The Performance of Strip-Fiber EM Calorimeter - Linearity, Energy Resolution –

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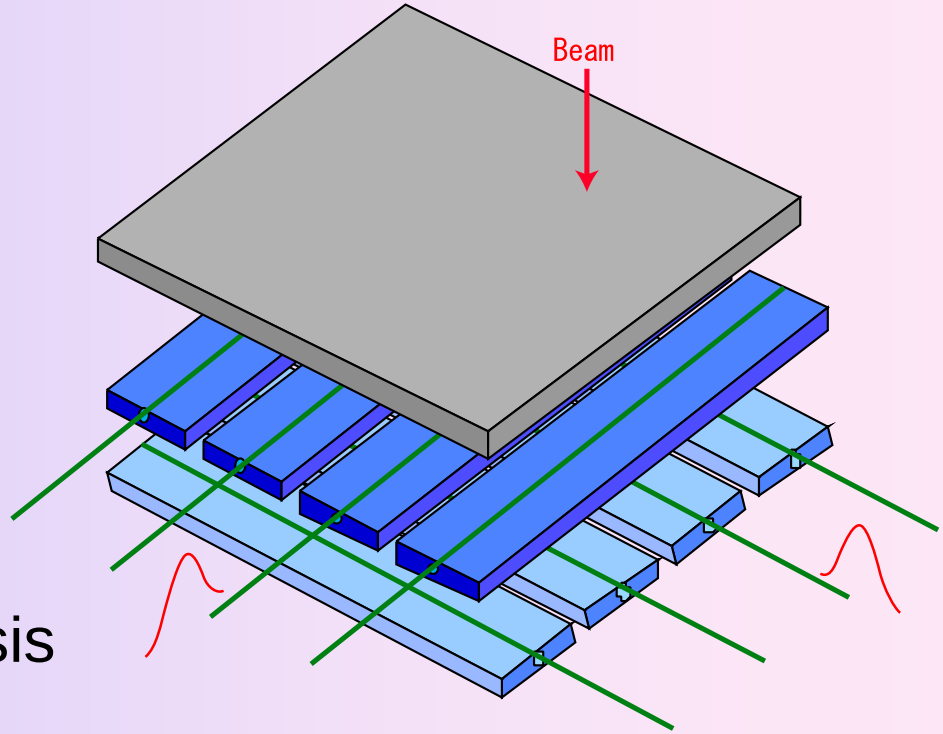
Introduction
Calorimeter
Test beam
Gain calibration
Linearity
Energy resolution
Summary

University of Tsukuba

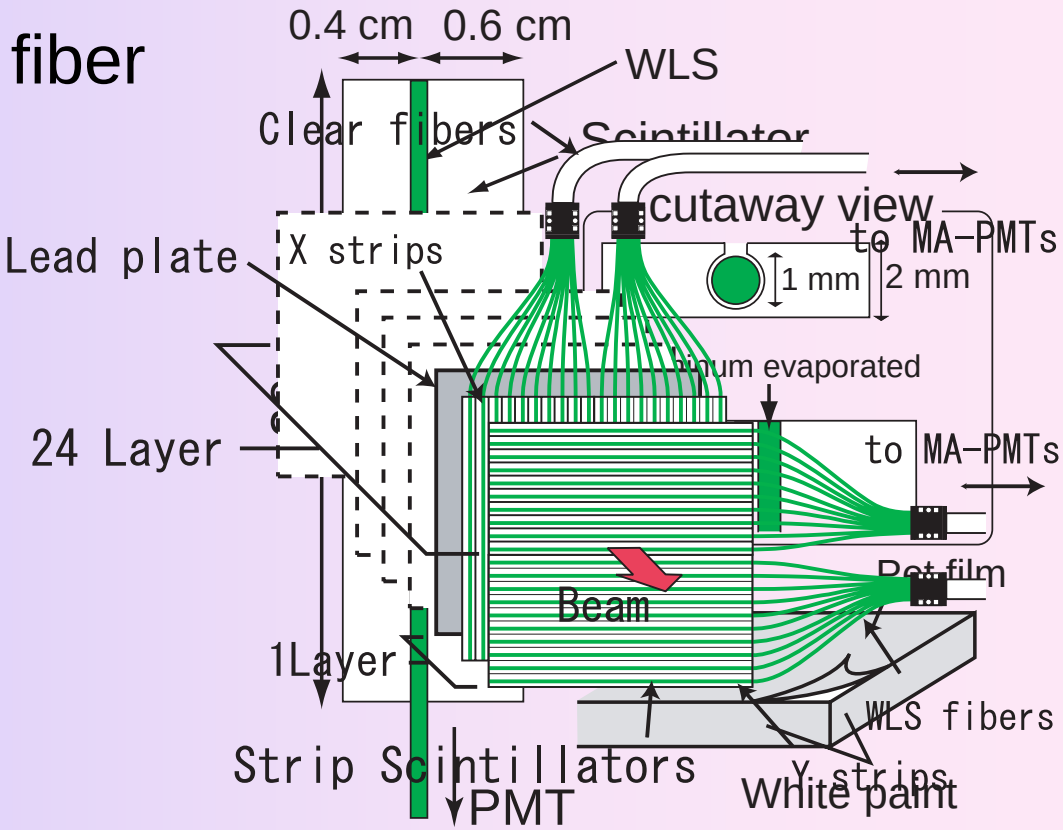
Introduction

- Requirements for LC EMCAL
  - Energy resolution
    - $\frac{\sigma_E}{E} = \frac{15\%}{\sqrt{E}} \oplus 1\%$
  - Linearity
    - 1%
  - Fine granularity
    - particle flow analysis
- Scintillator strip array EMCAL
  - Fine granularity



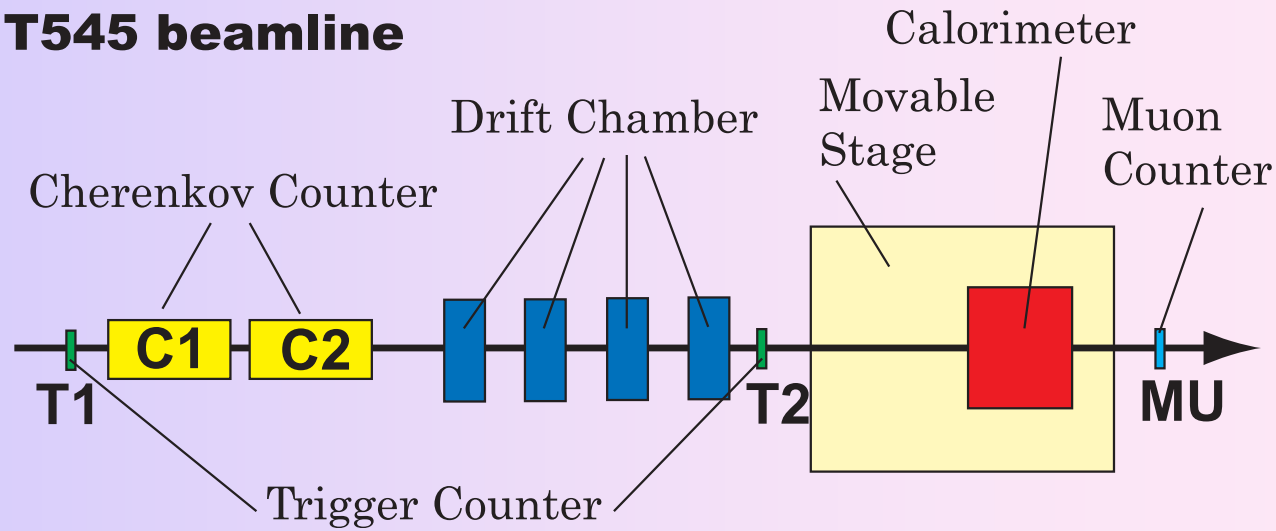
Calorimeter

- Module design for test beam
  - 1× 20cm× 2mm-thick Sci. strip
    - effective cell size: $1cm^2$
  - WLS fiber + clear fiber
  - 1 layer
    - Lead (4mm-thick)
    - X-strips×20
    - Y-strips×20
  - Total 24 layers
    - 17 X_0
    - 6 super layers
      - 1 SL = 4 layers



Test beam

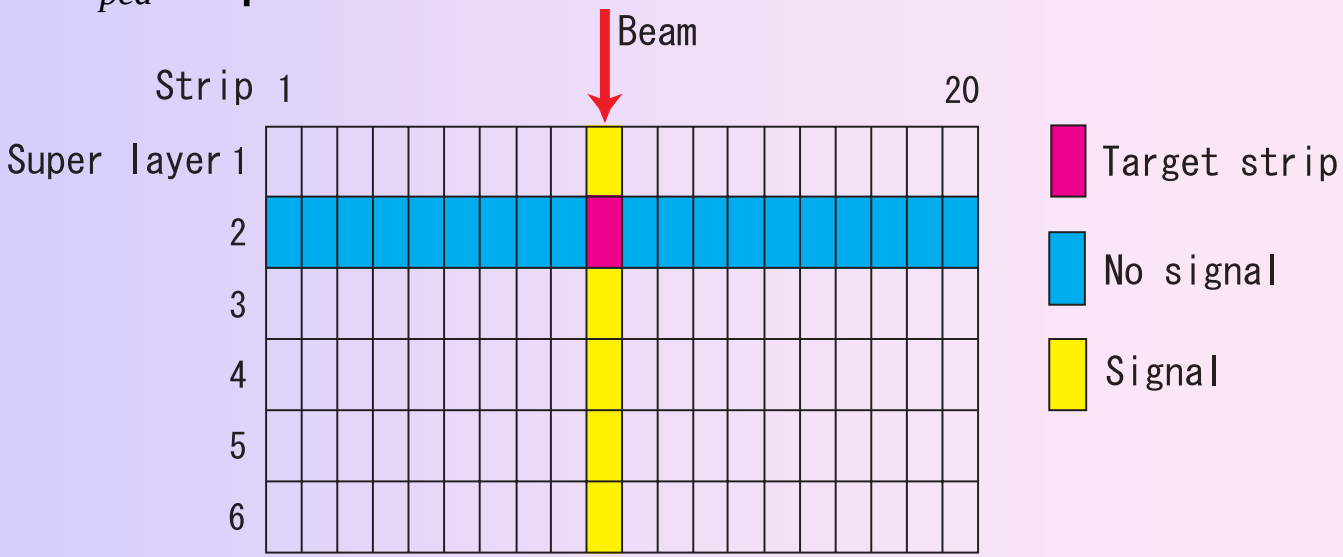
- KEK PS Mar 2004
  - Unseparated beams (e, pi, mu)
  - 1 - 4 GeV
- EMCAL on movable stage
- Scintillation counters
- Electron-ID with Cherenkov counters
- Tracking with drift chambers



Gain Calibration

Cuts for MIP events

- Inclusive trigger (T1&T2)
- All upstream and downstream superlayers of the target should have signals above the pedestals.
  - ped + 3 σ_{ped} < p.h.
- Signals of all other strips in the same superlayer as the target should be consistent with pedestal.
  - ped + 5 σ_{ped} > p.h.



MIP pulse height

- Fit function: asymmetric-gauss

$$f = \begin{cases} p_0 \exp\left(-\frac{1}{2}\left(\frac{x-p_1}{p_2}\right)^2\right) & (x < p_1) \\ p_0 \exp\left(-\frac{1}{2}\left(\frac{x-p_1}{p_3}\right)^2\right) & (x > p_1) \end{cases}$$

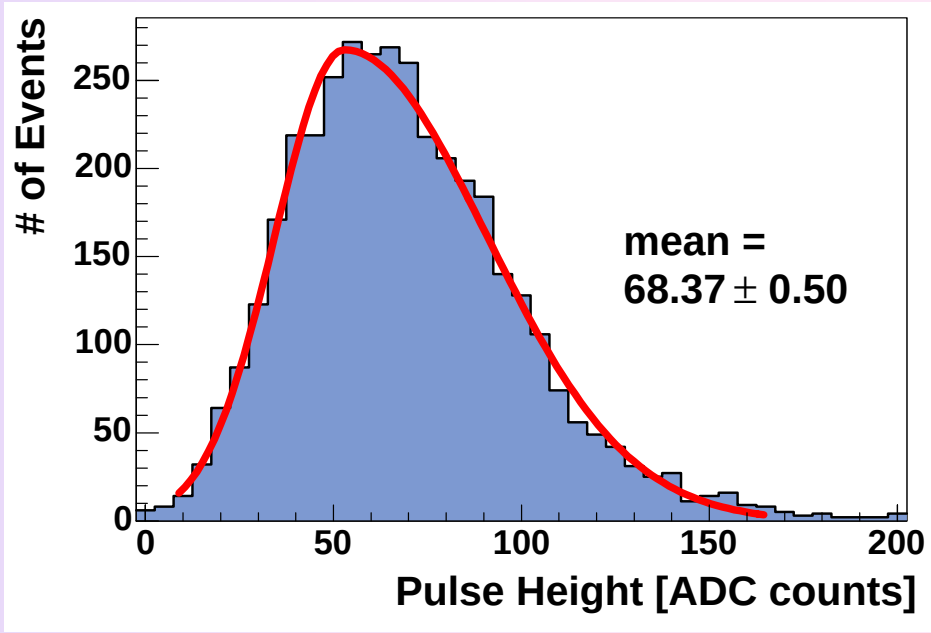
- Fit range:
  ped+3σ_{ped} < p.h. < mean+3p_3
- Binning: 5 counts/bin
- Constant:

$$\mu = \frac{\int_{-\infty}^{+\infty} xf dx}{\int_{-\infty}^{+\infty} f dx} = p_1 + \sqrt{\frac{2}{\pi}}(p_3 - p_2)$$

- Error:

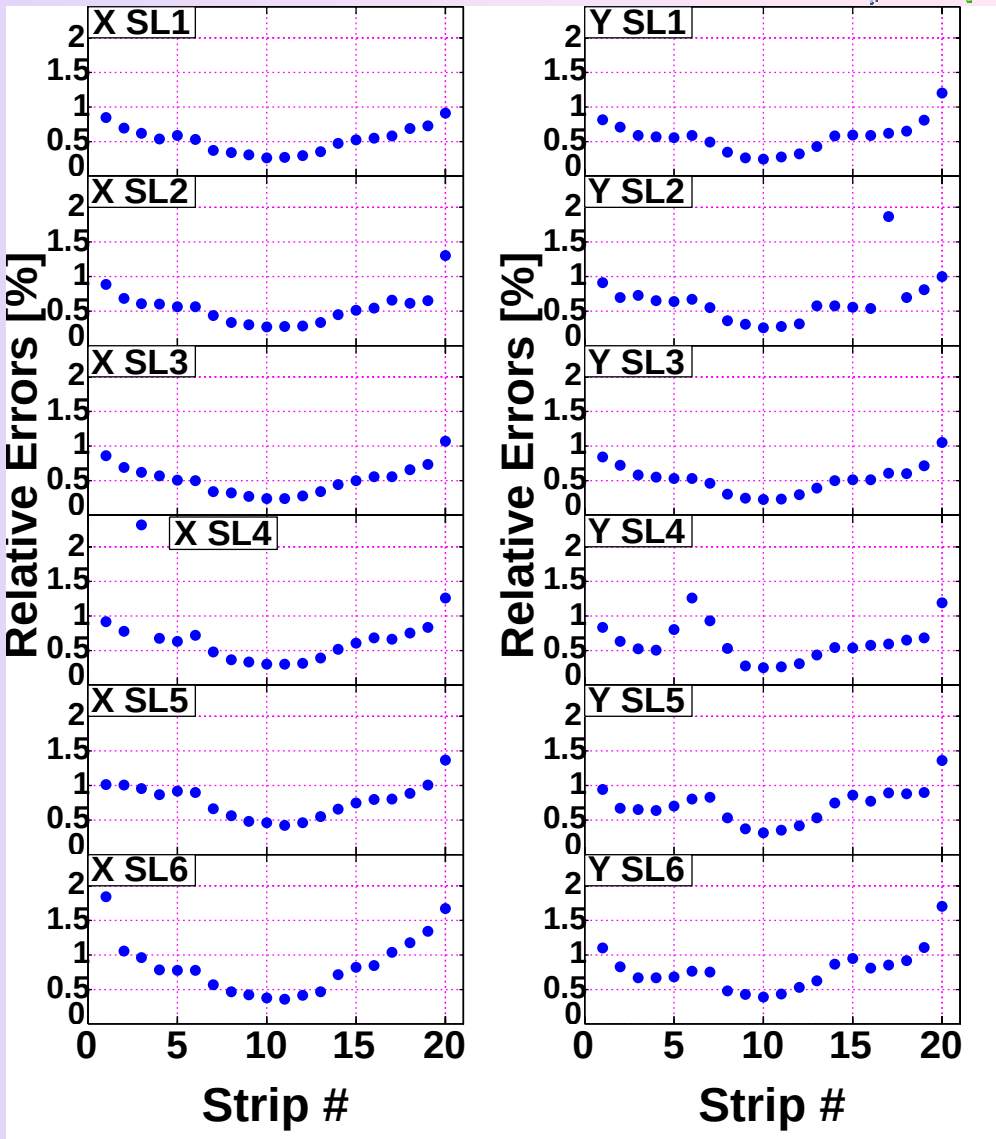
$$\sigma_\mu^2 = \sum_{i=0}^{3}\sum_{j=0}^{3} \frac{\partial \mu}{\partial p_i}\frac{\partial \mu}{\partial p_j}\mathrm{cov}(i,j)$$

$$= \sigma_1^2 + \frac{2}{\pi}\sigma_2^2 + \frac{2}{\pi}\sigma_3^2 - 2\sqrt{\frac{2}{\pi}}\sigma_{12} + 2\sqrt{\frac{2}{\pi}}\sigma_{13} - 2\frac{2}{\pi}\sigma_{23}$$



Relative errors

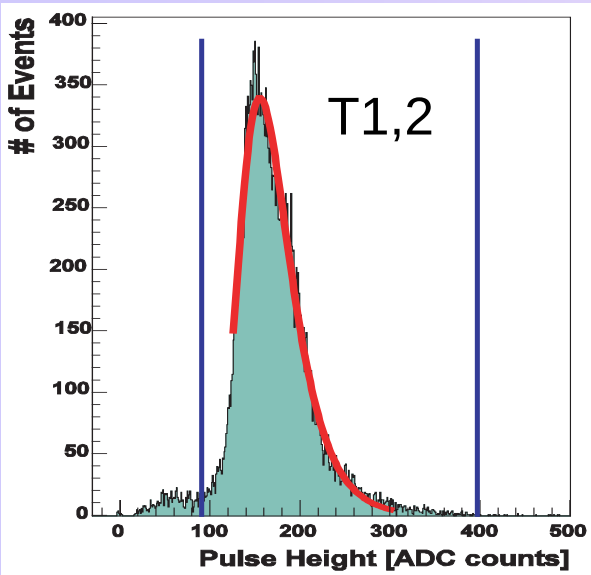
- Less than 1% for most strips
- about 0.3% in the central region

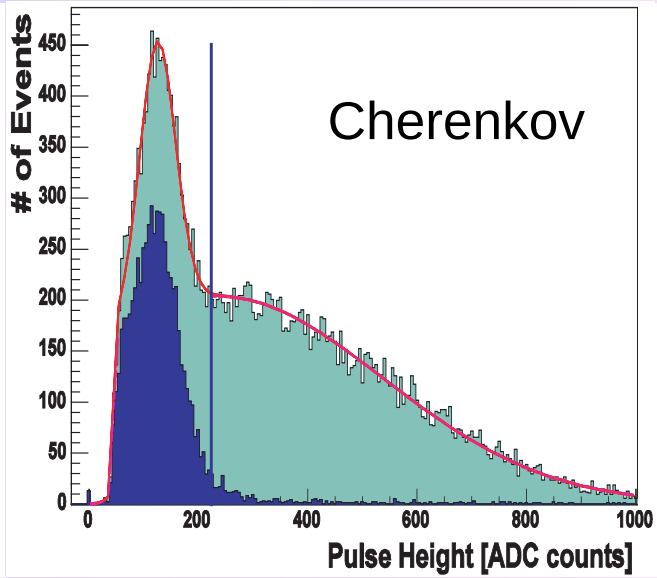


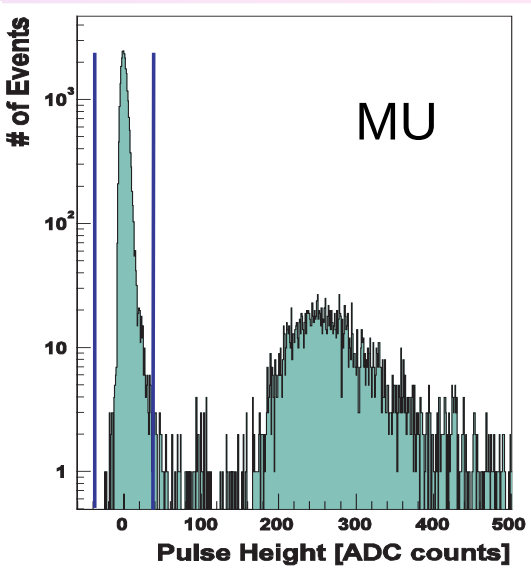
Linearity
Energy Resolution

Cuts for electron events

- Electron trigger (T1&T2&C1&C2)
- T1, T2
  - Consistent with one MIP
- Cherenkov
  - High enough to separate from pions and muons
- MU
  - Consistent with pedestal

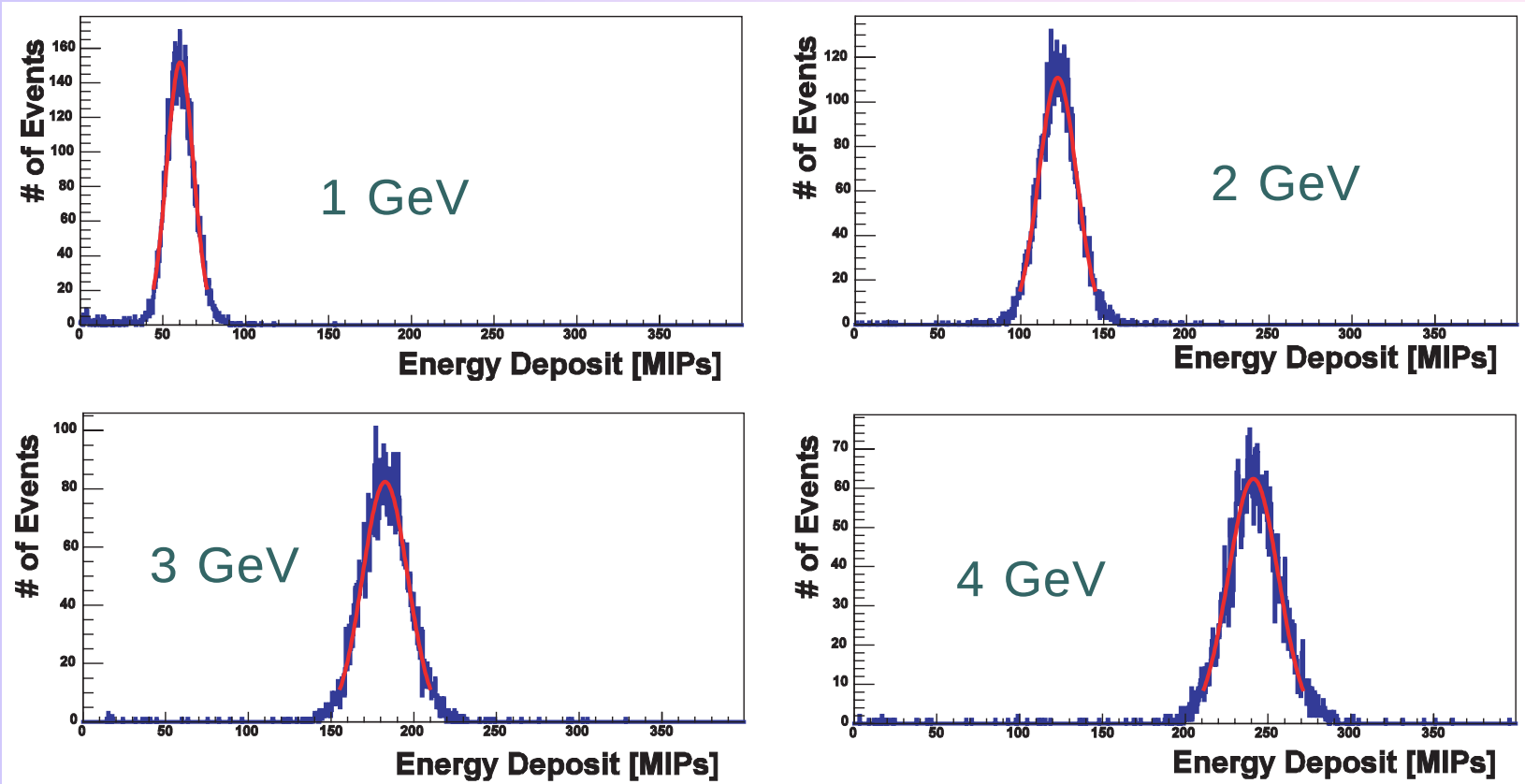






Energy distribution

- Fit function: gauss
- Fit range: mean $\pm 2\sigma$
- Binning: 0.4MIPs/bin



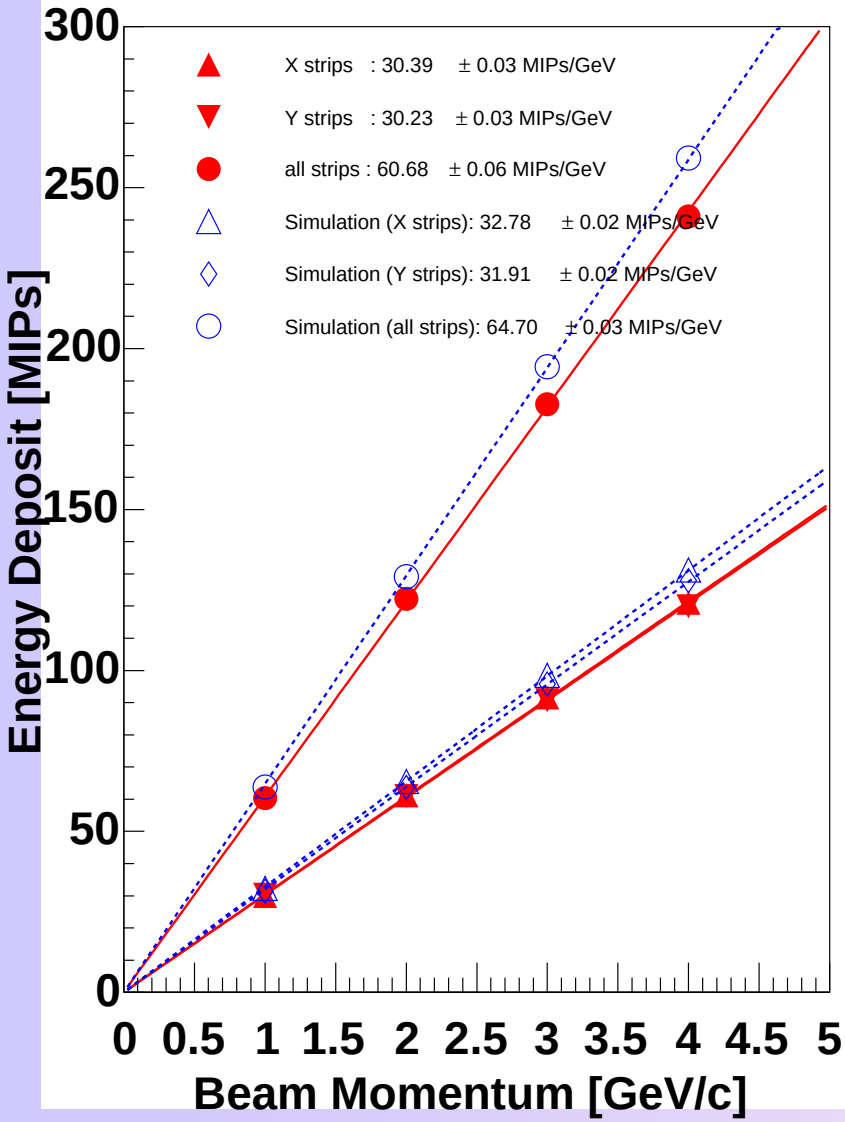
Systematic uncertainty

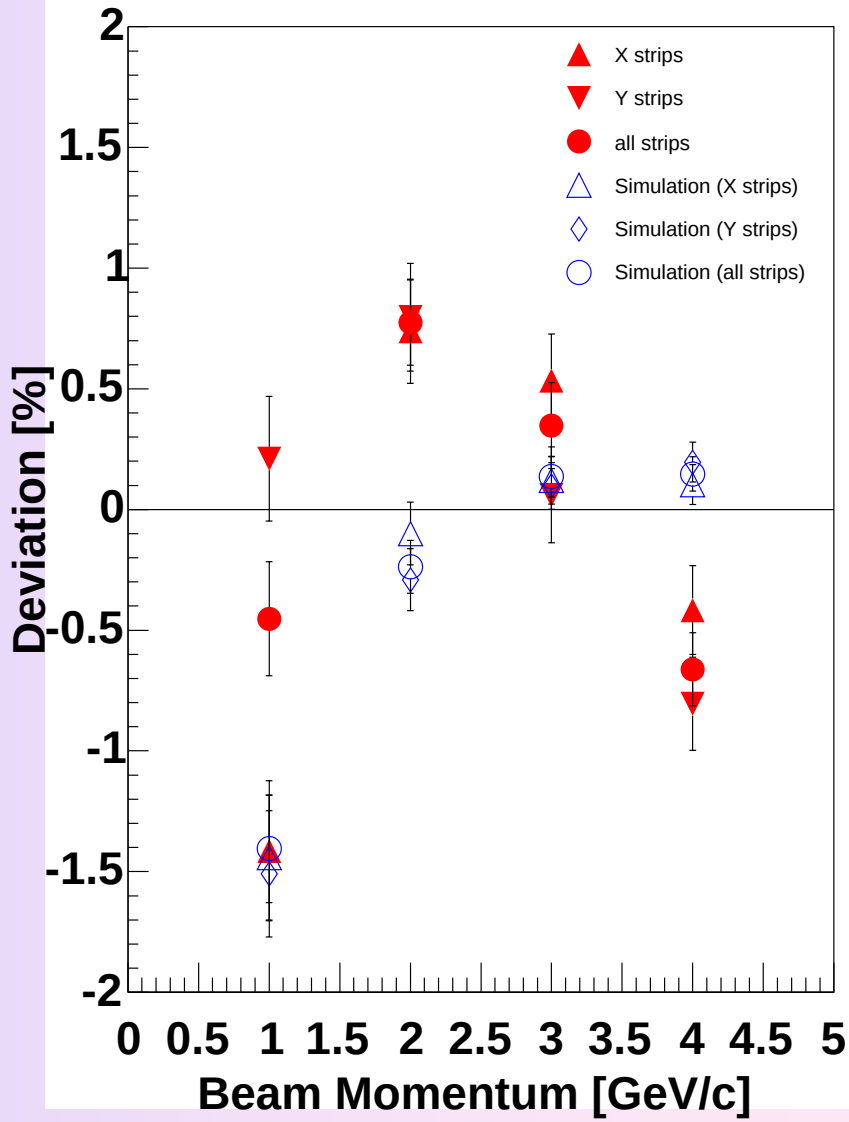
- Calibration uncertainty
- Pedestal uncertainty
- PMT gain drift
- Binning of energy distribution
- Beam momentum bite
  - 0.08%

Uncertainties at 4 GeV (all strips) [%]

	statistical	systematic			
		calibration	pedestal	gain drift	binning
energy	0.09	0.04	0.01	0.10	0.04
resolution	1.5	0.5	0.5	0.6	1.5

Linearity


X strips : 30.39 ± 0.03 MIPs/GeV
Y strips : 30.23 ± 0.03 MIPs/GeV
all strips : 60.68 ± 0.06 MIPs/GeV
Simulation (X strips): 32.78 ± 0.02 MIPs/GeV
Simulation (Y strips): 31.91 ± 0.02 MIPs/GeV
Simulation (all strips): 64.70 ± 0.03 MIPs/GeV
Energy Deposit [MIPs]
Beam Momentum [GeV/c]

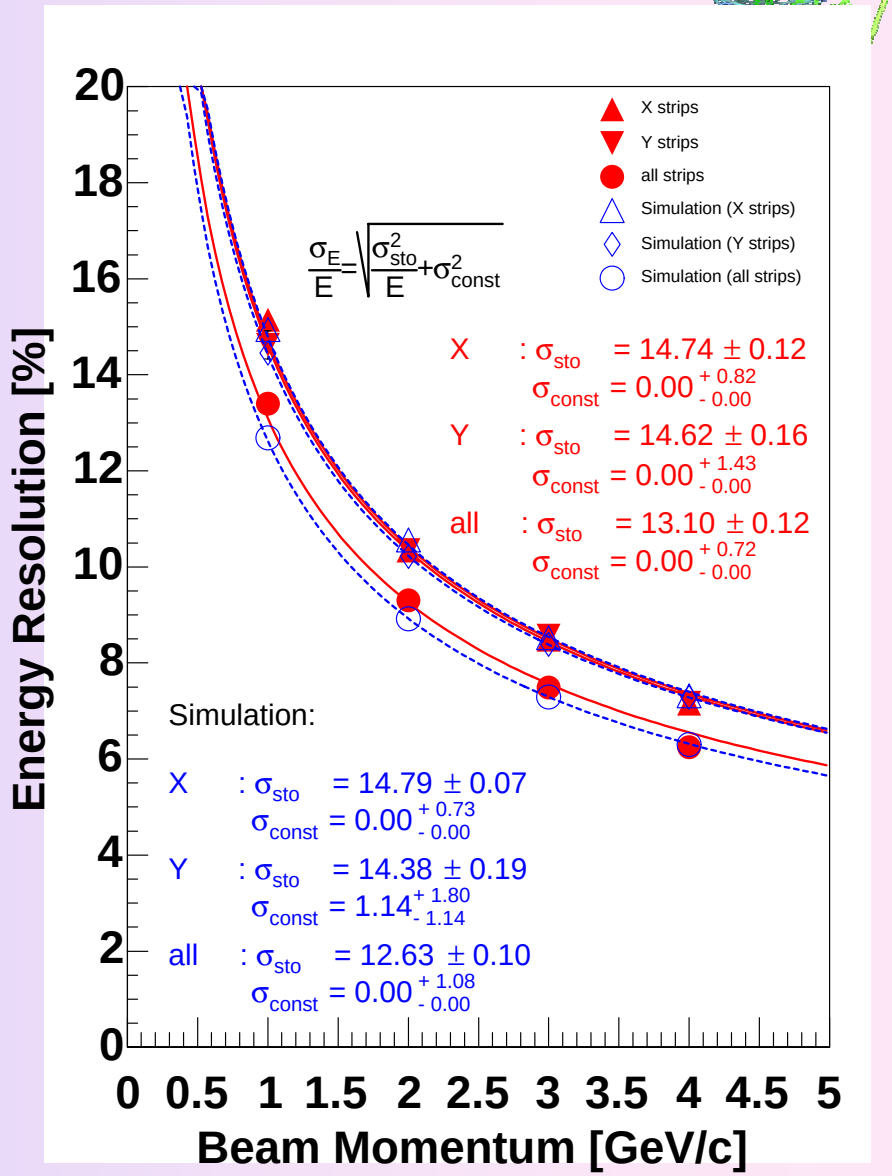

X strips
Y strips
all strips
Simulation (X strips)
Simulation (Y strips)
Simulation (all strips)
Deviation [%]
Beam Momentum [GeV/c]

Energy resolution

- Resolution parameters

$$\frac{\sigma_E}{E} = \frac{\sigma_{stochastic}}{\sqrt{E}} \oplus \sigma_{constant}$$

- All strips
  - Stochastic: $13.10 \pm 0.12\%$
  - Constant: $0.00^{+0.72}_{-0.00}\%$
- Simulation
  - + Photo statistics
  - + Noise effect



Parameter decomposition

- Stochastic term
  - sampling fluctuation
  - track length fluctuation
  - photo statistics
- Constant term
  - calibration uncertainty
  - non-uniformity

-> consistent with zero

- Noise effect
  - pedestal fluctuation

$$\sigma_E = \sigma_{sampling} \oplus \sigma_{track} \oplus \sigma_{photo} \oplus \sigma_{noise}$$ at 1GeV

Parameter decomposition

	all strips	x(y) strips
resolution	13.1%	14.7%
noise effect	4.2%	5.0%
photo statistics (9.2pes/MIP)	4.2%	6.0%
subtracted σ_{noise} and σ_{photo} ($=\sigma_{sampling} \oplus \sigma_{track}$)	11.7%	12.4%
difference = track length fluctuation		
track length $\sigma_{track}^{all} = \sigma_{track}^{x(y)} / \sqrt{2}$	4.2%	6.0%
sampling	10.9%	

Summary

- Scintillator strip-array EMCAL was tested with test beam
  - Good linearity

    1% level
  - Good energy resolution
    - stochastic: $13.10 \pm 0.12\%$
    - constant: $0.00^{+0.72}_{-0.00}\%$
- Granularity -> next speaker