ILC Detector R&D Paper – University of Cambridge

Major R&D Efforts:

The PandoraPFA software package [1, 2] has been developed entirely in Cambridge. It consists of a robust and efficient C++ software development kit (SDK) and libraries of reusable pattern-recognition algorithms that exploit functionality provided by the SDK.

Algorithms have been developed to provide a particle flow reconstruction of events in fine-granularity detectors, such as those proposed for use at the ILC or CLIC. The reconstruction uses over 60 algorithms in order to carefully trace the paths of visible particles through the detector. The output is a complete list of the particles in an event, each with a reconstructed four-momentum and an identified particle-type. The algorithms represent the state-of-the-art in particle flow calorimetry at a Linear Collider.

The Pandora Linear Collider algorithms have recently been used for extensive detector optimisation studies, assessing the physics performance of the ILD_o1_v06 detector model with different configurations of the electromagnetic and hadronic calorimeters. A selection of the key plots is shown overleaf. A summary document is under construction and will be submitted for publication.

(Software) Engineering Challenges:

The implementation of large numbers of pattern-recognition algorithms in C++ can be extremely difficult. Algorithms must work as intended, be easy to maintain/extend and have tight control of memory management. The Pandora SDK addresses these issues directly: it provides a sophisticated Event Data Model and performs all event memory-management. Access to event objects and modification of these objects can only occur via algorithms requesting services provided by the Pandora SDK.

A key remaining challenge is to ensure algorithms are efficient and scale kindly with the number of input objects in an event. This is a matter for the algorithm author, rather than the framework, but the Pandora SDK provides a number of constructs to help address performance. These include KD-trees, which provide log(n) look-up of e.g. hits within a search-volume around a specified space-point. There is a cost associated with constructing KD-trees, but the reduction in e.g. hit-hit permutations can be enormous.

Detector R&D Plans:

Continued development of Pandora SDK and pattern-recognition algorithms, plus provision of support to users of Pandora. On-going Linear Collider work (including work performed by new PhD students in Cambridge) includes improvement of π^0 reconstruction and efforts to further-improve ability to identify and separate neutral hadrons from nearby charged hadrons. Detector optimisation studies will continue and will include full examination of performance of Pandora algorithms with digital and semi-digital HCAL detector models.

Collaborating Institutes:

Development of the Pandora framework and algorithms has been based exclusively in Cambridge, but detector optimisation studies have involved close collaboration with other institutes. ECAL and analogue HCAL studies have involved DESY, Shinsu University (Japan), and CERN. Upcoming (semi-)digital HCAL studies will involve the University of Lyon (France).

Applications beyond the ILC:

The Pandora SDK has been designed to aid development of pattern-recognition algorithms in generic fine-granularity detectors. As such, its use is not limited to the ILC. Pandora algorithms now provide a successful particle flow reconstruction in an upgrade model of the CMS detector, even in dense pile-up conditions. Algorithms have also been developed for reconstruction of cosmic ray and neutrino-induced events in liquid argon time projection chambers, having significant impact in the neutrino-physics community.

[1]. doi:10.1016/j.nima.2009.09.009
[2]. doi:10.1016/j.nima.2012.10.038

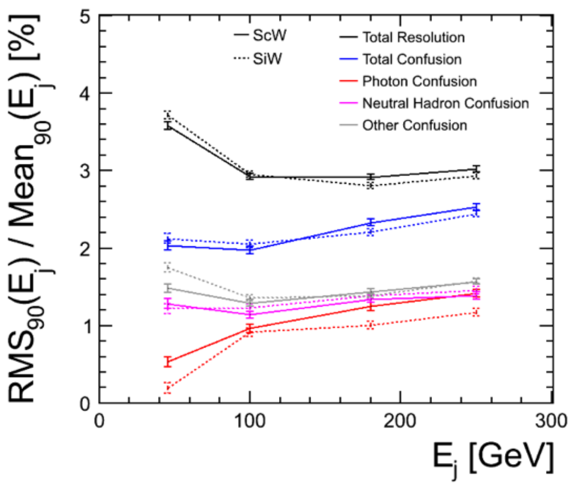

Figure 1. Jet energy resolution as a function of jet energy, including a breakdown of the resolution into contributing "confusion" terms. Illustrates performance of Pandora algorithms for ILD_o1_v06 with Silicon (Si) or Scintillator (Sc) as ECAL active material.

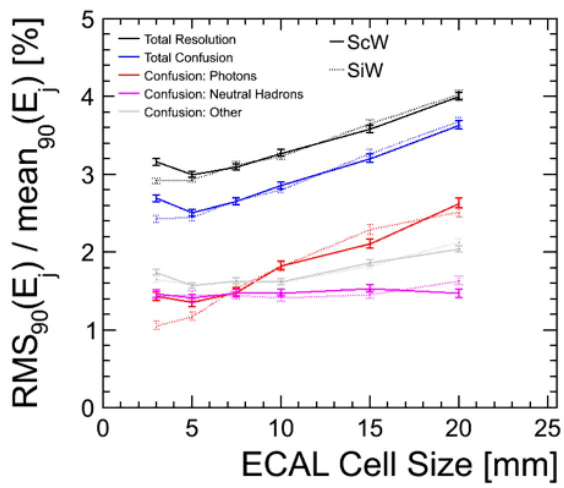

Figure 2. Jet energy resolution as a function of the ECAL cell size, for 250GeV jets in ILD_o1_v06. As expected, the photon confusion term (ability to separate photons from nearby hadrons) drives performance changes.

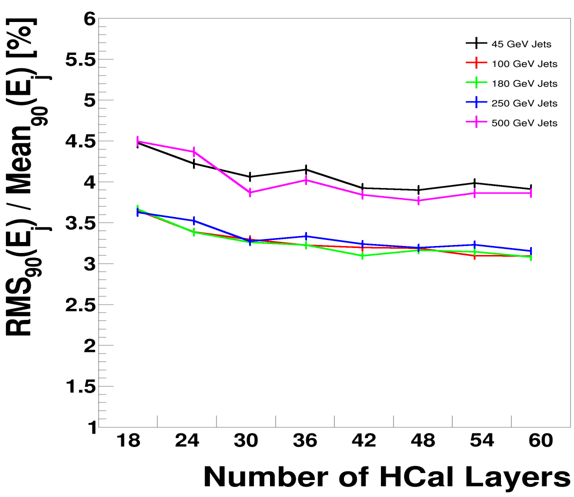

Figure 3. Jet energy resolution as a function of the number of layers in the HCAL, for a range of different energy jets in ILD_o1_v06.