University of Zurich[UZH]

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on Elementary Particle Physics
Moscow State University, August 24, 2013

Dark Matter Search with the XENON100 Experiment

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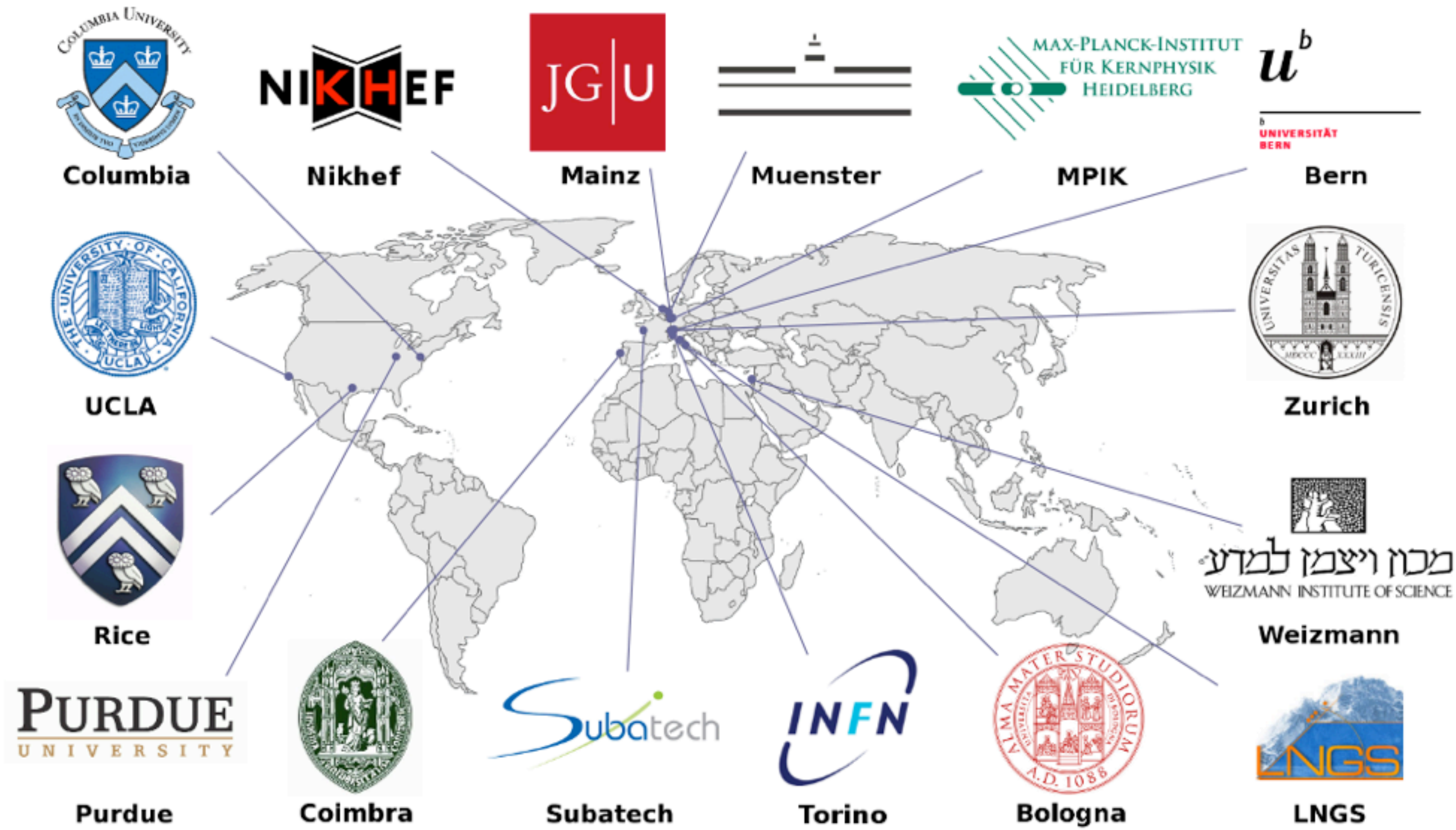
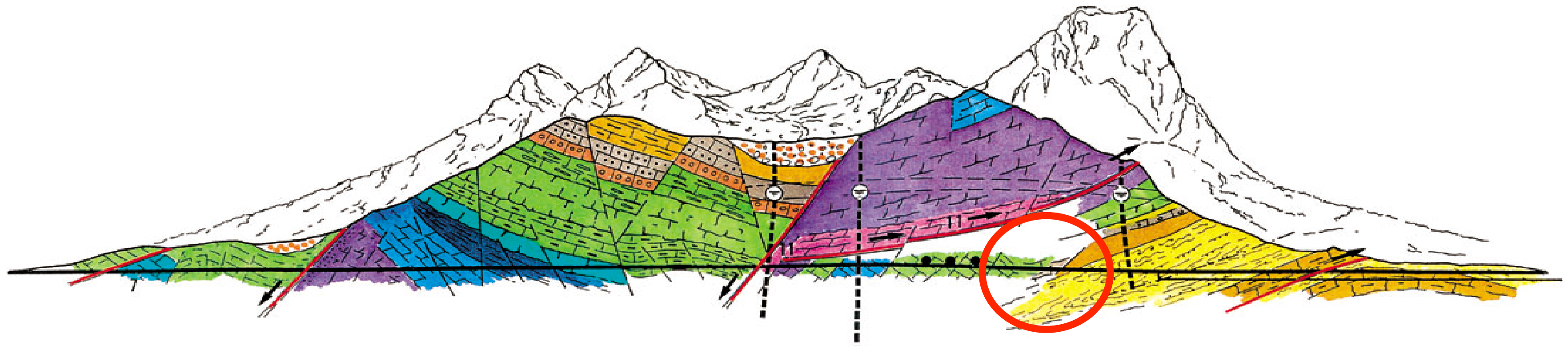
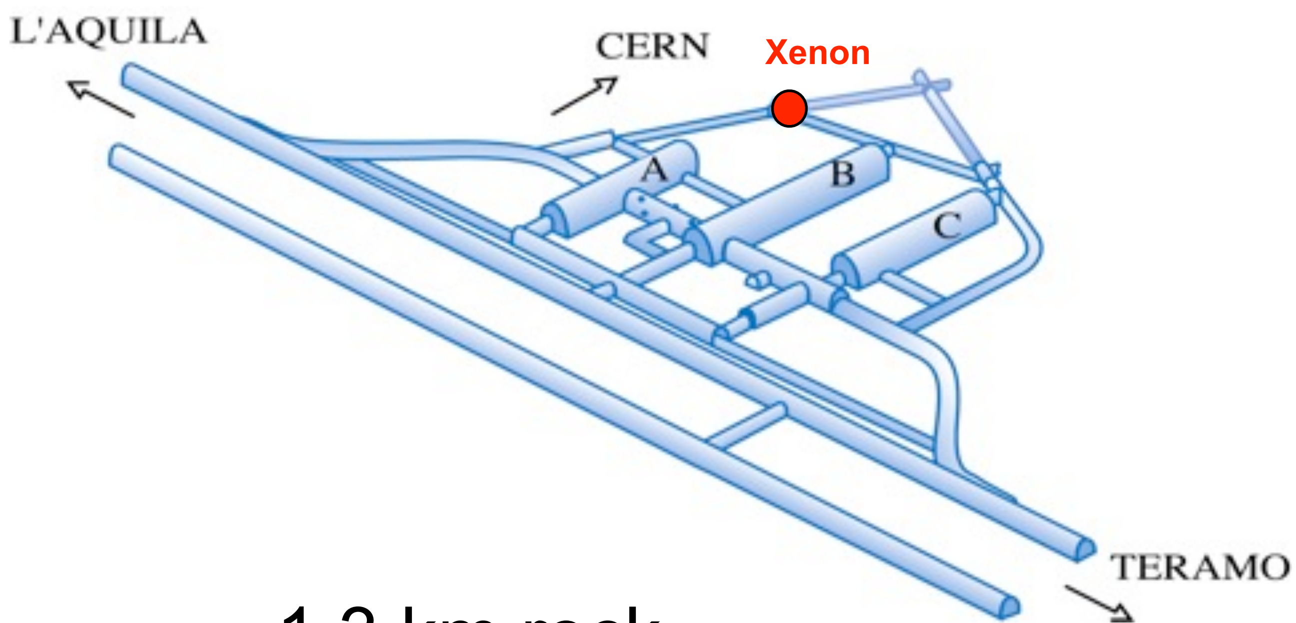
The XENON Collaboration



Location of the XENON100 Experiment





1.3 km rock

↓

3.1 km water equivalent shielding from cosmic rays

↓

factor 10^6 reduction of muon flux

Detection Principle

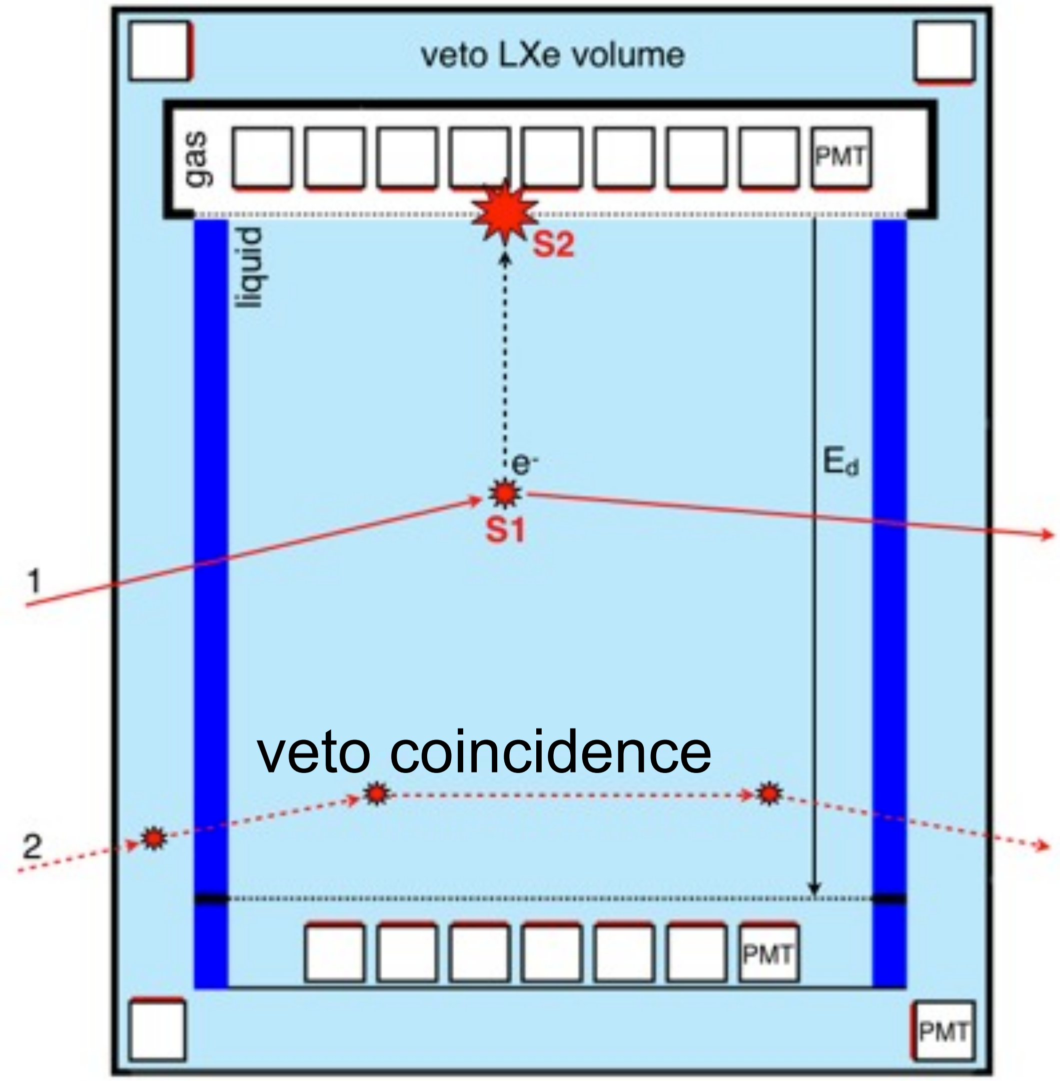
- particle interaction with the LXe target:

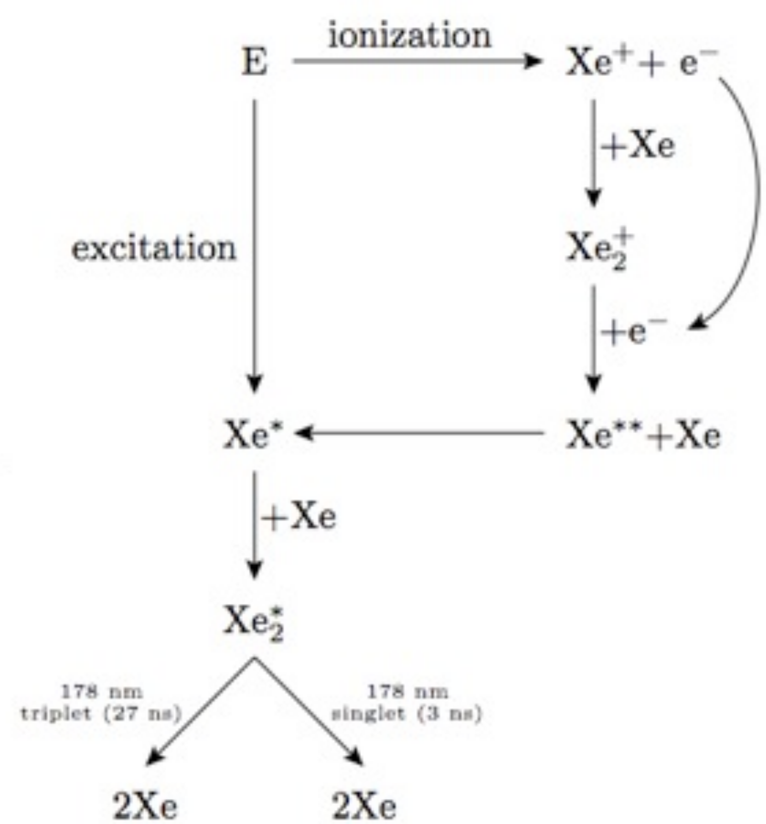
$\xrightarrow{h\nu}$ prompt scintillation (S1), λ = 178 nm

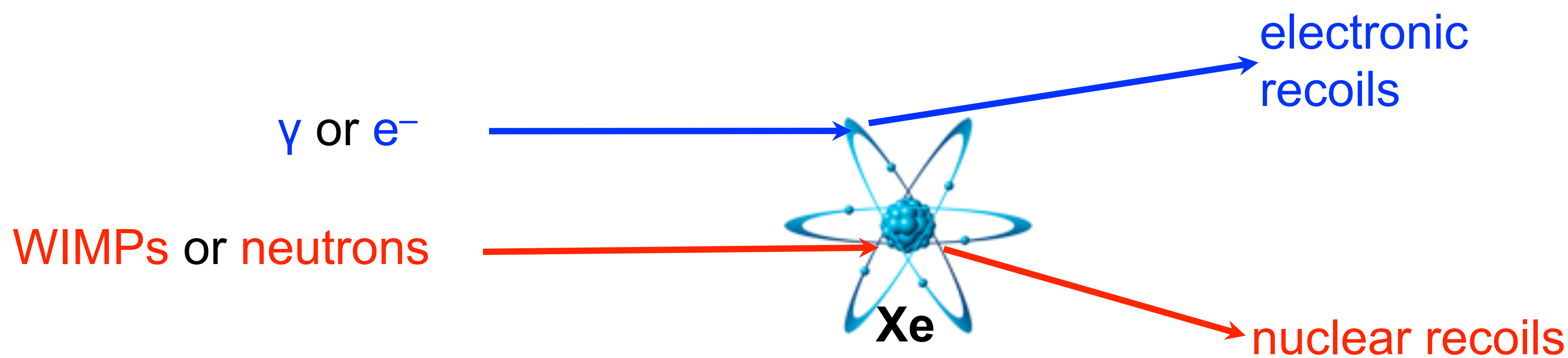
light detection with photomultiplier tubes

$\xrightarrow{e^-}$ ionization

charge is drifted and extracted into the gas phase, detected by PMTs as proportional scintillation light (S2)



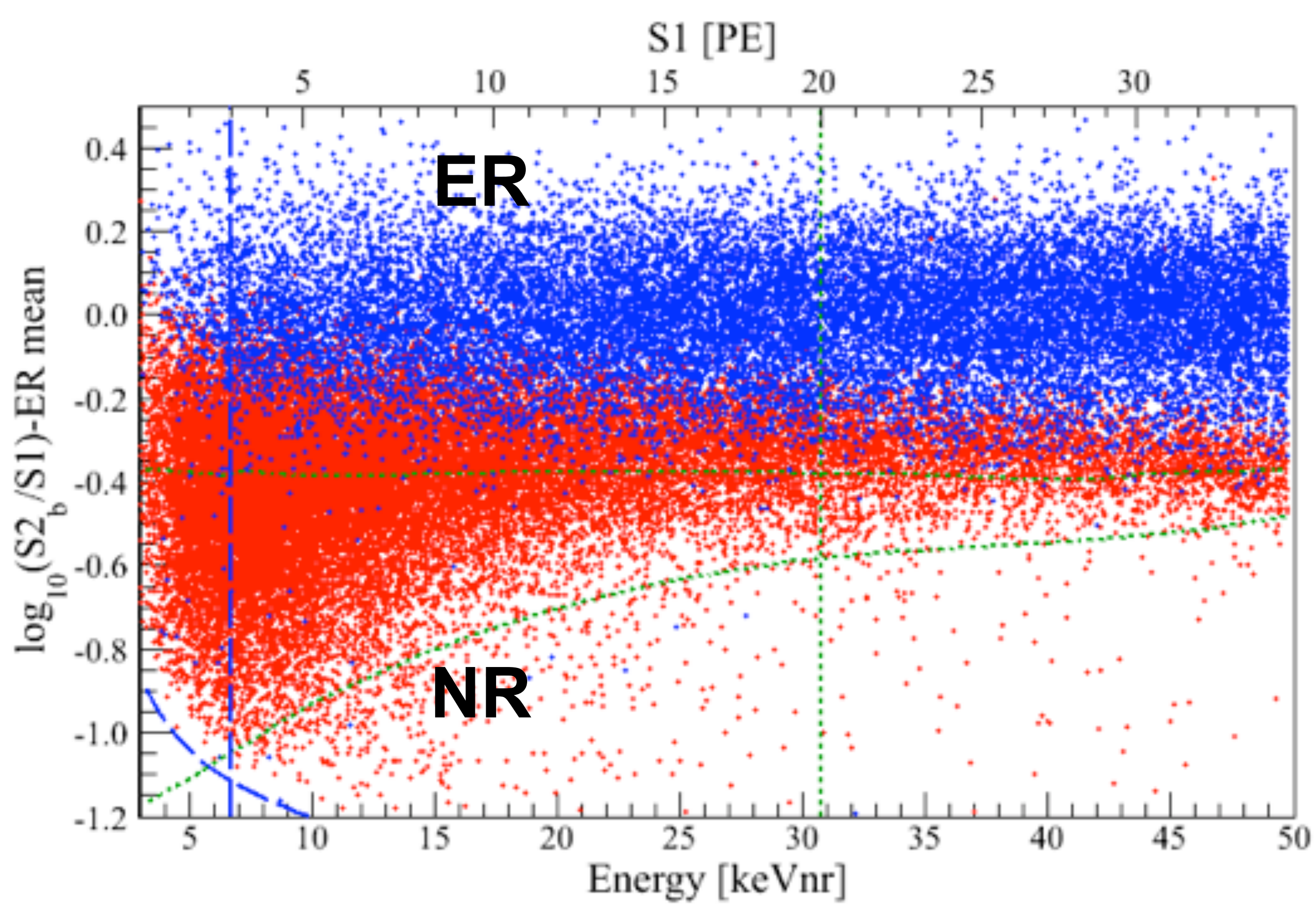




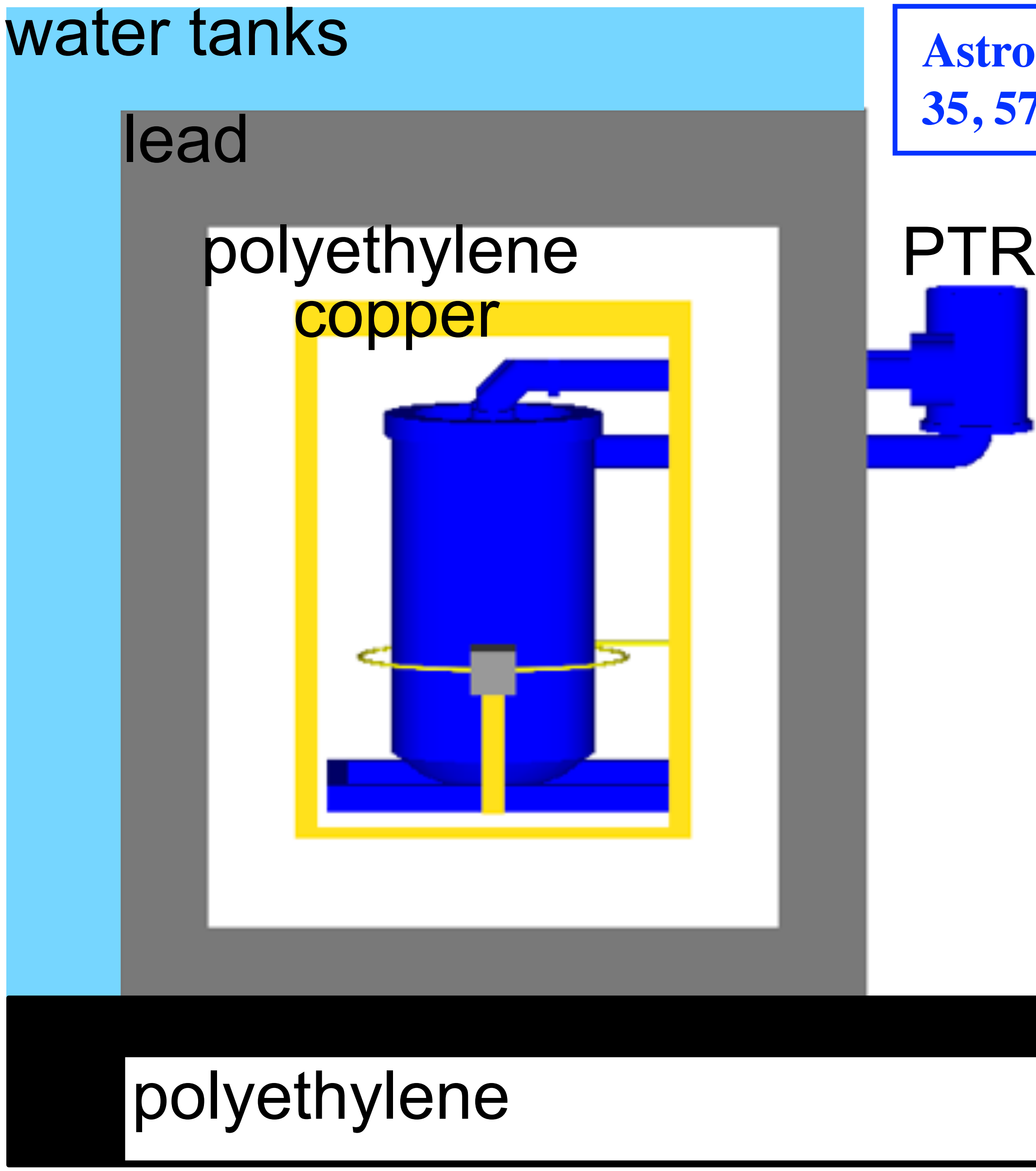
● ionization-to-scintillation ratio (S2/S1) depends on dE/dx, different probability for electron-ion pairs recombination

→ electronic recoil discrimination based on the ratio of scintillation and ionization, with efficiency >99%

$$(S2/S1)_{\gamma} > (S2/S1)_{WIMP}$$



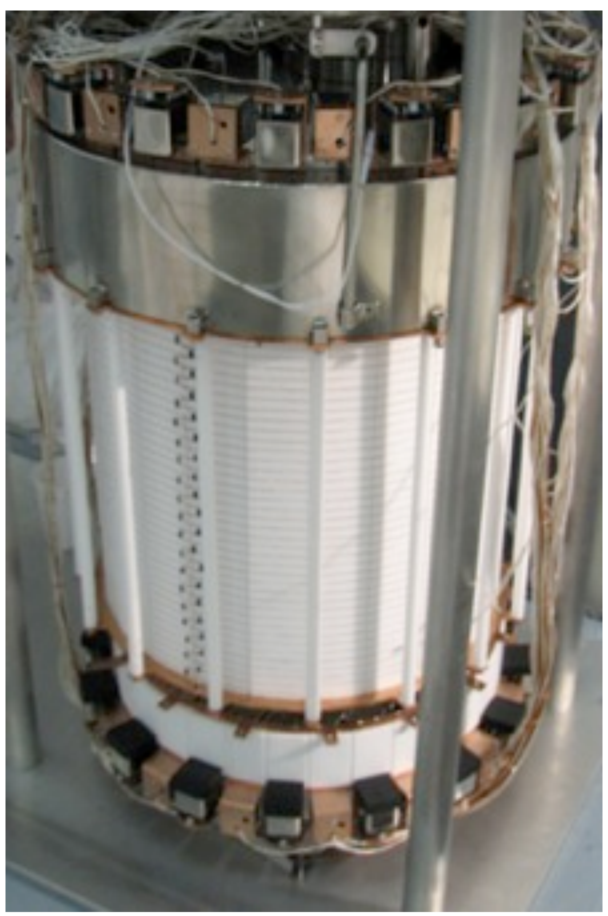
XENON100 Shield



Astroparticle Physics 35, 573 (2012)

water tanks	thickness 20 cm	→ neutrons
lead	15 and 5 cm (low ^{210}Pb), 33 t	→ gamma
polyethylene	20 cm thick, 1.6 t	→ neutrons
copper	5 cm thick, 2 t	→ gamma from outer shield
nitrogen flushing	~20 liters/minute	→ ^{222}Rn in the shield cavity

Design of the XENON100 Detector



Cryostat:
- double walled (1.5 mm thick)
- low radioactivity stainless steel
- total weight 70 kg

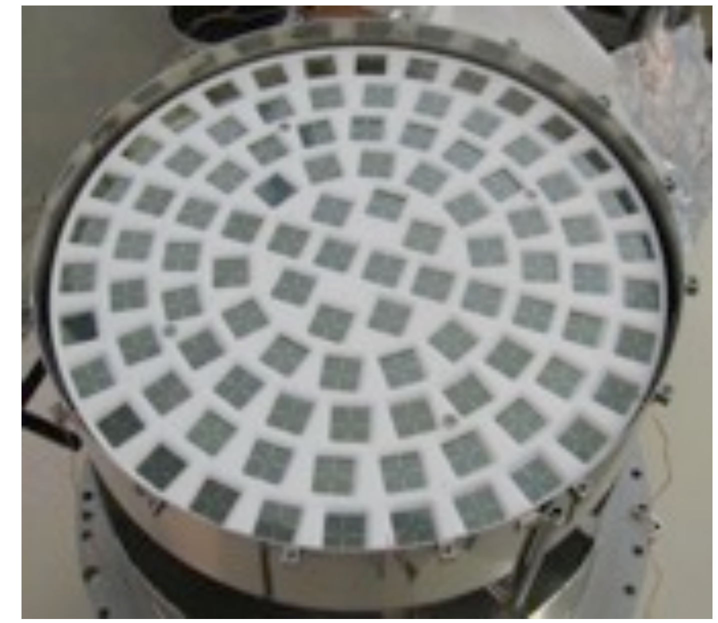
PTFE structure:
- 24 interlocking panels
- total weight of teflon 12 kg
- UV light reflector

'Diving bell':
- stainless steel
- weight 3.6 kg

Target:
- 62 kg of LXe
- 30 cm diameter, 30 cm height

Veto:
- 99 kg of LXe
- average thickness 4 cm
- instrumented with 64 PMTs

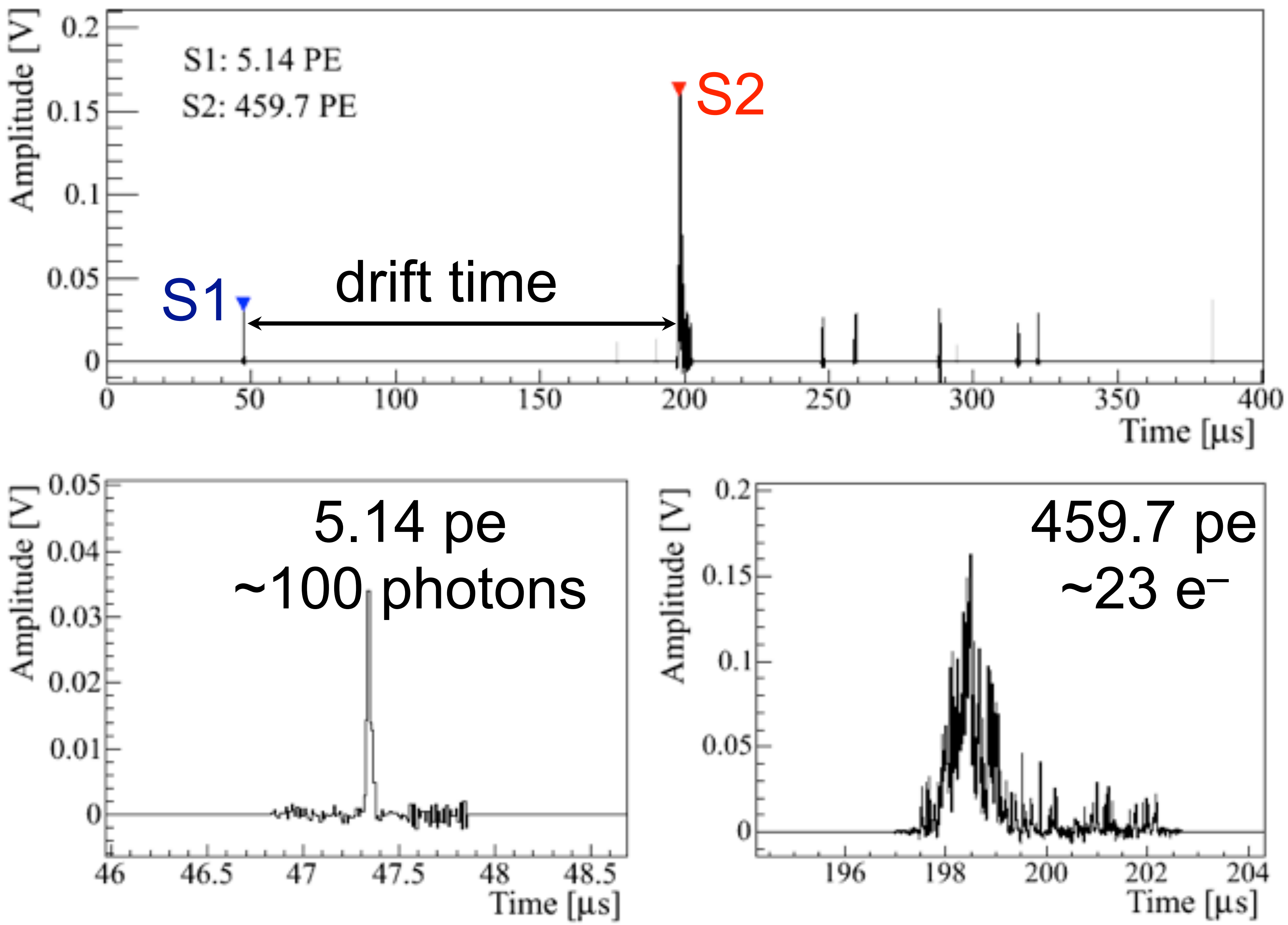
98 PMTs
in the top array
QE ≈ 25%



80 PMTs
on the bottom
QE ≈ 32%

Reconstruction of the Event Vertex

- Z-coordinate (interaction depth) is inferred from the delay time between S1 and S2



prompt scintillation signal (S1)

proportional scintillation signal (S2)

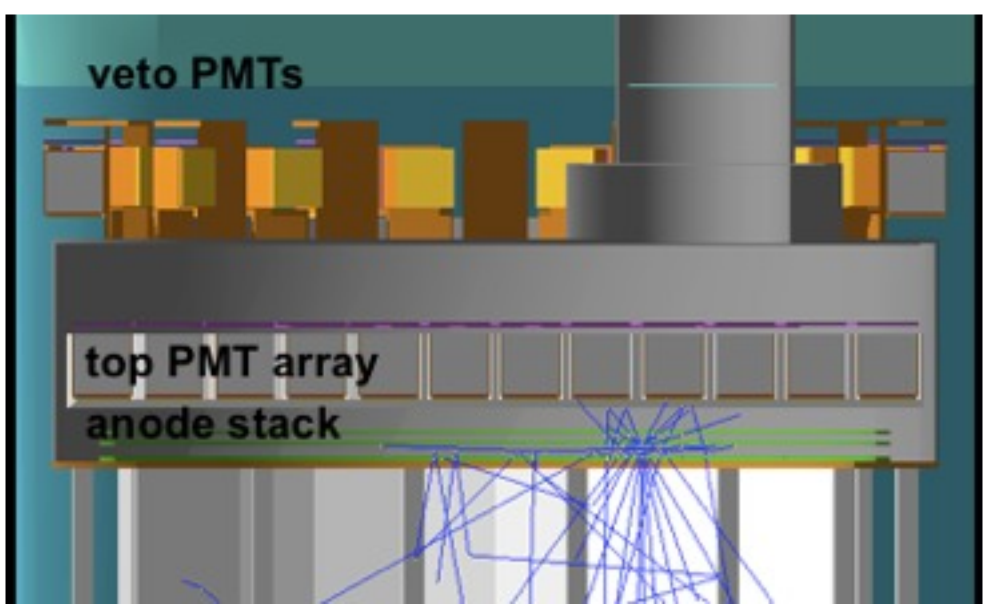
- The maximum e⁻ drift time at 0.53 kV/cm is 176 µs

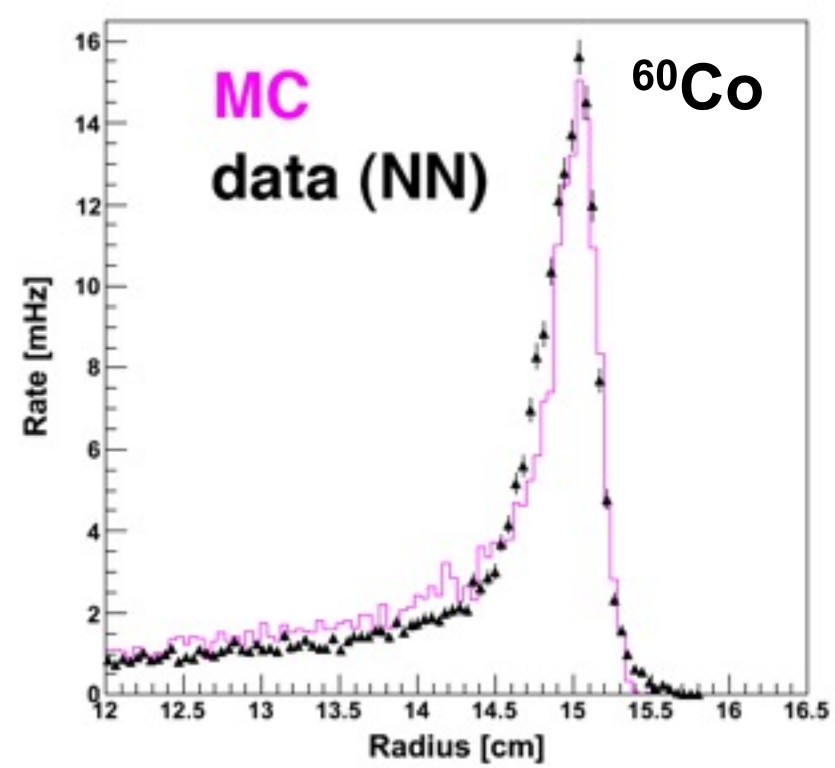
Reconstruction of the Event Vertex

● X and Y coordinates are reconstructed via light pattern identification (S2 is clustered on the top array)

● reconstruction algorithms are based on Neural Network, Support Vector Machines, and Chi2-minimization

→ they are 'trained' on the simulated S2 light patterns, which are generated with GEANT4





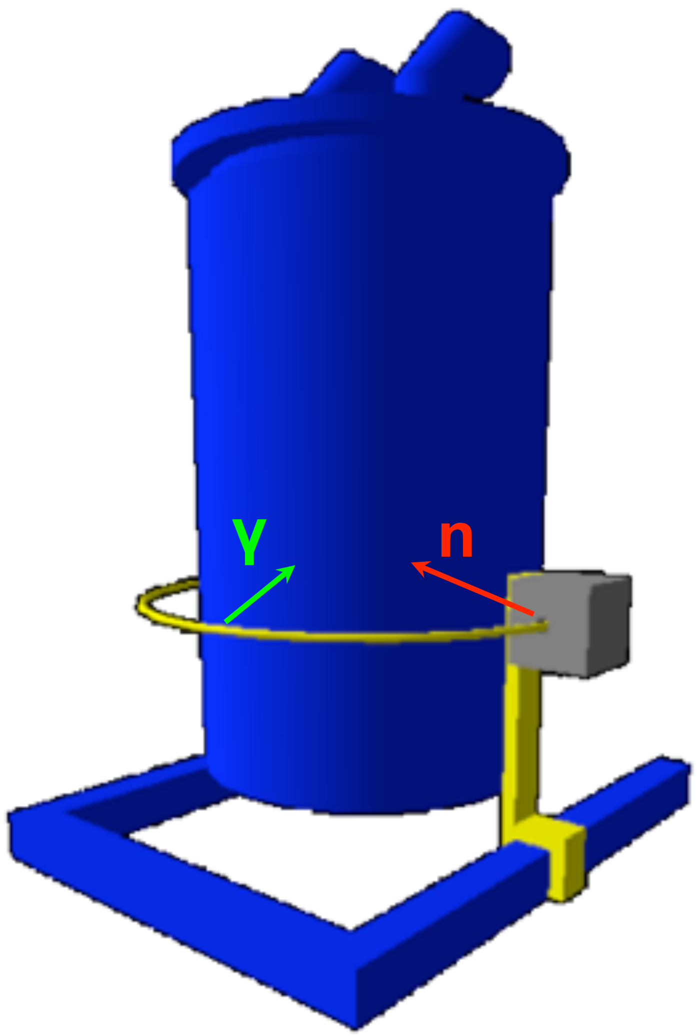
Detector calibration

- 122 keV γ-rays from ^{57}Co do not penetrate into the target volume

→ calibration with higher energy sources inserted through a copper pipe:

^{137}Cs (662 keV), ^{60}Co (1.17, 1.33 MeV), ^{232}Th (wire)

- ^{241}Am-Be neutron source is placed behind the lead brick (against 4.4 MeV γ-rays)



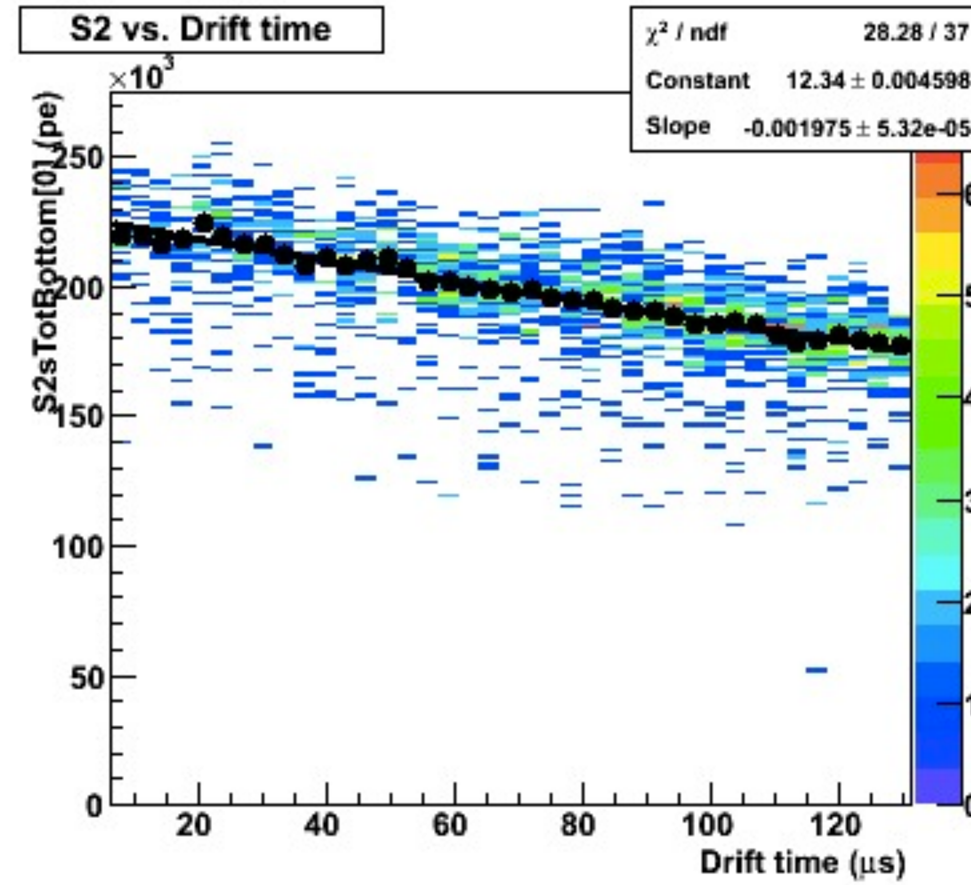
Signal Corrections

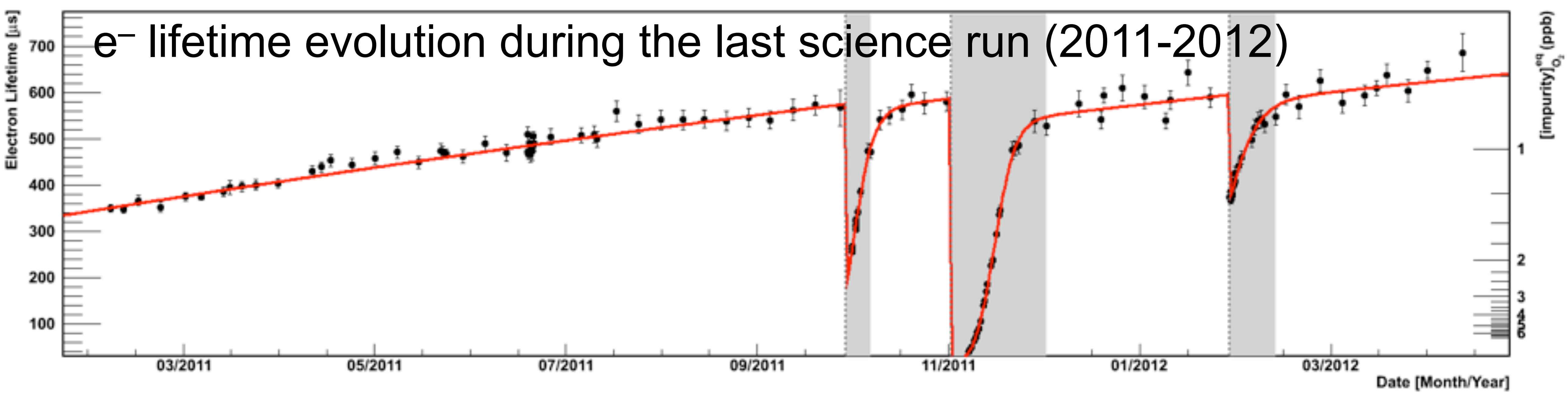
- S2 is exponentially falling with drift time due to finite electron lifetime

→ continuous Xe purification in gas phase through a hot getter (SAES) at a flow rate of ~10 slpm

→ e^- lifetime continuously increasing

→ regularly measured with ^{137}Cs, and correction applied





- S1 light yield 1.6 pe/keV (at 662 keV_{ee})

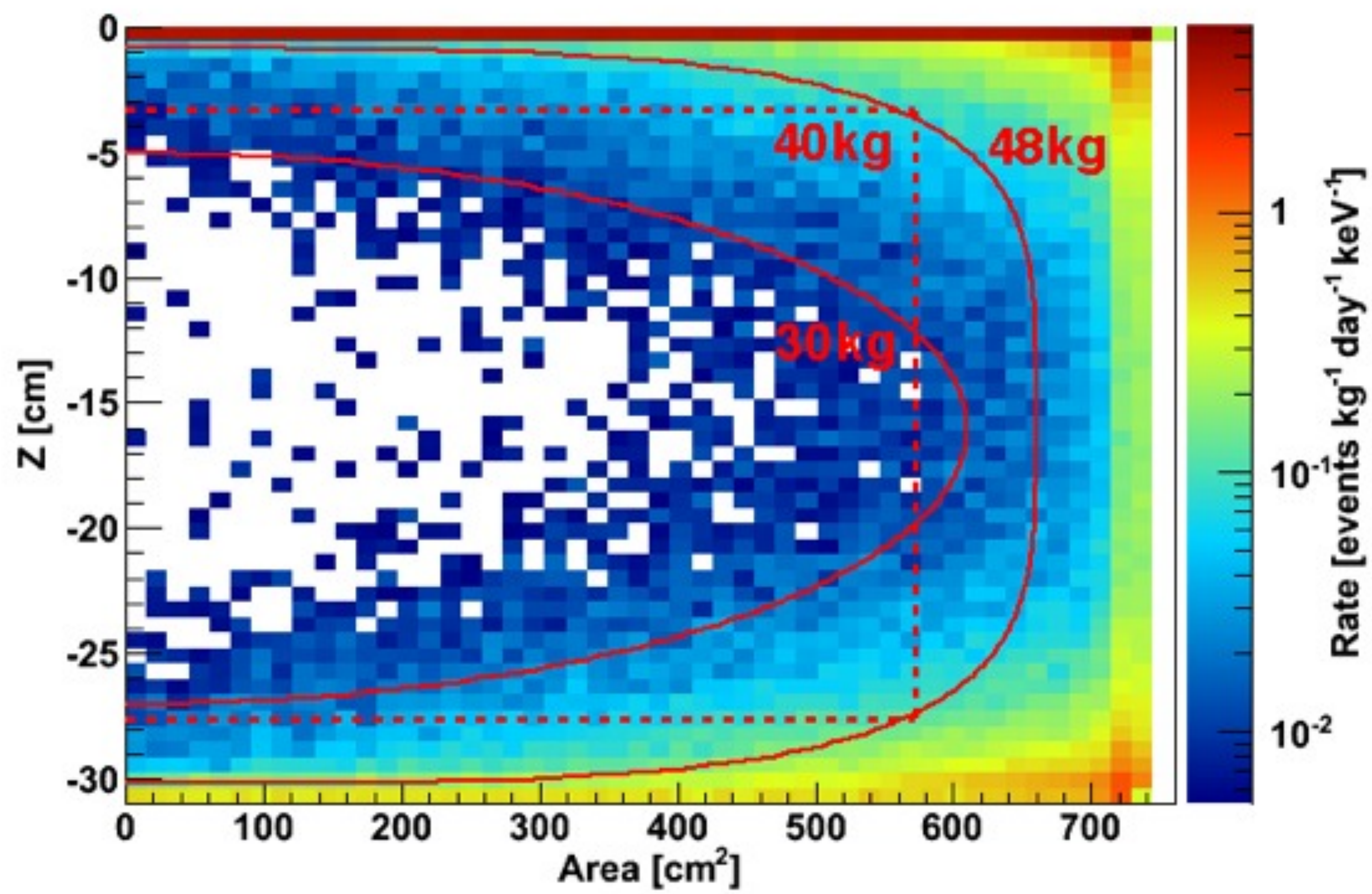
3D sensitivity and background rejection

- 3D position sensitivity provides background reduction

→ single scatter identification and multiple scatter cut

→ fiducialization of the target volume
(self-shielding capability of liquid xenon, ρ ≈ 3 g/cm^3, Z = 54)

- MC,
electromagnetic
background
in the WIMP-search
energy range



Electronic recoil background

PRD 83 082001 (2011)

- natural radioactivity in the detector and shield materials
- ^{222}Rn contamination in the shield cavity
- intrinsic contamination of ^{222}Rn, ^{85}Kr in the liquid xenon

- cosmogenic activation of the detector components during construction and storage at the Earth surface

Nuclear recoil background

arXiv:1306.2303 (2013)

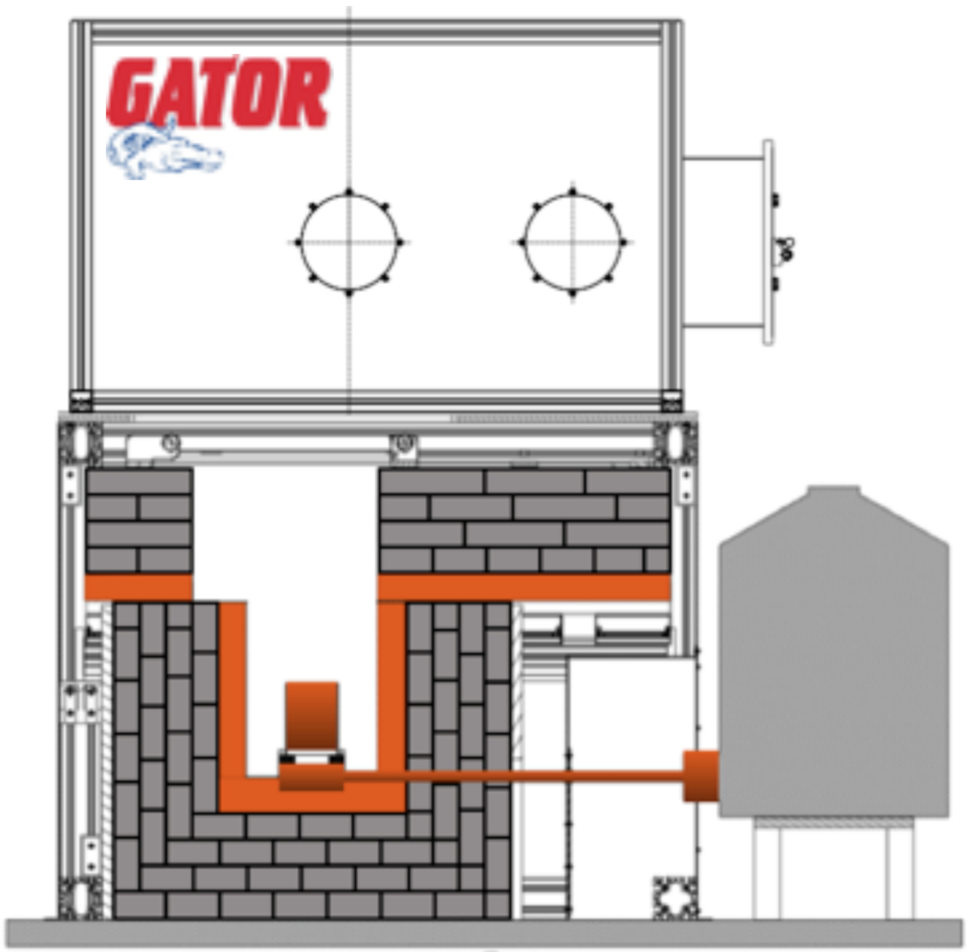
- muon-induced neutrons

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

Background level in the WIMP-search energy range after discrimination is 5×10^{-5} events/kg/day/keV

Backgrounds: Materials screening

● All materials used in the experiment have been screened for radioactive contamination with a 2.2 kg high purity Ge detector (‘Gator’ @ LNGS)



JINST
6, P08010 (2011)

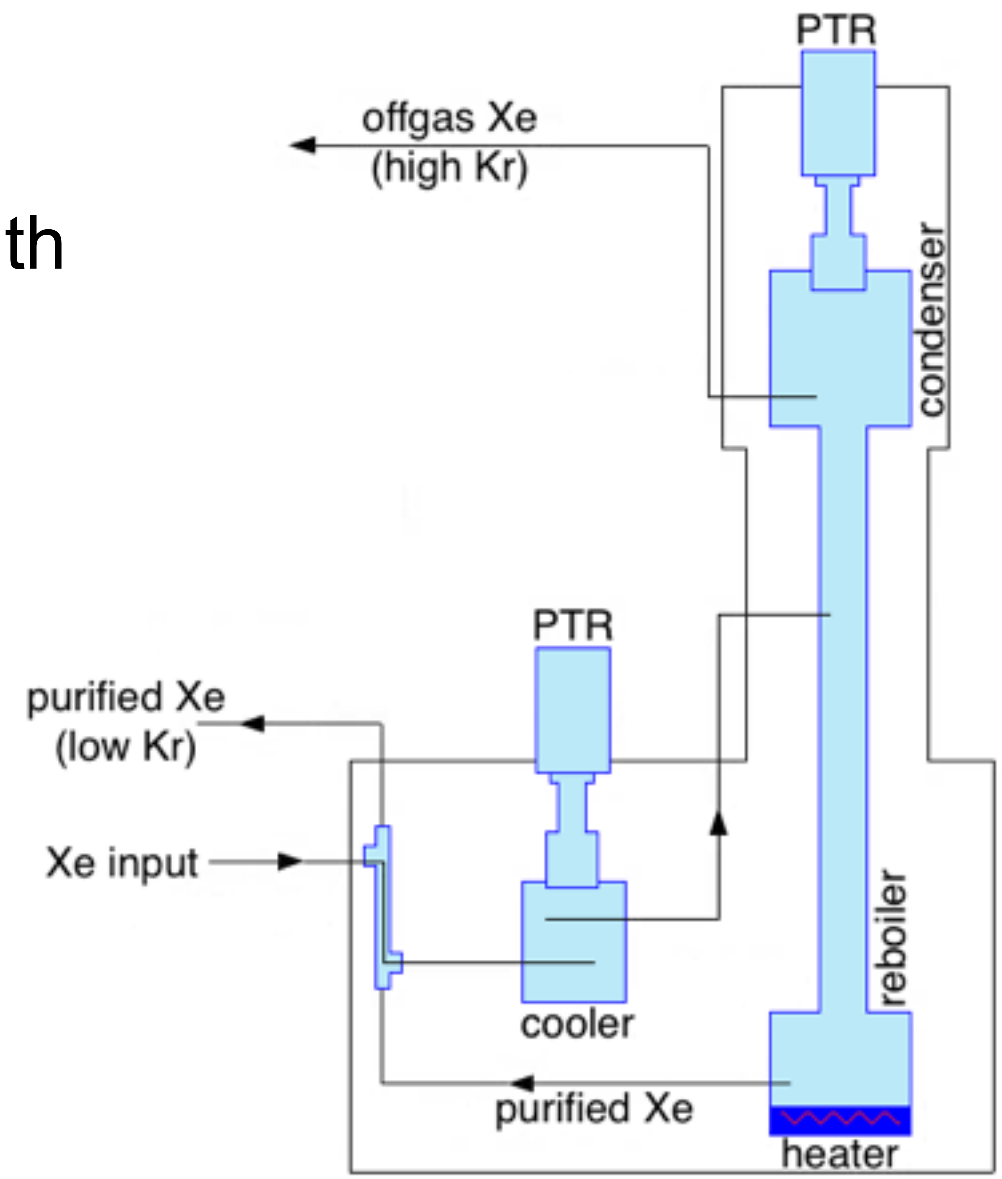
Astroparticle Physics
35, 34-49 (2011)

→ The screening results are used for material selection and as an input for the Monte Carlo simulations with GEANT4

Backgrounds: Krypton in liquid xenon

- xenon contains krypton at ppb (parts-per-billion) level
- natural krypton contains 2×10^{-11} of ^{85}Kr
- uniformly distributed background from β-decay
  ($T_{1/2}$ = 10.8 years, Q_{β} = 687.1 keV)
  1 ppt of ^{nat}Kr → ~0.02 events·kg^{-1}·day^{-1}

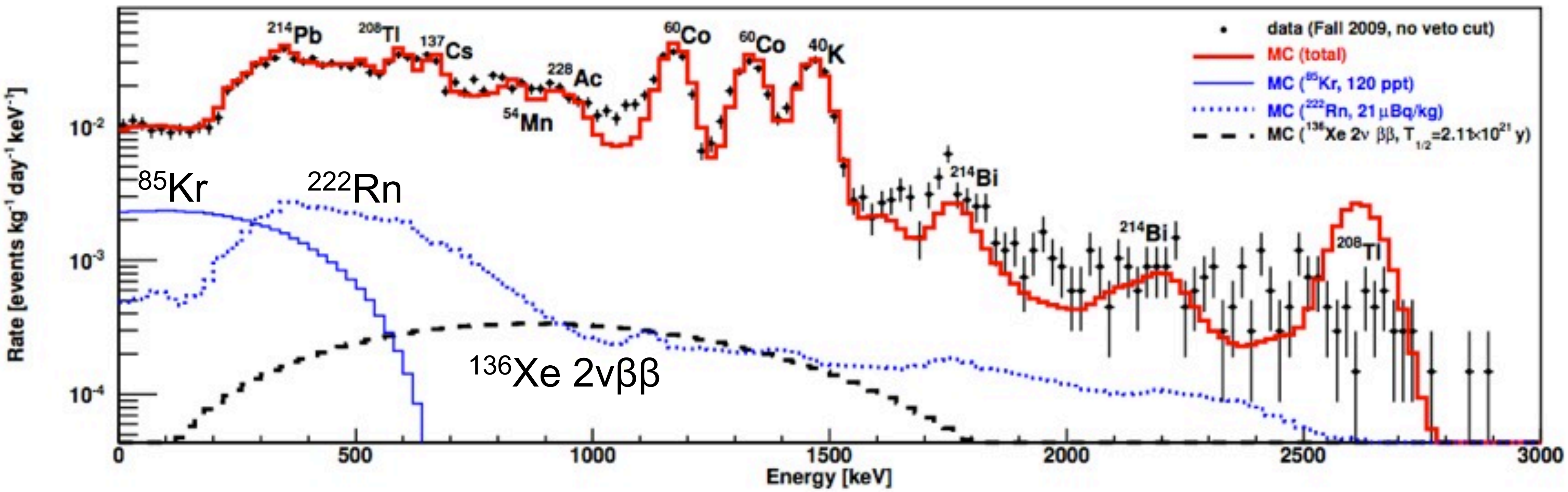
- on site purification with a cryogenic distillation column down to ppt (parts-per-trillion) level



Electronic Recoil Background

- Excellent agreement between the measured data and MC

PRD 83 082001 (2011)

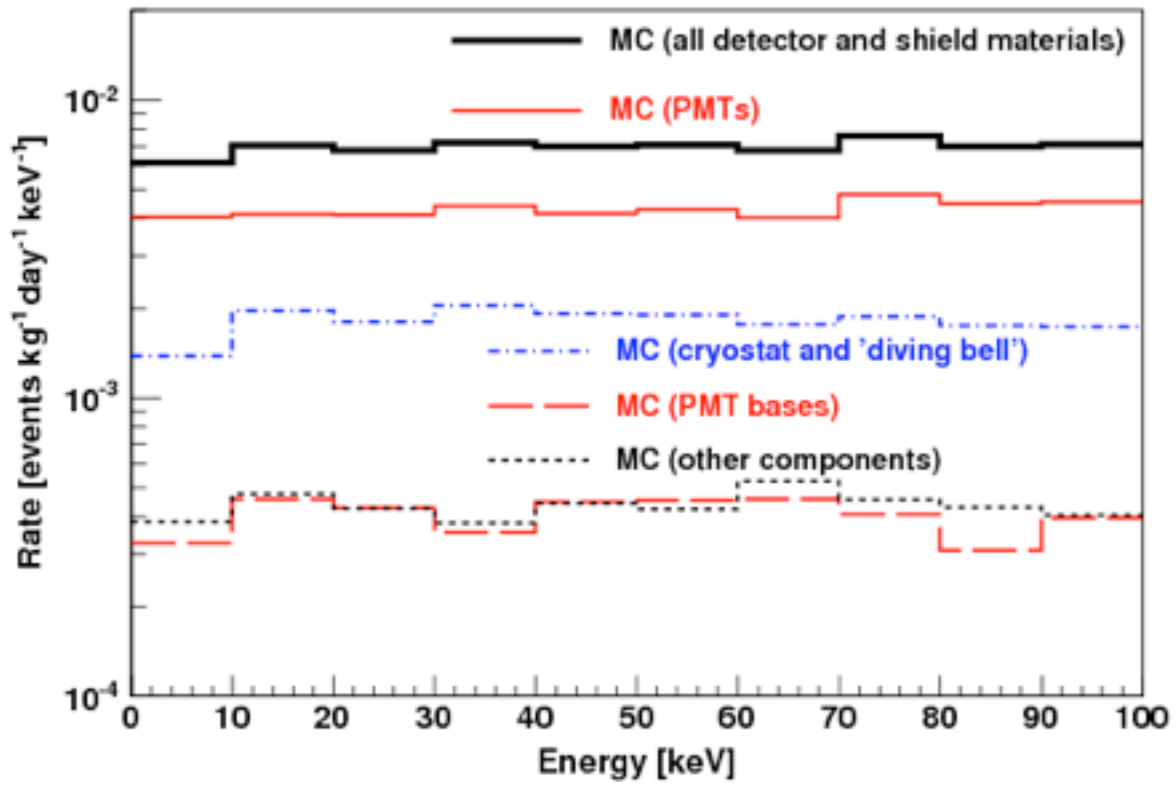


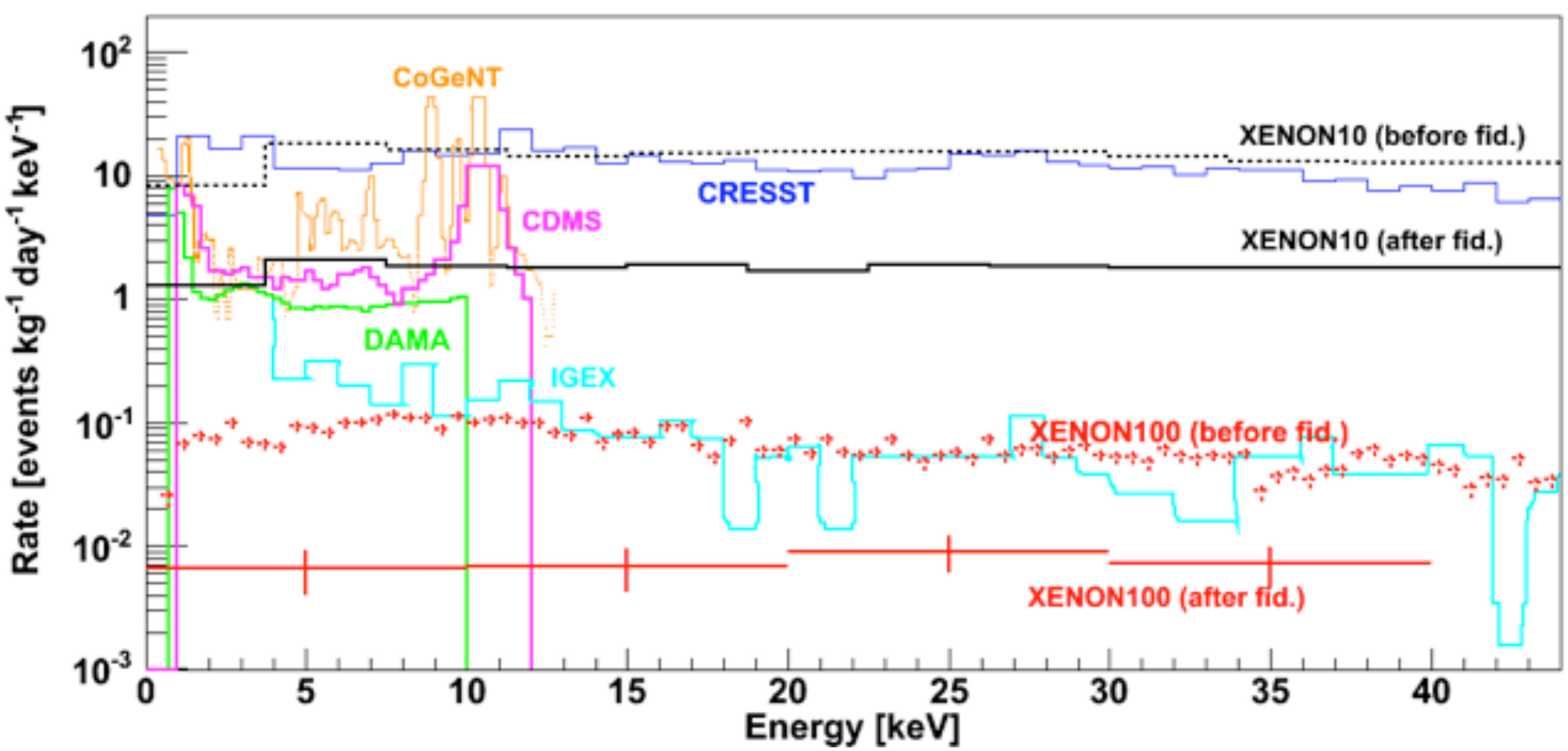
- ^{nat}Kr contamination measured by RGMS:19±1 ppt
- ^{222}Rn contamination studied via alpha-spectroscopy and delayed coincidence methods
- BG level before discrimination (5.3±0.6)×10^{-3} events/kg/day/keV

Electronic Recoil Background

- Main background component – intrinsic contamination in LXe (^{222}Rn and ^{85}Kr)

- Background from detector components is dominated by PMTs (65%). Stainless steel cryostat contributes 25%





- achieved level of EM background is two orders of magnitude lower than in any competing DM search experiment

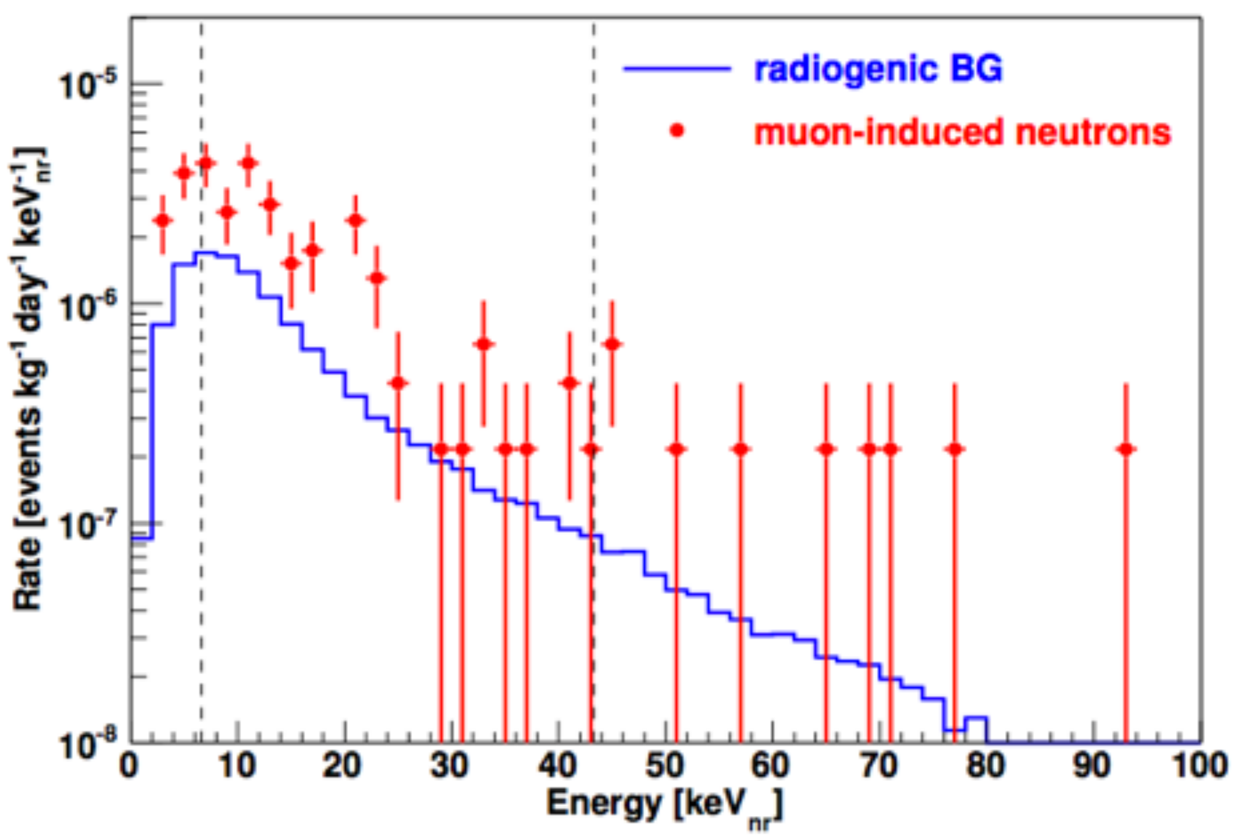
Saturday, August 24, 13

Nuclear Recoil Background

● Radiogenic neutron production rates and energy spectra are calculated with SOURCES-4A

● Cosmogenic neutrons are simulated with MUSUN-MUSIC packages, and propagated with GEANT4

● Total neutron background in the 2012 data release is (0.17 +0.12 –0.07) events, compared to the total ER background estimate of (0.8±0.2) events, hence does not limit the sensitivity of the XENON100 experiment



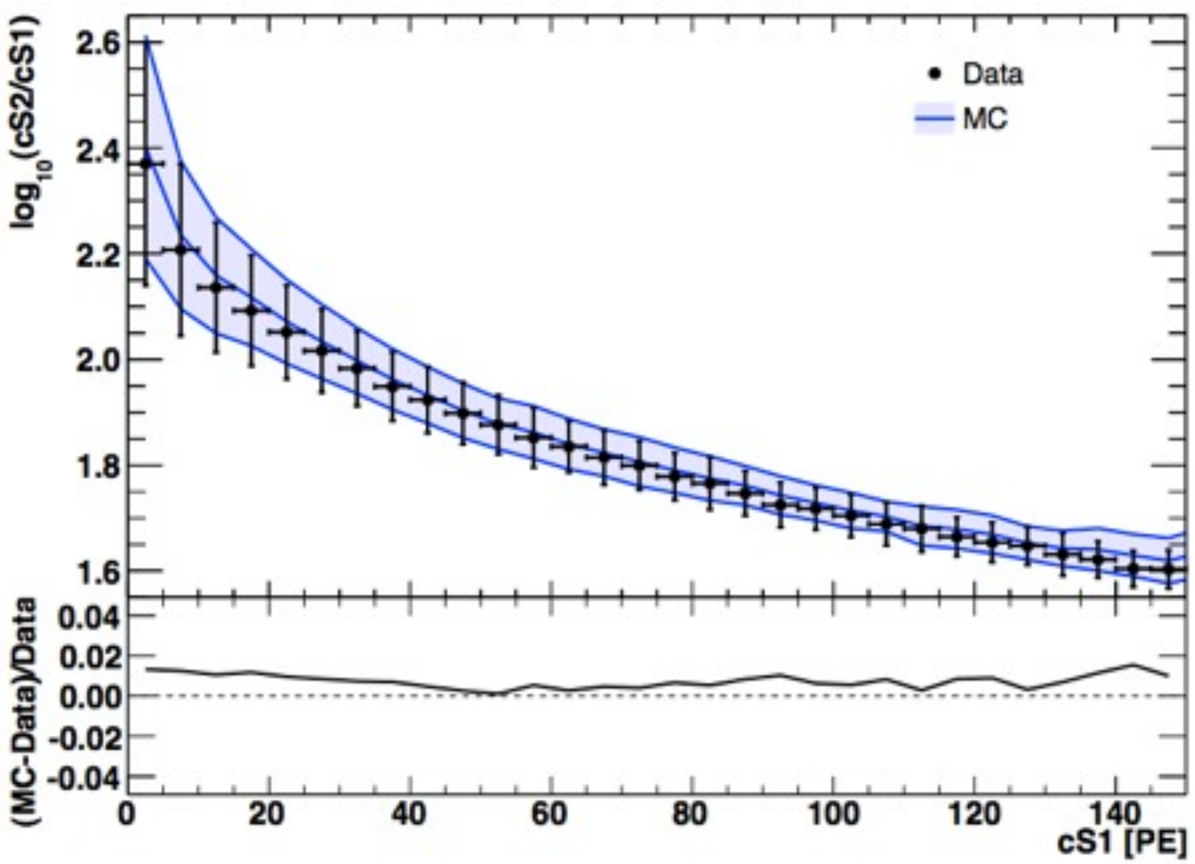
arXiv:1306.2303 (2013)

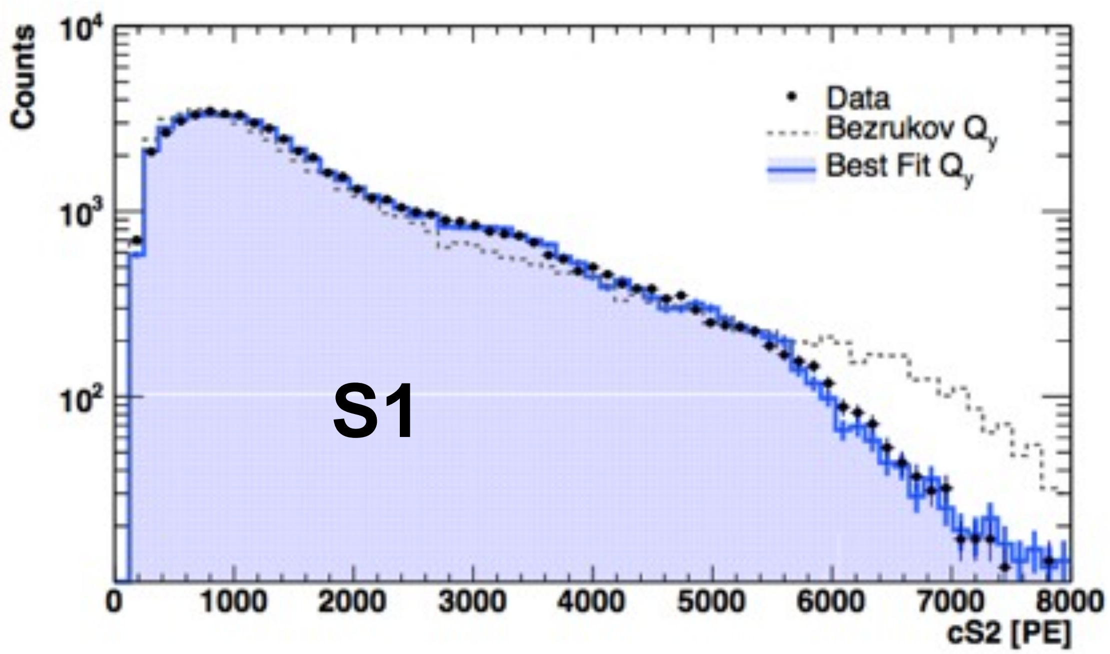
PRD 88, 012006 (2013)

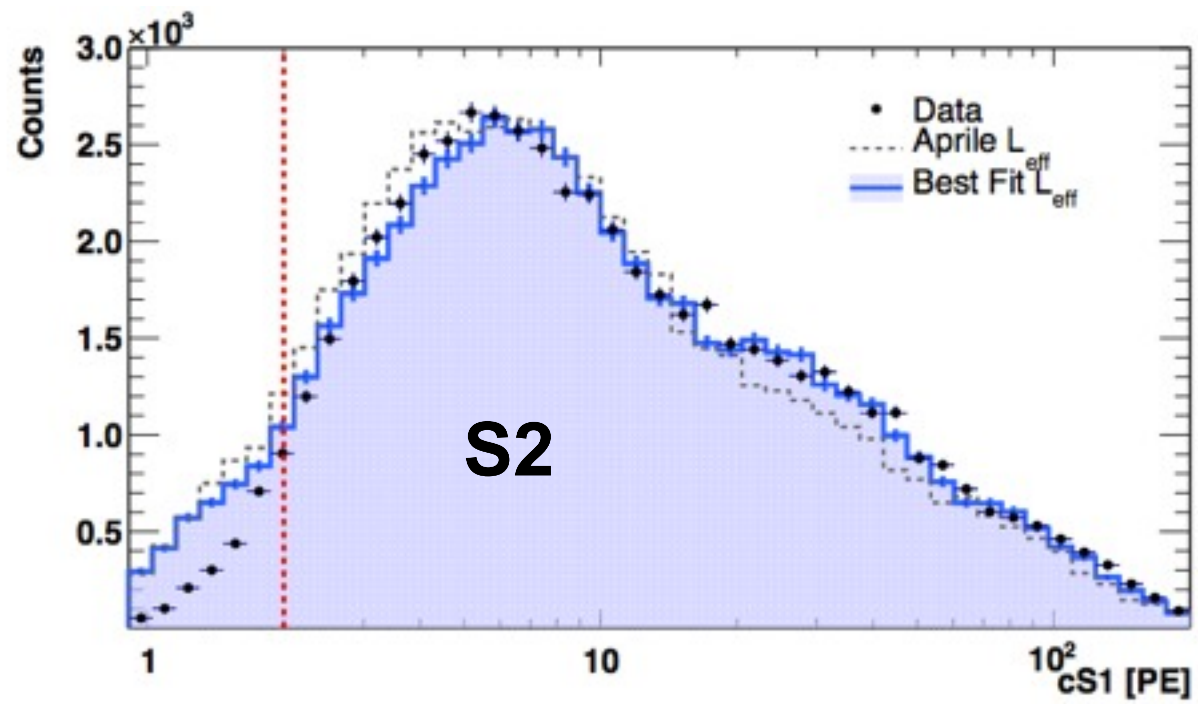
- ^{241}Am-Be neutron calibration

- Simulation of both scintillation (S1) and ionization (S2) signals

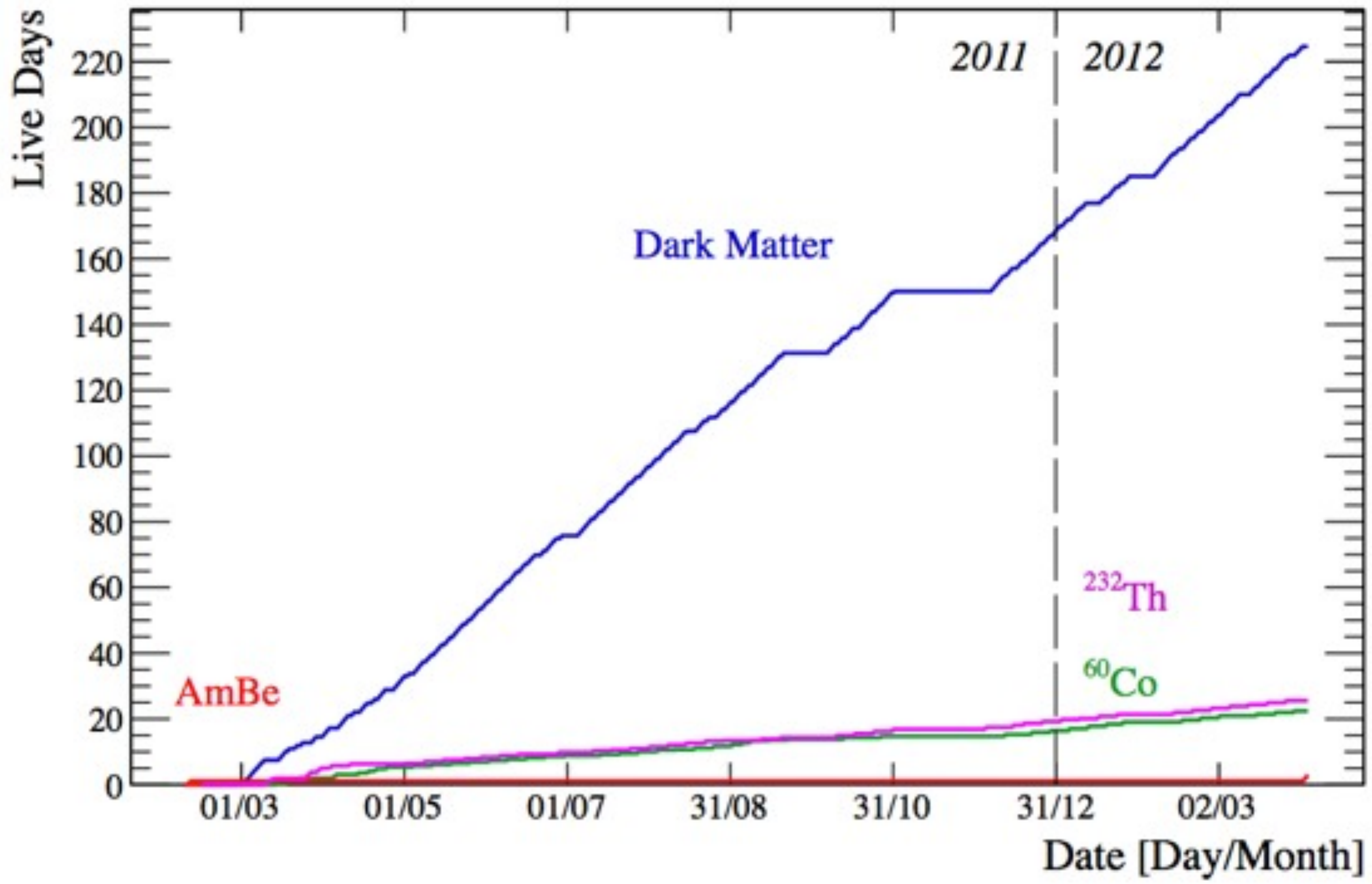
- Absolute data–MC matching at % level down to 3 keV_{nr}







Data Acquisition of the Last Science Run

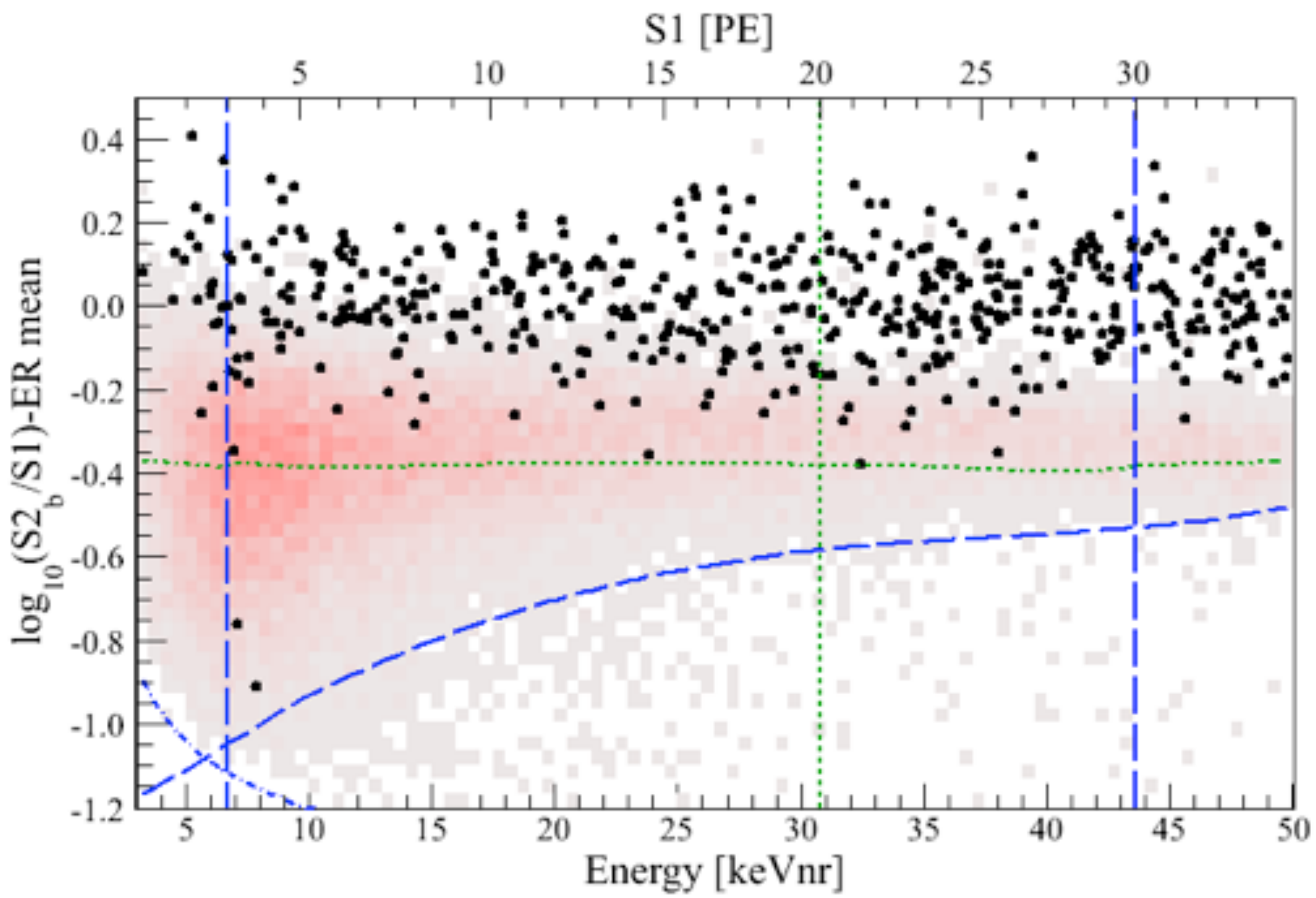


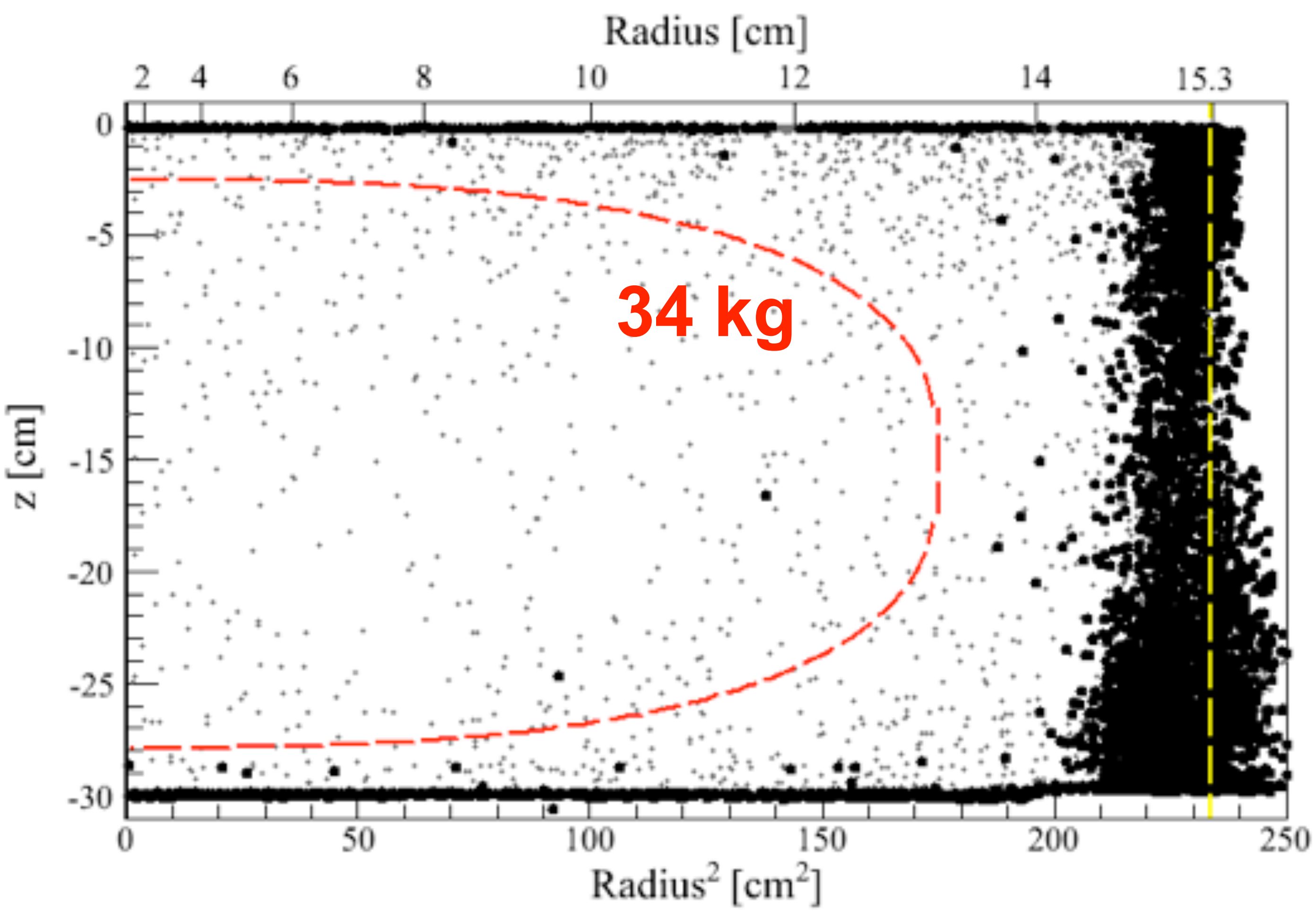
- Acquisition period: from February 28, 2011 to March 31, 2012
  - → Data following maintenance periods removed from analysis
  - → Longest run of a liquid xenon detector (224.6 live days)
  - → Stable detector parameters: T variation <0.16%, P variation <0.7%
  - → Electron lifetime monitored with ^{137}Cs increased from 375 to 610 μs

Dark Matter Search

- Latest science run (Run 10, 2011-2012)

PRL 109, 181301 (2012)





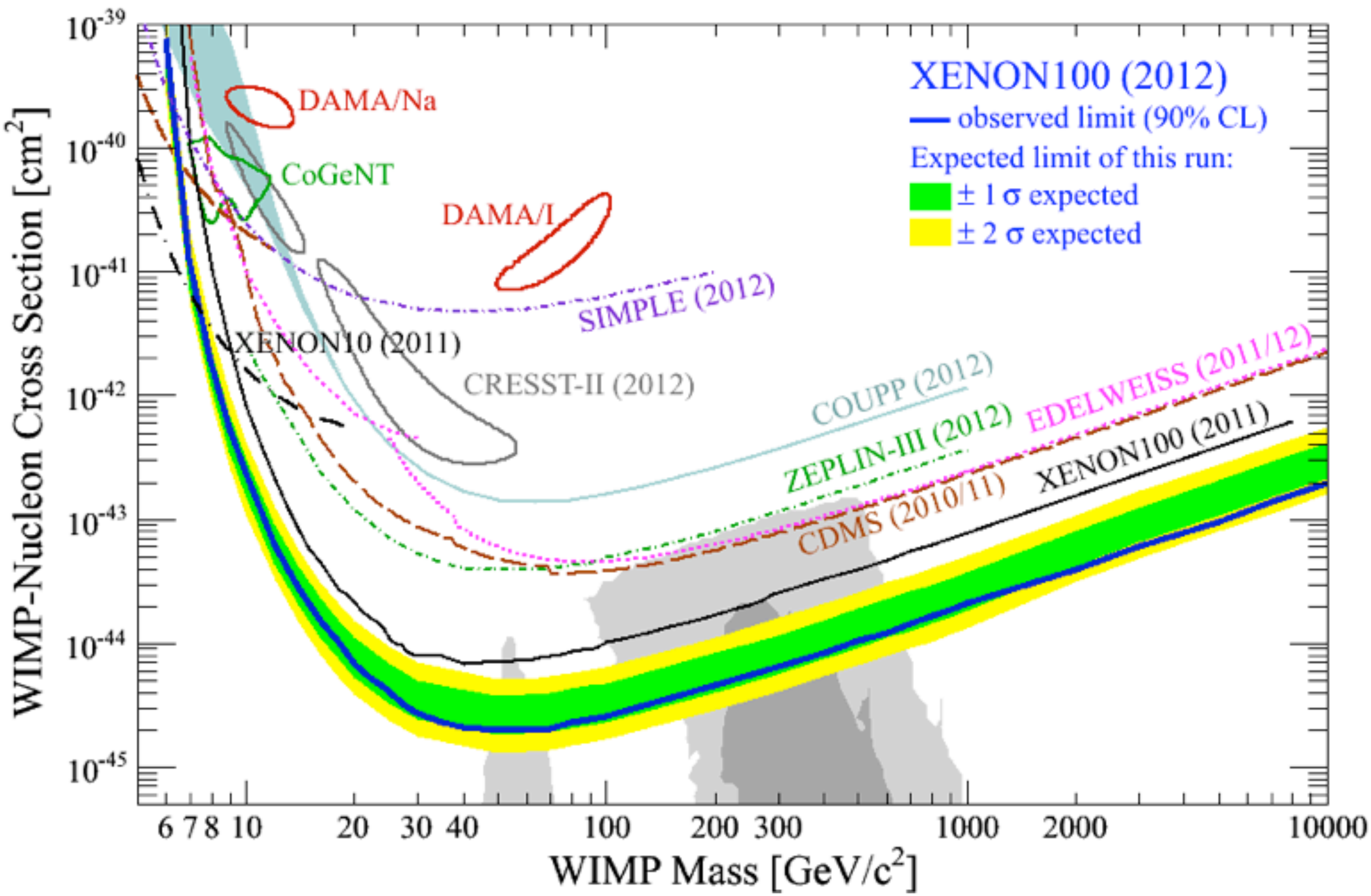
- 2 events observed in the signal region (expected BG 1.0±0.2)

Dark Matter Search

- Latest science run (Run 10, 2011-2012)

PRL 109, 181301 (2012)

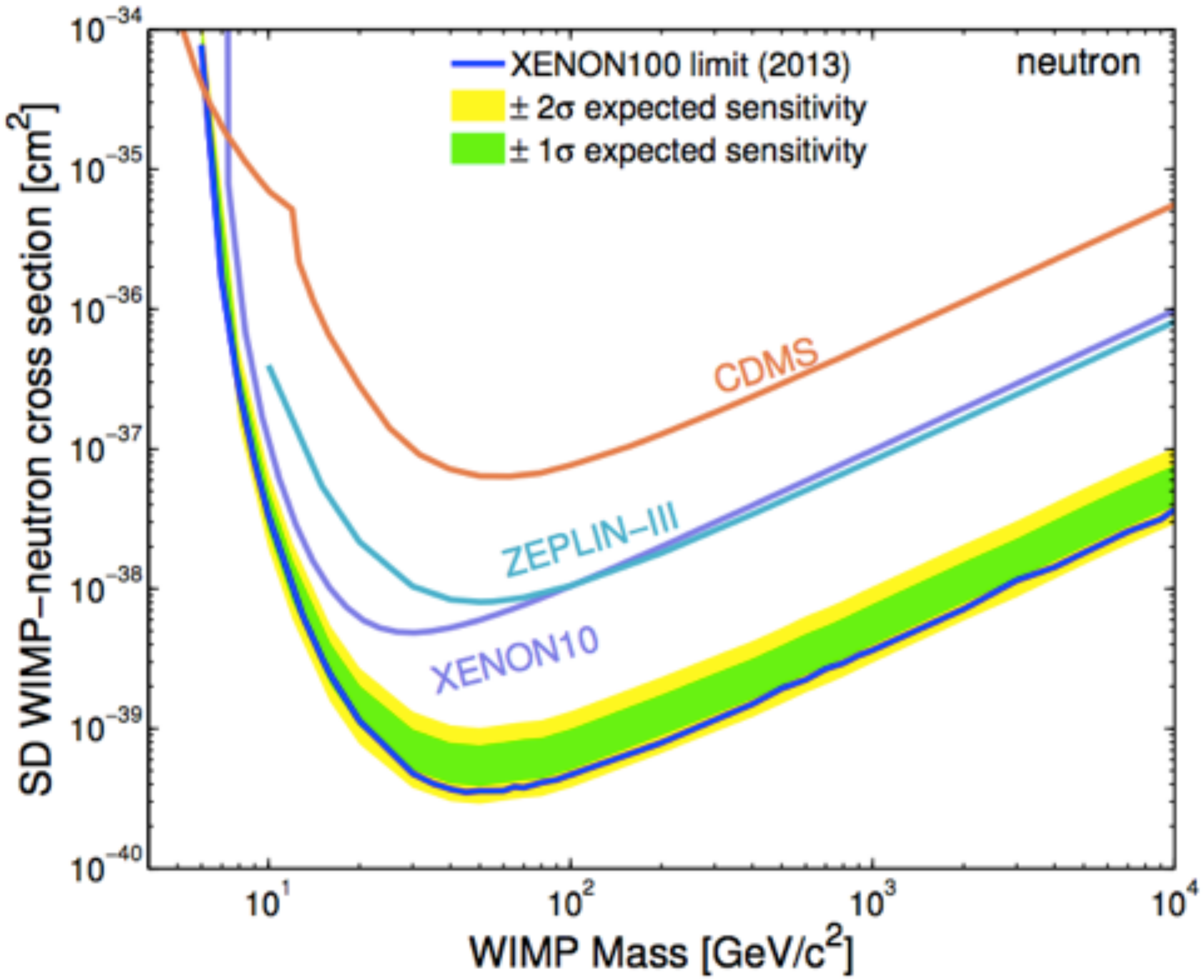
- Spin-independent WIMP-nucleon scattering

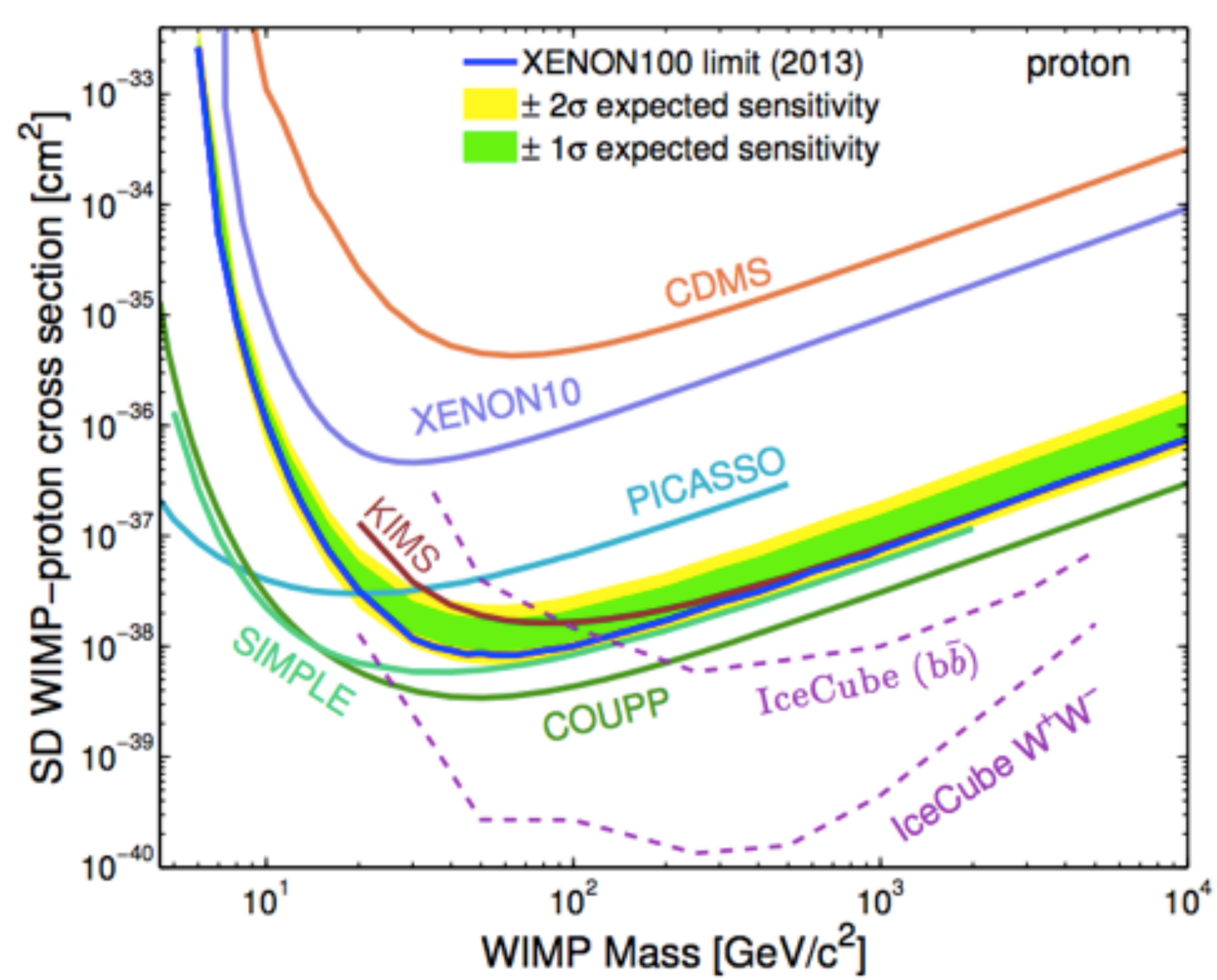


Dark Matter Search

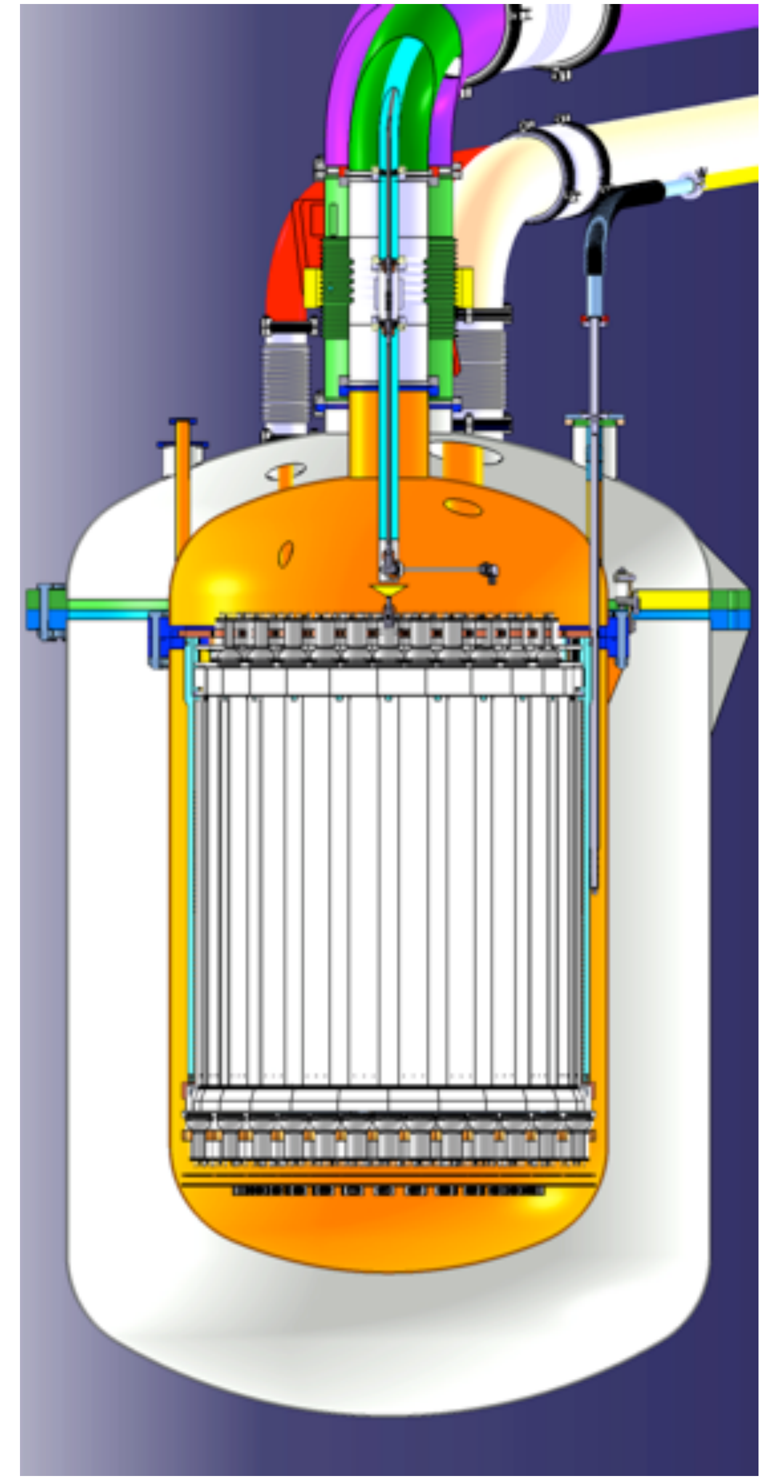
- Spin-dependent WIMP-nucleon scattering

PRL 111, 021301 (2013)





Next Step - XENON1T



- Construction underway. Start in 2015
- Total LXe mass >3t
- 1m drift length TPC
- Water shield (Cerenkov muon veto)
- 100 times lower BG

  < 0.5 ppt of ^{nat}Kr

  < 1 μBq/kg of ^{222}Rn

Summary

● XENON100 has set the most stringent limits on spin-independent WIMP-nucleon cross-section in 2012

● The detector is running and taking dark matter search data. Krypton concentration is lowered to 1.3 ppt (90% C.L.)

● The XENON1T is underway. Started construction of the water tank in Hall B at LNGS