Building accelerator components: A 3D-printed Beam Position Monitor

Nicolas Delerue
Didier Auguste, Julien Bonis, Frederick Gauthier,
Stéphane Jenzer, Alexandre Moutardier, Oleg Trofimiuk
LAL (CNRS and Univ. Paris-Sud/Université Paris-Saclay)

Motivation

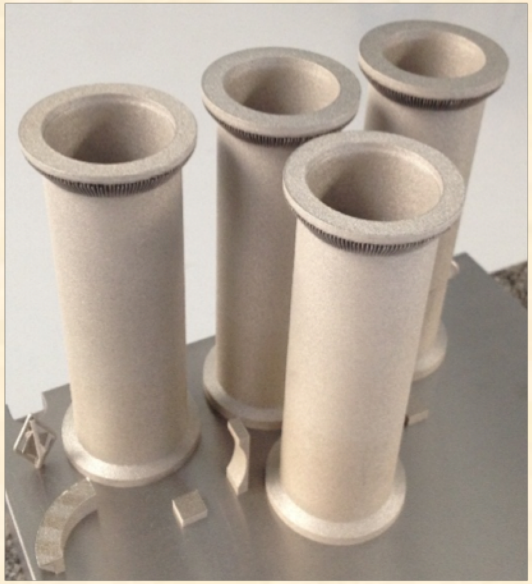
- The arrival of plastic additive manufacturing has led to several parts designed for use <u>around</u> particle accelerators.
- Can metal additive manufacturing be used <u>in</u> particle accelerators?

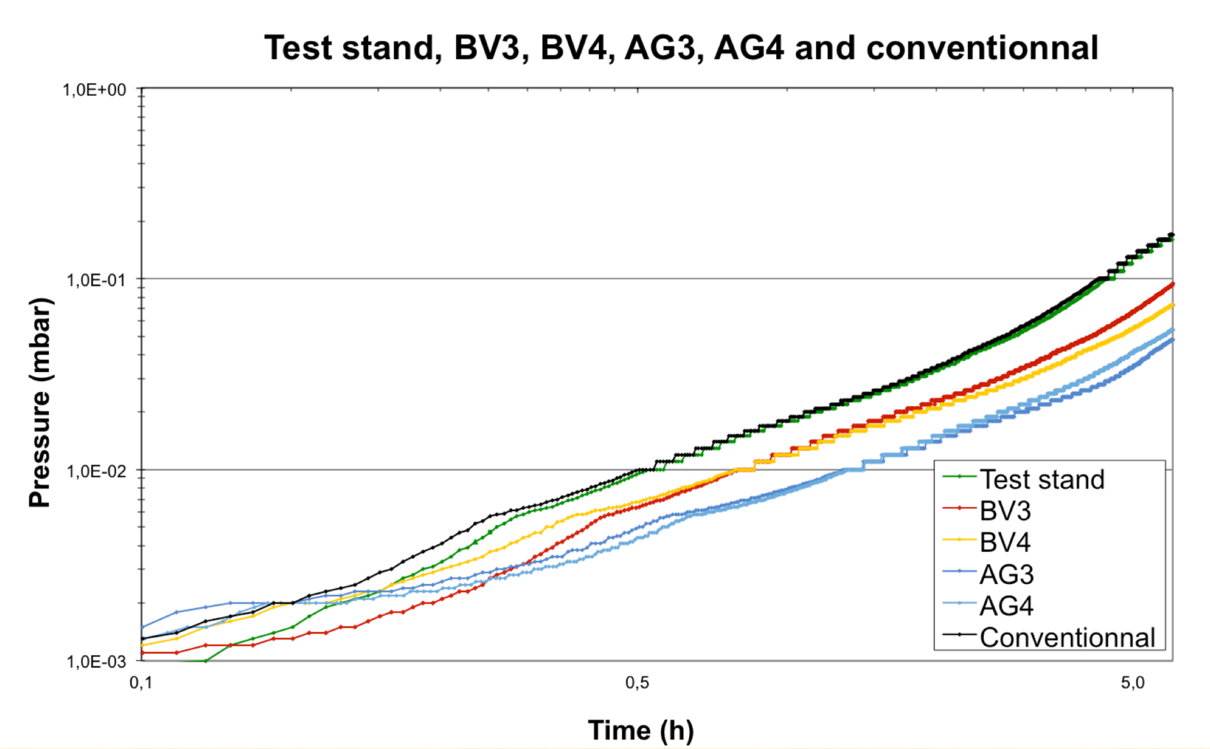
Challenges

- Parts for particle accelerators must comply to several constraints:
  - Ultra-High Vacuum
  - Conductivity
  - Impedance
  - Radiation
  - …

Ultra-high vacuum

- See presentation by Eric Mistretta yesterday.
- Building a beam pipe in additive manufacturing was not cheaper but it was a required step before more complicated parts.

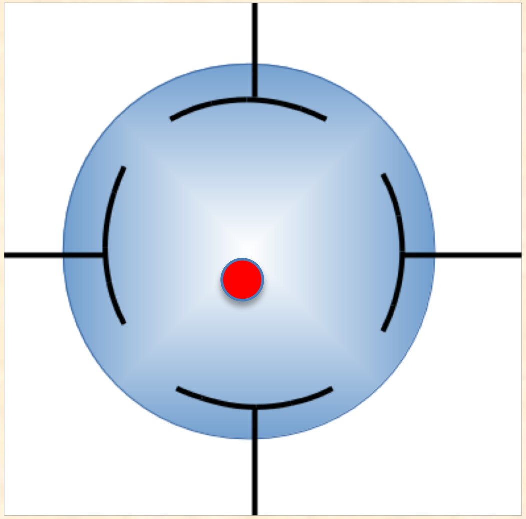




Conductivity

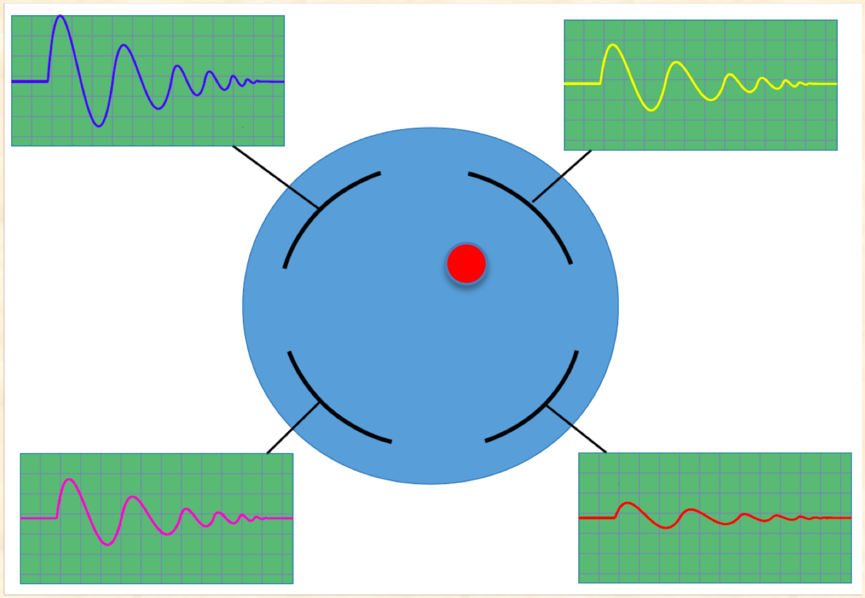
- After the UHV qualification we wanted to test conductivity.
- The choice was to build a beam position monitor (BPM), a device often used in particle accelerators with 4 electrodes.

Operating principle of a Beam Position Monitor



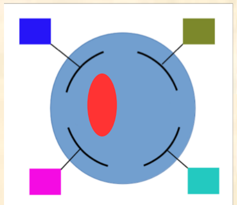
- A BPM is made of 4 electrodes in a vacuum chamber.

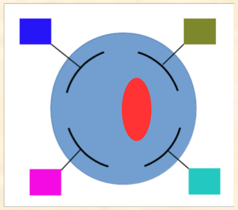
Operating principle of a Beam Position Monitor

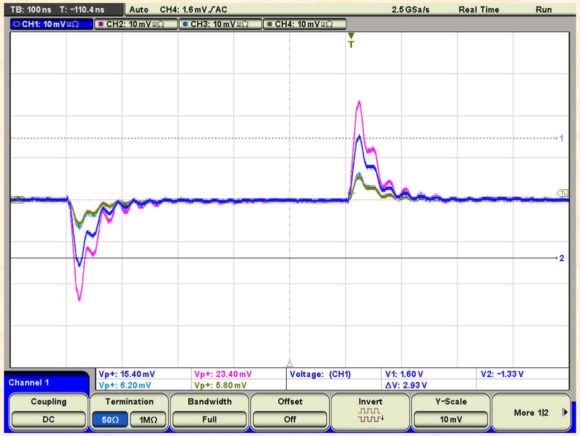


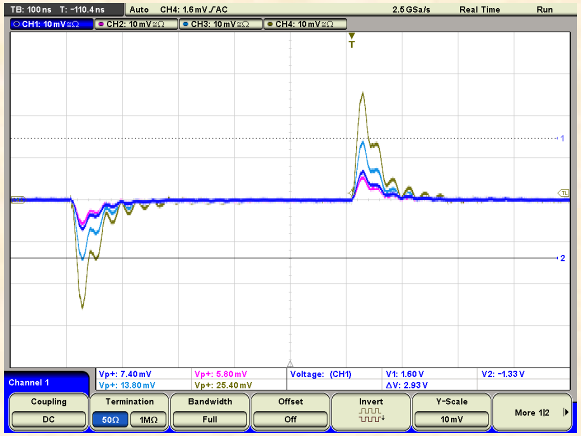
- A BPM is made of 4 electrodes in a vacuum chamber.
- When charged particles pass near the electrodes they induce a signal.

Operating principle of a Beam Position Monitor





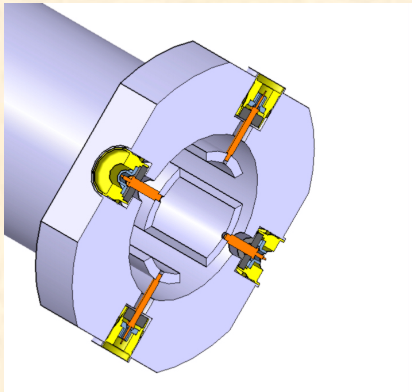


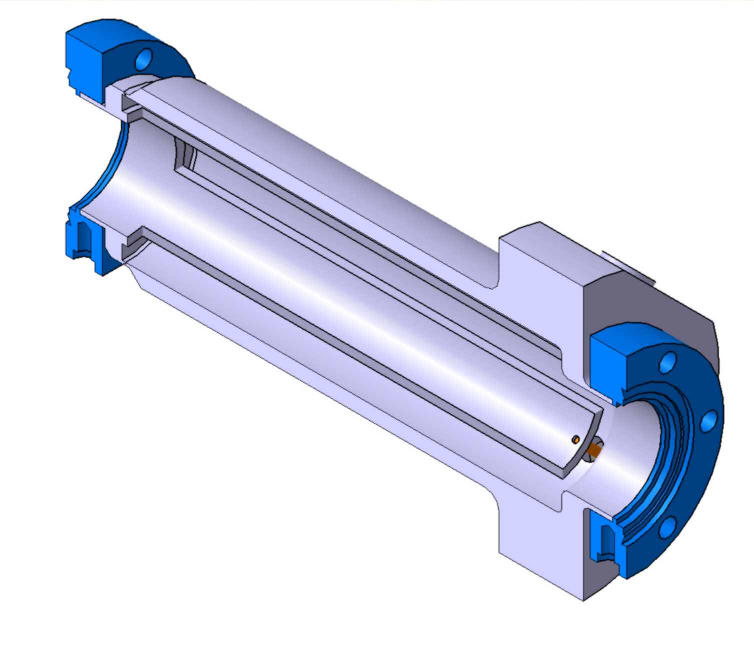


- The signal induced is higher on the closest electrodes and lower on the farther electrodes.
- The difference between the signal on two opposite electrodes will give the position of the charged particles.

ThomX's BPM

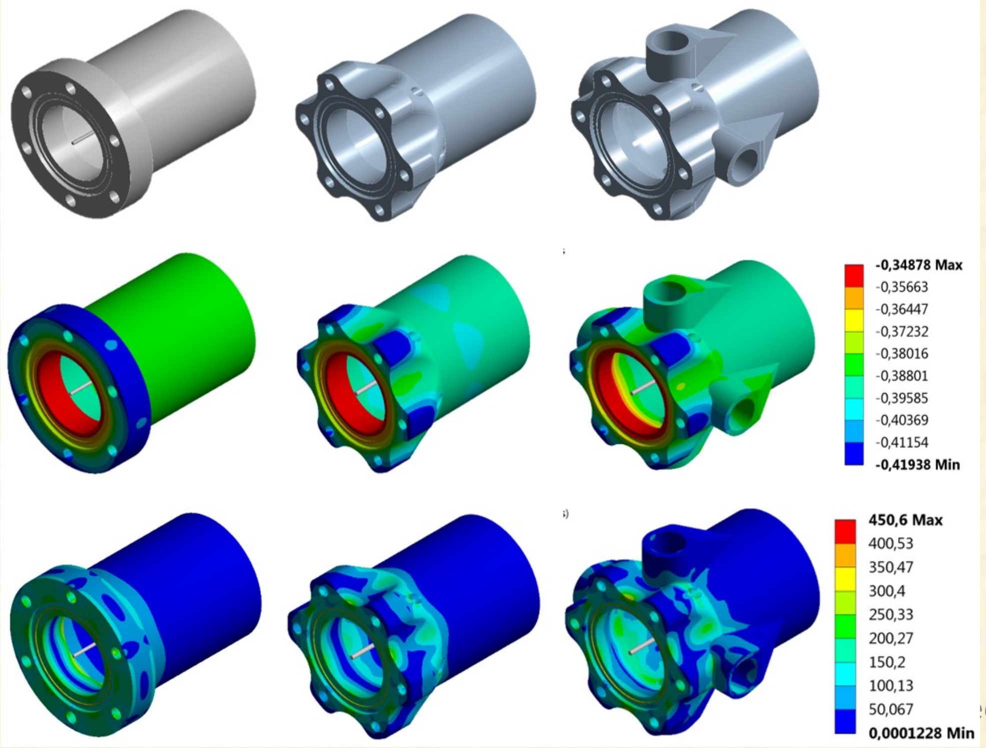
- Several BPMs have been produced at LAL for the ThomX project.

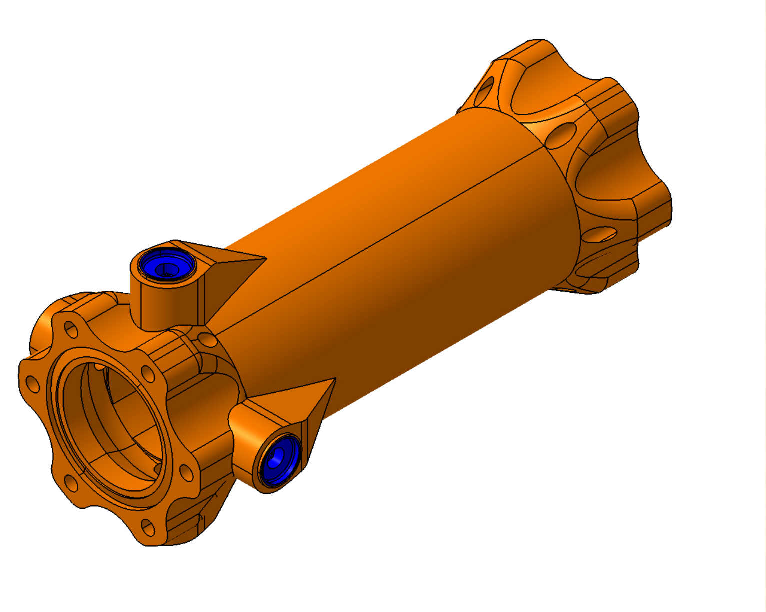




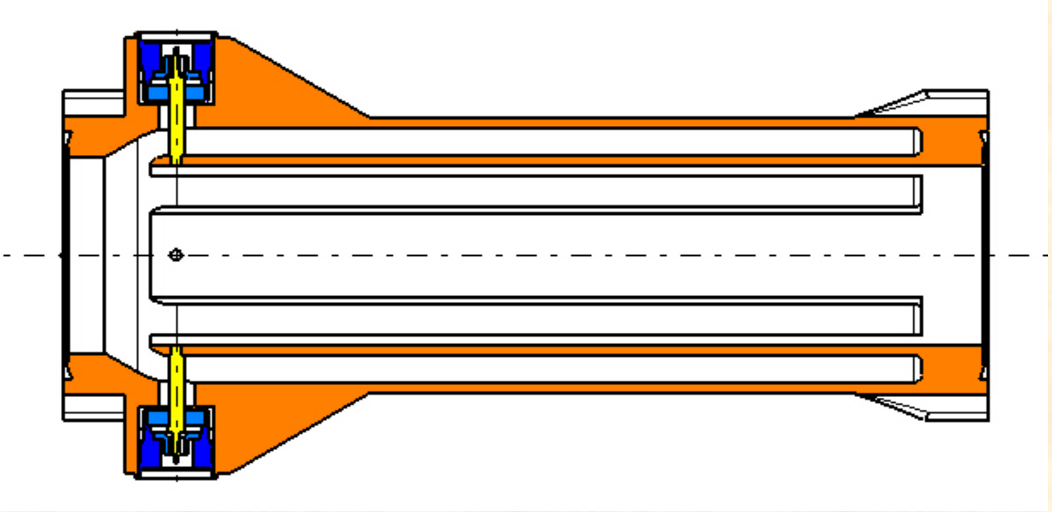
Topological optimisation

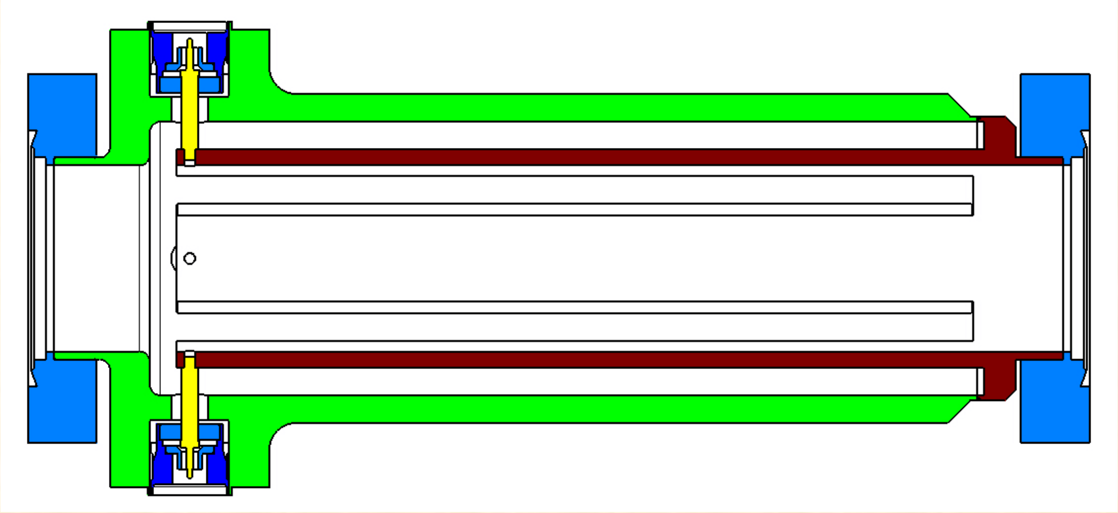
- The ThomX design has been topologically optimized.





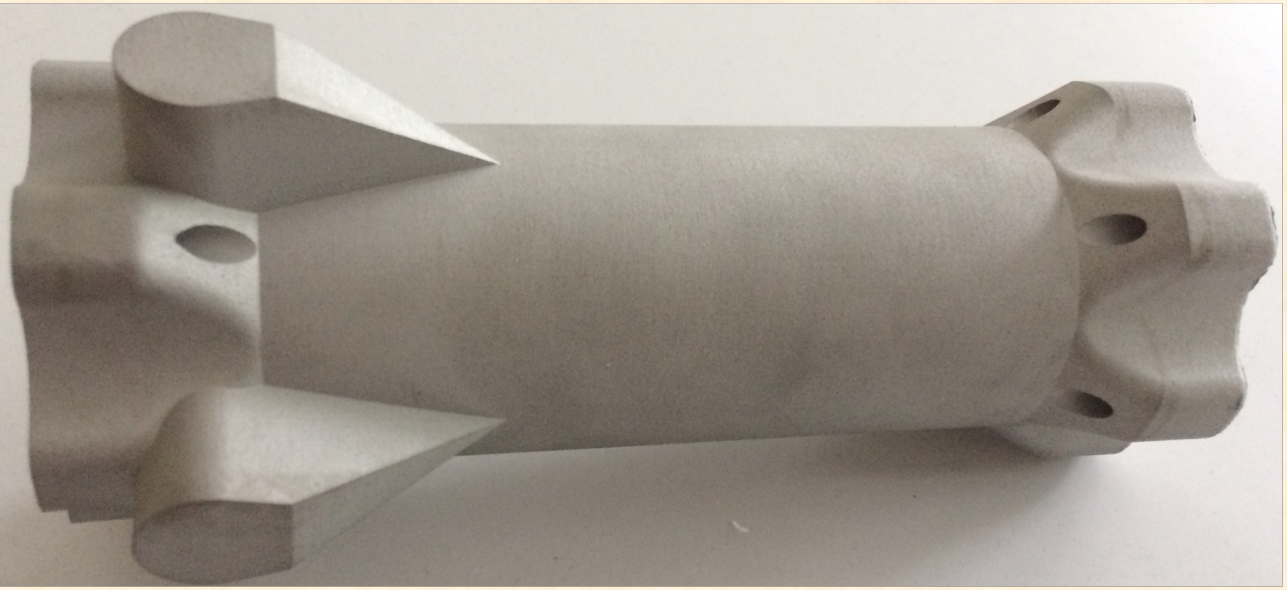
Savings with 3D printing





- Topological optimisation allows to build a shorter BPM with the same functionality.
- Cost reduction: 50%
- Production time: 2 weeks instead of 6 weeks.
- Better mechanical accuracy (some shapes were impossible with traditional manufacturing).
- 60% of the original weight.

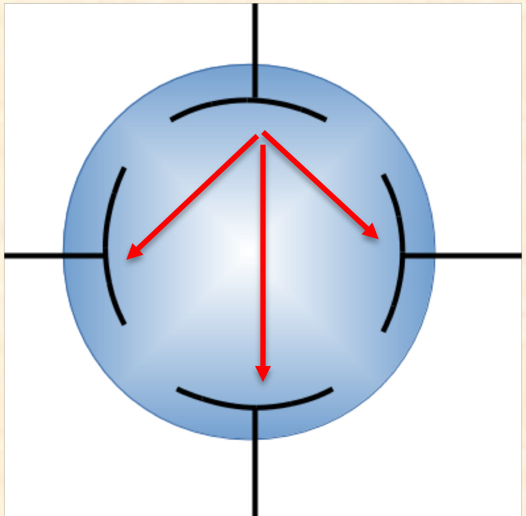
The 3D printed BPM



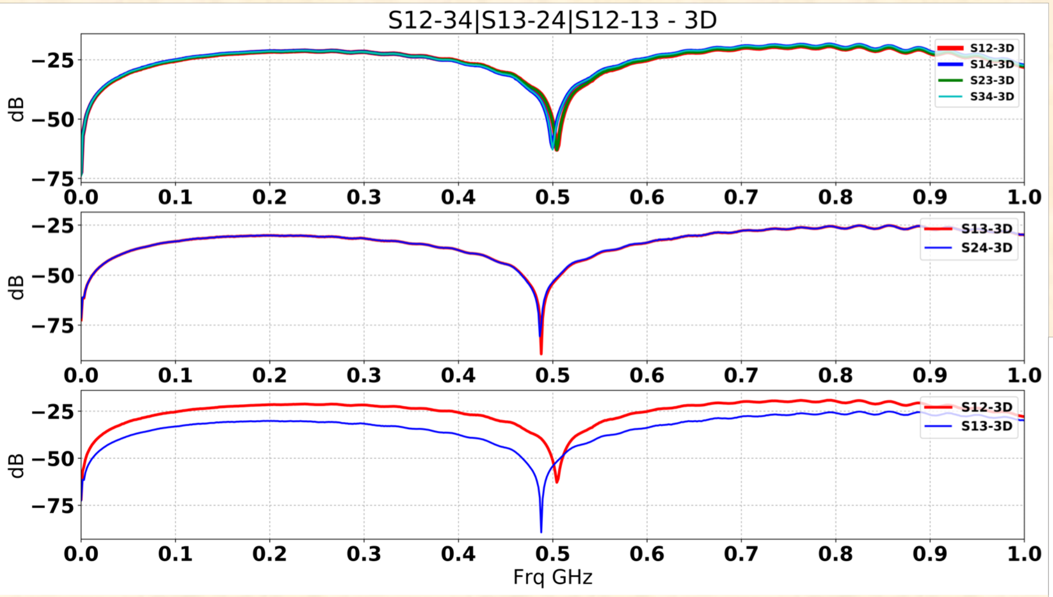
- Postprocessing:
  - Electrical feedthrough (including an insulator) were welded after.
  - The flanges'knifedge had to be machined.

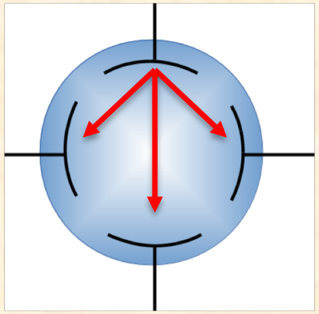
First electrical test: Network analyser

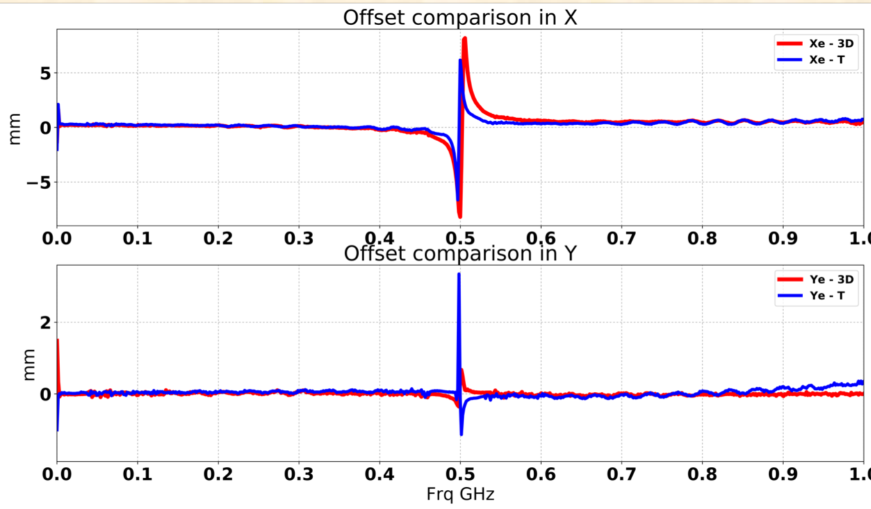
- One of the goal of producing the BPM was to demonstrate that electrical properties were acceptable.
- The BPM was tested using a network analyser to measure the electrical transmission between the electrodes (as is done for real BPMs).



Network analyser tests results



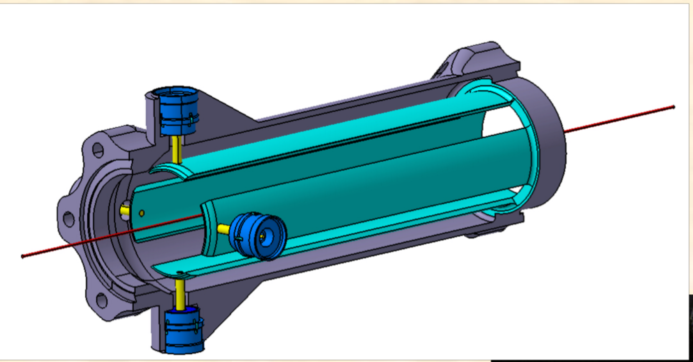




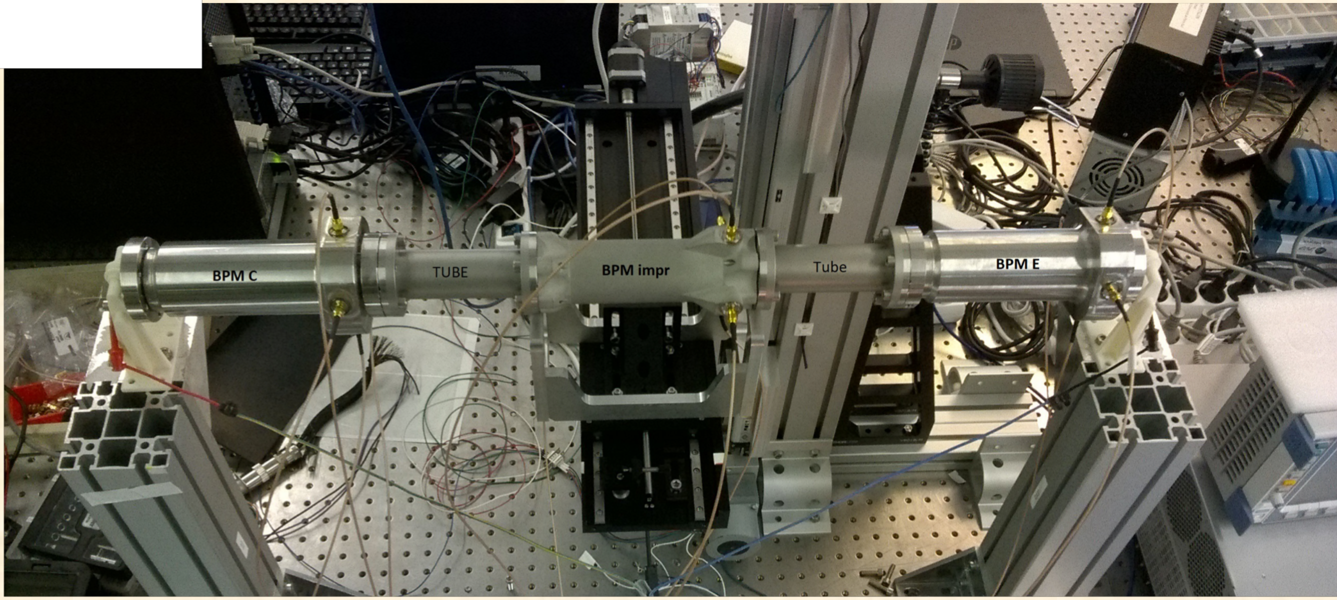
The electrical properties of the BPM were found to be similar to those made with traditional manufacturing.

	X		Y	
	20 MHz to 200 MHz	20 MHz to 400 MHz	20 MHz to 200 MHz	20 MHz to 400 MHz
Trad. manuf. (raw value)	17 ± 3	11 ± 3	3 ± 2	4 ± 2
i3D (raw value)	13 ± 2	8 ± 3	1 ± 2	1 ± 2
Trad. manuf. (k=14 mm)	238(36) μm	154(44) μm	36(26) μm	51(24) μm
i3D (k=14 mm)	178(30) μm	107(48) μm	36(26) μm	20(31) μm

Measured average electrical offset between the electrodes. The top two lines of values are raw value and the bottom two lines assume a linear calibration coefficient k=14 mm.

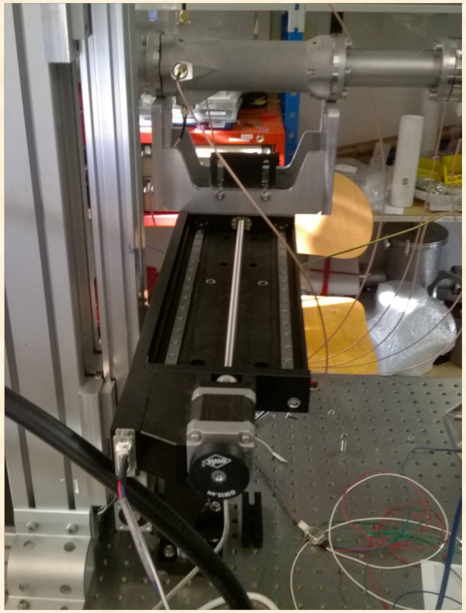


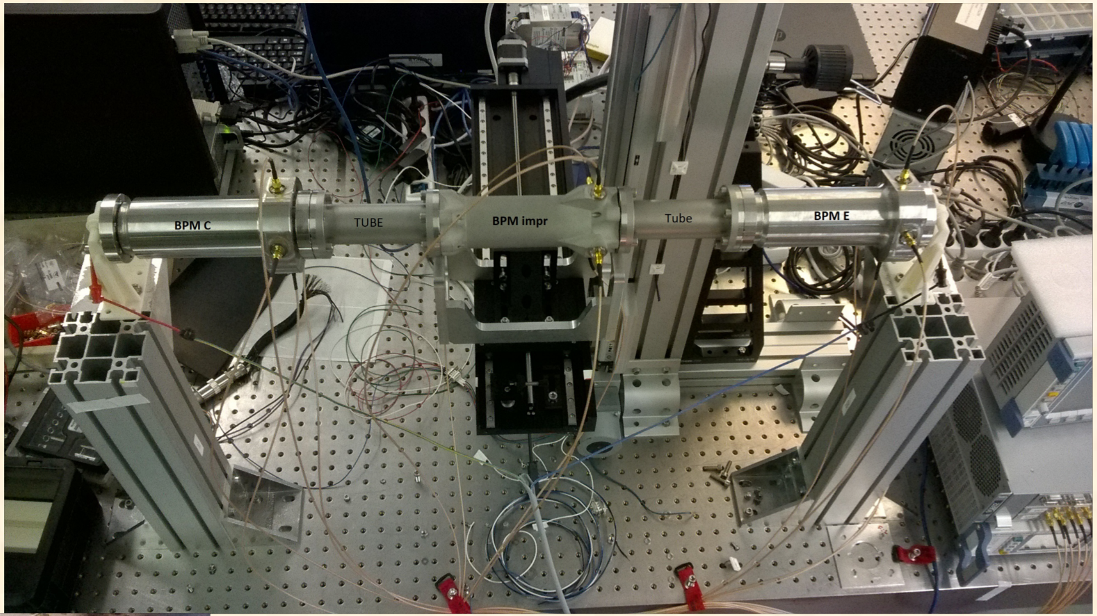
Second tests: stretched wire

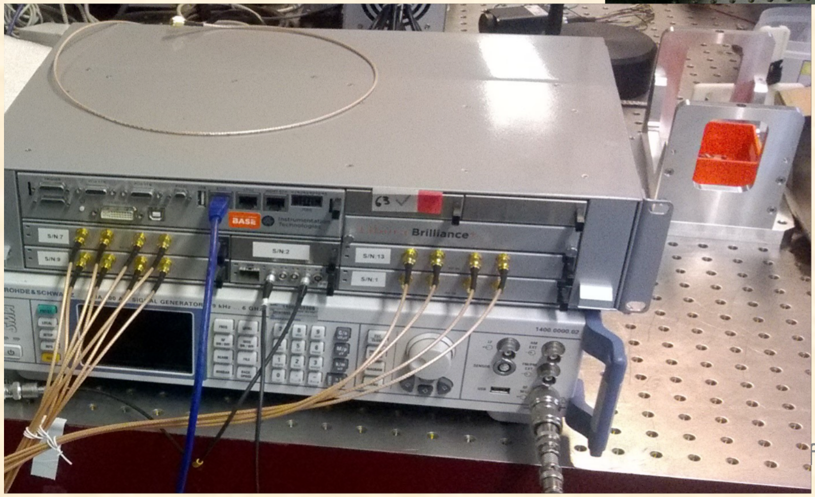


- In this test a stretched wire goes through the BPM and the induced signal is measured.
- The performances of two traditional BPMs were compared with those of the i3D BPM
- Internship of Alexandre Moutardier.

Stretched wire measurements: test bench

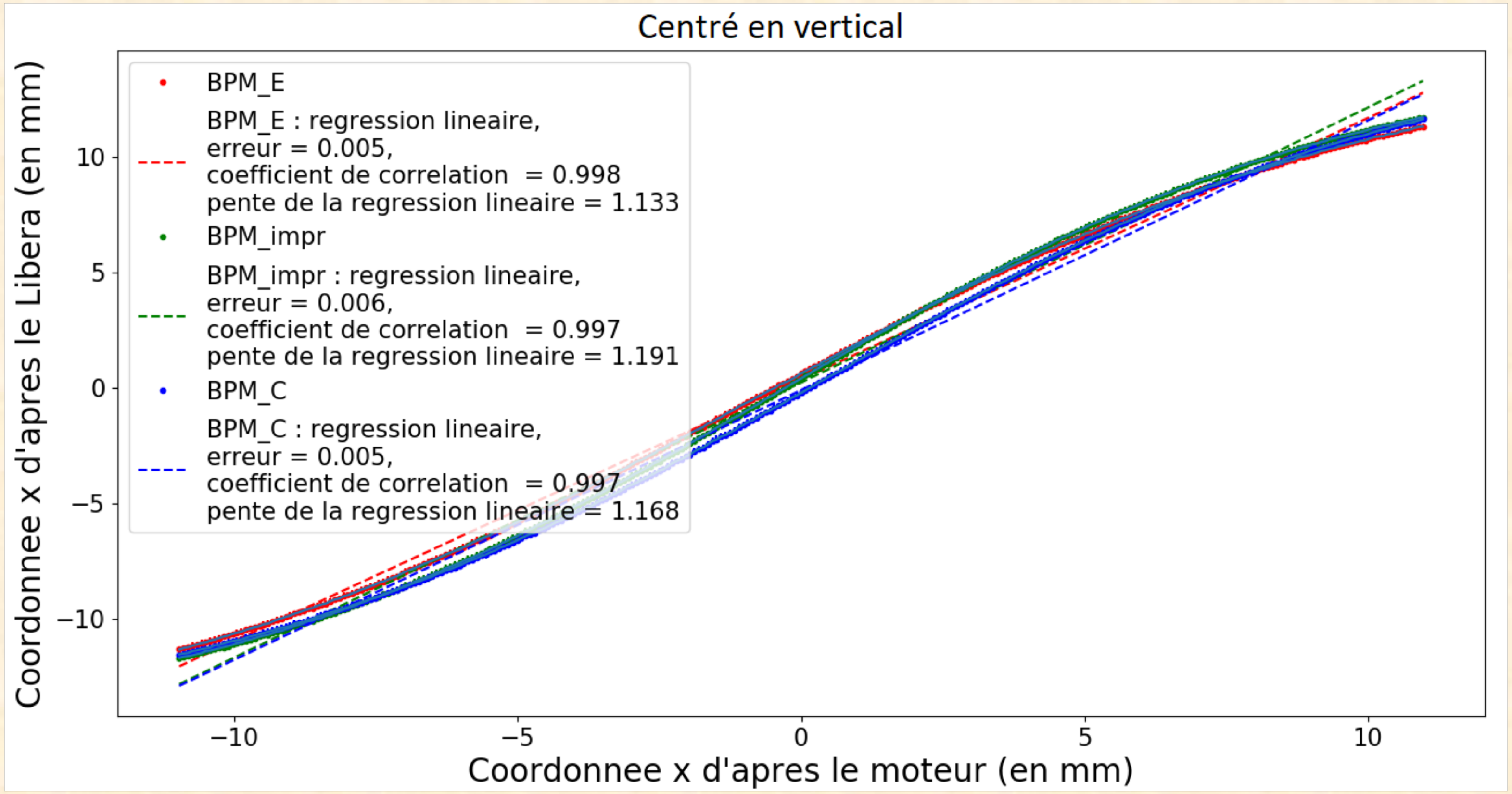






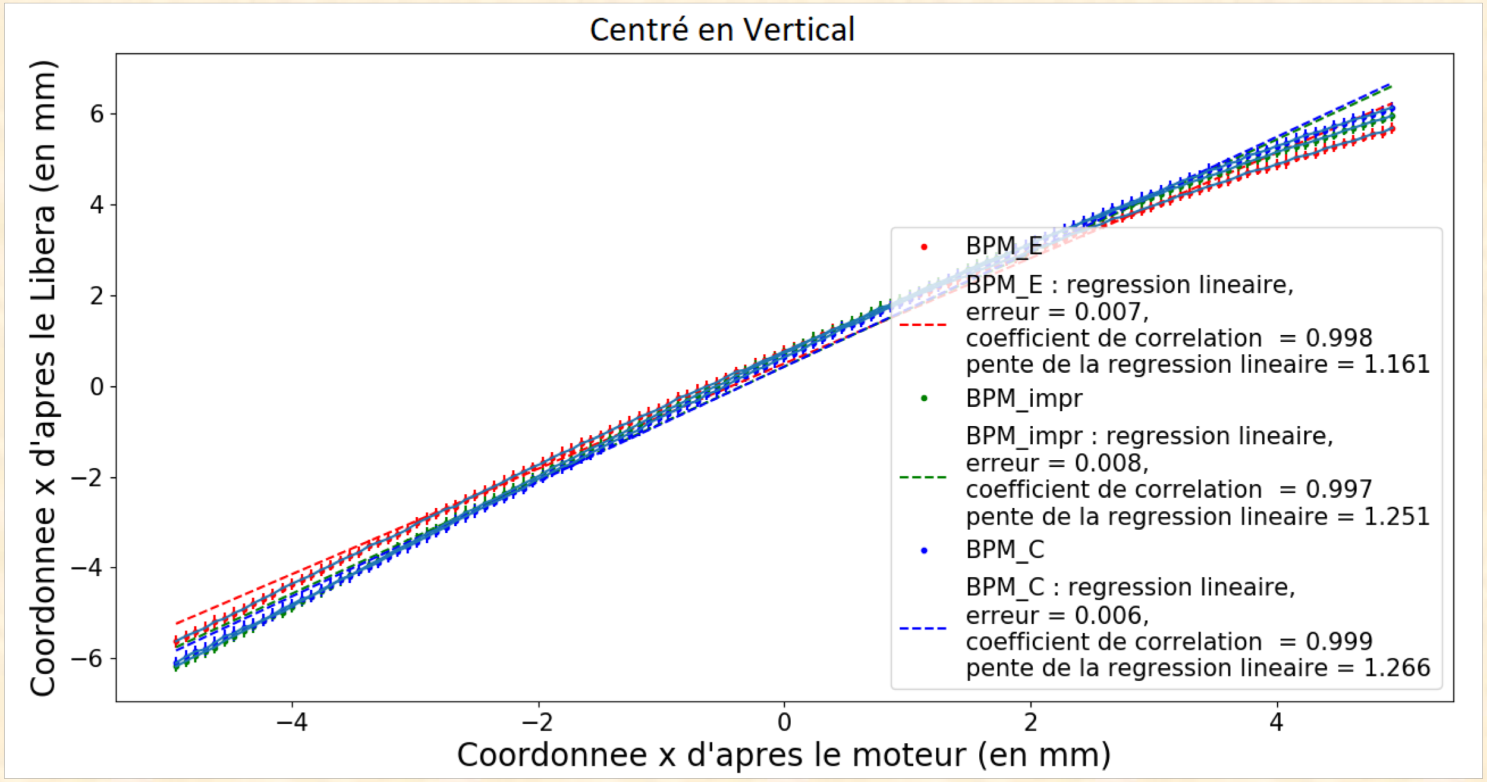
- The acquisition electronics was exactly the same than in an accelerator.

Stretched wire measurement



- The stretched wire data were found to be similar for the 3 BPMs.

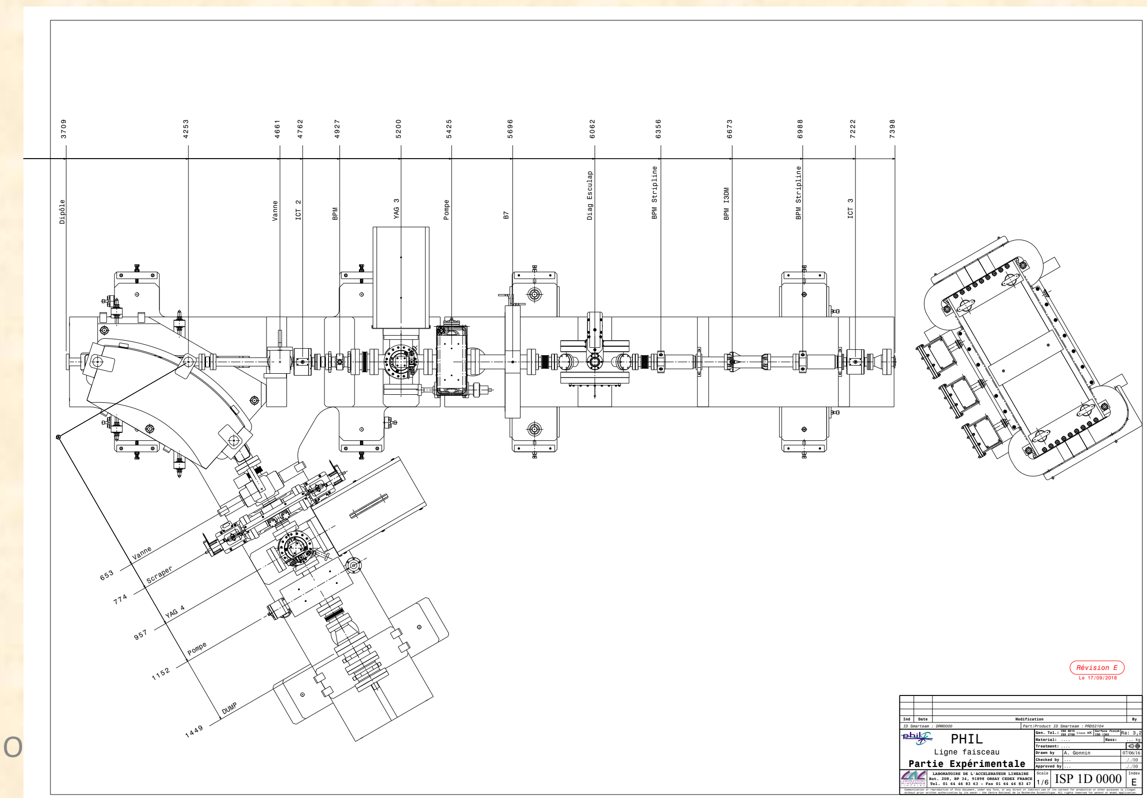
Stretched wire measurement



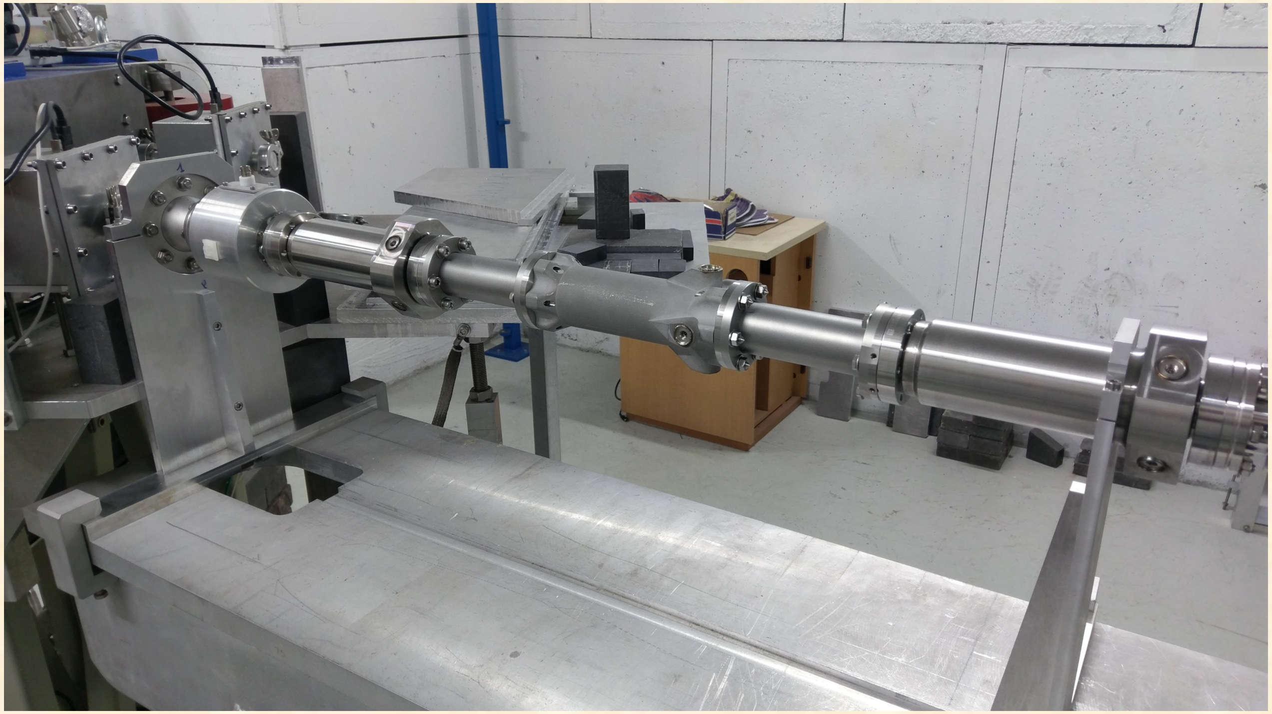
- The stretched wire data were found to be similar for the 3 BPMs.

Beam tests on a particle accelerator

- As the BPM had been fully qualified on the bench it was decided to test it on a particle accelerator.
- We used the PHIL Photoinjector (3 MeV electrons) at LAL.



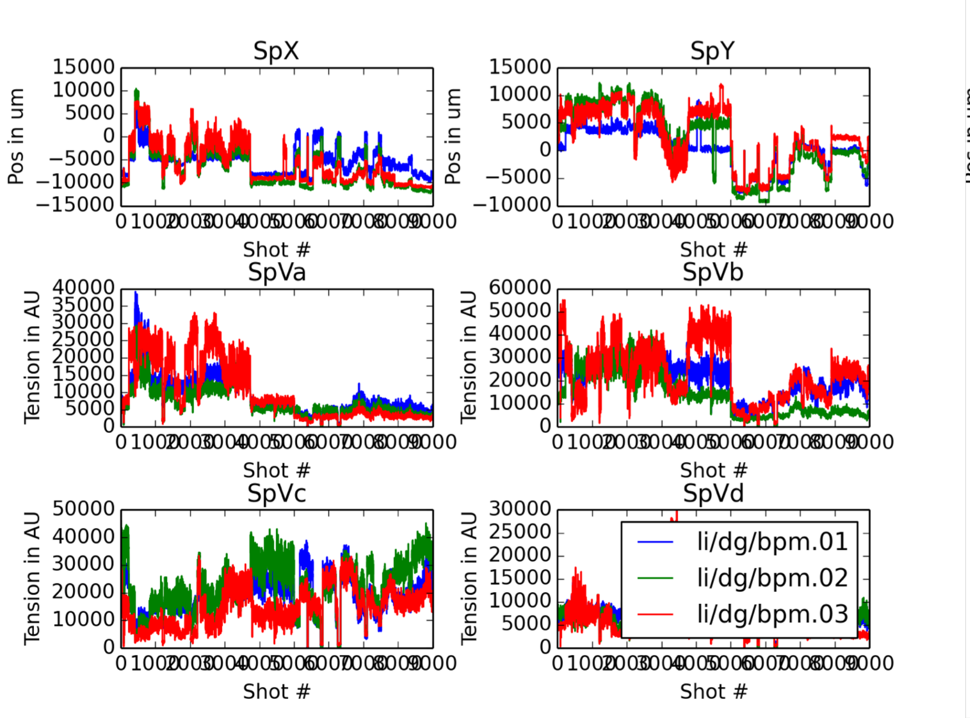
Beam tests on a particle accelerator

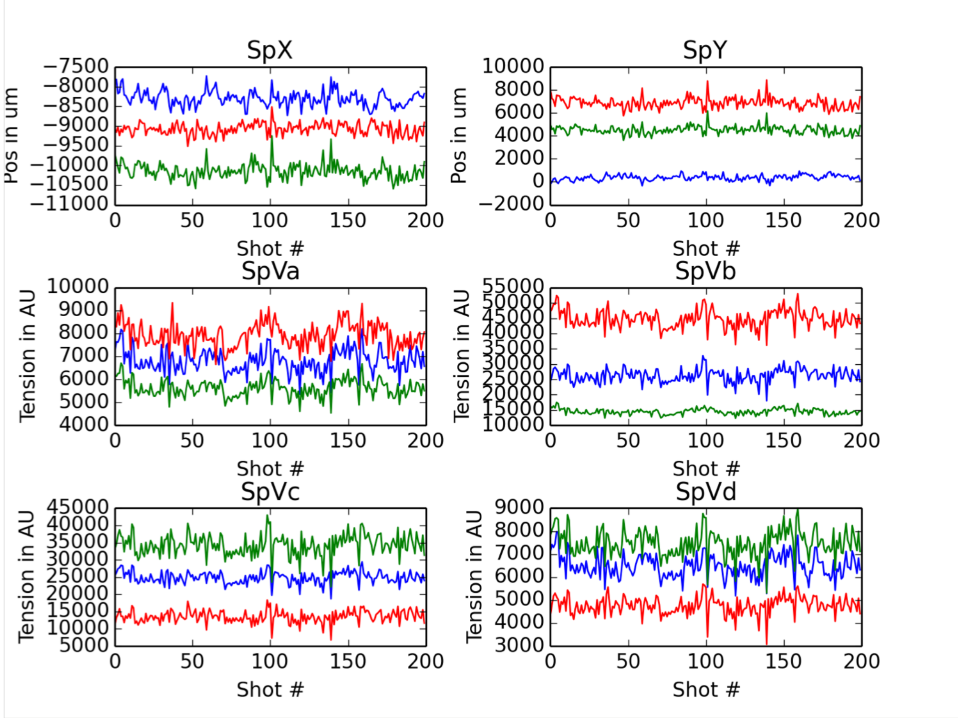


- The three BPMs were installed on the accelerator and connected with standard readout electronics.

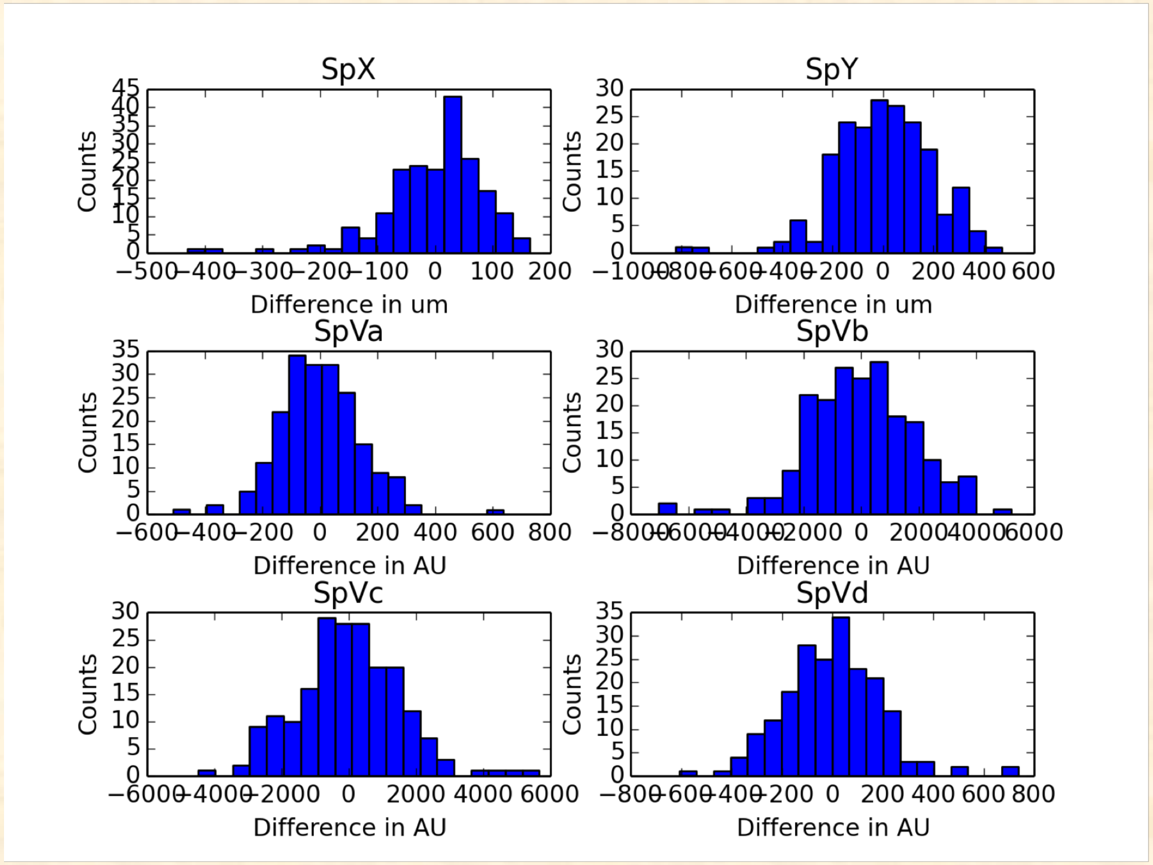
Beam tests on a particle accelerator

- Results are very preliminary
- We installed the BPM and then changed the magnet parameters.
- Electric gain was higher on the 3D printed BPM.





Beam tests on a particle accelerator



- Very low residual => no significant issue in the triplet.

Outline

- We have tested a 3D printed beam position monitor on test bench and in a particle accelerator.
- The next step will be to measure the impedance of these parts (but this is very challenging!).
- The observed performances are comparable to those of a traditionally manufactured BPM.
- If we need to build spare BPMs for our accelerator we may decide to use 3D printing!
- For complex parts 3D printing leads to cheaper and more accurate parts.
- 3D-printed accelerator components are a reality!