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Calorimeter for JLC Experiment

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JLC-CAL group is a collaboration of KEK, Kobe, Konan, Niigata, Shinshu, and Tsukuba

1) Required Performance

Design Criteria in a de-coupled CAL parameter space

2-jet mass resolution better than Γ_Z , Γ_W

- Hardware Compensation for excellent hadron energy Resolution and Linearity
- Fine Granularity for precise topological reconstruction

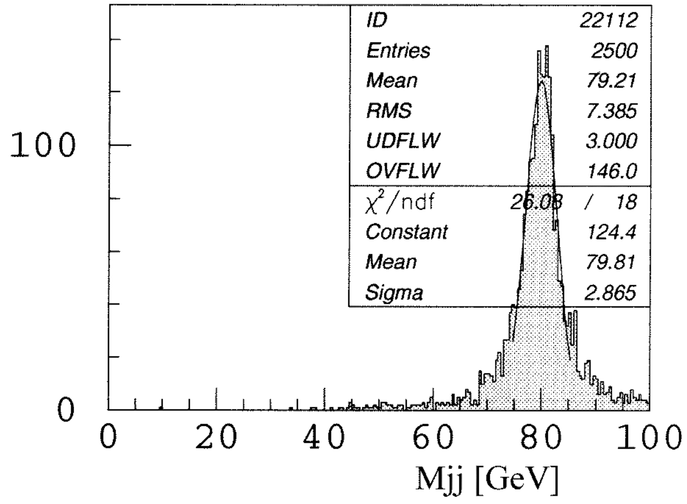
No software compensation

No extremely-fine granularity

Technology Choice

Tile/Fiber Sampling Calorimeter

- Crackless Hermeticity
- Low Cost
- Design Flexibility
- Well-established technology



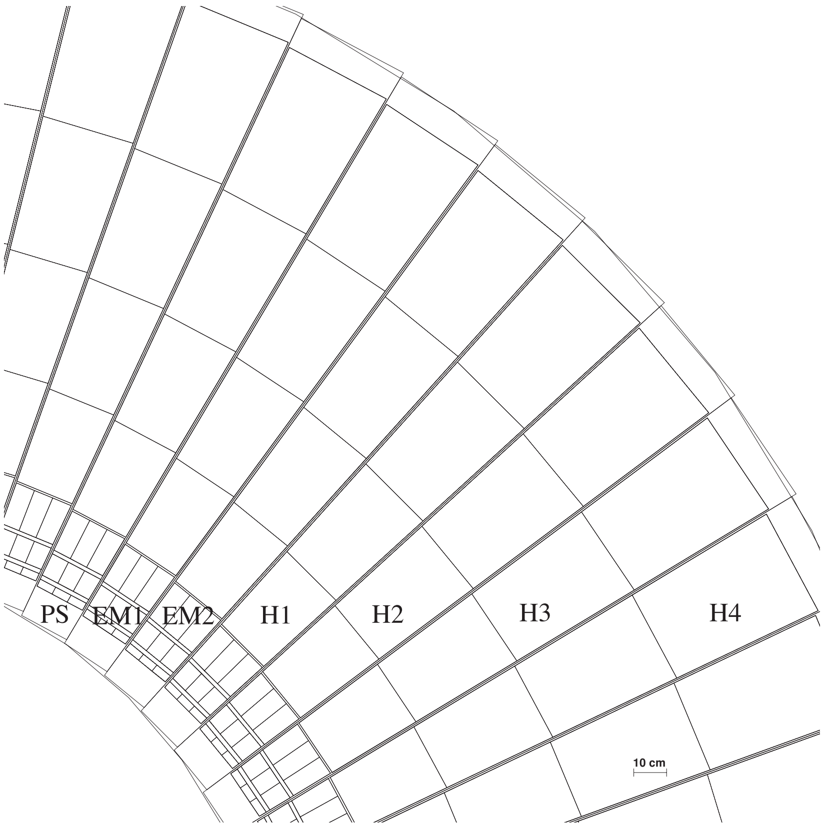
Reconstructed W mass for e+e- -> W+W- at √S=400GeV

Result of quick-simulation. SHmax is not used for analysis.

Thus contribution of track-cluster association error is as large as ~1.9GeV. Better result expected with SHmax analysis.

2) Basic parameters of revised baseline JLC calorimeter

magnetic-field option	2T-case	3T-case
Inner Radius	250cm	160cm
Outer Radius	400cm	340cm
Angular Coverage	$\lvert\cos\theta\rvert < 0.985$	$\lvert\cos\theta\rvert < 0.966$ (Full)
	$\lvert\cos\theta\rvert < 0.994$	$\lvert\cos\theta\rvert < 0.991$ (Partial)
SHmax scheme	**Scintillator-Strip Array** (1cm-wide)	option=Si-pad (1cm x 1cm)
EMC	$\sigma_E/E = 15\%/\sqrt{E} + 1\%$	
transverse	**6cm x 6cm (24mrad)**	**4cm x 4cm (24mrad)**
longitudinal	3 sections (6+12+20 layers)	
HCAL	$\sigma_E/E = 40\%/\sqrt{E} + 2\%$	
transverse	**18cm x 18cm (72mrad)**	**12cm x 12cm (72mrad)**
longitudinal	4 sections (25+30+35+40 layers)	
Thickness		
PreSH	**4Xo (4mm x 6 layers)**	
EMC	**23Xo (4mm x 22 layers)**	
HCAL	**6.5λo (8mm x 130 layers)**	



Configuration of Baseline Barrel Calorimeter

3) Proof of Performance

[A] Energy Resolution & Linearity

- Related to Material Choice and Global Design
- Must be verified by **Beam Test**

[B] Granularity

- Related to Component Design
- Must be verified by **Full Simulation**

..... Easy to tune at any stage in the case of Tile/Fiber scheme

Strategy;

- **1st** Establish energy resolution & linearity with tile/fiber test module

  DONE
- **2nd** Optimize granularity by full simulation with tile/fiber structure implemented

  In Progress

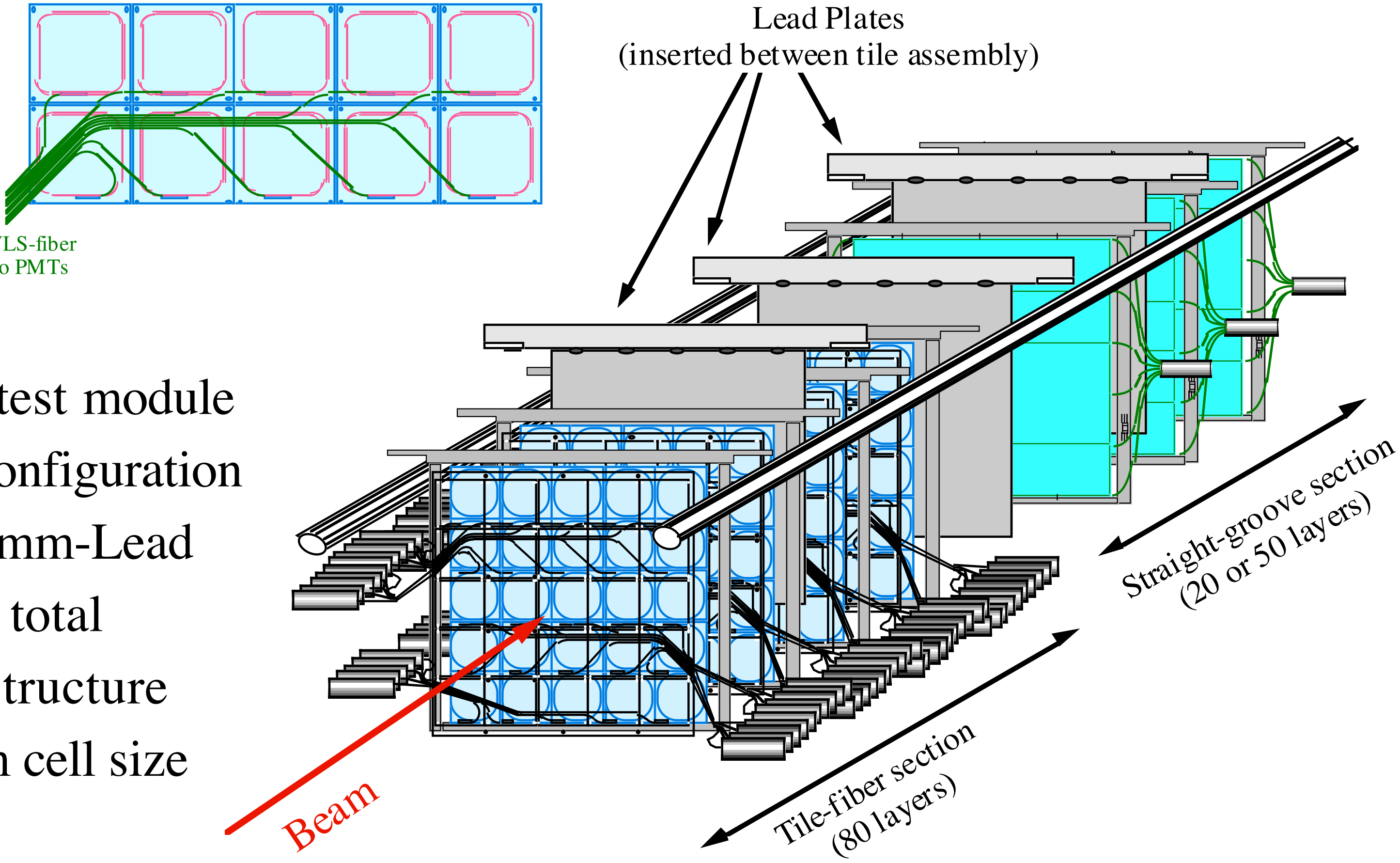
[A] Beam tests done at KEK (1-4GeV) and at FNAL (10-200GeV) to prove ;

a) **Energy Resolution** / Gaussian Response / Hardware Compensation

b) **Linearity** / Dynamic Range

c) Tower Boundary Uniformity

d) e/π Separation Capability


WLS-fiber
to PMTs
Lead Plates
(inserted between tile assembly)
Straight-groove section
(20 or 50 layers)
Tile-fiber section
(80 layers)
Beam

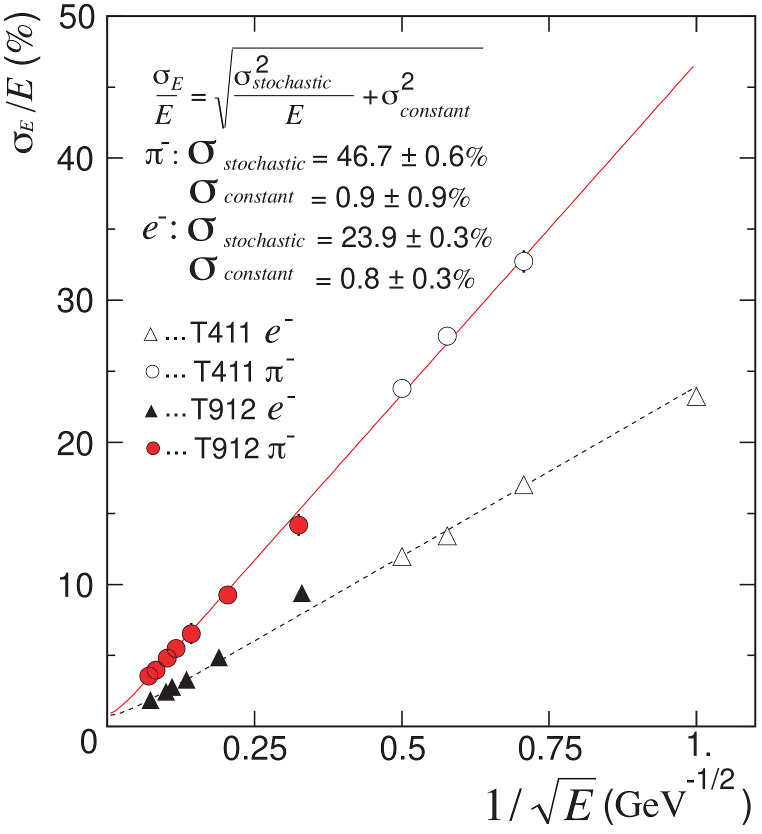
Schematic View of

Hadron Calorimeter test module

with Tile/Fiber configuration

- 2mm-Sci + 8mm-Lead
- 130 layers in total
- 5 x 5 tower structure
- 20cm x 20cm cell size

a) Energy Resolution



Energy resolution of tile/fiber hadron calorimeter test module.

π ; $\sigma_E/E = 46.7 \pm 0.6\%/\sqrt{E} + 0.9 \pm 0.9\%$

worse than design due to 'fiber-routing' acryl plate

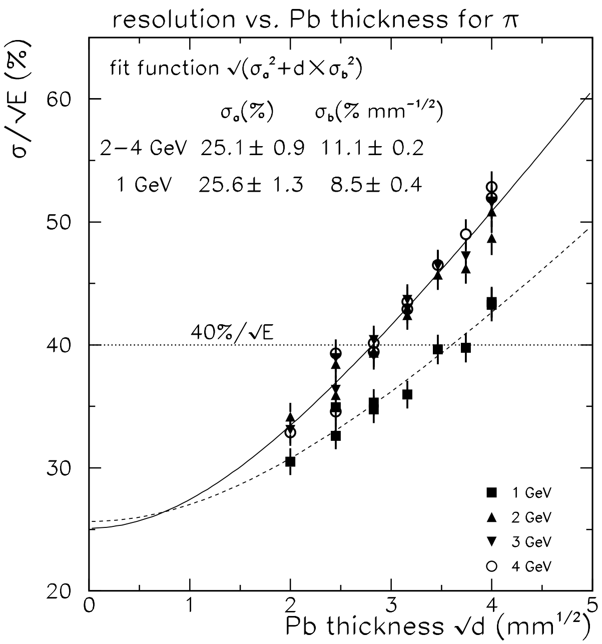
•••• **Should be OK but needs verification.**

Effect of acryl plate (measured by beam tests)

- No effect on compensation if placed downstream of scintillator
- No effect on EM energy resolution regardless its location
- Deteriorate hadron energy resolution regardless its location

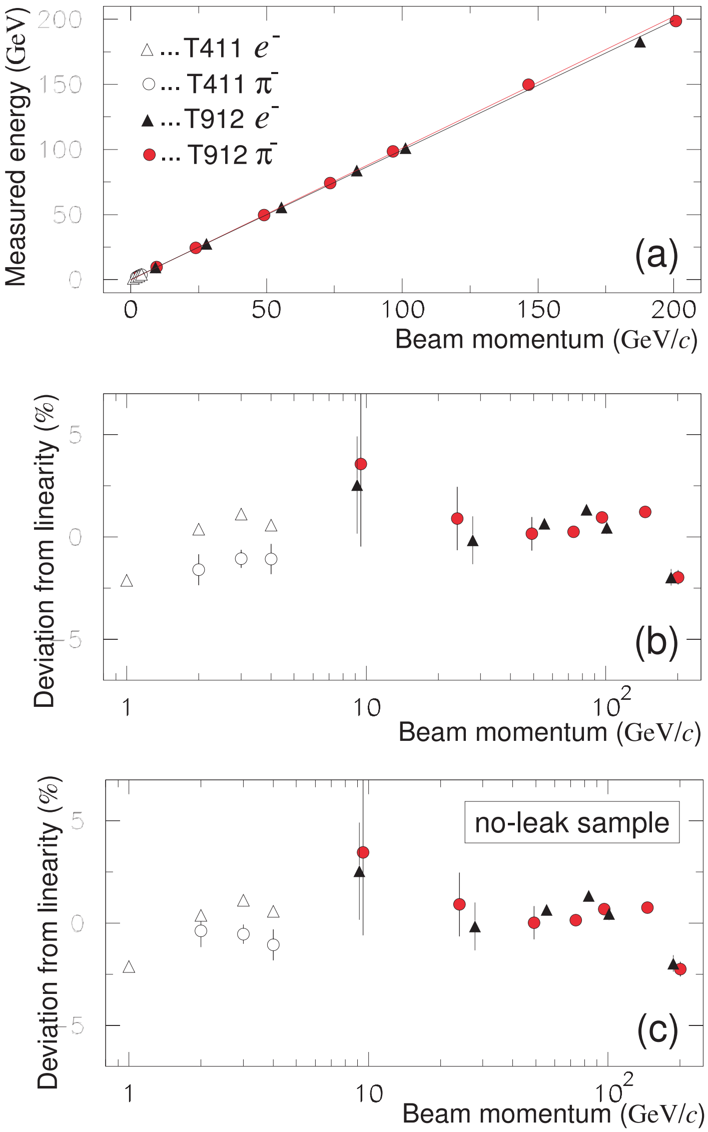
Beam test result of acryl plate effect (4GeV)

Position of Acryl	EM resolution	π resolution	e/π ratio
No acryl plates	12.0±0.5 %	20.5±0.4 %	1.03±0.02
Upstream of Sci	11.6±0.5 %	22.7±0.4 %	1.07±0.02
Downstream of Sci	12.0±0.5 %	22.8±0.4 %	1.01±0.02



Energy resolution of HCAL test module w/o acryl plates.

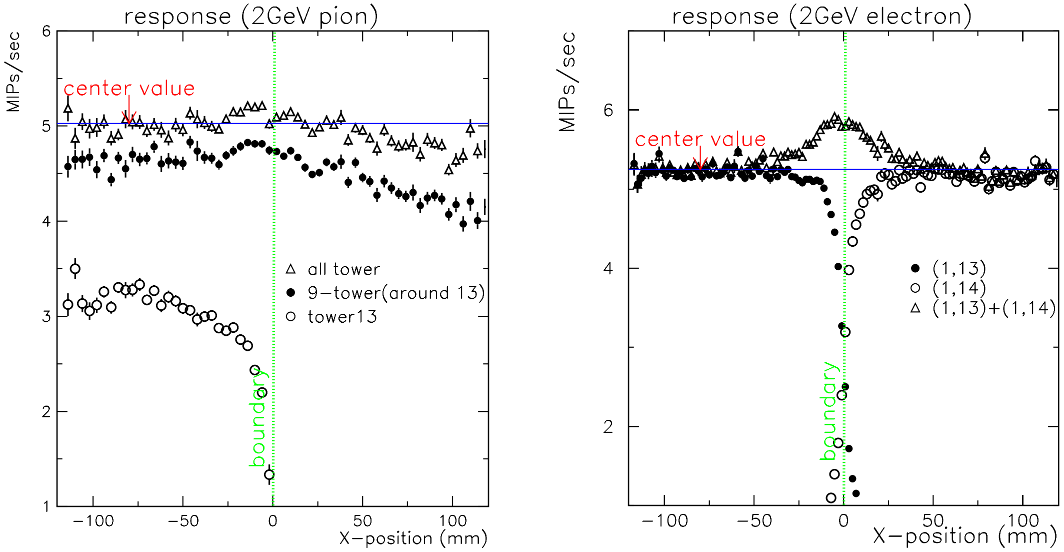
b) Linearity



Good Linearity thanks to Hardware Compensation.

(better than 1% from 2 GeV to 150 GeV)

c) Tower Boundary Response

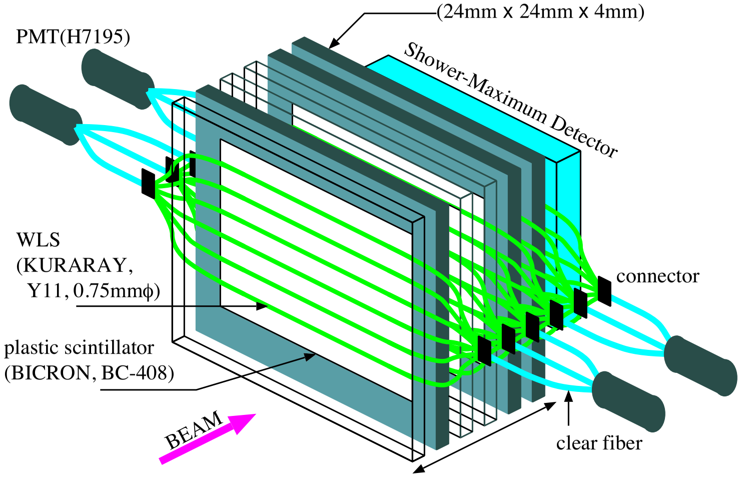


- No significant anomaly was observed at the tower boundary for pions.
- Slight anomaly was observed for electrons.

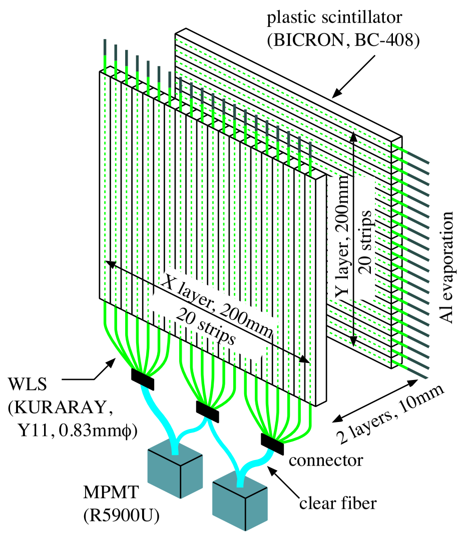
EM module must be designed with more uniform response.

d) e/π separation and PreSH/SHmax

Preshower Detector


Pb plate
(24mm x 24mm x 4mm)
Shower-Maximum Detector
PMT(H7195)
WLS
(KURARAY,
Y11, 0.75mmϕ)
plastic scintillator
(BICRON, BC-408)
connector
BEAM
clear fiber

Shower-Maximum Detector


plastic scintillator
(BICRON, BC-408)
Y layer, 200mm
20 strips
Al evaporation
X layer, 200mm
20 strips
WLS
(KURARAY,
Y11, 0.83mmϕ)
2 layers, 10mm
connector
clear fiber
MPMT
(R5900U)

Combined performance of

- PreSH
- SHmax (Scint-Strip)
- HCAL

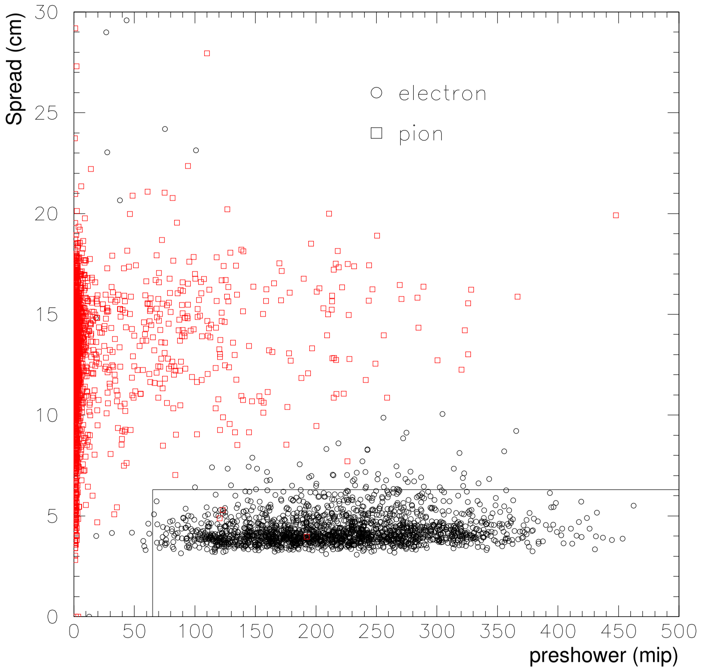
measured with test beam.

- pion rejection ~1/1400
- with Ɛe ~ 98%

  Quite Satisfactory
- position resolution 2~3mm

  due to noise/cross talk

  Needs improvements



[B] Granularity Optimization

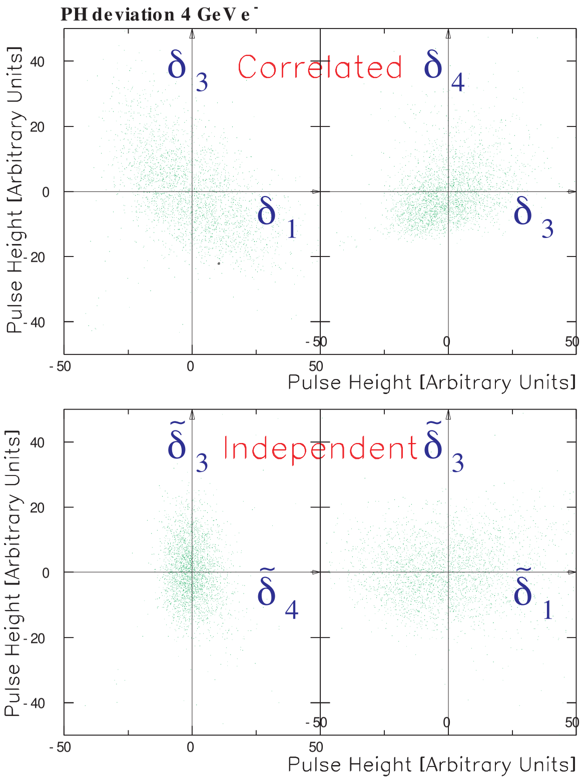
Optimization with a full simulator based on GEANT3

- Tuning of calorimeter response in progress
- Hadron-clustering algorithm under development
- Cluster-track association algorithm under development

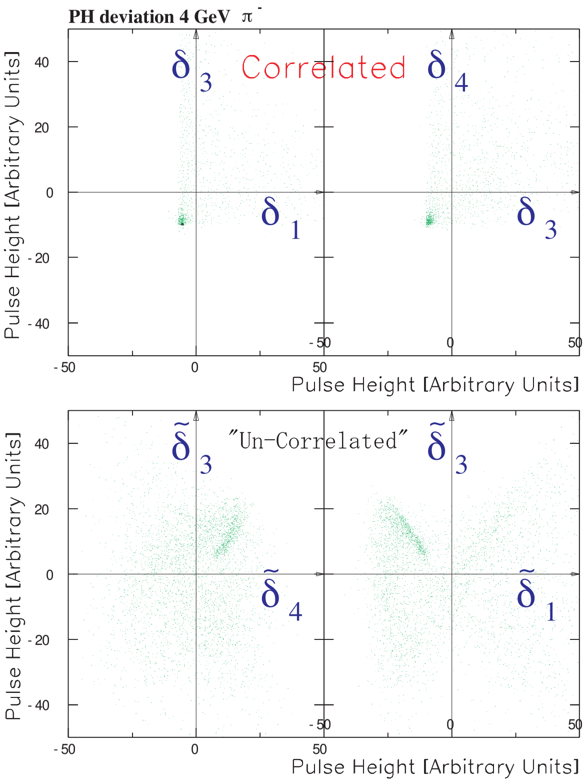
- Implementation of hadron shower generator with realistic fluctuation

  Still working hard to make 'Un-Correlated' distribution function.

Yet a lot to do before reconstruction of physics processes for optimization.



Un-correlated fluctuation for EM

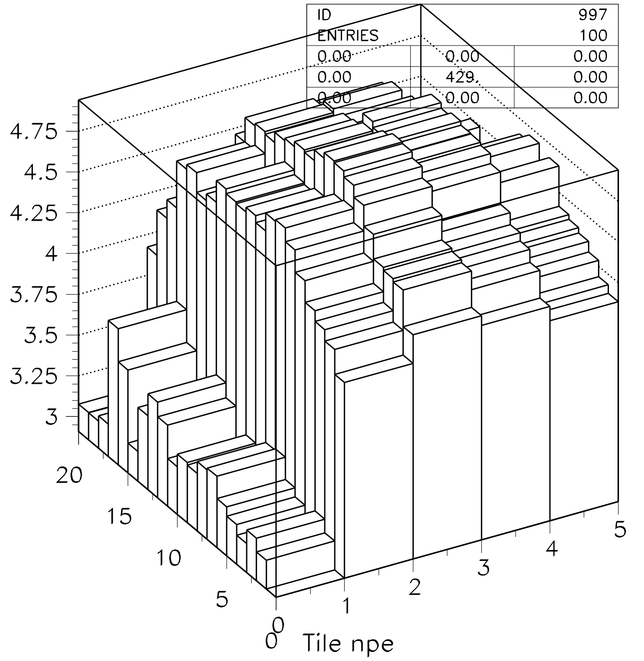


Correlated fluctuation for hadrons

4) Other R&D Items

a) Scintillator-strip EMCAL

- much finer-granularity
- reasonable cost by casting/extrusion of strips
- non-uniformity over a strip ~ 4.8%
  similar to traditional square tiles (~ 4.6%)
- requires super multi-channel photo-detectors
- crossed-strip layout need study
  ghost-rejection capability by full simulation
- energy decomposition algorithm be studied
  for multi-hit in a cell.



Photon yield uniformity over a 1cm-wide strip

b) Direct-readout Scintillator-strip SHmax

- Attach high-gain APD directly at the end of scintillator-strip ... eliminate WLS cost
- Punch-through be rejected by blind-Si behind.

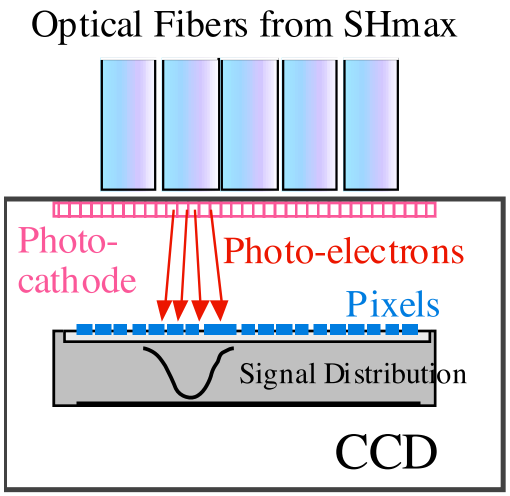
……. under study.

c) Photon Detectors

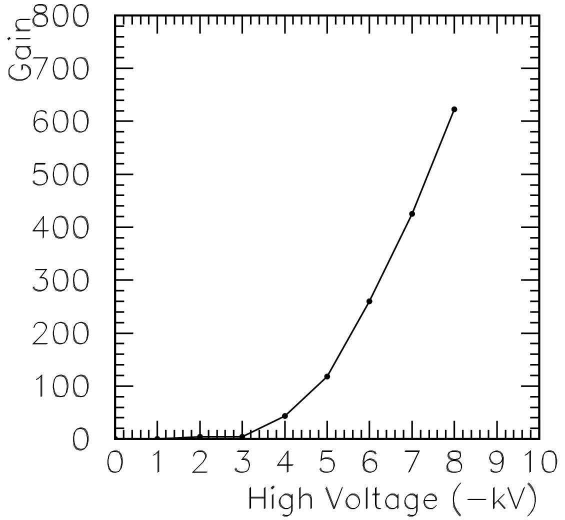
- EMC/HCAL

  multi-channel HPD/HAPD : promising (however cost-down needed)
- Scintillator-Strip EMC/SHmax need

  super-multichannel photo-detector.
  - 61ch-HPD ; tests in progress
  - EBCCD ; tests in progress. Higher gain needed.


Optical Fibers from SHmax
Photo-cathode
Photo-electrons
Pixels
Signal Distribution
CCD

Principle of EBCCD



Gain vs photo-cathode voltage for proximity-focused EBCCD

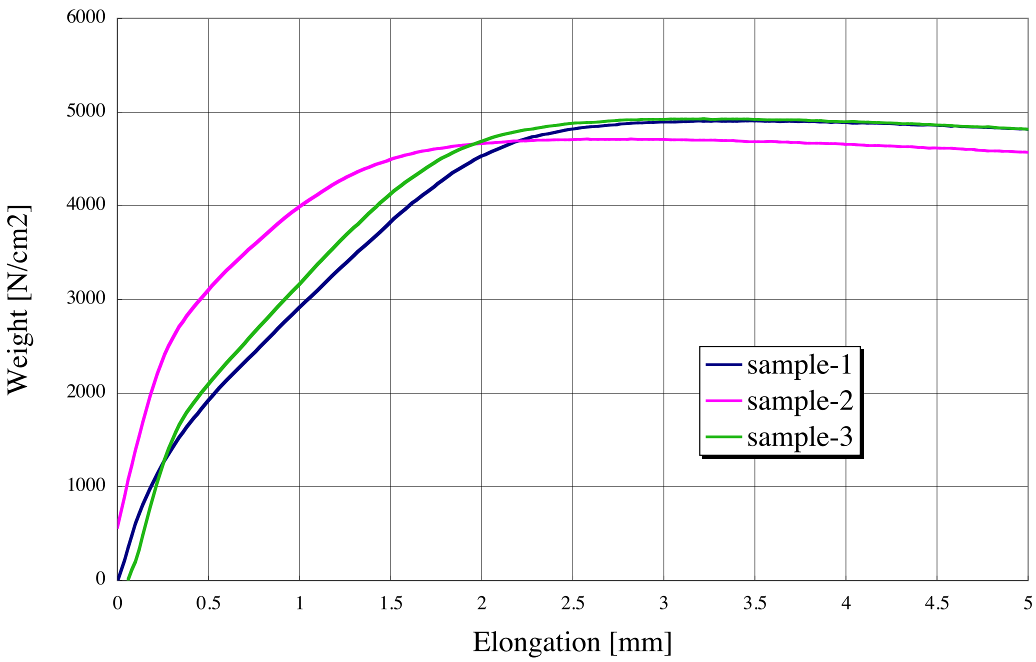
d) Strong Lead Alloy

Hardware Compensation ... Lead as passive/structural material

==> Lead alloy with high rigidity and tensile strength needed.

Temporary target = strength of copper

	tensile strength (yield)
Copper	**64MPa**
Pure Lead	7MPa
Lead Alloy	50MPa (preliminary)



- Other samples being tested.
- Young modulus under calibration.

5) Summary

Baseline design of JLC calorimeter

- high performance expected ; **hermeticity, resolution, linearity**
- with **well-established technology** ; tile/fiber scheme
- with **reasonable cost** ; casting enables further cost reduction
- **design flexibility** ; completely decoupled resolution & granularity by hardware compensation scheme

Proof of Principle --- Finished.

However verification with full simulation is severely behind schedule.