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A Full-Acceptance Detector (FAD) for the SSC: an Overview*

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ABSTRACT

The status of the FAD initiative to provide a full-acceptance detector at the SSC is reviewed.

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1. Introduction

There is a need at hadron colliders to exploit more fully the intrinsic diversity present in high energy hadron-hadron collisions. The goal of the initiative known as FAD (Full Acceptance Detector) is to provide the SSC program with a detector optimized for diversity. The basic criterion for the detector design is to be sensitive to all physics, at the expense of being optimized (at least initially) for very little. It aims at exploratory physics—the physics which is not already existing in the design books but which just has to be discovered, or which will be predicted sometime between now and SSC commissioning. In some sense FAD would serve as the bubble-chamber of the SSC, but hopefully with even more information per event than bubble chambers provided.

As far as this writer is concerned, the nonnegotiable design criteria for the FAD are that (1) all charged particles of generic p_t be observed with momenta well measured, that (2) all photons of generic p_t be observed and well measured, and that (3) the physics of rapidity-gaps (diffraction) not be compromised. At the SSC the full-acceptance criterion implies a rapidity coverage of order $\pm$ 11 units of pseudorapidity.

The FAD initiative began [1] in 1991, and by the end of that year the FAD Working Group was formed. By now it consists of more than a hundred members. A sequence of very useful meetings has been held, including a week-long workshop in Boulder, Colorado last summer [2]. In addition the enterprise has spawned a variety of other initiatives, including experimental proposals at Fermilab [3,4] to explore physics topics stimulated by thinking about the FAD physics opportunities. These proposals in turn are stimulating new measurements and analyses [5,6] within the large collider detector groups at Fermilab. In addition, the common design problems faced by FAD and by collider B-physics initiatives have led to an increasingly close coupling between the FAD and hadron B-physics communities.

The physics topics which have been stimulated and advanced by thinking about the FAD detector include (1) study of hard diffraction, *i.e.* observation of events containing both rapidity gaps and jets, (2) searches for cosmic-ray anomalies via collider measurements in the forward direction, (3) the related speculative ideas regarding the possibility of producing disoriented chiral condensate (regions of vacuum having an anomalous chiral orientation) in high energy nucleon-nucleon collisions, (4) searches for pattern structure in multiparticle and multijet final states, and (5) strategies for searching for the Higgs boson utilizing rapidity-gap signatures. It also has stimulated revival of the idea of using leading particles as tags for one-meson-exchange processes [7]. This technique would, *e.g.*, allow the study of $\pi\pi$ and π-nucleon interactions at cms energies of many TeV.

2. Status of the Conceptual Design of the Detector

In order to accept and measure all produced particles in each event, the detector must be sensitive to production angles down to tens of microradians. This implies a very long device. The length is constrained by the structure of the SSC machine lattice. At the ten to twenty percent level of accuracy, the free space between the medium-β focussing quadrupoles is anticipated to be 100 + 100 meters. The β^* at the collision point (which is in one of the collision regions on the west side of the SSC, opposite to SDC and GEM), will be larger than for the generic detectors, leading to a reduced luminosity. It is anticipated [8] that the luminosity will be at least 10^{32} cm^2 sec under standard operating conditions, when the luminosity at SDC is 10^{33}. A general picture of the presently considered "baseline" architecture is shown in Fig. 1.

Pseudorapidities up to 9 can be accepted in the detector free space of $\pm$ 100 meters from the collision point. This part of the detector is called the central detector. Particles with pseudorapidities in excess of 9 are for kinematic reasons alone of low p_t, with typical energies in the multi-Tev regime. Per event they are few in number, but enter the aperture of the focussing system and must be detected downstream. The emergent neutral beam can be detected via compact calorimetry located 500 to 900 meters downstream from the collision point. A subgroup of FAD has been actively at work at the detection problems presented [9].

The problem of detecting the charged particles with pseudorapidities in excess of 9 has not yet received enough attention. A possible approach is to use silicon microstrip tracking planes in Roman pots to acquire and measure all but the most energetic ones

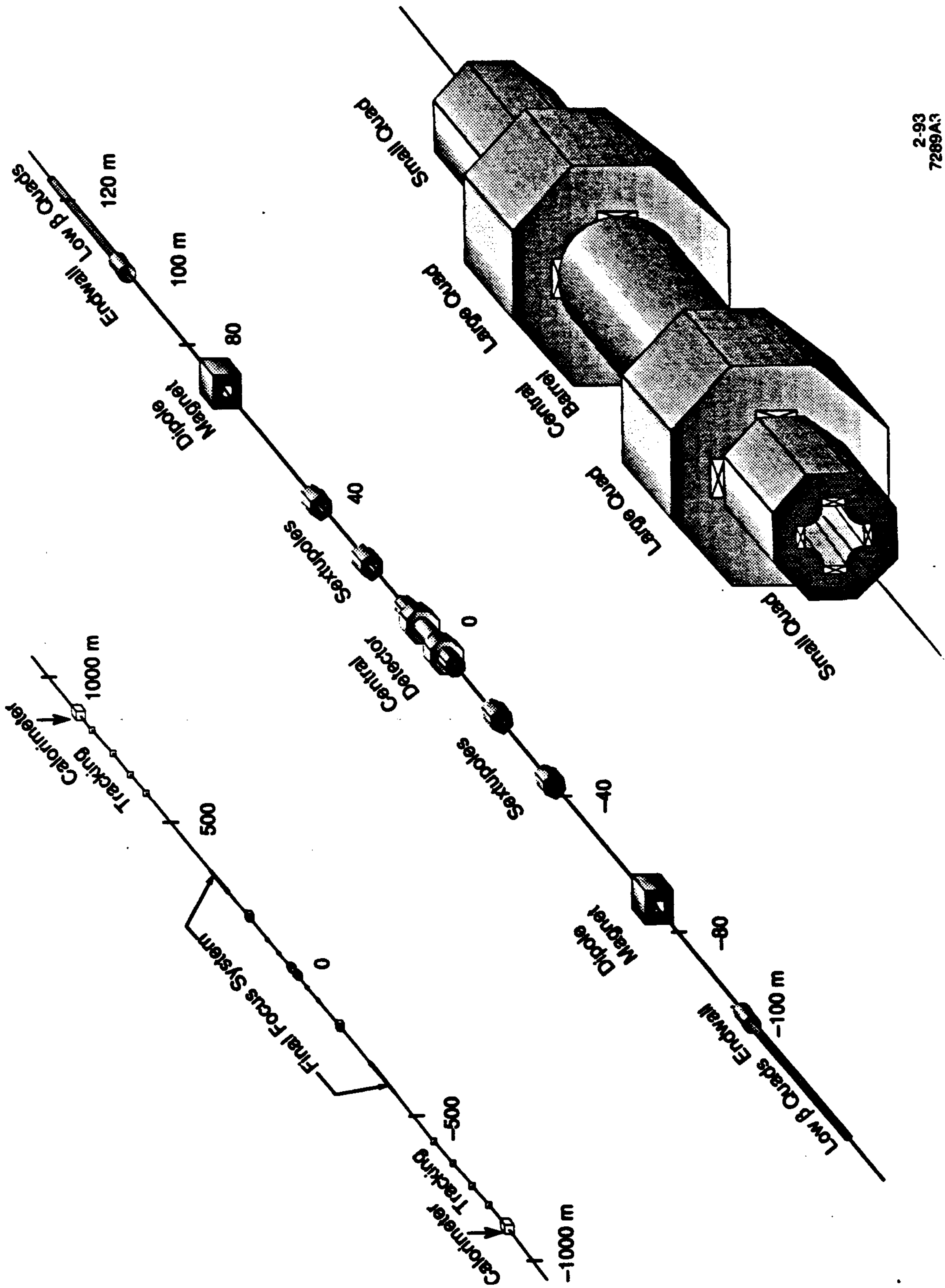

Figure 1. General layout of the FAD detector.

just upstream of the medium-β systems. The remainder may be magnetically rigid enough to exit the magnetic system without crashing into a coil or yoke, and be detectable in a downstream spectrometer. The far-forward working group suggest a tracking system downstream of the beam-splitting dipole to capture in particular decay products of neutral strange particles. This would be followed by compact electromagnetic/hadronic calorimetry far downstream.

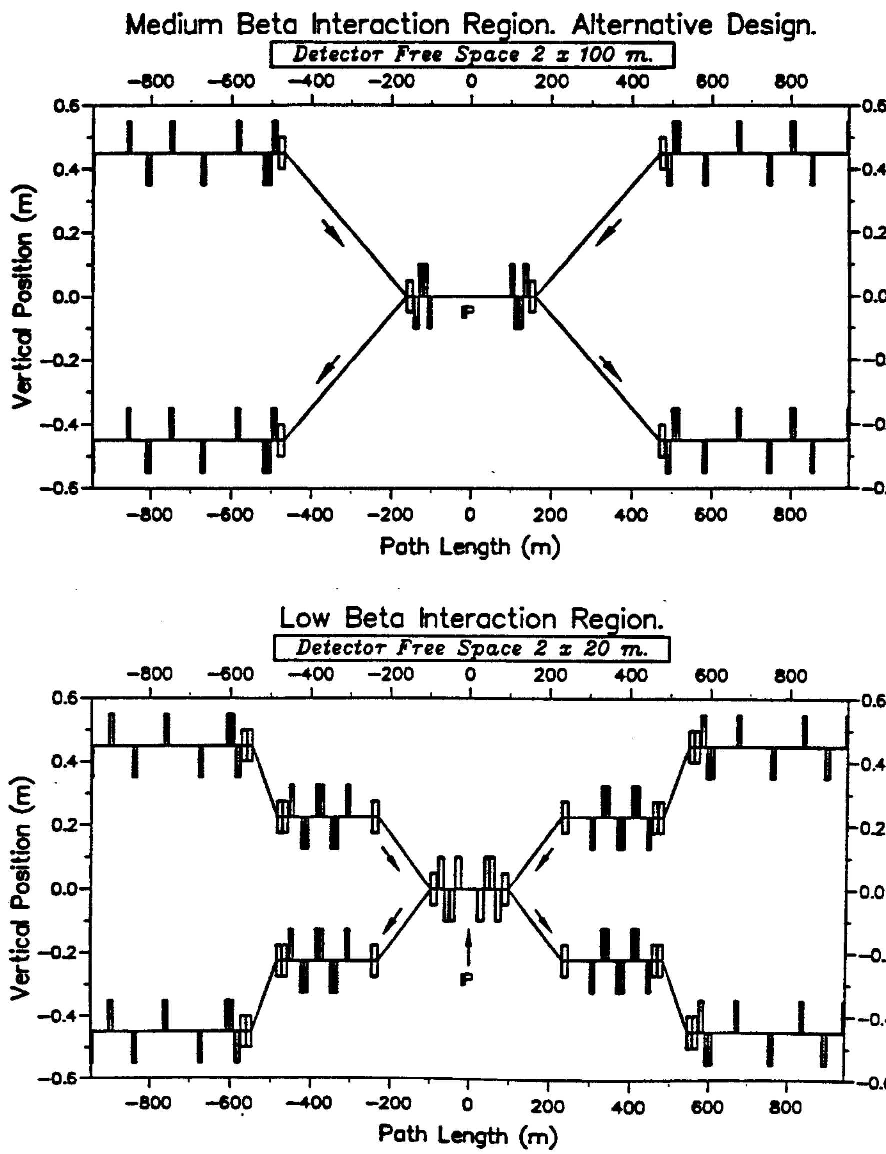

Figure 2. Layout of the "Far-Forward" portion of FAD: (a) Preferred lattice choice for medium-β; (b) "Baseline" lattice for low-β; medium-β baseline design is similar.

A layout of the far forward region is shown in Fig. 2. This is shown for one option for the SSC machine lattice under consideration by the SSC Laboratory. The much less desirable "baseline" design, which incorporates a double-dogleg insertion for suppression of vertical dispersion, is also shown.

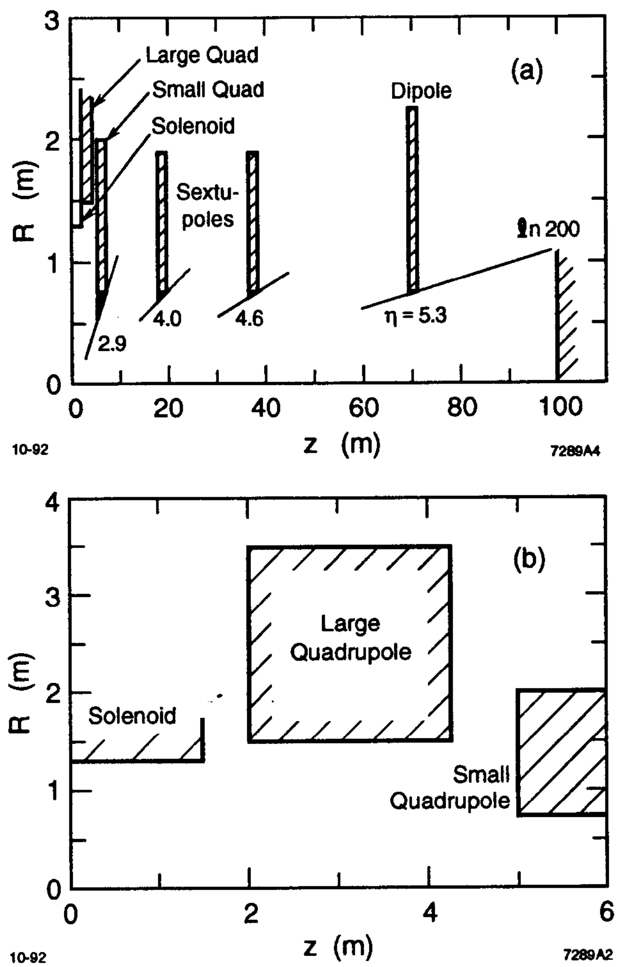

Figure 3. Conceptual design of the "central" detector: (a) Global architecture, (b) Central architecture.

A tentative choice of conceptual design for the central detector was made last summer in the Boulder workshop. It is shown in Fig. 3. The architecture is aggressively multistage, with an unconventional choice of analyzing magnets, featuring quadrupoles and even sextupole magnets. The primary design criteria for the magnetic architecture were taken to be as follows:

1. There should be negligible transverse magnetic field in the region of the beam pipe, so that almost all charged particle trajectories (very low p_t excepted) are straight lines. This makes the problem of controlling the background generated

by collision secondaries striking the beam-pipe (a very serious problem) much more tractable. This requirement invites use of solenoids, higher multipole magnets, or toroids. The higher multipoles appear to be the preferred choice.

2. The sagitta of a charged particle trajectory with p_t of 1 GeV should be between 3 and 30 cm, independent of its pseudorapidity. This criterion is typical of that used in proposed B-physics spectrometers. Provided that a tracking system of standard quality can be matched to this, independent of pseudorapidity (which does appear to be feasible), it follows that the detector should at all rapidities have as good performance, in terms of magnetic analysis, as the generic B-detectors. In any case this latter goal can be taken as defining the FAD design specification for its magnetic architecture for all rapidities within the central detector. The sagitta versus rapidity at p_t = 1 GeV is exhibited in Fig. 4 for the candidate FAD architecture.

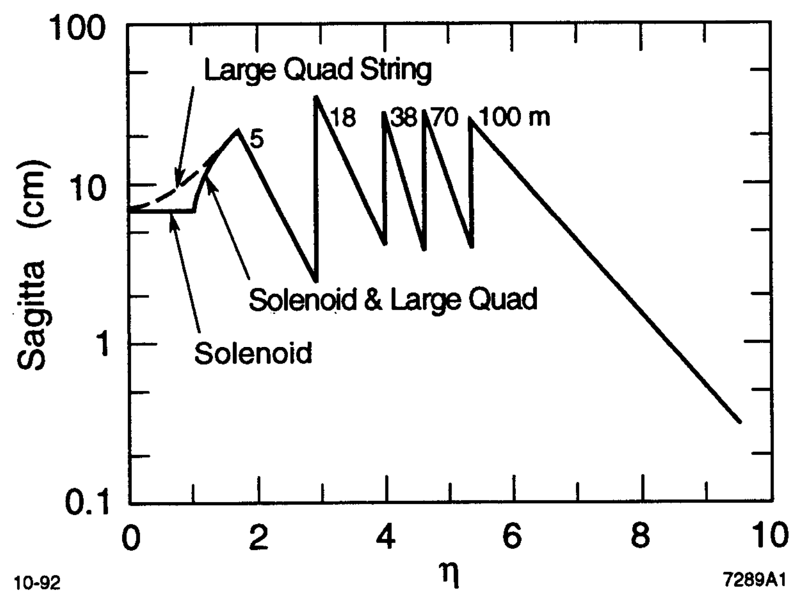

Figure 4. Sagitta vs. pseudorapidity at p_t = 1 GeV for the FAD magnetic architecture.

The remaining features of the central detector have only been defined in general terms. One can anticipate designs where a produced particle first sees an inner tracking system of silicon microvertex detectors, composed of a sequence of annular disks (for forward rapidities) arranged in projective geometry. The region of say 20 to 50 cm from the collision axis is available for particle identification via standard Cerenkov threshold cells. The acceptance per cell should be no larger than $\delta\eta \times \delta\phi$ of 0.3 × 0.3; this is appropriate in the rapidity interval of 2 to about 5. Use of transition-radiation detectors in the forward region (*e.g.* rapidities of 6 to 9, which impinge on a calorimeter wall at 100 meters from the collision region), appears to be an attractive option to study further [10]. A variety of tracking options appear to be available in the outer region of the spectrometer, 0.5 to 1.5 meters from the besam axis, where the major part of the bending occurs. Straw tubes and scintillating fibers are only two of the possible candidates. In any case a goal for tracking resolution of $\delta p/p$ at p_t of 1 GeV of no more than 1% has been specified.

In front of each magnetic stage will naturally be an annular calorimeter wall. Emphasis in FAD goes to electromagnetic calorimetry, with hadron calorimetry compromised if necessary. The electromagnetic calorimeter specifications were taken to be a constant term no more than 2% in the energy resolution, and generic performance for the inverse-square-root term. Spatial resolution was chosen to be sufficient to separate γ's from π^0 decays up to p_t of the π^0 of 5 GeV. The depth of the hadron calorimeter walls was chosen to be 10 to 15 interaction lengths of iron per wall. In the forward direction this is still not an inordinate amount of tonnage.

Beam-pipe design is a crucial problem. Together with members of the B-physics community, an attack has been mounted on it. The notes of Kirk McDonald [11] should be consulted for more details, but in brief there exist three pseudorapidity regions to separately consider. For rapidities less than 3 or so, a small cylindrical beryllium pipe with detectors on the outside seems adequate. For rapidities in excess of 5.5 or so, a sequence of conical, "flared" pipe sections seems to be an essential choice; only a small fraction (a few percent) of produced secondary photons and charged particles strike the front edge of the cones (Fig. 5). They may make a mess, but at least the source is in a predictable location, so that protection may be designed in. In the intermediate rapidity range of 3 to 5.5, the finite length of the luminous region creates parallax, making the flare solution much less effective. One possibility, shown in Fig. 6, is to enlarge the pipe in this interval and insert the inner tracking system within. Physically this section would extend from about 20 cm downstream to 2 meters downstream.

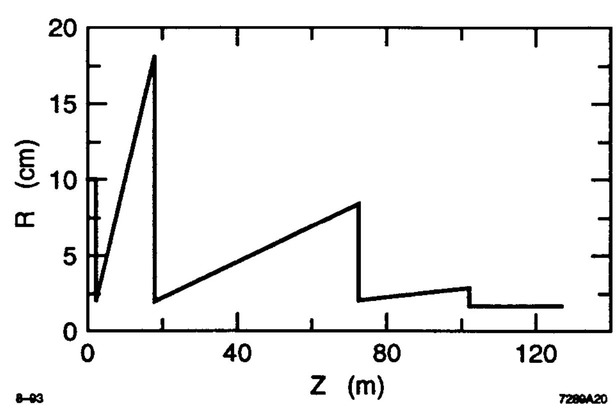

Figure 5. Example of a flared beam-pipe design for the FAD central detector.

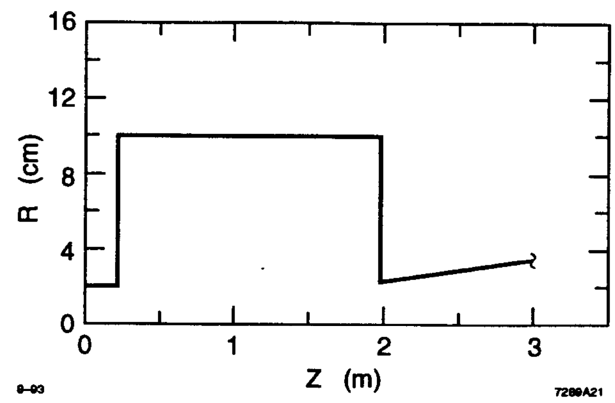

Figure 6. Example of a beam-pipe design for the central portion of FAD.

The use of ultralight materials for the beam pipe has been investigated by Wayne Vernon [12], who advocates a pipe of large radius and very low density, flared beyond 3 meters, with disk and rod structural reinforcements in the transverse dimensions. Extensive use of ultralow density carbon-foam composites is a feature of this approach.

3. Staging of the Detector Construction

It will not have escaped the attention of the reader that the detector under consideration is very expensive, in the few hundred million dollar range if fully built [13]. It will also not escape anyone's attention that the resources to build it do not appear now to be in sight. So why this activity? It is that there appears to be a practical staged approach, with good physics available at each stage, and with Stage I affordable even within the present austere climate. At the first meeting of the FAD working group there was a tentative consensus to choose $30M, a little less than half of what is allocated by SSC to "small" experiments, as a realistic Stage I budget. There was also a consensus that the full-acceptance philosophy be adhered to if at all possible, even for Stage-I. In other words, the investment per unit rapidity in the detector should be roughly uniform, just like the minimum-bias particle production.

A possible Stage I detector might be designed along the lines of the Pisa-Stony Brook experiment [14] at the CERN ISR, which did much to establish the nature of multiparticle production phenomenology at the hadron collider energy scale. The detection elements are all scintillator with pixel size of $\delta\eta \times \delta\phi$ of say 0.7×0.7. Each pixel in rapidity is sampled with enough scintillator planes (the rearmost portion with lead converter interspersed) to determine the charged multiplicities and the electromagnetic E_t. A considerable amount of the physics of hard and soft diffraction (including possibly the rapidity-gap strategy for Higgs search), as well as much of the basic phenomenology of multiparticle and multijet production, is addressed with such a simple device, which involves no more than a few thousand photomultiplier channels. The cost is most certainly well below the FAD budget ceiling.

Of course one would not stop at that. But some reflection shows that this Stage-I device can be the prototypical cortex of a much more sophisticated, intelligent detector which still triggers at Level I on global event patterns, which this Stage-I detector would necessarily be designed to do. So from the point of view of data acquisition architecture, this scintillator-based starting point may be an especially useful device.

The portions of the detector which do get special attention at the Stage-I level will depend on the sociology of the collaboration, as well as the nature of the most interesting physics topics in the year 2005 or so. As it stands now the pseudorapidity interval of 2 to 5 is especially interesting to those in FAD interested in B-physics. The pseudorapidity interval of 6 to 9 is especially relevant for those interested in cosmic-ray exotica, disoriented chiral condensate, and hard diffraction. The far-forward spectrometer is of interest to the soft-diffraction and leading-particle communities, as well as being of special interest to cosmic-ray shower phenomenologists, who anticipate a major change in leading-particle physics at the SSC energy scale relative to reasonable extrapolations from lower energies [15]. And it is hard to imagine that the popular central-barrel region of rapidities less than 3 will not attract its own community of enthusiasts.

Nevertheless, one may feel that in the present climate these considerations are still premature. So, again, why worry about the ultimate Stage-N FAD detector now? The reason is that it is important to understand the Stage-N device in order to intelligently design the placement of the tonnage, *i.e.* magnets and calorimeter walls (possibly passive initially), because they tend not to change with time. Not only are those elements awkward to physically move or replace, but they also tend to define the tracking architecture, which in turn defines a software architecture, which in turn is typically near-impossible to replace. Since the tonnage is not inordinately expensive, and because it arguably should be in place before commissioning of the SSC machine, it probably will or should exist in the Stage-I detector. This in turn drives the need for consideration now of the Stage-N detector as a whole.

4. Critical-Path Issues

SSC commissioning is a decade away at best, and the lead time for design and construction of a small, inexpensive Stage-I FAD is a lot less than a decade. Nevertheless, there is a need for serious design activity right now. This is mainly driven by the SSC construction schedule, in particular the machine-lattice design and the tunnel and collision-hall design in the FAD collision region. FAD needs to interact rather strongly with this activity, which is going on now.

We have already mentioned the problem of the far-forward detector design, in particular the need for enough free space downstream of the medium-β focussing system for a neutral beam to emerge and be detected 500 to 900 m downstream of the collision point. The extant "baseline" lattice in Fig. 2b constricts greatly this neutral-beam free space, because of the double-dogleg and dispersion-suppressing quadrupoles. An acceptable lattice which accomplishes the dispersion suppression via skew quadrupoles in the arcs may exist [16], and is much preferred by FAD. In any case close interaction with the SSC is necessary to protect this physics.

A related problem, this the responsibility of FAD alone, is to understand the problem of detecting the leading charged particles; this will influence the specifications on the apertures of the low-β quads and splitting-dipole magnets.

In the central detector, the unusual collection of large-aperture multipole magnets, to our knowledge never used in any open-geometry spectrometer, needs to be studied in detail. We already appeal [17] to magnet-designers in the major laboratories to provide assistance in evaluating these with respect to feasibility, cost, power consumption, and design choice (iron-and-copper vs. superferric vs. $\cos 2\theta$ superconducting). This problem is common to B-physics detectors and the FAD, and the appeal is a joint one. At present there is some work being initialed at LBL and Saclay.

In addition to the question of the magnet design, the tracking problems are a little different than what is conventionally encountered. There does not appear to be a fundamental difficulty, but studies need to be performed to learn the new ways, and to convince skeptics that they will work.

Another critical issue is the compatibility of FAD with B-physics. There already exists the issue of whether it makes sense to combine a B-physics program and the FAD into one detector within one collision region. Aside from sociology (a non-trivial concern), the objective question is whether optimizing a B-physics detector dedicated to the specific, difficult goal of observing CP violation compromises the full-acceptance physics done downstream of it. Likewise there should be no compromising of the goals of the B-physics experiment by combining it with the FAD. Whether such compromises are intrinsic needs to be determined. If there is no necessity for any significant compromise in either direction, there is a clear advantage in merging the enterprises. Obviously there is time pressure involved in resolving this question.

Finally, there remains the problem of backgrounds. There is widespread concern within and outside the FAD group that there will be serious backgrounds generated by secondaries striking the inner apertures of the calorimeter walls. However searches for the origin of such severe backgrounds via hand calculation have not uncovered a serious problem, provided some care is taken in keeping downstream detection elements a prudent distance away from background sources. There also exists some data from test beams [18] and CDF experience [19] which can be brought to bear on this problem. And a beginning has been made in setting up Monte Carlo simulations for this problem [20]. Likewise the beam pipe is also a source of background, not only from interaction of the collision products, but also from beam-halo interactions. This source has been under study at the SSC [21]. For the FAD geometry, Mokhov [22] reports a large soft-neutron flux in the vicinity of ter beam pipe. This flux is not quite as big as what is encountered at SDC and GEM, but enough to be a serious concern.

5. Present and Future Plans

At present there is the need to document well what has been accomplished thus far. The material in these proceedings comprises a step forward in that direction. In order to advance the critical-path issues enumerated in the previous section, we look forward to workshop activity this summer in Snowmass (late June) and Aspen (September).

In addition, some detector R&D relevant to the FAD has gained support under the auspices of the Texas Commission, and a variety of detector component designs have been specifically considered for use in an ultimate FAD. These include high-pressure gas calorimetry [23], "shish-kebab" calorimetry [24], silicon pixel detectors [25], gas microstrip detectors [26], and fiber optic data links [27] to transport large amounts of data over the considerable distances present in the FAD detector.

Another line of activity involves interim experimental programs which explore FAD physics issues such as hard diffraction and disoriented chiral condensate. At present there is activity at Fermilab within CDF[5] and DØ[6] on hard diffraction, and an approved small experiment ("minimax", T864[4]) in the Fermilab collider to search for disoriented chiral condensate. Further down the line but this side of SSC is RHIC, where the idea of full-acceptance physics is received with interest. These activities cannot help but promote the SSC FAD initiative, both sociologically and via information and experience gained in those enterprises.

What happens to the FAD initiative after this summer will obviously depend on the status of the SSC at that time. Assuming no major crisis occurs, there still remains a question of whether the delay in commissioning of the machine will delay the call for "small-experiment" proposals to the SSC. If there is no delay, *e.g.* because tunnel construction is chosen by SSC management not to be delayed, proposals may be due in 1994. If this is the case a collaboration will have to be organized this fall in time to prepare a proposal. There is a real difference between a collaboration and the present working group. If the time frame is that short, there will have to be a big effort to create a strong group and a convincing proposal. Nevertheless there has been steady progress in the evolution of the full-acceptance ideas, and I am cautiously optimistic that the FAD can in fact be realized.

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