Occupancy at High Luminosity

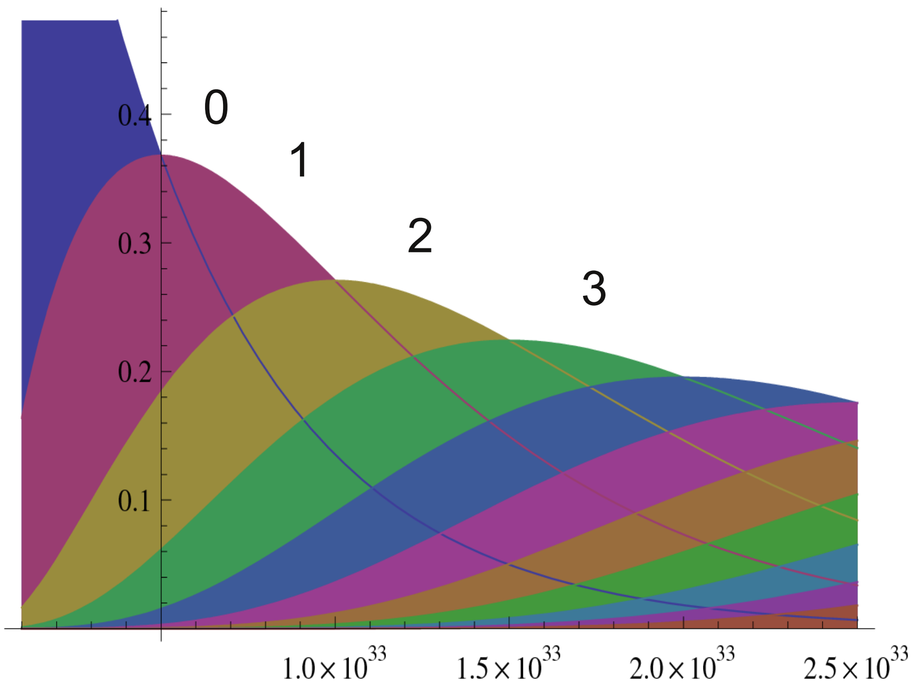
Frédéric Machefert

Laboratoire de l'Accélérateur Linéaire
December 18th, 2009

Average number of collisions per B event

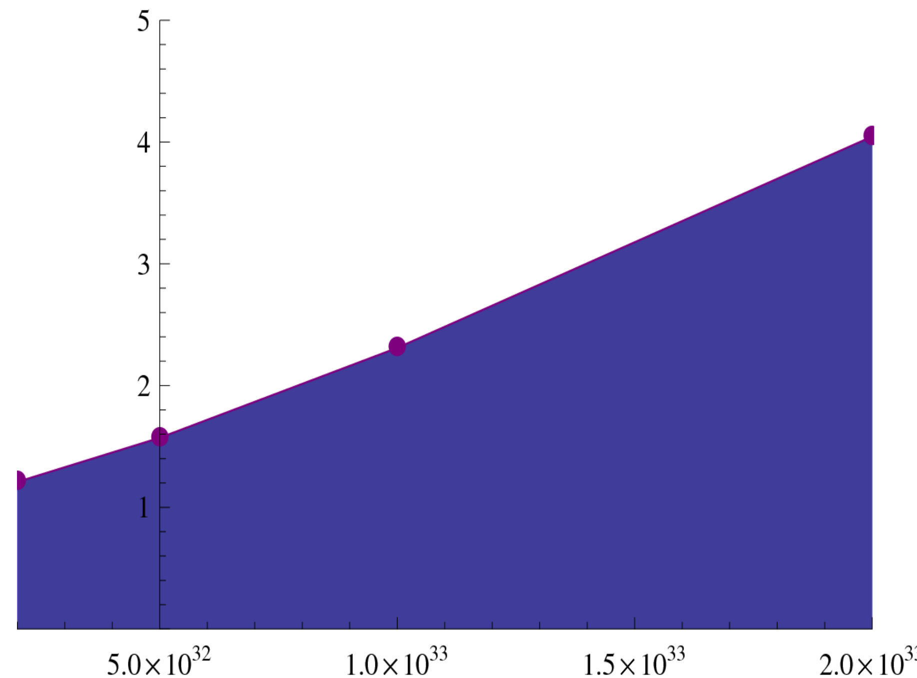
- The luminosity is planned to reach up to 2×10^{33}
  - The average pile up from 2×10^{32} up to 2×10^{33} increases from 1.2 up to 4.0
  - This is evaluated from the events having at least one collision

Type of Event per crossing



Luminosity

Pile up



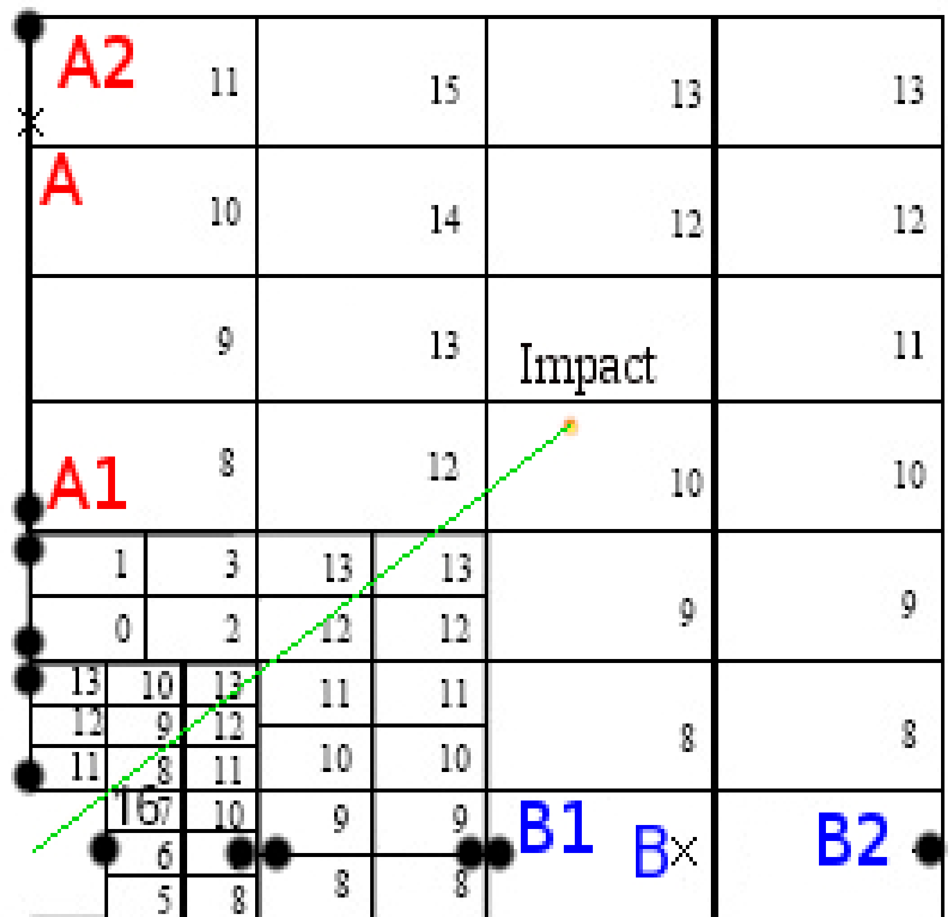
Luminosity

The pile up at 12 positions

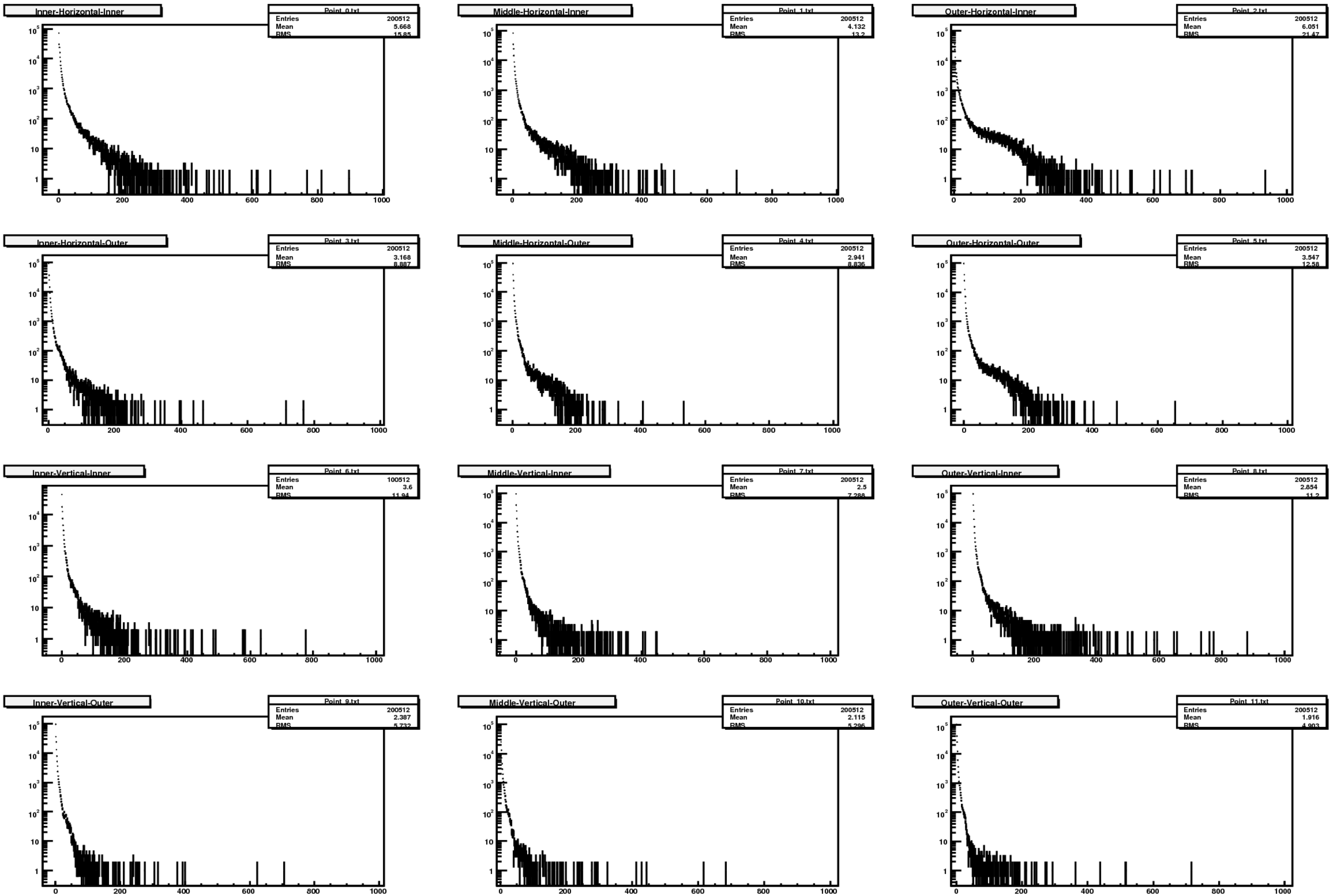
- The pile up has been evaluated by getting the occupancy of the calorimeter from single minimun-bias events.

- Pile up histograms have been extracted from the actual LHCb simulation and by modifying the CaloDigi algorithm in Boole.

- The pile up has not been “measured” for each cell (more than 6000)
  - 12 points have been chosen
  - The pile up at a position on the calorimeter is obtained by linear interpolation
  - This is not the best solution !



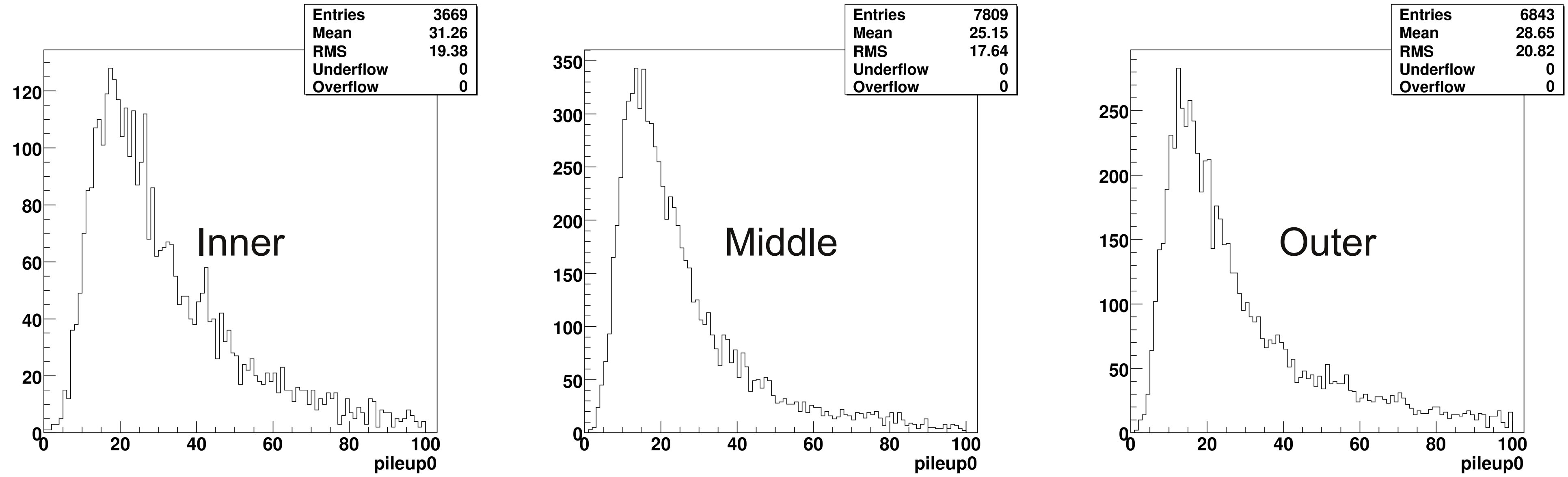
The pile up at 12 positions



Detector Resolution

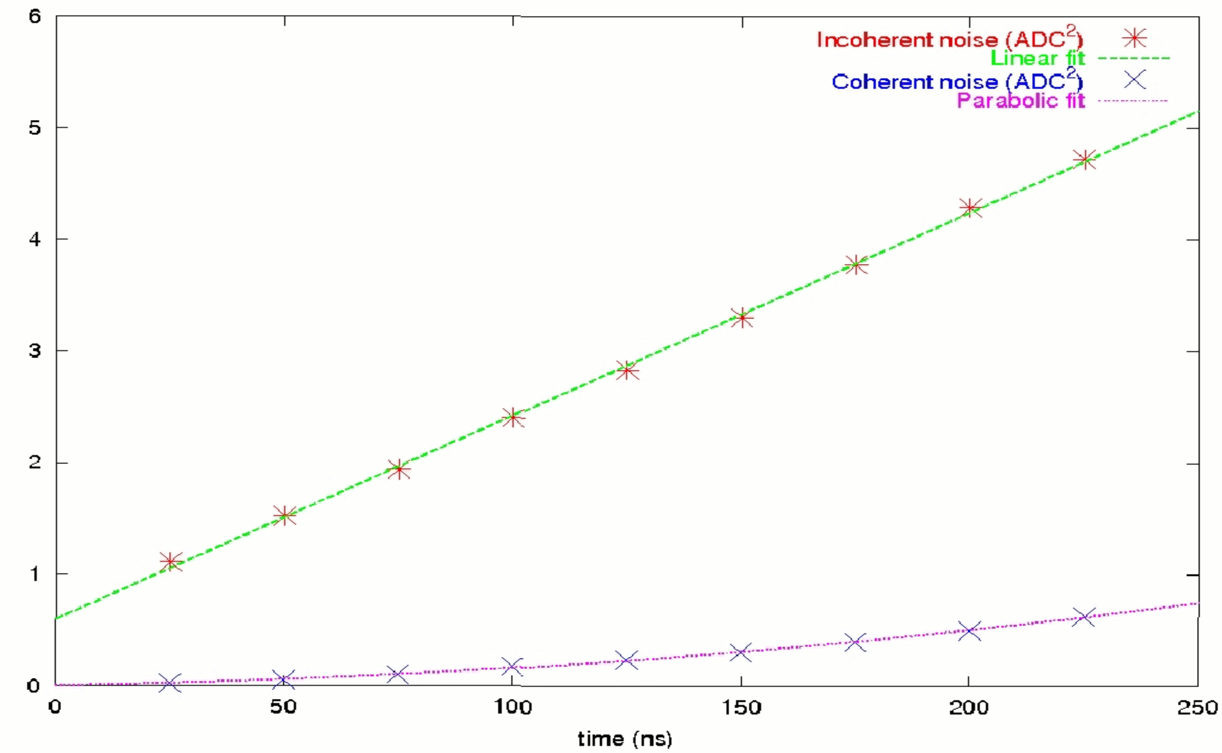
Pile up

- From the previous plots a minimum bias event will contribute to
    - From 4 (inner, outer) to 3 (middle) ADC counts per cell on average
- We make the hypothesis that any collision induces such a pile up
    - For a B event with N collisions (including the one responsible for the B)
    - Add N times the average collision pile up
    - Counting on 9 cells (cluster), the pile up would reach on average
        - 36/27 ADC counts in a cluster



Electronics Noise

- This may be compared with the average noise of the electronics
  - I took what we have now as the baseline for the upgrade
  - In a cell
    - Incoherent noise : 1.1ADC
    - Coherent noise : <0.1 ADC
  - In a 3x3 cluster
    - ~ 4ADC



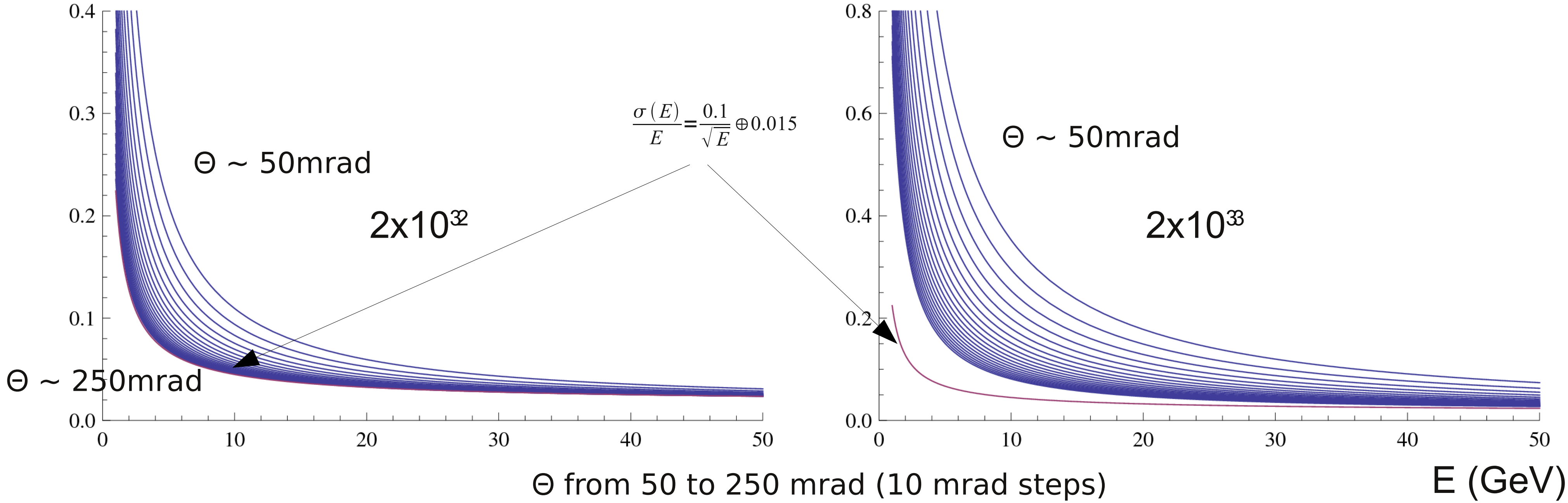
Resolution

- The present accepted resolution at 2×10^{32} is $$\frac{\sigma(E)}{E}=\frac{0.1}{\sqrt{E}}\oplus 0.015$$
  - But is probably closer to

$$\frac{\sigma(E)}{E}=\frac{0.1}{\sqrt{E}}\oplus 0.015\oplus\frac{0.050}{E\,\theta}(Pile\ up)\oplus\frac{0.010}{E\,\theta}(Electronics)$$

  - And could reach at 2×10^{33}

$$\frac{\sigma(E)}{E}=\frac{0.1}{\sqrt{E}}\oplus 0.015\oplus\frac{0.175}{E\,\theta}(Pile\ up)\oplus\frac{0.010}{E\,\theta}(Electronics)$$



Effect of the pile up on the resolution

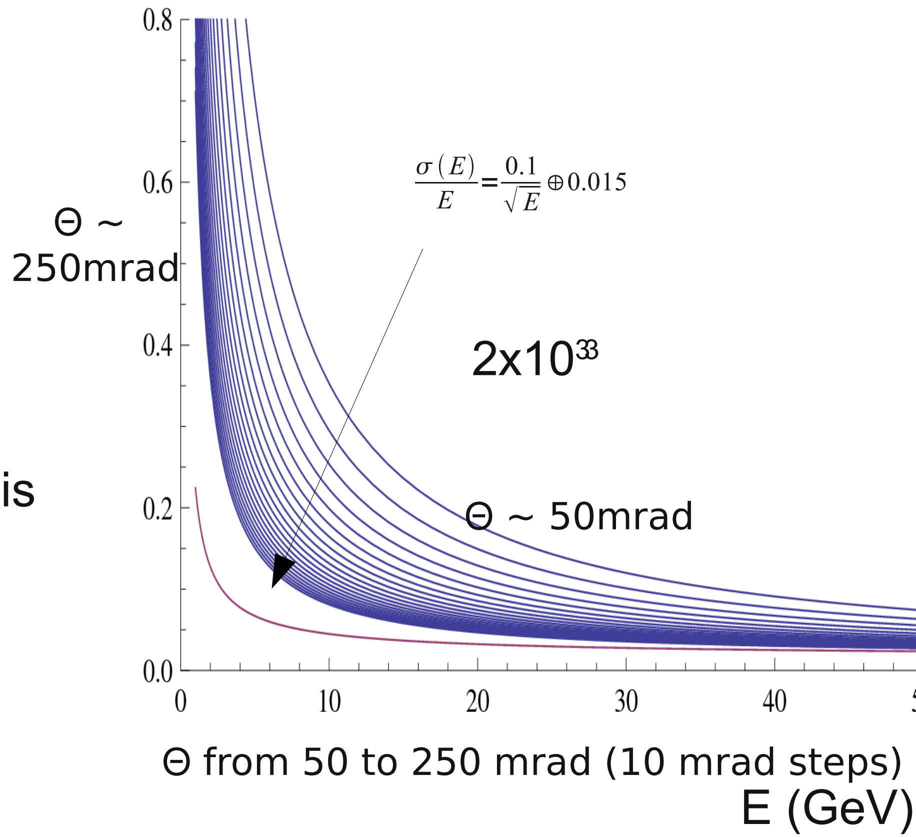
- Pile up is already an important effect at the current luminosity
- At higher luminosity it could prevent from doing any low Pt photon physics
  - Take 2 examples
    - High Pt photons : $B_s \rightarrow \phi\gamma$, $<Pt_\gamma>$ ~ 3.5GeV/c , θ ~ 100 mrad
    - Low Pt photons : $B \rightarrow D^*K$, $<Pt_\gamma>$ ~ 400MeV/c , θ ~ 100 mrad

Energy Resolution for Low/High pt (%)				
Luminosity	Resolution Calo	Pile Up	Electronics	Total
2,00E+032	6.1/2.6	12.5/1.4	2.3/0.26	14.1/3.0
5,00E+032	6.1/2.6	16.3/1.9	2.3/0.26	17.5/3.2
1,00E+033	6.1/2.6	25.0/2.9	2.3/0.26	25.8/3.9
2,00E+033	6.1/2.6	43.8/5.0	2.3/0.26	44.2/5.6

- Already at high Pt, the resolution is excessively degraded. Low Pt extreme case looks hopeless...

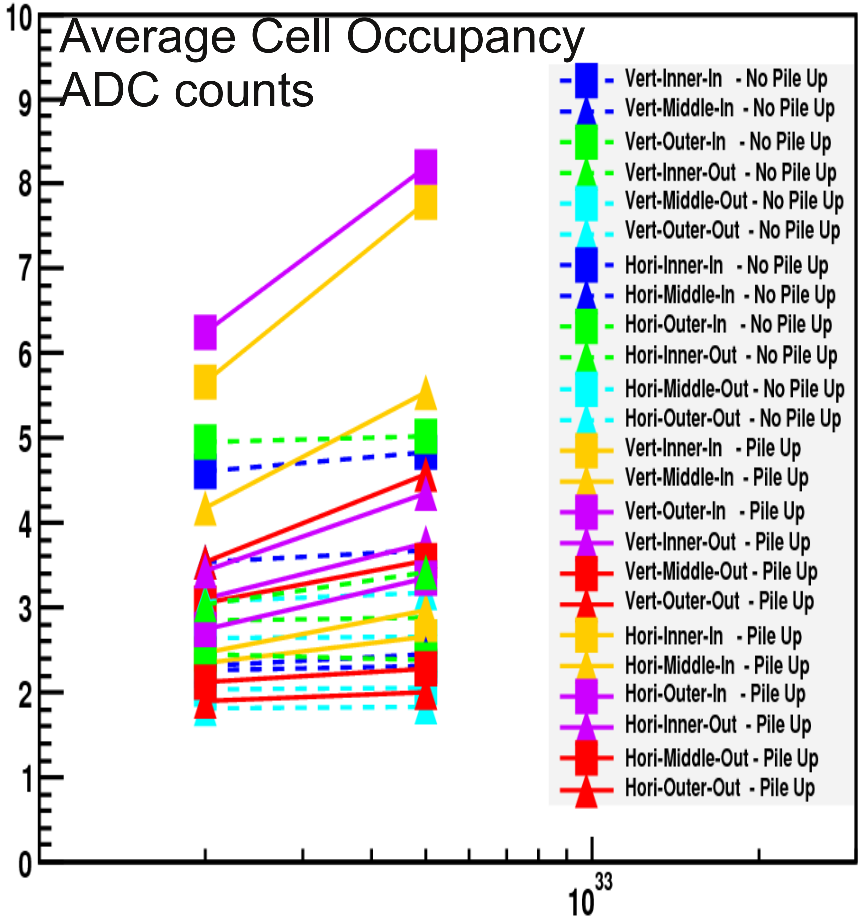
Cross-checks on Pile Up predictions

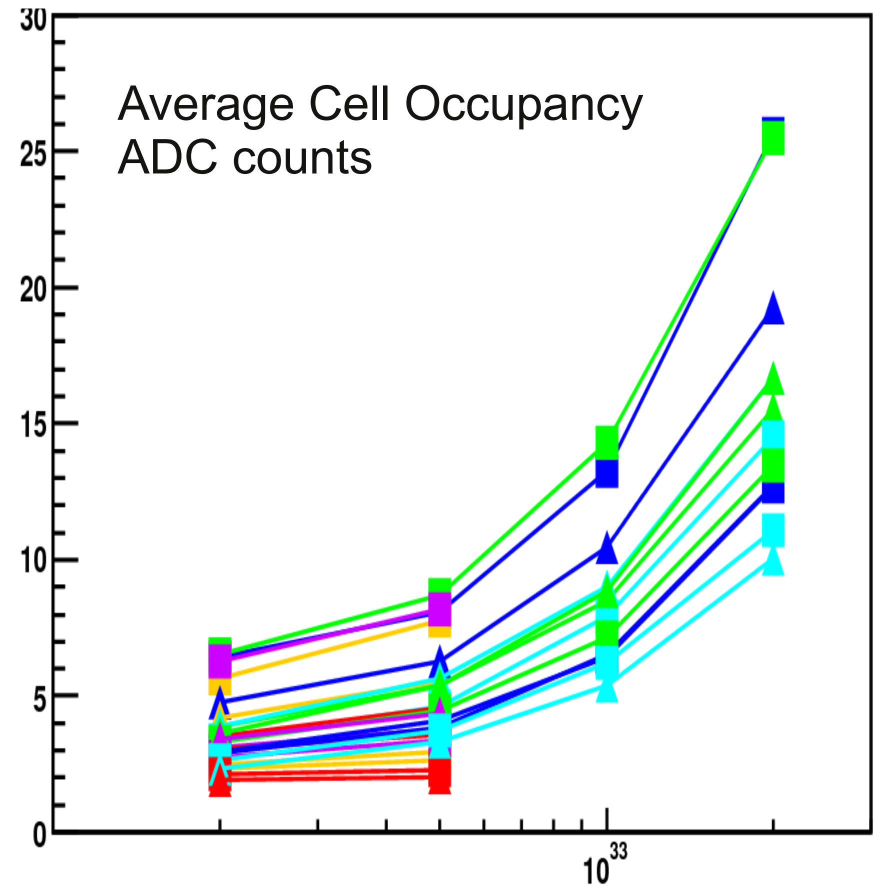
- The only indications on the pile up at high luminosity come from an approximative simulation of the effect
  - Use Boole generated events at $2x10^{32}$ cm^{-1}.s^{-2}
    - Select single collision events
    - Extract occupancy for specific cells in ADC counts for min-bias events
  - Generate a MC event at any luminosity by « adding » the contributions of N « single collision events »
    - Event per event get an appropriate random N (depends on the luminosity)
      - Take into account the LHC bunch structure (identical to nominal)
    - Extract random occupancy according to Boole MC probability densities
- The conclusion is that the photon resolution is degraded by the pile up. The effect is not negligible



$$\frac{\sigma(E)}{E}=\frac{0.1}{\sqrt{E}}\oplus 0.015\oplus\frac{0.175}{E\,\theta}(Pileup)\oplus\frac{0.010}{E\,\theta}(Electronics)$$

Comparing predictions up to $5x10^{32}$ $cm^{-2}.s^{-1}$





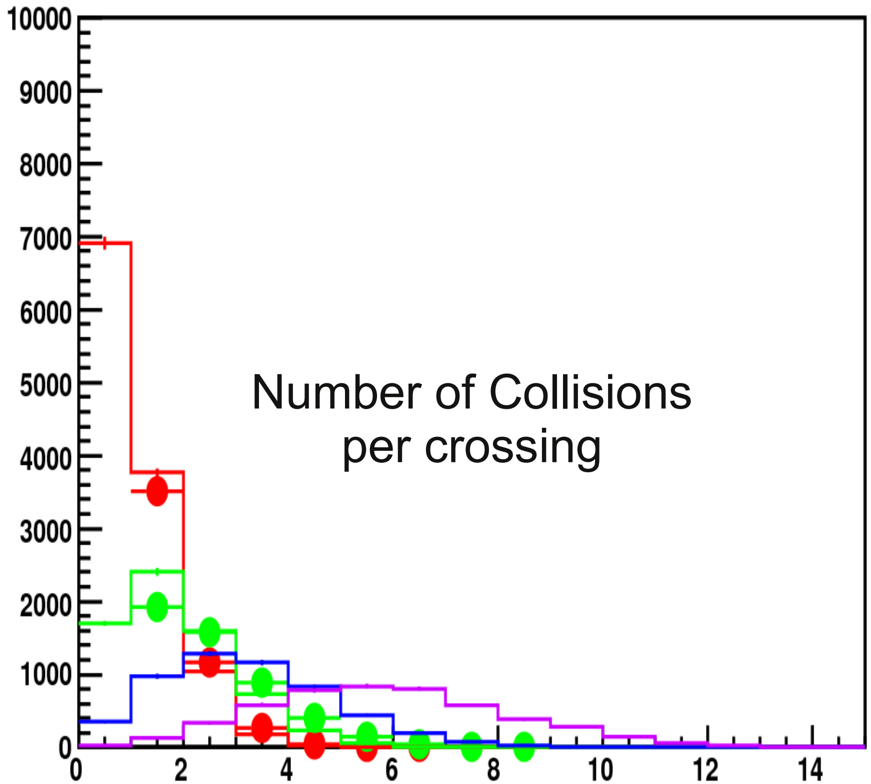
Signal in 12 cells on the ECAL surface
Min-bias events (Gauss)

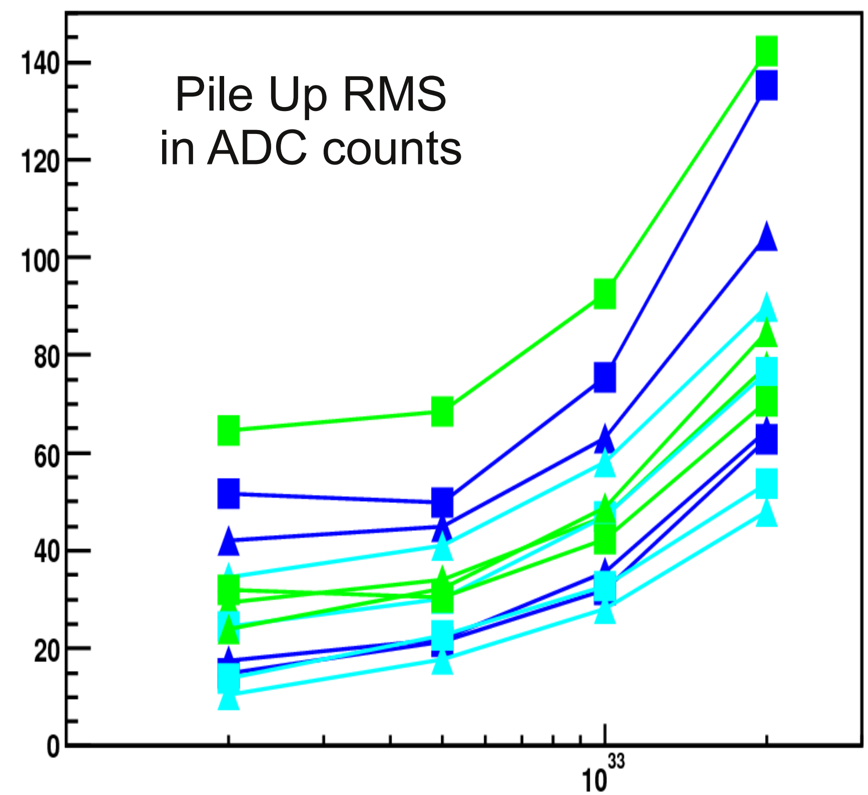
- Dotted lines : 2 MC (2 and $5x10^{32}$ $cm^{-2}.s^{-1}$) asking for 1 collision per crossing only
- Lines : Same two MC samples without the collision constrain (pile up included).

Signal in 12 cells on the ECAL surface
Min-bias events

- The same pile up events as previously (Gauss – kept for comparison)
- The emulation of the pile up by adding up several single collision min-bias events (not Gauss and up to $2x10^{33}$).

Comparing predictions up to $5x10^{32}$ $cm^{-2}.s^{-1}$





Number of collisions per crossing in the high luminosity simulation (private code) for $2x10^{32}$, $5x10^{32}$, 10^{33} and $2x10^{33}$ $cm^{-2}.s^{-1}$ (histo).
Number of collisions in the two Gauss MC samples at $2x10^{32}$ and $5x10^{32}$ $cm^{-2}.s^{-1}$ (dots).

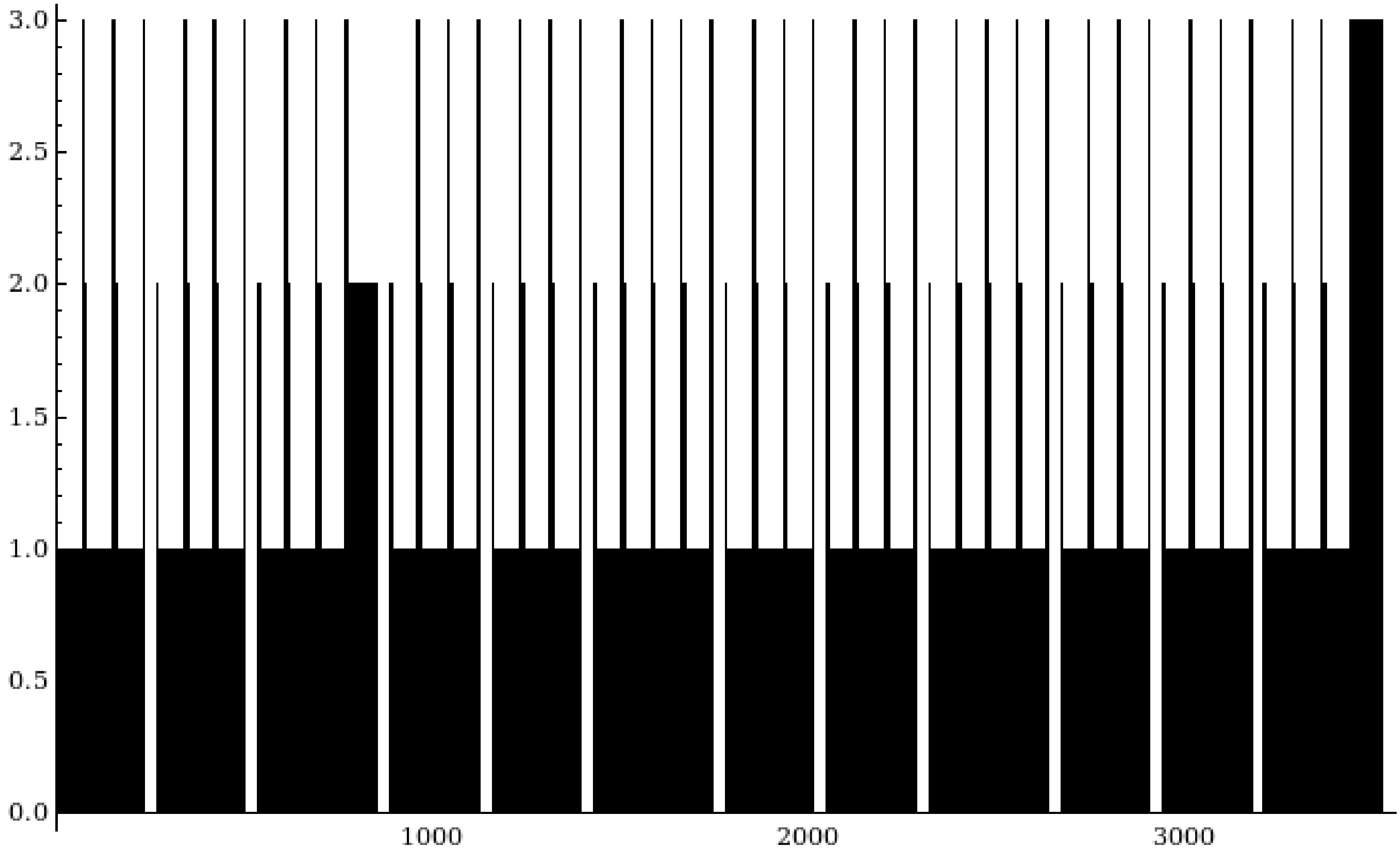
RMS of the signal/PileUp in 12 (3x3)-clusters on the ECAL surface (Min-bias events) for luminosities of $2x10^{32}$, $5x10^{32}$, 10^{33} and $2x10^{33}$ $cm^{-2}.s^{-1}$.
This is evaluated around the 12 points by simulating 9 similar cells.

Photon and Pion reconstruction

Introduction

- The purpose is to have a rapid idea of the effect of the luminosity on photon/pion reconstruction
  - The answer is not so reliable as the full simulation
  - But, this is very fast (I could produce millions of events in each case looked at)
  - Moreover, I wanted to be able to “tune” the corrections of the electronics
    - Subtract on the smallest signal among the N last for example
- This is a small monte-carlo with the following ingredients
  - The LHC bunch structure
    - Gaps in the bunch structure are taken into account
    - N events means in fact N bunch crossing (empty or not) or 25 ns
  - The energy deposit shape which is in Brunel to describe photon/pions
    - One description per zone
  - The usual calorimeter energy resolution
  - An estimation of the pile up per proton-proton collision
  - An estimation of the noise
- The program does the following
  - It generates collisions according to the luminosity
  - Creates a neutral pion and reconstruct the two photons taking into account the previously mentioned effects

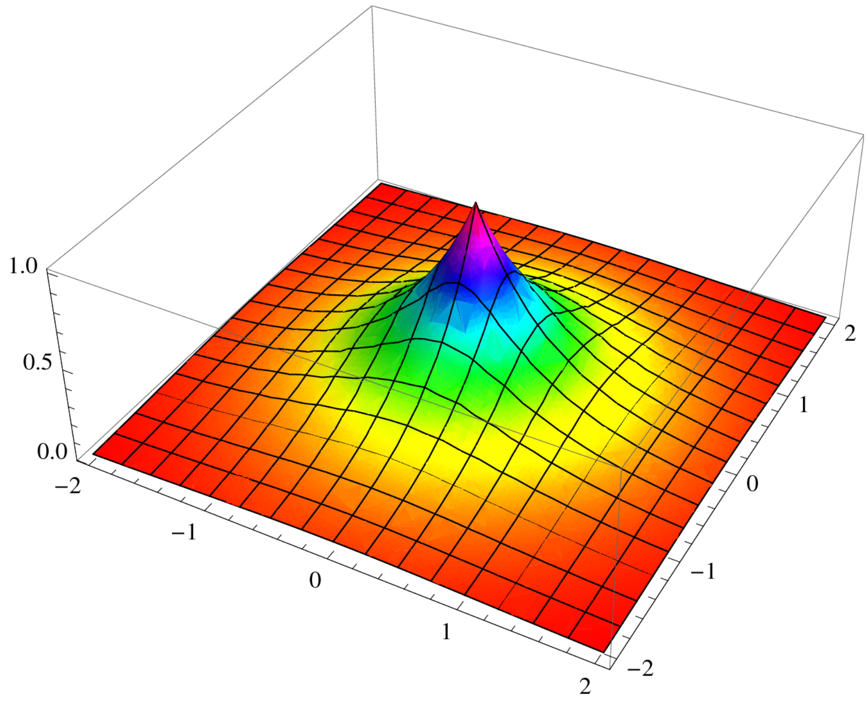
LHC bunch structure

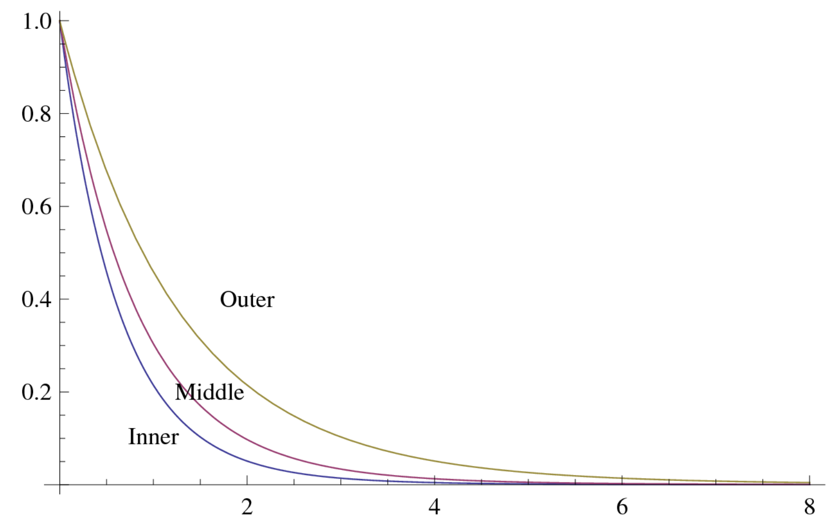
- The code
  - 0-2-3: No beam/A single beam
  - 1 : Two beams, collision allowed
  - 

What will be the bunch structure later ?

The photon deposit (I)

- The energy deposit : double exponential function

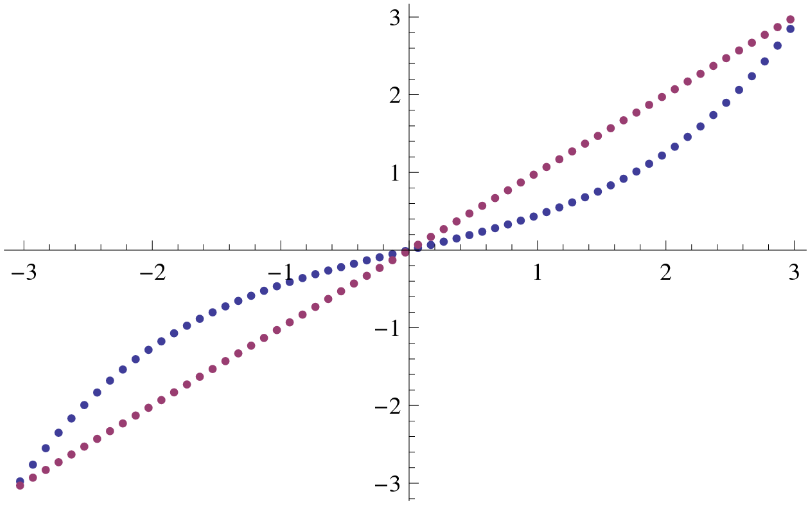




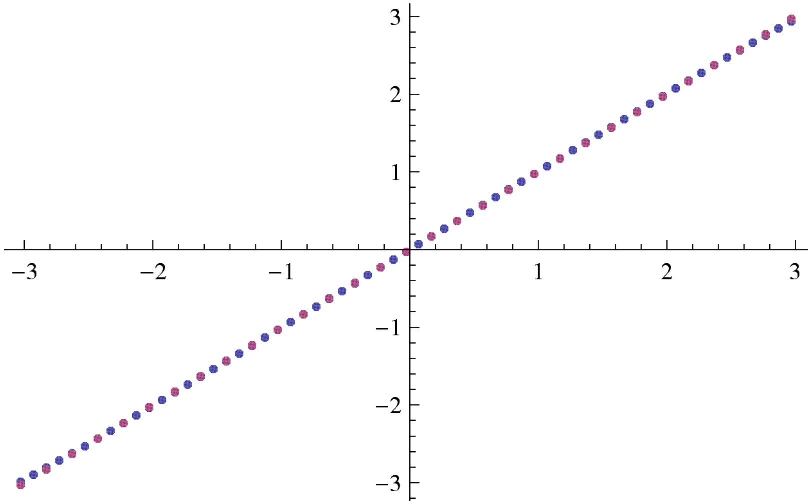
- This energy is integrated
  - on each the 9 cells of the 3x3 cluster
  - taking into account the impact position in the central cell

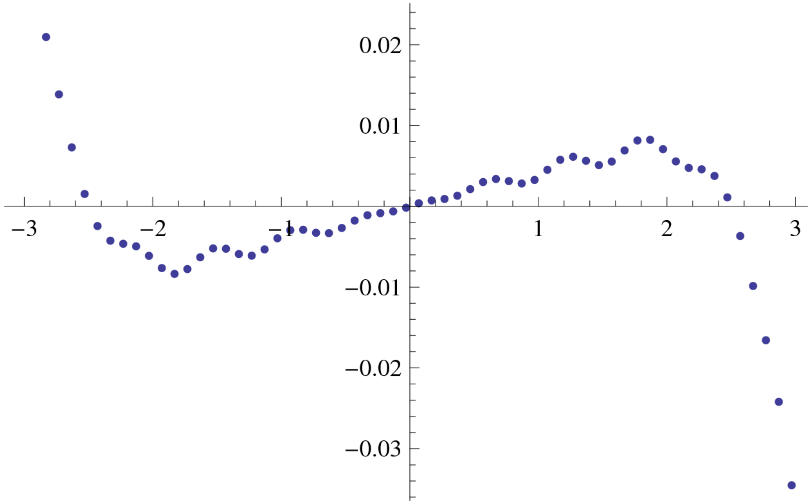
The photon deposit (II)

- The position is evaluated
  - By an energy weighted barycenter



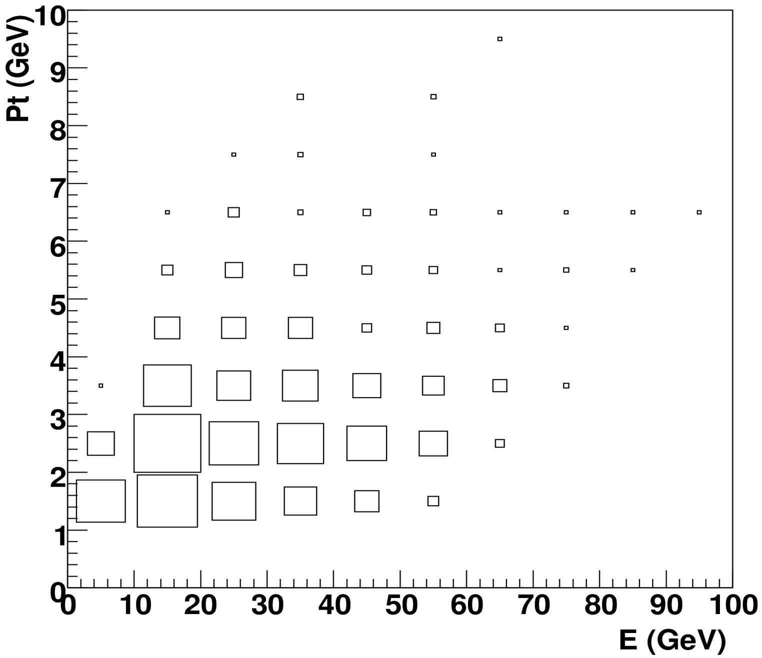
  - Corrected for the S-shape





Neutral pion generation

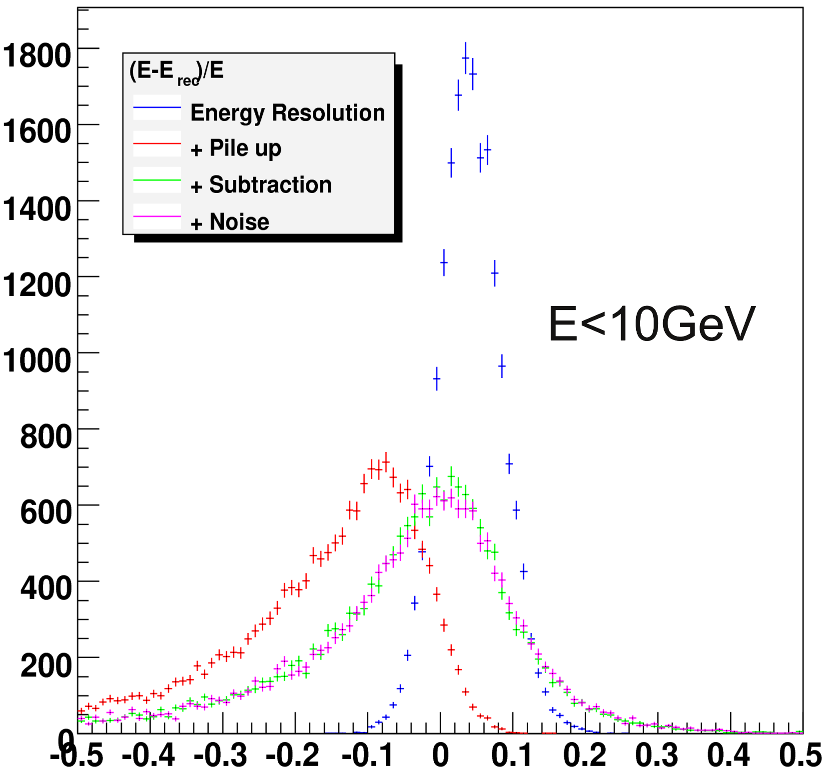
- The purpose is to study the effect on physical photons and pions
  - The (Pt,E) distribution of the neutral pions from B->3π decays is taken from the LHCb simulations

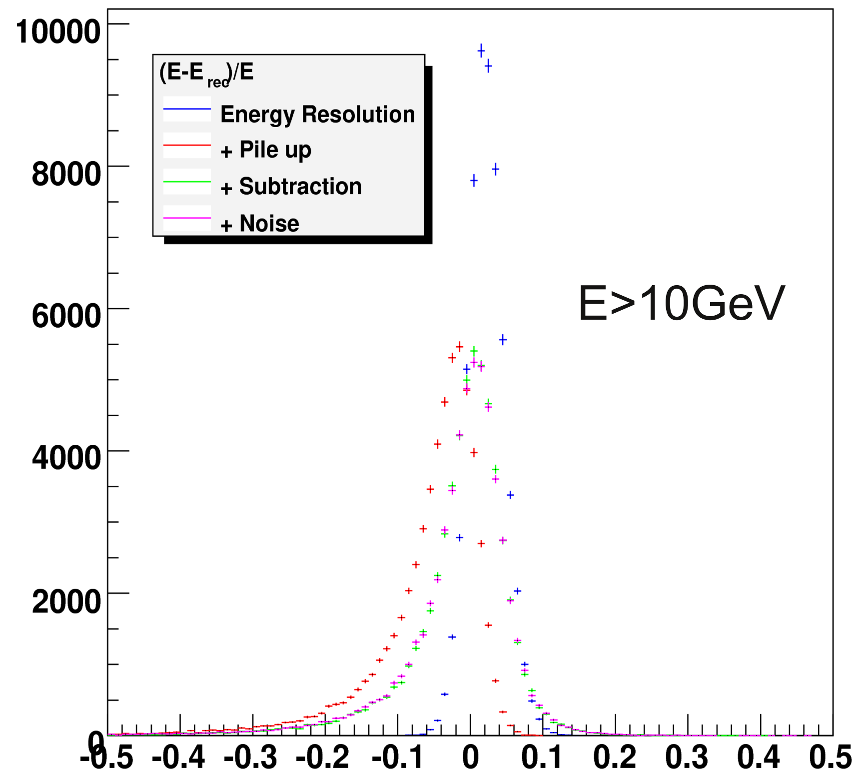


  - A “random π^0” from the above 2D-distribution is chosen
    - The corresponding photons are calculated
    - The impact position/zone/energy are defined
- The possible overlap between photons is not taken into account
- There is never any pollution by conversion... This will slightly improve the mass resolution

Energy Resolution (I)

- What do we get at 2x10^{32} ?
  - Energy resolution is fitted by an asymetric gaussian shape
  - When the resolution is plotted, the two sigmas are given

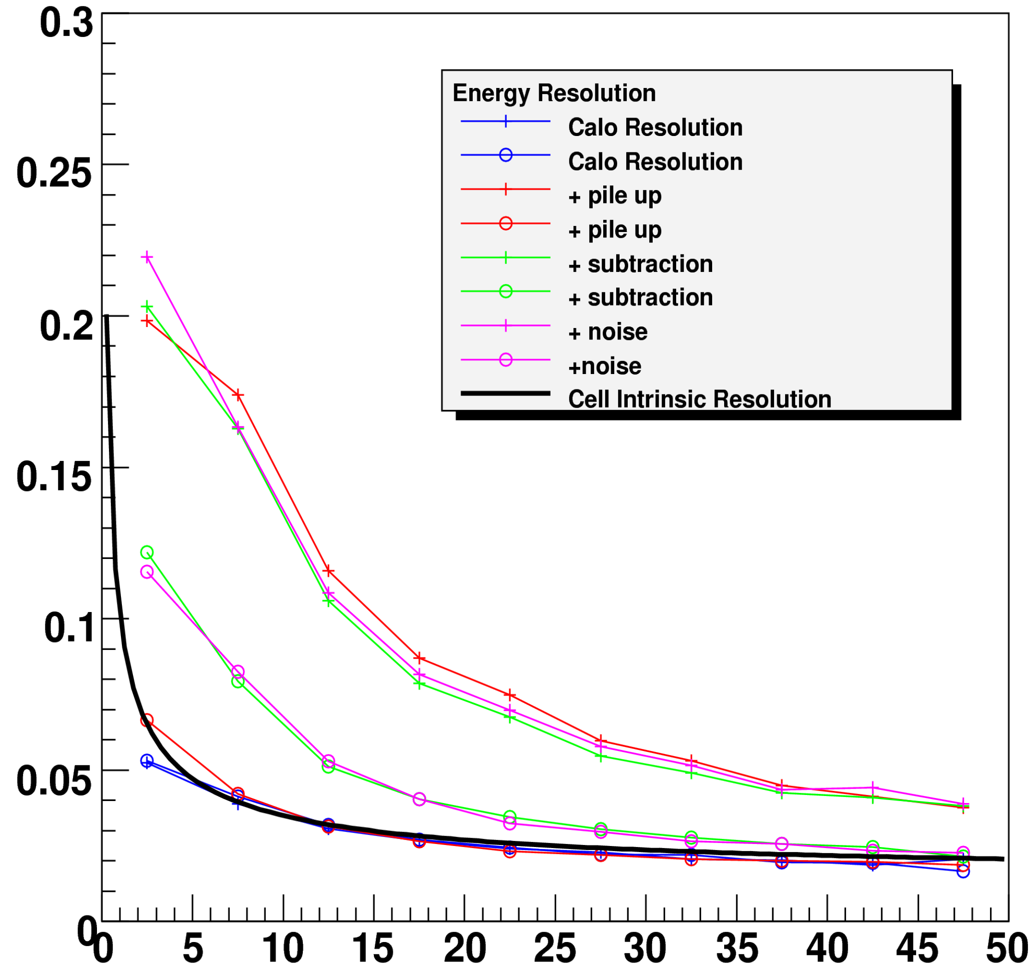




Inner region

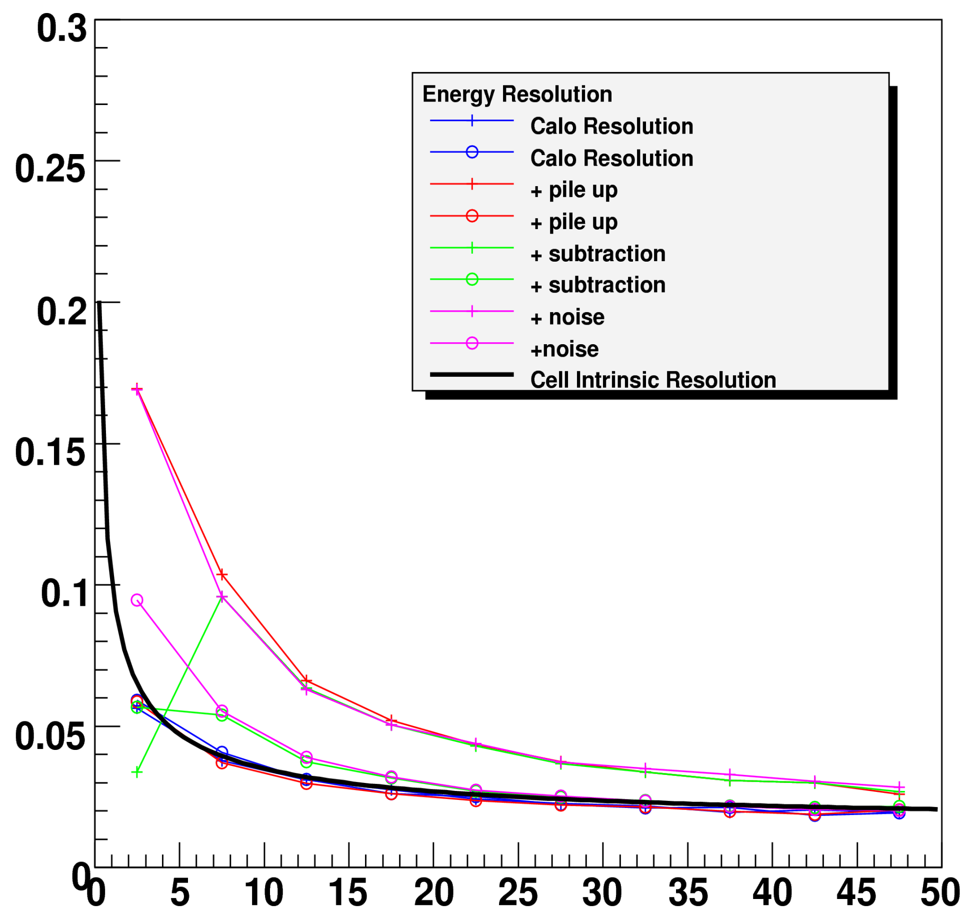
Energy Resolution (II)

- Resolution summary at $2x10^{32}$ for the Inner part
  - The pile up is far from being a small effect
  - Pile up distort the energy shape
  - The subtraction/noise only slightly degrades the sigmas



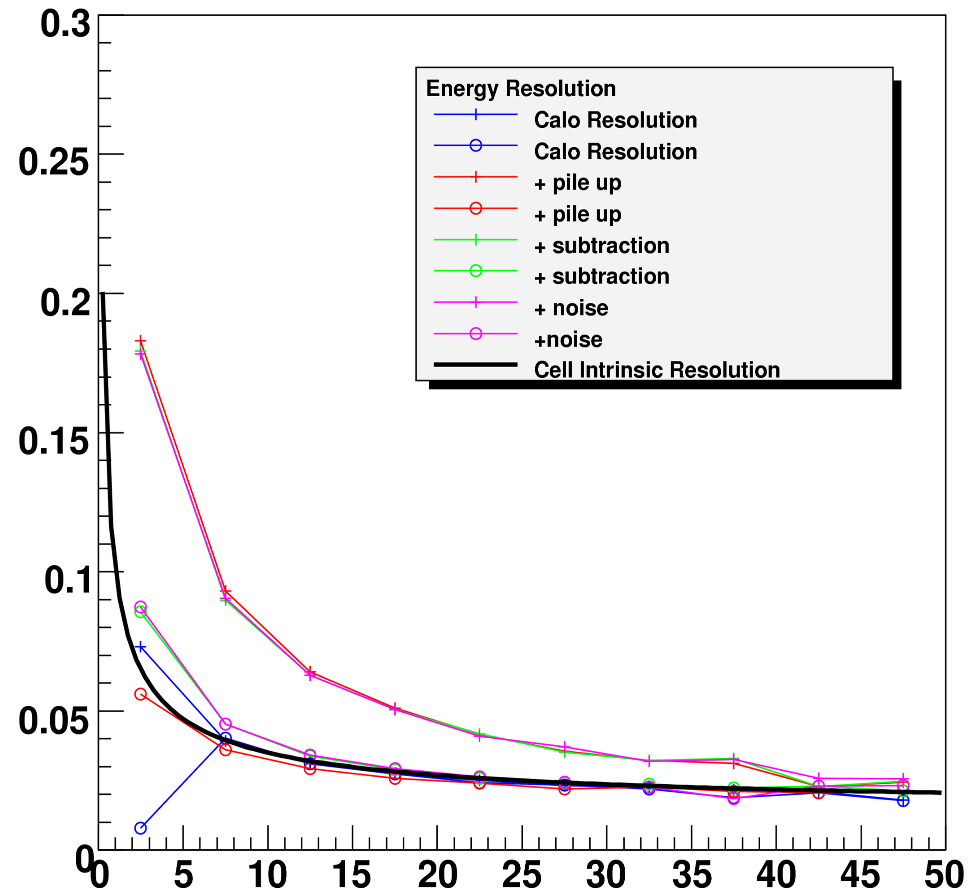
Energy Resolution (III)

- 210^{32} – Middle part
  - Here the pile up effect is more limited
    - This is expected : pile up is smaller in the middle region



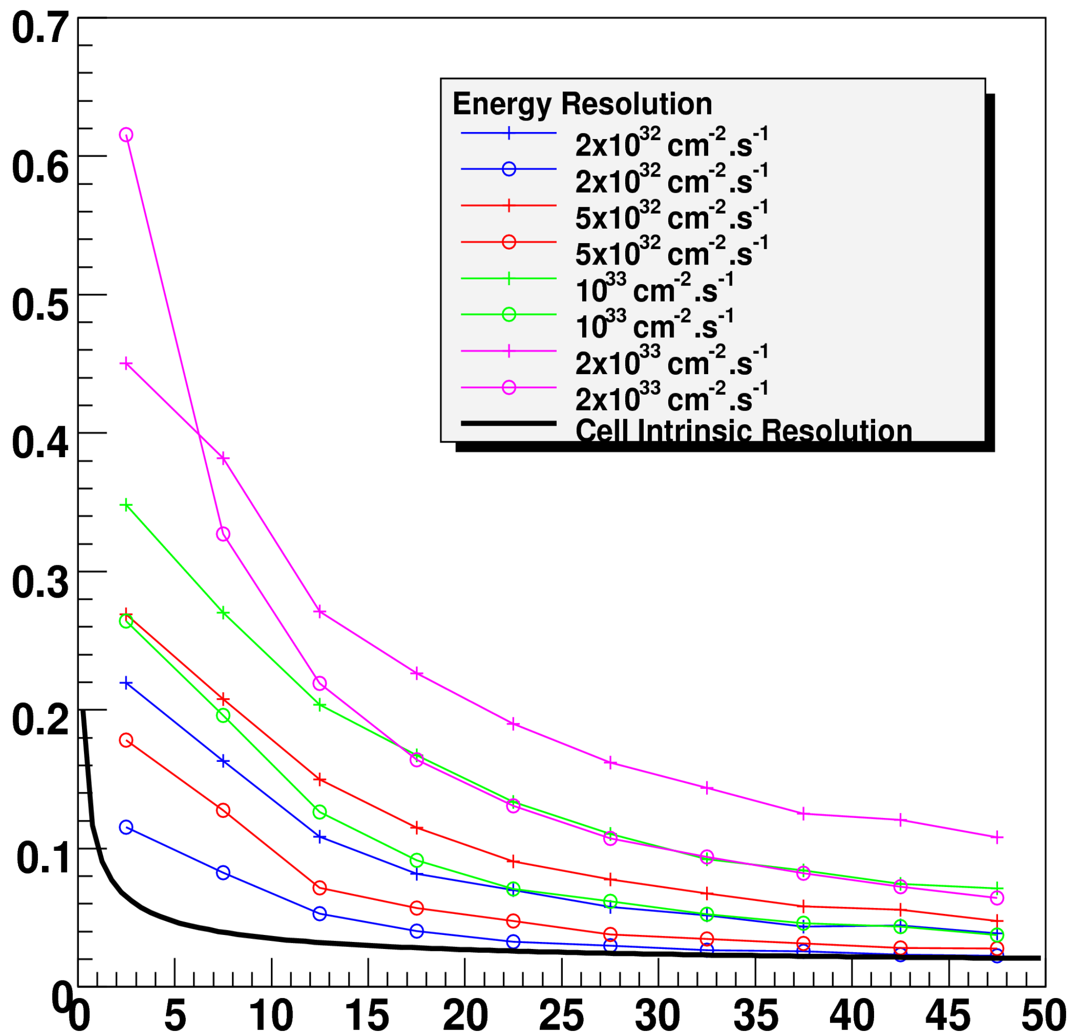
Energy Resolution (IV)

- 2×10^{32} – Outer part
  - In the outer, the pile up is of the same order as in the inner because of the cell size
  - The pile up effect seems to be less
    - The Pt of the signal is larger and the pile up is lower with respect to the signal



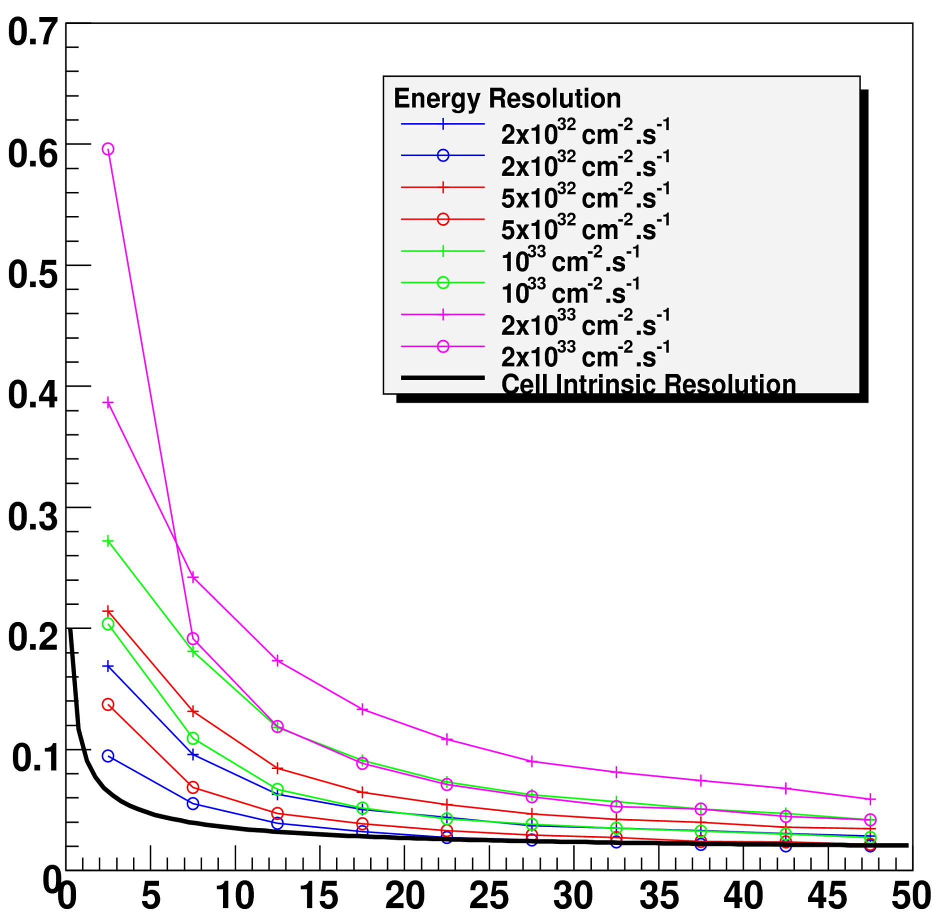
Energy Resolution vs Luminosity

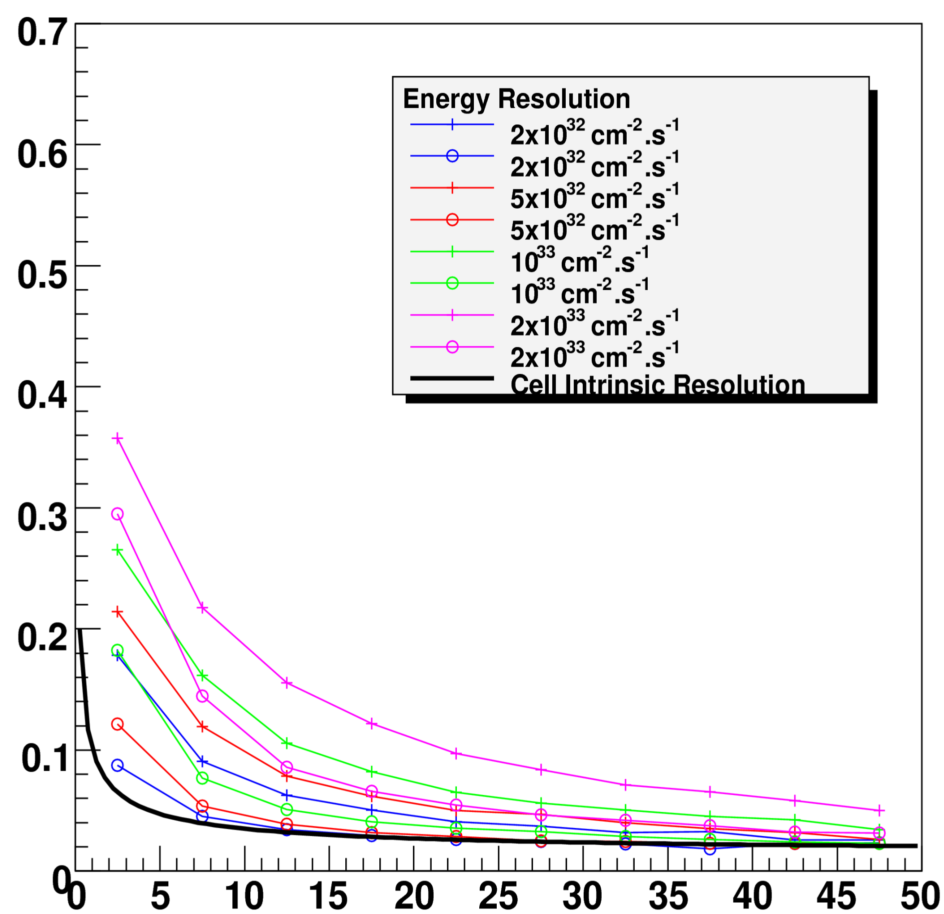
- Varying Luminosity – All effects included – Inner part
  - The pile up starts to be a problem as we typically degrade by a factor 2 the resolution going from $2x10^{32}$ to 10^{33}



Energy Resolution

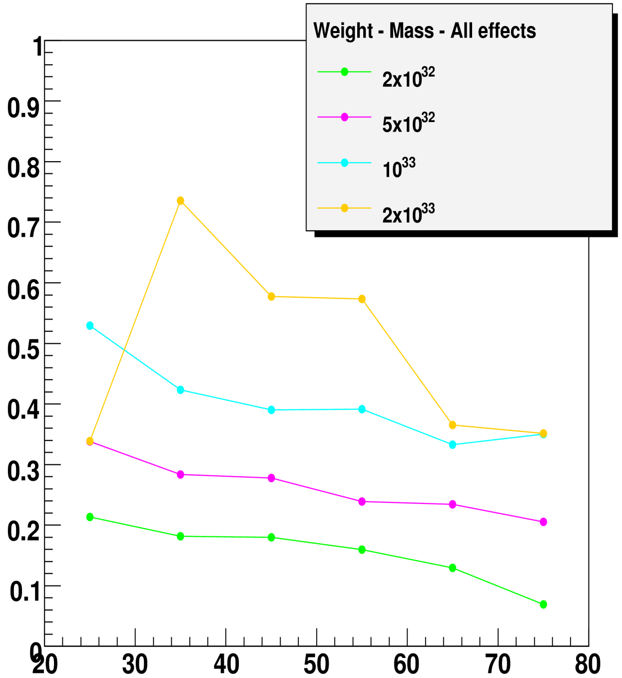
- Varying Luminosity – All effects included – Middle/Outer part
  - Pile up is not so annoying here as in the inner

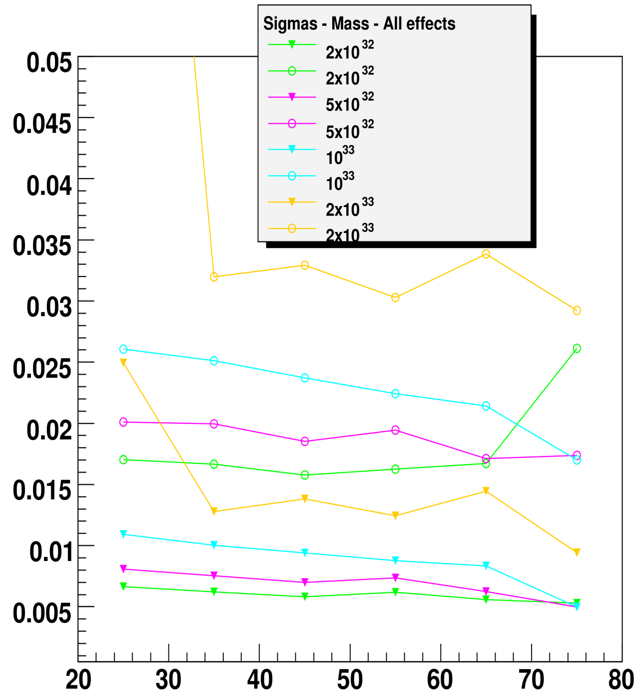


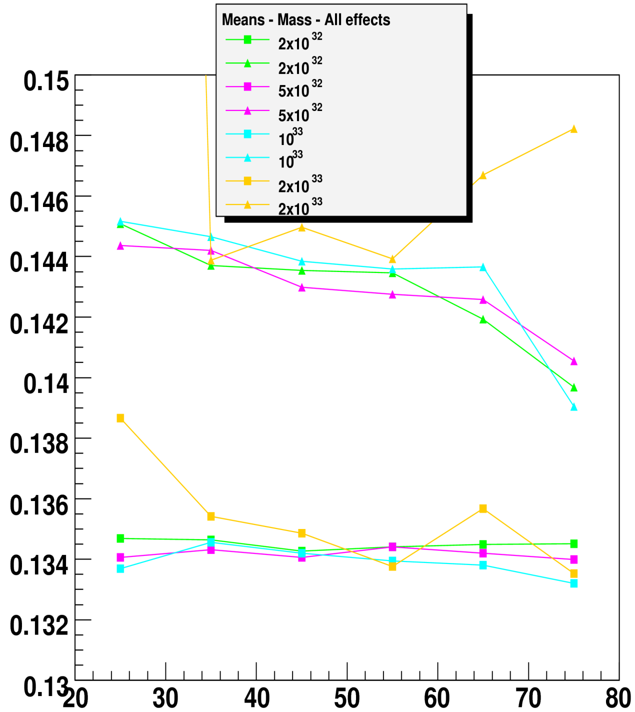


Pion mass reconstruction

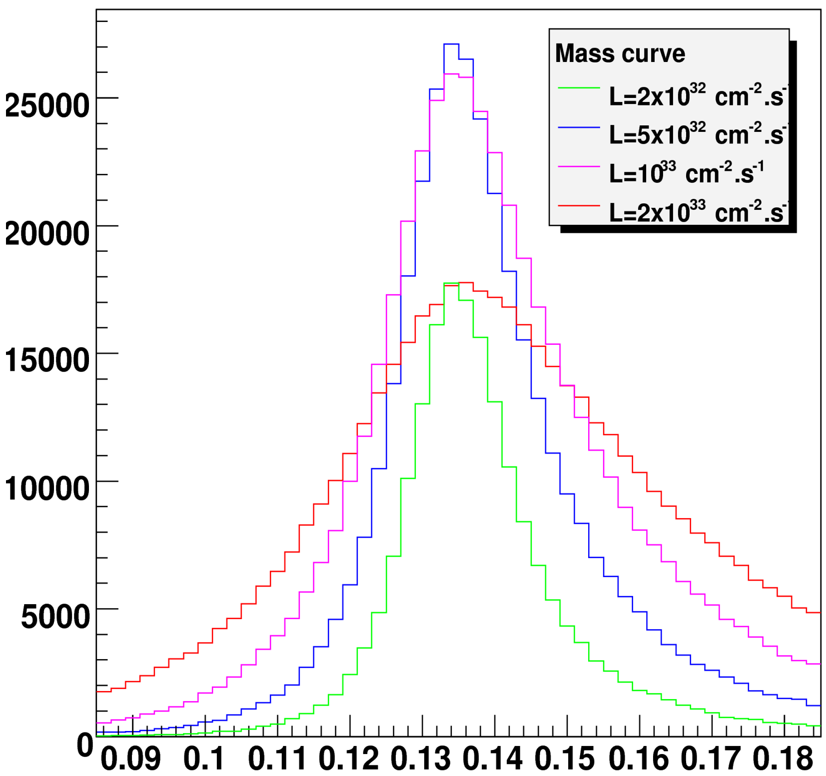
- Mass resolution wrt the luminosity
  - Fit with a sum of two gaussians
    - The contribution from the larger component gets more and more important
    - Globally the resolution is degraded by a factor 2 from $2x10^{32}$ to 10^{33}
    - The pile up effect is still visible by the mean of the second gaussian



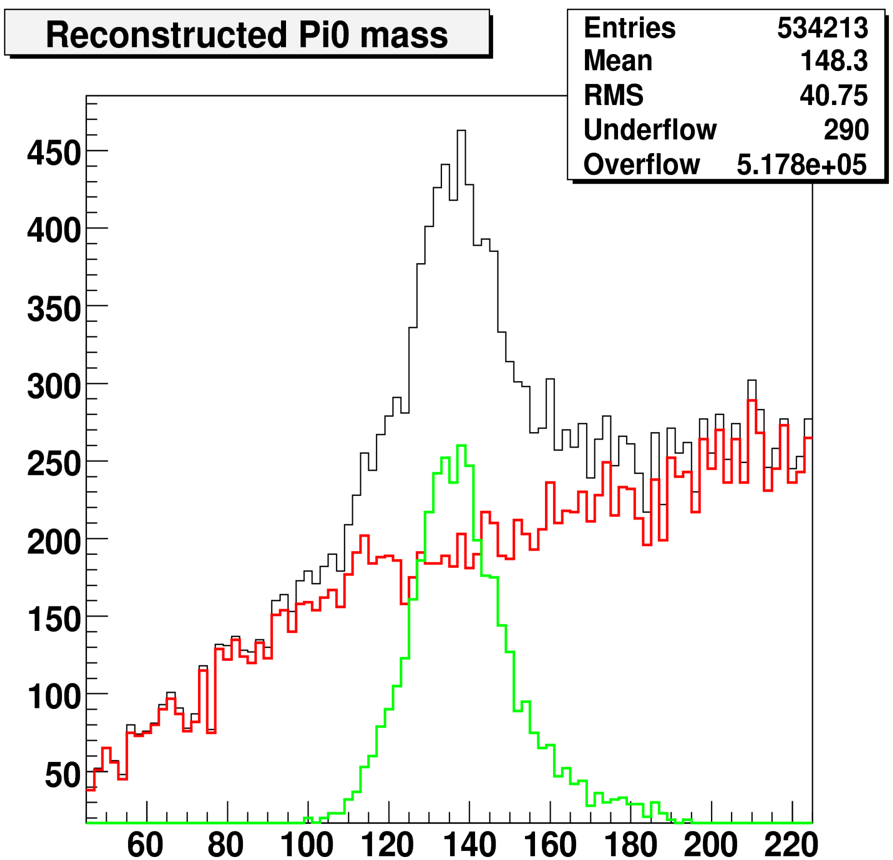




Mass Resolution



The simulation shows already a slight asymmetry at $2x10^{32}$



LHCb simulation
“loose” MC Assoc cut

Conclusions on Detector Resolution

- Pile up is a large contribution at $2x10^{32}$ and becomes the largest one above
  - Notice that the "accepted resolution" was measured in test beam without any material in front of the ECAL
  - The "real" intrinsic resolution of the ECAL looks closer to $$\frac{\sigma(E)}{E} = \frac{0.15}{\sqrt{E}} \oplus 0.015$$
    - Ref : http://indico.cern.ch/getFile.py/access?contribId=3&resId=1&materialId=slides&confId=25234
- The effect could be limited by a factor √(4/9) by taking 2x2 cells
- This is not possible in the inner as the cell size would lead to a large leakage
- In 201?, the inner part of the calorimeter should be replaced
  - the resolution will be much degraded by the accumulated dose
- What is the purpose of replacing the inner part of the calo if the resolution is extremely degraded by the pile up anyway ?
- Could we imagine a dense detection medium material (PbW0) in the inner
  - Reduce the cell size by a factor 1.5
  - Reduce the pile up effect by a factor 1.5...

Conclusion on Reconstruction

- The pile up effect is already not negligible at the present luminosity
  - Resolution is estimated with particle gun ?
  - The MC associator rely on the energy matching between the MC photon and the cluster energy
    - Does this bias the “visibility” of the effect

- The pile-up effect typically degrades by a factor two the photon energy and pion mass resolutions between $2x10^{32}$ to 10^{33} in the inner
- The effect is not so strong in the two other regions
- This will lead to adjustment on the B mass cut windows in the analysis