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

Yoshino Kaminaga (the Univ. of Tokyo) for the XENON collaboration

I. ^{85}Kr background in XENONnT

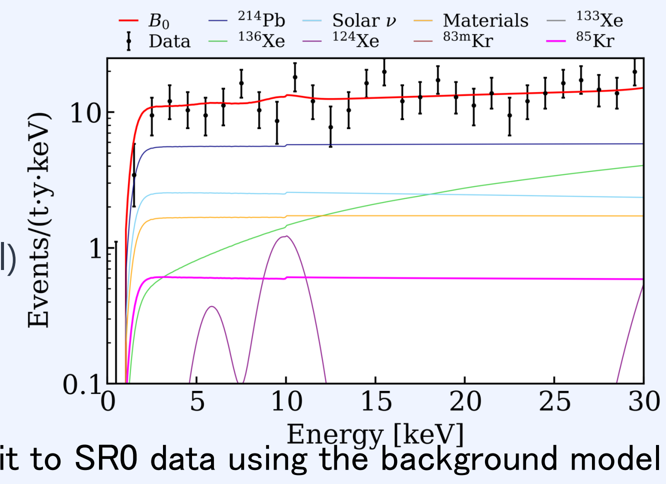
Rare event search experiment

- Reduction of background sources
- Precise background estimation

} are important!

^{85}Kr

- A BG component especially in low energy region
- Contaminated in collecting Xe
- Reduced by distillation (ppb→ppt level)



Fit to SR0 data using the background model

Background model B0 with fit constraints

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

~60% uncertainty
the 2nd most dominant BG
in solar pp ν, light DM search...

From "Search for New Physics in Electronic Recoil Data from XENONnT", PRL, 129, 161805 (2022)

Current ^{85}Kr abundance estimation

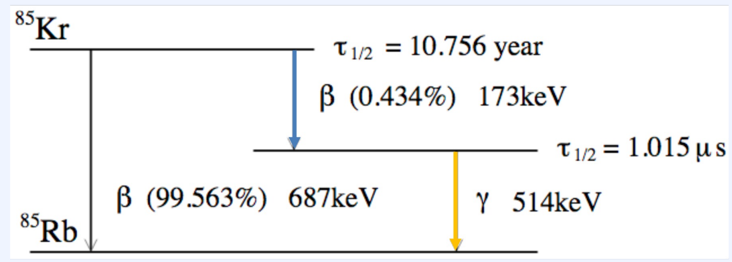
- Measure Kr in Xe by the rare gas mass spectroscopy(RGMS)
- Measure ^{85}Kr/^{nat}Kr ratio in air
- Estimate ^{85}Kr in Xe.

∴ ^{85}Kr/^{nat}Kr ratio uncertainty is not taken account.

Motivation：**to measure ^{85}Kr in Xe directly using its signal**

New estimation method: delayed coincidence count

^{85}Kr rare decay event with prompt β & secondary γ



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

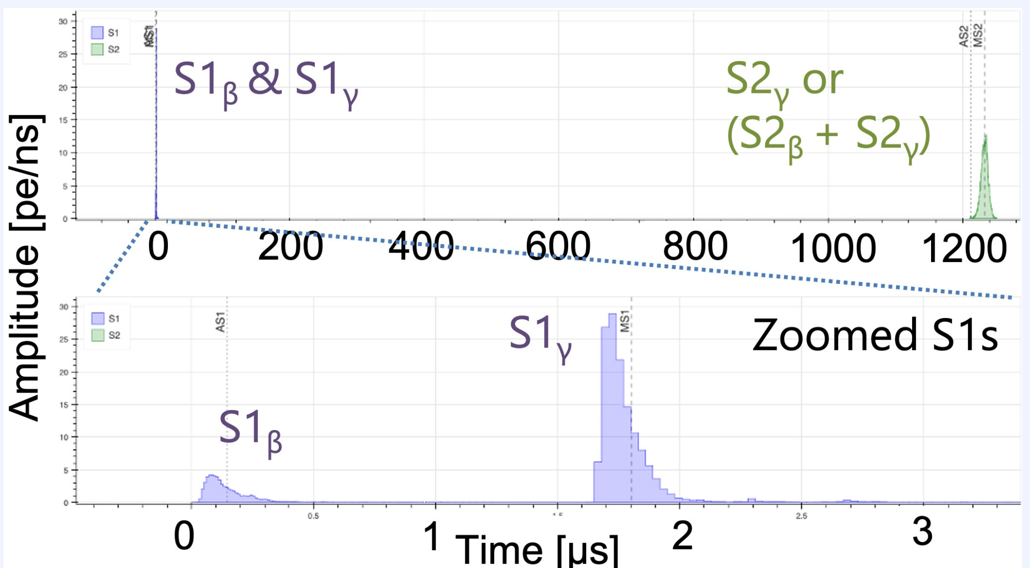
Cons：

- Time-consuming (due to the branching ratio ~0.43%)

III. Selection criteria for ^{85}Kr rare decay events

^{85}Kr rare decay event

- $S1_\beta$：Scintillation light by prompt β
- $S1_\gamma$：Scintillation light by secondary γ
- $S2_\beta$, $S2_\gamma$：Ionization signals by β & γ
  May be merged due to its wide width



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

Selection

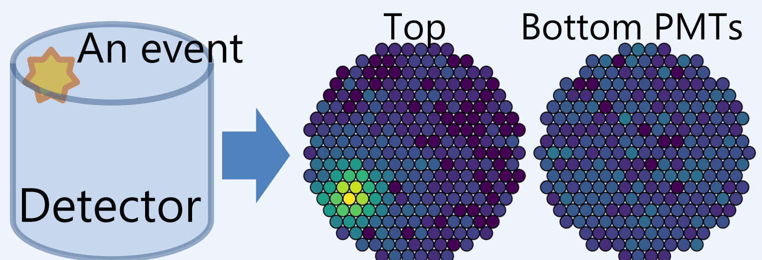
Select ^{85}Kr events and exclude BG events

Main BG：Accidental coincidence (AC) events

Criteria：**99% signal quantile** or **good S/√N ratio**

Parameters：

- Number of photoelectrons ⇒ S1, S2 magnitudes
- Area fraction top (AFT) ⇒ z positions

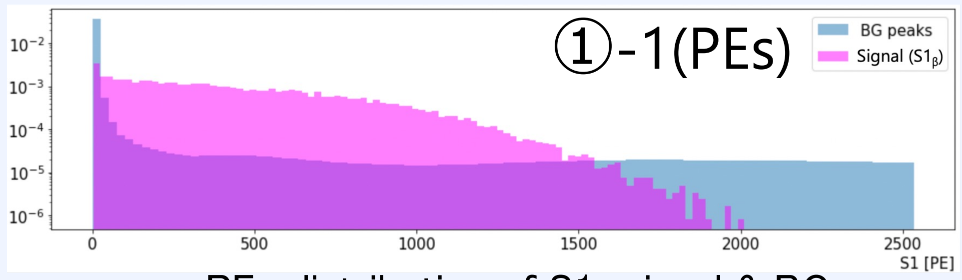


100% detected at top array
∴ AFT=top/total~1

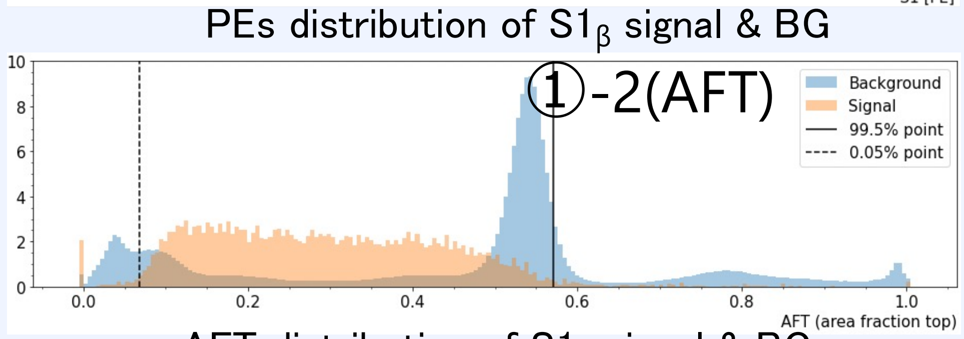
- Rise time & Width of waveforms
- Timings

Used data

- Geant4-based simulation
- ^{220}Rn calibration data as $S1_\beta$, $S2_\beta$ signal
- e+e- annihilation events data as $S1_\gamma$, $S2_\gamma$ signal



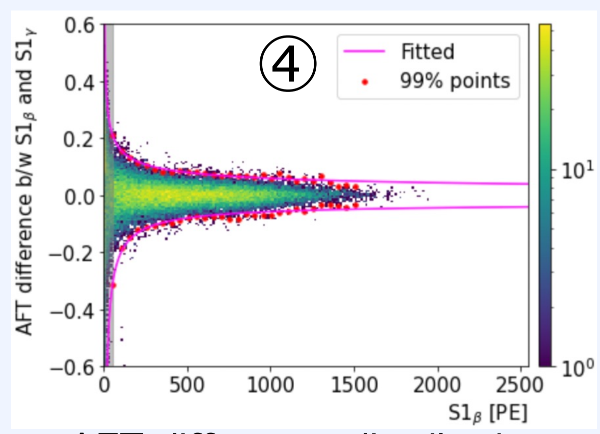
PEs distribution of $S1_\beta$ signal & BG



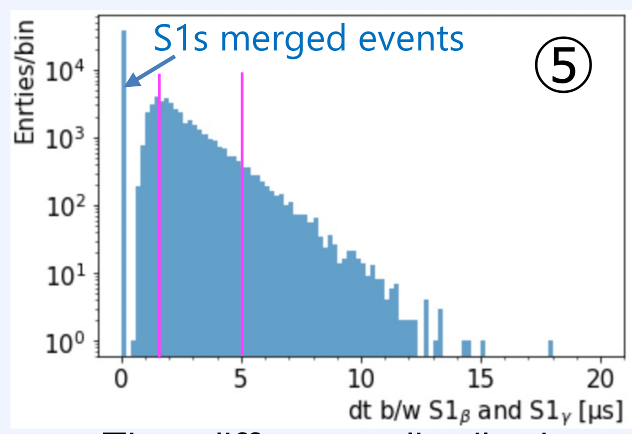
AFT distribution of $S1_\beta$ signal & BG

^{85}Kr selection criteria and their efficiency of signals and BGs
(BG events used for remaining BG estimation were selected by PEs)

Selection	Criteria	Signal acceptance	Remaining BG
⓪ Fiducial volume	4.37±0.13 t	-	$\pm 3.2_{stat}$ %
① $S1_\beta$	Multiple parameters	$82.8\pm0.2_{stat}\pm0.4_{sys}$ %	$0.9\pm0.1_{stat}$ %
② $S1_\gamma$	Multiple parameters	$94.0\pm0.2_{stat}\pm0.4_{sys}$ %	$27.3\pm0.2_{stat}$ %
③ $S2_\gamma$ or ($S2_\beta$+$S2_\gamma$)	[57050 pe, 313340 pe]	$>99.9\pm<0.1_{stat}-0.2_{sys}$ %	-
④ AFT difference	99% quantile	$98.8\pm0.1_{stat}\pm0.9_{sys}$ %	$34.9\pm0.2_{stat}$ %
⑤ time difference	[1.5 μs, 5μs]	$39.8\pm0.2_{stat}\pm0.2_{sys}$ %	3.5×10^{-4} %
Total		$30.6\pm3.2_{stat}\pm1.1_{sys}$ %	2.8×10^{-7} %



AFT difference distribution of simulated ^{85}Kr events



Time difference distribution of simulated ^{85}Kr events

IV. Result in Science Run 0

Science Run 0 (SR0) has 97.1d exposure time

Validation of BG estimation

Check sidebands of selections

- **Time difference** [10 μs, 1010 μs]：
  52.1 events/SR0(expected), 52 events/SR0(found)
- **AFT difference** [-0.4, 0.4] - 99% signal region：
  4.2 events/SR0(expected), 3 events/SR0(found)

∴ Expected BG numbers are consistent with found events.

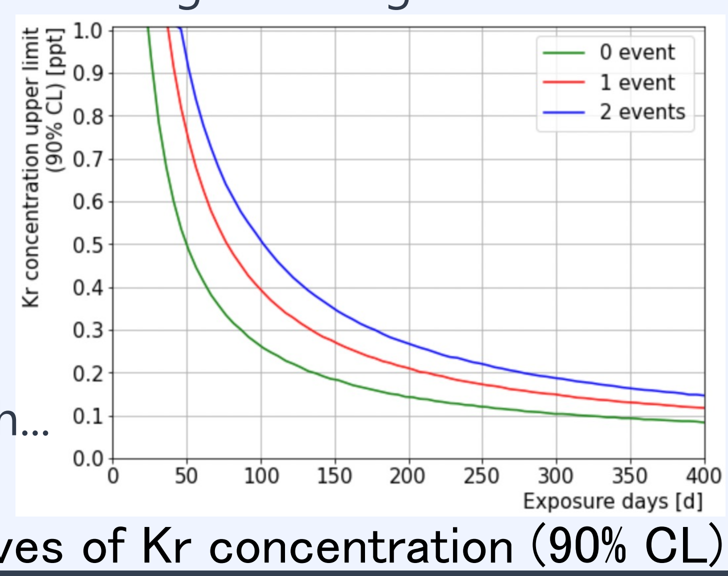
^{85}Kr event search

- Expected：0.51 ± 0.02 events/SR0 (at 56 ppq of Kr)
- Found：0 events in SR0 ⇒ Probability：60%

∴ Upper limit of Kr concentration (90% CL) = **270 ppq**

V. Summary and future

- Signal acceptance ~31%, the main loss was caused S1s merged events.
- There would be ~0.18 AC BG events in SR0 (~100d).
- The result in SR0 was consistent with a result by RGMS.
- Improving the signal acceptance by evaluating S1s merged ratio.
- Reducing AC BG by optimizing selection criteria using S/√N ratio.
- Preparing the online Kr monitor.
- Giving an upper limit of ^{85}Kr abundance by extending exposure.
- Contributing to solar pp ν, DM search...



Upper limit curves of Kr concentration (90% CL)