Energy reconstruction in the combined SiW ECAL and AHCAL system at CERN and Fermilab

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Analysis Goal

Combined setup:

- SiW ECAL
- AHCAL
- TCMT

Datasets:

- CERN 2007, 10-80 GeV
- FNAL 2008, 2-60 GeV

- Following CAN-015 note for CERN test beam 10-80 GeV.
- Energy reconstruction and software compensation in the energy range 4 - 80 GeV.
- PhD and a publication.

Calibration for Energy Reconstruction

Weights (CERN Calibration)

- $\omega_{ecal} = 0.00496$, previous analysis (0.00490)
- $\omega_{hcal} = 0.02781$, JINST 7 P09017 (0.02813)

SiW ECAL:

- layers 1-10 have 1.4 mm width $\rightarrow \omega_{ecal}$
- layers 11-20 have 2.8 mm width $\rightarrow \omega_{ecal} \cdot 2$
- layers 21-30 have 4.2 mm width $\rightarrow \omega_{ecal} \cdot 3$

AHCAL:

- layers 1-38 have 5 mm width $\rightarrow \omega_{hcal}$

TCMT:

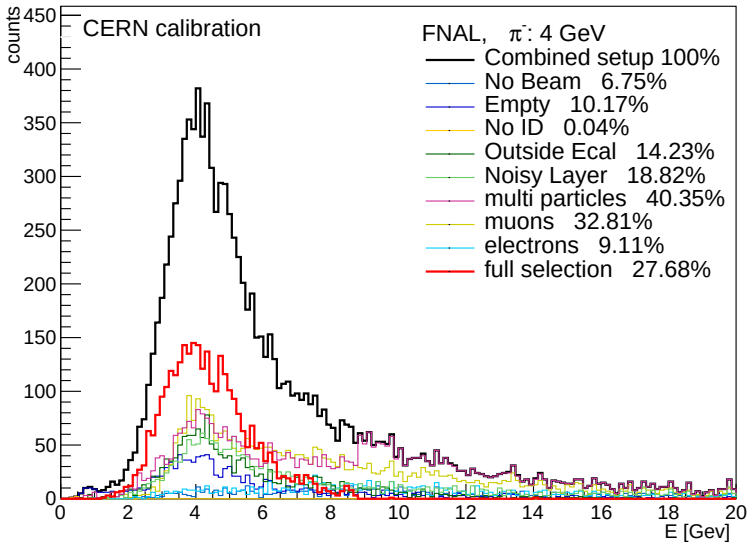
- layers 1-8 have 19 mm $\rightarrow \omega_{hcal}$
- layers 9-16 have 105 mm $\rightarrow \omega_{hcal} \cdot 5$

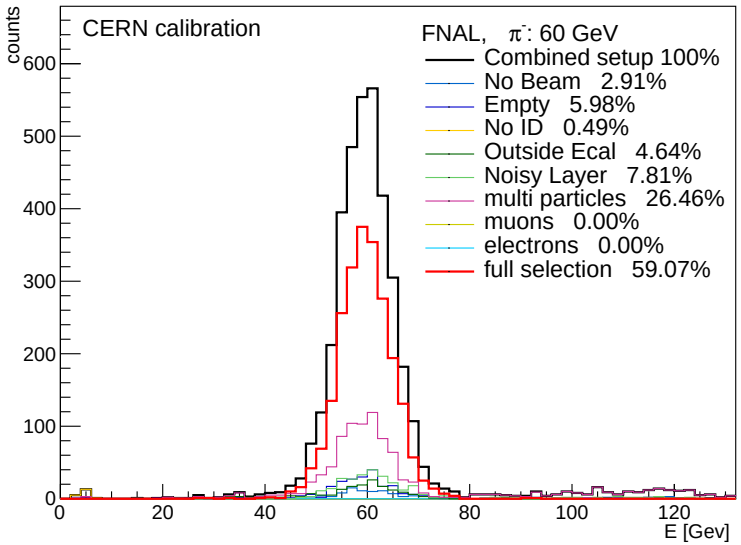
Event Selection for combined System (1)

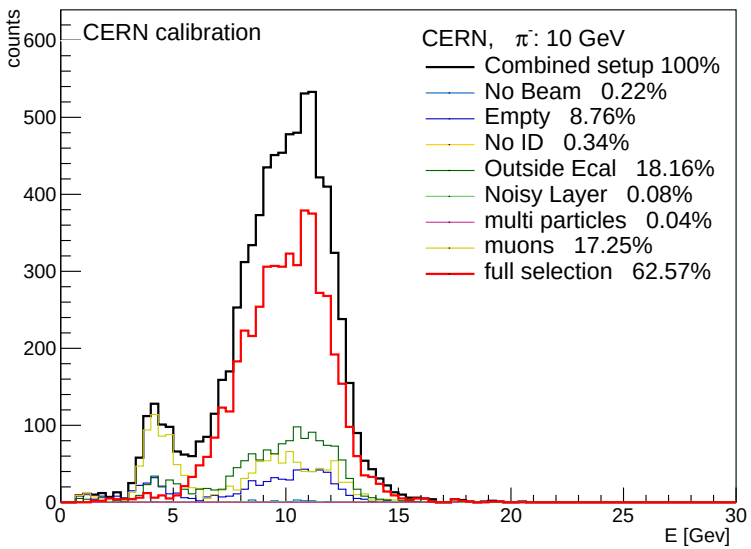
First cut-list:

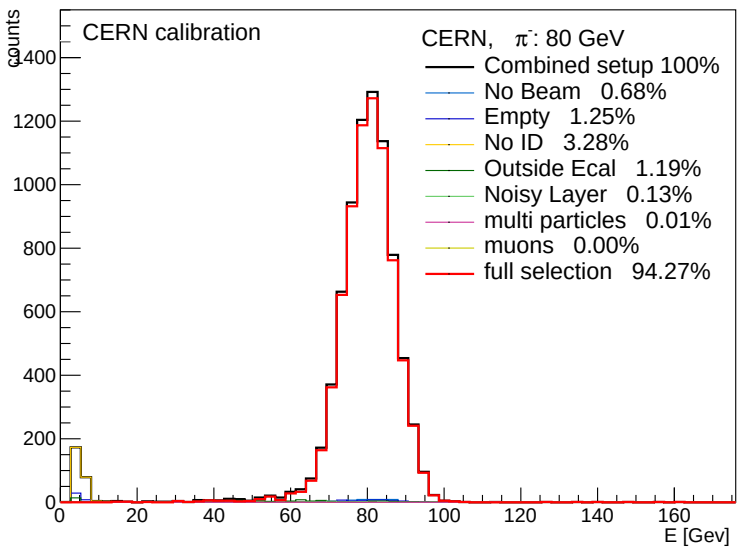
- Beam trigger
- Empty events: $n_{hits}^{ECAL} < 25$ or $n_{hits}^{HCAL} < 11$
- Not identified events: $E_{reco} < 0.15 E_{beam}$
- Ecal Fail:
  - noisy layers
  - hits outside ECAL center
- Multi-particle events:
  - $E_{reco} > (E_{beam} + 2.4\sqrt{E_{beam}})$
  - MULTIPLICITY COUNTER
- Muons cut: hits in TCMT>11 (for $E_{beam} < 60$)
- Electron cut: Cherenkov counter

First cut-list (independent cuts)



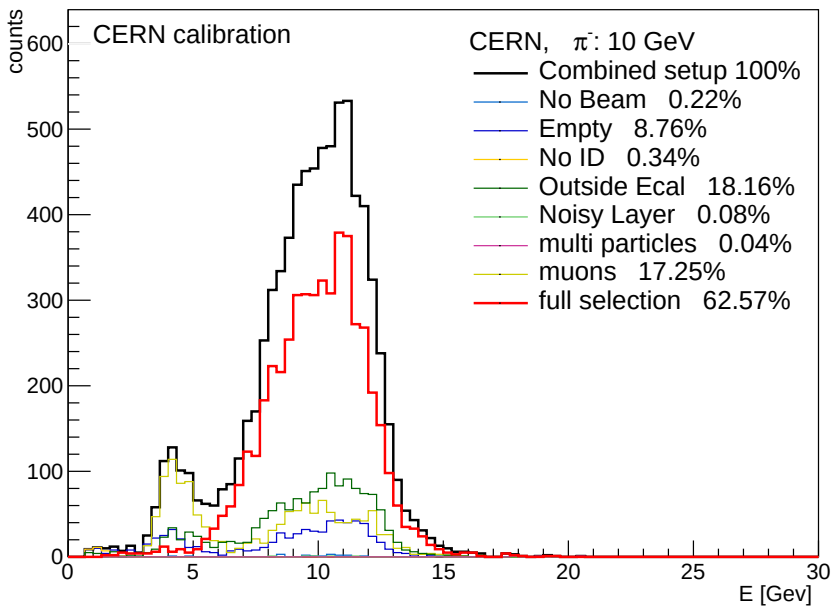


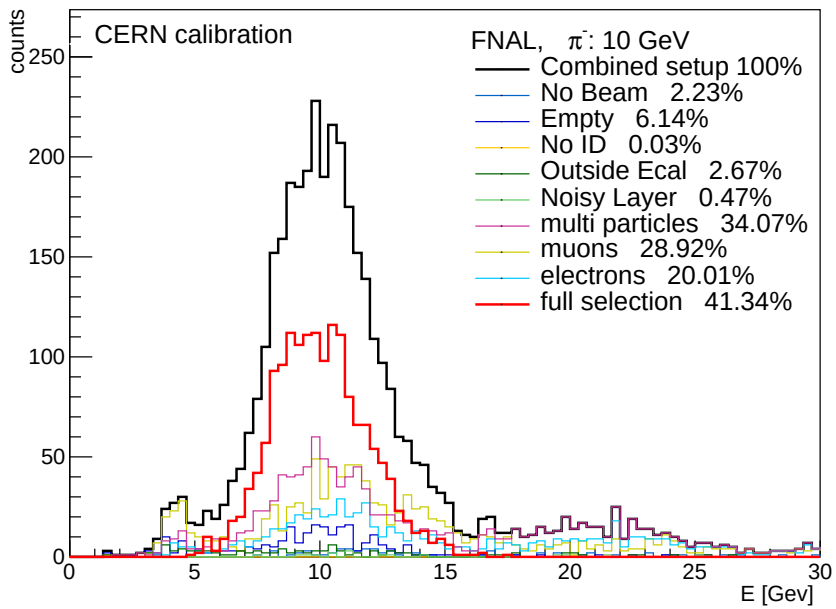




First cut-list (independent cuts) 10 GeV

cut	CERN [%]	FNAL [%]
selected	62.44	41.28
no beam	0.21	2.22
empty	8.76	6.13
no id	0.39	0.05
outside Ecal	18.15	2.66
noisy layer	0.07	0.46
multi	0.02	33.91
muons	17.25	28.91
electrons (Cherenkov)		20.01

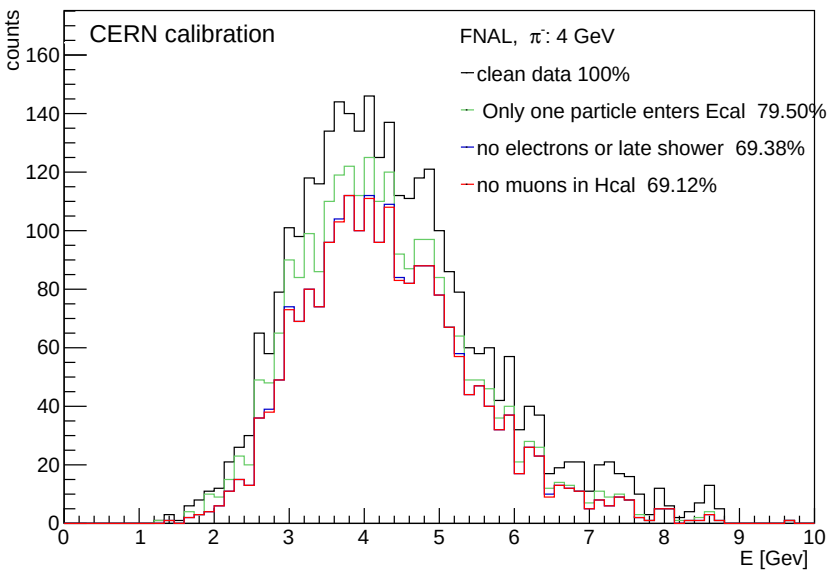


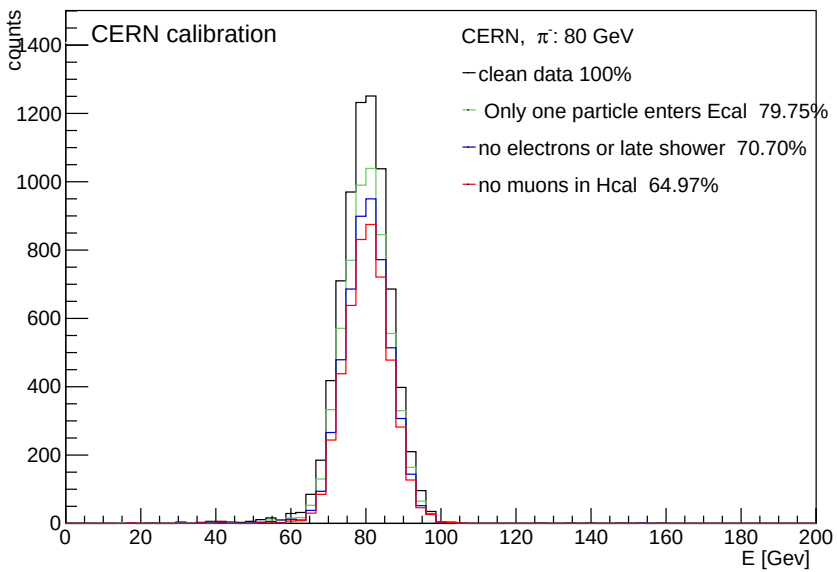


Event Selection for combined System (2)

Second cut-list:

- Only one particle enters Ecal
- Electron cut: removing events with FHI<6
- Late Shower removing events with FHI>55
- Muon cut: removing events without an interaction



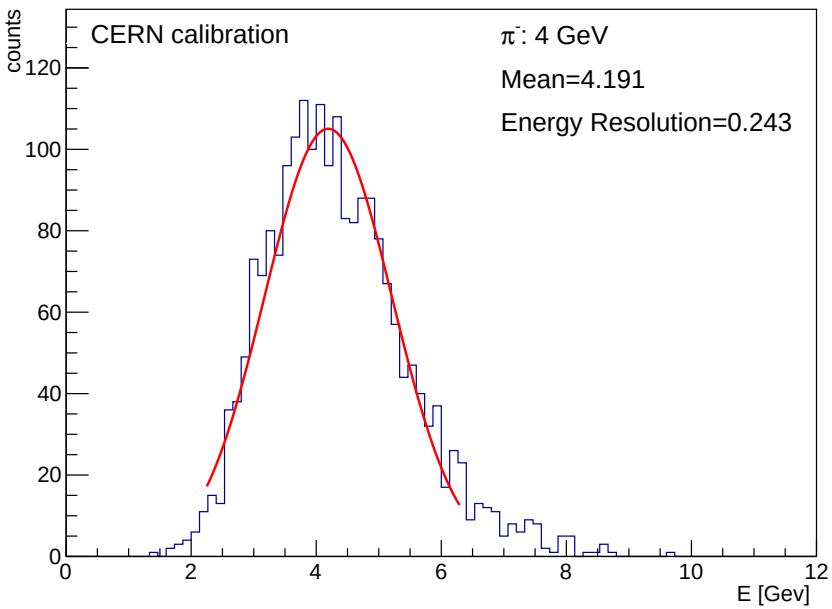


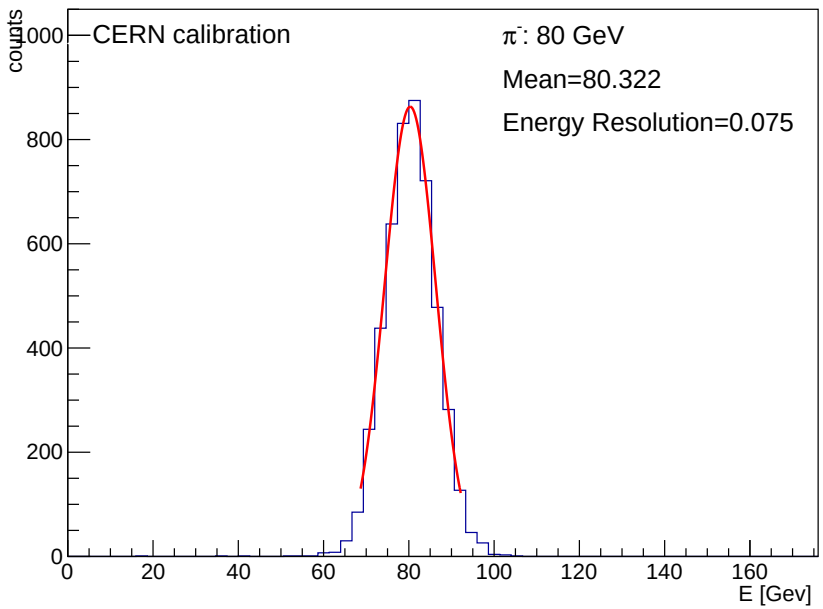
Fit

Gaussian fit in two stages:

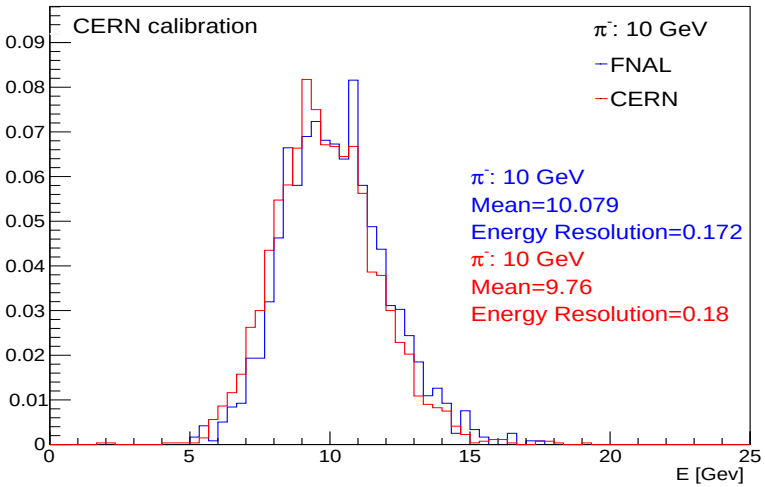
- full range $\Longrightarrow \mu$, σ
- interval of $\pm 2\sigma$ around $\mu \Longrightarrow E_{reco}$, σ_{reco}

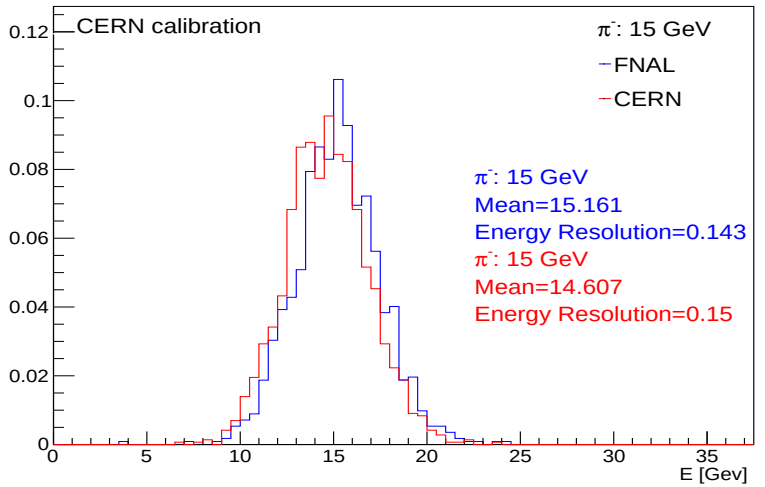
Energy resolution: $\frac{\sigma_{reco}}{E_{reco}}$

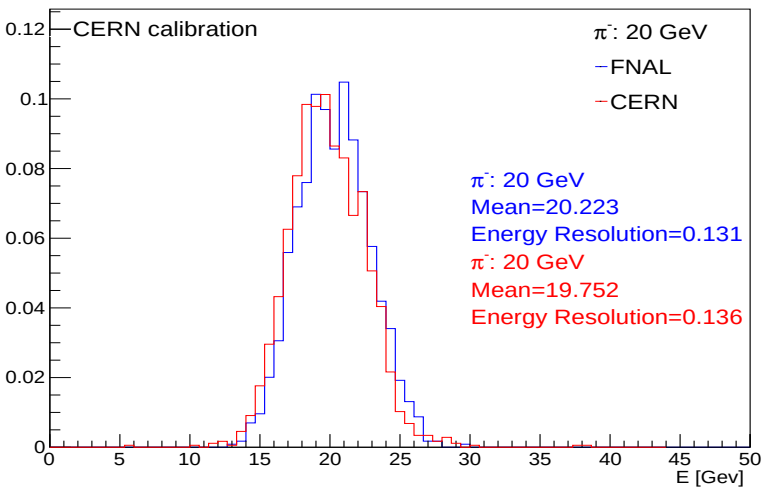


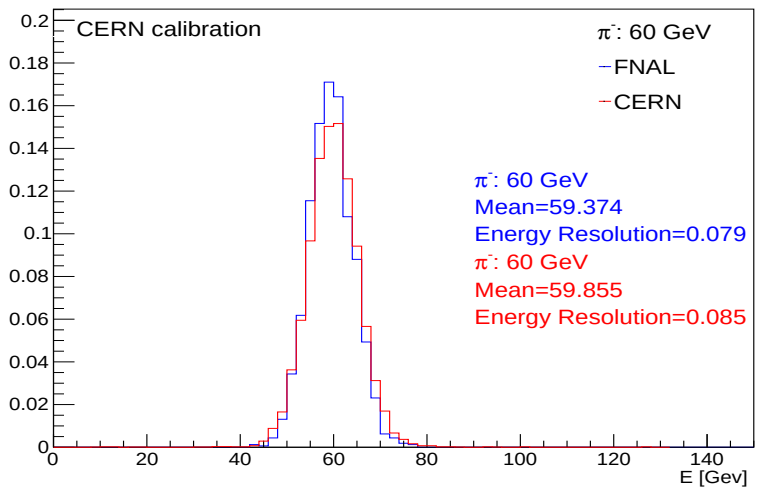


CERN vs FNAL



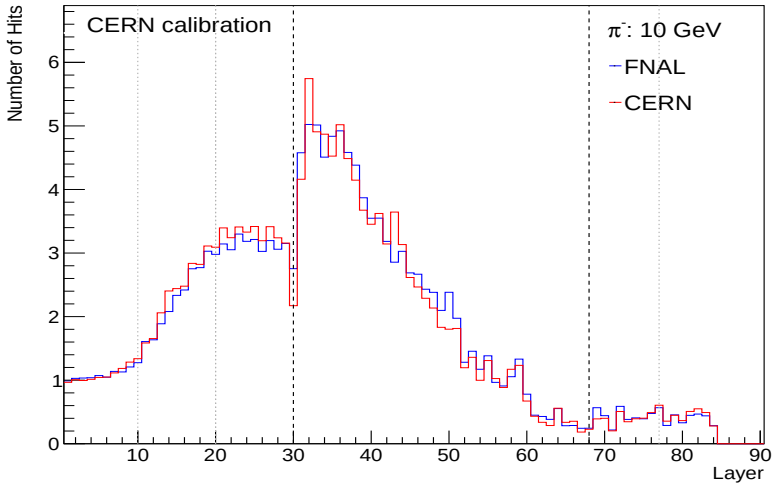


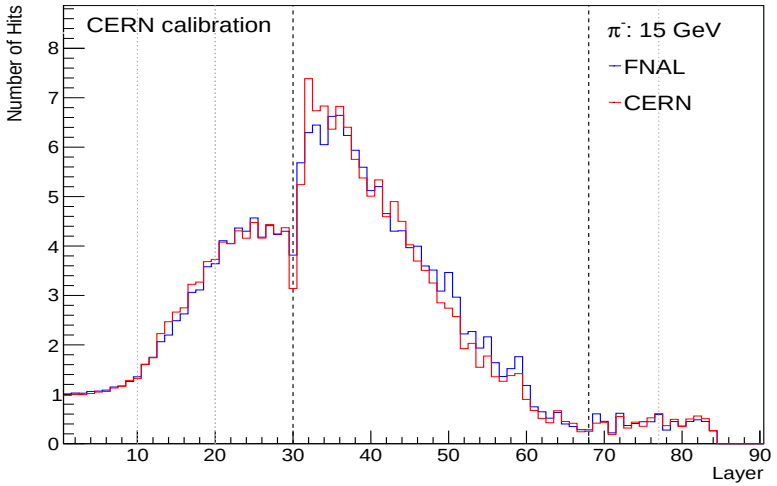


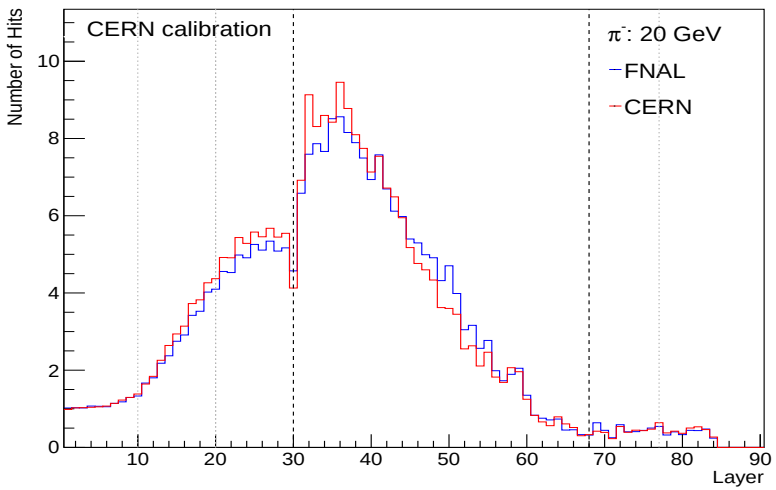


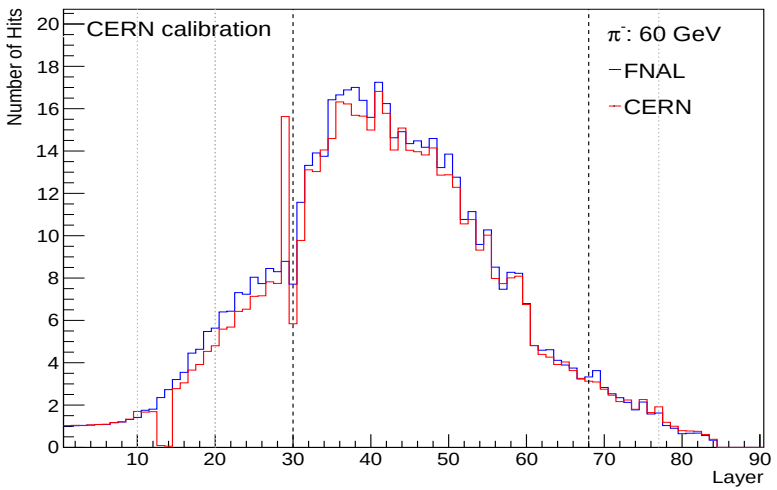
FNAL: energies are slightly higher

Longitudinal Profile : Hits per Layer



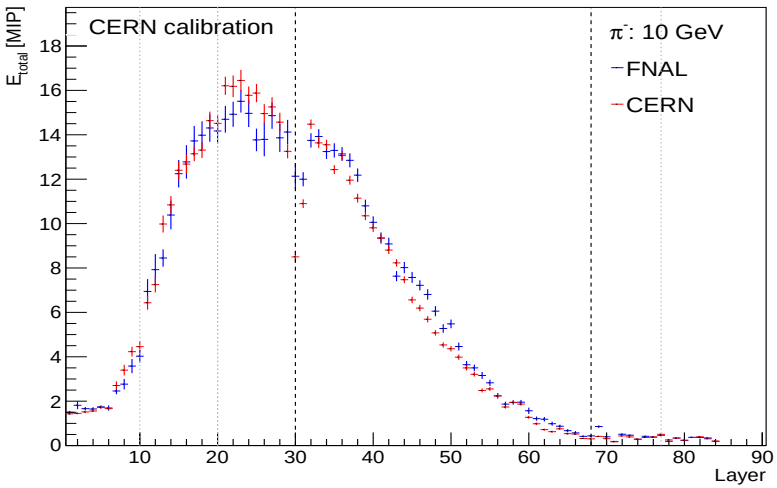


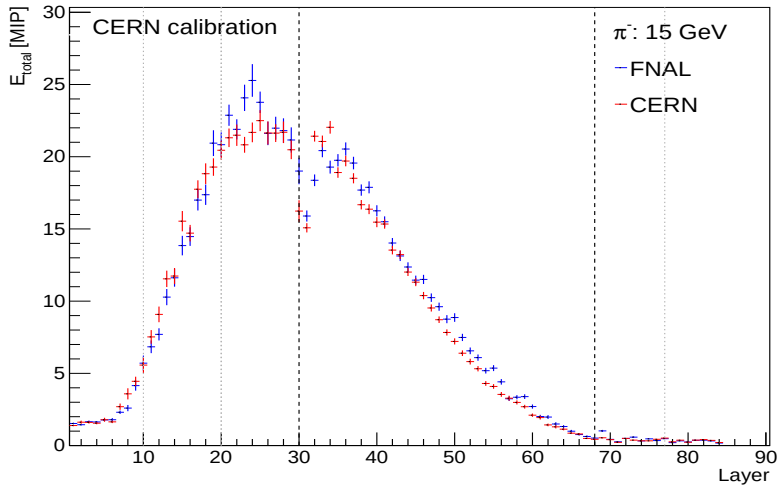


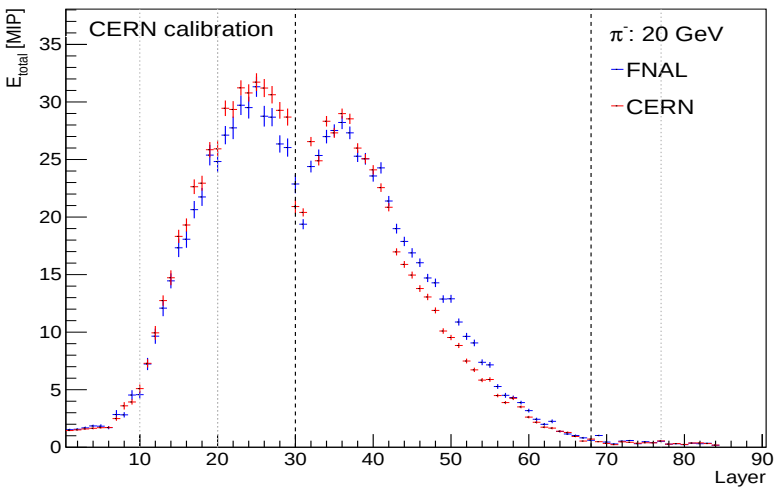


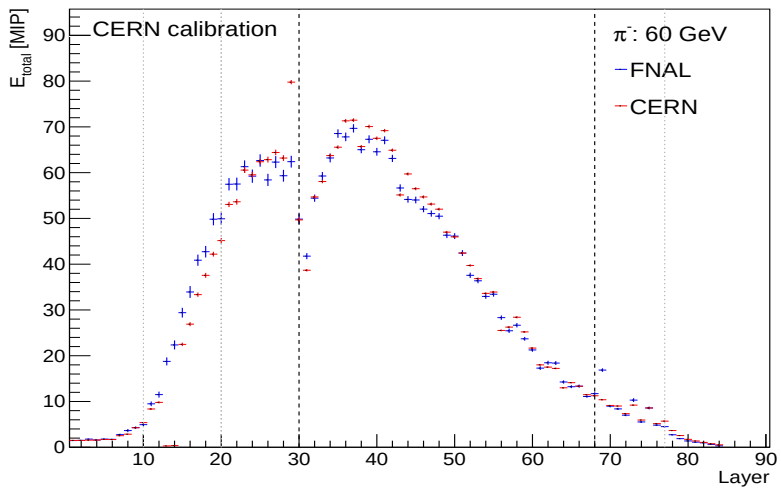
FNAL: less hits in ECAL, more hits in AHCAL

Longitudinal Profile : Energy per Layer



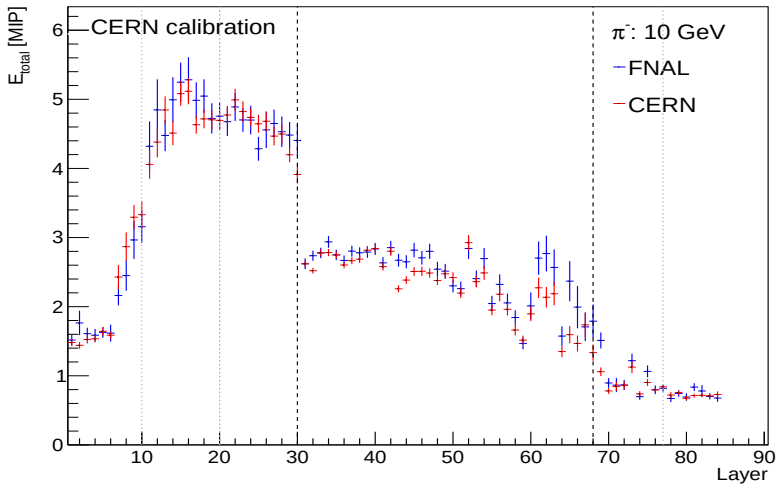


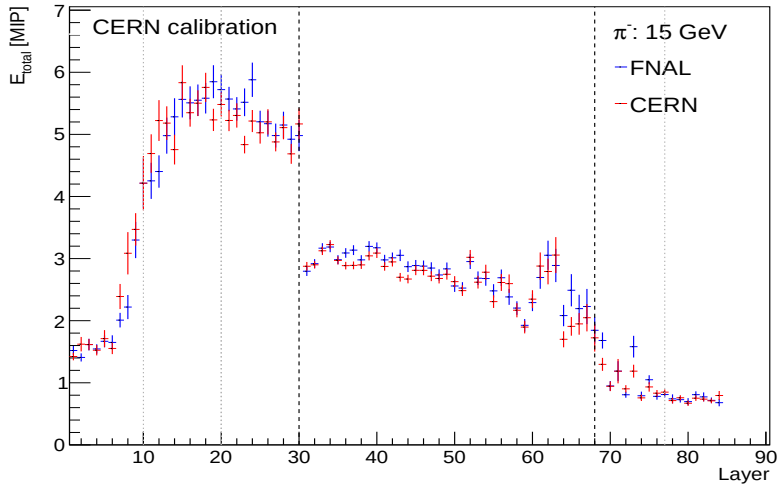


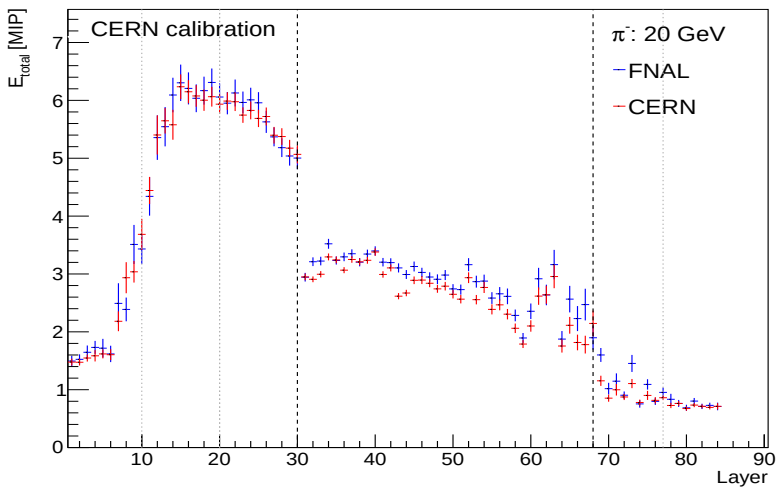


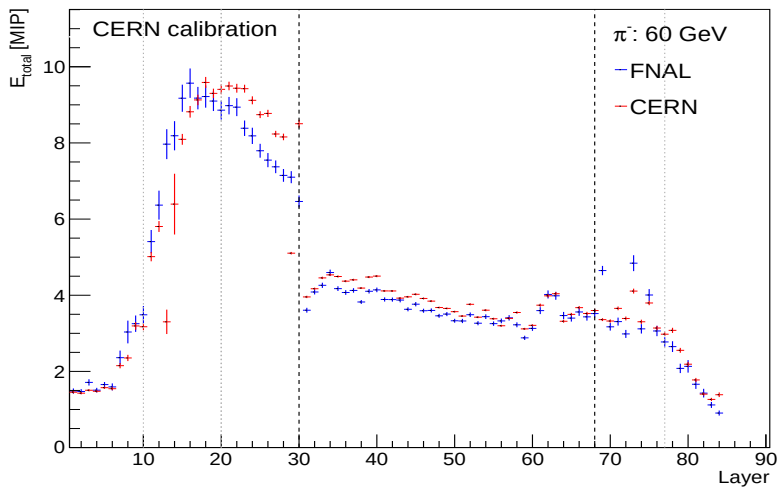
FNAL: higher energy per layer in AHCAL

Average Hit Energy per Layer





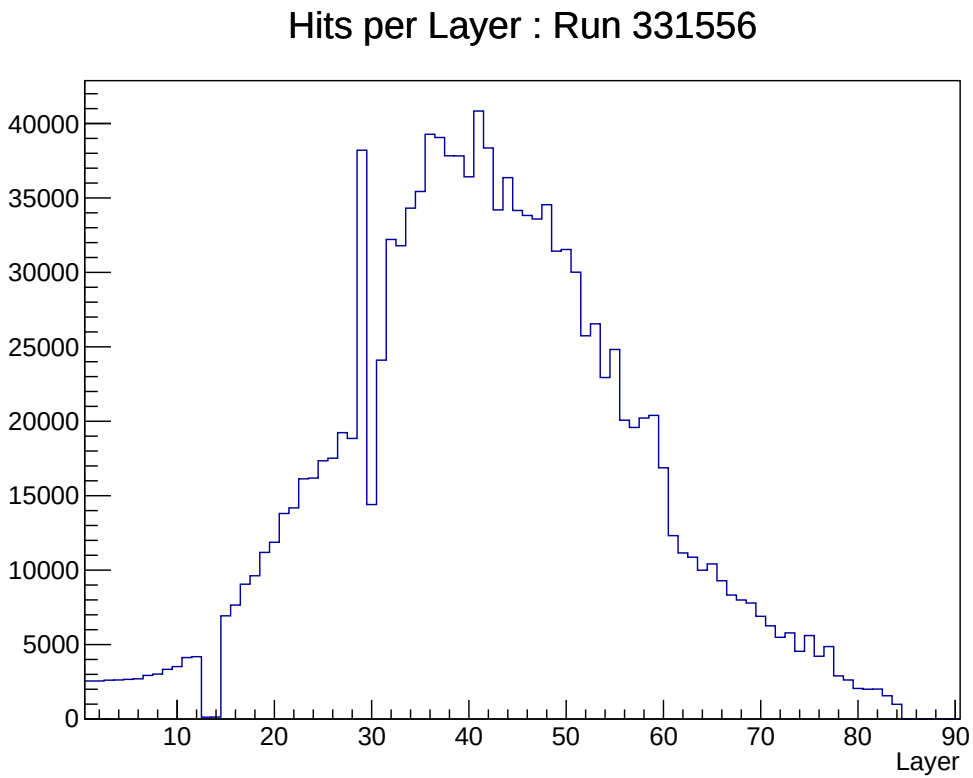




CERN - Bad Runs

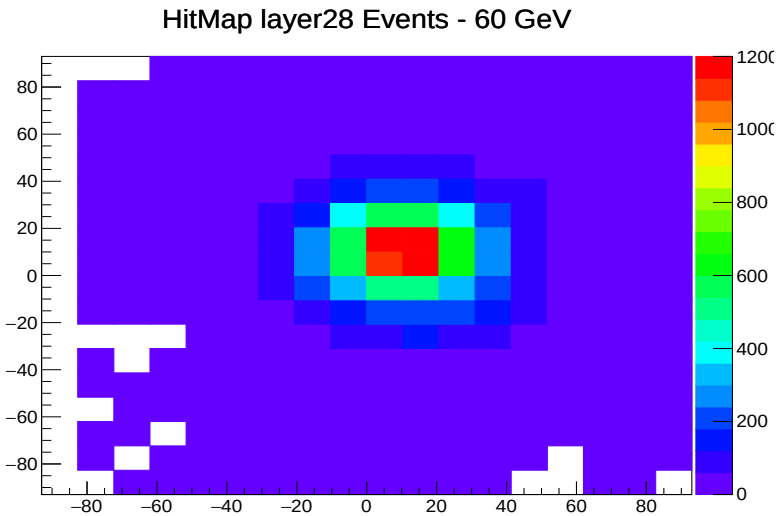
Too many hits in layer 29 ECAL.
No hits in layers 13 & 14 ECAL.

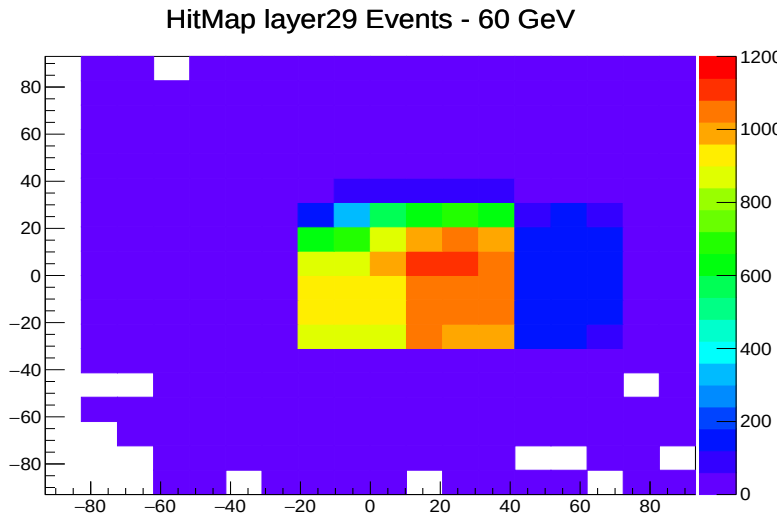
60 GeV: 331556 331664 331568 331655
80 GeV: 331654 331567 331554

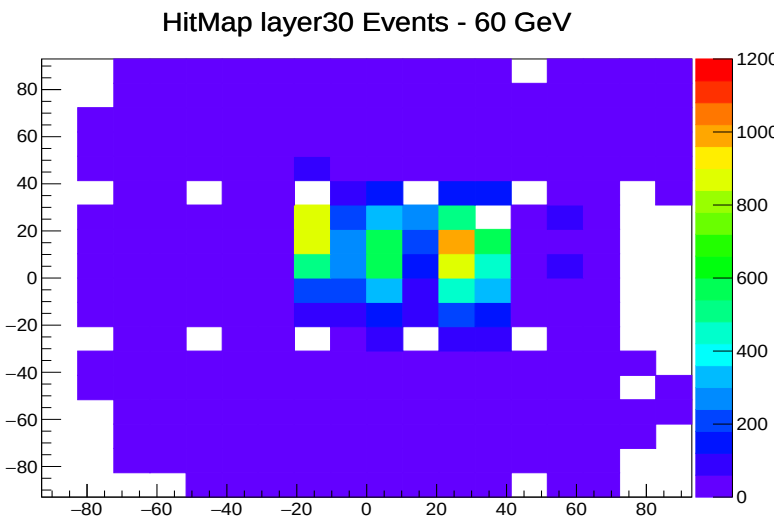


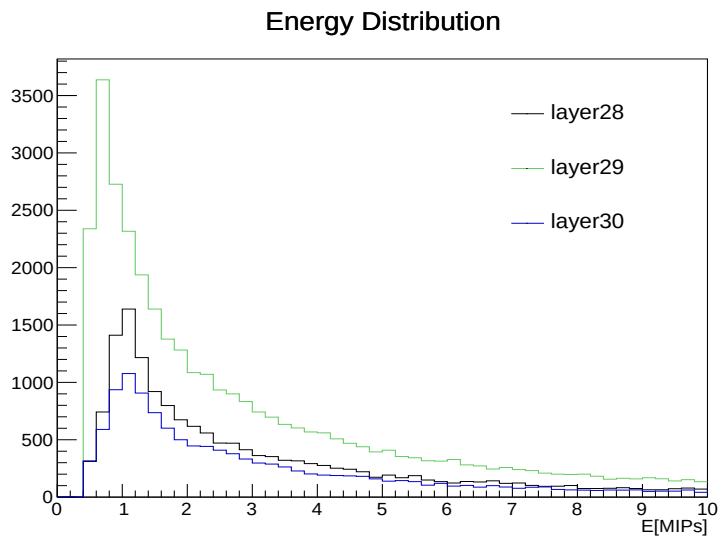
CERN 60 GeV - run 331556

Beam shape is gone from layer 29





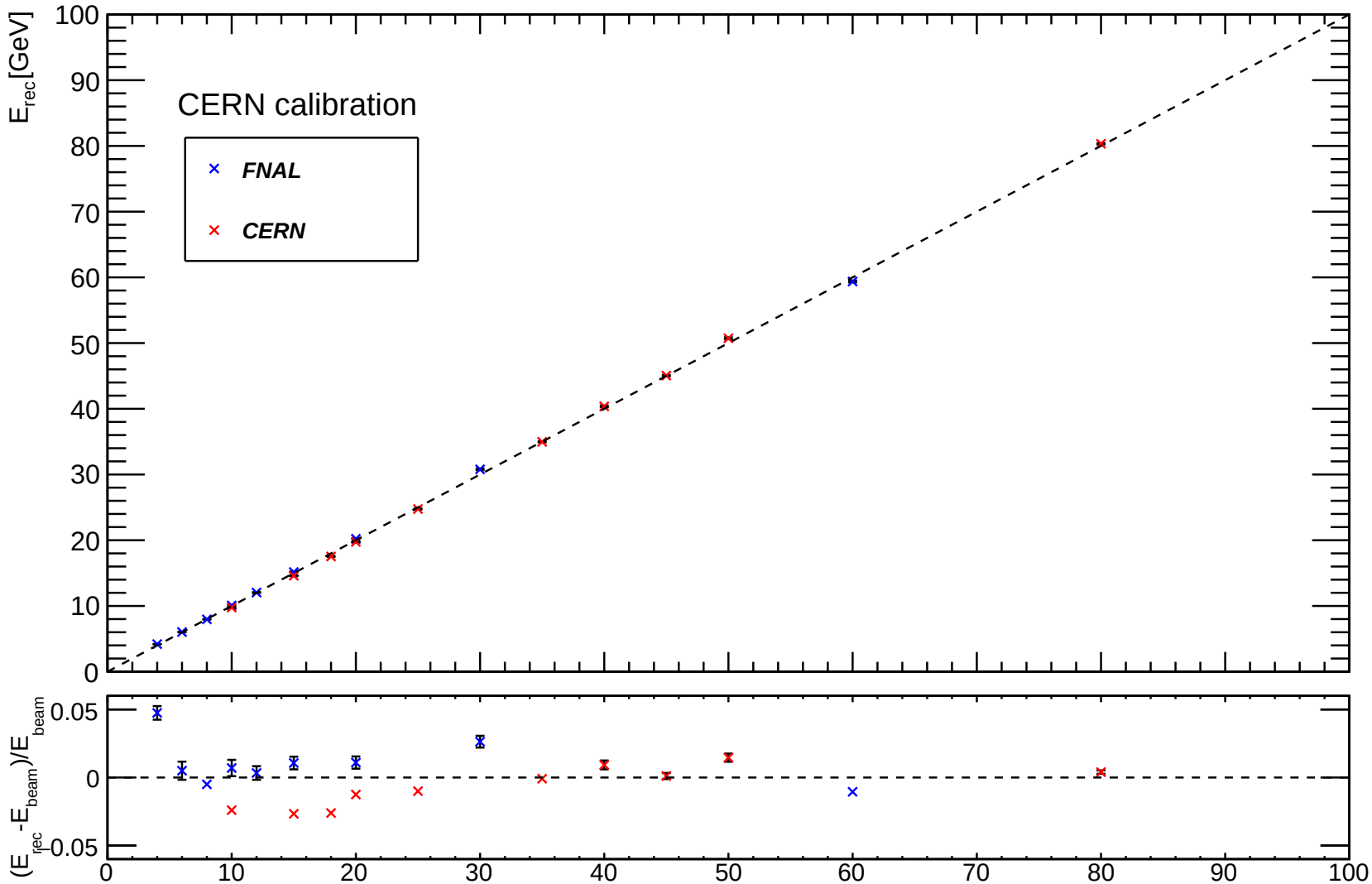




Energy reconstruction

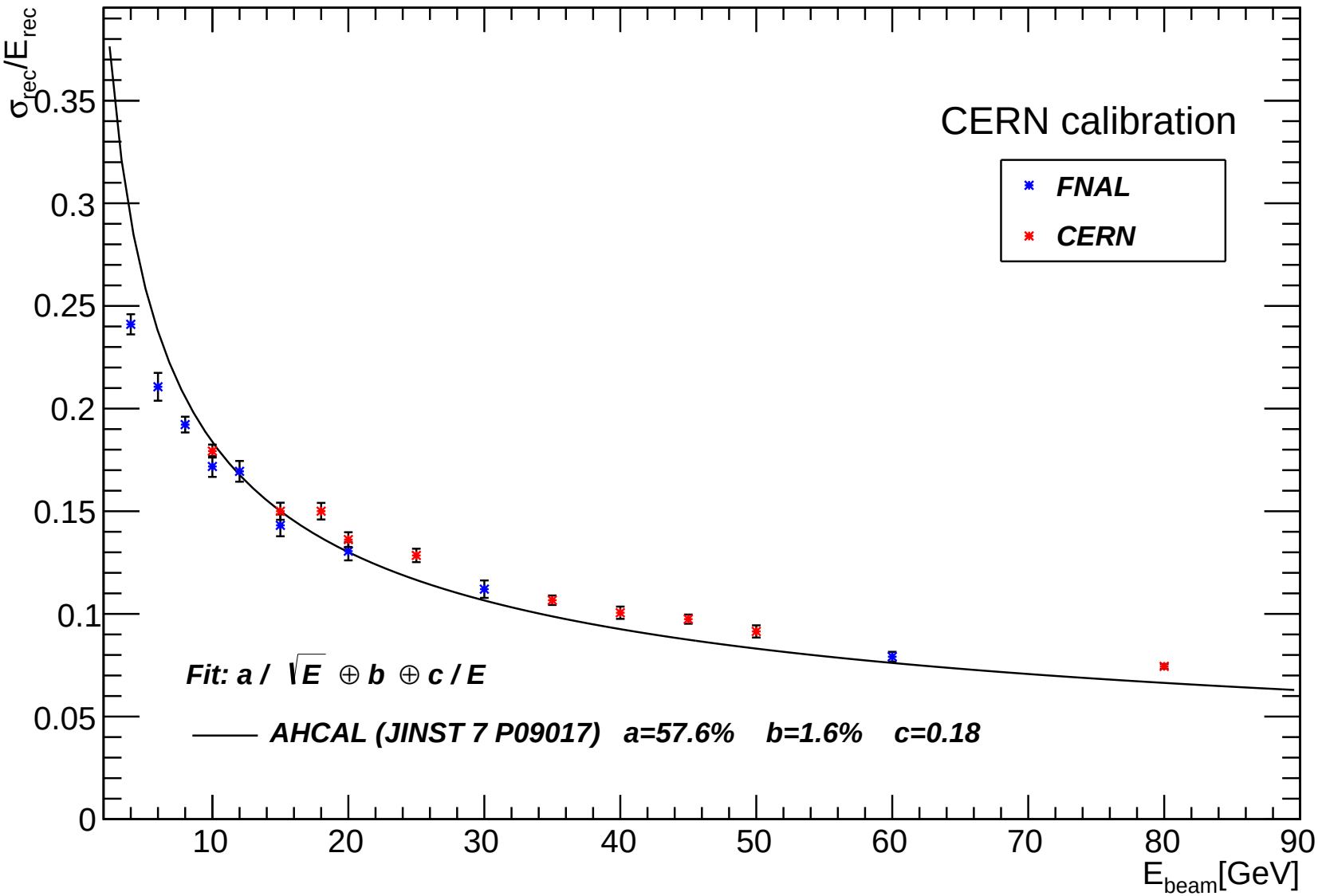
Using the CERN weights for both datasets.

FNAL energies are ~ 3% higher than CERN energies.



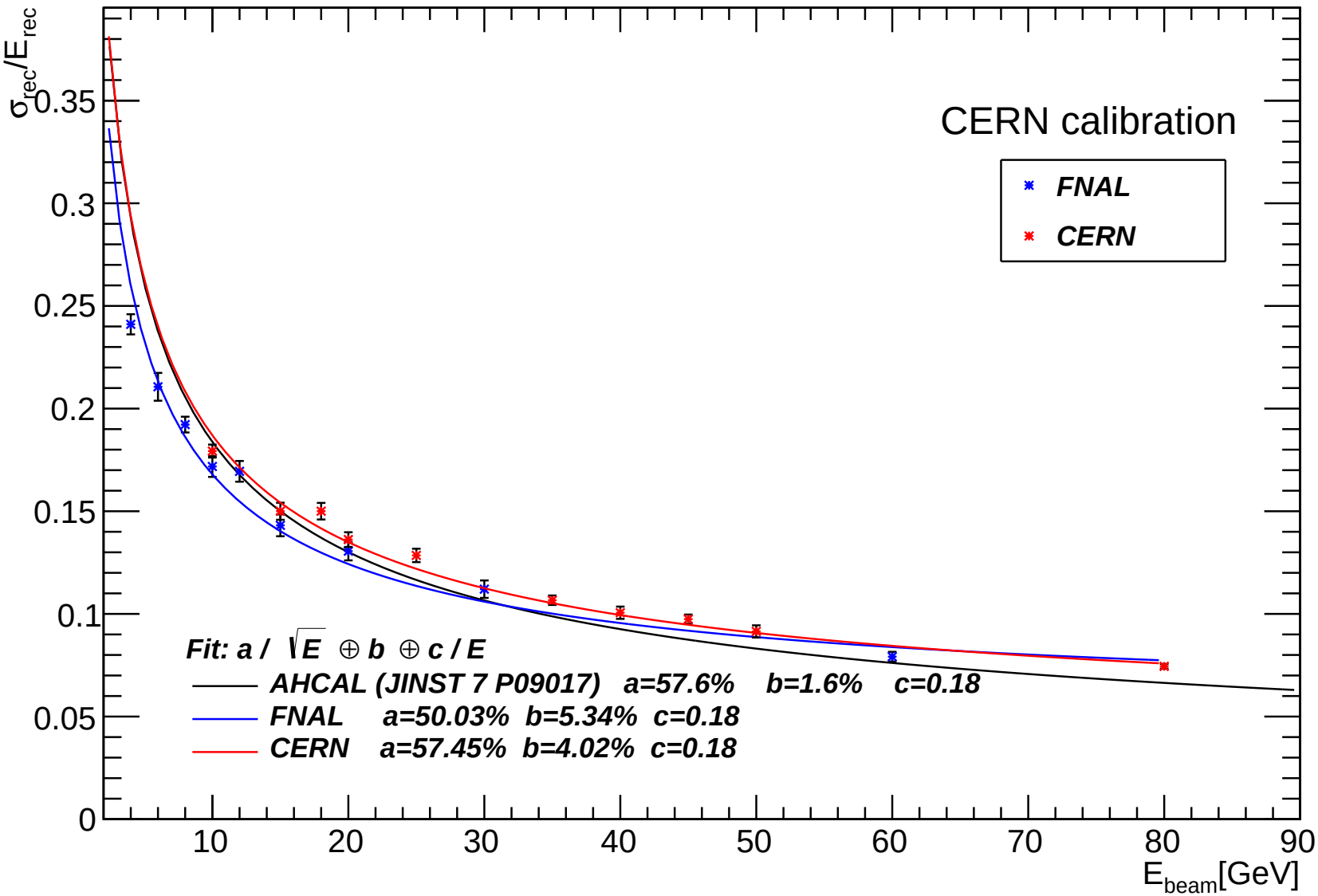
Energy resolution

Energy resolution compared with AHCAL fit from JINST 7 P09017



Energy resolution

Energy resolution compared with AHCAL fit from JINST 7 P09017



CERN Calibration

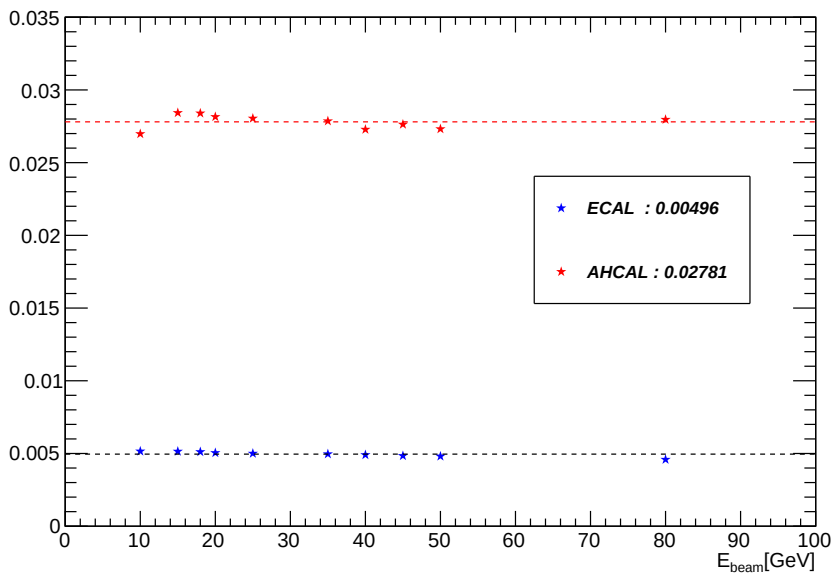
- starting with weights from previous analysis:
  - $\omega_{ecal} = 0.00490$
  - $\omega_{hcal} = 0.02813 = \frac{1}{w_e[MIP/GeV]} \cdot \frac{e}{\pi} = \frac{1}{42.3^*} \cdot 1.19$

    *JINST 6 (2011) P04003

- χ^2 minimization for each energy:

$$\chi^2 = \sum_{events} \left(E_{ecal}\omega_{ecal} + (E_{hcal} + E_{tcmt})\omega_{hcal} - E_{beam} \right)^2$$

- Average weights: $\omega_{ecal} = 0.00496$, $\omega_{hcal} = 0.02781$



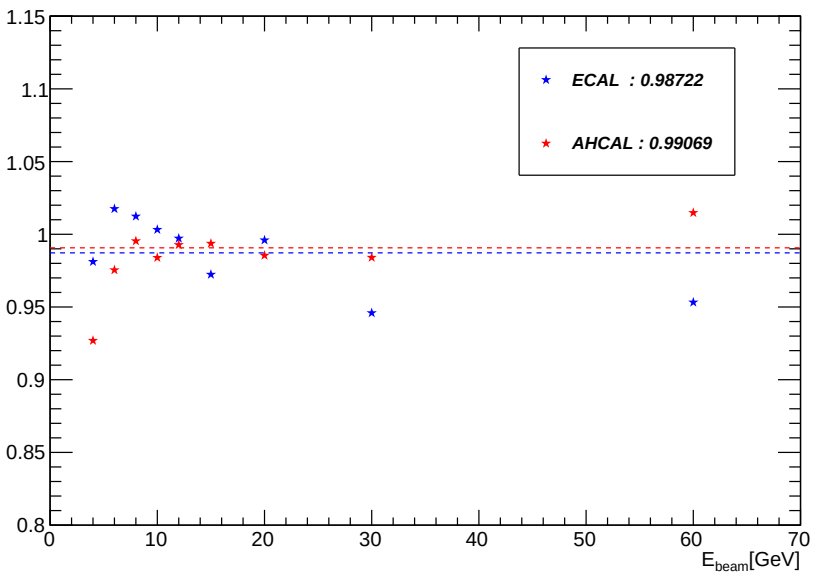
FNAL Calibration

- starting with CERN calibration:
  - $\omega_{ecal} = 0.00496$
  - $\omega_{hcal} = 0.02781$
- χ^2 minimization for each energy:

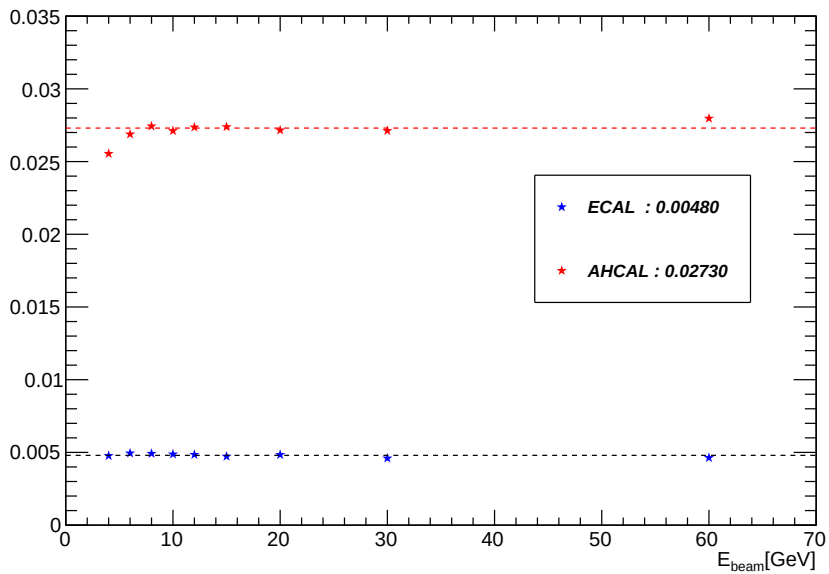
$$\chi^2 = \sum_{events} \left(E_{ecal}\omega_{ecal} + (E_{hcal} + E_{tcmt})\omega_{hcal} - E_{beam} \right)^2$$

- average weights (excluding 4 GeV): $\omega_{ecal} = 0.00480$, $\omega_{hcal} = 0.02730$
- difference of $\sim 3\%$ for ECAL and $\sim 0.8\%$ for AHCAL.

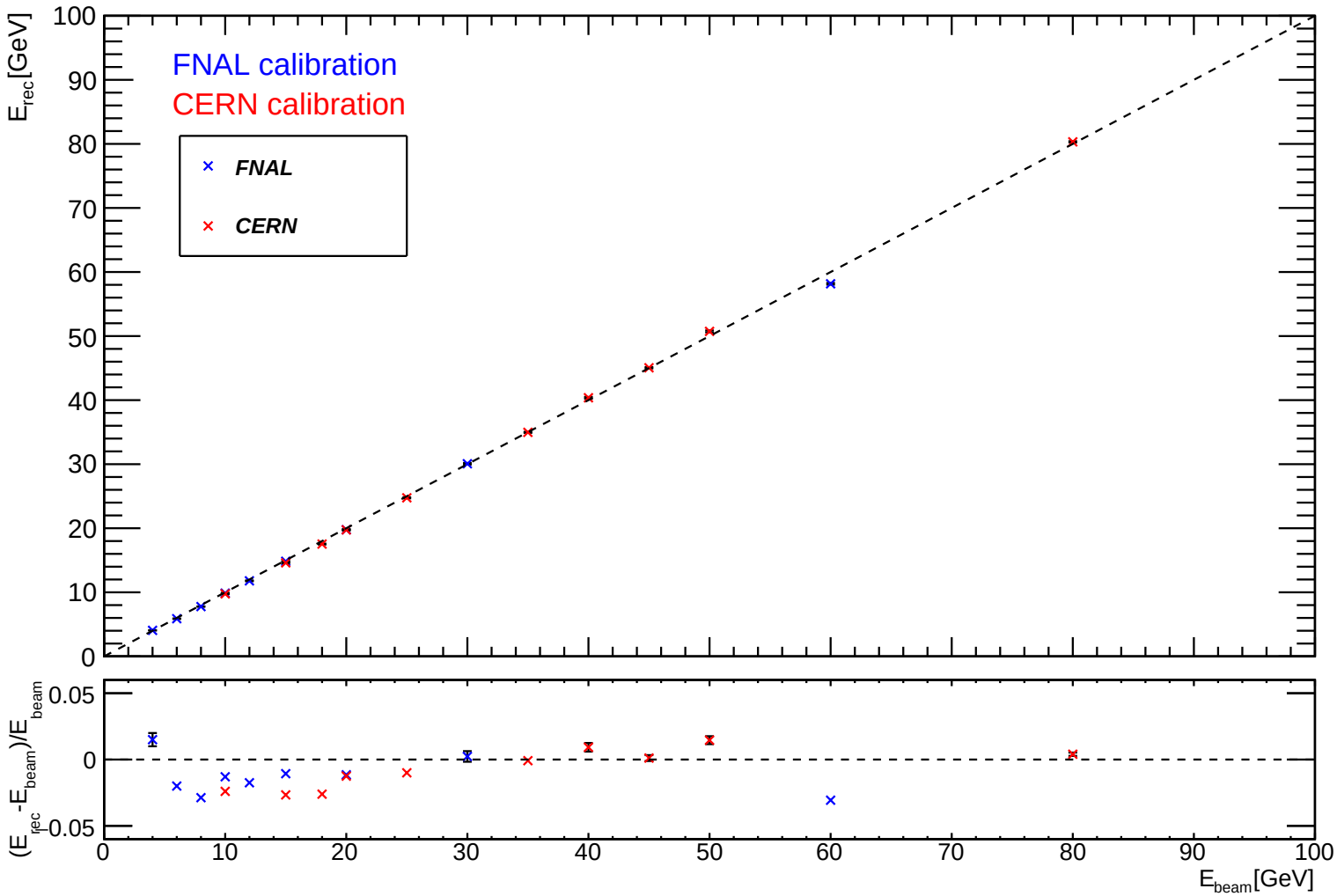
Deviations from CERN Weights



FNAL Weights



New Calibration for FNAL : Energy reconstruction

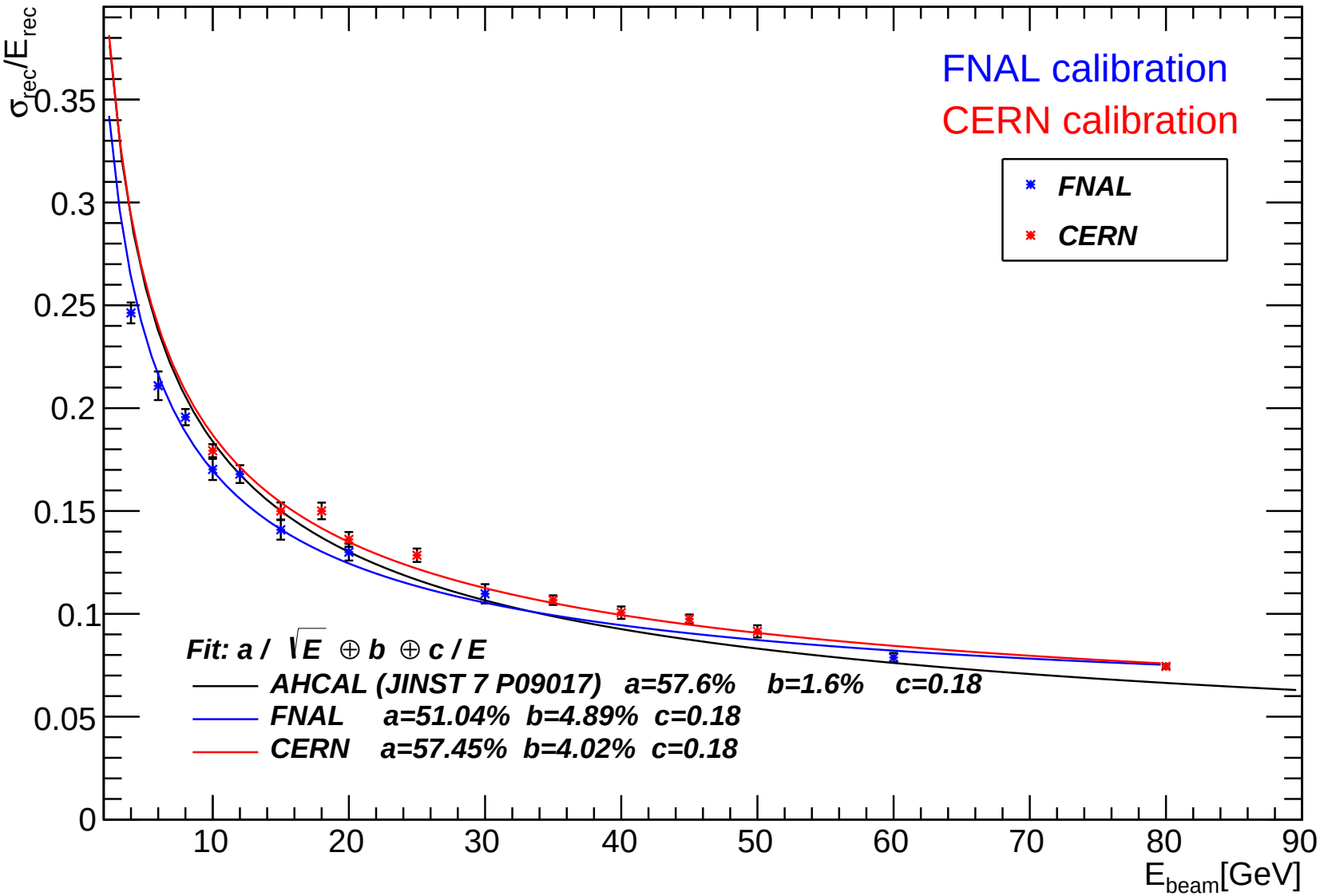


Both datasets show the same trend (excluding 4 & 6 GeV).

New Calibration for FNAL : Energy resolution

FNAL fit changed from: $a = 50.03\%, b = 5.34, c = 0.18$

to: $a = 51.04\%, b = 4.89, c = 0.18$

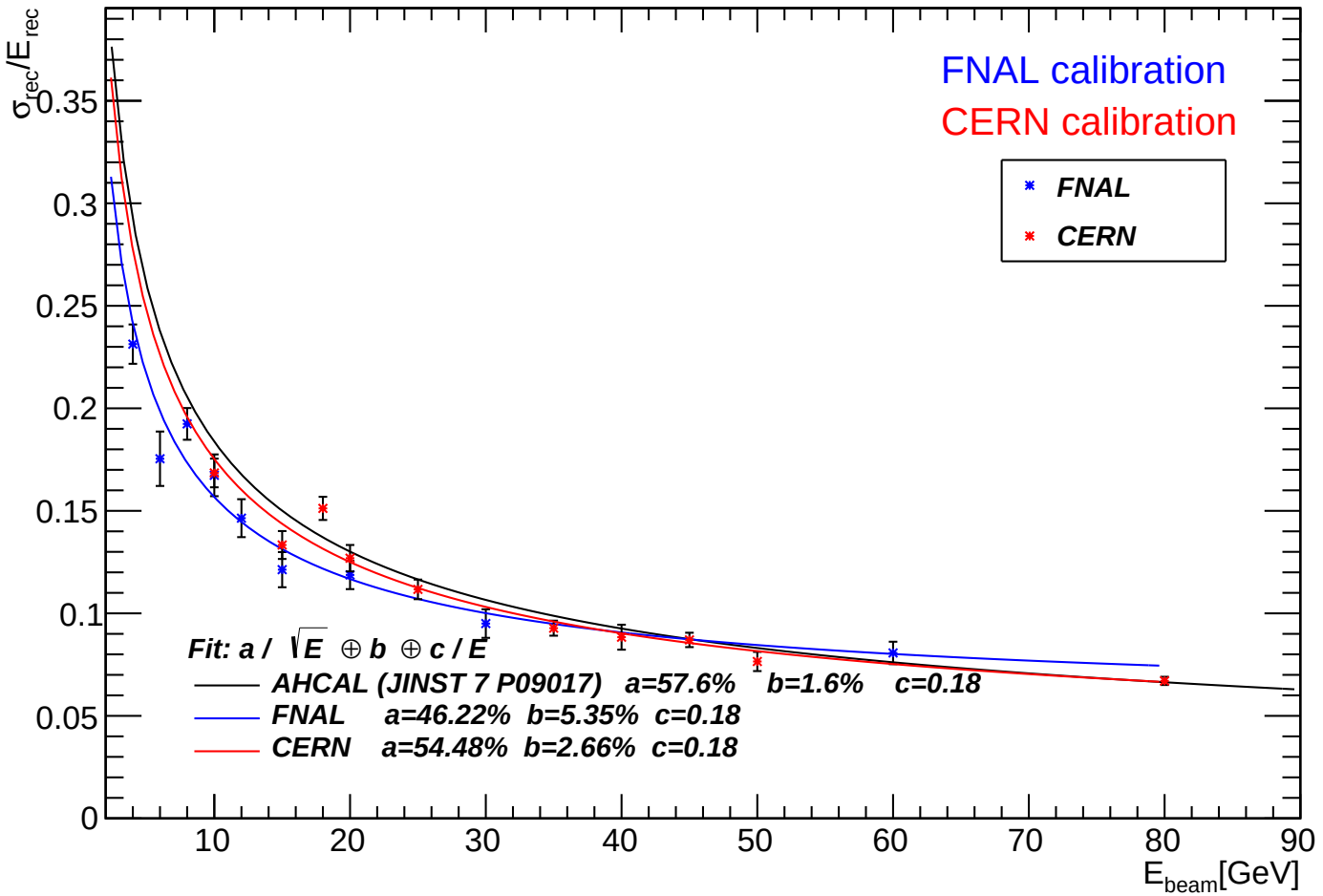


Comparison to JINST 7 P09017

Selcting only events with **FHI in first 5 layers in AHCAL** as was required in JINST 7 P09017.

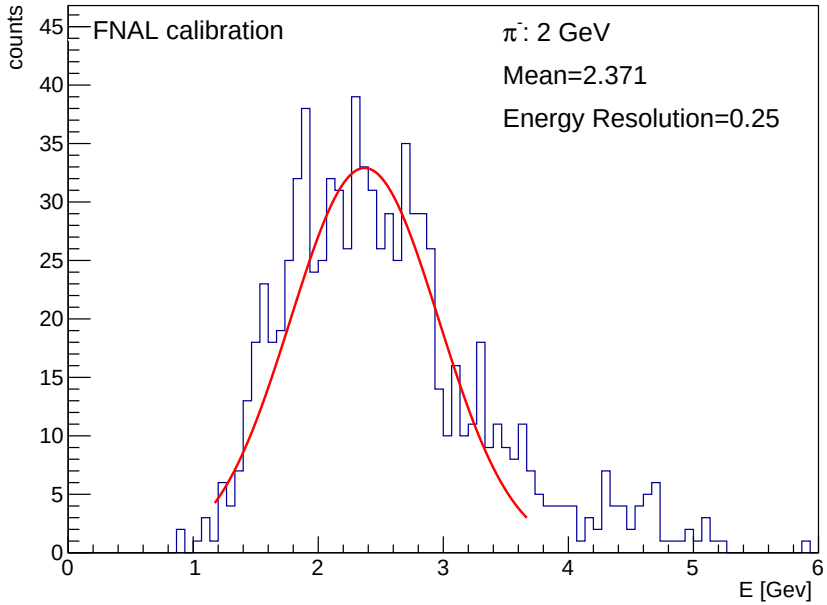
CERN fit changed from: $a = 57.45\%, b = 4.02, c = 0.18$

to: $a = 54.48\%, b = 2.66, c = 0.18$



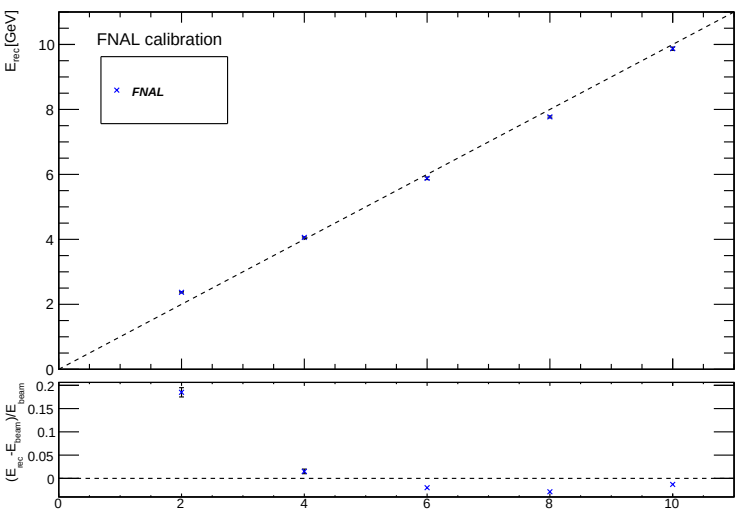
FNAL 2 GeV

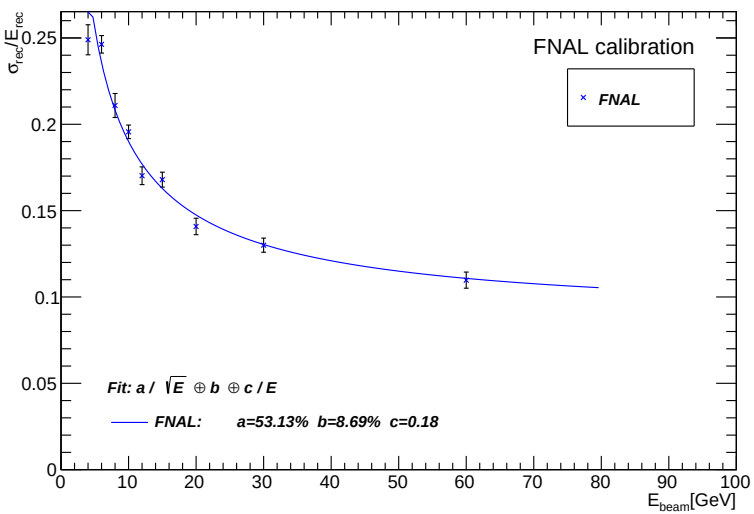
2 GeV data is excluded from the analysis due to the difficulty to select single π events.



Large tail:

- electron contamination
- multi particle events





Summary and Outlook:

- Energy reconstruction for: SiW ECAL+AHCAL+TCMT in the range of 4-80 GeV (FNAL+CERN test beams).
- Optimizing the selection of π^- events.
- Applying calibration weights fitting to CERN data, including layer thickness.
- CERN calibration: FNAL energies are $\sim 3\%$ higher than CERNs.
- Calibration weights for FNAL data: difference of $\sim 3\%$ (ECAL) and $\sim 0.8\%$ (AHCAL) compare to CERN weights.
- CERN and FNAL calibrations: both datasets show the same trend (excluding 4 & 6 GeV).

Outlook:

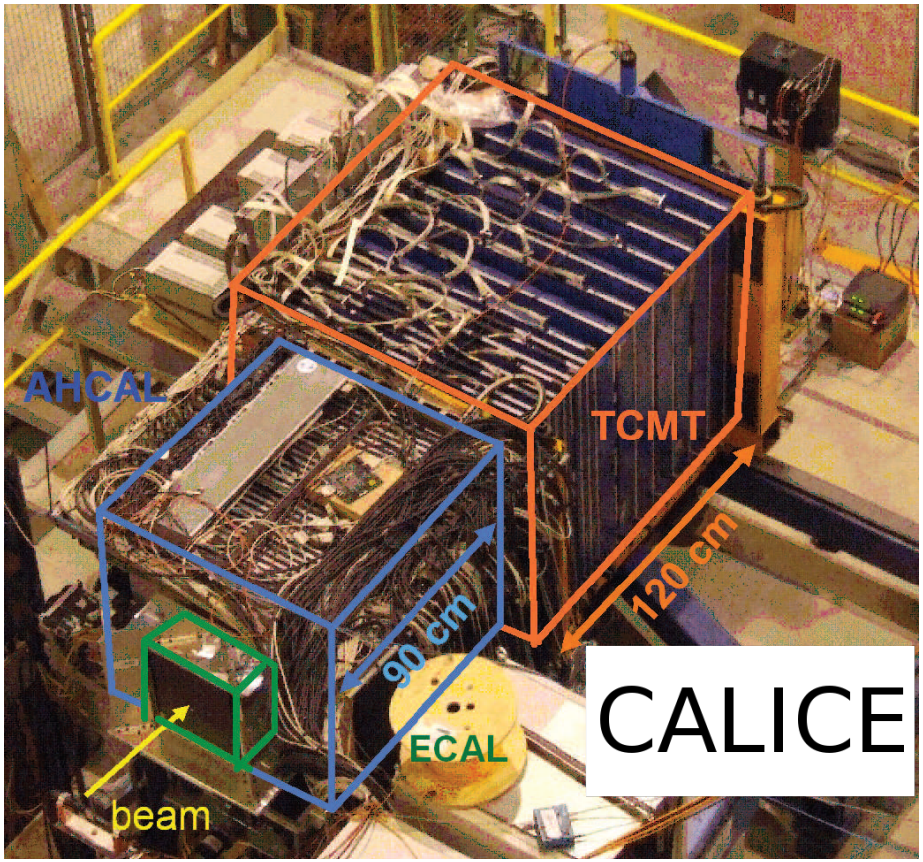
- Checking cut efficiencies via MC.
- Comparing data with MC.
- Testing different software compensation techniques

Thank you for your attention ☺

BACKUP

CALICE Prototype

Combined system consisting of three sampling calorimeters with different technologies:

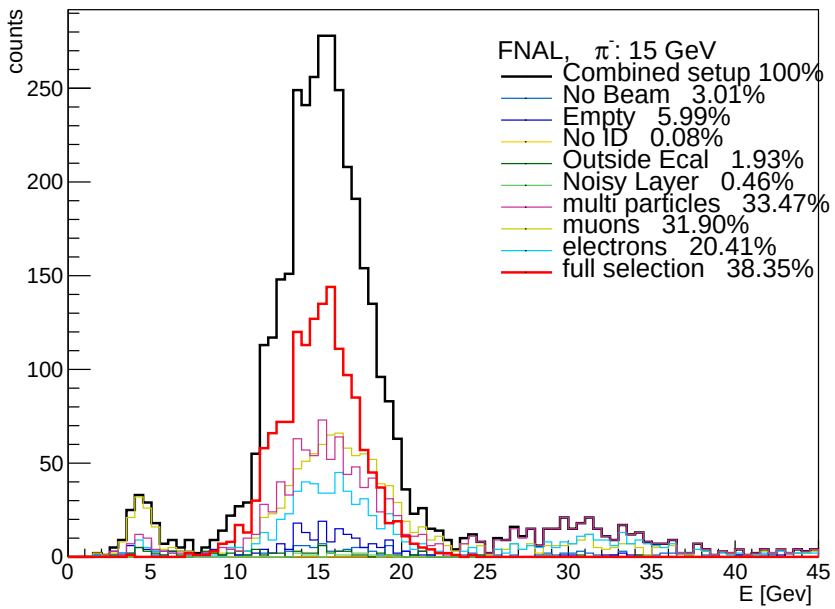


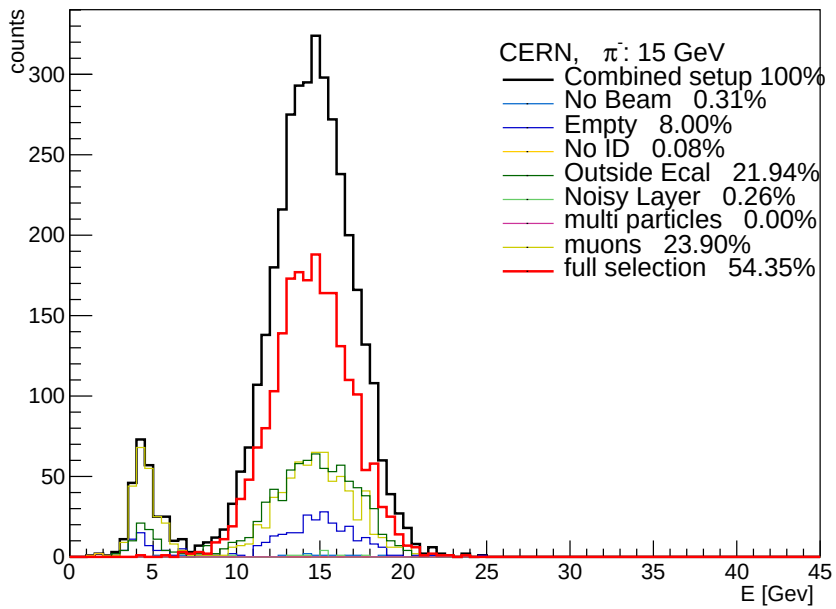
- **SiW ECAL**
  - Silicon sensors
  - Absorber Material: tungsten
  - 30 layers, 9720 channels
- **AHCAL**
  - Silicon photomultipliers
  - Absorber material: steel
  - 38 layers, 7608 channels
- **TCMT**
  - Silicon photomultipliers
  - Absorber material: steel
  - 16 layers, 320 channels

Test beams from 2006 - 2011 at DESY, CERN, FNAL

First cut-list (independent cuts) 15 GeV :

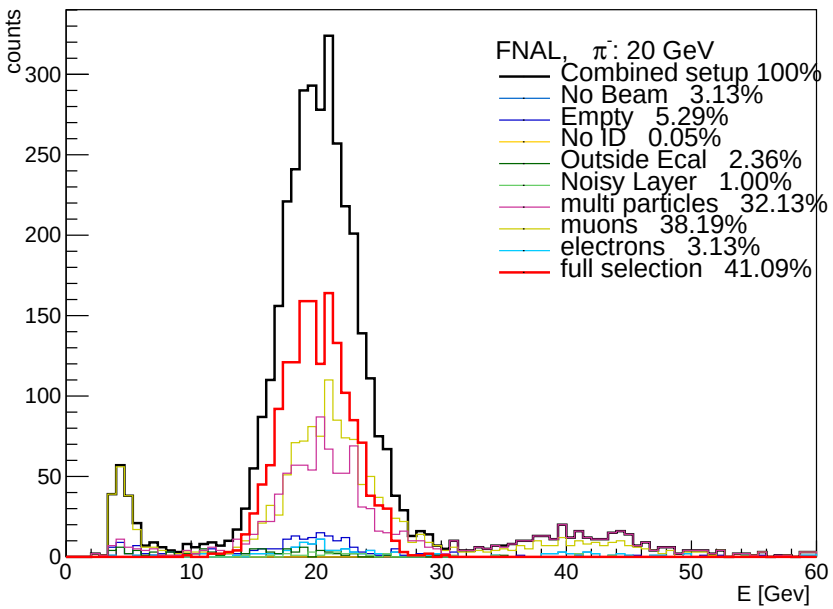
cut	CERN [%]	FNAL [%]
selected	54.34	38.35
no beam	0.30	3.00
empty	8.0	5.98
no id	0.10	0.07
outside Ecal	21.93	1.92
noisy layer	0.25	0.46
multi	0.0	33.29
muons	23.89	31.90
electrons (Cherenkov)		20.41

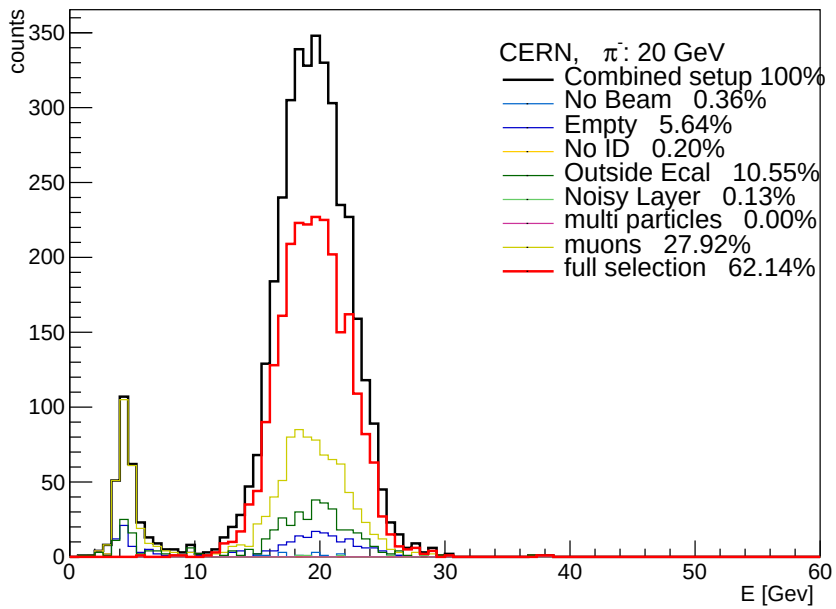




First cut-list (independent cuts) 20 GeV :

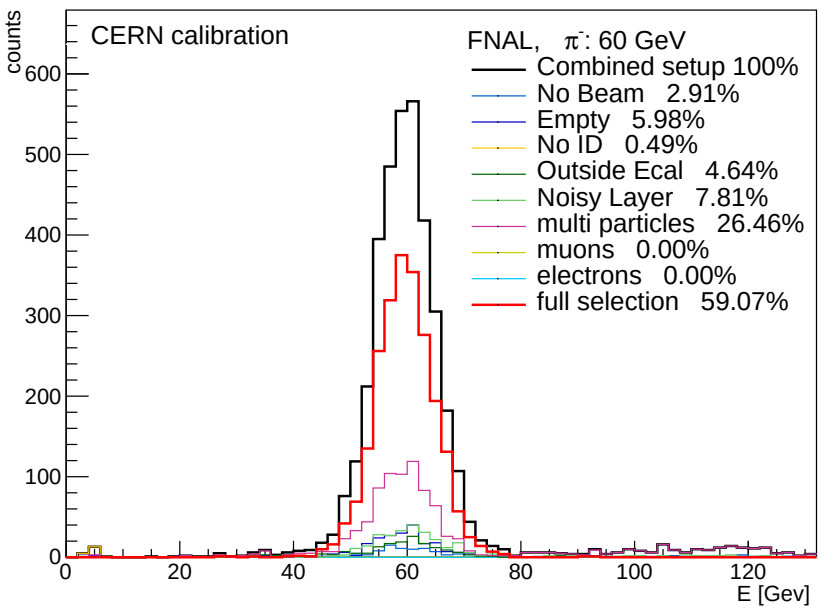
cut	CERN [%]	FNAL [%]
selected	62.11	41.11
no beam	0.35	3.13
empty	5.64	5.29
no id	0.63	0.31
outside Ecal	10.55	2.36
noisy layer	0.12	1.00
multi	0.0	31.87
muons	27.91	38.19
electrons (Cherenkov)		3.13

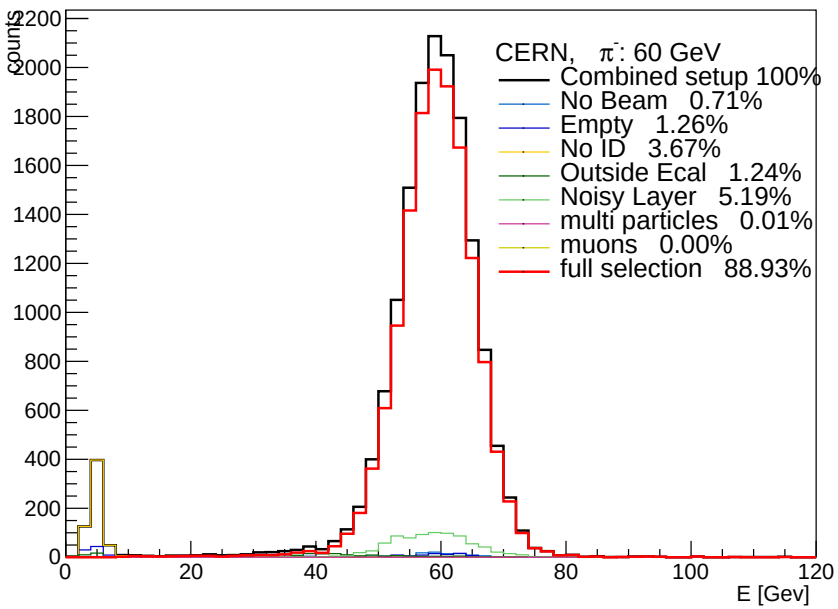




First cut-list (independent cuts) 60 GeV :

cut	CERN [%]	FNAL [%]
selected	88.91	59.17
no beam	0.71	2.91
empty	1.26	5.98
no id	3.70	0.49
outside Ecal	1.24	4.64
noisy layer	5.19	7.81
multi	0.01	26.33





Second cut-list:

10 GeV:

cut	CERN [%]	FNAL [%]
one MIP in ECAL	73.83	84.08
reject electrons (FHI)	54.71	75.24
reject muons in AHCAL	54.31	74.61

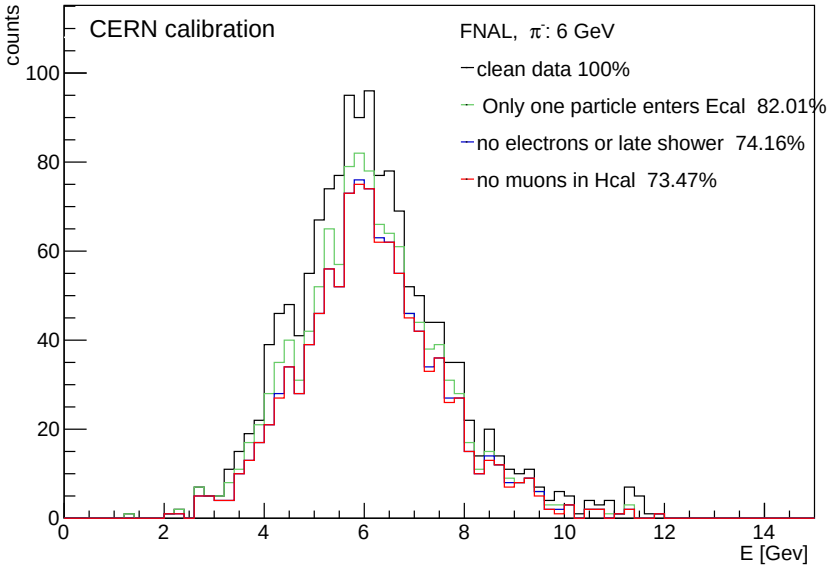
15 GeV:

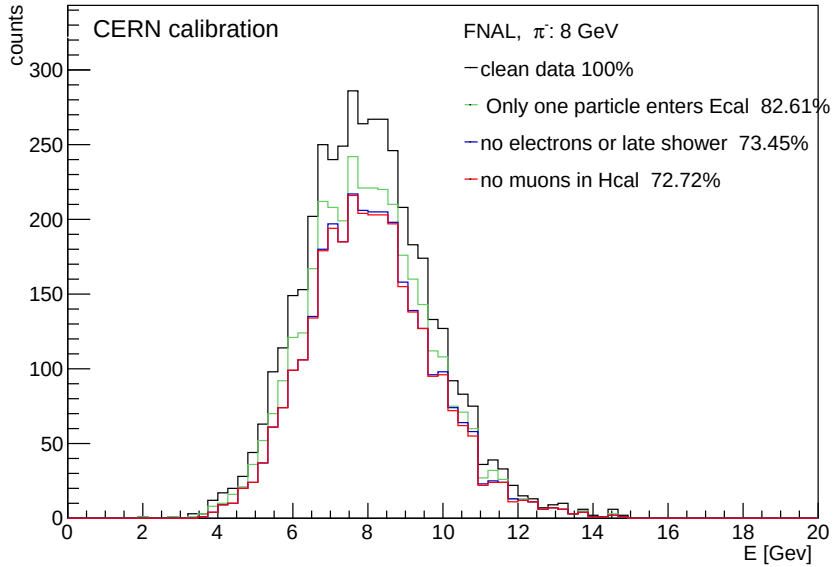
cut	CERN [%]	FNAL [%]
one MIP in ECAL	78.35	83.51
reject electrons (FHI)	69.18	75.34
reject muons in AHCAL	68.09	75.13

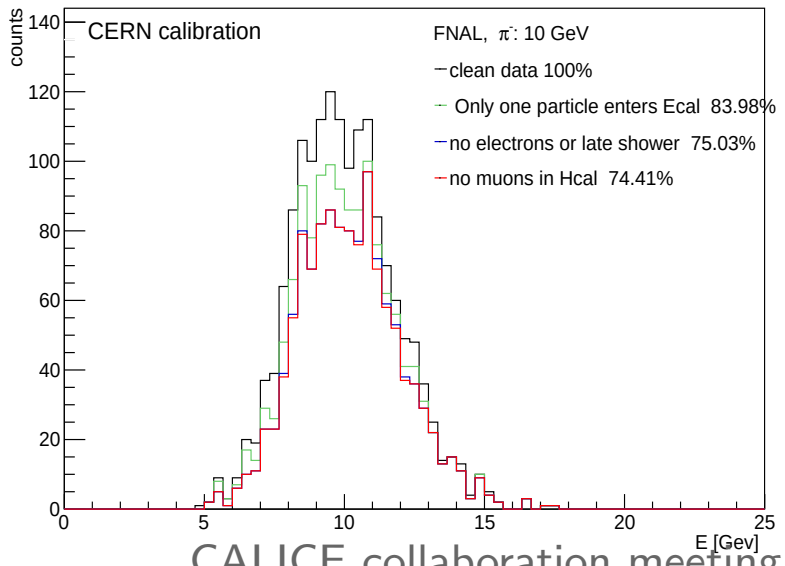
20 GeV:

cut	CERN [%]	FNAL [%]
one MIP in ECAL	82.15	81.22
reject electrons (FHI)	73.02	72.35
reject muons in AHCAL	71.96	71.69

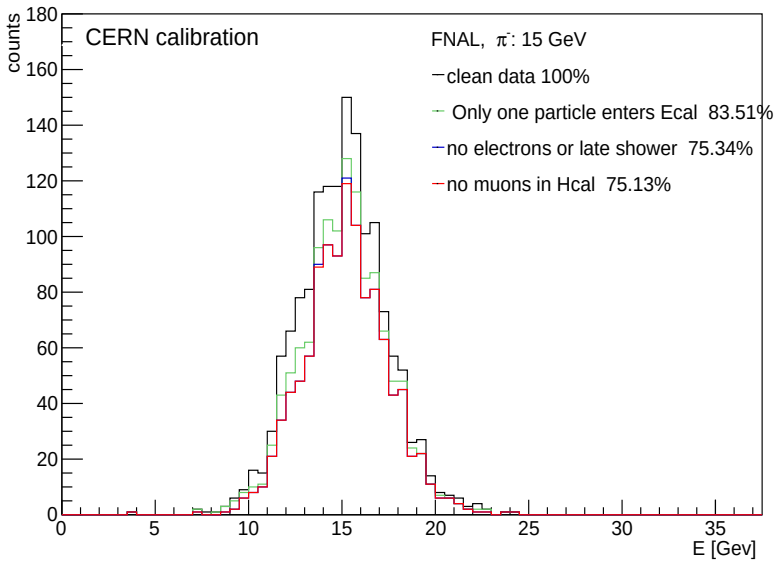
Second cut-list : FNAL

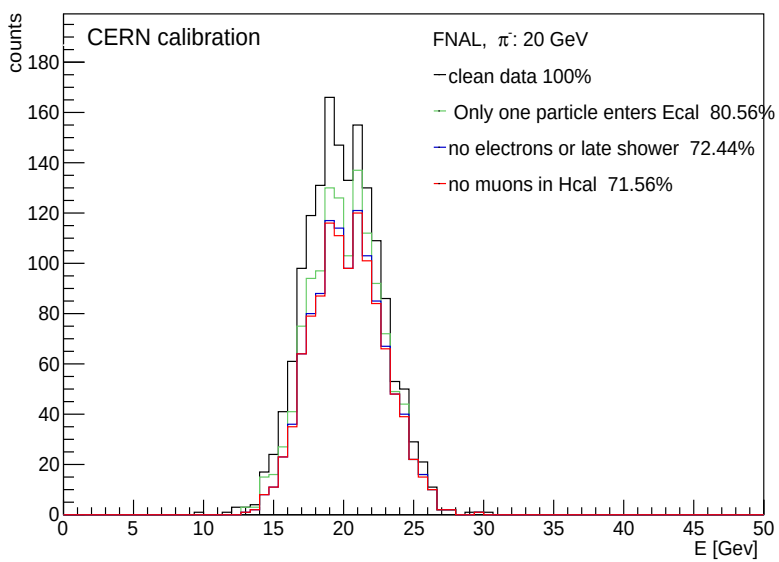


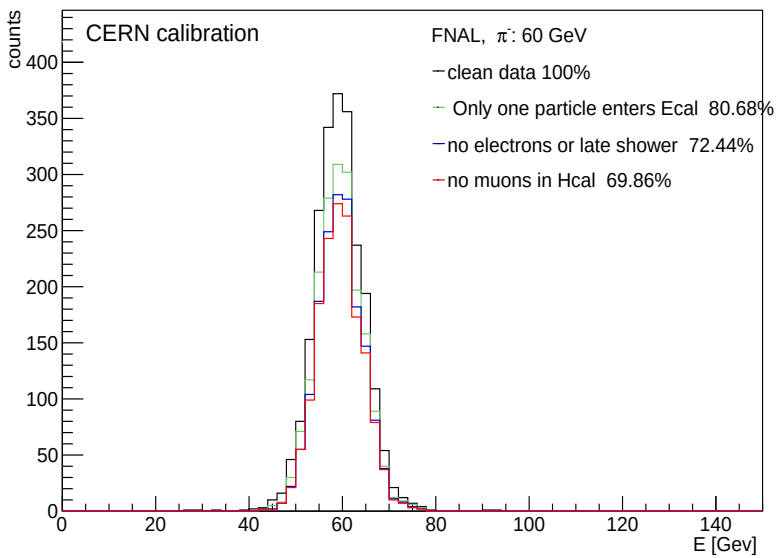




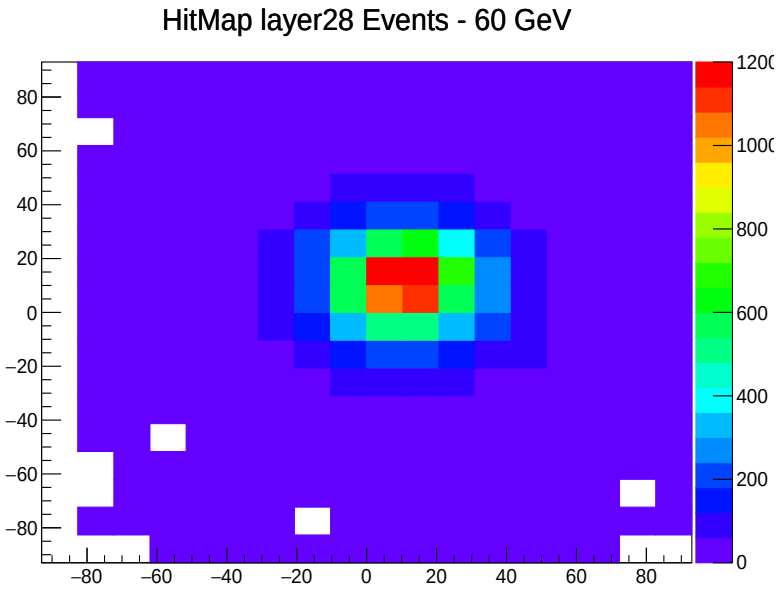
Second cut-list : FNAL

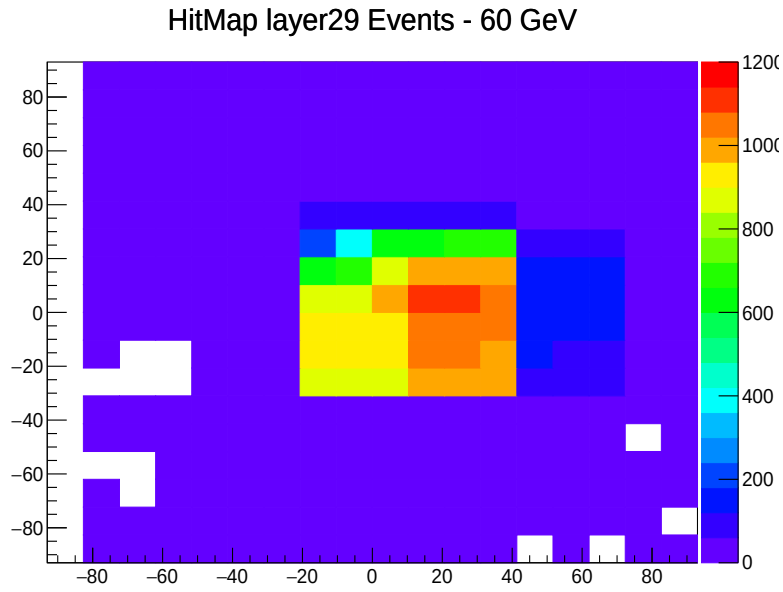


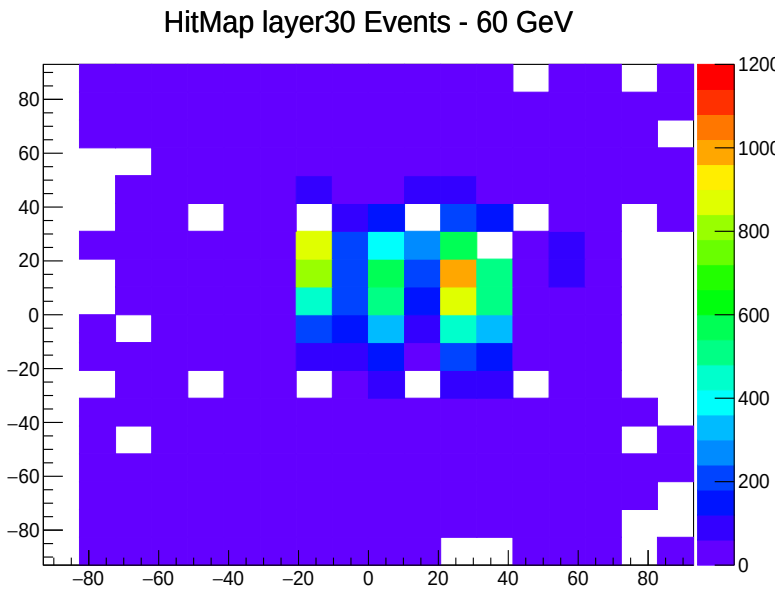




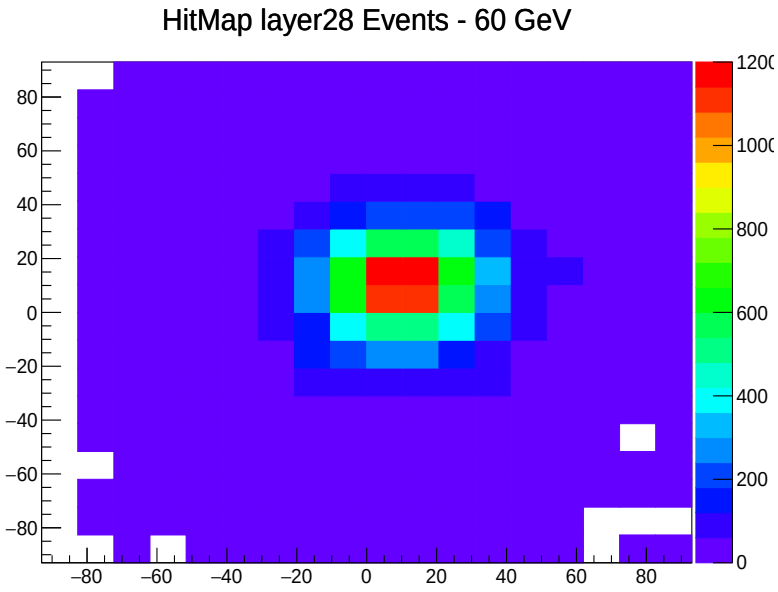
CERN 60 GeV - run 331664

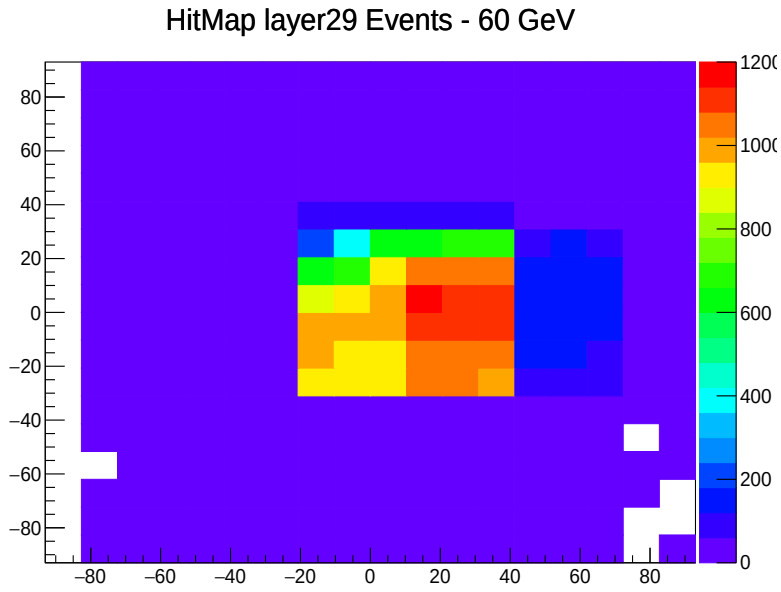


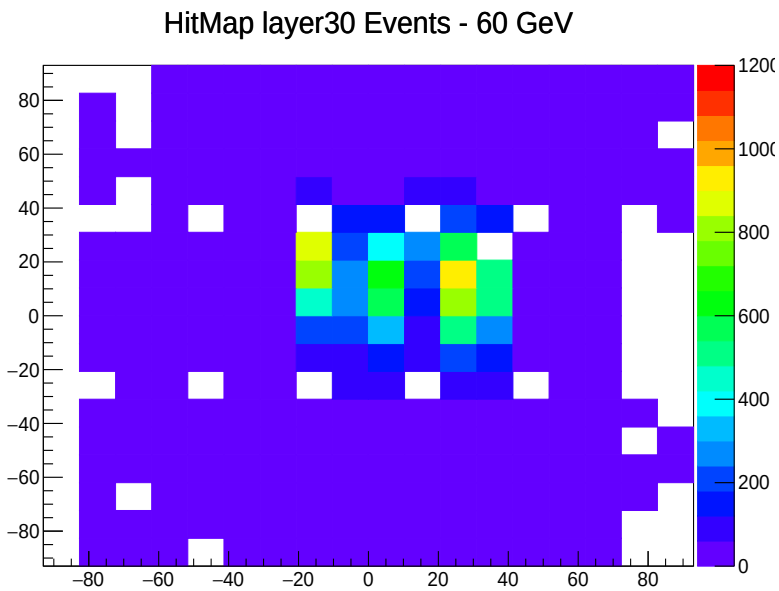




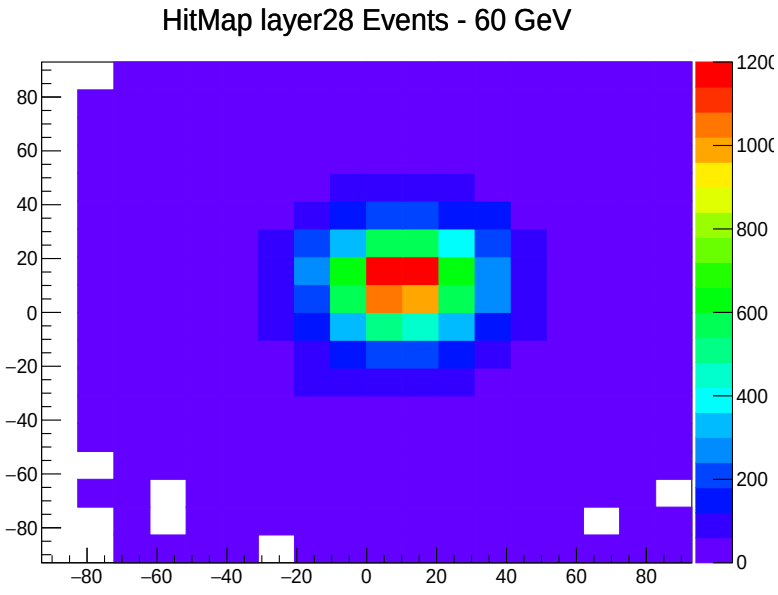
CERN 60 GeV - run 331568

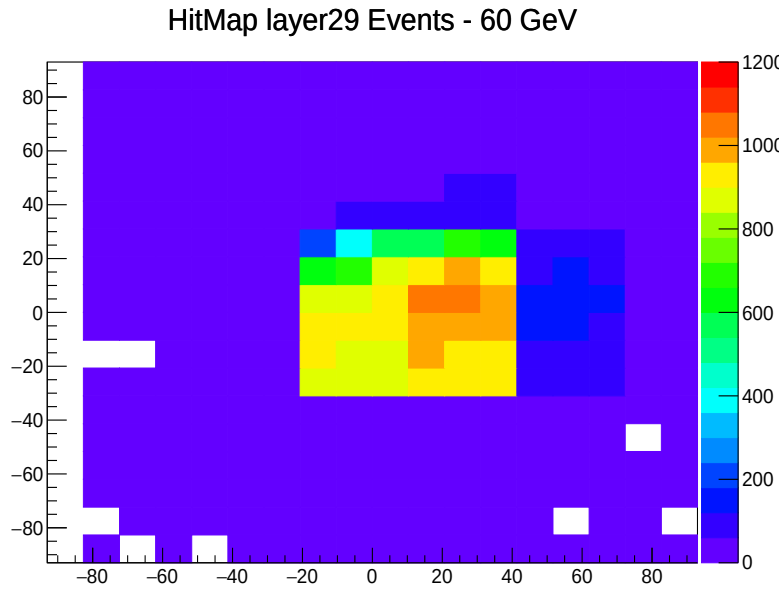


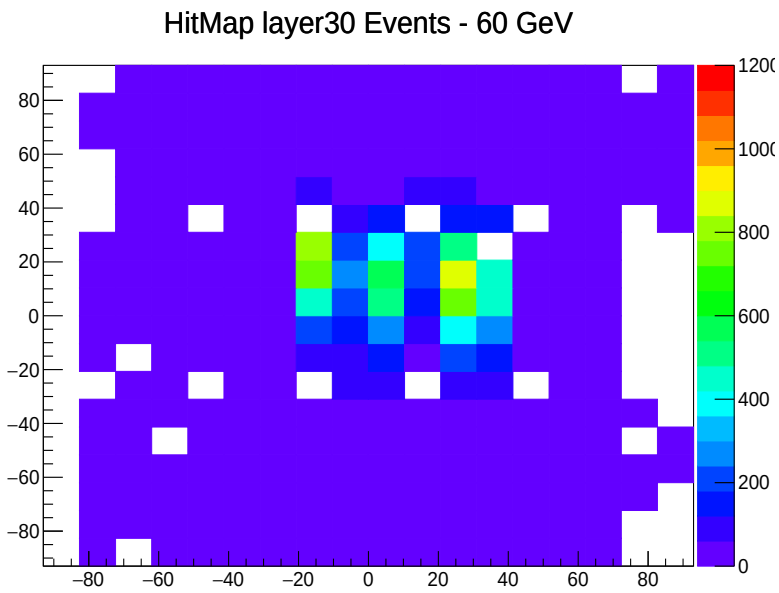




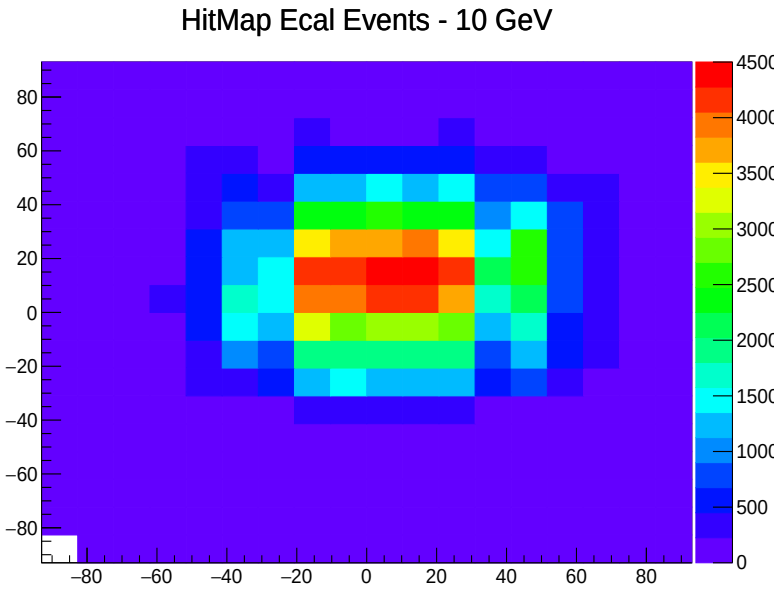
CERN 60 GeV - run 331655

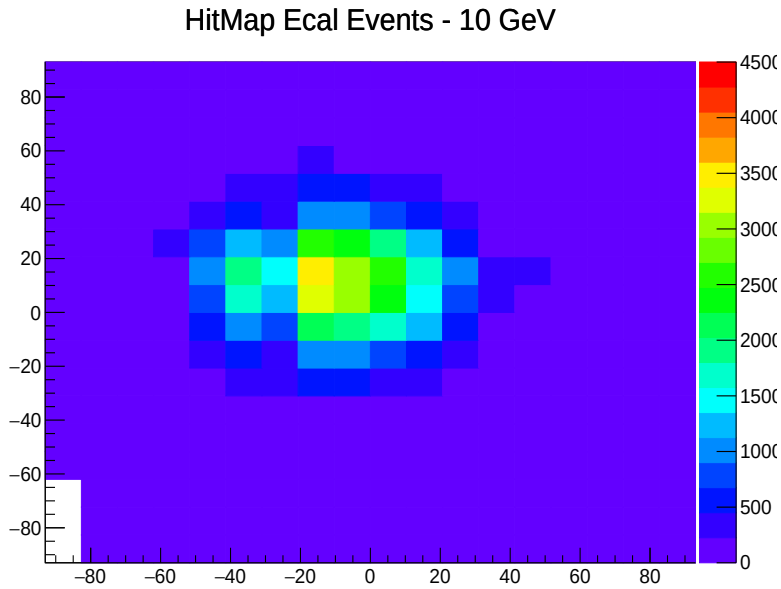


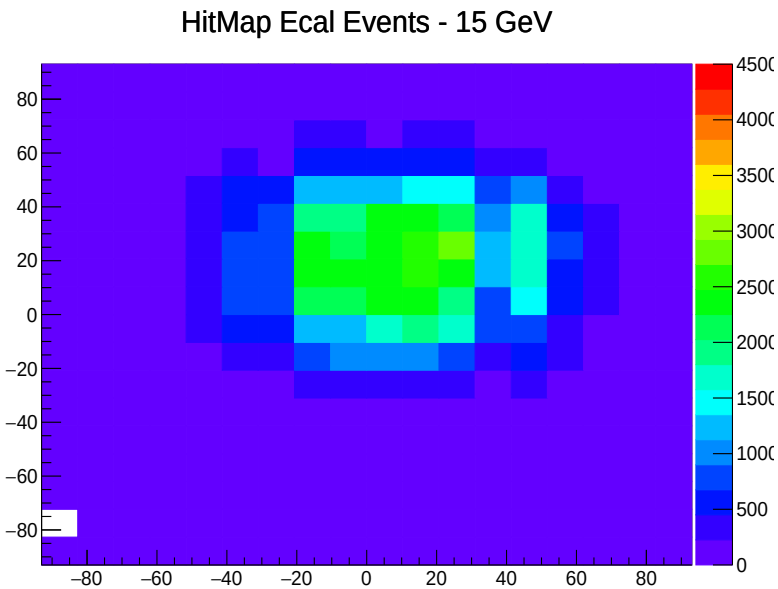


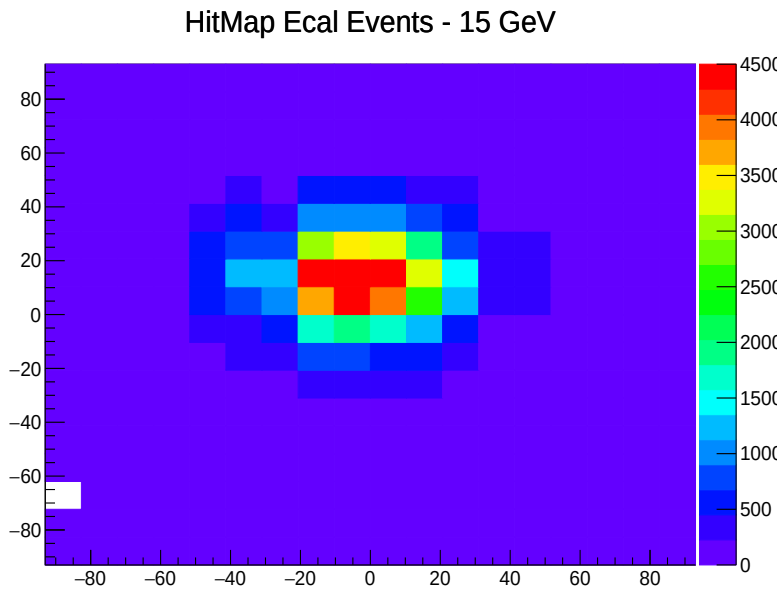


Ecal hitmap : CERN vs FNAL

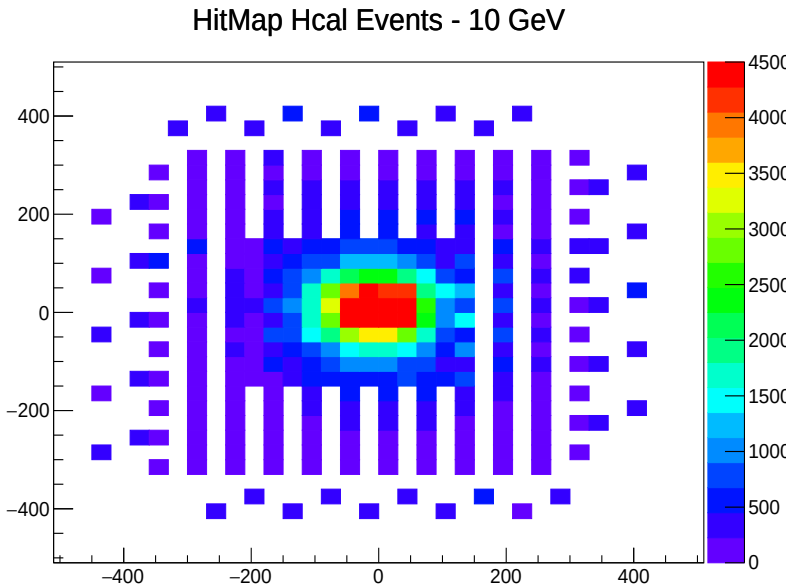


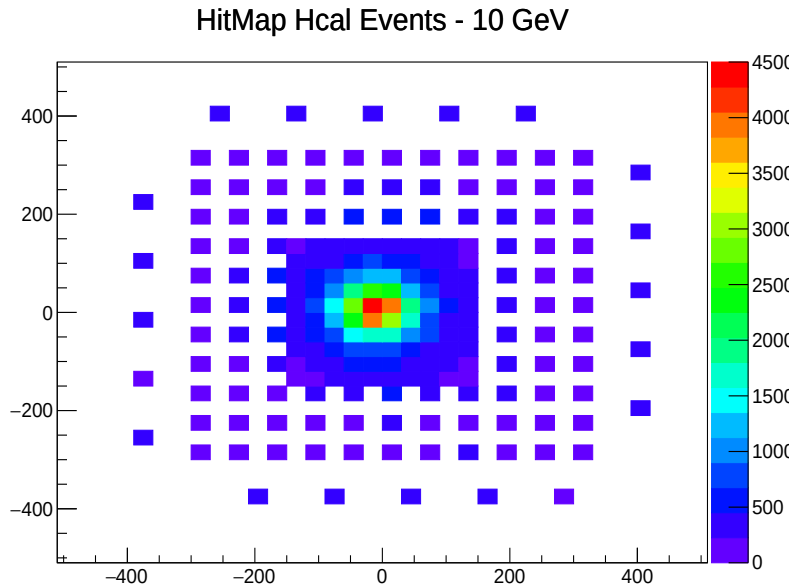


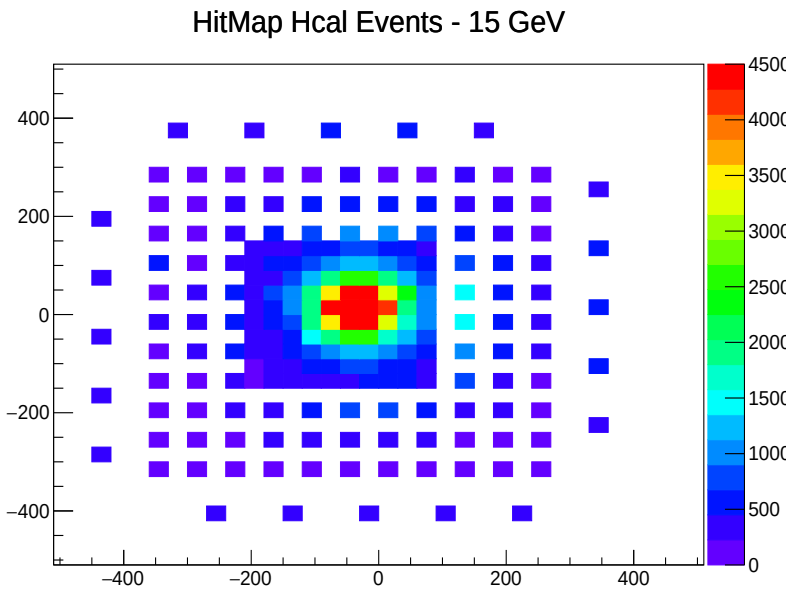


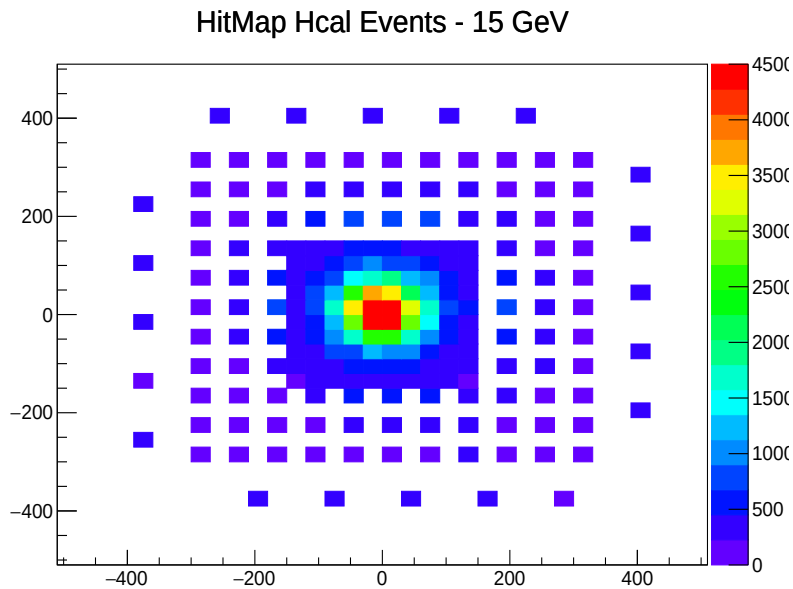


Hcal hitmap : CERN vs FNAL









Event Selection for combined System:

First cut-list:

- Beam trigger
- Empty events: $n_{hits}^{ECAL} < 25$ or $n_{hits}^{HCAL} < 11$
- Not identified events: $E_{reco} < 0.15 E_{beam}$
- Ecal Fail:
  - noisy layers
  - hits outside Ecal center
- Multi-particle events:
  - $E_{reco} > (E_{beam} + 2.4\sqrt{E_{beam}})$
  - multiplicity counter
- Muons cut: hits in TCMT>11 (for $E_{beam} < 60$)
- Cherenkov counter

Second cut-list:

- Only one MIP in Ecal
- Electron cut: removing FHI<6
- Late Shower and Muon cut:
  removing FHI>55 and no interaction