"Performance of the Optimized Mechanical Design of the CLIC Main Beam Quadrupole Magnet Prototype"

M. Modena, C. Petrone, CERN

Outline

1. European Strategy for Particle Physics and introduction to CLIC project

2. Procurement challenges and previous status on CLIC MBQ activities (as reported at MT23 Conf.)

3. Advancement with prototype procurement and results

4. PACMAN program main results

5. Conclusions

Outline

1. European Strategy for Particle Physics and introduction to CLIC project

2. Procurement challenges and previous status on CLIC MBQ activities (as reported at MT23 Conf.)

3. Advancement with prototype procurement and results

4. PACMAN program main results

5. Conclusions

European Strategy for Particle Physics

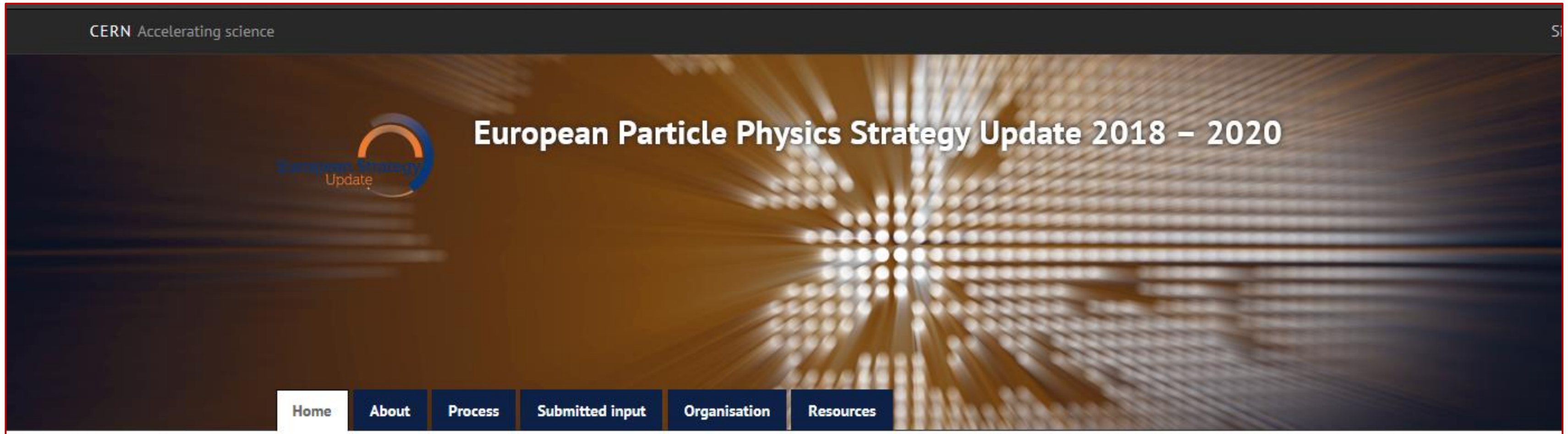
***CERN**, the European Organization for Nuclear Research, <u>is studying the next generation of accelerators for particle physics,</u> under the aegis of the **European Strategy for Particle Physic** process.*

Voir en français

In Granada, the European particle physics community prepares decisions for the future of the field

The European particle physics community is meeting this week in Granada, Spain, to discuss the roadmap for the future of the discipline

13 MAY, 2019



CERN Accelerating science

European Particle Physics Strategy Update 2018 – 2020

Home | About | Process | Submitted input | Organisation | Resources

Welcome

The European Strategy for Particle Physics provides a clear prioritisation of European ambitions in advancing the particle physics science. The Strategy is due to be updated by May 2020 to guide the direction of the field to the mid-2020s and beyond.

To optimally inform all participants in the process, the Secretariat of the European Strategy Group (ESG) called upon the particle physics community across universities, laboratories and national institutes to submit written input by 18 December 2018 to prepare the discussions on the Strategy Update which will take place in 2019.

Global Perspective

The European Strategy takes into account the worldwide particle physics landscape and developments in related fields, and was initiated by the CERN Council to coordinate activities across a large, international and fast-moving community with the aim to maximise scientific returns.

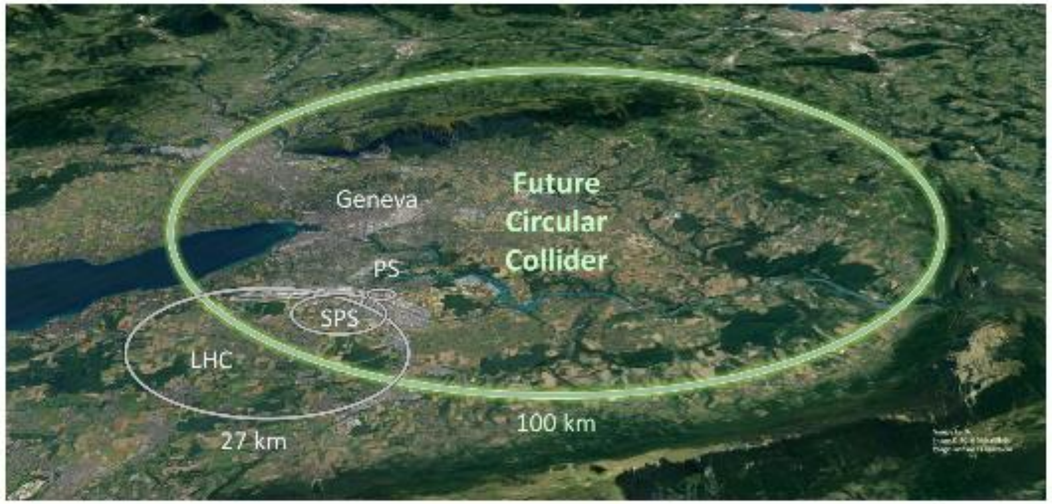
UPDATES

Open Symposium
In Granada, the European particle physcis community prepares decisions for the future of the field. *Read more*

The detailed **timetable** of the Symposium is available at this link.

Submitted Input
Community proposals submitted to the Strategy Update process are available here.

European Strategy for Particle Physics

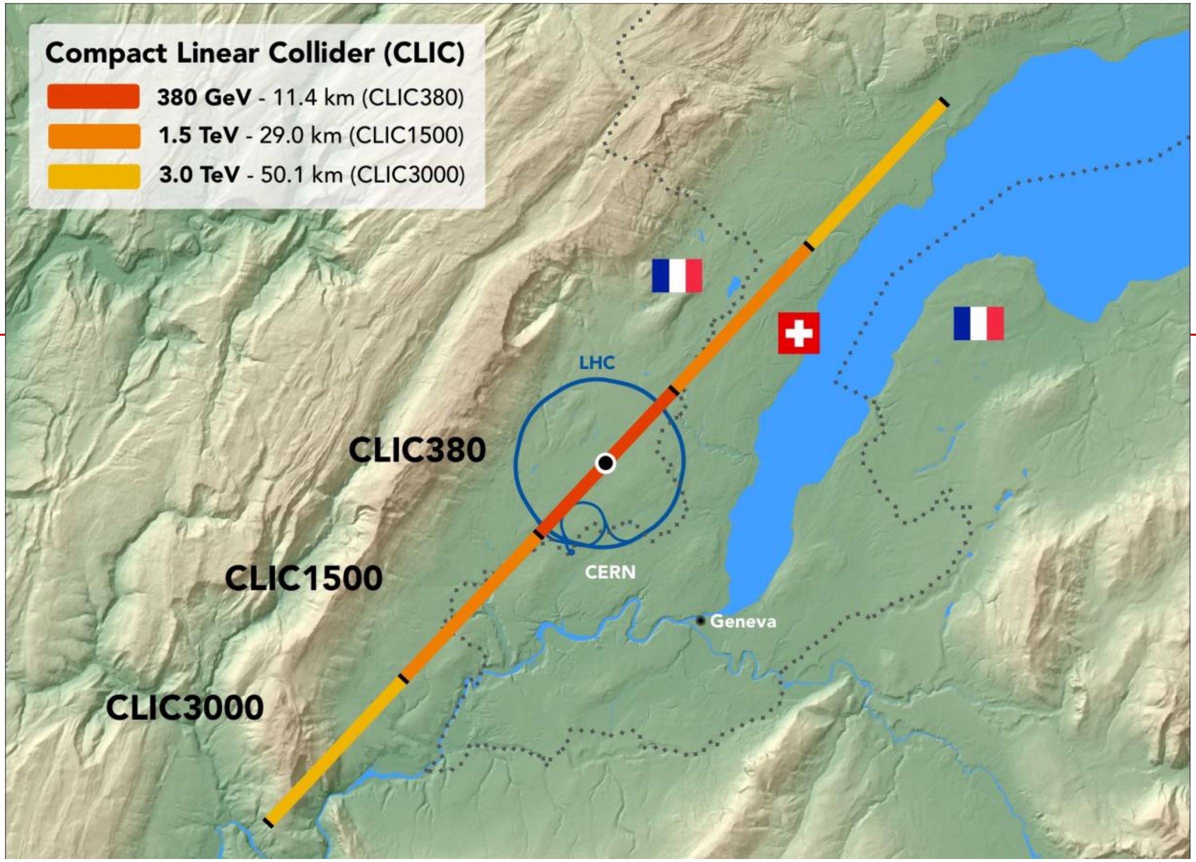


A schematic map showing where the Future Circular Collider tunnel is proposed to be located (Image: CERN)

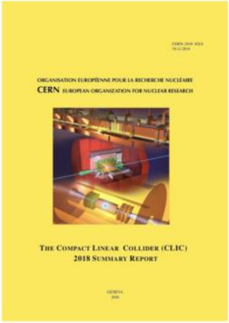
The Future Circular Collider Study (FCC) is developing designs for a higher performance particle collider to extend the research currently being conducted at the Large Hadron Collider (LHC), once the latter reaches the end of its lifespan.

The goal of the FCC is to greatly push the energy and intensity frontiers of particle colliders, with the aim of reaching collision energies of 100 TeV, in the search for new physics.

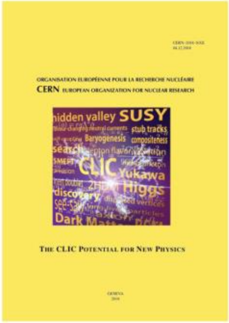
CLIC is designed to be built in stages of increasing collision energy: starting at 380 GeV, 1.5 TeV, with a final energy of 3 TeV. In order to reach this energy in a realistic and cost efficient scenario, the accelerating gradient has to be very high - CLIC aims at an acceleration of 100 MV/m, 20 times higher than the LHC.



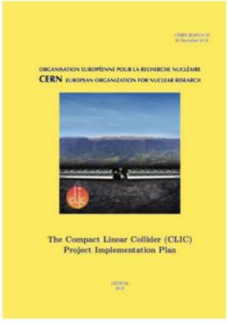
Input to European Strategy for Particle Physics



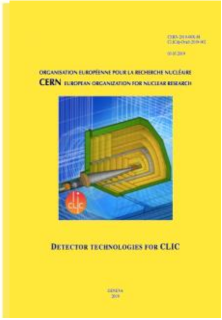
CERN-2018-005-M
http://dx.doi.org/10.23731/CYRM-2018-002



CERN-2018-009-M
http://dx.doi.org/10.23731/CYRM-2018-003



CERN-2018-010-M
http://dx.doi.org/10.23731/CYRM-2018-004



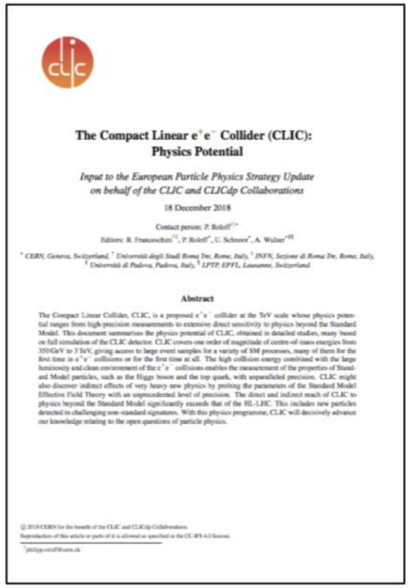
CERN-2019-001
http://dx.doi.org/10.23731/CYRM-2019-001

The Compact Linear e⁺e⁻ Collider (CLIC): Accelerator and Detector

Input to the European Particle Physics Strategy Update on behalf of the CLIC and CLICdp Collaborations

18 December 2018

Abstract



The Compact Linear e⁺e⁻ Collider (CLIC): Physics Potential

Input to the European Particle Physics Strategy Update on behalf of the CLIC and CLICdp Collaborations

18 December 2018

Abstract

CLIC input to the European Strategy for Particle Physics Update 2018-2020

Formal European Strategy submissions

- **The Compact Linear e+e- Collider (CLIC): Accelerator and Detector** (arXiv:1812.07987)
- **The Compact Linear e+e- Collider (CLIC): Physics Potential** (arXiv:1812.07986)

Yellow Reports

- **CLIC 2018 Summary Report** (CERN-2018-005-M, arXiv:1812.06018)
- **CLIC Project Implementation Plan** (CERN-2018-010-M, arXiv:1903.08655)
- **The CLIC potential for new physics** (CERN-2018-009-M, arXiv:1812.02093)
- **Detector technologies for CLIC** (CERN-2019-001, arXiv:1905.02520)

Journal publications

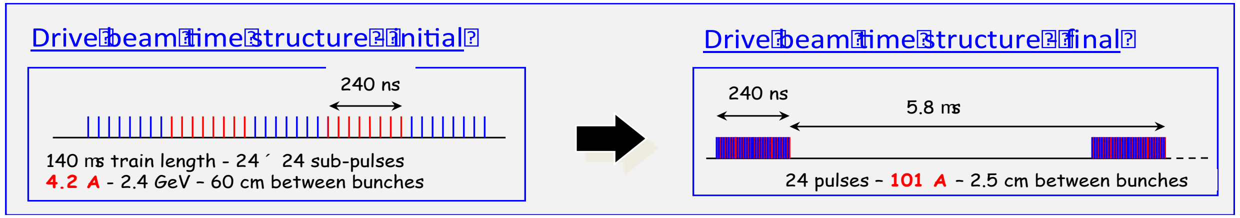
- **Top-quark physics at the CLIC electron-positron linear collider** [In journal review] (arXiv:1807.02441)
- **Higgs physics at the CLIC electron-positron linear collider** (Journal, arXiv:1608.07538)
  - Projections based on the analyses from this paper scaled to the latest assumptions on integrated luminosities can be found here: CDS, arXiv.

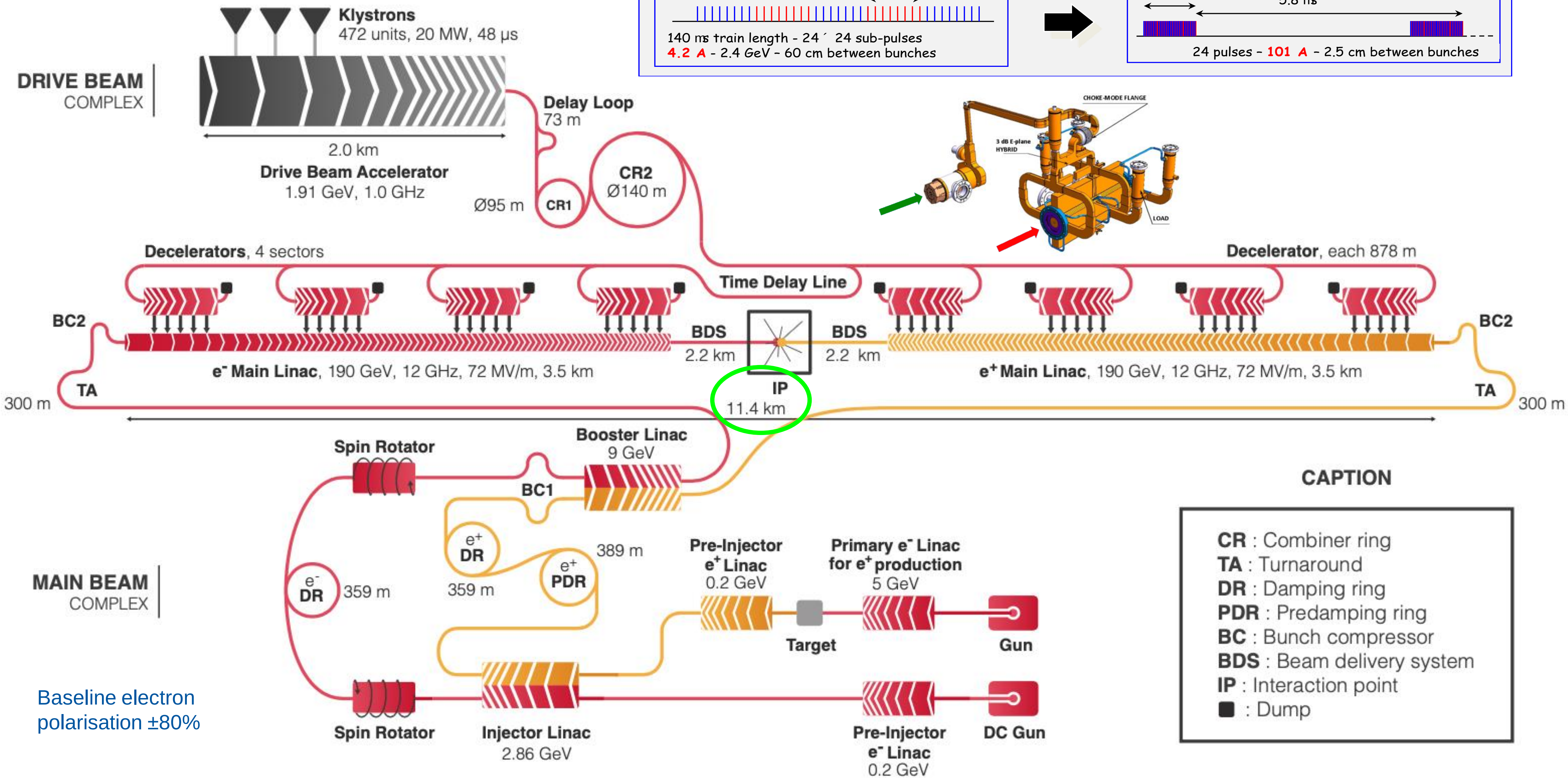
CLICdp notes

- **Updated CLIC luminosity staging baseline and Higgs coupling prospects** (CERN Document Server, arXiv:1812.01644)
- **CLICdet: The post-CDR CLIC detector model** (CERN Document Server)
- **A detector for CLIC: main parameters and performance** (CERN Document Server, arXiv:1812.07337)

Link: http://clic.cern/european-strategy

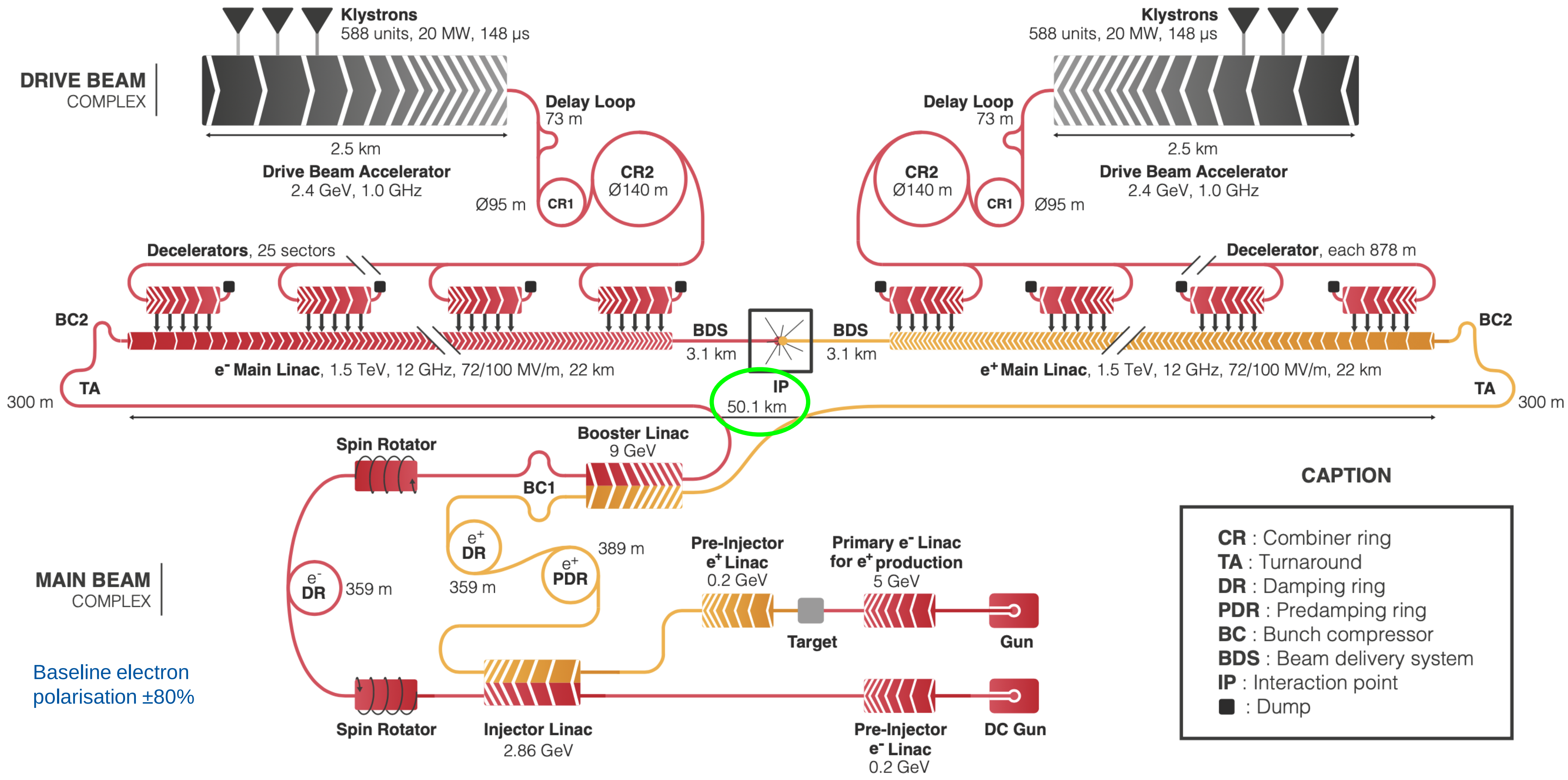
CLIC 380 GeV layout and power generation





Baseline electron polarisation ±80%

CLIC layout – 3TeV



Baseline electron polarisation ±80%

Outline

CLIC magnets procurement challenges

Independent from the acceleration technology chosen (“Drive Beam” or Klystrons), the accelerated e^+ and e^- beams will be focused by a family of quadrupoles called Main Beam Quadrupoles – MBQ (all with same cross-section and gradient but with different lengths). The procurement of the MBQs will represent a challenging industrial project.

For the CLIC Stage1 (*11.4 km length, for a 380 GeV centre-of-mass energy*), **1144 MBQs** will be needed

MBQ Type	Magnetic length [mm]	Quantity
MBQ Type1a	430	712
MBQ Type2a	1010	432

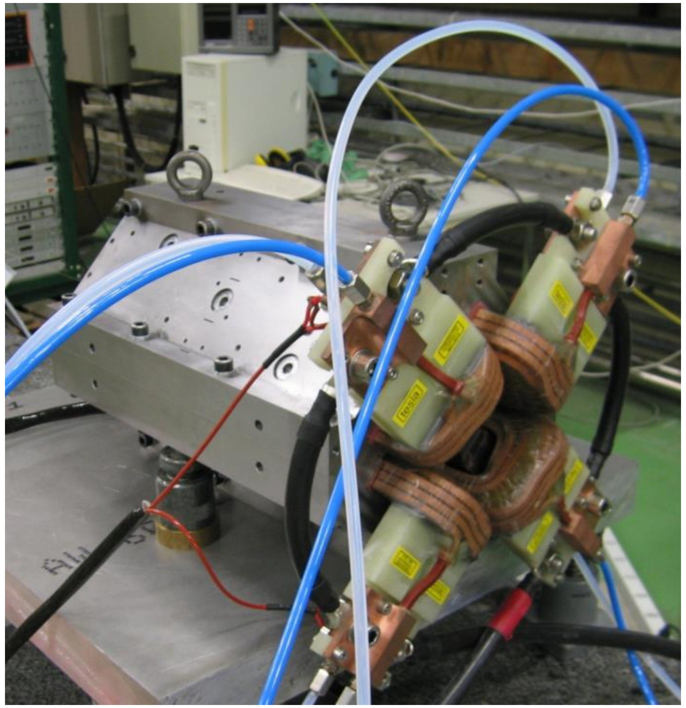
For the CLIC Stage3 (*50.1 km length, for a 3 TeV centre-of-mass energy*), **4020 MBQs** will be needed

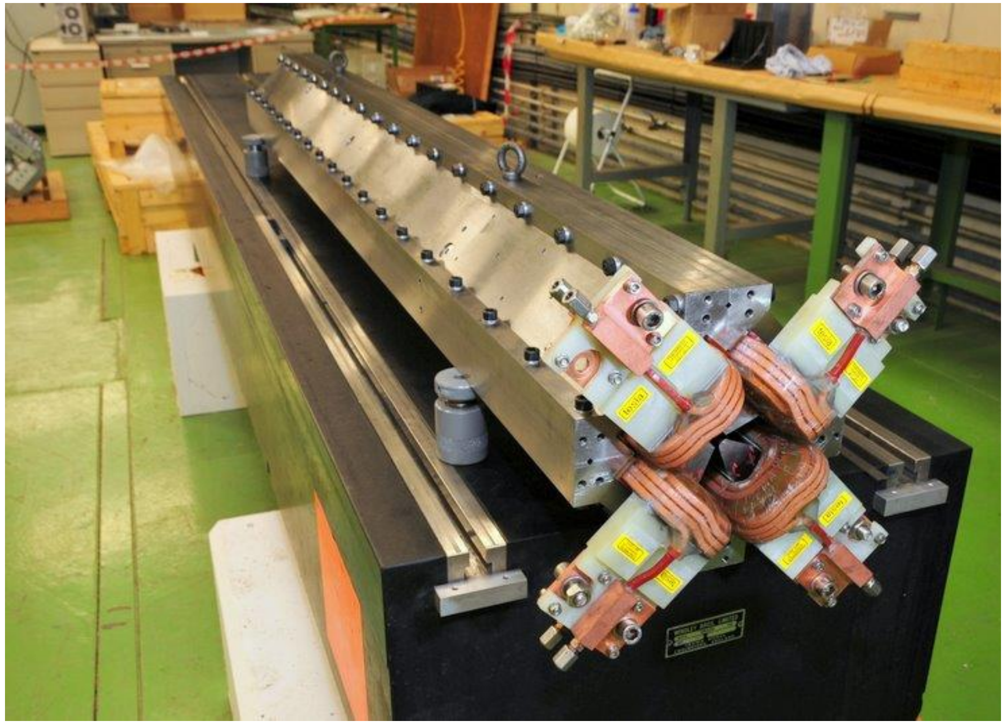
MBQ Type	Magnetic length [mm]	Quantity
MBQ Type1	350	308
MBQ Type2	850	1276
MBQ Type3	1350	964
MBQ Type4	1850	1472

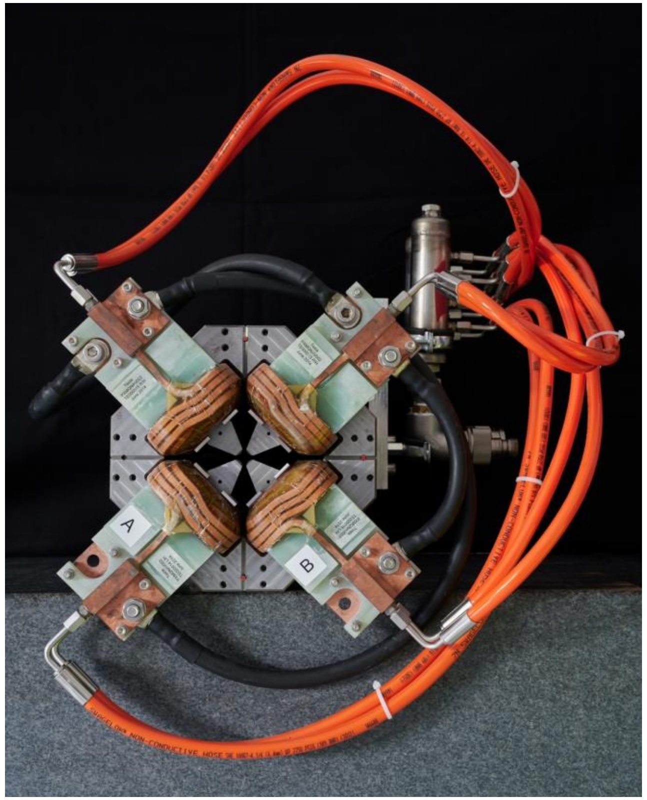
CLIC magnets procurement challenges

In the past years the MBQ magnet family was subject of a R&D phase with the procurement of several prototypes, with the aim of investigate:

- The correctness and performances of the magnet design
- The feasibility of the manufacturing techniques
- The industrial aspects of such type of procurement (companies qualification, difficulties, etc.)

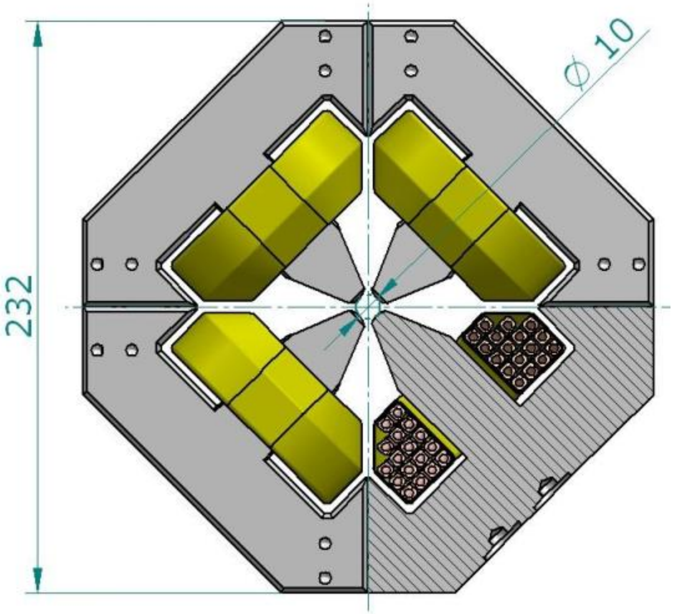


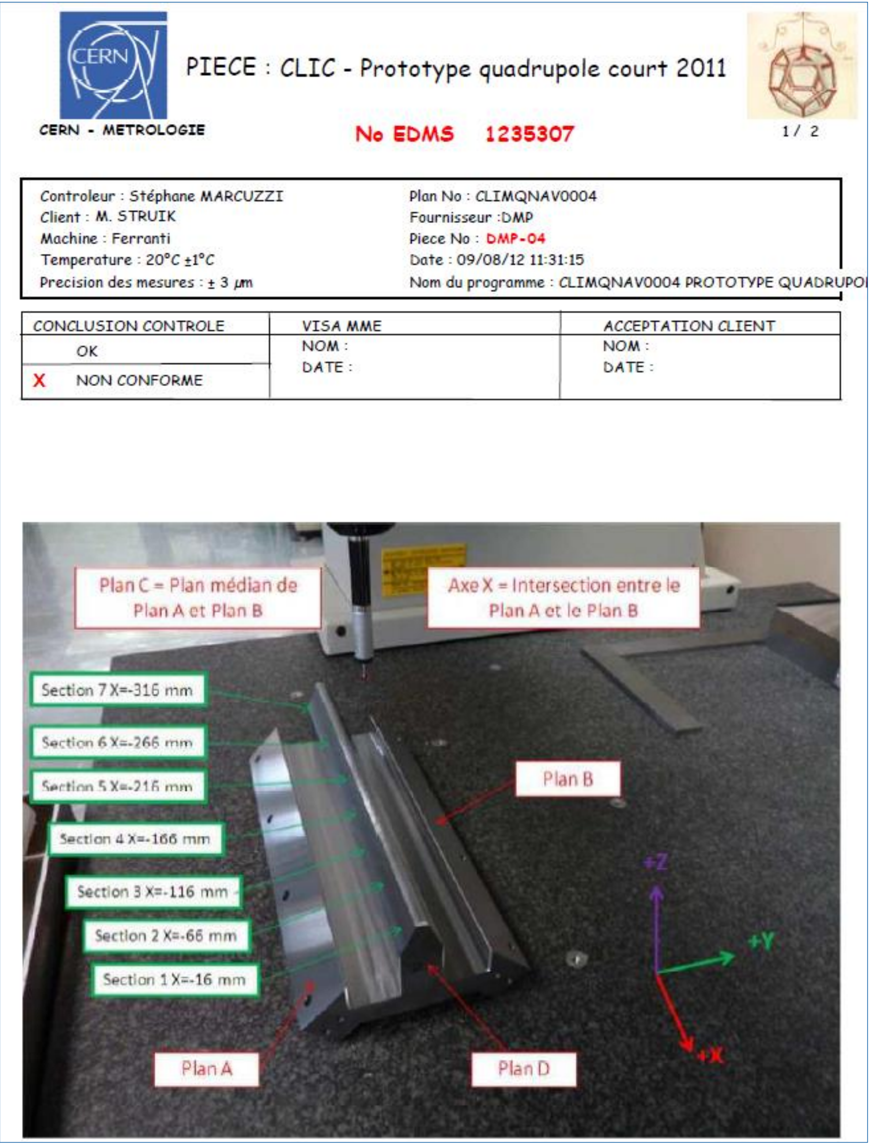




CLIC magnets procurement challenges

The quadrupole magnets are manufactured with solid iron quadrants (steel1010 grade), since they are expected to operate at constant current (200 T/m gradient required all along the linear accelerator).

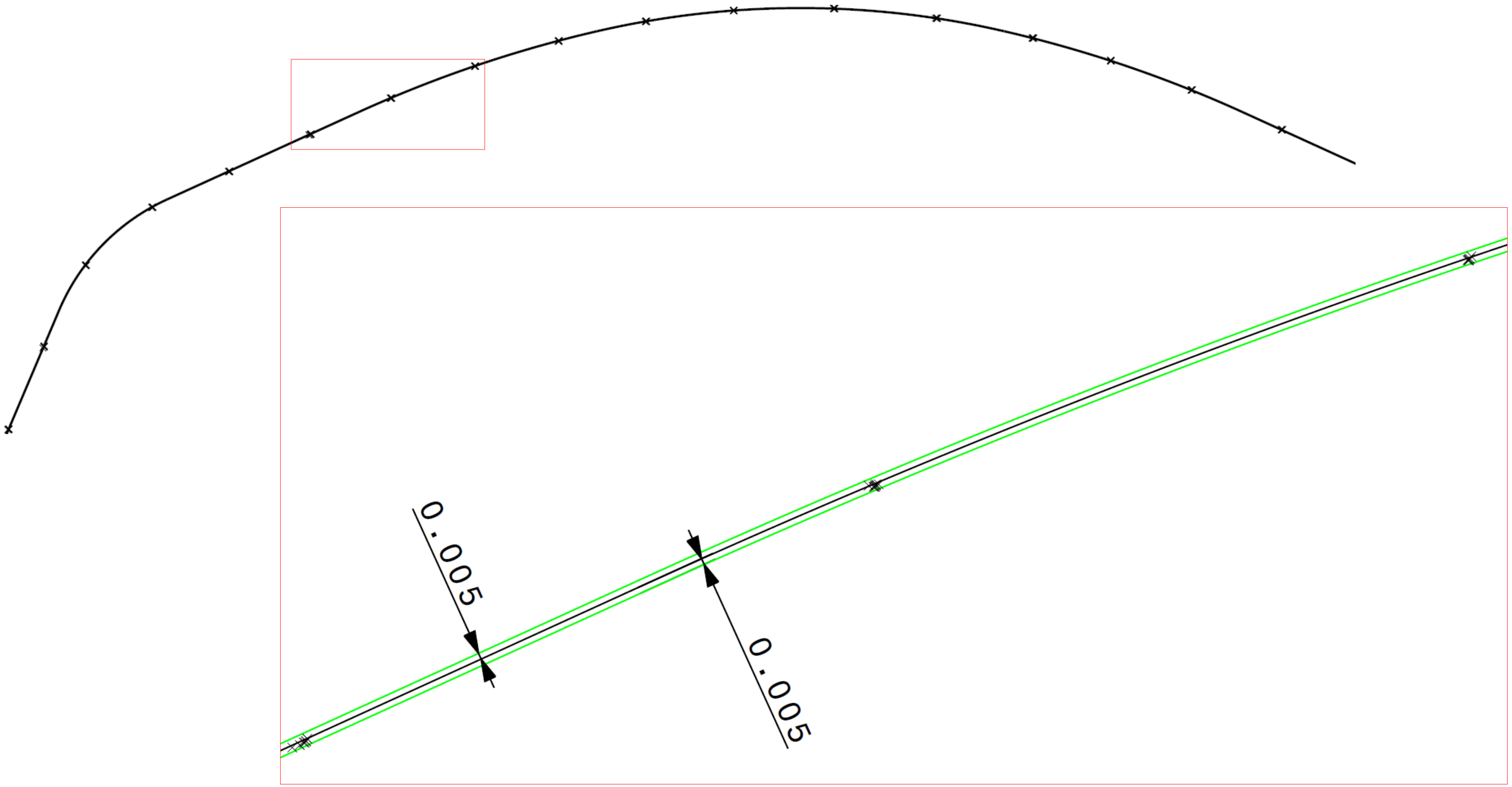




After some iterations with different precise machining companies, we think to have assess the optimal mechanical machining precision (by fine grinding) achievable for such type of procurement (following time/cost considerations).

CLIC magnets procurement challenges

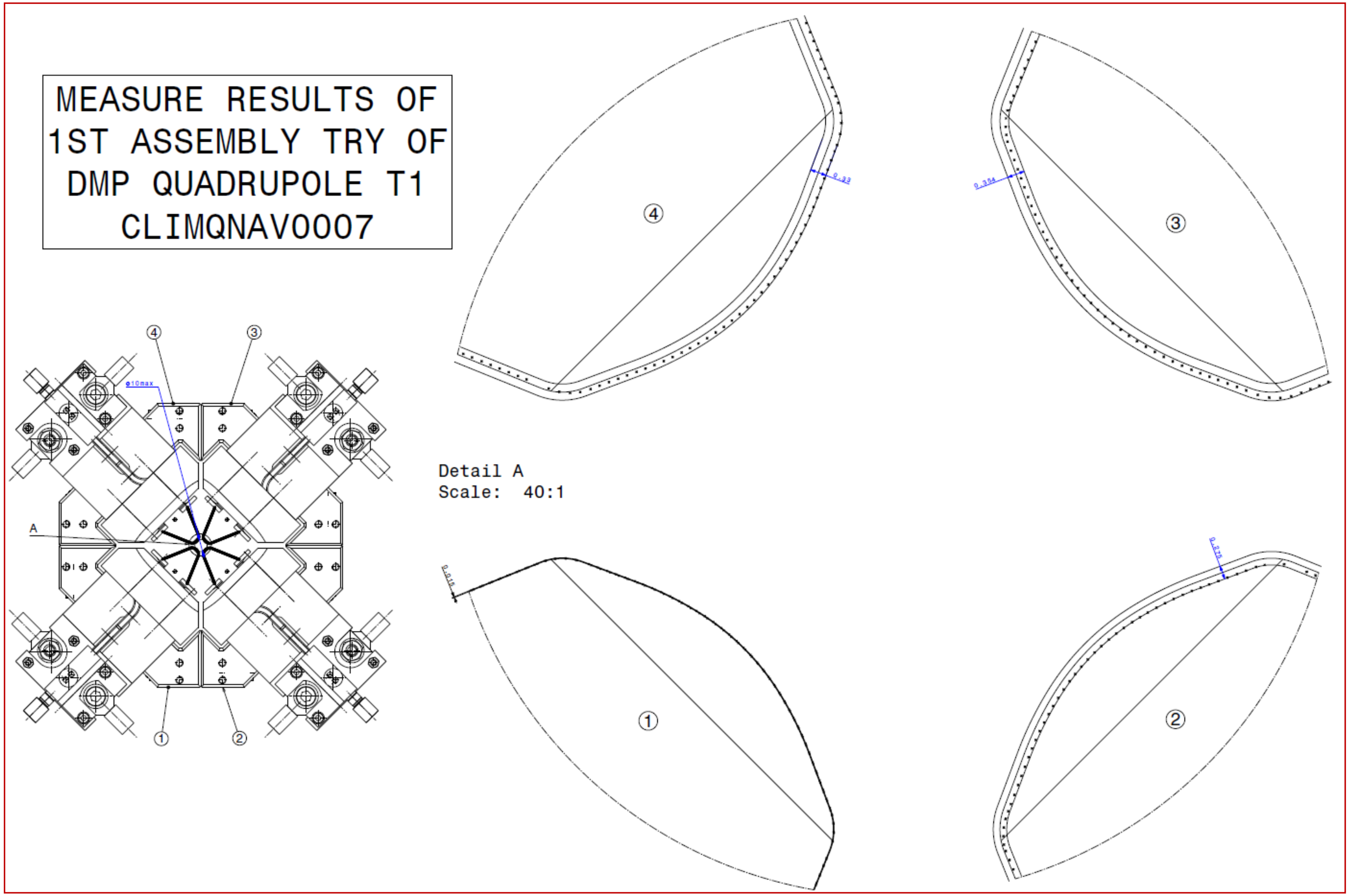
For the single quadrants, machining tolerances of ±7 µm (in average) on the most critical surfaces (poles profile and quadrant mating planes) were obtained with techniques and production times that could be envisaged for series productions of these sizes.



CLIC magnets procurement challenges

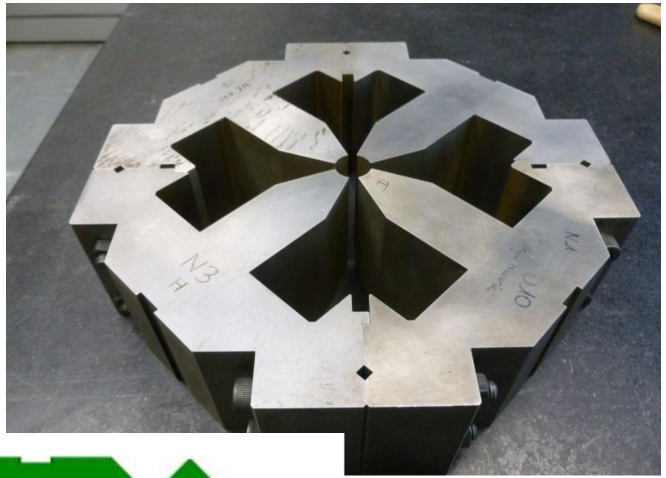
For the four quadrants (full magnet assembly), a mechanical precision (overall) of ±0.3-0.35 mm mm was obtained, showing that was still a lot to do on this point.

In addition to mechanical measurements (not evident for a so small magnet bore), magnetic field quality (measured by the multipoles content) is considered the most important indicator of the mechanical assembly precision.

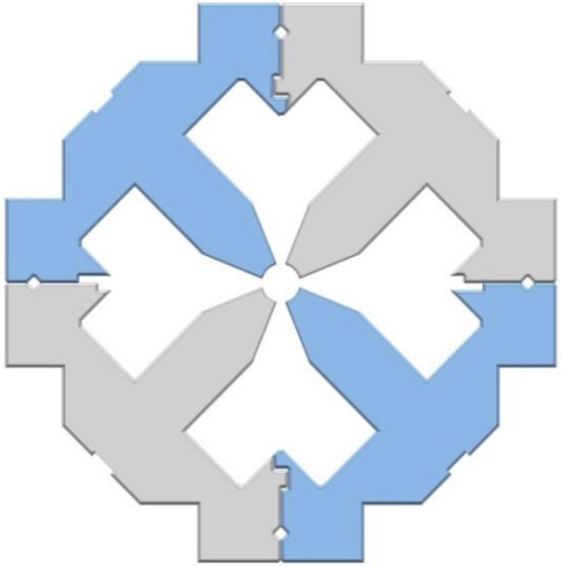


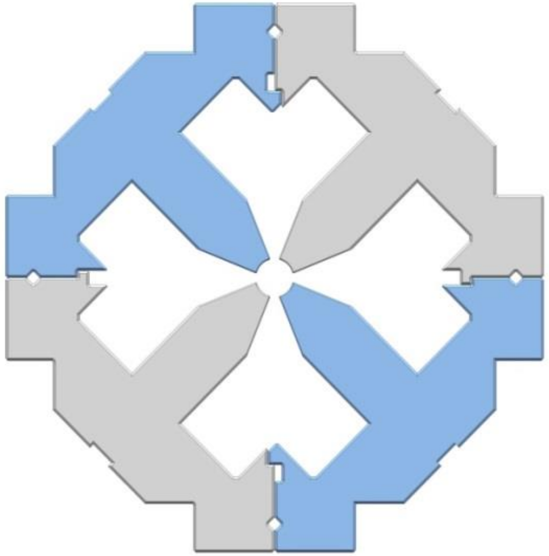
CLIC magnets procurement challenges

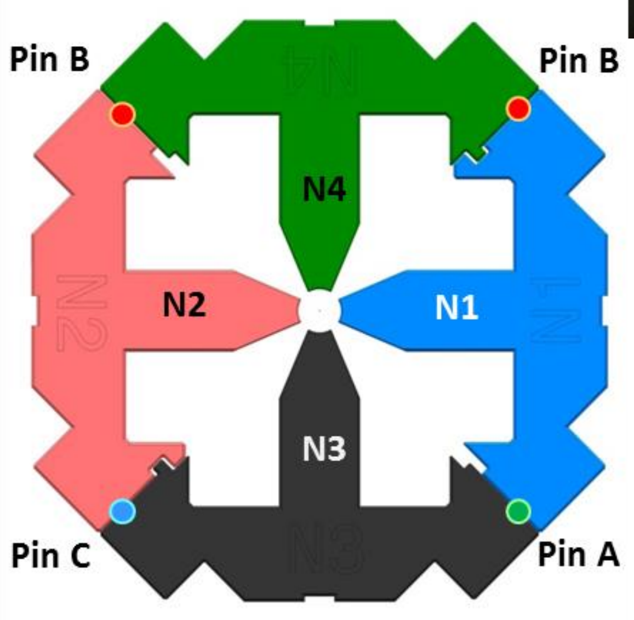
A program of assembly tests, based on high precision dummy quadrants, was launched to try to select the most promising assembly method:



Through repetitive assembly tests done with "ad hoc" pieces produced by EDM, we could conclude that the most precise assembly method is through "pins in V-shapes".
We achieved a cilindricity error of ~13 μm compared to ~74 μm without pins (2nd method utilized in the magnet prototypes)







Outline

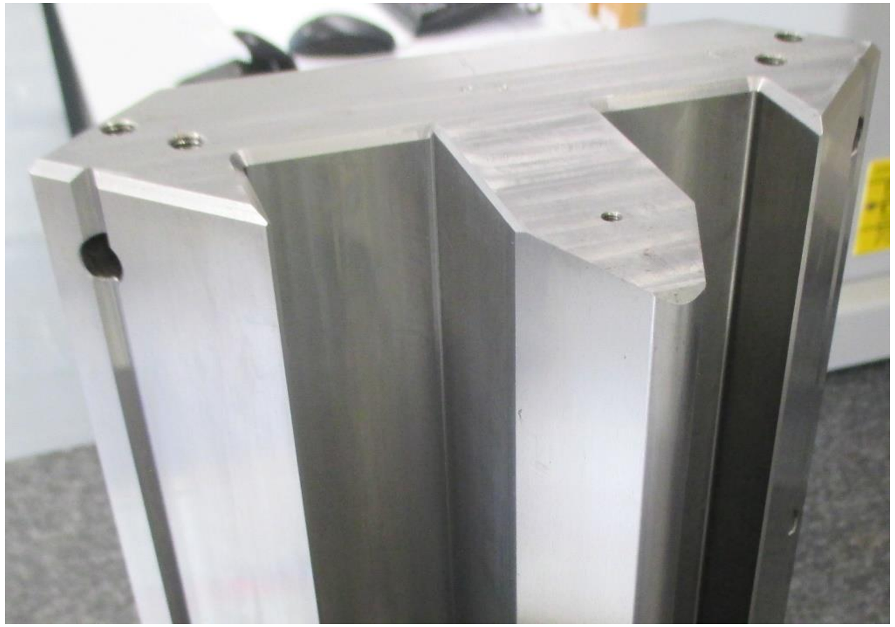
New results from MBQ magnets procurement

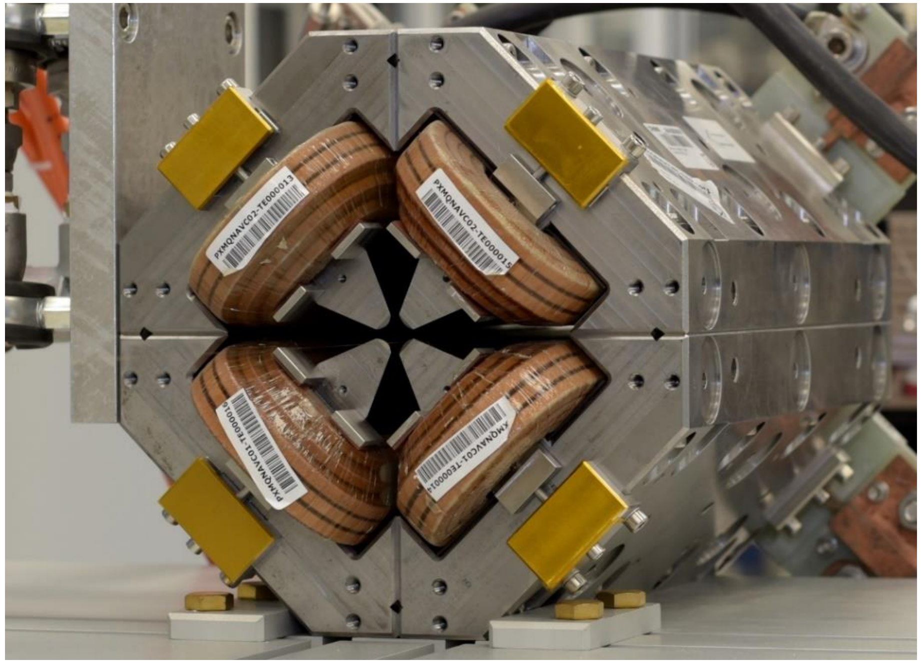
Having identified the most promising assembly method ("pins in V-shapes"), we decided to implement this solution on a set of quadrants already previously assembled and measured.

This would bring two major advantages:

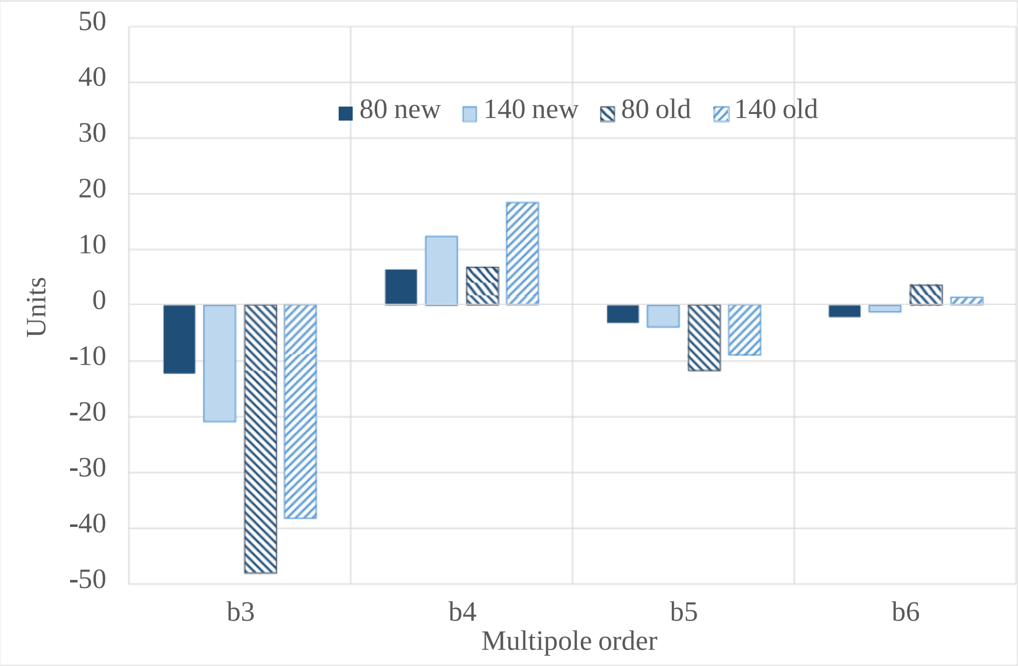
a. Limit the cost
b. Possibility to repeat and compare the magnetic measurements in order to evaluate on the same assembly the effect of the improved assembly method.

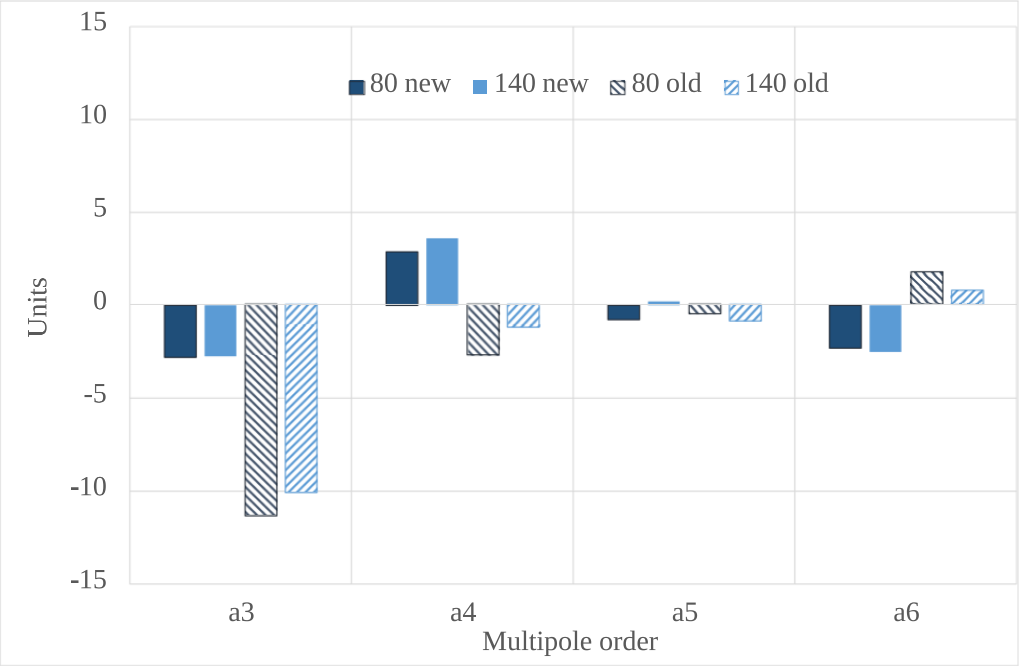
The "V" grooves were re-machined by the manufacturer (DMP-Spain) and then quadrant measured (and accepted), and finally assembled and magnetically measured by CERN





New results from MBQ magnets procurement





So, the measurements refer to the <u>same set of quadrants</u>, with the <u>same systematic machining errors</u> (ex. on the poles profile). The difference between the two set of measurements (solid vs. pattern fill) are consequently due to the different assembly method and its precision.

The improvement is visible on both Normal and Skew components content.

(To be noted that several years elapsed between the to set of measurements based on stretching and oscillating wire techniques for a so small magnet bore. The measurement system was subjected to several improvements and amelioration and comparison of the two set of measurement should consider this).

Outline

1. European Strategy for Particle Physics and introduction to CLIC project

2. Procurement challenges and previous status on CLIC MBQ activities (as reported at MT23 Conf.)

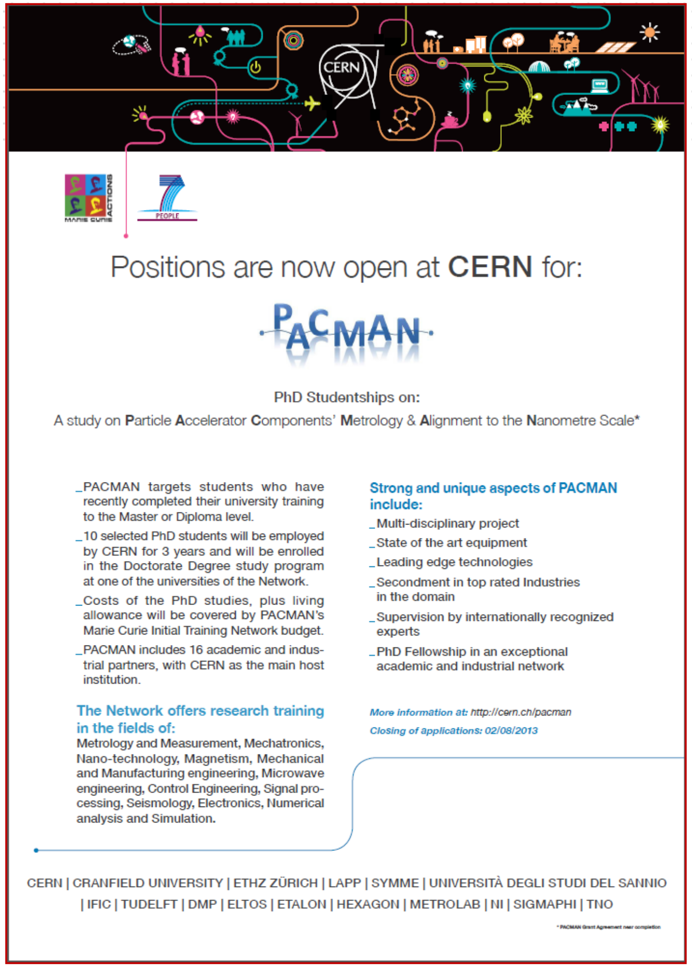
3. Advancement with prototype procurement and results

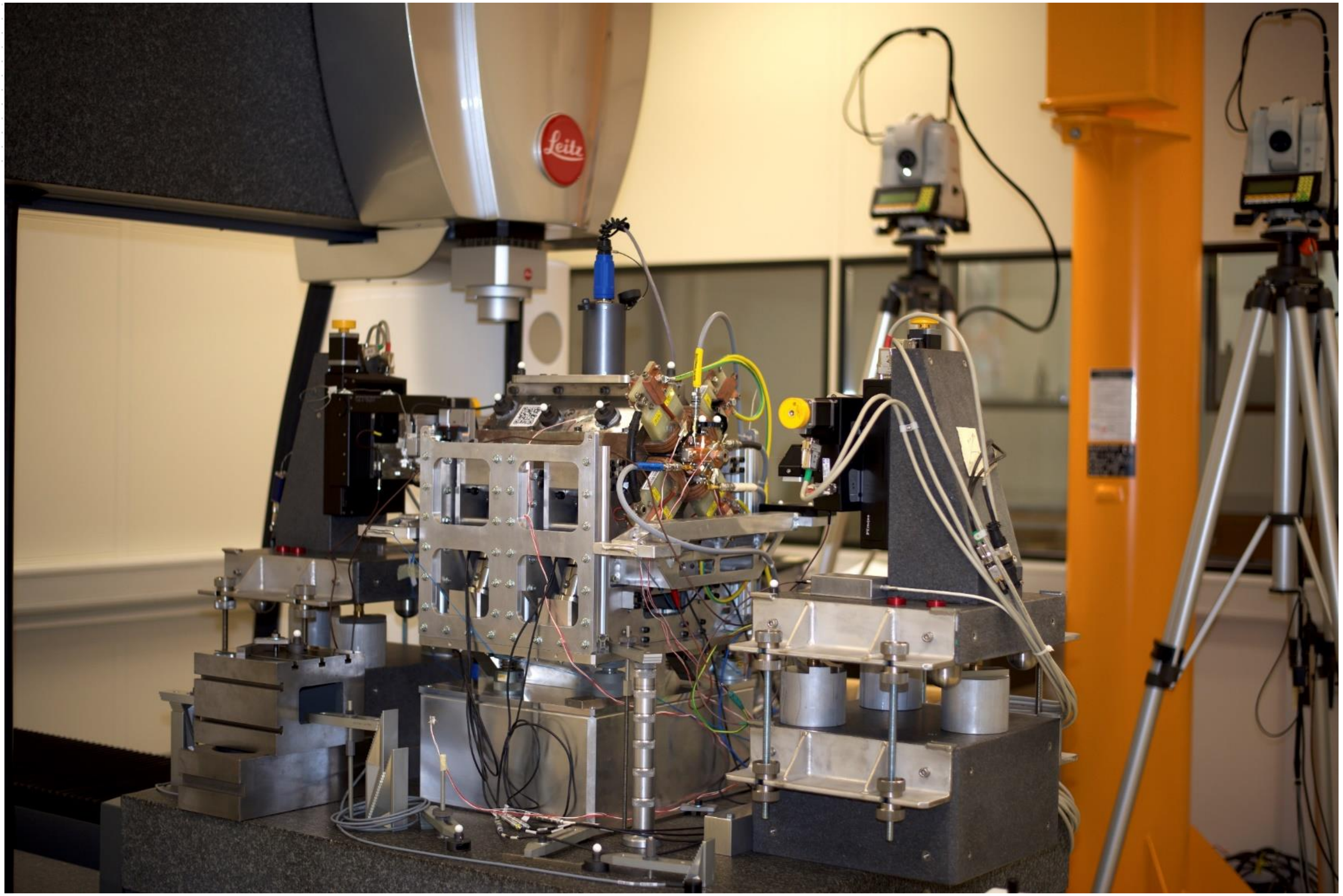
4. PACMAN program main results

5. Conclusions

PACMAN Program

In parallel of these prototype development phases evolution, we had also the completion of the PACMAN (***P****article* ***A****ccelerator* ***C****omponents* ***M****etrology and* ***A****lignment to the* ***N****anometre scale*) project, from the recruitment Phase to the final PACMAN Collaboration Meetings and reporting.





PACMAN Program

The PACMAN project main aim was to propose innovative methods to fiducialize the reference axes of accelerator components using a stretched wire. Methods to precisely locate the magnetic axis of the MBQ quadrupole and the electromagnetic zero of a Beam Position Monitor (BPM) and accurately refer them to the accelerator modules global alignment system were demonstrated.

An improvement in the efficiency and accuracy of the fiducialization/alignment process like the one proposed would be critical for a successful industrial program aiming to the procurement and high-precision assembly of a huge number of components as needed for CLIC.

The Project received funding from the European Unions 7th Framework Programme “Marie Curie actions”. It started in September 2013, and it had a four years duration. The studies and research brought seven Ph.D. Fellows to obtain their Doctorate successfully.

Outline

1. European Strategy for Particle Physics and introduction to CLIC project

2. Procurement challenges and previous status on CLIC MBQ activities (as reported at MT23 Conf.)

3. Advancement with prototype procurement and results

4. PACMAN program main results

5. Conclusions

CONCLUSION

- CLIC accelerator project is under study at CERN under the aegis of the European Strategy for Particle Physics project

- The MBQ magnets would be the backbone of the two main linacs of the CLIC complex

- The results of the final actions for the R&D on MBQ magnets was reported

- Thanks to the development and procurement of some prototypes, it was possible to select a magnet design and assembly methods convenient for the needed large procurement. The presented field quality results show the improvement provided by the final assembly method selected.

- The MBQ magnet is also one of the accelerator components studied in the PACMAN project. The project main target was the development of novel methods and tools to allow the parallel fiducialization of accelerator components, with the aim of defining innovative and efficient techniques for the procurement and fiducialization of a large numbers (more than 20000) accelerator modules

Acknowledgment:

The MBQ development activities were possible thanks to the part-time contribution of several colleagues and collaborators from CERN Magnet Group and CLIC Project that we would like to thanks.

Among them: R. Leuxe, E. Solodko, M. Struik, A. Vorozhtsov.

In the same way, we would like to

thanks all the participants to the PACMAN projects, (Fellows and CERN supervisors) for their contribution and support, in particular: D. Caiazza, N. Catalan Lasheras, A. Cherif, J. Doytchinov and H. Mainaud Durand.

Thanks for the attention

References:

- [1] ”A Multi-TeV Linear Collider Based on CLIC Technology (C
- LIC Conceptual Design Report)”, SLAC-R-985; KEK Report 2012-1; PSI-12-01; JAI-2012-001; CERN-2012-007; 12 October 2012.
- [2] ”Updated baseline for a staged Compact Linear Collider”, CERN-2016-004; arXiv:1608.07537; CERN-2016-004.
- [3] M. Modena et al. ”Performances of the Main Beam Quadrupole Type1 Prototypes for CLIC”, IEEE Transactions on Applied Superconductivity, Vol. 24, NO. 3, June 2014, 4002504.
- [4] M. Modena, et al. ”Results on Ultra-Precise Magnet Yoke Sectors Assembly Tests”, IEEE Transactions on Applied Superconductivity, Vol. 24, NO. 3, June 2014, 9001304.
- [5] C. Petrone, et al., ”Measuring field multipoles in accelerator magnets with small-apertures by an oscillating wire moved on a circular trajec- tory”, 2012 JINST 7. http://iopscience.iop.org/1748-0221/7/05/P05003.
- [6] C. Petrone, ”Wire methods for measuring field harmonics, gradients and magnetic axes in accelerator magnets”. CERN-THESIS-2013-130 CERN, https://cds.cern.ch/record/1601973.
- [7] C. Petrone, et al., ”Multipole correction of stretched-wire measurements of field-gradients in quadrupole accelerator magnets”. August 23, 2013. doi:10.1088/1748-0221/8/08/P08010.
- [8] D. Caiazza et al. ”New solution for the high accuracy alignment of accelerator components”, Physical Review Accelerators And Beams 20, 083501 (2017); DOI: 10.1103/PhysRevAccelBeams.20.083501.
- [9] H. Mainaud Durand et al. ”Main Achievements of the PACMAN Project for the Alignment at Micrometric Scale of Accelerator Components”; CERN CLIC Note 1124.