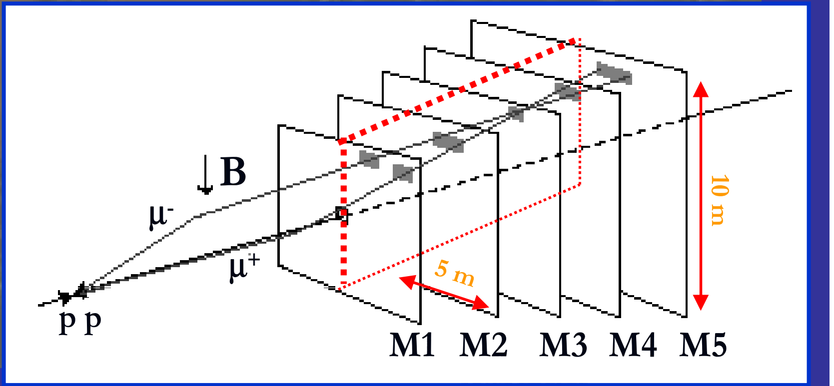
Time Calibration of the LHCb Muon System

Outline

- The LHCb Muon System
  - Requirements
  - The Detector
- Instruments for Time Calibration & Monitoring
  - The DIALOG and SYNC ASICs
- The Time Calibration procedure
- First Commissioning Results

The Muon System

- LHCb: B physics at LHC – Bunch Crossing 40 MHz
- Crucial role in the first Trigger level (L0) (accept rate 40 MHz - output rate 1 MHz)
  - Provide a high p_T muon trigger at the L0 with the 95% efficiency
- **5 Stations: 1380 detectors** (MWPC & 3-GEM)
  - **20 different** types of detectors, with different time responses
  - **Time spectra from detectors are relatively wide (~4 ns of rms)**
  - **120k FE Channels**: space-point binary information with respect to the bunch crossing
  - Around 8**,000 signal cables** (LVDS) of different lengths



The Muon Detector: Front End

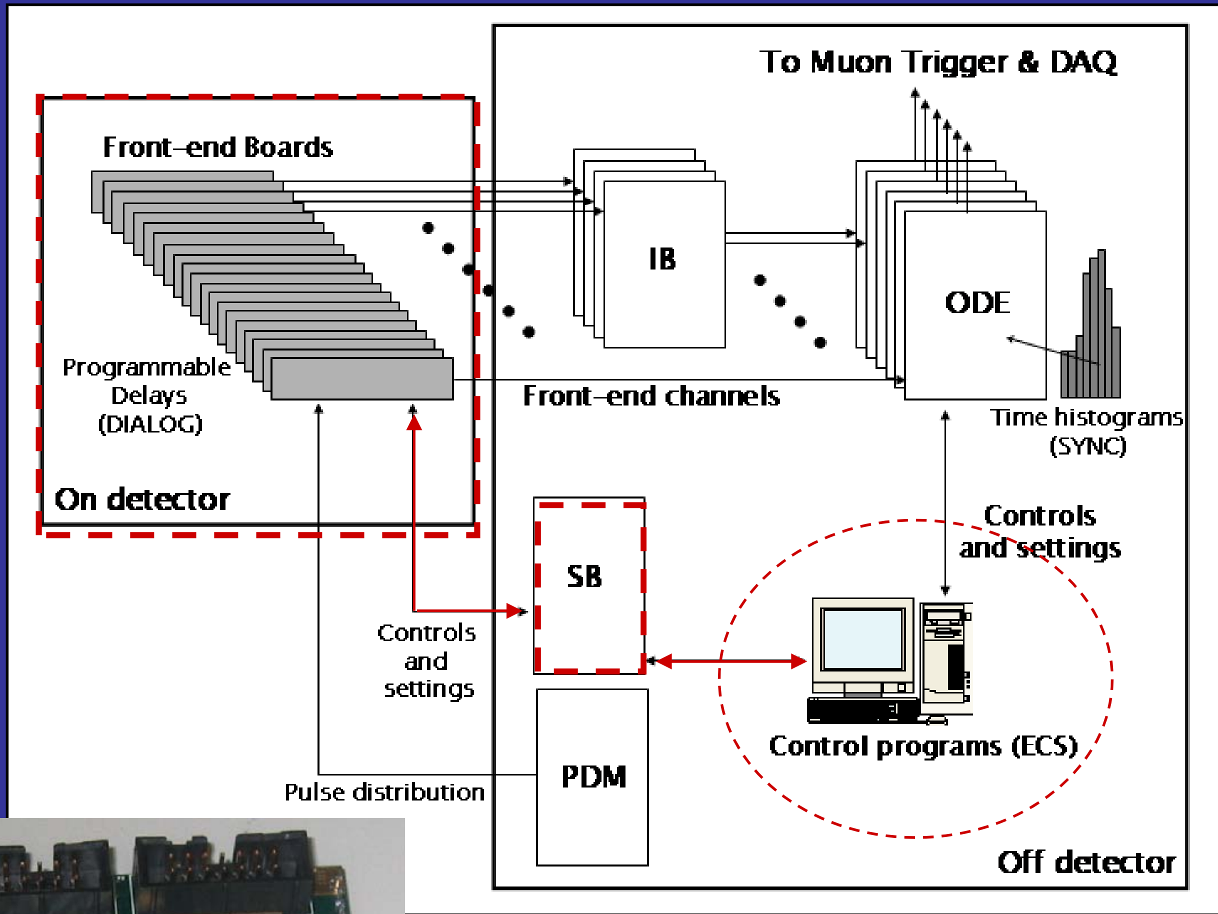
1380 DETECTORS
MWPC / 3-GEM

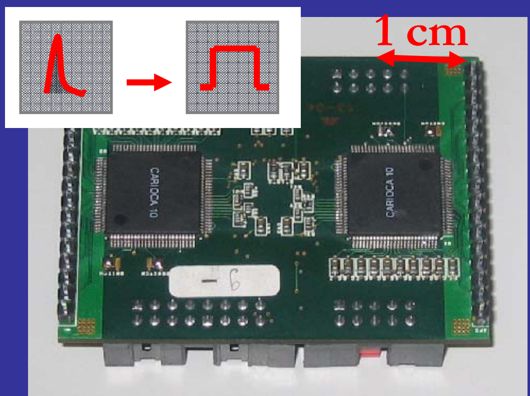
Detector dimensions
M1 (40x32 cm^2)
M5 (163x49 cm^2)

122,112 Front End CHANNELS (PCH)

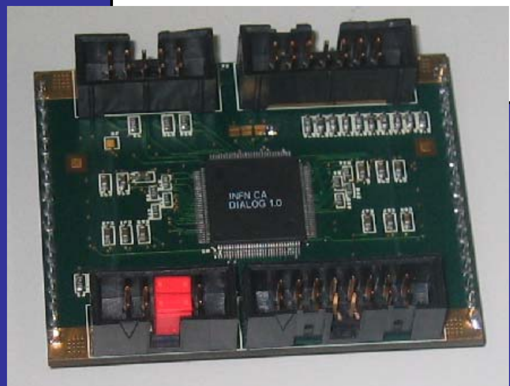
⇩

7632 FE boards (CARDIAC):
Two ASICs:
- CARIOCA (ASD chip)
- DIALOG (time alignment and monitoring)





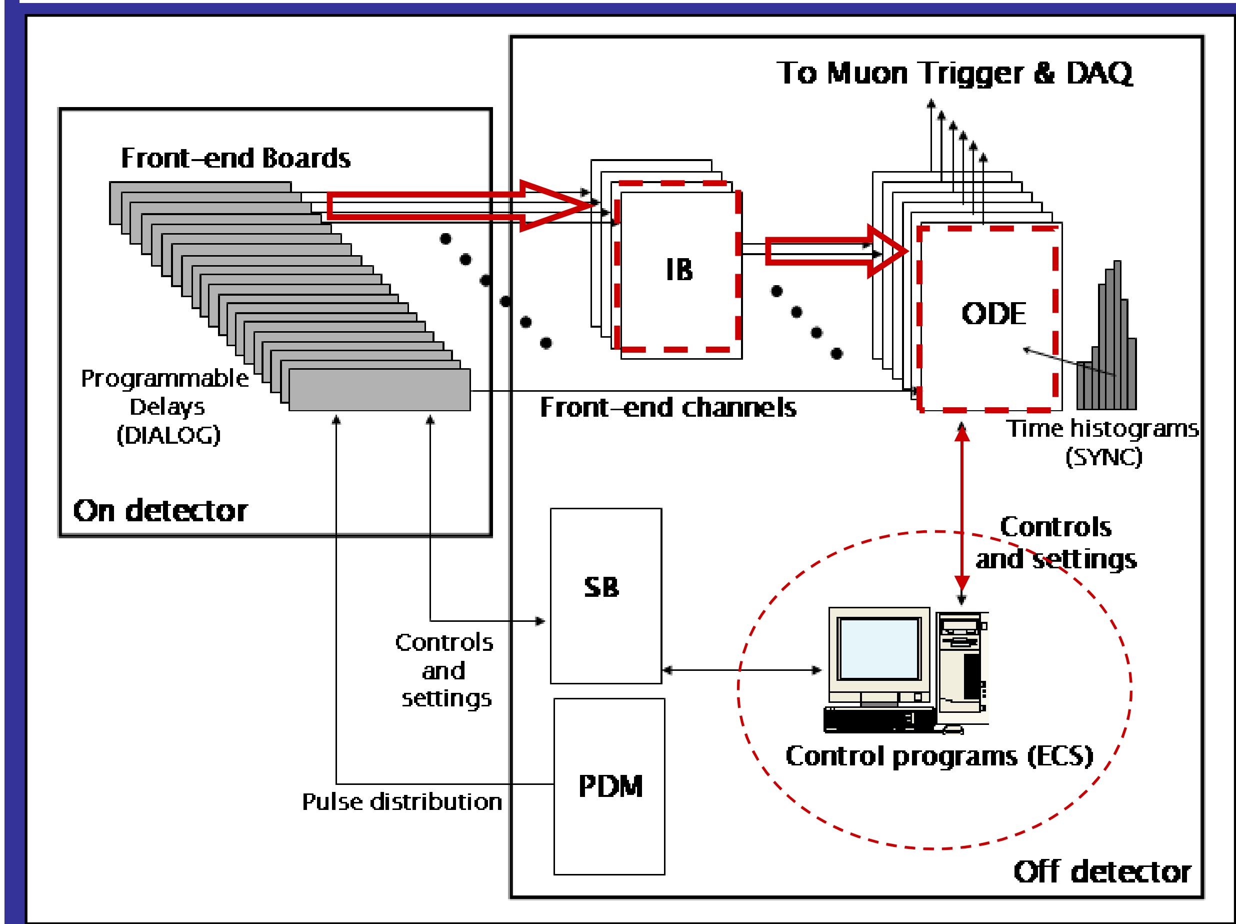
2 CARIOCA (16 PCH)

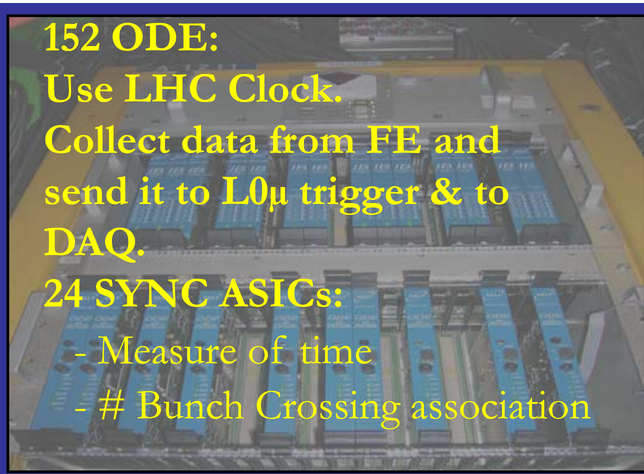


1 DIALOG
16 input / 8 output

DIALOGs are configured and Read back by SB (156) using ECS – PVSS programs

The Muon Detector: Read Out

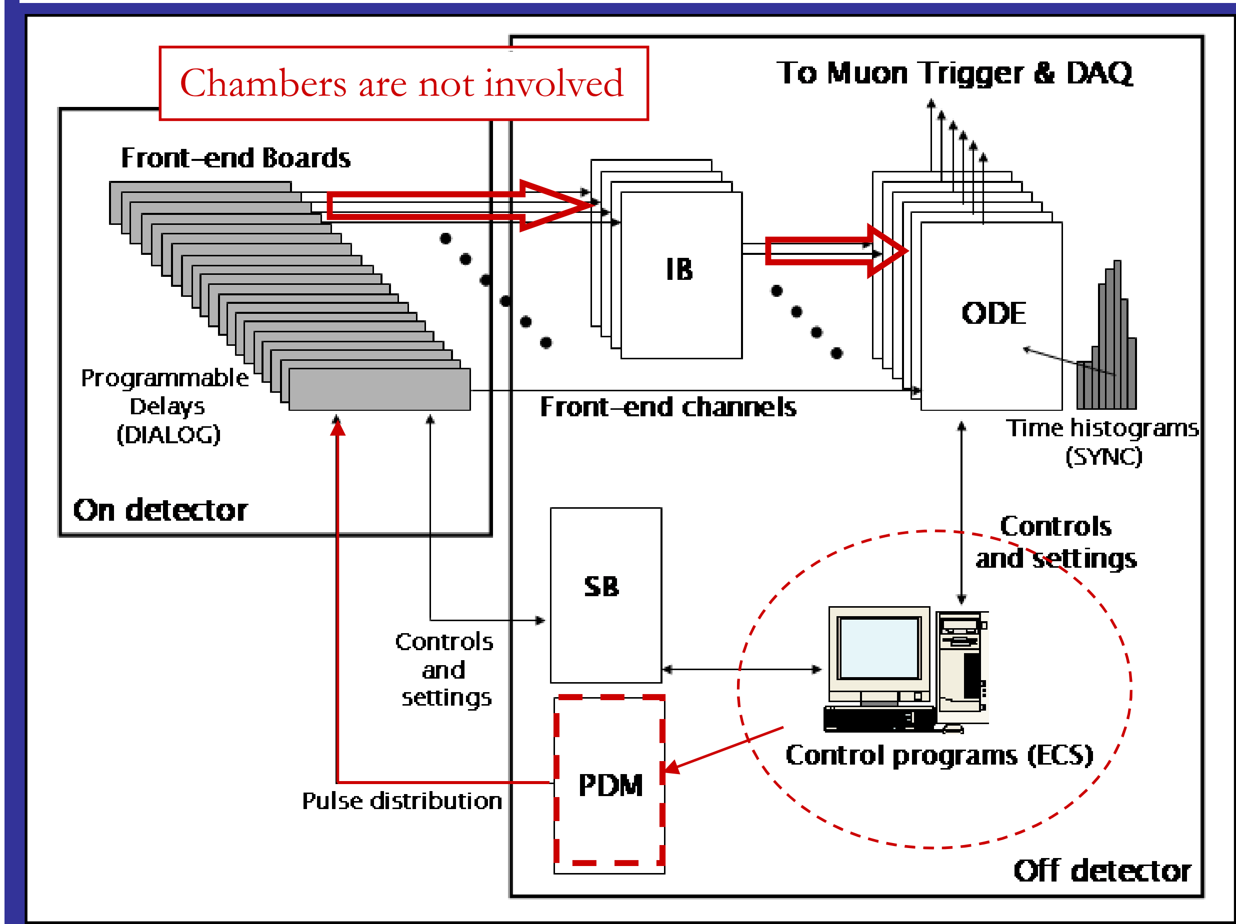




152 ODE:
Use LHC Clock.
Collect data from FE and send it to L0μ trigger & to DAQ.
24 SYNC ASICs:
- Measure of time
- # Bunch Crossing association

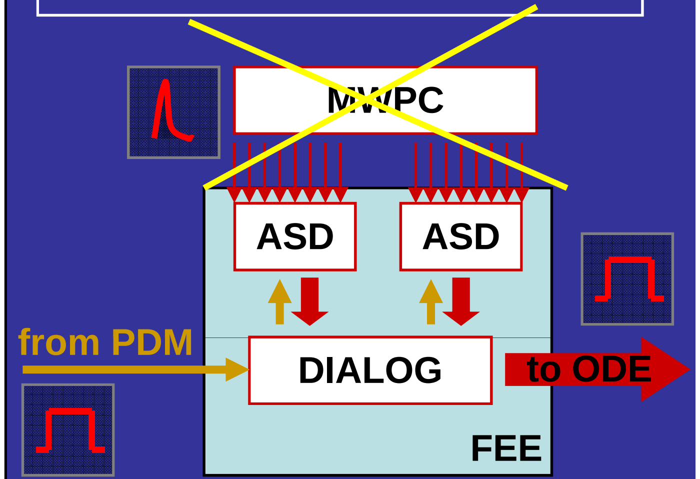
The L0 μ Trigger uses a coarser granularity: from 122,112 PCH to 25,920 Read Out CHANNELS (LCH).
PCH Logical combination starts on DIALOG and is completed on IB boards (168).
Electronic Chain: 10÷20 m of LVDS cables.

The Muon Detector: Pulse System



PDM: pulses to FEE synchronous to a given BX number

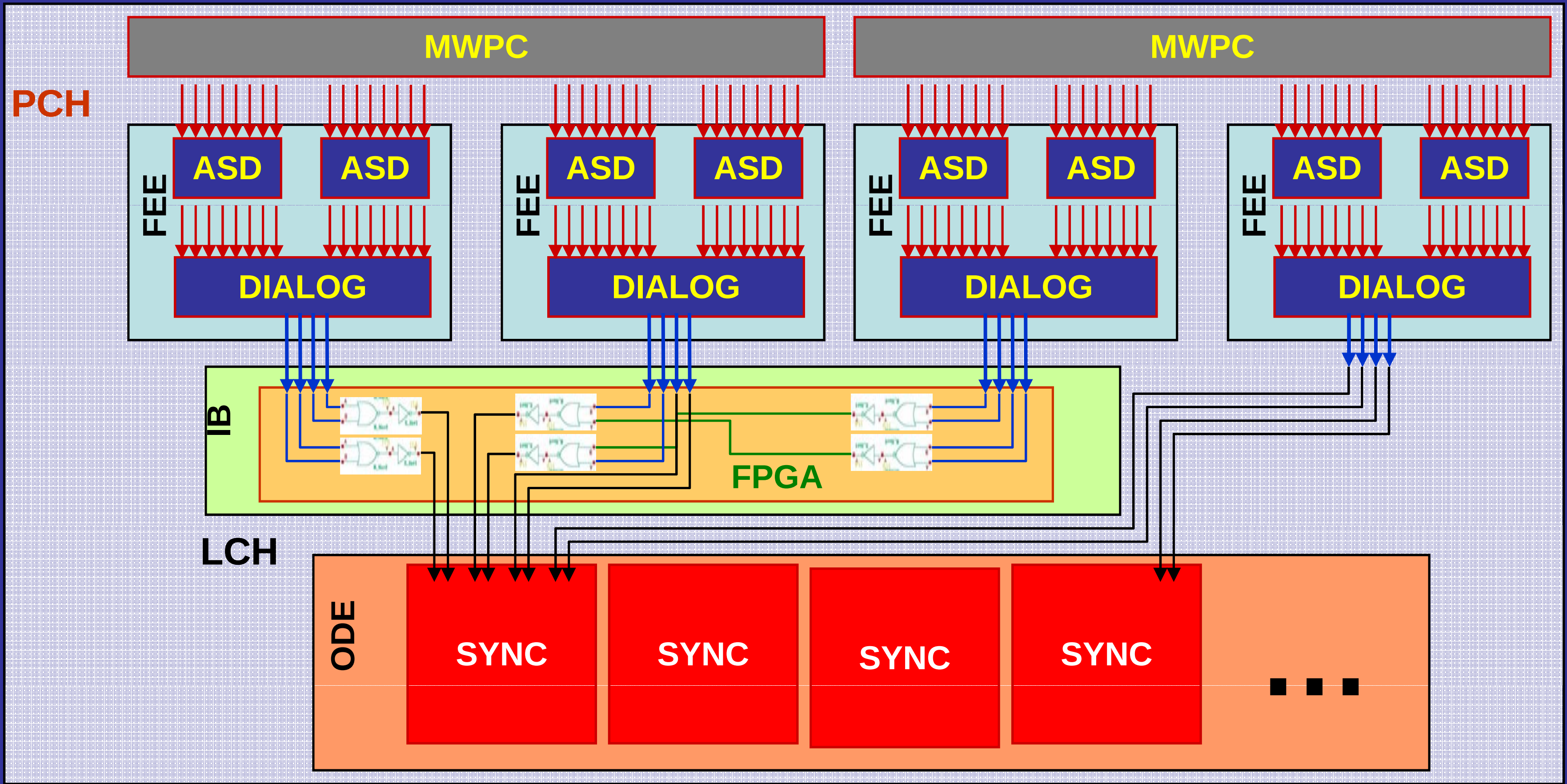
- Use LHC Clock.
- Pulse reproduced by DIALOG and sent to CARIOCA
- Chambers are not involved



A Challenging Feature: Connectivity

Connection complexity:

- 12 different types of electronic chain connections (number of PCHs & logical combinations)
- Each type contains 1 ODE + (0 ÷ 3) IB + (24 ÷ 72) CARDIAC and therefore up to 1152 PCHs



LHCb Muon System - Requirements

1. Detect μ with 99% efficiency within a 20 ns time window
2. Identify the Bunch Crossing which generates the event
3. Select the μ track and reconstruct the p_T (20% resolution)

- **122,112** FE Channels must be:
  - logical OR combined to obtain the LCH granularity needed by L0 trigger (25,920 LCH)
  - time aligned

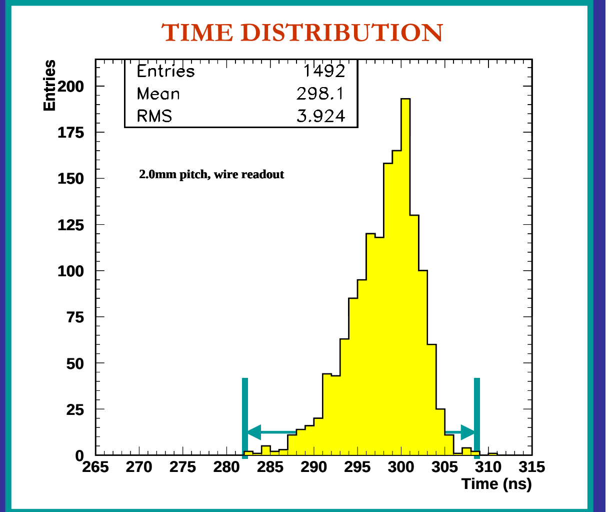
- **Before synchronization signals generated by the same BX but coming from different channels have different absolute delay Δt (more than one BX)**
- **To reach the 95% trigger efficiency the signals must be time aligned (~ 2 ns)**

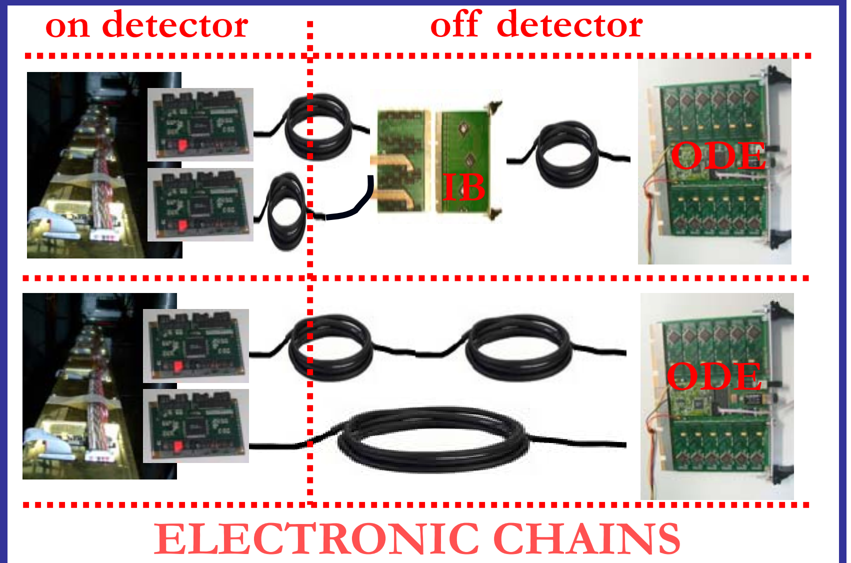
LHCb Muon System - Requirements

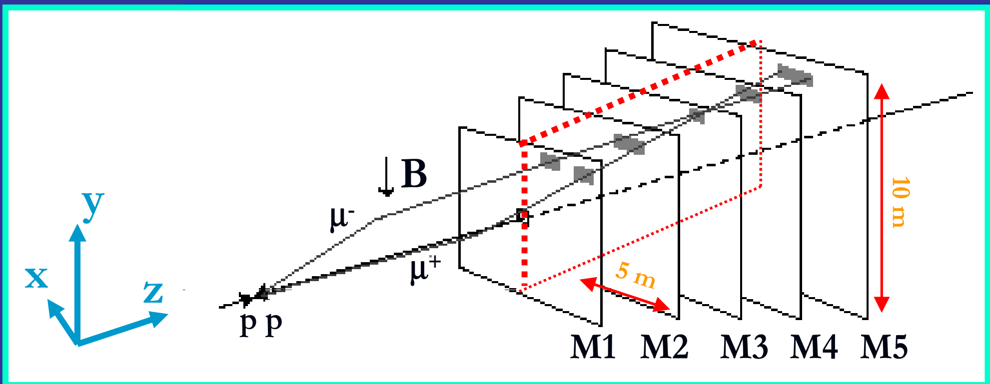
TOTAL TIME DELAY Δt

- Particle time of flight (along z axis M1 (**40 ns**) and M5 (**63 ns**)) Relative delay among different PCH: up to **23 ns** along z and **4 ns** in the same station
- Detector time distribution (rms ~ **4 ns**)
- Electronic chain contribution (delay and jitter):

  - Cable lengths: 10÷21 m
    (delay of 6 ns/m and jitter 50 ps/m, **(60÷126) ns**)
    Relative delay: up to **66 ns**
  - Logical stages:
    CARDIAC (delay **16 ns**, jitter **220 ps**)
    IB (delay **20 ns**, jitter **500 ps**)





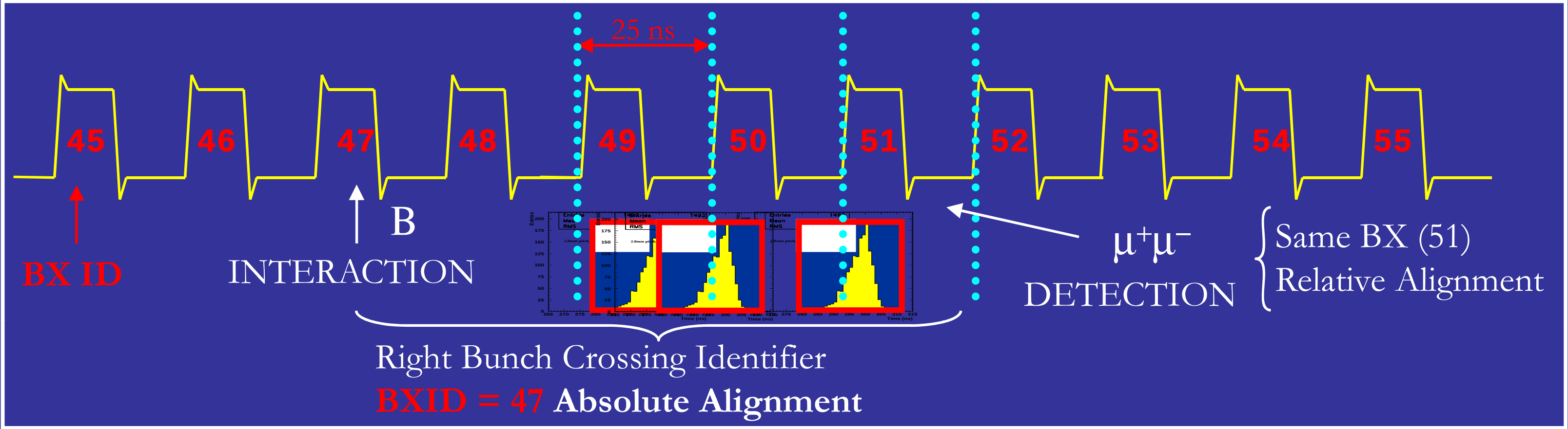


LHCb Muon System - Requirements

Time Alignment … for each PCH channel (122,112)

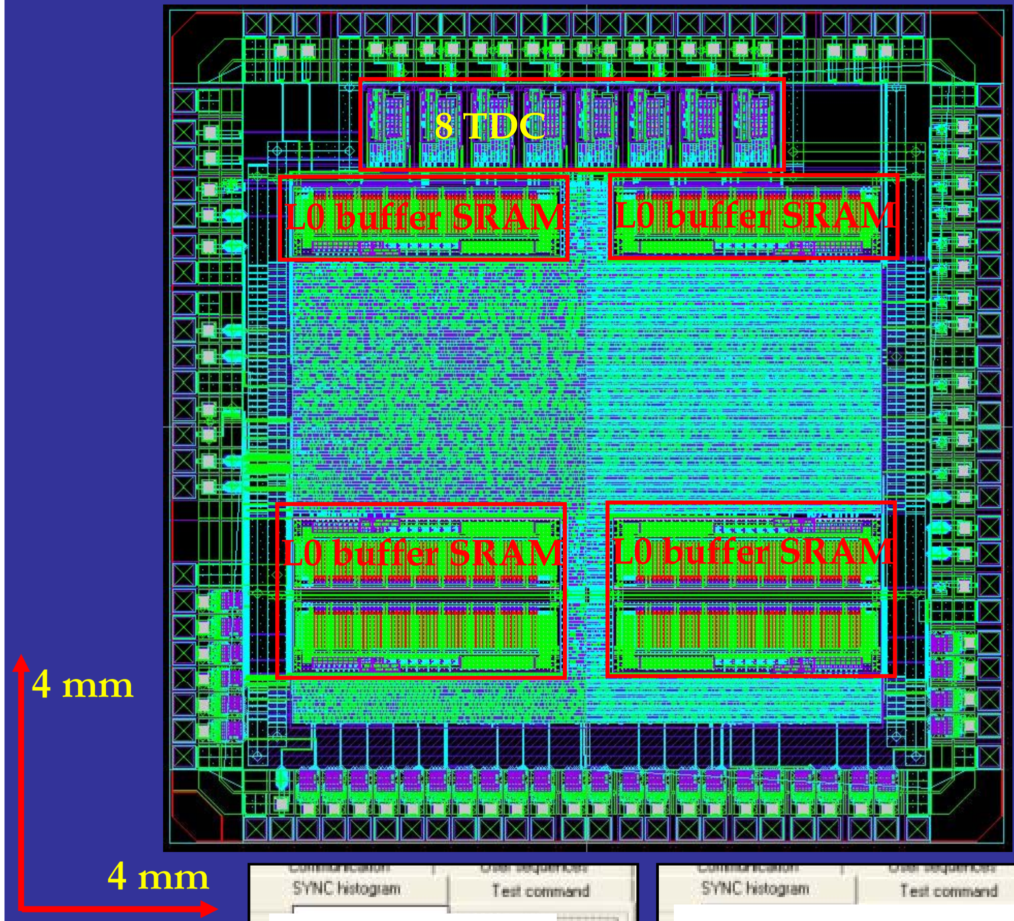
$\Delta t = \Delta t_F + \Delta t_C$

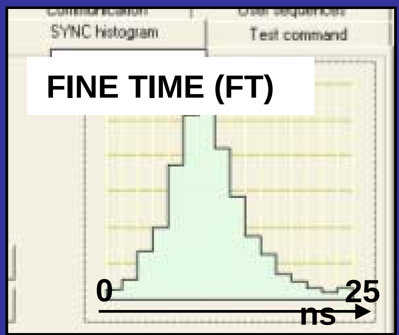
- Fine Delay $\Delta t_F = \Delta t - \Delta t_C$ (phase within the bunch crossing)
  - Owing to the nature of the Muon Detector, it is needed to measure the time of the hits inside the clock period, building the time spectra and centering them inside the 25 ns window, in order to maximize detection efficiency
- Coarse Delay $\Delta t_C = \mathrm{Int}(\Delta t/25\ \mathrm{ns})$ (integer number of Bunch Crossings)
  - For a given event, align all the hits within one ODE board and give them the **SAME Bunch Crossing Identification** (relative alignment)
  - Give the hits the **RIGHT Bunch Crossing Identification BXID** (absolute alignment)

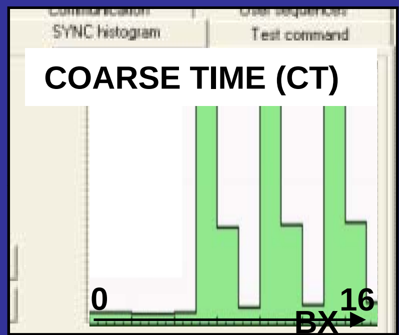


Custom Synchronization Tools: SYNC

SYNC layout







- Measure the hit time arrival at the ODE board level, before the hits are dispatched to L0.
  END OF CHAIN: SYNC ASIC

SYNC on ODE (IBM CMOS 0.25µm)

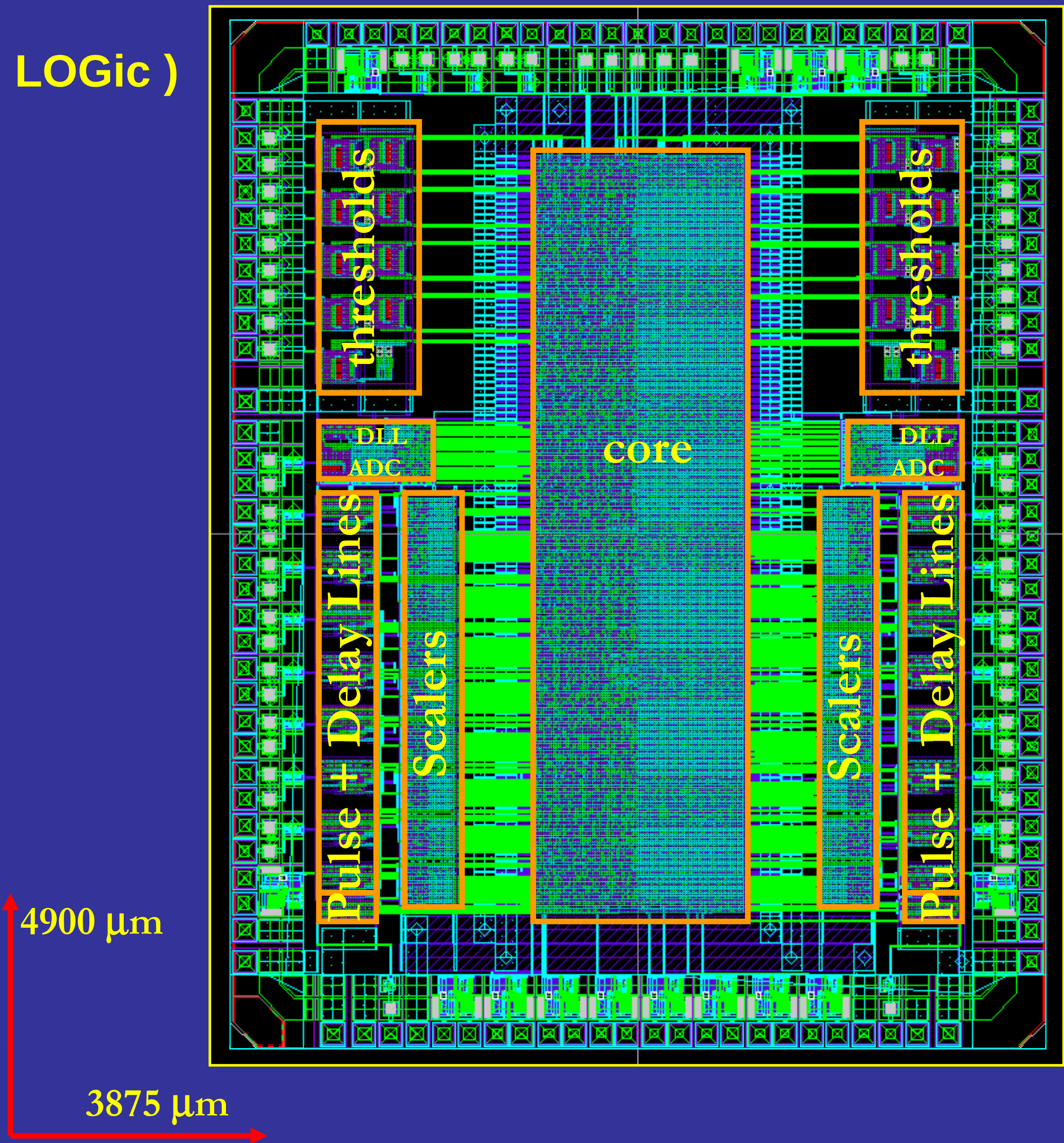
- 8 input LVDS CH
- 1 TDC for each input channel
  - 1.5 ns resolution in 25 ns period
- Time histogram x SYNC input channel selected by ECS
  - 16 counters of 24 bits each
  - Fine Time (FT) histograms
    - on input hits or on L0-passed hits
  - Coarse Time (CT) histograms (on orbit start)
- BXid association
  - Master clock from TTCrx: BX Counter
- Coarse delay tuning: BXId tagging
  - Up to 3 pipelined steps of 25 ns per input CH
  - BX counter offset

Custom Synchronization Tools: DIALOG

DIALOG layout
(DIagnostic time ALignment and LOGic)

DIALOG on FEE (IBM CMOS 0.25µm)

- 16 input & (8 to 2) output LVDS CH
- Starts the PCHs logical combination (OR 2/4/8)
- Fine delay tuning 1.6 ns x 31 steps (per single input channel)
- Possibly mask every input CH
- Each FE channel can be pulsed at a programmable BX



Synchronization: different strategies for different scenarios

Nominal Beam Conditions

- Directly gives the absolute alignment but requires a "good" event rate:
  - RIGHT BX identification without using the L0 trigger response (ECS world)
  - DAQ data analysis used only to verify L0 μ trigger efficiency
  - not the case in the (long) startup period
  - now considered as a cross-check

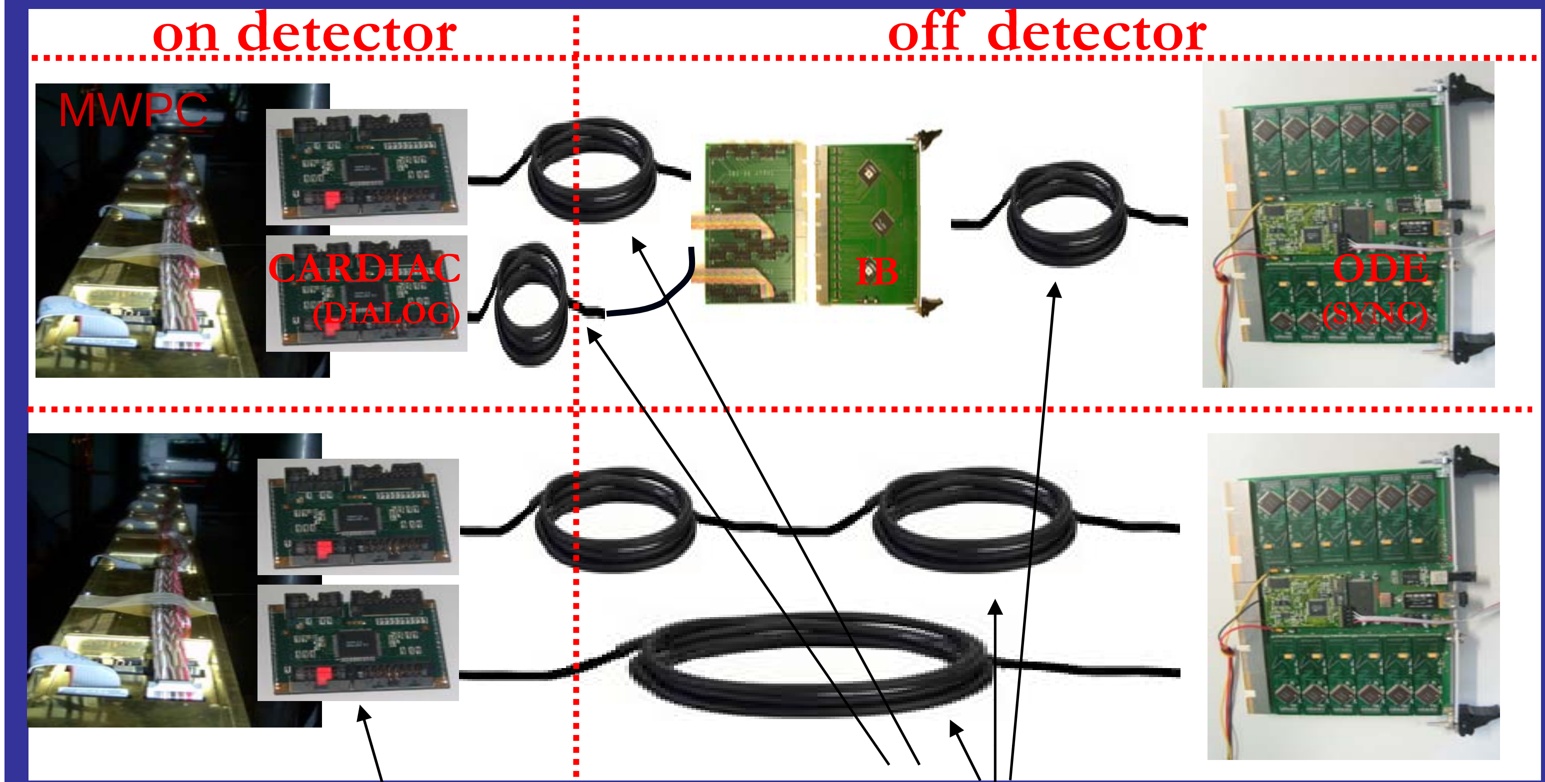
Pulse System + non nominal trigger

- Present strategy:
  - **STEP 1** (ECS world – Pulse System): SAME BX identification (relative alignment) without using the L0 trigger response
  - **STEP 2** (DAQ world):
    - DAQ data analysis (using non nominal trigger) with the software LHCb framework
    - Pulse run to verify step 1 for LCH
    - BEAM ON: chamber responses and time of flight contribution to calculate the offset between SAME and RIGHT BXid (absolute alignment)

Relative Alignment in present scenario

The internal LCH alignment can be done (2   48 PCHs for 1 LCH):

- Enabling FE channels (PCH) one by one according with connections mapping at the beginning of the electronic chain
- Generating a pulse, on FE board, in a given BX by means of the Pulsing System
- Measuring time on SYNC, building the histograms and applying the delay on corresponding DIALOG and SYNC



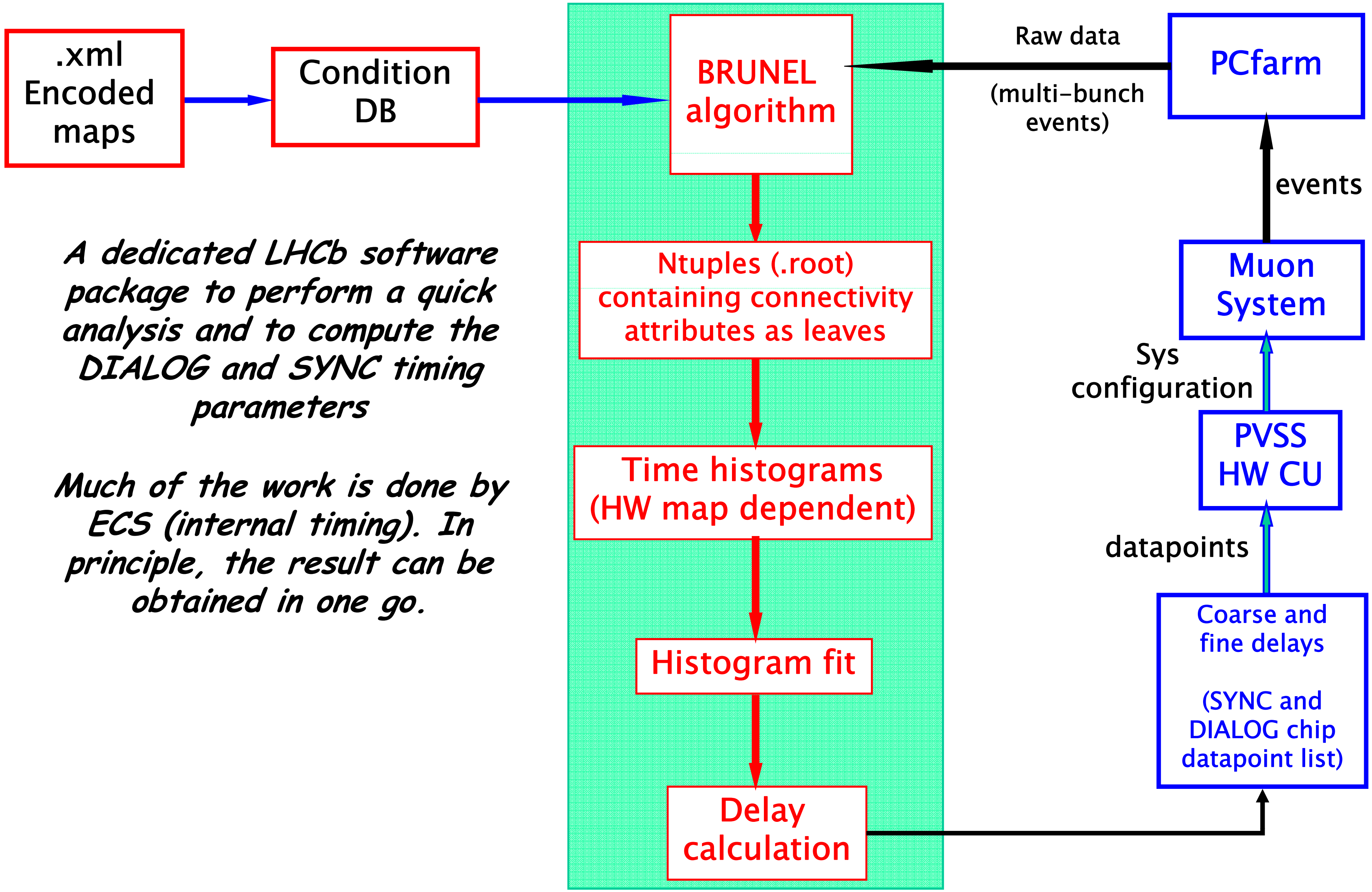
The same FE channel can belong to different logical channels (Inter-channel skew below 2 ns)

DAQ only sees logical channels LCH

PCH masking & pulsign on DIALOG

LVDS cables (different lengths)

Time Alignment SW Structure (DAQ)



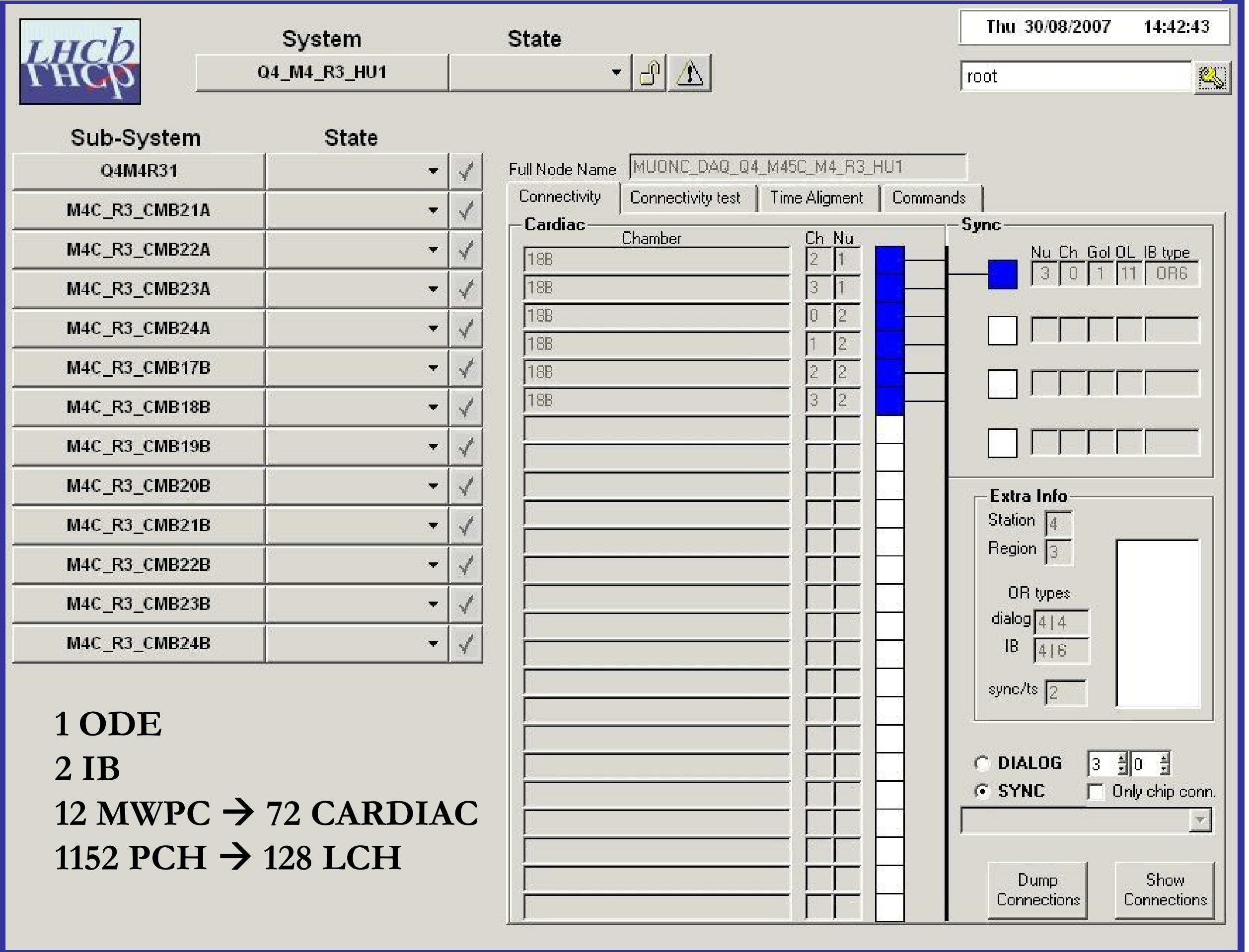
A dedicated LHCb software package to perform a quick analysis and to compute the DIALOG and SYNC timing parameters

Much of the work is done by ECS (internal timing). In principle, the result can be obtained in one go.

Commissioning

What we are doing now…

1. Test of system connectivity from Chambers to ODE
   - The test is performed on one ODE and its associated connectivity tree: IB and all the FE channels connected to it
   - Each ODE is independent of the others and has one of the 12 types of electronic chain Connection map
   - Connection Maps are being integrated in the ECS-PVSS control program



1 ODE

2 IB

12 MWPC → 72 CARDIAC

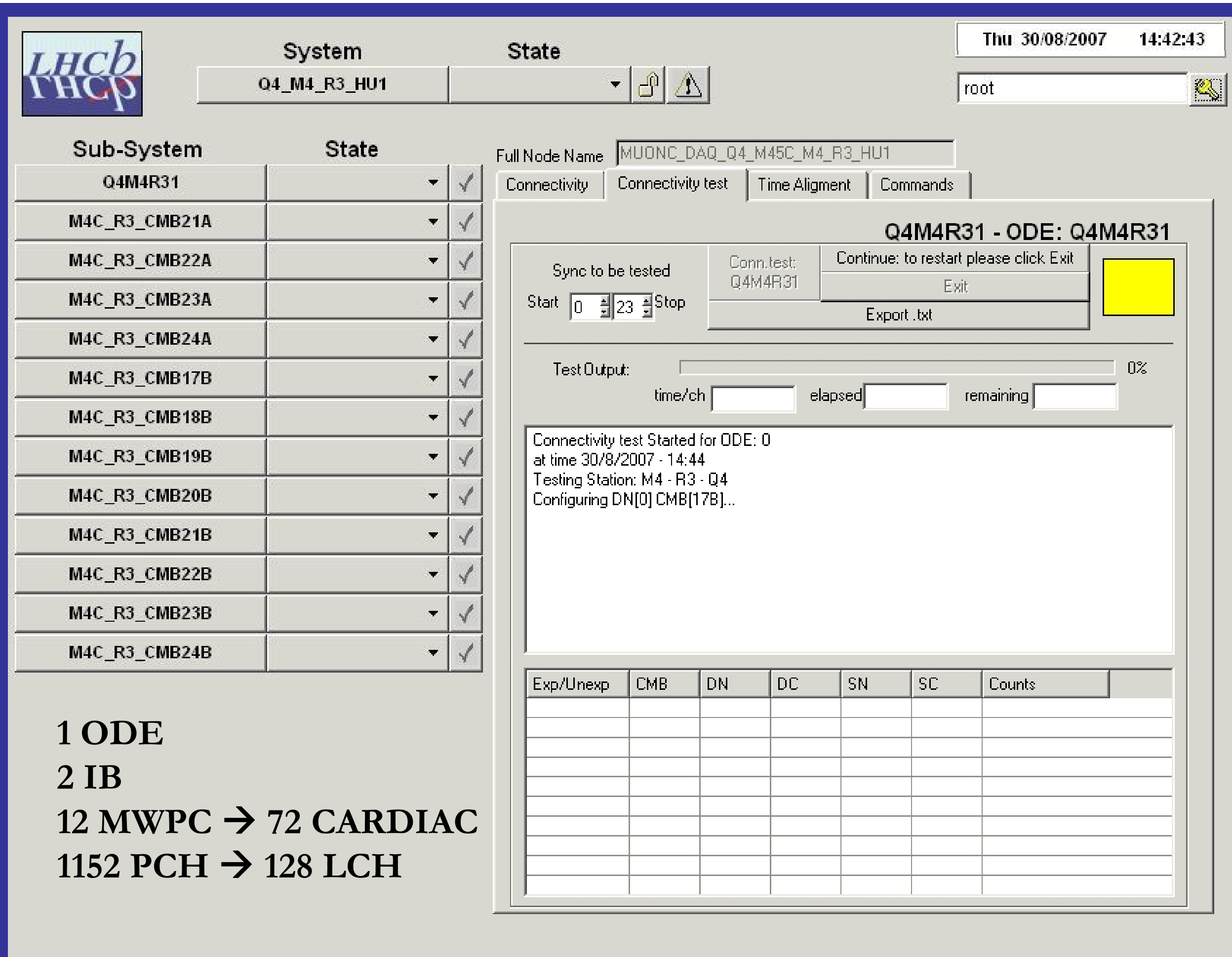
1152 PCH → 128 LCH

Commissioning

What we are doing now …

… Connectivity Test

- Due to complexity of connections, the alignment cannot be pursued manually. A dedicated SW has being developed.



1 ODE
2 IB
12 MWPC → 72 CARDIAC
1152 PCH → 128 LCH

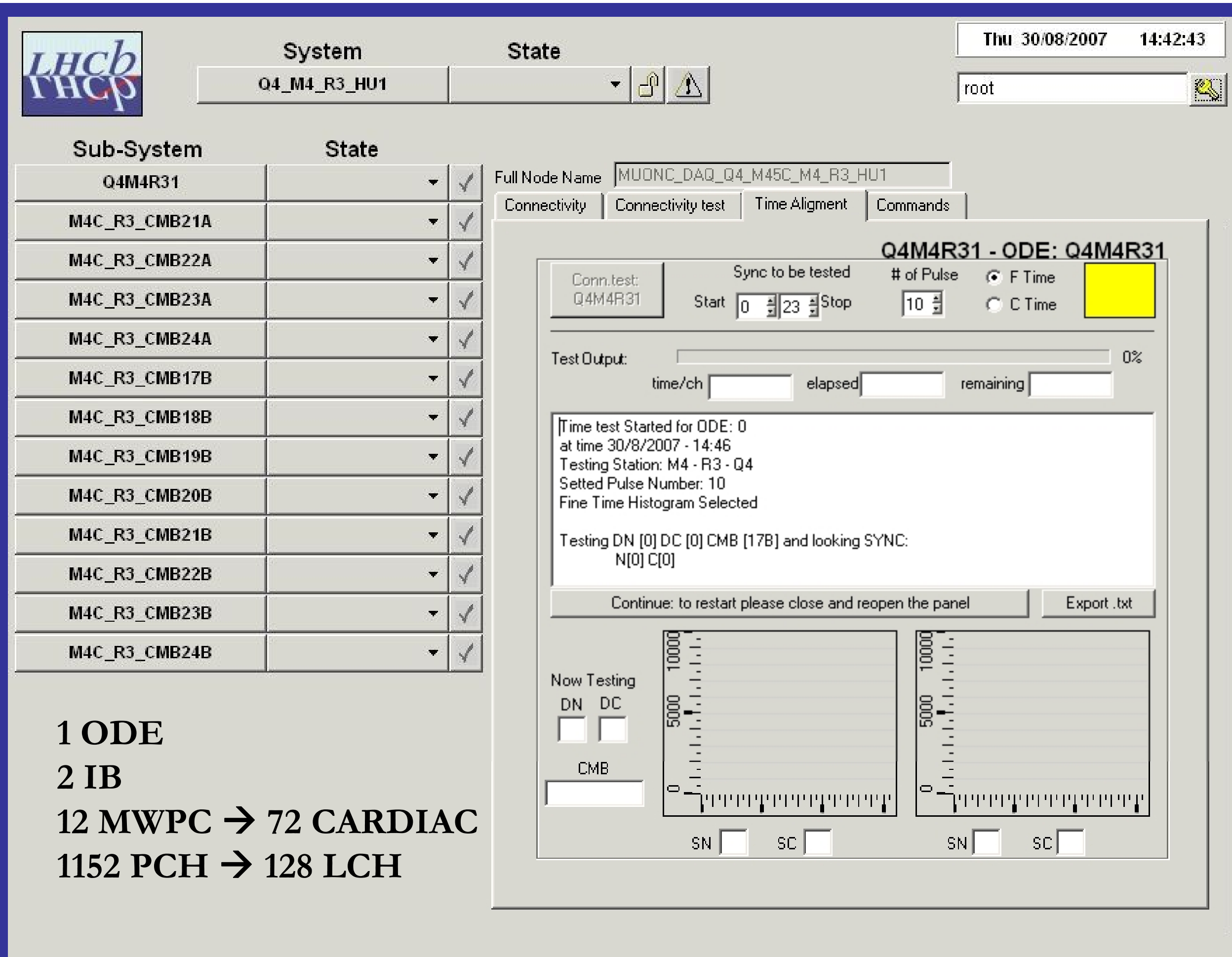
- To make the test we:
  - Set low threshold (on DIALOG) for discriminator (time distribution of FE channel is a flat distribution of noise signals)
  - enable only one PCH channel at a time (on DIALOG) to test every single connection
  - download the FT histograms (from SYNC) of each LCH channel for all the 24 SYNCs the ODE
  - Verify that the only one PCH channel enabled is seen from the right SYNC (chip and channel), while all the other SYNCs don't see anything

Commissioning

What we are going to do …

2. Once verified the correct connectivity of one ODE, we'll have to reach the Relative (Internal) Time Alignment, that is SAME BXid for LCH of one ODE

- Same structure of connectivity test, but using synchronous pulse signals instead of noise
- Download time histograms acquired on SYNC for each LCH channel
- Calculate Fine Time (FT) adjustment and compensate Fine Time delay on DIALOG
- Calculate Coarse Time (CT) adjustment and compensate Coarse Time delay on SYNC



Conclusions

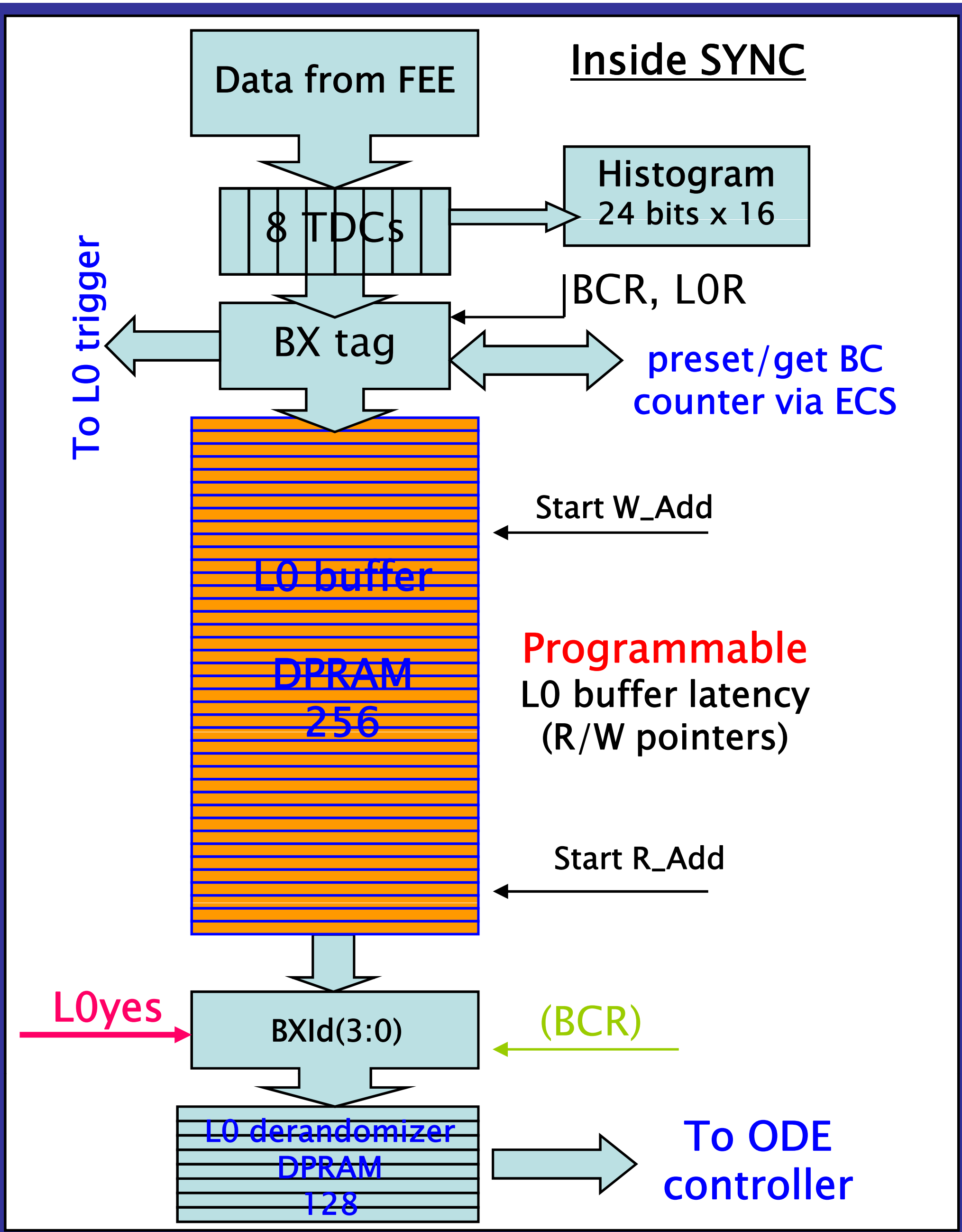
- The Muon System is characterized by a large number or FE channels, logically combined before readout with complex connectivity maps, varying from region to region

- Dedicated full custom ASICs, DIALOG & SYNC, were developed as instruments for calibration and monitoring

- The Time Alignment Procedure can be started even without the beam using the Pulse System

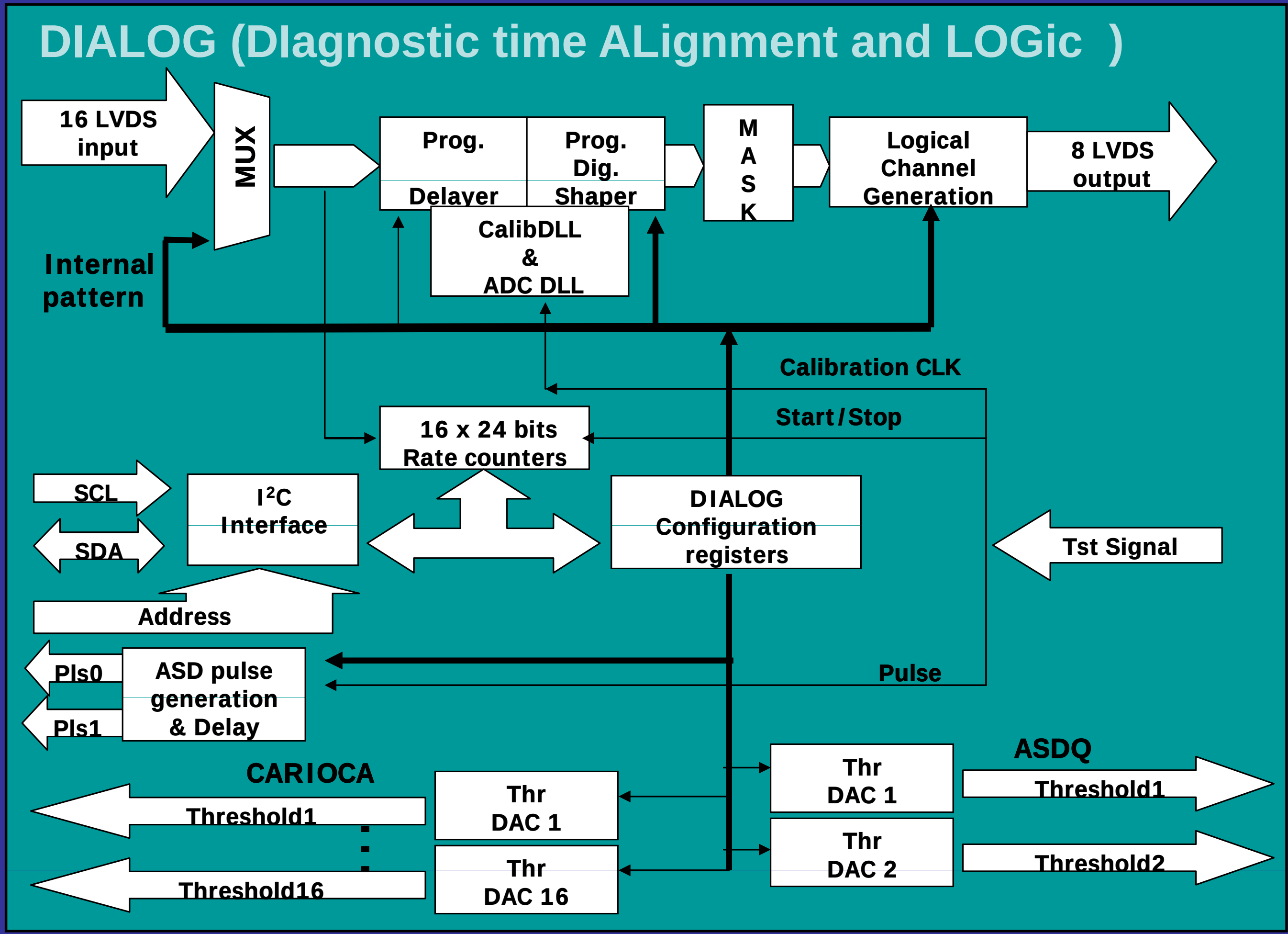
- Commissioning
  - current phase: test of Muon System connectivity
  - next phase: relative alignment of PCHs

SYNC



Inside SYNC
Data from FEE
8 TDCs
Histogram
24 bits x 16
BCR, L0R
BX tag
To L0 trigger
preset/get BC
counter via ECS
Start W_Add
L0 buffer
DPRAM
256
Programmable
L0 buffer latency
(R/W pointers)
Start R_Add
L0yes
BXId(3:0)
(BCR)
L0 derandomizer
DPRAM
128
To ODE
controller

DIALOG


DIALOG (DIagnostic time ALignment and LOGic)
16 LVDS input
MUX
Prog. Delayer
Prog. Dig. Shaper
M A S K
Logical Channel Generation
8 LVDS output
Internal pattern
CalibDLL & ADC DLL
Calibration CLK
Start/Stop
16 x 24 bits Rate counters
SCL
SDA
I²C Interface
DIALOG Configuration registers
Tst Signal
Address
Pls0
Pls1
ASD pulse generation & Delay
Pulse
ASDQ
Thr DAC 1
Thr DAC 2
Threshold1
Threshold2
CARIOCA
Thr DAC 1
Thr DAC 16
Threshold1
Threshold16