Technical Note: ^{11}C Spallation Production Measurement

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Abstract

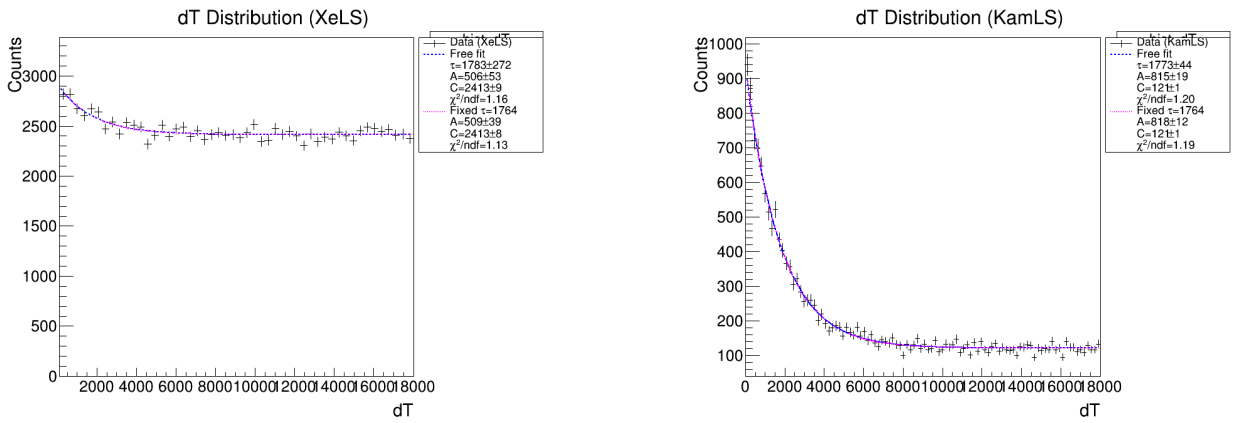
This technical note describes the ^{11}C measurement in KLZ and how the rate is extracted.

Spallation Event Selection

- Standard FBE muon selection cuts
- Standard MoGURA neutron selection cuts
- Neutron Shower Cuts ($N_n = 1$)
- $0\nu\beta\beta$ selection cuts, except for spallation-related cuts
- XeLS ^{11}C Candidate cuts
  - Energy Range : 1.0-1.6 MeV
  - Radius : 0-160 cm
  - dT : 100-18,000 s (5 hours)
- KamLS ^{11}C Candidate cuts
  - Energy Range : 1.4-2.4 MeV
  - Radius : 220-350 cm
  - dT : 100-18,000 s (5 hours)
- dR Cut : < 80 cm

Fit to dT

dT of muon-event pairs where the neutron shower contained 1 observed neutron is shown in Figure 1.



(a) XeLS

(b) KamLS

Figure 1: dT of muon-event pairs where the neutron shower contained 1 observed neutron.

Rate Calculation

The calculation of expected number of detected, selected, and correlated ^{11}C-μ pairs. Not trying to calculate the expected number of background "accidentally correlated muon-event pairs", only the true ^{11}C-μ pairs.

$$I_{C11} = Y_{C11} \times E_{FBE} \times (1 - dt_{MoG}) \times \epsilon_{dR} \times \epsilon_{dT} \times \epsilon_{FV} \times \epsilon_{E} \tag{1}$$

- I_{C11}: Integral of the exponential component of the fit, "Observed $\mu-^{11}$C pairs" $[events]$

$$I_{C11} = A_{C11} \cdot \tau \cdot \frac{e^{\frac{-100}{\tau}} - e^{\frac{-18000}{\tau}}}{(18000 - 100)/50} \tag{2}$$

  - **XeLS : 10,153 events**
  - **KamLS : 3,794 events**
  - Used the fit with fixed ^{11}C lifetime
  - $(18000 - 100)/50$s is the dT histogram bin spacing

- Y_{C11}: **Final Result** Production rate of ^{11}C in KamLS, XeLS $[events/kton \cdot days]$

- E_{FBE}: Exposure, Livetime : $[kton \cdot days]$

  - **XeLS : 16.36 kton-days**
  - **KamLS : 130.68 kton-days**
  - Volume of the target region, density, Livetime
  - LiveTime excludes the first 5 hours of each FBE run

- dt_{MoG}: MoGURA Deadtime Fraction: [unitless]

  - **1.88%**

  - simply scale up based on the deadtime since muons that occur during deadtime will not be able to create accurate pairs.
  - Go through the FBE and MoGURA runs and check for overlap.

- ϵ_{dR}: $dR < 80$ cm cut efficiency (from FLUKA tuned with ^{11}C), for each data period [unitless]
  - **XeLS : 57%**
  - **KamLS : 56.4%**
  - Also from Kelly's new FLUKA simulation

- ϵ_{dT}: dT > 100s cut efficiency (from known ^{11}C half-life) [unitless]
  - **94.5%**
  - Simply integrate the exponential decay distribution between 100-18,000 s

- ϵ_{FV-E}: Fiducial Volume & Energy Cut Efficiency (KLG4Sim) [unitless]
  - **XeLS : 79.7%**
  - **KamLS : 40.5%**
  - Calculate the efficiency from the energy and radius cuts described in the first section.

Simply solve for Y_{C11}:

$$Y_{C11} = \frac{I_{C11}}{E_{FBE} \times (1 - dt_{MoG}) \times \epsilon_{dR} \times \epsilon_{dT} \times \epsilon_{FV-E}} \tag{3}$$

Systematic Errors

- A_{C11}, exponential amplitude, fit uncertainty : $A_{C11} = 2,181 \pm 87$, $\frac{87}{2,181} = 4.0\%$
- Exposure Uncertainty, from 0ν analysis uncertainty $\sim 4\%$
  - 4% uncertainty stated for uncertainty in xenon exposure, mainly driven by FV uncertainty, similar for Carbon?
- Neutron Tagging Efficiency Error: $74.5\% \pm 0.4\%$
- FLUKA simulation Systematic : dR Cut, Neutron Production
- FLUKA simulation Statistical (insignificant)
- Energy Scale Uncertainty : (use 1 sigma of kB, R contour)

Results

- **XeLS** : $1,470$ $events/day/kton$
- **KamLS** : 669 $events/day/kton$

Previous results from KamLAND: $1,106 \pm 178$ events/day/kton 2009 spallation paper, 973 ± 10 events/day/kton from ^7Be solar neutrino measurement.

There is a large discrepancy between my results and the previous measurements. Also the trend is inconsistent, XeLS rate is too high, KamLS rate is too low.

Possible Errors

- different livetime for different volume regions?
- Different event selection efficiency for different volume regions? Currently using the standard selection for $0\nu\beta\beta$ analysis.