Simulation study of scintillator-based calorimeter

Hiroyuki Matsunaga (Tsukuba)
For GLD-CAL & ACFA-SIM-J groups

Main contributors:
M. C. Chang, K. Fujii, T. Takeshita,
S. Yamauchi, A. Nagano, S. Kim

Simulation and Reconstruction session
LCWS05 at Stanford

Motivation

- Basic studies of calorimeter behavior for single particle in simple (testbeam) configuration
  - Energy resolution, linearity
  - lateral/longitudinal shower profiles
    - It is extremely important to understand lateral shower profile for particle flow analysis
- Comparison with previous testbeam results
  - Understand the detector responses in detail
  - Get detector effects which should be implemented in full simulator

Outline

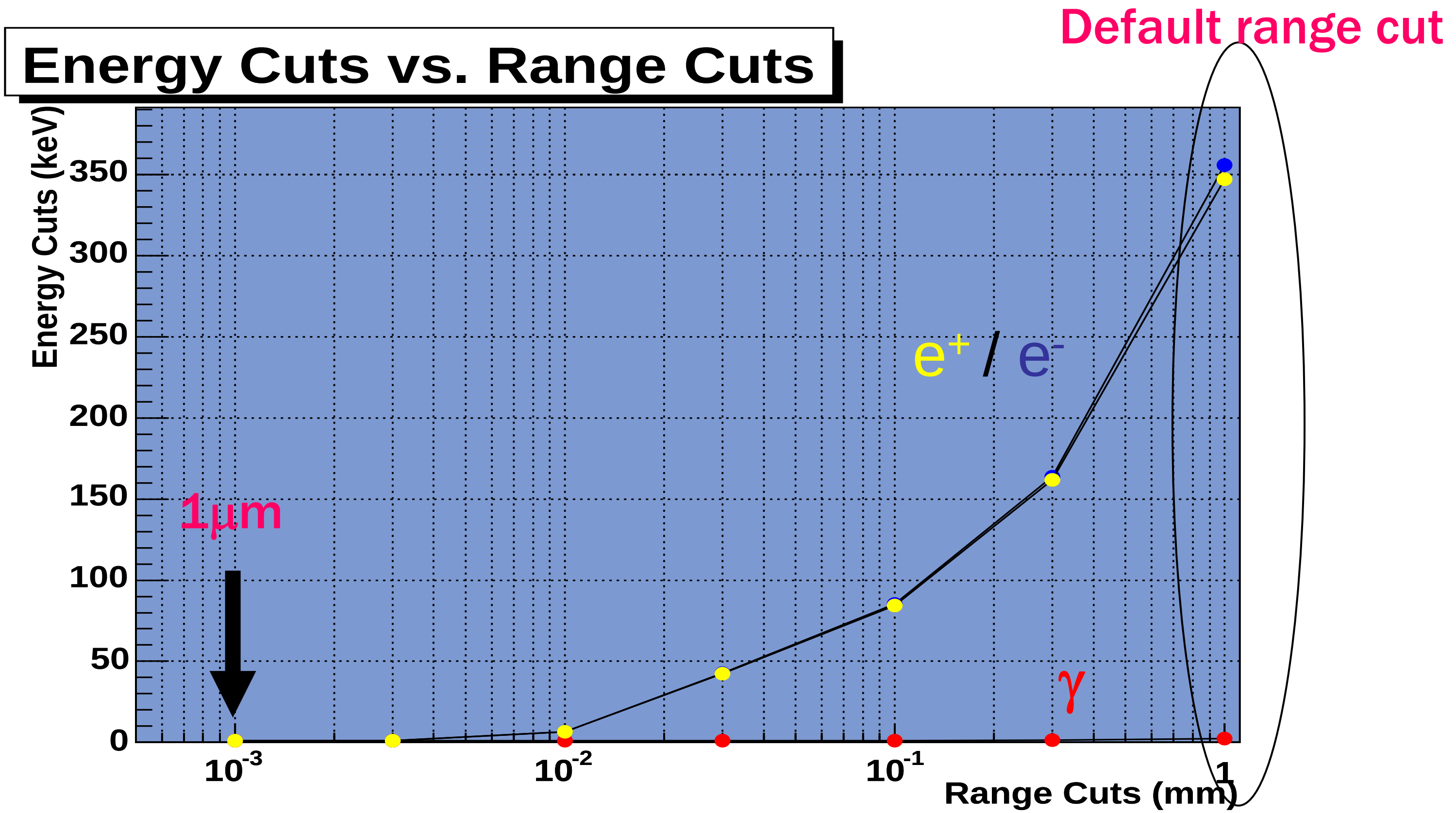
- "Range cut" study for Geant4
- Tile-scintillator ECAL
  - Energy resolution
- Strip-scintillator ECAL
  - Energy resolution, linearity
  - lateral / longitudinal shower profiles
- Summary and Outlook

Range cut

- Geant4 parameter set by user
- How it works ?
  - When the range of the particle for the next step is calculated to be less than the range cut, GEANT4 kills the particle and deposits all of its energy there.
  - A secondary particle is not created if its range is less than the range cut.
- 1mm by default
- Used Geant4 6.2p2
  - Problem in EM process for thin material; Should be fixed in 7.0 patch-01 (claimed by Geant4 team)

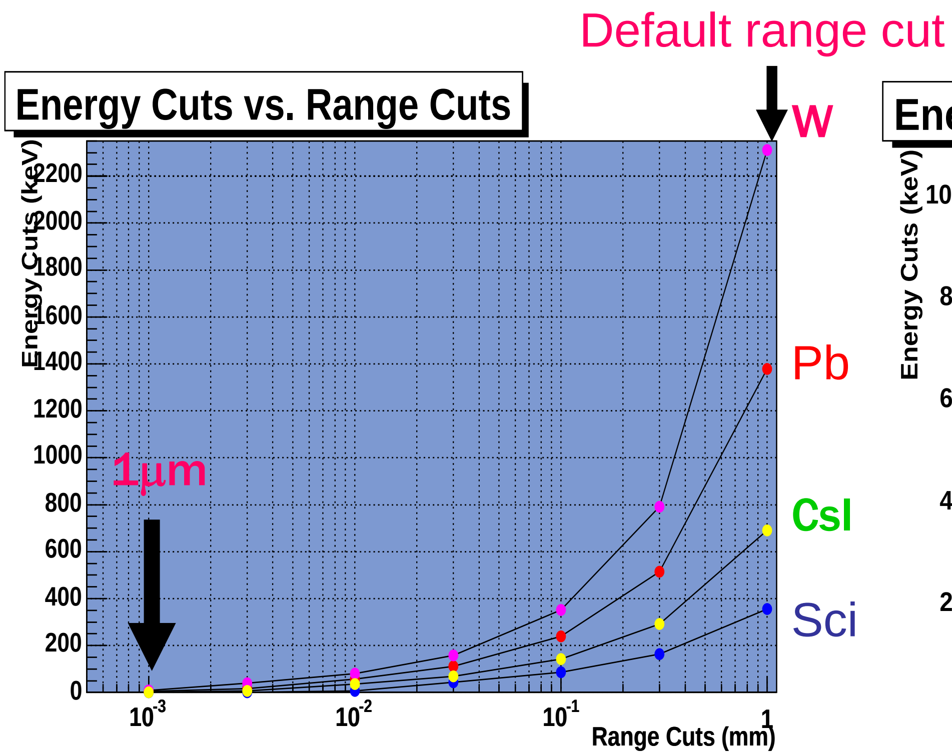
Energy cuts vs. Range cuts in scintillator

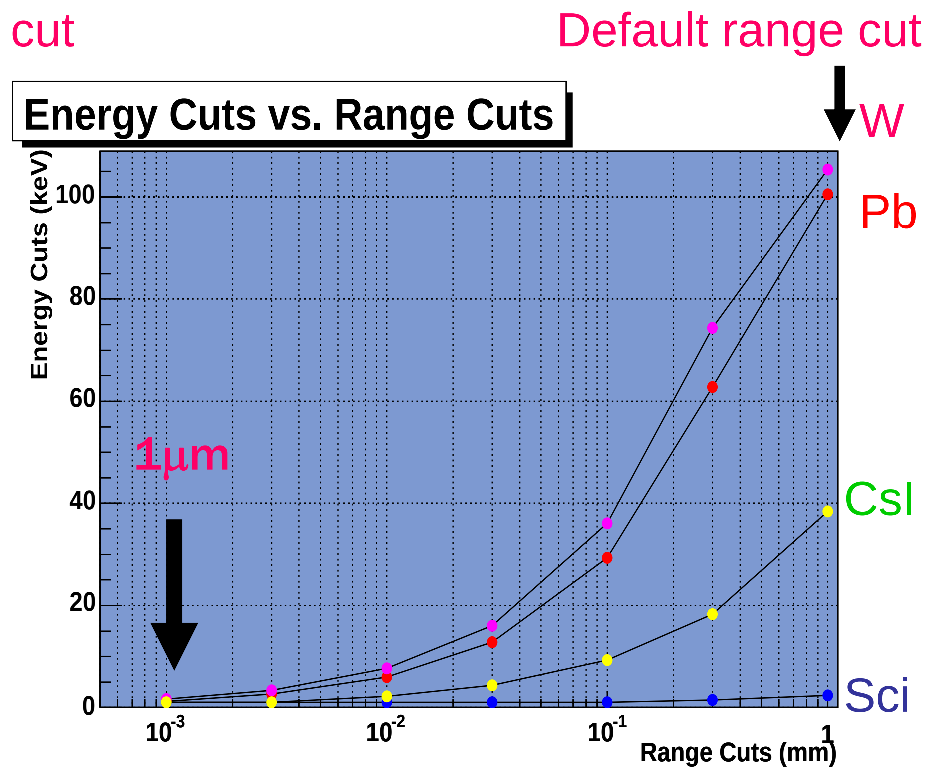
- Default range cut (1mm) seems too large



Energy cuts vs. Range cuts for e^{+}/e^{-} and γ

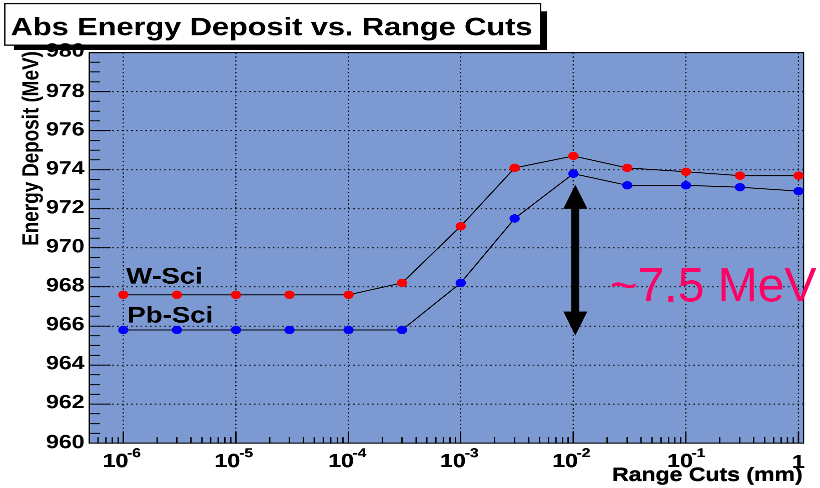
- **Large difference between absorbers and active media at larger range cuts**

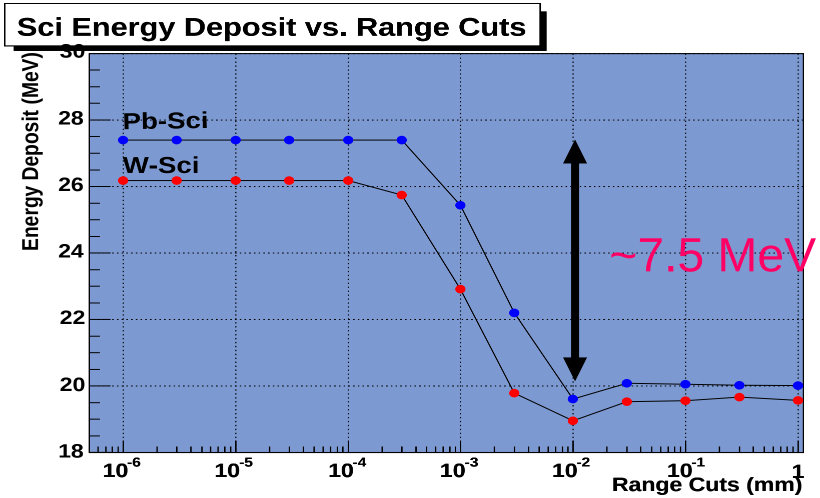




Energy deposits vs. Range cuts

- Two configurations with same radiation length
  - 2.5mm W / 1mm Sci
  - 4mm Pb / 1mm Sci
- Threshold behavior seen from ~0.3 to ~10 μm
  - Gap ~7.5 MeV (Pb/Sci)
  - More energy deposits in absorber at higher range cuts
  - 27.5 MeV vs. 20MeV in scintillator (Pb/Sci)
- Sum of energy deposit is constant





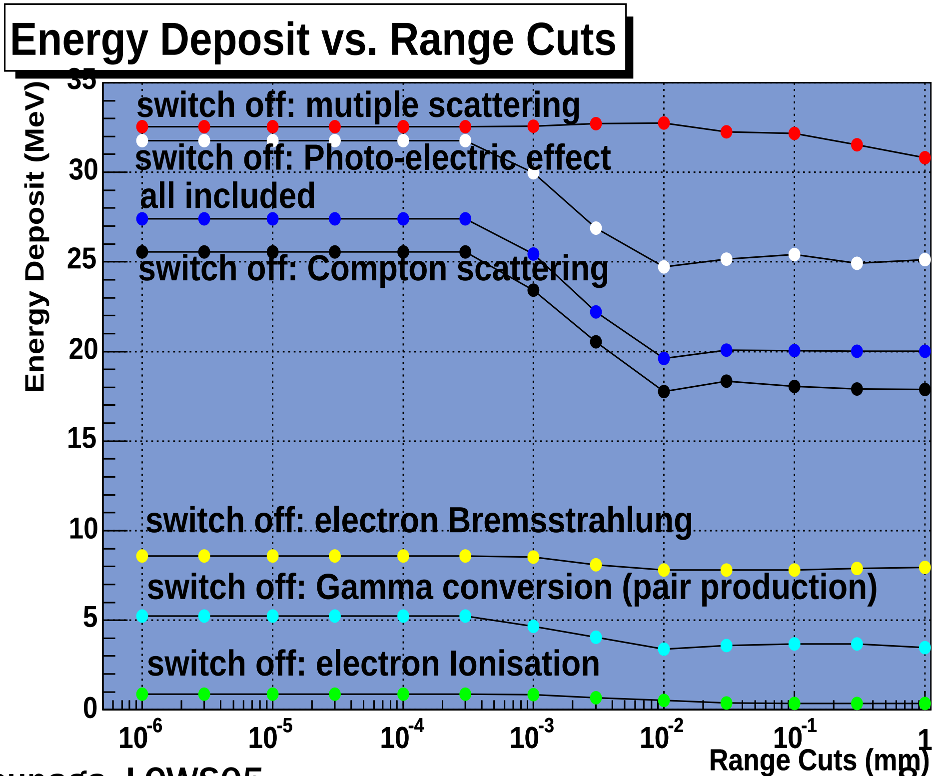
1μm

Decompose contributions from physics effects

- Threshold effect comes mainly from multiple scattering
  - Most frequent process
- mean-free-path for multiple scattering is around the threshold region
- **Should set the range cut ~1 μm or less** (limited by CPU)
  - Will try to check again with 7.0p1

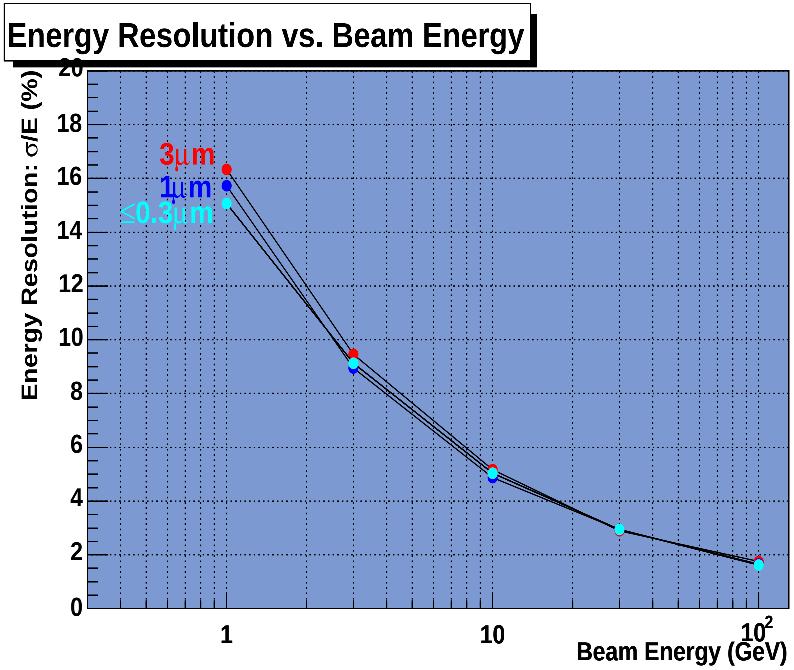
Pb(4mm)/Sci(1mm)

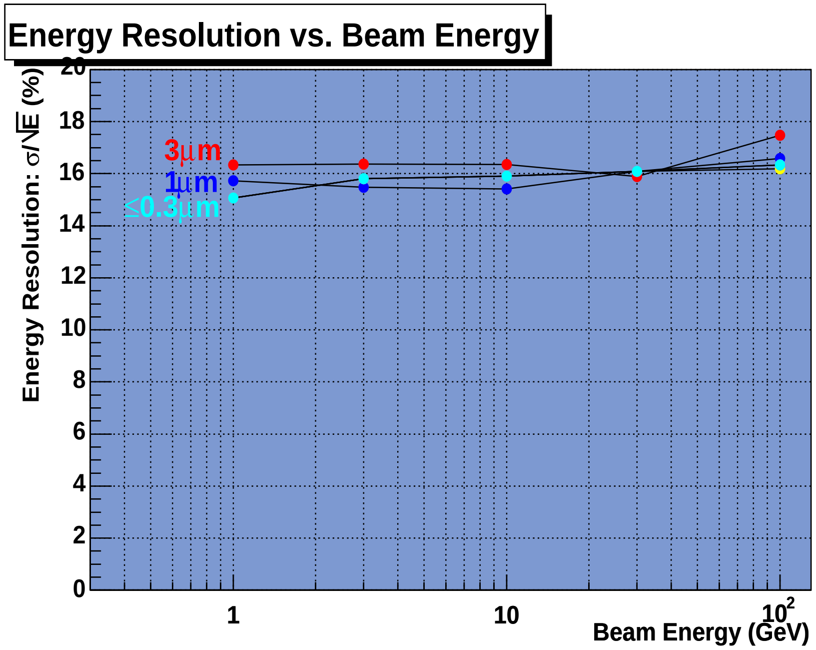
Energy deposit in scintillator



ECAL Energy Resolution

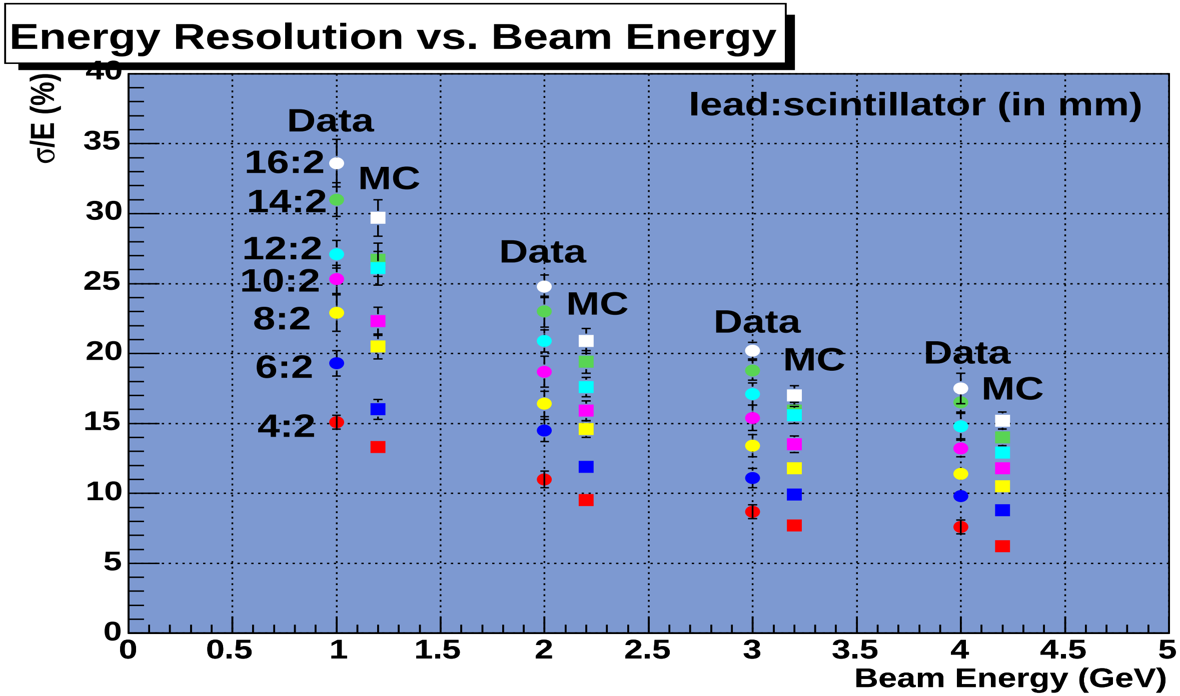
- 4mm Pb / 1mm Sci. , electron injection
- 16 %/$\sqrt{E}$ with ~1 μm range cuts (0.3, 1, 3 μm)
  - Nearly expected values





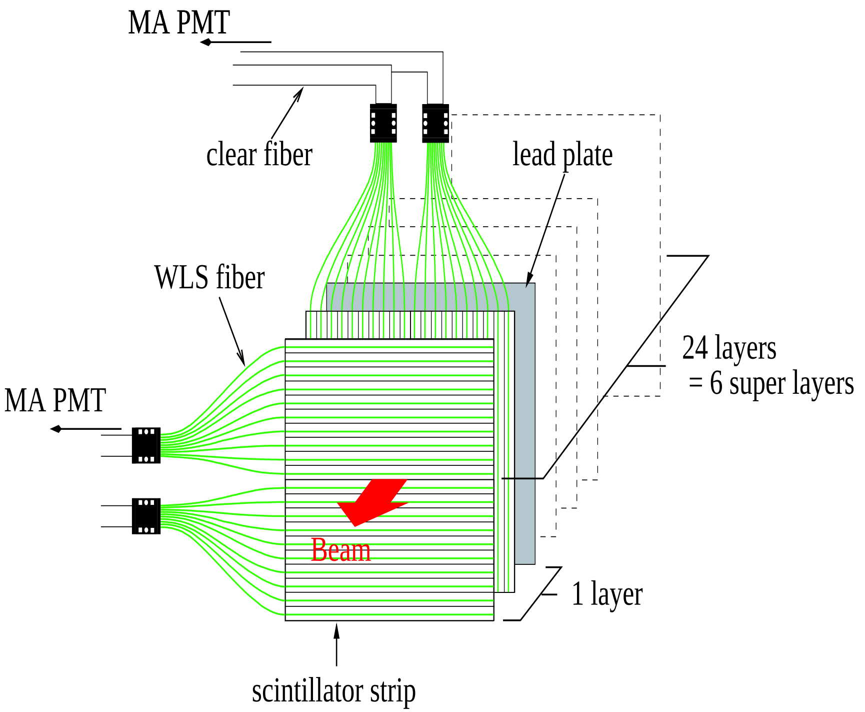
Energy Resolution for various Pb thicknesses

- Compare with testbeam results (T405 & T411 at KEK)
- Scintillator thickness is 2mm (fixed), 1 - 4 GeV electron beam
- MC results are slightly better than data
  - MC does not include detector effects, e.g. photo statistics



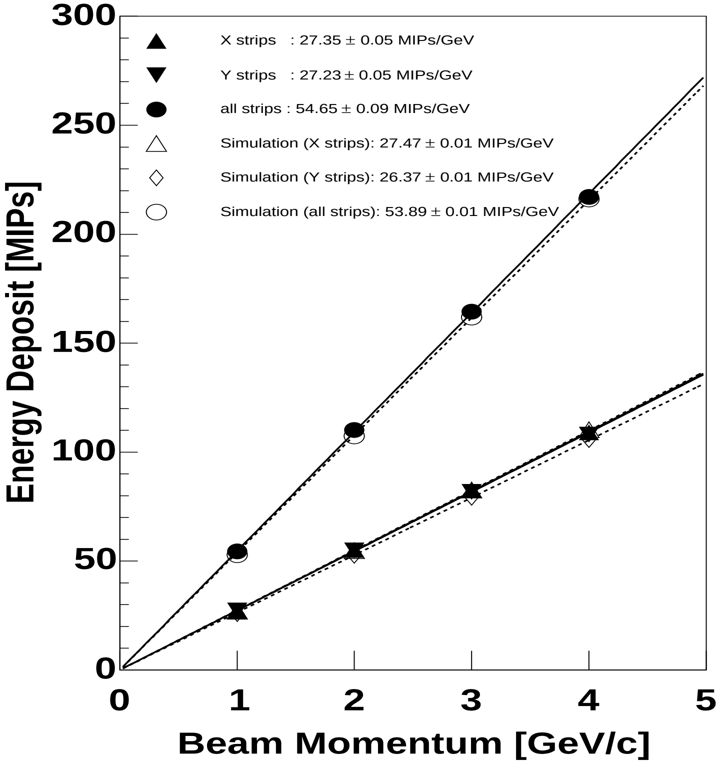
Scintillator-Strip ECAL

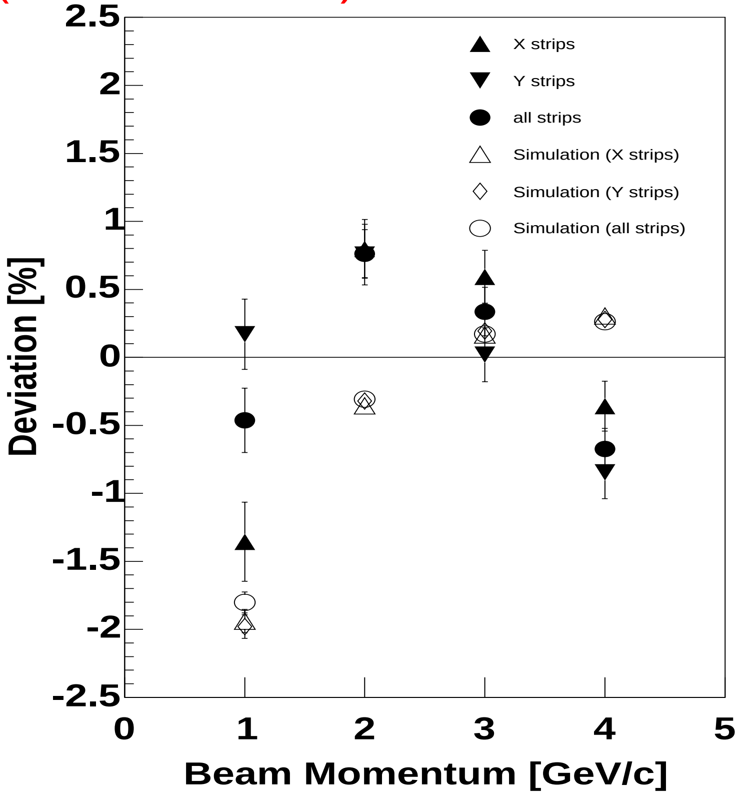
- Using 1cm-wide scintillator strips
- 2-dimensional array
  - 1cm effective granularity
- 4mm Pb + 2 x 2mm sci. in a layer
- 24 layers (6 superlayers)
- Beam tests were carried out at KEK in 2002 and 2004



Linearity

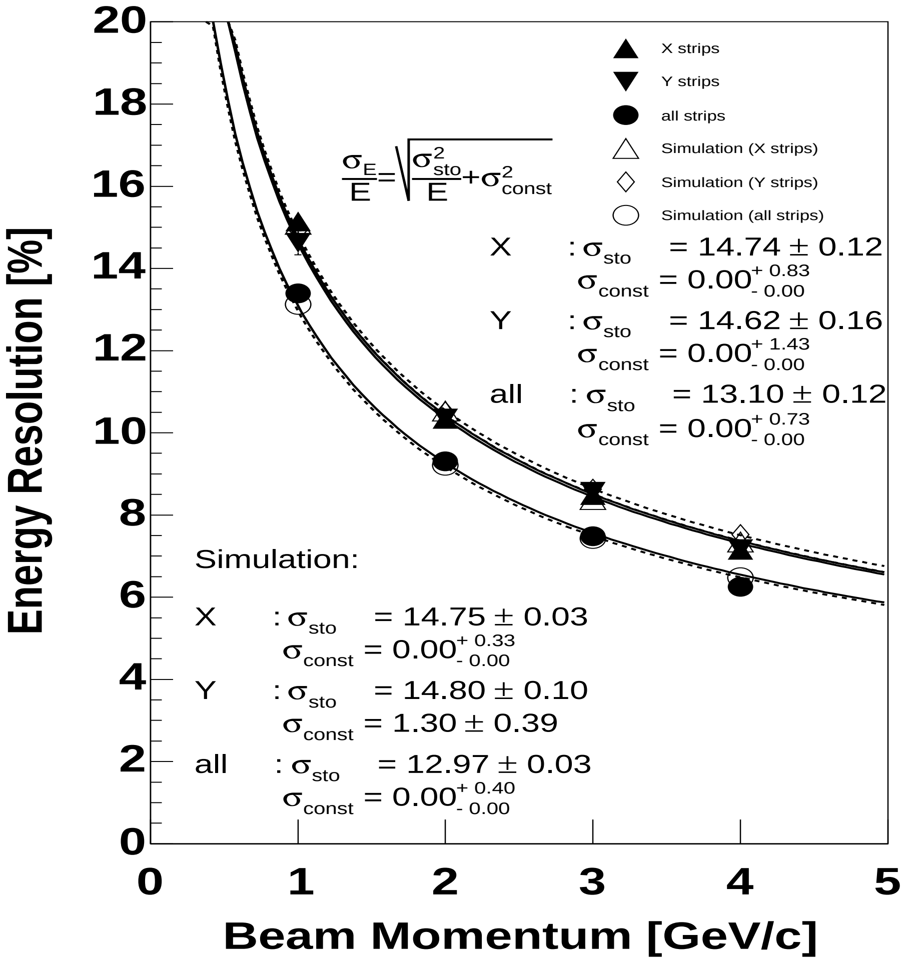
- MC takes account for light leakages between strips, noises, photo statistics effect, etc.
- Good agreement with data
  - Even for absolute energy deposits (in unit of MIPs)





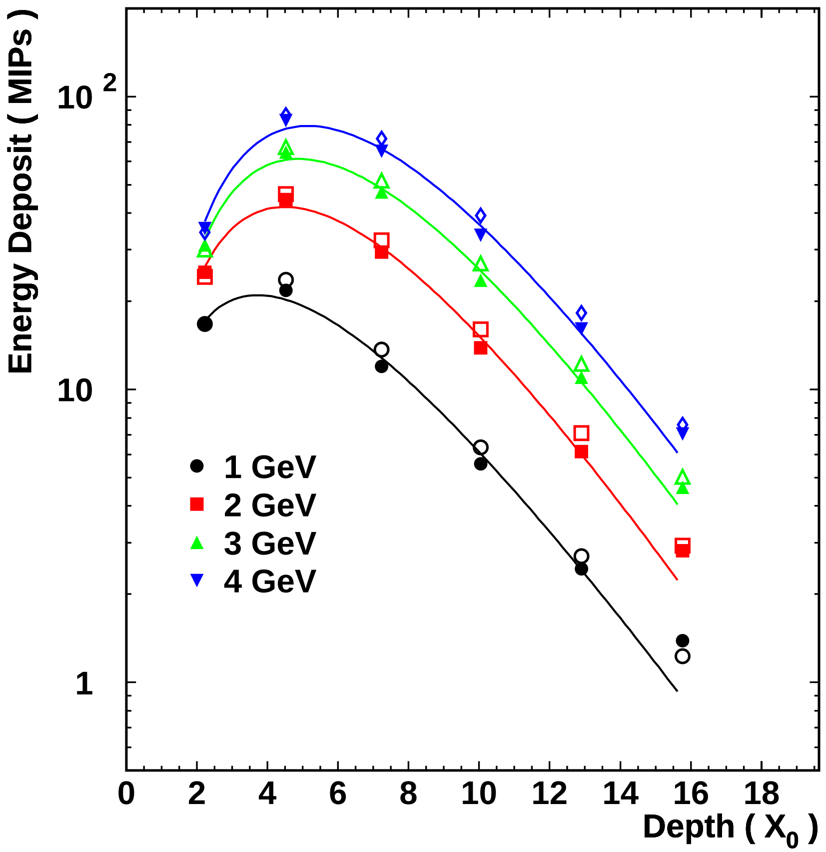
Energy Resolution

- Using energy deposits from all strips :
  - Stochastic term ~13%
  - Constant term ~0%
- Good agreement between data and MC



Longitudinal Shower Profile

- Longitudinal shower profile agrees with data
  - Absolute values are well reproduced
- Shower-maximum
  ~ 2nd superlayer

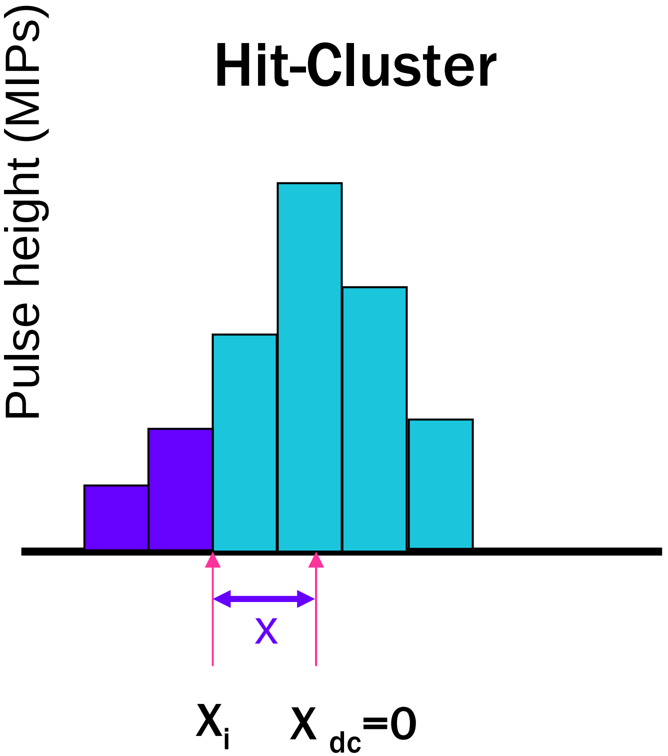


Lateral shower profile

- Introduce energy fraction I(x) :

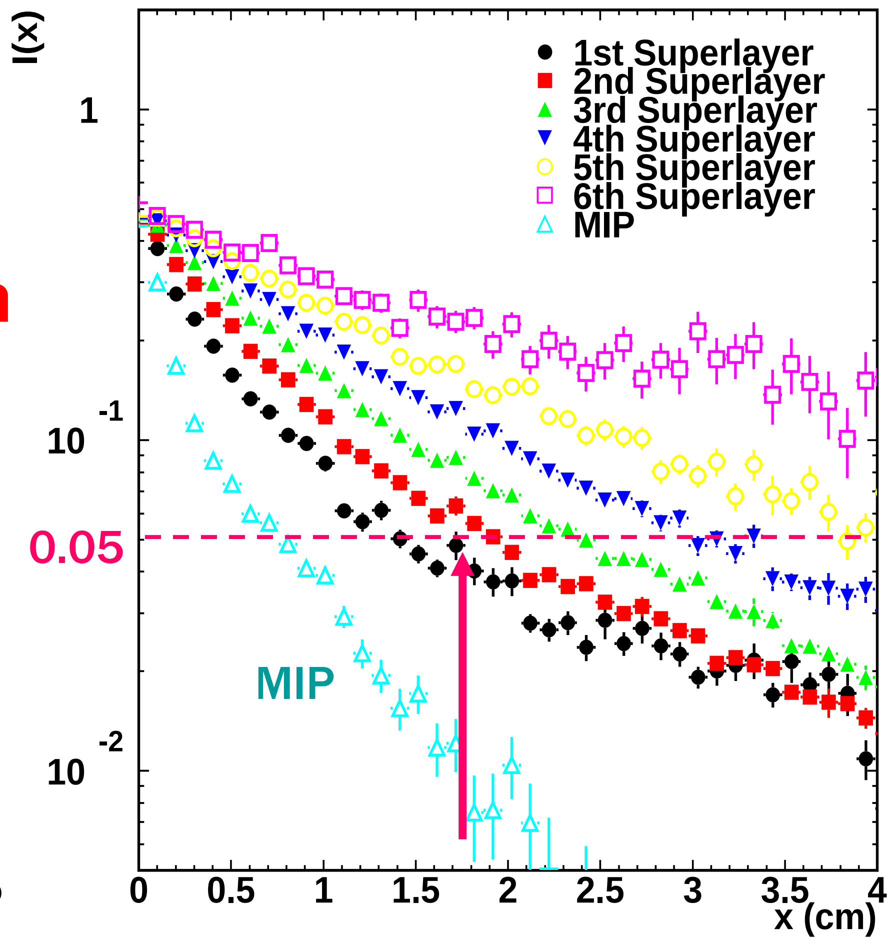
$$I(x) = \int_{-\infty}^{x} dx'\, PH \Big/ \int_{-\infty}^{\infty} dx'\, PH$$

  - $X = X_i - X_{dc}$
  - X_{dc}: incident position determined by drift chambers
  - X_i : position of i-th strip
  - I(0) = 0.5



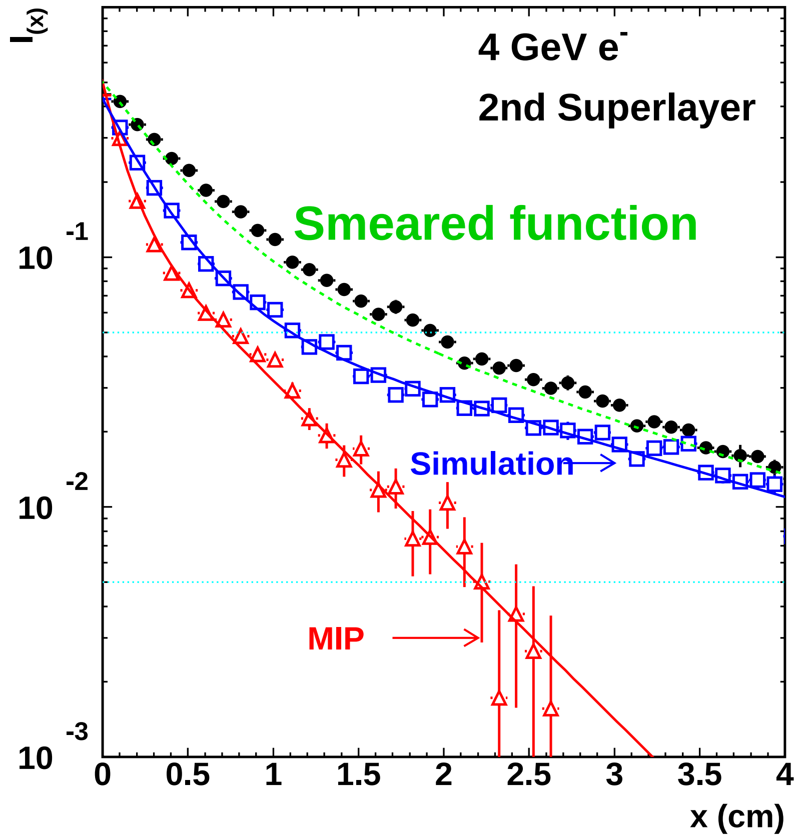
Integrated lateral shower profile

- 4GeV electron (each superlayer), MIP
- Width for 90% containment is **~1.7cm for 2nd superlayer** (shower maximum)
- Most MIP spread originates from light leakage between adjacent strips and cross-talks in MA-PMTs



Smeared spread function

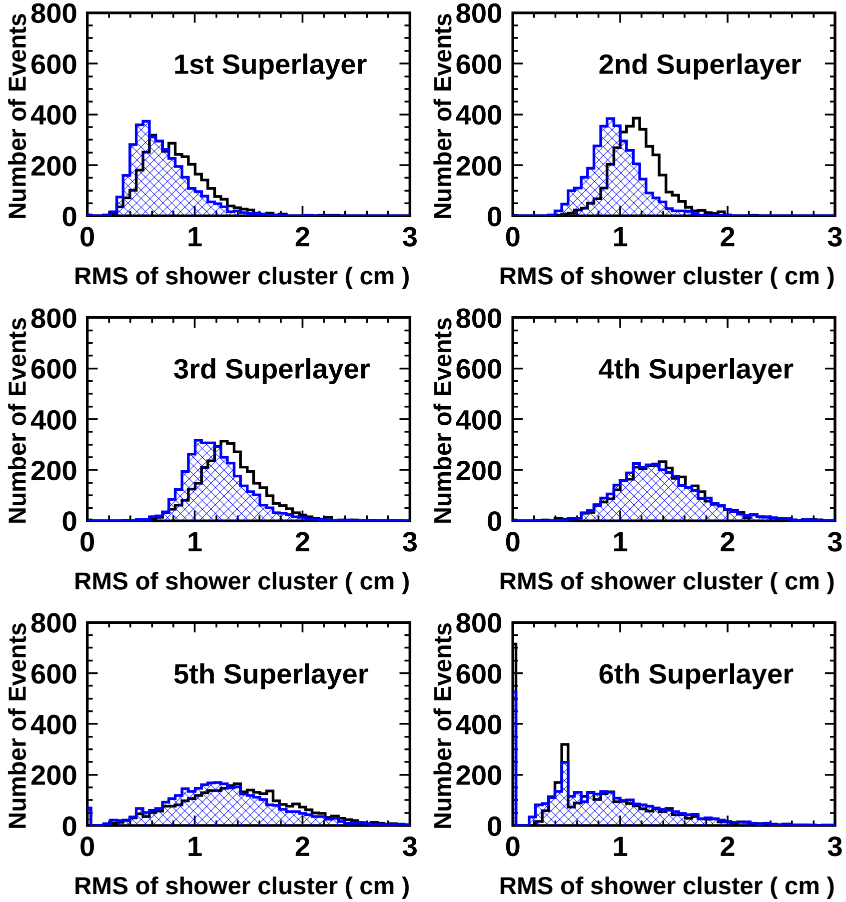
- GEANT3-based shower simulation shows smaller width than data
  - Some detector effects (such as light leakage) are not implemented in simulation
- Smeared function using MIP signal spread agrees with data very well !



RMS of lateral shower profile

- Checked RMS of hit cluster in each superlayer
  - Implemented light leakage and cross-talks in simulation
- Slightly Narrower cluster widths in MC, especially for 1~3 superlayers :
  - Narrow clusters
  - Large pulse heights
- More detector effects?

Data, Simulation



Summary and outlook

- Geant4
  - Range cut value should be less than ~1 μm
- Sci-Tile calorimeter
  - Energy resolution agrees with data
- Sci-Strip calorimeter
  - Energy deposits and resolution are consistent with data
  - Good agreement for longitudinal profile
  - Lateral shower profile is almost understood
- Outlook
  - Study for hadrons in progress
    - Need to understand hadronic processes in GEANT4
    - SLAC Geant4 team provides physics list for LC
  - Performance study of optional HCAL digital calorimeter
  - PFA study with simple CAL detector and with full simulator