

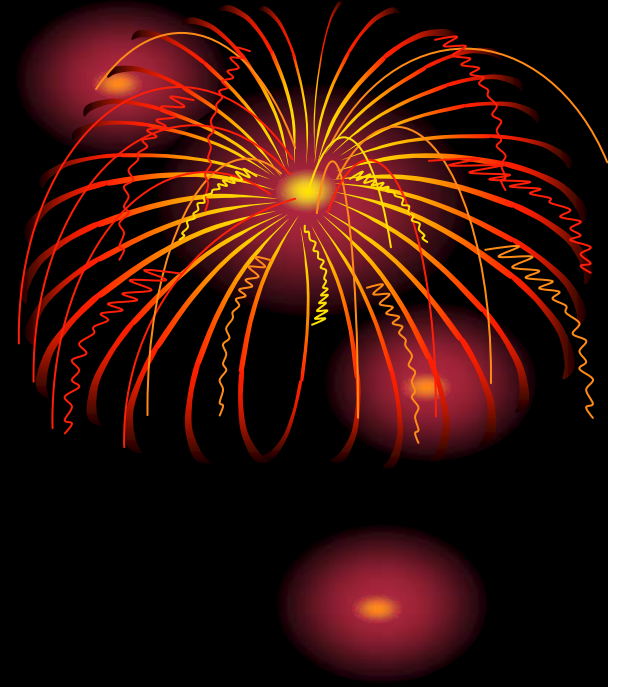
Rapid SC changes:

Can it ever work?

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Acknowledgements : K. Cornelis, R. Steerenberg, K. Hanke

YES !



It works already !

But with some limitations...

# Issues for (rapid) SC changes

Classes of issues :

- Controls limitations
- Equipment limitations
- Magnetic effects

Operational issues :

- Switching between operational super-cycles
- Setting up of new super-cycles

# Switching between existing operational SCs

# Controls : SPS

- During the long shutdown of 2005 the SPS control system went through a major upheaval:

- Front-end control from SL\_EQUIP to FESA.
- High level controls from CTREE/TZ to LSA.
- Change of the timing and cycling philosophy.
- New logging and statistics system.
- New beam and software interlock systems.

Thanks to a smooth  
and fruitful  
CO-OP-BI collaboration !

- The conversion was not complete, but the most critical items were targeted. The actual achievements exceed my most optimistic expectations! The migration is expected to finish by the end of 2007.

- Thanks to this considerable effort, the SPS can perform rapid SC changes, i.e. on the time scale of ~1 minute.

- Example : switch between SCs with different MD segment length morning/evening/WE to optimize duty cycle for FT/CNGS.

# Controls in general

## ■ Intrinsically both the CPS and SPS control systems presently support rapid SC changes:

- The settings are resident (i.e. pre-loaded) in the front-ends... and SC switching is just a matter of loading the appropriate timing sequence.
- This is achieved despite a radically different organization of settings in the SPS/LHC and CPS controls worlds.

## ■ Observation from the 2006 run:

### 1. The 'effective' SC switching time was frequently longer than needed.

This limitations came from the update of the timing sequence for the PS and booster. To take full advantage of the control systems capabilities we must:

- Either: announce/prepare cycle changes sufficiently in advance to update the timing sequence (15 mins ?) BEFORE the new SC is required.
- Or: make sure any change at the level of the booster/PS cycles that is made on the running SC is 'immediately' propagated to all 'SCs of the day'.
- And: ease the use of the sequence editor - see Rende's presentation.


### 2. Isolde (also PS?) users complained about lack of pre-warning on SC changes.

# Equipment limitations : SPS

■ Almost all equipment in the SPS is able to follow a SC cycle change without intervention or overhead.

■ Exceptions: (same items were also identified as issues for multi-cycling by K. Cornelis & Co)

- **Non PPM collimators used for beam scrapping** (momentum & transverse) must be moved back and forth between LHC & FT/CNGS settings.
- For (high intensity) LHC beams the **electrostatic septa** for slow extraction are retracted (~ 1-2 minutes) and the voltage ramped down (e-cloud, sparks).



Switching between LHC (high intensity) and FT/CNGS beams takes 2-3 minutes (without beam) when the tasks are well synchronized. A (simple) sequencer would be helpful to drive the tasks - we should profit from the LHC sequencer development.

No overhead as long as the two SCs involve only FT/CNGS OR only LHC.

# Limitations : PS

- No limitations or overhead when switching between 2 operational SCs. This assumes that any limitations due to non-fully PPM equipment are already taken into account in the SCs.



# Setting up new SCs

# New SC issues

- Assumption : a new SC is required based on already operational cycles.

We are not concerned with NEW beams or cycles, but we want to reshuffle existing cycles within the SC.

- Are there any additional issues?

- CPS:

- ✓ Settings are intrinsically organized by cycles (and not by SC). There are no limitations except for non-fully PPM devices that constrain the cycle order.
- ✓ Changing the SC just changes the order in which the cycles are played.

- SPS:

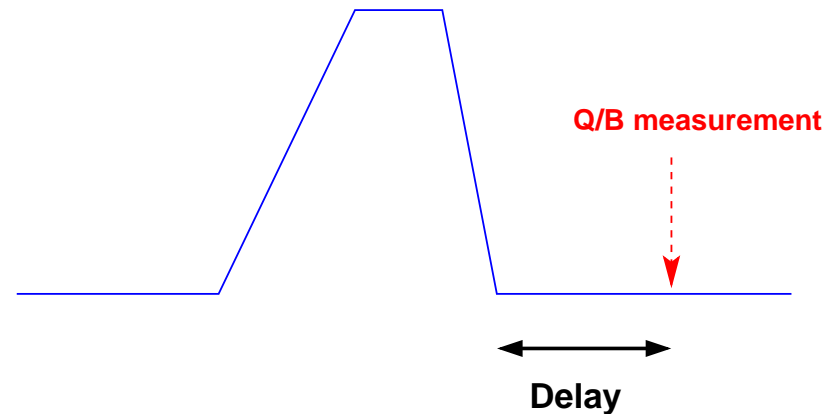
- ✓ Settings are intrinsically organized by SC, even if the individual cycle settings are independent. To build the new SC, the settings of each cycle must be 'imported' from a pre-existing SC. In 2006 the 'import' suffered from initial bugs (related to settings structure), but was OK after ~ 2 months. It will be further improved for 2007.
- ✗ Remnant fields and eddy currents introduce a dependence of the cycle settings on the details of the SC.

# SPS Magnetic Effects

- The SPS main magnets are driven far into saturation on 400/450 GeV cycles.
  - Optimum settings required for high intensity beams can depend on the SC composition. Very little quantitative information is available since this would require to test a large variety of SCs. But there is evidence of a dependence of chromaticity on the FT momentum.
  - The effect is expected to be small for combinations of 400/450 cycles.
- The SPS is subject to long lasting eddy currents that impose
  - Either: A **minimum** or **fixed** delay between ramp-down and injection of the next beam.
  - Or: A change of dipole and quadrupole settings when the cycle composition is changed.

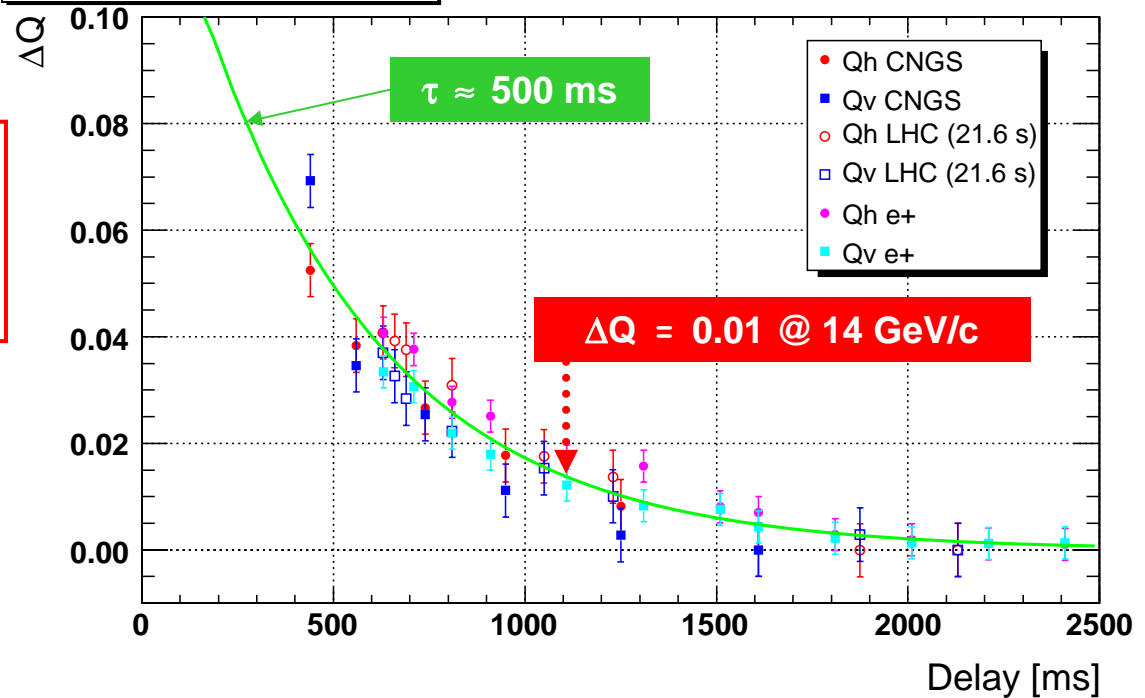
# Eddy Currents @ SPS

- SPS beams are affected by long lasting Eddy currents due to the mains ramp down that affect the momentum and the tune of the following beam.
- The field corrections depend on the delay to the preceding down-ramp.



To move a cycle around within a SC WITHOUT re-tuning, the delay must be  $\geq 1$  BP! (not the case for the CNGS cycle!)

Tune Decay at 14 GeV/c



# Example : FT-3xCNGS SC

➤ SCs A & B only differ in the cycle order.

➤ Crucial difference between A & B:

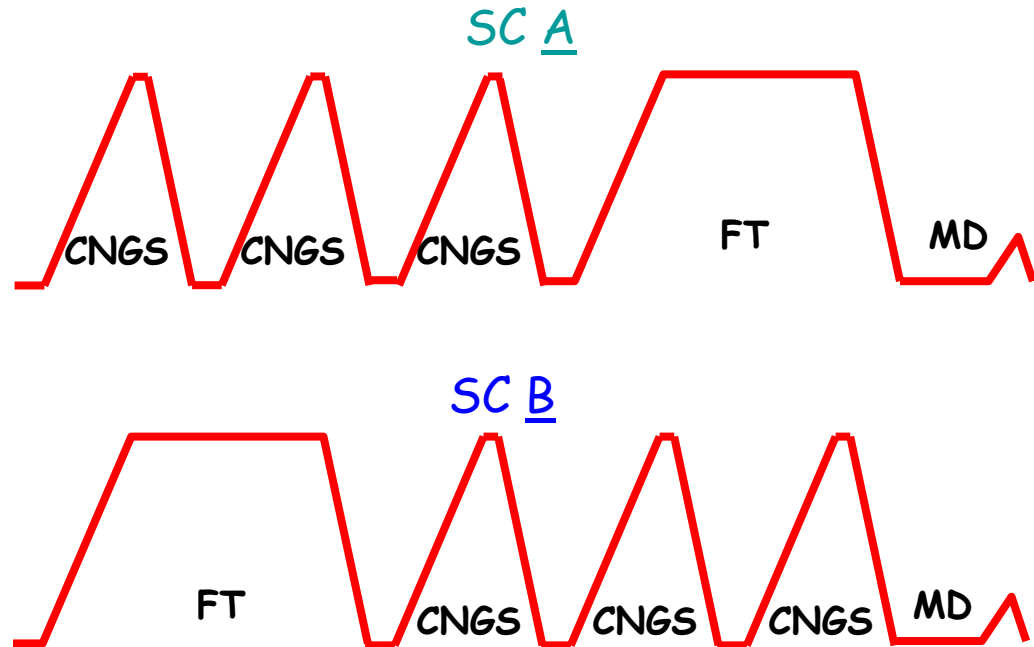
- A: CNGS cycle No.1  $\neq$  No. 2 & No. 3 because there is no ramp down from 400 GeV in front of it!

→ No Eddy currents on 1<sup>st</sup> CNGS.

Tune & B field corrections are different for CNGS 1 and CNGS 2&3.

- B: All CNGS cycles preceded by a ramp down from 400 GeV.

Same Eddy current effects for all 3 CNGS cycles.



➤ SC B was prepared in the fall of 2006:

- It was neither used with really high intensity nor tuned 'to the last bit'.
- **For moderate intensities ( $2-3 \times 10^{13}$ ) it seemed possible to use the SAME settings for all CNGS cycles.** To be confirmed with higher intensities.
- Small differences in optimal settings have been observed (RF phase loop)...

# Other observations : SPS

■ For FT and CNGS cycles that have much faster ramps than the nominal LHC cycle, we have frequently observed that:

- Good settings of a given cycle, when copied onto a (apparently) similar/identical (new) cycle in another SC could result in significant performance degradation of the 'copy'. The symptoms are more beam loss (from a few to ~50%) in the first 500 ms of the ramp, around transition.
- Restarting a good cycle after an interruption (of say 1 week) could also result in similar performance degradations.
- 'Cure': readjustment of tune, chromaticity, octupoles.

■ Where is the root of the reproducibility problem?

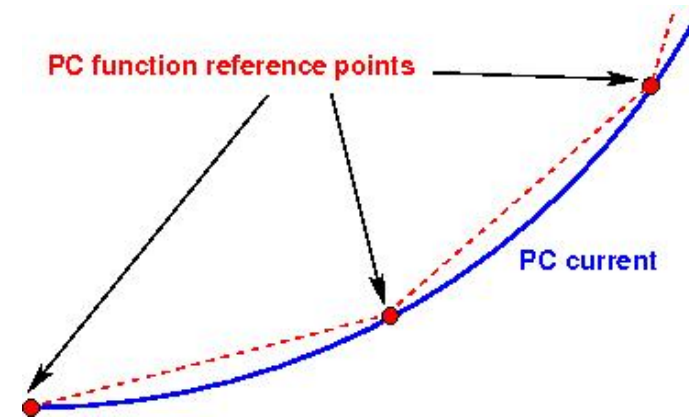
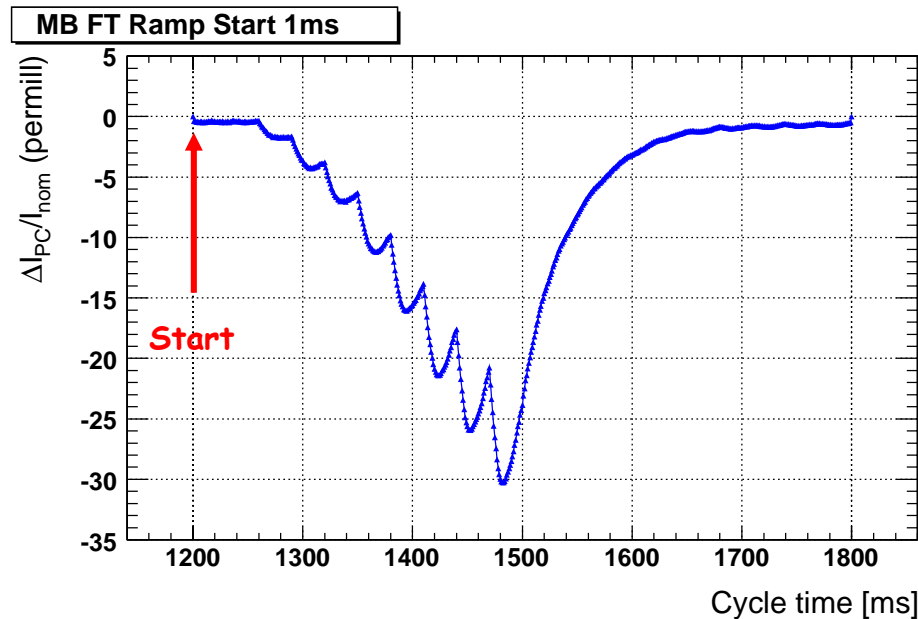
- Controls ?
- Equipment ?
- Magnetic ?
- A mixture CO+EQ+MAG ?

So far the cause has  
not been identified !

# Power Converter Tracking I

- The ramp functions of the SPS main converters consist of reference points spaced by 30 ms (or integer multiples of 30 ms). The 30 ms are a heritage of former SPS converter control systems....
- For fast ramps (FT/CNGS) the converter current does not follow the 'bare' reference functions, in particular during at the ramp start. The PC effectively performs a smooth interpolation between the reference points.

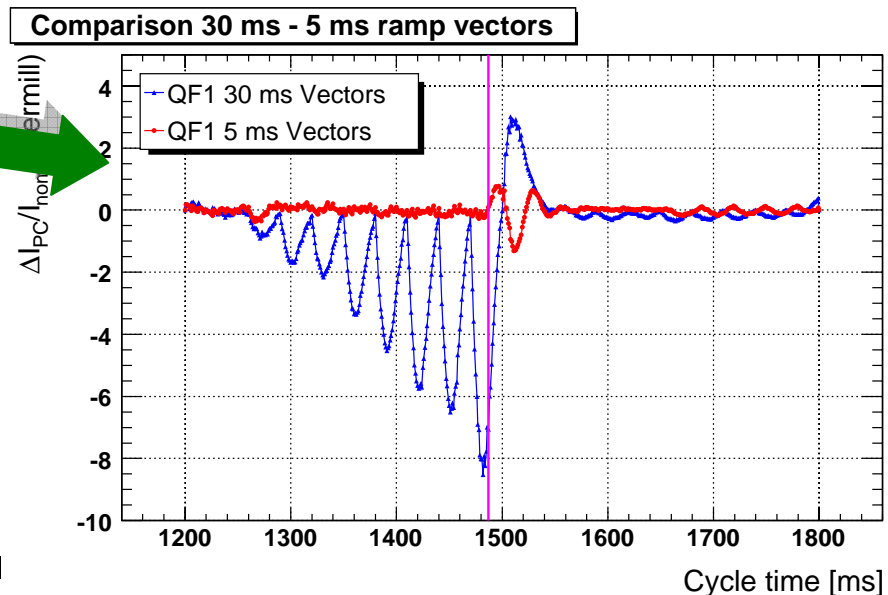
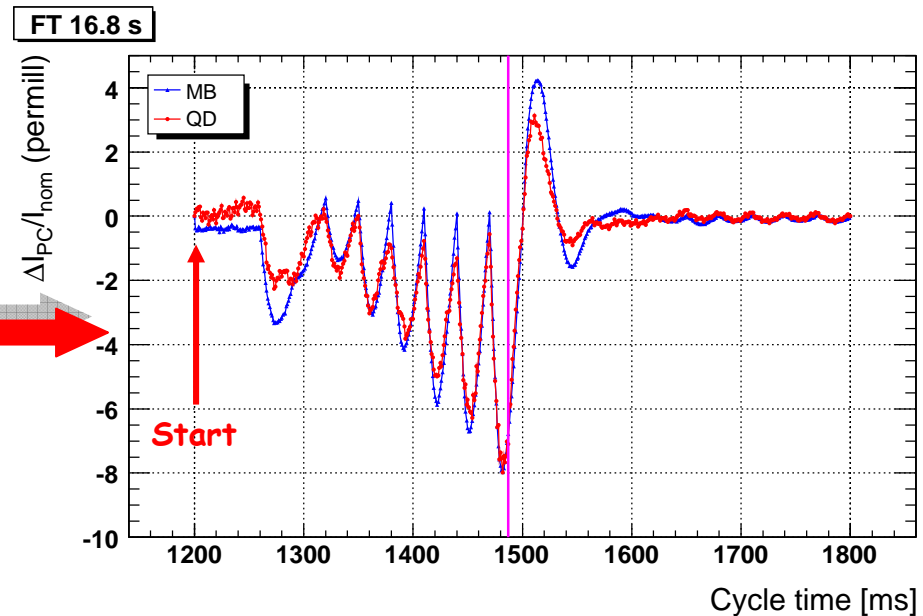
PC current error for FT ramp start



# Power Converter Tracking II

- To ensure that the PCs produce the current we want, the error signal is fed back to the reference function ('Autotrim'). This procedure converges, but leaves large 'tracking' errors between the reference points (with 30 ms spacing).
- Fortunately the relative error is the same for dipoles and quads : the tune is ~ OK.**
- The beam is very sensitive in this region near transition, and it is possible that the 'tracking' and reproducibility issues are related...
- Tests performed at the end of 2006 show that **this problem can be solved by providing ... smoother functions with ~5 ms point spacing.**
- In parallel PO is on working improvements for the PC regulation (reduce lag & large errors before FB).

→ There is some hope that the situation could improve in 2007 for the fast FT/CNSG ramps !





# Upcoming problem ?

- With the present timing system, there is room for 24 USERS, respectively 24 resident cycle settings in the equipment FEs.
  - In practice **this number is only 16 for the SPS**, because 8 USERS are reserved for special cycles (Pulse Start/Stop and Coasts).
- To avoid a complete chaos, OP tries to define meaningful USER names and associate certain USER (names) to certain beams (FT,CNGS,LHC nominal, pilot ...).
  - LHC beams are big 'USER consumers' in all machines because of the many variants (bunches, intensities).
  - At the SPS, to have resident settings for the same TYPE of cycle (for example CNGS) embedded into different SCs with different settings, a number of USERS must be reserved for each beam type (CNGS1,CNGS2,CNGS3).
    - At the SPS we are at the limit with our 16 USERS !!!

- For certain machines (booster, SPS) there is an interest to increase the number of USERS to 32 (for example). See also Rende's presentation.
- For the SPS this will depend strongly on how we will operate in the LHC area...

# Conclusion

## Yes we can make rapid SC changes!

Between 2004 and 2006 we have transformed the old SPS control system into a state-of-the-CO-art system. There are still many things to polish, but we are on the right track. And we have harvested the first fruits in the late summer of 2006.

The SPS has some (known) HW limitations when switching between LHC and FT/CNGS operation. The time overhead is the range of few minutes.

Reproducibility issues at the SPS will be studied further in 2007.

CO should start thinking about an increase in the number of timing USERS.