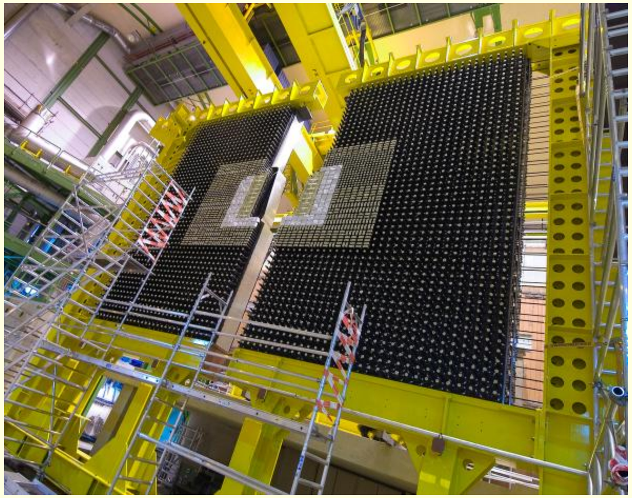
The LHCb Electromagnetic calorimeter: calibration & monitoring

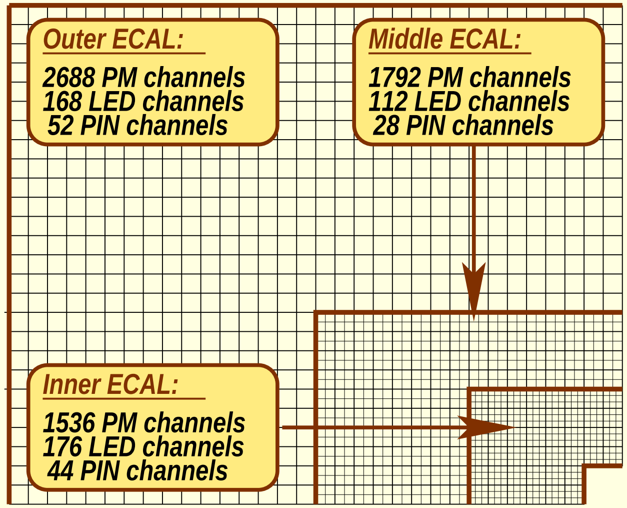
Irina Machikhiliyan
ITEP (Moscow) / CERN
on behalf of the LHCb Collaboration

Operational environment

- ECAL is a part of Calorimeter System, which includes also Scintillator Pad Detector (SPD), Preshower detector (PS) and Hadron Calorimeter (HCAL).
- ECAL goals:
  - Pre-selection of events containing B-decays: identification of energetic electrons, photons and neutral pions (L0 trigger);
  - Reconstruction of precise kinematical parameters of neutral particles;
  - Participation in PID;
- Design requirements:
  - Energy resolution: on the level of $10\%/\sqrt{E} \oplus 1\%$;
  - Transverse segmentation: small enough to separate two showers from π^o decays and to minimize pile-up;
  - Response time: compatible with LHC bunch spacing 25ns;
  - Maximal radiation dose: 2.5 kGy / year;
  - Z-position from i.p.: 12.5 m;
  - Lateral size: 7.8 m x 6.3 m;

General features

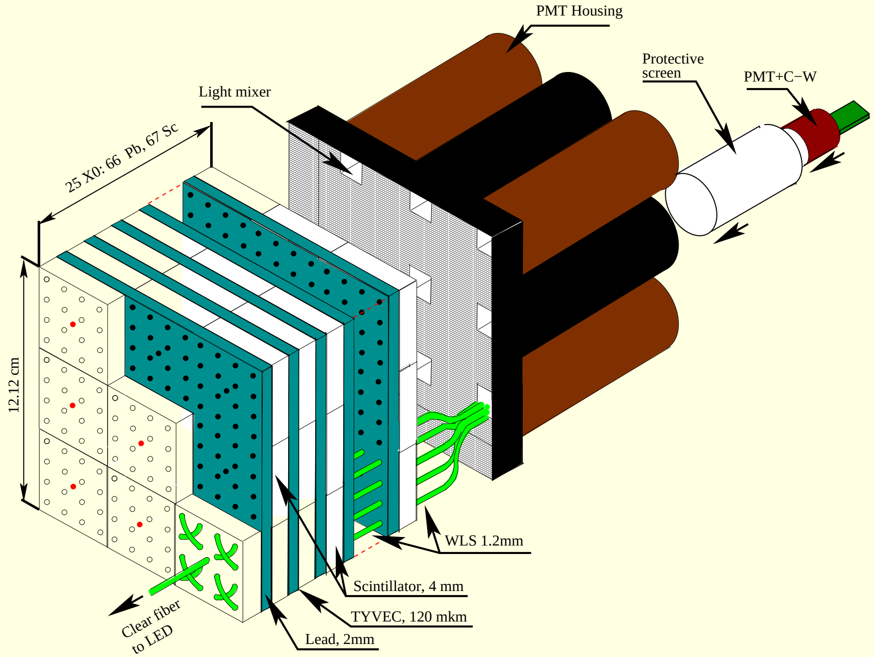




- Modular wall-like structure;
- Two independently retractable halves;
- Three sections (Inner, Middle and Outer) of different granularities;
- Detector media: sampling absorber-scintillator structure;
- Light collection system: WLS fibers;
- Light readout device: photomultiplier (PM) HAMAMATSU R7899-20;
- Front-End electronics: ‘dead time’-less shaping and integration of PM response at 40 MHz rate;
- LED based Monitoring System;
- ECAL dynamic range: follows ‘transverse energy’ rule: E(max)=7 + 10 /sin(θ).

Irina.Machikhiliyan@cern.ch

ECAL module



Test e-beam performance studies:

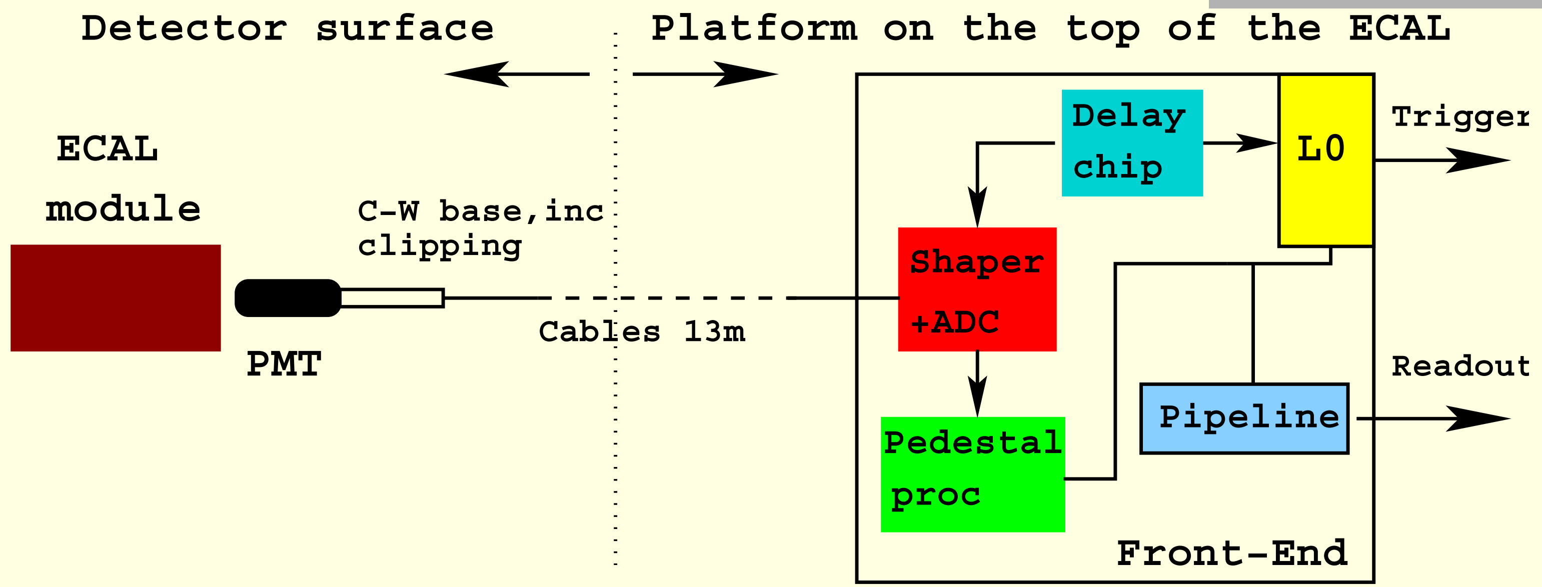
- Energy resolution:
  - Inner module: (8.2±0.4)%/√E ⊕ (0.87±0.07)%
  - Outer module: (9.4±0.2)%/√E ⊕ (0.83±0.02)%
- Non-uniformity of light collection over Sc tile: better than ±1% (50GeV electrons scan);
- Equivalent energy deposition of the MIP: 0.33 GeV;

Pre-installation measurements with cosmic particles:

	Inner	Middle	Outer
<Light yield> per cell, Np.e./GeV	3100	3500	2600
Response on MIP, cell-to-cell variation, %	8%	5.3%	6.7%

Irina.Machikhiliyan@cern.ch

Front-End Board

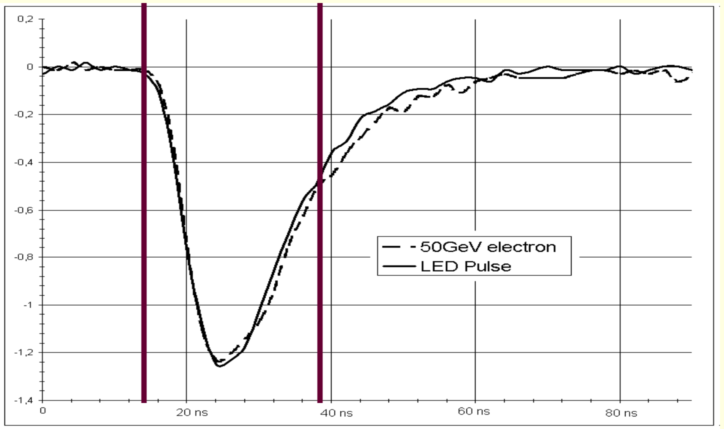


- Signal processing:
  - Shaper integrator + 12-bit (80 pC) 40 MHz two-stage bipolar flash ADC + delay chip to compensate for different arrival times of PM signals;
  - pedestal subtraction (suppression of low-frequency noise);
  - conversion to 8-bit Et calibrated signal;
- Selection of cluster candidate with highest Et for L0;
- Formatting of data block and dispatch it to the DAQ (upon request);

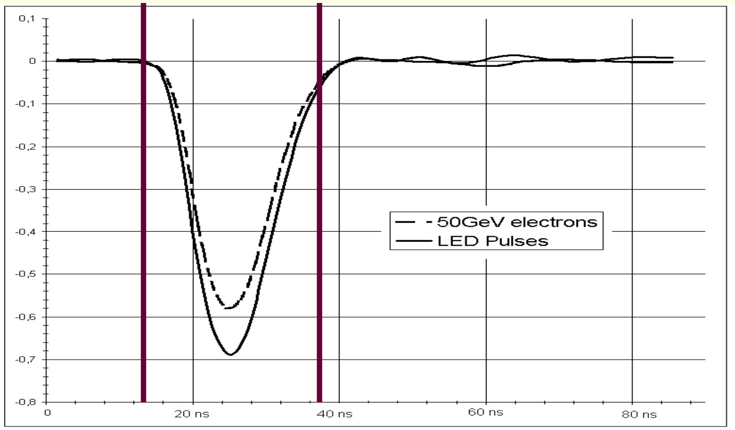
Irina.Machikhiliyan@cern.ch

Time alignment for physical data taking

- PM power supply: clipping chain to cancel signal tail and thus to minimize pipe-up from previous BX;
- Resulting PM output pulse duration is comparable with LHC bunch spacing -> **fine time alignment becomes extremely important;**



PM anode current pulse



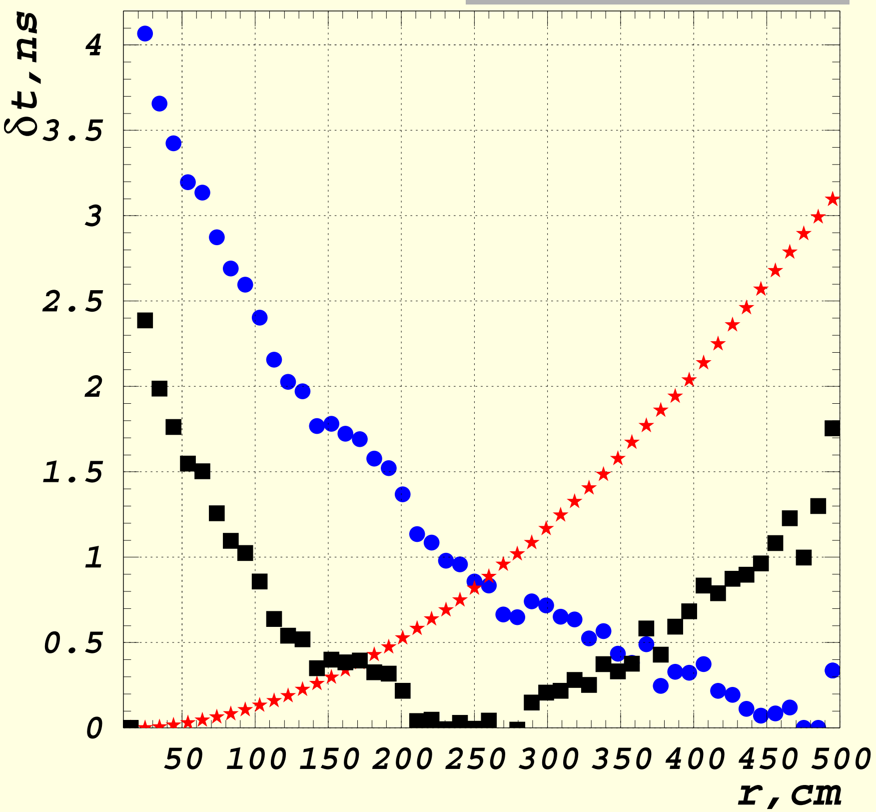
Pulse after clipping chain

 Irina.Machikhiliyan@cern.ch

Time alignment for physical data taking (cont)

Two major factors contribute in the relative timing of PM output pulse depending on cell position:

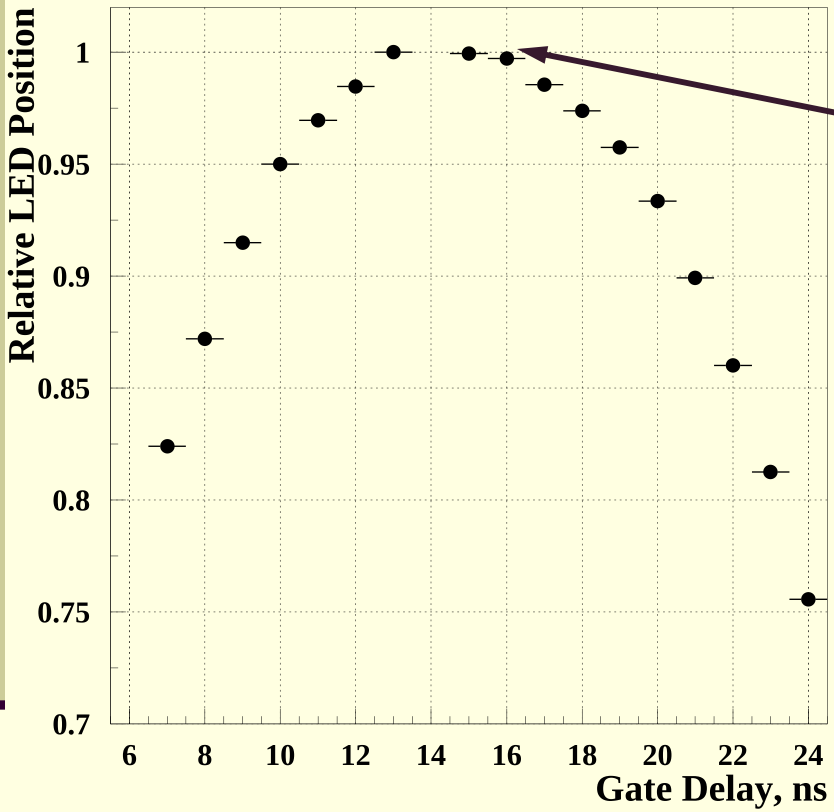
- PM transit time ~ 1/√HV ;
- Particles time of flight;



- Blue: PM transit time
- Red: time of flight
- Black: net relative delay

Irina.Machikhiliyan@cern.ch

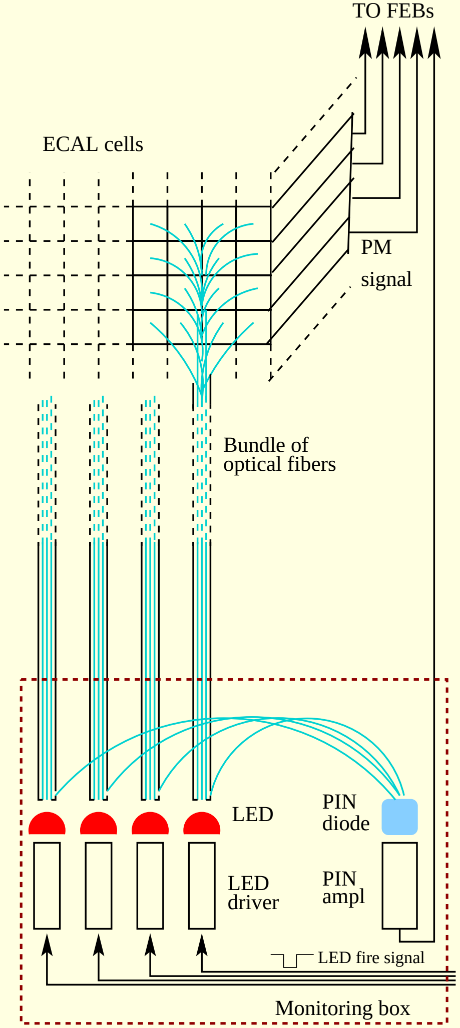
Time alignment for physical data taking (cont)



Example dependence of PM response to LED on relative ADC gate delay, PM gain 1K

- Expected cell-to-cell difference: well compatible with ADC flat-top;
- The moment the first beam will be available:
  - start with general ECAL synchronization with accelerator cycle as well as other sub-detectors;
  - then go on with fine tuning of relative timing on the level of individual cells;
- Dedicated tools: special time-alignment events (TAE) in order to read out several consecutive BX around the one under interest;

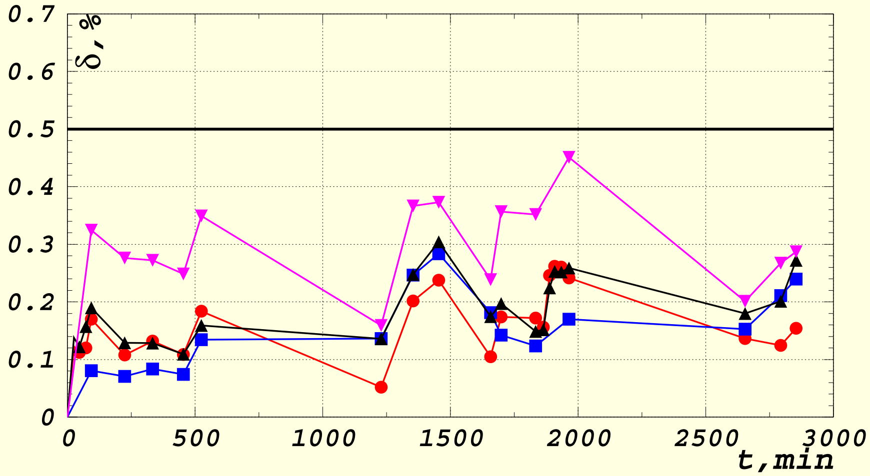
Monitoring system



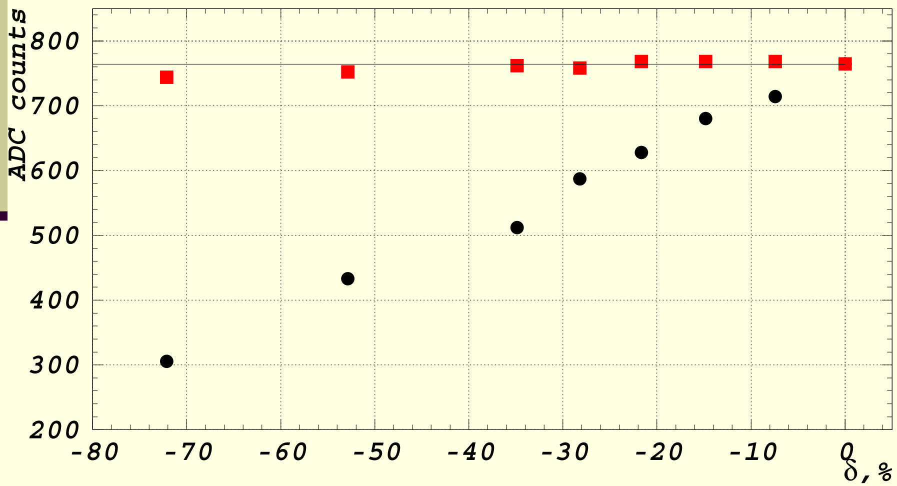
- Major goals:
  - trace readout chain stability;
  - check readout channels serviceability;
- One LED serves a group of channels (9 in the Inner, 16 in the Middle/Outer sections);
- LED light is transported to PMs via long clear fibers arranged in bundles (2÷8 m length);
- Adjustable delaying of individual LED fire pulse is in the range 0÷300 ns, the step is 1ns;
- LED intensity is controllable spanning the noticeable part of the ADC dynamic range;
- Stability of LEDs themselves is traced by PIN photodiodes (one PIN per group of four or two LEDs);

Irina.Machikhiliyan@cern.ch

Precise monitoring of LED stability with a help of PIN diode



LEDs stability as measured by PINs: better than 0.5% for 2 days (on the basis of 4 LEDs)



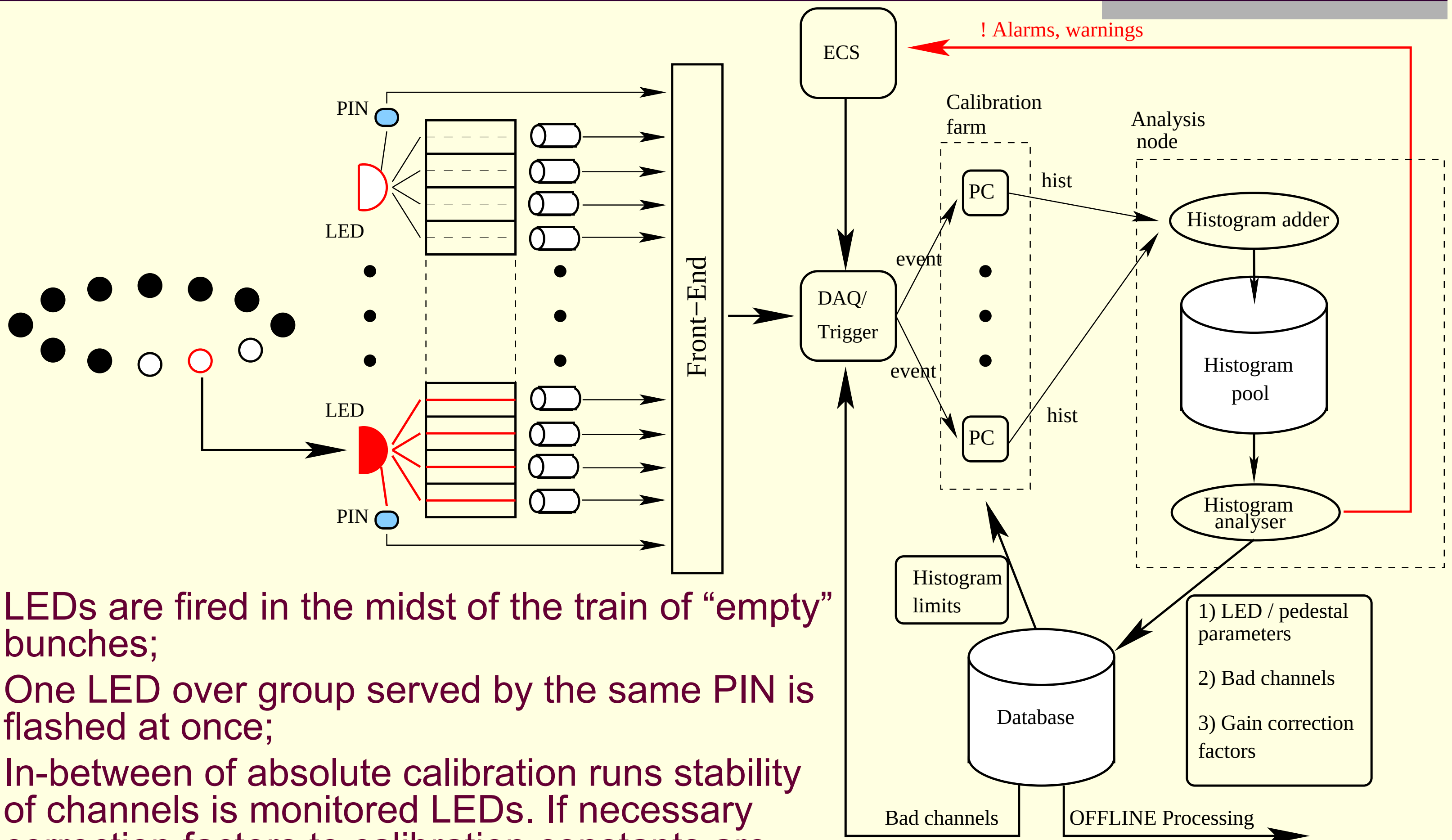
Correction of emulated LED drift by PIN (one PM):

- Black dots: original readings
- Red squares: corrected readings

Accuracy of the correction is better than 1% up to 30% change in LED magnitude

Irina.Machikhiliyan@cern.ch

Monitoring by LEDs: general strategy

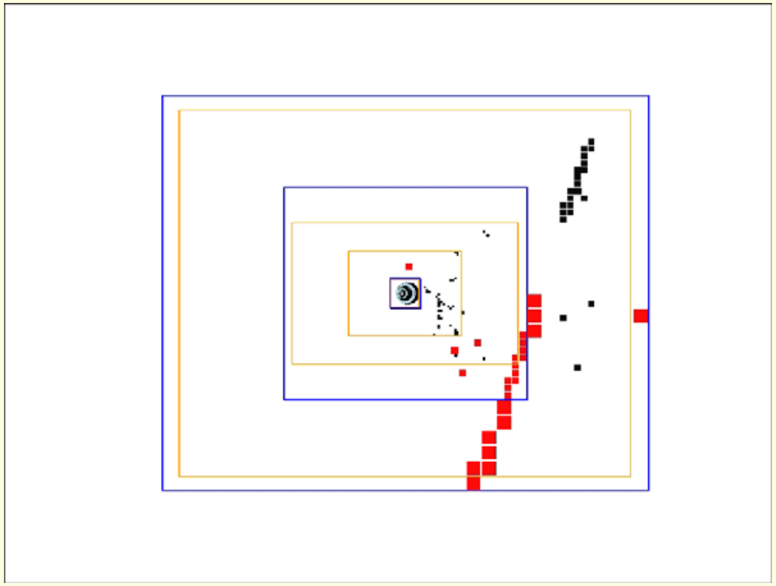


- LEDs are fired in the midst of the train of “empty” bunches;
- One LED over group served by the same PIN is flashed at once;
- In-between of absolute calibration runs stability of channels is monitored LEDs. If necessary correction factors to calibration constants are provided (relative calibration);

Irina.Machikhiliyan@cern.ch

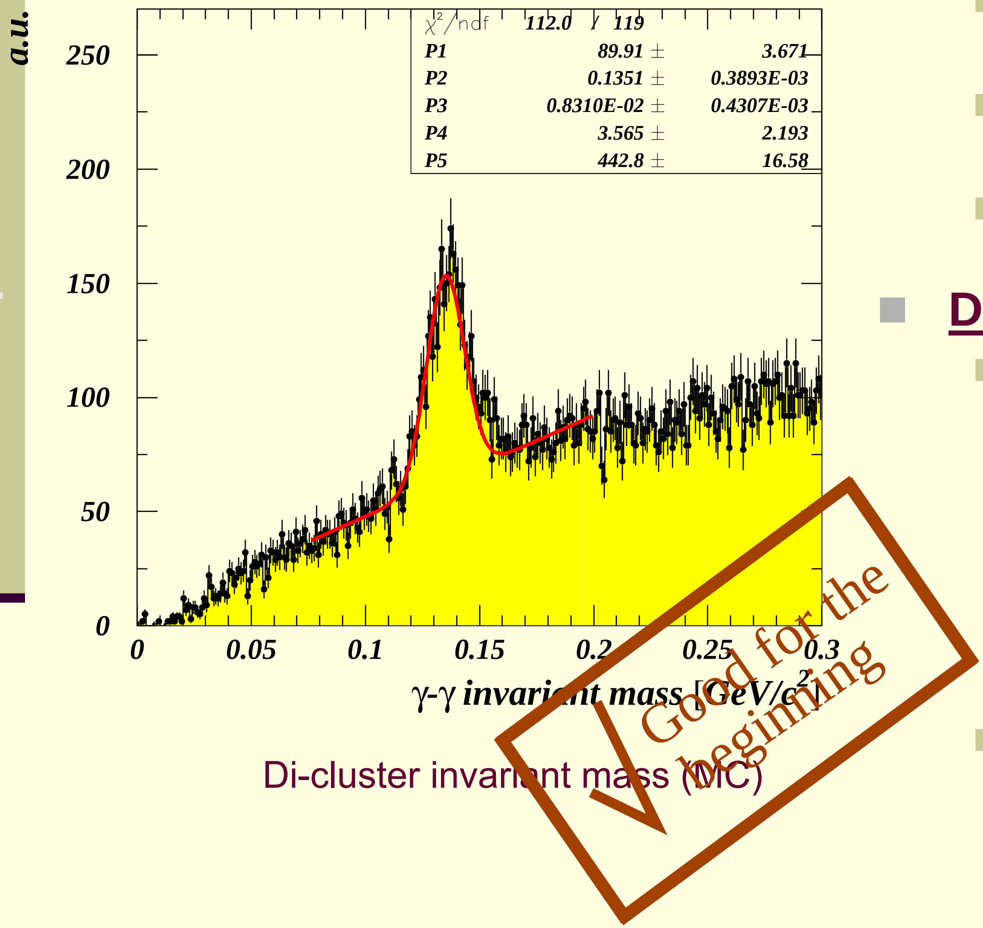
Global LHCb commissioning on cosmics

- Goals:
  - Commissioning of the detector including trigger and DAQ chains;
  - Mutual time alignment of (some) LHCb subsystems;
  - Time inter-alignment inside sub-detectors;
- TAE sequences ±7 BX around the one under interest;
- ECAL participates in the CALO trigger, based on coincidence between ECAL and HCAL;
- ECAL PMs gain is set to 300K (far above the nominal range);



One cosmic track as seen by ECAL (black) and HCAL (red)

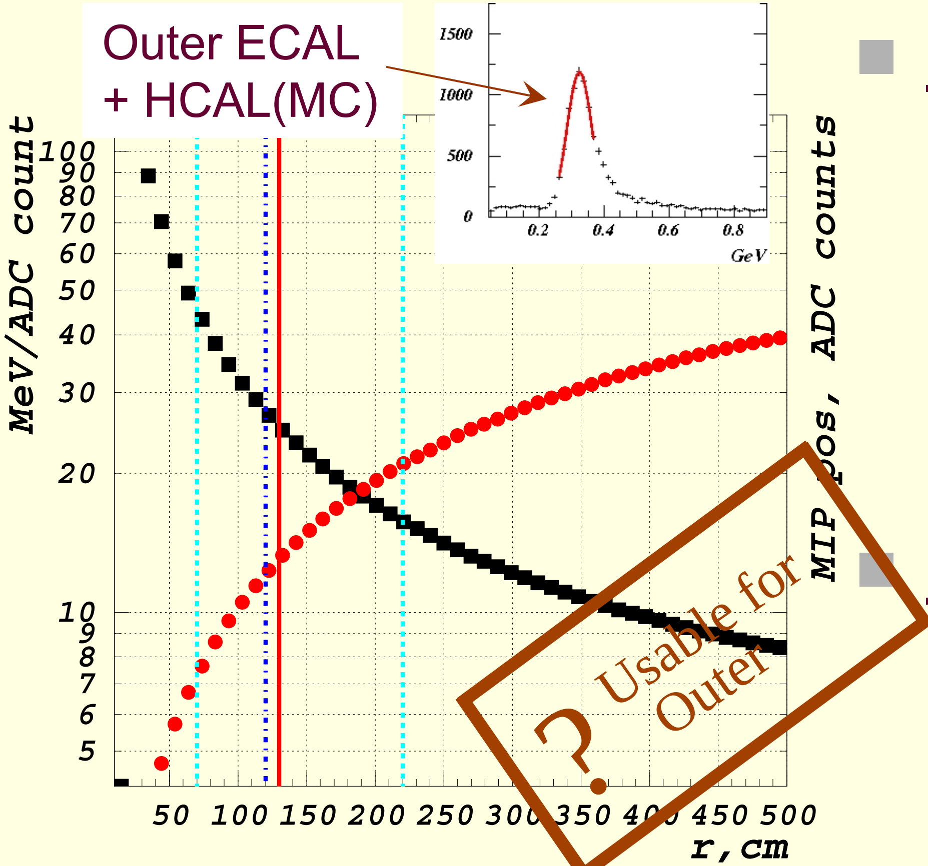
Absolute calibration algorithms: resolved π^o



Di-cluster invariant mass (MC)

- **Advantage:**
  - Copiously produced in pp-interactions;
  - Minimal info from other subsystems;
  - No sophisticated cuts, good S/B ratio;
- **Disadvantage:**
  - 2.5 X0 lead converter in front of ECAL (in-between SPD/PS):
    - PS data has to be used: either for full reconstruction of shower energy or for selection of γ's which did not interact in the lead wall;
    - In the last case: significant statistics loss;
  - ECAL should be calibrated already at the level of ~10÷15%;

Absolute calibration algorithms: MIPs



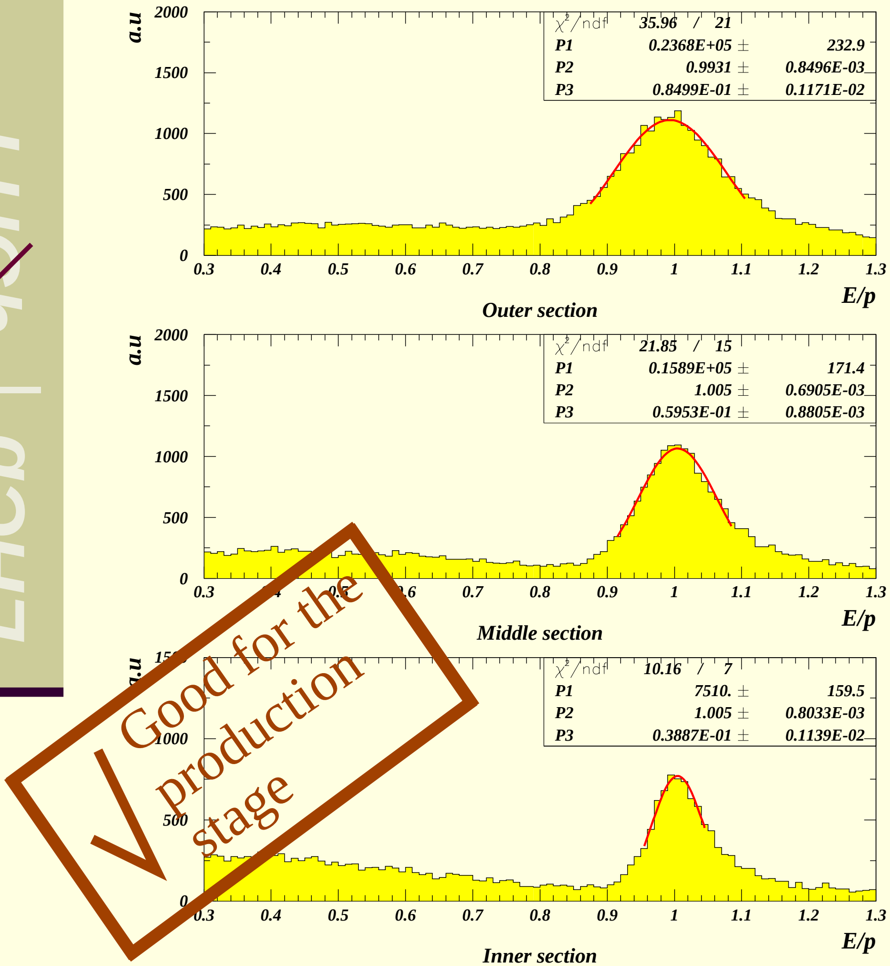
Red dots: MIP position in terms of ADC counts vs distance from the beam pipe (r);

Black squares: MeVs per ADC count vs r;

- **Advantage:**
  - Copiously produced in pp-interactions;
  - Easy to reconstruct;
  - Relies only on energy deposition in individual cell – influence of the rest of ECAL cells is minimal
- **Disadvantage:**
  - Requires (minimal) participation of another subsystem: HCAL, tracker or both;
  - **Very small signal -> low precision (3% at best)**

Irina.Machikhiliyan@cern.ch

Absolute calibration algorithms: electrons



E/P distributions for different ECAL sections (MC)

- **Advantage:**
  - High precision of the method (~0.5%);
- **Disadvantage:**
  - Requires full detector operational;
  - Careful selection of candidates (effects of material in front);

The LHCb Electromagnetic calorimeter

☑ All sub-components are installed in the experimental hall and commissioned;

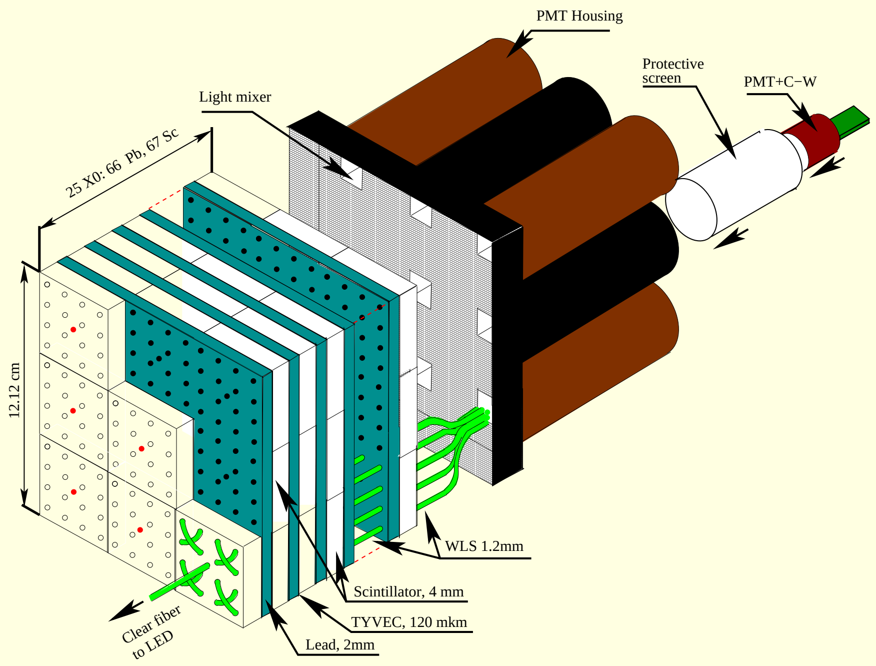
- For now:
  - studying the behavior of ECAL as whole system;
  - developing and testing of software for monitoring, time alignment, calibration;
  - participating in global LHCb commissioning and

waiting for first collisions!

SPARE SLIDES

Irina.Machikhiliyan@cern.ch

Construction of the module



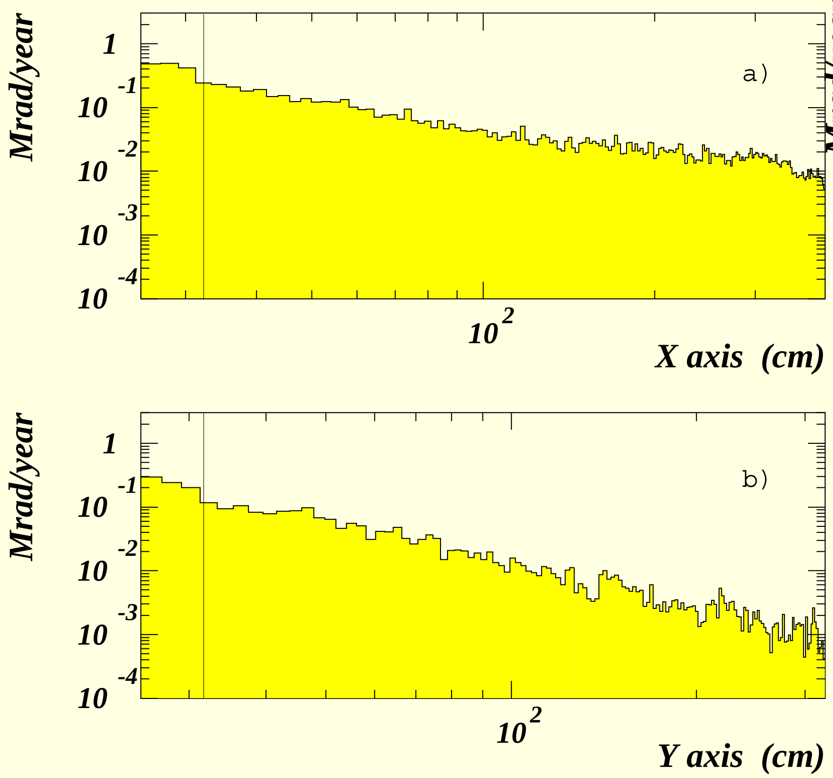
- Absorber: Lead;
- Scintillator: BASF-165H based plastic + 2.5% p-terphenyl + 0.01% POPOP;
- Volume ratio Pb:Sc 2:4;
- Moliere radius: 3.5 cm;
- Transverse size 12.12 x 12.12 cm²;
- WLS fibers: Y-11(250) MSJ (KURARAY);

	Inner	Middle	Outer
# cells/module	9	4	1
# fibers/module (WLS+clear)	72+9	72+4	32+1
<Light yield>, Np.e./GeV	3077	3516	2569

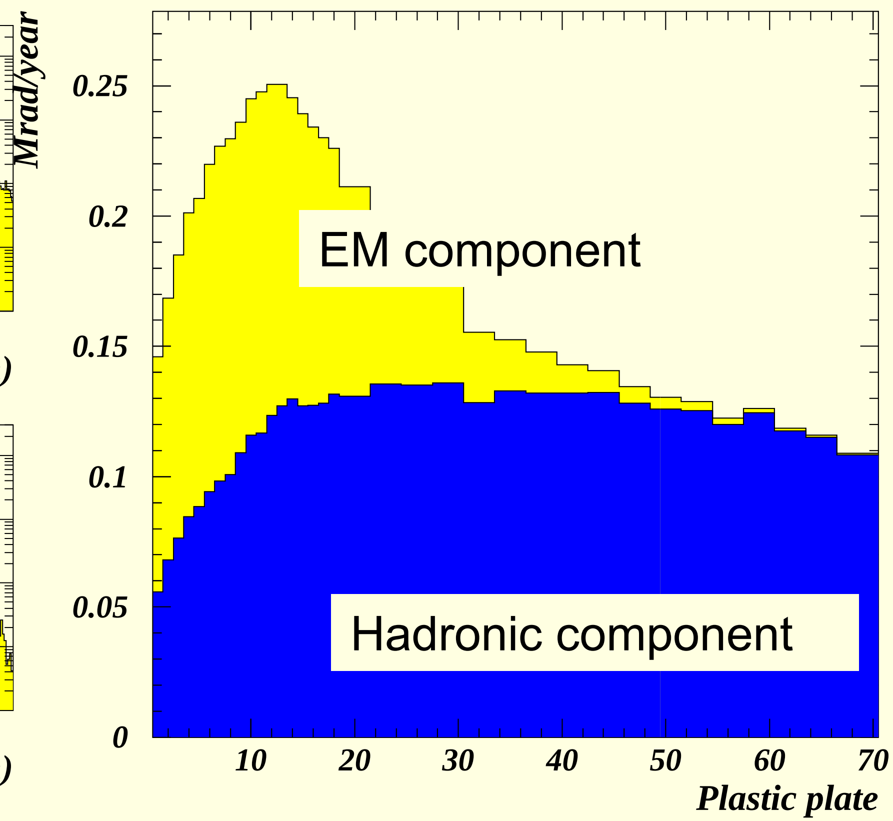
Irina.Machikhiliyan@cern.ch

Expected radiation environment

Radiation dose in the LHCb ECAL

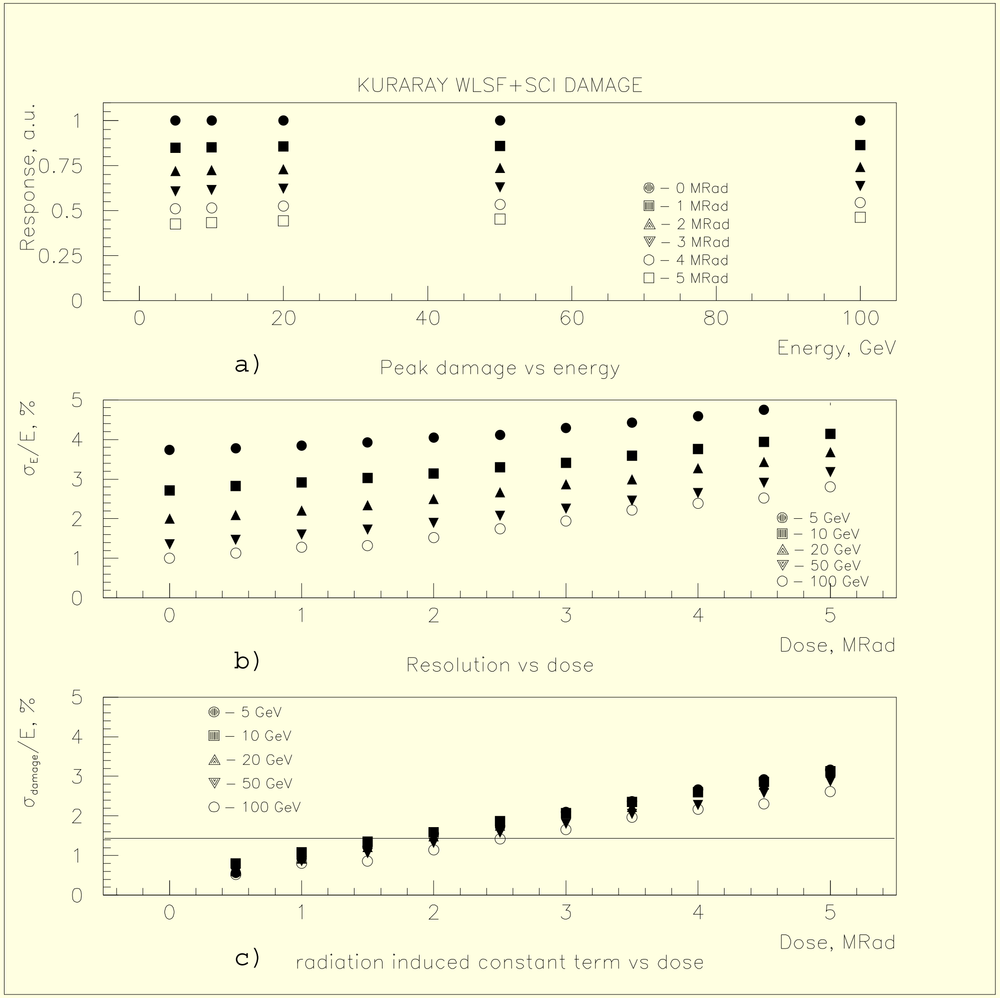


Longitudinal dose in the LHCb ECAL



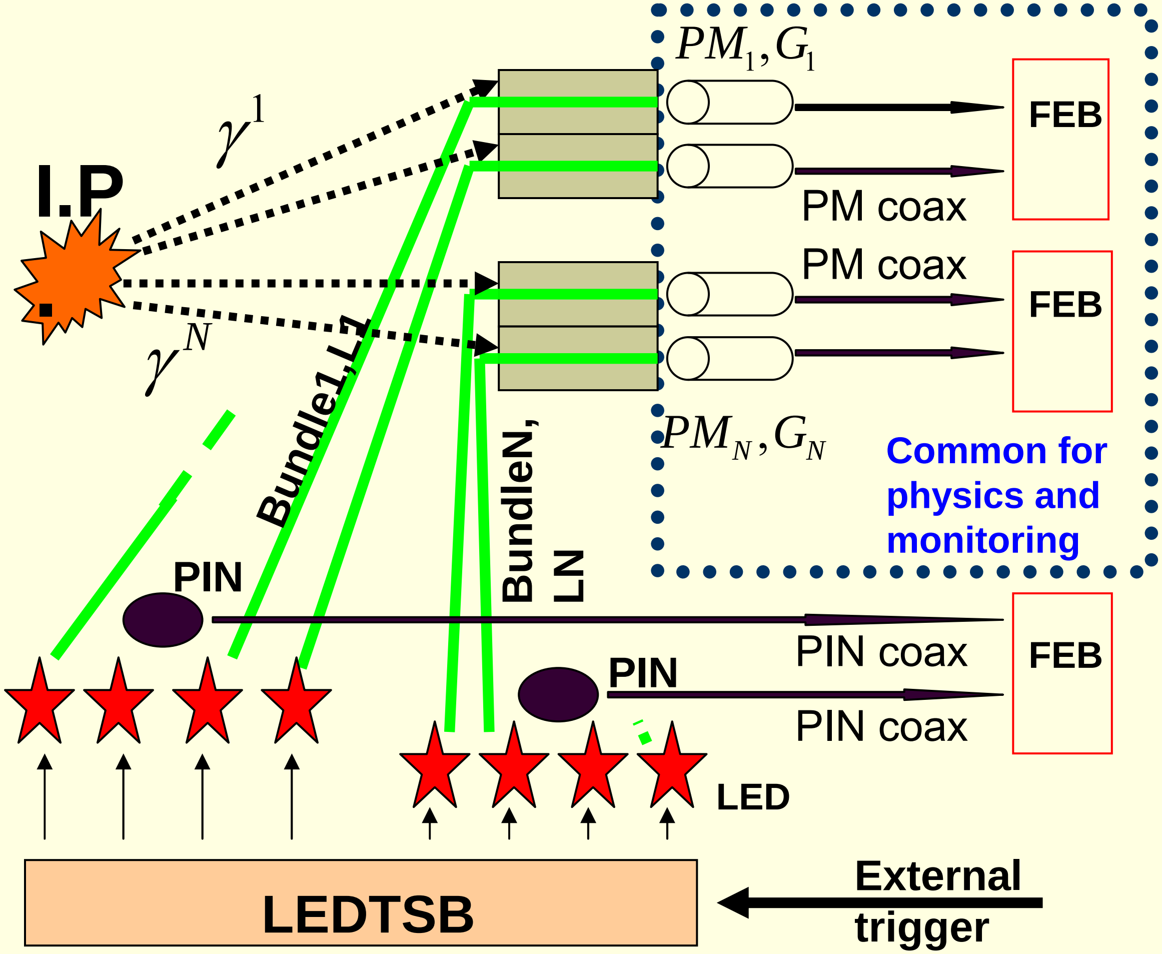
Irina.Machikhiliyan@cern.ch

Behavior of module components under irradiation



Irina.Machikhiliyan@cern.ch

Monitoring system time alignment



- Timing of PM response on LED can differ up to 2÷3 BX;
- Shared segment of physical and monitoring signal paths: timing is adjusted by FEB-system and fixed by the requirement of an optimal PM response on particles;
- The rest of monitoring signal path: PM responses on LEDs are synchronized by adjustable delaying of LED fire pulse (the range 0÷300 ns and the step 1ns);

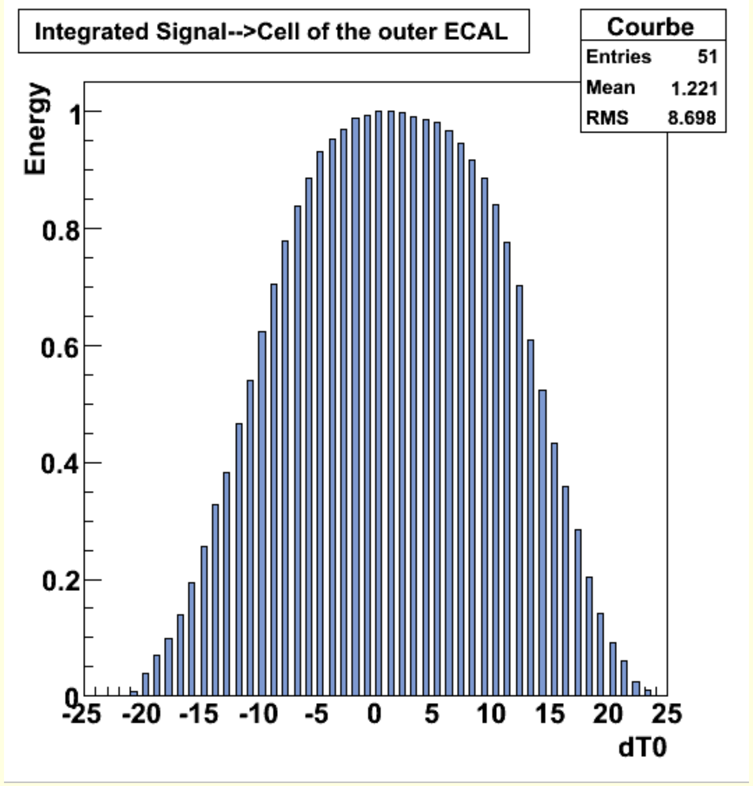
Irina.Machikhiliyan@cern.ch

Strategy with the beam:

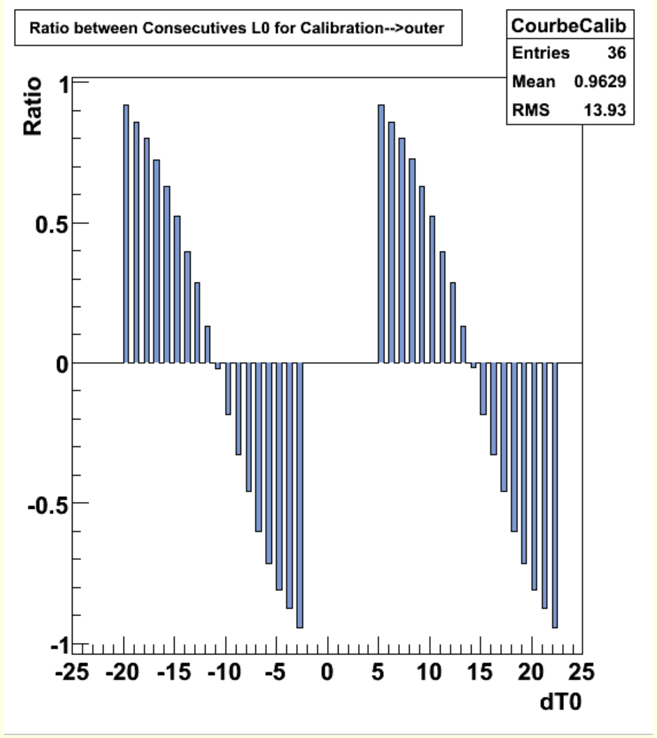
- Achieve good time alignment;
- Perform absolute calibration:
  1. Rough calibration / check of initial settings correctness on the level of whole detector. Different energy flow / occupancy methods are under consideration. Expected accuracy ~15%, details depend on LHC start-up scenario (beam energy, magnetic field presence, etc)
  2. Fine absolute calibration on the level of individual cells response (π^o, MIP, E/P)
- In-between of absolute calibration runs - monitor stability of channels with LEDs. In case of drift – provide correction factors to calibration constants (relative calibration);

Time alignment by physical data (MC studies)

Y. Amhis and J. Lefrancois



The expected shape of the integrated signal (electrons p = 100GeV)



$$Rj = \frac{\sum_{i}^{Nevt} E_{ij}(Current) - \sum_{i}^{Nevt} E_{ij}(Next)}{\sum_{i}^{Nevt} E_{ij}(Current) + \sum_{i}^{Nevt} E_{ij}(Next)}$$

Time alignment by physical data-II (MC studies)

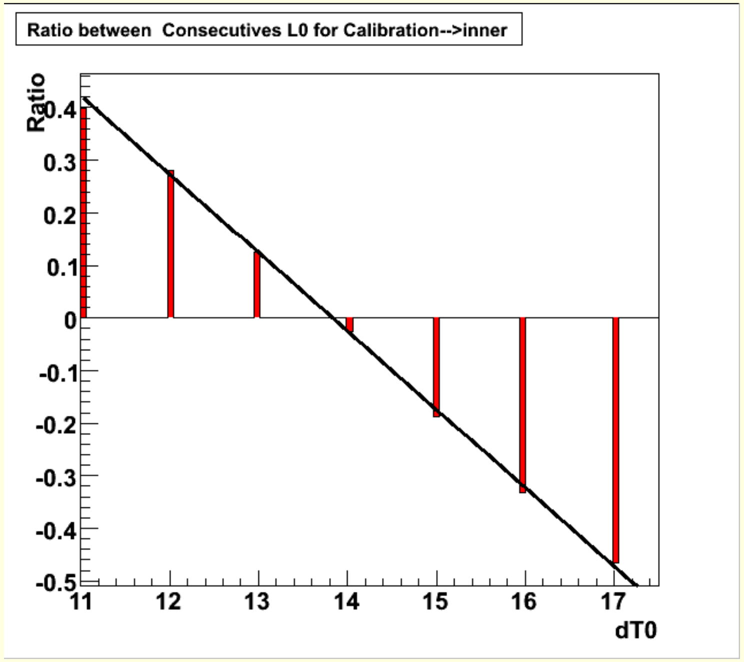
Y. Amhis and J. Lefrancois

- Fit the linear region
  10< dT0<18 ns

$$R = -0.149 dT0 + 2.06$$

- So obtain:
  a relation between the ratio R and the distance to the maximum of the integrated signal where the sampling will be done.

➔ R(dT0=13ns) =0.125
➔ R(dT0=14ns)=- 0.02



LHCb | LHCb

Irina.Machikhiliyan@cern.ch