Instrumentation for SSC Test Beams

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Abstract

Effective utilization of the SSC test beams for detector studies and calibration will require sophisticated beamline instrumentation. Current plans call for the Laboratory to develop an inventory of efficient and reliable intensity monitors, particle tracking systems, and particle identification systems which can cover the full range of particle energies and species expected to be demanded of the facility. Here we present some of those demands and the draft designs of the needed apparatus.

I. Introduction

Instrumentation for SSC test beams can be divided into two broad categories: that used for establishing and maintaining the desired flow of particles to the calibration hall, and that used in counting, tagging, or otherwise analyzing the beam to provide information to the experimenters making use of it. For the sake of this report, devices used in the former category will be referred to as "monitors", and those in the latter will be called "tagging" elements. Monitor systems are primarily the concern of the SSC Accelerator Systems Division, while tagging elements, since they are directly driven by the end-users, come under the jurisdiction of the Physics Research Division. This document is written from the Physics Research perspective, so it addresses only the tagging elements.

II. Instrumentation Specifications

Here we will analyze the requirements of the experiments which we anticipate will become parts of the experimental physics program. For the sake of this analysis we model this program as being composed of two colliding beam detectors: SDC [1] and L* [2], and one extracted beam experiment: SFT [3], which uses 20 TeV protons. We emphasize that this is only a model: while it is not inconsistent with any published plans of the Laboratory it also does not imply any intention on the part of the SSC Lab to carry out these particular experiments.

A. Demands of the Collider Experiments

Calorimeter Calibration

Taking the more demanding designs for calorimetry in the SDC experiment we find that the energy resolution will be $\Delta E/E = 40\%/\sqrt{E} \oplus 2\%$ for the hadronic section and $\Delta E/E = 15\%/\sqrt{E} \oplus 0.5\%$ in the electromagnetic compartment. (The symbol $\oplus$ indicates addition in quadrature. The energy "E" is measured in GeV.) In both scenarios the position resolution of the electromagnetic section of the calorimeters may be as fine as ± 2 mm.

The finest anticipated resolutions for calorimetry in L* are $\Delta E/E = 50\%/\sqrt{E} \oplus 2\%$ for the solid scintillator hadronic calorimeter which is used in combination with a barium fluoride electromagnetic calorimeter having $\Delta E/E = 1.3\%/\sqrt{E} \oplus 0.5\%$. The entire forward calorimeter structure in this experiment will use TMS as the sensitive medium. This provides $\Delta E/E = 17\%/\sqrt{E} \oplus 1\%$ electromagnetic resolution and $\Delta E/E = 54\%/\sqrt{E} \oplus 2\%$ hadronic resolution.

In order to effectively provide calibration and final testing of these calorimeters, the test beam energy and composition must be known better than the anticipated response of the detectors themselves. To probe a calorimeter having intrinsic resolution of $1.3\%/\sqrt{E} \oplus 2\%$ one must determine the incident particle energy to around 0.3 % absolute. Measuring the width of the calorimeter response requires that the relative energies of beam particles be known to a fraction of this, or about 0.05%.

Correct calorimeter calibration also requires knowledge of the type of the incident beam particle. This is needed because calorimeters respond differently to electrons and photons than they do to hadrons. This difference in response is used, in fact, to determine the particle species in the calorimeter. The calorimetry of both SDC and L* is designed to identify electrons with a rejection power of about 100:1. To test this in a beamline will require that the beam particles be identified somewhat better than this, or with a rejection power of order 1000 to 1.

Tracking Chamber Calibration and Testing

Both L* and SDC may use large-cell drift chambers in the outer regions of the detectors to track muons. At least some of these drift chambers will need to undergo final testing in a beam at the SSC site as late as reasonable before they are placed in their final positions in the experimental halls. The primary demand in these tests will be precision location of the beam particles. Since the drift chamber resolution will typically be about 150 μm (each wire taken alone), the beam track location must be known with slightly better precision.

Further demands on beam alignment accuracy will be made by the other tracking detector assemblies. Scintillating fiber trackers will have cell sizes of order 0.8 mm ($\sigma \approx 300 \mu m$), and straw tube drift cells will achieve position measurement resolutions of around 100 μm. Both detector types may

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require a tagged beam for establishment or validation of the engineered alignment because of inherent uncertainties in the positioning of their components. Plastic scintillating fibers are naturally flexible and imprecise, for example. All of the outer tracking chamber requirements can be met if the calibration beam position is known to about 50 μm.

More challenging will be the testing of the silicon inner trackers for the two detectors. Silicon strips and/or pixels are envisioned with sizes as small as 25 μm. Clearly, the only way to provide beam position information with a resolution meeting the survey needs of the silicon trackers will be to employ several layers of similar detectors in the beamline tracking system.

B. *Extracted B-physics beam*

The smaller SSC experiments have an advantage over the large, major ones in that they can postpone construction of detector elements, and therefore the final selection of technologies, to only a few years prior to turn-on. Because of this difference in scheduling the small experiments will be able to use the SSC test beams for developing and testing detector technologies as well as final calibration. This delayed schedule also allows the SSC scientific program planners to defer selection of experiments, so there is no "preferred" small physics experiment at present.

Tracking

The proposed "Super Fixed Target" (SFT) experiment would use a combination of silicon strips, silicon pixels, and proportional wire chambers as tracking detectors in a fixed-target arrangement. The pitch of the precision silicon strips would be less than or equal to 25 μm. The plans for the wire chambers call for wire spacing as small as 1 mm. Since all of these would be planar devices (typical for fixed-target experiments) the demand for survey using a test beam would likely be minimal or nonexistent. In any case, all but the 25 μm planes could be accurately probed using techniques similar to those already envisioned for the colliding beam detectors.

The muon system proposal consists of absorber with Resistive Plate Chambers (RPC's) interleaved. There is no difficulty meeting the position resolution requirements for testing these chambers (≥1 mm discharge size). It is expected that the test beam may be used for an extensive R&D program to develop them.

Particle Identification

For identifying charged particles SFT proposes a Ring Imaging Cerenkov counter (RICH). The device would be large (~750 m^3), and capable of differentiating among pions, kaons, and protons at momenta up to 300 GeV/c. The SFT Letter of Intent discusses design choices based on a misidentification rate of roughly 4.5% (20:1 rejection). Again, this is not a challenge for test beam instrumentation designed to accommodate the more demanding requirements of the collider detectors.

Calorimetry

The SFT proposal calls for an electromagnetic calorimeter with resolution $\sigma(E)/E \approx 9\%/\sqrt{E} \oplus 2\%$. This resolution is compatible with tagging systems required for the collider detectors.

C. *Summary of Specifications*

A summary of the test beam tagging system performance as described above is given in Table 1. The most demanding of the requirements in each category, i.e. those that drive the design of the test beam system, are indicated in boldface type.

Expermient	dX (mm)	dP/P Rel.	dP/P Abs	Part. ID Rejection
SDC				
Vertex	**0.01**			
Inner Tracker	0.01			
Fibers	0.30			
Straws	0.10			
E-Cal	2.00	2.4%	0.4%	**1000:1**
H-Cal		6.4%	1.1%	
Muon	**0.15**			
L*				
Inner Tracker	0.01			
Fibers	0.30			
Straws	0.10			
E-Cal		**0.3%**	**0.05%**	1000:1
H-Cal		8.0%	1.3%	
Muon	0.15			
SFT				
Silicon	0.01			
PWC's	0.30			
RICH				200:1
E-Cal		1.7%	0.3%	
Muon	1.00			

Table 1. Summary of Test Beam Tagging Requirements

III. INSTRUMENTATION PLANNED TO MEET THE SPECS

A. *Momentum Tagging*

As shown in Table 1, momentum tagging of the test beams is needed for calorimeter calibration and, to a lesser extent, for testing particle identification devices. The strictest requirement is for the L* BaF_2 electromagnetic calorimeter: $\Delta p/p \leq 0.3\%$ absolute, ≤0.05% particle-to-particle.
Momentum tagging will be done by placing sets of tracking chambers in the beamline that measure the bend in the particle trajectories as they pass through a magnet. Thus four detectors are required: two before and two after the analyzing magnet. Using the present beamline optics design [4] we have an analyzing magnet which provides a 6 milliradian bend, and the maximum chamber separations are $L_{12} \leq 170$m, $L_{34} \leq 20$m. Thus conventional 1mm pitch proportional wire chambers at all four stations would provide absolute momentum resolution $\sigma_p/P \sim 0.34\%$. The magnetic field must be uniform and known to better than this precision, of course. Resolution of 0.05% will be provided for a subset of the full beam by placing 100 μm silicon strip detectors in locations near the two downstream wire chambers.

B. Position Tagging

Position tagging of the broad spray of muons can be achieved using relatively large wire chambers near the detector being tested. A 320mm x 320mm aperture drift chamber is being developed for this application. With a per-plane resolution of about 200μm, stacks of a few of these planes will provide beam position tagging adequate for all of the SSC detectors except the Vertex and Inner Tracking systems. These precision silicon strip or pixel detectors will require silicon strip tagging devices with smaller than 25 μm pitch for their calibration.

C. Species Tagging: e/μ/h

As indicated in Table 1, test beam tagging elements must be capable of positively identifying electrons and muons at the level of 1000:1 in the beam delivered to the calibration hall. Thus, for example, if the beam contains 10% unwanted particles the tagging system must work at the 100:1 level. Figure 1 shows the ranges of momenta over which two species of particles can be separated at this level or better by various techniques using the beamline tagging devices described below.

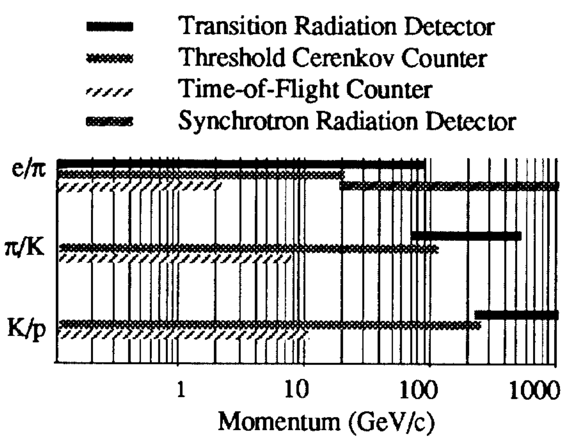

Figure 1. Useable momentum range of various particle identification techniques given limits on length (20m) and diameter (500mm) of detector.

To identify the electrons in the presence of heavier particles at energies above about 20 GeV one can employ a Synchrotron Radiation Detector (SRD). Installation of this type of device requires observation of the photons produced when the electrons pass through a bend in the beamline. As long as the size of the bend and the clear drift distance downstream of it allow placement of the photon detector outside of the beam halo this technique will work.

For simple discrimination between particles heavier or lighter than a chosen mass a long gas filled pipe with a single mirror and phototube at the downstream end is an economical choice. The design requires about 20m of parallel beam for each of two independent counters to achieve an efficiency of 90% or better for tagging the lighter particles.

The Transition Radiation Detector being considered for use in SSC test beams is based upon a device developed at Fermilab for a hadron beam fixed target experiment [5]. This is a modular device consisting of sets of radiator / detector assemblies. The discriminating power of the TRD can be adjusted, and the expense of the installation varied, by adding fewer or more modules to the system. The advantage of the TRD over Cerenkov counters or Synchrotron Radiation Detectors at those momenta where more than one technique applies is that it makes very few demands on the beam optics (beam does not need to be parallel, for example), and it requires relatively little real estate in the beamline.

IV. IMPLEMENTATION

Figure 2 shows a schematic diagram of the instrumentation in the secondary branch of a testbeam. The first magnet sweeps the spray of secondaries from the primary target across the momentum slit placed in front of the second magnet. Between the second and third bends are shown wire chambers, a Cerenkov counter, and a TRD. Following the last bend and before the final focus quadrupoles are a second Cerenkov, silicon strip detectors, and the SRD. In practice, of course, it may not be necessary to install all of these tagging elements in every beamline.

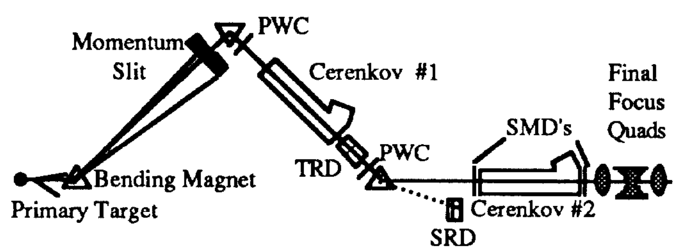

Figure 2. Beamline Instrumentation Schematic

V. REFERENCES

[1] G.H. Trilling, et al, SDC Letter of Intent to the SSCL, November 1990.
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[5] D. Errede, et al, "The E769 TRD", submitted to Nucl. Inst. and Meth., March 1991.