DarkLight Review

DarkLight Collaboration

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1 Introduction

The DarkLight experiment is designed to use the ARIEL electron beam incident on a thin tantalum foil target to search for evidence of a "dark photon" or A' via electron-positron pair production. A pair of magnetic spectrometers will measure electron and positron momenta and compare the measured invariant mass with that expected from QED radiated photon pair production and from random coincidences. This experiment is motivated in part by the reported ATOMKI result near 17 MeV.

Before the actual DarkLight experiment can run there are a number of studies to be made to verify the feasibility and performance of the experimental setup and it's interaction with the ARIEL beam. The following sections outline these tests and provide a checklist of steps to be made along the way.

2 Target Alignment

A scattering chamber and target ladder has been installed on the ARIEL beamline. The scattering chamber has two, 2 inch beam flanges (entrance and exit) and two, 1 inch viewing flanges with glass windows at 45° to starboard and 135° to port of the beam. The target ladder can be raised or lowered using a motor control either locally or remotely. A linearly variable differential transducer, LVDT, attached to the target ladder can be used to determine its position. Nominally, three positions are used to centre a 10 µm thick tantalum foil, or a 1 µm thick tantalum foil, or a beryllium oxide screen on the beam axis. The target ladder can also be fully retracted to clear a 2 inch aperture for the beam.

Caution: The target ladder motor control cable MUST be connected before switching on the motor power.

To align the target ladder positions with respect to the LVDT reading a theodolite, optical level, or optical camera aligned to the nominal beam height must be positioned to view the target ladder through one of the view ports. The motor drive should be then operated to centre, in turn, the tantalum foils and the BeO screen at the beam height noting the readout from the LVDT at each height. This should be repeated driving the target up and down and noting any discrepancy in LVDT reading depending on the direction of travel. LVDT readings for the "usable" area of the target foils should be noted as well. The LVDT reading when the target ladder is above the 2 inch beam aperture should also be noted.

Care should be taken not to drive the target ladder to its extreme limits in either direction.

3 Initial Foil Test with Beam

The interaction of the ARIEL electron beam with the DarkLight target is interesting for both the beam's effect on the target and for the target's effect on the beam downstream of the target. There is a chance that the electron beam could burn a hole in the tantalum foil, The tantalum foil could also blow-up the beam through multiple scattering causing excessive beam loss downstream of the DarkLight target.

For these tests we assume the steps in Sec. 2 have been made and that the LVDT values determined are available and will be used in the following.

These tests require a thermal imaging camera to be focused on the target to record the foil temperature as a function of the beam energy and current. An optical camera is also required to observe the beam profile on the BeO screen and to observe any visible effects on the thin tantalum foils.

It is assumed that the beam envelope at the target does not change with the beam current and that the beam can be switched on and off without changing the beam envelope so that the target ladder can be moved without causing significant changes in the beam.

These tests will be performed at 31 MeV incident on the 1 µm tantalum target. This target is preferred to reduce multiple scattering in the actual experiment. The energy loss from ionisation in 1 µm tantalum is approximately 1.9 keV or 1.9 mW per µA of beam current. The critical energy for tantalum is 8.09 MeV so the dominant energy loss will be through bremsstrahlung that will go roughly as E/X_0 where E is the beam energy and X_0 is the radiation length (0.4094 cm for tantalum). Therefore for a 31 MeV beam the total energy loss will be around 9.5 keV or 9.5 mW per µA of beam current. Not all of this power will be deposited in the tantalum foil as some will be radiated away from the foil. But for the purposes of this discussion let's use 9.5 mW per µA as an upper limit for the energy deposited in the foil. This energy will heat the foil but hopefully not melt the foil if sufficiently low currents are maintained and thermal radiation and conduction to the frame is adequate.

The purpose of these tests is to determine what safe currents are possible without melting the target foils. The steps are as follows:

1. Establish the nominal beam tune with the target ladder fully retracted. The beam current should be less than 100 nA or 3.1 W. Adequate to illuminate the BeO screen but not too much to irradiate the beamline downstream of the target.

2. Turn the beam off and lower the BeO target into position.

3. Turn the beam on and observe the beam spot on the BeO screen. Adjust the beam tune to produce a waist of the BeO screen.

4. Reduce the beam current to 10 nA. Is the beam spot still visible? Is the shape still a waist? If yes reduce the current to 1 nA.

5. Turn the beam off and position the thin tantalum foil on the beam axis.

6. Turn the beam back on at 1 nA of current (approximately 10 µW).

7. Observe the effect of the beam on the tantalum foil using the optical camera. Is there distortion or discolouration? Monitor the foil temperature using the infrared camera. Monitor the situation over 30 minutes.

8. Depending on the effect observed in step 7 and in consultation with the accelerator personnel stop the test or increase the beam current judiciously and repeat steps 7 and 8.

It would be interesting to see how much current the thin tantalum foil can withstand without failing but this may not be possible. Opinion of the accelerator personnel must be followed.

The above test procedure can be repeated with the thicker tantalum foil. The thicker foil is less interesting for the actual experiment. The energy deposited is ten times greater and multiple scattering also worse but heat conduction to the frame may be better and its mechanical stability superior. So testing might provide some useful information for the future.

4 Background and Rate Studies with Test Magnet

A test magnet and support stand will be shipped from MIT to TRIUMF. This is not the final spectrometer but a good approximation to study rates and backgrounds.

The magnet connects to the 45° starboard port on the scattering chamber and can be energised to bend electrons or positrons produced in the target onto a detector situated near the magnet focal plane. This assembly can not be used in the current position of the target system. The scattering chamber, magnet, and support structure would have to be moved upstream by some amount still to be determined. An alternative position would be to relocate everything to a position immediately before the beam dump.

The former location has limitations in the downstream beam profile that might limit the usable beam current or require modifying the target foil so that only an edge of the foil could be lowered into the halo of the beam. For the purpose of this discussion we will assume that this position is used for the tests pending an examination of the space available before the beam dump and that the thin tantalum foil is used without modification (*i.e.* all the beam passes through the target. The beam current shall also be restricted to the lower of the limit determined in Sec. 2 for the thin tantalum target or 100 nA (3.1 W of total beam power).

The procedure for these tests will be similar as above:

1. Establish the nominal beam tune with the target ladder fully retracted. The beam current should be less than 100 nA or 3.1 W. Adequate to illuminate the BeO screen but not too much to irradiate the beamline downstream of the target.
2. Turn the beam off and lower the BeO target into position.
3. Turn the beam on and observe the beam spot on the BeO screen. Adjust the beam tune to produce a waist at the BeO screen.
4. Reduce the beam current to 10 nA. Is the beam spot still visible? Is the shape still a waist? If yes reduce the current to 1 nA.
5. Turn the beam off and position the thin tantalum foil on the beam axis.
6. Turn the beam back on at 1 nA of current (approximately 10 µW).
7. Observe the background rates in scintillation detectors strategically placed around the scattering chamber and in the focal plane detectors. Consider adding lead shielding.
8. Energise the test magnet to the correct field for the kinematics of elastic scattering $e^- + Ta$ scattering.
9. Observe the rates in the focal plane detectors. Is an elastic peak seen?
10. Reverse the magnet current to look for $e^+ + Ta$ elastic scattering. Observe rates and look for peak.
11. Depending on the results in steps 7–10 and in consultation with the accelerator personnel increase the beam current judiciously and repeat steps 7–10.