The Performance of the Physics Prototype of the CALICE ScWECAL for ILD

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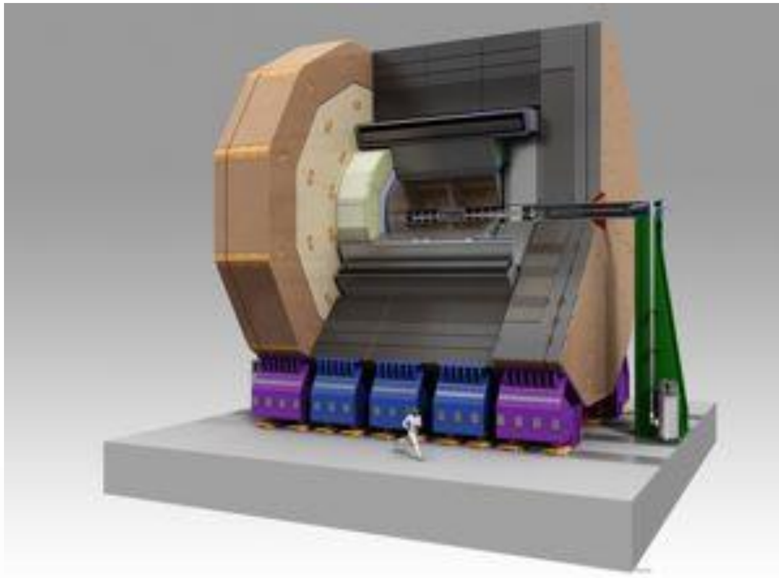
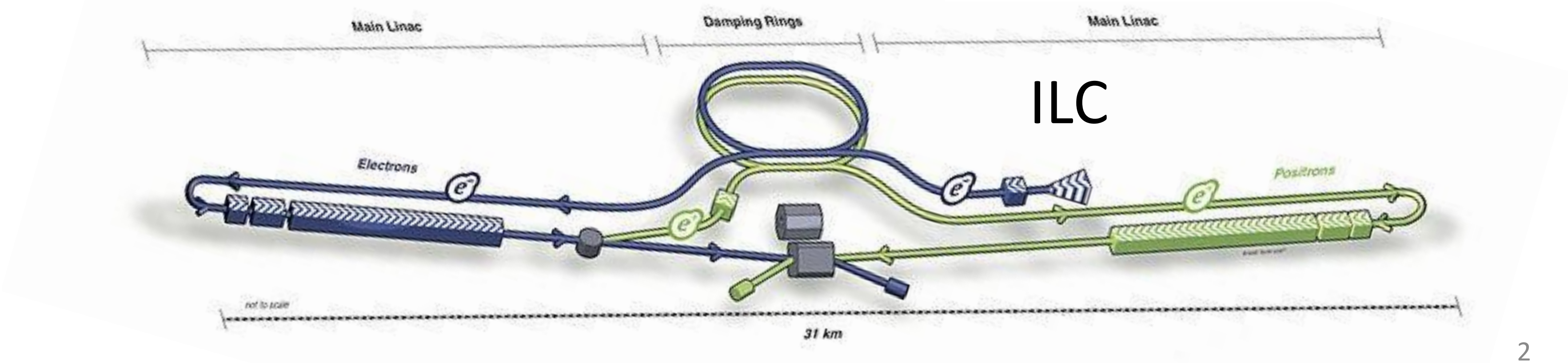
On behalf of CALICE Collaboration

ILC experiment and ILD detector

- ILC : e-e+ linear collider $\sqrt{s}$ = 250 GeV ~ 1 TeV
  - Higgs factory
  - *W* and top mass precise measurement
  - new physics search
- ILD : one of the multi purpose detector for ILC
  - Excellent jet energy measurement using Particle Flow Algorithm
  - Calorimeter is required fine granularity to identify each particle in a jet
    → number of readout channel ~ 10 M

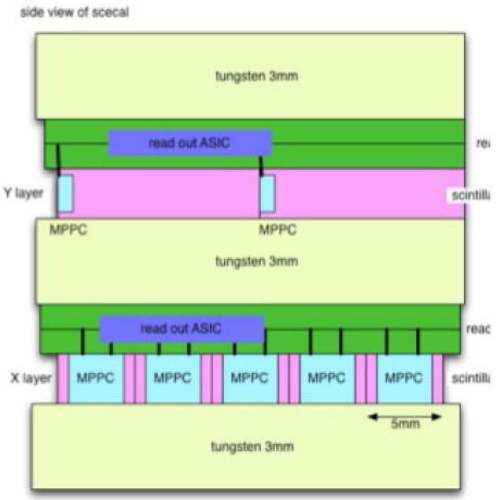
ILD

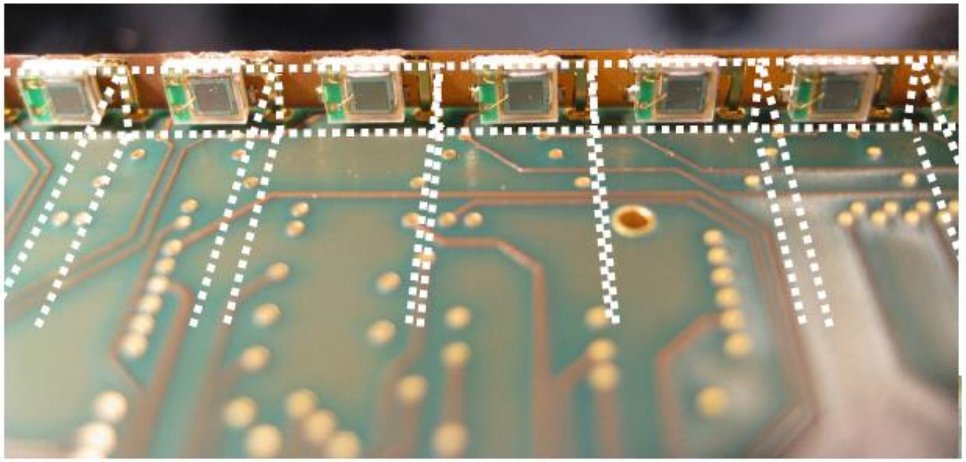




ScWECAL for ILD

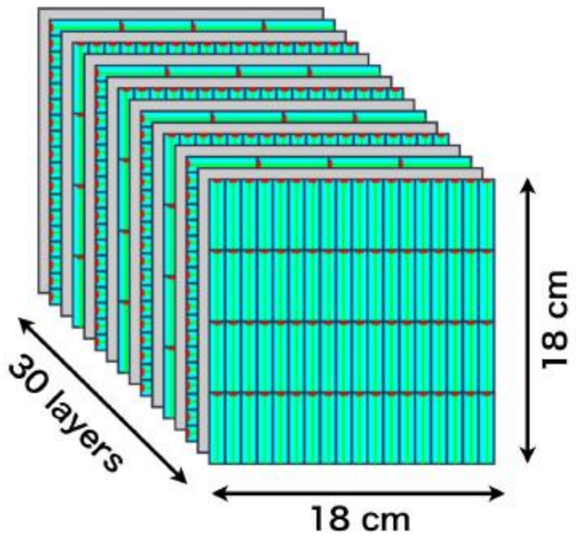
- Development of Pixelated Photon Counter (PPD)
- highly segmented by scintillation counter
- without large dead volume
- ScWECAL : scintillator tungsten electromagnetic calorimeter
- sampling calorimeter with 30 of absorber and sensor layers
- ScWECAL has the potential to reduce the cost of ILD.



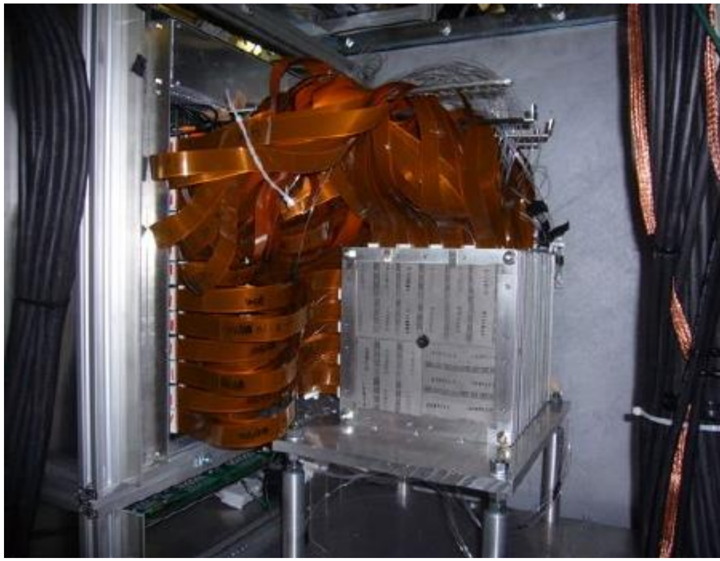


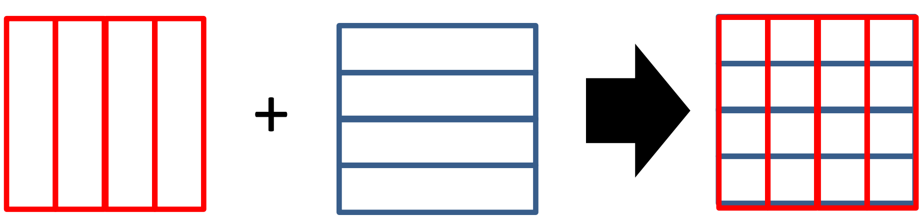
Design of ScWECAL Physics Prototype

- Absorber layer : 3.5mm tungsten
- Active layer :
  $10 \times 45 \times 3 mm^3$ scintillator + WLSF + MPPC
- Cross section : $18 \times 18\ cm^2$
- Depth : 30 layers (~27 cm)
- 2160 channel



We achieve an effective granularity of almost $10 \times 10\ mm^2$ by orthogonally oriented scintillator layers.

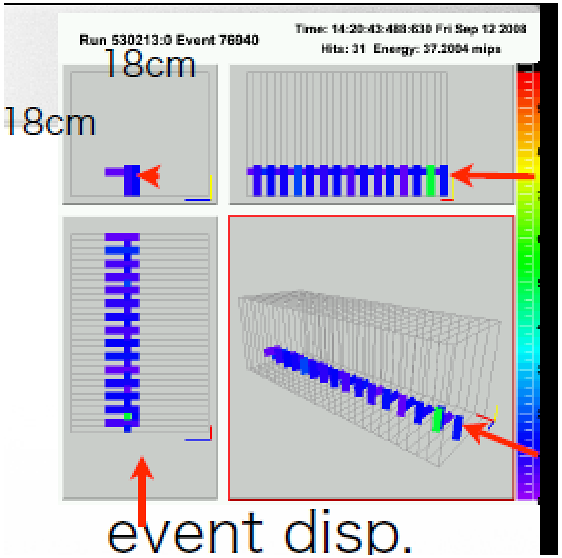


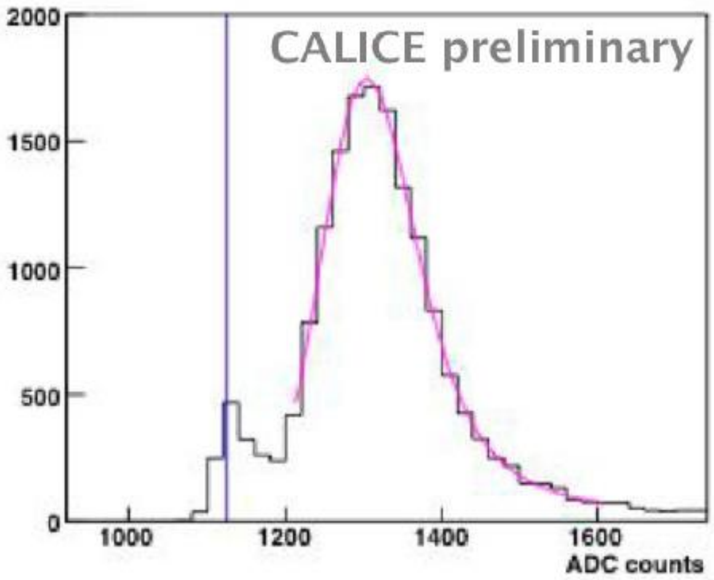


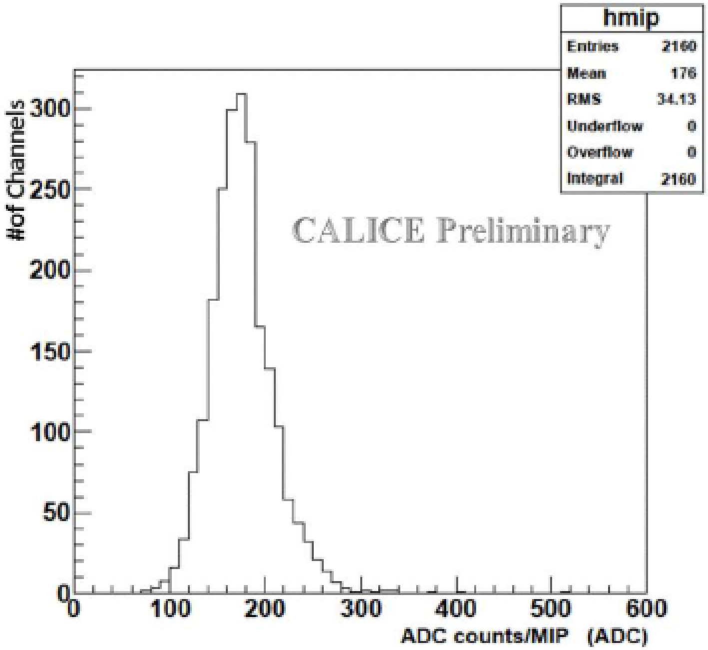
MIP Calibration

MIP calibration with 32 GeV muon.

We fit MIP peak with gaussian convoluted landau function for each channel (2160ch).

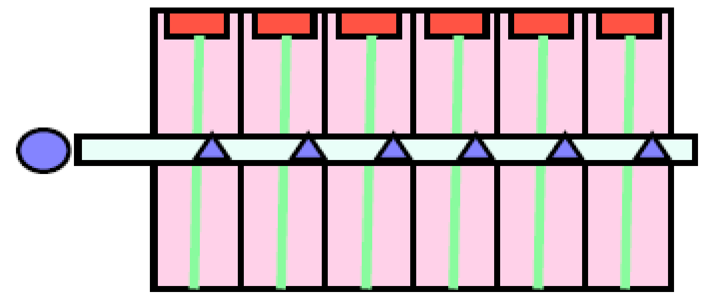




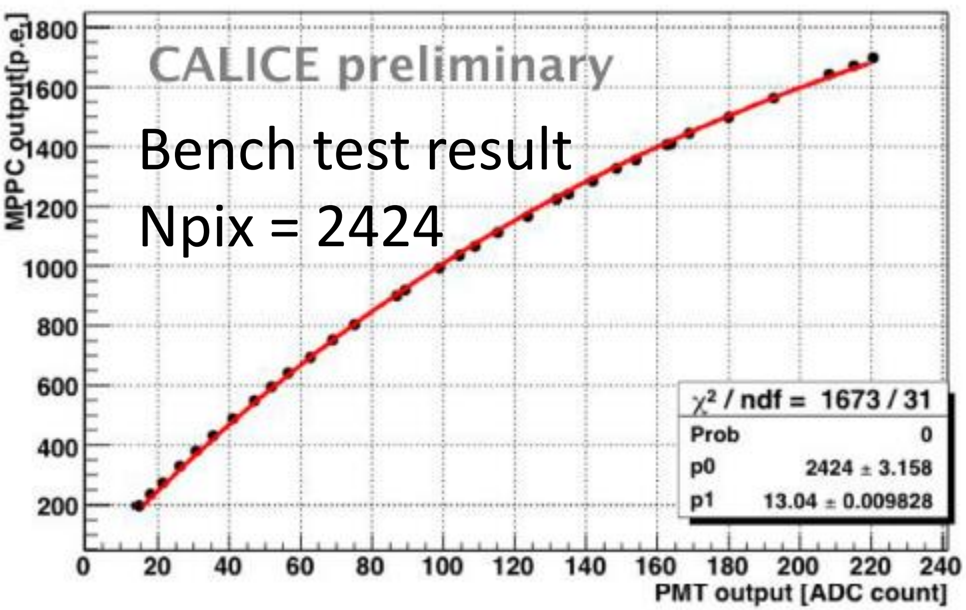


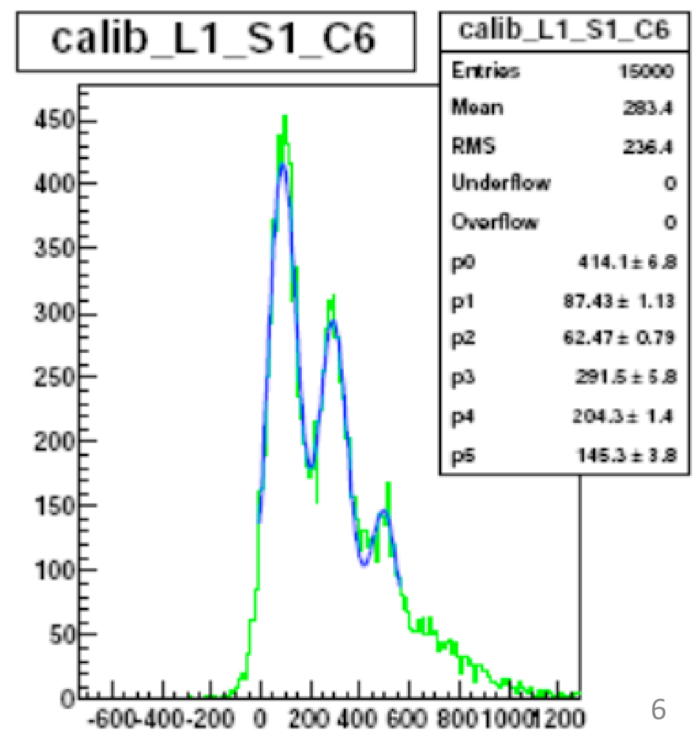
MPPC Gain Monitoring and Saturation Correction

- Gain monitoring with LED + fiber
- MPPC saturation correction



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

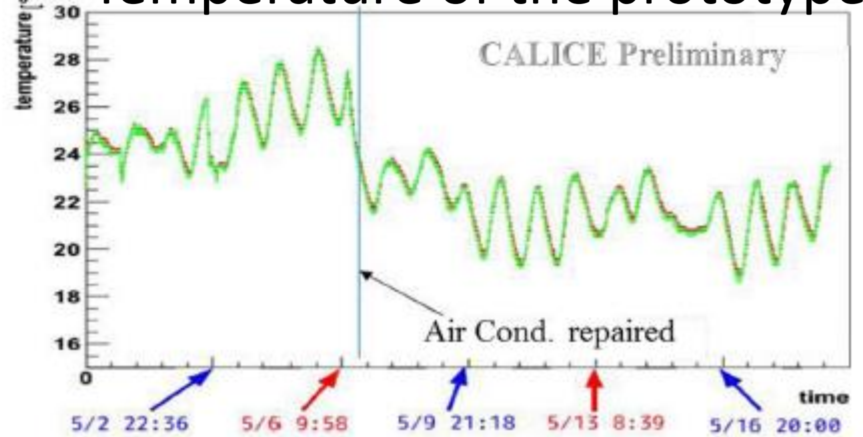




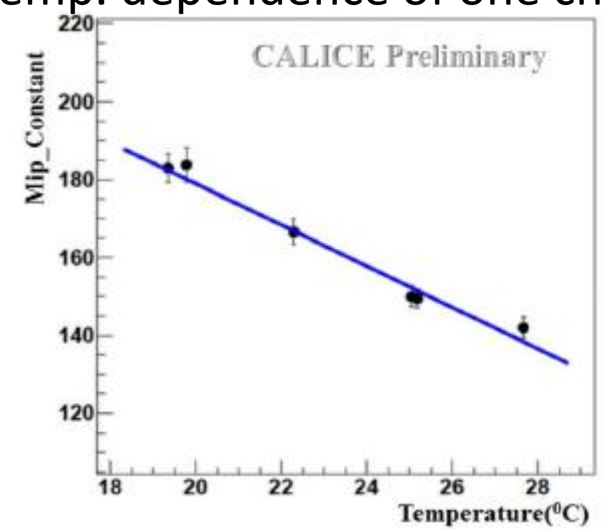
Temperature Correction

- MPPC gain is sensitive for temperature.
- We monitored temperature on the surface of the prototype.
- We fitted MIP response with linear function to estimate gain-temperature dependence.

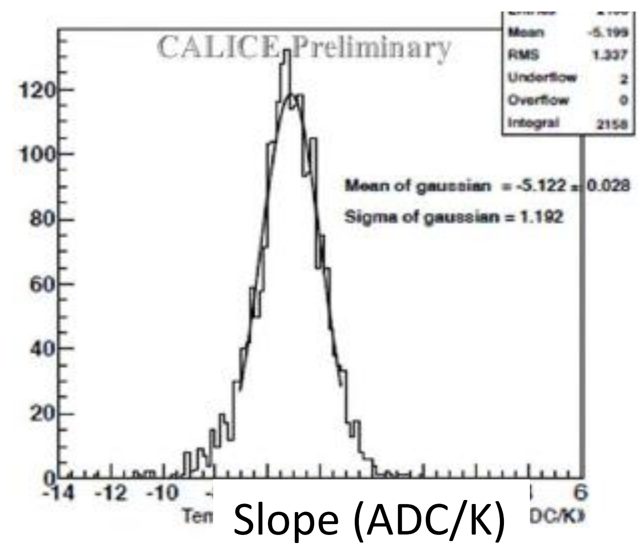
Temperature of the prototype



Temp. dependence of one channel.



Temp. dependence of all channel.



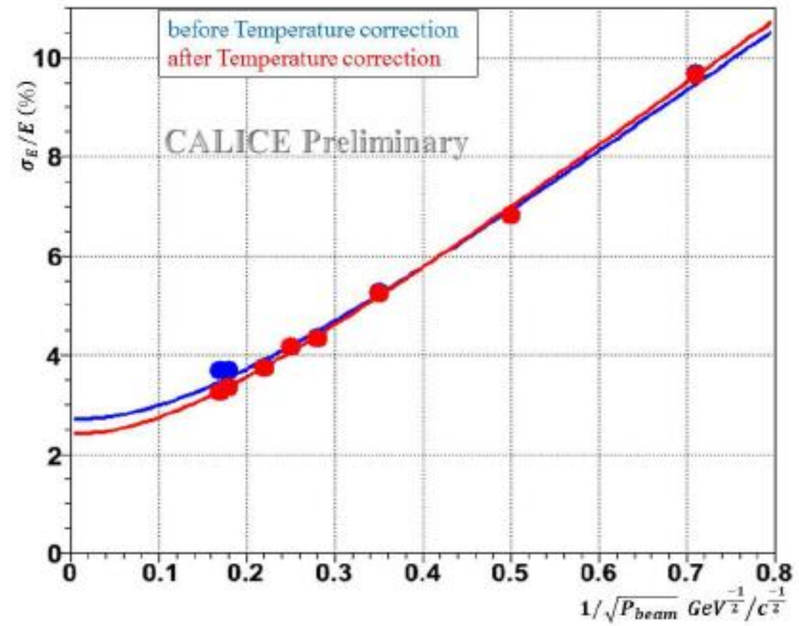
ScWECAL Performance

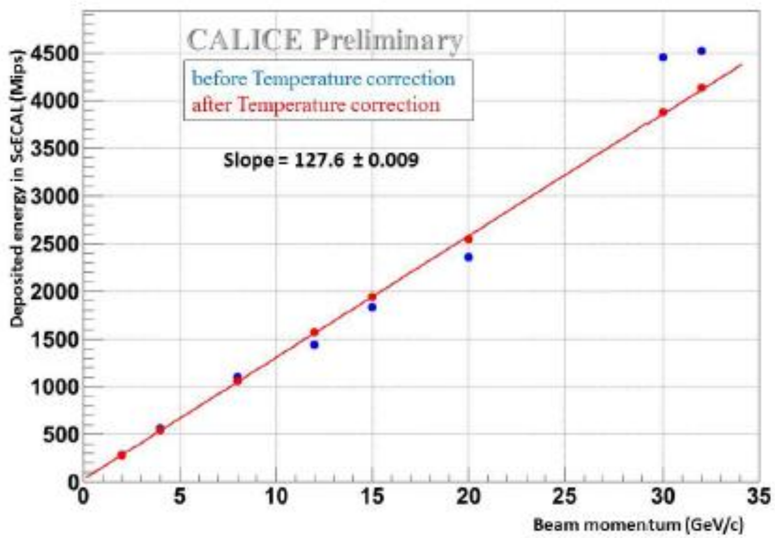
- 2 – 32 GeV e^- beam

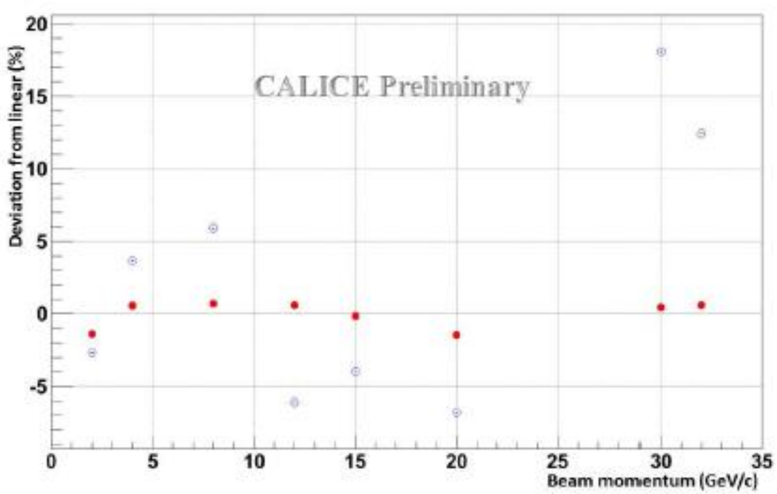
after applied all calibrations and corrections

- Deviation from linear function is less than 2 %.
- Stochastic and constant term of Energy resolution are as followings

- σstoc. = 13.13 ± 0.03(stat.) %
- σconst. = 2.41 ± 0.01 (stat) %







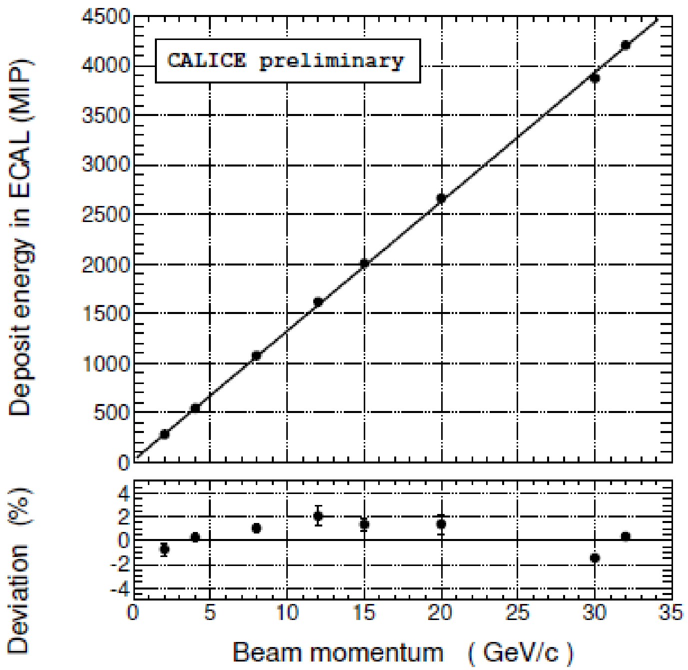
ScWECAL Performance cont.

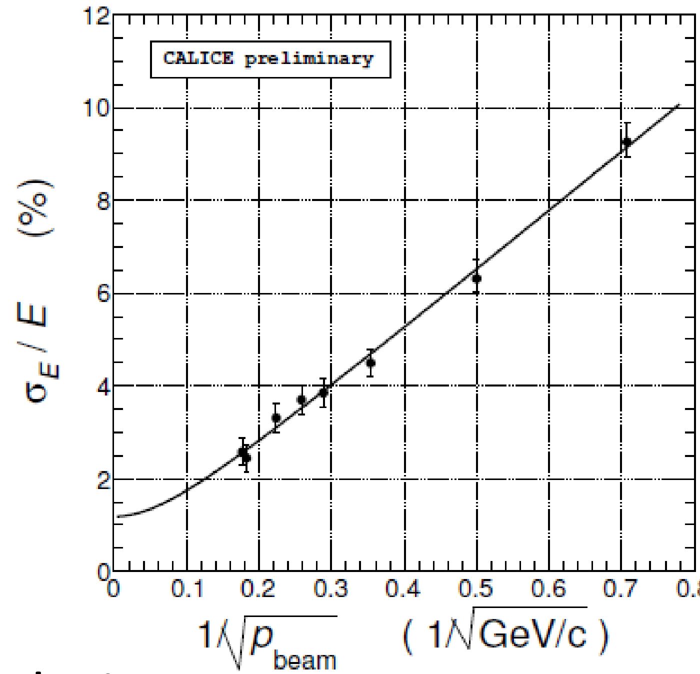
Beam Momentum Spread

Fluctuation of beam momentum at FNAL MT6

2.7 ± 0.3 % for 1-4 GeV, 2.3 ± 0.3 % for > 8 GeV

We Quadratically subtract beam momentum spread





Electron energy resolution

Stoc. = 12.9 ± 0.1(stat.) ± 0.4 (syst.)%

Const. = 1.2± 0.1(stat.) $^{+0.4}_{-1.2}$ (syst.)%

Systematic Uncertainties

These systematic uncertainties are estimated with measured data

Source	$\Delta\sigma_{\text{stochastic}}$ (%)	$\Delta\sigma_{\text{constant}}$ (%)
Beam momentum fluctuation	$\pm$ 0.41	$^{+0.43}_{-1.18}$
Event selection	$< \pm 0.01$	$< \pm 0.01$
ADC-MIP conversion (stat. uncertainty of conversion factor)	$\pm$ 0.08	$\pm$ 0.07
ADC-MIP conversion (uncertainty of temp. correction)	$\pm$ 0.01	$\pm$ 0.01
ADC-photon conversion factor	$< \pm 0.01$	$< \pm 0.01$
Inter calibration constant	$< \pm 0.01$	$< \pm 0.01$
Number of effective pixels of the PPD	$\pm$ 0.07	$\pm$ 0.06

Simulation with Mokka

- We simulated our TB with Mokka which is based on Geant4.

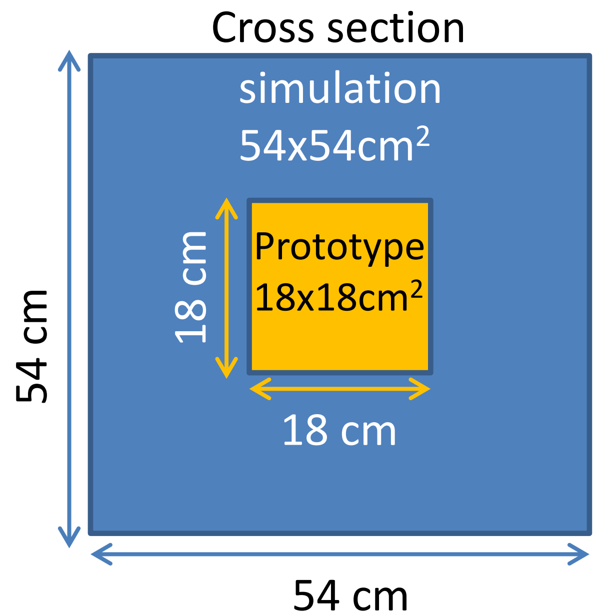
Mokka : mokka-07-06-p02
Geant4 : geant4-09-04-pathc-01

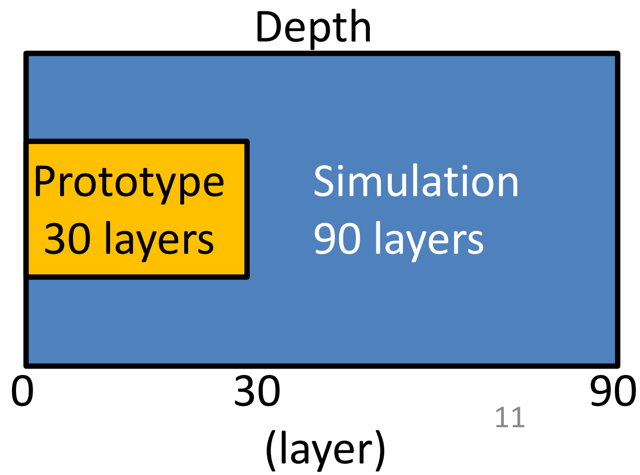
- We reconstruct events with ilcsoft.

Ilcsoft : v01-11
Marlin : v01-00

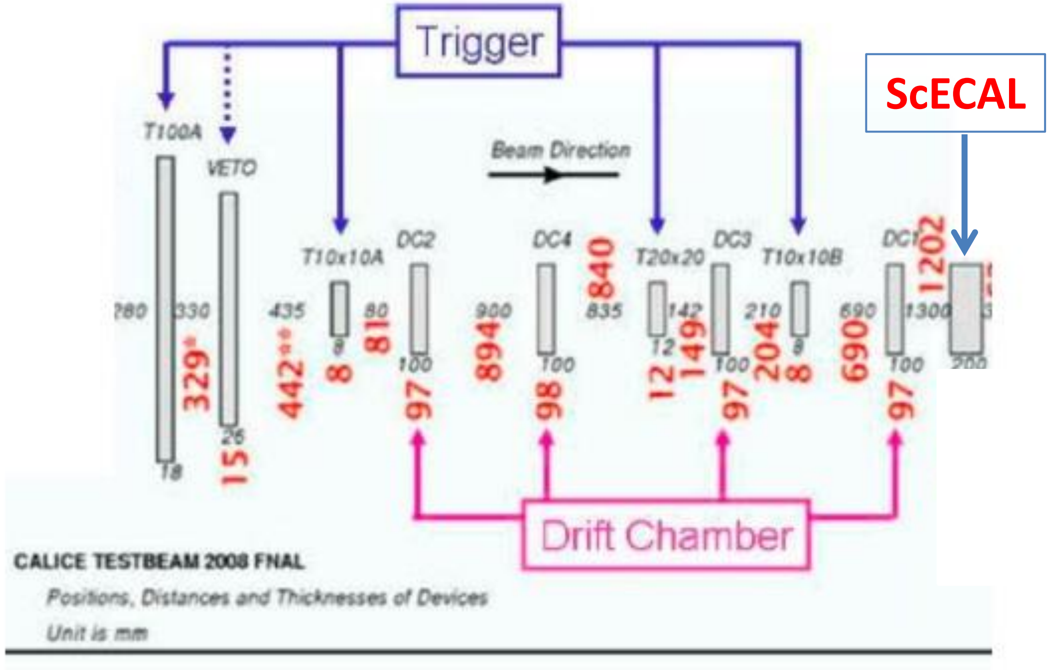
- Detector design in the simulation

- 27 times larger volume than prototype
- 90 layers, $54x54cm^2$
- scintillator size $10x45x3\ mm^3$
- 2160 ch in prototype volume
- 58320 ch in simulation volume





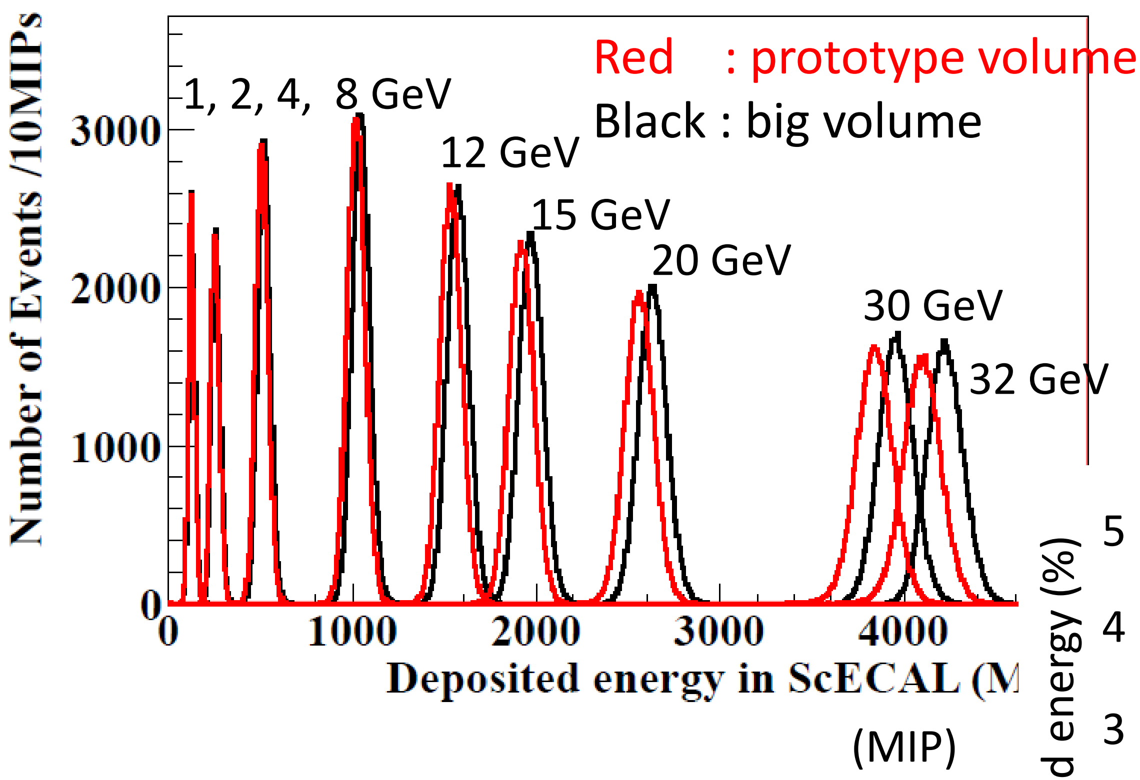
Materials in the Simulation



- 4 trigger and 1 veto scintillators
- 4 drift chambers
- ScWECAL ($54x54cm^2x90$layers)
  - Absorber : W+C+Co+Cr 3.49mm , 14.25 g/cm^3
  - Active layer : scintillator 10x45x3 mm^3
- No HCAL

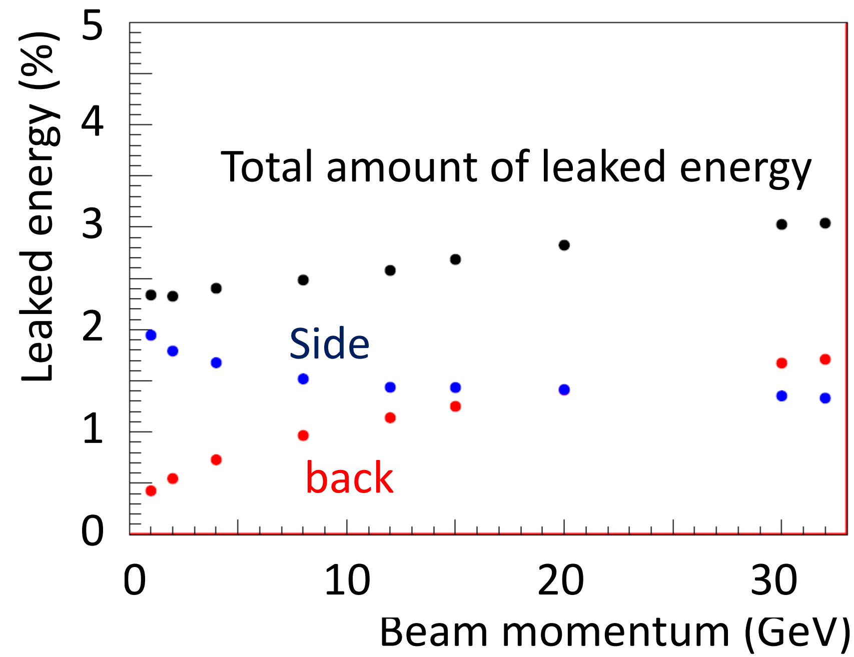
Energy Leakage

Energy spectrum



2.3 – 3 % of total energy leak outside of the prototype volume

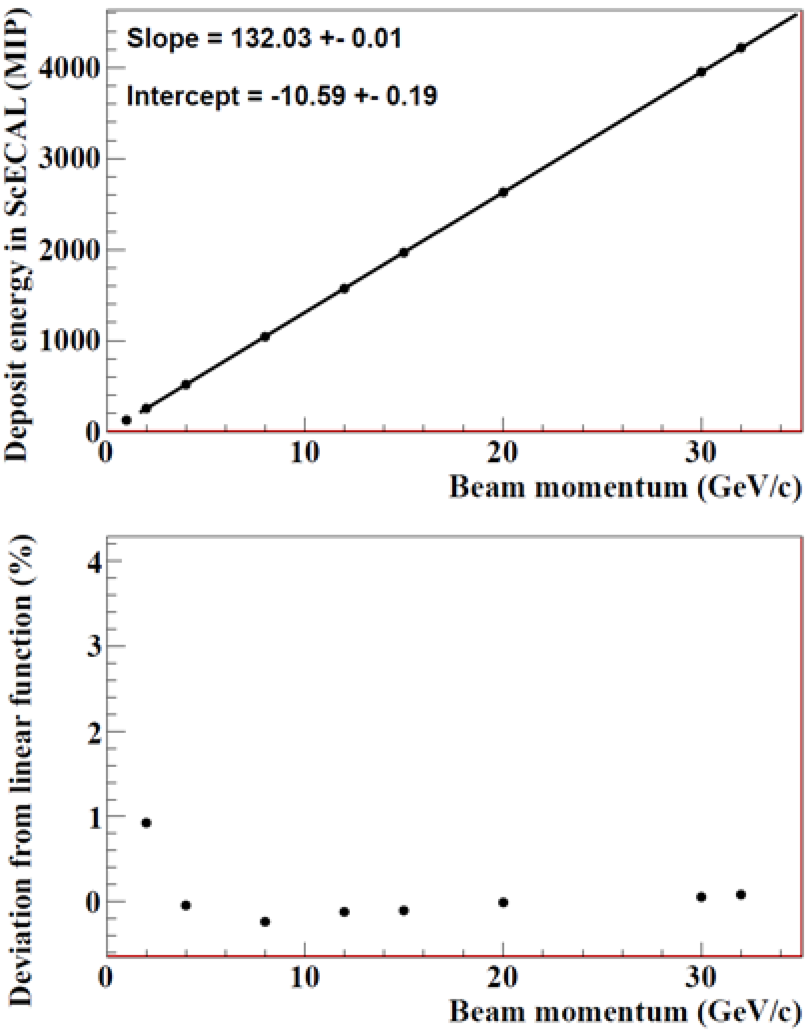
Leakage/total energy (%)



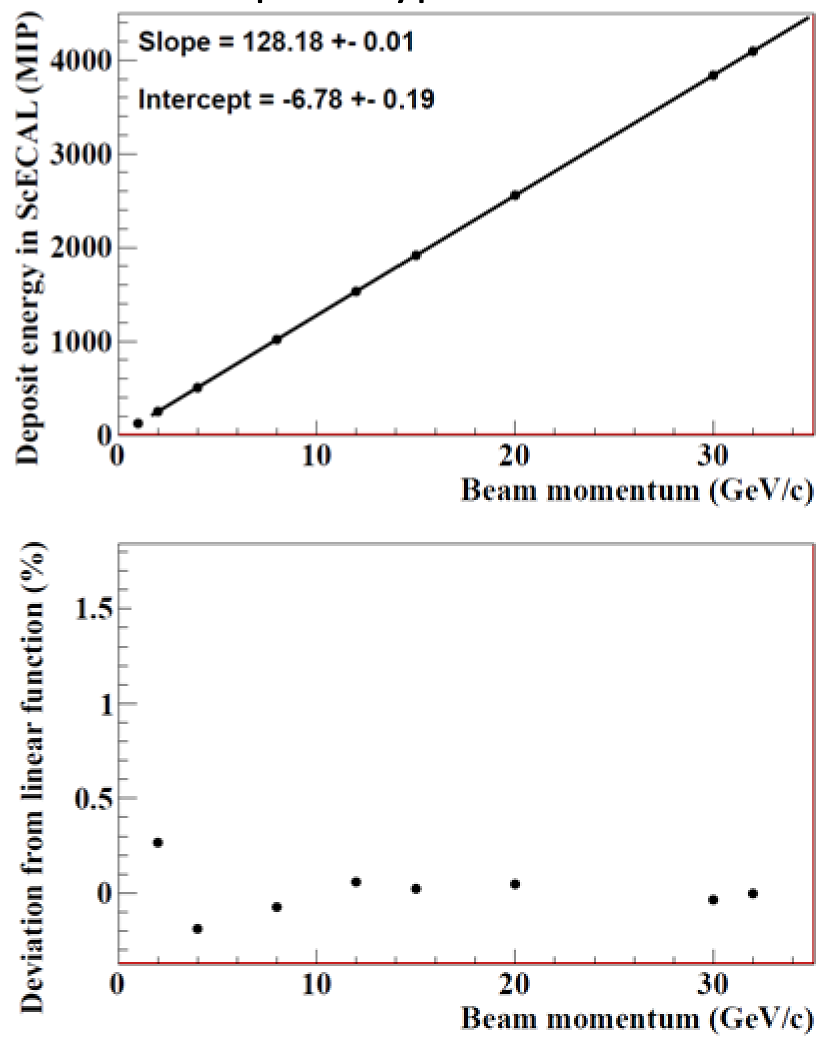
ScWECAL Response

- Energy leakage reduce 3% of slope of linear function
- for each energy deviation is within 1%

Large volume

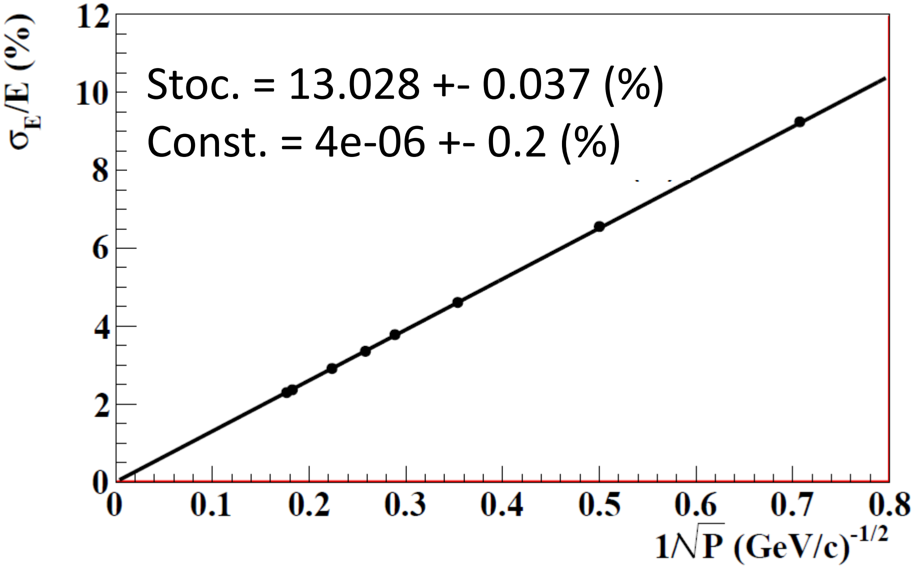


prototype volume

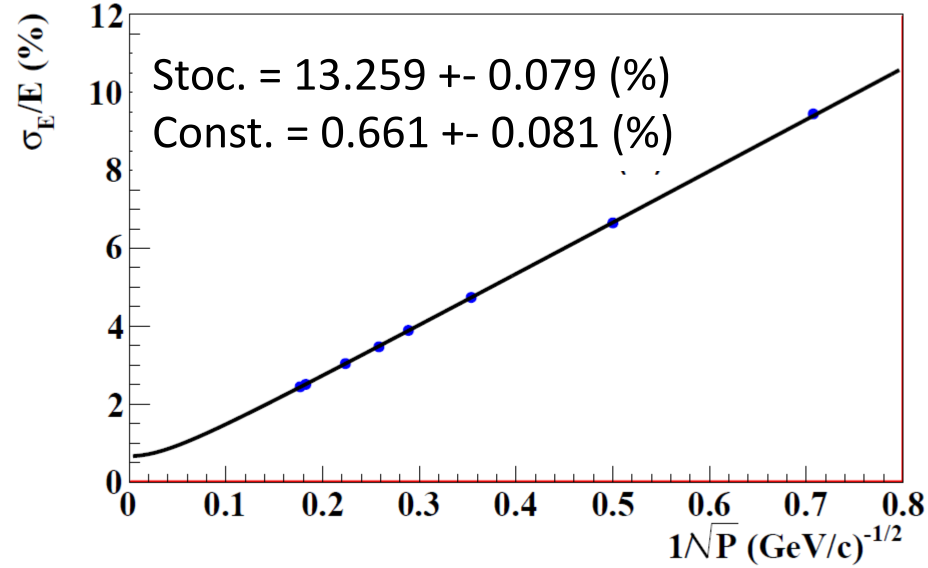


Energy Resolution

Large Volume



Prototype Volume



~ 3% energy leakage makes 0.66% constant term of energy resolution.

Stochastic term is also increase ~ 0.2%

We estimate systematic uncertainty with leakage $\pm$ 1 sigma

+ 1σ : const. = 0.676, -1 σ = 0.657

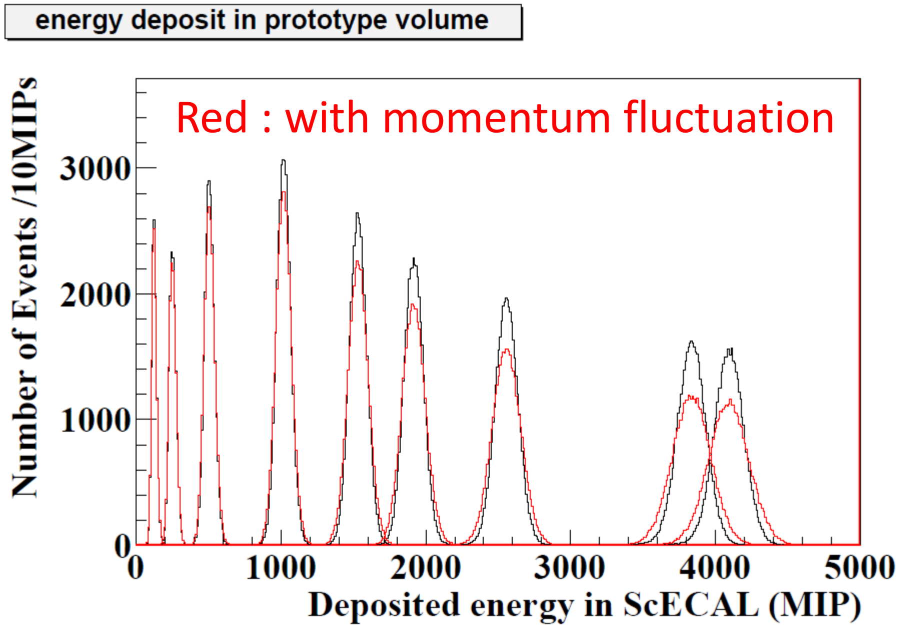
Δconst $\pm$ 0.02%

Const = 0.66$\pm$0.08 $\pm$ 0.02 % ($\Delta\sigma_{const.}$ is dominated by fitting error)

Momentum Spread

Fluctuation of beam momentum at FNAL MT6

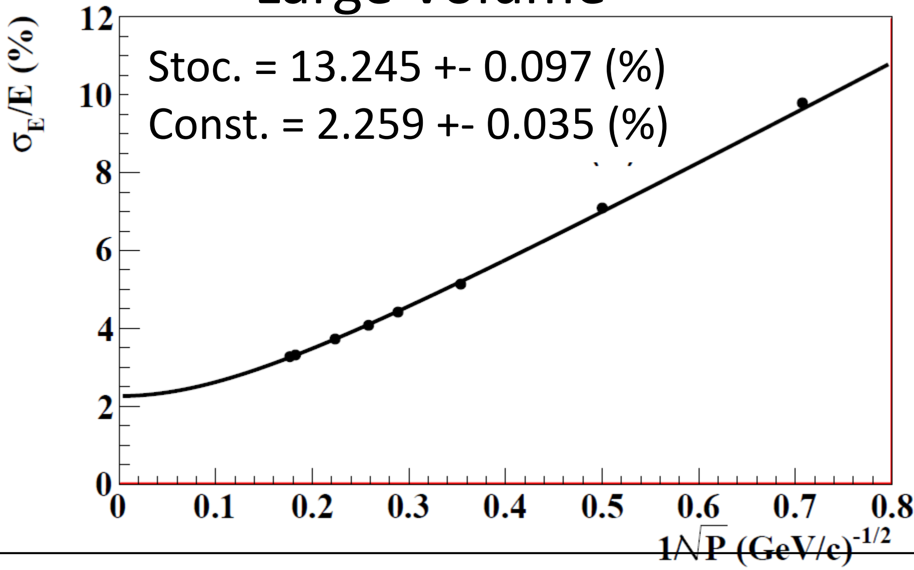
- 2.7 $\pm$ 0.3 % 1-4 GeV
- 2.3 $\pm$ 0.3 % > 8 GeV



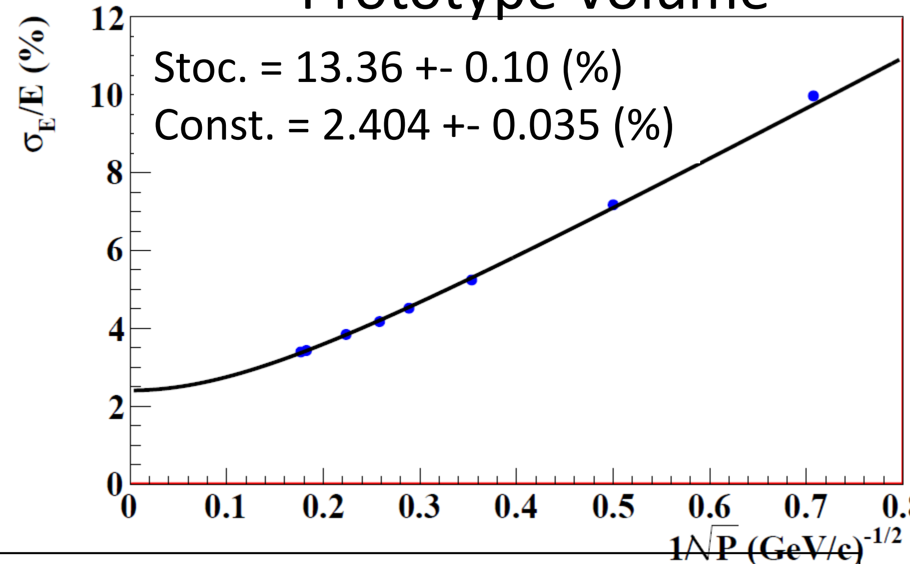
Momentum spread makes broader shape , but does not change mean value.

Energy resolution

Large Volume



Prototype Volume

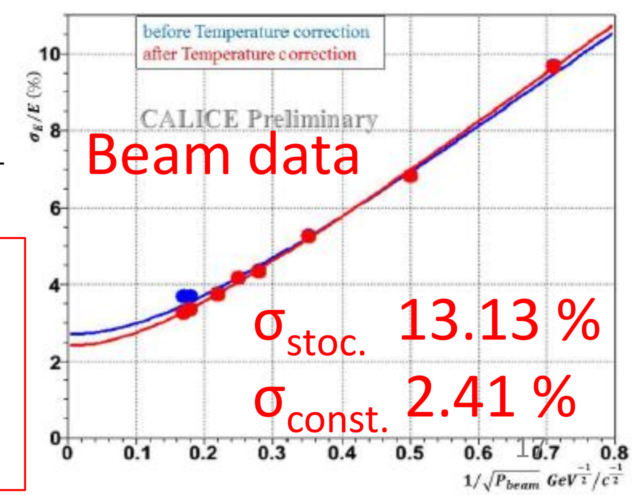


Momentum spread makes 2.26 % constant term

We estimate systematic uncertainty with P spread $\pm$ 1 sigma

+ 1σ : const. = 2.56%, -1 σ const. = 1.94%

const. = 2.26 $\pm$ 0.04 (stat.) $^{+0.30}_{-0.33}$ (syst.)%



Estimated energy resolution (P spread & E leak)

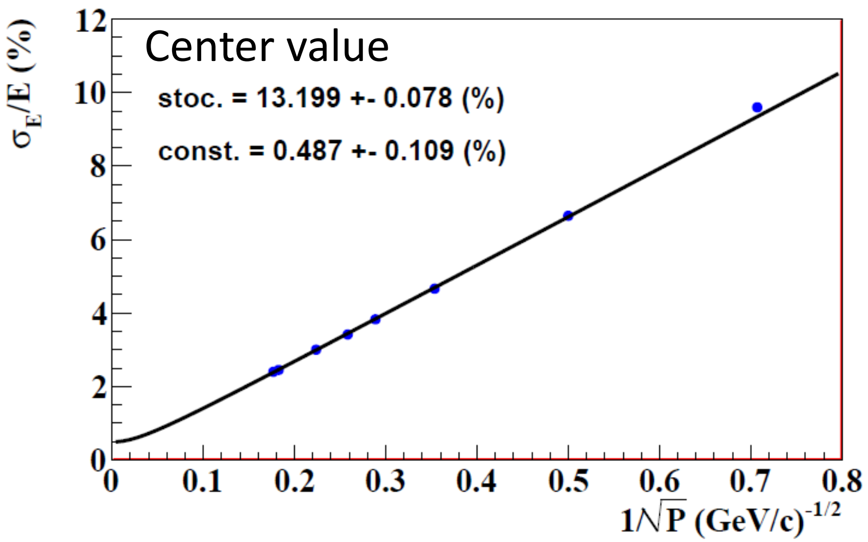
Stoc. = 13.36 $\pm$ 0.1 (stat.) $\pm$ 0.45 (syst.)%

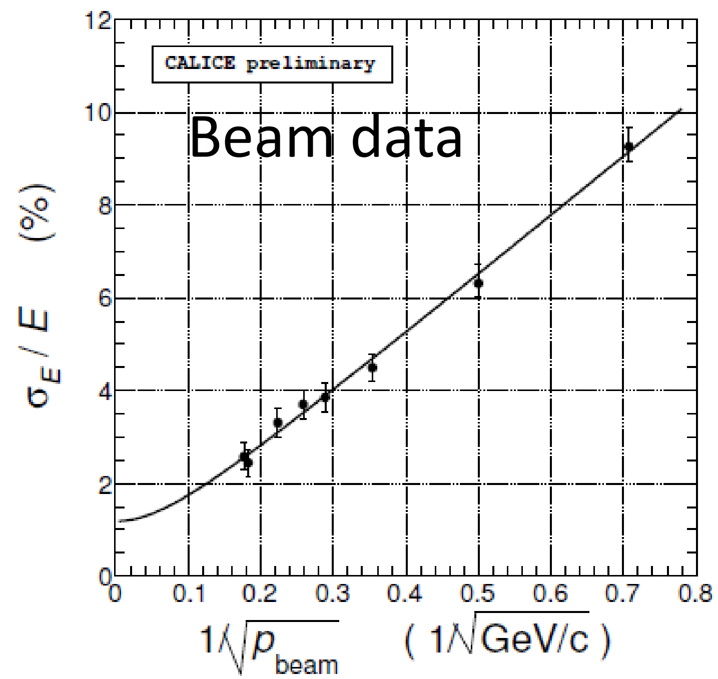
Const. = 2.40 $\pm$ 0.09 (stat.) $^{+0.30}_{-0.33}$ (syst.) %

Energy resolution
Same Method as beam data analysis

We quadratically subtract beam momentum spread from measured width

Simulation Prototype Volume





$13.20 \pm 0.08\,(\text{stat.}) \pm 0.45\,(\text{syst.})$

$0.49 \pm 0.1(\text{stat.})\,^{+0.80}_{-0.49}\,(\text{syst.})\%$

$12.9 \pm 0.1(\text{stat.}) \pm 0.4\,(\text{syst.})\%$

$1.2 \pm 0.1(\text{stat.})\,^{+0.4}_{-1.2}\,(\text{syst.})\%$

Simulation result is in good agreement with Beam data result.

Conclusion and plans

- ScWECAL physics prototype
  - linear response for 2 – 32 GeV electron (deviation < 2%)
  - Good energy resolution
- Simulation result is in good agreement with beam data result.
  - We understood the ScWECAL prototype well
- Feasibility of ScWECAL is demonstrated.

Next step

- We will publish the TB result in this year.
- First technological prototype study is in progress.
- Second technological prototype will be tested with e+ or e- beam in this year
  - Multilayer readout, power pulsing
- R&D of scintillator + MPPC readout