Latest results from XENON1T and status of the XENONnT experiment

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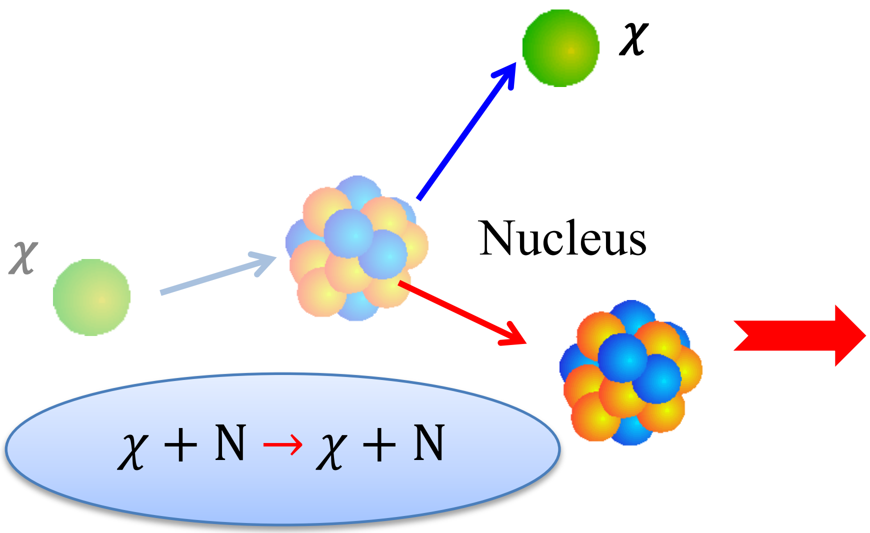
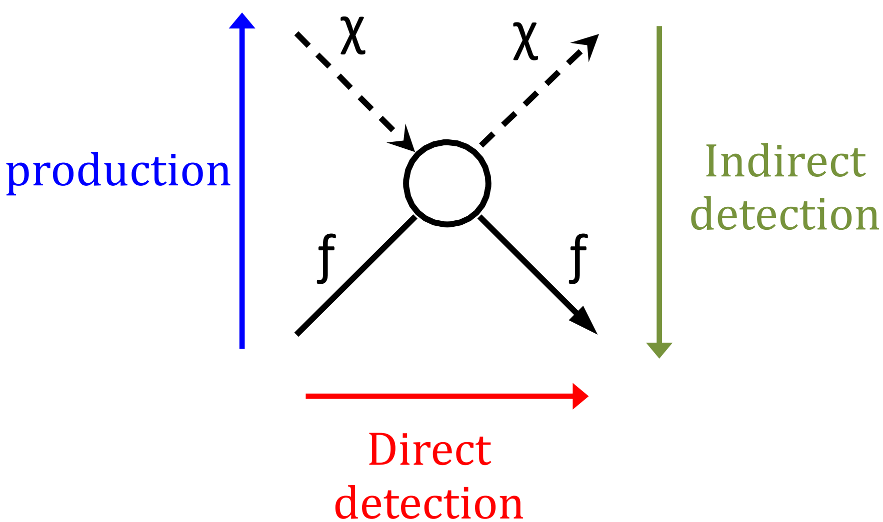
WIMP direct detection principle

Nuclear Recoil (NR)



Recoil energy
~1-100 keV

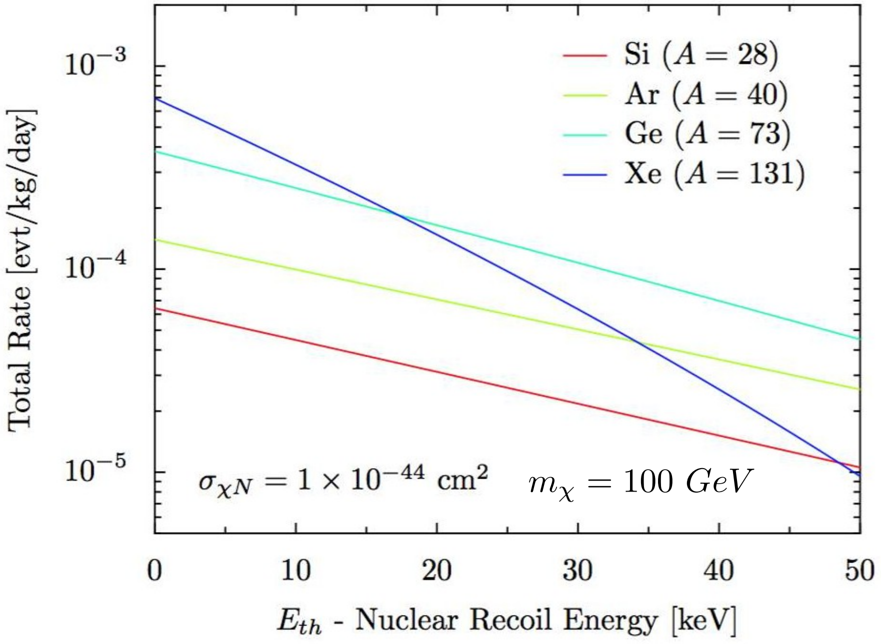


Electronic Recoil (ER)

γ and β particles interact with the atomic electrons
➔ Background in « standard WIMP analysis »

Why Xenon ?

- Large mass number A (131) (Interaction cross section ∝ A^2)
- 50% odd isotopes (^{129}Xe, ^{131}Xe) for Spin-Dependent interactions
- Kr can be reduced to ppt levels
- High stopping power, i.e. active volume is self-shielding
- Efficient scintillator (178 nm)
- Scalable to large target masses
- Electronic recoil discrimination with simultaneous measurement of scintillation and ionization



XENON Collaboration

~160 scientists

28 institutions

11 countries

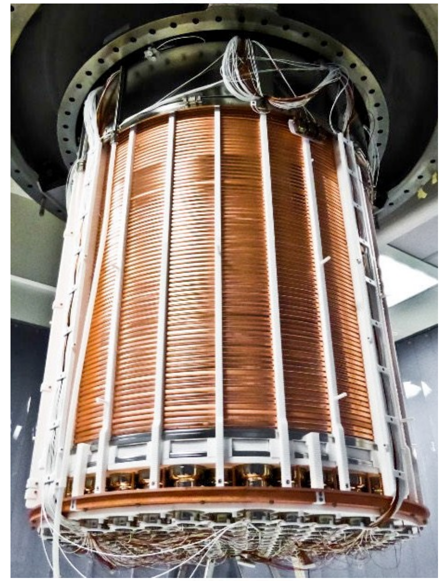
Phases of the XENON Program

XENON10
2005 – 2007
15 cm drift TPC
Total: 25 kg
Target: **14** kg
Fiducial: 5.4 kg

Achieved (2007)
$\sigma_{SI} = 8.8 \cdot 10^{-44}$ cm^2
@ 100 GeV/c^2

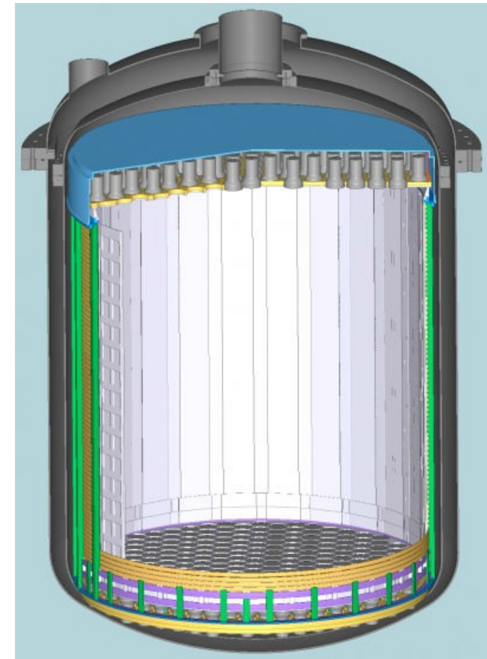
XENON100
2008 – 2016
30 cm drift TPC
Total: 161 kg
Target: **62** kg
Fiducial: 34/48 kg

Achieved (2016)
$\sigma_{SI} = 1.1 \cdot 10^{-45}$ cm^2
@ 55 GeV/c^2



XENON1T
2011 – 2018
100 cm drift TPC
Total: 3 200 kg
Target: **2 000** kg
Fiducial: 1 300 kg

Achieved (2018)
$\sigma_{SI} = 4.1 \cdot 10^{-47}$ cm^2
@ 30 GeV/c^2

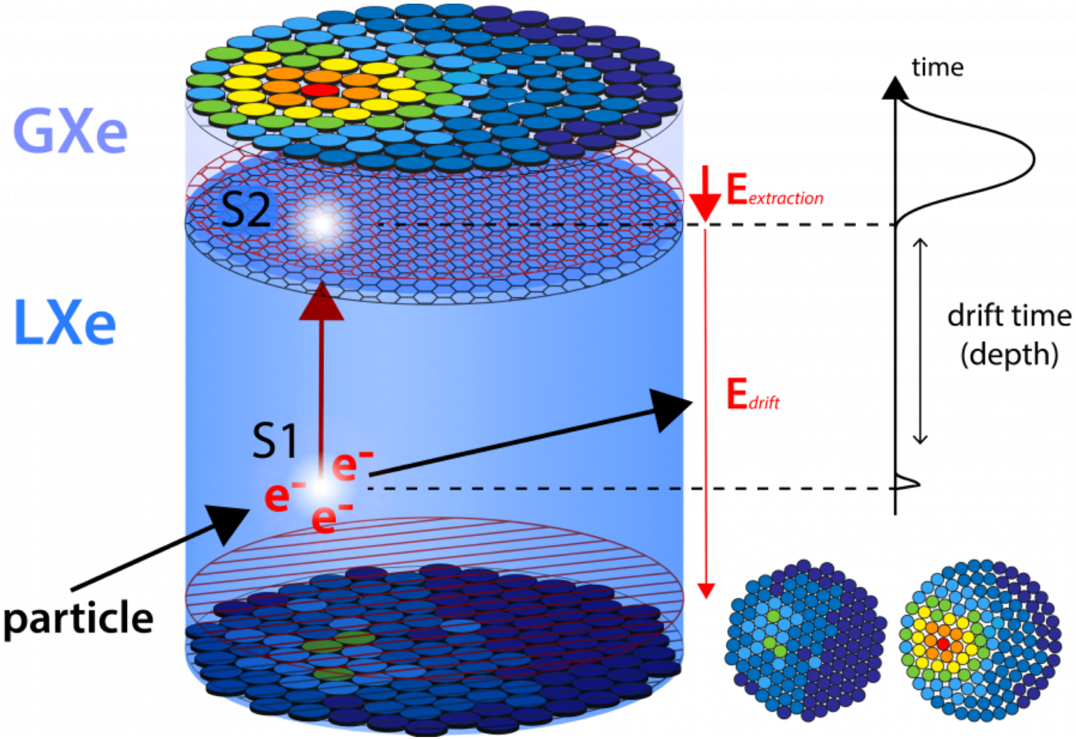


XENONnT
2019 – 2023
150 cm drift TPC
Total: 8 400 kg
Target: **5 900** kg
Fiducial: ~ 4 000 kg

Projected
$\sigma_{SI} = 1.6 \times 10^{-48}$ cm^2
@ 50 GeV/c^2

Dual phase TPC: principle

TPC = Time Projection Chamber

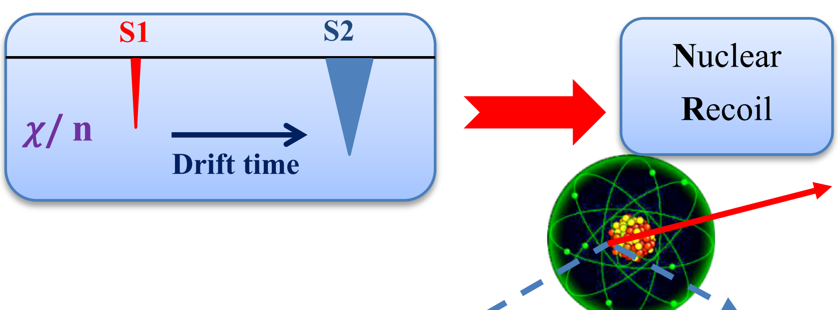


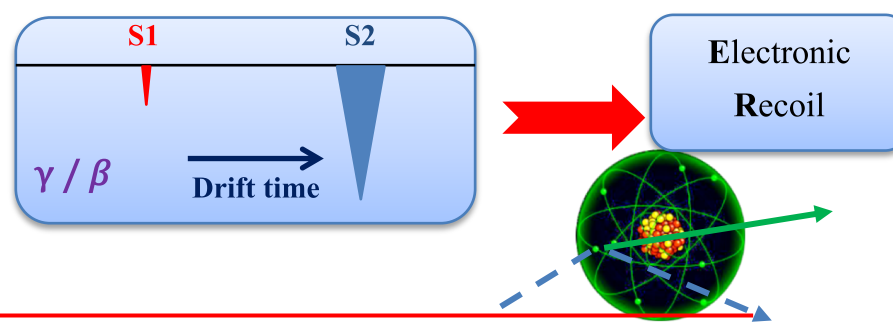
S1:
→ Photon (λ = 178 nm)
from Scintillation process

S2:
→ Electrons drift
→ Extraction in gaseous phase
→ Proportional scintillation light

3D reconstruction :
→ X,Y from top array
→ Z from Drift time

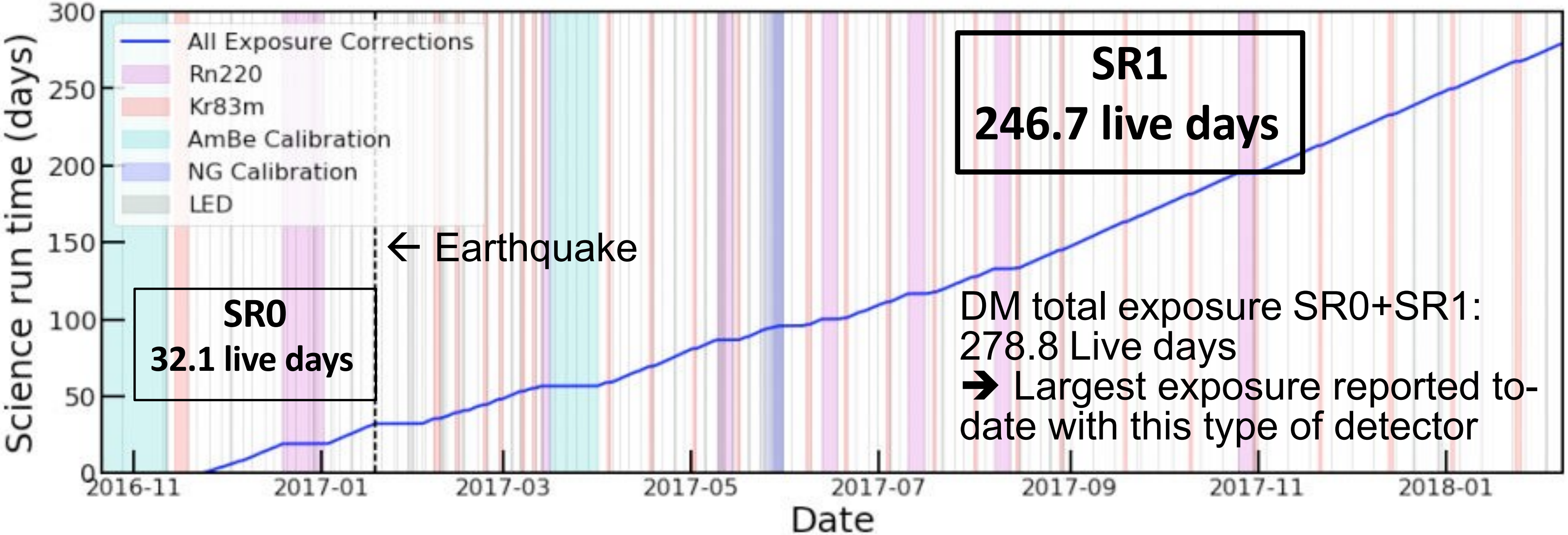
$$(S2/S1)_{WIMP,n} < (S2/S1)_{\gamma,\beta}$$



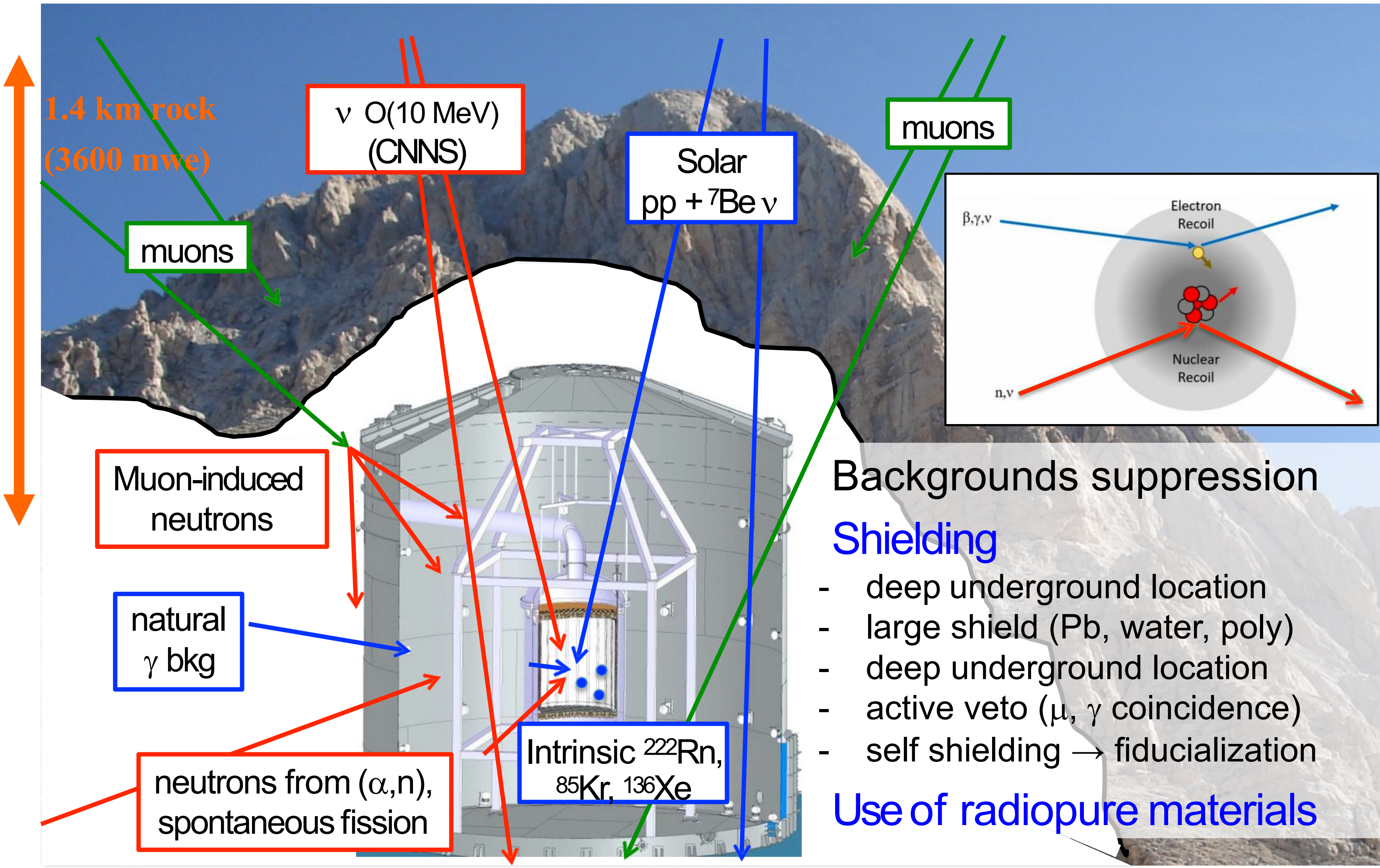


Uses of S1 & S2 with data

- "Standard" nuclear recoil WIMPs models:
  - SI WIMP-nucleon interactions
  - SD WIMP-nucleon interactions
  - Low mass WIMPS
  - …
- DM-electron scattering:
  - Solar axions
  - Axion-like particles (ALPs)
  - …
- Leptophilic models:
  - Annual modulation
  - Exotic models: WIMP axial-vector coupling to electrons,
    mirror dark matter, luminous dark matter
  - …
- Neutrino physics:
  - $0\nu\beta\beta$ decay with 136Xe
  - 2ν double electron capture with 124Xe
  - …



Origins of backgrounds



Backgrounds suppression

Shielding

- deep underground location
- large shield (Pb, water, poly)
- deep underground location
- active veto (μ, γ coincidence)
- self shielding → fiducialization

Use of radiopure materials

XENON1T facility

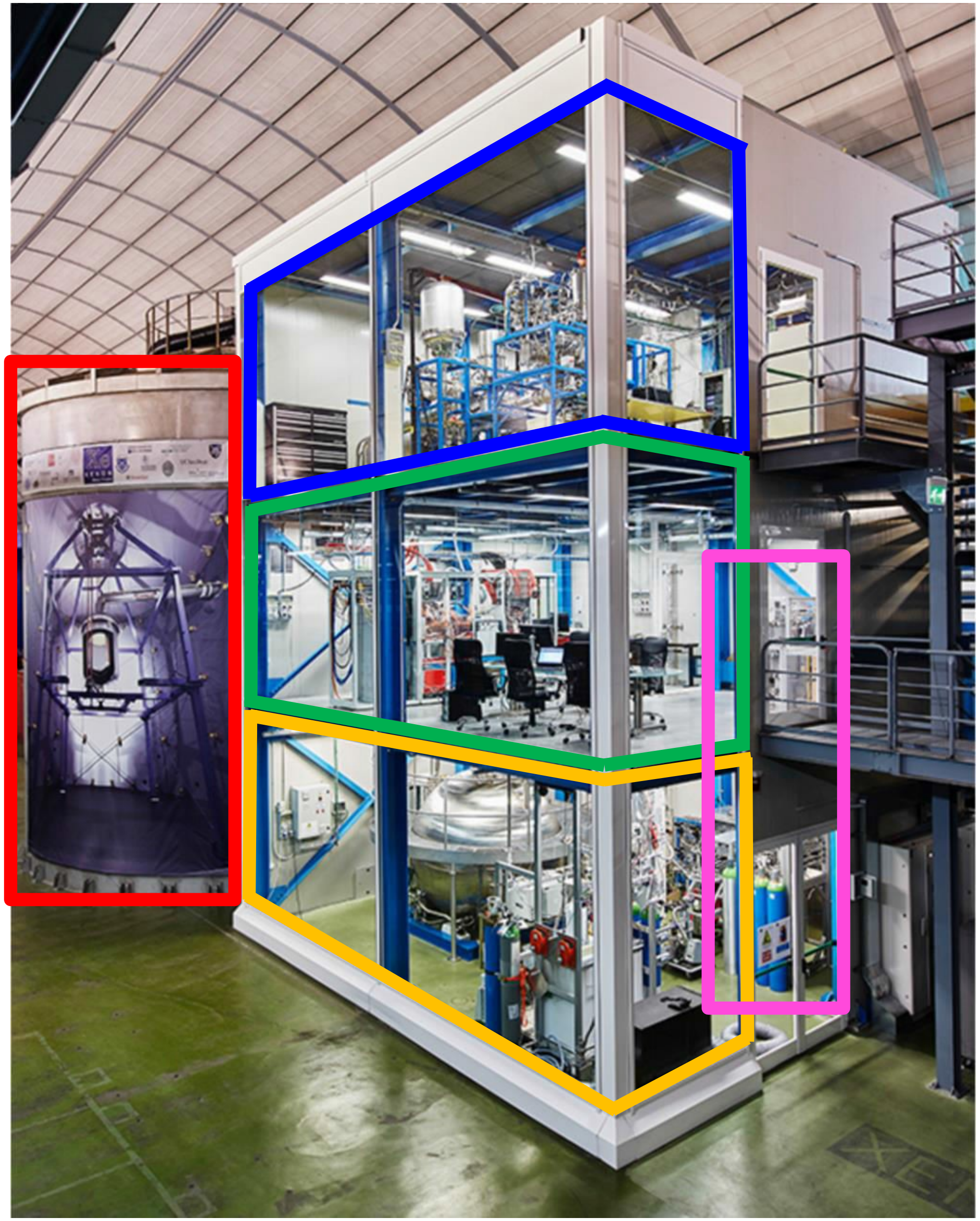
Water shield: deionized water as passive radiation shield
Muon veto: Active muon veto against muon induced neutrons (84 PMTs)

Cryogenics: Stable conditions (3.2 LXe)
Purification: LXe flow through getters, remove impurities

DAQ: Each channel has its own threshold, Flexible software algorithms
Readout: Up to 300MB/s for high rate calibrations

ReStoX: Emergency recovery up to 7.6 tons of LXe
Passive: No active cooling required to keep Xe contained

Kr Distillation: Remove Kr from system during fill or online
Rn Distillation: Initial tests show promising reduction for Rn



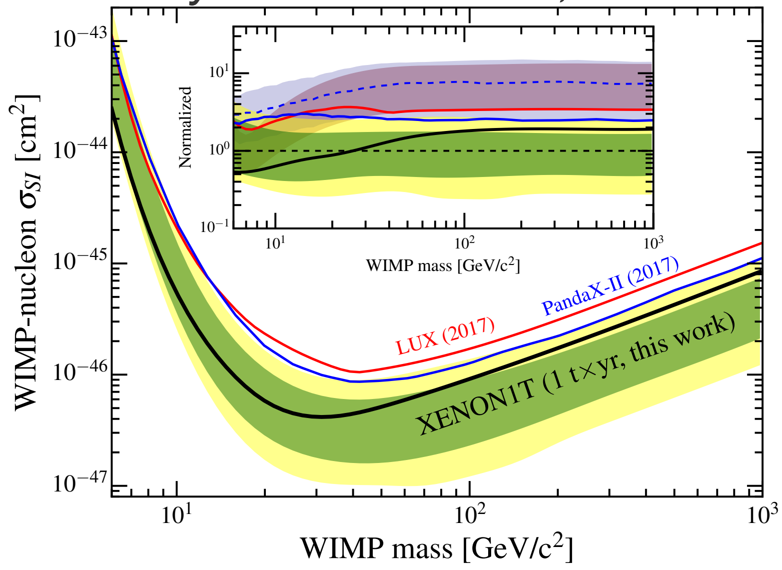
Limits on WIMP cross-section

Spin independent analysis:

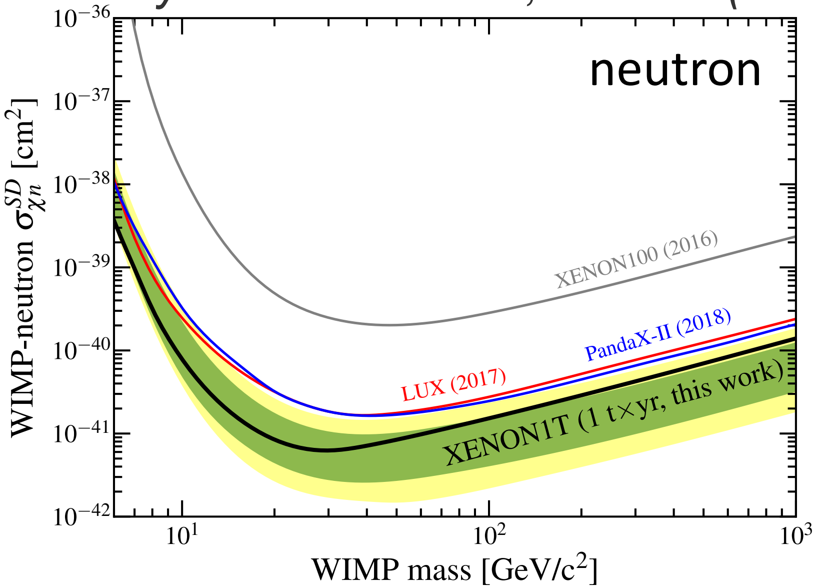
- Sensitivity 7 times improvement over previous experiments
- Strongest exclusion limits (at 90% CL) on WIMPs > 6 GeV/c^2.
- Minimum at 30 GeV : **σ_{SI} < 4.1.10^{-47} cm^2**

Phys. Rev. D 100, 052014 (2019)
Phys. Rev. D 99, 112009 (2019)
JINST 14 (2019) no.07, P07016

Phys. Rev. Lett. 121, 111302



Phys. Rev. Lett. 122, 141301 (2019)



Spin dependent analysis:

- Odd-nucleon isotopes in ^{nat}Xe, abundance:
  - ^{129}Xe 26.6%
  - ^{131}Xe 21.2%
- Same data and quality criteria as for SD analysis
- Most stringent limit for WIMP-neutron scattering

Light Dark Matter (S2 only analysis)

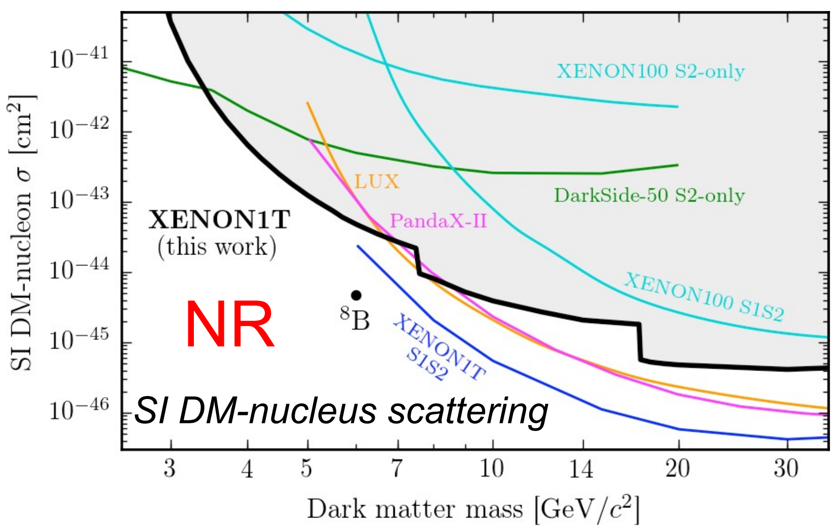
- Constraints on light DM model using S2 signal only

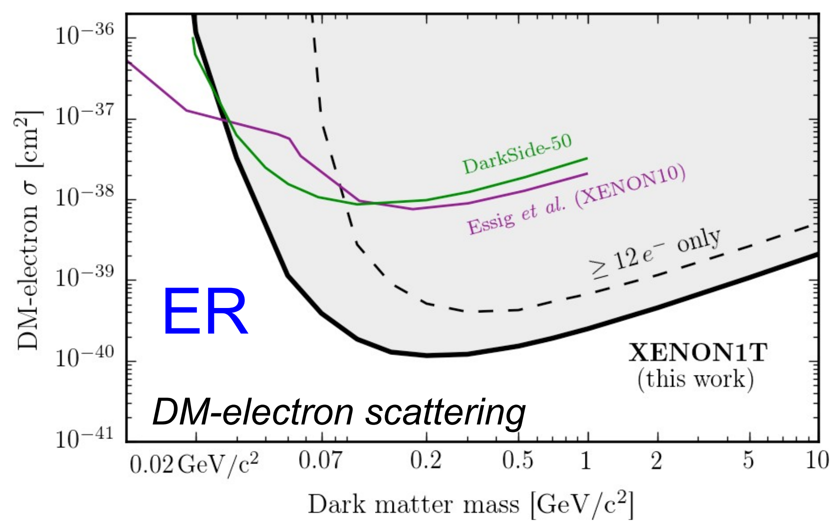
  S2-only technique is sensitive to 2-3x lower energies than traditional analyses

- In some models, DM collides with electrons : ER

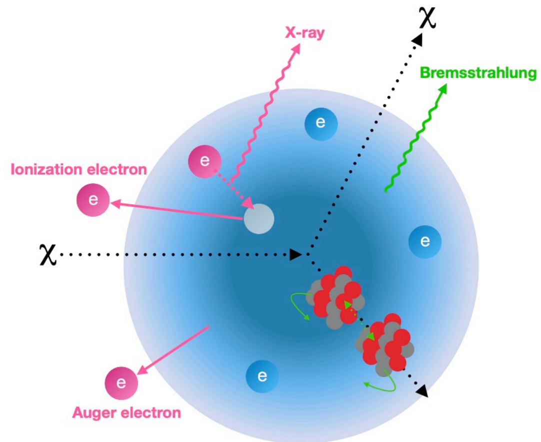
- much larger S2 signals than NR of the same S1 size
- S2-only searches improve the energy threshold for these models by as much as a factor of ten.

Arxiv: 1907.11485, Accepted PRL



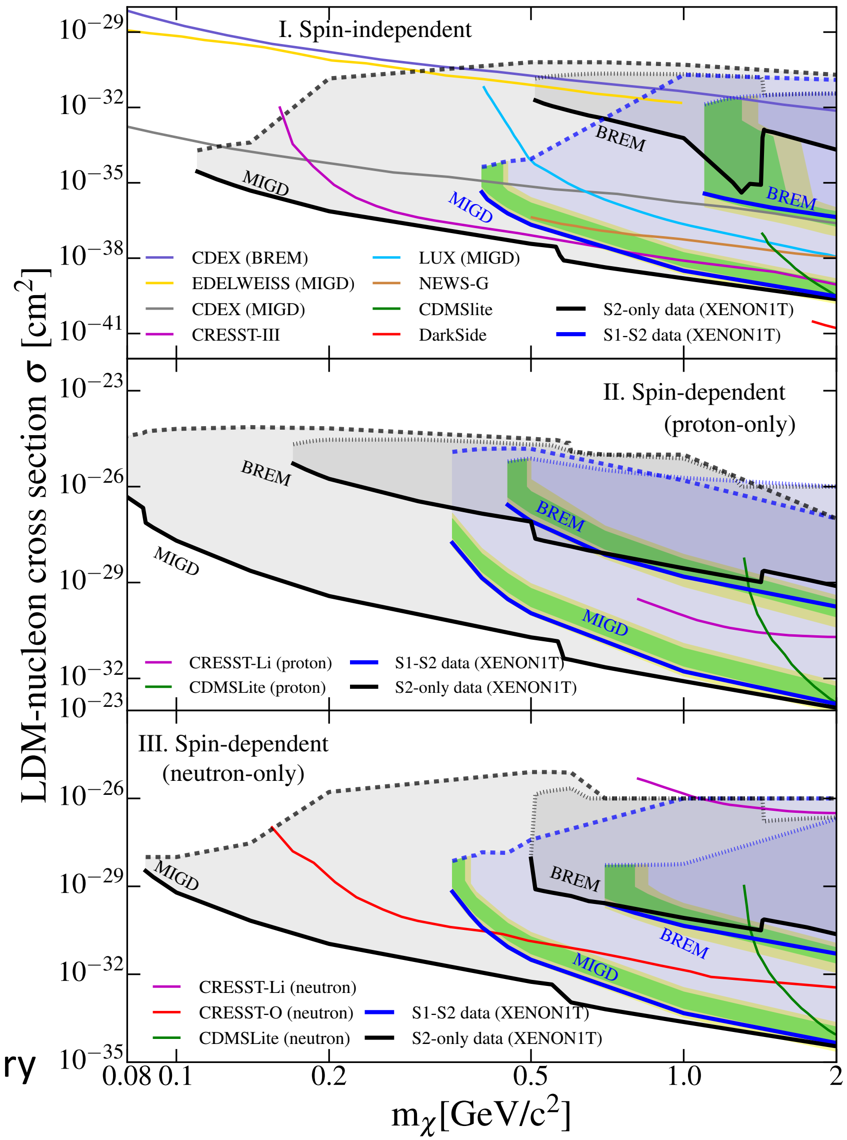


Light Dark Matter (S2 only analysis)



NR
+
ER

Arxiv: 1907.12771, Accepted PRL



Probe of light DM-nucleon elastic interactions:

ER induced by secondary radiation (Bremsstrahlung and Migdal effect) that can accompany a NR

- ➔ ER induced signal < 1 keV
- ➔ S2 only analysis

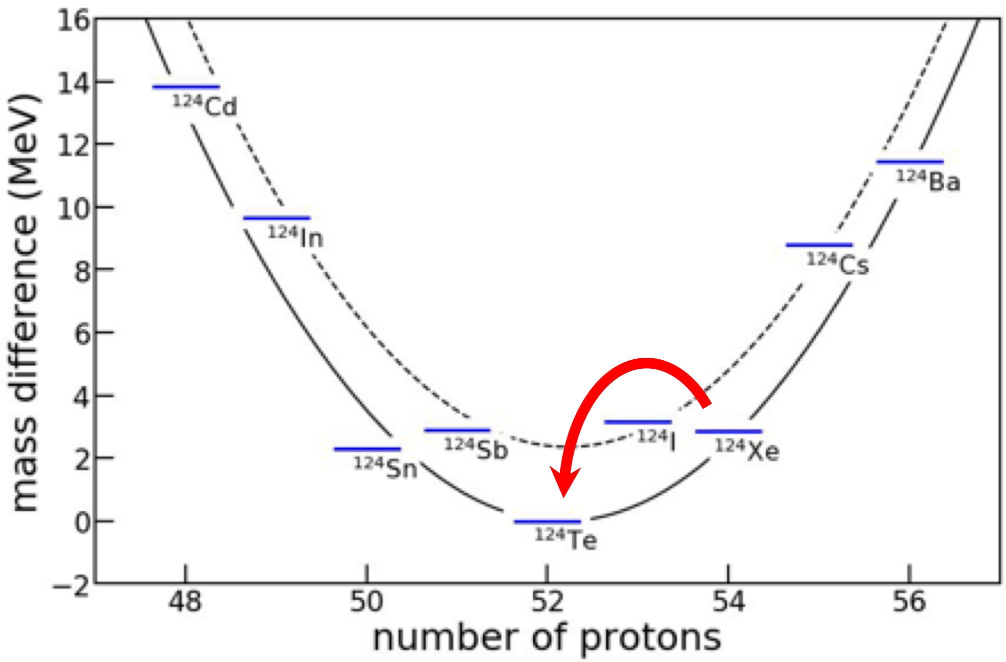
Bremsstrahlung:

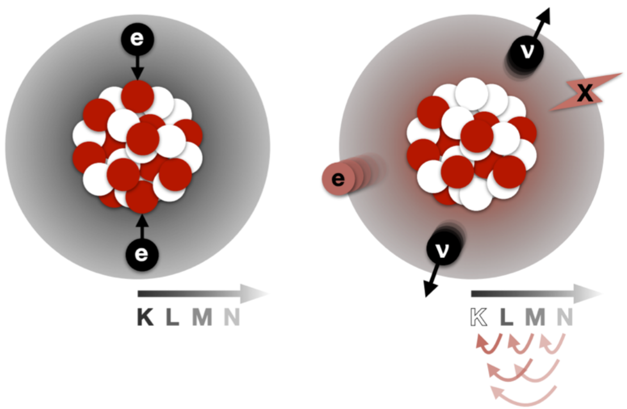
Irreducible contribution that can accompanies scatters by the de-polarization of the atom.

Migdal effect

The process of ionization/excitation of an atom in not instantaneous and the Migdal effect could produce secondary electronic recoils that can accompany a nuclear recoil.

Double electron capture (DEC) with ^{124}Xe





Abundance:
^{124}Xe ~ 1 kg / t

- $^{124}Xe + 2e^{-} \rightarrow {}^{124}Te + 2\nu_e$
- Vacancies on the K shell : Detectable cascade of X-rays and Auger electrons in the **keV-range (64.3 keV)**
- Large half-lives : > 10^{12}. $T_{univers}$
- Needs very **low background** experiment

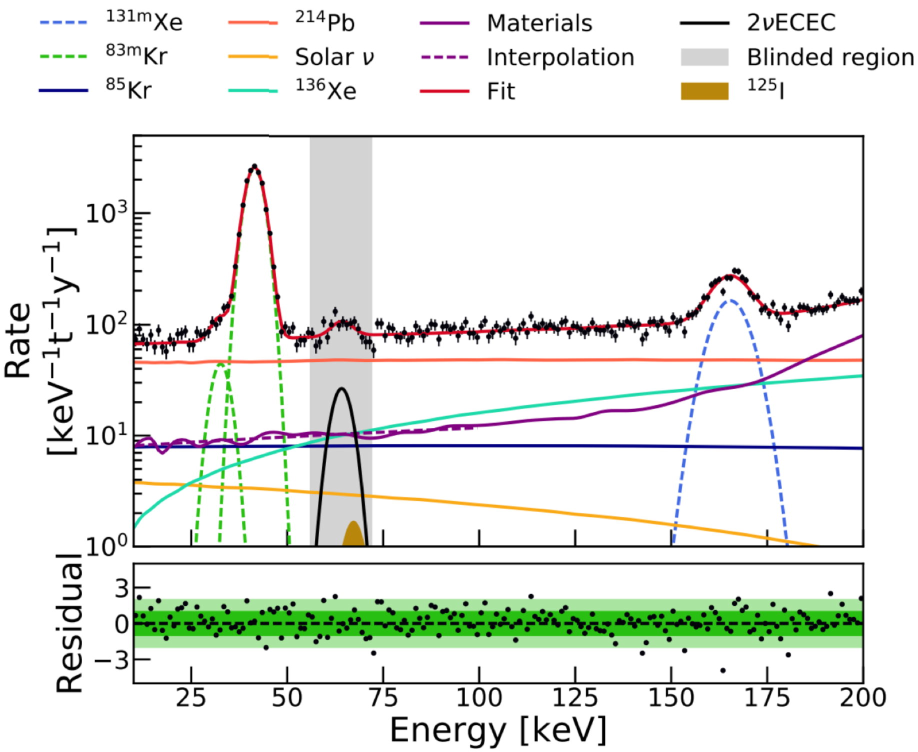
XENON1T

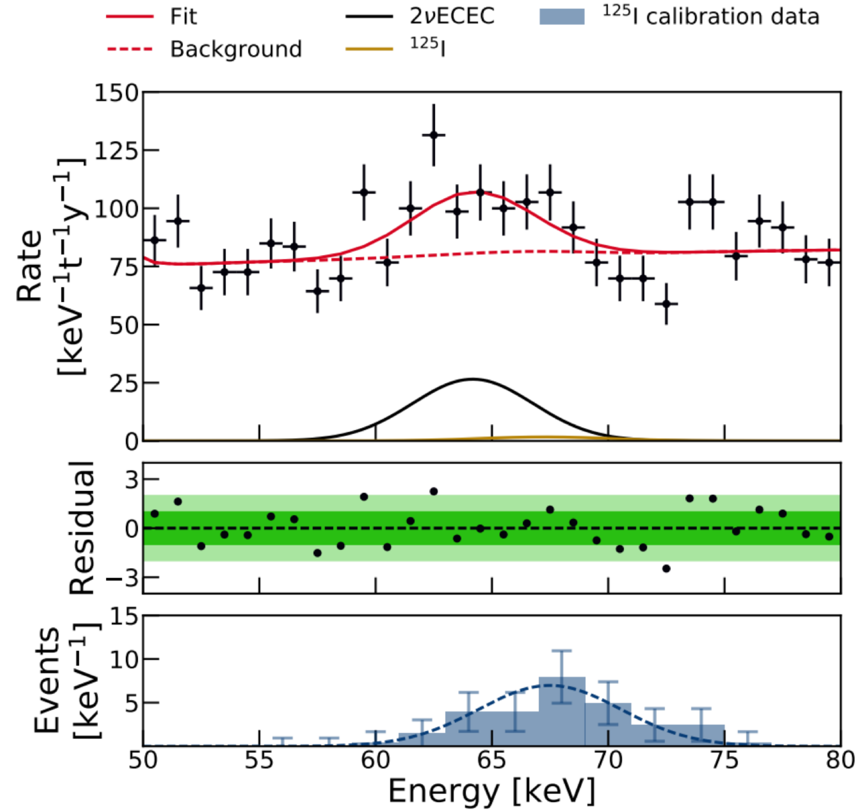
Known energy resolution

$$\frac{\sigma}{\mu} = (4.1 \pm 0.4)\ \%$$

@ 64 keV

Double electron capture (DEC) Results





- Blind analysis
- 177.7 live days
- 1.5 ton fiducial
- 1.49 kg of ^{124}Xe

<u>Best fit result:</u>

N_{DEC} = 126 (black)

$N_{I\text{-}125}$ = 9 (gold)

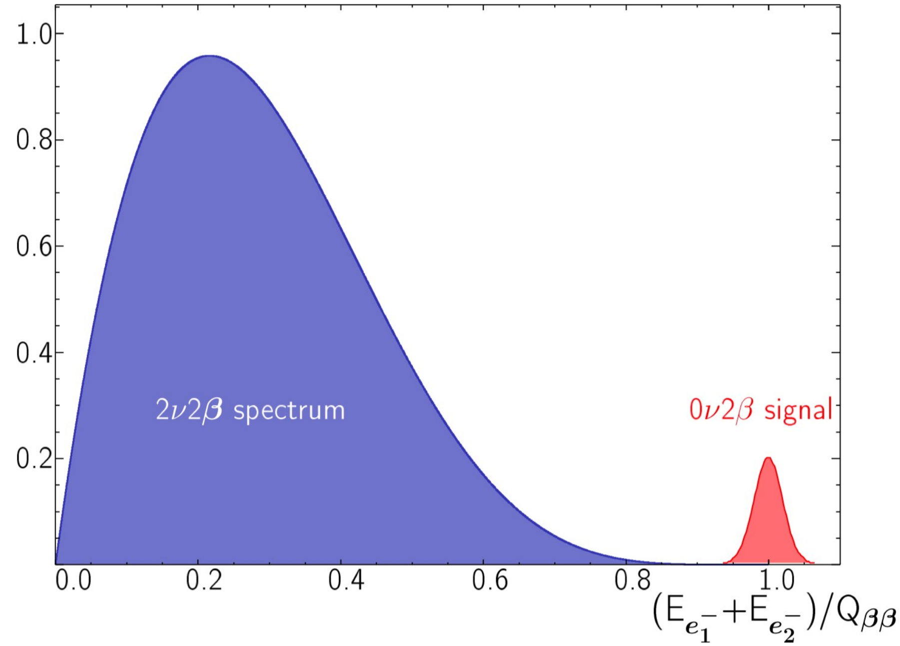
Exclude null hypothesis at 4.4σ

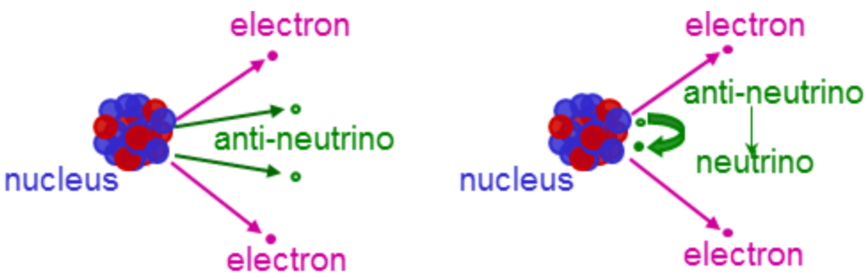
Half-life $T_{1/2} = (1.8 \pm 0.5_{stat} \pm 0.1_{sys}) \times 10^{22}$ y

Nature 568, 532–535

High energy analysis for $0\nu2\beta$ search

- $^{136}Xe \rightarrow ^{136}Ba + 2e^- + 2\bar{\nu}$
- $Q_{\beta\beta} = (2457.83 \pm 0.37)$ keV
- Neutrinoless mode:
  $^{136}Xe \rightarrow ^{136}Ba + 2e^-$
- Best lower limit from KamLAND-Zen:
  $T_{1/2} > 1.07 \times 10^{26}$ yr @ 90% CL



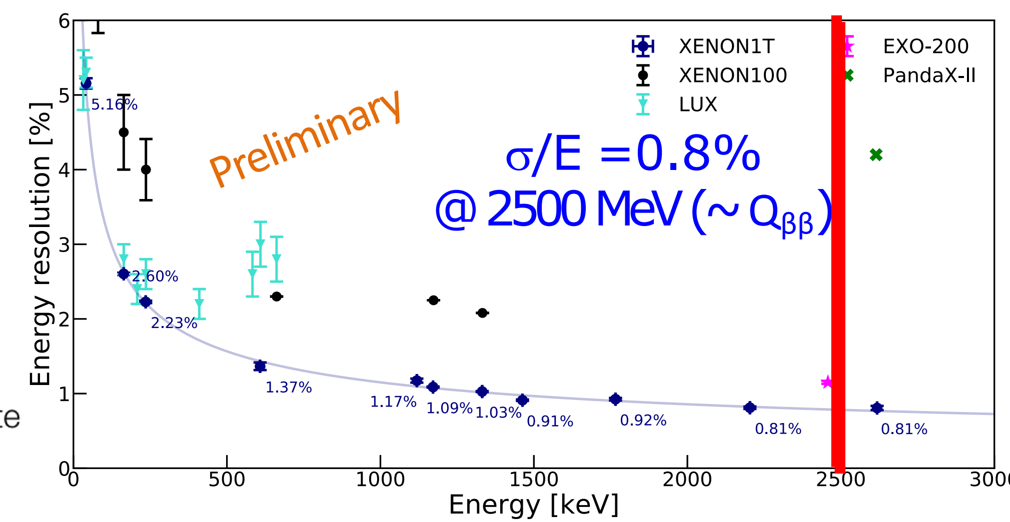


Two neutrino double beta decay

Neutrino-less double beta decay

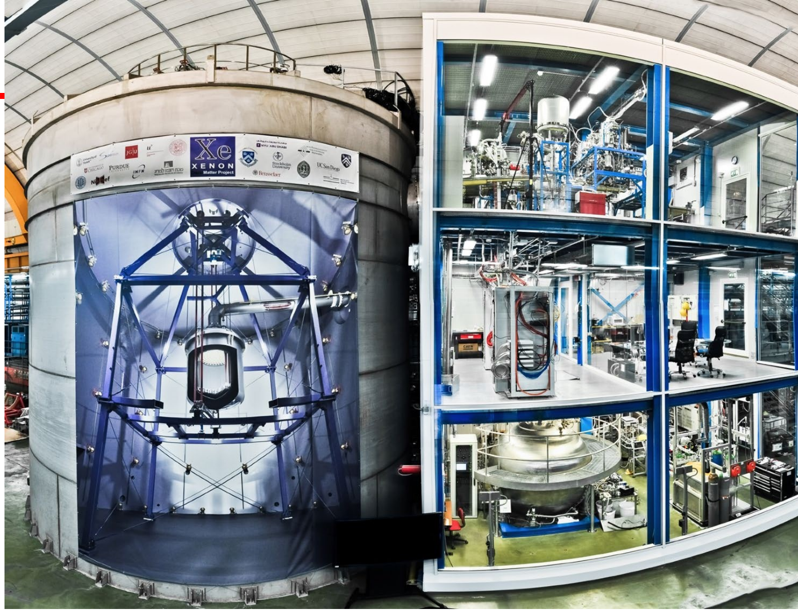
$$S^{0\nu} = \frac{\ln(2)}{1.6}\frac{\alpha\,\epsilon}{A}\sqrt{\frac{M\cdot t}{\Delta E\cdot b}}$$

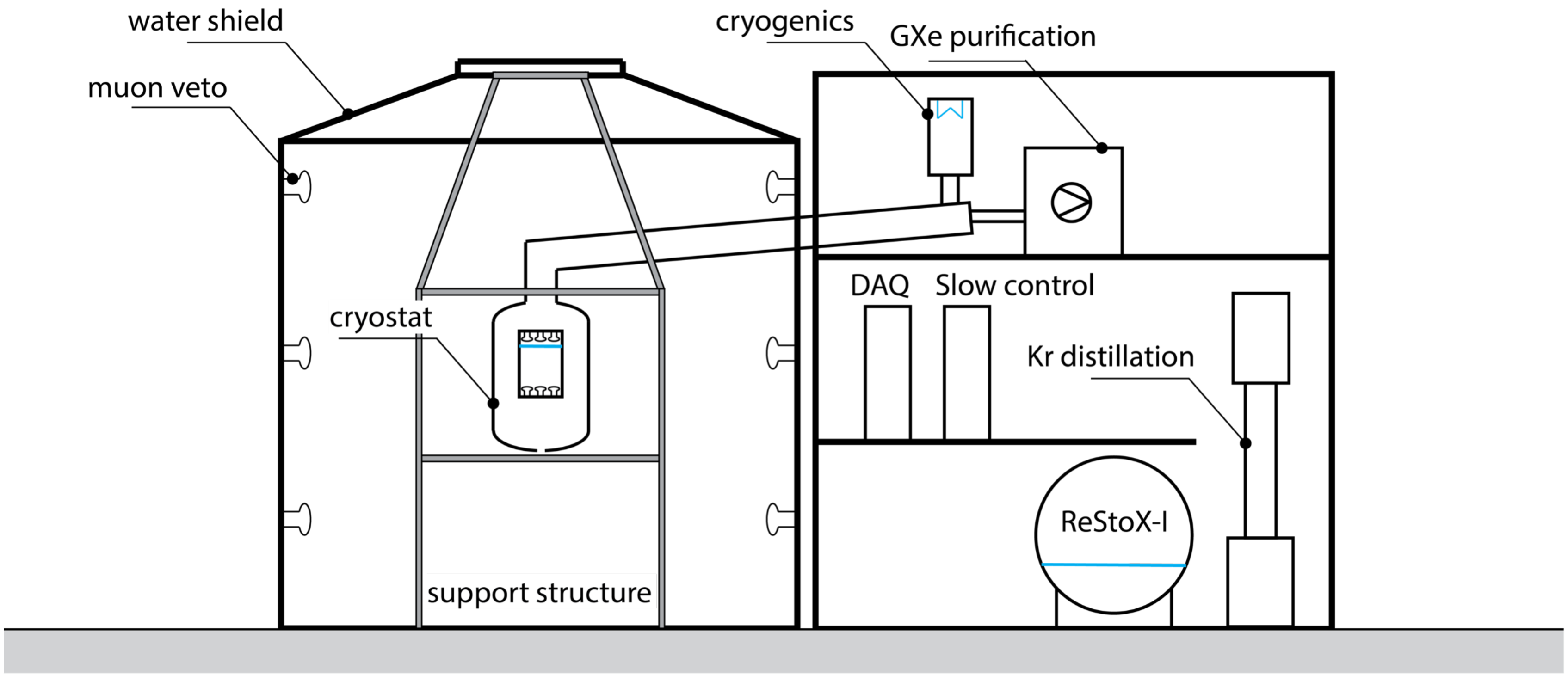
90% CL; Isotopic abundance (α); FV mass (M); Livetime (t); Background rate (b); Resolution @ $Q_{\beta\beta}$ (ΔE); Atomic mass (A); Detection efficiency (ϵ)



World best energy resolution in a LXe detector

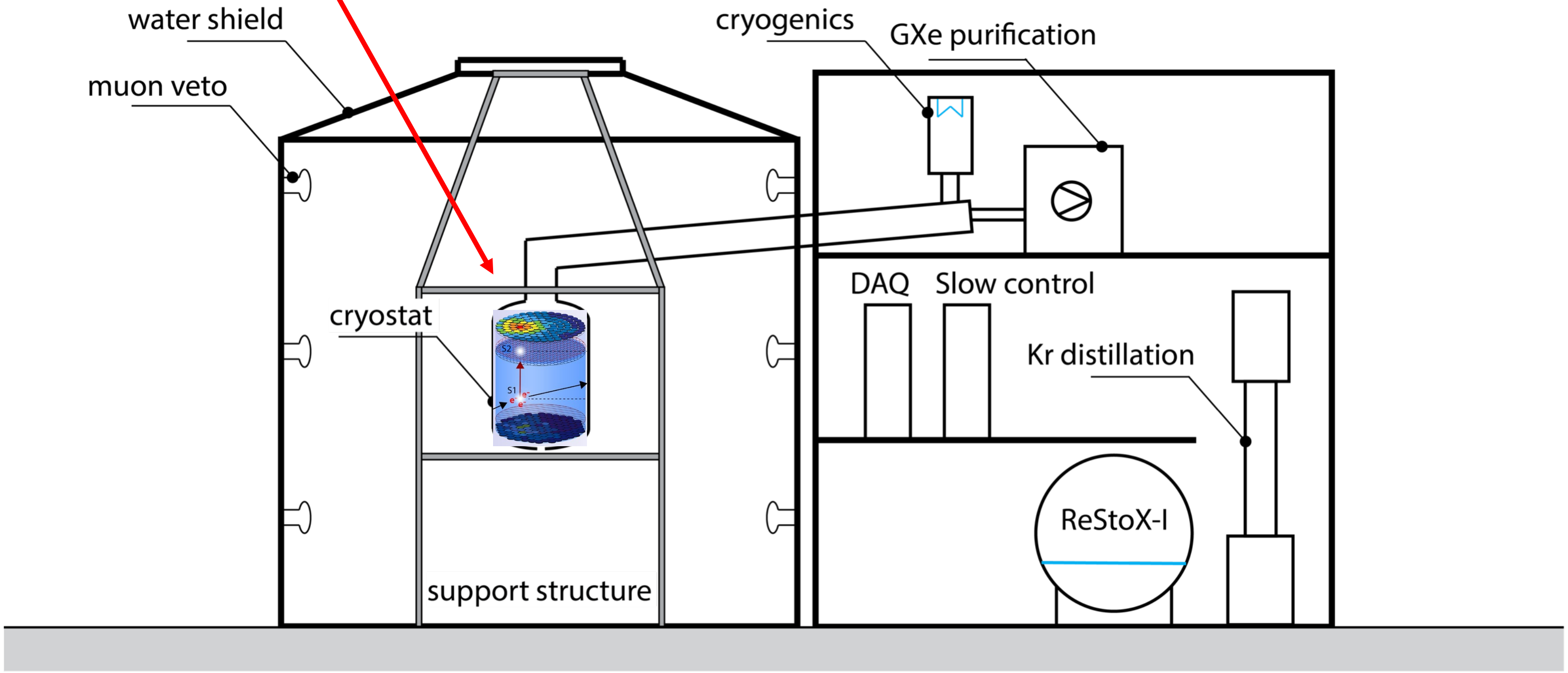
From XENON1T to XENONnT





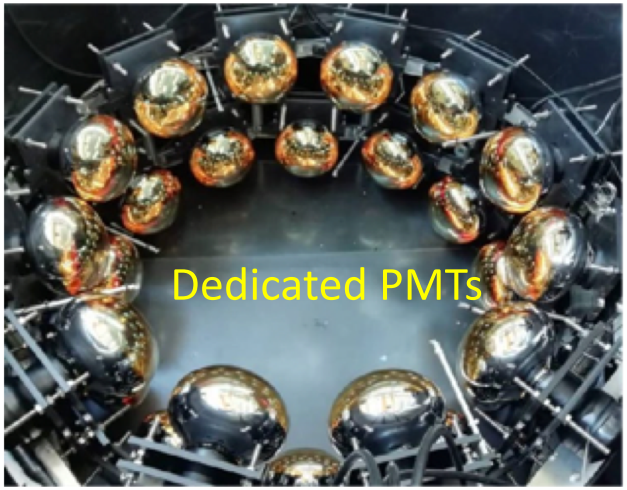
From XENON1T to XENONnT

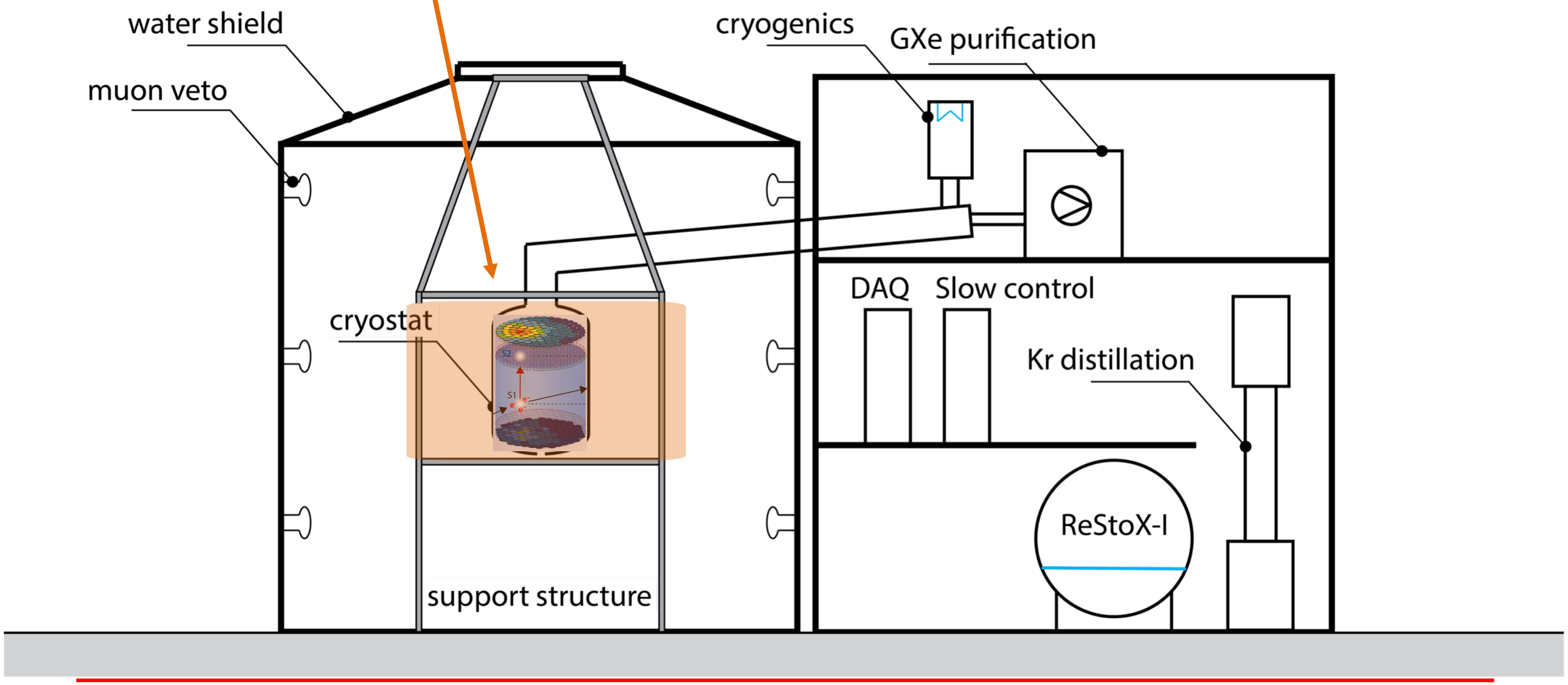
Larger TPC
- Total 8.4 t LXe
- 5.9 t in TPC
- ~ 4 t fiducial
- 248 → 494 PMTs



From XENON1T to XENONnT

Neutron Veto
- Inner region of existing muon veto
- optically separated
- 120 additional PMTs
- Gd in the water tank
- 0.5% $Gd_2(SO_4)_3$

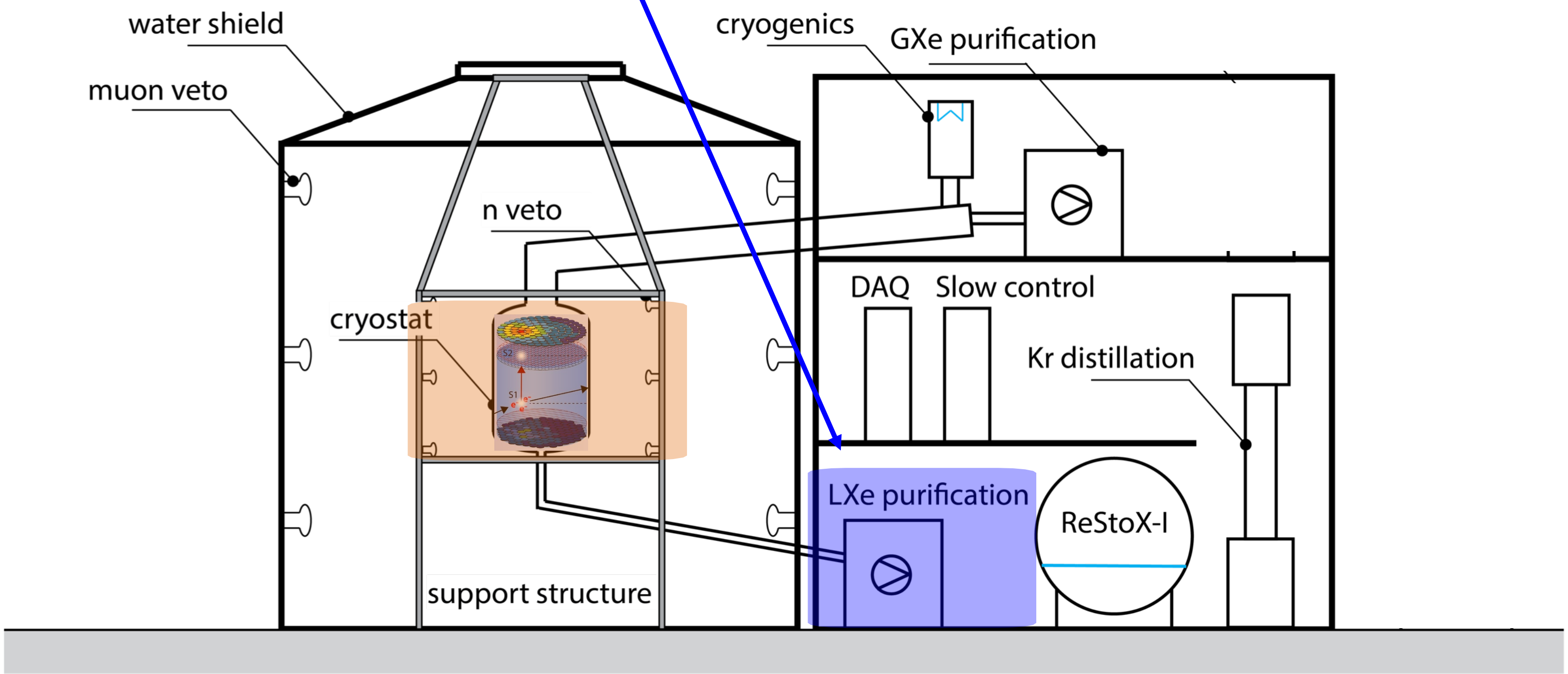




From XENON1T to XENONnT

LXe purification
- Faster xenon cleaning
- 5L/min LXe (2500 slpm)

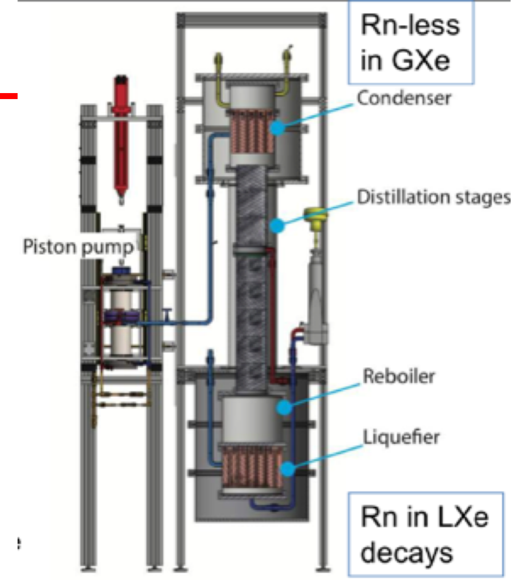
(XENON1T: 120 slpm)

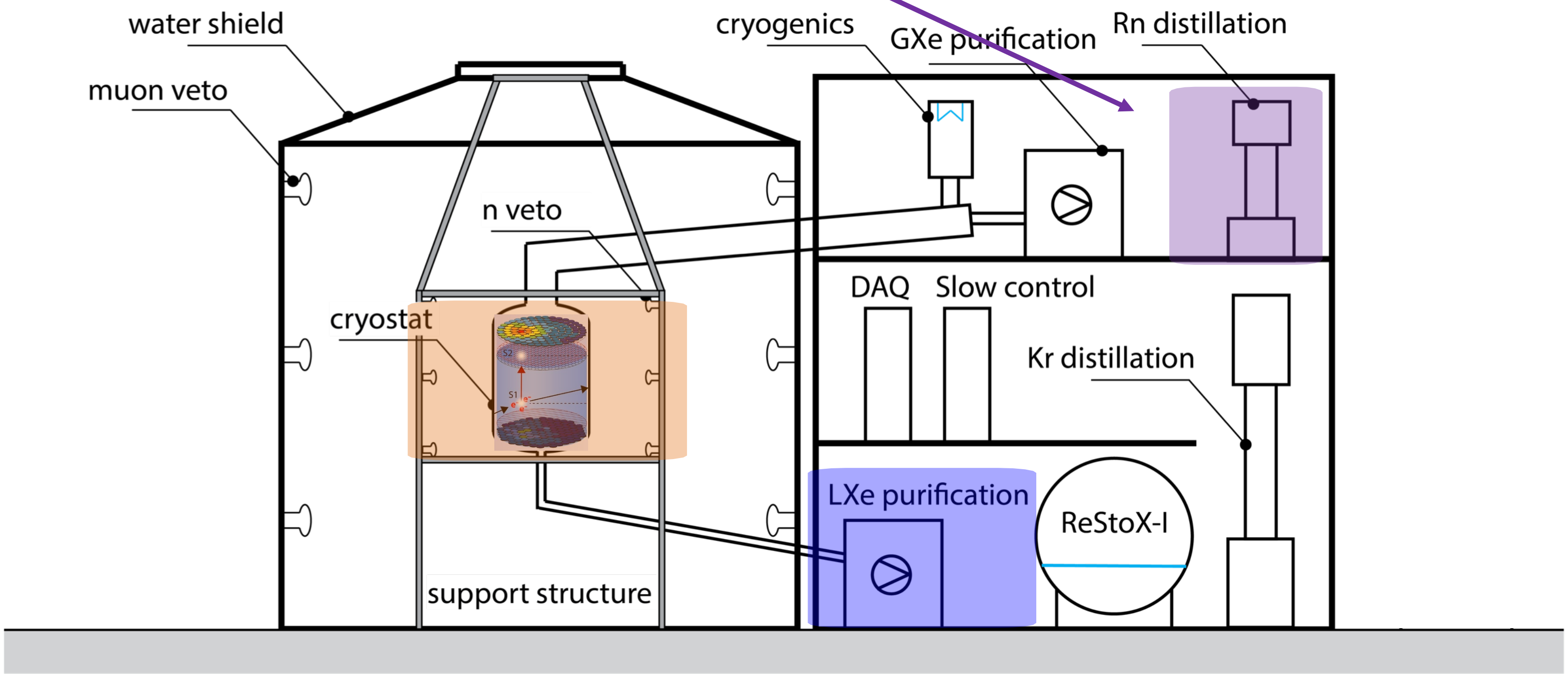


From XENON1T to XENONnT

222Rn Distillation

- Reduce radon from pipes, cables, cryogenic system
- New system, tested in XENON1T
- Reduction 1/10

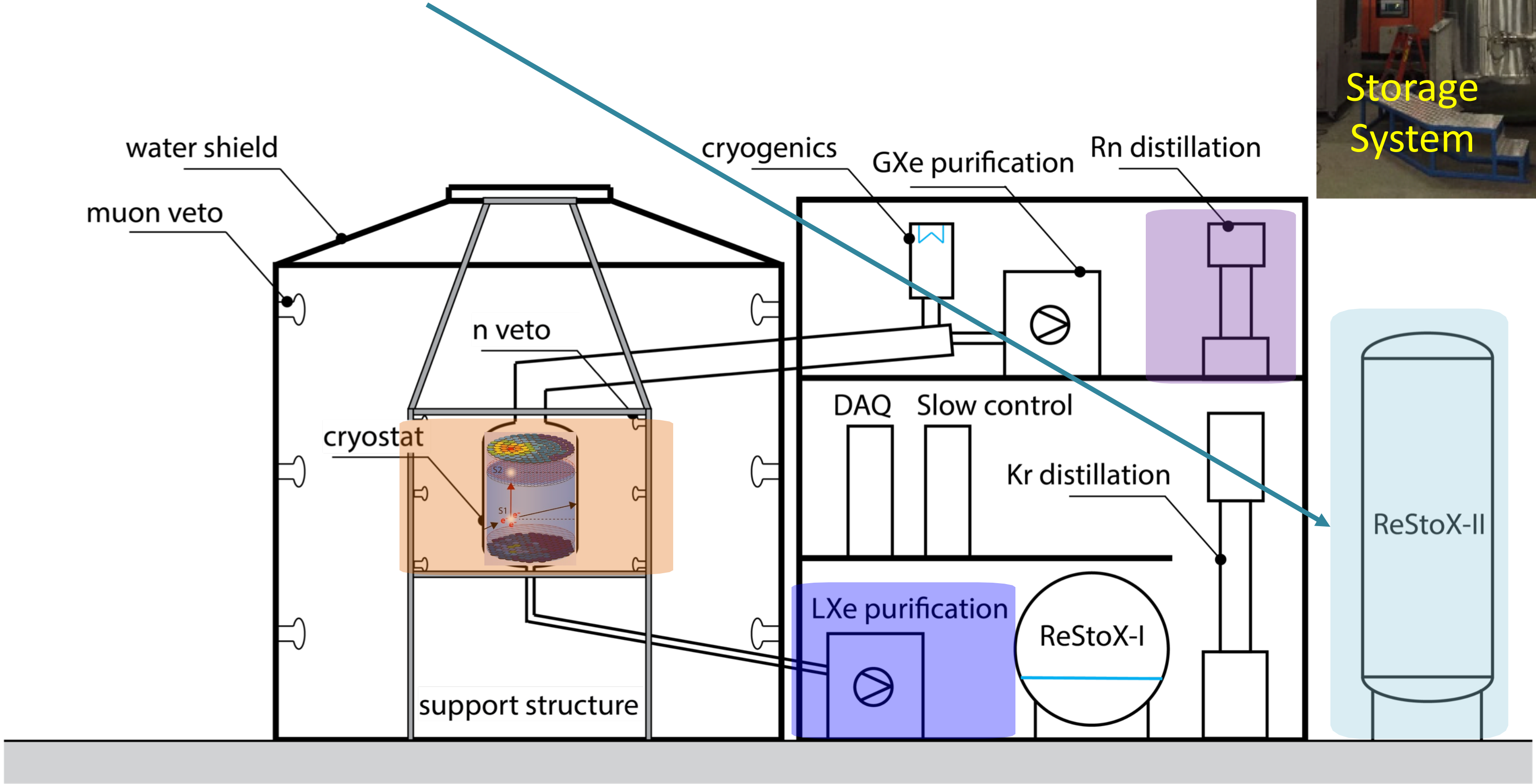




From XENON1T to XENONnT

Storage and Recovery (ReStoX-II)

- 10 tons capacity
- Storage in Solid / Liquid / Gas
- Fast recovery (1 ton / hour)



Conclusions

- **Strongest limit** on WIMP-nucleon SI cross-section above 6 GeV/c^2: minimum at 4.1·10^{-47}cm^2 for a WIMP of 30 GeV/c^2
- Low Energy NR / ER analysis.
- Ongoing data analysis to investigate other new-physics channels: annual modulation, neutrinoless double beta decay,...
- Double Electron Capture detection : longest half-life ever measured directly
- Proof that xenon-based Dark Mater search experiments are sensitive for rare event searches
- **XENONnT will improve the sensitivity by another order of magnitude. First light in 2020.**