Neutrinoless Double Beta Decay Search in XENON1T and XENONnT

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ONLINE ICRC 2021 THE ASTROPARTICLE PHYSICS CONFERENCE Berlin | Germany 37th International Cosmic Ray Conference 12–23 July 2021

XENON

IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom

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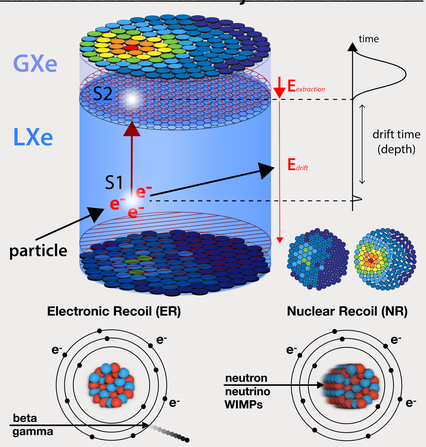
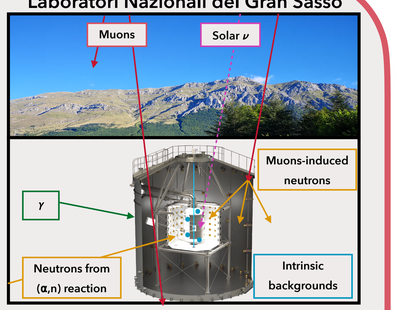
XENON Experiments

Dual-Phase Xe Time Projection Chamber:



Laboratori Nazionali del Gran Sasso



- 3D Position Reconstruction:
  - (x,y) position = S2 PMT hit pattern
  - z = drift time
- Energy reconstruction:
  - S1 & S2 area
- $0\nu\beta\beta$ expected signal → ER

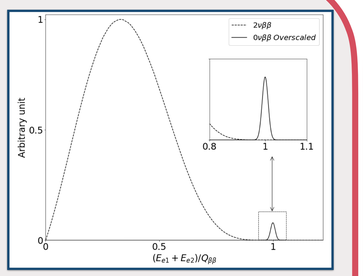
Main goal → WIMP dark matter candidate search Current best-limit hold by XENON1T [2]

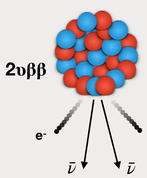
Sensitive to other rare event searches → $0\nu\beta\beta$ decay

$0\nu\beta\beta$ decay

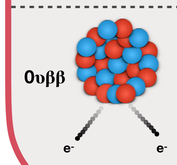
True Nature of Neutrino:

- Dirac or Majorana particle?
- Probe to answer this question → $0\nu\beta\beta$ decay
- Studied isotopes in XENON1T/nT:
  - ^{136}Xe, natural abundance: ∼8.9%
  - $Q_{\beta\beta}$ = 2457.83 ± 0.37 keV [1]





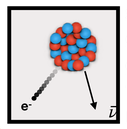
- Rare process
- Observed in several isotopes
- Allowed in the Standard Model



- Never observed so far
- Forbidden in the Standard Model
- Lepton number violation

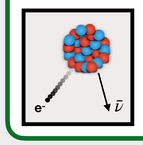
Signal & Background Models

Internal background → β and γ-decay of ^{214}Bi



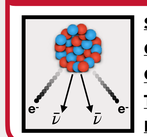
Shape: Continuum + peaks spectrum
Origin: ^{222}Rn materials emanation
Q_{value}: β→3269 keV, γ→2447.7 keV
$T_{1/2}$ = 19.9 min
Relevant for: 1T ☒ nT ☒

Internal background → β-decay of ^{137}Xe



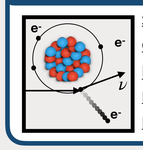
Shape: Continuum spectrum
Origin: n-capture on ^{136}Xe
Q_{value}: 4173 keV
$T_{1/2}$ = 3.82 min
Relevant for: 1T ☐ nT ☒

Internal background → 2νββ of ^{136}Xe



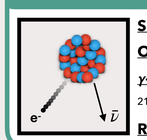
Shape: Continuum spectrum
Origin: 8.9% LXe natural abundance
$Q_{\beta\beta}$: 2457.83 ± 0.37 keV [1]
$T_{1/2}$ = (2.165 ± 0.075) x 10^{21} yr [5]
Relevant for: 1T ☒ nT ☒

Internal background → ν-electron scattering



Shape: Continuum spectrum
Origin: ^{8}B β^{+} decay in the Sun
Neutrino E_{max}: ∼ 15MeV
Flux: 5.25 x 10^{6} cm^{-2}.s^{-1} [6]
Relevant for: 1T ☐ nT ☒

External background → ^{238}U, ^{232}Th decay chain

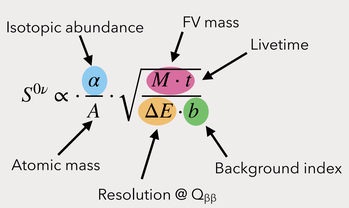


Shape: Continuum + peaks spectrum
Origin: Present in all materials
γ-peaks close to the ROI:
^{214}Bi = 2447.7 keV ; ^{208}Tl = 2614.5 keV
Relevant for: 1T ☒ nT ☒

- Expected signal energy spectrum for SS in the FV modelled by a Gaussian function
- Signal acceptance ∼93.2% (due to Bremsstrahlung γ that can generate MS events)
- Study of external bkg for XENONnT still ongoing

XENON1T [3]: The Past (2012-2018)

$0\nu\beta\beta$ Experimental Sensitivity & Requirements:

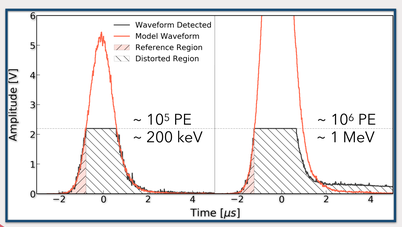


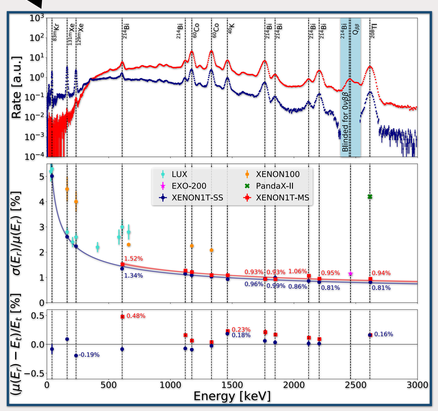
- Isotope abundance −
- Background level ✓
- Exposure ✓
- Energy resolution ✓

248 PMTs

High Energy Signal Correction [4]:

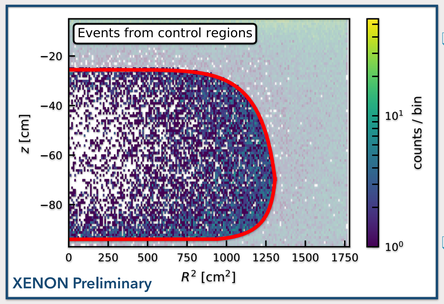
- Signal saturation start at $\mathcal{O}$(100 keV) energies
  - Correction based on non-saturated PMTs signal
- Improved Single/Multiple Site (SS/MS) event selection/rejection
- Energy resolution @ $Q_{\beta\beta}$: ∼0.8% (σ/μ)



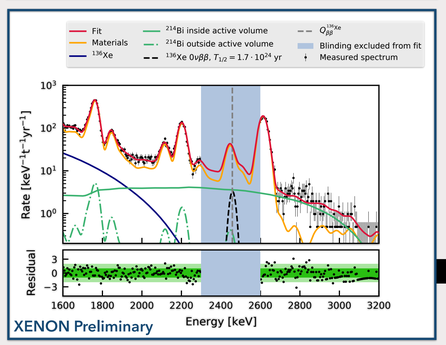


XENON1T $0\nu\beta\beta$ Data Analysis:

Blinded Data Analysis for SS events | Region Of Interest (ROI) → [2.3, 2.6] MeV | Livetime → 202.7 days



- Fiducial volume optimization:
  - No calibration @ $Q_{\beta\beta}$ → Control region near the blinded region
  - Maximization of the target mass while minimizing the background level
- Blinded Data/MC matching:
  - Fit of the high energy data points with our bkg model
  - Sensitivity estimation based on Toy-Monte Carlo from the bkg model with and without injected signal
  - **Expected sensitivity:** 1.7 x 10^{24} yr

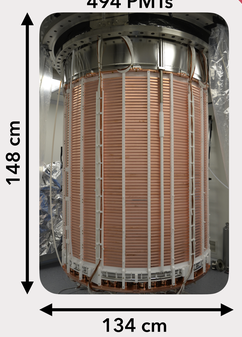


XENONnT: The Present

Improvements for $0\nu\beta\beta$ decay search wrt XENON1T:

- Active Mass increase x3
- Background reduction x1/10
- Dual read-out with different amplification to avoid signal saturation

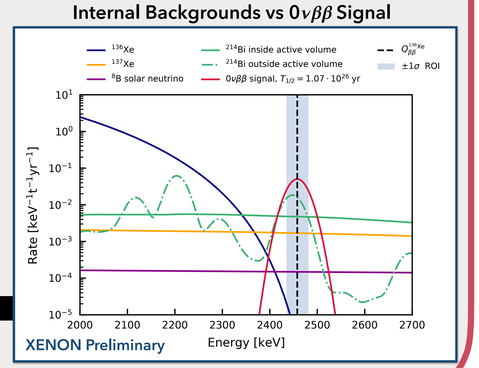
494 PMTs



Internal Background Study:

- Updated studies of the internal bkg assumed in XENON1T
- Inclusion of two internal bkg negligible in XENON1T:
  - ^{137}Xe β-decay → Production in the TPC itself and in the purification system (outside of the water tank)
  - ^{8}B solar neutrino → Irreducible bkg

Internal Backgrounds vs $0\nu\beta\beta$ Signal



Stay tuned for the upcoming results!

References

[1] M. Redshaw, E. Wingfield, J. McDaniel, and E. G. Myers, **Mass and double-beta-decay q value of ^{136}Xe**, in *Phys. Rev. Lett.* 98, 053003 (2007)
[2] XENON Collaboration, **Dark Matter search results from a one Tonne x Year exposure of XENON1T**, in *Phys. Rev. Lett.* 121, 111302 (2018)
[3] XENON Collaboration, **The XENON1T Dark Matter Experiment**, in *Eur. Phys. J. C.* 77: 881 (2017)
[4] XENON Collaboration, **Energy resolution and linearity of XENON1T in the MeV energy range**, in *Eur. Phys. J. C* 80:785 (2020)
[5] EXO Collaboration, **An improved measurement of the 2νββ half-life of Xe-136 with EXO-200**, in *Phys. Rev. C 89, 015502 (2014)*
[6] SNO Collaboration, **Combined analysis of all three phases of solar neutrino data from the Sudbury Neutrino Observatory**, in *Phys. Rev. C* 88 025501 (2013)

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