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CsI CALORIMETER DEVELOPMENT FOR A HIGH-PRECISION, GENERAL -PURPOSE DETECTOR FOR A TAU-CHARM FACTORY‡

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Abstract

Design, fabrication techniques, and preliminary test results for a CsI calorimeter for the Tau-Charm Factory (TCF) proposed for construction in Spain are presented. Selected CsI calorimeter studies undertaken by the U.S. Tau-Charm Collaboration, including simulations of machine-induced detector backgrounds in the CsI calorimeter, radiation damage characterization of CsI(Tl) and CsI(Na) crystals from five manufacturers, crystal segmentation and photodiode/wavelength shifter readout schemes, and development of mechanical support structure, are reviewed. A test of a prototype CsI calorimeter conducted in the TRIUMF in M11 (120-400 MeV) and M13 (30-120 MeV) beamlines is discussed.

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The Tau-Charm Project

The TCF is conceived as a high luminosity e^+e^- collider operating in the center-of-mass energy range of 3-5 GeV, with a high-precision, general-purpose detector. Its purpose is to make measurements involving the tau lepton (τ), tau neutrino (ν_τ), and charm quark (c), utilizing high statistics and the powerful constraint of full event reconstruction. The design luminosity of 10^{33} $cm^{-2}s^{-1}$ represents an improvement of two-to-three orders of magnitude over previous machines operating in this energy region. Likewise, the TCF detector, designed to be uniform in precision for measurements of all particles and fully hermetic, constitutes a substantial improvement in detector performance compared with other detectors used in this energy regime. (Figure 1.) A CsI barrel calorimeter ($|\cos\theta| \leq 0.95$) plays a central role in the τcF detector, since it facilitates high precision energy and angular resolution for particles that interact electromagnetically. These features are particularly important for detecting low energy (~10 MeV) photon showers and for e/π separation. A forward calorimeter made of BaF_2, coupled with a silicon tracking system, will give veto capability and close the calorimeter to $|\cos\theta| \leq 0.99$.

CsI Electromagnetic Calorimeter

The electromagnetic calorimeter will consist of ~10,000 CsI(Tl) or CsI(Na) crystal towers arranged in a unique, reentrant geometry (pointing toward the interaction region). To facilitate e/π separation and rejection of fake showers from neutron albedo, each crystal tower will be longitudinally segmented. A tower will consist of one or four front crystals of $\sim 4X_0$ depth, and one back crystal of $\sim 12X_0$ depth. (Figure 2.) All crystals in a tower are optically separated, and read-out of each is accomplished with two-four PIN photodiodes affixed to wavelength-shifting plastic. Multi-channel preamplifier circuitry contained within application-specific integrated circuits is mounted at the back of each crystal tower, for all photodiodes within the tower. The support structure for the crystals is made of low-mass composites organized in modules of ten crystals. The material preceding the CsI calorimeter is 10 cm of time-of-flight scintillator, a fully active medium which does not compromise calorimeter performance.

The calorimeter performance specifications are:

$$\delta E/E \sim 1\%/E^{1/4} + 1\% \quad (1)$$

$$\delta E/E \text{ (int. calib.)} < 0.25\% \quad (2)$$

These compare with $\delta E/E \sim 17\%$ for MARK III and BES, and $\delta E/E$ =

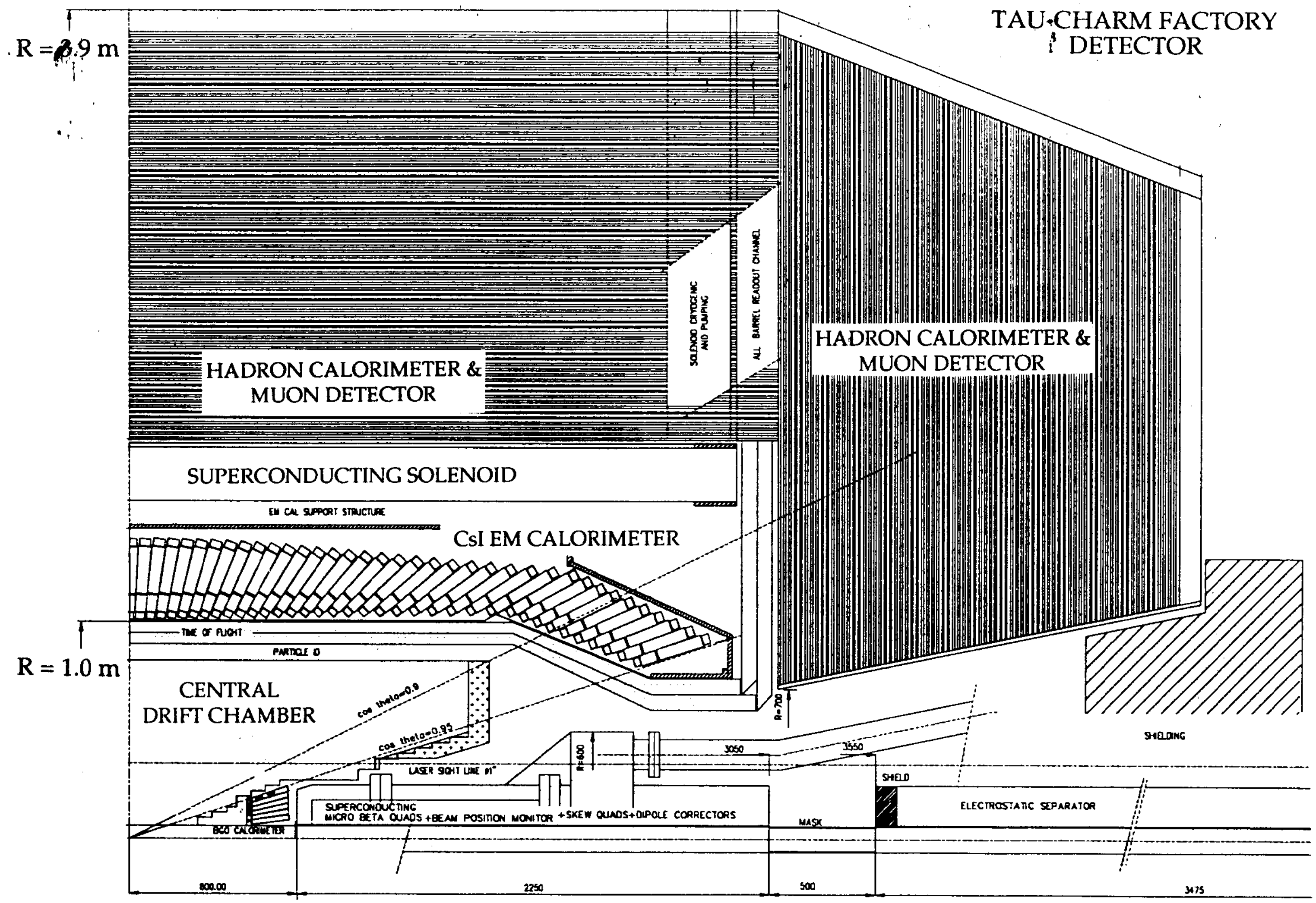

Figure 1. Side view of τcF detector showing detector subsystems, including low-Z gas drift chamber, time-of-flight scintillator, CsI crystal system, magnet, hadron calorimeter, and forward calorimeter and silicon tracking system.

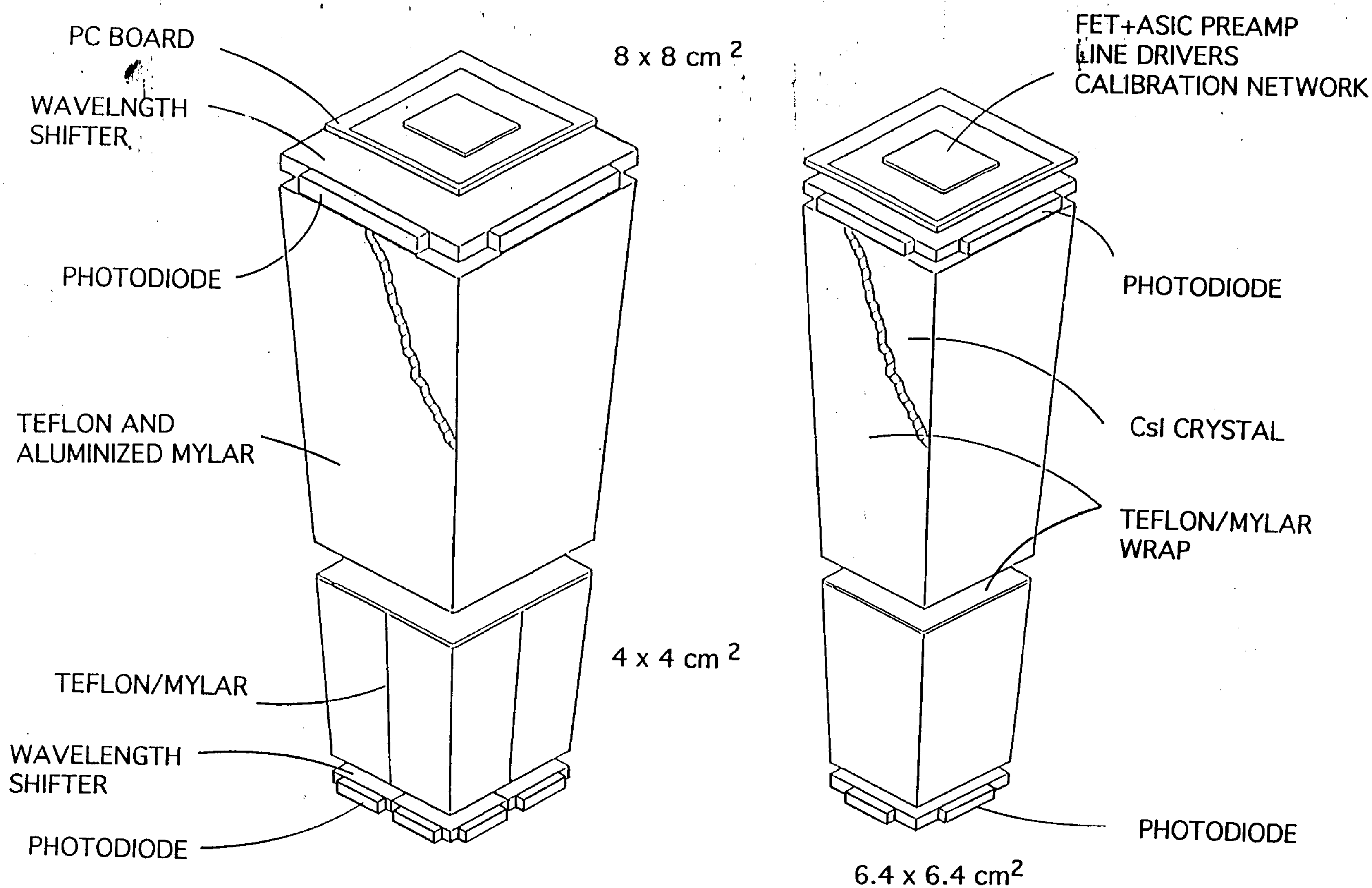

Figure 2. Two options for configurations of CsI calorimeter crystal towers, showing longitudinal and transverse segmentation of crystals, and wavelength shifter-photodiode-preamplifier readout.

$0.35\%/E^{3/4}$ + (1.9-0.1)E% for the CLEO II barrel calorimeter.

Crystal Support Structure

The net weight of the CsI to be utilized in the crystal calorimeter is ~40 tons. The support structure design currently under evaluation involves the use of carbon fiber-composite boxes (one/tower), precision-jigged into 50 kg ten-tower modules. To insure stability of the calibration over time, the support structure is designed to remove all loading on the crystal surfaces. Additionally, a minimum of material will be placed in front of the crystals, so support and access will be via strong-back structures at the rear of the towers. Finite element analysis using ANSYS indicates that the ten-pack design can likely achieve support structure design goals. Using a mandrel and autoclave, glass fiber boxes have been manufactured at SLAC, and creep tests of individual, loaded boxes are underway. For further mechanical testing, a ten-pack module will be constructed.

Radiation Issues

Computer simulations using Orsay optics and an optimal masking scheme have been undertaken to study radiation in the CsI calorimeter from the large circulating current (600 mA/beam) in the τcF rings. Assuming a 1 nT vacuum is maintained, the two-hour luminosity lifetime limit is dominated by beam-beam bremsstrahlung. The other major sources of background are electroproduced hadrons from beam gas interactions, lost beam particles that are Coulomb or bremsstrahlung scattered, and particles lost from the injected beam. The studies indicate that the CsI calorimeter will see <5 Rads/yr, which compares very well with the radiation hardness of CsI, ~10^3 Rads/yr.

Although the expected radiation doses in the CsI calorimeter is relatively low, the potential for signal pile-up due to frequent beam crossings (1/40 ns, compared to the time constants of 1μs for CsI(Tl) and 0.5 μs for CsI(Na)), and pedestal shifts in the crystal system due to frequent beam injections, warrant additional studies. Taking into account crystal readout and signal shaping, simulations indicate there will be eight background clusters/event where the clusters have an energy of $\geq$ 10 MeV, and one background cluster/event where the cluster has an energy of $\geq$ 20 MeV. Coarse timing will be used to uniquely assign shower energies to beam crossings, and to eliminate these clusters.

The potential for pedestal shifts in the crystal system is also being studied. The worse-case scenario for crystal activation occurs at injection, with a maximum dose of ~50 mR over ~2 minutes. To study afterglow, numerous 12.83 cm^3 crystal samples from five different vendors were irradiated using a ^{60}Co γ-source. With the results scaled to full-size, 1555.2 cm^3 crystals, the activation energy 200 s after irradiation varied from 2-7 MeV for CsI(Tl) crystals, and from 10 keV - 12 MeV for CsI(Na) crystals. Large variations were seen amongst crystals from the same and from different manufacturers. While the integrated activation energy is comparable to smaller detector signals, the shaping amplifiers are sensitive to signals with time constants about that of the crystal decay time (~1 μs), and will not process signals occurring on the much shorter time scale of the crystal phosphorescence.

Additional studies of light output and crystal uniformity using sample and full-size crystals and ^{60}Co and ^{137}Cs sources have been completed. Future plans include small (~10-50 mR) and large (~kR) irradiation of full-size crystals, in which attenuation length changes become important, to study crystal light output and activation.

TRIUMF Beam Test of CsI Calorimeter Prototype

To gain experience with all aspects of the CsI calorimeter system, a beam test of a CsI calorimeter prototype was undertaken in the TRIUMF M13 (30-120 MeV) and M11 (120-400 MeV) beamlines, August 15-24, 1992. This test utilized 46.5k cc of CsI configured in 14 central towers (12 CsI(Tl) and two CsI(Na)) and 12 guard towers (CsI(Tl) crystals loaned by Cornell University). Several longitudinal and transverse segmentation schemes were tried, where crystals in a tower were optically separated from one another and had individual waveshifter/multidiode readout. The towers contained a total of 132 channels. In addition to testing crystal doping and segmentation schemes to optimize position and energy resolution, the experiment was also intended to study the effects of intercrystal materials, mechanical and electronics packaging, vendor performance in meeting engineering specifications for full-size crystals, and $e/\pi/\mu$ separation and the identification of hadronic interactions at the energies typical of a τcF. Results will be presented in the near future.

Acknowledgments

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