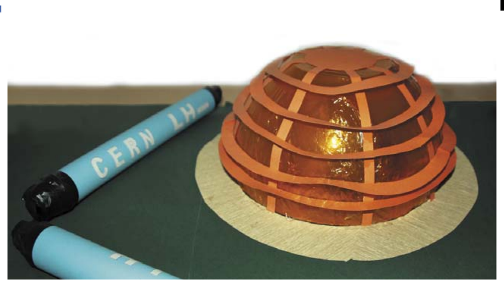
Electromagnetic simulation of BPMs embedded into collimator jaws



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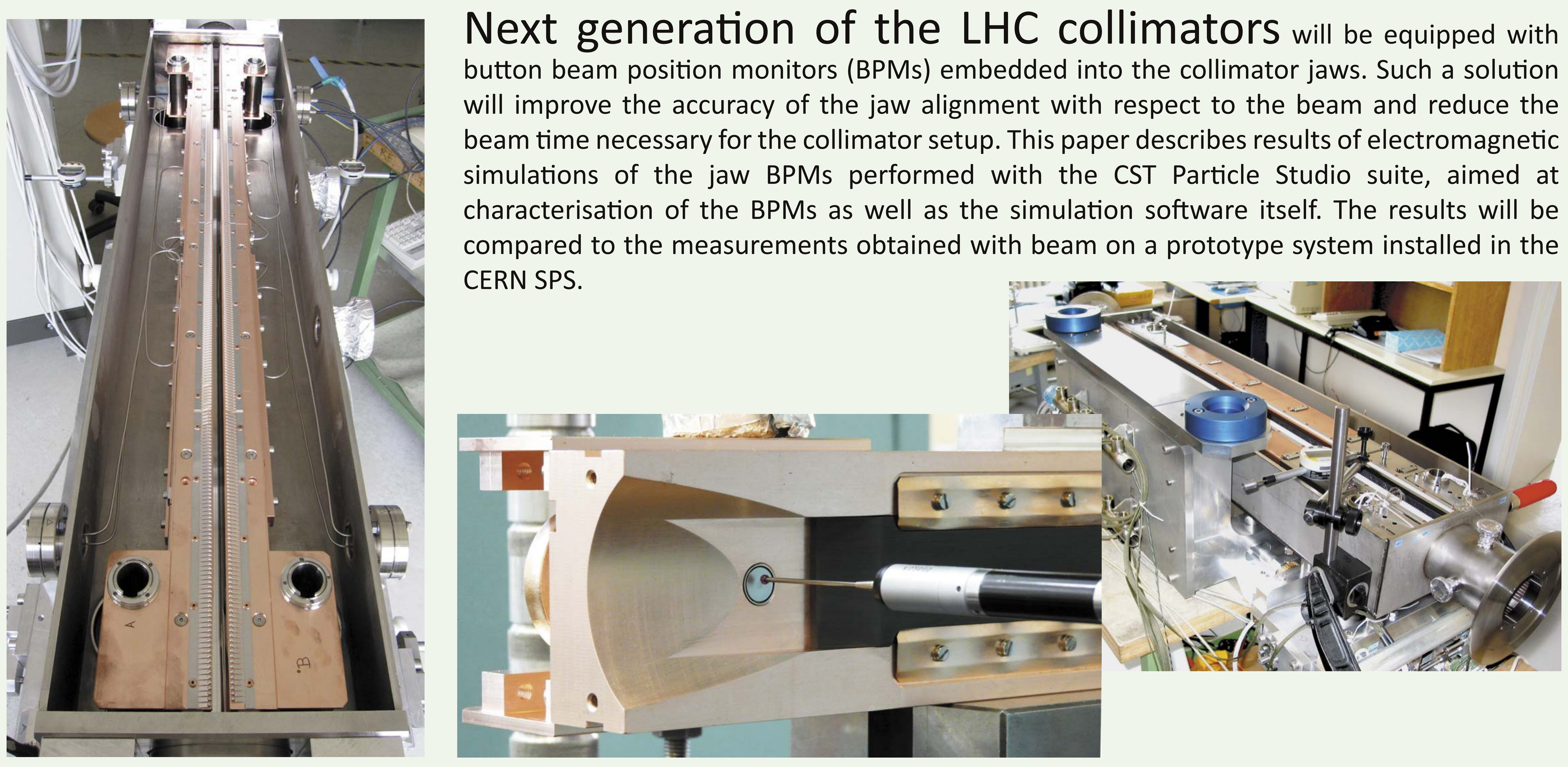


Fig 1. Photographs of Collimator "Demonstrator" and its parts in the lab before installation into the SPS ring.

Next generation of the LHC collimators will be equipped with button beam position monitors (BPMs) embedded into the collimator jaws. Such a solution will improve the accuracy of the jaw alignment with respect to the beam and reduce the beam time necessary for the collimator setup. This paper describes results of electromagnetic simulations of the jaw BPMs performed with the CST Particle Studio suite, aimed at characterisation of the BPMs as well as the simulation software itself. The results will be compared to the measurements obtained with beam on a prototype system installed in the CERN SPS.

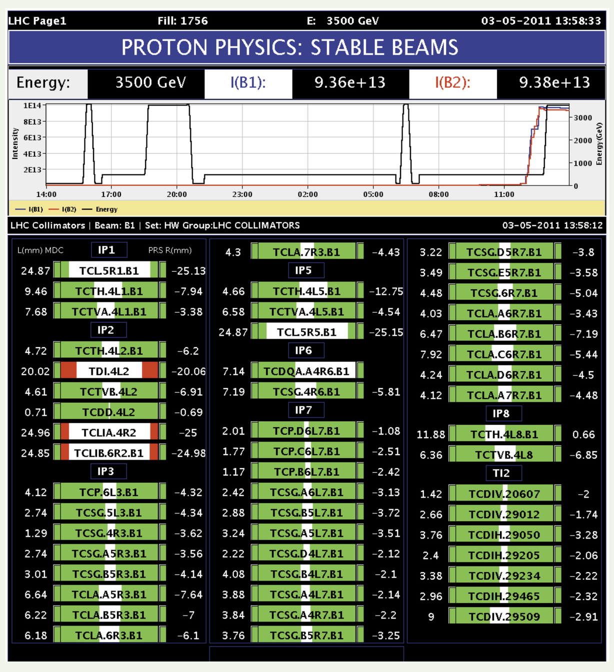


Fig 2. A view of the LHC collimator jaws setup during physics run. Green blocks are the left and right jaws respectively, white is the gap in between, red blocks are the jaws at the maximum opening (injection collimators fully open after the injection process).

Collimator "Demonstrator" is the nickname of this collimator since it was developed as a prototype to test the embedded BPM technology at CERN. It exists as a single specimen of it's kind and is installed in the SPS. Many more are prototyped and targeted to be produced and placed in the LHC. Currently the various absorbant materials for jaw plates (glidcop, Cu-diamond, Al-diamond, ceramic tiles, metal foil, etc.) are undergoing tests for best fitting the desired performance (to collimate 362MJ stored energy per beam at 7TeV with 3e14 protons).

BPM pickups are positioned at both ends (extremities) of each collimator jaw. Each jaw has independant upstream/downstream and vertical/horizontal tilts. The pickups, positioned in the middle, were put as a backup in case one of the extremities suffers from particle loss. They are not considered anymore due to ineffectiveness on closed jaws operation.

The beam used in the simulations is modeled by a single bunch with a gaussian charge distribution of Q = 1.7e-8 C (1.15e11 protons) and σ = 0.25 ns (nominal LHC bunch parameters)

Beam sweeps were performed with horizontal and vertical beam offsets (x_{beam}, y_{beam}), various bunch lengths (σ) and various jaw openings (d) to study the behaviour of the position measurement and the simulation tool itself. Thorough comparison with real beam data is planned with the upcoming focused machine development time.

Simulation model

Button depth: 10 mm
Button head diameter: 10.3 mm
Button casing diameter: 12.2 mm
Jaw extremity height: 80 mm
Jaw extremity length: 97 mm
Jaw total length: 1194 mm

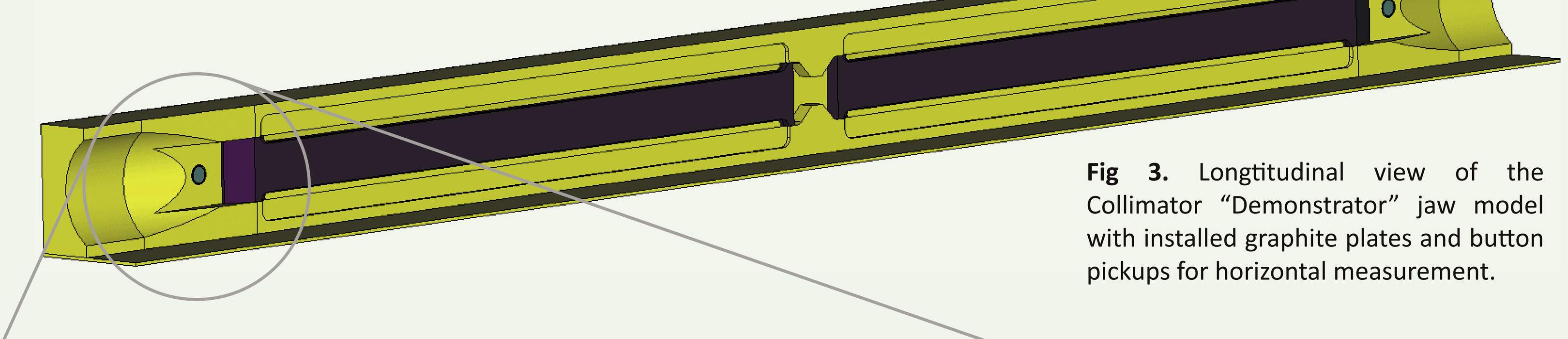


Fig 3. Longtitudinal view of the Collimator "Demonstrator" jaw model with installed graphite plates and button pickups for horizontal measurement.

Jaw body: Copper (hard-drawn, el. res. = 16.8 nΩm)
Jaw plates: "Electro" graphite R4550 (el. res. = 13 μΩm, 780 x more than Cu)
Buttons: Stainless Steel 316L + ceramic rings

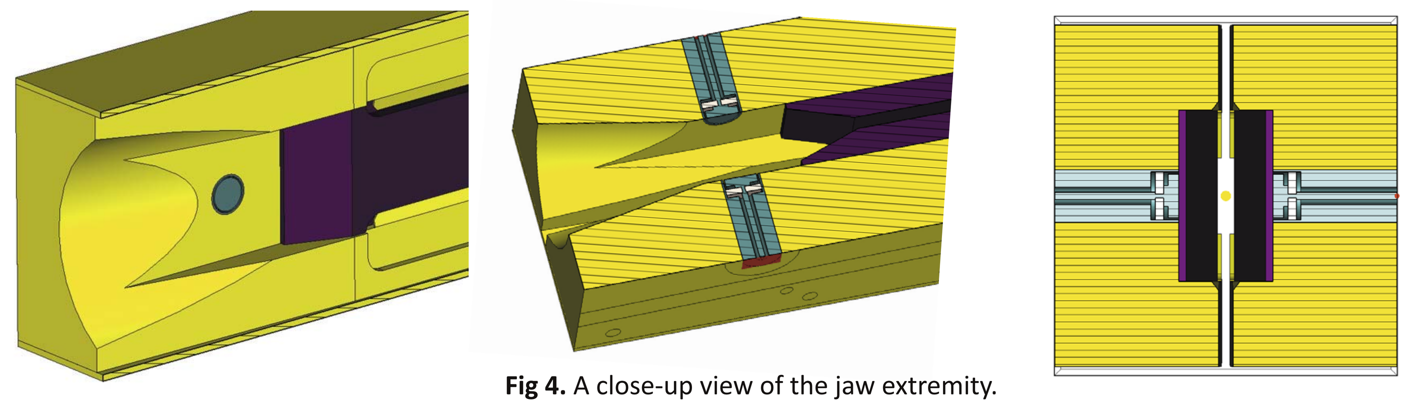
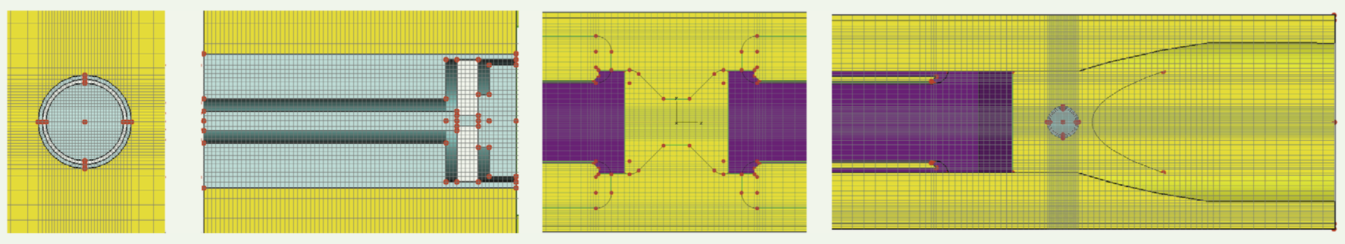


Fig 4. A close-up view of the jaw extremity.

Fig 5. 1 cm-diameter stainless steel buttons were manually meshed with locally high meshcell density.



Meshing scheme was chosen to trade-off the accuracy of the values of port signal peaks and simulation time on a regular desktop PC.

Total amount of meshcells (avg. per model): 6 million
Lines per wavelength: 10. Lower mesh limit, mesh line ratio: 15. Equilibrate mesh ratio: 1.19

Simulation running time (avg., per single beam location): 90 minutes
PC used: Intel 3.16 Core2 Duo, 8Gb RAM, Win7x64 + CST Studio Suite v2010

Simulation

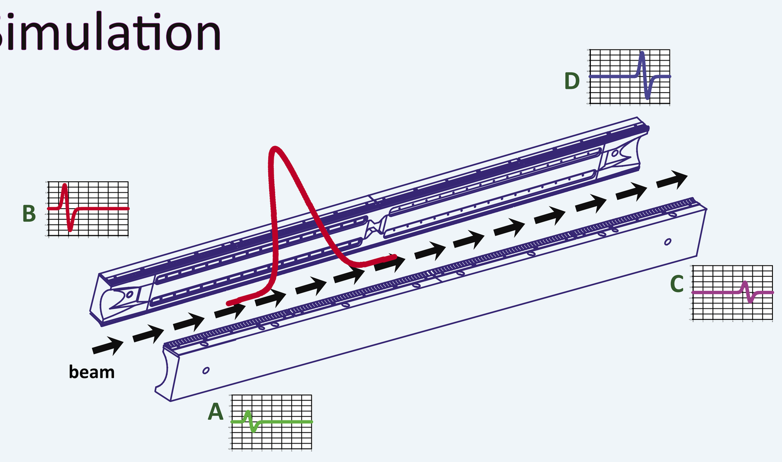


Fig 6. Collimator sketch with an offset beam and port notations.

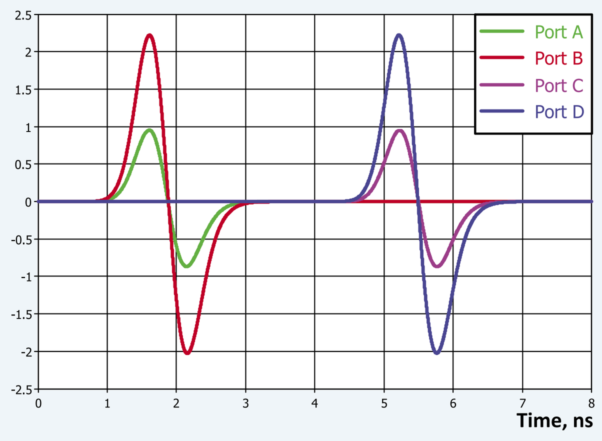


Fig 7. Typical view of the port time signals for displaced beam. d = 15 mm, σ = 250 ps, x_{beam} = 4.5 mm, y_{beam} = 0

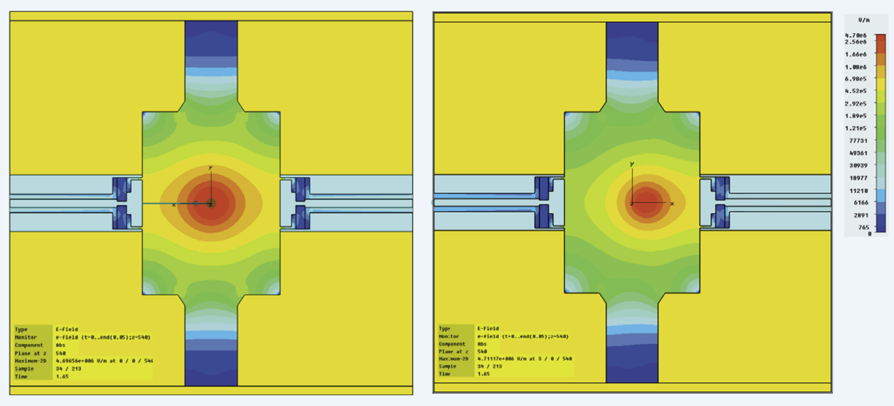


Fig 8. E-fields of the centered and offset beam passing through the cutting plane at ports AB of the collimator model.

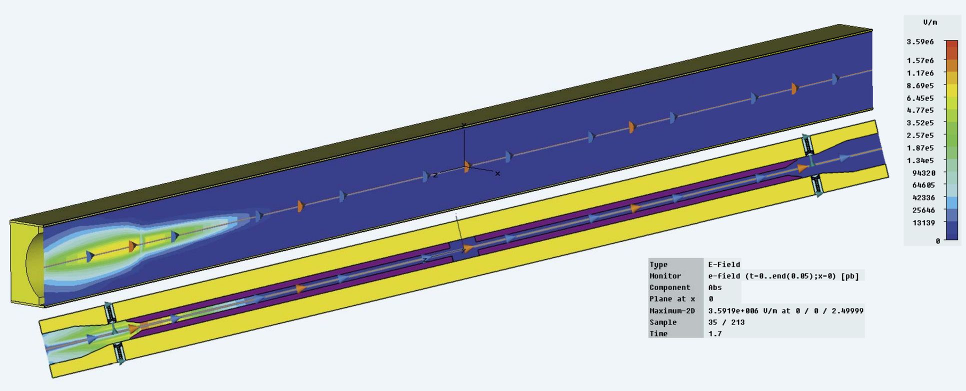


Fig 9. E-field of the centered beam passing through the longtitudinal cutting plane (z = 0) of the collimator model.

Beam sweep 1: Jaw distance + Horizontal shift

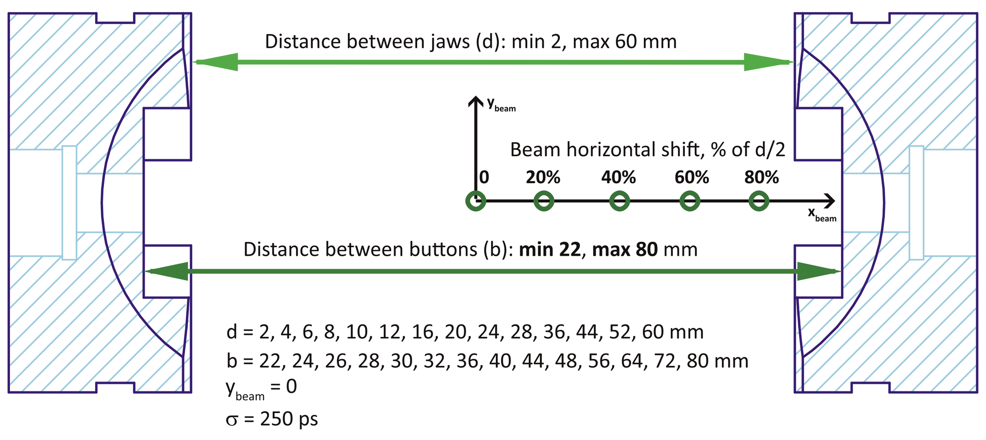


Fig 10. Beam horizontal sweep schematic. For each jaw distance a set of 5 beam locations on the positive X axis was simulated. Assuming that the offset signals on the negative X axis are symmetric to the positive ones, the full axis was mapped. The measured position was then obtained from the formula (right). The linear conversion factor between measured and simulated beam position will be referred to as **SLOPE**.

$$x_{measured} = \frac{b}{2} \cdot \frac{U_B - U_A}{U_B + U_A}$$

$$x_{measured} = SLOPE \cdot x_{beam}$$

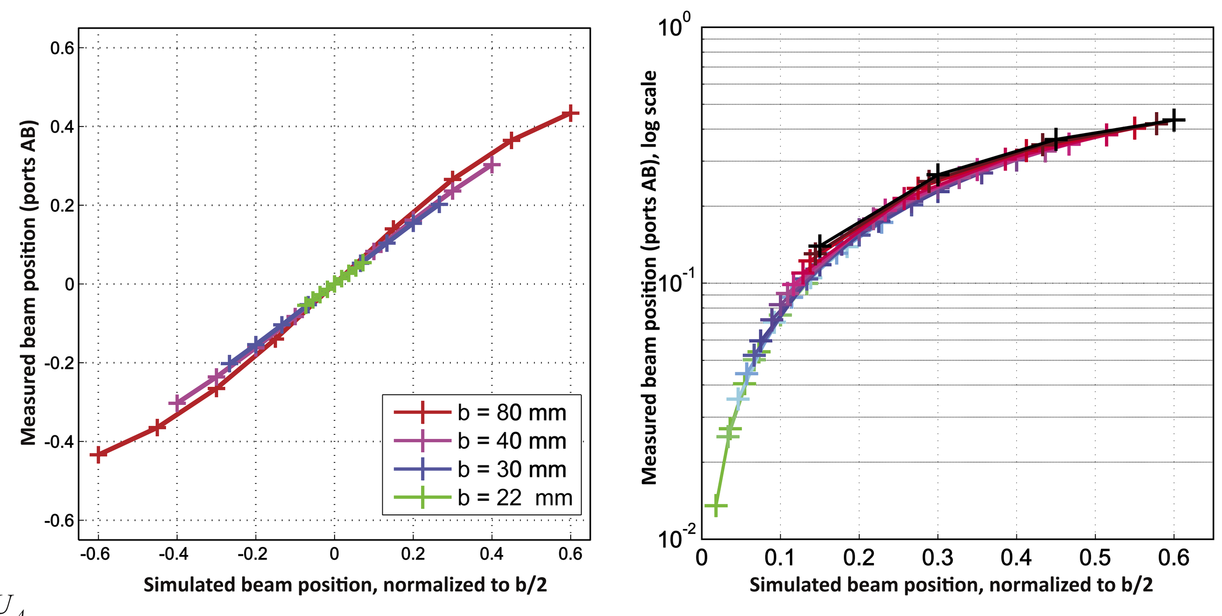


Fig 11. Normalized simulated beam position vs. measured position for various jaw distances (linear and log scales).

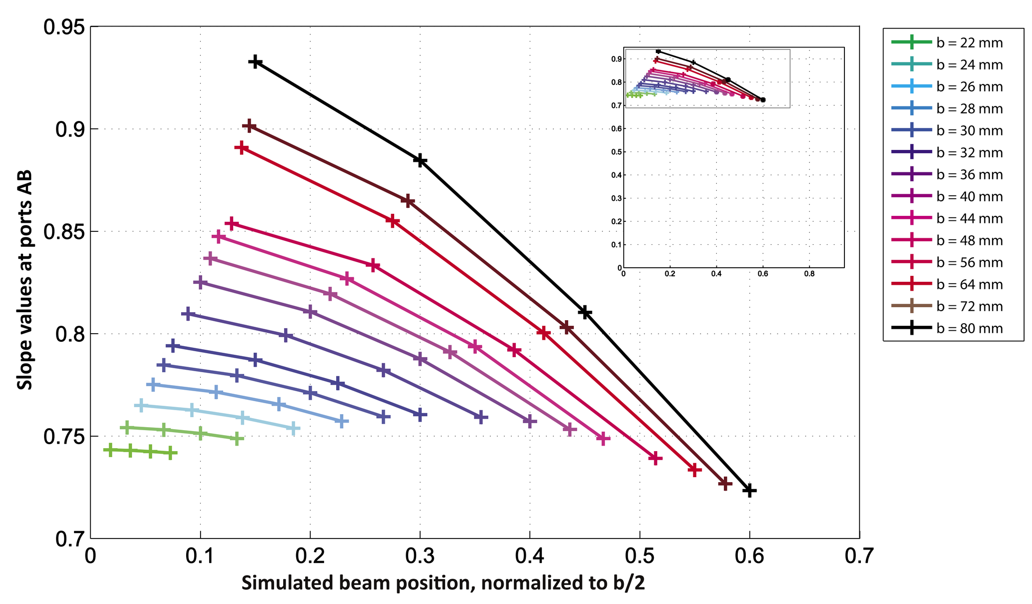


Fig 12. Normalized simulated beam position vs. linear conversion factor for various jaw distances.

Beam sweep 2: Jaw distance + Hor. shift + Bunch length variations

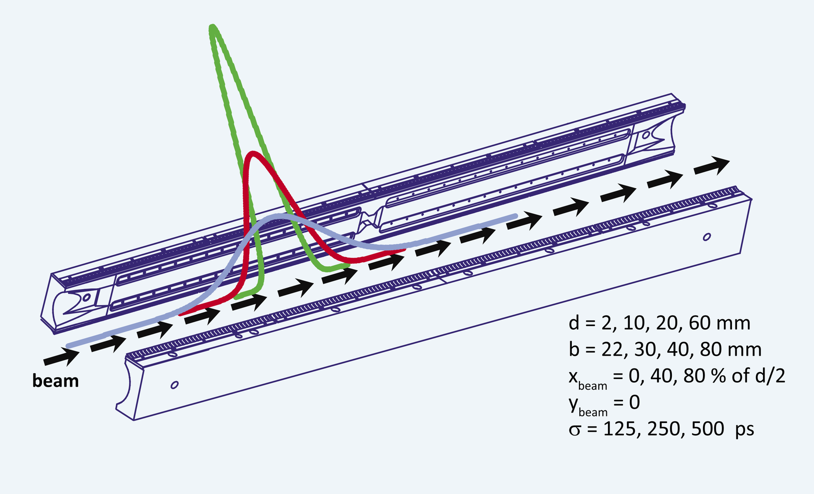


Fig 13. Bunch length sweep schematic. For each jaw distance a set of 3 beam locations on the X axis for 3 various bunch lengths was simulated.

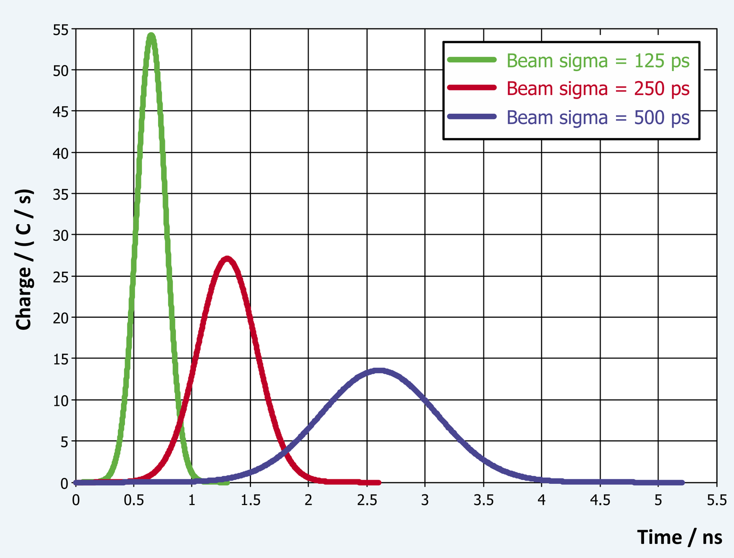


Fig 14. Longtitudinal charge distribution of the simulated bunch lengths.

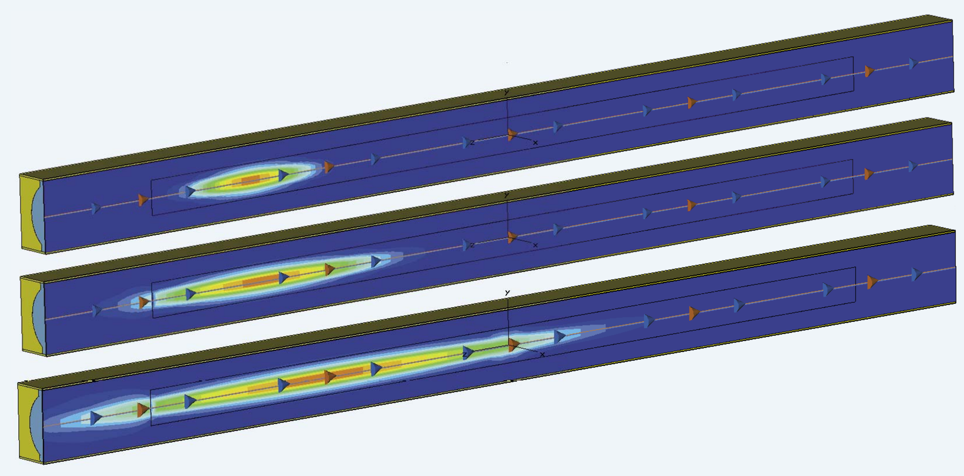


Fig 15. E-fields of centered 125, 250 and 500 picosecond bunches passingthrough the longtitudinal cutting plane (z = 0) of the collimator model.

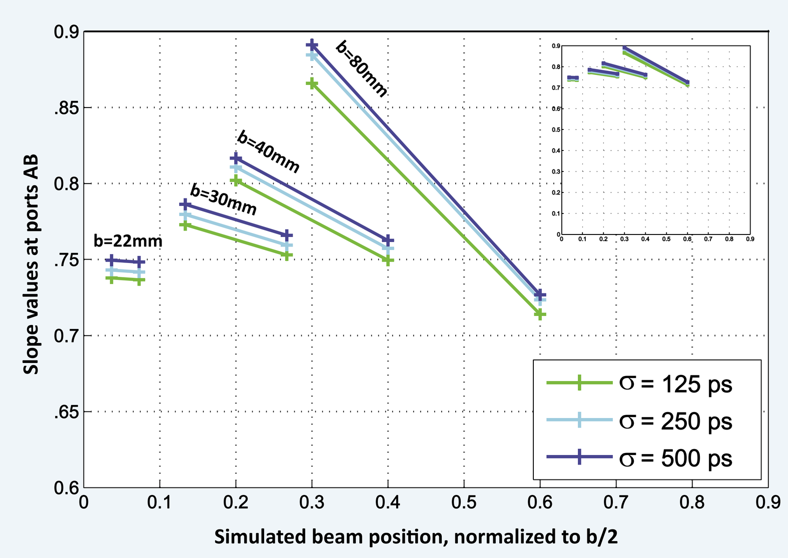


Fig 16. Normalized simulated beam position vs. linear conversion factor for various jaw distances and bunch lengths.

Beam sweep 3: Jaw distance + Hor. shift + Vertical shift

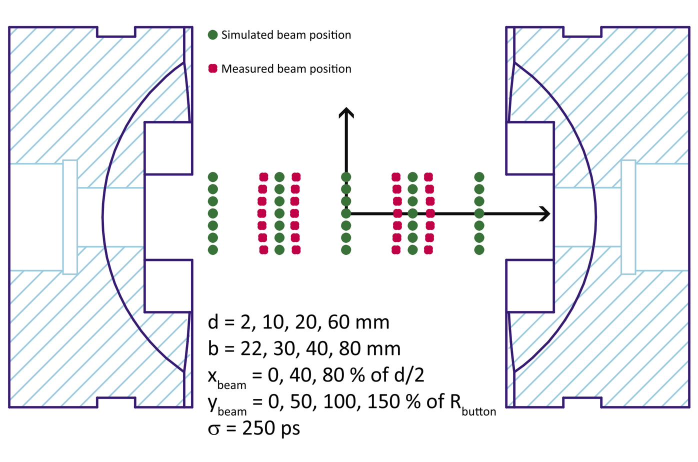


Fig 17. Beam vertical sweep schematic. For each jaw distance a set of 12 beam locations was simulated (3 horizontal and 4 vertical). The 2D area around the beam center was mapped and measured as described in the previous sweep.

The mapped red points are obtained from actual simulated data and show how the measured linearity error increases with beam displacement from center. For this map of points the simulations were performed for d = 60 mm and the beam placed at: x_{beam} = 0, 12, 24 mm and y_{beam} = 0, 2.5, 5, 7.5 mm. Similar point maps were built for other jaw distances. Position correction is straightforward.

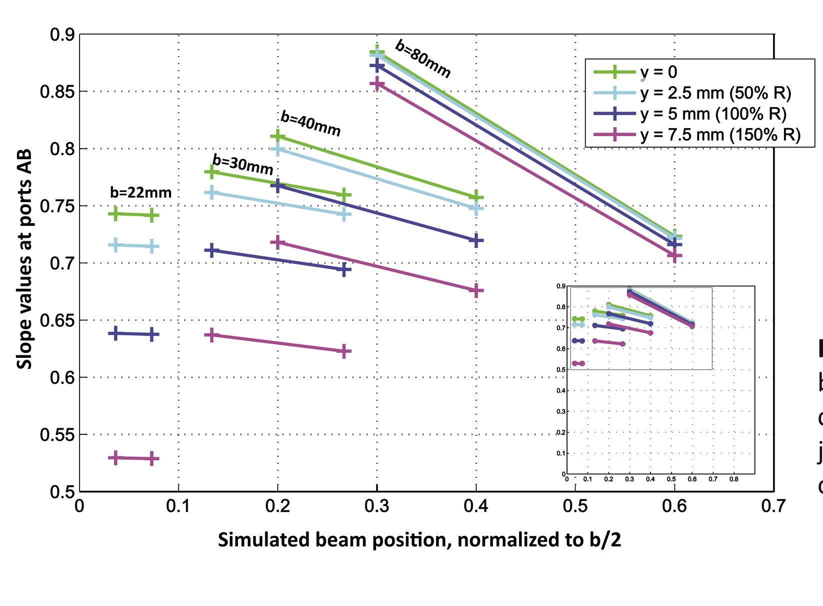


Fig 18. Normalized simulated beam position vs. linear conversion factor for various jaw distances and vertical offsets.

Acknowledgements

The authors would like to acknowledge the help of Ralph Assmann, Alessandro Bertarelli, Stefano Redaelli, Benoit Salvant and Marc Timmins, whose expertise, understanding, and patience helped to understand the mechanical and technical aspects of the collimators, as well as the simulation tool and treatment of the results.