MEASURED PERFORMANCE OF THE LHC COLLIMATORS LOW LEVEL CONTROL SYSTEM

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Outline

- The LHC collimation system
- Motorization solution
- Control requirements
- Low-level control system
- Measured performances
- Conclusions

The importance of the collimators in the LHC

The LHC nominal beam energy is equivalent to:

One US aircraft carrier at 11 knots

A mis-stereed beam can provoke:

1. Damage to the machine

The energy in the two LHC beams is sufficient to melt almost 1 ton of copper

2. Quenches:

For example, local transient loss of 4×10^7 protons at 7 TeV

The LHC collimation system has to protect a machine of 2 billions $ and reduce noise to the LHC experiments absorbing particles out of the nominal beam core

The LHC collimators

Road Map

- **The LHC collimation system**
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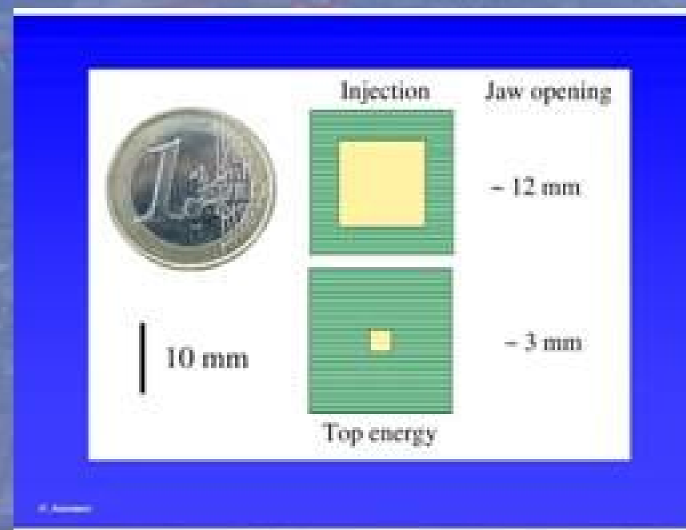
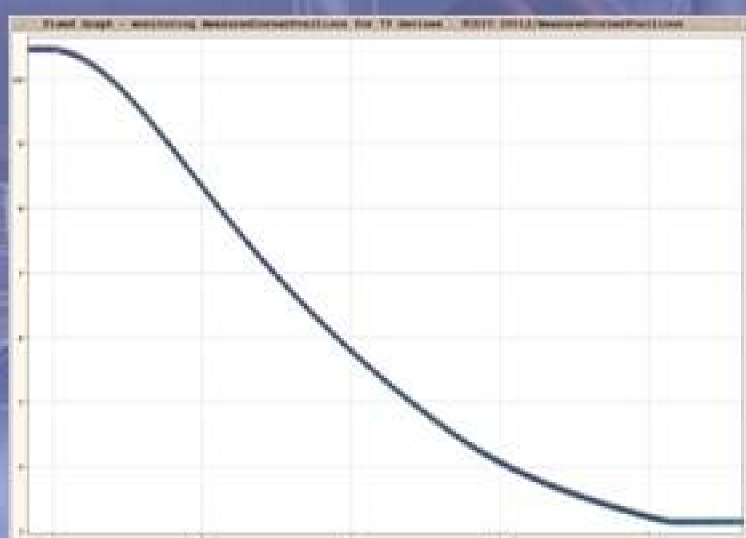
A collimator has two parallel jaws

Each jaw is controllable in position and angle





The jaws positioning accuracy is function of the beam size (1/10 beam size). At top energy 20 um accuracy is required

The LHC collimators system

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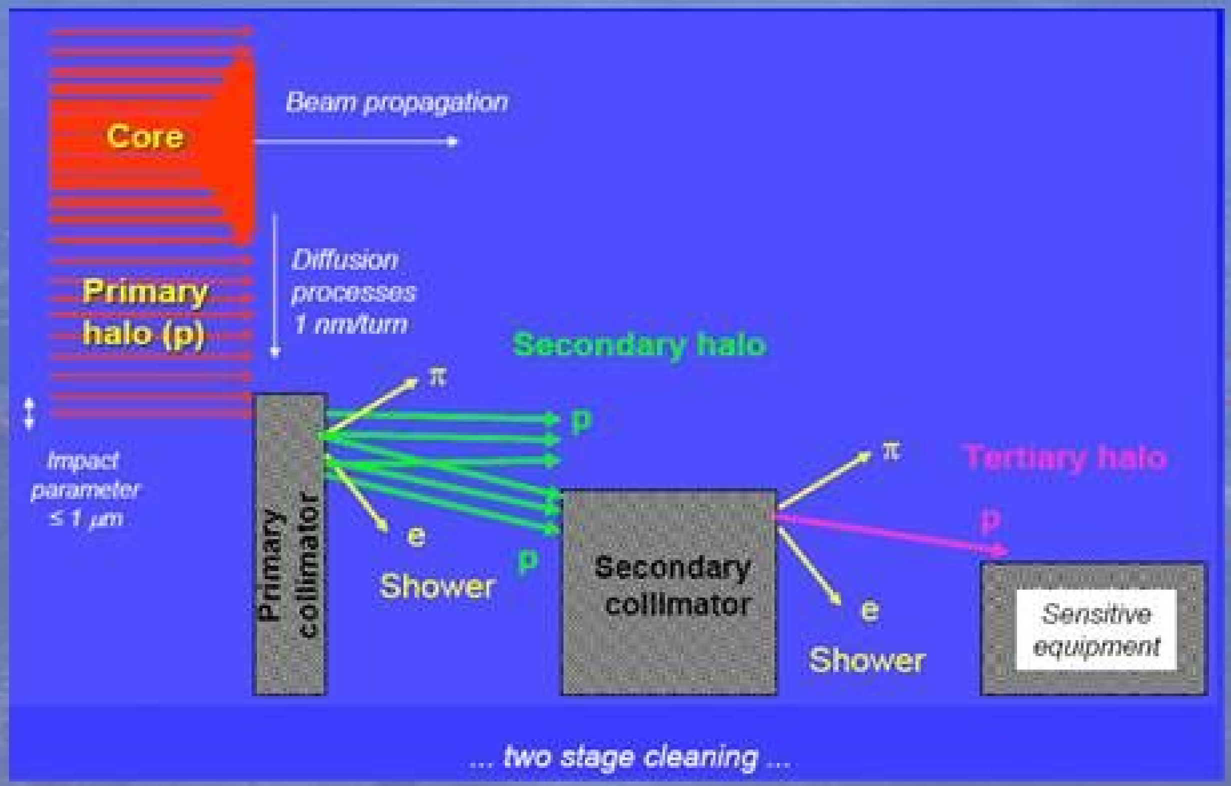
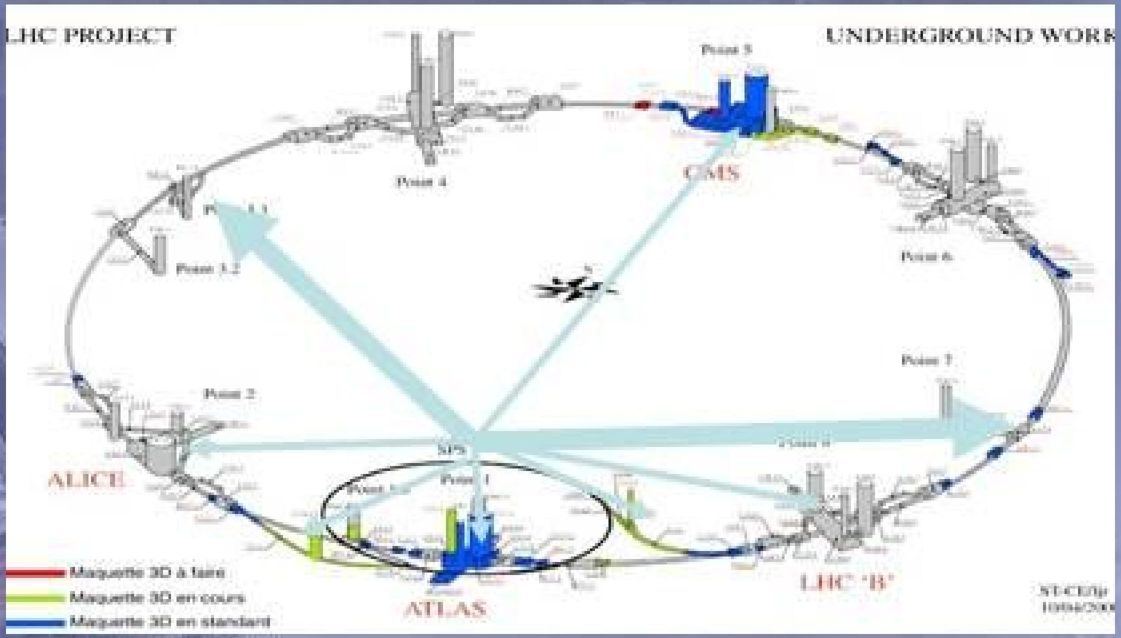


The collimation system is based on different collimators types and

up to 108 collimators distributed over 6 points in the machine

Jaw positions are correlated primary – secondary– tertiary

Also during movements they have to stay in sync within few ms



The Motorization Solution

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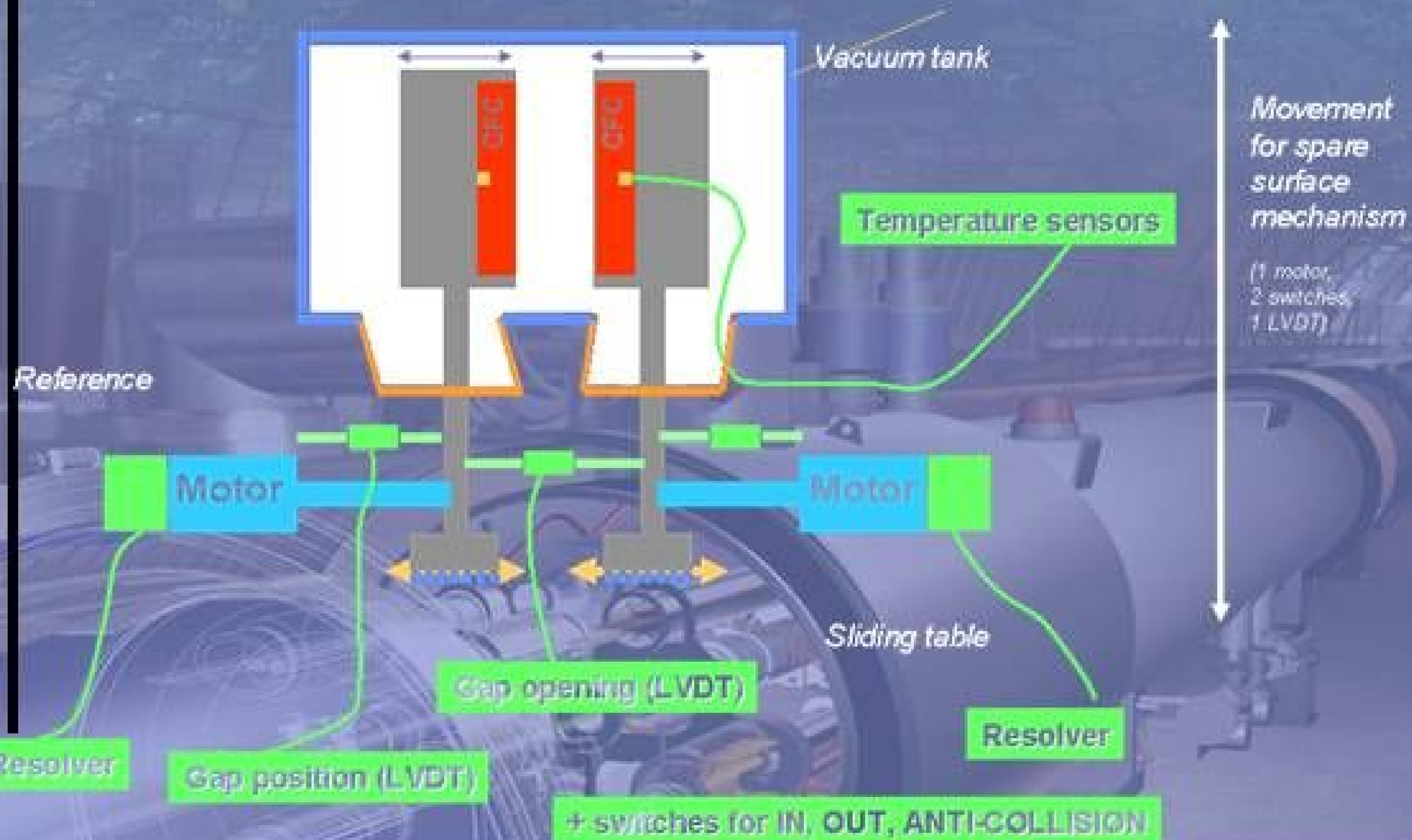
Collimator Axes Motor type: Stepping Motors Controlled in open loop (4 for the jaws `axes + 1 for the vertical axis)

Steps Loss Detection: Resolvers (4 for the jaws` axes)

Positions Survey: LVDT sensors in redundant number (5 for the axes absolute position and 2 for the jaws` gap)

Side view at one end



The control requirements

555 stepping motor Axes to control:

- **Jaws positioning accuracy:** fraction (1/10…) of the beam size (200 µm!!).
- **Syncronization between the two motors of the same jaw:** much less than 1 ms to reduce vibrations
- **Motion profiles:** jaws in different collimators need to be locked for more than 30 minutes to movement functions sent by a central supervisory application. The motion start is provided by a Trigger sent via optical fiber
- **Response delay to a digital trigger:** < 1ms
- **Syncronization between all the 555 collimators motors all along a motion profile:** < 10 ms

Road Map

The control requirements

750 positioning sensors to survey:

- **Survey frequency:** position sensors have to be read at least at 100 Hz to check in Real-Time that the actual position lies within a given limit function
- **Synchronization between survey process and profile generation:** few ms
- **Low level rack dimensions:** maximum 400 mm deep. Limited space in the rack (in one 400 mm deep rack we need to install the controls for at least two collimators)
- **Reliability:** since collimators protect the machine the first requirement of the control system is reliability

The control architecture

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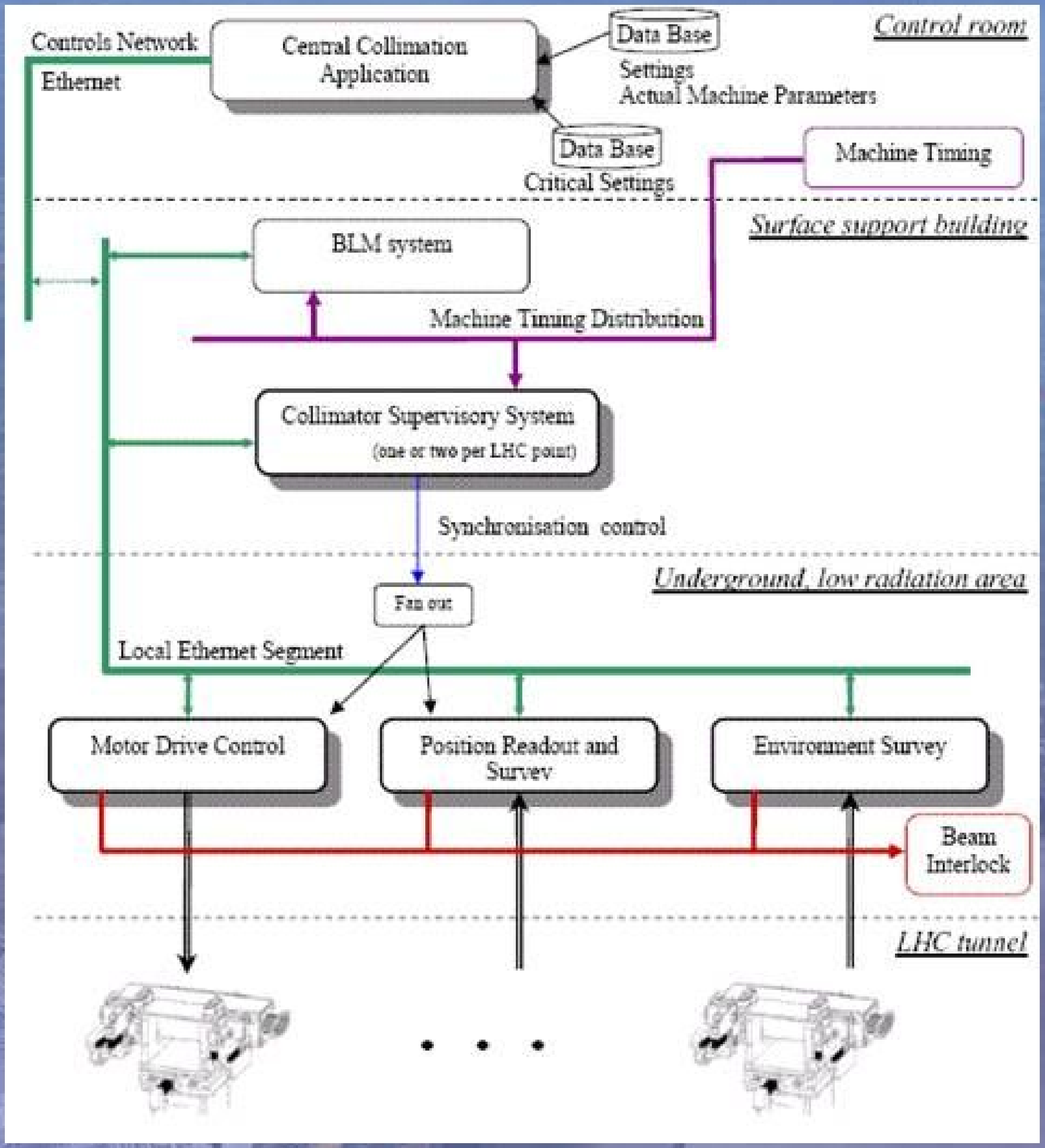

Control system software architecture

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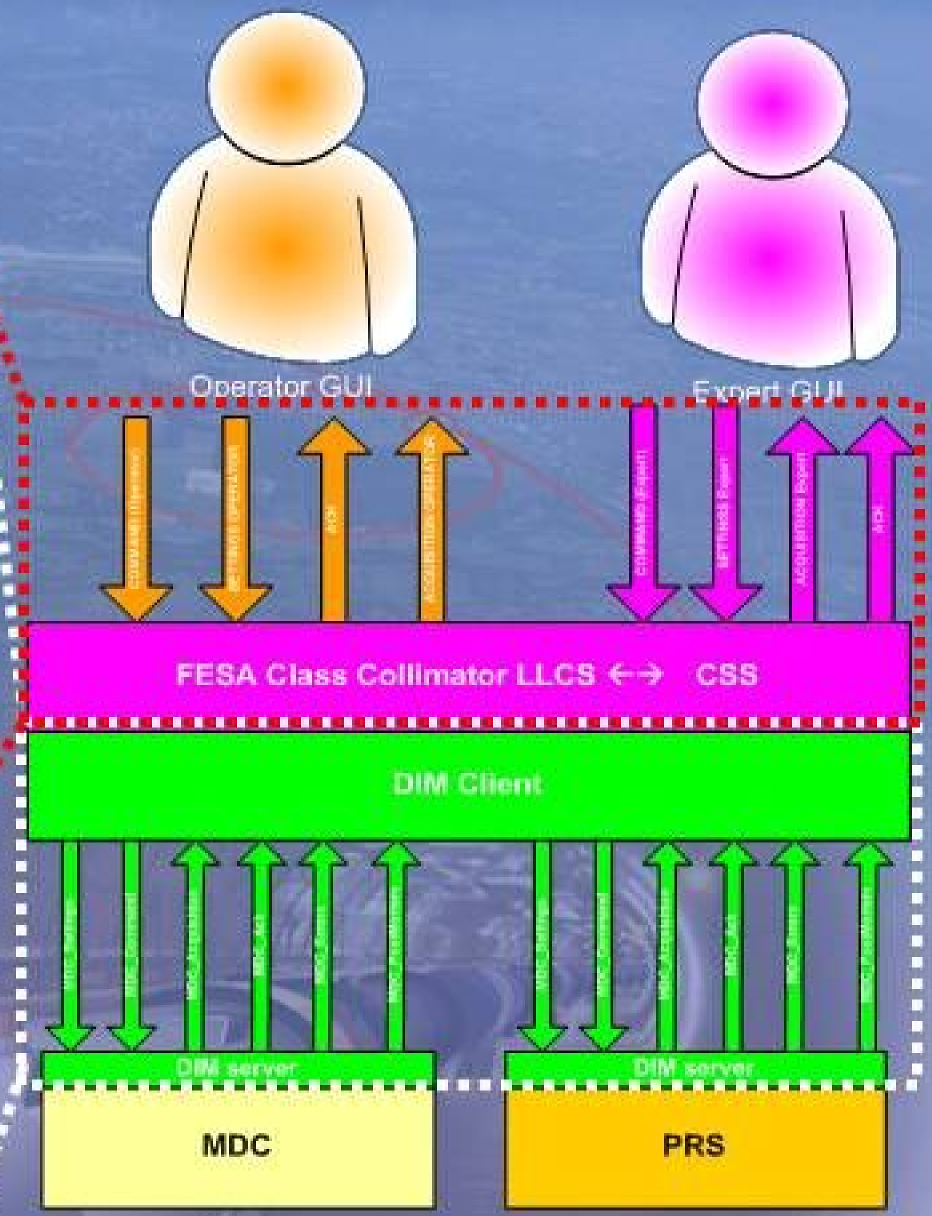
The new Front-End Software Architecture (FESA) is a comprehensive framework for designing, coding and maintaining LynxOS/Linux equipment-software that provides a stable functional abstraction of accelerator devices
See details at:
http://project-fesa.web.cern.ch/project-fesa

network support TCP/IP
(See details at http://dim.web.cern.ch/dim/)
The DIM Server library was successfully compiled for Pharlap



The control system synchronization solution

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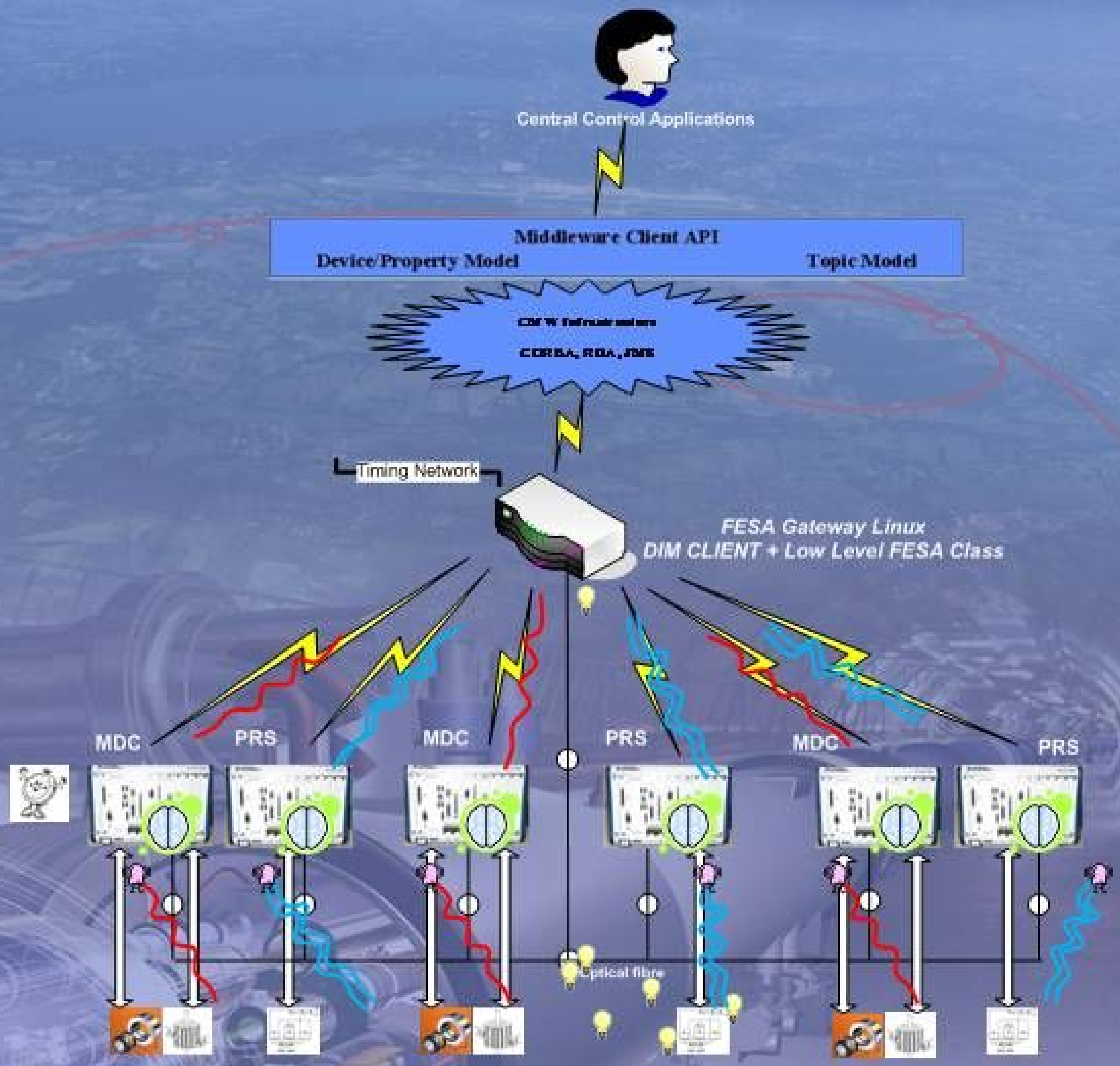

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MDC hardware architecture

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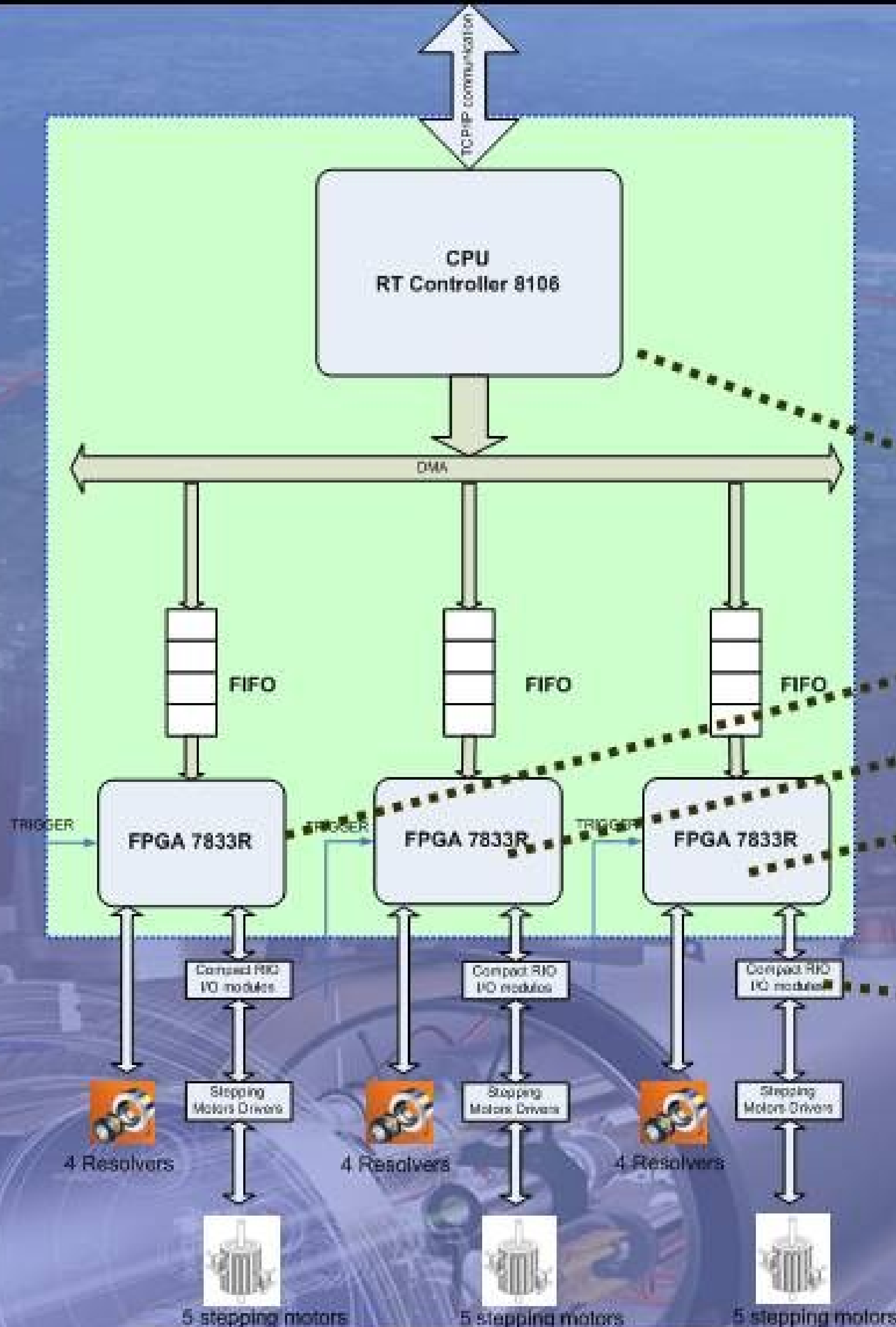
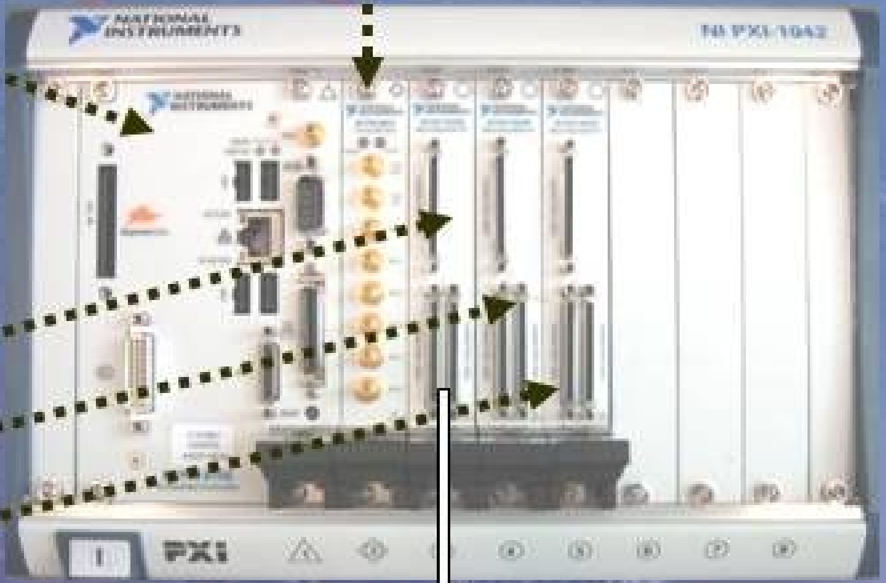


Timing Card 6653 with 45 ppb clock stability



MDC RT tasks architecture

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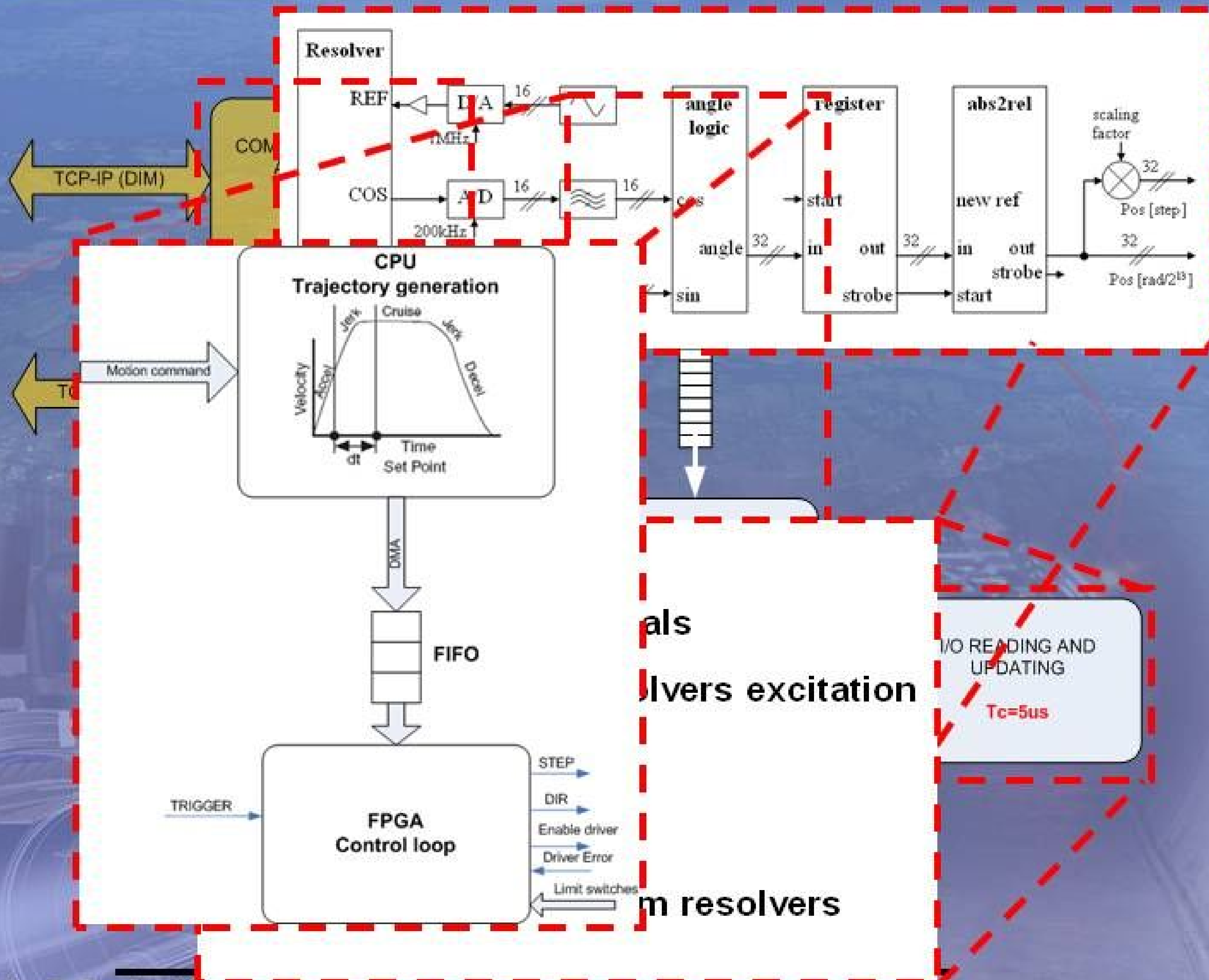
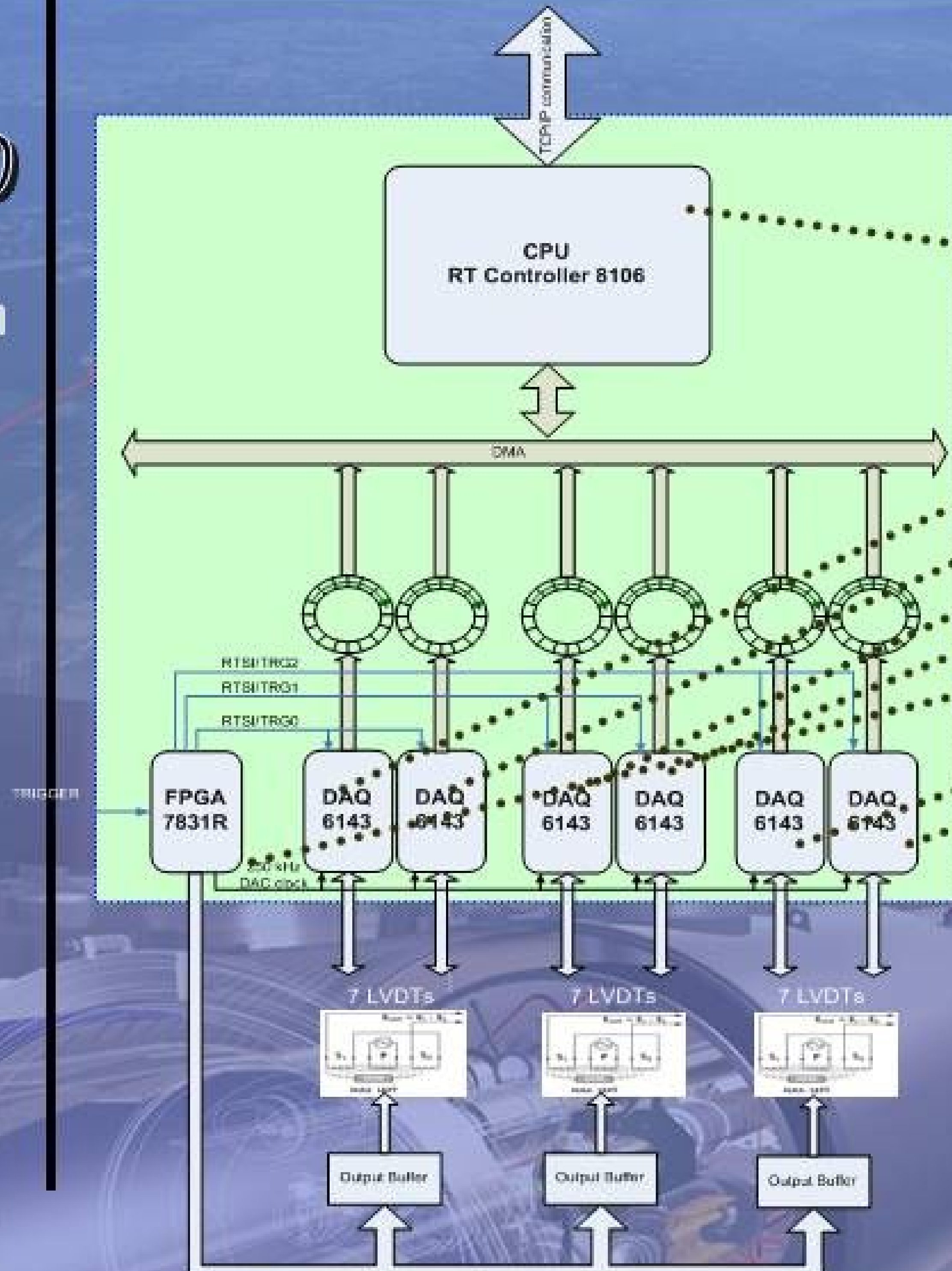


PRS hardware architecture



All the PXIs chassis are syncronized with the 10 MHz clock.

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PRS RT tasks architecture

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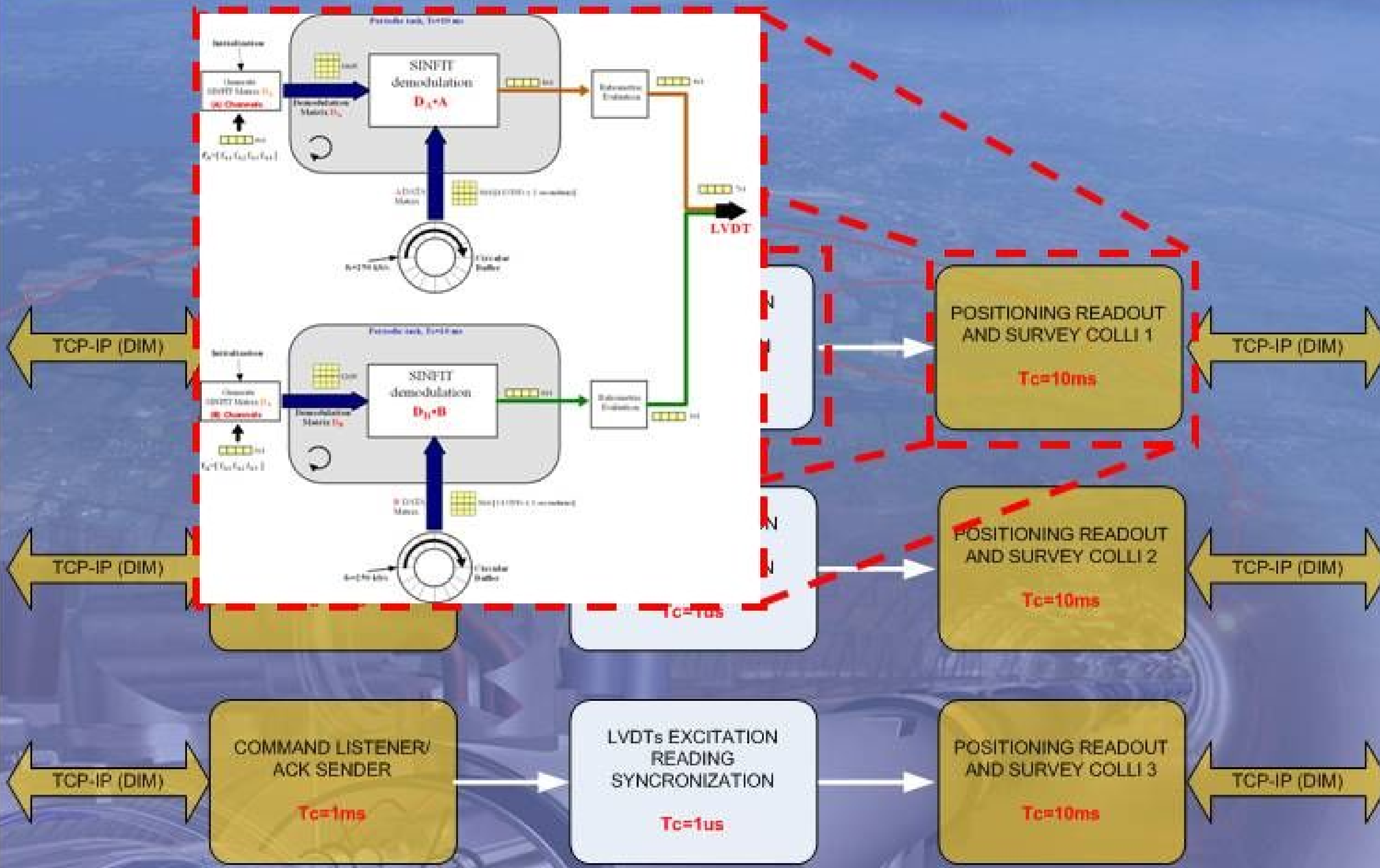
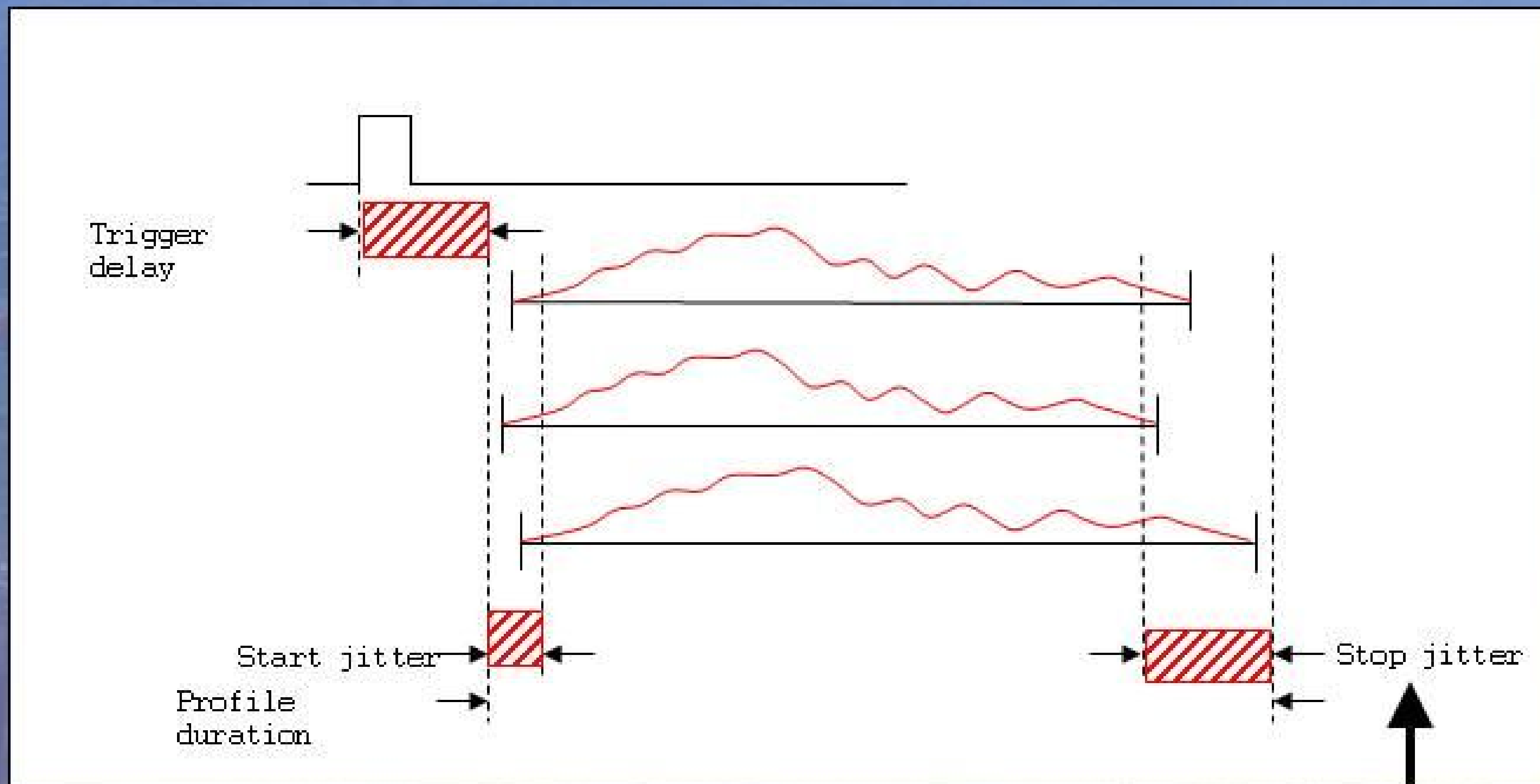


MDC measured performances



Determined by local clock

Trigger delay ~ 120 us

Start jitter: 4 us

Stop jitter: 50 us

Profile duration: ~30 minutes

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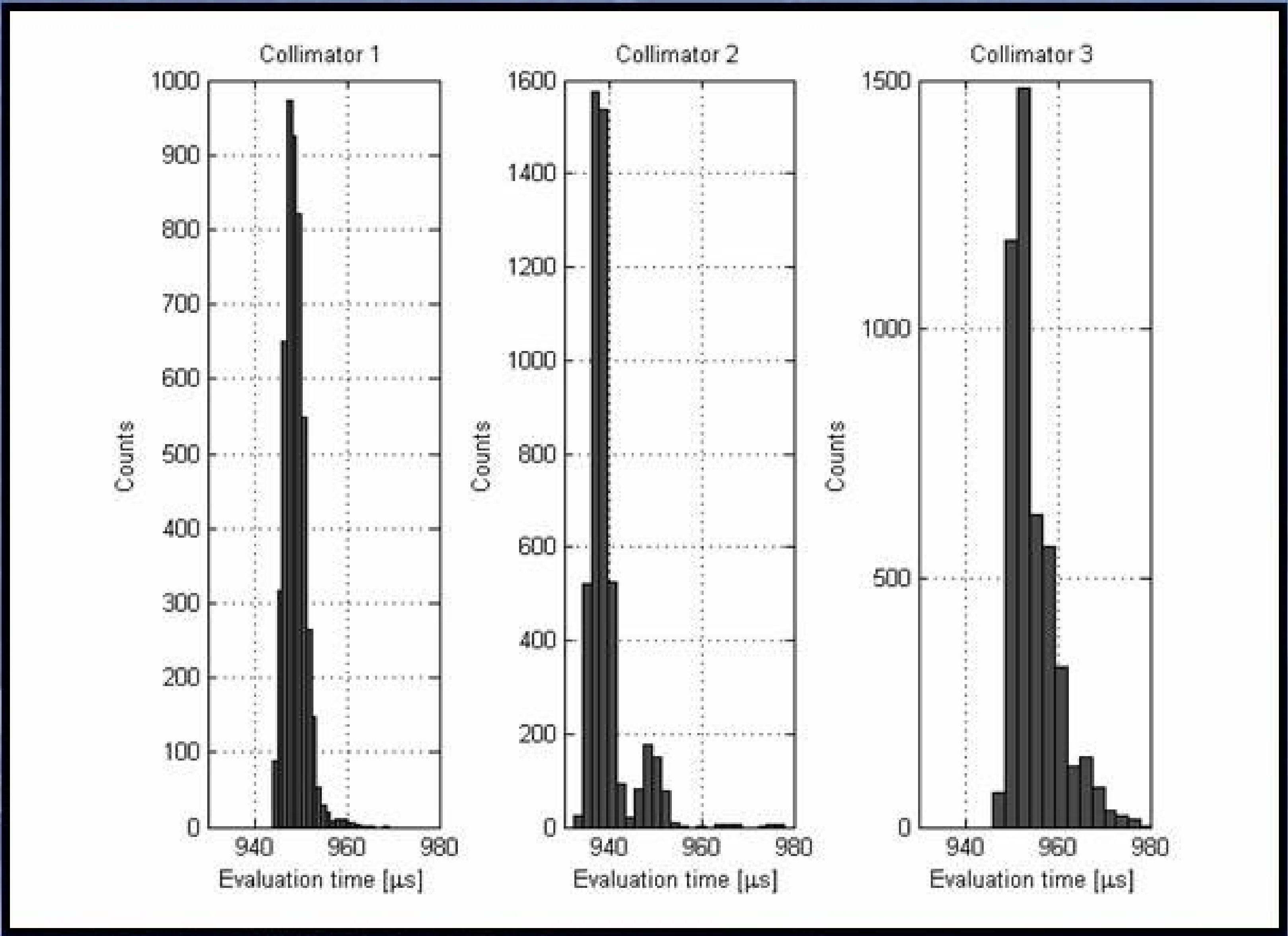
PRS measured performances

21 LVDTs are read in less than 1 ms with a negligible jitter. The requirement about 100 Hz reading frequency is easily satisfied



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PRS measured performances

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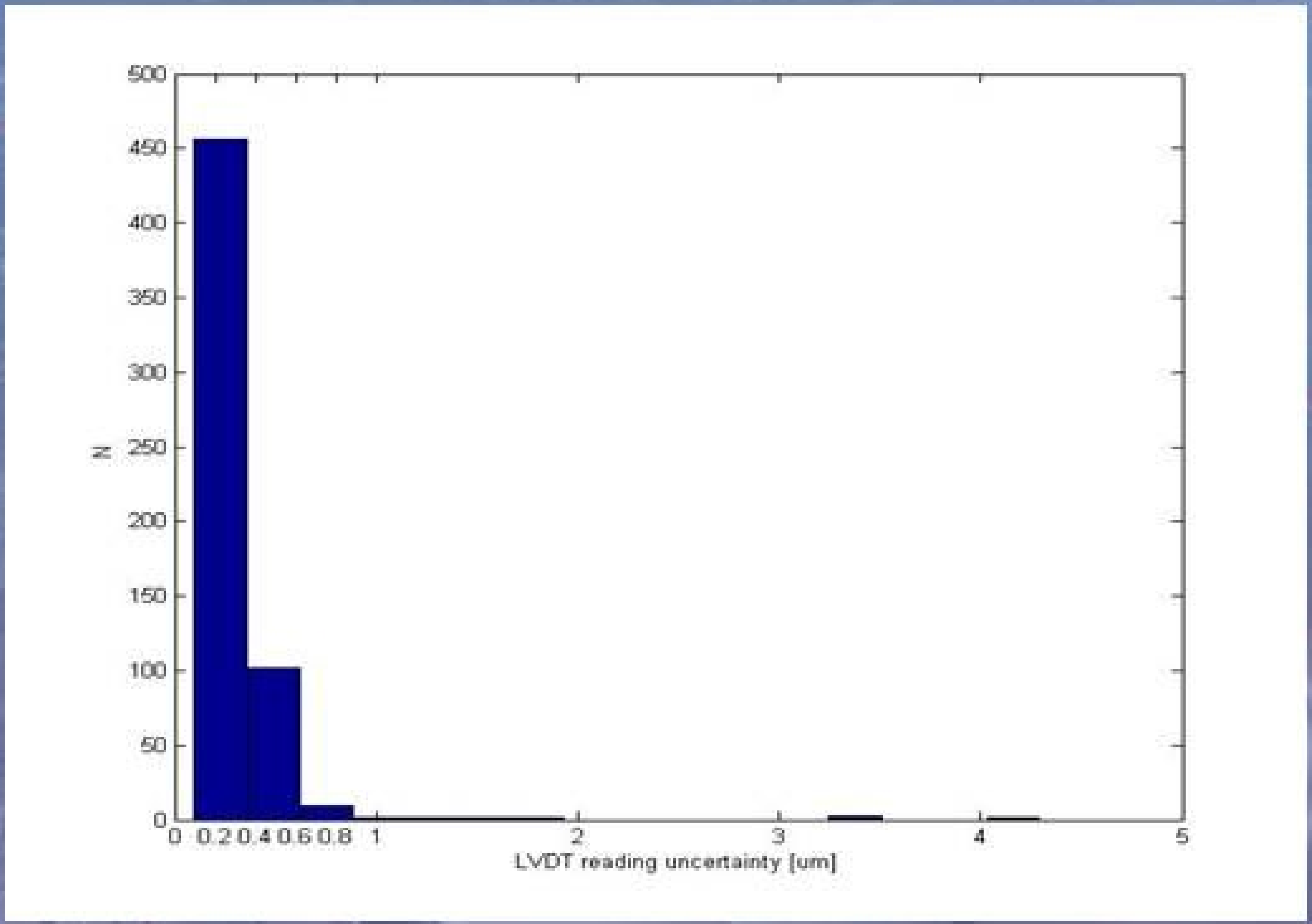
PRS Reading uncertainty: **0.3 um typical**



Distribution of 658 LHC Collimators LVDT reading uncertainty evaluated on 100 repeated measurements at 1 Hz

PRS measured performances

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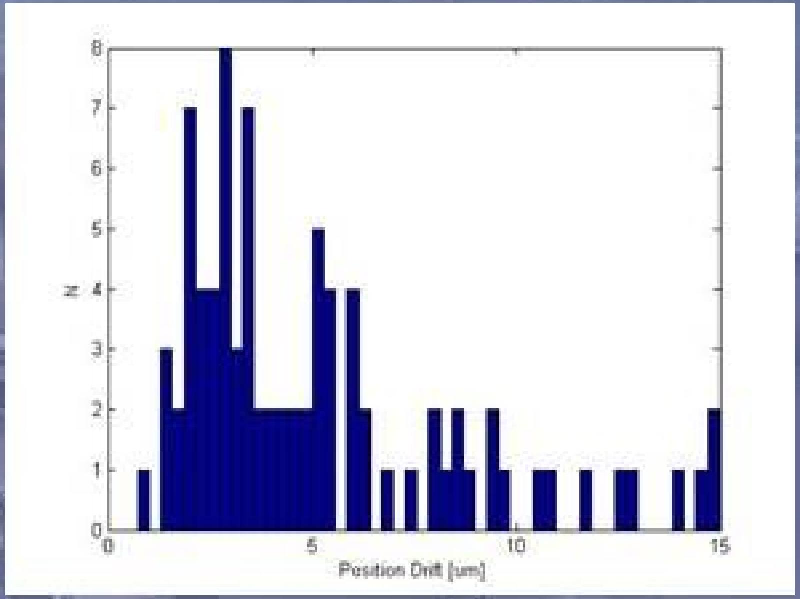
PRS long term stability

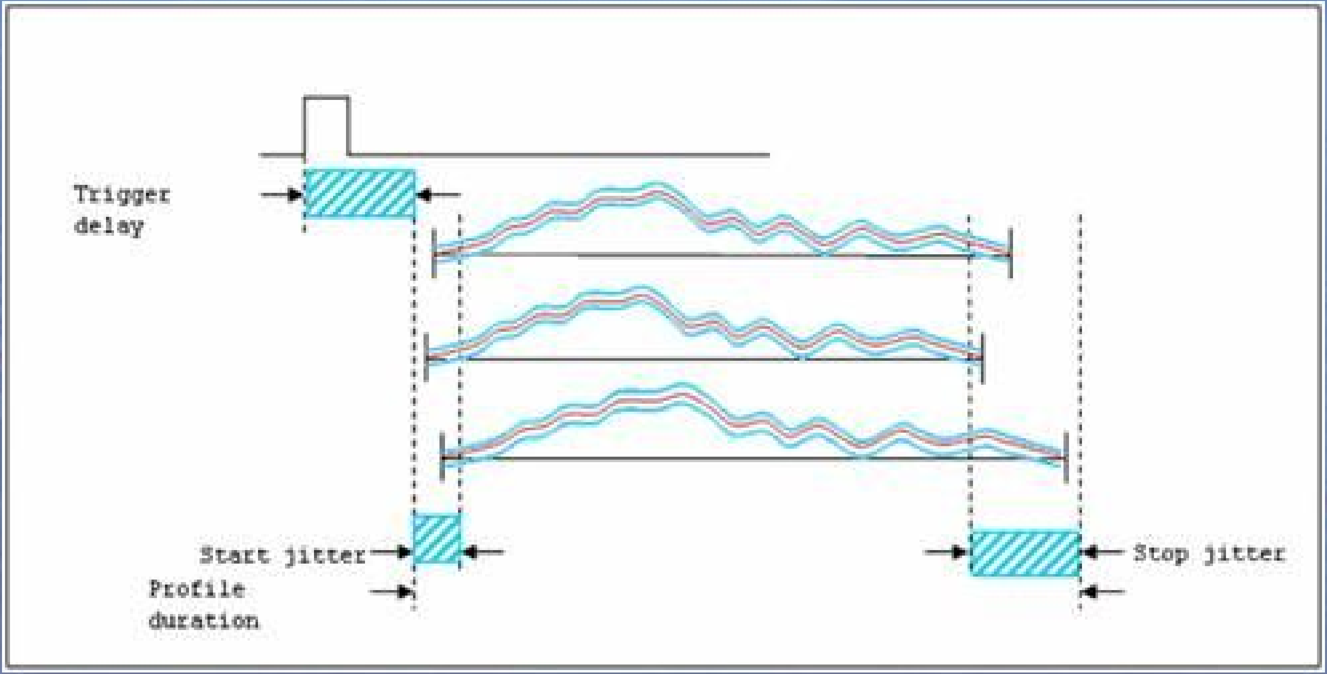
The main causes of reading drift are the temperature and DAQ card stability

- LVDT temperature sensitivity: 1 um/ °C (we have PT100 inside the sensor. We could compensate this drift)
- PRS temperature sensitivity: Thermal cycles showed that the reading drift produced by temperature excursion on the only PRS is actually negligible compared to that of the sensor
- Daq Card stability: according to the spec. less than 1 um drift per year is expected



Drift Distribution of 85 LHC Collimators LVDT over 3 weeks

PRS measured performances



Survey start jitter: 1.8 ms
Survey stop jitter: 2 ms
Survey profile duration : ~30 minutes

- The jitter parameters refer to the monitoring profiles of all the 108 collimators
- The values in the table represent average values on 30 repeated threshold profiles.
- The PRS timestamps are used to perform these measurements

Global system measured performances

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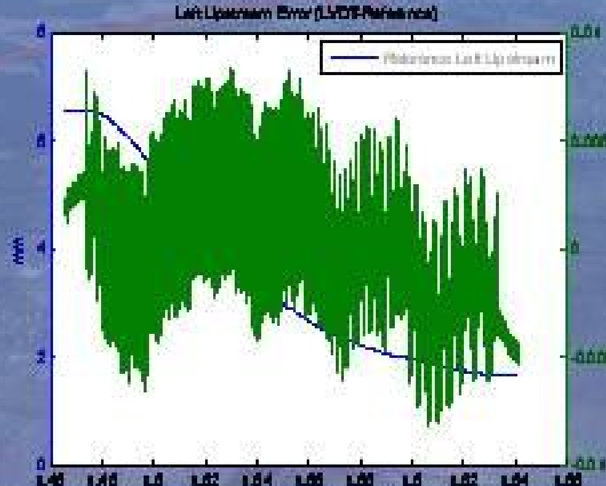
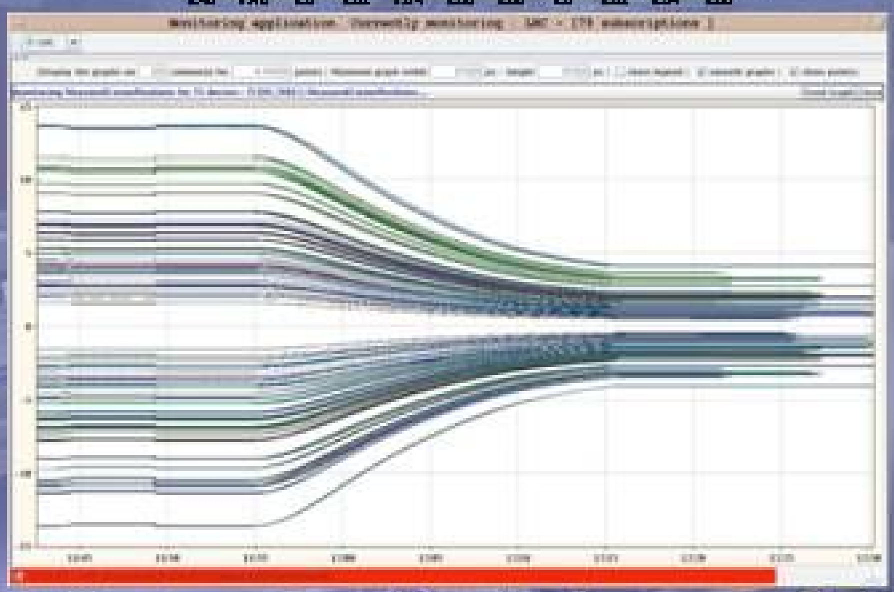
Motion profiles positioning accuracy

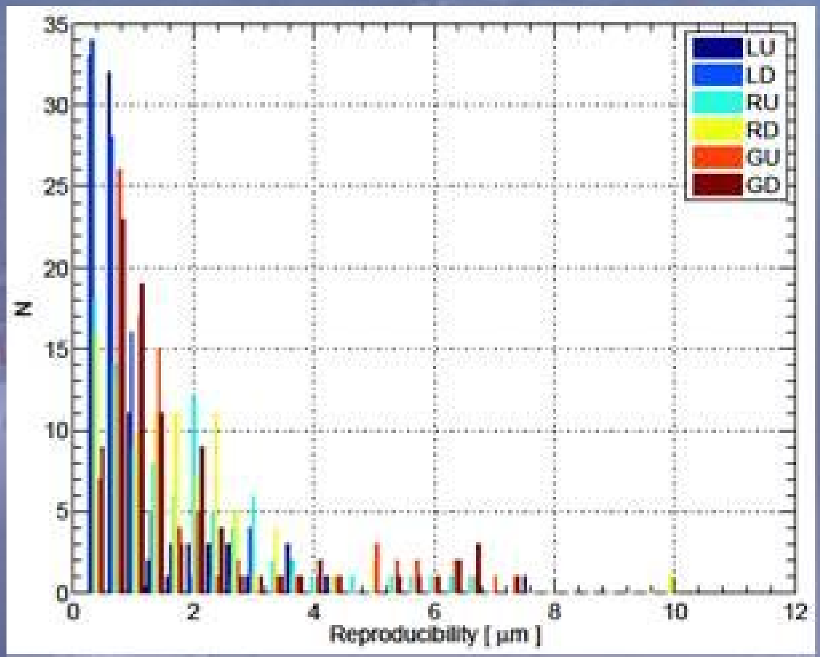
Taking as the test profile the 5 Tev energy ramp, we define for each collimators` axis over 30 repeated executions

- **positioning systematic error:** the average of the max error (i.e. difference between the LVDT reading and the requested position) over all the profile
- **positioning repeatability** as the standard deviation of the max error over all the profile





75 collimators: Synchronized ramps to 5 TeV (Nominal Beta functions)



Reproducibility of the collimators axes positioning over 1 day and 11 profiles

A. Masi, R.Losito, S.Redaelli,
Measured Performance of the LHC Collimators Low-level control system, ICALEPS 2009

Some installation pictures

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Conclusions

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	Required	Measured
Positioning repeatability	±20 um	below 10 um
Motion profiles synchronization	few ms	~100 us
Synchronization between axes of the same jaw	below 1 ms	few us
Survey profiles synchronization	few ms	~2 ms
Position sensors reading accuracy	few um	below 1 um
Position sensors long term stability	± 10 um	± 10 um

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Acknowledgements

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We are indebted to NI for the precious support received. In particular the System Engineering Group (Doug, Brent and Christian) and all the R&D people that were involved in this project as well as the Big Physics team (Stefano, Murali, Joel, Christian).

Last but not least Chris and Giuseppe

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Thank you very much for your attention