Estimation of ^{85}Kr background in the XENONnT using delayed coincidence count

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I. XENONnT experiment

Large direct dark matter search experiment

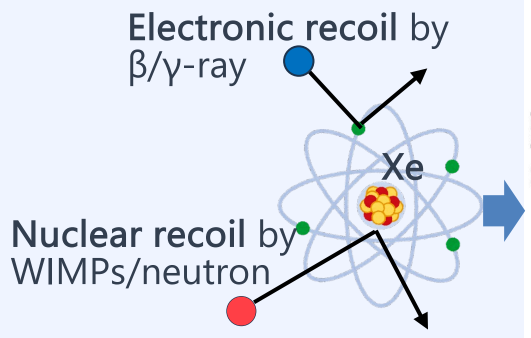
- Underground laboratory in Gran Sasso, Italy
- Started from 2019
- Using ~8.6t of xenon (Xe)
- Liquid Xe; an excellent scintillator

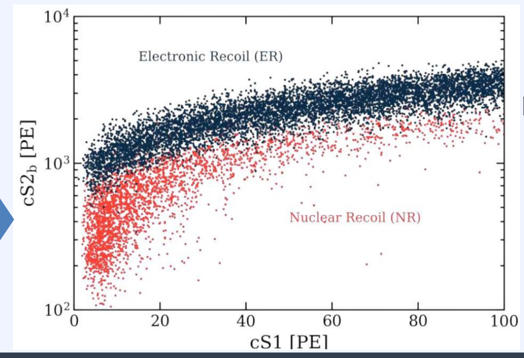
XENON collaboration

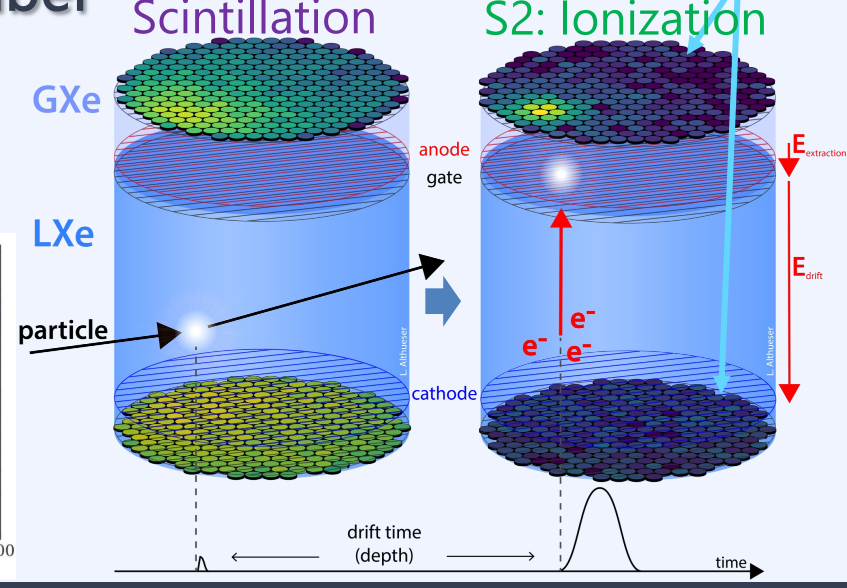
II. Detector and Signals

Dual-phase Xe Time Projection Chamber

- 3D positions of interaction w/ S1&S2 (x, y : S2 position, z : $time_{S2} - time_{S1}$)
- Particle identification : $(S2/S1)_{NR} < (S2/S1)_{ER}$

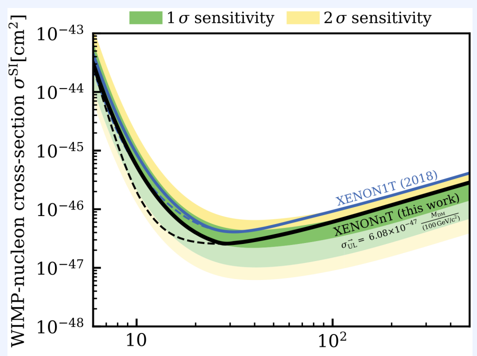






III. Physics targets

Dark Matter – WIMPs search

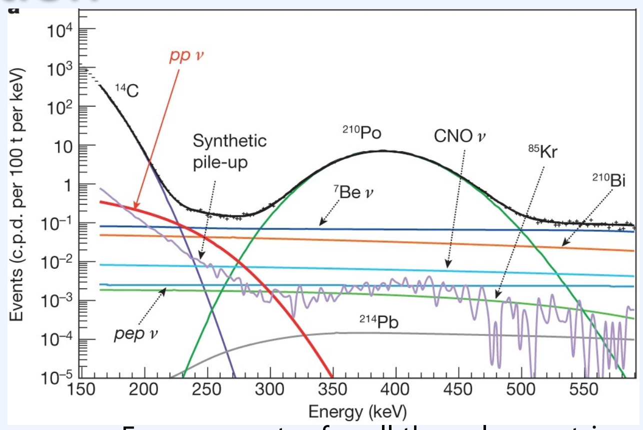


Upper limit on WIMP-nucleon cross-section at 90% CL
Phys. Rev. Lett. 131, 041003

- Weakly Interacting Massive Particles
- A good candidate of DM
  - ・mass ~x100 of proton
  - ・Very rare event (expected: ≦1 event/year)

Solar pp neutrino observation

- 89.9% of solar neutrinos
- Energy < a few hundred keV
- Observe w/ ~1% uncertainty to reveal solar activity
- We have a good environment
  - ・Not interfered by ^{14}C
  - ・Low energy threshold (~1 keV)



Energy spectra for all the solar neutrino and radioactive BG components.
Borexino Collaboration. *Nature* 512, 383–386 (2014)

Reduction of background sources
Precise background estimation
} are important for rare event searches!

IV. ^{85}Kr background in XENONnT

The Second most dominant BG in low energy region

- A β-ray source (Q-value: 687 keV)
- Contaminated in collecting Xe
- Reduced by distillation (ppb→ppt level)

Background model with fit constraints

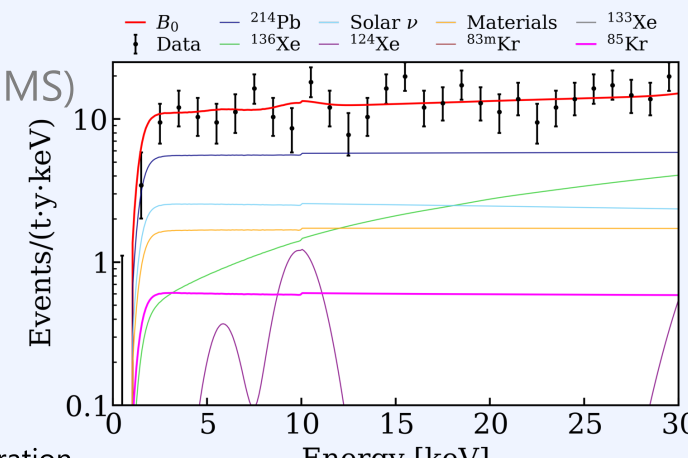
Component	Constraint [Events/t・y・(1~140)keV]
^{214}Pb	(570, 1200)
Materials	270 ± 50
^{85}Kr	90 ± 60

Current abundance estimation

- $^{85}Kr/^{nat}Kr$ ratio in air (2×10^{-11}).
  - Its fluctuation is not taken into account
- Kr concentration in Xe (56 ± 36 ppq) from the rare gas mass spectroscopy (RGMS)
  - ~60% uncertainty

Introducing a new estimation

Purpose: Measure ^{85}Kr in Xe **directly**
Idea: Use signals characteristic of ^{85}Kr

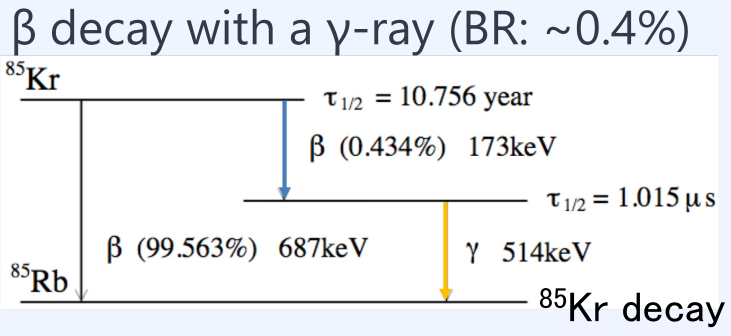


XENON collaboration, PRL, 129, 161805 (2022)
Fit to SR0 data using the BG model

V. Estimation of ^{85}Kr by the delayed coincidence count

The analysis strategy

- Count ^{85}Kr rare decay event
  - ・β decay with a γ-ray (BR: ~0.4%)



^{85}Kr decay scheme

- Calculate Kr concentration

$$\text{Kr concentration in Xe} = N_{event} \times \left(\frac{4.4\,t(FV)}{132\,g(Xe)} \times N_0 \times 0.004 \times 1.77\times10^{-4}\right)^{-1}$$

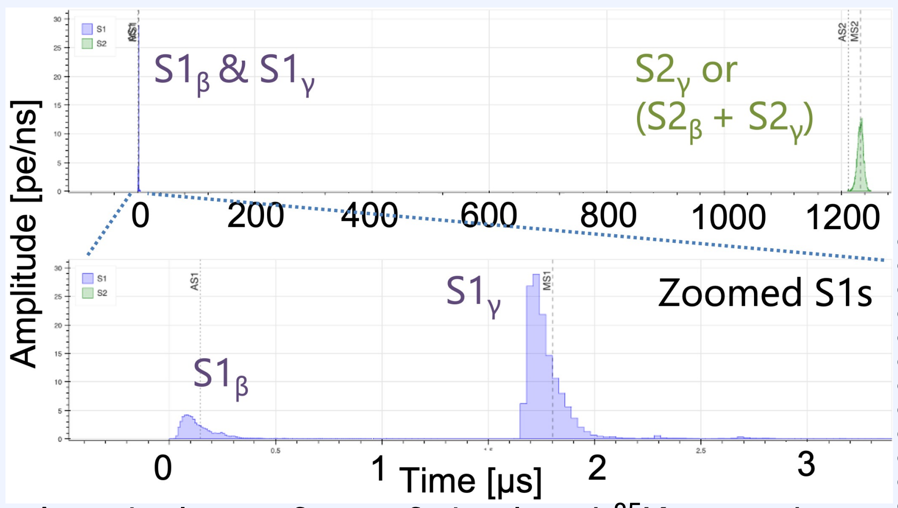
(N_{event}: Number of events [event/FV/day]; $\frac{4.4\,t(FV)}{132\,g(Xe)}$: Xe[mol/FV]; N_0: Avogadro number; 0.004: branching ratio; 1.77×10^{-4}: ^{85}Kr decay probability in a day)

Pros :
- Independent of $^{85}Kr/^{nat}Kr$
- Can be used as Kr monitor
- The larger the exposure, the lower the upper limit of ^{85}Kr

Cons :
- Time-consuming (small BR)

Selection

Select ^{85}Kr events and exclude BG events
Main BG : Accidental coincidence (AC) events



A typical waveform of simulated ^{85}Kr rare decay

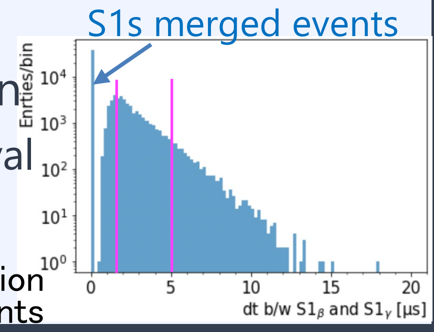
Used data :
- Geant4-based simulation
- Calibration data (energy close to ^{85}Kr)

Used parameters :
- S1, S2 magnitudes
- Z position difference b/w $S1_\beta$ and $S1_\gamma$
- Rise time & Width of waveforms
- Time difference b/w $S1_\beta$ and $S1_\gamma$

Definition of Criteria :
High signal acceptance or Good S/√N

Quality of the selection

- Signal acceptance: $(30.0 \pm 3.2_{stat.} \pm 1.1_{sys.})$ %
- BG reduction: 2.5×10^{-7} %
  - ⇒ 0.22 events/100d
- The largest signal loss: time difference selection
  - ・Two S1s w/ <0.5μs interval cannot be separated...



Time difference distribution of simulated ^{85}Kr events

VI. Result in Science Run 0 (97.1 days)

Validation of BG estimation

The number of events in SR0 found in the ^{85}Kr selection sideband

Sideband parameter	Expected	Observed
Time difference	60.2 ± 7.8	54
Z position difference	7.4 ± 2.7	7

⇒ Expected was consistent w/ observed BG

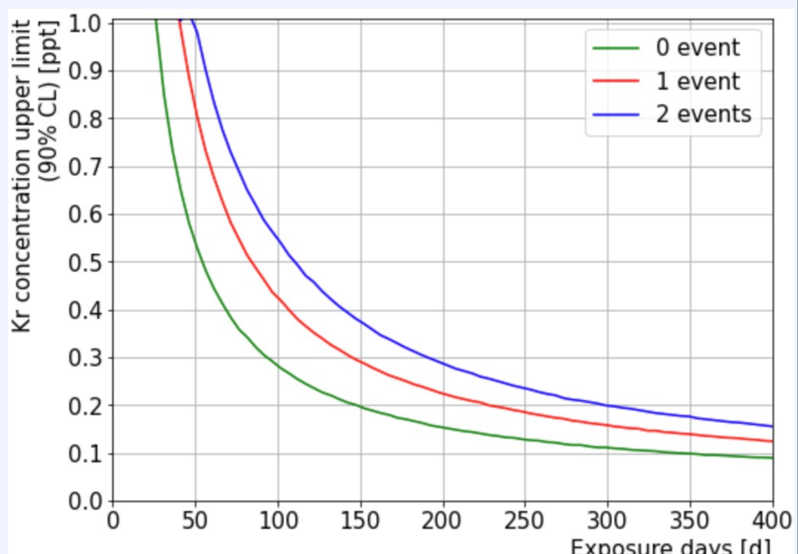
^{85}Kr event search

The number of ^{85}Kr event in SR0

Expected	Observed
0.5 ± 0.3	0

Assuming 56 ± 36 ppq

⇒ **Result was consistent w/ RGMS** (61% of chance)
Upper limit of Kr concentration (90% CL) = **290 ppq**



Upper limit of Kr concentration in Xe

VII. Summary

- Kr concentration estimation by delayed coincidence count was introduced.
- Signal acceptance was 30%, remaining AC BG events was 0.21 in SR0.
- The result in SR0 set 290 ppq as the upper limit of the Kr concentration, which was consistent with the current measurement.
- It will contribute to the significance of solar pp ν observation in XENONnT.
- The selection should be improved to set the upper limit more efficiently.