Commissioning of the CMS DT electronics under magnetic field

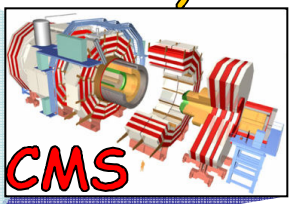
Cristina Fernández Bedoya

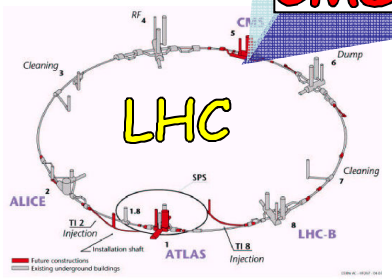
CIEMAT. Madrid, SPAIN.

on behalf of the CMS DT community

September 22nd, 2009. Paris, France.

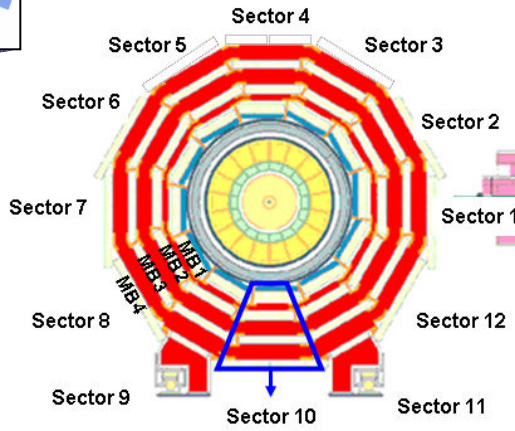
DT (Drift Tube) Chambers at CMS

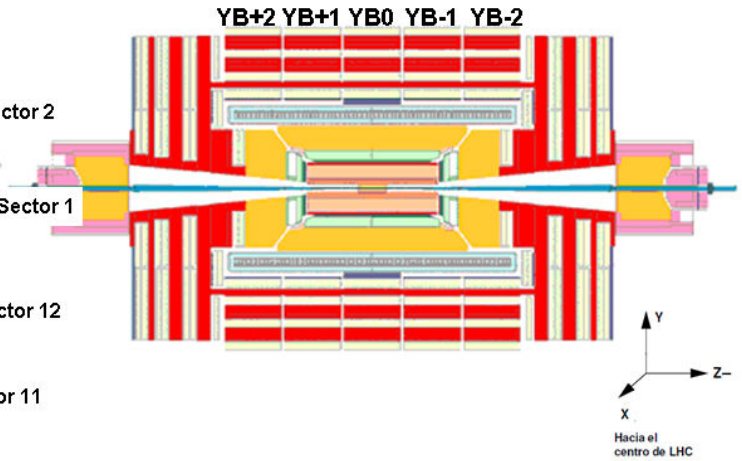




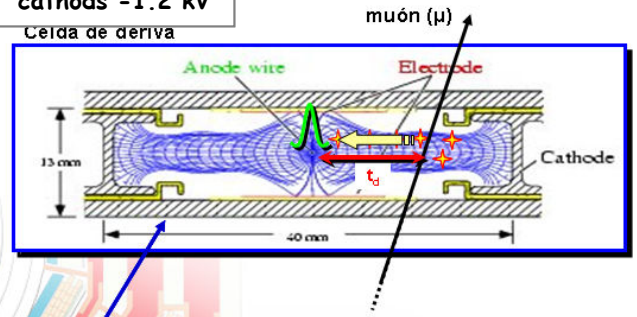
250 chambers
- 5 wheels
- 12 sectors/wheel
- 4 stations/sector:
  - MB1, MB2, MB3, MB4

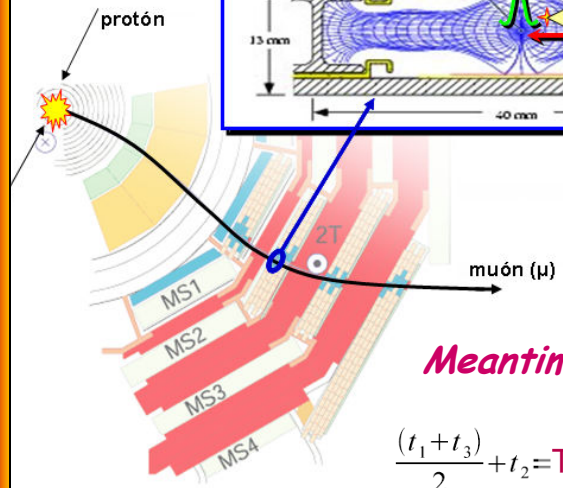
172,200 drift cells

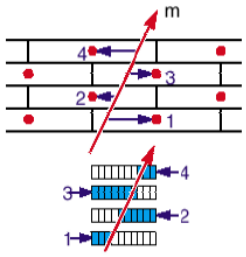




Gas: Ar/CO2 (85/15)%
High Voltage: wires 3.6 kV
strips 1.8 kV
cathods -1.2 kV







Meantimer

$$\frac{(t_1+t_3)}{2}+t_2=T_{MAX}$$

3 Superlayers per chamber (2 SLΦ, 1 SLθ)
Almost linear space-time relationship V_d~55 μm/ns
Resolution per wire ~200 μm
Efficiency ~ 99%

Covers $0<\eta<1.2$

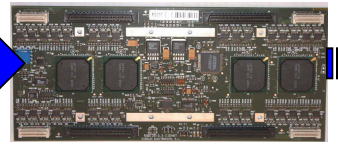
- Provide muon identification
- Precise momentum measurement. Good p_T resolution at high transverse momenta.
- Reliable and robust trigger:

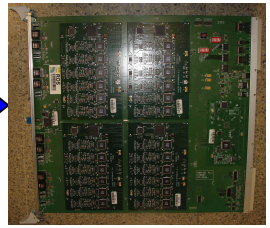
  p_T standalone measurement @ Level-1 and High Level Trigger and precise Bunch Crossing (BX) assignment.

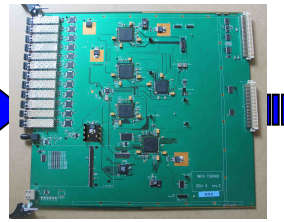
DT Read-Out System

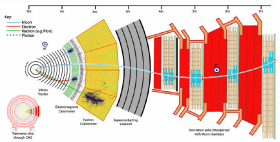
UXC Cavern | USC55 Service cavern

DT CHAMBERS → ROB → ROS → DDU









30 m copper
240 Mbps
~16 Mbps throughput

75 m optical
800 Mbps
~80 Mbps throughput

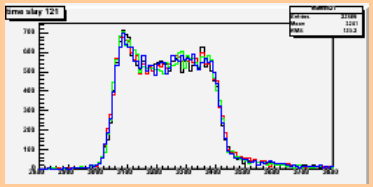
S-LINK64
320 MB/s
~ 200 MB/s throughput

Chambers

- 5 wheels
- 60 sectors
- 250 chambers
- 660 super-layers
- 1640 layers
- ~172200 channels

Minicrates

- 1500 ROB
- 128 ch/ROB
- Time digitalization (0.7 ns resolution)
- 1 µs time window



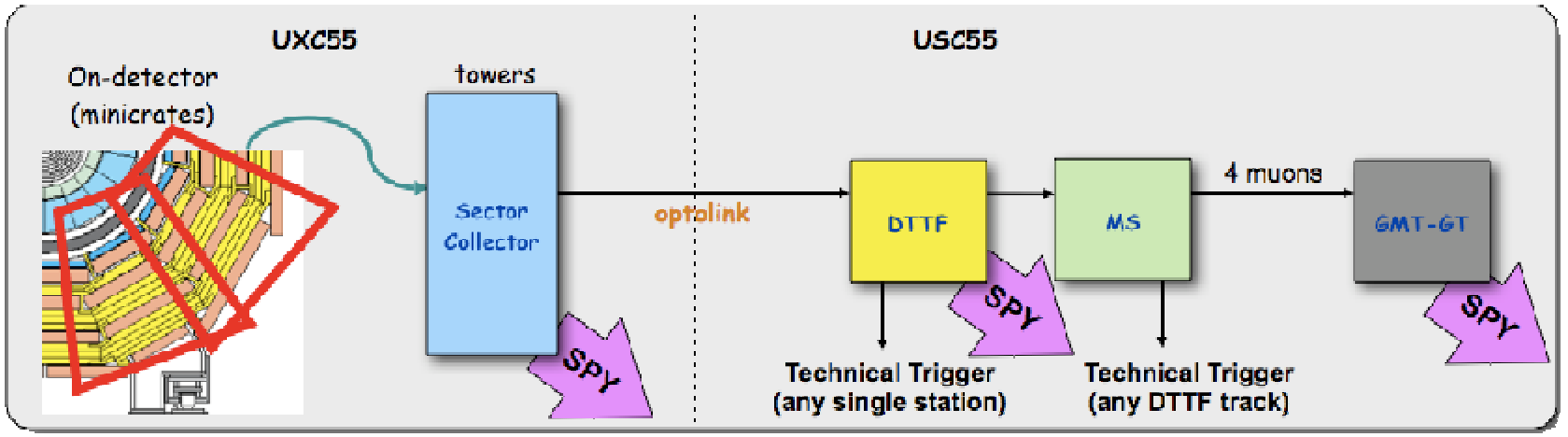
Sector Collector

- 60 ROS
- 25 ch/ROS => 1 sector
- Data merging
- Data quality monitoring
- ~ 260 bytes muon event size/ROS

DDU (Device Dependent Unit)

- 10 DDU => half a wheel
- 12 ch/DDU (only half needed)
- Data merging
- Data quality monitoring
- TTS interface
- ~ 0.7 kB muon event size/DDU

DT Trigger System



Minicrates
(1/chamber = 250)

- Track Segment and BX Identification
- Ghost busting
- Best 2 TS / chamber sorting

Sector Collector
(1/sector = 60)

- Trigger synchronization
- Local trigger spy (timing and quality data of TS injected to DAQ)

Track Finder
(Phi: 1/sector = 72
+ Eta: 1/wedge = 12)

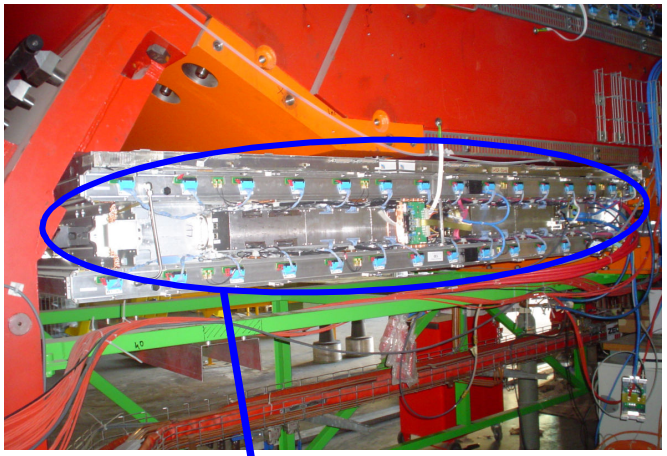
- Extrapolation and matching of TS (build full muon tracks)
- Local phi assignment
- Eta value assignment
- Pt assignment
- Full In/Out spy

Muon Sorter
12 Wedge Sorter
1 Barrel Sorter

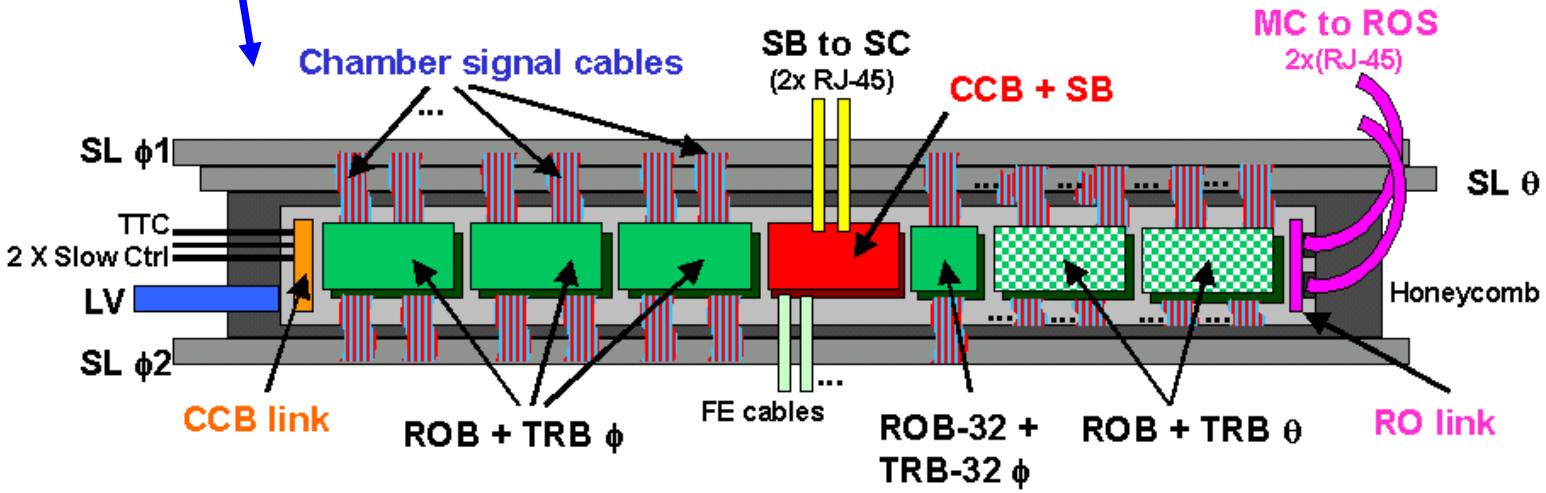
- Ghost busting
- Global phi assignment
- Final sorting of 4 best muon candidates for the Global Muon Trig

Minicrate

Attached to the DT Chambers it contains the first level read-out, trigger and full chamber control electronics.



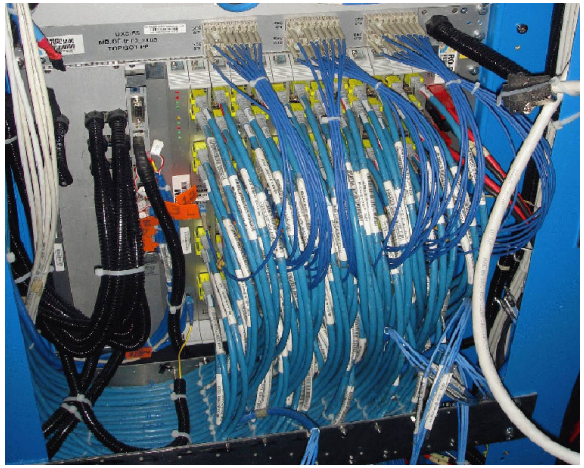
- **CCB: Full chamber control and monitoring: configures, sets thresholds, reads temperatures, etc.**
- **CCBlink: Connects the CCB to the external DT DCS system.**
- **TRB: Searches track segments and performs bunch identification.**
- **SB: Performs track selection and transmits to TSC.**
- **ROB: Time digitalization of signals coming from the chambers.**
- **ROLINK: Collects outputs from ROBs and sends it to the ROS.**



Sector Collector

In the racks on a lateral of the CMS wheel it contains the second level read-out, trigger and full chamber control electronics.

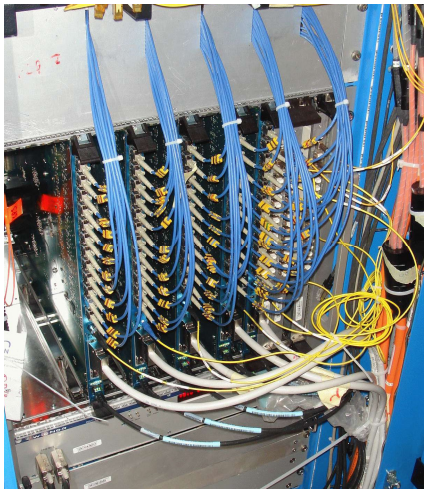
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
CONTROLADOR VME LINCO				OPT. RS-485 CONV.		TIM	ROS S6 y S7	TSC S6 y S7	ROS S5 y S8	TSC S5 y S8	ROS S4 y S9	TSC S4 y S9	ROS S3 y S10	TSC S3 y S10	ROS S2 y S11	TSC S2 y S11	ROS S1 y S12	TSC S1 y S12	PANEL DE INTERCONEXIÓN	



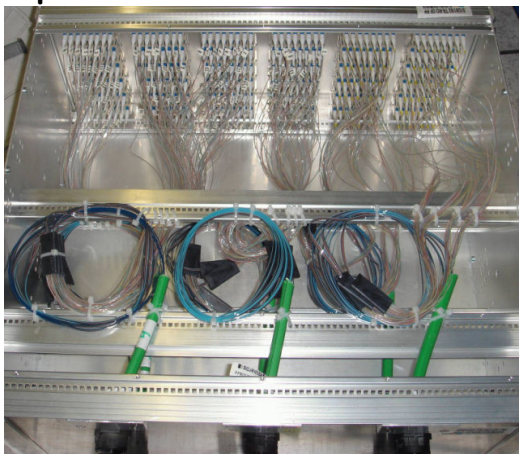
Electronics at USC (Underground Service Cavern)

Final steps before CMS global DAQ and Trigger systems

Read-out: DDU



Optical fibers from UXC to USC

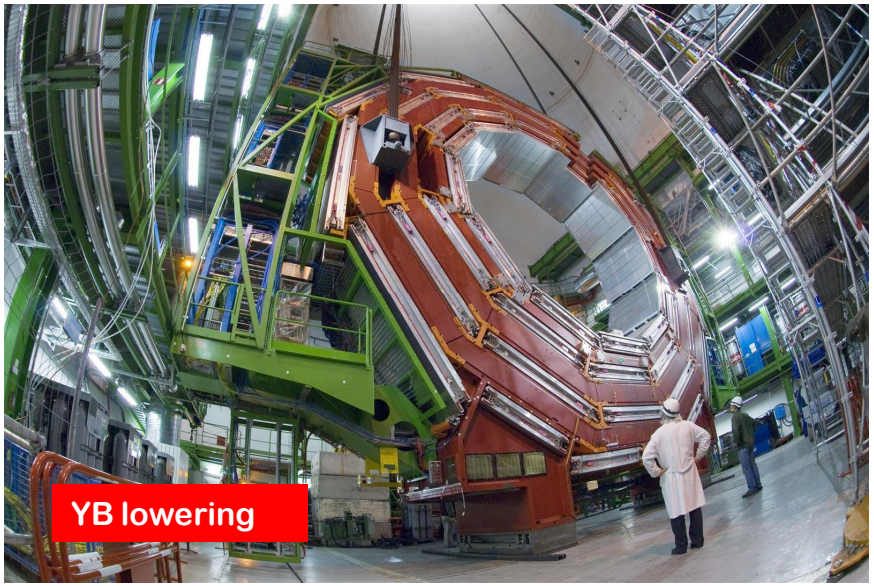


Trigger: Track Finder

DT Chambers assembly and installation

DT test & storage area
ISR (CERN)

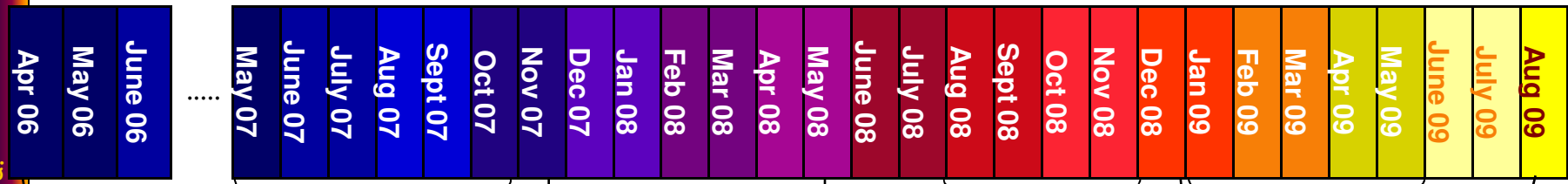
* Chambers assembled in Italy, Spain and Germany
* Minicrates attached at CERN ISR
* Installation from summer 2004 to November 2007 (surface / underground)
* Several steps of testing at all levels


YB lowering

DT installation

DT commissioning

* Once chambers are installed =>integration with the rest of the systems: final water, gas, HV, LV, read-out, DCS, trigger, etc.
* Verification on each step. A long story of cosmics data taking…



Start sector commissioning on surface

Sector commissioning underground

Wheel commissioning

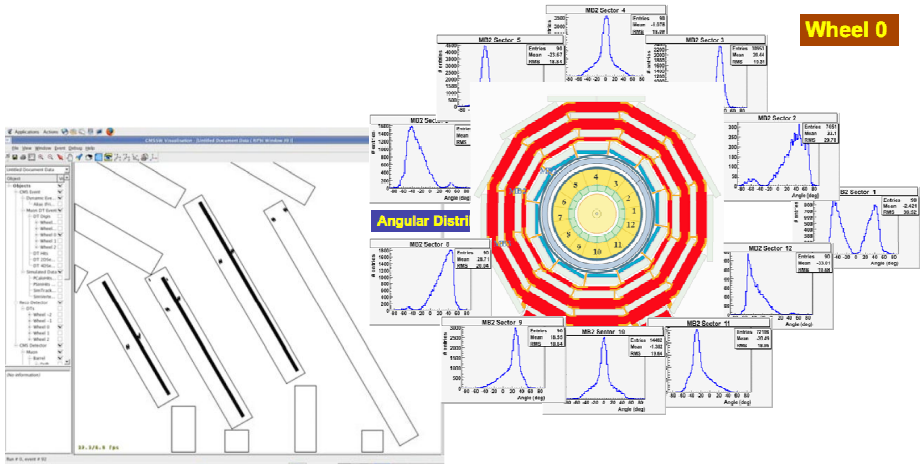
Running 100% of the detector

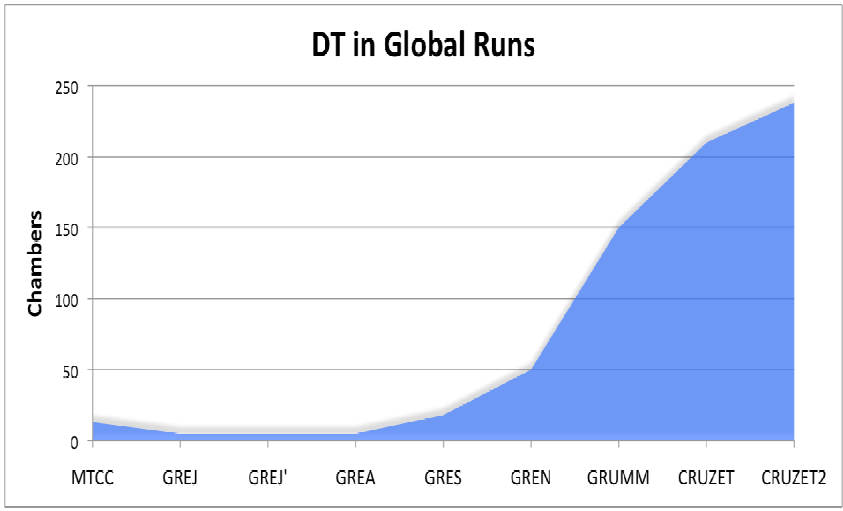
CRUZET, BEAM, **CRAFT08**

Shutdown

MWGR

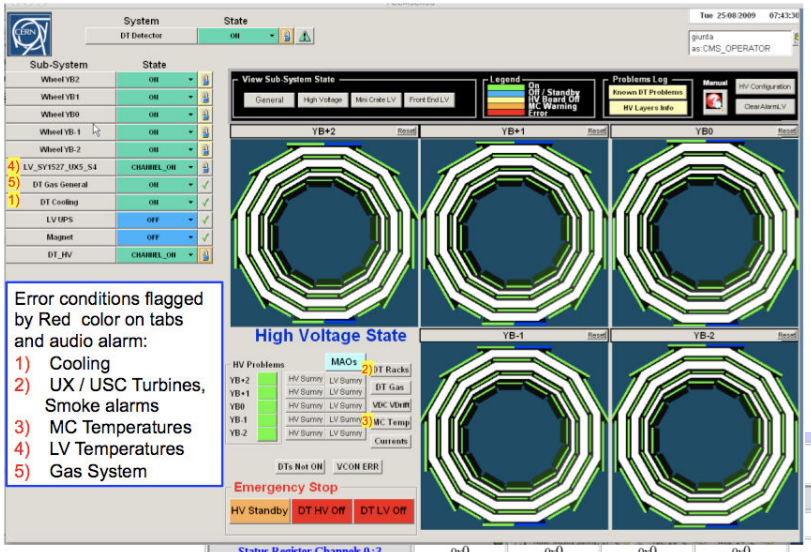
CRAFT09

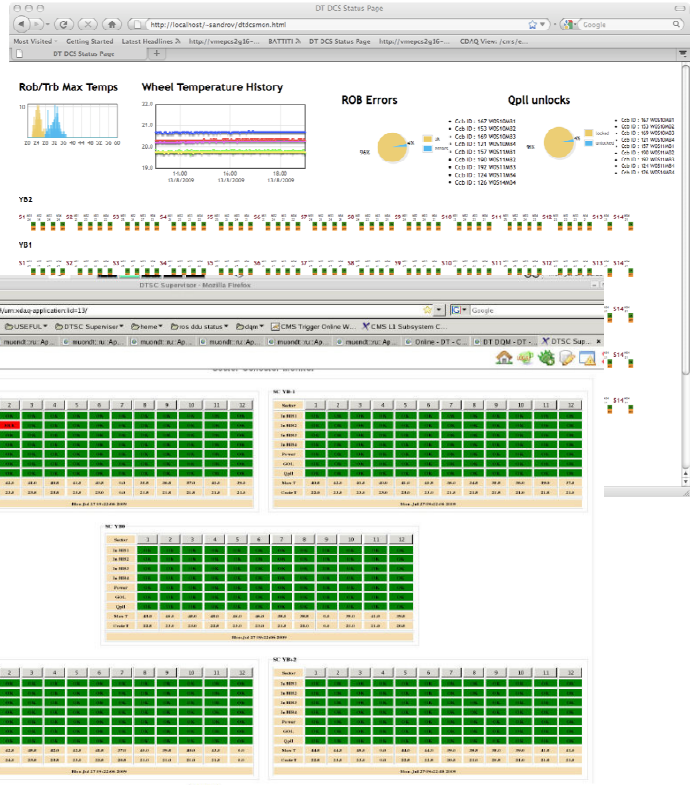




DT DCS: Control and Monitoring System

* DT DCS system has been evolving together with the integration of the system
* All basic parts can be now <u>configured and monitored in an easy and flexible</u> way
* Further work is being done in stabilizing and obtaining <u>comprehensible synthetic information at one glance</u>

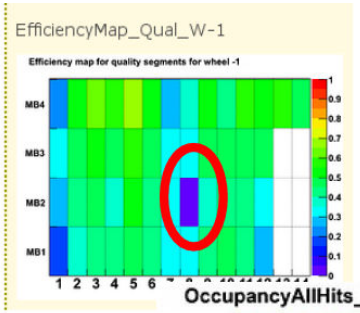


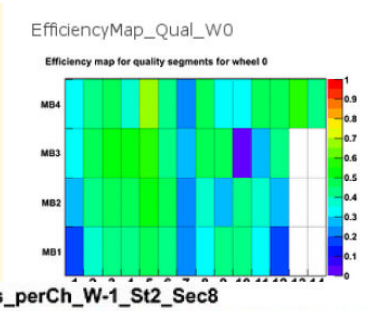


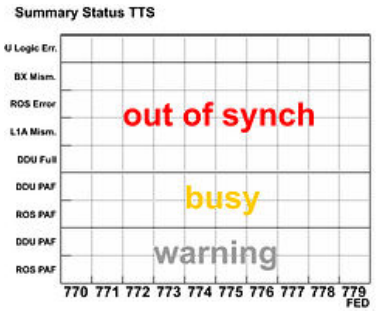
	YB+2
	0x306
Status Register Channels 0÷3	0x0 0x0 0x0 0x0 0x0
Status Register Channels 4÷7	0x0 0x0 0x0 0x0 0x0
Status Register Channels 8÷11	0x0 0x0 0x0 0x0 0x0
Fifo Status Register Channels 0÷3	0xf00000 0xf00000 0xf00000 0xf00000 0xf00000
Fifo Status Register Channels 4÷7	0xf00000 0xf00000 0xf00000 0xf00000 0xf00000
Fifo Status Register Channels 8÷11	0xf00000 0xf00000 0xf00000 0xf00000 0xf00000
Status Register 3	0x10481 0xc0000 0xc0000 0xc0000 0xc0000
Output Fifo Full Reg.	1 0 0 0 0
Output Fifo Empty	0 1 1 1 1
TTCrx Not Ready Reg.	0 0 0 0 0
QPLL Not Locked Reg.	0 0 0 0 0
QPLL Error	0 0 0 0 0
Output Fifo and SLink Status Register	0x28 0x17 0x17 0x17 0x17
TTS Mask (4 bits)	0x2 0x8 0x8 0x8 0x8

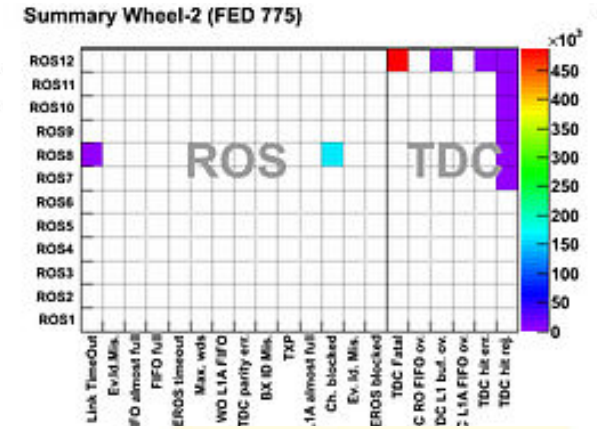
DT DQM: Data Quality Monitoring

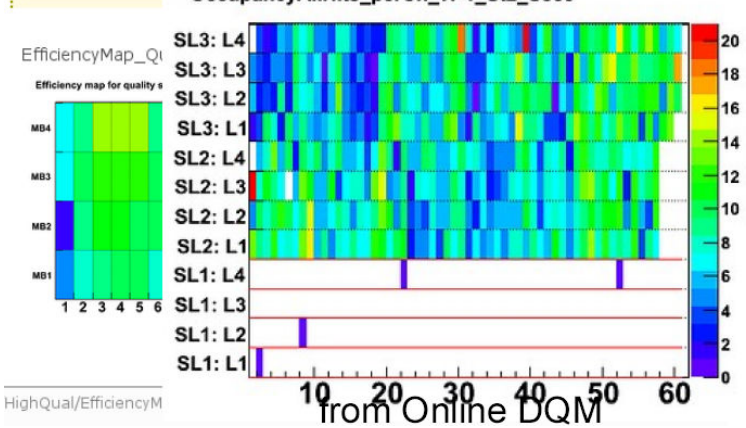
- Online monitoring allows subsystem shifters to check the **quality of the data as being produced by the detector and provide fast feedback**
- Offline monitoring has also become a standard reference to extract information of the **performance of the detector** and of the local reconstruction
- Many plots are present to study **detector efficiency, data integrity and trigger performance**
- But more important, a small number of plots have been produced in order to **summarize the status** of the detector in a concise way

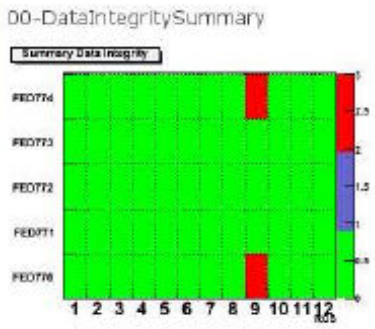


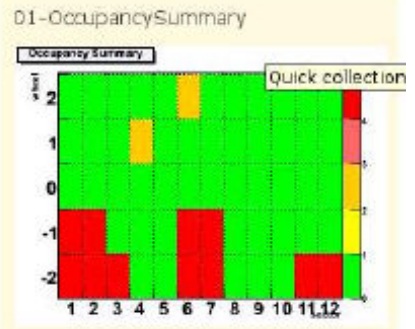






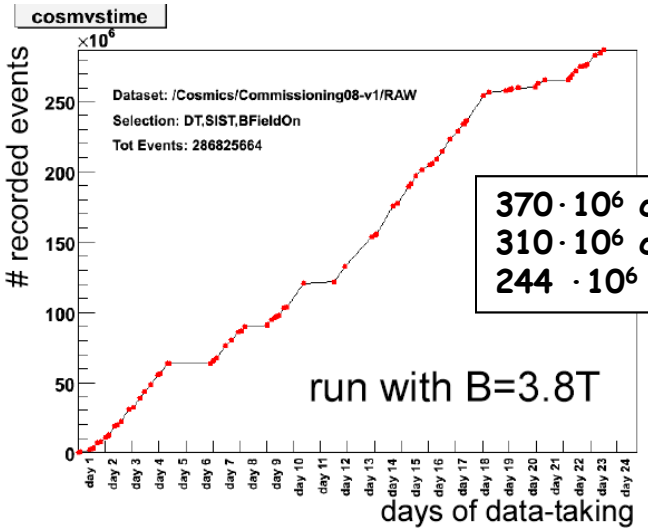






CRAFT (Cosmic Run at Four Tesla)

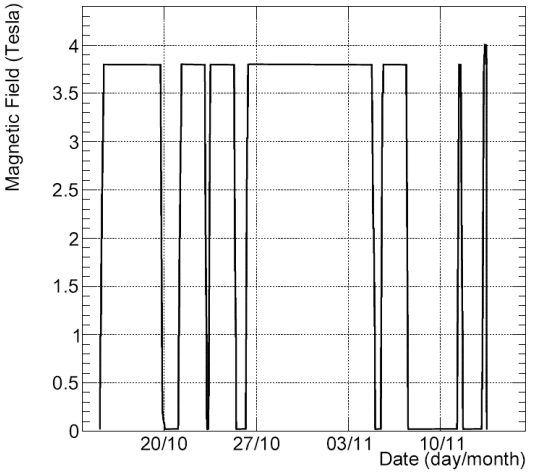
Two campaigns:
* October 13rd to November 11th, 2008 (CRAFT08)
* July 23rd to September 1st, 2009 (CRAFT09)

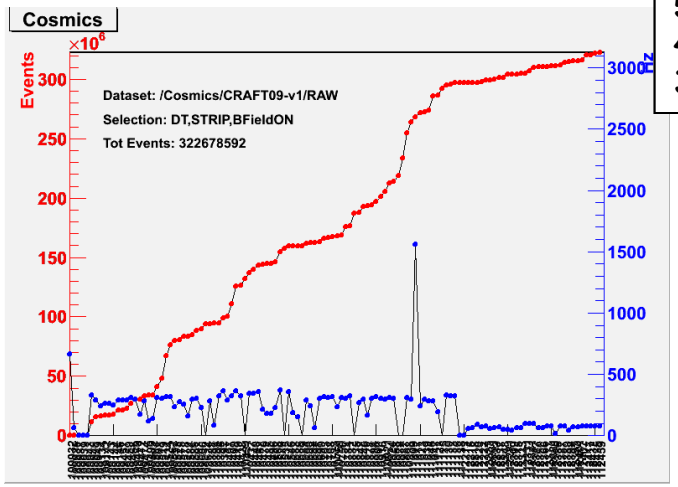


CRAFT08

370 · 10⁶ cosmics CRAFT08
310 · 10⁶ cosmics collected by DT
244 · 10⁶ cosmics with DT and Bfield on

83% by DT

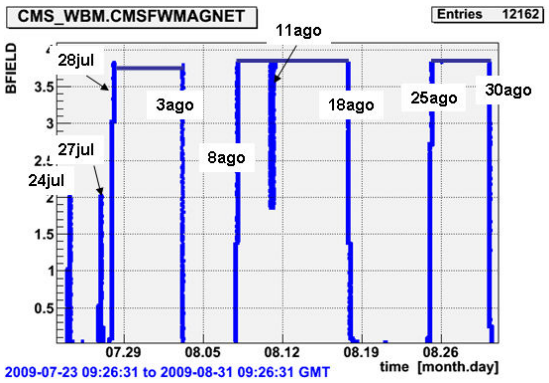




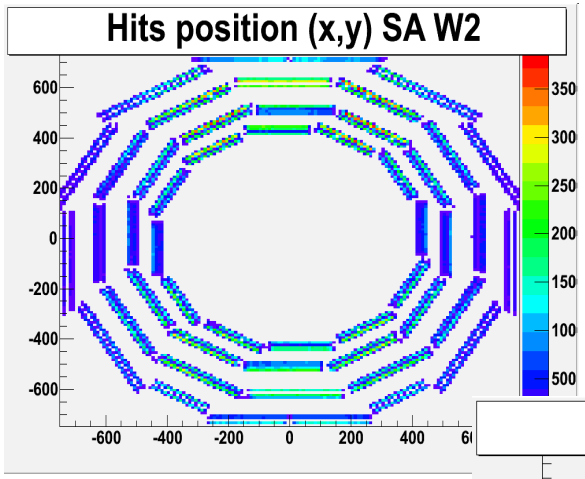
523 · 10⁶ cosmics CRAFT09
480 · 10⁶ cosmics collected by DT
322 · 10⁶ cosmics with DT and Bfield on

CRAFT09

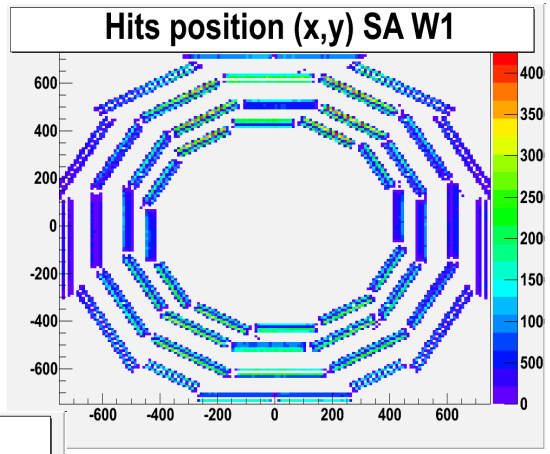
92% by DT

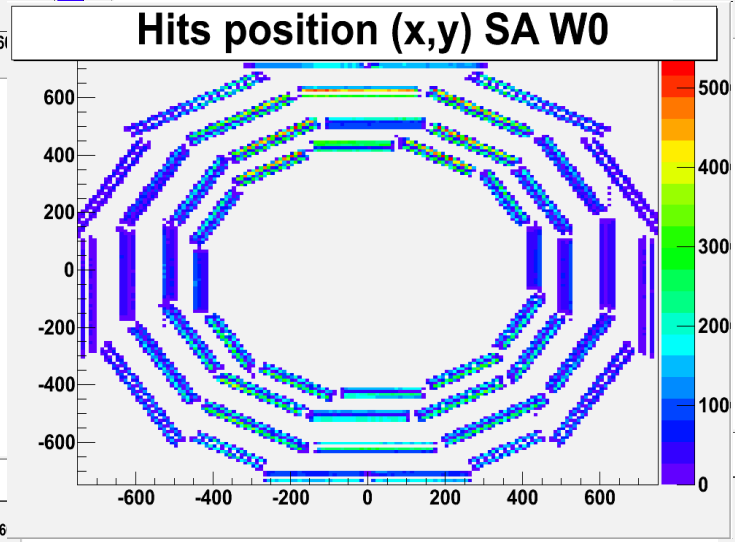


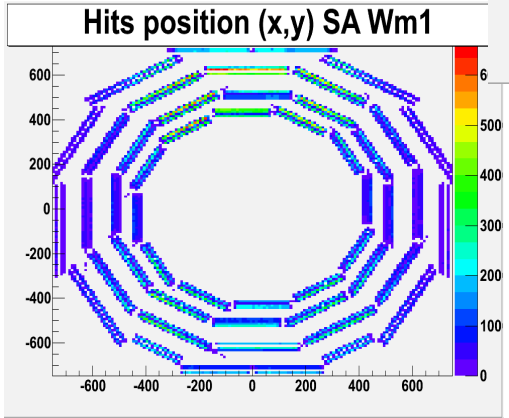
DT at CRAFT



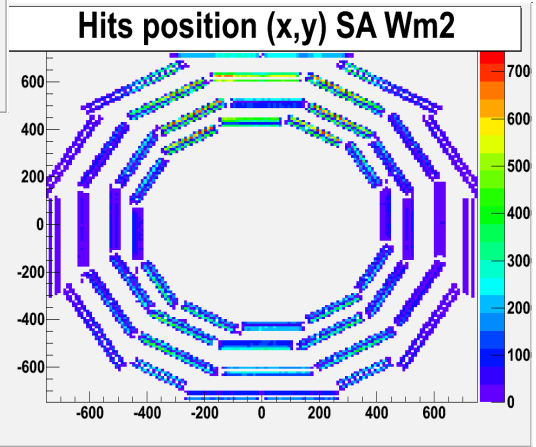
~100% of the DT detector IN







Pending approval

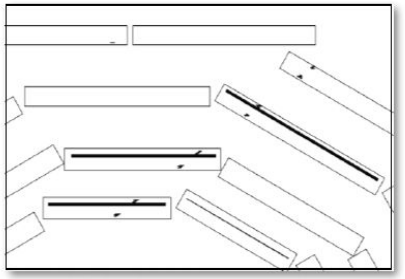


CRAFT. DT System Set-up

* A dedicated muon trigger was set-up in order to work with cosmics:

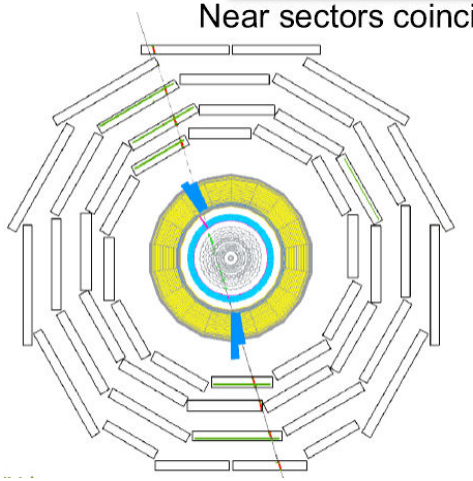
* Coincidence of at least two chambers in the same or nearby sector without requiring that the muon tracks point to the nominal interaction point

  - upper/lower sectors synchronized among them
  - Top delayed with respect to bottom (~1,5 bx, TOF of vertical muons)
  - Trigger at the same BX cosmic muons crossing both top and bottom sectors.



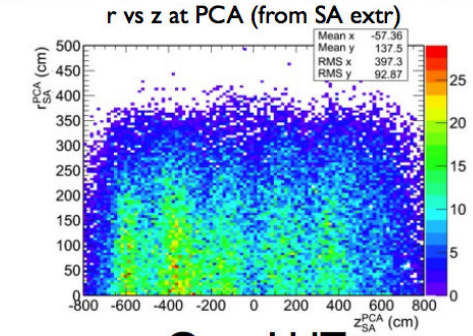
Near sectors coincidence tests

* The last week of CRAFT09 was run with bottom-only L1 muon triggers, and tighter muon roads appropriate for LHC collision muons

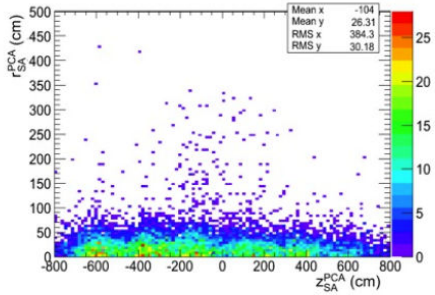


* LHC Look-Up Tables clearly do the job: distance of closest approach to beam axis is much narrower

Comparison open/closed LUTs



OpenLUT

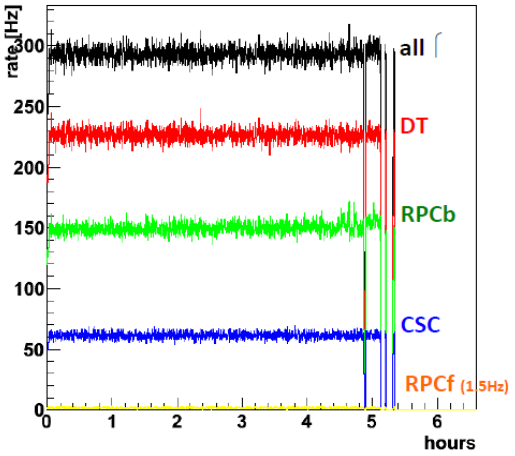


ClosedLUT

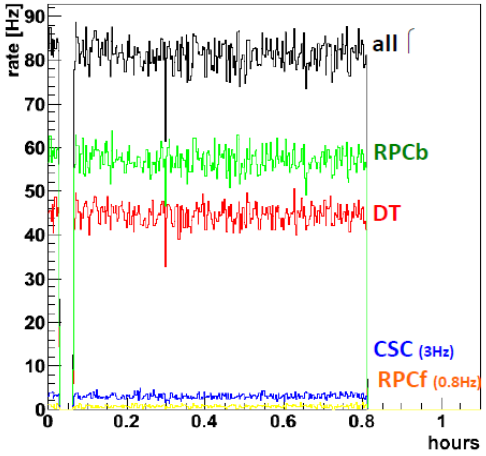
CRAFT. DT System Set-up

* DT trigger rates have shown stable through time

"Cosmics" setup
Run 109508

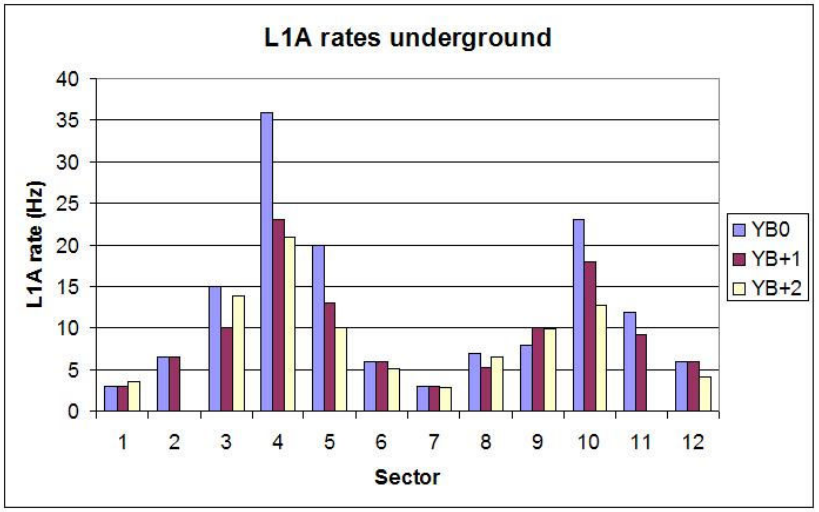


"LHC" setup
Run 112392



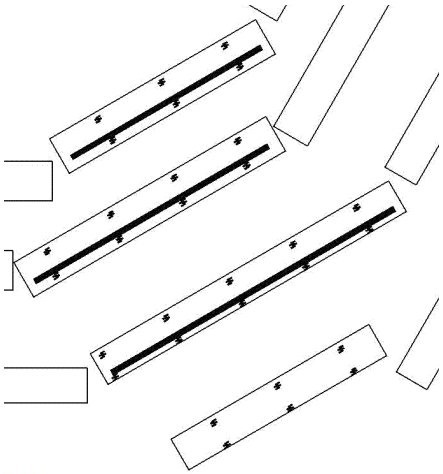
* Average trigger rates during most of the runs:
  - 300 Hz muons
  - 100 Hz calibration
  - 600 to 80 kHz random triggers

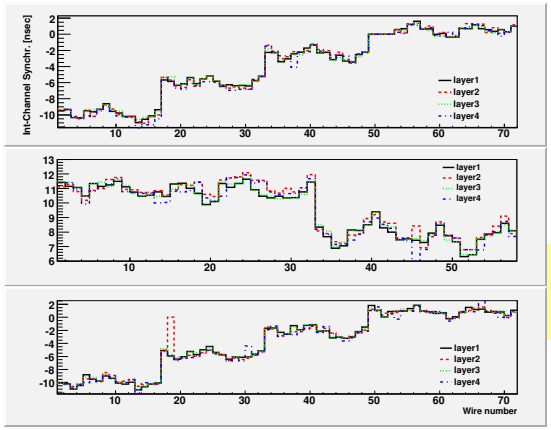
* Calibration stream has been run satisfactorily during the abort gaps



Calibration mechanism: Test Pulses

*** Signals are injected at front-end level simulating vertical tracks along the chamber**

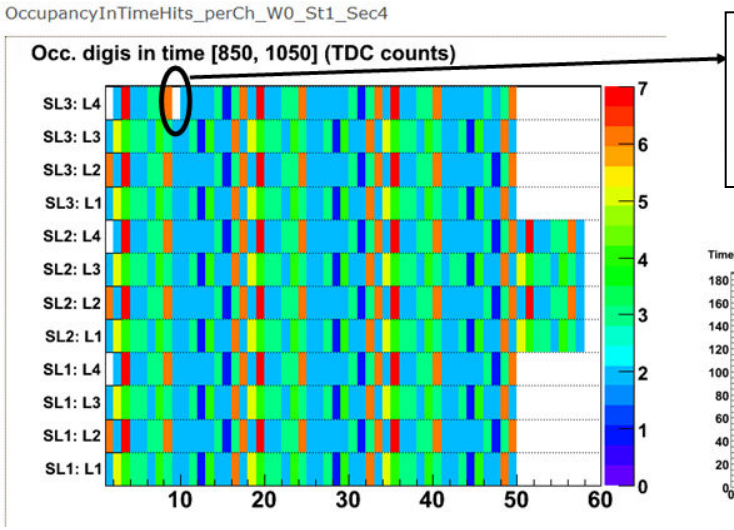




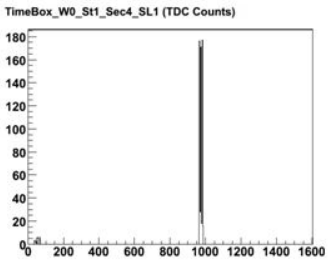
Interchannel synchronization

*** Performs scanning of dead channels in all the electronics chain**

*** Allows interchannel synchronization in the calibration of the detector**



Dead channel in the electronics
No signal in the test pulse



Running the calibration stream in the abort gap:

CRAFT08: Some problems of trigger signals in the physics gap => Solved

CRAFT09: New timing configuration allows better performance

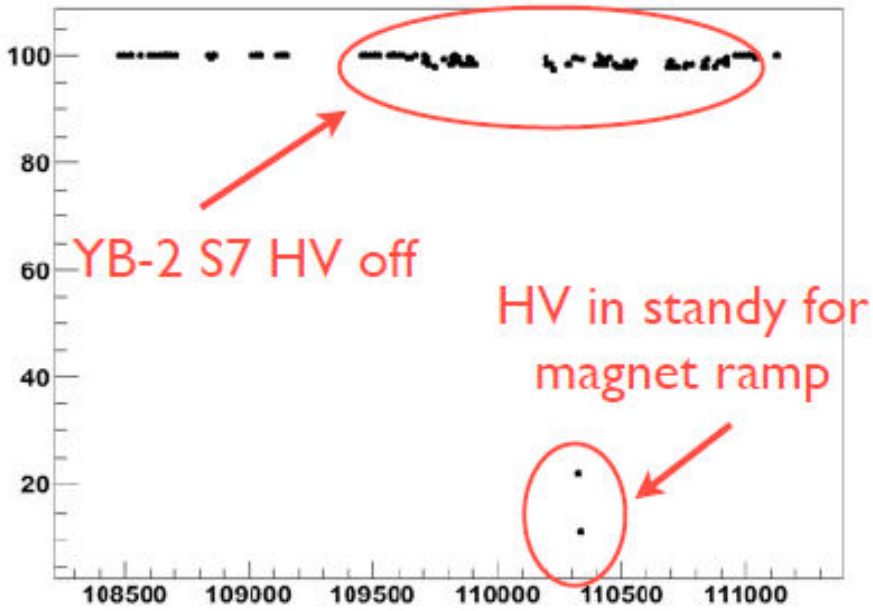
CRAFT. DT stability

* CRAFT08 ~4 weeks of continous data taking

* CRAFT09 >5 weeks of continous data taking

* Drift tubes was ON always except during magnet ramps where HV was lowered for safety reasons

%DT system vs run in CRAFT09



CRAFT. DT performance

	Low Voltage	High Voltage	Front-end	ROB	TRB	CCB
CRAFT08	3 sectors/wheel (communication problems)	1 connector, others by water leaks	0,013% (23 cells dead out of 172200)	5 ROBs (0,3%) flaky connector	3 TRB (0,2%) problematic	2 (0,8%) Minicrates with communication problems
CRAFT09	1 module	2 problems in commercial modules	0,013% (23 cells dead out of 172200)	1 ROB (0,06%) with problems	2 TRBs (0,1%) with problems	1 (0,4%) Minicrate with communication problems

Most of the problems have been fixed in the winter shutdown 2008/2009.

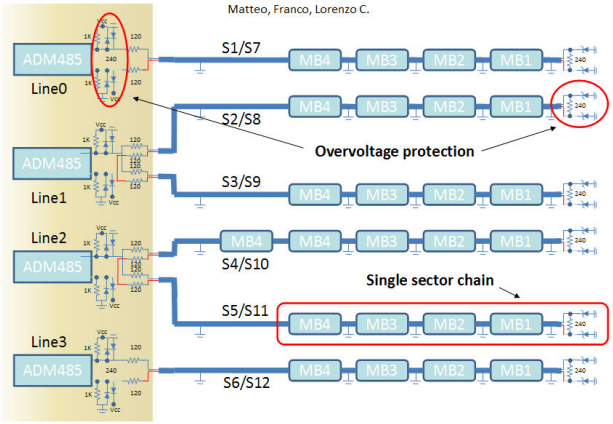
Opening of the Minicrates and reparation procedure is safe, though it implies opening of the CMS wheels.

Most of the problems could be due to continuos power cycles that provoque thermal stress => Present goal is to move to an ALWAYS ON system

* Minicrate DCS (Detector Control System)

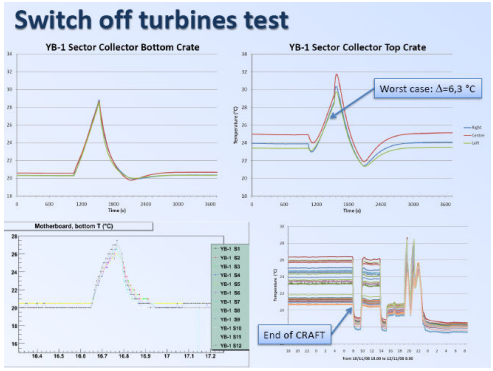
Several problems (12 failures (4.8%)) in the secondary link in 2008

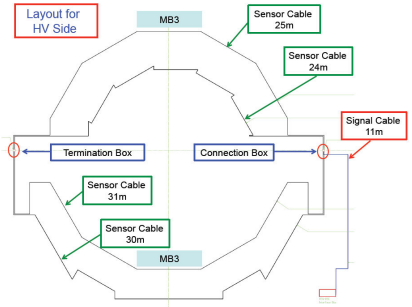
Secondary link has been improved, upgraded scheme with surge protection has been implemented.

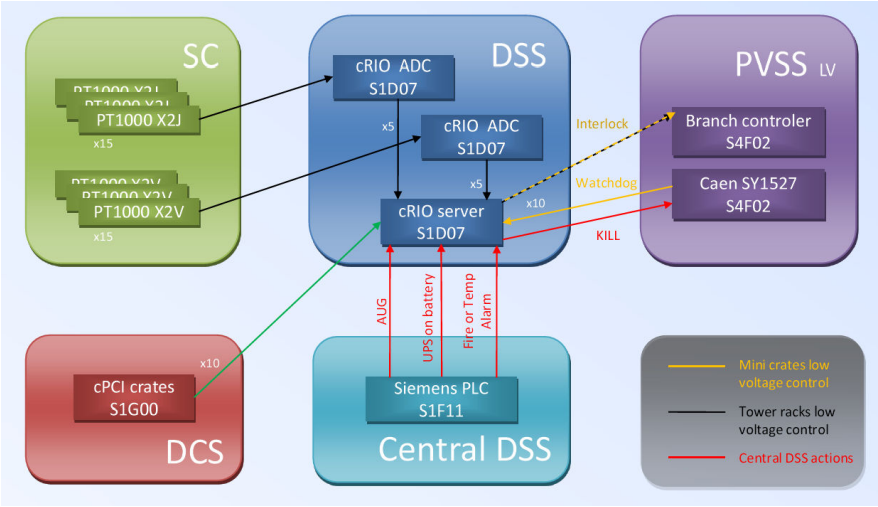


DT Safety aspects

* Water leak problems at CRAFT08 triggered the installation of a water leak system in the detector, basically finished.







·First level of safety is implemented on the DT-DCS (software based).

·DT-DSS system is a hardware based system.

·A watchdog driven mechanism insures the continuous check of the DT DCS status and cuts the LV if monitoring it is notproperly working

· Checks temperature inside SC racks and switches off in case of problems with cooling.

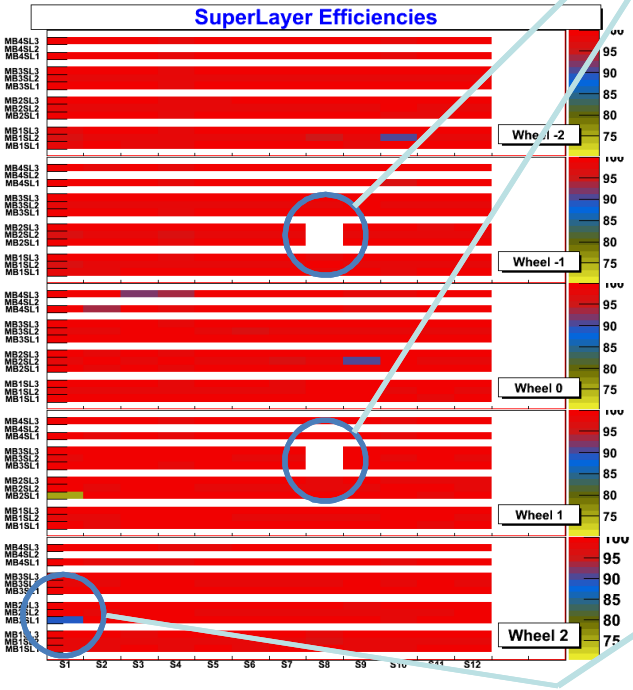
The detector control and safety systems have been expanded and strengthened

Slowly progress toward centrally supervised operation

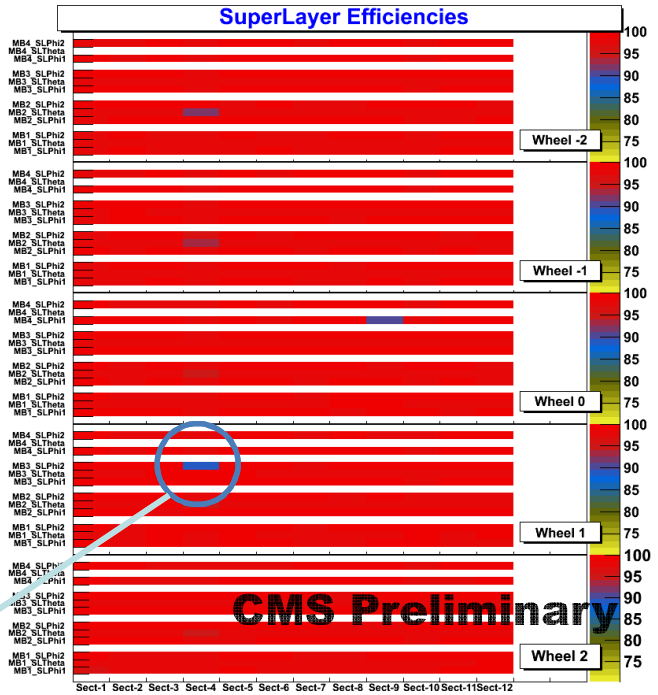
DT Efficiency

chambers OFF

CRAFT08



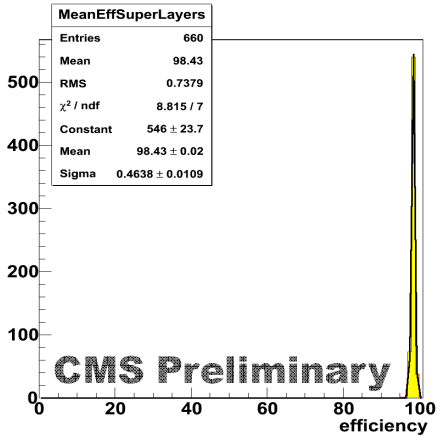
CRAFT09



HV problem in a single layer

Very similar in both campaigns and very close to 100%

Mean efficiency of cell hit detection (within a SuperLayer) computed w.r.t. offline reconstructed segments



DT Read-out performance

* Excellent data integrity through both data taking campaigns

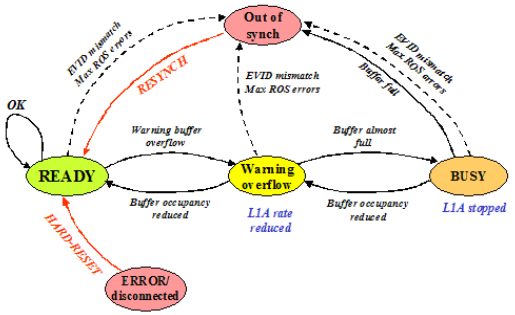
* CRAFT09: ~15 events/460 M some inconsistency:
  - -Bunch crossing ID mismatches,
  - -L1A event ID mismatch,
  - -missing corrupted header/trailers

* No problems seen when running at high trigger rate (~100kHz), data integrity not affected, no backpressure and no bottlenecks in the read-out path

* Configuration time of the DT DAQ system < 1 min

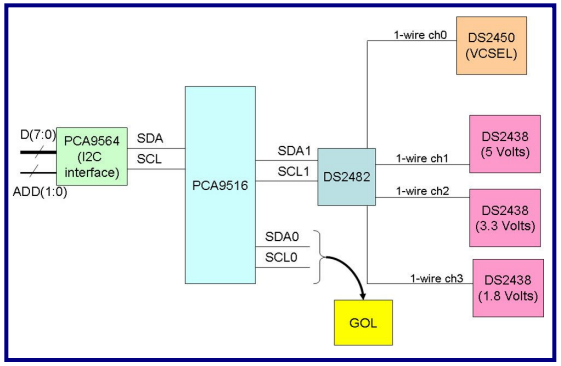
* Very few times a problem in the read-out path forced to stop the data acquisition: Twice in CRAFT08 and twice in CRAFT09.

* DT Trigger throttling system has been strenghthened and in CRAFT09 the read-out was able to recover with a resynchronization command (at some point will be automatic)



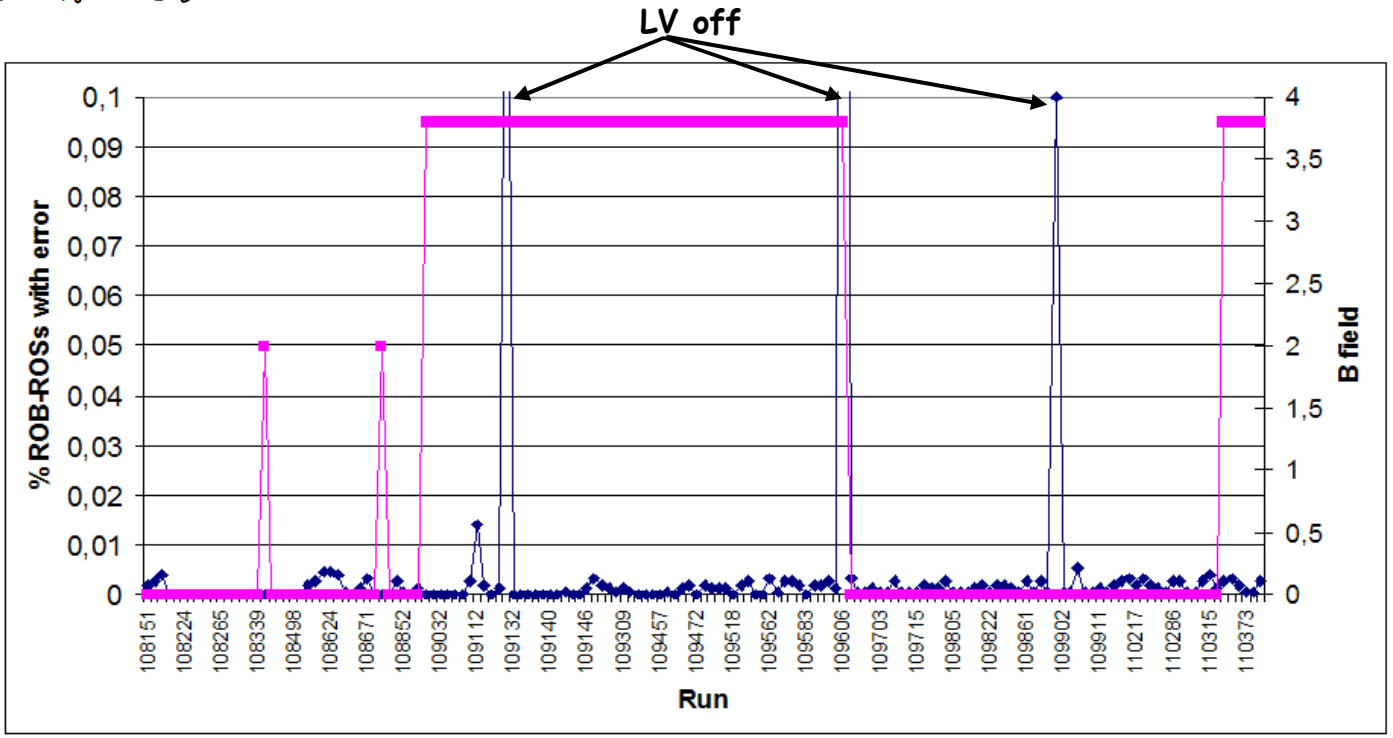
DT Read-out performance

* No issues have been found for running with B field ON
* Only effect observed was few problems when reading the 1-wire temperature sensors in ROS boards (4 boards out of 60 = 6%) while ramping up the magnet.
* It is solved with a power cycle of the crate



CRAFT09

No observable effect in the data integrity due to B field

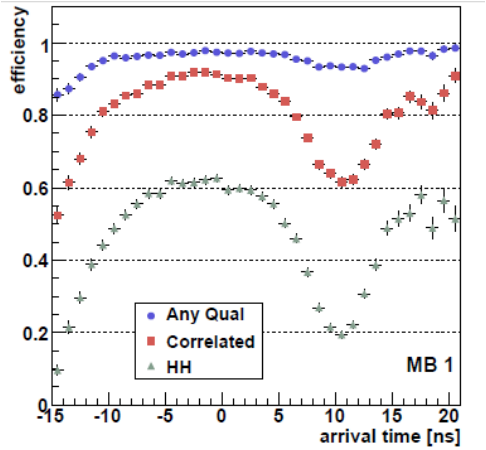


DT Local Trigger Performance

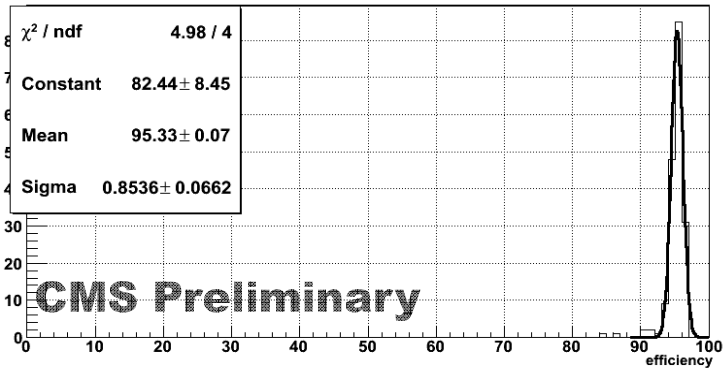
DT trigger has performed as expected:

- measured efficiency is high:
  - 95% for any quality
  - 73% for high quality correlated triggers (phi)

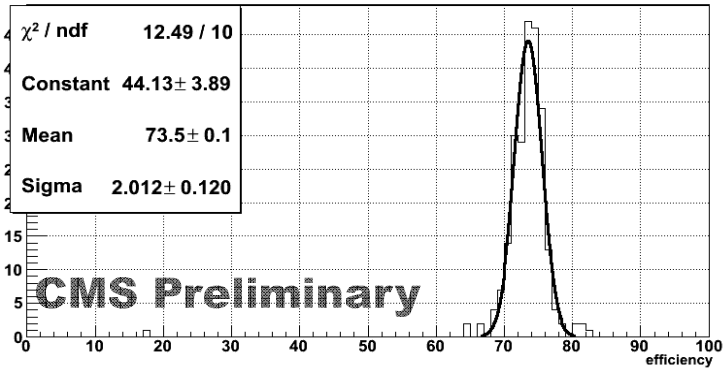
* DT trigger system is optimized for LHC operation, trigger efficiency is lower with cosmics
* Muons produced in LHC collisions will cross the DT detector at a well defined time with respect to the BX clock
* Cosmic rays cross at any time, there is an intrinsic inefficiency due to this uniform arrival time.
* Expected efficiency goes to 98% with synchronous beam



Trigger Efficiency - Phi View (Any Quality)

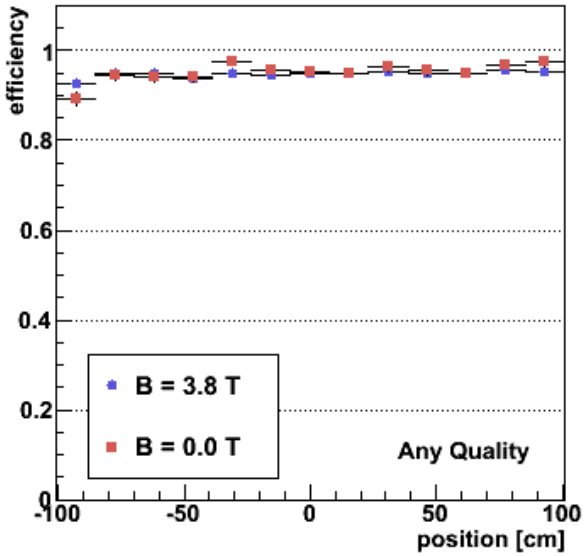


Trigger Efficiency - Phi View (High Quality - HH/HL)

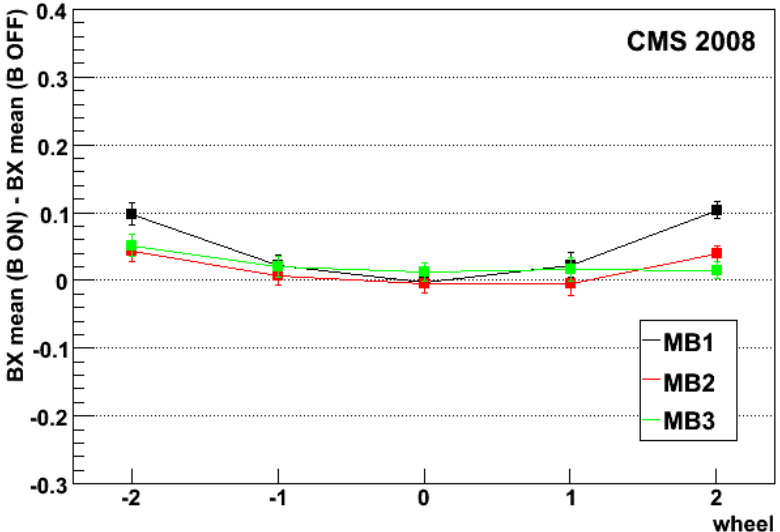


DT Local Trigger Performance

Trigger efficiency is independent of B field



Also, no significative differences observed in system synchronization



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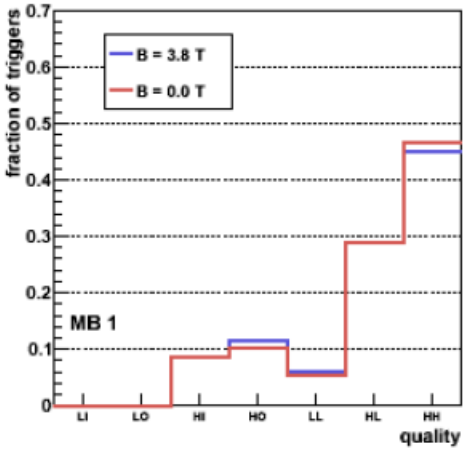
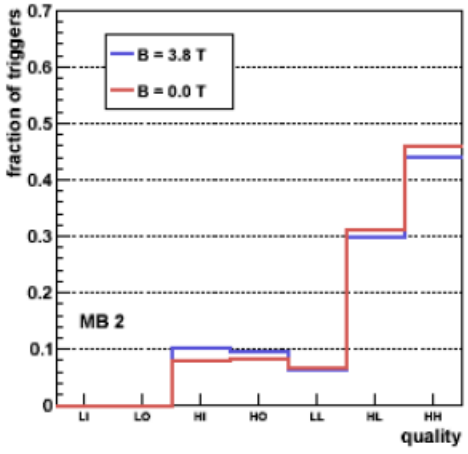
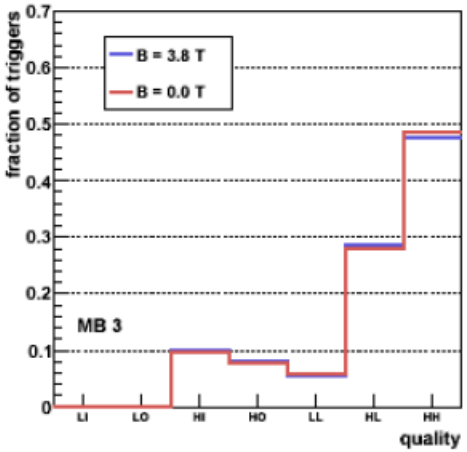
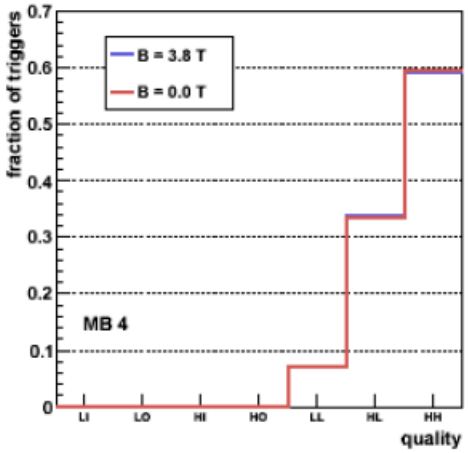
DT Local Trigger Performance



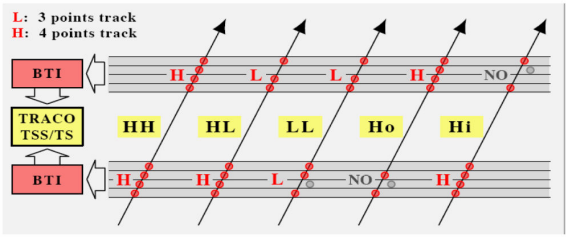






Trigger qualities also remain unaffected with B field

H ➔ hits in 4 layers of a SuperLayer
L ➔ hits in 3 layers of a SuperLayer
(i➔ inner SL, o➔ Outer SL)

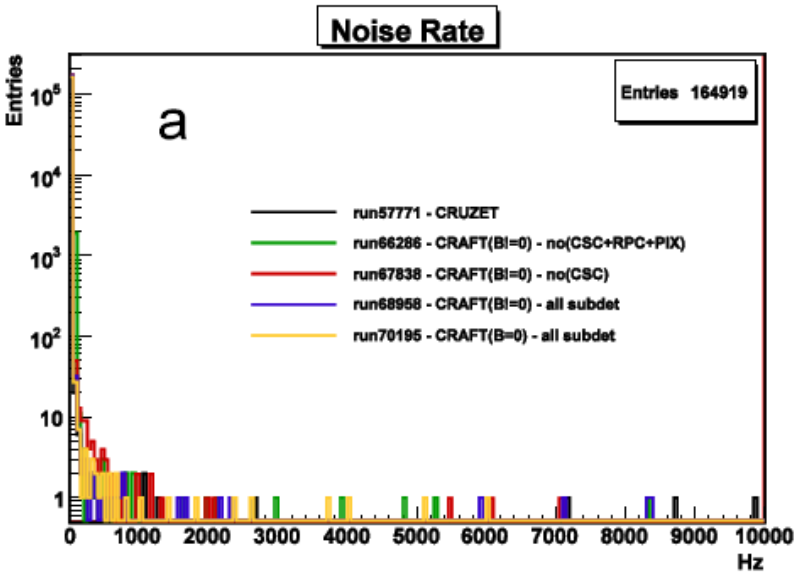


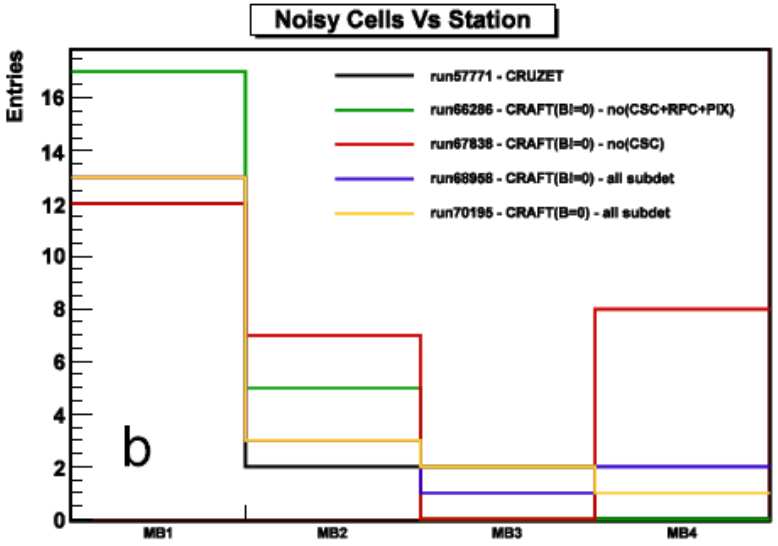
Distribution of the quality of the trigger primitives for data taken with and without magnetic field, in the YB-2 of the muon barrel.

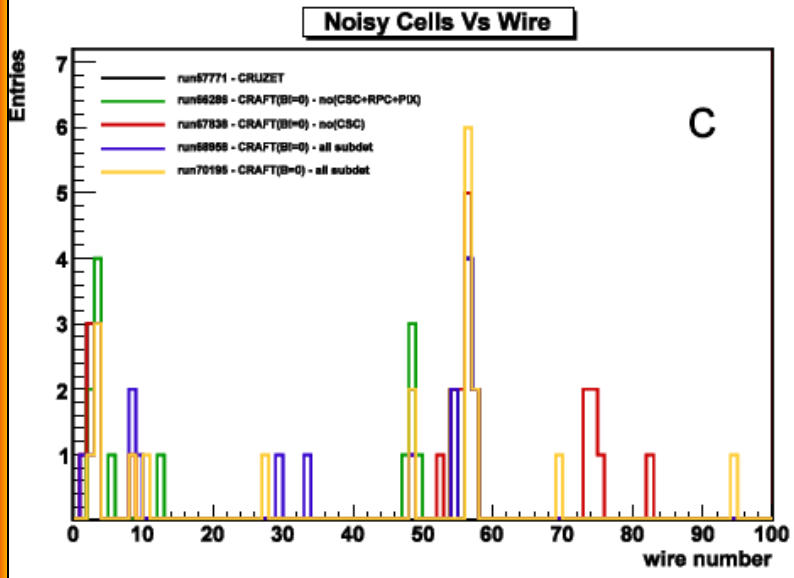
24

DT Noise

CRAFT08





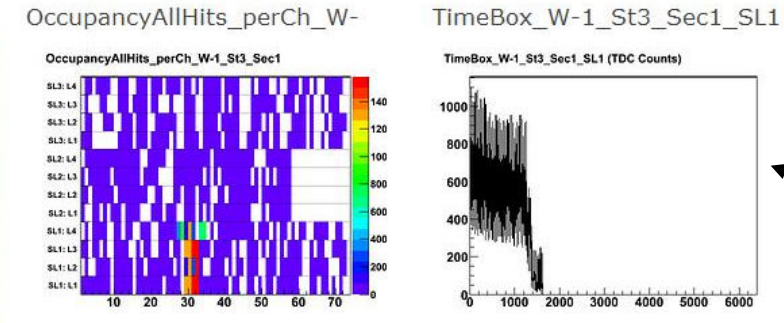


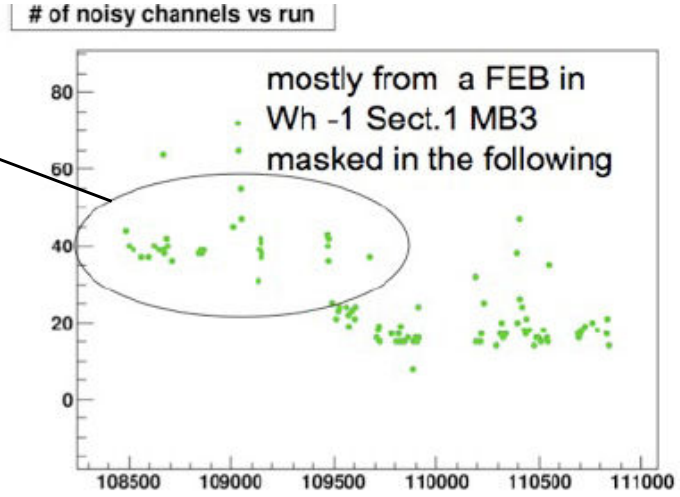
- Noisy cell when hit rate>500 Hz. (to be compared with expected background during LHC 1-10kHz/cell).
- The number of noisy cells is low (20-30 cells out of 172200) and stable during different run conditions (B field ON/OFF, other subdetectors)
- MB1s noiser than other chambers (smaller size) and usually noise is located in the edges of the chambers (where the HV cables pass through).

DT Noise

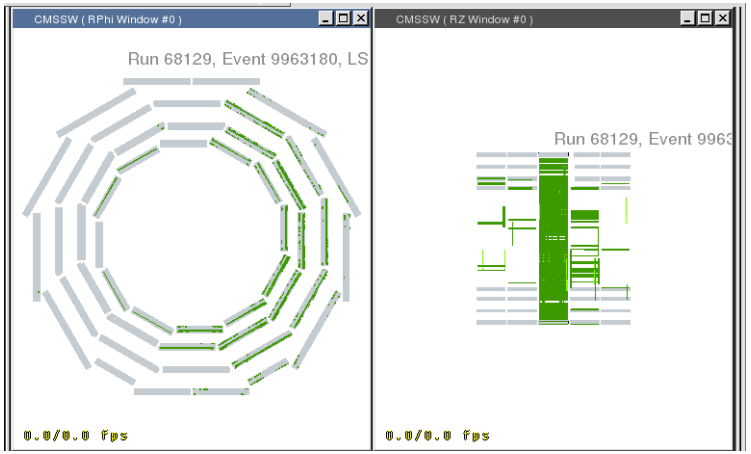
CRAFT09

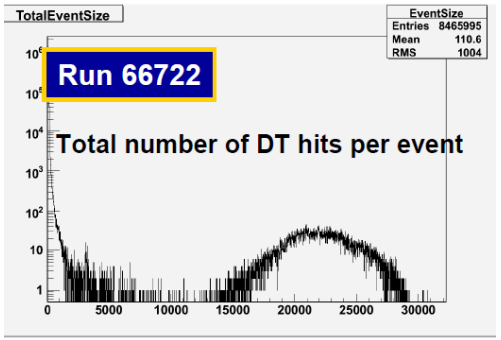
Electronic noise remains very low (20-30 cells > 500 Hz)





- Though… both in CRAFT08 and CRAFT09 we have seen sporadically very big noisy events (20k hits) that still need to be understood.
- They do not affect chamber performance (a cut is applied on them afterwards) but studies are on going in order to try to get rid of them
- No relation with B field





Firmware upgrades

Between CRAFT08 and CRAFT09 some firmware upgrades have taken place in many parts of the system.

They respond to improvements mainly in the monitoring part that have arised after experience during operation.

The upgrades have been made succesfully in all parts, no major concern has been found

Most of them have been remotely done, mechanism is safe, though usually time consuming (hours)

Minicrate:

- New architecture of the configuration (split in 3 subset: trigger, read-out, front-end).
- easier book-keeping, allows Trigger Supervisor to configure its part independently.
- Improve check of ROB status.
- Check CRC of the configuration to verify that nothing changes in time.

ROS:

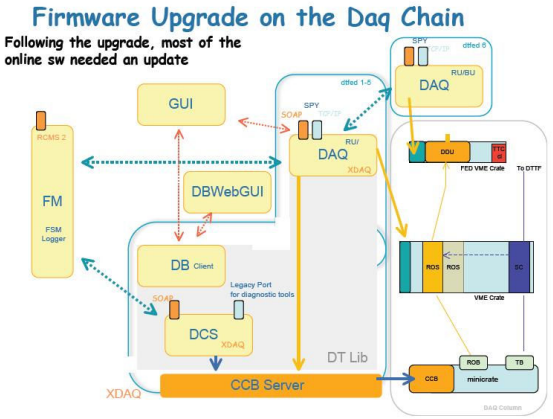
- New Error Handling
- New Configuration Parameters
- New monitoring registers

DDU:

- New Error Handling
- New Configuration Parameters (e.g. TTS thresholds)
- Full TTS support
- Full TTC support
- New monitoring registers
- New bits in the dataflow

This changes affect the online software, requiring upgrade of:

- Configuration database
- DAQ software for configuration and monitoring
- DQM software: Unpacker



TSC:

- VME bug
- Gain access to the JTAG chain
- Include pattern generators

PHTF, ETTF, BS, WS:

- Include rate counters
- Pattern generators
- Change output phi value

In summary...

* The DT system is an example of a complex electronic system that is behaving very efficiently and stable during data-taking

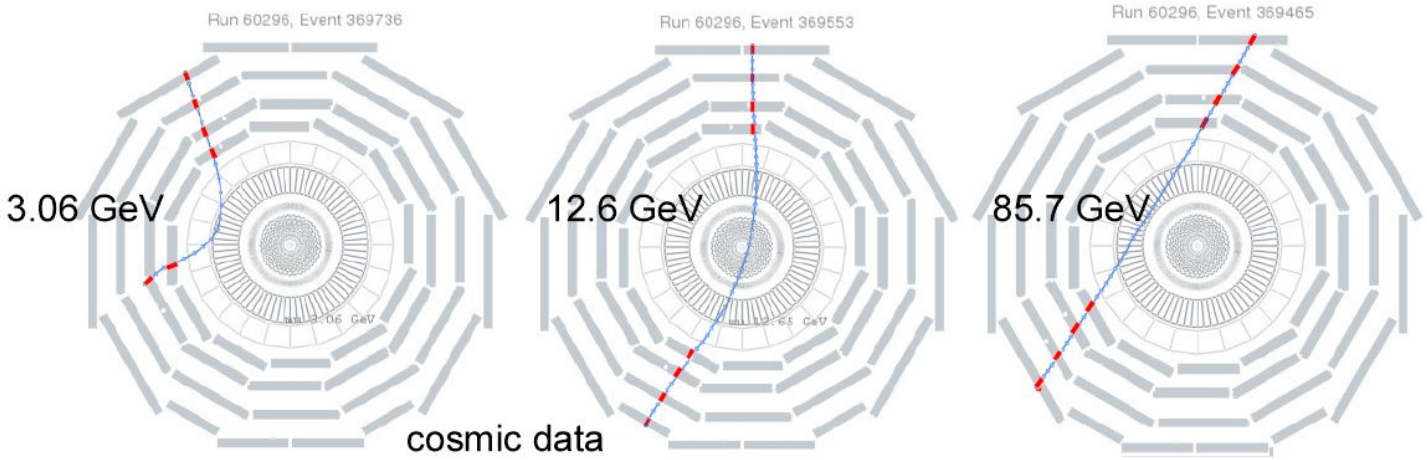
Big system!

Channels	172200
HVB	10868
FEB	10708
HPTDC	6000
BTI	12000
Electronic boards	>4000
FPGAs	~3000
HV modules	240
LV modules	210
Copper links	>3000
Optical links	>500

* The quality of the DT data is very good and independent of B field
  - Very few integrity problems
  - DT Trigger has the expected performance
  - Efficiencies and resolutions as expected

* The cosmic data collected during this exercise have been invaluable to study the performance of the detector and start first physics studies

* The operational experience for an extended period of time provide further confidence that the system is ready for LHC physics once beam operations resume in 2009

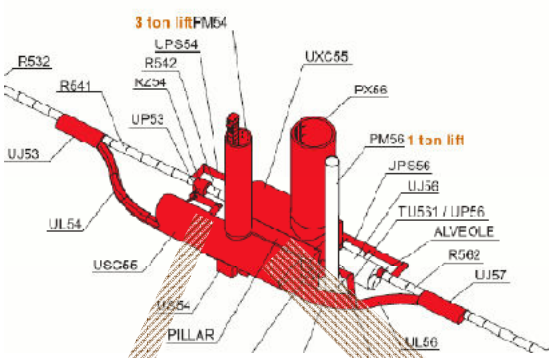


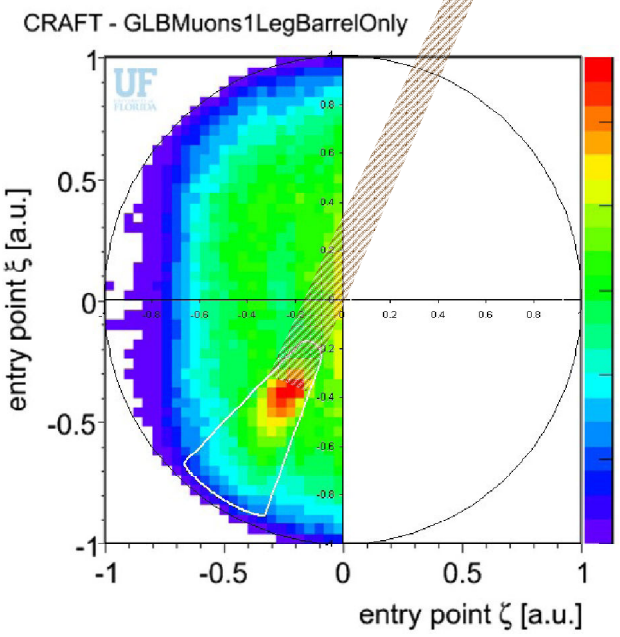
twepp-09
Paris,
France
Topical Workshop on Electronics for Particle Physics
September 21-25, 2009

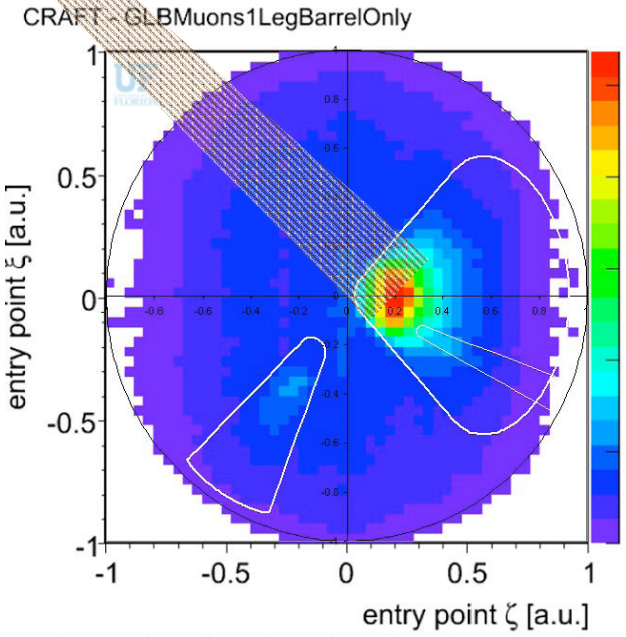
Back-up

Muon origin extrapolation to surface

The overall distribution of triggered muons in the cavern clearly shows the "shadows" of the service shafts



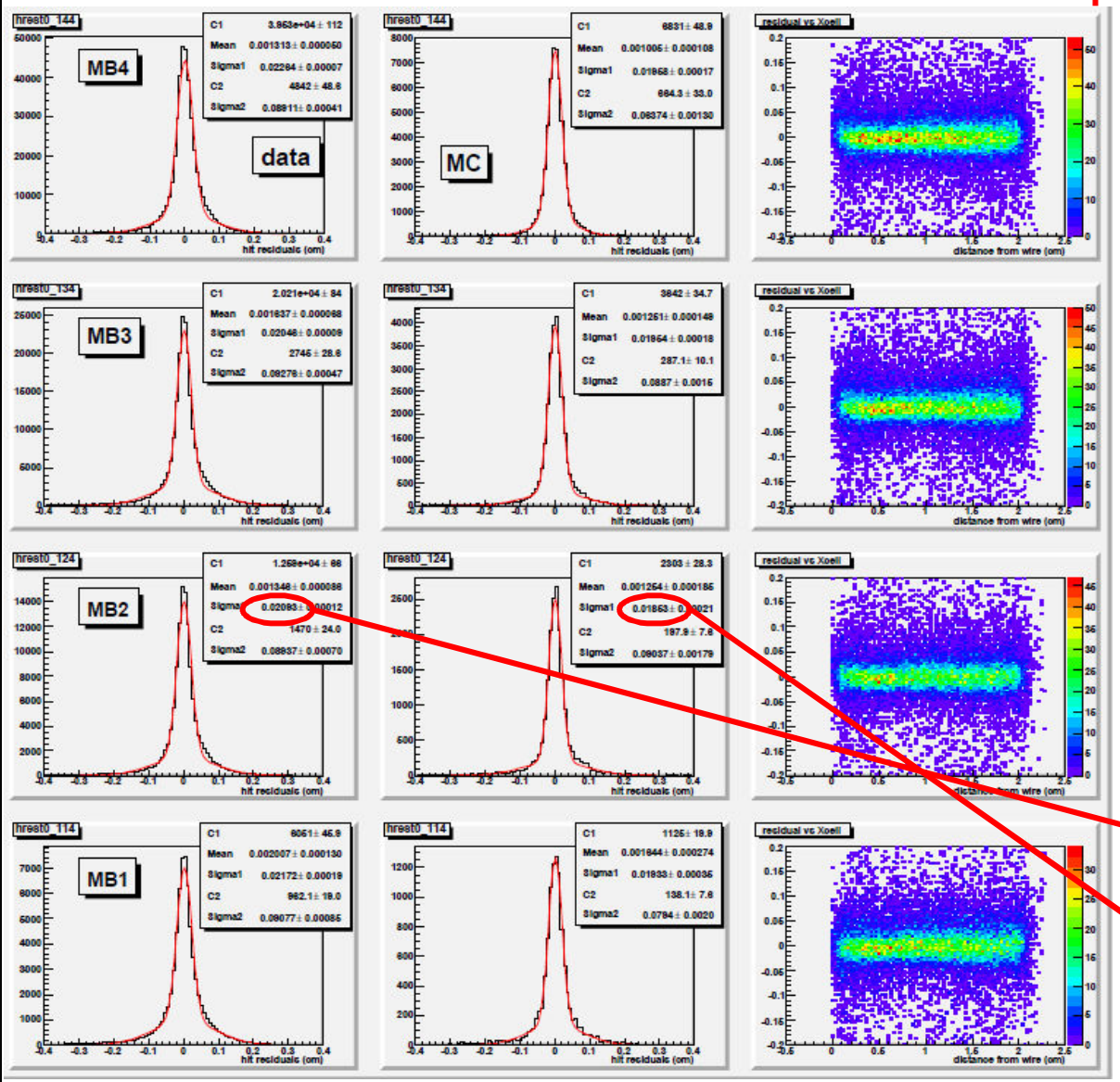




DT Performance: Resolution

Very similar in both campaigns

Data **Monte Carlo** **Residuals vs hit position**

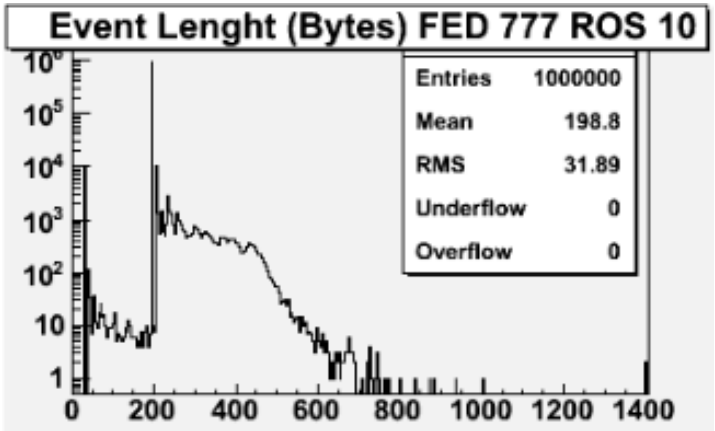


Resolution (cell level)

DATA
σ= 200-260 μm

MONTE CARLO
σ= 190 μm

DT Read-out performance



Average 200 bytes/sector
168 bytes from TSC data (debugging)

Event size
1119 kB/FED
11 kB full DT

DT links performance

* 1500 ROB-ROS copper link (10-40 m):
  118 parity bits out of 5 10^{13} bits

* 60 ROS-DDU optical links: no parity errors found

* ~240 TSC-Track Finder optical links:
  CRAFT09: 4 unlocks in total

CRAFT09

Number of DT-RO parity errors

YB+2	MB1	MB2	MB3	MB4
1		1		
2				
3				
4		1		
5		1		
6			4	
7				1
8				
9			1	
10			1	
11				
12	1			

YB+1	MB1	MB2	MB3	MB4
1	1	1		
2				
3				
4				
5				
6	1			
7			62	24
8				
9			1	
10				
11			1	
12				

Problematic link

YB0	MB1	MB2	MB3	MB4
1				
2			1	
3				
4			2	
5				1
6				
7				
8				
9			2	
10		1	2	
11				
12				

1 parity error => 1 bit

Runs 108151 to 111753

YB-1	MB1	MB2	MB3	MB4
1				
2				
3		3		
4				
5				
6				
7				
8			1	
9				
10				
11				
12				

YB-2	MB1	MB2	MB3	MB4
1				1
2				
3				
4				
5				
6	1	1		
7				
8				
9				
10				
11				
12				

CRAFT. DT performance

* **Low Voltage system:**
  - CRAFT08: 3 sectors in all wheels (S7, S10 and S11) sporadically switching off (problem of communication with the modules, fixed)
  - CRAFT09: 1 module changed

* **High Voltage system:**
  - CRAFT08: 1 connector with problems, other caused by water leaks
  - CRAFT09: 2 problems in some comercial modules

Front-end electronics:

- The number of dead channels in the front-end electronics is very low and stable
- Dead channels in the front-end electronics:
  0,013%
  (23 out of 172200)

	Wheel	Sector	MB	SL	Layer	cell
1	-2	2	4	3	1	14
2	-2	3	3	2	1	16
3	-2	4	1	2	1	24
4	-2	10	3	1	1	55
5	-2	10	4	1	3	17
6	-1	3	1	1	1	49
7	-1	4	2	2	3	23
8	-1	9	2	1	4	29
9	-1	10	4	1	1	24
10	0	1	2	2	3	33
11	0	4	1	3	4	9
12	0	4	4	1	1	10
13	0	7	1	3	2	44
14	0	12	2	3	4	29
15	1	4	1	1	1	49
16	1	5	2	3	2	4
17	1	7	3	3	2	26
18	2	3	3	1	4	27
19	2	3	4	1	3	30
20	2	8	3	3	1	5
21	2	8	3	3	3	5
22	2	8	4	1	4	72
23	2	11	3	2	3	48

CRAFT. DT performance

* **Minicrate electronics**:

* 1500 ROB (Read Out Boards):
  - CRAFT08: 5 ROBs (0,3%) with sporadic problems due to a flaky connector
  - CRAFT09: 1 ROB (0,06%) that still remains with problems

* 1500 TRB (Trigger Boards):
  - CRAFT08: 3 TRB (0,2%) problematic
  - CRAFT09: 2 TRBs (0,1%) with problems

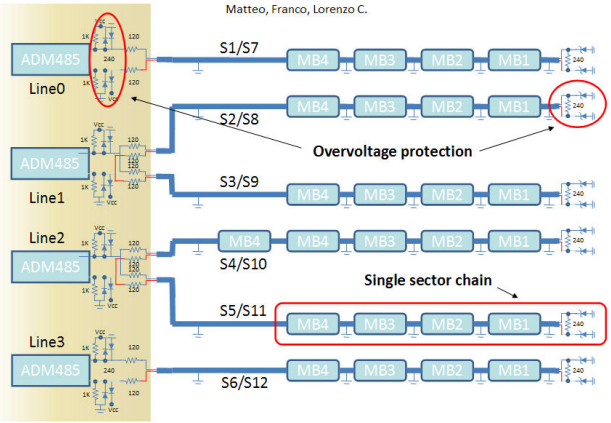
Most of the problems have been fixed in the winter shutdown 2008/2009.

Opening of the Minicrates and reparation procedure is safe, though it implies opening of the CMS wheels.

Most of the problems could be due to continuos power cycles that provoque thermal stress => Present goal is to move to an ALWAYS ON system

* **Minicrate DCS (Detector Control System)**

- CRAFT08: 2 Minicrates with communication problems Several problems (12 failures (4.8%)) in the secondary link

- CRAFT09: Just 1 Minicrate with communication problems

Secondary link has been improved, upgraded scheme with surge protection has been implemented.