# Performance of the Scintillator-Strip Electromagnetic Calorimeter Prototype for the Linear Collider Experiment

CALOR2010@Beijing Mar 10-15th 2010

Satoru Uozumi (*Kyungpook National University, Korea)*

*for the CALICE Collaboration*

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- The Scintillator-strip ECAL
- Beam test of the ECAL prototype
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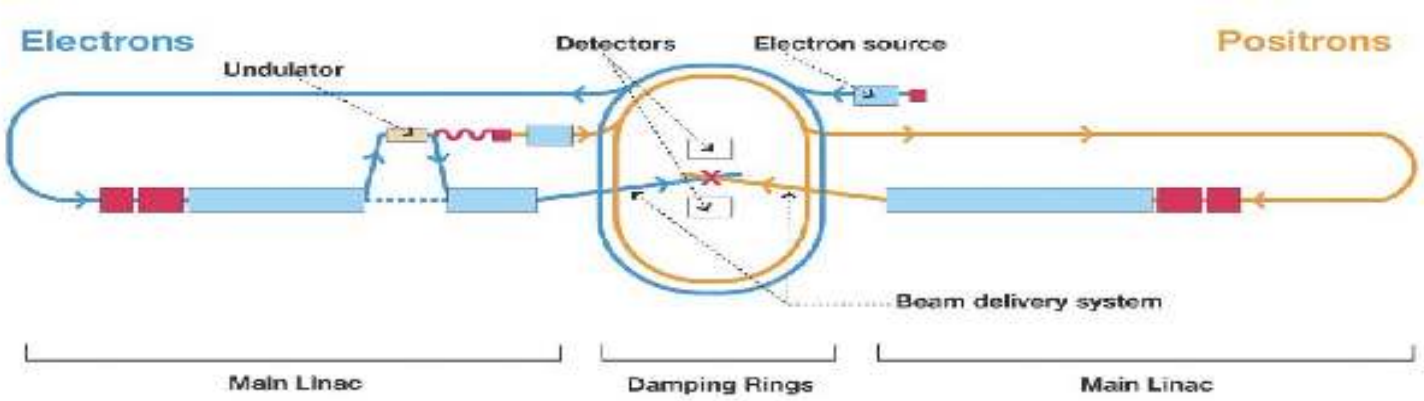
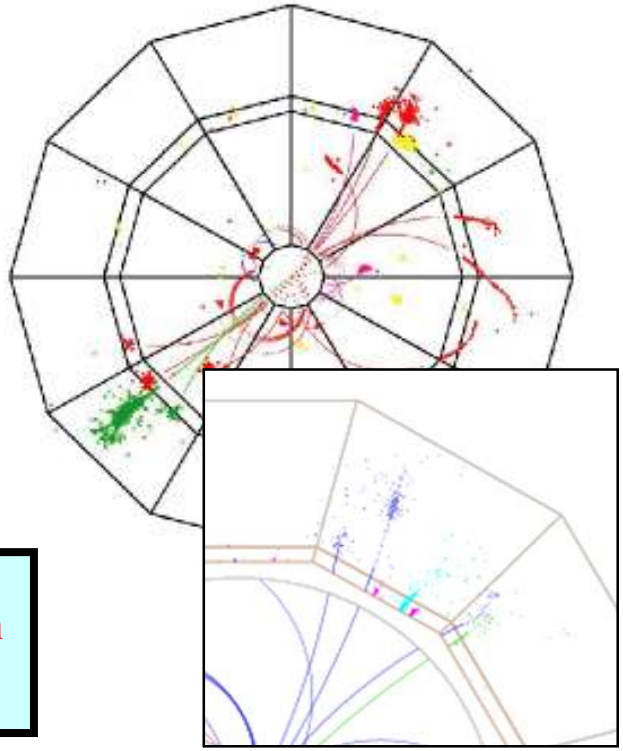
# Jet Energy Measurement at the ILC experiment




- $e^+e^-$ collider with center-of-mass energy at 500 ~ 1000 GeV.
- ILD (International Large Detector) is one of the detector concepts proposed for the ILC experiment.
- Various precision measurements expected:
  - $e^+e^- \rightarrow H, W, Z, tt$, SUSY, etc …
    → Multi-jets final states.
- Particle Flow Algorithm (PFA) allows precise jet-energy measurement $(\sigma_E/\sqrt{E} = 30\%)$.



$$E_{TOT} = p_e + p_\mu + p_{\text{charged hadron}} + E_\gamma + E_{\text{neutral hadron}}$$
[ tracks only] [calorimeter only]

- Separation of jet particles in the calorimeter is required for the PFA

→ **Fine granular calorimeter** is necessary.

# CALICE

Calorimeter for ILC

# CAlorimeter for the LInear Collider Experiment

*330 physicists/engineers from 57 institutes and 17 countries coming from 4 continents*

Main Task : Develop fine granular calorimeter for Particle Flow Algorithm at the ILC experiment.

## Electromagnetic CAL:

- Scintillator-Tungsten

(Kobe / Shinshu / Tsukuba / Niigata / Tokyo / Kyungpook universities)

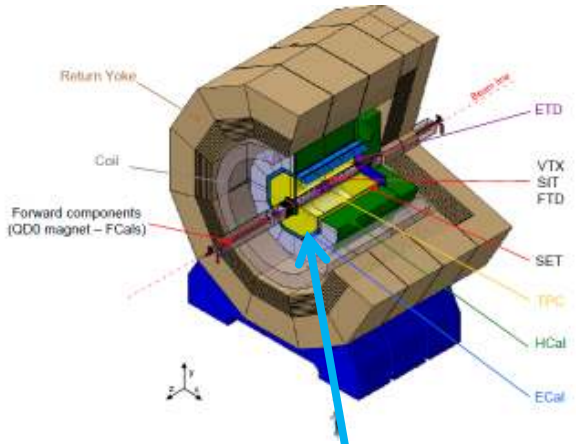
- Silicon-Tungsten
- Digital SiW ECAL (MAPS)

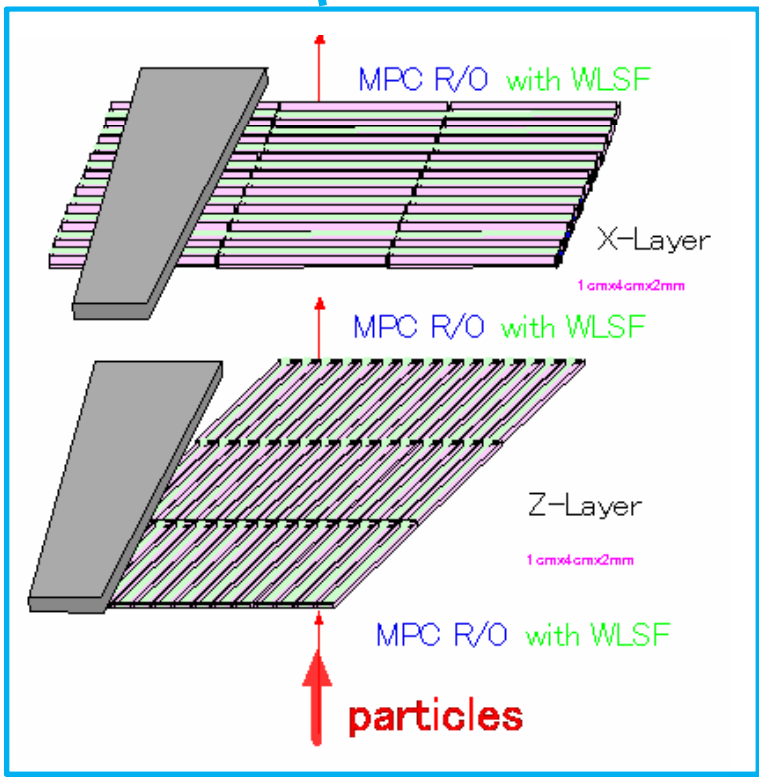
## Hadron CAL:

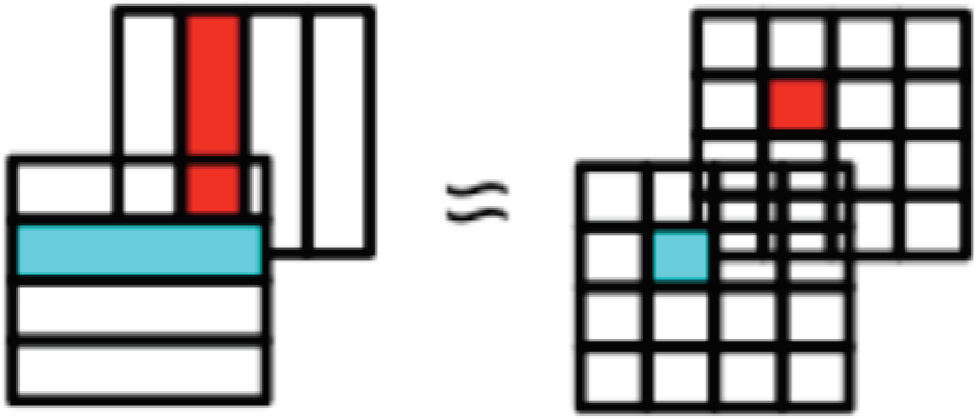
- Analog (Scintillator) HCAL
- Digital HCAL

# The Scintillator-Strip Electromagnetic Calorimeter

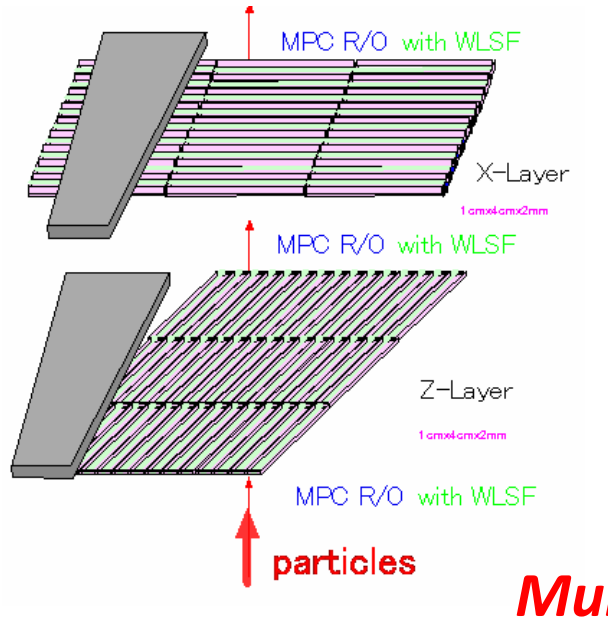
- Sampling calorimeter with Tungsten-scintillator sandwich structure.
- Scintillator-strip technology adopted to achieve fine granularity.
- Lateral Segmentation : 1 ~ 0.5 cm
- Huge Number of channels (~10M channels).
- Need to establish sufficient performance while keeping the low production cost.
- **First need to establish the feasibility!**



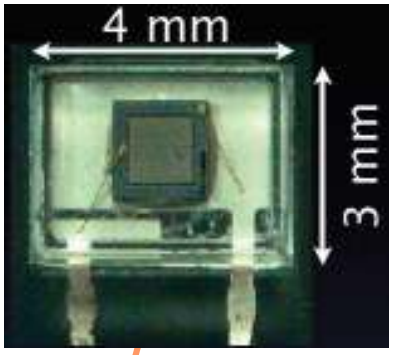



# Elementary Components (Scintillator-Strip & Photo-Sensor)




***Wavelength Shifting Fiber (Y11 1mm$\phi$)***

***Multi-Pixel Photon Counter (MPPC)***

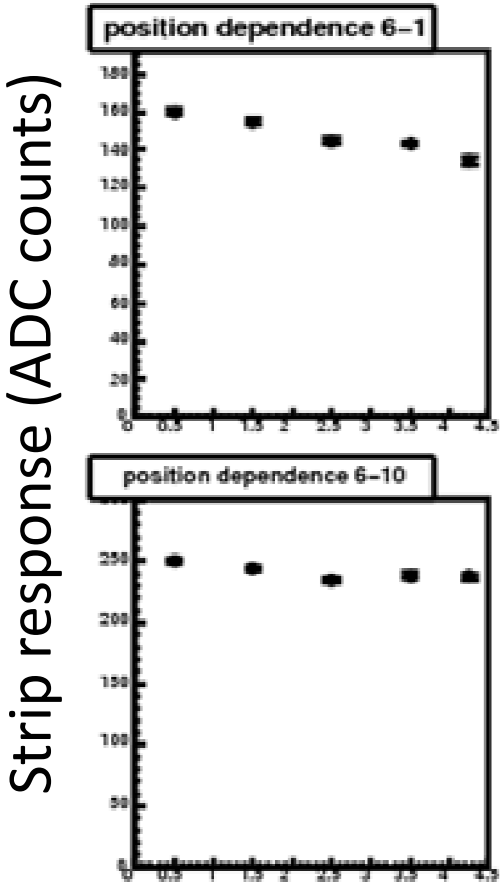



4.5 x 1 x 0.2 cm

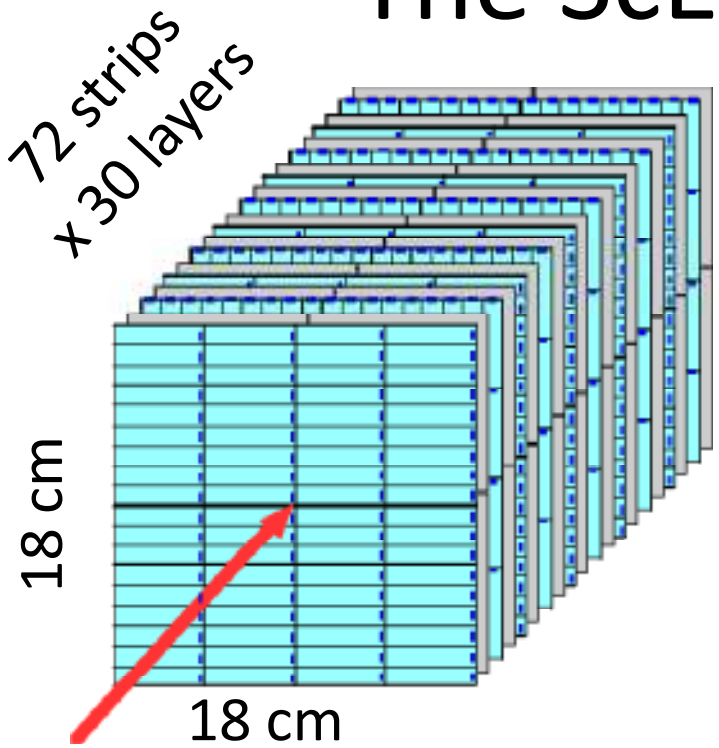
***Plastic scintillator strip by extrusion technique***

**MPPC**

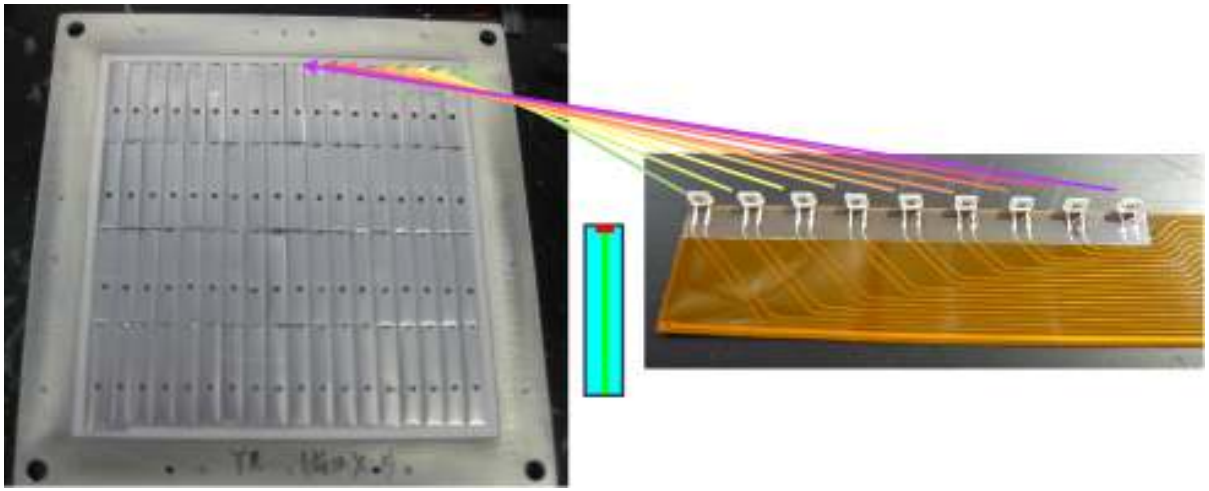
**Scintillator strip**

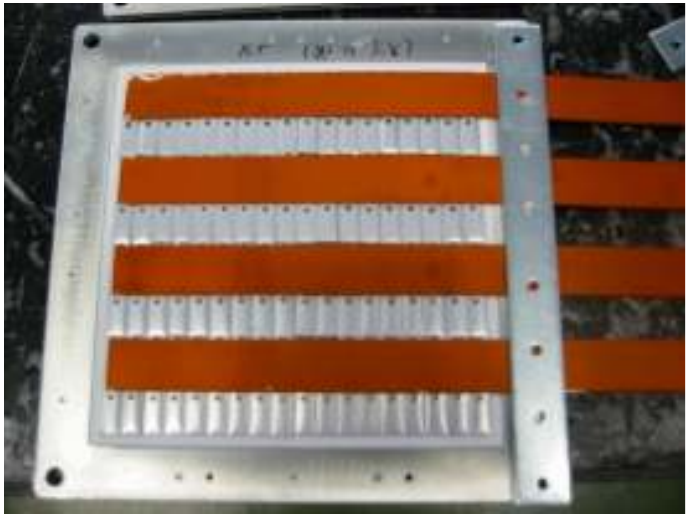


# The ScECAL 2nd Prototype



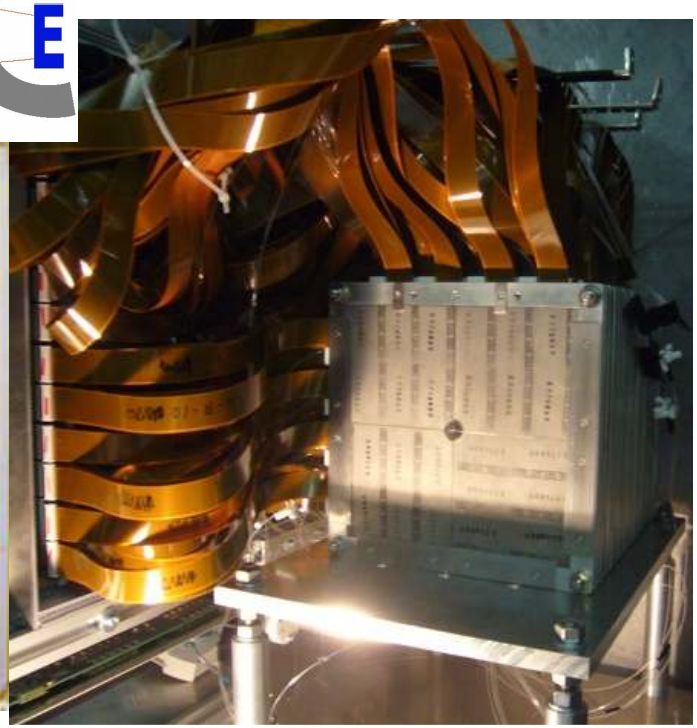

- The technical prototype to establish the ScECAL feasibility.
- Sandwich structure with scintillator-strips (3 mm) and tungsten layers (3.5 mm).
- Extruded scintillator and the MPPC are fully adopted.
- Strips are orthogonal in alternate layers.
- 72 strips x 30 layers = 2160 channels.





# Beam Test in Sep 2008 @ MTBF

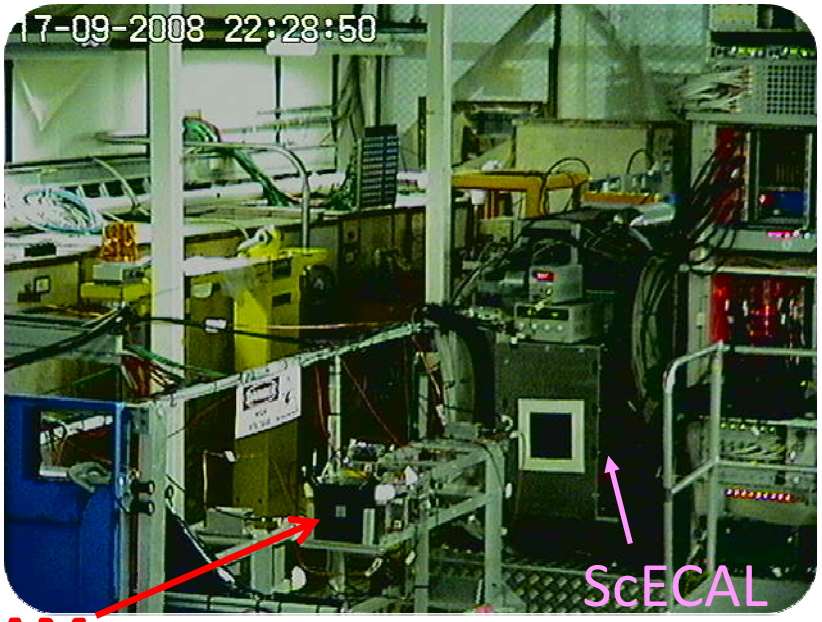
- Objective : Establish the feasibility of Scintillator-ECAL + Analog HCAL with various types of beams in wide energy range.
  - Evaluate Energy resolution, Linearity for electrons and pions.
  - $\pi^0$ reconstruction ability of the Scintillator-ECAL
  - Position and angular scan.
- Beam running during Sep 2008 / May 2009 at FNAL Meson Test Beam Facility.

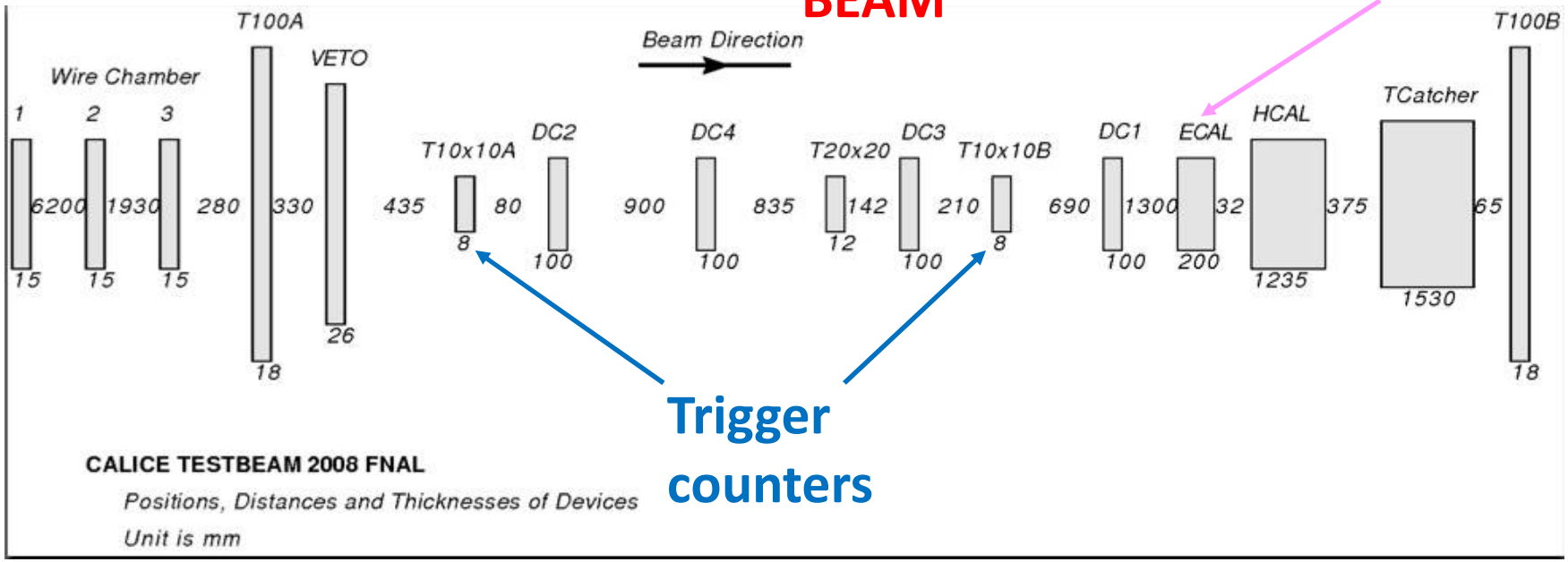


# The Fermilab Meson Test Beamline

Various types of beams available

- 1-32 GeV electrons
- 1-60 GeV pions
- 32 GeV muons
- 120 GeV protons
- Cerenkov counter available
  to discriminate electron or pion.

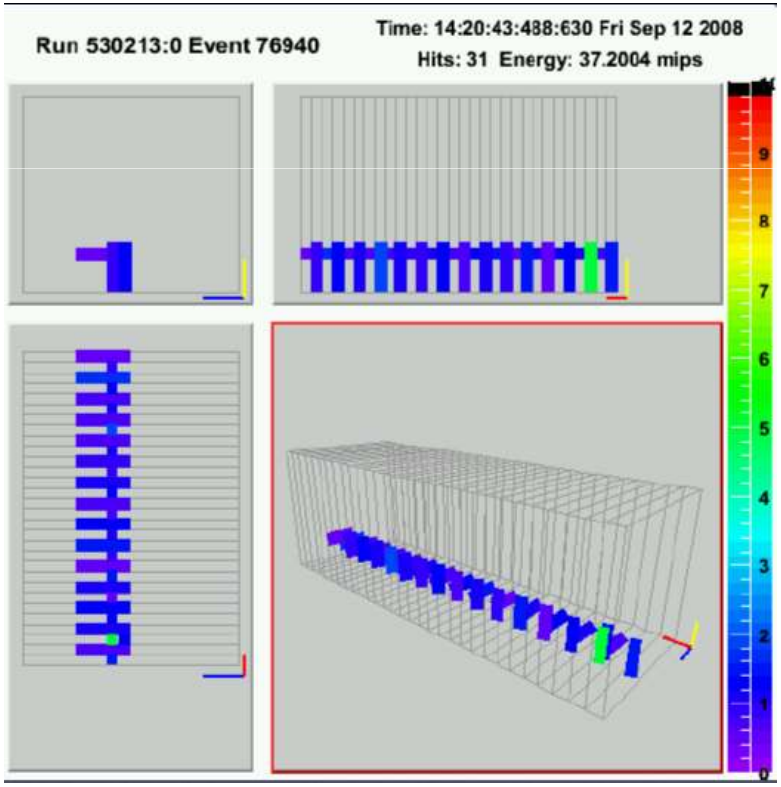


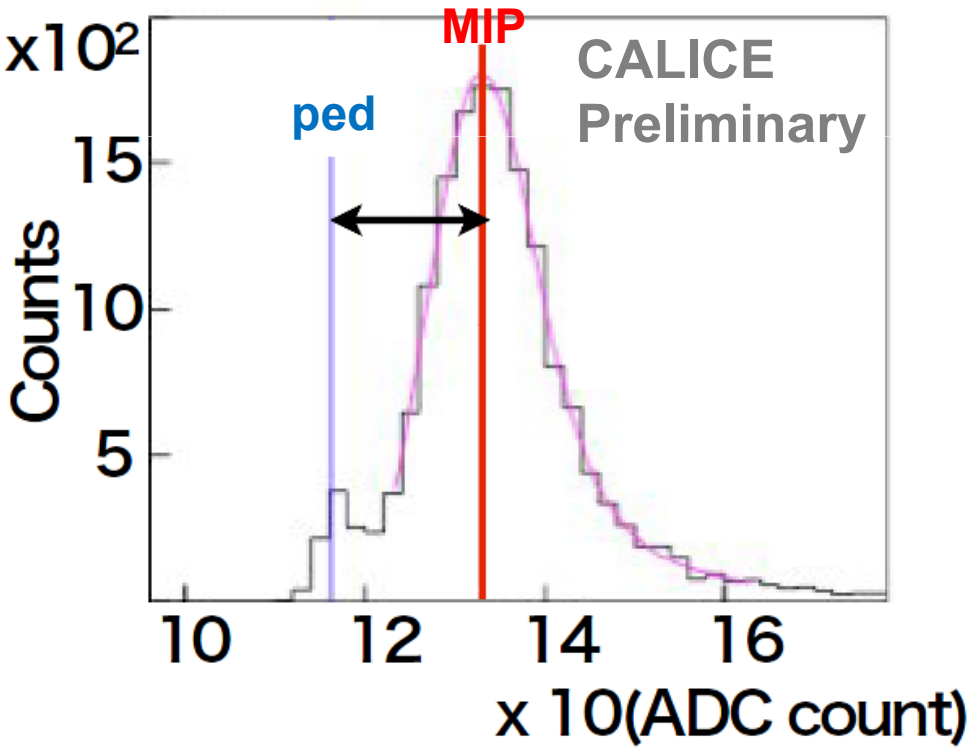
# Strip-by-strip response calibration with muons

The scintillator strip response calibration has been done using Minimum Ionizing Particle (MIP) signal by muon beams.

A typical muon event passing the ScECAL



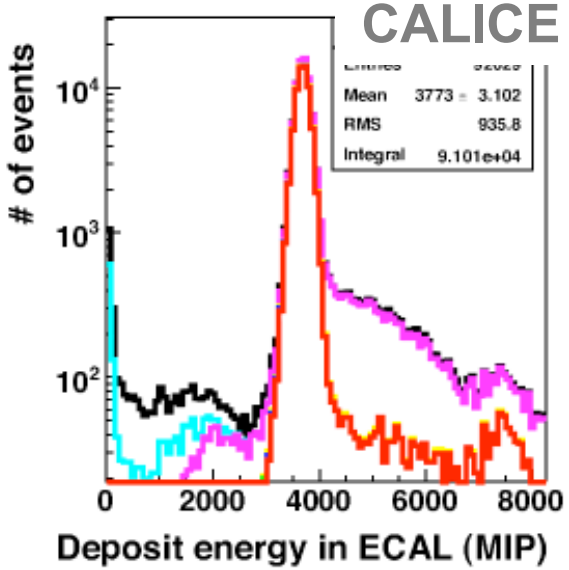

MIP equivalent signal on one strip

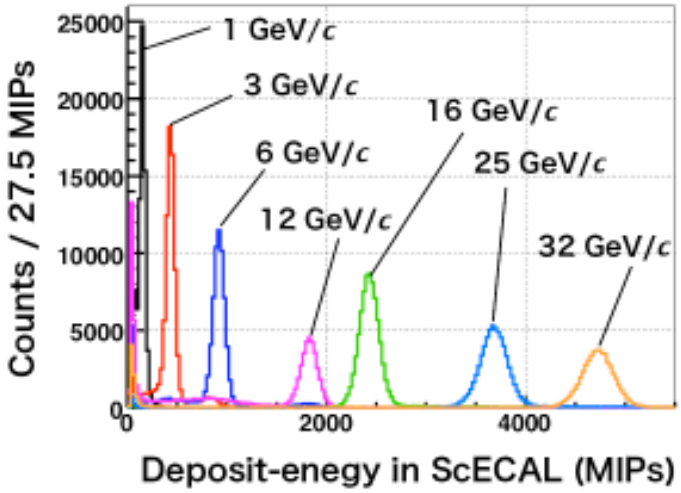


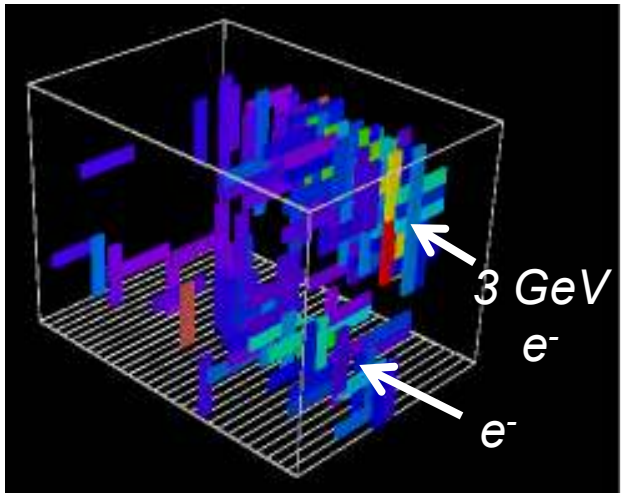

Uncertainty of the response calibration < 1% (statistical error only)

# Electron event selection

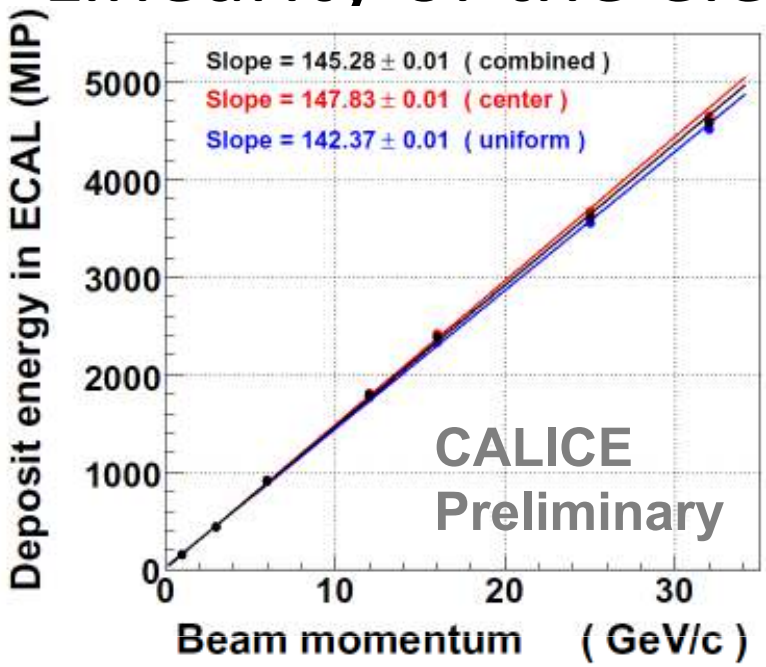
- The first task is evaluate the ScECAL performance for electrons.
- The beam is mixture of $e^-$ / $\pi^-$ / $\mu^-$ components.
- Cerenkov counter signals have been used for the electron trigger, however still offline event selection is necessary to purify the electron sample.
- Event selection is done based on :
  - Longitudinal / lateral shower shape
  - $\pi^-$ / $\mu^-$ veto by the HCAL signal located at downstream

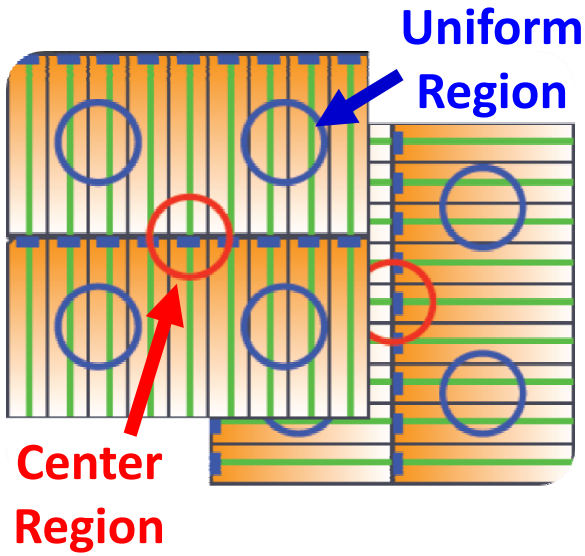


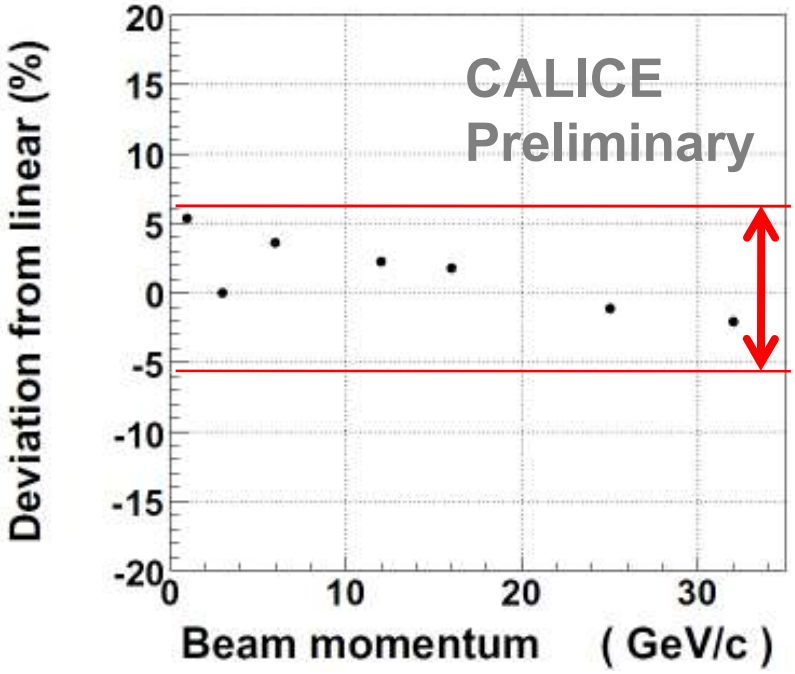



# Linearity of the electron energy measurement

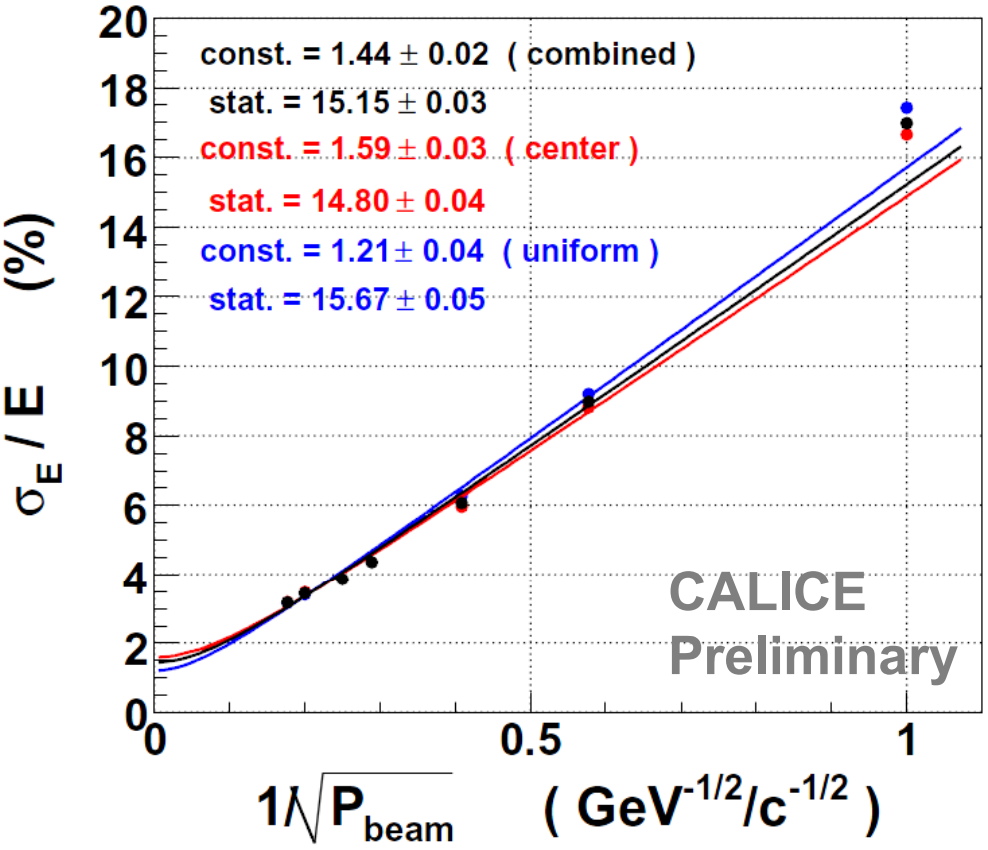


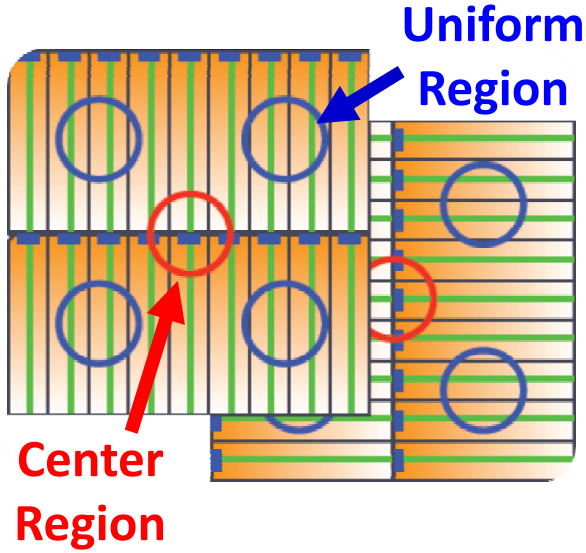




- Reasonably uniform response over the entire detector region.
- ~±6 % of non-linearity in 1-32 GeV energy region, needs to be improved.
- Reason under investigation, possibly due to:
  - contamination of $e^-$ data by $\pi/\mu$
  - Lateral and longitudinal shower leakage
  - Gain change of photo-sensor

# Energy Resolution for electrons



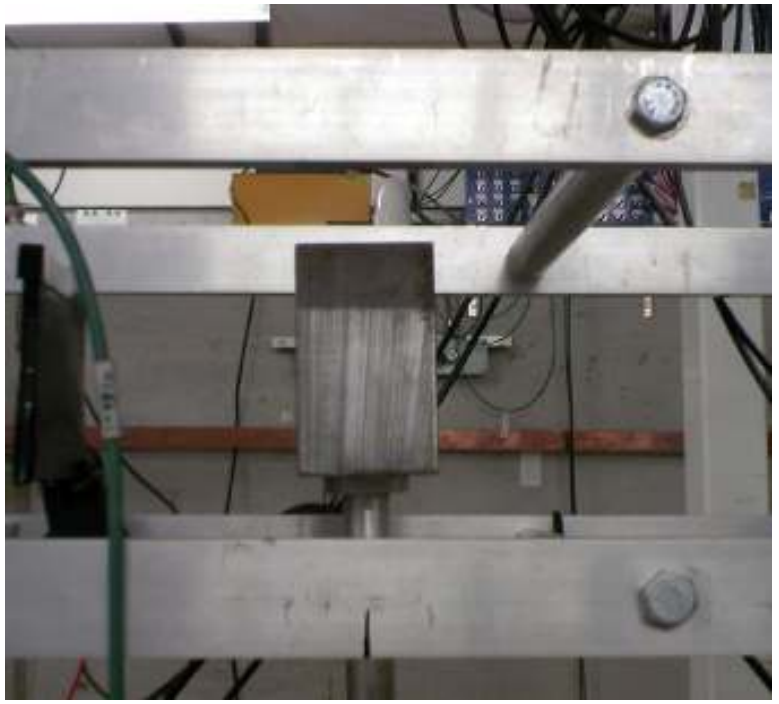




$$\frac{\sigma}{E} = \frac{(15.15 \pm 0.03)\%}{\sqrt{E}} \oplus (1.44 \pm 0.02)\%$$ (preliminary, errors are stat only)

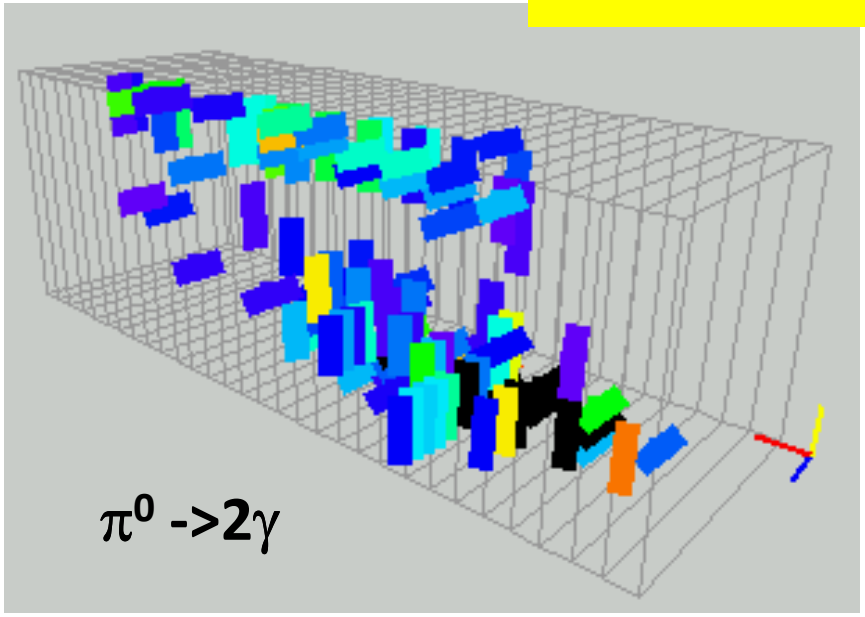
- Observed constant term rather large, investigation underway.
- Also due to the shower leakage or the gain variation of photo-sensor?

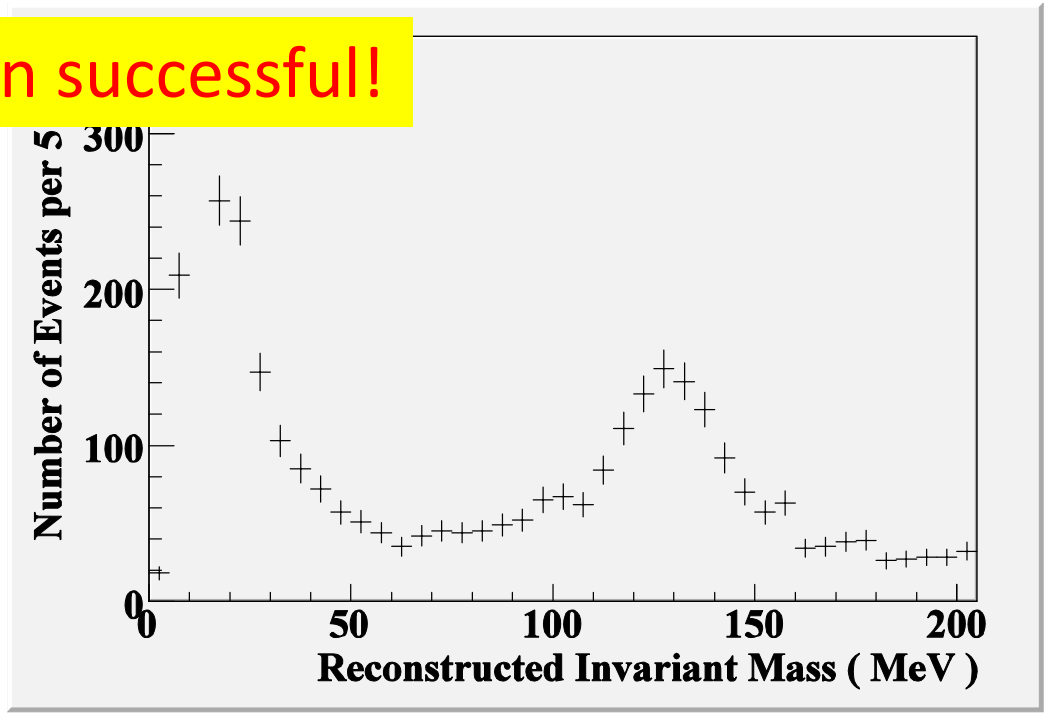
# $\pi^0$ runs (very preliminary)

- Ability of $\pi^0$ reconstruction from $2\gamma$ might be useful to improve jet energy resolution.
- Generate $\pi^0$ by putting iron on beamline and injecting 16-32 GeV $\pi^-$ beam.
- Try reconstruction of the generated $\pi^0$ with Scintillator-ECAL.



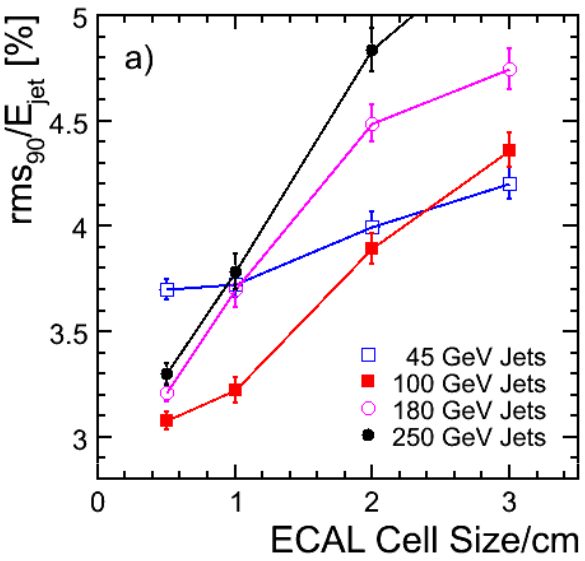
$\pi^0$ detection successful!



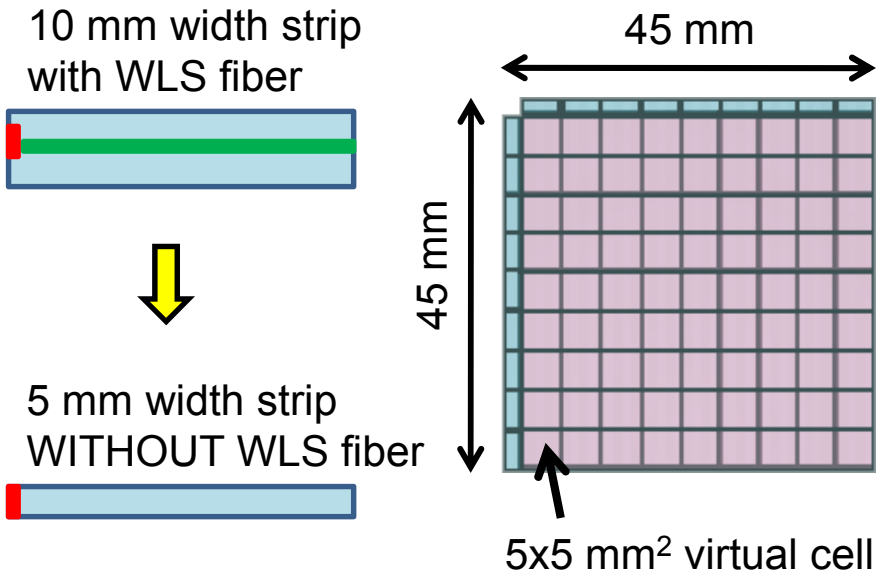
# 10 mm to 5 mm width strip

*Jet Energy Resolution with PFA*

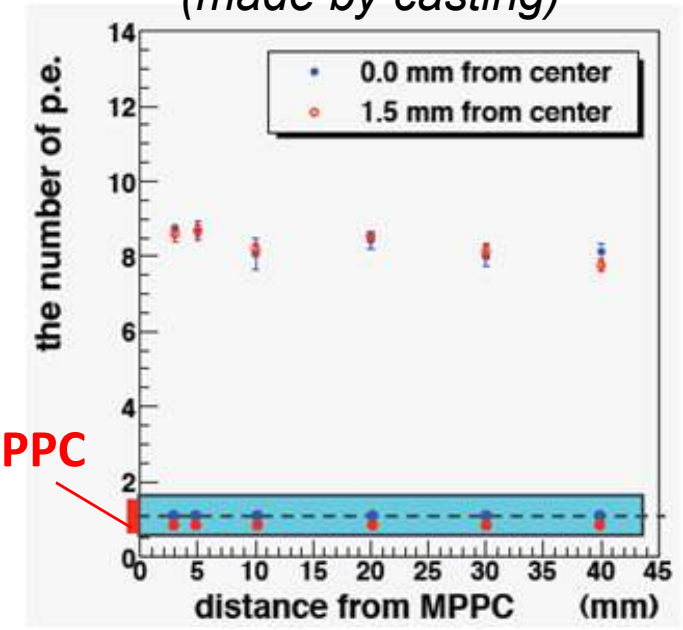



Further step :

- For precise measurement of jets with E > 100 GeV, 5 mm segmentation will be desirable.
- It can be still possible with 5 mm width scintillator strips.
- First measurement the 5mm scintillator strip shows encouraging result.




*Light yield of 45 x 5 x 2 mm strip (made by casting)*



# Summary

- For the future linear collider experiment, the Scintillator-strip ECAL is being developed in CALICE collaboration.
- Results of the prototype tests show promising feasibility of the ScECAL.
- Further analyses of the beam test are currently underway.

- Next step – even finer granularity with 5 mm strips.