FUTURE CIRCULAR COLLIDER

Status of the Arc Half Cell Mock-up project

FCC-ee Arc Half Cell Mock-up Project team – CERN EN/MME

F. Carra, ***A. Piccini***

On behalf of the Mock-up Working Group

Wednesday 12th June 2024 / FCC Week 2024

Outline

1. FCC-ee arc half-cell mock-up project – Introduction
2. Previous and ongoing design studies
3. Status of the 1:1 Mock-up
4. Status of the SSS demonstrator
5. Conclusion / Next steps

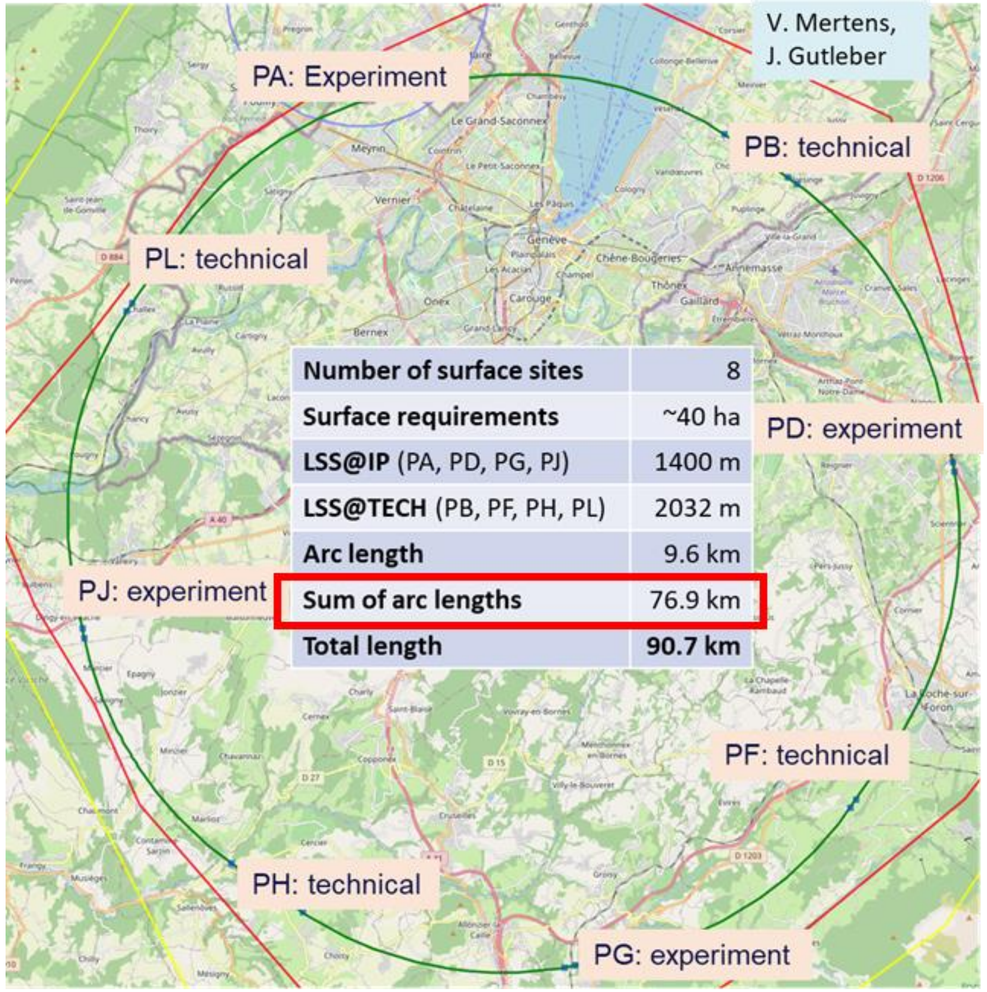
Arc Half-Cell Mock-up project motivations

Arc half-cell = the most repeated region of mechanical hardware in the tunnel
→ *77 km over 90 km are arc cells*

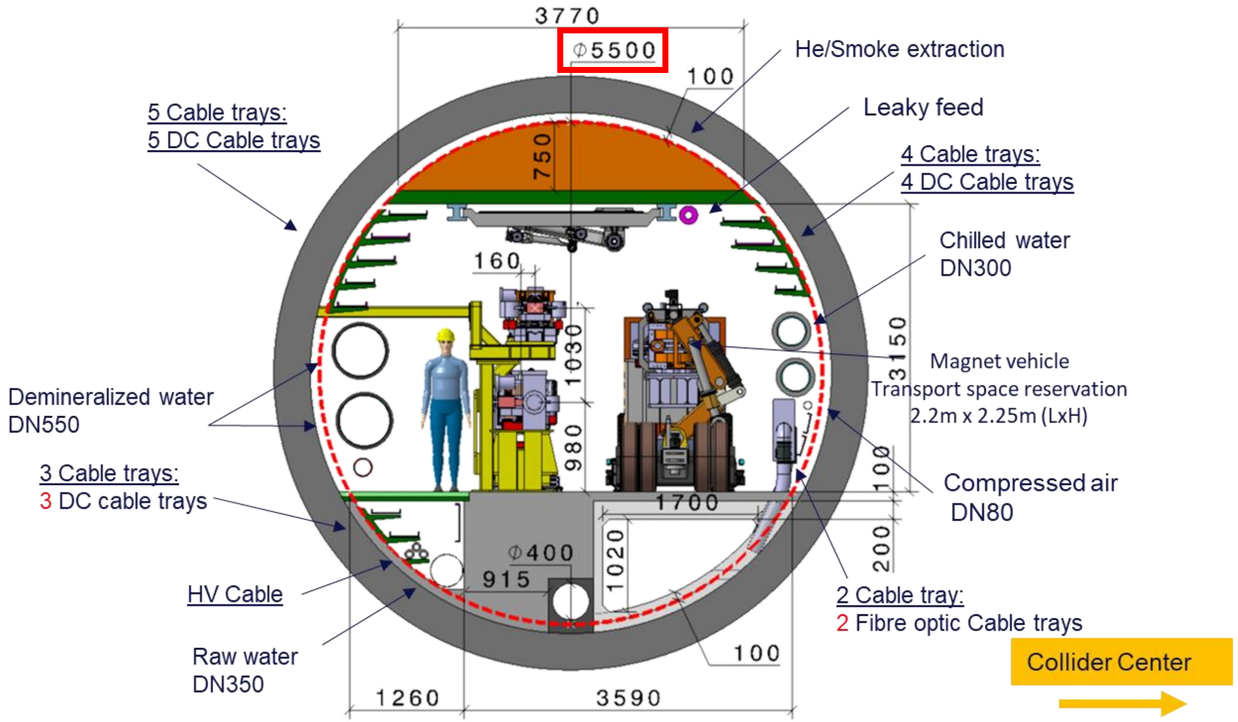
Goals =
→ Construct a half arc cell mock-up to **test aspects** related to:

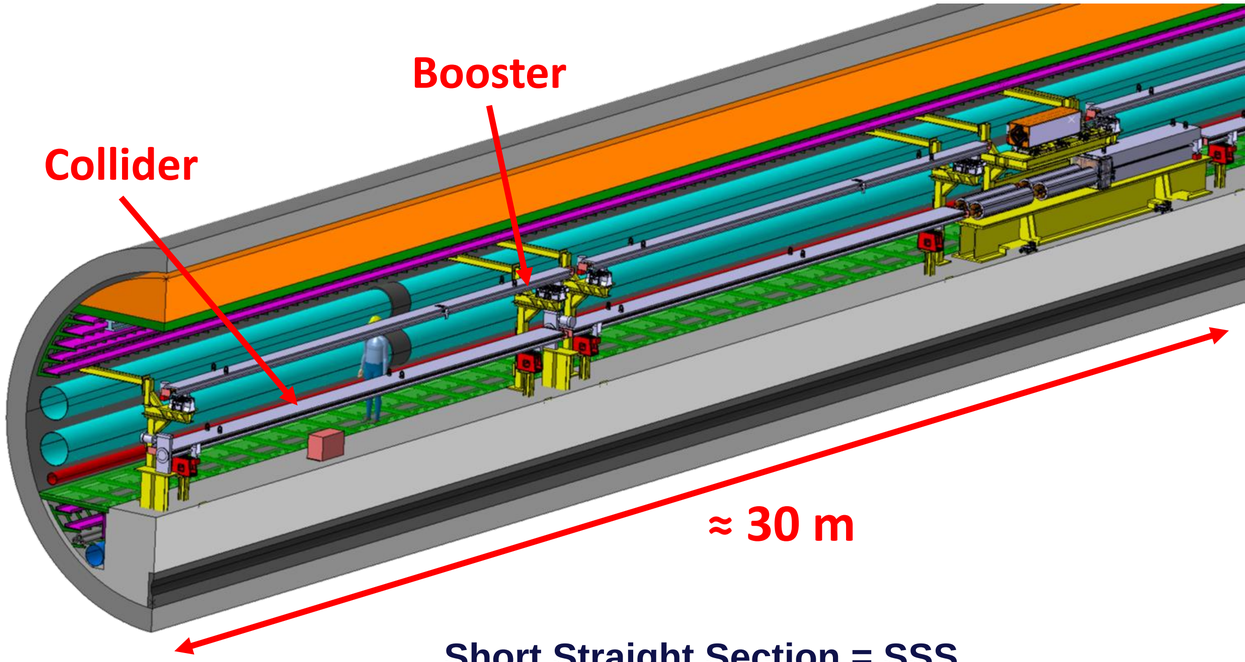
- Cost
- Integration
- Assembly
- Stability inspection
- Security
- Fabrication, machining capabilities for critical components
- Transport
- Installation
- Alignment
- Maintenance
- Safety

→**"Visual" driver** for FCC stakeholders, visitors and collaborating researchers

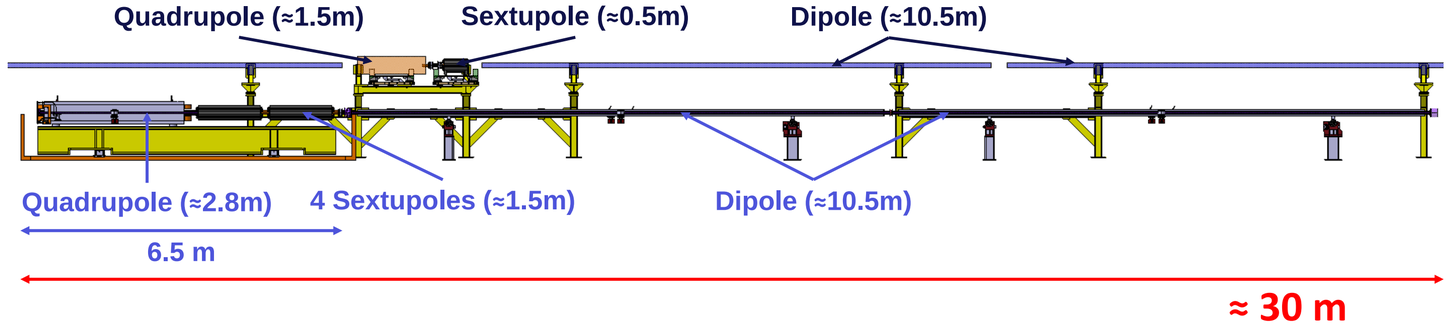


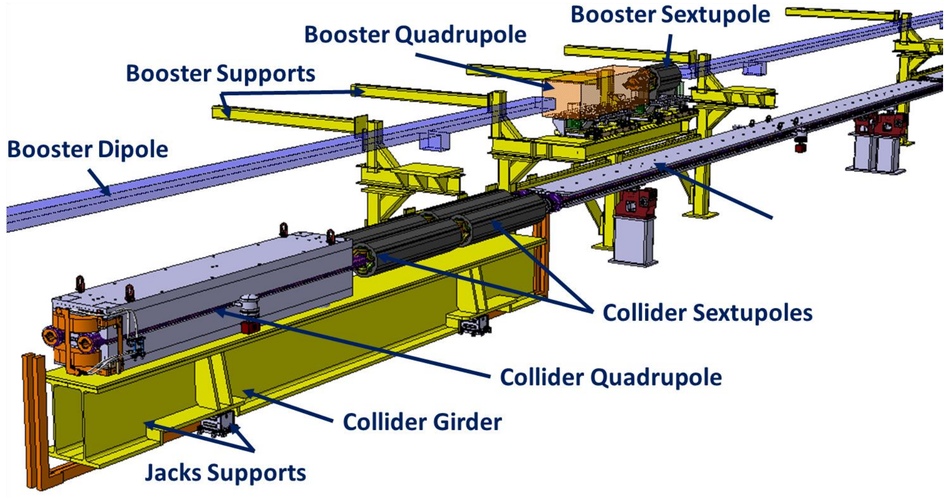
How does an Arc Half-Cell look like?





Short Straight Section = SSS





Courtesy F. Valchkova-Georgieva, M. Timmins, C. Tetrault

AHCM project – previous studies 2022/2023

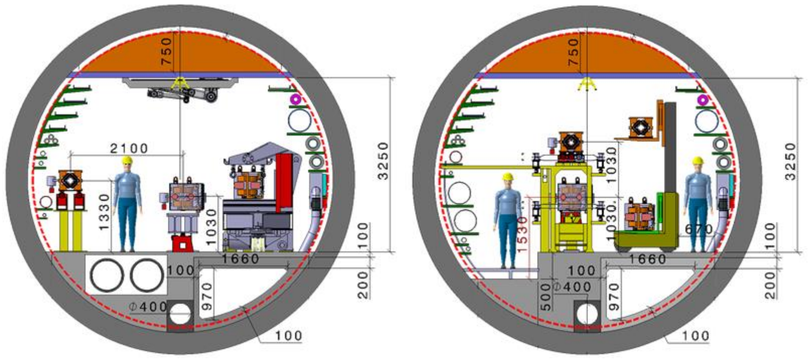
1. **Arc cell configurations**

2. **Booster-Collider placement configurations** (with tunnel reduction from ø6.3 to ø5.5 m!)

3. **Configuration of the SSS and preliminary design of girders, supporting systems, jacks** → cost estimation for the mid-term review!

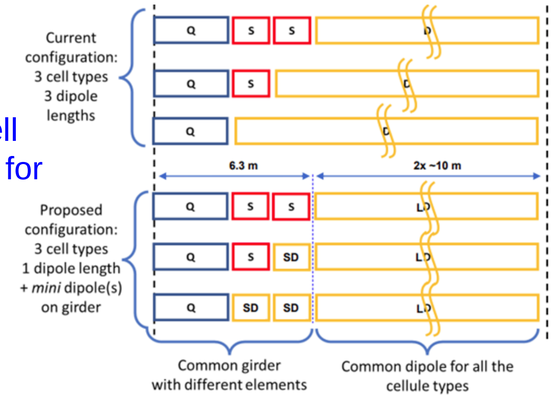
4. **Design study of the magnet / vacuum system interfaces** → leading to inter-beam distance increase from 30 to 35 cm

5. **Documentation in a series of contributions** (Phase I Final Report, Mid-term review report, IPAC paper, JINST special issue)

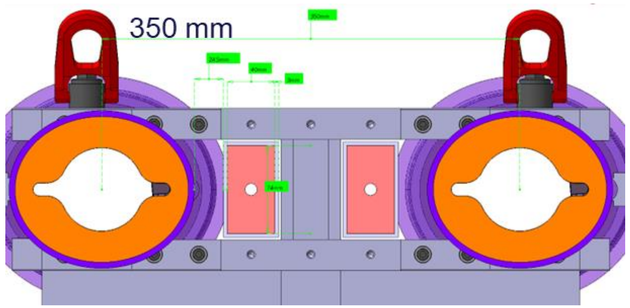


Horizontal vs Vertical booster placement

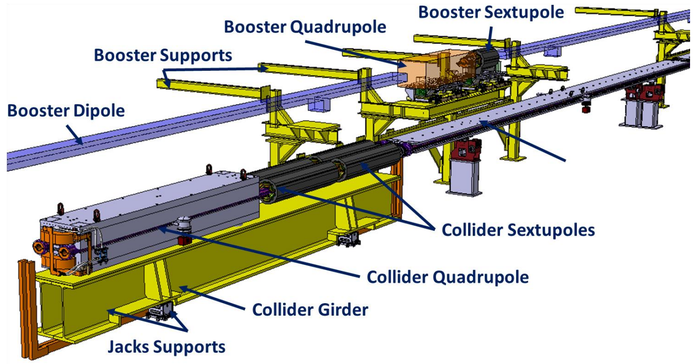
Short half-cell configurations for the collider

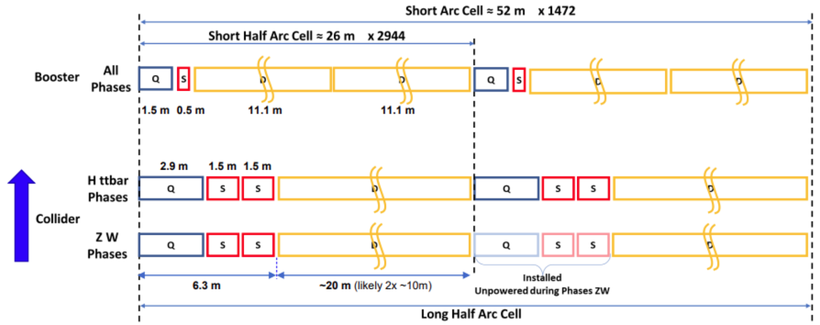


Vacuum system integration in dipoles



SSS configurations, supports design





Arc cells: from Z / W to Zh /$t\bar{t}$ phase

Courtesy F. Valchkova-Georgieva, M. Timmins, C. Tetrault, J. Bauche, C. Garion, L. Baudin

AHCM project – ongoing design studies

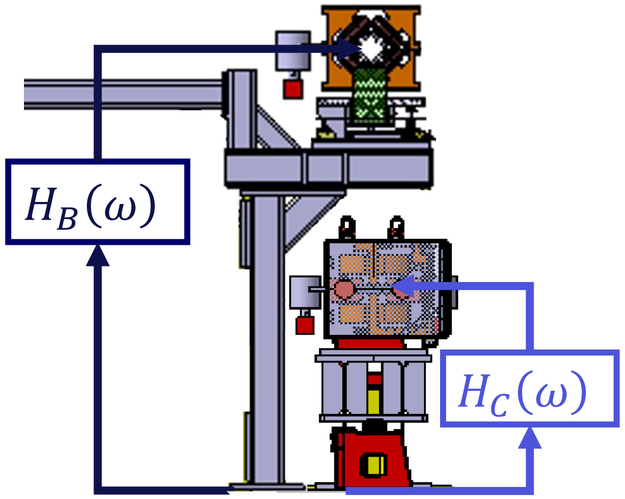
1. Optimization of supporting systems (iterations between design and simulations)

BOOSTER support

→ *Test / compare different:*

- *Geometries,*
- *Fixations,*
- *Etc.*
- *Height,*
- *Shift,*

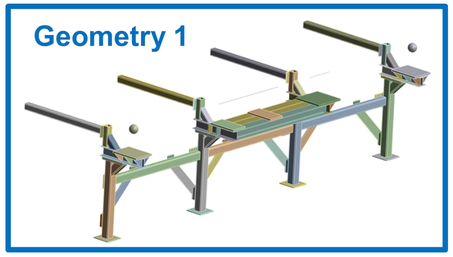
→ **Structural and stability analysis of supports**

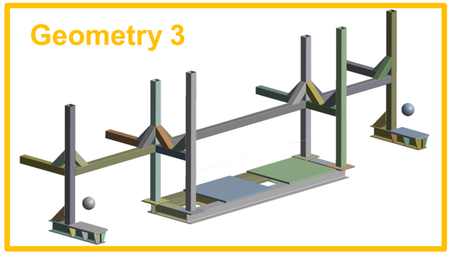


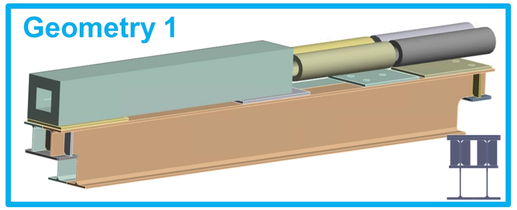
COLLIDER girder

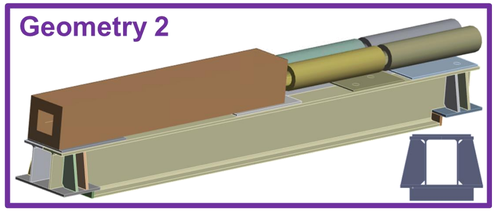
→ *Test / compare different:*

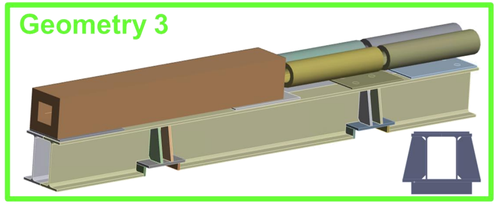
- *Geometries,*
- *Material,*
- *Etc.*
- *Position of jacks,*
- *Number/position of jacks,*

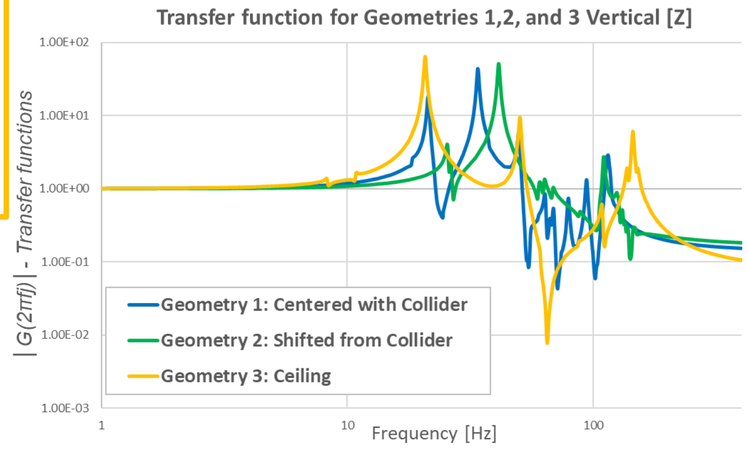


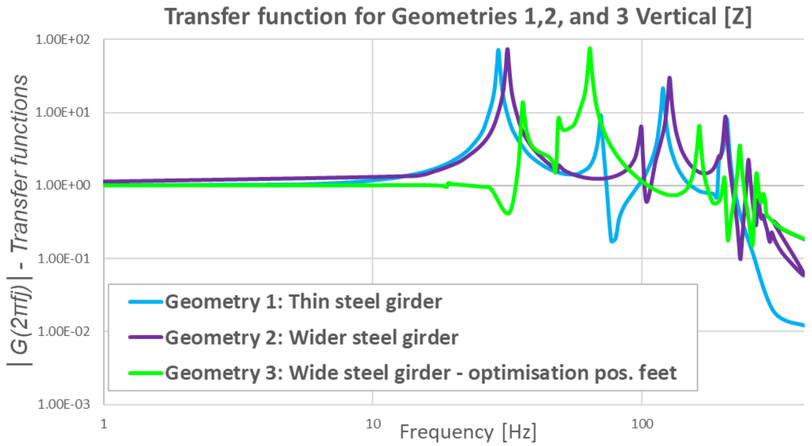












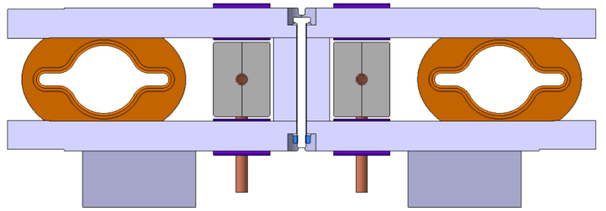
AHCM project – ongoing design studies

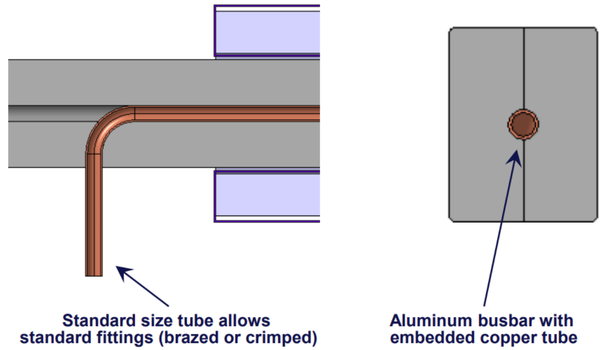
2. **Studies of the interfaces** (magnets-girder, girder-ground, position of supports, …)

3. **Integration of new collider magnets** (quadrupole, sextupoles and dipoles)

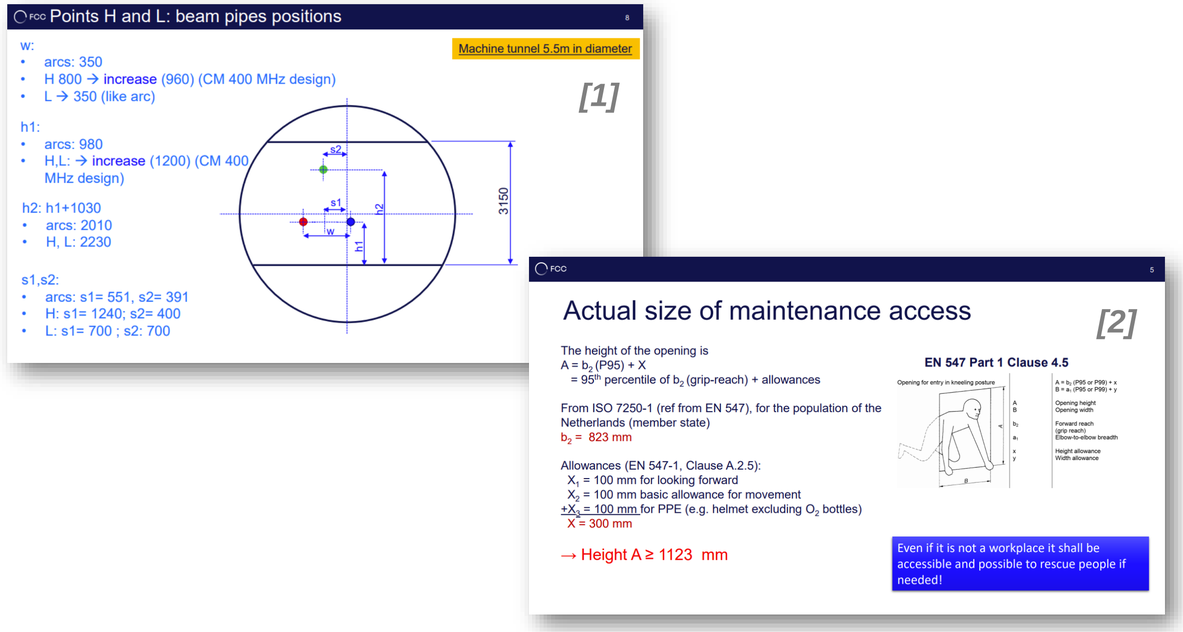
4. **Interconnection studies dipole-dipole** (busbar, water circuit connection scheme, optimization of interconnection length)

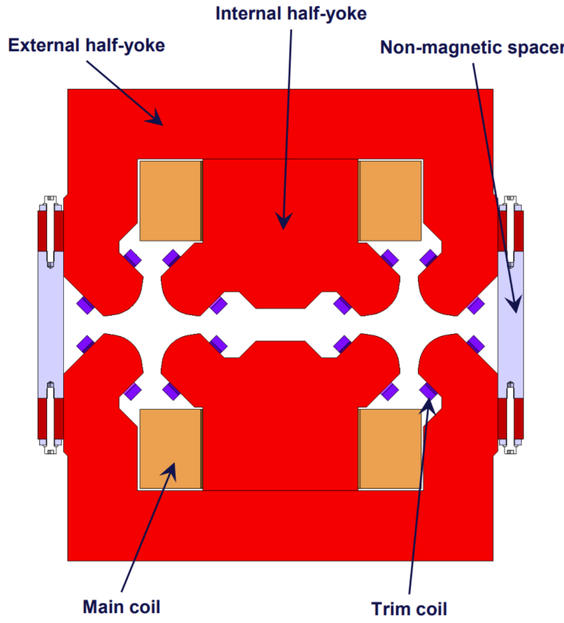
5. **Increase of the beamline height 980 → 1200mm** (following safety recommendations + space needed in RF zones → update the design of the girder and booster support)





Busbar technology





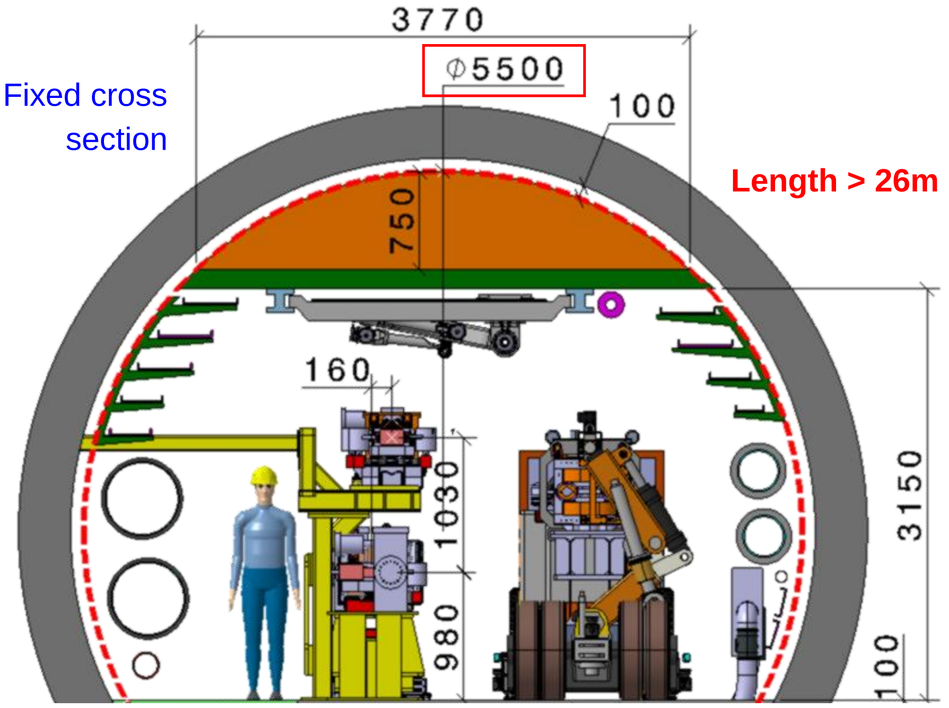
New quadrupole cross-section

Courtesy C. Tetrault, J. Bauche

[1] The FCC-ee SRF System: Preliminary integrations […] – V. Parma, F. Cottenot, N. Favre, M. Timmins

[2] Workplace accessibility – A. Henriques, T. Otto, O. Rios

AHCM project – 1:1 Mock-up



WHEN?

Mid-March: we fixed the arc layout for the mock-up

→ **Q2-Q3 2024:** Mock-up systems design

→ **Q3-Q4 2024:** Elements fabrication

→ **Q1 2025:** Installation of the first version

→ **2025…:** Evolution of the Mock-up

WHERE?

B. **355/358** compatibility evaluated and confirmed – *negotiations ongoing*

WHY?

Short term objective = A mock-up allowing to test the integration of simplified elements within a short timeframe. *("Visual" driver for FCC stakeholders).*

Long term objective = An **evolving** mock-up allowing equipment groups to install and test their equipment.

WHO?

MME-driven with strong collaboration with **ACE** and equipment groups (MSC, VSC, GM, CEM, BI, …)!

1:1 Mock-up core team & structure

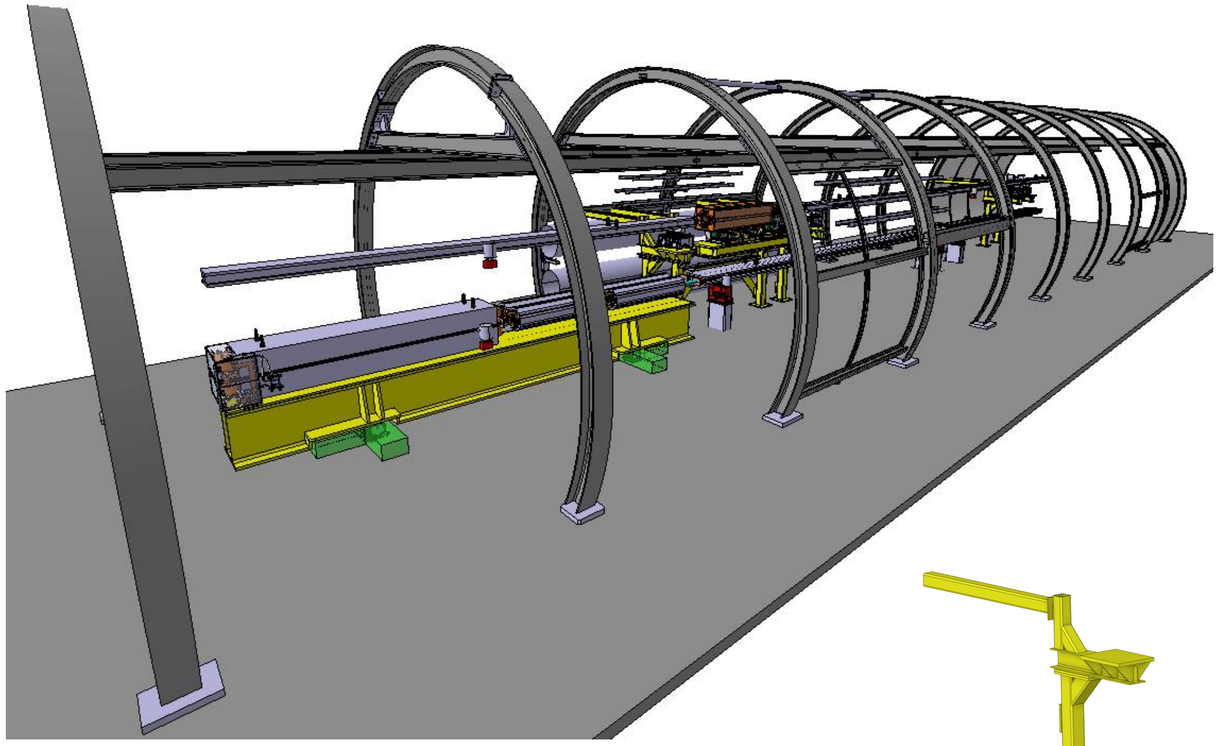
Project Coordination
Federico Carra

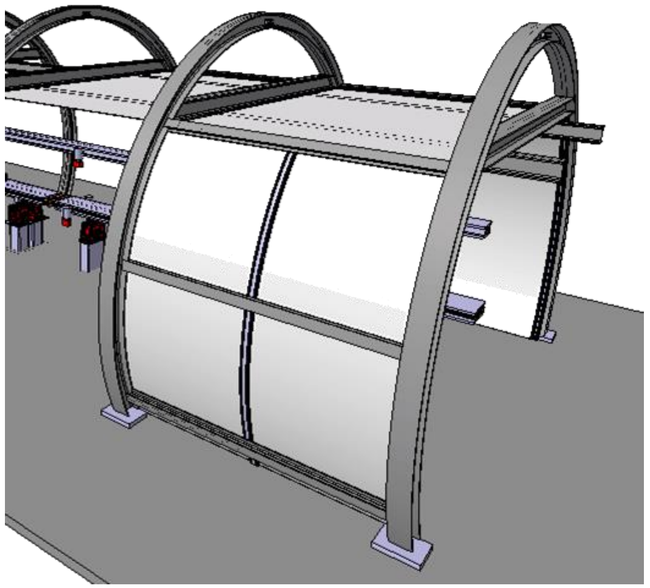
Budget, timeline, link with FCC management

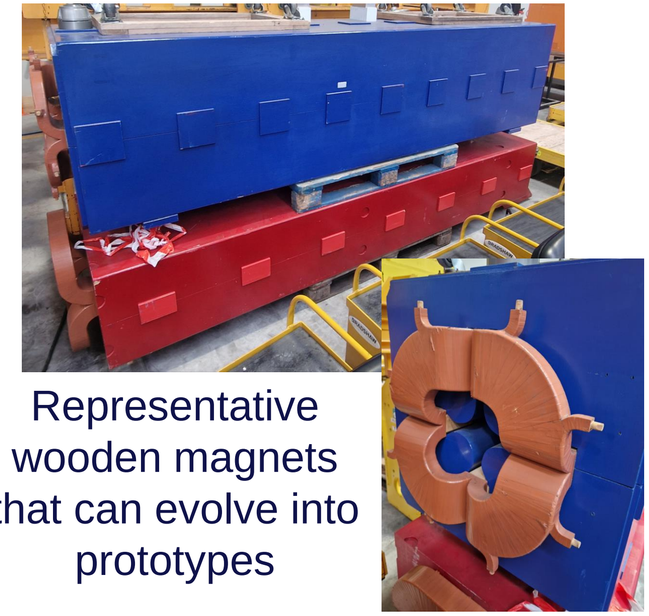
ACE-COS	ACE-INT	MME DO	MME Eng. Unit
Pascal Catherine *(w. J. Bossy)*	Melvyn Rouchouse *(w. J. Coupard)*	Callum Tetrault *(w. M. Timmins)*	Audrey Piccini *(+ TRN)*
Feasibility of components, cost, **fabrication**	Integration & layout, **design** of components	**Link** with FCC-ee arc functional components	Structural **calculations**, meeting organization

What will be installed in the 1:1 Mock-up?

The envelope will consist of arches reinforced by beams and closed by plates/sheets



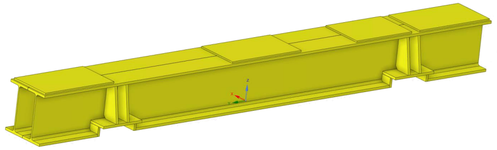




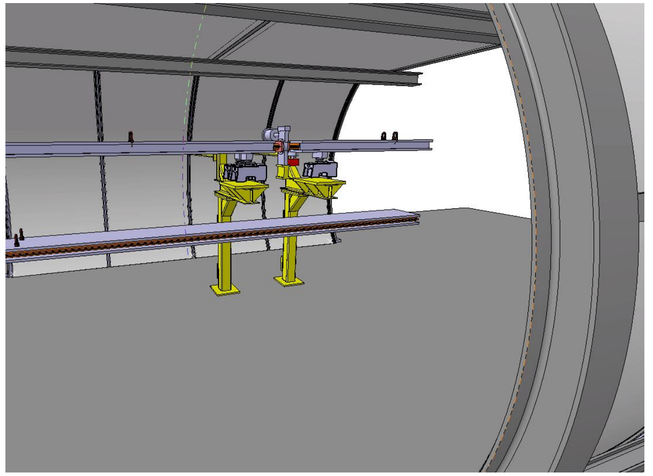
Representative wooden magnets that can evolve into prototypes

(example SPS wooden magnets)

Install real structures for booster and collider supports



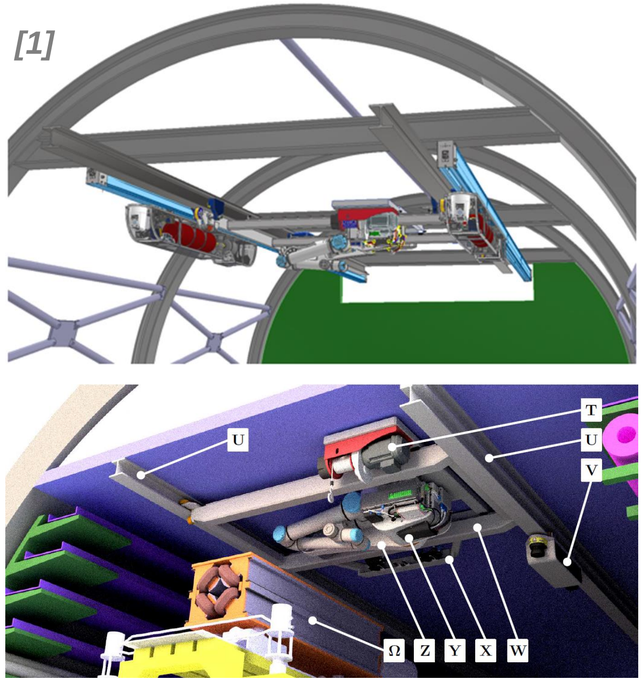
Girder = PAEC collaboration



Courtesy M. Rouchouse

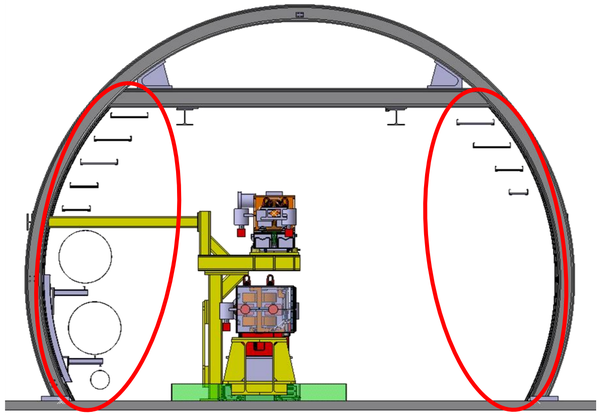
What will be installed in the 1:1 Mock-up?

[1]

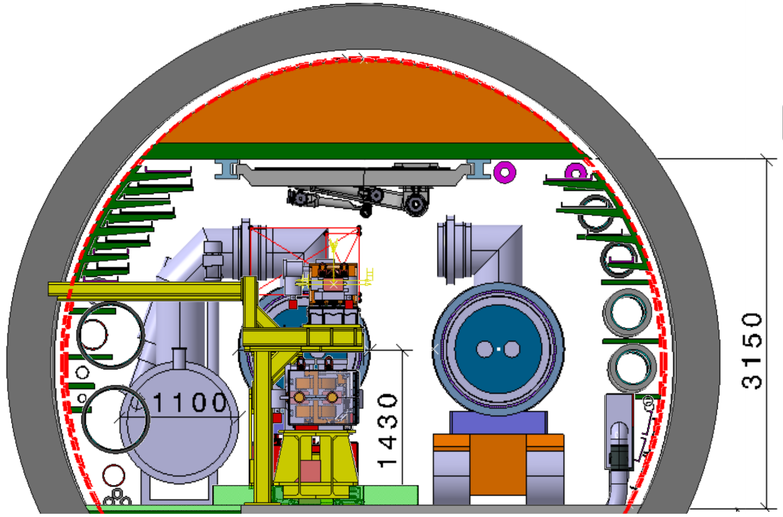


The FCC robot prototype will be installed and will move on two rails (BE/CEM)

Install a fire door to test safety aspects (HSE)



Services like pipes, cable trays will be fixed on the envelope



Use virtual reality to visualise the evolution of FCC-ee high and low energy phase → FCC-hh

Courtesy M. Rouchouse, H. Gamper, F. Valchkova-Georgieva

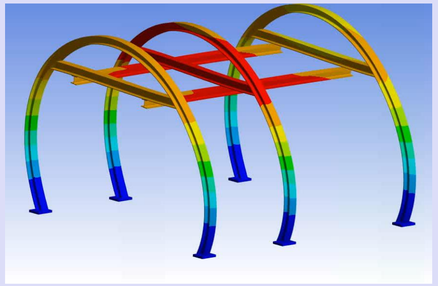
[1] Safety robotics (FCC-Week) – H. Gamper

AHCM project – 1:1 Mock-up ongoing studies

→ **Drawings of the mock-up** (under completion, will be followed by approval)

→ **Concerning the design of the mock-up structure:** numerous discussions in progress and many groups involved

Structural calculations
(envelope, basements, etc.)



Manufacturing feedbacks

Discussion with **EN/HE**:
Compatibility between transport equipment and the structure + building + components to be installed

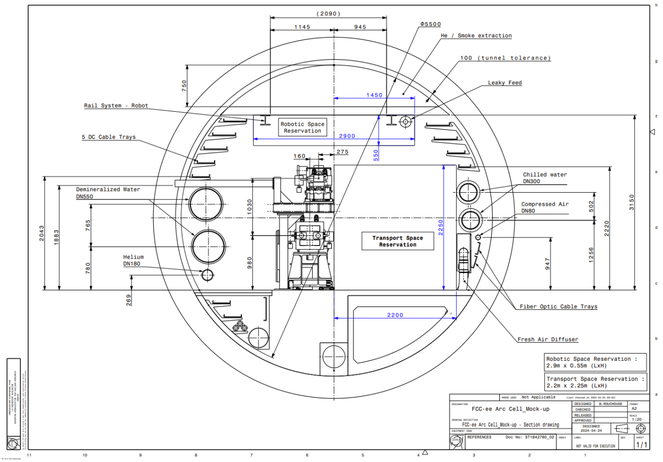
Design and iteration studies for the Mock-up

Cost estimation

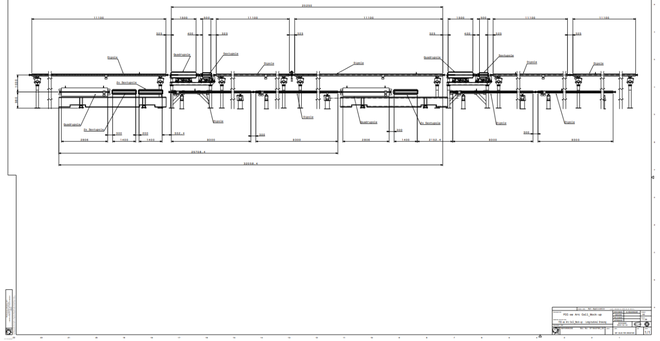
Discussion with **HSE**:
Safety constraints, norms and standards to consider

Discussion with **BE/CEM**:
Structure in line with robot integration

Discussion with **SCE**:
Anchoring of the structure, compatibility with the building



Drawings ongoing



Courtesy M. Rouchouse

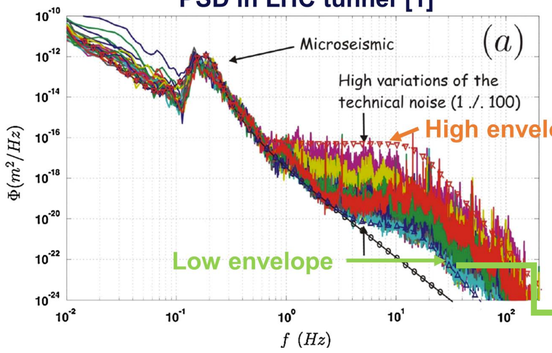
AHCM project – SSS demonstrator

Goal = How do the different elements of the SSS affect stability? *Where to invest design and prototyping efforts!*

→ ***Simulations*** *can predict the accelerator movement generated by random vibrations (e.g. ground motion)*

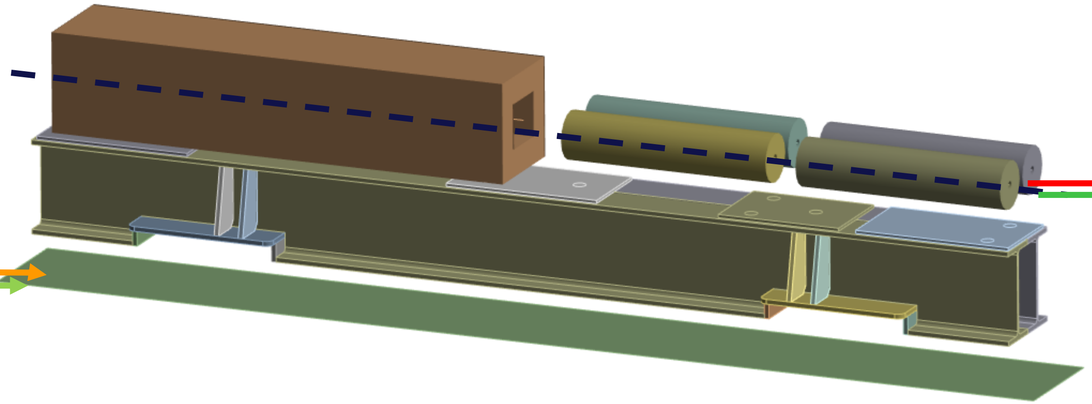
INPUT – Ground

PSD in LHC tunnel [1]

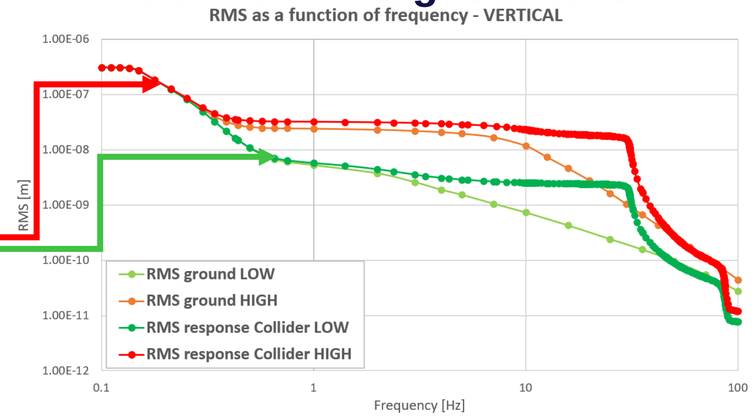


Envelope generated using experimental measurements

Simulations *of* ***6.5m-long*** *collider SSS*

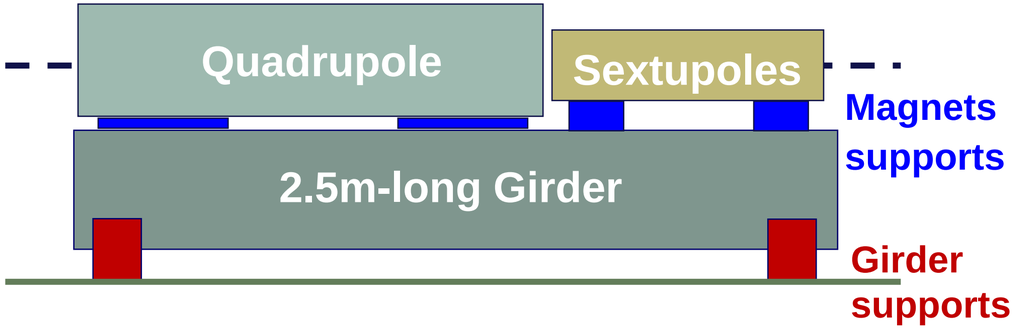


OUTPUT – Magnetic axis



Envelope of results obtained by simulations

Experimental *demonstrator of* ***2.5m-long*** *collider SSS*



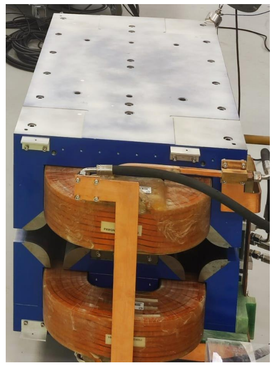
→ ***Experimental benchmarking*** *is needed to tune simulations (uncertainties / assumptions!)*

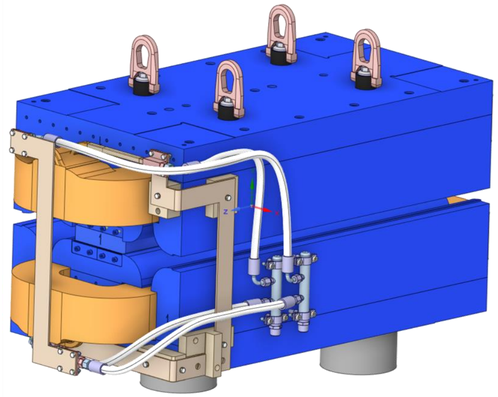
→ *Then, extrapolate to 6.5m*

→ ***Specifications:*** *discussion with experts J. Wenninger, G. Roy, F. Zimmermann etc. – Update at the end of 2024*

[1] Seismic response of linear accelerator - C. Collette, K. Artoos, M. Guinchard, and C. Hauviller

AHCM project – SSS demonstrator





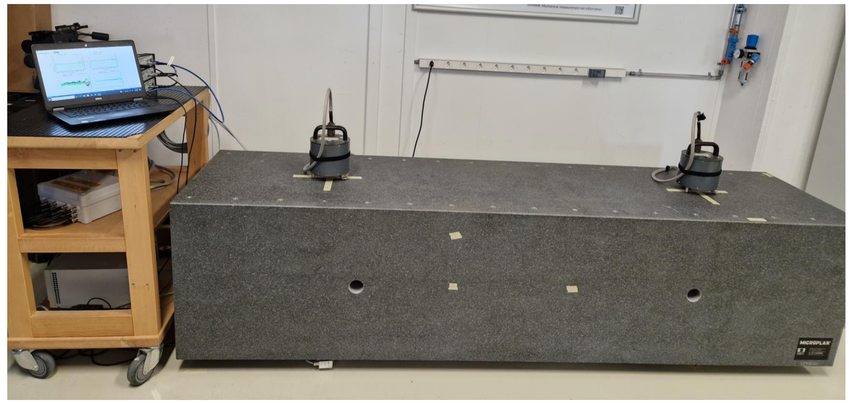
Step 1: Characterisation of a Quadrupole Prototype

1m-long Quadrupole Prototype based on design parameters of CDR (1,5 ton)

EXP: Experimental modal analysis

SIMU: Compare with modal simulations

One configuration of the **2.5m** collider SSS demonstrator

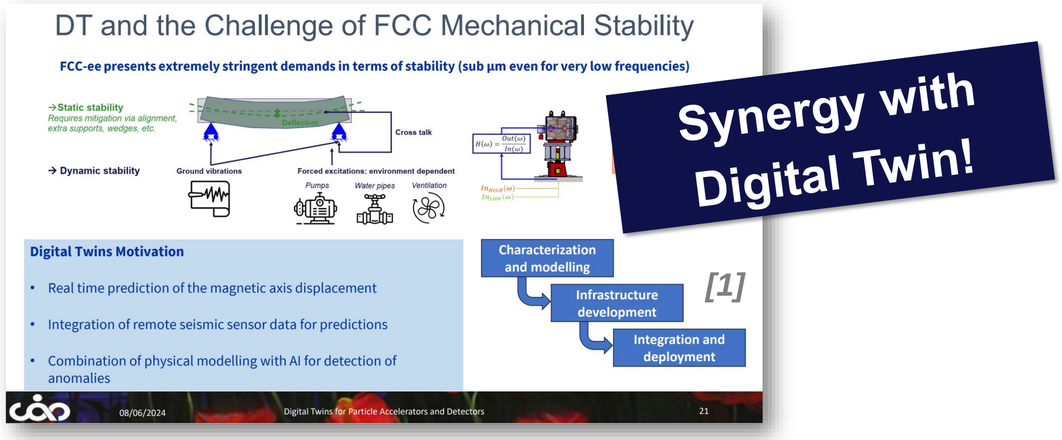


Step 2: Characterisation step by step of a simplified supporting structure

2.5m-long girder + 1m-long Quadrupole + Load cells and/or Jacks + Dummy sextupoles etc.

EXP: Experimental modal analysis + Transfer function with the ground motion

SIMU: Compare with modal and random vibration simulations



Synergy with Digital Twin!

Steps example:

Step 1

Quad.

Step 2a

2.5m-long Girder

3/4 supports

Step 2b

Quad.

2.5m-long Girder

Step 2c

Sext. Quad.

2.5m-long Girder

3/4 supports

Step 2d

Sext. Quad.

New 2.5m Girder

3/4 supports

ETC.

[1] Digital Twins for Particle Accelerators and Detectors – O. Sacristan

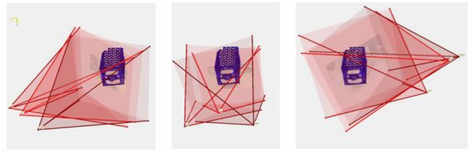
AHCM project – SSS demonstrator

1st step: characterization of the prototype quadrupole

3. Results of the experimental campaign – Modal analysis

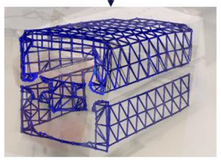
Experimental Modal Analysis / FCC quadrupole

M. Guinchard, D. Thuliez



Shaker excitation :
White noise
Accelerometer : 100 (m/s²)/V

3 Sets of measurements + stitching process



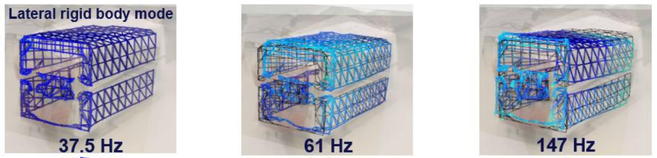
Geometry scan performed with 747 scan points

3. Results: experimental vs simulations

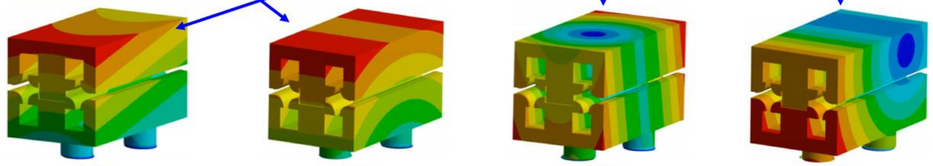
Comparison of the rigid body mode

→ *Tests with 10 mm elastomer under each foot (Chloroprene/Styrene-butadiene)*

Experimental results:



Simulation results:

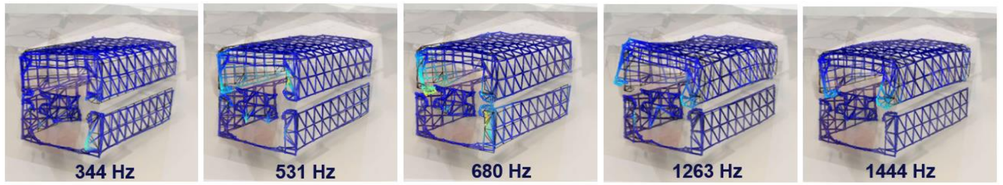


DONE!

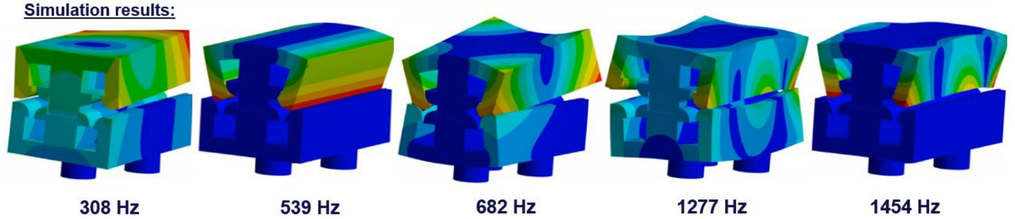
3. Results: experimental vs simulations

Comparison of specific mode shapes results

Experimental results:



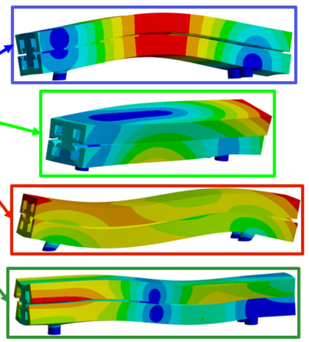
Simulation results:



3. Results: extrapolation of simulations

Mode shape results for the 2.9 m long quadrupole

SIMULATION 1 m long		SIMULATION 2.9 m long	
Modes	Frequency (Hz)	Modes	Frequency (Hz)
S1	187	S1	88
S2	308	S2	181
S3	363	S3	260
S4	460	S4	269
S5	539	S5	290
S6	597	S6	362
S7	614	S7	430
S8	652	S8	469
S9	682	S9	476
S10	780	S10	482
S11	810	S11	529
S12	867	S12	547
S13	973	S13	559
S14	1037	S14	580
S15	1151	S15	594
S16	1277	S16	608
S17	1314	S17	628
S18	1332	S18	642
S19	1349	S19	659
S20	1418	S20	669
S21	1454	S21	684



→ The mode shapes have relatively high frequencies
→ The rigid body modes are of lower frequency = important to work on magnet fixation

Courtesy M. Guinchard, D. Thuliez

AHCM project – External collaborations

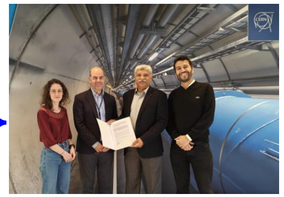
- **LAPP Annecy (France)**: working at the definition of the impact of mechanical vibrations on the beam stability (analytically and with MAD-X)

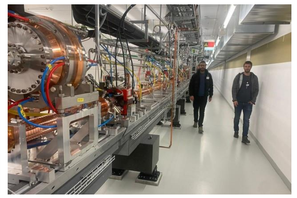
→ *Dedicated addendum signed in 2023, **A. Faus-Golfe***

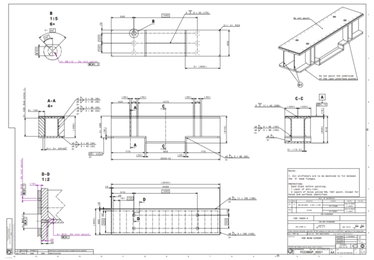
- **PSI (Switzerland)**: collaboration with the team led by J. Wickstroem (& M. Wurm) → feedback and exchanges on design, fabrication and costs of girders, supporting systems *(interesting visit in January at SwissFEL, SLS)*

- **PAEC (Pakistan)**: definition of hardware to be produced at PAEC, contact is K. M. Hassan, very good proposal received (short & long girders + dummy sextupoles)

*Signature of addenda to MoU done! Managed by **E. Tsesmelis***







- **Chulalong University (Thailand)**: Bachelor thesis ongoing, P. Lersnimitthum working at vibrational crosstalk between booster and collider

- **University La Sapienza (Italy)**: cooperation on the digitalization of SSS, towards the definition of a Digital Twins

Informal collaborations or in the scope of already existing frameworks

- ***Chalmers (Sweden)**: exploratory discussions launched by A. Unnervik, on possible studies around jacks optimizations for series productions*

→ *Ongoing discussions*

Conclusions

→ One of the important goals of the **Feasibility Study** is the **Mock-up** of the arc half-cell for FCC-ee, and it is going at full speed! (start installation Q1 2025)

→ After preparatory work to find the best solution for the arc configuration, we are now moving to the **design and construction of the mock-up and demonstrators**

- The **1:1 Mock-up** is currently being developed, with contributions from many groups.
- The **optimisation design studies** for the supporting structure account for a significant part of our work.
- These optimisation studies are completed by the **experimental campaign** allowing us to identify where to invest our efforts.

→ We can also rely on our many collaborations!

Thank you for your attention!

And thanks to AHCM Working group: C. Tetrault, M. Timmins, M. Guinchard, D. Thuliez, O. Sacristan, M. Rouchouse, P. Catherine, J. Coupard, J. Bossy, P. Lersnimitthum

And thanks to all the contributors and for sure forgetting someone: H. Gamper, J. Bauche, C. J. Eriksson, L. V. Freeden, H. De Maynard, X. Genillon, S. Pelletier, J. Wenninger, F. Valchkova-Georgieva, G. Roy, F. Zimmermann, T. Raubenheimer, S. Di Giovannantonio, J.P Burnet, P. Brunero, E. Tsesmelis, L. Baudin, O. Rios