

# FCC-ee Arc Half-Cell Mock-up

F. Carra (CERN)

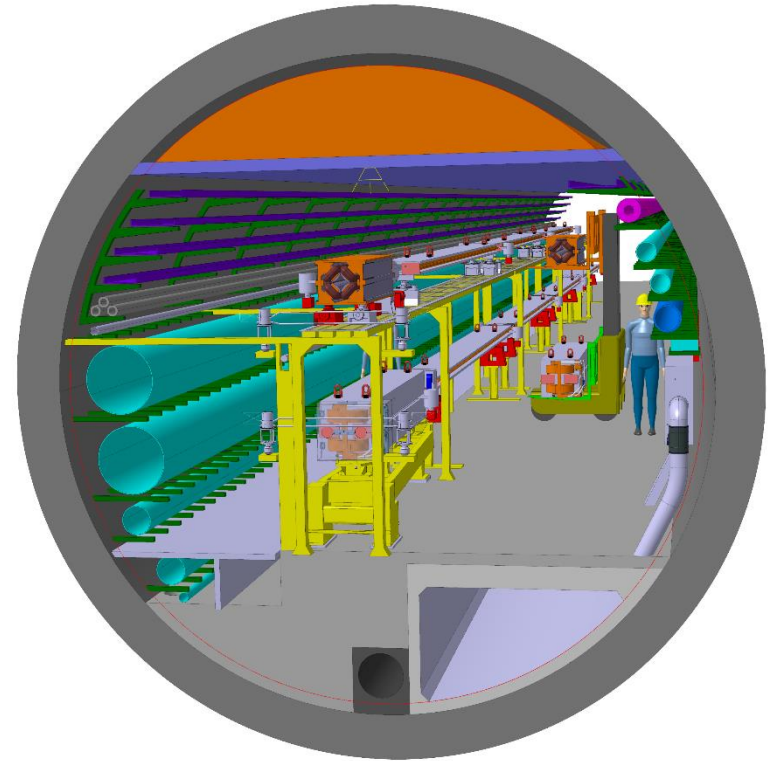
*with contributions from many colleagues, including: J. Bauche, S. Atieh, L. Baudin, M. Di Castro, C. Eriksson, C. Garion, M. Garlasché, R. Losito, D. Perini, T. Raubenheimer, D. Smakulska, M. Timmins, F. Valtchkova-Georgieva, F. Zimmermann.*

# Layout

- Aim of the project
- Timeline
- Arc cell configuration(s)
- Needed studies and challenges
- Novel concepts
- Conclusions

# Aim of the project

- **Arc half-cell**: most recurrent assembly of mechanical hardware in the accelerator (~1500 similar FODO cells in the FCC-ee)
- **Mock-up** → Functional prototype(s) → Pre-series → Series
- Building a mock-up allows optimizing and testing **fabrication, integration, installation, assembly, transport, maintenance**
- Working with demonstrators of the different equipment, and/or structures with equivalent volumes, weights, stiffness



*Arc perspective view, F. Valchkova-Georgieva*

# Status

- **Arc configuration:** CDR (2019) + updates during FCC feasibility study
- **Conceptual design to fabrication**
  1. Confirmation/update of the functional specifications
  2. Arc integration study
  3. Engineering design of systems and interfaces
- For **collider AND booster**

Table 2: RMS magnet misalignment values. (The definition of the misalignment parameters are defined in Fig. 1.

Type	$\Delta X$ ( $\mu\text{m}$ )	$\Delta Y$ ( $\mu\text{m}$ )	$\Delta\text{PSI}$ ( $\mu\text{rad}$ )	$\Delta S$ ( $\mu\text{m}$ )
Arc quadrupole*	50	50	<del>400</del>	150
Arc sextupoles*	50	50	400 <sup>300</sup>	150
Dipoles	1000	1000	<del>400</del>	1000
Girders	150	150	-	1000
IR quadrupole	100	100	250	250
IR sextupoles	100	100	250	250
BPM**	40	40	100	-

\* misalignments relative to girder placement

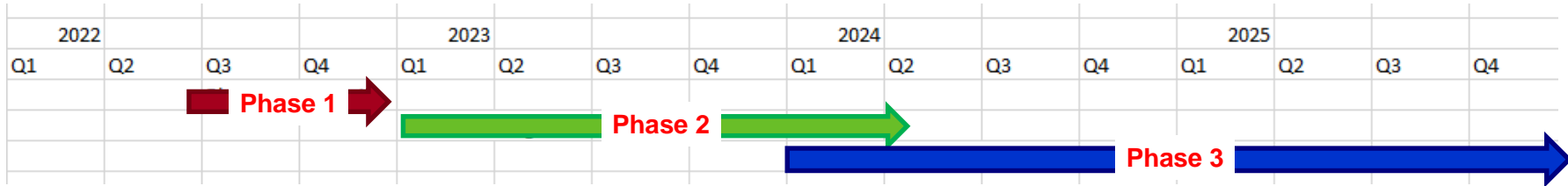
\*\* misalignments relative to quadruple placement

*T. Charles et al., "Update on the Low Emittance Tuning Of the e+/e- Future Circular Collider," IPAC'21*

*T. Charles, "Optics correction studies", FCC week, 31<sup>st</sup> May 2022.*

# Timeline

*T. Raubenheimer*

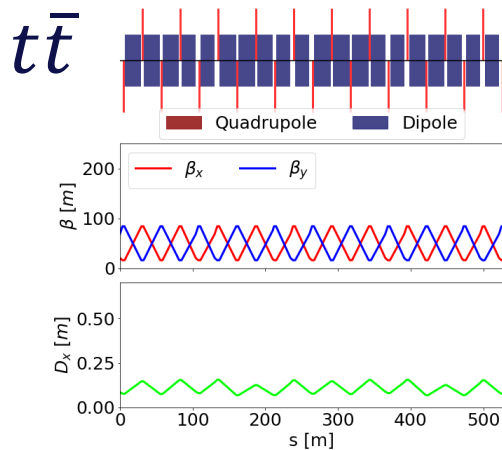
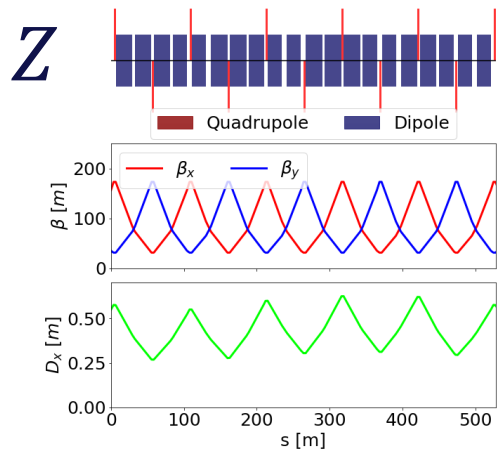


- **Phase 1: Concept development** → functional spec + integration studies. Develop 3D model for ‘representative’ arc half-cell.
- **Phase 2: Engineering design** of half-cell mock-up systems and delivery of 2D functional and fabrication drawings.
- **Phase 3: Fabrication** of half-cell mock-up with tunnel boundary with representative components and systems (non-operational).

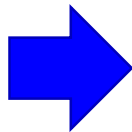
# Arc cell configuration(s)

*T. Raubenheimer, "Accelerator Overview", FCC week, 30<sup>th</sup> May 2022.*

*M. Hofer, "Baseline optics and layout of the FCC-ee collider ring", FCC week, 31<sup>st</sup> May 2022.*



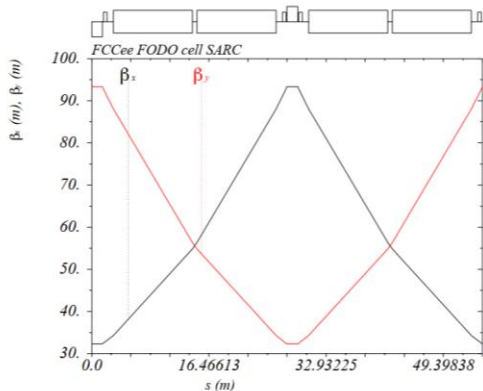
- New configuration for arc optics with long  $\sim 100$  m FODO cells at Z & W and short  $\sim 50$  m cells at Zh and  $t\bar{t}$  (more details in Tor's [talk](#) earlier this week)
- Total arc length  $9.6 \times 8 \sim 77$  km



- FCC arcs are constructed from roughly 750 long cells or 1500 short cells
- Integration study (Phase I): to give also inputs on how to best **evolve from long cell (low energy) to short cell**

# Arc cell configuration(s)

- **Arc half-cell**
  - 1 **Quadrupole**
  - 0, 1, 2 **Sextupoles**
  - Up to ~24 m **Dipoles** (segmented, variable length)



Booster

D: dipole, Q: quadrupole, S: sextupole

Spacing between magnets (m)			
D-Q	0.3	(A)	
Q-S	0.3	(B)	
S-S	0.1		
S-D	0.3	(C)	

Case	Arrange	Length of D
(A)	Q-D	24.432
(B)	Q-S-D	22.732
(C)	Q-S-S-D	21.232

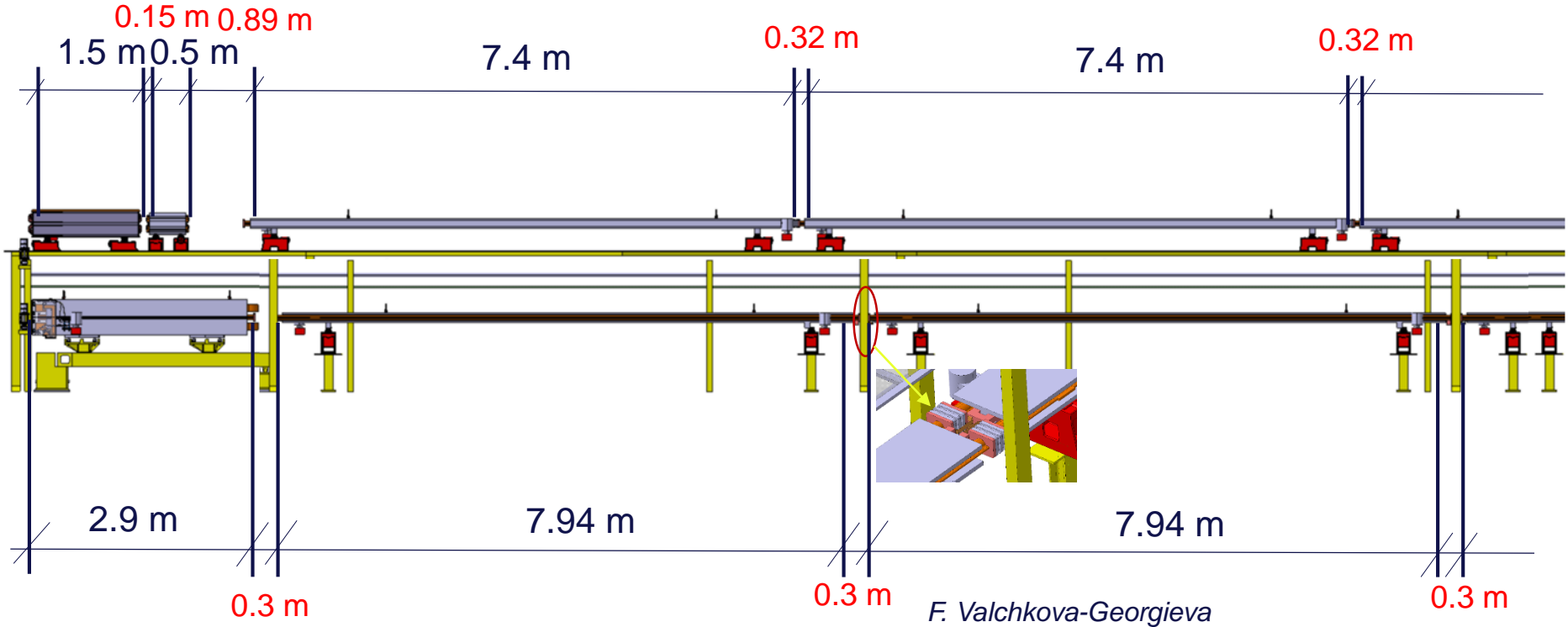
Length (m)		
Q	2.9	twin aperture
S	1.4	single aperture

F. Valchkova-Georgieva

# Arc cell configuration(s)

**“Case A”**: quadrupole followed by 24.432 m dipole(s)

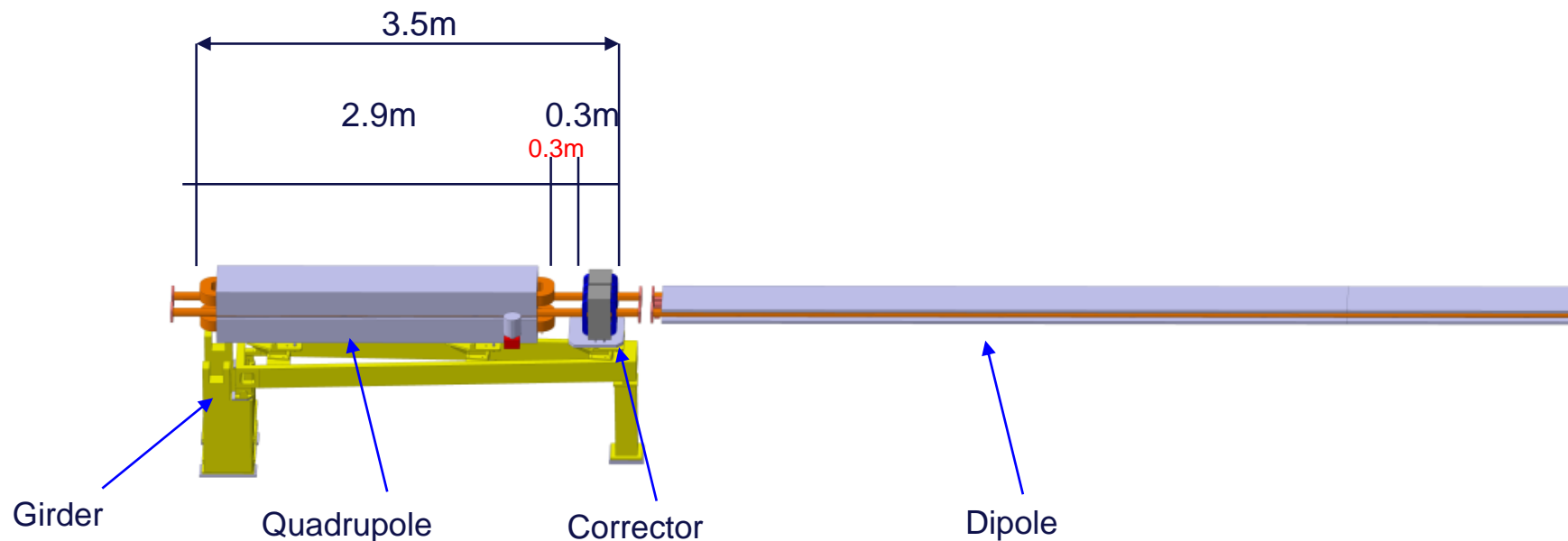
Side view





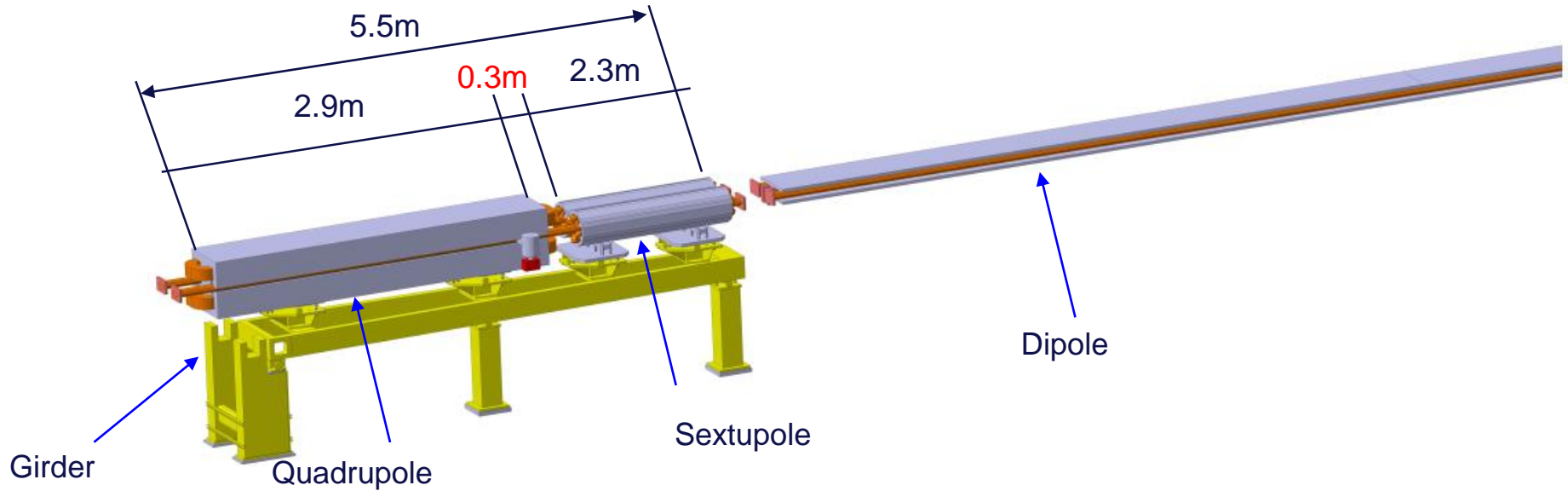
# Arc cell configuration(s)

**“Case A”: 1 quadrupole followed by dipole(s)**



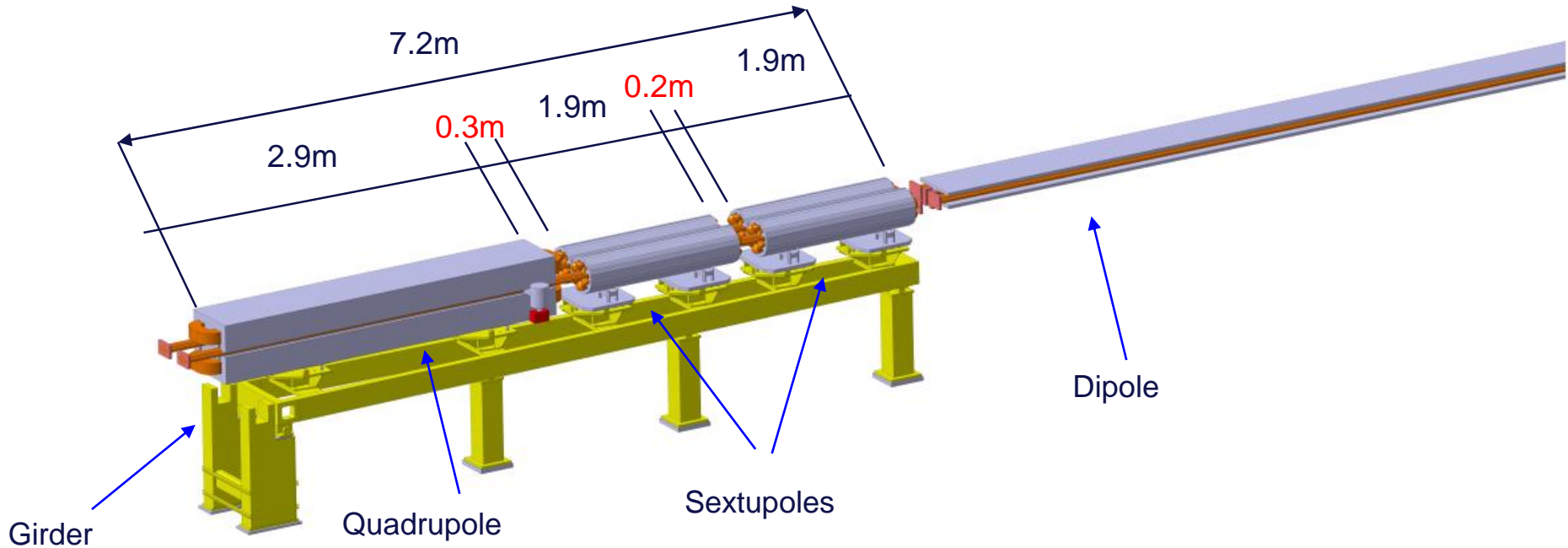
# Arc cell configuration(s)

**“Case B”: 1 quadrupole + 1 sextupole, followed by dipole(s)**



# Arc cell configuration(s)

**“Case C”: 1 quadrupole + 2 sextupoles, followed by dipole(s)**



# Arc Half-Cell Mock-up Project (Phase I)

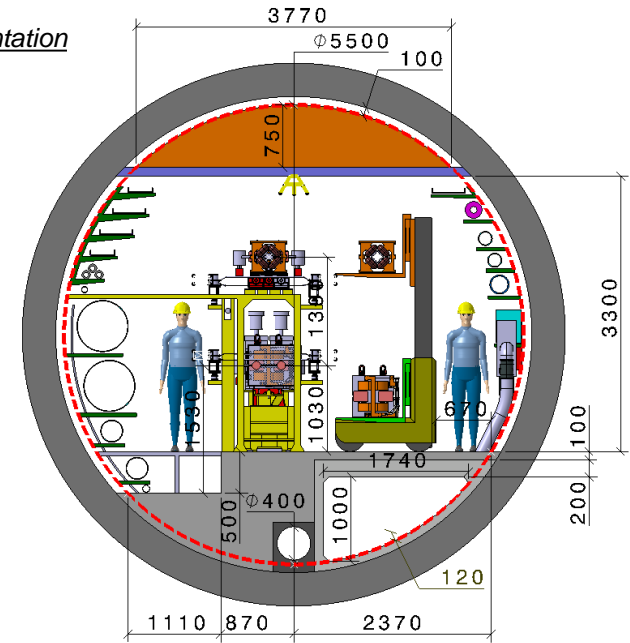
## ▪ Mandate\*

- *Develop an optimal integrated solution for the mechanical layout of an Arc Half-Cell considering machine performance, installation, operation, and maintenance, as well as necessary technical infrastructure in the tunnel.*
- *Identify the components of a representative Arc Half-Cell that will verify the key challenges.*

## ▪ Main deliverables

- 3D model + 2D cross-section drawings of arc region
- Compact report explaining main choices
- To be presented at FCCIS meeting in December '22

\* Extract from T. Raubenheimer's presentation at the Arc Half-Cell Mock-up kickoff



F. Valchkova-Georgieva

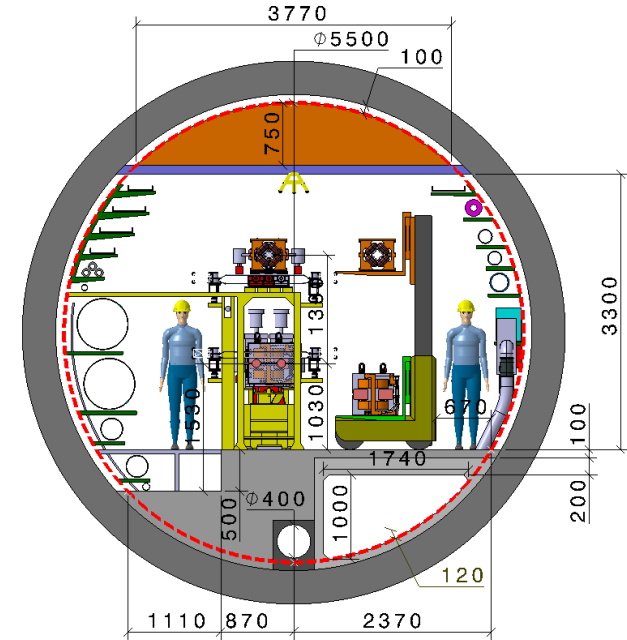
Collider Center



# Needed studies and challenges (Phase I)

## ▪ Needed studies & challenges\*

- Horizontal separation of the e<sup>+</sup> and e<sup>-</sup> rings in the arcs
- Vertical placement / separation between collider and booster (*and: is vertical superposition the only solution?*)

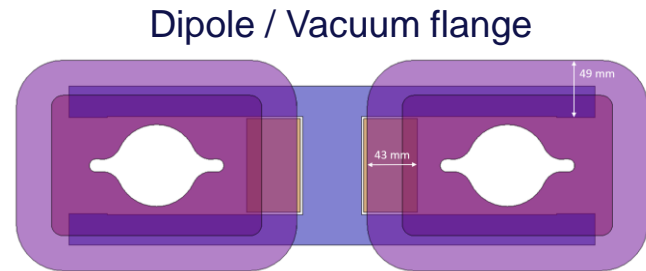


\* More detailed list & Project structure in T. Raubenheimer's [presentation](#) at the Arc Half-Cell Mock-up kickoff

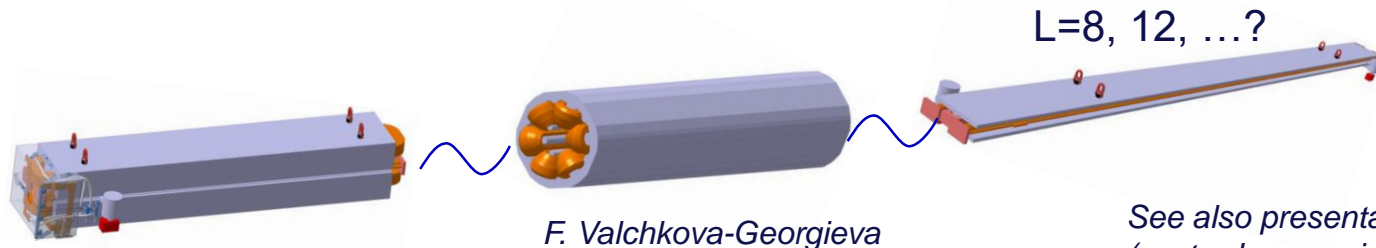
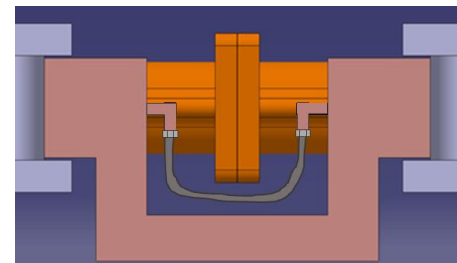
# Needed studies and challenges (Phase I)

## ▪ Needed studies & challenges\*

- Horizontal separation of the e<sup>+</sup> and e<sup>-</sup> rings in the arcs
- Vertical placement / separation between collider and booster (*and: is vertical superposition the only solution?*)
- Define preferred dipole length (*and: continuity or separation between dipoles/busbars?*)
- Design interfaces between magnet and vacuum systems



D-D interface



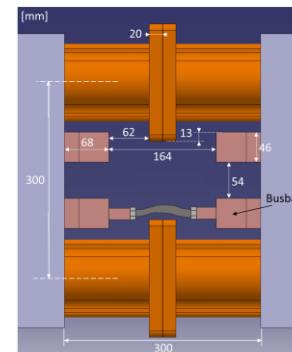
See also presentations from J. Bauche, C. Garion (yesterday morning, Technology R&D session)

# Needed studies and challenges (Phase I)

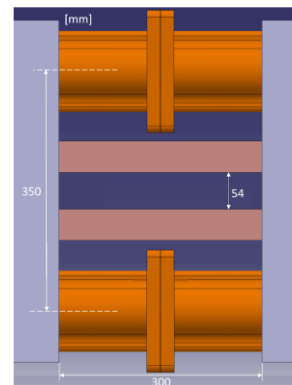
J. Bauche, C. Eriksson

## ▪ Needed studies & challenges\*

- Horizontal separation of the e+ and e- rings in the arcs
- Vertical placement / separation between collider and booster (*and: is vertical superposition the only solution?*)
- Define preferred dipole length (*and: continuity or separation between dipoles/busbars?*)
- Design interfaces between magnet and vacuum systems (*and: integration of correctors, beam instrumentation, ...*)
- Optimize the power & cooling connections for the magnets, vacuum, and beam diagnostics
- Develop supporting system in line with installation and alignment procedures (*w. girder*)
- **And... booster elements!!!**



300 mm beam separation



350 mm beam separation

# Design standards

- Quality standards for the design of components must be used at the earliest stage
- EN-MME quality manual available (EDMS 1724368)
- Consider use of advanced materials (e.g. polymer concrete girder)
- To be linked/integrated with guidelines for robot-friendly design (from Remote maintenance code of practice\*)

\*see M. Di Castro, "Code of practice for robotic-friendly design", 2nd Coordination of FCC Technology R&D programme meeting.

D. Perini

EDMS No	REV.	VALIDITY
1724368	1.0	RELEASED
REFERENCE		
CRN-QA-1724368 rev. 1		

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MANUEL

**MANUEL QUALITÉ DU BUREAU D'ÉTUDES EN-MME**

Ce document définit les règles d'élaboration et les meilleures pratiques de travail et d'organisation du bureau d'études au sein du pôle EN-MME.

Cette documente également pour objectif de faciliter les différents utilisateurs et collaborateurs impliqués dans les projets du bureau d'études.

La structure de ce document est basée sur la norme ISO 9001 : 2008.

EDMS No	REV.	VALIDITY
1053973	3.3	APPROVED
REFERENCE		
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INSTRUCTION QUALITÉ / QUALITY INSTRUCTION

**RÈGLES PRATIQUES D'EXÉCUTION ET DE CONTRÔLE DES DESSINS**

**PRACTICAL RULES FOR THE PREPARATION AND VERIFICATION OF DRAWINGS**

Ce document, rédigé en français, définit les directives pour la réalisation, la vérification et la validation des dessins au CERN.

This document, written in French, provides guidance for the preparation, verification and validation of drawings at CERN.

EDMS No	REV.	VALIDITY
943040	6	APPROVED
REFERENCE		
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CATIA METHODOLOGY

**Usage instructions of CATIA at CERN**

ABSTRACT: This document summarizes the instructions and procedures intended for the CERN design offices, for their subcontractors as well as for collaborators in particular. The objective is to standardize the use of the design tool - CATIA - for the accelerators and the experiences at CERN.

RÉSUMÉ: Ce document recense des consignes et procédures destinées aux bureaux d'études du CERN, à leurs sous-traitants ainsi qu'aux différents collaborateurs. L'objectif étant d'harmoniser l'utilisation de l'outil de conception CATIA pour les accélérateurs et expériences du CERN. Le version française est disponible dans le même manuel EDMS.

EDMS No	REV.	VALIDITY
1355517	1.1	DRAFT
REFERENCE		
CRN-QA-PR-007 rev. 1.1		

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Memorandum

**EN-MME Engineering Calculations: Data Storage Procedure**



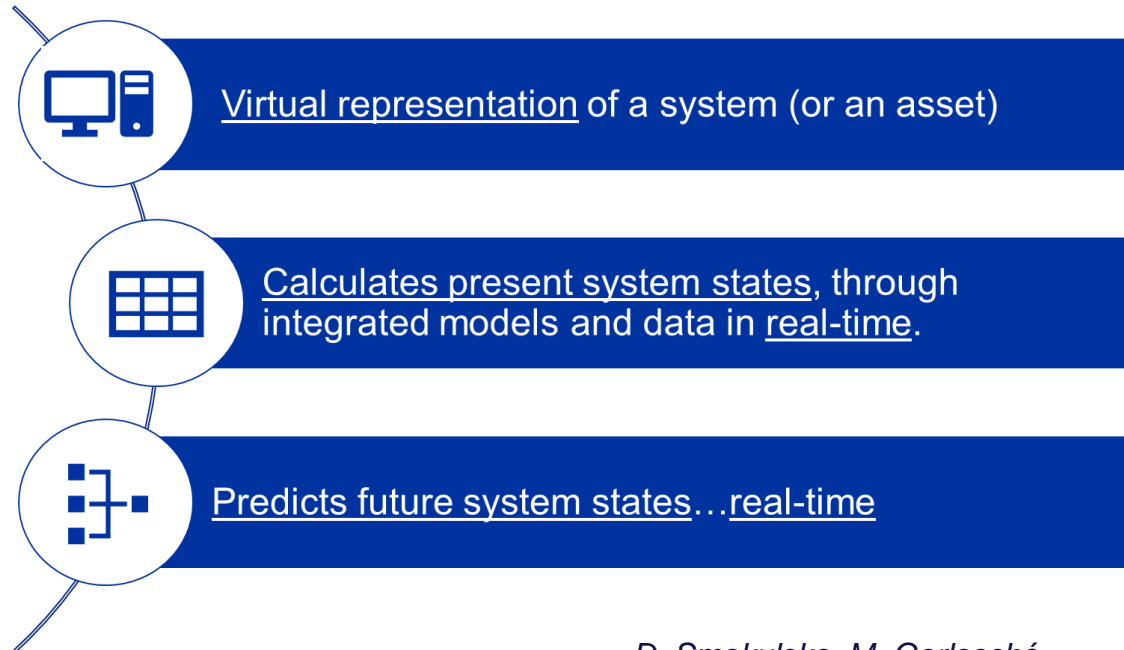
Easier remote or hands-on manipulation than chain-type connection

M. Di Castro



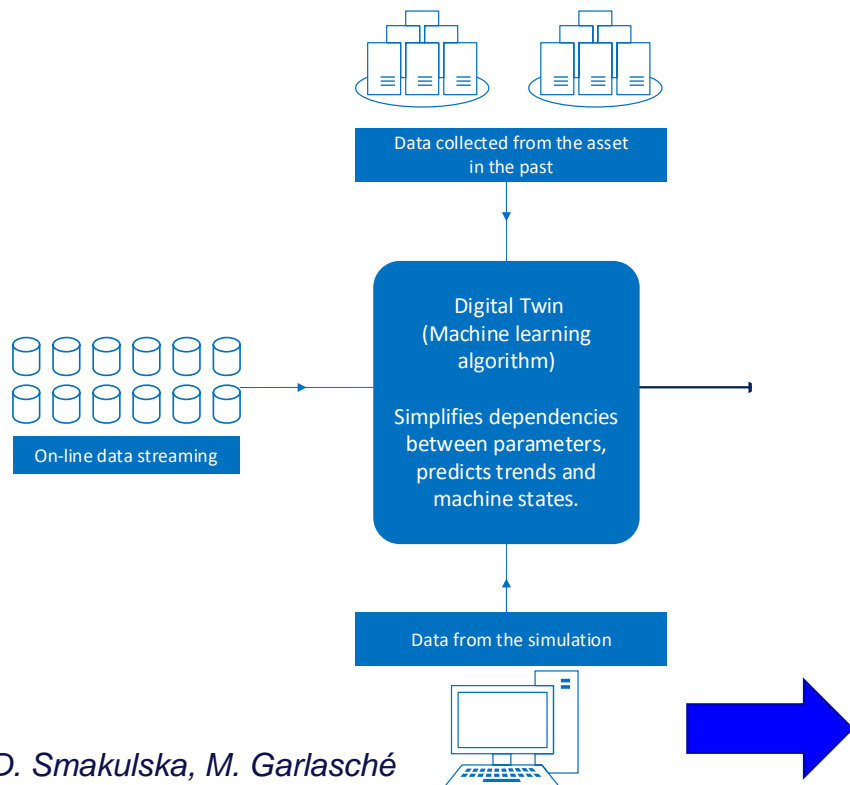
# Novel concepts: Digital Twins

## What is a Digital Twin?



# Novel concepts: Digital Twins

*See also the interesting presentations from yesterday afternoon on alignment, vibrations (FCC-ee afternoon session)*



Digital Twin IS MORE than just

- data acquisition & monitoring
- a set of simulations
- experience from historical

## OUTPUT

### Normal Operation:

- Determine system state through data acquisition
- Real time, ALSO for parameters not directly acquired

### Failure:

- Forecast system state, real time interpretation
- Repair scenarios: real time analysis, system-wide

Complexity of the system is tailored to the specific needs

**To be considered for mock-up girder and magnets:** displacements, vibrations, strains, temperature, etc.

# Conclusions

- The design and construction of a **mock-up of an arc half-cell** of the FCC-ee is proposed, in order to investigate aspects such as fabrication techniques, integration, installation, assembly, transport, maintenance.
- The project is divided into **three phases**:
  - **Phase I** (end of 2022) focuses on the integration studies of the arc configuration and the interfaces between its systems
  - **Phase II** (2023-2024) will tackle the engineering design of each element
  - **Phase III** (2024-2025) will involve fabrication and assembling steps
- Concepts such as **robot-friendly systems** and **digital twins** must be taken into consideration already during the early stage of the design.
- **Strong interaction and feedback** from Accelerator and Infrastructure Pillars, and in particular with Integration, Technology R&D, Collider Ring Optics, Booster Ring, Geodesy and Survey, will be key
- Phase I has started, and a platform for discussion has been set (<https://indico.cern.ch/category/15513/>)  
→ **contact us to discuss inputs and ideas!**



Thank you  
for your attention.