Performance of the Scintillator-Strip Electromagnetic Calorimeter Prototype for the Linear Collider Experiment

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Jet Energy Measurement at the ILC experiment

- e^+e^- collider with center-of-mass energy at 500 ~ 1000 GeV.
- ILD (International Large Detector) is one of the detector concepts proposed for the ILC experiment.
- Various precision measurements expected:
  - e^+e^- → H, W, Z, tt, SUSY, etc...
  → Multi-jets final states.
- Particle Flow Algorithm (PFA) allows precise jet-energy measurement \( (\sigma_E/\sqrt{E} = 30\%) \).

\[
E_{TOT} = p_e + p_\mu + p_{\text{charged hadron}} + E_\gamma + E_{\text{neutral hadron}}
\]

[ tracks only] [calorimeter only]

- Separation of jet particles in the calorimeter is required for the PFA
  → Fine granular calorimeter is necessary.
Main Task: Develop fine granular calorimeter for Particle Flow Algorithm at the ILC experiment.

**Electromagnetic CAL:**

- **Scintillator-Tungsten**
  
  (Kobe / Shinshu / Tsukuba / Niigata / Tokyo / Kyungpook universities)

- **Silicon-Tungsten**

- **Digital SiW ECAL (MAPS)**

**Hadron CAL:**

- **Analog (Scintillator) HCAL**

- **Digital HCAL**

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**CALorimeter for the LInear Collider Experiment**

330 physicists/engineers from 57 institutes and 17 countries coming from 4 continents
The Scintillator-Strip Electromagnetic Calorimeter

• Sampling calorimeter with Tungsten-scintillator sandwich structure.
• Scintillator-strip technology adopted to achieve fine granularity.
• Lateral Segmentation: 1 ~ 0.5 cm
• Huge Number of channels (~10M channels).
• Need to establish sufficient performance while keeping the low production cost.
• First need to establish the feasibility!
Elementary Components (Scintillator-Strip & Photo-Sensor)

- **Scintillator strip**
- **Multi-Pixel Photon Counter (MPPC)**
- **Wavelength Shifting Fiber (Y11 1mm)**
- **Plastic scintillator strip by extrusion technique**

**Strip response (ADC counts)**
- Position along the strip (cm)
The ScECAL 2\textsuperscript{nd} Prototype

- The technical prototype to establish the ScECAL feasibility.
- Sandwich structure with scintillator-strips (3 mm) and tungsten layers (3.5 mm).
- Extruded scintillator and the MPPC are fully adopted.
- Strips are orthogonal in alternate layers.
- 72 strips x 30 layers = 2160 channels.
Beam Test in Sep 2008 @ MTBF

- **Objective:** Establish the feasibility of Scintillator-ECAL + Analog HCAL with various types of beams in wide energy range.
  - Evaluate Energy resolution, Linearity for electrons and pions.
  - $\pi^0$ reconstruction ability of the Scintillator-ECAL
  - Position and angular scan.
- Beam running during Sep 2008 / May 2009 at FNAL Meson Test Beam Facility.
The Fermilab Meson Test Beamline

Various types of beams available
- 1-32 GeV electrons
- 1-60 GeV pions
- 32 GeV muons
- 120 GeV protons
- Cerenkov counter available to discriminate electron or pion.
Strip-by-strip response calibration with muons

The scintillator strip response calibration has been done using Minimum Ionizing Particle (MIP) signal by muon beams.

A typical muon event passing the ScECAL

MIP equivalent signal on one strip

Uncertainty of the response calibration < 1% (statistical error only)
Electron event selection

• The first task is evaluate the ScECAL performance for electrons.
• The beam is mixture of $e^- / \pi^- / \mu^-$ components.
• Cerenkov counter signals have been used for the electron trigger, however still offline event selection is necessary to purify the electron sample.
• Event selection is done based on:
  - Longitudinal / lateral shower shape
  - $\pi^- / \mu^-$ veto by the HCAL signal located at downstream
Linearity of the electron energy measurement

- Reasonably uniform response over the entire detector region.
- \( \sim +6 \% \) of non-linearity in 1-32 GeV energy region, needs to be improved.
- Reason under investigation, possibly due to:
  - contamination of e\(^-\) data by \( \pi/\mu \)
  - Lateral and longitudinal shower leakage
  - Gain change of photo-sensor
Energy Resolution for electrons

![Graph showing energy resolution](image)

\[
\frac{\sigma}{E} = \frac{(15.15 \pm 0.03)\%}{\sqrt{E}} \oplus (1.44 \pm 0.02)\% \quad \text{(preliminary, errors are stat only)}
\]

- Observed constant term rather large, investigation underway.
- Also due to the shower leakage or the gain variation of photo-sensor?
\(\pi^0\) runs
(very preliminary)

- Ability of \(\pi^0\) reconstruction from \(2\gamma\) might be useful to improve jet energy resolution.
- Generate \(\pi^0\) by putting iron on beamline and injecting 16-32 GeV \(\pi^-\) beam.
- Try reconstruction of the generated \(\pi^0\) with Scintillator-ECAL.

\(\pi^0 \rightarrow 2\gamma\) detection successful!
Further step:

- For precise measurement of jets with $E > 100$ GeV, 5 mm segmentation will be desirable.
- It can be still possible with 5 mm width scintillator strips.
- First measurement the 5mm scintillator strip shows encouraging result.

Jet Energy Resolution with PFA

Light yield of 45 x 5 x 2 mm strip (made by casting)
Summary

• For the future linear collider experiment, the Scintillator-strip ECAL is being developed in CALICE collaboration.
• Results of the prototype tests show promising feasibility of the ScECAL.
• Further analyses of the beam test are currently underway.
• Next step – even finer granularity with 5 mm strips.