FCC-ee Arc Half-Cell Mock-up

F. Carra (CERN)

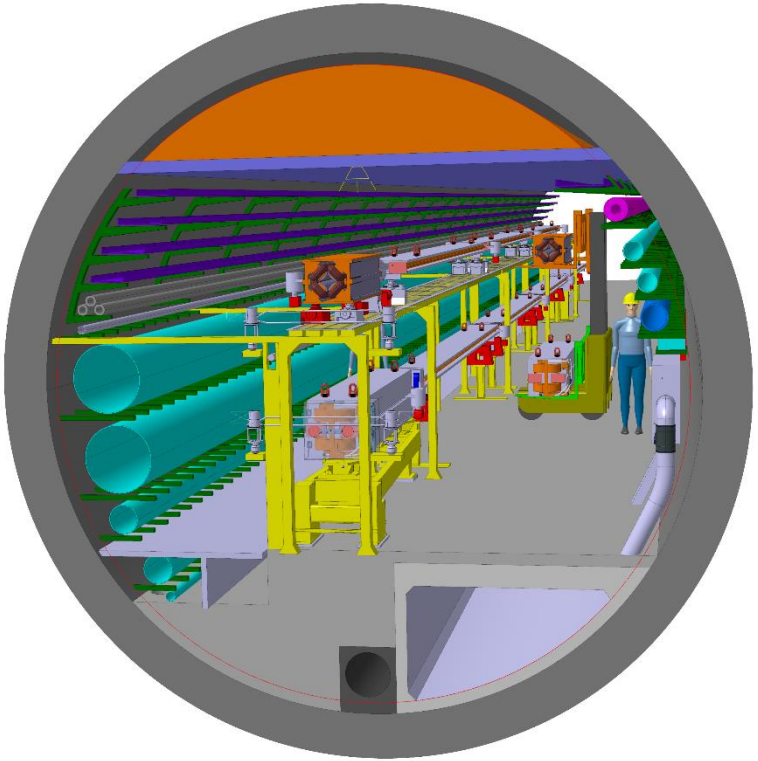
with contributions from many colleagues, including: J. Bauche, S. Atieh, L. Baudin, M. Di Castro, C. Eriksson, C. Garion, M. Garlasché, R. Losito, D. Perini, T. Raubenheimer, D. Smakulska, M. Timmins, F Valtchkova-Georgieva, F. Zimmermann.

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	ΔX (μm)	ΔY (μm)	ΔPSI (μrad)	ΔS (μm)
Arc quadrupole*	50	50	400	150
Arc sextupoles*	50	50	400	150
Dipoles	1000	1000	400	1000
Girders	150	150	-	1000
IR quadrupole	100	100	250	250
IR sextupoles	100	100	250	250
BPM**	40	40	100	-

300

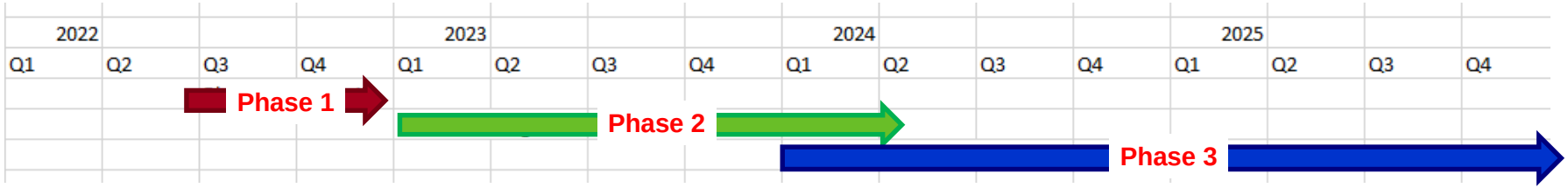
* misalignments relative to girder placement
** misalignments relative to quadruple placement

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, 31st May 2022.

Timeline

T. Raubenheimer



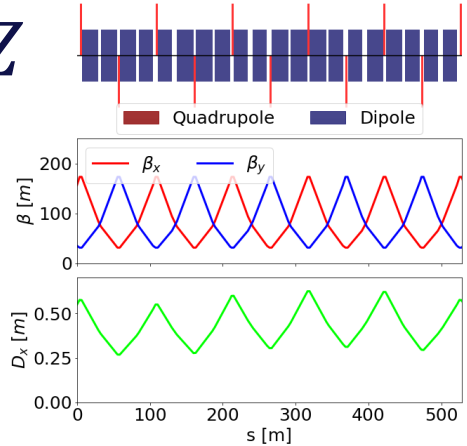
- **Phase 1: Concept development** → functional spec + integration studies. Develop 3D model for ‘representative’ arc half-cell.
- **Phase 2: Engineering design** of half-cell mock-up systems and delivery of 2D functional and fabrication drawings.
- **Phase 3**: **Fabrication** of half-cell mock-up with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

Arc cell configuration(s)

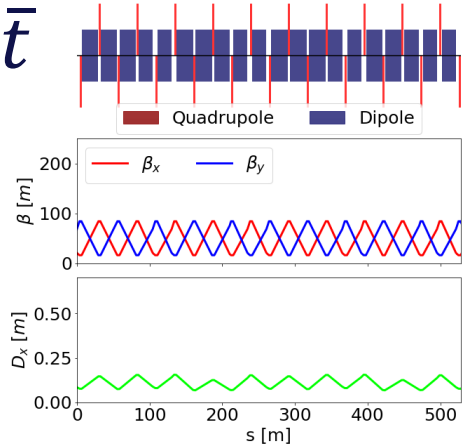
T. Raubenheimer, "Accelerator Overview", FCC week, 30th May 2022.

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

Z



$t\bar{t}$

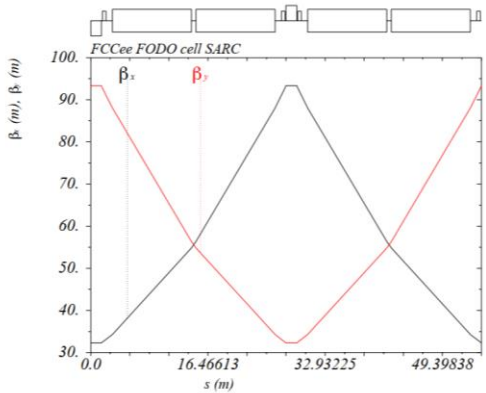


- New configuration for arc optics with long ~100 m FODO cells at Z & W and short ~50 m cells at Zh and $t\bar{t}$ (more details in Tor's talk earlier this week)
- Total arc length 9.6 x 8 ~ 77 km

- 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**

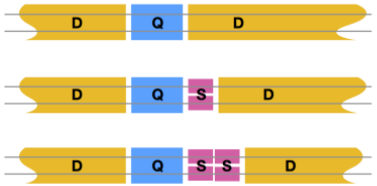
Arc cell configuration(s)

- **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			
Q-S	0.3			
S-S	0.1			
S-D	0.3			
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		

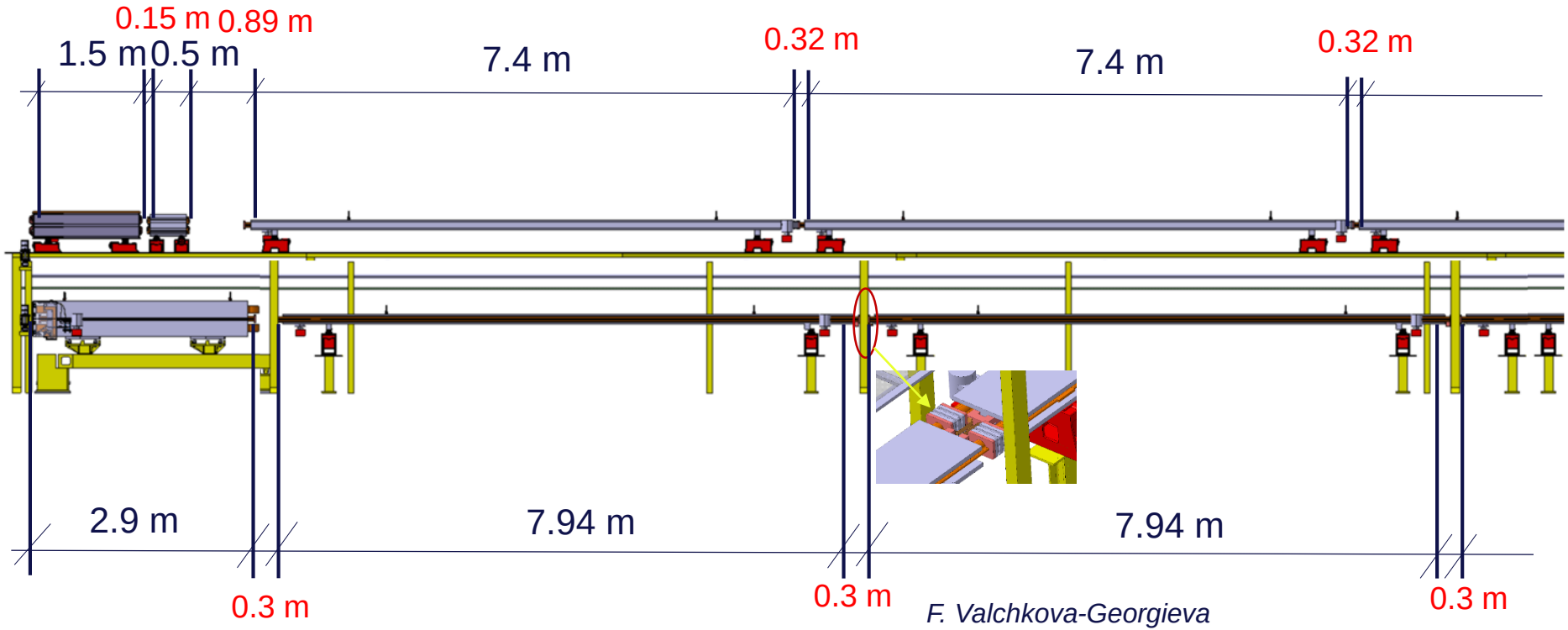


F. Valchkova-Georgieva

Arc cell configuration(s)

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

Side view



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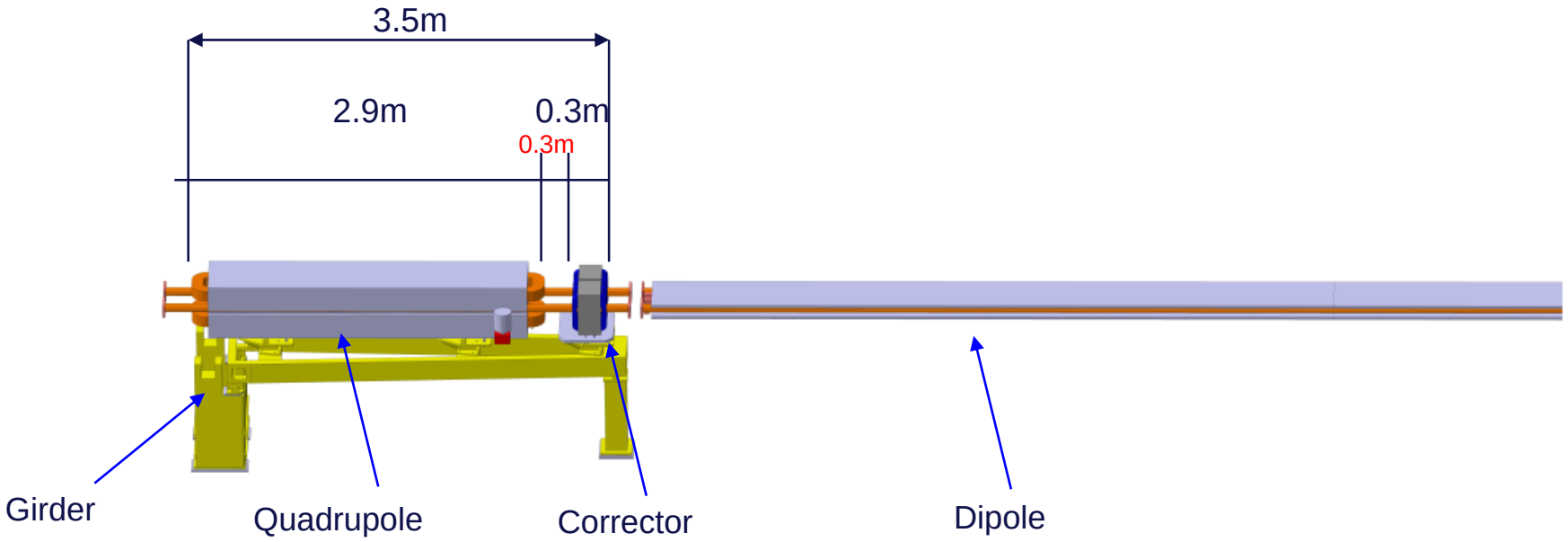
Arc cell configuration(s)

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



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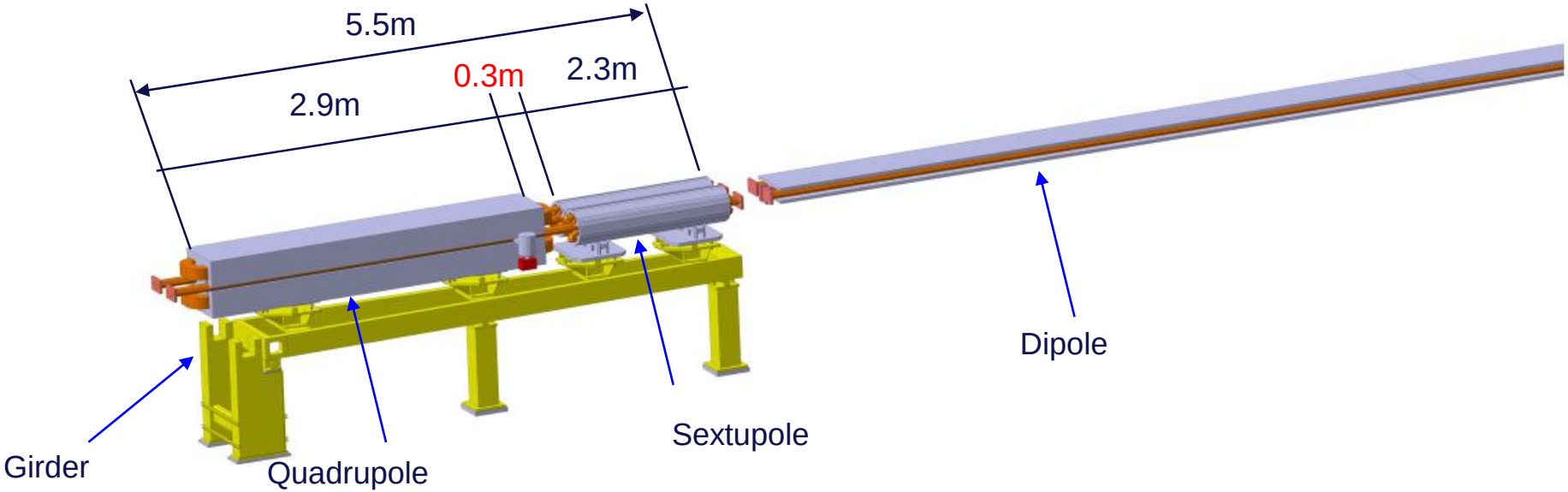
Arc cell configuration(s)

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



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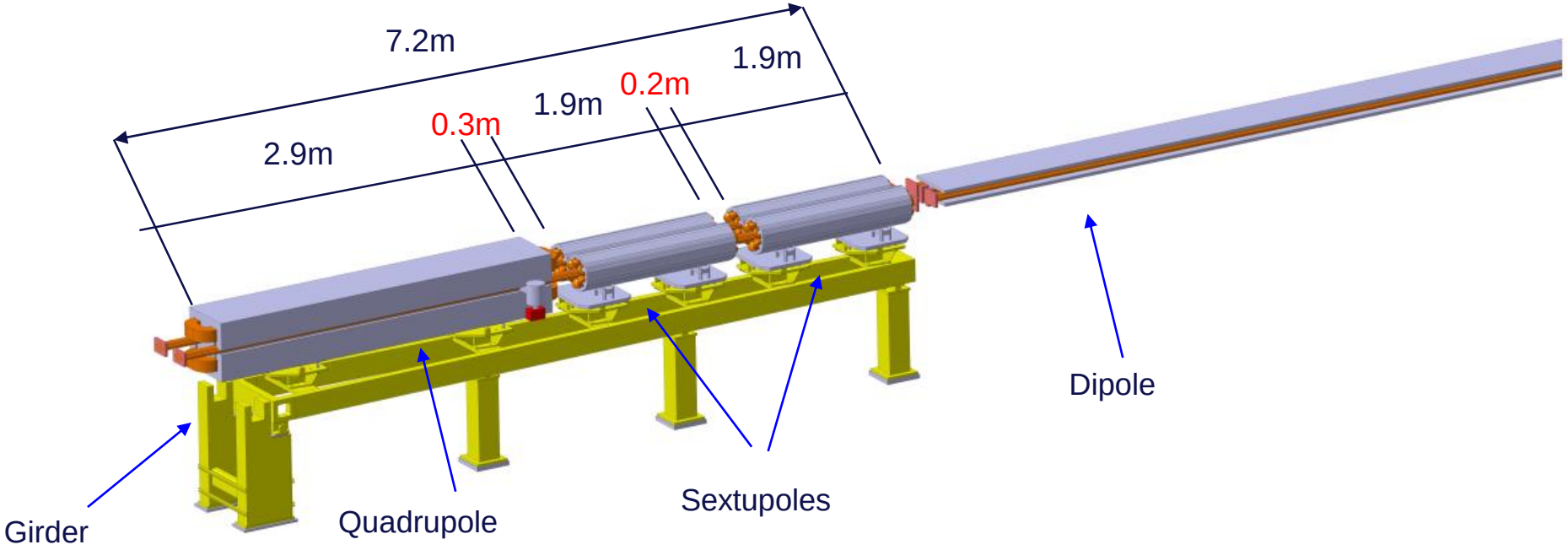
Arc cell configuration(s)

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



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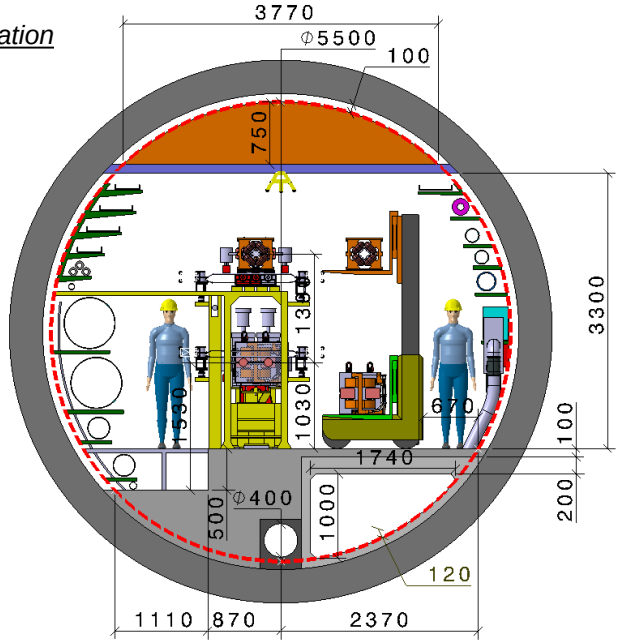
Arc Half-Cell Mock-up Project (Phase I)

- **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*

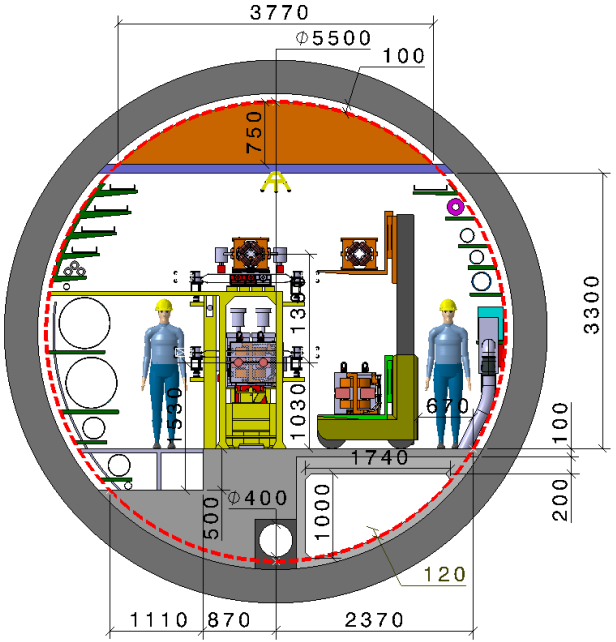


F. Valchkova-Georgieva

Collider Center

Needed studies and challenges (Phase I)

- **Needed studies & challenges***
  - Horizontal separation of the e+ and e- rings in the arcs
  - Vertical placement / separation between collider and booster *(and: is vertical superposition the only solution?)*

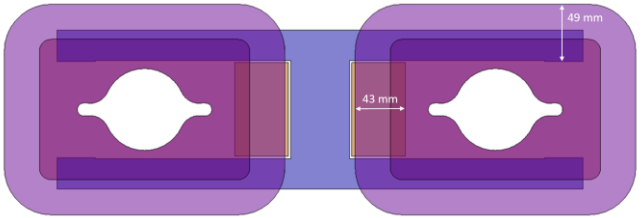


** More detailed list & Project structure in T. Raubenheimer's presentation at the Arc Half-Cell Mock-up kickoff*

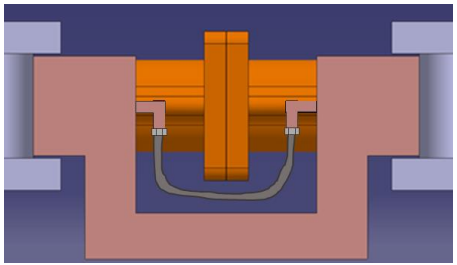
Needed studies and challenges (Phase I)

- **Needed studies & challenges***
  - Horizontal separation of the e+ 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

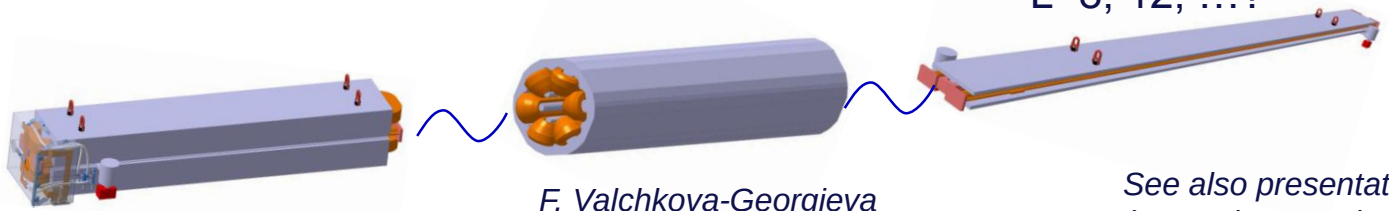
Dipole / Vacuum flange



D-D interface



L=8, 12, …?



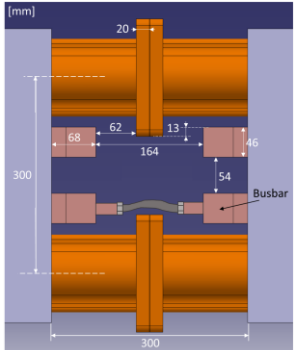
F. Valchkova-Georgieva

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

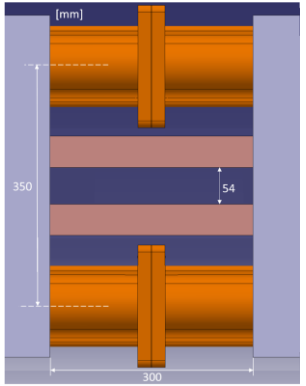
Needed studies and challenges (Phase I)

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



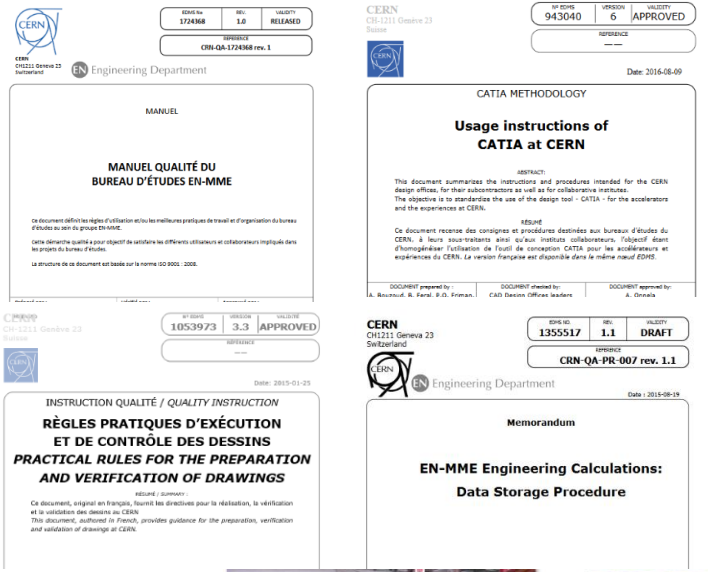
350 mm beam separation

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 fo 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.*

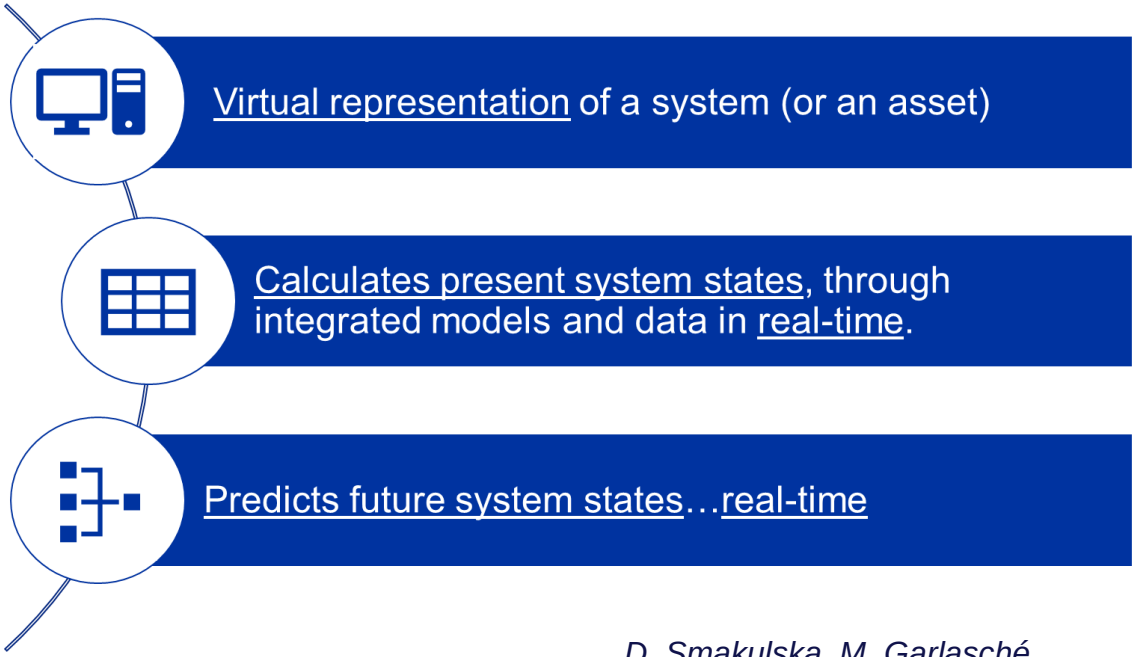
D. Perini



M. Di Castro

Novel concepts: Digital Twins

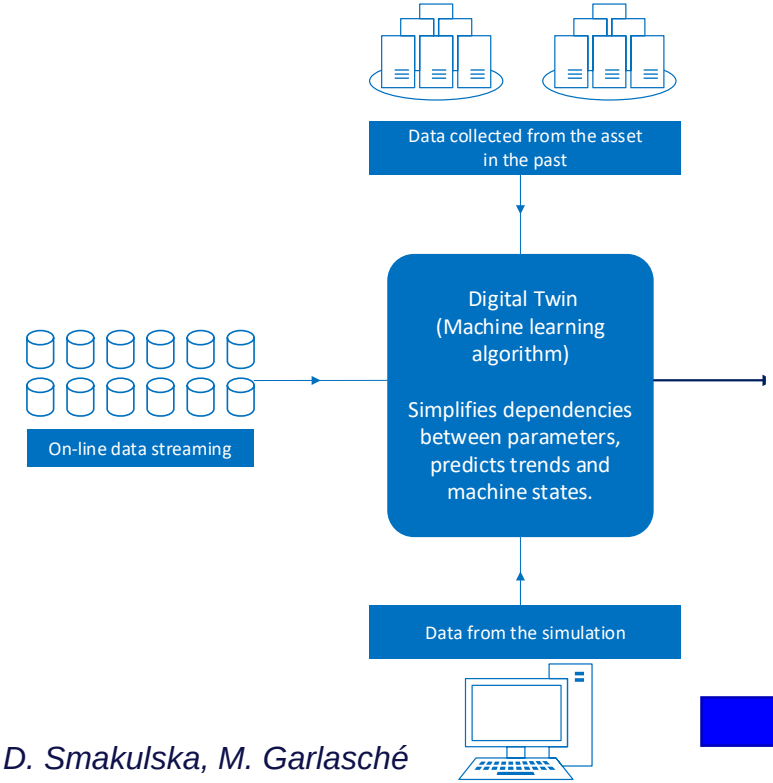
What is a Digital Twin?



D. Smakulska, M. Garlasché

Novel concepts: Digital Twins

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



D. Smakulska, M. Garlasché

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.