Thickness and Density Measurements for the 10- wafer Silicon Target used in PRIMEX II

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Abstract

Measurements were made for the thickness and density of the 10-wafer stacked silicon target used in the PRIMEX II experiment. This information will be used for obtaining differential cross sections. The silicon used in the semiconductor wafers has natural isotopic abundance. The central part of the target has a thickness of 1.0015 ± 0.0003 cm. The density of the target material is 2.316 ± 0.008 g/cm^3. The fractional uncertainty in ρT for the target is ±0.35%.

Introduction

In the Primex experiment the differential cross section for π^0 photo-production is proportional to the $\pi°$ decay width. Therefore, in the Primex experiment it is important to measure absolute differential cross sections with high accuracy. Absolute cross sections are obtained by dividing the yield of photo-produced π^0's by the number of target atoms/cm^2 in the target. This paper will discuss the thickness (T) and density (ρ) measurements for the silicon target. From these measurements it is possible to calculate the number of atoms/cm^2. To limit systematic errors in our measurements, we designed a three-piece tooling plate for measuring the thickness of the target at different positions. A water immersion apparatus was used to measure the density of the target material.

Target material

The silicon target consists of 10 disks, each with 1" diameter and approximate thickness 1 mm, attached by several beads of "rubber cement" that extended down the length of the target stack. Each disk is a mono-crystal silicon semiconductor wafer, doped with phosphorus. The mean resistivity of the material, 40 Ωcm, implies a number density of phosphorus atoms that is approximately 10^{14} cm^{-3}. Compared to the number density of silicon atoms in the target, the density of phosphorus is reduced by around 9 orders of magnitude. Silicon used in the producing the semiconductor has natural isotopic abundance.

Thickness measurements

Each disk, shown in Fig. 1, has a polished surface. The polished surfaces were orientated so that they faced the incoming photon beam. The orientation of the target was denoted by a letter "T" for the top of the target, written on the target holder. The target was dissembled using the solvent dichloromethane (DCM). As the glue dissolved, an X-Acto knife was used for further disassembling. Upon completion of disassembly, each disk was

placed into plastic Pyrex dishes and given a label from 1-10, in order of its orientation to the incident beam.

We designed a tool that consisted of a top plate with 7 holes and second top plate with 3 holes (see Fig. 2). The diameter of each hole (0.25") is equal to the diameter of the micrometer head used to measure the thickness of the disks. In order to increase the number of measurement points, the 7 hole plate was rotated 90° with respect to the top of the disk, and the 3-hole plate was rotated 90°, 180°, 270°, 360° with respect to the target disk. A total of 25 measurements were taken for each disk. The digital micrometer used (Mitutoyo Micrometer Model NO. 293-721-30) has an accuracy of ±0.00005'', or ±0.0001cm.

The total thickness of the target at a given (x,y) position is given by the summed thicknesses of the ten wafers:

$$T(x,y) = T_1(x,y) + \cdots + T_{10}(x,y)$$

The uncertainty in *T(x,y)* is given by

$$\sigma_T = \sqrt{N}\sigma_A$$

where σ_A is the accuracy of the micrometer (±0.0001cm) and N is the number of wafers. The total uncertainty in target thickness is ±0.0003 cm. The fractional uncertainty in target thickness is approximately ±0.03%.

Fig. 3 shows a 3-d image of the target thickness measurements. Fig. 4 shows the thickness of the ten wafer target stack as a function of (x,y) position. Fig. 5 shows the (x,y) coordinates of the measurement points.

Archimedes Density Measurements

In order to obtain the density for the target material, we ran buoyancy tests on four silicon disks that were not used in PRIMEX II. The apparatus used to weigh each foil consisted of a very thin aluminum rod with a spoon that was suspended from a plastic circular base (see Fig. 6). This apparatus and a beaker holder were placed on a scale (0.0001g accuracy) where we measured the mass of each foil in air, then in water (High Performance Liquid Chromatography grade water, HPCL) four consecutive times, and then in air again. The beaker was filled to roughly 100 ml of water. The temperature of the water was measured to be 24±1 °C, and a temperature correction was applied to obtain the water density (see CRC Handbook of Chemistry and Physics). According to the Archimedes principle of water immersion, we measured the mass of each film immersed in water (m_{water}) and in air (m_{air}), along with the density of water as a function of the temperature $\rho_{water}(T)$ to determine the density of each film.

$$\rho_{SiFilm} = \frac{\rho_{water}(T)}{1 - \frac{m_{water}}{m_{air}}}$$

In our preliminary measurements we noticed that the scale would give very precise results when we measured each disk in air. However the results were less precise when measuring the disk while immersed in water. Perhaps this was due to air bubbles trapped in finite areas of each disk (i.e. scratches) or some external turbulence entering the scale. We needed to account for these errors. In an effort to reduce some systematic errors, we re-zeroed the scale after each measurement. If the drifting zero values were greater than ± 0.003 g then the measurement was discarded. Implementing this criterion, approximately 50% of the initial measurements taken were not accepted into the data set. Below is a table of the data set.

Disk #	m_{Air}	m_{Water}	Zero Drift of Scale
1	1.1726		0
		0.6658	-0.0007
		0.6658	0.0029
		0.6693	-0.0024
		0.6683	-0.0014
	1.1725		0
2	1.1818	0.6726	0.0016
		0.6741	0.0014
		0.6719	0
		0.6764	0.0009
	1.1816		0
3	1.1824		0
		0.6744	0.0008
		0.6715	-0.0026
		0.6716	-0.0017
		0.6728	0.0022
4	1.1824		0
	1.1673		0
		0.6641	0.0014
		0.6659	0
		0.6620	-0.0006
		0.6648	0.0014
	1.1676		0

Each of the four disks was measured four times, for a total of 16 measurements. The distribution of densities is shown in Fig. 7. The mean density of the distribution is 2.316 g/cm^3, and the standard deviation of the distribution is 0.008 g/cm^3.

According to the CRC Handbook of Chemistry and Physics the density of pure silicon is 2.329 g/cm^3. Our density measurement is below the CRC value by approximately 1.6 standard deviations.

Summary

- Silicon in the target has natural isotopic abundance
- Central part of the silicon target has a thickness of 1.0015 ± 0.0003 cm.
- Density of the target material is 2.316 ± 0.008 g/cm^3.
- Fractional uncertainty in ρT is approximately ±0.35%, dominated by the uncertainty in ρ.

Figures

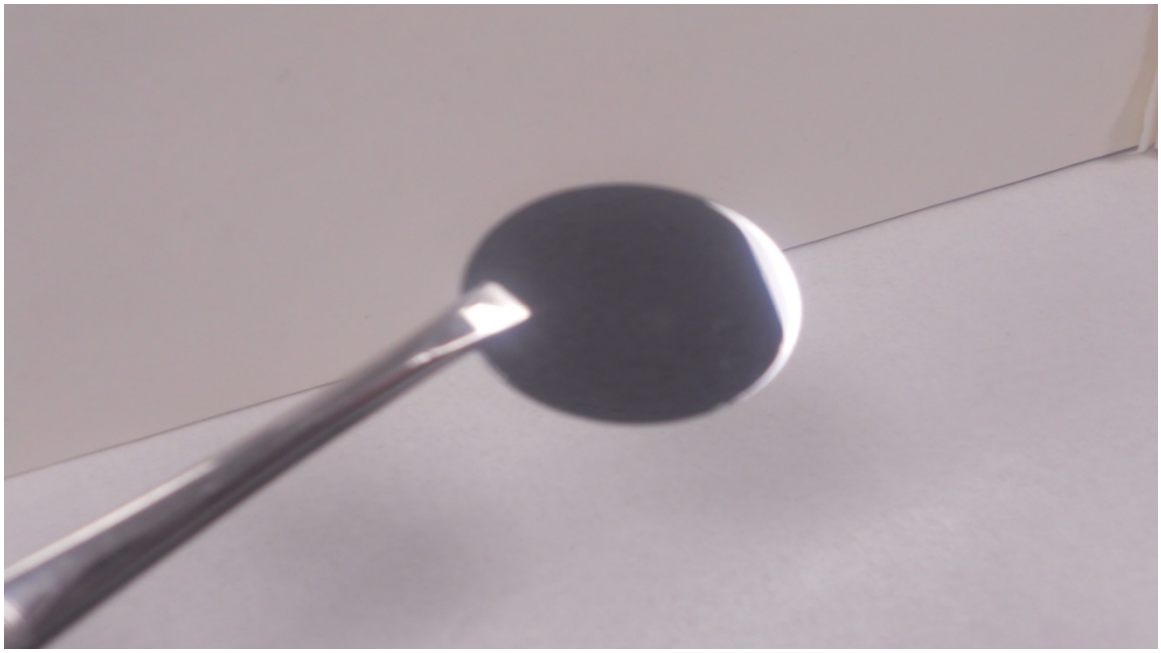

Fig. 1. Polished surface of a Silicon wafer used in the PRIMEX II experiment.

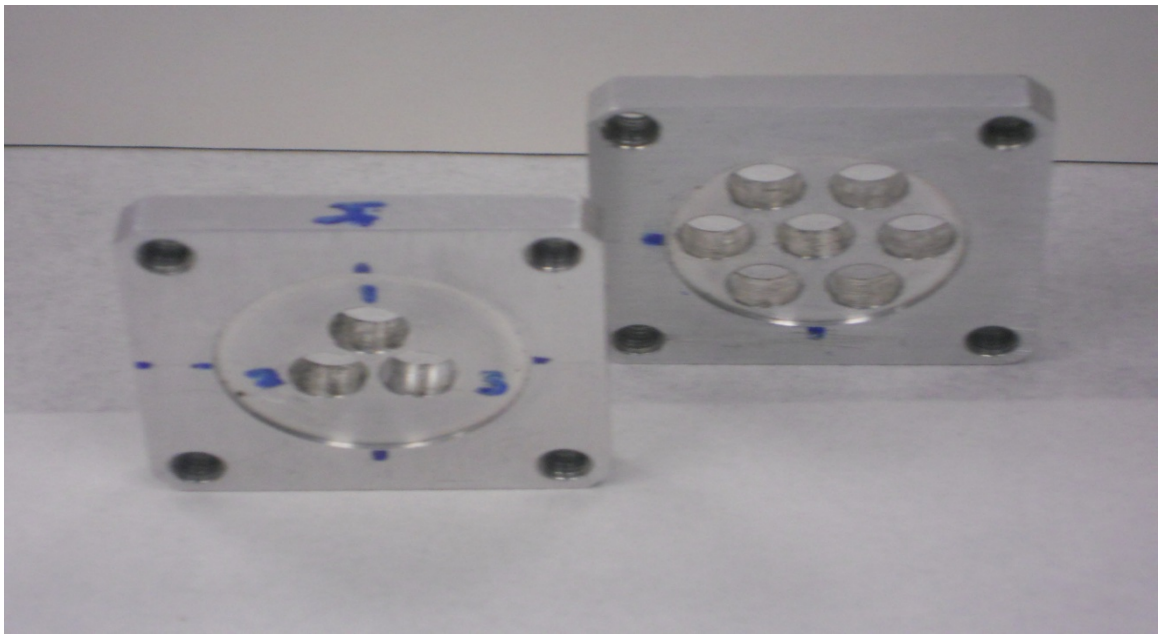

Fig. 2. Aluminum plates machined with holes equivalent to the diameter of a 0.25” micrometer head

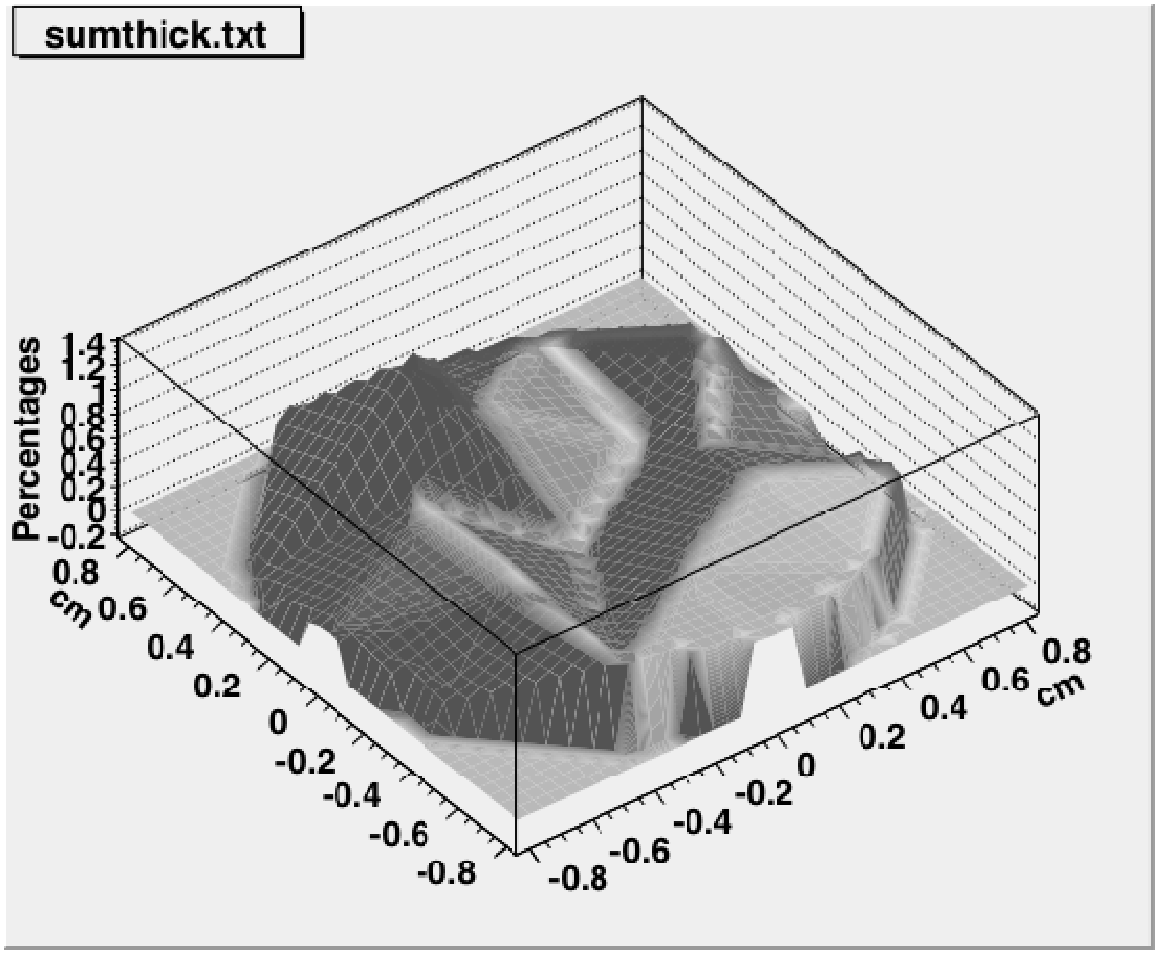

Fig. 3. Fractional variations in % of target thickness relative to target center. Note the depression in the central area of the target as seen by the incident beam.

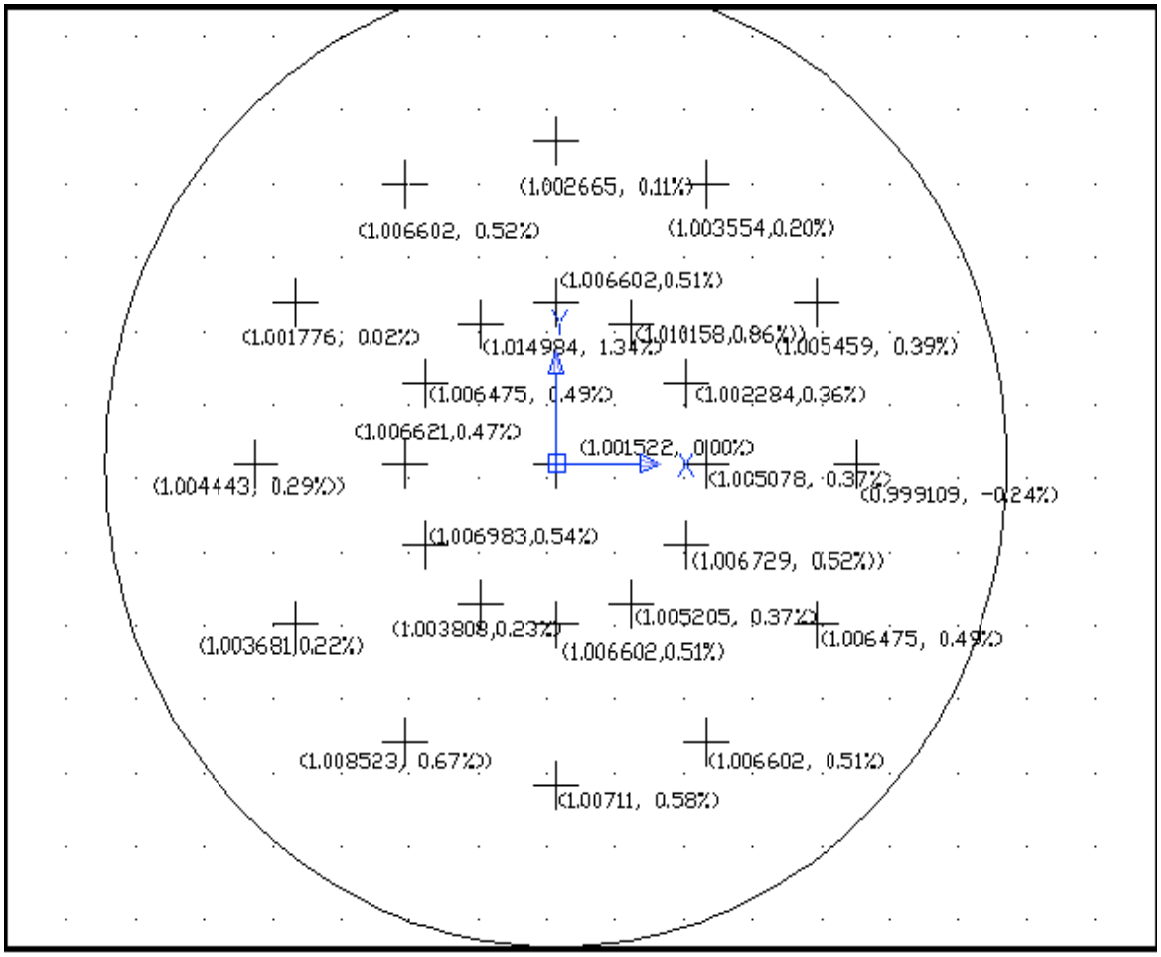

Fig. 4. Target thickness (cm) and percent difference from target center as seen by the incoming beam.

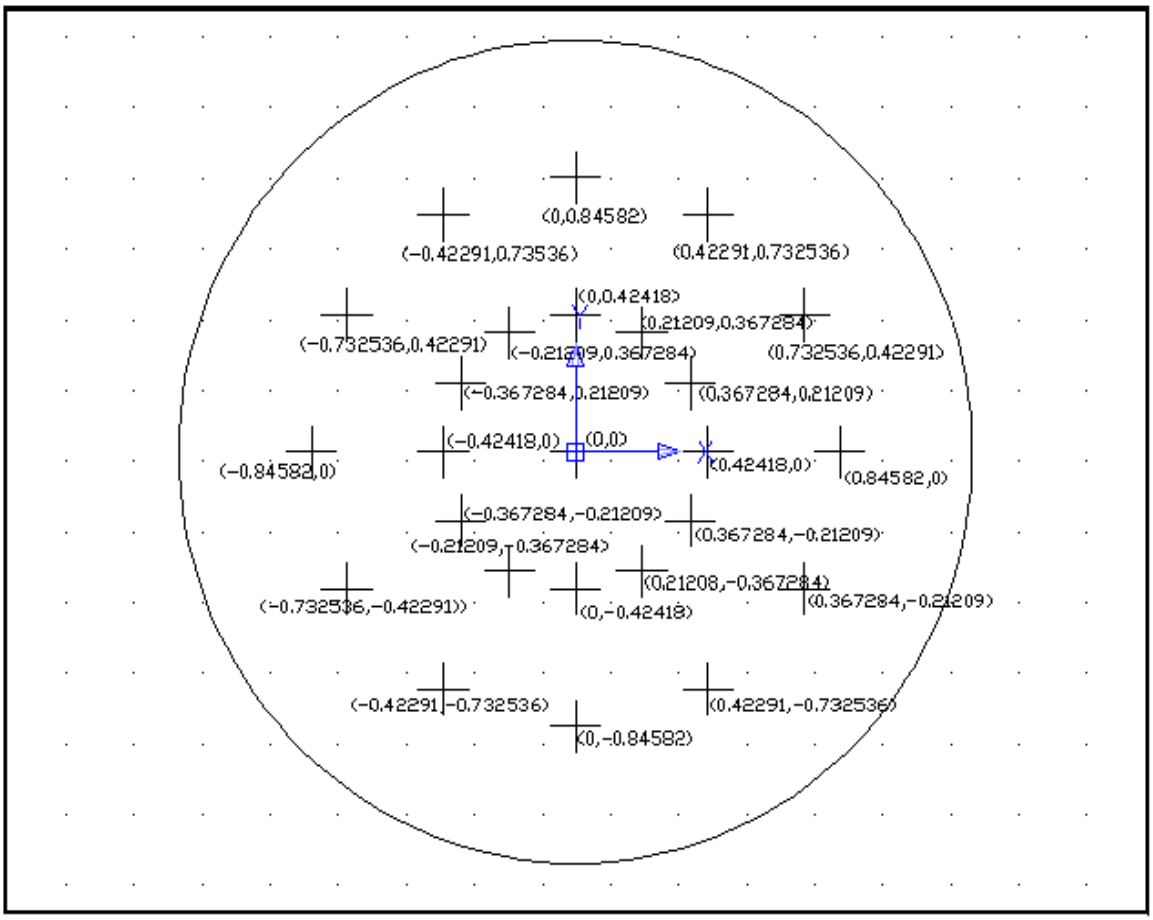

Fig. 5. (x,y) coordinates (cm) of the measurement points as seen by the incoming beam.

Fig. 6. Apparatus used for the water immersion method of measuring the masses of each of the 4 Si disks

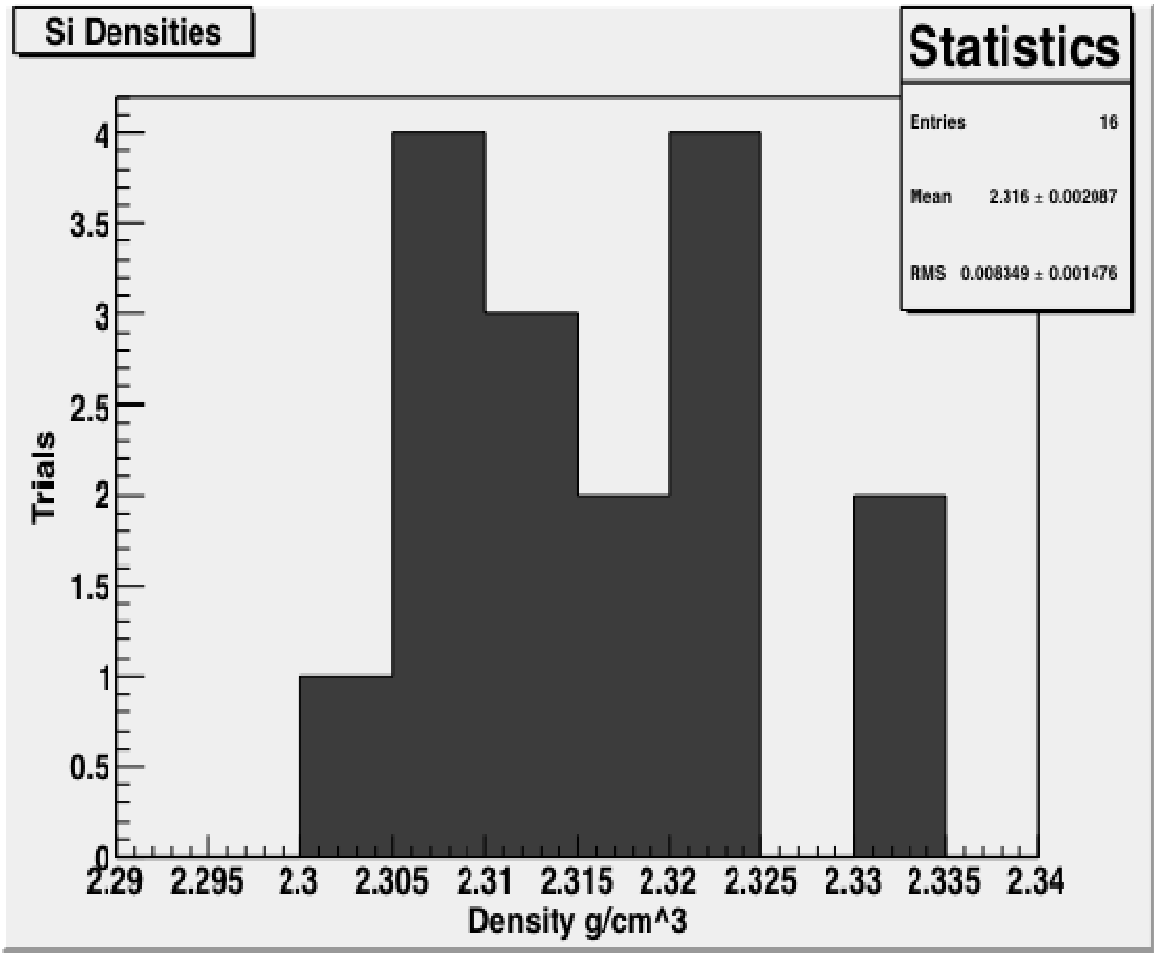

Fig. 7. Histogram of density measurements for the four silicon disks tested.