Real-time feedbacks @ LHC

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for the non-dormant AB feedback team,

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A bit of history…

LEP is very good example of what you can achieve in a collider with real-time control, and what you loose if you do not have it !

Inefficiencies in ramping and squeezing LEP beams was largely related to two control aspects :

- Tune stabilization
  - For a long time tune control during the ramp and squeeze relied on reproducibility and feed-forward from one cycle to the next – with moderate success.
  - The advent of real-time tune control was a major breakthrough in ramping efficiency when it became finally operational for LEP2.

- Orbit stabilization
  - LEP was severely affected by orbit drifts that were difficult to control with feed-forward mechanism.
  - The BPM system was not designed to provide real-time data, and up to the last day beams lost during the ramp accounted for a significant fraction of the machine inefficiency : ~10% or more !

… that should not repeat itself at the LHC

The LHC is orders of magnitude more tricky than LEP :

- The very large stored energy in the beam implies
  - very precise positioning of protection elements,
  - excellent collimation performance,
  - excellent overall control of the global orbit.

  which require excellent orbit stability.
- Large and dynamic perturbations affect orbit, tune, chromaticity… at injection, in the ramp and during the squeeze. Real-time control is necessary to stabilize those parameters.

→The LHC beam instrumentation has been designed to provide real-time data at least for orbit and tune where adequate measurements are available.

Real-time Systems at the LHC

- Orbit :
  - Very large and complex system – 2000 BPM readings, 1000 steering dipoles.
  - Covers the entire ring.
  - Operates nominally at 10 Hz (but possibly up to 25 Hz).

- Tune :
  - Modest system – 4 parameters and some 30 PCs (up to 50 Hz ?).

- Chromaticity and higher order multi-poles :
  - So far difficult to measure on the beams…, so feed-forward of settings and multipole (prediction) factory are likely to be used (at least initially).
  - Many systems of moderate complexity.
  - May potentially profit from a generic real-time infrastructure / framework.

Orbit FB Status

- Orbit FB is so far the most advanced system :
  - A lot of proto-typing was performed with beam at the SPS in 2003/4:

    BPM system, network communication, control algorithms, SW…
  - Requirements are well defined.
  - Perturbations and correction strategies have been already studied in detail.
  - Control specifications are well advanced.
  - Work on control issues was stopped during the second half of 2004 because CO had no resources.

- The orbit FB is a complex system :
  - Large size : involves > 100 front-end systems.
  - Complex network communication based on CERN technical network.
  - Important demands on computing power (large matrix inversions…).
  - Largest demands in terms of controls compared to tune…

Orbit FB Architecture

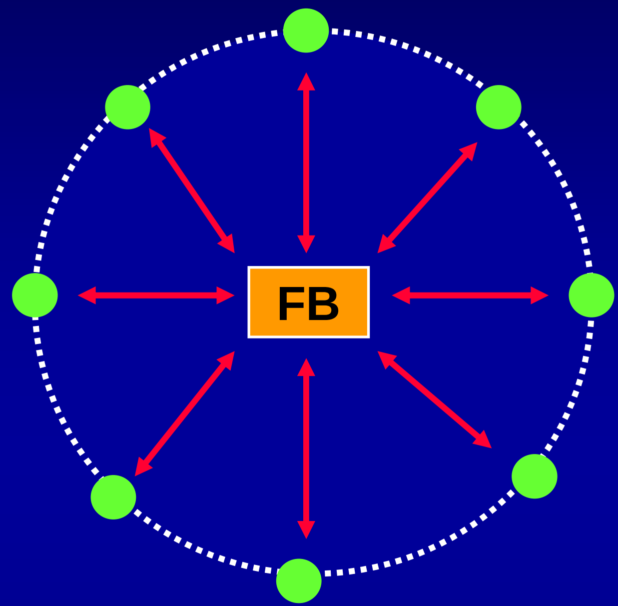
Centralized control

✓ entire orbit information available.

✓ all correction strategies are possible.

✓ can be easily configured and adapted.

× network is critical : delays and large number of connections.



Comparison with 3rd generation synch. light sources :

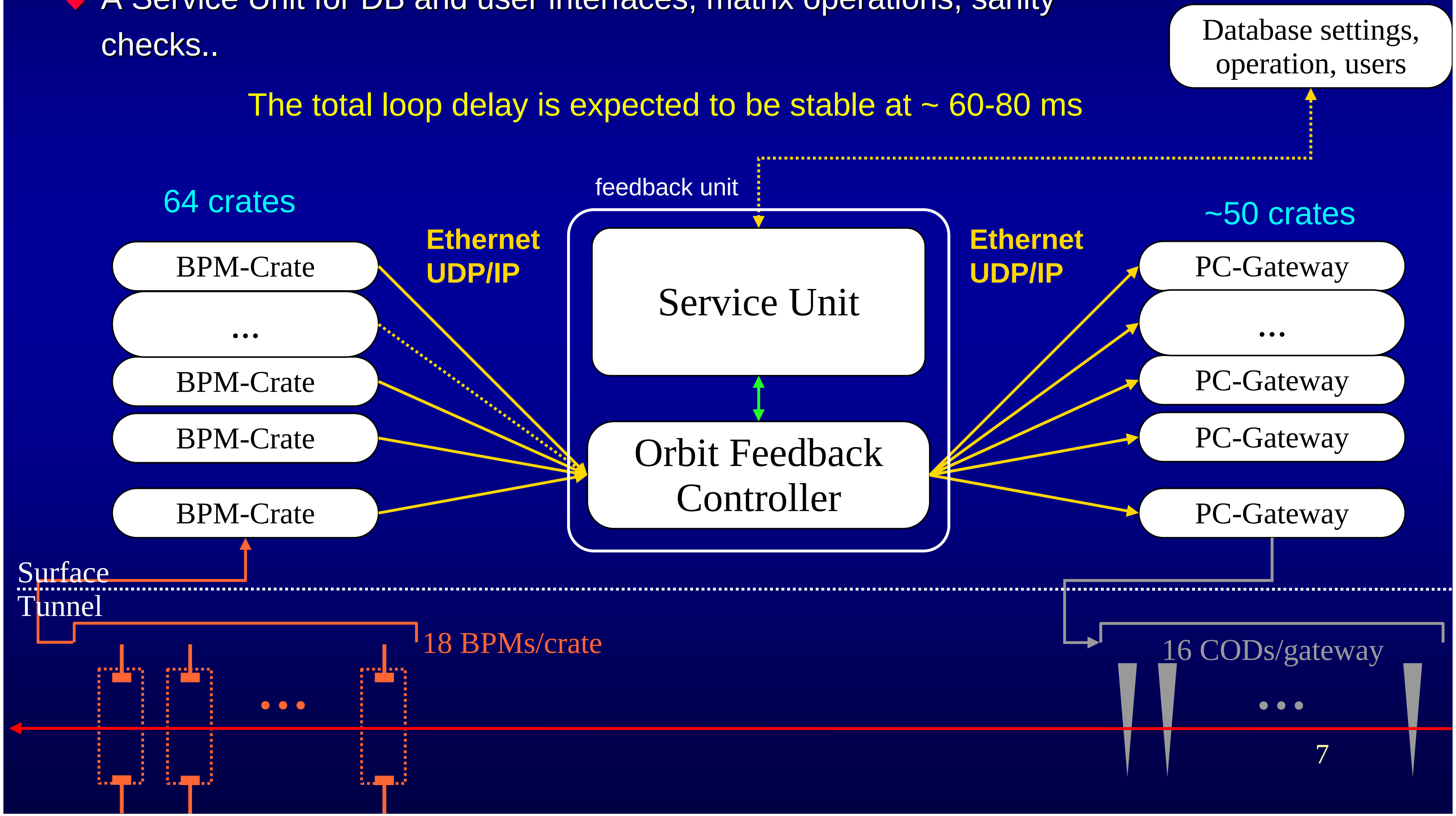
- Modern design trends are towards centralized control.
- Use of standard network solutions is chosen / considered seriously in many places (with QoS [Quality of Service]).
- The LHC system is ~ 100 times slower that FBs at light sources, but the large geographical distribution makes the system unique.

Orbit FB Control Layout

Central FB unit has 2 functional parts

- Time-critical controller unit to compute the corrections (hard real-time).
- A Service Unit for DB and user interfaces, matrix operations, sanity checks..

The total loop delay is expected to be stable at ~ 60-80 ms



Example for Orbit FB Issues

- BPM Front-end :
  - The real-time data stream must not be perturbed by read-out of multi-turn data that can represent many MBytes / crate.

- Central controller :
  - One main CPU is needed (and is adequate) to handle the real-time control loop at 25 Hz, which includes a large matrix multiplication.
  - Optics changes, BPM failures and other configuration changes imply the 'inversion' of two or more huge matrices (up to ~ 1000 x 600)

    → requires ten's of seconds on a P4 CPU.

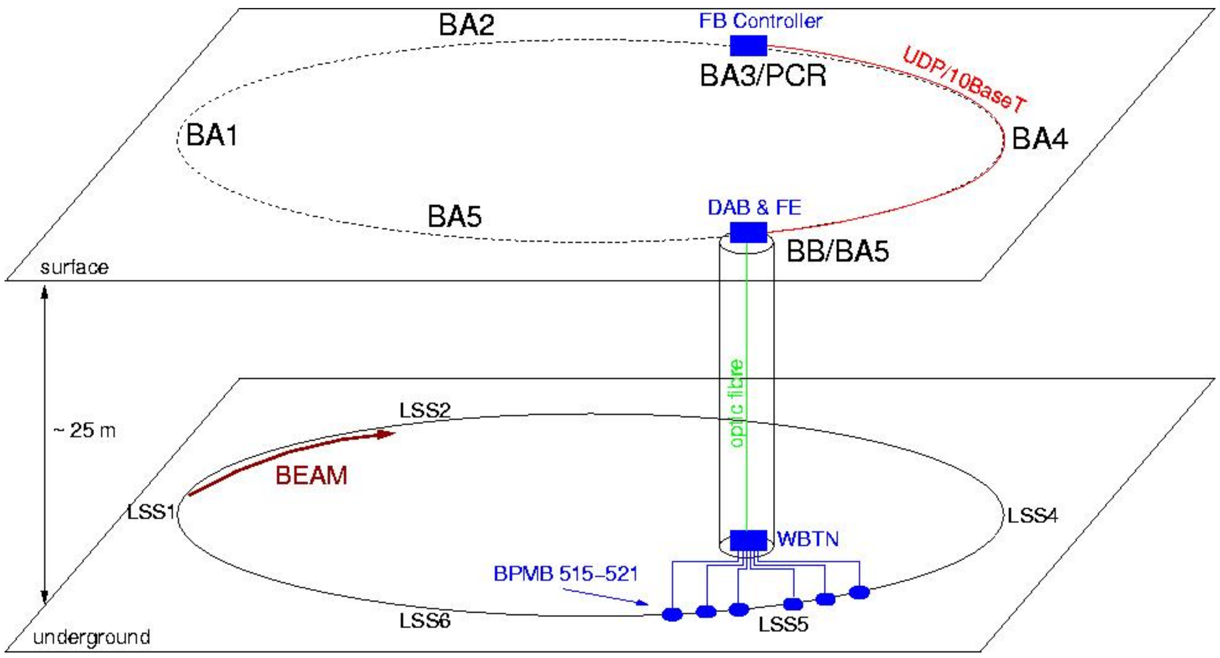
    → additional CPU + communication of the inverted matrices to the control CPU.
  - Parallel lower priority tasks must collect the beam energy, react on timing changes, verify BPM data quality, log data… → an additional CPU.

The 2 points have an issue in common : export/import of large data volumes without disturbing a critical real-time task.

SPS Proto-type layout

An orbit FB test was set up at the SPS and tested in 2003/2004 :

- 6 dedicated BPMs equipped with standard LHC electronics.
- Standard SPS CODs used as steering magnets (~14 Hz bandwidth).
- Data transport to the control room and back using the CERN technical network.



SPS Proto-typing / 1

- Aims of the proto-typing work in 2003/2004 :
  - BPM acquisition & readout test, up to 100 Hz.

    The system consisted of ONLY 6 BPMs !
  - Feedback loop design : controller, gains, transfer functions, influence of delays. Comparison with feedback models.
  - Networking tests (2004 with the new network infrastructure).
  - Overall FB performance in terms of stabilization at the SPS :

    The achieved stability of < 2 μm rms during coasts at 270 GeV is comparable to a number of 3rd generation light sources.

  → very successful, a lot of valuable experience was accumulated !

- From the central controller point of view (SW) the SPS did not represent a challenge – the system is just too small !

SPS Proto-typing / 2

- Central controller SW for 2003 :
  - Objective was to have ‘working SW’, no aims to re-use for the LHC.
  - Main difficulty arose from SPS cycling : FB had to be switched ON/OFF safely on appropriate beam.
  - Performance OK.

- Central controller SW in 2004 :
  - A proto-type FB framework was developed.

    This was done <u>against my advice.</u> For me it was too early for such work. I would have preferred more studies on the tricky issues of data transfer, multiple CPUs… which had to be done in OP.
  - The resulting system worked, but :

    - It is MUCH too configurable : almost a night-mare for the user.

      → requires re-engineering.

    - Not proven to be suitable for the complexity of the LHC system.

The orbit FB 'Test-bed'

The test-bed developed by R. Steinhagen is a complement to the Orbit Feedback Controller :

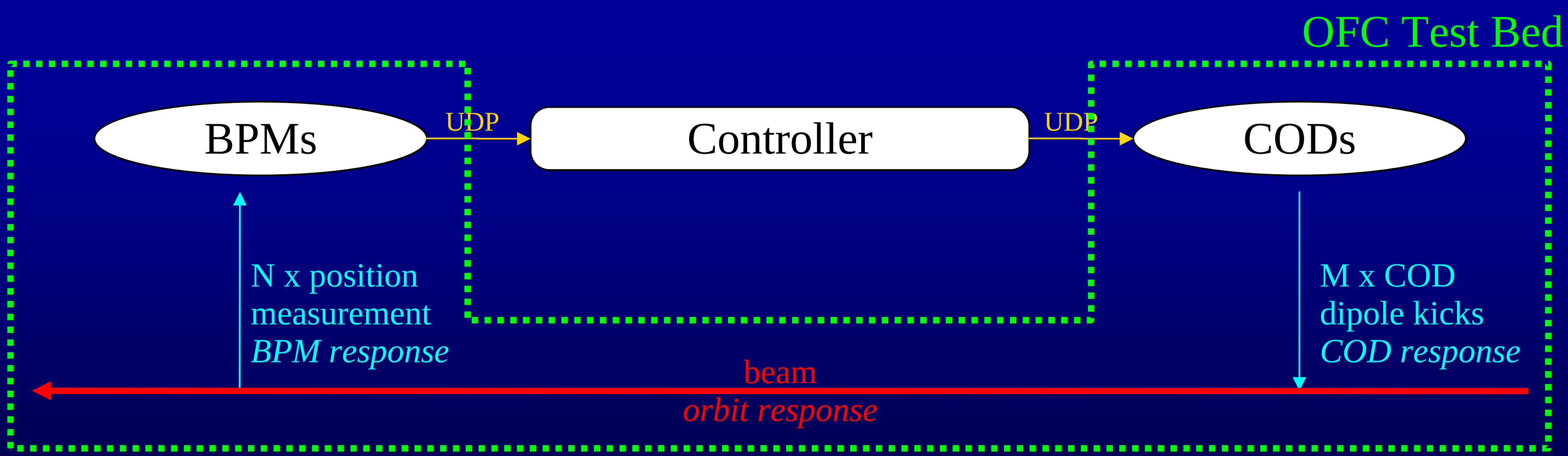
- Simulates the orbit response of COD →BEAM →BPM

  Includes the correct dynamic behaviour of the PC + magnet circuit.

- Same data delivery mechanism & encoding as in the real front-end

  Transparent for the FB system → simple "offline" debugging.

- Feedback performance can be tested and validated under various scenarios with the test-bed.



CO's part

Demands to CO are simple and should be well known:

- The FB hardware architecture must be defined.
  - The computing requirements prevent the use of a single CPU !
- The systems must be implemented and tested.
  - Based on proto-type or new framework. Suitable for all feedbacks ?
  - Support and help from OP for algorithms, UIs and individual SW components.

- Manpower estimate :
  - ~ 2 FTEs (possibly ~1 FTE for a 'stripped down LHC startup' system).
  - Work has to start ASAP to be ready mid-2007.

- The work organization must be redefined :
  - Responsibilities and 'executive power'.