UNIVERSITY of COIMBRA

Xe
XENON
Dark Matter Project

Direct Dark Matter Search with the XENON program

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IFIC
INSTITUT DE FÍSICA CORPUSCULAR

On Behalf of the XENON Collaboration

The XENON Collaboration

~ 100 scientists

from 16 institutions

Direct Dark Matter Search

- **Elastic scattering WIMPs - target nuclei**

$\longrightarrow$ **low energy** nuclear recoils with **low rate**

- **Interaction**

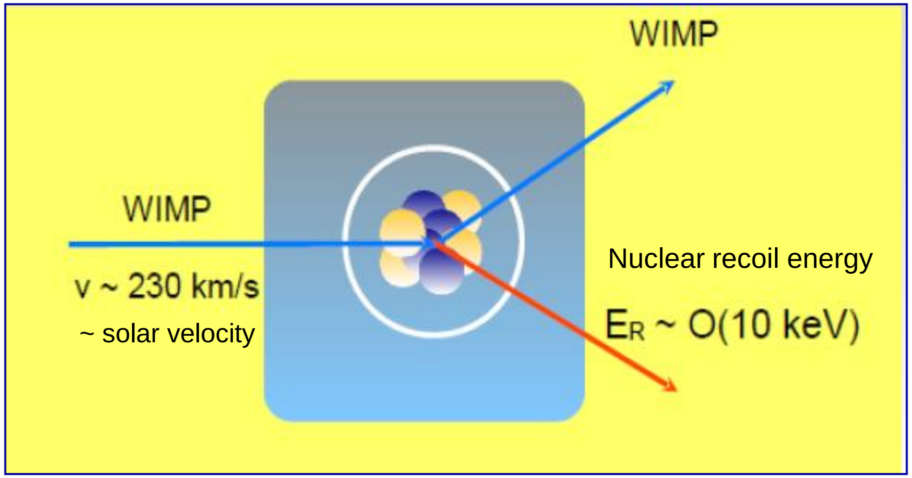
✓ **Spin Independent (SI)**

Possible with all nuclei

✓ **Spin Dependent (SD)**

Only possible with odd mass nuclei

(^{129}Xe, ^{131}Xe) if the WIMP carries spin



- **Detector requirements**

✓ (Ultra) low background $\longleftarrow$ Low rate signal

✓ Low energy threshold $\longleftarrow$ Low energy signal

✓ High target mass $\longleftarrow$ Small cross section

Liquid Xenon as a detection medium

Heavy nucleus (A ~ 131)
High rate expected for SI interactions ($\sigma \sim A^2$)

$$R \propto N_T \frac{\rho_0}{m_\chi} \sigma_{\chi N} \langle v \rangle$$

50% odd mass isotopes (^{129}Xe, ^{131}Xe)
Exploring SD interactions

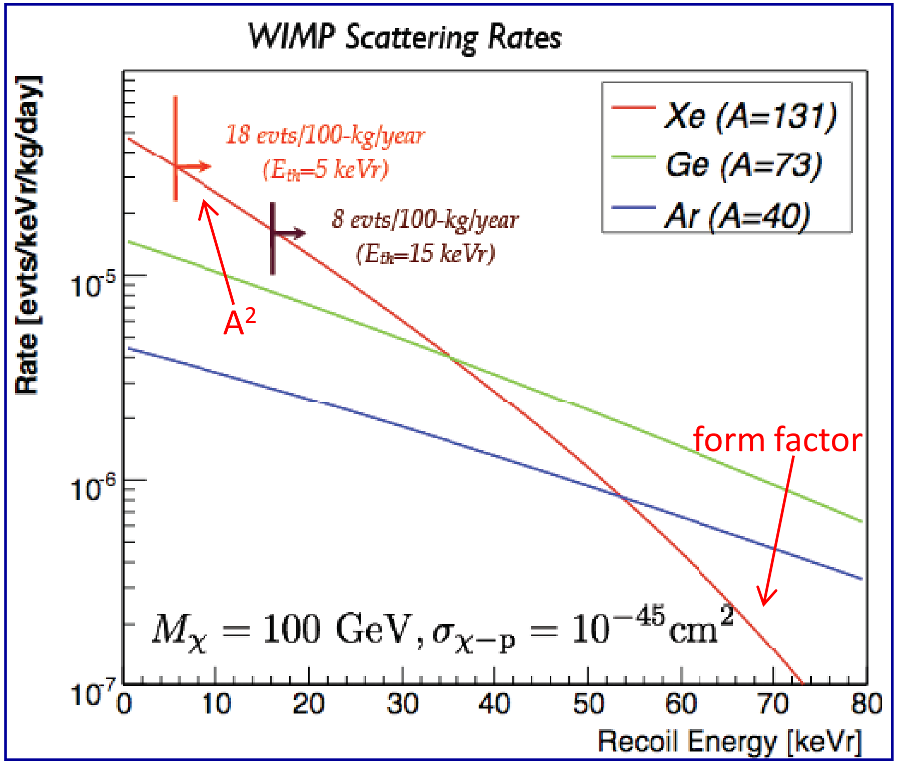
High Z = 54 and density ρ = 3 g/cm³
✓ Excellent self-shielding (low background)
✓ High stopping power (compact detector)

Scalability to larger detectors at an affordable cost (~ 1 k$/kg today)

Charge and light
✓ Highest yield among the noble liquids
✓ 178 nm UV photons
✓ Efficient scintillator (~ 80% NaI light yield) and fast response (2.2 ns)

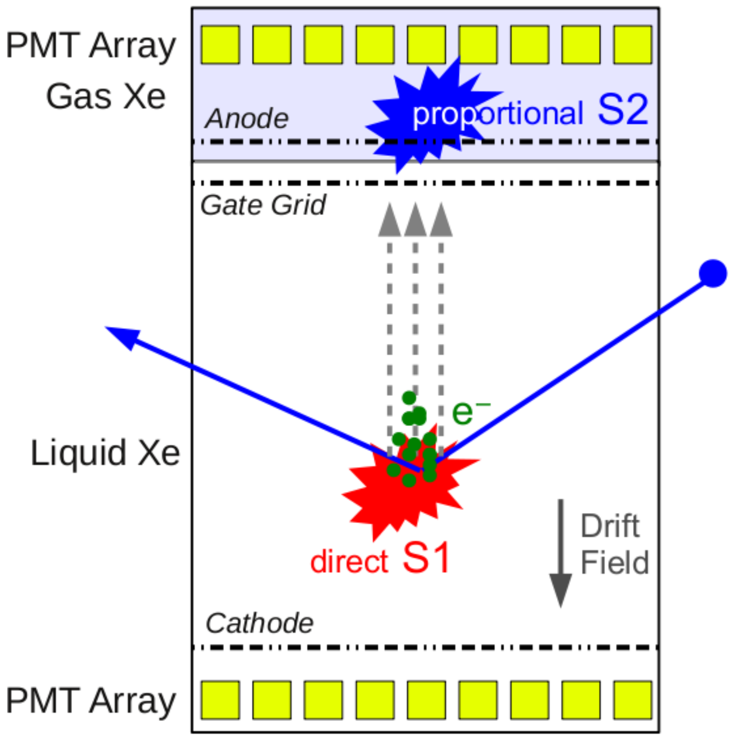
"Easy" cryogenics @ ~ -100 ºC

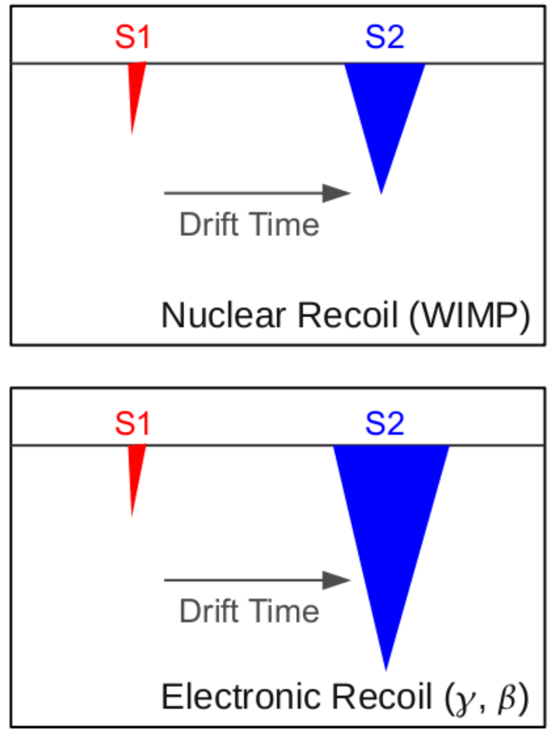
Intrinsically pure:
✓ No long-lived Xe isotopes
✓ Kr can be reduced to ppt level

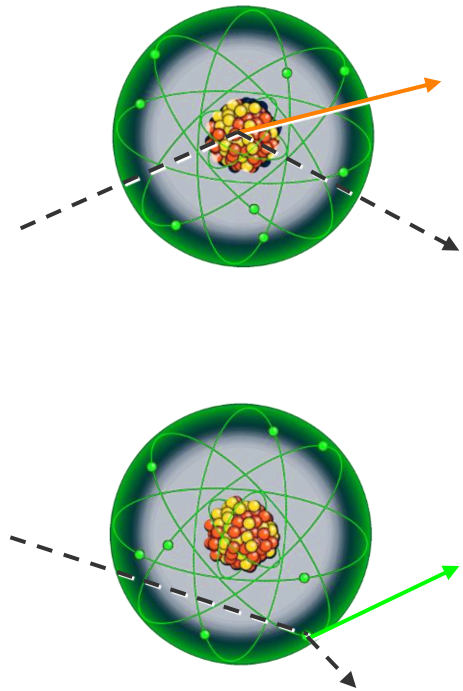


✓ **Xenon is a good target!**

Principle of two-phase TPC







✓ **Prompt scintillation signal (S1)**

Charges are extracted to GXe

✓ **Proportional scintillation signal (S2)**

E. Aprile et al. (XENON100),
Astroparticle Physics 35, 573 (2012)

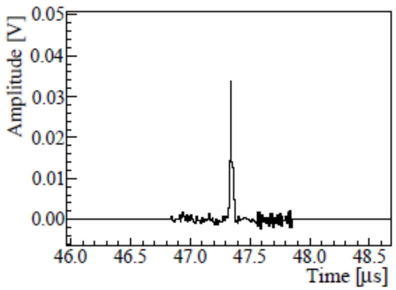
Electron recombination is stronger for NR

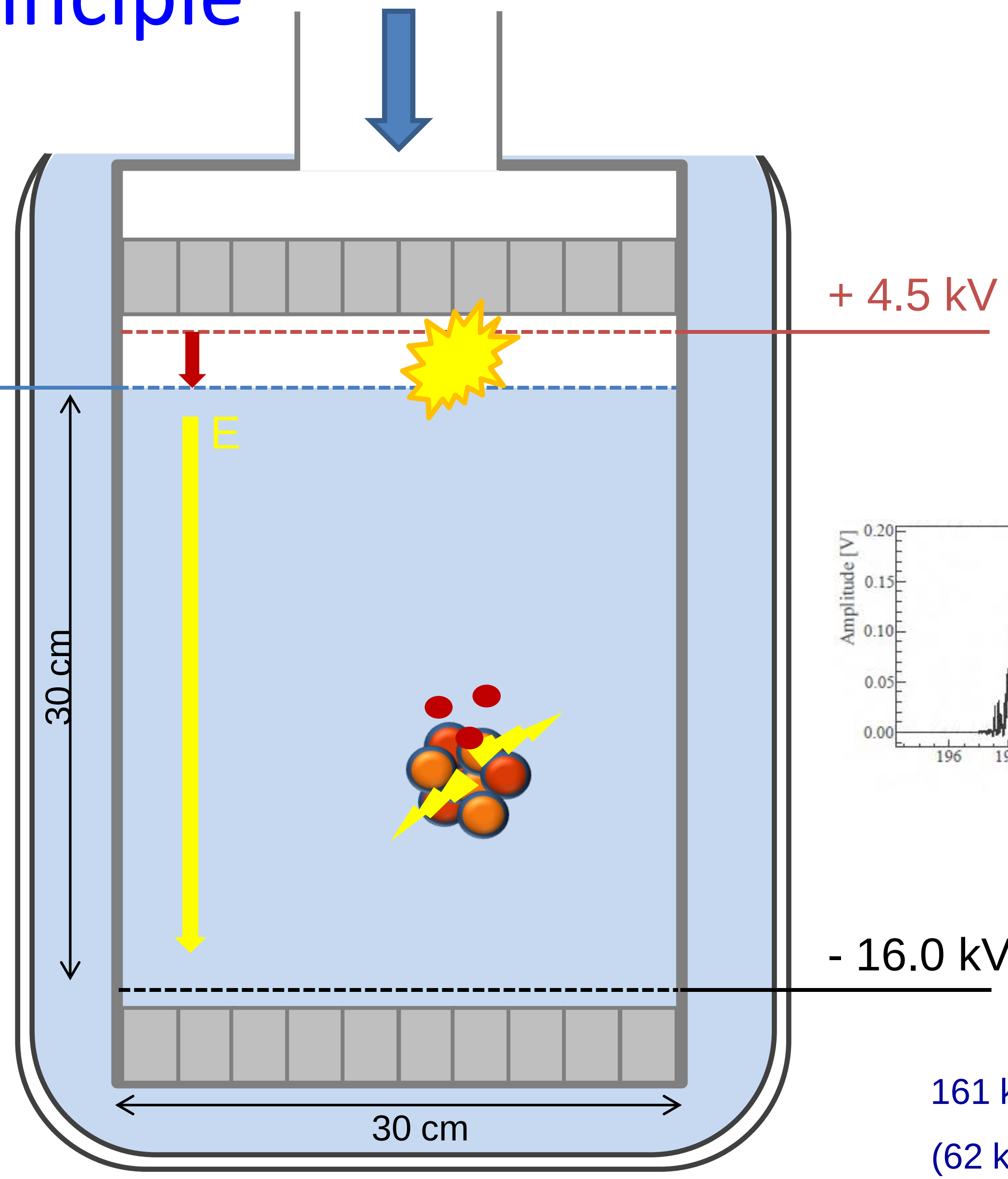
→ **$(S2/S1)_{WIMP} << (S2/S1)_{\gamma,\beta}$**

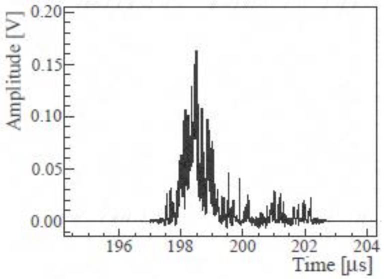
→ ER - NR discrimination

ER = electronic recoil, NR = nuclear recoil

Detection principle



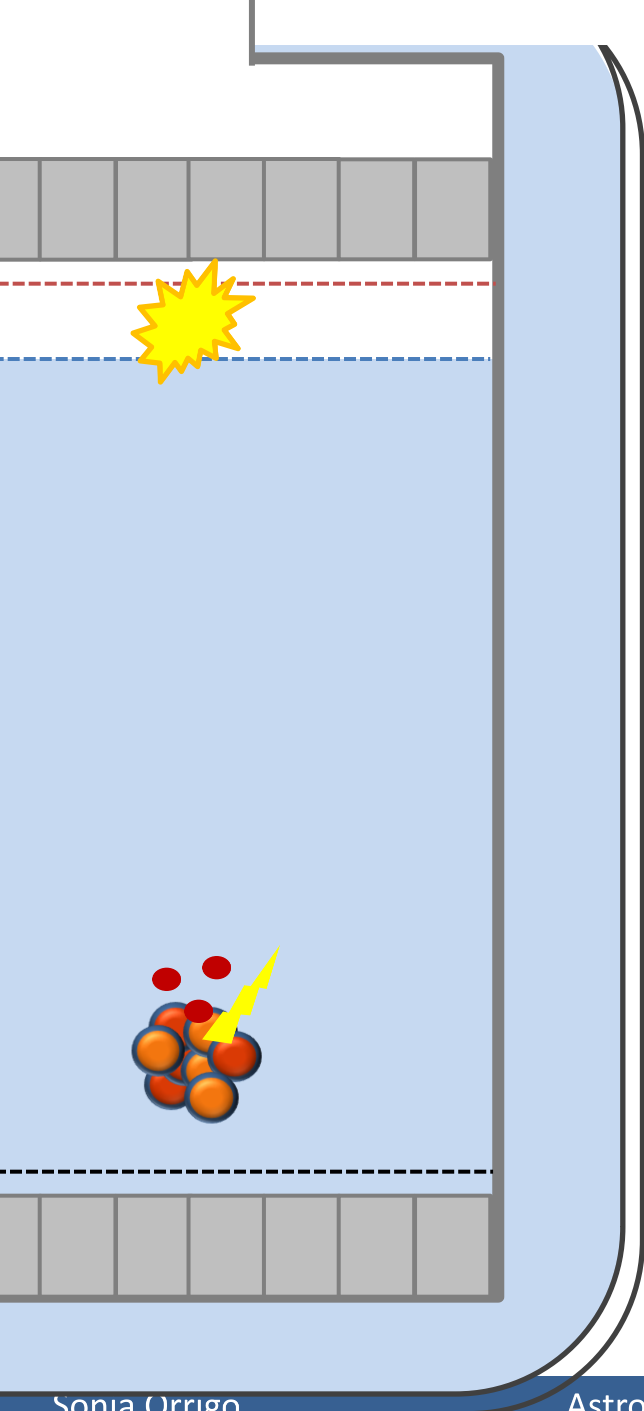


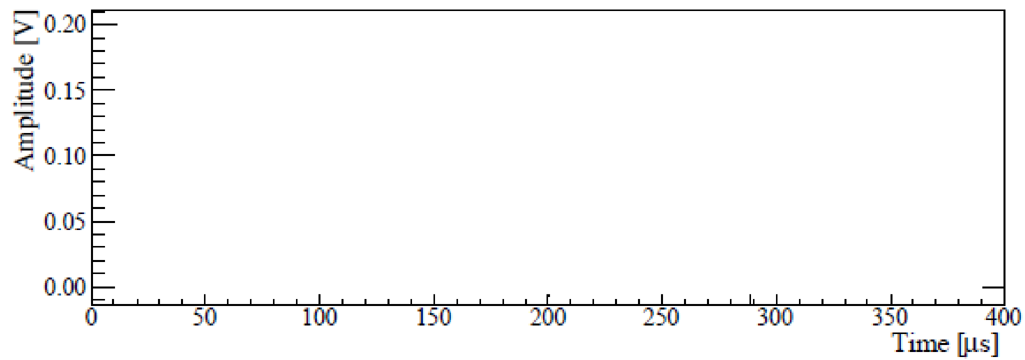


161 kg LXe in total

(62 kg inside TPC)

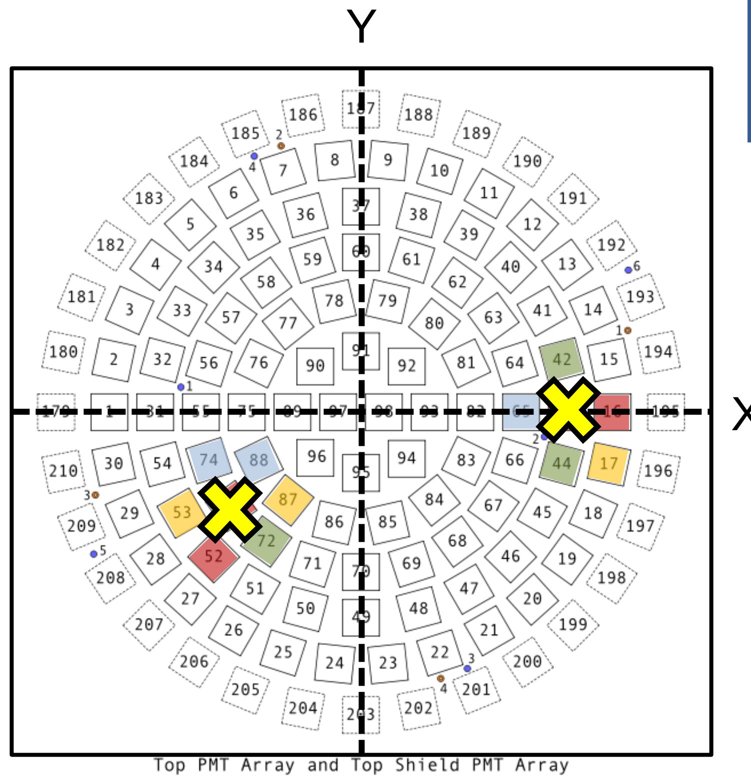
Reconstruction of the event vertex (Z position)

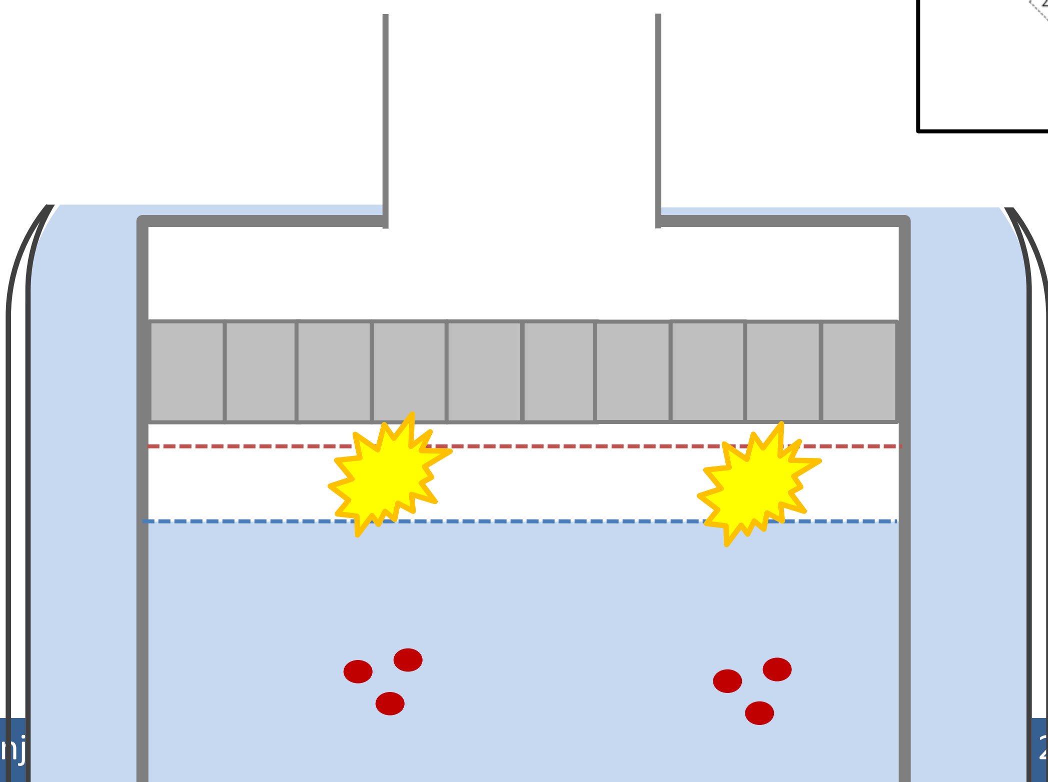




- ✓ $z(\Delta t) = v_{drift}\,\Delta t$
- ✓ $v_{drift} \approx 1.73$ mm/µs
- ✓ Resolution $\sigma_Z < 0.3$ mm

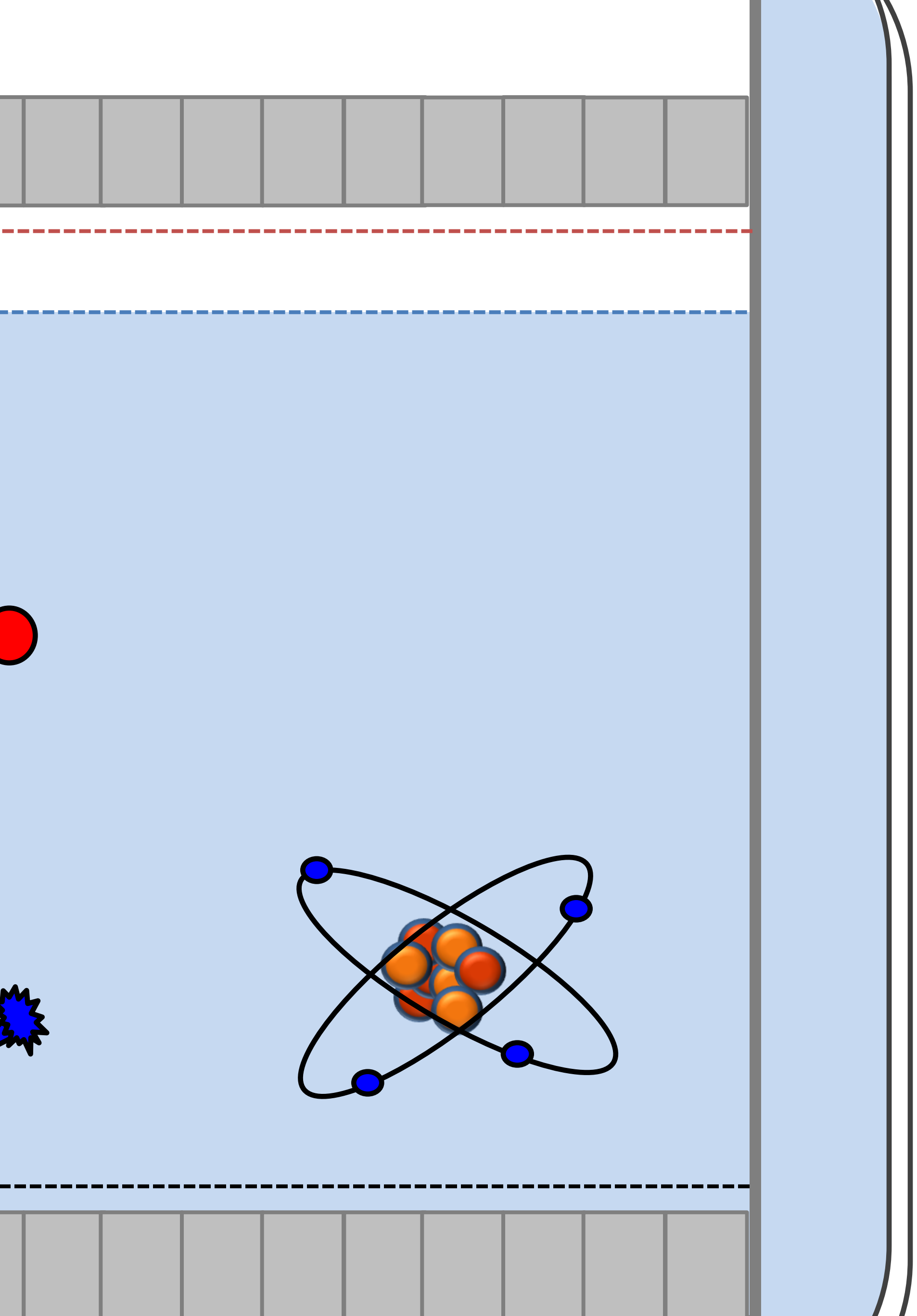
Reconstruction of the event vertex (X, Y positions)



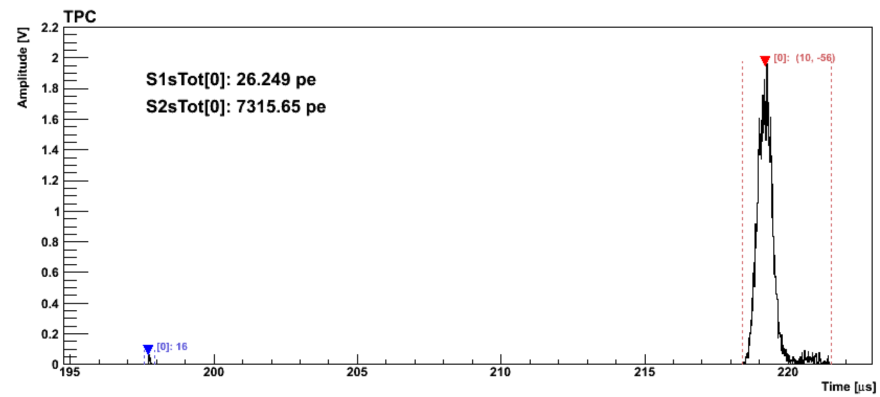


Resolution $\sigma_{X,Y} < 3$ mm

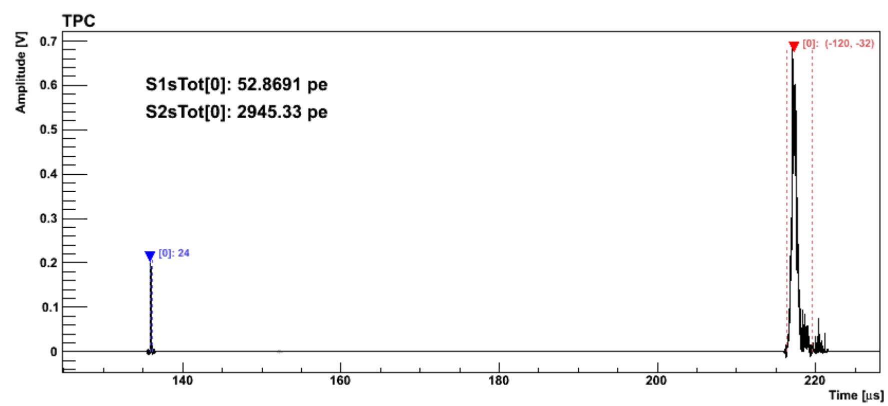
Particle discrimination



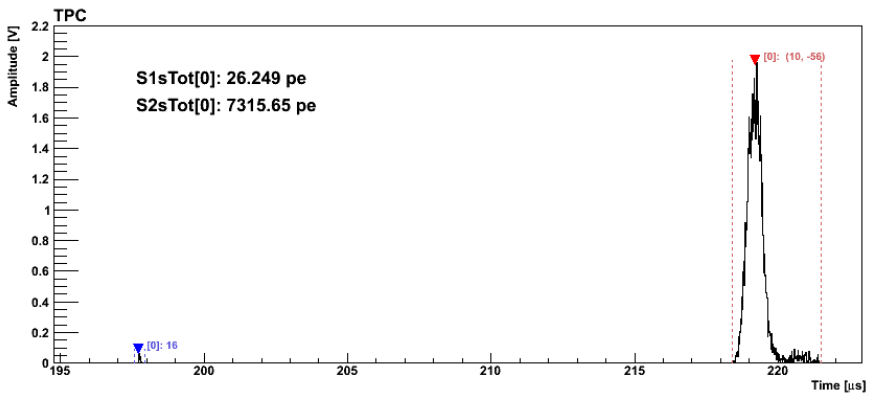
electronic recoil

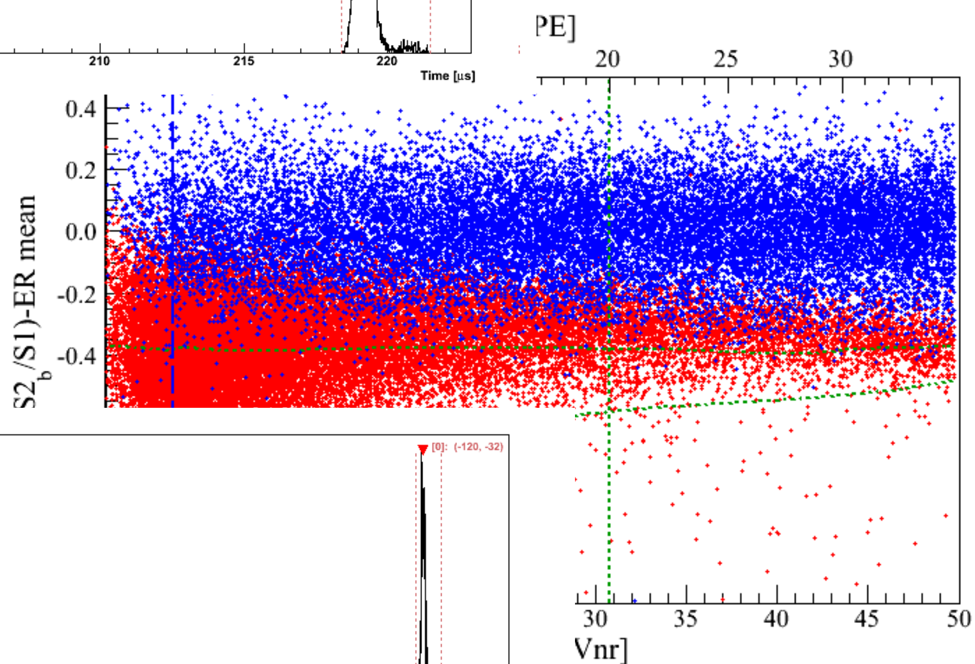


nuclear recoil



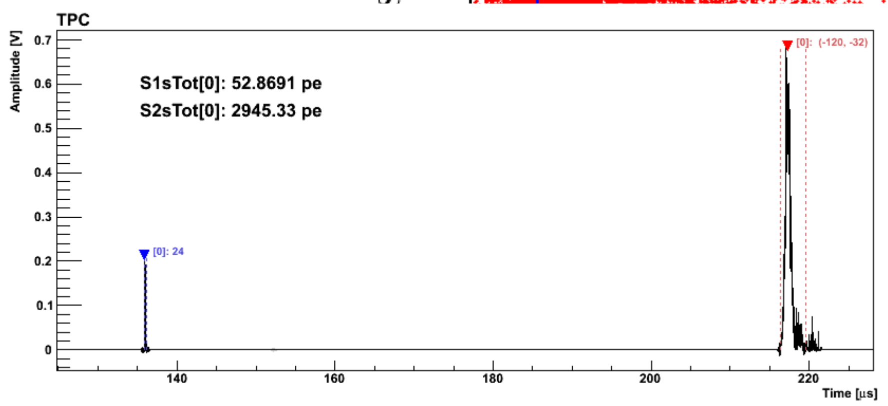
Particle discrimination





electronic recoils

nuclear recoils



The phased XENON program

Past: 2005-2007

XENON10

15 kg active mass

$\sigma_{SI} < 8.8 \times 10^{-44}$ cm^2 (2007)

Present: 2008-201?

XENON100

62 kg active mass

$\sigma_{SI} < 2.0 \times 10^{-45}$ cm^2 (2012)

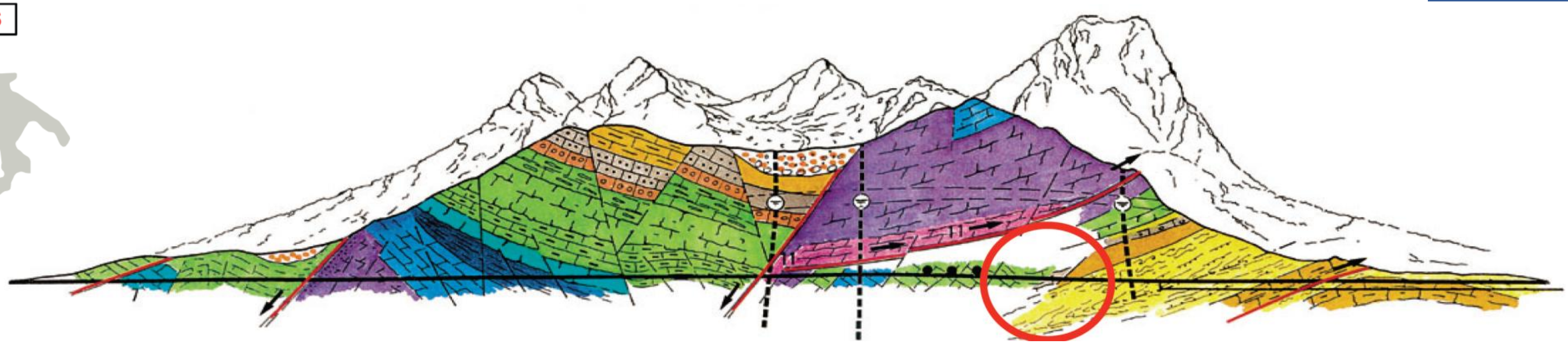
Future: 2013-2017

XENON1T

~ 2.2 ton active mas

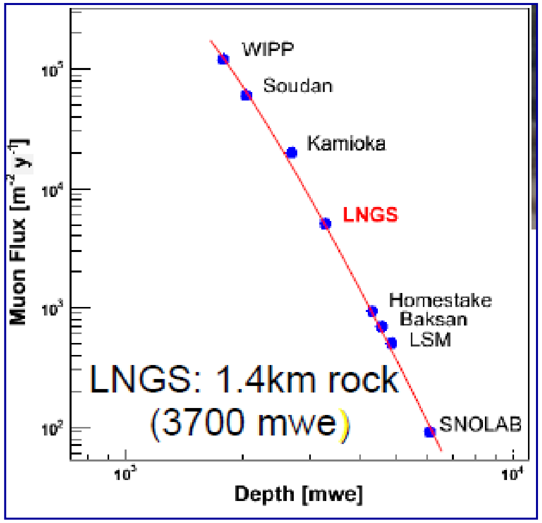
$\sigma_{SI} \sim 2 \times 10^{-47}$ cm^2 (*proj.*)

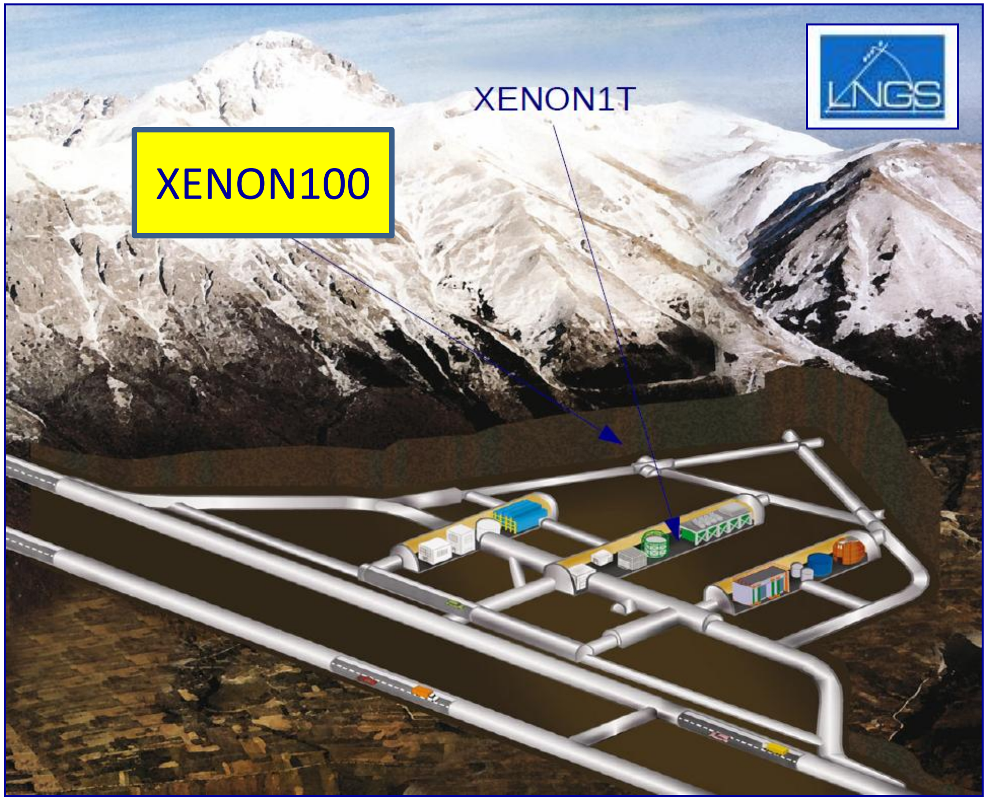
Location of the XENON Experiments



Laboratori Nazionali del Gran Sasso, Italy

1.4 km of rock → 3700 m.w.e. shielding from cosmic rays → factor 10^6 reduction of muon flux





The XENON100 detector

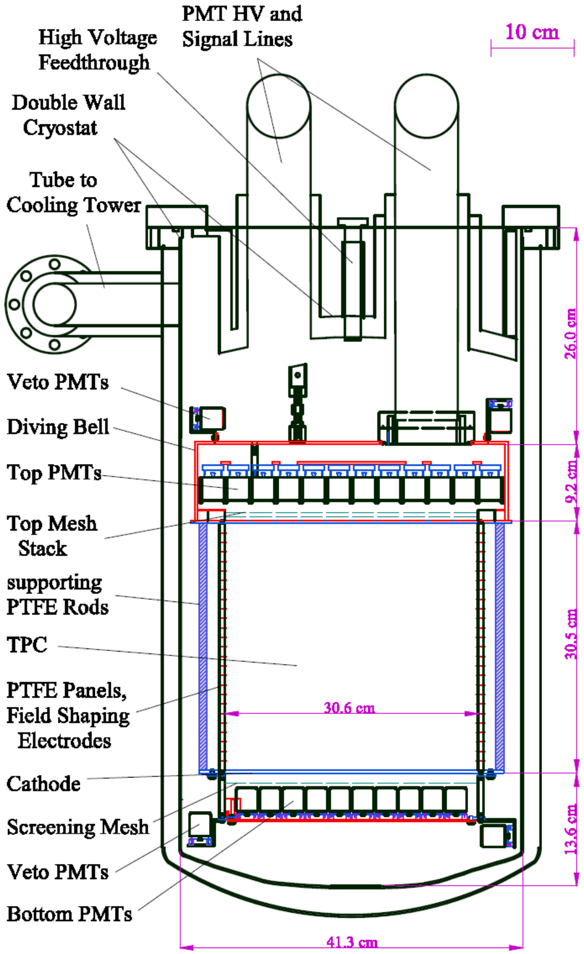
- **161 kg LXe total mass**
  - ✓ Factor 10 more than XENON10
  - ✓ 62 kg sensitive volume
  - ✓ 99 kg active veto
  - ✓ 30 cm drift length and 30 cm radius
- **Electric fields**
  - ✓ Drift = 0.53 kV/cm
  - ✓ Extraction = 12 kV/cm
  - ✓ 100% electron extraction to GXe
- **PTFE structure** (12 kg)

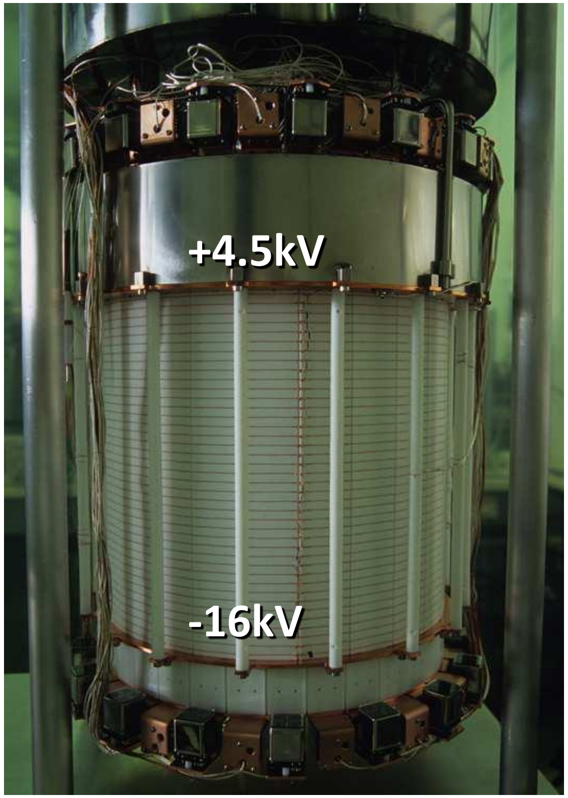
Good UV reflector and insulator

- **Extremely low background**
  - ✓ Factor 100 lower than XENON10
  - ✓ Material screening and selection
  - ✓ Detector design
  - ✓ Active/passive shielding

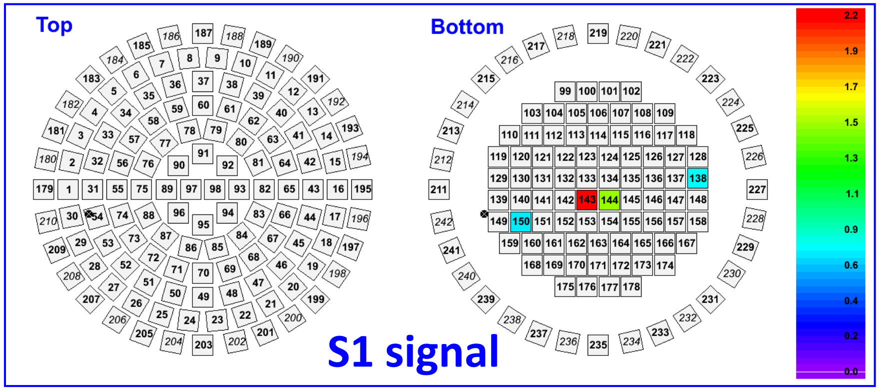
E. Aprile et al. (XENON100), Astroparticle Physics 35, 573 (2012)

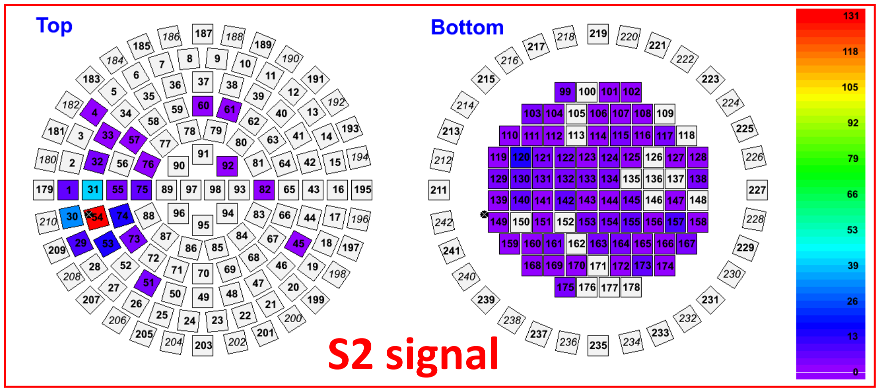
- **Cryostat**
  - ✓ Double-walled (1.5 mm thick) low radioactivity stainless steel (tot. 70 kg)

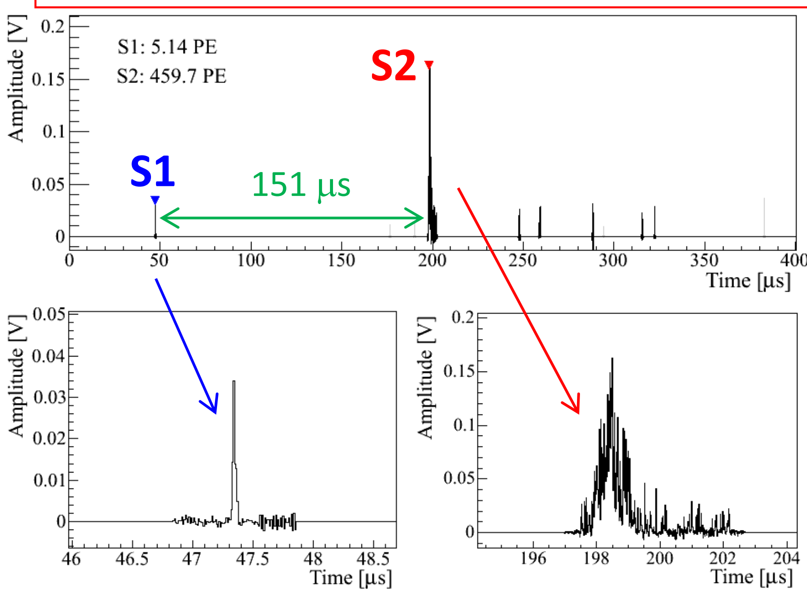




The XENON100 PMTs

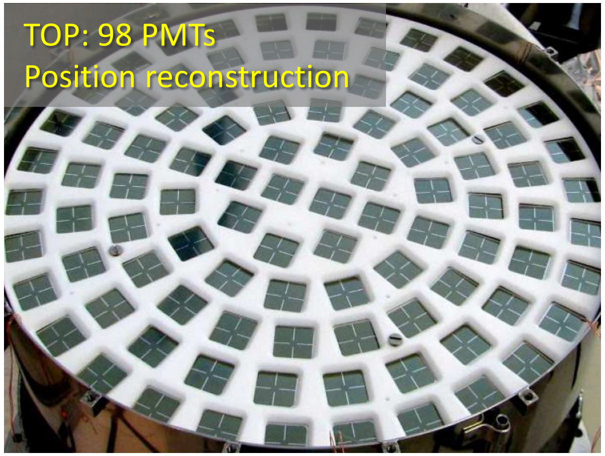


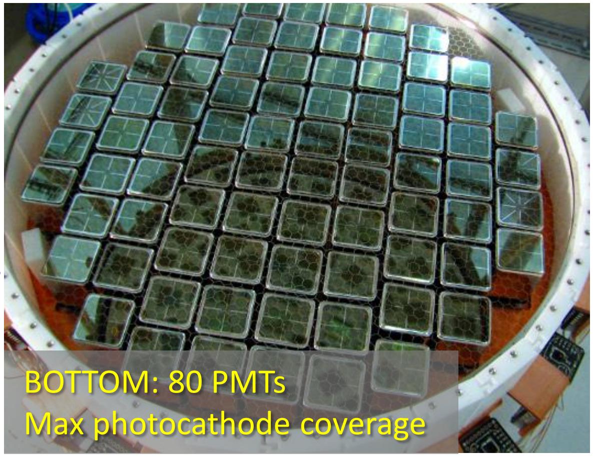




- **PMTs: 242 low intrinsic radioactivity** (<10 mBq/PMT)
  Hamamatsu R8520-06-Al 1”x1”
  ✓ QE > 30% @178nm
- **3D event localization**
  X,Y res. 3 mm
  Z res. 0.3mm, sep. 3 mm
- **Active Veto** for BG reduction

E. Aprile et al. (XENON100), Astroparticle Physics 35, 573 (2012)





Backgrounds

Electronic recoil (ER) background

✓ Natural radioactivity in the detector and shields materials

✓ ^{222}Rn contamination in the shield cavity

✓ Intrinsic contamination in LXe (^{222}Rn, ^{85}Kr)

✓ Cosmogenic activation of the detector components during construction and storage at the Earth surface

E. Aprile et al. (XENON100), Phys. Rev. D 83, 082001 (2011)

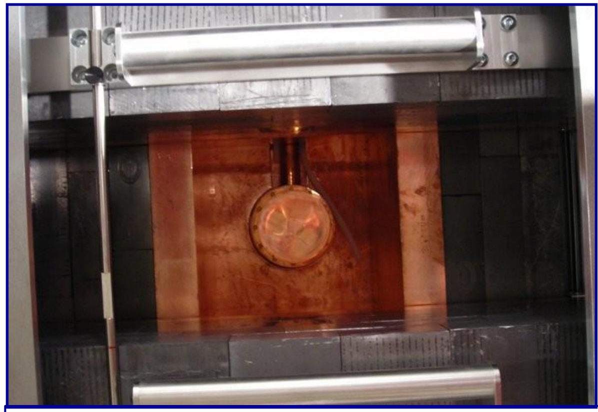
Nuclear recoil (NR) background

✓ Muon-induced fast neutrons

✓ (α,n) reactions and spontaneous fission due to natural radioactivity in the detector and shields materials

E. Aprile et al. (XENON100), J. Phys. G: Nucl. Part. Phys. 40 (2013) 115201

Backgrounds: material screening



✓ GATOR: 2.2kg high purity Ge detector operated by UZH @ LNGS

L. Baudis et al., JINST 6 (2011) P08010

- **All XENON100 construction materials screened and selected**

E. Aprile et al. (XENON100), Astroparticle Physics 35, 43 (2011)

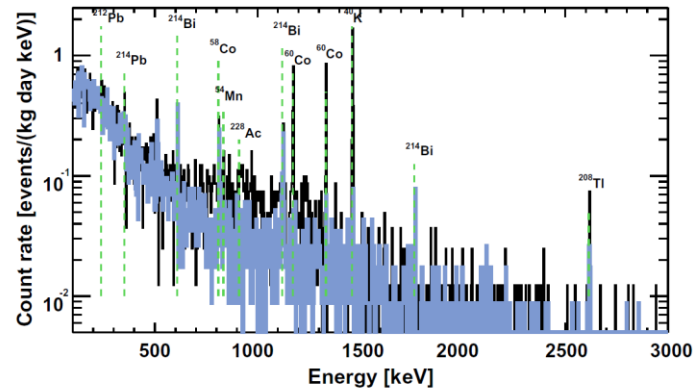
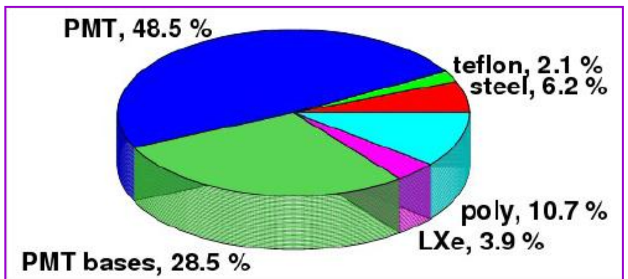


Fig. 1. Example of a measurement with Gator: 7 *Hamamatsu* R8520 PMTs were screened (entry 34 in Table 1). The lines from their intrinsic radioactive contaminations (solid black) are clearly visible above the Gator background spectrum

- Gamma backgroung from events in ROI



- Screening results used for MonteCarlo simulations

Component	Amount	Total radioactive contamination in materials [mBq/amount] ^{238}U / ^{226}Ra	^{232}Th	^{60}Co	^{40}K	other nuclides
Cryostat and 'diving bell' (316Ti SS)	73.61 kg	121.46	147.23	404.87	662.52	
Support bars (316Ti SS)	49.68 kg	64.58	144.07	69.55	352.73	
Detector PTFE	11.86 kg	0.71	1.19	0.36	8.89	
Detector copper	3.88 kg	0.85	0.62	5.21	0.78	
PMTs	242 pieces	60.50	111.32	181.50	1972.30	^{137}Cs: 41.14
PMT bases	242 pieces	38.72	16.94	2.42	38.72	
TPC resistor chain	1.5×10^{-3} kg	1.11	0.57	0.12	7.79	
Bottom electrodes (316Ti SS)	0.23 kg	0.43	0.45	2.14	2.36	
Top electrodes (316Ti SS)	0.24 kg	0.85	0.43	1.73	1.16	
PMT cables	1.80 kg	0.85	1.97	0.37	18.65	^{108m}Ag: 2.67
Copper shield	2.1×10^3 kg	170.80	24.69	6.59	80.26	
Polyethylene shield	1.6×10^3 kg	368.0	150.4	-	1120.0	
Lead shield (inner layer)	6.6×10^3 kg	4.3×10^3	3.6×10^3	7.2×10^2	9.6×10^3	^{210}Pb: 1.7×10^8
Lead shield (outer layer)	27.2×10^3 kg	1.1×10^5	1.4×10^4	2.9×10^3	3.8×10^5	^{210}Pb: 1.4×10^{10}

Backgrounds: the XENON100 passive shield

From outside to inside

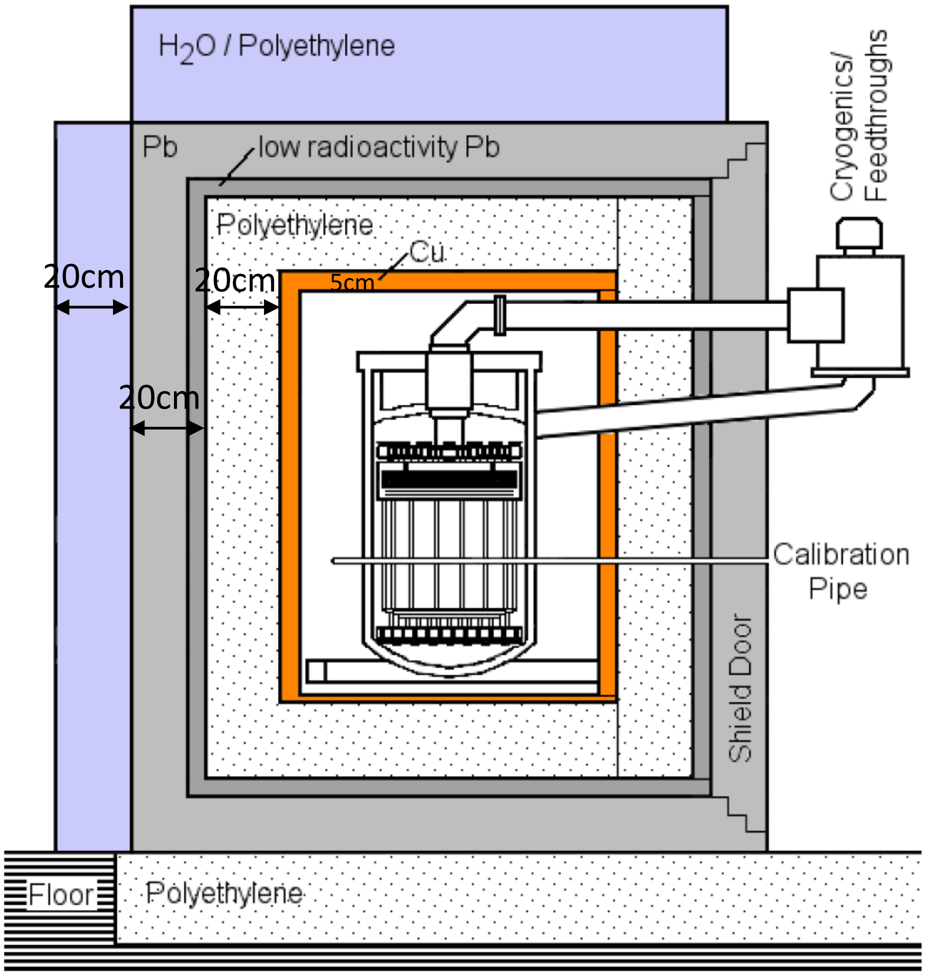
- **20 cm H_2O** (not on all sides)
to moderate neutrons produced
in the cavern rock

- **15 cm Pb + 5 cm low activity Pb**
to stop γ-rays

- **20 cm polyethylene**
to moderate neutrons produced in Pb

- **5 cm Cu**
to stop γ-rays from polyethylene

- **N_2 gas** (17 slpm)
continuously purging the shield cavity
to keep the ^{222}Rn level < 1 Bq/m^3



E. Aprile et al. (XENON100), Astroparticle Physics 35, 573 (2012)

3D sensitivity and background rejection

- **Take advantage of the LXe self-shielding**

✓ Gammas from external sources and detector components are stopped at the edges

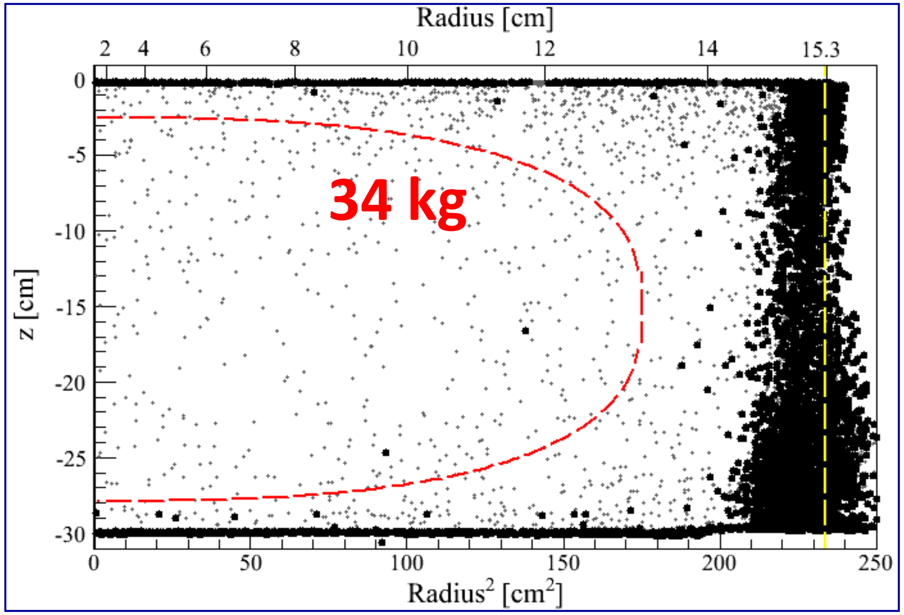
- **Using the 3D position sensitivity for background reduction**

✓ **Fiducialization**: selection of an ultralow-background target volume

✓ Reject all events having a coincident signal in the 99 kg **active veto**

✓ Identification of **single scatters** rejecting the double scatters

✓ Remaining BG dominated by internal impurities (e.g. ^{85}**Kr**)



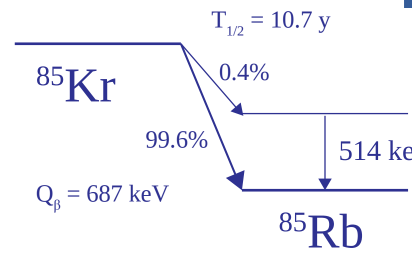
BG from published data (Run10)

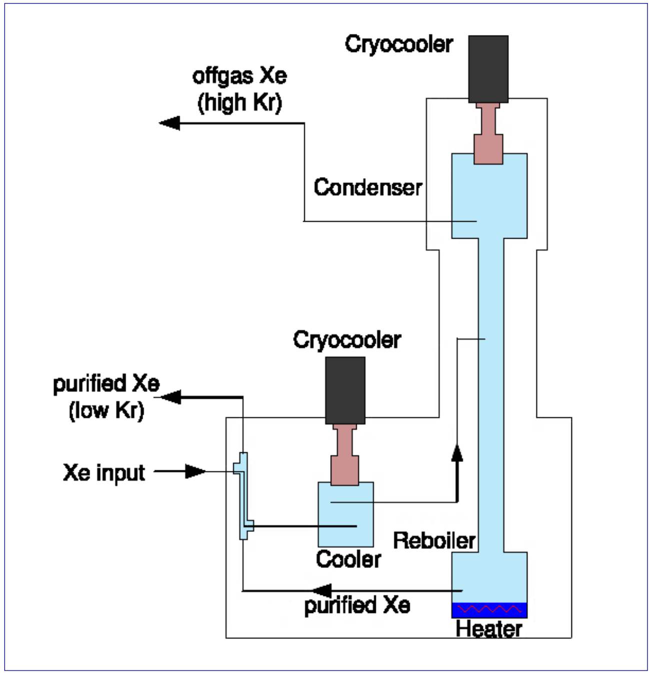
E. Aprile et al. (XENON100), Phys. Rev. Lett. 109, 181301 (2012)

Backgrounds: ^{85}Kr removal from LXe

- **Xe** has no long lived isotopes but it **contains ^{nat}Kr at ppb level**
- **Kr contamination of 7 ± 2 ppb** measured in the commercial Xe filling XENON100
- **^{nat}Kr contains ^{85}Kr with 2×10^{-11}** isotopic abundance, giving an uniformly distributed BG from β^- -decay (Q_β = 687 keV, $T_{1/2}$ = 10.7 y)
- **A cryogenic distillation column** installed next XENON100 is used to reduce the Kr conc. to ppt level
- **After purification** the Kr concentration has been reduced to **19 ± 4 ppt** in Run10

E. Aprile et al. (XENON100), Astroparticle Physics 35, 573 (2012)



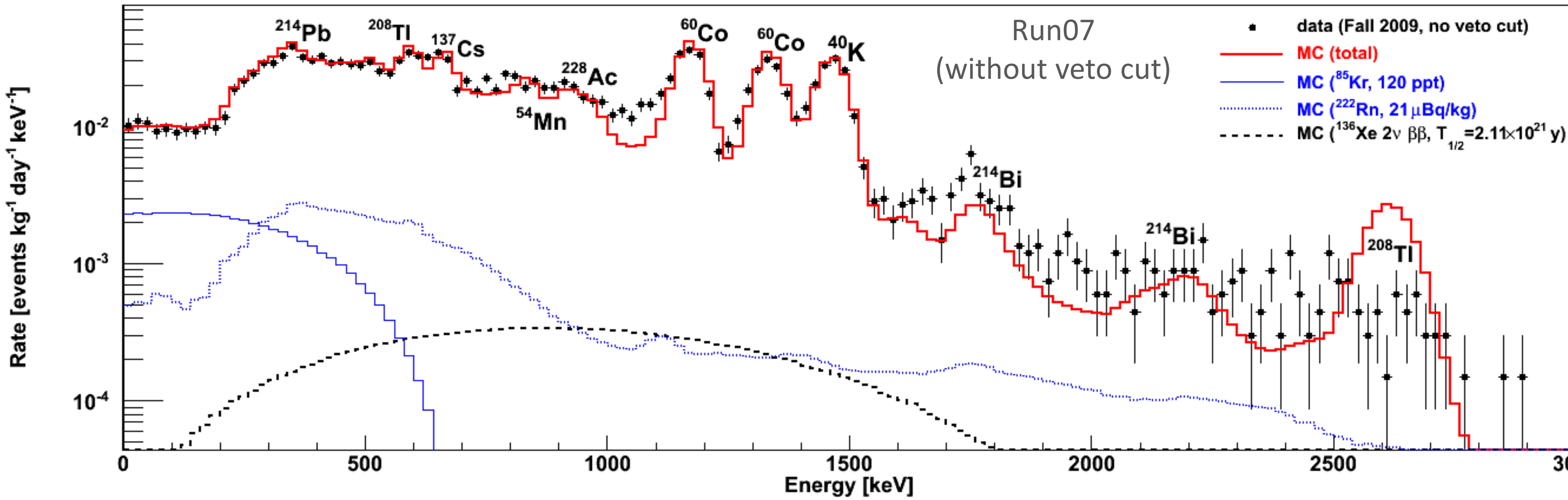


Boiling point @1atm:

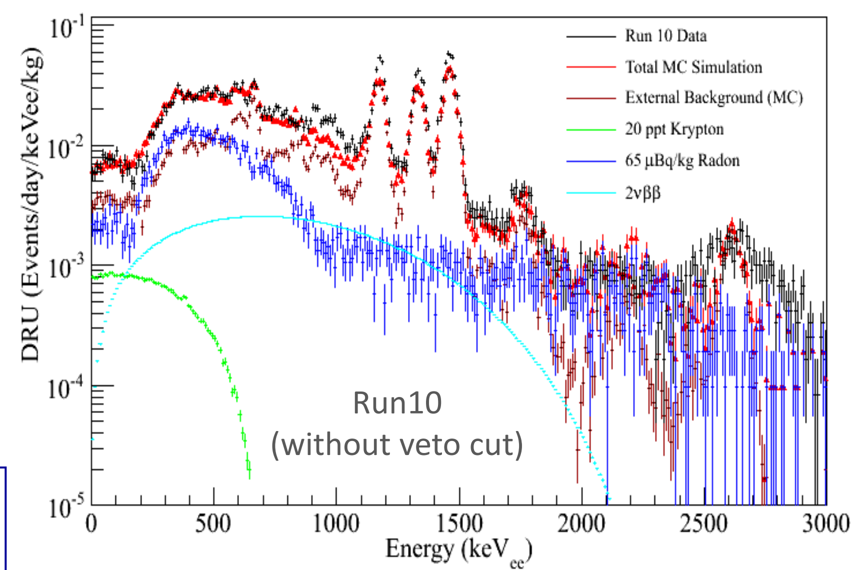
- ✓ 120K for Kr
- ✓ 165K for Xe

Electromagnetic background in XENON100

E. Aprile et al. (XENON100), Phys. Rev. D 83, 082001 (2011)



- **ER background: excellent agreement between MC simulations and measured data in the full energy range**
  - ✓ Activity taken from screening measurements only
  - ✓ No MC rate tuning!
- **Measured single scatter rate below 100keV**
  - ✓Before LXe veto cut: ~ 10^{-2} evts/kg/keV/day
  - ✓After LXe veto cut: **5×10^{-3} evts/kg/keV/day**



- **Factor 100 lower BG than XENON10 with factor 10 more mass**
- **Lowest BG ever achieved in DM experiments**

Nuclear recoil background and predictions

- **Nuclear recoil (NR) background**

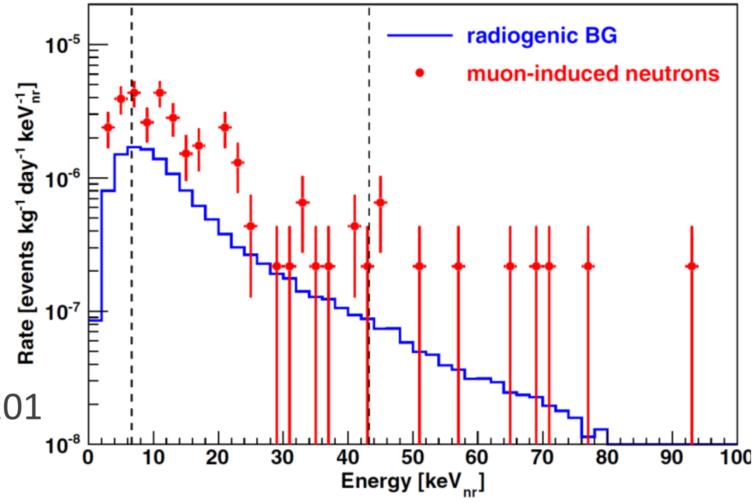
✓ NR background prediction based on MC simulations (GEANT4) with exact geometry and measured radioactive contaminations of all the detector components

(1) Muon-induced fast neutrons (70% of the total)

(2) (α,n) reactions and spontaneous fission due to natural radioactivity in the detector and shields materials

- NR BG expectation for Run10: **0.17 +0.12 -0.07 events**

✓ Not limiting the sensitivity of the experiment



E. Aprile et al. (XENON100), J. Phys. G: Nucl. Part. Phys. 40 (2013) 115201

- **Electronic recoil (ER) background**

✓ ER background prediction based on data from ^{60}Co/^{232}Th calibration sources and non-blinded background data

- ER BG expectation for Run10: **0.79 ± 0.16 events**

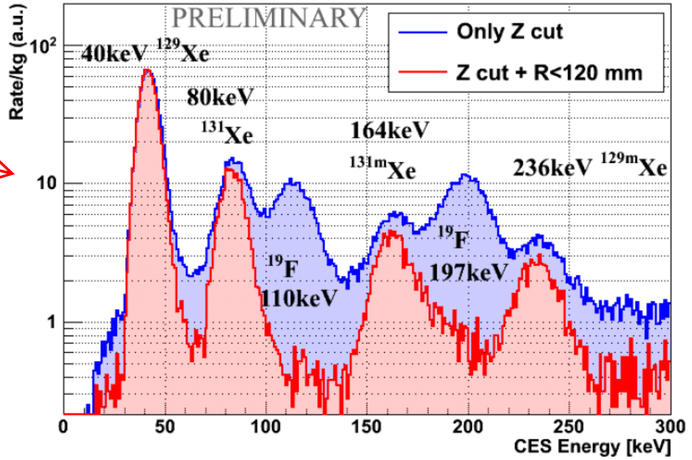
- **Total background prediction for Run10: 1.0 ± 0.2 events**

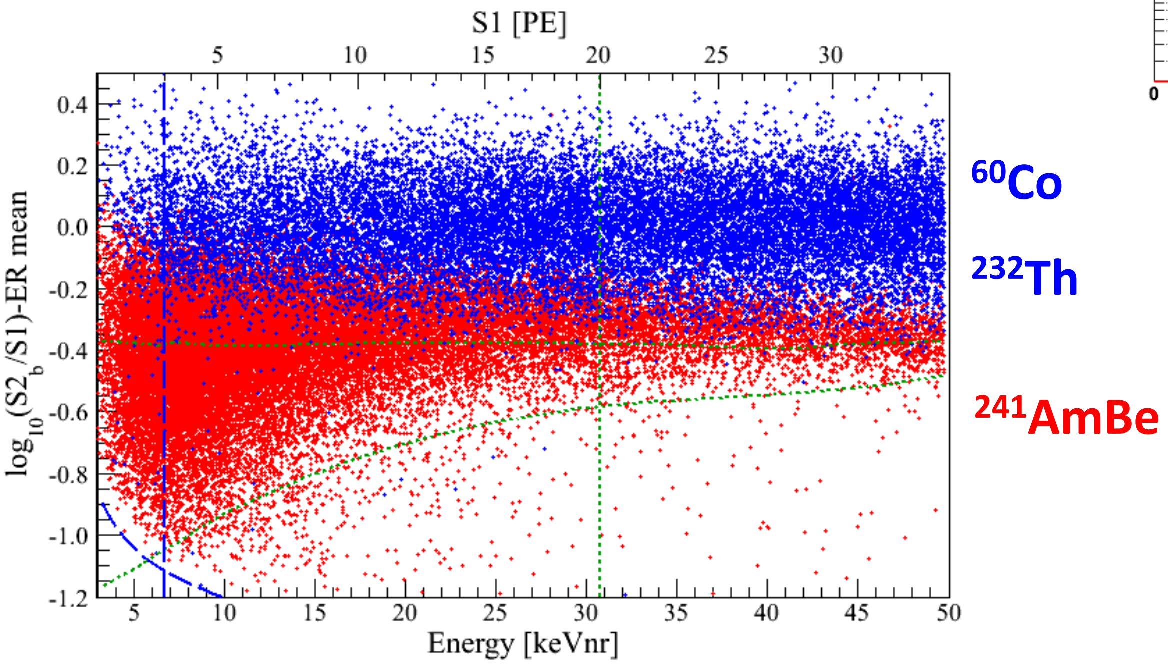
Calibrations and ER / NR discrimination

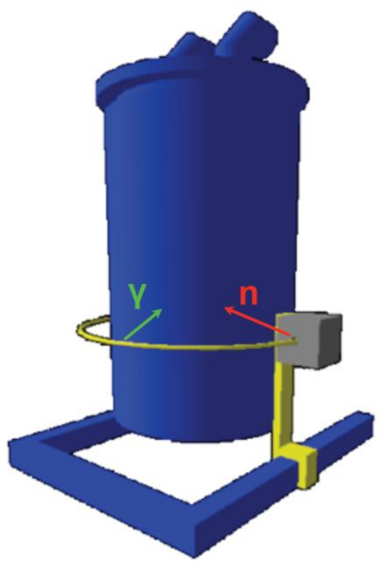
- ✓ **ER band** calibrated with **^{60}Co & ^{232}Th** sources
- ✓ **NR band** calibrated with **^{241}AmBe** source

$(S2/S1)_{NR} \ll (S2/S1)_{ER}$

ER lines during neutron calibration

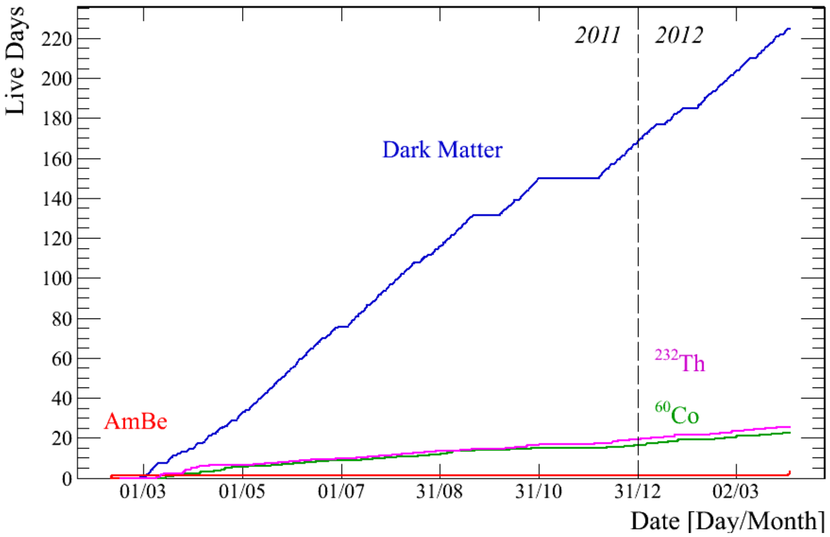




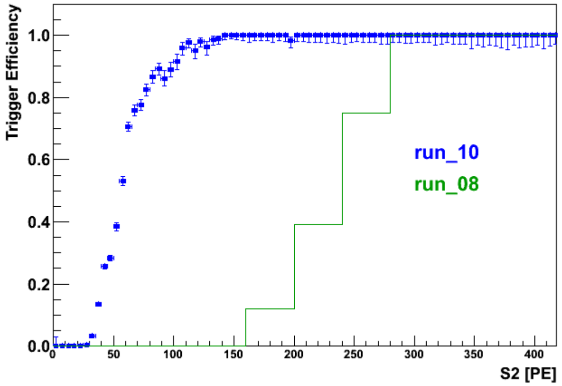


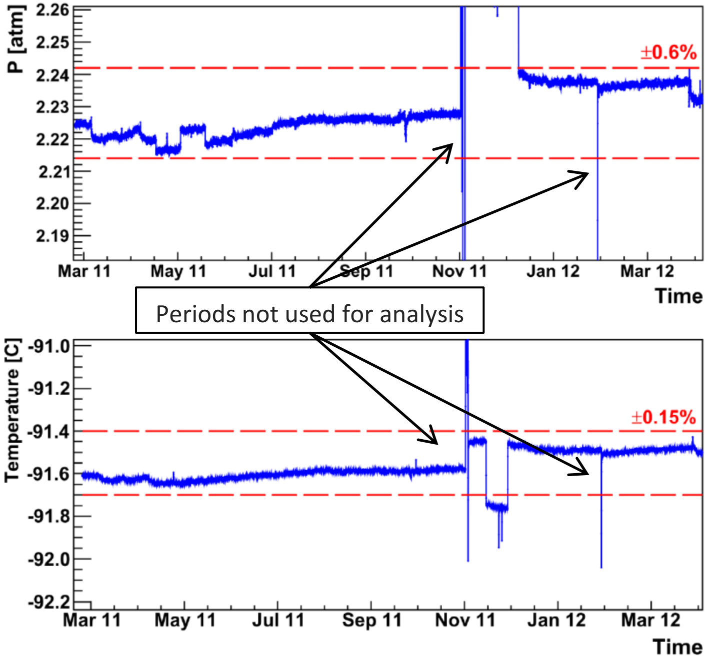
E. Aprile et al. (XENON100), arXiv: 1207.3458

XENON100 Run10: 225 live days



- **Data taking: 28 Feb 2011 – 31 March 2012**
  - ✓ More than double exposure than Run08
  - ✓ Improved statistics of ER & NR calibrations
  - ✓ Improved LXe purity (factor 10 lower ^{85}Kr)
  - ✓ Lower thresholds: S1 > 3 PE and S2 > 150 PE
  - ✓ Excellent stability of the detector parameters
  - ✓ Data following maintenances are removed





E. Aprile et al. (XENON100), JINST 7 (2012) T12001

- **XENON100 is the 1st large size LXe detector operated continuously in stable conditions for that long (to our knowledge)**

Blind data analysis

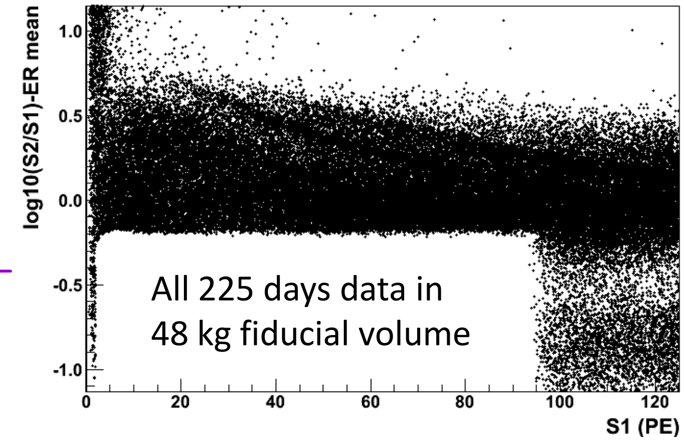
Blind analysis (data is blinded between 2 - 100 PE)

✓ The analysis (data quality and topology selection) is defined on calibration data (^{241}AmBe, ^{232}Th , ^{60}Co, BG outside ROI)

Detector stability

✓ Selection of periods with stable HV, low Rn level, stable thermodynamics of the detector (P, T, …)

(1)



Selection of physical interactions

✓ Reject noise, stability of PMTs, S1 seen by at least 2 PMTs

Selection of single scatters (WIMPs make a single interaction)

✓ Only one S2 peak, only one S1 peak, active veto cut

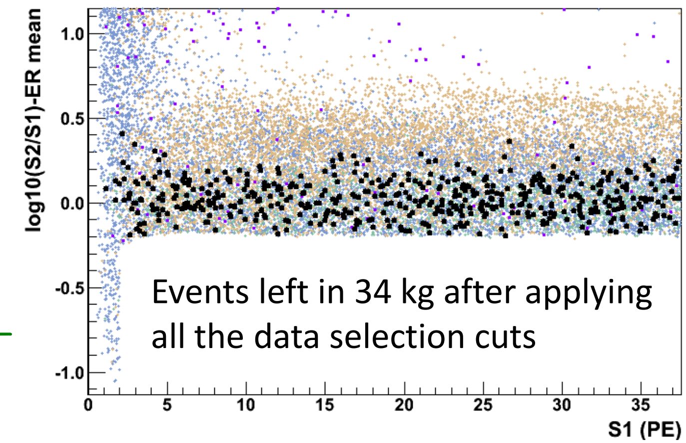
Consistency Cuts

✓ S1 and S2 PMT hit patterns and S2 pulse width consistent with a single interaction vertex at the reconstructed position

Fiducialization

✓ 34 kg elliptic volume

(2)

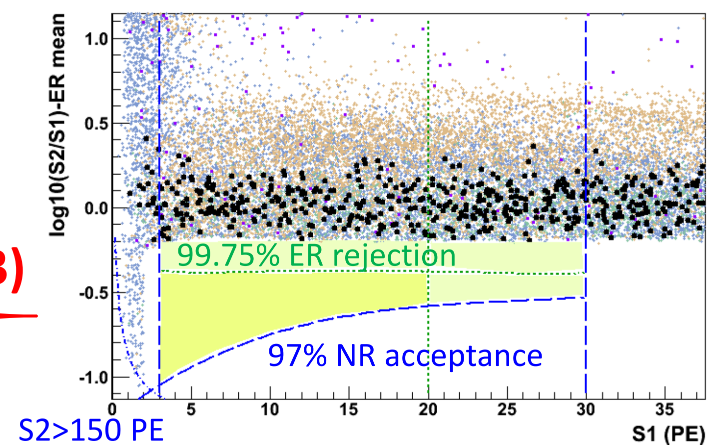


Definition of WIMP search region (ROI)

✓ (3<S1<20 or 30) PE, 97% NR acceptance, 99.75% ER rejection

✓ Trigger threshold S2 > 150 PE is irrelevant for this analysis

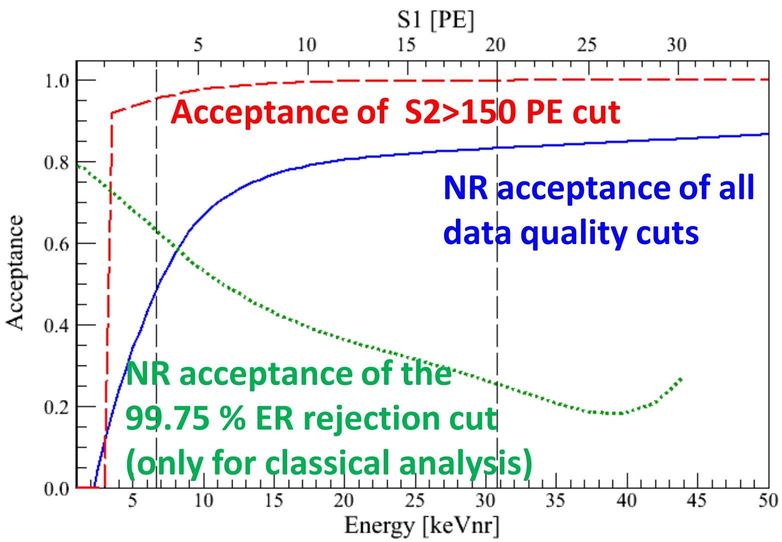
(3)

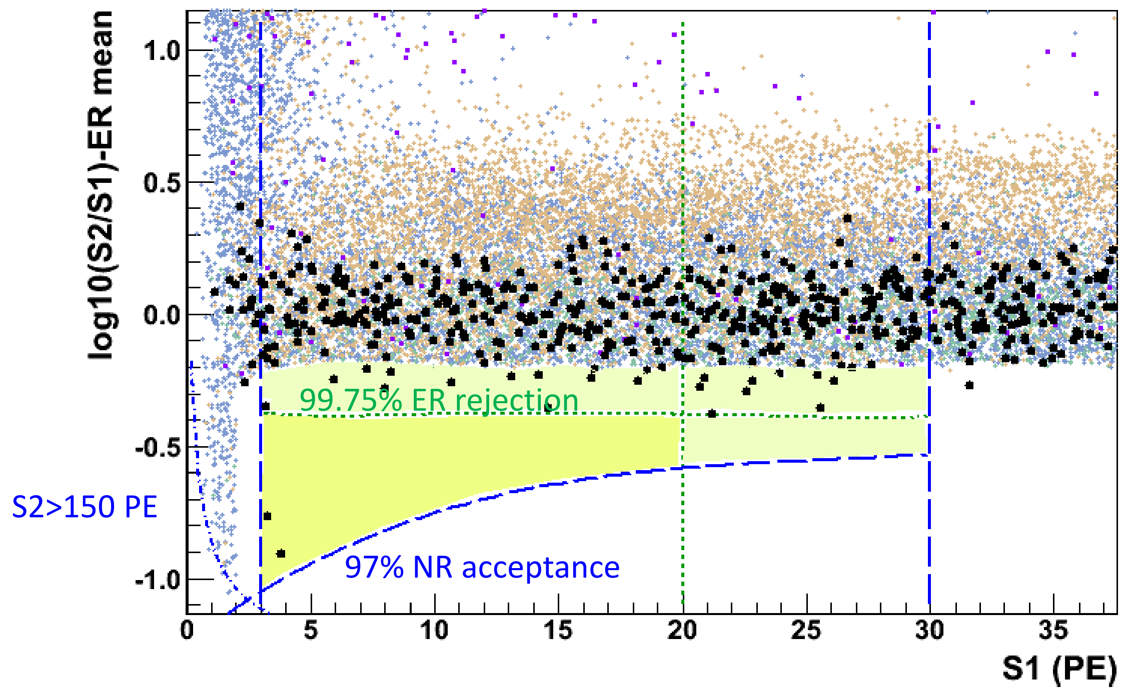


E. Aprile et al. (XENON100), arXiv: 1207.3458

Unblinding 225 days

- ✓ **Cut-based analysis:** (3<S1<20) PE, 97% NR acceptance, 99.75% ER rejection at 50% NR acceptance
- ✓ **Profile Likelihood analysis:** (3<S1<30) PE
- ✓ Trigger threshold S2 > 150 PE is irrelevant for Run10





- **After all the analysis is fixed**
- **2 events are found** in the predefined benchmark region

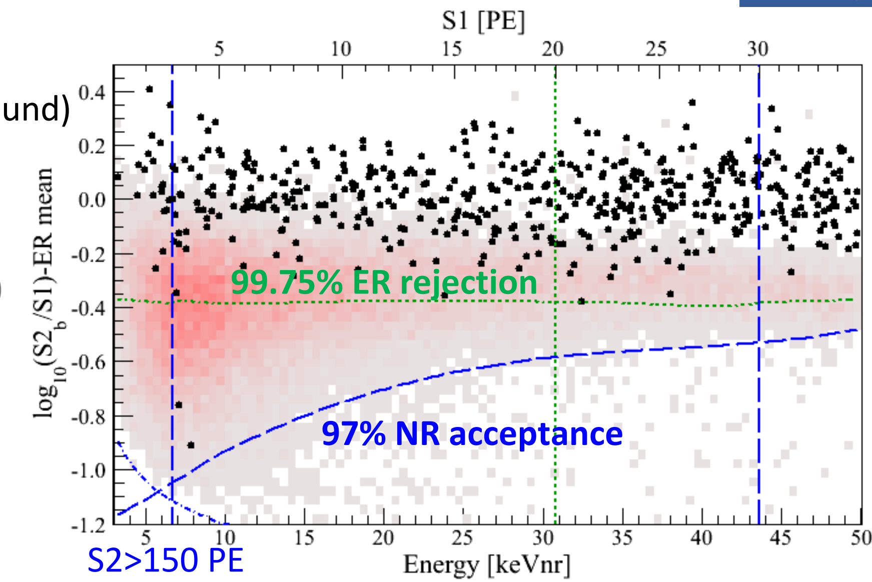
E. Aprile et al. (XENON100), Phys. Rev. Lett. 109, 181301 (2012)

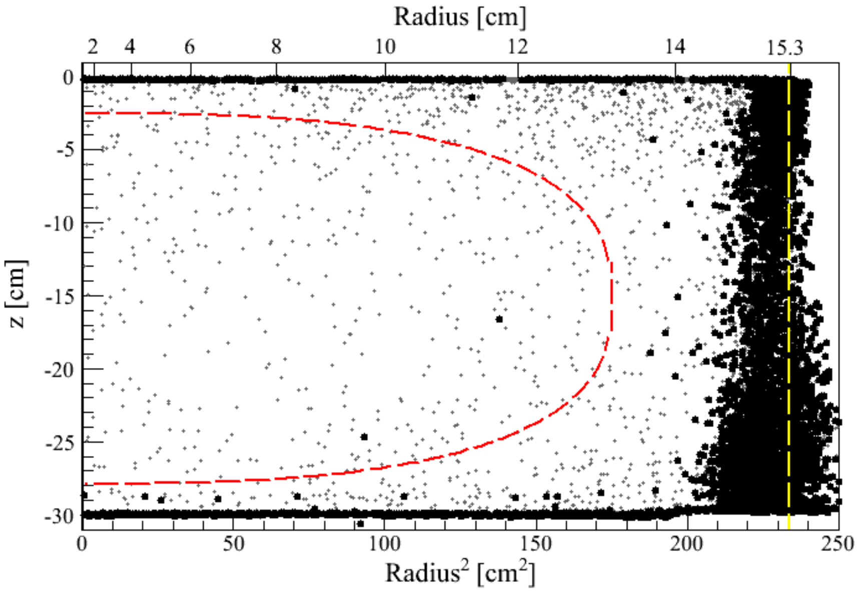
Unblinding 225 days of XENON100 data

- **XENON100 Run10**
  - ✓ 224.6 live days of data
  - ✓ 34 kg fiducial volume
  - ✓ Data blinded in WIMP ROI
- **Background expectation**

(1.0 ± 0.2) event in 224.6 days

- ✓Expected **ER** leakages = **0.79 ± 0.16** (by calibration)
- ✓ **NR** background prediction = **0.17** $^{+0.12}_{-0.07}$ (by MC)
- ✓ Verified on the high energy sideband



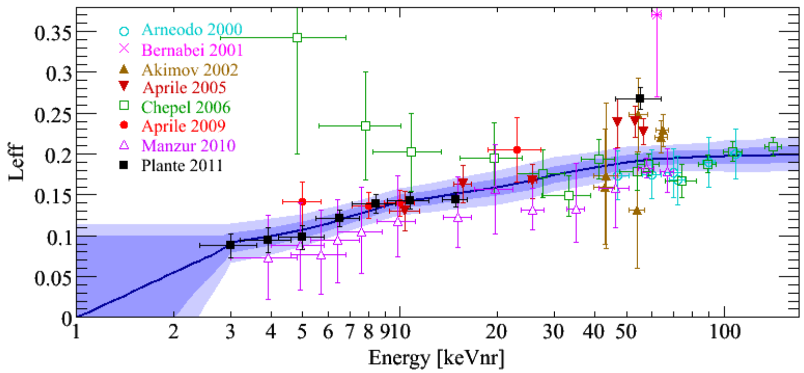


- **After unblinding: 2 WIMP-like candidates** inside the predefined ROI & 34 kg fiducial volume @ 3.3 and 3.8 PE

  (1) 26.4% Poisson probability that background oscillated to 2 events
  (2) Profile Likelihood analysis does not reject the background only hypothesis
  → **No evidence of dark matter in the data**
  → Calculate upper limit

E. Aprile et al. (XENON100), Phys. Rev. Lett. 109, 181301 (2012)

Spin-Independent Results



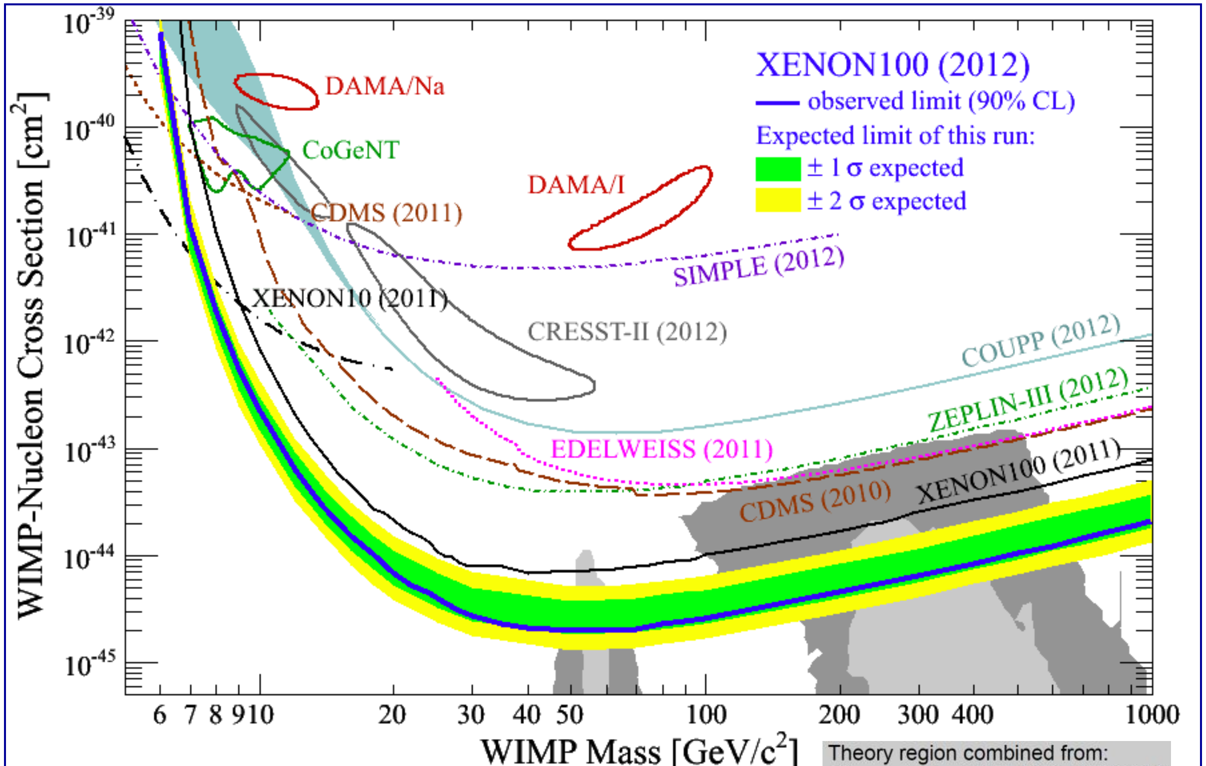
✓ L_{eff} global fit of available data, including new data (G. Plante et al., Phys. Rev. C 84, 045805 (2011))

✓ Blue band represents uncertainties

✓ Logarithmic extrapolation below 3 keV_{nr} to L_{eff} = 0 at 1 keV_{nr} (including large uncertainty)

v_0 = 220 km/s v_{esc} = 544 km/s ρ_0 = 0.3 GeV/cm^3

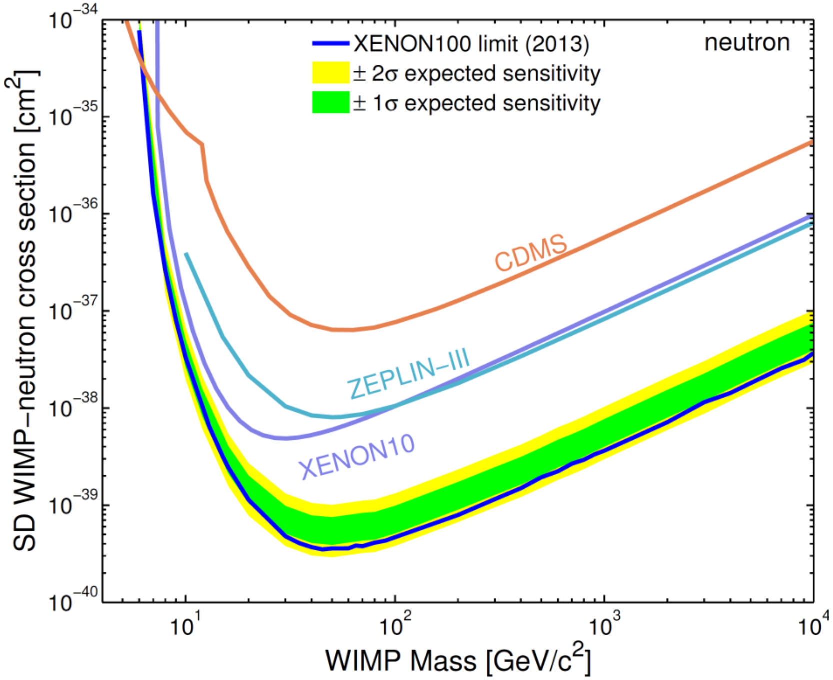
- **The limit on SI WIMP-nucleon elastic scattering cross section** is extracted by **Likelihood analysis**
- **World's most sensitive limit** over a large WIMP mass range
  $\sigma < 2.0 \times 10^{-45}$ cm^2
  for a 55 GeV/c^2 WIMP at 90% c.l.
- **It excludes** part of the predicted region for SUSY candidates and other signal indications above (CoGeNT, DAMA, CRESST-II)

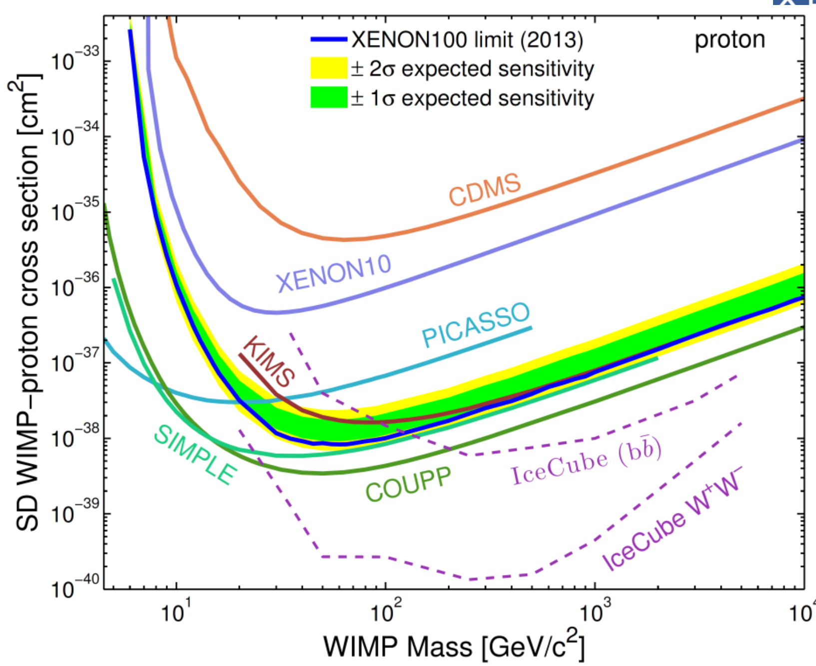


Theory region combined from:
Strege et al., JCAP 1203, 030(2012)
Fowlie et al., arXiv:1206.0264
Buchmueller et al., arXiv:1112.3564

E. Aprile et al. (XENON100), Phys. Rev. Lett. 109, 181301 (2012)

Spin-Dependent Results





- **Isotopes with a non-zero nuclear spin: 26.2% of ^{129}Xe ($J^\pi = 1/2^+$) and 21.8% of ^{131}Xe ($J^\pi = 3/2^+$)**
- **Set limit on pure WIMP-neutron and pure WIMP-proton cross sections**

✓ Same data and event selection as the SI search: 224.6 live days x 34 kg of exposure

✓ Nuclear model used: *Menendez et al.*, Phys. Rev. D86, 103511 (2012)

(1) Most sensitive limit on pure neutron coupling above 6 GeV/c^2

$\sigma_n < 3.5 \times 10^{-40}$ cm^2 for a 45 GeV/c^2 WIMP at 90% c.l.

(2) Competitive limit on pure proton coupling

weaker sensitivity because ^{129}Xe & ^{131}Xe have an unpaired neutron but even number of protons

E. Aprile et al. (XENON100), Phys. Rev. Lett. 111, 021301 (2013)

Control of systematics: NR response

- **Verification of the Nuclear Recoil energy scale**

✓ XENON100 NR energy scale includes all the measurements of direct neutron scattering experiments

- **Monte Carlo simulation of AmBe neutron source**

✓ Simulation of both **scintillation (S1)** and **ionization (S2)** signals

- **Basic steps**

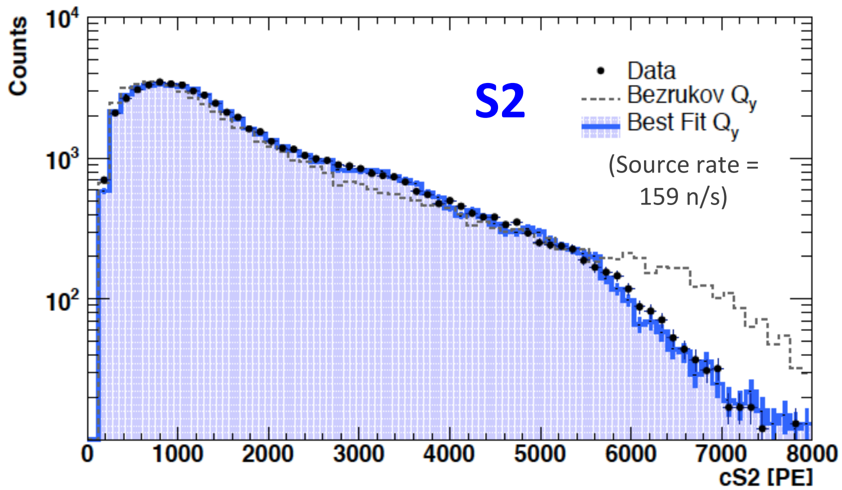
✓ Input AmBe spectrum (ISO 8529-1 standard). Analysis robust against variations of this spectrum

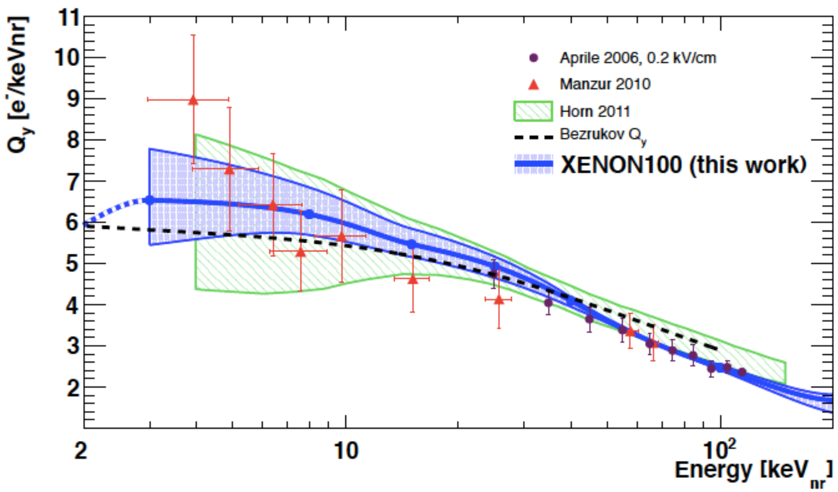
✓ Source strength measurement (PTB, Germany): **(160 ± 4) n/s**

✓ Complete MC description of the detector including detector shield (water, lead, polyethylene, copper)

✓ **E_{dep} is converted to S1 and S2** using L_{eff} and Q_y including thresholds, resolutions and acceptances from data

Step 1: using L_{eff} from direct measurements → reproduce S2 spectrum → obtain optimum Q_y

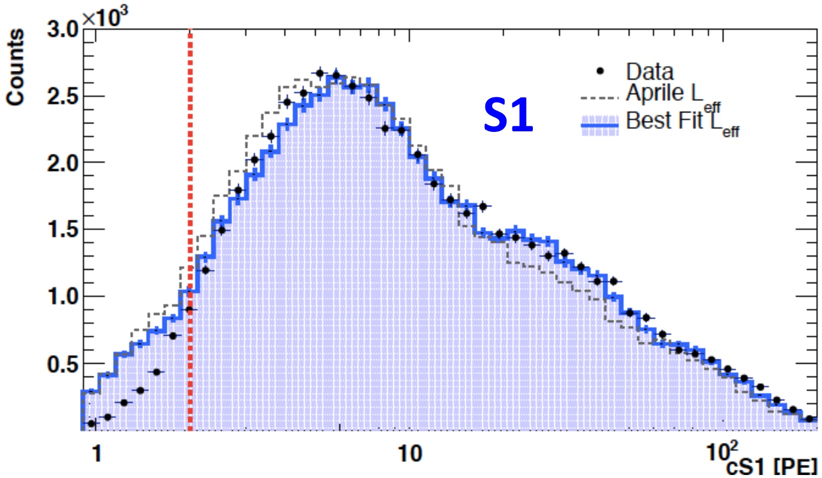


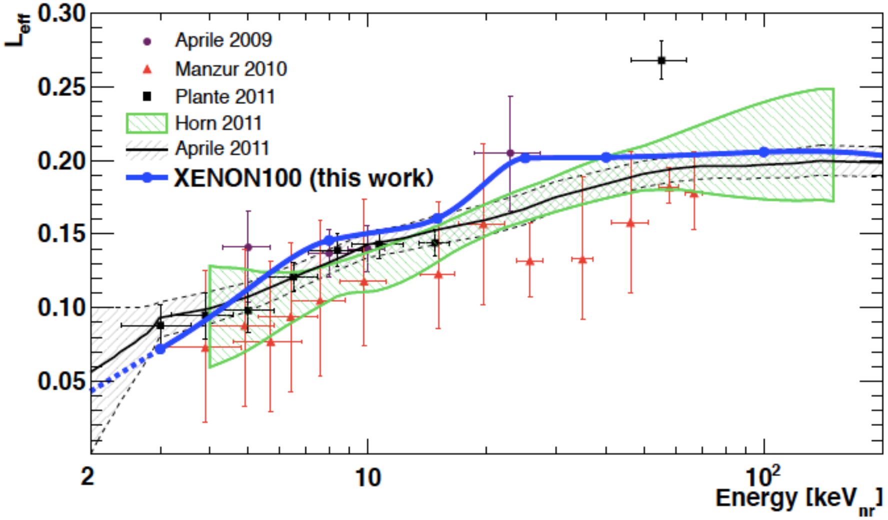


E. Aprile et al. (XENON100), Phys. Rev. D 88, 012006 (2013)

Control of systematics: NR response

Step 2: using the obtained Q_y → reproduce S1 spectrum → obtain a new L_{eff}





- **Excellent agreement over the whole spectrum down to 2 PE (~ 5 keV_{nr})**

  ✓ Poor agreement below 2 PE due to unknown efficiencies below threshold

- **L_{eff} from best fit matches perfectly to the previous measurements**

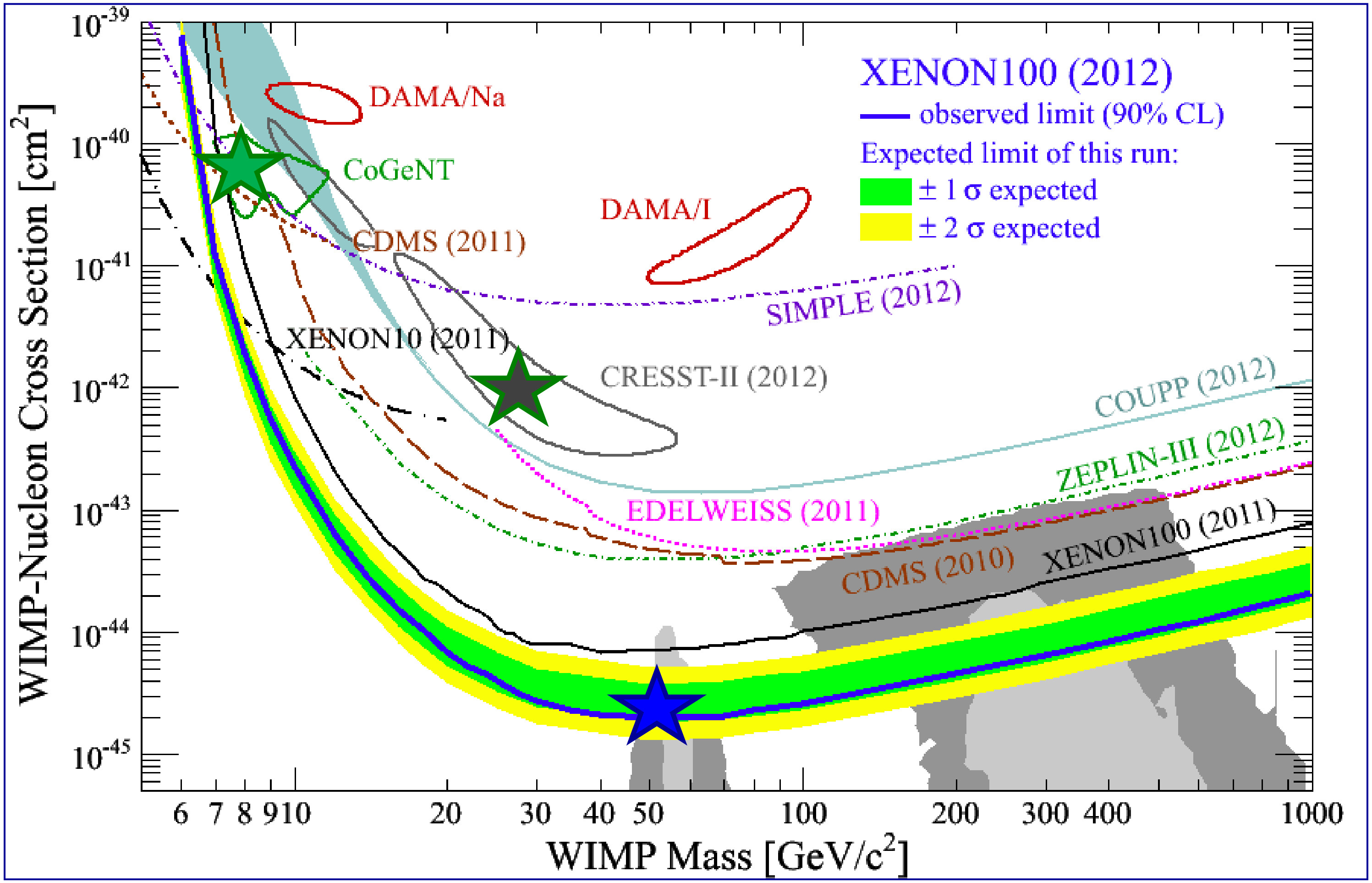
  ✓ Consistency strengthens the reliability of analysis

→ Results of XENON100 remain unchanged using this L_{eff}

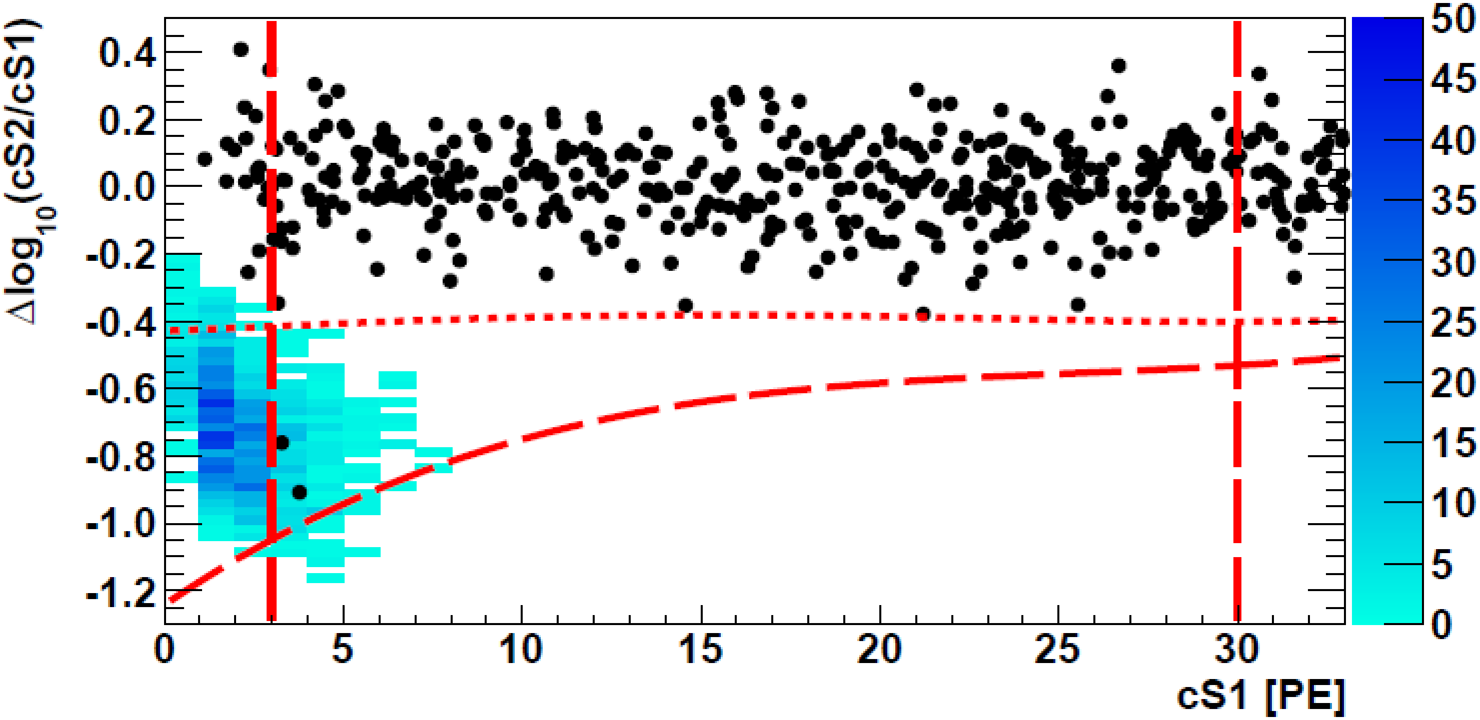
→ Excellent understanding of the detector response to NRs

E. Aprile et al. (XENON100), Phys. Rev. D 88, 012006 (2013)

What XENON100 would see if...



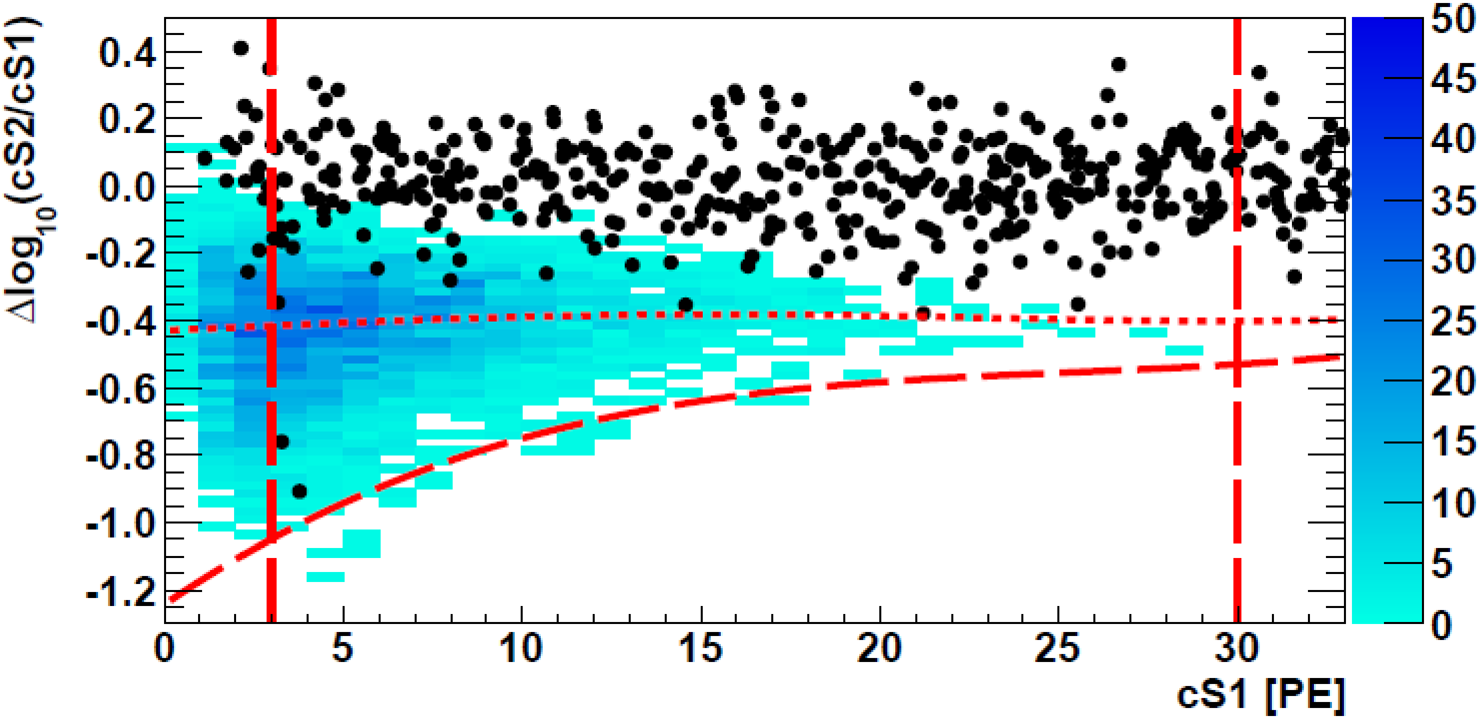
Assume CoGeNT signal
(σ = 3 x 10^{-41} cm^2, m_χ = 8 GeV/c^2)



XENON100 would observe > 200 events in signal region

E. Aprile et al. (XENON100), Phys. Rev. D 88, 012006 (2013)

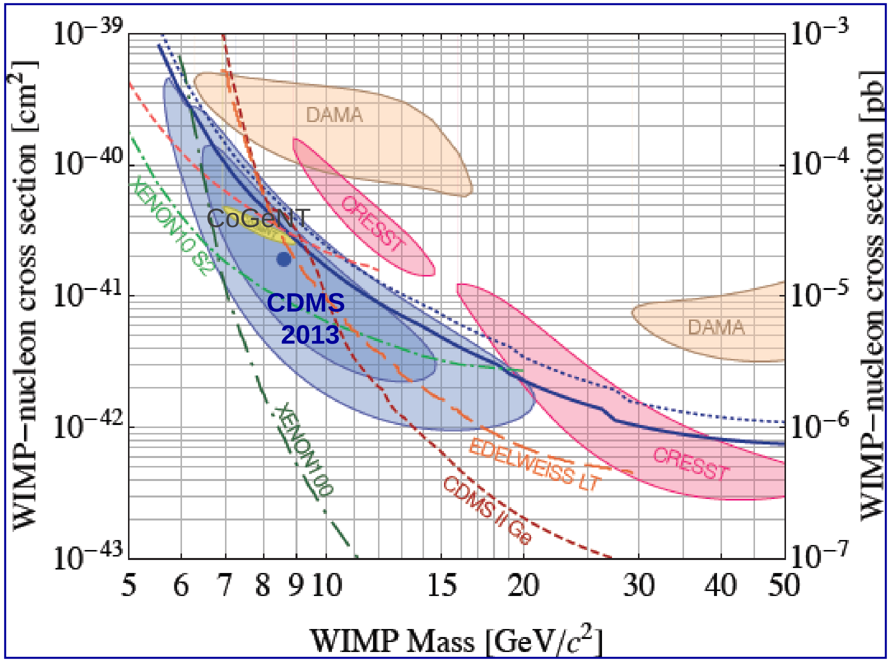
Assume CRESST signal
(σ = 1.6 x 10^{-42} cm^2, m_χ = 25 GeV/c^2)

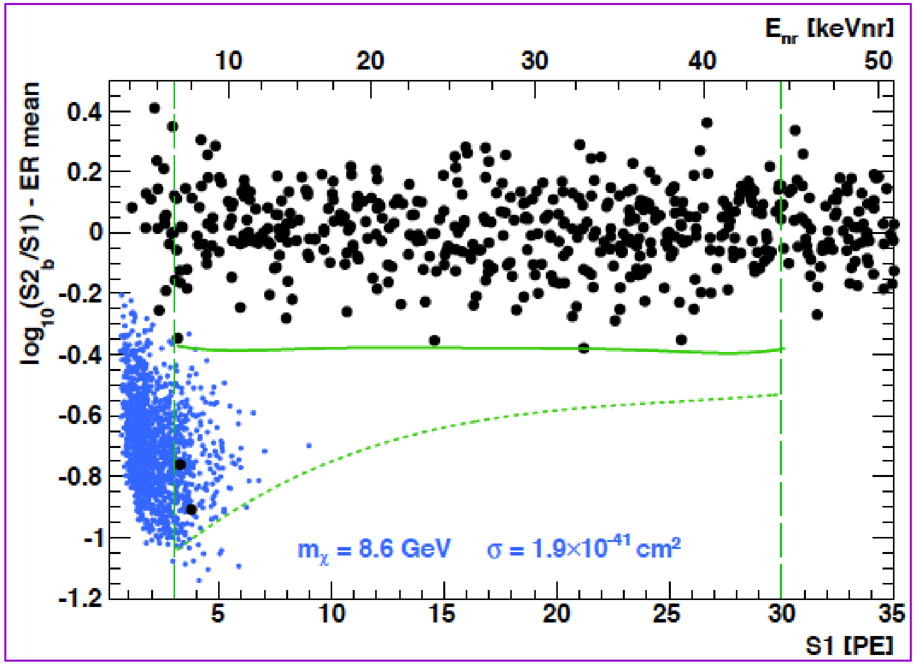


XENON100 would observe > 1400 events in signal region

E. Aprile et al. (XENON100), Phys. Rev. D 88, 012006 (2013)

Assume CDMS signal (1.9 x 10^{-41} cm^2)





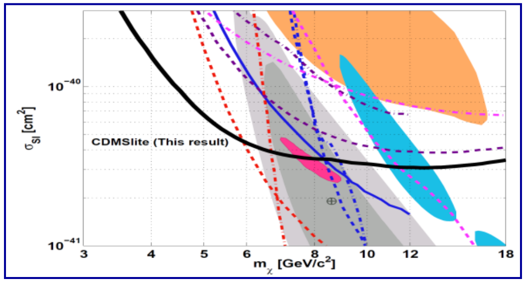
✓ CDMS best fit at 1.9 x 10^{-41} cm^2 at 8.6 GeV/c^2

WIMP mass: CDMS Collaboration, arXiv: 1304.4279

XENON100 would observe > 200 events

✓ New results of CDMSlite cut away the upper part of the CDMS allowed region:

CDMS Collaboration, arXiv: 1309.3259



XENON100: future goals

Ongoing physics analyses

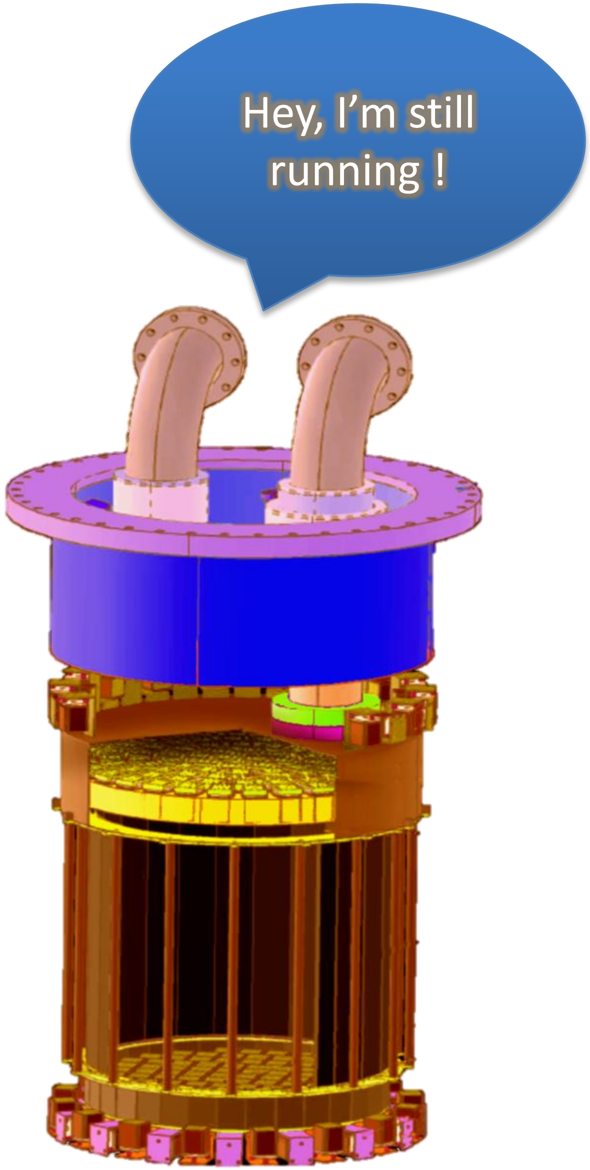
- ✓ Search for annual modulation in low-energy ER
- ✓ Search for solar and galactic axions
- ✓ Light dark matter (using an S2-only analysis)

Improve detector characterization

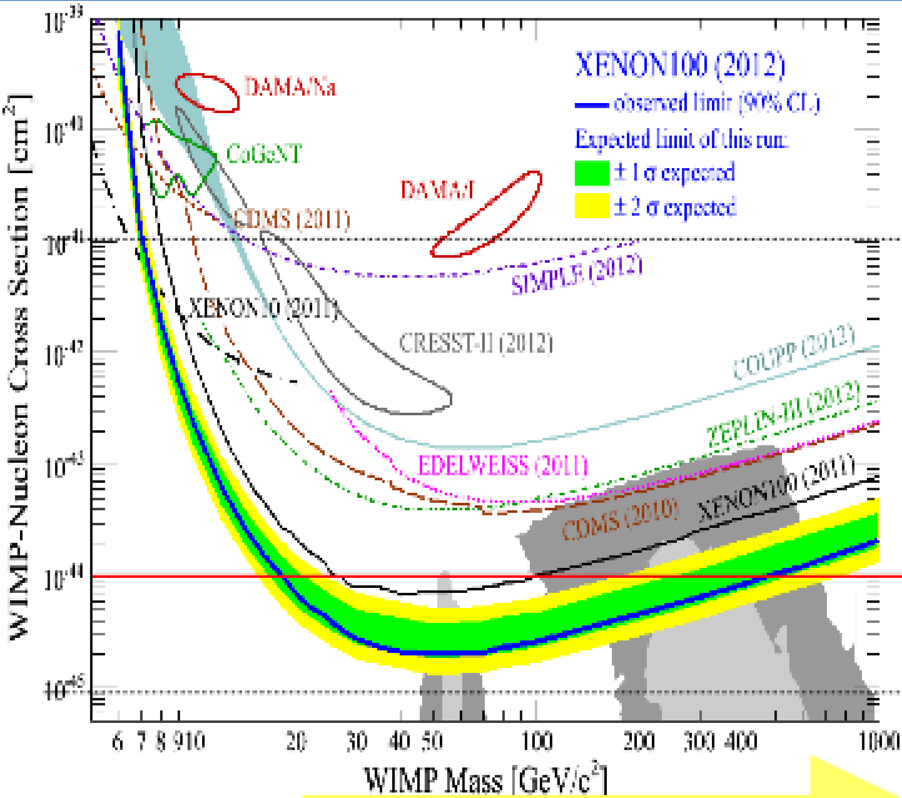
- ✓ Response to single electrons
- ✓ Combine S1 and S2 energy scales for NR

Continuing data acquisition

- ✓ Performed a new AmBe calibration for NR
- ✓ Further reduction of Kr: now at **0.95 ppt**
- ✓ Test new ideas to calibrate XENON1T

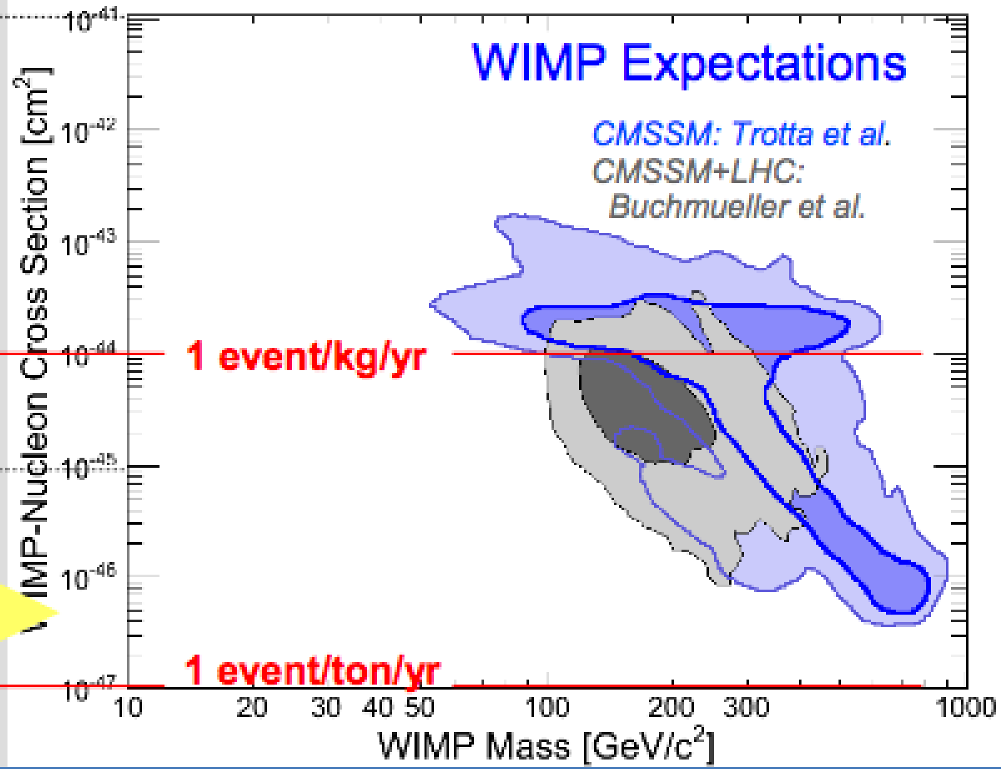


The next future: XENON1T



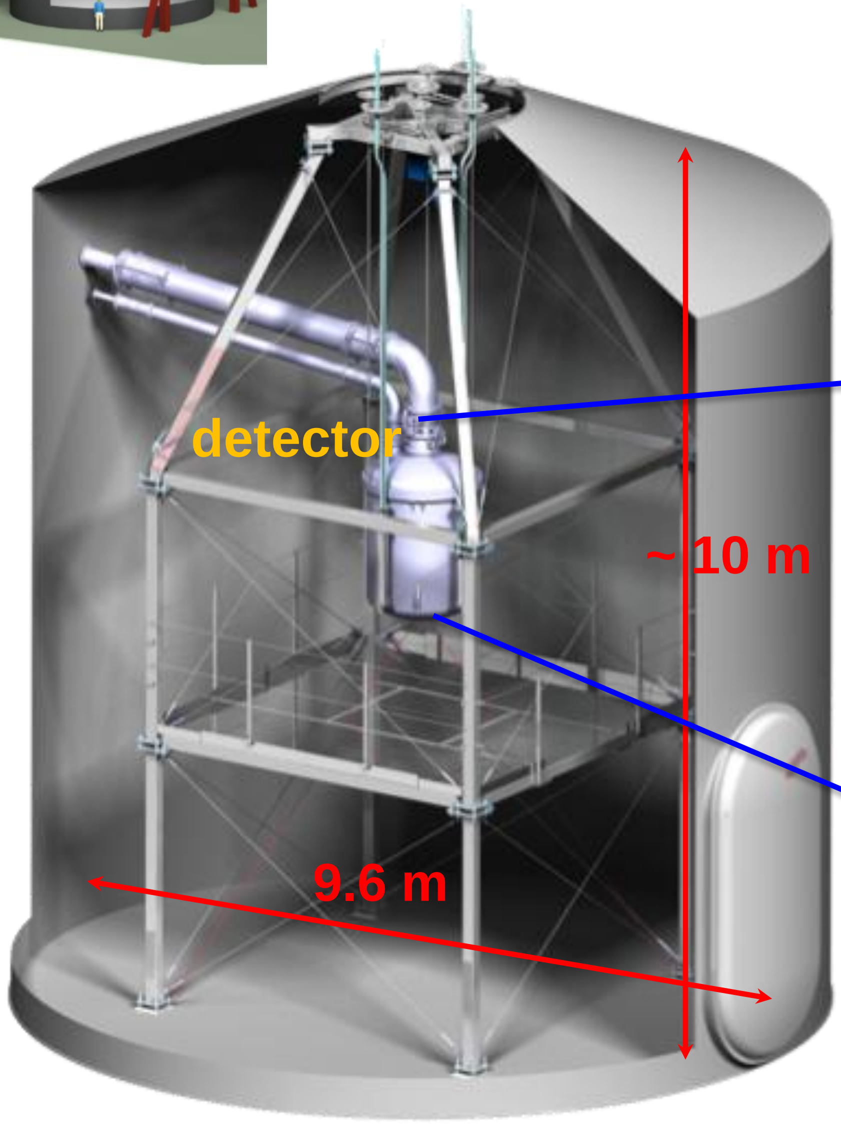
How do we get there?

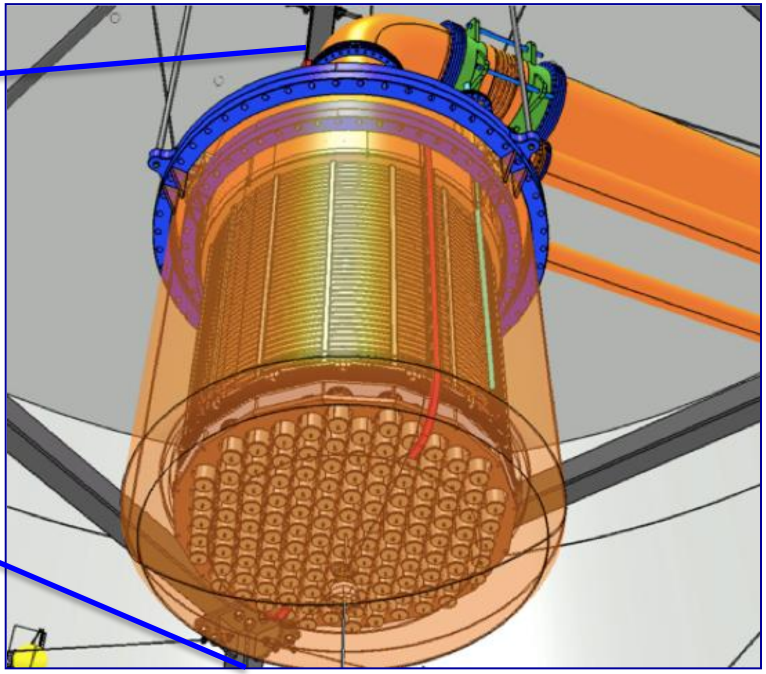
- **XENON100 started probing the region for SUSY candidates…**
- **… but we want to explore further!**



XENON1T

- ✓ **1 m** drift TPC with **3.5 ton** of LXe in total
- ✓ **10 m** water shield as a passive neutron shield and a Cherenkov veto
- ✓ Fully funded and under construction @LNGS

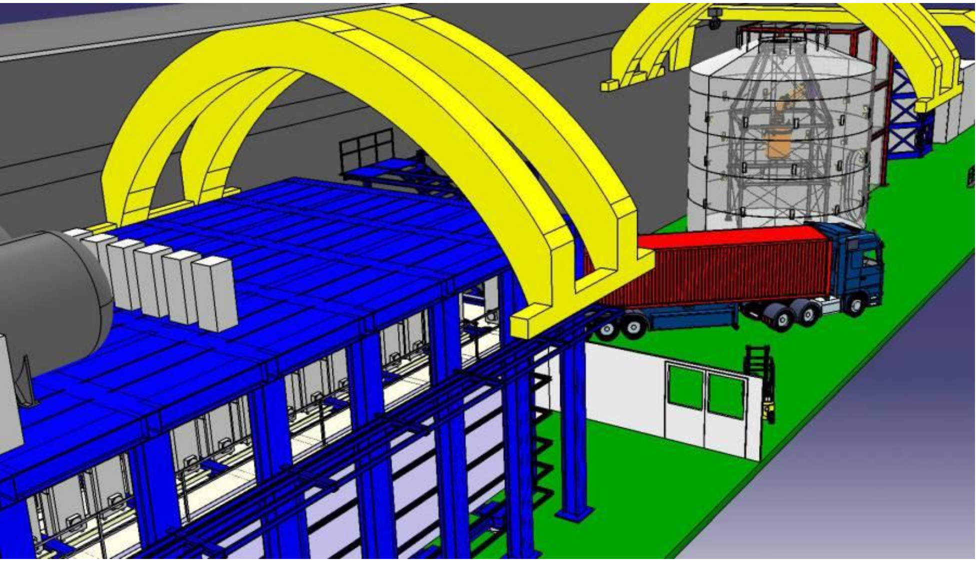




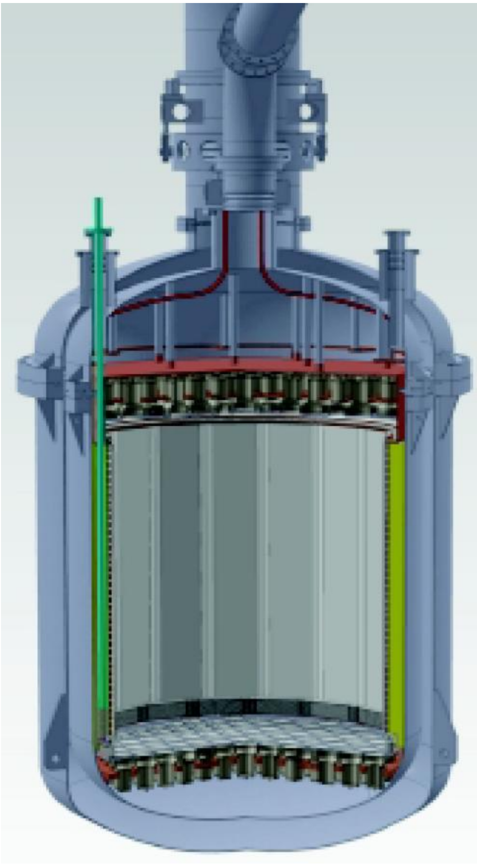
The XENON1T location

Status of XENON1T: under construction!

- **Construction of the support building and water tank started in summer 2013**
  - ✓ Installation completed by the end of the year
- **Other major systems will be installed since January 2014**
- **Commissioning in late 2014**
- **Science data in 2015**

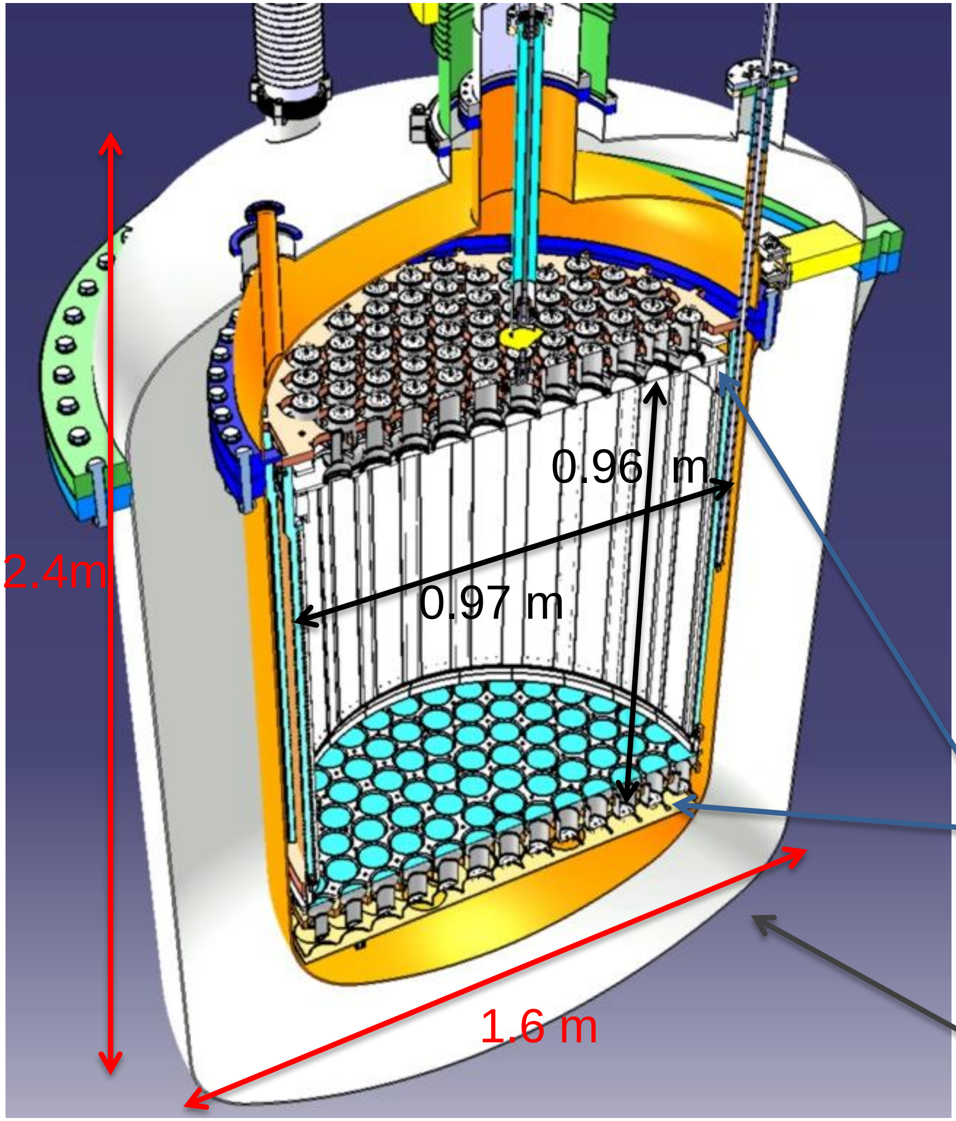


Detector design



- **Cryostat**
  - ✓ Double-walled Ti stainless steel vacuum insulated
  - ✓ 1.5 m high by 1.3 m diameter
- **TPC**
  - ✓ Teflon UV reflector
  - ✓ 248 low radioactivity PMTs
- **Cryogenics**
  - ✓ 200 W pulse tube refrigerators
  - ✓ Long term stability in XENON100
  - ✓ Redundant system
- **Purification**
  - ✓ Xenon continuous recirculation
  - ✓ Two heated getters in parallel
  - ✓ High recirculation rate (~ 100 slpm)

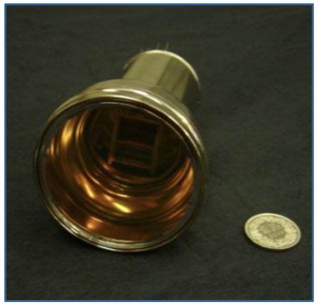
The XENON1T detector



- **TPC with 1m drift length x 1m diameter**
  - ✓ High voltage **100 kV** (field 1kV/cm)
- **Total LXe mass 3.5 ton**
  - ✓ **2 ton** active inside the TPC
  - ✓ Part of the outside LXe used as an **active veto**
  - ✓ **1 ton** sensitive target (fiducial volume)
- **Background goal < 1 ev in 2 ton-year exposure**
  - ✓ Factor **100** lower background than XENON100
  - ✓ Low radioactivity components
  - ✓ ~ 10 cm self-shielding

248 low radioactivity photon detectors

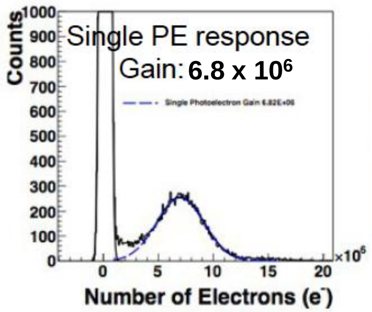
Cryostat in low radioactivity stainless steel

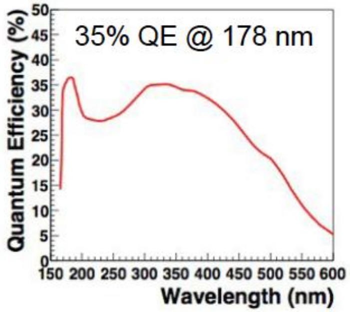


The XENON1T PMTs

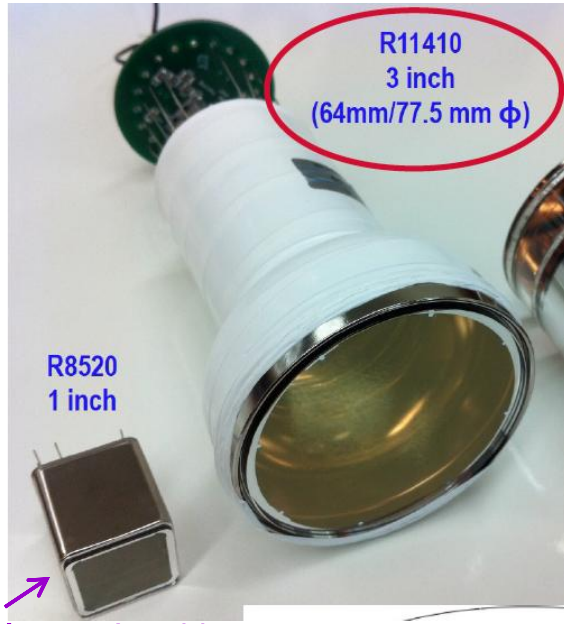
PMTs

- ✓ Low radioactivity 3” PMTs Hamamatsu R11410
- ✓ 2 arrays of **121 (bottom)** + **127 (top)** PMTs
- ✓ QE 30% min., > 35% achieved @178nm
- ✓ Ongoing program for screening and test in LXe



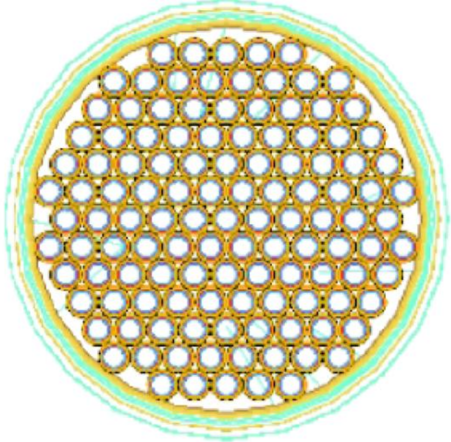


K. Lung et al., NIM A 696, 32 (2012)

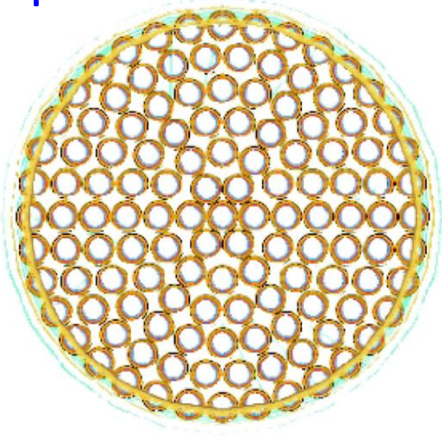


Used in XENON100

BOTTOM: max light collection



TOP: cylindrically symmetric position reconstruction



Backgrounds for XENON1T

- **Background goal < 1 event in 2 ton-year exposure**

- **Nuclear recoils: neutrons**

(1) (α,n) reactions and spontaneous fission due to natural radioactivity in the detector/shields materials

✓ Material selection: low U/Th contamination

→ low α and (α,n) production

✓ Reject multiple neutron scatters

(2) Muon-induced fast neutrons

✓ Active Cherenkov muon veto: tag muons in the 10 m large water tank (also passive shield)

✓ **Reject > 99.5%** of neutrons with μ in veto

- **Electronic recoils**

(1) External gammas from natural radioactivity and activation in the detector and shields materials

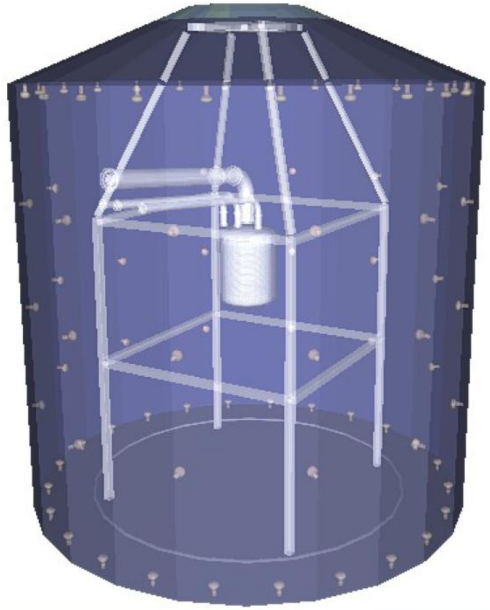
✓ Material screening and selection

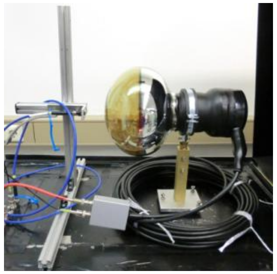
✓ Suppression via LXe self-shielding (fiducialization): external γs easily stopped at edges, βs from the internal impurities dominate

(2) Intrinsic ^{222}Rn and ^{85}Kr contamination in LXe

✓ Cryogenic distillation column for Kr

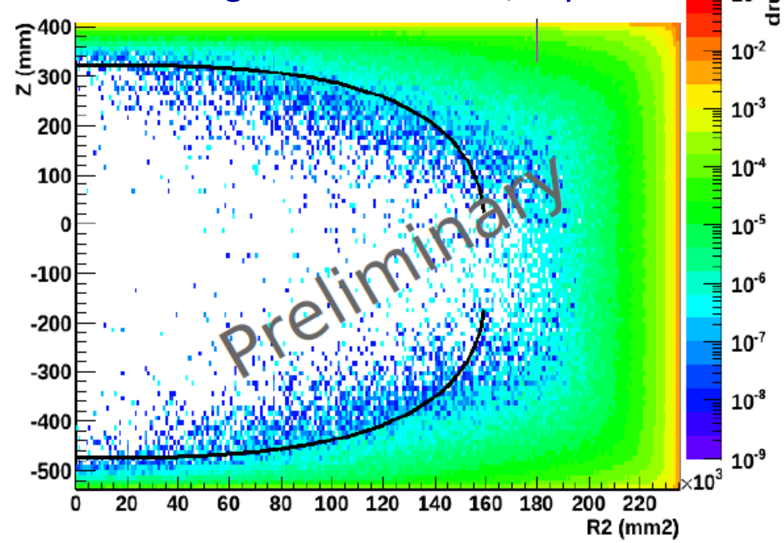
✓ Online Rn removal by Rn adsorption tower





84 high QE 8” PMTs Hamamatsu R5912 with water-tight base

Gamma background from PMT, Cryostat



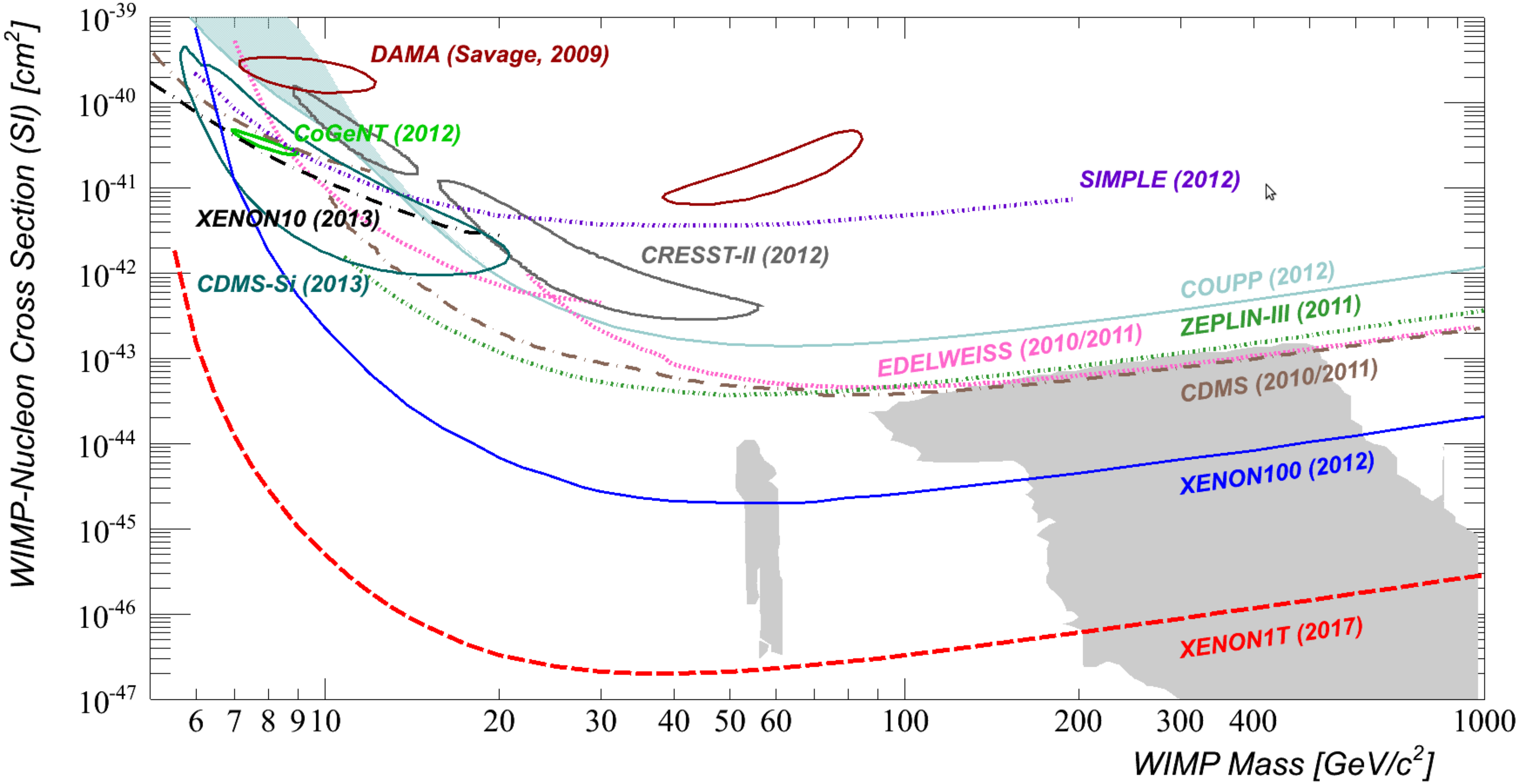
Reducing intrinsic backgrounds

- ^{85}Kr
  - ✓ Building a cryogenic distillation column for Kr removal
  - ✓ Aim: ^{nat}Kr/Xe < 0.5 ppt
  - ✓ High throughput: 3 kg/h (3.5 tons in ~ 1.8 month)
  - ✓ Custom gas purity diagnostics (online and offline)

- ^{222}Rn
  - ✓ Noble gas produced in the ^{238}U decay chain
  - ✓ It can originate from any surface and dissolves well in LXe
  - ✓ $T_{1/2}$ = 3.8 days, with short-lived daughters and long-lived ^{210}Pb

    ⇨ Removal is necessary
  - ✓ Reduce Rn emanation inside cryostat
  - ✓ Aim: ^{222}Rn < 1 μBq/kg
  - ✓ Extensive emanation screening
  - ✓ Attenuate Rn by passing xenon through charcoal filter

XENON1T projected sensitivity



- **Spin independent sensitivity goal: 2.0 x 10^{-47} cm^2 for a 50 GeV/c^2 WIMP**

✓ Probe most of the SUSY-favored phase space → **Strong discovery potential**

Scaling it up again: XENONnT

- **XENONnT is the XENON1T setup with:**

✓ Larger TPC and inner cryostat

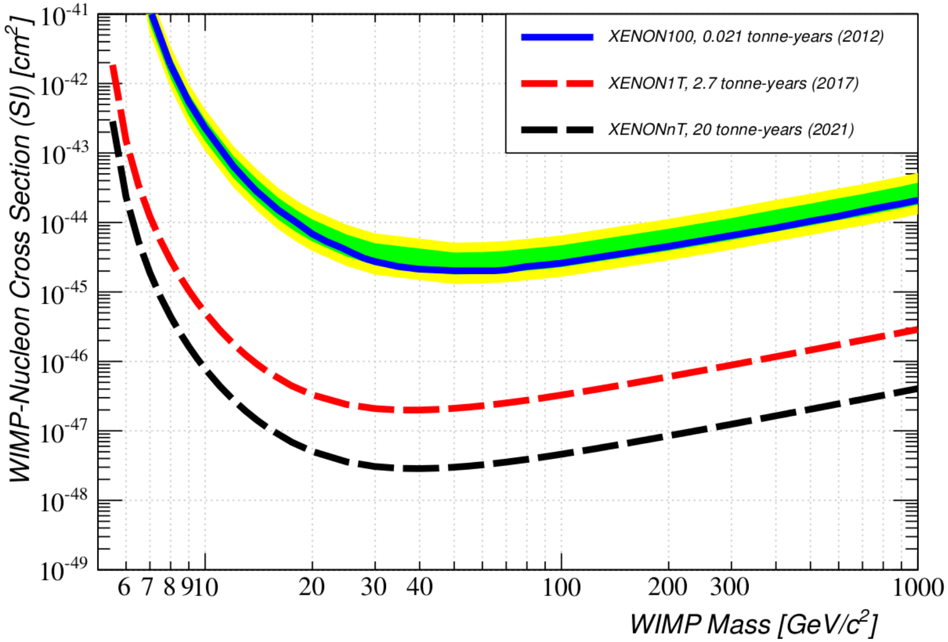
✓ Almost double number of PMTs

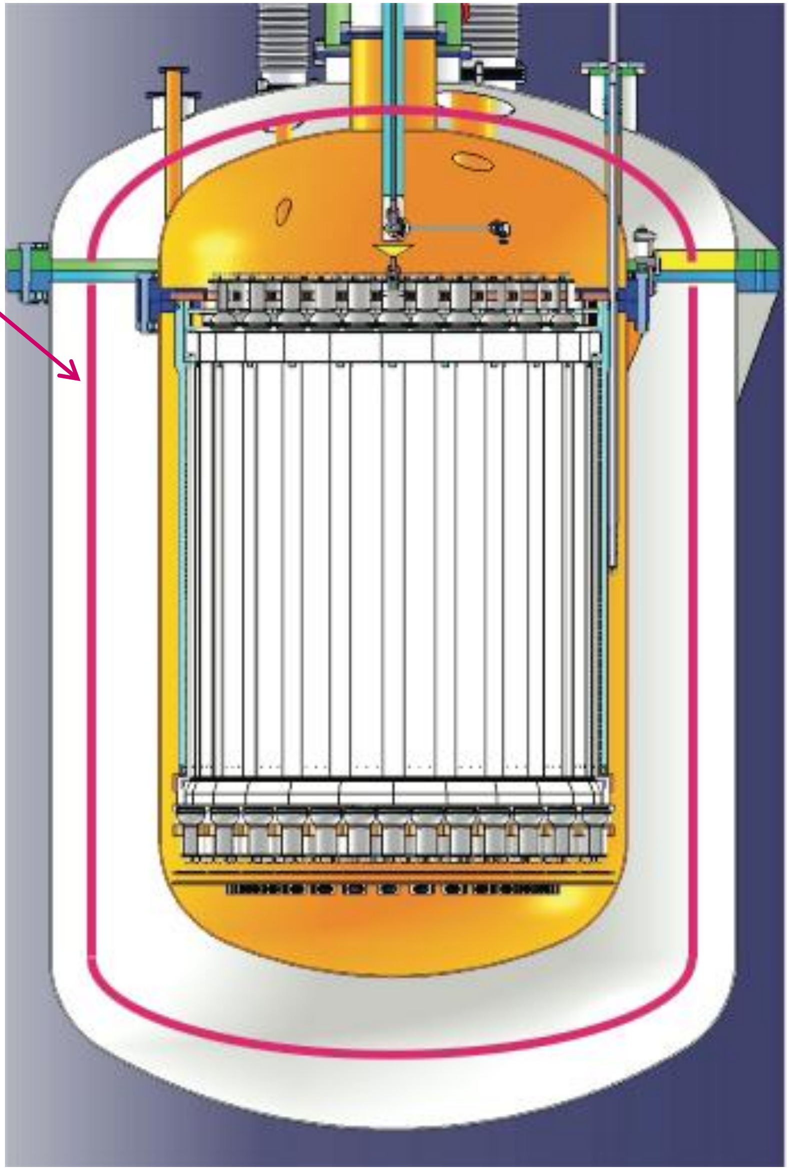
✓ All the other systems (from the outer cryostat to outside) remain the same

- **Potential sensitivity 2.0 x 10^{-48} cm^2**

✓ Aimed exposure **20 ton-year**

- **Starting from 2018**





Summary and Outlook

The XENON project continues to lead the field for direct dark matter detection

XENON100

- ✓ Most sensitive spin independent limit

  σ_{SI} < 2.0 x 10^{-45} cm^2 at 55 GeV/c^2
- ✓ New spin dependent results:

  Most sensitive limit above 6 GeV/c^2 for pure neutron coupling

  σ_n < 3.5 x 10^{-40} cm^2 at 45 GeV/c^2

  Also sensitive to pure proton coupling, consistent with other limits
- ✓ Ongoing physics analyses
- ✓ Improve detector characterization
- ✓ Continuing data acquisition

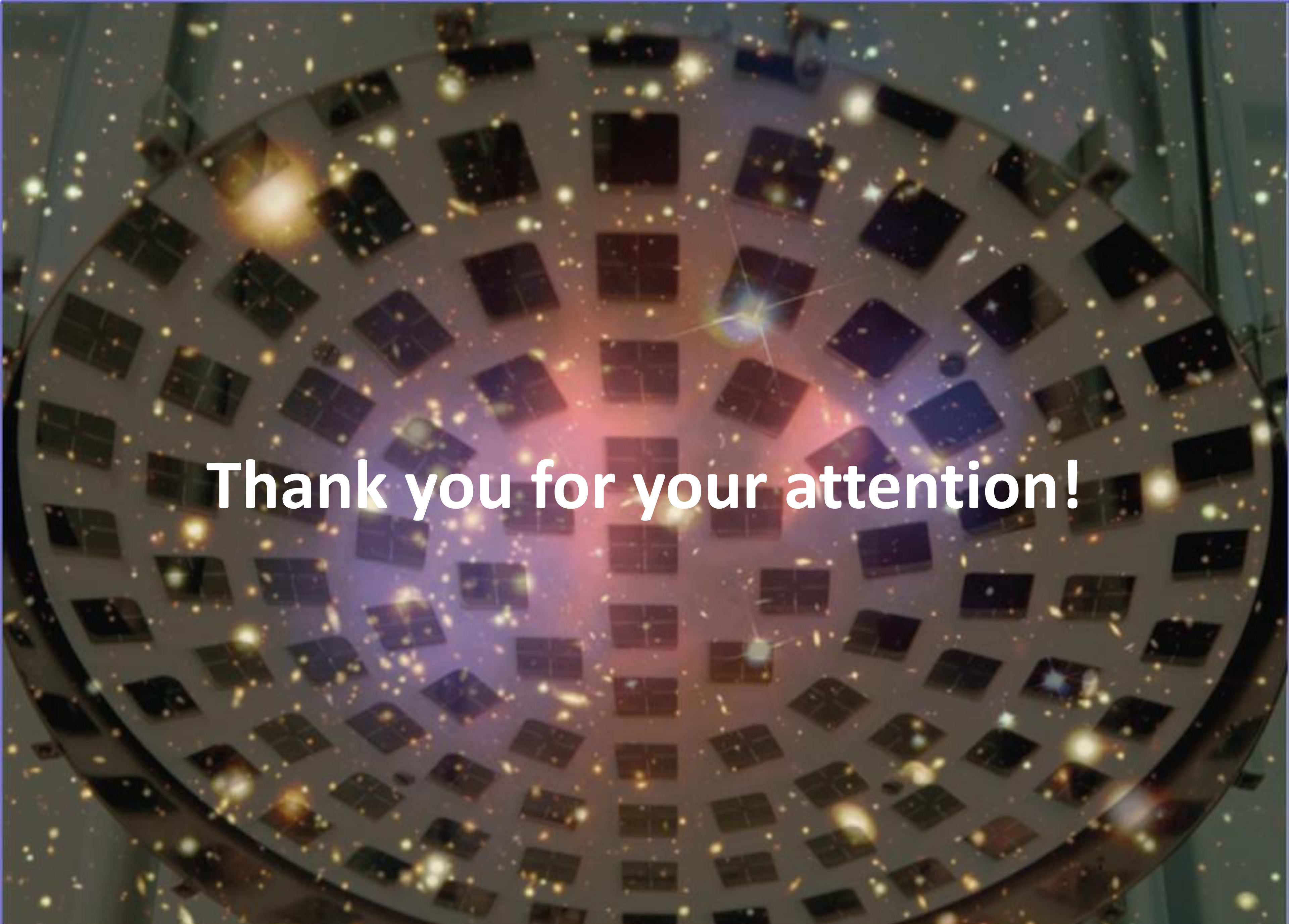
XENON1T

- ✓ Sensitivity goal: **σ_{SI} = 2 x 10^{-47} cm^2** by 2017
- ✓ Reduce background by factor 100

  10 m water shield + intrinsic radiopurity
- ✓ Construction started in 2013, commissioning in late 2014
- ✓ **Science data taking in 2015**

XENONnT

- ✓ Sensitivity goal: **σ_{SI} = 2 x 10^{-48} cm^2** by 2023



Thank you for your attention!