The Scintillator ECAL Beam Test at FNAL

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Contents

- **Introduction**
  - ScECAL for ILD
  - Extruded Scintillator R&D
- **Beam Test**
  - Desy Beam Test
  - FNAL Beam Test
- **Results**
- **Summary & Plan**

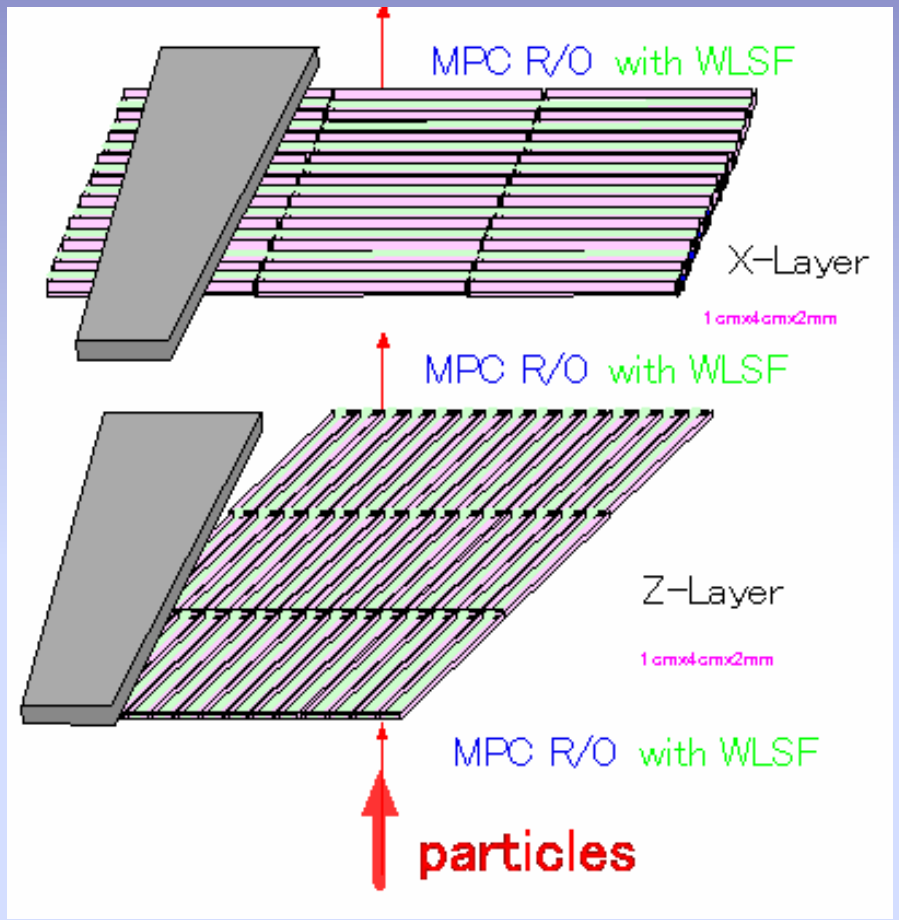
The Scintillator-Strip Calorimeter For the ILD

- Sampling calorimeter with Tungsten-Scintillator sandwich structure
- Scintillator strip structure to achieve fine granularity
- Signal of all the strips are read out individually
- Huge Number of channels

  (~10M for ECAL, and ~4M for HCAL)

Extruded Scintillator + Si photo-sensor

reduce production cost and keep required performance



Scintillator strip
(4.5 x 1 x 0.3 cm)

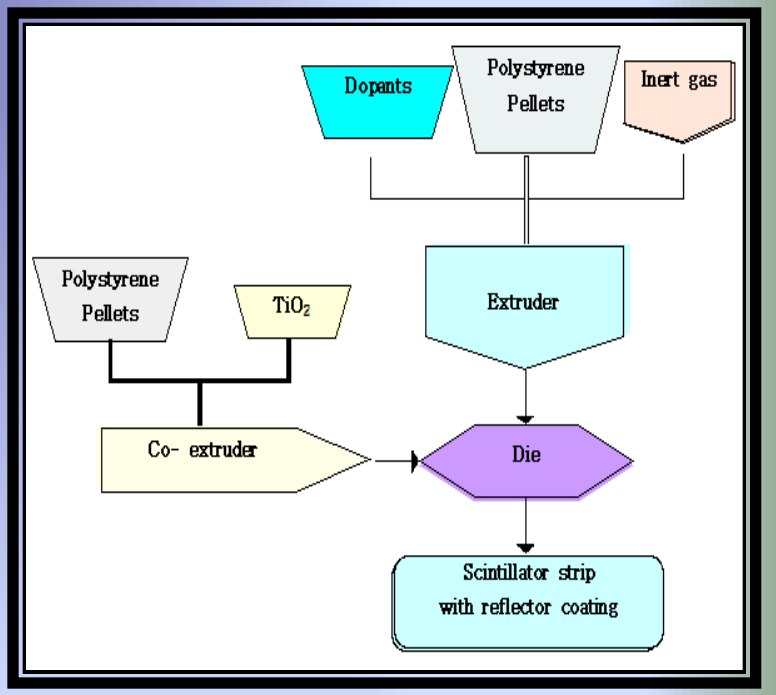
Extruded Scintillator

Robustness, production, and handling of the Scintillator

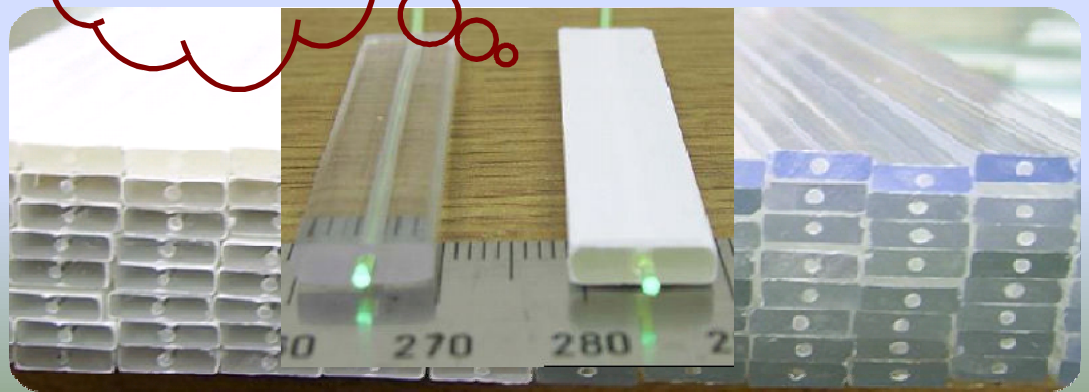
Low cost method to produce Scintillator needed

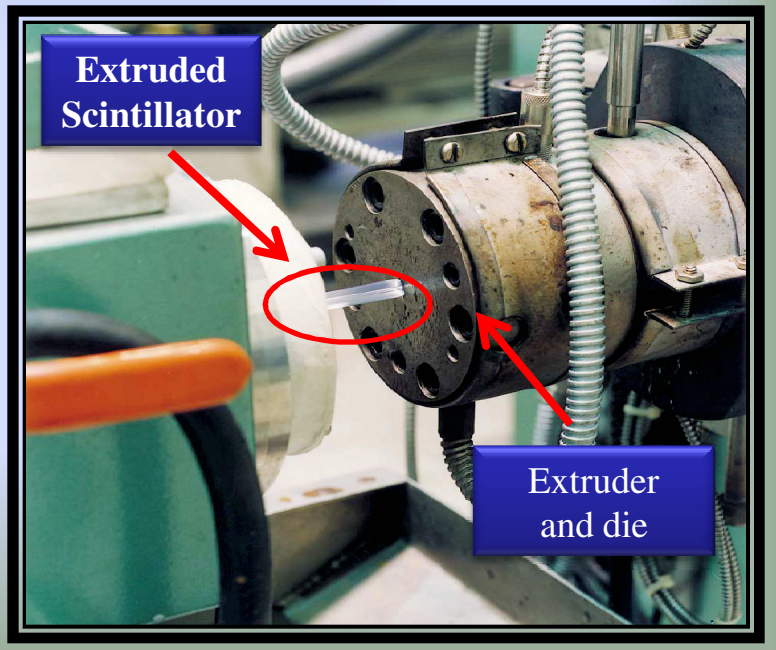
Extrusion Technique

- Light Reflector comes simultaneously
- Reduce lots of procedures
- High reliability
- Low cost
- As long as a fine cell scheme is concerned
  → Extrusion technique

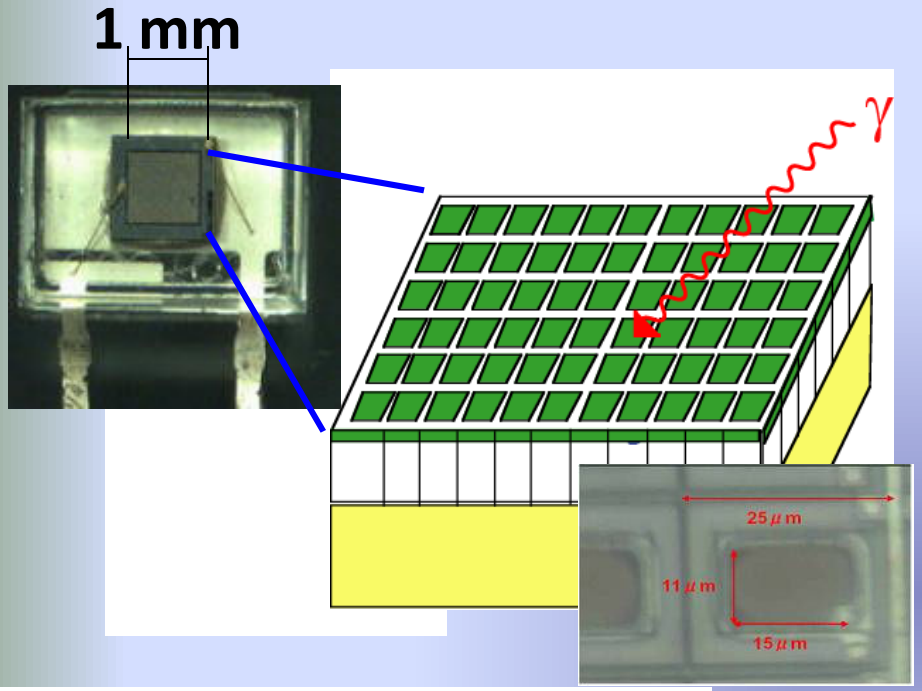


Extruded Fine Strip Scintillator for ScECAL with 1cm x 0.3cm

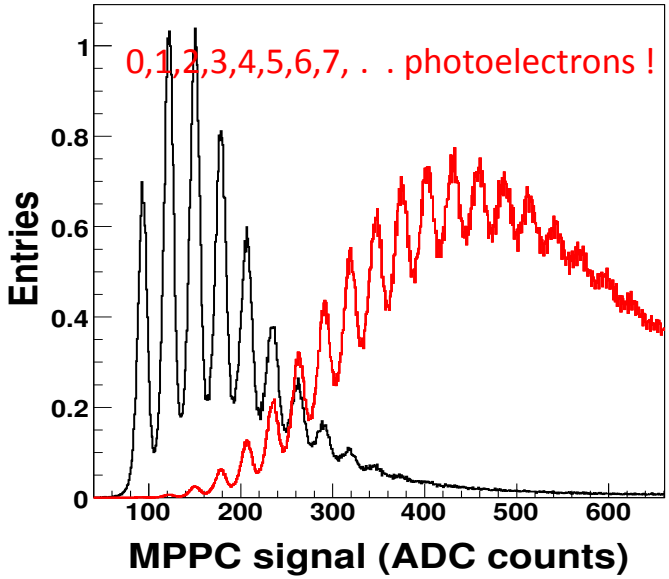




MPPC- Multi-Pixel Photon Counter



- Consists of Geiger-mode APD pixel matrix.
- High Gain (10^5~10^6)
- Enough Photon Detection Efficiency
- Compact
- Low cost
- Insensitive to magnetic field
- Dark noise exists
- Input vs output is non-linear

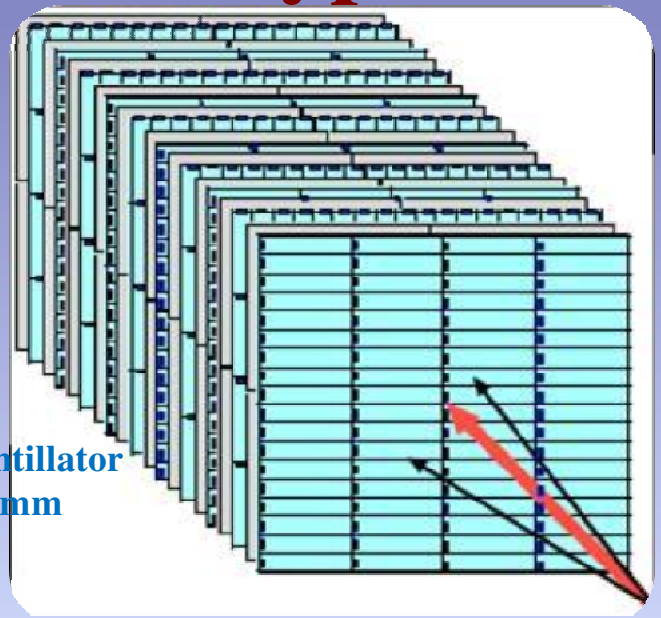


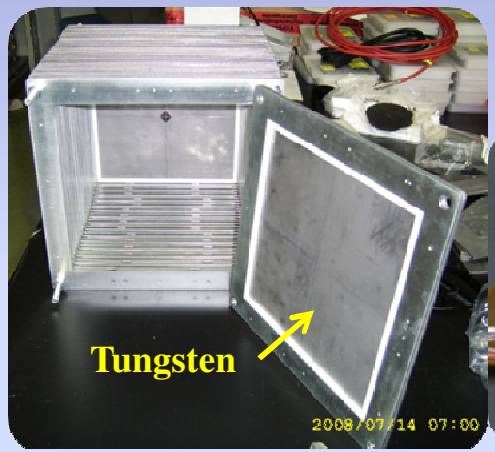
- Reasonably good performance for the Sci-strip readout.
- However the device is still new and needs further improvements.

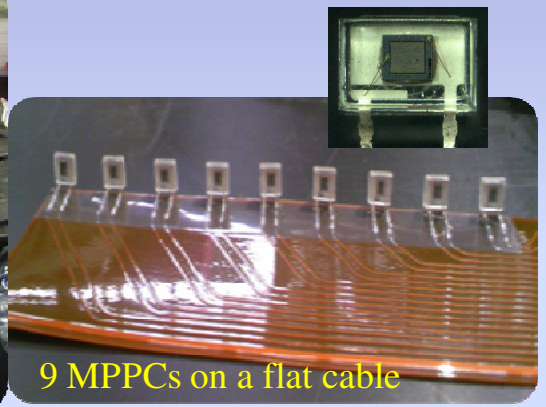
The Scintillator-ECAL Prototype

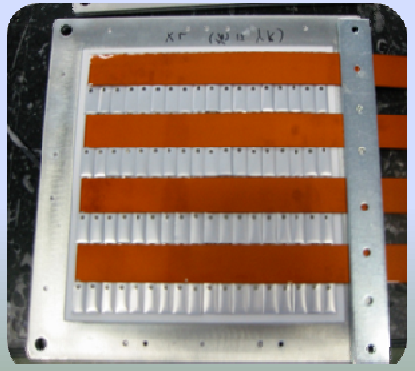
- The 2nd prototype is **4 times** larger than the DESY BT module **(18 x 18 cm², 30 layers)**

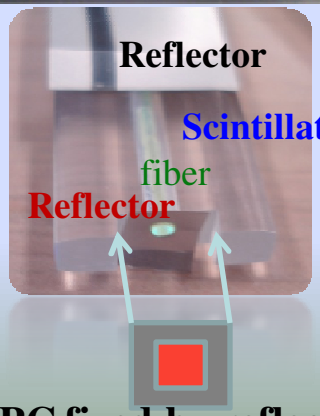
- Fully adopt with extruded Scintillator
- Precise positioning of MPPC and fiber
- MPPC Gain monitoring system
- MPPC: **2160** readout channels



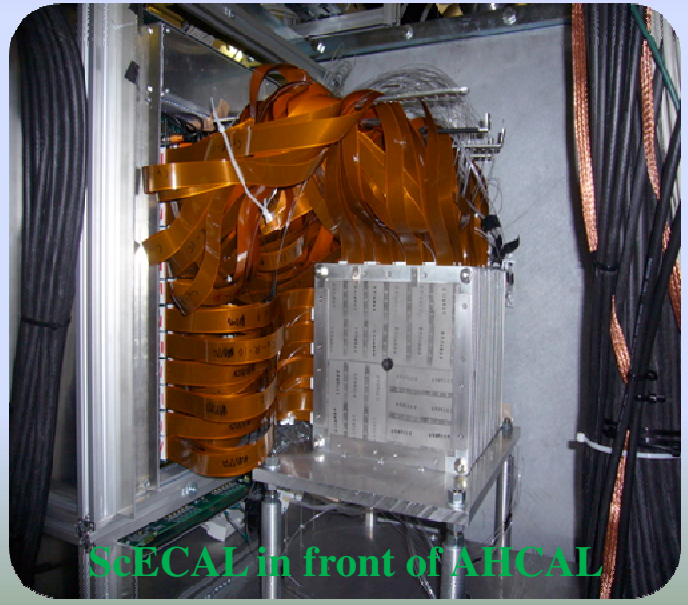




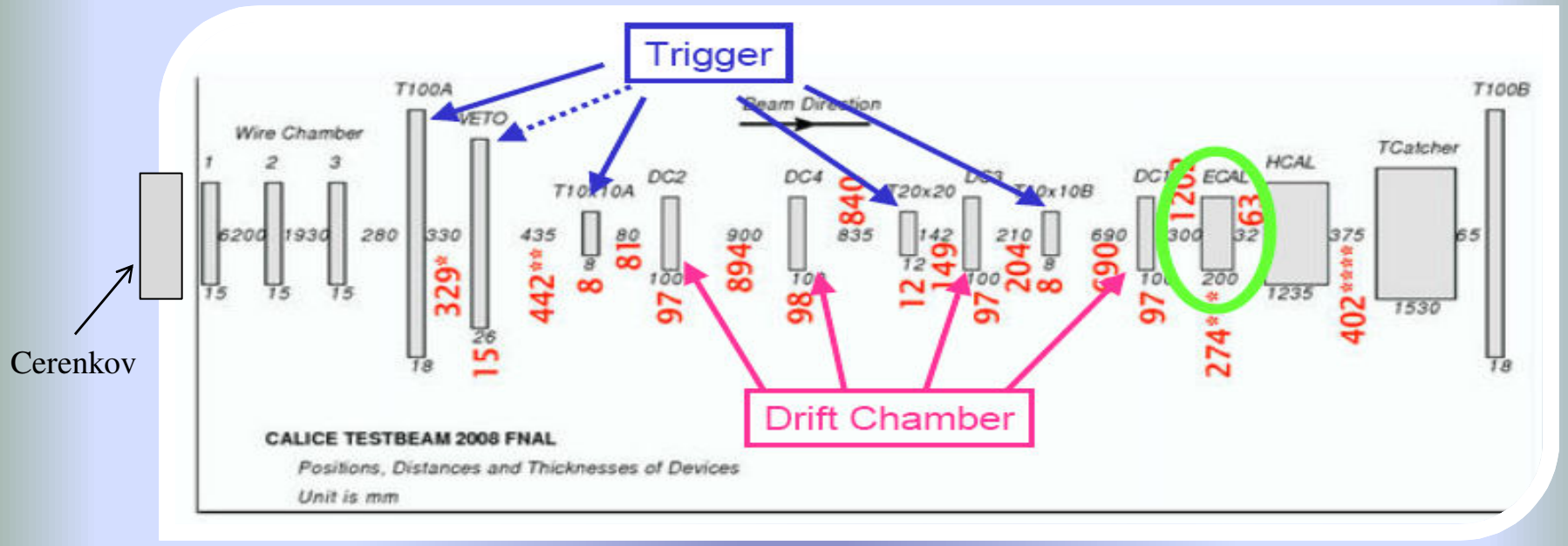




MPPC fixed by reflector



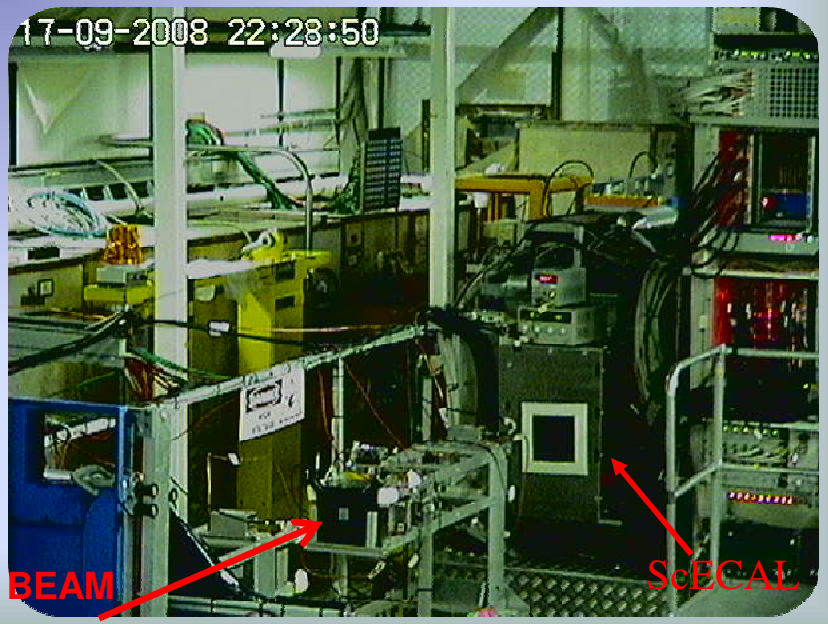
MT6 Test Beam User Area at FNAL



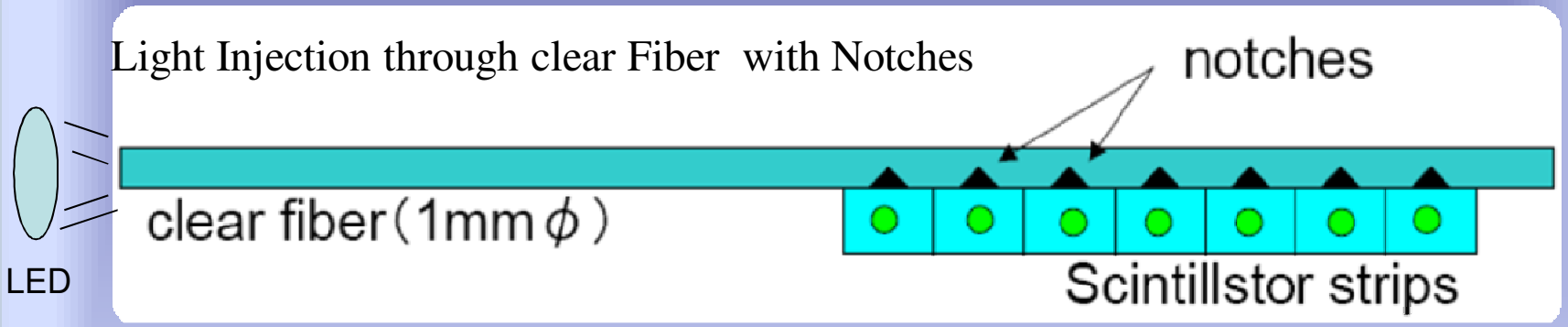
Beam Test: 2008 & 2009

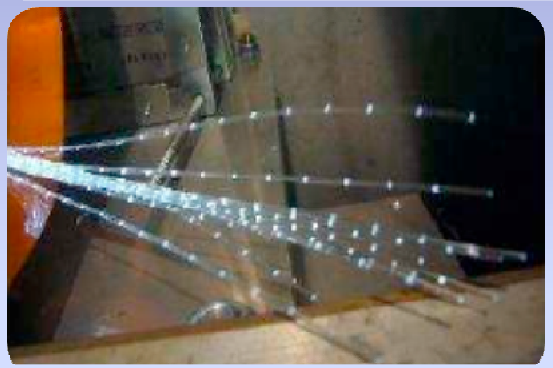
Various types of beams available

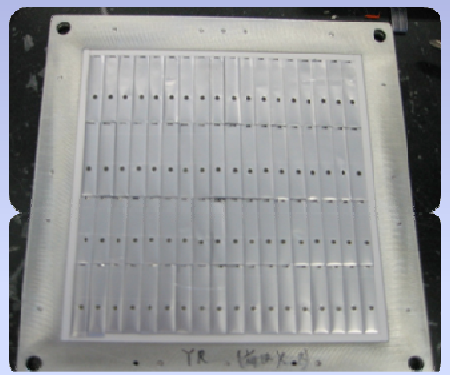
- 1-32 GeV electrons
- 1-60 GeV pions
- 32 GeV muons
- 120 GeV protons
- Cerenkov counter available to discriminate electron or pion



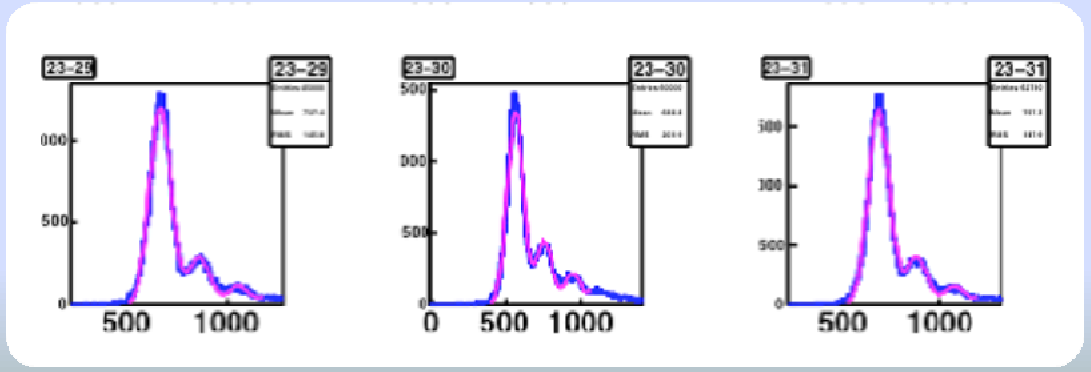
MPPC Gain Monitoring System





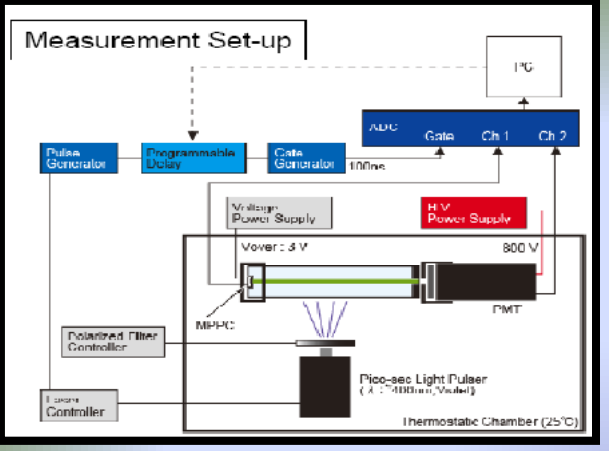


- LED lights are distributed by clear fibers, then fibers distribute the light through notches on them



MPPC can separate peaks of p.e. and distance between them gives us absolute gain of MPPC

MPPC Saturation Correction



- The MPPC is a non-linear device, as one pixel can detect one photon at once
- For a short light pulse input, response to input light can be theoretically calculated as

Output of correction

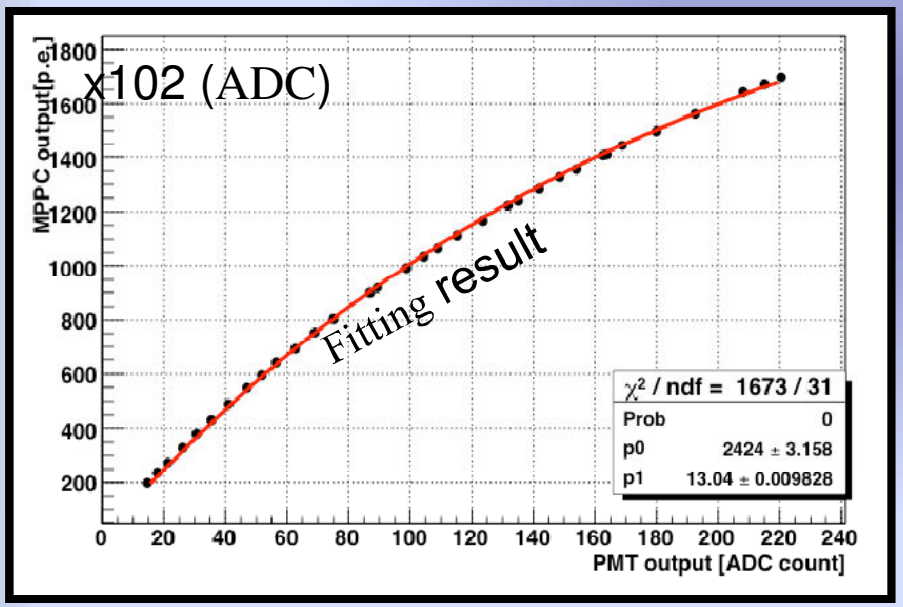
new value of response

$$N_{fired} = N_{pix}\left(1-\exp\left(\frac{-\varepsilon N_{in}}{N_{pix}}\right)\right)$$

Input for correction

# of photon from each channel

- **For the 1600-pixel MPPC, it is not the case since recovery time is an order of a few nsec, one pixel can detect a photon several times**



MPPC response

PMT response

x10 (ADC)

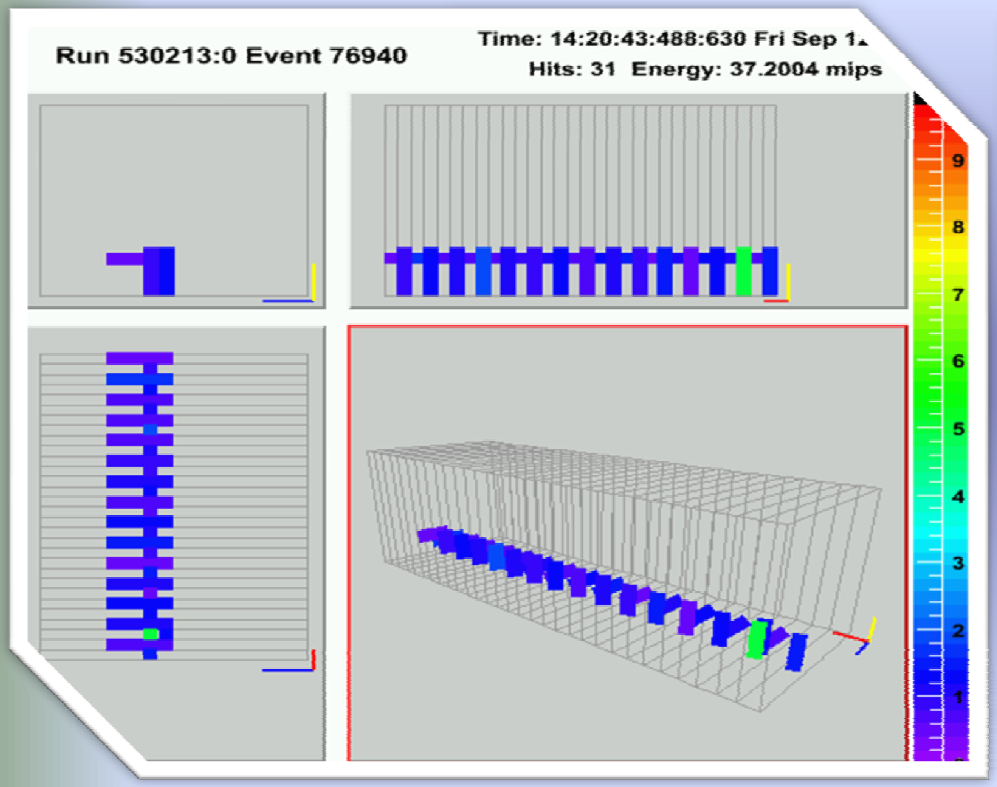
Result of fitting: $N_{pix} = 2424$

- Reverse function of fitting result of this function was used to make saturation correction

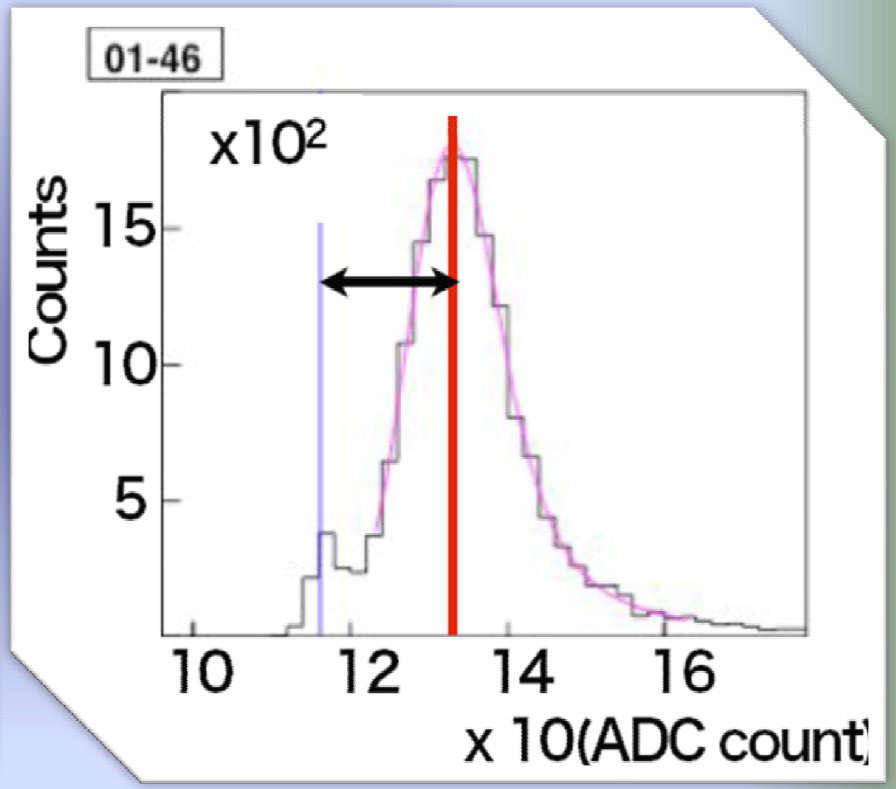
For each event of each channel, MPPC saturation correction was made

Calibration of each strip Scintillator

- Muon beam runs made with iron shutter put upstream of exp site was used

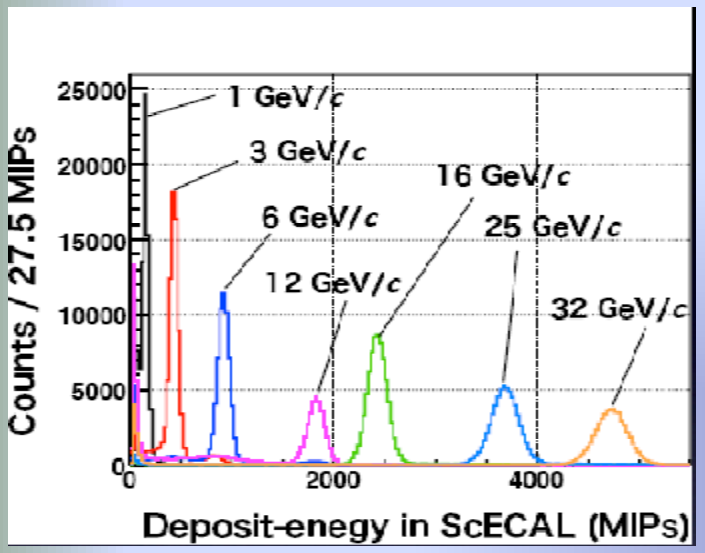


A typical MIP (Muon) event in the Online monitor

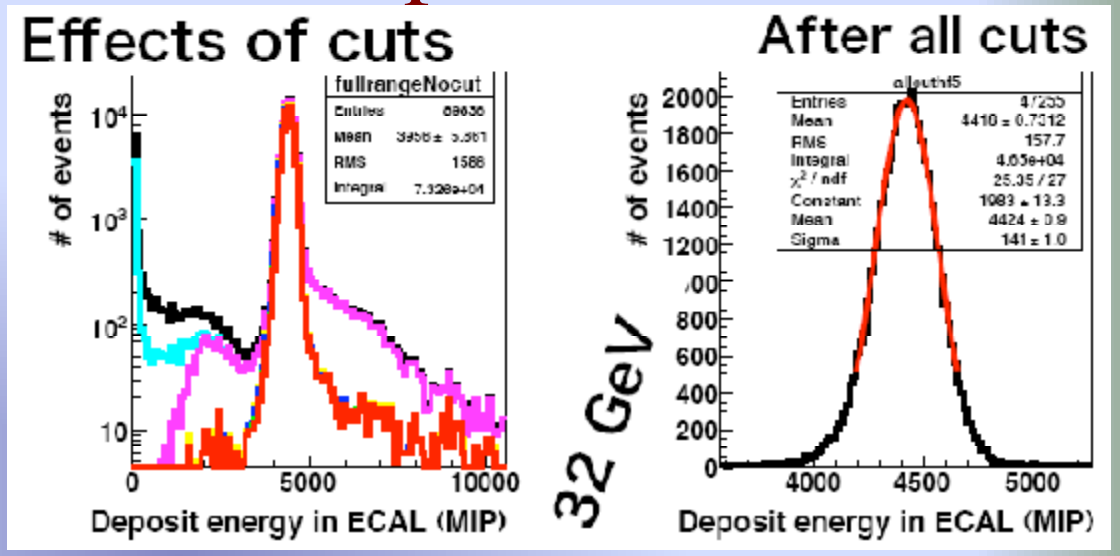


ADC count distribution of MIP event for a channel (1st layer, 46th channel)

Event selections and spectra



Spectra, before any selection cut but Cerenkov



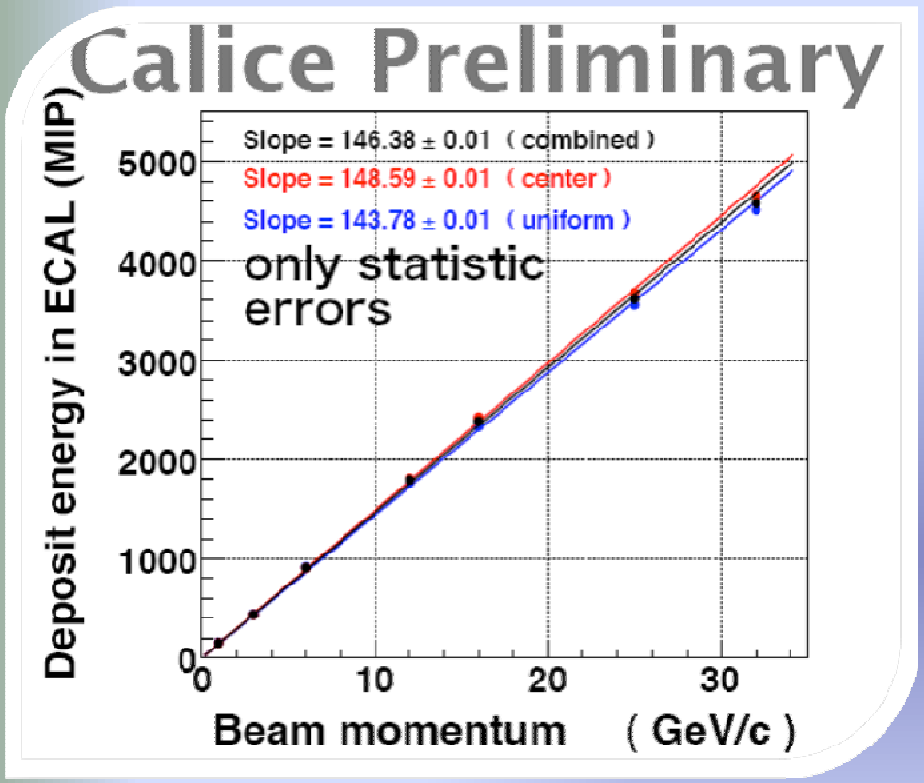
Each cut variation was investigated to make sure that the cut did not induce a bias.

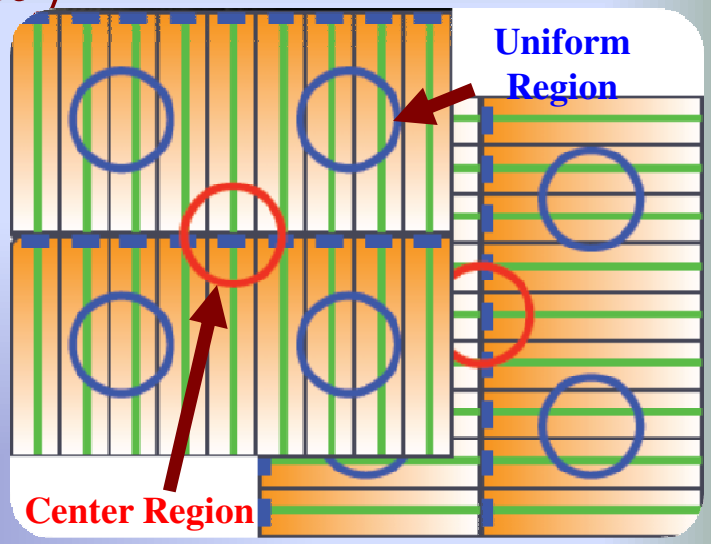
Selection criteria

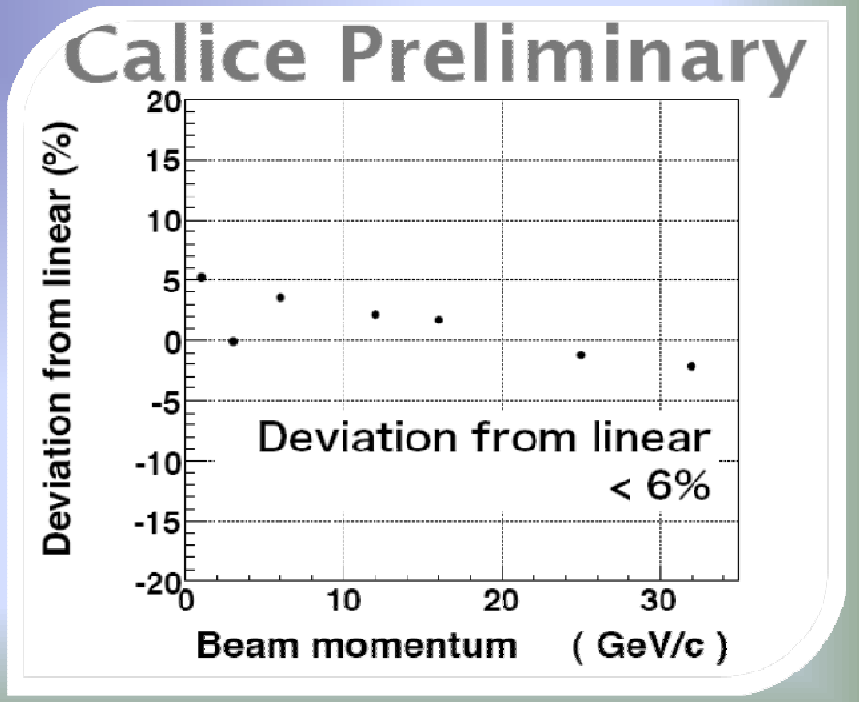
In order to reject Pions, Muons and shower leakage

- Shower maximum is required to be in the first part of ScECAL
- Maximum energy deposit in the shower is consistent with electron event
- To reject the event with the large signal in HCAL
- Energy in last layer of HCAL must be consistent with zero
- central of the shower must be consistent with ScECAL center

September 2008, Linearity



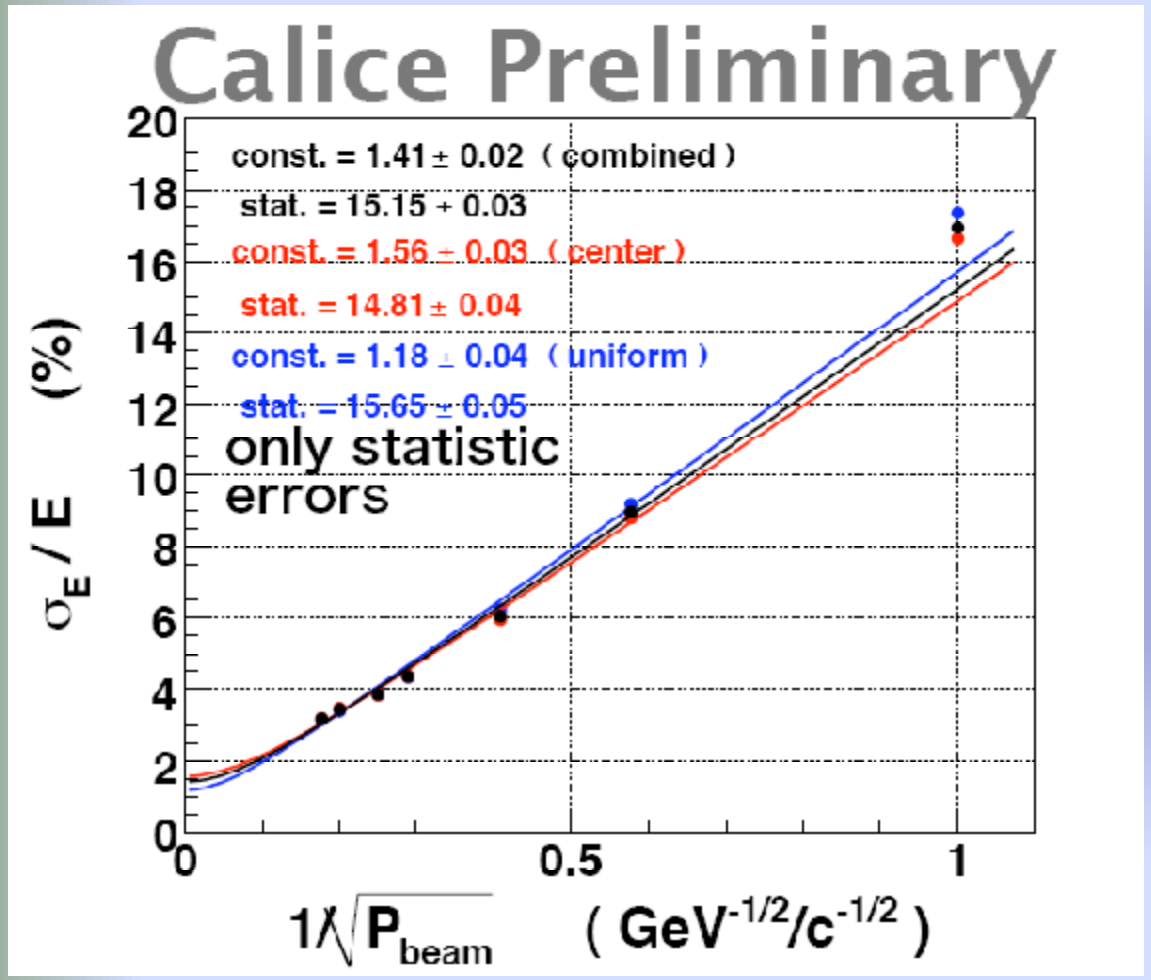


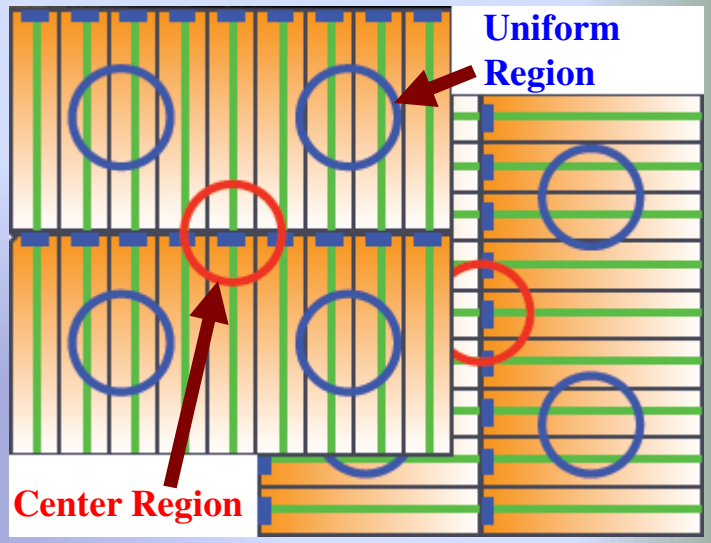


Candidates to correct residual deviation

- Correct with more detail MPPC saturation correction
- Investigate some energy leakage (maybe small)
- Apply temperature correction

Sep 2008, energy resolution





Calice Preliminary

constant term	1.41±0.02%
stochastic term	15.15±0.03%

* only statistic errors

Summary/Plan

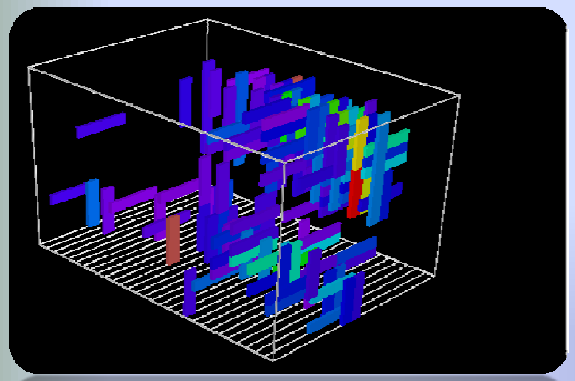
- ScECAL group of CALICE made 18 cm x 18 cm 2nd prototype
- Beam test at FNAL Sep. 2008, and May 2009
- less than 6% deviation from linearity is observed
- σ_{const} ~ 1.41% & σ_{stoch} ~ 15.15±0.03%

Detail investigation of selection/corrections are under way

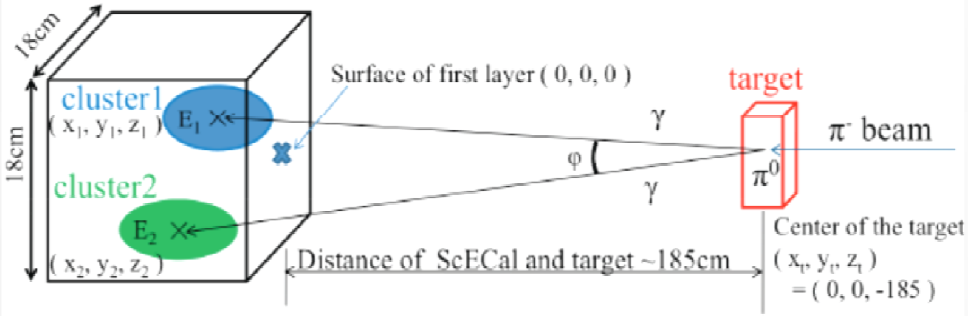
- Temperature correction
- MPPC saturation
- To eliminate the influence of Pion contamination
- To study the performance in combination with HCAL and Tail Catcher

BACKUP

π0 Run September 2008



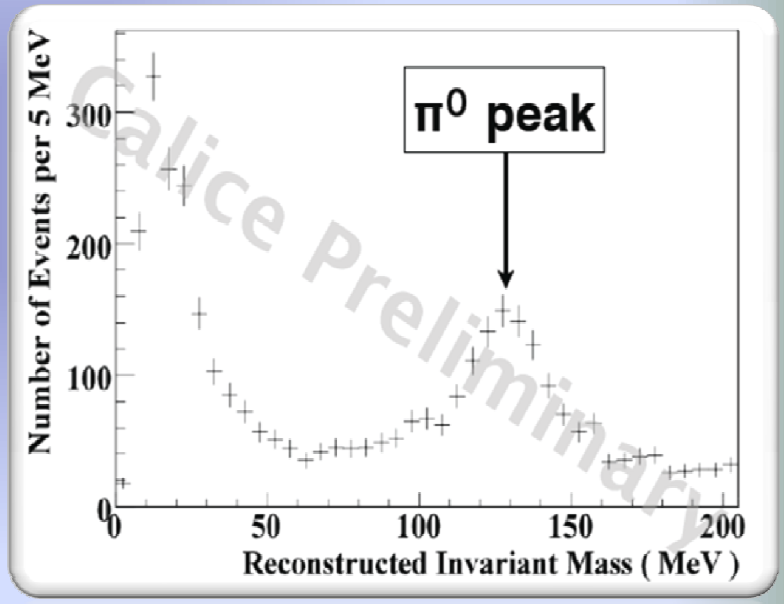
- Ability of π^0 reconstruction from 2 g is useful to improve jet energy resolution
- Generate π^0 by putting iron on beamline and injecting 16-32 GeV π^- beam
- Try reconstruction of the generated p^0 with Scintillator-ECAL



(Invariant Mass) = sqrt($2*E_1*E_2*(1-\cos(\varphi))$)

In case two gammas have equal energy,

Energy of π^0 (GeV)	3	4	5	10	15
Distance of two clusters (cm)	16.7	12.5	10.0	5.0	3.3

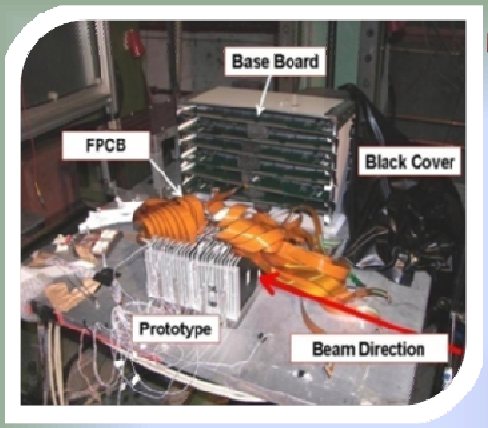


π⁻ :16,25,32 GeV
π⁺: 60 GeV(2009)

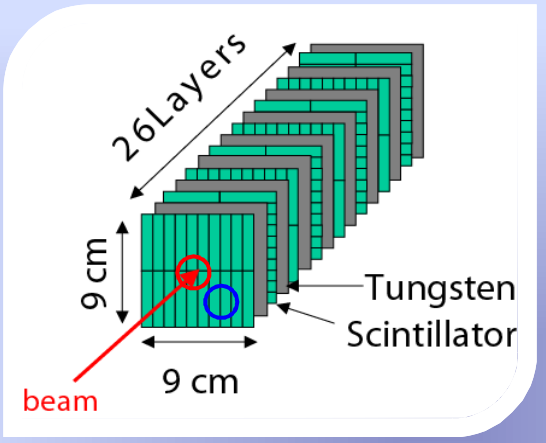
Reconstructed mass was well done (Rather small invariant mass than M_{π^0} so far).

π^0 detection is successful!

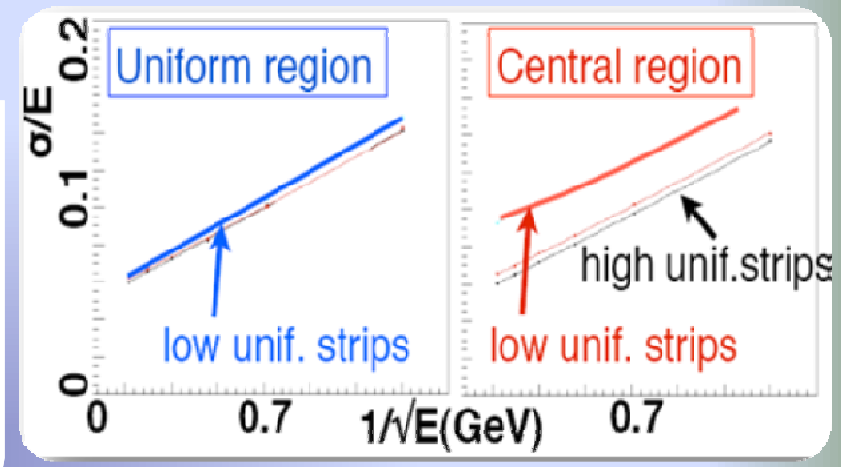
The ScECAL 1st Prototype



- 9 X 2 Strips / Layer
- 26 layers = $18X_0$
- 468 Ch
- 1 X 4.5 X 0.3 cm strip
- Fiber in a hole
- With out Fiber
- MPPC readout
- Beam test at Desy 2007



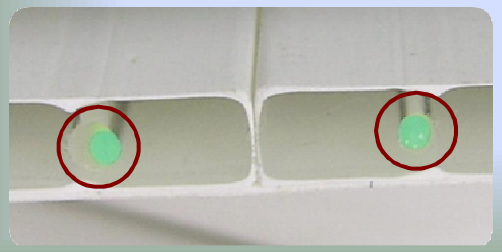
σ_{stoch} ~ 14%, σ_{const} = 2.0% w/ high uniform

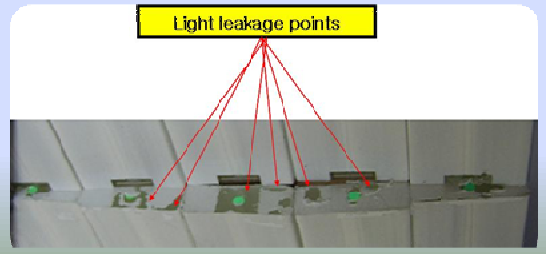


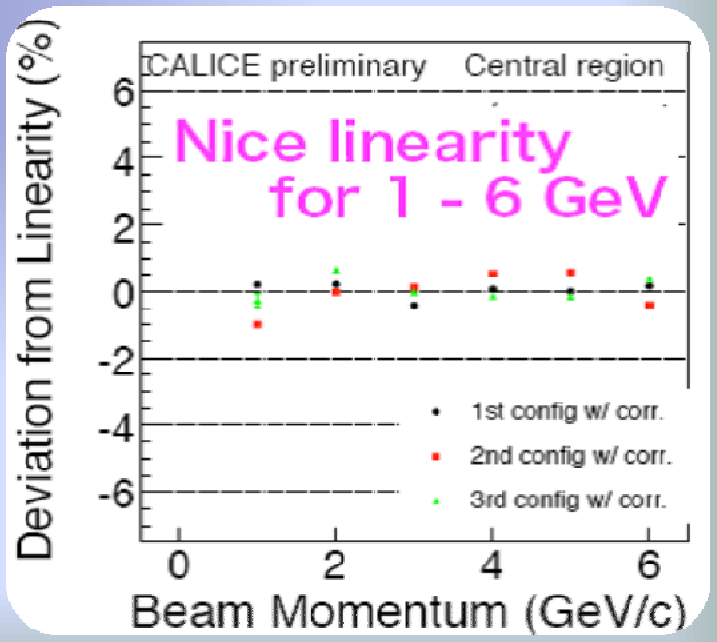
Problems associated with at Desy Beam Test

High constant term causes problems in very high energy
It usually happens when the light is not uniform in strip by strip
Some plausible problems found

- Fiber loose in hole cause **light loss**
- Mismatched MPPC & Fiber
- Light reflector in far side edge from MPPC ripped off







The MPPC has lots of advantages

	Photomultiplier	MPPC
Gain	~10^6	10^5~10^6
Photon Detection Eff.	0.1 ~ 0.2	**0.2 (3100pix.) ~ 0.5 (100pix.)**
Response	fast	fast
Photon counting	Yes	Great
Bias voltage	~ 1000 V	~ 70 V
Size	Small	Compact
B field	Sensitive	Insensitive
Cost	Expensive	Not expensive
Dynamic range	Good	Determined by # of pixels
Long-term Stability	Good	Being checked
Robustness	decent	Being checked
Noise (fake signal by thermions)	Quiet	1 pixel noise exist (order of 100 - 500 kHz)