Search for the two-neutrino electron capture with positron emission of ^{124}Xe with the XENONnT experiment

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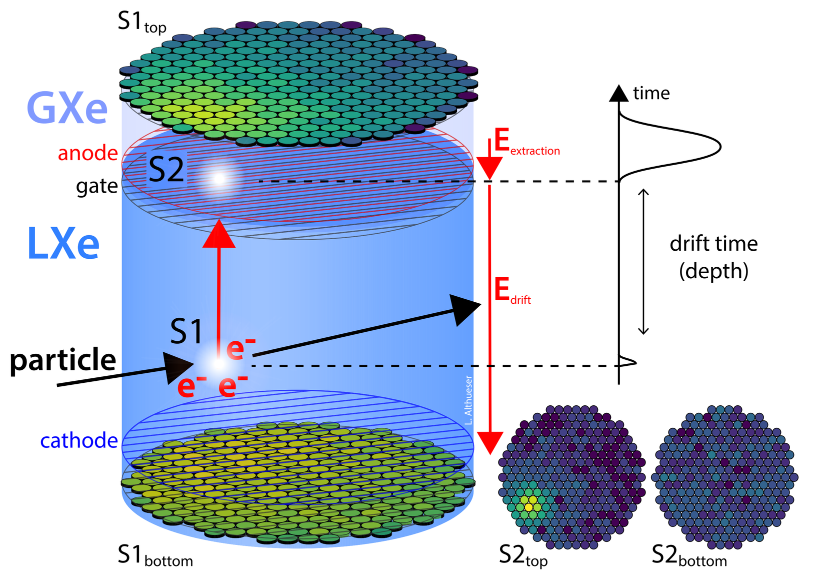
XXXI International Conference on Neutrino Physics and Astrophysics

June 16-22 2024, Milan

The XENONnT experiment



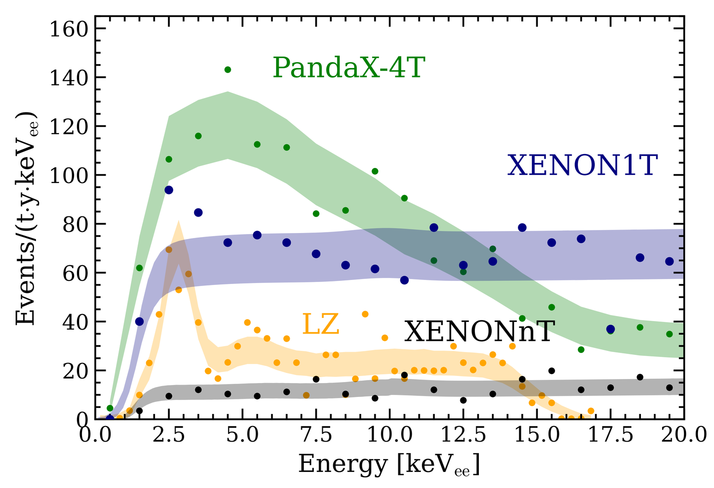
Working principle of a dual-phase liquid xenon time projection chamber

- The XENONnT experiment [1] operates a **dual-phase liquid xenon time projection chamber** (TPC) located at LNGS designed to directly detect dark matter
- **5.9 tonne active mass** monitored by 494 PMTs, enclosed in a neutron veto and a water Cherenkov muon veto

- 3D position and energy reconstruction via prompt light signal (S1) and secondary delayed light from drifted electrons (S2)

- Electronic recoil (ER) background rate of 16.1 events/(keV ·tonne ·yr) in the [1, 30] keV range [2] in the first science run (SR0)

- The **unprecedented low background rate** and excellent energy resolution enable the search of other rare events such as **double weak decays of ^{124}Xe!**



Two-neutrino electron capture with positron emission (2νECβ$^+$) of ^{124}Xe

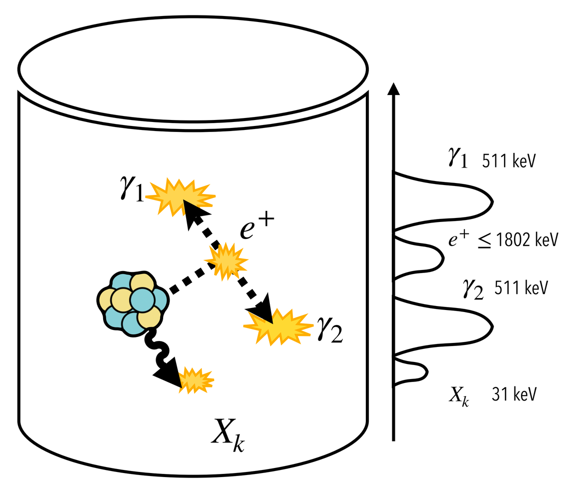
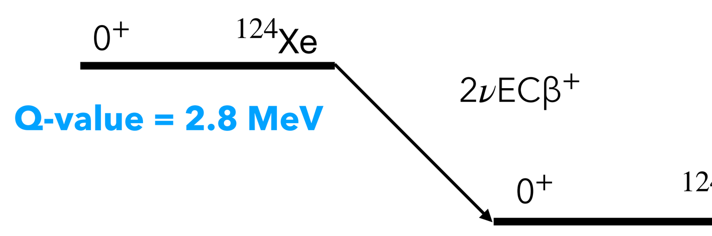


Diagram of the emitted quanta and their reconstructed S2 following the 2νECβ$^+$decay



- Predicted **half-life of (1.7 ± 0.6) ·10^{23} yr**
- Abundance of 0.095% in natural xenon (5.6 kg in the XENONnT active mass)
- The 2νECβ$^+$of ^{124}Xe decay mode with the highest probability of observation in a multi-tonne scale detector [3]

- The decay produces X-ray emission or secondary processes of Auger electrons (X_k) and γ-rays from the e^+e^- annihilation

$$^{124}\text{Xe} + e^- \rightarrow {}^{124}\text{Te} + e^+ + 2\nu_e + X_k$$

- Expected to yield a signature with multiple S2 signals and a single S1 signal
- **Resolving individual ionisation energy depositions is essential to exploit the signature of this decay mode**

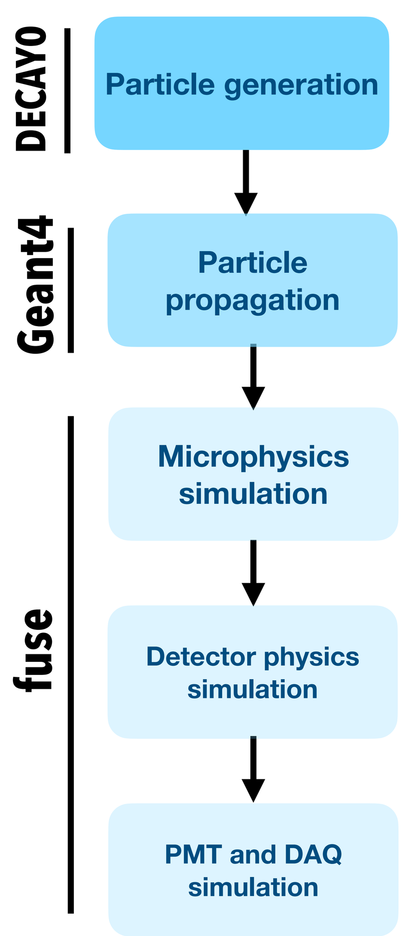
Analysis workflow

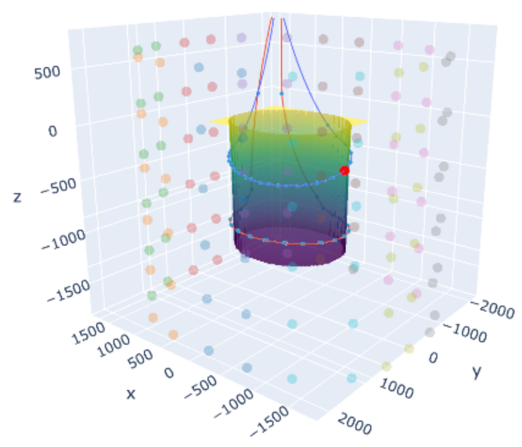
Motivated by the challenge to unambiguously identify the complex decay signature in our detector

MC simulation → Validation with calibration data → Machine Learning discriminator → Application to data → Statistical Inference

Simulation

- Signal and background events produced with the XENONnT Monte Carlo pipeline serve to train the machine learning discriminator
- To this end, the fuse [4] simulations package, which converts energy deposits into real data waveforms, is under validation for high energies
- Simulations - data matching for the ^{232}Th calibration source are ongoing

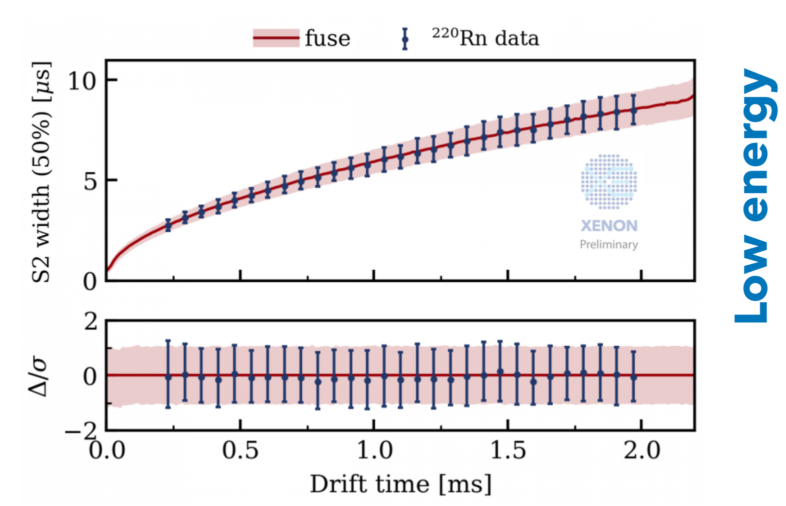


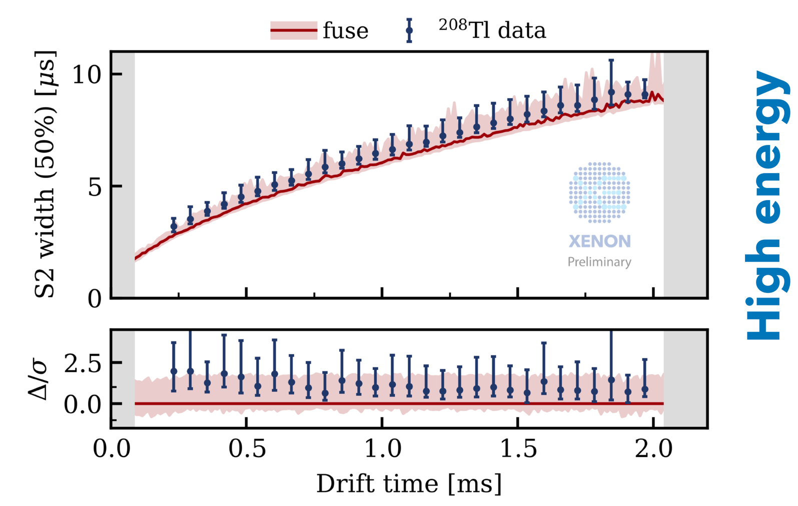


3D diagram of the calibration u-tubes of XENONnT. The red dot represents one of the positions of the external ^{232}Th calibration source

Software validation

- Precise modelling of waveform topologies is essential for accurate reconstruction of multi-scatter signals at low and high energies
  - e.g., S2 signal spread as a function of the interaction depth must match in simulations and calibration data
- **High accuracy** to model the detector response **at low energies already achieved**
- **Next steps to achieve the same precision for high-energy searches identified, paving the way for groundbreaking discoveries**





References

[1] E. Aprile et al. The XENONnT Dark Matter Experiment
[2] E. Aprile et al. Search for New Physics in Electronic Recoil Data from XENONnT Phys.Rev.Lett. 129 (2022)
[3] Christian Wittweg et al. Detection prospects for the second-order weak decays of ^{124}Xe in multi-tonne xenon time projection chambers Eur.Phys.J.C 80 (2020)
[4] XENON Collaboration (2024). XENONnT/fuse: 1.3.0 (1.3.0). Zenodo. https://doi.org/10.5281/zenodo.11551366

xenonexperiment.org/