In Response to the Call for ILC Detector R&D Supplemental Proposals

An LSO/LYSO Crystal Array

for a Precision Lepton/Photon Detector at the ILC

David Hitlin and Ren-yuan Zhu

California Institute of Technology

Address: 356-48, HEP, Caltech, Pasadena, CA 91125

Telephone: (626) 395-6694

E-mail: hitlin@slac.stanford.edu

Collaborators from SLAC (USA), RAL (UK) and IHEP (China) to be identified

1 Introduction

The design of detectors being considered for the International Linear Collider (ILC) is largely being driven by the goal of improving of jet mass resolution by implementing the particle flow algorithm (PFA). We believe that a different design approach, emphasizing precision lepton and photon detection, could provide an interesting complementary alternative. We therefore propose to carry out a research program to develop an array of LSO/LYSO crystals and to measure its properties in a beam test. The array will serve as a prototype for an LSO/LYSO crystal calorimeter, which would be a key component in a precision lepton/photon detector at the ILC.

The concept of precision lepton/photon detectors has been pursued in the past; recent examples are the GEM detector at SSC and the CMS detector at LHC. The ILC will provide an opportunity to do precision physics at the new energy frontier, measuring the quantum numbers of the Higgs boson, *e.g.* its spin, a precision measurement of the Higgs couplings, which may reveal extra dimensions, as well as direct searches for SUSY and extra dimensions. A precision lepton/photon detector would have an advantage in the ILC physics program, since the energy and momentum of leptons and photons are well-described by perturbative theories. Unlike jets, in which perturbative uncertainties are large, leptons and photons can be used as precision probes for new physics. The discovery potential of precision lepton and photon detector was demonstrated by the Crystal Ball experiment through its study of radiative transitions and decays of charmonium [1]. Figure 1 (Left)shows nearly all the principal radiative transitions of the charmonium system simultaneously measured by the Crystal Ball's NaI(Tl) crystal calorimeter. The design goal of the CMS lead tungstate ($PbWO_4$) crystal calorimeter [2] is to maximize its discovery potential in searching for narrow resonances in photon and electron final states at LHC. Figure 1 (Right) shows the expected background-subtracted Higgs peak reconstructed with its two decay photons by the CMS $PbWO_4$ calorimeter. The potential for Higgs discovery via this decay channel is directly related to the energy resolution of the calorimeter.

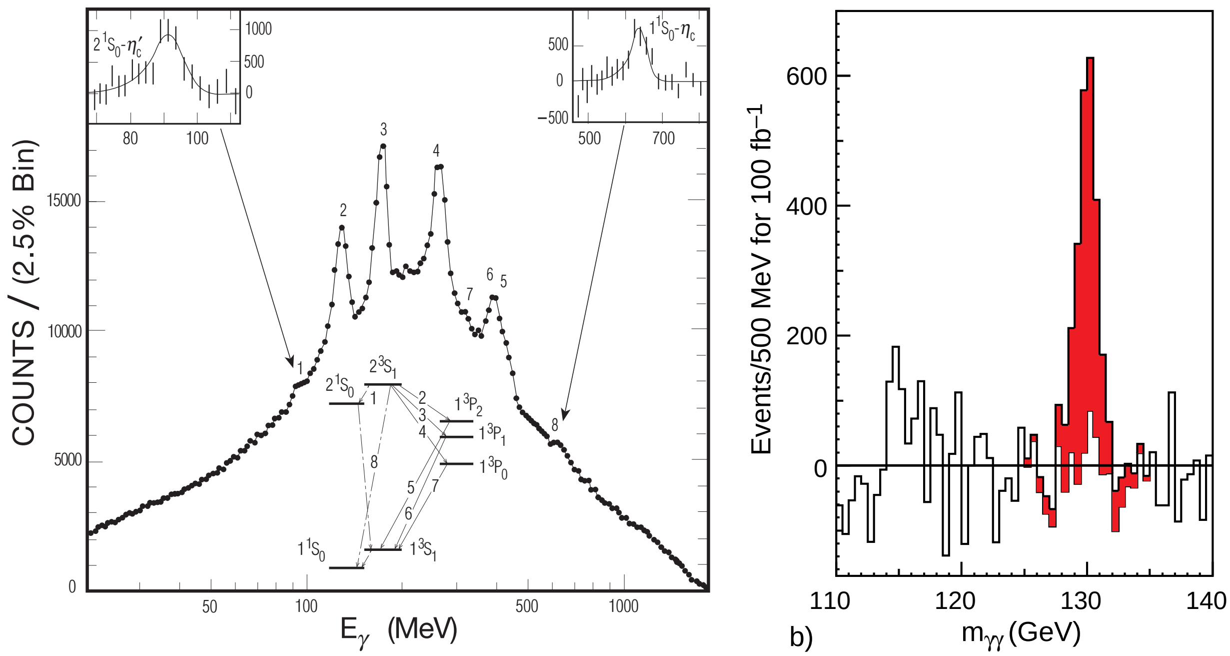

Figure 1: Left: An inclusive photon spectrum measured at the ψ' by the Crystal Ball NaI(Tl) crystal calorimeter at SLAC [1]. Right: The expected background-subtracted Higgs mass peak reconstructed from two photon decays measured by the CMS $PbWO_4$ crystal calorimeter [2].

By using kinematic constraints available at the e^+e^-collider, a precision lepton/photon detector can also measure jet energy and jet-jet mass much better than direct calorimeter measurements. This is due to the fact that jet directions are measured with an accuracy an order-of-magnitude better than the corresponding jet energies [3]. The precision lepton/photon detector concept is complementary to all other existing ILC detector concepts, and has so far not been pursued for the ILC. To enhance the overall physics potential at the ILC, the Caltech group, together with scientists at SLAC, RAL (UK) and IHEP (Beijing) propose to develop a key component of a precision lepton/photon detector for the ILC. The other ILC detector concepts have been developed over the last five or more years; it is thus urgent to start R&D immediately along this new direction and to provide for timely development of this detector concept.

2 An LSO/LYSO Crystal Calorimeter for the ILC

While the overall design is yet to be completely defined, the key detector component for the proposed precision lepton photon detector is an LSO/LYSO crystal calorimeter. In the last decade, cerium-doped silicate-based heavy crystal scintillators have been developed for the medical industry. Mass production capability of cerium-doped lutetium oxyorthosilicate (LSO or Lu_2SiO_5) [4] and lutetium-yttrium oxyorthosilicate (LYSO or $Lu_{2(1-x)}Y_{2x}SiO_5$, where x is 5–10% [5, 6] crystals of sufficiently large size already exists. One intrinsic advantage of LSO/LYSO crystals is their high density, which is much higher than all other crystal scintillators, except $PbWO_4$. This makes a compact LSO/LYSO calorimeter possible, and thus reduces the overall cost. The second advantage is their fast, bright scintillation light. The light output is higher than all other crystal scintillators, except NaI(Tl) and CsI(Tl) [7]. The decay time of the scintillation light (40 ns) is also faster than most other crystal scintillators. LYSO crystals have also been shown to be more radiation-hard than other crystals [8]. LSO and LYSO crystals thus have a unique combination of desirable properties, with very wide dynamic range and, due to the high light output, extended low energy reach, making them ideal as the basis for a precision calorimeter for photons and electrons [9].

By comparing with the CMS $PbWO_4$ crystal calorimeter, we can estimate the expected energy resolution of an LSO/LYSO crystal calorimeter. This extrapolation is reliable, since crystal calorimeters usually achieve their design resolution *in situ* [7]. The design energy resolution of the CMS $PbWO_4$ calorimeter is [2]:

$$\sigma_E/E = \mathbf{2.5}\%/\sqrt{E} \oplus \mathbf{0.55}\% \oplus 0.2/E, \tag{1}$$

where E is in GeV.

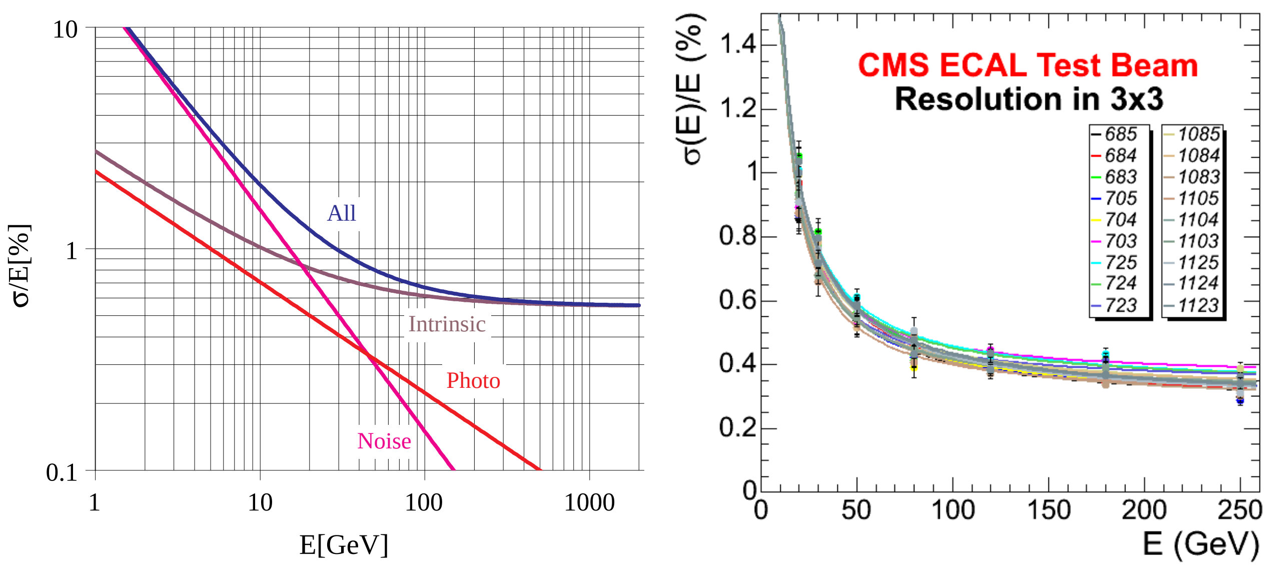

Figure 2: Left: The various contributions to the design energy resolution of the CMS $PbWO_4$ calorimeter [2]. Right: The energy resolution of two groups of 9 $PbWO_4$ crystals as a function of electron energy, obtained in the CMS ECAL beam test [10].

Figure 2 (Left) shows the CMS design energy resolution as a function of energy. The resolution is dominated by three contributions: from photoelectron statistics (stochastic), intrinsic shower leakage (stochastic and constant) and readout noise (noise). Figure 2 (Right) shows the energy resolution as a function of electron energy measured in the CERN test beam for two groups of 3×3 crystals, independent of their impact position on the crystal front face [10]. The measured resolution in the low and middle energy region agrees with the design resolution. It also shows a smaller constant term than the design because of the perfect calibration in the test beam.

Assuming the same readout scheme as the CMS $PbWO_4$ calorimeter, the expected energy resolution of an LSO/LYSO based crystal calorimeter would be

$$\sigma_E/E = \mathbf{2}\%/\sqrt{E} \oplus \mathbf{0.5}\% \oplus 0.001/E, \tag{2}$$

providing a fast calorimeter over large dynamic range with very low noise. Such a calorimeter would provide excellent physics potential for the ILC.

3 Availability of LSO/LYSO Crystals

We have recently done a detailed investigation of commercially available full size LSO/LYSO samples from various vendors [8]. It should be noted that the difference between LSO and LYSO is one of details of crystal growth; their properties and performance are almost identical. Fig. 3 shows four long crystal samples with dimensions of 2.5×2.5×20 cm. They are, from top to bottom: a BGO sample from Shanghai Institute of Ceramics (SIC), LYSO samples from Crystal Photonics, Inc. (CPI) and Saint-Gobain Ceramics & Plastics, Inc. (Saint-Gobain) and an LSO sample from CTI Molecular Imaging (CTI).

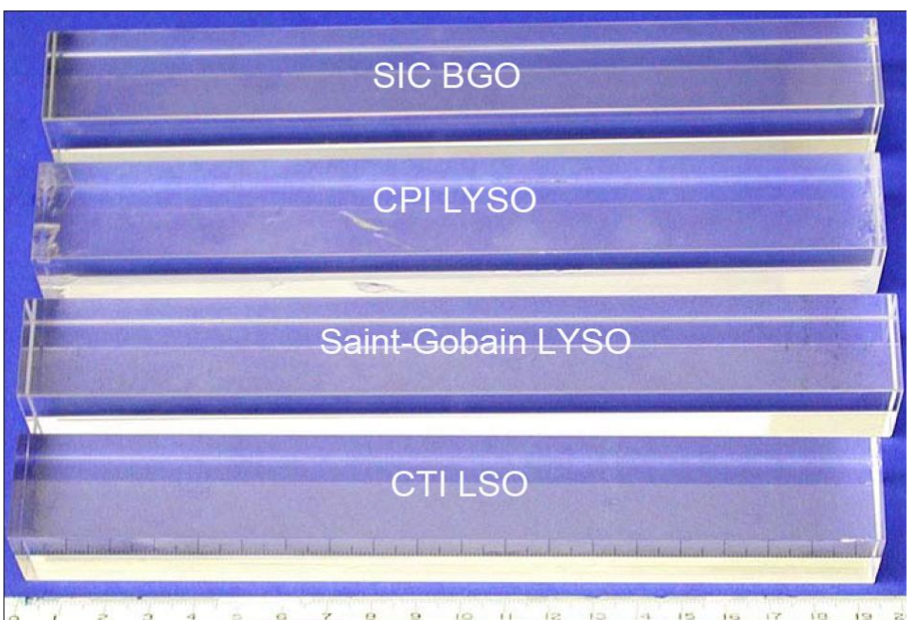

Figure 3: A photo showing four long (2.5×2.5×20 cm) crystal samples.

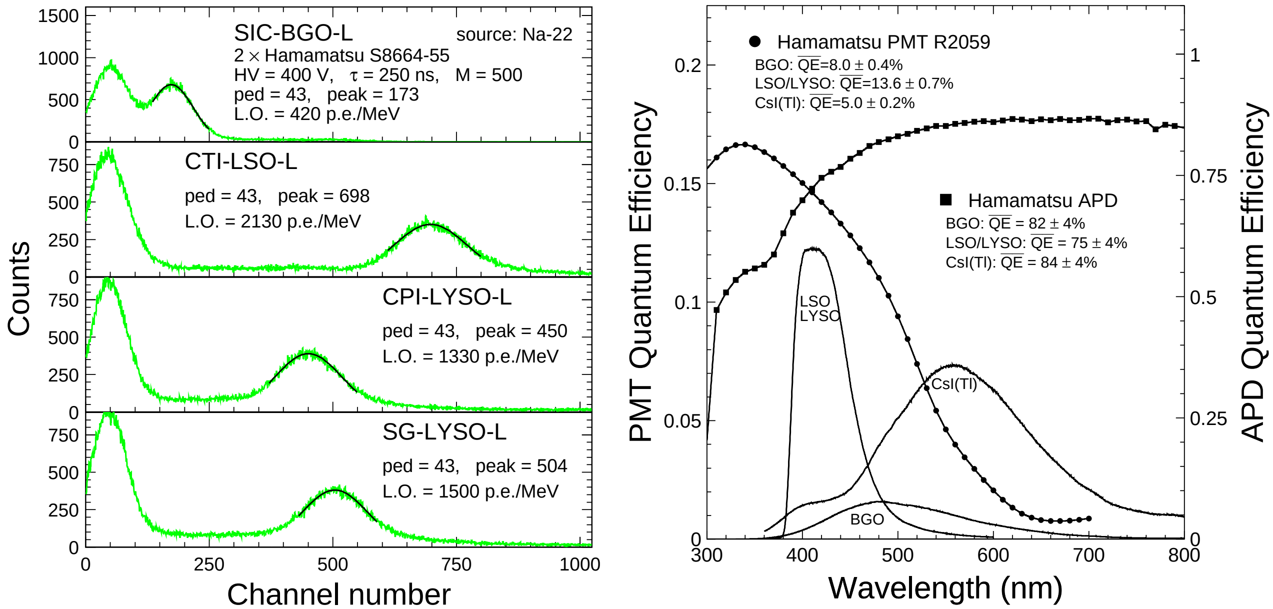

Figure 4: Left: The spectra of 0.511 MeV γ-rays from a ^{22}Na source measured with a coincidence trigger using two Hamamatsu S8664-55 APDs for long BGO, LSO and LYSO samples of $2.5 \times 2.5 \times 20$ cm size. Right: The quantum efficiencies of a Hamamatsu R2059 PMT (solid dots)and a Hamamatsu S8664 APD (solid squares) are shown as a function of wavelength, together with the emission spectra of the LSO/LYSO, BGO and CsI(Tl) samples, where the area under the emission curves is proportional to their corresponding absolute light output.

Figure 4 (Left) shows spectra of 0.511 MeV γ-rays from a ^{22}Na source observed by these samples with coincidence triggers. The readout devices used are two Hamamatsu S8664-55 APDs, which have dimensions of 5×5 mm. The γ-ray peaks are clearly visible for the long LSO and LYSO samples, much more distinct than for the BGO sample. The energy equivalent readout noise in our laboratory APD readout system is below 40 keV for the LSO and LYSO sample, due to the good match of the LSO/LYSO emission spectrum to the quantum efficiency of the Hamamatsu S8664-55 APD, which produces a weighted quantum efficiency of 75% as shown in Fig. 4 (Right).

The current market price of LSO/LYSO crystals ($40/cc) is too high for HEP applications. To address this issue, we plan to investigate LSO and LYSO crystal samples from two crystal growers in China: Sichuan Institute of Piezoelectric and Acousto-optic Technology (SIPAT) and Shanghai Institute of Ceramics (SIC), in addition to commercial vendors. such as CTI, CPI and Saint-Gobain. By introducing competition, the cost of the LSO/LYSO crystals can likely be significantly reduced from the current market price.

4 Proposed Research Program

Caltech has received a DOE Advanced Detector Research grant for $240,000 over three years to work with vendors to improve the properties of LSO/LYSO crystals. This work will include improving light output uniformity, optimizing doping, reduction of trace impurities that contribute to phosphorescence, and improving yield. We expect that this will result in a significant reduction in the cost of crystals. This proposal, for $700,000 over two years, $350k each for FY07 and FY08, is aimed at developing an array of 49 full length (25X_0) LSO/LYSO crystals, with associated readout, to be placed in a test beam. The crystals will be procured from various vendors, including existing commercial vendors such as CTI, CPI and Saint-Gobain, as well as SIPAT and SIC in China. The requested funds will be used to support one FTE of staff scientist, to procure the LSO/LYSO crystals and readout devices, such as Hamamatsu APDs, necessary material and supplies. The breakdown of the request is shown in Table 1. No ancillary equipment funds are requested at this stage. In addition to the FTE staff scientist, Ren-yuan Zhu will spend a significant fraction of his research time on this project and will oversee its success.

Table 1: Request for Developing an LSO/LYSO Crystal Array (k$) in FY07 and FY08

item	FY07	FY08	Total
1 FTE Staff Scientist	100	100	200
LSO/LYSO Crystals	150	150	300
Crystal Readout	100	100	200
TOTAL REQUEST	350	350	700

References

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