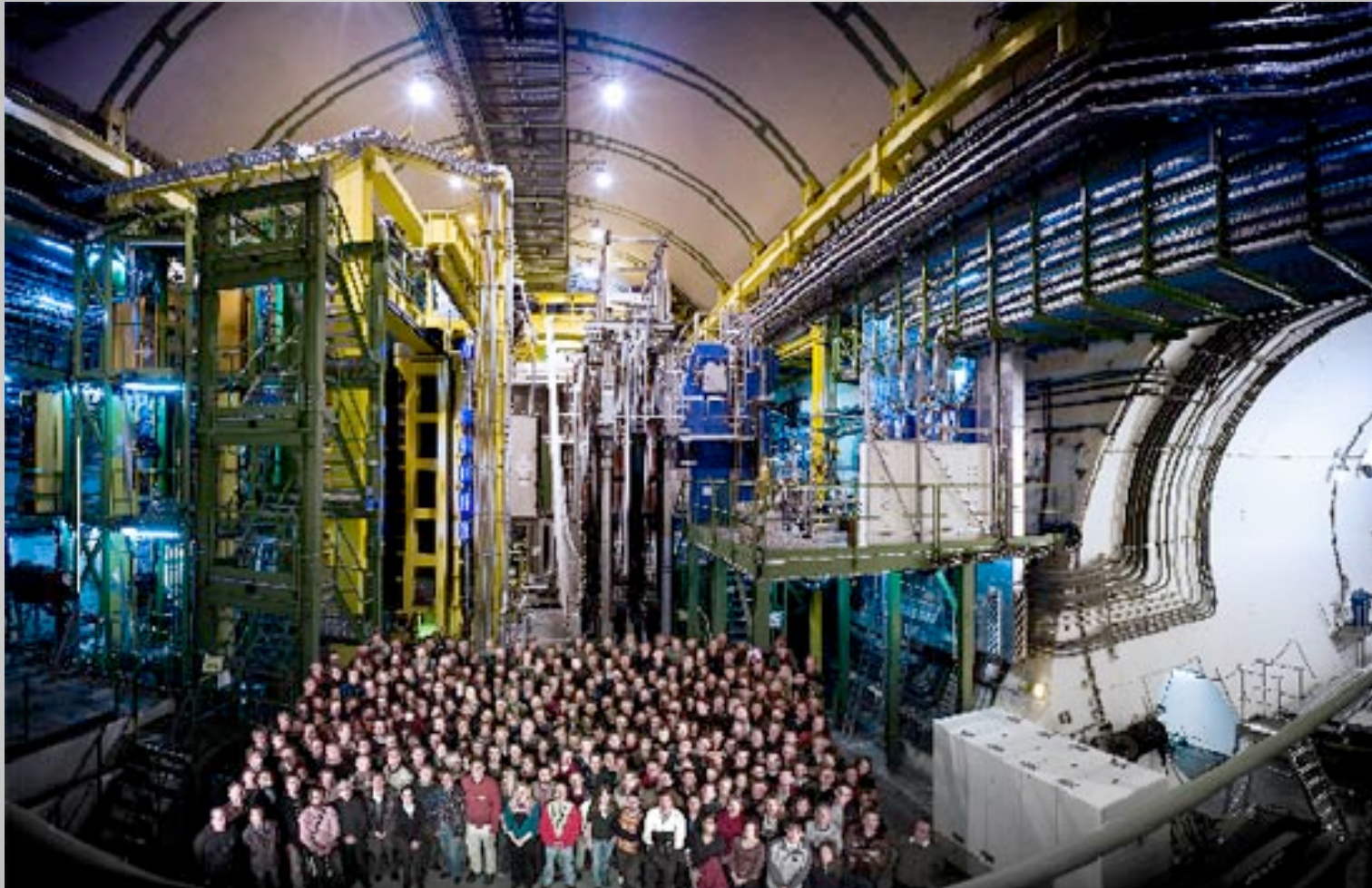


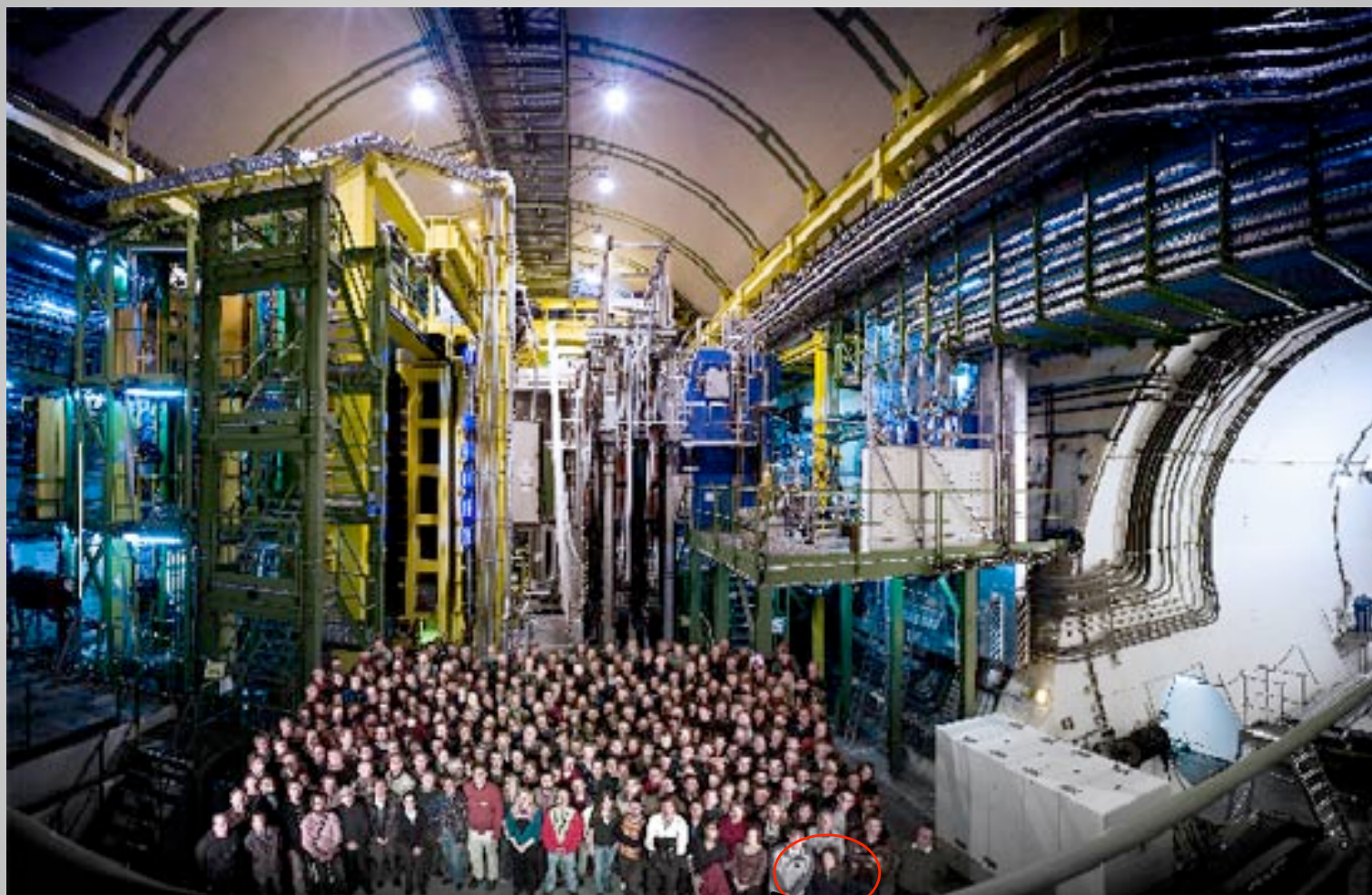
Time alignment of the ECAL and HCAL at LHCb And a little look at first data



Yasmine Amhis

Séminaire Annecy - 5 mars 2010

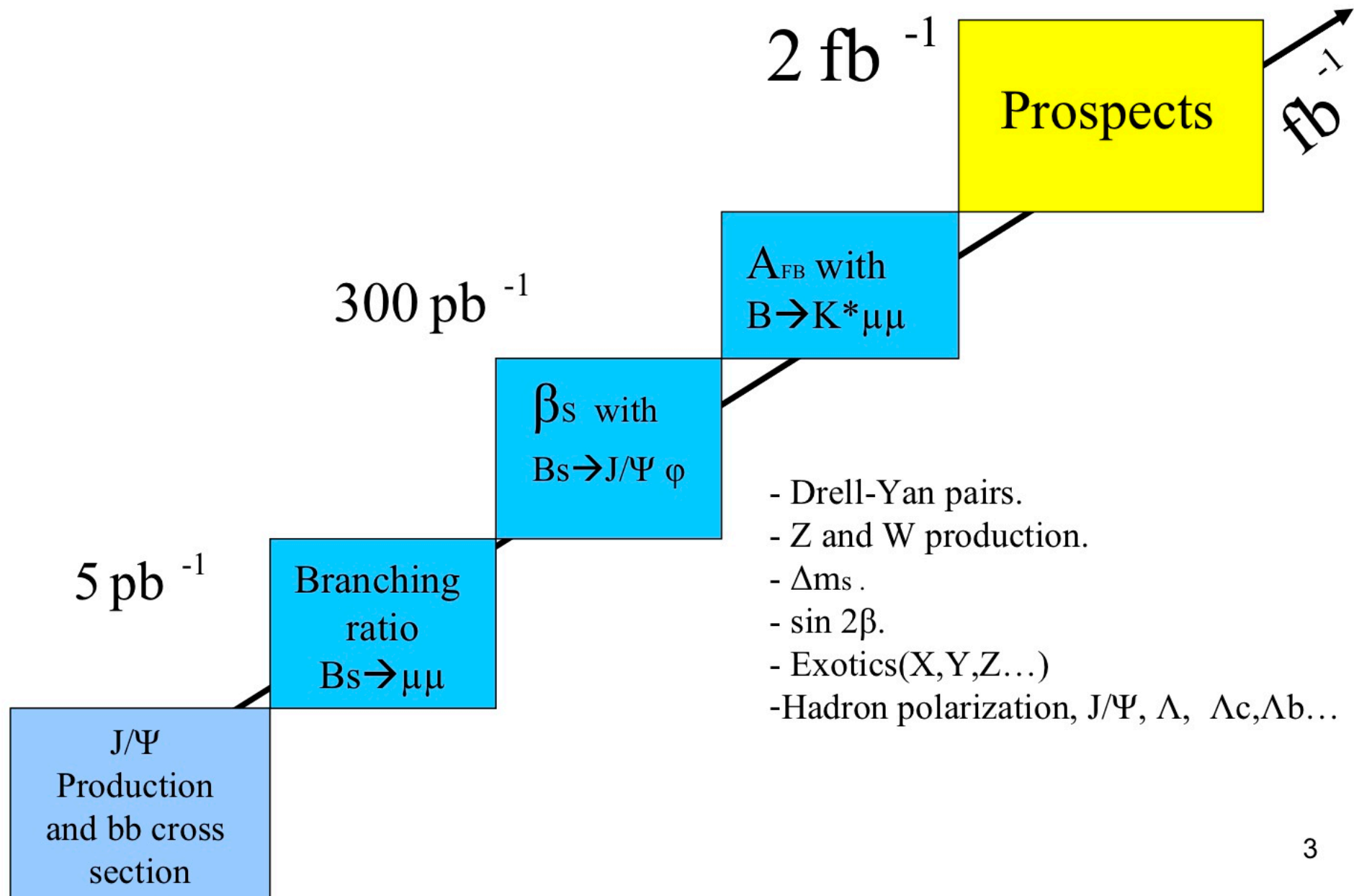
Time alignment of the ECAL and HCAL at LHCb And a little look at first data



Yasmine Amhis

Séminaire Annecy - 5 mars 2010

Definition of «Early» Physics & Outline.



p-p at 7 TeV + 7 TeV ...one day...

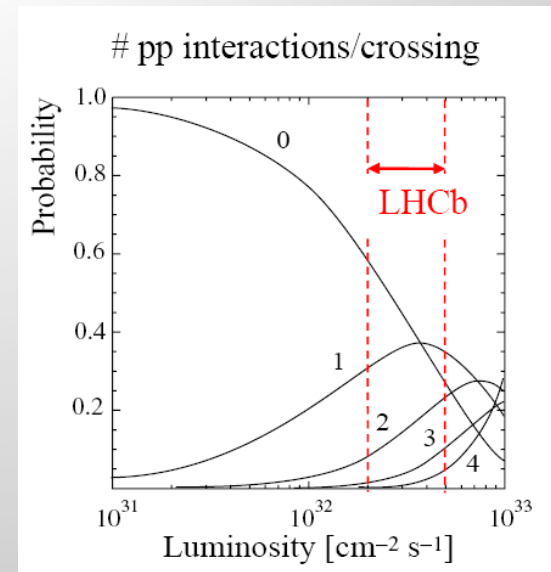
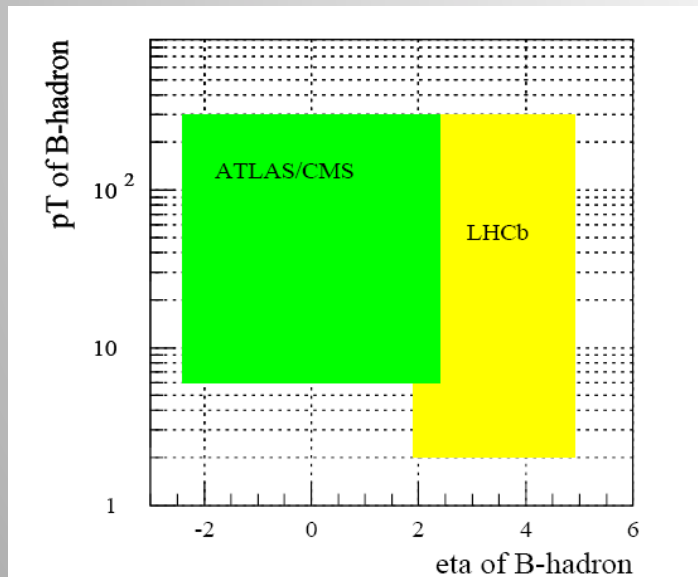
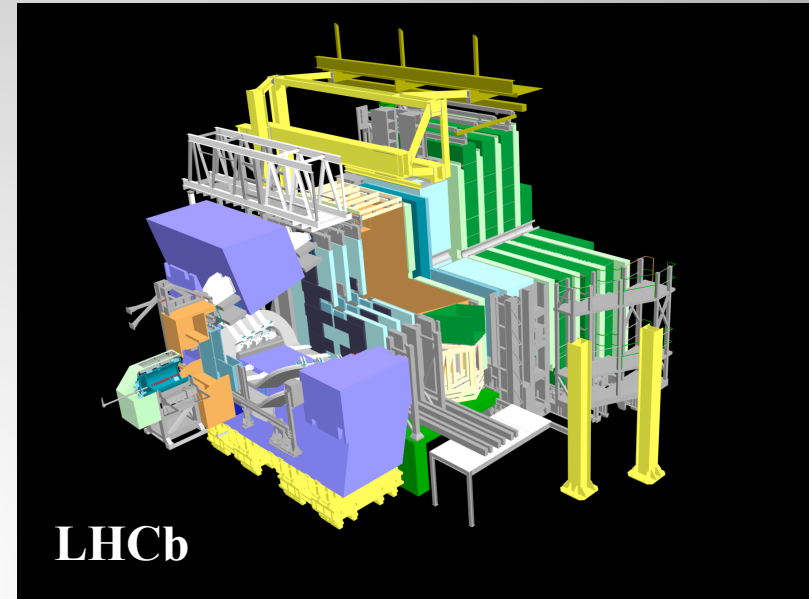
- Crossing rate 40 MHz.
- Luminosity at LHCb: $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$.

Beauty, beauty...

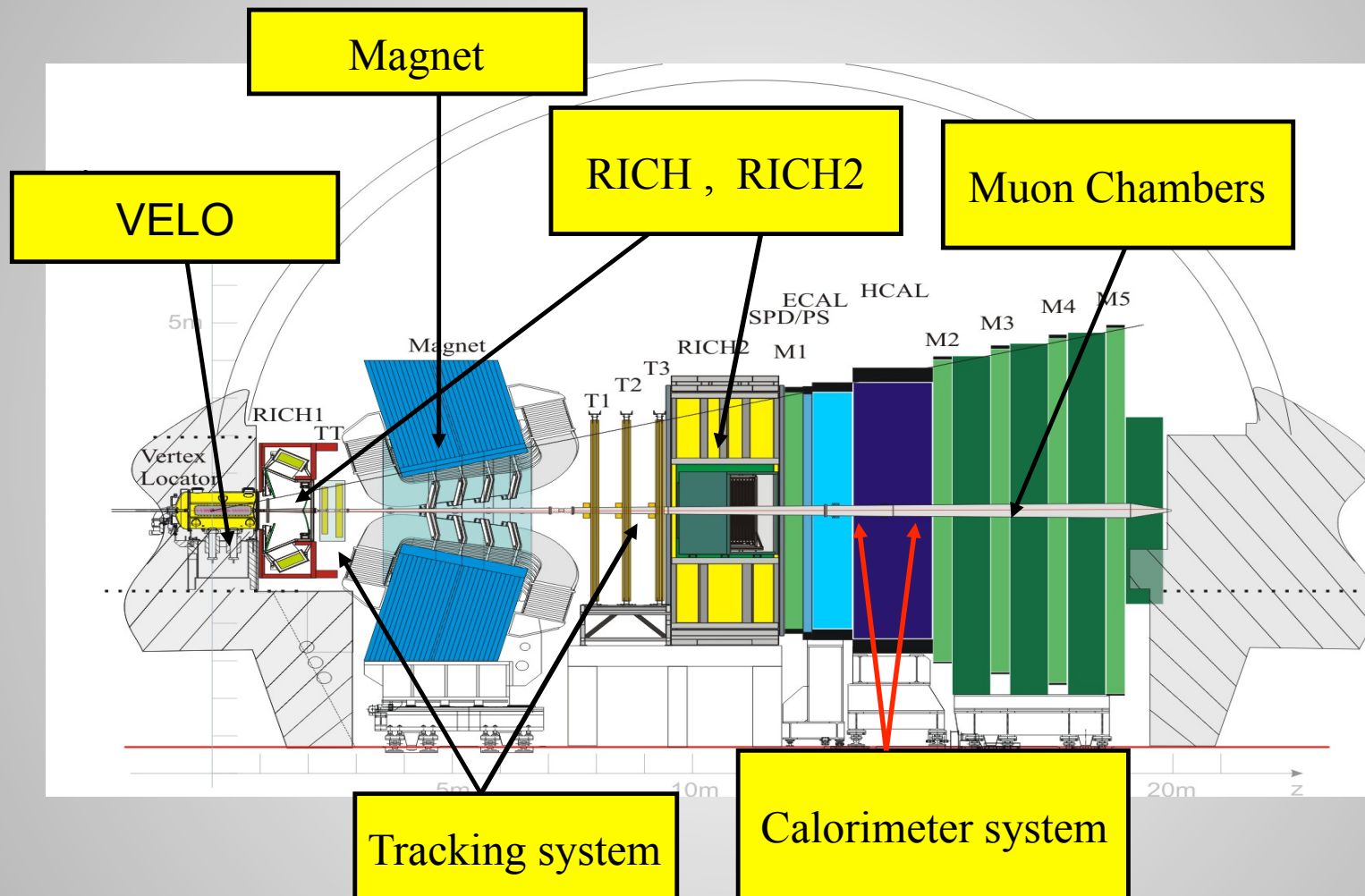
- Large bb cross section: $\sim 500 \mu\text{b}$
 10^{12} pairs / year.
- Production of $B^0, B^+, B_s^0, B_c^+, \Lambda_b$

-Hadronic environment...

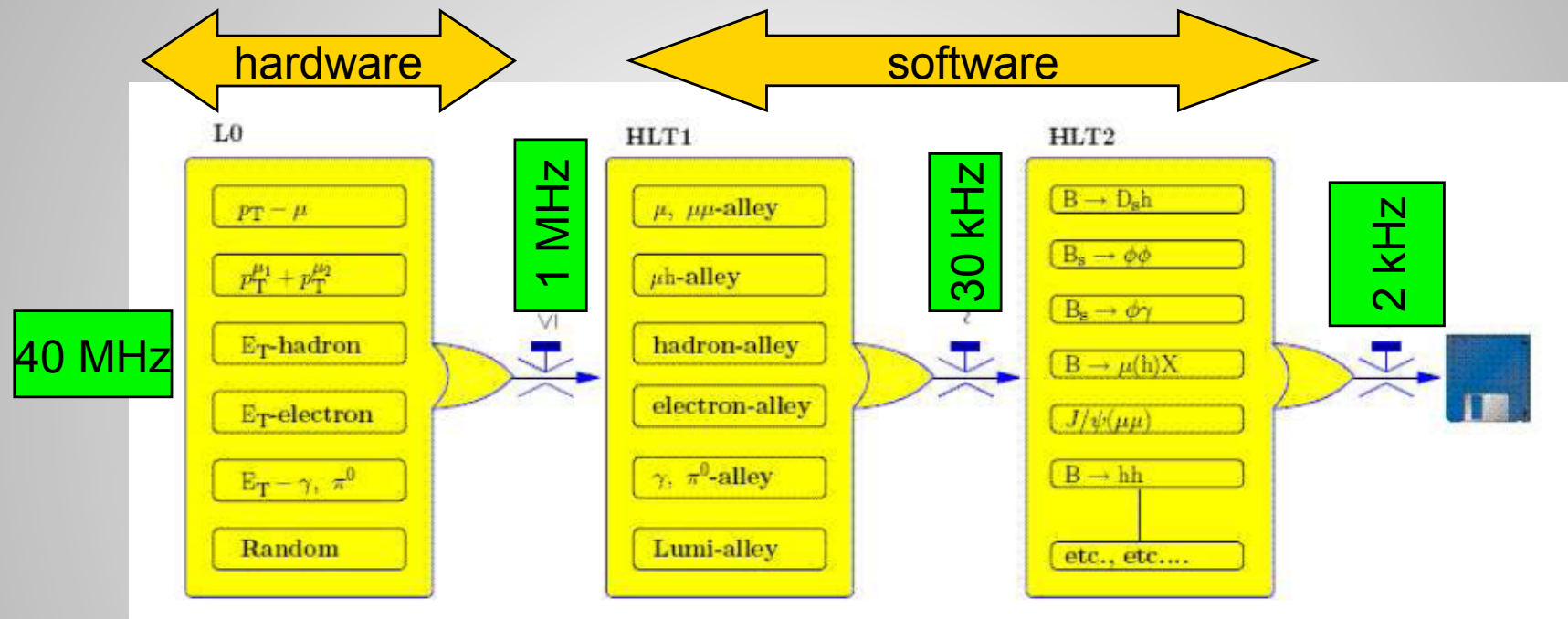
- MB cross section $\sim 60 \text{ mb}$.



LHCb



Trigger system



L0 :

- Pile-Veto.
- Calorimeters.
- Muons.

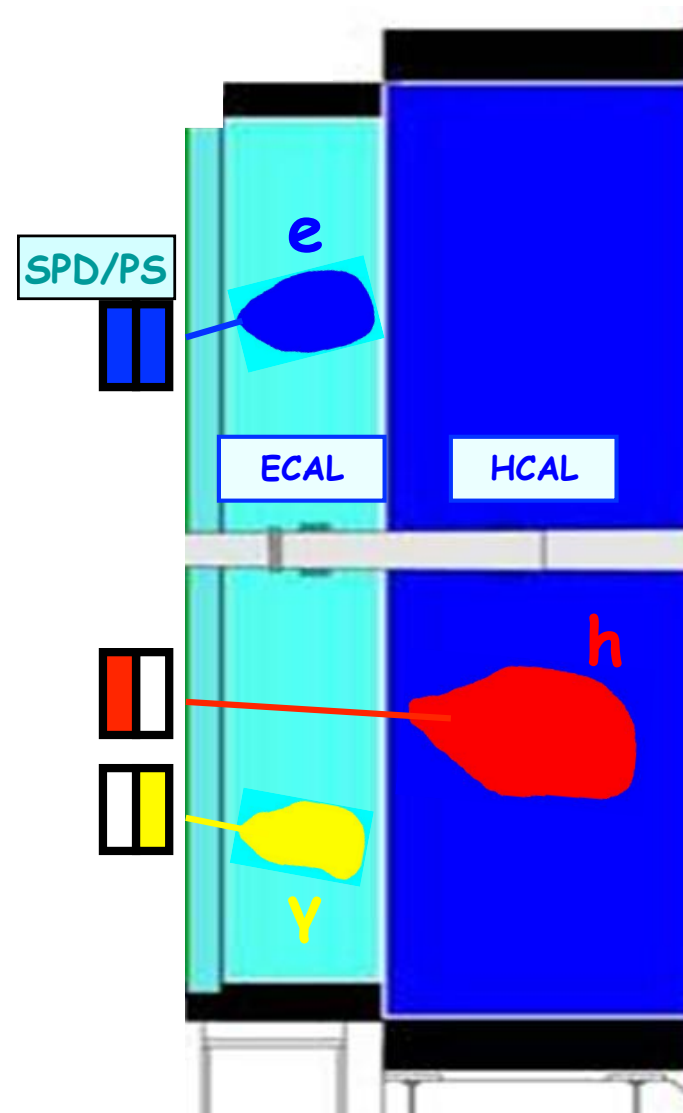
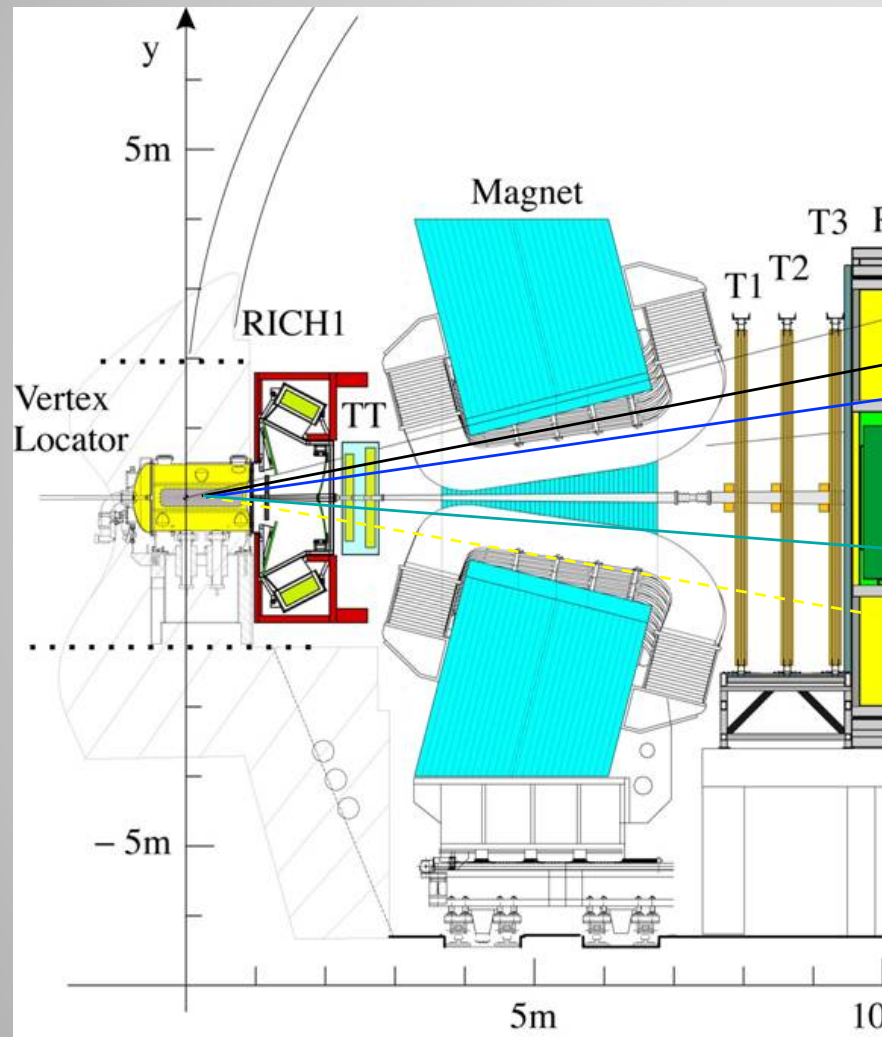
HLT1:

confirms the L0
objects.

HLT2:

Online reconstruction

Un petit peu de calorimétrie...

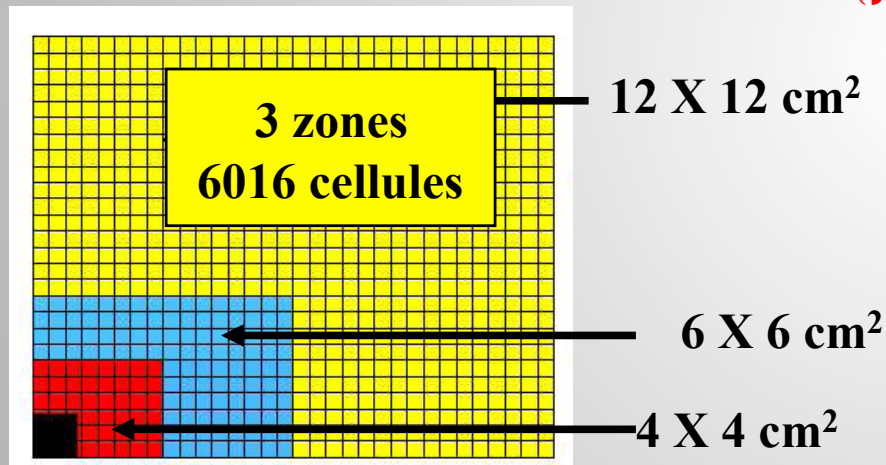


The ECAL and HCAL

ECAL:

- Resolution $\sim 10\%/\sqrt{E} \oplus 1\%$
- Fast response (25ns).
- Small transverse segmentation.
- π^0 , e^- , photons reconstruction.

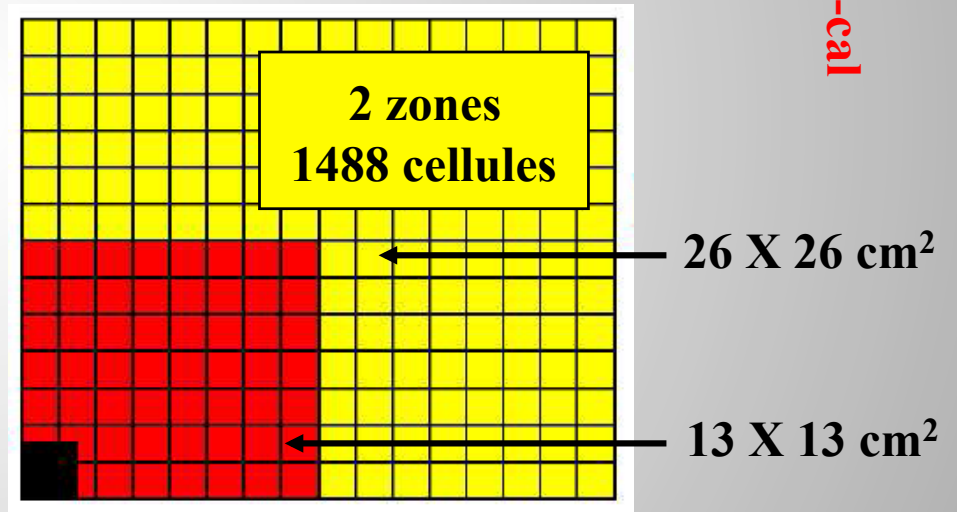
Shashlik Module



HCAL:

- Resolution $\sim 80\%/\sqrt{E} \oplus 10\%$
- Fast response (25ns).
- Transverse segmentation.

Module Tile-cal



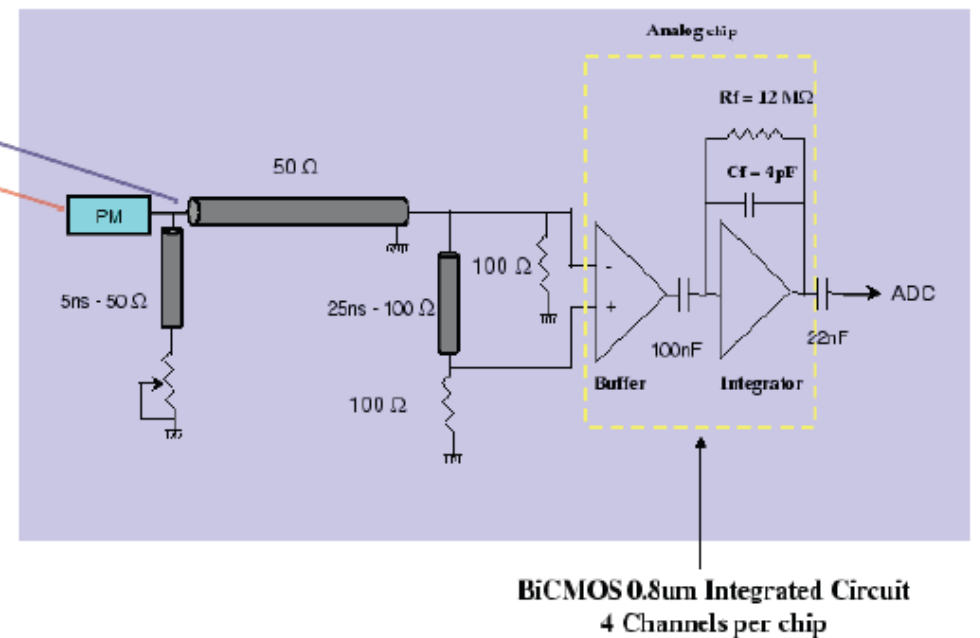
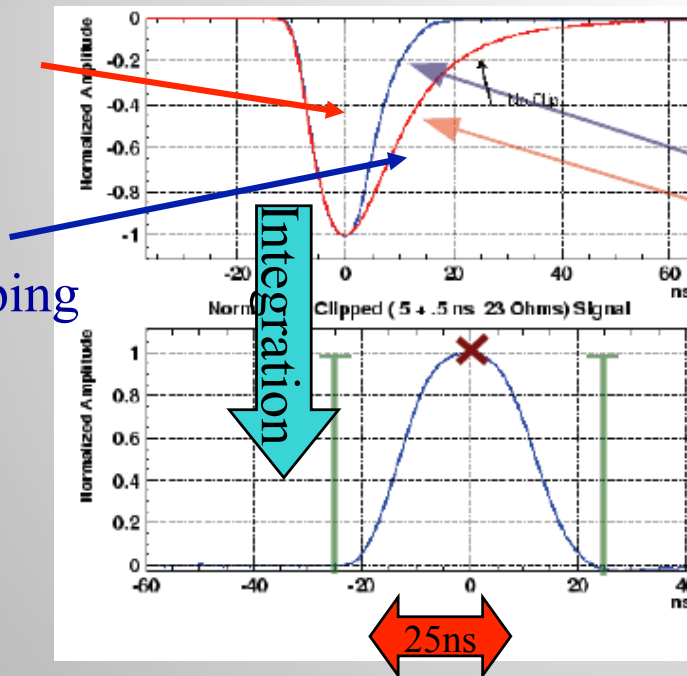
- Common electronics.
- Scintillators + fibres.
- PM+ FE Cards.

Front-end electronics for the ECAL and HCAL



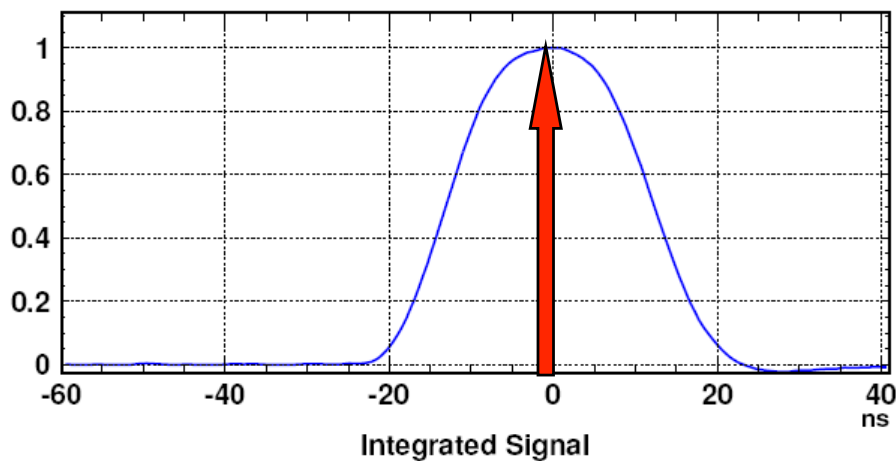
After PM

After Clipping



The amplitude of the signal is proportional to the energy deposits.

What is time alignment?



- A procedure to correct for all sources of possible delays (Δt) to be able to sample the signal at the **maximum**.

$$\Delta t = T(\text{LHC clock}) - T(\text{ADC})$$

If the time alignment is perfect : $\Delta t = 0\text{ns}$.

Time misalignment sources:

- Cable length variation ($\sim 1\text{ns}$)
- High Voltage (HV) ($\sim 4\text{ns}$)
- Position of the cells -- $\cos \theta$ effect.

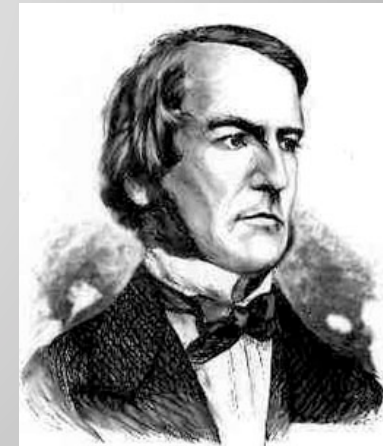
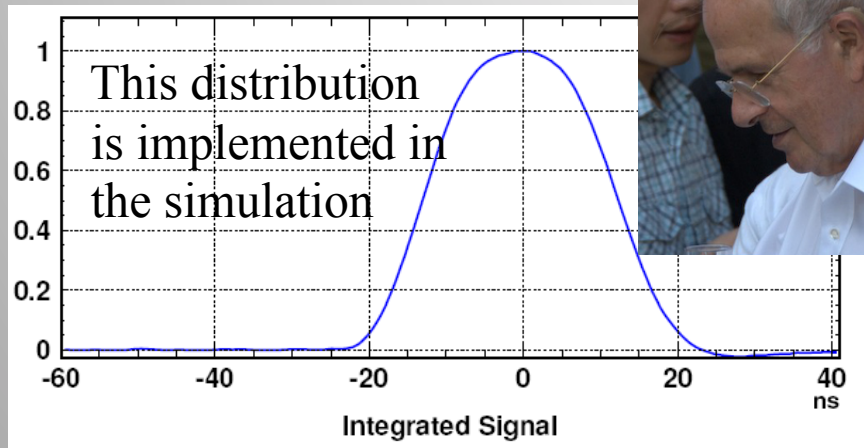
We need to evaluate a correction Δt for:

- **6016** ECAL channels.
- **1488** HCAL channels.

How is the analysis done?

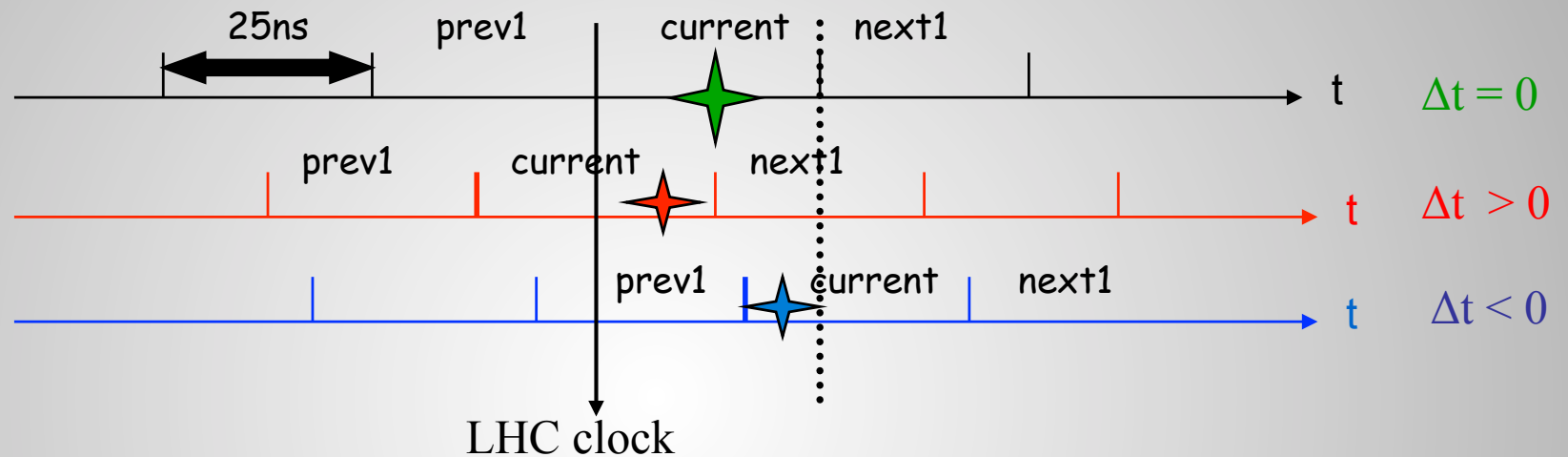


Generation and
Simulation of Minimum bias events

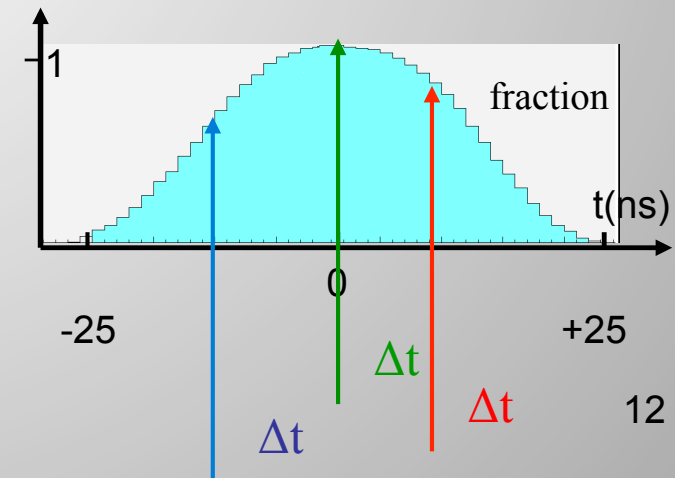


Digitization
Electronics

How do we take into account the « time » in the MC



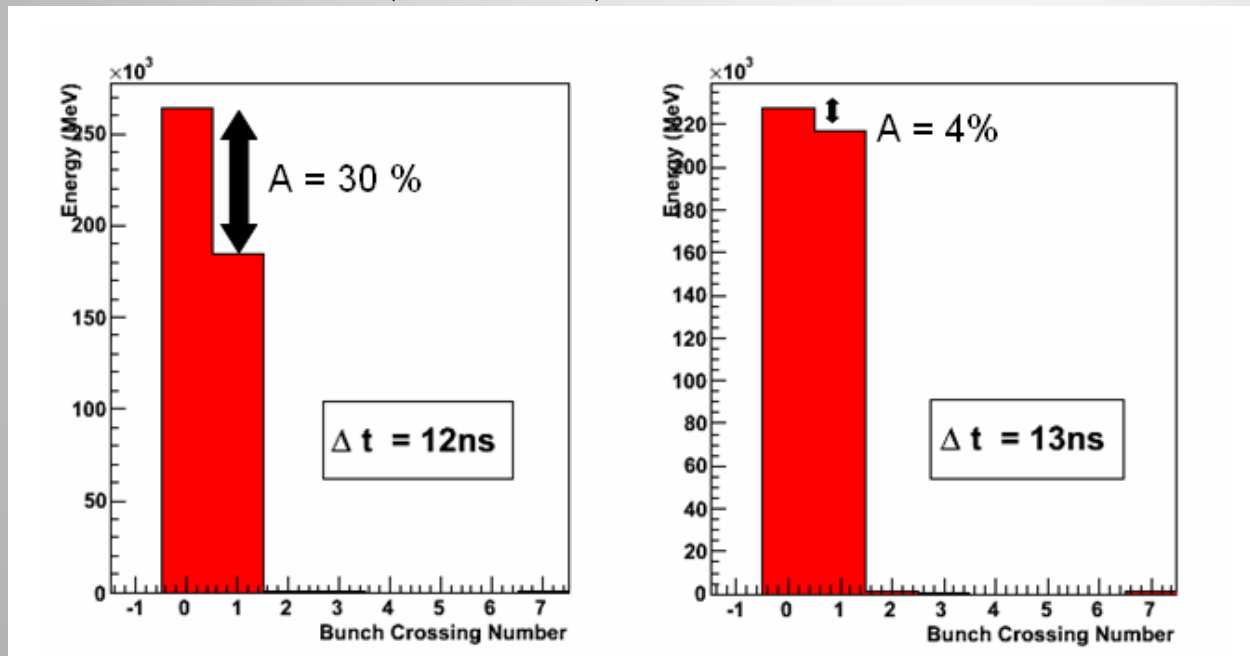
- Use 25 ns time bins.
- Add an additive constant:
 $\Delta t = \text{Constant} \times 1 \text{ ns}.$



Where do we best measure Δt ?

Define a variable called A :

$$A = \frac{E(\text{Current}) - E(\text{Next1})}{E(\text{Current})}$$



Very high sensitivity to a 1 ns variation around the mid-height.

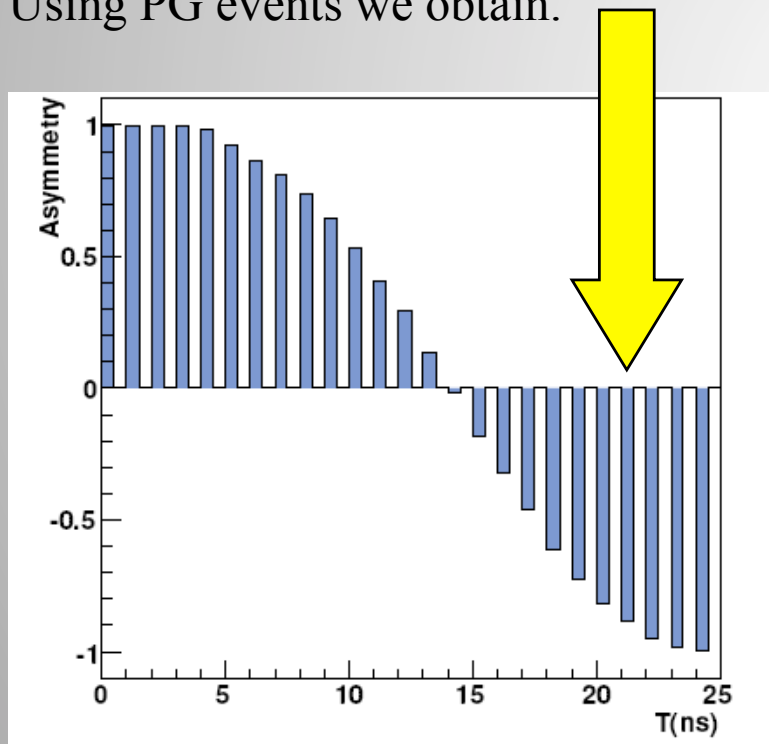
We will use this region to perform the time alignment.

Form the asymmetry to Δt

- For each cell j we define :

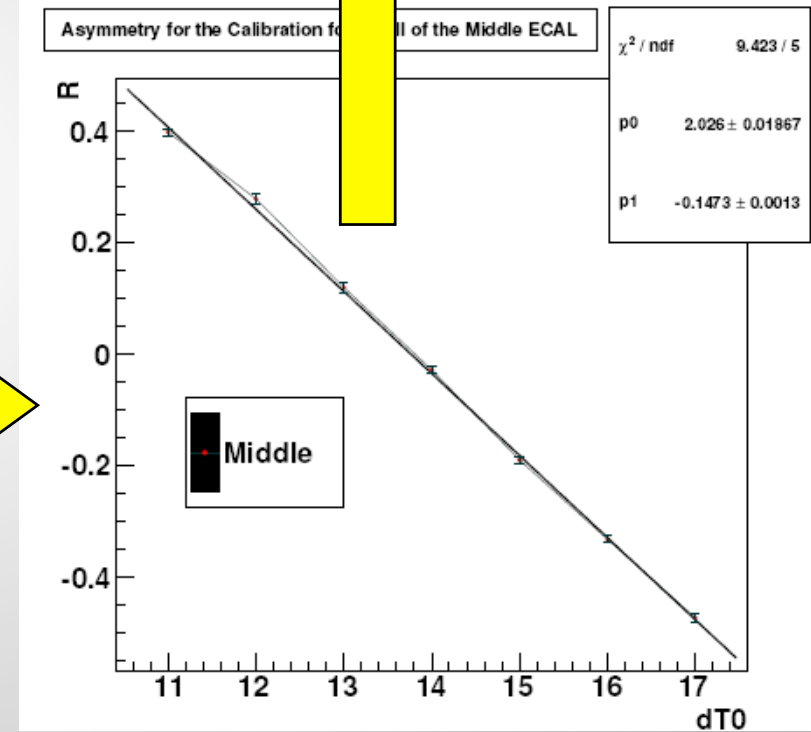
$$R_j = \frac{1}{N} \sum_{i=1}^{i=N} \frac{E_i(\text{Current}) - E_i(\text{Next1})}{E_i(\text{Current}) + E_i(\text{Next1})}$$

- One can measure R on data.
- Using PG events we obtain.



Zoom

Using the asymmetry on can compute the corresponding delay Δt .



Tolérance:

$$R(\Delta t = 13.5 \text{ ns}) < R_j < R(\Delta t = 12.5 \text{ ns})$$

Study of realistic cases

- Monte Carlo productions:

- Use the criteria obtained with PG events.
- Generate 55 k MB events, with $\Delta t = 13$ ns. :
 - 7 TeV beams + magnetic field.
 - 7 TeV beams + no magnetic field.
 - 450 GeV beams + no magnetic field.

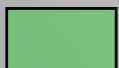
- Increasing the amount of time aligned cells:

- Remove low energy cells:

$$E^T_{ij}(Current) + E^T_{ij}(Next) > 300 \text{ MeV}$$

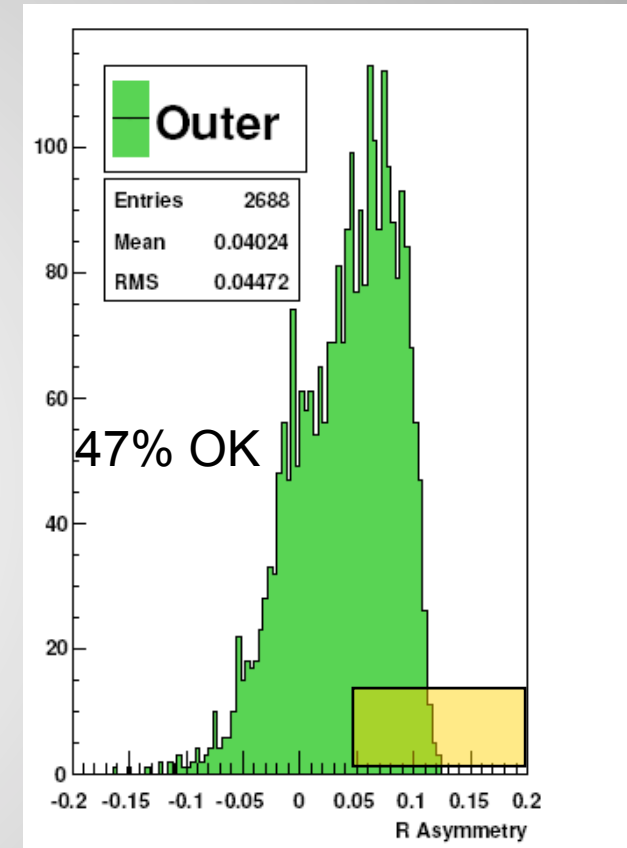
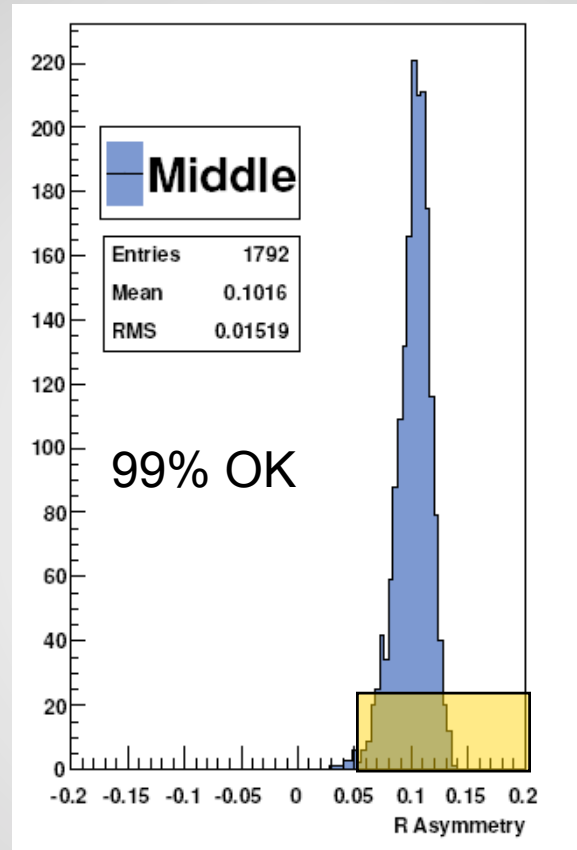
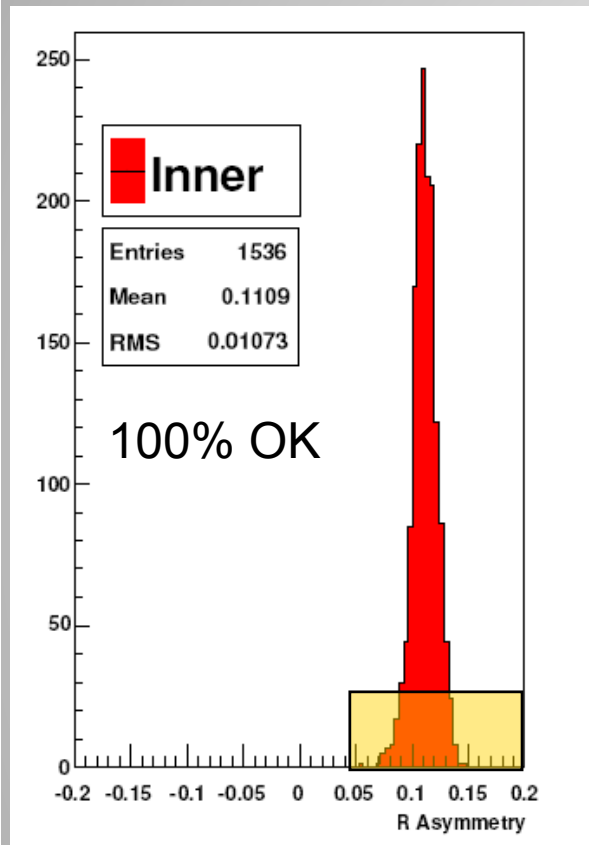
- Use an iterative method:

$$\left| R_j - r_{ij} \right| < 20 \times rms(R_{Inner}) \text{ avec : } r_{ij} = \frac{E_{ij}(current) - E_{ij}(Next1)}{E_{ij}(current) + E_{ij}(Next1)}$$



The time alignment is very precise in the inner ECAL zone.

55 k events +7 TeV +magnetic field

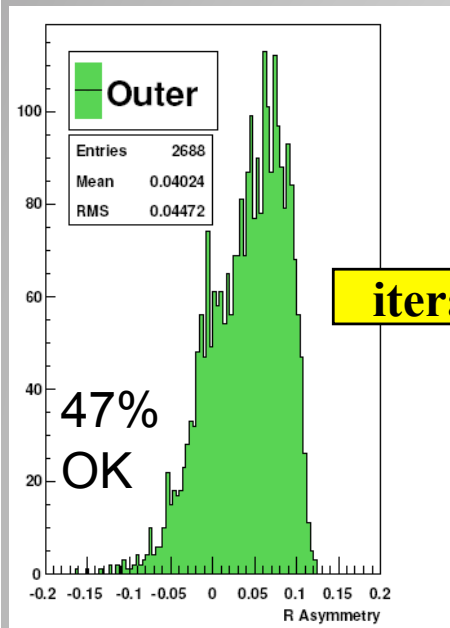


Criteria reminder:

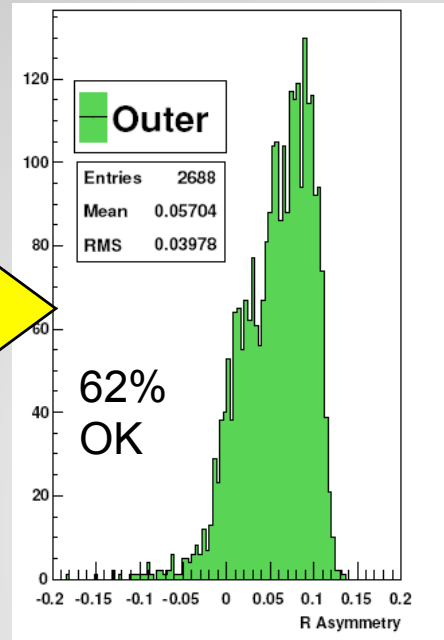
$R(\Delta t = 13.5 \text{ ns}) = 0.05$
 $R(\Delta t = 12.5 \text{ ns}) = 0.20$

Only 47 % of the cells are aligned with the required precision (0.5 ns) in the outer region.

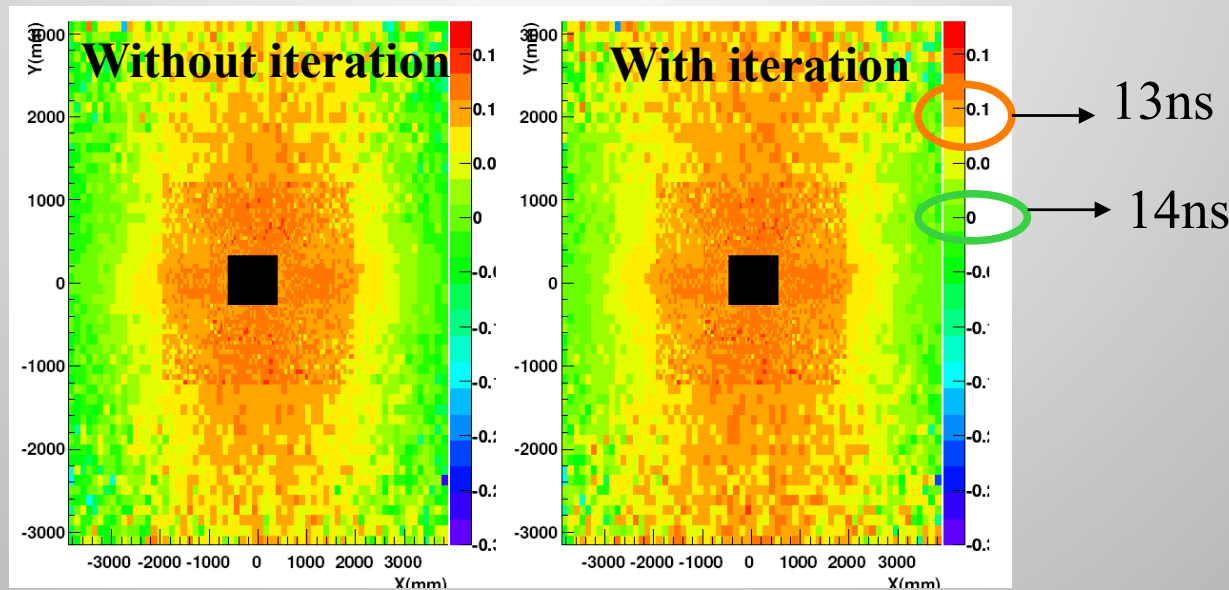
55 k Events + 7 TeV + magnetic field + 1 iteration



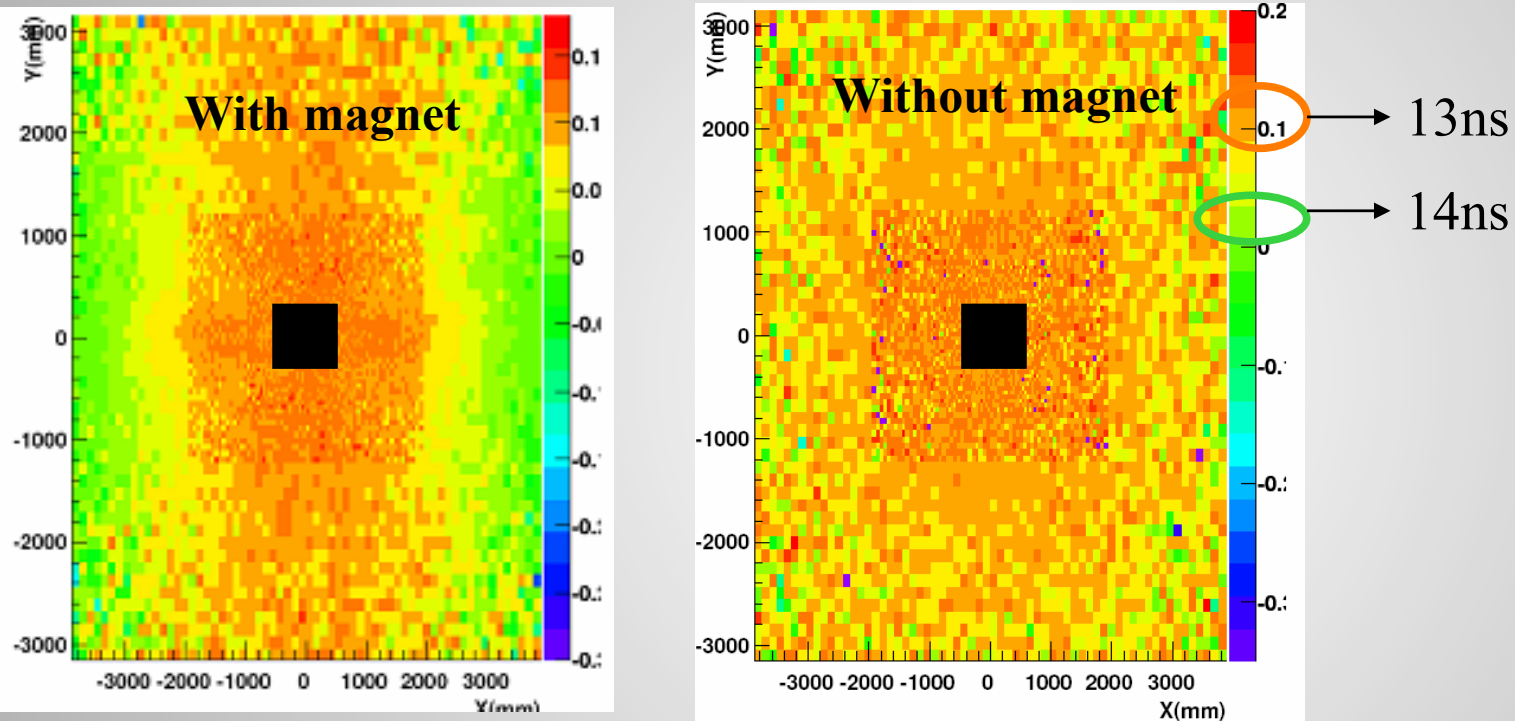
iteration



Using the iterative method increases the rate of aligned cells by 15% in the outer region of the ECAL.



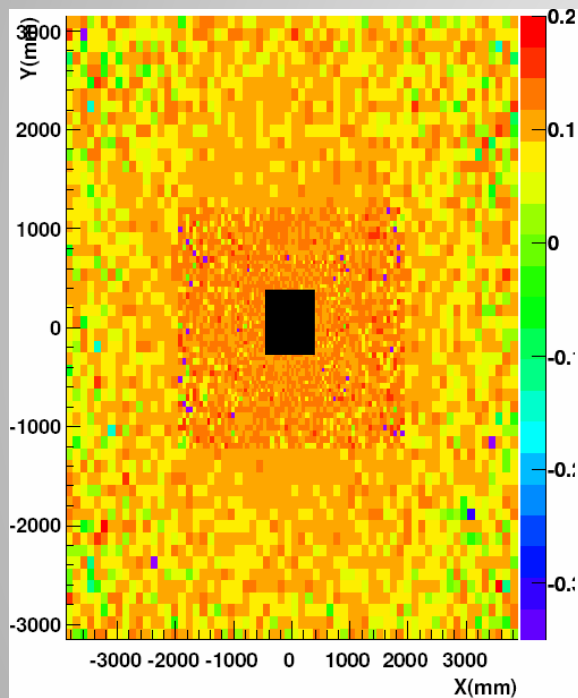
55 k events +7 TeV +1 iteration



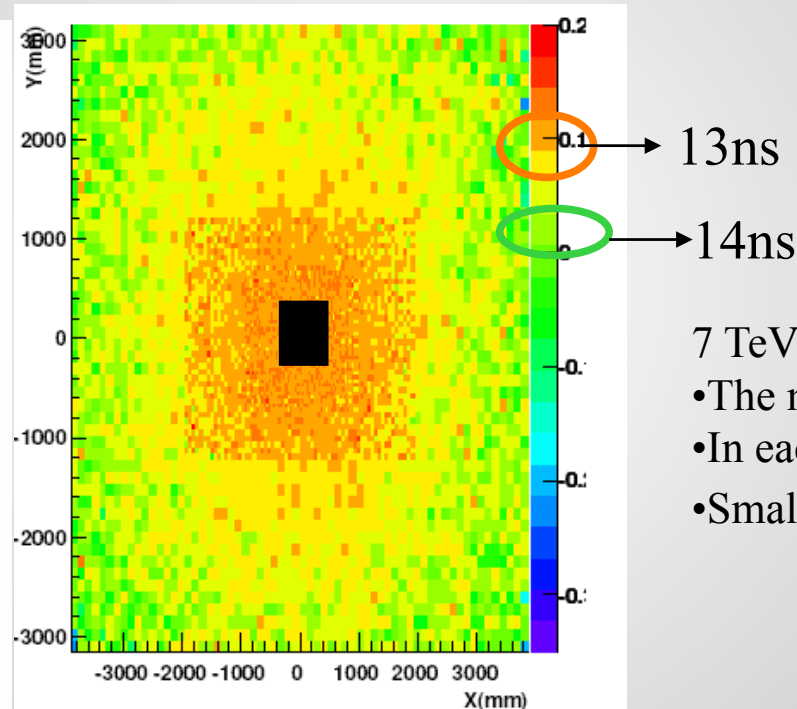
Rate of aligned cells goes from
62% to 81% in the Outer ECAL zone.

57k events + 450 GeV + magnet off

7 TeV / without magnet
+ 1 itération



450 GeV / without magnet
+ 1 itération



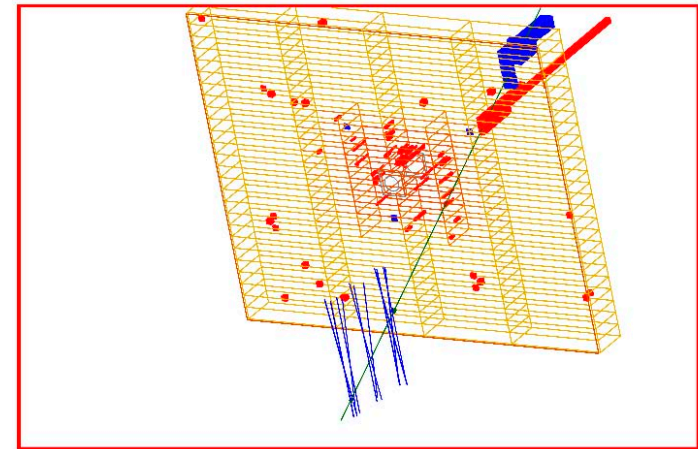
7 TeV $\rightarrow$ 450 GeV :

- The mean value of the energy
- In each cell is smaller.
- Smaller multiplicity.

The rate of aligned cells goes down by 13 % in the Outer ECAL region.

Cosmics at LHCb

- Why are these events useful?
 - Test the whole DAQ chain.
 - L0 commissioning.
 - Sub-detectors alignment (space-time).
- Cosmics properties:
 - Not synchronus.
 - Dedicated L0 based on an coincidence between the ECAL and HCAL.
 - Low statistics.



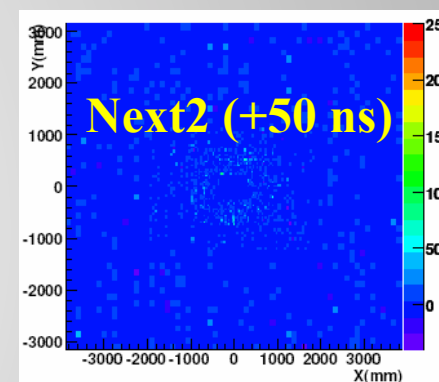
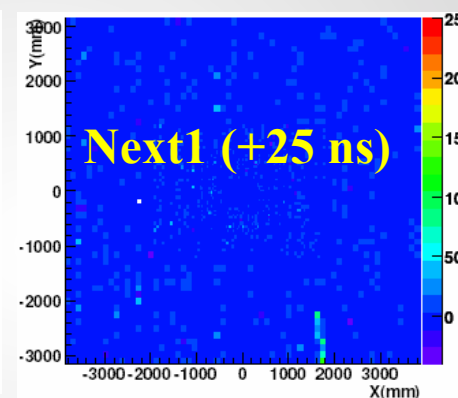
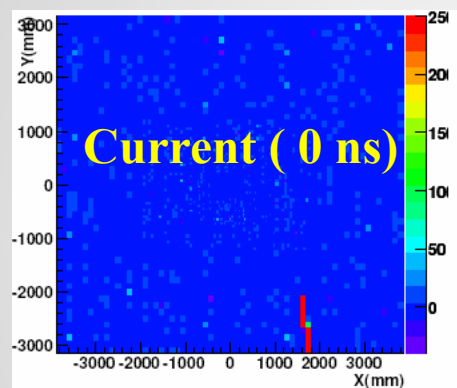
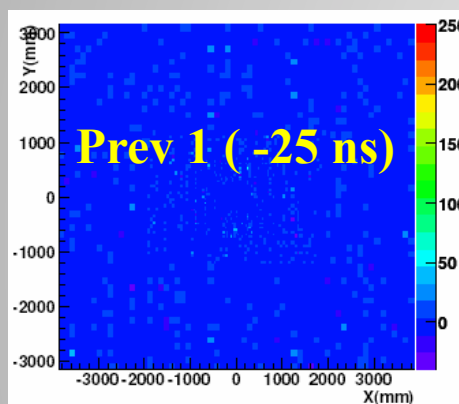
Cosmics identification

Cleaning:

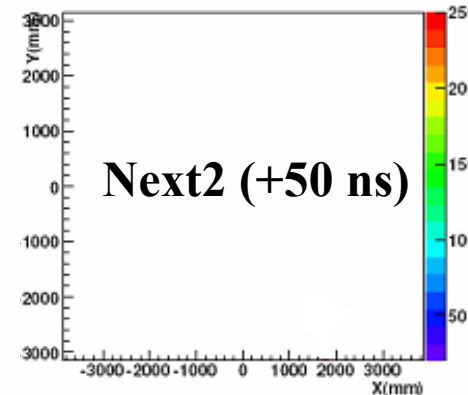
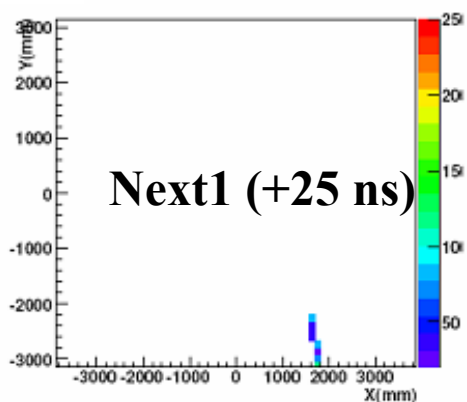
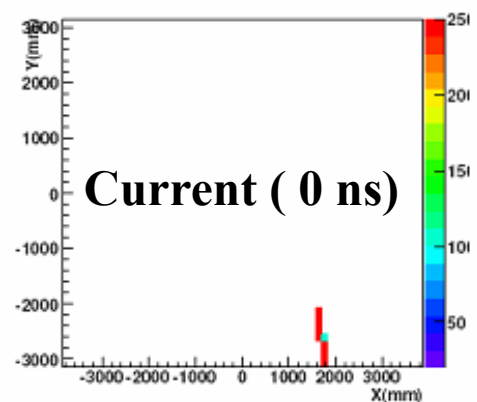
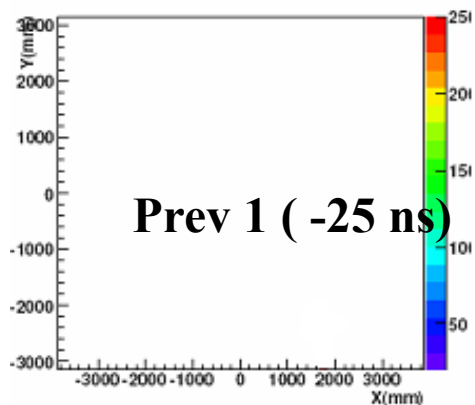
$$E(\text{Prev1}) + E(\text{Current}) + E(\text{Next1}) > S$$

ECAL: $S = 100$ coups ADC

HCAL: $S = 10$ coups ADC

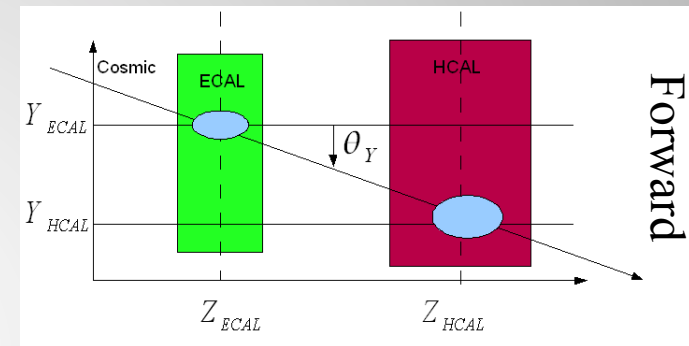
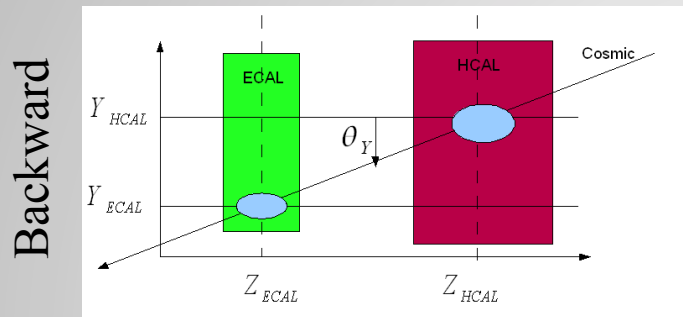


After cleaning:

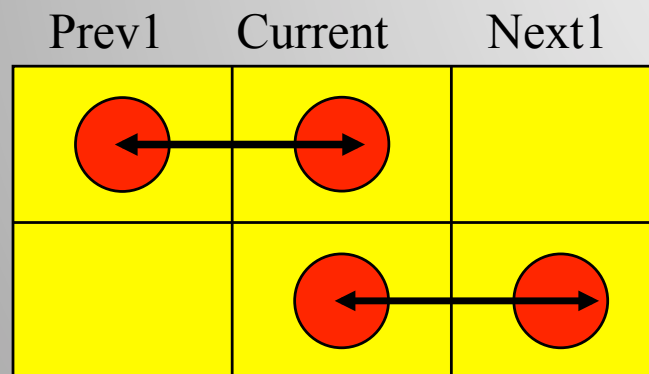


Cosmics reconstruction

- Find a cluster in the ECAL et le HCAL.
- Reconstruction the direction .



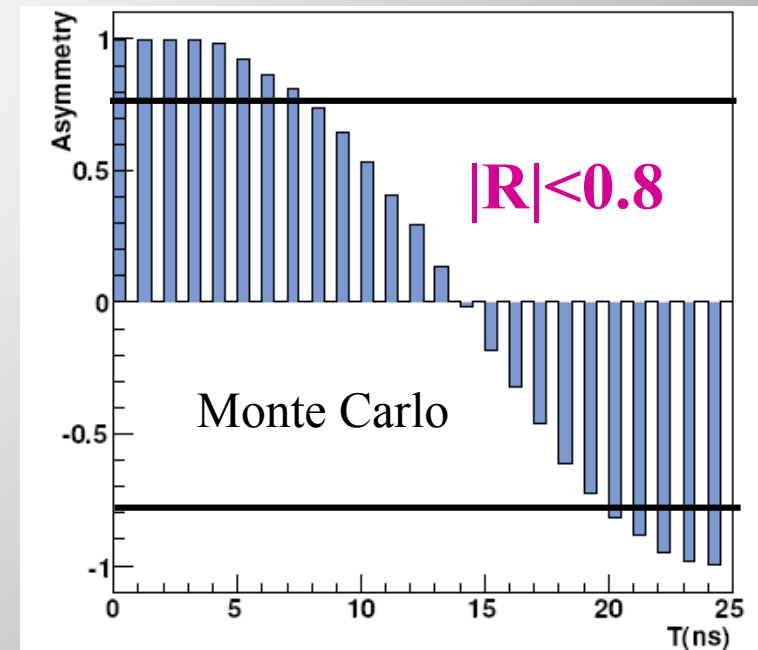
- Reconstruction of the « time »



R(C/P)

R(C/N)

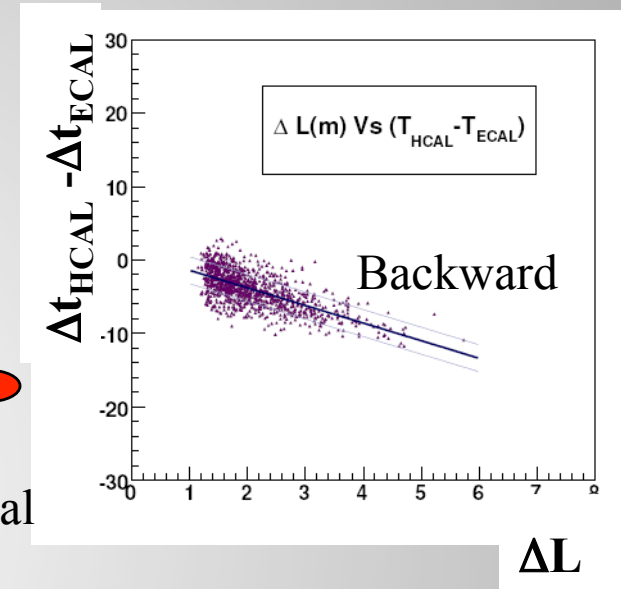
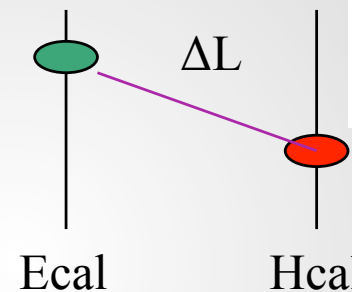
Conversion



Relative time alignment between the ECAL and the HCAL

- Plot $(\Delta t_{\text{HCAL}} - \Delta t_{\text{ECAL}})$ as a function of ΔL .
- Fit this distribution with a simple line.

$$(\Delta t_{\text{HCAL}} - \Delta t_{\text{ECAL}}) = SL \times \Delta L + \text{offset}$$

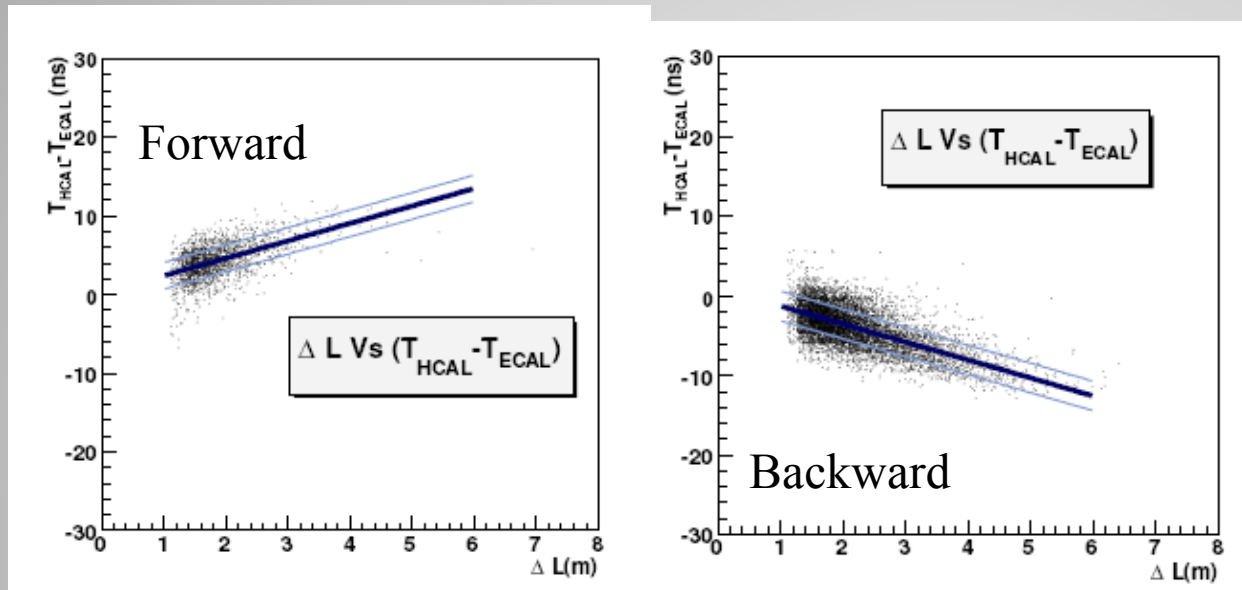


- SL is the inverse of the speed of the cosmic between the ECAL and the HCAL.

What do we expect?

- The cables length are corrected $\rightarrow \text{offset} = 0$ ns.
- Cosmics fly at the speed of light $\rightarrow SL = 3.3$ ns/m

Relative time alignment between The ECAL and the HCAL

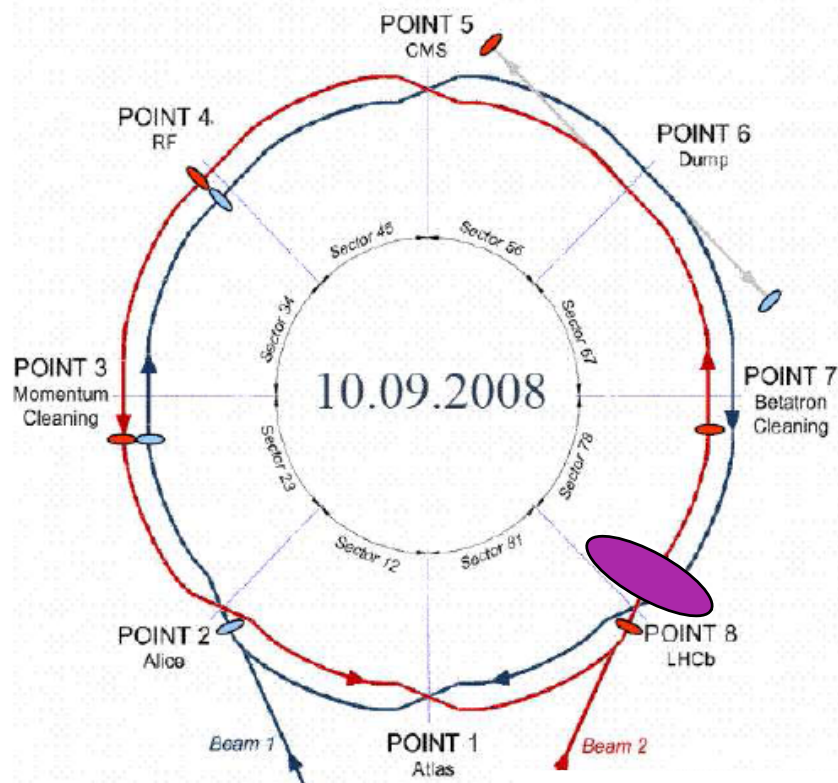


After a few iterations, we finally obtain an **offset** close to zero.

$$\begin{aligned} \text{slope} &= (2.25 \pm 0.19) \text{ ns} / m & \text{slope} &= (-2.29 \pm 0.16) \text{ ns} / m \\ \text{offset} &= (0.82 \pm 2.13) \text{ ns} & \text{offset} &= (1.05 \pm 2.09) \text{ ns} \end{aligned}$$

The relative time alignment between the ECAL
and the HCAL is given by the error on the offset
 $\sim 2\text{ns}$.

Le LHC on Septembre the 10th 2008...



Beam 1

Beam 2

- ~1hour of **Beam 1**
- **Beam 1** + Closed collimator
Hadronic shower production.
- We used these events to check the HCAL internal time alignment.

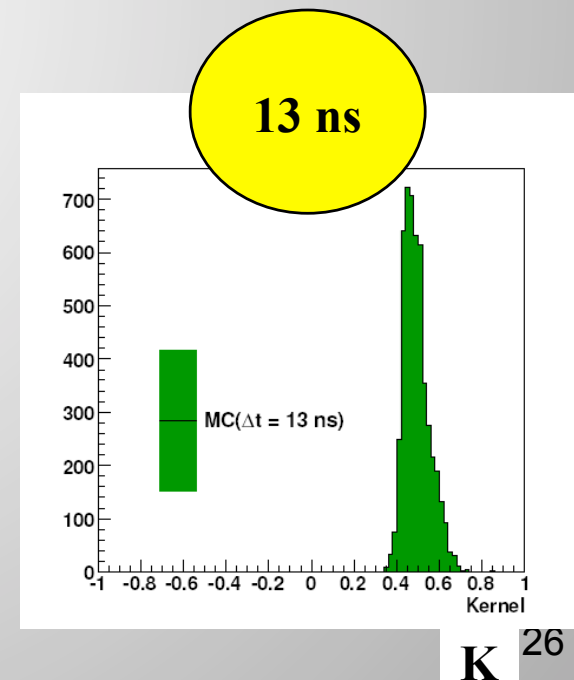
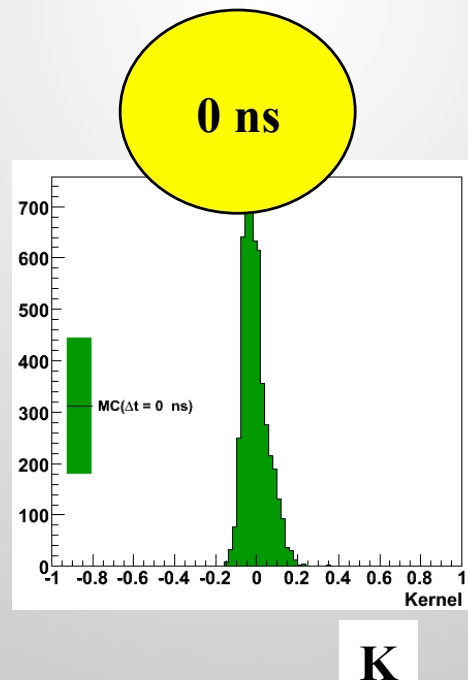
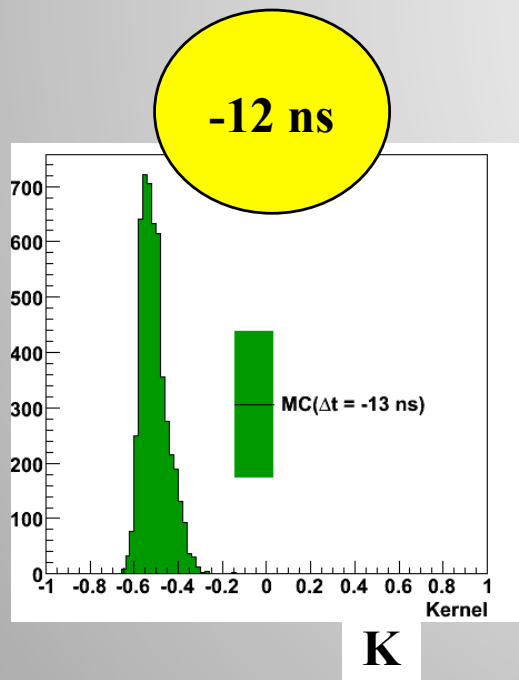
For safety reasons the ECAL was off.

Online variable



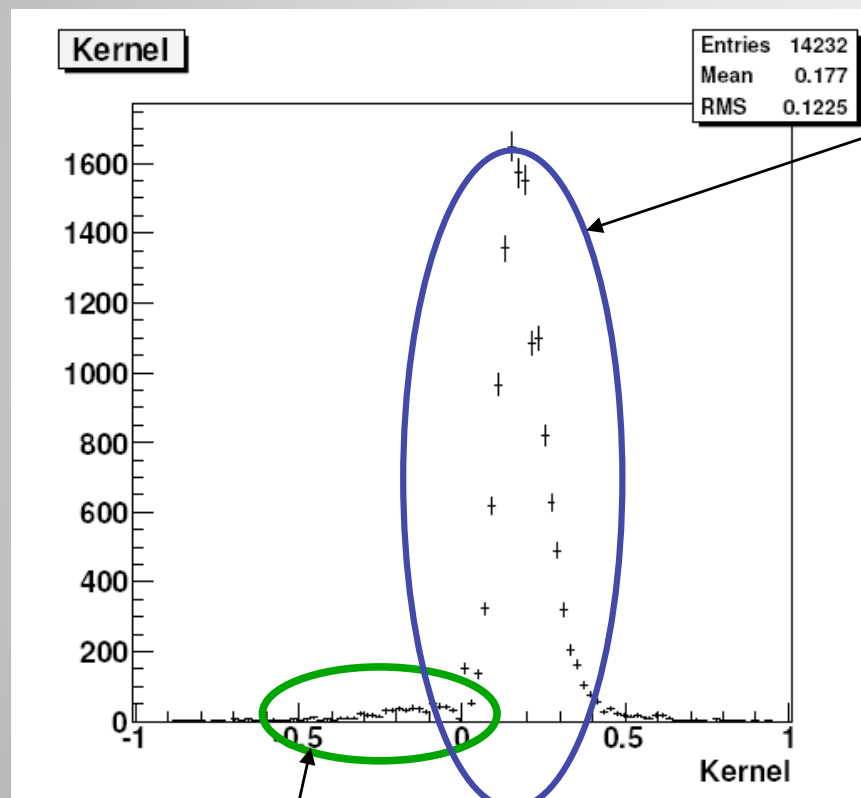
Kernel:

$$K_j = \frac{\text{sgn}(E_j(\text{Next1}) - E_j(\text{Prev1})) \times [E_j(\text{Prev1}) + E_j(\text{Next1})]}{[E_j(\text{Prev1}) + E_j(\text{Current}) + E_j(\text{Next1})]}$$



Time structure of the beam events

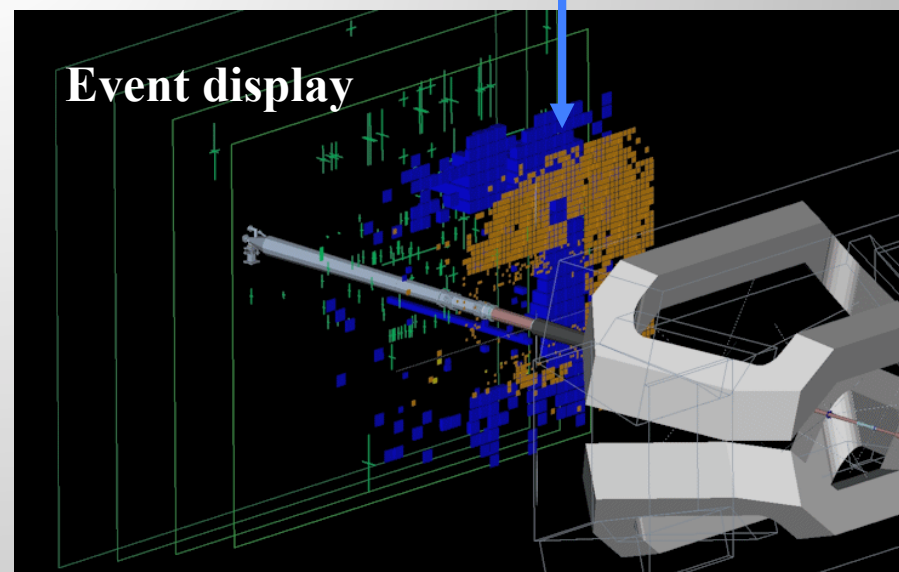
They are two categories of events:



Flat distribution of K

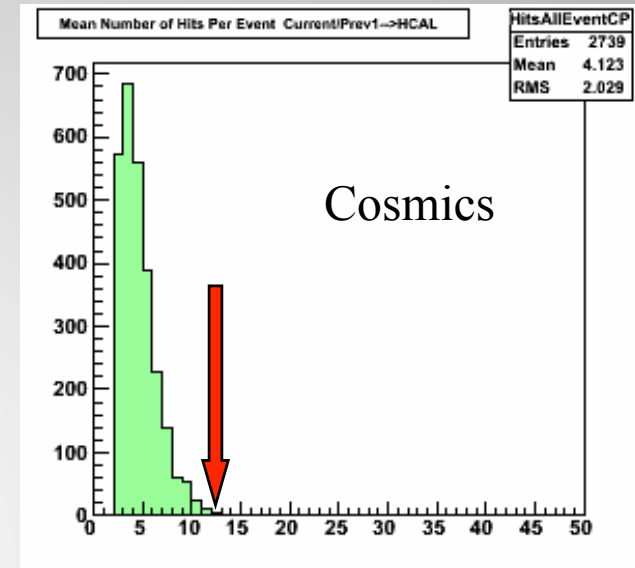
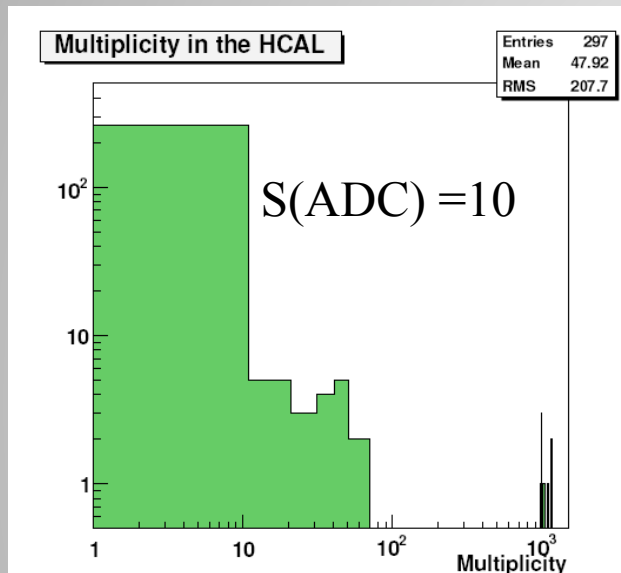
Synchronized events centered around
 $K = 0.1$.

HCAL
SPD

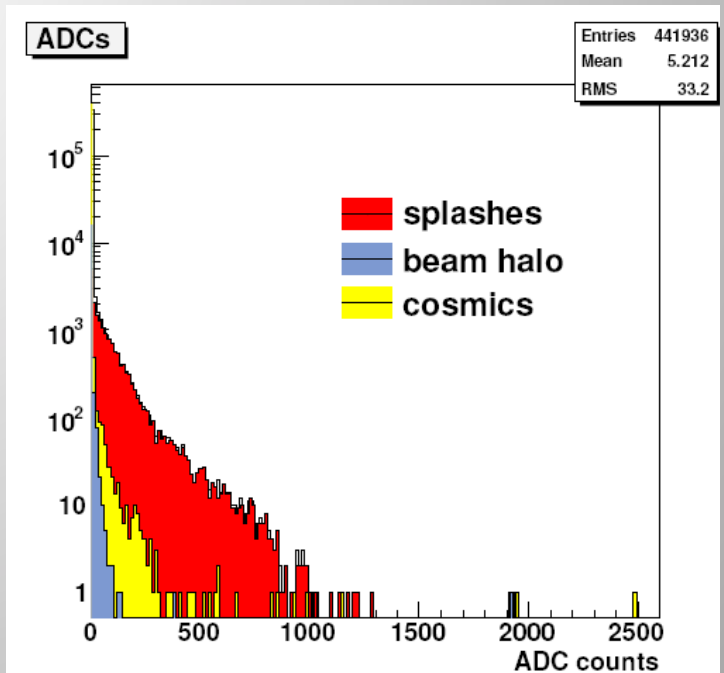


Event classification

We classify these events using their multiplicity.



Catégorie	Nb d'événements	Multiplicité moyenne M
$M > 100$	12	1044
$10 < M < 100$	20	34
$0 < M < 10$	265	3

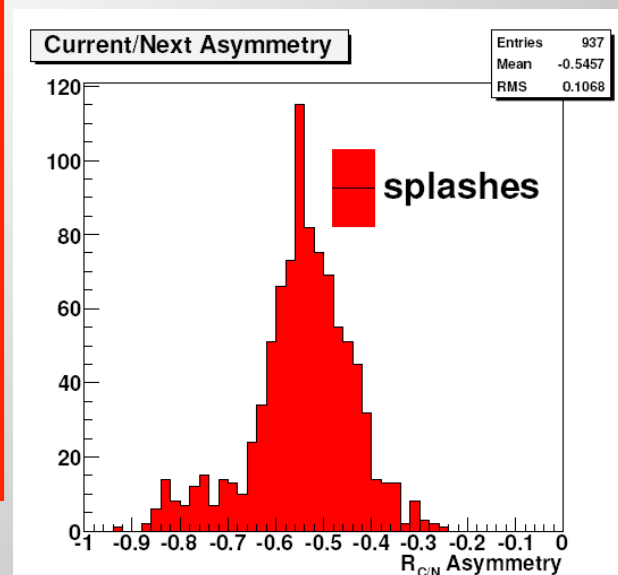
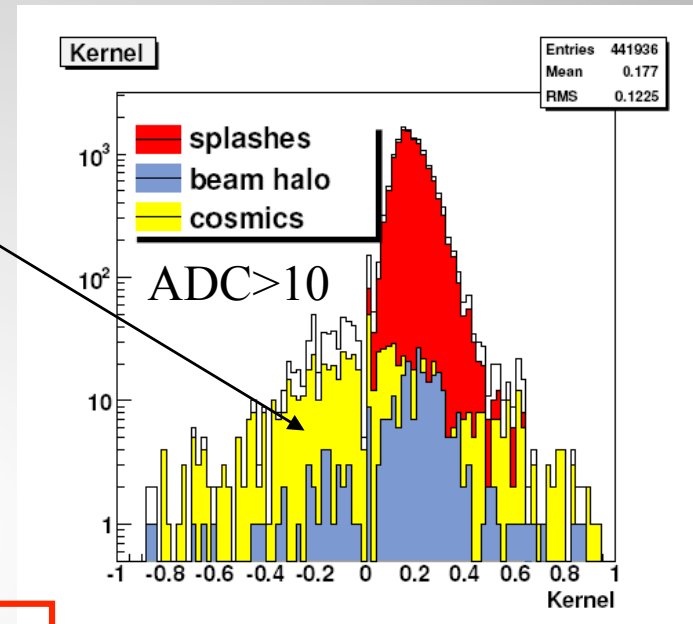


Event classification

Since they are not synchronized cosmons
Are uniformly distributed.

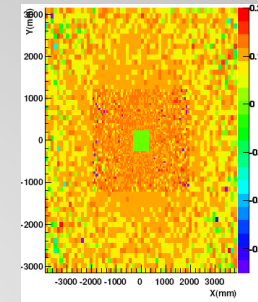
We remove all the beam halo events and 88 %
of cosmons.

For splashes the alignment with
The global LHC clock is
 $\text{rms} (R(C/N)) = 0.106 \rightarrow$
 $\Delta t = 0.8 \text{ ns.}$



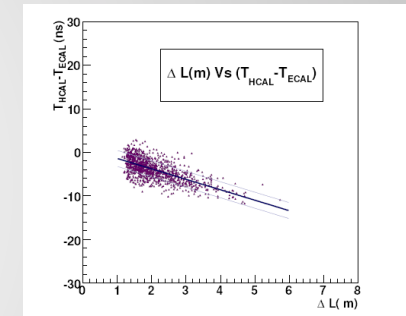
Conclusion for the time alignment

- We established a method to perform the time alignment:
 - We found the right conditions and the necessary amount of data (~ 10 min of beam)



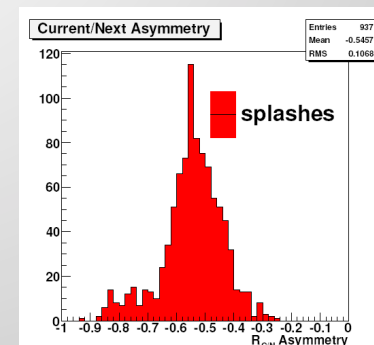
We applied this method to cosmic events.

- Internal time alignment : < 1 ns
- Relative time alignment between the ECAL and the HCAL ~ 2 ns

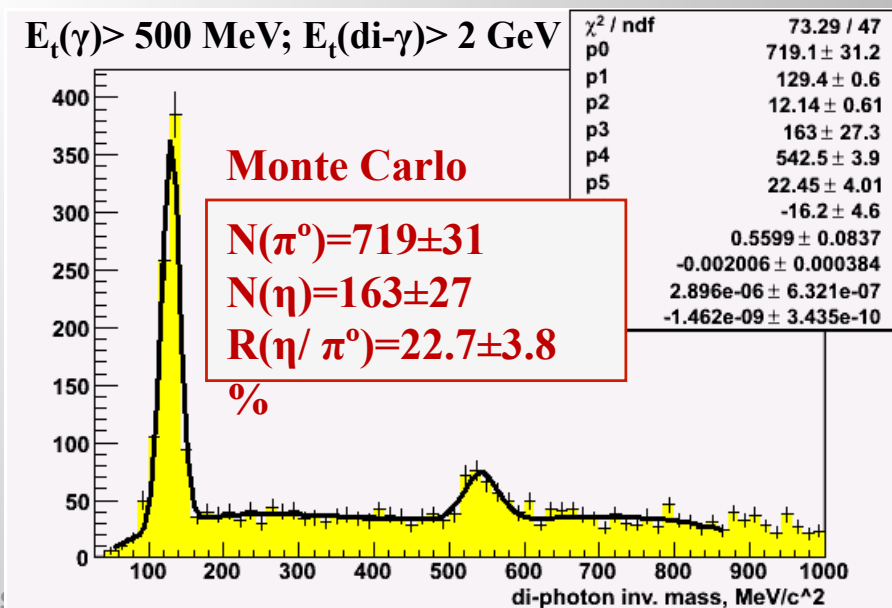
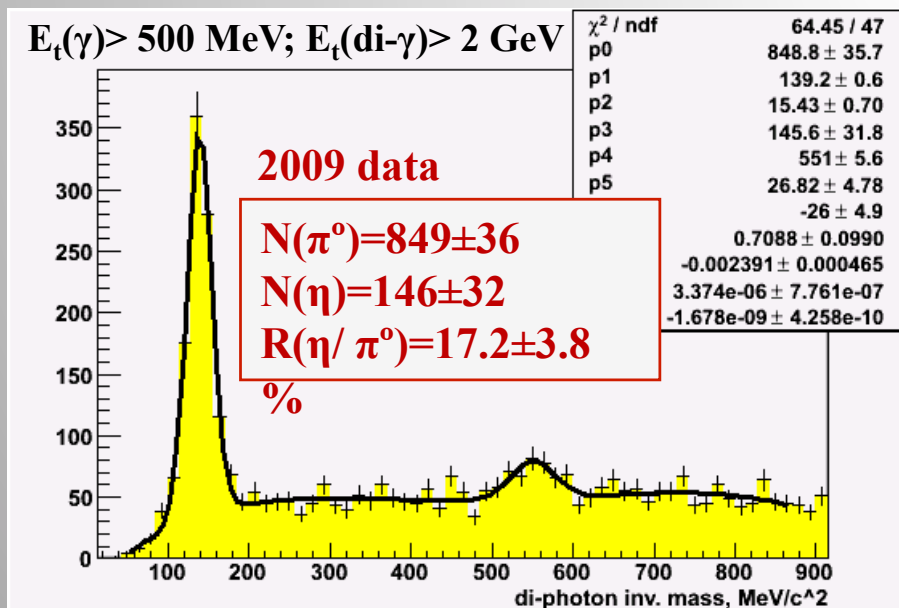
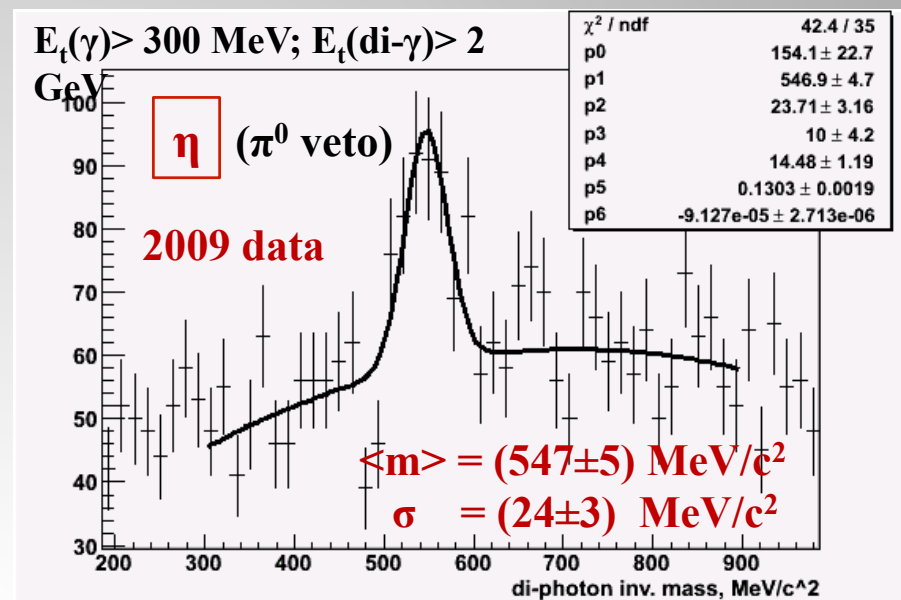
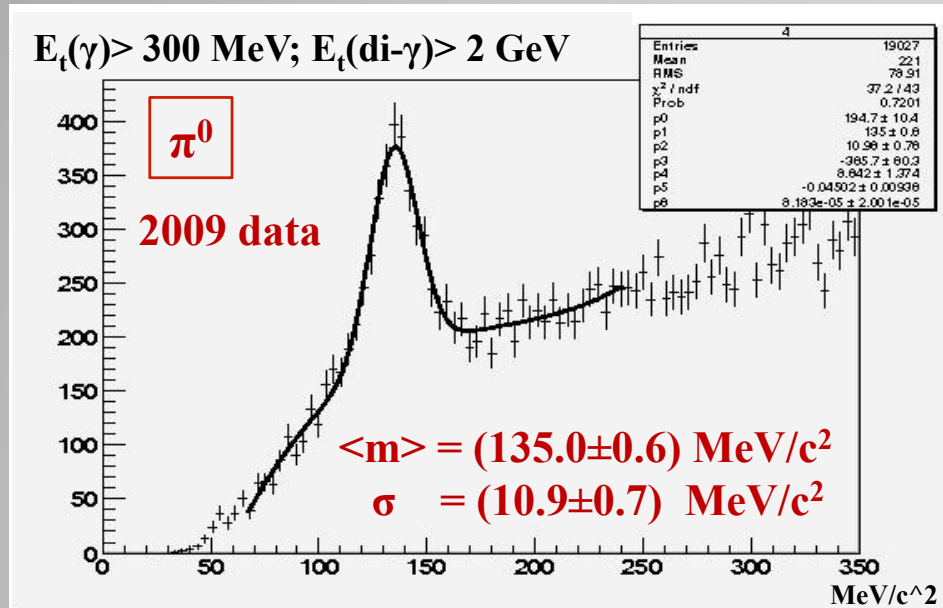


We used beam 1 events

- The alignment of the HCAL with the LHC clock is ~ 0.8 ns.



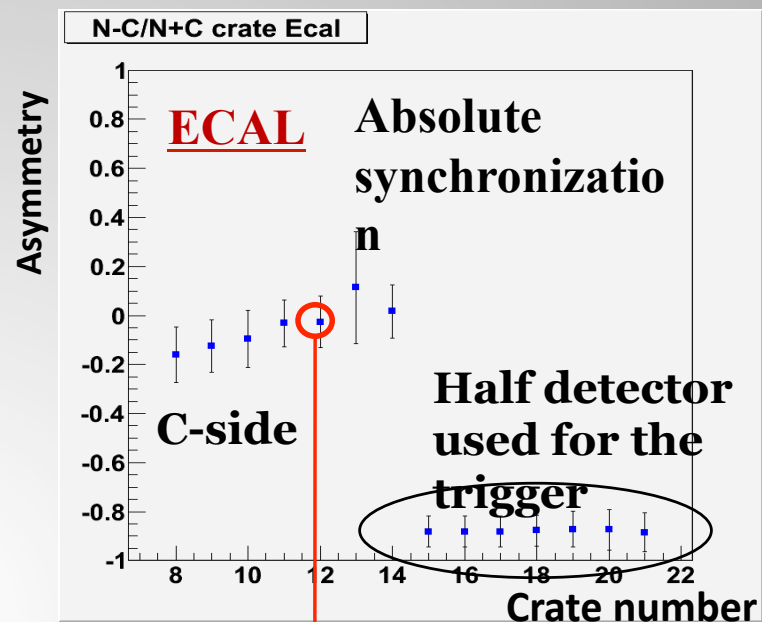
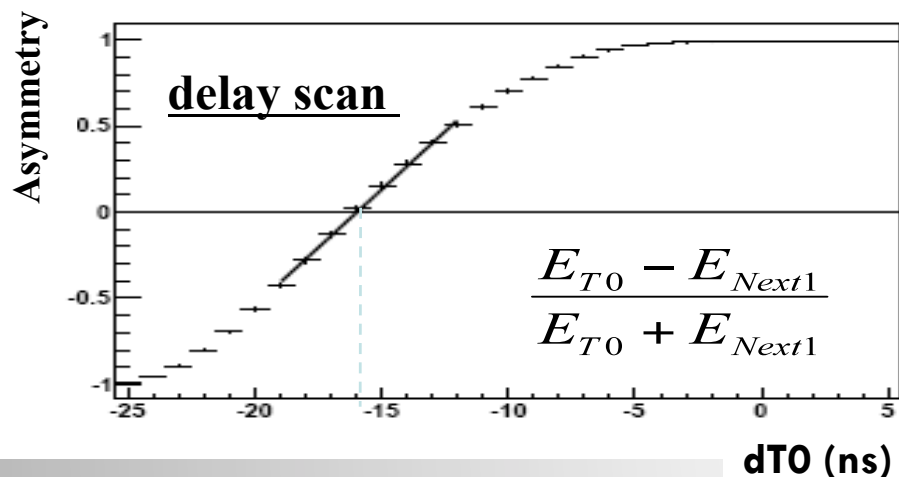
Plots shown at the LHCC



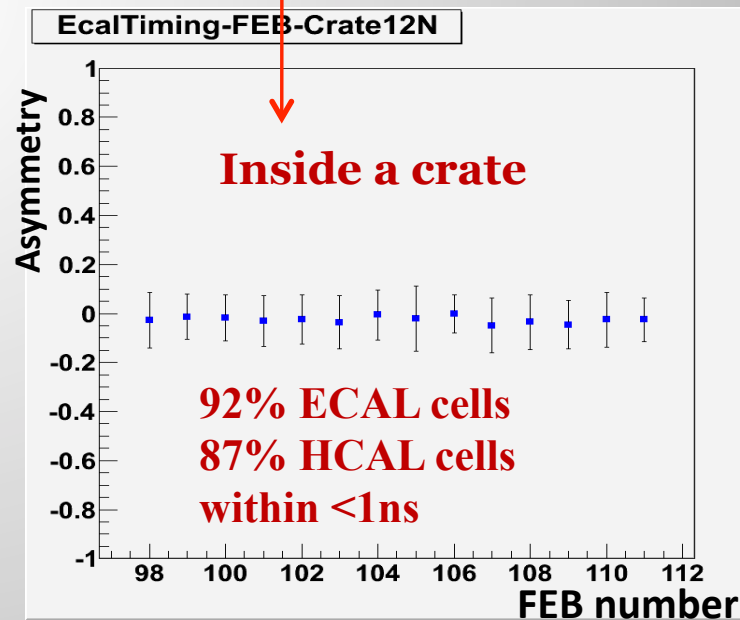
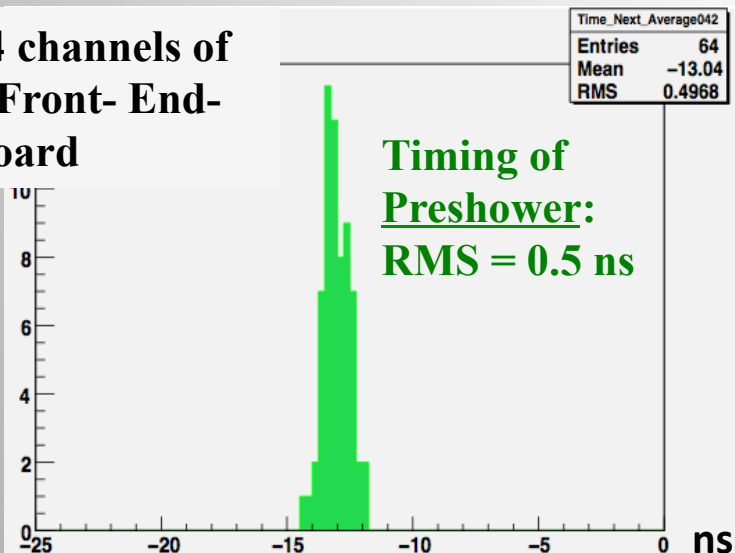
Plots shown at the LHCC

➤ 99.8 % of channels operational

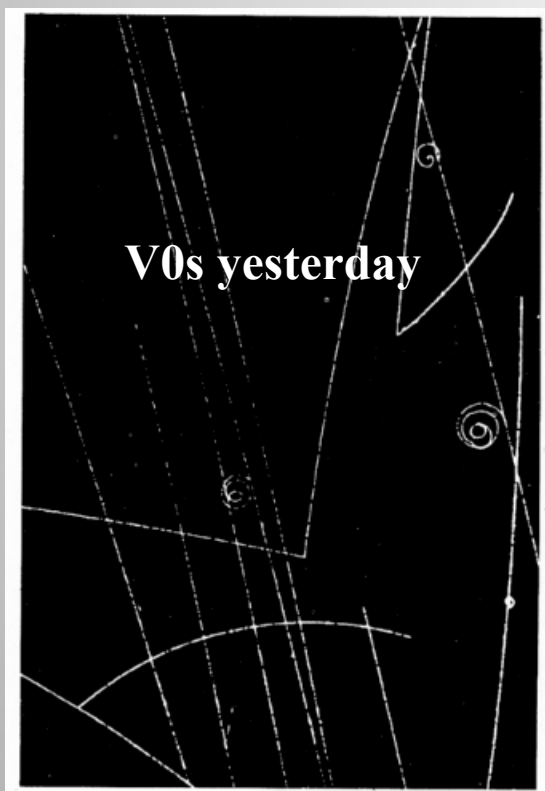
Use consecutive bunch crossings to compute asymmetries for absolute synchronization with LHC beam



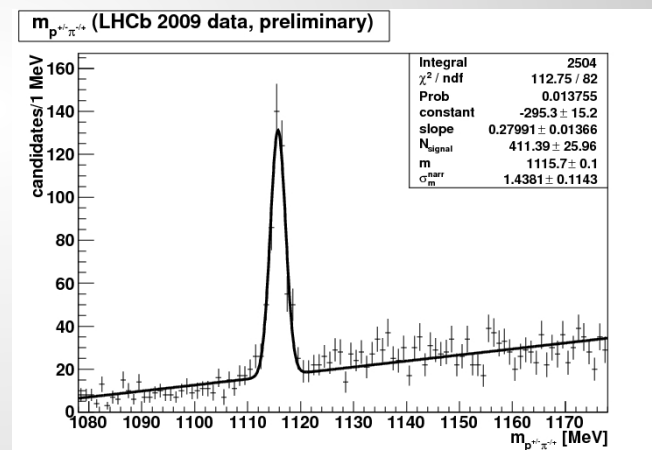
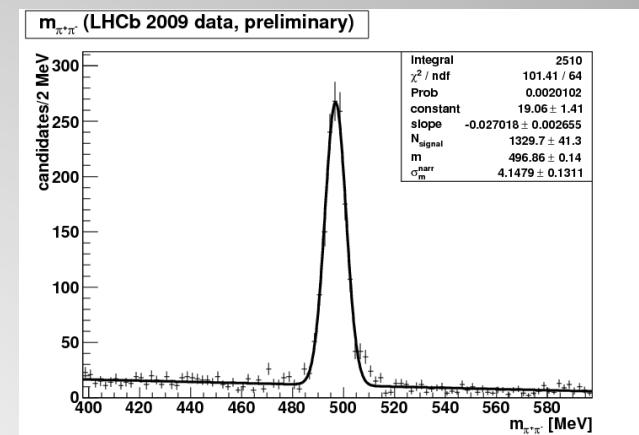
64 channels of a Front-End-Board



The hot topic with 2009 data: V0 analysis



Velo Open – No pid

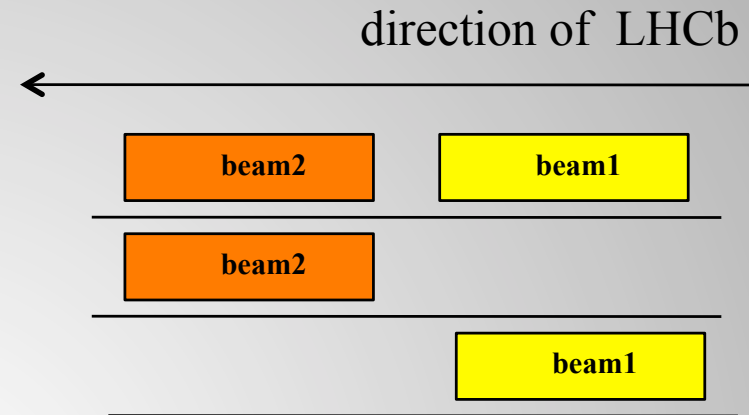


My contribution :

Measurement of the L0 Trigger efficiency.
Beam gas background subtraction.

Beam-gas subtraction

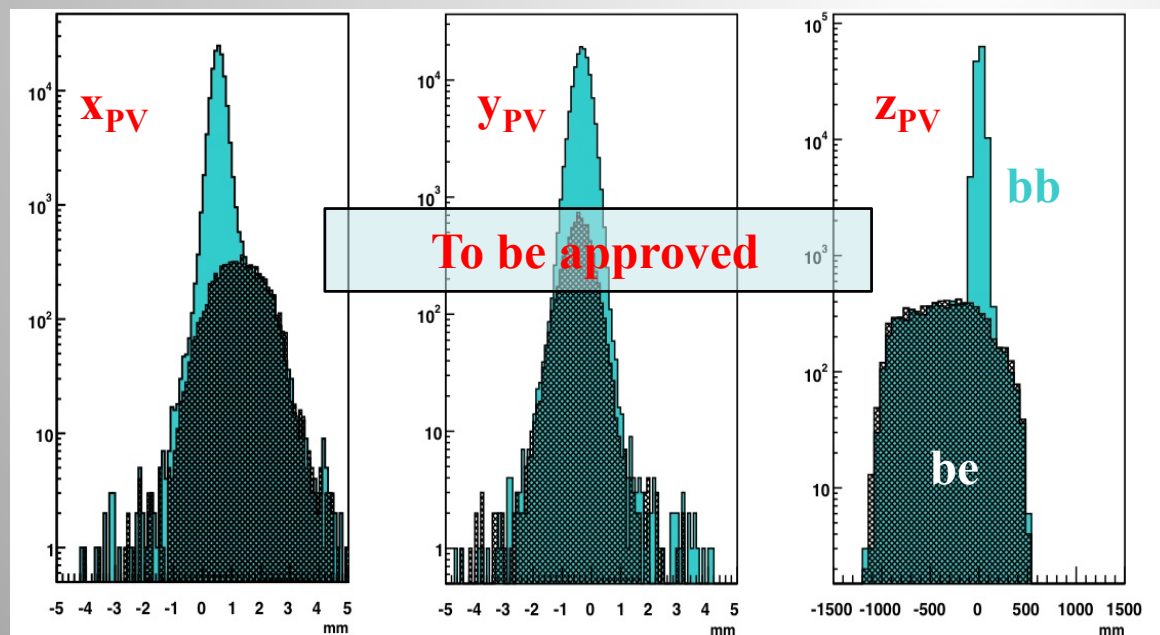
- Beam-gas subtraction:
 - Always apply any selection separately on bb and be events
 - Get number of selected beam-beam collisions as
- Use bunch IDs:
 - beam1-beam2 (bb) crossings:
 - contain bunch-bunch + beam-gas collisions
 - beam1-empty (be) crossings:
 - contain beam-gas collisions only
- Normalisation:
 - Expect $\beta = 1$ from naïve bunch counting
 - Need to determine correct value and uncertainty, taking into account differing (as well as run- and time-dependent) bunch currents



$$N_{\text{bunch-bunch collisions}} = N_{bb} - 1/\beta \times N_{be}$$

Beam-gas normalisation

- Extract normalisation factor β from number of PVs in region $z_{PV} < -200$ mm where only beam-gas collisions contribute
- Run-by-run variations observed
- **OK to use average β** obtained from whole sample as long as exact same sample is used in the V^0 analyses
- Extracted value of β **does not depend on selection**; use all reconstructed PVs (no V^0 requirement) to maximize statistics



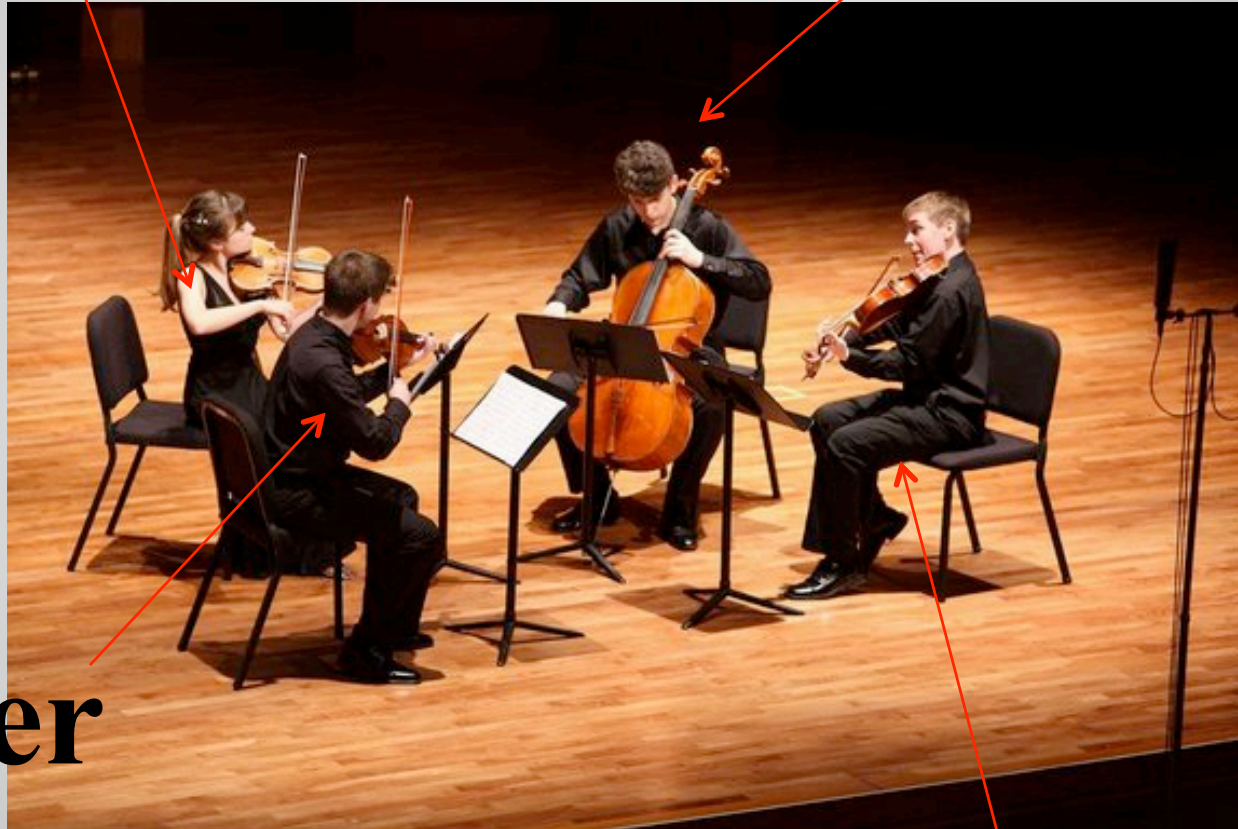
Run	beta
63949	0.89 +-0.04
63815	0.98 +-0.12
63814	0.98 +-0.20
63813	0.99 +-0.07
63809	1.28 +-0.12
63807	1.34 +-0.06
63801	1.21 +-0.06
63713	0.70 +-0.12
63691	0.94 +-0.23
63690	0.99 +-0.10
63688	1.00 +-0.25
63687	1.04 +-0.09
63686	1.05 +-0.08

$$\beta = 1.09 \pm 0.02$$

Conclusion

People

Detector



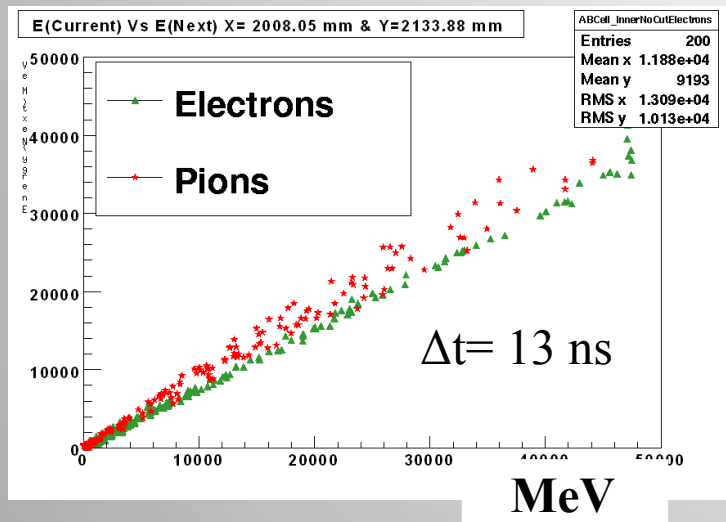
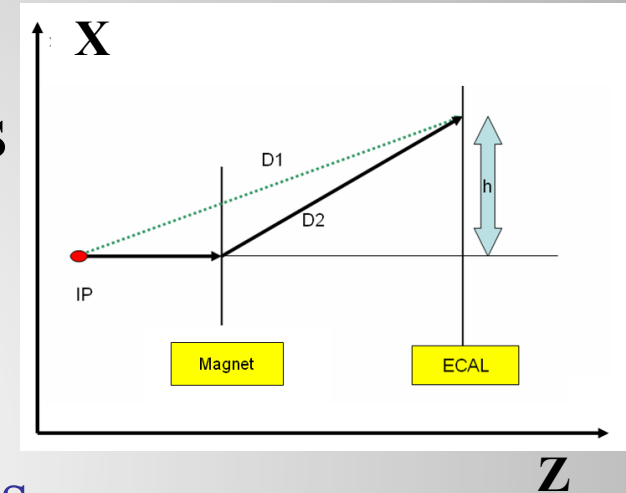
Trigger

If we imagine that HEP is a bit like music...
All the pieces are now together!

LHC

Identification des sources de mauvais alignement en temps dues à la nature des particules.

- Effet du champ magnétique:
pour protons $p > 5 \text{ GeV}$ effet $< 0.5 \text{ ns}$
- Différence entre les pions chargés et les électrons dans le ECAL: $\sim 0.5 \text{ ns}$



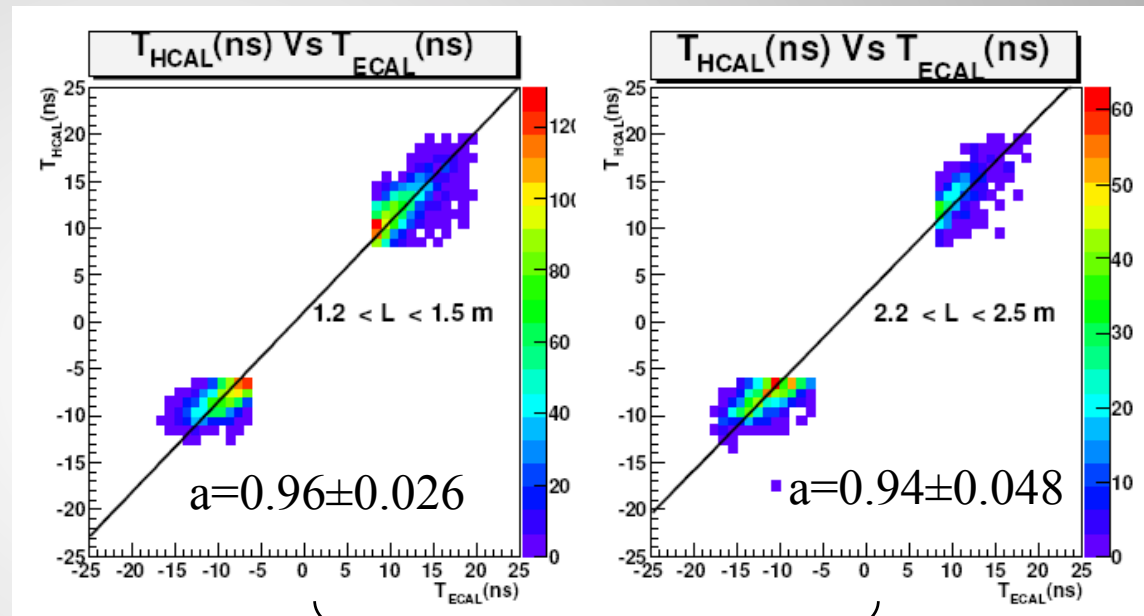
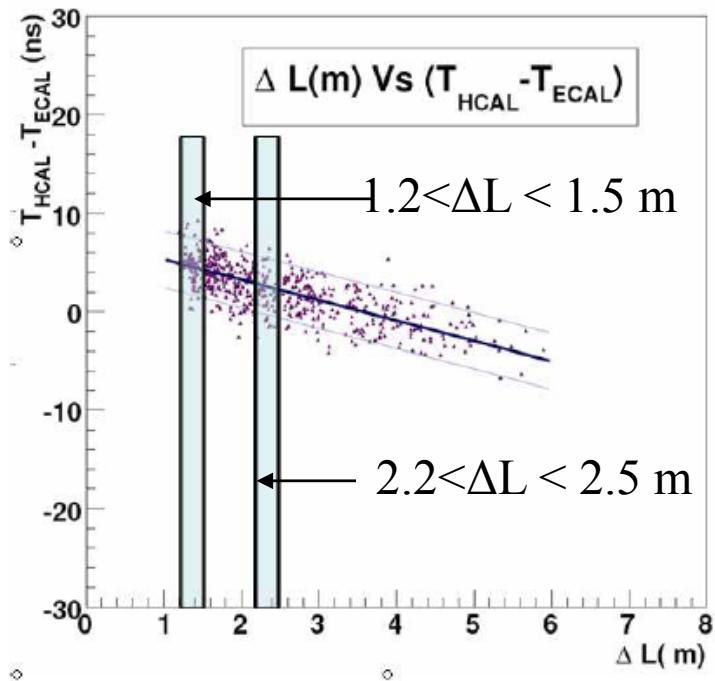
Les gerbes initiées par les pions chargés démarrent plus tard que les gerbes électromagnétiques ($\lambda_1 = 1.1 \text{ cm}$ dans le ECAL)

- Effet des particules de bas β : $\sim 1.5 \text{ ns}$

Utilisation des données cosmiques

Étude de la corrélation des événements cosmiques entre le ECAL et HCAL.

- Dans tous les runs analysés $SL < 3.3$ ns/m.
- On raffine la sélection des cosmiques:

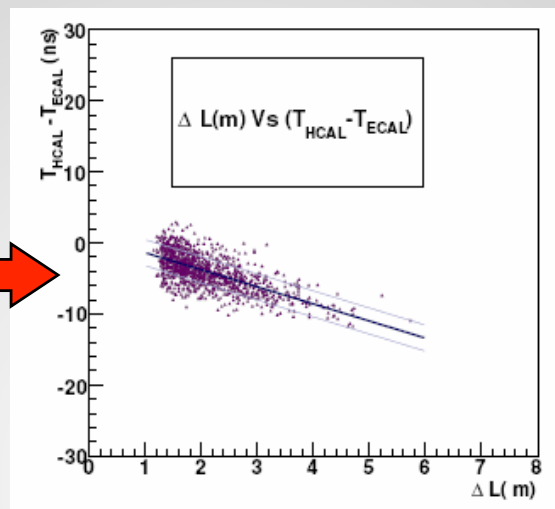
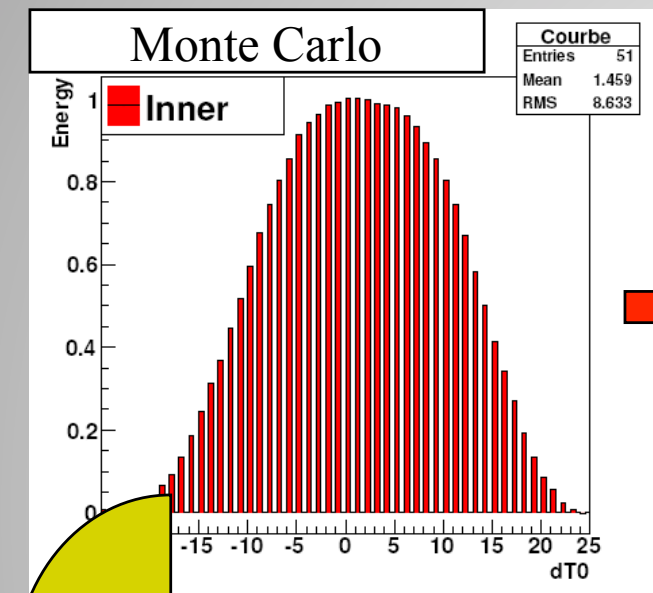


- On regarde la corrélation entre le temps ECAL et le temps HCAL dans deux tranches de ΔL .
- On demande pour le ECAL/HCAL Forward NN: $\Delta t > 8$ ns
- Forward PP: $\Delta t < -6$ ns

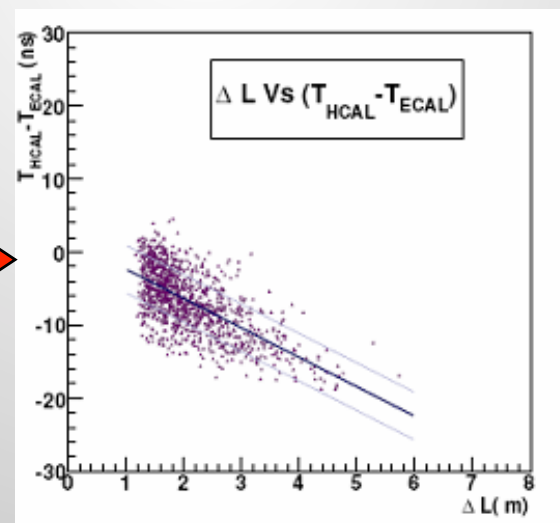
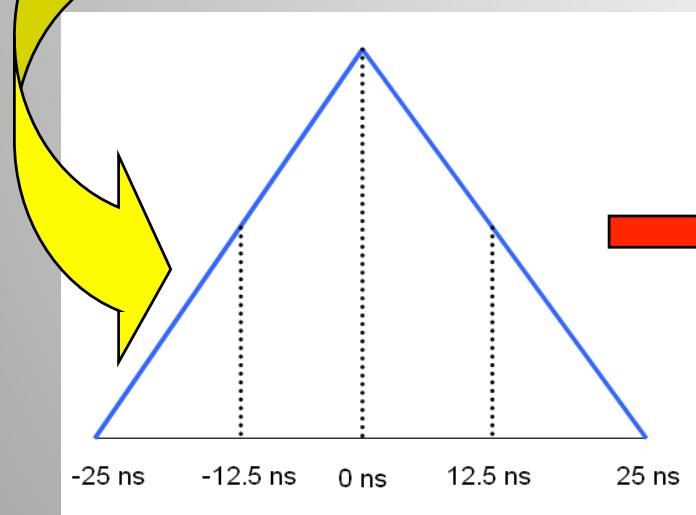
La combinaison des deux cas nous
Donne $SL = 1.94$ ns/m < 3.3 ns/m

Le biais observé dans la mesure de SL
N'est pas entièrement due aux critères de sélection.

Étude de l'impact de la forme du signal



$$SL = (-2.44 \text{ ns} \pm 0.38 \text{ ns}) \text{ ns/m}$$



$$SL = (-4.02 \text{ ns} \pm 0.37 \text{ ns}) \text{ ns/m}$$

Remarques:

-SL est très sensible
À la forme du signal.

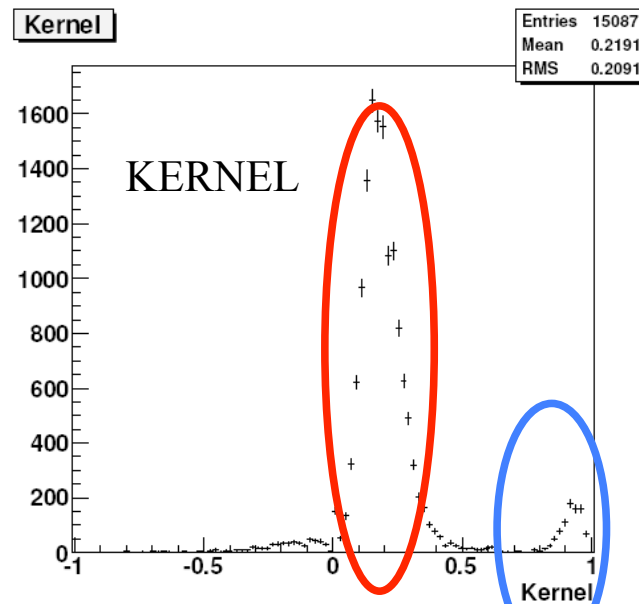
-Ceci peut être
en partie
à l'origine du biais
observé.

-Il est nécessaire de
mesurer cette courbe
sur les données
faisceau.

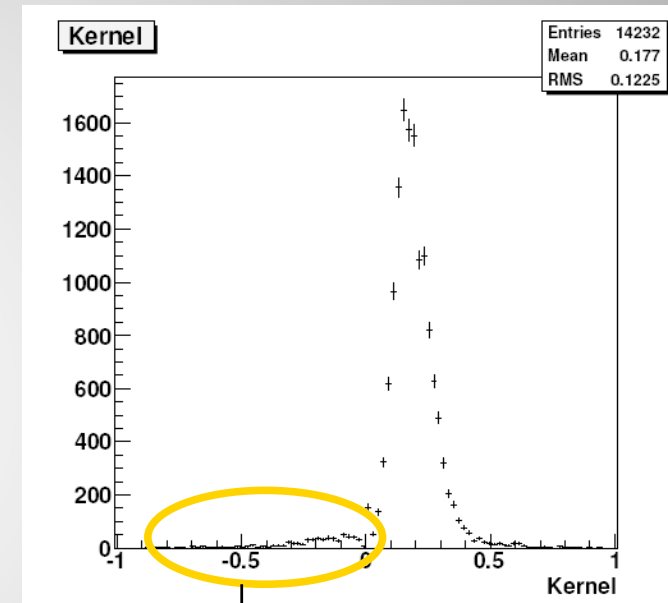
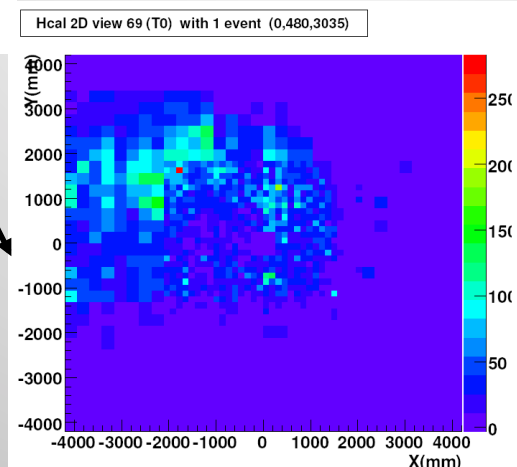
Utilisation des données faisceau

Structure en temps des événements des données faisceau

On remarque l'existence de deux populations d'événements

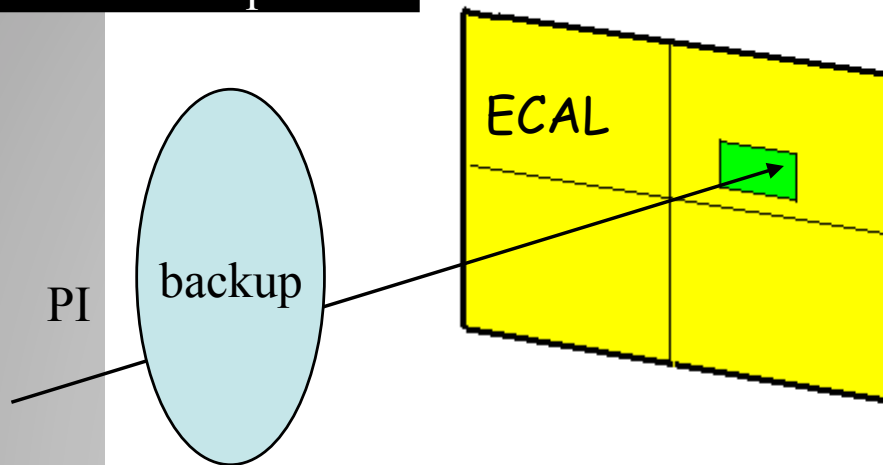


La seconde population appartient à un événement asynchrone de haute multiplicité. Que l'on retire dans la suite.



On voit une population clairement centrée autour de $K = 0.1$ Et troisième population Avec K allant jusqu'à -0.5

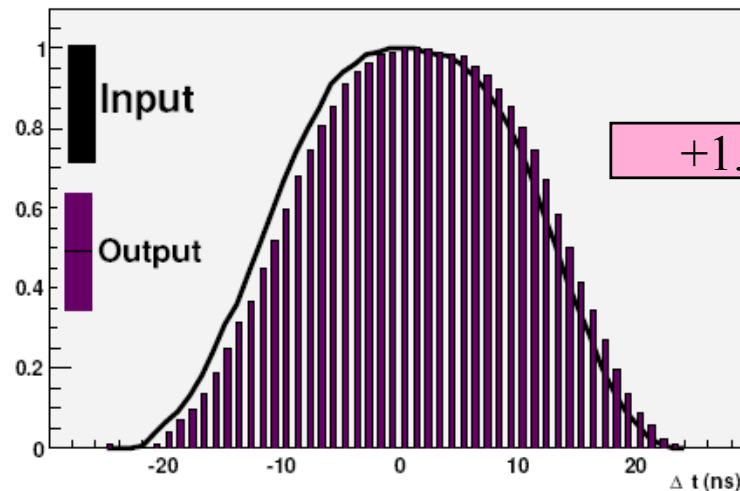
Procédure d'alignement en temps



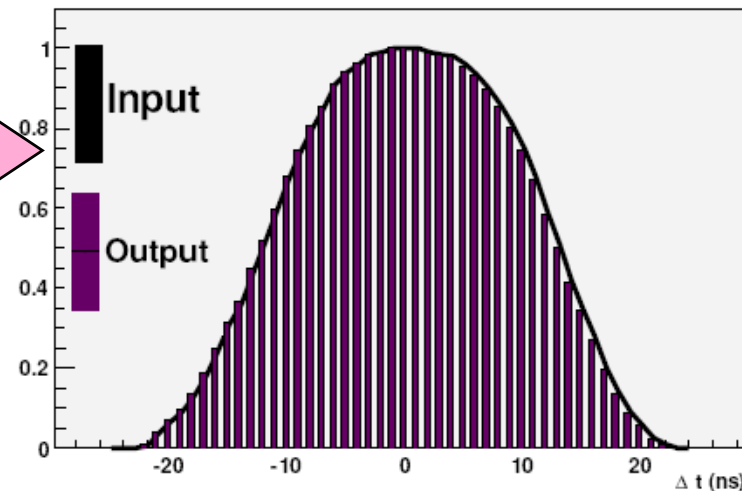
Vérification de la prise en compte du temps dans la simulation

- On génère des événements ParticuleGun dans le ECAL:
Electrons de 100 GeV de moment.
Venant du point d'interaction (0,0,0)
- On fait varier Δt de -25 ns à +25 ns par pas de 1 ns.

Integrated signal of a cell of the inner ECAL



Integrated signal of a cell of the inner ECAL



On observe un décalage de 1 ns entre la distribution utilisée à l'entrée de la simulation et celle obtenue à la sortie de la digitisation.
Ceci est dû à la définition du temps zéro dans la simulation.

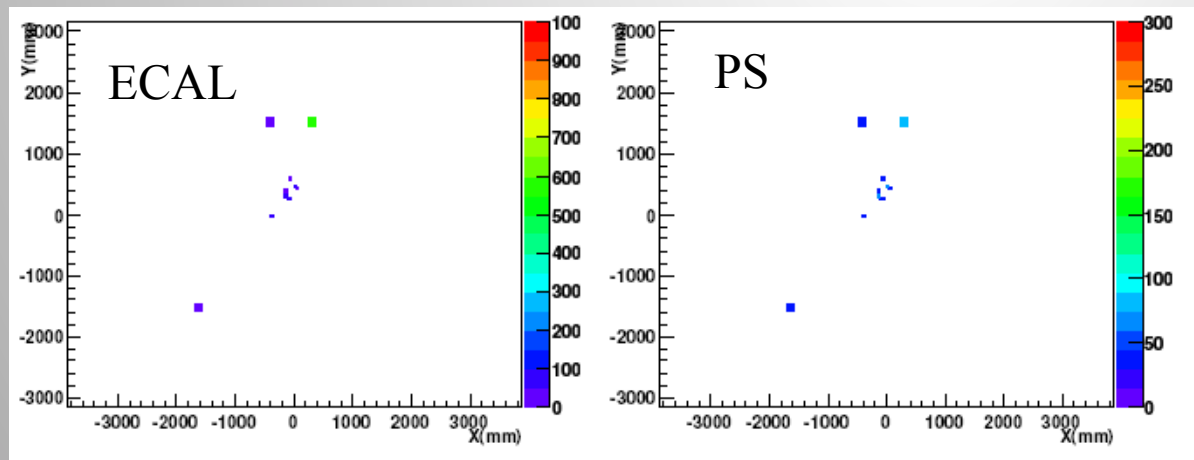
Comment mesurer la forme du signal intégré sur les données.

Problématique:

- La forme du signal intégré utilisée dans la simulation a été obtenue grâce à des tests en faisceau.
- In situ* cette forme aurait pu varier.
- Nous devons trouver un moyen de la mesurer sur les données.

Méthode:

- Il est nécessaire de balayer le signal intégré dans le ECAL avec un pas de 1 ns.
- On utilise les dépôts dans le PreShower pour sélectionner les cellules dans le ECAL

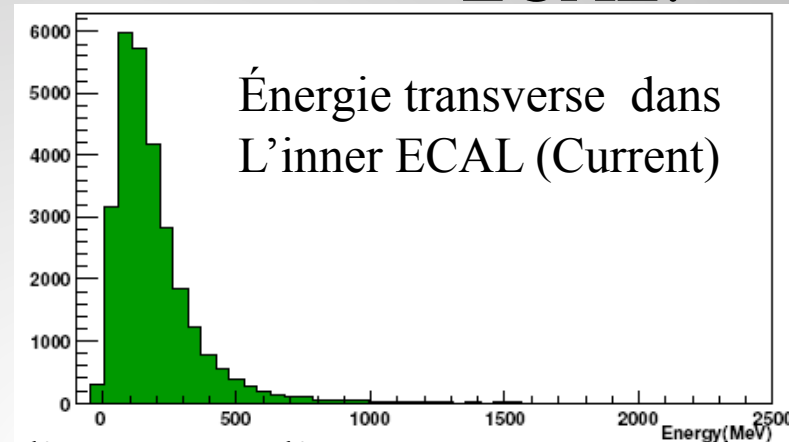
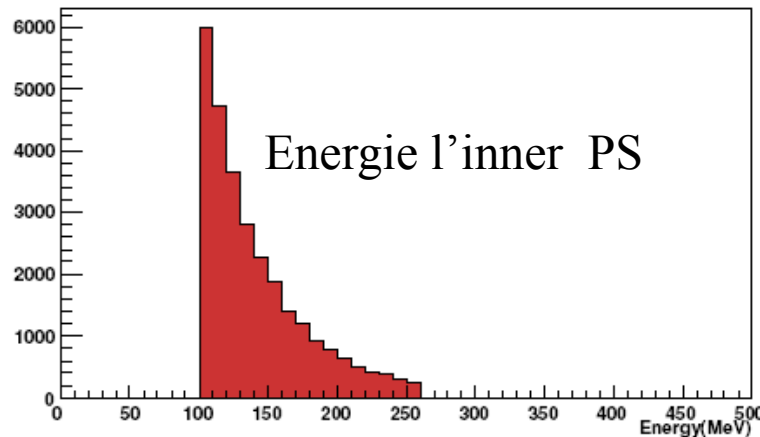


On génère 50 k d'événements
Minimum bias sans champ
Magnétique à 5 TeV pour
 $\Delta t = 0, 2, 5, 13, 15$ et 18 ns

Event display d'un événement minimum bias.

Procédure d'alignement en temps

Données générées avec
 $\Delta t = 12 \text{ ns}$ dans le
ECAL.



Les coupures sur les cellules du PS varient d'une zone à l'autre pour respecter la variation de la multiplicité d'une zone à l'autre.

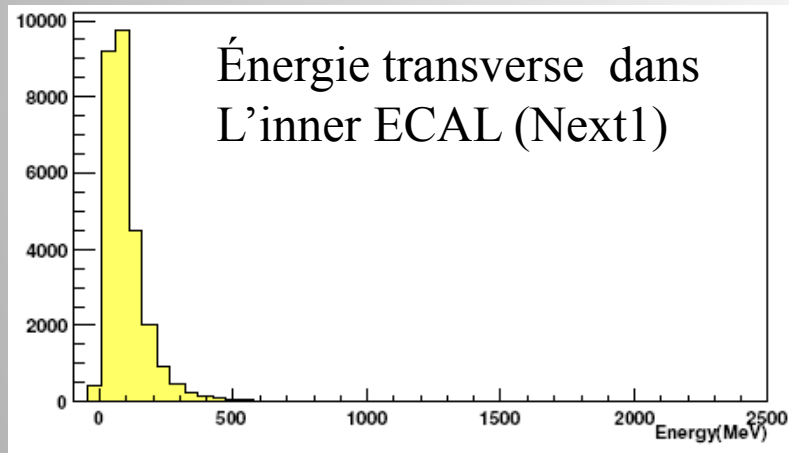
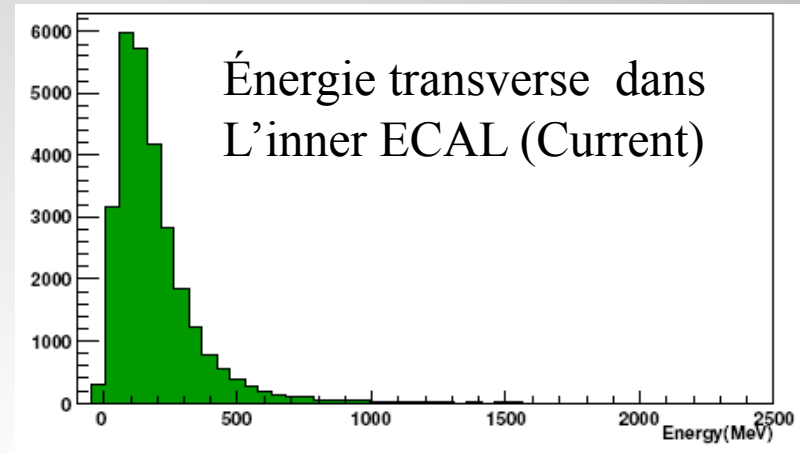
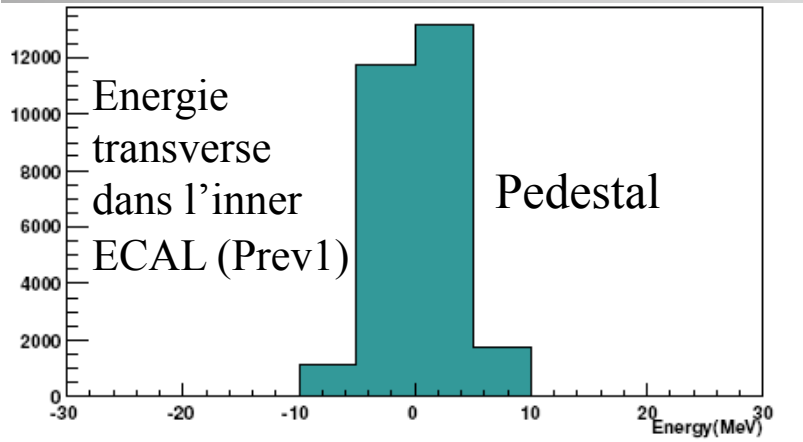
On optimise la coupure appliquée sur les cellules du PreShower dans chaque zone pour avoir une précision meilleure qu'1% sur l'estimation de l'énergie transverse dans le ECAL. On obtient le jeu de coupures sur le PreShower et la précision sur le ECAL suivante:

Inner 100 MeV avec 0.51% de précision .
Middle 50 MeV avec 0.68% de précision
Outer 45 MeV avec 0.57% de précision.

En utilisant 50 k d'événements
minimum biais

Procédure d'alignement en temps

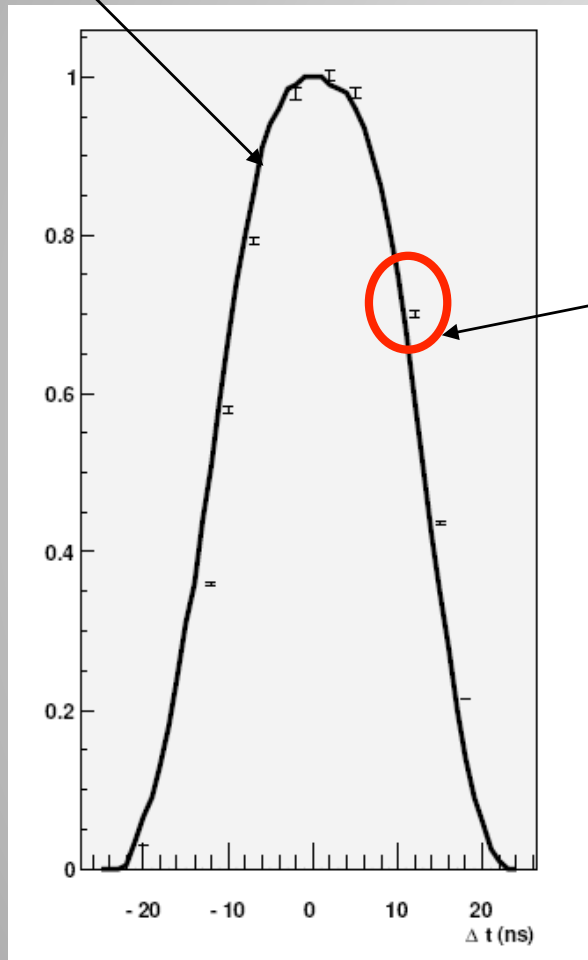
Données générées avec Δt
= 12 ns dans le ECAL.



- Nous introduisons un décalage de 12 ns
La fraction d'énergie « perdue » dans
l'échantillon central se retrouve dans
l'échantillon Next1.
- Comme nous l'attendions seul le pedestal contribue
dans l'échantillon Prev.

Procédure d'alignement en temps

Courbe obtenue avec
des événements ParticleGun



$\Delta t = 12$ ns.

Comment retrouve-t-on la forme du signal intégré

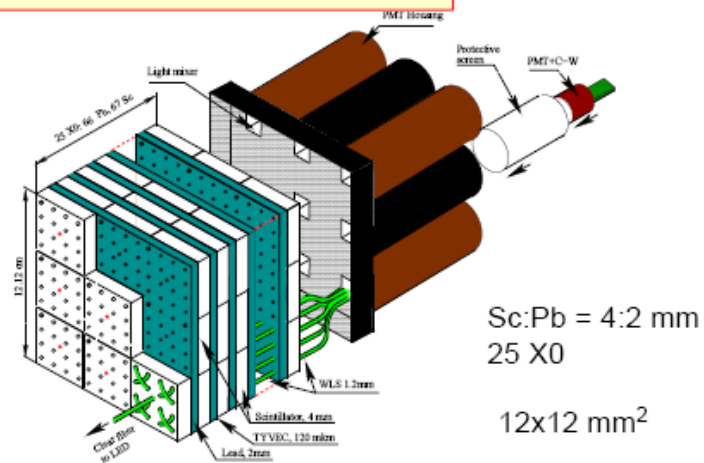
Pour chaque **point** du balayage on calcule le rapport de l'énergie transverse moyenne dans l'échantillon central pour des données générées avec un certain décalage Δt par rapport à l'énergie transverse moyenne pour $\Delta t = 0$ ns.

Pour tous les points mesurés nous avons une précision inférieure à 1 %.

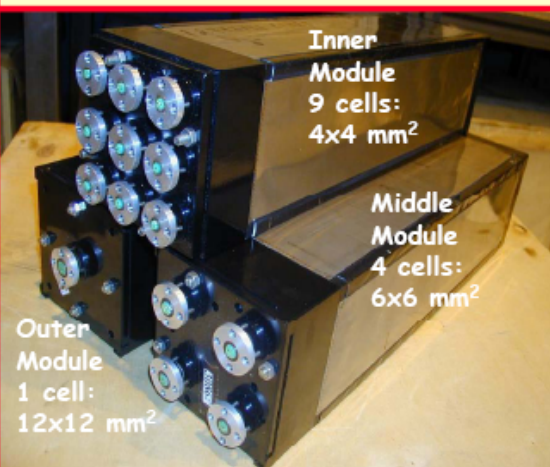
On peut donc retrouver le forme en utilisant $\sim 50k$ de données minimum biais par point.

En supposant que nous enregistrerions les événements à 100 Hz, nous aurions besoin ~ 10 minutes par point.

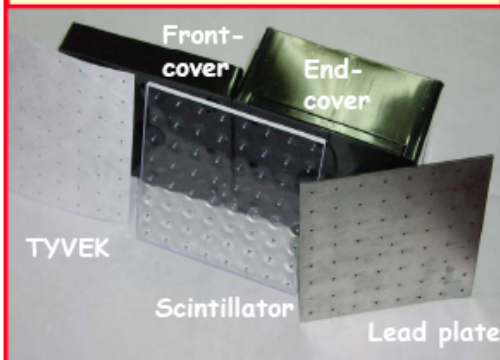
ECAL Shashlik modules



3312 shashlik modules with 25 X0 Pb



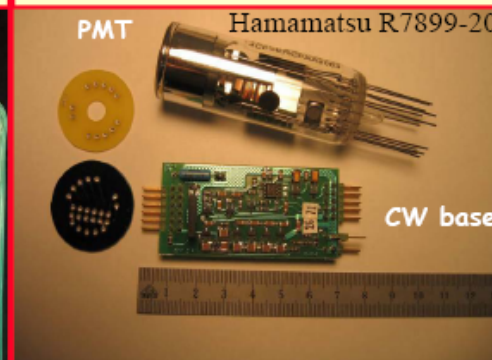
Scintillators, lead-plates, covers



Fibres with loops



PMT and CW base

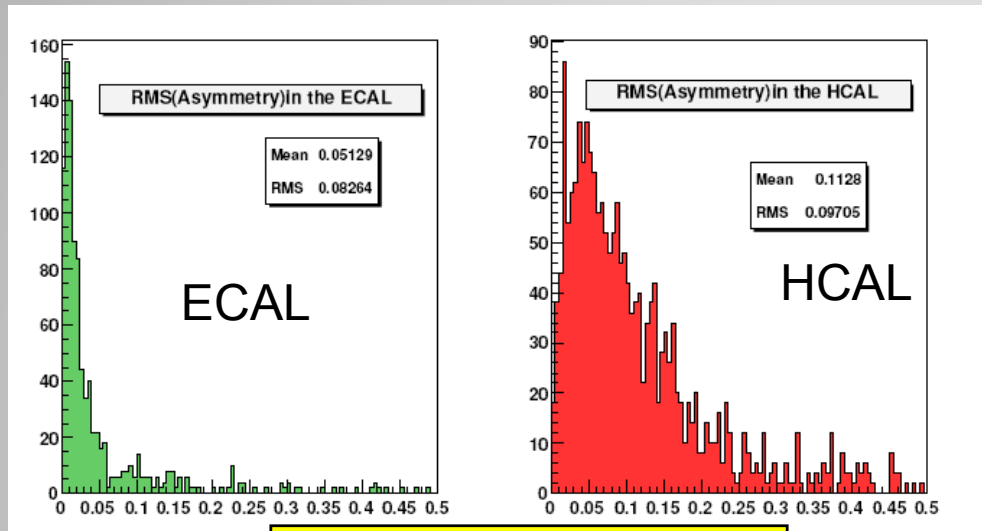


ECAL

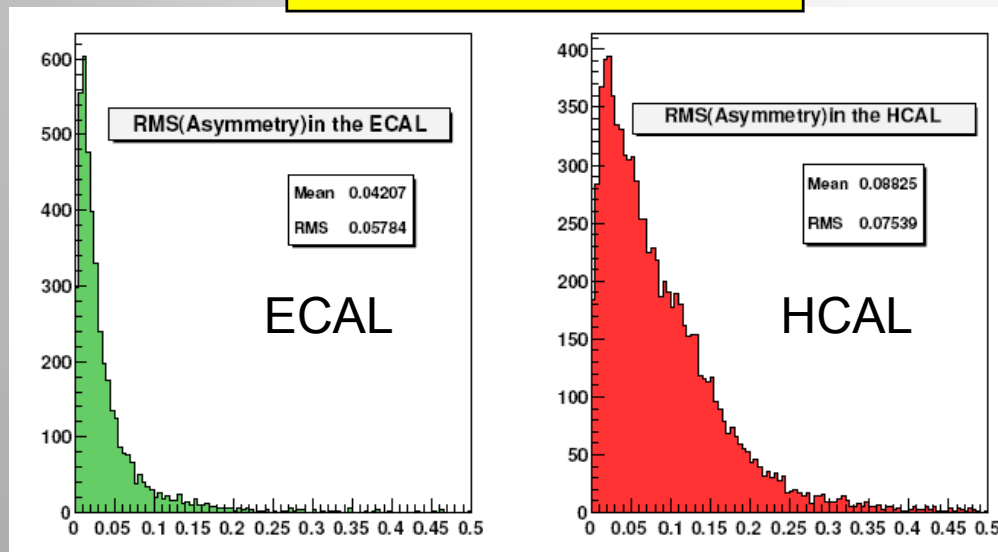
Radiation Max 250 krad/year

ECAL/ HCAL internal time alignment

Before correction



After correction



Evaluated using the dispersion of the asymmetries within one cluster.

HV corrections:

$$\Delta t \propto \sqrt{HV}$$

Before corrections

ECAL 0.34 ns

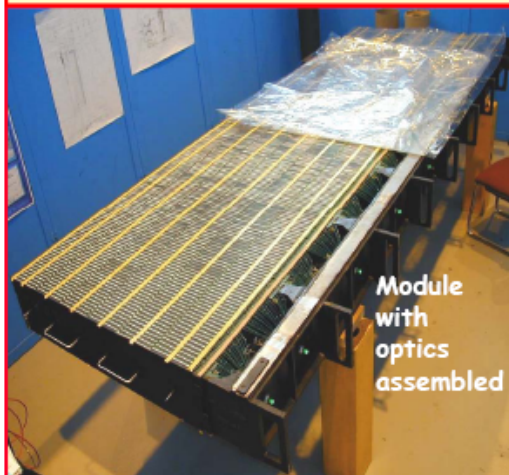
HCAL 0.75 ns

After corrections:

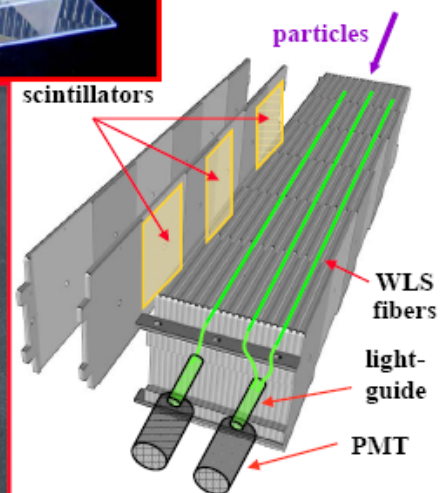
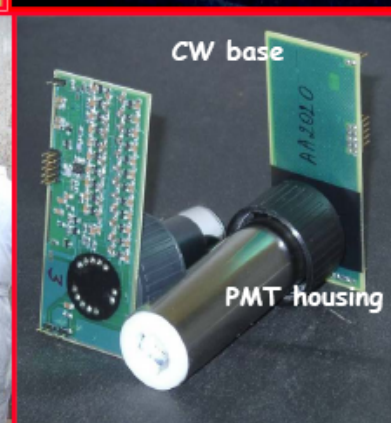
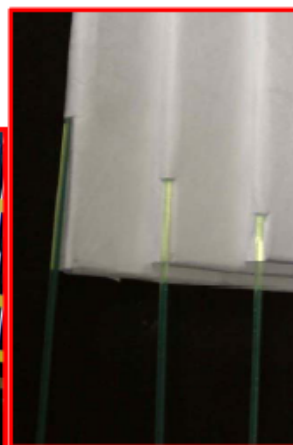
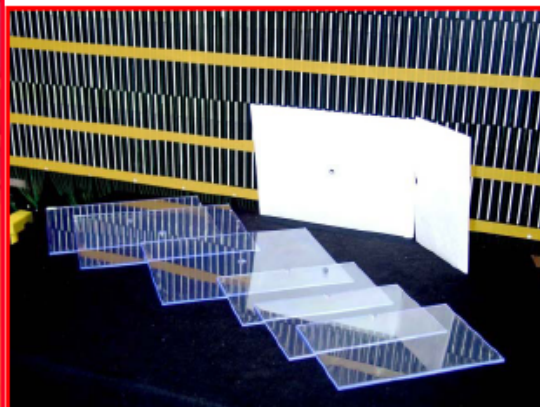
ECAL : 0.28 ns

HCAL : 0.58 ns

52 modules with longitudinal tiles



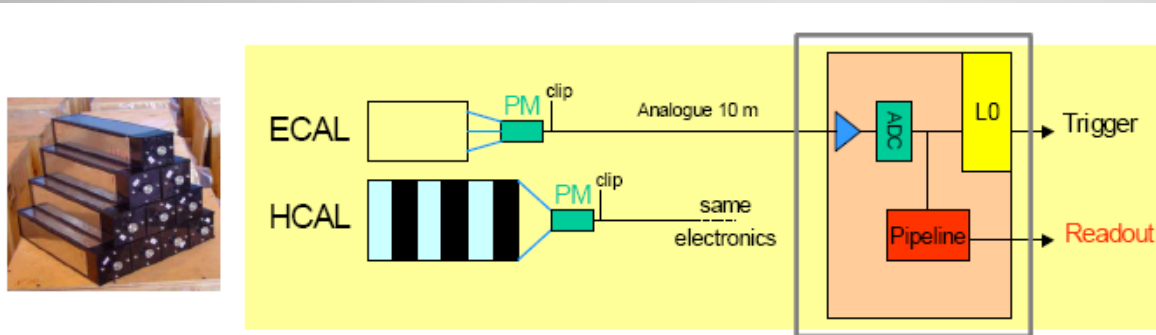
HCAL tile-cal modules



HCAL

Radiation Max 50 krad/year

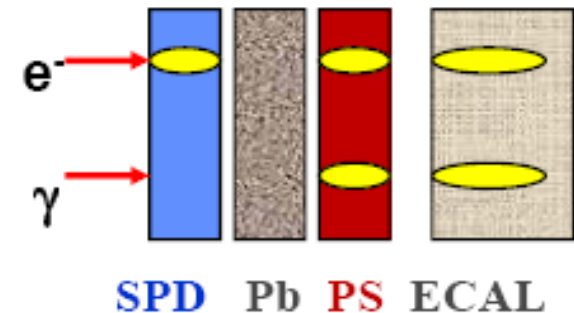
Électronique ECAL/HCAL



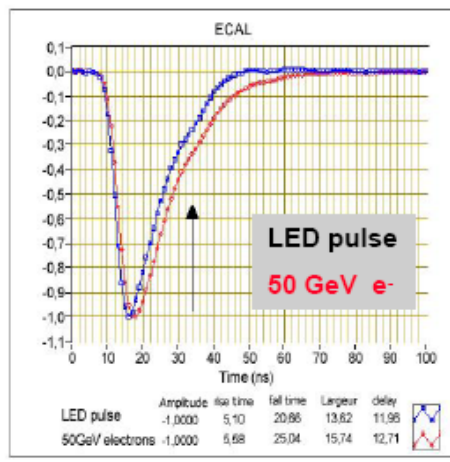
- Shaper integrateur + 12-bit (80 pC) 40 MHz ADC + delay chip
- Suppression du pedestal pour le bruit de basse fréquence.
- Selection des clusters pour le L0
- donnés envoyées à la DAQ

SPS/PS

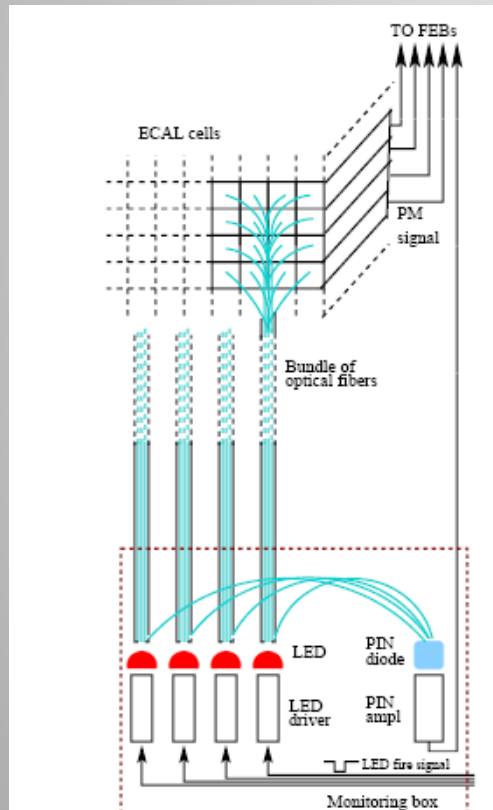
- 2 couches de scintillateurs espacées par $2.5 X_0$ de plomb
- PS: séparation électron/pion.
 - ADC 10-bit
 - Bruit < 1.2 coups ADC avec 10 ADC/Mip
- SPD photon/mip séparation
 - Digital read-out.
 - Buit < 3 mV pour 100 mV/MIP
- Radiation Max 150 krad/an



LED



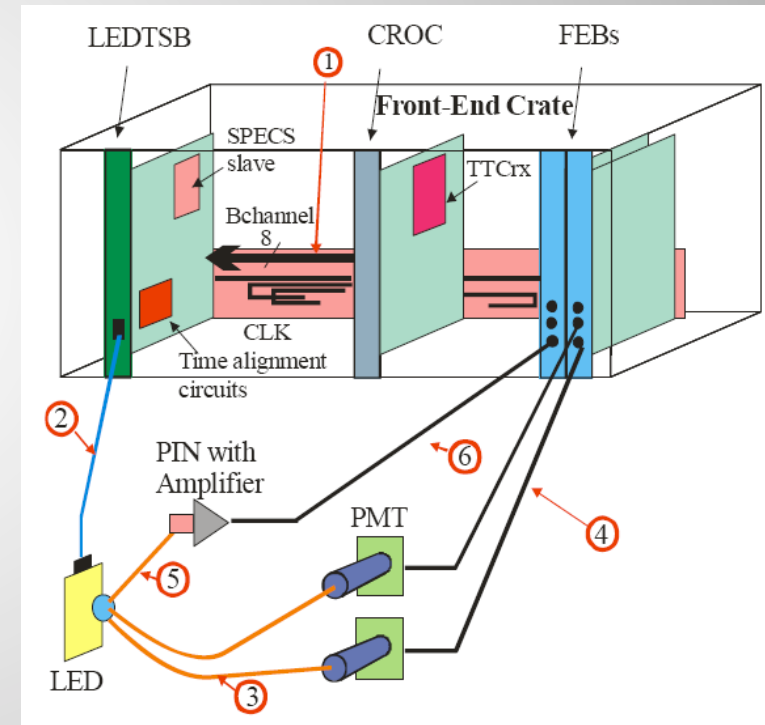
- Control de l'alignement en temps
- Utilisation des bunchs vides pour tourner le system de monitoring.
- Control du gain meilleur que 1 %
- rate des pulse et la lumière ajustable.
- pulse court et peu de dispersion.
- »emulate « les particules dans toute la Gamme dynamique.



Alignement préalable grâce aux LEDs

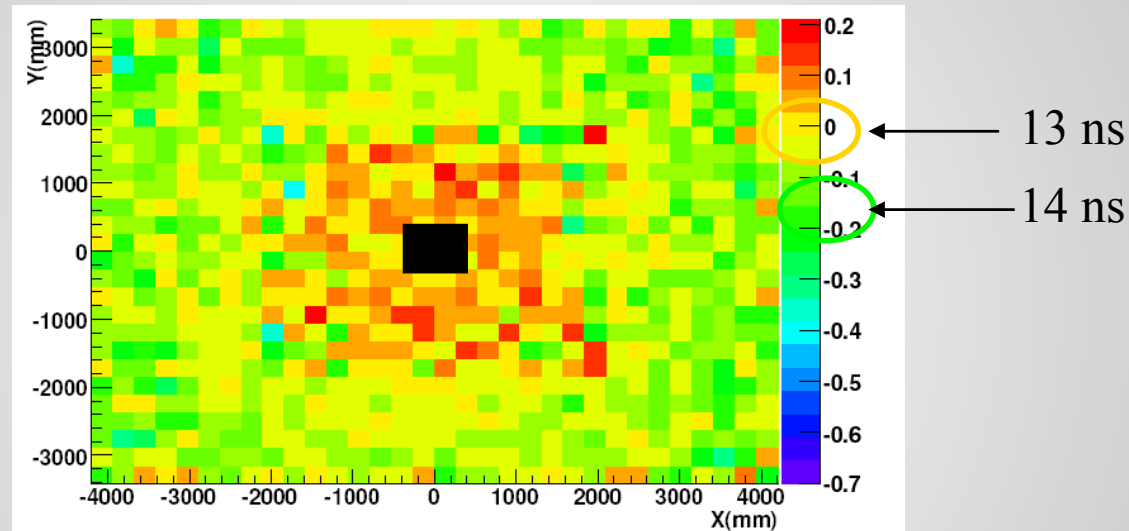
Utilisation des LED:

- Le chemin de l'électronique est le même que pour les signaux du ECAL/HCAL.
- La forme du signal des LED est très similaire.
- Les LED éclairent des groupes de PMs au même moment avec la même intensités.
- On peut mesurer les variations l'énergie mesurée d'un PM à l'autre
- On peut obtenir $\Delta t \sim 5$ ns pour le ECAL et $\Delta t \sim 2$ ns pour le HCAL.



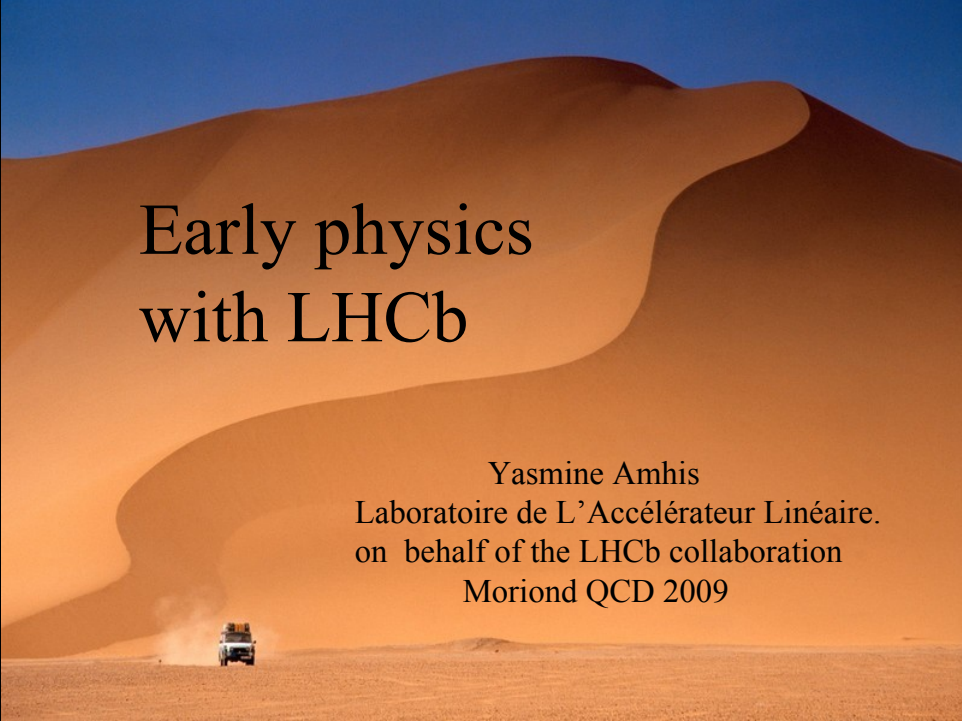
Alignement en temps dans le HCAL

- La méthode de l'asymétrie est appliquée au HCAL et est testée sur 50 000 événements minimum biais.



- Cellules alignées à mieux que 0.5 ns sans itération:
 - 99% dans la zone Inner.
 - 93% dans la zone Outer.
- Les cellules du HCAL sont plus grandes → meilleur alignement en temps que dans le ECAL avec une statistique équivalente.

Run	bb	bunch-IDs	be	bunch-IDs
63949	1235	1397	101	182
	1559	1721	992	1073
	2285	2447	1883	1964
	2609	3017	2774	2885
63815	2209	2774	101	424
63814	2209	2774	101	424
63813	2209	2774	101	424
63809	2209	2774	101	424
63807	2209	2774	101	424
63801	2209	2774	101	424
63713	2209	2774	101	1883
63691	2209	2774	101	1883
63690	2209	2774	101	1883
63688	2209	2774	101	1883
63687	2209	2774	101	1883
63686	2209	2774	101	1883



Early physics with LHCb

Yasmine Amhis
Laboratoire de L'Accélérateur Linéaire.
on behalf of the LHCb collaboration
Moriond QCD 2009

LHCb in a nutshell

► High statistics:

- $L = 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$.
- $\sigma_{b\bar{b}} \sim 500 \mu\text{b}$.
- $\sim 10^{12} b\bar{b}$ per year in 2 fb^{-1} .
- $B^\pm, B^0, B_s, B_c, \Lambda_b$

► Tracking & Vertexing:

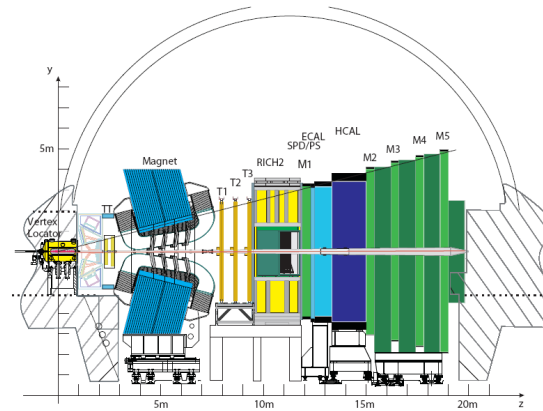
- Mass resolution $\sim 15\text{-}20 \text{ MeV}$
- Proper time resolution: $\sim 40\text{fs}$.

► Particle identification:

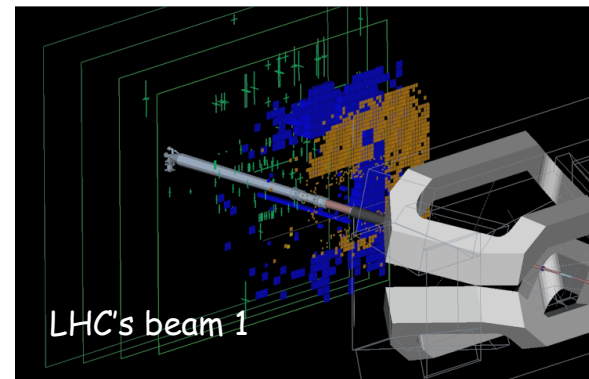
- Pion/Kaon separation over $2 \text{ GeV} < P < 100 \text{ GeV}$.

► Trigger:

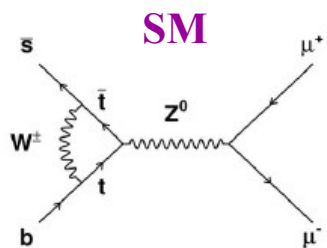
- First Level (L0) based on high Pt trigger: photons, electrons hadrons and muons.
- High Level Trigger.



LHCb commissioning,
Stefano's Talk

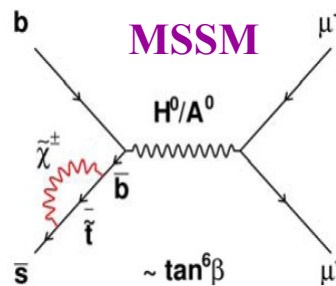


«Very » rare decays: $B_s \rightarrow \mu\mu$



$$SM Br = (3.35 \pm 0.32) \times 10^{-9}$$

$$\text{TeVatron : @ 90\% CL } (\sim 2 \text{ fb}^{-1}) < 45 \times 10^{-9}$$



Large SUSY contributions are possible.

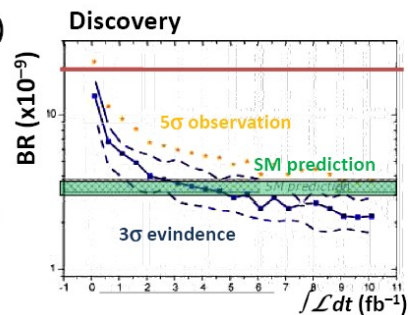
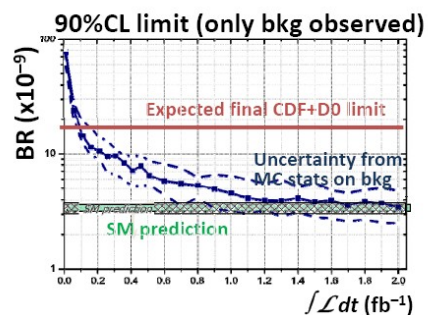
Event selection:

-Main background:

$$b \rightarrow \mu \quad b \rightarrow \mu$$

-Suppressed by:

Mass & Vertex resolution
+ Particle ID.



Exclusion @ 90 CL :

$$0.25 \text{ fb}^{-1} \rightarrow Br < 10^{-8}$$

$$2 \text{ fb}^{-1} \rightarrow Br < \text{SM prediction}$$

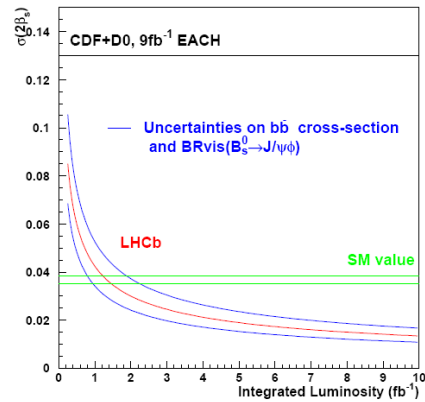
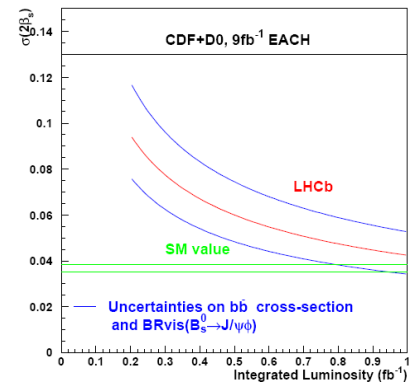
Discovery :

$$3 \text{ fb}^{-1} \rightarrow 3\sigma \text{ evidence}$$

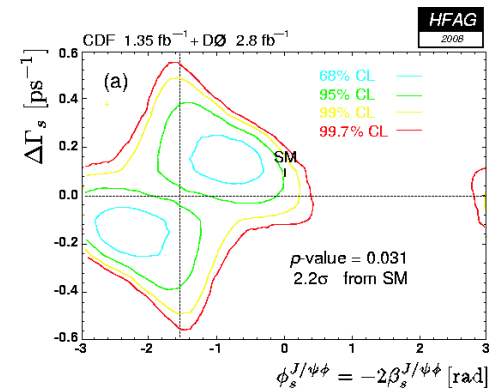
$$10 \text{ fb}^{-1} \rightarrow 5\sigma \text{ observation}$$

β_s sensitivity

LHCb-Roadmap-2009



$$90\% \text{ CL } \left\{ \begin{array}{l} \phi_s \in [-2.85, -1.65], [-1.47, -0.29] \text{ rad} \\ \Delta\Gamma_s \in [-0.264, -0.036], [0.036, 0.264] \text{ ps}^{-1} \end{array} \right.$$



Combined results
from D0 and CDF

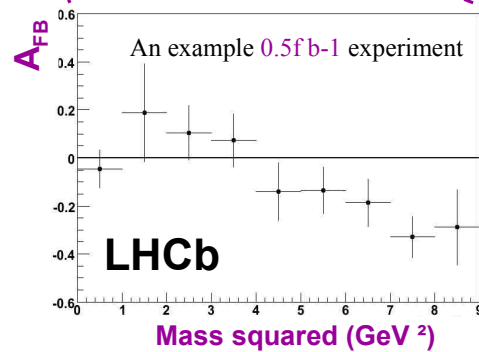
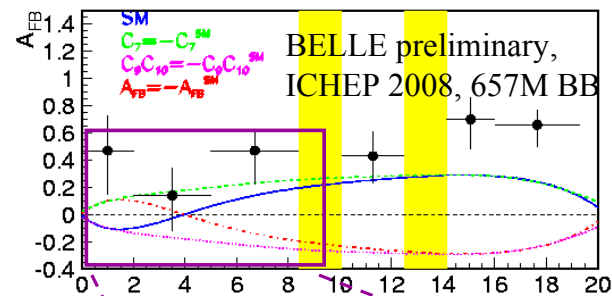
Standard Model value: $\phi_s = -0.0368 \pm 0.017$

L (fb ⁻¹)	0.5	2	10
$\sigma_{\text{stat}}(\phi_s)$	0.060	0.030	0.013

Reminder: $\phi_s = -2\beta$

9

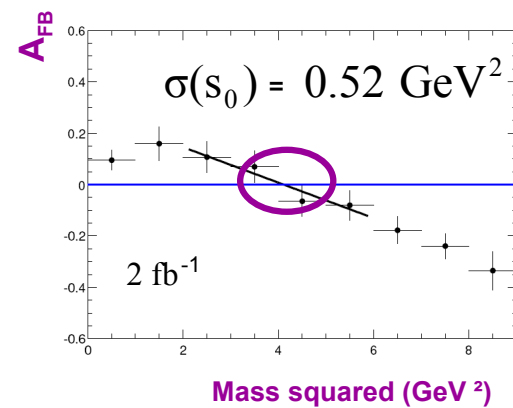
Rare decays: $B \rightarrow K^* \mu \mu$



NB: Opposite sign
convention to BELLE

Event yield in 2fb⁻¹:

Channel	Signal	B/S
$K^* \mu \mu$	7200	~ 0.5



13