LOW RADIOACTIVITY TECHNIQUES

2024

WORKSHOP IX

JAGIELLONIAN UNIVERSITY IN KRAKÓW

^{212}Pb and ^{214}Pb Beta Decay Branching Ratios Measurement with XENONnT

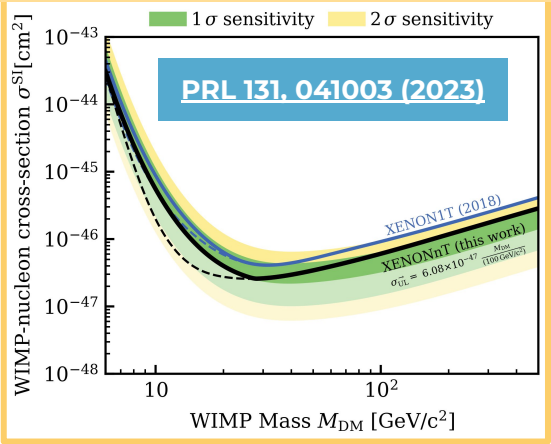
C. Ferrari

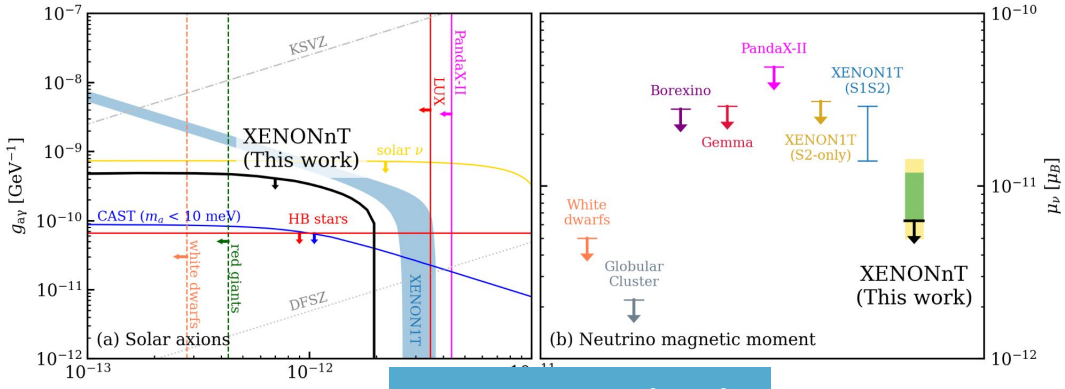
On behalf of the **XENON** Collaboration

The XENONnT Experiment

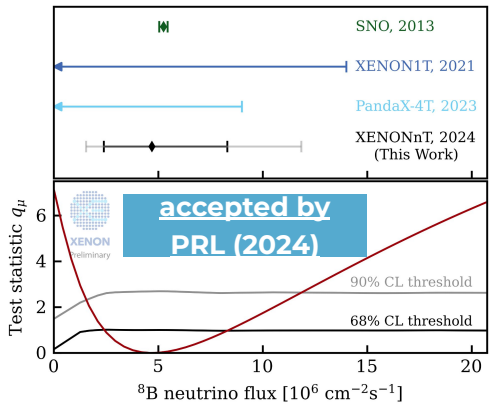
The **XENONnT** experiment is primarily designed to **direct WIMP dark matter searches**.

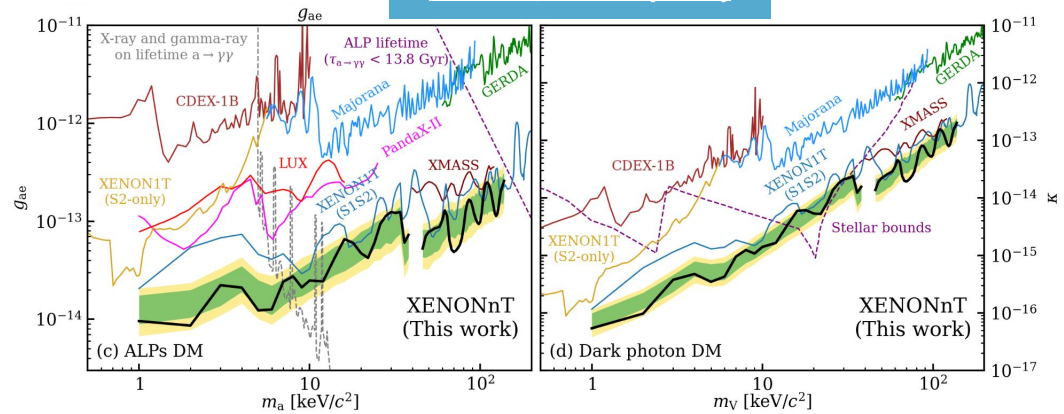
Thanks to the demonstrated low levels of background, this experiment is also suitable for other **new-physics rare-events searches** as well as **nuclear physics precision measurements**, benefiting from the low-energy threshold and the large experimental exposure.



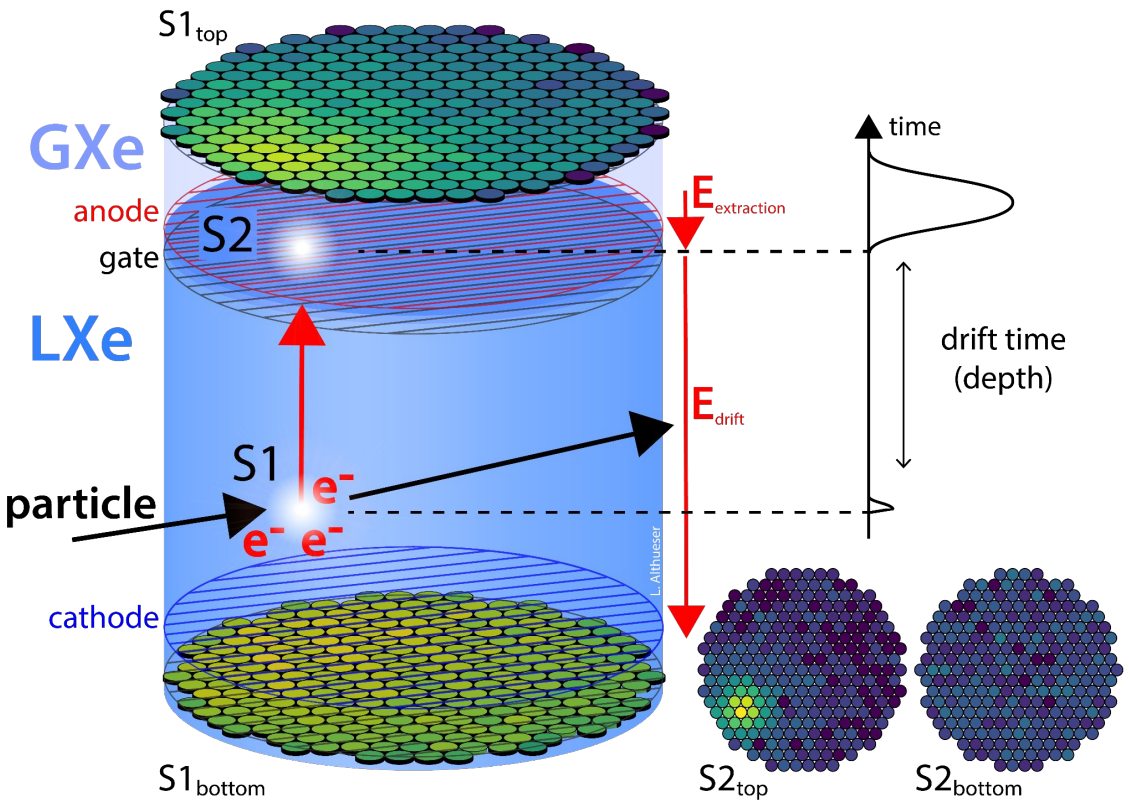


PRL 129, 161805 (2022)





The XENONnT Core Detector



- **5.9 t LXe** instrumented with a **cylindrical TPC:**
  - drift field of 23 V/cm
  - r=66.4 cm, h=150 cm
- **Detection** via **prompt scintillation** light (**S1**) and **delayed ionization** signal (**S2**)
- **Event position reconstruction:**
  - (x,y) from S2 top PMTs pattern
  - z from drift time
- **Particle discrimination** in (cS1, cS2)
- **Combined Energy Scale:** **CES** = W (cS1/g1 + cS2/g2)

The XENONnT Background Mitigation Systems

Christian Weinheimer LRT Talk on Thu

Eur. Phys. J. C 82, 1104 (2022)

Radon Removal System:

- Continuous Rn distillation
- Lowest LXe ^{222}Rn bkg ever measured: < 1 µBq/kg

JINST 18 (2023) 07, P07054

nT DAQ:

- Triggerless DAQ
- Subsystems linked mode
- Slow Control

Neutron veto:

- Hosted in the water Cherenkov muon veto
- Neutron capture on H
- SR0 neutron tagging efficiency ~ 53%
- Now improved by loading Gd salt

Eur. Phys. J. C 84, 784 (2024)

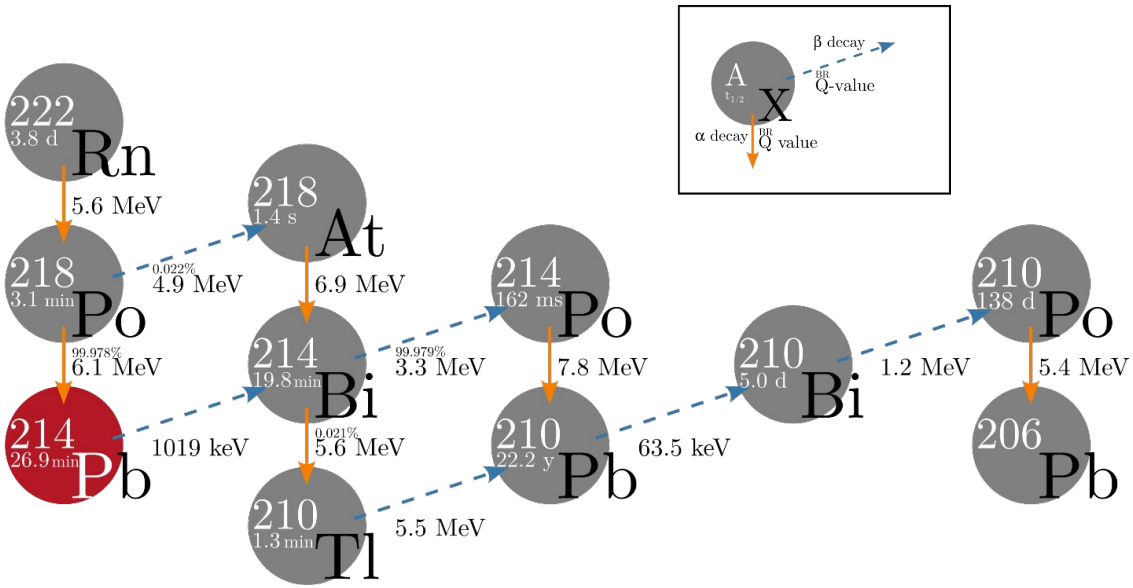
Hosted in **LNGS** underground facilities providing an overburden of 3600 m.w.e.

Eur. Phys. J. C 82, 860 (2022)

Liquid Purification:

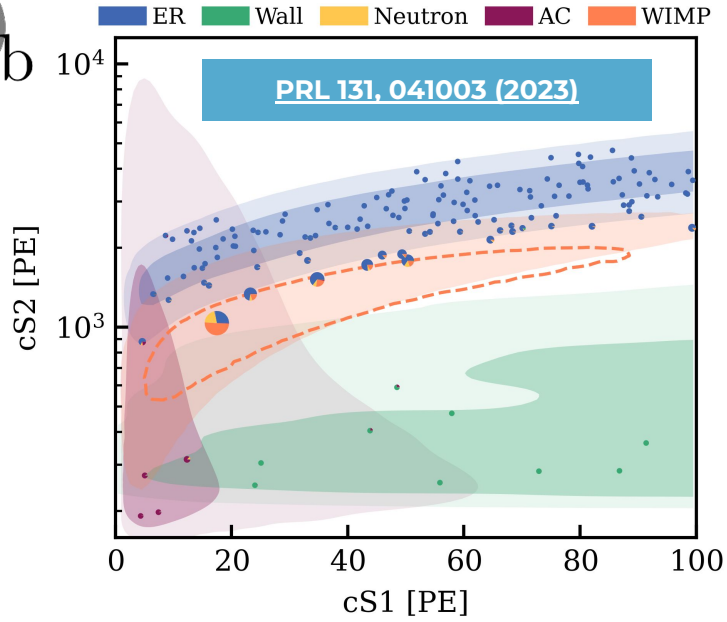
- Removes electronegative impurities (O_2 and H_2O)
- Average electron lifetime 15 ms
- Reduces S2 z dependences and improves S1 LCE

The XENONnT Radon Background



- ^{222}Rn generate **^{214}Pb** isotope that constitutes the **major ER background** contribution below 35 keV, impacting **WIMP** searches

- **Radon** background is primarily introduced by material **Th** and **U contamination**
- Outgassed **^{222}Rn** can penetrate more easily than ^{220}Rn and **homogeneously** diffuses in the full **Xe volume**

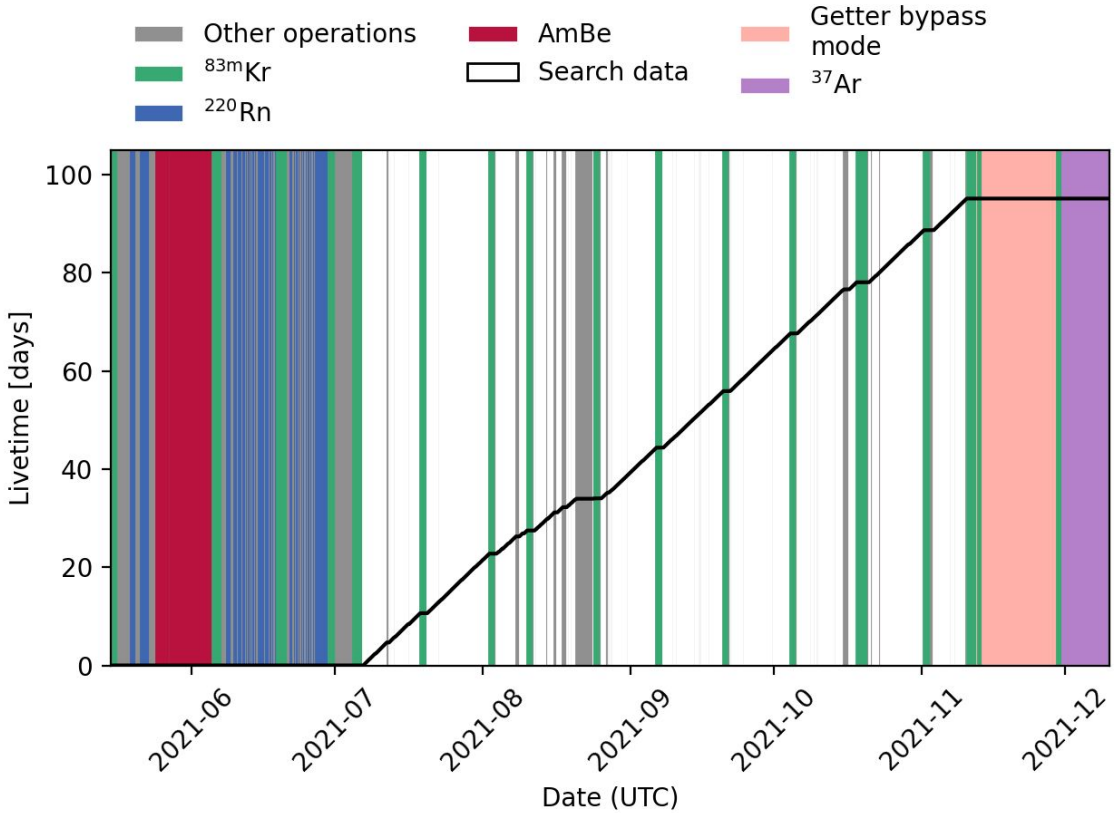


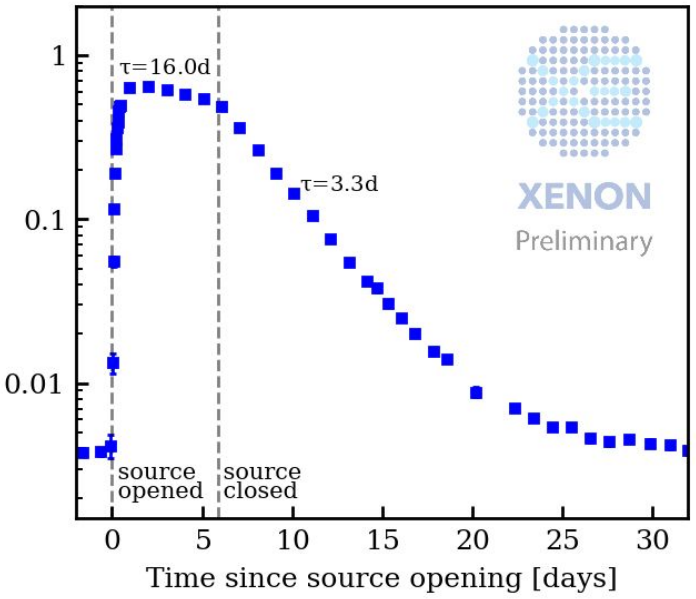
The XENONnT Radon Calibration Campaigns for WIMPs

- Importance of ER band characterization **^{220}Rn** calibration campaign in SR0 and **^{222}Rn** one in SR1

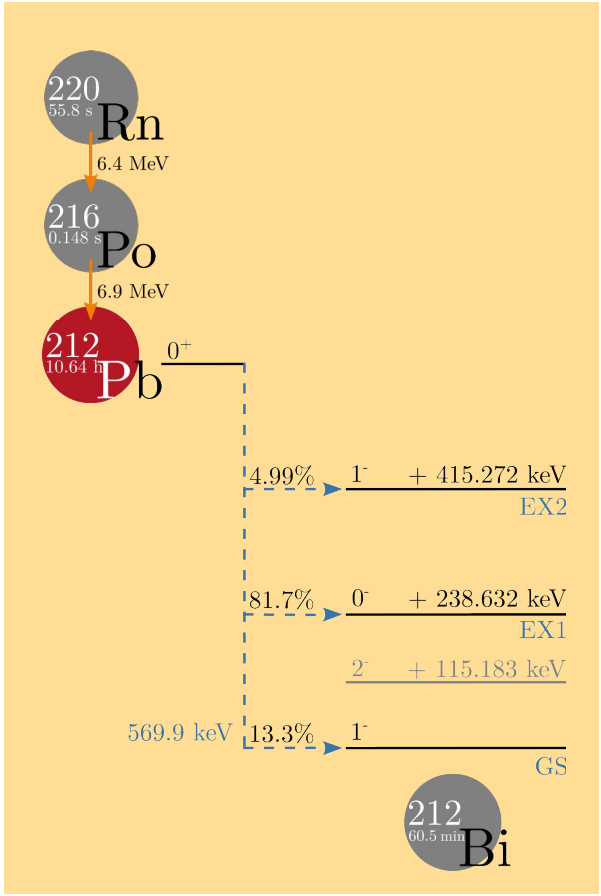
Appl. Radiat. Isot. 194, 110666(2023)

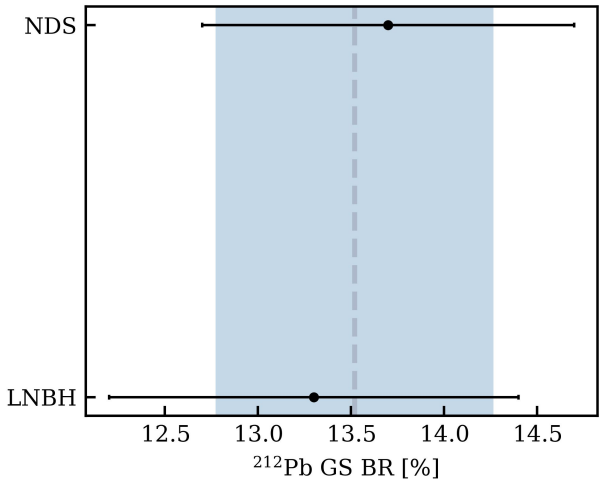
ArXiv (2024)





Radon Data beyond WIMP Studies - ^{212}Pb

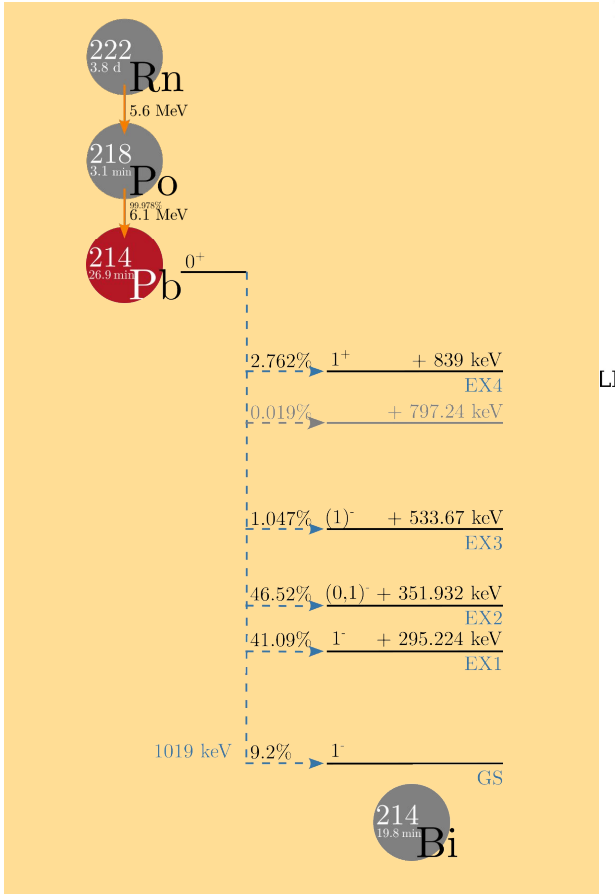


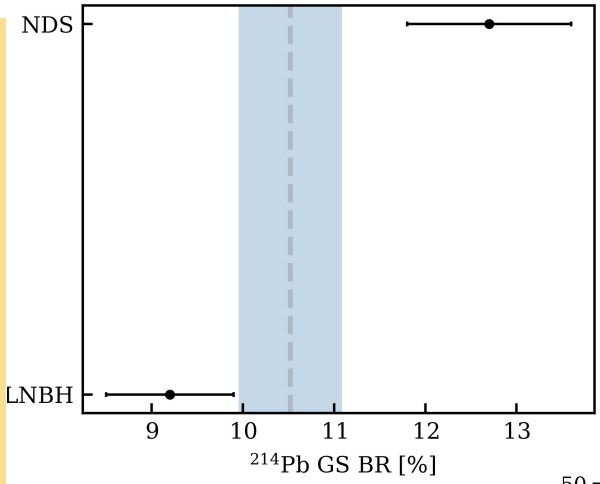


- **Literature** values for **^{212}Pb Ground State** (GS) **branching ratio** (BR) are obtained with **indirect** measurements
- XENONnT we can perform a **direct measurement** of **any** possible **^{212}Pb BR of the decay scheme**.

- The XENONnT Science Run 0 **^{220}Rn Calibration campaign** can be exploited for this kind of nuclear physics studies.
- Moreover, given the high-statistics collected in the calibration runs, there is the chance of improving the GS BR measurement by reducing its **relative uncertainty, currently at 7.3% and 8.3%**, according to **NDS** and **LNBH**

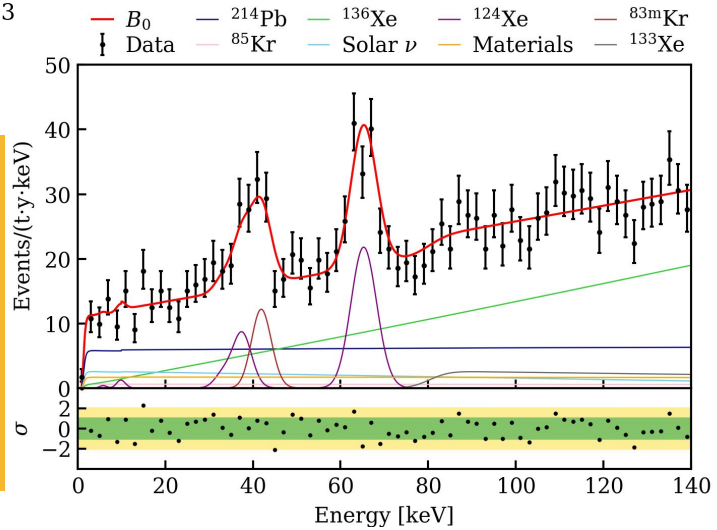
Radon Data beyond WIMP Studies - ^{214}Pb



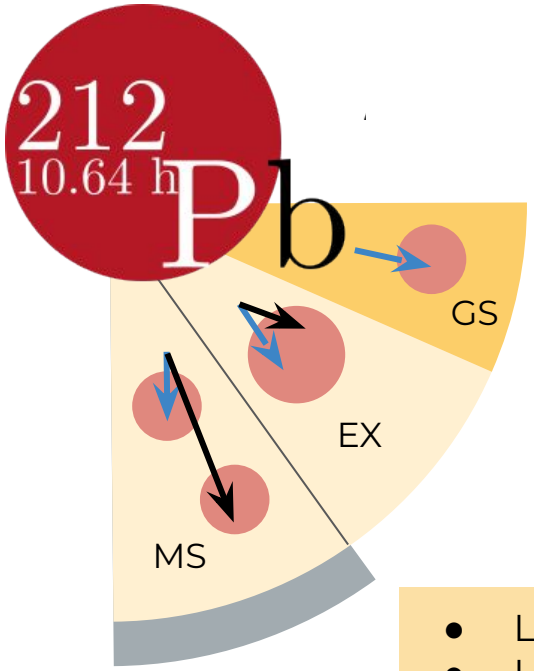


- Low Energy ER Physics searches will benefit from a more precise **^{214}Pb GS BR** measurement, since **only decays to GS contribute** in the ROI of these searches

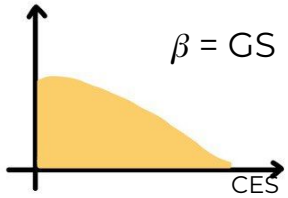
- Literature values for ^{214}Pb GS BR present a **4.7σ discrepancy**
- Each with a **relative error** larger than **7%**



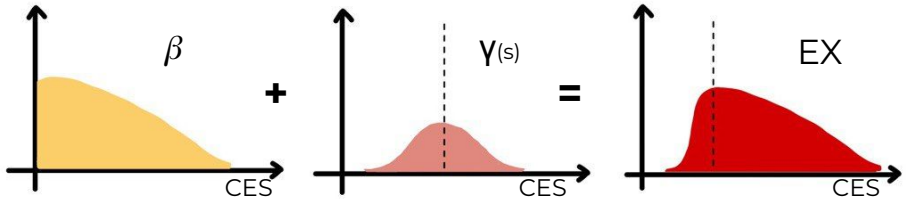
The $^{212/214}$Pb Event Topology



GS: Ground State energy spectra



EX: Excited States energy spectra

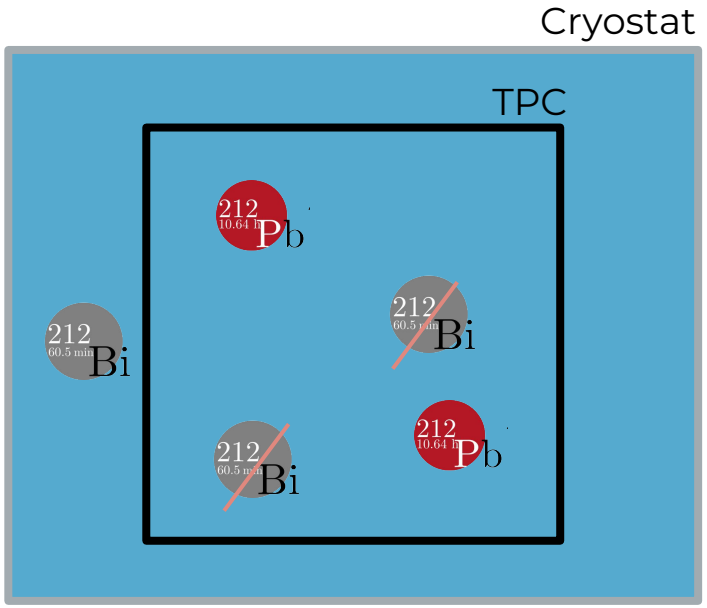


- LXe has **very high stopping power**
- LXe TPC is **limited in temporal resolution**
- Partial spatial resolution: **rejection of multiple scatter (MS) events**

- We consider **only single site** events
- When ^{212}Pb decays into an excited state of ^{212}Bi the **reconstructed energy** will be a **sum** of both the beta energy and the de-excitation one.

The Backgrounds to the $^{212/214}$Pb Branching Ratios Studies

- **Constant** backgrounds are modeled by exploiting **Science Background Runs** (normally utilized for WIMPs or other rare-events studies). They include:
  - ^{136}Xe
  - ^{124}Xe
  - Materials
  - etc..
- **Neutron activated** backgrounds, introduced by neutron calibration campaigns, can be modeled and constrained. They include:
  - ^{129m}Xe
  - ^{131m}Xe
  - ^{133}Xe
- **Source-induced** backgrounds are introduced by the calibration itself. In the case of ^{212}Pb we observed the **Bismuth skin backgronud**.



- **^{212}Bi** beta decays is followed by a **non temporally resolved ^{212}Po** alpha decay, which **shift** the event energy **above the MeV** scale.
- When **outside the TPC**, Bismuth gammas can penetrate inside triggering an event.

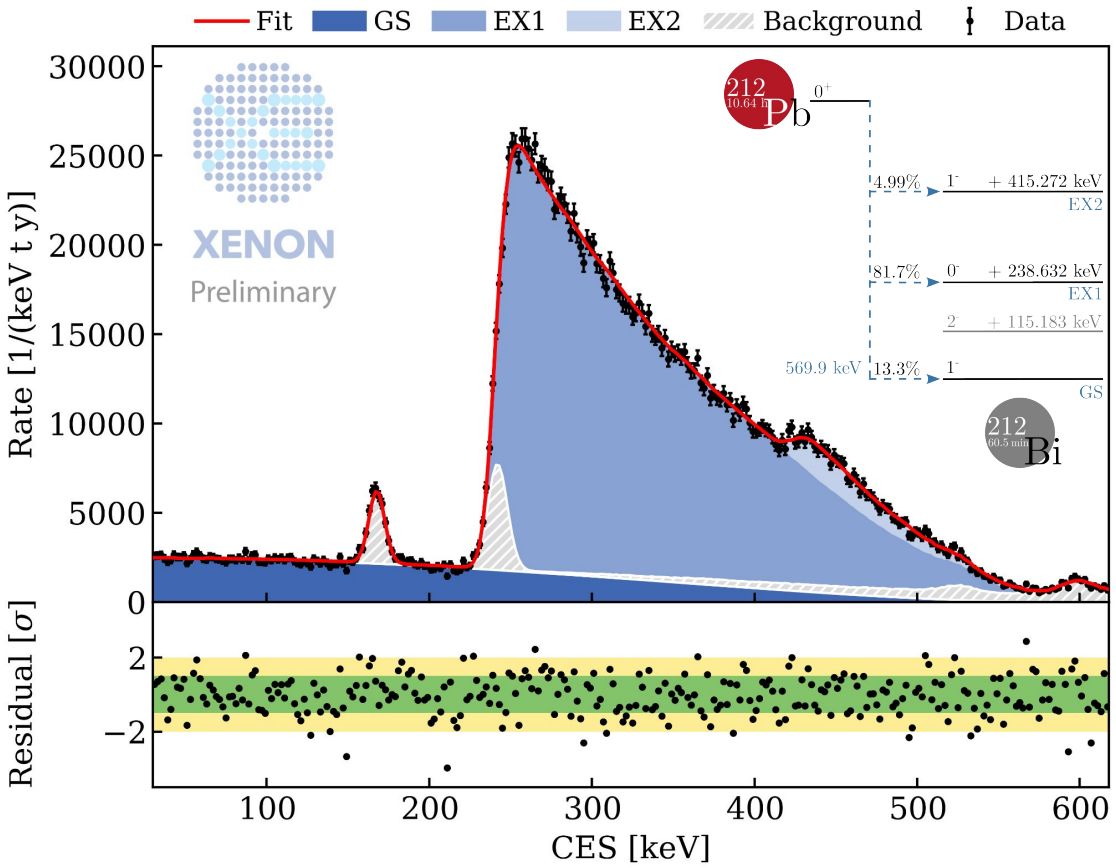
The ^{212}Pb Fit Results

- Via background+signal modeling software we fitted the ^{220}Rn calibration data.
- The model used for **^{212}Pb GS** beta spectrum is the **forbidden** version of this paper:

  Phys. Rev. C 102, 065501 (2020)

- The models used for the excited states are those generated by GEANT4

- With this method we estimated a statistical relative uncertainty on the ^{212}Pb GS BR of about **0.77%**
- The improvement w.r.t. literature is of about a factor **10**



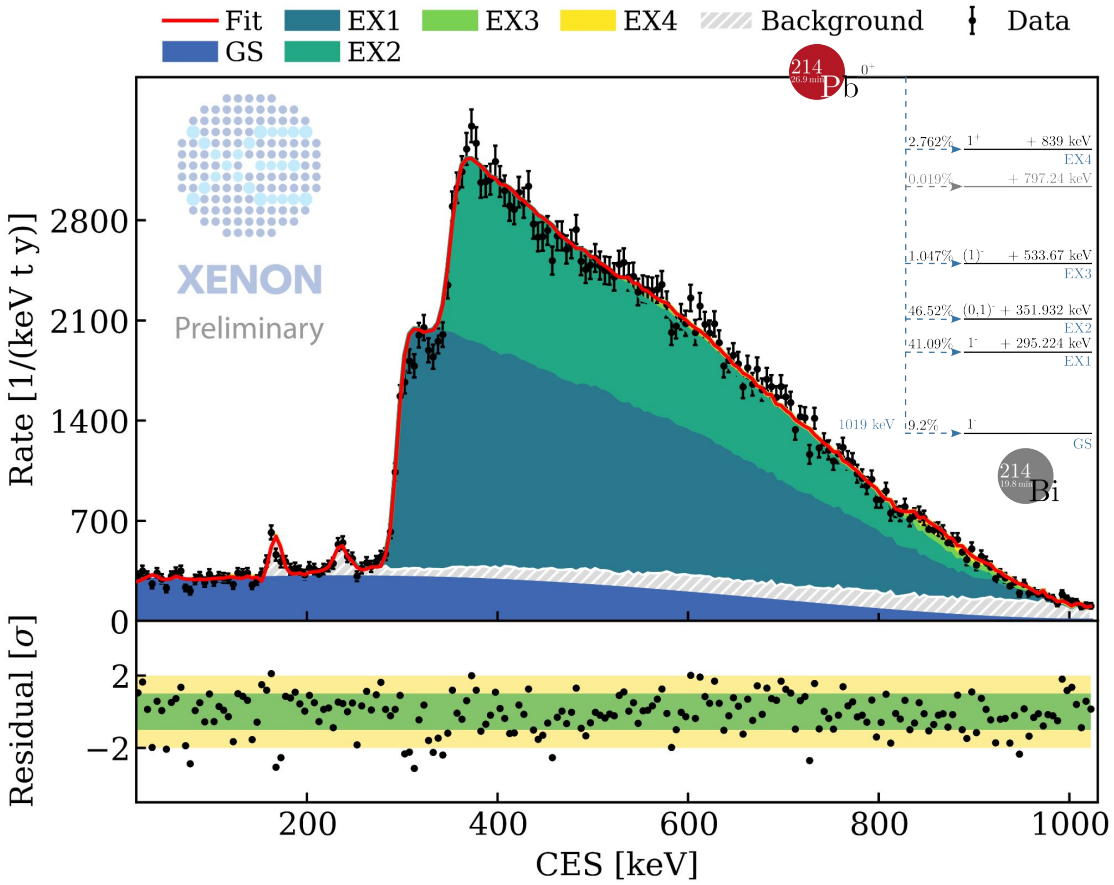
The ^{214}Pb Fit Results

- Via background+signal modeling software we fitted the ^{222}Rn calibration data.
- The model used for **^{214}Pb GS** beta spectrum is the **forbidden** version of this paper:

  Phys. Rev. C 102, 065501 (2020)

- The models used for the excited states are those generated by GEANT4

- With this method we estimated a statistical relative uncertainty on the ^{214}Pb GS BR of about **3.5%**
- The improvement w.r.t. literature is of about a factor **2**



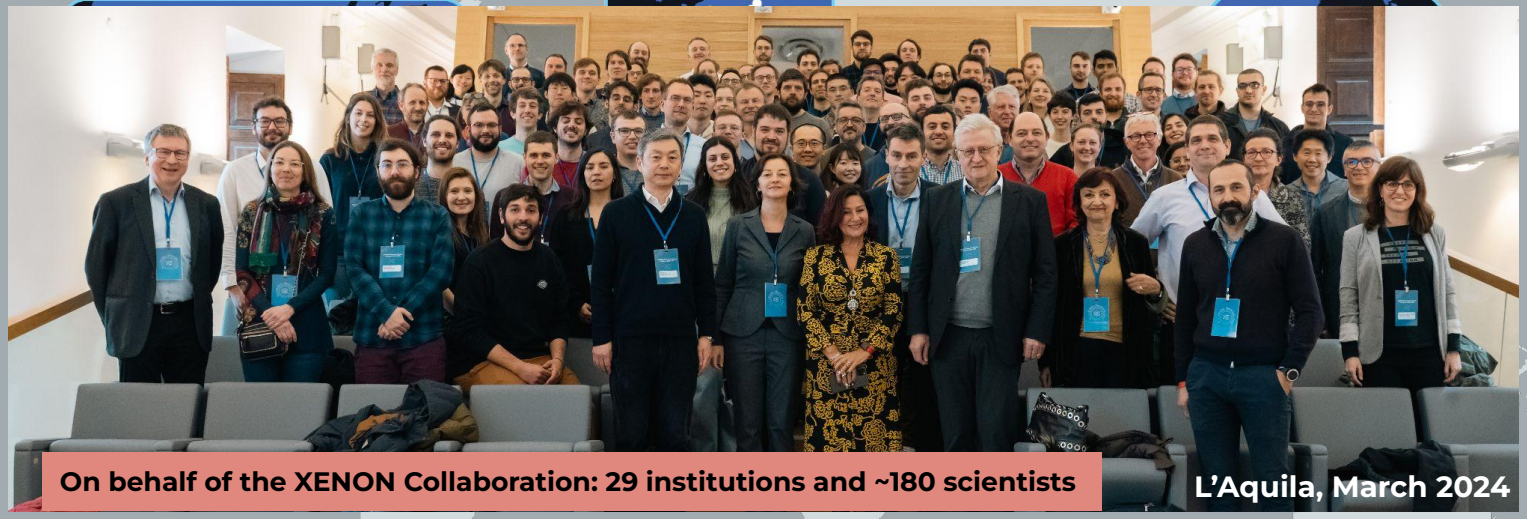
Conclusions

- With the presented analysis we have **demonstrated** the **feasibility** of exploiting an experiment such as **XENONnT** to perform **nuclear physics** studies with
  - **Improved precision**
  - **Direct assessment** to, for example, ground state branching ratios

- These analyses are **still under review** within the Collaboration. Stay tuned for new updates.

- Currently on-going parallel studies focusing on the same energy region

Thank you for you attention



On behalf of the XENON Collaboration: 29 institutions and ~180 scientists

L'Aquila, March 2024

AMERICA

- UC San Diego — San Diego
- Houston
- The University of Chicago — Chicago
- Columbia University in the City of New York — New York City
- Purdue University — Lafayette

EUROPE

- Zurich
- KIT Karlsruhe Institute of Technology — Karlsruhe
- WWU Münster — Münster
- Uni Freiburg — Freiburg
- JGU — Mainz
- Max Planck Institute for Kernphysik — Heidelberg
- Nikhef — Amsterdam
- Stockholm University — Stockholm
- 1290 Universidade de Coimbra — Coimbra
- Subatech — Nantes
- LPNHE Paris — Paris
- INFN Torino — Torino
- Alma Mater Studiorum A.D. 1088 — Bologna
- Università degli Studi dell'Aquila — L'Aquila
- INFN LNGS — Assergi
- Napoli

MIDDLE EAST

- Weizmann Institute of Science — Rehovot
- NYU Abu Dhabi — Abu Dhabi

ASIA

- Tsinghua University — Beijing
- Westlake University — Hangzhou
- Shenzhen
- The University of Tokyo — Tokyo
- Nagoya University — Nagoya
- Kobe University — Kobe

LOW
RADIOACTIVITY
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2024
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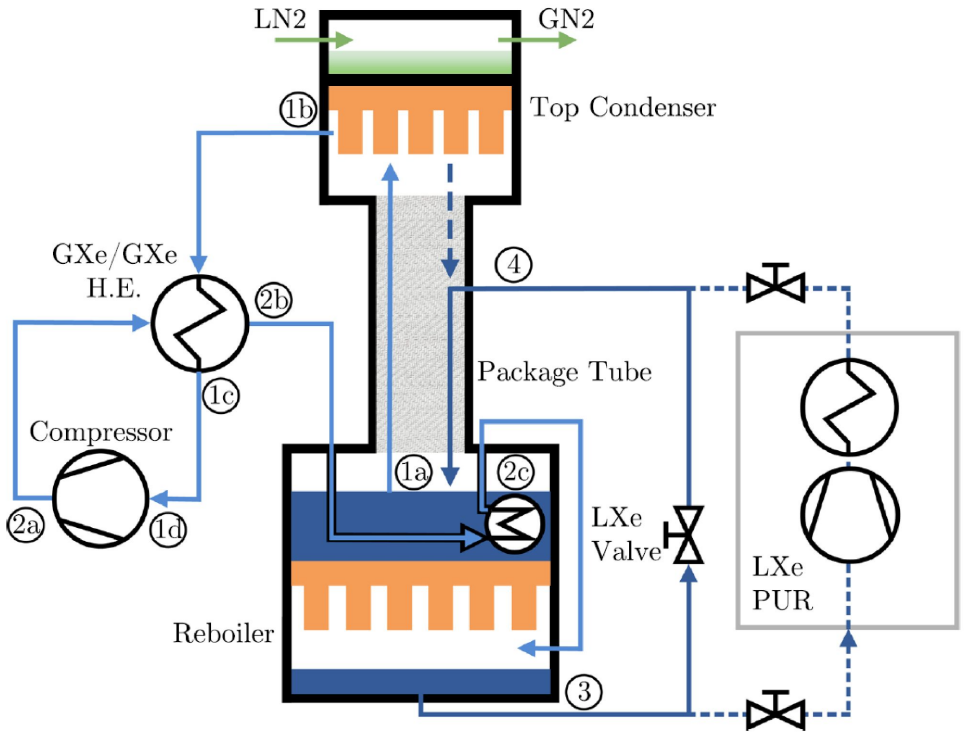
JAGIELLONIAN UNIVERSITY
IN KRAKÓW

Backup

GSSI

INFN
LNGS

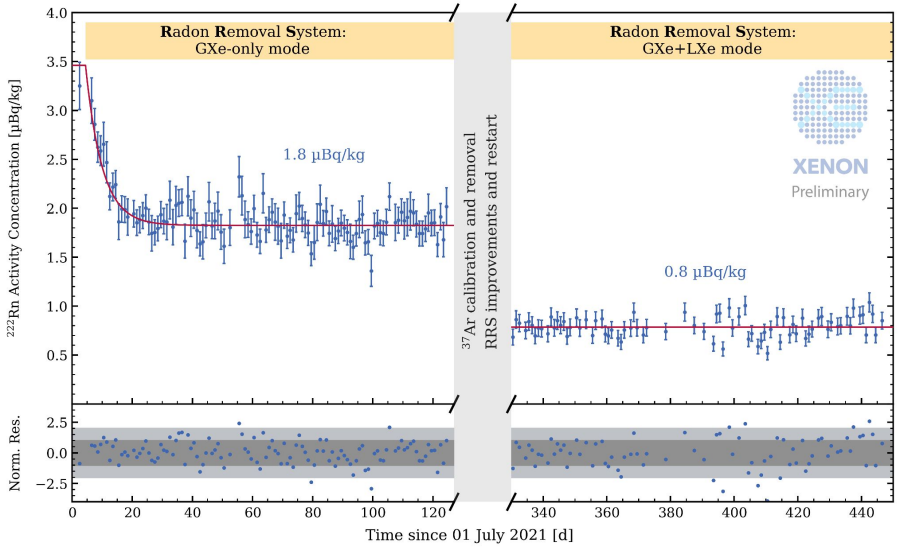
The XENONnT Radon Removal System



Eur. Phys. J. C 82, 1104 (2022)

Christian Weinheimer LRT Talk on Thu

- Cryogenic distillation utilizes **difference in vapor pressure** between **Rn** and **Xe**
- Can be run concurrently in two independent modes: **GXe-only** or **GXe+LXe**
- Lowest ^{222}Rn bkg ever measured in LXe TPC detectors: **< 1 µBq/kg**



From cS1, cS2 to CES