Technical Note: ^{11}C Spallation Production Measurement

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Abstract

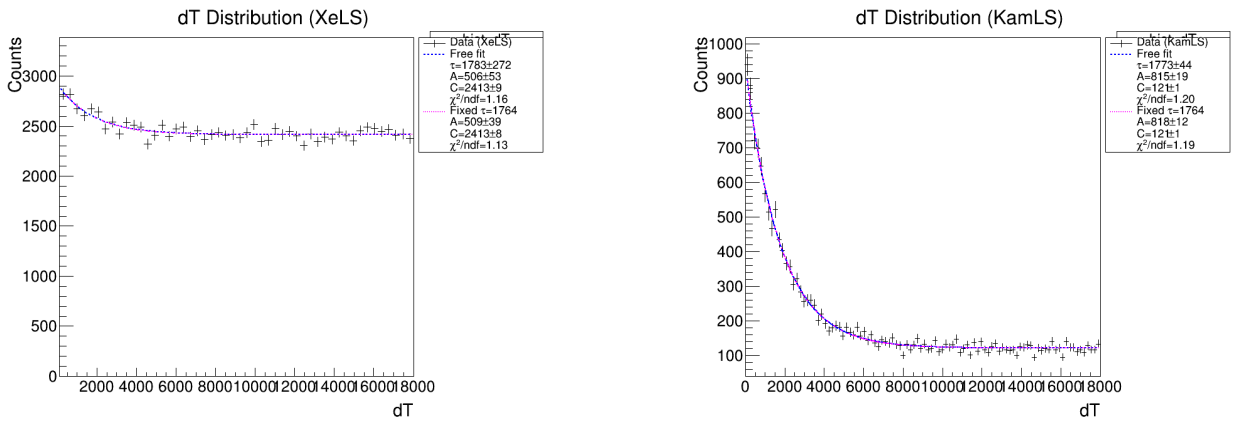
This technical note describes the ^{11}C measurement in KLZ and how the rate is extracted.

Spallation Event Selection

- Standard FBE muon selection cuts
- Standard MoGURA neutron selection cuts
- Neutron Shower Cuts ($N_n = 1$)
- 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.

$$I_{C11} = Y_{C11} \times E_{FBE} \times (1 - dt_{MoG}) \times P_n(1|^{11}C_{spall}) \times \epsilon_{dR} \times \epsilon_{dT} \times \epsilon_{FV} \times \epsilon_E \quad (1)$$

- I_{C11}: Integral of the exponential component of the fit, "Observed $\mu-^{11}$C pairs" $[events]$
- Y_{C11}: Production rate of ^{11}C in KamLS, XeLS **final result** $[events/kton \cdot days]$
- E_{FBE}: Exposure, Livetime : $[kton \cdot days]$
  - Go through FBE runs and sum up muon veto/detector deadtimes, integrate FV.
- dt_{MoG}: MoGURA Deadtime Fraction: [unitless]
  - simply scale up based on the deadtime since muons that occur during deadtime will not be able to create accurate pairs.
  - Have to go through the MoGURA/FBE runs and check for overlap.
- $P_n(1|^{11}C_{spall})$: Neutron Production : How many muons that create ^{11}C create exactly 1 **observed** neutron [unitless]
  - Muons that create ^{11}C and create 1+ neutrons, some fraction of those have only one detected (Toy MC calculation using Neutron Tagging Efficiency and FLUKA simulated neutron yield)
  - Can estimate the rate of muons creating other isotopes, should be 1% of ^{11}C production in the analysis dT range.
- ϵ_{dR}: dR cut efficiency (from FLUKA tuned with ^{11}C), for each data period [unitless]
- ϵ_{dT}: dT $>$ 100s cut efficiency (from known ^{11}C half-life) [unitless]

- ϵ_{FV}: Fiducial Volume Cut Efficiency (KLG4Sim) [unitless]
- ϵ_E: Energy Cut Efficiency (KLG4Sim) [unitless]

Simply solve for Y_{C11}:

$$Y_{C11} = \frac{I_{C11}}{E_{FBE} \times (1 - dt_{MoG}) \times P_n(1|^{11}C_{spall}) \times \epsilon_{dR} \times \epsilon_{dT} \times \epsilon_{FV} \times \epsilon_E} \tag{2}$$

Systematic Errors

- A_{C11}, exponential amplitude, fit uncertainty : $A_{C11} = 509 \pm 39$, $\frac{39}{504} = 7.7\%$
- 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)

Result