BDT Application in SDHCAL

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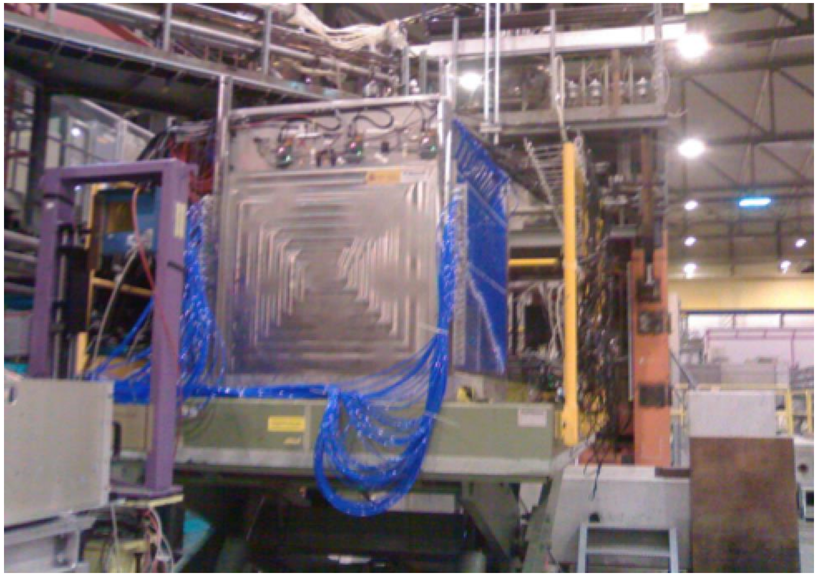
Outline

Introduction to SDHCAL and analysis of 2015 test beam data

Particle identification using BDT in SDHCAL

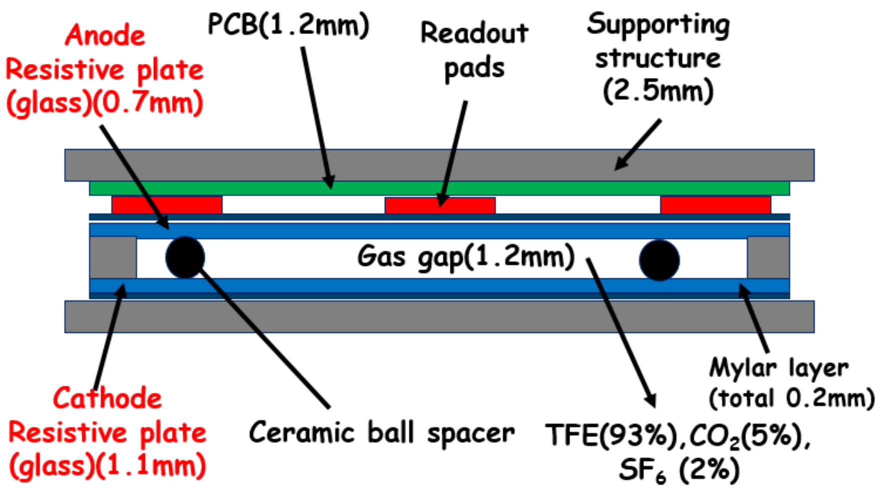
SDHCAL Prototype

- Total Size:1x1x1.4m^3
- Total Layers: 48
- Total Channels (pads): 440,000
- Power consumption: $10\mu W/channel$



Test Beam at CERN/SPS

Structure of per layer



$(0.12\lambda_I, 1.14X_0)$

Stainless steel Absorber(15mm)

Stainless steel wall(2.5mm)

GRPC(6mm$\approx 0\ \lambda_I, X_0$)

Stainless steel wall(2.5mm)

ASIC HARDROC(64 channel)
three-threshold (Semi-digital)
110fC,5pC,15pC

Data Samples and Selections

Data sample:SPS_Oco_2015

Particle: Pi+

Energy:10-80GeV with uniform

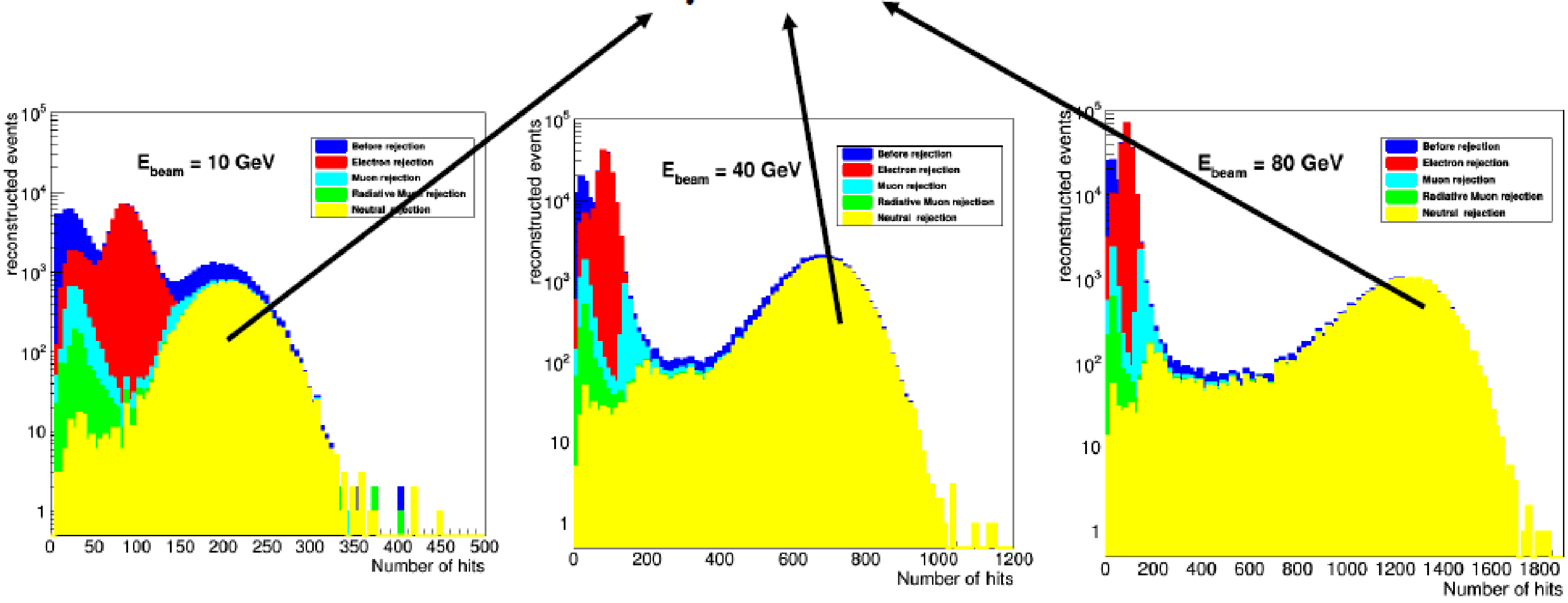
10 GeV energy gap

Type	Selections	Detail
Physical cut	Electron rejection	Shower start >=5 or Nlayer > 30
	Muon rejection	Nhit/Nlayer > 3.2(previous is 2.2)
	Radiative muon rejection	Nlayer(RMS > 5cm)/Nlayer>20%
	Neutral rejection	Nhit(belong to first 5 layers)> =4
Artificial cut	Beam position cut	r<r(given)

CALICE collaboration. "First results of the CALICE SDHCAL technological prototype." Journal of Instrumentation 11.04 (2016): P04001.

Hadron Samples and Selections

Contributed by hadron showers



Applying 4 rejections step by step

Electron rejection -> Muon -> Radiative Muon -> Neutral rejection

Hadron Samples and Selections

Energy(GeV)	Total Events	After Electron rejection	After Muon rejection	After Radiative muon rejection	After Neutral rejection
10	123974	82223	10810	9685	9675
20	92053	68981	10250	9710	9701
30	49299	38134	7715	7319	7313
40	247428	190603	31329	29582	29544
50	97496	74933	14556	13644	13627
60	97988	76819	13629	12642	12625
70	101626	78547	10914	9865	9852
80	249478	196340	18884	15577	15541

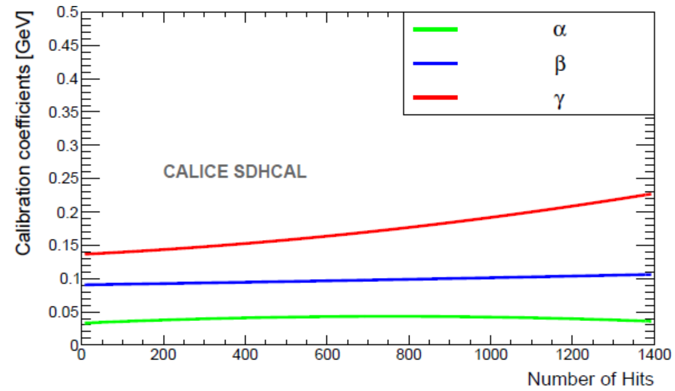
Energy Reconstruction

- **Energy reconstruction formula:**

$$E_{reco} = \alpha N_1 + \beta N_2 + \gamma N_3$$

α, β, γ are parameterized as functions of total number of hits (N1 + N2 + N3)

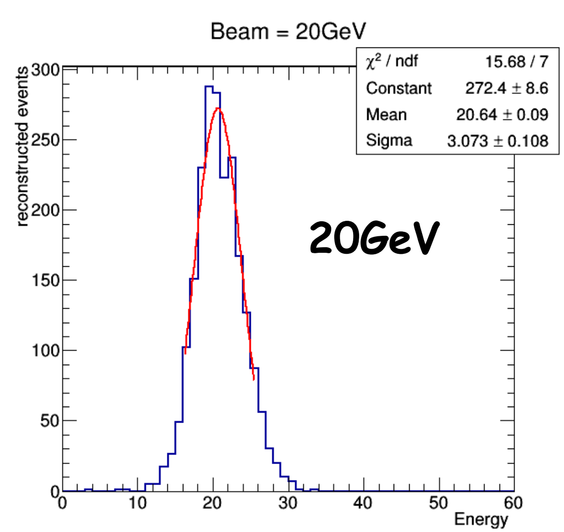
$$\alpha = \alpha_1 + \alpha_2 N_{total} + \alpha_3 N_{total}^2$$
$$\beta = \beta_1 + \beta_2 N_{total} + \beta_3 N_{total}^2$$
$$\gamma = \gamma_1 + \gamma_2 N_{total} + \gamma_3 N_{total}^2$$

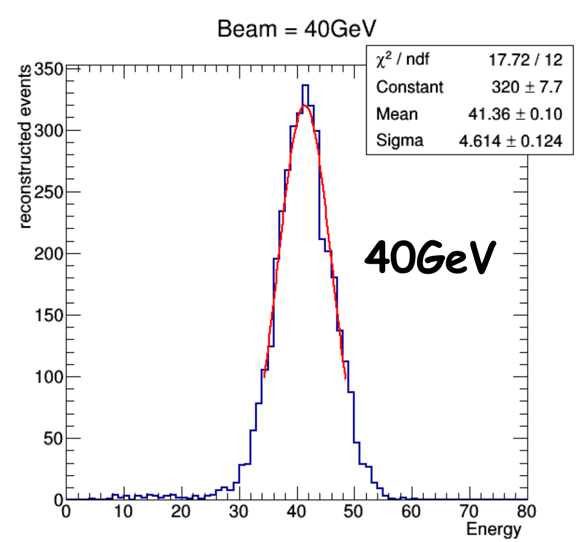


- **optimizer**

$$\chi^2 = \sum_{i=1}^{N} \frac{(E_{beam}^i - E_{reco}^i)^2}{\sigma_i^2}$$

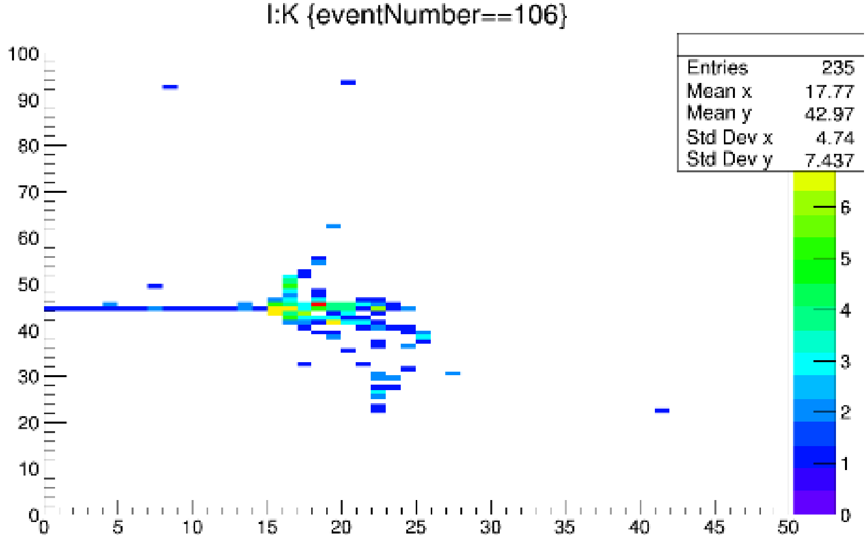
$$\sigma_i = \sqrt{E_{beam}^i}.$$

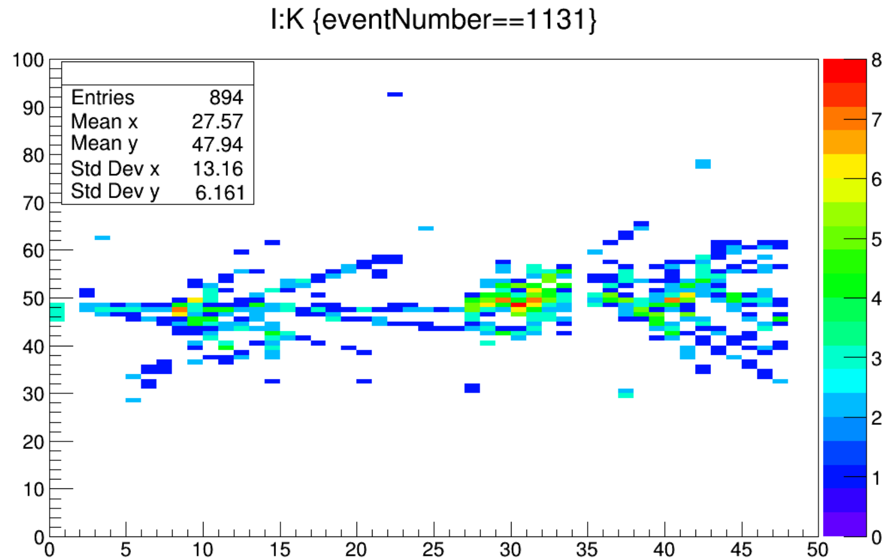




The distributions are fitted with a Gaussian function in a 1.5σ energy range around the mean

Shower Shape





Shower is fully contained in SDHCAL prototype

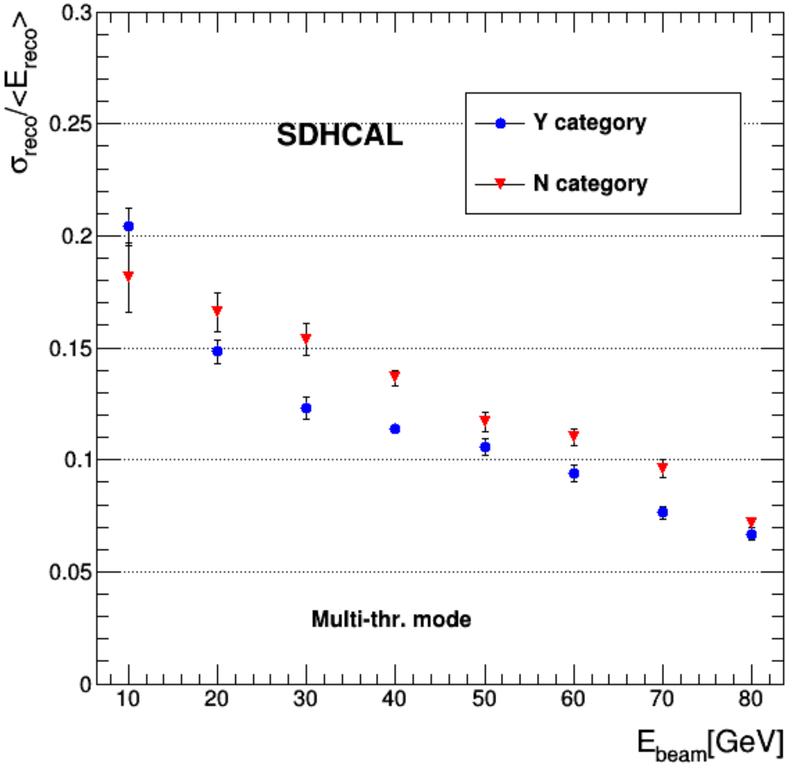
Y-Category Event

If last 4 layers are fired, shower is not fully contained in SDHCAL prototype

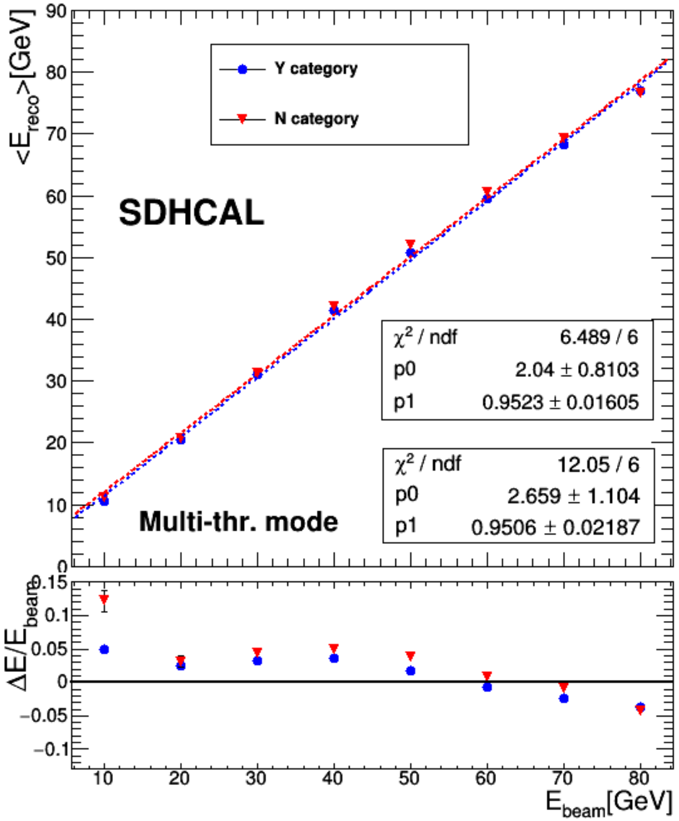
N-Category Event

Analysis Results

Resolution



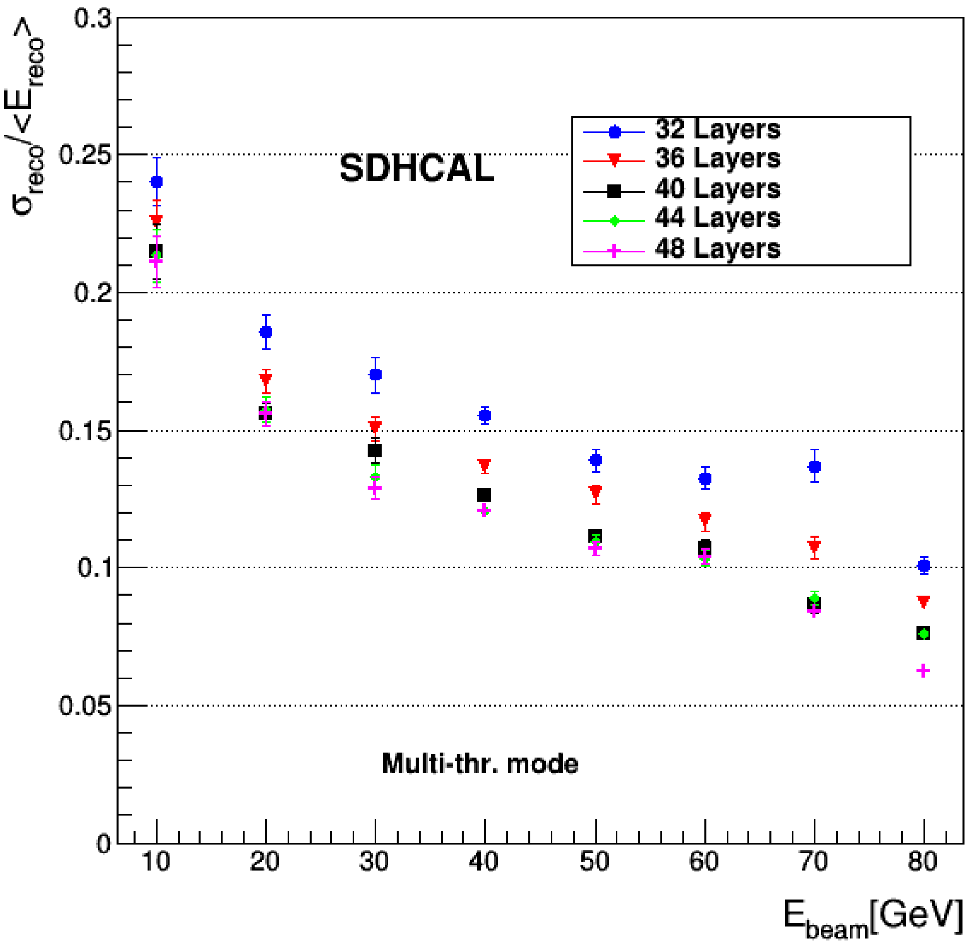
Linearity



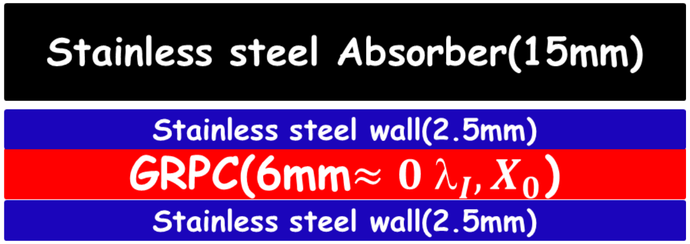
➔ The energy resolution for Y category is better than that for N category.

➔ Linearity is comparable for both Y and N categories.

Optimization for layer numbers



$(0.12\lambda_I, 1.14X_0)$



➔SDHCAL has 48 layers which aims for ILC Detector
- 6mm RPC+20mm absorber

➔Optimization no. of layers for CEPC at 240GeV

➔40-layer SDHCAL yields decent energy resolution.

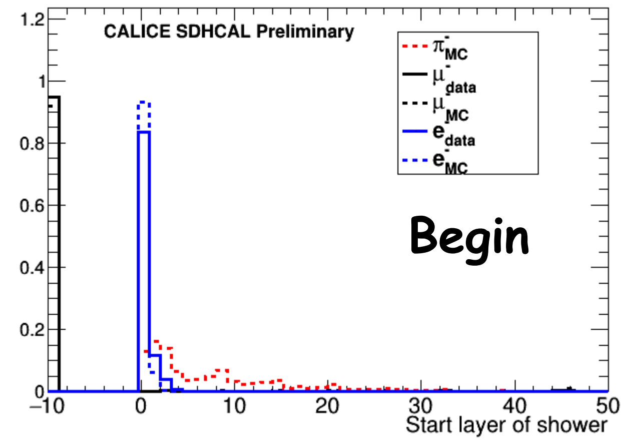
SJTU

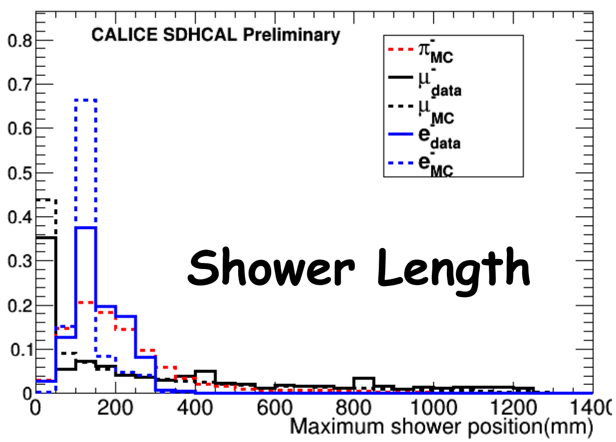
Introduction to SDHCAL and analysis of 2015 test beam data

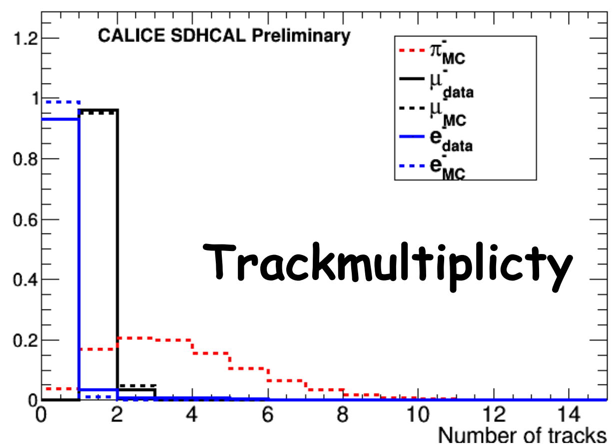
Particle identification using BDT in SDHCAL

BDT Input Variables for SDHCAL

- **BDT 6 input variables:**
  1. First layer of the shower (Begin)
  2. Number of tracks in the shower (TrackMultiplicity)
  3. Maximum shower position (Length)
  4. Shower density (Density)
  5. Shower radius (Radius)
  6. Ratio of shower layers over total fired layers (NInteractinglayer/Nlayers)







- Pion Signal: 160000 events

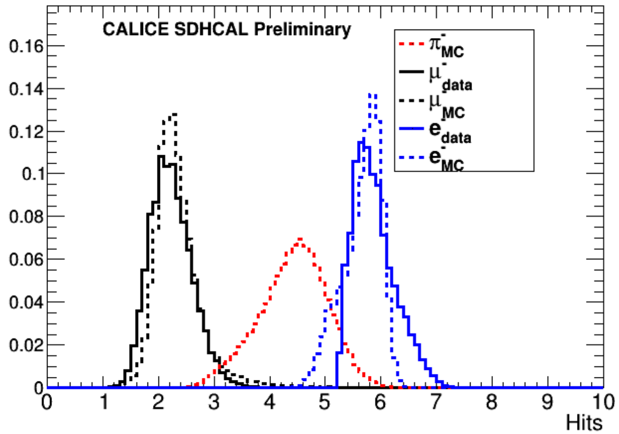
  Electron: 160000 events

  Muon: 120000 events

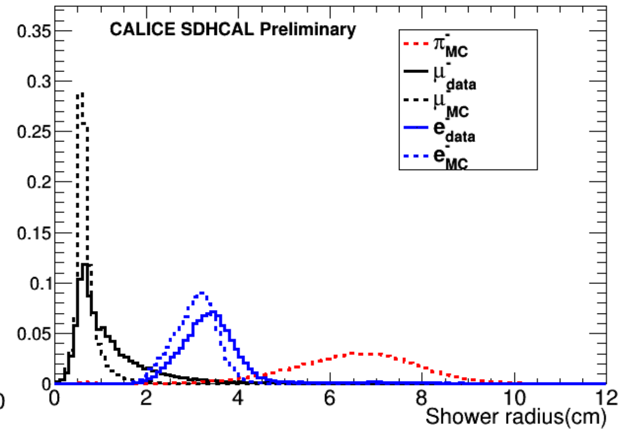
  E=10-80GeV @ 10 GeV step

- BDT training : test = 1 : 1

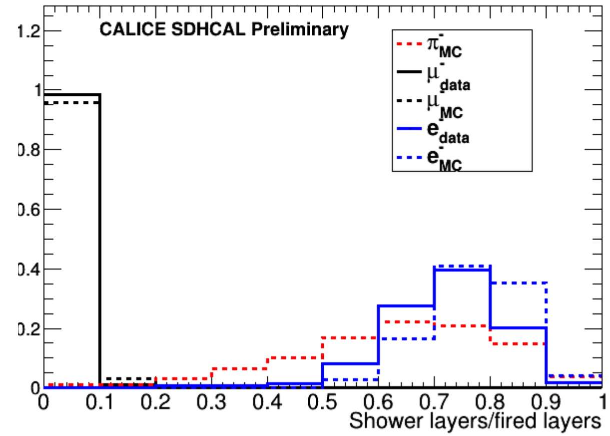
BDT Input Variables: Ranking



Density



Radius



NInteractinglayer / Nlayer

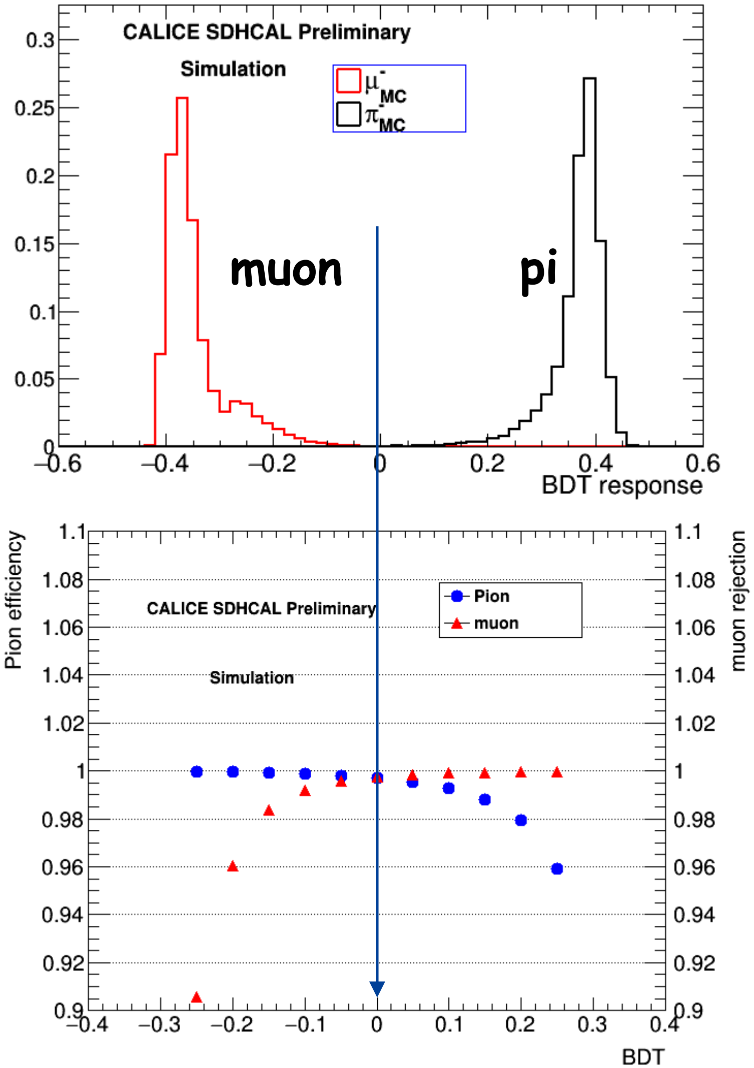
Variable Ranking: Pion vs muon

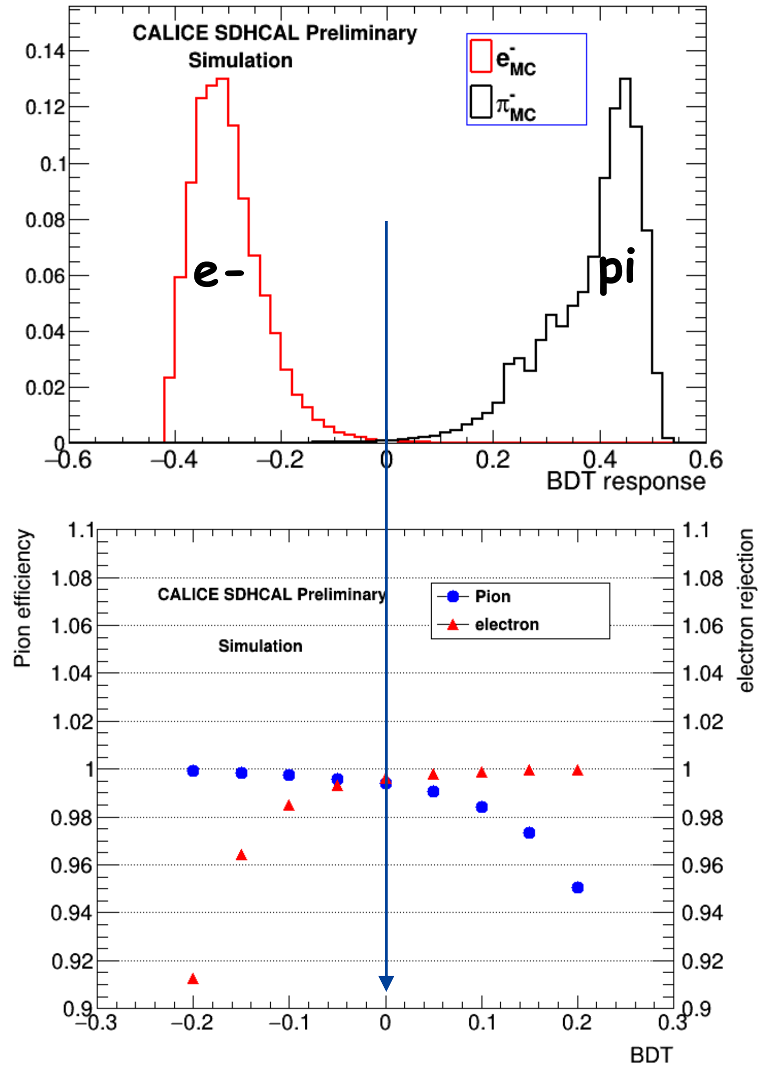
Rank : Variable	Variable relative weight
1 : Density	0.2525
2 : Radius	0.2205
3 : NInteractinglayer/Nlayer	0.2093
4 : Length	0.2020
5 : TrackMultiplicity	0.1157

Variable Ranking: Pion vs electron

Rank : Variable	Variable relative weight
1 : Density	0.2057
2 : Radius	0.2019
3 : NInteractinglayer/Nlayer	0.1857
4 : Begin	0.1472
5 : Length	0.1466
6 : TrackMultiplicity	0.1128

BDT Output and Performance





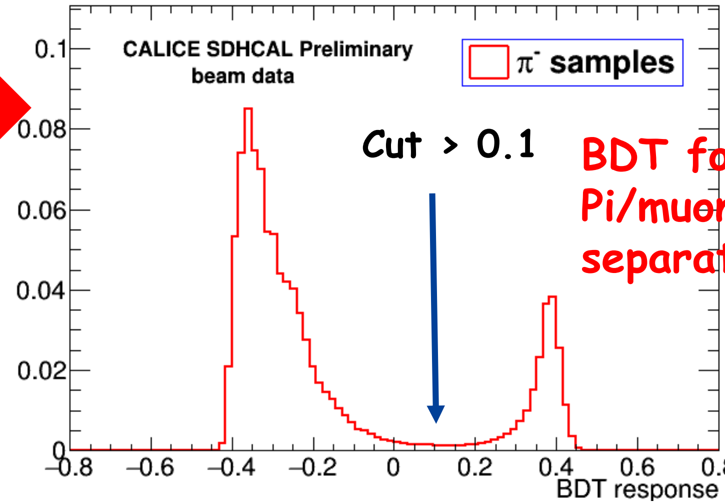
Pion eff. vs Backgrounds eff.

- For same Pion efficiency, we compare electron & muon efficiencies from "simple cut" and "BDT" methods.
- BDT has modest improvement for electron suppression and significant improvement for muon suppression.

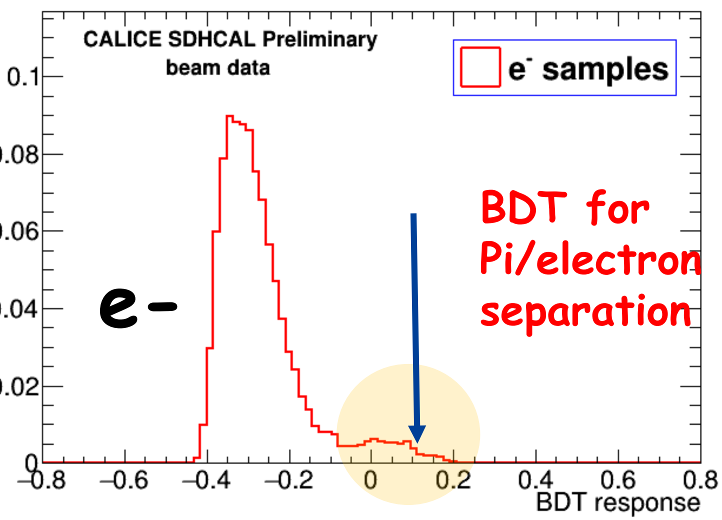
Energy	simple cut			BDT		
	eff_{pion}	$eff_{electron}$	eff_{muon}	eff_{pion}	$eff_{electron}$	eff_{muon}
10GeV	55.7%	0.0%	0.1%	55.7%	0.0%	0.0%
20GeV	70.5%	0.0%	0.3%	70.5%	0.0%	0.0%
30GeV	80.9%	0.0%	0.6%	80.9%	0.0%	0.1%
40GeV	87.2%	0.1%	0.6%	87.2%	0.0%	0.1%
50GeV	90.6%	0.1%	0.9%	90.6%	0.1%	0.1%
60GeV	93.0%	0.2%	1.0%	93.0%	0.2%	0.2%
70GeV	94.7%	0.3%	1.2%	94.7%	0.2%	0.2%
80GeV	95.7%	0.3%	1.1%	95.7%	0.2%	0.2%

BDT for TB Data

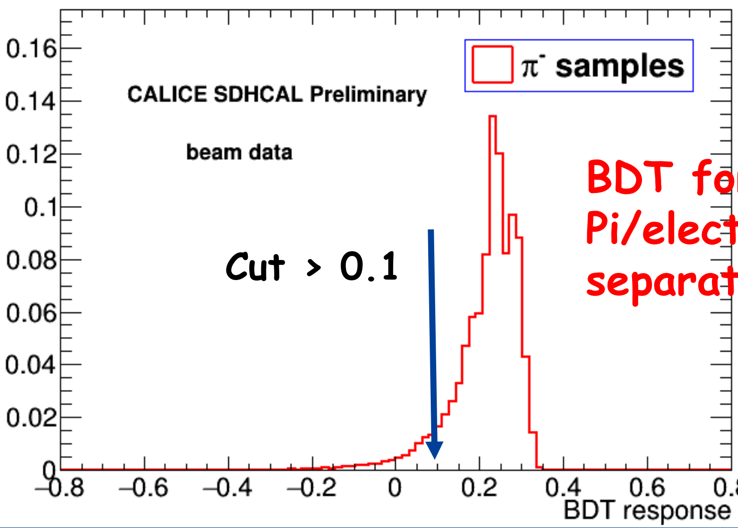
- **Test Beam Data (SPS-2015)**
  - Hadron 10,20,30,40,50,60,70,80GeV
  - Muon 10,20,30,40,50,60,70, 80GeV
  - Electron 10,20,30,40,50GeV



BDT for Pi/muon separation



BDT for Pi/electron separation



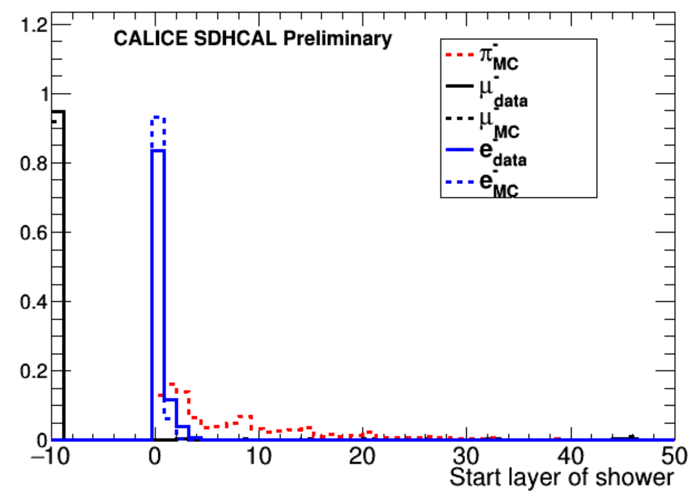
BDT for Pi/electron separation

Particle ID using BDT (Data)

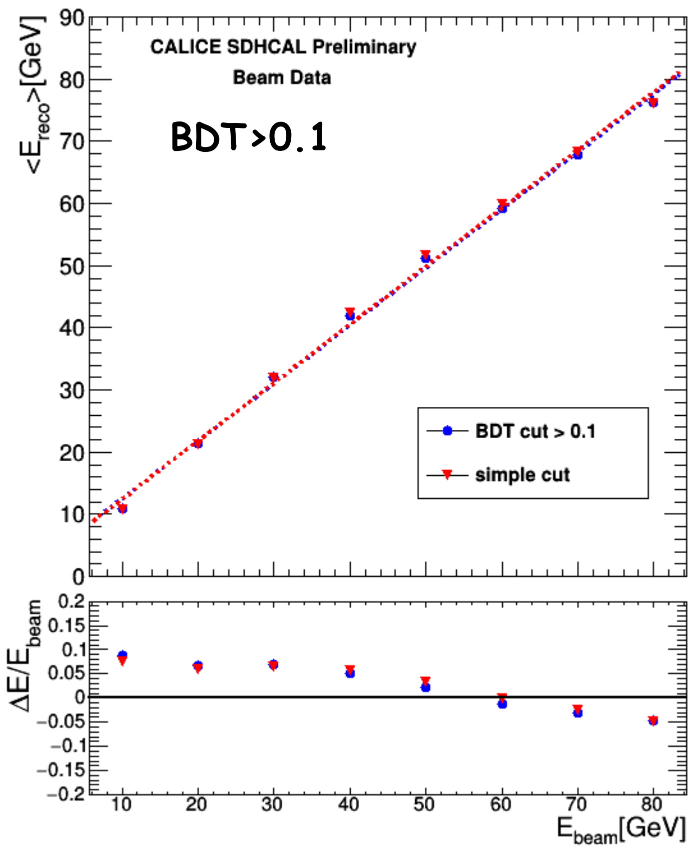
- Number of "pion" events obtained from "simple cut" and "BDT".
- The statistical gain for "BDT" is mainly at low energy region, it can be explained by absence of "event rejection" cut in BDT which helps to save low E pion events.

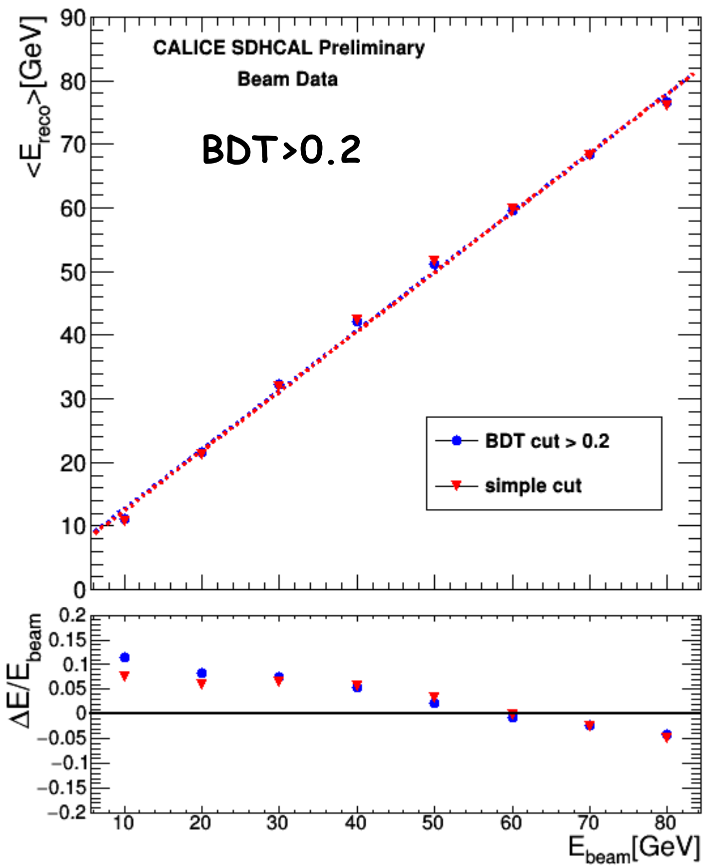
Electron rejection	Shower start >=5 or Nlayer > 30

Energy	simple cut	BDT cut > 0.1	BDT cut > 0.2
10GeV	4691	6953	5094
20GeV	5047	6413	5167
30GeV	4192	4634	3733
40GeV	15287	15644	12061
50GeV	7760	7812	5971
60GeV	7348	7347	5384
70GeV	5700	5572	3687
80GeV	8534	8337	5447



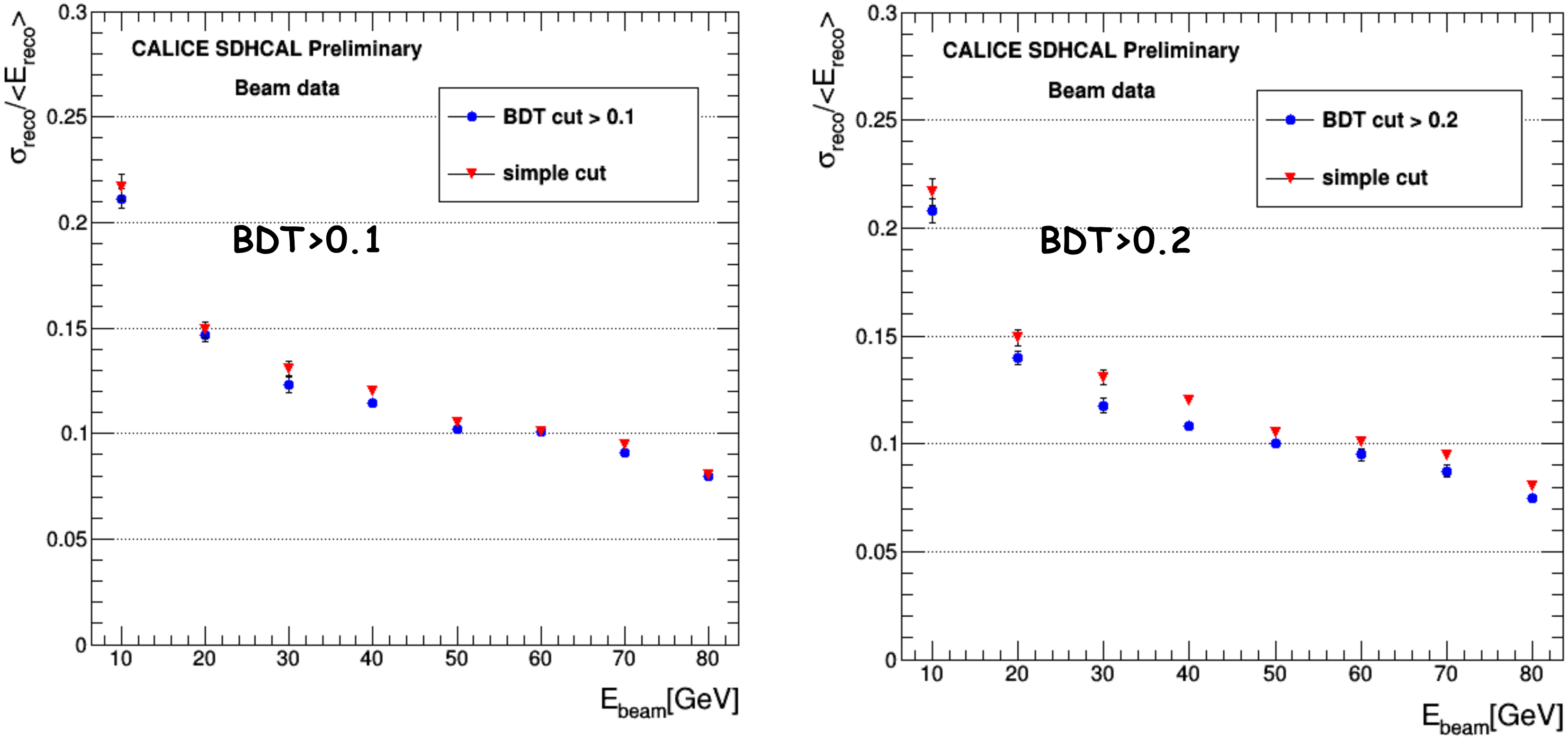
Linearity





- Linearity for "simple cut" and "BDT" are comparable

Energy Resolution



◆ Resolution for "BDT" is slightly better than that for "simple cut"

Summary and Future Plan

- Brief introduction to SDHCAL and analysis of 2015 TB data
- Particle identification using BDT in SDHCAL
  - PID with BDT is robust and reliable: Good pion efficiency with high electron and muon rejection comparing to "simple cut" method.
  - Good resolution and linearity in agreement with "simple cut" method

➔ **Future Plan:**

- Check the overlap events for "simple cut" and "BDT"
- Using purified TB data for BDT training
- Using more energy points or continuous energy spectrum for BDT training and estimate particle energy

Thanks !

Shower Density

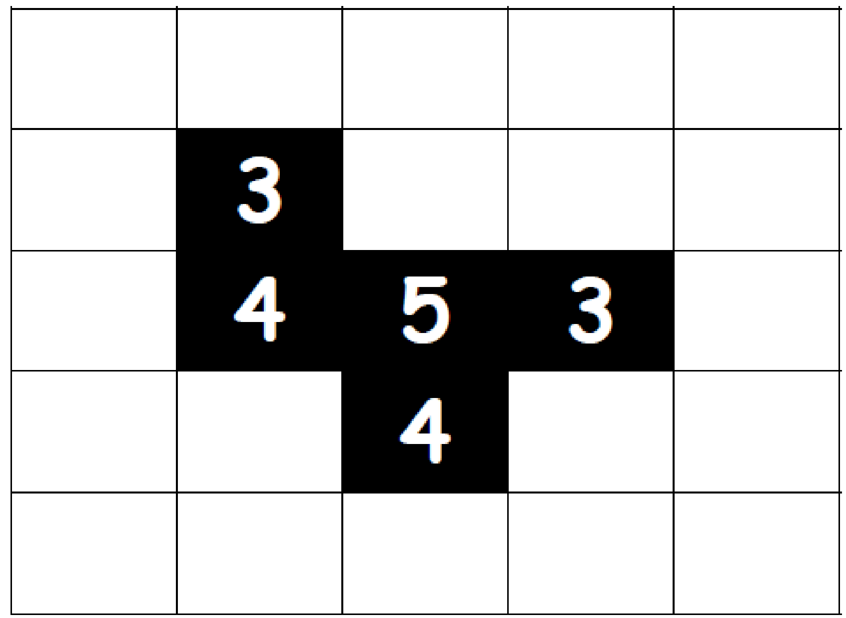
Density

As we known, EM components are more dense than hadronic parts, So we hope to help separate two category using density information

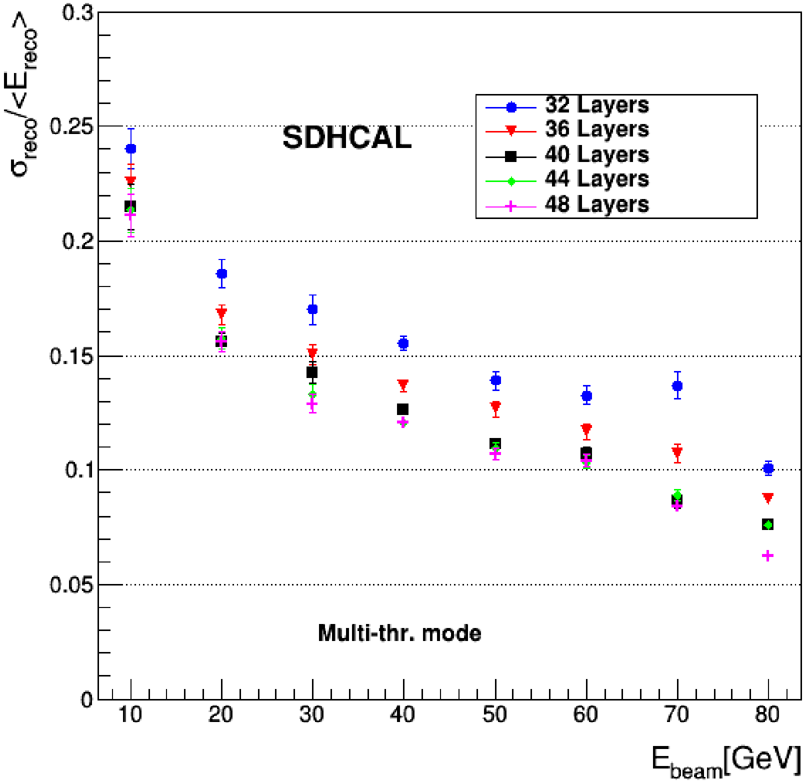
For every hit, you count the number neighbored itself(including itself) and then you add all number togother.

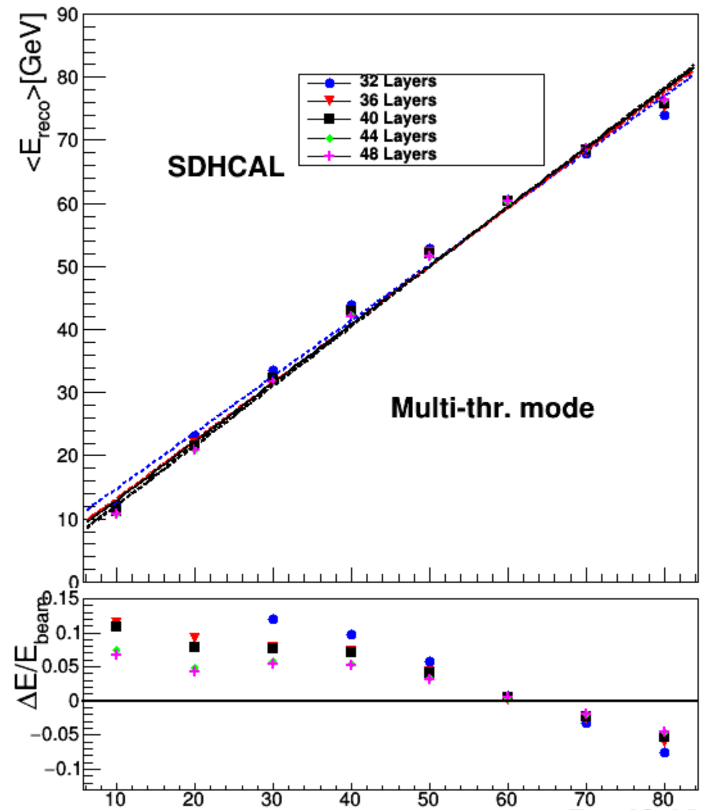
Finally the density equal to total number over total hits

Density=(3+4+5+4+3)/5=3.8



Optimization for layer numbers





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Stainless steel Absorber(15mm)

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- 6mm RPC and 20mm Stainless steel absorber

➔ Optimization no. of layers for CEPC at 240GeV, 40-layer SDHCAL yields decent energy resolution.