Appendix: Description of the ADMX design

The ADMX system consists of a magnet cryostat, with its own LN\textsubscript{2} and \(^4\text{He}\) sections. The magnet cryostat has an inner bore in the center into which an insert, containing the cavity, SQUID and associated cryogenics (including the dilution refrigerator) can be lowered. The current bid is for the procurement of a dilution refrigerator as part of the insert and this section is intended to provide a general description of the ADMX system and its location in order to understand better our requirements and constraints on the dilution refrigerator's design and performances.

The wall of the inner bore of the system can be heated to 300 K for exchange of insert. The bottom of the inner bore reaches 20 to 30 K with the insert installed and cold. Figure 1 shows a picture of the magnet cryostat on the loading dock at the University of Washington (left) and the main magnet as being lowered in a pit, where it is sitting during operation (right).

*Fig. 1.* ADMX main magnet cryostat. The cryostat is approximately 4 m tall and 1.6 m in diameter. It is located on the campus of the University of Washington, Seattle.

An old version of the insert being removed from the main magnet is shown in Fig. 2. The cavity is at the bottom and a \(^4\text{He}\) reservoir above that. In the insert under construction, the space between \(^4\text{He}\) reservoir and cavity is quite a bit larger.
Fig. 2. ADMX insert. The dilution refrigerator will be contained in an insert similar to this.

The dilution refrigerator will cool a microwave cavity that is about 45 cm (18 inches) in diameter and 1.1 m (43 inches) in length. The cavity is copper-plated stainless steel, with an approximate weight of 80 lb and it will be thermally connected to the dilution refrigerator only through direct mechanical contact at the top of the cavity. The dilution refrigerator will also cool a SQUID microwave amplifier, which sits about 40 inches above the cavity, connected by a copper rod. The goal for the operating temperature is 50 mK.

Vendors are encouraged to provide a cost.trade study that could help in optimizing the refrigerator performance. In addition, we are interested in estimates of cooling power vs. temperature vs. cost over the 50–100 mK range.

One reason of concern is the ability of the dilution refrigerator to cool the large mass of the cavity. The cooling will mainly occur through the thermal conductivity (κ) of the stainless steel, the Cu plating being too thin to provide better thermal conductivity. Another important particularity of our design is that the cavity is placed in a magnetic
field of 8 T and that the mixing chamber will feel much of this field. The SQUID is in a compensating coil, providing nearly zero field in the region of the SQUID. There are also passive mu-metal and superconducting shields for the SQUID. Vendors are asked to address the possible effect of magnetic field on the performance of the mixing chamber.

Figure 3 shows the drawing of the entire assembly, produced for an earlier phase of the experiment (some details have changed). The main magnet and the compensation coil are dark brown, the cavity is copper colored. The space between the bottom of the 4 K reservoir and the top of the cavity has changed significantly.

*Fig. 3.* The ADMX cryostat, showing outer chamber with 8 T magnet, and insert with cavity, SQUID, and cryogenics.
The space for the dilution refrigerator is shown in detail in the following set of drawings (Figs. 4-9). All dimensions are in inches. The first picture (Fig. 4) shows a fridge plumbing ISO view with cutaway reservoir. The dilution refrigerator must fit below the 4 K reservoir, passing through the cutout in the 1 K flange shown. Note that we plan to have 2 pumped 4Helium pots, one solely for condensing the mixture and one for cooling radiation shields and for intercepting heat from the 4 K space. Both are fed through capillaries from the 4 K reservoir.

![Diagram of dilution refrigerator plumbing](image)

**Fig. 4.** Fridge plumbing ISO view.

Figure 5 shows the fridge plumbing side view with cutaway reservoir. There is a closed cycle refrigerator (not shown) providing a 40 K plane about half way from the top plate to the reservoir. A side view of the space for the dilution fridge with lengths is shown in Fig. 6. (Figs. 5 and 6 are on the next page.)
Fig. 5. Fridge plumbing side view with cutaway reservoir.

Fig. 6. Side view of the space for the dilution fridge.
The next three images, Fig. 7, show various ISO views: the dilution refrigerator space, a view with labels, and view with some dimensions.

*Fig. 7. Various ISO views*
Finally, here is a top view of the space where the still and mixing chamber pass through the 1 K flange (Fig. 8). The 2 inch circle on center is reserved for the conduction cooling of the SQUID. The square block with tapped holes is for the thermal connection to the top of the cavity.

![Fig. 8. Top view of the space for the still and mixing chamber.](image)

The physical connections we will have to the 100 mK space are:

1. 3x 0.50" OD 0.0625" wall thickness x 25cm stainless steel tube,
2. 2x 0.5" OD, 1/16" thick, 22cm L SS tube,
3. 2x 1/4" D, 26cm L Macor rod,
4. 107x 36 AWG P-Br, 8x 32 AWG P-Br 25cm L (wires).
5. 4x coax connection, 25 cm long.
As mentioned, there are two 1 K pots, which we are building for the experiment. Here is a picture of the prototype, before adding the capillary. The pot has a diameter of 2 inches and a length of 2.5 inches. The large port on the bottom is for a level sensor.

Fig. 9. The 1 K pot.
The main magnet produces 8 T and the mixing chamber will see much of that field. Fig. 10 shows the on-axis field profile. (Note: in kilogauss and cm!) The mixing chamber will be at about the 55 cm level, but off axis, where the field is about 5000 gauss higher. We estimate about 5.1 T at the mixing chamber.

*Fig. 10. Magnetic field profile, measured from cavity center.*
Finally, Fig 11 shows a sketch of the laboratory where the dilution refrigerator will be operated. The laboratory is part of the Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington, Seattle. The green areas at top are where the gas handling system and pumps will be placed. The gas handling system and pumps are of order 16 to 20 feet away from the cryostat. The gas handling system and pumps could see up to 50 gauss field.

Note that testing of the delivered refrigerator is planned to occur at the University of Florida, after which the entire refrigerator will be shipped to Seattle for installation in the experiment.

*Fig. 11. Drawing of the ADMX laboratory site.*