Design optimization, simulation and bench test of fine-granularity tile/fiber EM calorimeter test module

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1. Introduction

'Standard' Calorimeter Analysis for jets (Use calorimeter energy only for neutral particles)

a) Reconstruct single-particle cluster in jets. ----> Granularity & Moliere radius are essential.

b) Assign correct energy to each cluster. ----> Single-particle Energy Resolution is essential.

c) Remove clusters generated by charged particles.

d) Remove clusters generated by backgrounds.

Both Granularity and Energy Resolution be balanced. (Detectors so far mostly had good σ_E but poor granularity.)

This was highly polished up by ALEPH as 'Energy Flow Analysis' by fully taking advantage of its granularity.

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There is another approach which does not do clustering but do hit attachment to a track.

a) Precise hit attachment ; needs granularity

b) Precise energy assignment to remnant hit-group ; needs energy resolution

* Might have a possibility to bias toward tracking momentum --> Needs demostration

Design Criteria of Detector System

- **Two-jet mass resolution** comparable to natural width of *W/Z*,
- **Hermeticiy** to determine missing momentum precisely,

and
- **Timing resolution** capable of separating bunch-crossing (2.8ns).

Hardware-compensating tile/fiber calorimeter has been chosen to achieve the criteria.

Why tile/fiber configuration

I can't help thinking about multiplying channels ($O(10^8)$) by O($10) ...... (taken from M.B. and mod'ed)

True reasons are ;

- Excellent hermeticity. (for CDF-style. SDC-style has very small dead region.)
- High potential for fine longitudinal granularity (even layer-by-layer readout possible).
- Reasonable cost and established technology.

But
- unable to achieve the finest transverse granularity ; is this really mandatory ?

Why hardware compensation

- Excellent **energy resolution** and **linearity** for hadrons.

  Already established by series of beam tests at KEK and at FNAL.

- Small Moliere radius (because of thin sensor material and heavy-metal absorber).

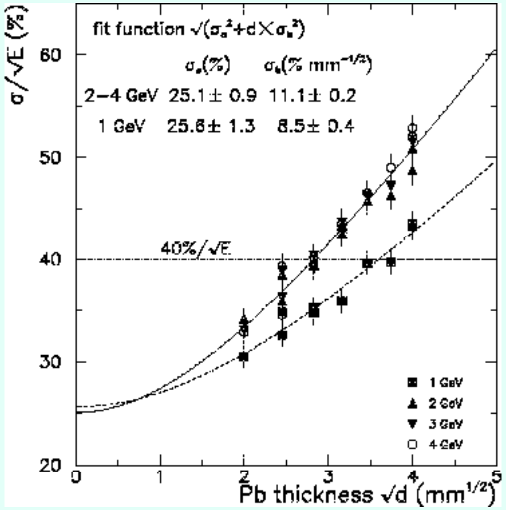
NOTE

1) Hardware-compensation sacrifices neither granularity nor EM energy resolution.

σ_E/E for electrons has already been establised to be $15.4\%/\sqrt{E} \oplus 0.2\%$.

2) Non-compensating calorimeter gives biased energy measurement

for overlapping hadron showers due to non-linear response.

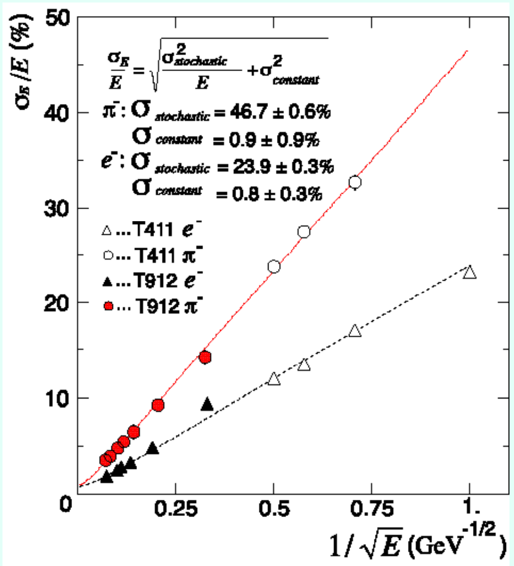


<---- SDC-type achieves

$40\%/\sqrt{E}$ for π

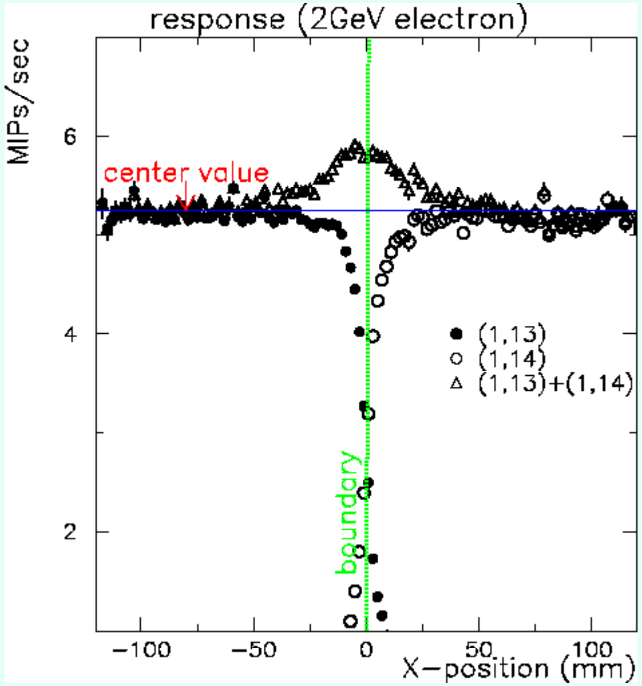
CDF-type achieves ----->

$46\%/\sqrt{E}$ for π



2. Purpose of the EM Test Module

a) Establish **technical feasibility** for fine-granularity tile/fiber structure for EMC.



b) Establish **anomaly-less response**.

Tile/fiber HCAL had response enhance of 10% on WLS-fiber for e^-.

Solutions

- Dilution by Staggered WLS-fiber layout
- Suppression by thinner tile (i.e. thinner bottom thickness)

c) Measure **response map** and implement to full simulators.

d) Some other generic features (e/π ID, shower profile,...)

*) Event-simulation study is mandatory to validate granularity.
This be done BEFORE module construction in usual sense.
NOT this time becasue KEK test-beam facilities will be shut down by the end of next year.
(No high-energy testbeam facilities at least until 2007 in Japan).

3. Test Module Design

Investigate the finest granularity achievable with tile/fiber structure within reasonable cost and effort.

Module Structure

- 4cm x 4cm x 1mm-thick scintillator tiles interleaved with 4mm-thick hard-lead (+1mm acryl).

  (Hardware-compensating ratio)
- Longitudinal sections of 3.6Xo-thick each (5-layers-ganged, 8-samplings over 28Xo-EM)

  $R_{Moliere}$ = 24mm --> Needs additional shower-position detectors

What to Examine (potential problems on hardware)

- Tile fabrication/machining is not a problem ; Mega-tile molding will work fine for any sizes.
- **Bending radius of a WLS fiber** imposes strong limits.

  Manufacturer's recommendation is r = 50mm for 0.5mm-φ fiber

  CDF established 20mm, STAR established 13mm ---> Examine by ourselves.
- **Cost of fibers** imposes another limits (smaller tiles --> more fibers).

  O($20) x 10^6 fibers (cost for test-module-scale production).
- Fabrication effort be examined (labor cost).

4. Bench Test

a) Tile ; fabricate-ability, photon yield and uniformity

b) WLS-fiber ; bend-ability and deterioration. To do. Not yet.

c) EBCCD (or MCHPD) ; Not this time. Use conventional MAPMT for the test module.

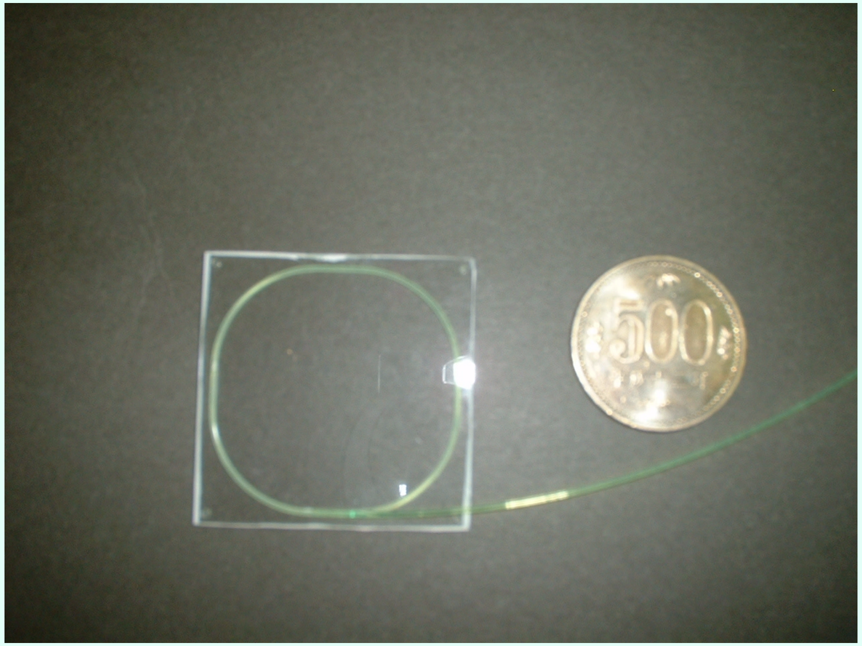
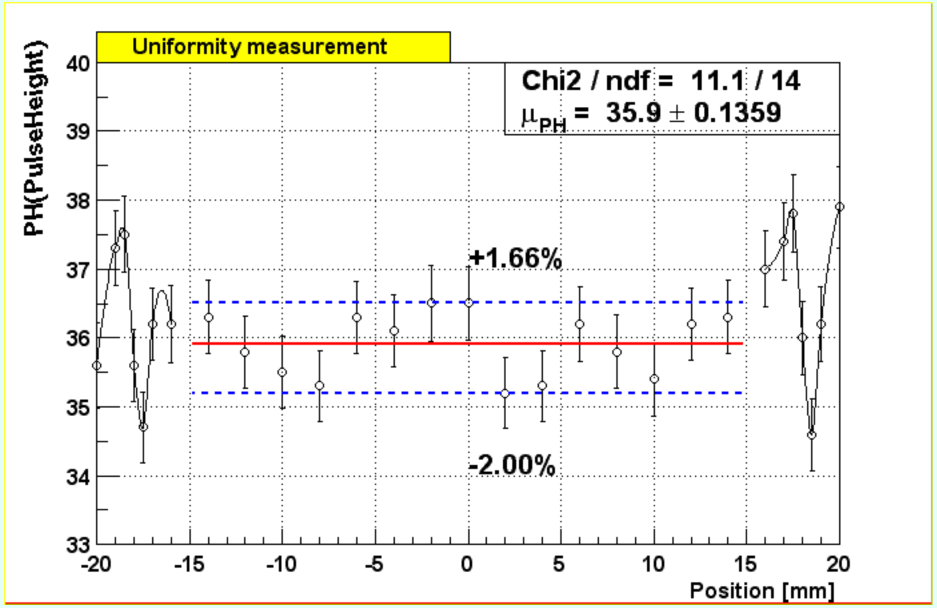


Photo of a tile with a 500yen coin



Light-yield uniformity

500yen

2euro

1dollar

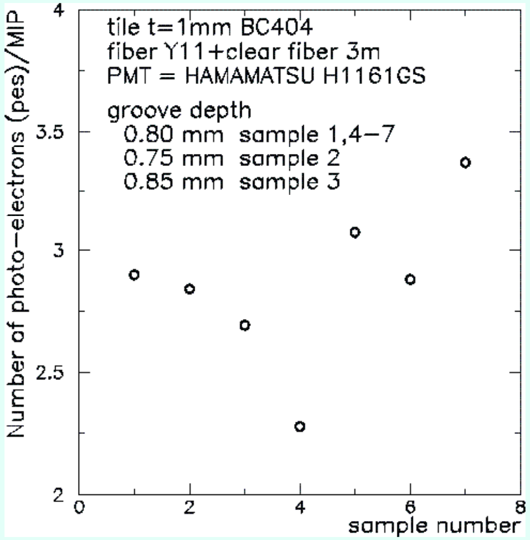
500won

Better than +-2% in central region ; very good.

>-5% on WLS-fiber, >+5% near WLS-fiber ; needs stagger.

4. Bench Test - continued

Photon yield smaller than expected from the existed measurement.

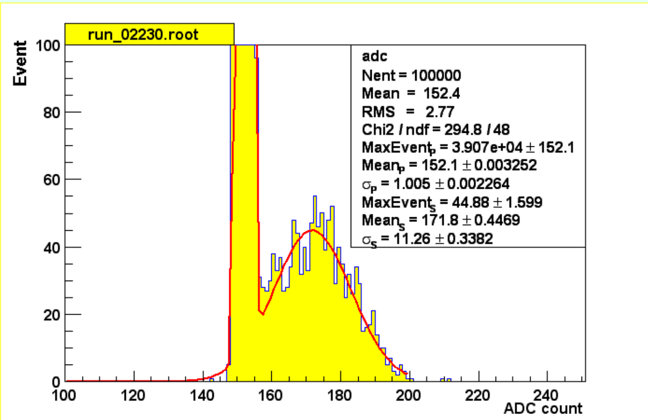


<----- Photelectron yeild of **10cm x 10cm x 1mm** tiles ~ **2.8p.e.**

Empirical Law ; Np.e. scales as thickness/area

---> **7p.e.** expected for **4cm x 4cm x 1mm** tiles at design stage

However new measurement resulted in ;



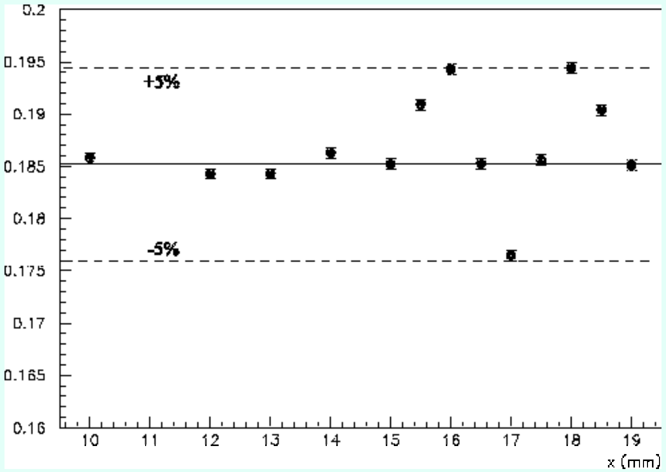
<----- Photelectron yeild of **4cm x 4cm x 1mm** tiles ~ **2.2p.e.**

Small bending radius could have caused significant light loss.

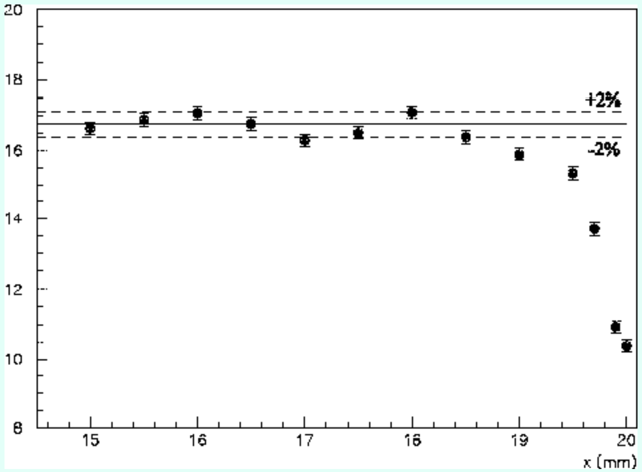
- Scintillator-Strip EMC might be better ?
- ATLAS-HCAL scheme might be better ?
  (similar for TESLA-HCAL)

5. Simulation

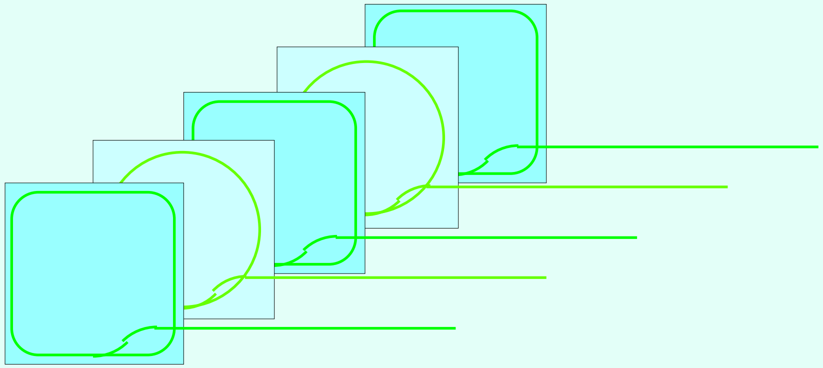
GEANT simulation of test-module responses with measured-uniformity embedded.



Response of the 1st layer to **muons** reflects embedded non-uniformity.



Response of the 1st SuperLayer to **electrons** shows weakened non-uniformity. Effect of inter-tile gap (0.5mm) is prominent.



- Staggered WLS-fiber layout to cure WLS anormaly.
- Mega-Tile molding should cure the dip caused by a gap between tiles. (However cross-talk comes up.)

6. Beam Test (plan)

Combined test of

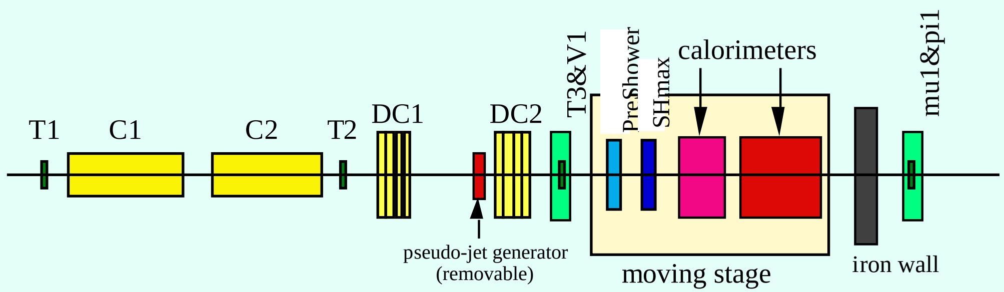
- **Preshower detector.**
- **SciStrip-SHmax** ; conventional WLS-fiber readout and APD direct-readout.
- **RectTile-EM** ; Only 2-SuperLayer this time. Full-module next year.
- **SciStrip-EM** ; See Matsunaga-san's talk.

To be done this fall at KEK proton synchrotron ; 1-4GeV unseparated beams.

(Test at higher energy, as done for HCAL at FNAL, is not planned ; EM response extrapolate-able)

Notes • Use MAPMT this time. MCHPD/EBCCD not yet ready to integrate into a test module.

• Use individually-machined tiles this time instead of molded Mega-Tile.



6. Beam Test (continued)

Two types of SHmax counters ;

a) Conventional WLS-fiber readout

Established. Rather costy.

b) Direct-attached APD-readout

• Less-expensive and easy to make.

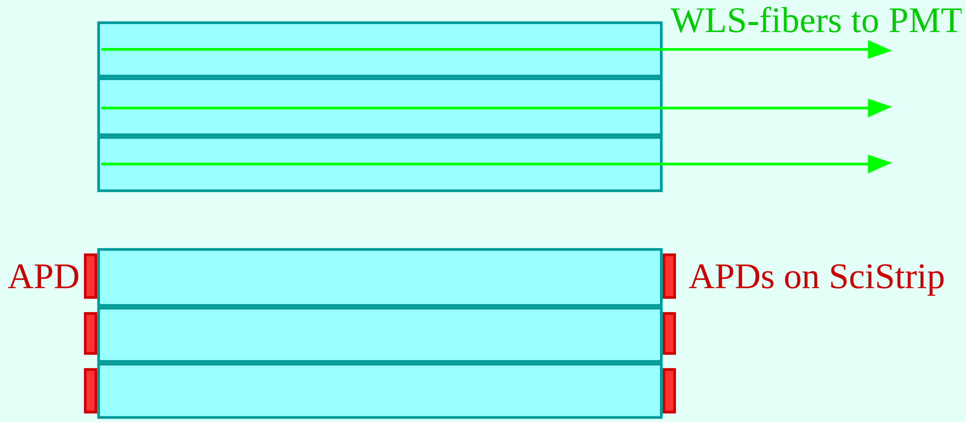
• Low S/N at room temperature (at present).

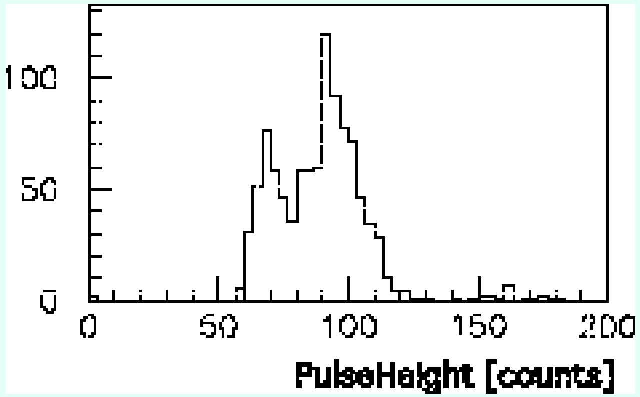
---> Better APD / preamp ?

Less noise / Higher gain / cost

Peltier-cooling ?

Should do well but mass/cost probelm.





Pusle-height spectrum with beta-ray for APD-readout at room temperature. HPK S8664-55 is used. Nphoton = 200.

7. Summary

- Energy resolution and granularity are essential parameters of CAL.
- Capability of compensating tile/fiber calorimeter on above under examination.
- Energy resolution & Linearity already established by beam tests (both EM&hadron).

- Granulatiry under investigation ;
  - performance estimation by simulation (rather slowly)
  - performance validation by testbeam measurement (need hurry-up)
  - establishment of technical feasibility

- **Fine-granularity EM test module under construction to test this fall ;**

  a) Establish technical feasibility for fine-granularity tile/fiber structure.

  b) Establish anomaly-less response.

  c) Measure response map and implement to full simulators.