

MARATHON Pass 2 Analysis Primer

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I. OVERVIEW

iii. Livetime

II. REPLAY

iv. Tritium Decay

(Tyler Hague)

Target composition

Tritium decays to helium via the β -decay process ${}^3\text{H} \rightarrow {}^3\text{He} + e^- + \bar{\nu}_e$, with a half-life of

III. CALIBRATIONS

i. E/p

$$\tau_{1/2} = \ln(2)\tau = (4500 \pm 8) \text{ days}$$

(Mike Nycz)

This results in a time-dependent target composition, with a decreasing (increasing) population of tritium (helium) nuclei. These effects must be quantified and corrected in order to accurately extract the normalized tritium yield from tritium target data.

ii. VDC

The target cell was filled with an initial tritium number density n_T^0 , and initial helium number density n_H^0 . As tritium decays to helium, these number densities evolve in time as

iii. Raster

(Tyler Hague)

$$n_T = n_T^0 e^{-t/\tau} \quad (1)$$

iv. BCM

$$n_H = n_H^0(1 - e^{-t/\tau}), \quad (2)$$

(Mike Nycz)

where t is the number of days since the target was filled. Since the decay process preserves the total number of nuclei, the total number density n_{tot} is constant in time:

v. BPM

$$\begin{aligned} n_{tot} &= n_T + n_H \\ &= n_T^0 + n_H^0 \end{aligned} \quad (3)$$

BPM PreBeam Check

With these quantities, the helium fraction can be defined:

vi. Optics

$$f_H = \frac{n_H}{n_T + n_H} = \frac{n_H}{n_{tot}} \quad (4)$$

IV. CORRECTIONS

Given an infinite amount of time, all of the tritium will decay to helium. Therefore $f_H \rightarrow 1$ as $t \rightarrow \infty$.

i. PID

Normalized yield correction

i. Positron Subtraction

The normalized yield is defined as:

(Tong Su)

$$Y = \frac{N}{Qn}, \quad (5)$$

ii. Endcap Subtraction

where N is the number of detected electrons, Q is the beam charge incident on the target, and n is the target number density. Assume that N includes all corrections

(Tong Su)

(deadtime, efficiency, endcap contamination, etc.) *not* related to tritium decay. In practice, the yield is extracted from multiple runs, so the number of detected electrons and luminosity must be summed over run number i :

$$Y = \frac{\sum N_i}{\sum Q_i n_i}, \quad (6)$$

The required correction must account not only for the evolution of the target composition (quantified in the previous section), but also for the fact that some of the detected electrons N will have actually scattered from a helium nucleus instead of a tritium nucleus. Begin by expressing the raw, uncorrected normalized yield (which is measured) as

$$Y_{raw} = \frac{\sum (T_i + H_i)}{\sum Q_i (n_{T,i} + n_{H,i})} \quad (7)$$

where T and H are the number of detected electrons scattered by tritium and helium, respectively. For time-dependent quantities (such as $n_{T,i}$ and $n_{H,i}$, given by Equations 1 and 2), the subscript indicates the value of the quantity at the time of run i . The goal is to obtain the normalized tritium yield Y_T in terms of Y_{raw} and correction factors, where

$$Y_T = \frac{\sum T_i}{\sum Q_i n_{T,i}}. \quad (8)$$

Due to the helium contamination, the correction factor will depend on the normalized helium yield

$$Y_H = \frac{\sum H_i}{\sum Q_i n_{H,i}}. \quad (9)$$

From equation (7), only a few steps of algebra are required to obtain Y_T . Recall that the total number density $n_{tot} = n_T + n_H$ is constant in time, and note that the tritium fraction $n_{T,i}/n = 1 - f_{H,i}$, where f_H is the helium fraction defined by Equation 4.

$$\begin{aligned} Y_{raw} &= \frac{\sum (T_i + H_i)}{\sum Q_i (n_{T,i} + n_{H,i})} \\ &= \frac{\sum T_i}{n_{tot} \sum Q_i} + \frac{\sum H_i}{n_{tot} \sum Q_i} \\ &= \left(\frac{\sum_i T_i}{\sum_i Q_i n_{T,i}} \right) \left(\frac{\sum_i Q_i n_{T,i}}{n_{tot} \sum_i Q_i} \right) + \left(\frac{\sum_i H_i}{\sum_i Q_i n_{H,i}} \right) \left(\frac{\sum_i Q_i n_{H,i}}{n_{tot} \sum_i Q_i} \right) \\ &= Y_T \left(\frac{\sum Q_i (1 - f_{H,i})}{\sum Q_i} \right) + Y_H \left(\frac{\sum Q_i f_{H,i}}{\sum Q_i} \right) \end{aligned}$$

To simplify notation, define the charge-averaged helium fraction:

$$\langle f_H \rangle \equiv \frac{\sum Q_i f_{H,i}}{\sum Q_i} \quad (10)$$

Thus,

$$Y_{raw} = Y_T (1 - \langle f_H \rangle) + Y_H \langle f_H \rangle, \quad (11)$$

and finally,

$$Y_T = Y_{raw} \left(\frac{1}{1 - \langle f_H \rangle} \right) - Y_H \left(\frac{\langle f_H \rangle}{1 - \langle f_H \rangle} \right) \quad (12)$$

Uncertainty propagation

Pending

v. Boiling

(Tong, Mike)

vi. Radiative Corrections

(Hanjie Liu)

V. BINNING AND COMBINING

Bin width Choice

Bin Centering

Combining Kinematic Overlap