^{42}Ar background in nEXO

Venkatesh Veeraraghavan

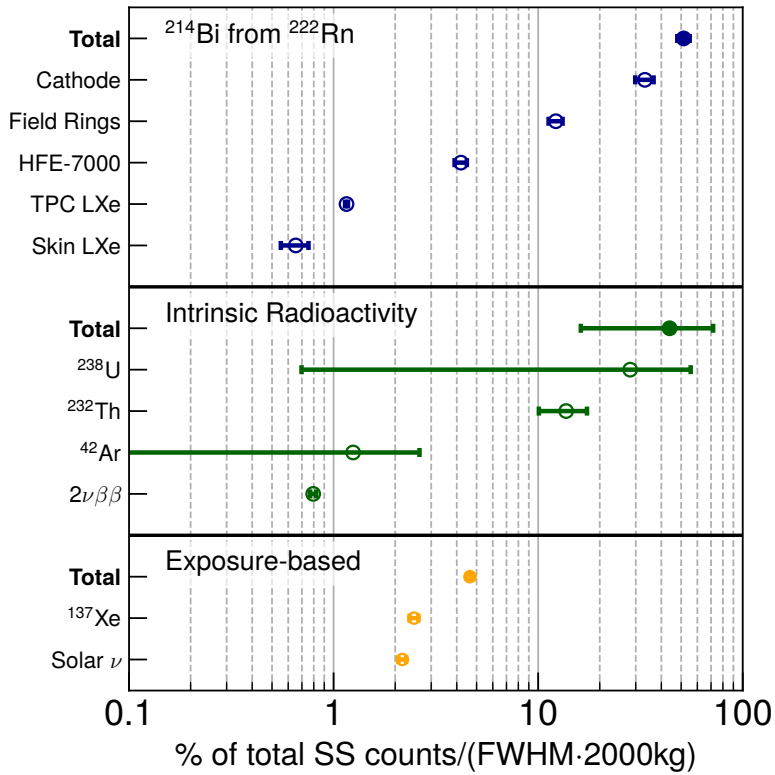
University of Alabama,
Iowa State University

Low Radioactivity Techniques 2022
17-Jun-2022

Introduction

- nEXO background sources
  - Intrinsic radioactivity
  - Steady-state ^{222}Rn
  - Expossure-based
- $N_{\text{SS bkg}}^{\text{1 year, inner two tonnes}} = 0.5$
  - Imperative to identify, study and quantify all kinds of backgrounds
- Focus of this presentation: ^{42}Ar in $^{\text{enriched}}$Xe

Most recent nEXO sensitivity paper



J. Phys. Nucl. Part. Phys. 49, 015104 (2022)

^{42}Ar background for nEXO

- Trace amounts of argon could be present in $^{\text{enriched}}$Xe
- ^{42}Ar is a background for nEXO

$$^{42}_{18}\text{Ar} \xrightarrow[T_{1/2} = 32.9\ \text{y}]{100\%\ \beta^-} {}^{42}_{19}\text{K} \xrightarrow[T_{1/2} = 12.4\ \text{h}]{100\%\ \beta^-} {}^{42}_{20}\text{Ca}$$

Nuclide	Q-value (keV)
^{42}Ar	599
^{42}K	3525

- 2424 keV γ-ray co-incident in ^{42}K decay (BF 0.0002)
- To quantify ^{42}Ar background for nEXO
  - Estimate ^{42}Ar in $^{\text{enriched}}$Xe
  - Use nEXO detector design information
    - nEXO simulations
    - fraction of ionic ^{42}K
    - effect of xenon re-purification
    - efficiency of purifier to remove ^{42}K

^{42}Ar estimate in $^{\text{enriched}}$Xe

- Measurements of relative abundance of ^{42}Ar in $^{\text{natural}}$Ar

Experiment	Year	Relative abundance of ^{42}Ar in ^{40}Ar	
		atoms/atom (10^{-21})	Specific activity (μBq/kg)
DBA	1998	< 6 (90% C.L.)	< 60 (90% C.L.)
DBA	2003	< 4.3 (90% C.L.)	< 43 (90% C.L.)
GERDA	2014	$9.1^{+0.8}_{-2.0}$ to $16.8^{+2.2}_{-1.8}$	91^{+8}_{-20} to 168^{+22}_{-18}
DBA	2016	$9.2^{+2.2}_{-4.6}$	92^{+22}_{-46}
DEAP	2019	4.04 ± 0.59	40.4 ± 5.9

- Measurement of argon content in $^{\text{enriched}}$Xe

$$7.6 \pm 1.8 \cdot 10^{-9} \text{ g/g [EXO-200, 2012]}$$

- Relative differences for ^{42}Ar and ^{40}Ar during centrifugal separation, assumed to be in the range of 1-9
- ^{42}Ar content in $^{\text{enriched}}$Xe
  - 0.7 to 16.1 pBq/kg
  - 5 to 119 atoms in entire $^{\text{enriched}}$Xe in nEXO TPC

Modeling of ^{42}K background in nEXO

- Differential equation for ^{42}K

$$\frac{dN_K(t)}{dt} = \frac{N_A(t)}{\tau_A} - \frac{N_K(t)}{\tau_K} - N_K(t) \cdot \left(\frac{f}{V}\right) \cdot \epsilon$$

  f/V is fraction of xenon that encounters purifier/unit time
  ϵ is efficiency of purifier to remove ^{42}K

- Number of ^{42}K decays in 1 year

$$N_K^{1\text{ year}} = \frac{\mathcal{A}_A(0) \cdot M_{\text{LXe}} \cdot \tau_A \cdot 0.0208}{1 + \tau_K \cdot \frac{f}{V} \cdot \epsilon}$$

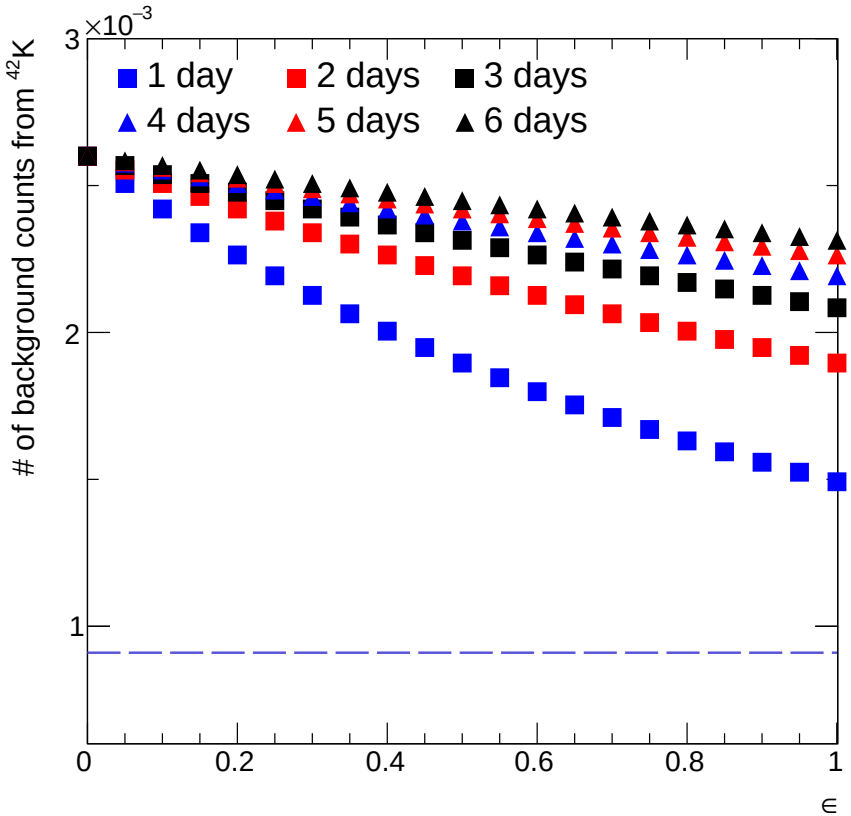
- Ionic ^{42}K drift to cathode, neutral ^{42}K remain in active LXe
- MC efficiency for ^{42}K decays

nEXO part	Efficiency (10^{-3})	
	SS	MS
Active LXe	6.0 (0.4%)	2.2 (0.7%)
Cathode	$7 \cdot 10^{-5}$ (38%)	$6.8 \cdot 10^{-4}$ (12%)
Inactive LXe	$6 \cdot 10^{-5}$ (41%)	$4.1 \cdot 10^{-4}$ (16%)

SS (single site): Energy deposited in single spatial location
MS (multi site): Energy deposited in multiple locations

^{42}Ar background for nEXO

- Xenon re-circulation time period is 4 days
- Efficiency of purifier to remove ^{42}K is unknown



- Background count (1 year, inner two tonnes): $2.6 \cdot 10^{-3}$
  - mass separation factor between argon isotopes: 9
  - ionic fraction of ^{42}K: 0.76
  - ϵ=0 and arbitrary f/V

^{42}Ar background for nEXO

ϵ	f/V (day^{-1})	$f_{^{42}K^+}$	Relative mass separation ($\frac{^{40}Ar}{^{42}Ar}$)	$N_{bkg}^{1\ year}$	f_{BKG} (%)
0.0	1-4	0.76	9.0	$2.6 \cdot 10^{-3}$	0.29
			1.0	$2.9 \cdot 10^{-4}$	0.03
		0.0	9.0	$1.1 \cdot 10^{-2}$	1.21
			1.0	$1.22 \cdot 10^{-3}$	0.13
1.0	1	0.76	9.0	$1.49 \cdot 10^{-3}$	0.16
			1.0	$1.65 \cdot 10^{-4}$	0.02
		0.0	9.0	$6.31 \cdot 10^{-3}$	0.7
			1.0	$7 \cdot 10^{-4}$	0.08
	4	0.76	9.0	$2.2 \cdot 10^{-3}$	0.24
			1.0	$2.4 \cdot 10^{-4}$	0.03
		0.0	9.0	$9.3 \cdot 10^{-3}$	1.02
			1.0	$1.03 \cdot 10^{-3}$	0.11
1.0	1	0.76	1	$7 \cdot 10^{-5}$	0.008

Summary

- A central objective for nEXO is to identify, study and quantify the exhaustive set of backgrounds relevant to the experiment
- Background from ^{42}Ar in LXe resides in the central region of the nEXO TPC and is treated here
- The analysis presented here has been adapted from EXO-200 [Mitchell Hughes dissertation, 2019]
- Background from ^{42}Ar in LXe has been determined to be $\mathcal{O}$ (1%) and not expected to significantly affect nEXO's sensitivity

nEXO collaboration