Summary of D5

CALORIMATRY and MASKS

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Try to be NEUTRAL.

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1 Introduction

The author would like to express great thanks to all the speakers and participants of the session D5. Talks and discussions were really fruitful for highlighting problems to solve toward designing calorimeters at LCs.

2 Short Summary of Individual Talks

Followings are the list of the talks presented at the session D5, 'Calorimetry and Masks'. Highlights of each talk were briefly reviewed at the section. They are however ommitted in this paper because they can be seen on the original reports in this proceedings.

Two characters in [ ] at the end of the speaker's names are reference identifyers used in the summary.

1. Yoshiaki Fujii (KEK) [YF]
   Expected Performance of Tile-fiber Calorimeter and other JLC-CAL R&Ds.

2. Gray Bower (SLAC) [GB]
   Detector Optimization for Jet Identification.

3. Richard Dubois (SLAC) [RD]
   LCD Small and Large Calorimeter : Single Particle Resolution.

4. Uriel Neuenberg (University of Colorado) [UN]
   General Issues of Calorimetry Associated with the Search for Selectrons
   Calorimetric Resolution Using GEANT 3.0
   Energy Measurement in the Forward Direction

5. Ren-Yuan Zhu (CALTECH) [RZ]
   Crystal Technologies for LC.

6. Stephen R. Magill (ANL) [SM]
   Detector Issues for Two Photon Physics at a High Energy Linear Collider

7. Volker Korbel (DESY) [VK]
   A Sandwich Sampling Calorimeter with Tileplate and Wavelengthshifter Readout from the DESY ECFA Study Group.

8. Paolo Checchia (Universita di Padova) [PC]
   CALEIDO COLLABORATION : Shashlik Calorimeter Prototypes for a LC.

9. Jean-Claude Brient (LPNHE-Ecole Polytechnique) [JB]
   A Calorimeter for Energy Flow

3 Summary from the viewpoint of General Study

3.1 Physics Process / Requirements

It is very important to have very good 4-vector reconsturction of jets, namely of partons[GB], under various event topology such as

$$e^+e^- \to ZH, \quad Z \to \nu\bar{\nu} \qquad (1)$$

for the simplest case which gives only two jets, or

$$e^+e^- \to ttH \qquad (2)$$

for complicated case which gives 8 jets. Even more jets will be observed in some SUSY channels[JB]. We need to eventually achieve excellent 2-jet mass resolution even under such complicated event topology. It is important to be able to separate W and Z by their reconstructed mass for precision study of weak couplings[YF].

Two results were reported about 2-jet mass reconstruction[YF,JB]. One is for the simplest reaction (1), and the other is for W^+W^- pair production.

ZH	σ_{m_H}	$\sim$1.3GeV	with rather simple quick simulator[YF]
		$\sim$2.0GeV	with rather realistic quick simulator[JB]
WW	σ_{m_W}	$\sim$3.2GeV	with rather simple quick simulator[YF]

Importance of energy resolution[YF] and granularity[JB] was discussed. Results of full simulation should be examined.*)

*) I missed some talks in E-W session which presented full simulation results.

Isolated electrons/photons are always good signals for new physics, and crystals can offer the best sensitivity to those signals[RZ]. However this must be mentioned in a context of S/N or $S/\sqrt{S+N}$ ratio, and realistic simulation results are indispensible.

There were two discussions about two-photon processes ; one was as a signal[SM], and the other was as a background to the SUSY signal[UN]. Both stressed necessity of very forward detector, either as a calorimeter or as a tagger or as a veto. Two-photon process has 5-orders larger cross section than selectron production, and to veto forward electrons are essentially important to reduce two-photon backgrounds to SUSY study[UN].

Requirements on forward calorimeters are as follows.

For two-photon physics[SM];
- $\theta_{min} \sim$ 30mrad
- $\sigma_\theta \sim$ a few mrad
- σ_E not important

For B.G. suppression[UN];
- $\theta_{min} \sim$ 20mrad
- σ_E not needed (E_{thres} needed, though)

There were also discussions about off-vertex γ reconstruction[VK,JB]. This study requires either fine granularity or position measurement at least at two depth. Impact parameter resolution of 10mm would be achieved with two sets of position detectors[VK]. Effect of this resolution on physics is an open question yet.

There was no arguement about endcap calorimeter.

3.2 Simulation Algorism

There was a trial to identify event type using jet property only without assuming physics of events[GB]. Analysis at generator level succeeds to separate light quark jets, heavy quark jets, or weak boson jets with fairly high efficiency using Njet, jet mass, rapidity distribution, etc.. Analysis with detector simulation is not yet optimized, and scores are not yet very good especially for NLC-S detector. Results with well-tuned simulation are awaited for.

Energy flow analysis (EFLOW®) is well proven at ALEPH analysis[JB]. Though the analysis is complicated, procedures are well established, and it is said that tune-

up time after T0 of LC should not be so long. This analysis is powerfull when appied for high-granularity calorimeter, and gives high performance in background rejection and fake-photon isolation. Comparison with various jet reconstruction method should be fruitful.

There was an attempt to make a hadron shower generartor with realistic fluctuation[YF]. Usual parametrized hadron shower generators do not have fluctuation which often leads to $e/\pi/\gamma$ misidentification. This new shower generator will be quite useful for quick simulators.

3.3 Feedback from Simulation Results to Detector Design

Study of two-photon processes require detectors of resonable performance around and inside the mask region[SM]. Position resolution would be more important than energy resolution for these detectors ; 5mm-pad would be needed for θ measurement. These detectors should extend as forward as possible, about $\sim$30mrad for example, to avoid loss of hadrons into the beam pipe.

The mask itself shall be the worst-performance detector in this region. Therefore installing the mask at the very forward region of about $\sim$30mrad would be worse than installing it at reasonably forward region of $\sim$100mrad, leaving space inside the mask for reasonable-performance detector. However influence of huge backgrounds on hadron detection with such detectors inside the mask should be investigated separately.

In order to tag very forward electrons which cuased two-photon reaction, a gas cherenkov counter was proposed to be installed at very forward region[UN]. In this region, huge background comes into detectors due to beamstrahlung. These backgrounds are huge number of low energy electron/photons. Therefore a gas cherenkov counter of appropreate pressure with pre-radiator can pick up high energy electrons coming from two-photon reaction separated from the backgrounds.

EFLOW® analysis requires very fine granularity to achieve its best performance[JB]. It also needs to have high density to resolve nearby clusters. On the other hand, energy resolution would not be essentially important. For example, EM calorimeter of $12\%/\sqrt{E}$ and that of $20\%/\sqrt{E}$ gives jet energy resolution of 42% and 45%, respectively. For this EFLOW® analysis, therefore, W-Si calorimeter seems almost ideal. Pad size of $1cm \times 1cm$ could be even better than sufficient, and simulation on coarser pad size would be necessary.

Effect of a solenoid to calorimeter resolution was studied[RD,VK]. Both studies show that coil significantly worsen energy resolution. Even if 3λ of the hadron calorimeter stays inside the coil, 0.4λ-thick coil (which is about 2Xo in case of aluminum) deteriorates energy resolution from $38\%/\sqrt{E}$ to $43\%/\sqrt{E}$[VK]. This study shows that R&Ds toward thinner coil, less than 1Xo for example, is necessary, even though this seems quite challenging for solenoids of $B^2R = 30[T^2m]$ or more.

Simluation of photon vertex reconstruction was done assuming two layers of CDF-type scintillator-strip shower position detectors[VK]. For photons with ener-

gies larger than a few tens of GeV, vertex resolution of ~10mm can be achieved. However several GeV photons can only be reconsrtructed with 100mm accuracy. Detailed simulation on number of layers, position resolution of a layer, and distance between layers should be necessary.

3.4 Simulated Performance

It is well known that sampling calorimeter gives larger signal in B-field than that without B-field[2]. This is interpreted as curl of shower particle in B-field. In addition to this curling effect, plastic scintillator itself generates more photons in B-field[3] by ~10%. Simulation of showers in B-field was done, and results consistent to the curling effect effects were obtained[RD,UN]. This gives some estimate for the simulation accuracy.

Results of EM-shower simulation on energy resolutions were given for W-Si calorimeters[RD,UN,JB]. However very little comparison was made with existing simulation studies[1]. Results for NLC and for TESLA have slight difference to each other, and some significant discrepancy to the experimental result by SICAPO collaboration[4]. It seems some tuning of simulation parameters are yet needed.

Also results of hadron shower simulation were presented[RD,UN,VK,JB]. Those results are significantly different from each other. Though some results showed reasonable agreement to experimental results[UN], in general, hadron shower simulation can not reproduce experimantal results without well-tuned shower terminator. Installation of a parametric shower with realistic fluctuation[YF] would improve simulation results.

Only one result for jet energy resolution was presented[JB]. TESLA detector $\oplus$ EFLOW® analysis achieved quite excellent resolution of $\sim 40\%/\sqrt{E_{jet}}$. Comparison with other detectors/algorithms are needed.

3.5 Hardware R&D

There are extensive design studies going on. JLC group is more or less concentrating on affordable-in-cost and sufficient-in-performance option. On the other hand, NLC/TESLA group are investigating various possibilities, even ultimate performance option. Characteristics of various calorimeter option are summarized in Table 1.

Tile-fibers, crystals, and liq.Ar are well-established calorimeters.

In the case of crystals, discovery potential for new particles are quite high[RZ]. On the other hand, it has been commonly said that crystals have worse hadronic resolution due to its off-compensation. However it was reported that L3 achieves as good jet energy resolution as ALEPH[RZ], for example. So crystals have no such demerit at LEP level. However what linear colliders should achieve is much better than what LEP/SLD do. Therefore further study is needed to really establish hadron measurement ability of crystals. Also needed is to study possibility and performance on shower direction measurement.

Table 1: Characteristic feature of various calorimeters.

Type	Examples	Granularity	Resolution	Comments
Tile-fiber (σ-fiber)	JLC, NLC-L TESLA SDC, STAR CDF, CMS	Longitudinal ~excellent Transverse ~modest	EM ~15%/$\sqrt{E}$ Had ~40%/$\sqrt{E}$	• Well-established. • Shower-direction measurement easy.
Shashlik	TESLA Phenix HERA-b LHC-b	Longitudinal ~not good Transverse ~fine	EM ~10%/$\sqrt{E}$ Had ~? %/$\sqrt{E}$	• Established for fixed-target only. • Shower-direction difficult.
Crystal	NLC CMS L3	Longitudinal ~not good Transverse ~fine	EM 2~4%/$\sqrt{E}$ Had ~? %	• Well-stablished. • Shower-direction difficult.
W-Si	NLC, TESLA $\mathcal{L}$@LEP/SLD SICAPO SECC	Longitudinal ~excellent Transverse ~excellent	EM ~15%/$\sqrt{E}$ Had ~? %	• Expensive. • Speed ? • Shower-direction excellent.
liq.Ar	ATLAS GEM H1 D0	Longitudinal ~excellent Transverse ~excellent	EM ~10%/$\sqrt{E}$ Had ~50%/$\sqrt{E}$	• Mass before EM ?. • Hermeticity ? • Shower-direction excellent.

Noble liquid calorimaters have well-balanced performances as indicated in the Table 1. However it would have a problem in hermeticity, which is far more important for e^+e^- colliders than for hadron colliders or ep colliders. Also cryogenic container mass would be a problem for high-precision study.

Tile-fiber calorimeters are one of the most established ones, but rather newer than above two. There are two types of tile-fiber calorimeters ; one is SDC/STAR type, and the other is CDF-endplug/CMS type. These two types differ significantly in their feature. Nevertheless both two types have many nice features and are almost ideal for hadron calorimeters[YF]. However they have a difficulty in making small tile size, and this sets practical limit in transverse segmentation. This would be a problem to use as EM calorimeters. EM calorimeter of the JLC is designed with $10cm \times 10cm$ tiles, which gives sufficient performance helped with their large radius[YF]. On the other hand, TESLA aims at making $\sim 5cm \times 5cm$ tiles[VK]. This seems to require further R&Ds for thinner fibers, multi-turn readout and uniformity.

Shashlik calorimeters have been widely adopted recently for fixed target experiments. It was also extensively studied as an option for CMS calorimeter.

Shashlik calorimeter has more light yield than tile-fiber calorimeters, and can achieve much finer transverse segmentation. The most difficulty of this type is

longitudinal segmentation. To solve this problem, many designs have been tried so far such as 'RGB-readout'[5] or 'fast/slow-scheme'[6]. TESLA first proposed to make groups of WLS fibers so that each group reads out its own longitudinal section only. This scheme needs much more fibers than above two designs.

Present idea of TESLA shashlik (CALEIDO) is to install a vacuum photodiodes directly to the side of the tiles of the first section[PC]. Several beam tests have already been done, and excellent performances have been achieved with compact photo-detectors as tetrodes or APDs. It should be noted that pion rejection of 4.0×10^{-4} was achieved with this vacuum photodiode read out. It was also observed, however, that the vacuum photodiode gap introduced some energy leakage and position measurement anomaly for particles hitting near the gap. These effect was shown to be correctable using impact point information for single-particle level, but performance in jet environment should be further studied.

W-Si calorimeter was studied extensively by SICAPO collaboration[4] and by SECC[7] collaboration. Also this has been popularly used at LEP/SLC as luminosity monitors. Basic performances are thus fairly well-known as a result of these studies. However application to large-scale detectors are yet open.

There is no doubt that W-Si calorimeters can achive performance required for the linear collider detectors. The only concern seems to be the cost. Not only silicon detectors but also tungsten itself are quite expensive. Therefore physics study must be carefully done from the view point that such an ultimate performance is really necessary or not.

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