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# Design Goals for the CLAS Start Counters

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## 1 Overview

In order to identify particles by the time-of-flight (TOF) technique, it is necessary to determine the flight time of particles of known momenta through a known trajectory. For experiments with CLAS, the time of interaction is obtained by determining the beam bucket that produced the event, and the TOF scintillators measure the time at the end of the trajectory. For experiments with an electron beam, the beam bucket is determined by identifying the final-state electron (with a combination of Cerenkov and calorimeter information), and tracing this $\beta$=1 particle back to the interaction point. For tagged photon experiments, especially those that have a single charged particle in the final state, independent information about the beam bucket must be obtained from another source. The plan is to install a system of small counters around the target, in the space occupied by the mini-toroid during electron-beam experiments, which has sufficient resolution to identify the beam bucket of the interaction. The time of interaction will then be determined by the RF time structure of the beam which gives the precise time of each beam bucket. The counters are used to determine the flight start time of particles and are therefore called "start counters."

## 2 Performance Goals

There are several performance characteristics which the start counter system should achieve. However, on occasion these may be conflicting requirements. In the following we attempt to list the expected performance for these counters.

## 2.1 Geometry

The geometry is constrained to fit around the Saclay cryogenic target and have enough clearance for the photon beam size at the lowest energies (see Figure 1). The design must also a) cover the required acceptance for CLAS. b) build a support structure which does not interfere with the rest of the detector, and c) limit the scintillator thickness to minimize multiple scattering.

### 2.1.1 Acceptance

The start counters should have an acceptance greater than that of Region 1 drift chambers for an extended cylindrical target 10 cm long and 4 cm in diameter. This corresponds to a range of scattering angles between 7 and 145°, and full azimuthal coverage.

### 2.1.2 Support Structure and Cabling

The support structure of the the counters must be confined to the shadow region and attached to a frame on the upstream end of the detector (presumably the support ring used to hold the cryogenic target). All photomultipliers and cabling must be placed outside the region of detector acceptance. The preferred routing of cables is to bring them upstream before stringing them to the forward carriage which holds the trigger electronics.

### 2.1.3 Magnetic Field

The magnetic field inside the region of the mini-toroid is shown in Figure 2, which shows a maximum field at the location of the photomultipliers of less than a few Gauss. It indicates that photomultiplier tubes may be easily shielded in this region.

### 2.1.4 Multiple Scattering

The multiple scattering angle $\theta_{ms}$ due to a material of thickness t, for particles traversing at an angle $\theta$ is given by

$$\theta_{ms} = \frac{13.6}{\beta p}\sqrt{\frac{t}{X_o \ \cos\theta}} \tag{1}$$

Table 1: Momentum and angular resolution of the drift chamber system including various contributions to the multiple scattering. The Start Counter thickness assumed is 3 mm, drift chamber (DC) position resolution 0.02 cm and CLAS torus at full excitation. (The beam pipe and target were not included.) The tracks used were generated between 0.8 and 3.5 GeV, scattering angle $\theta$ between 30°and 40°. and azimuthal angles ±10° relative to the mid-plane.

| *Materials Included* | $\sigma_p$ (%) | $\sigma_\theta$ (mrad) | $\sigma_\phi$ (mrad) | $\sigma_d$ (cm) | $\sigma_y$ (cm) |
|---|---|---|---|---|---|
| vacuum | 0.12 | 0.13 | 0.71 | 0.018 | 0.17 |
| He + DC gas | 0.29 | 0.35 | 0.83 | 0.031 | 0.19 |
| He + Start | 0.14 | 0.83 | 1.10 | 0.029 | 0.18 |
| He + DC gas + Start | 0.29 | 0.90 | 1.26 | 0.037 | 0.18 |

where $X_o$ is the radiation length of the material. Materials inside of Region 1 contribute only to the angular and target position resolution. (The momentum resolution is insensitive to the thickness of these materials.) There are three main contributions to multiple scattering in this region: a) the target proper, b) carbon fiber beam pipe surrounding the target and c) the start counters. The target position resolution is proportional to the angular resolution times the distance to the interaction point. The worst-case multiple scattering due to the target is approximately 1.1 mrad. This assumes the length of the cryogenic target is 10 cm. (The radiation length $X_o$ of liquid hydrogen is 865 cm.) The worst-case multiple scattering due to the carbon fiber tube (1 mm thickness, $X_o$ = 18.8 cm) is 2.0 mrad at 14°. To keep the multiple scattering angle due to the start counter less than 1.5 mrad, we obtain the following constraint:

$$\frac{t}{\cos\theta} \leq 0.52\ cm. \tag{2}$$

Figure 3 shows the thickness traversed by tracks at various scattering angles in the sector mid-plane for a 3 mm thick scintillator and a single bend between a straight section and the nose cone. Table 1 shows the effect on momentum and angular resolution of multiple scattering in the start counters compared to that obtained with the material in the drift chambers.

## 2.2 Time Resolution

The time spread of electronic start counter signals have special constraints because they are to be used in coincidence with the tagger timing counters as inputs to the Level 1 trigger. This coincidence will be used to reduce the accidental rate written to tape. However. the ultimate time performance will be achieved in software with various corrections to the raw data. The software-corrected time will be used to determine the RF beam bucket of the interaction.

### 2.2.1 Hardware

The signals resulting in the hardware time resolution will be used in coincidence with the tagger as an input to the asynchronous input of the Level 1 trigger. Experiments requiring high tagging rates and an unbiased detector trigger will have high accidental rates which can only be reduced using a tight timing coincidence between the tagger and the start counters. Therefore precautions must be taken to minimize the variation in signal times which are used in the hardware coincidences. For relativistic particles ($\beta = 1$), flight time variations are about 1.3 ns. The flight time variations increase to 2.6 ns for $\beta = 0.5$. The maximum variation in propagation times in the scintillator is about 7 ns. Taking the first hit in the coupled paddle design (see Section 2.4 below) gives a maximum time of 3.5 ns . This variation becomes negligible by using mean-timing electronics. Time walk corrections are less than 1 ns, but must be taken into account, preferably at the hardware level with constant fraction discriminators. The time of the interaction at the target for $\beta = 1$ particles should be determined in hardware to $\pm$ 2 ns. Due to considerations given above, there is an unavoidable asymmetric time smearing for lower velocity particles.

### 2.2.2 Software

The software-corrected time resolution will be used to determine the RF bucket which produced the interaction and shall be less than $\sigma = 330$ ps. This corresponds to a "$3\sigma$" probability for events in a Gaussian distribution occurring in a time interval of less than 2 ns. However, the time distributions are often non-Gaussian and therefore we also require that the confidence interval between $\pm$ 1 ns result in a probability of greater than 98%. This means that the software-corrected times will give values that differ by more than 1 ns from the true value less than 2% of the time.

### 2.2.3 Analysis

We briefly digress from listing the requirements for the Start Counter to outline the procedure for the subtraction of accidental coincidences to determine the rate of a reaction in tagged photon beam experiments. For illustration we choose an experiment which must run at the highest possible rates. The CLAS trigger may require, for example, a single charged track. The Start Counter signals are put into coincidence with the Master OR output of the tagger T-counters, which is used as an asynchronous input to the trigger processor. This coincidence is made with tight timing to minimize the accidental rate, as the coincidence window within the trigger processor itself must be very broad to accept a broad range of signals. The Level 1 trigger output is then the coincidence of this signal with the CLAS trigger with the timing of the leading edge determined by the asynchronous signal. Figure 4 shows the software-corrected times for accidental coincidences between the Start Counter and the tagger hits as well as true plus accidental coincidences for a one-to-one ratio. To correct for accidental coincidences we take advantage of the bunch structure of the machine and subtract the accidental rate in neighboring bunches assuming a uniform acceptance across bunches. By placing cuts at $\pm 1$ ns relative to the RF bunch structure to select the in-time bunch, systematic errors due to the placement of the cuts are minimized because there are no events —or very few— at the location of the cuts.

However, the trigger efficiency will depend on the overlap coincidence between the Start Counter and tagger as well as the hardware time smearing of the signals. In order for the procedure to work, we require that the hardware coincidence be 100% efficient for accepting the RF bunch with true events and one bunch on either side of it. Due to smearing of the signals, the hardware coincidence will not be fully efficient for accepting events in the bunches at $\pm 4$ ns. In particular, the trigger will have an asymmetric acceptance for slow particles, which will be lost as the time increases between the tagger signal and the hits of the slow particle in the Start Counter.

## 2.3 Rate Capability

The electromagnetic background in the start counters has been parameterized as [2]

$$R = 0.06 \frac{N_\gamma/s(E_1 < E_\gamma < E_2)}{\ln(E_2/E_1)}. \tag{3}$$

For experiments which will use the high energy range of the tagged photon beam (e.g. Exp 93-031), the estimated total rate in the start counter will be 3 MHz, or 1 MHz per coupled-paddle. The electronics for the start counter must therefore be designed to handle several times this rate.

## 2.4 Coupled-Paddle Design

The design which in prototypes best matches our design criteria was suggested by Tim Smith *et.al.* [1]. In this design a single scintillator piece covers two adjacent sectors, but are joined only in the forward direction. Light from each hit is read out by two photomultiplier tubes at the end of each scintillator. The average time gives a position-independent measurement of the hit. Measurements of the resolution of a prototype yield an average time resolution over the counter of approximately 330 ps.

# References


[1] Timothy P. Smith, Jan Distelbrink and George Briggs, "A 'Coupled-Paddle' Design for the Start Counter of CLAS," CLAS-NOTE-95-003, May 1, 1995.

[2] M. Guidal, C. Marchand and E. Smith, 'Electromagnetic Background in the Start Counter Induced by Photons," CLAS-NOTE-95-009, March 14, 1995.

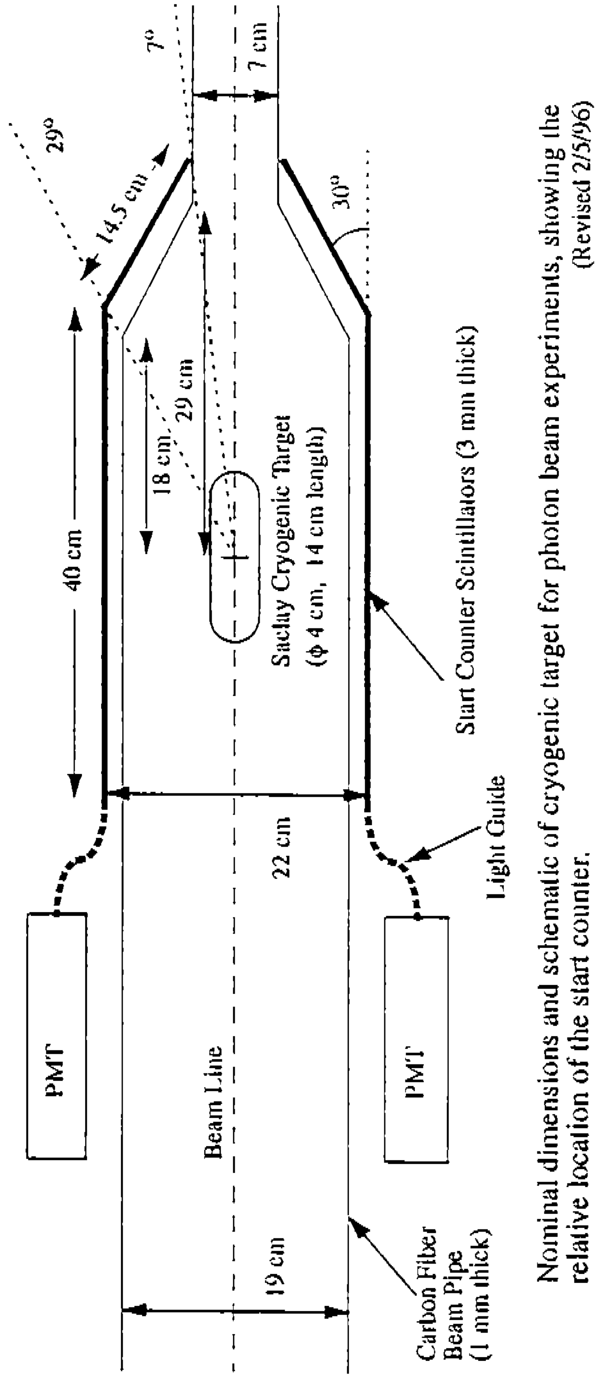


Figure 1: Target region showing the Saclay cryogenic target, carbon-fiber beam pipe and start counters.

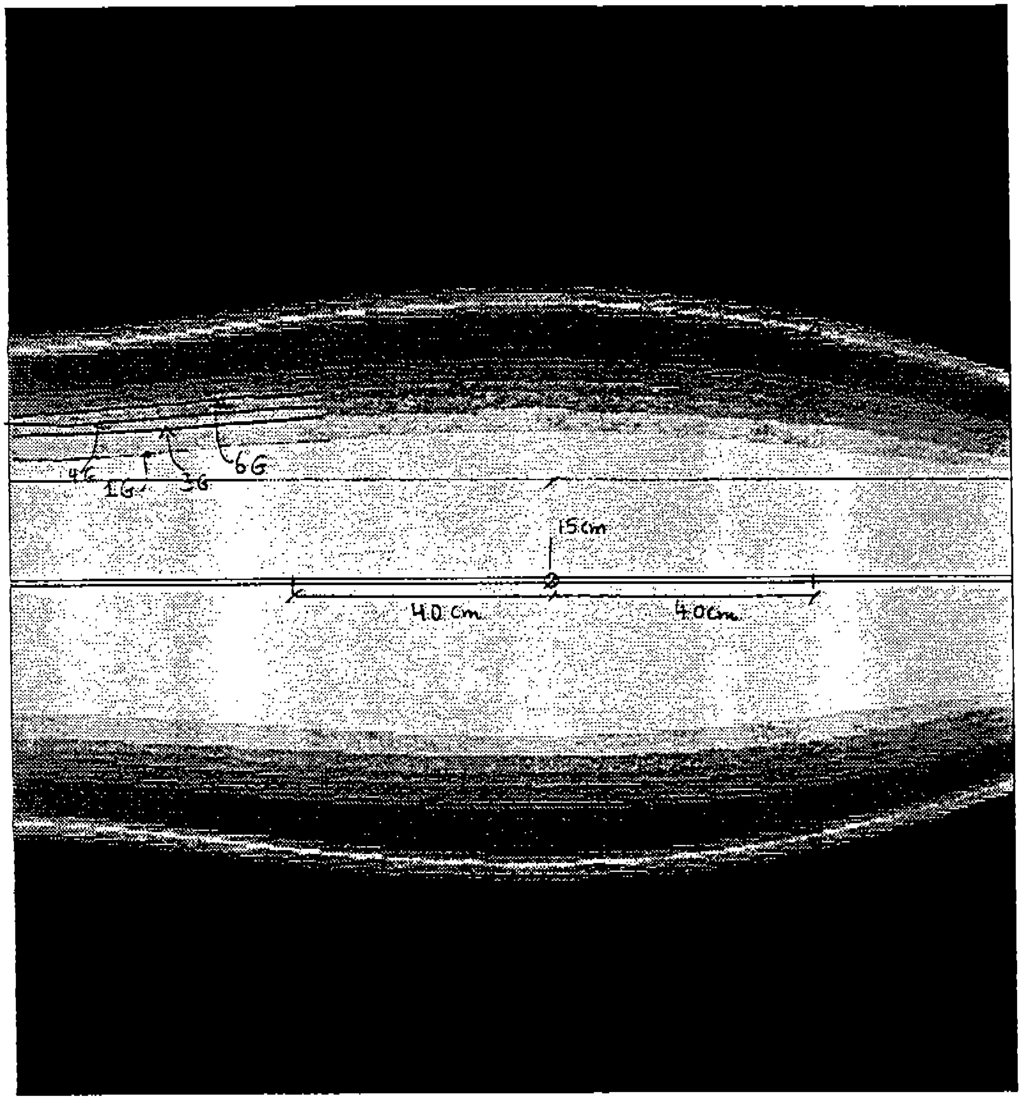


Figure 2: Magnetic Field in the region of the start counters. Within 15 cm of the beam line the magnetic field intensity is less than one Gauss.

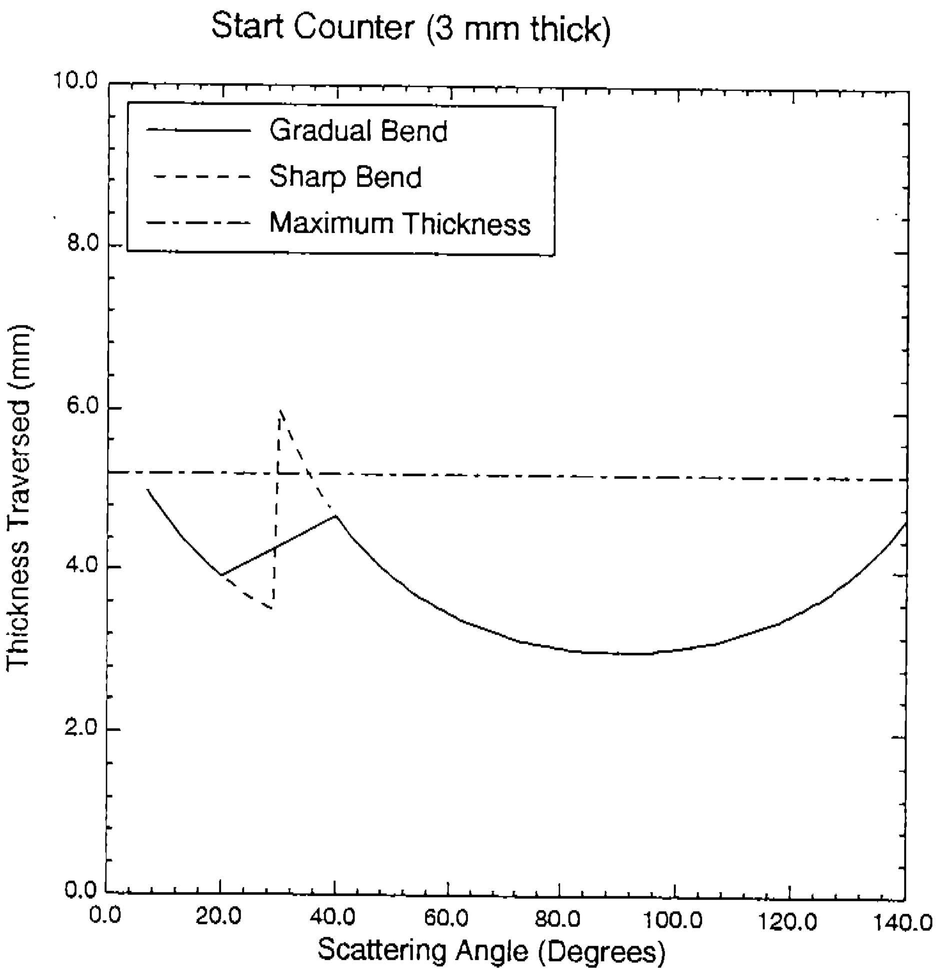


Figure 3: Material traversed by tracks at various scattering angles in the mid-plane for a 3 mm thick scintillator.

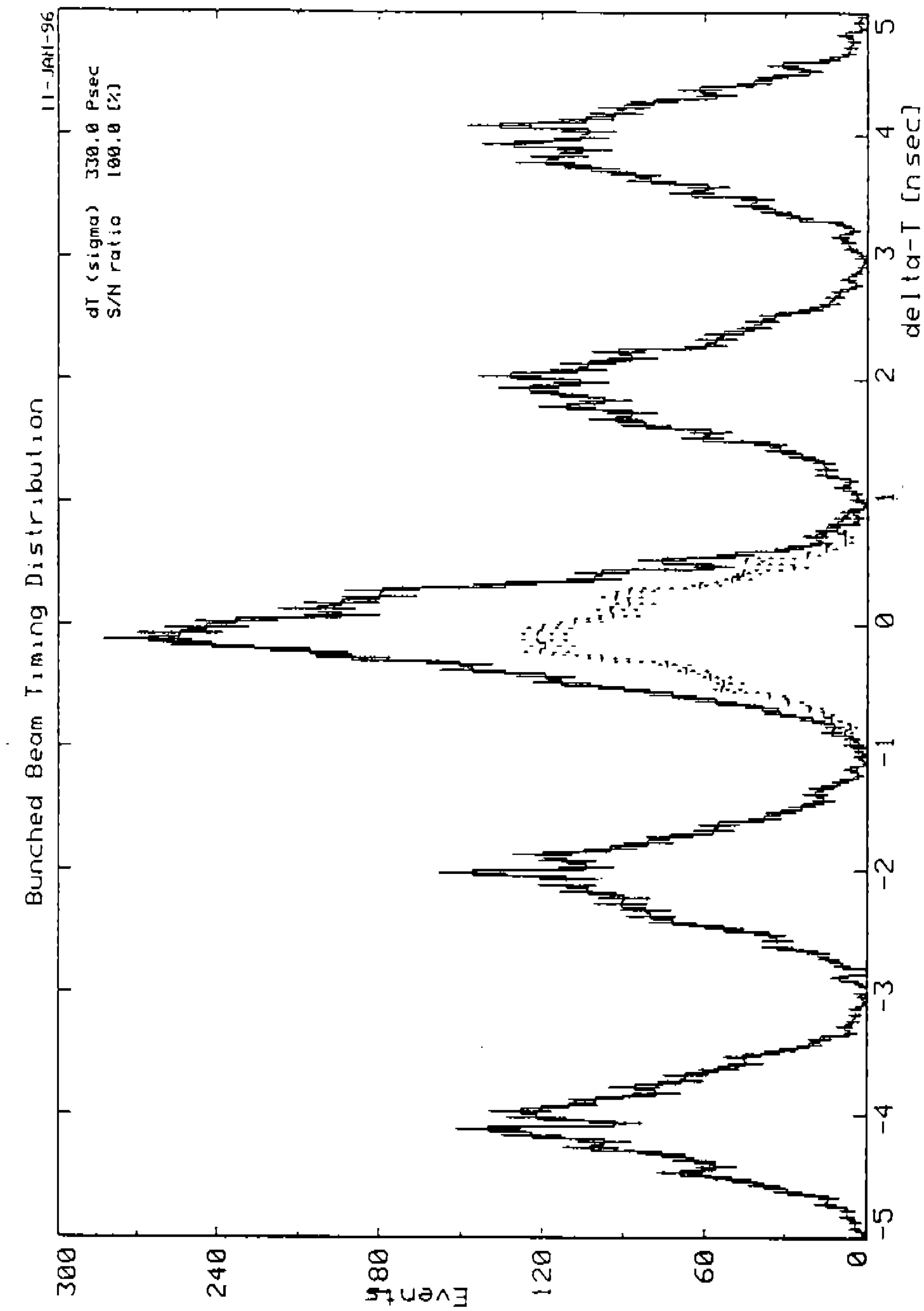


Figure 4: Plot showing the software-corrected time at the target for accidental and true coincidences between the hits in the start counter and the tagger T-counters. The number of true and accidental coincidences in the center bunch is taken to be one-to-one.