THE WORKING GROUP ON INSTRUMENTATION, TEST BEAMS AND SSC R&D

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Abstract

The topics of Instrumentation, Test Beams and SSC R&D obviously cover a broad range of interests, and the activities of this working group were likewise diverse in scope. With regard to instrumentation, the emphasis was on R&D requirements for the next decade as determined by projected collider and fixed-target programs. Requirements for electronics were also reviewed, in anticipation of the need to operate at higher luminosity in collider runs, and at rates up to 53MHz in fixed-target runs. Test beam requirements are derived from R&D needs for detectors and electronics, and by the new requirements brought on by the SSC. Special topics were also considered with regard to silicon electromagnetic calorimetry and TRD's.

1 Introduction

The Working Group on Instrumentation, Test Beams and SSC R&D developed along several independent paths. Subsequently each of these paths developed into independent subgroups that submitted their own report. The groups were divided into Detector R&D headed by David Anderson, Electronics headed by Dave Christian, Calibration and Test Beams headed by Ray Stefanski, SSCL Test Beam Needs done by Jim Bensinger, and Transition Radiation Detectors headed by Marleigh Sheaff.

*On behalf of the working group. Participants in each section are given in the footnotes.

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Jim Russ also submitted a paper on silicon calorimetry. Many of the subgroups had substantial contributions from several individuals and these are cited in each report. The remainder of this section contains the reports of the subgroups.

2 Report of the Detector R&D Subgroup †

The subgroup heard eight prepared talks, half of which were on the topic of scintillation fibers. Besides the time spent in prepared talks, the first day was spent discussing what detector R&D should be done at Fermilab to enhance physics at Fermilab and at the SSC. The second day was dedicated to discussing how detector R&D could be stimulated and supported at Fermilab, keeping in mind existing financial and personnel constraints.

There were four talks on the afternoon of the first day and four on the morning of the second day. All of these talks were attended by other working groups. A summary of these contributions follows:

Craig Woody (BNL) described his work with very fast crystalline scintillators, BaF_2 and pure CsI. BaF_2 has a very fast scintillation component (0.6 ns) and has been shown to be radiation hard to levels of $> 10^7$ rad. Work was presented on how to reduce the slow component of BaF_2 (600 ns) with the use of optical filters and small levels of dopants. Pure CsI looks very promising because it is inexpensive and also has fast components (10 ns and 30 ns). Like BaF_2, it also has a slow component (> 1000 ns) which is also difficult to eliminate.

David Anderson (Fermilab) gave two talks. The first was on the new very compact Cherenkov radiator for EM calorimetry, PbF_2. This material has a radiation length of <1cm and from a test at KEK has been shown to give in excess of 1300 photoelectrons per GeV. PbF_2 is about 1000 times more radiation hard than lead glass and there is hope that it can be made hard enough for physics at the SSC.

The second talk by Anderson was a review to the literature on very high rate gas counters. It has been shown by work from Radeka's group at BNL that chambers can be built with an efficiency of 99.8%, a signal width of 15 ns at the base, timing resolution of 4ns FWHM, and a rate capacity in excess of $10^7 sec^{-1} cm^{-2}$.

The last talk of the day was by Bob Tschirhart who discussed high-rate, large-area (> 1 m) TRDs. The solution is long straw tubes filled with Xe (for high stopping power) and methane (to increase the drift velocity). There is still a lot of work to be done on the mechanics of long straws and on the high-rate readout. It is felt that TRDs will give an e/π separation of 100.

On the second day the first talk was by Dave Herzog (U of I, Urbana) who reported on the work that they are doing with scintillating fibers and lead

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calorimetry. The application is nuclear physics at LEAR. He showed us how they built their modules which were Pb, scintillator, and glue (40%, 50%, 10% by volume). Their resolution was $6.5\%/\sqrt{E}$. The fibers were inclined to the beam by 3 to 6 degrees to prevent particles from going down the fibers.

Hans Paar (CERN) showed the results of the work at CERN on lead - scintillating fiber hadron calorimetry. By using pulse-shape analysis alone they got an e/π rejection ratio of 100. By using a 2 Xo shower pre-radiator, they believe that they can increase the e/π rejection ratio to 1000. It was pointed out that in order to get hadron compensation one must use a gate of 100 ns, no matter what detection technique is used.

Dick Gustafson (Mich.) showed us the Scintillating fiber/lead luminosity monitor that they have developed for L-3 at CERN. The monitor is 50/50 Pb/scintillator. The readout is with photodiodes. An early test gave a resolution of $12.5\%/\sqrt{E}$. From EGS simulations they are expecting a resolution of $8\%/\sqrt{E}$.

Jim Freeman (Fermilab) presented the work that is being carried on by some members of CDF to develop wavelength-shifter fiber readout for pads of scintillator. This is similar to work that was done at Saclay for the UA1 upgrade proposal. The CDF results are very encouraging. The biggest advantages for CDF are that the technique would use the existing calorimeter iron, would be inexpensive, and would provide good longitudinal segmentation.

A later contribution to the talks was given by Nikos Giokaris (Rockefeller) describing his work on exploring the possibilities of doing calorimetry with high-pressure gas (argon or xenon) ionization chambers. A small test vessel has been built and measurements have been made in argon at pressures of up to 170 atm. The results of these tests show that at 100 atm argon with 1.3% methane and a field of 1 keV/mm one can achieve a signal that is 8% that of liquid argon but with an electron collection time of only 55 ns/mm. The cell had little sensitivity to oxygen contamination until levels in excess of 80 ppm were reached in pure argon, and levels in excess of 20 ppm in Ar plus 1.3% methane.

In Table 1, a list is given of the major detector development topics that should be addressed at Fermilab for the future of Fermilab experiments and for the SSC. This is the majority view of our small working group, and cannot be all inclusive.

It is felt that liquid argon calorimetry and muon detection are in pretty good shape and that ongoing R&D is sufficient. Warm liquid calorimetry still requires substantial effort, but we do not see Fermilab getting more deeply involved than its present level of support of the WALIC collaboration.

Table 1: Detector R&D to be Done at Fermilab

Detector System	Technology Used	Work to be Done
Vertex Det.	Silicon	front end electronics growth of electronics on wafer
	Sci. fibers	solid state readout and materials
Tracking	Sci. fibers	solid state readout and materials
	Straws	construction and gases
Calorimetry	Sci. fiber	construction techniques readout schemes and materials calibration
	PbF_2	improved growing techniques beam test, and rad hardness studies
	Inorganic sci.	new materials suppress slow comp.
	Sci. plate	wavelength fiber readout
	High pressure	mechanical designs and gases
High Speed RICH		develop hadron blind RICH develop high rate capability look for new photosensors look for new readout schemes
TRD		study gas develop long straws and supports readout
Generic R&D		looking for new materials and techniques

3 Report on Silicon Electromagnetic Calorimetry †

The study of silicon as the sampling layer in electromagnetic calorimetry has been going on for many years. Early work focussed on measuring the obtainable energy resolution. Recent results have demonstrated a performance of $15\%/\sqrt{E}$ with a negligible constant term over the energy range of 1 to 10 GeV for electrons, using one radiation length sampling. In many Fermilab experiments, the electron and/or photon energy is low enough that one might want to choose finer grain sampling, perhaps 0.5 radiation length, and improve the energy resolution to order $8\%/\sqrt{E}$, still with no constant term. This is not as good as can be obtained with continuous media like BGO, of course, but silicon electromagnetic calorimetry has a different set of strengths.

The charge collection time in silicon is very short, about 7 ns for electrons. The fast silicon response can be matched by radiation-hard readout and signal processing electronics. The goal is to have one bunch timing for the signals, if possible, completely eliminating pileup. This makes silicon electromagnetic calorimetry very attractive for high rate environments.

Another aspect of high rate operation is high particle density, with an accompanying particle identification problem for electrons. Silicon calorimetry offers a good solution to this difficulty. Spatial segmentation in both depth and transverse dimensions can be tuned to enhance electron identification. Hadron/photon overlap is reduced by having good shower centroid and shape information. Hadron/electron confusion is reduced by good longitudinal segmentation, for shower development tests. Good two dimensional shower profile information will improve electron/photon overlap problems and aid in separating single photons from neutral pion decays.

The radiation tolerance of silicon for calorimetry has been studied extensively over the past three years, aiming at SSC applications. Leakage current multiplication is not a big problem for calorimetry, and use of silicon under conditions expected even in forward regions at the SSC for electromagnetic calorimetry looks quite promising. This technique, based on a sampling method, will not solve all high-rate, high-flux electromagnetic calorimetry problems. However, it is a method which might find a host of applications after the upgrade, especially for fixed target work.

4 Report of the Subgroup on Electronics *

The subgroup heard six prepared talks and held a lively discussion on the future needs for electronics design at Fermilab with a focus on the need for integrated

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circuit design.

The prepared talks ranged from a description of existing "programmable gate arrays" to descriptions of possible SSC frontend electronics. One of the talks described conclusions reached during the workshop by a CDF subgroup on the question of how to upgrade the CDF calorimetry readout system. A summary of each talk follows:

William Dougherty (U. Washington) described the present capabilities of "Programmable Gate Arrays". These user-configured CMOS devices load programs from PROM's or directly from a computer in 30 milliseconds. The top performers operate at up to 100 MHz and contain the equivalent of 9000 gates and 144 user input/output channels with selectable TTL or CMOS thresholds. Flexible software design tools facilitate programming at several levels of abstraction, from Boolean logic equations and function macros to direct gate level manipulation. Connection routing may be automatic, manual, or a combination thereof. Users were cautioned that fully automatic routing using available tools can lead to logic networks that execute slowly. Full design simulation accurately calculates throughput delays. The devices are obtainable from several manufacturers for $20-$40 per chip, and complete programming packages which run on 286/386 computers may be purchased for about $6000. Applications including a CCD buffer/controller and reconfigurable trigger logic were described.

Henry Lubatti (U. Washington) described tests that his group has done using sample "Acoustic Charge Transport" (ACT) devices. ACT's are high speed monolithic GaAs charge transfer devices that can be used to pipeline analog signals for times of the order of microseconds. During storage the signal can be nondestructively sampled and the resulting information can be used to determine the disposition of the raw data when it reaches the end of the pipeline.

Analog input signals are converted to a series of discrete charge packets. The charge packets are confined to a transport channel in the device. They are transported by a piezoelectric traveling potential wave, generated by a copropagating surface acoustic wave. The packets move continuously at the speed of sound in GaAs ($3\text{mm}/\mu\text{s}$) that is generated by a transducer on the device. The packets may be repeatedly sensed during the transport process by a series of electrodes placed on the surface of the ACT device without deleterious effect on the signal extracted at the end of the delay line. The desired relative delay between nondestructive sensing and output is achieved by placing the sensing taps at the appropriate location along the transport channel. The outputs of the sensing taps may be independently weighted (-1 to +1) and combined directly on the ACT chip to perform signal shaping.

Devices have been built which operate in the 360 to 600 MHz range with charge transfer efficiencies greater than 0.99995 with a dynamic range of 150 - 1,500,000 electrons (approximately 80 dB). At a frequency of 360 MHz the charge packets are approximately 4μm long (1/2 SAW wavelength).

Tests of resolution with a Co^{60} source indicate the response of the ACT after a 960 ns delay is equivalent to convoluting with a Gaussian of width 25 keV. The group has also tested an ACT with 64 taps and demonstrated that one may clip any signal which can be represented as a sum of exponentials; that is, one may restore the base line to zero after a time $t > t'$, where t' is selectable in steps of (7.5 + N) ns and N is the number of exponentials.

Tom Droege (Fermilab) described plans for upgrading the CDF calorimeter frontends and readout system. Some of the features of the new system are: 1) The level 0 trigger will now include inputs from the calorimetry. 2) The frontend cards will use delay lines to hold the data while a level 0 trigger decision is being made (rather than sample and hold capacitors). 3) The MX scanners will be replaced with very simple scanners that use fixed readout lists. This makes the system faster and more "data driven." 4) A data path which is separate from the control path will be established. 5) The trigger supervisor will be eliminated; each trigger level will communicate only with levels immediately above and below it. The philosophy behind these changes is very similar to that expressed in the remainder of the talks, all of which described pipelined systems.

David Christian (Fermilab) presented an overview of the readout system for silicon strip detectors being developed for E771 and E789 for use in the upcoming (1990) fixed target run. The system consists of amplifiers mounted on the SSD's, and a family of FASTBUS modules which discriminate the amplifier outputs, store the discriminated signals while a trigger decision is made, encode into lists of hit strips, and send the lists to the next readout system level. The amplifiers are implemented using a semicustom bipolar integrated circuit manufactured by Tektronix. They are fast and stable enough to provide single bucket resolution and a one-two bucket memory time. The discriminators are also implemented using Tektronix bipolar ASIC's. The system uses fast ECL memory instead of cable to hold signals while a trigger decision is made. It includes very fast pipelined encoders which produce ordered lists of hit strips when a trigger is received. Up to twelve encoders feed a single "sequencer" module which sends the information to the next level of the readout system. The system is "data driven" in that no external control signals other than a trigger are required. High speed module to module communications in the FASTBUS crate occur using synchronous point to point connections on a custom auxiliary backplane. The standard FASTBUS backplane is used for initialization, debugging, and monitoring.

Rick Van Berg (U.Penn) described an ongoing R&D project aimed at demonstrating a frontend readout system appropriate for use at the SSC. Using both high speed bipolar and CMOS technologies, a Penn/ BNL/Leuven/AT&T group is designing and fabricating a readout system for high speed gas tracking detectors. The basic design parameters are: average rate per wire 5 MHz, desired time accuracy <0.5ns, double pulse resolution < 30 ns, input noise < 1200 electrons rms, on detector storage of data through Level 1 ($\approx$ 1 microsecond) and Level 2 ($\approx$ 30 microseconds) trigger decision times, readout of digital data at an event rate of

$\approx 10^4$ Hz (10^8 Hz raw event rate reduced by 10^4 combined trigger rejection), and total power budget of about 10mW per element. A high speed preamplifier and three stage shaper has been fabricated and tested in an AT&T bipolar linear array process. A fully pipelined, deadtimeless TVC and mixed analog digital storage and digitization circuit has been fabricated in the MOSIS 1.6 micron process and tests will begin in September. If the present pieces work as designed, all of the design specifications except for the total power will have been met or exceeded. Further iteration of these designs will take place over the next few months and a complete test system should become available sometime in 1990.

Bill Foster (Fermilab) described a readout and triggering scheme for an SSC detector based entirely on scintillator. All of the elements (tracking fibers and calorimetry) would be readout through phototubes and would be very fast. The expressed goal was to construct "CDF quality" trigger tags for e, μ, total E_t, and missing E_t for every 16 ns beam crossing. The proposed system is a purely digital synchronous parallel pipeline. A package of custom and commercial microelectronics would be mounted on every phototube which would do analog to digital conversion, form partial sums including information from nearest neighbors, and pass results to an adjacent element. This system would combine frontend electronics with a very deep readout and computation pipeline mounted on the detector. Bill also described a method to find stiff tracks in the scintillating fiber tracker in a similar synchronous pipeline. These tracks would be used together with calorimeter information to form the e and μ^- triggers. The cost estimate for this system was $10M.

The electronics subgroup also held a discussion of issues related to ASIC design. The question addressed was "What IC design capability should Fermilab develop and maintain?" There was general agreement that experiments at Fermilab in the 1990's will absolutely require new high density, low power, low noise, and moderately fast electronics. In many cases, the only way to provide all of the desired properties will be to use full custom or semicustom ASIC's. In particular, there was general agreement that the following detectors would require ASIC designs: 1) Vertex detectors at the Collider (e.g. SVX, BVX) 2) High rate silicon strip or fiber vertex detectors for fixed target experiments 3) High density, high or medium rate particle i.d. detectors (e.g. RICH).

In addition, there was a consensus that it will often be much cheaper to integrate electronics for a detector rather than use discrete solutions, even when density or power are not serious constraints. Based on the experience of those present, the group expressed the belief that the cross- over point at which ASIC solutions become cost effective today is approximately 10000 channels. This cross-over point can be expected to move towards fewer and fewer channels in the coming decade.

The technologies that are certain to be needed for the next decade include high speed bipolar (for instance the Tektronix process used in the E771/E789 SSD readout system) and small feature size CMOS. It is also possible, but less likely, that GaAs or Silicon on Insulator processes will become attractive for particular applications. No set of tools and skills will be applicable to all possible future scenarios, but a strong commitment to integrated circuit design now will place the Lab in a strong position to support experimental needs well into the 1990's.

5 Report of the Subgroup on Calibration and Test Beams †

This subgroup considered the many requirements for test and calibration beams. The single most important development for test beams at Fermilab will be the construction of the new Main Injector. This new facility will make it possible to bring beams to the fixed target areas all year round. This will greatly enhance the potential for calibration and R&D work that will be done at Fermilab after 1994.

There must be a distinction made here between test beams and calibration beams. Beams that are used for calibration purposes will be occupied by a single detector group for a substantial length of time. Test beams are generally set aside for relatively short term studies with specific problems at issue. In addition to the calibration beam work there will likely be a need for facilities that will allow these short term tests. MBottom may serve this purpose for some of the studies, but a high rate capability beam should be set aside for these activities. This beam should be equipped with a good computing and data acquisition system.

Test beam use in the 1990's should be directed toward the Tevatron Upgrade Programs and the SSC. The two collider detectors at Fermilab will clearly need calibration beams over the coming years. The SSC detector proposals will demand an increasing fraction of test beam time over the next few years. In the beginning, however, their needs will be mainly for test beams in the sense mentioned above.

The biggest need for collider calibration beams is clearly high flux beams of electrons and pions over a broad energy spectrum. High energy electron and pion beams are needed to study the containment of electromagnetic and hadronic showers in calorimeter modules. Energy leakage strongly affects the energy resolution and needs to be limited to about 5%. There clearly will be a need to test prototype calorimeter modules for the SSC. Low energy test beams are as important for detectors at the Tevatron as for the SSC. Most calorimeters are non-linear in the low energy range. This is mostly due to the specific calorimetric design and the low energy nuclear processes which occur in the calorimeter modules. Since jets always contain a large component of low energy particles, even at SSC energies, it is crucial to understand the low energy hadron response. Currently, it is not well understood for lack of low energy pion data, and thus one is limited practically in jet studies. Also, a large systematic uncertainty is introduced when subtracting the

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underlying event, because of lack of knowledge about the low energy response. At the moment, in the NW testbeam for example, one can easily get energy response points at 150, 100, 75, 50, and 25 GeV/c. Going much below this point becomes increasingly painful, as lower energies result in longer and longer periods over which a statistically useful sample of events can be obtained. Practically, even 10 GeV/c is too low, since the flux is such that one useful data point takes about an entire 8 hour shift or longer. In comparison, when taking data at 50 GeV/c a data sample of 1000 electron events could be taken in 10 minutes.

Obviously, the 120 or 150 GeV/c main injector beams used as primary beams for such calibration beams would be a great help, as opposed to the current Main Ring primary beam. Several such calibration beams should be planned as permanent facilities, like the MT area for CDF and the NW area for D0. Ideally, CDF would like a switchable electron/pion beam with useful flux from 500 MeV/c up to about 200 GeV/c. Of course this will be impossible with a Main Injector calibration beam alone. The question here is, can beamlines be switched between the Tevatron beam and the Main Injector beam? This will be discussed further below.

The calibration beam situation for D0 is similar to the one for CDF, though with more emphasis on low energy. Since CDF is a magnetic detector, the measurement of the momentum of charged particles in the central tracker and the corresponding energy response of the calorimeter constitutes a "built in" calibration. The cut-off below which charged particles spiral in the CDF detector is 500 MeV. This gives the CDF detector, in principle, a calibration with data down to 500 MeV. Since the D0 detector does not have a central magnetic field, knowledge of the low energy response of the calorimeter is even more important.

Low energy test and calibration beams imply a good knowledge of the momentum and particle content of the beam. In order to know the beam momentum to an accuracy of better than 1% a very accurate field map of the magnets in the beam line is desired. To enable the experiments to trigger only on the particles of interest, tools for particle identification, like Cherenkov counters, need to be added to the beam line.

Another possible need is to add photons into the pion/electron beamlines. Although the electromagnetic showering of photons and electrons is nearly identical, this capability would add greatly to the understanding of photon efficiencies and acceptances, which is necessary in issues such as searches for exotic particles which decay into a photon and a non-interacting particle. In the NW testbeam photons were obtained from Dalitz decays of pizeros in paraffin, sweeping out all charged particles. However, the fluxes were not very useful.

Turning to R&D or "test" beams there is clearly a need for as large fluxes as possible to investigate radiation damage, and high rate readout schemes. Although radiation damage of materials used in high energy detectors is slowly becoming better understood, the actual use of a beamline as opposed to sources or reactors is clearly superior due to the completely different geometries of radiation damage in these situations e.g., damage as a surface or skin effect. Another point is that some radiation effects are not only dosage but rate related. In most calibration beams it is difficult to accumulate sufficient dosage without getting involved in an extensively long run. Facilities such as the Main Injector would make these tests easier to achieve. Thus, one can imagine a beamline or beamlines where one can select between the primary beam itself (either from the Main Injector or the Tevatron), or secondary beam if the flux is sufficiently high, and a large staging area for many detector prototypes which can be rapidly moved in or out of the beam, or simply sit to study annealing effects. Since new detectors have to operate in a high luminosity environment and have to deal with enormous data taking rates, high intensity beams from the Main Injector could be used for testing data acquisition systems designed to deal with high event rates. The designs and operation of data acquisition systems for very high event rates become more and more complicated and are more and more challenging. A facility to test these designs could be provided by the Main Injector.

An important aspect of the calibration test-beams should be the requirements for floor space, beam height and crane coverage required for the manipulation of calorimetry modules. It has been requested to have the capability to scan the front surface of the modules for detailed calibration, uniformity and edge effects studies. In addition, a likely request is that of exposing calorimeter modules to showers entering "off-axis" to the normal collision point. It is unlikely that steering of the test beam could provide for scanning more than of the order of 10 cm x 10 cm of the front face of the module. Based on present experience we could expect to be faced with the handling of modules of sizes of order 350 cm wide x 100 cm tall x 150 cm deep weighing in excess of 20 Tons.The present beam heights at Fermilab, in excess of 150 cm, should be adequate for vertical scanning of modules. The floor space required, in excess of 400 cm on either side of the beam is available at all experimental stations at Fermilab with the possible exception of the MB area. It is unlikely that crane capacities to move entire modules could be provided at any of Fermilab's experimental areas. Present crane capacities, less than 12 Tons, should be adequate for assembly of full modules and installation of support structures and ancillary equipment. In summary, Fermilab could provide the mechanical requirements for calibration test-beams of forthcoming test proposals, once a beam line becomes available.

A program of study should be carried out to examine the use of bent crystals for extraction of a beam from the Tevatron or the Main Injector. Such techniques would substantially reduce the cost of capital equipment needed for delivering low intensity beams to the experimental areas. There is also an SSC application. The SSC does not contain any provision for extraction from the Main Ring. Conventional extraction systems require increased aperture of the ring, and consequently add substantially to the cost of the project. The use of a crystal septum for the extraction system would allow the development of a modest program of extracted beams without affecting the overall cost of the project.

In the '92 fixed target run, the SSC program will require three beams. These might include some use of MT, shared with CDF Upgrade usage. The NWest beam might also be used by SSC groups, shared by D0. The complex of beams at Lab E and Lab F might serve as a more or less dedicated test beam area. If the CDF Upgrade, the D0 Upgrade and a new C0 detector are all approved, the lab will have to set aside additional beams for calibration work for all of these detectors. The SSC and Tevatron collider experiments will have to compete for beams with experiments in the fixed target program.

The '92 run would be the last run before the HEP shutdown for construction of the Main Injector. A fixed target program would not be available until 1994. In the '94 run, major calibration work will be required for the Tevatron collider detectors. The SSC detectors will be involved in crucial prototype work. This will pose a very heavy demand for fixed target beams at Fermilab. It is conceivable that as many as five or six beams will be needed entirely for the collider program at the Tevatron and SSC.

The SSC Laboratory may build its own calibration beam facility to be operational in 1996. The SSC use of Fermilab beams should decrease after this time. However, both ANL and Fermilab may be involved in the construction of major detectors for the SSC (and many Fermilab physicists may become SSC users.) As such it is likely that detector modules constructed at facilities at these laboratories will require test and calibration beams at Fermilab. This work will be enhanced by the first availability of fixed target beams during collider runs. In addition, the facilities at Fermilab will be well understood by then. Also, Tevatron users will continue to need calibration beam support. The demand for test and calibration beams at Fermilab can, therefore, be seen to continue throughout the decade.

6 SSCL Test Beam Needs at Fermilab for the Early 1990s †

The SSC will usher in not only a new era in physics but will also place demands on experimental detectors well beyond those placed by current experiments. The energy scale, luminosity, bunch spacing, and radiation environment all require scientific and technological solutions that go beyond current practice in our field. This work cannot wait until the existence of useable test beams at an SSC laboratory, but rather must be addressed immediately by a truly national program that uses all the resources that this country has available.

The SSC Laboratory has suggested a rapid time scale for letters of intent and preliminary approval for proposals. Even without an explicit concern for proposals, the need for working detectors when the machine becomes operational requires that many of the technical questions be answered immediately so that design for experiments may proceed.

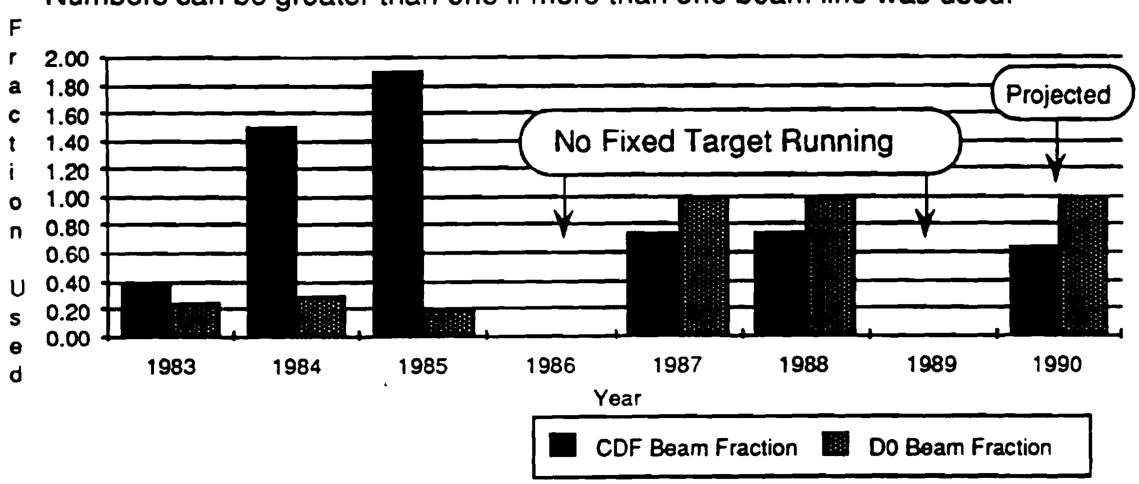
†This section was prepared by James R. Bensinger SSC Laboratory and Brandeis University

We foresee a steadily increasing need for test and calibration beams starting as soon as possible and continuing until well past SSC startup. Initially we expect a proof of principle type of test requiring only modest setup and perhaps sharing time in existing beamlines. After that we expect prototyping of partial or full modules, mostly calorimetry. When final designs are established there will have to be a substantial calibration effort with, in some cases, every module in an experiment being calibrated in a test beam.

The scale of this effort will vary with technology and the experiment but the experience of the current program at the Tevatron at Fermilab indicates that experiments at the SSC will require at least one dedicated beam line per experiment long before the experiments become operational. The history of beamlines used by CDF and D0 is shown in Fig. 1. After facilities are available at the SSC much of this effort will move to Texas; however, that will not be until after the mid '90's. Even at that time substantial effort will continue wherever resources have been developed. In order for experiments at the SSC to succeed, existing national resources must be quickly brought to bear on this problem.

Figure 1 **Fraction of Available Beam Time used by CDF and D0**

Numbers can be greater than one if more than one beam line was used.



Tracking chambers and a variety of specialized devices, in particular gamma dependent devices such as TRD's and synchrotron radiation detectors, will need test beam time at Fermilab. We expect, however, that the bulk of the beam time will be used for calorimetry testing. At the present time there is no one calorimetry technology of choice that has clearly demonstrated viability in the SSC environment.

Some problems common to all calorimeters include establishing the e/π response and resolution for the particular choice of absorber, sensitive medium, and readout strategy. Given a particular design, what is the optimum thickness and granularity of the electromagnetic calorimeter for pion rejection? What is the appropriate depth of the calorimeter for containment of the hadronic shower? Some of these issues would be able to be studied without a beam test, but usually one needs the environment of the accelerator to make sure everything is working properly. Other problems are indigenous to the particular detector type. These include:

Scintillator: With new classes of radiation resistant scintillators there is renewed interest in the use of this material for SSC calorimetry. What needs to be studied is the effect of radiation damage on real calorimetry modules. Test would include studies of both fiber and plate geometries. Useful tests to date have been on samples of bare scintillator. Issues include dose rate damage dependence, recovery, damage profiles in a calorimeter, electromagnetic vs hadronic shower damage, damage to optical readout systems, primary scintillation light loss vs transmission losses, and calibration of damaged regions.

Liquid Argon: We feel that the most important issue to resolve immediately is the question of what absorber will be used in the calorimeter. To some extent this is a simulation question. If e/π is 1.22 ± 0.1 (SLD), how will this effect the physics? Some people would say that the uranium/liquid argon results are excellent and the lead/liquid argon results have large errors and were done with shallow stacks. Since there is such a large price difference (and structural difference), it is crucial to measure precisely the e/π for lead/liquid argon as quickly as possible. What is needed is a beam test of a lead/liquid argon stack of sufficient size to undoubtedly contain the shower with fast (50 and 100 nsec shaping time) electronics in a beam of hadrons and electrons. To test the high rate capability, the intensity at some momentum should be $\geq 10^7/sec$. This test should be started within 1 year. In a somewhat later time scale (1.5-3 years from now), there will be real prototype modules for calorimeters with the right geometry to verify the performance of the device at high rates- noise, cross talk, etc.

Warm Liquid: This is the least understood technology but it is now at the stage where it is necessary to perform a major beam test. The first issue to be addressed is a comprehensive study of e/h compensation with warm liquids, as a function of absorber material and ratio of absorber-to-warm liquid. These results will provide important constraints on the Monte-Carlo models used to predict calorimeter performance, critical for this technology since there is so little experience with operational calorimeters. Warm liquid technology can only be considered viable with an "existence-proof" of a full-size warm-liquid calorimeter prototype (i.e., 10 interaction lengths deep and at least 0.6x0.6 meter squared transverse). This will require at least 2 years more of test-beam effort to study various realistic "swimming-pool" geometries, materials, and signal readout schemes for speed and signal -to-noise. There may need to be several design permutations tested in a beam. One possibility is the emergence of a hitherto ignored warm liquid with a higher mobility which is also safer than those being presently considered.

Beyond the soundness of the design and gaining operating experience with the detector are the issues of lepton identification (both electron and muon) and jet energy measurement and resolution. For leptons one is interested in the full energy range with particular interest in the high energy end. Jets are for the most part a collection of low energy hadrons (1 to 50 GeV). Thus, careful measurement of calorimeter response at low energies is important. Because some jets have leading particles an additional scanning with pions of all energies is also needed.

To study lepton identification the beams should go to the highest possible energy, with fluxes of 100 to 1000 Hz for each particle type (electron, muon, and pion) at that energy. The minimum flux at which useful data could be taken is about 1 hertz. The beam momentum bite can be quite broad as long as the particle momenta are individually identified. For hadrons much of the operation will be with a flux similar to the lepton studies except when studying issues of pile up. For this fluxes of 10^7 will be needed, although these could be at the lower energy. A typical resolution for sampling a electromagnetic calorimeter is $[15\%/\sqrt{(E)} \pm 1\%]$. This provides a severe constraint for beam instrumentation systems. Further, the e/π separation in the calorimeters is expected to be in the 100 to 1000 range. Thus the beam particle types should be identified to better than 1000:1. In particular, the electron content of particles identified as pions should be below this level.

For muons the issue is also how often pions look like muons either by not interacting or by hadronic shower punch through giving a muon signature. Here again the muon content of particles identified as pions should be below 1000:1. True muons can be identified by survival in or beyond the beam dump. The requirements for hadronic studies are somewhat less severe. Mass identification (pion, kaon, or proton) should at least cover the range 1 to 50 GeV with a 50:1 reliability.

Test beams of this kind are really only available at Fermilab. Thus the lab will play a critical role in the success of the U.S high energy program. To perform tests of this nature and to develop the technology and detectors that will be needed, several high quality test beams will have to be available for this work beginning with the 1992 fixed target run, these beams will continue to be needed for most of the decade.

7 Report of the Subgroup on Transition Radiation Detectors †

The decision to form a Transition Radiation Detector subgroup was made when, in our discussions, we realized that while each of us was investigating the use of this technique for a different experimental goal, the detector requirements were very similar. By pooling our ideas and our resources, we felt that we could more quickly come up with a viable design from which prototype modules could be constructed. Our intention is to have a prototype to test during the the latter part of the next Fixed Target run.

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We have available two Monte Carlo programs for TRD design studies. A preliminary cross check has indicated that they give similar results with similar inputs. More experiment specific Monte Carlos to generate momentum distributions both for the electrons and background pions over the regions to be covered, will be performed by each of us for our intended application. It is expected that differences from experiment to experiment may result in the need to tune the parameters slightly, especially in the construction of the radiators, but that the same basic design will be appropriate for all. The experimental applications being discussed, all for identification of electrons at the trigger level (i. e., within ~ 2 μsec) in a high rate environment, are for a CP violation experiment in a dedicated K-long beam at the Main Injector (Tschirhart), a Fixed Target beauty experiment (Errede), and a collider-based beauty experiment (BCD) covering both the central and forward regions (Sheaff).

The design we are working on is for TRD's that have the following properties:

They must be compact and present as little material as possible to traversing particles. This can be achieved with a "fine sampling"[1], TRD where many detector planes are interspersed with radiators containing a small number of foils to minimize the deleterious effect of foil self-absorption of the generated x-rays. Previous design efforts have concluded that TRD's made from radiators containing of order 20-50 foils followed by single xenon-filled chamber planes of depth 2-4 mm make optimum use of the allowed space and radiator material[1,2]. A π/e rejection factor of at least 100 and a high electron efficiency, ~90%, for particle momenta between 1 and 20 GeV/c can be realized in a total depth of order 30 cm, and an integrated radiation length of 2-3%. For the forward region of the B-Collider-Detector and for the Fixed Target beauty experiment which resembles it, more depth and radiator material can be allowed and more is needed to reject higher momentum pions.

They must be fast. Thus, the detector cell size must be small and the gas with which it is filled must have a reasonably high drift velocity. Drift times of 80-120 nsec are typical for cells with 2-3 mm drift space filled with xenon-CH_4 or xenon-methylal[3,4]. This is probably fast enough if the average cell occupancy is not too high (say, $\sim$ a few percent), but we intend to carry out tests using these gases in various ratios with an admixture of CF_4. Previous studies by others have shown that a factor of 1.5 to 2 speed-up in drift velocity (at least) can be achieved in such mixtures[5]. This would improve the rate capability of the device. Our current plan is to use straw tube chambers as fine sampling detectors[6]. Not only are the cell sizes small, but this design eliminates the need for thin large area windows at the interface between the chambers, which are filled with a xenon mixture, and the radiators, which are flushed with helium. Since the weight of xenon is so much greater than that of helium, large windows cannot be stretched tight enough to keep them from deforming at the bottom of the cells. In the case of planar cathodes where these windows are the cathodes, the cathode-wire separation increases toward the bottom of the cells which results in lower gains in this region.

Previous experiments have used thin interface volumes filled with CO_2, e.g., and have added helium to the chamber gas to make the weight of the gases in the two volumes the same[7]. This is not the best solution in that it doubles the number of windows and reduces the amount of xenon in the chamber gas, which makes it necessary to increase the depth of the detector cells to keep the x-ray absorption efficiency high (thus increasing the maximum drift times). In the case of wire cathodes, the windows bow out at the bottom of the cell creating a non-active volume filled with xenon outside the cathode wires, so that x-rays are absorbed where they can not be detected[8]. In addition, the high cost of xenon necessitates a closed recirculating gas system where differential pressures need to be controlled to better than 0.01 inches of water, which is difficult and expensive.

Straw drift tubes have been wound which are capable of withstanding pressure differentials of up to 10 atmospheres[9]. Thus it should be relatively easy to construct a cell array that is gas tight. We envision a double-walled box structure in which the tubes could be mounted which would be filled with helium in the inner volume and with the xenon mix in the outer volume. Mechanical design is one of the most difficult challenges to be faced. Not only must the system be gas-tight, but solid electrical connections must be made and the signals carried out in an orderly way for the very large number of channels involved. Since large area coverage is required for all the applications planned, ease of construction and relatively low construction costs are important to the mechanical design.

The electronics must be fast and integration times short to allow for the use of "cluster counting" techniques[10,11] in discriminating the TR x-rays from the typical signals due to passage of a minimum ionizing particle through the cell. Suitable circuits using discrete components already exist at the lab for use in our prototype tests[4]. The systems envisioned for use in the experiments have a sufficiently large number of channels to require use of large-scale integrated circuits containing amplifiers, shaping circuits, discriminators, and "bucket brigade" storage to hold the signals until the experiment trigger is received. Since there is already at least one initiative in the community to develop I. C.'s of this type suitable for use in wire chambers[12], we do not plan to duplicate this effort ourselves but will more likely use an existing chip design, modifying the parameters as appropriate for our application. In order to use the TRD in the trigger, and to match the signals in three dimensions to both track information and calorimeter towers, tests will be carried out on the possibility of using resistive plastic straws with pads etched on the outside in cylindrical shapes. Whether the signal shaping required to discriminate x-rays from typical track ionizations by "cluster counting" can be maintained in a pad readout scheme is a question of interest and will be studied.

Since the x-ray yield at each foil/helium surface is small, of order α, it is important to construct the radiators from materials which have been optimized to produce TR photons in the region of the x-ray spectrum where absorption in xenon is highest. We will make significant use of the Monte Carlo programs to aid us in this part of the design effort. Ease of construction favors the use of matting constructed of polypropylene (CH_2) fibers. A recent report indicates that such radiators are almost as efficient in producing TR x-rays as stacks of regularly spaced foils[13]. We intend to try both types, "dimpling" the foils to separate them in the case of the stack. Another possibility is to grade the foils, putting the thicker foils, which produce a stiffer photon spectrum than the thinner foils and which, because of their thickness, absorb more of the TR x-rays, upstream of the thinner foils. Since the absorption cross section for x-rays is larger at the low end of the spectrum, this choice of foil placement means that the lower energy photons produced by the thinner foils traverse as little material as is possible.

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