Direct Dark Matter Detection with XENON1T

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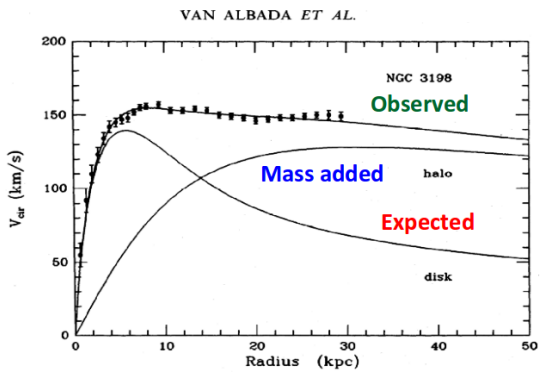
on behalf of the XENON Collaboration

PASCOS
Quy Nhon July 10-16, 2016

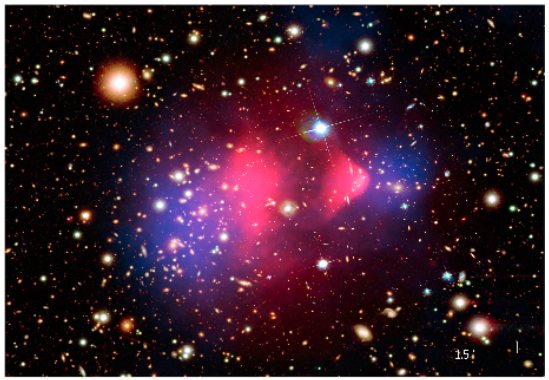
University of Zurich[UZH]

Dark Matter

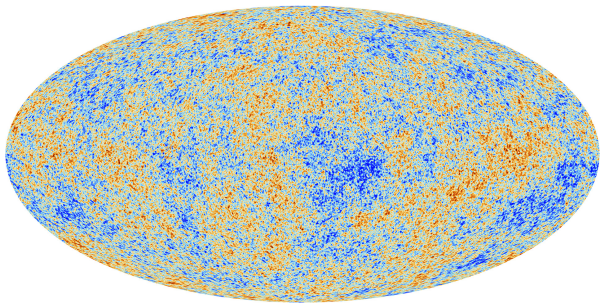
Indications of dark matter from Cosmology and Astronomy:



rotation curves



Bullet cluster

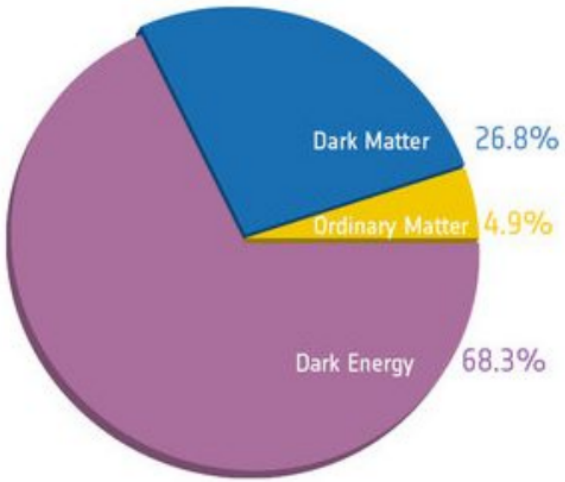


CMB

Dark Matter properties:

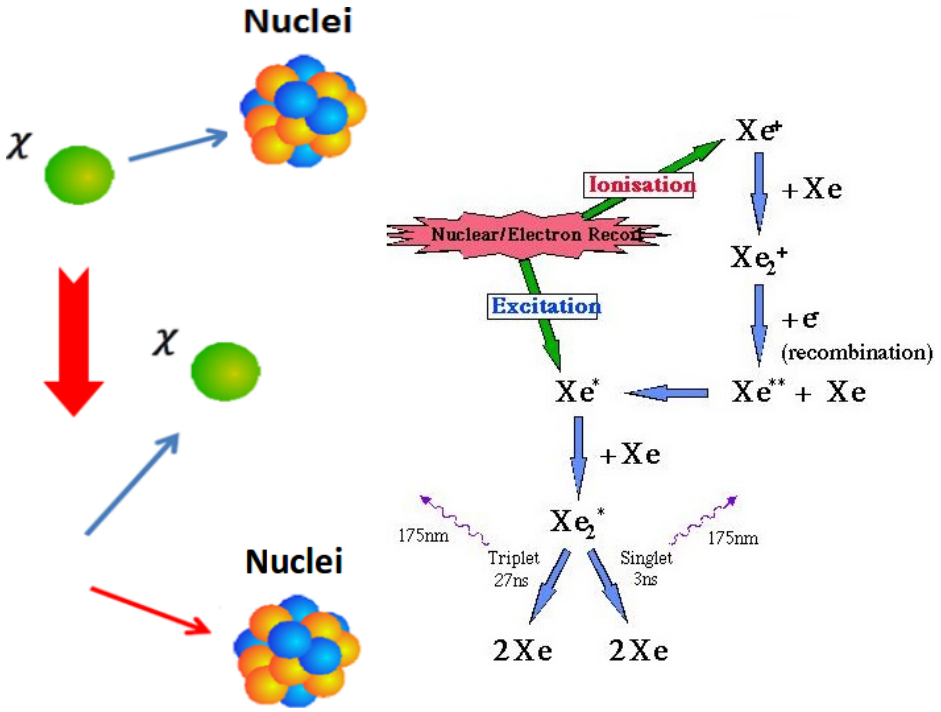
- Non baryonic
- Neutral
- Non relativistic
- Non SM particle

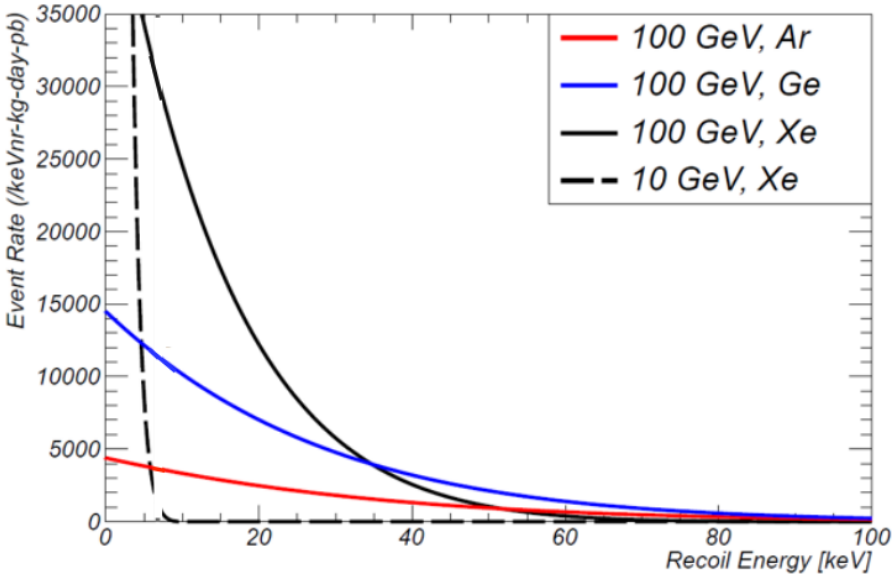
One of the most favoured candidates as dark matter particle:
Weakly **I**nteracting **M**assive **P**article



Energy density

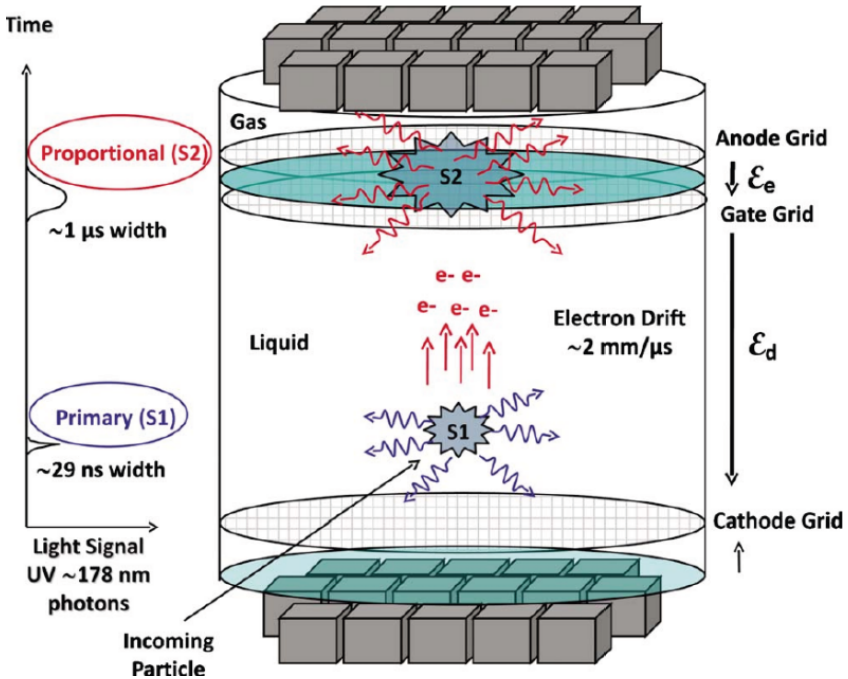
Direct Detection with Xenon





- High mass number and stopping power ($A \sim 131$, $\rho = 3\frac{g}{cm^3}$).
- Higher rate for Spin Independent Interactions (Proportional to A^2).
- Odd isotopes (Xe^{129},Xe^{131}) allow for Spin Dependent interactions.
- High light yield, light output @ 178 nm and fast response.
- Accessible cryogenic temperatures (182 K at 2 bar).
- No long-lived radioisotopes (expect Xe^{136} , $T_{1/2}=2.2 \cdot 10^{21}$ years).

The Detection Method

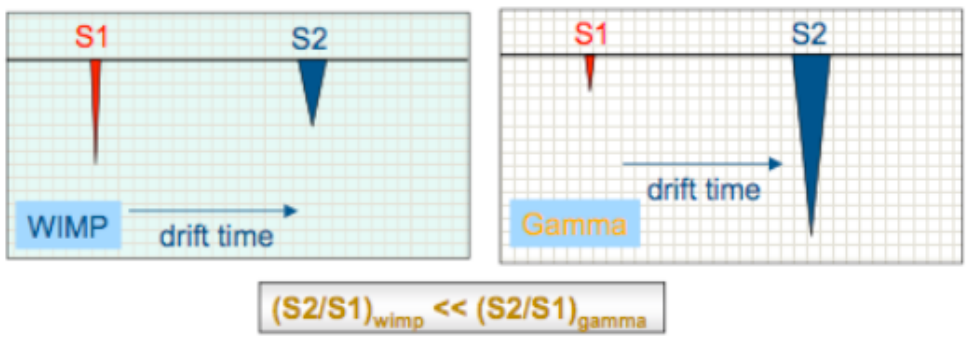


Principle:

- Prompt scintillation in liquid Xenon (S1).
- Secondary scintillation in gaseous Xenon (S2), which is proportional to the produced charge.
- (S1/S2) ratio depends on dE/dx and allows discrimination between nuclear/electronic recoil.

Event Reconstruction:

- Hit pattern of the S2 signal on top PMTs gives x-y $\delta r<10$ mm.
- Drift time provides z coordinate $\delta z<0.3$ mm.



XENON program

XENON10

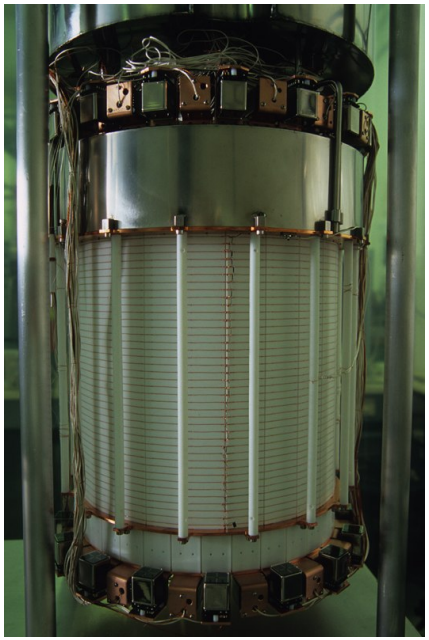
2005-2007

M = 25(15) kg

L = 15 cm

$\sigma_{SI} \simeq 10^{-43}$

(100 GeV)



XENON100

2007-...

M = 161(62) kg

L = 30 cm

$\sigma_{SI} = 2 \times 10^{-45}$

(55 GeV)

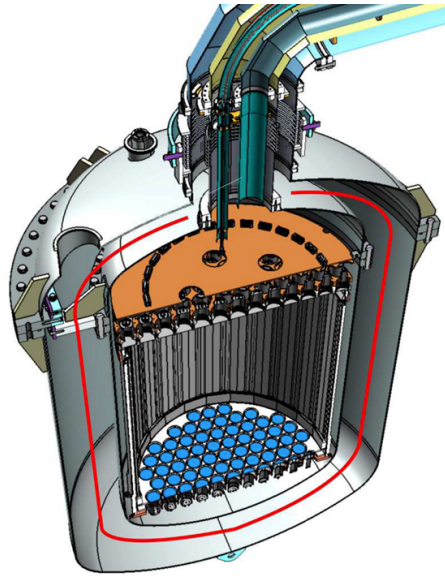
XENON1T

2016- ...

M = 3200 kg

L = 100 cm

$\sigma_{SI} \simeq 2 \times 10^{-47}$



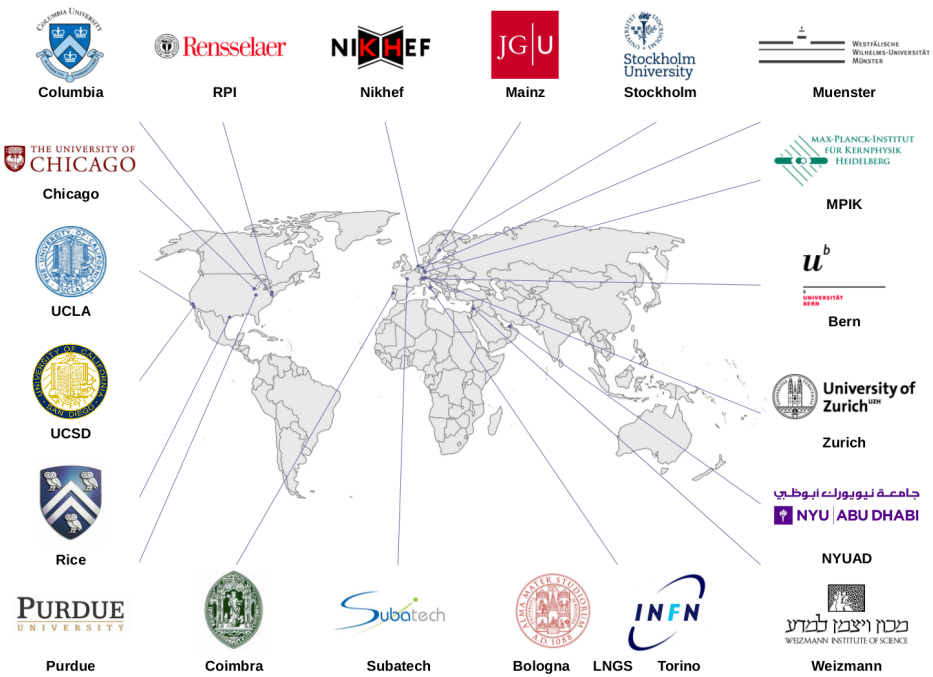
XENONnT

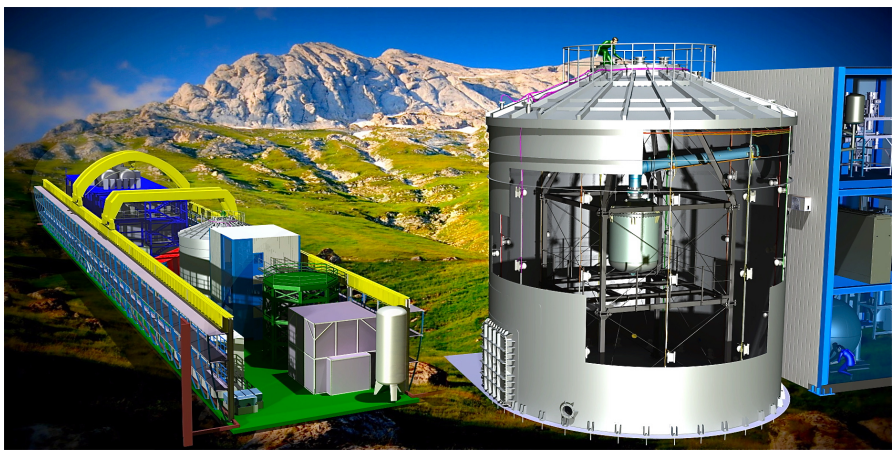
2018- ...

$\sigma_{SI} \simeq \times 10^{-48}$

XENON1T at Gran Sasso

- The XENON1T experiment is located at Gran Sasso National Laboratories (LNGS) in Italy.
- Rock overburden of 1.4 km (3600 m w.e., Muon reduction by $\sim 10^6$)
- 21 institutions with around 130 collaborators.
- Direct detection of dark matter in the form of WIMPs with a TPC via their elastic scattering off xenon nuclei.

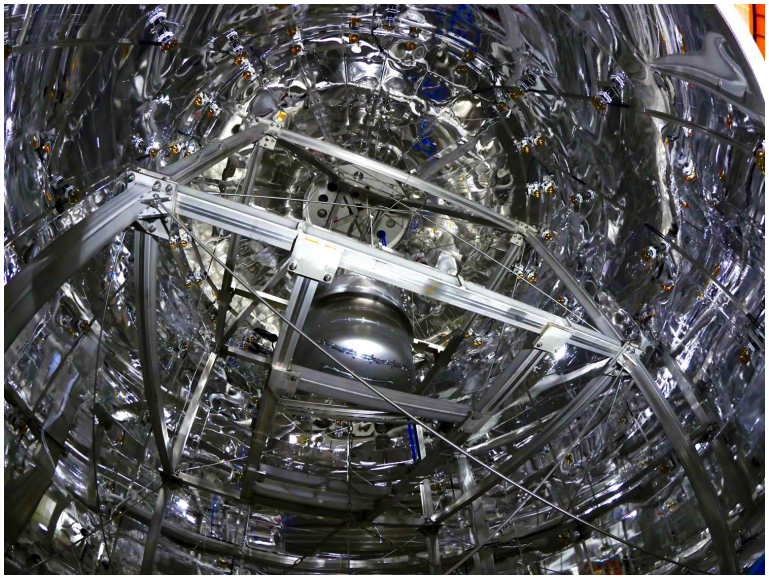


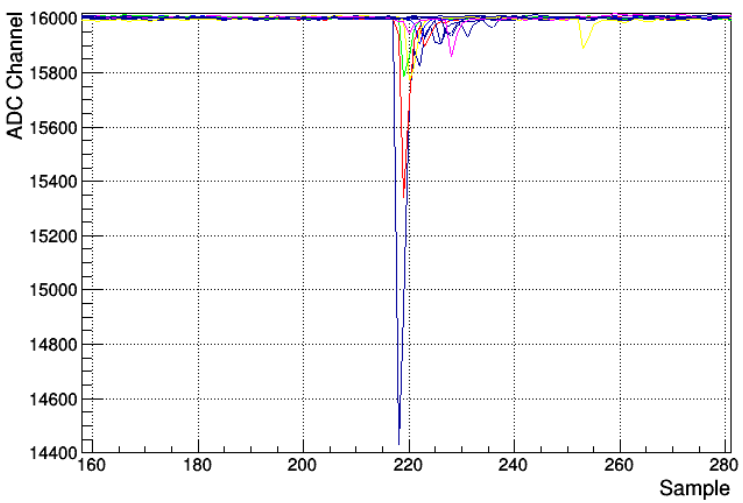


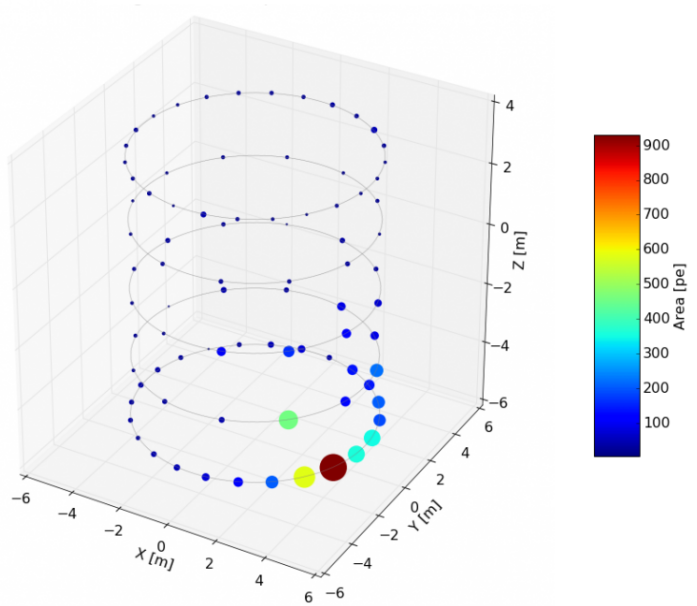
XENON1T Infrastructure

Active Water Cherenkov Muon Veto

- Water tank internally covered with reflector film, 700 m^3 DI water.
- 84 high QE PMTs (8", R5912ASSY).
- 99.78 % veto efficiency for muons and 71.4 % for induced shower from interactions inside the rock.
- Muon background $<$ 0.01 events/t.y in the WIMP search region.
- JINST 9(2014)11006 arXiv:1406.2374

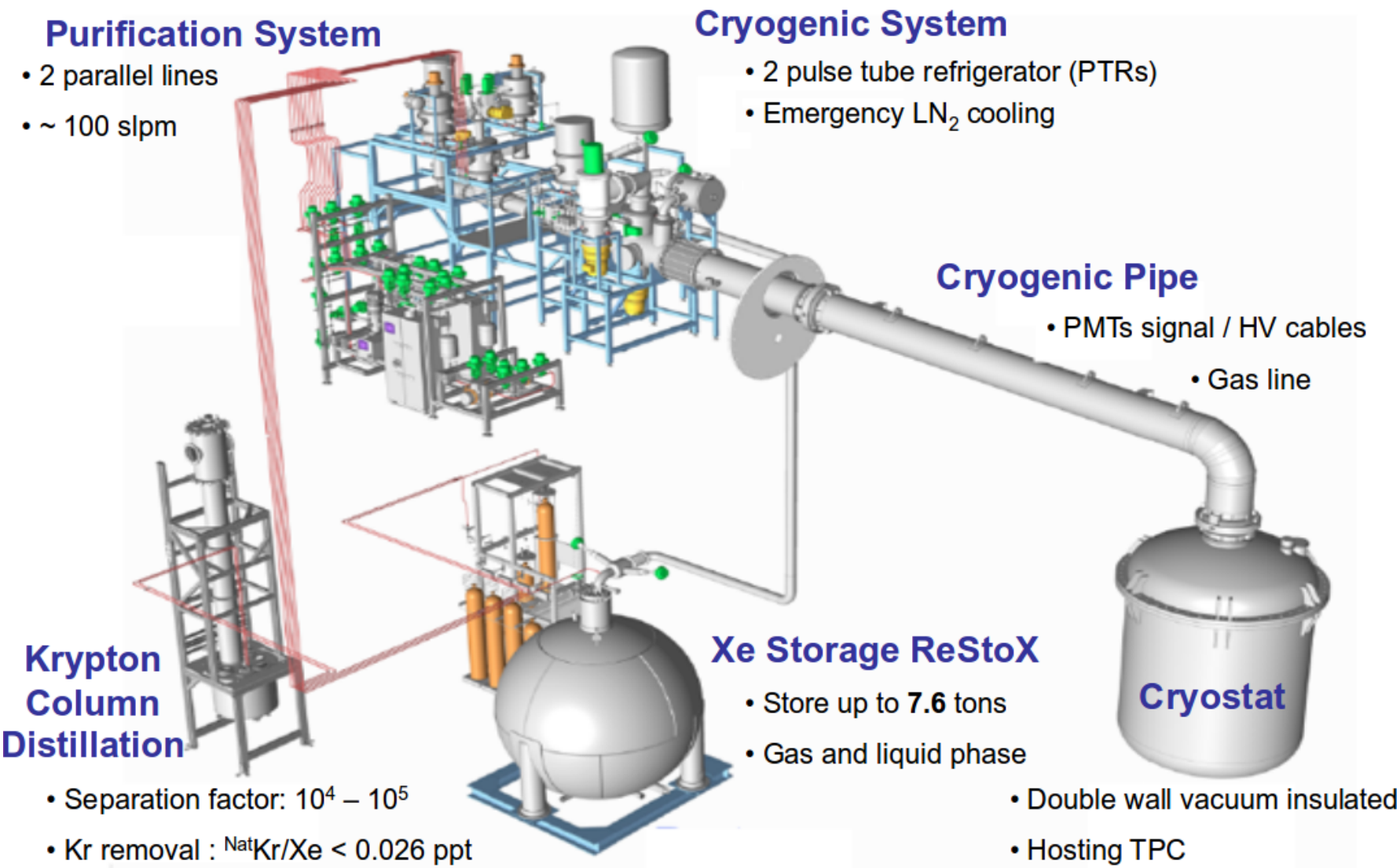






First Detected Muon!

Xe Cryogenics and Purification



Purification System

- 2 parallel lines
- ~ 100 slpm

Cryogenic System

- 2 pulse tube refrigerator (PTRs)
- 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

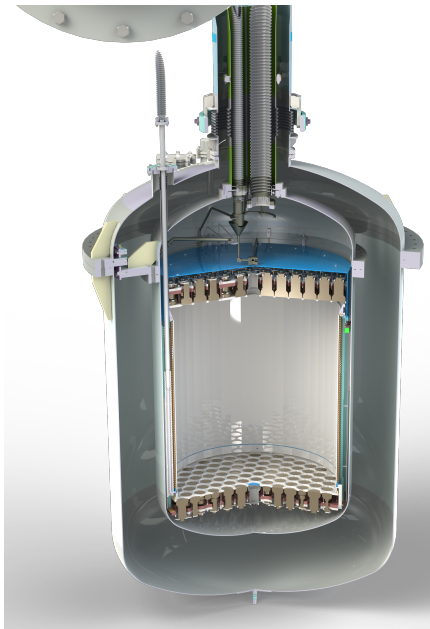
- Store up to **7.6** tons
- Gas and liquid phase

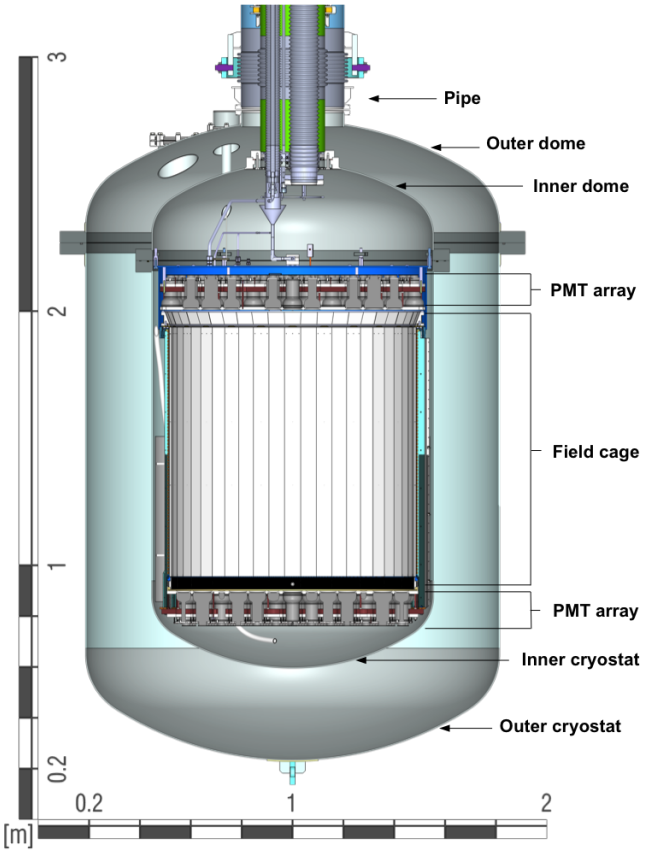
Cryostat

- Double wall vacuum insulated
- Hosting TPC

The XENON1T Time Projection Chamber (TPC)

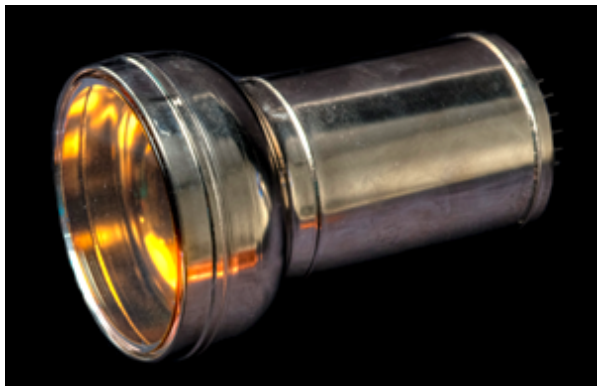
- Active mass 2 t LXe.
- High-reflectivity Teflon to optimize light collection.
- Drift field of order of $\mathcal{O}(1\ \mathrm{kV/cm})$. Extraction field of order $\mathcal{O}(10\ \mathrm{kV/cm})$ at liquid-gas interface (design).
- 74 copper field shaping rings and 2 resistor chains.

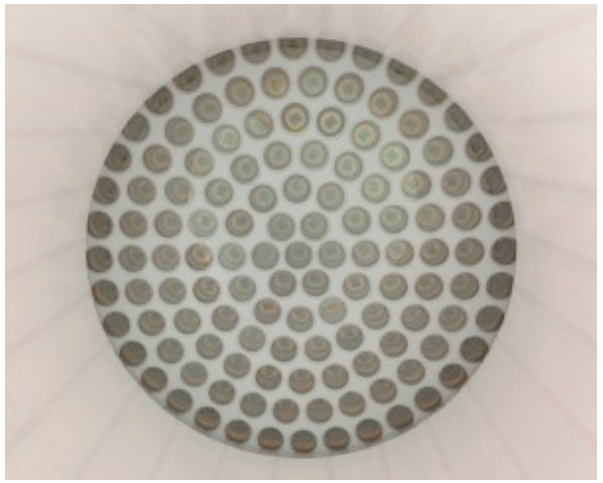


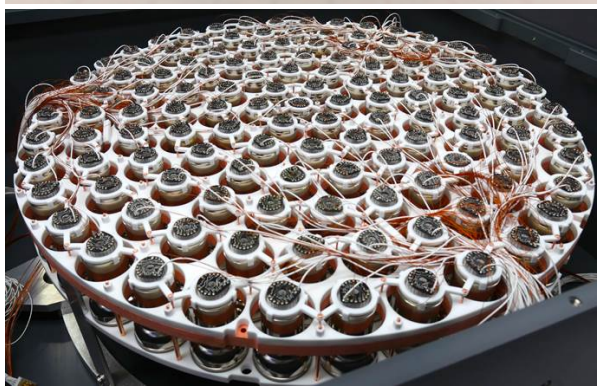


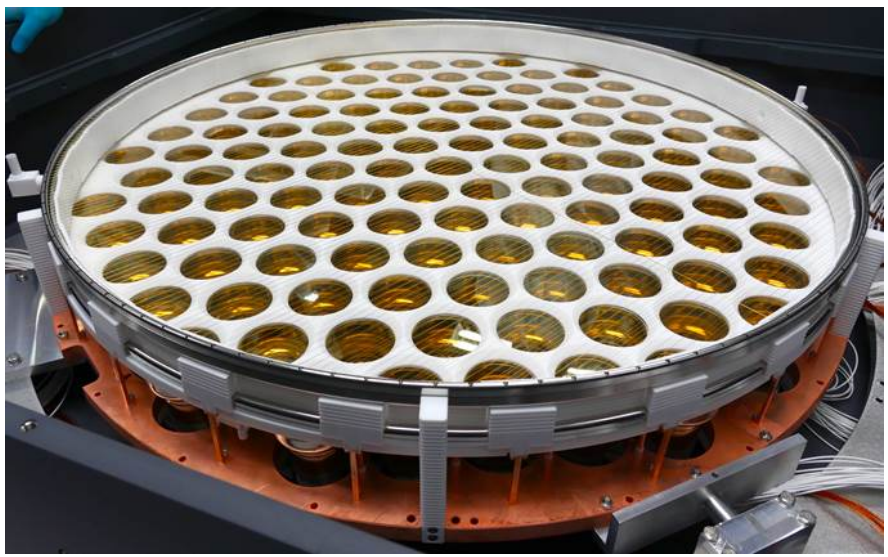
The Light Detectors Hamamatsu R11410-21

- Average gain $\simeq 5 \times 10^6$ at 1500 V and average QE $\simeq$34% for 175 nm.
- Dark Count $\simeq$ 40 Hz at LXe T.
- SPE resolution $\simeq$ 40%
- Reduced radioactivity in collaboration with Hamamatsu (Eur.Phys.J. C75 (2015) 11 or arXiv:1503.07698)
- 127 on top and 121 on bottom arrays.









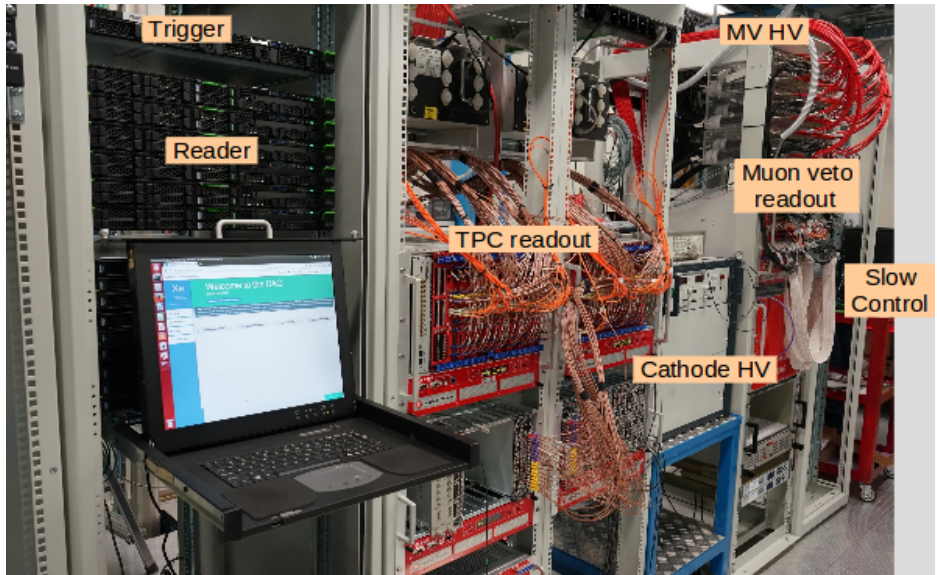
The Data Acquisition

Low threshold

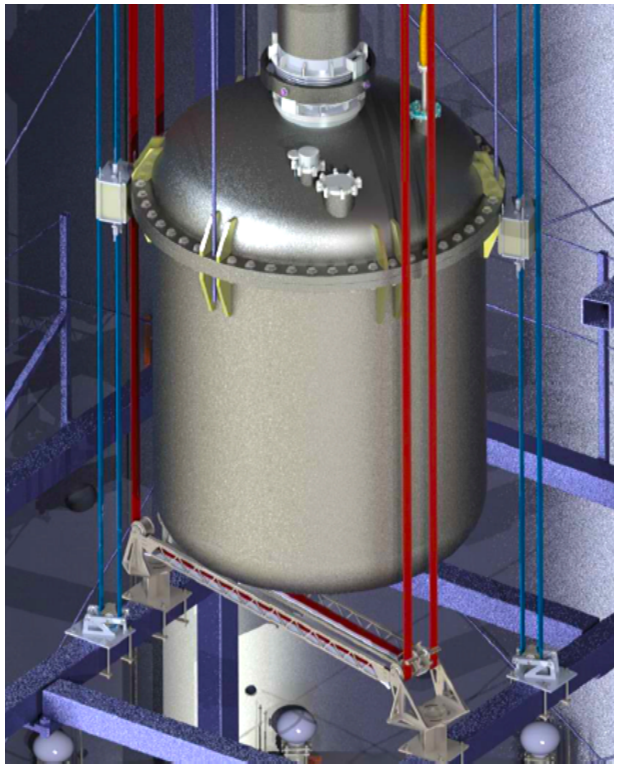
- Software trigger readout with threshold at 1/3 p.e independently.
- Software trigger uses a sharded MongoDB cluster to sort and build events.

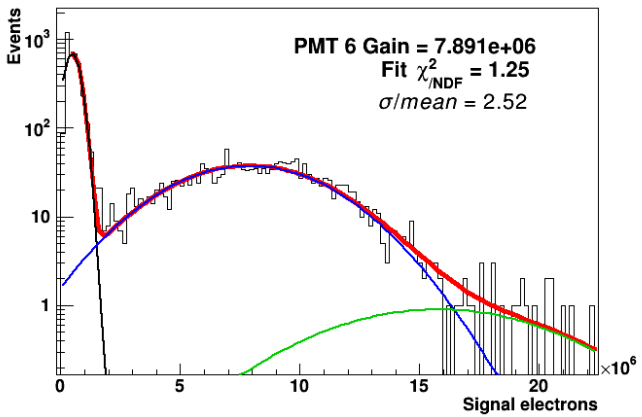
High rate

- Rates up to 300 MB/s (1kHz) allowing continuous readout for strong calibration sources. No deadtime in DM mode.
- HE veto module (Skutek DDC10) removes high energy events in calibration.



The Calibrations





External sources

Neutron generator: Mono energetic 2.45 MeV neutrons from D-D generator for nuclear recoil calibrations.

Gamma sources: To monitor xenon purity , position resolution (^{228}Th, ^{137}Cs).

Internal sources

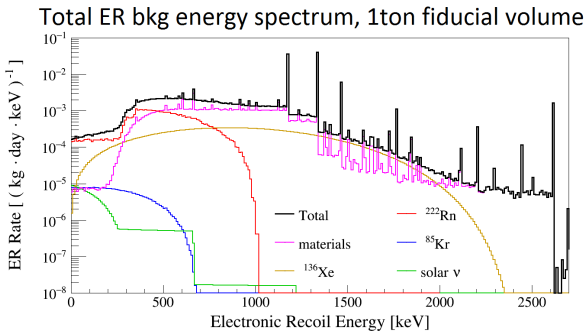
Short-lived radioactive isotopes mixed with xenon through the recirculation system for low energy electronic recoil calibrations (^{83m}Kr , ^{220}Rn and TCH_3).

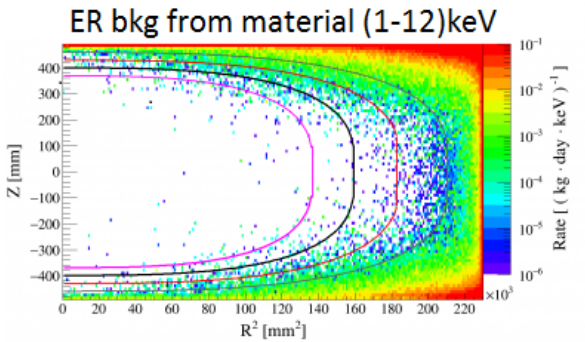
Light calibration

Required for regular monitoring response of the PMTs. Different optical fibers types are used to guide the light from LEDs (inside the control room) to the PMT arrays.

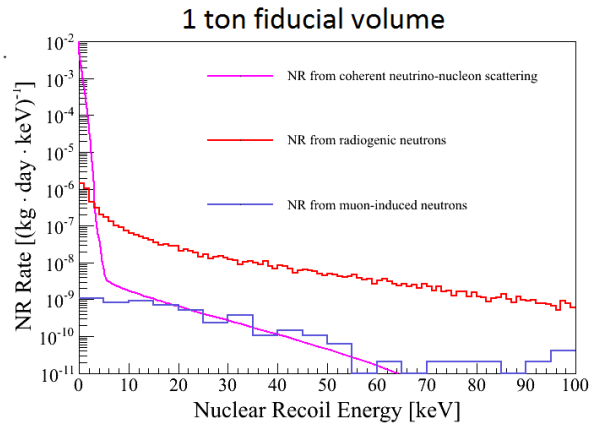
Expected Nuclear and Electronic Backgrounds

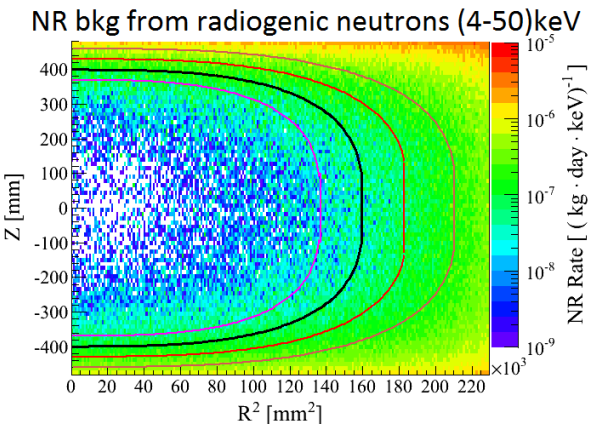
Expected Electron Recoil Backgrounds:





Expected Nuclear Recoil Backgrounds:



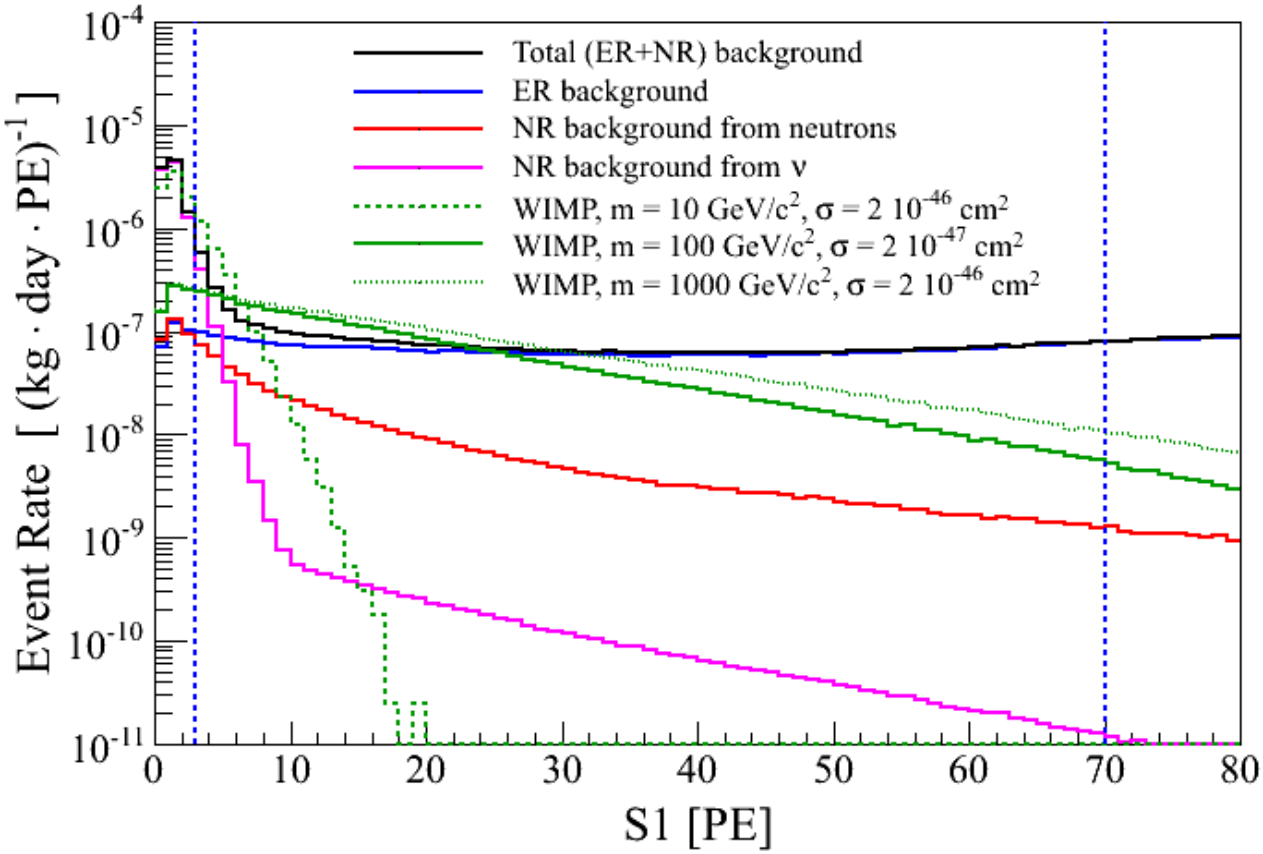


- Results from material screenings are used as input for MC.
- JCAP04(2016)027

Total background

$$\textit{Total ER} : (720 \pm 60)(t.y)^{-1}(1 - 12\,keV,\ 1.62(t.y)^{-1}\ \textit{after discrimination})$$

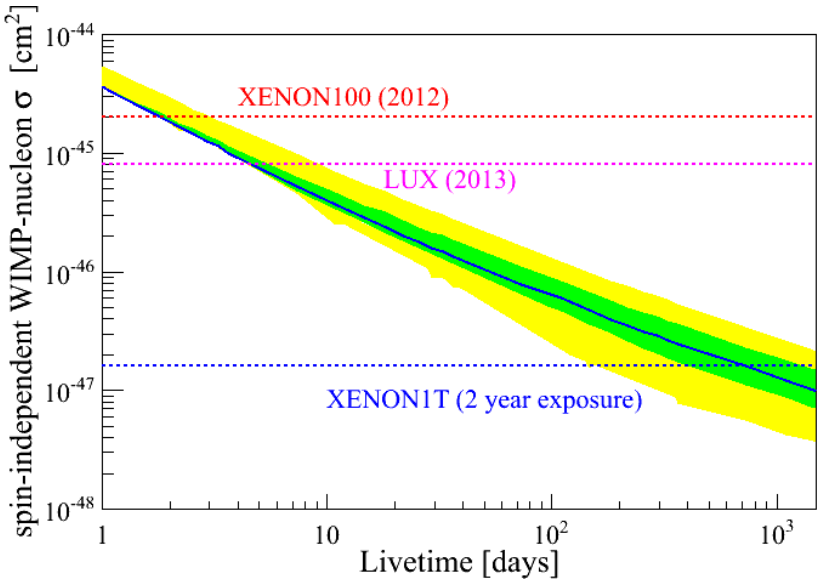
$$\textit{Total NR} : (0.62 \pm 0.12)(t.y)^{-1}(4 - 50\,keV,\ 0.46(t.y)^{-1}\ \textit{after discrimination})$$

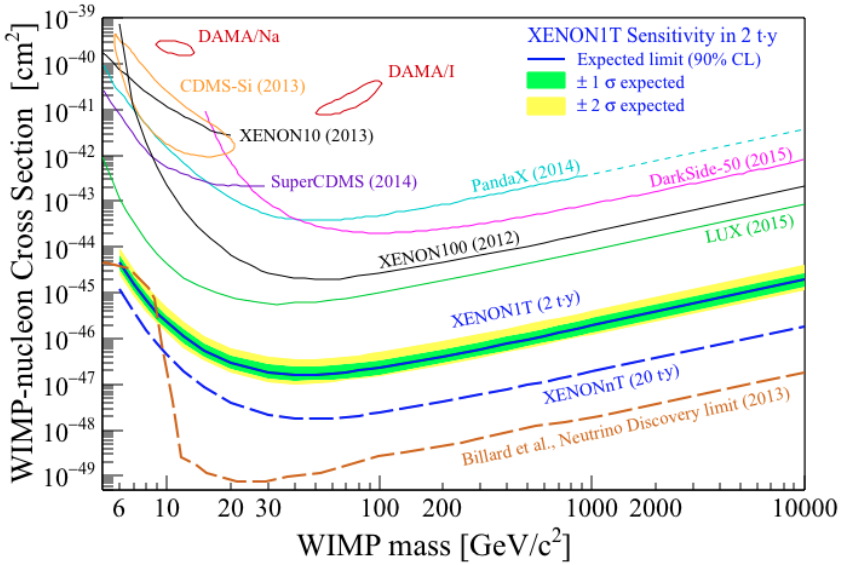


Source	Bgd (ev/y)
ER from materials	~0.07
^{222}Rn (10μBq/kg)	~1.39
^{85}Kr (0.2 ppt of ^{NAT}Kr)	~0.07
^{136}Xe 2v2β	~0.02
Solar neutrinos	~0.08
Total ER	~1.62
Total NR	~0.46

Single scatter, 1t FV, [2,12]keVee, [4,50]keVr, 99.75% S2/S1 discrimination, 40% NR acceptance

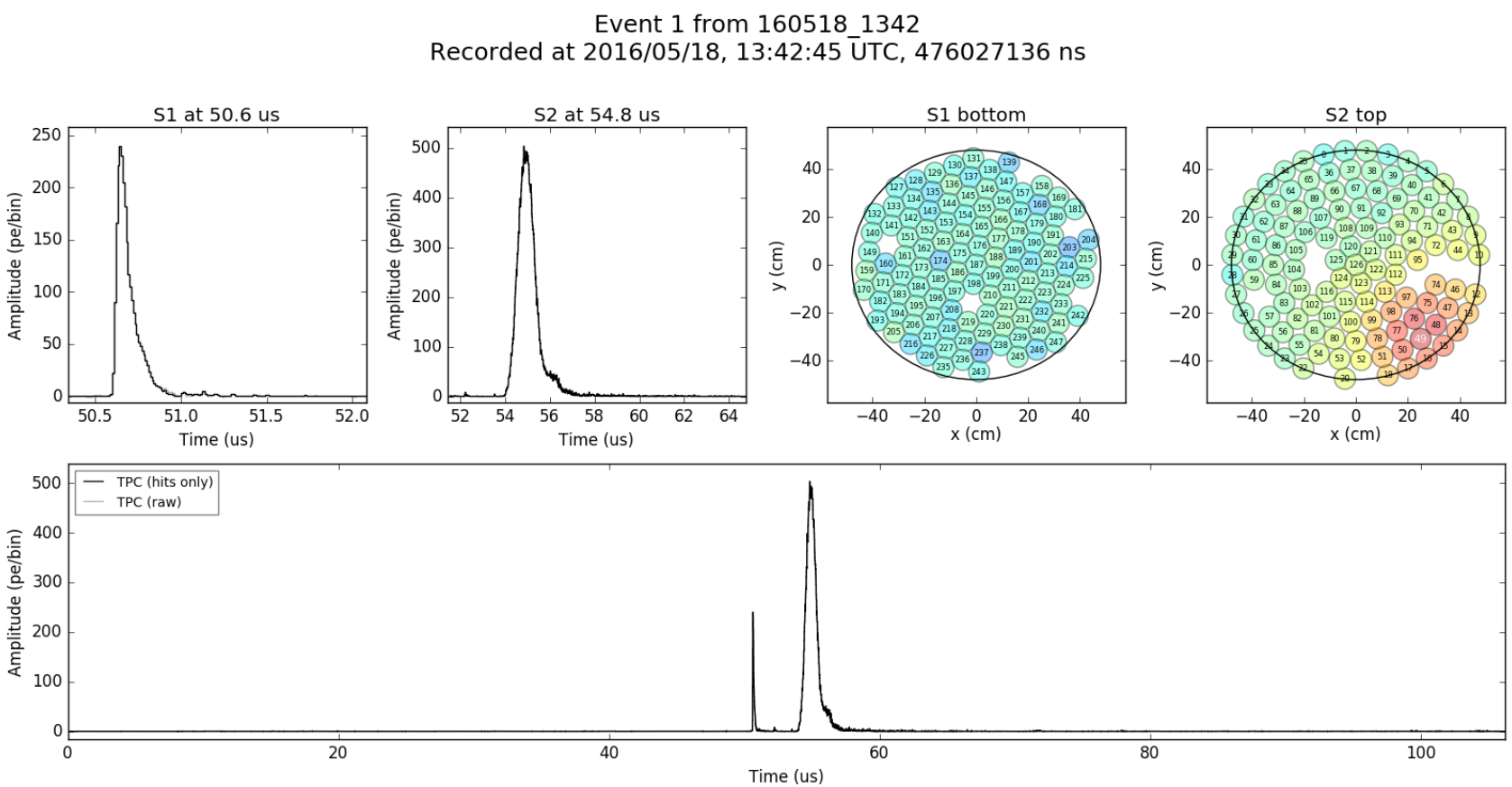
Projected Sensitivity





- Expected to overcome presently world-leading limits just within 10 days of data taking in dark matter mode.
- Expected to reach with a 2 t·y exposure a sensitivity to spin-independent WIMP-nucleon interactions of $1.6 \cdot 10^{-47}$ cm^2 for a 50 GeV/c^2 (99.75% ER rejection, 40% NR acceptance and 1t fiducial volume)

Commissioning Status



- Both light (S1) and charge (S2) are being detected from a 2 tons dual phase Xe TPC!
- The total mass of 3.2 t of LXe is being continuously purified to reach the desired charge yield at the applied field.

Summary and Outlook

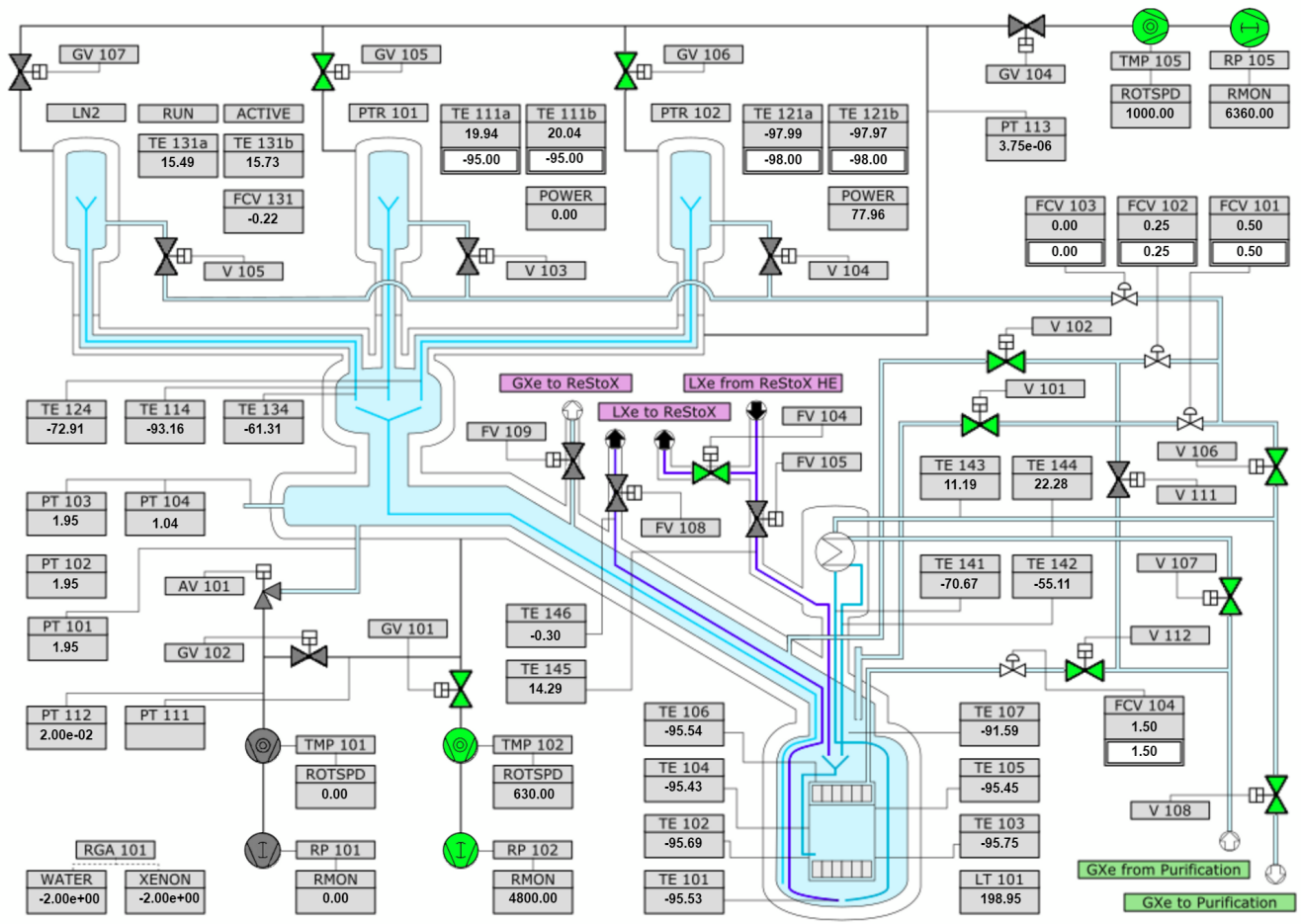
- XENON1T has been successfully constructed at Laboratori Nazionali del Gran Sasso and will be the most sensitive WIMP detector in the world for WIMP masses above few GeV.
- The commissioning of several subsystems are ongoing.
- The TPC is working and the LXe purification is ongoing, in order to increase the electron lifetime.
- The calibration of the detector has started (PMT gain calibration, position calibration, Light Yield Measurements, etc).
- Water filling has started.
- First science run expected by this fall
- Working on the upgrade to XENONnT, which will be an order of magnitude better than XENON1T.

Thank you for your attention !

Backup Slides

Slow Control System

- Safety of Xenon experiment is crucial.
- Distributed local controllers per subsystem; central monitoring, secure remote control, and history database.
- Based on industrial process control hardware and software.



Restox (recovery and storage of xenon)

- Stores up to 7.6 tonnes of xenon both in liquid (cooled with LN2) and gaseous form (room temperature).
- Double-wall , vacuum insulated sphere of 2.1 m radius rated to 72 bar.
- LXe recovery of the detector within few hours in emergency.

Distillation column

Distillation column

- XENON1T requires < 0.2 ppt of ^{Nat}Kr/Xe (1ppb-1ppm for ^{Nat}Xe).
- Measured separation factor of 1.2×10^5 with Kr enriched xenon and achieved 0.026 ppt.
- S. Rosendahl et al., JINST 9 (2014) P10010

Purification system

- Continuous GXe recirculation up to 100 slpm.
- Uses high-flow heated getters