Simulation of the performance of the CNAO facility's Beam Delivery System

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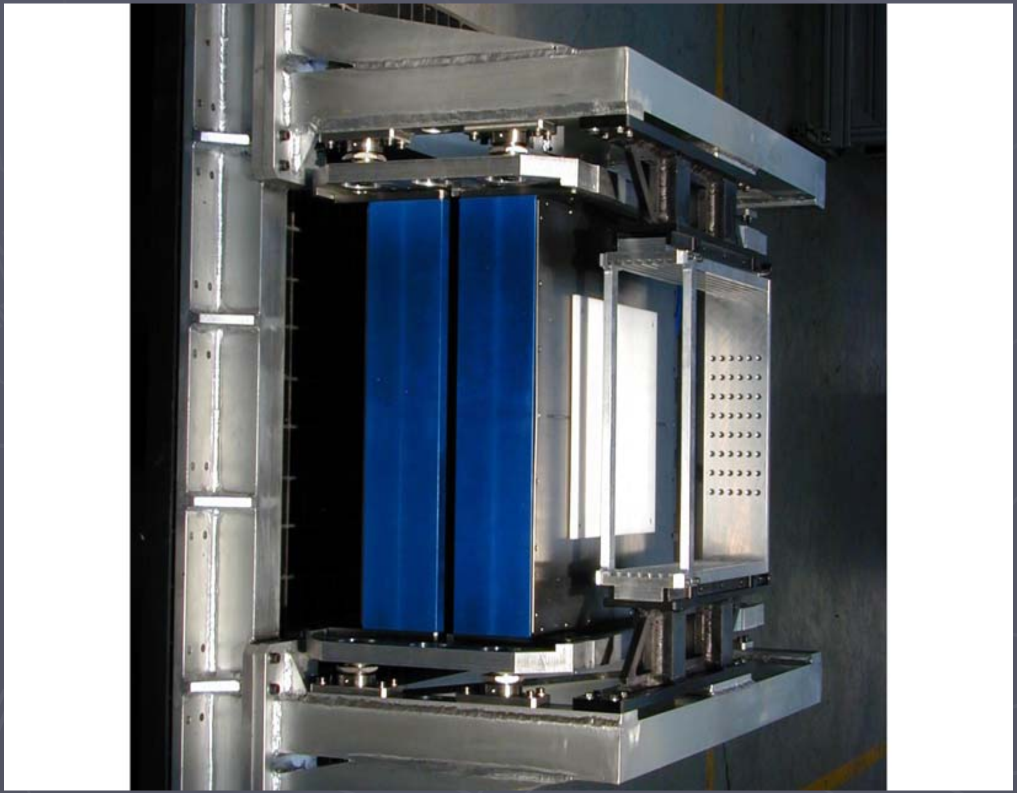
Centro Nazionale di Adroterapia Oncologica (CNAO)

- CNAO (National Centre of Oncological Hadrontherapy): under construction at Pavia, Italy.
- Synchrotron.
- Proton and ion therapy.
- Active beam delivery: after the irradiation of a voxel the beam is scanned to the next one without turning it down.
- The Turin section of the INFN is responsible of the construction and operation of the Beam Delivery System (BDS).

The BDS of CNAO (I)

5 detectors to check online the number of particles per voxel, the beam position and the beam size.

N_2 as active medium



Two integral chambers: to measure beam fluency (number of particles).

Two strip chambers: to measure the beam X and Y position.

- 128 strips/chamber, 1.65 mm

A pixel chamber: to measure beam size, position and intensity.

- 32x32 pixels, pitch= 6.6 mm

The BDS of CNAO (II)

►The data acquisition, computation of parameters and comparison with reference parameters is performed with 4 FPGAs (*Field Programmable Gate Array*) ⇨ High speed.

- FPGA1: integral chambers read-out. Check the number of particles per voxel (frequency 1 MHz).
- FPGA2: strip chambers read-out. Computation and check of the beam position (frequency 10 kHz).
- FPGA3: pixel chamber read-out. Computation and check of the beam position and size (frequency 5 kHz).
- FPGA4: computes a position correction if necessary and communicates it to the scanning magnets (also the position of a new voxel).

Purpose of this study

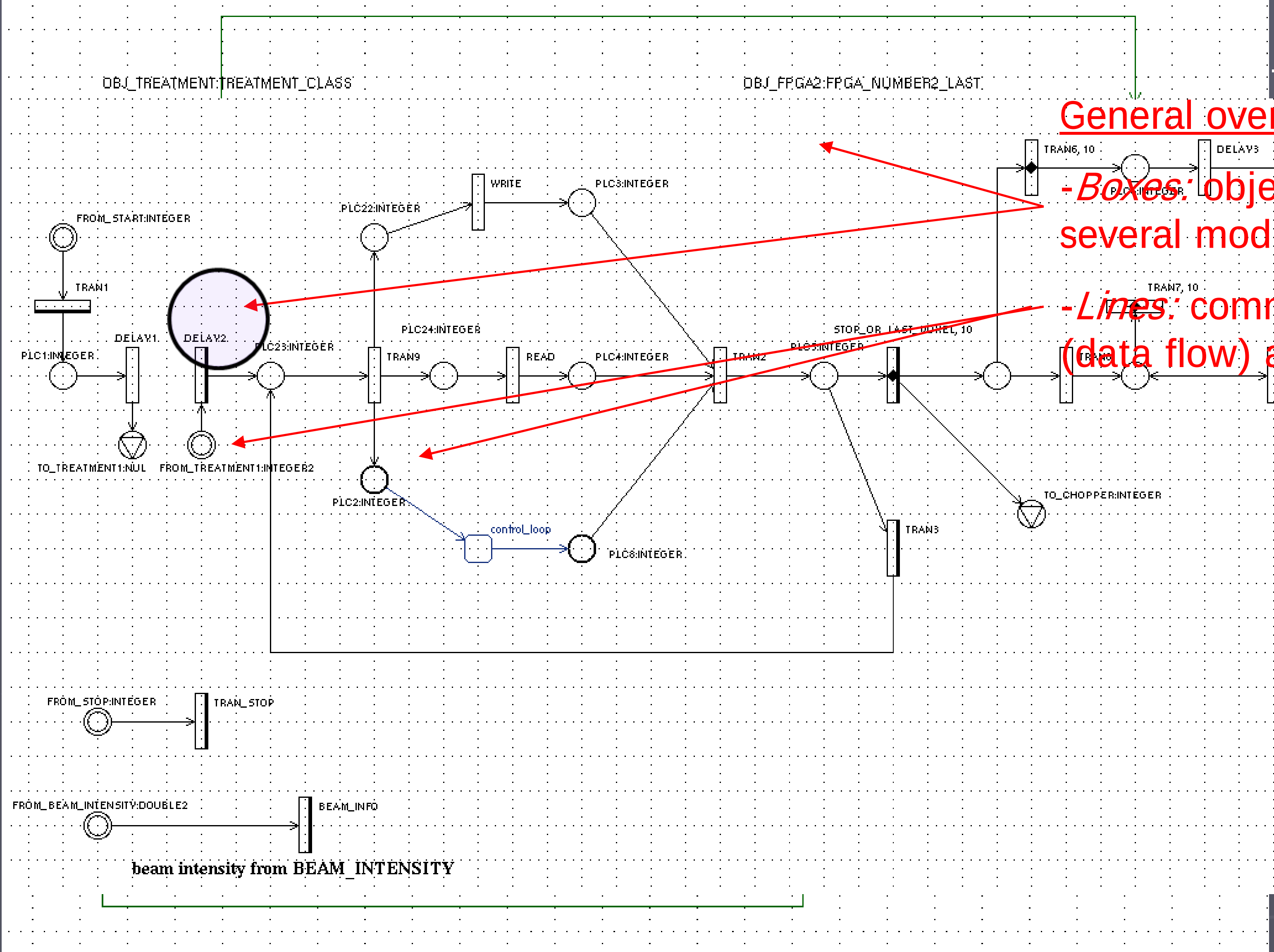
- General:
  - To implement a full simulation of the BDS, including internal (FPGAs, detectors) and relevant external modules, and the communication among them in order to study the real-time behaviour of this large system. It can help to improve and optimize the operation of the BDS and to study the response of the system in some critical cases.
- In this talk we will show some results regarding:
  - the measurement of the beam position. It probably constitutes the most critical part of the BDS.
  - the “feedback” (fine-tuning of the beam position) between the BDS and the scanning magnets.

FABER toolkit

- The BDS has been simulated using the FABER software http://www.fabersoftware.com
- Object Oriented language. Combination of a graphical programming to model the time and data flow with C/C++ routines to model activities.
- This package supports an easy implementation of concepts like delays, synchronization or communication, thus allowing to simulate complicated real-time systems.

BDS simulation

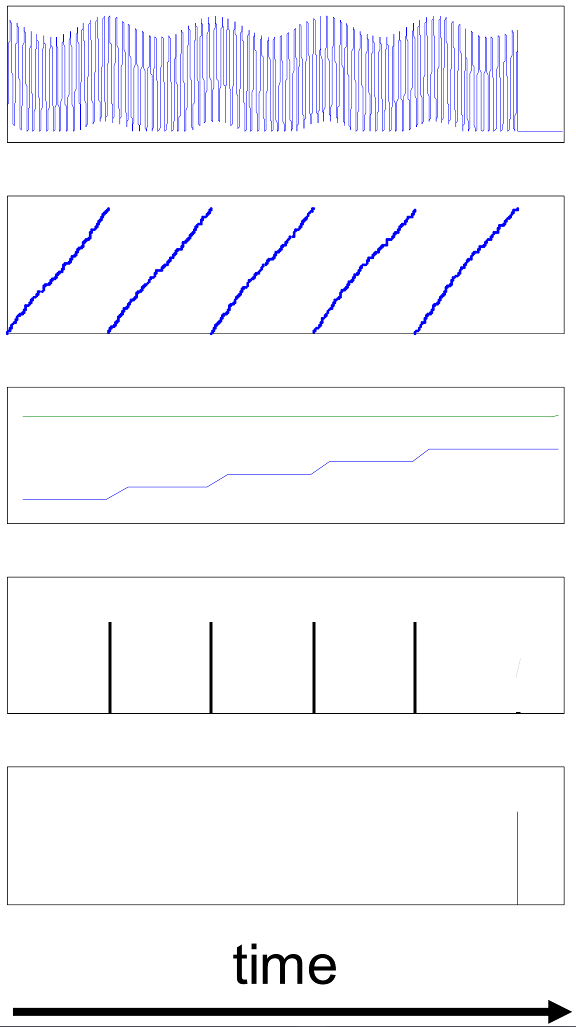
Example: FPGA1



General overview:

- *Boxes:* objects representing several modules.
- *Lines:* communication lines (data flow) among objects.

Specific results (I)



An example: 5 voxels aligned along the X axis.

beam intensity

number of particles measured with the integral chambers

X and Y position measured with the strip chambers

“new-voxel” signal created by FPGA1

“end-of-treatment” signal

Specific results (II)

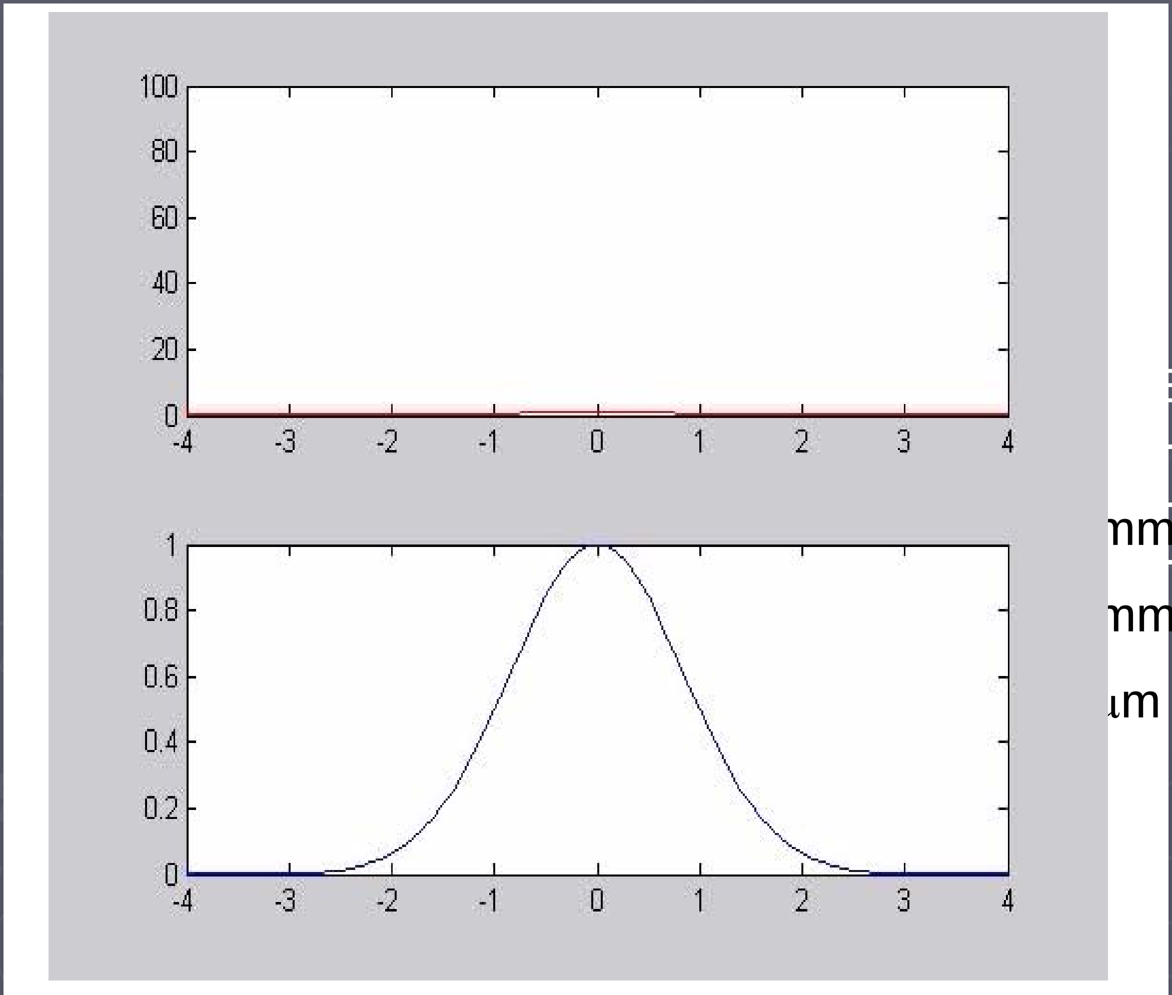
Position measurement (FPGA2) after NEW VOXEL event.

The beam scanning from a voxel to the next one can cause problems to the position computation of FPGA2:

1. the beam may have not arrived to the specified position before the next measurement. Wrong position determination!
2. even if it has arrived, the scanning produces an asymmetric broadening of the signal integrated in 100 μs that can distort the position measurement.

Specific results (II)

Position measurement (FPGA2) after NEW VOXEL event.



mm

mm

um

Example:

- scanning speed = 20 m/s
- new voxel signal at t=0
- distance to next voxel = 1 mm

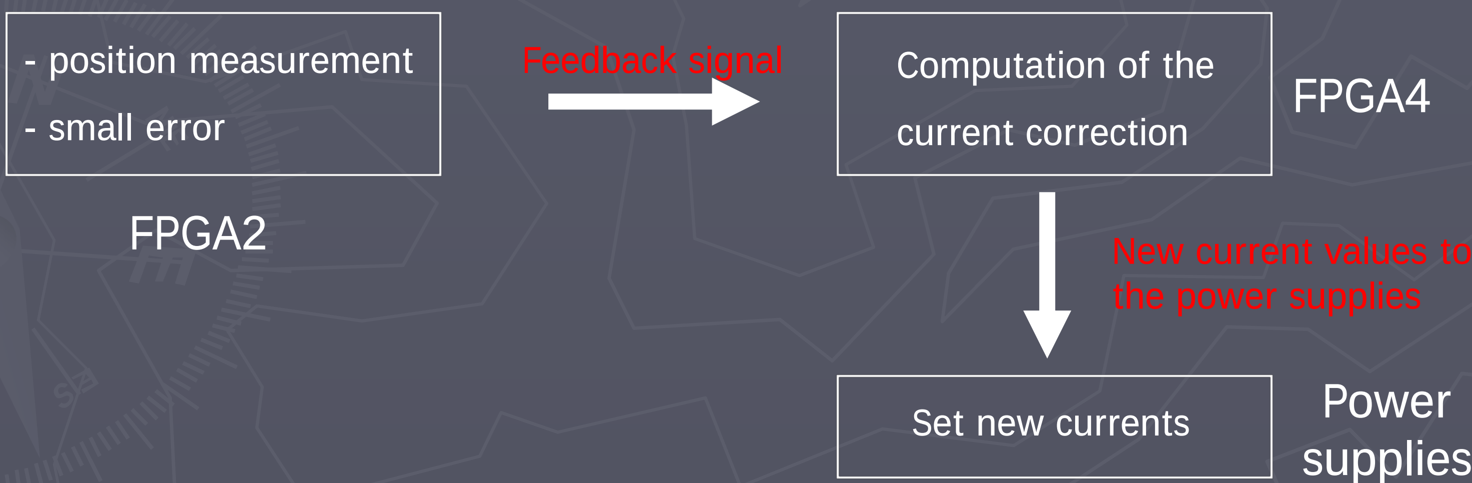
POSSIBLE FALSE INTERLOCK EVENT!!!!

The first measurement after a new voxel event must be neglected.

Specific results (III)

Feedback FPGA4-scanning magnets (position fine-tuning).

- If FPGA2 measures a positioning error larger than a given threshold it will create an INTERLOCK signal (and the beam will be turned off).
- If it measures a smaller error, a position fine-tuning involving FPGA2, FPGA4 and the power supplies of the scanning magnets will be activated.



Specific results (III)

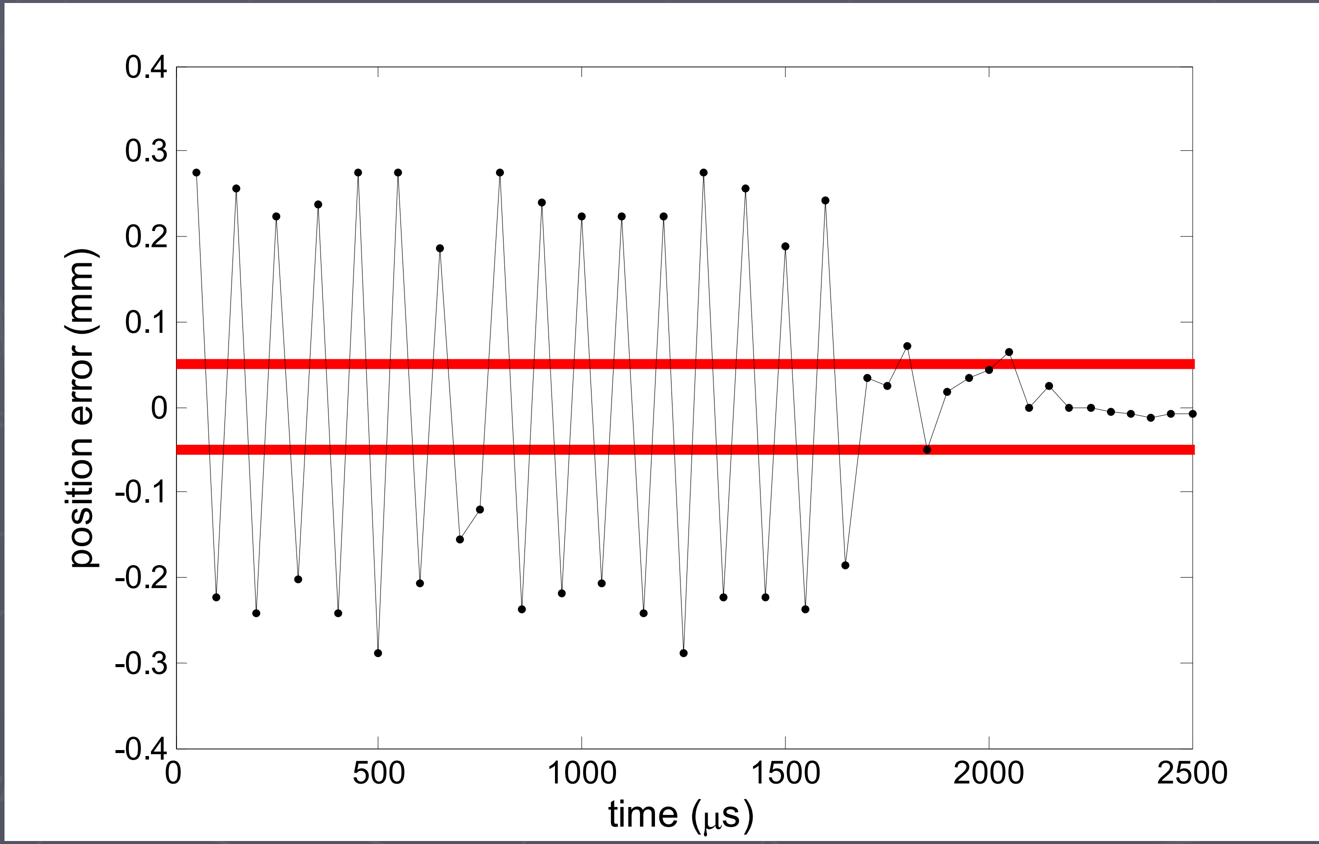
Feedback FPGA4-scanning magnets (position fine-tuning).

<u>Problem:</u> a measured position error can be ficticious (at least in part), for example due to an “integration” or “statistical” effect, and not a real error.

If we apply a correction factor accounting for all the measured error, we could in fact not to correct the error but to create a new one, entering into a continuous (or long) feedback loop.

Specific results (III)

Feedback FPGA4-scanning magnets (position fine-tuning).



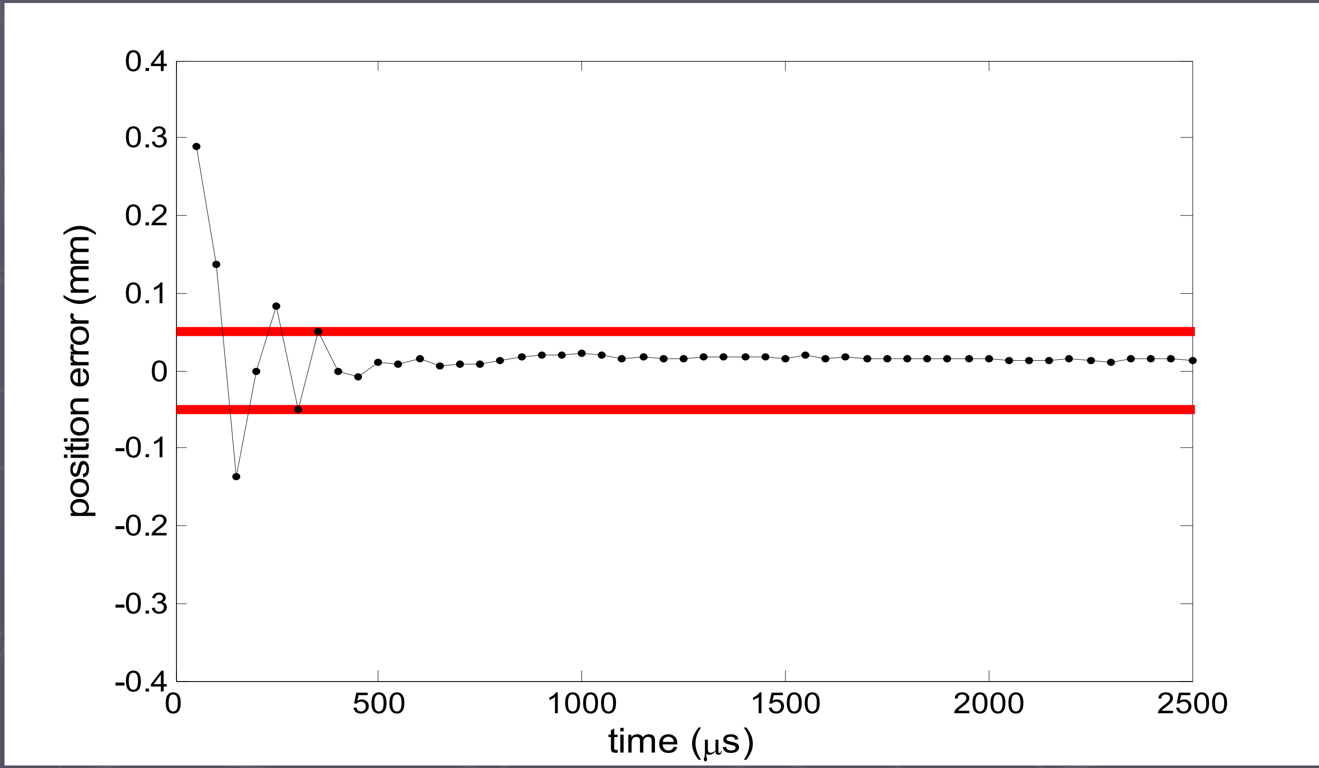
<u>Example:</u> correction of a 0.2 mm positioning error.

- C beam, E= 400 Mev/u, $F=4\times10^{8}$ C/s

Specific results (III)

Feedback FPGA4-scanning magnets (position fine-tuning).

A method to avoid this effect is to apply a correction factor accounting not for the full measured error but for a part of it (e.g. 50%). With this method we obtain a smooth and fast “convergence” to the desired position.



Example: correction of a 0.2 mm positioning error.

- C beam, E= 400 Mev/u, $F=4\times10^{8}$ C/s

Summary and conclusions

- A full simulation of the BDS of CNAO has been implemented.

- The BDS has been modelled including all the relevant communications among its internal parts and also with external systems.

- In this presentation we have discussed the following items:

  - the effect of the beam scanning on the position computation. It has been shown that the first position measurement after a new voxel signal must be neglected.

  - the feedback between the BDS and the scanning magnets.

Acknowledgements

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Thanks for your attention!

谢谢你的注意