Project: Hall C Solid targets for X>1, CAFE, EMC etc.

Tittle: Solid Target Thicknesses for Fall 2022

Document Number: TGT-CALC-22-035

Revision: 0

Author: Dave Meekins

Applicable Codes and Standards
N/A

Reference:
Leo: Techniques for Nuclear and Particle Physics Experiments

Reference Drawing(s):

Description:
Solid target thicknesses determined from measurements made in EEL and ORNL. These solid targets are in the general shape of a puck. Assays provided by American Elements, Alpha, and ORNL. Masses when measured at JLAB have uncertainty of 0.5 mg. Uncertainties on diameter (measured at at least 2 locations) are conservatively estimated at 0.02 mm. Note not all targets are installed on ladder 1. Lithium targets are not listed here.

Boron Carbide:

B4C-10 and B4C-11 supplied by American Elements

B4C-10:
Assay 96.6% Boron-10
Chemical purity 99.99%

$d := 12.57 \cdot mm$ diameter of puck

$m := 0.7152 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.241\ cm^2$ area of puck

$\rho t := \frac{m}{A} = 0.576\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.002\ \frac{gm}{cm^2}$ uncertainty in areal density

$t := 2.45 \cdot mm$ measured thickness

$\rho := \frac{\rho t}{t} = 2.352\ \frac{gm}{cm^3}$ density

B4C-10:
Assay 99.8% Boron-11
Chemical purity 99.99%

$d := 12.58 \cdot mm$ diameter of puck

$m := 0.7867 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.243\ cm^2$ area of puck

$\rho t := \frac{m}{A} = 0.633\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.002\ \frac{gm}{cm^2}$ uncertainty in areal density

$t := 2.6 \cdot mm$ measured thickness

$\rho := \frac{\rho t}{t} = 2.434\ \frac{gm}{cm^3}$ density

Copper:
Supplied by GoodFellow 99.999% pure

$d := 12.75 \cdot mm$ diameter of puck

$m := 1.2032 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.277\ cm^2$ area of puck

$\rho t := \frac{m}{A} = 0.942\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.003\ \frac{gm}{cm^2}$ uncertainty in areal density

Calcium 48:

The Ca48 target was fabricated from material left from an emergency fabrication for CREX after a beam missteering event caused the original target to melt and alloy with the copper heat sink. The batch/lot for this material from ORNL is 900242. The isotopic enrichment of Ca48 is 90.04%.

$d := 12.775 \cdot mm$ diameter of puck

$m := 1.3466 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.282\ cm^2$ area of puck

$\rho t := \frac{m}{A} = 1.051\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.003\ \frac{gm}{cm^2}$ uncertainty in areal density

Calcium 40:

The Ca40 target was fabricated at ORNL batch number is 118740. Enrichment is 99.965%.

$d := 12.71 \cdot mm$ diameter of puck

$m := 0.9959 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.001 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.269\ cm^2$ area of puck

$\rho t := \frac{m}{A} = 0.785\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.003\ \frac{gm}{cm^2}$ uncertainty in areal density

Note: mass and diameter of puck determined at ORNL

Iron 54:

The iron 54 target was fabricated at ORNL. The batch is 166644. The enrichment 97.68%.

$d := 12.69 \cdot mm$ diameter of puck

$m := 0.4645 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.265\ cm^2$ area of puck

$\rho t := \frac{m}{A} = 0.367\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.001\ \frac{gm}{cm^2}$ uncertainty in areal density

Note: mass and diameter of puck determined at ORNL

Aluminum:

Aluminum is from American Elements 99.9% pure.

$d := 12.73 \cdot mm$ diameter of puck

$m := 0.5854 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.273\ cm^2$ area of puck

$\rho t := \frac{m}{A} = 0.46\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.001\ \frac{gm}{cm^2}$ uncertainty in areal density

Titanium

Target from American Elements. 99.99% pure.

$d := 12.73 \cdot mm$ diameter of puck

$m := 0.3747 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.273\ cm^2$ area of puck

$\rho t := \frac{m}{A} = 0.294\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.001\ \frac{gm}{cm^2}$ uncertainty in areal density

Beryllium:

Be target from AE 99.5% pure

$d := 12.49 \cdot mm$	diameter of puck
$m := 1.2077 \cdot gm$	mass of puck
$\delta d := 0.02 \cdot mm$	uncertainty in diameter
$\delta m := 0.0005 \cdot gm$	uncertainty in mass
$A := \frac{\pi}{4} \cdot d^2 = 1.225\ cm^2$	area of puck
$\rho t := \frac{m}{A} = 0.986\ \frac{gm}{cm^2}$	areal density of target
$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$	uncertainty in area
$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.003\ \frac{gm}{cm^2}$	uncertainty in areal density

Carbon:

From AE 99.99% pure

$d := 12.63 \cdot mm$ diameter of puck

$m := 0.7188 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.253\ cm^2$ area of puck

$\rho t := \frac{m}{A} = 0.574\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.002\ \frac{gm}{cm^2}$ uncertainty in areal density

Silver:
From AE 99.9% pure

$d := 12.82 \cdot mm$ diameter of puck

$m := 0.6821 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.291\ cm^2$ area of puck

$\rho t := \frac{m}{A} = 0.528\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = 0.002\ \frac{gm}{cm^2}$ uncertainty in areal density

Other solid targets:

Other targets were measured and installed for the previous configuration and documented in TGT-RPT-22-001. There values are listed here.

Units are g/cm^2

- Ni64 0.2607 +/- 0.0005
- Ni58 0.2408 +/- 0.0004
- Au 0.4047 +/- 0.0006
- Sn 0.5462 +/- 0.0006

Thorium Target:
Thorium was supplied by GoodFellow and consists of 5 foils punched from the same sheet of material which is nominally 0.05 mm thick and 99.5% pure. See log entry 4011074 for more details.

Foil 1

$d := 12.31 \cdot mm$	diameter of puck
$m := 0.0809 \cdot gm$	mass of puck
$\delta d := 0.03 \cdot mm$	uncertainty in diameter
$\delta m := 0.0005 \cdot gm$	uncertainty in mass
$A := \frac{\pi}{4} \cdot d^2 = 1.19\ cm^2$	area of puck
$\rho t_1 := \frac{m}{A} = 0.068\ \frac{gm}{cm^2}$	areal density of target
$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.006\ cm^2$	uncertainty in area
$\delta \rho t_1 := \left(\left(\frac{\delta m}{A}\right)^2 + \left(\frac{m}{A^2} \cdot \delta A\right)^2\right)^{\frac{1}{2}} = \left(5.35 \cdot 10^{-4}\right)\ \frac{gm}{cm^2}$	uncertainty in areal density

Foil 2

$d := 12.38 \cdot mm$	diameter of puck
$m := 0.0830 \cdot gm$	mass of puck
$\delta d := 0.05 \cdot mm$	uncertainty in diameter
$\delta m := 0.0005 \cdot gm$	uncertainty in mass
$A := \frac{\pi}{4} \cdot d^2 = 1.204\ cm^2$	area of puck

$\rho t_2 := \frac{m}{A} = 0.069 \ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.01 \ cm^2$ uncertainty in area

$\delta \rho t_2 := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = \left(6.948 \cdot 10^{-4} \right) \frac{gm}{cm^2}$ uncertainty in areal density

Foil 3

$d := 12.61 \cdot mm$ diameter of puck

$m := 0.0868 \cdot gm$ mass of puck

$\delta d := 0.01 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.249 \ cm^2$ area of puck

$\rho t_3 := \frac{m}{A} = 0.07 \ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.002 \ cm^2$ uncertainty in area

$\delta \rho t_3 := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = \left(4.153 \cdot 10^{-4} \right) \frac{gm}{cm^2}$ uncertainty in areal density

Foil 4

$d := 12.31 \cdot mm$ diameter of puck

$m := 0.0760 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.19\ cm^2$ area of puck

$\rho t_4 := \frac{m}{A} = 0.064\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t_4 := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = \left(4.686 \cdot 10^{-4} \right) \frac{gm}{cm^2}$ uncertainty in areal density

Foil 5

$d := 12.23 \cdot mm$ diameter of puck

$m := 0.0809 \cdot gm$ mass of puck

$\delta d := 0.02 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.175\ cm^2$ area of puck

$\rho t_5 := \frac{m}{A} = 0.069\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.004\ cm^2$ uncertainty in area

$\delta \rho t_5 := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = \left(4.815 \cdot 10^{-4} \right) \frac{gm}{cm^2}$ uncertainty in areal density

Foil 7

$d := 12.27 \cdot mm$ diameter of puck

$m := 0.0821 \cdot gm$ mass of puck

$\delta d := 0.03 \cdot mm$ uncertainty in diameter

$\delta m := 0.0005 \cdot gm$ uncertainty in mass

$A := \frac{\pi}{4} \cdot d^2 = 1.182\ cm^2$ area of puck

$\rho t_7 := \frac{m}{A} = 0.069\ \frac{gm}{cm^2}$ areal density of target

$\delta A := \frac{\pi}{2} \cdot d \cdot \delta d = 0.006\ cm^2$ uncertainty in area

$\delta \rho t_7 := \left(\left(\frac{\delta m}{A} \right)^2 + \left(\frac{m}{A^2} \cdot \delta A \right)^2 \right)^{\frac{1}{2}} = \left(5.423 \cdot 10^{-4} \right) \frac{gm}{cm^2}$ uncertainty in areal density

total thickness:

$\rho t := \rho t_1 + \rho t_2 + \rho t_3 + \rho t_4 + \rho t_5 + \rho t_7 = 0.409\ \frac{gm}{cm^2}$

$\delta \rho t := \left(\delta \rho t_1^{\,2} + \delta \rho t_2^{\,2} + \delta \rho t_3^{\,2} + \delta \rho t_4^{\,2} + \delta \rho t_5^{\,2} + \delta \rho t_7^{\,2} \right)^{\frac{1}{2}} = 0.001\ \frac{gm}{cm^2}$

Dummy Targets

Dummy targets fabricated from solid piece of ASTM B209 AL7075. Density of the base metal was measured prior to machining

$\rho := 2.791 \cdot \frac{gm}{cm^3}$ base density

$\delta\rho := 0.01 \cdot \frac{gm}{cm^3}$ uncertainty in density

$t_1 := 0.86 \cdot mm$ Thickness of target 1 at beam location (center of foil)

$t_2 := 0.846 \cdot mm$ Thickness of target 2 at beam location (center of foil)

$\delta t := 0.01 \cdot mm$ uncertainty in thickness

$\rho t_1 := \rho \cdot t_1 = 0.24 \frac{gm}{cm^2}$ areal thickness of foils 1

$\delta\rho t_1 := \left(\left(t_1 \cdot \delta\rho\right)^2 + \left(\rho \cdot \delta t\right)^2\right)^{\frac{1}{2}} = 0.003 \frac{gm}{cm^2}$ uncertain of area thickness foil 1

$\rho t_2 := \rho \cdot t_2 = 0.236 \frac{gm}{cm^2}$ areal thickness of foils 1

$\delta\rho t_2 := \left(\left(t_2 \cdot \delta\rho\right)^2 + \left(\rho \cdot \delta t\right)^2\right)^{\frac{1}{2}} = 0.003 \frac{gm}{cm^2}$ uncertain of area thickness foil 1