CONF-8606215-31

SUMMARY, SMALL ANGLE SPECTROMETERS

BNL 38914

E. Courant and K. J. Foley+
Brookhaven National Laboratory,* Upton, NY 11973

P. E. Schlein+
University of California,† Los Angeles, Los Angeles, CA 90024

J. Rosner
University of Chicago,§ Chicago, IL 60637

J. Slaughter
Yale University,** New Haven, CT 06511

C. Bromberg
Michigan State University,†† East Lansing, MI 48824

L. Jones
University of Michigan,§§ Ann Arbor, MI 48109

A. Garren, D. Groom, and D.E. Johnson
SSC Central Design Group,*** c/o Lawrence Berkeley Laboratory, Berkeley, CA 94720

BNL--38914

DE87 003205

Introduction

This subgroup considered many aspects of experiments at small angles at the SSC. While not totally neglected in the past[1] this region is not currently very fashionable in SSC studies. To some degree our discussions had a "Mallory-like" attitude,[2] though we did identify some interesting Physics to be pursued. Here we will briefly list some of the topics discussed, referring the reader to individual papers for more details. We also call the reader's attention to the importance of the forward direction for lepton detection, a subject treated elsewhere.[3]

A. A Small Angle Spectrometer (K. Foley + P. Schlein)

They considered the characteristics of a spectrometer designed to study very forward production of states in the mass region $\gtrsim$ 1.6 TeV. The purpose is is to preserve access to the range of CM energy available at the Tevatron and to take advantage of the different kinematics in order to improve the quality of measurement; for example, particle identification is more easily achieved in a small solid angle detector than in the generic 4π device. An angular range of 0.2 to 200 mrad was chosen. Assuming that one can place detectors 2 cm from the beam (the planned magnet aperture is 2 cm radius) this can be accomplished in ~ 200 m free space. The apparatus is shown in Fig. 1. Three spectrometers are used in order to cover the full angular region with reasonably sized apparatus. Each spectrometer contains tracking chambers, ring imaging Cerenkov counters, EM and hadronic calorimeter and muon capability. Silicon detectors inside the vacuum pipe are used for vertex detection.

+ Group Leaders
* Work supported by the U.S. Department of Energy under Contract DE-AC02-76CH00016.
† Work supported by the National Science Foundation, Grant No. PHY85-09175.
§ Work supported by the U.S. Department of Energy under Contract DE-AC02-82ER40073.
** Work supported by the U.S. Department of Energy under Contract DE-AC02-76ER03075.
†† Work supported by the National Science Foundation, Grant No. 8316451
§§ Work supported by the National Science Foundation, Grant No. PHY84-09615.
*** Operated by Universities Research Association, Inc. under contract with the U.S. Department of Energy.

B. "bj" Spectrometer (J. Slaughter)

As part of the discussion leading up to Snowmass 86, J. D. Bjorken emphasized that the large central "4π" detectors cover a small fraction of the available phase space.[1] The well instrumented acceptance of these detectors is at most 1.5 units of rapidity out of a total spread of approximately 10 units. Bjorken's concern was that we simply do not know what will be important 30 years from now in the intermediate mass scales. Given that the SSC will be the premier machine for experimental high energy well into the 2020's, it is essential that enough contingency be built into the machine. It was partially in response to these concerns that the 100 meter intermediate IR's were added to the reference design.

There are already some specific examples of "non-central" physics. The classic examples of elastic scattering and total cross section have long been included in the plans for the SSC. However studies of inclusive particle production at reasonable x_F, greater than .01, have not. (Particles with an $x_F \geq .01$ and p_t of 300 MeV have angles $\leq$ 1.5 milliradians.) Numerous discussions at Snowmass 86 have already lead to the conclusion that intrinsic Beauty physics, i.e. CP violation and rare decays, may be best done in a forward spectrometer. The rationale and an initial design are given in these proceedings in the "Report from the Heavy Quark Working Group". Another example is the contribution by Carl Bromberg. The theoretical justification for the mass scale of the SSC has been that 1 Tev is a safe upper limit by which something interesting should appear. It is entirely possible that the next few years will see discoveries at the few hundred Gev mass scale at CDF and DØ. The elucidation of those phenomena may well require specialized spectrometers. One can also argue that understanding the backgounds to the very rare hard processes may require careful measurement of the ordinary physics in other kinematic ranges.

Several meetings were held at Snowmass 86 as well as a followup meeting at Fermilab on September 5, 1986 to discuss the ramifications of the Bjorken ideas for the design of the machine. The outcome of these discussions was that the 100 meter regions are an excellent provision for the forward physics we can easily imagine (for example intrinsic Beauty physics), allowing good coverage up to rapidities of about 7. In addition, a bypass or at the very least, stubs for bypasses on both sides of the ring will

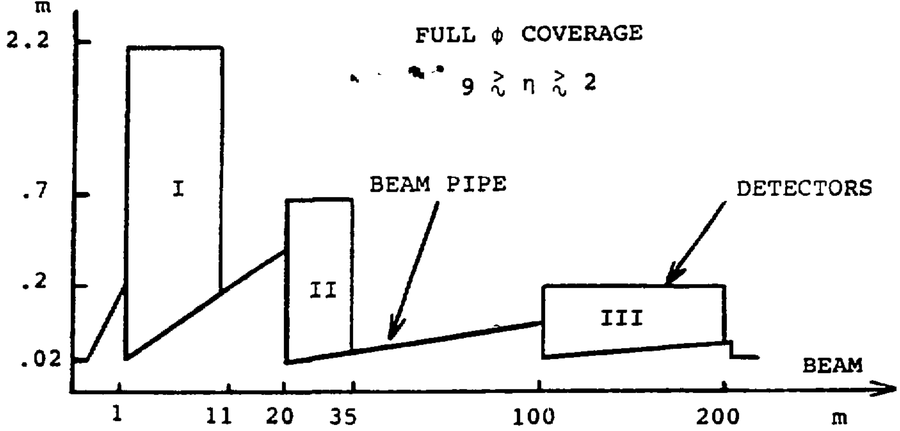

Figure 1
(Note square root scales)

provide plenty of contingency for the more speculative scenerios which require coverage out to the kinematic limit.

The fundamental consideration is quite simple, based on kinematics. Charged paricles can be manipulated, hence bent and measured, by magnets, either as part of the machine lattice or not. The requisite spectrometer length is therefore design dependent. However this is much less the case for neutral particles. The straight section required by a given experiment is determined by the smallest angle, i.e. highest rapidity, neutral particle - g, hyperon, K^o, or the unexpected - that is to be measured. Table 1 is an elementary reminder of psuedo-rapidity versus angle. Angle is (transverse momentun)/(total momentum), so a 10 Tev particle with a p_T of 1 Gev corresponds to 100 micro-radians. If we assume that 10 cm is a minimum radius at which a particle can be measured in a calorimeter because of shower size, then "distance" is the appropriate distance of the wall from the interaction point.

Table 1

Rapidity	Angle In Deg	Angle Rad	Distance	P for Pt = .5 Gev
0.0	90.	1.57		
1.0	42.2	.735	.11 m	.55 Gev
2.0	15.4	.269	.36 m	1.8 Gev
3.0	6.	.100	1.0 m	5.0 Gev
4.0	2.1	.037	2.7 m	13.6 Gev
5.0	.77	.0135	7.4 m	37. Gev
6.0	.28	.0050	20.0 m	100. Gev
7.0	.10	.0018	55.6 m	55.6 Gev
8.0	.04	.00067	149.0 m	149. Gev
9.0	.01	.00025	400.0 m	745. Gev
9.9	.006	.0001	1000.0 m	2000.0 Gev

Another length criterion might be the desire to efficiently observe leading hyperons. For example if one requires momentum analysis of lambda decay products beyond two decay lengths, ...

In addition to his call for contingency, Bjorken has also developed a specific design philosophy for a spectrometer that can accept a wide interval of rapidity. In this design, the spectrometer consists of a sequence of stages, each one designed to accept an interval of rapidity. Each stage contains a quadrupole magnet, tracking elements, and a calorimeter end wall. The length of each stage, i.e., the distance of the end wall from the interaction point scales with rapidity: thus the (n + 1)th wall is of order 3 times the distance of the nth wall. To the extent that most particles are produced with a uniform rapidity distribution out to some maximum rapidity, all walls experience the same flux. In addition, the quadrupoles form a beam transport system with a characteristic length for bands of momentum, so that charged particles also spread out uniformly in the tracking elements.

Don Groom has analyzed some of the accelerator issues raised by this design in SSC-88.

C. A Dipole Spectrometer (C. Bromberg)

A spectrometer based on dipole magnets was considered by C. Bromberg. An important feature of this design is the use of the dipole analyzing magnets to separate the two beams on either side of the IR thus preventing problems due to beam-beam interactions. As in the other designs, multiple spectrometers are used to get good angular coverage with detectors of reasonable size.

D. Toroid Spectrometer (L. Jones)

This is a spectrometer based on an aircore superconducting toroid. As mentioned in his discussion of magnet geometries this type of magnet is ideal for forward spectrometers with the largest kick at small angles and no disturbance of particles inside the inner conductors. With the high currents possible in modern superconductors the area excluded from measurement by the coils is quite small so this type of magnet deserves careful consideration in forward spectrometers.

E. Magnet Choices (L. Jones)

There are basically four choices which can be made for a small angle spectrometer as far as magnetic analysis of the outgoing particles is concerned. These are listed below with the assets and liabilities of each enumerated.

1. No magnet: energy of small angle particles determined calorimetrically or by the use of accelerator magnets for particles within the vacuum pipe.

The advantage of this solution is that there is no perturbation to the machine lattice and no obstructions between the vertex and the particle detectors (i.e. no coils, return yokes, etc.). For many purposes the resolution of the calorimeter, about $50\%/\sqrt{E}$ (GeV), would be quite satisfactory for forward, high-rapidity particles. Neutral hadrons are analyzed as well as charged hadrons.

The liabilities are that there is no information on the sign of charged particles and no information on muons. Further, the density of high-rapidity particles in laboratory solid angle suggests that, even at 100 m from the vertex, the secondaries may be close enough so that their cascades would overlap in a calorimeter (due to their lateral spread), frustrating a clean identification of the energy of each secondary.

2. Dipole magnet: B-field perpendicular to beam lines.

The advantage is that secondaries are swept out of the beam pipe even at angles within the pipe, so long as their momenta are less than the beam's. The magnets could be straightforward, although quite large. The particle tracking would be much as in traditional fixed-target spectrometers.

The liabilities are that the dipole bend on the 20 TeV beams must be compensated. Further, in order to have enough $\int Bdz$ to adequately analyze small-angle, very high energy particles, the larger angle, soft secondaries are wrapped up and become difficult to analyze.

3. Quadrupoles: a sequence of large aperture quadrupole magnets as proposed by Bjorken.

These have the advantage that, as secondaries diverge from the beam axis, they get a larger and larger kick until they are thrown out of the magnet aperture. Meantime their momenta can be well measured by chambers.

The liabilities are that the quadrupoles affect the stored beams and must be considered part of the accelerator lattice. The scheme as proposed by Bjorken requires over a kilometer of path so that small-angle particles will come out to a large enough radius to get a significant kick. Since $B \propto r$, high-rapidity, high momentum, small angle particles are most poorly measured.

4. Axial current, solenoidal field. A superconducting current sheet on the surface of the vacuum pipe carrying current parallel to the beams would produce $B_\phi \propto 1/r$, the return current would be brought back at a convenient radius (50-100 cm).

The advantage of such a magnet is primarily that the $P_\perp$ kick is greatest for the small angle, high rapidity, high momentum particles, while the lower momentum particles which are mostly produced at larger angles are still deflected sufficiently for good analysis without being wrapped up. There is also no effect on the beam orbits.

There are two liabilities. There is an obstructed region corresponding to the thickness of the vacuum tank plus coil and related structures. This may occlude an interval of rapidity of $\Delta y \sim 0.1$. And there is no analysis of secondaries produced at angles such that they remain within the beam pipe. These angles may be up to 500 μradians. Such secondaries might still be analyzed using the machine magnets.

Some questions

Before a forward spectrometer can be fully designed, some important issues remain to be resolved. They include:

1. Realistic beam crossings, taking into account the effects of beam-beam interactions.

2. How close to the beam can one really place detectors? Most of the small angle spectrometers use low luminosity, so the radiation levels calculated at a few cm radius from beam-beam interactions are not overwhelming. However, in real life one might have to go to a larger radius with a consequent increase in length -- one should also note that if one demands the best results from hadron calorimetry, the effective minimum distance to the beam is increased by the shower size of the calorimeter, maybe a few cm.

3. Most of the proposals for small angle spectrometers involve the use of silicon vertex detectors many silicon devices specify maximum "storage" temperatures as low as 100°C! One must hope that the manufacturers are not too serious since we expect that anything inside the vacuum pipe will require "baking."

Conclusion

We feel that we have demonstrated that good measurements are possible at small angles. Indeed the ability to cover a large range of rapidity with a detector of small cross sectional areas makes tasks like particle ID easier. The price that one pays is the need for long spectrometers. Given that, with present plans, the SSC is the main high energy machine for the next several decades, provision should be made for a long ($\gtrsim$ 100 m) IR in the basic machine, with longer spectrometers, if needed, to be built in a future bypass. We recommend that the ring be stretched to accommodate at least one bypass with short stubs to provide for their future development.

References

1. See for example, the following papers from Proc. of the 1984 Summer Study on the Design and Utilization of the Superconducting Super Collider, June 23-July 13, 1984, Snowmass, Colorado:
   a) M. Witherell, p. 643.
   b) D.C. Imrie, p. 649.
   c) L. Jones, p. 652.
   d) J. Orear, p. 743.
   d) J.W. Cronin, p. 170.
   e) G. Theodosiou et al., p. 641.
2. "BECAUSE IT IS THERE!"
3. G.D. Gollin, in "$\bar{p}p$ Options for the Supercollider," Proc. of the Workshop at Chicago, IL, Feb. 13-17, 1984, Eds. J.E. Pilcher and A.R. White (Argonne National Laboratory and University of Chicago, 1984), p. 226; B. Adeva, these proceedings; D. Carlsmith, D, Hedin, and B. Milliken, these proceedings; D. Carlsmith et al., "SSC Muon Detector Group Report", these proceedings.

DISCLAIMER