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Search for Dark Matter with The XENON1T Experiment

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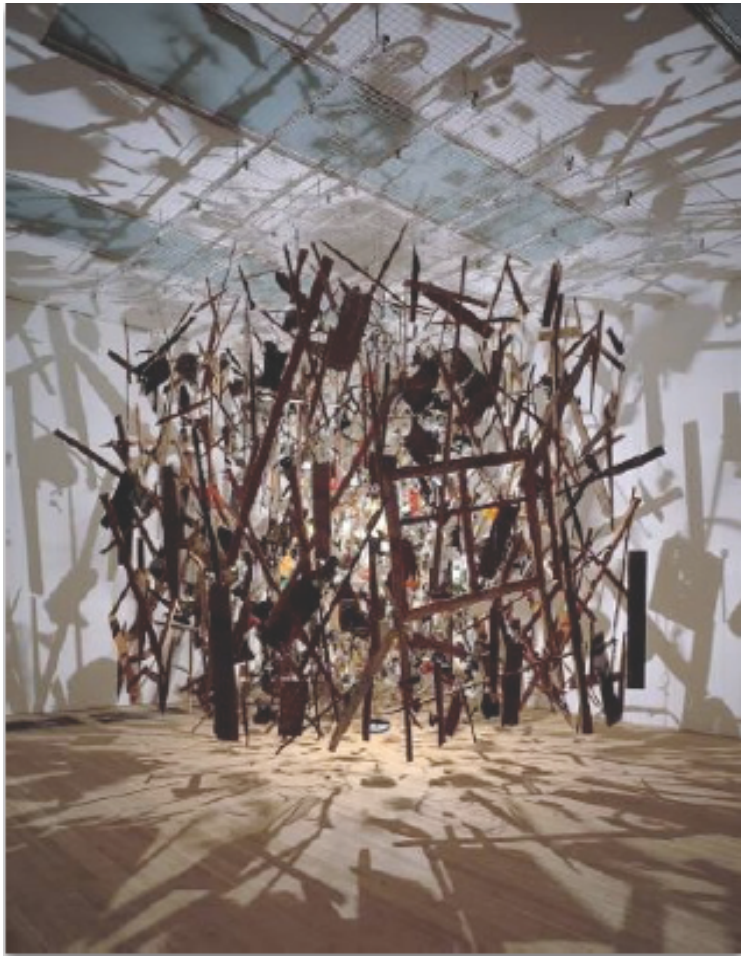
On behalf of the XENON collaboration

Outlines

- Direct Detection
- XENON1T at LNGS
- Detector principle
- XENON1T Overview
- Expected Backgrounds
- Status
- Summary and Outlook



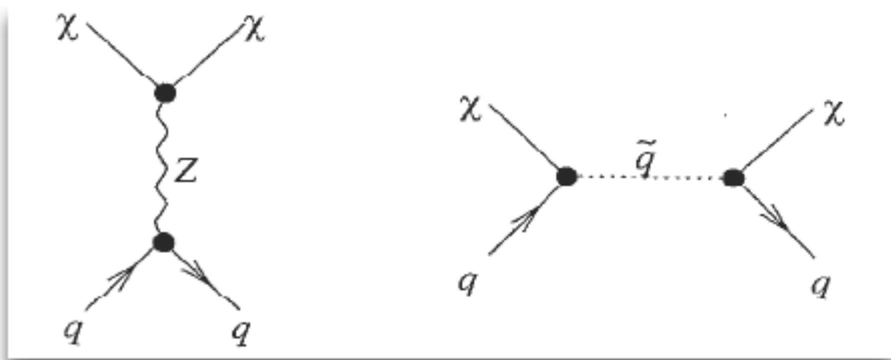
Direct detection : Interaction Cross Section

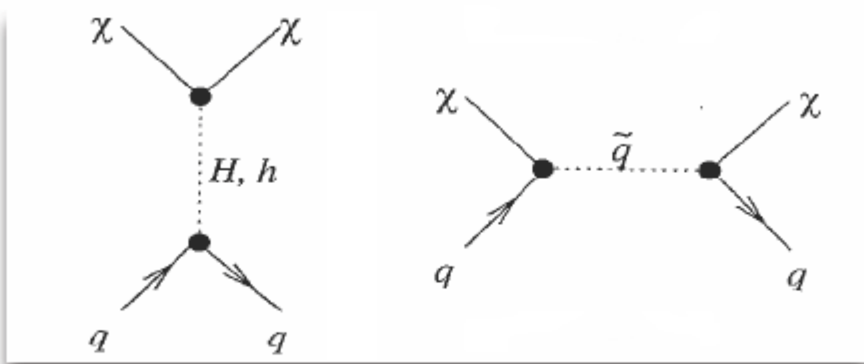
- General form of cross section for the WIMP interaction with matter :

$$\sigma_A = 4G_F{}^2 \left(\frac{M_\chi M_A}{M_\chi + M_A} \right)^2 C_A F(q^2)$$

C_A → Nuclear enhancement factor

- Depends on the target used for the detector !





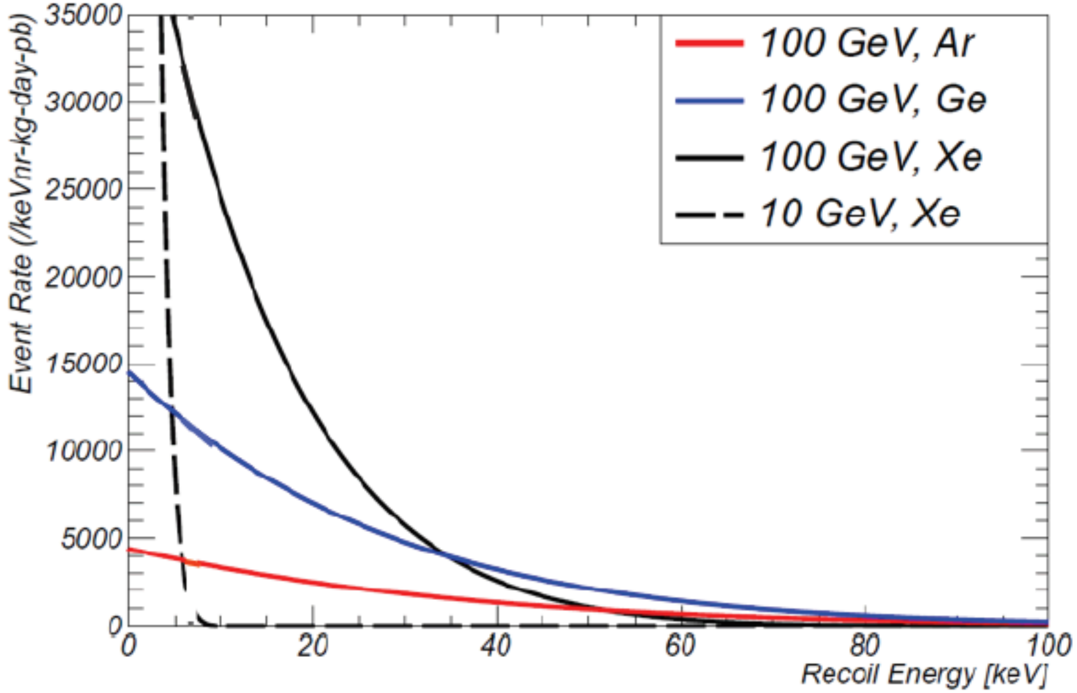
Axial-Vector : Spin-Dependent (SD)

$$C_A^{SD} \propto \left\langle S_{p,n} \right\rangle^2$$

Scalar : Spin-Independent (SI)

$$C_A^{SI} \propto A^2$$

Direct Detection with Xenon



- High mass number: A ~ 131
  → SI interactions scale as A^2
- 50% odd isotopes:
  → ^{129}Xe, ^{131}Xe for SD interactions
- High stopping power:
  → Z=54, ρ = 3 gcm^{-3}
- Accessible cryogenic temperatures:
  → Liquid at 182 K at 2 bar.
- Low intrinsic radioactivity:
  → No long-lived radioisotopes (with the exception of ^{136}Xe, $T_{1/2} = 2.2 \times 10^{21}$ y),
  → ^{85}Kr can be reduced to sub-ppt
- Efficient scintillator:
  → High light yield, light output at 178 nm and fast response.

XENON Dark Matter Project

Finally What we need ???

The detection depends of : WIMP mass, spin coupling, background !

$1\,keV \leq \text{Recoil Energy} \leq 100\,keV$	→	Low threshold detectors.
Very low Rate	→	Large volume detectors.

Background is the principal problem of all Dark Matter experiments!

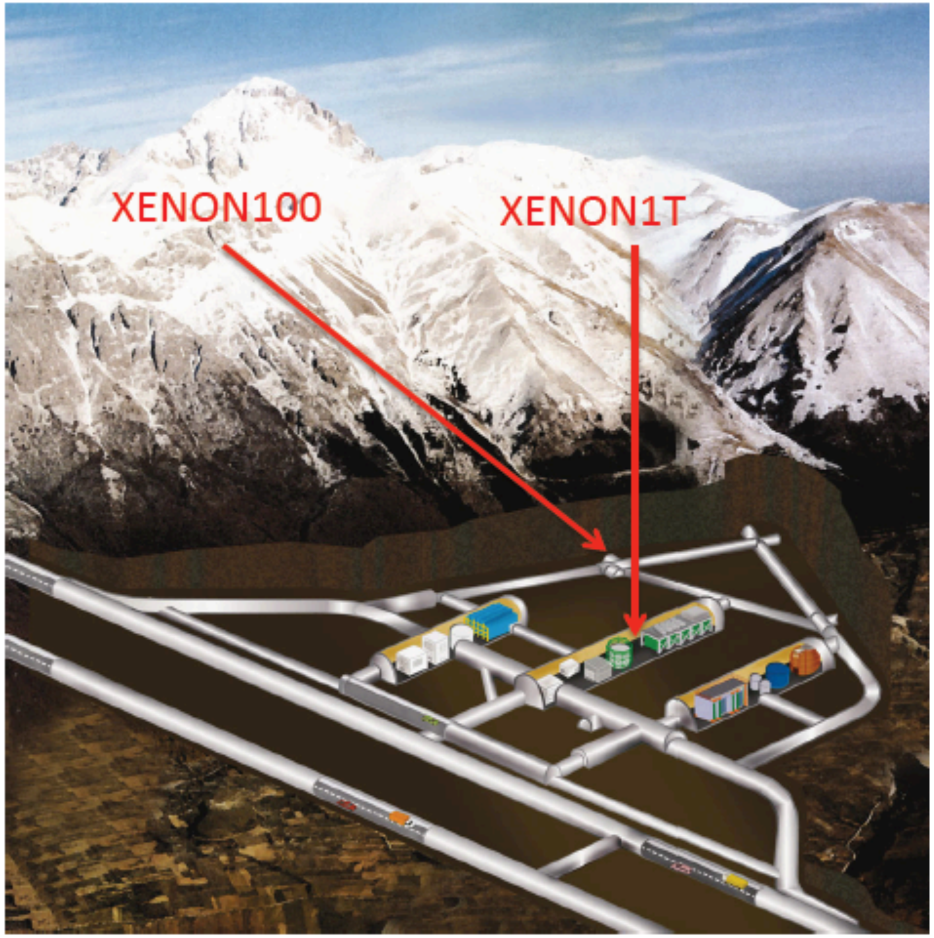
Enemies : muon-induced neutrons, gammas, neutrons, intrinsic betas decays, alpha background, neutrinos !

XENON AT LNGS

- **XENON Experiment is located at Laboratori Nazionali del Gran Sasso in Italy.**
- **Rock coverage from the mountain of 1.4km (3600 m w.e.)**

XENON collaboration

- 21 institutions
- ~150 collaborators



XENON as a detector medium

XENON EXPERIMENT:

- Active target :

Double phase Xenon (gas + liquid).
→ Favourable nucleus for SI.

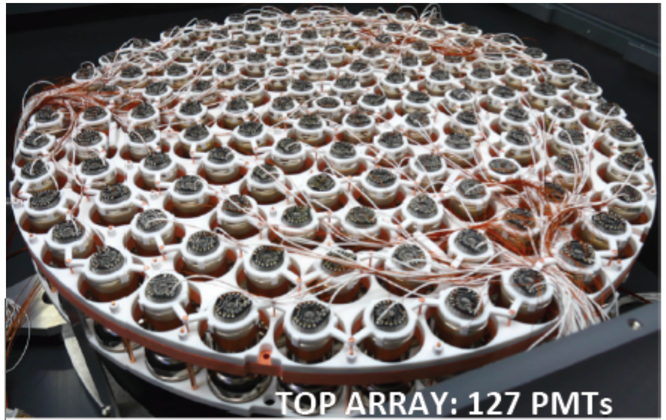
- Detector :

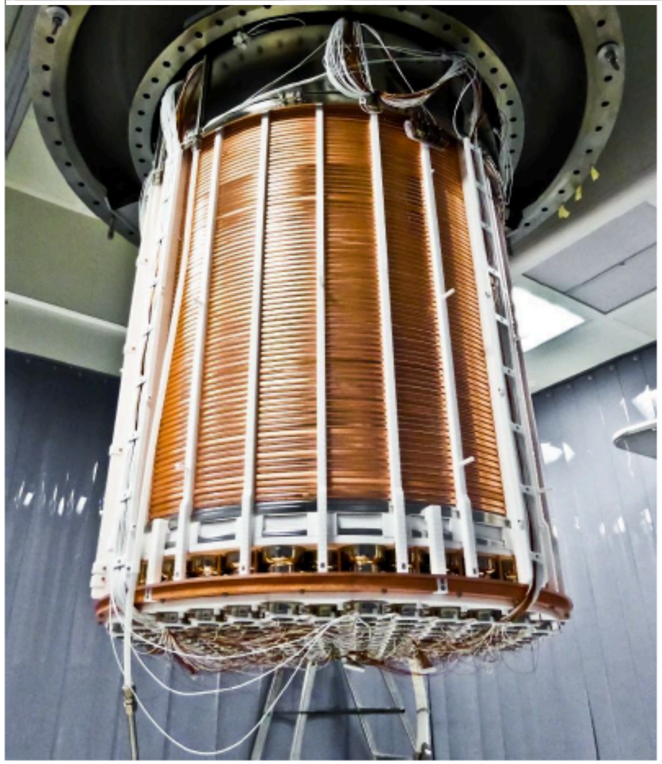
Time Projection Chamber (TPC) within a cryostat.

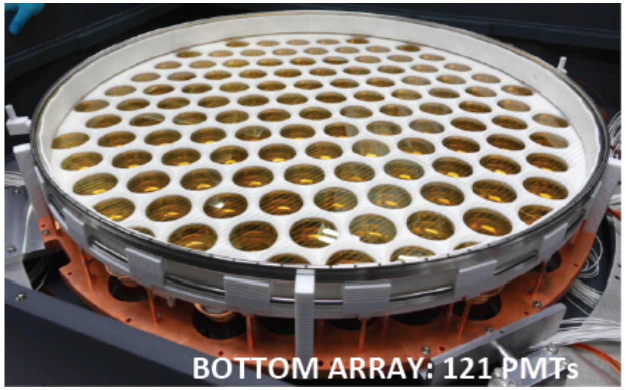
- Read-out :

Photomultipliers : 248 PMTs from Hamamatsu.

[PMT model: R11410-21 (3"), 6 R8520 in the veto region]

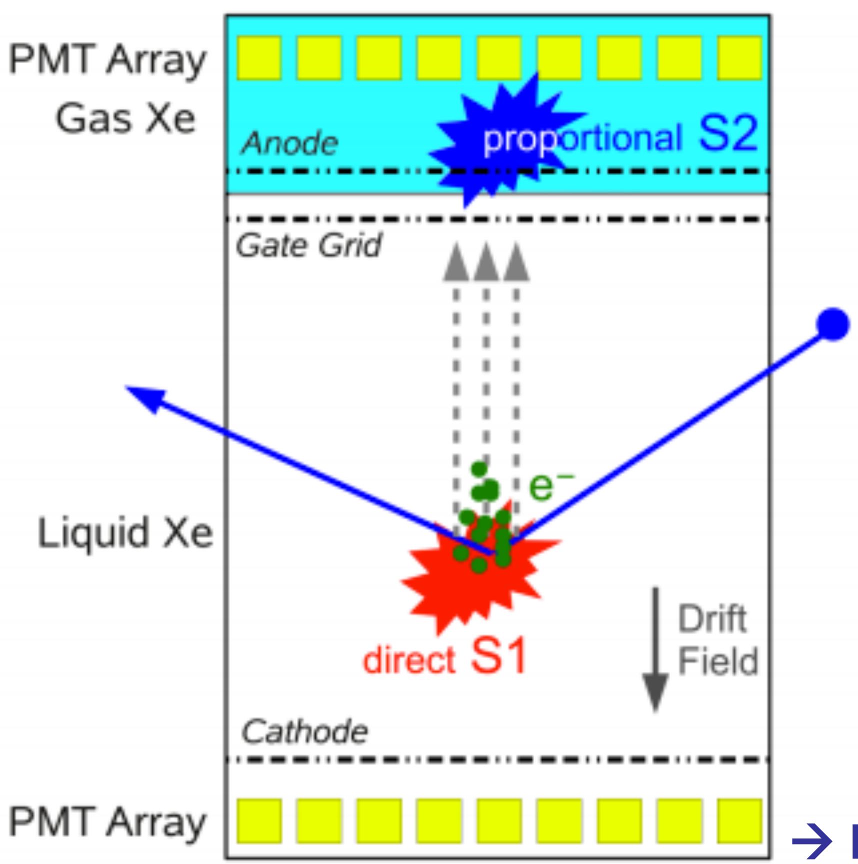






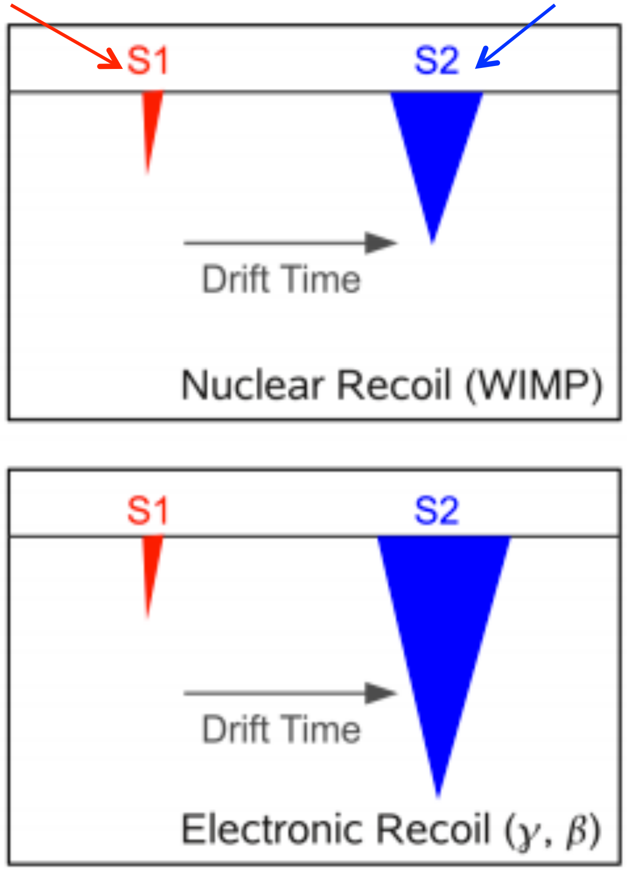
XENON1T Detector Principle

Time Projection Chamber (TPC)



Initial interaction:
Prompt scintillation (LXe)

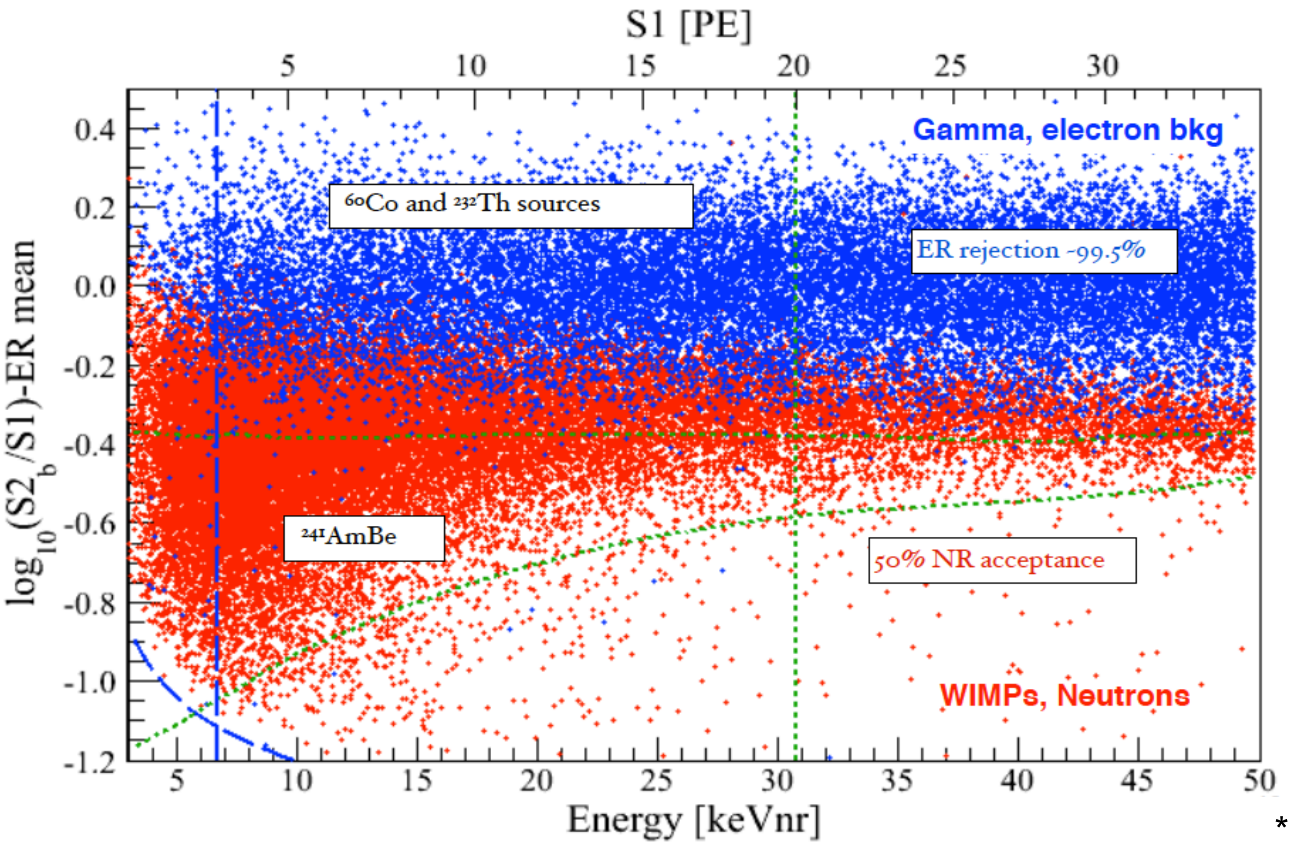
Drifted electrons:
Proportional scintillation (GXe)



→ Background discrimination and fiducialization

XENON1T Detector Principle

- **Background discrimination :** $$\frac{S2}{S1}_{ER} > \frac{S2}{S1}_{NR}$$
- **Z-position :** Drift time proportional to interaction depth
- **X-Y position :** Hit pattern on photo-sensors

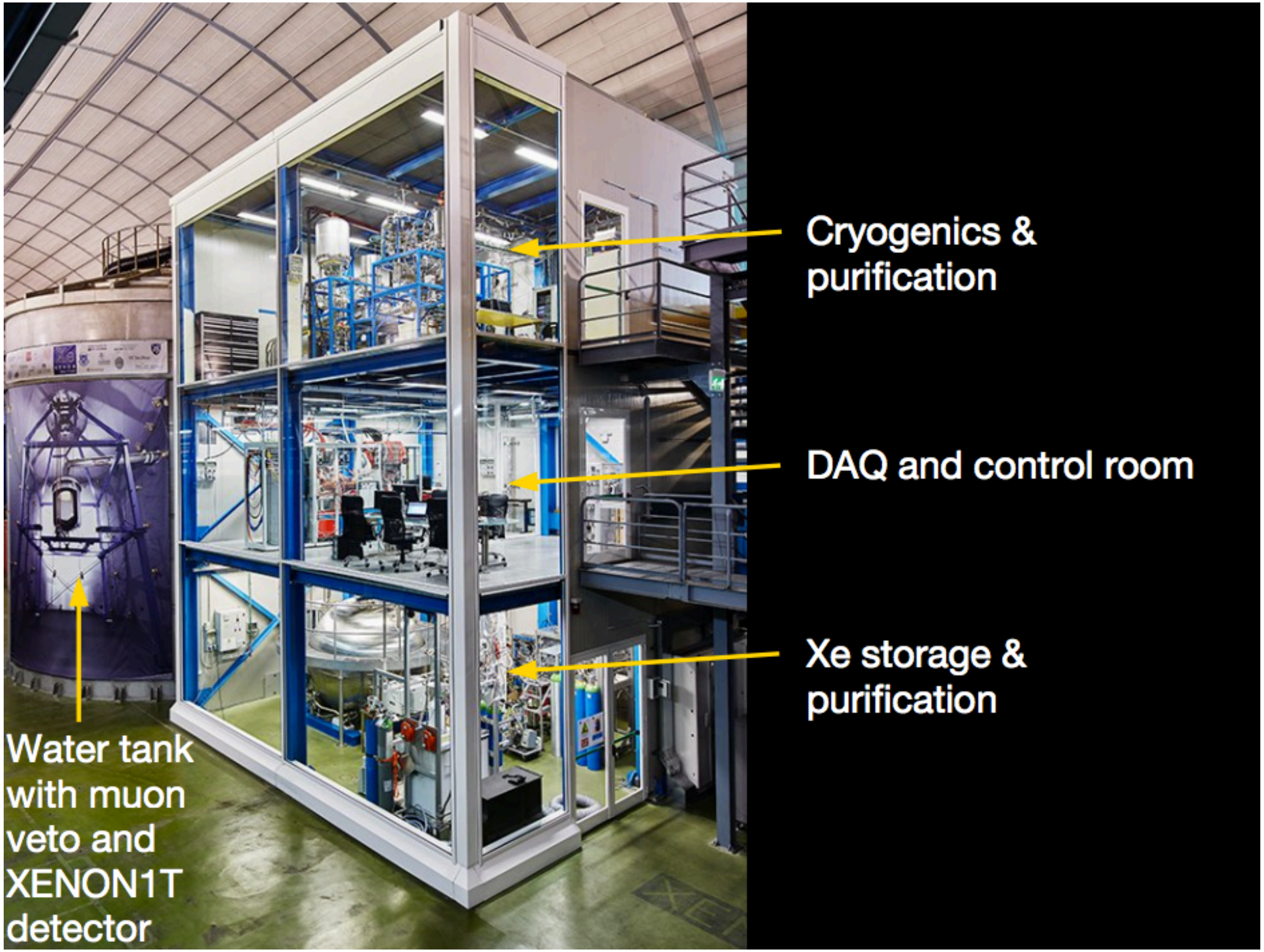


** From XENON100*

Xe
XENON
Dark Matter Project

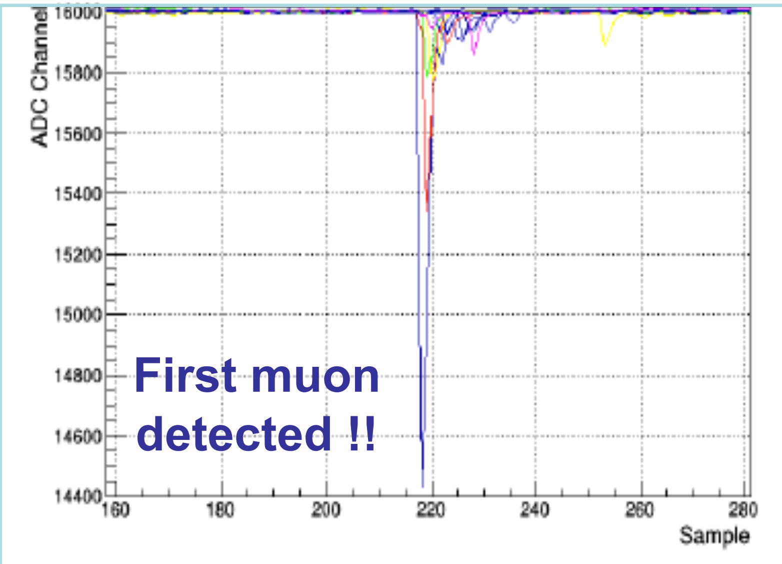
XENON1T Overview and Status

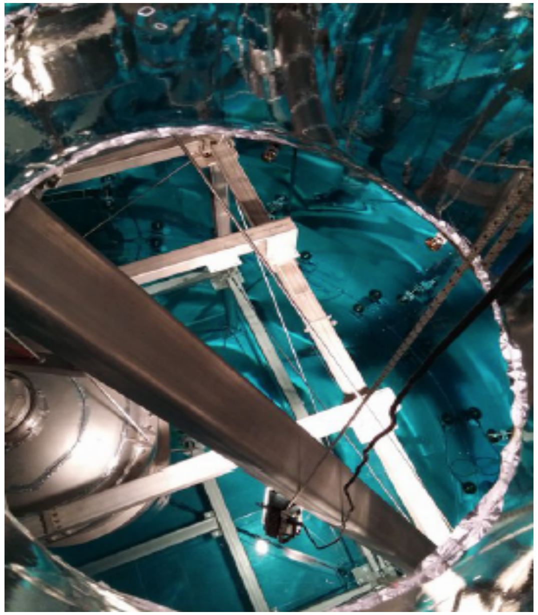
XENON1T Infrastructure

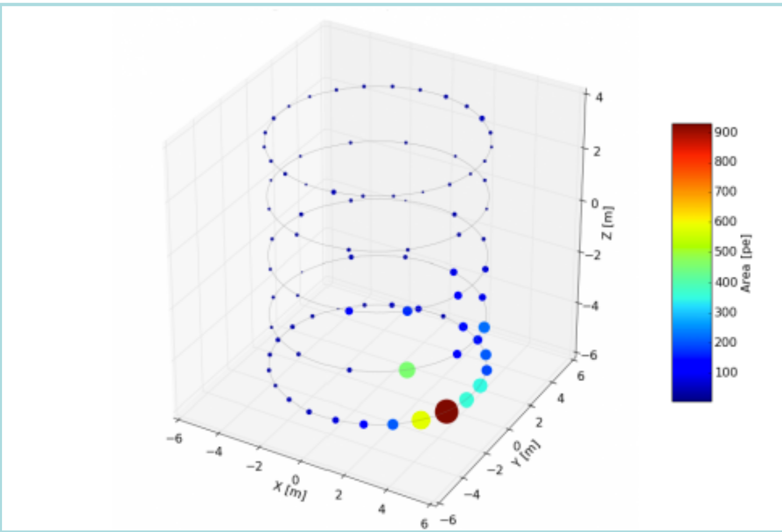


Xe
XENON
Dark Matter Project

Water Tank: a Water Cherenkov Muon Veto



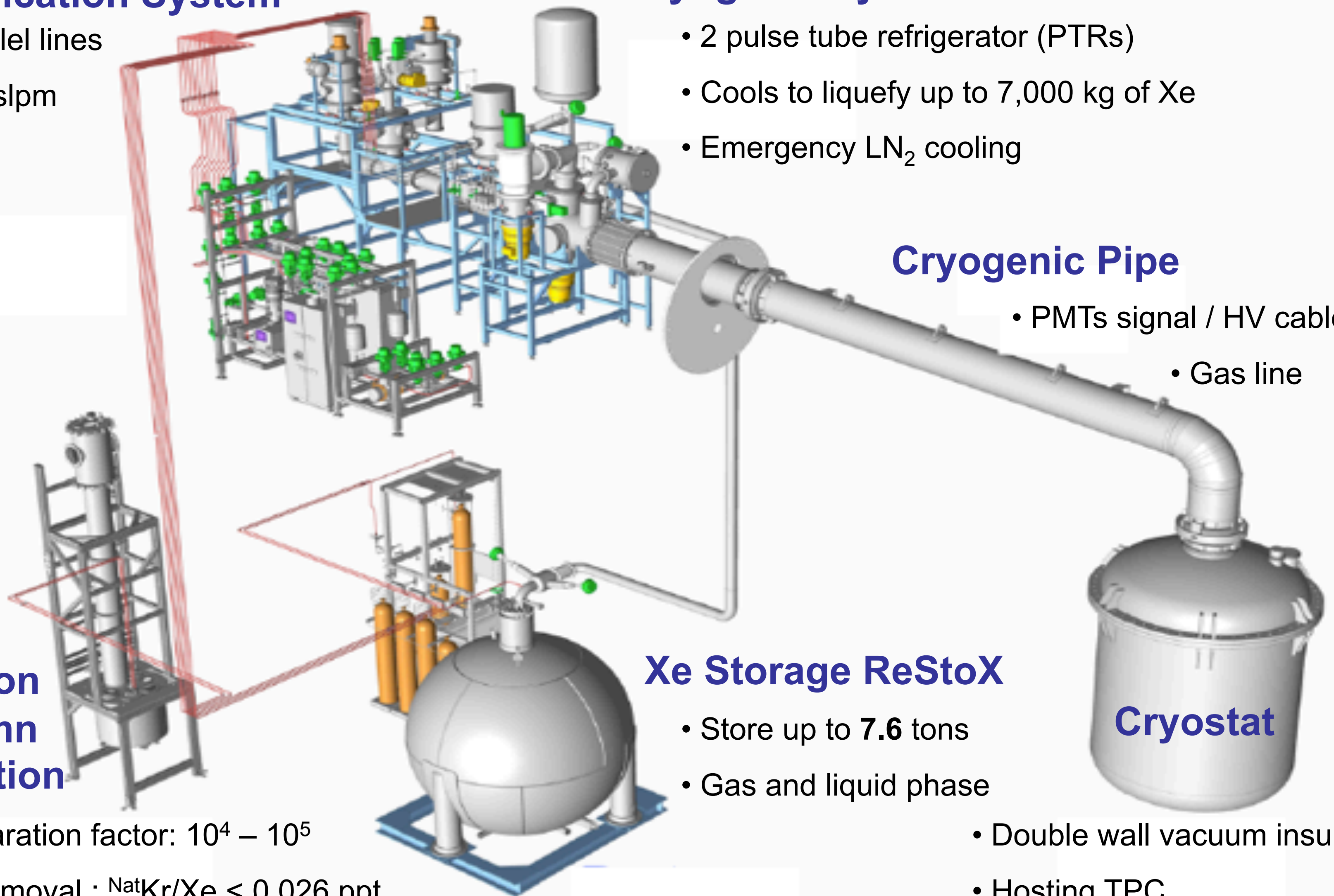




- XENON1T cryostat immersed into 700 m^3 of demineralised water.
- Tank cladded with high-reflectivity foils and equipped with 84 high QE PMTs.
- Passive shield against external background as neutrons, gammas from the environment.

** XENON1T Muon Veto paper: JINST 9 P11006 (2014)"*

XENON1T : Overview



Purification System

- 2 parallel lines
- ~ 100 slpm

Cryogenic System

- 2 pulse tube refrigerator (PTRs)
- Cools to liquefy up to 7,000 kg of Xe
- Emergency LN_2 cooling

Cryogenic Pipe

- PMTs signal / HV cables
- Gas line

Krypton Column Distillation

- Separation factor: $10^4 - 10^5$
- Kr removal : $^{Nat}Kr/Xe < 0.026$ ppt

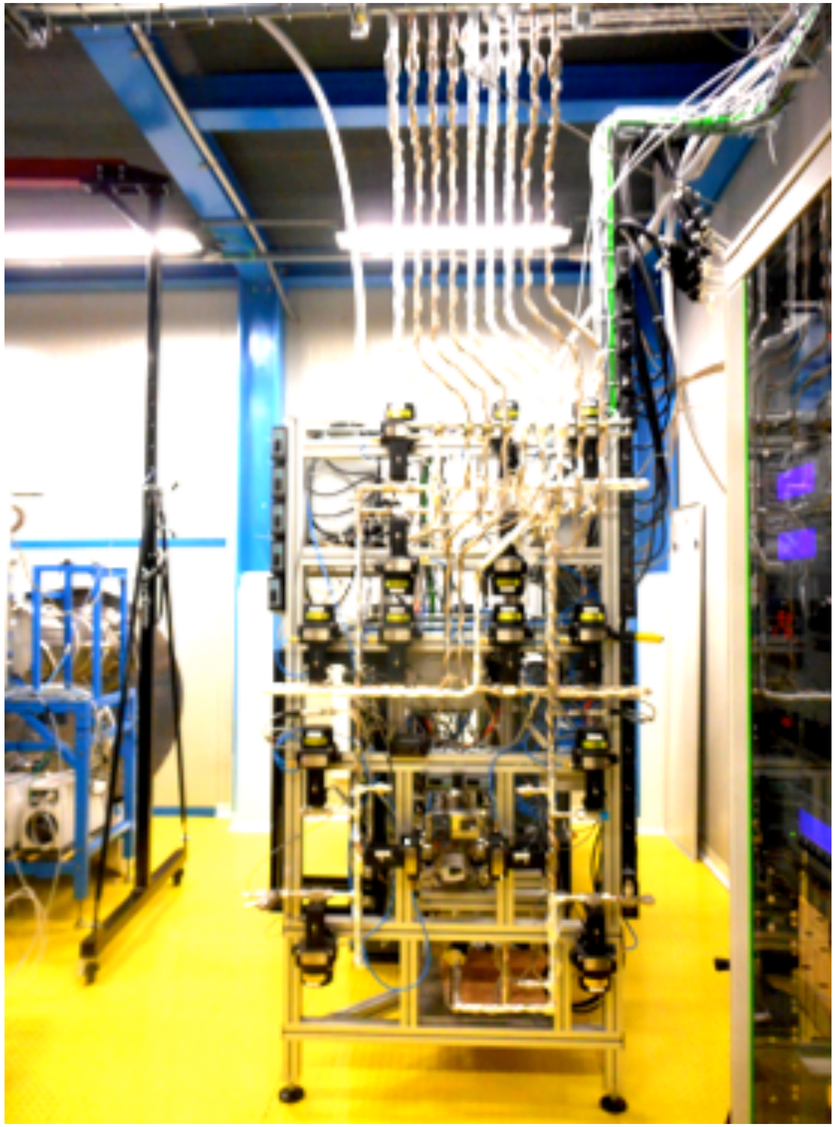
Xe Storage ReStoX

- Store up to **7.6** tons
- Gas and liquid phase

Cryostat

- Double wall vacuum insulated
- Hosting TPC

Purification System



- Charge/light attenuated by impurities
- Outgassing continuously contaminates Xe

→ **Continuous recirculation**

- Cleaning of 3.5 tons of xenon

→ **High flow rate : goal 100 SLPM**

- High flow parallel purifiers:

→ Purification for electronegative elements (O_2, H_2O) with hot zirconium oxide getter.
→ Gas cleaned to one part per billion (ppb)

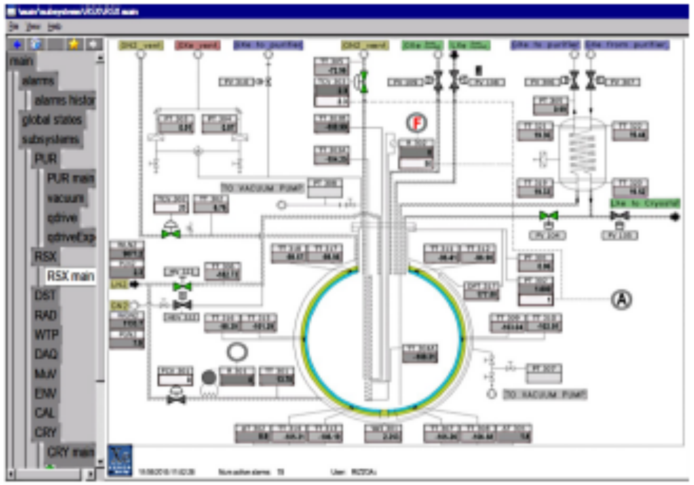
- HALO+ Analyser:

→ Monitor performance of purifier
→ Continuously measure H_2O concentration.

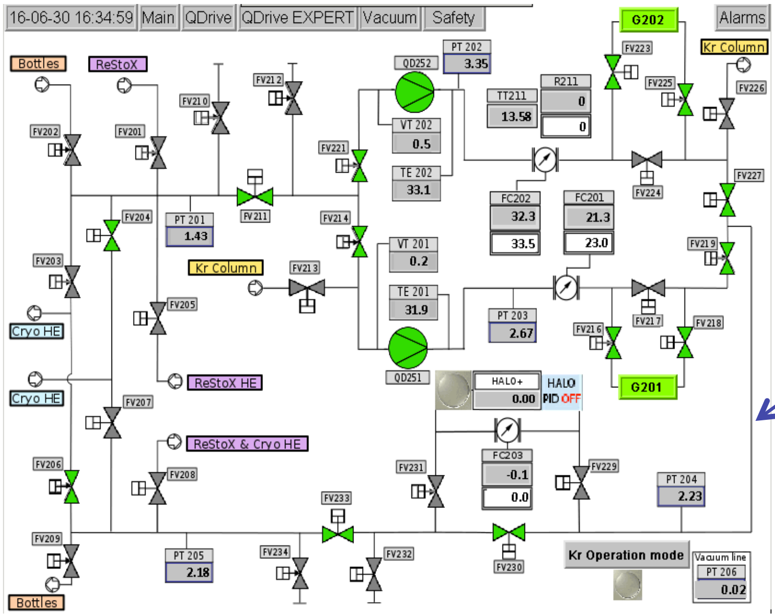
Slow Control System

- Ensures the complete safety of the experiment.
- Distributed local controllers per subsystem; central monitoring, control and database.
- Based on industrial process control hardware and software (GE)
- Critical operations are guarded and can be executed only if conditions are safe.

Control Room – SCADA screens



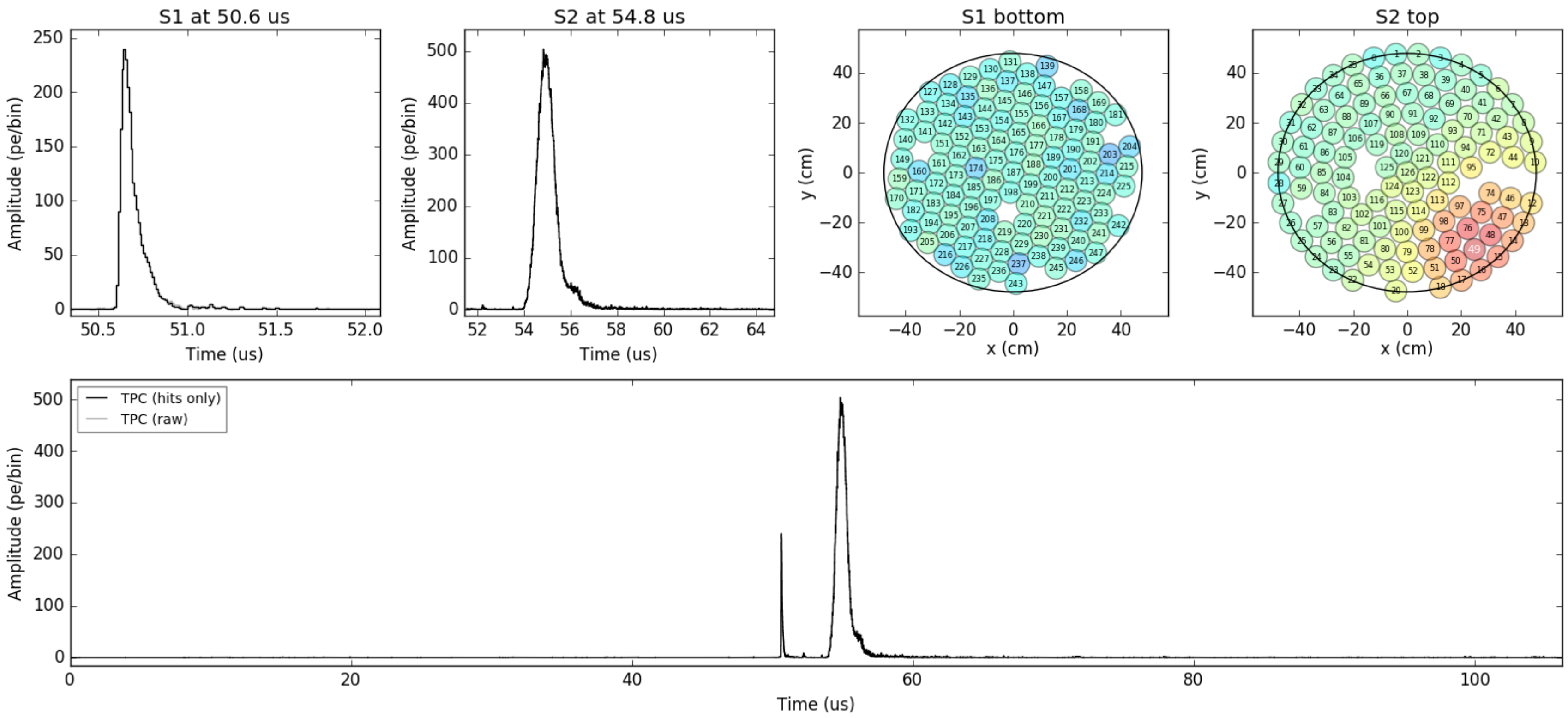
Historian database and interfaces



Example of the touch screen of the PUR System

First light !

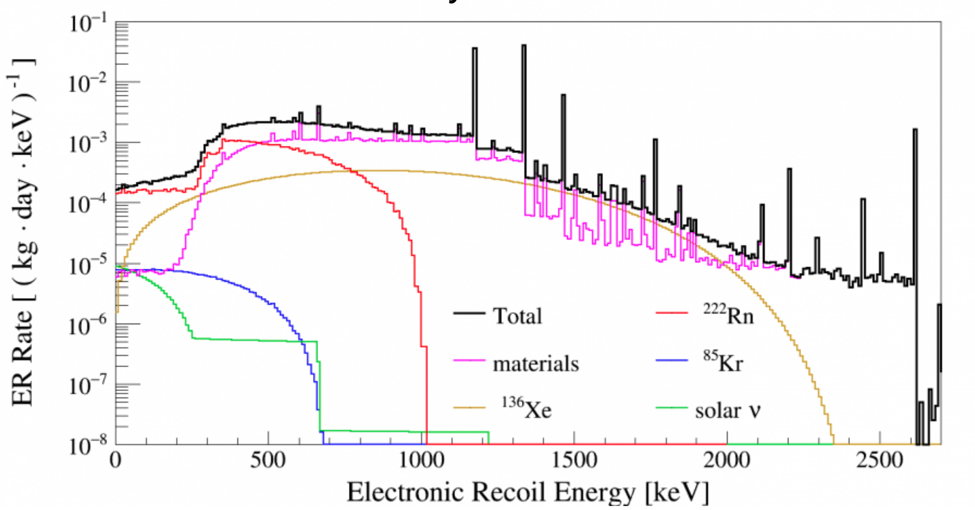
One of the first S1 and S2 signals from 3 tons of a dual phase Xe TPC

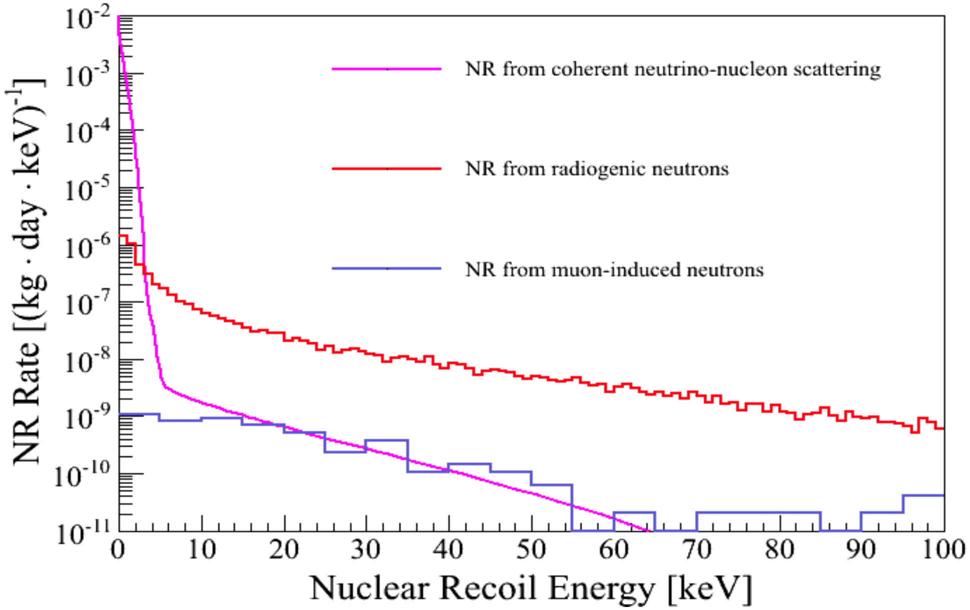


Both charge and light are being detected. The total mass of 3.2 t of LXe is being continuously purified to reach the desired charge yield at the applied field.

Expected Backgrounds

** Physics reach of the XENON1T dark matter experiment, JCAP 1604 (2016) no.04, 027"*



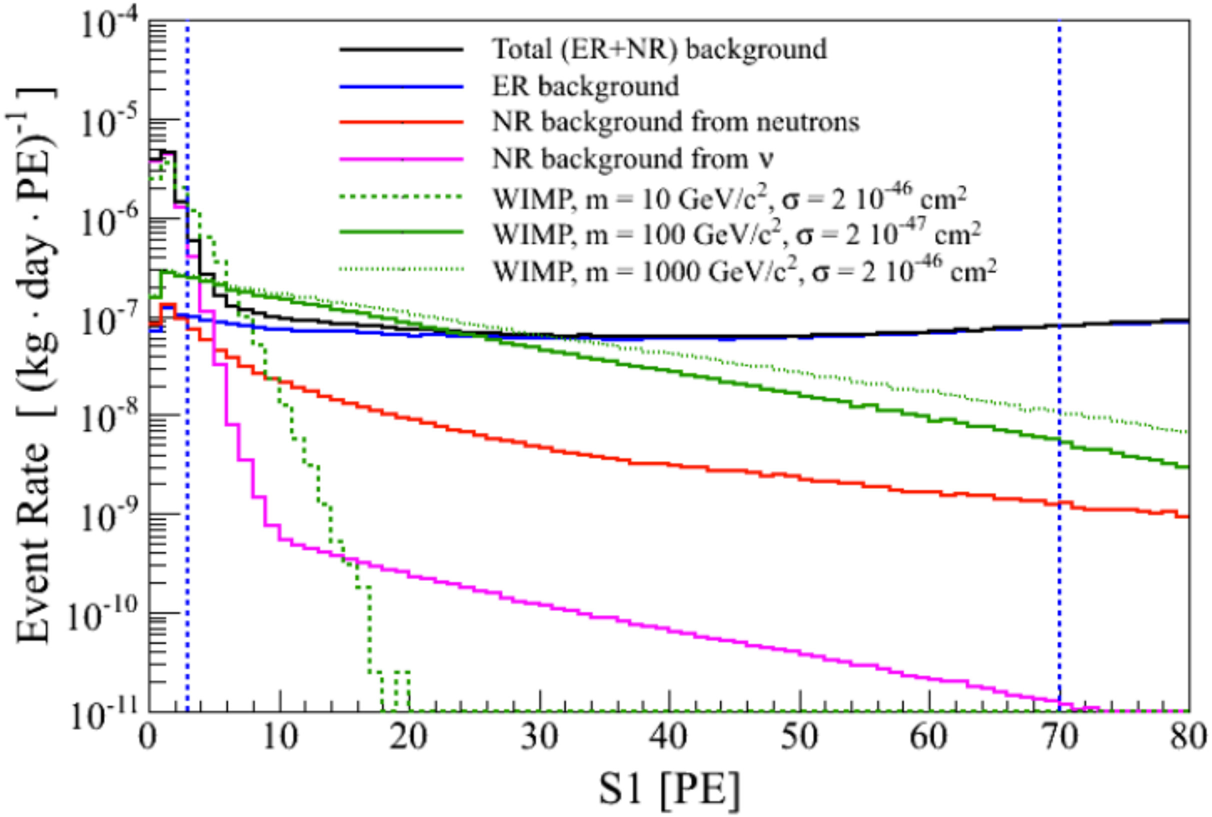


Source	Bgd (ev/y)
ER from materials	~0.07
^{222}Rn (10μBq/kg)	~1.39
^{85}Kr (0.2 ppt of ^{NAT}Kr)	~0.07
^{136}Xe 2v2β	~0.02
Solar neutrinos	~0.08
Total ER	~1.62
Total NR	~0.46

Single scatter, 1t FV, [1,12]keVee, [4,50]keVr, 99.75% S2/S1 discrimination, 40% NR acceptance

Total Expected Backgrounds

** Physics reach of the XENON1T dark matter experiment, JCAP 1604 (2016) no.04, 027"*

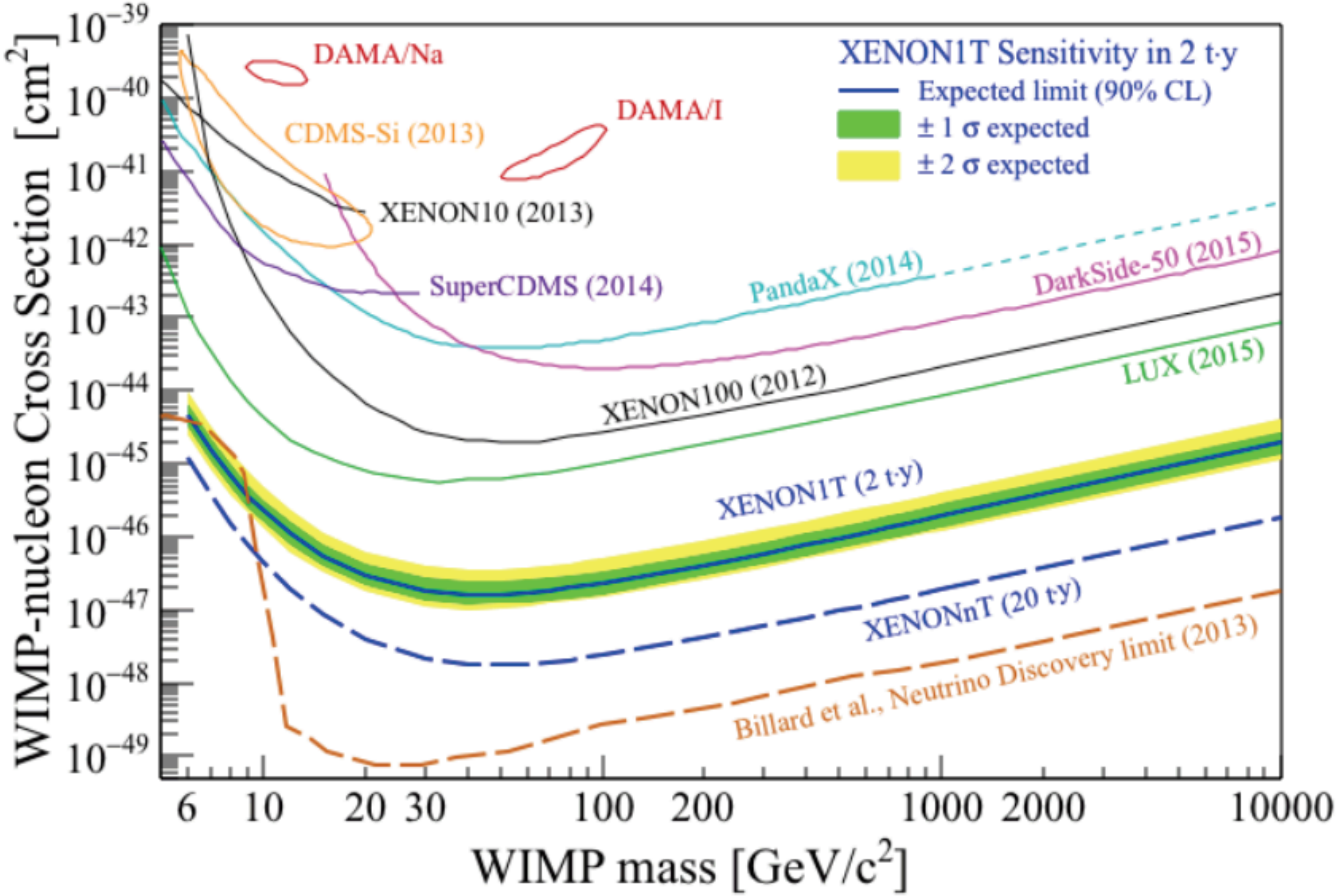


- **3-70 PE** S1 region
- **4-50 keV** NR energy region
- **2 t x y** exposure
- **99.75%** XENON100- like ER rejection
- **40%** NR acceptance

- Background estimation:
  - **Total Nuclear Background: 0.91 events**
  - **Total Electronic Background: 3.25 events**

Expected Sensitivity

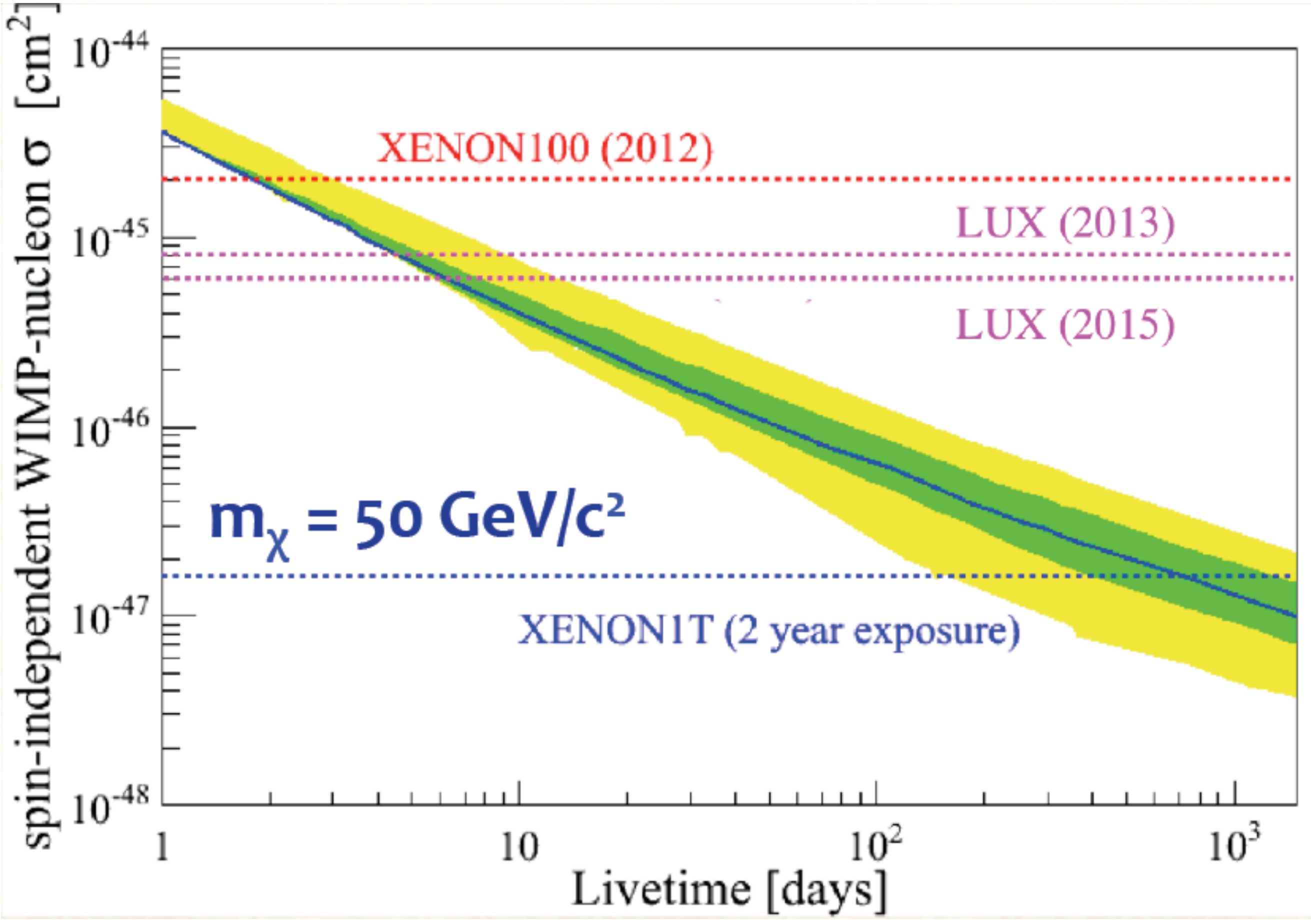
** Physics reach of the XENON1T dark matter experiment, JCAP 1604 (2016) no.04, 027"*



1.6×10^{-47} cm^2 at 50GeV/c^2 in 2 ton year exposure

Expected Sensitivity

** Physics reach of the XENON1T dark matter experiment JCAP 1604 (2016) no.04, 027"*



Expected to overcome presently world-leading limits just **within 10 days** of data taking in dark matter mode.

Summary and Outlook

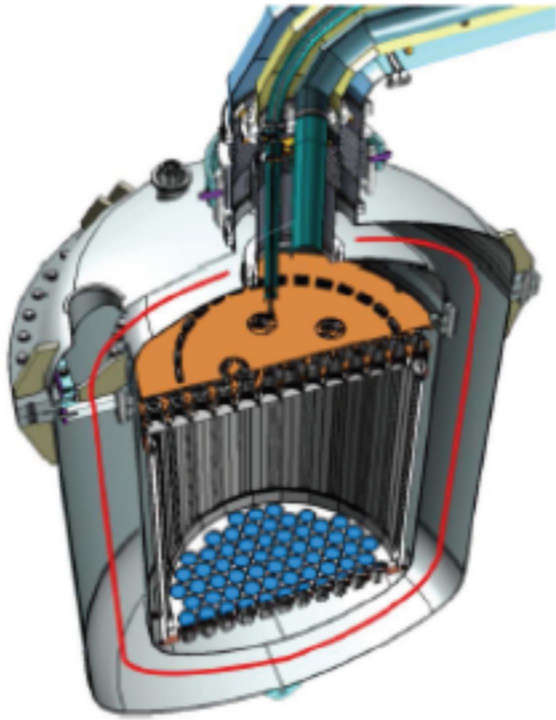
- XENON1T is in commissioning:
  → Operation of all infrastructures demonstrated.
  → Cherenkov light from muons observed.
  → LXe purification ongoing, electron lifetime increasing.
  → Regular data acquisition / data analysis ongoing.
  → Water tank now is closed and is being filled !

- First science run expected by this fall

- Upgrade to XENONnT:
  → An order of magnitude better than XENON1T.

** Physics reach of the XENON1T dark matter experiment, JCAP 1604 (2016) no.04, 027"*

XENONnT



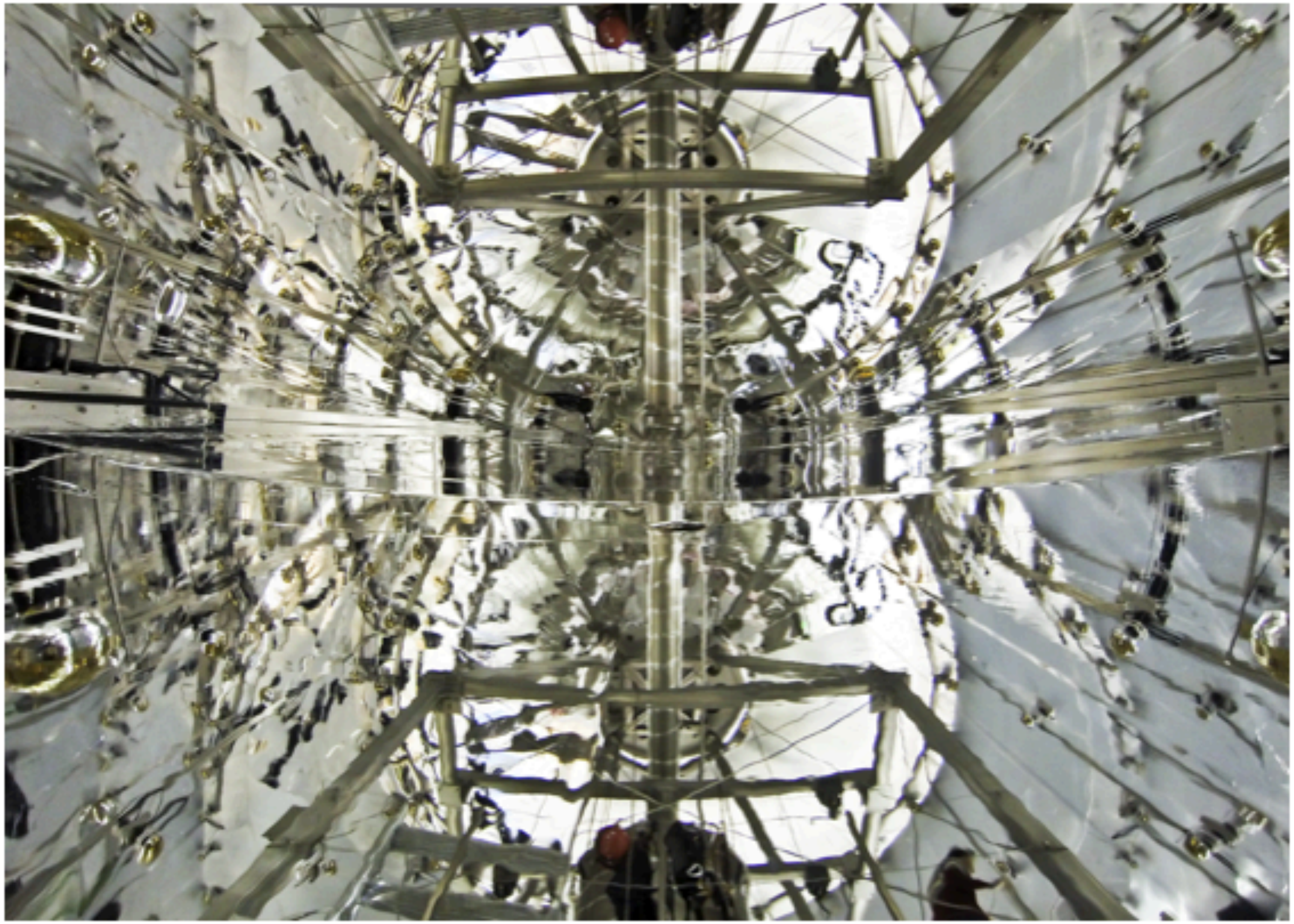
Xenon mass **~7.6 t**

Expected Sensitivity (50 GeV, 20ty):

2×10^{-48} cm^2

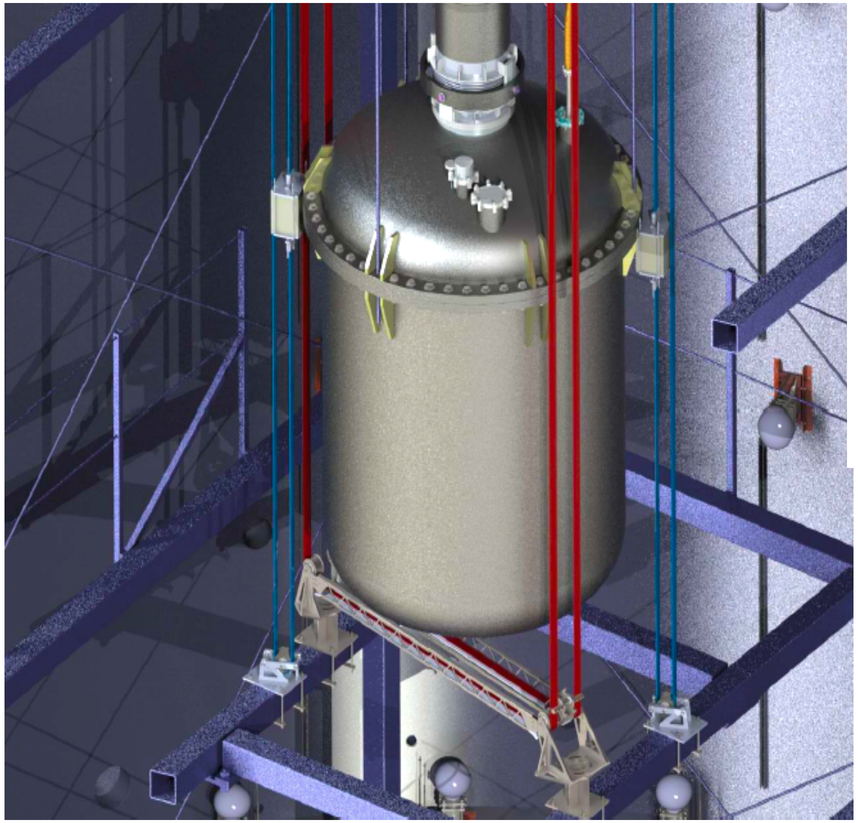
M-C.Piro

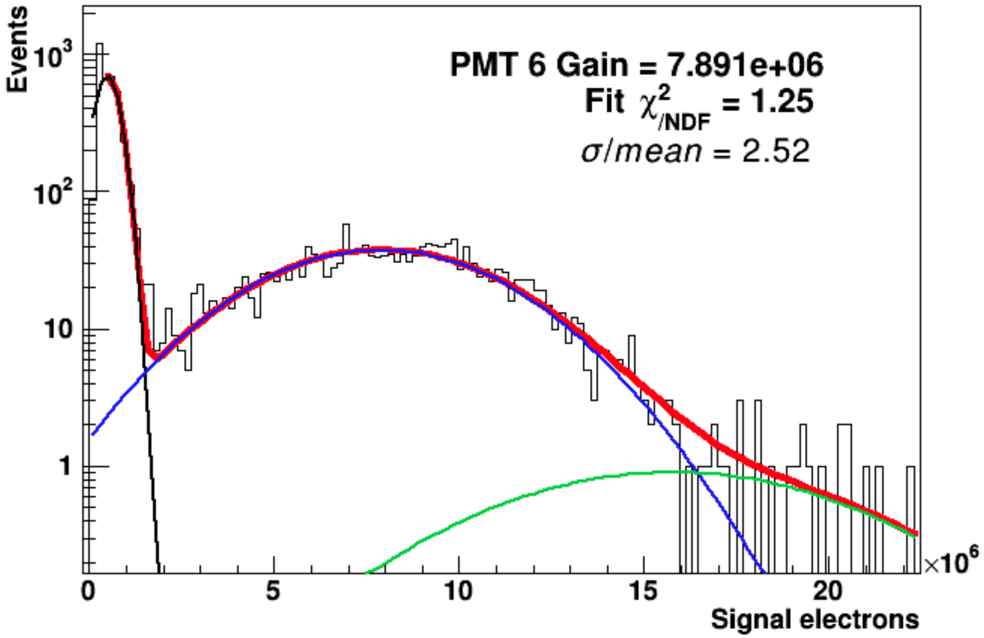
Thank you for your attention !



Calibrations

Installation in the Water Tank





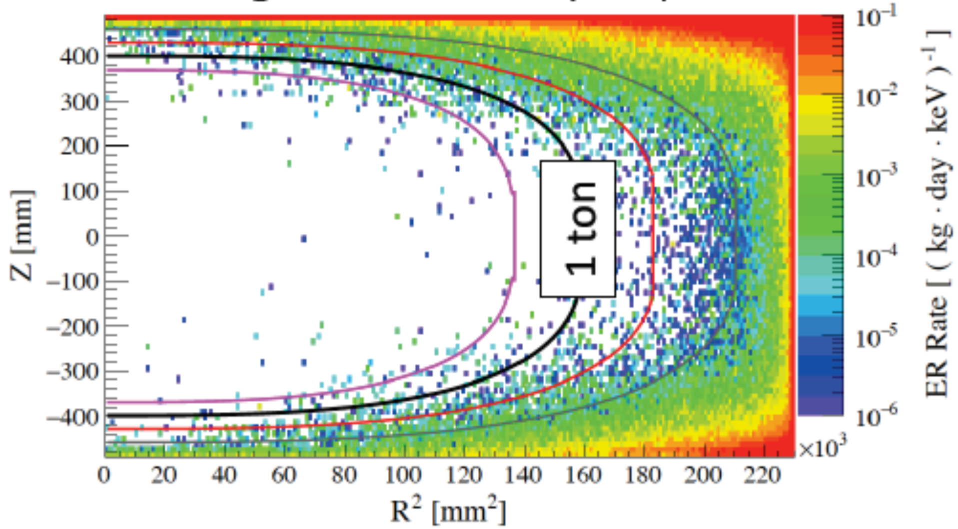
- Regular PMT gain calibrations with LEDs
- Deployable external and short-lived internal radioisotopes for calibration
- D-D neutron generator for NR band

→ Currently monitoring light yield and Xe purity

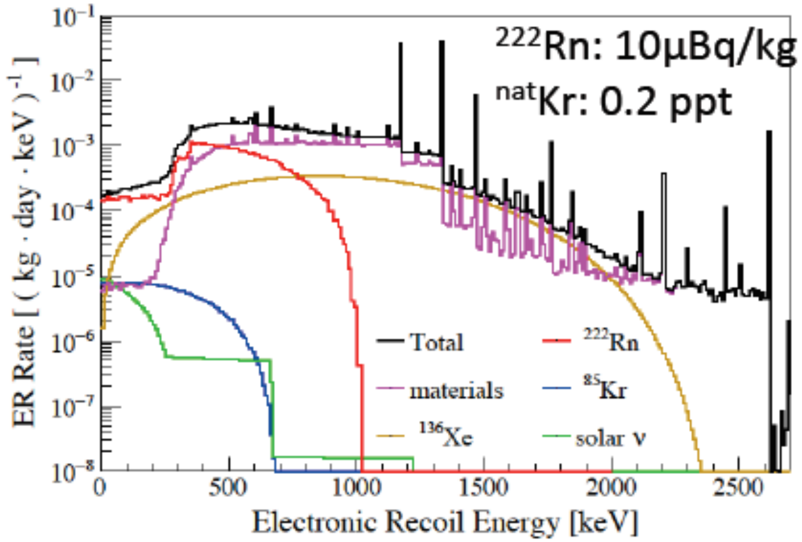
Electronic Recoil background

* *Physics reach of the XENON1T dark matter experiment, JCAP 1604 (2016) no.04, 027"*

ER bkg from material, (1,12) keV



Total ER bkg energy spectrum

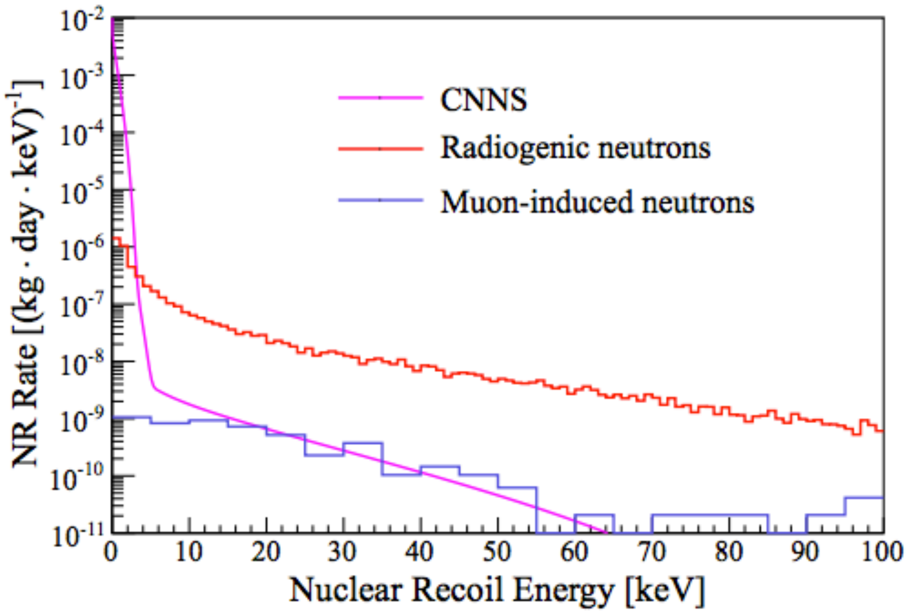


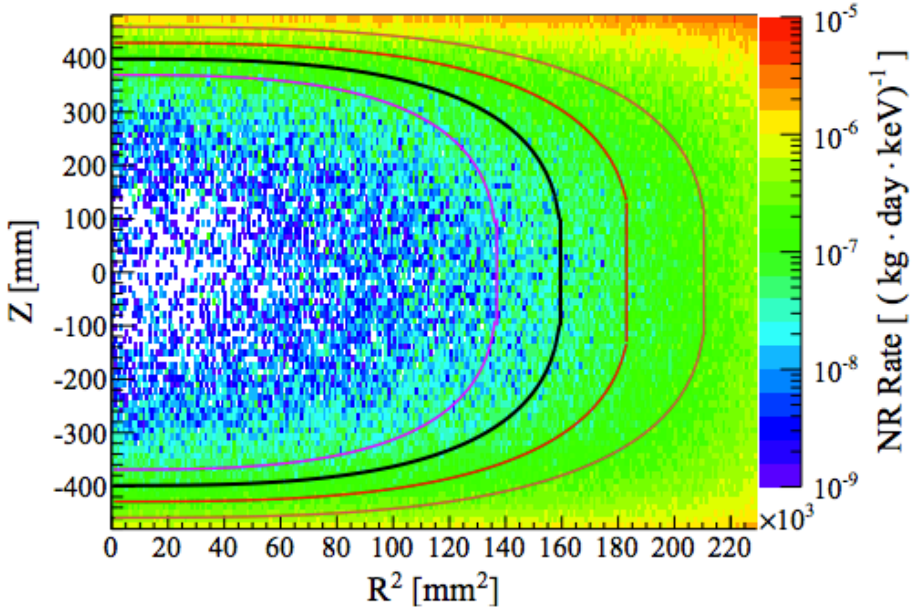
ER background in 1 ton FV, (1,12) keV, before ER/NR discrimination

Source	Background $[(\mathrm{kg} \cdot \mathrm{day} \cdot \mathrm{keV})^{-1}]$	Background $[\mathrm{y}^{-1}]$	Fraction [%]
Materials	$(7.3 \pm 0.7) \cdot 10^{-6}$	30 ± 3	4.1
^{222}Rn	$(1.54 \pm 0.15) \cdot 10^{-4}$	620 ± 60	85.4
^{85}Kr	$(7.7 \pm 1.5) \cdot 10^{-6}$	31 ± 6	4.3
^{136}Xe	$(2.3 \pm 0.3) \cdot 10^{-6}$	9 ± 1	1.4
Solar neutrinos	$(8.9 \pm 0.2) \cdot 10^{-6}$	36 ± 1	4.9
Total	$(1.80 \pm 0.15) \cdot 10^{-4}$	720 ± 60	**100**

Nuclear Recoil background

** Physics reach of the XENON1T dark matter experiment, JCAP 1604 (2016) no.04, 027"*





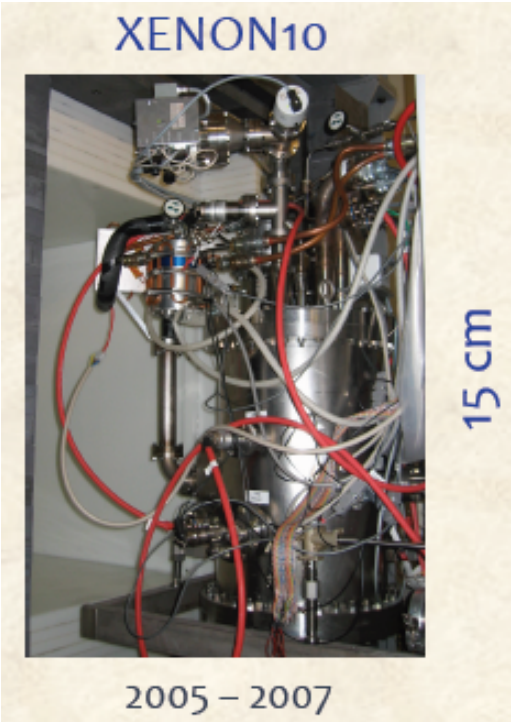
Source	events / ton / year
CNNS	$(1.8 \pm 0.3) \times 10^{-2}$
Radiogenic	0.6 ± 0.1
Muon-induced	< 0.01

1 t Fiducial volume, (4,50) keV

Before discrimination/NR acceptance

XENON dark matter program

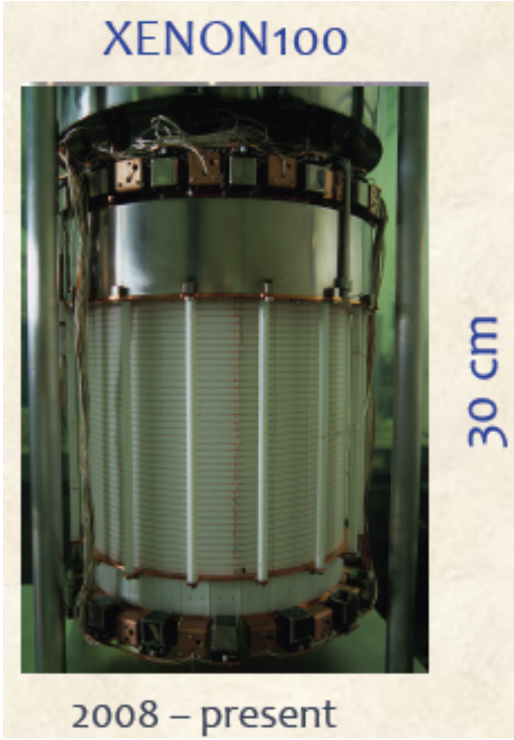
* SI WIMP



Xenon target = **15 kg**

Sensitivity* (100 GeV, 2007):

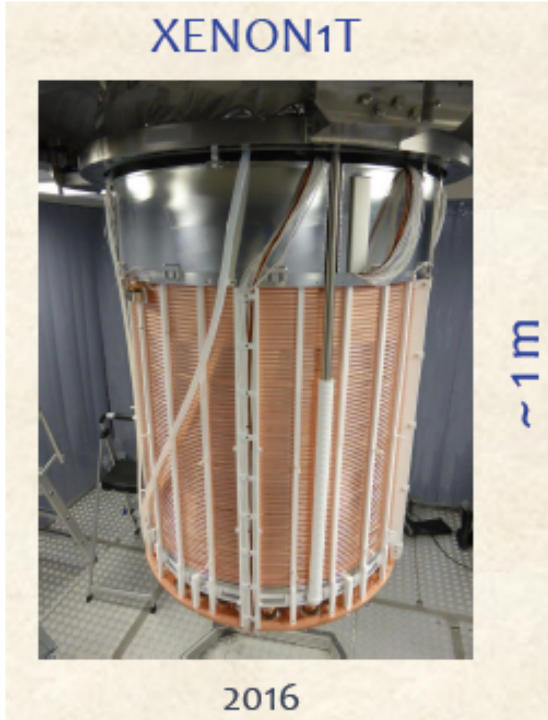
8.8×10^{-44} cm^2



Xenon target mass = **62 kg**

Sensitivity* (55 GeV, 2012):

2.0×10^{-45} cm^2



Xenon target mass = **2000 kg**

Expected Sensitivity* (50 GeV, 2018):

1.6×10^{-47} cm^2

Sensitivity increases with exposure (target mass, time) and background reduction