Pile-up effect on energy measurement

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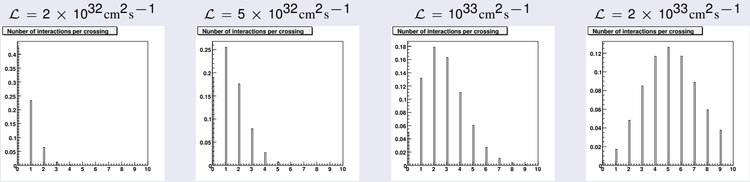
LHCb calorimeter upgrade meeting

Introduction

The upgrade consists in increasing the luminosity at the LHCb IP



Number of interactions per crossing at different luminosities.

Present luminosity is $\mathcal{L} \sim 4.0 \times 10^{32} \mathrm{cm}^{-2} \mathrm{s}^{-1}$

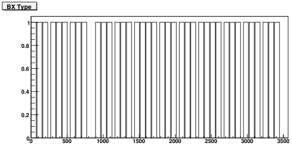
- Foreseen maximum luminosity is $\mathcal{L} = 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1} \rightarrow 2 \times 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$. Direct consequence : the event multiplicity is larger.
- The events get piled-up and the energy/position reconstructed are overestimated/smeared.

This may be looked at

- Using LHCb data sample
- With MC samples

The method based on real data

1. The ADC counts are extracted with present data (no pile-up)
   - for each calorimeter cell (3 areas) get an ADC count spectrum
   - for each event recorded
     A large vector of 6016 integers is obtained per event
     (More than 1 million events on disk)
2. The beam conditions (pile-up) at a certain luminosity are evaluated and permit to *generate* event conditions (pile-up) for a certain luminosity
   - Poisson law : get rate for a certain number n of interactions per crossing
   - Use the LHC bunch structure to decide if bunches are crossing or not



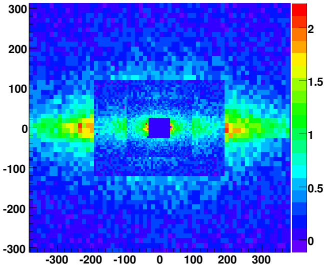
3. For a *high luminosity* add the generated number of events, i.e. add the 6016 rows of consecutively recorded vectors (real data events)

Pros/cons of the method :

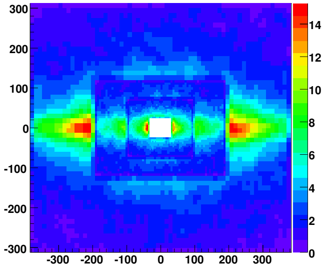
- Pros : based on real data
- Cons : 3.5 instead of 7TeV, no spill-over effect from 40MHz, only triggered events.

Calorimeter map - Average

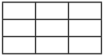
$\mathcal{L} = 2 \times 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$



Cell averaged signal (ADC counts)

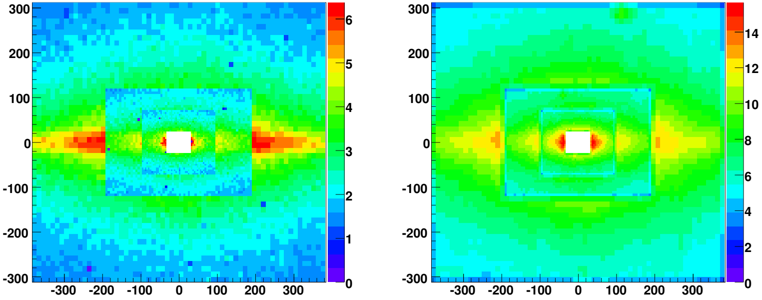


Cluster (9 cells) averaged signal (ADC counts)

- A cluster is made by a group of 9 cells 
- 2D representation shows the cluster signal/RMS (central cell position)
- Border effects are clearly visible (clusters made by less than 9 cells)
- Recall 1ADC count = 2.5MeV in Pt.

Calorimeter map - RMS

$\mathcal{L} = 2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$



Cell signal RMS (ADC counts)

Cluster signal RMS (ADC counts)

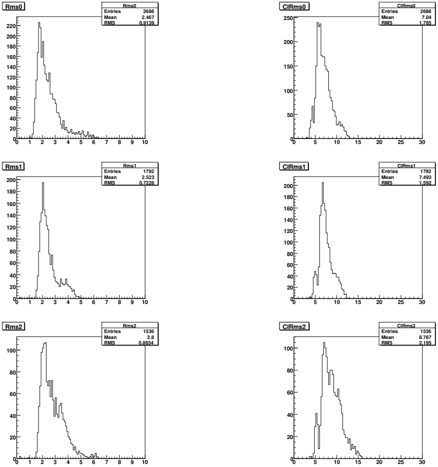
RMS per zone

$\mathcal{L} = 2 \times 10^{32} \mathrm{cm}^{-2} \mathrm{s}^{-1}$

Outer

Middle

Inner

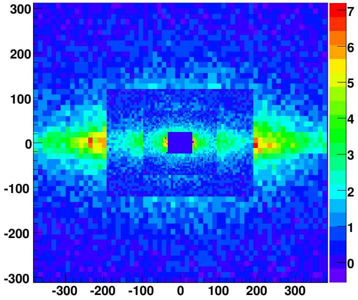


Cell RMS

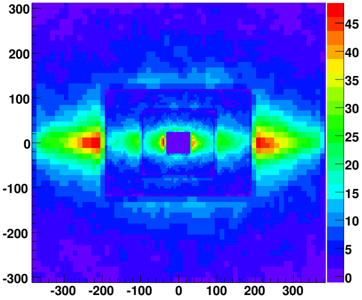
Cluster RMS

Calorimeter map - Average

$\mathcal{L} = 5 \times 10^{32} \mathrm{cm}^{-2} \mathrm{s}^{-1}$



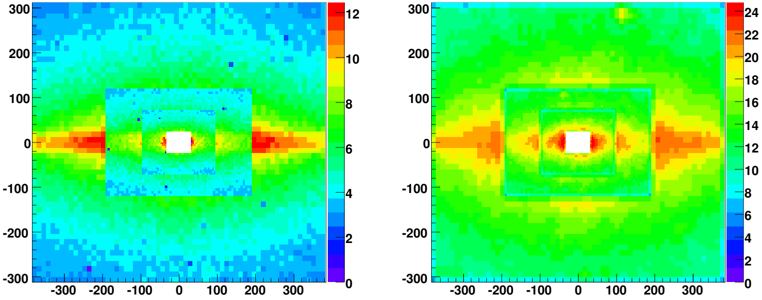
Cell averaged signal (ADC counts)



Cluster (9 cells) averaged signal (ADC counts)

Calorimeter map - RMS

$\mathcal{L} = 5 \times 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$



Cell signal RMS (ADC counts)

Cluster signal RMS (ADC counts)

RMS per zone

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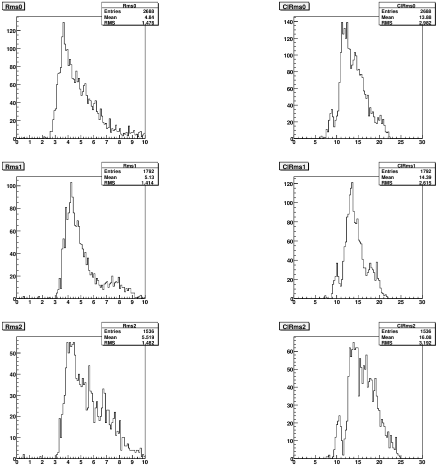
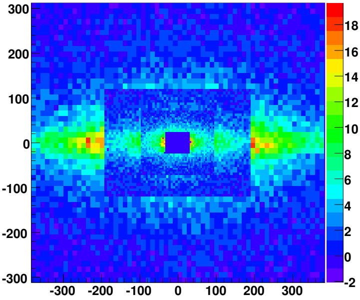


Cell RMS

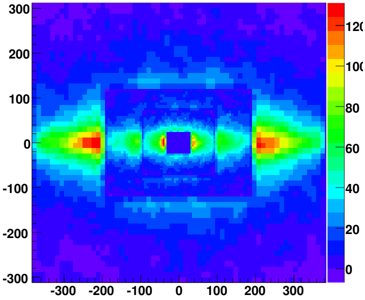
Cluster RMS

Calorimeter map - Average

$\mathcal{L} = 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$



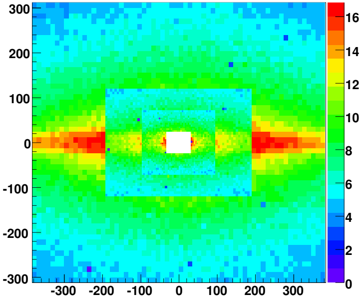
Cell averaged signal (ADC counts)



Cluster (9 cells) averaged signal (ADC counts)

Calorimeter map - RMS

$\mathcal{L} = 10^{33}\text{cm}^{-2}\text{s}^{-1}$



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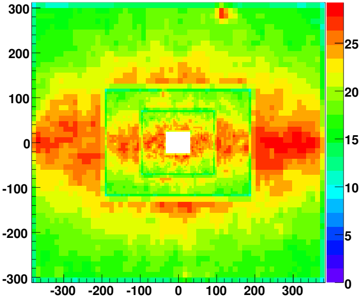

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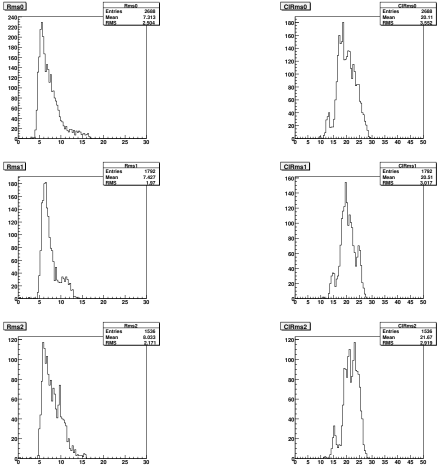
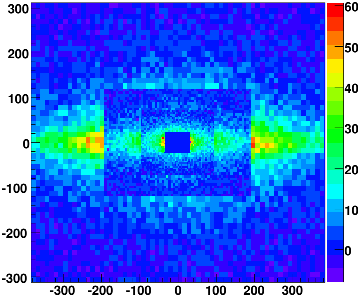


Cell RMS

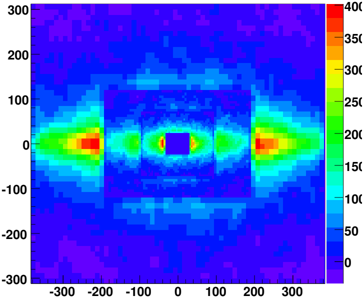
Cluster RMS

Calorimeter map - Average

$\mathcal{L} = 2 \times 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$



Cell averaged signal (ADC counts)



Cluster (9 cells) averaged signal (ADC counts)

Calorimeter map - RMS

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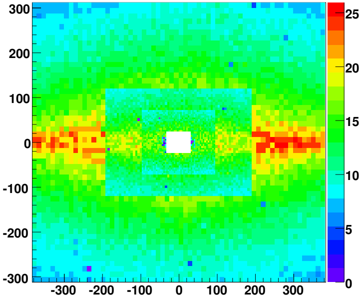
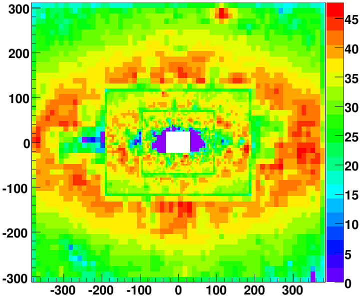


Cell signal RMS (ADC counts)



Cluster signal RMS (ADC counts)

RMS per zone

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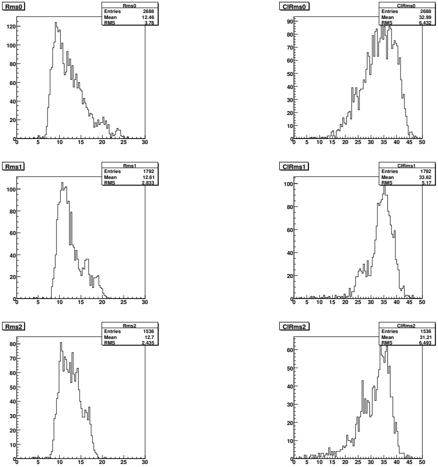


Cell RMS

Cluster RMS

Conclusion on the Data driven estimation

Resolution effect of the pile-up

A quantitative conclusion on the pile-up is difficult to get as the RMS obtained is widely spread and the average is not representative.
The energy of the real data sample used is twice too small

- This is clearly an optimistic assumption

Still if we try to take the average

- the calorimeter resolution could be expressed by

$$\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E}} \oplus 1.5\% \oplus \frac{0.0025 \times RMS}{E\theta}(\mathrm{pile-up}) \oplus \frac{0.01}{E\theta}(\mathrm{electronics})$$

$\mathcal{L}$	$2x10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	$5x10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	$10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	$2x10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
RMS	12.	15.	18	22
$0.0025 \times RMS$	0.030	0.038	0.045	0.055

Ought to be checked by MC studies.

Upgrade MC sample

4 samples of 50k events each : $B_s \to \phi\gamma$

- $\mathcal{L} \sim 2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$: Red
- $\mathcal{L} \sim 5 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$: Green
- $\mathcal{L} \sim 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$: Blue
- $\mathcal{L} \sim 2 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$: Violet

Method

Photons are selected according to :

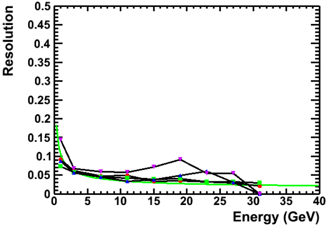
- their origin ($\Delta z < 50\mathrm{mm}$, $\Delta r < 100\mathrm{mm}$ wrt IP)
- No conversion before the calorimeter
- Association MCtruth/RecPhoton
- A Pt cut (either 250 or $500\mathrm{MeV}$)

Determine $\frac{E^{\gamma}_{Rec} - E^{\gamma}_{MC}}{E^{\gamma}_{MC}}$ and fit the resolution with an asymmetric gaussian

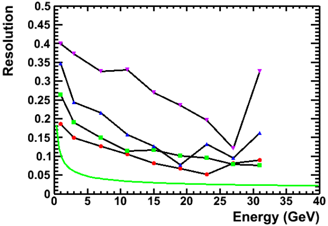
- 2 “resolutions” :
  left : should correspond to the intrinsic resolution without pile-up
  right : should show the pile-up effect

Energy Resolution : $P_t > 250$MeV/c

Resolution “Left”

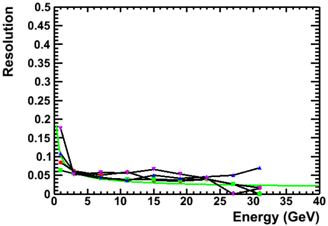


Resolution “Right”

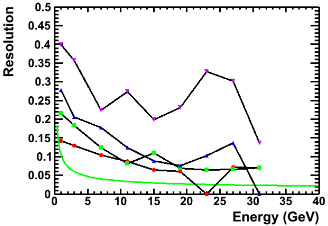


Energy Resolution : $P_t > 500 MeV/c$

Resolution “Left”



Resolution “Right”



Conclusions

Data driven estimation

- Photons at 100mrad :

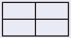
$\mathcal{L}$	$2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$		$10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	
Resolution	Total	Pile-up	Total	PIle-up
400MeV	7.4%	4.7%	14.3%	13.1%
3.5GeV	2.3%	0.5	2.7%	1.5%

Monte Carlo study

- Estimation on Monte Carlo confirms non-negligible effect
- Resolution is not Gaussian at all
- Effect is reduced on high P_t deposit

Conclusions

What solutions could be envisaged ?

- Can we reconstruct photons in 2×2 clusters (outer, middle) ? 
- Must study effect on Energy and Position
- Present high luminosity events could permit to make analysis on *real data*
- Such a solution is probably not applicable in the inner (Moliere radius $\approx$ cell size)

Upgrade MC sample production

- No SPD/PRS (baseline)
- 2 solutions :
    - Choose several luminosity samples
    - Make samples according to their pile-up (PV number) and mix events to produce any L sample
- Standard key channels production ($B_d \rightarrow K^*\gamma$ or $B_s \rightarrow \phi\gamma$) on upgrade conditions