NICOLE BALLINGALL-PRICE, TOWARDS INFINITY, LIMESTONE CARVING, 2013

FCC Special Technologies

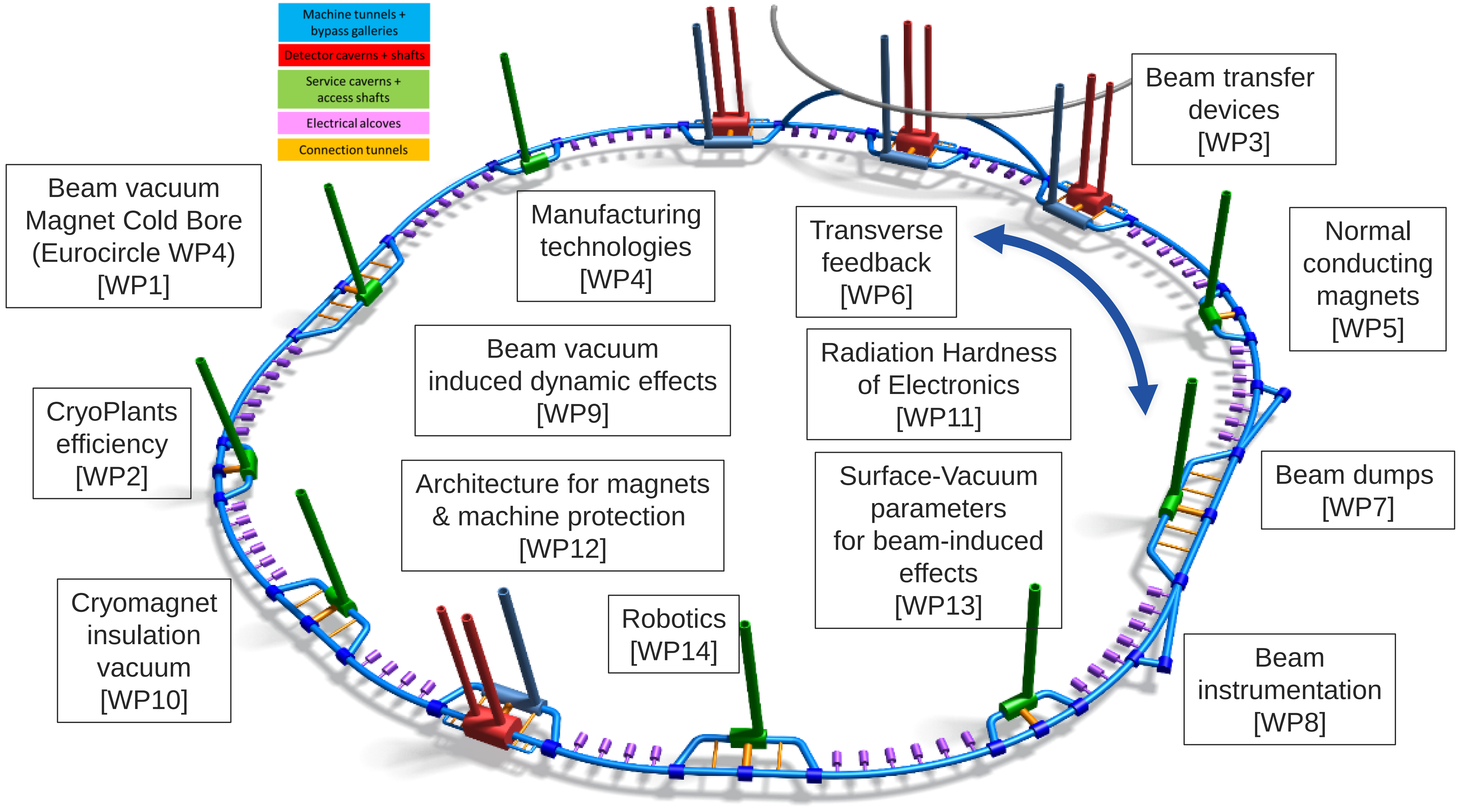
Dr. José Miguel JIMENEZ
Dr. Olivier BRUNNER

FCC Special Technologies

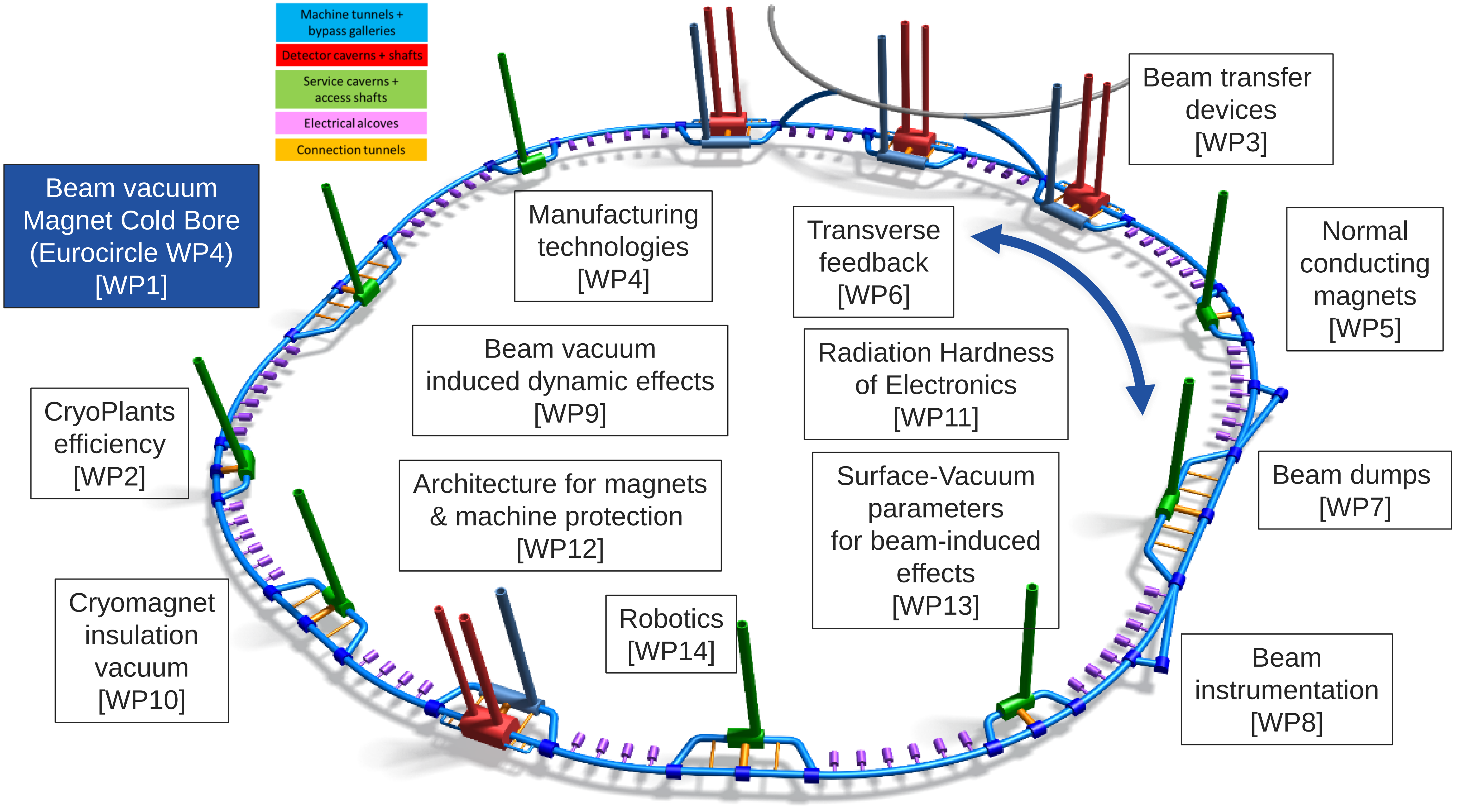
Mandate

- Study the **special technologies** at conceptual aspects required for the FCC accelerator and identify the possible design and performance limitations for the accelerator.
- Identify challenges, **opportunities for technological breakthroughs** and set the R&D program.
  - Understand impacts of technologies
  - Prioritize R&D topics
  - Define scope, schedule, cost guidelines
  - Reporting on Specific Technologies R&D Programs
- Set up **Collaborations** to address standard FCC issues and R&D opportunities
- The R&D activities will then be followed in the frame of the **Accelerator R&D** which includes:
  - High field Magnet Program
  - Superconducting RF Program
  - **Special Technology Program (all except Magnets and RF)**

Dr. José Miguel JIMENEZ (Coordinator)
CERN, Technology Department
Dr. Olivier BRUNNER (Deputy Coordinator)
CERN, Beams Department



Machine tunnels + bypass galleries
Detector caverns + shafts
Service caverns + access shafts
Electrical alcoves
Connection tunnels
Beam vacuum Magnet Cold Bore (Eurocircle WP4) [WP1]
CryoPlants efficiency [WP2]
Cryomagnet insulation vacuum [WP10]
Manufacturing technologies [WP4]
Beam vacuum induced dynamic effects [WP9]
Architecture for magnets & machine protection [WP12]
Robotics [WP14]
Transverse feedback [WP6]
Radiation Hardness of Electronics [WP11]
Surface-Vacuum parameters for beam-induced effects [WP13]
Beam transfer devices [WP3]
Normal conducting magnets [WP5]
Beam dumps [WP7]
Beam instrumentation [WP8]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Beam vacuum – Magnet Cold Bore (Eurocircle WP4) [WP1]

Work Package objectives

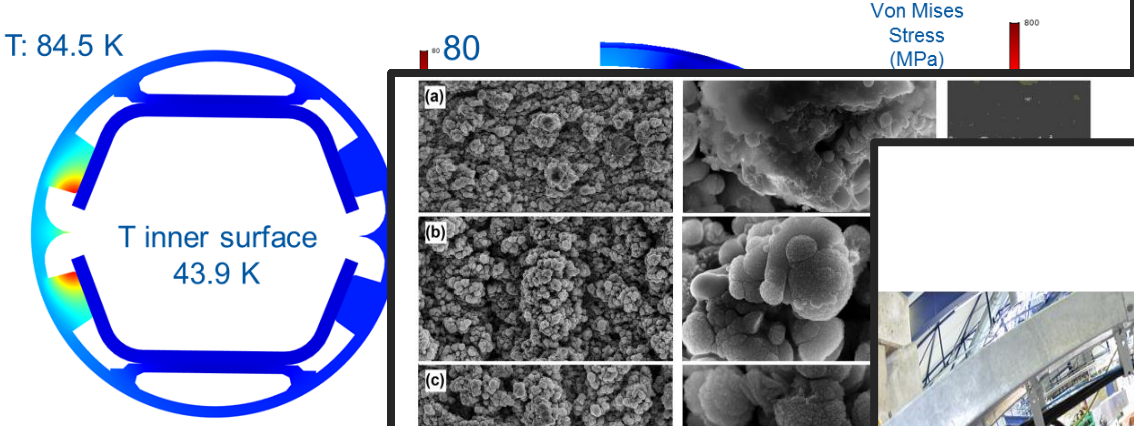
- Develop an overall, **integrated design** for the cryogenic beam vacuum system consisting of:
  - **beam screen**;
  - proximity cryogenics;
  - magnet cold bore;
  - vacuum system.
- Study **synchrotron radiation heat load** distribution and mitigation.
- Study **gas density** distribution.
- Consider novel **mitigation techniques for electron cloud**.
- Design, manufacture, and test at ANKA prototypes of beam screens.

Francis Perez [(ALBA (ES)] & Paolo Chiggiato [CERN]

Beam vacuum – Magnet Cold Bore (Eurocircle WP4) [WP1]

Major achievements

Max T: 84.5 K

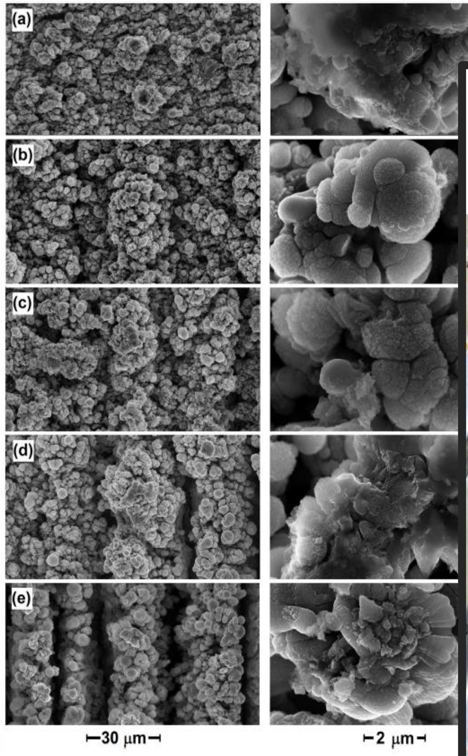


Temperature profile

- 3D massive model
- Heat deposition field based on **SynRad simulation**

Localised temperature increase (reflector tip and ribs)

Screen temperature less than 4 K higher than the He temperature

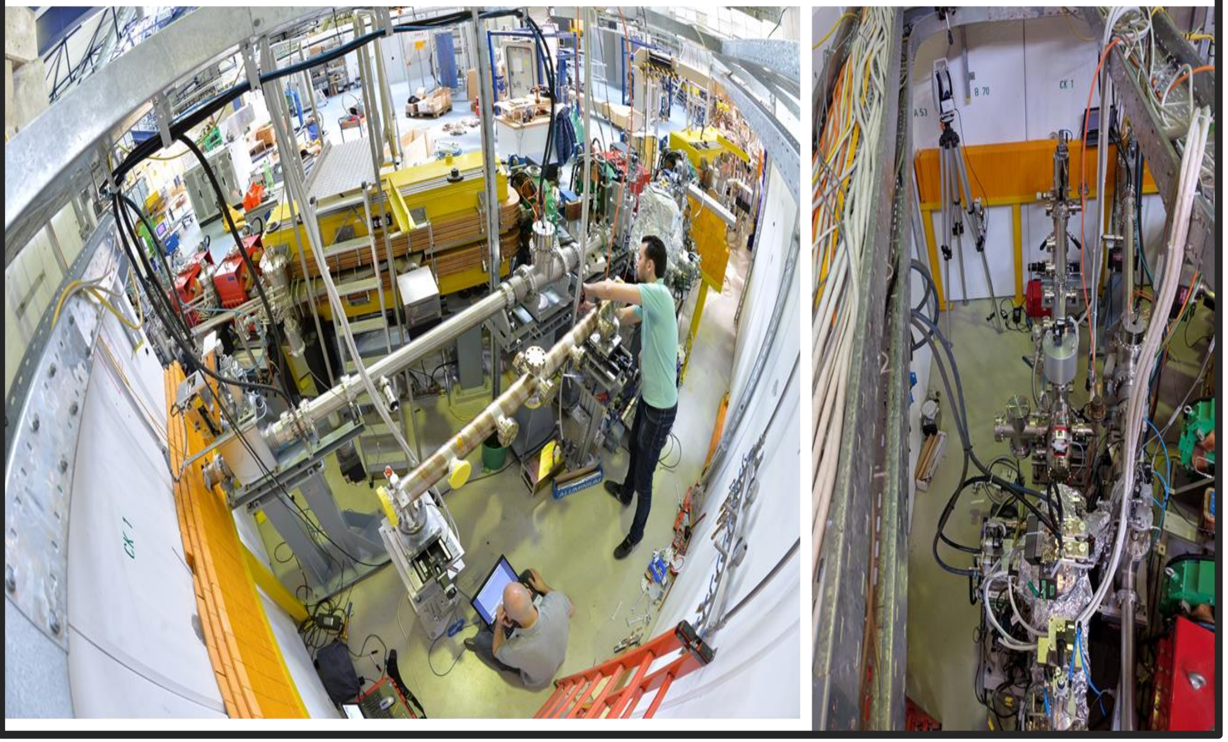


Laser treated surface for eclo

Investigation includes:

Installation completed in ANKA

Ready to take photons



Francis Perez [(ALBA (ES)] & Paolo Chiggiato [CERN]

Beam vacuum – Magnet Cold Bore (Eurocircle WP4) [W

On the way to the CDR contribution

[WP1]

Wed 15:30-15:50
Francis Pérez

Thu 08:30-08:50
Luis Antonio Gonzalez Gomez

Thu 09:10-09:30
Javier Fernandez Topham

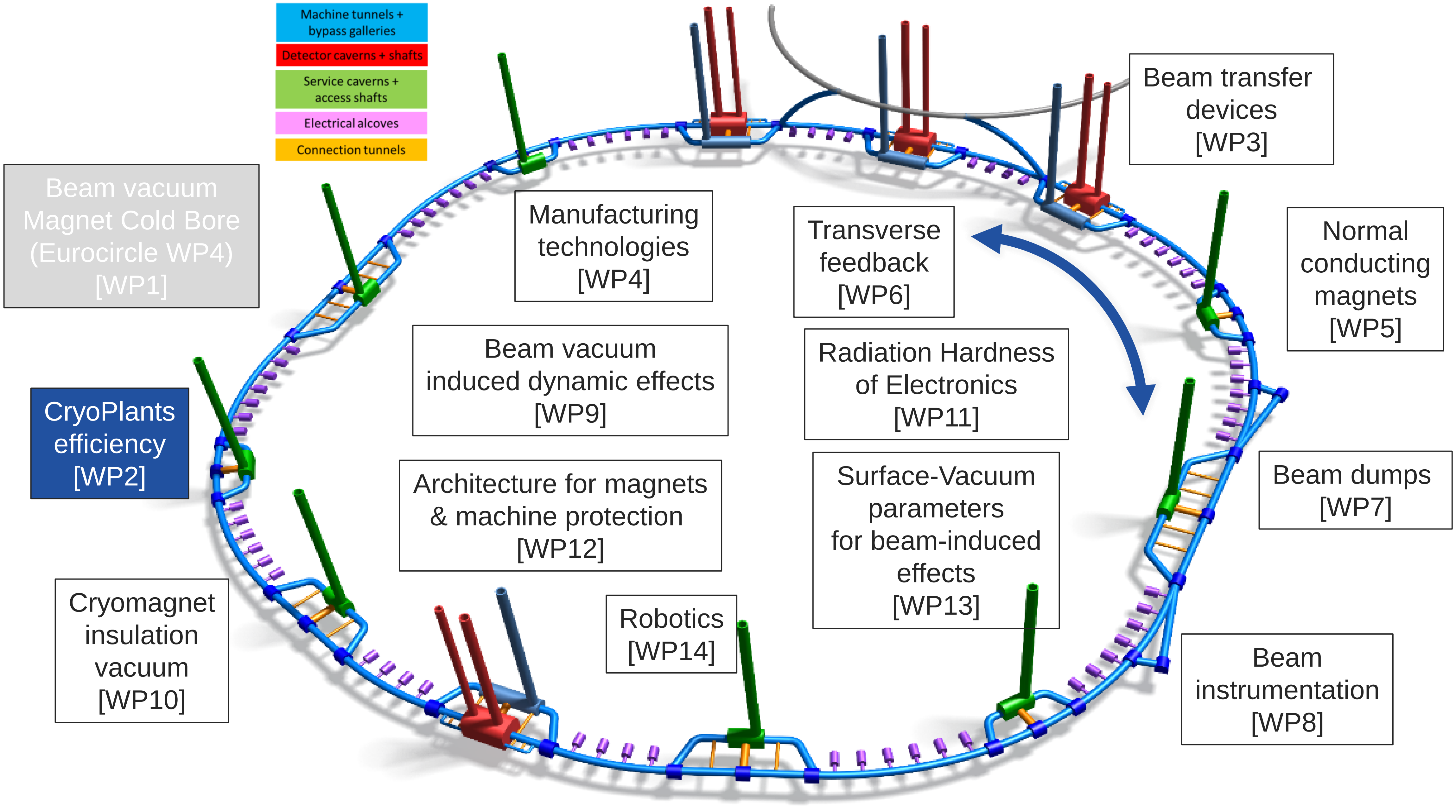
Thu 11:10-11:30
Angelo Infantino

Thu 11:30-11:50
Eliana La Francesca

Next steps	Cryogenic beam

• Conditioning of the testing set-up.
• Measurement of temperature distribution.
• Photoelectron current measurement.
• Desorption yield measurement.
 	
• Gas adsorption-desorption on laser treated surfaces.
• SEY on laser treated surfaces at cryogenic temperatures.
 	
• Proposal for localised photon absorbers.
• Proposal for interfaces at the cold-warm transitions.
	• Gas density requi
	• Photon flux chara
	• Beam screen cha
	  ◦ Mechanical a
	  ◦ Thermal aspe distribution.
	  ◦ Laser treated surfaces as multipacting mitigation.
	• Photon absorption at dipole extremities.
	• Gas density simulation and vacuum stability.
	
	• Indicative nr of pages: 30

Francis Perez [(ALBA (ES)] & Paolo Chiggiato [CERN]

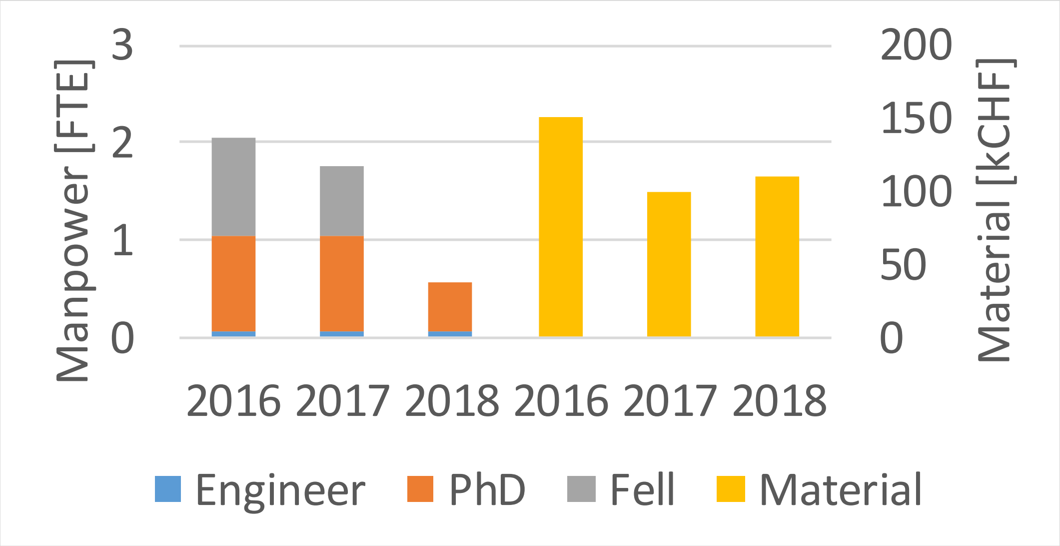


Laurent Tavian [CERN]

CryoPlants efficiency [WP2]

Scope, resources & contributions

- Scope: Identify the challenges, the showstoppers and look towards opportunities for technology breakthroughs related to:
  - **5 kW magnetic refrigeration** allowing reaching temperature down to 1.6 K for FCC-ee RF cavity cooling.
  - **Proximity cryogenics** for the superconducting magnets and the beam screen for FCC-hh
- Resource



- External contributions:
  - **CEA-INAC-SBT** collaboration (magnetic refrigeration) → 0.25 FTE.y
  - **Graz University** of Technology: PhD contribution

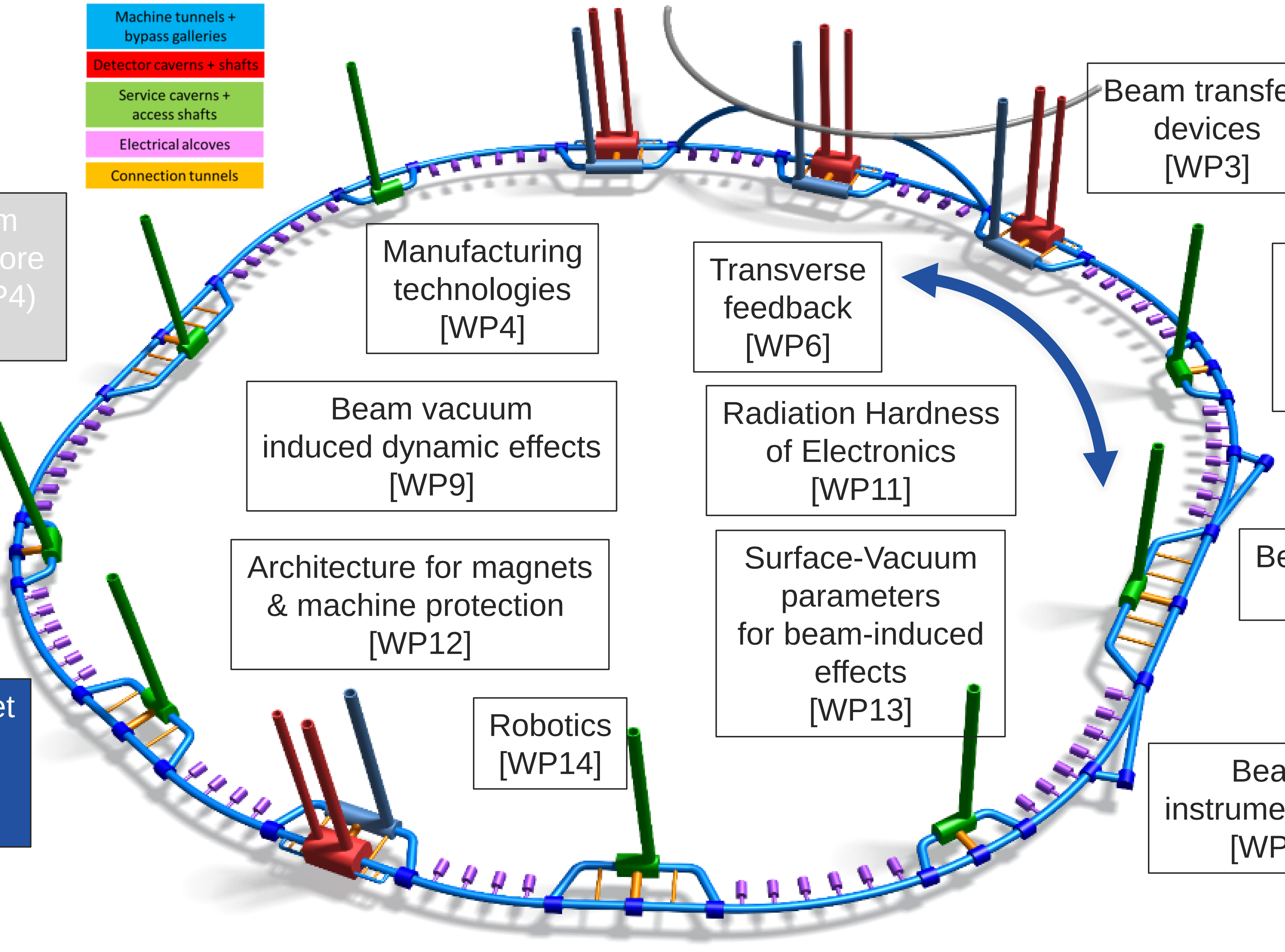
Laurent Tavian [CERN]

CryoPlants efficiency [WP2]

On the way to the CDR contribution

Next steps	Cryogenic challenges
Magnetic refrigeration at 1.6 K for FCC-ee: • preliminary design report issued https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.20.041001) • Task completed Proximity cryogenics of FCC-hh: • Beam screens cooling: Reference cooling scheme proposed Transient operation addressed. • Cold mass cooling: Operating temperature defined (2 K) Reference cooling scheme proposed. • Cryogenic distribution: Sizing of the main headers done • Next milestones Transients during magnet current ramp-up and fast ramp-down Transients during resistive transitions of SC magnets	• Overview • Function, constraints, architecture • Temperature levels • Cooling scheme • Operating modes • Cryogenic distribution • Refrigeration plants • Instrumentation and controls • Storage

Laurent Tavian [CERN]



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Paolo Chiggiato [CERN]

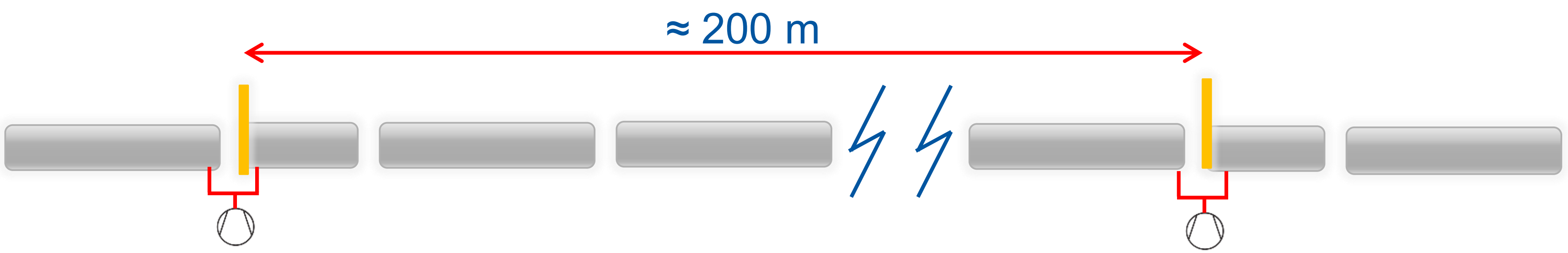
Cryomagnet insulation vacuum [WP10]

Scope

Study the feasibility of **an alternative/complementary pumping** in the insulation vacuum of the FCC-hh, for example pumping by cryosorption.

The problem

Pumping in LHC insulation vacuum:



For FCC-hh: ≈ 80 km of arcs.:

Not desirable to adopt the same pumping scheme as in the LHC would require 400 turbomolecular pumps:

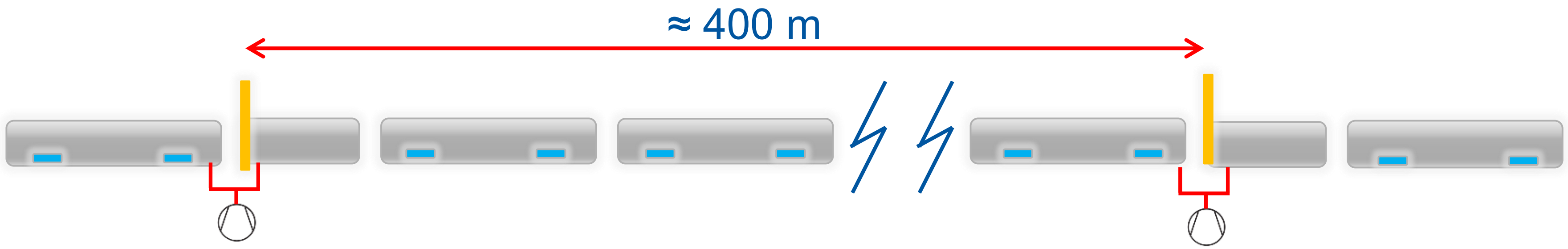
→ Impressive costs for pumps, controllers, cables, and maintenance!

→ No means to detect He leaks before appearance of thermal insulation failure

Cryomagnet insulation vacuum [WP10]

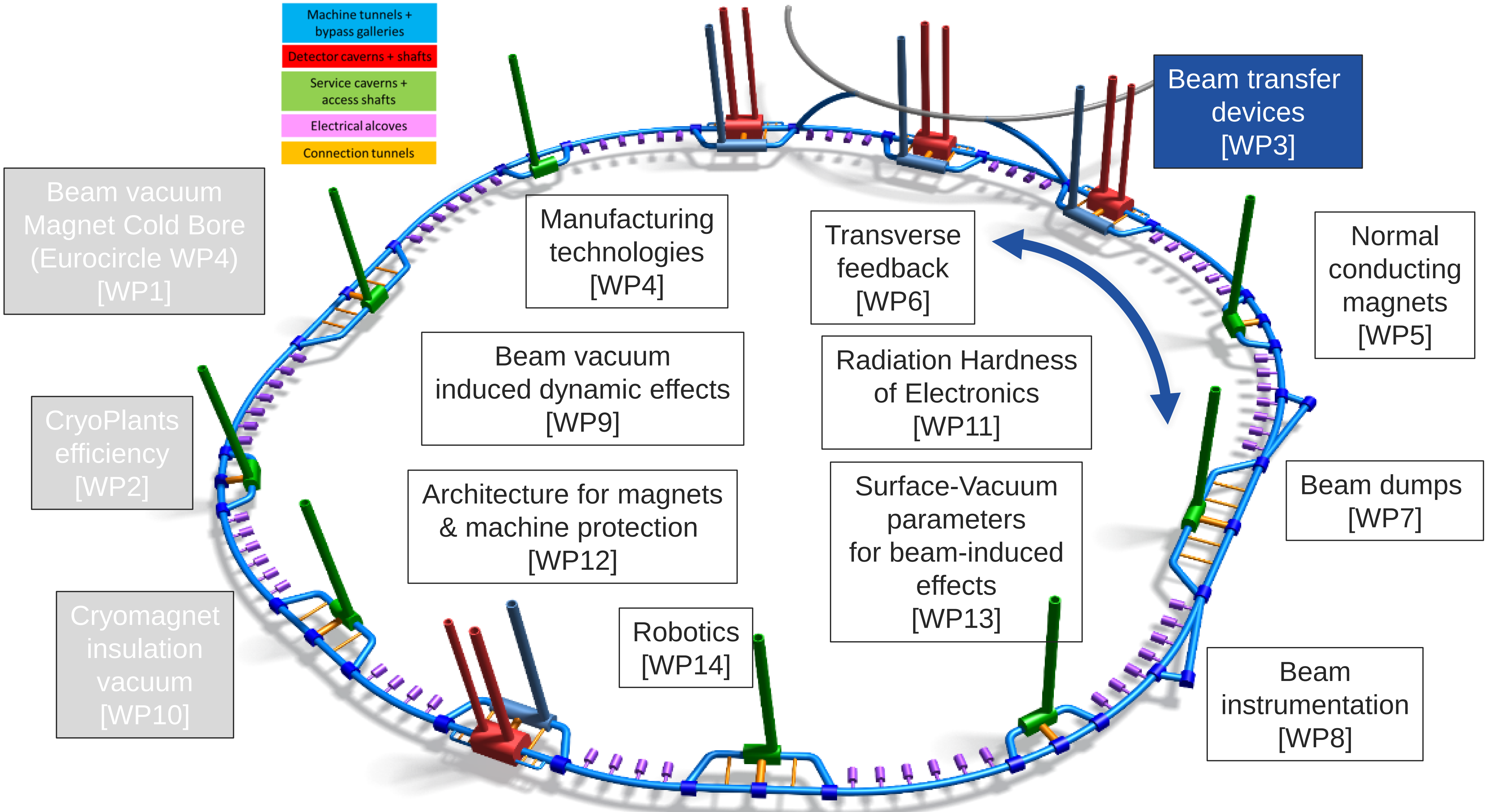
On the way to the CDR contribution

Integration of He/H_2 local adsorber in the dipole magnets, possibly in thermal contact with the C' line (cold-mass support cooling) at 4.5 K.



First proposal: sheets made of compressed carbon material.

Collaboration agreement with Universities to be set up. **Looking for Partners!**



Brennan Goddard & Mike BARNES [CERN]

Beam transfer devices [WP3]

Work Package objectives

Key parameters and new technologies for the FCC **injection and extraction kickers** and **septum magnets** are being studied.

Technologies under study include:

- **Solid state switch** technology for FCC kicker pulse generators for reasons of high reliability, modularity, cost and maintainability:
  - Switch topology
  - Critical components for high reliability and performance
- Studies and development of existing and **novel methods of shielding** the kicker magnet yoke from the FCC beam
- Studies and development of a **compact**, or **massless**, **septum** system to provide flexibility in the design of the injection and extraction insertions, and economies in power consumption, installation cost and complexity
- Development of **ultra-high-reliability triggering** and synchronisation concepts for highly segmented dump systems
- Development of novel methodologies to analyse vast amounts of measurement data in order to increase **system availability** and **reliability**.

Brennan Goddard & Mike BARNES [CERN]

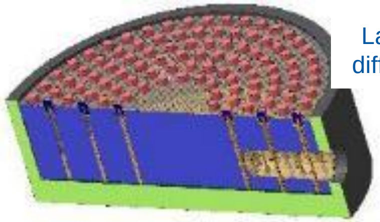
Beam transfer devices [WP3]

Status report

- WU 3.1: Kicker Generator with Solid State Switch Technology:
  - Testing of solid state switches and critical components – ongoing for both Marx Generator (2TUP49) and Inductive Adder (Wed. Talk).
  - Preliminary designs exist for both Marx and Inductive Adder
- WU 3.2: Kicker Magnet R&D
  - Preliminary calculations demonstrate need for beam screen.
- WU 3.3: Septum Magnet R&D
  - Lambertson based solution studied (presented FCC week 2016)
  - Massless septa and Superferric solution studies ongoing;
  - Superconducting Shield (SuShi) – in collaboration with the Wigner Institute (HU) ongoing
- WU 3.4: Fast Electronics, Triggering and Switch Controls
  - Studies of laser triggered thyristors ongoing
  - Development of an Artificial Intelligence prototype ongoing


MOSFET test card


HTS tape (25 layers) prototype


Laser diffuser

Brennan Goddard & Mike BARNES [CERN]

Beam transfer devices [WP3]

On the way to the CDR contribution

Beam transfer challenges

- Solid State Switch Technology for Injection Kicker Systems (6 pages)
  - Characterization and choice of critical components
  - Marx Generator including topology for reliability
  - Inductive Adder
- Injection Kicker Magnets (3 pages)
  - Beam coupling impedance considerations
- Septa topology potential and limitations (6 pages)
  - LHC-like Lambertson solution in new extraction layout
  - RF leak field compensation
  - Massless septa study
  - Superconducting septa variants
- Septa proposed for the FCC (4 pages)
  - Injection
  - Extraction
- Fast Electronic, Triggering and Switch Controls (5 pages)
  - Technological considerations for dump switch firing
  - Machine learning for improved diagnostics and prediction

[WP3]

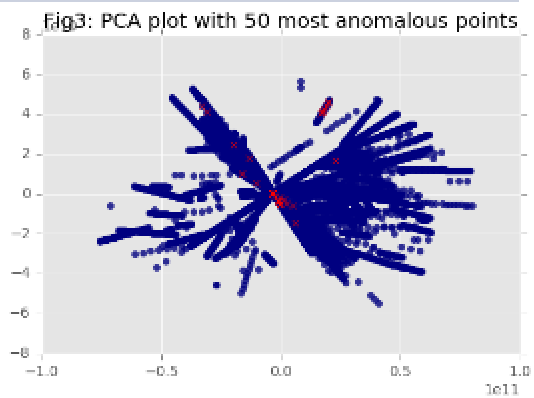
Wed 13:30-13:50
Wolfgang Bartmann

Wed 14:40-15:00
David Woog

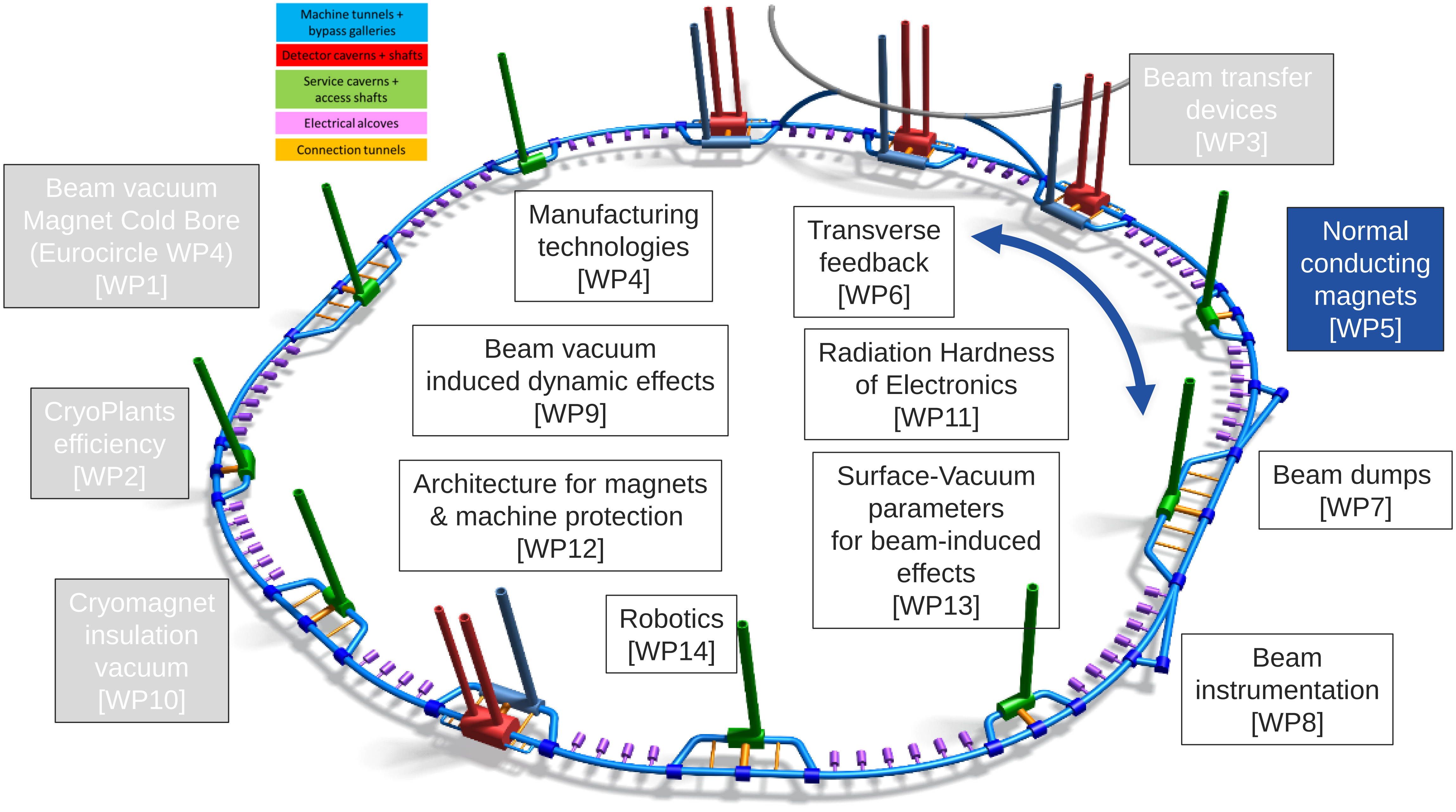
Thu 10:50-11:10
Alejandro Sanz Ull

Thu 13:30-13:50
Kei SUGITA

Thu 13:50-14:10
Daniel Barna



Brennan Goddard & Mike BARNES [CERN]

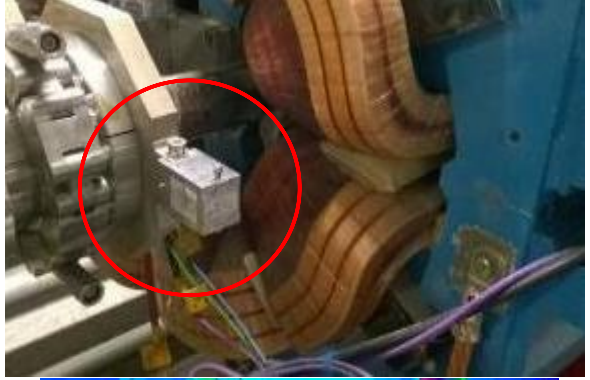


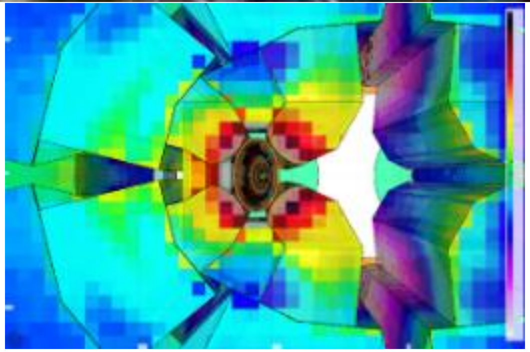
Davide Tommasini & Attilio Milanese [CERN]

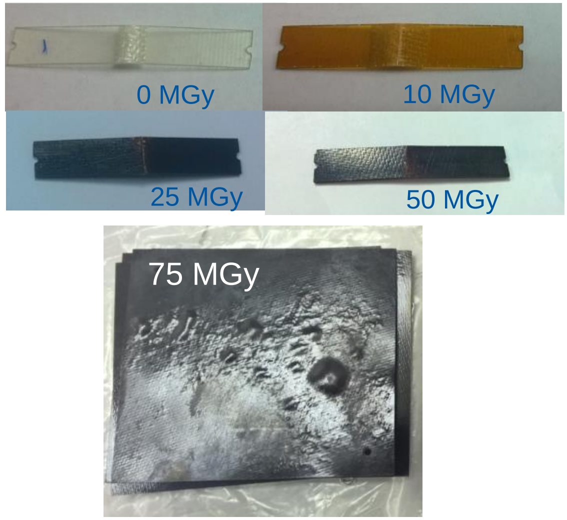
Normal conducting magnets [WP5]

Status report

- Improved understanding of the **radiation dose levels** in the **betatron** and **momentum** cleaning insertions thanks to radiation monitoring carried out in 2015-2016 LHC Run and intensive modelling campaign. Two independent experimental set of data (BLM and RPL) were correlated via numerical modelling.
- **Local shielding of the coils** of the most exposed magnets has been designed and partly implemented during LS1, the work will be completed during LS2. **High efficiency capable to reduce dose to 35%**.
- Manufacturing of **radiation resistant coils for LHC quadrupoles** with new technology could however still be explored because it would:
  - Provide more freedom in the operation of the collimation scheme;
  - Keep safety margins in case the reality of operation will give higher radiation doses than expected from an extrapolation of the present operation;
  - Investment in know how for the future, not only the FCC but also magnets for highly radiation exposed locations as for example the target areas.



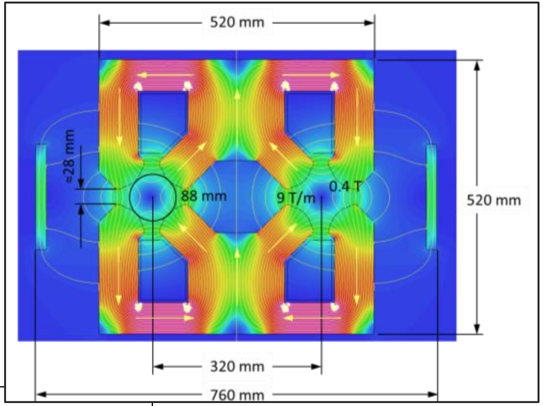




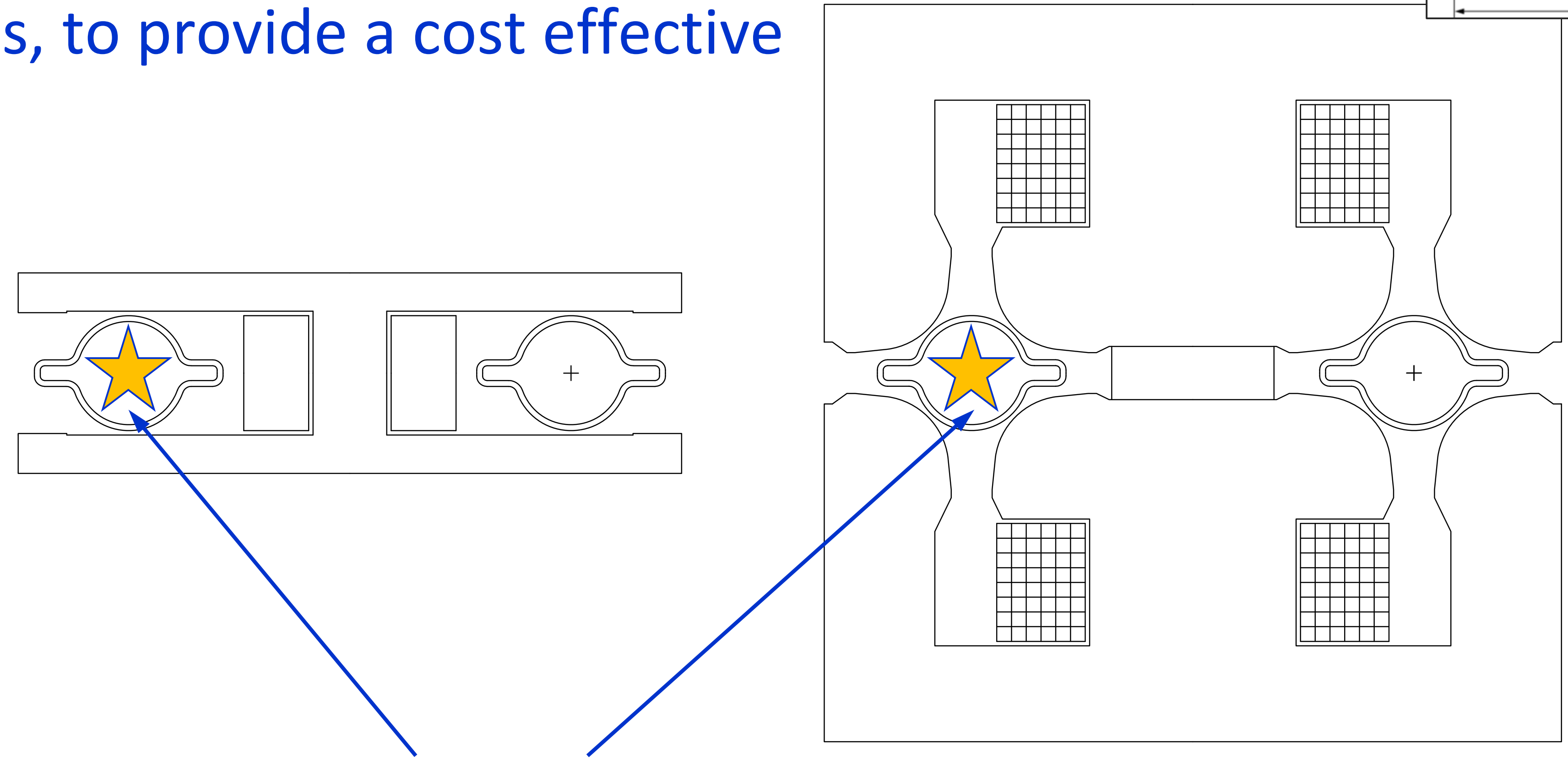
Davide Tommasini & Attilio Milanese [CERN]

Normal conducting magnets [WP5]

FCC-ee twin design



The proposed main dipoles and quadrupoles for FCC-ee are twin designs, to provide a cost effective solution.



free field in one aperture 50% power saving

Davide Tommasini & Attilio Milanese [CERN]

Normal conducting magnets [WP5]

On the way to the CDR contribution

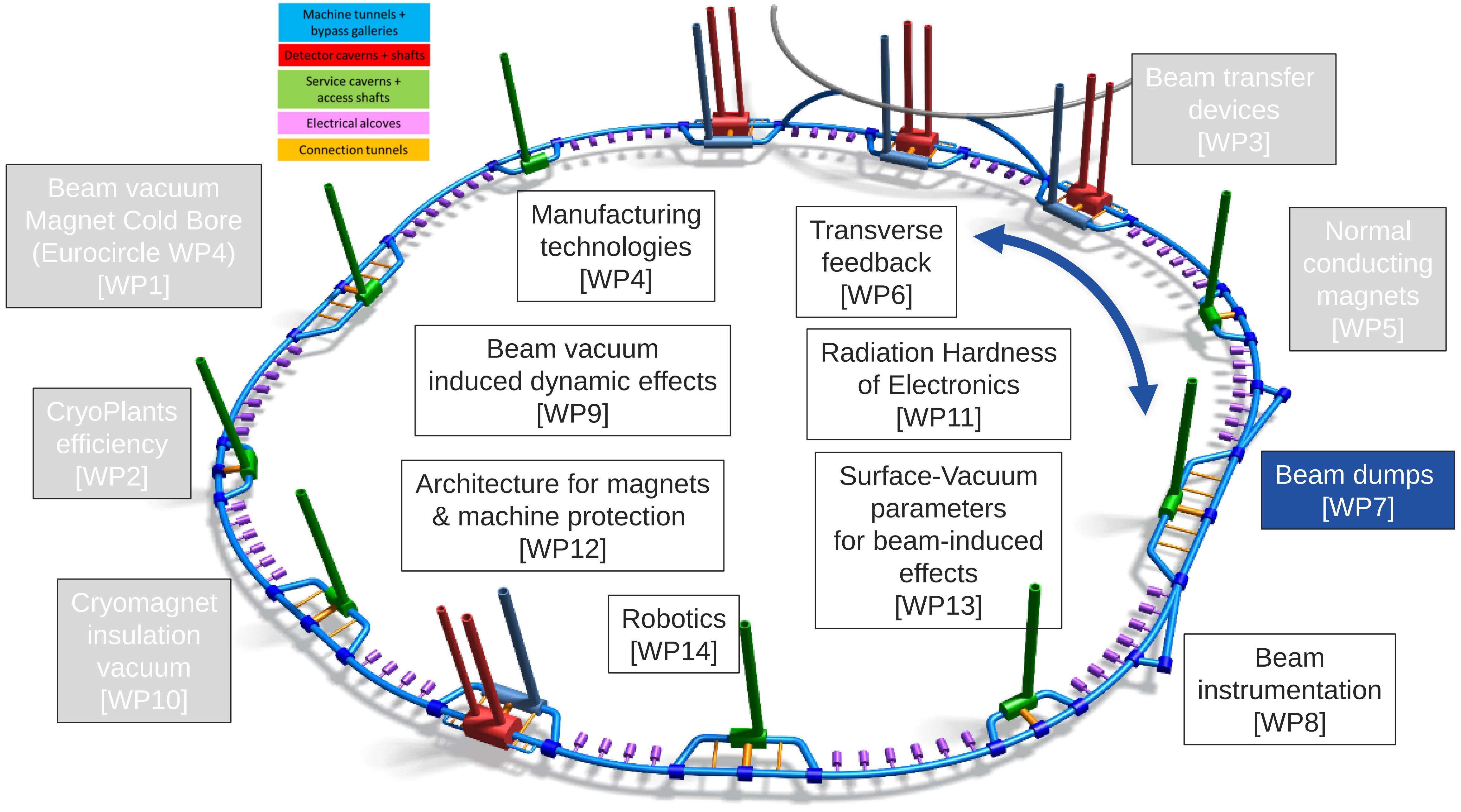
[WP5]

Thu 14:30-14:50
Attilio Milanese

Thu 14:50-15:10
Matthias Mentink

NC magnet challenges

- Plan the **construction of prototypes** for several reasons, in particular:
  - To prove experimentally the twin configuration.
  - To assess the field quality with respect to beam physics targets, considering the low field and very elongated pole (for the dipole) and the unconventional asymmetries (for the quadrupole).
  - To push forward the integration with the vacuum chamber and its peculiar geometry.
  - As a starting point for a further optimization, in view of a series production of thousands of units.
- **Learn from the on-going studies made in the frame of HL-LHC** for the radiation resistance of coils.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Beam dumps [WP7]

Work package objectives

CERN (EN-STI)
S. Gilardoni
M. Calviani
F. Cerutti
A. Lechner

(EN-MME)
F. Bertinelli
A. Bertarelli

3 work packages:

- 7.1 **Energy deposition/interaction** in materials up 50 TeV
- 7.2 **Thermomechanical feasibility** of the FCC-hh beam dump and other critical protection devices in the extraction line
- 7.3 Research and development of a **new class of materials** (such as very low density carbon foams or graphite or graphite powder)

Scope:

- Engineering and conceptual design of beam dumps
- Simulation of the interaction between particle beams and matter up to 50 TeV proton beam energy (applicable also to HE-LHC)
- Research and development of advanced materials for beam intercepting devices, starting from characterization of exiting or non-conventional materials with also beam tests.

Simone Gilardoni [CERN]

Beam dumps [WP7]

On the way to the CDR contribution

[WP7]

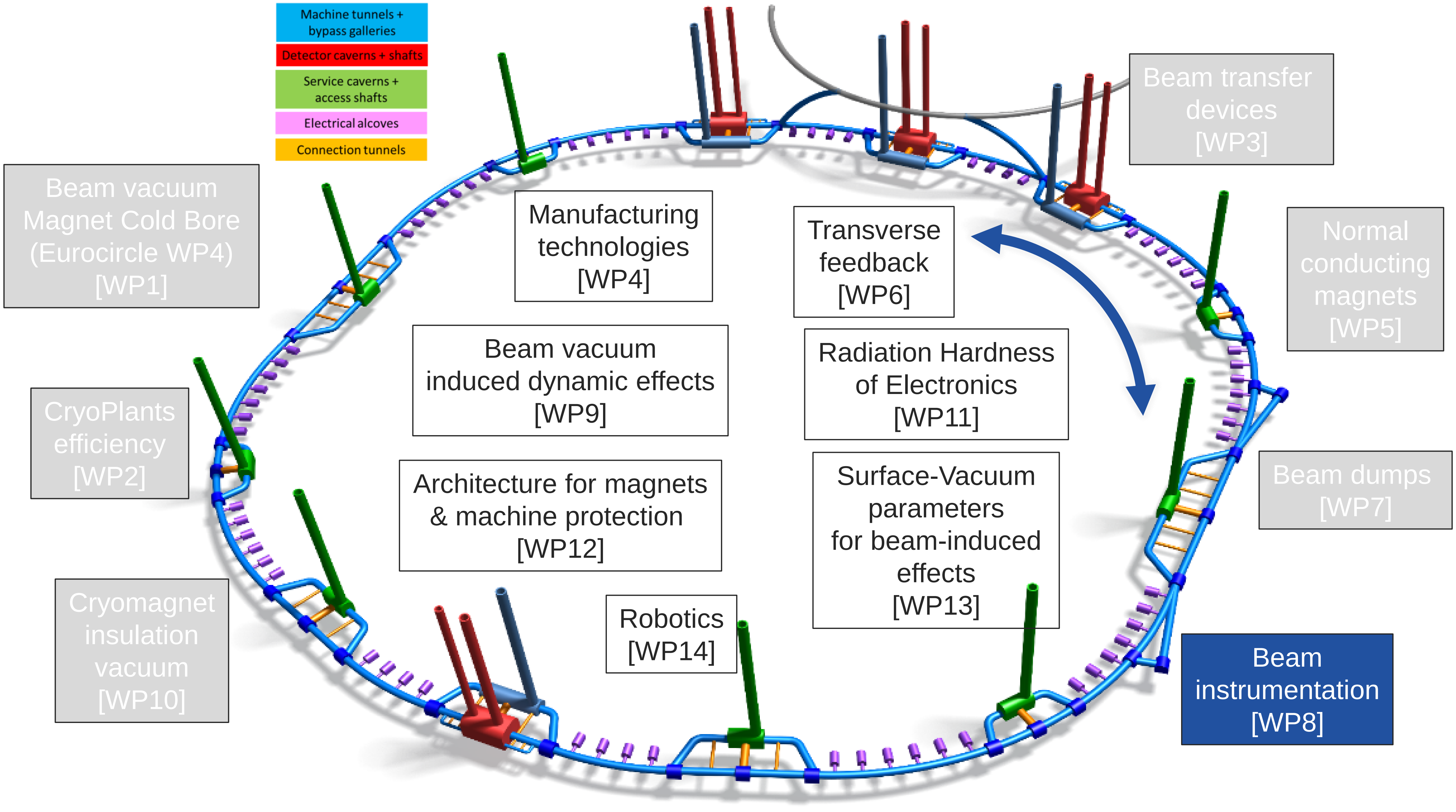
Wed 13:50-14:10
Simone Gilardoni

Wed 14:10-14:30
Anton Lechner

Beam dump challenges

- Introduction about challenges of dumping FCC beam
- Existing beam dump design and known operational constraints (integrity and safety aspects)
- Design choices: possible options
- FLUKA and thermo-mechanical calculations on more promising conceptual design
- Future developments:
  - Innovative designs (different dumps configurations, different absorbing material segmentations)
  - Innovative materials (low graphite, carbon foam, powders, etc..)
- Options

Simone Gilardoni [CERN]



Hermann Schmickler & Rhodri Jones [CERN]

Beam instrumentation [WP8]

Status report

- BPMs:
  - Electronics prototype in order to measure the **resolution for turn by turn** measurements (single bunch) for signals levels corresponding to $5^* 10^8$ protons measured with a 30 mm button.
  - Paper study for a BPM with 4+N sensors for interlocked BPMs.
- Transverse profiles:
  - Development from a gasjet sheet monitor to a **gasjet scanner**. Simulations and construction of a prototype.
  - Theoretical & experimental studies to improve halo diagnostics from a contrast ratio 10^{-4} to 10^{-6} including apodization and a semitransparent cover for the central beam. Studies of parasitic light sources and their mitigation.
  - **X-ray interferometry** for proton profile evaluations.
- Versatile communication link (rad-hard) based on HEP chips and fibre optics.

Hermann Schmickler & Rhodri Jones [CERN]

Beam instrumentation [WP8]

Already existing collaborations

[WP8]

Wed 16:10-16:30
Hermann Schmickler

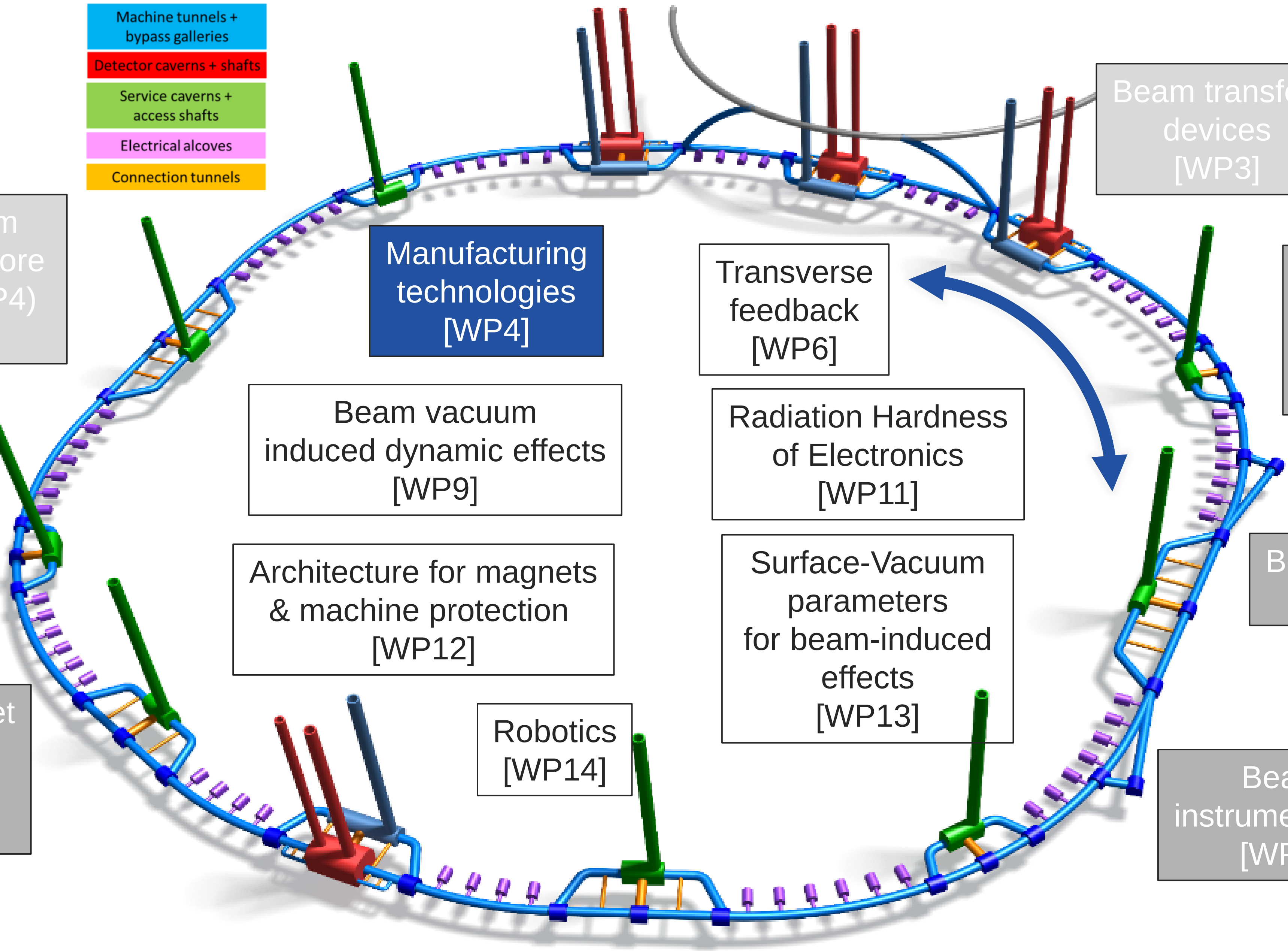
KEK & Australian Synchrotron Collaboration:

- SR monitor collaboration for FCC-ee and FCC-hh
  - Provide the optimum technique & configuration for FCC-hh & FCC-ee SR monitors
- Design of an X-ray interferometer for measurement of small vertical beam size in FCC-ee
  - Identify beam and photon parameters at the source point for the FCC-ee
  - Characterize spectrum and angular divergence of the synchrotron radiation
  - Devise an extraction system for the synchrotron radiation
  - Optimize parameters of the X-ray interferometer
  - Develop a K-edge filter to obtain a quasi-monochromatic x-ray beam
  - Study x-ray polarization and background subtraction
  - Construction of an X-ray interferometer prototype and its testing at the Australian Synchrotron
  - Design & construction of an X-ray interferometer for proof-of-concept testing at the Australian Synchrotron

Goethe Universität Frankfurt am Main / Institut für Angewandte Physik:

- Electron beam profile monitors
  - Document parameters and performance of electron profile monitor and identify possible applications within the FCC complex
  - Design and build electron profile monitors
  - Test monitor with ion beam and quantify performance

Hermann Schmickler & Rhodri Jones [CERN]



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Francesco Bertinelli & Cédric Garion [CERN]

Manufacturing technologies [WP4]

Scope

2 workpackages :

- 4.1: Additive Manufacturing for **accelerator components**
- 4.2: Additive Manufacturing for **vacuum systems**

Scope:

- Introduce AM as a qualified, referenced alternative for the production of accelerator components throughout laboratories world-wide,
- New materials: copper and niobium parts manufactured by Selective Laser Melting (SLM) or Electron Beam Melting (EBM) for SRF,
- Thick and leak tight coatings, joining of dissimilar metals.

External contributors:

- AIDIMME (ES): EBM copper
- Danish Technological Institute (DK): SLM copper
- Mines Paris Tech (FR)
- Suppliers of powders and AM

Francesco Bertinelli & Cédric Garion [CERN]

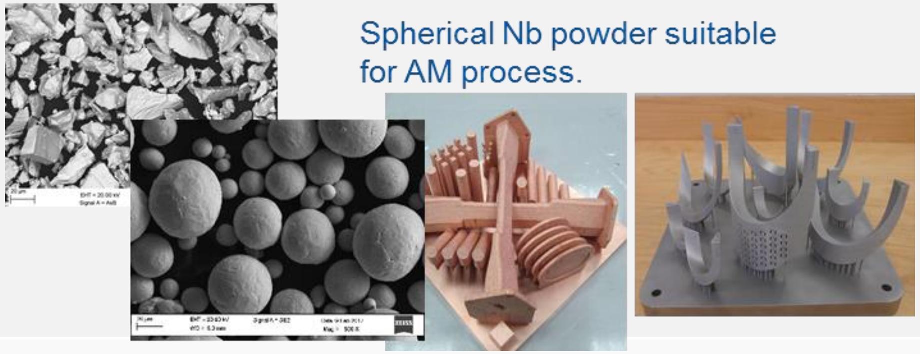
Manufacturing technologies [WP4]

Status, results and milestones

CERN (EN-MME / TE-VSC)
Francesco Bertinelli   Romain Gerard
Cedric Garion   Gilles Favre

WP4.1: Additive Manufacturing for accelerator components

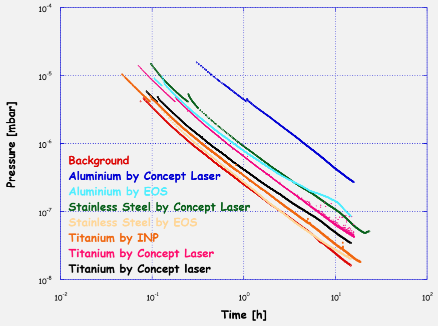
- Benchmarking and characterisation of **powders** (Cu and Nb) finished
- Identified suitable suppliers of powders
- Ongoing in-depth characterisation of **EBM copper**
- Ongoing Material development for Copper
- First dissemination papers published.



Spherical Nb powder suitable for AM process.

WP4.2: Additive manufacturing for vacuum systems

- **Leak tightness** of stainless steel, titanium, aluminium and copper samples
- **Thermal outgassing** of stainless steel, titanium and aluminium samples



Next expected milestones:

- Development of **Nb** in MME AM workshop at CERN
- **Vacuum and RF** characterisation of EBM copper
- Material characterisation and optimisation of the process for SLM copper

Next expected milestones:

- Vacuum characterisation of **cold sprayed coatings**
- **Redesign** of a vacuum component to include AM technology

Francesco Bertinelli & Cédric Garion [CERN]

Manufacturing technologies [WP4]

Status, results and milestones

[WP4]

Thu 09:30-09:50
Cédric Garion

Thu 09:40-10:00
Julien Gargiulo

Thu 10:30-10:50
Fabrizio Niccoli

WP4.1: Additive Manufacturing for accelerator components

1. Introduction
2. Powder Characterisation and benchmarking results
3. Material development in AM
    a. SLM niobium
    b. SLM copper
    c. EBM copper
4. Topics of interest for AM for accelerator components
    - Copper plating of AM materials
    - Innovative surface finish technologies
    - Design considerations and topology optimisation
5. Conclusions

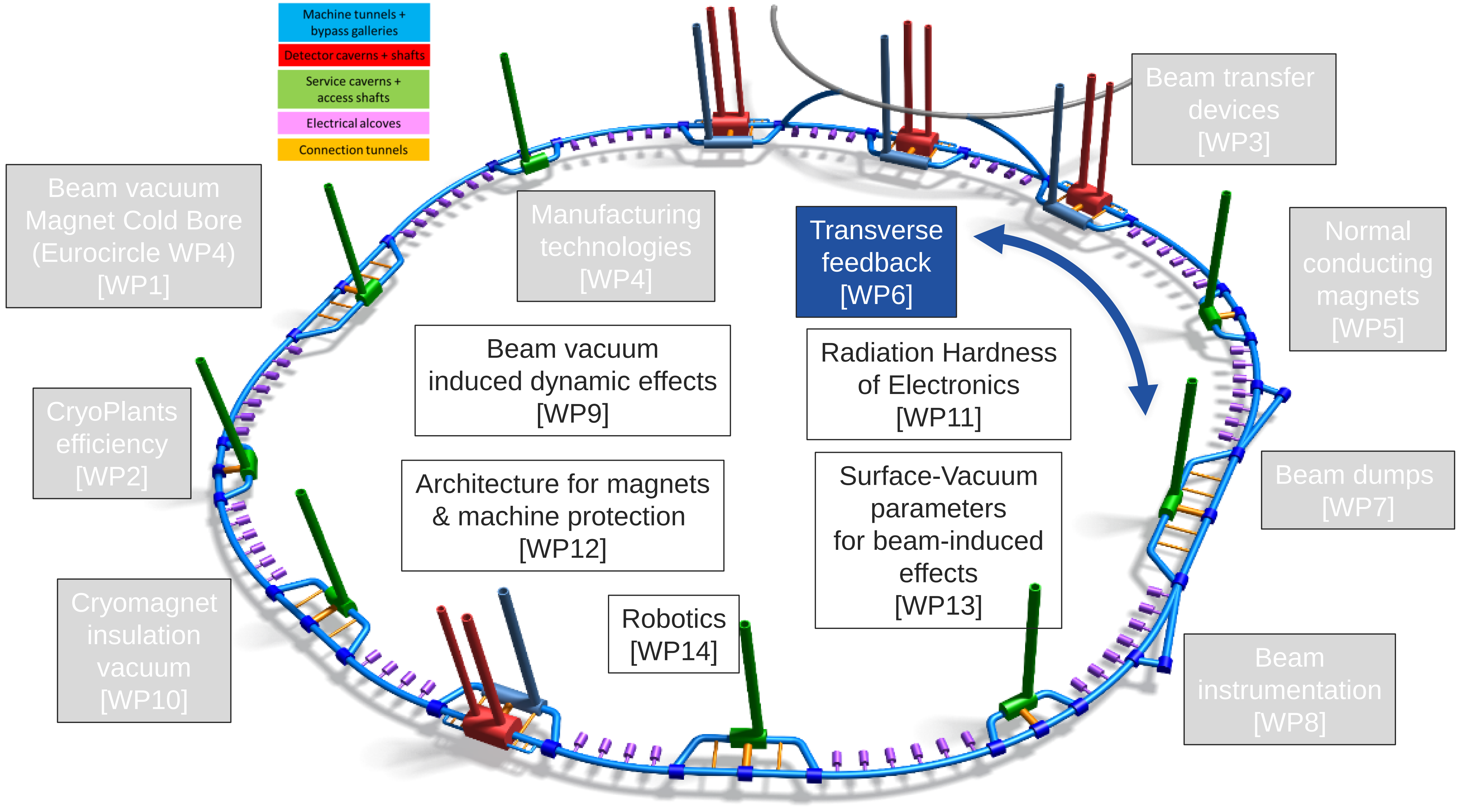
Expected length: 20 pages

WP4.2: Additive manuf systems

1. Introduction
2. Vacuum performance
    a) Leak tightness
    b) Thermal outgassing for baked and unbaked materials
3. Material development in cold spray coating
    a. Intrinsic properties of aluminium coating
    b. Coating on different materials
4. Design of vacuum components
5. Conclusions

Expected length: 15 pages

Francesco Bertinelli & Cédric Garion [CERN]



Wolfgang Hofle [CERN]

Transverse feedback system [WP6]

Scope

FCC different types of transverse feedback systems are studied in simulation:

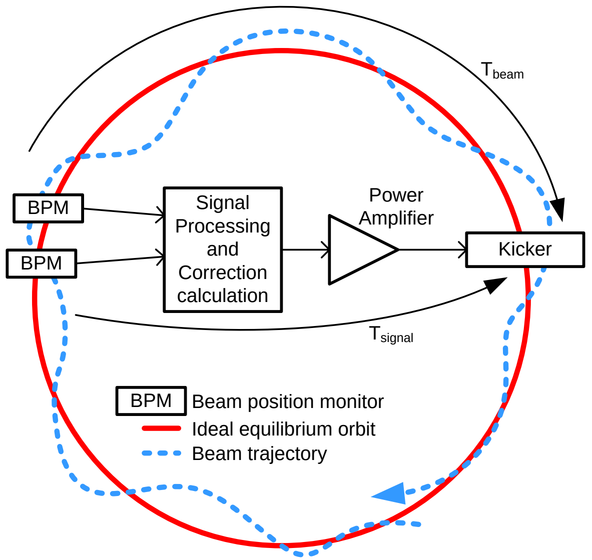
- FCChh
  - **Transverse coupled bunch feedback** with options for 5 ns and 25 ns bunch spacing.
    - Based on experience from the LHC transverse feedback system (ADT) extending existing technology.
  - **Intra-bunch feedback (wide-band)**.
    - Leveraging on collaboration with John Fox, SLAC-Stanford and US-LARP with prototyping for LIU SPS developments: **kicker development and signal processing**.
- FCCee
  - **Coupled bunch feedback, extremely fast growth rates**
  - Based on technology and experience from B-factories

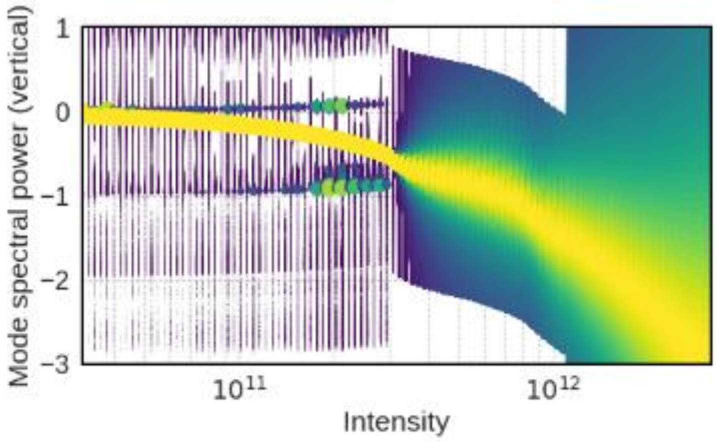
Wolfgang Hofle [CERN]

Transverse feedback system [WP6]

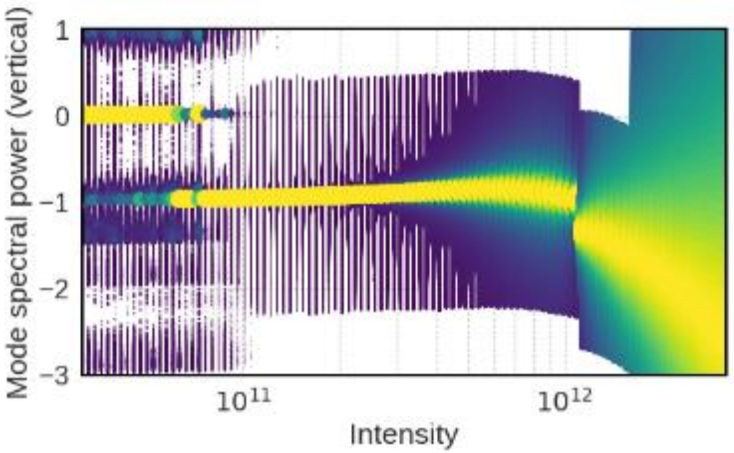
Simulations: results achieved

- Design of feedback systems relies on macro-particle simulations that integrate beam dynamics and feedback action.
- Simulation environment developed to treat **coupled bunch** and **intra-bunch** feedbacks.
- Input: FCC **impedance model** .





TMCI without transverse feedback



with rigid dipole feedback: no mode coupling

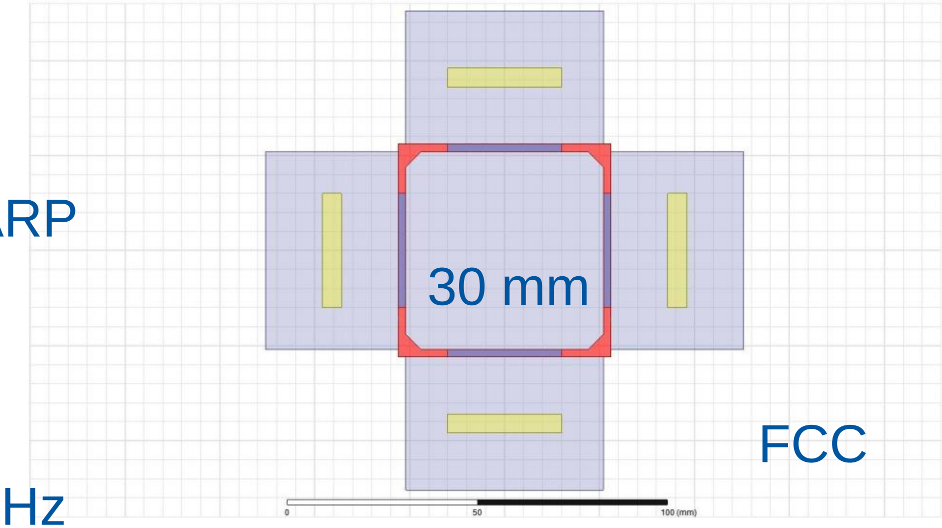
Jani Komppula, Kevin Li

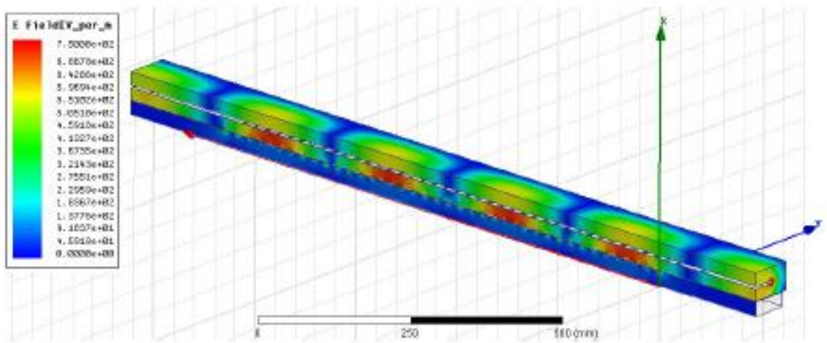
Wolfgang Hofle [CERN]

Transverse feedback system [WP6]

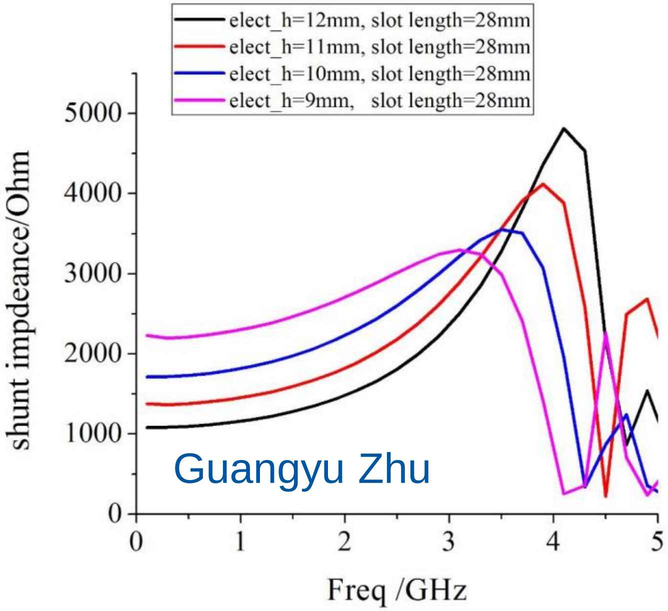
Perspectives: kicker design

- R&D for SPS **intra-bunch feedback** (LIU and US-LARP supported)
  → **Faltin type kicker being built**
  (strip-line with slotted shield to beam pipe)
- Applicable to FCC intra-bunch feedback for up to 4 GHz





SPS prototyping:
J. Cesaratto et al. (SLAC), IPAC'2013
M. Wendt (CERN), IPAC'2017

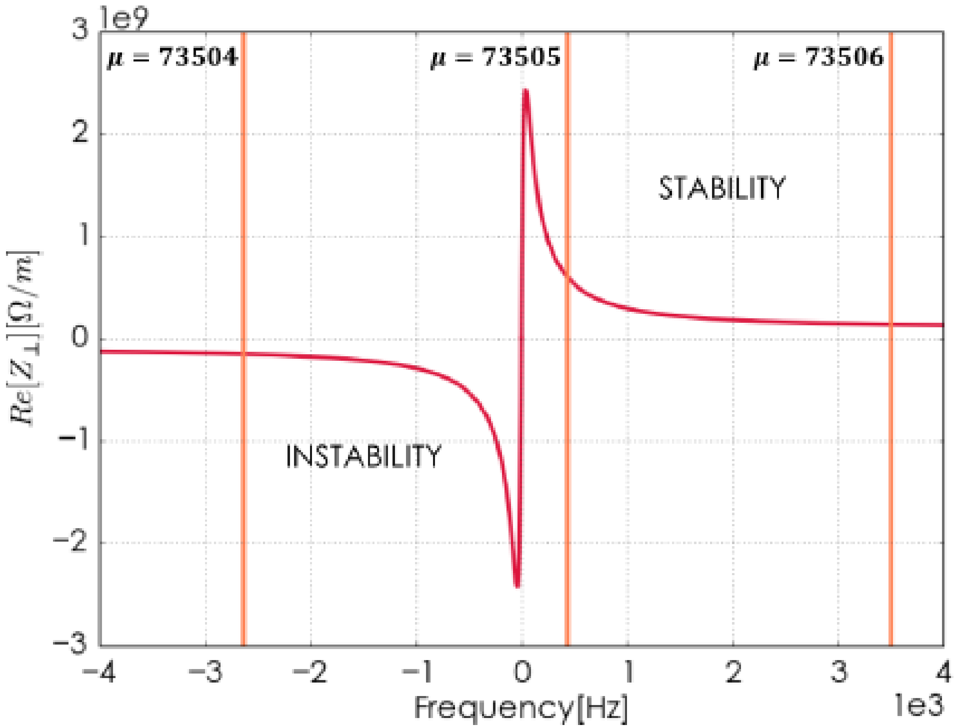


Wolfgang Hofle [CERN]

Transverse feedback system [WP6]

FCCee transverse feedback

- Impedance and **Instability** estimates done
  - M. Migliorati, E. Belli, Univ. Roma La Sapienza
- Strong coupled bunch feedback needed
  - **Fast rise-times of 6 turns** at operation on Z peak (45.5 GeV)
  - Extension of existing technology from B-factories
  - **Feedback design and technologies presented at last meeting in Rome** (A. Drago, LNF-INFN, Frascati)



Impedance spectrum driving resistive wall instability in FCCee
M. Migliorati et al. IPAC’17

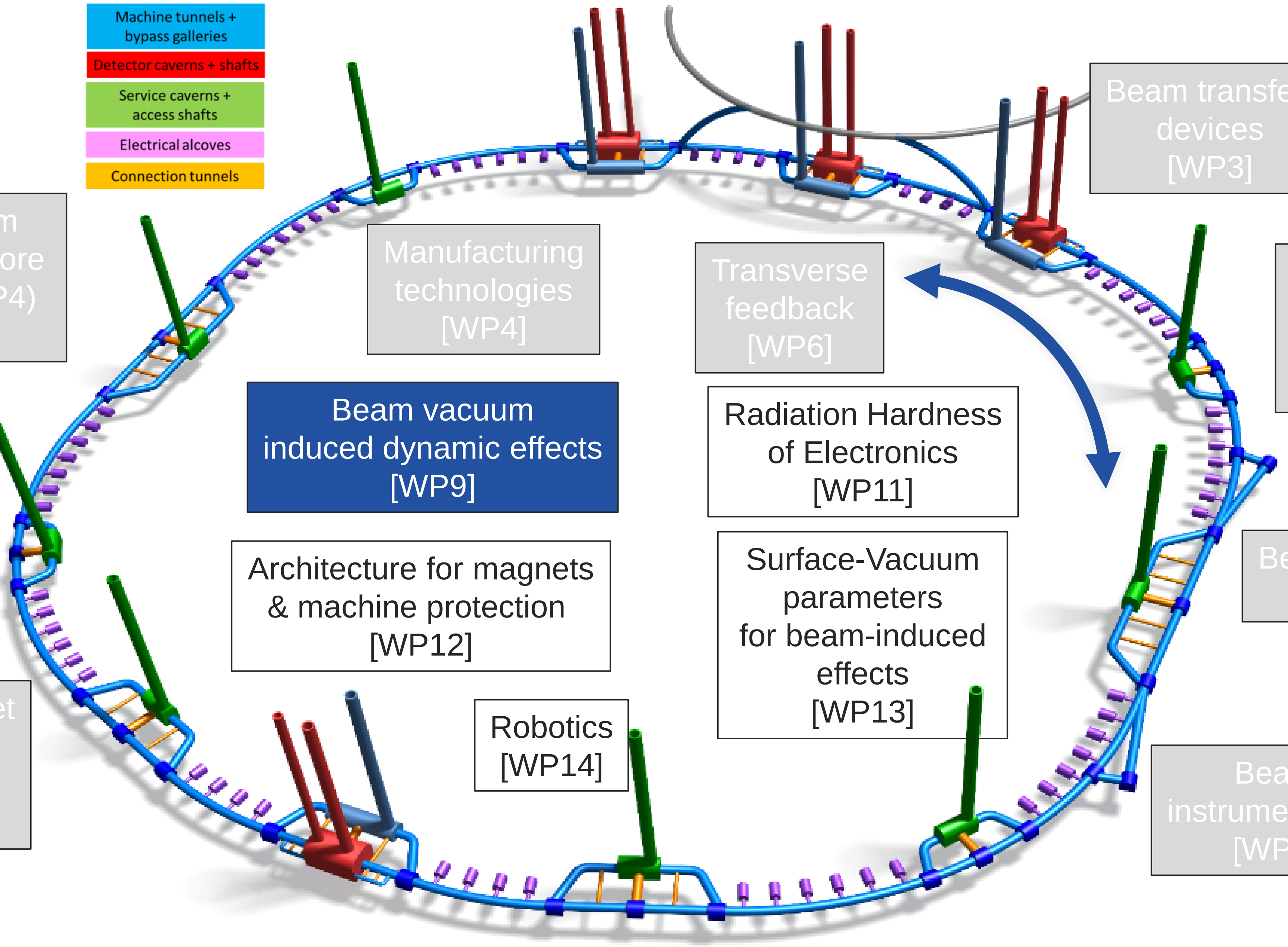
Wolfgang Hofle [CERN]

Transverse feedback system [WP6]

On the way to the CDR contribution

Transverse feedback challenges
• Simulation Results with feedback for FCChh • Kicker Design Options • Signal Processing • Injection Damping for FCChh • Instability mitigation ○ Transverse coupled bunch instabilities for FCChh and FCCee, with fast growth rates ○ Intra-bunch Feedback for FCChh: Electron Cloud and TMC feedback • Need for continued and increased collaboration with experts in the field ○ Leveraging on experience at SLAC and B-factories world-wide (LNF-IFNF Frascati, KEK)

Wolfgang Hofle [CERN]



Beam vacuum Magnet Cold Bore (Eurocircle WP4) [WP1]

CryoPlants efficiency [WP2]

Cryomagnet insulation vacuum [WP10]

Manufacturing technologies [WP4]

Beam vacuum induced dynamic effects [WP9]

Architecture for magnets & machine protection [WP12]

Robotics [WP14]

Transverse feedback [WP6]

Radiation Hardness of Electronics [WP11]

Surface-Vacuum parameters for beam-induced effects [WP13]

Beam transfer devices [WP3]

Normal conducting magnets [WP5]

Beam dumps [WP7]

Beam instrumentation [WP8]

Paolo Chiggiato, Sergio Calatroni & Roberto Kersevan [CERN]

Beam vacuum - induced dynamic effects [WP9]

Scope

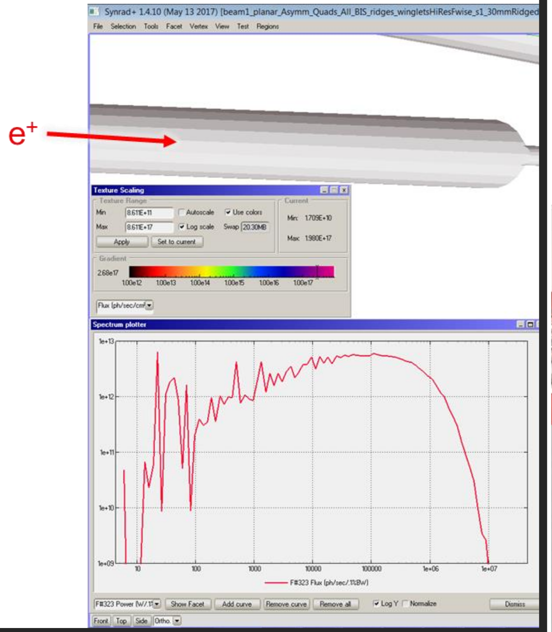
- WP 9.2: Find out the best vacuum system for the **FCC-ee arcs and experimental regions** in terms of performance, feasibility, and costs.
- WP 9.3: **Tl-based superconducting** coatings for the FCC-hh.
- WP 9.4: **HTS coated conductors** for the FCC-hh beam screen.

Paolo Chiggiato, Sergio Calatroni & Roberto Kersevan [CERN]

Beam vacuum - induced dynamic effects [WP9]

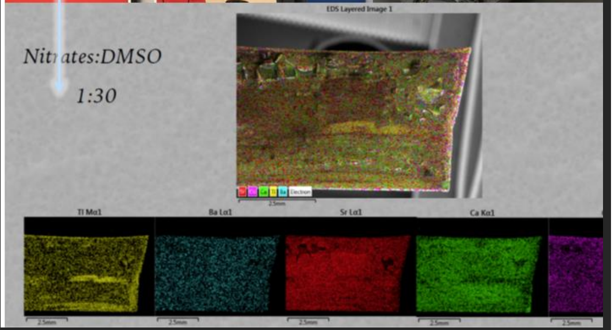
Status report

WP 9.2: Vacuum system for the FCC-ee arcs and experimental regions



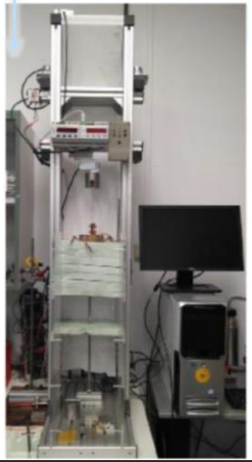
WP 9.3: First Deliverables achieved

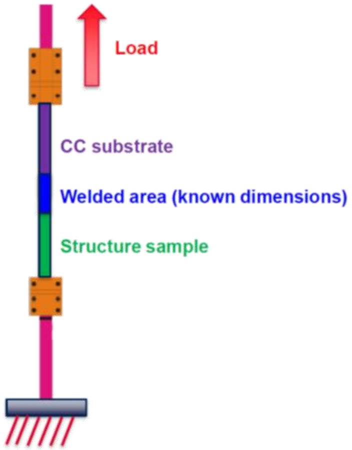
- Laboratory for preparation of Tl-based
- First samples of Tl-HTS are being proc
- New large-area high-resolution Hall-pr
- Next Deliverable: report on precursor

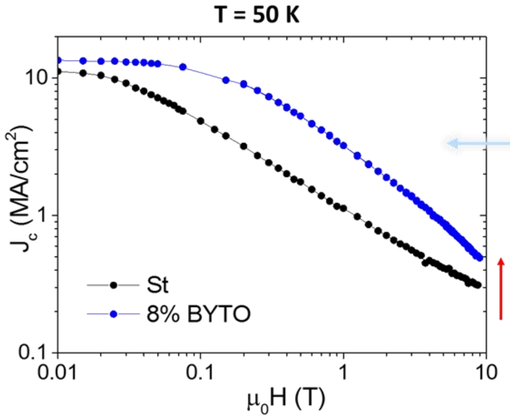


WP 9.4: Collaboration signed, first Deliverables achieved

- Selected REBCO tapes undergoing transport measurements, including nano-engineered tapes for better pinning (higher depinning frequency)
- Development of tensile test machine started, for qualification of assembly process
- First SEY results at room temperature and cryogenic temperature
- RF test device for samples being commissioned (in partnership with Universitat Politècnica de Catalunya · BarcelonaTech)
- Next Deliverable: full definition of RF test system for small samples at 9 T







Beam vacuum - induced dynamic effects [WP9]

Next milestones

Beam vacuum challenges

- **Update the 3D models** and re-run the ray-tracing montecarlo codes for SR and molecular flow (SYNRAD+ and Molflow+, respectively), in order to obtain results consistent with those of other WPs;
- **Collaboration with the MDI working group** in terms of beam-impedance and also special vacuum chamber design in the vicinity of the detectors;
- Start another round of discussions with the working group dealing with **FLUKA analysis**, in order to get updated results for the new lattice configurations;
- Collaboration for the design of beam instrumentation is also to be started: so far no actual design neither of the thousands of BPM blocks, nor of the very delicate areas where the superconducting RF cavities will be installed has been carried out;
- Follow any special design for polarization wigglers and their attendant high-power SR fans, which were responsible for a rather large number of vacuum leaks in LEP…

Paolo Chiggiato, Sergio Calatroni & Roberto Kersevan [CERN]

Beam vacuum - induced dynamic effects [WP9]

On the way to the CDR contribution

[WP9]

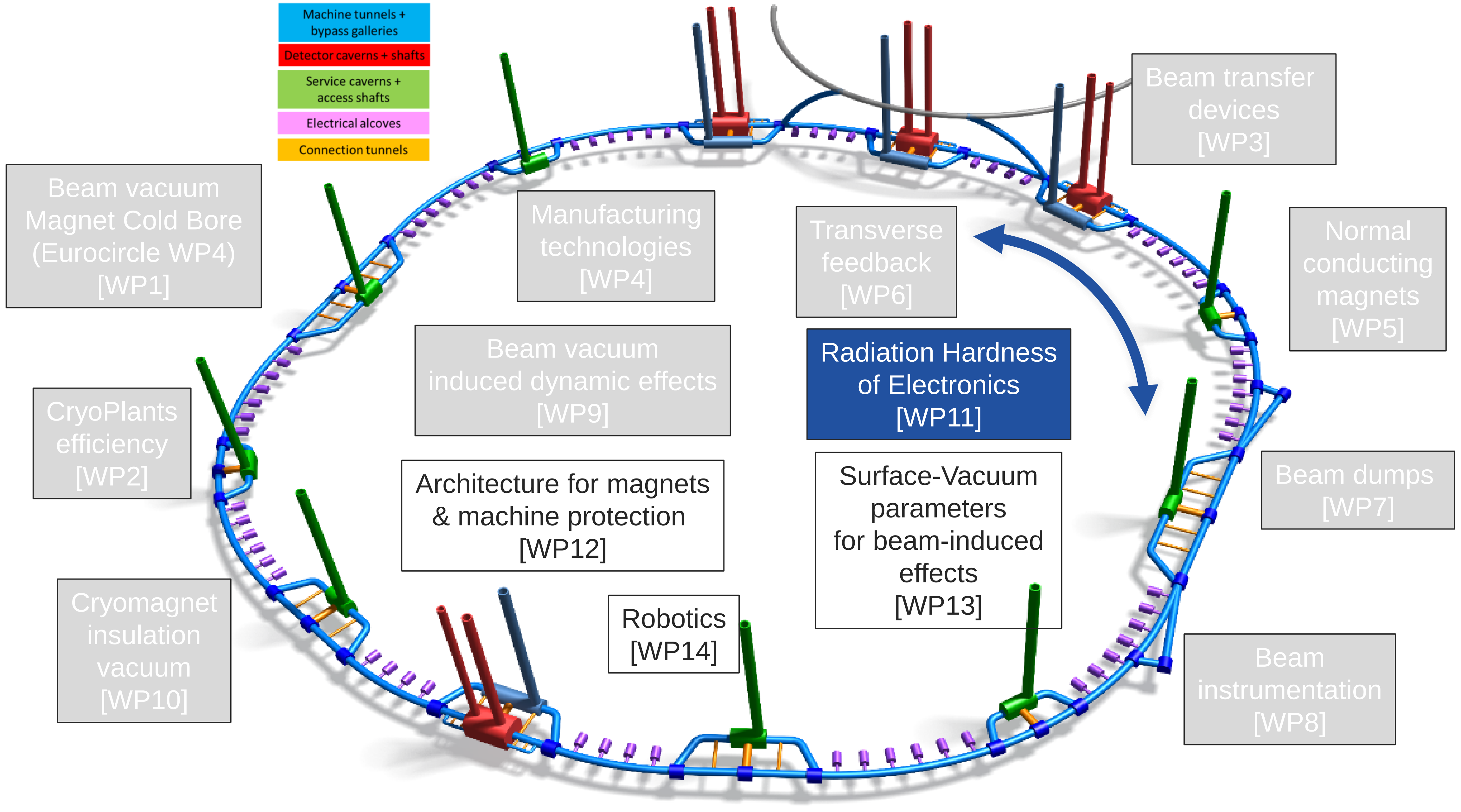
Wed 15:50-16:10
Roberto Kersevan

Thu 08:50-09:10
Ignasi Bellafont

Beam vacuum challenges

- Introduction (with Machine Physics issues related to vacuum)
- Synchrotron Radiation Issues
  - Power density / Photon Flux / Special areas
- Synchrotron Radiation-Induced Gas Loads
  - Distributed absorbers / Lumped absorbers
- Vacuum Chamber Cross-section and Materials: Different Options and Choice
  - Materials: Al, Cu, SS: pros and cons
  - Thin-films: NEG, TiN, amorphous carbon (α-C)
  - Clearing electrodes
- Vacuum Pumping System: Different Options and Choice
  - Distributed pumps (multi-NEG strip, SuperKEKB-like) / Lumped pumps
- Pressure Profiles
- Vacuum Components
  - Low-loss flanges / Low-loss gate valves
  - Special components: masking absorbers for SC cavities; masking for BPM blocks; masking for special components and IR area.

Paolo Chiggiato, Sergio Calatroni & Roberto Kersevan [CERN]



Mar Capeans Garrido [CERN]

Radiation Hardness Assurance [WP11]

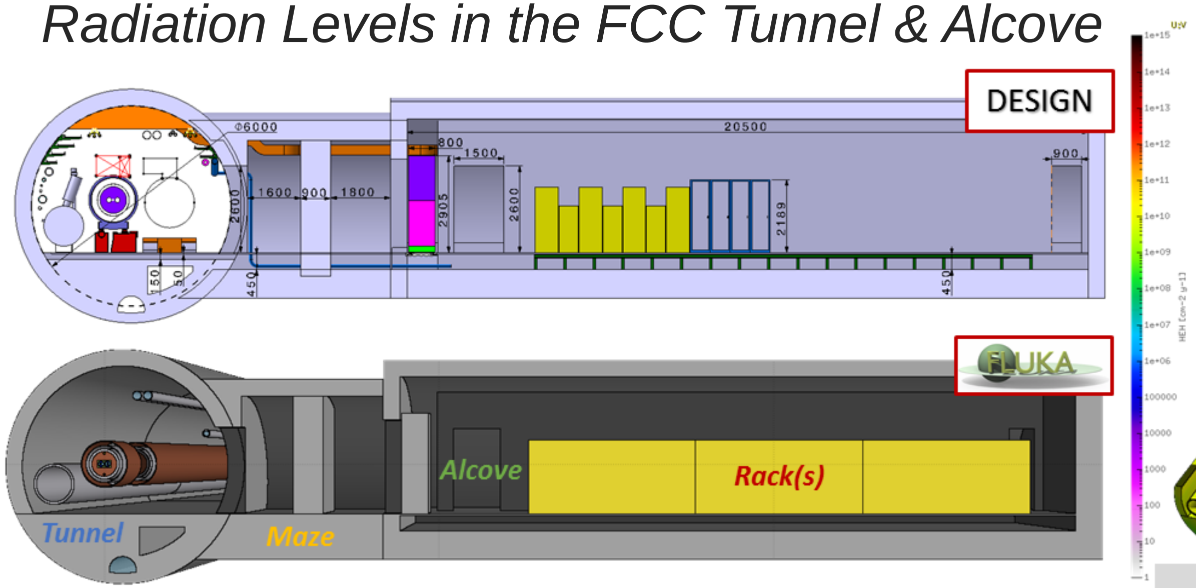
Scope & deliverables

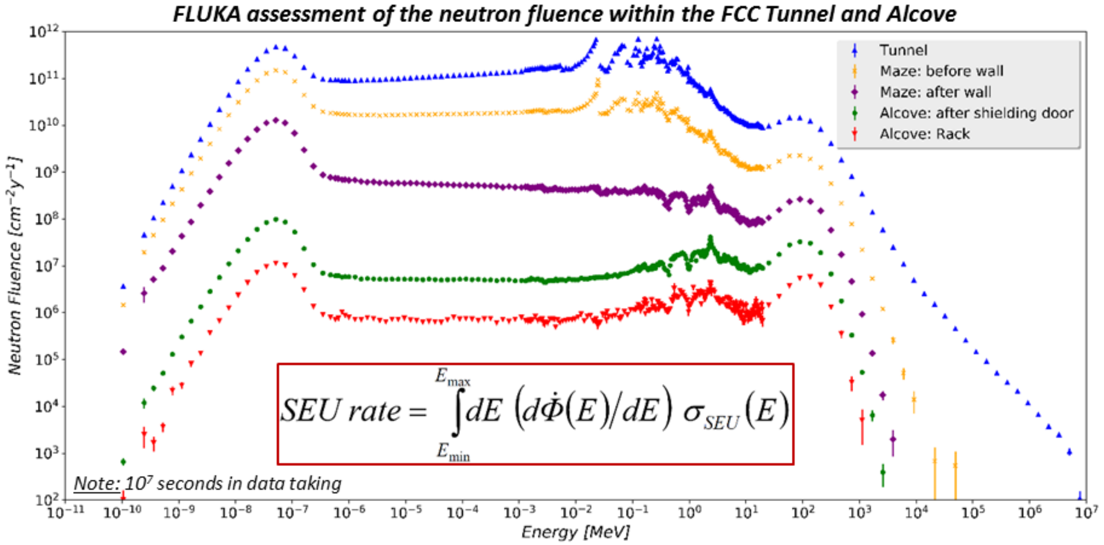
FCC Task 11	Deliverables	Month	By end of	Status
TASK 1 Field conditions and radiation levels at FCC	D1-1. Evaluation of FLUKA models' needs	**M6**	**Mar'16**	✓
	D1-2. FLUKA tuning for FCC	**M12**	**Sep'16**	✓
	D1-3. Agreement on FCC target radiation field/levels	**M14**	**Nov'16**	✓
TASK 2 FCC Qualification Protocols	D2-1. Define overall FCC qualification requirements for RHA	**M12**	**Sep'16**	**ongoing**
	D2-2. Evaluation of current irradiation facilities and testing infrastructure	**M20**	**May'17**	**ongoing**
TASK 3 Equipment needs for the accelerator, detectors, service systems	D3-1. Identification of technologies used at FCC with their expected radiation levels	**M14**	**Nov'16**	**ongoing**
	D3-2. Catalogue of critical equipment (technology, supplier, function, etc.)	**M18**	**Mar'17**	**starting**
TASK 4 Development efforts on radhard components for HL-LHC	D4.1 Evaluate HL-LHC VS FCC needs of rad hard components	**M20**	**May'17**	**ongoing**
TASK 5 New Technologies	D5.1 Prototype status and definition of developments linked to technologies	**M20**	**May'17**	**ongoing**
	D5.2 Radiation tester of advanced components/systems	**M36**	**Sep'18**	**ongoing**
	D5.3 Radiation sensor	**M40**	**Jan'19**	**ongoing**

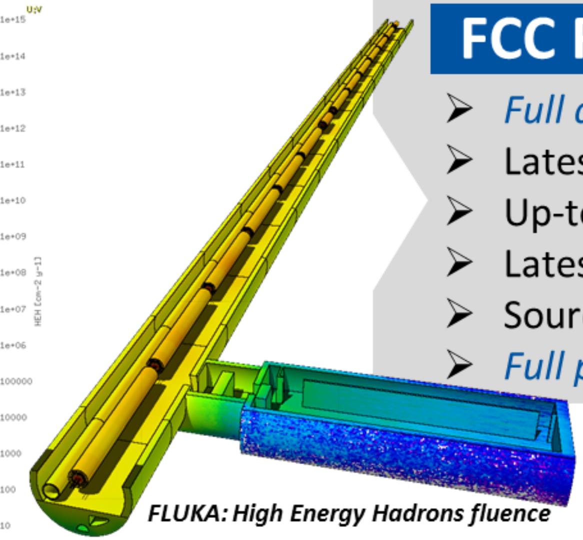
Mar Capeans Garrido [CERN]

Radiation Hardness Assurance [WP11]

Radiation Levels in the FCC Tunnel & Alcove







FCC FLUKA model:

- *Full arc cell*: 12 dipoles + 2 quadrupoles
- Latest layout of *tunnel & alcove* infrastructure
- Up-to-date tentative *gas-density profile*
- Latest design of the *main dipole*
- Source: *Beam-gas interactions @ 50 TeV/c*
- *Full particle transport*

Main achievements:

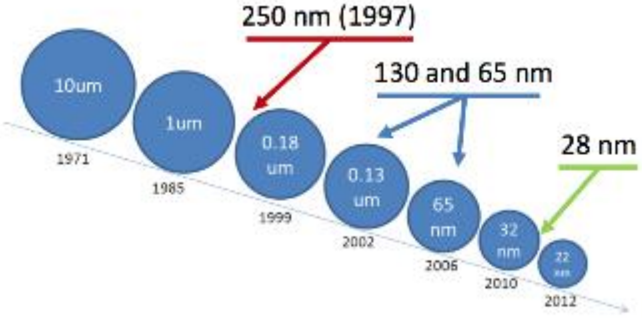
- ✓ *Strong interaction* across many areas of expertise
- ✓ *Design*: FLUKA simulation used for finalising the design of the *tunnel and alcove infrastructure*.
- ✓ *R2E*: assessment of the radiation levels in *critical areas* for electronics:
  - *Dose* (long term effects): below the magnet (power converter) factor ~200 LHC
  - *High Energy Hadrons* (Single Event Effects):
    - Tunnel: below the magnet (power converter) factor ~500 LHC
    - *Alcove:* Fluence *≤ RRs alcove* in LHC Point IP 1/5
- ✓ *Qualification requirements* already beyond current availability

A. Infantino

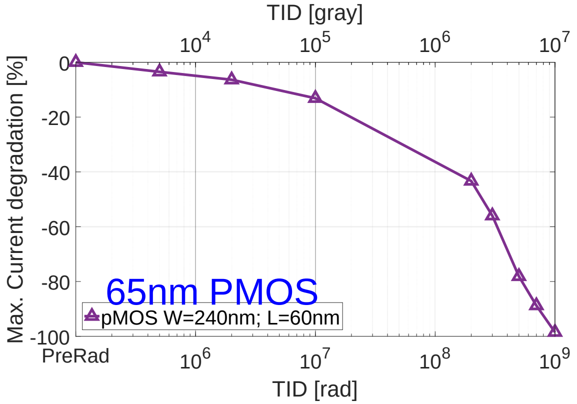
Radiation Hardness Assurance [WP11]

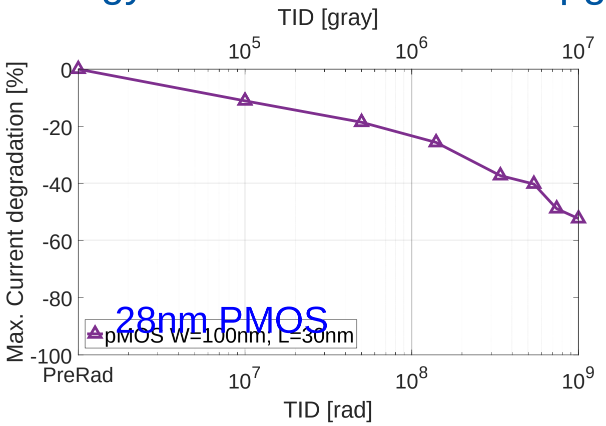
Technology demonstrators

Deep submicron CMOS technologies (F.Faccio, G.Borghello)



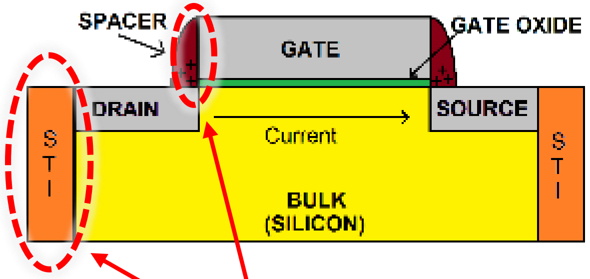
CMOS transistors in sub-250nm nodes have a very thin gate oxide, almost insensitive to radiation effects (Total Ionizing Dose). However the thick lateral (STI) and spacer oxides are still prone to defect buildup that, at very large TID levels, affects the performance of short- and narrow-channel transistors.
The **complex physical mechanisms of radiation effects in the STI and spacer oxides have been studied** in detail in the 65nm technology chosen for HL-LHC upgrades.





Radiation-induced degradation of the on-current in transistors with sizes commonly used in digital design in 65 and 28nm CMOS technologies.

MOSFET Cross Section



First measurements of 28nm transistors evidence a different response to TID, and an overall larger tolerance. Several 40nm and 28nm CMOS processes will be studied to extract possible trends and select the best option for ASIC design.

Radiation Hardness Assurance [WP11]

On the way to the CDR contribution

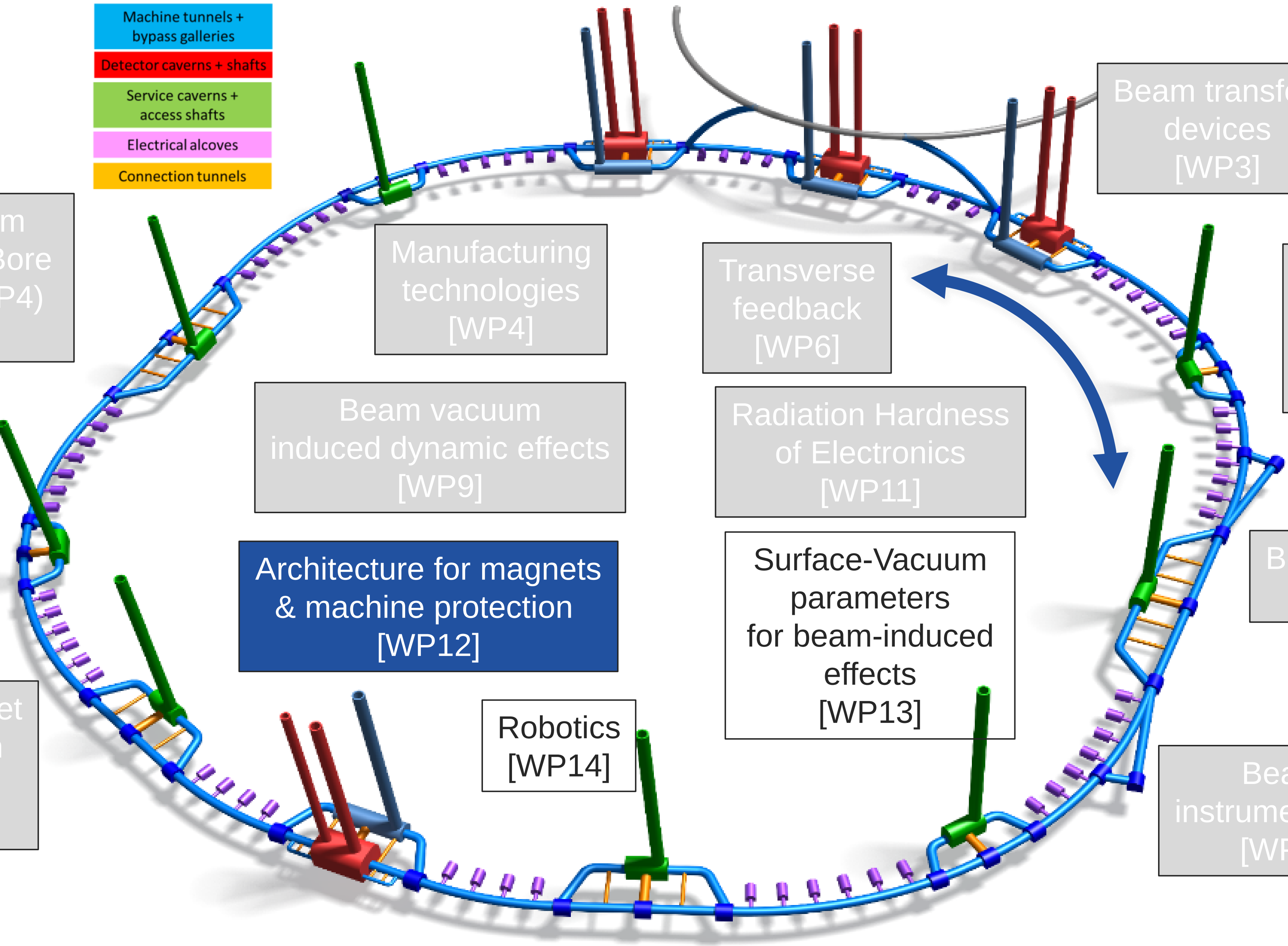
[WP11]

Wed 16:30-15:50
Ruben Garcia Alia

Favor a unique chapter summarizing all RHA for FCC

1. **Field conditions and radiation levels at FCC** (5p)
   - Documentation of Fluka models, tunnel layout and corresponding radiation maps/levels, assessment of radiation levels on critical areas for electronics.
2. **Equipment needs and RHA strategies for the accelerator, particle detectors and service systems.** (5-7p)
   - Catalog of technologies used at FCC and radiation levels they will be exposed to.
   - Strategies for RHA taking into account maintenance, equipment availability and reliability and remote operation.
3. **Qualification Protocols** (5p)
   - Definition of qualification requirements (safety factors, sample size, procedures) for components and systems, including particle detectors and FE electronics. Limitations of COTS-based designs.
   - Limitations of current irradiation facilities and testing infrastructure at CERN and available worldwide; proposal of upgrade programs for facilities at CERN.
4. **Rad-hard technology trends** (5-8p)
   - Communication technologies: ehernet-based, fiber optic-based and wireless solutions.
   - Miniaturization, compactness, Deep submicorn CMOS technologies, On-chip optical/electrical.
   - MGy dosimetry.
5. **Final summary for identified showstoppers and long-term R&D requirements (beyond CDR)** (3p)

Mar Capeans Garrido [CERN]



Beam vacuum Magnet Cold Bore (Eurocircle WP4) [WP1]

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Architecture for magnets & machine protection [WP12]

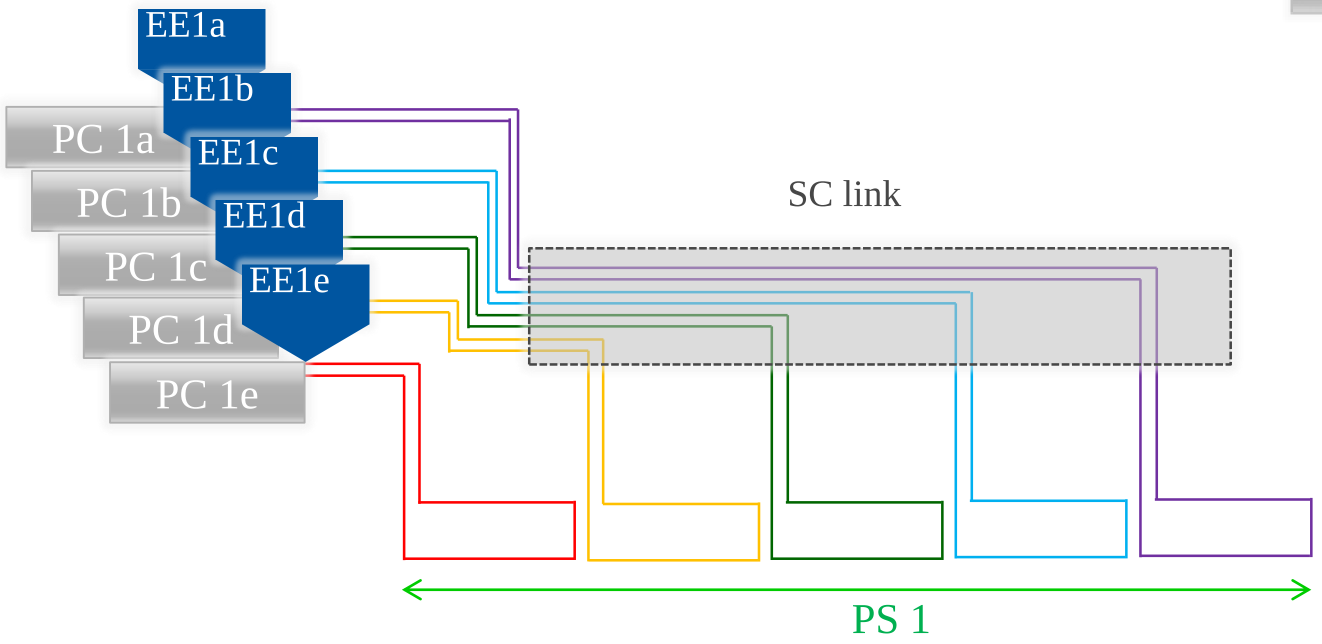
Surface-Vacuum parameters for beam-induced effects [WP13]

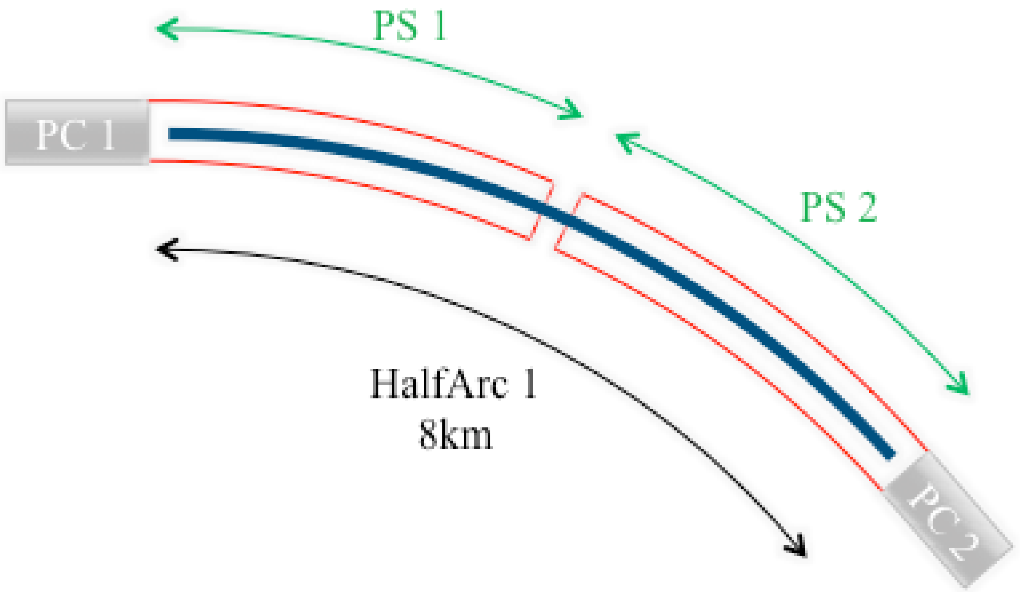
Robotics [WP14]

Andrzej Siemko [CERN]

Studies of the layout of main dipole circuits

Proposal for FCC Powering Sectors (PS)



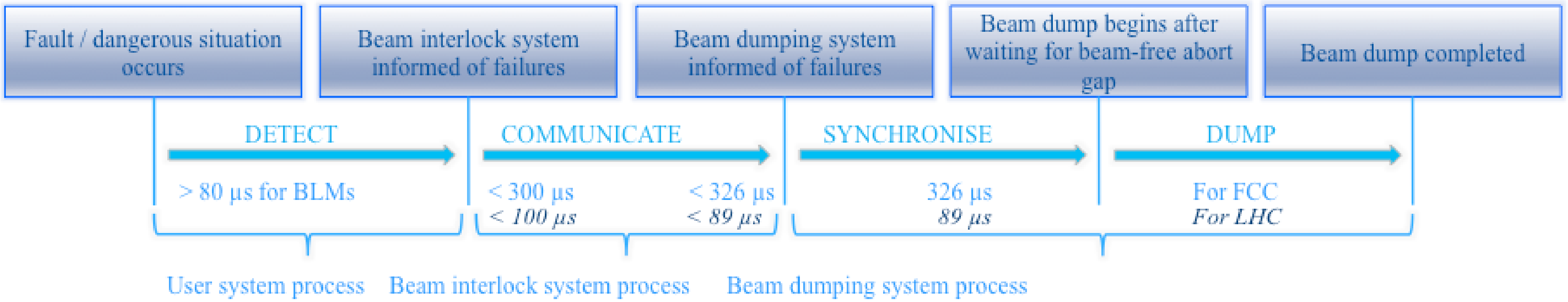


Study of possible circuit layouts to **reduce the stored energy** and **limit the voltage to ground** during the fast power abort

Architecture for magnets & machine protection [WP12]

Concept, architecture of machine protection & interlocks

- Ongoing studies on Machine Protection of the FCC-hh - execution time for a beam dump



Name	Failure scenario	Magnet length	Nominal field	Nominal deflection or focusing strength	Beta-function at magnet	Required time constant of field decay	Comment
Separation dipole 'D1' in IRA / IRG	Powering failure of all the 4 MBXA magnets	12.5 m	4.27 T	0.00032 rad	25 km (left) 61 km (right)	> 33 s	Less critical
Separation dipole 'D1' in IRA / IRG	Quench of 1 magnet	12.5 m	4.27 T	0.00032 rad	61 km (right)	> 100 ms	Need to be careful
Low-β triplet quadrupoles	Quench of 1 magnet (MQXC.3RA)	30.81 m	86 T/m	0.000514 m^{-2}	77 km	> 139 ms	Need to be careful
Main dipole	Quench of 1 magnet	14.3 m	15.92 T	0.001366 rad	335 m (max.)	> 55 ms	Less critical
Main quadrupole	Quench of 1 magnet	6.29 m	357 T/m	0.00214 m^{-2}	350 m (max.)	> 8.6 ms	Less critical
Warm dipole in collimation insertion	Powering failure of MBW.A6R3.B1	9.09 m	1.45 T	0.000079 rad	718 m	> 0.27 s	Less critical
Warm quadrupole in collimation insertion	Powering failure of MQWA.D4R3.B1	8.31 m	29 T/m	0.000174 m^{-2}	1068 m	> 0.023 s	Less critical

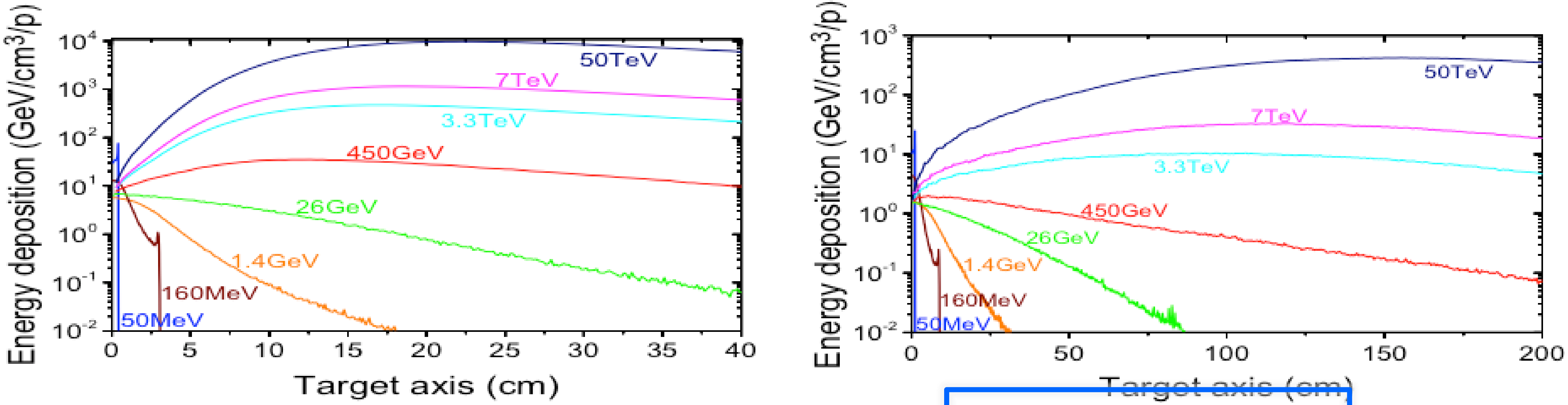
- Studies on Beam Impact & Machine Protection of the FCC-hh
  - Top critical equipment failure modes **(to be continued)**

Andrzej Siemko [CERN]

Architecture for magnets & machine protection [WP12]

Concept, architecture of machine protection & interlocks

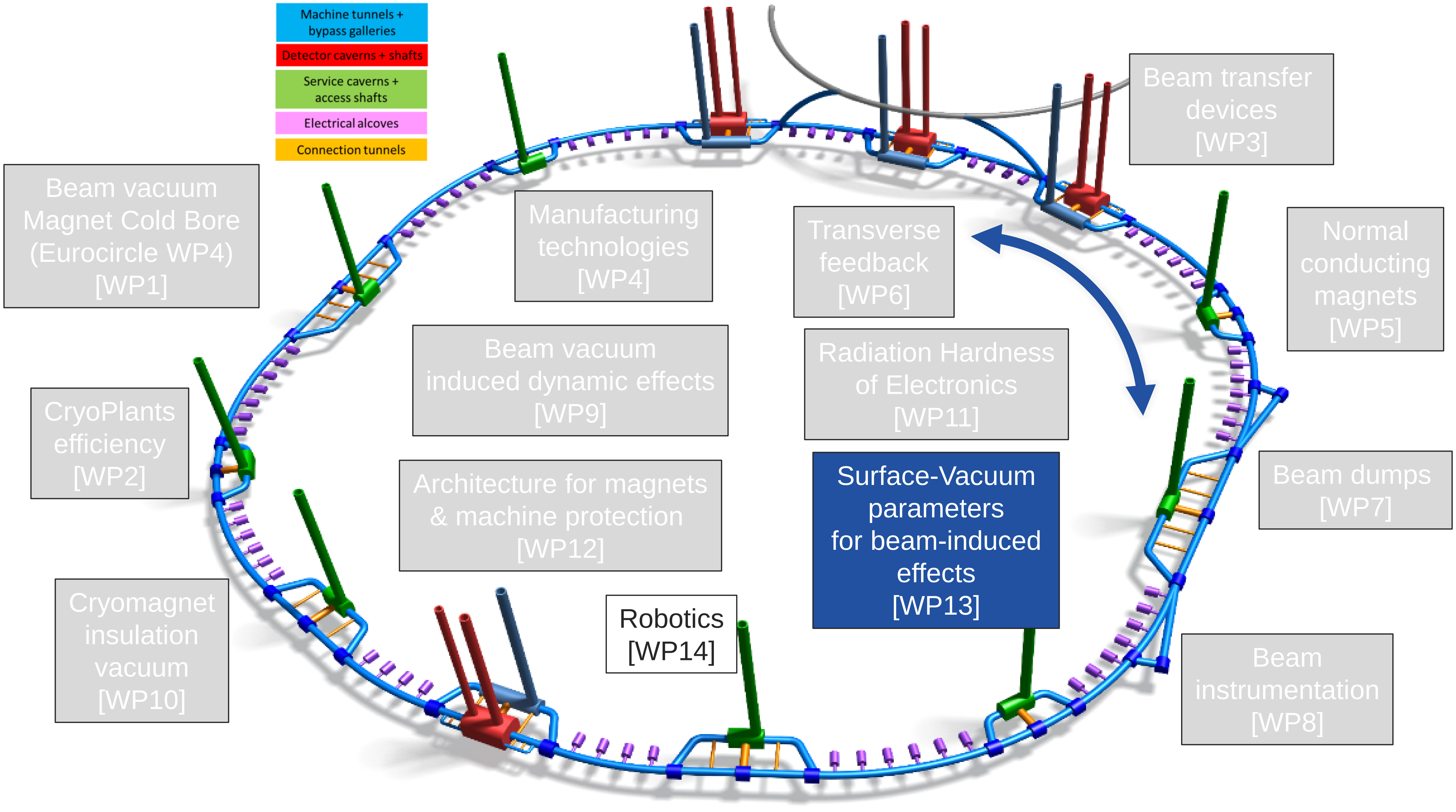
Energy deposition studies: Beam Impact & Machine Protection of the FCC-hh



Energy deposition of proton in typical materials (Left: copper, Right: graphite)

- Beam size $\sigma_{x,y} = 0.2$ mm, beam energy from **50 MeV to 50 TeV**.
- For each energy, another two typical beam sizes were studied, in addition to 0.2 mm.
- **The integral study provides a reference for quick assessment of beam impacts on 'targets' in FCC-hh and its injector chain.**

Andrzej Siemko [CERN]



Paolo Chiggiato, Vincent Baglin, Mauro Taborelli & José Miguel Jimenez [CERN]

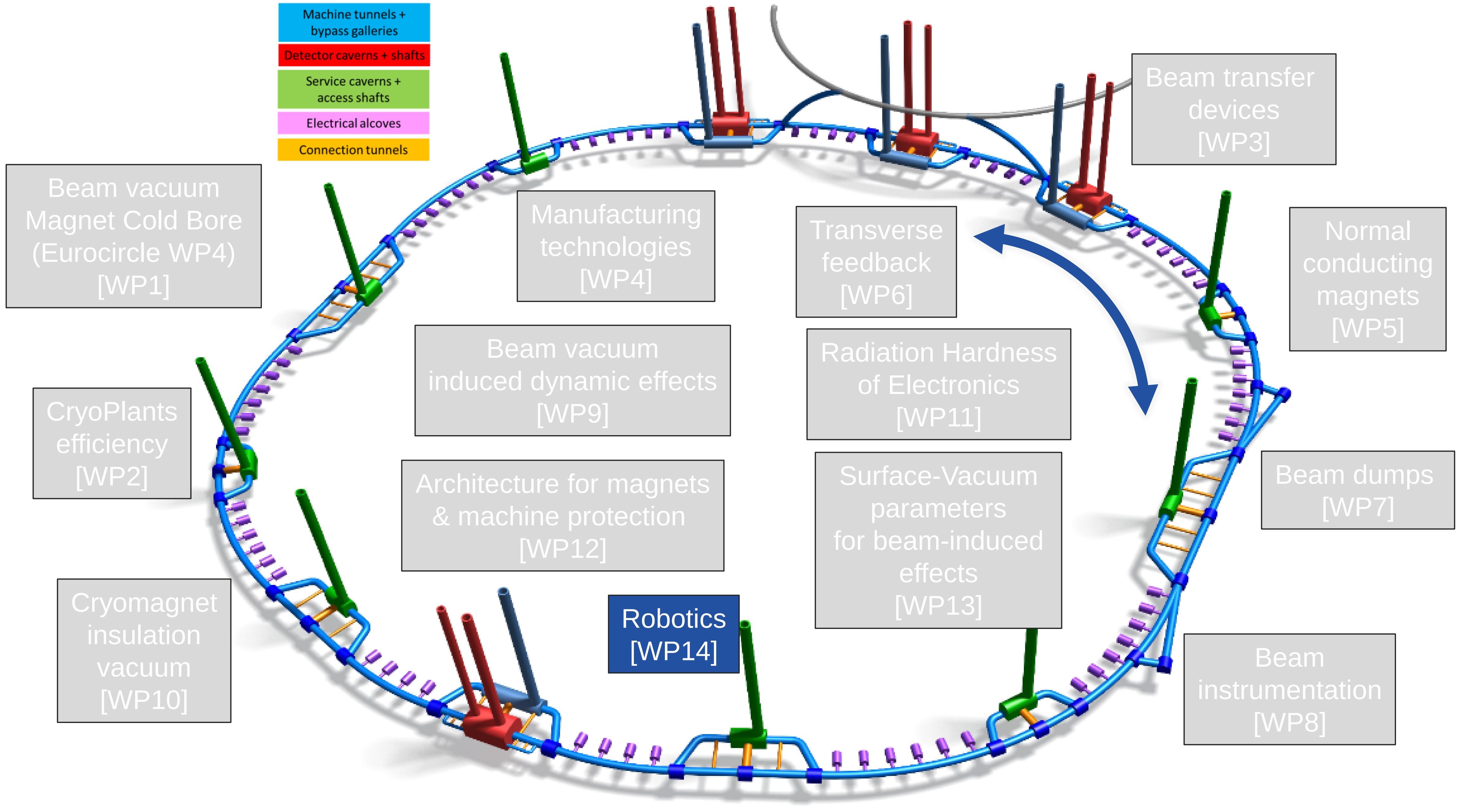
Surface-Vacuum parameters for beam-induced effects [WP13]

On the way to the CDR contribution

Scope	Surface-Vacuum parameters challenges

• Designs of beam pipes and their vacuum systems are based on simulations on the **thermal**, **mechanical**, **gas density**, **electron cloud** and **impedance** behaviours.
• **Simulations need precise inputs** and surface characteristics are those known with the lowest degree of precision with respect to thermal and mechanical properties.
    • Desorption properties: Electron, ion, and photon induced desorption at different temperatures and gas adsorption loads.
    • Thermal properties: Emissivity and photon interaction (reflection and absorption)
    • Electron cloud: photoelectron yield and secondary electron yield as a function of surface temperature, gas load, electron dose and applied magnetic field; and SE energy distribution.
	• Evaluation of set-up at CERN and propose internal investment or external collaboration to **cover the whole spectrum of measurements**.
	• Select the **materials and surface treatments** of importance for the FCC-hh.
	• Identification of **key simulation parameters** and analysis of impacts for the outcome of their simulations.
	• Induce desorption at **different temperature** (whenever possible and relevant) for the selected materials.
	• **Reflectivity** of FCC-hh synchrotron radiation.
	• **PEY** and **SEY**, possibly **angle** resolved, at variable **temperature**, magnetic **field**, **gas load** and **electron dose**.

Paolo Chiggiato & José Miguel Jimenez [CERN]



Simone Gilardoni [CERN]

Remote handling impact on Accelerator design & infrastructures [WP14]

Scope and resources

CERN (EN-STI)
M. Di Castro
A. Masi
S. Gilardoni
M. Calviani
K. Kershaw

3 work packages:

- 14.1 Integration study for the **remote handling/manipulation**
- 14.2 Development of the remote handling concepts
- 14.3 Dissemination of guidelines for best practice on **mechanical design** and process optimizations **compatible with robotic tele-manipulation**

Scope:

- Evaluate the **compatibility of the LHC integration** with remote handling and propose a new concept of acceleration-infrastructure interface which will ease this remote handling.
- Analyze the methods and the procedures to be used in the design of new equipment or preparation of dismantling and installation of new devices in order to **optimize their dismantling**, **installation**, **maintenance**, and **operation**, including exchange, handling and transport activities with respect to individual and collective dose to personnel.
- Definition of guidelines for the design of novel devices and procedures will be focused on the **compatibility with future robotic and remote handling** solutions for tele-operation

Timeline

- **2018:** review of existing experience on accelerator complex. Definition of **work plan** for following years.
- **2019:** Guidelines definition for generic HW design. **Simulation of most representative cases for Robotic interventions** FCC specific.
- **Beyond 2019:** **Technology revision**, R&D. By 2025 technology should be defined to follow installation.

Simone Gilardoni [CERN]

Remote handling impact on Accelerator design & infrastructures [WP14]

On the way to the CDR contribution

Next steps	Remote handling challenges

• Task 1: **Development** of the remote handling concept, including:
  • Identification of possible robotic solutions compatible with the needs of future remote handling needs in FCC. These solutions will be then customized for each common needs , i.e. design of specific tools, integration of the robotic solutions for the specific interventions.
• Task 2: **Integration** study for the remote handling/manipulation
  • Integrate the remote handling/telemanipulators in the tunnel cross section to reserve space.
• Task 3: **Dissemination** of guidelines:
  • Dissemination of guidelines for best practice on mechanical design and process optimizations compatible with robotic tele-manipulation
	• Robotics for interventions in harsh environment
	• Existing applications, technologies handling technologies in accelerator domain
	• FCC specific case: robotic systems for 100 km machine
	  • Guidelines for HW design for robotic installation and maintenance
	  • Which robotic technologies
	  • RP and geological/geometers survey
	• Safety aspects, availability and reliability
	• Future of robotics
	• Robotic support for Fire-Brigades/Safety related interventions
	  • Robotics for reconnaissance
	  • interventions and human guidance
	  • human health monitoring at distance

Simone Gilardoni [CERN]

Wednesday afternoon

"Gardenlounge I/II and LA Café" 12:00

14:00

- Physics benchmarks and detector specifications
- Radiation environment — "Bellevue"
- FCC-hh Detector Magnets System baseline and variants
- FCC-hh Detector Magnet and Detector Integration

- Beam transfer technology challenges, includin...
- Collimators and dumps for FCC-hh
- Design studies for the FCC-hh beam dump
- Hydrodynamic tunneling studies for...
- David Woog — Magnetic core and s...

15:00 Coffee break — "Wintergarten" 15:00

16:00

- Tracker design overview
- Tracker performance studies
- Muon systems — "Bellevue"
- Trigger & Data Acq... — Jim Brooke

- Progress with the cryogenic vacuum s...
- Proposal and simulation of the FC...
- Summary of the requirements the FC...
- Status overview of the radiation hardness a...

17:00 Teatime — "Wintergarten"

Thursday morning

09:00

- Jana Faltova — Electromagnetic calorimet...
- Hadron calorimetry at the FCC-hh experiment
- Digital Electromagnetic Calorimetry at the FCC-hh — Tony Price
- A high granularity hadronic calorimeter for multi TeV jets

- Test of FCC-hh beam screens at the ANKA beam...
- Photon tracing and... — Ignasi Bellafont
- Thermo-mechanical simulation of the FCC-hh b...
- Cold plasma spray applic... — Cedric Garion
- Vacuum characterisation of 3D prin... — Julien Gargiulo

- Civil enginee... optimisation development
- Supply and distribution of electrical e...
- A ventilation system for the FCC
- Cryomagnet transport — "Bellevue"

10:00 Coffee break — "Wintergarten"

11:00

- Shape memory alloys for remote connection of beam pipes in radio... — Fabrizio Niccoli
- High field normal conducting massless sept...
- FLUKA Montecarlo modelling of the FCC arc cell: radiation environment...
- Reflectivity and Photo Yield measurements of technical surfaces. — "Tiergarten I-II-III"

- Overview of injector complex — John Seeman
- Linac and damping ring — Salim Ogur
- e+ system — "Charlottenburg I-II"
- Prebooster ring — Ozgur Etisken
- Booster ring — Bastian Harer — "Charlottenburg I-II"

- Overview of t... development — "Bellevue"
- Design and s... 15 T demons...
- Design and status of canted cosθ
- Common coil design update — "Bellevue"

Thursday afternoon

"Gardenlounge I/II and LA Café"

14:00

- Design status for ... — Kei SUGITA
- First experimental results with a... — Dr. Daniel Barna
- Design of 6 T superconducting dipole for...
- FCC-ee Warm magnets design — Attilio Milanese
- Magnet development for FCC detectors

- Towards a conceptual design for FCC cryogenics — "Bellevue"
- Cryogenic refrigeration with neon-helium mixtures for... — Steffen Kloeppel
- Technical specifications for industry studies on the FCC cryogenic system — Francois Millet
- Cryogenic distribution for FCC-hh — Pawel Duda

- FCC-eh Configuration and Performance — Oliver Bruning
- Detector Design — Peter Kostka
- IR design — Oliver Bruning — "Charlottenburg I-II"
- Civil Engineering for FCC-eh IR
- PERLE ERL Facility Design — Max Klein

- Developme... and timing
- Radiation hard scintillator — "Pavillon"

15:00 Coffee break — "Wintergarten"

16:00

- FCC-hh operation schedule and turn-around... — Arto Niemi
- FCC availability and integrated luminosity — "Tiergarten I-II-III"
- FCC safety strategy for the CDR — Thomas Otto — "Tiergarten I-II-III" 16:15 - 16:40
- Radioprotection matters — Markus Widorski

- Hard QCD, PDFs and EW — Daniel Britzger — "Charlottenburg I-II"
- SM and BSM Higgs — Uta Klein
- Top Physics — Orhan Cakir — "Charlottenburg I-II"
- New Physics — "Charlottenburg I-II"
- High Density and eA Physics — "Charlottenburg I-II"

- Baseline parameters — "Pavillon"
- Optics development for HE-LHC — Yuri Nosochkov
- HE-LHC Triplet — "Pavillon"
- Nonlinear analysis and ... — Demin Zhou
- HE-LHC photon flux electron cloud

- Magnet sta... CDR — "Bellevue"
- Cost mode... the CDR
- Conductor status towards th...

17:00 Teatime — "Wintergarten"

Closing remarks

- Progress made towards identification of critical items…
  - It's an iterative process… decided to add ***Surface-Vacuum*** and ***Robotics*** work packages
- Scope, deliverables and milestones were compiled…
  - and **adjusted for Berlin WS in view of the CDR**.
- CERN Resource impact evaluated…
  - and **commitments have been confirmed**.
- Scenario "à la carte" is favoured, come and talk with us… never too late !
  - for once, Technologies allow ***conceptual dreams***.
- Same dynamic observed with Partners…

Dream the next generation of Accelerator Components… take off!

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FCC Special Technologies Work Package

Dr. José Miguel JIMENEZ
Dr. Olivier BRUNNER

Thanks to all contributors…

Dr. José Miguel JIMENEZ (Coordinator)
CERN, Technology Department
Dr. Olivier BRUNNER (Deputy Coordinator)
CERN, Beams Department

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