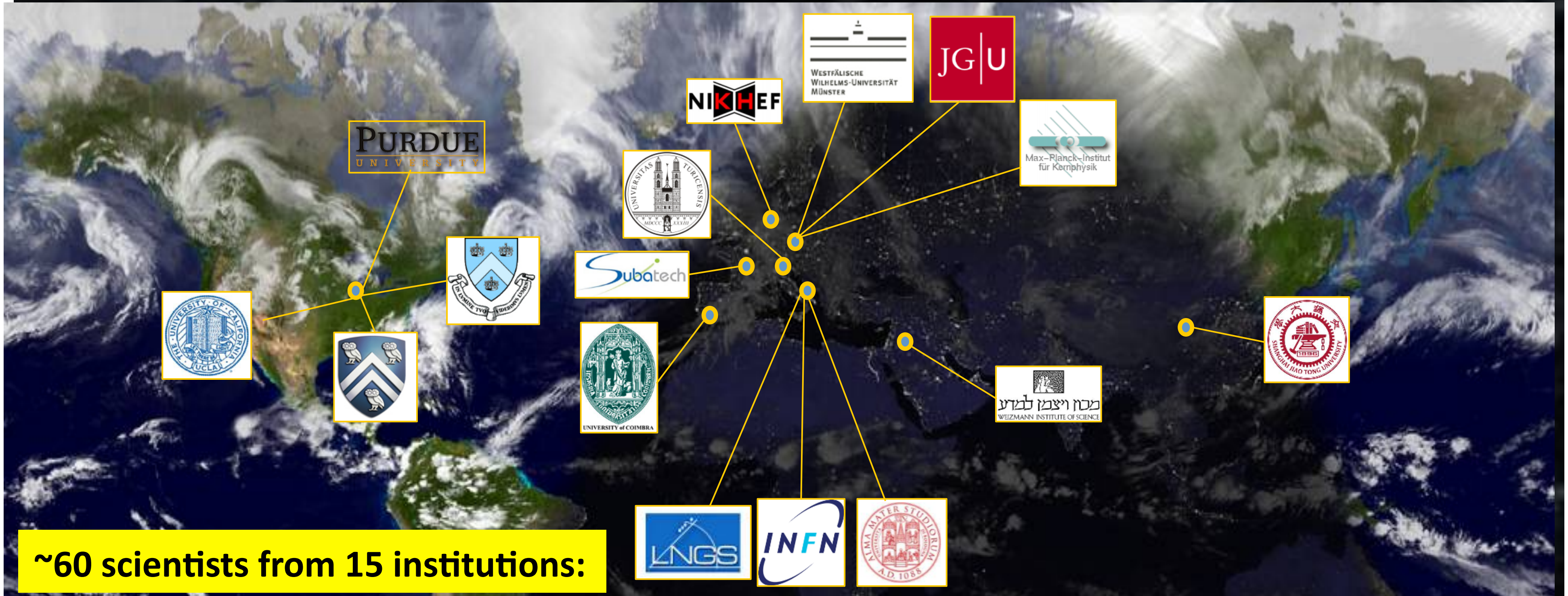
Results from the XENON100 experiment

Rino Persiani, University & INFN Bologna
on behalf of the XENON collaboration

Vulcano Workshop, May 28, 2012

XENON collaboration institutes



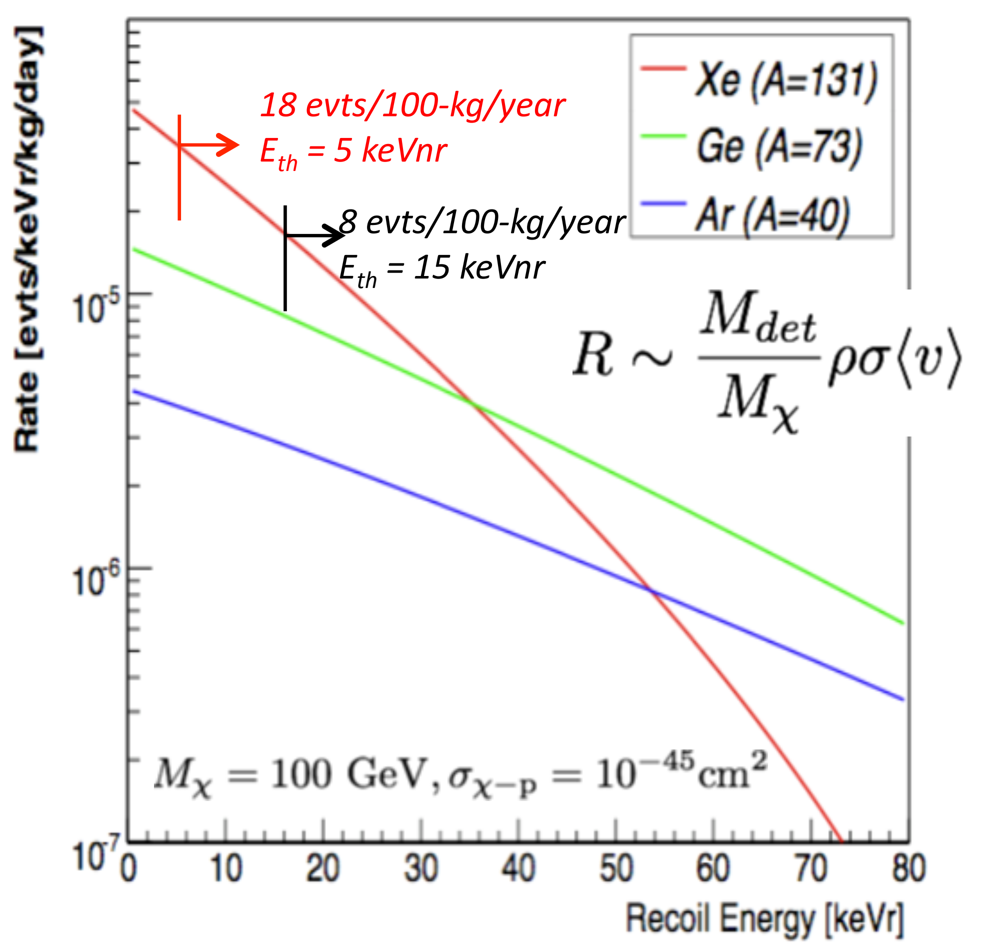
~60 scientists from 15 institutions:

University of California Los Angeles
Rice University Houston
Purdue University
Columbia University of New York
Universidade de Coimbra
Subatech Nantes
NIKHEF Amsterdam
Willhelms Univesitat Munster

J.Gutenberg – Universitat Mainz
Max-Plank-Institut Heidelberg
Universitat Zurich
Laboratori Nazionali del Gran Sasso
Università e INFN Bologna
Weizman Institute Rehovot
Jiao Tong University Shanghai

Xenon intrinsic properties

- Self shielding: high Z=54 and high density ρ=2.8 kg/l
- Scalability: possibility to build compact detectors scalable to larger dimensions
- Odd-nucleon isotopes: high A=131 with ~50% of odd isotopes. Sensitive to both Spin Dependent and Spin Independent
- Intrinsically pure: no long lived Xe isotopes and ^{85}Kr removed to ppt
- Charge & light: highest yield among the noble liquids
- "Easy" cryogenics: -100 °C

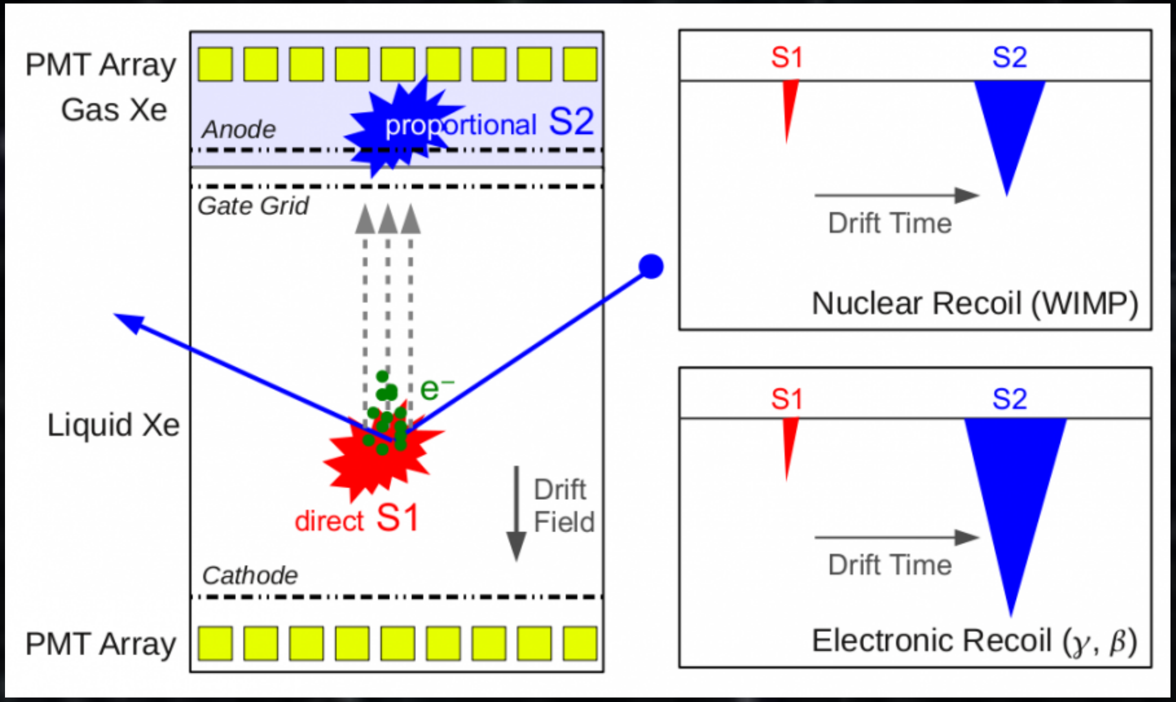


$$R \sim \frac{M_{det}}{M_\chi} \rho \sigma \langle v \rangle$$

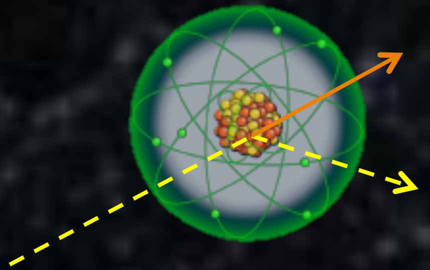
2-phase Xe TPC

- Electron/Nuclear recoils discrimination
- 3D position sensitivity (fiducialization volume)

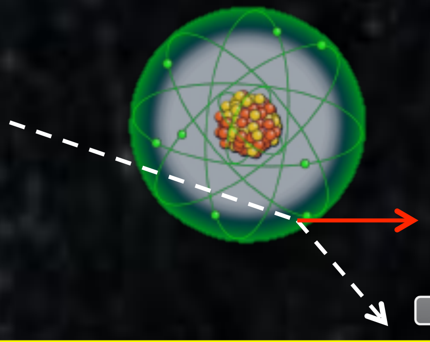
Background reduction



n/WIMPs: nuclear recoils

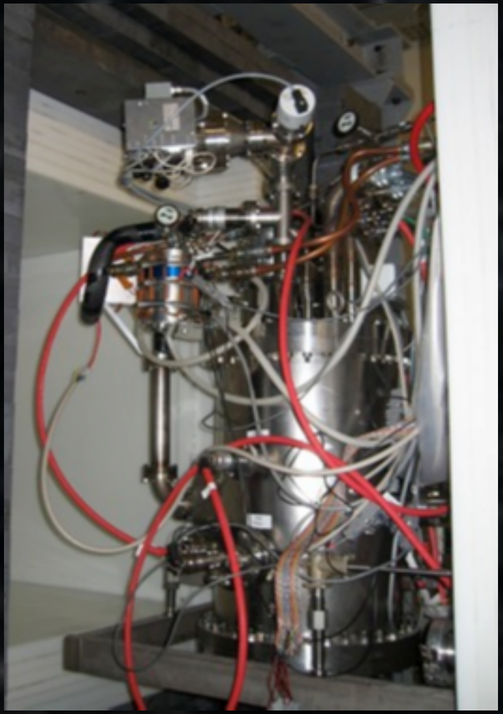


e⁻/γ: electron recoils



The XENON program

PAST (2005-2007)



XENON10

(2007) σ_{SI} = 8.8 x 10^{-44} cm^2

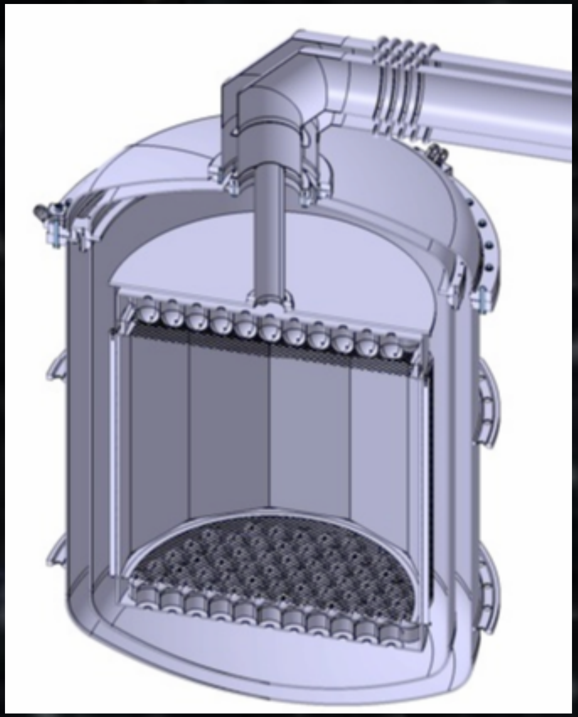
PRESENT (2008-2012)

XENON100

(2011) σ_{SI} = 7 x 10^{-45} cm^2

Proj. (2012) σ_{SI} = 2 x 10^{-45} cm^2

FUTURE (2011-2017)

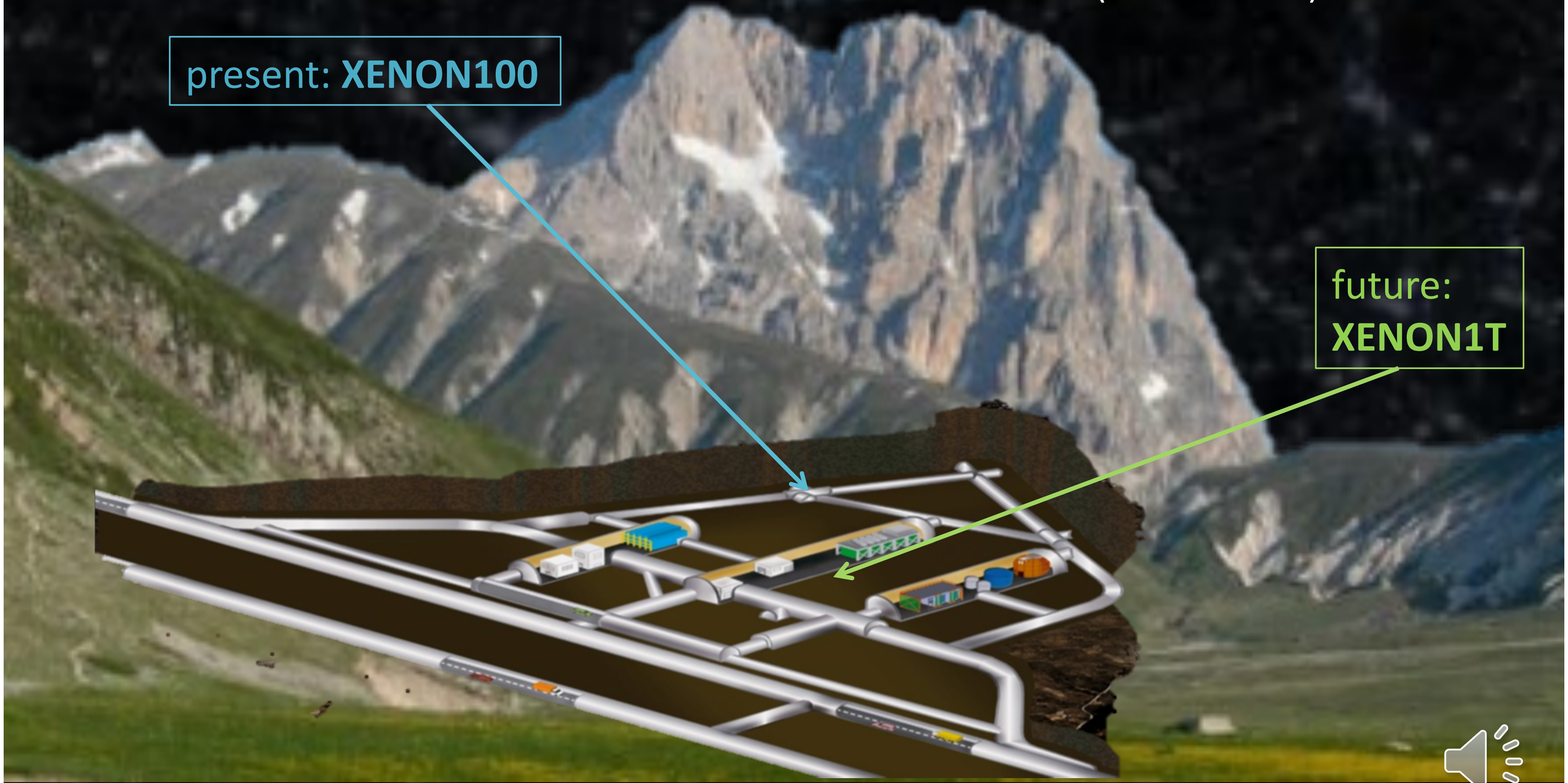


XENON1T

Proj. (2017) σ_{SI} = 2 x 10^{-47} cm^2

XENON @ LNGS

under 1400 meters of rock
(3400 m w. e.)

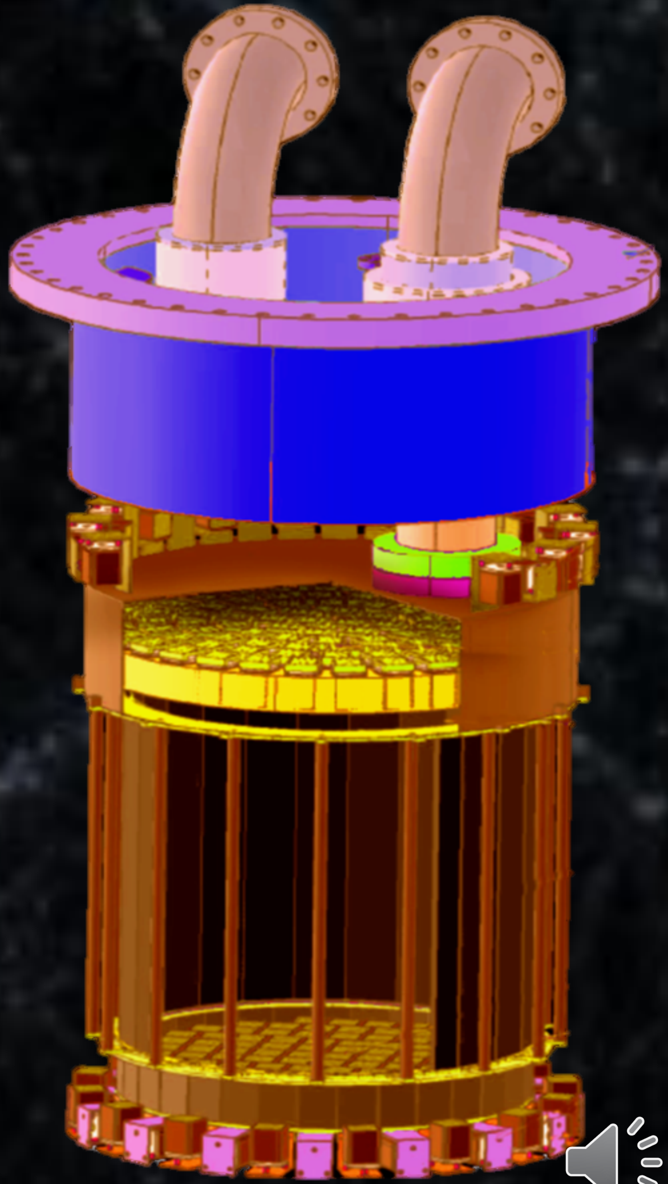


present: **XENON100**

future:
XENON1T

The XENON100 phase

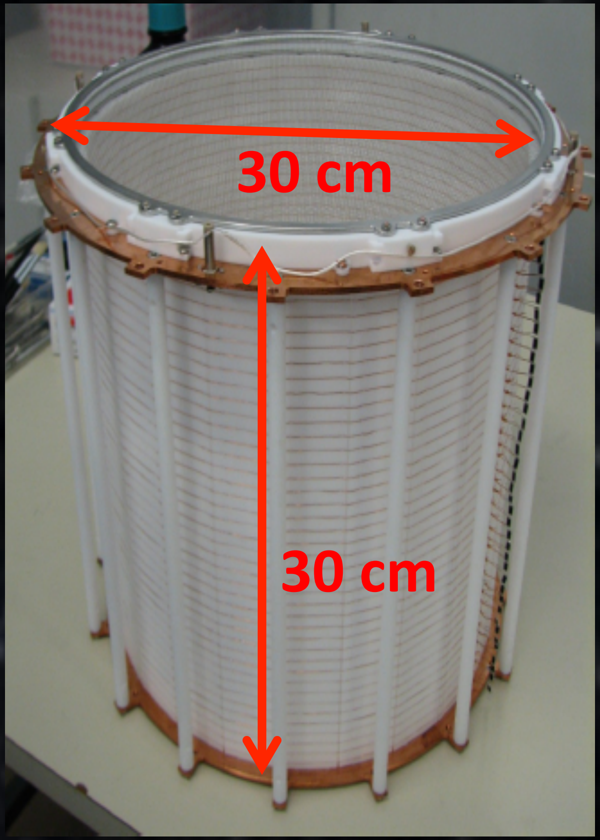
- 100x less background than XENON10
- 10x more fiducial mass than XENON10
- Cryocooler and FTs outside the shield
- Materials screened for low radioactivity
- LXe scintillator active veto
- Improved passive shield system
- Dedicated Kr Distillation Column
- 162 kg of ultra pure LXe



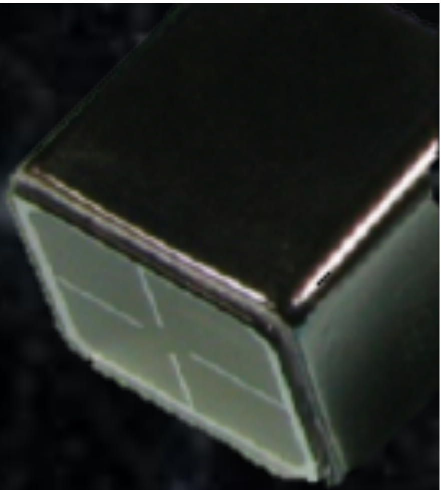
XENON100 TPC

- The TPC is made of 24 PTFE interlocking panels
- The PTFE has a high reflectivity for xenon wavelenght to increase the light collection
- The TPC can host 62 kg of LXe

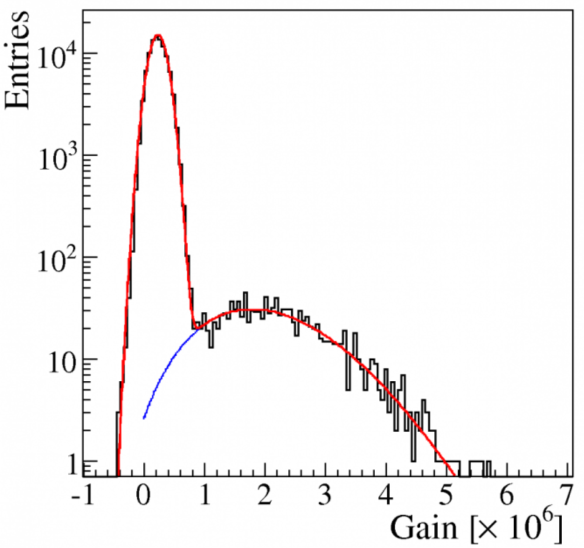
- The cathode near the bottom is set at -16 kV
- The field is homogeneous through field shaping rings equally spaced in the TPC at different voltages
- A ground mesh is placed just few mm below the liquid level to close the drifting field
- An anode mesh, placed on the top of the TPC few mm above the LXe, provide a higher electric field region to extract the drifted electrons and produce proportional scintillation light (S2)

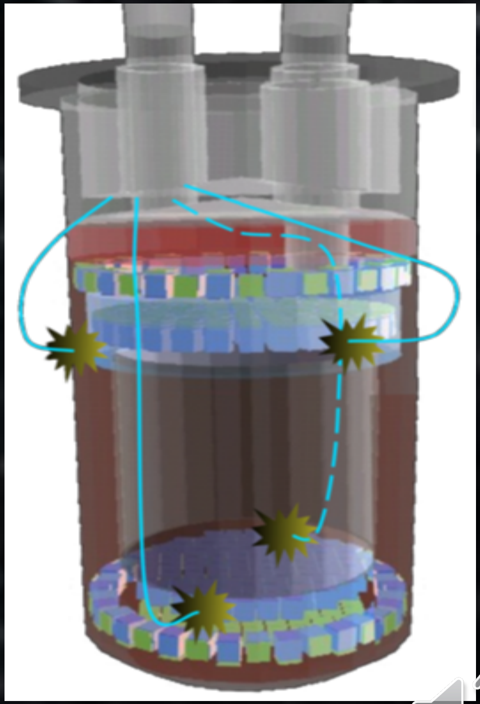


XENON100 PMTs

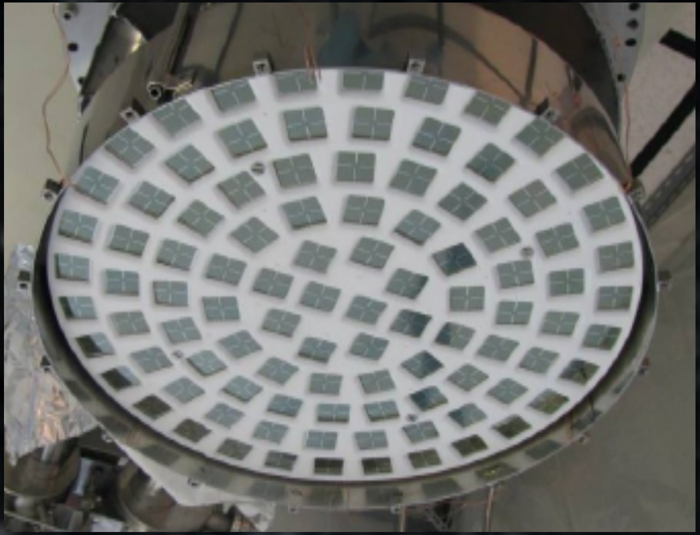


- 1’’ square metal-channel Hamamatsu R8520-06-A1
- Optimized for 178 nm, low temperature (-110 °C) and high pressure (up to 6 bar)
- Low radioactivity < 1 mBq in $^{238}U/^{232}Th$ per PMT
- 242 PMT overall
    - 98 in the top array
    - 80 in the bottom array
    - 64 in Lxe veto looking up, down and inward
- Regular gain monitoring





XENON100 PMTs array



The top PMT array is composed of 98 PMTs

They are kept in Xe gas using a bell system

The radial distribution is optimized to reconstruct the position of the interaction with good spatial resolution (using the PMT pattern distribution of the S2 signal)

The bottomPMT array is made of 80 PMTs

They are selected especially for high QE (to detect small S1 signals)

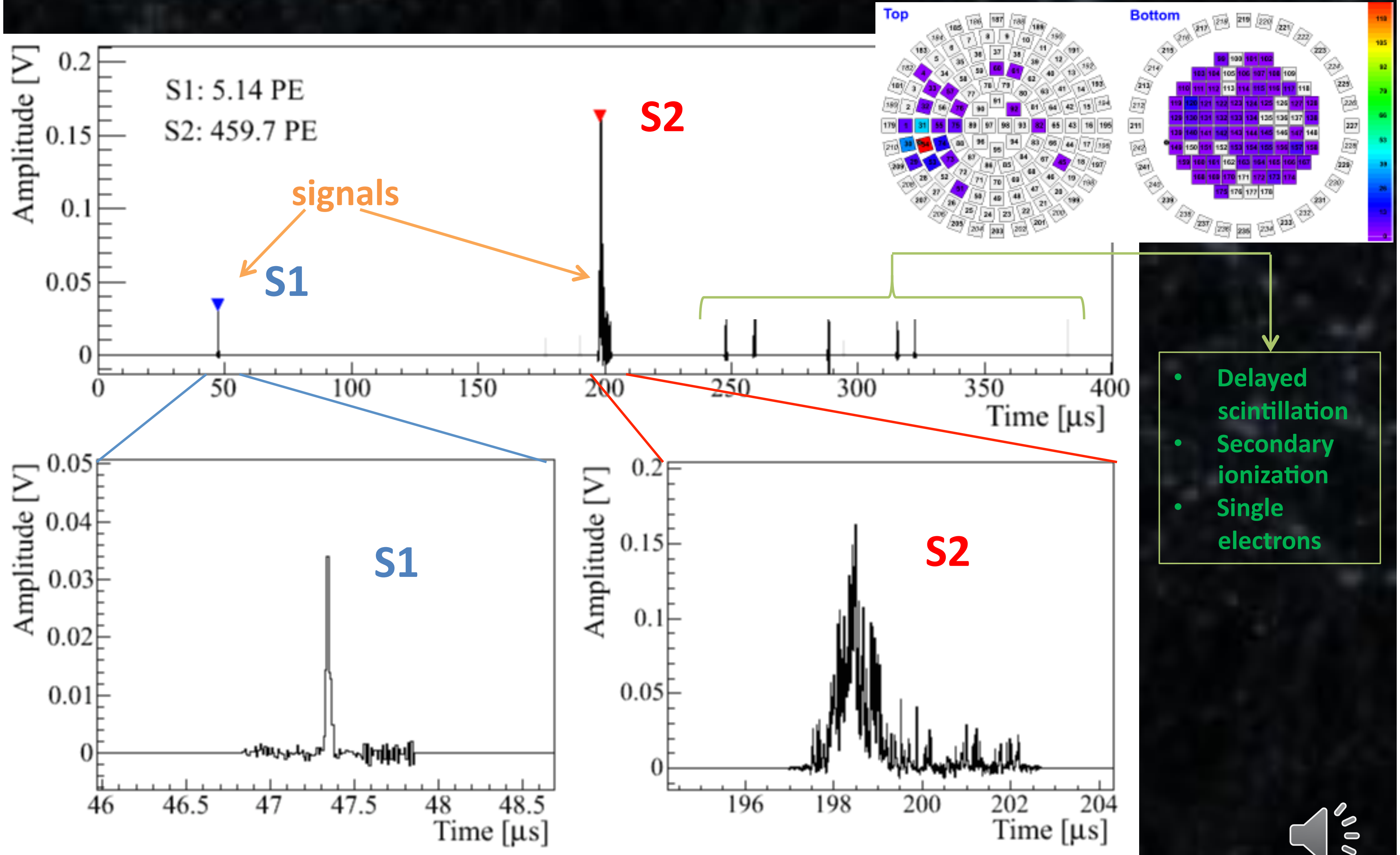
Highly packed to maximize the amount of light detected

XENON100 Shield

4 layers of different materials:

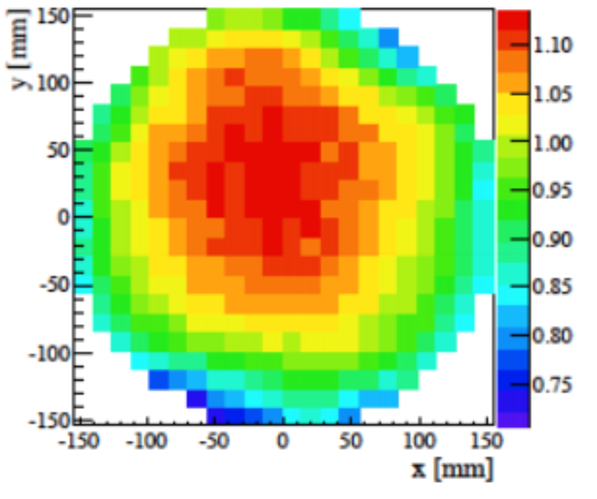
- 20 cm of **water & polyethylene** (to stop neutrons from rock)
- 20 cm of **lead** (to stop gammas from radioactivity from the rock). 15 cm of standard lead in the external part and 5 cm of low activity lead
- 20 cm of **polyethylene** (to stop neutrons from outside and lead)
- 5 cm of **copper** (to stop gammas from the polyethylene)

What do we get from the detector



- Delayed scintillation
- Secondary ionization
- Single electrons

Position dependent signal corrections

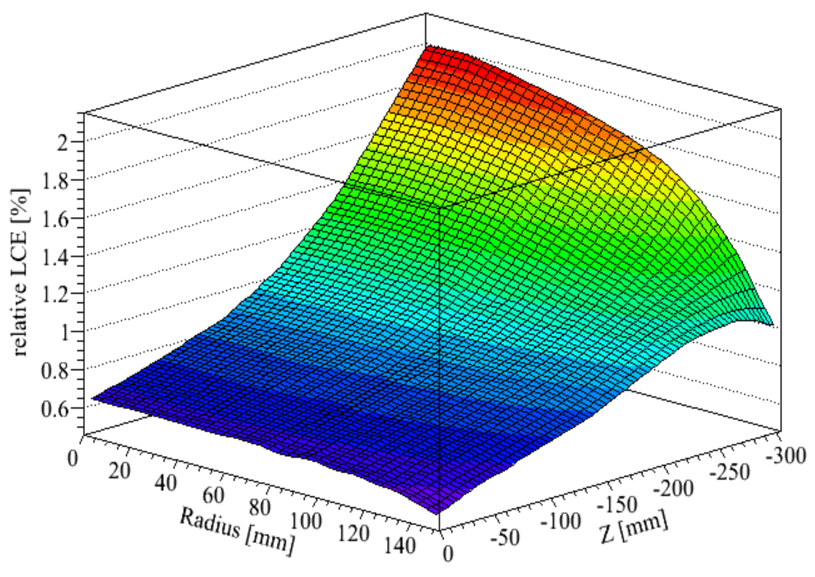


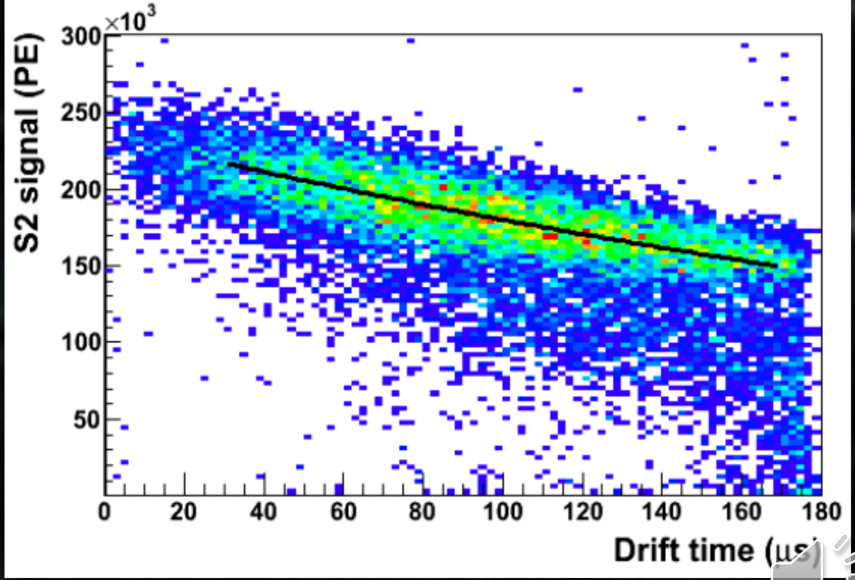
S1 collection efficiency: a factor of 3 difference from bottom to top

S2 dependence on x-y: depends on the levelling of the TPC

S2 dependence on Z: depends on the impurity in the LXe

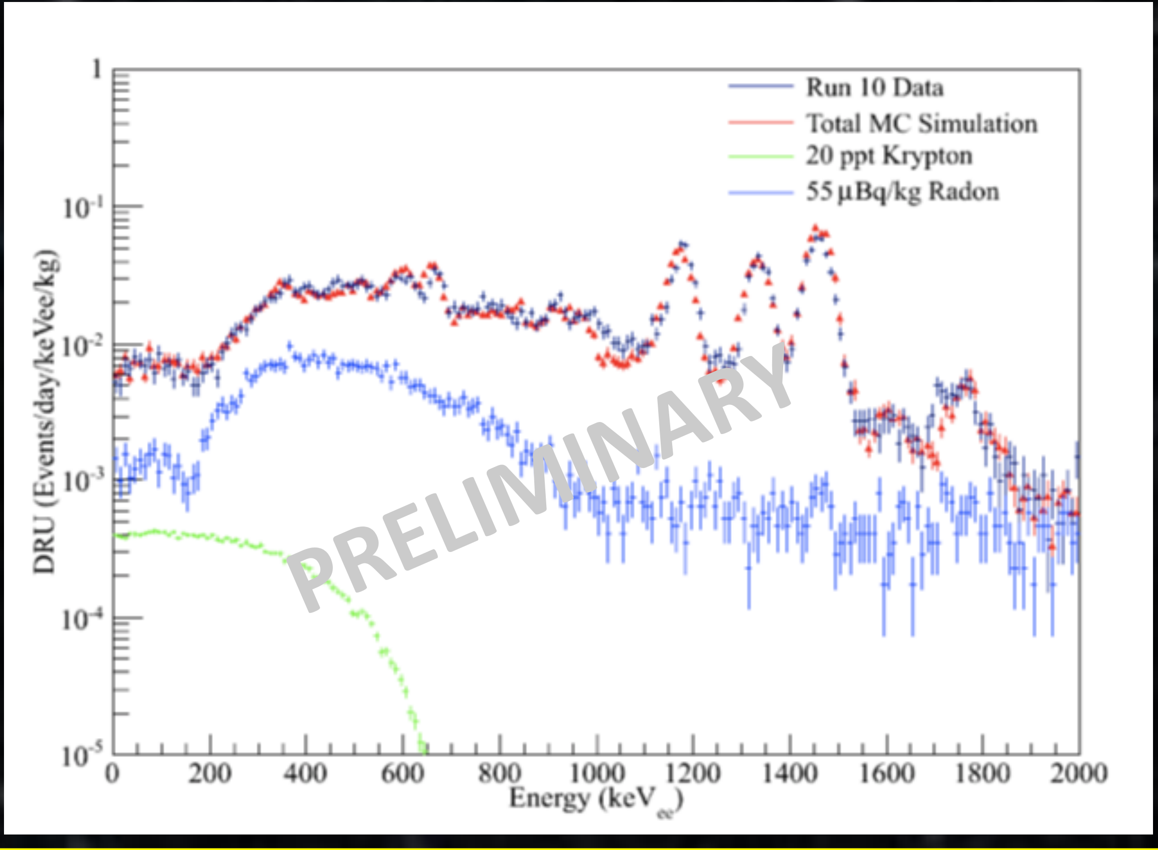
(E. Aprile *et al.*, Astropart. Phys. 35, 573-590 (2012): arXiv 1107.2155)



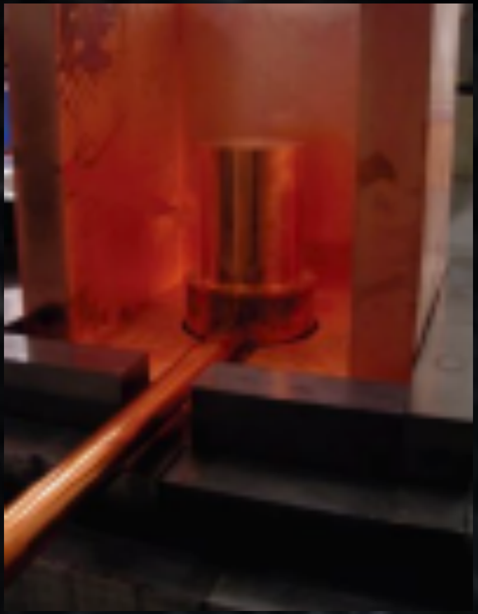


XENON100 background

- Monte Carlo simulations of XENON100 EM background in very good agreement with measured data
- Background is well understood in the full energy range



XENON100 material screening



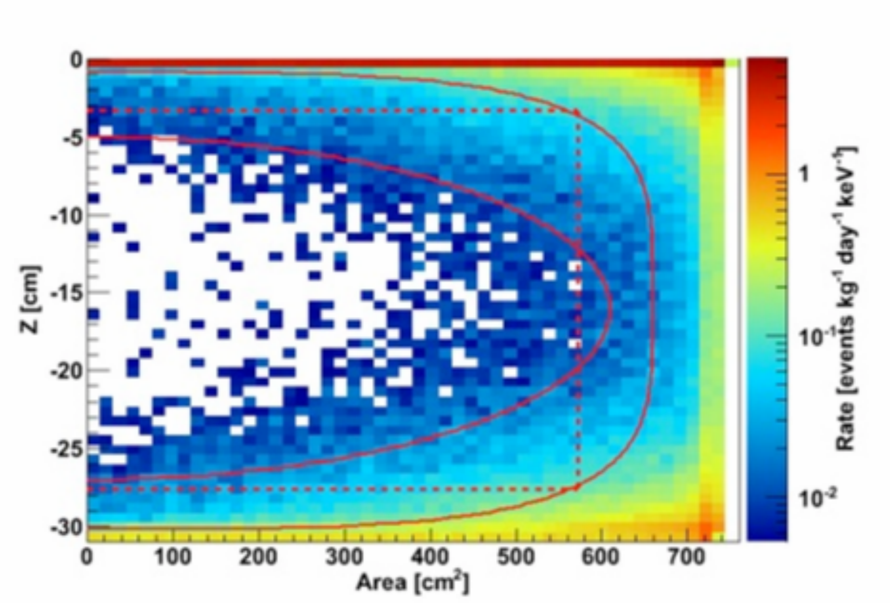
Material screening underground with a dedicated
2.2 kg HPGe detector at LNGS
(L.Baudis *et al*., arXiv:1103.2125)

All XENON100 construction materials were screened and selected
(E.Aprile *et al*., Astropart. Phys. 35:43-49 (2011), arXiv:1103.5831)

The gamma background from materials in the region of interest came mainly from PMTs and the detector vessel

XENON100 background reduction

Fiducial Volume cuts are optimized on Monte Carlo prediction for high rejection efficiency and high target mass



3D position information:

- S2 hit pattern: $\Delta r < 3$ mm
- Drift time: $\Delta z < 2$ mm

The background in the 30 kg fiducial volume in the WIMP-search energy region is ~10 mdru even before applying the LXe veto cut

The LXe veto with 100 keVee average threshold reduces the background rate down to the level of ~5 mdru, where ^{85}Kr in LXe starts to dominate
(E.Aprile *et al*., Phys. Rev. D 83, 082001 (2011), arXiv:1101.3866)

XENON100 ^{85}Kr

Traces of the radioactive ^{85}Kr in Xe gas is an irriducible background in XENON100: it's uniformly distributed in LXe

^{85}Kr decays beta with an end point of 687 keV and τ ~11y

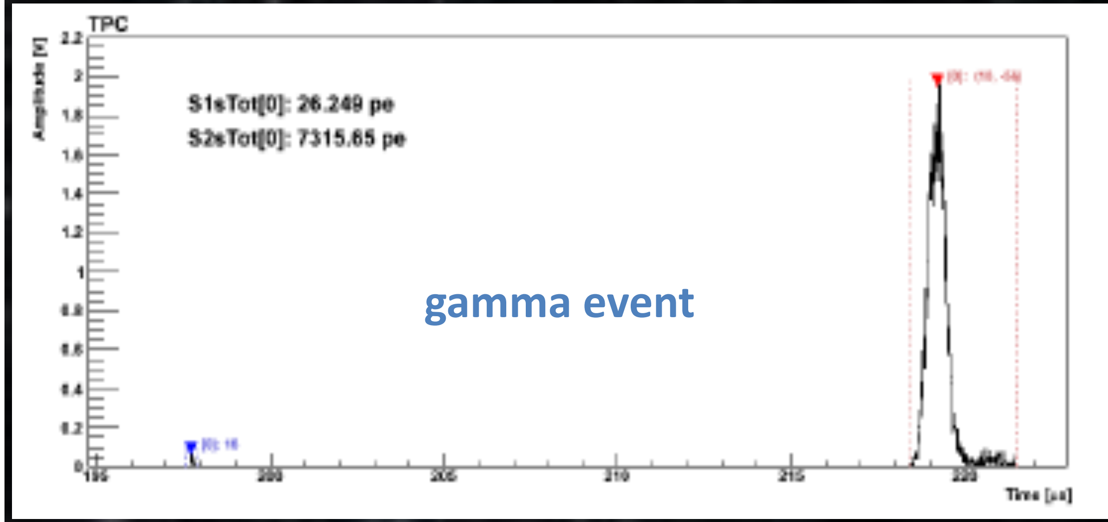
^{85}Kr/Kr ~ 2×10^{-11}

Xe gas with a Kr/Xe concentration of 10^{-8} is commercially available

To reduce the concentration of Kr in Xe we use a dedicated cryogenics distillation column

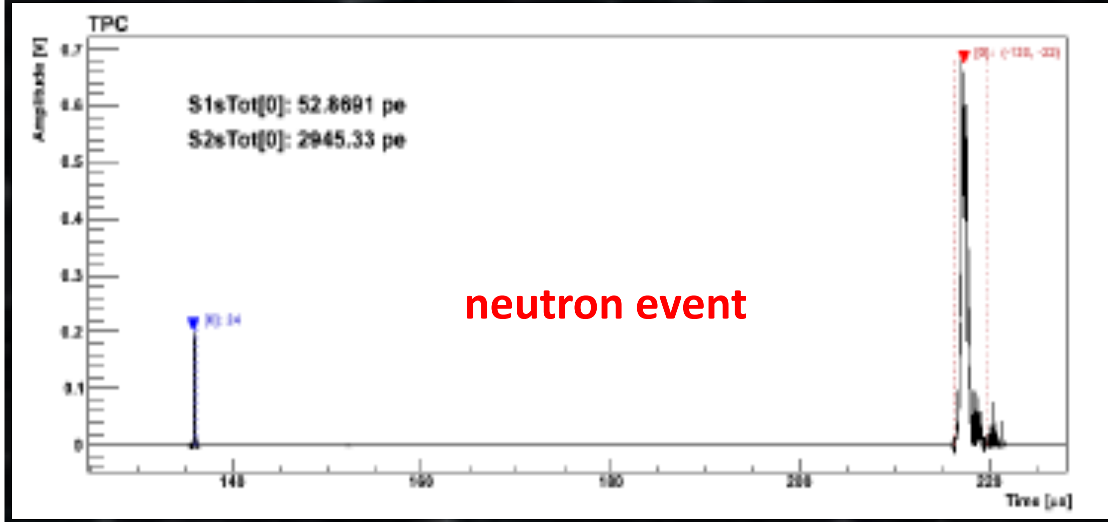
The column was designed to give a reduction of 10^3

Neutron/gamma discrimination



S1sTot[0]: 26.249 pe
S2sTot[0]: 7315.65 pe

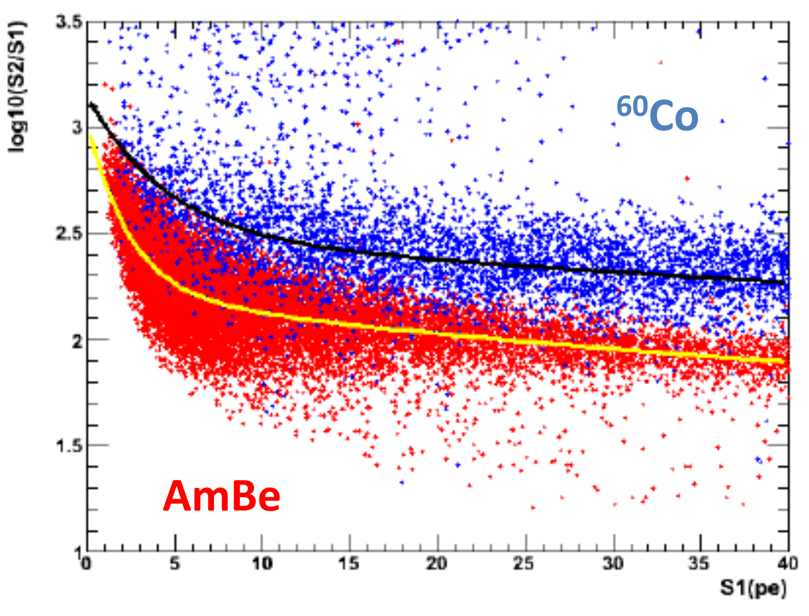
gamma event



S1sTot[0]: 52.8691 pe
S2sTot[0]: 2945.33 pe

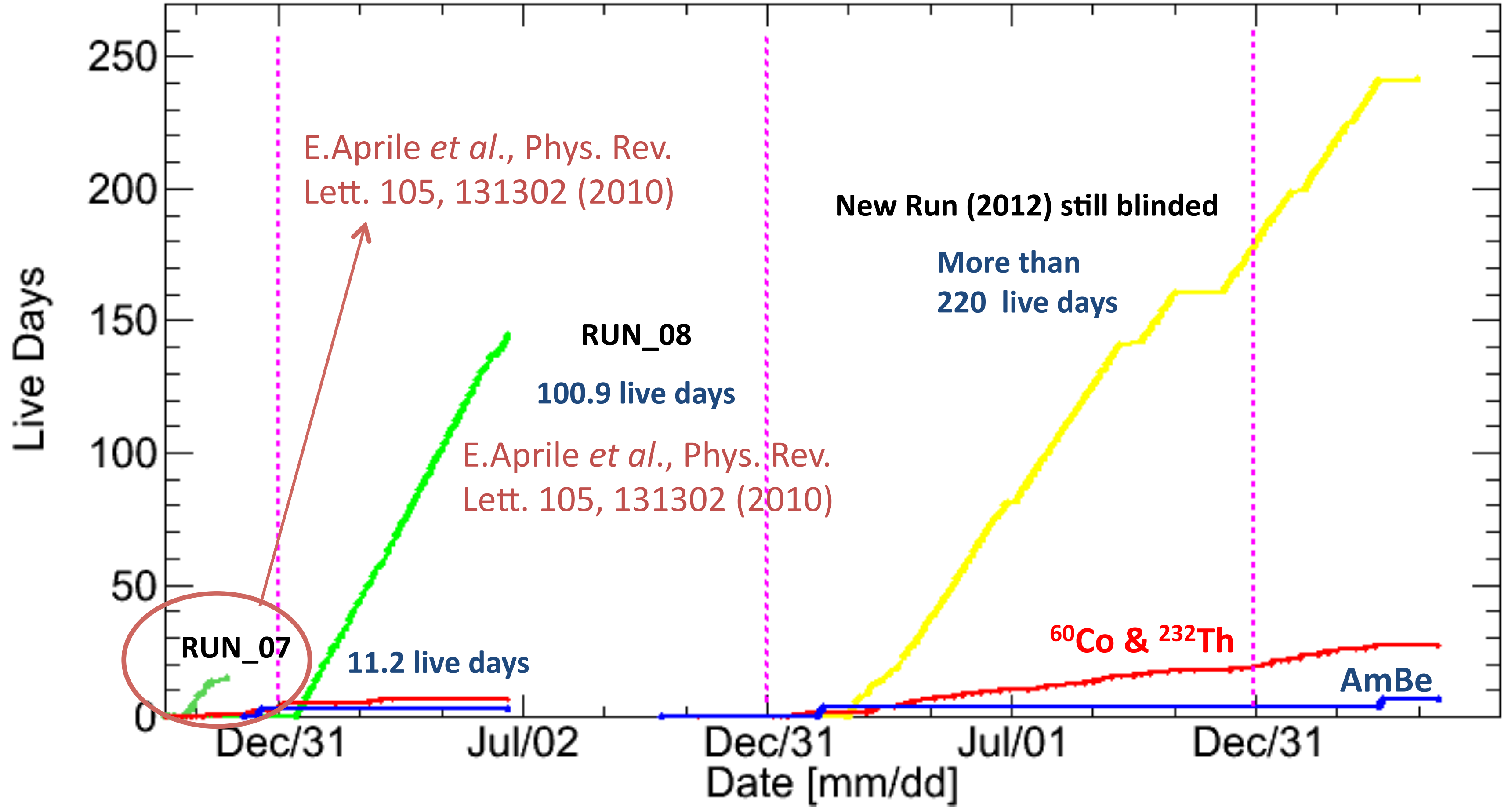
neutron event

$$\left(\frac{S2}{S1}\right)_{n,\chi} \ll \left(\frac{S2}{S1}\right)_{e,\gamma}$$



The discrimination power is 99.5% at low energies for a 50% neutron acceptance

Data taking overview



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

RUN_07

11.2 live days

RUN_08

100.9 live days

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

New Run (2012) still blinded

More than 220 live days

^{60}Co & ^{232}Th

AmBe

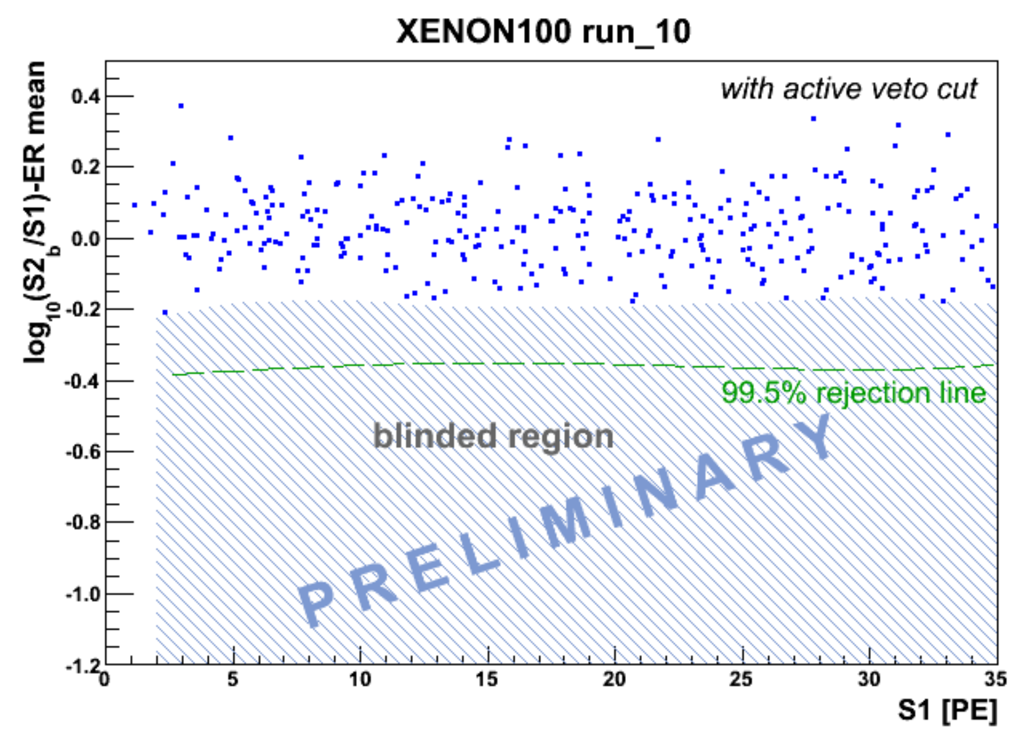
Blinded analysis

Before starting the cut developement we blind the data below the 10% quantile of the electron recoil band (through calibration)

These data are not available to anybody in the collaboration until the end of the analysis

Before unblinding the data we have to:

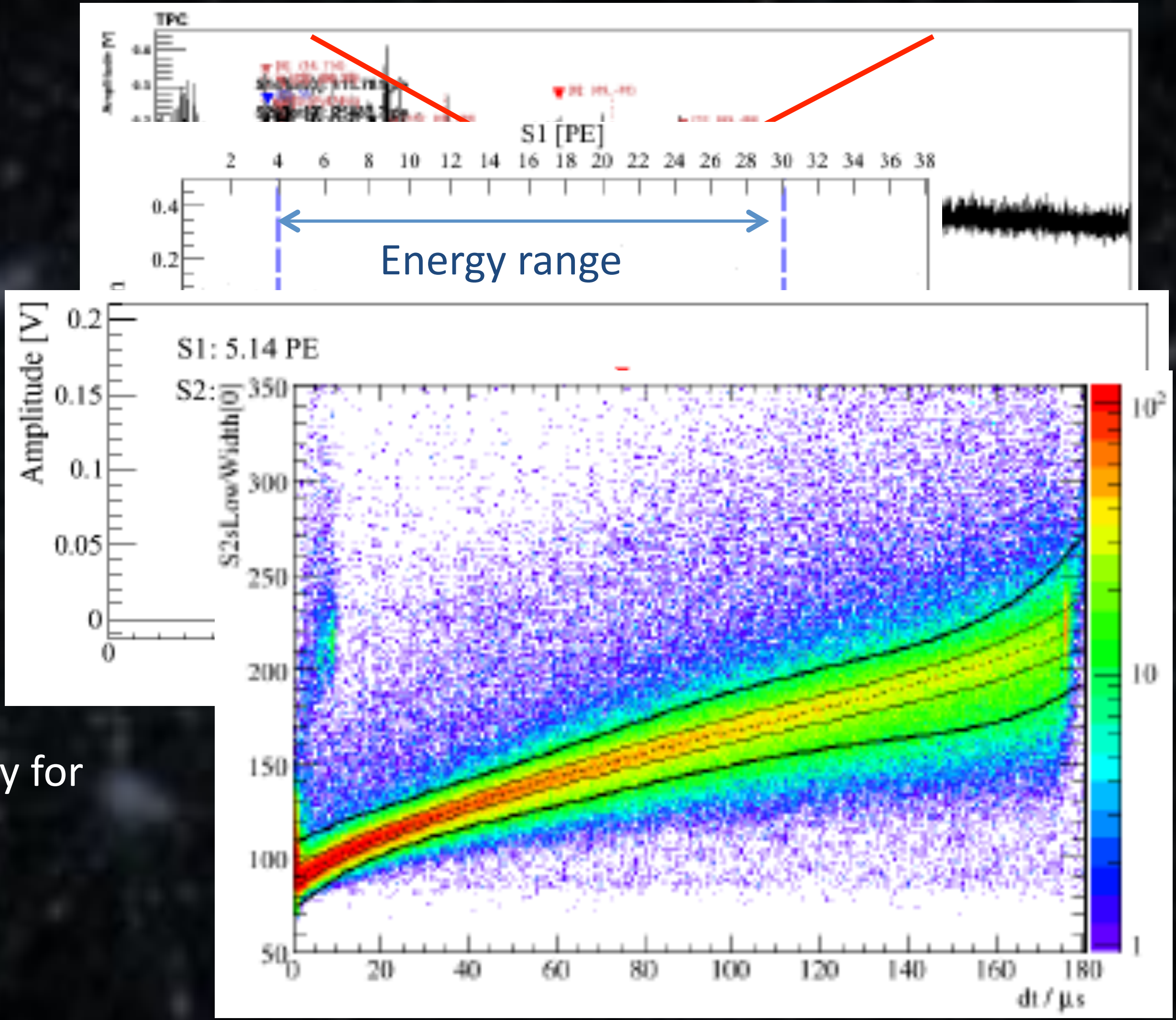
- Define the cuts
- Evaluate the rejection power of the cuts
- Calculate the total acceptance of the signal in the ROI
- Predict the background events in the ROI



100.9 days run

We defined the cuts:

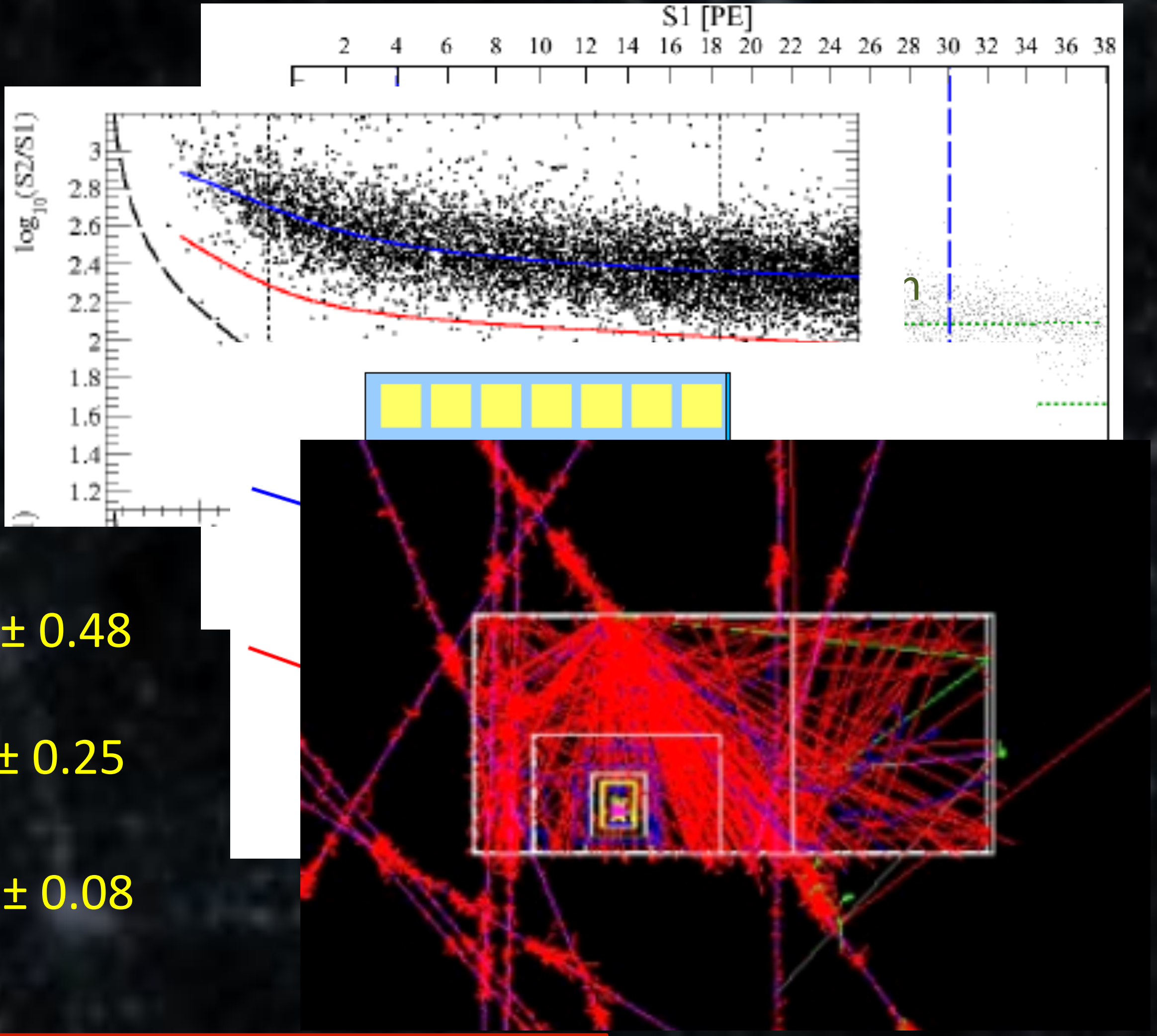
- Basic data quality cuts
- Energy cuts
- Single event selection
- Consistency cuts
- Fiducial Volume cut
- NR/ER discrimination (only for benchmark region)



Predicted background

Expected background in:

- 48 kg Fiducial Volume
- 100.9 live days
- 99.75 % ER rejection



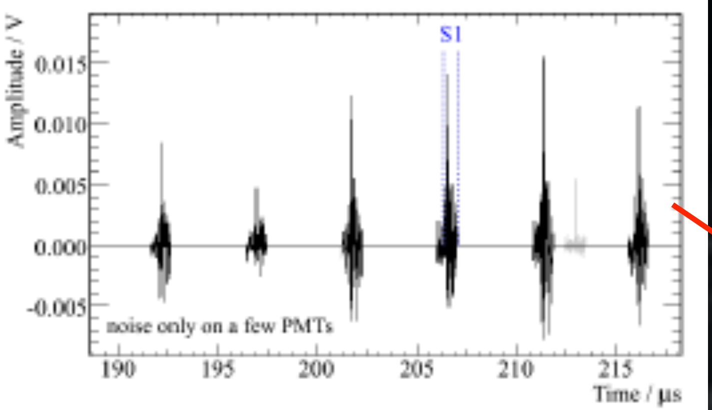
☐ gaussian leakage : 1.14 ± 0.48

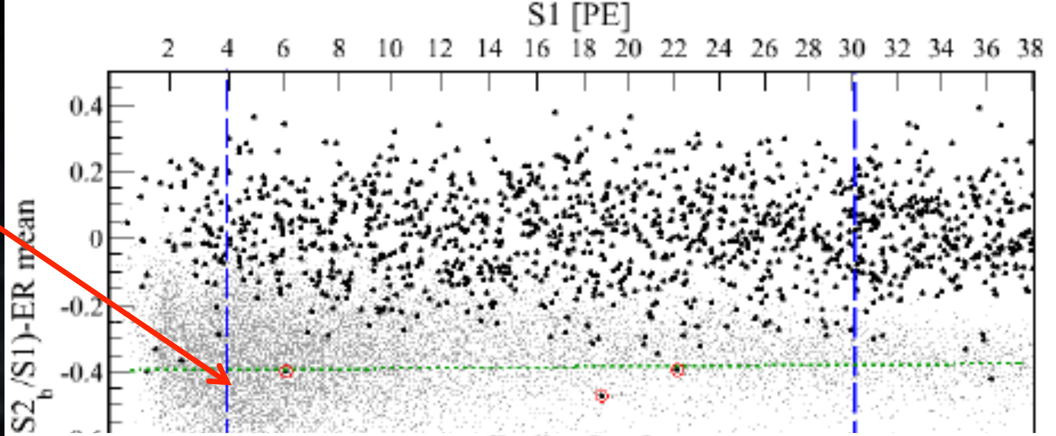
☐ anomalous leakage : 0.56 ± 0.25

☐ Neutron background : 0.11 ± 0.08

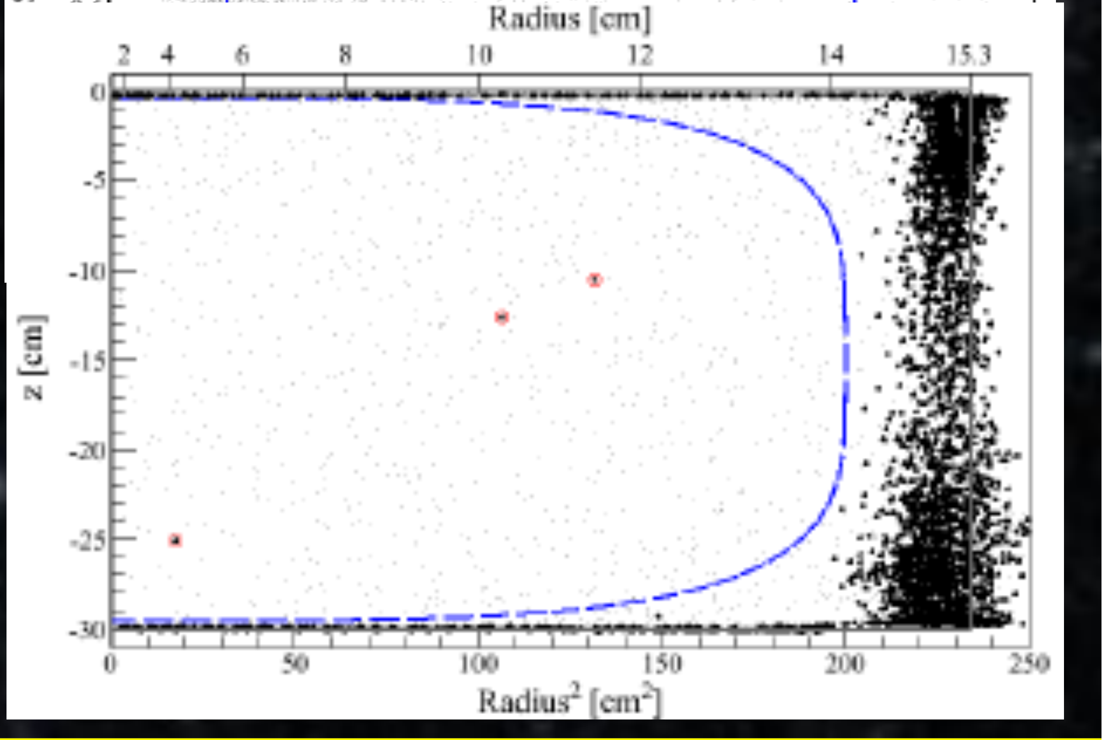
Total background events expected: 1.8 ± 0.6

Unblinding





Post-unblinding cut remove the noisy events



We observed 3 events

- Likelihood for 3 or more events is 28%
- Profile likelihood analysis also does not yield significant signal (calculate limit)

Nuclear Recoil energy scale

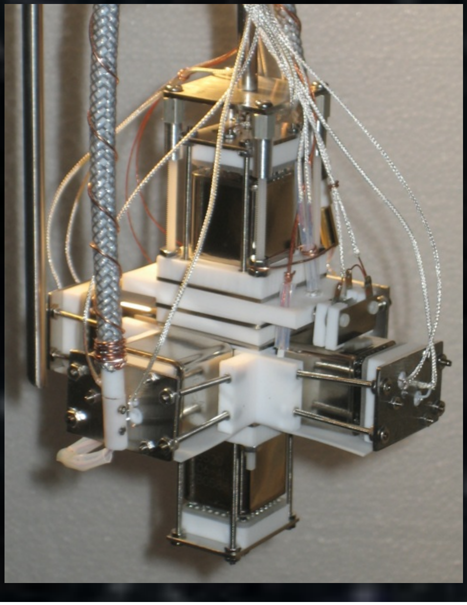
Nuclear Recoil Energy: $$E_{nr} = \frac{S1}{L_y} \cdot \frac{S_{ee}}{S_{nr}} \cdot \frac{1}{\mathcal{L}_{eff}}$$

where: $L_y(122\ \text{keVee}) = (2.2 \pm 0.1)$ pe/keVee

$S_{ee} = 0.58$

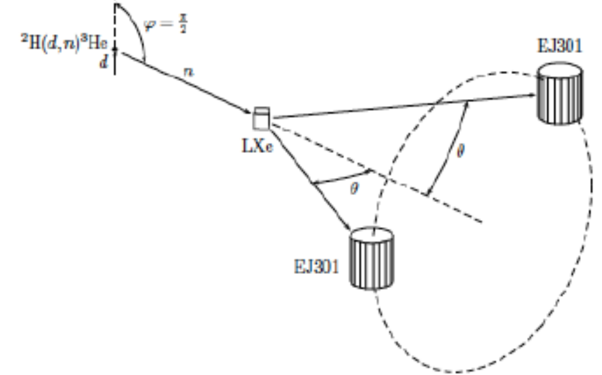
$S_{nr} = 0.95$

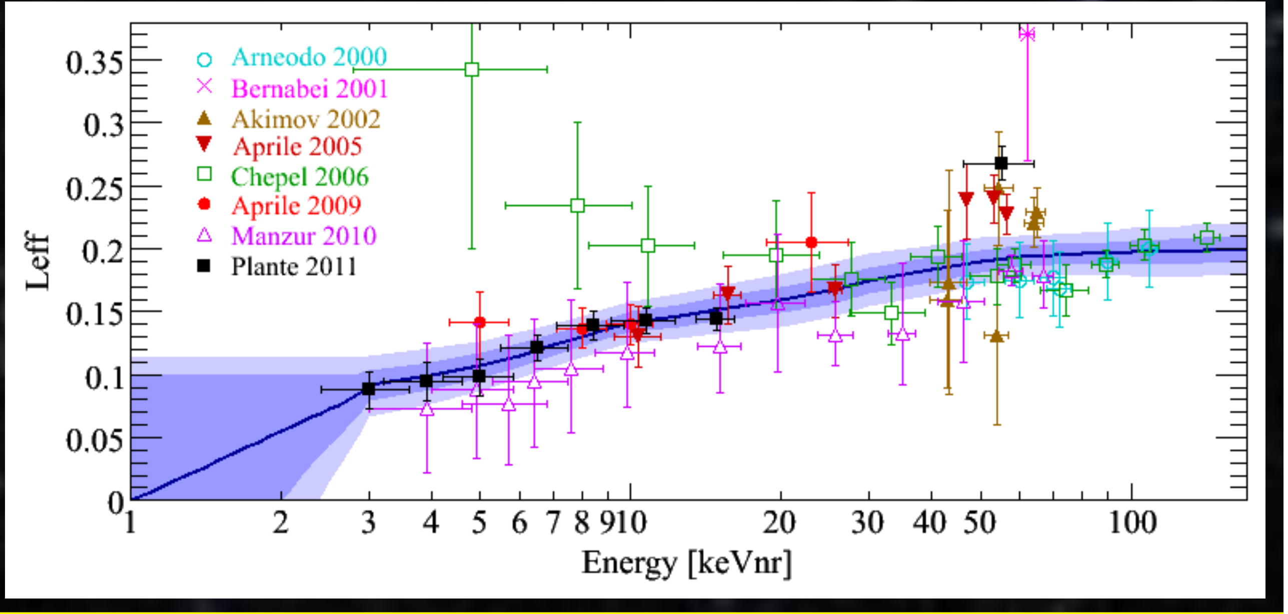
S_{ee}/S_{nr} is the quenching factor of the electric field



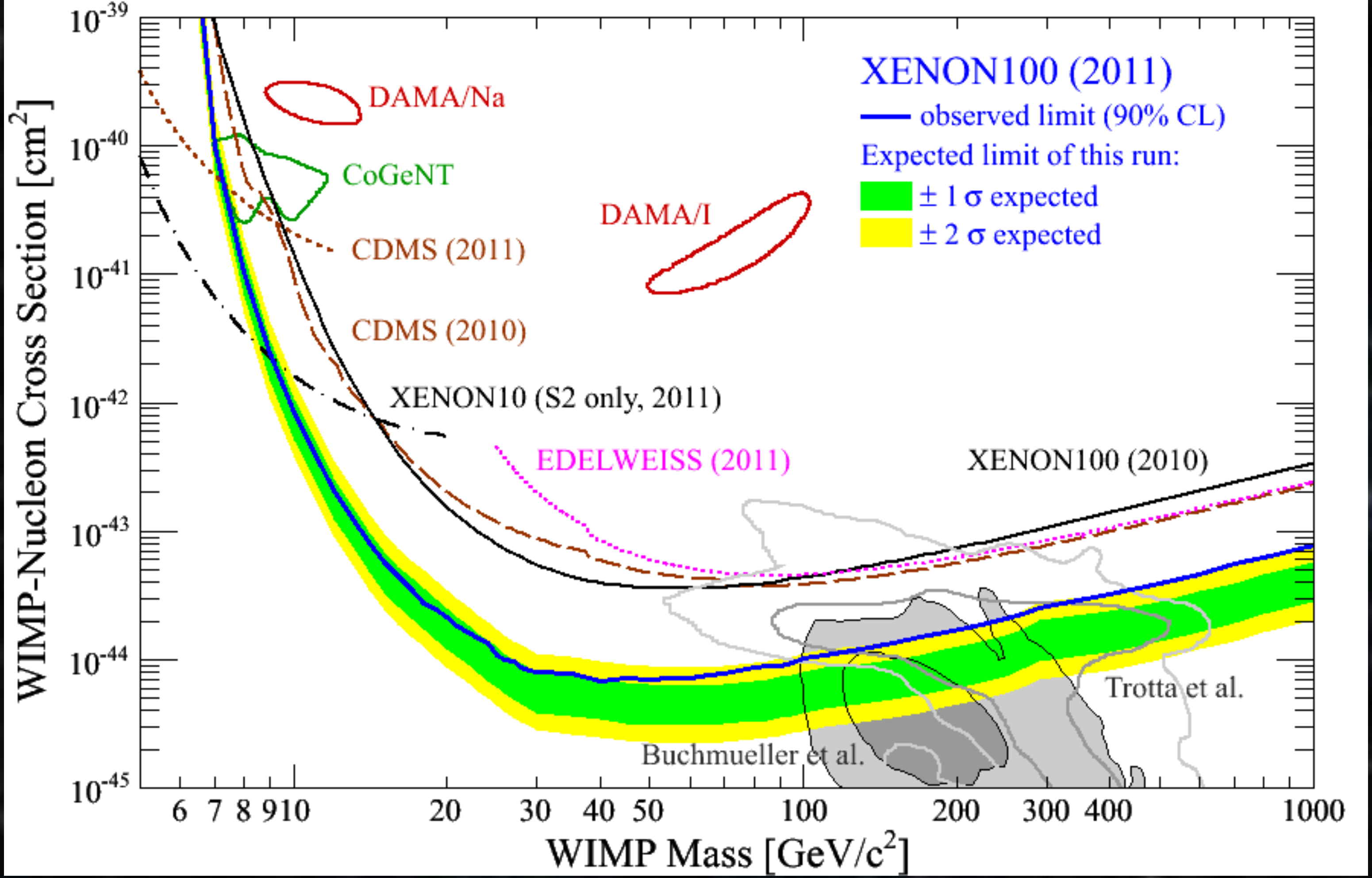
Plante *et al.*, Phys. Rev. C 84, 045805 (2011)

$$E_r \approx 2E_n \frac{m_n M_{Xe}}{(m_n + M_{Xe})^2}(1 - \cos\theta)$$





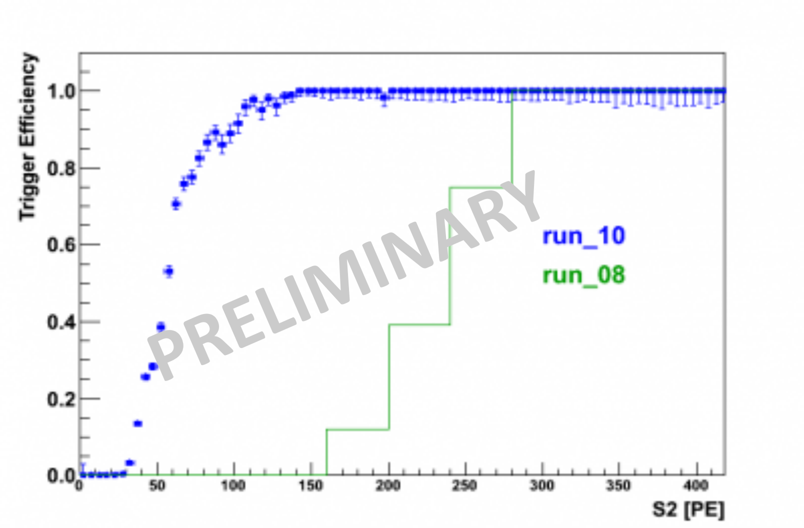
WIMP limit

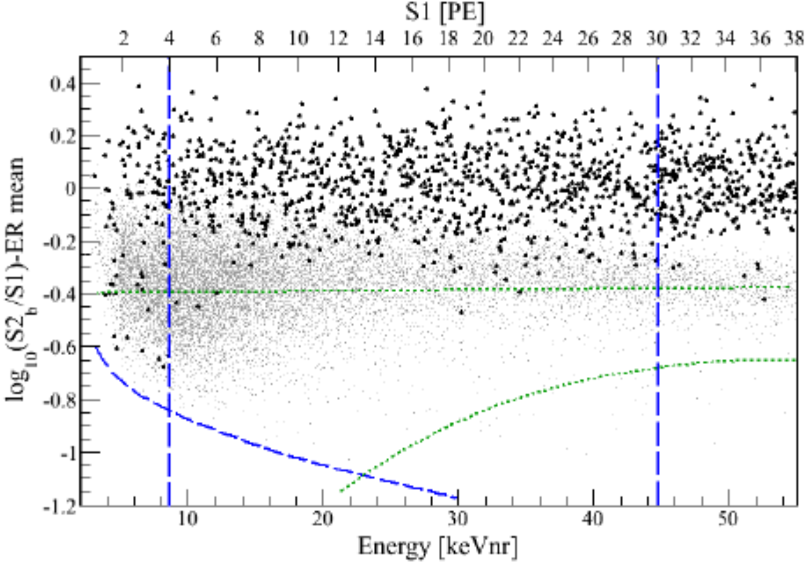


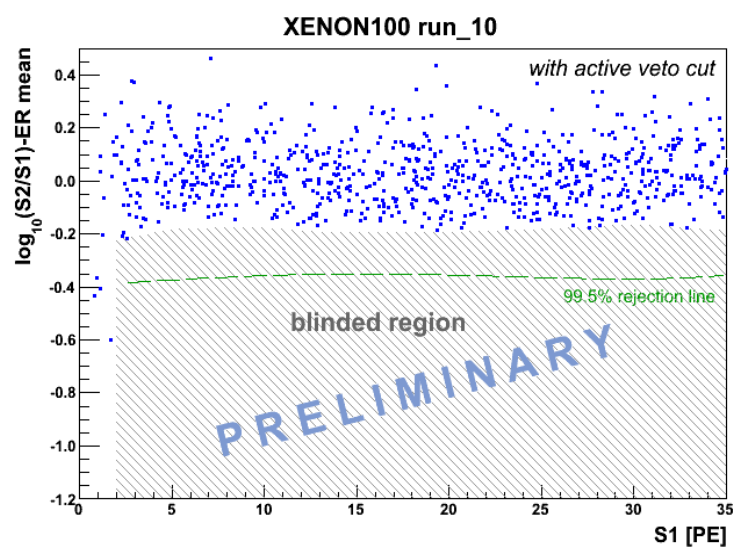
E. Aprile *et al.*, Phys. Rev. Lett 107, 131302 (2011): arXiv 1104.2549

Progress towards unblinding

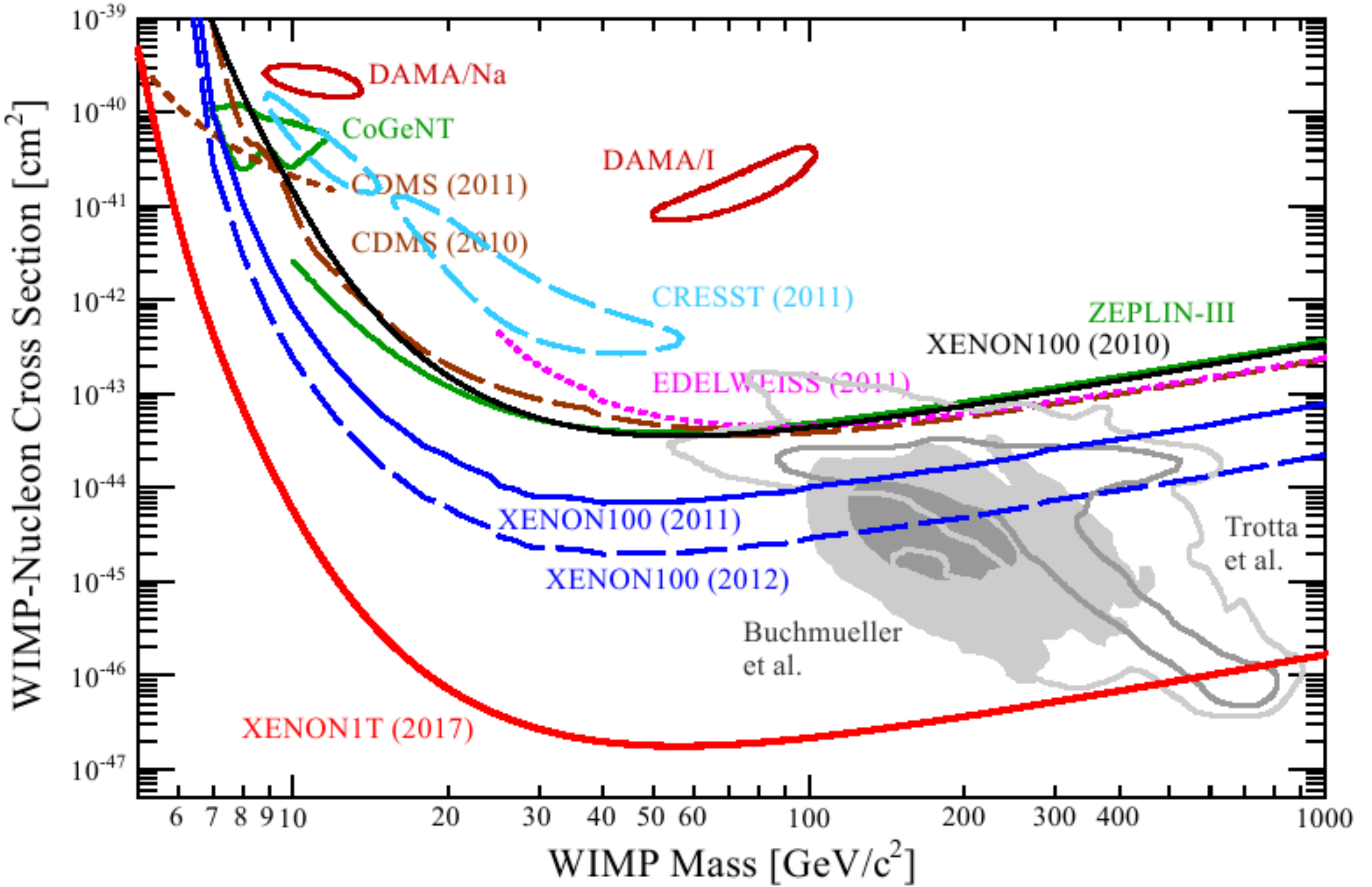
- ✓ We have more about 225 live days of DM data
- ✓ We lowered the trigger threshold (from 300 pe to 150 pe in S2)
- ✓ We lowered the ^{85}Kr concentration in LXe by a factor 5 (with respect to the 100.9 live days run)
- ✓ Improved Lxe purity (current e-lifetime ~700 μs)



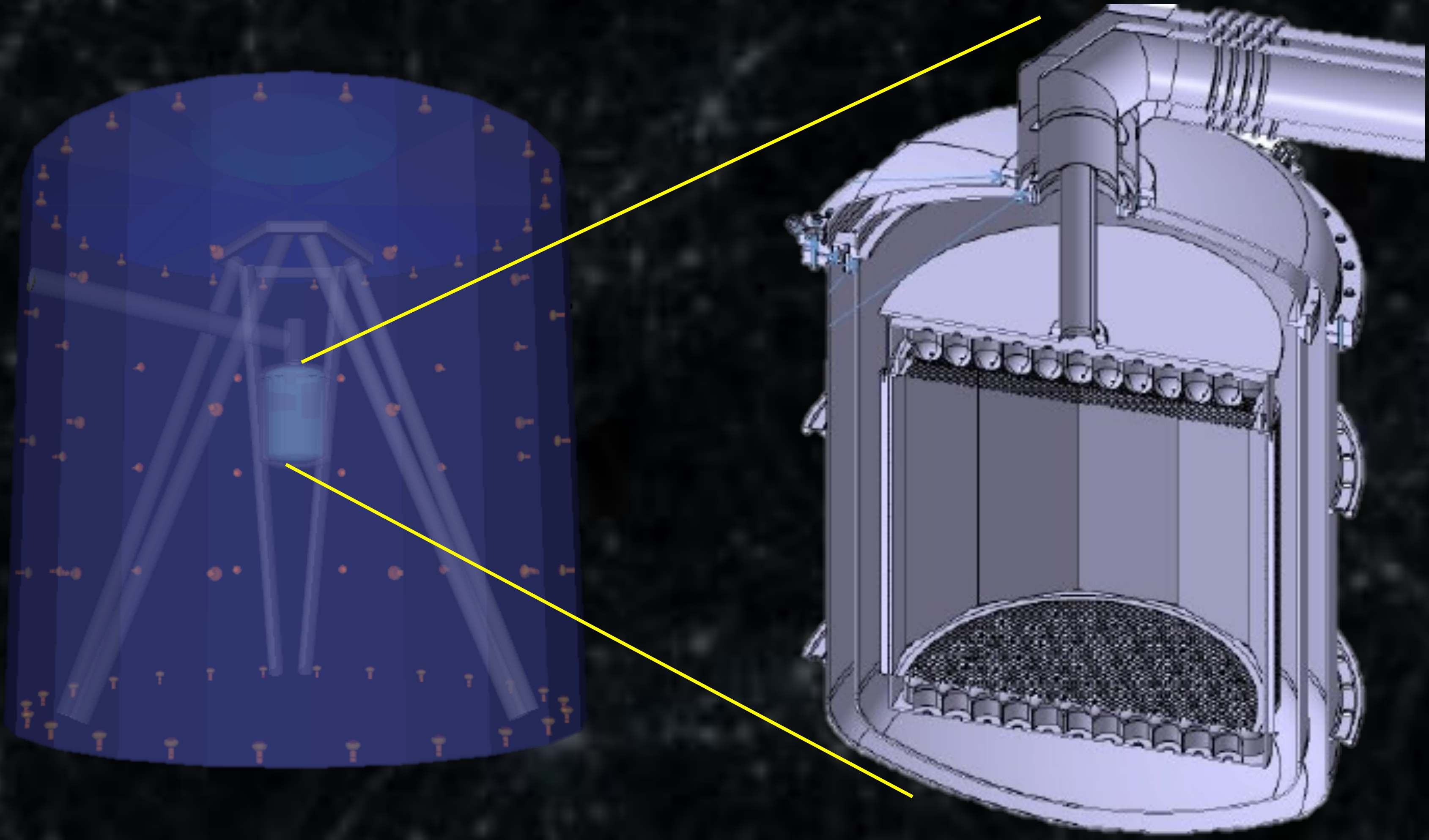




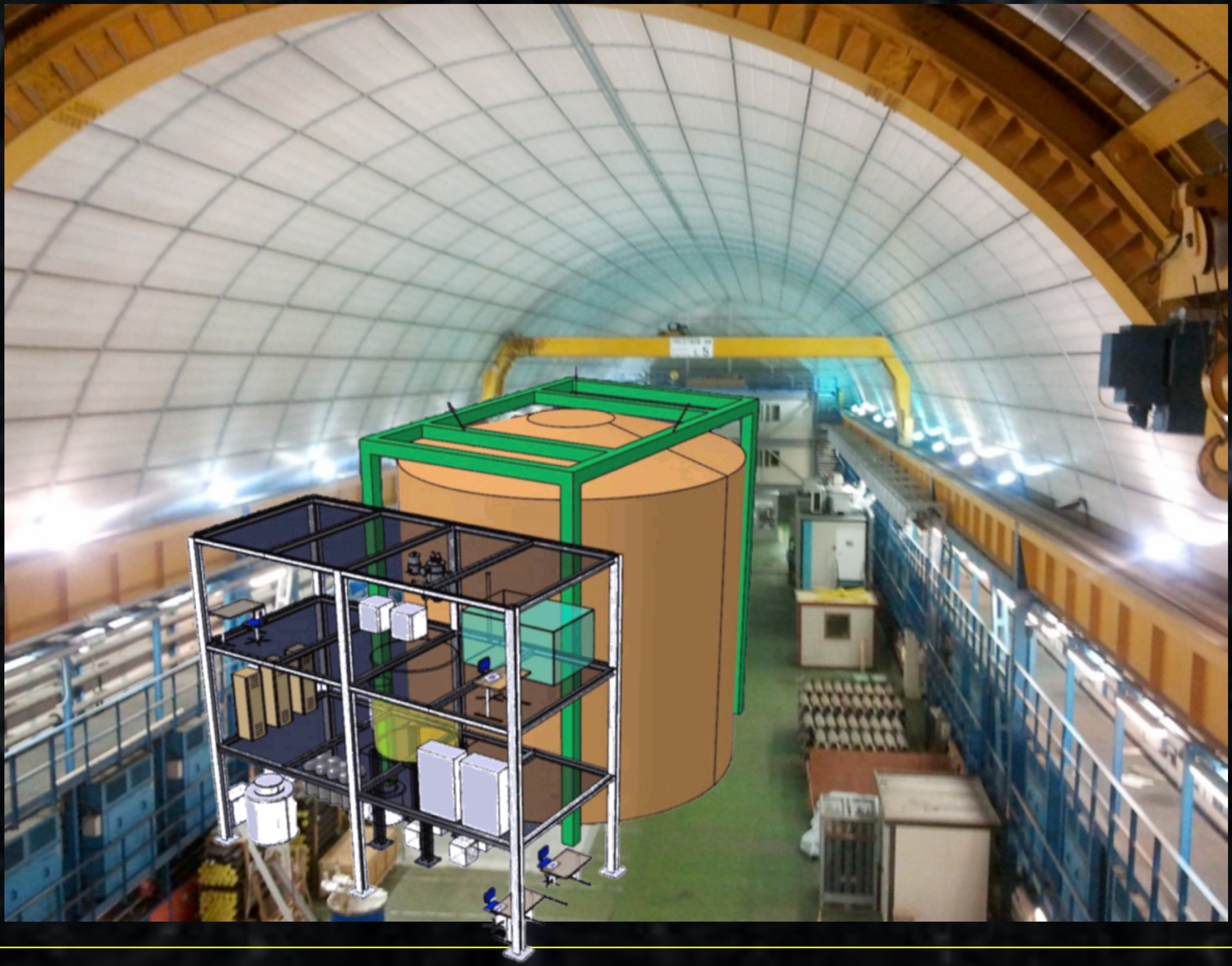
XENON Sensitivity Goal



The future: XENON1T



XENON1T: Location



XENON1T: overview

- Target: 2.4 ton of liquid Xenon with 1.1 ton in the fiducial volume
- Shield: 5 m radius Water Cherenkov Muon Veto
- Background: 0.01 mdru (100x lower than XENON100)
- Location: approved by INFN for LNGS Hall B
- Status: Construction start in fall 2012
- Science Run: projected to start in 2015
- Sensitivity: 2×10^{-47} cm^2 at 50 GeV with 2.2 ton-years

Summary

- XENON100 is to-date the largest mass and lowest background TPC for Dark Matter in operation underground
- A 100 days exposure has been collected in 2010. 3 events in the signal region have been observed for a background expectation of 1.8 ± 0.6 events
- These data have yielded the most stringent limit on SI WIMP-nucleon cross section. Minimum at 7.0×10^{-45} cm^2 for a WIMP mass of 50 GeV/c^2
- A blind analysis of more than 220 days is near completion (few weeks)
- XENON1T has been approved to be built in Hall B in LNGS
- Tests for many of the needed new technologies have already started