The XENON Program

Gabriella Sartorelli, Dark Matter WG

March 2014

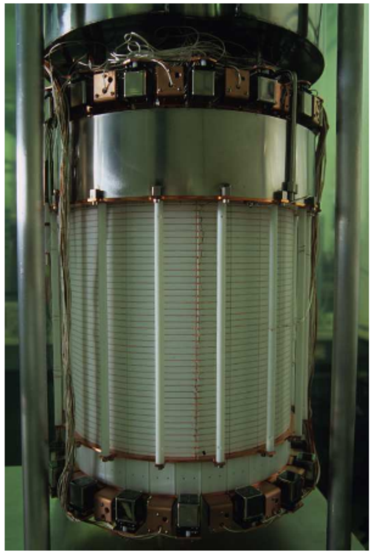
The XENON Program

XENON10

2005-2007
15 cm drift TPC – 25 kg

Achieved (2007)
σ_{SI} = 8.8 x 10^{-44} cm^2

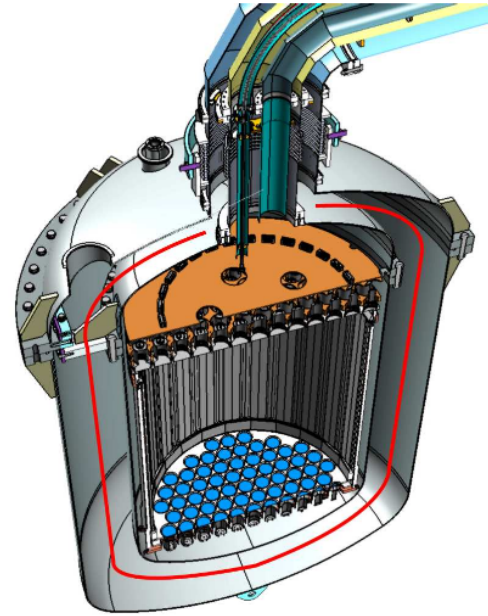
XENON100



2008-2015
30 cm drift TPC – 161 kg

Achieved (2011)
σ_{SI} = 7.0 x 10^{-45} cm^2
Achieved (2012)
σ_{SI} = 2.0 x 10^{-45} cm^2

XENON1T / XENONnT

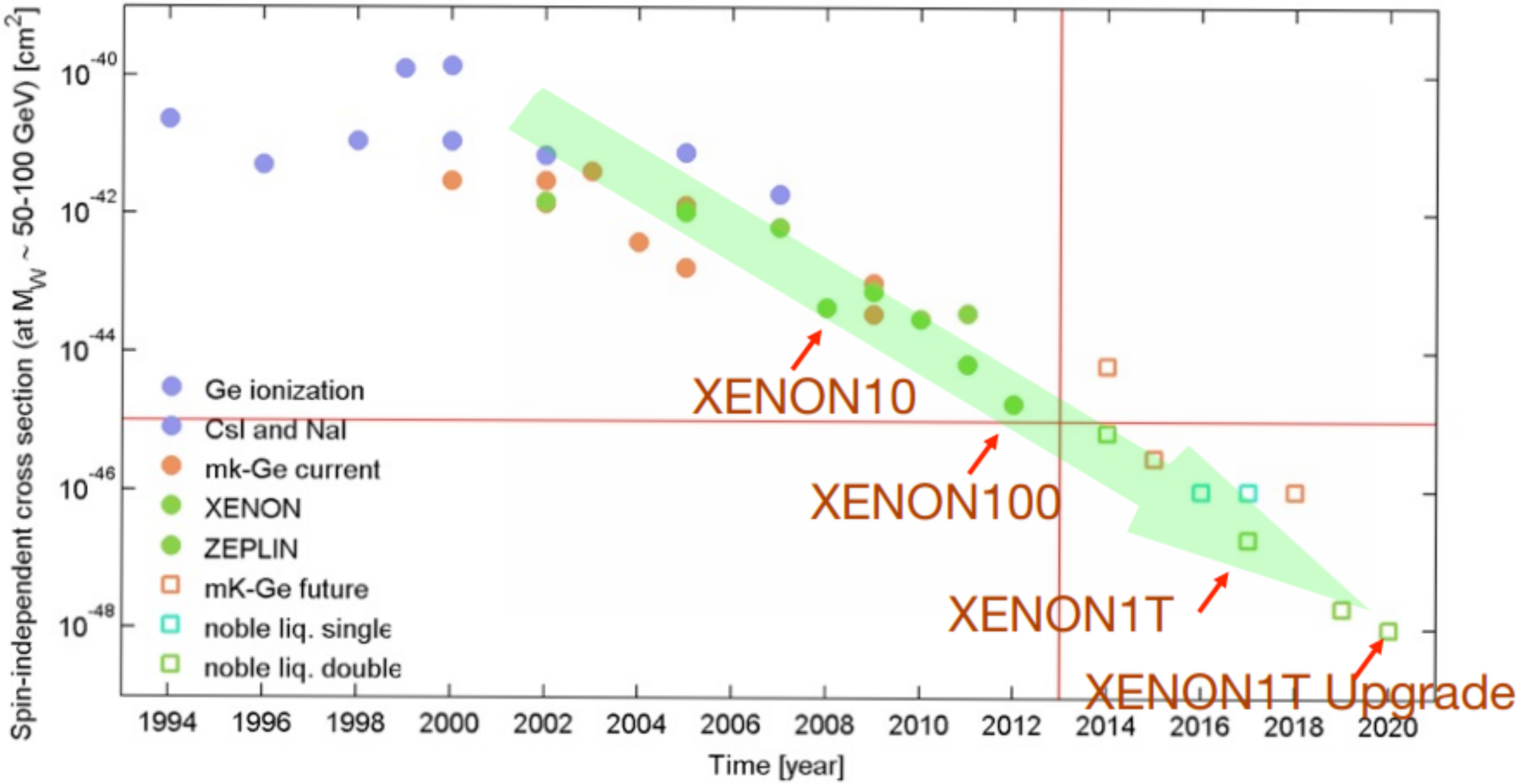


2012-2017 / 2017-2022
100 cm drift TPC - 3300 kg / 7000 kg

Projected (2017) / Projected (2022)
σ_{SI} = 2 x 10^{-47} cm^2 / σ_{SI} = 3 x 10^{-48} cm^2

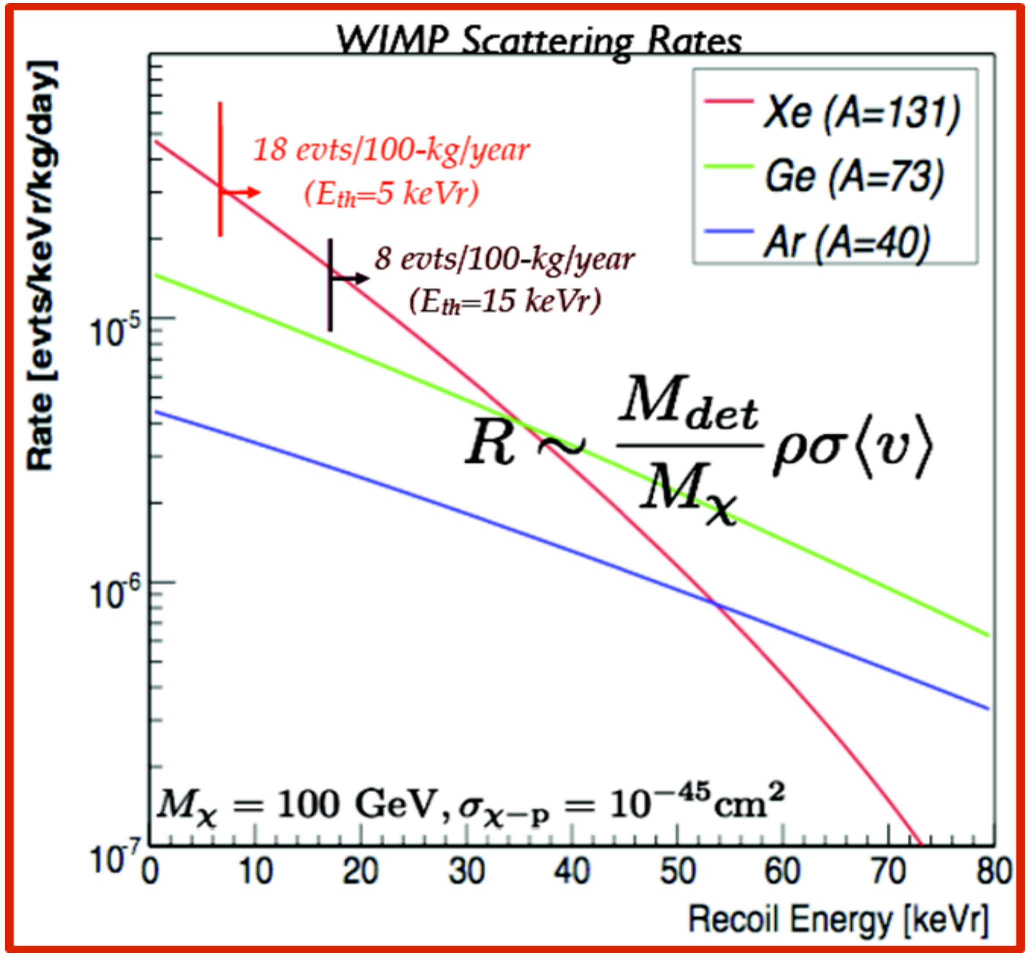
DM Direct Detection Sensitivity

Progress over time driven by LXe TPC experiments



Why use Xenon?

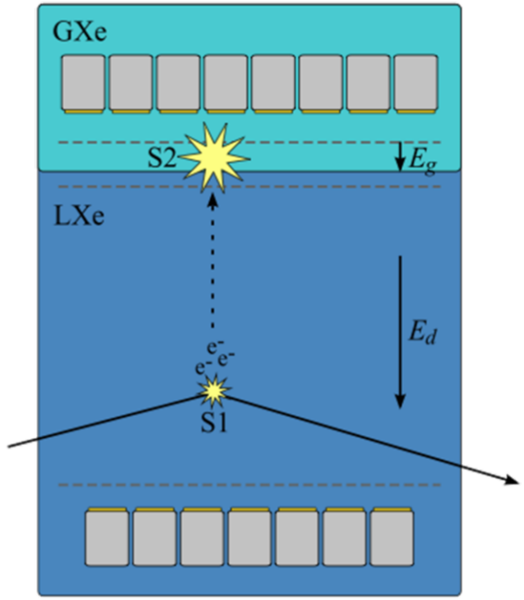
- Heavy nucleus (A~131): good for SI (coherent scattering off all nucleons) plus SD sensitivity (~50% odd isotopes)
- Charge & Light: highest yield among noble liquids and best self-shielding
- Low energy threshold: PMTs within liquid for efficient light detection
- Background rejection: by charge-to-light ratio, 3D-event reconstruction and fiducialization, LXe self-shielding
- Intrinsically pure: no long-lived radioactive isotopes
- Scalability: effort scales with surface while sensitivity scales with volume



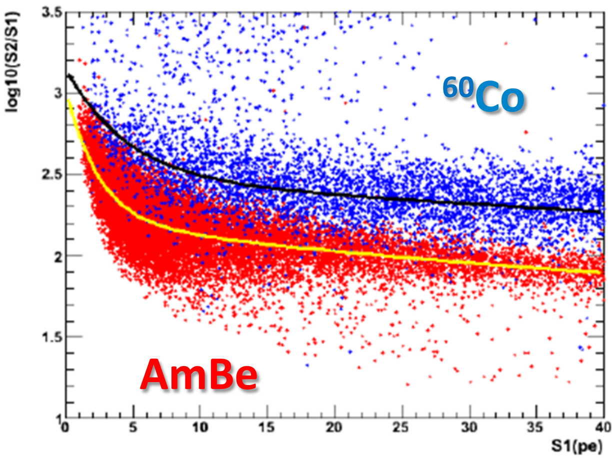
Xenon dual phase TPC

Detect two signals with photomultipliers:

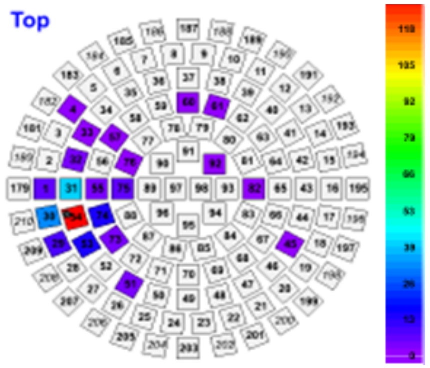
- Prompt scintillation (S1)
- Ionization via proportional scintillation (S2)



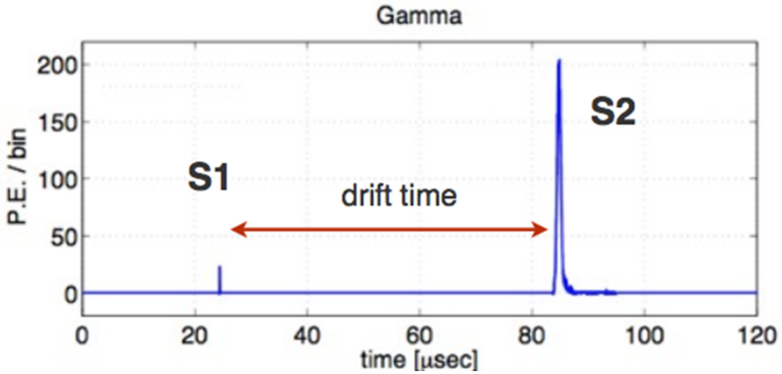
- ➢ 3D position reconstruction
- ➢ Nuclear-Electron Recoil discrimination



XY - coordinate

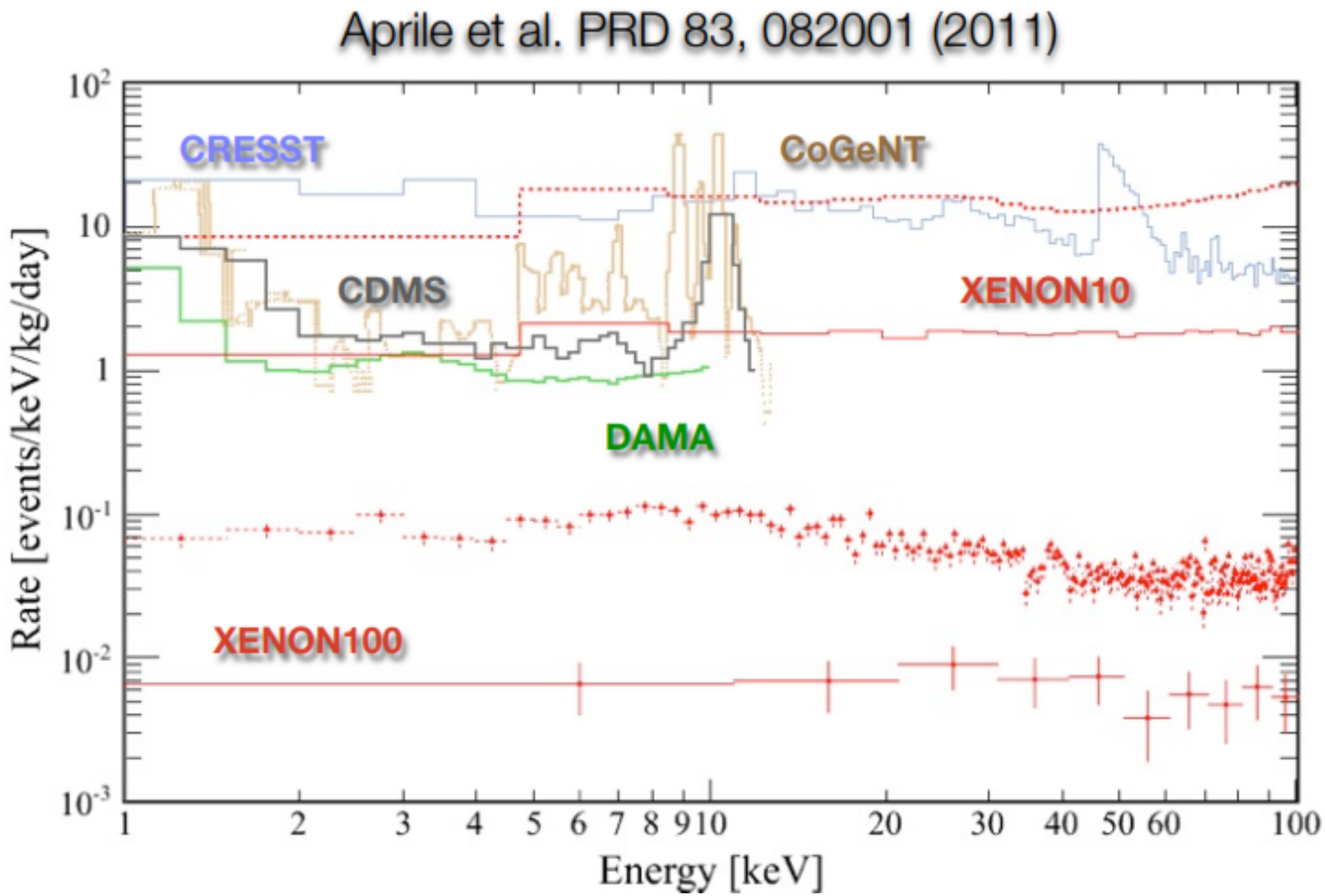


Z - coordinate



XENON100: an ultra-low background experiment

~5 x 10^{-3} evts/kg/keV/day after veto cut and before S2/S1 discrimination



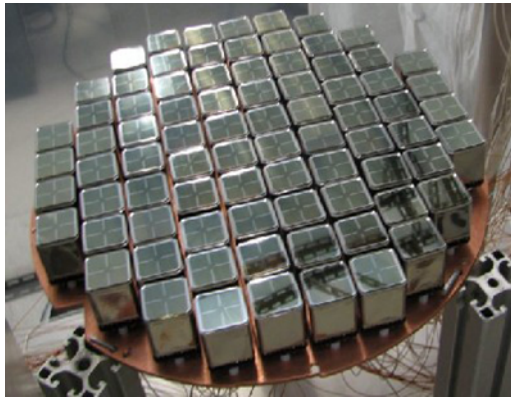
XENON100: The Detector

TPC:

- 30 cm drift length and 30cm ϕ
- 161 kg total (62 kg sensitive volume)
- Material screening and selection
- Active liquid xenon veto
- 100x lower background than XENON10

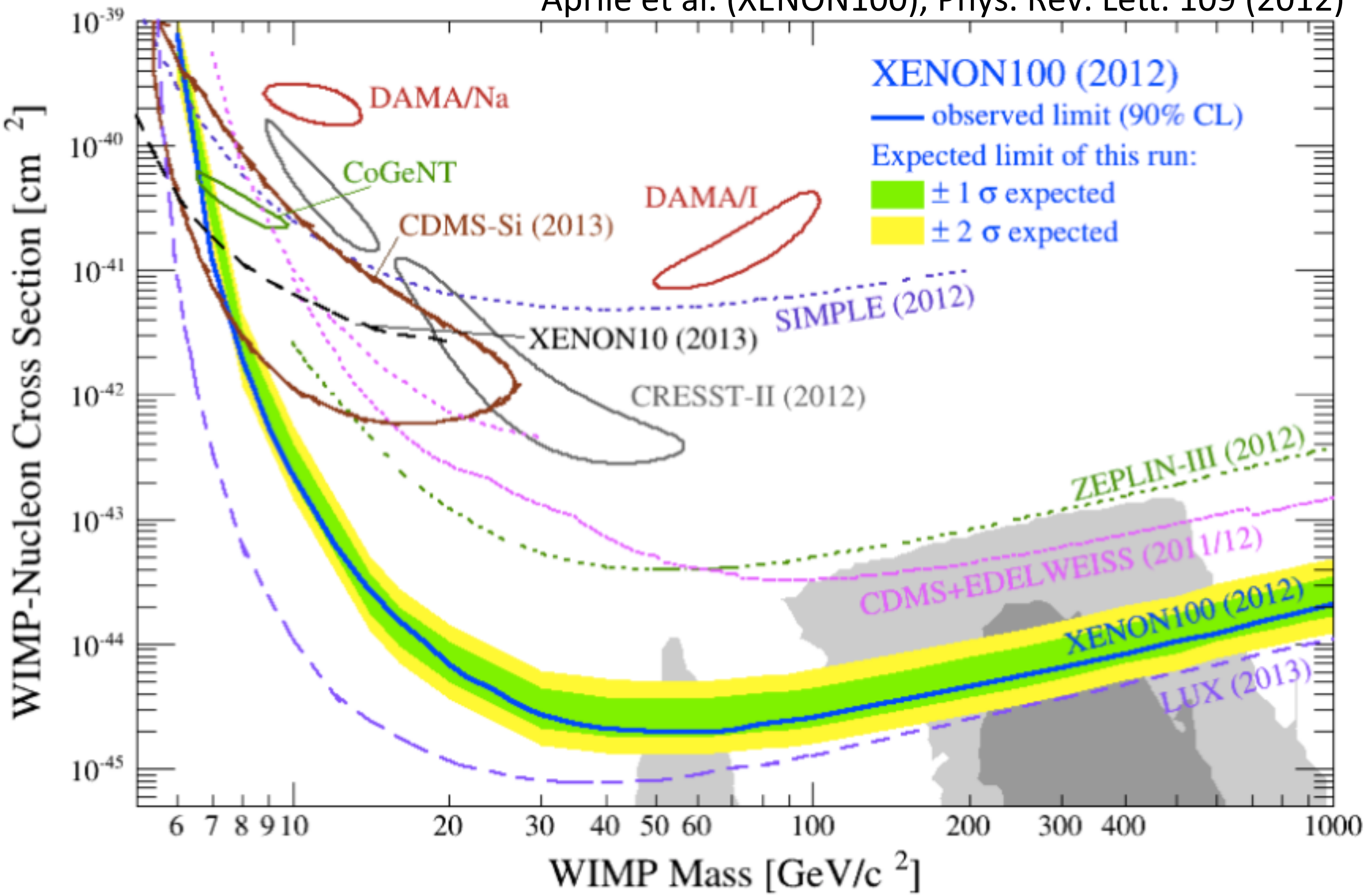
PMTs:

- 242 Hamamatsu R8520 in TPC and Active Veto
- High QE: Bottom tubes > 30%
- Low Radioactivity: < 10 mBq/ PMT

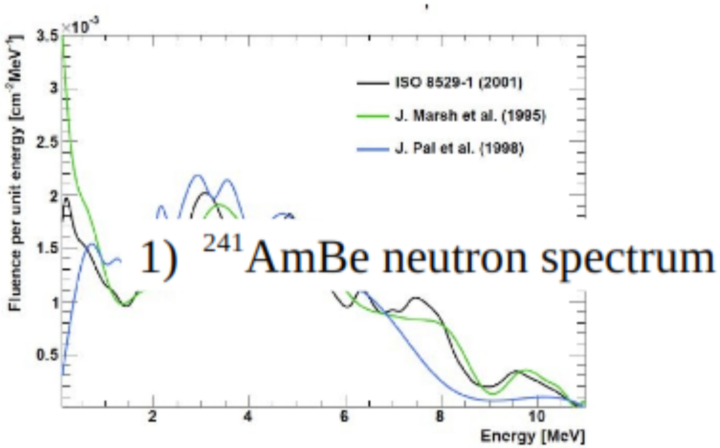


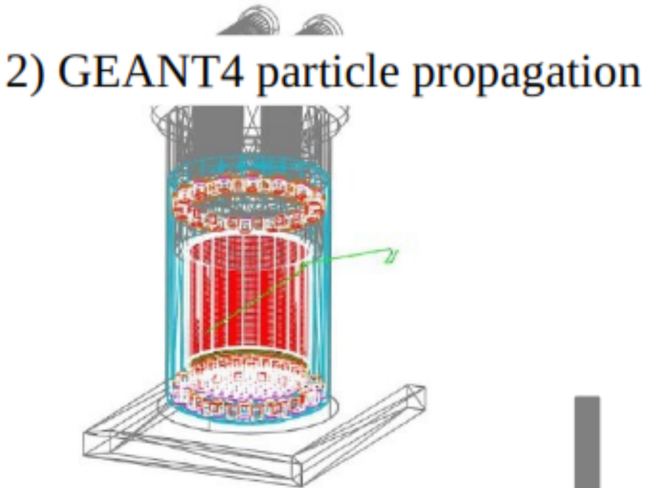
XENON100: Spin Independent Limit

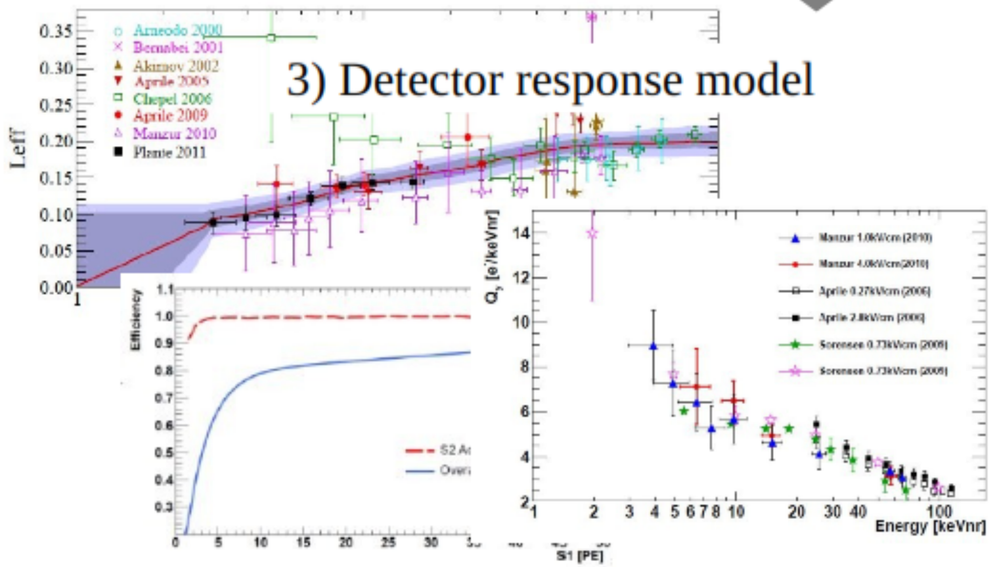
Aprile et al. (XENON100), Phys. Rev. Lett. 109 (2012)

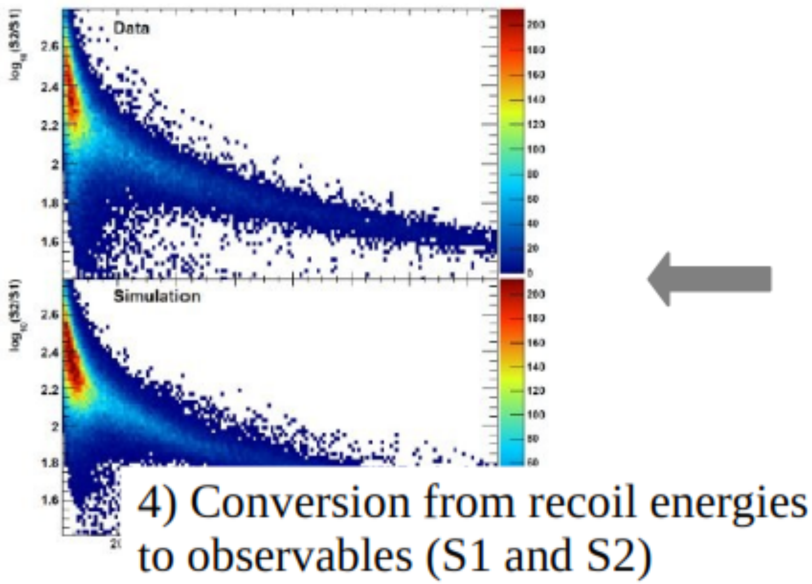


Modeling (MC) the responce to NR





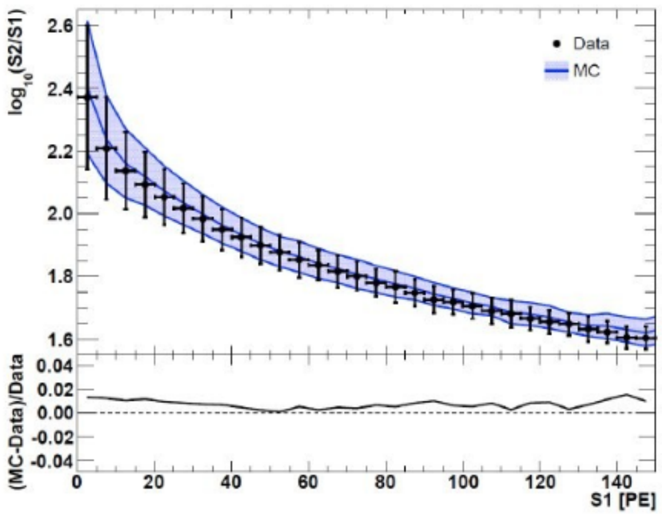


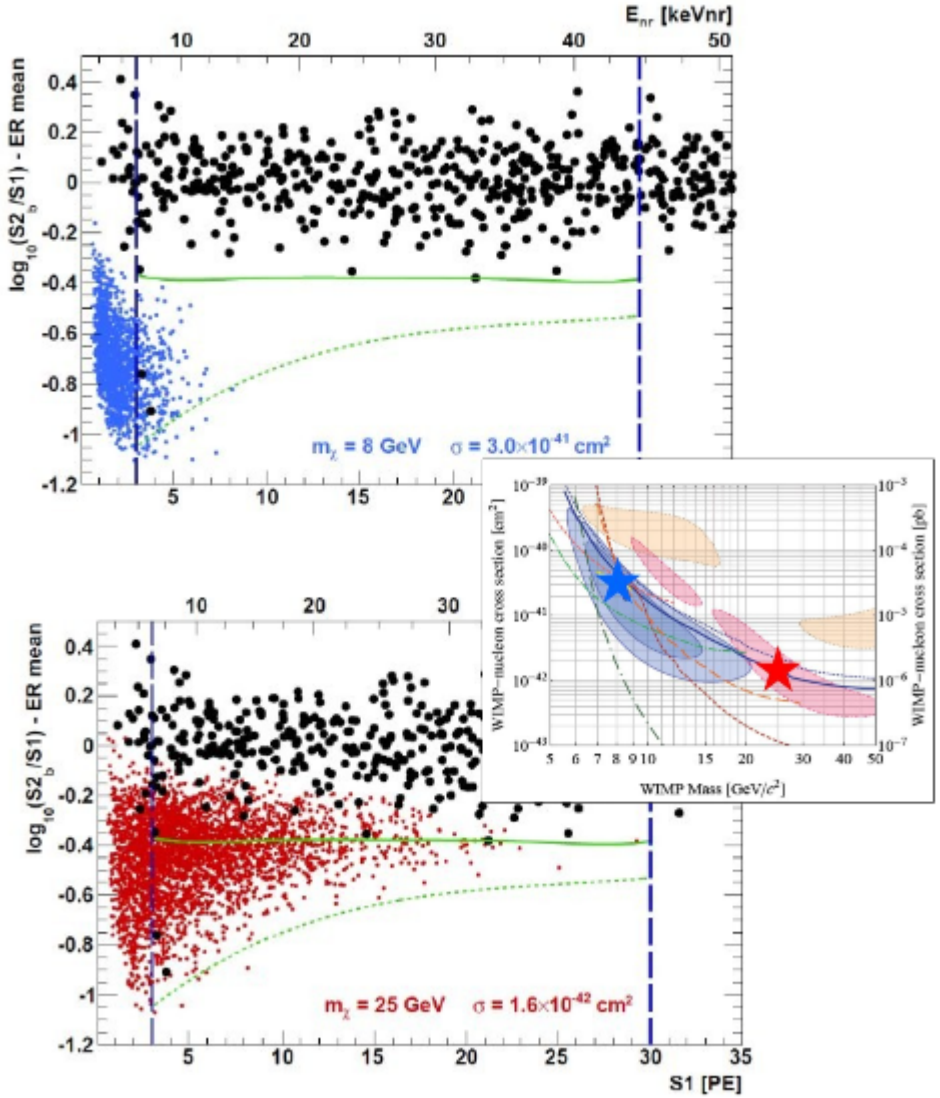


Expected WIMP signal

Extracting the Q_Y (S2) and L_{eff} (S1) from XENON100 Data, we are moving towards a future 2D analysis

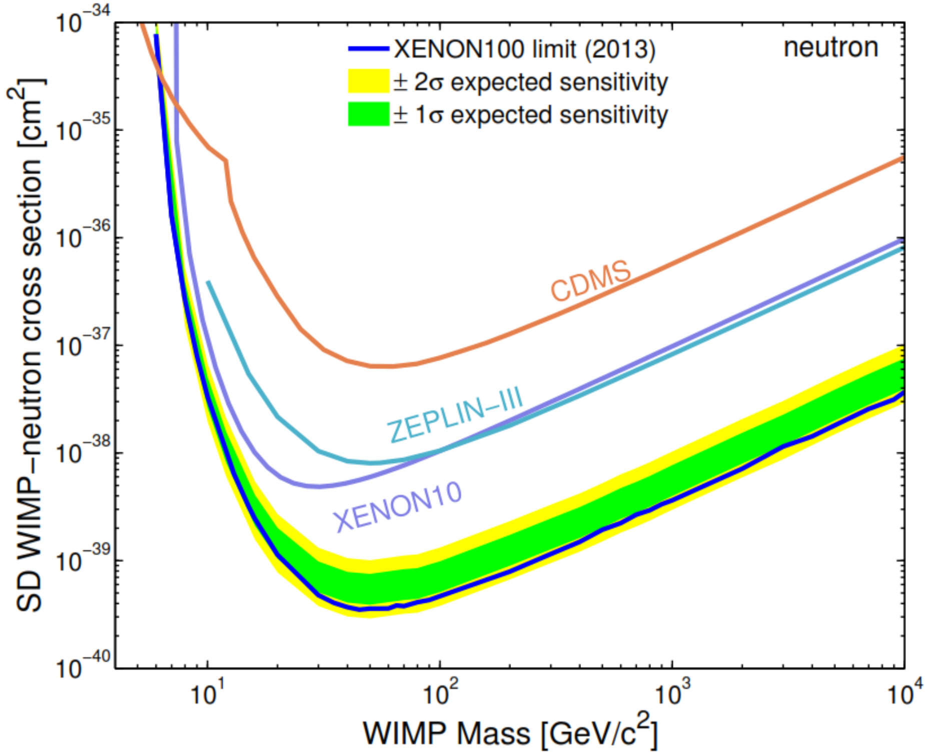
E. Aprile et al. (XENON100), Phys. Rev. D88, 012006 (2013)



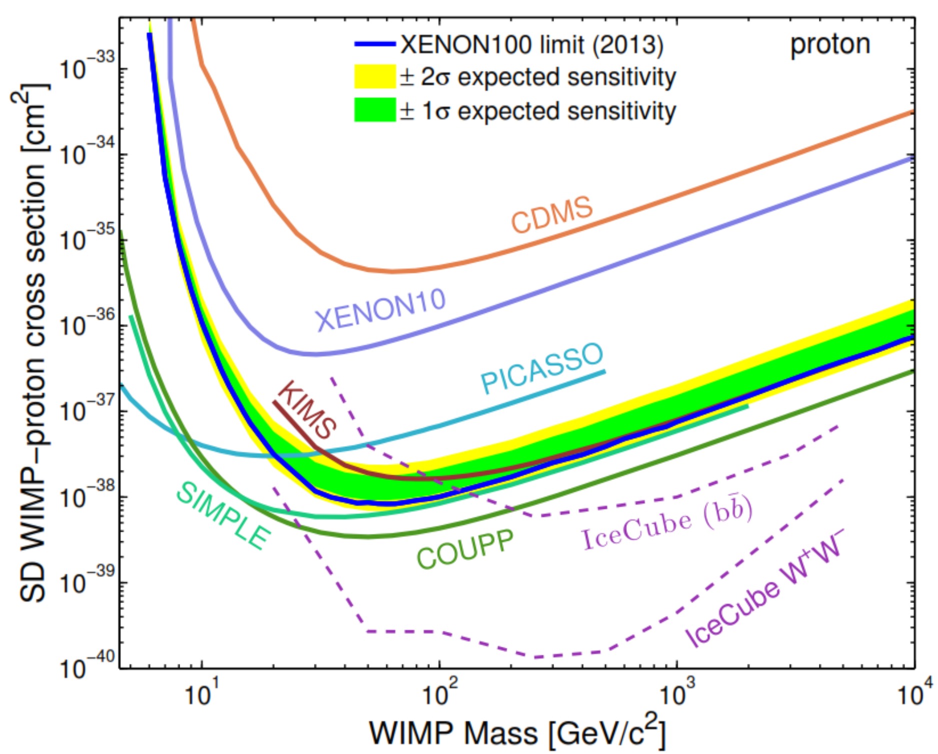


XENON100: Spin Dependent Limit

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



WIMP–neutron coupling



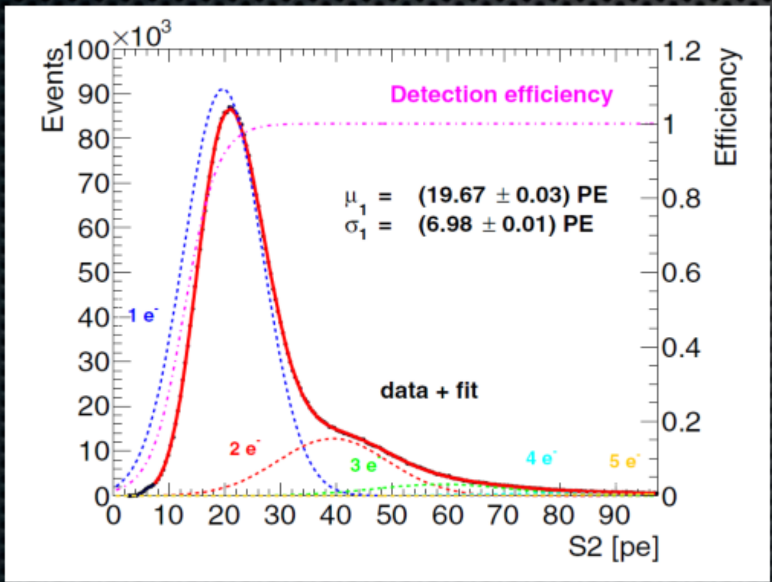
WIMP–protron coupling

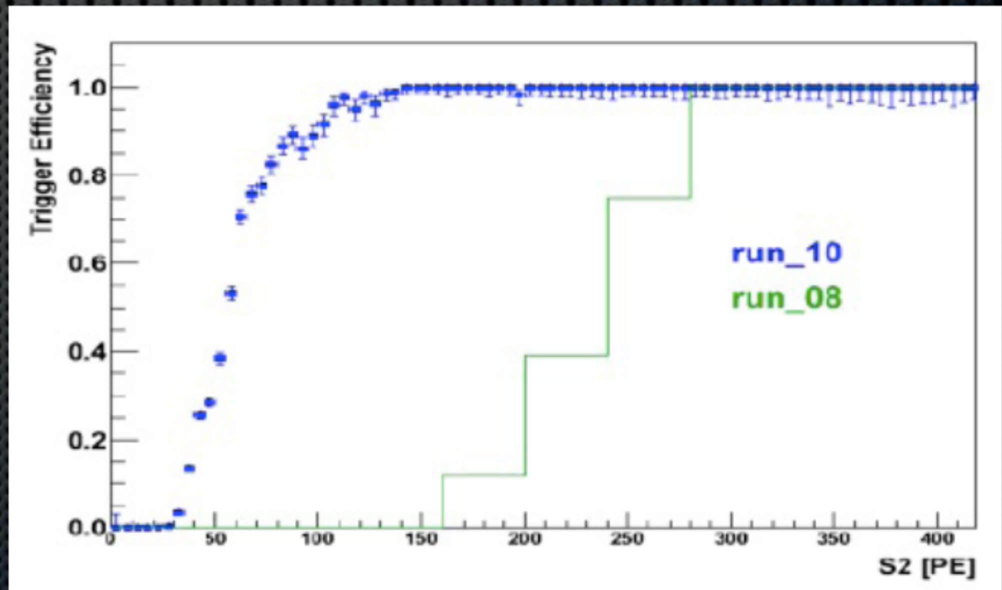
MeV/GeV WIMP search with XENON100

- GeV WIMPs will give NRs which can be detected through S2 signal only: 100% trigger efficiency for events with >8 electrons (~20pe/e gain) Aprile et al. PRL 109 (2012)

- WIMPs with ~50 MeV can eject a few electrons of Xe atoms also detectable via S2 only analysis and the single-e detection ability of XENON100 Aprile et al. Phys.G: Nucl.Part.Phys. 41(2014)

→ Analysis of 225 days data based on S2 signal and annual modulation signature near completion



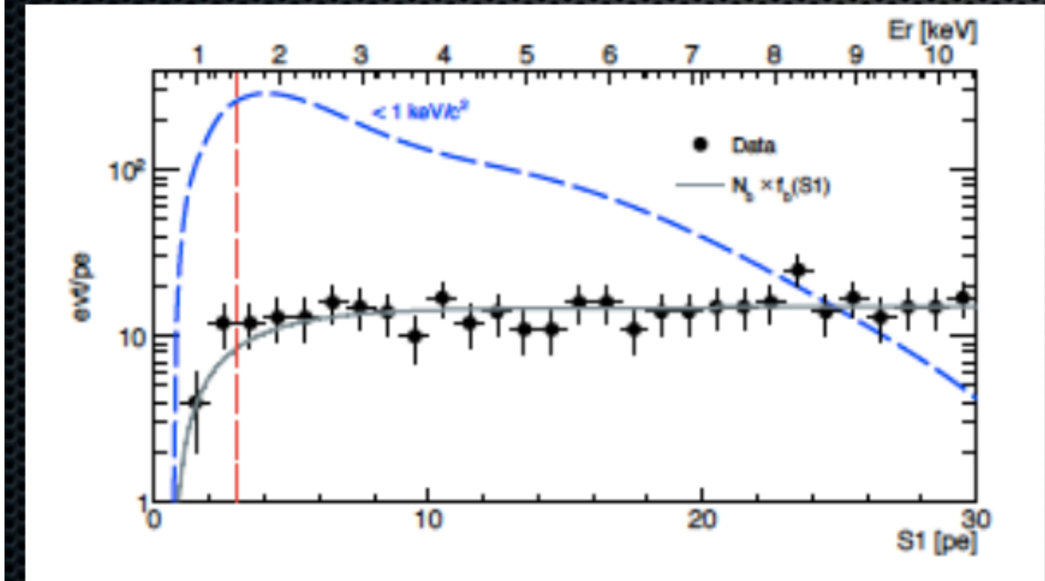


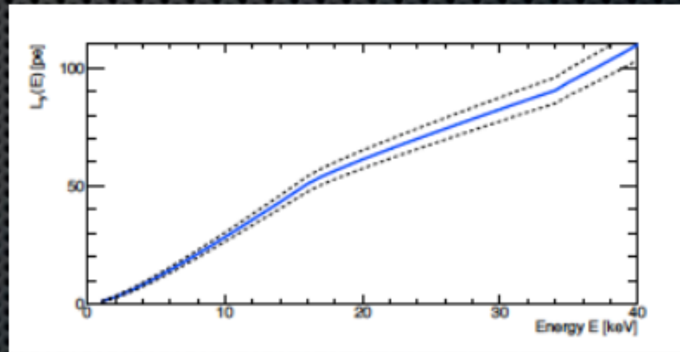
AXION Search with XENON100 Data

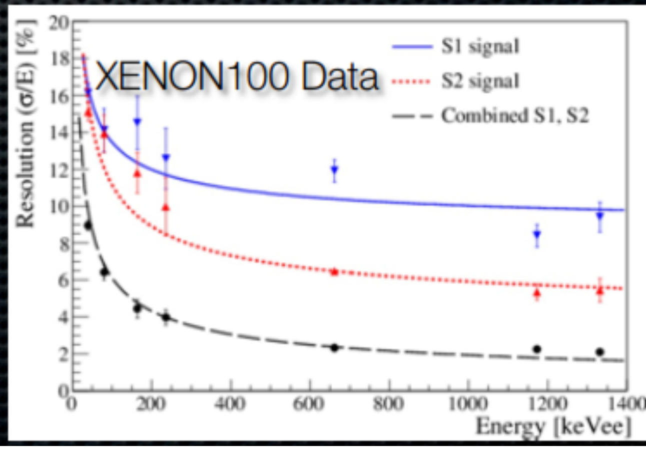
- XENON100 low background and threshold allow a sensitive search for Axions and ALPs scattering with atomic electrons via the axioelectric effect producing ERs with energy equal to axion mass minus e-binding energy in Xe → solar axions (continuum spectrum) and galactic (monoenergetic) axions

- S1(PE) converted to keV_{ee} based on recent measurements of scintillation efficiency and its quenching with field by Columbia and UZ groups. 3PE threshold corresponds to 2 keVee.

- The combined charge and light energy scale in LXe will allows for very good energy resolution as needed for these searches







What's next for XENON100?

<u>New physics analyses</u>
- Search for annual modulation
- Search for solar and galactic axions
- Light dark matter (S2-only analysis)

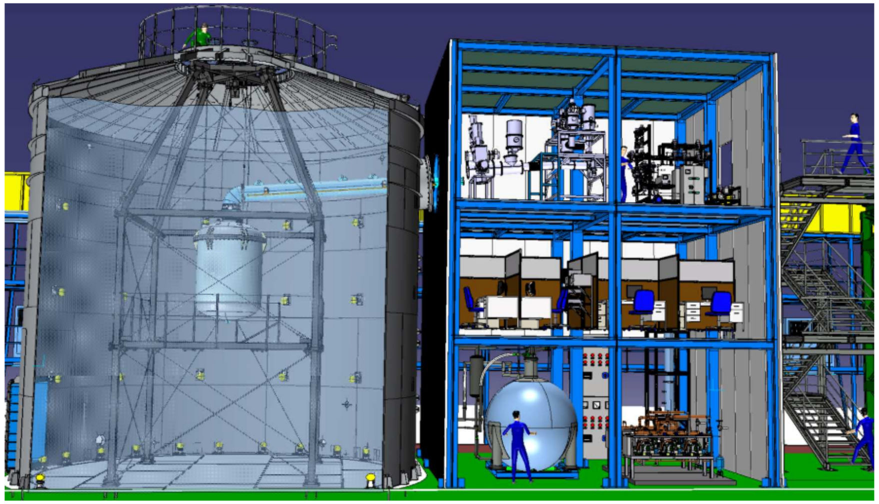
<u>Further detector characterization</u>
- Response to single electrons
- Combined S1 and S2 NR energy

<u>Continued data acquisition</u>
- New ^{241}AmBe NR calibration
- Increased stats for ER calibration
- Further reduced Kr (1.8 ± 3 ppt)
- Investigate Rn reduction
- New calibration techniques for XENON1T

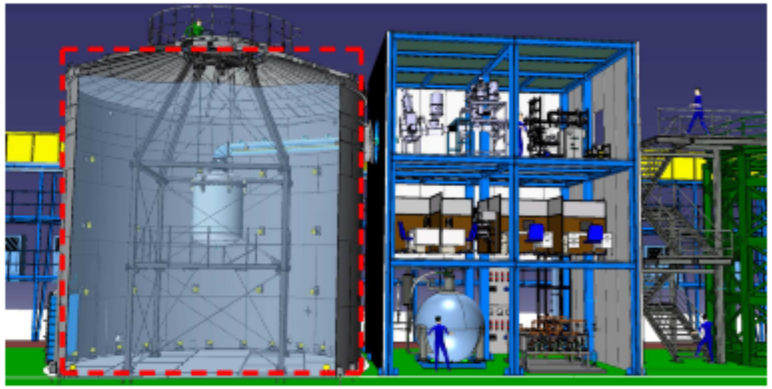
XENON1T: overview

- Two-phase TPC with 1 meter drift and ~1 m diameter electrodes, filled with 3.3 tonnes of Xe
- Experiment designed to enable a fast upgrade to a larger diameter TPC with 7 tonnes of Xe
- Detector-associated systems use largely proven technologies developed for XENON100
- New challenges presented by the scale-up addresses with multiple R&D set-ups
- New 3 inch PMTs developed for XENON1T: average QE~36% at 178 nm and low activity
- Detector shielded by water instrumentes as Cherenkov muon veto
- Status: under construction
- Commissioning of major plants at LNGS starts May 2014
- Science Goal: 10-47 cm2 with 2 ton-years of data or by 2017

XENON1T: (very near) future

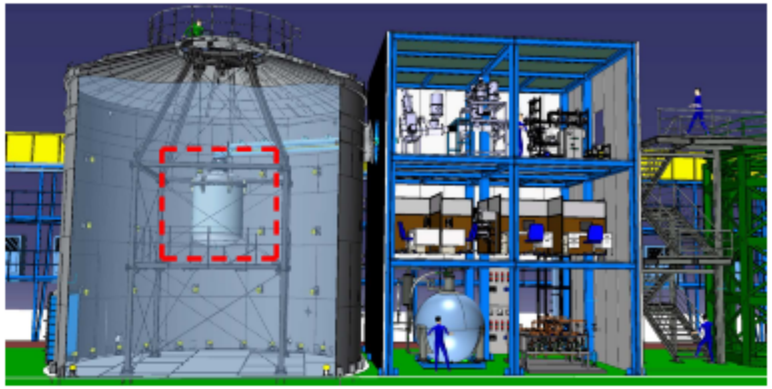


Water Cherenkov Muon Veto



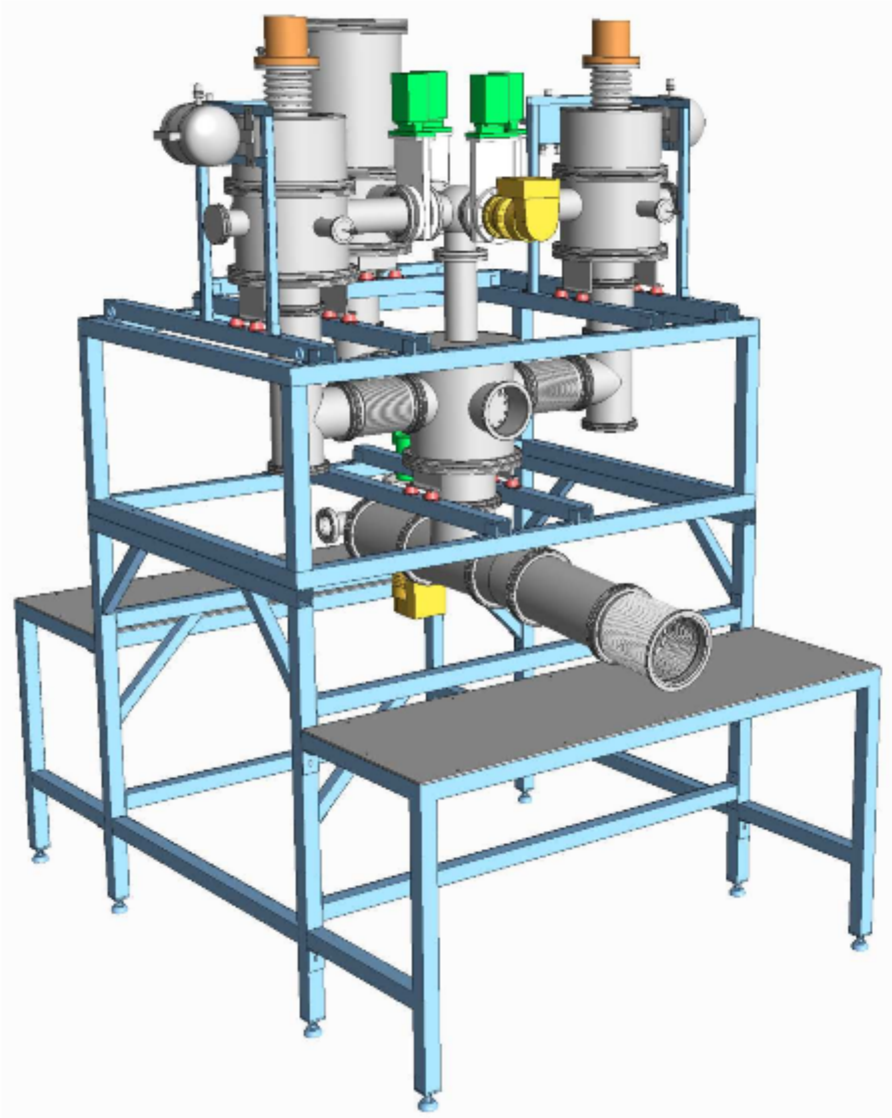
- Water tank $10\,\mathrm{m}$ high and $9.6\,\mathrm{m}$ diameter
- Interior lined with 3M specular reflector foil
- Water tank construction completed 2013/12
- 84 high QE 8" Hamamatsu R5912 PMTs
- μ-induced neutron background < 0.01 evt/yr
- Trigger efficiency $> 99.5\%$ for neutrons with μ in water tank, ~78% with μ outside

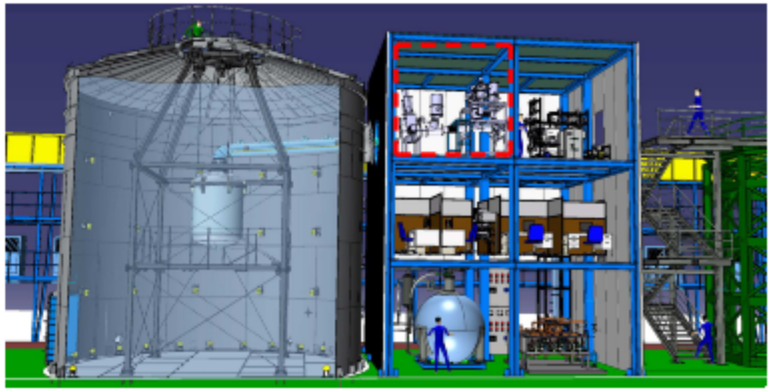
Cryostat and TPC



- Double-wall vacuum insulated cryostat, constructed from selected low-activity stainless steel
- Outer vessel $2.4\,\mathrm{m}$ high, $1.6\,\mathrm{m}$ diameter, inner vessel $\sim 2\,\mathrm{m}$ high, $1.1\,\mathrm{m}$ diameter
- $1\,\mathrm{m}^3$ TPC, ~3.3 tons of LXe, ~1.3 ton fiducial mass
- 248 3" PMTs Hamamatsu R11410-21, 36% average QE, $< 1\,\mathrm{mBq/PMT}$ in U/Th
- Background $\times 100$ lower than XENON100
- Custom low-activity high voltage feedthrough

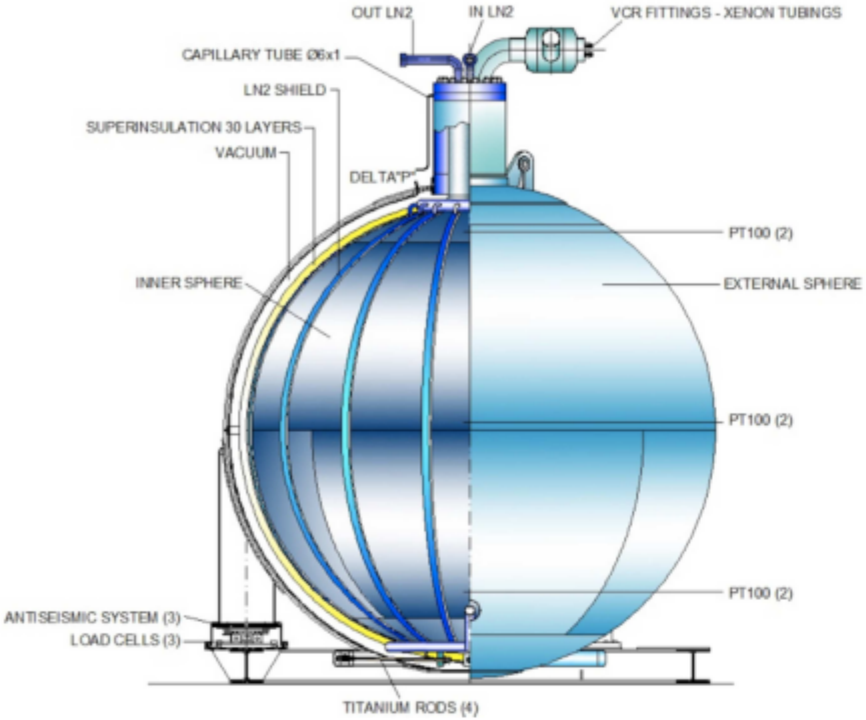
Cryogenics

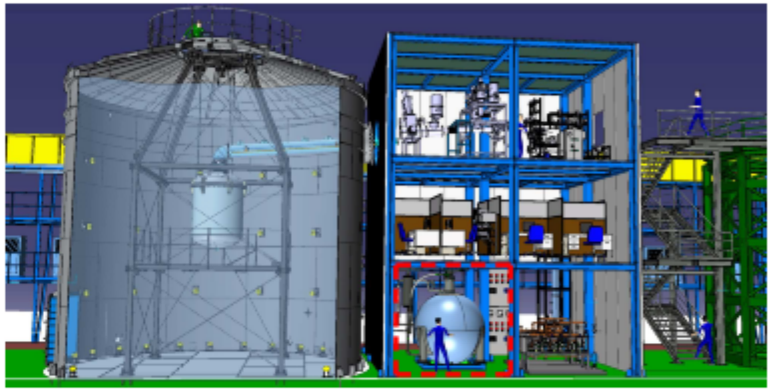




- Design based on experience acquired by operating XENON10, XENON100, and XENON1T Demonstrator
- Heat load below 50 W (without circulation)
- Redundant 200 W pulse tube refrigerators
- One PTR can be serviced while the other is in operation
- Backup liquid nitrogen cooling
- Circulation at ~100 slpm through heat exchangers

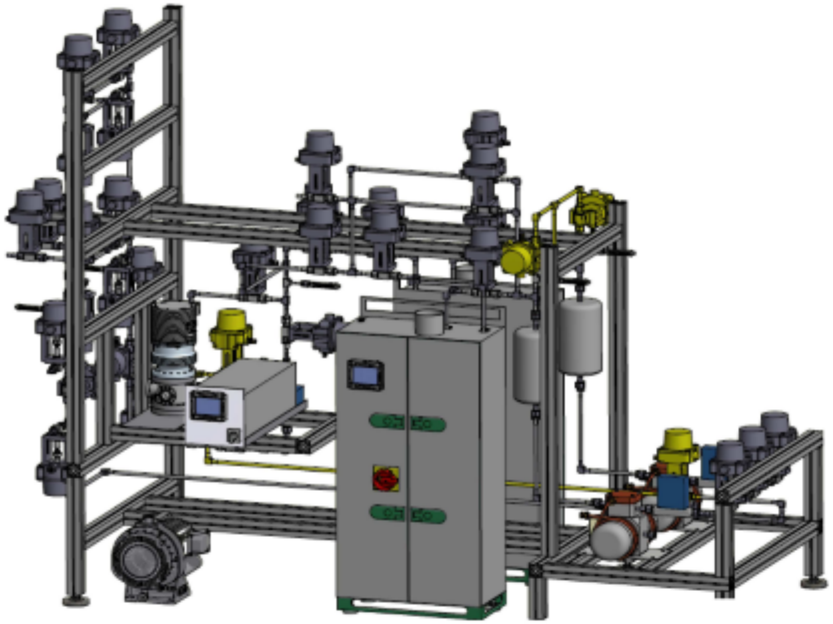
Xenon storage

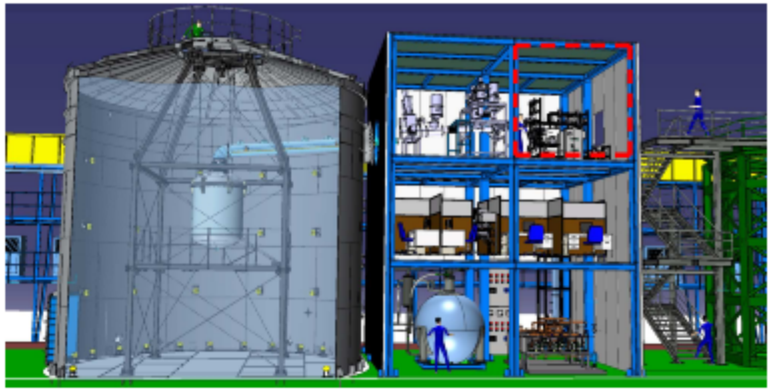




- Double-wall, high-pressure (70 atm), vacuum insulated, LN2 cooled sphere
- Designed to store ~7.6 tons of xenon, in liquid form at $-100°C$ or in gaseous form at room temperature
- Detector can be filled with liquid xenon directly instead of condensing xenon gas
- In case of emergency, liquid xenon from the detector can be recovered in a few hours

Purification System



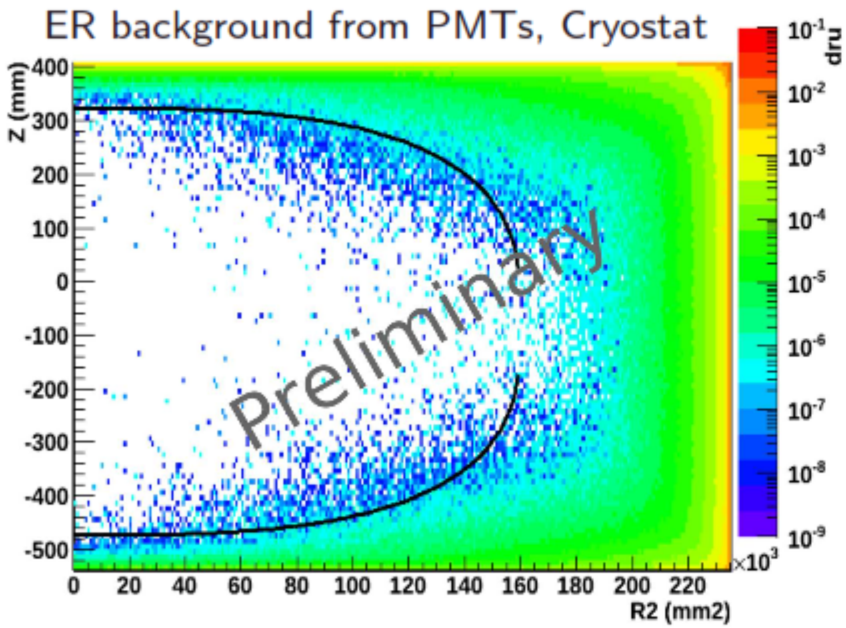


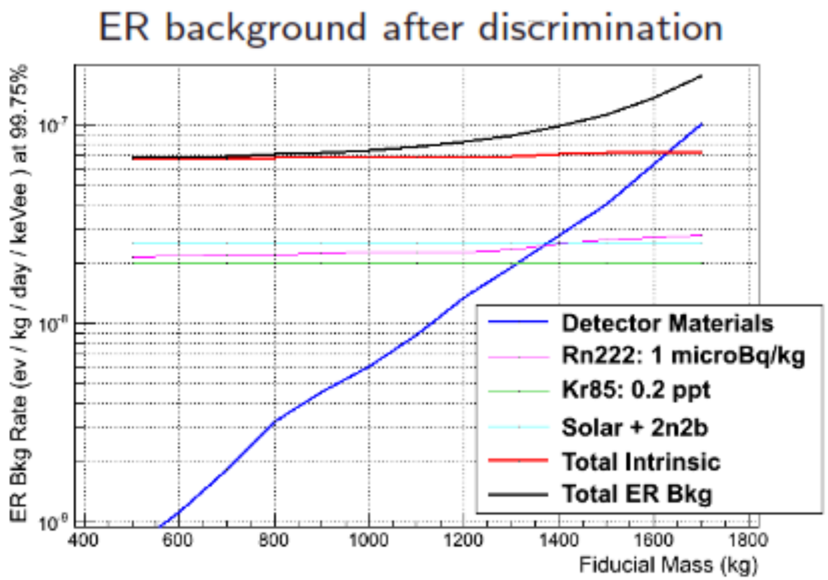
- Continuous GXe circulation at ~100 slpm
- Purification using high-flow heated getters
- Two parallel circulation pumps and purification circuits
- GXe purity in-situ analytics
- Continuous monitoring of impurity concentrations (e.g. H_2O)

Kr removal

- Building custom designed cryogenic distillation column for Kr removal
- XENON1T Kr/Xe concentration requirement is $< 0.5\,\mathrm{ppt}$, aim at $< 0.1\,\mathrm{ppt}$ with the column
- High throughput, $3\,\mathrm{kg/hr}$ at 10^4 separation
- 3.5 tons in ~1.8 months (single pass)
- Custom gas purity diagnostics (online, $^{83m}\mathrm{Kr}$ tracer, and offline, ATTA, RGMS, RGA + cold trap)

Backgrounds

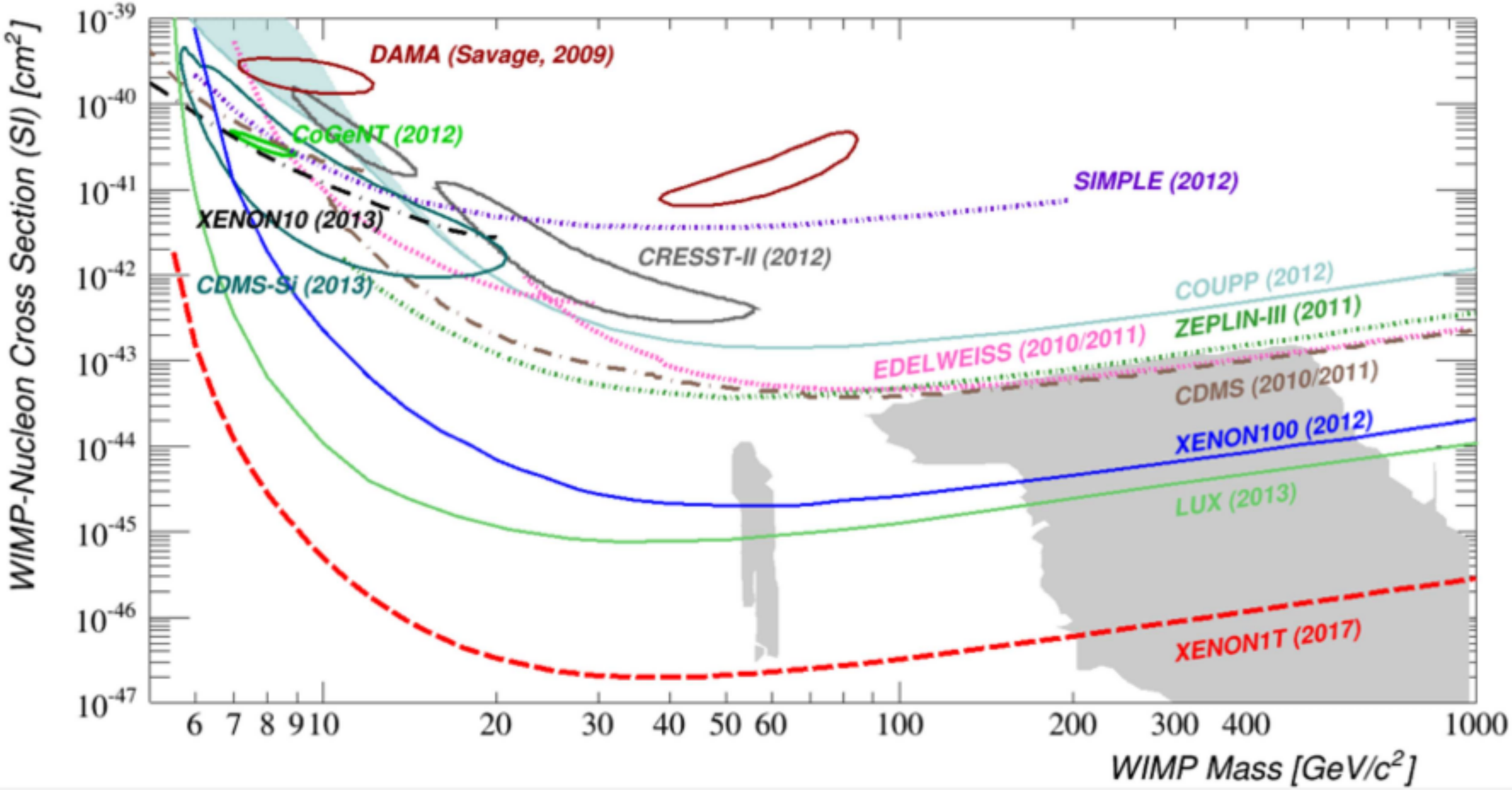




- Full MC simulation of the detector (TPC, PMTs, cryostat, water shield) with GEANT4 to predict ER background
- Neutrons from (α, n) calculated with SOURCES-4A
- Background rejection through: single scatter requirement, fiducialization, S2/S1 discrimination, Cherenkov muon veto

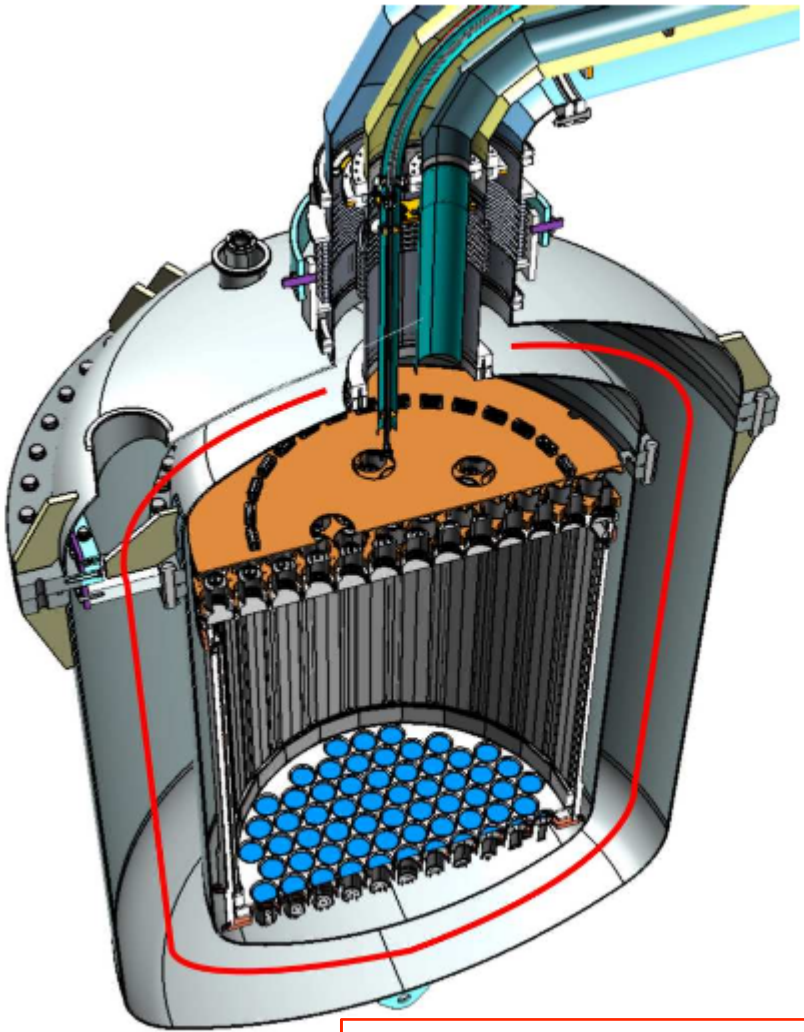
- Intrinsic backgrounds ($^{85}\mathrm{Kr}$, $^{222}\mathrm{Rn}$) need to be kept at very low levels
- Total ER background rate expected to be below $5 \times 10^{-5}\,\mathrm{evts/keV_{ee}/kg/day}$ before S2/S1 discrimination

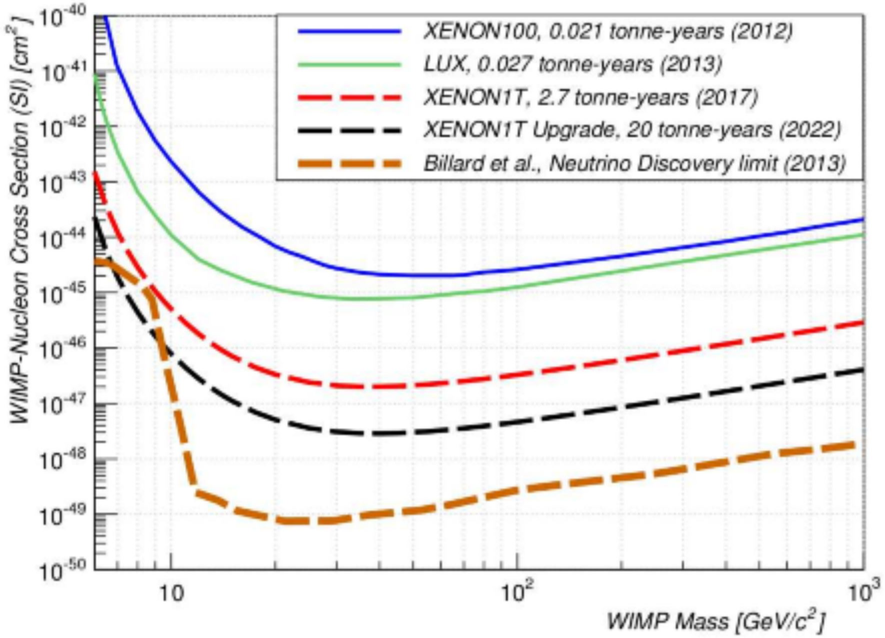
Sensitivity



- Spin-independent WIMP-nucleon interaction cross section sensitivity of $2 \times 10^{-47}\,\mathrm{cm}^2$ for WIMPs with a mass of $50\,\mathrm{GeV}/c^2$

Near future (> 2017) XENON1T upgrade (XENONnT)





- Rapid deployment possibility: no modifications to infrastructure required, only construction of a larger inner vessel and TPC.
- Target mass of ~6 tons, sensitivity to spin-independent WIMP-nucleon elastic scattering cross sections of 3×10^{-48} cm^2.

The black dashed limit is obtained taking into account only intrinsic backgrounds (0.2 ppt of ^{85}Kr and 0.5 Bq/kg of ^{222}Rn) and backgrounds due to neutrinos.

WIMP search summary and XENONnT (G2) expected sensitivity