シンチレータストリップを用いた高性能電磁カロリメータの開発

（公募研究A１）

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9-Mar-2004, 科研費特定領域　第2回研究会 in Tsukuba
(Special thanks to Dr. Matsunaga)

- Introduction
- Hardware study with test beams
- Photon sensors
- Simulation study
- Future plan
- Summary

Introduction

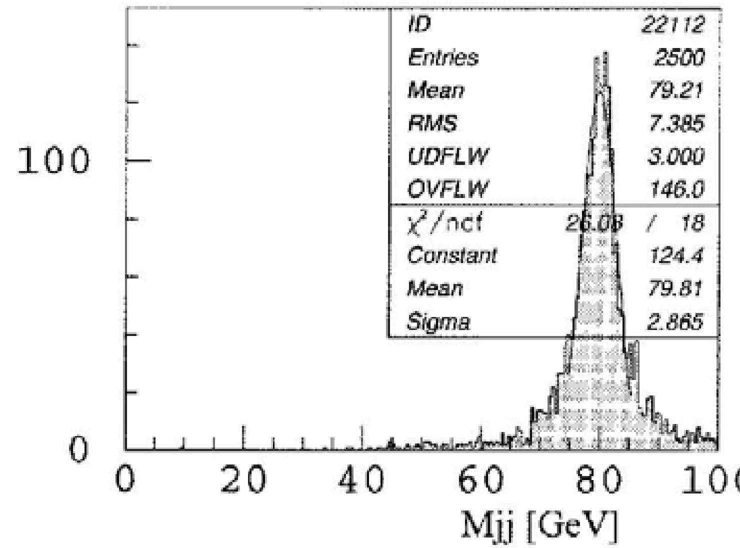
- Design criteria for LC calorimeter
  - good energy resolution for single particles
  - fine transverse/longitudinal granularity for "particle flow" analysis
  - hermeticity
  - operational in strong magnetic field
- Required performance
  - 2-jet mass resolution better than W/Z natural width

Our approach to the design criteria

- Baseline design :

  Lead/plastic scintillator sampling calorimeter for both ECAL and HCAL

  - Hardware compensation for excellent hadron energy resolution and linearity
  - Good hermeticity
  - Good granularity
  - Established technology and reasonable cost
  - According to fast simulation, this conservative design can fulfill design criteria



Reconstructed W mass for $e^+e^- \to W^+W^-$ at 400GeV

(result of fast simulation in which ECAL cell size was 10cm)

$\sigma\,(M_{jj}) = 2.9\text{GeV}$

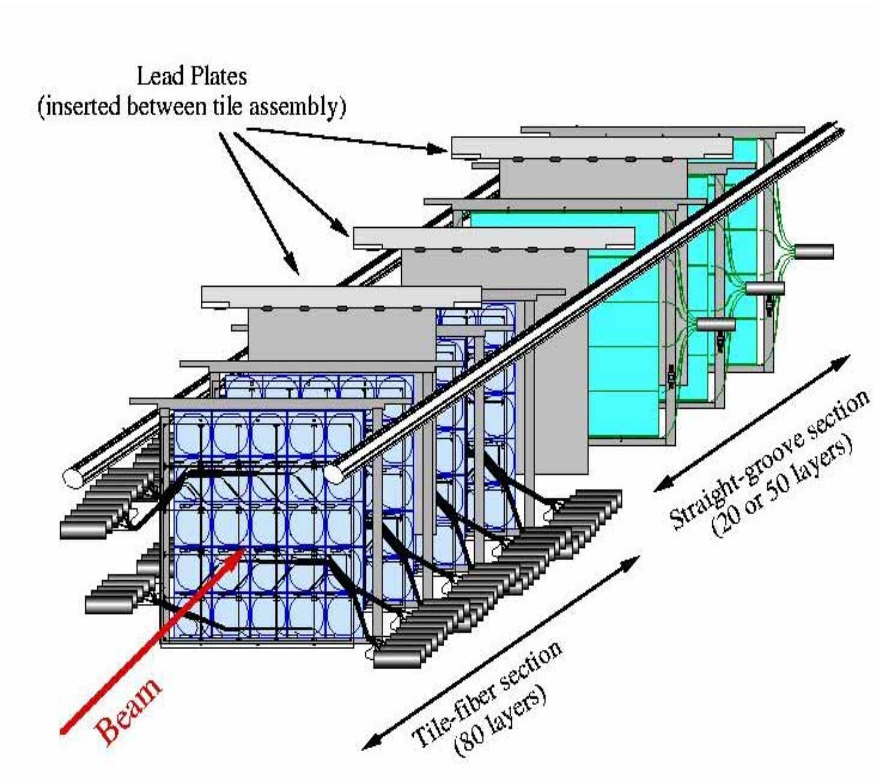
Our previous studies

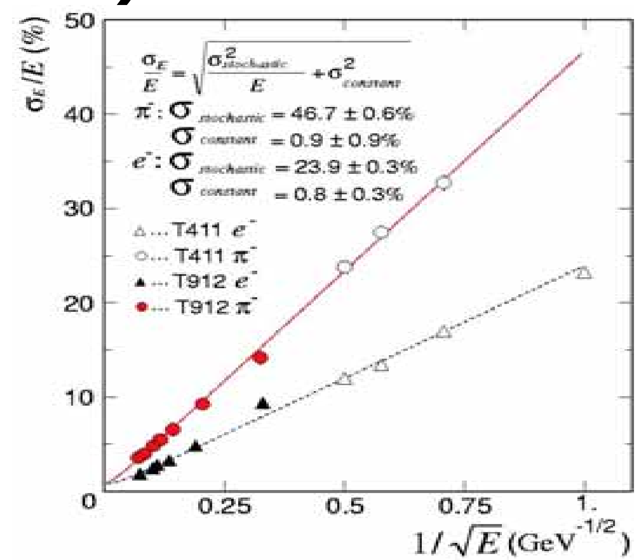
- Study on energy resolution and linearity
  - Test beam measurements at KEK and FNAL
    - ECAL with 4mm-Pb/1mm-Sci :

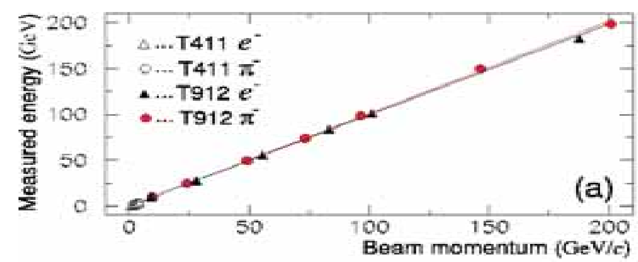
      $\sigma_E/E = 15.4\%/\sqrt{E} + 0.2\%$ for electrons
    - HCAL with 8mm-Pb/2mm-Sci /2mm-Acryl :

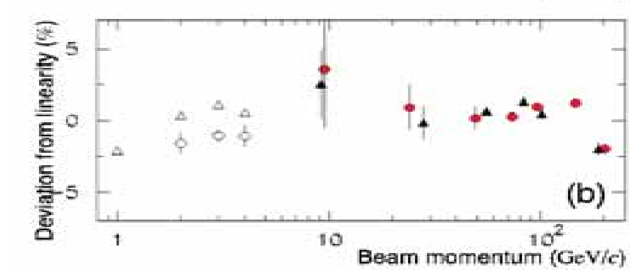
      $\sigma_E/E = 46.7\%/\sqrt{E} + 0.9\%$ for pions
- Tile/fiber calorimeter with hardware compensation has been verified to meet our design criteria for energy resolution and linearity even with current design of granularity
  - Detailed simulation study must be done

HCAL studies with test beam (1996-1999)









- Good energy resolution and linearity thanks to hardware compensation

Fine granularity ECAL

- Currently studying fine granularity ECAL with Pb/Sci sampling technique
  - examine “particle flow” analysis capability
- Baseline design : tile/fiber ECAL
  - 4cmx4cmx1mm-Sci + 4mm-thick Pb
- Optional design : strip-array ECAL
  - 1cmx20cmx2mm-Sci + 4mm-thick Pb
- Shower-max detector with scinti-strips
  - Conventional WLS readout
  - Directly-attached APD readout
- Require multi-channel photon sensors operational in magnetic field

Purposes of test beam studies

(1) Tile/fiber ECAL

- examine uniformity with staggerd WLS layouts

(2) Strip-array ECAL

- uniformity measurement for the simulator inputs
- measure energy, position, shower direction
- examine 2-cluster separation and ghost-rejection

(3) WLS-readout SHmax

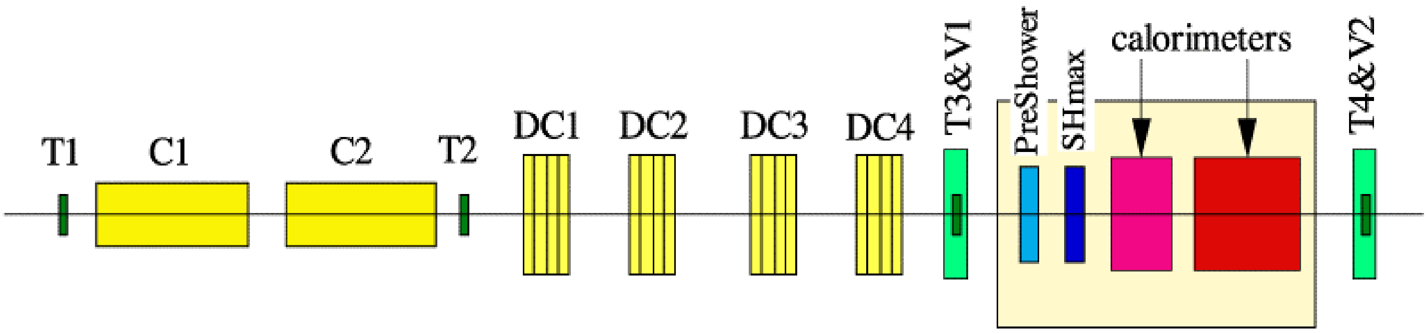
- position resolution
- e/π separation

(4) Direct-APD SHmax

- examine feasibility : S/N for MIP signal
- position resolution

Test beams for new ECAL design

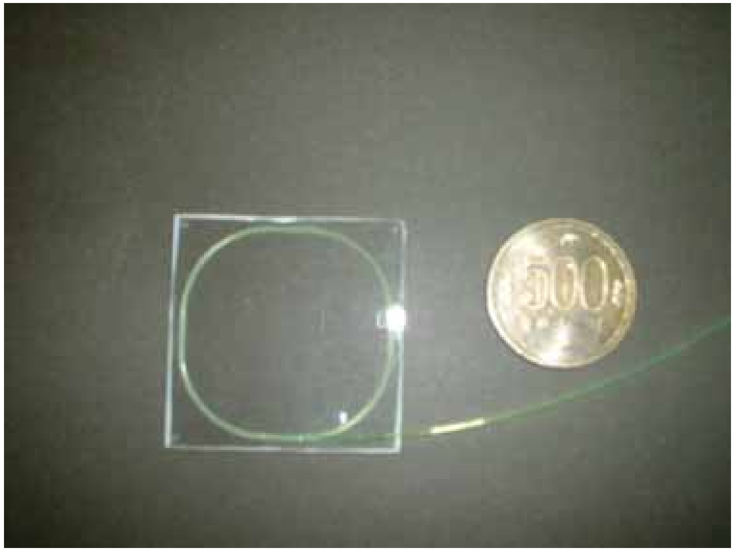
- 2002 Nov.: T517 at KEK (e/μ/π, 1-4 GeV)
  - tile/fiber ECAL, strip-array ECAL, scinti-strip SHmax
- 2003 Sept.: test at DESY (e, 1-6 GeV)
  - scinti-strip SHmax
- 2004 March: T545 at KEK (e/μ/π, 1-4 GeV)
  - tile/fiber ECAL, strip-array ECAL, scinti-strip SHmax
  - probably the last opportunity for KEK PS beamline

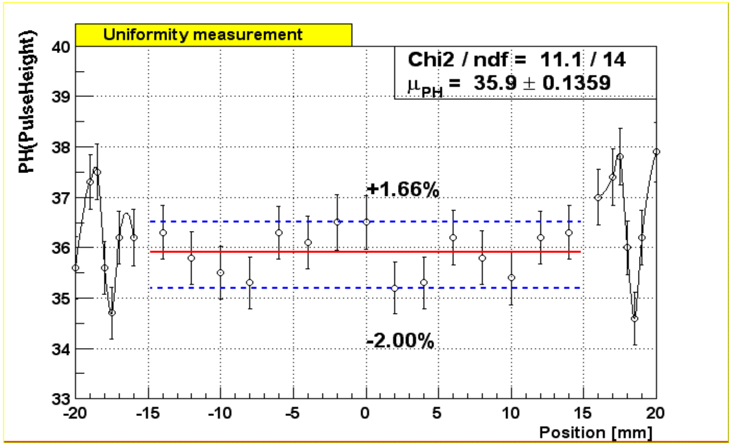


Setup of T517 test beam measurement

(1) Tile/fiber ECAL

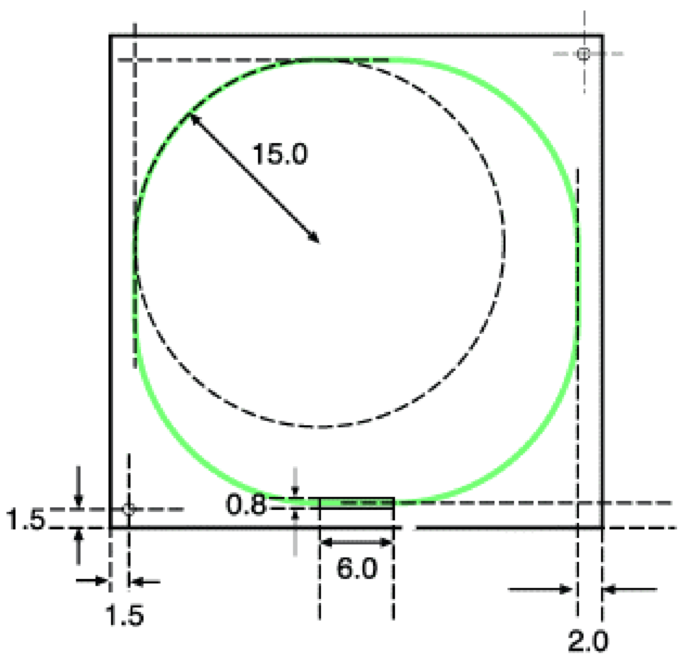
- Small cell size of 4cm x 4cm, 0.7mmϕ-WLS
- Effect of small bending radius of WLS fiber ?
- Non-uniformity (around tower boundary) ?
- Only 2 super layers (2002)
- Full-depth, mega-tiles (2004)
- Multi-anode PMTs



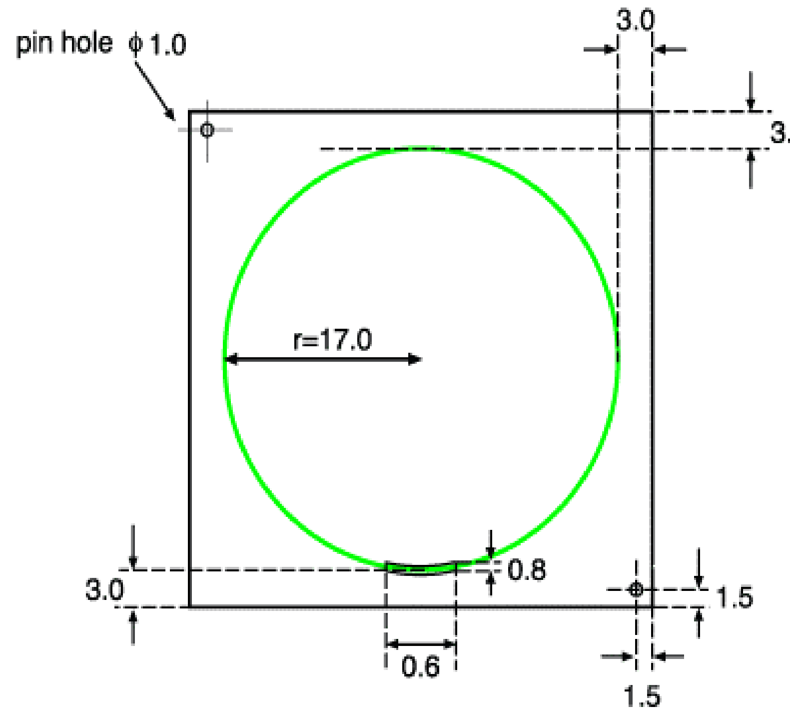


WLS fiber configuration

- Two types of groove layout to smear non-uniformity



Roundish-square groove layout

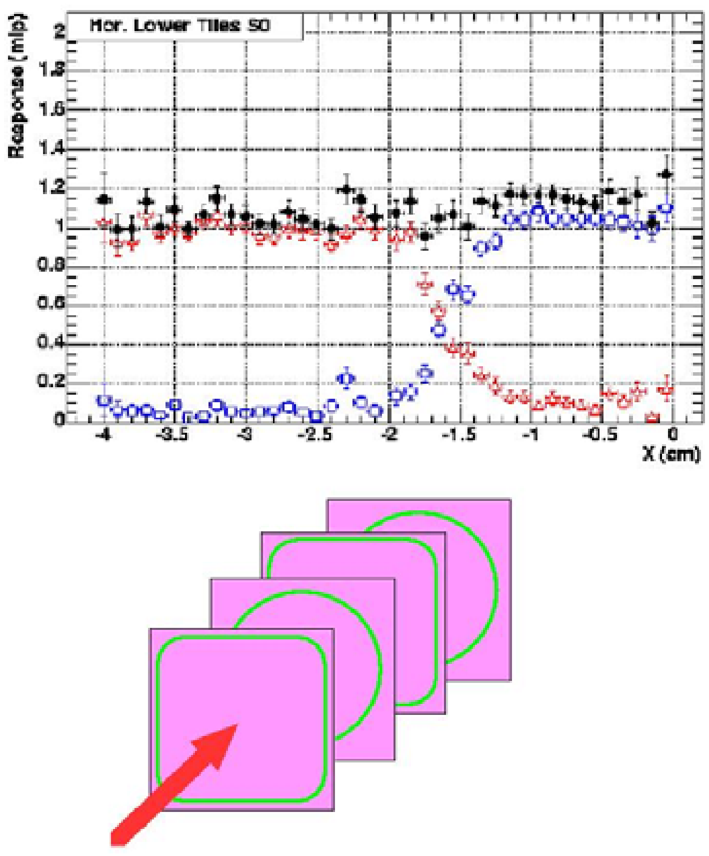


Circular groove layout

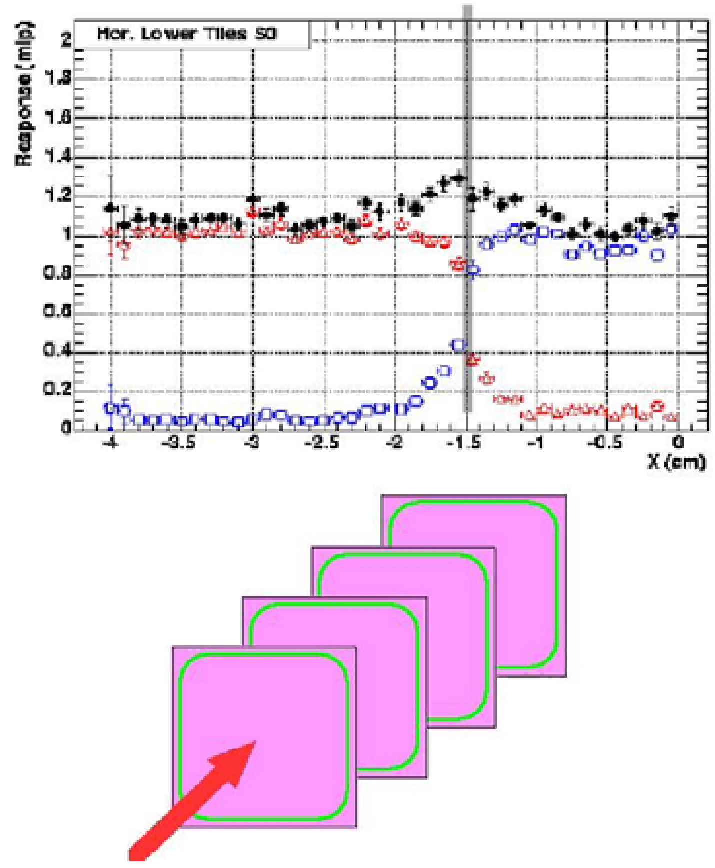
Non-uniformity measurements

- Better uniformity with alternating layout

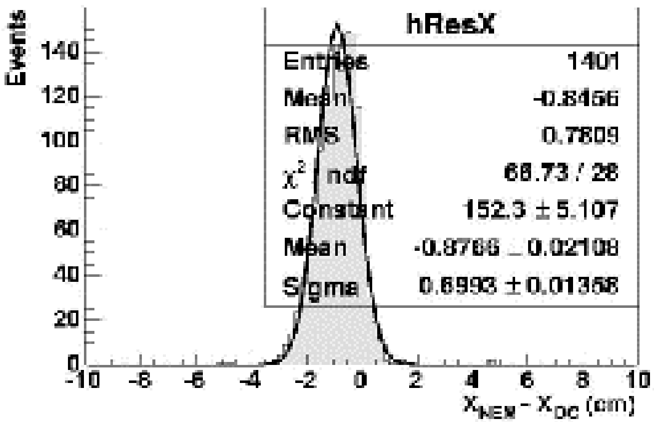
Alternating WLS

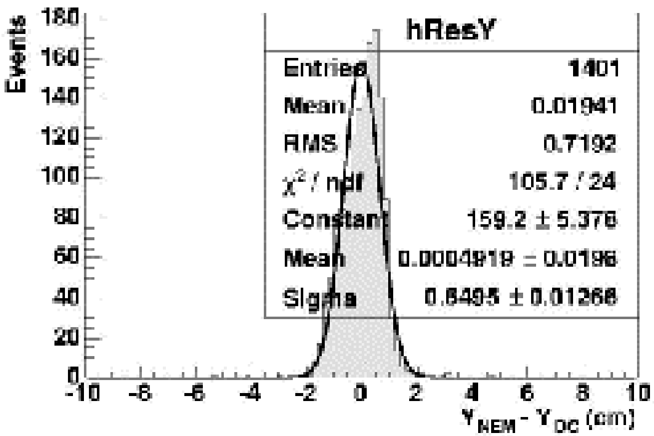


Aligned WLS



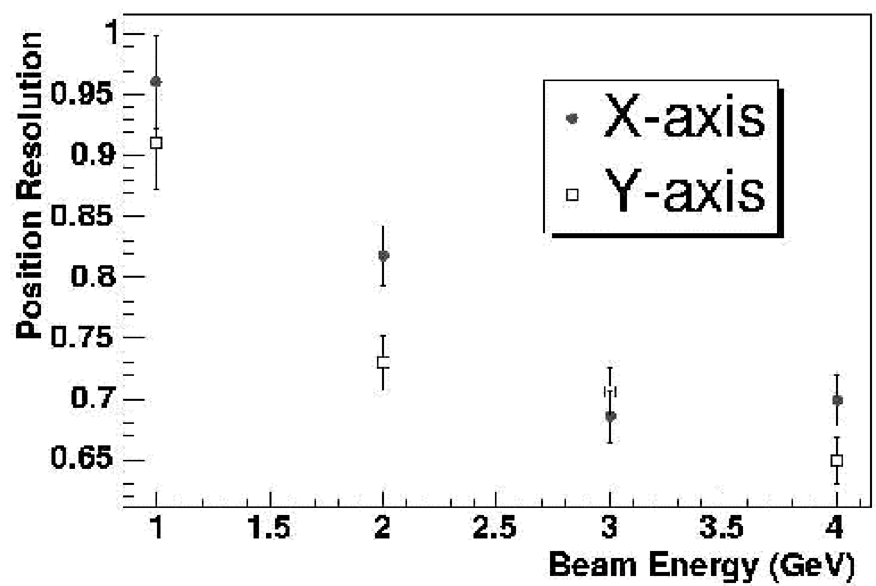
Spatial resolution





- Position resolution of 2nd S.L.

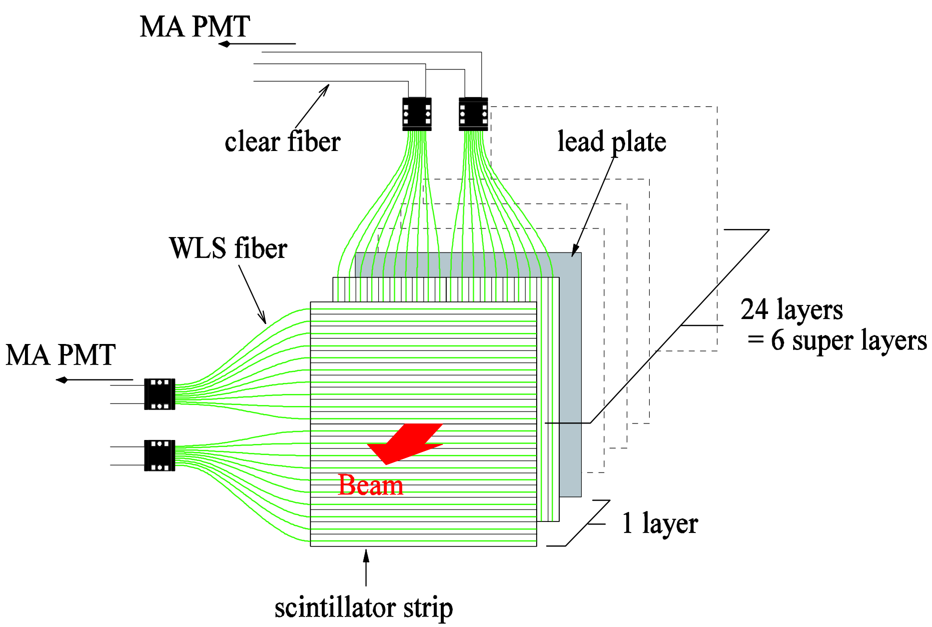
  σ (x or y) ~ 0.7cm at 4GeV



as a function of beam energy

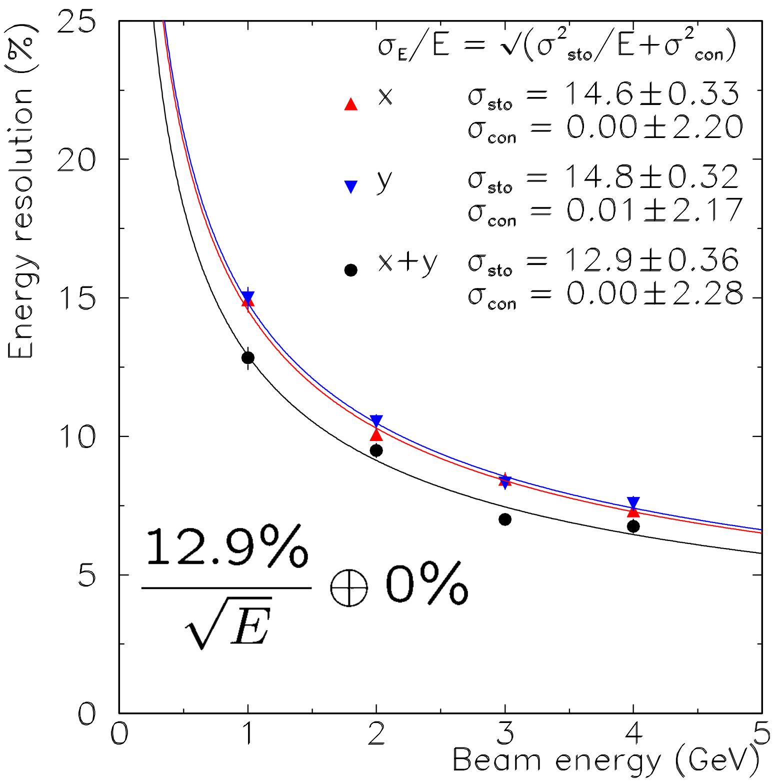
(2) Strip-array ECAL

- Full-depth test module was constructed and tested in 2002
- 24 layers ($17X_0$), 6 super-layers
- 1 layer = lead plate (4mm-thick) + x-strips + y-strips
- 20cm x 1cm x 2mm scinti-strip with 1mmϕ-WLS
- Multi-anode PMTs (tentatively for beam test)

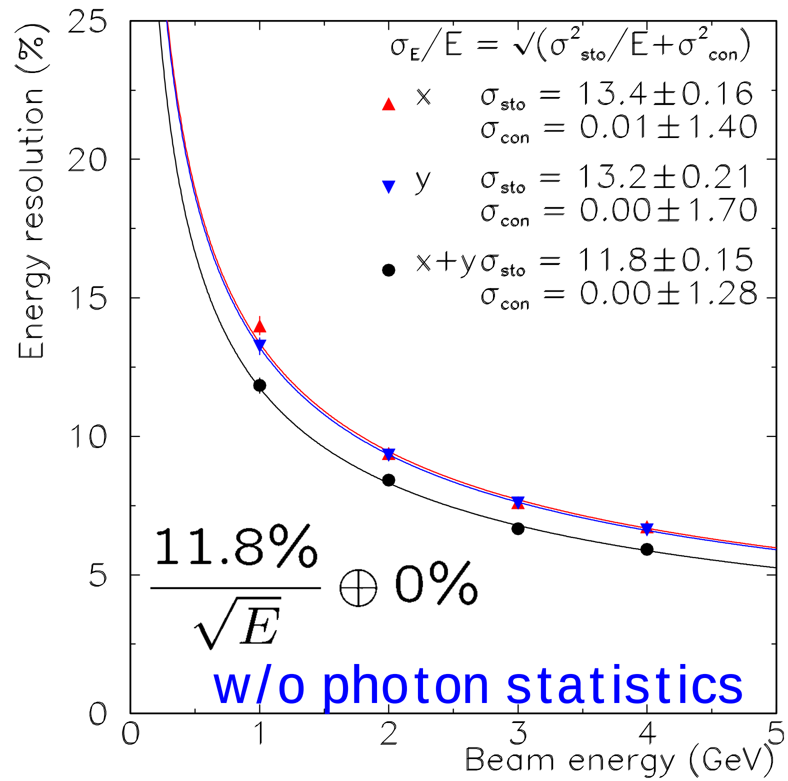


Energy resolution

Test beam



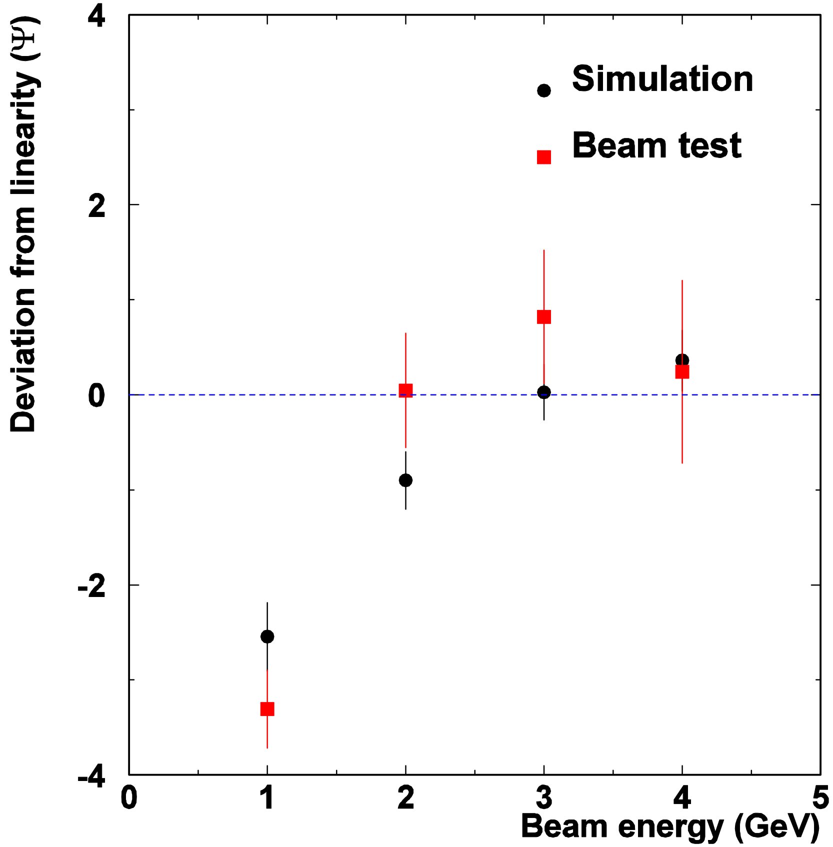
GEANT3 simulation



If photon statistics is taken into account, beam test results are consistent with simulation.

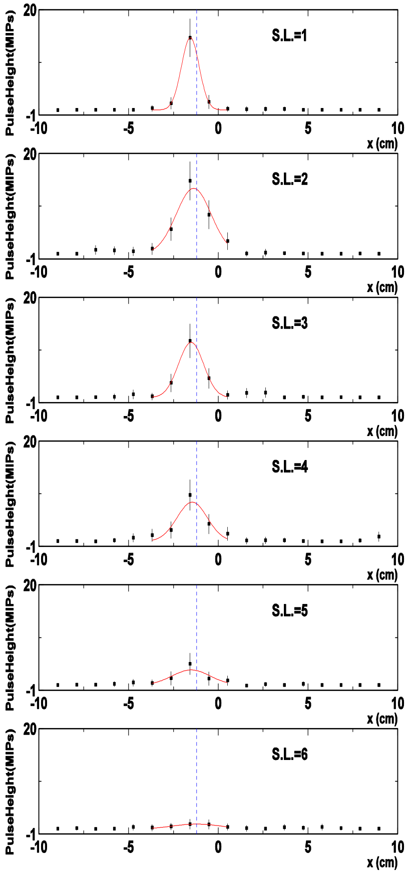
Linearity

- Linearity : < 3.5%
    - < 1% above 2GeV
    - deviation at 1GeV : due to material in front of ECAL ?
- In good agreement with simulation

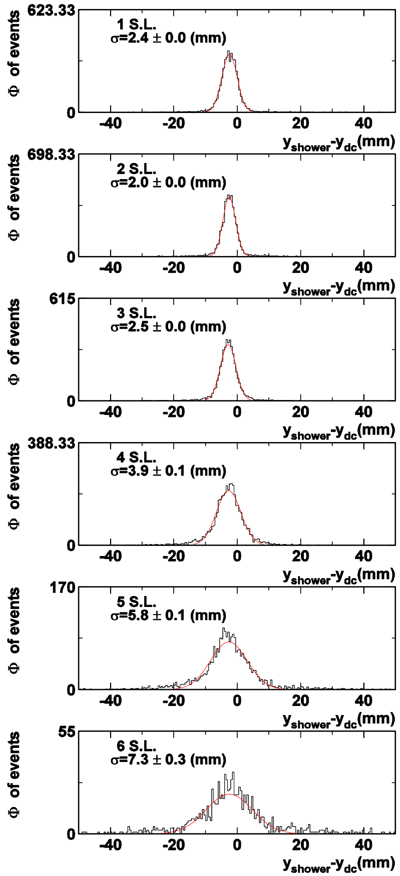


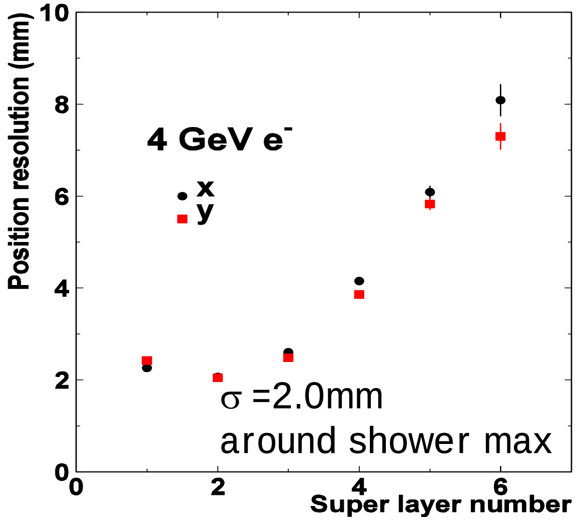
Spatial resolution

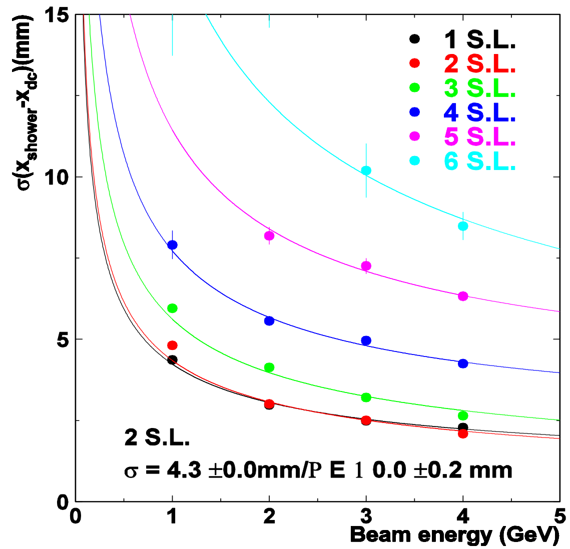
A 4GeV electron event :
Fitted to Gaussian



Position resolution
for 4GeV electron

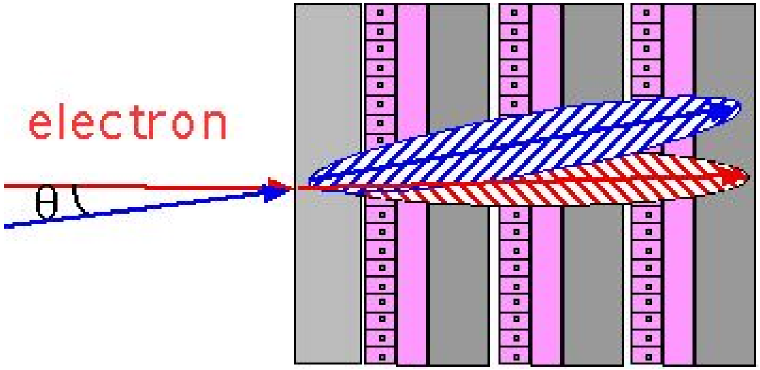


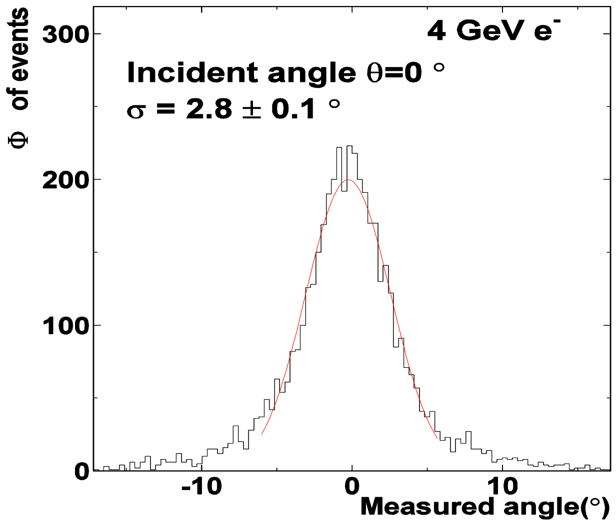


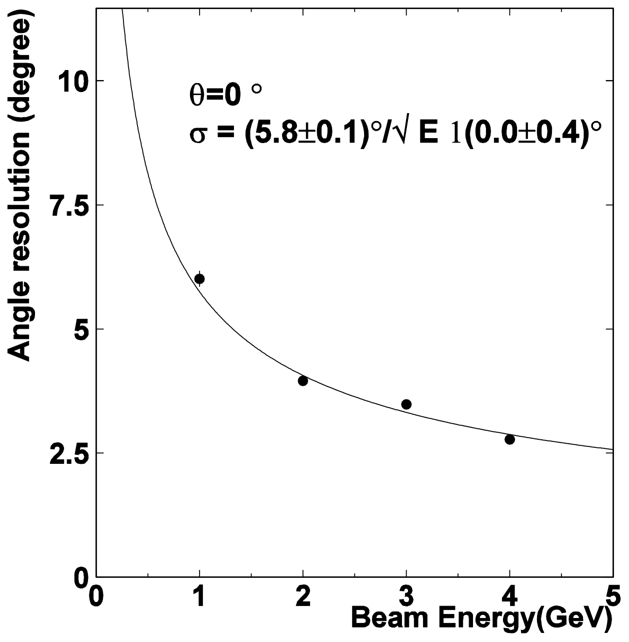


Angle measurement

- Shower-axis angle is determined by linear fitting points in the first 5 S.L.
- Mean S.L. position in beam direction is calculated with weighted mean of energy deposit obeying shower curve

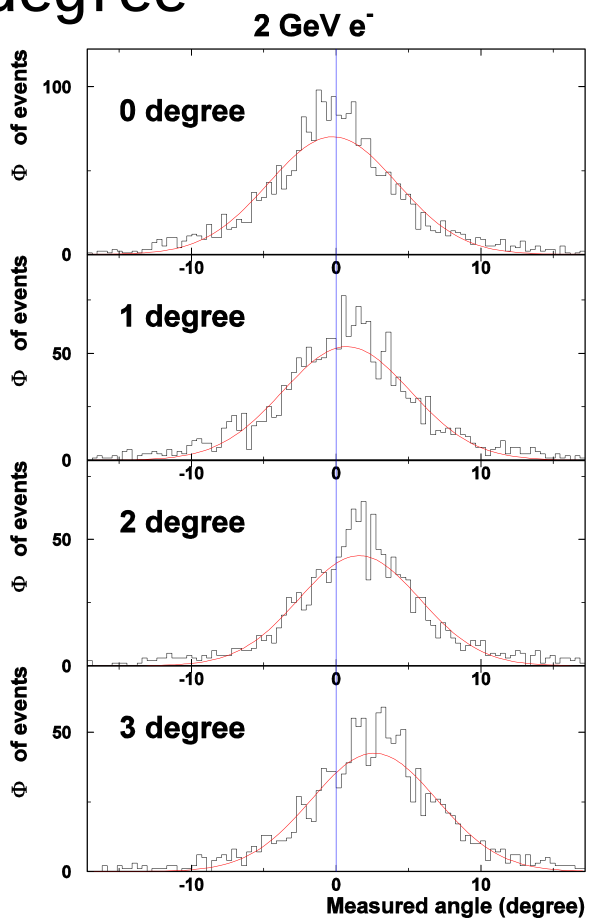


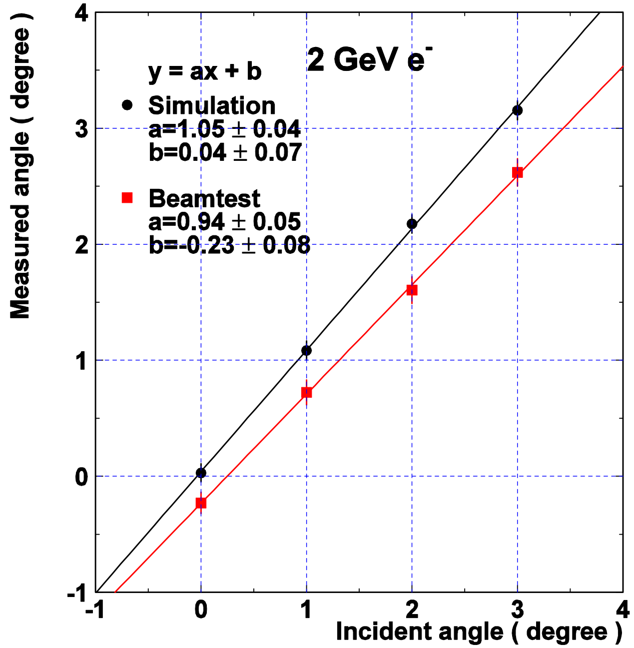




Angle measurement (cont.)

- Incident angle : 0 ~ 3 degree

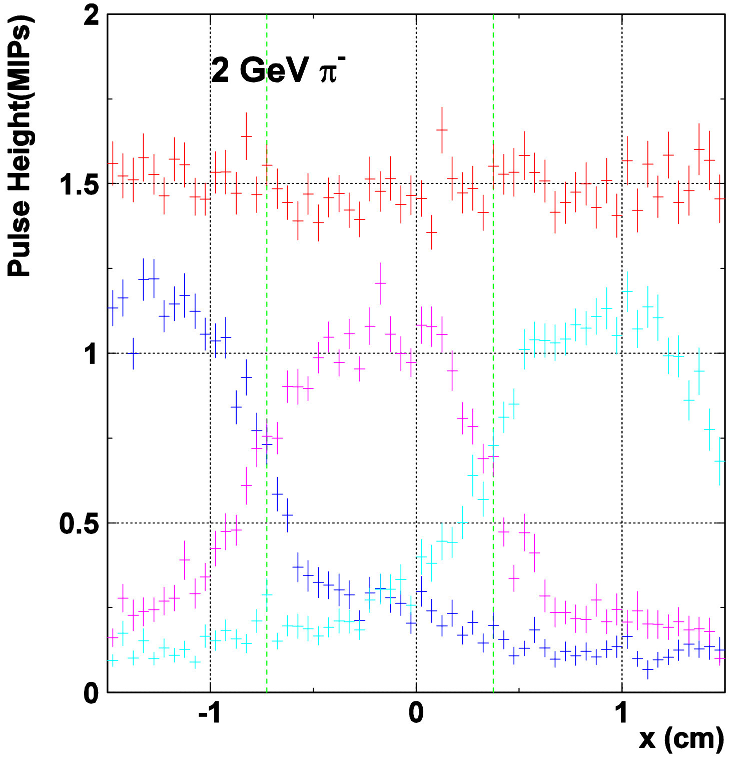


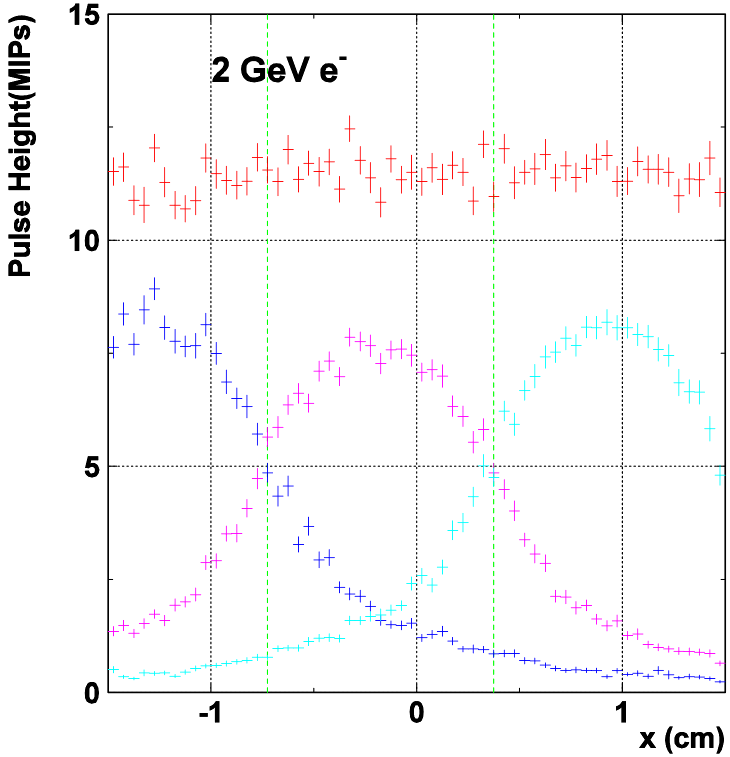


- Offset due to mis-alignment ?
- Ignoring offset, angles are correctly measured within errors

Response uniformity

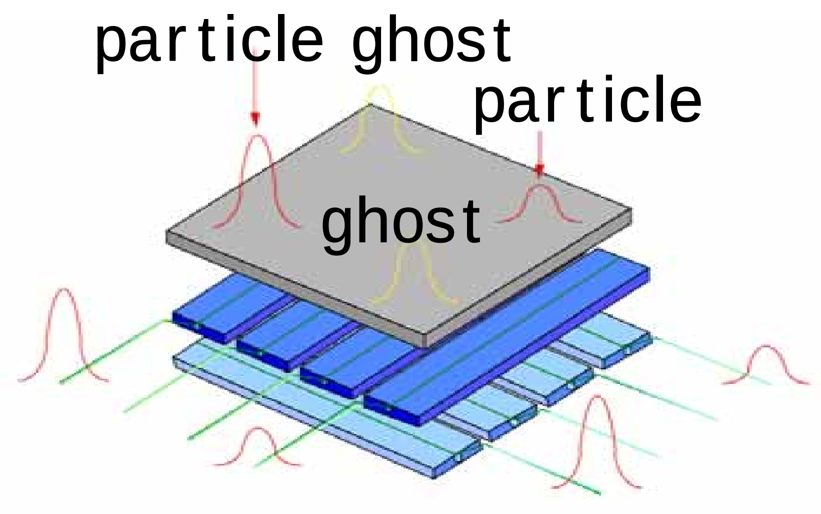
- Response in 1st super layer for 2Gev π and e
- Response-sum over strips : uniformity < 5%



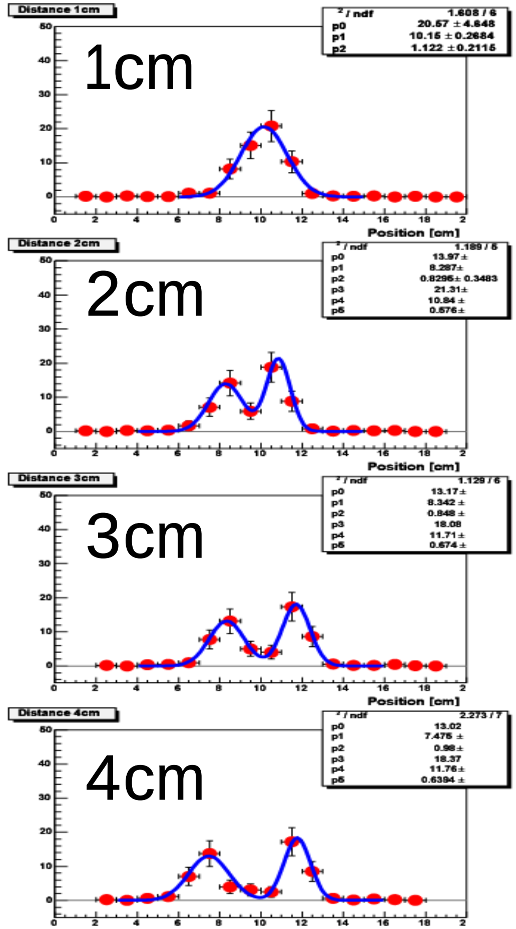


2-particle separation / ghost rejection

- For strip-array ECAL, ghost must be rejected
  - pulse height analysis could help for rejection
- 2-particle separation and ghost rejection : study in progress

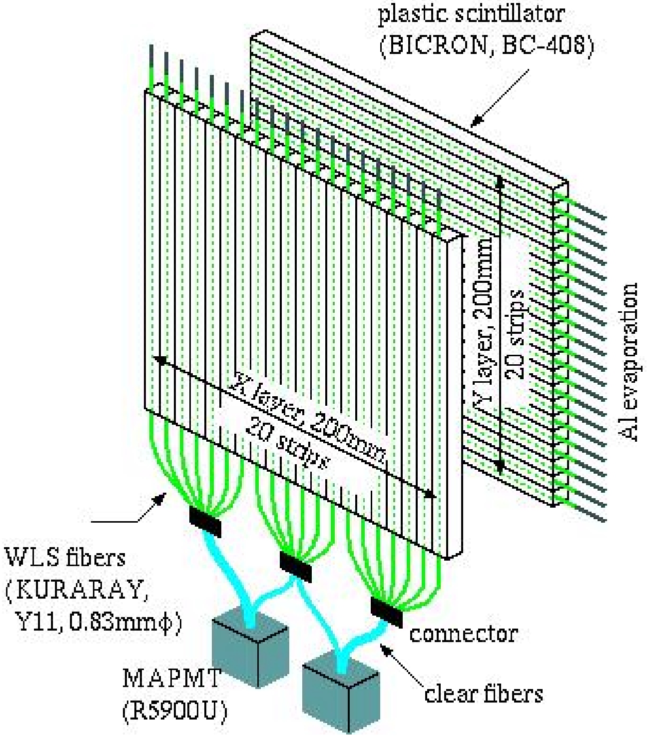


2 cluster separation in 1-dim. (2nd S.L.)

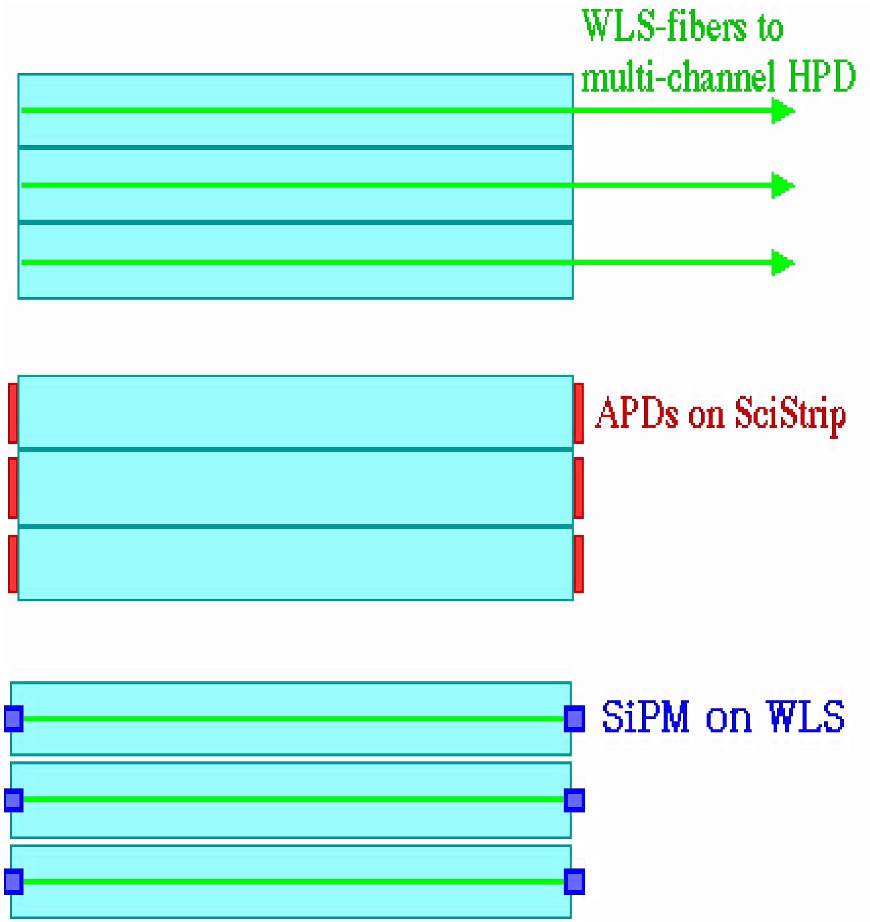


(3,4) Shower-max detectors

- For tile/fiber ECAL case, position detector at shower maximum is needed for
  - better position resolution
  - better track-cluster matching
  - good e/π separation capability
- Scinti-strip detector is a natural option for our ECAL
  - baseline design : WLS readout
  - optional design : directly-attached APD



Readout of scinti-strip



- Strip-size :

  20cm x 1cm x 1cm

- Conventional readout:

  WLS + clear fiber to

  - MA-PMTs (tested)
  - HPDs (2004)

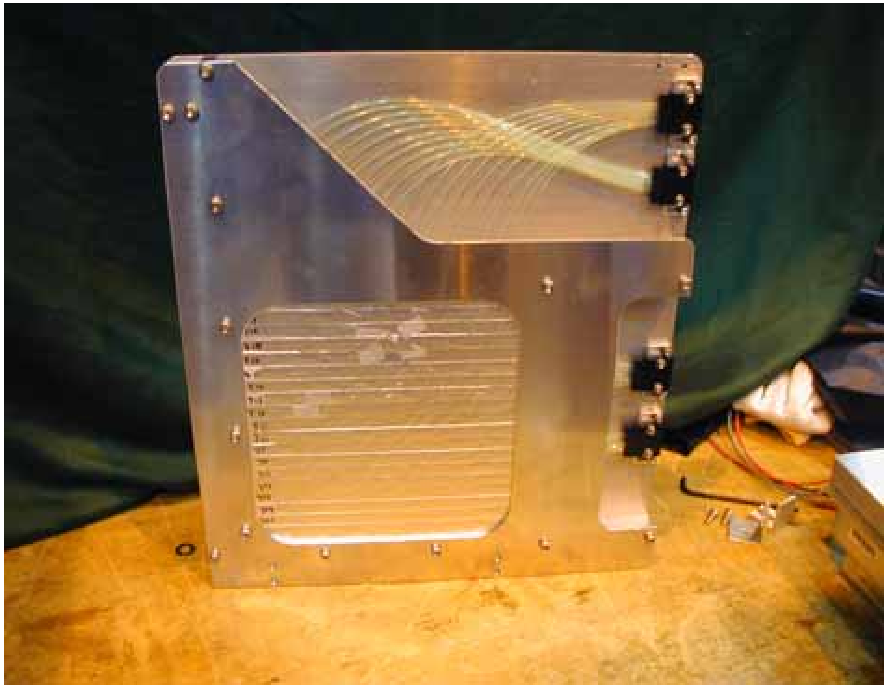
- Directly-attached APDs on scinti-strip (tested)

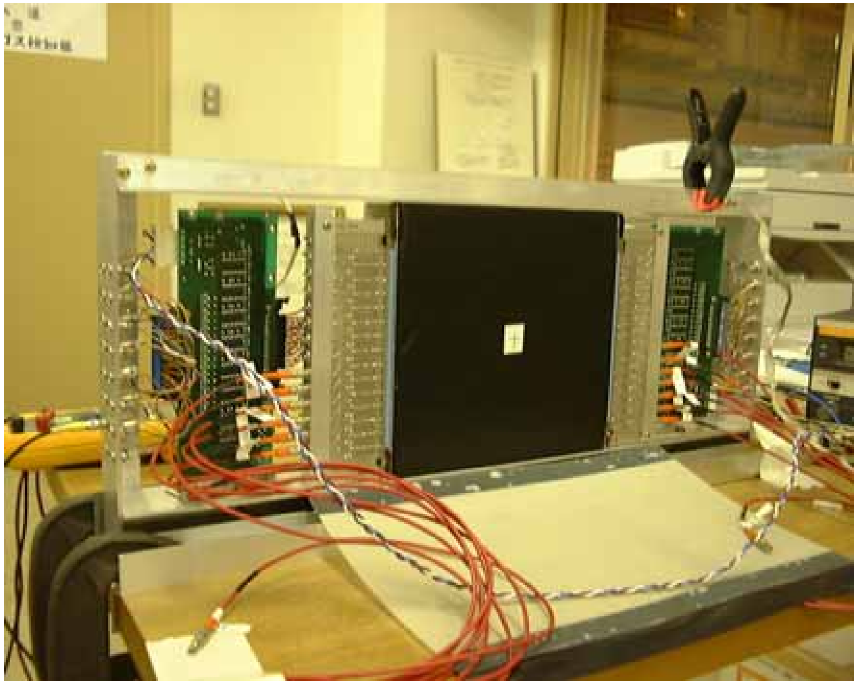
- SiPMs directly on WLS (2004)

SHmax test modules

Scinti-strips with WLS fibers

Scinti-strips with directly attached APDs





(3) Position resolution of SHmax (WLS read out)

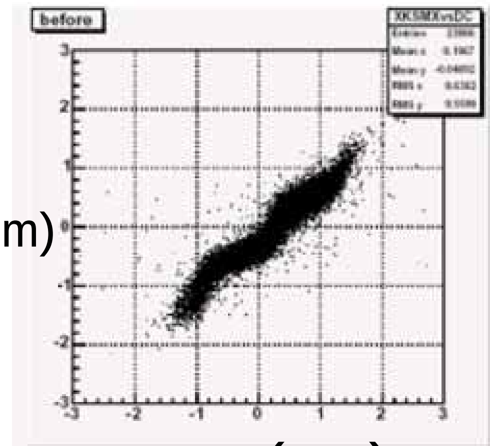
6 GeV electrons

(DESY)

- X_{SM} : measured position with Gaussian fit
- X_{DC} : incident position determined by drift chambers

Before S-shape correction

x_{SM}(cm)

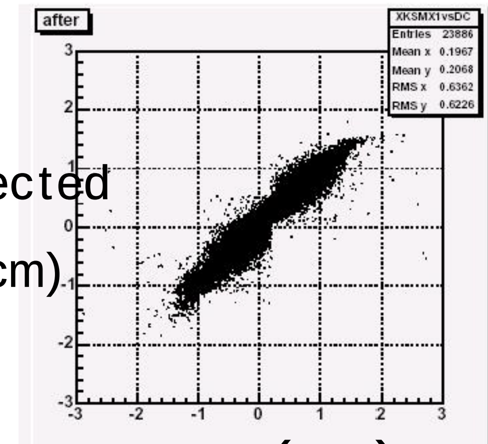


x_{DC}(cm)

After S-shape correction

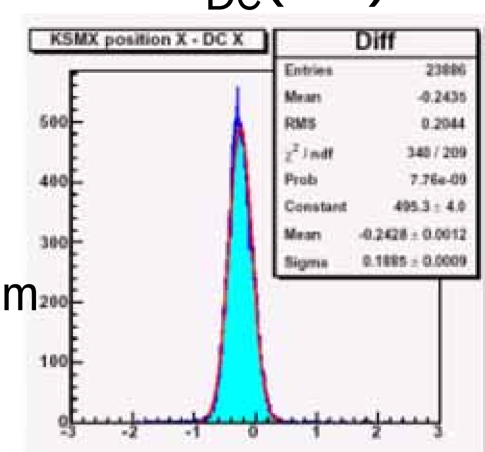
corrected

x_{SM}(cm)



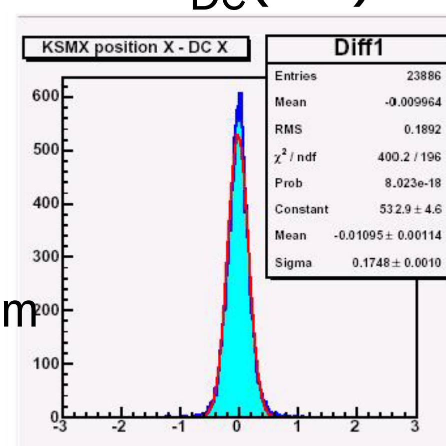
x_{DC}(cm)

σ = 1.9mm



x_{SM}-x_{DC}(cm)

σ = 1.7mm

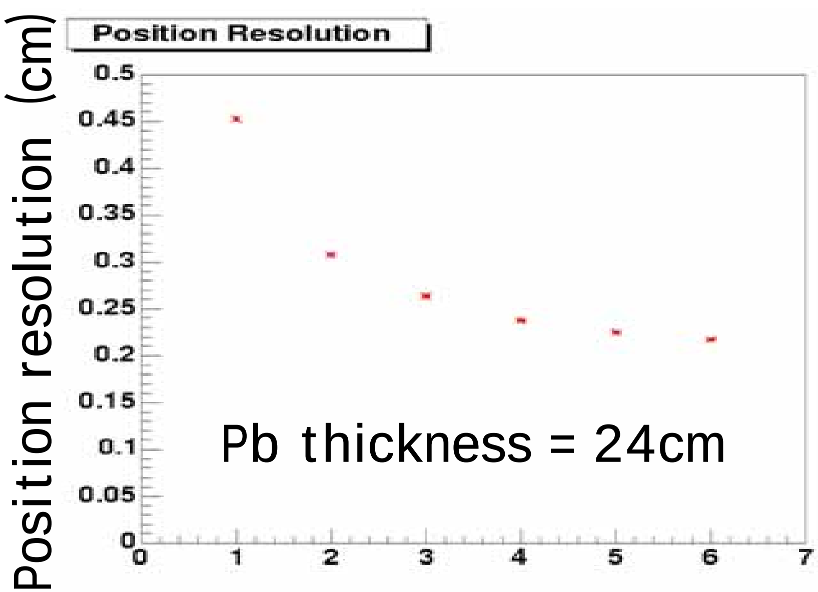


x_{SM}-x_{DC}(cm)

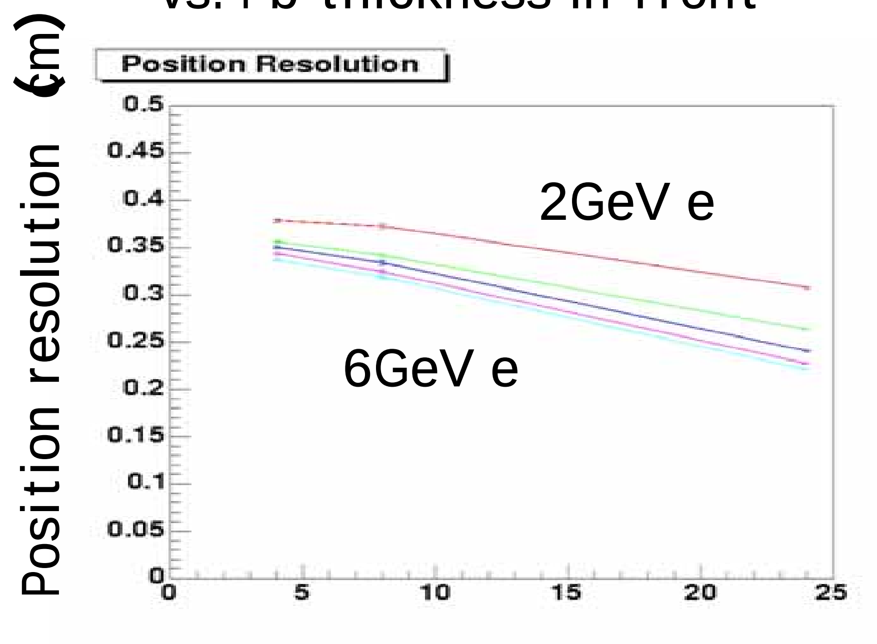
Position resolution of SHmax (cont.)

Electron incident position is determined with weighted mean of 5 strips for figures below:

vs. electron energy



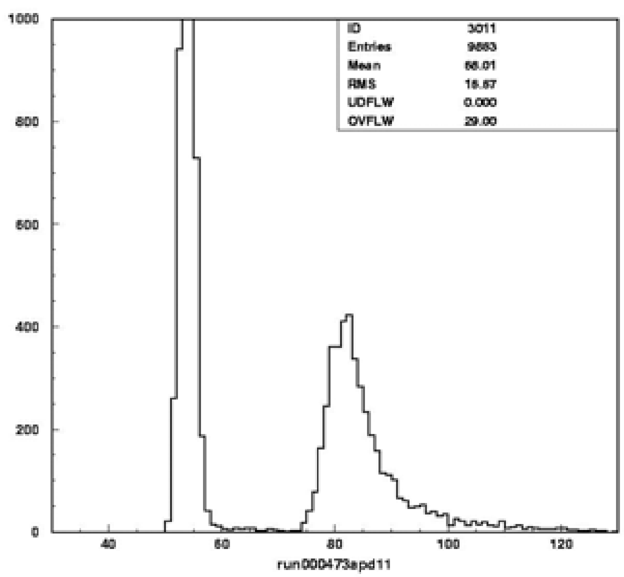
vs. Pb thickness in front



(4) Performance of APD-SHmax

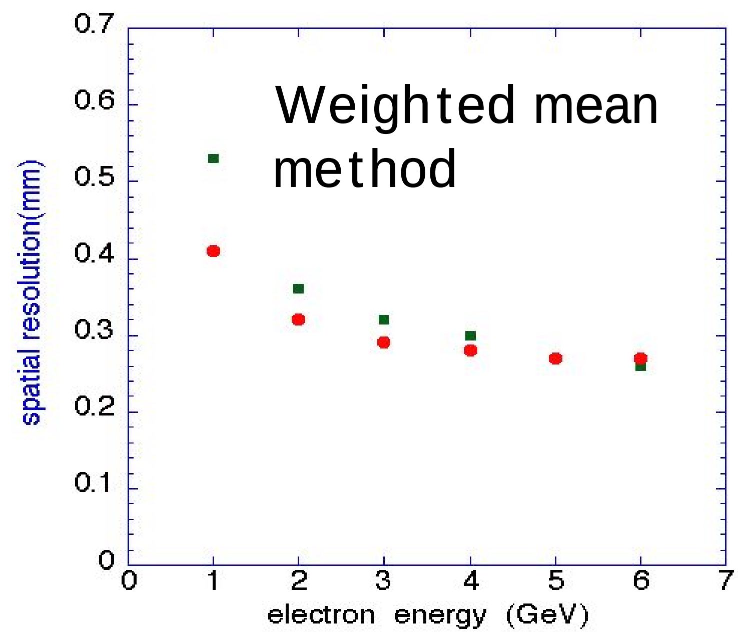
- APD : Hamamatsu S8864-55
  - Active area : 5mm x 5mm, gain ~ 50
  - Temperature coefficient : ~5%/degree ⟶ corrected

MIP signal is well separated from pedestal



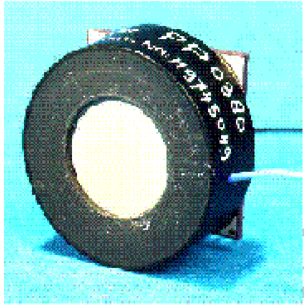
ADC

Spatial resolution as a function of electron energy

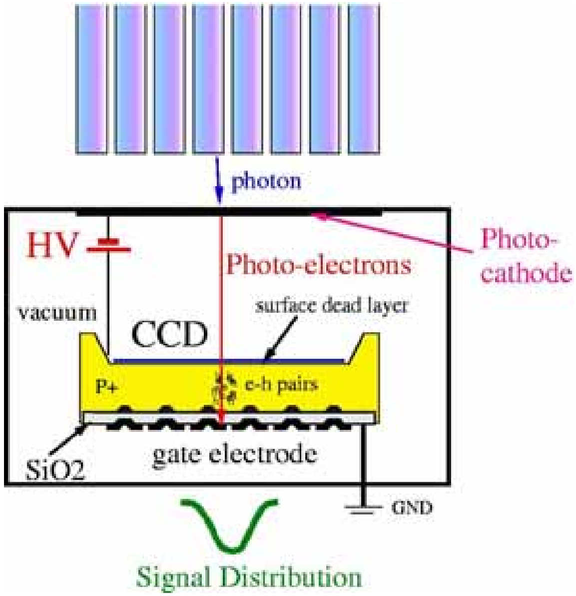


Photon sensors

- Multi-pixel Hybrid Photodiode (HPD)
  - DEP-HPD used for CMS-HCAL
  - We have tested Hamamatsu 64 pixels HAPD (Dr. Suyama)
    - Gain = 6 x 10^4 (good)
    - Commercially not yet available

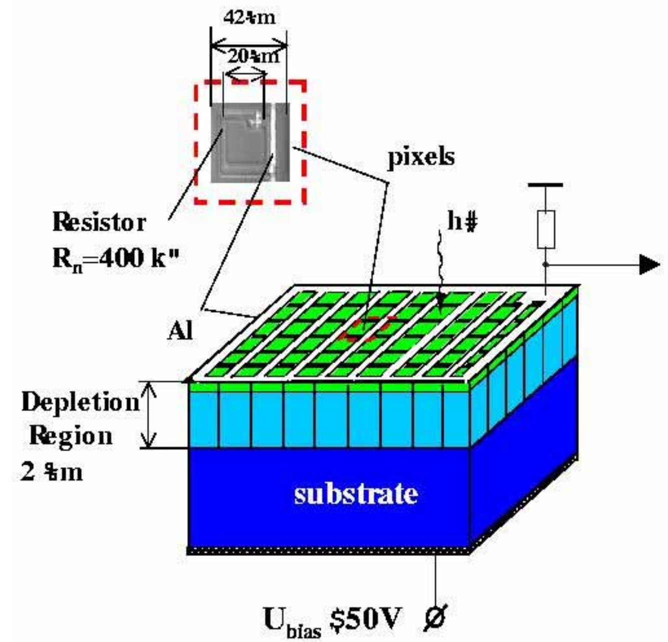


- Electron-bombarded CCD (EBCCD)
  - Suitable for fiber readout
  - ～400 fibers/device possible
  - Low gain (< 1000), but
  - Sensitivity to single-photon
  - Slow read out, no timing information
- Will be tested with SHmax in 2004 test beam



Photon sensors (cont.)

- SiPM
  - Micro-APD cells operated in Geiger mode
  - 1ch/device, compact, cheap (a few $/device)
  - High gain (~10^6), but significant noise rate
  - Can be directly attached to WLS fiber
  - ~10 SiPM from DESY to be tested in 2004 beam test
  - HPK is developing a similar photon sensor



Simulation studies

- Implemented geometry for both options of ECAL into GEANT3-based full simulator
  - Detailed studies, such as shower clustering and track-cluster matching, are still under study
- Will move to GEANT4-based simulation
  - Basic implementation is done; need more refinement
- Behind schedule due to insufficient man power and need to do beam test before KEK-PS shutdown

Future plan

- Finalize ECAL hardware study in 2004
- Accelerate simulation studies
  - Full simulation in GEANT4 framework
  - Jet clustering
- Continue to study photon sensors
  - SiPM, HPD, EBCCD….
- International collaboration : photon sensors, scinti. production, …
- Engineering study

Summary

- Fine granularity ECAL based on lead/scintillator sampling is being studied :
  - established technology, reasonable cost
  - energy resolution, linearity, hermeticity
  - a series of beam tests is being carried out: tile/fiber ECAL, strip-array ECAL, SHmax Final beam test starts soon.
  - new photon sensors are being tested
  - simulation studies are in progress