Tracker material study with the energy flow through the CMS electromagnetic calorimeter

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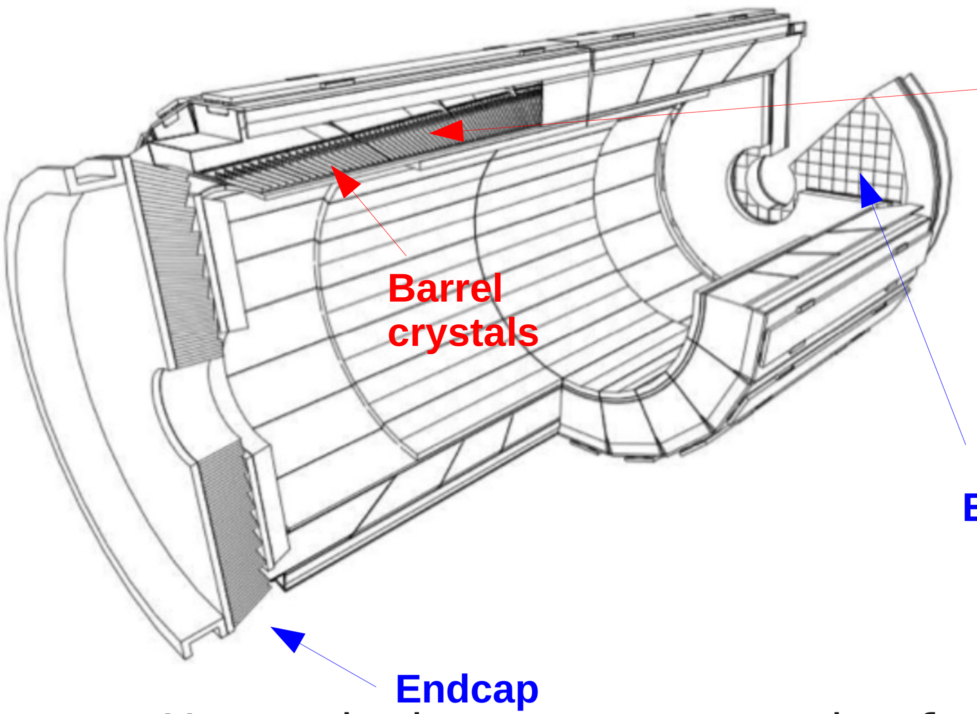
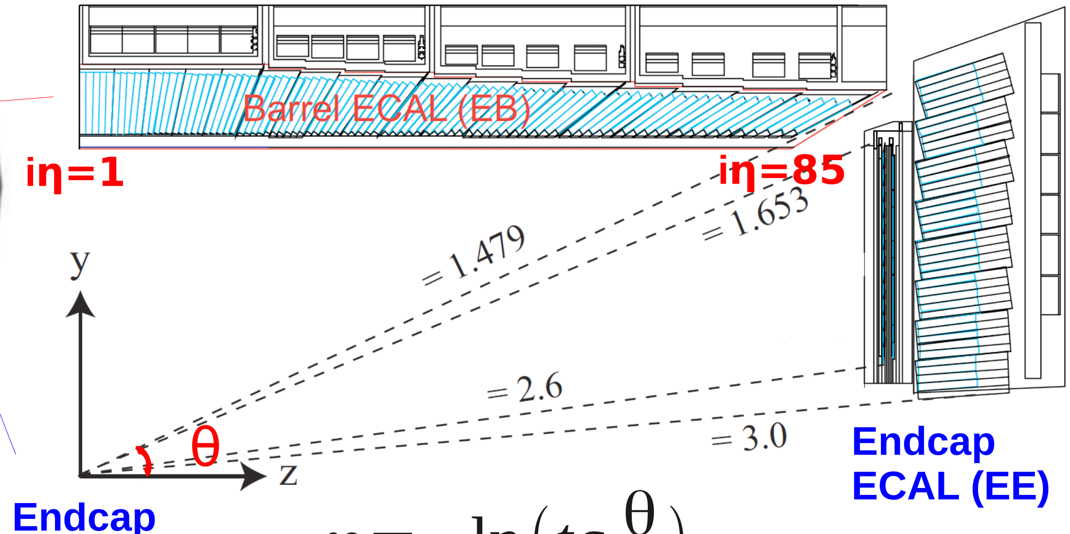
The electromagnetc calorimeter (ECAL)

To detect photons and electrons





$$\eta = -\ln\left(tg\frac{\theta}{2}\right)$$

- Hermetic, homogeneus made of lead tungstate crystals (75848)
- **Barrel (EB)** | η | <1.479
- **Endcaps (EE)** 1.479<| η | <3
- Good energy resolution

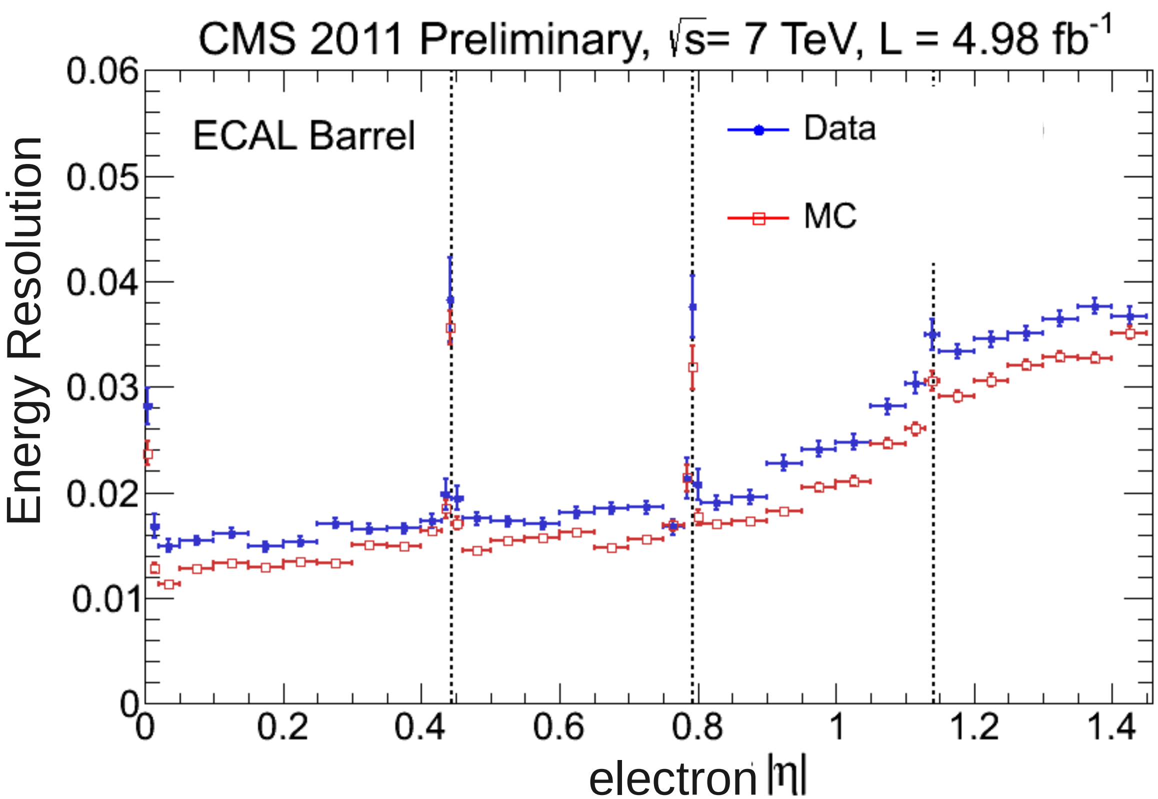
Crystal identified with (iη , iφ)
iη ϵ [1,85] → EB+
iη ϵ [-85,-1] → EB-

360 crystals in iφ for each value of iη

Problem

ECAL energy resolution is a crucial parameter in a lot of analysis

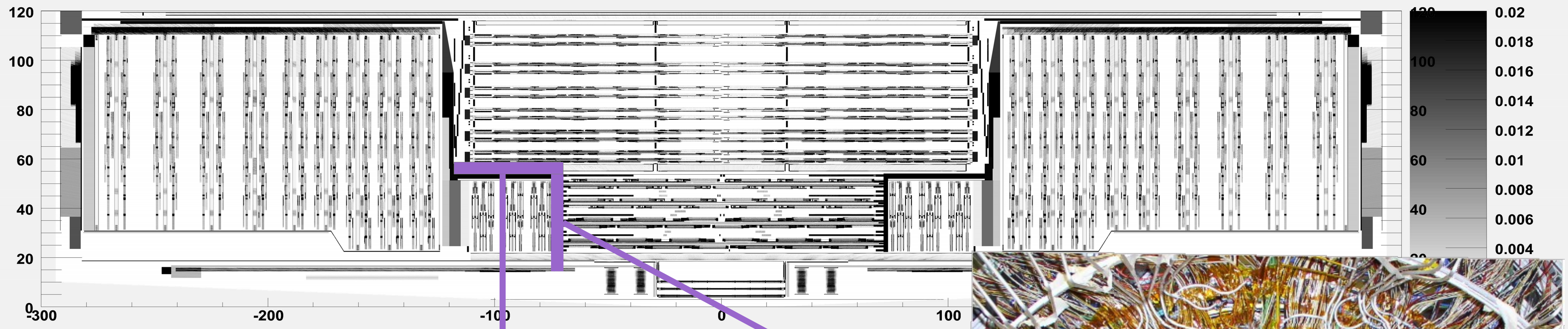
Problem: ECAL energy resolution obtained in $Z \rightarrow e^+e^-$ events $\neq$ ECAL energy resolution expected by MonteCarlo simulation



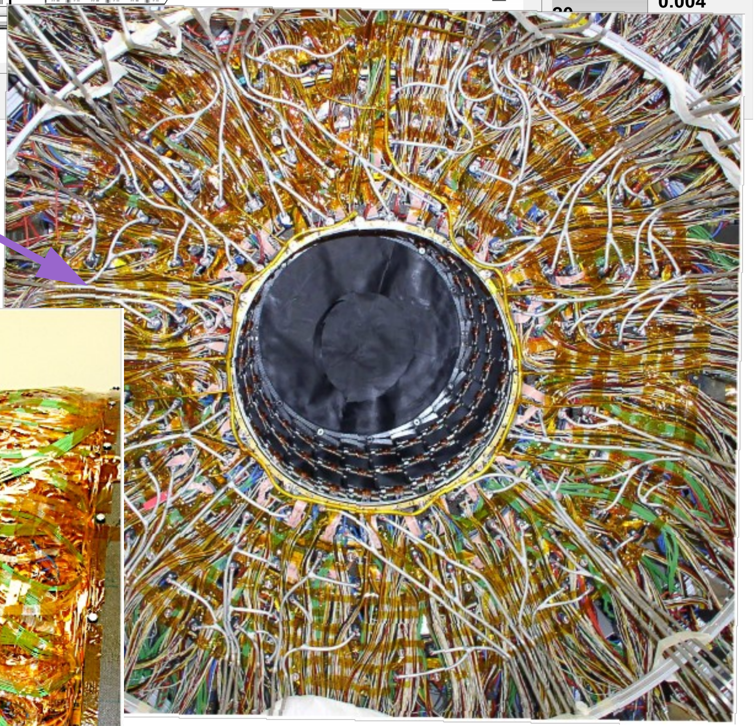
Cause: Inaccurate description of the tracker material (services)

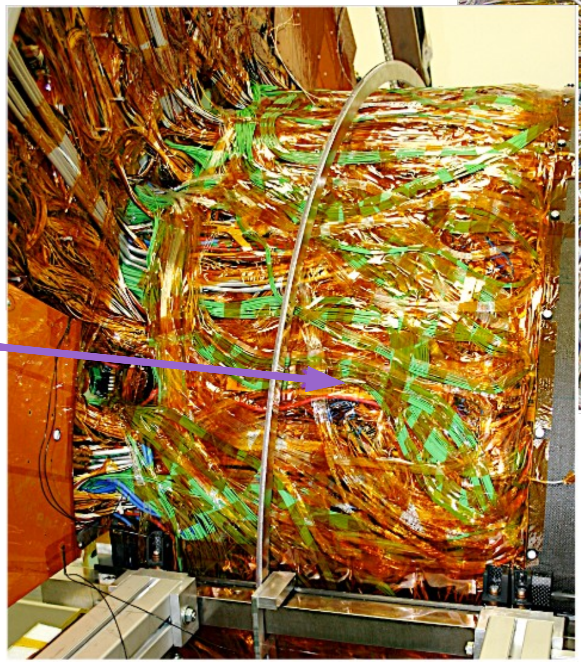
Problem

Tracker Structure

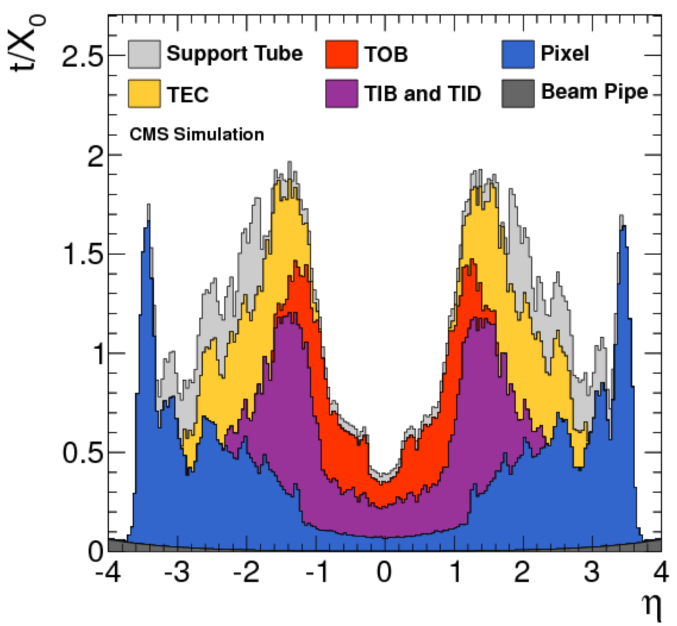


SERVICES





Distribution of the tracker material as a function of η



Problem

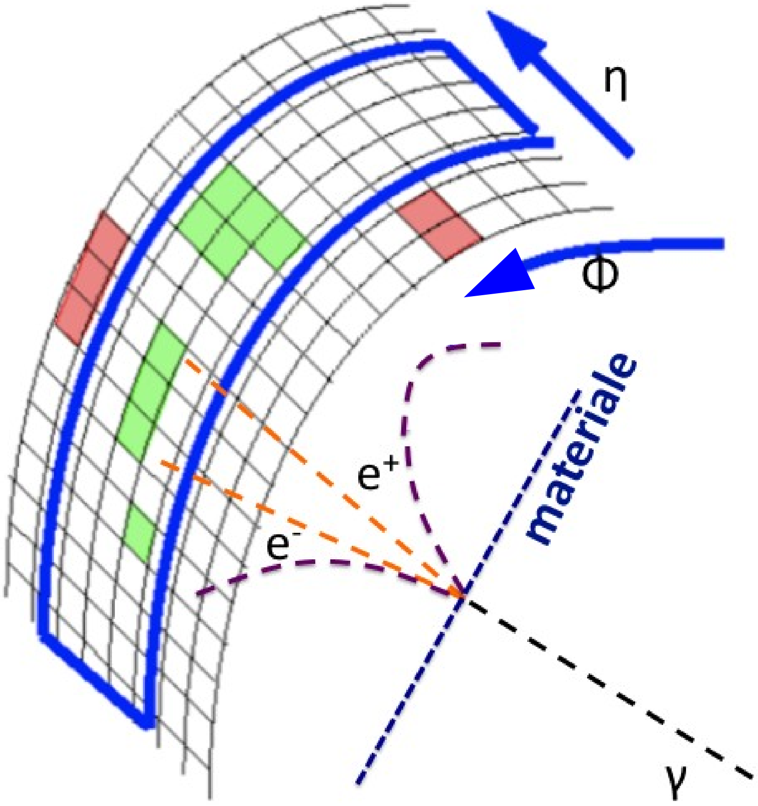
Combined action of the tracker **material** and the **magnetic field (B)**

For the **material**
$\gamma \rightarrow e^+e^-$

B changes the trajectory of e^+ and e^-.

↓

some e^+ or e^- can not reach ECAL



Goal of the study:
Obtain a better description of the tracker material than the estimate made during the detector construction

e^+e^- without B
e^+e^- with B

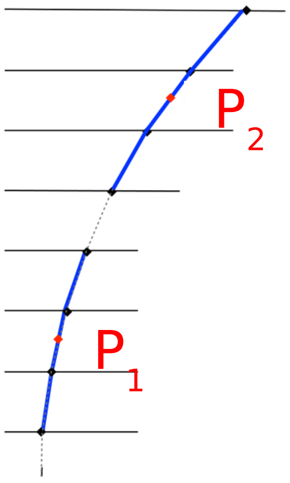
Methods to estimate the tracker material

Study the momentum lost:

Momentum variation ∝ material

- Use of high energy electrons that radiate photons for bremsstrahlung

$$f_{brem} = \frac{p_i - p_f}{p_i}$$



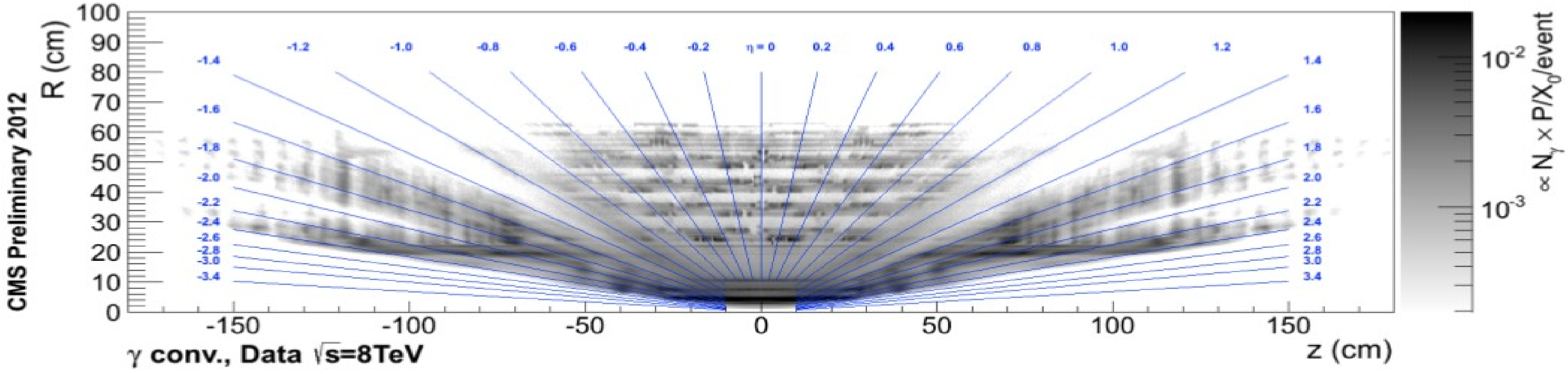
- Use of charged pion with $P_t \sim 1$ GeV that do multiple scattering: study of the difference between P_2 e P_1

Conversion method:

In presence of material $\gamma \to e^+e^-$

Pairs produced ∝ material

Conversions map



Methods non sensitive to the outer layers of the tracker material

The Energy Flow method

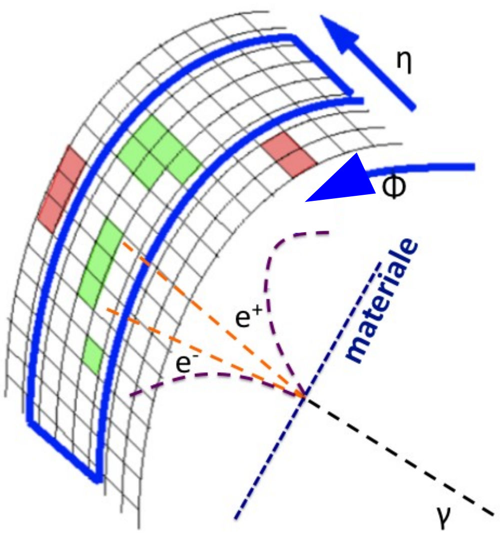
Energy Flow through the ECAL crystals:

$$S_{xtal} = \Sigma_i (E_t^i)_{xtal}$$

Transverse energy sum for an high number of Minimum Bias events

Energy Flow ratio in ECAL crystals:

$$R_{xtal} = \frac{(S_{xtal})_{Boff}}{(S_{xtal})_{Bon}}$$



Gives a measure of the amount of tracker material because of the combined action of the **tracker material** and the **magnetic field**.

In fact

$$(S_{xtal})_{Bon} < (S_{xtal})_{Boff}$$

Data

Run of Minimum Bias events with **magnet off (Boff)** (~2.6*10^8 events)
Run of Minimum Bias events with **magnet on (Bon)** (~2.0*10^8 events)
Taken in the same period

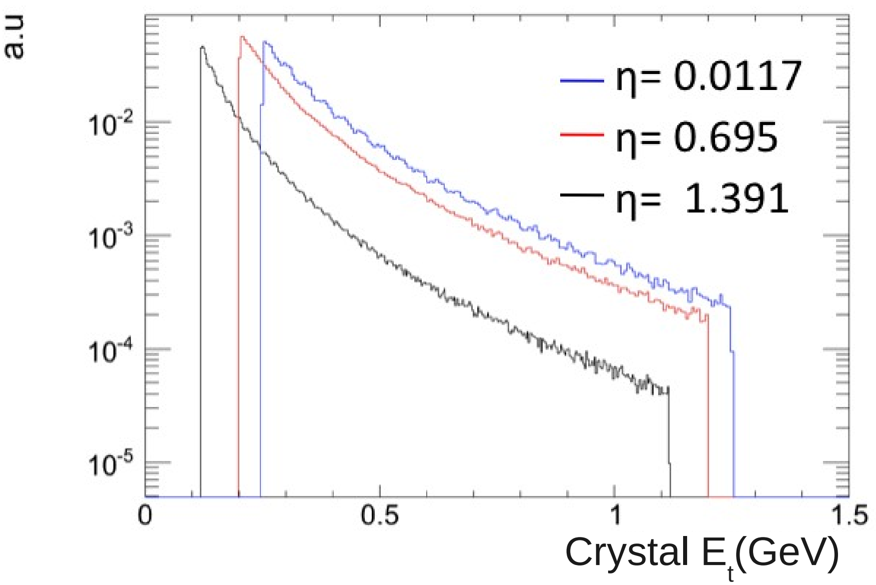
In the analysis only crystals with energy deposits between a **lower threshold** and an **upper threshold** have been considered

E_{min} =400 MeV → To cut the noise

Maximum value of transverse energy

$$(E_t)_{max} = (E_t)_{min} + 1\,GeV$$

To reduce fluctuations caused by rare high energy deposits



Average number of energy deposits between the cuts ~3.7*10^5

Analysis Flow

- Obtain energy flow for magnet off and magnet on events separately

- Determine the energy flow ratio for each ECAL crystal

- Compute the corrections for the effect that influence the energy flow:
  - Beam spot position effect
  - Border effect

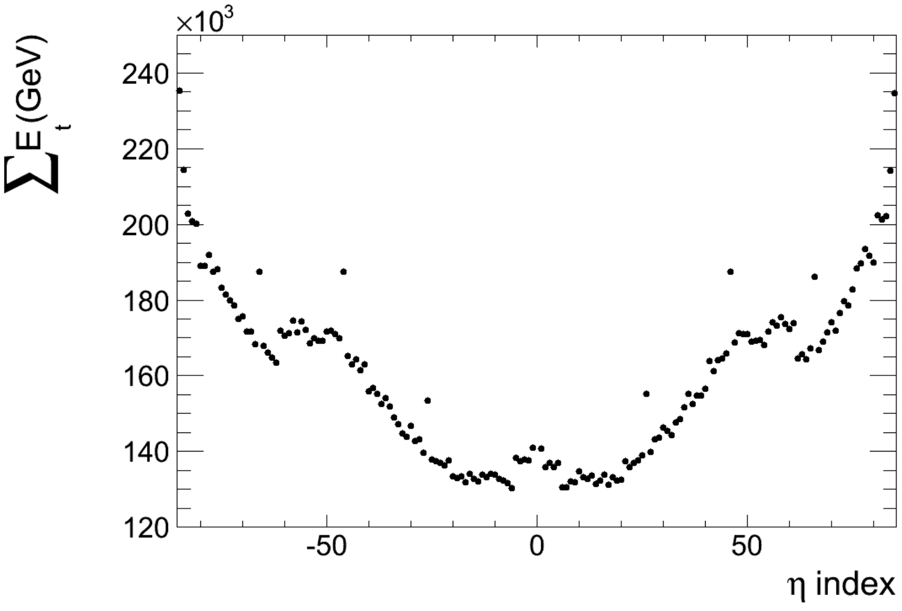
- Comparison between data and MonteCarlo (MC):

$$\frac{R_{data}}{R_{MC}} \neq 1 \longrightarrow$$ Tracker material not well implemented in MC

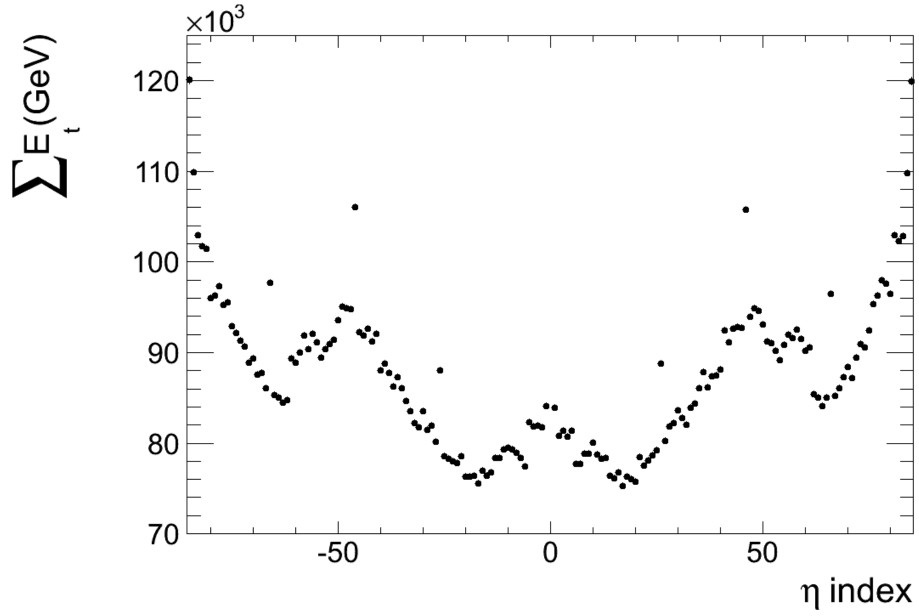
Energy Flow through ECAL

$S_{xtal} = \Sigma_i \left(E_t^i\right)_{xtal}$ as a function of η index for magnet off and magnet on data

Magnet off data



Magnet on data



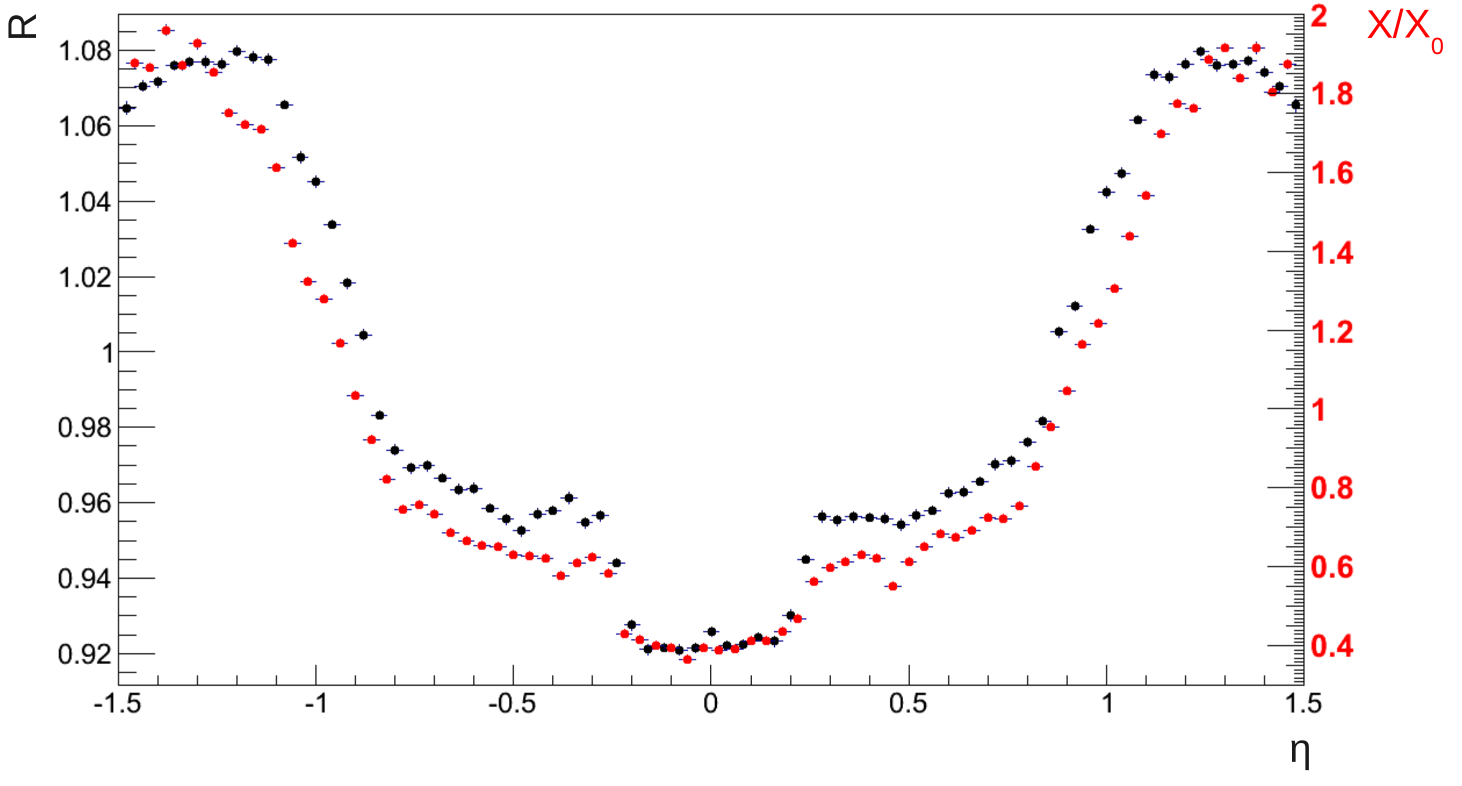
Energy Flow Ratio

Energy flow ratio

$$R_{xtal} = \frac{\left(S_{xtal} / <S>\right)_{Boff}}{\left(S_{xtal} / <S>\right)_{Bon}}$$

Mean of S_{xtal} in the ECAL barrel

$$S_{xtal} = \Sigma_i \left(E_t^i\right)_{xtal}$$



Correlation between R and the tracker material (X/X_0)

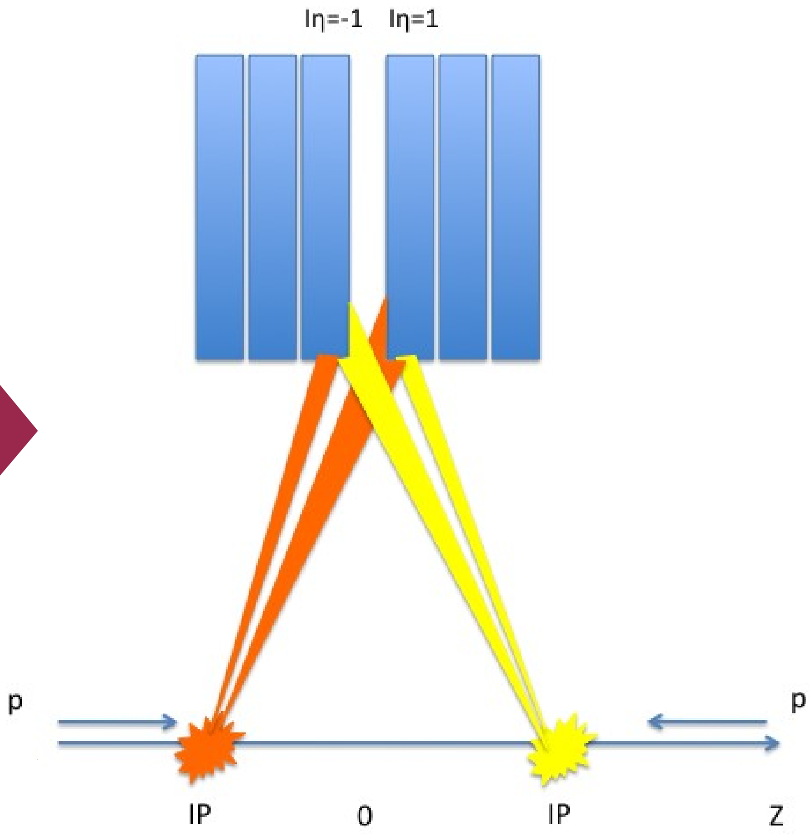
Beam spot position effect

The interaction point of the two beams doesn't match always with the center of the detector (z=0). It can take place at a few cm from z=0.

IP= Interaction Point Position

z=0 center of the detector

Beam spot position effect on the energy flow

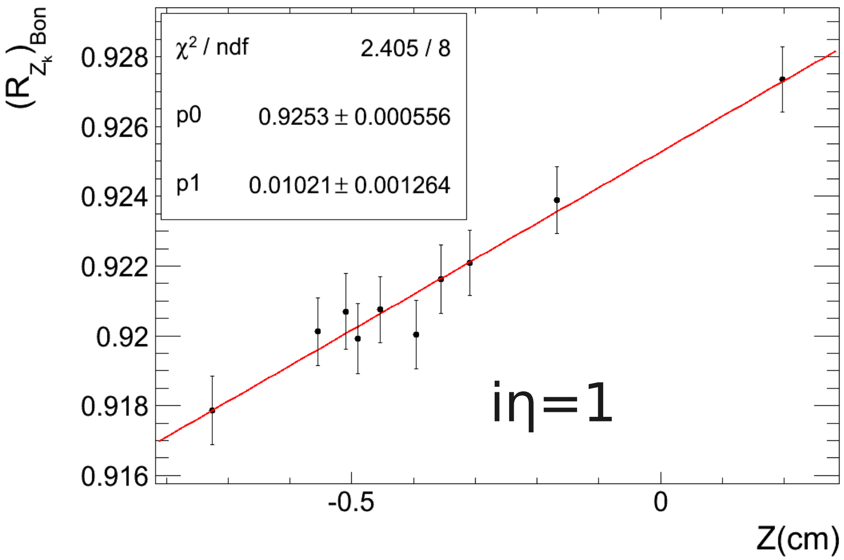


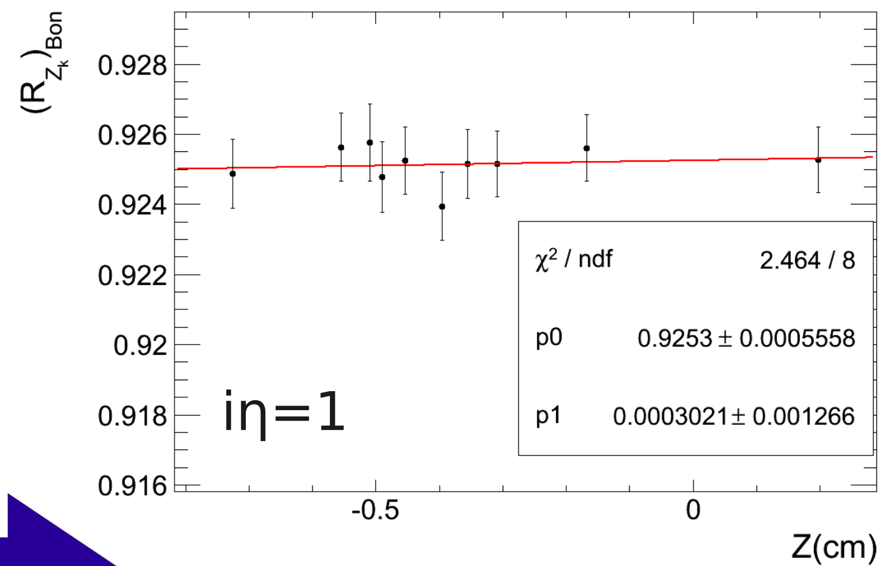
Beam spot position effect

Computing of the corrections:

R has been calculated in Z_k intervals and it has been studied as a function of Z

Bon

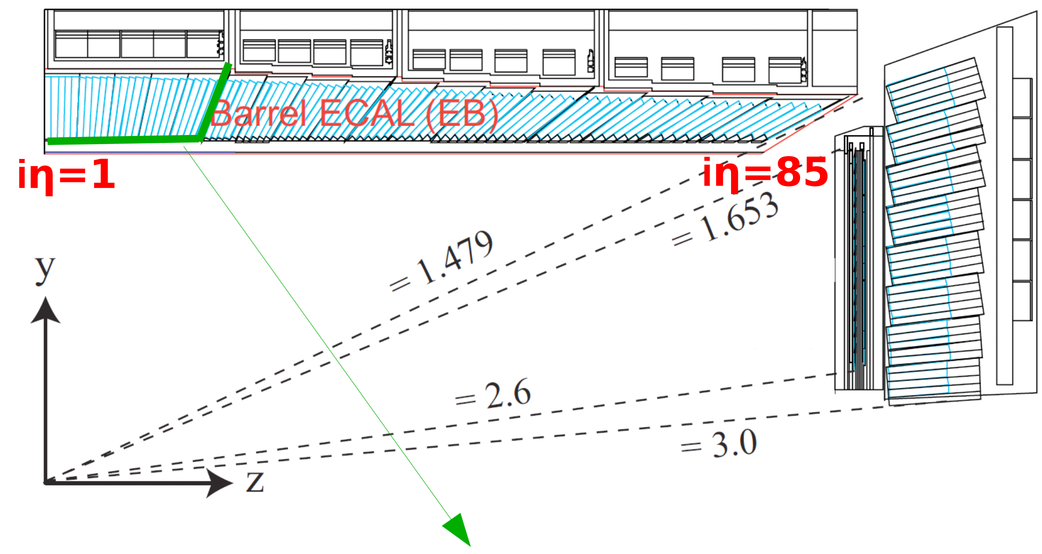




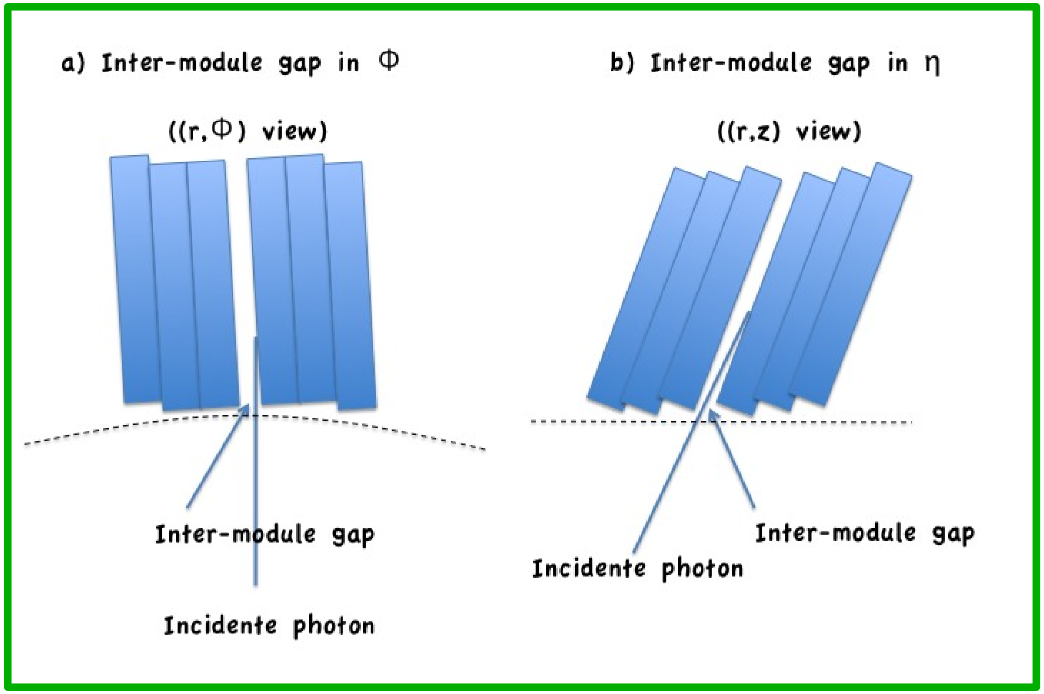
The corrections lead E_t and R to the value that they would have if IP is equal to z=0

Border effect

The crystal axis is not pointing to the center of CMS. They are tilted by 3° with respect to the center of the detector, to maximize the detector acceptance.



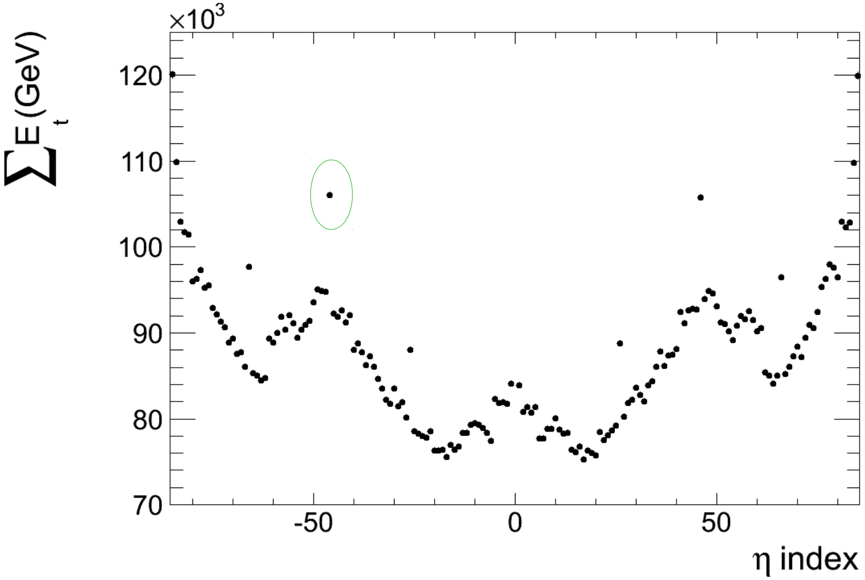
The particles entering in the module gap hit the lateral face of the crystal at the border



Border crystal collects more energy than the other

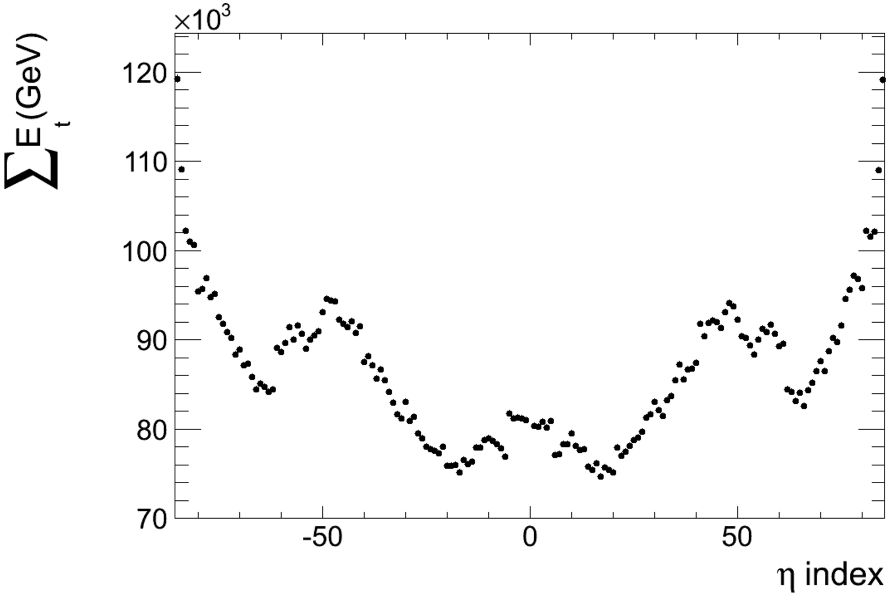
Border effect

Energy flow for magnet off data



The corrections have been determined by normalizing <$S_{crystal}$> to the average in the adjacent rings

Energy flow for magnet off data, corrected for the border effect

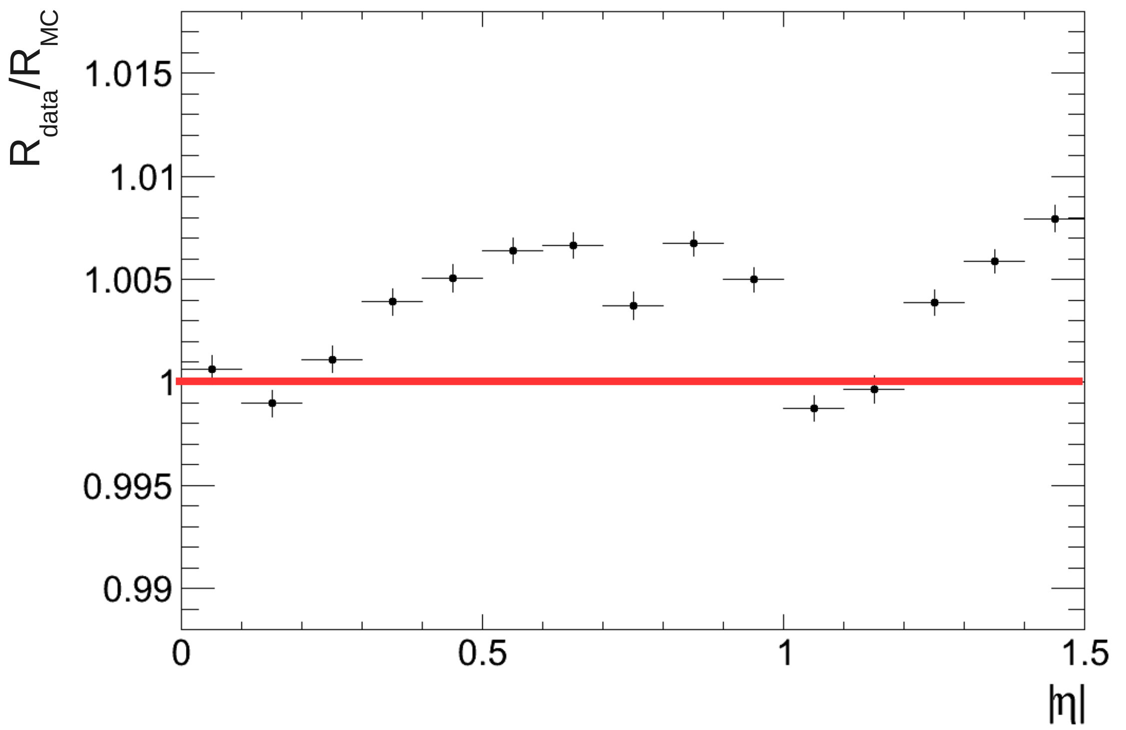


Corrections take values from ∼3% → ∼15%

Comparison between data & MonteCarlo

The ratio R_{data}/R_{MC} gives informations about the inaccuracy on the description of the tracker material.

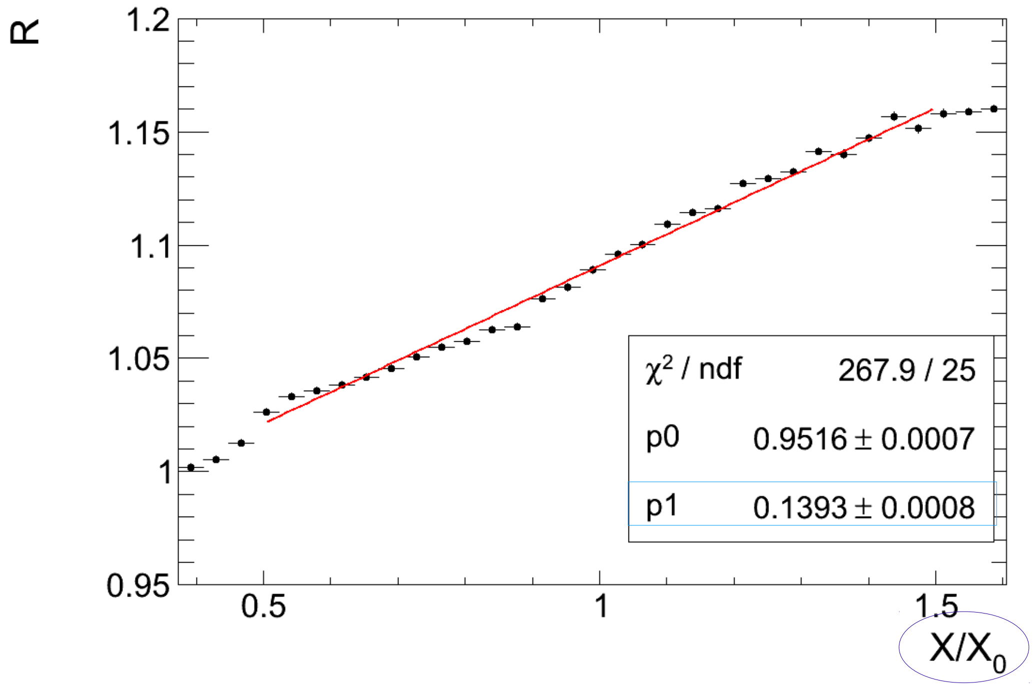
$R_{data}/R_{MC} \neq 1 \rightarrow$ tracker material not well implemented in the MC



These measures have to be calibrated to have a direct information on the needed additional material (in radiation length)

Comparison between data & MonteCarlo

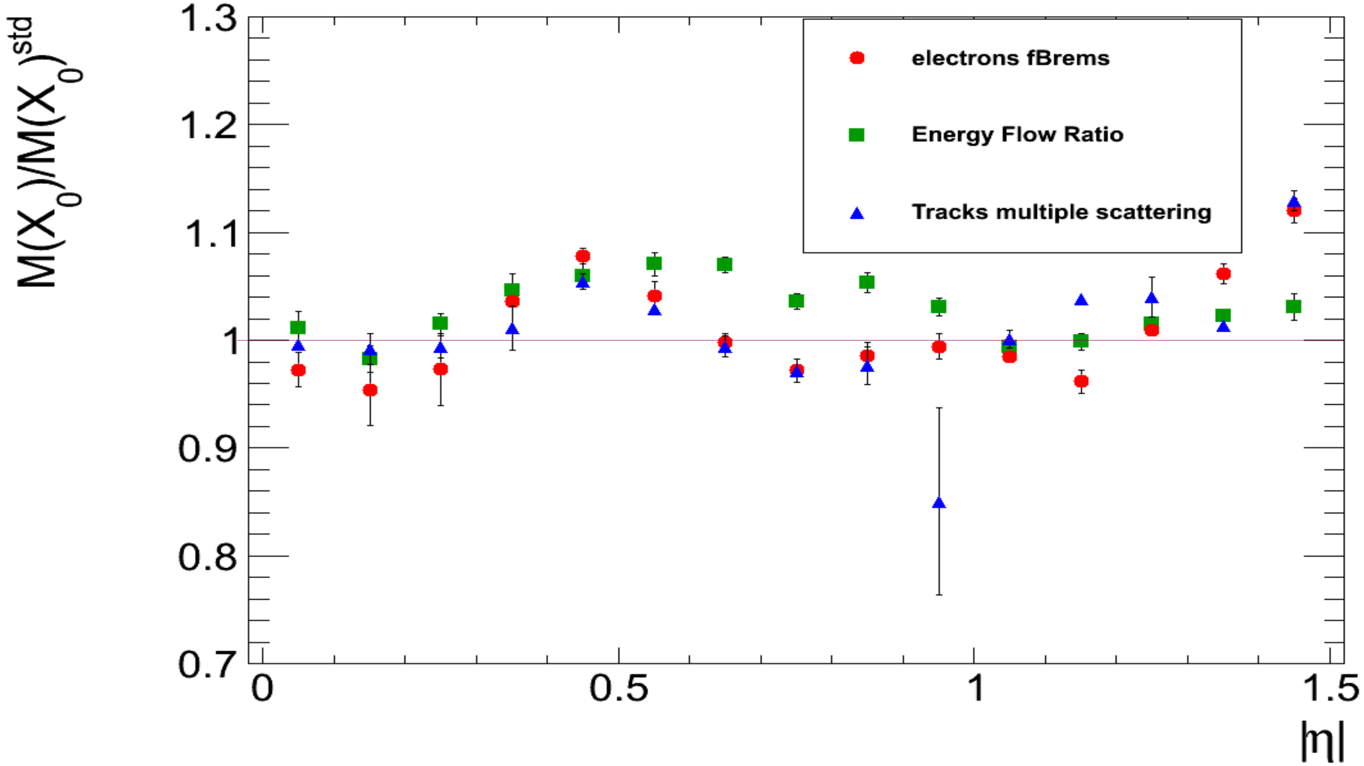
Mean of R as a function of X/X_0



$1/p1$ Factor used to convert R_{data}/R_{MC} in the amount of material to be added to the material in the MC simulation (**$\Delta M(X_0)$**)

$$\frac{R_{data}}{R_{MC}} = 0.01 \rightarrow \Delta M(X_0) = 0.07\, X_0$$

Results



$$M(X_0) = \boxed{M(X_0)^{std}} + \Delta M(X_0)$$

Measure of the material made during the detector construction

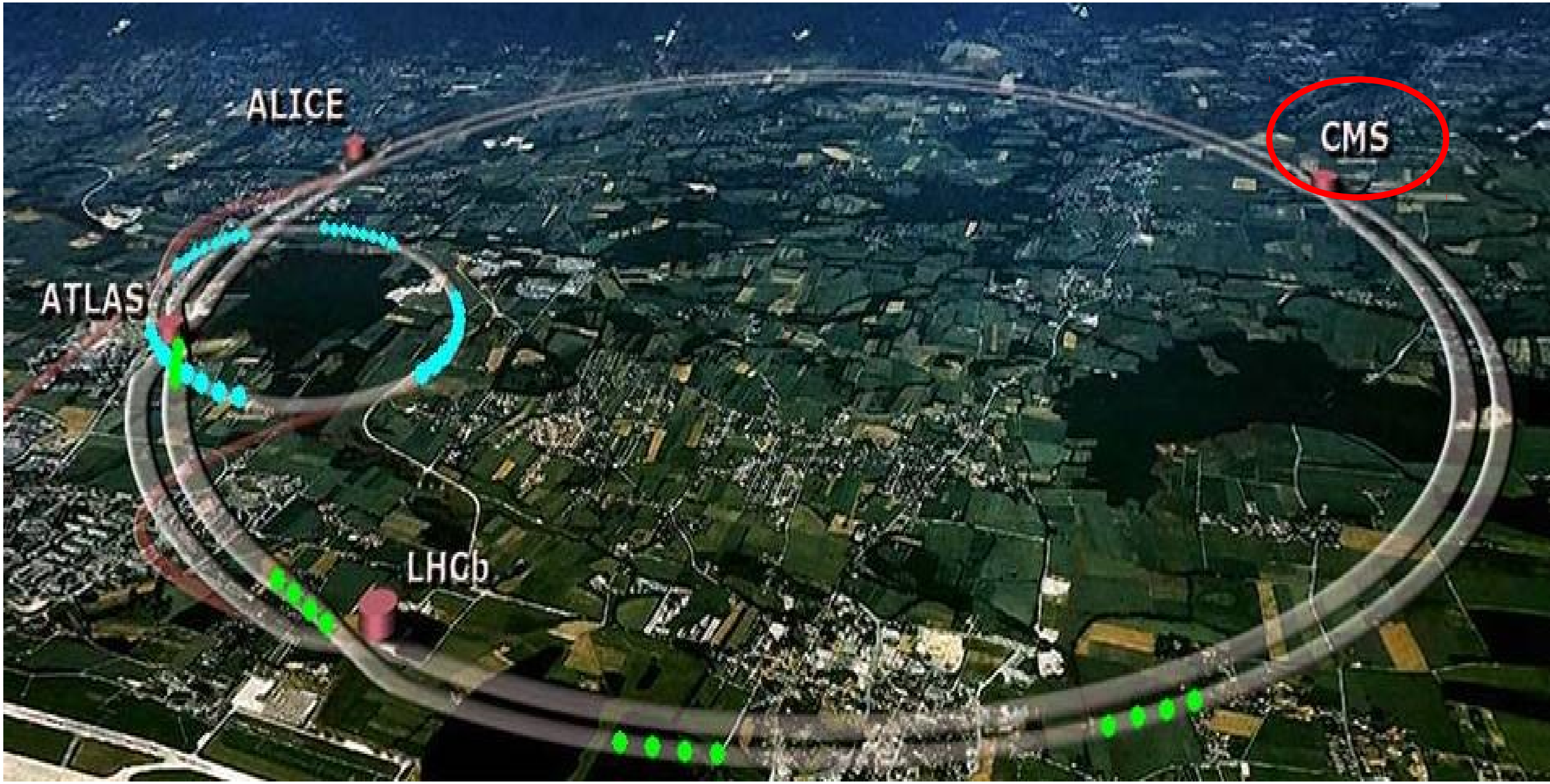
- Quite good agreement with other methods
- Larger additional material for 0.5 <|η| <1
- The **energy flow method** is the only one that take into account the outer layers of the tracker material

Conclusions

- ECAL energy resolution is a key parameter in a lot of analysis: Its knowledge is crucial
- A new method to study the amount of tracker material in front of ECAL has been proposed
- This method uses only calorimetric quantity:
  It is the only one that take into account the outer layers of the tracker material
- Good agreement with the other methods
- These results are used in the new MC production aimed to the validation of the new measure of the tracker material through the data-MC compatibility in the energy resolution.

BACKUP

CMS experiment at LHC



CMS: Compact Muon Solenoid, one of the two multi-purpose experiment at **LHC**

LHC: Large Hadron Collider, p-p accelerator at CERN, Geneva
Run 1: 2009 → 2012 $\sqrt{s}$=7-8 TeV
Run 2: from 2015 $\sqrt{s}$=13-14TeV

The electromagnetc calorimeter (ECAL)

	$PbWO_4$	**NaI(Tl)**	**BGO**
Density [g/cm^3]	8.28	3.67	7.13
Radiation lenght [cm]	0.89	2.59	1.12
Molière radius [cm]	2.2	4.5	2.4
Peak emission [nm]	425	410	480
LY(related to NaI(Tl)[%])	1.3	100	15
Time emission [ns]	5-15	250	300

Longitudinal distance for which an electron traversing the material loses on average 1/e of its energy through diffusion processes. For E~TeV the 98% of the longitudinal development is contained in $25X_0$.

$$R_M = \frac{21.2\, MeV * X_0}{E_C[MeV]}$$

describe the transversal development of an electromagnetic shower.The 90% of the shower is contained in a cylinder with a radius equal to 3.5 R_M

Energy resolution

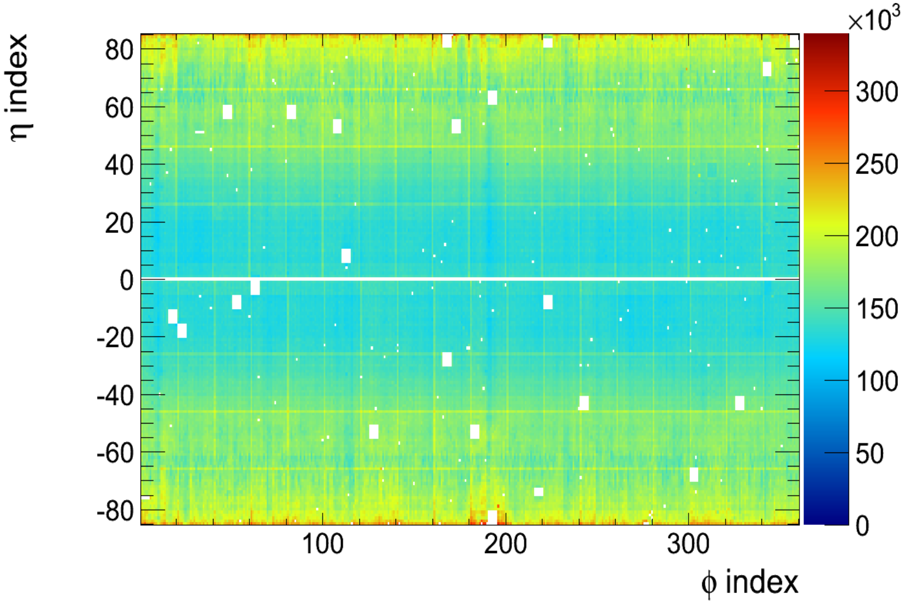
$$\frac{\sigma(E)}{E} = \frac{S}{\sqrt{E}} \oplus \frac{N}{E} \oplus C$$

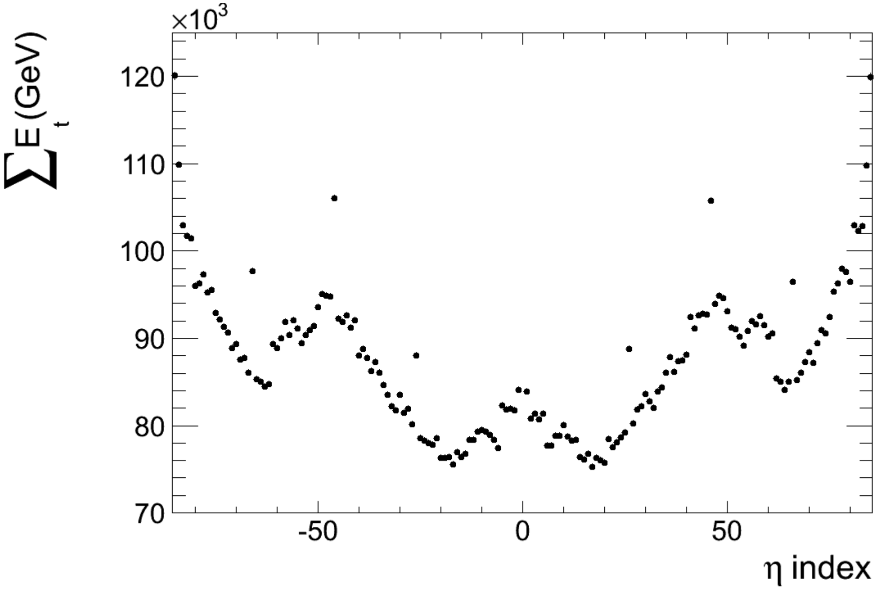
For e $$E_C = \frac{610\, MeV}{Z}$$

Energy Flow through ECAL

$S_{xtal} = \Sigma_i (E_t^i)_{xtal}$ For magnet off data

GeV



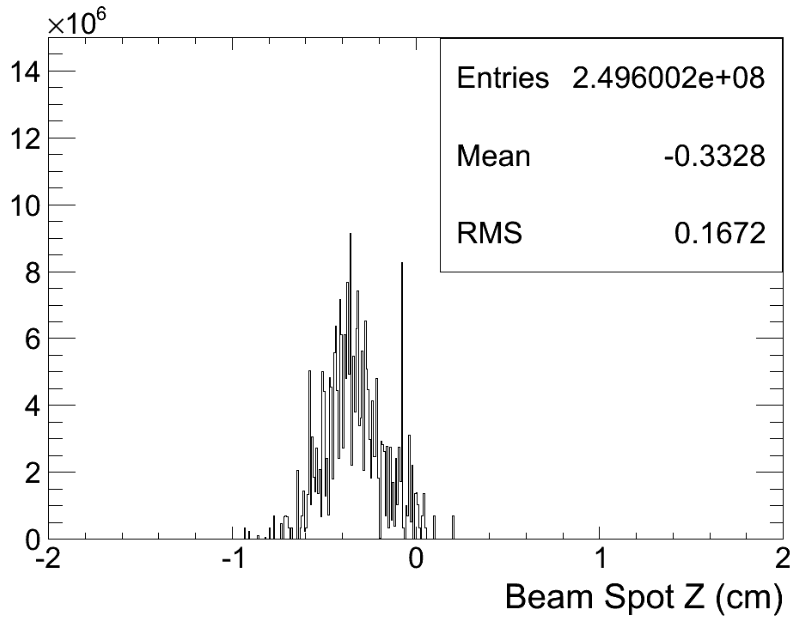


Beam spot position

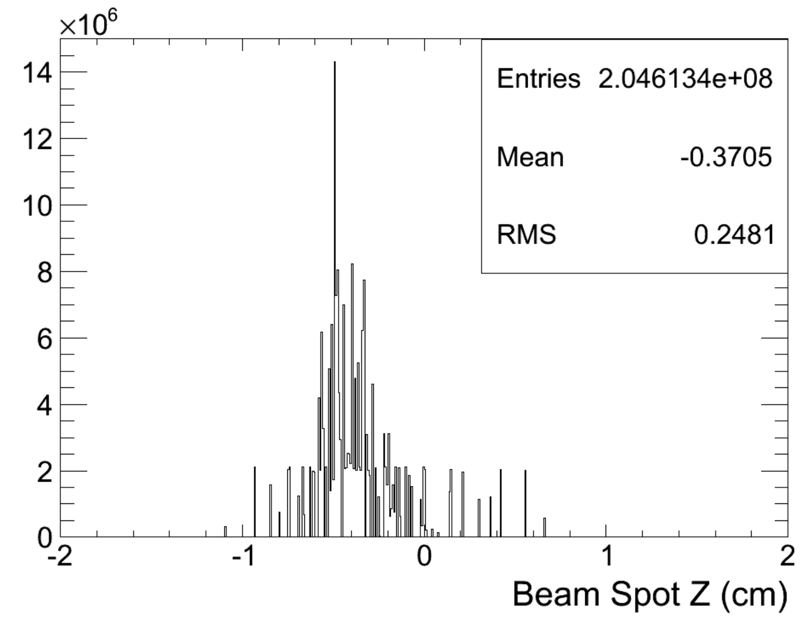
The interaction point of the two beams doesn't match always with the center of the detector (z=0). It can take place at a few cm from z=0.

Beam spot position distribution for the two groups of data

Magnet off data



Magnet on data



Beam spot position

Computing of the corrections for Boff data:

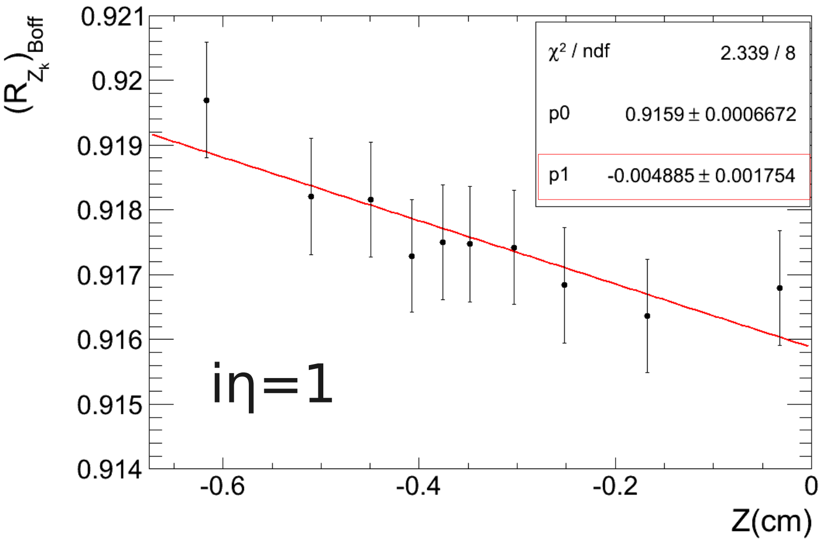
The beam spot position distribution has been divided into 10 intervals (Z_k):

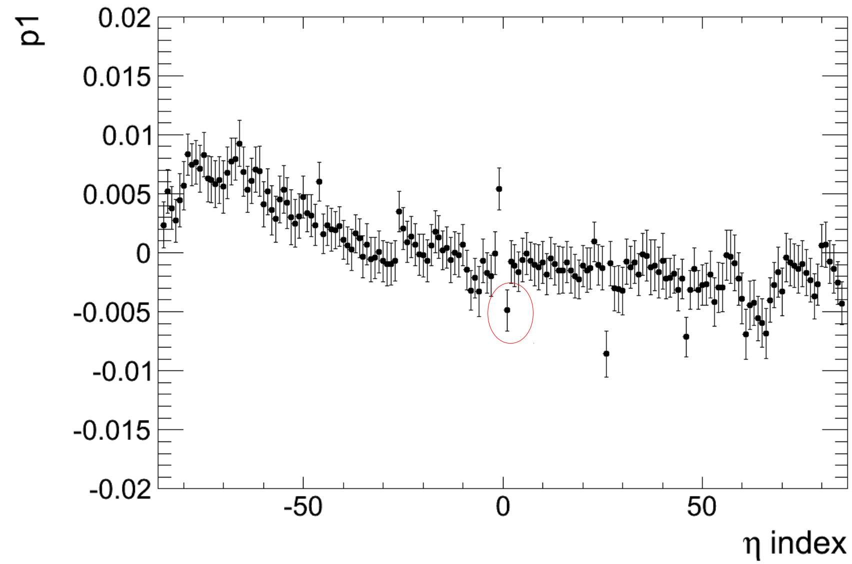
This quantity has been defined

$$\left(R_{Z_k}\right)_{Boff} = \frac{\left(\left(\Sigma E_t^i / < \Sigma E_t >\right)_{Z_k}\right)_{Boff}}{\left(\Sigma E_t^i / < E_t >\right)_{Bon}}$$

It has been studied as a function of the beam spot

Boff





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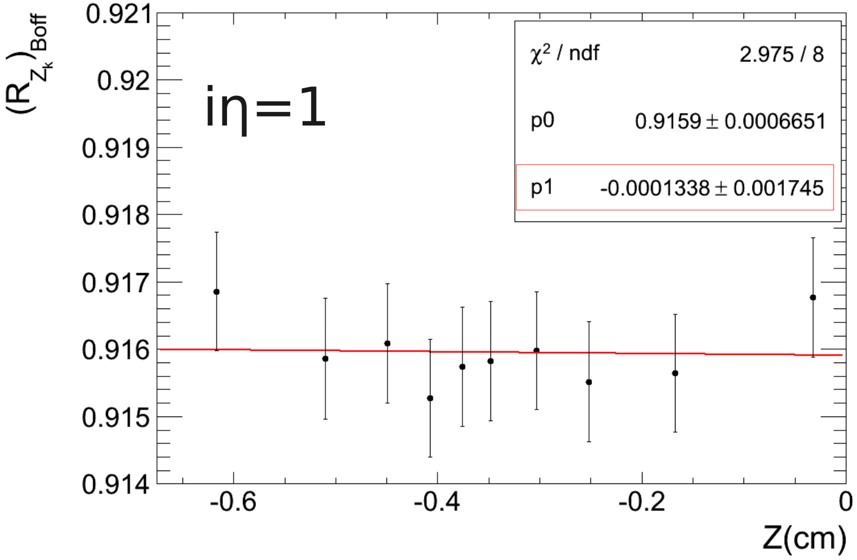
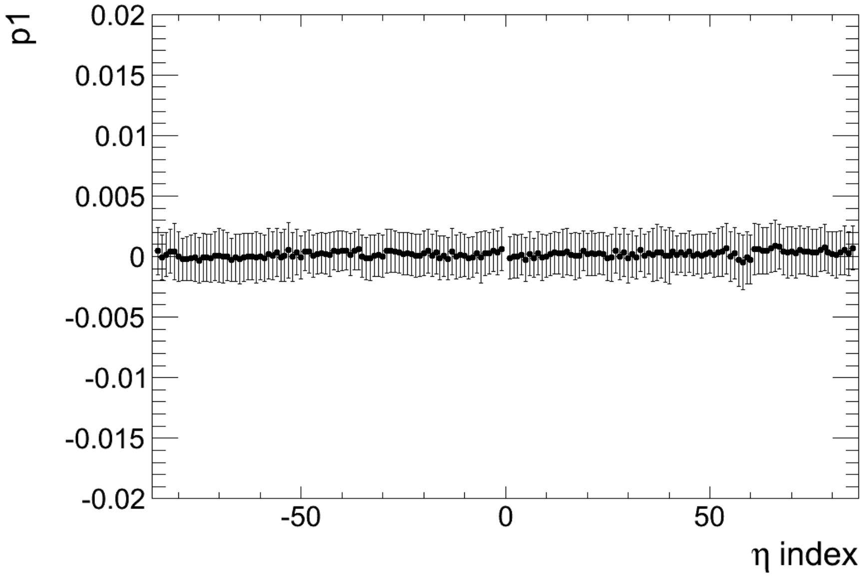
After the correction

$$\left(E_t^{corr}\right)_{Boff} = \frac{E_t}{p1 * Z + 1}$$

Boff





Beam spot position

Computing of the corrections for Bon data:

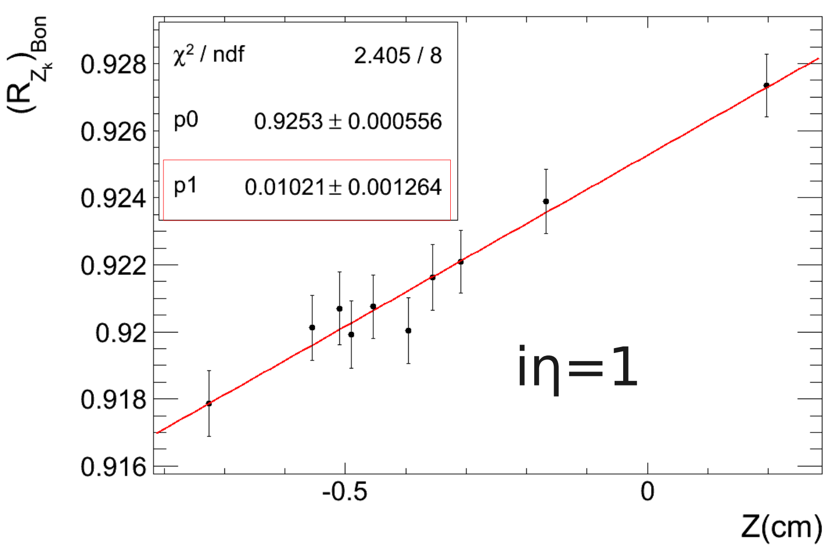
The beam spot distribution has been divided into 10 intervals (Z_k):

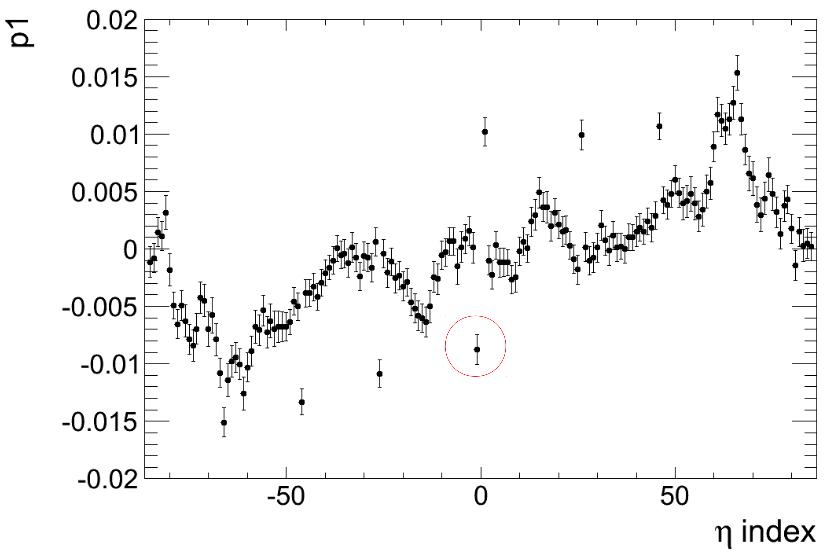
This quantity has been defined

$$\left(R_{Z_k}\right)_{Bon} = \frac{\left(\Sigma E_t^i / < \Sigma E_t >\right)_{Boff}}{\left(\left(\Sigma E_t^i / < E_t >\right)_{Z_k}\right)_{Bon}}$$

They have been studied as a function of the beam spot

Bon





Beam spot position

Computing of the corrections for Bon data:

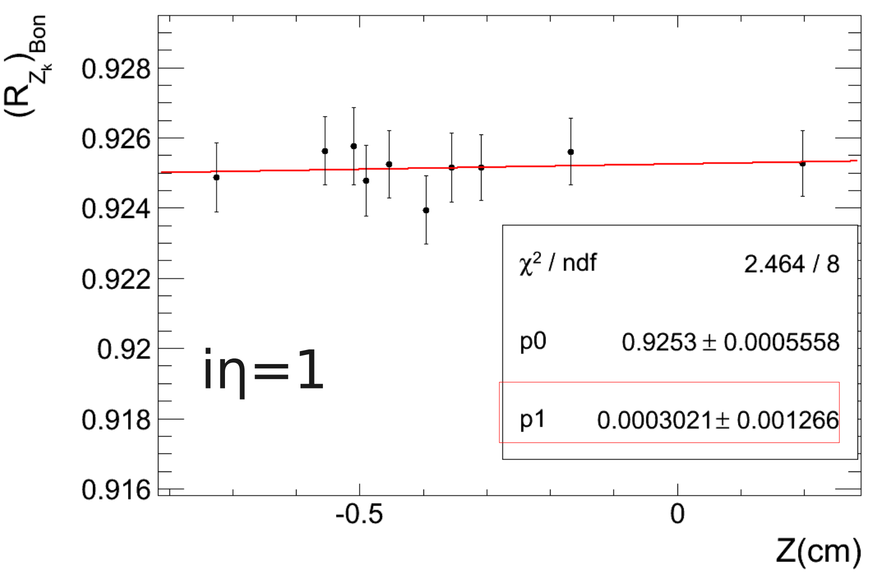
The beam spot position distribution has been divided into 10 intervals (Z_k):

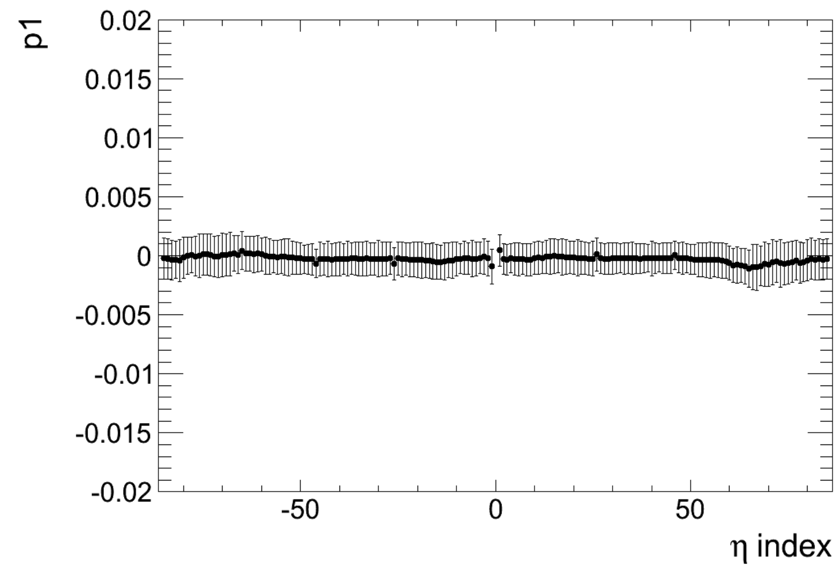
This quantity has been defined

$$(R_{Z_k})_{Bon} = \frac{\left(\Sigma E_t^i / < \Sigma E_t > \right)_{Boff}}{\left(\left(\Sigma E_t^i / < E_t > \right)_{Z_k}\right)_{Bon}}$$

After the correction $$(E_t^{corr})_{Bon} = E_t * (p1 * Z + 1)$$

Bon

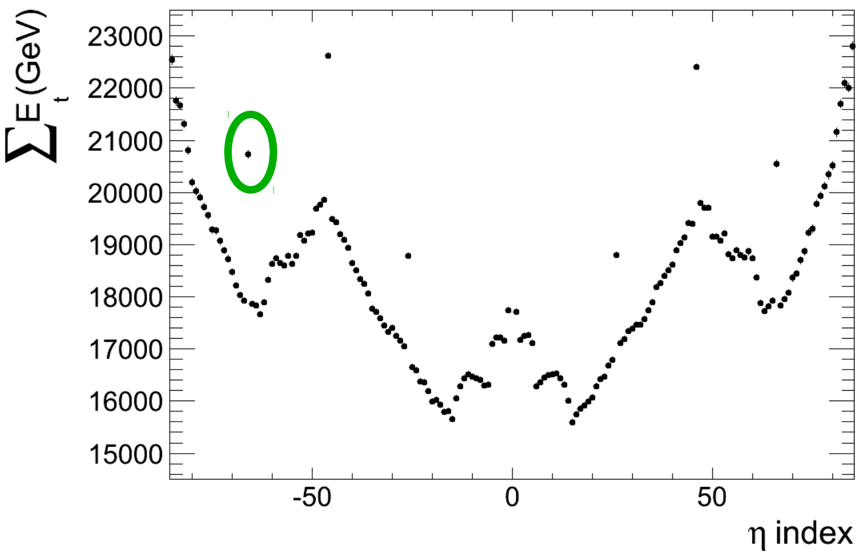


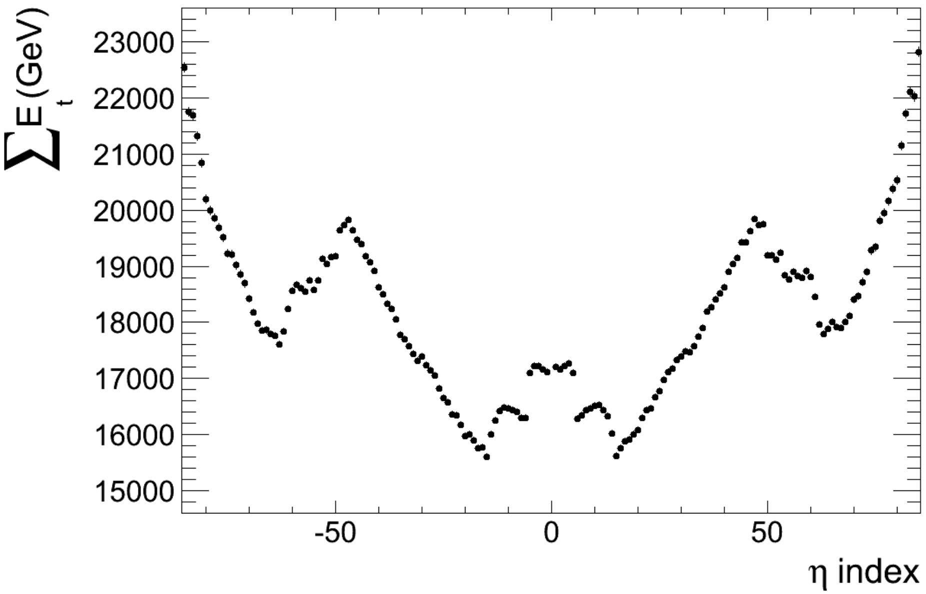


Border Effect

Corrections derived from MC and for iη and iϕ ECAL coordinate

iη border correction





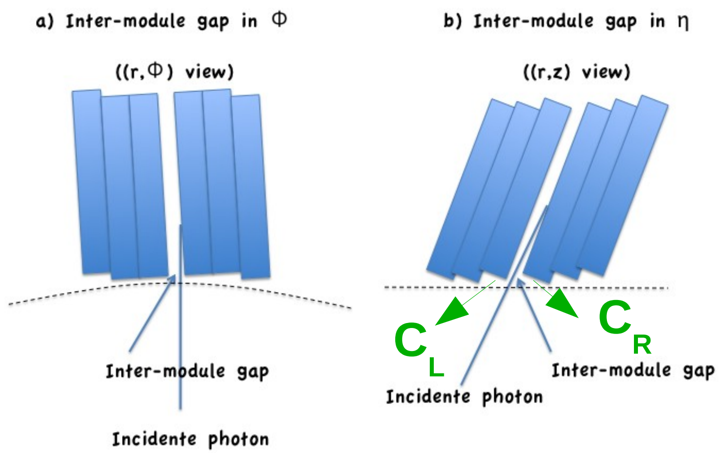
$$C^{\pm}_{\eta_i} = \frac{<E_t(\eta_i)> - (<E_t(\eta_{i+1})> + <E_t(\eta_{i-1})>)/2}{(<E_t(\eta_{i+1})> + <E_t(\eta_{i-1})>)/2}$$

Total correction

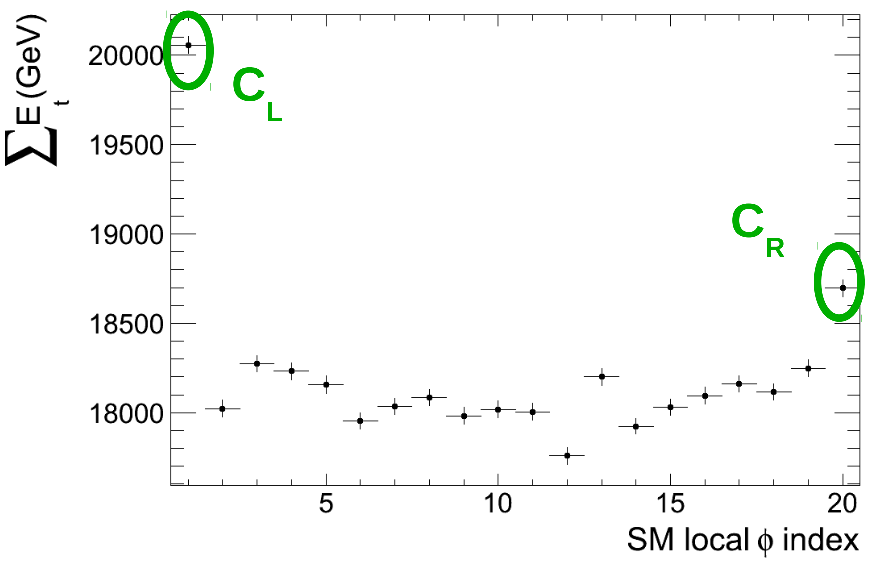
$$C_{\eta_i} = \frac{C^{+}_{\eta_i} + C^{-}_{\eta_i}}{2}$$

Border Effect

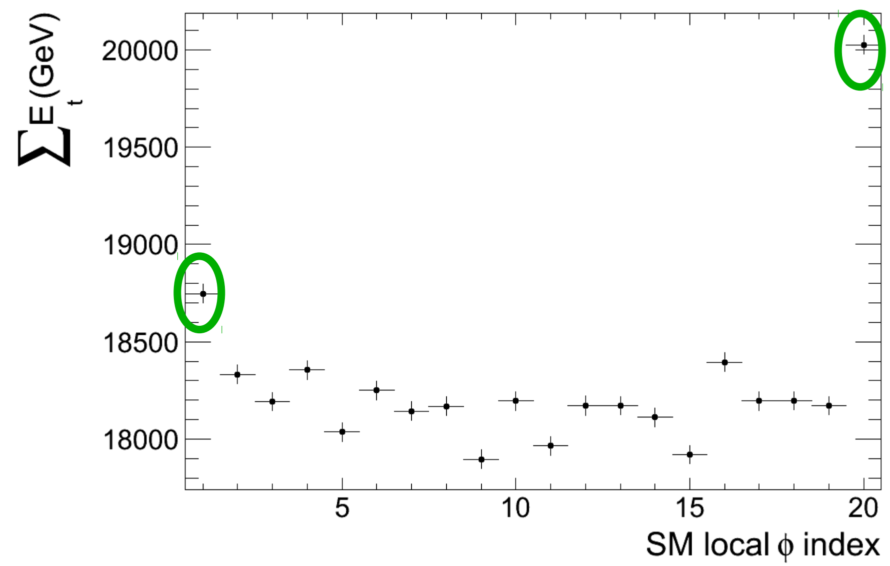
iϕ border correction for magnet on MC, derived for EB+ and EB- separately due to the crystals staggering



EB -



EB +



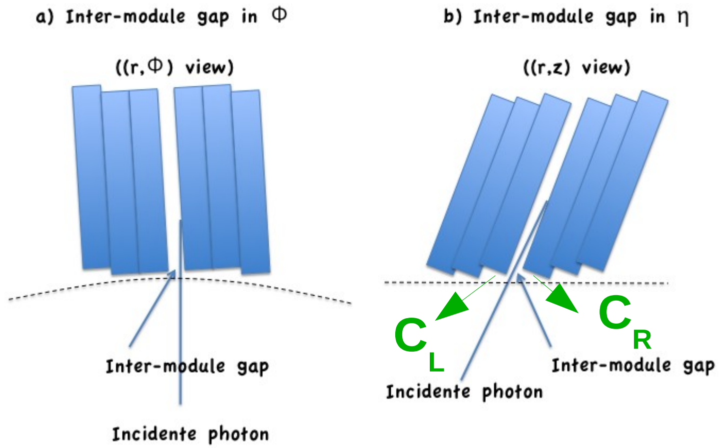
$$(C_\Phi^\pm)_{R(L)} = \frac{<E_{t_B}> - <E_t>}{<E_t>}$$

Total correction

$$(C_\Phi)_{R(L)} = \frac{(C_\Phi^+)_{R(L)} + (C_\Phi^-)_{R(L)}}{2}$$

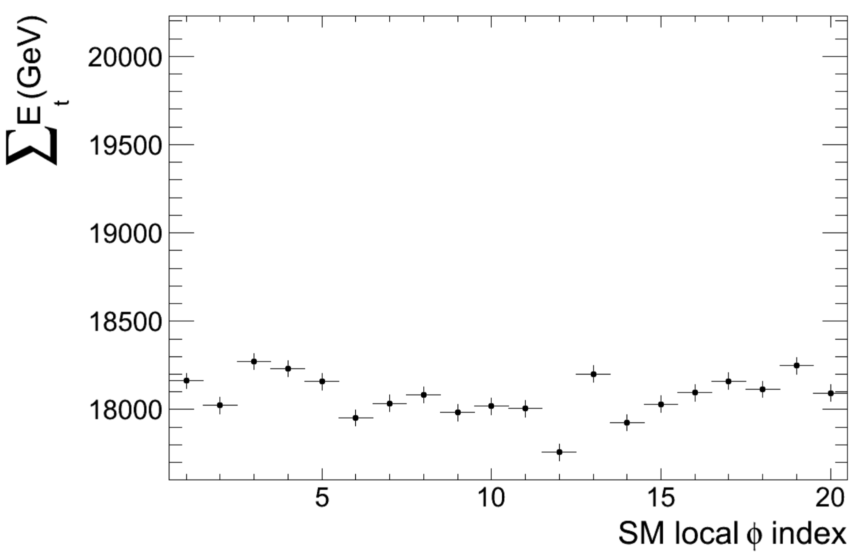
Border Effect

iϕ border correction for magnet on MC, derived for EB+ and EB- separately due to the crystals staggering

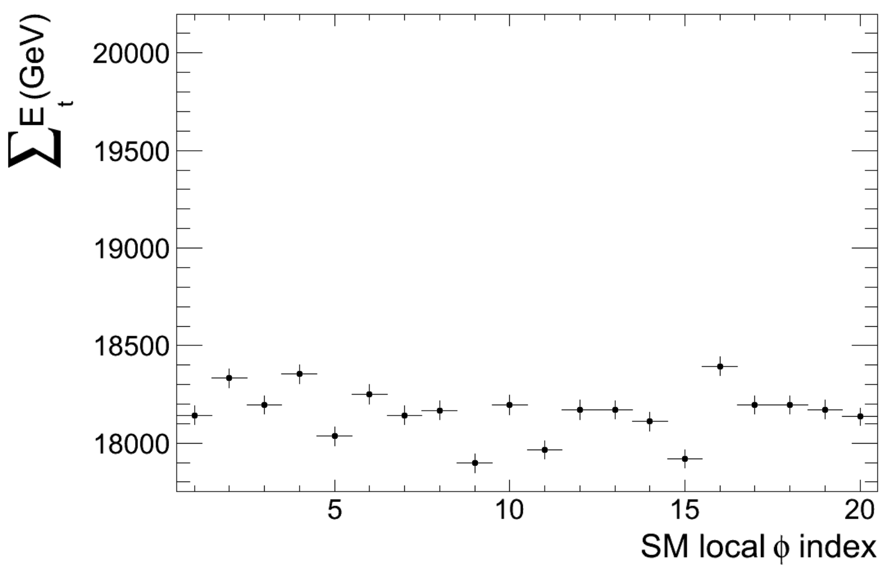


After corrections

EB -



EB +



Border Effect

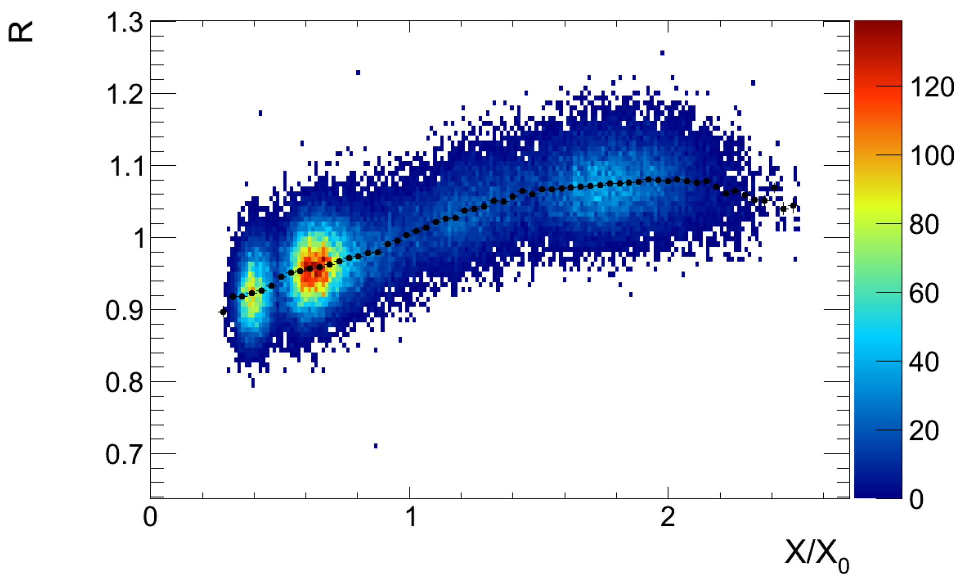
Table of border corrections for magnet off and magnet on MC

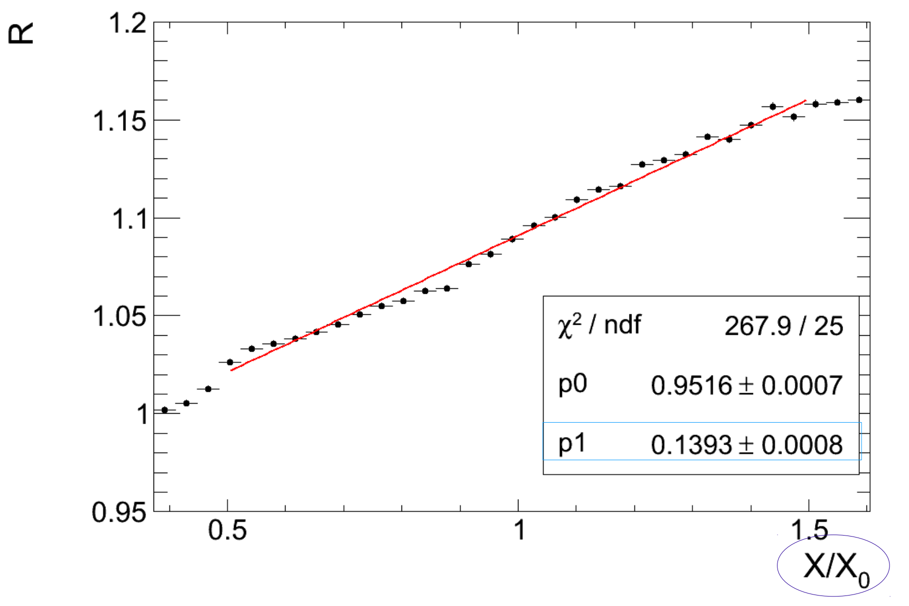
	B_{off}	B_{on}
$C_{\eta_i=1}$	$(\ \ 3.5 \pm 0.1)\%$	$(\ \ 3.3 \pm 0.2)\%$
$C_{\eta_i=26}$	$(11.0 \pm 0.3)\%$	$(11.2 \pm 0.3)\%$
$C_{\eta_i=46}$	$(13.6 \pm 0.3)\%$	$(14.6 \pm 0.3)\%$
$C_{\eta_i=66}$	$(14.0 \pm 0.4)\%$	$(15.4 \pm 0.4)\%$
$(C_\phi^+)_R$	$(\ 9.8 \pm 0.8)\%$	$(10.1 \pm 0.7)\%$
$(C_\phi^-)_R$	$(10.3 \pm 0.7)\%$	$(10.8 \pm 0.8)\%$
$(C_\phi^+)_L$	–	$(\ 3.2 \pm 1.0)\%$
$(C_\phi^-)_L$	–	$(\ 3.4 \pm 1.0)\%$
$(C_\phi)_R$	$(10.0 \pm 1.1)\%$	$(10.4 \pm 1.1)\%$
$(C_\phi)_L$	–	$(\ 3.3 \pm 1.0)\%$

Boff and Bon correction are not the same so they have been derived separately

Correlation between R and tracker material

Correlation between the energy flow ratio and the tracker material (X/X_0)





$$\Delta M(X_0) = \frac{1}{p1}\left(\frac{R_{dati}}{R_{MC}} - 1\right)$$

$$M(X_0) = M(X_0)^{std} + \Delta M(X_0)$$

Measure of the material made during the detector construction