Simulation of a Position Sensitive Tungsten Pin Cushion Detector

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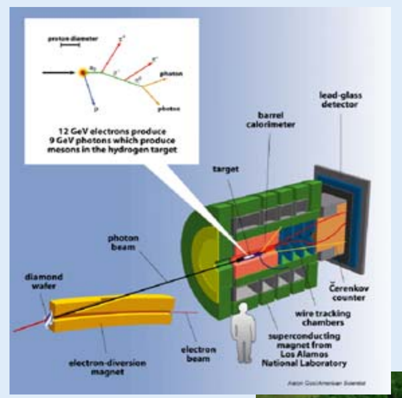
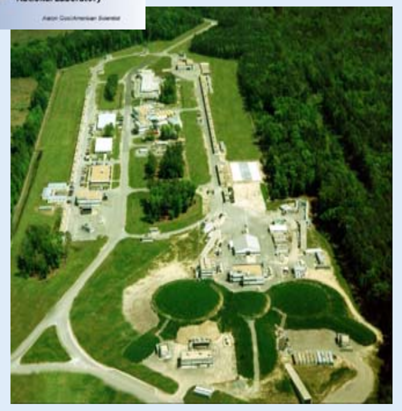
The GlueX Experiment

The GlueX project is an experiment that hopes to confirm our present theory on the nature of quark confinement by making detailed measurements of the meson spectrum (Fig. 1).

Because mesons are composed of only a quark and an antiquark this makes them the ideal system in which to study the complicated dynamics of the gluon field.

This experiment will produce mesons by using gamma rays to excite a deuterium nucleus. For our proposes it would be advantageous to use a highly polarized beam of gamma rays, possible through the use of precise





(Fig. 1) Above: Diagram of the GlueX experimental apparatus.

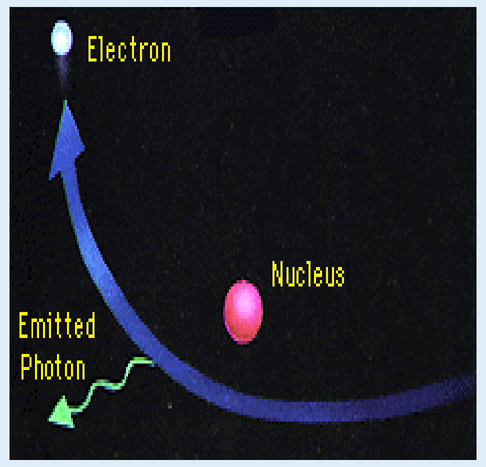
Side: Aerial view of Jlab; the location where the GlueX will take place.

Coherent Bremsstrahlung

In a typical bremsstrahlung process (Fig. 2), lite, ultra-relativistic particles hit a radiator, releasing radiation. While this process does provide the neccessary flux needed for the GlueX experiment it is impossible to make a coherent, polarized beam of photons in this way.

Coherent bremsstrahlung uses as a radiator a highly ordered crystal such as diamond. This retains the sufficient flux we need plus another attractive feature, coherence.

In coherent bremsstrahlung, there is a well defined relationship between the energy of the emitted photon and it's emission angle, which we can exploit to further increase the level of coherence.



(fig.2) A picture representing the Bremsstrahlung process. An electron is slowed down by it's attraction to a nucleus and emits a photon in the process

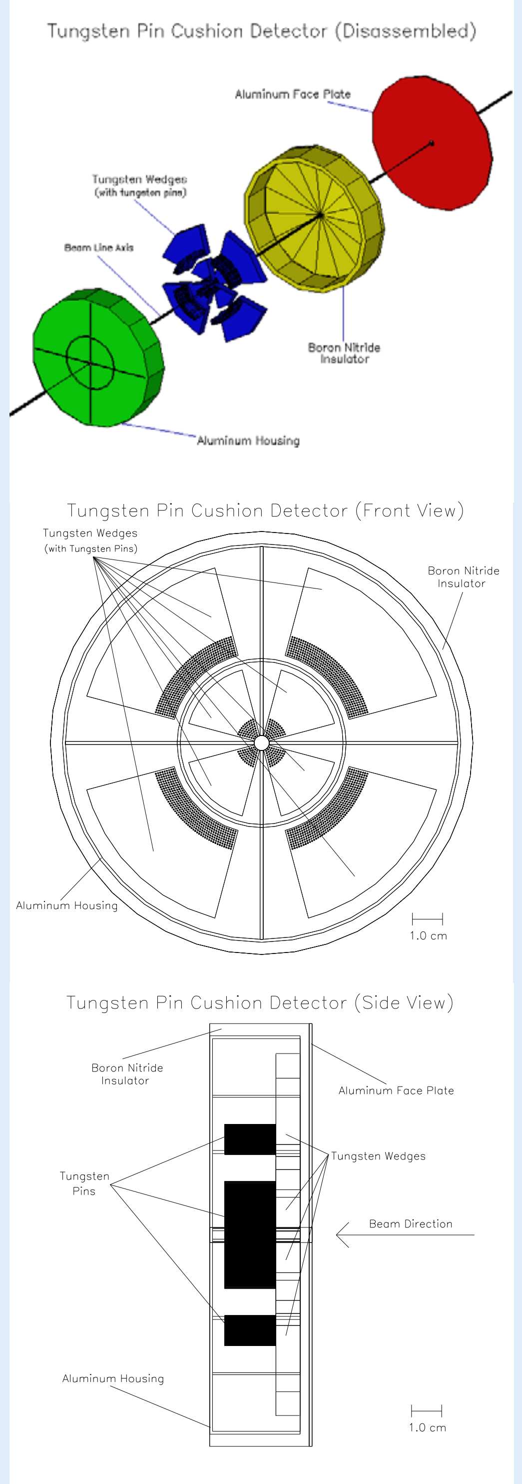
The Tungsten Pin Cushion Detector

Because of the small aperture of the collimator and the large distance between the beam source and the collimator, aiming the gamma ray beam on the collimator face with be a challenge.

Fortunately, a team at SLAC[1] has already solved a similar problem. The SLAC team made a simple but effective device which they call a “tungsten pin cushion detector” (TPCD) (Fig. 5).

When a gamma ray enters a tungsten wedge, it can produce an e^-e^+ pair, the e^-e^+ pair can then ionize an atom of tungsten creating a delta ray. The delta rays eventually reach ground and are recorded as a current at that wedge.

The detector has 8 wedges, whose currents are measured separately. The current on each wedge is dependent on the beam position. Once the nature of this dependence is known, we can use current measurements from the TPCD to find the direction of the beam.



(Fig. 5) Right: These pictures show different views of the tungsten pin cushion detector. This design was used in Geant to simulate its sensitivity to changes in beam direction.

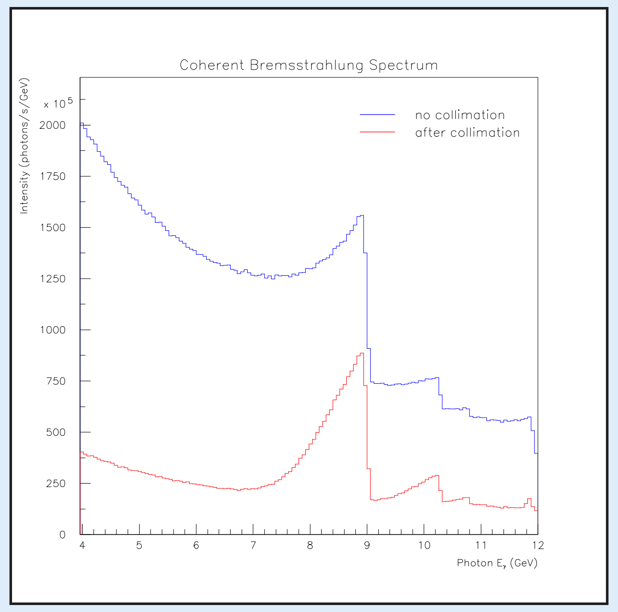
Why Collimation?

In coherent bremsstrahlung, the higher the emission angle the lower the energy of the emitted photon. Since lower energy photons reside in the outer halo of the gamma ray beam, a collimator can further increase the level of coherence by absorbing these “noisy” low energy photons (Fig. 3).

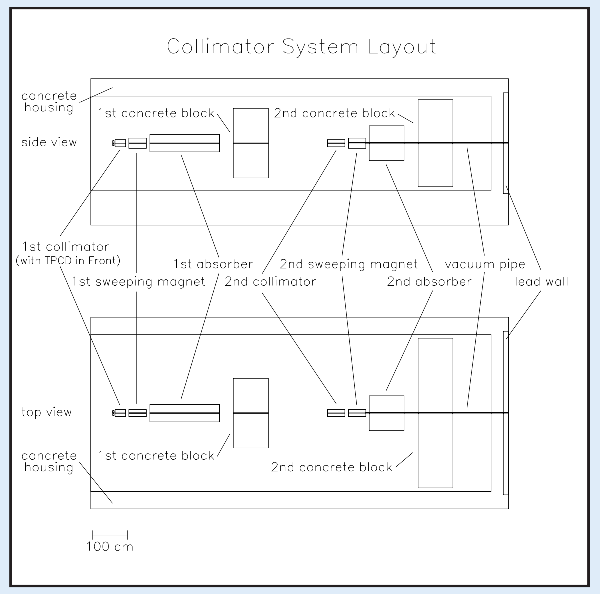
Also, as the emission angle increases, the degree of linear polarization decreases, so in the process of “shaving” off this outer halo of photons we also increase the polarization of the gamma ray beam.

The collimator (Fig. 4) consists of two stages. A tungsten anulus with an inner diameter of 5 mm stops large angle gamma rays while letting low angle photons pass through. Photon which are stopped by the tungsten anulus produce copious amounts of charged secondary particles which are then swept away with a magnet. This process is repeated again in the second stage of the collimator

It has been determined that collimation will be most effective if the collimator is placed 100 m from the gamma ray source. However, due to size constraints the distance between the beam source and the collimator will be closer to 80 m.



(Fig. 3) This figure shows the effect that collimation has on the coherent bremsstrahlung spectrum. notice the relative increase after collimation in the number of photons with energies between 8 and 9 GeV compared with the number of those with energies less than 8 GeV.



(Fig. 4) This figure shows the basic design of the GlueX collimator system. Gamma ray photons with large emission angles hit the primary collimator; interact and begin a secondary particle shower. Charged secondarys are sweep away by magnets and are deposited in the absorber and concrete block. The process is repeated again to further increase the level of linear polarization.

Simulating the TPCD

Using Geant, a physics simulation program, a system for collecting and utilizing data using spread sheets from a simulated GlueX experiment was created. A particle that enters any one of the eight tungsten wedges is added to the spread sheet, and with it, any information about the particle that we programmed the computer to record.

To get an idea of the kind of data acquisition system and ammeter that will be needed to measure the current from the TPCD, we did a simulation of the detector in Geant and recorded the current in one of the tungsten wedges. The current was between the nano and picoamp range, which is certainly possible to detect.

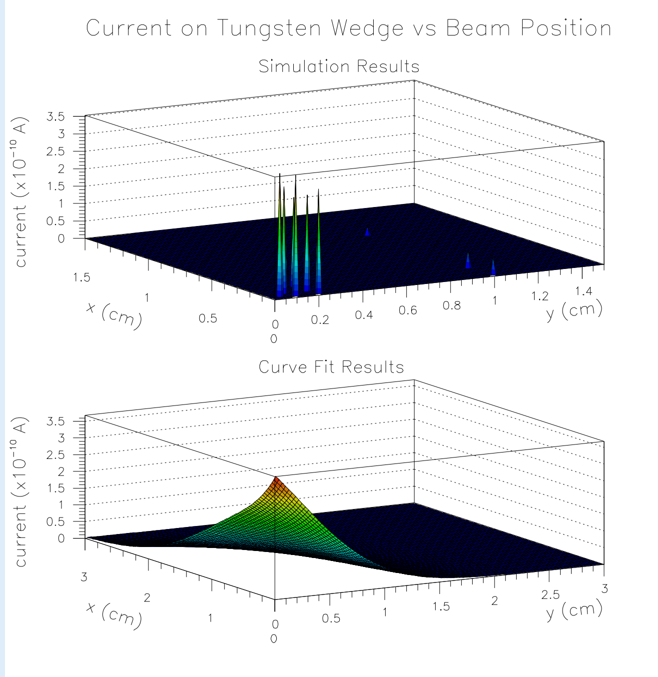
The simulated TPCD also showed a great sensitivity to changes in beam position. There was a noticeable difference in current between the wedges even when the beam was positioned little more than a half of a millimeter off the beam axis.

Testing the TPCD

In order to test the TPCD’s ability in determining the beam position, we ran several simulations at different beam positions. For each simulation we recorded the amount of charge induced in each tungsten wedge and the position of the beam during that simulation.

Once we knew the charge created on a wedge, we made a plot of beam position versus current. Afterwards, a function was fitted to the plot and used to calculate the current on a tungsten wedge for a given position (Fig. 6). With our fitting function we could predict the current in a tungsten wedge for some arbitrary beam position.

To test the accuracy of our fitting function we ran a simulation with the beam off axis and compared the predicted value of the current in a tungsten wedge with the simulated value. the results were correct to the first decimal place, which was within range of the uncertainty in the simulated value.



(Fig. 6) The plots above show a side by side comparision of the simulated tungsten wedge current vs beam position and the results of a curve fit to that data.

Conclusions

The simulations that we have run to test the TPCD’s reponse to beam position were and will have to be run using a higher number of statistics. We are already in the process of improving the accuracy of our simulation. We have created a program that simulates a beam that emits one photon at a time and after each emission the beam is redirected to a random location within a given area. This beam will cover a large area of the TPCD and when run with a large number of statistics ($\sim 10^9$) this should be able to yield an accurate curve fit of the simulated data.

Of course nothing beats a real world test of an actual TPCD. We are currently working with several parties on making an actual TPCD. Much work will need to be done to create a reliable data acquisition system for the TPCD. Hopefully we can start testing a our TPCD design before the end of the year.

References: 1.) G. Miller and D. R. Walz Nucl. Instr. and Meth 117 (1974) 33-37