Positive Hadrons at CALICE Hadron Calorimeter

ITEP team

CALICE/EUDET AHCAL meeting, DESY, December 200

Plan

1. **Runs: rejection, alignment, selection**
2. **Energy scale and particle identification**
3. **Common run properties**
4. **Longitudinal and transversal distributions**
5. **Difference between π^+ and proton**
6. **Conclusion**

Simulation is under way.

2007 run list and reasons for run rejection

e^- **30 GeV:** 330385, 330430 e^+ **30 GeV:** 331314, 331436

π^- **35 GeV:** 330551, 330557, 330561, 330569, 330590, 330596, 330960

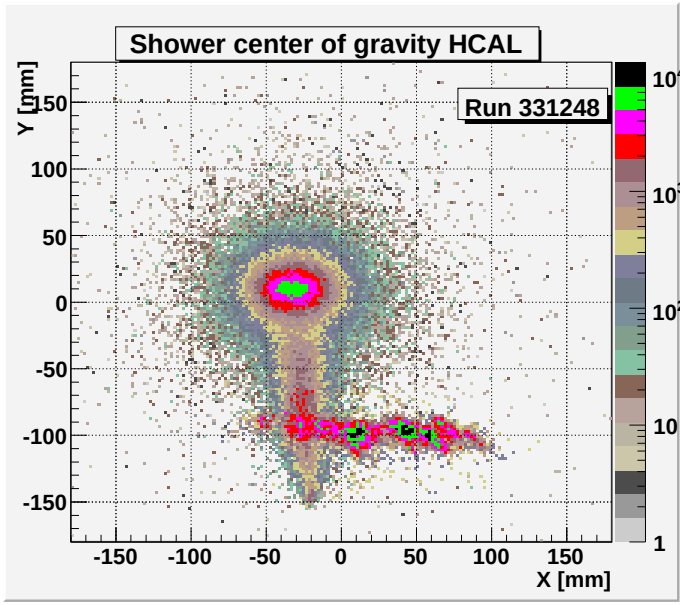
π^- **40 GeV:** 330274, 330437, 330440, 330466, 330511, 330560, 330570, 330591, 330600

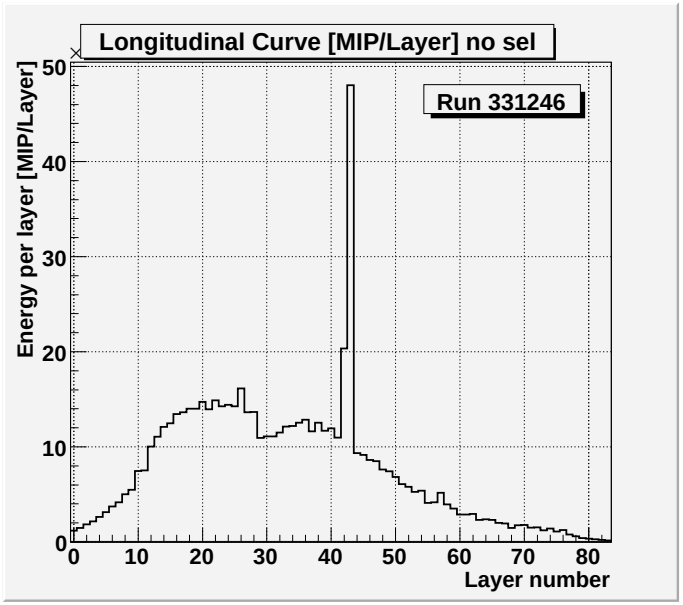
π^- **50 GeV:** 330273, 330283, 330411, 330436, 330467, 330516, 330558, 330589

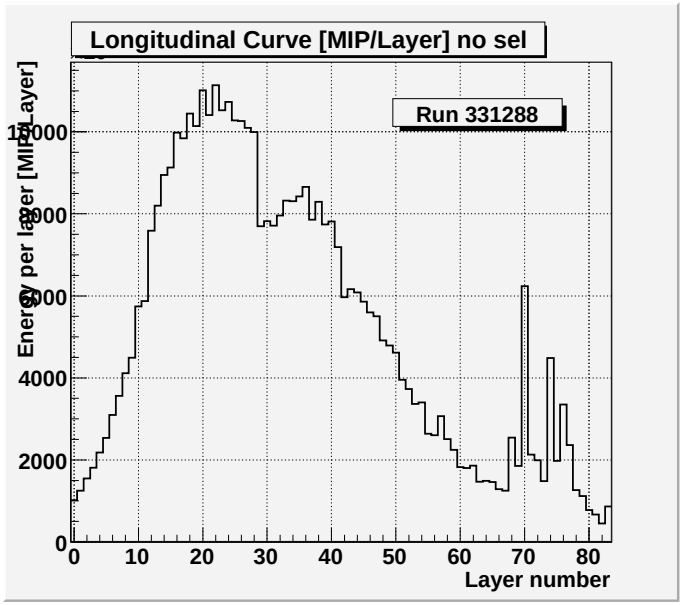
π^+ **30 GeV:** 331251, 331296, 331298, 331340, 331341, 331431, 331432

π^+ **40 GeV:** 331248, 331249, 331250, 331287, 331288, 331290, 331338, 331339

π^+ **50 GeV:** 331246, 331284, 331285, 331286, 331335, 331337



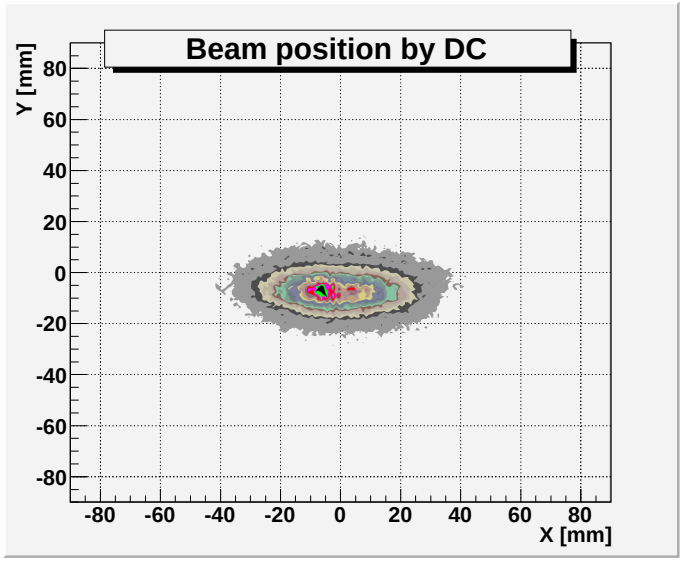


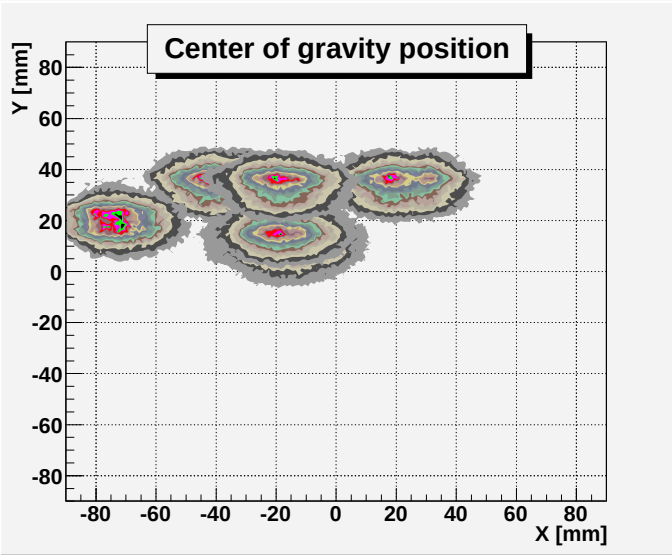


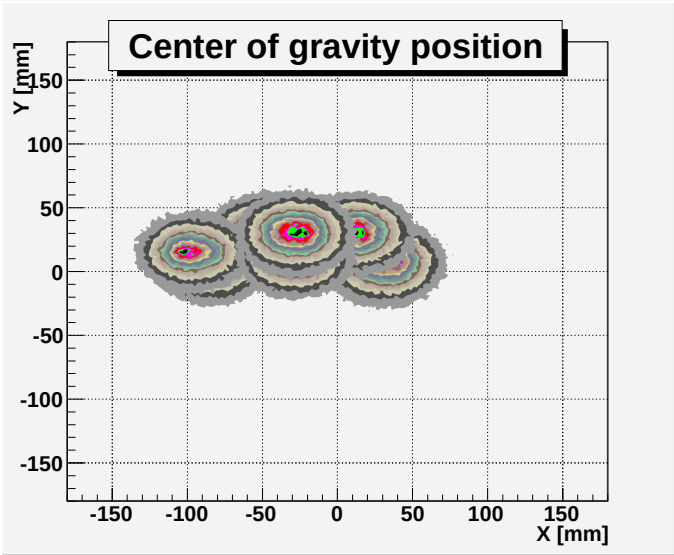
Noise in HCAL or bad calibration or proton purity (we have ignored an existing noise in ECAL)

Calorimeters alignment

Beam position is usually stable (more or less) **ECAL** **HCAL**







Here is of about seven runs with the same beam energy and particle type.

Almost each run has its own position of center of gravity that is vary in different calorimeters

We had chosen the central axis of beam to be a reference axis for each particular run.

Special alignment database was created for all these runs

If we need an exact axis for particular event we had used Drift Chambers beam prediction in addition.

Run energy calibration check

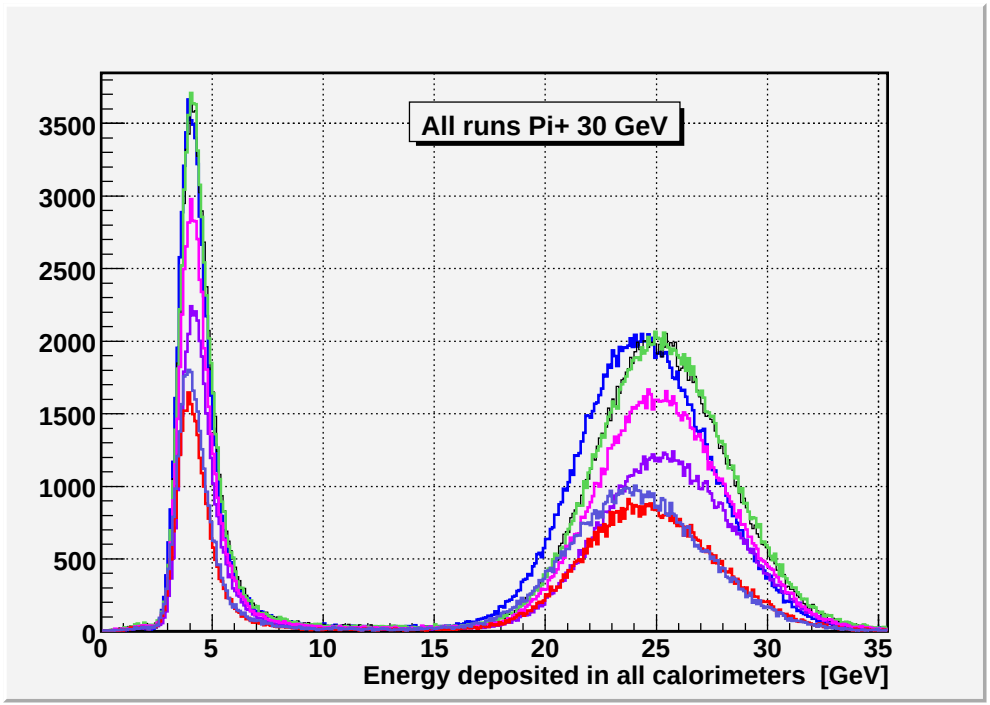
ECAL coeffs: $3.09/266.;\ 2.09/266.;\ 1.09/266.;$ **(odd);** $3.0/266.;\ 2.0/266.;\ 1.0/266.;$ **(even)**

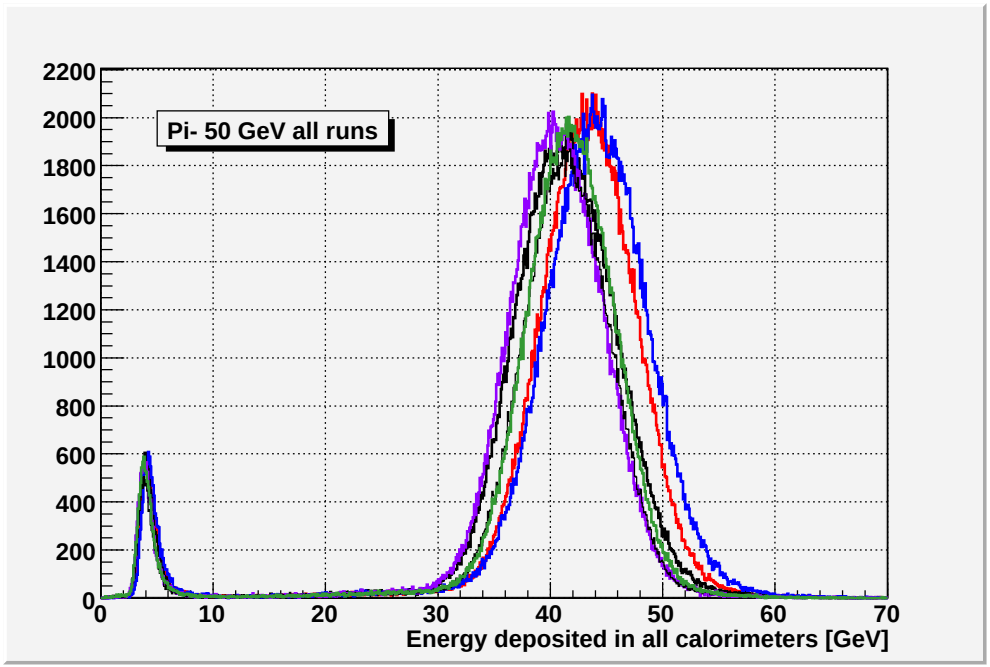
For HCAL we used: $MIP_{vis} = 875.0$ **[keV];**

$$hcal = 28.62 * MIP_{vis};\quad tcmt1 = 28.62 * MIP_{vis};\quad tcmt2 = 28.62 * 5.0 * MIP_{vis};$$

Such energy calibration leads to correct reconstructed energy for electron beam in both calorimeters.

We had observed a significant difference in measured energy for runs with formally the same energy of beam particles in the electromagnetic scale.



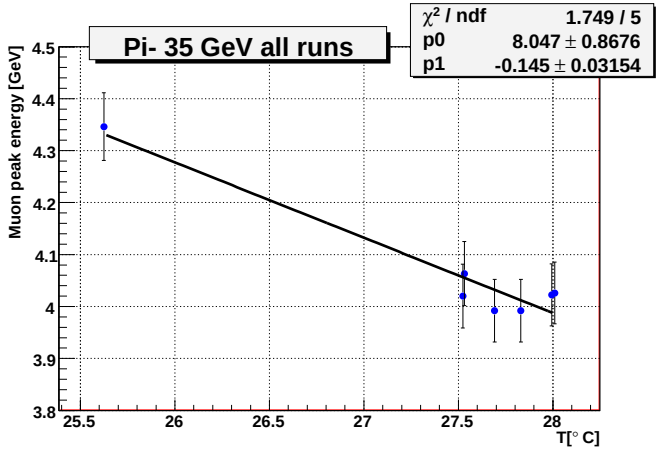


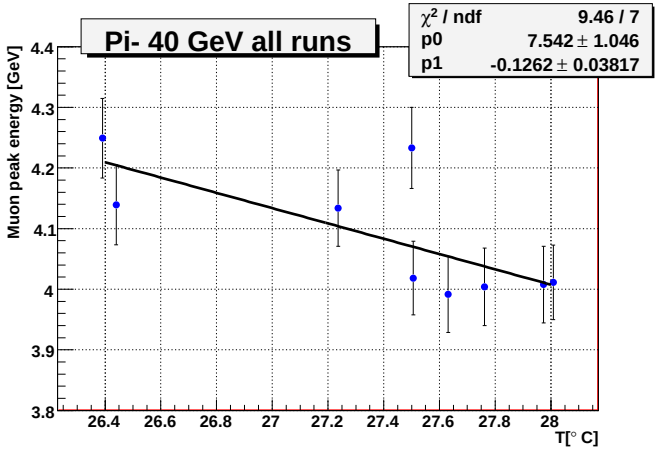
One of the reasons could be a temperature dependence of SiPM response.

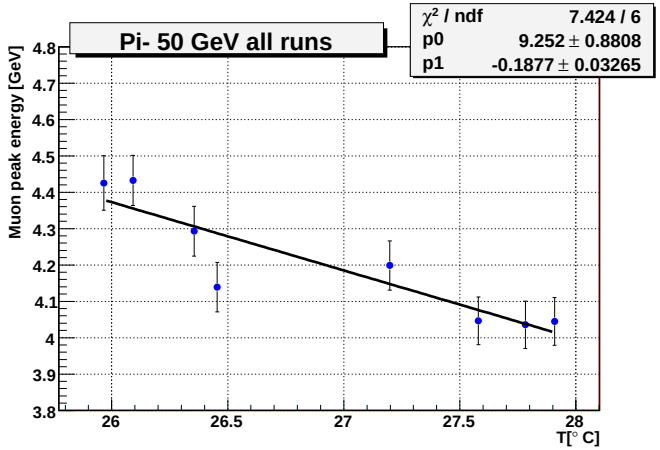
Temperature correction of muon calibration coefficients was not applied yet.

Temperature dependence

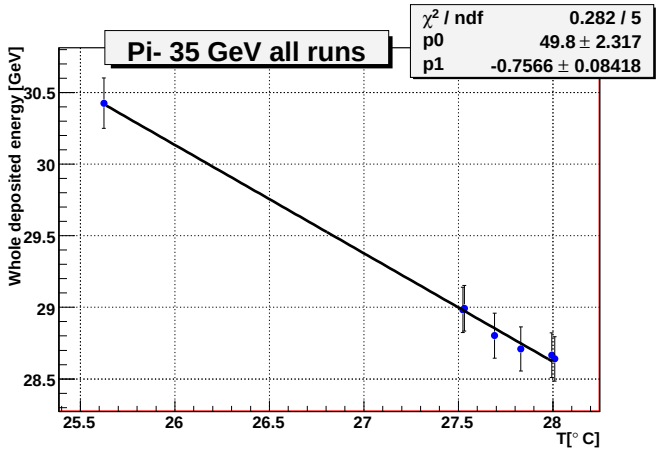
Muon peaks

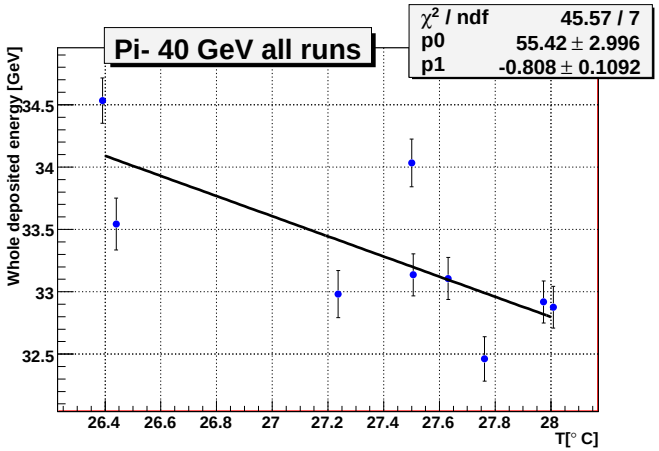


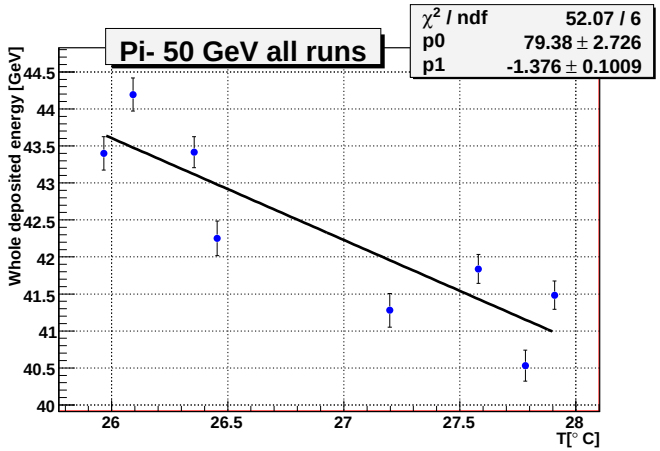




Hadron peaks





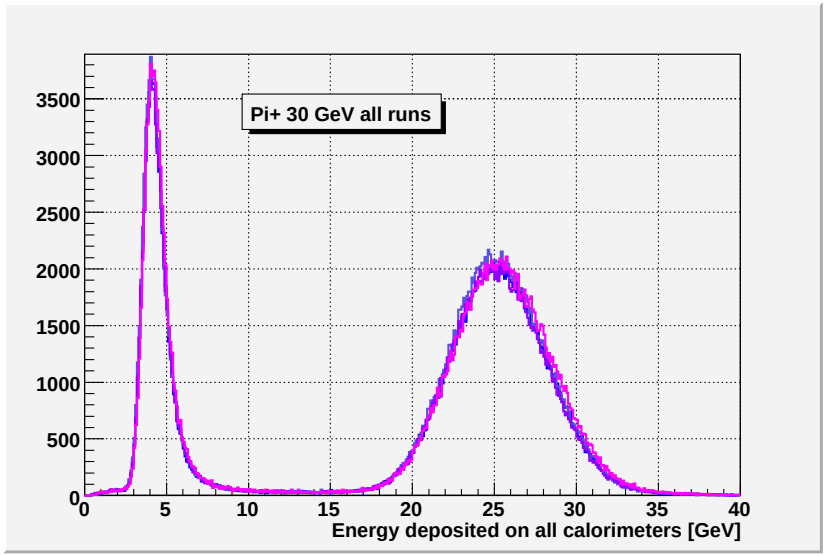


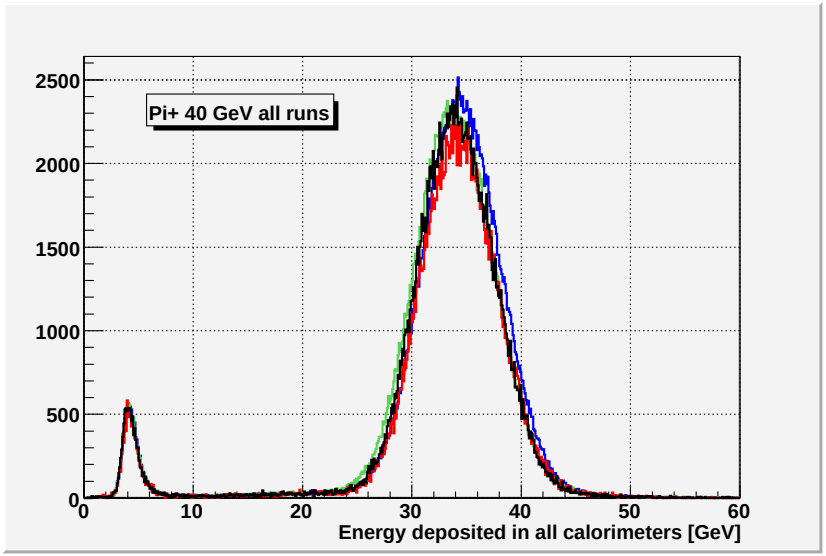
Correlation is visible, but a large spread of amplitudes does not allow to apply any reasonable correction.

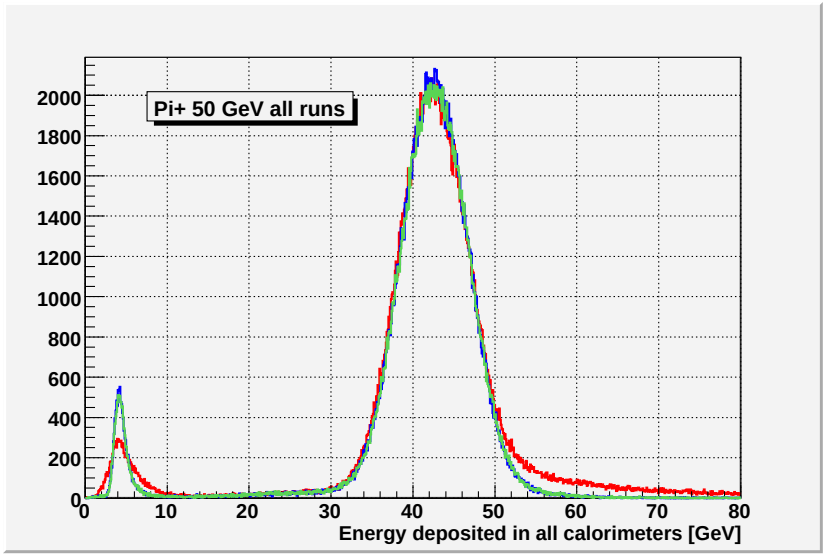
Some other factors are represented here as well.

For positive beam calorimeter temperature maps does not exist yet.

Run energy calibration check (positive)



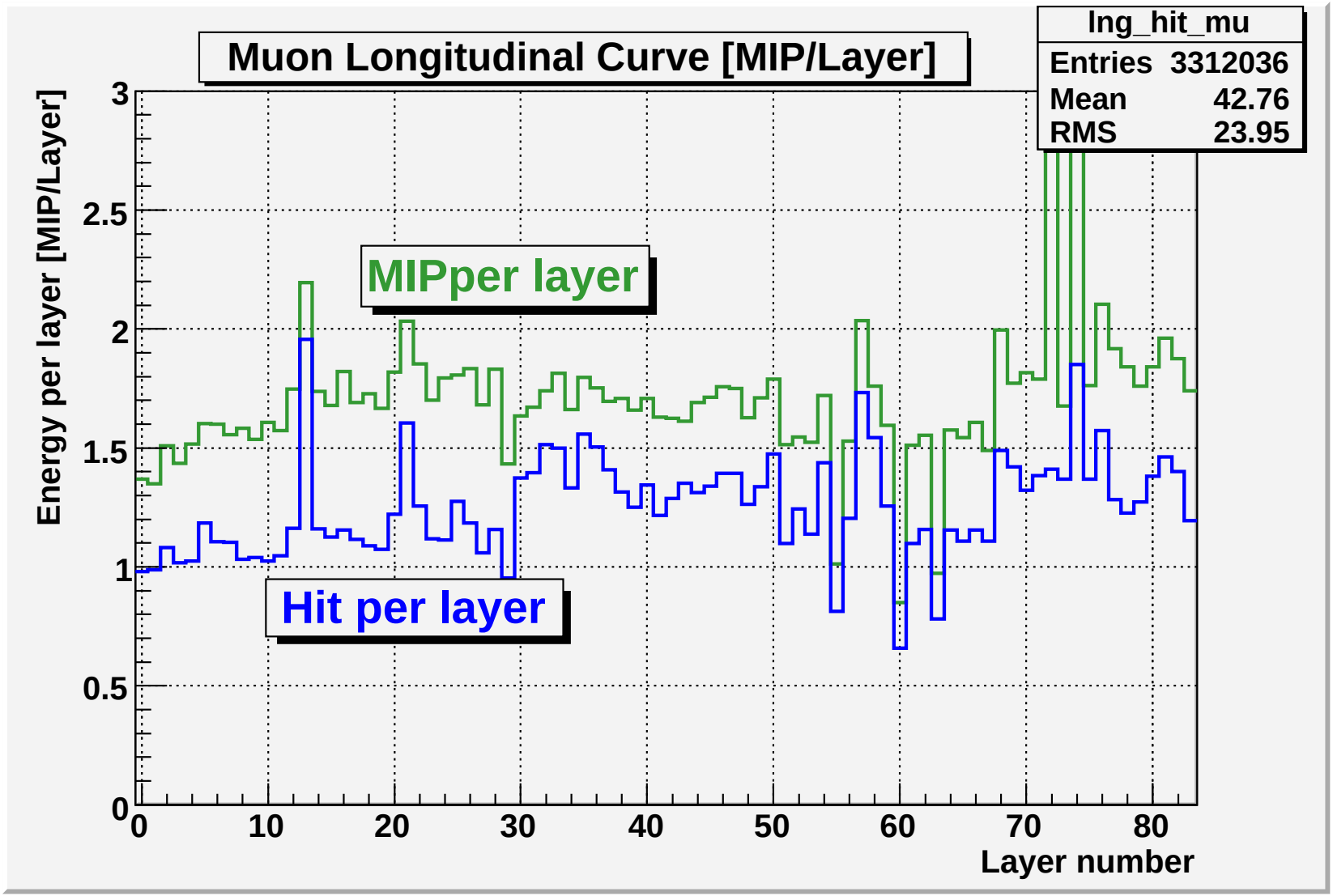




Run in red was rejected

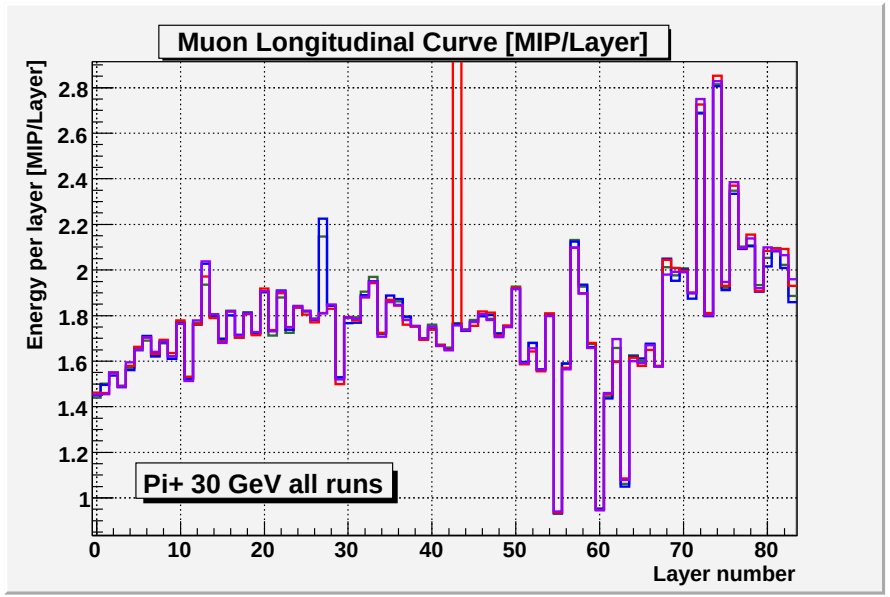
For positive beam we had chosen runs that have the same shape of energy distribution.

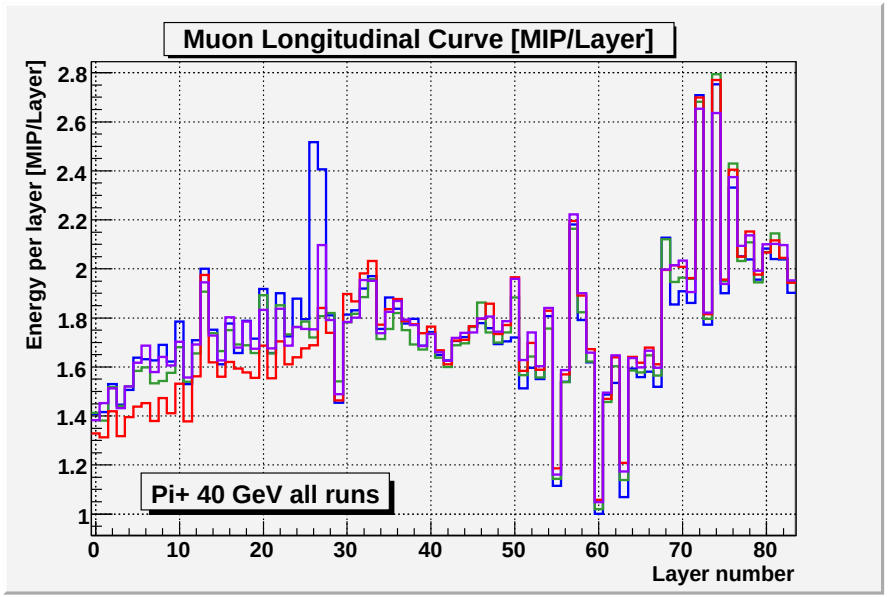
Muon calibration

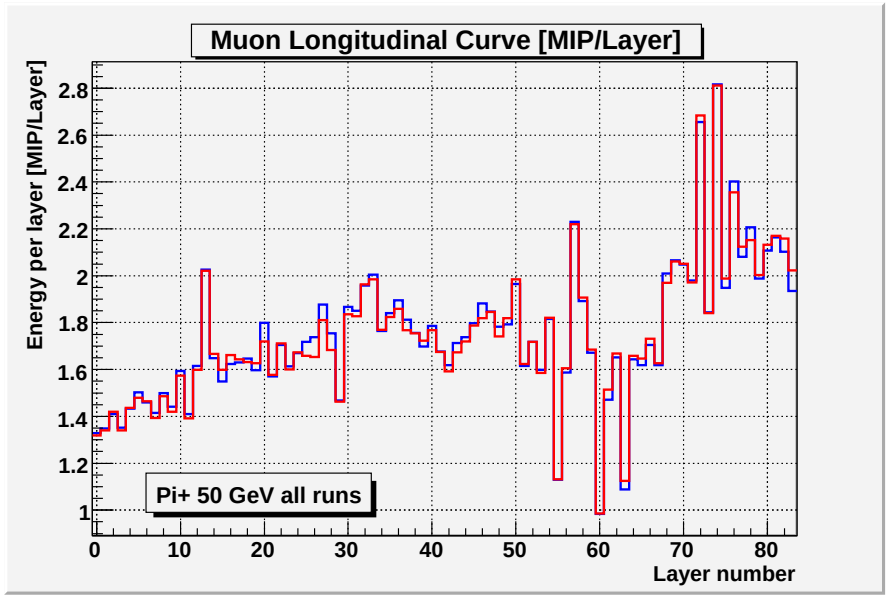


Efficiency to register of muon is good enough to see more than one hit per layer.

Energy calibration quality by muons



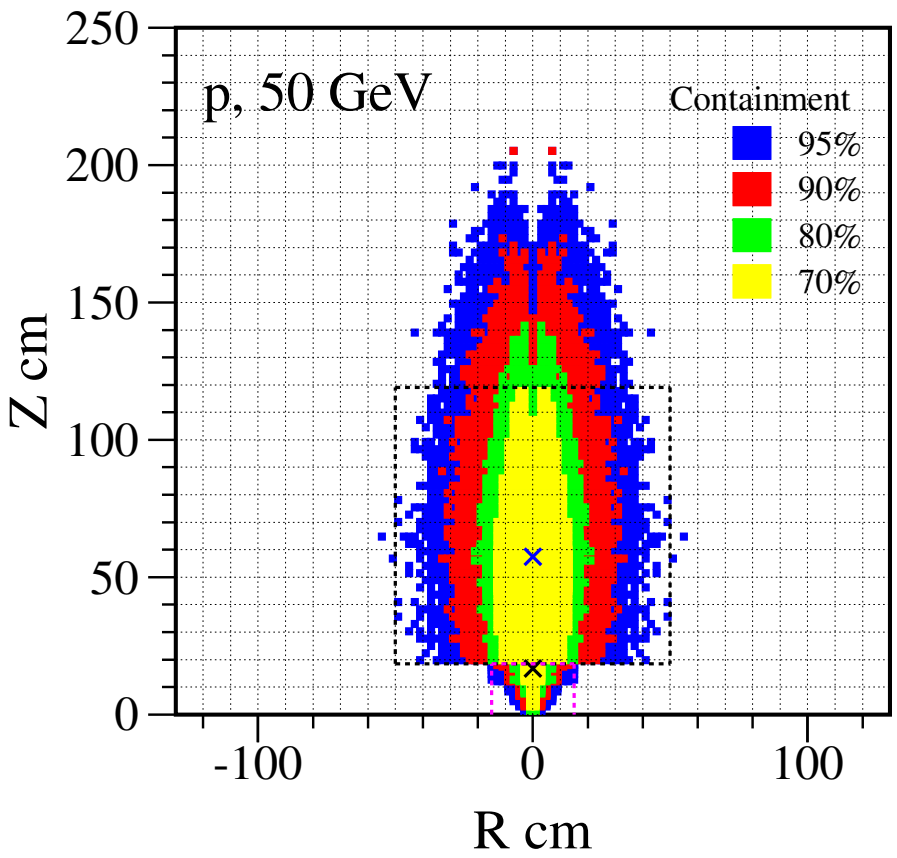




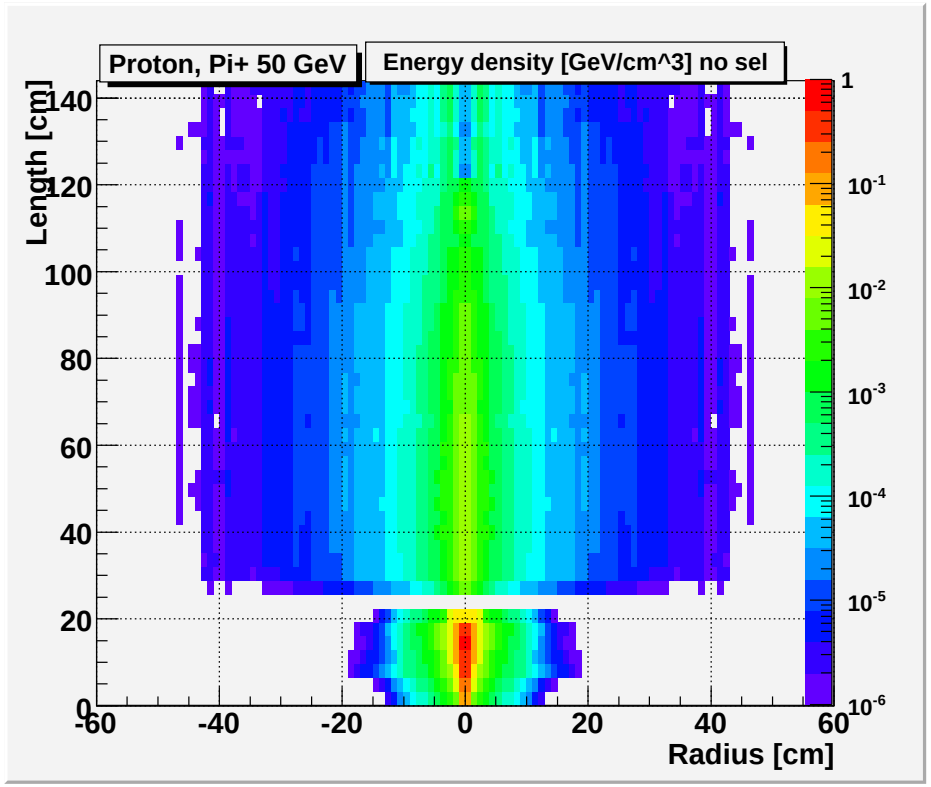
These longitudinal curves include whole signal at each layer but not only cells that crossed by muon track.

Mean value of Landau distribution should be of about 1.5 of most probable value (MPV). HCAL calibration was done in the way that MPV of each tile is equal 1.0 with accuracy of about 3-5%. What we see here is the effect of noise, when value is larger then expected; and effect of existence of dead cells in the case of value is smaller than expected. Any case it is a calibration quality for now.

Dreams and reality



Prediction at July 2003



CALICE Run 331335 at August 2007

At this picture one can see the disadvantages of reality, first of all a gap between ECAL and HCAL;

that will lead to impossibility to use ECAL for analysis of hadron showers.

A few words about ECAL using

We will use ECAL as a dead material in front of HCAL; just ask a track in ECAL, and how much energy was lost in its volume; to correct of injected particle energy.

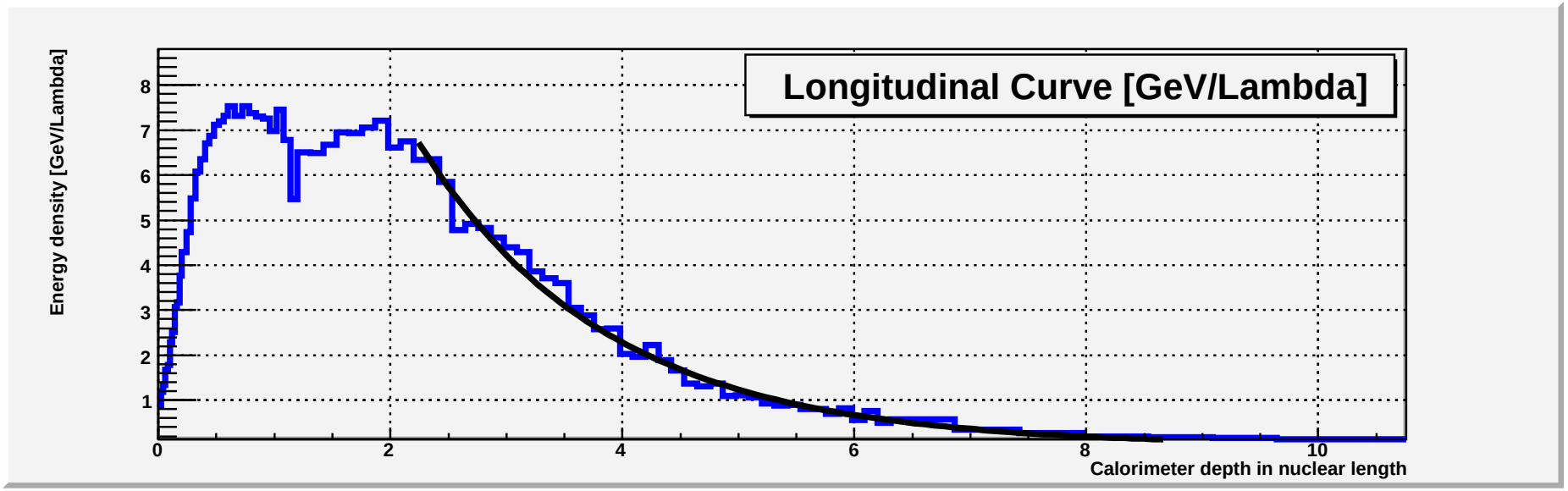
Tree reasons:

1. ECAL was rather noisy at these runs.

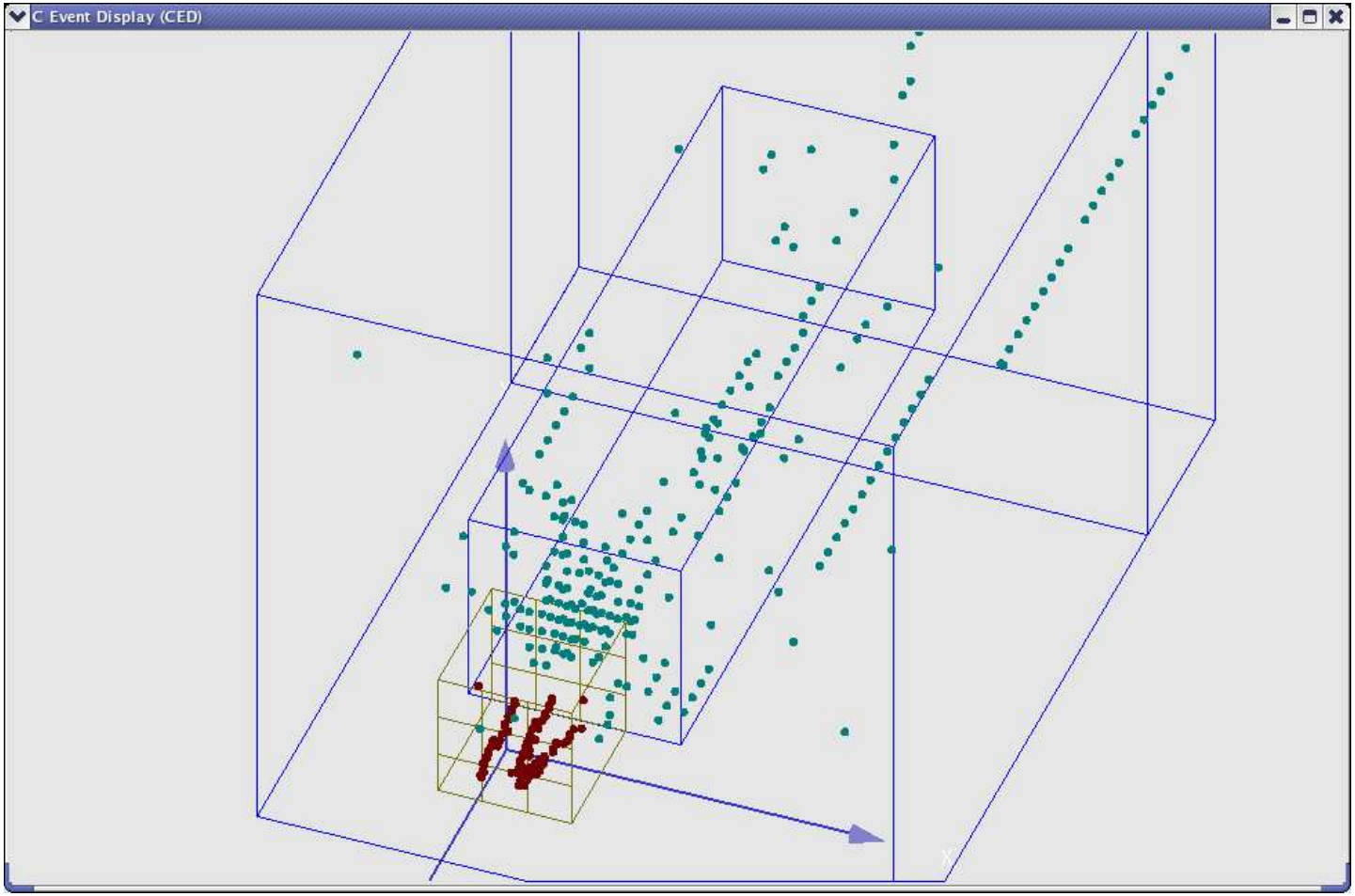
2. More significant: ECAL is too small to keep an information about hadron shower, even if shower is started at the middle of ECAL. Hadron shower is wide but ECAL consists of big amount of dead material around small sensitive region (electronics and additional tungsten), that dead materials absorbed energy, and it does not allow to measure correctly particles passed through the ECAL and could be caught by much wider HCAl front layers.

3. Significantly large gap between calorimeters; it changes spatial density of hadron shower.

Both 2,3 leads to energy losses at the top of shower development.



Event rejection

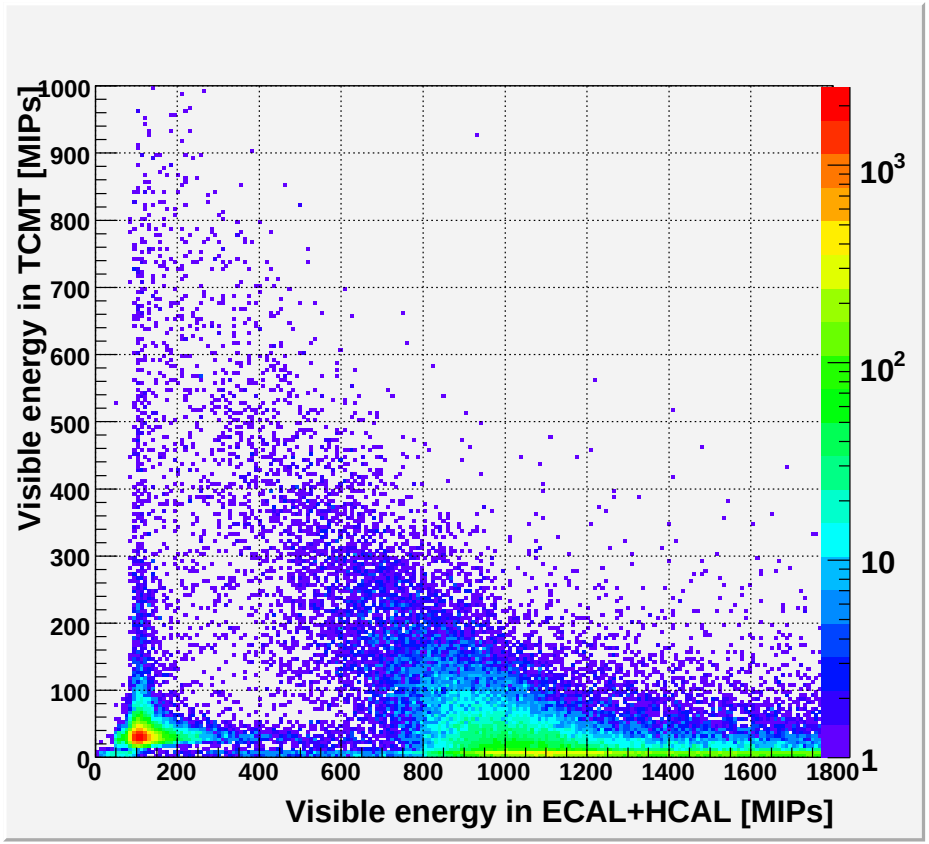


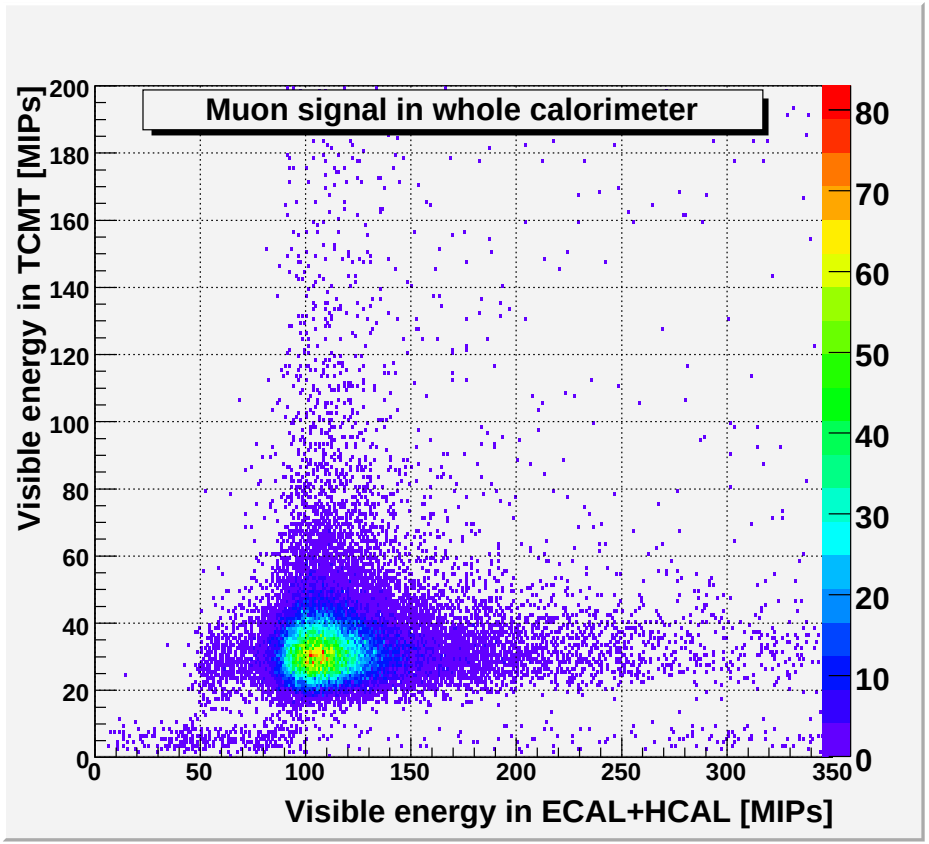
Typical event that we called “trash”. They could be found using defense ring made by first 5 layers of HCAL starting from radius 28 cm up to the biggest calorimeter radius. If energy in that ring is larger than 1 GeV or number of hits is larger than 13, event is called ”trash”; and it never used in analysis.

The same kind of ”trash” is visible in Monte–Carlo events, its generated at the beam line, UNNEEDED.

Muon Identification

It's easy to find muons due to a large beam energy used in analysis (30 – 50 GeV).





We cut left bottom corner with visible spot originated by muons; and exclude a pure noise visible spot.

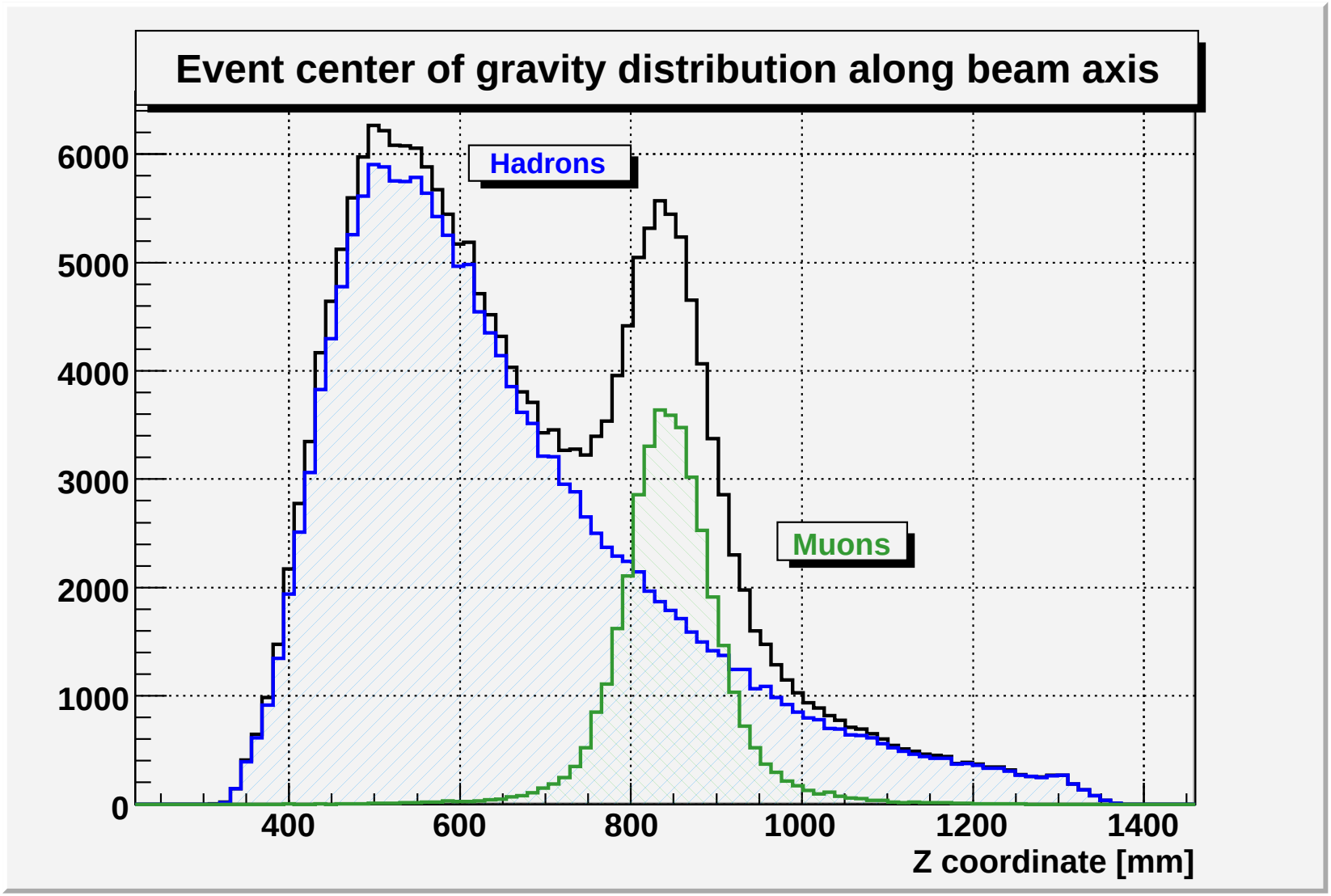
Muon spot is an overlap of two landau distributions in both parts of the calorimeter.

Parameters of muon spot are rather stable from run to run.

Efficiency of this muon ID is of about 100%, so we may use it to find an efficiency of Cherenkov counter and purity of the $proton$ sample.

Center of gravity distributions

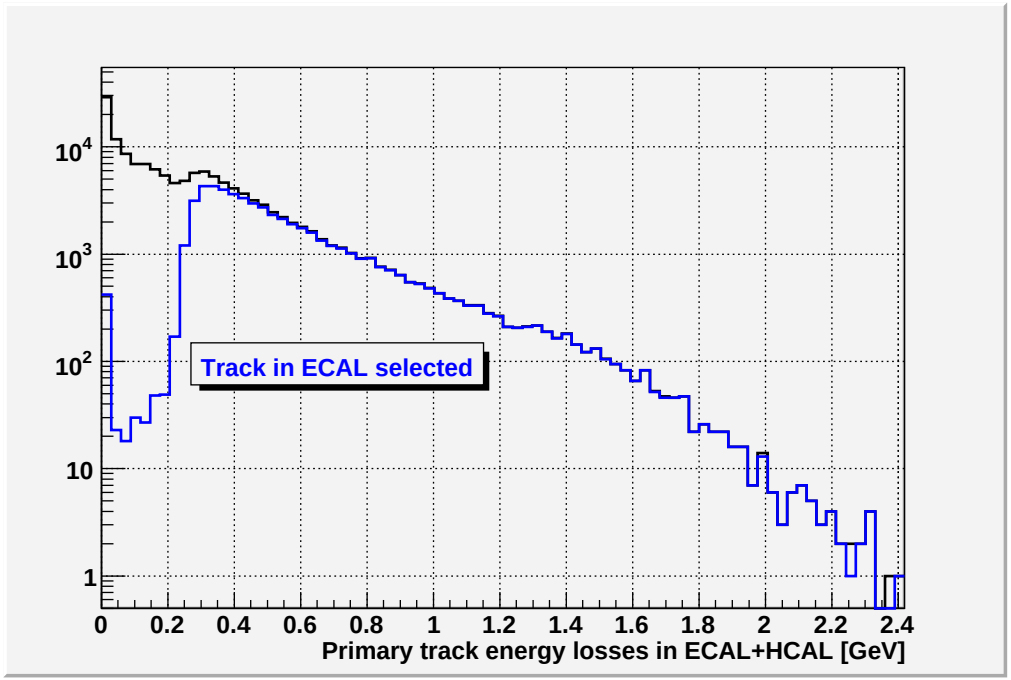
To check the quality of muon identification we show here the distribution of event center of gravity using muon ID.

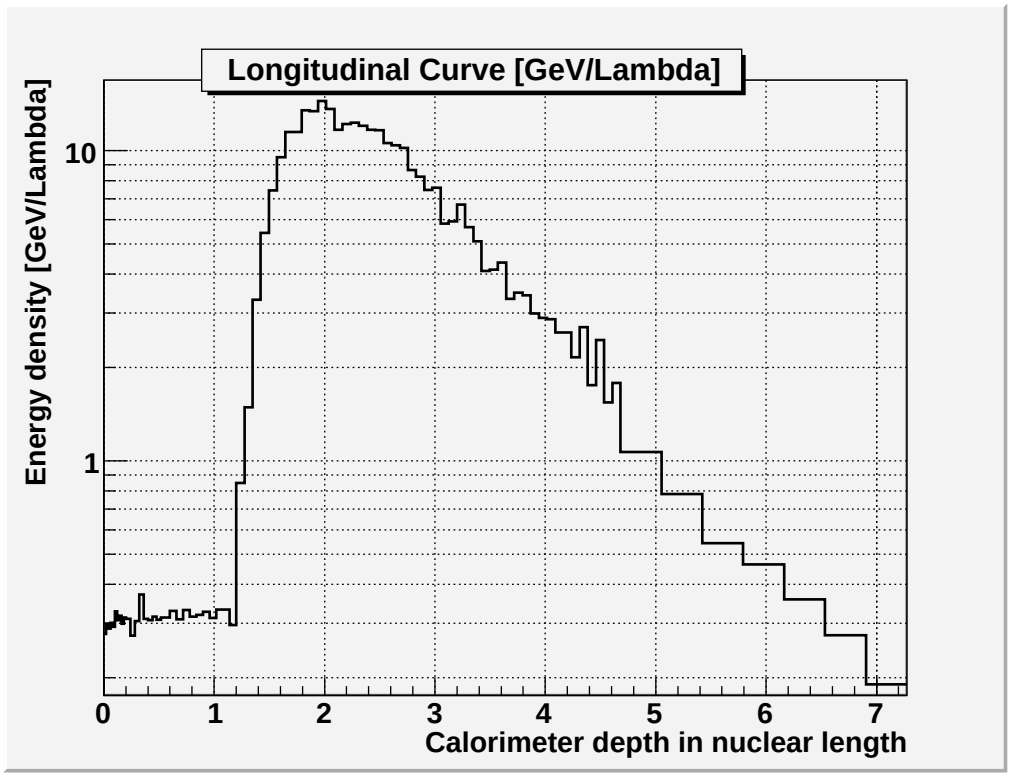


Event selection

When ”trash” and muons were found the rest of positive beam events suppose to be hadrons.

We had ignored of negligible amount of possible positrons in the beam.





We have chosen “Track in ECAL” events for further analysis. Typical shower shape is shown here.

Purity of proton sample

Suggestions:

let: $N^{beam} = N_{\mu}^{beam} + N_{\pi}^{beam} + N_{prot}^{beam}$; positive beam consists of tree type of particles only;

trigger consists of beam counts plus trash;

let: $\epsilon_{\mu}^{calo} = 100\%$ muon identification efficiency by calorimeter; i.e. $N_{\mu}^{beam} = N_{\mu}^{calo}$;

let: $\epsilon_{\mu}^{cher} = N_{\mu}^{cher}/N_{\mu}^{calo}$; cherenkov counter efficiency extracted from beam data for each run separately;

let: $\epsilon_{\mu}^{cher} = \epsilon_{\pi}^{cher}$; cherenkov counter efficiency the same for pions and muons at these energies;

then: $N_{on}^{cher} = N_{\mu}^{cher} + \epsilon_{\pi}^{cher} \times N_{\pi}^{beam}$; $\Rightarrow$ $N_{\pi}^{beam} = (N_{on}^{cher} - N_{\mu}^{cher})/\epsilon_{\pi}^{cher}$;

then: $N_{off}^{cher} = N_{prot}^{beam} + (1-\epsilon) \times (N_{\mu}^{beam} + N_{\pi}^{beam})$ $\Rightarrow$ $N_{prot}^{beam} = N_{off}^{cher} - (1-\epsilon) \times (N_{\mu}^{beam} + N_{\pi}^{beam})$.

So: **Purity of proton sample is:** $N_{prot}^{beam} \ / \ [N_{prot}^{beam} + (N_{\pi}^{beam})(1-\epsilon)]$**;**

Purity of proton sample

Proton sample purity become to be worse with increasing of energy

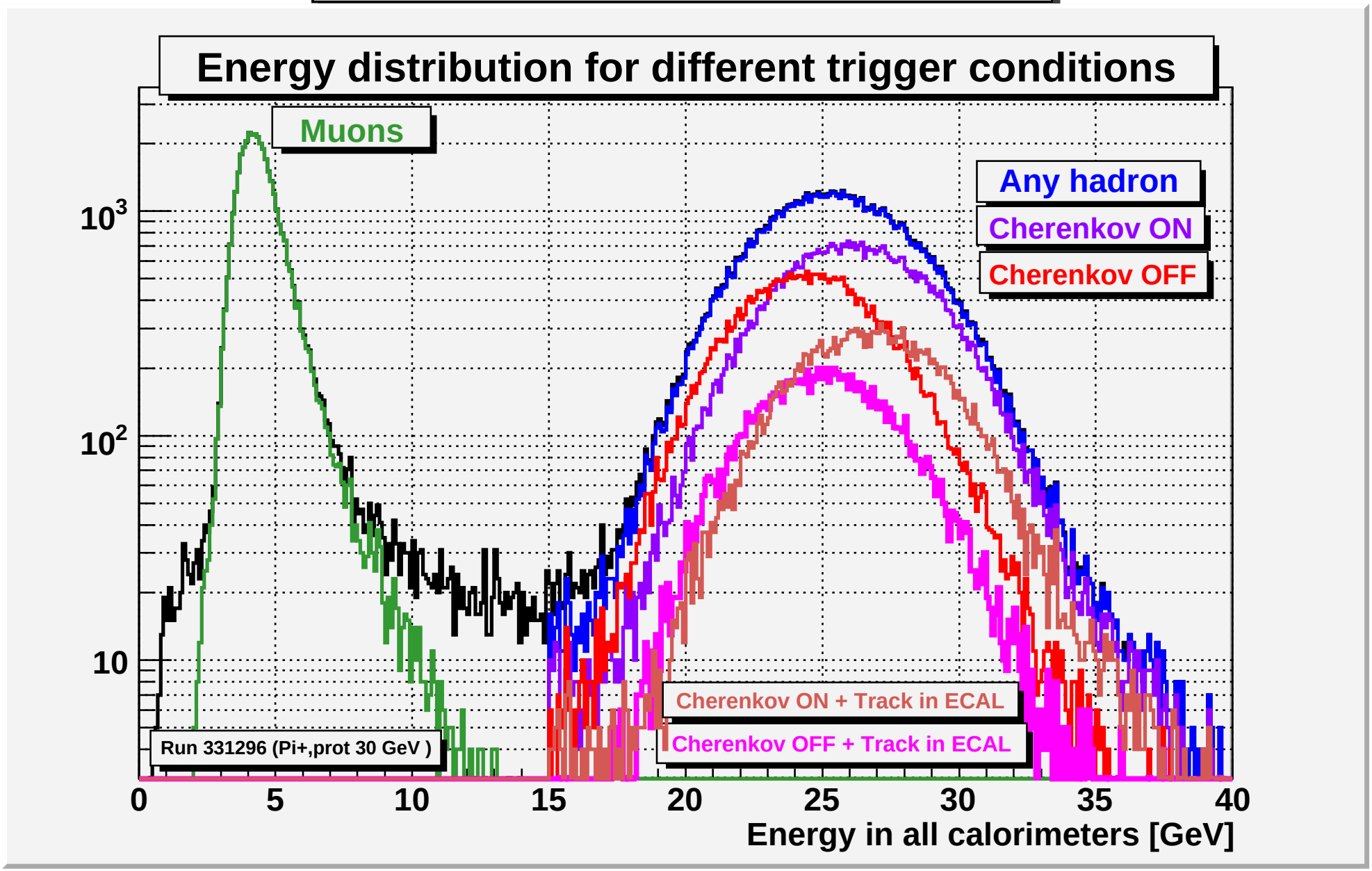
due to less efficiency of Cherenkov counter and significant decreasing of relative number of protons in the beam

Run	N_{trig}	N^{beam}	N_{μ}^{calo}	N_{μ}^{cher}	ϵ_{μ}	N_{on}^{cher}	N_{off}^{cher}	N_{π}^{beam}	N_{prot}^{beam}	Purty
331296	132313	128757	39142	37911	0.97	91192	37565	55011	34604	0.95
331298	214637	208762	63710	61663	0.97	147623	61139	88814	56238	0.95
331340	215560	209659	63454	61510	0.97	147860	61799	89079	57126	0.95
331341	172677	168044	50646	49114	0.97	118640	49404	71695	45703	0.95
331290	74712	72087	3392	3250	0.96	58992	13095	58178	10518	0.81
331338	224082	216140	10011	9644	0.96	177438	38702	174179	31950	0.83
331339	225511	217636	10055	9717	0.97	178182	39454	174325	33256	0.85
331335	227387	217695	9693	9279	0.96	182885	34810	181352	26650	0.77
331337	224884	215155	9438	9070	0.96	180816	34339	178714	27003	0.79

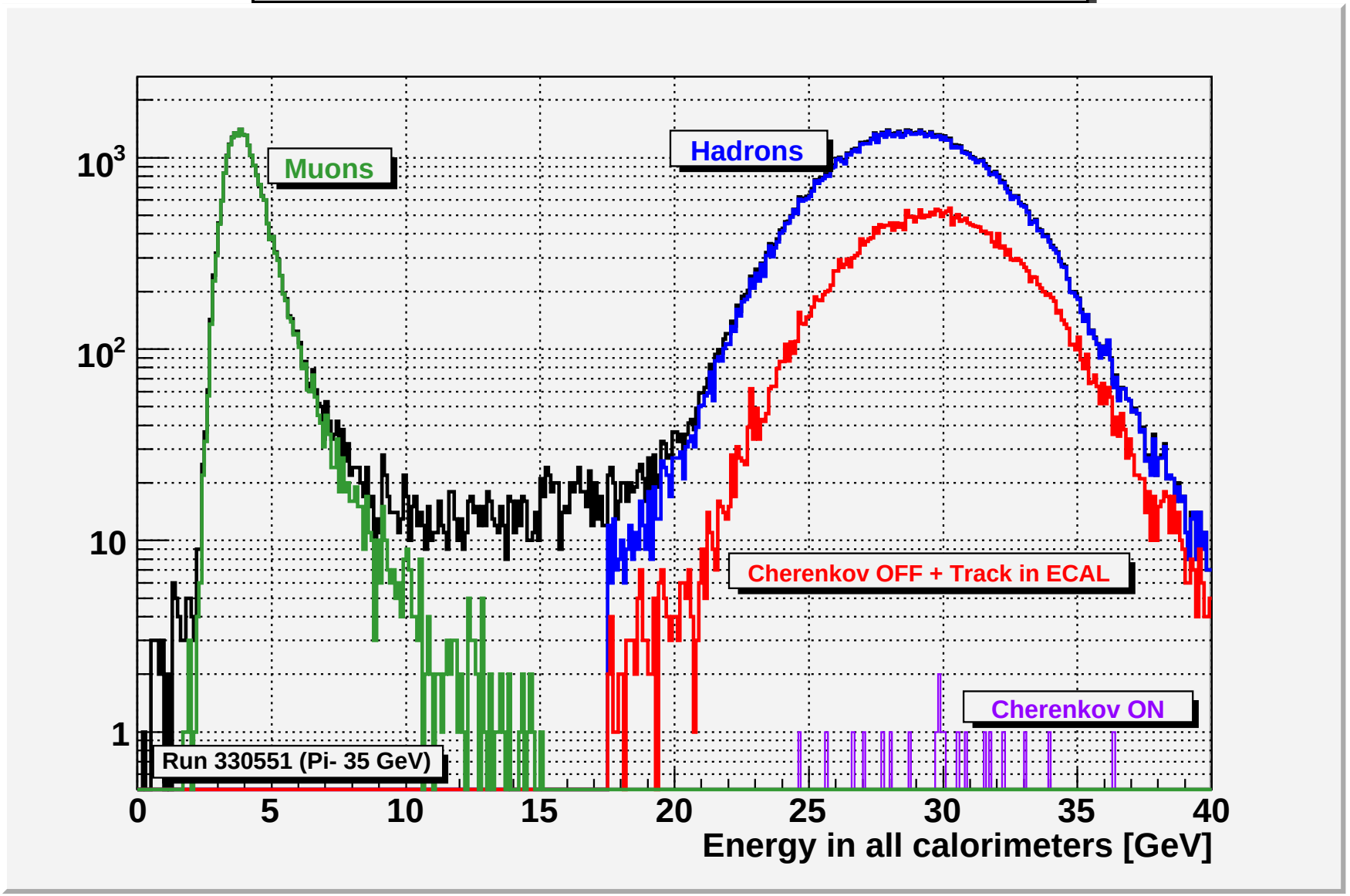
A number of runs were rejected from analysis due to low proton sample purity.

For some runs Cherenkov counter had no correct pressure in it.

Trigger summary (positive beam)



Trigger summary (negative beam)



As it is visible a purity of negative pion beam is good in this particular run.

Common Run Properties (energy sum of all calorimeters)

Run 30 GeV	E μ^+ [GeV]	σ [GeV]	E π^+ [GeV]	σ [GeV]	E $proton$ [GeV]	σ [GeV]
331296	4.36	0.668	26.72	2.84	25.10	2.70
331298	4.32	0.672	26.34	2.81	24.73	2.57
331340	4.31	0.665	26.43	2.82	24.80	2.59
331341	4.28	0.664	26.32	2.79	24.72	2.59
Run 40 GeV	**E μ^+ [GeV]**	**σ [GeV]**	**E π^+ [GeV]**	**σ [GeV]**	**E $proton$ [GeV]**	**σ [GeV]**
331290	4.30	0.679	35.07	3.31	33.36	2.91
331338	4.32	0.689	35.43	3.39	33.62	3.09
331339	4.33	0.680	35.44	3.37	33.63	3.11
	μ^-		π^-			
330560	4.00	0.613	33.65	3.24		
330570	4.01	0.598	33.60	3.20		
330591	4.02	0.567	33.90	3.27		
330600	3.98	0.609	33.92	3.32		

Run 35 GeV	E μ^- [GeV]	σ [GeV]	E π^- [GeV]	σ [GeV]
330551	3.99	0.584	29.62	2.98
330557	3.99	0.578	29.48	2.95
330561	4.02	0.583	29.46	2.95
330569	4.02	0.586	29.43	2.94
330590	4.06	0.607	29.90	3.08
330596	4.01	0.593	29.90	3.05

Run 50 GeV	E μ^+ [GeV]	σ [GeV]	E π^+ [GeV]	σ [GeV]	E $proton$ [GeV]	σ [GeV]
331335	4.33	0.698	44.30	3.82	42.49	3.51
331337	4.34	0.705	44.35	3.84	42.46	3.51
	μ^-		π^-			
330467	4.19	0.660	43.90	3.82		
330558	4.04	0.636	42.31	3.64		
330589	4.04	0.638	42.79	3.81		

All numbers are valid for conventional energy calibration (see Run energy calibration check)

Next part – Physics

We are trying to investigate differences between three hadron cascades based on these samples:

1. Shower created by π^-

2. Shower created by π^+

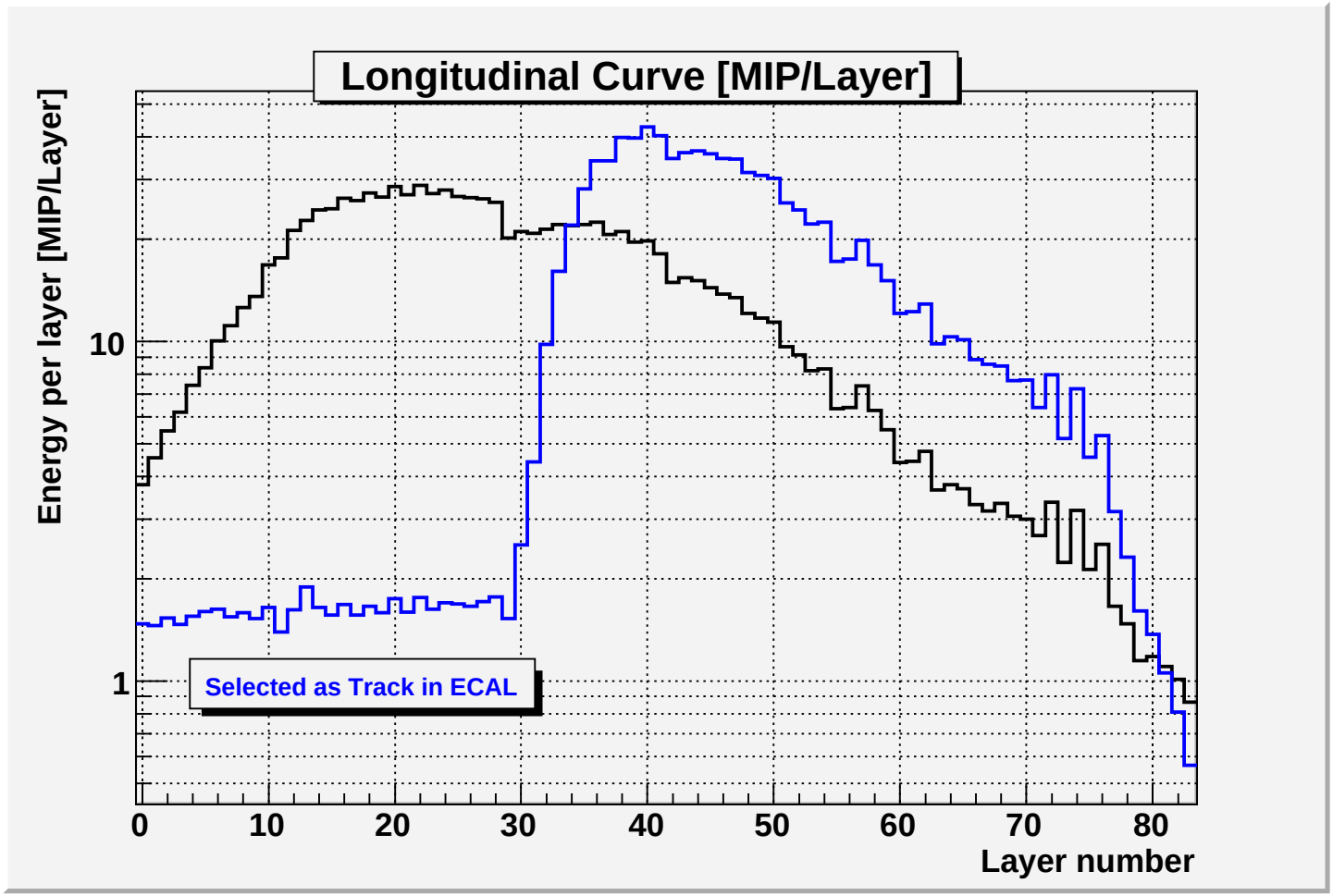
3. Shower created by $proton^+$

The differences should be observable in the total inelastic cross–section; that leads to different length of the primary track (distance from the calorimeter face to the first interaction point (FIP))

Another topic is a difference in the quark content of the π^- π^+ and $proton^+$; that should lead to difference of the yield of π^0 at the FIP. That leads to a difference in the spatial distribution of electromagnetic piece of energy at the beginning of hadron shower; and it could be caught by DeepAnalysis of hadron shower.

This part of work is not finished for lack of reasonable hadron shower model for showers started from FIP
and for lack of model parametrization in terms of energy decomposition into electromagnetic and hadronic parts.

Remarks on the longitudinal shower profile



As it is visible the level of one MIP per layer is reaching after 80–th layer of calorimeter.

Following of this: the calorimeter length should be at least six nuclear interaction length to catch a shower up to the level of one MIP per layer in average !

(last calorimeter layer is 83-th in this enumeration scheme)

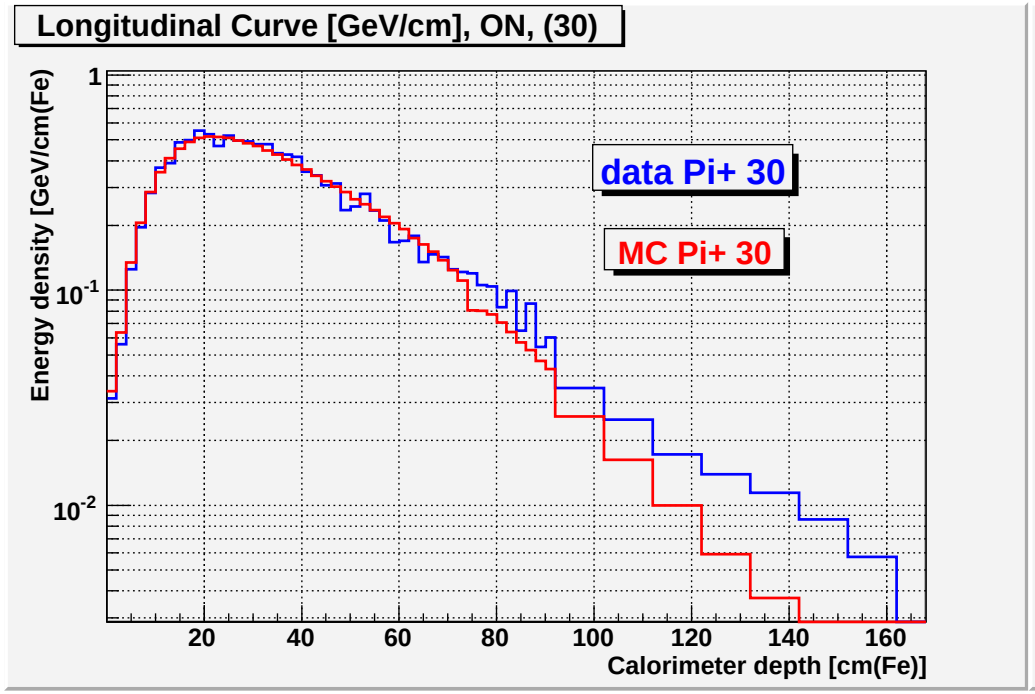
About units for spatial distributions

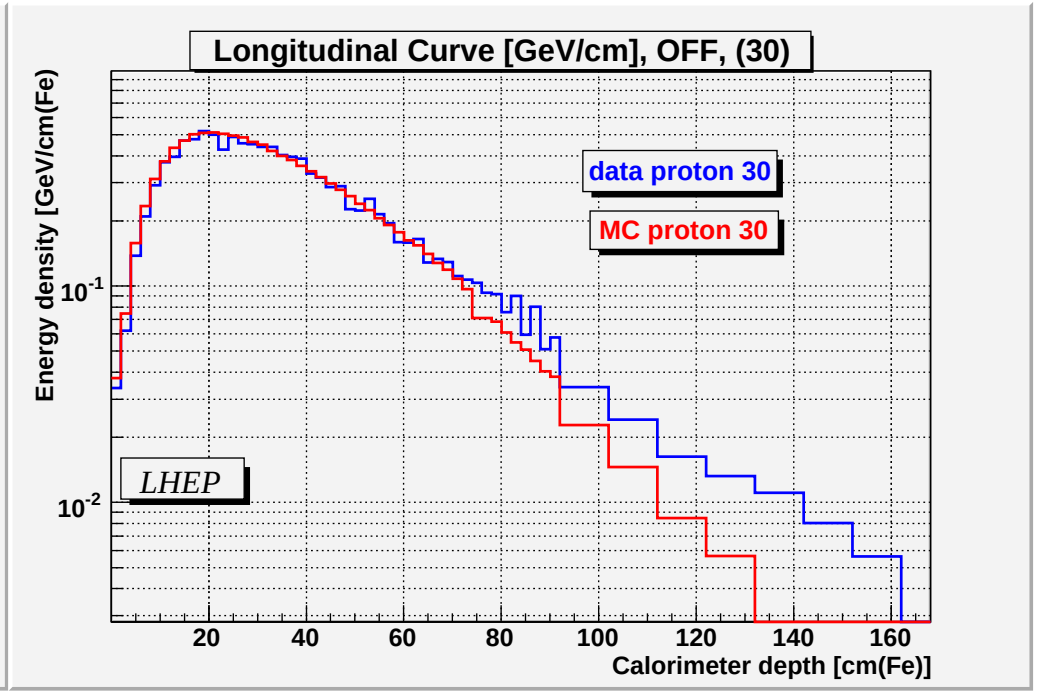
We have chosen [centimeters of pure Iron] as a unit to represent as longitudinal as transversal profiles of hadron shower instead of [Λ] or [cm] in 3–D space. The reason for this is: $1/\overline{\Lambda} = \sum_i w_i/\Lambda_i$. Looking at this equation we can see than the main contribution is Iron; and $\overline{\Lambda}$ is only slightly depends on the presence of the other materials in sampling structure.

Transversal case is not so simple, because of distribution of particles in perpendicular direction to the sampling structure proportional of usual centimeters in Z and so the difference in the cross–sections of Iron and atoms in scintillator is more significant that in the longitudinal case. But we still will use a [cm of pure Iron] to get a regular 3–D representation of any distributions.

In the case of using of [Λ] as a unit; that could be defined from total inelastic cross–section as $\Lambda \sim 1/\sigma_{tot}$.
We actually do not know neither type of particle nor its energy in the shower to find a $\sigma_{tot}(ID, Enr)$ that is a function of both variables.

Longitudinal Shower Profile



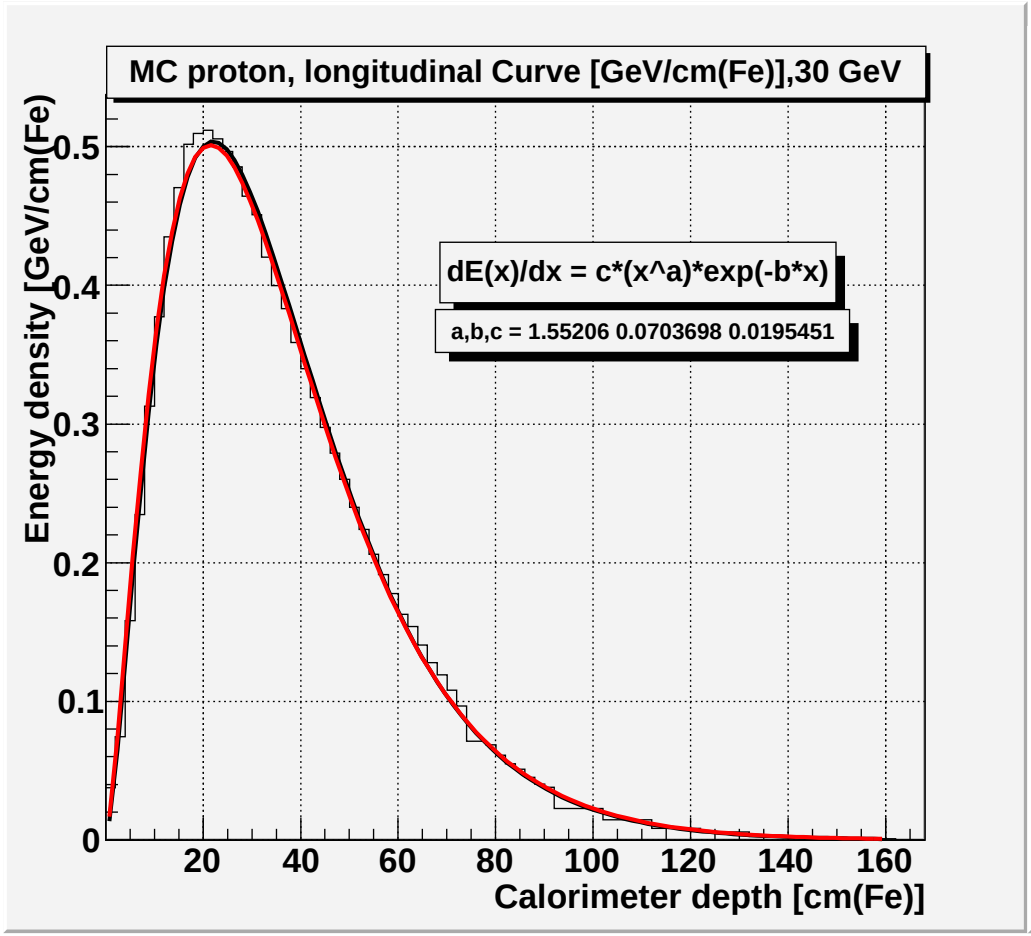


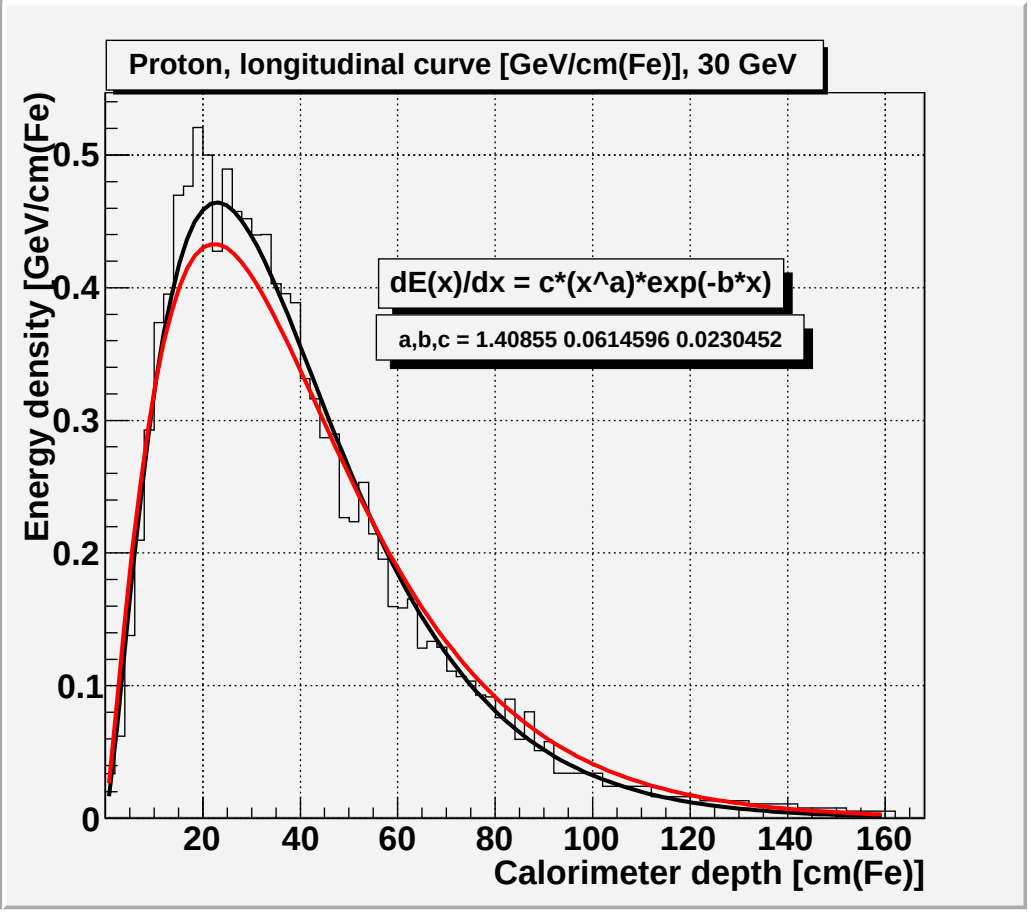
There is a visible large discrepance between MC and data at the tail of hadron shower.

We could not compare with QGSP–BERTINI physics list because it was simulated without application of Birks law and time cut.

Thanks to Shaojn Lu (MPI, Munchen) for Monte–Carlo simulations.

Longitudinal Shower Profile

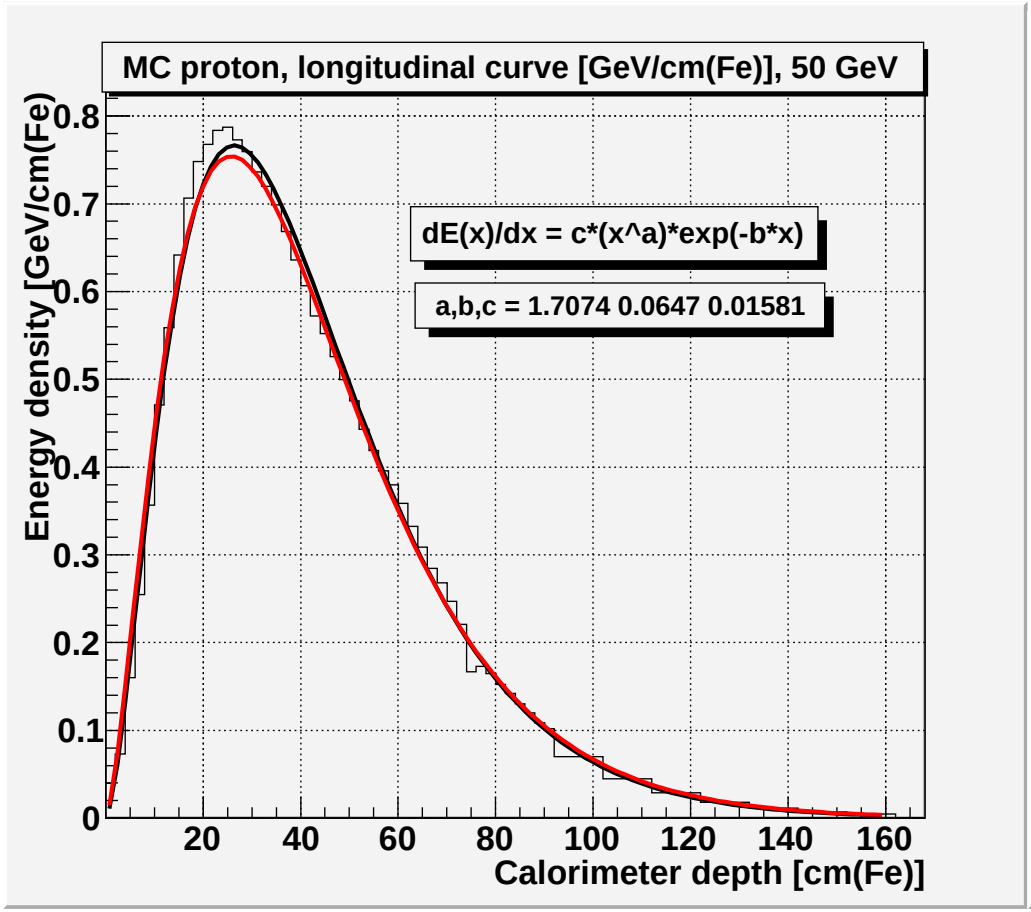


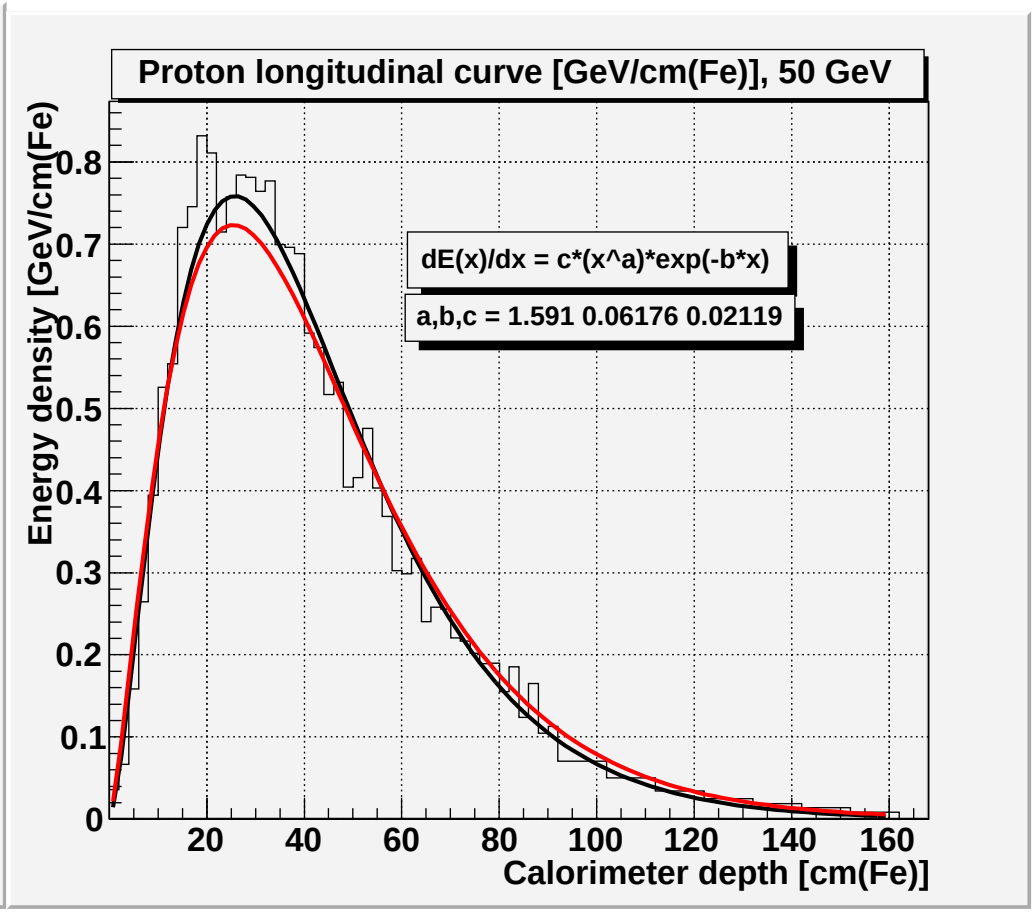


A conventional definition of longitudinal shower shape defined as: $dE/dl = l^{\beta} \times exp(-l/\Lambda_{calo})$

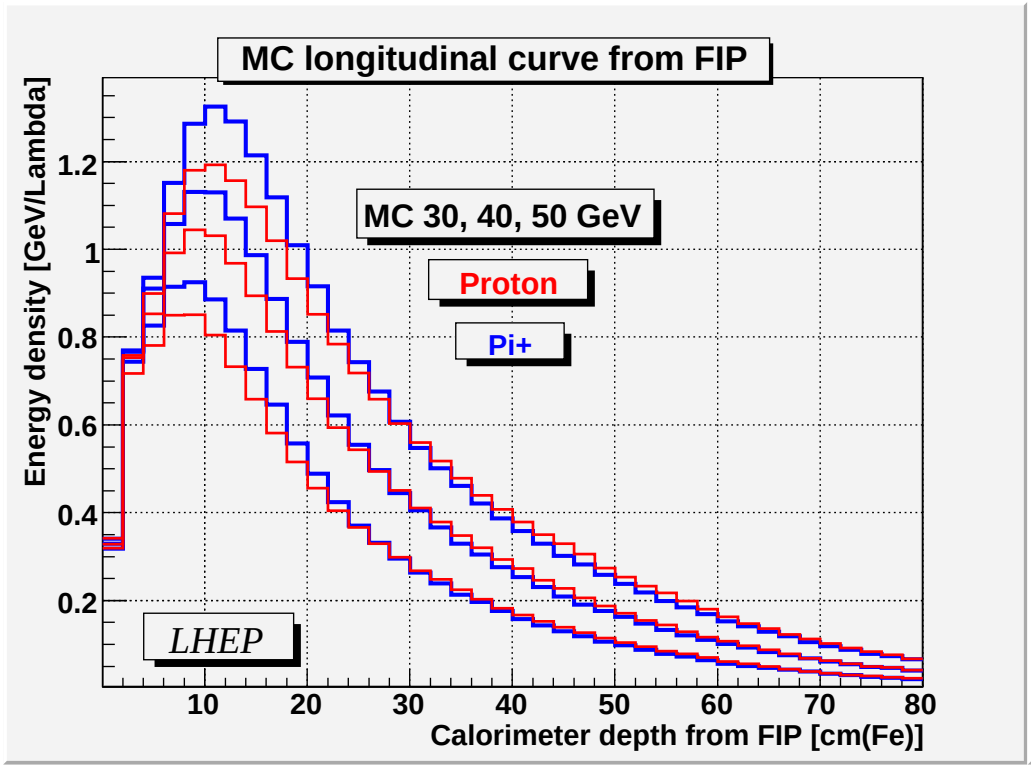
is well fitted to the MC but much worse with the real data.

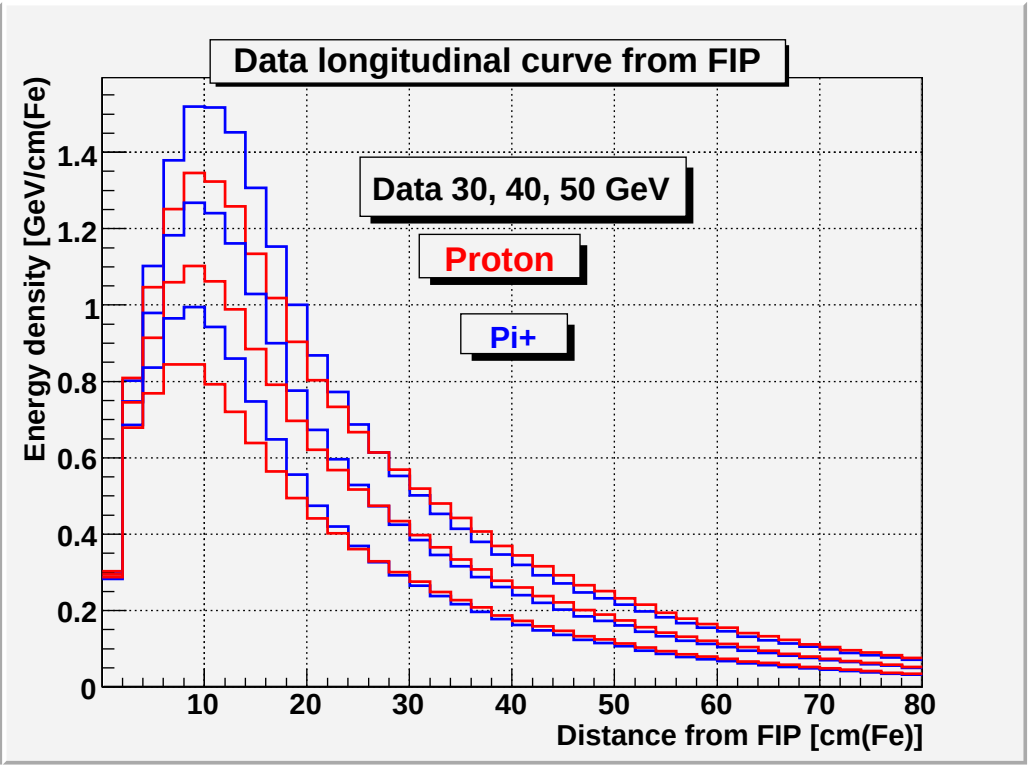
Longitudinal Shower Profile





Longitudinal Shower Profile from FIP

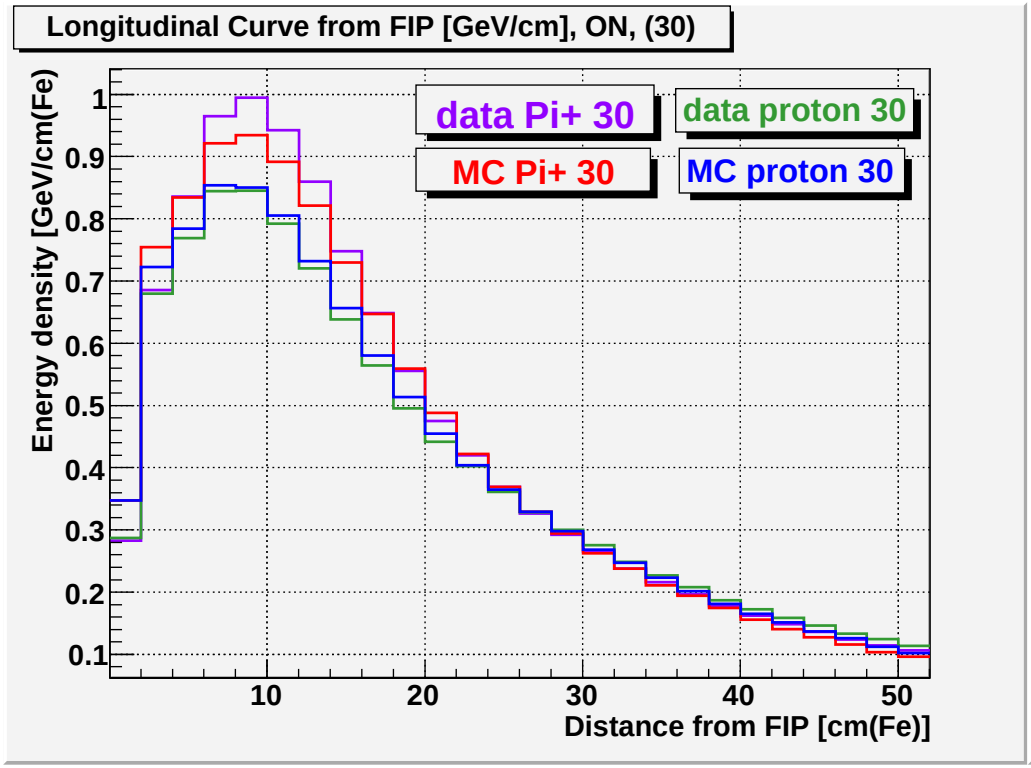


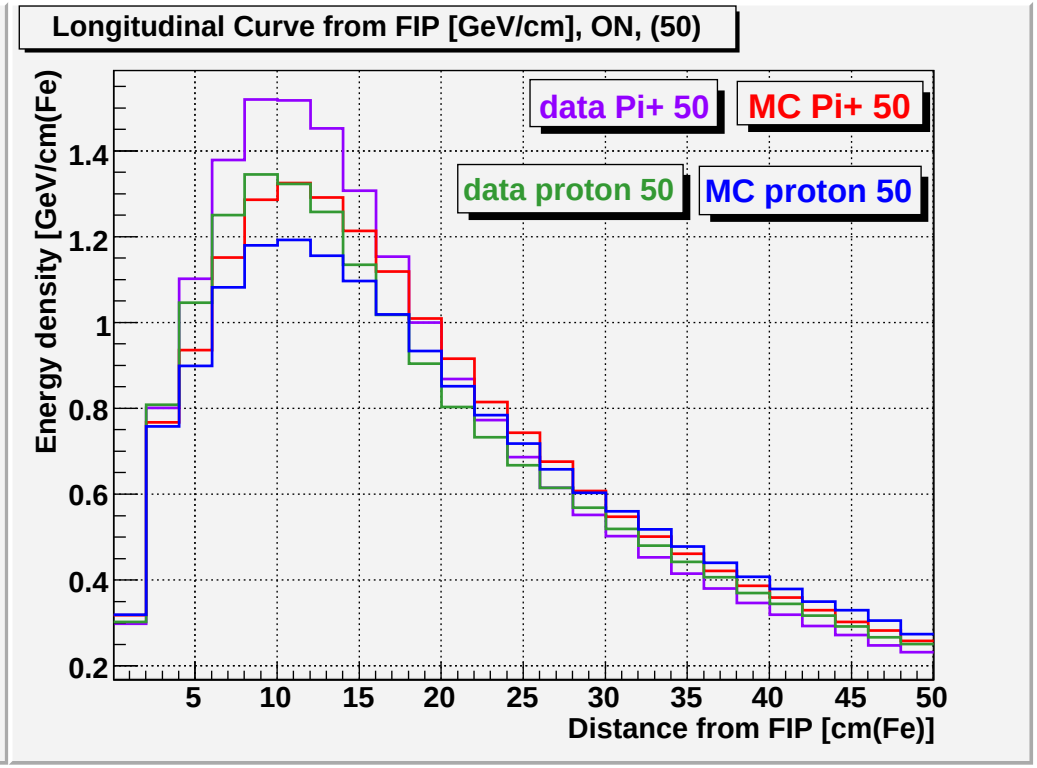


Longitudinal shower profile started from first interaction point FIP could not be fitted by convention form of shower profile.

So, numerical comparison of shower is waiting for the shower model; and we will show qualitative comparison only.

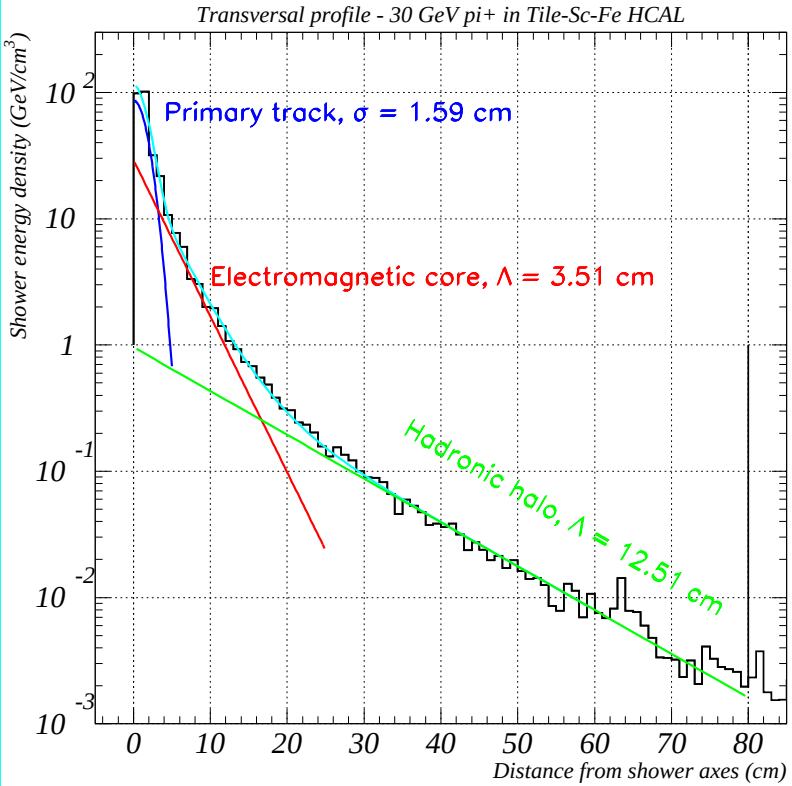
Longitudinal Shower Profile from FIP





Requirements on the electronic cell sizes for HCAL:

- The hadron shower spatial variations are much larger than the electromagnetic ones because more processes are involved in its development.



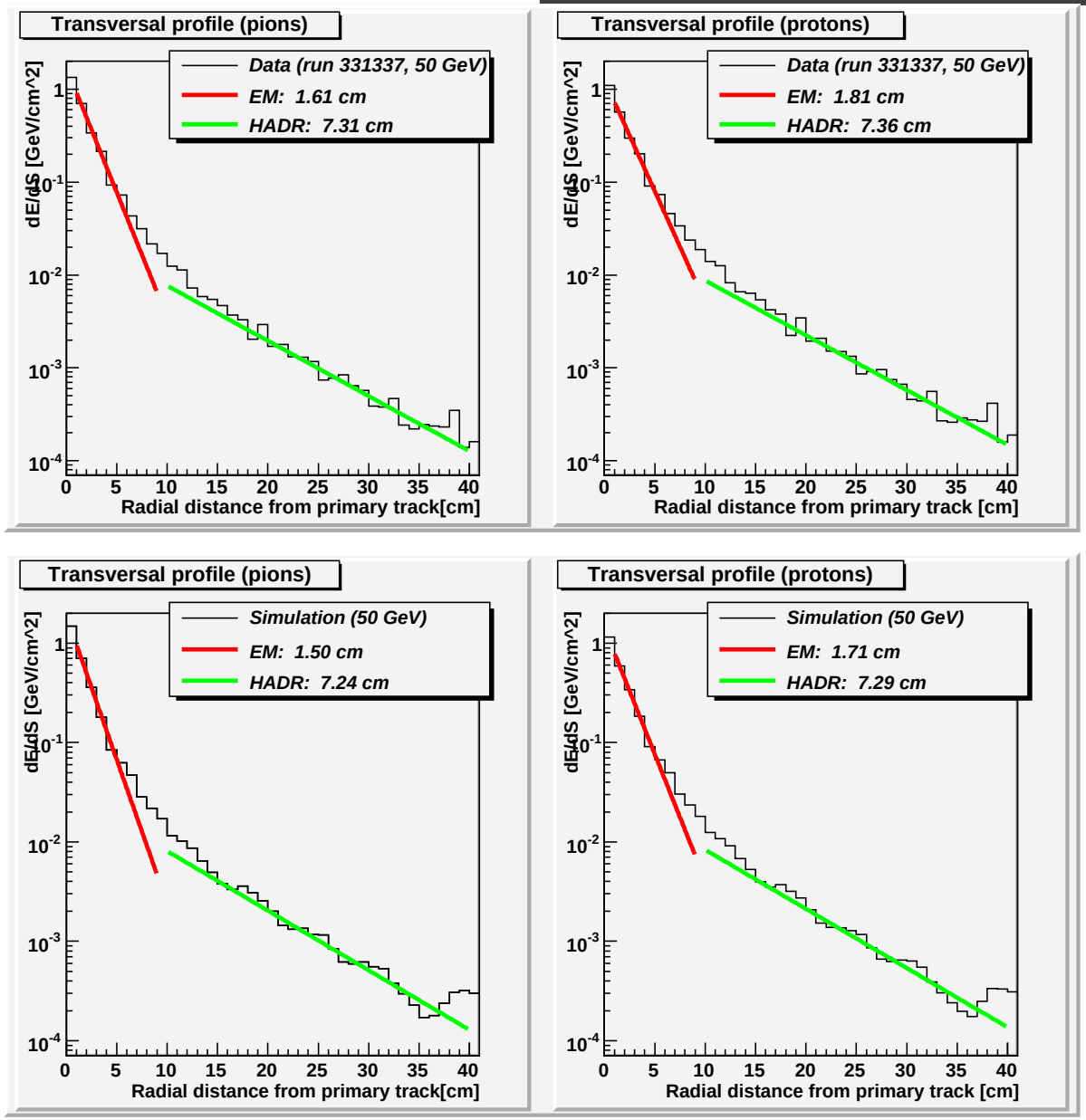
For particles that have MIP in ECAL

- The tiny spatial effect exists: the hadron transversal shower shape density has three component.
- **The first is the primary ionization track.**
- **The second is the narrow core that is mostly made of the electromagnetic part of hadron cascade.**
- **The third one, that is the pure hadron tail around the axis with an exponential behaviour.**

⇒ So, the cell size for hadron calorimeter should be close to the size of the transversal hadron shower core for the first few interaction length to collect the shower core along the predicted direction.

⇒ The cell sizes should be close to X_0 value for the particular sampling structure to follow this requirement.

Transversal Shower Profile

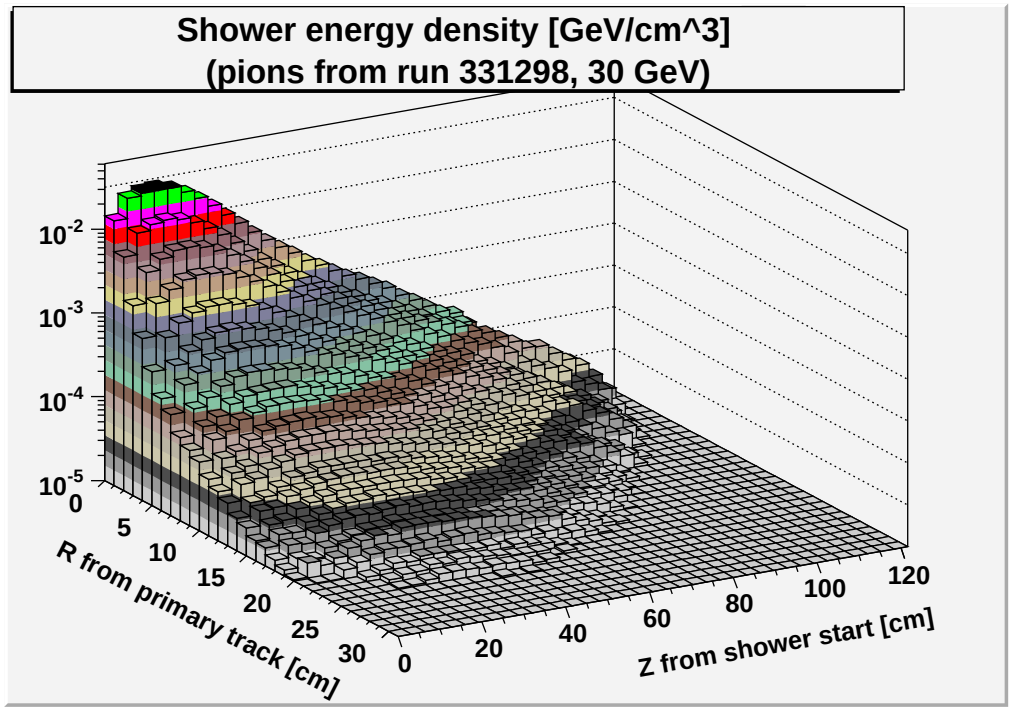


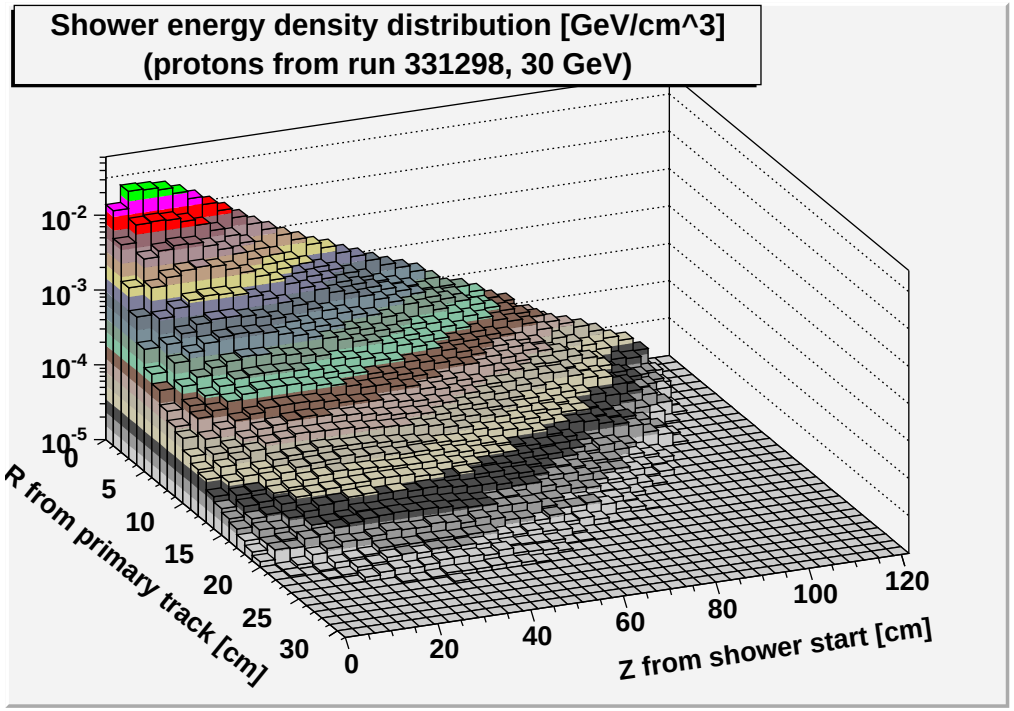
Neither experimental nor simulated transversal shower profiles shows a difference between π^+ and $proton$.

The reason for this is a mixture of different types of particles and integral on various particle energies.

3-D Energy density distribution

Primary track with end point that is a hadron shower starting point was found, then we can draw such plots.





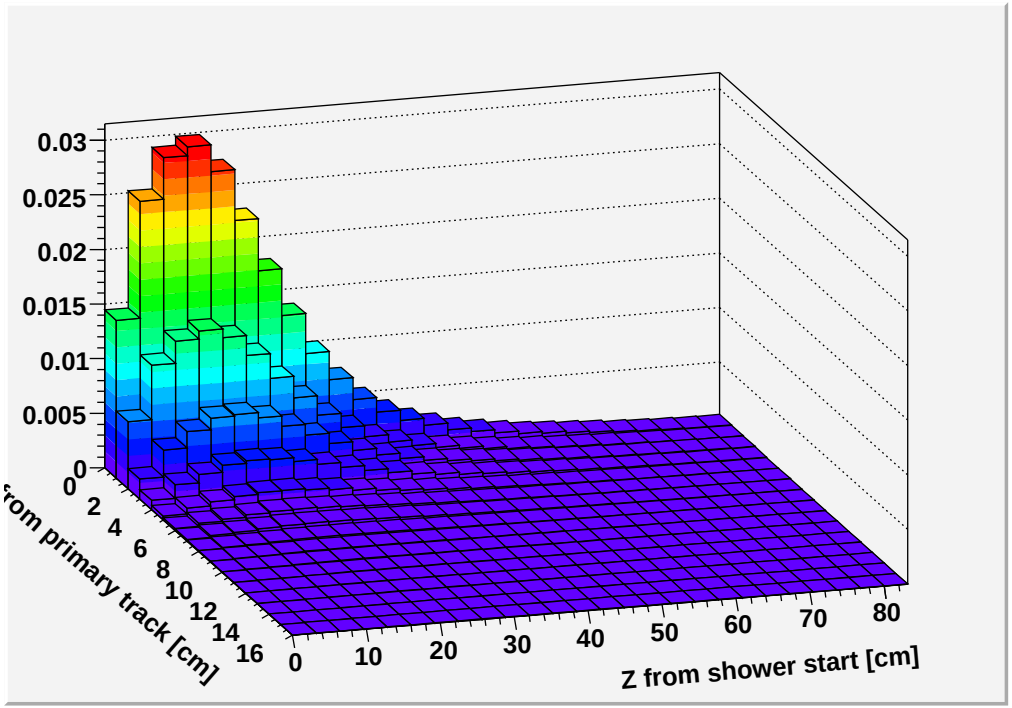
π^+ $proton$

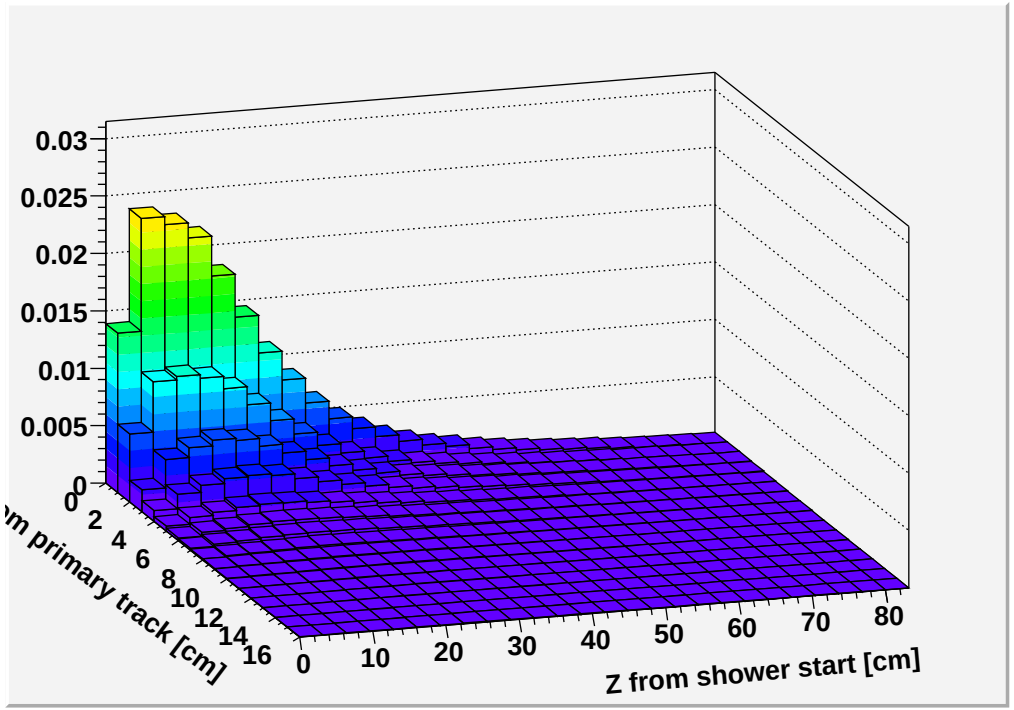
There is almost no visible difference in 3-D shower shape for these two particles.

They are plotted for showers started in HCAL but only for those that started before 30th HCAL layer to diminish the effect of leakage.

3-D Energy density distribution

π^+ **But if one look at these distributions in another way, one can see a difference.** $proton$



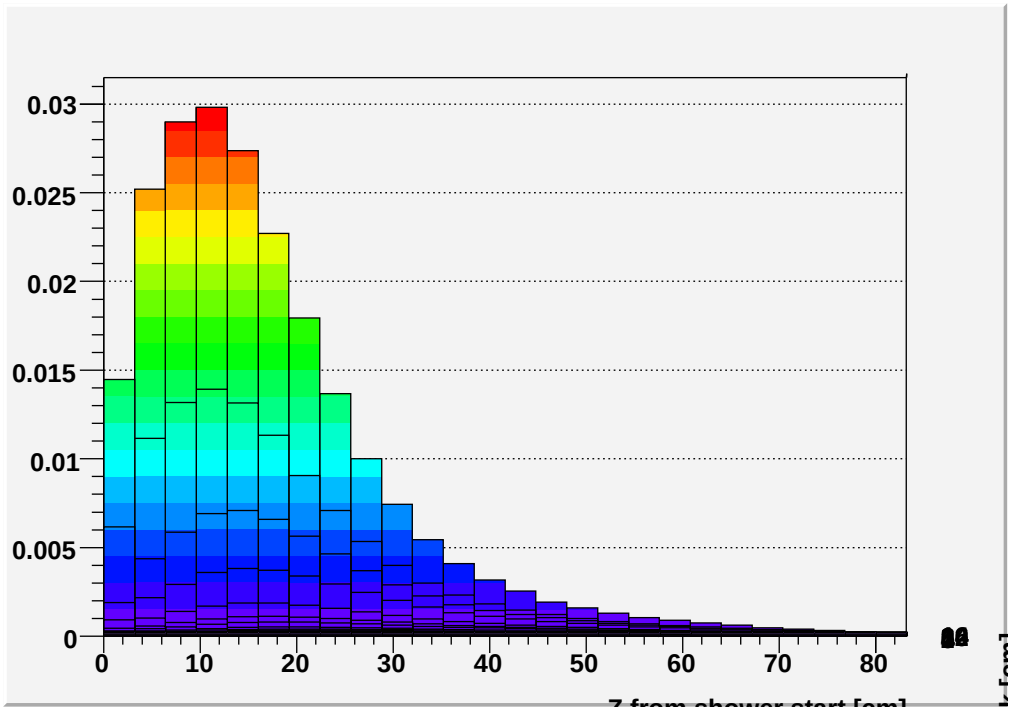


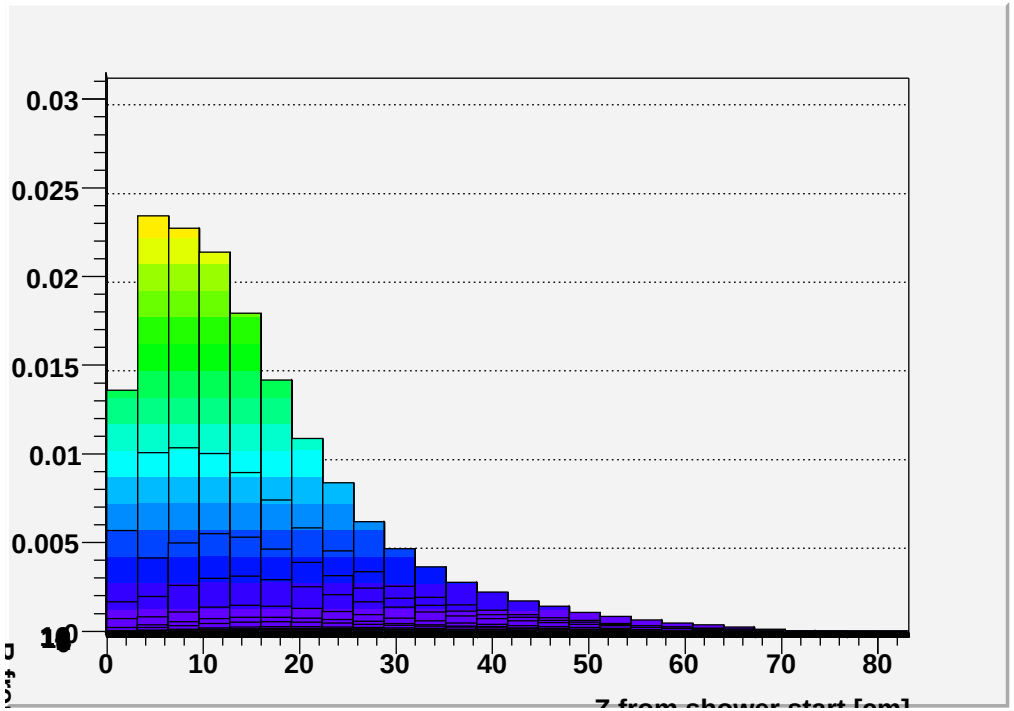
Difference is not so big but sensible. And it follows by an expectation. π^+ has a big probability to convert into π^0 on nuclei. In the case of $proton$ the probability to create high energy π^0 at the Iron nuclei is less.

3-D Energy density distribution

Let us look at these plots once more:

The distance from starting point to the maximum of shower is of about 10 cm, this also support a hypothesis that the electromagnetic shower is an origin of difference, because it is more or less exactly equal of usual distance between EM shower start and its maximum in our HCAL

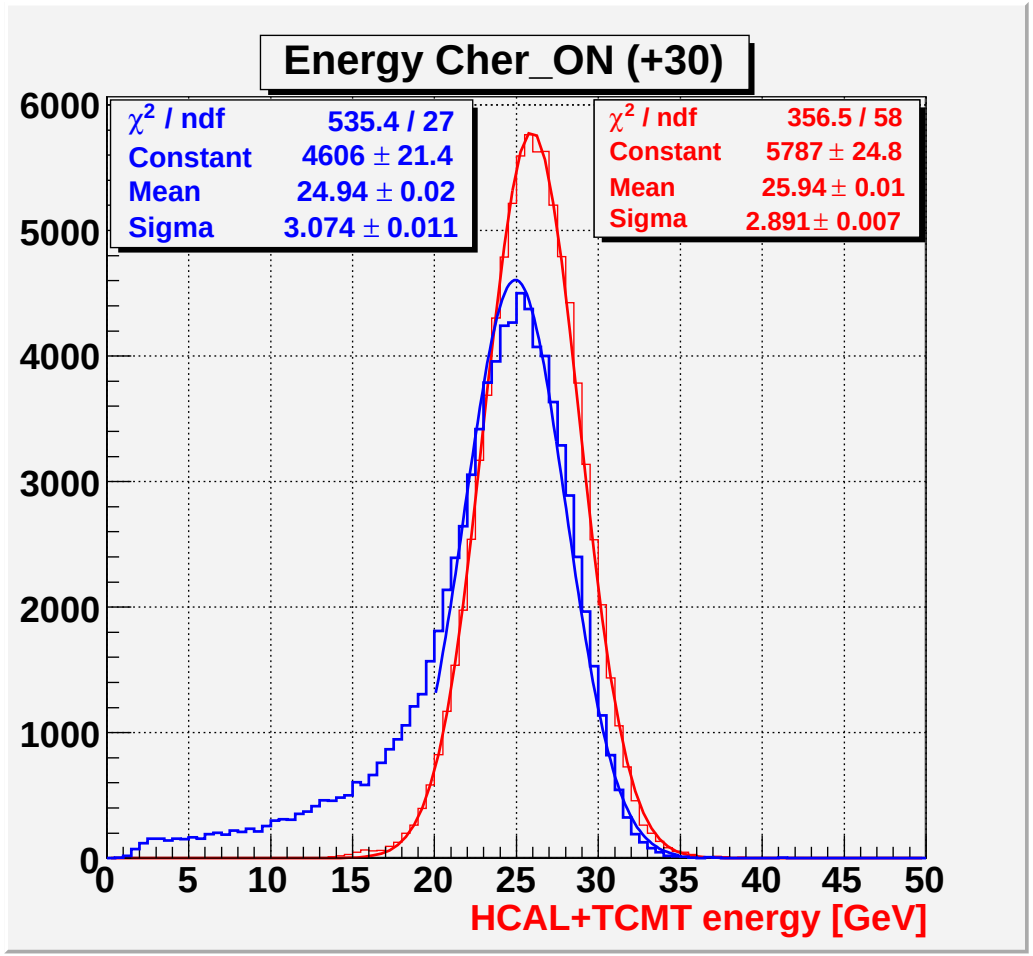




π^+ $proton$

The $proton$ shower develops in the other way; and distance to shower maximum even less than in case of π^+

Leakage

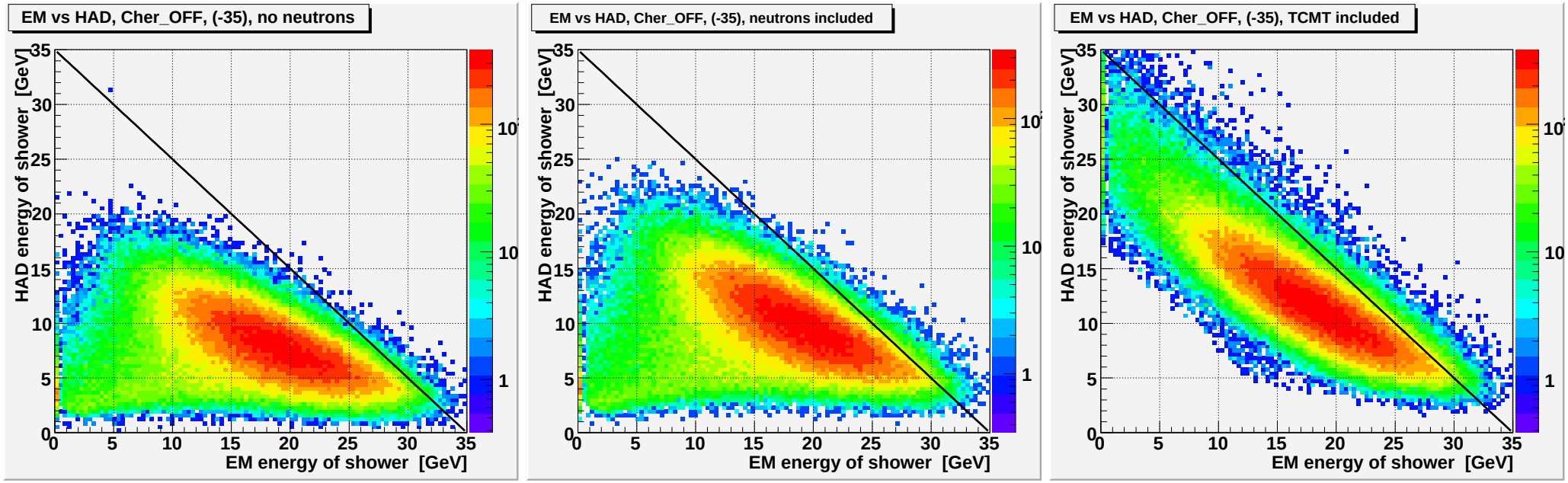


Selecting condition “Track in ECAL” we, of course, reduce a calorimeter length by of about one lambda.

To compensate this we will use TCMT in addition to HCAL.

Leakage and DeepAnalysis

One event is one entry to this histogram.

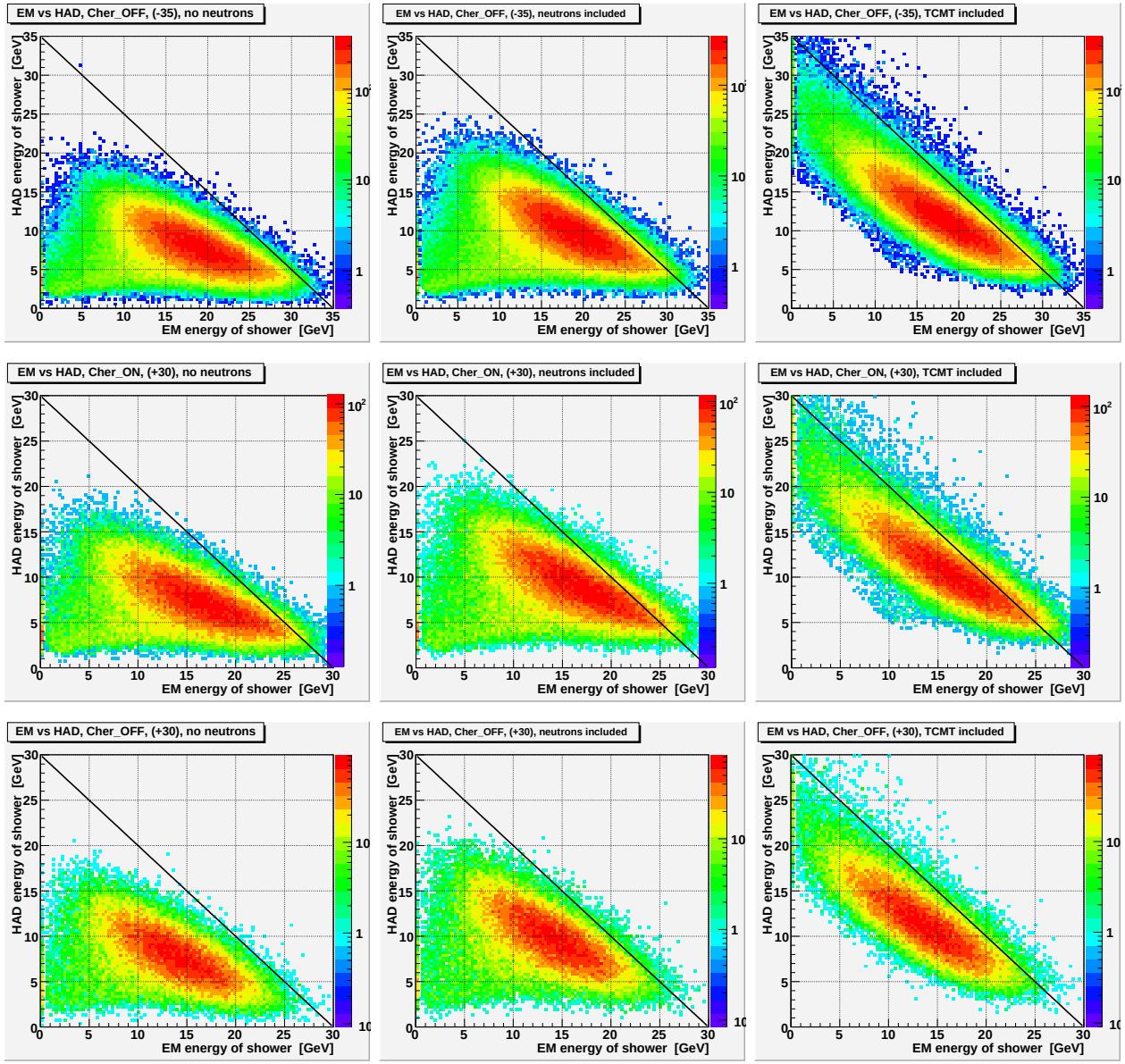


Leakage destroys a DeepAnalysis results dramaticaly.

At this case we will use TCMT energy to put it as Hadronic part of shower to correct the shower decomposition for the leakage.

Maybe one can image the method of energy leakage correction that could be based on these distributions.

Energy Rescaling



π^-

π^+

$proton$

DeepAnalysis shower decomposition shows different types of the partial energy distribution for different beam particles.

We cannot represent it numerically yet for lack of the shower model in terms of these variables (Electro–Magnetic energy and HADRon energy of shower).

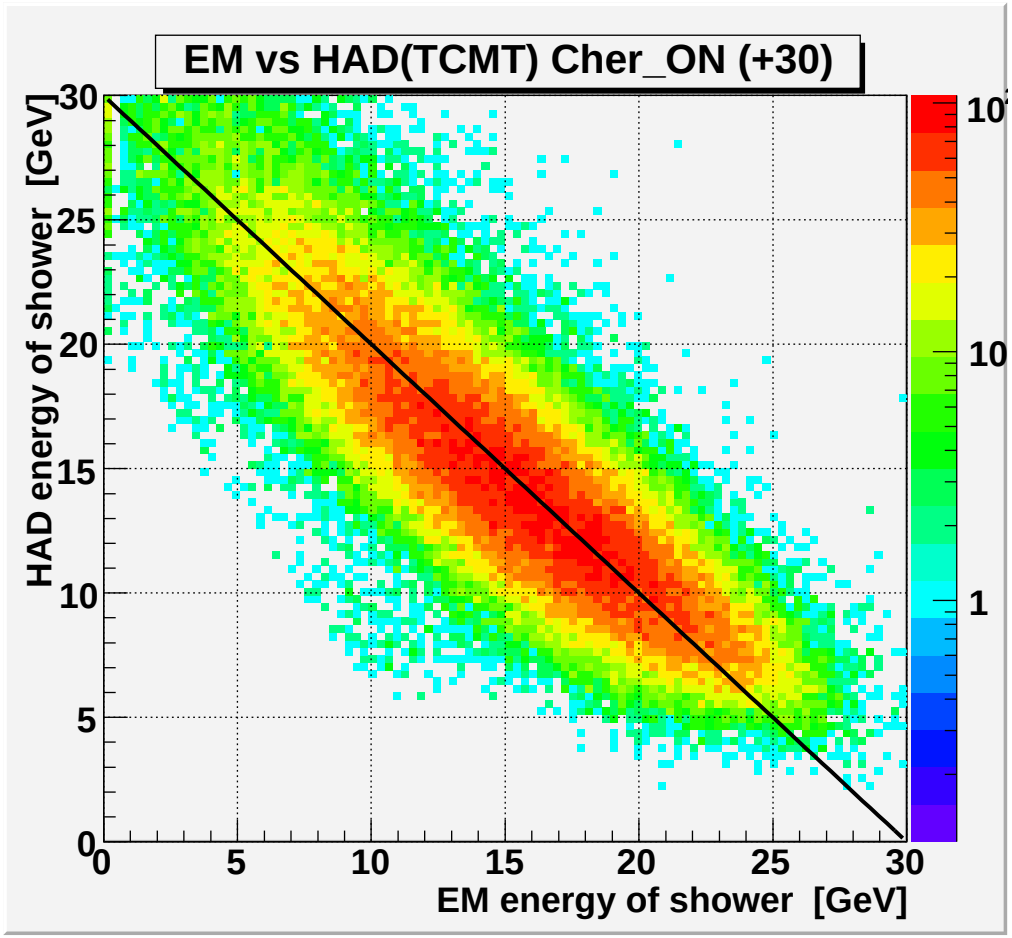
To build a parametrization of such a model is an issue for further investigations.

Now we can only recalibrate/correct/rescale sum of energies to get a better energy resolution by "rotating" of these distributions.

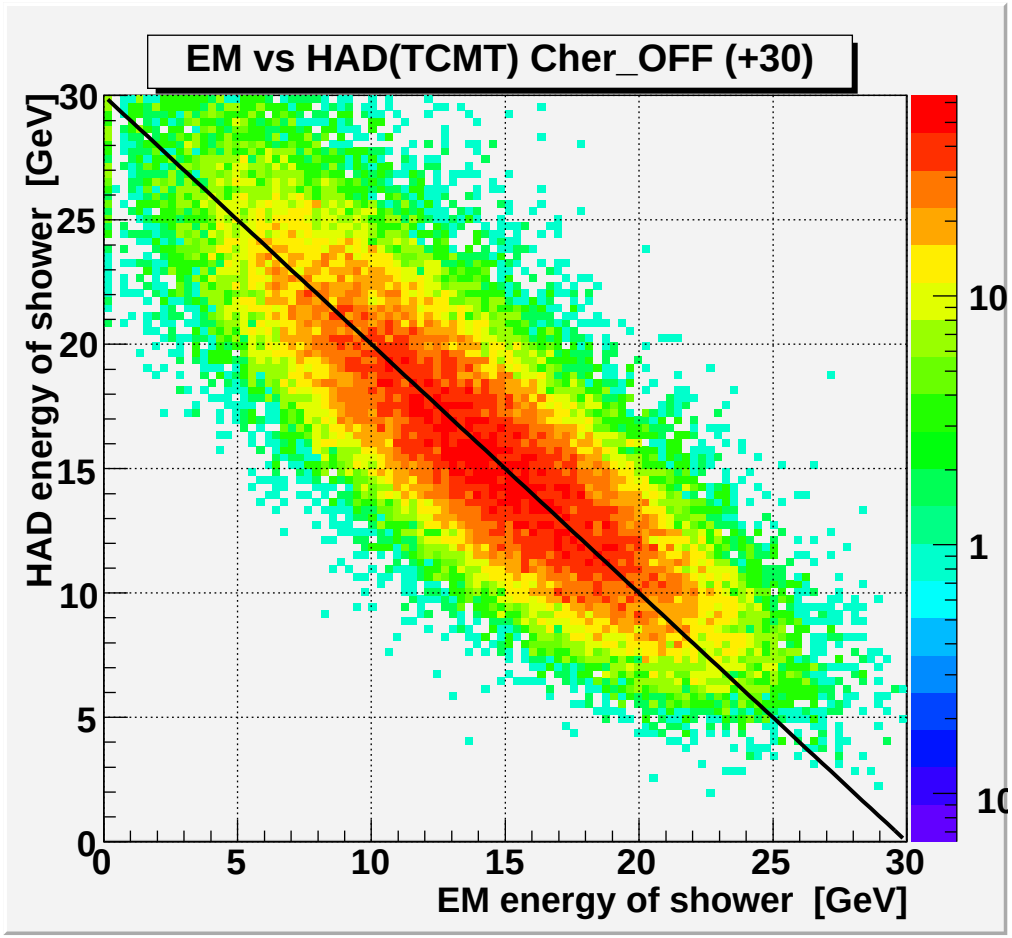
This is not a conventional calorimetric "software compensation"; even if it looks like.

DeepAnalysis application

π^+



$proton$



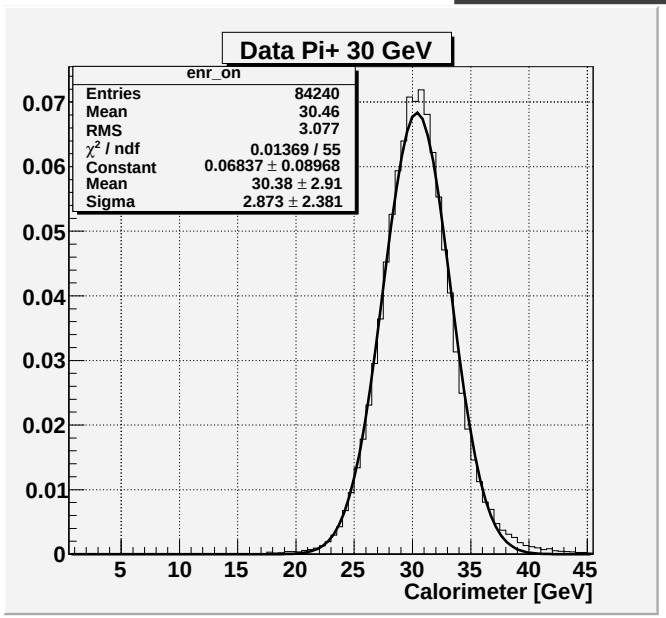
1.326*(HADR+TCMT) and 0.98*EM

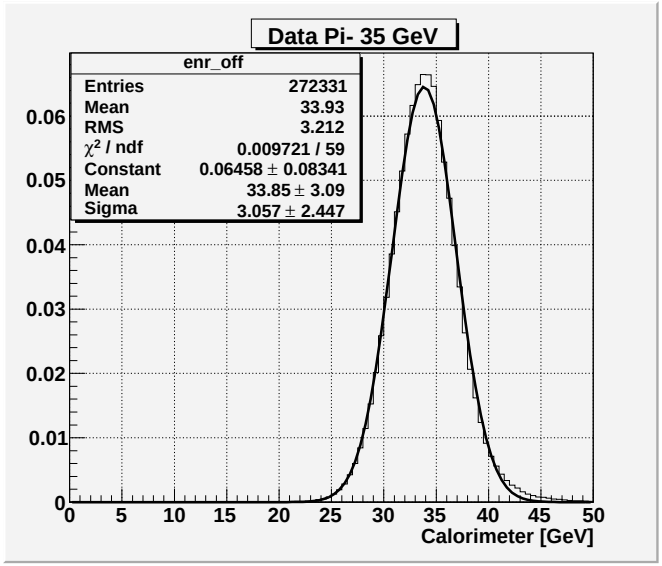
1.35*(HADR+TCMT) and 1.06*EM

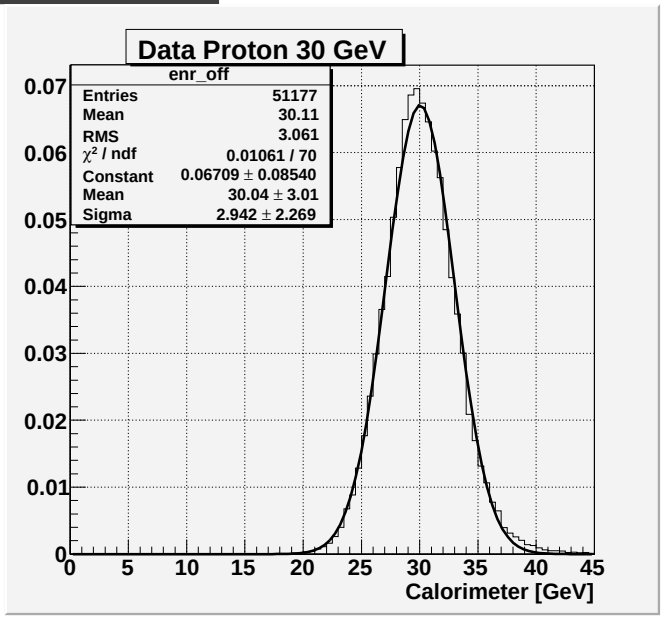
Recalibration needs to apply different coefficients to the “rotation” for the different types of beam particles to get the best possible energy resolution due to differnt Electro–Magnetic content for different types of shower.

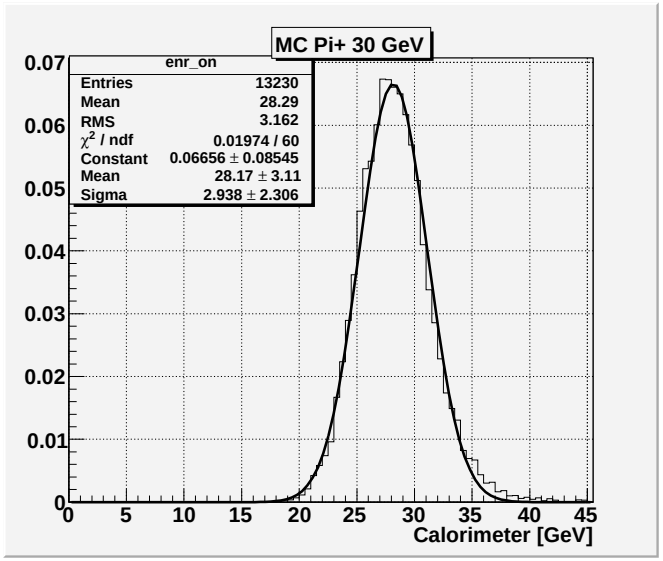
Energy sum takes into account a track energy in ECAL as well.

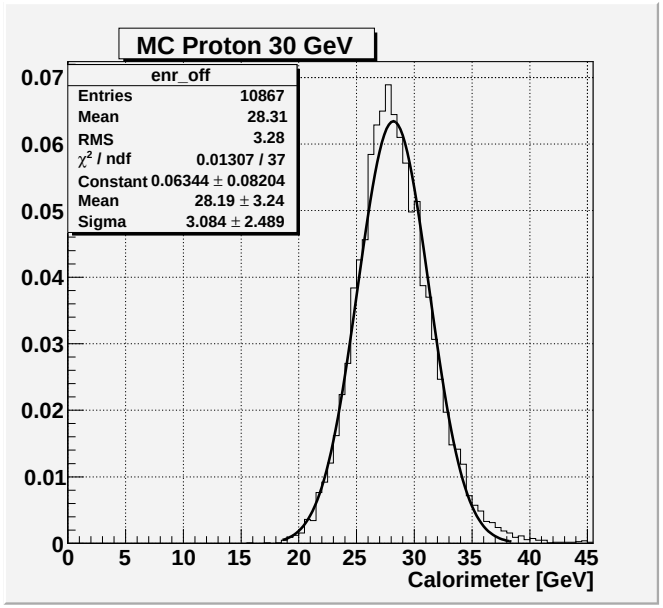
Resolution for recalibrated energies



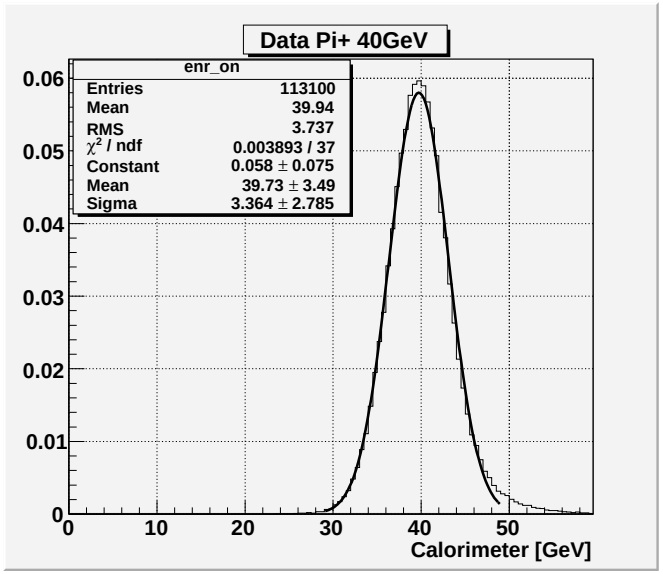


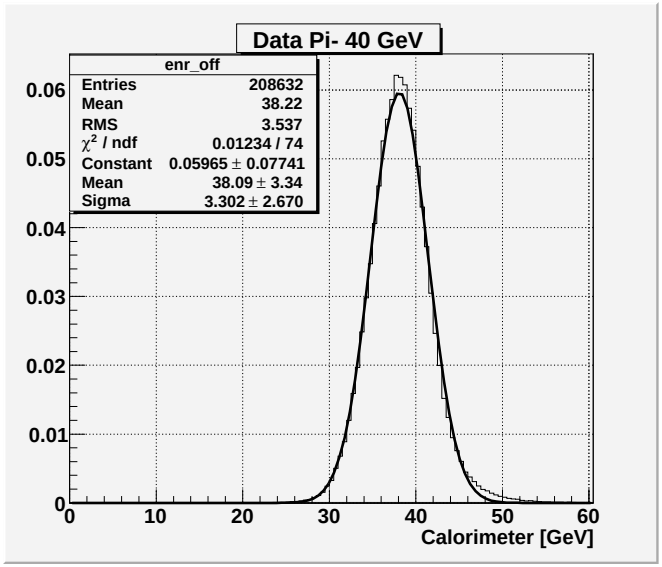


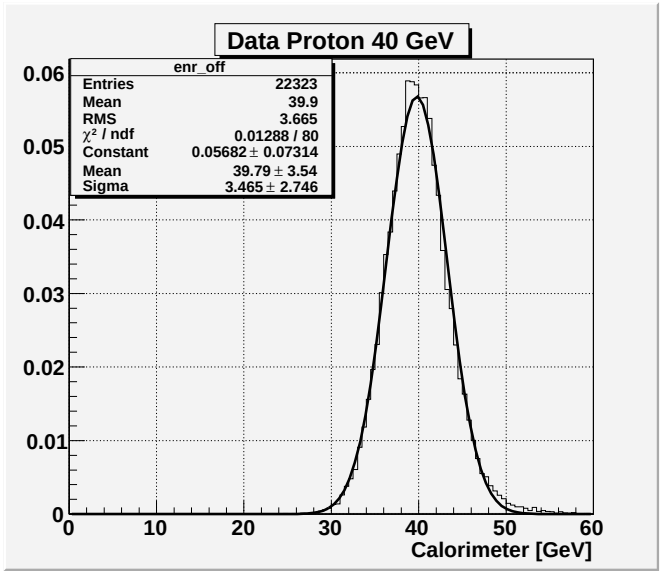


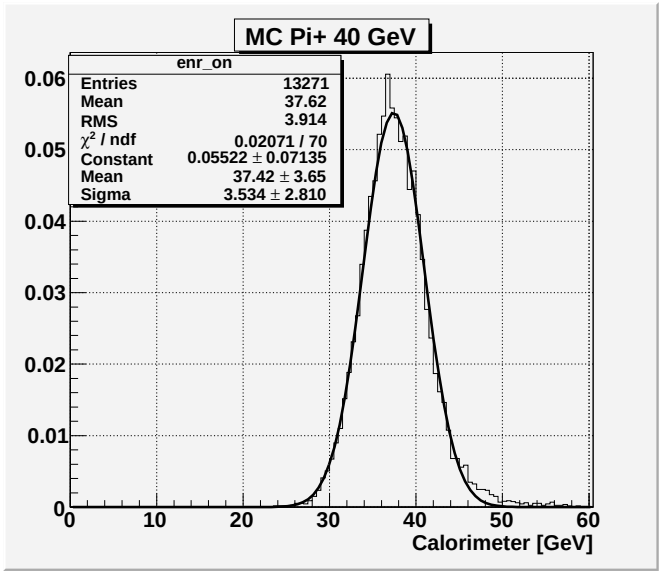


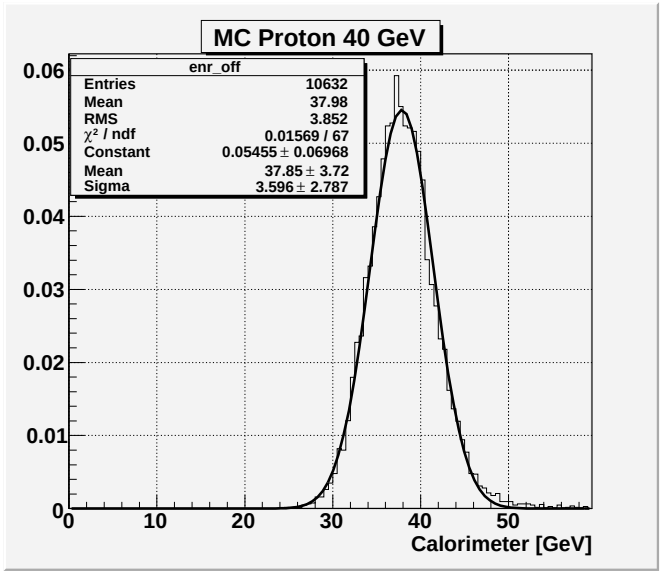
Resolution for recalibrated energies



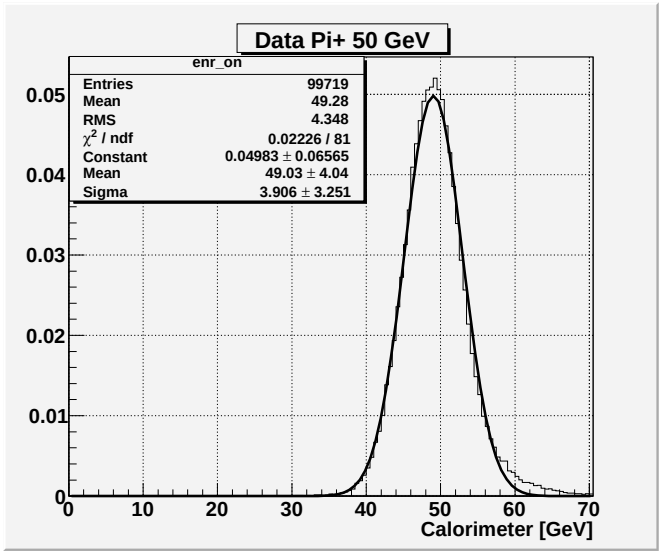


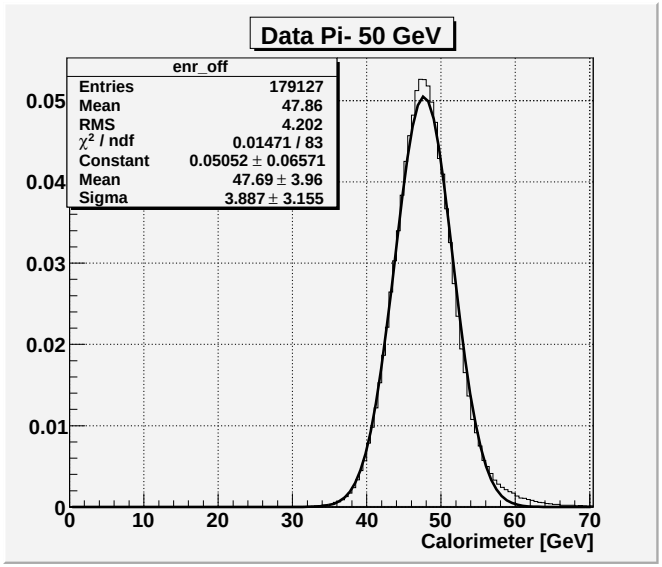


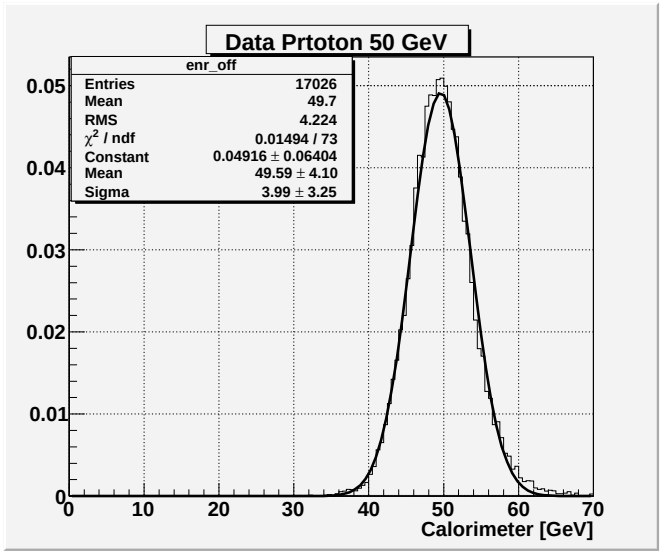


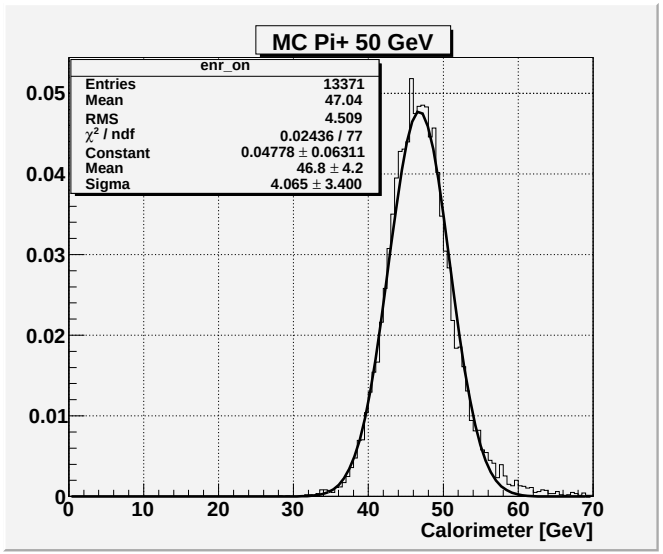


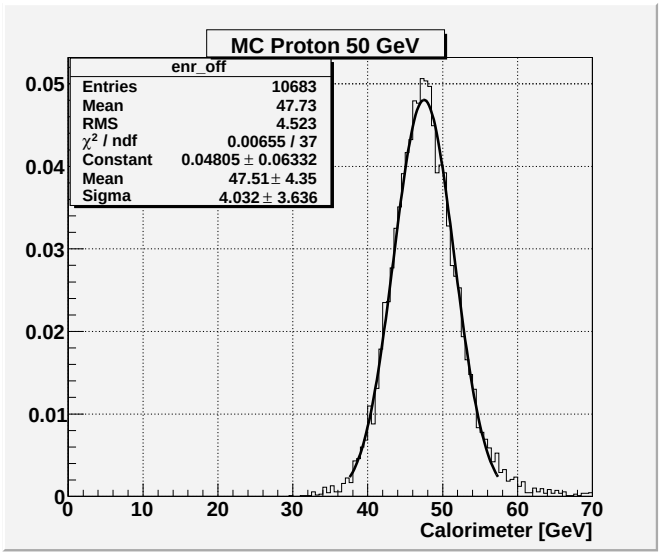
Resolution for recalibrated energies



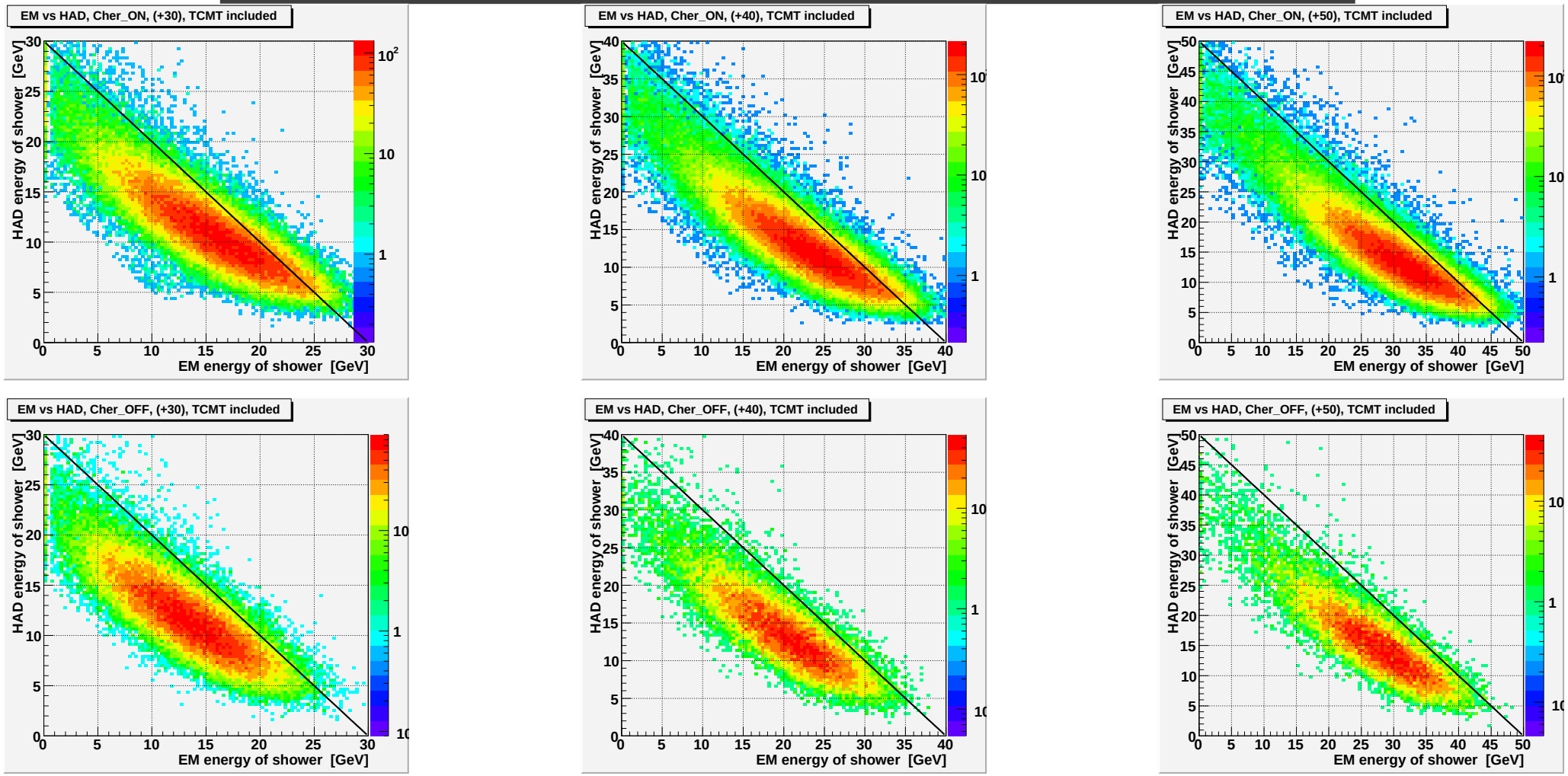








π^0's amount in hadron showers versus energy



Amount of EM energy in shower increases with increasing energy of beam as for proton as for π^+. Such a behaviour was predicted many years ago (see. T.Gabriel NIM 1995). But from the other side, it could be a feature of DeepAnalysis program; as higher energy as higher spatial density of energy – DeepAnalysis could make a mistake.

Speculations instead of Conclusion

I could not escape a pleasure to say some speculations about charge exchange for π–s on Iron nuclei.

This speculation almost have no deal with calorimetry, just a physics.

It should be a bigger cross–section for the process $\pi^- Fe \rightarrow \pi^0 + X$ than for $\pi^+ Fe \rightarrow \pi^0 + X$,
and it should be much less cross–section for $p^+ Fe \rightarrow \pi^0 + X$

And that we see after the analysis of the experimental data.

A speculation is the speculation – it could be proved during serious investigations as in theory as in experiment.

And CALICE data are ready to read from disk.

Good luck for PhD students.