Latest results from the XENON Dark Matter Program

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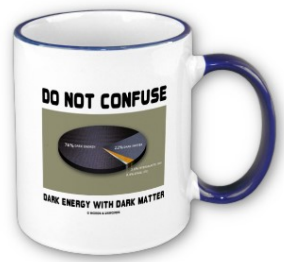
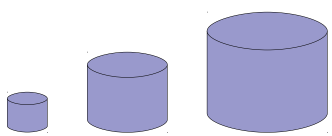
on behalf of the XENON Collaboration

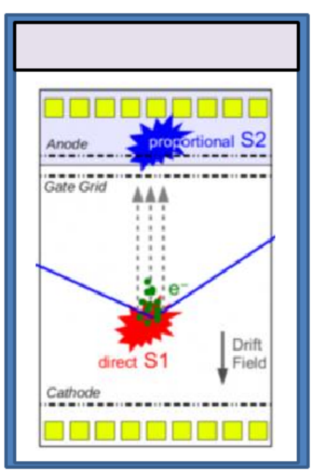
The XENON program



Science Objective : Explore WIMP Dark Matter with a sensitivity to Spin Independent cross section < $2 \cdot 10^{-47}$ cm^2 by 2017



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

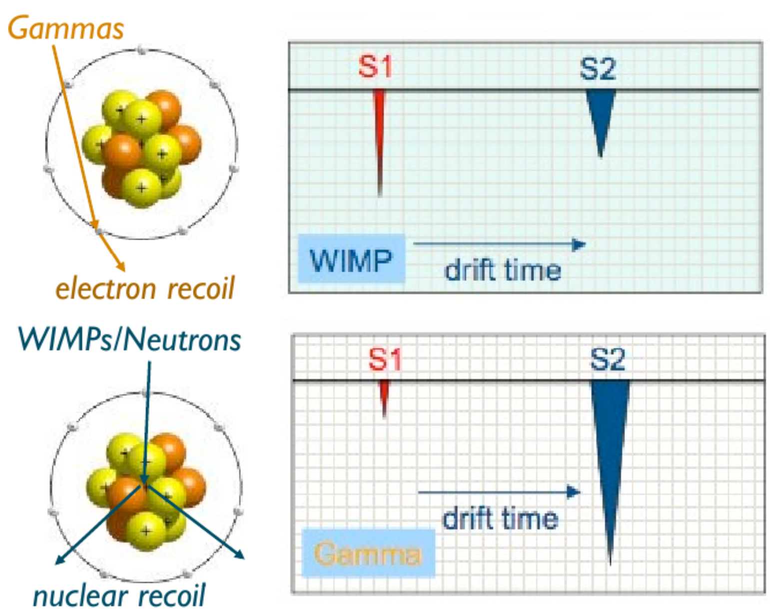


Detection technique : LXe (sensitive to both scalar and axial coupling) two-phase LXe TPC with simultaneous charge and light detection via PMTs with low radioactivity and QE > 30% at 178 nm

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

Advantages of two-phase xenon TPC principle

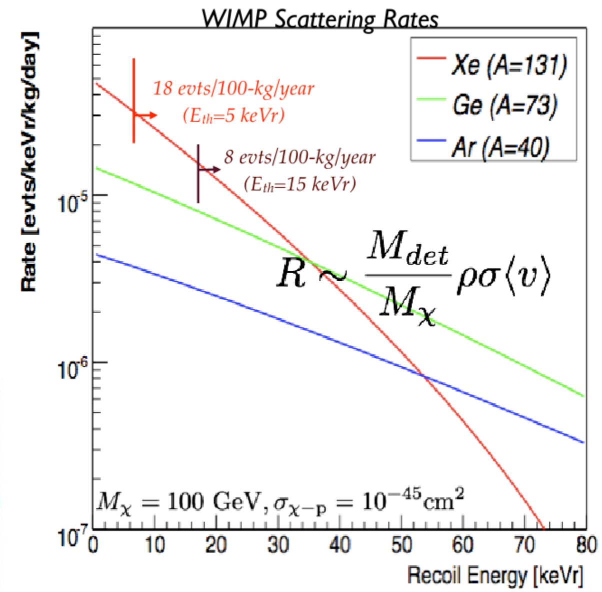
Background rejection: charge-to-light ratio

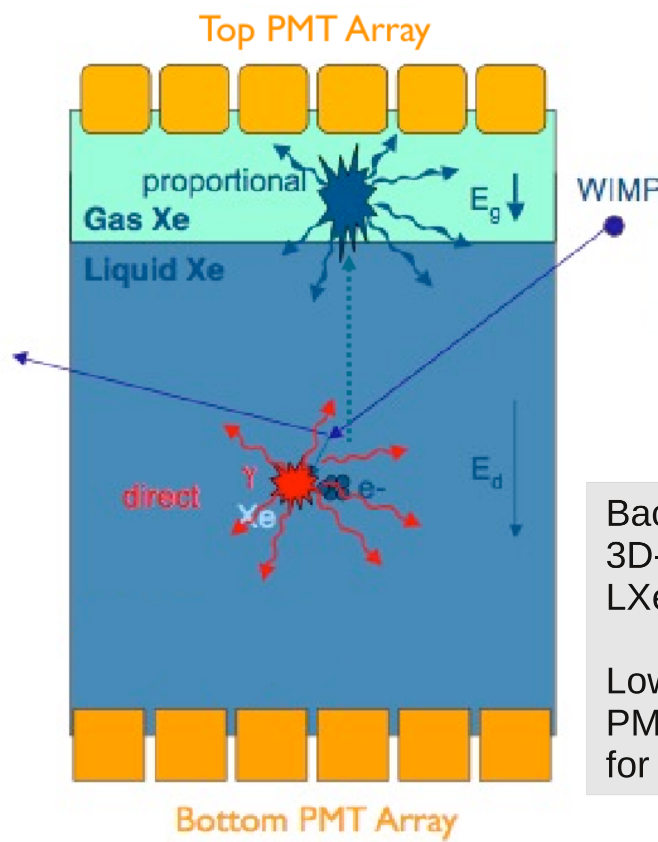


$(S2/S1)_{wimp} << (S2/S1)_{gamma}$

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

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





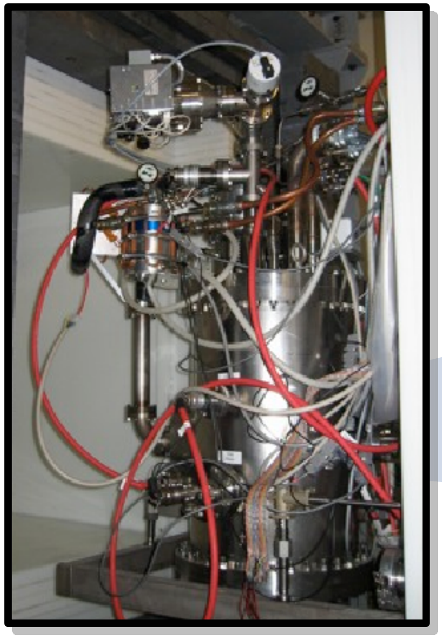
Scalability: massive target at modest cost

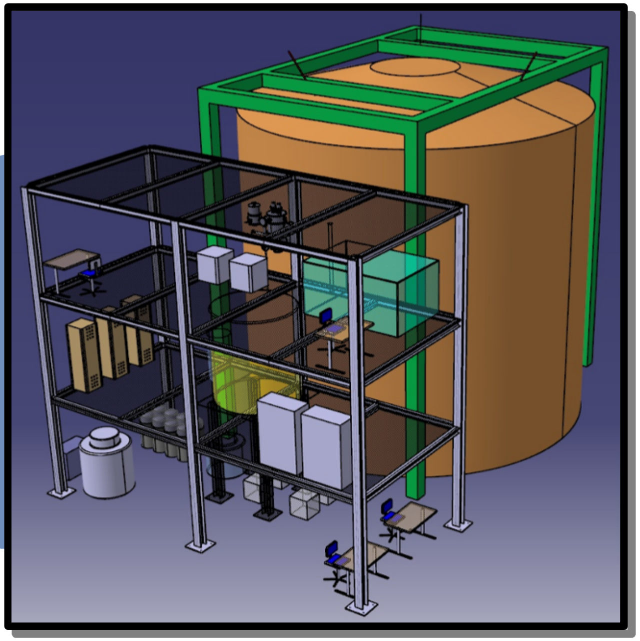
Intrinsically pure: no long-lived radioactive isotopes

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

Low energy threshold: PMTs within liquid for efficient light detection

The XENON program roadmap: growing in target size...





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

XENON100
Achieved (2011)
$\sigma_{SI} = 7.0 \cdot 10^{-45}$ cm^2

Still operating since 2009 !

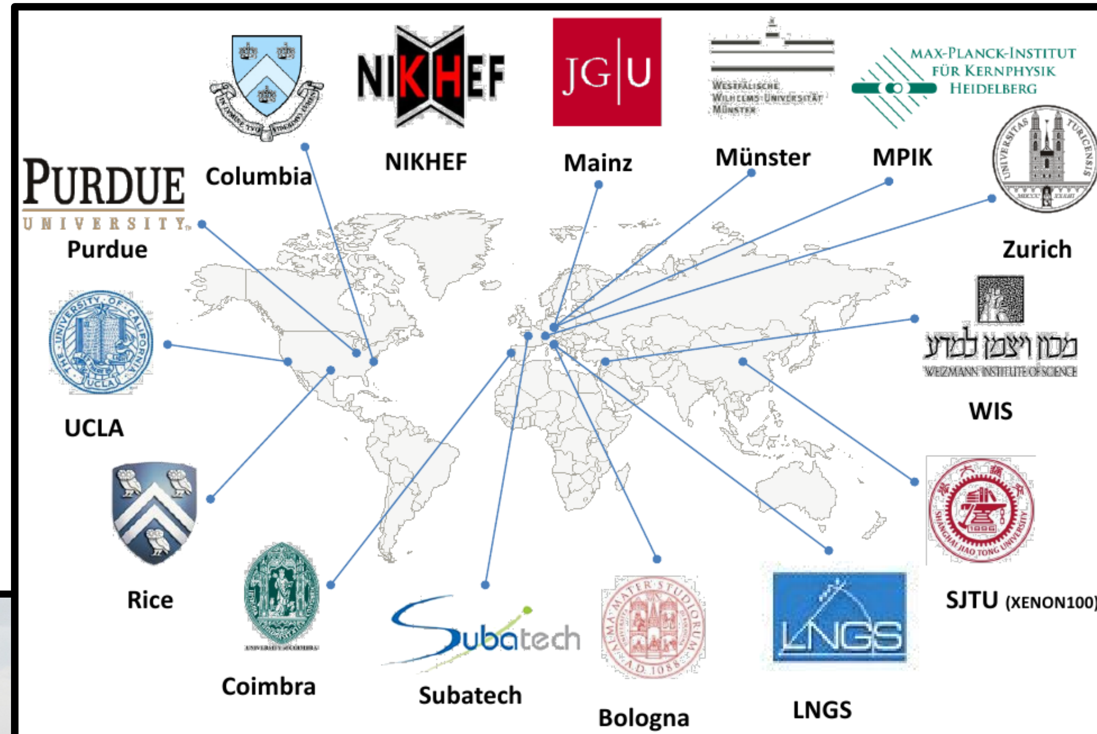
Projected (2012)
$\sigma_{SI} \sim 2 \cdot 10^{-45}$ cm^2

XENON1T
Projected (2017)
$\sigma_{SI} = \sim 10^{-47}$ cm^2

In advanced design phase
Construction in the end of 2012

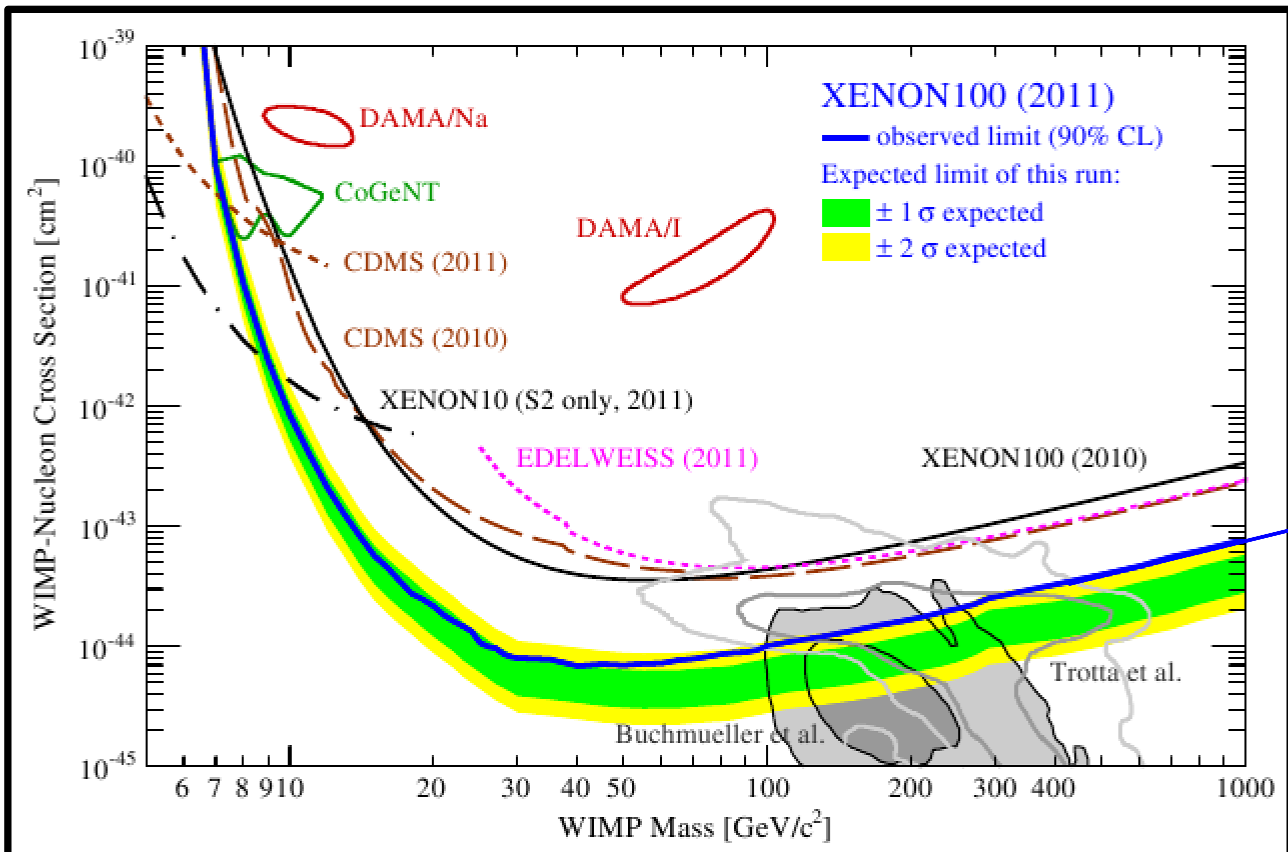
... and people

The XENON Collaboration



The Status of Dark Matter Direct Detection

Aprile *et al.*, Phys. Rev. Lett. **107**, 131302, 2011



100.9 days of data took on 2010 and unblinded in spring 2011

No significant excess found:

- 3 candidates in the search region
- 1.8±0.6 expected background

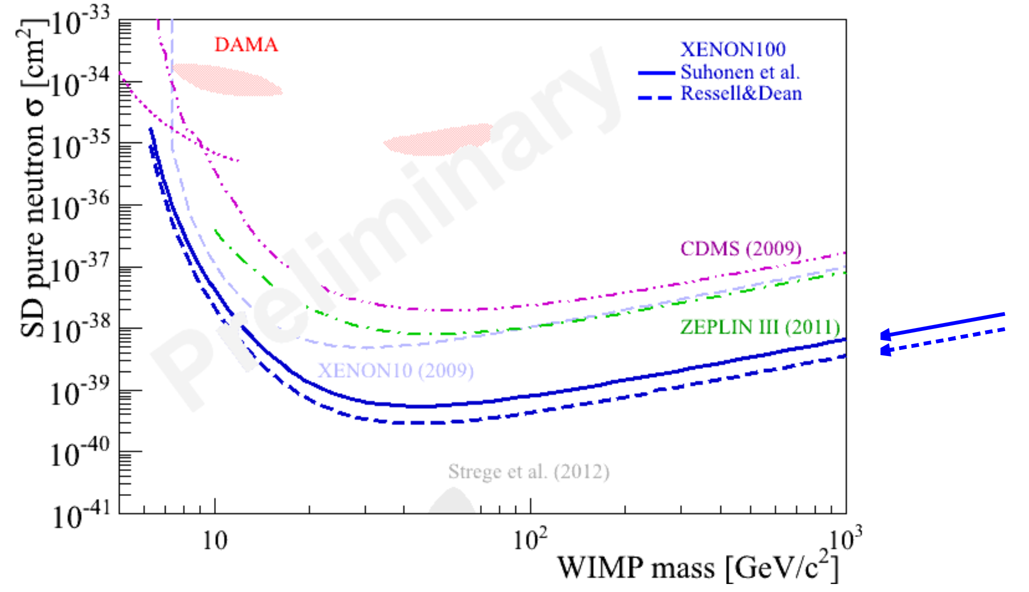
Limit at M_W = 50 GeV:

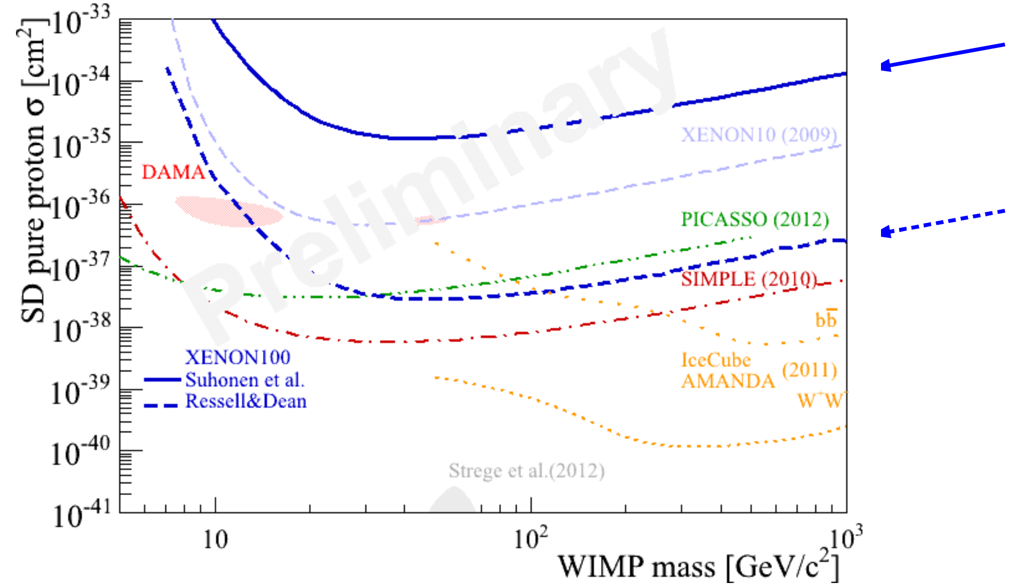
7×10^{-45} cm^2 (90% C.L.)

New XENON100 Spin Dependent Limit (preliminary)

Analysis for SD coupling of WIMPs to ^{129}Xe (26.2%) and ^{131}Xe (21.8%) (unpaired n)

- Paper in internal referee phase
- Same data (from 2010 data taking) and event selection as for SI analysis
- Profile Likelihood analysis used: Phys. Rev. D 84, 052003 (2011)
- Result by using 2 nuclear models:
  - Suhonen et al. (——)
  - Ressell&Dean (--------)
- New best limits for pure neutron coupling (relatively small impact of nuclear model)
- Pure proton coupling (strong dependence on nuclear model used)





Status of new data: 2011-2012

- **Data taking** for Dark Matter search is terminated!
  From March 1st 2011 up to now. **More than one year** of continuous operation

- More than **220 live days** of data collected

- Excellent Detector Performance and Stability

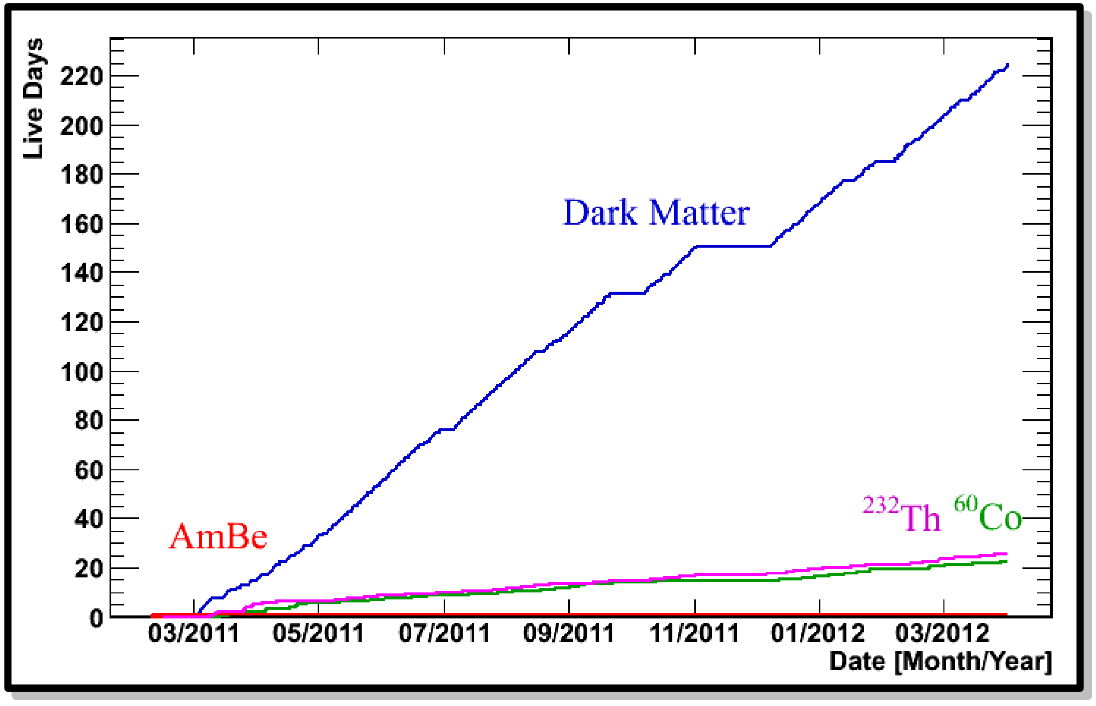
- **Kr** in Xe reduced by a factor 20 by cryogenic distillation

- Increased **Gamma** calibration statistics

- Increased **Neutron** calibration statistics (two exposure campaigns: at beginning and at about the end of the run)

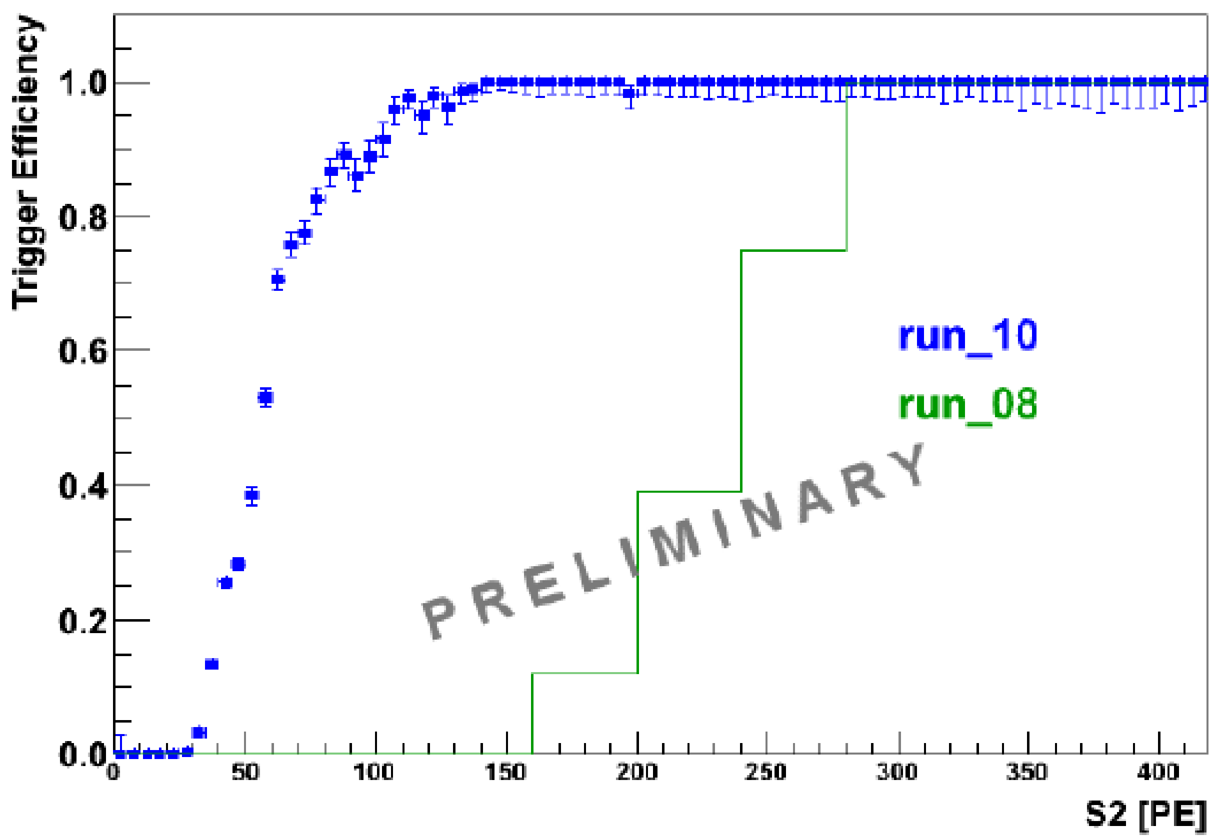
- Lowered S2 trigger **threshold**

- **Blind analysis** in advanced state

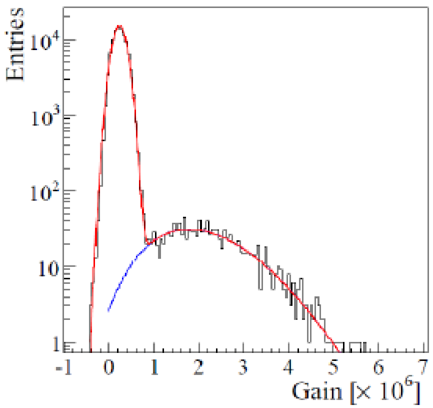


Improved trigger efficiency

- 100% efficiency above S2 = 150 photoelectrons
- ability to trigger on very low energy events (~10 electrons!)



Calibrations

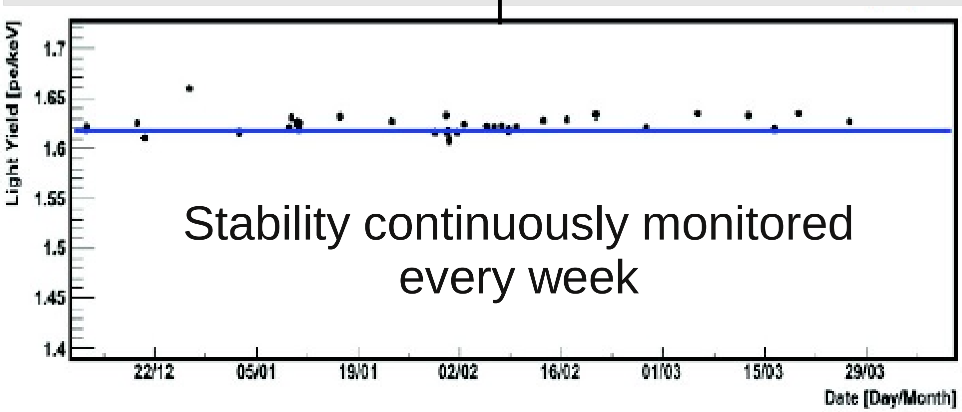


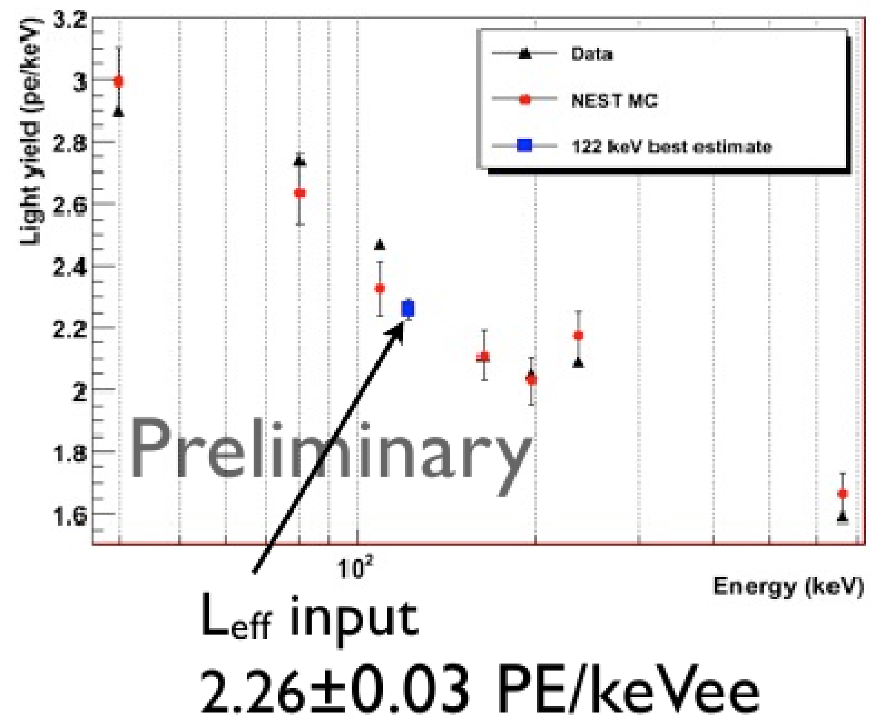
PMT gain calibration

- Equalized to a mean gain of ~2.6 x 10^6 by adjusting the PMT HV
- Determined by stimulating single PE emission by using a blue LED (λ = 470 nm, ν = 100 Hz)
- Optical fibers used to transport the light in the TPC
- A calibration of all 242 PMTs **every week**
- Average gain stable during physics run **stable within 2%**

Gamma calibrations for the yield of primary light

- 40 keV (^{129}Xe (n,n'γ)^{129}Xe), by ^{241}AmBe
- 80 keV (^{131}Xe (n,n'γ)^{131}Xe), by ^{241}AmBe
- 164 keV (^{131m}Xe), by ^{241}AmBe
- 236 keV (^{129m}Xe), by ^{241}AmBe
- 662 keV (^{137}Cs)



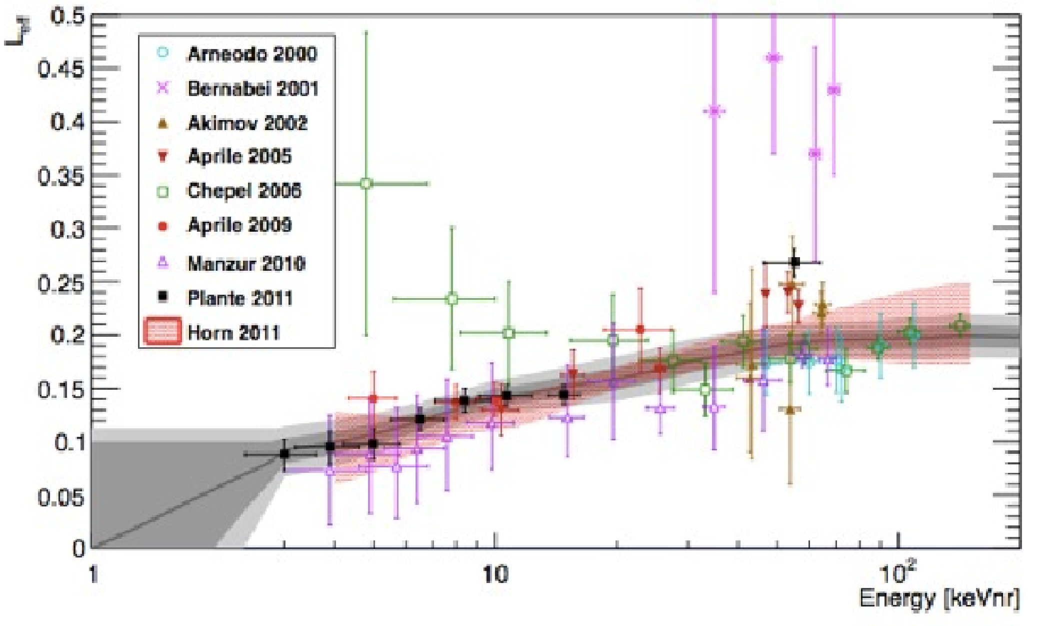


Scintillation efficiency for Nuclear Recoils

- Energy scale is set by using scintillation signal ($S1$): $$E_{\rm nr} = \frac{S1}{L_{y,\rm er}} \frac{1}{\mathcal{L}_{\rm eff}(E_{\rm nr})} \frac{S_{\rm er}}{S_{\rm nr}}$$

- $L_{y,er}$ is the light yield for electron recoils of 122 keV_{ee}
- S_{nr} and S_{er} are the quenching factors due to drift field
- L_{eff} is the relative scintillation efficiency and it is given by:

$$\mathcal{L}_{\rm eff}(E_{\rm nr}) = \frac{L_{y,\rm er}(E_{\rm nr})}{L_{y,\rm er}(E_{\rm ee} = 122\ {\rm keV})}$$

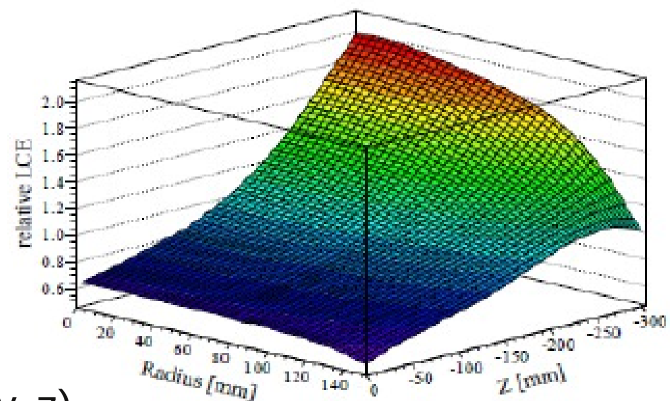


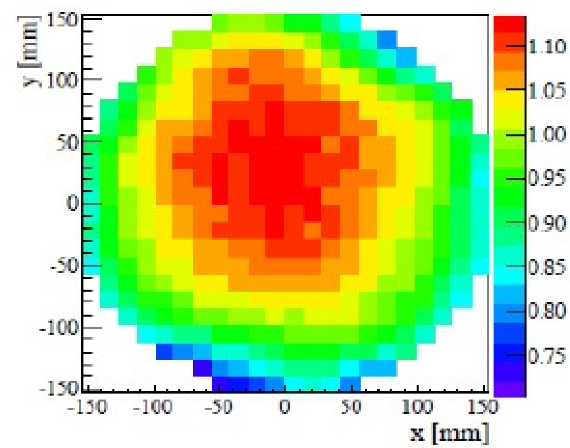
Plante et al., Phys. Rev. C 84, 045805, 2011

Data reconstruction and corrections

3D position reconstruction

- X,Y from the light on the Top PMTs
- Z from the measured drift time (dt = t_{S2} - t_{S1}, v_{drift} ~1.74 mm/µs @ 533 V/cm)
- Three different algorithms studied: Neural Network (used), Support Vector Machine, χ^2
- Achieved resolution: δr < 3 mm, δZ < 300 µm





E. Aprile et al. (XENON100), Astropart. Phys. 35:573-590,2012

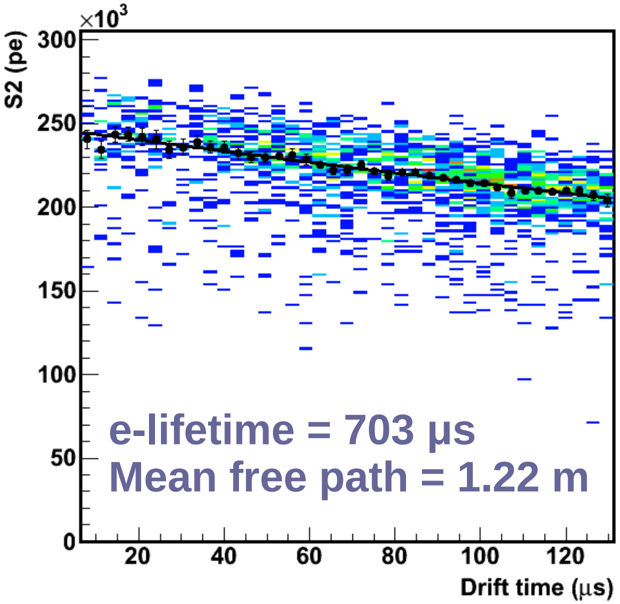
3D corrections

- S1 Response
  - Light collection efficiency map (x,y,,z)
  - LY @ 122 keVee

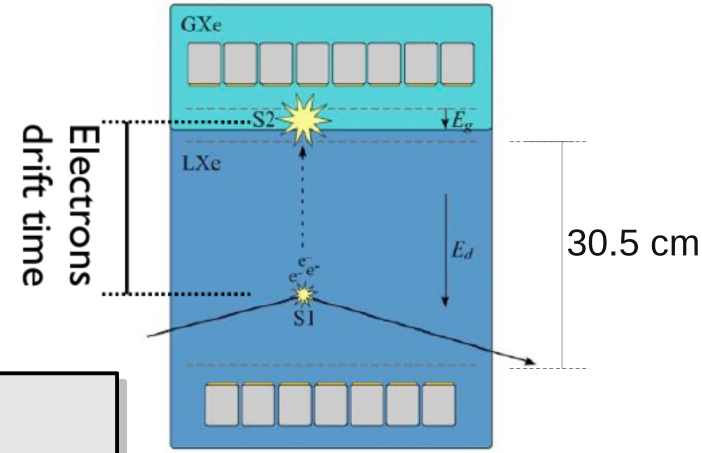
- S2 Response
  - Electron attachment by impurities in LXe (z)
  - Variation of the S2 light collection efficiency (x,y)

- Corrections obtained with ^{137}Cs and AmBe (40 keV inelastic) ^{131m}Xe (164 keV) with an agreement better than 3%.

Electron Lifetime during 2011-2012 Dark Matter search

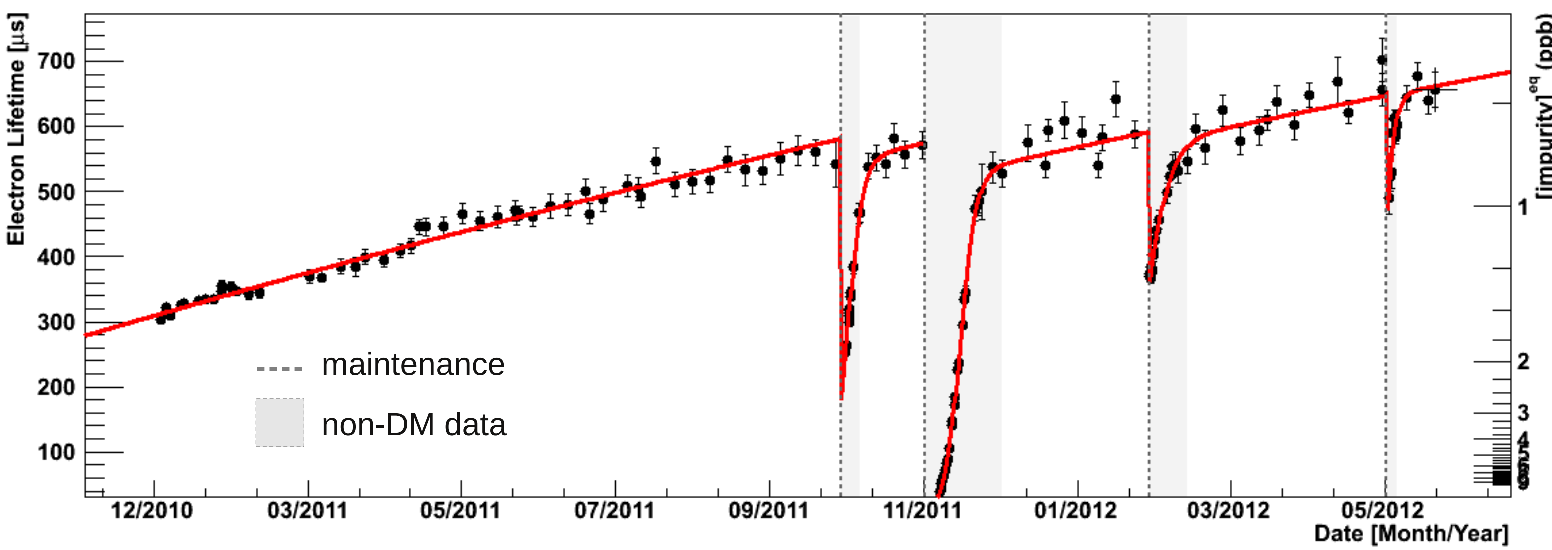


Amplitude of S2 signal vs Drift Time



Ultra high purity liquid xenon!

We reached 0.7 ppb O_2 - equivalent



Electronic – Nuclear recoil discrimination

Electronic recoil band

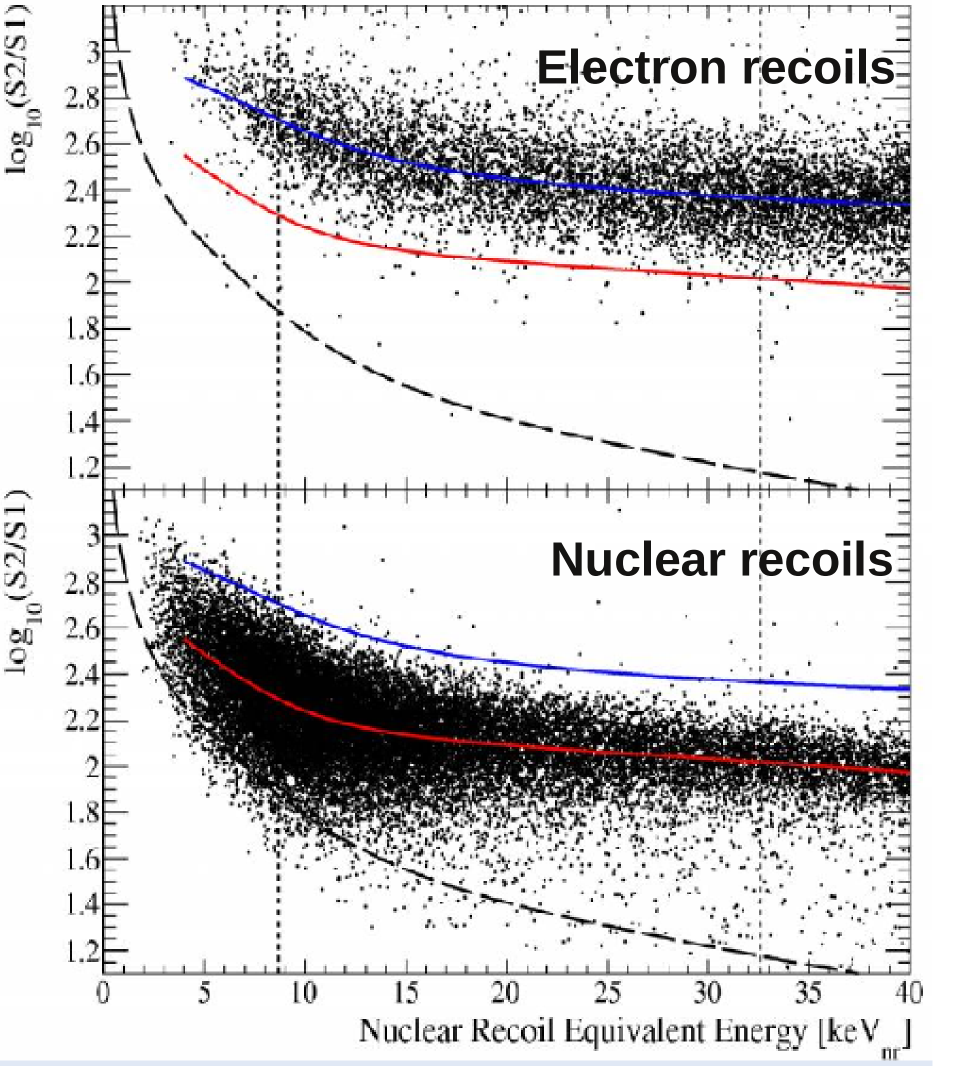
- Electronic recoil with ^{60}Co and ^{232}Th

Data collected all the time for a total of 40 effective days.

Neutron recoil band

- Nuclear recoils with $^{241}AmBe$

Two exposure campaigns: one at beginning and one at the end of run

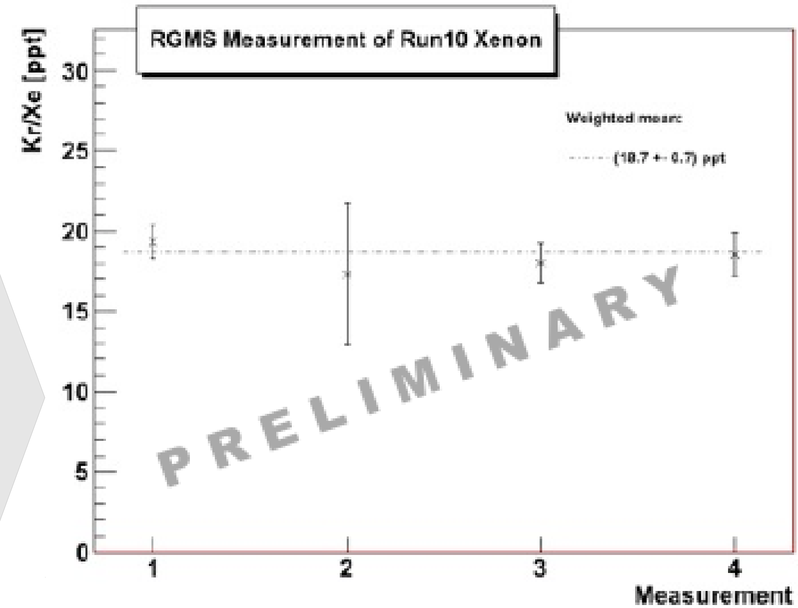


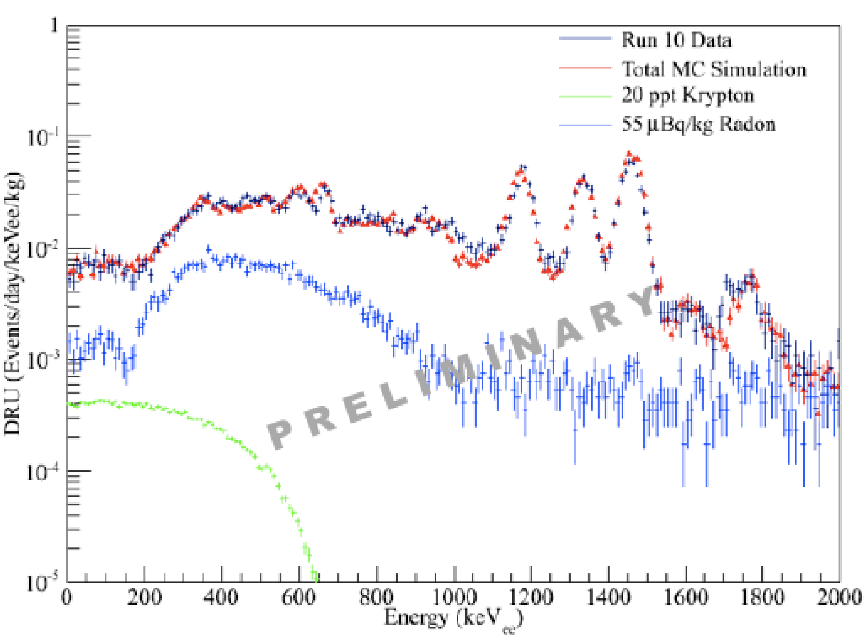
E. Aprile et al., Phys. Rev. Lett 105, 131302 (2010)

Significantly reduced background

- Kr85 is an internal background, cannot be removed by self-shielding
- Long-lived β^- emitter (99.6%), E_{max} = 687 keV β^- decays indistinguishable from gamma background
- Sensitivity of published data (PRL107, 2011) limited by high Kr/Xe level from accidental leak

- In Fall 2010, Kr removed by distillation of the Xe with on-site distillation column
- Kr/Xe reduced significantly! Dedicated measurement
- with RGMS gives for current search a Kr/Xe level of (19±1) ppt
- Similar value from delayed coincidence analysis

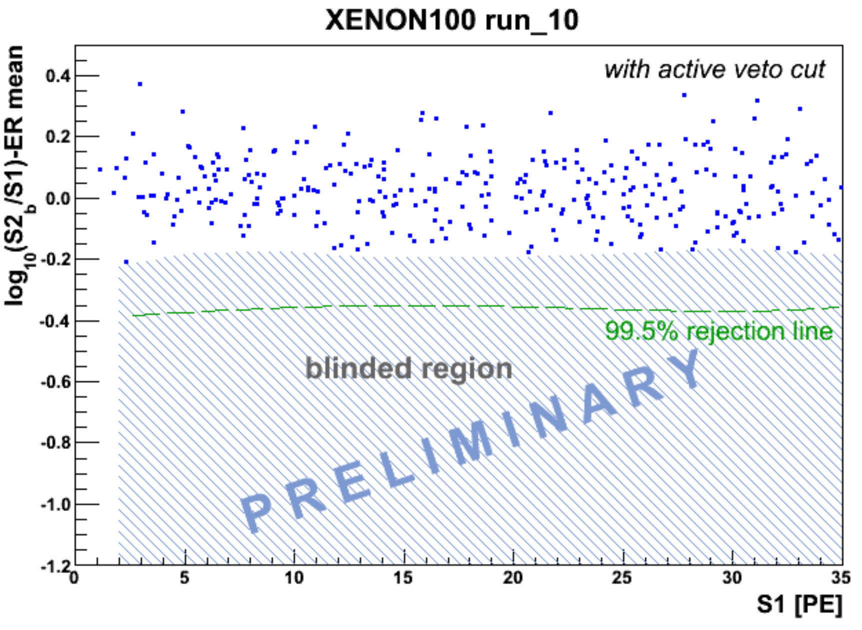




- In WIMP search region background is around 5 x 10^{-5} evts/kg/keV/day after S2/S1 discrimination
- Factor 100 less than XENON10 and than other DM experiments (see PRD 83, 2011)

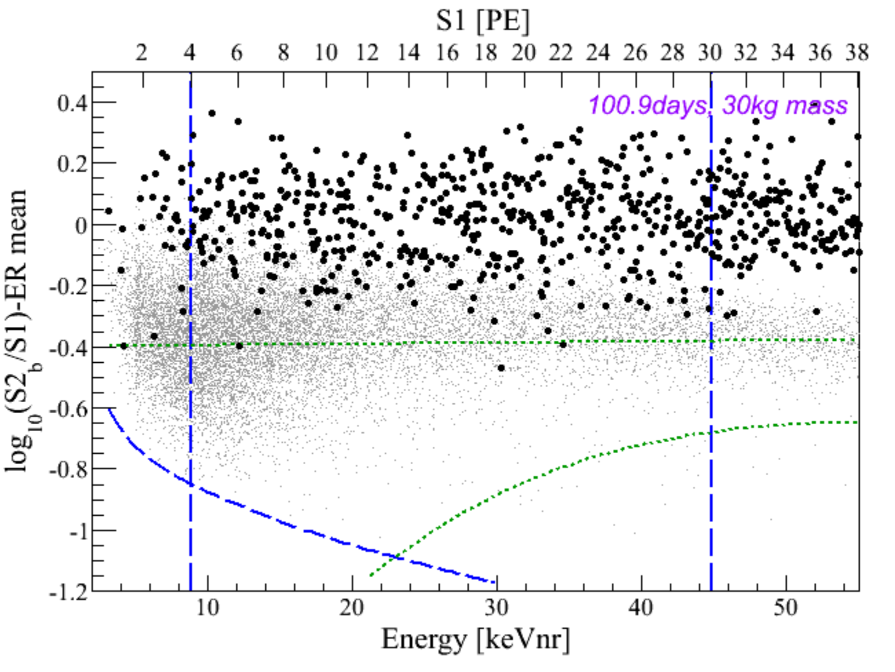
Significantly reduced background

30 kg Fiducial – 198 days



30 kg Fiducial – 100.7 days

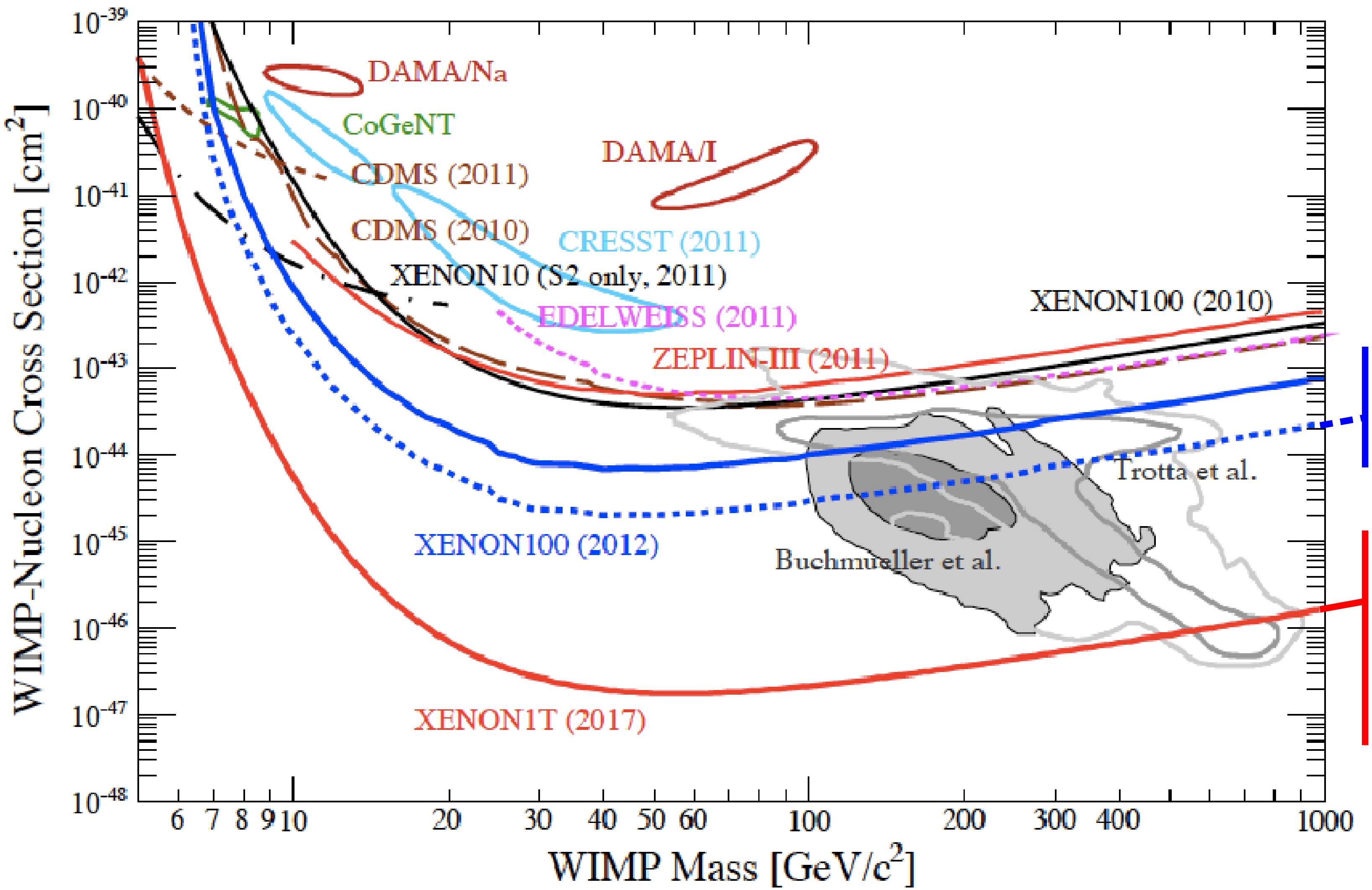
Compare with 100 days in previous run



Aprile et al., Phys. Rev. Lett. ***107****, 131302, 2011*

Background now comparable with that of first XENON100 result
E. Aprile et al., Phys. Rev. Lett. ***105****, 131302, 2010*

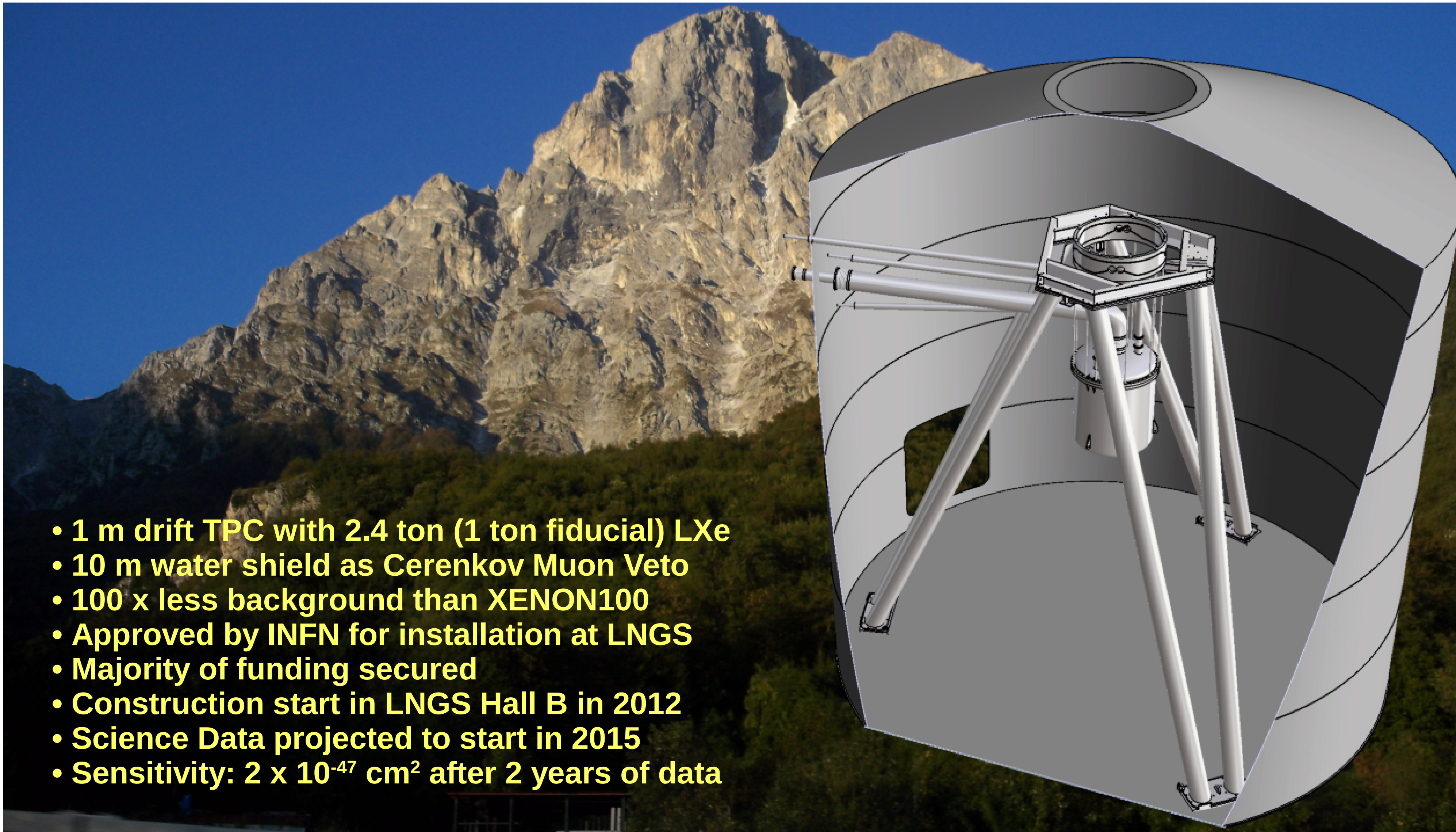
XENON projected sensitivity



Stay tuned!
Still few weeks

XENON1T already in advanced design study. Construction in Fall 2012

The near future: XENON1T



Big detectors require new solutions...

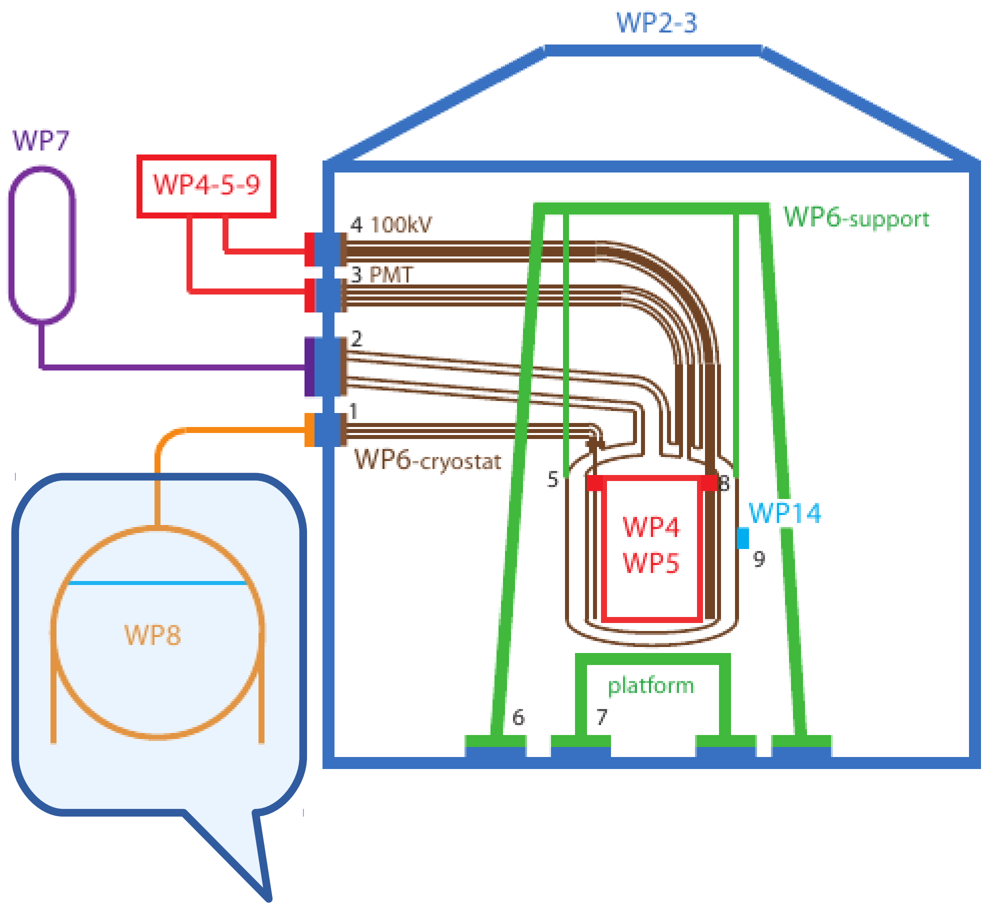
XENON1T must handle 2.4 tons of liquid xenon and detect electrons after long drift lengths (impurities <100 ppt O_2 eq.)

- XENON1T must be filled with an already purified and liquefied xenon

- We need a fast procedure to fill and recover it

- Krypton and Radon contamination during xenon operations must be minimized

Solution: a new concept of storage and recovery system



WP8 : The XENON1T storage and recovery system

XENON Dark Matter Project

The **Re**covering and **Sto**rage system of **X**ENON1T: **ReStoX**

Very compact station,
(L x l x H) = 2,7m x 2,7 m x 3,3 m
for a 3 ton storage capacity

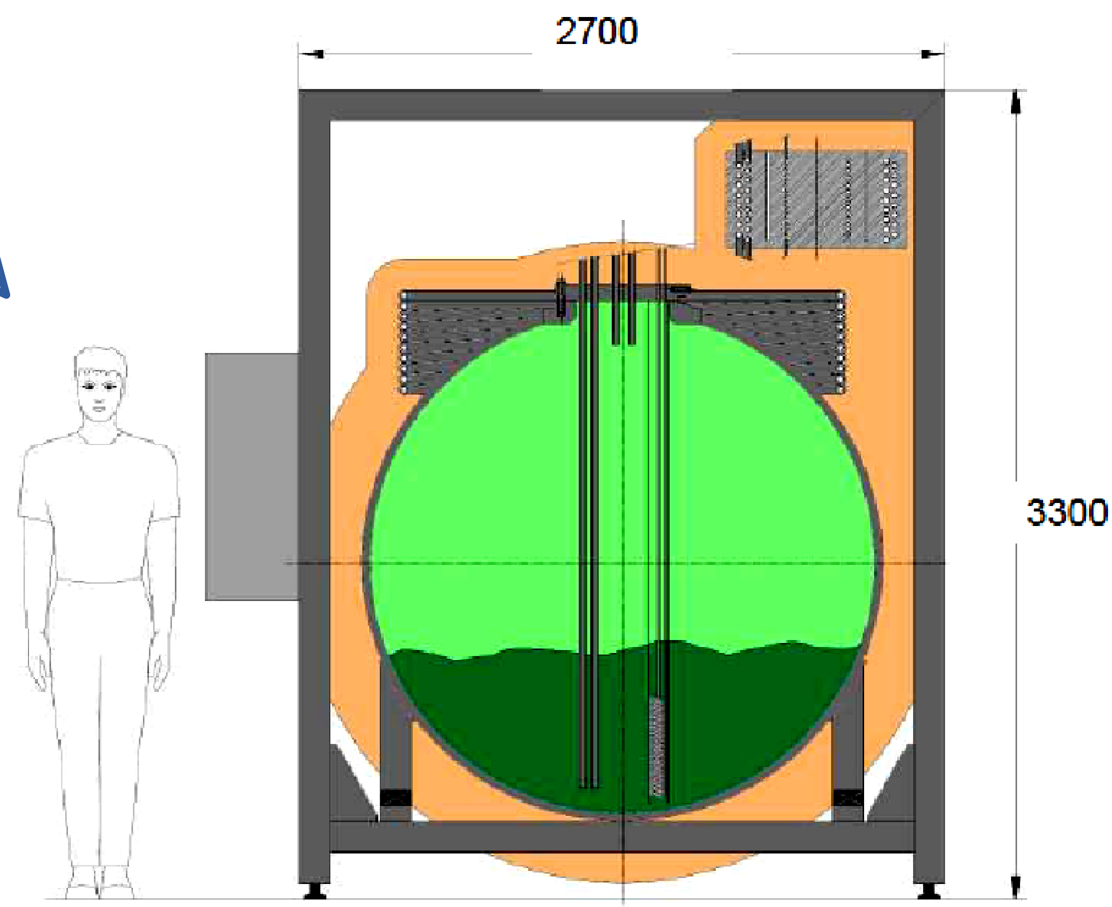
Temperature ranges from
room temperature (GXe at 65 bar)
down to -108 °C (LXe)

Able to keep high purity
all the time

Developed in partnership with

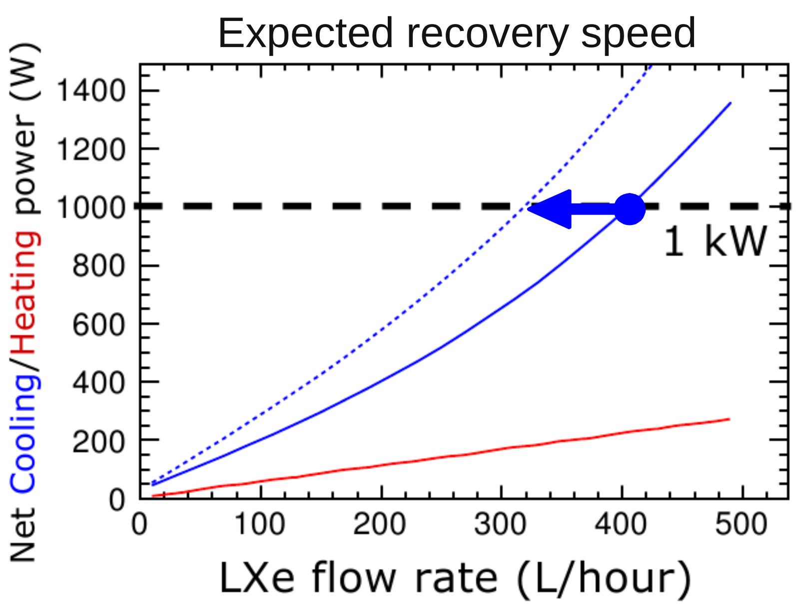
AIR LIQUIDE ADVANCED TECHNOLOGIES

Subatech

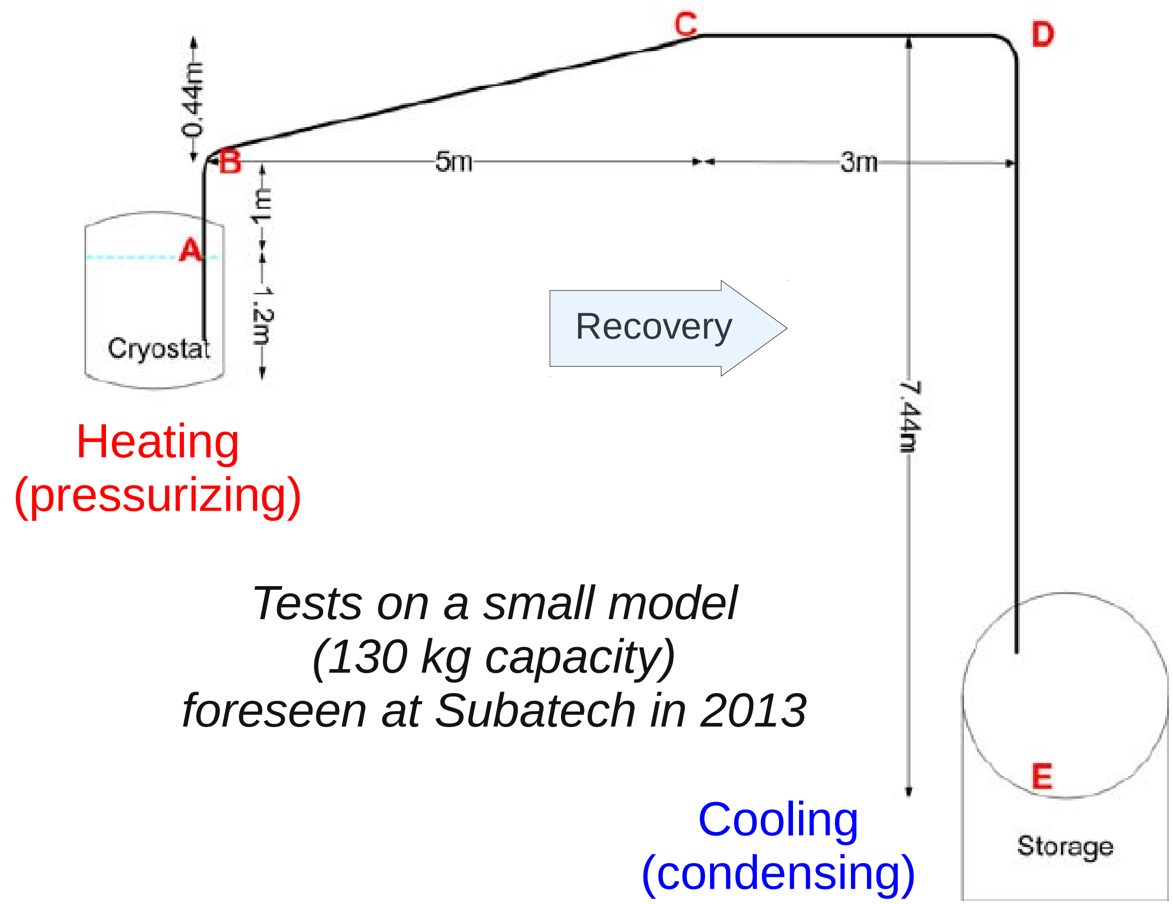


ReStoX: Xenon recovery in several hours

Requirements:
- The recuperation procedure must be fast (emergency)
- Safe and reliable even in case of cryogenics losses
- Use pressure difference to transfer LXe
- Low radon/krypton contamination



A 300 liter/hour LXe transfer can be achieved with high cooling power!



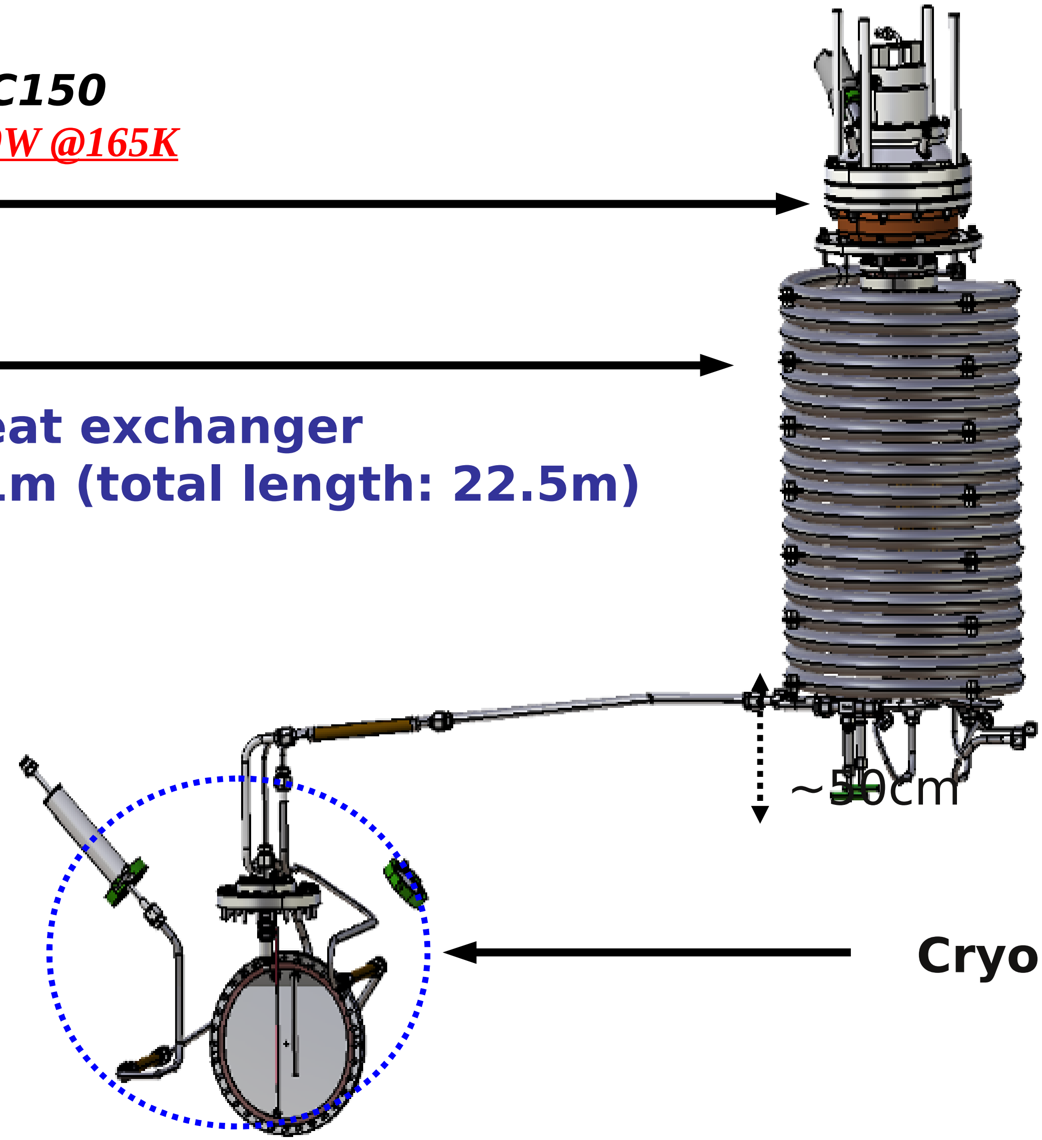
Tests on a small model (130 kg capacity) foreseen at Subatech in 2013

R&D to validate the ReStoX concept done in Subatech

Model: Iwatani PC150

Cooling power up to <u>200W @165K</u>

Heat exchanger
~1m (total length: 22.5m)

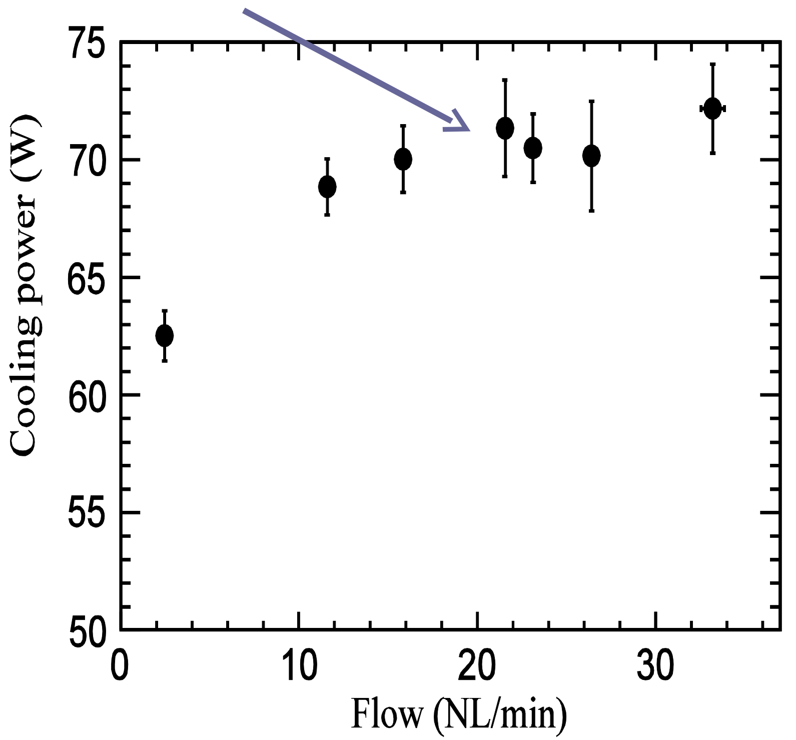


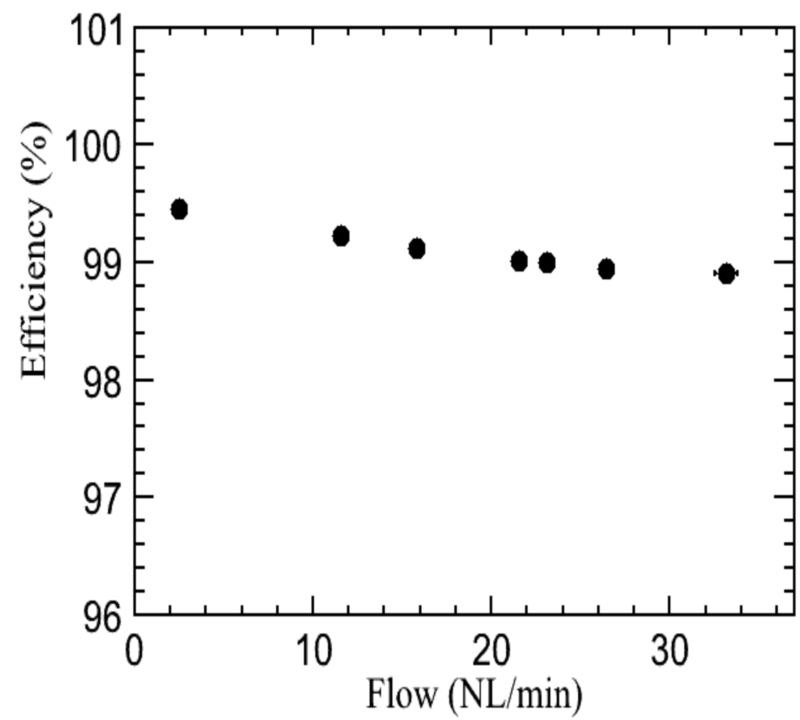
Cryostat

Cryogenics R&D is very promising

Presented by Wan-Ting Chen (Subatech) at
24th International Cryogenic Engineering Conference - International Cryogenic Materials Conference 2012
(ICEC24-ICMC2012)

Cooling power used to maintain the pressure of cryostat
→ Nearly no change in high flow!





99% @ 33NL/min is achieved!

Summary and prospects

- **XENON100** data taking for Dark Matter search is terminated! From March 1^{st} 2011 up to now. More than one year of continuous operation
- More than 220 live days of data collected, more than a factor 2 with respect to the previous run
- Many news in the latest year: excellent Detector Performance and Stability, Kr in Xe reduced by a factor 20 by cryogenic distillation, increased Gamma and Neutron calibration statistics, lowered S2 trigger threshold
- Blind analysis in very advanced state (stay tuned!)

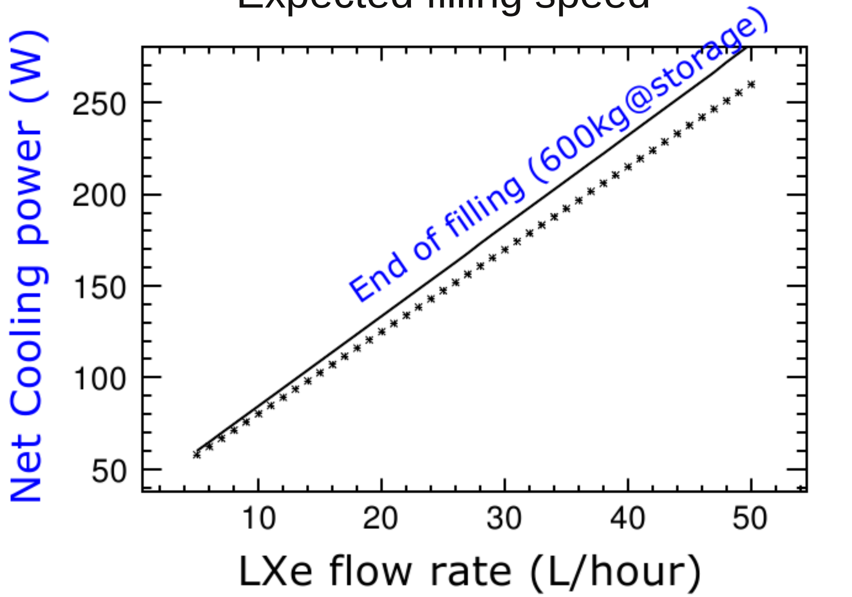
- Collaboration is already working on next generation: **XENON1T**
- Many news in the latest year: advanced design study, approved by INFN for construction at LNGS in Hall B, approved by US funding agencies (NFS), construction on Fall 2012

Backup...

ReStoX: Capability to fill xenon in few days

Requirements:
- Safe and reliable even in case of cryogenics losses
- Use pressure difference to transfer LXe
- Low radon/krypton contamination

Expected filling speed



Quite dependent by cooling power
A 10-50 liter/hour LXe transfer
can be achieved