CLAS Note 92-011

A Summary
of the
Current Design
for the
CEBAF Hall B
Bremsstrahlung Photon Tagging Spectrometer

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ABSTRACT

An overview of the current version of the design of the CEBAF Hall B Bremsstrahlung Photon Tagging Spectrometer is given. Elements of the system are described separately, followed by a summary of anticipated capabilities during the first round of experiments. A list of institutions participating in the working group designing and constructing the tagger is also presented.

Introduction

Members of the Photon Tagger Working Group of the CEBAF Large Acceptance Spectrometer Collaboration have discussed and debated intensely the appropriate design for the Hall B Bremsstrahlung Photon Tagging Spectrometer (hereafter called simply "photon tagger), particularly during the past three years. Though many design parameters have yet to be finalized, the general design of the device has begun to mature to the extent that some specificity is available for most components. While members of the working group are aware of this collective wisdom, those outside the working group may not be fully aware of the degree to which the work has progressed. The purposes of this note are to supply a rough sketch of where things stand presently, to disseminate the current thinking of the group about the tagger design, and to encourage interested parties to provide their input and participation to the group.

The reference design criteria frequently alluded to in working group discussions are spelled out in the Conceptual Design Report for CEBAF Basic Experimental Equipment (CDR).[1] As described in the CDR, the photon tagger should provide a tagged photon beam with a fractional energy resolution of at least $\delta E_\gamma / E_\gamma$=0.3% with energies between 20% and 95% of the energy of the electron beam E_0 when fully completed. The CDR criteria also specify a design goal of a tagged photon flux of 3×10^7 photons per second in the tagged energy range. Figure 1 illustrates the physical location of the photon tagger with respect to the CLAS and the layout of Hall B.

Though some components of the photon tagger are still being designed, this note reviews briefly the present vision of the various elements of the device and provides references to previous documents circulated within the working group which give further detail on elements of the spectrometer. This note begins with an overview of the various elements of the tagger, followed by a summary of the capabilities of the device. A final section indicates the present list of institutions involved in the Photon Tagger Working Group.

Photon Tagger Components

While the designs of photon taggers in use bear general similarities, most have unique features appropriate to the accelerator providing the incident electron beam, the environment housing the tagging detectors, and special desired characteristics for each device; the same considerations apply for the CEBAF photon tagger. In this section, the various elements of the tagger are discussed in turn to indicate the particular design path being pursued at CEBAF. While the sketch provided below is current, some evolution of the design is expected as further study by the working group continues.

The elements are presented in the following order: radiator, magnet, vacuum chamber, focal plane detector, collimation, and beam monitoring systems. (Figures 1-3 should be helpful in understanding the layout of the various components of the system.) The authors of various documents circulated within the working group and referenced in this summary can supply copies of those documents upon request to interested parties; CLAS Notes referenced should be obtained from CEBAF. Also indicated throughout this CLAS note are anticipated readout and control schemes for the various components utilizing the CLAS data acquisition system.

Radiator

The radiator assembly for the photon tagger will consist initially of a ladder containing slots for several targets of various thicknesses of radiator material, typically $10^{-3} - 10^{-4}$ radiation lengths. These various radiator foil thicknesses will permit some crude control of the tagged photon intensity. One of the target ladder slots will be empty, permiting radiator in/radiator out comparisons. The radiator will be located outside the field of the tagger magnet described below, with some adjustment of radiator position with respect to the magnet likely. A phosphorescent screen target will also be placed on the ladder to assist in beam tuning and monitoring, as well as one or more wire "harp" targets.

The radiator assembly will be viewed remotely by a television camera, and target positioning will be accomplished remotely by an electromechanical mechanism which permits the ladder to stop only when a target slot is in the beam. Ladder operation will be interfaced to the accelerator beam control system for Hall B and to the slow control software in the CLAS data acquisition system.

For polarized photon studies, an oriented crystal radiator may be used, though such a radiator will most likely not be available for the first round of experiments. Such a target would use a diamond radiator manipulated by a computer-controlled goniometer via the slow control system of the CLAS data acquisition software system, and would replace the normal ladder target for polarized tagged photon experiments.

Magnet

The properties of the tagger magnet and associated optics have been outlined in some detail in a previous CLAS Note by Dan Sober,[2] which should be consulted for additional information beyond the brief summary presented here. (Indeed, that document is a "must read" reference for those interested in working with the photon tagger.) Figure 2 shows the magnet and vacuum chamber assemblies (the latter described below) and their nominal dimensions.

The electrons passing through the radiator enter a vacuum chamber within a uniform magnetic field produced by a room temperature modified Elbek-type dipole magnet and are bent downward. The bottom pole edge of the magnet (i.e., that edge facing the focal plane detectors) is straight and approximately 6 meters in length, and inclined at an angle of 15 degrees from the horizontal, sloping towards the Hall B floor in the direction of the produced photons. The gap between the pole faces is 6 cm. The momentum dispersion along the nominal focal plane is approximately 12 cm/% except for the lowest energy electrons ($E/E_0 < 0.1$); this nominal focal plane is approximately 9.5 m long.

If the uniform magnetic field extended along the straight line determined by the pole edge to the point where full energy electrons would cross it, the deflection angle for those electrons would be 32 degrees. However, the exit pole face is truncated at the high energy electron end so that the final deflection of the full energy electrons is 30 degrees. The full energy electrons then pass into a low power (about 1 kW power dissipation) beam dump located about 6 m beneath the floor of Hall B.

The magnet yoke measures approximately 6.2 m in length, and 1.5 m in breadth in the plane perpendicular to the deflection plane. The yoke height (i.e., dimension in the scattering plane) varies from about 0.5 m at the entrance and exit tips to about 1.5 m at the center section of the yoke. The yoke is constructed of layers of varying shapes of iron, and has an iron mass of about 3 $\times 10^5$ kg. Photons from the radiator pass through a vacuum line running parallel to the Hall B floor through the yoke of the magnet to the collimation system.

Power for the water-cooled pancake coils, consisting of four individually water-cooled layers of five conductor turns each, is fed to the system from the downstream end of the magnet. The approximate power consumption of the magnet power supply for 4 GeV operation is about 48 kW. However, since the yoke uses a minimum amount of iron and is thus near saturation, a considerable increase in power is needed to power the magnet for operation above 4 GeV; for instance, the power needed to supply the field necessary for 5.5 GeV operation is about 115 kW.

The present design of the photon tagger magnet and the power supply chosen should provide adequate fields to permit tagging of photons over the 0.2 to 0.95 $\times E_0$ range noted above for incident energies up to about 5.5 GeV. The present design yields a nominal field strength for 4 GeV incident electrons of approximately 1.1 T.

The magnet will be supported by an assembly gantry which will permit the magnet to be assembled layer by layer on the Hall B floor, and then subsequently hoisted and inserted into the tagger magnet alcove of Hall B. The gantry almost completely subtends the width of the tagger alcove.

The photon tagger magnet design yields slight transverse defocussing of the deflected electrons which may permit polarized photon measurements by detecting the transverse deflection of the electrons striking the focal plane. The transverse deflection at the focal plane can be related to the deflection at the radiator and, hence, provide polarization information. Such transverse deflection angle measurements require special detectors for the focal plane, as described below.

Magnet field selection and monitoring of the coolant flow and temperature will be through the slow control system of the CLAS data acquisition system.

Vacuum chamber

Figure 2 illustrates the relationship of the vacuum chamber assembly and the tagger magnet. Electrons deflected in the tagger magnet pass through a vacuum chamber formed from above by a wall following and just above the deflected full energy trajectory, from the sides by the pole faces of the magnet, and from below by a thin exit window made of "sailcloth" material, the latter material being a 20 mg/cm^2 Kevlar woven cloth bonded to a 1 mg/cm^2 aluminized nylon window. End plates of the chamber provide attachment points for the entrance and exit beam pipes for the full energy electron beam. It is anticipated that the exit window material will be bonded to the vacuum chamber exit flange using an adhesive.

Properties of possible window materials for the tagger have been reported in a previous CLAS Note.[3] From the preceding discussion of the magnet dimensions, it is obvious that the evacuated volume is quite large; the exit window alone is about 20 cm in width and 9.5 m long (ref. 3 estimates the energy needed to evacuate such a chamber is 100 kJ, equivalent to lifting the entire tagger magnet 20 cm). The exit window material thus must meet the requirements of strength and of providing minimal scattering thickness for the deflected electrons passing through the window to the focal plane detectors. The impact of window thickness on the tagger photon resolution, as described in ref. 3, is considerably less than 5×10^{-4} for 800 MeV electrons, representing an estimate of the "worst case" contribution.

The vacuum chamber extends about 4.5 meters beyond the magnet pole face straight edge to provide an evacuated path for the highest energy deflected electrons. This "rooster tail" chamber extension requires some additional external strengtheners and support since that portion of the chamber cannot use the magnet yoke for support.

Monitoring of the vacuum system will be accomplished through the CEBAF data acquisition slow controls system.

Focal plane instrumentation

The tagger focal plane design has evolved considerably over the past several years. The focal plane consists of two separate planes of scintillator detectors oriented so that their elements are perpendicular to the paths of the deflected electrons (so-called "Venetian blind" geometry).

The first plane of scintillators, aligned with a linear extrapolation of the 0.2 to 0.8 E_0 focal plane and called the "E" (for energy) plane, consists of 384 4-mm-thick plastic scintillator counters. These counters have varying heights and widths perpendicular to the incident electrons appropriate to subtending constant momentum interval and constant deflected electron transverse scattering angle, respectively. Figure 3 (reproduced here from ref. 2) illustrates schematically the orientation and positions of the focal plane with respect to the magnet and radiator, and also shows several deflected electron trajectories.

Each counter overlaps its two adjacent counters by one-third their height, creating a total of 766 separate energy bins by recording coincidences or anti-coincidences. (Using such a scheme requires that great care must be taken in the beam monitoring design to provide a means of normalizing energy channels determined by overlapping counters; the present ideas for monitoring are discussed below.)

These E counters record deflected electron positions along the focal plane and, thus, the energies and momenta of the scattered electrons; hence, these counters provide the energy tagging for the photon beam. No additional information beyond this "hit/no-hit" information is obtained from these counters; in particular, no analog information is obtained from the E-plane counters.

Because of the large number of counters associated with the E plane, readout of these counters must be performed in the most cost-effective manner possible. By specializing these counters to a purely "hit/no-hit" function, however, the readout scheme can be of a relatively simple design. Several methods have been attempted and rejected, including using waveshifting fibers and multianode photomultiplier tubes as described in ref. 4. The present readout scheme, developed with the assistance of the "Detector Meister" group, calls for the use of inexpensive side-coupled photomultiplier tubes with conventional plastic lightguides. To facilitate changing phototubes in the event of failure, a "wrap-around" lucite slotted tube holds the light guide in place on the phototube; the tube can be slid out as necessary.

The signals from the E-counter photomultiplier tubes are then processed by simple discriminators, whose output signals then feed multihit pipeline time-to-digital converters (TDCs). The choice of a TDC readout scheme will reduce the cost consumed by using cable delays and simplify time alignment of the 384 counters. Threshold adjustment will be possible locally at the electronics racks and remotely via the slow control system. A multiplexing scheme for providing remote viewing of any of the 384 phototube signals for diagnostic purposes is being investigated; that equipment may also be controlled by the slow controls system.

To properly associate a tagged photon with the appropriate accelerator beam bucket (one bucket each 2 ns) and CLAS event requires a time resolution of $\sigma = 300$ ps or better. For the photon tagger, a second plane of scintillators called the T plane is used to provide this timing information. The 48 T plane counters are approximately 2.5 cm thick plastic scintillators and subtend a fixed number of E counters located in front of them; some spacing between the E and T planes may be used to provide a "telescopic" effect for the E counters. The T counter heights are consonant with covering approximately 1/48 of the tagged electron flux, and their widths are also related to the deflected electron scattering angles in the same manner as the E counters.

Because the T counter information must have a timing resolution of 300 ps or better, the T counter readout scheme will be more elaborate than that for the E counters. The 48 T counter scintillators are read out by two high-quality phototubes attached to plastic lightguides on the transverse ends of each T counter scintillator. These 96 phototube signals are then fed to discriminators (most likely constant fraction discriminators) whose logic signals are AND-ed to provide immunity to phototube noise. Additional gating of these 48 T counter ANDs will provide the photon tagger event signal for the CLAS electronics. The T-counter AND signals are also sent to multihit pipeline TDCs for comparison with the E counter signals and final tagging information, and to scalers for normalization redundancy. Finally, the T counter AND signals are also sent to high precision TDCs for determining the precise timing information for each event.

During tagged photon experiments, the photon tagger TDCs and scalers will be read out during event processing by the CLAS data acquisition system as part of the event data stream. Separate CLAS event and normalization event triggers will be used, though the "history" contained in the multi-hit TDCs will also be used for normalization purposes as discussed below.

The E and T planes are supported in a common support structure attached to the magnet yoke and rooster tail. This structure also will permit insertion of additional off-median-plane counters, called "ϕ-counters." These ϕ-counters may be used for polarized photon experiments for performing a crude measurement of the transverse scattering angle of the deflected electrons. Because of the limited space available for these counters between the exit flange of the vacuum chamber and the E plane counters (less than 3 cm), mounting and alignment of these counters for polarization measurements will be a formidable task. The feasibility and desirability of this option are still being investigated at this time. Provision for "hit/no-hit" logic from these counters into the tagger event electronics has also been made. However, it is not anticipated that these counters will be available for the first round of experiments.

High voltage control

High voltage for the E plane counter photomultiplier tubes will be provided by high voltage bus lines, with groups of 4 phototubes per bus. The bus lines for the E counters will be remotely controlled from the Hall B counting room with the slow controls system and locally at the instrumentation racks on the Hall B floor. By suitable preselection of phototubes, this level of control for the E counters should be satisfactory for the "hit/no-hit" discrimination performed by the E counter electronics.

Remote control of each of the 96 T counter phototube high voltages will be supplied by the CLAS slow control software. Local control for each of the T counter phototube high voltages will also be possible within the experimental hall at the instrumentation racks.

Collimator system

As noted above, photons traverse the magnet yoke in an evacuated beam line parallel to the experiment hall floor to the photon collimation system. While not demanded at high incident electron beam energies, collimation will be advisable for tagger operation at electron energies of 1 GeV or lower in order to provide a suitably small beam spot (3 to 8 cm in diameter) at the center of the CLAS.

No definitive design exists for the collimation system at this time; however, possible designs are being actively simulated at this time. Several design options for collimation are being explored at this time, including a movable array of nickel collimators of different sizes, and a system of adjustable jaw collimators. The collimator will be followed by a magnet system to sweep knock-on charged particles from the collimator material away from the CLAS and other downstream detection systems.

Control of the collimator position and sweep magnet power supply will be supplied by the slow controls software.

Beam monitoring

A recent working draft by Sober[5] circulated within the working group has outlined normalization schemes under consideration for monitoring the photon beam from the tagger; that paper should be consulted for details of the procedures to be employed. While the photon beam monitoring system is still under design at this time by members of the Tagger and Beam Monitor Working Groups, it is anticipated that the flux monitoring scheme will utilize at a minimum a pair spectrometer located in the exit alcove of Hall B for high flux measurements, and a total absorption counter for low intensity normalization of the photon tagger and pair spectrometer. The working group is also seeking out other possible inexpensive schemes and devices for relative monitoring. Beam position monitoring will use a combination of devices presently used for accelerator beam monitoring and perhaps instruments specially designed for Hall B needs.

The associated detectors and electronics for the pair spectrometer and total absorption counter will be interfaced with the tagger TDCs. The beam monitoring system will be needed to perform the following functions: provide the tagged photon flux absolute normalization, determine individual energy channel efficiencies for those channels determined by E counter overlap, assist in time calibration and alignment of the E and T counters, and to serve as a relative luminosity monitor. The use of multihit pipeline TDCs for the E and T counter discriminator outputs provides a "history" of hit information for all E and T counters prior to the CLAS/tagger event which triggered the readout of the event data stream. This history will be utilized for providing a constant check of the reliability of the efficiency and normalization measurements.

The pair spectrometer magnet will be 1 to 2 m in length with a gap of about 15 cm necessary to allow the full photon beam profile to pass through the gap. The nominal field strength for the magnet will be approximately 1 T. Crude pair energy measurement is desirable, but the number of counters needed is more driven by the desire to provide a useful spectrometer event rate with accidental events spread somewhat uniformly over the range of pairs accepted. Time calibration of the E and T counters can also be facilitated by the pair spectrometer.

The total absorption counter will consist of a multi-element lead glass array which can be inserted for flux normalizations of the pair spectrometer and other in beam monitors at reduced photon beam intensity. This counter can also provide checks on energy channel efficiencies for channels formed by overlapping counters.

As noted above, readout of the photon tagger TDCs and scalers for normalization and efficiency measurements will be carried out by the event processing software in the CLAS data acquisition system. The slow control system will be used to control the pair spectrometer magnet power supply and voltages (and, perhaps, positioning) of the total absorption counter.

Capabilities of the Tagger

A summary of capabilities anticipated for the tagger during the first round of experiments is presented here. As noted several times above, several elements of the tagger design are still in early stages of design. Thus, while some confidence is possible in the following parameters, some variation at turn-on is likely. Additionally, cost considerations may preclude full instrumentation of the photon tagger focal plane for the intial round of experiments. The effect on various capabilities of this initial "de-scoping" of the photon tagger instrumentation is noted where appropriate, and anticipated capabilities with full instrumentation are also noted.

Available photon energies

Though cost considerations may prevent instrumentation of the full focal plane for the tagger for the first round of experiments, it is anticipated that at least the range 0.5 to 0.95 E_0 will be instrumented. Thus, using the range of nominal available incident electron beam energies (1 to 4 GeV), photon energies of 0.5 to 3.8 GeV can be made available. With full instrumentation, the range specified in the CDR should be achieved, providing photons from 200 MeV to 3.8 GeV over the range of available CEBAF electron energies.

Available Photon flux

At present it appears the available tagged photon flux for use in the first round of experiments, with incomplete instrumentation of the focal plane as noted above, should be at least 1.5×10^7 photons per second distributed in a typical bremsstrahlung distribution within a beam spot no more than approximately 6 to 8 cm in diameter. When full instrumentation of the focal plane is achieved, the design goal of 3×10^7 over the entire tagged photon energy range should be obtained, and perhaps exceeded.

Photon flux on target obviously depends on the photon collimation used and the diameter of the experimental target within the CLAS; this point is further discussed in ref. 2. Also, it should be remembered that the *usable* photon flux on target in practice may depend greatly on the maximum data rate that can be handled by CLAS, which is still somewhat uncertain but most likely will be from 1 to 2 kHz.

Photon energy resolution

The photon energy resolution achievable by the CEBAF photon tagger should be at least as good as that specified in the CDR (0.3% E_0) for even the lowest photon energies. It appears very likely that a resolution between 0.1% and 0.2% of E_0 can be obtained over the available energy spectrum using the overlapping E counter design described above, with the poorer resolution applicable to the lowest energy photons.

Individual energy bins, defined in software by coincidences and anticoincidences of individual E counters, will subtend approximately 0.001 E_0, with rates between about 50 kHz for the high photon energy bins to 150 kHz for the low photon energy bins in the intial operation period with limited focal plane instrumentation. Crude energy information (with a resolution of about 1.6% E_0) provided by hits on the T-counters can provide fast information for the CLAS trigger logic above level one.

Polarized photons

Two methods for producing polarized photons were mentioned above: oriented crystal radiators and off-median-plane electron detection. Each method has been successfully used elsewhere, but it remains uncertain whether either success can be transferred to the CEBAF photon tagger in a cost-conscious revision of the present complement of equipment. While provision for these possiblities is being made in the tagger design and each option is being explored at some level, cost considerations preclude initial installation of either system; thus, first round experiments will not utilize polarized photons.

Absolute normalization

Absolute photon flux normalization uncertainties are still being studied at this time, but it appears that 2 to 3 percent absolute flux uncertainties in each energy bin are certainly practical. A design goal of 1 percent is being discussed, but a definitive statement awaits further design of the photon beam flux monitoring system.

Participating Institutions

The following institutions have made commitments to the design and construction of the photon tagger in Memoranda of Understanding with CEBAF:

Arizona State University

Catholic University of America

George Washington University

Georgetown University

University of South Carolina

University of Virginia

Virginia Polytechnic Institute and State University.

Details of the commitments of the institutions and individuals involved may be found in the appropriate Memoranda of Understanding. Additional interest and participation by others is welcome and encouraged.

REFERENCES

1. Conceptual Design Report: CEBAF Basic Experimental Equipment, April 1990, Part B, pg. Q-1.
2. Daniel I. Sober, "A Guide to the Optics of the Tagged Photon Magnet", CLAS Note 91-012.
3. Hall Crannell, "Thin Exit Window for the CEBAF Photon Tagger", CLAS Note 91-019.
4. Barry Ritchie and Richard Sealock, CLAS Note 91-004.
5. Daniel I. Sober (The Catholic University of America), "Calibration Systems for the Hall B Tagged Photon Beam: Shower Counter and Pair Spectrometer", unpublished (April 1, 1992).

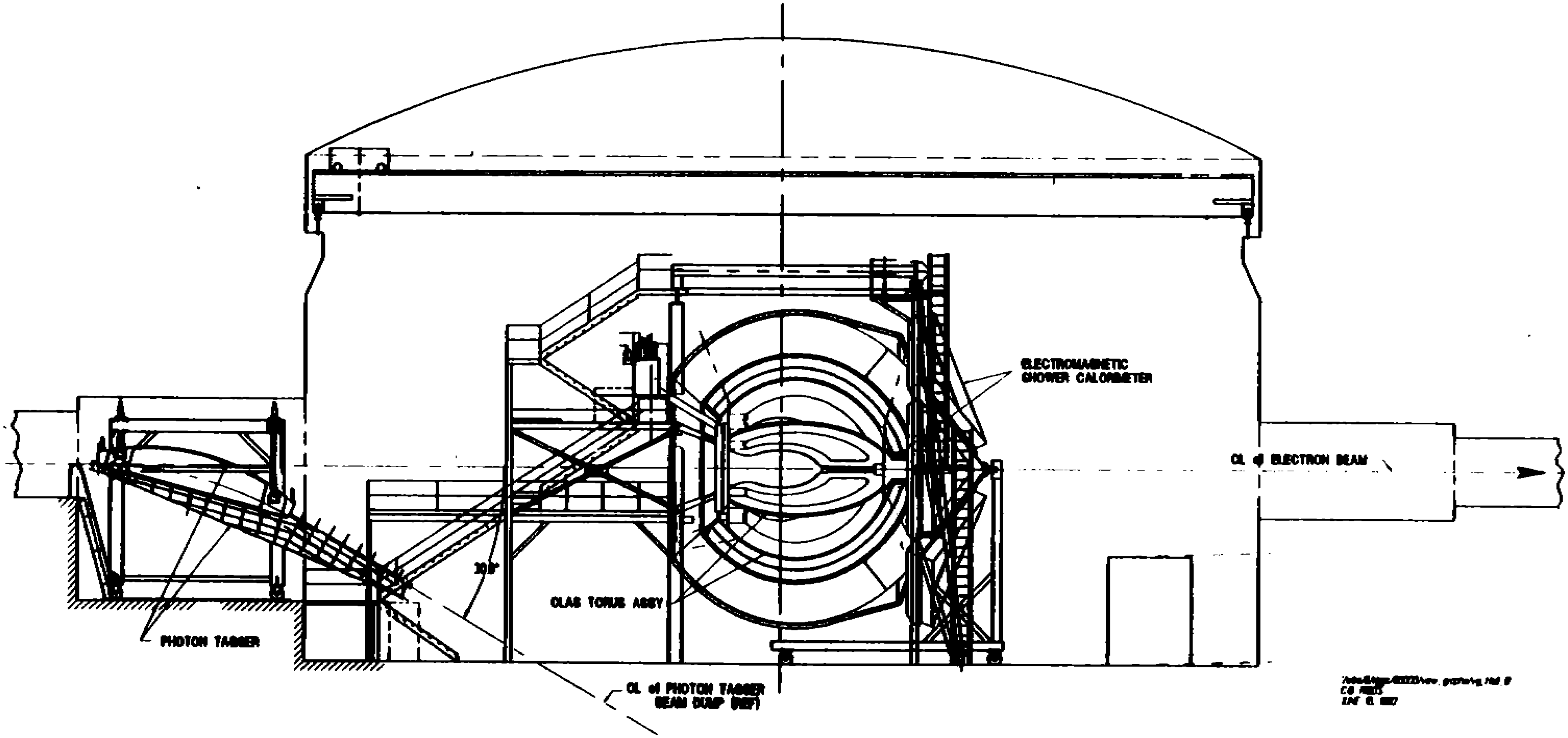

Figure 1:

PRELIMINARY ARRANGEMENT LAYOUT OF HALL-B,
CLAS TORUS/SPACE FRAME, EXPERIMENTAL PHYSICS
EQUIPMENT & RELATED SUPPORT STRUCTURES

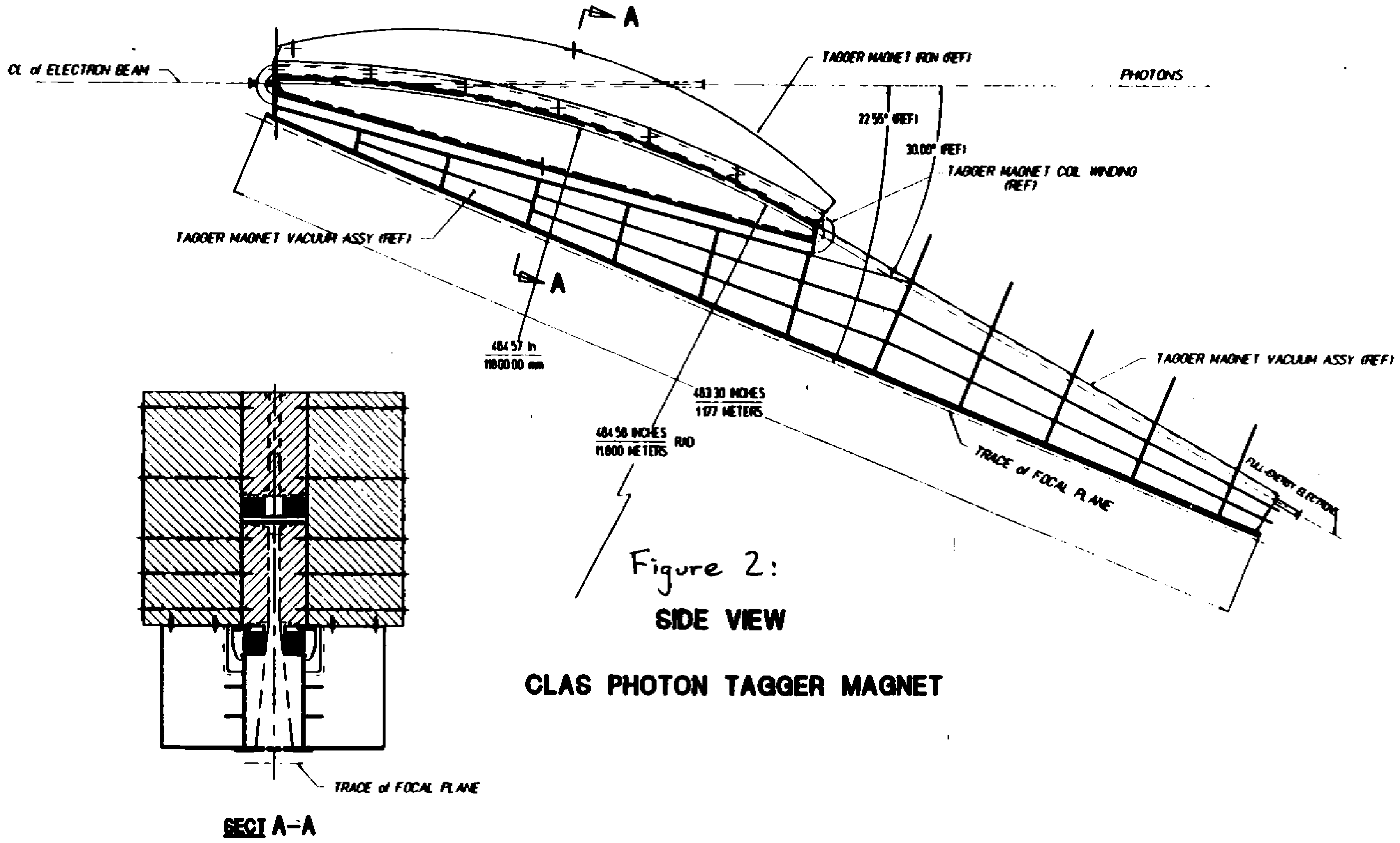

Figure 2:

SIDE VIEW

CLAS PHOTON TAGGER MAGNET

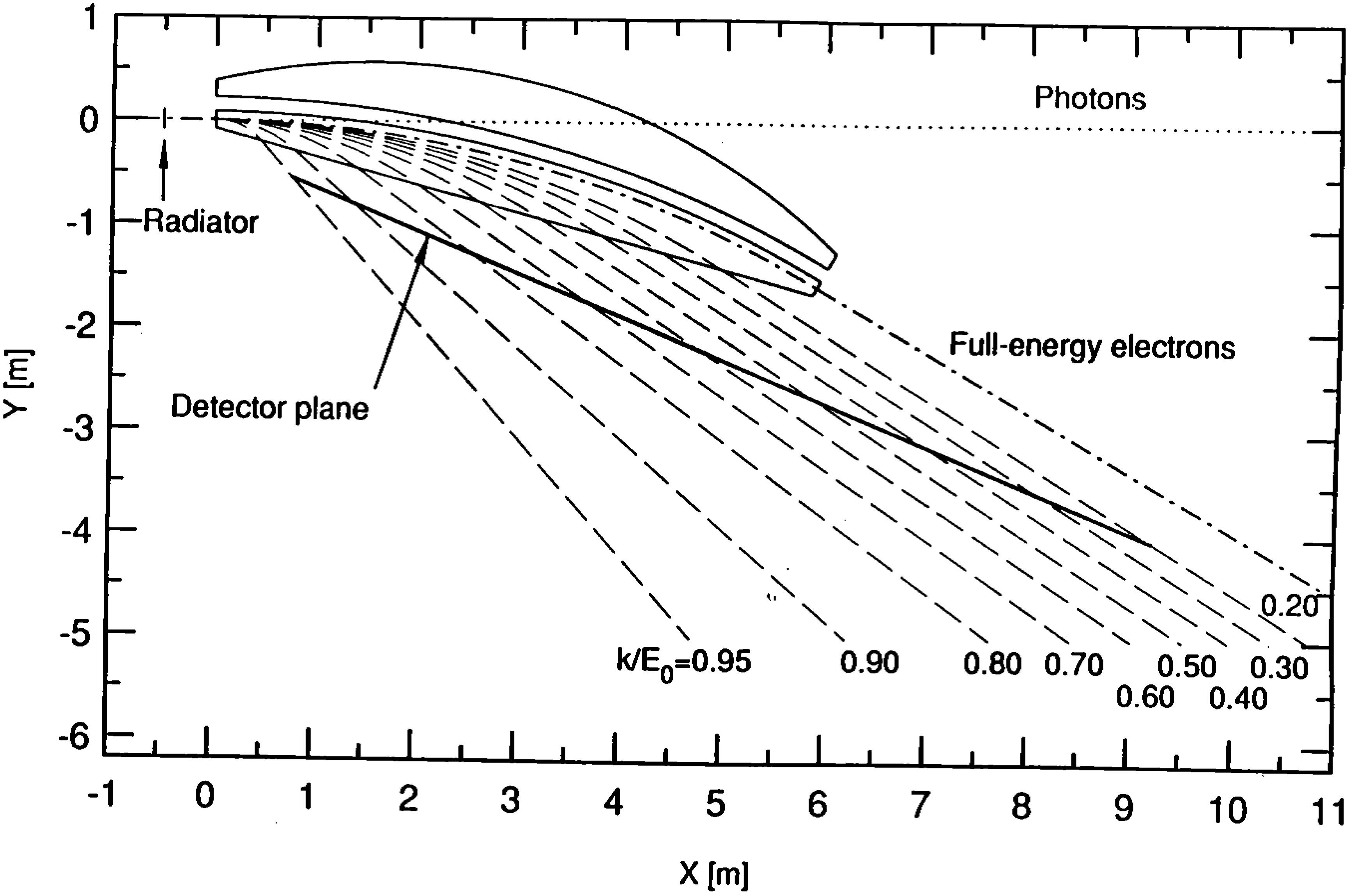

Figure 3. Elevation view of the magnet, detector plane, and selected electron trajectories. The origin of the coordinate system is at the point where the incident beam enters the magnet field.(From Ref. 2)