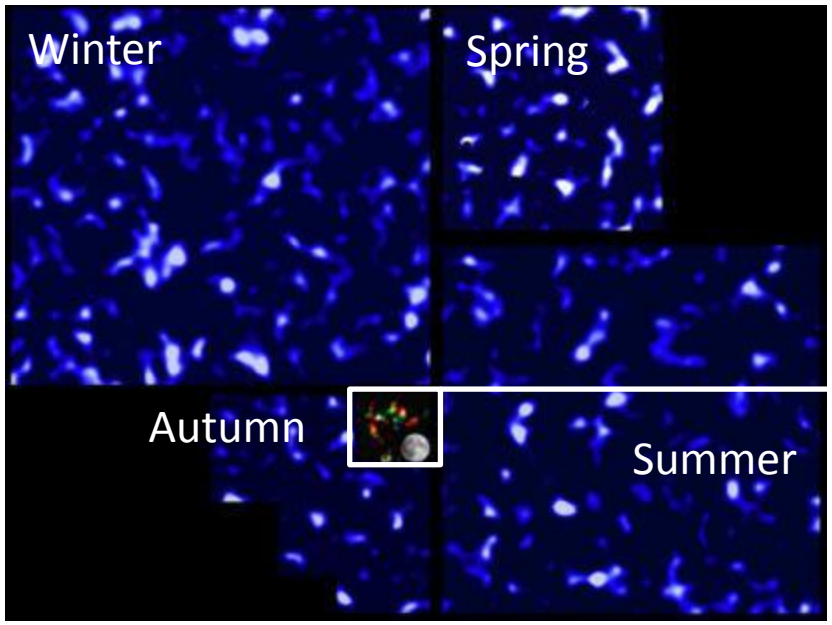




W.N. Colley and E. Turner (Princeton University), J.A. Tyson (Bell Labs, Lucent Technologies) and NASA

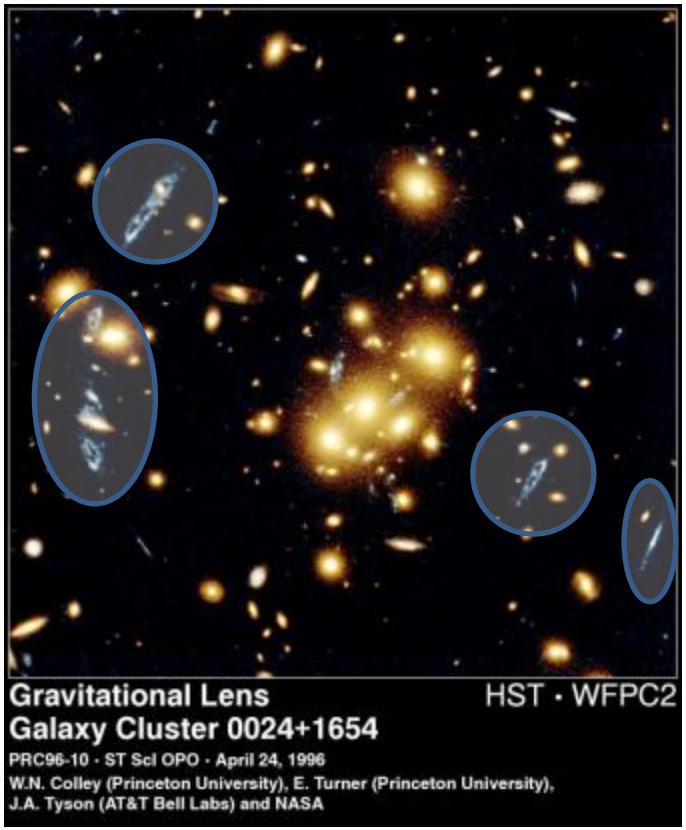
One can see it by gravitational effects…

Gravitational lensing



Previous DM map

Dark matter reconstructed map by Canada-France-Hawaii Telescope Lensing Survey



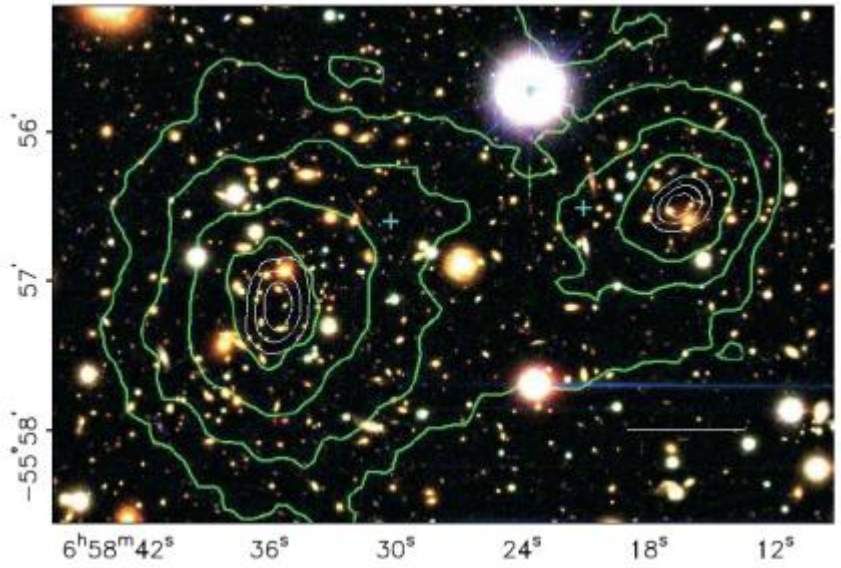
W.N. Colley and E. Turner (Princeton University), J.A. Tyson (Bell Labs, Lucent Technologies) and NASA

L. Van Waerbeke, C. Heymans, CFHTLensing Collaboration, AAS meeting (2012)

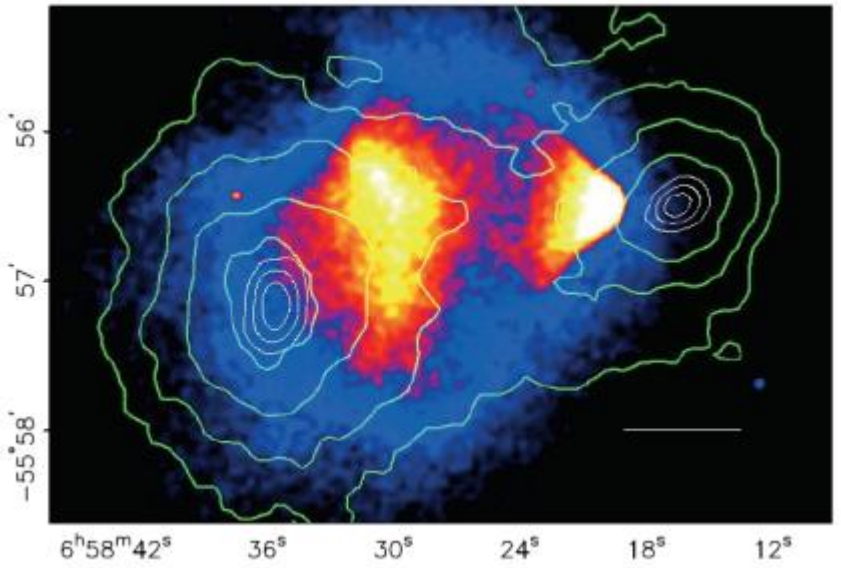
One can see it by gravitational effects…

Cluster collision

The « **Bullet Cluster** »



Map of gravitational potential from weak gravitational lensing



Superimposed X-ray plasma image (Chandra X Observatory)

The gravitational potential does not follow the plasma distribution (main baryonic mass component) but rather traces the galaxies distribution…

D. Clowe et al., Astrophys. J. 648 (2006) L109

What do we know about Dark Matter?

From observations

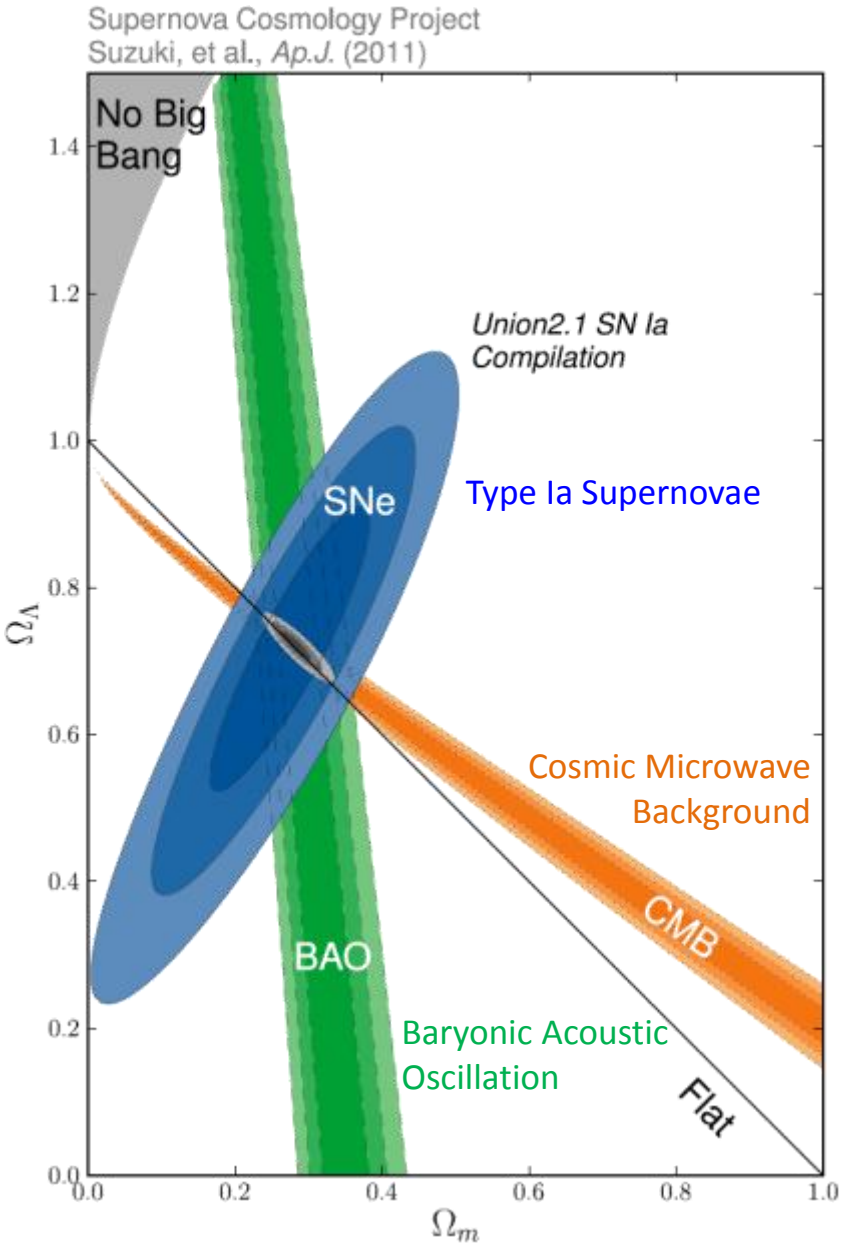
73 % Dark energy (Ω_Λ: Dark Energy density)
27 % Matter (Ω_m: Matter density)
- **22,5 % non-baryonic matter**
- **4,5 % baryonic matter**; only 0,5 % is visible!

Characteristics of the DM candidate

Low interaction rate with electromagnetic radiation and baryonic matter
Must be **stable** (relic density)
Should be **non-relativistic** (structures)

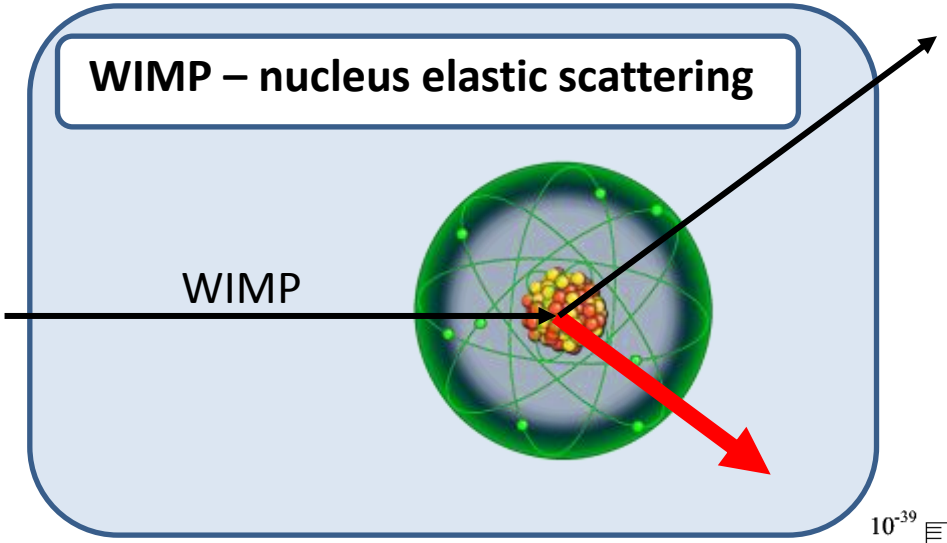
Weakly Interactive Massive Particle

Supersymmetry provides an excellent DM candidate : the **lightest neutralino**.



K. Nakamura et al.(PDG), JP G 37, 075021 (2010) , updated in 2012

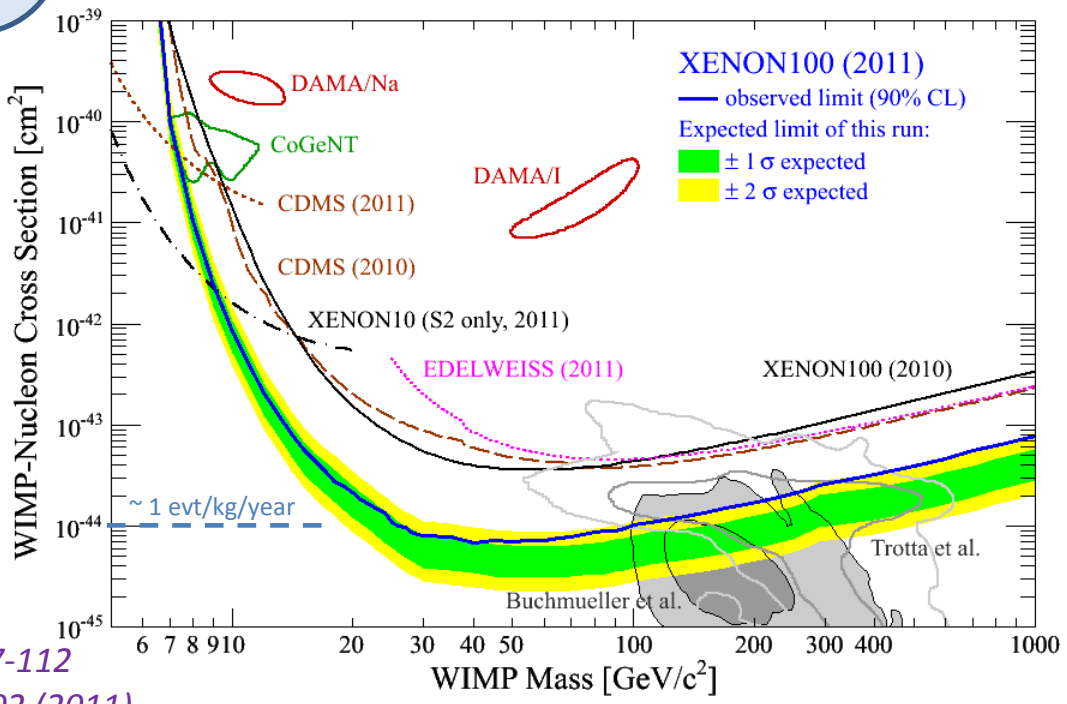
Direct Dark Matter Detection



Energy deposition by nuclear recoil (~1-100 keV_{nr})

Event rate as low as 1 evt/kg/year

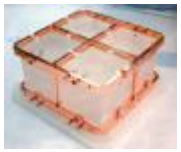
Exclusion limits



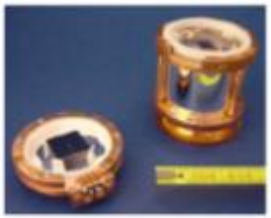
J.D. Lewin, RF. Smith, Astroparticle Physics 6 (1996) 87-112
E. Aprile et al. (XENON100), Phys. Rev. Lett. 107, 131302 (2011)

Direct Dark Matter Search Modalities

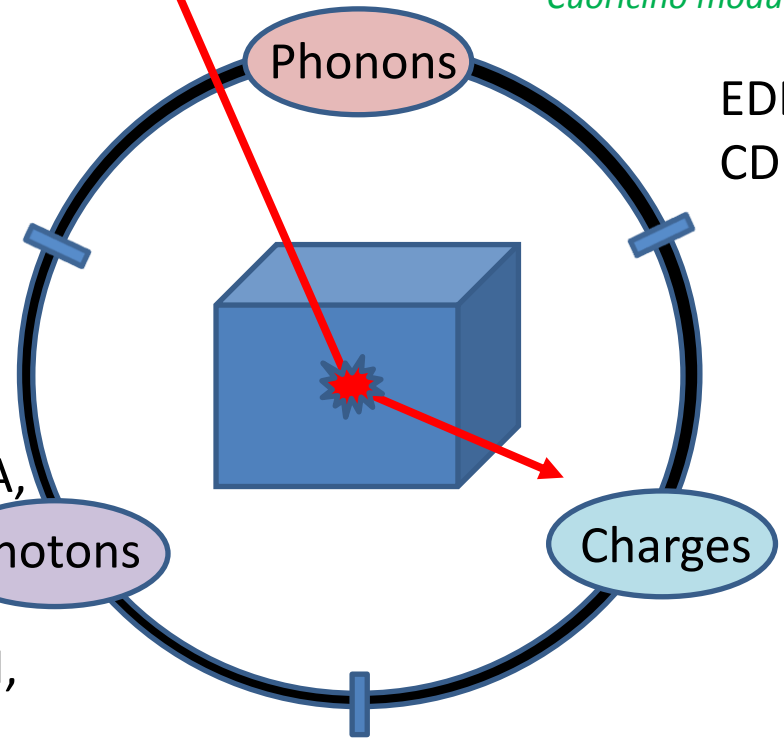
CRESST-I, CUORICINO



Cuoricino module



CRESST-II



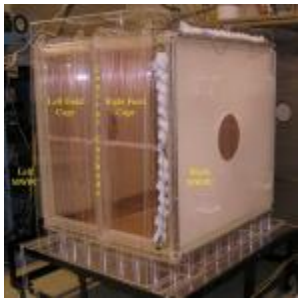
EDELWEISS
CDMS

CDMS module

XMASS

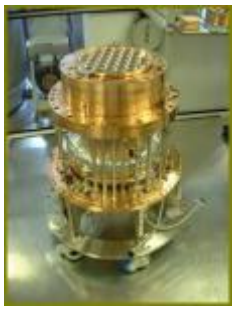
DAMA/LIBRA,
KIMS,
XMASS,
DEAP/CLEAN,
ZEPLIN-I

CoGeNT, DM-TPC,
DRIFT, MIMAC,
NEWAGE



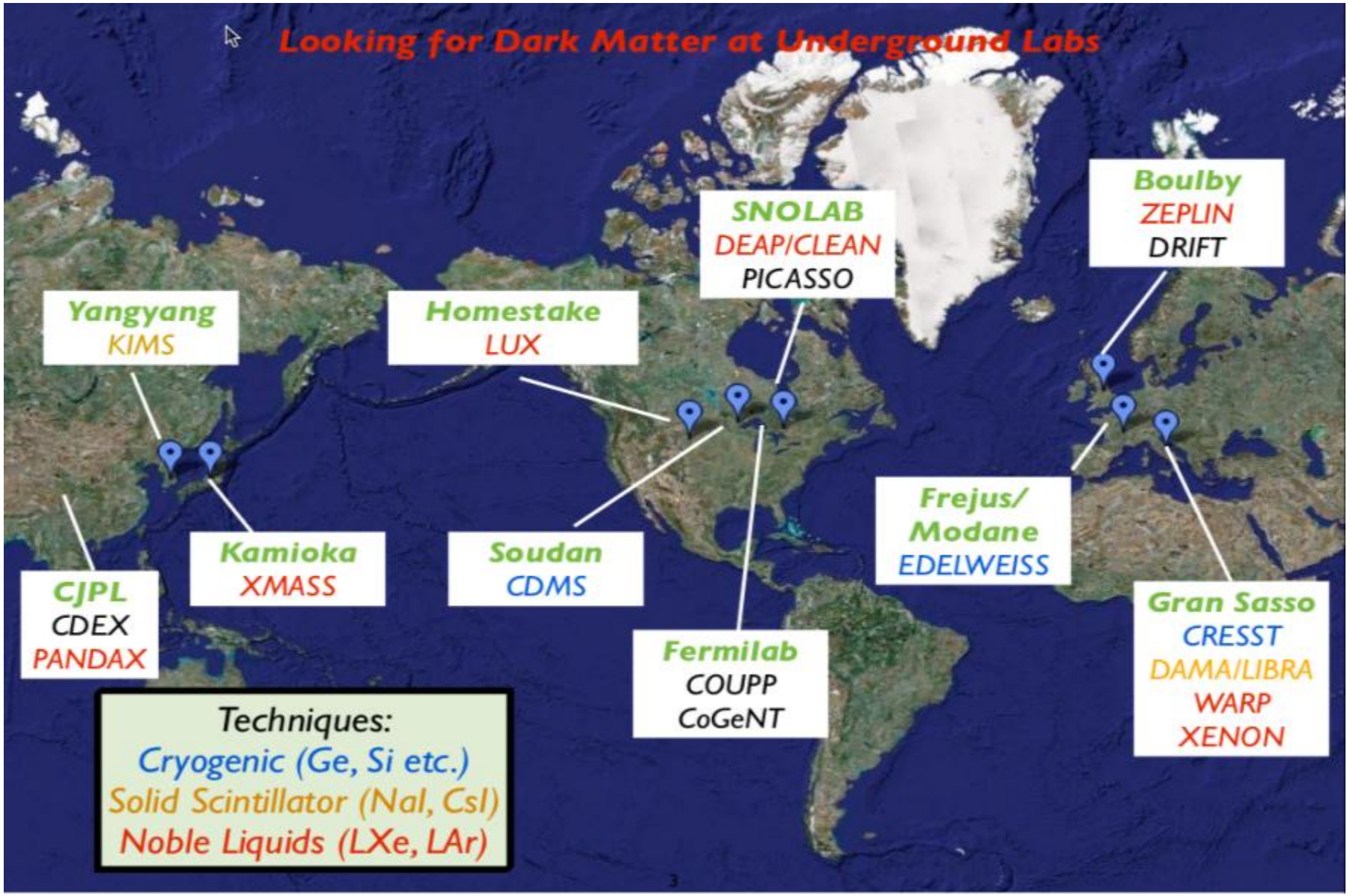
DRIFT

ZEPLIN-II/III, **XENON**,
LUX, WARP, ArDM,
PANDA-X



ZEPLIN-III

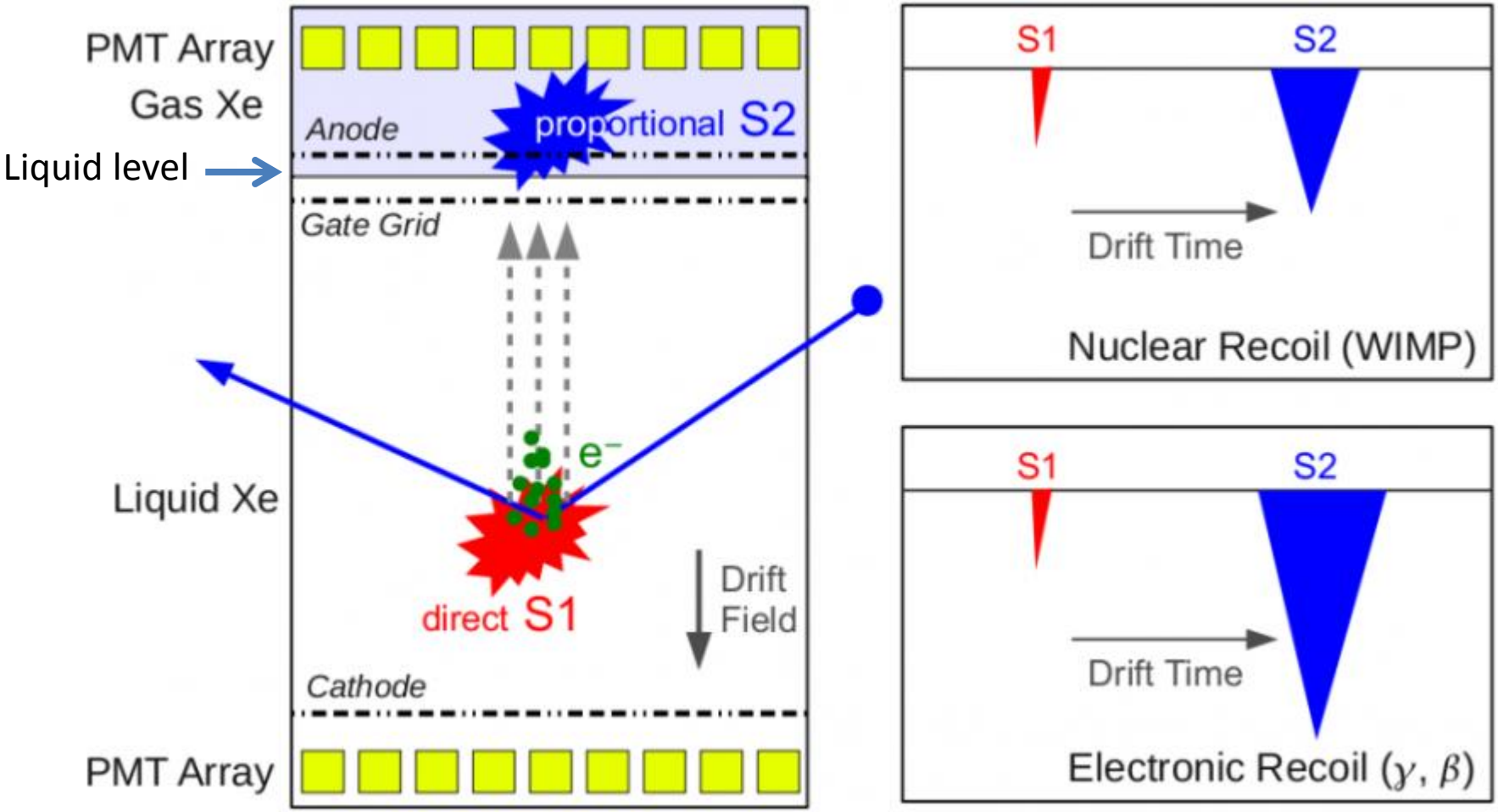
Direct DM Detection around the world



XENON100 : Underground experiment

Laboratori Nationali del Gran Sasso, Italy
1400 m Rock (3600 water equivalent, reducing muon flux ~10^6)

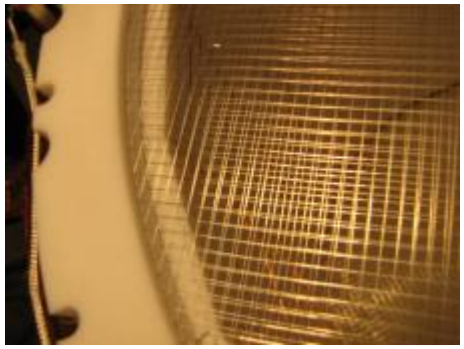
A double phase liquid xenon TPC



Nuclear/Electronic recoil **discrimination** and **fiducialization**

XENON 100 detector

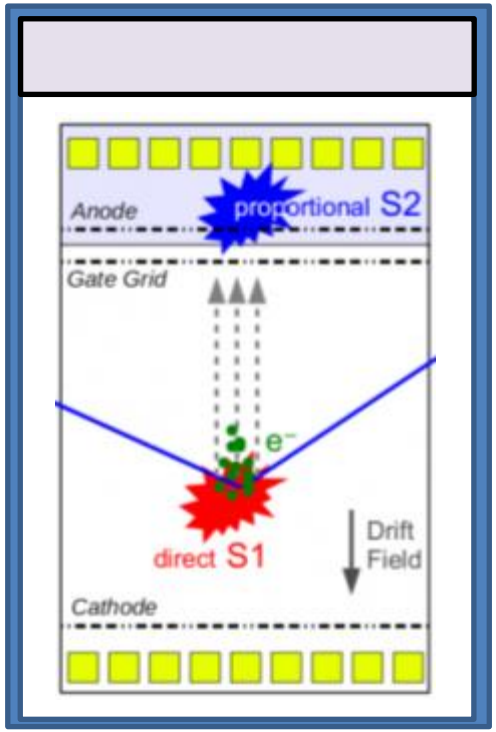
Meshes



161 kg of LXe
- 99 kg active veto
- 62 kg TPC
- 48 kg fiducial volume

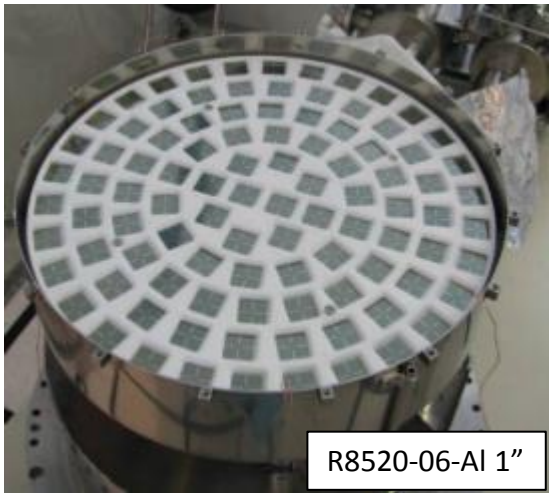
TPC

PTFE panels



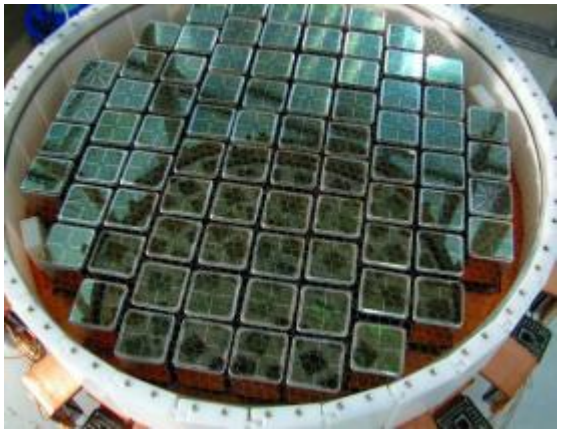
Veto PMTs

Top Array : 98 PMTs



(X,Y) reconstruction

Bottom Array : 80 PMTs



Maximum coverage

Removing the background

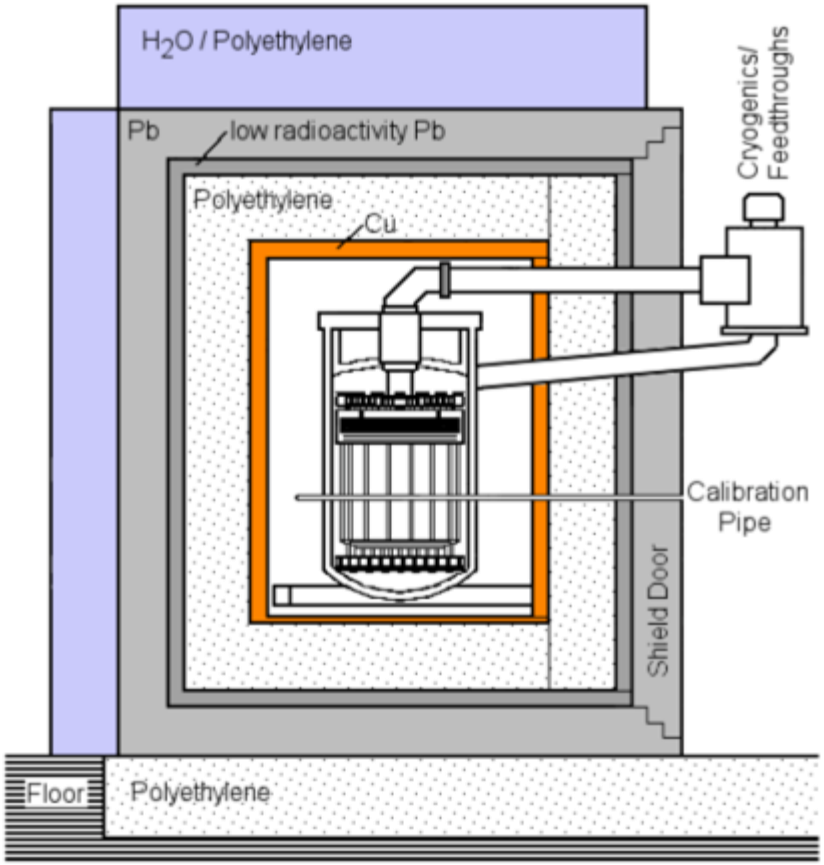
- **Electromagnetic background :**
  - Self-shielding
  - Nitrogen purging (^{222}Rn)
  - OFH copper
  - Low activity materials (TPC)
  - Pb layer + Pb with low ^{210}Pb contamination

- **Neutron background :**
  Water and Polyethylene

- **Multiple scattered events :**
  Veto PMTs
  Z position and PMT pattern

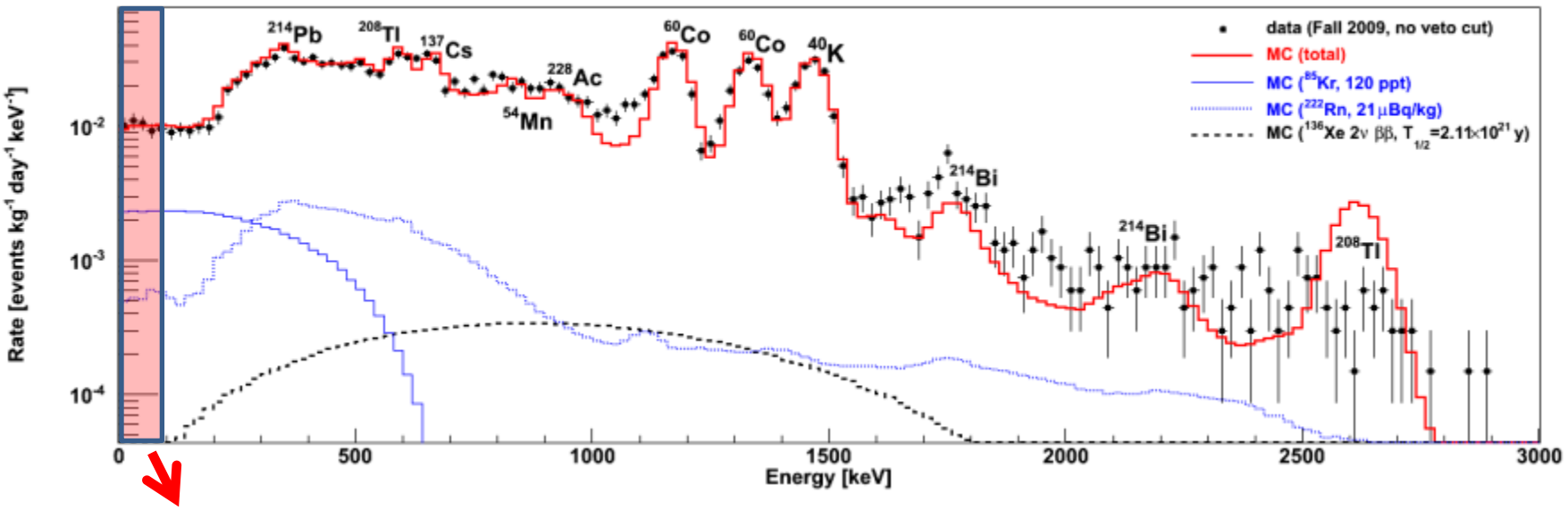
- **Krypton removal :**
  (^{85}Kr/^{nat}Kr ~10^{-11})
  β emitter
  E_{max} = 687 keV; τ=10.76 y

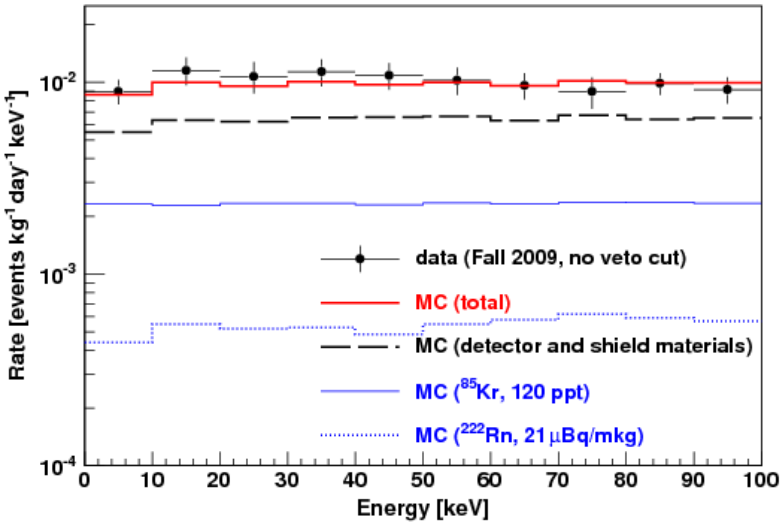
XENON 100 Detector



Krypton column

Electromagnetic background





Measured ER background in agreement with MC

- No fine tuning of rate!
- Activity taken from screening measurements

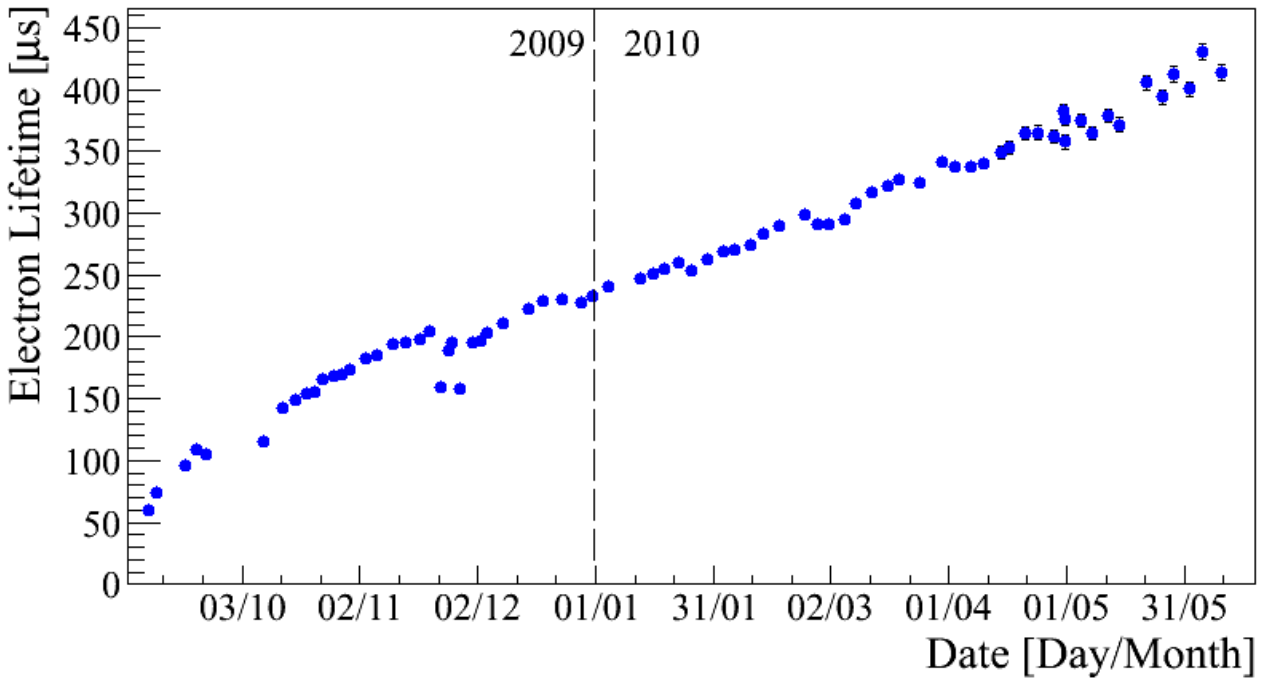
Rate below 100keV : **$6.1.10^{-3}$ evts.kg^{-1}.keV^{-1}.d^{-1}**

E. Aprile et al. (XENON100), Phys. Rev. D 83, 082001 (2011) & E. Aprile et al. (XENON100), Astropart.Phys.35:43-49,2011

Toward ultra-pure LXe

Charge yield

- Electrons are captured by electronegative impurities during the drift (30 cm)
- Xenon is continuously purified in gaseous phase
- Electron lifetime is measured with ^{137}Cs γ source during calibrations



E. Aprile et al. (XENON100), arXiv:1107.2155

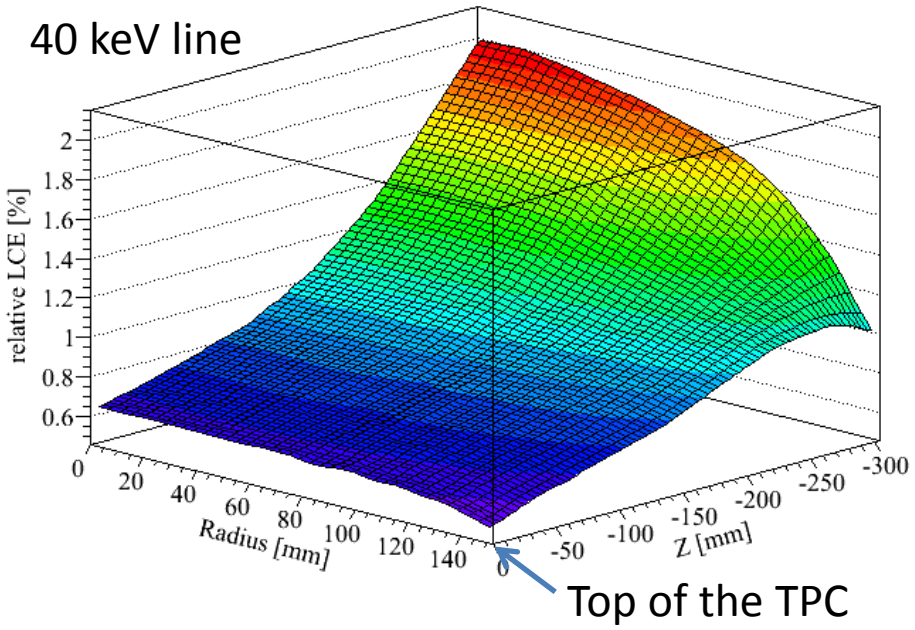
Position corrections of S1 & S2 signals

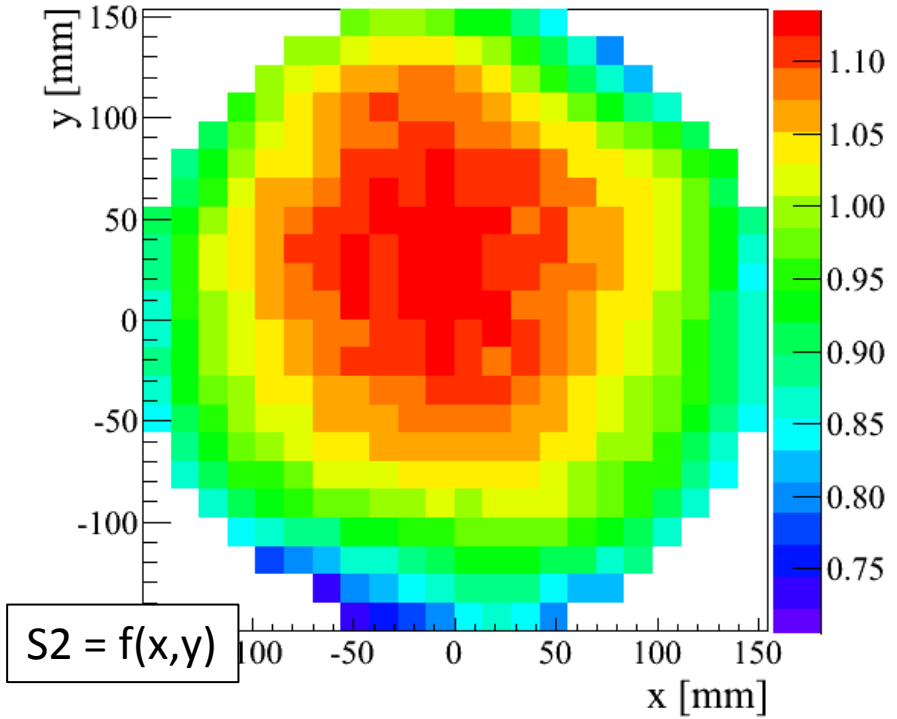
Primary scintillation (S1):
- Light collection efficiency measured with ^{137}Cs, AmBe, ^{131m}Xe

Proportional scintillation (S2):
- Charge attenuation by drift time (τ_e)
- XY corrections

Spatial resolution : $\sigma_{(x,y)}$ ~ 3 mm and σ_z ~ 0.3 mm

S1 correction map factor = f(r,z)

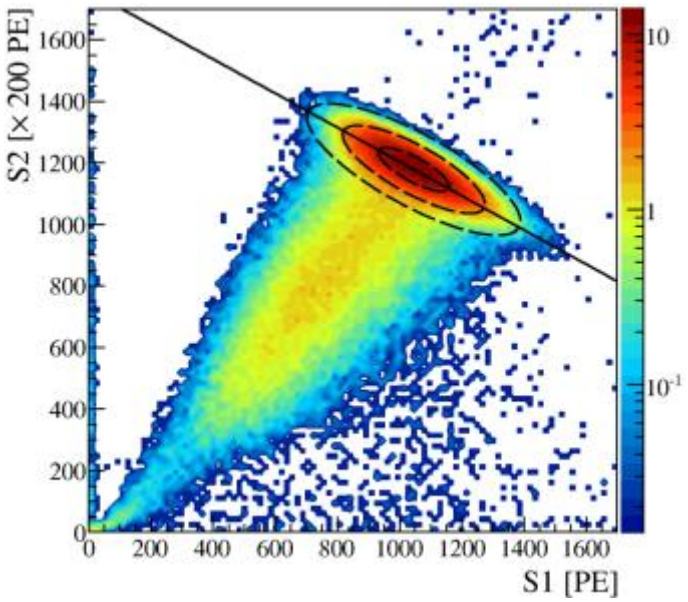


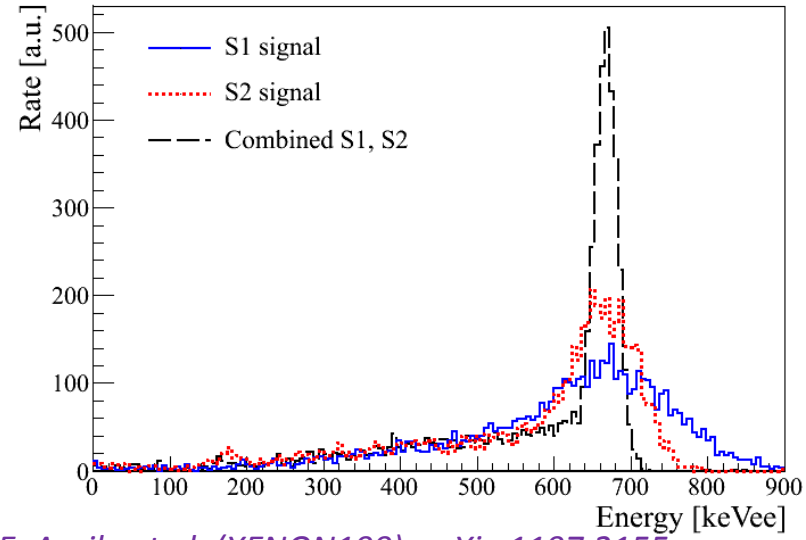


E. Aprile et al. (XENON100), arXiv:1107.2155

Gamma Calibrations

S1, S2 anti-correlation



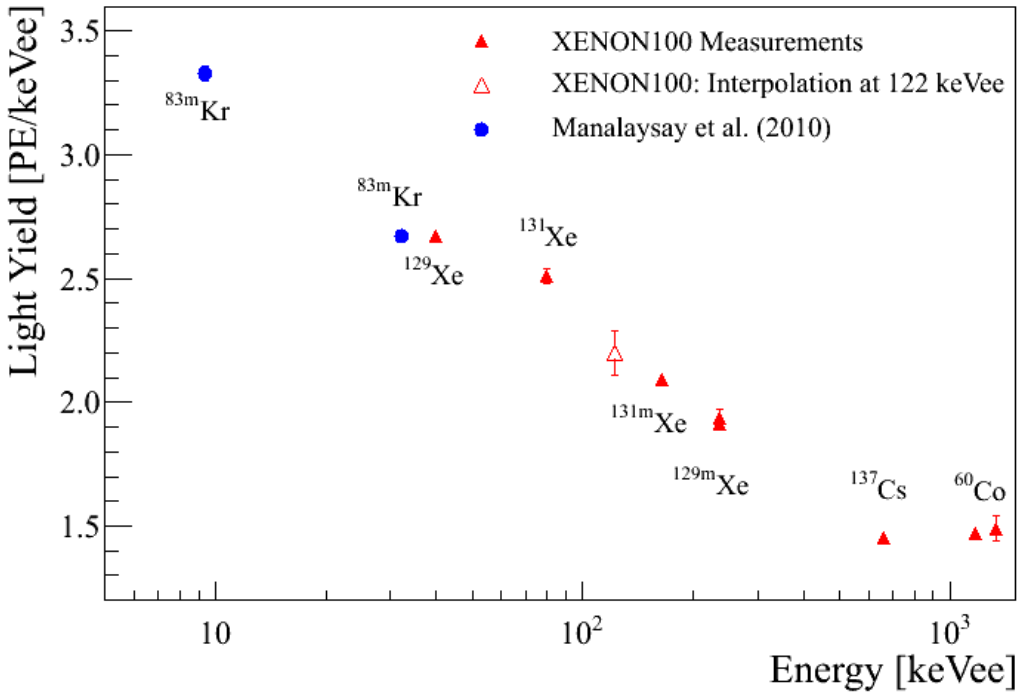


E. Aprile et al. (XENON100), arXiv:1107.2155

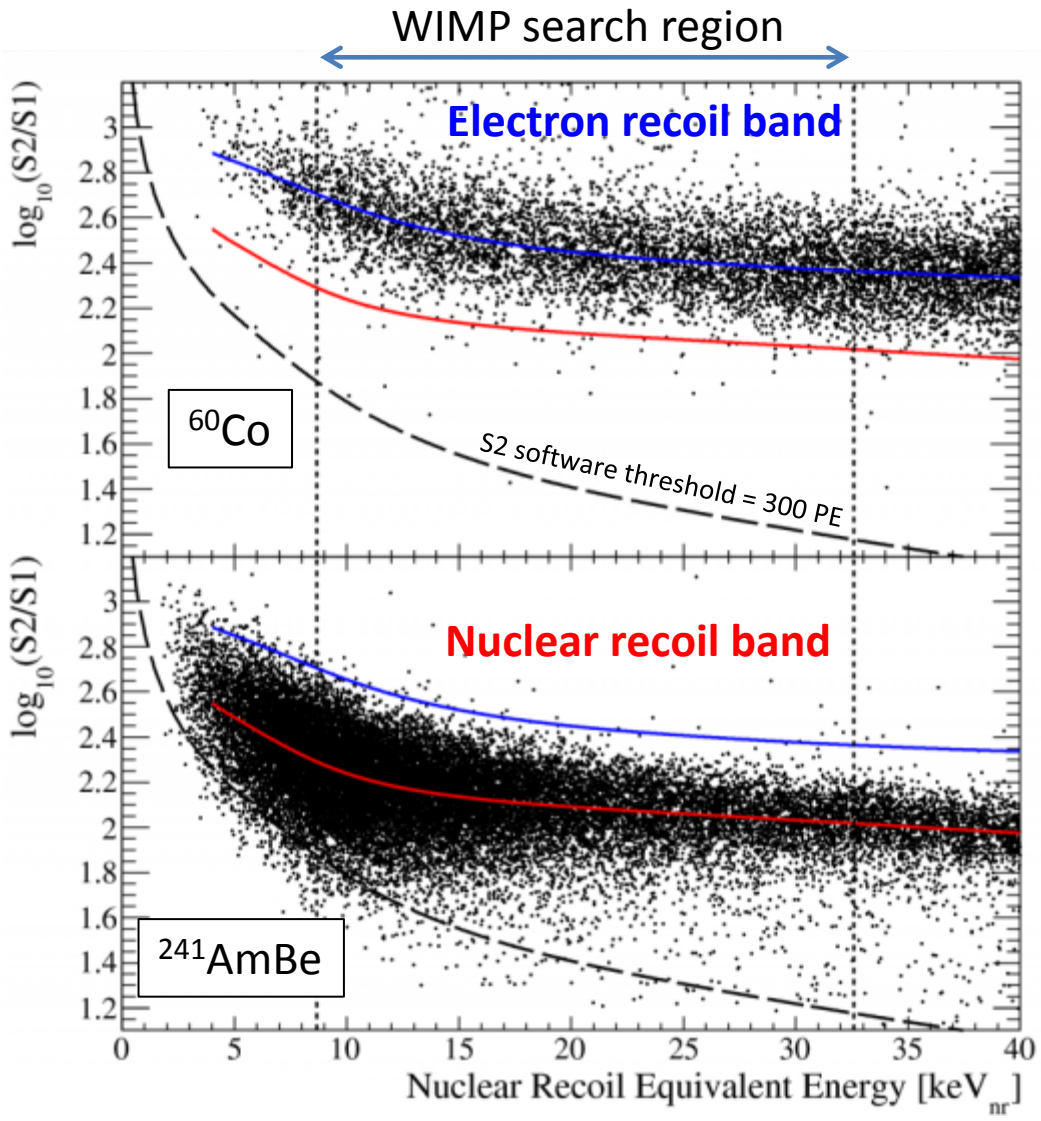
Different calibration sources

- 662 keV_{ee} (^{137}Cs), 1.17/1.33 MeV_{ee} (^{60}Co)
- 40 keV_{ee} (^{129}Xe (n,n'γ)129Xe) by $^{241}AmBe$
- 80 keV_{ee} (^{131}Xe (n,n'γ)131Xe) by $^{241}AmBe$
- 164 keV_{ee} (^{131m}Xe) by $^{241}AmBe$
- 236 keV_{ee} (^{129m}Xe) by $^{241}AmBe$

LY(122 keV_{ee}) = 2.20±0.09 pe/keVee @ 0.53kV/cm

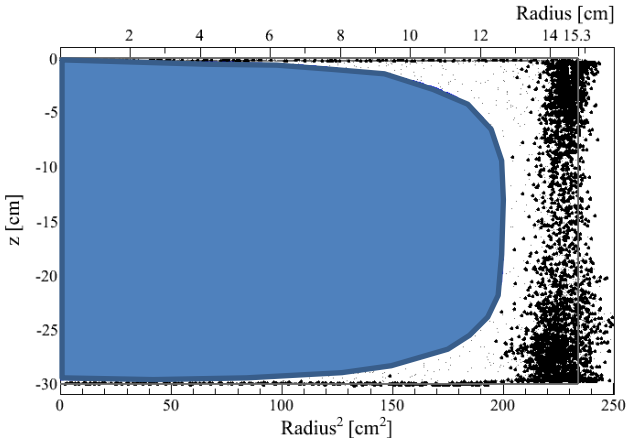


Background discrimination



Identification of recoil species by S2/S1 ratio

- from ^{60}Co γ-ray source and ^{241}AmBe neutron source
- selecting single scattered events



E. Aprile et al. (XENON100), Phys. Rev. Lett. 105, 131302 (2010)

Results from 100.9 days run

Electron Recoils

Statistical Leakage:
1.14 ±0.48 Events
Anomalous Leakage:
0.56 (+0.21/-0.27) Events

Nuclear Recoils

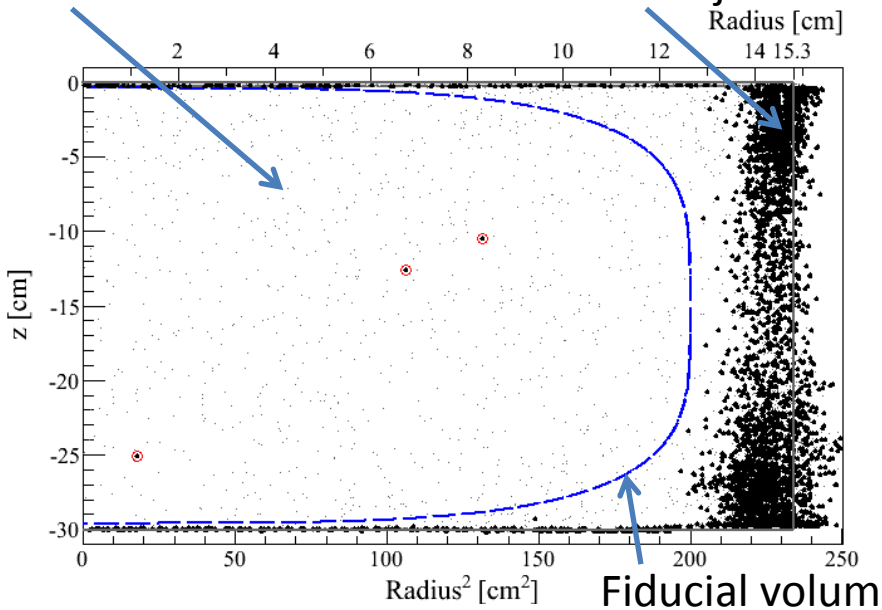
0.11 (+0.08/-0.04) Events

Predicted Background: 1.8 ± 0.6 Event

3 WIMP candidates in search region consistent with background prediction

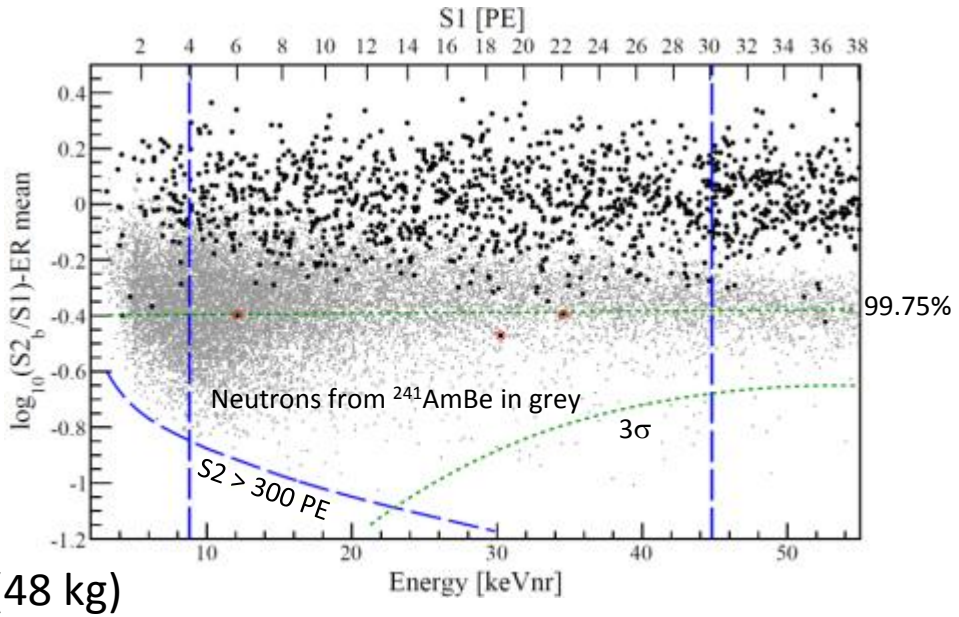
All events

Events below 99.75% rejection



Fiducial volume (48 kg)

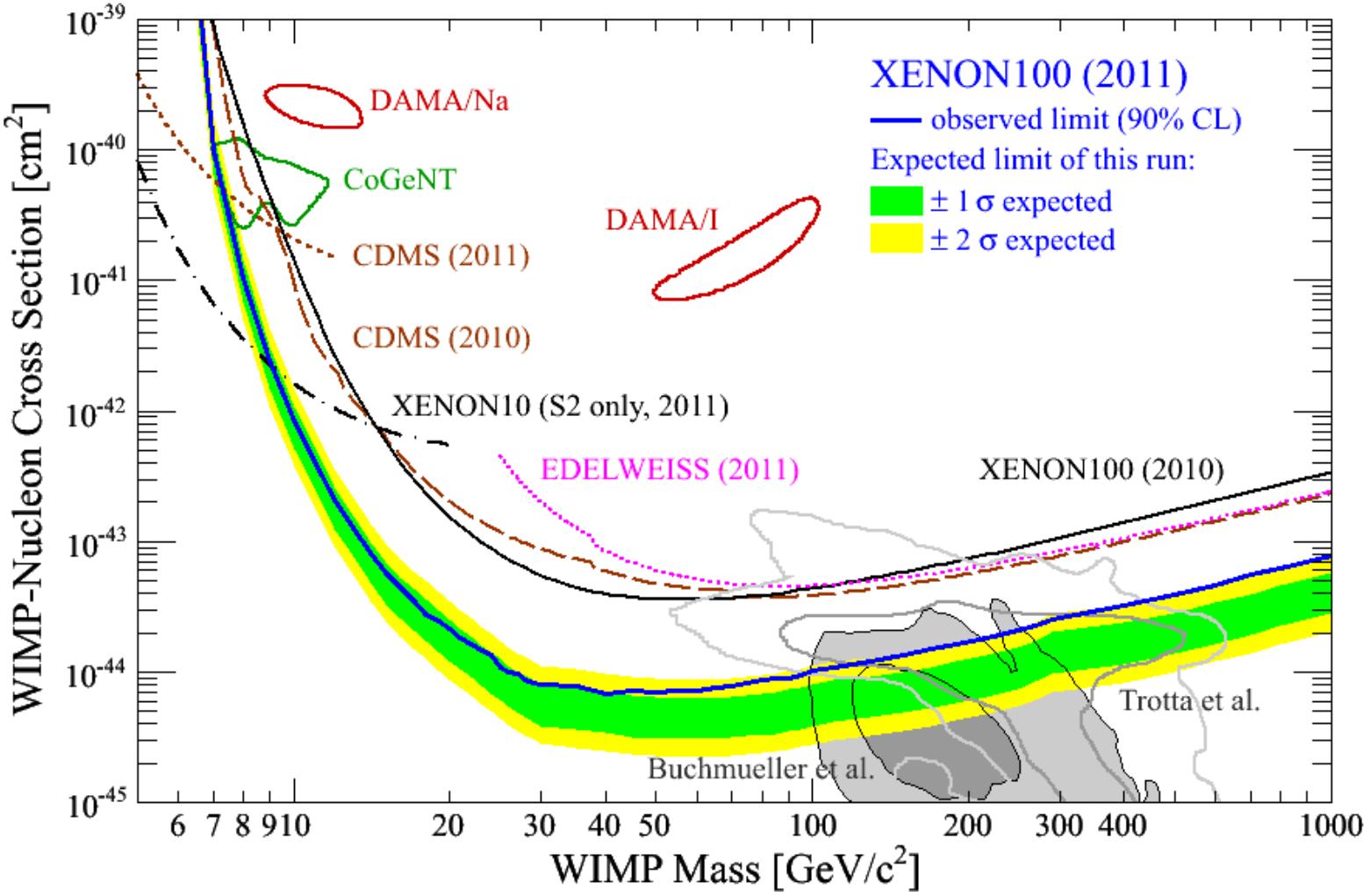
WIMP search region (8.4-44.6 keV$_{nr}$)



E. Aprile et al. (XENON100), Phys. Rev. Lett. 107, 131302 (2011)

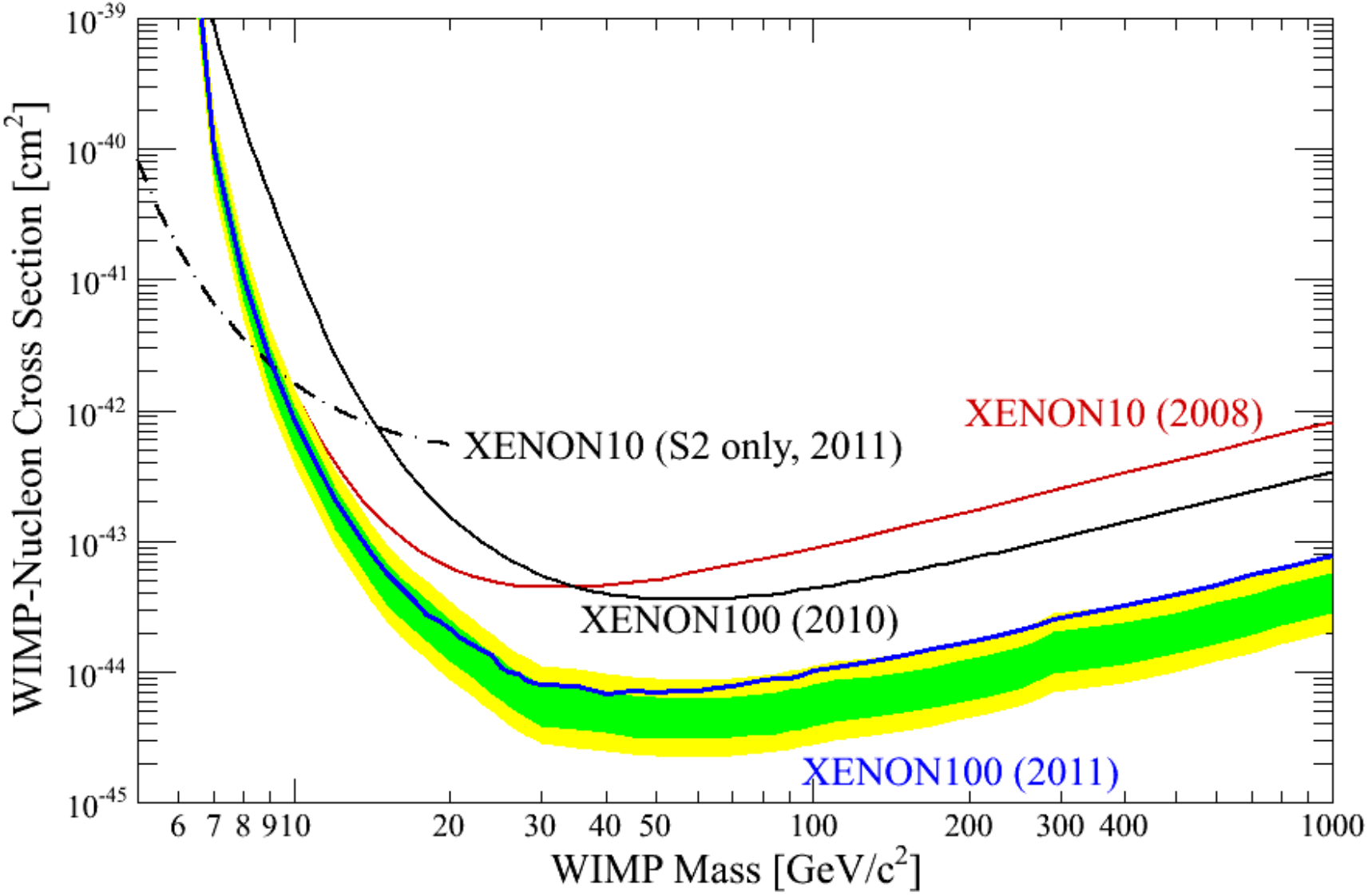
WIMP exclusion curves in σ_{SI} vs m_χ space

Lowest limit in the world : **$7.0.10^{-45}$ cm^2 @ 50 GeV/c^2**



E. Aprile et al. (XENON100), Phys. Rev. Lett. 107, 131302 (2011)

XENON is progressing fast

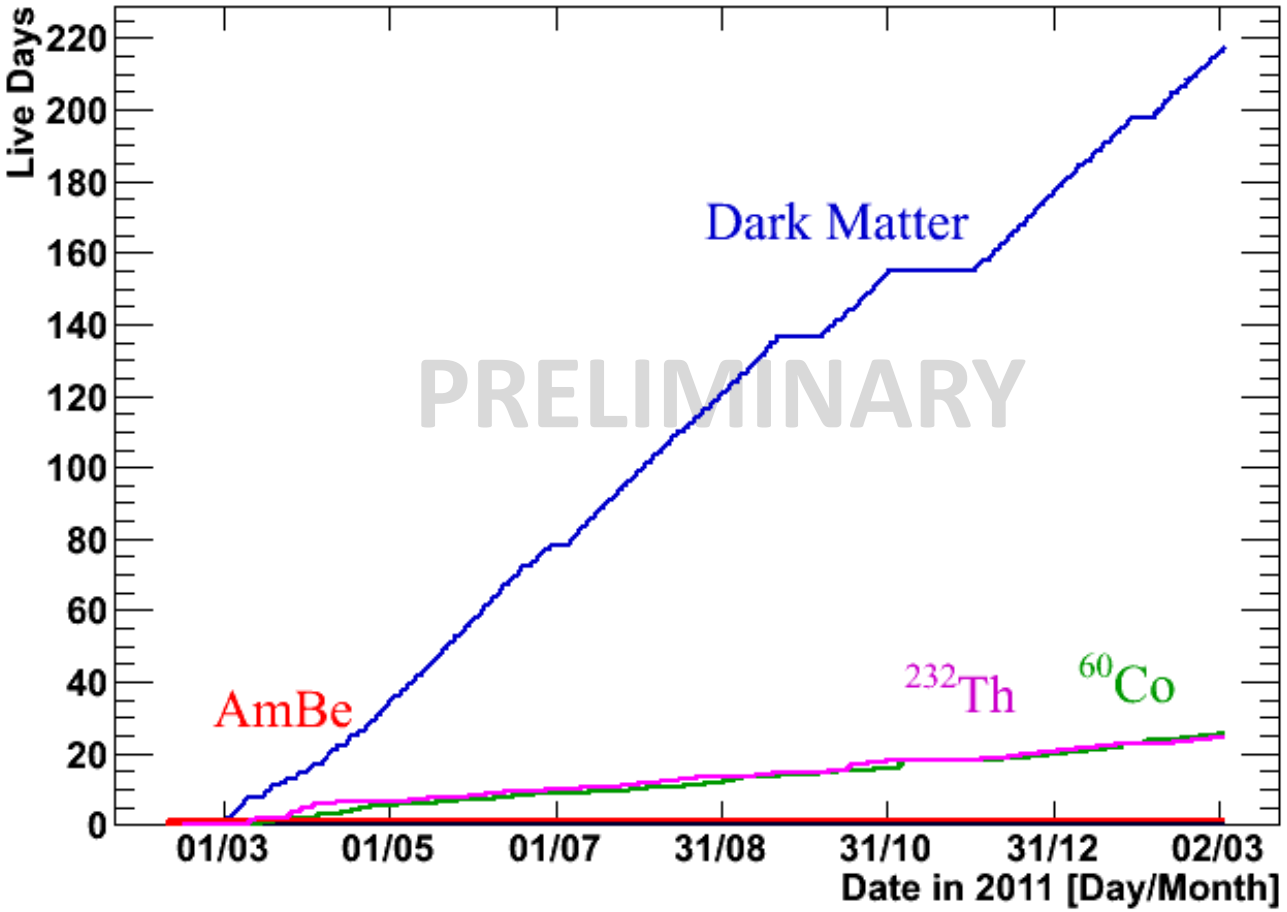


and is still taking data!

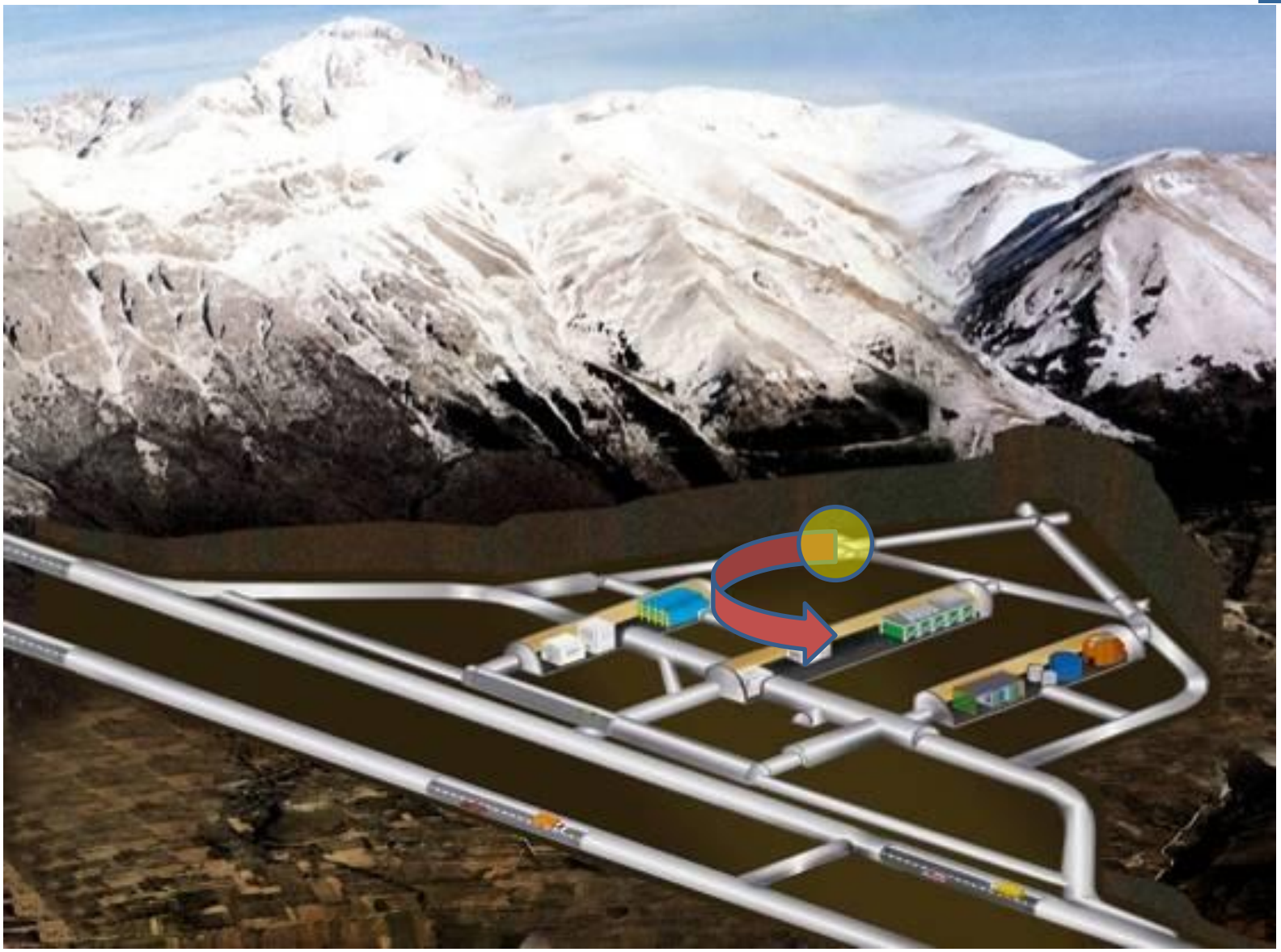
Improvements

- Less Kr (50% background reduction)
- Improved S2-based trigger with lower trigger threshold
- Better LXe purity, much more calibration data

➢ New analysis released soon



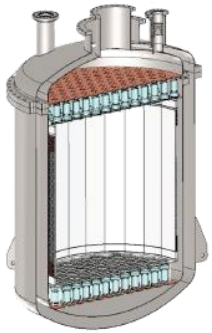
XENON is moving in Hall B

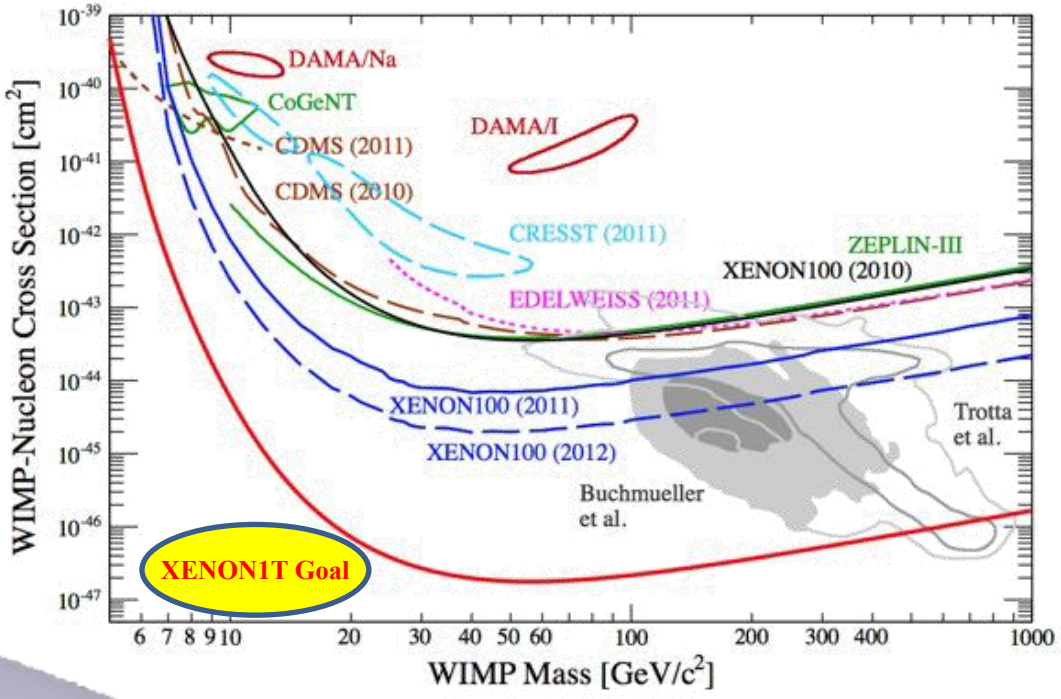


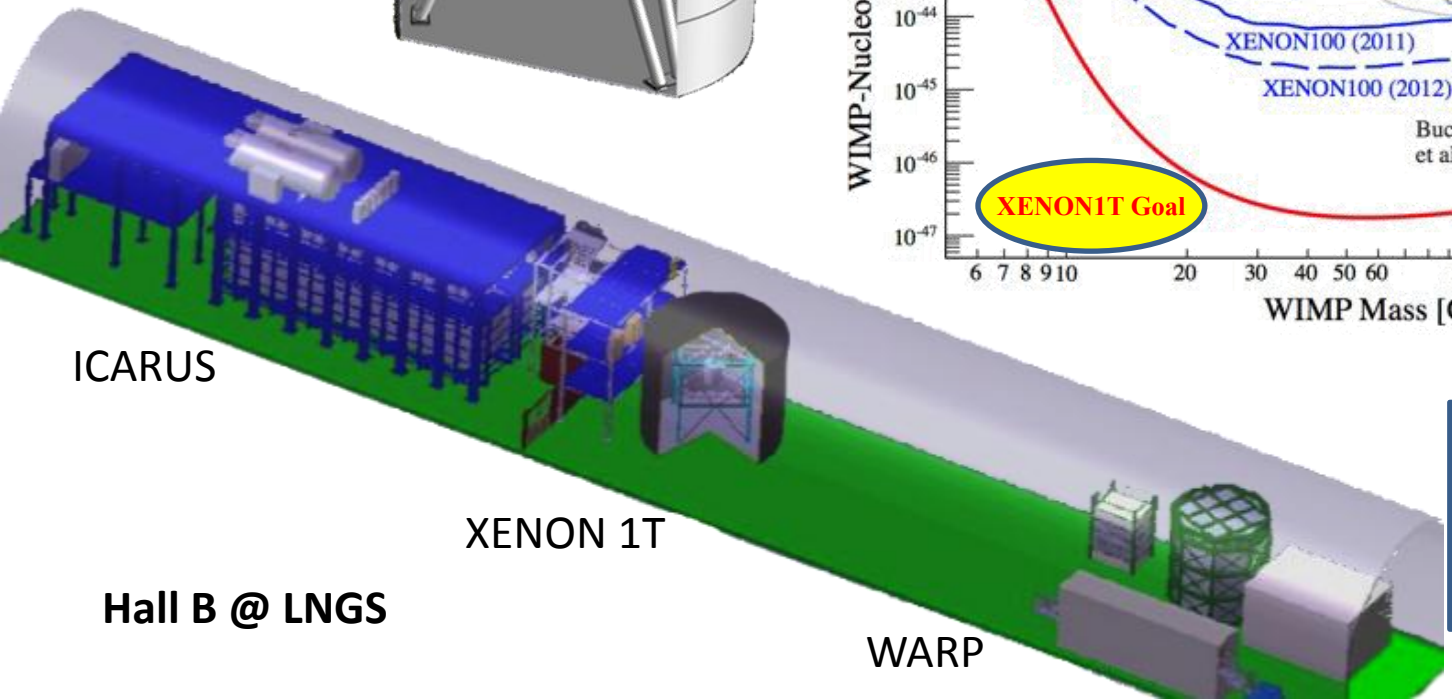
XENON1T experiment

is already under construction!

Goal : **1T fucial volume with 10^{-47} cm^2 sensitivity!**







ICARUS

XENON 1T

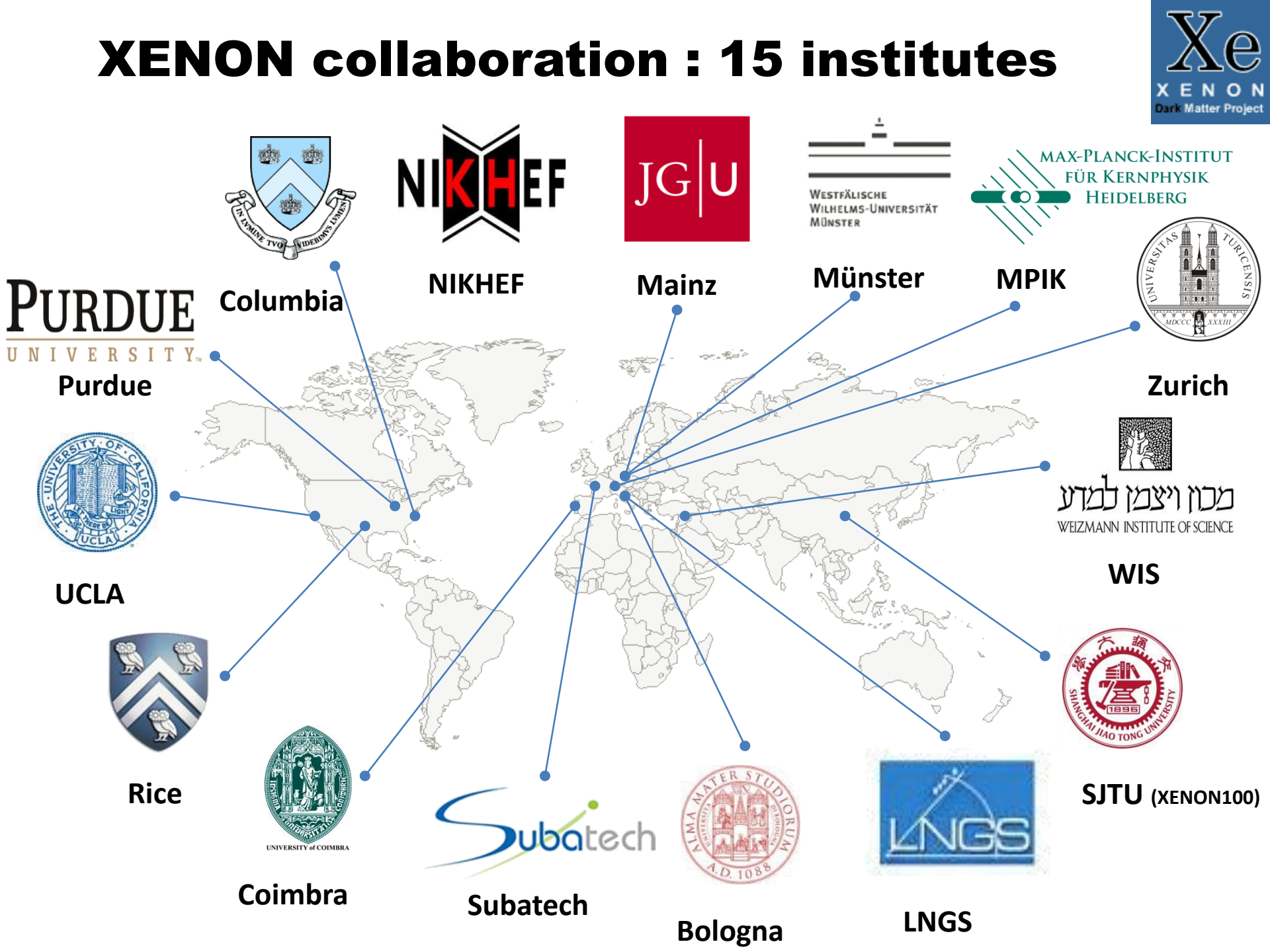
Hall B @ LNGS

WARP

2013 : installation
2014 : commissioning
2015 : data taking

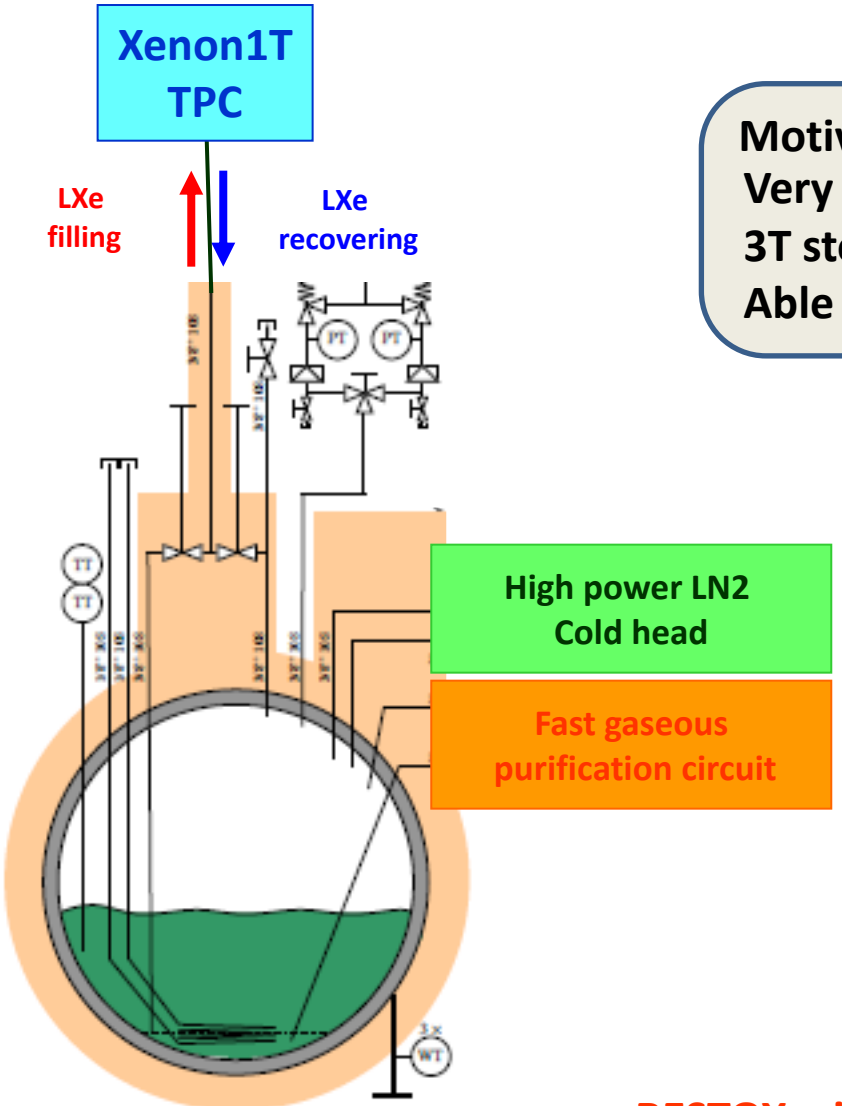
XENON collaboration people

XENON collaboration : 15 institutes



RESTOX : A Liquid Xenon station

(REcovering and STOrage system of Xenon1T)



Motivations :

- Very compact station
- 3T storage capacity from 20°to -108°C
- Able to keep high purity all the time

Time schedule:

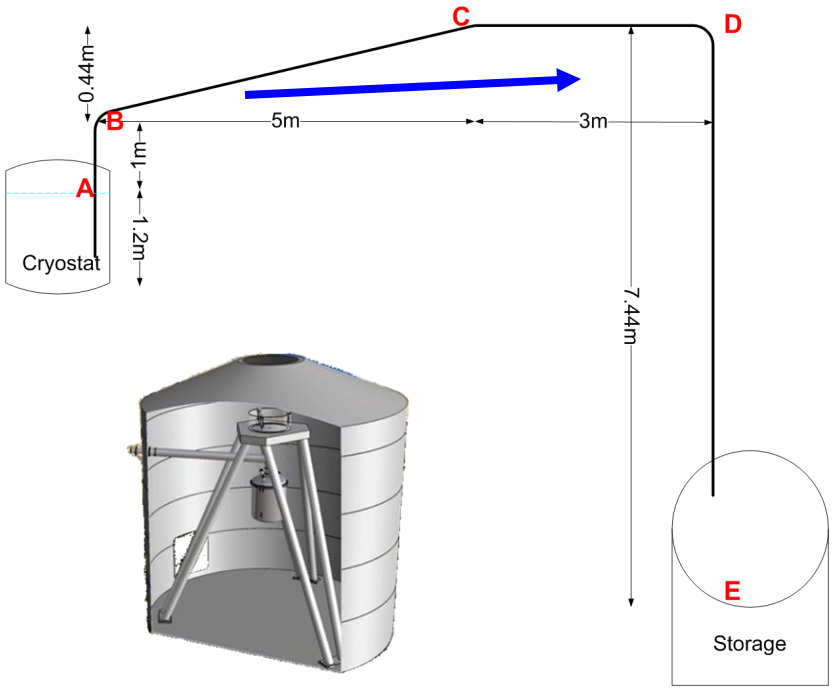
Construction will start in summer 2012

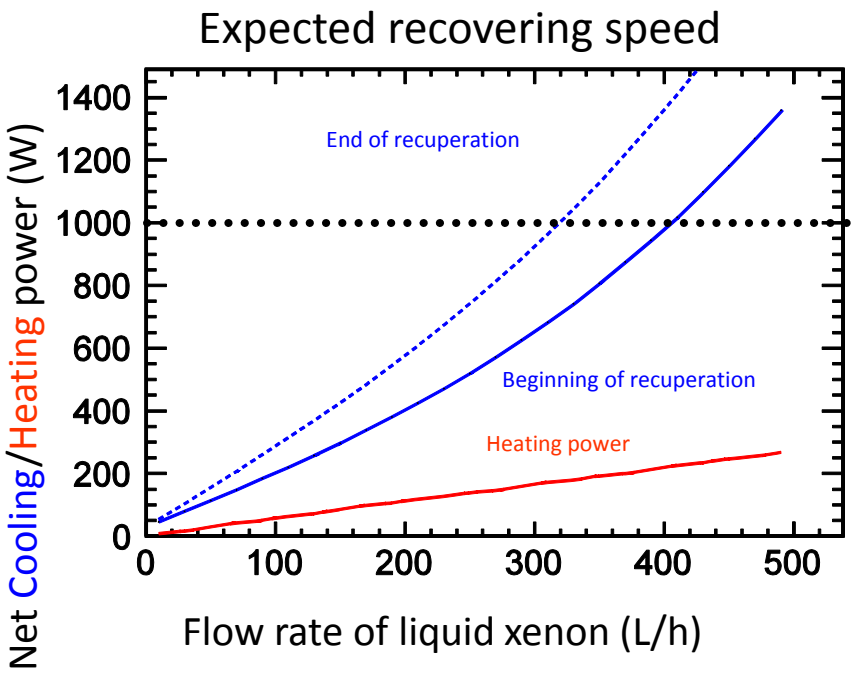
Installation for end of 2013

RESTOX will be easily scalable to larger sizes

RESTOX : A Liquid Xenon station
(REcovering and STOrage system of Xenon1T)

Pressure difference and ReStox cooling power (1 kW net)
will offer a fast and safe recovering process.

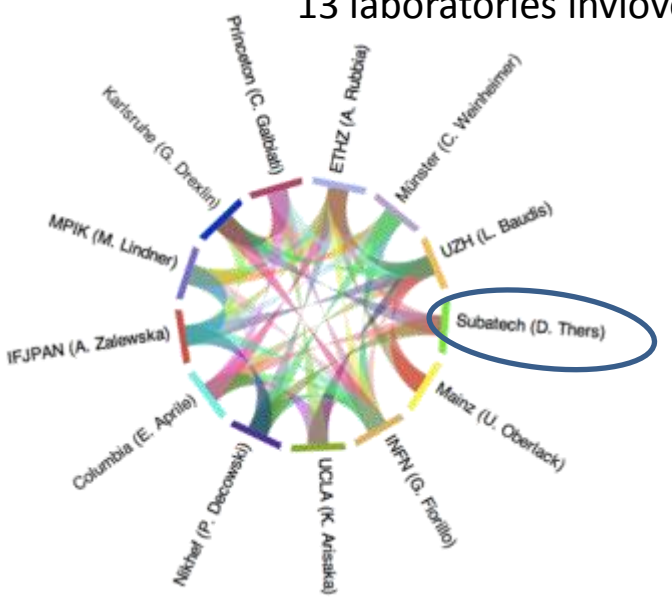


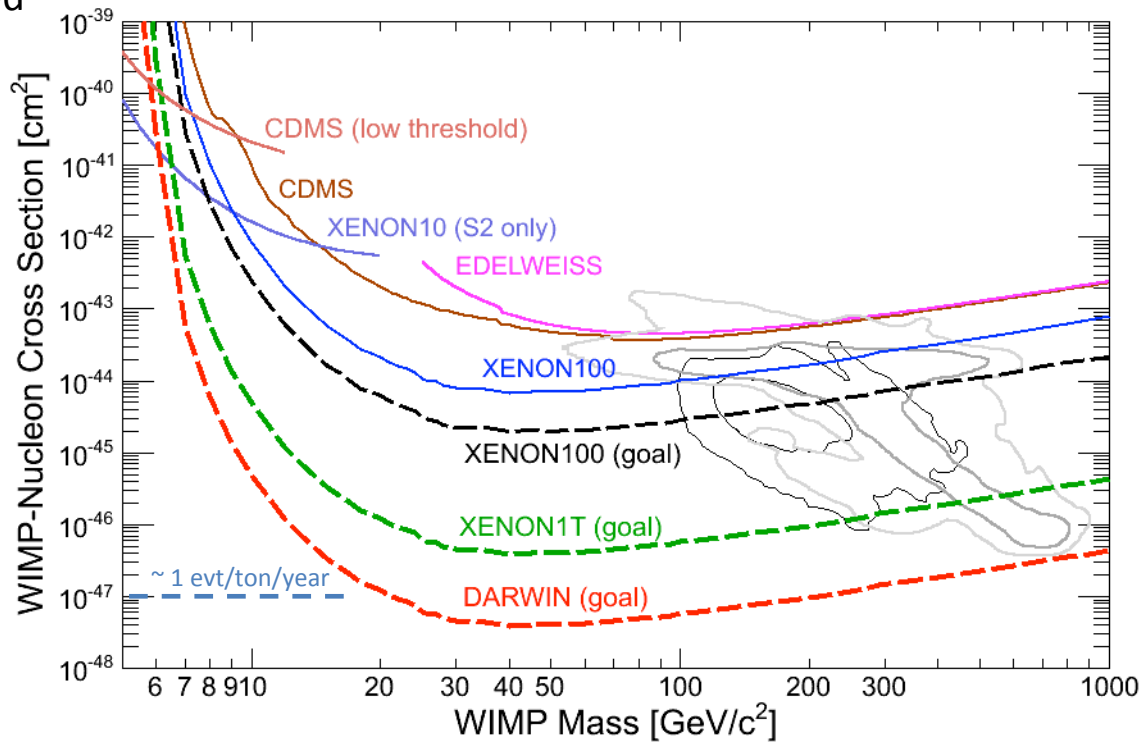


Tests on a small model (130 kg capacity) are foreseen in 2013 at Subatech

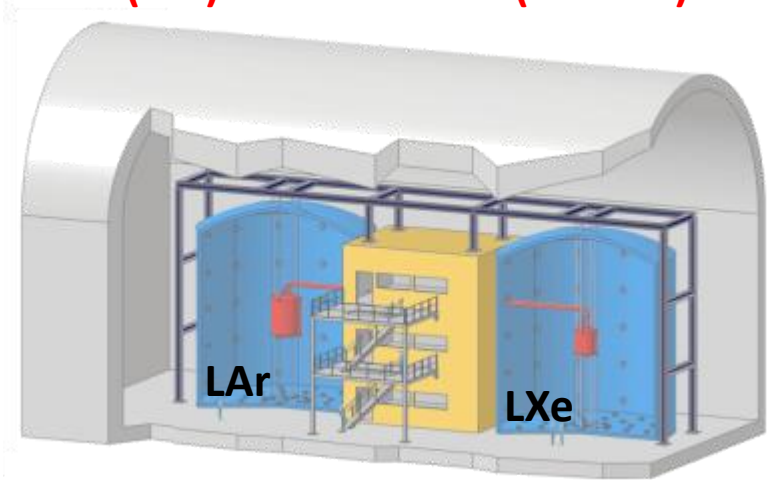
DARWIN : DARk matter WImp search with Noble liquids

13 laboratories invloved

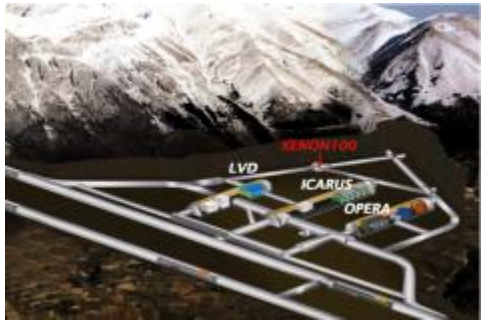




8 t (5 t) of LXe in total (fiducial)
20 t (10t) of LAr in total (fiducial)



Laboratoire Souterrain de Modane



Laboratori Nationali del Gran Sasso

dark matter wimp search in noble liquids
DARWIN

DARWIN project

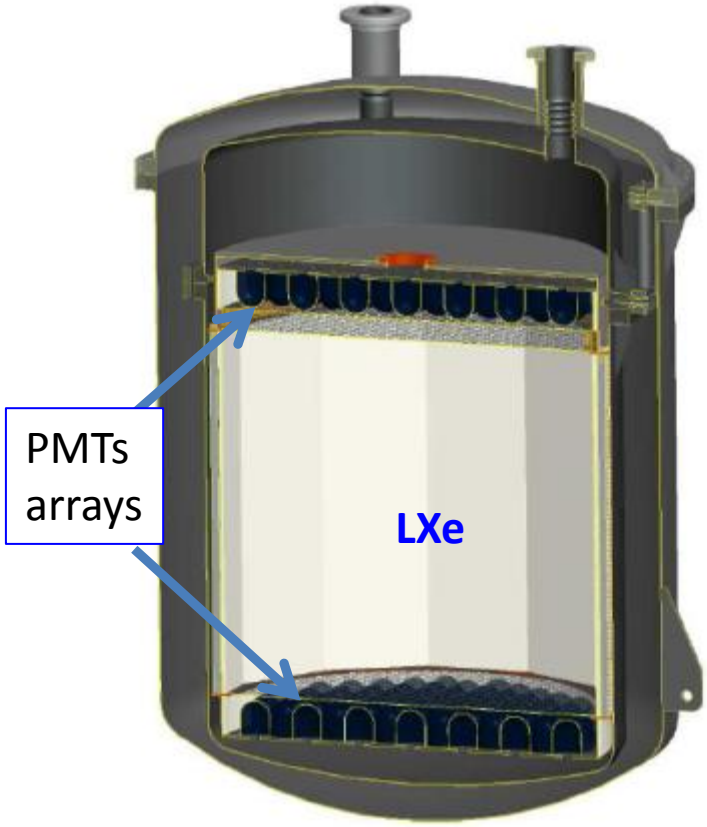
Design study of a next-generation noble liquid dark matter facility in Europe

- WP1 Management (UZH)
- WP2 Detector infrastructure (Münster)
- WP3 Light read-out (INFN)
- WP4 Alternative charge read-out methods (ETHZ)
- WP5 Electronics and DAQ (Subatech)
- WP6 Underground and shielding infrastructure (IFJ PAN)
- WP7 Material screening and background modeling (MPIK)
- WP8 Science impact (Nikhef)

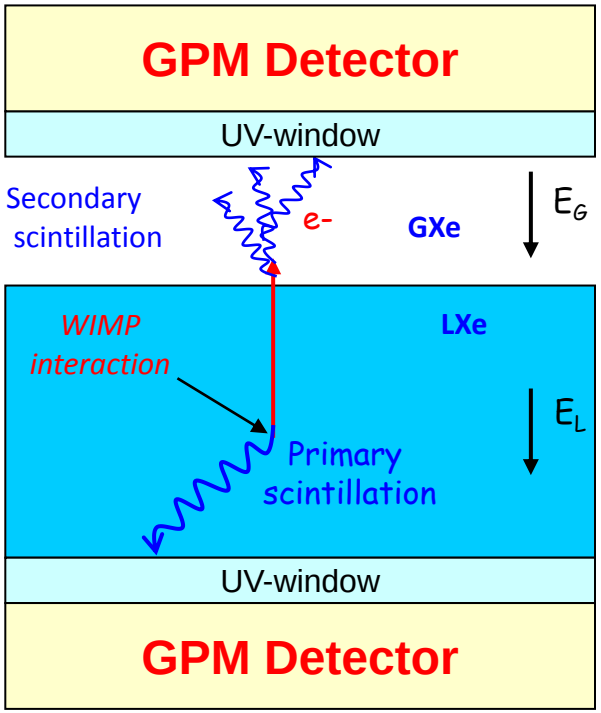
Improving the charge-readout sensitivity by maximizing the photodetection coverage and keeping localization power

Large-Area Gaseous PhotoMultipliers

Using Micro-Pattern Gaseous Devices : THGEMs and/or micromeshes



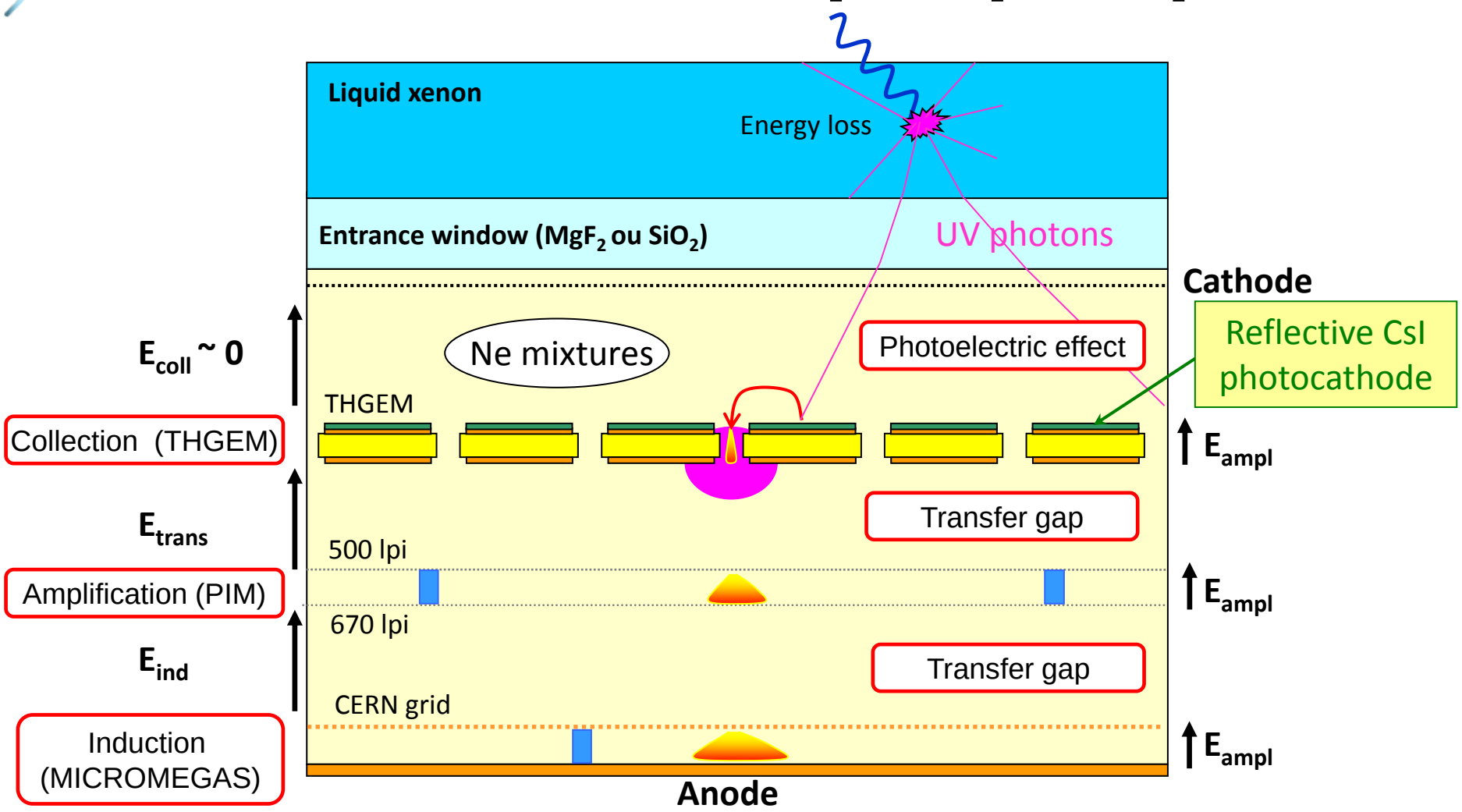
?



Collaboration between Subatech/WIS-Israel/Coimbra-Portugal

@ WIS : multiple THGEM concept (in two-phase LXe)
@ Nantes : THGEM/PIM/MICROMEGAS (in single phase LXe)

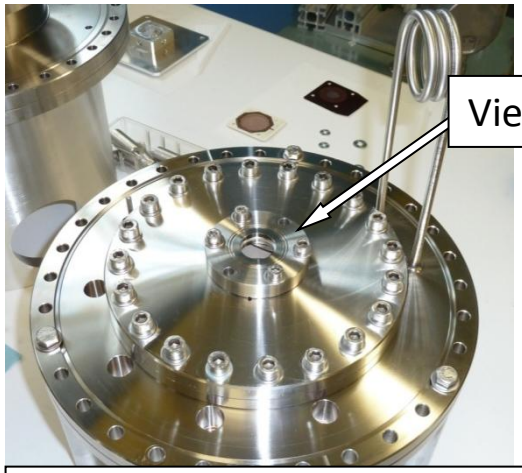
Gaseous Photomultiplier principle



THGEM: Efficient **photoelectron collection** + low gain
PIM/MICROMEGAS: **ion blocking** (prevents CsI damage) & gain

*S. Duval et al., 2009 JINST **4** P12008 & S. Duval et al., 2011 JINST **6** P04007*

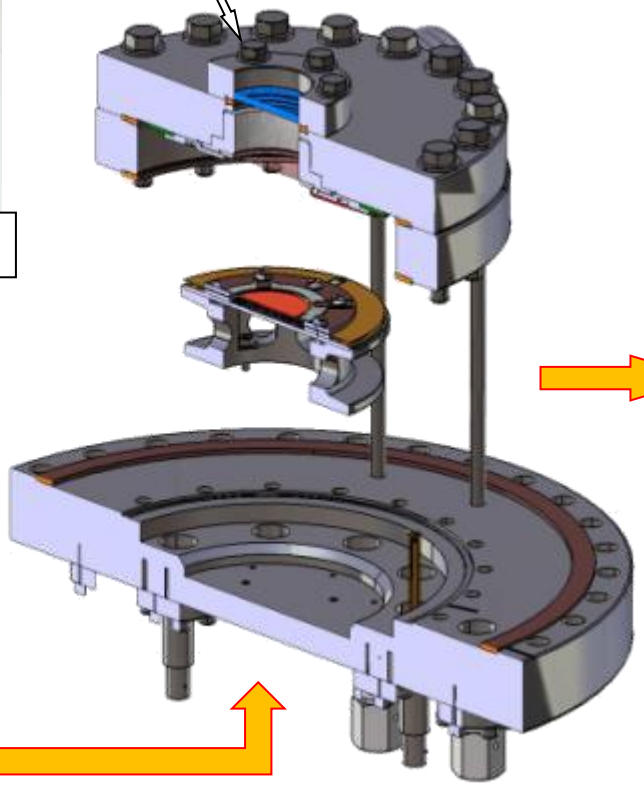
GPM detector

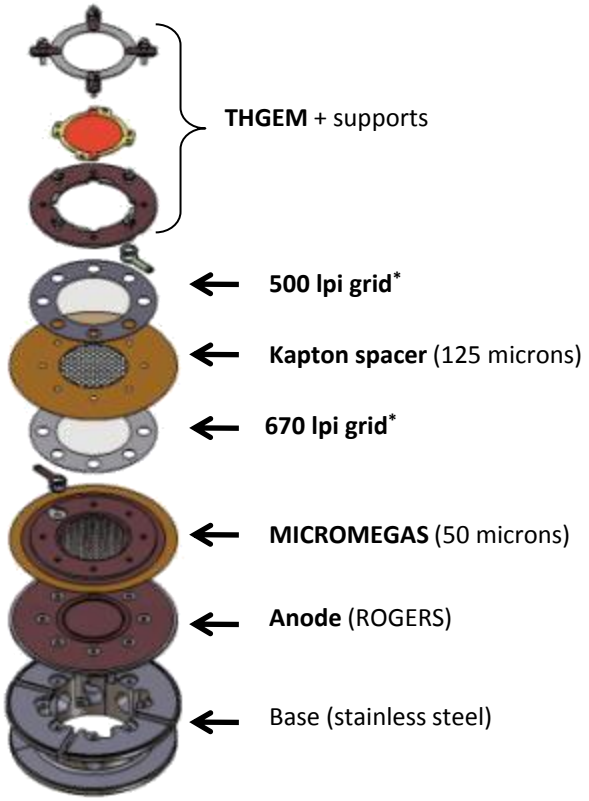


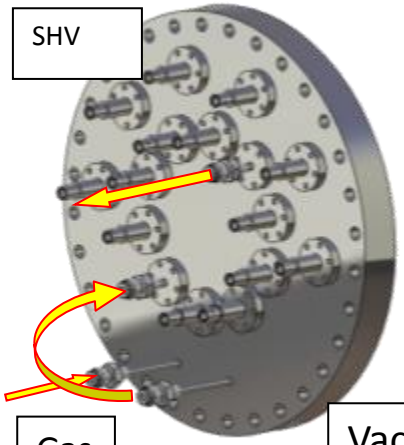
LXe GPM prototype (LXe side)

Viewport (MgF_2)

THGEM/PIM/MICROMEGAS
Internal structure

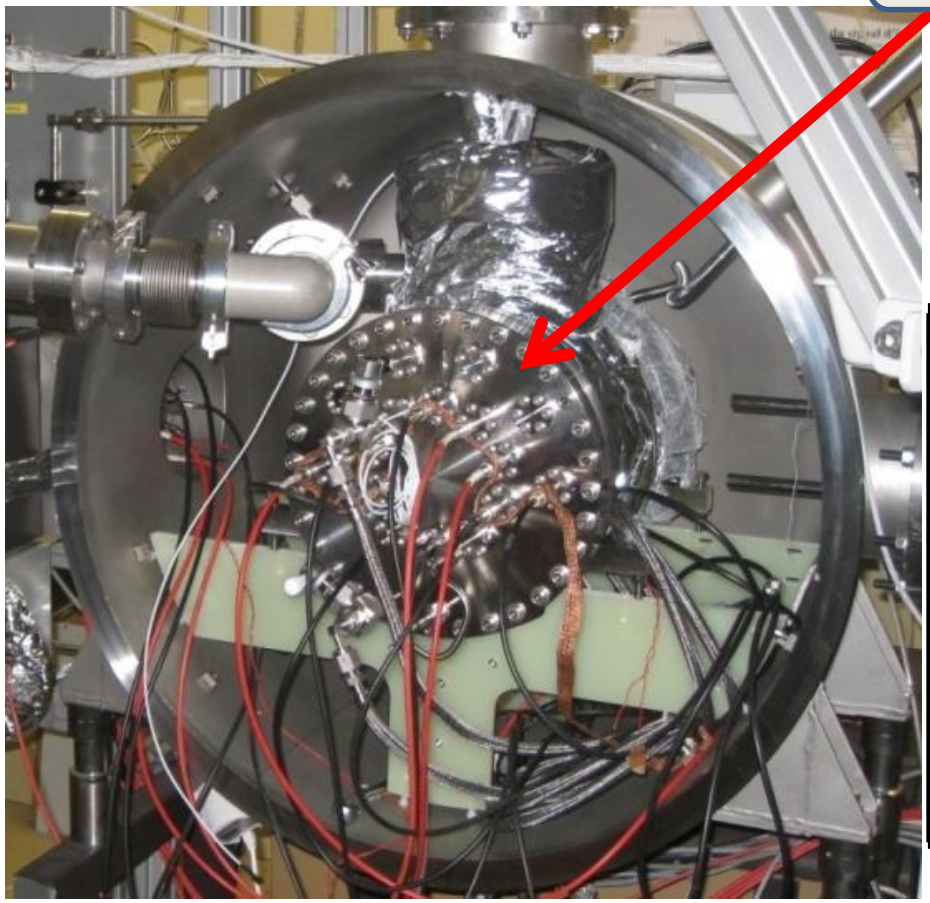


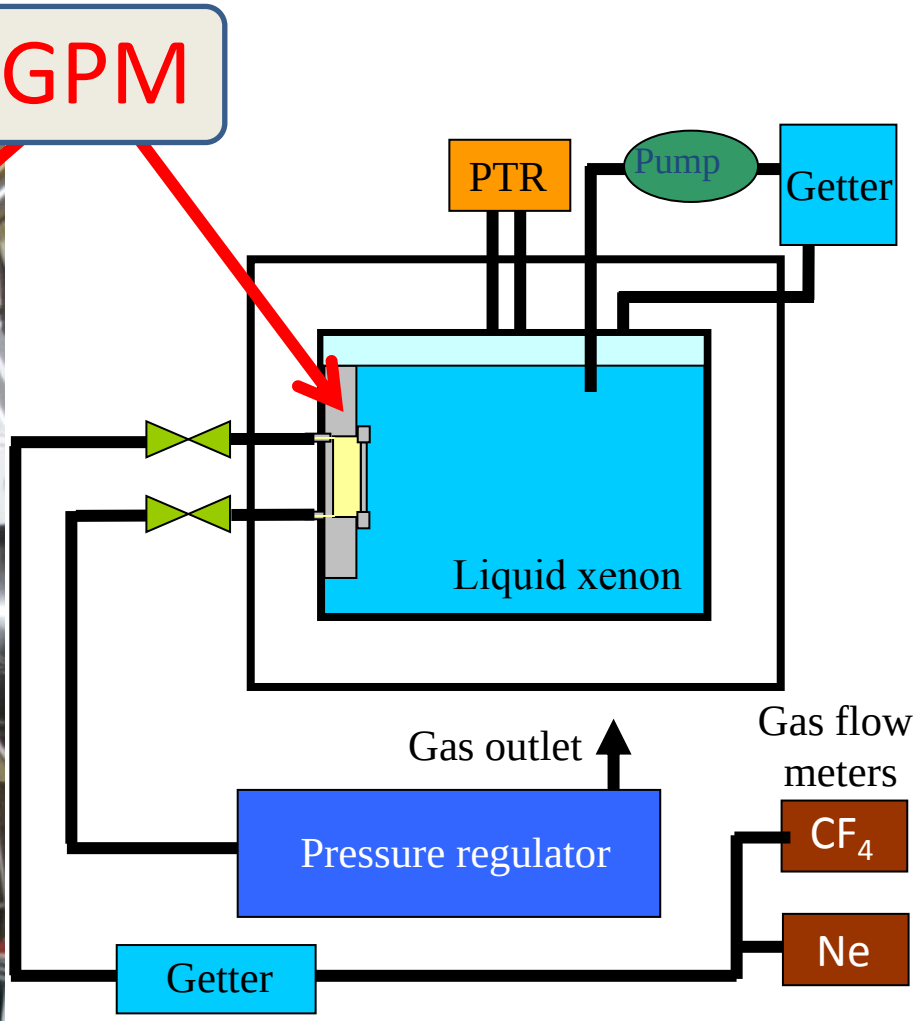




Vacuum side

Experiments in single-phase liquid-xenon

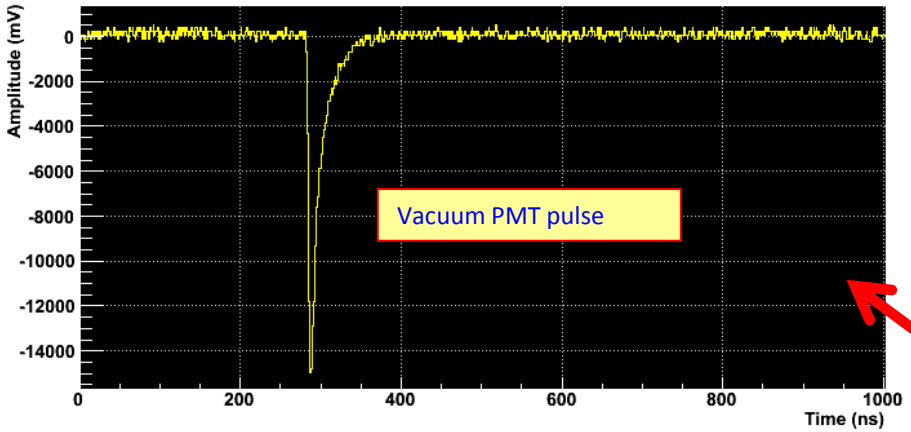


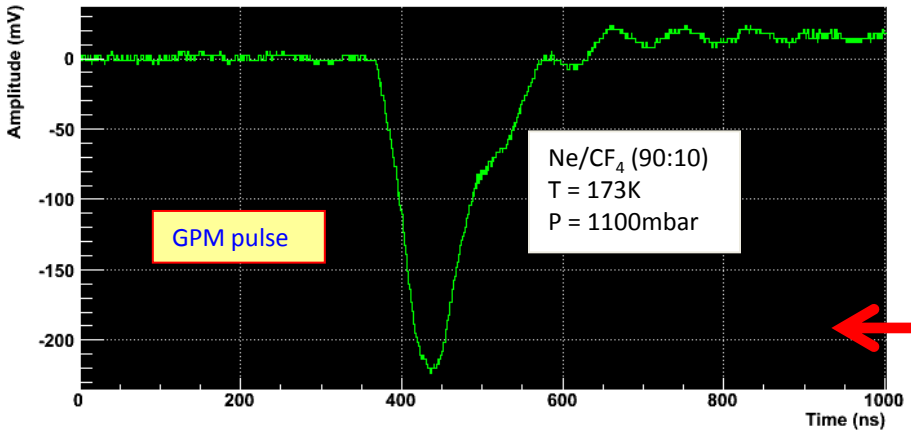


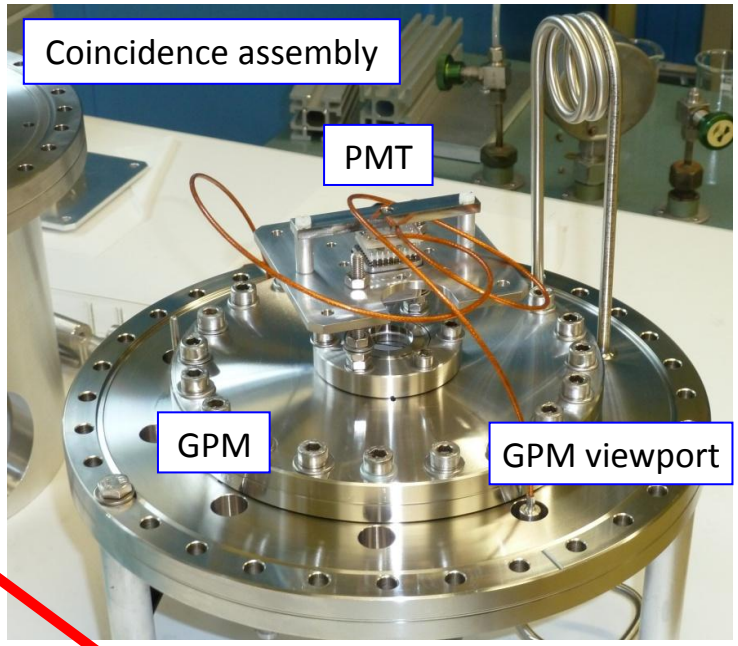
P_{GPM} = 1100 mbar, T = 171 K, P_{Xe} = 1200 mbar, flow rate < 2 ln/h, $\Delta T_{in/out}$ ~ 2K

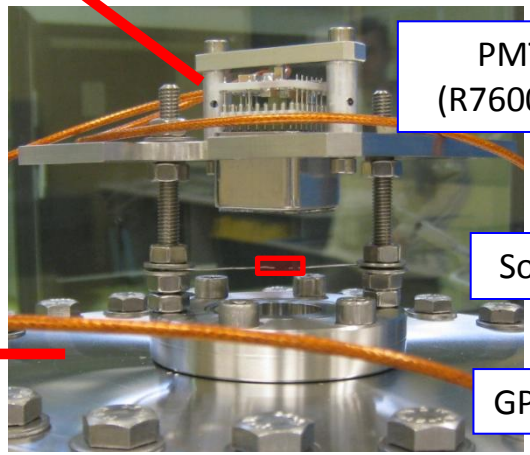
LXe Scintillation pulses recording

First pulse of a GPM in LXe !



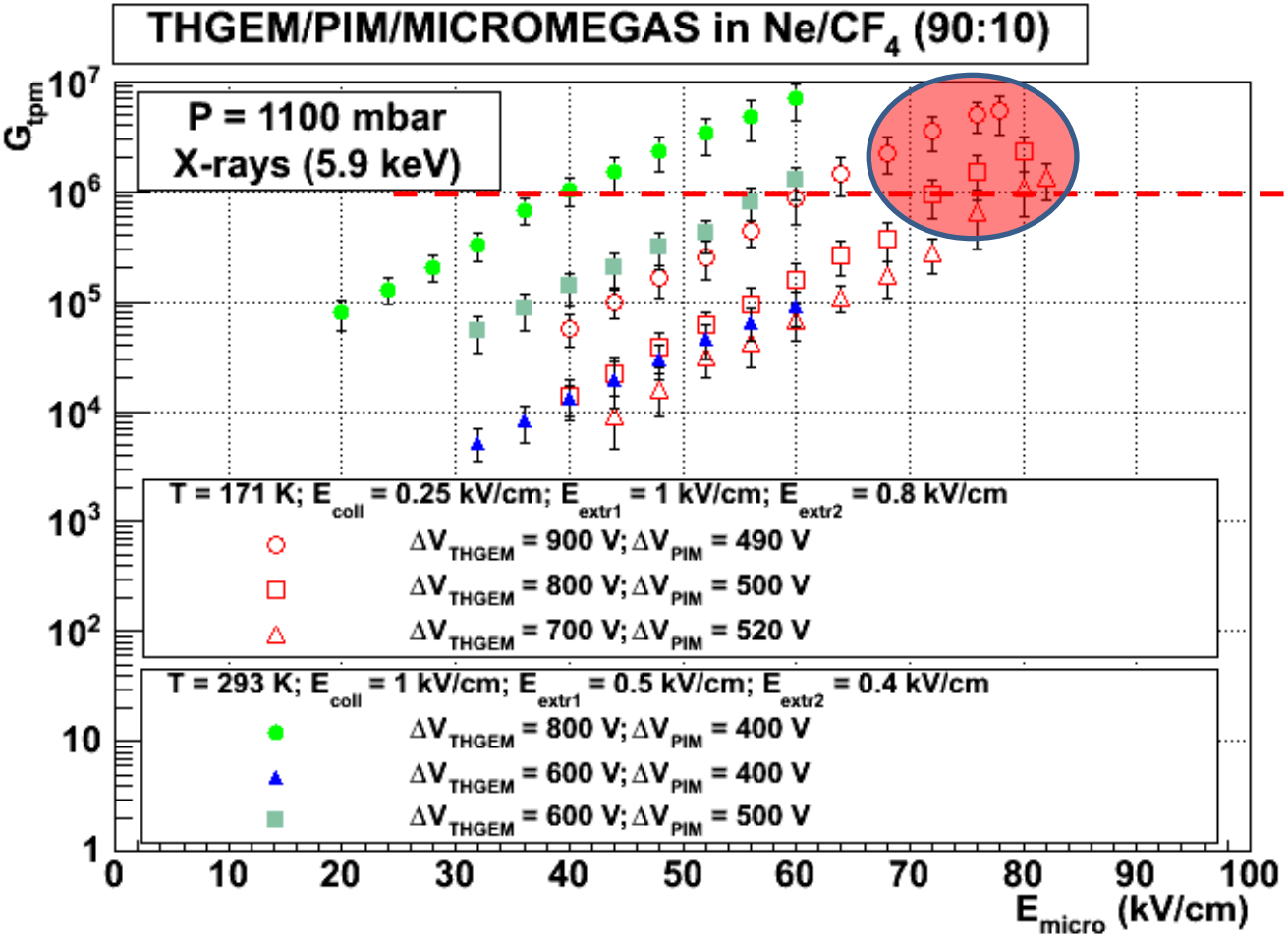




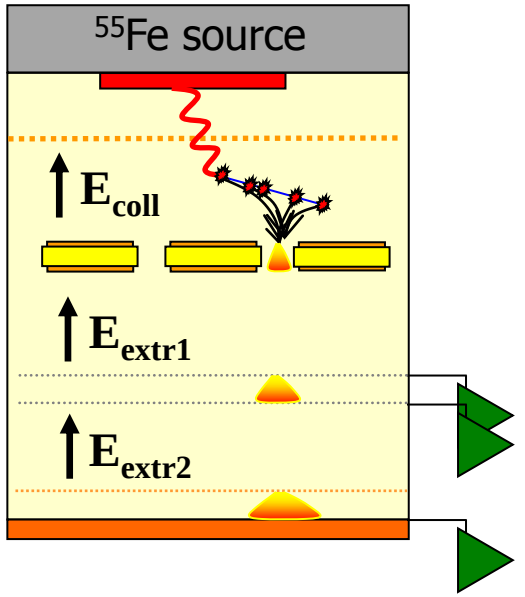


*S. Duval et al., 2011 JINST **6** P04007*

Gain measurements with ^{55}Fe

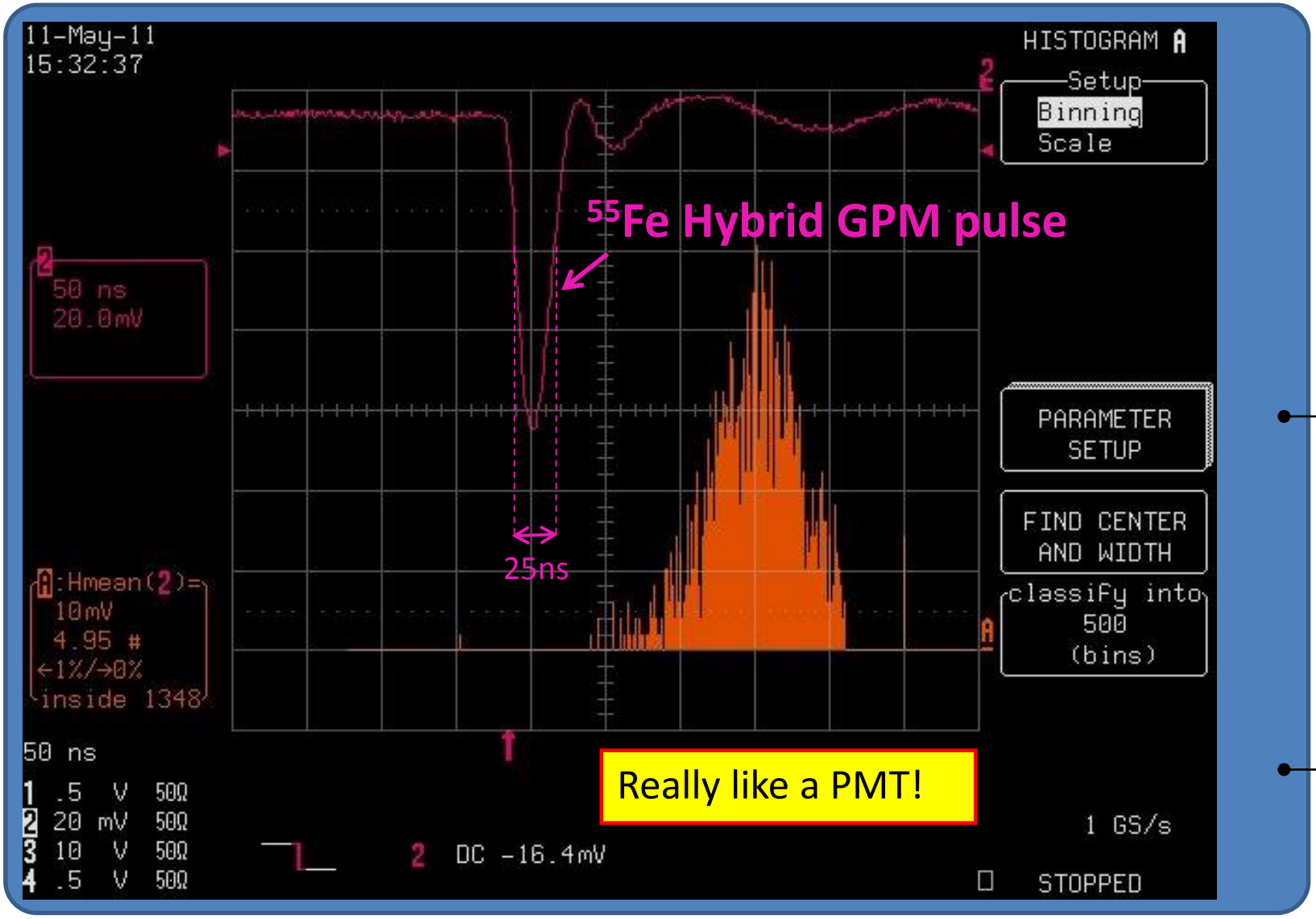


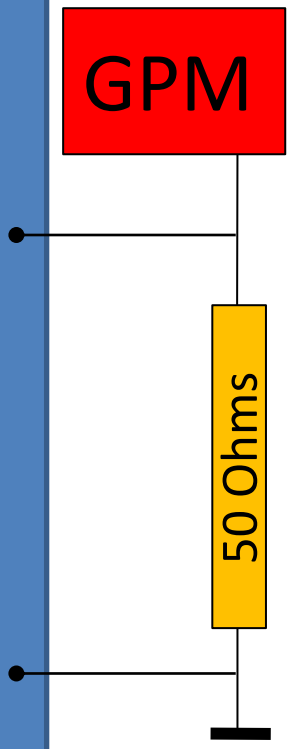
Total gain above 10^6!



S. Duval et al, NIM A (2011), doi: 10.1016/j.nima.2011.11.018

Fast signal direct readout



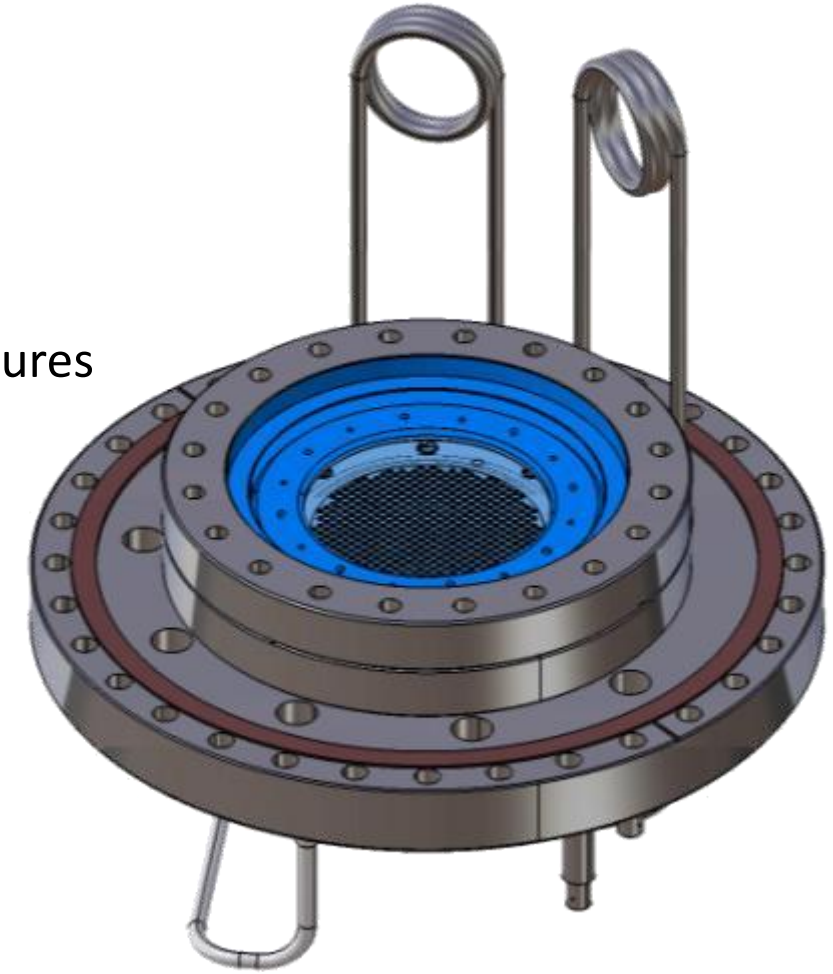


S. Duval et al., NIM A (2011), doi: 10.1016/j.nima.2011.11.018

Conclusion & Prospects

- Proof of concept (2010)
- High gains at LXe T ~10^6 (2011)
- Efficient ion blocking expected also in Ne-mixtures
- CsI photocathode studies in progress*
- Large-size prototype is designed and ready for being assembled

Toward 20 inches diameter window



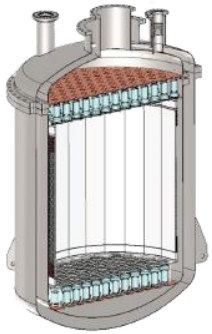
5” window

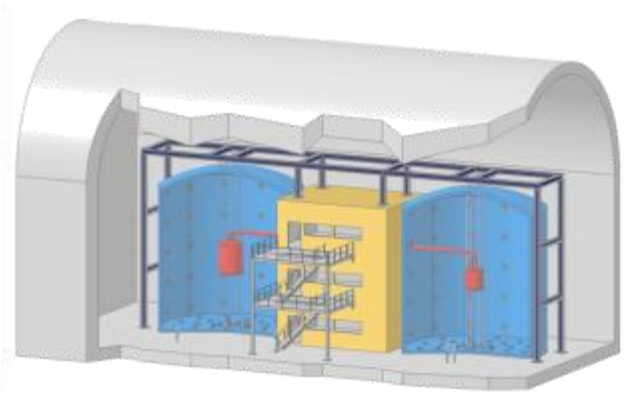
*A. Breskin et al., NIMA 639 (2011) 117-120 & S. Duval et al, NIM A (2011), doi: 10.1016/j.nima.2011.11.018

Conclusion & Prospects

Liquid xenon TPC is naturally well suited for large scale DM detectors







XENON10 XENON100 XENON1T DARWIN

Large area gaseous photomultipliers will play an important role in those experiments

but not only…

Other interesting applications :

- **3γ medical imaging** with single phase TPC at SUBATECH (collaboration with KEK-Japan)
- **Rare event noble-liquid detectors** (collaboration with WIS-Israel and BINP-Russia)