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SSC Detector Muon Sub-System Beam Tests

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We propose to start a test-beam experiment at Fermilab studying the problems associated with tracking extremely high energy muons through absorbers. We anticipate that in this energy range the observation of the muons will be complicated by associated electromagnetic radiation. Monte Carlo simulations of this background need to be tuned by direct observations. These beam tests are essential to determine important design parameters of a SSC muon detector, such as the choice of the

42
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tracking geometry, hardware triggering schemes, the number of measuring stations, the amount of iron between measuring stations, etc.

We intend to begin the first phase of this program in November of 1990 utilizing the Tevatron muon beam. We plan to measure the multiplicity, direction, and separation of secondary particles (mainly electrons) associated with the primary muon track as it emerges from an absorber. The second phase of beam test in 1992 or later (depending upon the Fermilab schedule) will be a full scale test for the final design chosen in our muon subsystem proposal.

1 Muon Measurement Simulations

High energy muons exiting steel toroid magnets are often accompanied by delta rays and electromagnetic shower remnants.⁽¹⁾ The fraction of clean muons decreases with energy as the processes of muon bremsstrahlung and direct pair production become more important (Fig. 1). Confidence in the Monte Carlo predictions of the spectra of these particles and of the multiparticle capabilities of the muon chambers is crucial to the design of the muon system.

The problem we are addressing is well illustrated by Figure 2 which shows a GEANT simulation of 100 GeV muons exiting an iron magnet and entering a set of argon-ethane chambers having aluminum walls. At the energies typical of SSC muons the problem of associated electrons cannot be ignored. We must be prepared to identify and characterize the muons in the presence of such electrons. The muons are seen to proceed along straight paths regardless of the intervening aluminum chamber walls. Because of absorption and scattering in the walls, the electrons on one side of a wall appear almost unrelated to those on the other side. As shown in Figure 3, background particles exiting the steel absorber typically consist of low multiplicity penetrating knockons and pairs of several MeV in energy with a broad angular distribution, accompanied by a fair number of X-rays and gamma rays. The electrons originate largely in the last few millimeters of the steel while the photons arrive from larger depths. Typically three quarters of the events containing background have only one or two excess charged particles. A chamber system able to distinguish several wide angle tracks from the muon track may effectively recover a large fraction of contaminated measurements, significantly reducing the number of required decoupled measurements.

The observed background track rate depends on the details of the chamber system. An energy deposition in the gas of only 1 KeV generates a hit, so careful attention must be paid to simulation thresholds in predicting these background rates. The spectrum and thickness dependence of the rate of knockons generated in

an aluminum wall typical of extruded proportional tubes are shown in Figures 4 and 5. Electrons below about 100 KeV do not make it out of the wall. In the gas itself (Fig. 6), there is about a 1% probability per cm of a knockon with range exceeding 1 mm. The Compton and photoelectric effect play an insignificant role in depositing energy in the gas of a typical chamber. The chamber system is largely transparent to the large soft photon component of the EM shower. Thus, the threshold may be typically as high as 500 KeV in the absorber, decreasing to 100 KeV in the wall and to 10 KeV in the gas itself.

To design an optimized detector for this regime requires a good Monte Carlo representation of the low-energy electron components associated with high energy muons. This is a region of little intrinsic interest generally disposed of by imposing a low-energy cut-off on both electrons and photons. Precisely because this region is commonly ignored it is important for us to confirm the detailed MC predictions by direct observations.

2 The Tevatron Muon Beam

The E665 Tevatron muon beam is normally tuned to a mean momentum of approximately $\bar{p}_\mu = 500 \text{ GeV}/c$. A measured muon momentum distribution is shown in Figure 7. The mean beam momentum can be tuned from 100 GeV/c to 700 GeV/c, which is the most interesting range for a SSC muon detector. Some of the parameters of the Tevatron muon beam used by E665 in 1987 are summarized in Tables 1 and 2.

Table 1. Tevatron Muon Beam (Typical)

typical $\bar{p}_\mu$	500 GeV/c
momentum spread (FWHM)	120 GeV/c
typical muon rate at 10^{12} proton/spill	0.5 MHz

Table 2. Beam Divergence

	horizontally	vertically
rms angular spread at BT4*	0.8 mr	0.5 mr
rms spread at BT4	2 cm	1 cm
rms spread at end of E665	3 cm	2 cm

* BT4 is the last beam tagging station at the entrance of the muon lab.

Although it is unnecessary to know the momentum of the muons on a particle by particle basis for this test, we plan to constrain the incoming muon trajectory

through the E665 beam spectrometer system by using the beam hodoscope information from E665. The mean beam momentum will be known quite accurately after correcting the average energy loss of muons in the E665 spectrometer (3 meters of iron and 3 meters of concrete). We would set up our apparatus downstream of the E665 absorber where there is approximately 20 meters of lab space available. We can debug the system using halo muons while E665 is running.

3 Detector

Our detector system consists of scintillating trigger counters, 4 stations of small drift chambers and absorber. Lead and iron of different thickness will be tested. A possible arrangement of the detector is shown in Figure 8. It will be located downstream of the Fermilab E665 experiment but upstream of the muon beam dump magnets. We request that Fermilab install concrete blocks both inside and outside the downstream radiation fence of the Muon Lab to allow us to place the detector at beam height. In addition, we request that Fermilab move the beam dump magnets 10m downstream of their present location.

3.1 Tracking

Multihit capability and extremely good two track resolution are key factors since we want to measure closely spaced tracks: the muon exiting from the absorber and other charged particles which may accompany it. Such capability is also very desirable in a SSC muon detector in order to find true muon trajectories and reduce ambiguities.

We plan to use four stations of multisampling drift chambers (jet chambers) following the design used by E665 for the vertex drift chambers which they are currently installing. The Seattle group has been involved in the design and fabrication of the E665 vertex chambers and will modify the existing design and fabricate the five (one spare) chambers needed for these tests. The chamber parameters are given in Table 3.

Because of the small size of the muon beam, the active area of the tracking chambers need not be very large. We choose a cell width of 2.75 in. (1.375 in. drift distance), which is the same as the large cell width in the E665, VCZ vertex chambers and allows us to use existing designs. We will have three cells in each chamber module with 6 sense wires in each cell. The total number of readout channels will be 18 for each module. The active area of the chamber will be 11 in. x 8.25 in. The chambers will have Al/Kapton windows so that we can introduce various thicknesses

of Al and other material to study the effect on the EM debris.

Of the four tracking stations shown in Figure 8, D1,2,4 define the muon trajectory and D3 measures the EM debris and our ability to sort out the muon track. Based on E665 vertex chamber performance we expect to achieve single wire resolution of $200\text{ }\mu\text{m}$ and double track resolution of $<2\text{ mm}$.

Table 3. Chamber Parameters

Number of sense wires per cell	6
Sense wire staggering	0.250 mm
Wire length	11"
Maximum drift distance	1.375"
Cell width	2.75"
Number of cells per module	3
Number of sense wires per module	18
Sense wire diameter	0.025 mm
Sense wire high voltage	1.0 kV
Sense wire tension	30-50 g
Cathode wire diameter	0.16 mm
Cathode wire high voltage	4.1 kV
Cathode wire tension	200 g
Chamber gas: Argon/Ethane	50/50

Table 4. ASIC Preamplifier Parameters

Number of channels per chip	4
Number of channels per board	16
Gain	1.5 V/pC
Bandwidth	30 MHz

Table 5. Hybrid Shaping Amplifiers

Number of channels per mother board	48
Signals return to base line:	25 ns

3.2 Electronics and Data Acquisition

We plan to use the E665 vertex drift chamber front end electronics. This system uses specially designed high gain/low noise ASIC preamplifier chips mounted on the chamber frame. Signals from the preamplifiers are sent to shaping amplifiers and discriminators and eventually readout by LeCroy fastbus TDC's.

The DaQ system for the SSC Muon Sub-System test beam studies in the E-665 muon beam at Fermilab will be provided by the experimenters.

The DaQ system for the SSC muon test stand will probably be located out on the floor of the new Muon Lab (outside the radiation fence) but as near to the test

stand as possible, in order to minimize cable runs. Space will be needed for the relay racks and associated equipment, as well as table/work space/terminal area, file cabinets, book shelves, etc.

The trigger for the initial muon studies will be formed simply from a multiplicity coincidence of several scintillation counters in the muon beam and the absence of signals from beam halo veto counters. Data-taking will NOT be interrupt driven for simplicity, and will thus be relatively slow. Once a trigger is generated, a common stop/inhibit will be generated for the FASTBUS TDC's, ADC's, Scalers, etc. The data will then be read out and packed into a specified event record format, most likely being written initially to a file on disk (and then copied to 8mm cassette tape after a run), or written directly to 8mm tape. Copies of the data taken in these muon studies will then be made locally using the 8mm dual cassette tape drive and distributed to all interested members of the collaboration for their own data analysis, along with code to read and unpack the events into a suitable format.

The DaQ system for the muon beam test stand will initially be debugged using cosmic ray muons and then with real beam. Once the DaQ system has stabilized and the beam-on operating environment in the Muon Lab is better understood, more sophisticated triggering schemes (e.g. using prompt hit information from the drift chambers) could be attempted for additional and more detailed studies, e.g. of the trigger efficiency for various hardware triggering schemes.

3.3 What Can We Study?

The prioritized goals of our 1990 test are:

1. Studying the number, energy and angular distribution of charged particles emerging from the absorbers along with muons and their dependence on muon energy, the type of material, material thickness, etc. This allows us to tune the Monte Carlo which we will use for designing the SSC muon system.
2. Studying the efficiency of muon track reconstruction and the smearing of the resolution due to secondary, accompanying charged particles for different types of tracking devices.
3. Testing prototype trigger schemes and their implementation. With this apparatus we can test both "bend angle" triggers which make a cut on the muon bend angle and "sagitta triggers" which make a cut on the sagitta of muons in a magnetic field. The latter requires a minimum of three measurements.
4. Test Čerenkov Triggers (lucite, gas, etc)

References

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List of Figures

1. Energy dependance of the fraction of "clean" 100 GeV muons exiting a 50 cm thick 1.8 Tesla steel magnet from a GEANT simulation with 1 MeV threshold. The —, X and boxes give the fraction with less than or equal to zero, one and two extra particles respectively.
2. GEANT simulation of a 100 GeV muon exiting a magnet into a set of chambers consisting of Argon-Ethane gas contained by aluminum walls.
3. Noise particle rates for 1000 muons of 100 GeV exiting a 50 cm thick 1.8 Tesla steel magnet with .5 MeV threshold.
 - a) Distribution of excess charged particle multiplicity.
 - b) Distribution of photon multiplicity.
 - c) Charge particle energy spectrum (GeV).
 - d) Photon energy spectrum (GeV).
 - e) Projected angle distribution of charged particles in the direction of the magnetic field.
 - f) Projected angle distribution of charged particles in normal to the magnetic field (Radians).
 - g) Projected spatial distribution of charged particles (cm).
 - h) Projected spatial distribution of photons (cm).
 - i) Location of production event for charged particles (cm). The plane $Z=0$ is the face of the magnet.
 - j) Location of production event for photons (cm).
4. Integral energy spectrum of electrons knocked out of a 1 mm thickness of aluminum by 100 GeV muons. The probability of a knockon exceeding an energy threshold is plotted versus threshold.

5. Probability that a 100 GeV muon knocks out an electron exceeding 1 KeV in kinetic energy from an aluminum wall as a function of wall thickness.
6. Integral probability for the production of knockons exceeding an energy threshold by muons in traversing 1 cm of Argon-Ethane gas.
7. Measured momentum distribution of E665 muon beam.
8. Arrangement of the detector.
 - a) Possible arrangement of our detector downstream of E665 absorber.
 - b) Enlarged view of set-up.

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Figure 1

Figure 2

NUM CHARGED

NUM PHOTON

E CHARGED (GeV)

E PHOTONS (GeV)

THETAx CHARGED (rad)

THETAy CHARGED (rad)

X CHARGED (cm)

X PHOTONS (cm)

Delta Ray Kinetic Energy Threshold (keV)

Figure 4

Figure 8b

SSC
LABORATORY

Memorandum of Understanding

between

**The Liquid Argon Calorimeter
Collaboration**

and

**The Superconducting Super Collider
Laboratory**

FY 1990

MEMORANDUM OF UNDERSTANDING FOR FY 1990

between

THE LIQUID ARGON CALORIMETER COLLABORATION

and

**THE SUPERCONDUCTING SUPER COLLIDER
LABORATORY**

This memorandum of understanding between the Liquid Argon Calorimeter Collaboration and the Superconducting Super Collider Laboratory (SSC Laboratory) is established to develop liquid argon calorimeter technology for possible use in future SSC detectors. This memorandum is intended solely for the purpose of providing a budget estimate and a work breakdown for the SSC Laboratory, the funding agencies, and the participating institutions. It reflects an arrangement which is currently satisfactory to the parties. However, it is recognized and anticipated that changing circumstances of this evolving research and development program will necessitate revisions. The parties agree to negotiate amendments to this memorandum that will reflect such required adjustments. A short summary describing the research objectives of this experiment is given in Appendix I.

A. Personnel (see Table 1 for a list of physicists)

- Collaboration contact person: Howard Gordon, BNL
- SSC liaison person: Thomas Dombeck

B. Equipment

- Listing of all expenses except physicist salaries: (Refer to Table 1.)

C. Test Beam Requirements

We intend to use a beam of π 's and e 's of momentum 0.5-20 GeV/C at BNL in FY91. We are in the process of discussing this with BNL.

D. Special Considerations

- The contact person or his representative will be responsible for any borrowed equipment and its timely return and designation of responsibility for maintenance of equipment provided by home institutions or SSC-borrowed equipment.
- Computing requirements will be met using existing computers with the exception of the DAQ computer for the test beam work. This is estimated to be \$41K and will either be borrowed or purchased in FY91.
- The experimenters will provide a bi-yearly written report on the progress made during the previous 6 months, including any modifications in scope, milestones or budget estimates.
- Funding for the project will be provided in allocations of a single year, with each successive year's funding dependent on successful progress to date as determined by an appropriate review process.

E. Milestones

- Start of Funding: Start of design of lead stack, associated electronics and cryostat. Start of work on electrode structures both using ferrite transformers and "electrostatic transformers." Start of study on how to shield ferrite transformers. Start of simulation effort.
- 9 months after start of funding: Cryostat complete. Start of stacking of lead test beam modules. Start of checkout of electronics. Results on shielding of ferrite transformers.

- 1 year after start of funding: Beam test of lead modules. Start of fabrication of prototype module with proper electrode structure for SSC.

F. Reporting

The collaboration will provide the SSC Laboratory with copies of all talks and publications resulting from this R&D project. A written report on the progress to date, with a projection of work and a budget for FY91, will be provided to the Laboratory by the beginning of September 1990.

G. Budget

The institutional budgets are shown in Table 1.

The SSC Laboratory has participated with DOE in identifying and selecting the Liquid Argon Calorimeter project for funding. It is expected that the DOE/OSSC will provide the Liquid Argon Calorimeter Collaboration with \$83K of operating funds and \$694K in equipment funds in FY 1990 for the above described detector R&D project. In addition, \$125K in FY 1990 operating funds is being sought by the Collaboration from the DOE/HEP division.

H. Signatures

The undersigned have agreed to fulfill to the best of their abilities the terms of this SSC memorandum of understanding between the Liquid Argon Calorimeter Collaboration and the Superconducting Super Collider Laboratory.

AGREED

Liquid Argon Calorimeter Collaboration

Date

Howard Gordon /dk

02/22/90

Howard Gordon

Brookhaven National Laboratory

R. Z. Schwitters

2/29/90

R. Schwitters, Director
SSCL

Appendix I. Physics Goals and Motivation

We propose to build a prototype lead liquid argon hadronic calorimeter. We will measure the performance of this device at shaping times of 50, 100 and 150 nsec and compare the results to those from NA34 (HELIOS) using uranium liquid argon with 100-nsec shaping time. Initially, we would test the device in a beam at BNL. We will design the electronics so that it may also be used for tests at Fermilab energies. Most of the funding in FY90 will be for this test stack. The proposed calorimeter stack will be approximately 100 cm $\times$ 100 cm with a depth of 169 cm (7.5 λ). It is segmented into three longitudinal sections, each weighing about 5 tons. Lead that is 12 mm thick, with 0.06% calcium and 1.3% tin added for hardness, will be used as an absorber. Each section contains 32 cells, each made up of a lead absorber, a 2-mm argon gap, a 1.6-mm G-10 printed circuit signal board, and another 2-mm argon gap. The signal boards will each have forty 2.5-cm strips. These strips alternate in X and Y. The interleaving of the X and Y strips provide information about the transverse profile of the shower and a measurement of the sampling fluctuations. The connection scheme and coupling transformers will follow closely the HELIOS method of achieving low-inductance charge transfer to the preamplifiers. The preamplifiers will be designed around an input JFET developed jointly by BNL and Interfet, Inc., which operates in liquid argon.

The external electronics consist of an intermediate amplifier stage and shaping and summing amplifiers. The intermediate amplifier stage is attached to the outside wall of the calorimeters cryogenics containment vessel, very close to the signal feedthroughs. A good electrical and mechanical connection between the vessel and the intermediate amplifier housing defines a Faraday cage containing the stack, preamplifiers, and intermediate amplifiers. Besides driving the signal cables, the intermediate amplifiers provide two fixed gains. This minimizes the dynamic range required for succeeding electronics and allows the same electronics chain to be used for tests at both the AGS and Fermilab energies. Signal cables are transformer-coupled at the output of the intermediate amplifiers to provide electrical isolation and to break ground loops.

Following the intermediate amplifier is a Fastbus-size printed circuit board which contains 24 channels of variable gain amplifiers, summing electronics, and shaping amplifiers. The variable gain amplifier stages are controlled by an onboard microprocessor. This microprocessor accepts gain information for the individual channels via a RS-232 port. Gain is adjustable over a $\pm 20\%$ range. Individual channels are normalized to a fraction of a percent by injecting a known charge via precision resistance inside the stack. One can also turn off individual channels at this point to aid in normalizing the gain per channel, test the cross talk, or to suppress noisy channels. The signal from the variable gain amplifiers is routed to two circuits. One circuit is a shaping amplifier with a fixed shaping time of 100 nsec. The output from these channels is readout via a CAMAC-based ADC system. The second circuit is an onboard summing amplifier. The 24 signal channels are summed at this point. It is important to note that the fast shape of the output signal from the stack preamplifiers is preserved throughout this chain. The output sums of the 24 channels are then summed again

in X and Y. The X, Y and total sums go to individual shaping amplifiers with changeable shaping times between 50 and 200 nsec.

In parallel with the beam tests, we will initiate a program that will lead to being able to design modules for the SSC. Two aspects of this are crucial. First are improvements to the HELIOS electrode structure. That structure has two deficiencies for SSC calorimetry; it uses strips rather than towers and the ganging of signal longitudinally is carried out in a relatively large volume at the side of the active area. For the SSC, the electrode structure must allow modules to be placed with a minimum of dead material between them. Second may be the necessity of operating the modules in a magnetic field.

Two parallel paths will be pursued towards these goals. BNL, Rochester and Michigan State will explore extensions and modifications of the HELIOS design using shield ferrite transformers. LBL will pursue the electrodes for a liquid argon detector based on the "electrostatic transformers."

We plan to start by building room temperature table-top "models" of several fundamental types of towers, designing and testing the readout characteristics. The "ionization current" in such a setup can be simulated by a photodiode triggered by a laser. Except for the temperature, such a model should be an exact replica of a section of the actual detector.

Ferrite transformers saturate and become useless in a magnetic field ($>0.03T$). Thus, one also has to investigate whether and how one can shield the transformers against a field of 2T. The Rochester/BNL group has started to study and test a multiple shielding system using the "Russian Boxes" principle. These studies have to be continued in great detail, since the whole system of "cold transformer/preamplifier" hinges on the possibility of using it in the presence of a magnetic field.

These designs will be supported by calculations using SPICE and magnetic field maps.

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