Proposal To Build a Very High Rate Calorimeter to be Operated in Conjunction with Experiments E706 and E672

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INTRODUCTION

One of the great concerns associated with the proposed SSC is the question of whether or not one can do physics at a luminosity of 10^{33} ($10^8 s^{-1}$ and $\geq 10^7$ R/yr at small angles). To date there has been a good deal of discussion concerning instrumentation for the SSC, but little real effort along those lines.

This proposal is to construct a sampling calorimeter, to be positioned between the equipment provided by experiments E706 and E672 that will work at an expected rate of a few times $10^7 s^{-1}$. The calorimeter would use uranium as the converter material, and BaF_2,coupled to a low-pressure, photosensitive wire chambers, as the active elements.

The purpose of this instrument is to develop the technology needed for very high rate detectors of the future, as well as enhance the physics of experiments E706 and E672 at Fermilab.

BaF_2 SCINTILLATOR

BaF_2 has several properties that make it unique among crystal scintillators (see Table I for a short list of properties of BaF_2 ,BGO and NaI(Tl)) [1,2]. The first is that it has two emission spectra. The "short" or "fast" component, with a peak emission at 225 nm, has a decay constant of only 0.6 ns. This is about 500 times faster than BGO and NaI(Tl). BaF_2 is also the only solid scintillator to have been successfully coupled to a photosensitive wire chamber. This technique, which is only sensitive to the fast scintillation component, allows for a great deal of flexibility in construction and readout schemes, as well as operation in a magnetic field.

Table I

Properties of three scintillators

	BaF_2	BGO	NaI(Tl)
Density (g/cm^3)	4.9	7.1	3.7
Radiation length (cm)	2.1	1.1	2.6
dE/dx (min.)(MeV/cm)	~6	8	4.8
Peak emission (nm)	225 310	480	410
Decay constant (ns)	0.6 620	300	250
Temp. dependence (%/^{o}C)	0 -1.3	-0.96	small
Index of refraction	1.56	2.15	1.85
Light yield (photons/MeV)	$2x10^3$ $6.5x10^3$	$2.8x10^3$	$4x10^4$
Radiation Hardness	very high	fair	poor
Hygroscopic	No	No	Yes

BaF_2 is the most radiation hard of all the scintillators [3,4]. Samples

of BaF_2 have been exposed to as much as 10^8 R, with little noticeable effect. The crystals appeared to be self anealing, recovering almost completely from the irradiation in about two days. Finally, the light output of the short component of BaF_2 is not affected by temperature, at least in the range of interest, while the scintillation light of BGO varies by -1%/°C. In principle, This temperature stability makes BaF_2 much easier to calibrate.

WIRE CHAMBER READOUT

There has been a considerable amount of effort, over the last few years in the development of photosensitive wire chambers for the readout of BaF_2 [5-11]. The photosensitive agent in these chambers is tetrakis(dimethylamino)ethylene, TMAE, with an ionization potential of only 5.4 eV. Although the overlap of the emission spectrum of BaF_2 and the absorption spectrum of TMAE is not great, the system has proven to be quite successful. This type of readout has a clear advantage over PMTs, in that of being insensitive to the "slow" component of BaF_2, thus allowing operation at much higher rates.

The best results have been achieved with low-pressure wire chambers, operated at 3-20 Torr. The low pressure allows the chambers to operate at rates of more than two orders of magnitude higher than that of proportional counters at 1 atm pressure. This is because the positive ions drift several hundred times faster in the low pressure gas.

Low pressure is advantageous for photosensitive detectors because the associated chambers are insensitive to the passage of minimum-ionizing particles, and thus only sample the uv photons produced in the BaF_2. This allows their use in a sampling calorimeter, where the

charged particles, produced in the development of the shower, pass through them.

A final advantage of low- pressure chambers as fast photon detectors is that the amplification is almost parallel plate amplification, whereas the amplification in chambers of higher pressure is localized to the wires. Thus, at low pressure, the sensitive volume can be very thin. Only the photoelectrons that are produced near the cathode receive full amplification. This is important since the light from the BaF_2 is absorbed in several millimeters of TMAE, and if there were full sensitivity to all the photoelectrons, the signal risetime would be in the 60-100 ns range. This would be too long for our purposes.

One problem with TMAE as a photosensitive gas is that it has a low vapor pressure (~0.35 Torr at 20°C) [5] and an absorption length of about 20mm. This shortcoming has been overcome by using low pressure wire chambers, and by operating the chamber at higher temperatures. The TMAE vapor pressure is increased by factors of 5.6 and 10 at 45°C and 55°C respectively, with corresponding reductions in absorption lengths for the uv photons.

BaF_2 WITH WIRE CHAMBER READOUT

The development of BaF_2 with a wire chamber readout has, over the years, gone through many phases. In the early designs, TMAE was condensed as a thin film on a cold plate, thereby providing the first liquid photocathode ever reported [6]. An instrument of this kind [7] was shown to be able to produce a signal that was only about 25ns at the base. A timing resolution or 520ps FWHM was measured for 350 MeV alpha particles.

The next major step in the development of the instrument was a fully

absorbing electromagnetic calorimeter consisting of 14 BaF_2/wire-chamber units, shown in Fig.1 [9]. The BaF_2 crystals were 12cm in diameter and varied in thickness from 1-5cm. Figure 2 shows the pulse height spectra for 108MeV and 200Mev electrons, that were measured with

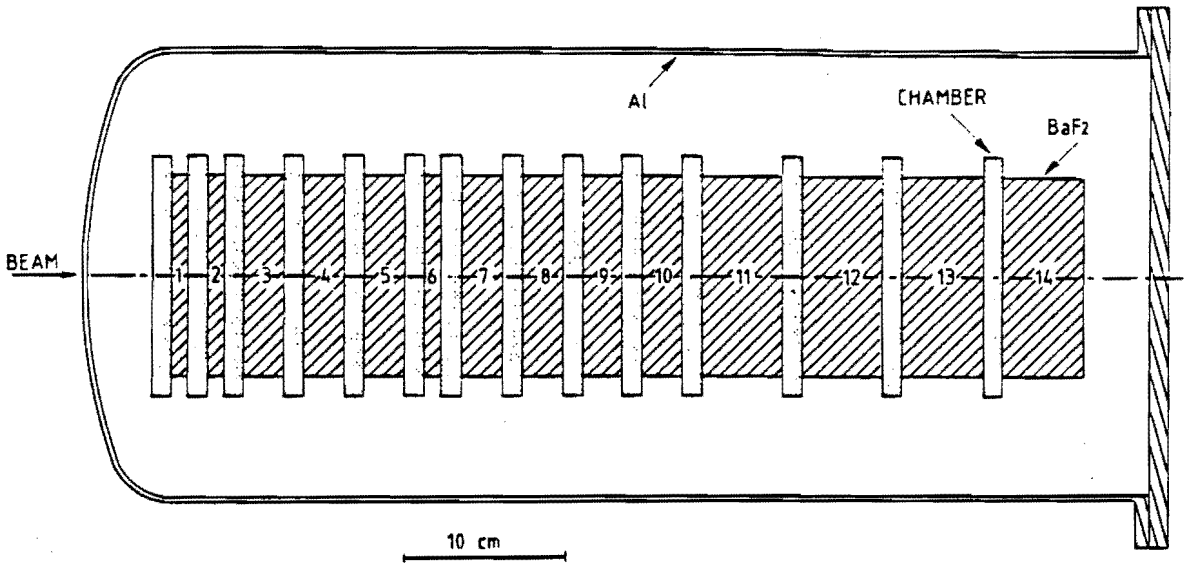

Fig.1 BaF_2 Calorimeter.

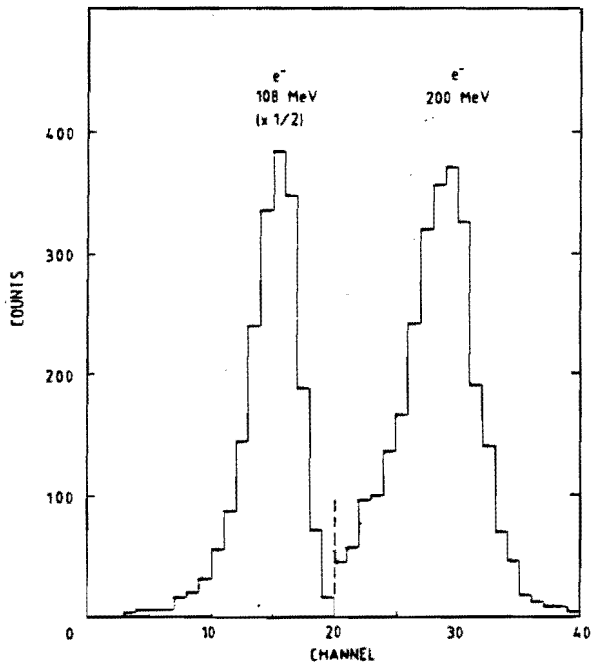

Fig.2 Pulse-height distribution for 108MeV and 200Mev electrons.

this instrument. When corrections were made for leakage from the calorimeter, a resolution or $\sigma/E=2.5\%/\sqrt{E}$ was obtained. This instrument allowed both the longitudinal and lateral shower development to be measured, as shown in Fig.3. (The new measurements made with this instrument by Charpak's group will be discussed at the presentation [13]).

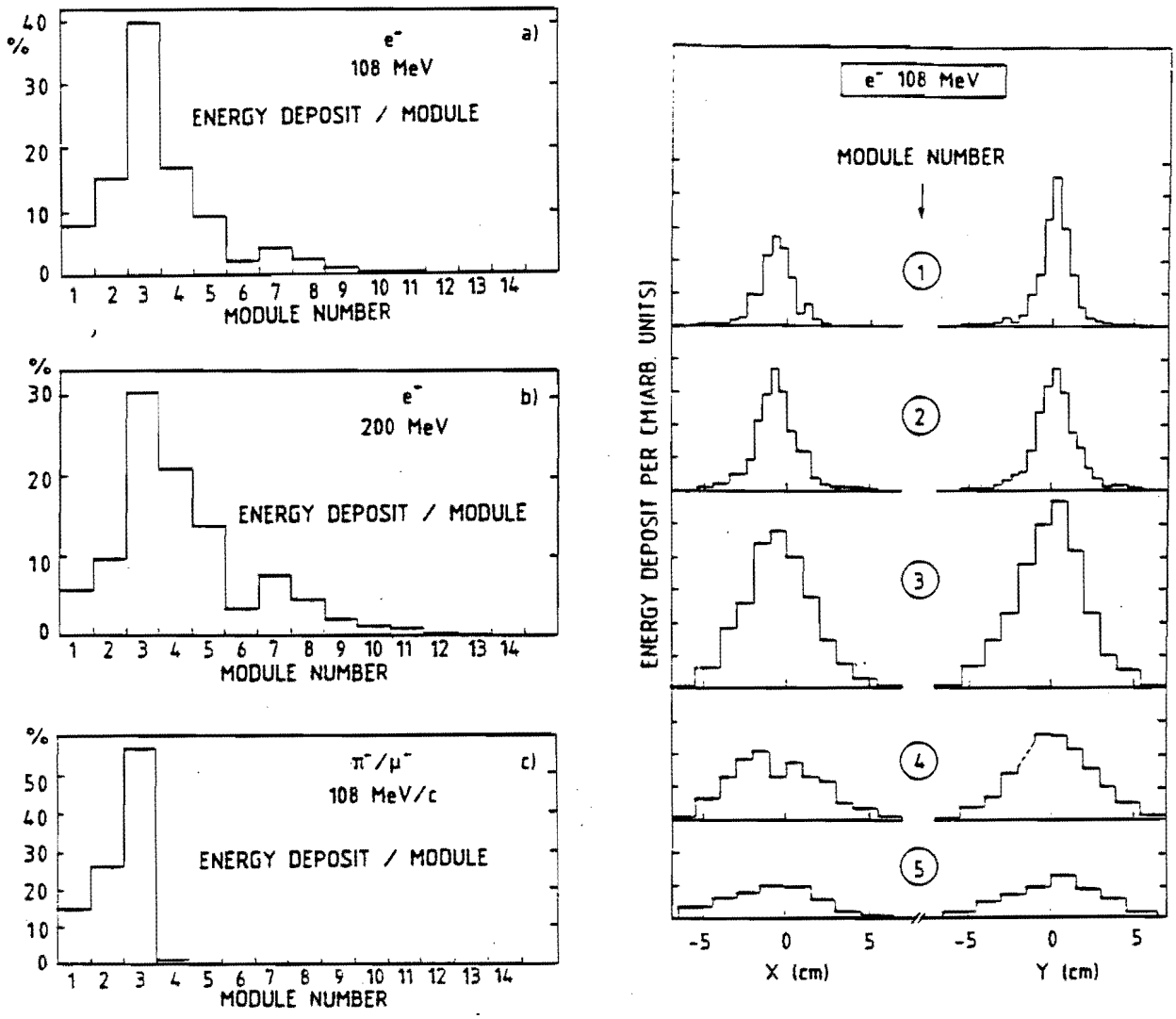

Fig. 3 Energy deposited per sample for 108MeV and 200Mev electrons and for 108MeV Pions. The second figure shows lateral shower development for 108MeV electrons in the first 5 samples.

The most recent work has been performed by Craig Woody at BNL and this author. The BaF_2 crystals used had a hexagonal cross section, 5cm face-to-face, with lengths that varied from 11-15cm. The main objectives of the tests where to see how short a signal could be obtained with the induced signal from a cathode pad, where capacitance is a problem; to measure how low the threshold could be set in a real instrument; and to study the effect of increased temperature on timing and energy resolution.

Figure 4 shows the signals from a burst of minimum-ionizing particles (pions). The signals are taken from a $25cm^2$ cathode pad and are a little over 20ns at the base. Later work has shown that, with some improvements to the electronics, this width can be reduced to about 15ns. This shows that a cathode pad readout, which lends itself to large structures, can be used in a high rate environment.

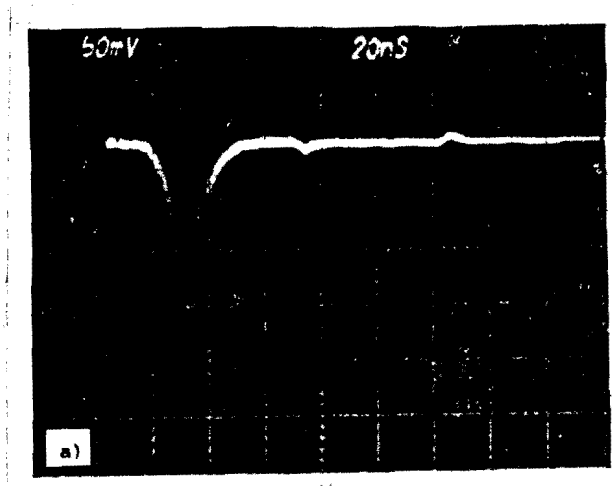

Fig.4 Signal from a burst of minimum-ionizing particles.

Because the tests at BNL were also directed at using BaF_2 as a low energy photon veto for a rare K decay experiment, the threshold was an important parameter. This was found to depend on the TMAE temperature,

and varied from a threshold of 2.5MeV at 20°C to 0.5MeV at 40°C.

PROPOSED CALORIMETER

A schematic of the proposed calorimeter is shown in Fig.5. It consists of three sections: electromagnetic, fine hadronic, and course hadronic. All sections will be operated in a common gas volume. Some of the specifications are listed in Table II. The converter will be made of square plates of uranium, 22cm on a side, "canned" in some material such as copper. The active components will be 1cm-thick disks of BaF_2, 17cm in diameter, followed by thin wire chambers. The total length of the instrument will be about 2 m.

The expected energy resolution of this instrument in this experiment is about $70\%/\sqrt{E}$ for both sections. The poor resolution of the electromagnetic section is largely due to material in the beam that is located before the calorimeter.

The electromagnetic section of the calorimeter would consist of 25Xo, divided into 5 samples. Unlike the rest of the calorimeter, the first two samples of this section would have lateral subdivisions in order to look for multiple particles, and to measure P_T. The expected single-particle resolution is about 2mm, and a two particle resolution of about 20mm. The remaining samples of the calorimeter will only yield energy information.

The hadronic sections contain a total of 11λ of uranium. The fine hadronic section contains 5λ, divided into 22 samples, while the course hadronic section contains 6λ divided into 8 samples.

There will be a total of 35 longitudinal samples in the calorimeter and 45-55 channels of electronics. The electronics that will be used have been developed by V. Radeka at BNL. The preamp is the same as the one

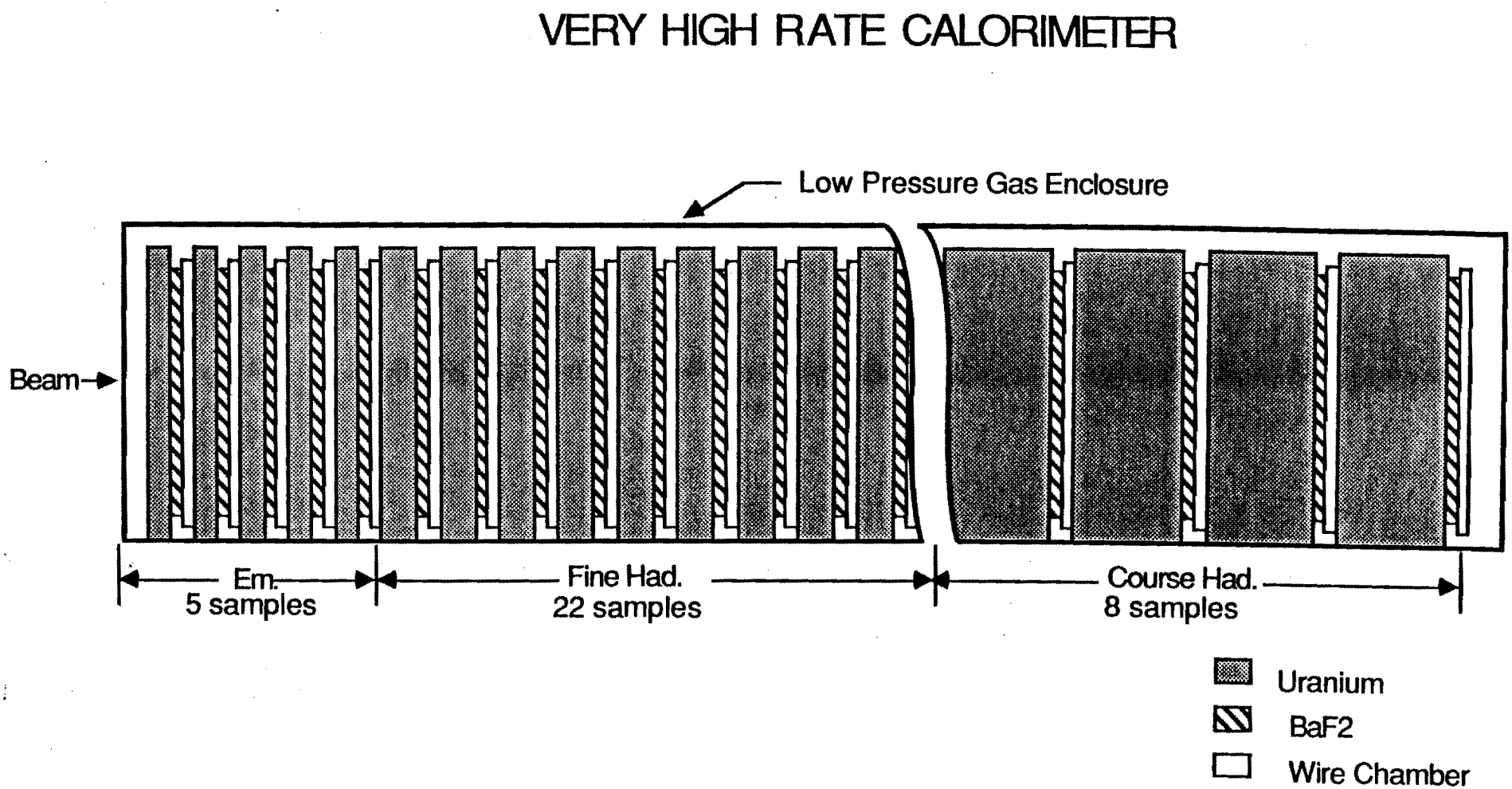

Fig. 5 Schematic of the proposed calorimeter.

Table II

Calorimeter Specifications

BaF_2

Diameter	17cm
Thickness	1cm

Proportional Counter

Cathode-to-anode	3mm
cathode	mesh
Anode	15μm wires, 1mm pitch
Gas	TMAE + isobutane or alcohol
Pressure	3-10 Torr
Readout	5mm cathode strips - first two samples anode - all other samples

Uranium	**E.M.**	**Fine Had.**	**Course Had.**
no. of samples	5	22	8
no. of X_0	25	--	--
no. of λ	0.8	5	6
thickness (cm)	1.6	2.5	7.5

used on the forward chambers for CDF. The second stage is a fast, delay line clipping, double pole zero amplifier developed for very high rate proportional counter applications.

E706

Experiment E706 will potentially benefit in three important ways from the availability of a fast BaF_2 calorimeter downstream of their liquid argon calorimeter.

1. The beam-muon background in M-West is anticipated to be several percent for negative-particle running (private communications from

R. Coleman). For the positive beam, when utilizing a hadron filter to increase the π^+ fraction in the beam, the muon contribution would increase substantially. Because, in E706, absolute yields must be measured to an accuracy of <20%, they must be able to ascertain the muon component of the beam. The proposed BaF_2 calorimeter would provide them with the capability of tagging muons in the high-intensity ($\geq 10^7$ s^{-1}) environment of E706.

2. Through measuring the energy deposited in the BaF_2 detector the experiment would be able to tag large-P_T events that have multiple-beamparticles. This information would help minimize contamination of π^+ (Cherenkov tagged) data from overlapping proton-induced events. An accurate absolute normalization of the π^+ yield is crucial to the extraction of the $q\bar{q}\rightarrow\gamma g$ reaction, a major goal of E706. Also, the availability of the BaF_2 calorimeter would provide a way of eliminating multiple-beam events at the trigger stage, thereby reducing unnecessary off-line computing time.

3. In their study of high-twist contributions to the direct photon signal, it would be of great value to measure directly the energy (or P_T) lost in the hole of the E706 downstream iron-scintillator calorimeter. This can be obtained from the BaF_2 detector, and thereby improve the efficiency of the search for such higher-twist events.

One of the long-term interests of the E706 experimenters is to search for exotic hybrid mesons through the investigation of $\pi^{\pm}$-nuclear interactions in the Coulomb field. This technique appears to be exceedingly promising, and particularly well suited to Fermilab energies. The idea is to excite $J^{PC}=1^{-+}$ mesons via the $\pi^{\pm}\gamma$ channel, and observe them

in $\pi^{\pm}\eta$, $\pi^{\pm}\eta'$, $\rho^{\pm}\eta$, or $\pi^{\pm}\pi^{o}$ modes. This requires a small, fine-grained, and fast electromagnetic calorimeter of the BaF_2 type. E706 plans to do trigger studies with this detector in order to judge the feasibility of the experiment.

E672

The BaF_2 calorimeter would benefit E672 by reducing background problems for the dimuon system. The 1984 test run indicated large backgrounds from shower remnants and particle scatters off the calorimeter and toroid walls. To remedy the problem they added more shielding and reduced the toroid hole. However, the forward E706

calorimeter with a small beam hole of 1.25 in. could be a new source of background. The BaF_2 calorimeter, acting as an active beam dump should protect E672 from background, and also reduce the amount of shielding necessary between the chambers, thereby decreasing multiple scattering of the muons and extending the accepted momentum range.

The overall acceptance will be reduced by no more than 5% as a result of moving the dimuon system 7 feet downstream.

FUTURE: SSC

Last year the SSC Central Design Group set up a Task Force on Detector Research and Development, chaired by Gilchriese. The Task Force summarized its report [14] by recommending that a vigorous program of basic generic research and development for SSC detector-needs should begin within the year. This should have as its highest priority the investigation of those areas which will involve major detector

subsystems at the SSC, and those areas which require solutions of problems unique to the SSC environment. Such areas include radiation damage studies of all relevant devices, increases in speed of tracking and calorimetric detectors and of associated electronics, new methods of particle tracking and calorimetry in high particle-fluxes, and cost reduction of electronics.

With the exception of cost reduction of electronics, the proposed BaF_2 calorimeter addresses all of the above mentioned areas of highest priority. The existence proof of such a detector would demonstrate that physics can be done at a luminosity of 10^{33}.

COST AND MAN POWER

The estimated costs of building the proposed BaF_2 calorimeter are listed in Table III.

The man power to be be provided by the Particle Detector Group, E706, and E672, will be discussed at the presentation.

Table III

Estimated Costs

Item	**Cost($)**	**Total(k$)**
BaF_2	37 @ 1585	58.6
uranium		10.0
electronics		
analoge	55 @ 160	8.8
ADC (FERA)	55 @ 85	4.7
TDC	55 @ 53	1.9
vacuum chamber		15.0
gas system		15.0
cables etc.		5.0
technician (0.5 yr)		15.0
TOTAL		**134.0**

TIME SCALE

Anticipating approval of the project by January 1, 1987, the proposed instrument should be completed in 10 months. This will make it ready for installation in time for the fixed target run scheduled for early 1988.

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