

The PACMAN project: results and perspectives

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CLIC workshop
07/03/2017

PACMAN



Introduction

PACMAN = a study on Particle Accelerator Components' Metrology and Alignment to the Nanometre scale

It is an Innovative Doctoral Program, hosted by CERN, funded by EU, providing training to 10 Early Stage Researchers (ESRs).

- Start date: 01/09/2013
- Duration: 4 years
- 10 ESRs, working towards a PhD thesis
- 17 academic & industrial partners
- First students started in February 2014, last one in September 2014.

Total EU contribution: 2.67 M€

CLIC budget: 1.6 MCHF

Objectives

Results achieved

Next steps and perspectives



Objectives

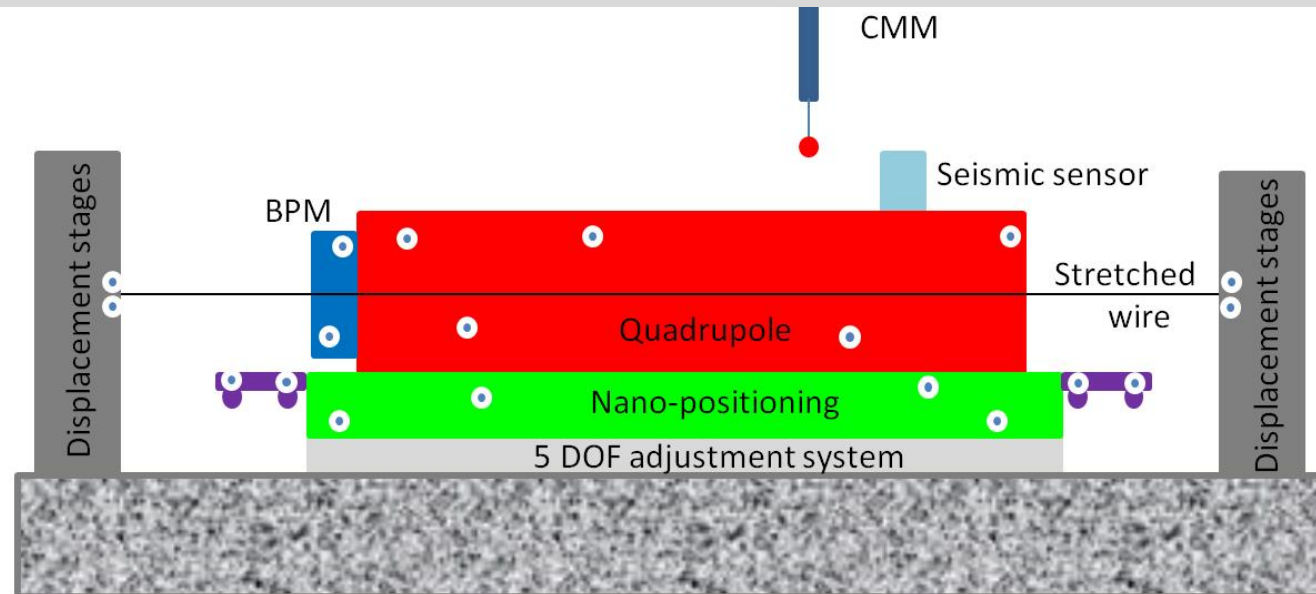
Propose an alternative solution for the high accuracy alignment of the accelerator components:

- using a stretched wire acting as a beam for the fiducialisation of components.
- combining references & methods of measurements in the same place to gain time and accuracy

To get this:

- develop very high accuracy metrology and alignment tools
- Validate them on a final bench: the Final PACMAN Alignment Bench

Extrapolate tools & methods developed to other projects

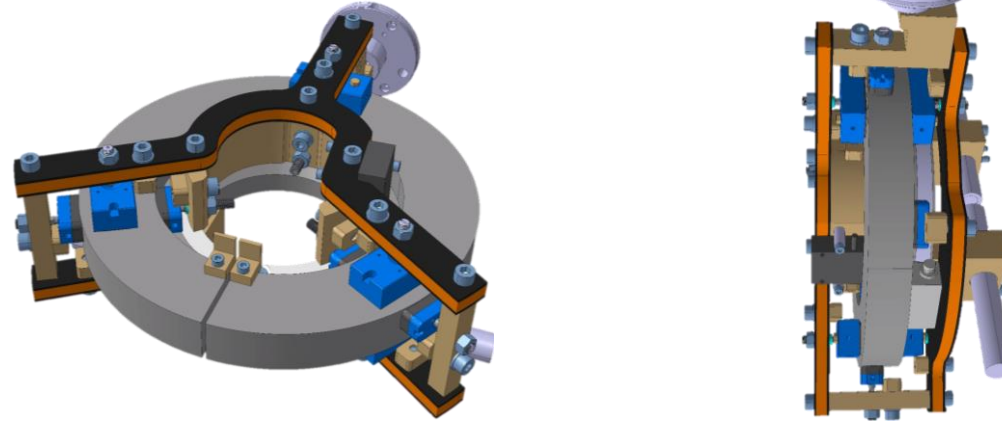


WP1

Determination of the position of the wire w.r.t fiducials

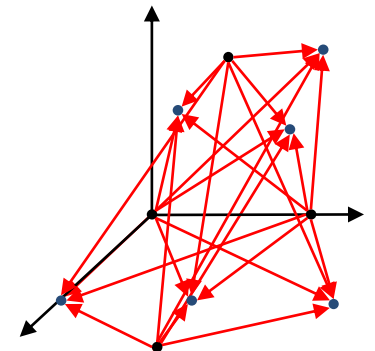
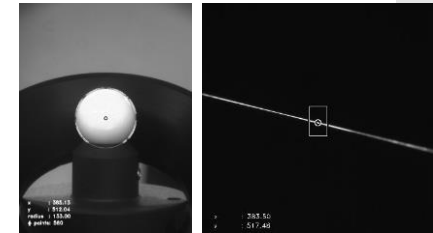
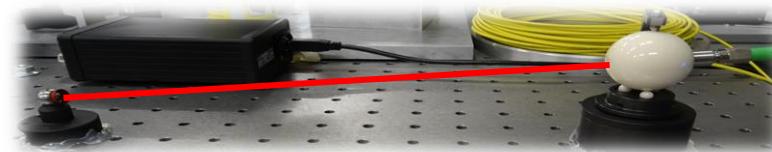
Characterisation of the CuBe wire

Design of a high precision, touchless and rotary sensor to be plugged on a CMM head:



Micro-triangulation: development of two algorithms to detect the wire and reconstruct the position of targets and wire in a unique coordinate system.

Frequency Scanning Interferometry (FSI): upgrade of the Multiline system + development of targets to perform multilateration measurements.

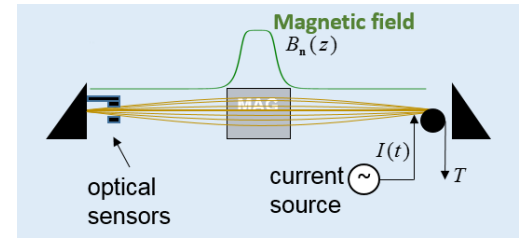


WP2

Magnetic measurements



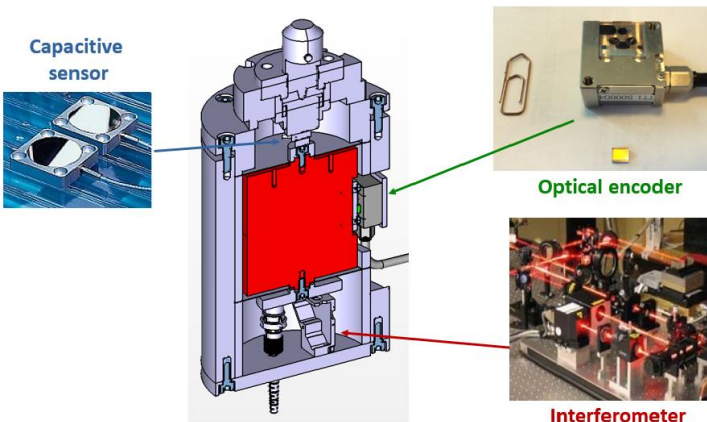
- Upgrade of the oscillating/vibrating wire method
 - 2 methods of magnet characterization compared:
 - Stretched wire based on Faraday's law
 - Oscillating/vibrating wire based on the Lorentz force
 - Background field correction put in place for the second method
 - Study of the multipole field error effect: a multipole correction proposed
 - Performance optimization of the vibrating wire with an uncertainty reduction for the vibrating wire
 - New wire bench developed
 - Repeatability tests of the vibrating wire at different magnet current
- Adaptation of the rotating coil method for small aperture magnets:
 - Development of new sensors (tangential and radial coils)
 - Different shafts designed, manufactured and tested with G10, synthetic sapphire, Accura bluestone)
 - New bench designed, assembled and under validation
 - PCB test protocol put in place
 - Different scenarios of calibration studied.



WP3

High accuracy engineering and nanopositioning

Direct comparison = no data ambiguity

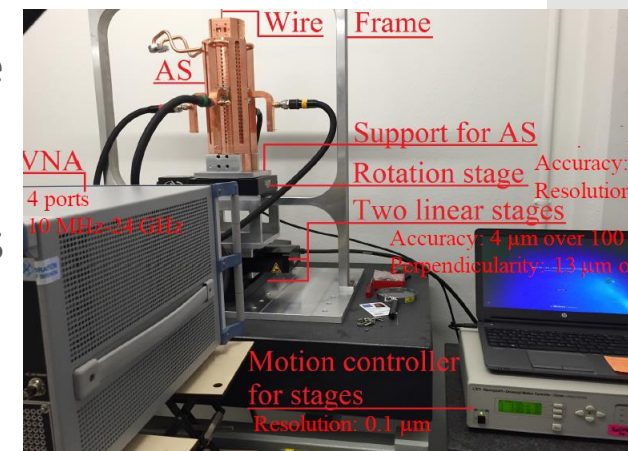
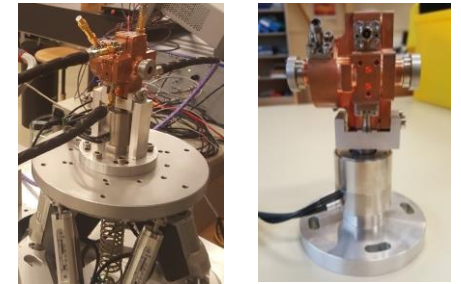
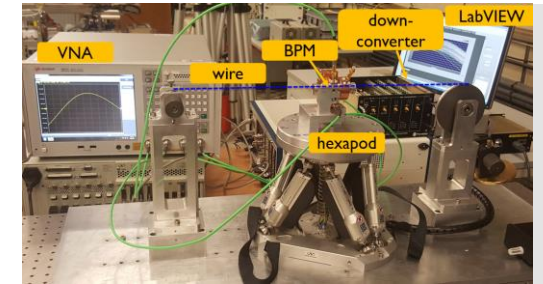


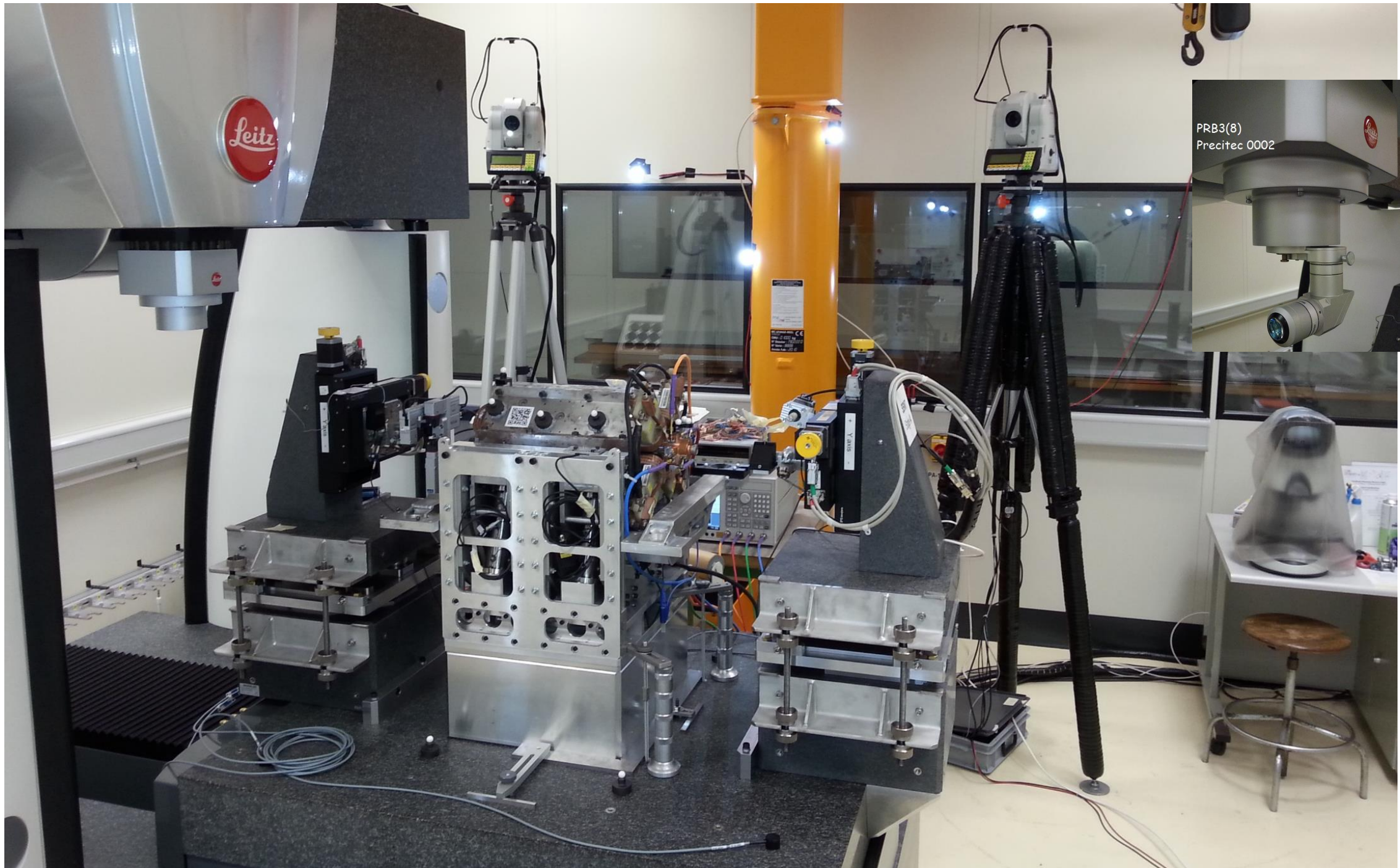
- Estimation of all errors in the fiducialisation process. Temperature has the most significant impact
- Study of an uncertainty budget of error of the PACMAN process according to GUM Supplement 1. Simulations have been performed and experiments are under way.
- Development of a seismic sensor fulfilling PACMAN requirements (bandwidth = 0.1 ~ 200 Hz, resolution < 0.1 nm (RMS @ 1 Hz), magnetic fields resistance)
 - After inventory of the existing sensors, development of a new sensor integrating 3 types of transducers: capacitive, optical encoder and interferometer to avoid data ambiguity.
 - Measurements under way.
- Upgrade of the existing support platform of Stabilization/nanopositioning system with no modes below 100 Hz
- Design and validation of a positioning controller of the nanopositioning system
- Study of a proposition for an alternative long range actuator (high stiffness > 100 N/m, heavy loads > 50 kg, high resolution < 1nm, large range > 1mm)

WP4

Microwave technology

- Determination of the electric center of a 15 GHz BPM:
 - Once the perturbation analysis was chosen to detect the electrical center: study of the BPM on many RF aspects, including linear & angular location of the center
 - Validation on a dedicated test bench & FPAB: micrometric repeatability
 - Study of the resolution adding a piezo stage: nanometric resolution below 4 nm detected!
- Determination of the EM field of an AS:
 - Determination of the center of EM field inside the middle cell:
 - Repeatability: $<1 \mu\text{m}$
 - Resolution: $2 \mu\text{m}$ (minimum step of AS displacement)
 - Accuracy: $\sim 1 \mu\text{m}$
 - Absolute fiducialisation in CMM soon!





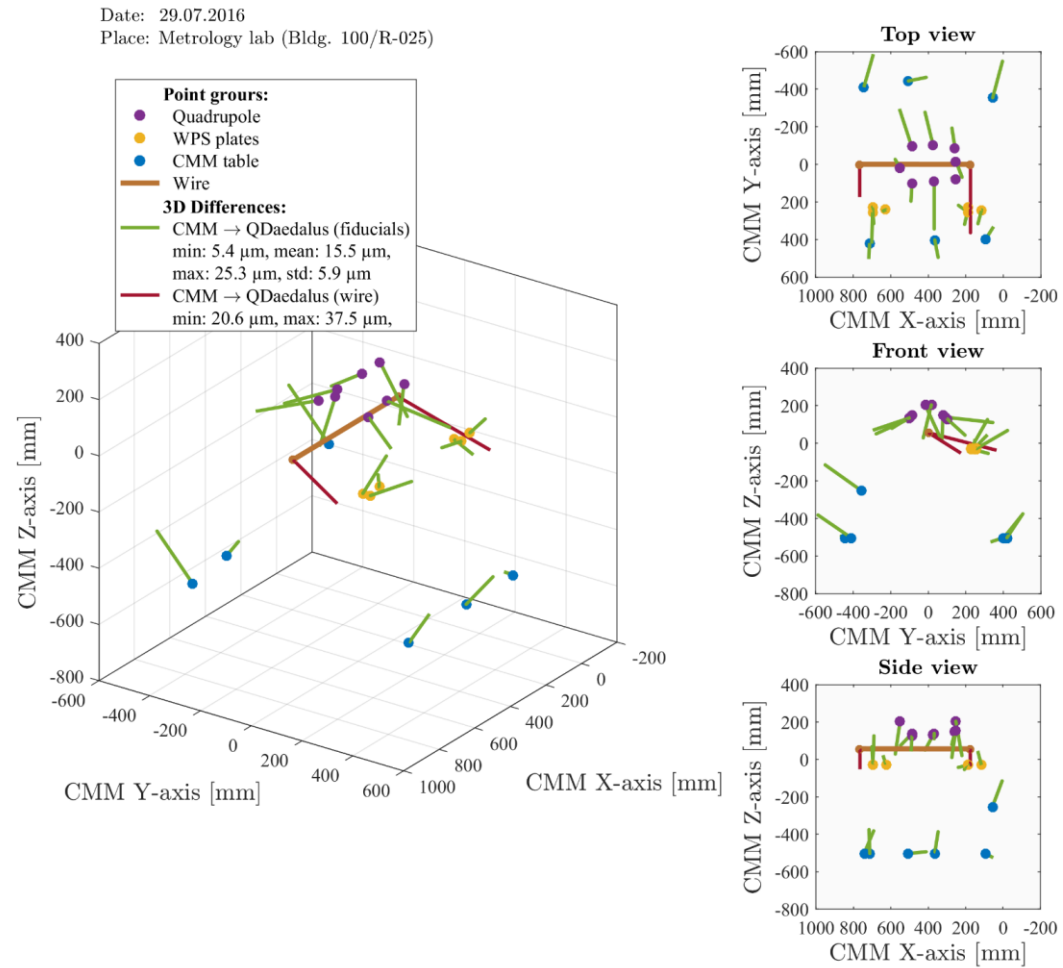
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Final PACMAN alignment bench

Results

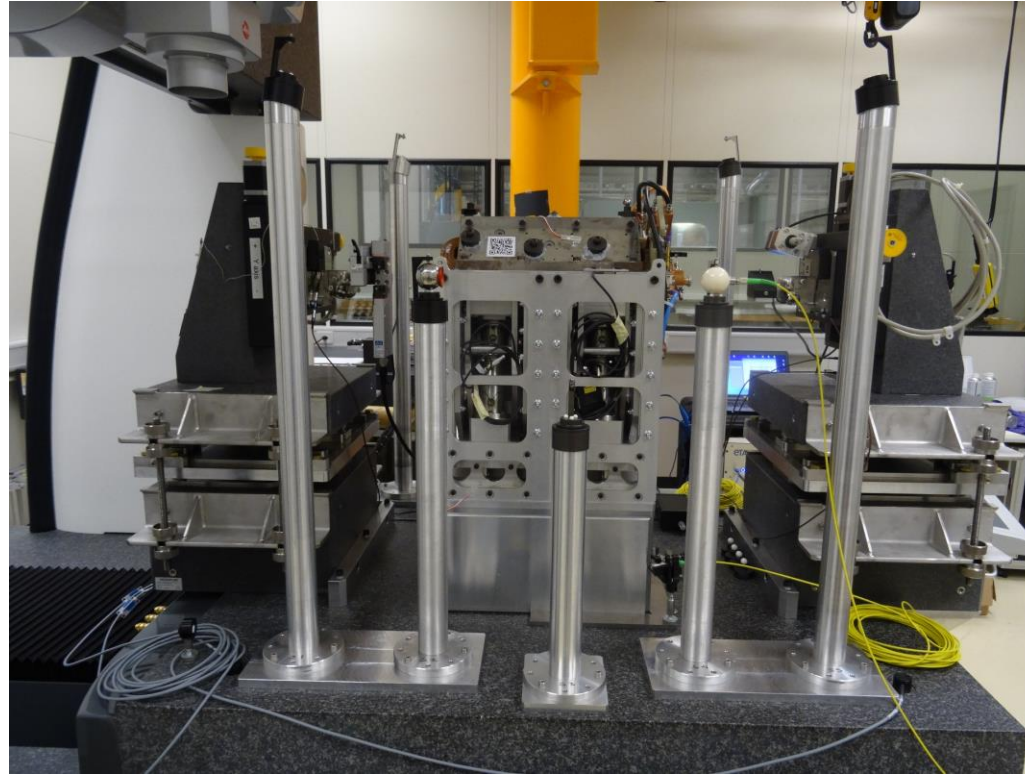
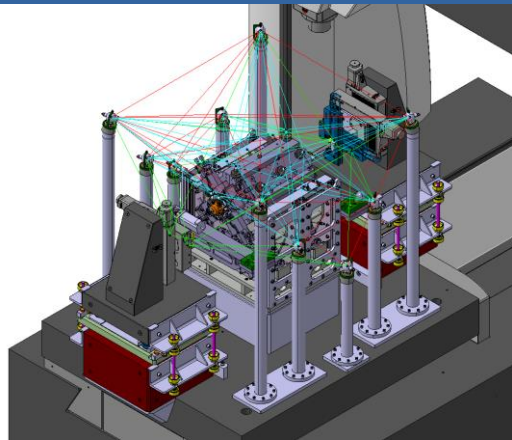


- Microtriangulation evaluated on the FPAB via cross-measurements with CMM: 85% of coordinates below $15\ \mu\text{m}$



Final PACMAN alignment bench

FSI results



- Repeatability measurements : 3D distances all below $5\ \mu\text{m}$
- Network accuracy: 3D distances all below $2\ \mu\text{m}$ on the magnet, some fixation problem seen on the fiducials of the stages.

Final PACMAN alignment bench

Results

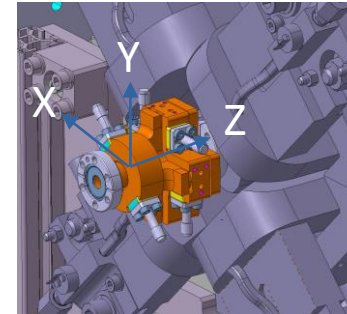
- Fiducialisation of MB quadrupole and BPM

Reference versus mechanical axis :

	Rad (μm)	Vert (μm)	Uncert. (μm)
Quad	-21.6	40.9	± 10
BPM	17.3	40.6	± 4

Offset between BPM/quad reference axes:

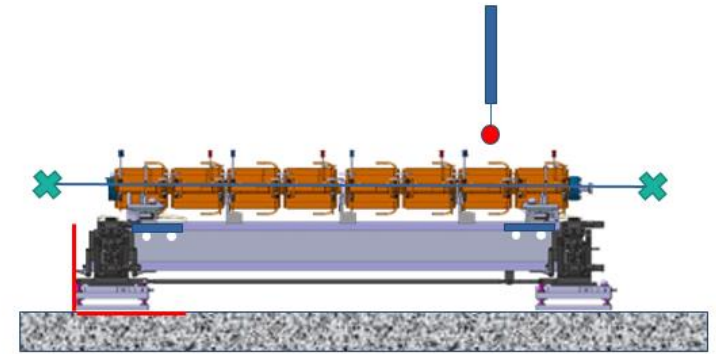
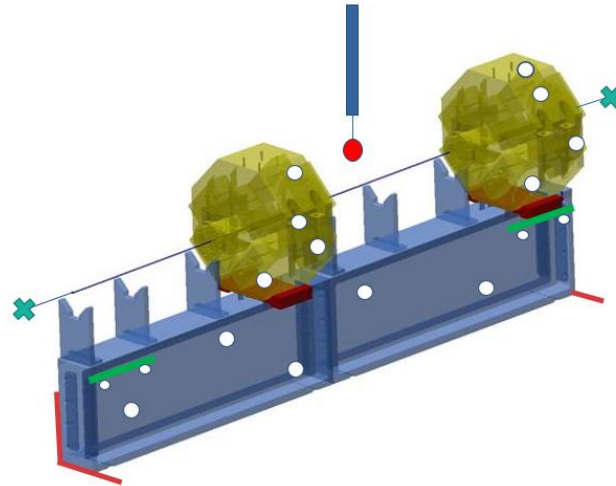
	Rad (μm)	Vert (μm)	Uncert. (μm)
Offset	27	-52	± 1.2



- Repeatability in locating the magnetic axis:
 - within $\pm 0.2 \mu\text{m}$ for magnetic center offset
 - within $\pm 0.9 \mu\text{rad}$ for the yaw and pitch
- Sub-micrometric repeatability concerning the determination of the electrical axis
- Accuracy of the nanopositioning system as good as the limit of the CMM (MPEE = $0.3 \mu\text{m} + 1 \text{ ppm}$), max. parasitic displacement measurement by CMM: lateral: $1 \mu\text{m}$, pitch: $1.7 \mu\text{rad}$, yaw: $1.3 \mu\text{rad}$
- Cross-check of the mechanical displacement applied to the magnet and the magnetic axis displacement measured via the vibrating stretched wire: offset below $0.7 \mu\text{m}$

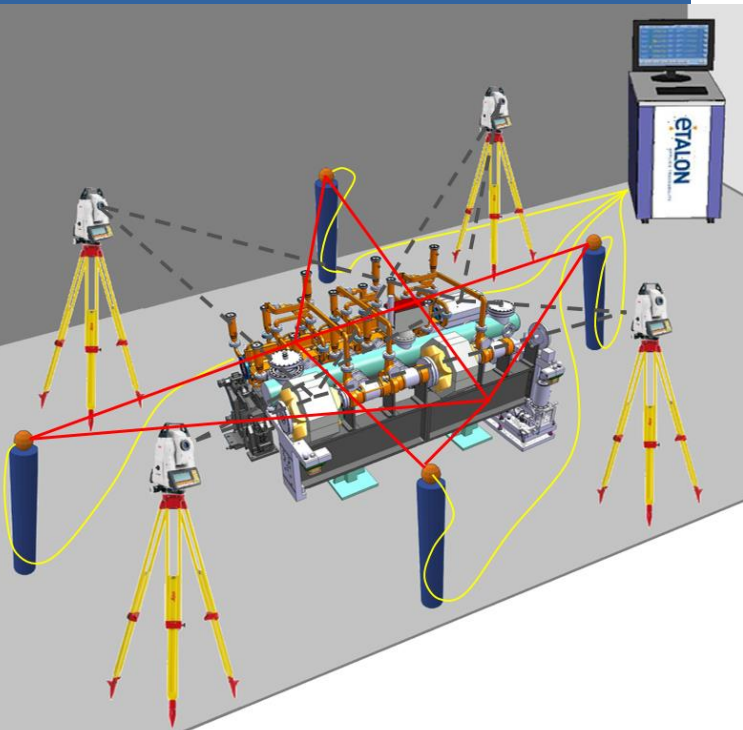
Perspectives

- Improve the accuracy and decrease time spent in the fiducialisation process of one or several components on the same support assembly.

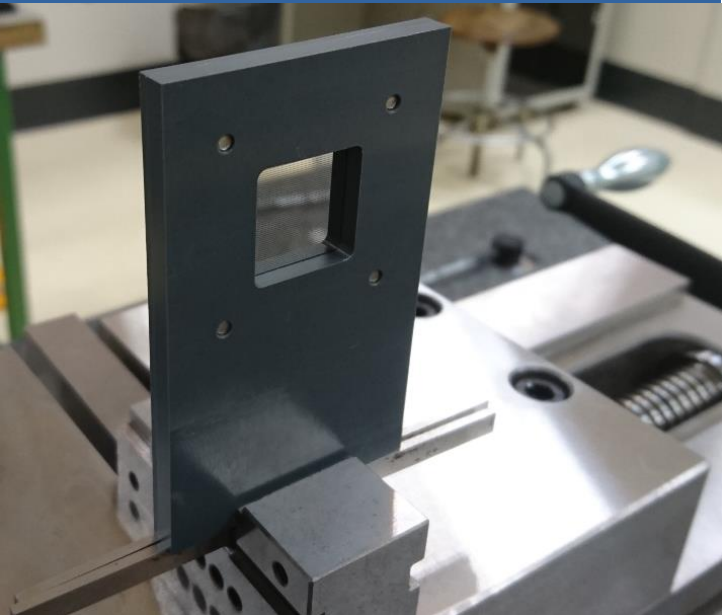


Extrapolation on FCC-ee for example.

- Develop very accurate portable measurements (either redoing the fiducialisation directly in the tunnel, or using the fiducials already determined during the fiducialisation process)



Other positive aspects



There are also indirect bonus coming from PACMAN and the hardware bought by the CLIC project:

- The FSI system:
 - it will be also used for the internal position of the crab cavities of HL-LHC at extreme conditions
 - It is considered for an implementation on specific calibration benches in the magnetic measurements laboratory
- Precitec sensor installed on the Leitz offer new possibilities of non contact high precision measurements, for electronic chip or mirrors
- The new stages developed for the project will be used for HL-LHC magnetic measurements
- Other developments applicable on other projects
 - Rotating coils for small aperture magnets on linac like ADAM
 - High accuracy fiducialisation on synchrotrons, HL-LHC and FCC-ee
- With KT: possible application using multi-pass interferometer in force feedback configuration.
- Strengthening of links with the partners and between the partners.

Summary

- A lot of “Premières” already achieved inside PACMAN:
 - Resolution of BPM ~ 4 nm using a wire instead of a beam
 - Smallest coil of 26 layers manufactured!
 - Most accurate portable system of measurement for large scale measurements ever developed.
 - 1st seismic sensor with 3 different transducers integrated
 - Most accurate absolute fiducialisation of quadrupole, BPM and AS ever achieved.
- Last slot of measurements of the Final PACMAN Alignment Bench foreseen just after the workshop, to conclude on the reproducibility of measurements, accuracy of FSI and micro-triangulation.
- PACMAN is a team work: a big thank you to the whole team of students, supervisors, academic supervisors, industrial partners.



MARCH 2017 20-22		CERN, Geneva
Final PACMAN workshop		
TOPICS	Metrology and Alignment Magnetic measurements Precision Mechanics Nano-positioning Microwave technology	ACTIVITIES Talent Speed-Dating Diversity Session Impact Brainstorming Publication in IOP Journal



<https://indico.cern.ch/event/332431> - <http://pacman.web.cern.ch>

Event designed by stefan / heath

- Talent speed dating between PhD students, fellows and firms + labs:
 - National Instruments, Hexagon metrology, Etalon, Terrabee, NPL, Cornwell institute, ESRF, etc.
- Diversity session
- Brainstorming session on future applications



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This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 606839



Thank you for your
attention

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07/03/2017

PACMAN



PACMAN is a team work :

The students:

- Claude Sanz
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- Peter Novotny
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- Silvia Zorzetti
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The academic supervisors:

- Paul Shore
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- Jo Spronck
- Luca Fanucci
- Angeles Faus Golfe

The CERN supervisors:

- Ahmed Cherif
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- Jean-Frédéric Fuchs
- Stefan Russenschuck
- Marco Buzio
- Michele Modena
- Andrea Gaddi
- Kurt Artoos
- Manfred Wendt
- Nuria Catalan Lasheras

The industrial partners:

- Jürgen Schneider, Norbert Steffens, Heinrich Schwenke, Marie-Julie Leray, Pascal Lequerre, Alicia Gomez, Teun van den Dool, Augusto Mandelli, Jacques Tinembart, Philip Keller, Miroslav Sulc

CERN support:

- Seamus Hegarty, Charlyne Rabe, Karen Ernst, Gregory Cavallo, Nicolas Friedli, David Mazur