Detector Issues: Radiation Hardness and Linearity

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Mar 19, 1999

1 Radiation Hardness

1.1 Description of the Detectors

As shown in Fig. 1, there are four detectors, each with different problems in terms of radiation damage. They are as follows:

1. The Moller detector
2. The pion detector
3. Forward eP detector
4. The wide angle eP detector

The most critical detector is the Moller detector which absorbs the highest radiation dose and must have the best energy resolution. As discussed below, the detector will be made up of copper with $\sim$5% quartz fibers, which has ample radiation hardness. The most sensitive component will be the phototubes, which can withstand $\sim$1 Rad. These will be located as shown in the figure behind $\sim$30 radiation lengths of lead at a radius where the incident fluxes are about 10% of the Moller flux.

The pion and eP detectors have less incident radiation, but will be made of the same materials although with a lower filling fraction of quartz. For these detectors, the phototubes can be mounded right behind the adsorber

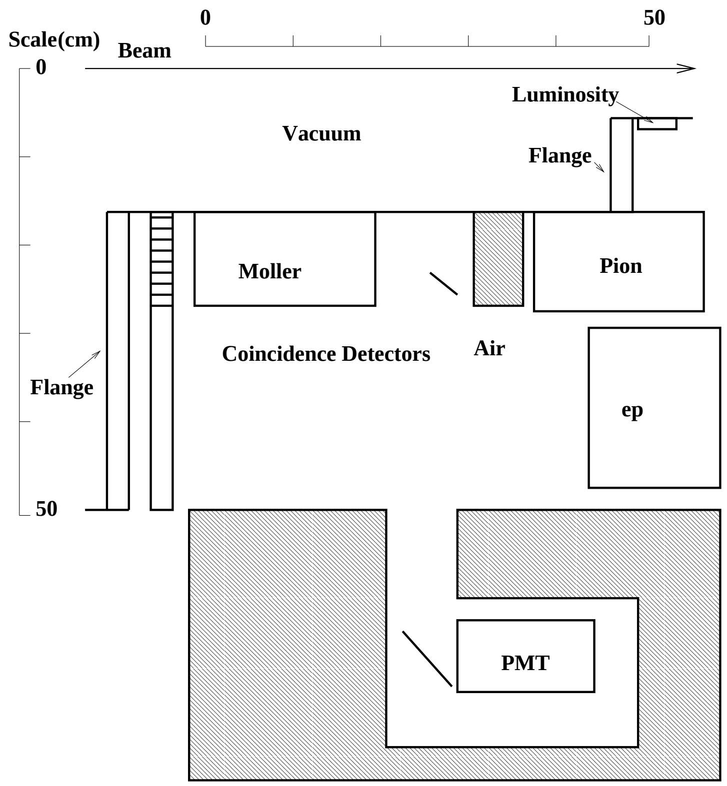

Figure 1: Schematic layout of detector

since the lower incident rate and thicker adsorber allowed will result in lower radiation fields.

The forward eP detectors, which actually have the largest flux density, will be just quartz. The lack of radiator will degrade the statistics by perhaps even a factor of 2, but ample flux is available. The fibers will also serve as light guides.

1.2 Radiation Resistance

The technology that we are choosing for our detector, a copper radiator filled with amorphous silicon fibers, is that same that CMS is using for forward particle detection at the LHC. [1] Hence it is moderately well developed for an environment equivalent to ours. The length of the Moller detector is chosen to be about 15 radiation lengths. This is a compromise between having enough lengths to keep the fluctuations due to the shower development to at worst the $\sim 10\%$ level while minimizing the thickness were a pion can interact.

The most critical part of the detector is where the shower intensity is at its maximum, where the ionization density is $\sim$100 times that of the incident particle. At the exit of the detector the radiation field is also high, about 20% of that of the shower maximum. This will require radiation hard light guides. Again following the CMS design, there will be air light guides with metal reflecting surfaces.

The particular fibers that we plan to use are Polymicro FVP800880930. The fiber material is silicon. The core is OH enriched which gives optimal transmission for bialkali phototubes. The reflective coating as also silicon for radiation hardness. Finally, there is a polymide coating. These materials in general and fibers made of these materials are known to be radiation hard. [2] The specific fibers have been tested by the CERN CMS collaboration to withstand $\sim$ 3 GRad, [3] which gives us an order of magnitude safety. The Cu radiator presents no radiation problems. Pure Cu will be chosen to minimize problems of induced radiation of impurities. In addition, Cu has good thermal conductivity to make it easy to dissipate the 50W of power deposited in the detector.

The most critical part of the detector will be the phototubes, which can withstand on the order of 1 MRad. Radiation fields behind the eP and pion detectors will be small enough so that the tubes can be shielded by the detector. The Moller detector will be thinner to minimize the sensitivity to pions, so the radiation just behind the detector will be too high. The tubes will be located behind the lead shield as shown.

The lightguides will be metal reflectors to avoid radiation problems. Since the light from optical fibers is well collimated, the light will require few bounces and ordinary reflectivity will be ample. All connecting materials can be made of metal to avoid radiation damage.

In summary, this design is quite conservative in terms of the components to withstand radiation damage.

2 Detector linearity

2.1 introduction

Detector nonlinearities are a potential source of systematic error in integrating asymmetry experiments. The requirement for linearity depends on several specific details of the experimental environment. Based on our design specifications for E158, the required linearity may be achieved straightforwardly with phototubes. We will also show our results from the JLab HAPPEX experiment, which faced similar problems and used phototubes.

In this section, we will review the issues relevant for the linearity requirement for E158. The method of the experiment is to measure the parity-violating asymmetry

$$A_{PV} = \frac{(D/I)_R - (D/I)_L}{(D/I)_R + (D/I)_L} \sim \frac{\Delta D}{2D} - \frac{\Delta I}{2I}$$

where D is the signal from the detector and I is the beam current. The subscript denotes the helicity of the electron beam. $\Delta D(I)$ is the difference between $D(I)$ for the different helicities. The linearity specification of the detectors depends upon three quantities, the size of the average raw asymmetry seen by the detector

$$A_{det} = \frac{\Delta D}{2D},$$

the desired error δA_{det}, and the fluctuations in ΔD.

2.2 E158 Requirements

For our experiment, the fluctuations in the detector $DeltaD$ are essentially the same as the beam intensity fluctuations $\Delta I/2I$ ~2%. Statistical fluctuations and other sources including position and energy are much smaller. Nevertheless, the linearity is relevant over only a small part of the dynamic range and the nonlinearity may be expressed as a single number $L \equiv A/A_{true}$, where A_{true} is the asymmetry that would be measured with perfectly linear detectors. The "non-linearity" then is simply $\delta L = L - 1$

There are two contributions to the average helicity correlated raw asymmetry A_{det}. One is the physics asymmetry that we are trying to measure and the other is the intensity asymmetry. With the intensity feedback, we plan to reduce the intensity asymmetry to 2×10^{-7}, which is comparable to the size of the electroweak asymmetry. We note that, in contrast to the situation for E158, a large intensity asymmetry (common in experiments with proton beams) would require extremely good linearity. The final error is projected to be about 10^{-8}, or about 4% of A_{det}. The effect of the nonlinearity is an error in the asymmetry δA given by

$$\frac{\delta A}{A} = \frac{\delta L}{L}.$$

Our specification is $\delta L < 0.5\%$, which translates to a negligible contribution to δA of 10^{-9}.

2.3 Properties of Photo Tubes

In many experiments, maintaining accurate photomultiplier calibration can be a difficult problem. There are many sources of slow drifts in gain, ranging from controllable effects such as voltage stability to complex effects such as high rates changing the temperature of the dynodes which in turn changes the gain. However, for an asymmetry experiment with a relatively stable beam as required for E158, these problems do not affect the asymmetry.

There are two controllable effects that do alter the linearity in an asymmetry experiment:

1. Resistance of the photocathode.

2. Anode current being comparable to base current.

Both of these effects are straightforward to avoid with simple design considerations at the percent level.

Another important feature of E158 is that it is straightforward to monitor and correct for any nonlinearities by using the toroids. The toroids, which have linearity better than 10^{-3}, provide a device capable of calibrating the detector linearity. In particular, if we define non-helicity correlated asymmetries based on adjacent pulses:

$$A_I = \frac{I_i - I_{i+1}}{I_i - I_{i+1}} : A_D = \frac{D_i - D_{i+1}}{D_i - D_{i+1}}$$

If we plot A_I vs A_D, we get a correlation with slope equal to the linearity L. Since the toroid noise is at least as good as 10^{-4} per pulse, and the detector noise is $\sim 2 \times 10^{-4}$ each pulse, L can be measured with the required precision in less that a second. Moreover, this calibration occurs simultaneously and automatically with normal data taking. We note that this procedure requires knowledge of the pedestals, which contribute to the denominator of the asymmetries. The pedestals are straightforward to measure with the instrumentation available at SLAC.

For our HAPPEX experiment at JLab, we had the identical requirement for nonlinearity. We observed that our phototubes were linear at the level required for E158 as shown in Fig. 2. The precision of the test shown here is much worse than anticipated for E158 for two reasons. The first is that our primary current monitor, a microwave cavity, does not yield useful signals for low currents, making pedestal measurements difficult. As a consequence, we had to use a much noisier "Unser" monitor for the linearity measurement. The second problem is that the JLab beam is quieter and the detector had more statistical noise. Nevertheless the HAPPEX results meet the linearity requirement for E158.

In summary, the calibration of the linearity of the detectors will be made with systematic errors on the level of 10^{-3} and negligible statistical errors. The calibration will be done simultaneously with data-taking. Moreover, the intrinsic nonlinearity, based on our HAPPEX experience, will be on the order of 0.5%, so the correction will be negligible.

References

[1] N. Akchurin *et al.,* Nucl. Instrum. and Meth. A 399 202 (1997).

[2] P. Gorodetzky *et al.,* Nucl. Instrum. and Meth. A 361 161 (1995).

[3] Larry Sulak, private communication.

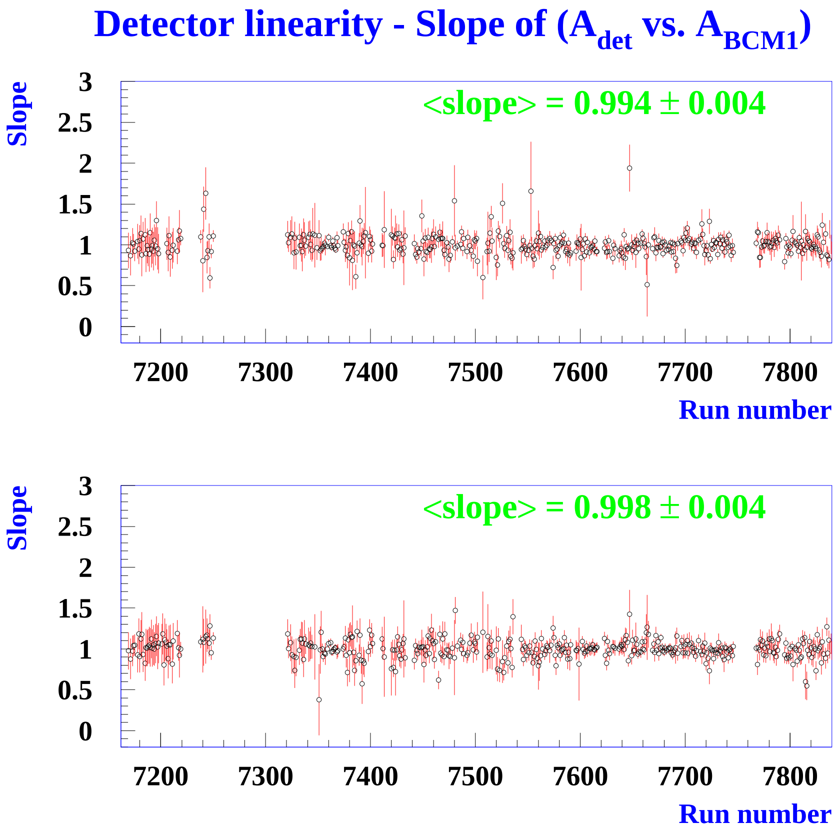

Figure 2: Results on linearity tests at JLab.