FUTURE CIRCULAR COLLIDER

Technical design and priorities

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CERN

SY workshop

FUTURE CIRCULAR COLLIDER
Innovation Study

4 October 2024

http://cern.ch/fcc

CERN

Content

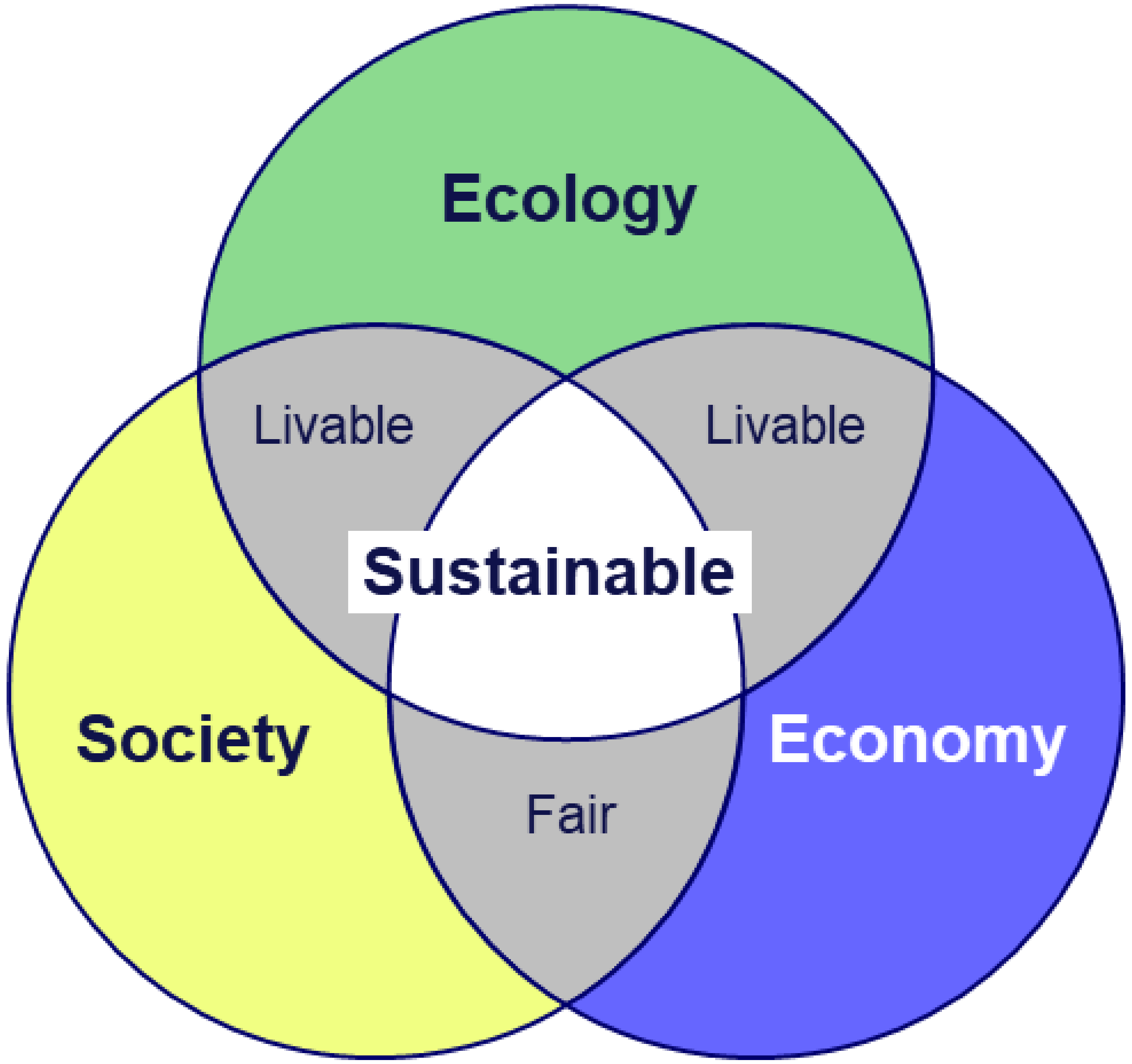
- FCC-ee update
- FCC-ee Pre-TDR at MTP2024
- FCC-ee Pre-TDR work package description
- FCC organisation
- FCC sustainability studies

FCC-ee UPDATE

Sustainability as key aspect of the project

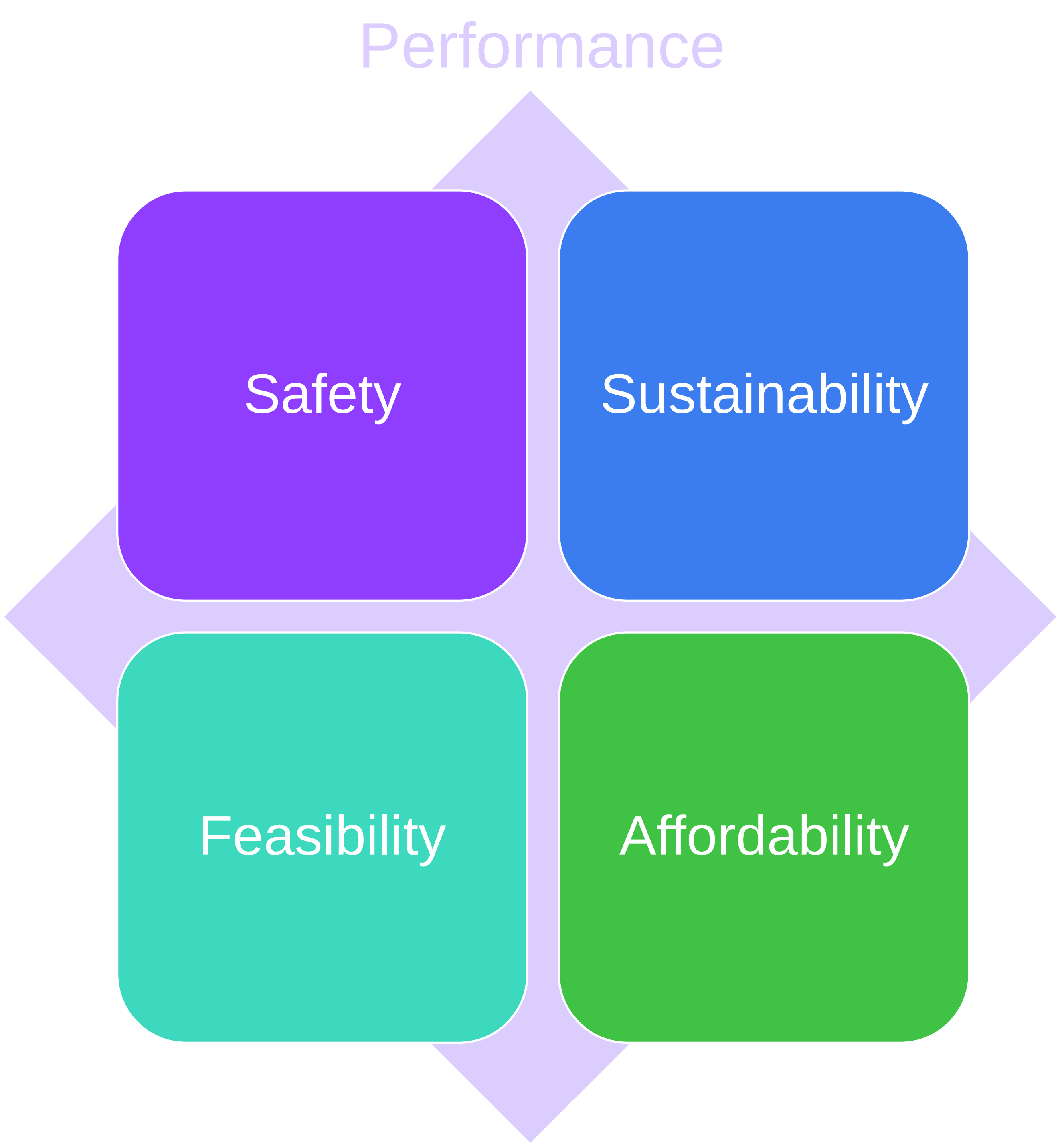
Energy and sustainability

The Future Circular Collider is under study and its sustainable development is a major focus toward its approval. Sustainability is introduced at all levels, from renewable energy sources to the design of accelerator system devices and technical infrastructures. The indirect emissions from purchased electricity have to be minimized by low-carbon sources such as the ones of the FCC construction. The study of waste heat supply to local communities will also be highlighted as well as the OpenSky laboratory to demonstrate the reuse of molasse. The collaborative works performed in the European Project; Research Infrastructure 2.0 framework will demonstrate the physics community's commitment toward sustainable research.



Engineering challenges

➢Safety	Develop safe concepts
➢Sustainability	Reduce the environmental impact
➢Feasibility	Identify challenges and propose solutions
➢Affordability	Cost optimisation
➢Performance	Reach physics objectives



Design focused on these criteria

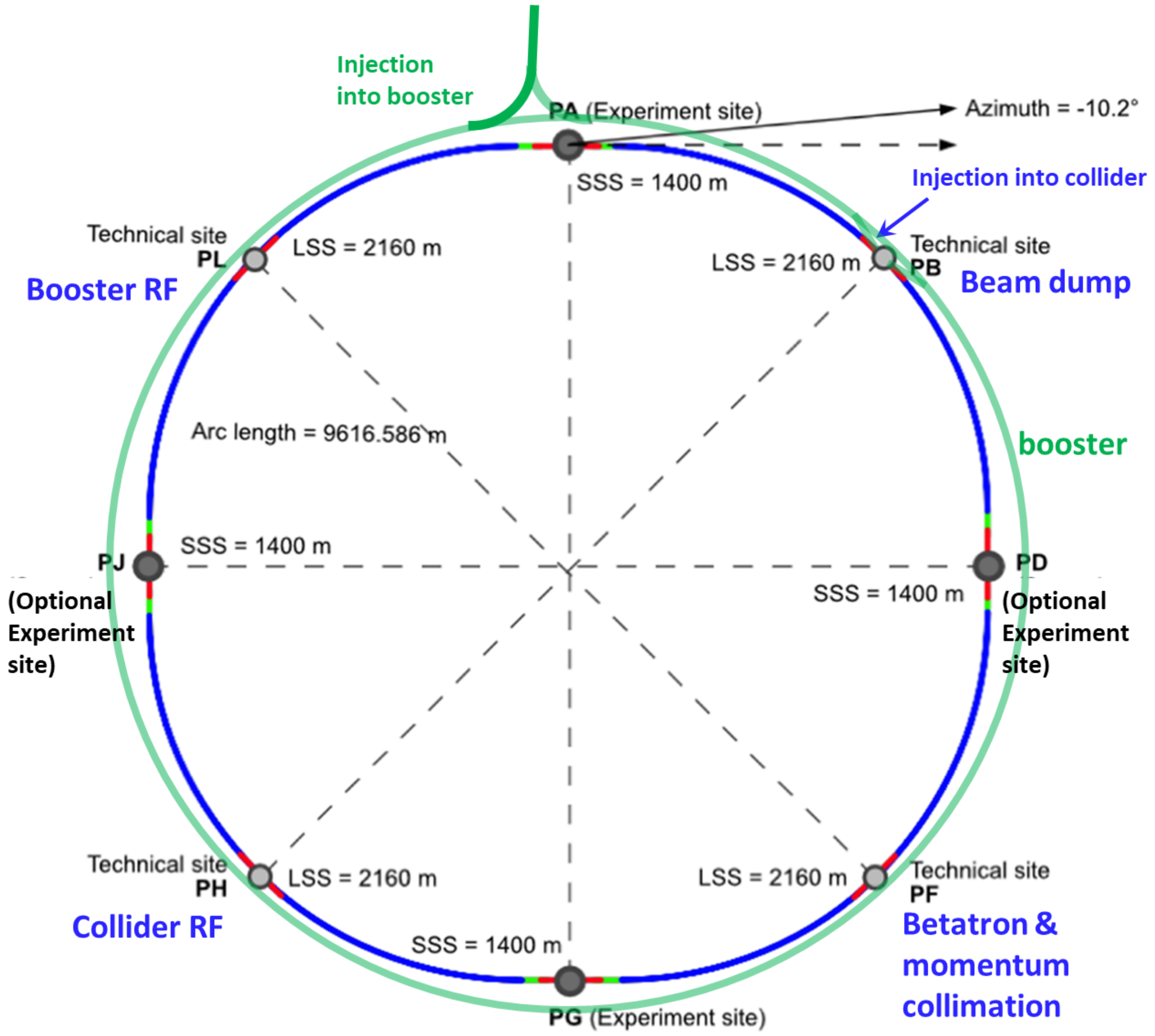
Energy Management and Sustainability Aspects for FCC, ESSRI2024

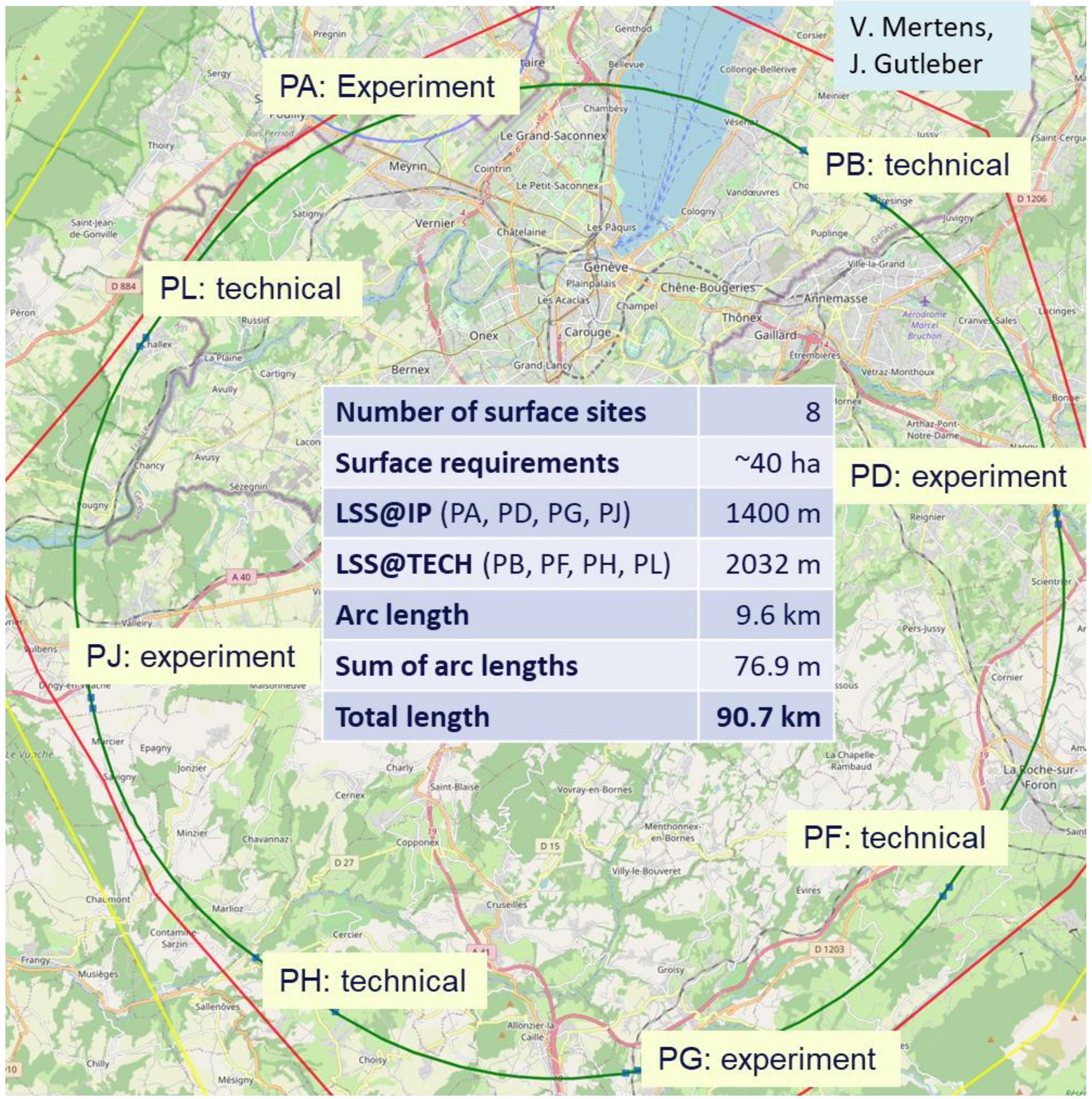
Reference layout PA31 – 90.7km

Layout chosen out of ~ 100 initial variants, based on **geology** and **surface constraints** (land availability, access to roads, etc.), **environment,** (protected zones), **infrastructure** (water, electricity, transport), **machine performance** etc.

"Avoid-reduce-compensate" principle of EU and French regulations

Overall lowest-risk baseline: 90.7 km ring, 8 surface points, 4-fold symmetry





Number of surface sites	8
Surface requirements	~40 ha
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**90.7 km**

FCC-ee underground schematics

Tunnel Circumference: 90.7 km

Excavated vol: 6.2M m³ (In the ground)

Access shafts: 12

Construction shafts: 1

Large experiment sites: 2

Small experiment sites: 2

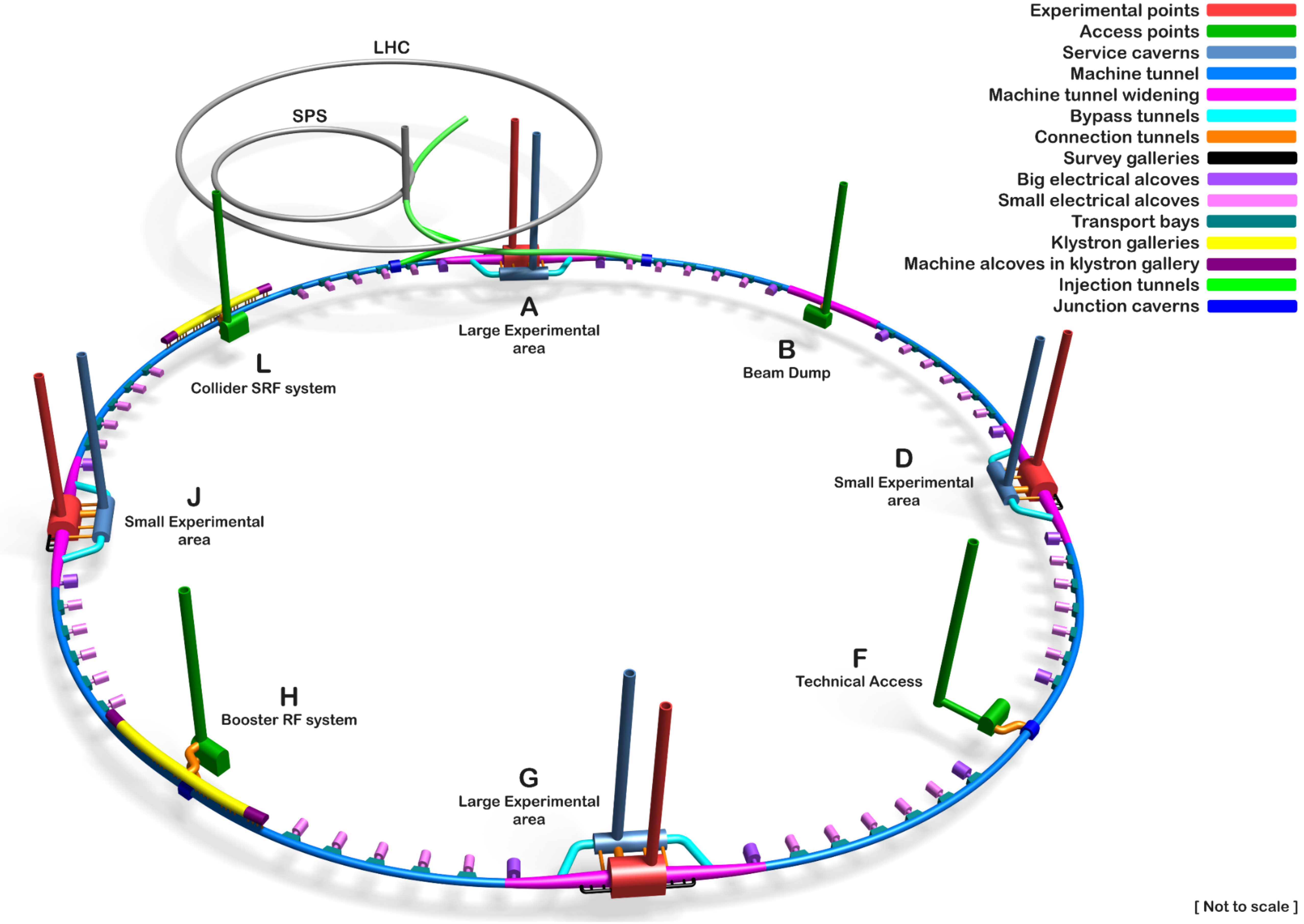
Technical sites: 4

Deepest shaft: 400m

Average shaft depth: 243m

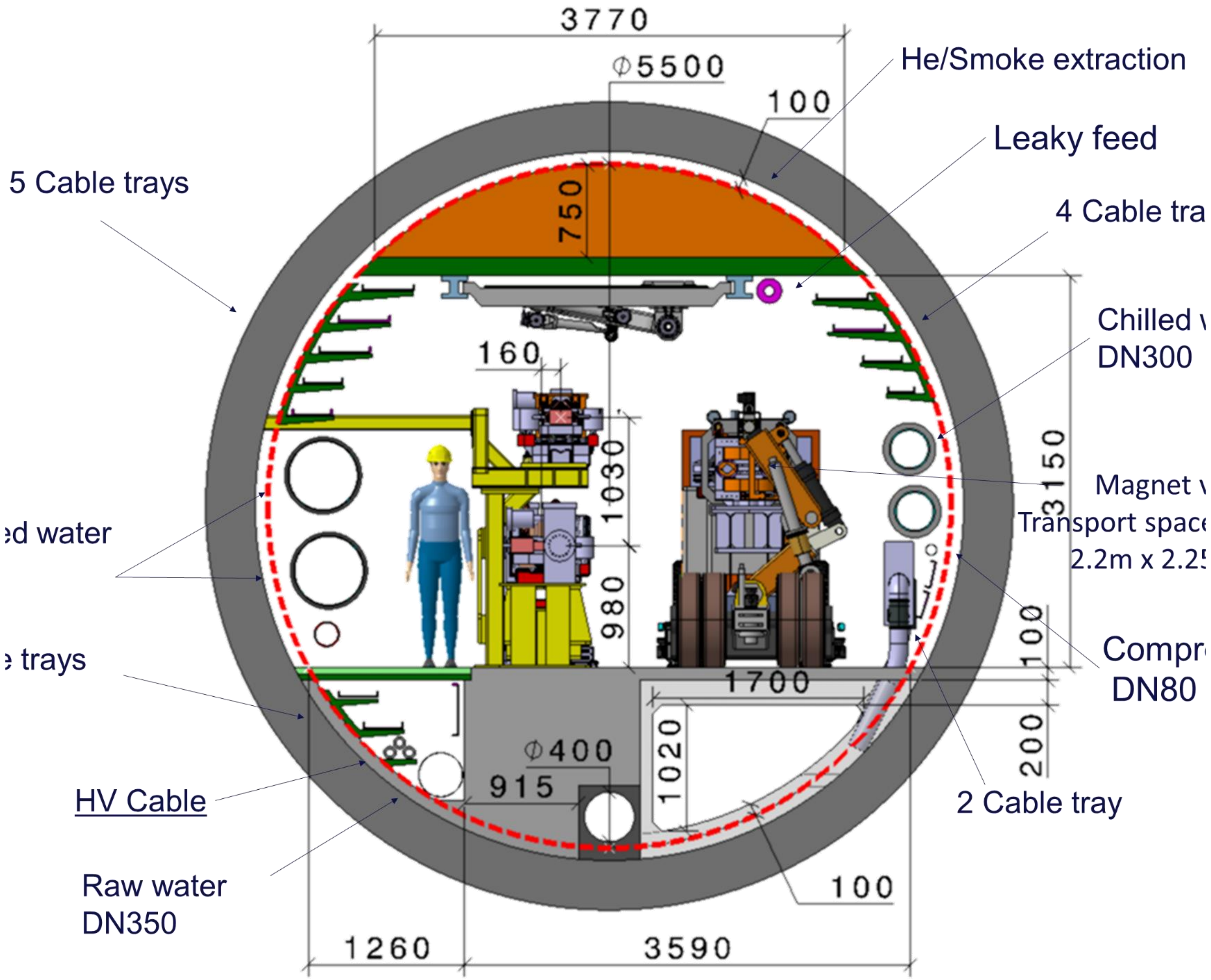
Total concrete volume: 1.9 M m³

Steel weight: 130,000 metric tonnes

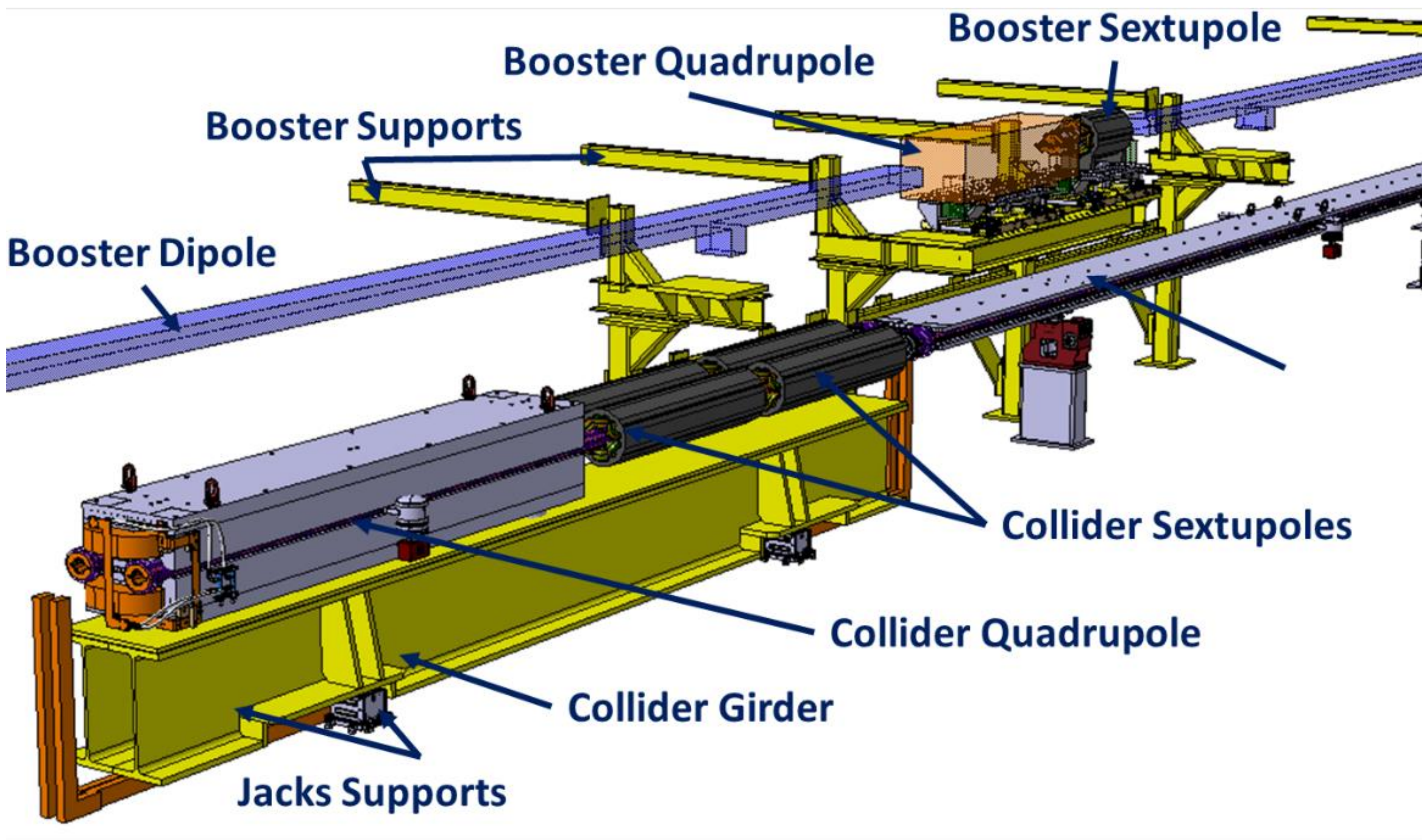


Update of integration

Cross-section of the arc tunnel (11km)



Magnet and support design

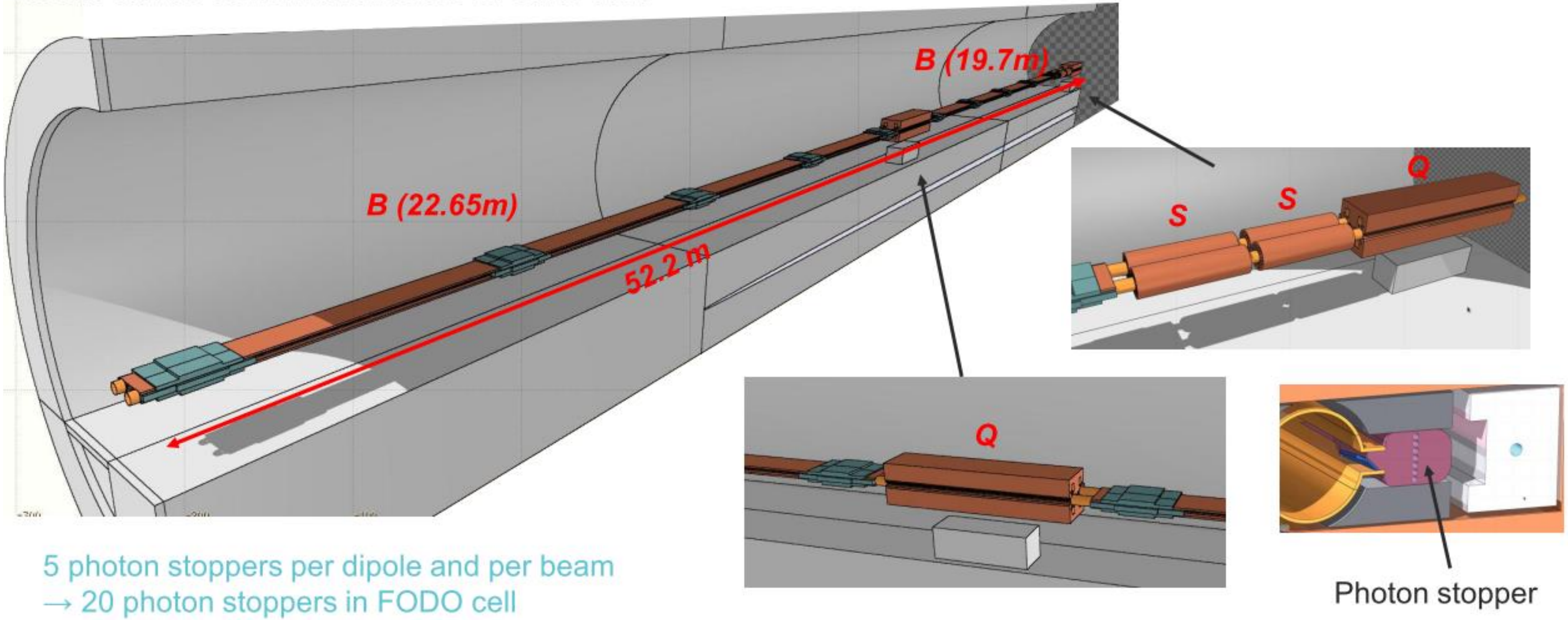


FLUKA model of FODO cell (ZH, ttbar)

Synchrotron radiations absorbers and shielding

Courtesy A. Letchner

Studied one type of FODO cell of GHC lattice (B-Q-B-S-S-Q), results can be somewhat different for other cells



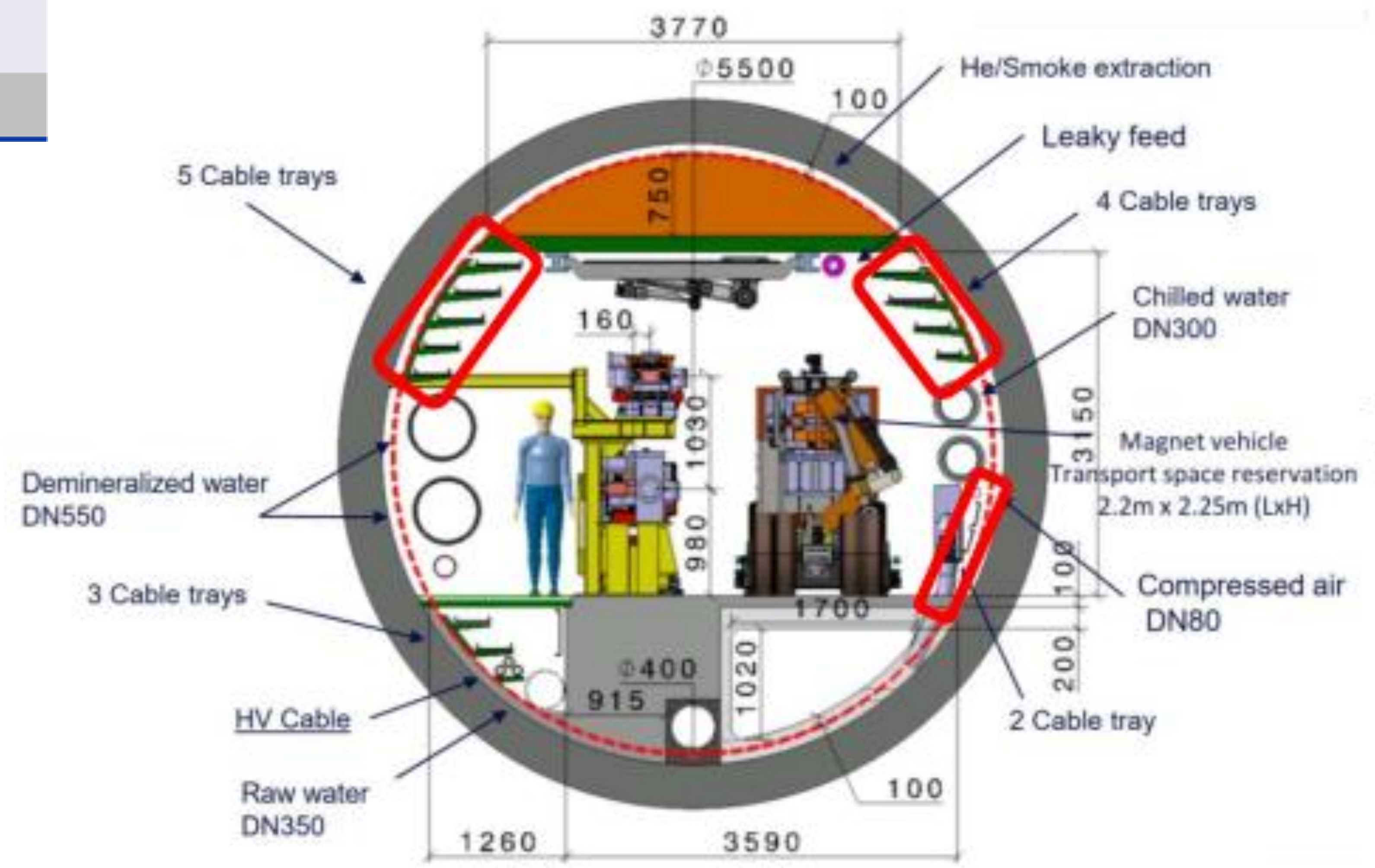
5 photon stoppers per dipole and per beam
→ 20 photon stoppers in FODO cell

Effect of shielding: cumulative dose (ttbar)

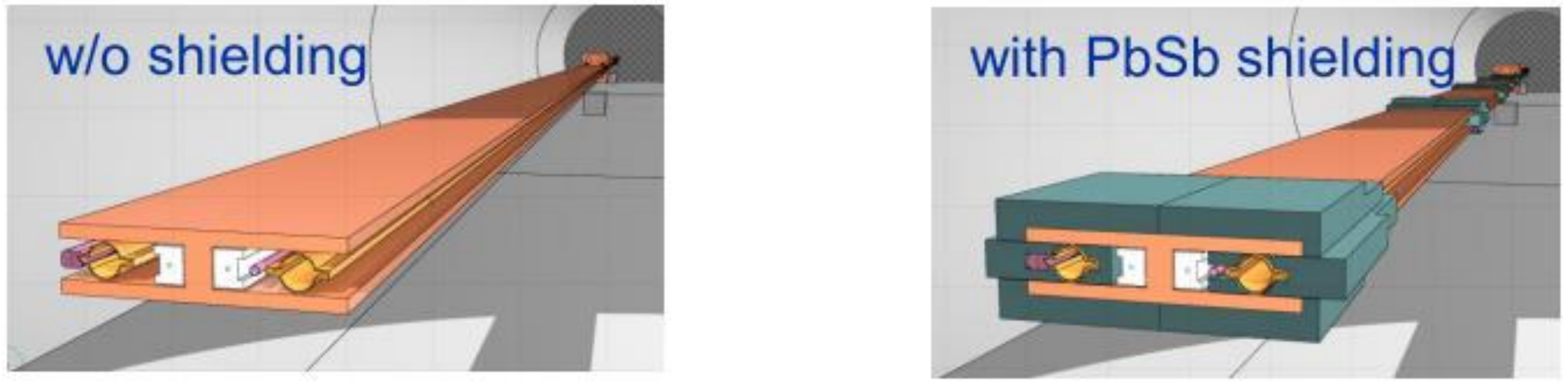
Synchrotron radiations absorbers and shielding

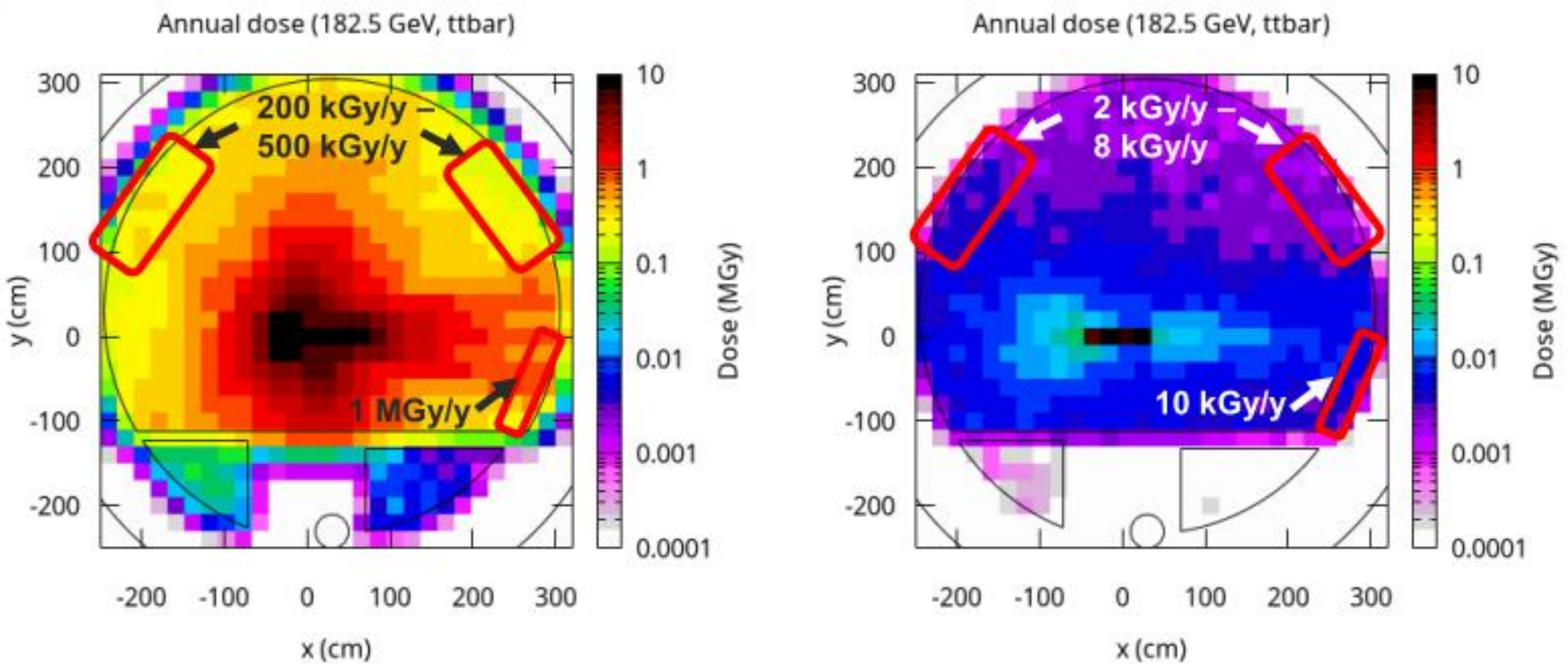
O(10^2) reduction of dose levels in tunnel

Shielding material for full ring	
Dipoles	2580
Photon stoppers	10
Shielding weight per stopper	400 kg
Total weight	10320 tons



Photon stoppers include W-alloy layer in both cases



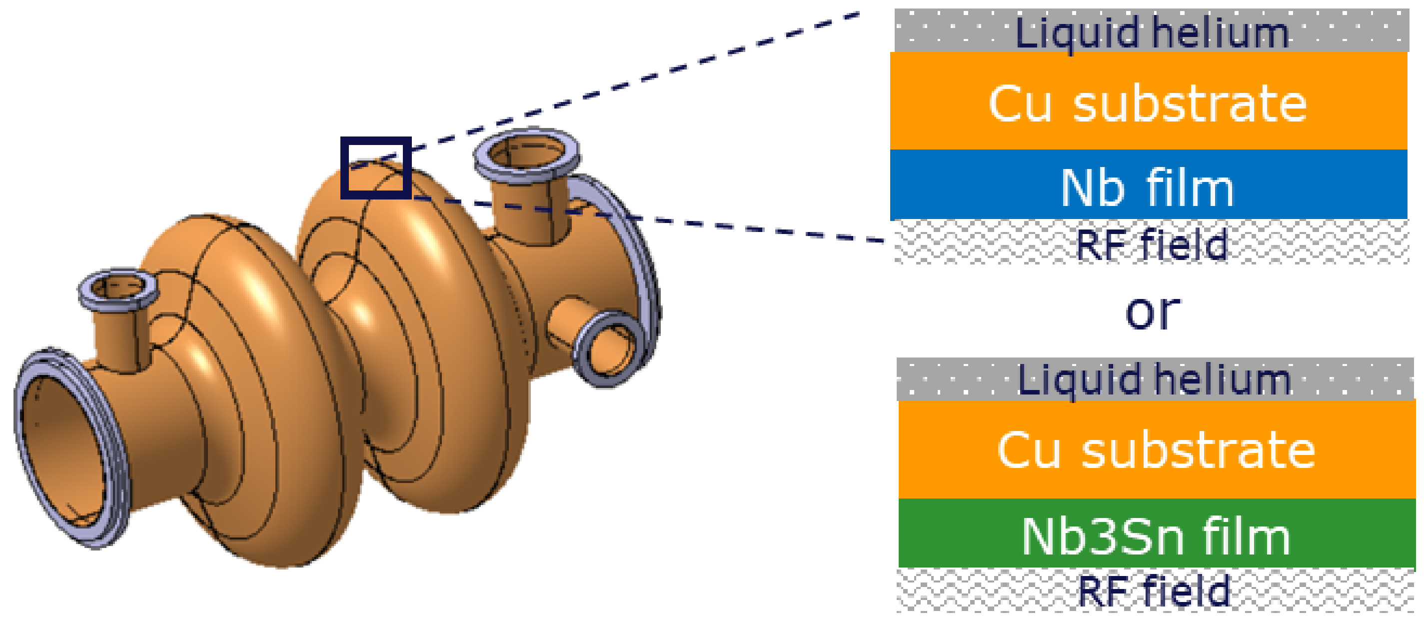


Update of RF

SRF new baseline

Material	λ(nm)	ξ(nm)	κ	T_c(K)	H_{c1}(T)	H_c(T)	H_{sh}(T)
Nb	40	27	1.5	9	0.13	0.21	0.25
Nb_3Sn	111	4.2	26.4	18	0.042	0.5	0.42

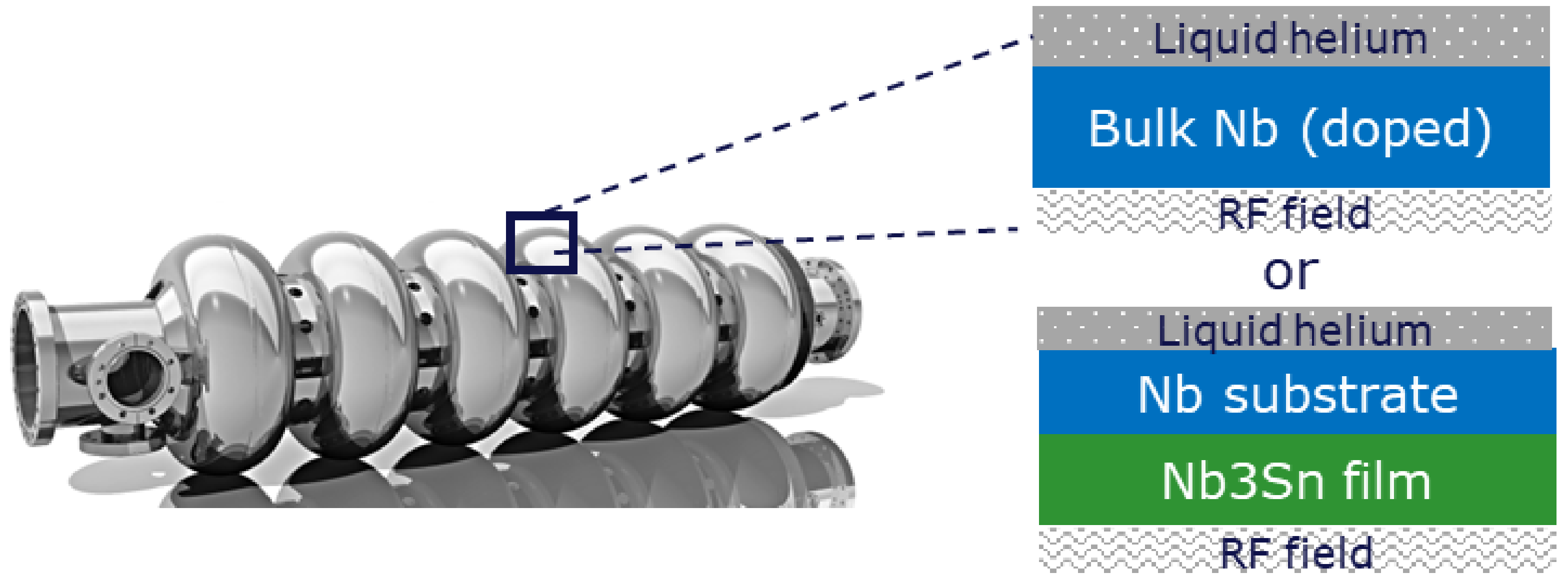
Courtesy Frank Peauger, ATDC 22-04-24



400 MHz cavity

Baseline option: advanced fabrication technics, advanced coating (HiPIMS) & advanced surface preparation recipes

Alternative option to improve the accelerating gradient E_{acc} and the Q_0 factor



800 MHz cavity

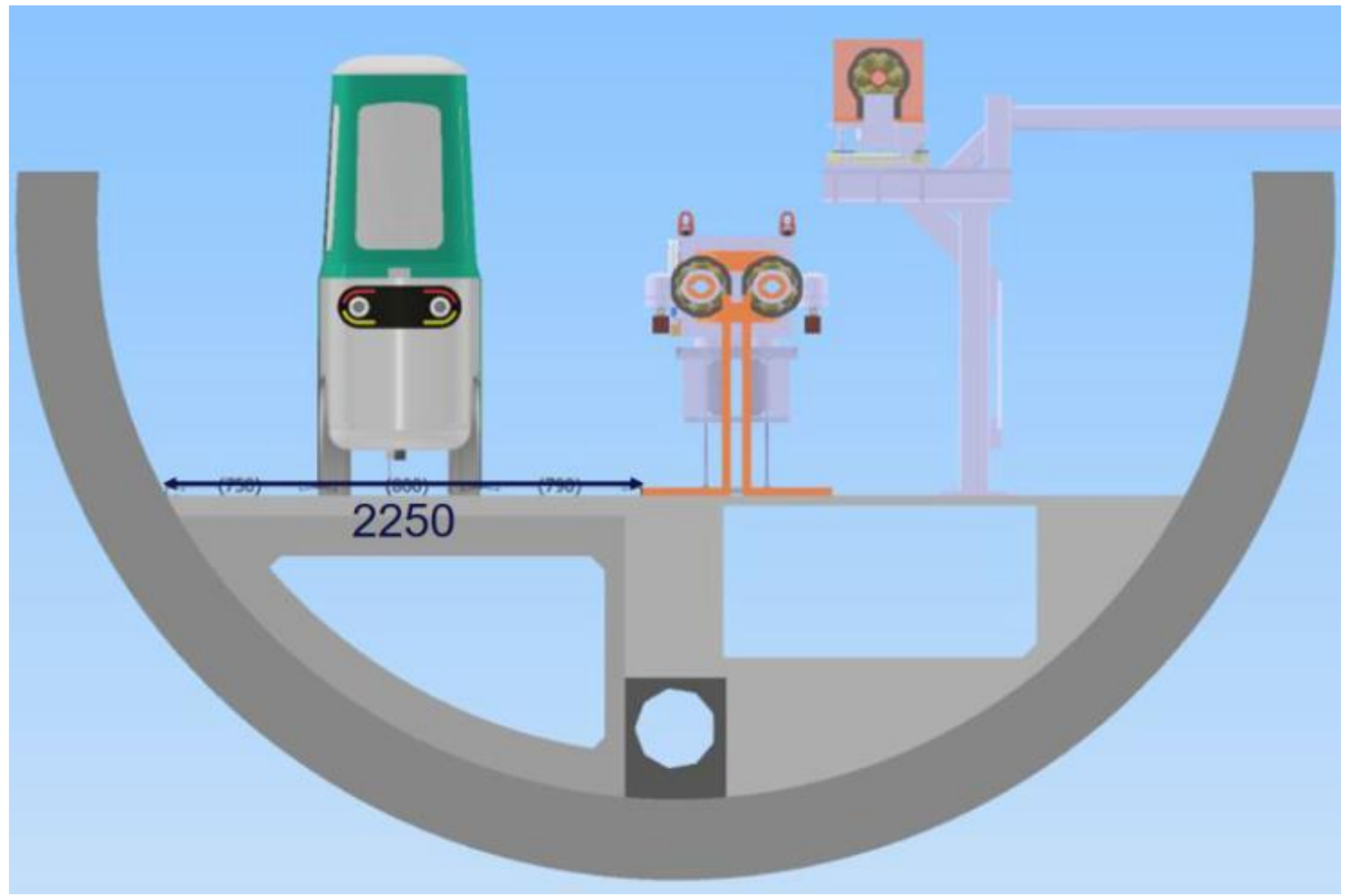
Baseline option: special surface processing (doping) to improve the Q_0 factor

Alternative option cavities to operate at 4.5 K instead of 2 K

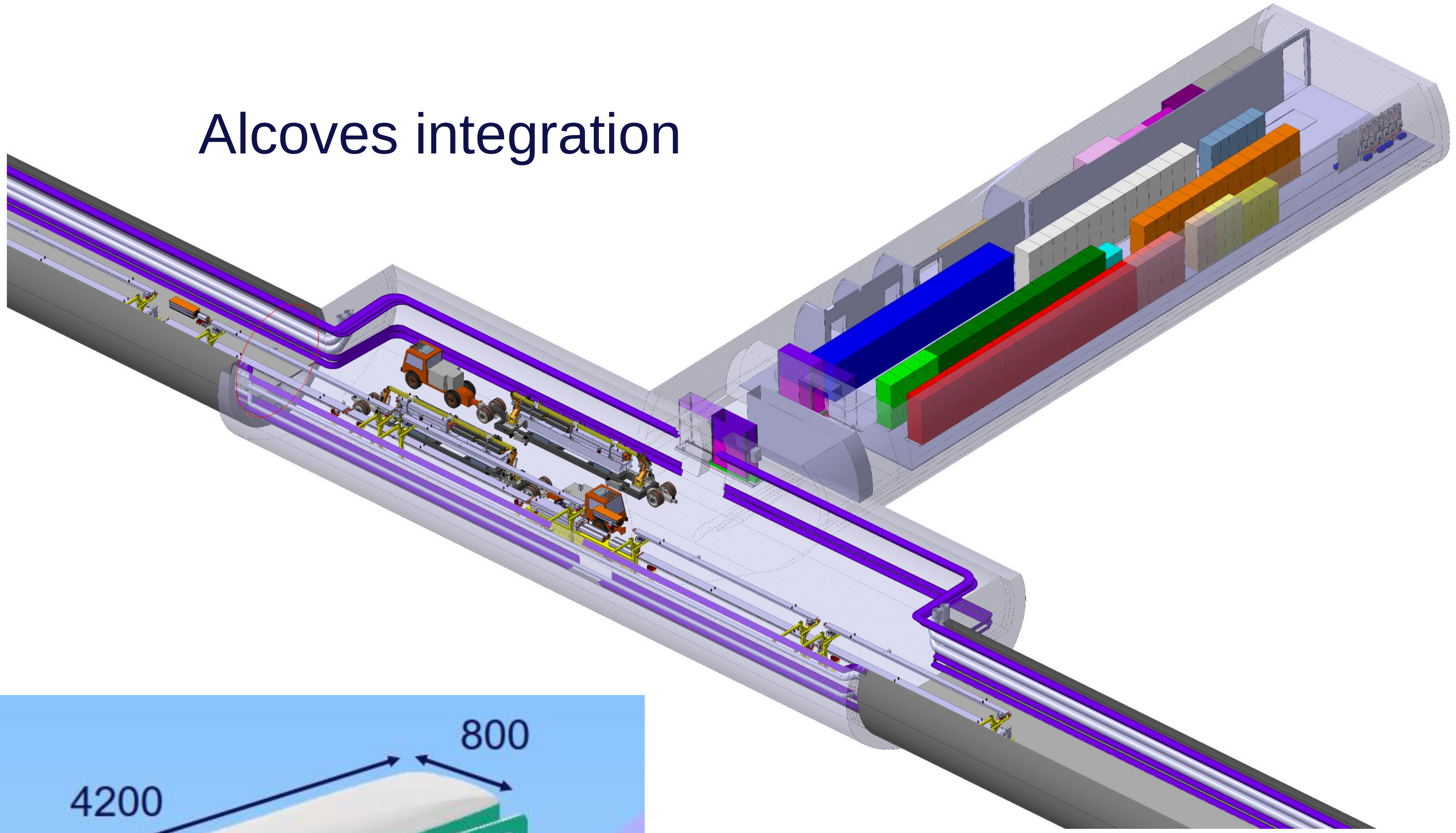
- New very attractive FCCee RF baseline which simplifies the SRF system configuration, with only 2 types of cavities.
- Specifications for cavity performances are challenging – high Q_0, high E_{acc} – for cost optimization.
- Encouraging test results obtained 400 MHz with HiPIMS Nb/Cu coating – will be improved with seamless and electropolished cavities (verified at 1.3 GHz).
- Doping of bulk Nb will be tried at 800 MHz with US labs (5 single cell cavities under fabrication).
- Nb3Sn is a game changer – requires strong R&D.
- Significant effort on SRF infrastructures upgrades (clean rooms, cold testing capabilities).
- Other studies on-going – not mentioned here : cryomodules, RF couplers, Nb/Cu at 800 MHz, non-mechanical freq. tuner, magnetic flux expulsion, SWELL…

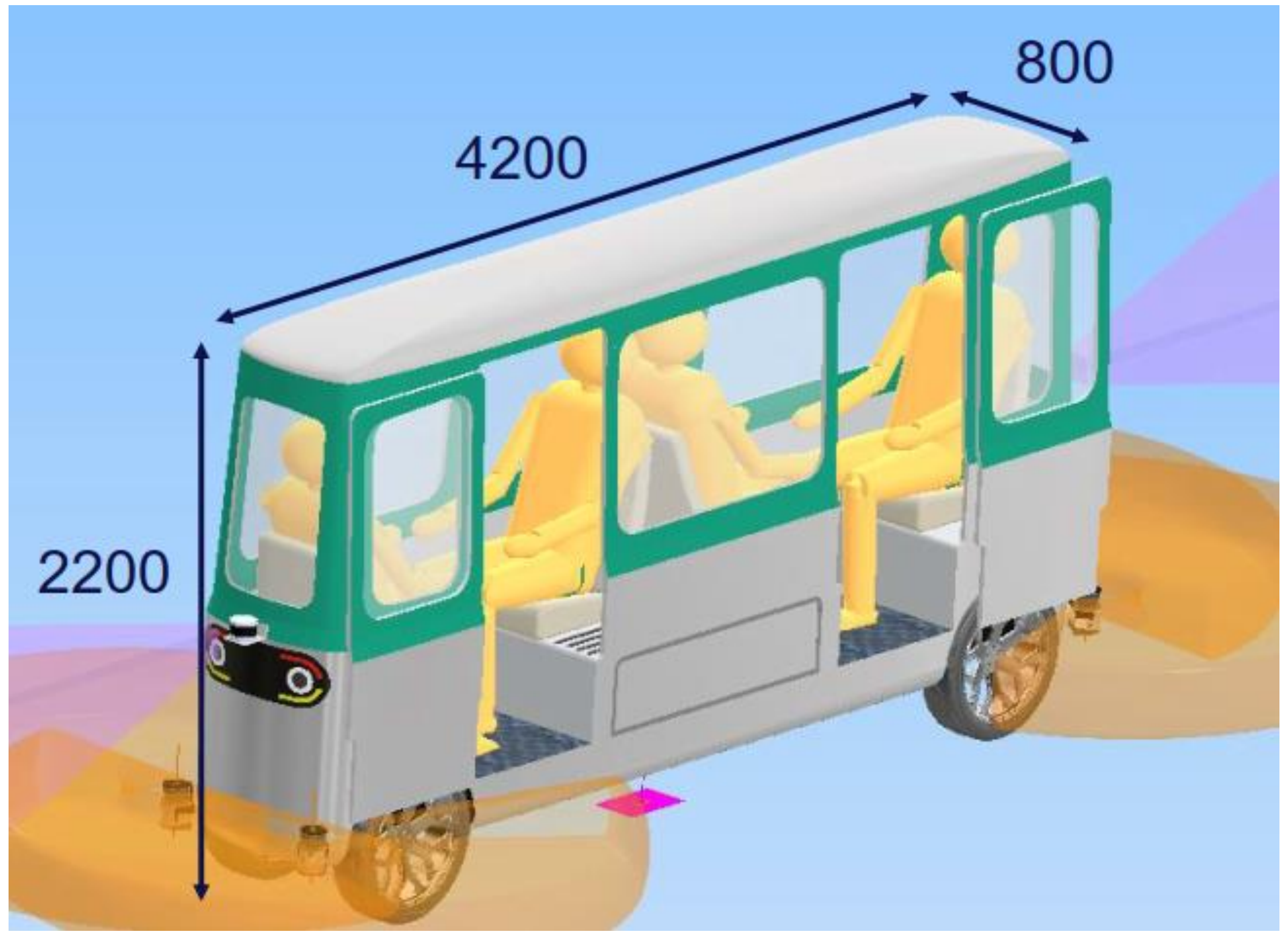
Update of personnel transport

People transport vehicle



Alcoves integration

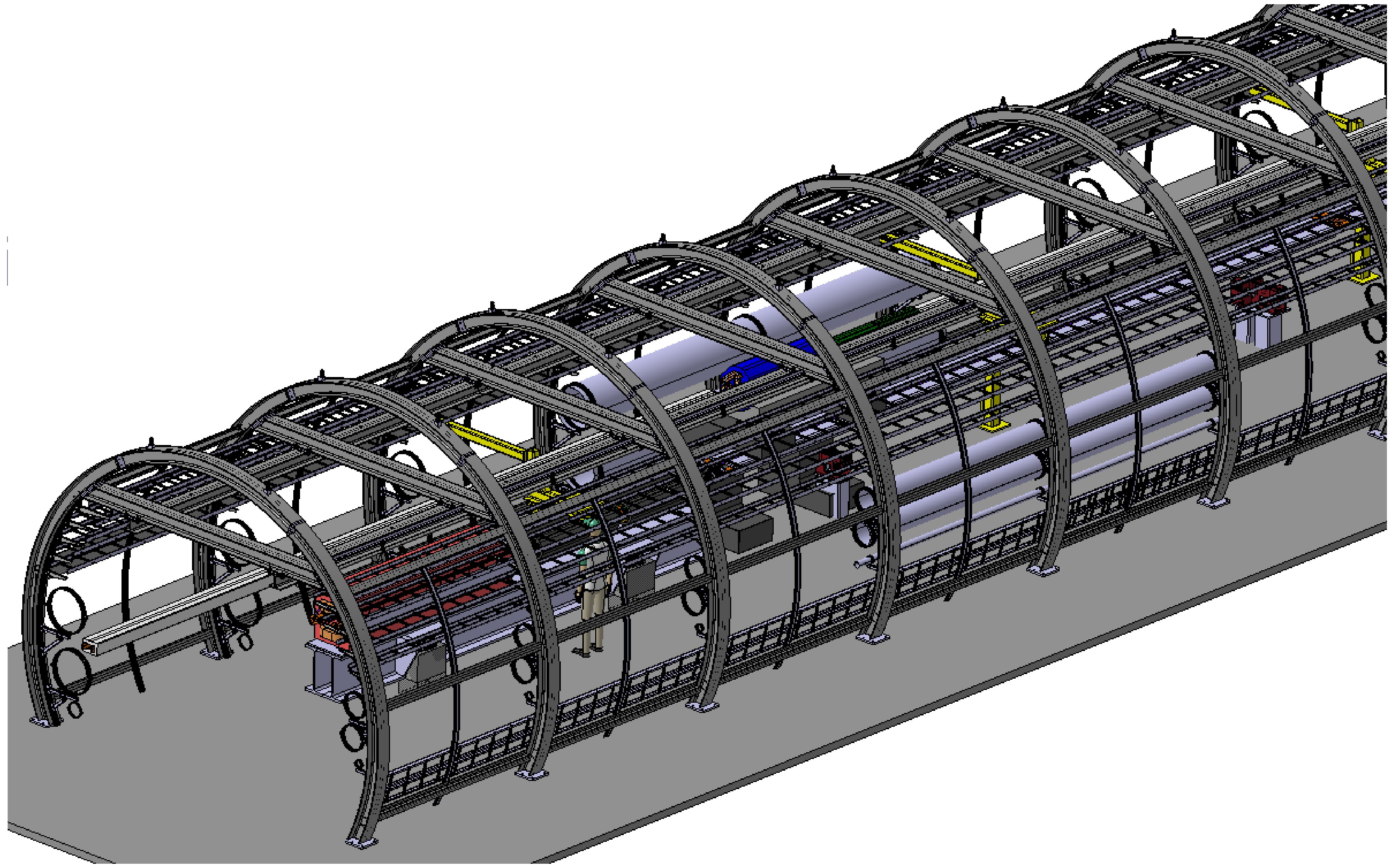




Arc cell mock-up

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
- Transport
- Installation
- Alignment
- Maintenance
- Safety
- Fabrication, machining capabilities for critical components

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

Reminder of planning

Mid-March: we fixed the arc layout for the mock-up, presented at FCC week

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

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

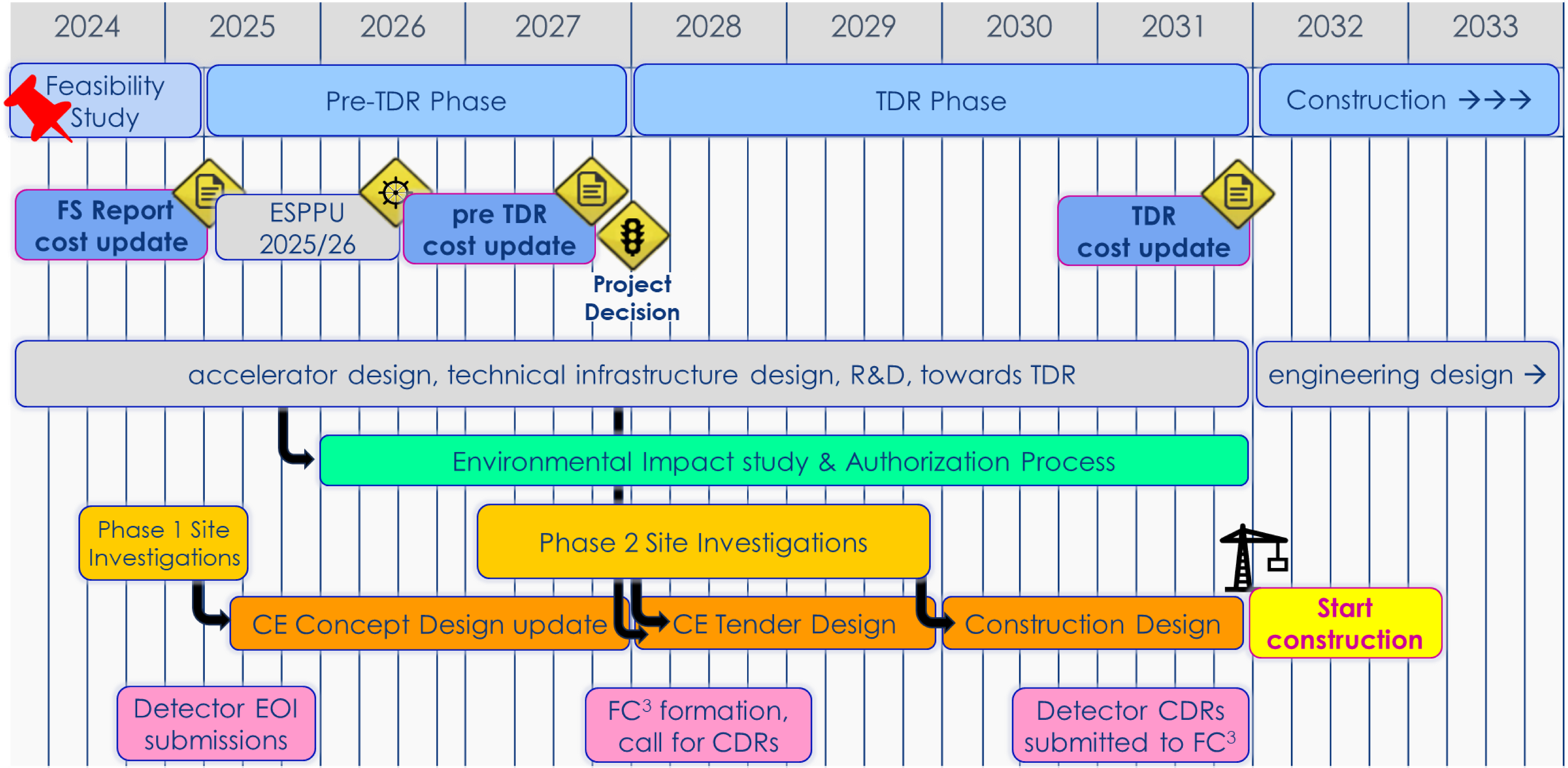
→ **Q1 2025:** Installation of the first version (combination of dummy and real structures)

→ **after 2025:** possible evolution of the Mock-up (replacement of dummy structures with real ones)

Courtesy F. Carra

FCC Pre-TDR at MTP2024

FCC timeline till start of the construction



Pre-TDR goal

Priorities as seen by DG

FCC studies

Main goal of the Feasibility Study: determine whether or not there are any showstoppers for the implementation of the project

The “pre-TDR” phase will bring the study to the level needed by the Council to take a decision at end-2027/beg-2028 on whether or not FCC should be approved

Note: project approvals are usually based on advanced technical documentation (goal of the FCC pre-TDR); construction start requires a full TDR

Main goal of “pre-TDR phase”: further develop the civil engineering and technical components and their integration, in particular to provide a consolidated cost estimate with reduced uncertainties (aim 5-20%, for part of the components)

Will cover the period April 2025 to end 2027 and be concluded with a pre-TDR

Total funding of ~ 139 M over 2.5 years for:
-- detailed R&D and design study of main technical components and civil engineering to reduce cost uncertainty
-- full project integration study, as needed for consolidated cost estimate
-- environmental impact study (quantitative analysis of impact of FCC-ee components and mitigation measures)
-- CERN contribution to detector conceptual design and integration studies

Council’s conclusions:
- ❑ a specific decision would be taken on the “pre-TDR phase” in due course (i.e. “pre-TDR phase” is not approved yet)
- ❑ however: necessary budget is allocated until such time as the Council’s decision is taken

Pre-TDR priorities

Priorities as seen by the Council

For 2027-2028, project approval, start of CE design contract:

- Compensation for the land used at surface sites (SAC)
- CO2 footprint over full project lifecycle (SAC, SPC, Council)
- Environmental impact and sustainability (FC, Council)
- Discuss sustainability issues for FCC-hh (SPC)
- Communication campaign with local population, including physics case, socio-economic benefits (SAC, FC, SPC)
- SCRF performance improvement (Q and gradient) (SAC)
- R&D on NEG coating to reduce risks (SPC)
- Procedures for conservation of He (SAC)
- Sensitivity to commodity prices (SAC)
- Continue to develop benchmarks as reference for FCC-ee cost (CRP)
- Revisit CERN's procurement policies and learn for other big facilities to ensure balanced industrial return without increasing cost (FC)
- Risks of not achieving FCC-ee luminosity (SPC)
- Provide discussions of additional science (dark sector, forward physics, etc.) (SPC)

Technical design

Pre-TDR priorities

Priorities as seen by technical designers

Very high priorities

- SRF
- Vacuum
- Radiations
- Energy consumption
- Alignment

High priorities

- Design of all accelerator systems
- Design of all infrastructures
- Integration

sustainability

- Eco-design
- Optimisation
- LCA
- Environmental impact

Affordability

- Industrial production
- Technology innovation
- Procurement strategy / in-kind

Goal:
Increase the technical design level to be able to define all subsurface areas and surface building

MTP 2024 posts

FCC posts

				2025	2026	2027	2028
SY	SY-ABT	FCC-MTP24-1	Electromagnetic kicker pre-design and impedance shielding	0,75	1,00	1,00	2,75
		Total		**0,75**	**1,00**	**1,00**	**2,75**
	SY-BI	FCC-MTP24-2	Concept and pre-design of arc and IR BPMs	0,25	1,00	1,00	2,25
		FCC-MTP24-3	Concept, machine protection aspects and pre-design of overall BLM system	0,50	1,00	1,00	2,50
		Total		**0,75**	**2,00**	**2,00**	**4,75**
	SY-EPC	FCC-MTP24-4	RF HEK and magnet powering, layout and CE implications	0,75	1,00	1,00	2,75
		FCC-MTP24-5	Environmental impact, sustainability and energy recovery	0,25	1,00	1,00	2,25
		Total		**1,00**	**2,00**	**2,00**	**5,00**
	SY-RF	FCC-MTP24-6	Impedance calculations	0,75	1,00	1,00	2,75
		Total		**0,75**	**1,00**	**1,00**	**2,75**
	SY-STI	FCC-MTP24-7	Energy deposition simulations for tunnel radiation and shielding	0,50	1,00	1,00	2,50
		FCC-MTP24-8	Final focus, IR, detector radiation and shielding studies, integration	0,25	1,00	1,00	2,25
		Total		**0,75**	**2,00**	**2,00**	**4,75**
	Total			**4,00**	**8,00**	**8,00**	**20,00**

SRF R&D posts not part of FCC

MTP 2024 MPA

FCC MPA

							2025	2026	2027	2028		
	Total						0,2	0,8	0,0	1,0	1,0	3,0
SY	SY-ABT	Beam transfer hardware component pre-designs, focusing on performance specifications, design concepts, impedance aspects (including electrostatic separators)	GRAD	2025	January	Memo	1,0	1,0	1,0			3,0
		Transfer line layout, optics and design, including failure cases and machine protection needs for ABT systems, absorber specifications and their impedance	DOCT	2025	January	Memo	1,0	1,0	1,0			3,0
		Total					**2,0**	**2,0**	**2,0**			**6,0**
	SY-BI	BLM system manufacturing	DOCT	2025	January	Memo	1,0	1,0	1,0			3,0
		BPM system performance aspects	DOCT	2025	January	Memo	1,0	1,0	1,0			3,0
		Instability monitoring	DOCT	2026	January	Memo		1,0	1,0	1,0		3,0
		Luminosity monitoring and polarimeter	GRAD	2025	January	Memo	1,0	1,0	1,0			3,0
		Total					**3,0**	**4,0**	**4,0**	**1,0**		**12,0**
	SY-EPC	Pre-design optimisation studies for FCC-hh and FCC-ee	DOCT	2025	January	Memo	1,0	1,0	1,0			3,0
		Pre-design studies for FCC-hh and FCC-ee with impact on CE	GRAD	2025	January	Memo	1,0	1,0	1,0			3,0
		Total					**2,0**	**2,0**	**2,0**			**6,0**
	SY-RF	Fundamental SRF R&D	DOCT	2026	January	Memo		1,0	1,0	1,0		3,0
		Impedance simulations and measurements	DOCT	2025	January	Memo	1,0	1,0	1,0			3,0
		Longitudinal beam dynamics	DOCT	2025	January	Memo	1,0	1,0	1,0			3,0
		Total					**2,0**	**3,0**	**3,0**	**1,0**		**9,0**
	SY-STI	Coupling FLUKA to tracking codes	DOCT	2026	January	Memo		1,0	1,0	1,0		3,0
		Dump, protection device and collimator conceptual designs	GRAD	2025	January	Memo	1,0	1,0	1,0			3,0
		Pre-injector positron/electron source	DOCT	2026	January	Memo		1,0	1,0	1,0		3,0
		Radiation input for environmental impact and TDR	GRAD	2025	January	Memo	1,0	1,0	1,0			3,0
		Radiation levels	DOCT	2025	January	Memo	1,0	1,0	1,0			3,0
		Total					**3,0**	**5,0**	**5,0**	**2,0**		**15,0**
	Total						**12,0**	**16,0**	**16,0**	**4,0**		**48,0**

MTP 2024 budget (M)

FCC budget

				2025	2026	2027	2028		
SY	SY-ABT	Average	0,0	140,0	140,0	140,0	140,0	140,0	**700,0**
	SY-BI	Average	0,0	280,0	350,0	350,0	490,0	420,0	**1 890,0**
	SY-EPC	Average	0,0	210,0	210,0	210,0	70,0	70,0	**770,0**
	SY-RF	Average	0,0	70,0	350,0	350,0	280,0	0,0	**1 050,0**
	SY-STI	Average	0,0	280,0	420,0	420,0	420,0	280,0	**1 820,0**
	Total		**0,0**	**980,0**	**1 470,0**	**1 470,0**	**1 400,0**	**910,0**	**6 230,0**

Pre-TDR work package Template

The pre-TDR phase needs to be clarified with departments and groups.
Additional resources already distributed to department.
But agreement has to be clarified with FCC project and department.

Proposal: Write Work package description (presented in ATDC 19 Sept, TIWG 9 Oct)

Draft template done for Electricity & Energy management,
to be adapted if needed for all WP.

Pre-TDR work package Template

FCC ORGANISATION

Pre-TDR organisation

Accelerators FCC-ee F. Zimmermann, T. Raubenheimer

Accelerator Technical Design
JP. Burnet, T. Raubenheimer
- Beam transfer systems
- Beam instrumentations
- Beam Intercepting Devices
- Magnets, MDI
- Vacuum
- Power converters
- Radiation & shielding
- Radio Frequency
- Survey & alignment
- System engineering and interface management

- Radiation WG
- *MDI WG*
- *Arc mock-up WG*
- *System engineering and interface management*

Collider & Booster Design
F. Zimmermann, C. Carli
- Parameters
- Optics
- Beam dynamics
- OP parameter interface
- Operation concept incl. BBA
- Machine protection
- Polarisation & energy calibration
- Interfaces

- *Booster design WG*
- *EPOL WG*
- *Machine protection WG*

Transfer Lines Design
W. Bartmann
- Parameters
- Optics
- Beam dynamics
- OP parameter interface
- Operation concept incl. BBA
- Machine protection
- Interfaces

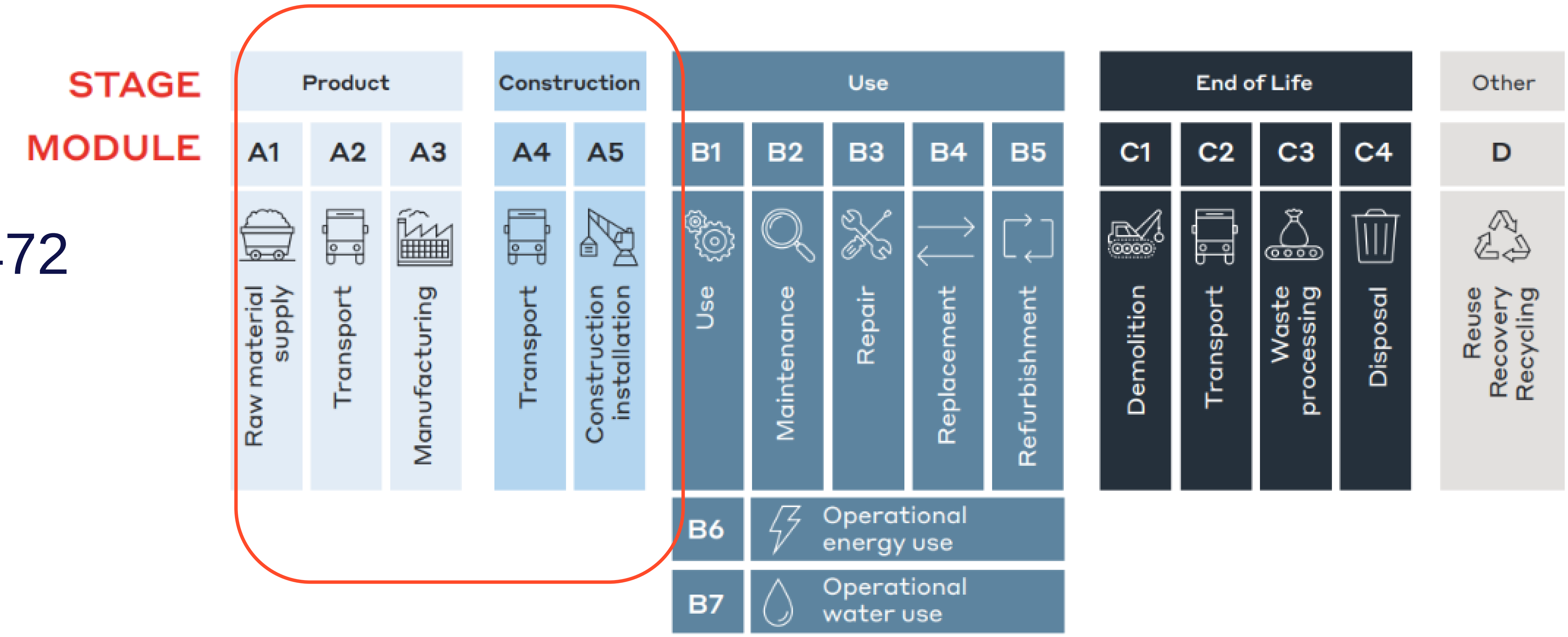
Injector 20GeV
P. Craievich, A. Grudiev
- e-/e+ sources
- Linacs
- Damping ring

No change…

FCC SUSTAINABILITY STUDIES

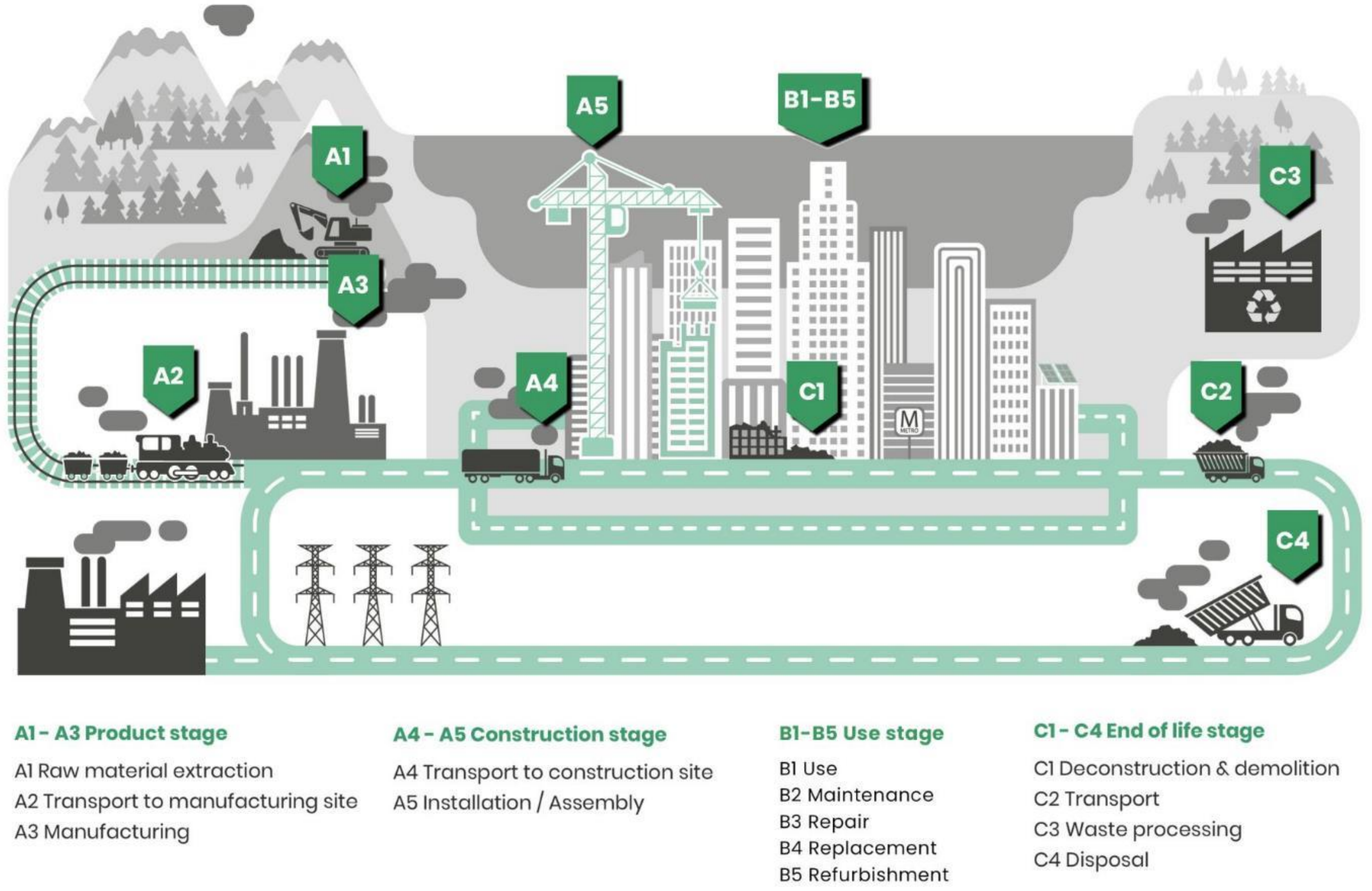
Greenhouse gas production of the construction

Life Cycle Assessment for civil engineering construction



Performed by WSP (BG consulting) consultant within the framework EN17472
Study includes surface sites and subsurface.

Sources of embodied carbon across the construction lifecycle



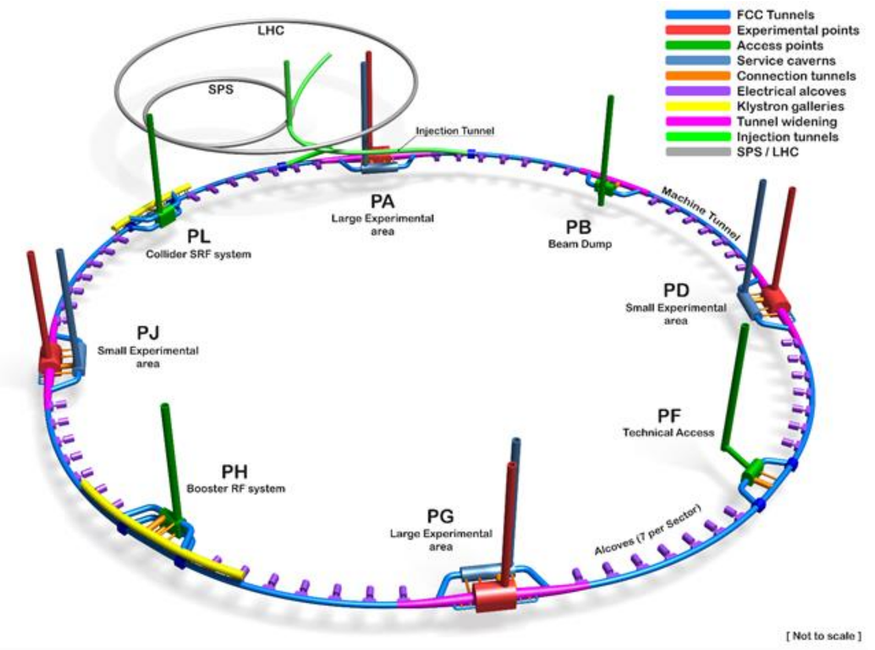
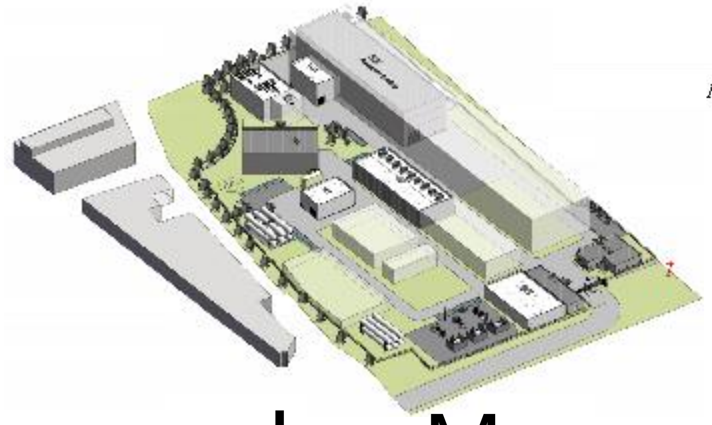
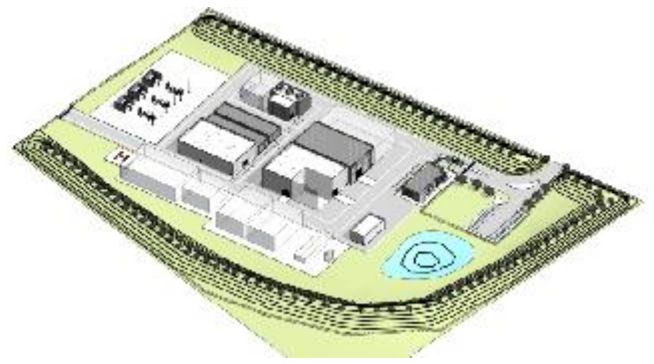


Figure 1 – Schematic model of the proposed sub-surface FCC structures





Presented at FCC week 2024 by Dr. Dasaraden Mauree (WSP)

Greenhouse gas production of the construction

Life Cycle Assessment for civil engineering construction

Performed by WSP consultant within the framework EN17472.
Study includes surface sites and subsurface.
Initial (classical construction techniques) gives 1.2MtCO_2e.
Optimised (selection of low carbon emissions techniques) gives 550ktCO_2e.

wsp

Impact CO2	Initial	Optimised	Reduction
Subsurface	1 056 391 tCO2(eq)	505 005 tCO2(eq)	52%
Technical site x4	54 800 tCO2(eq)	17 600 tCO2(eq)	68%
Experimental site x4	114 800 tCO2(eq)	31 200 tCO2(eq)	73%
Total	1 170 800 tCO2(eq)	553 805 tCO2(eq)	55%

FCC construction equivalent to
3-6 years of LHC experiments direct emissions
Between 1 to 2 times FCC total indirect emissions from purchased electricity (over 24 years)

Benchmark	Emission CO2	Optimised	Emission CO2	Reduction
Steel sheets, generic, 0% recycled content, S235, S275 and S355	3.91 kgCO2e/kg	Steel sheets, generic, 100% recycled content, S235, S275 and S355	0.87 kgCO2e/kg	77%
Steel fibre for concrete reinforcement, 0% recycled content (One Click LCA)	2.09 kgCO2e/kg	Steel fibre for concrete reinforcement, 100% recycled content (One Click LCA)	0.51 kgCO2e/kg	75%
Reinforcement steel (rebar), generic, 60% recycled content (only virgin materials), A615	1.41 kgCO2e/kg	Reinforcement steel (rebar), generic, 100% recycled content, A615	0.42 kgCO2e/kg	70%
Ready-mix concrete, normal strength, generic, C35/45 (5000/6500 PSI) with CEM I, 0% recycled binders (340 kg/m3; 21.2 lbs/ft3 total cement)	327.02 kgCO2e/m^3	Ready-mix concrete, normal strength, generic, C35/45 (5000/6500 PSI) with CEM III/A, 60% GGBS content (340 kg/m^3; 21.2 lbs/ft^3 total cement)	170.36 kgCO2e/m^3	48%
Ready-mix concrete, low-strength, generic, C12/15 (1700/2200 PSI), 0% recycled binders in cement (220 kg/m3 / 13.73 lbs/ft3)	217.91 kgCO2e/m^3	Ready-mix concrete, low-strength, generic, C12/15 (1700/2200 PSI), 40% recycled binders in cement (220 kg/m^3 / 13.73 lbs/ft^3)	149.41 kgCO2e/m^3	31%
Ready-mix concrete, normal-strength, generic, C40/50 (5800/7300 PSI), 0% recycled binders in cement	384 kgCO2e/m^3	Ready-mix concrete, normal-strength, generic, C40/50 (5800/7300 PSI) with CEM III/B, 75% GGBS content in cement	173.00 kgCO2e/m^3	39%

Waste heat supply study

Opportunities for waste heat use

Host states are requesting to include waste heat use in the design of future CERN projects from the beginning on.
This encompasses diverse aspects such as technical, economic, and societal dimensions.
→Identification of the opportunities and viability
→Feasibility of the technical concept
→Interactions with local authorities (FR) and SIG (CH)

Study carried out with Ginger Burgeap :

Phase 1 : Study on the consumption potentials
Phase 2 : Study of the energy recovering process and optimisation pathways
Phase 3 : Technical-economic assessment and complementary technologies (ongoing)

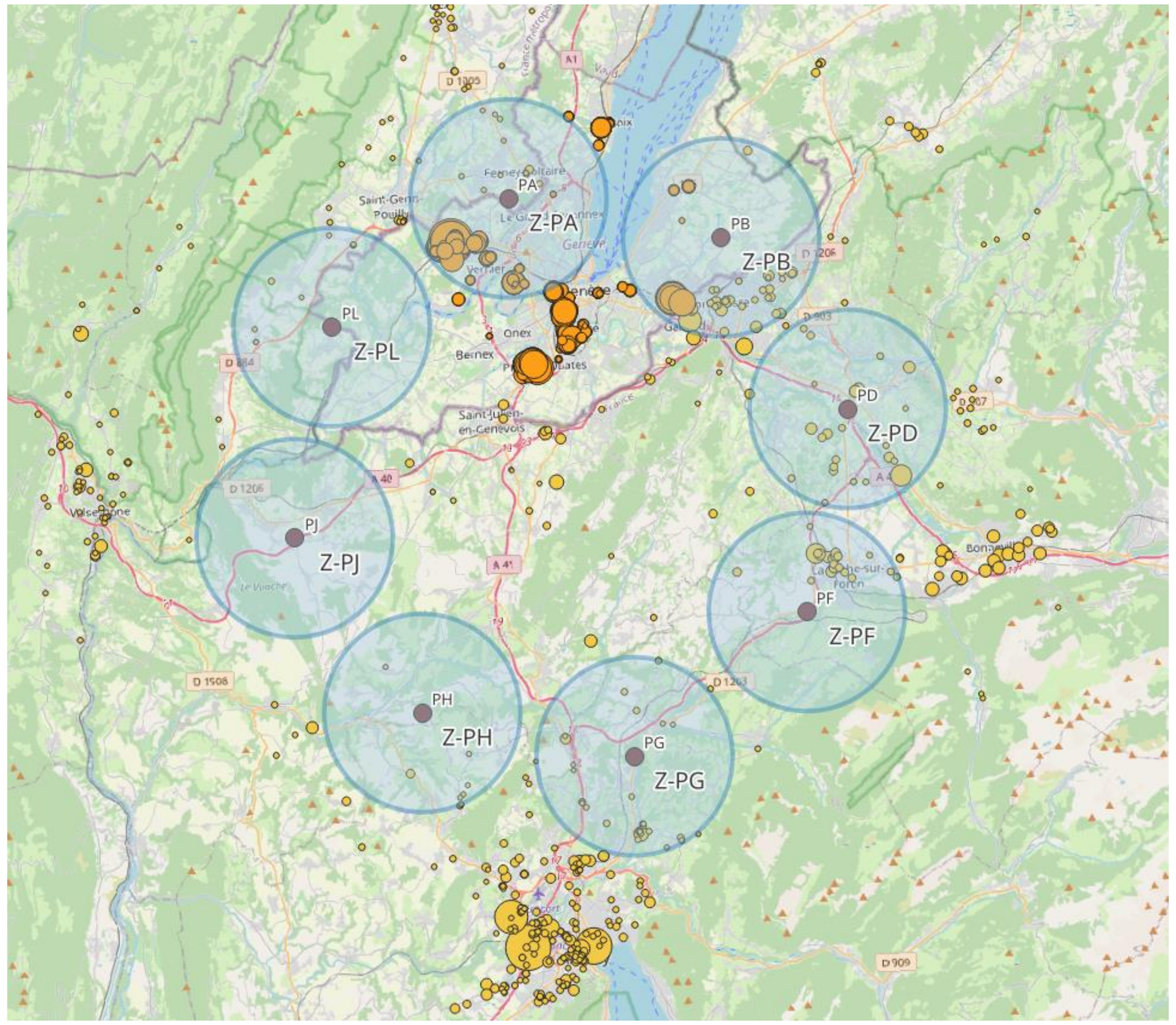
presented at FCC week 2024 by A. Guiavarch.

Waste heat supply study

Emitted heat – annual production (GWh)

Fatal heat per point available for reuse.
Data analysis of potential large heat consumers (100MWh/y) in a range of 5 km.

Site/Mode	Z	W	H	L. S	tt
PA	138	152	172	16	225
PB	15	18	23	0	34
PD	138	152	172	16	225
PF	15	18	23	0	34
PG	138	152	172	16	225
PH	230	314	336	4	524
PJ	138	152	172	16	225
PL	25	48	56	2	109
Total per year	**836**	**1 005**	**1 128**	**68**	**1 603**



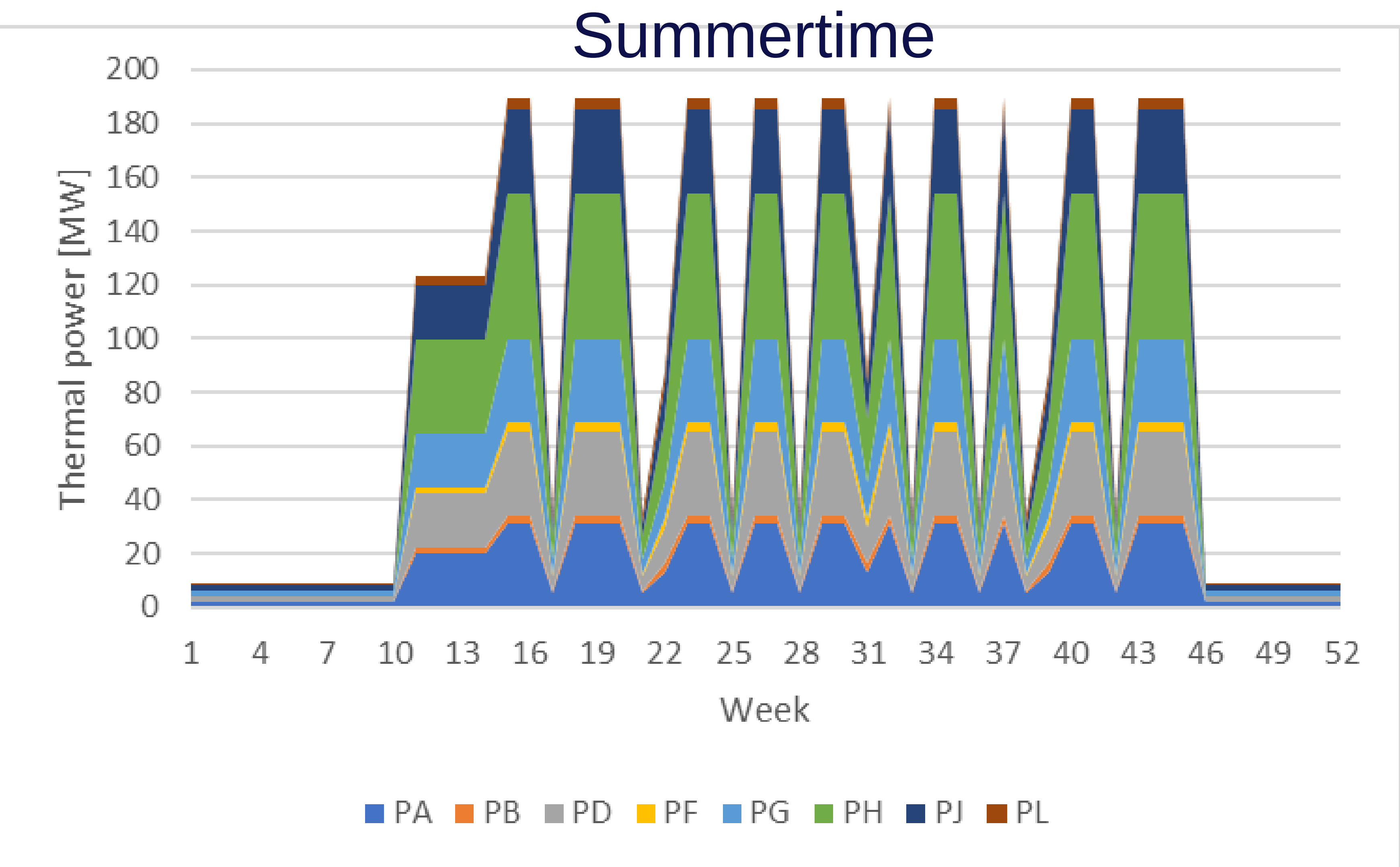
Temperature range : 40°C / 50°C (except 70°C for cryogenics)

Waste heat supply study

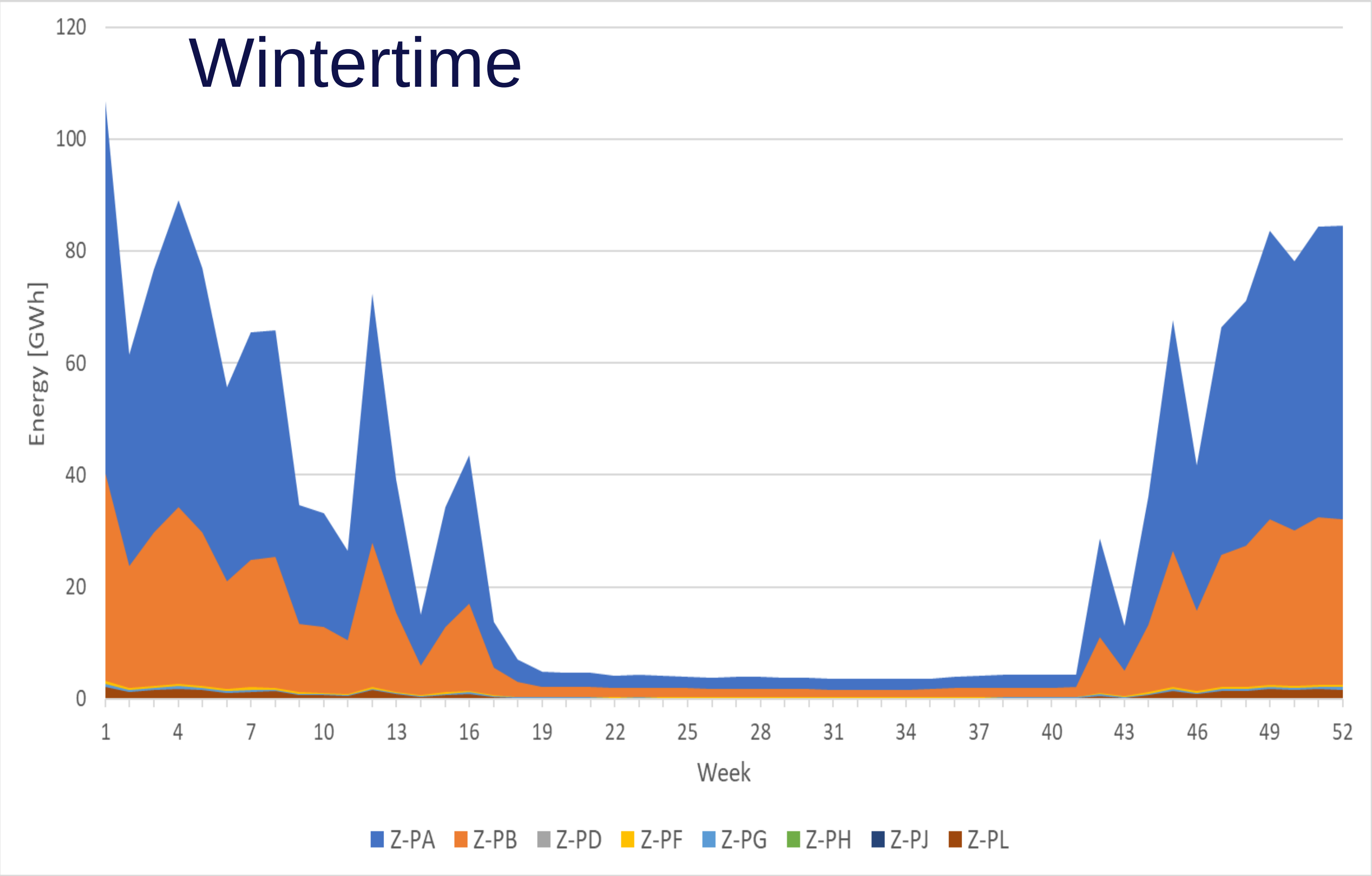
GINGER BURGEAP

Challenge to meet production with loads

FCC thermal energy production



Local thermal energy loads



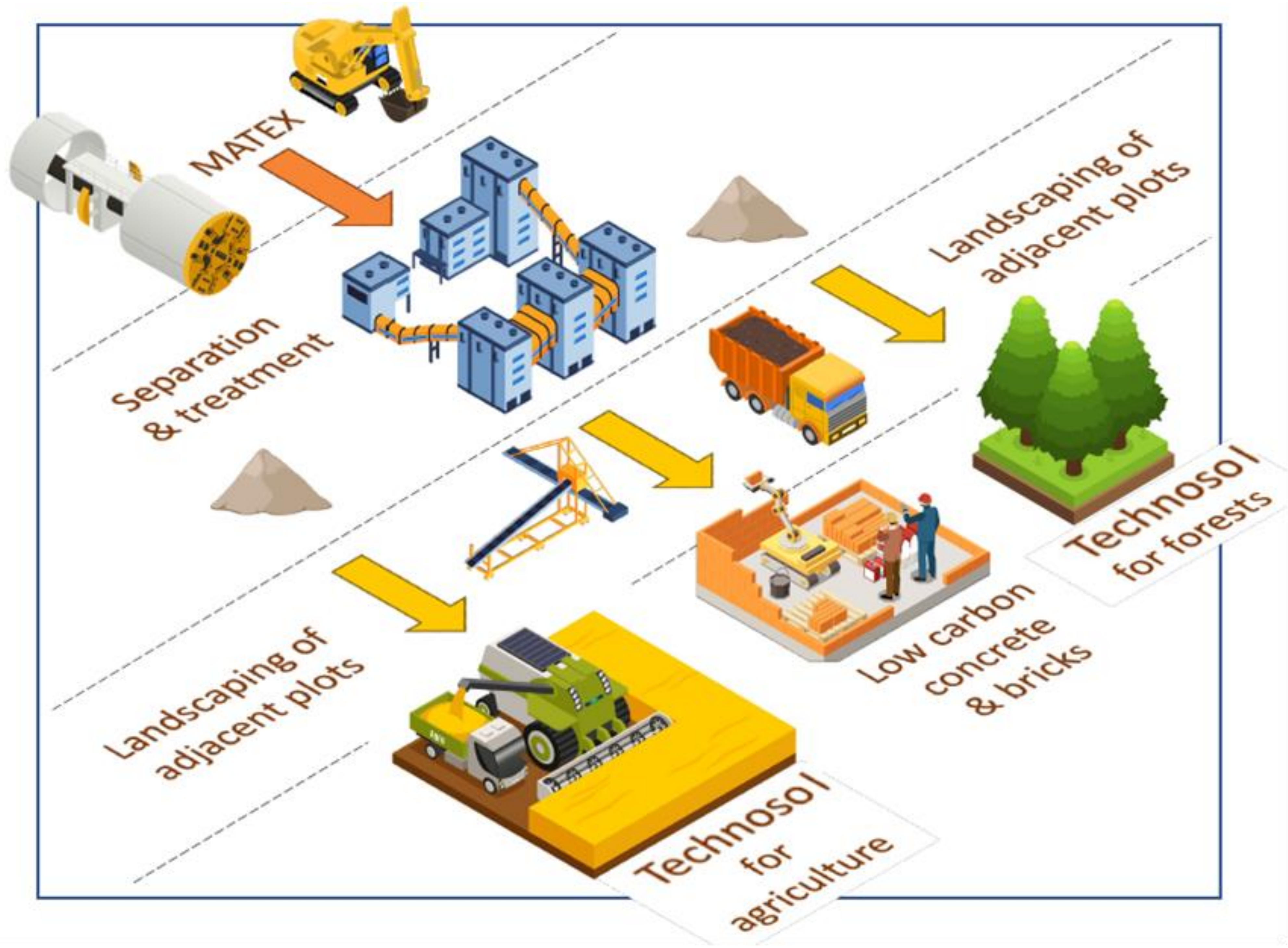
Period of time		Mode Z		
		Annual recovered heat [GWh]	HRR [1]	Efficiency
Base case	Target zones	223	27%	44%
	Target and extended zones	374	45%	73%
Time-shifted calendar	Target zones	308	37%	60%
	Target and extended zones	462	55%	89%
Site-to-site distribution	Target zones	278	33%	53%
	Target and extended zones	521	62% [1]	100%
No integration in urban areas with existing urban networks		64	16%	26%

Heat recovery rate, 27% (5km range), 45% with extended range.
Rate increase to 37% with calendar shift.
Max rate with extended range and calendar shift is 55%.
Needs large investment from host states.
Could decrease the indirect emissions by 20% to 50%

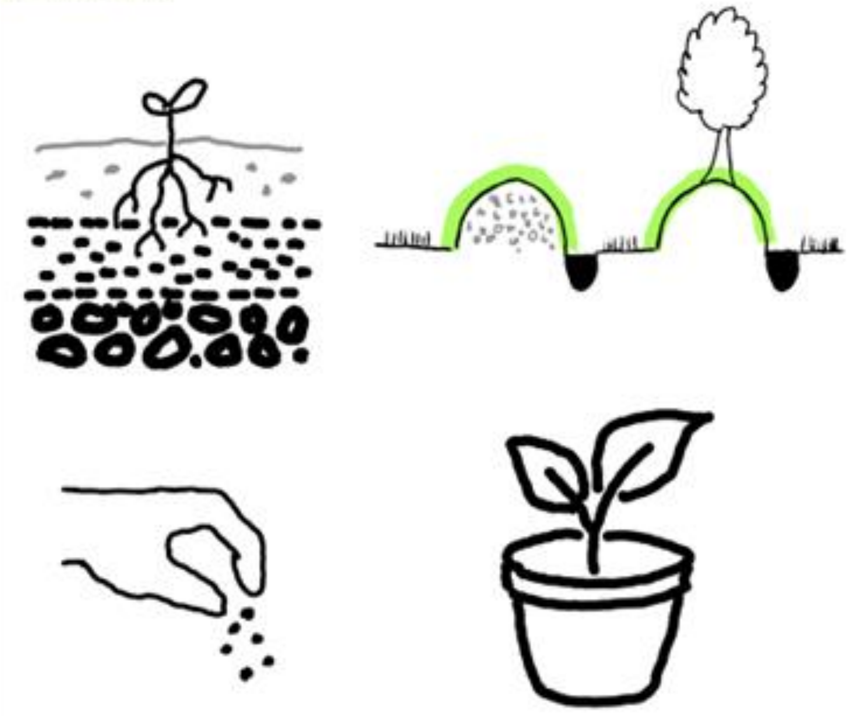
Reuse of excavated molasse - OpenSky lab

Innovative local approach for materials management

A new experimental site is under construction at LHC point 5 for demonstration of soil construction from molasse for different use cases and plant species

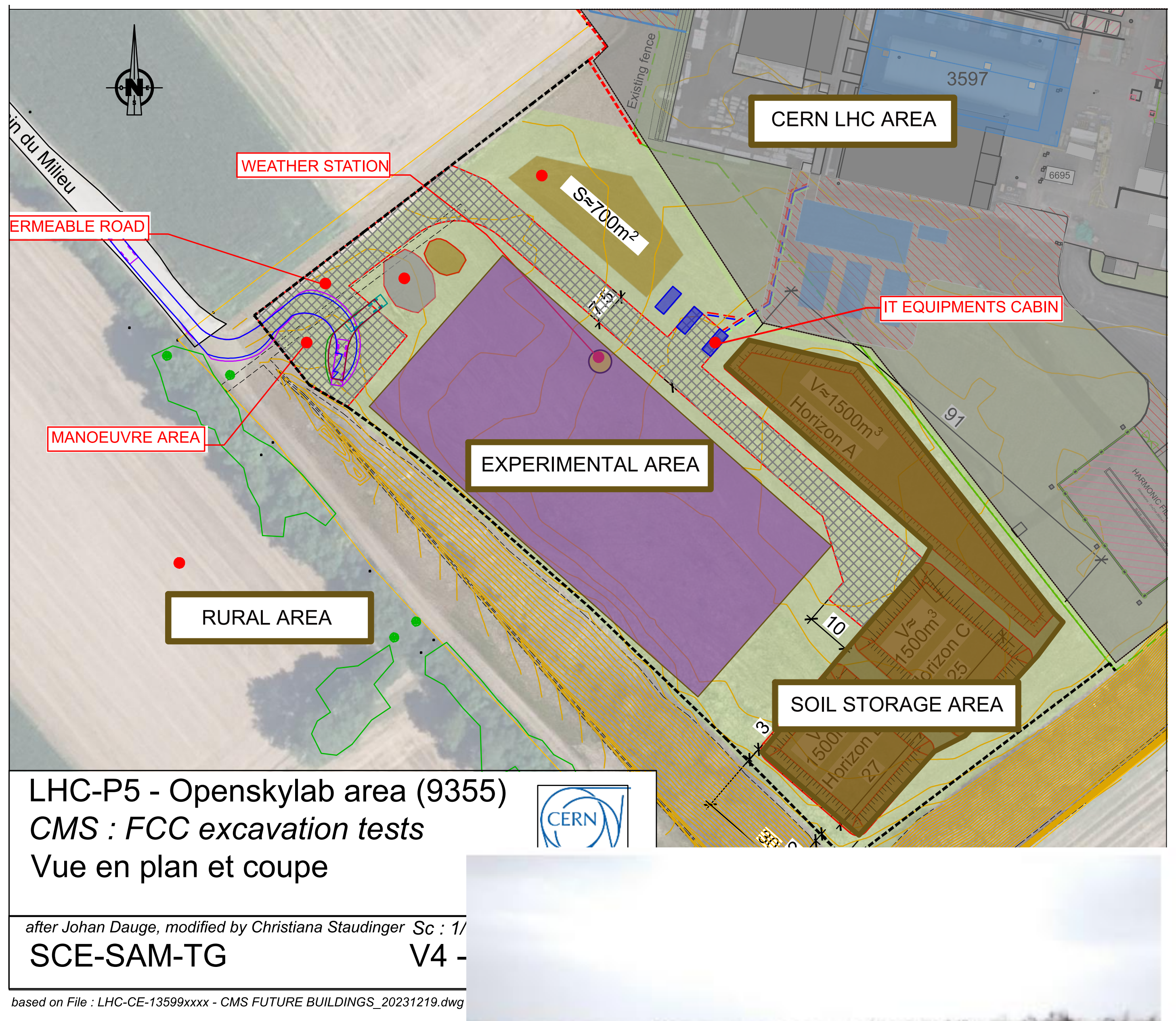


Reuse as constructed soil, substrate or amendment



Why the focus on constructed soils?

- Agriculture and forestry are promising use cases for transformed molasse materials
- Functional soils contribute to CO_2 capture and human health[1,2]



[1] Amundson et *al.*, 2021, [2] Banerjee et *al.*, 2023

Presented at FCC week 2024 by C.Staudinger

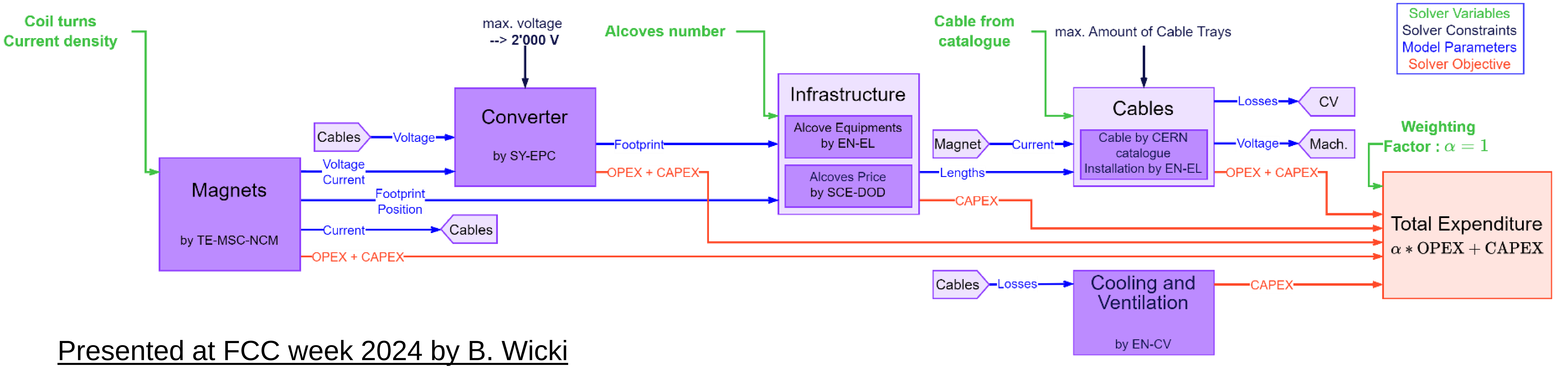
TOTEX optimization tool

Global optimisation Solving for Best TOTEX

Objective : reaching the minimum Total Expenditure while complying with constraints.
Solver's evolutionary optimisation algorithm identify the most likely optimal solution, meaning the best solution found within the given time frame.
Weighting Factor set to 1 so far, meaning that Operation and Capital Expenditure have the same weight when optimising.

$$TOTEX = \alpha * OPEX + CAPEX, \qquad \alpha = 1$$

OPEX calculated over 15 years of Operation



Presented at FCC week 2024 by B. Wicki

TOTEX optimization tool

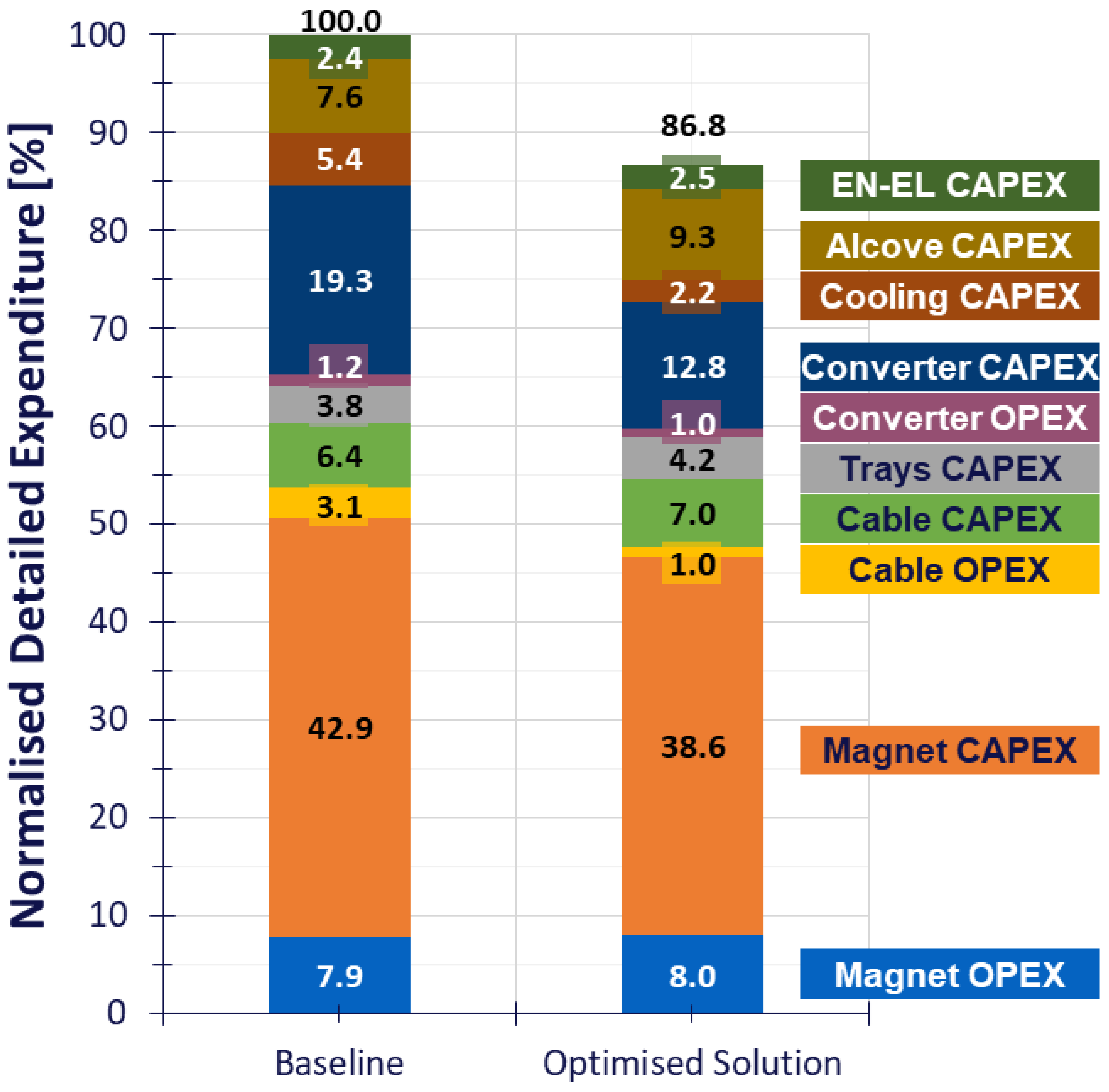
Global optimisation Solving for Best TOTEX

The Global Model found an optimised solution by considering **Capital** and **Operational Expenditures**.

Preliminary global optimisation results shows that:

- **≥9 alcoves** per arc seems to be optimal
- **Bigger cable Trays** needed.
- Booster Quadrupole powered from Big Alcoves.
- Collider Dipole, Quadrupole and Corrector in aluminium coil.
- But increasing magnet losses by 10%...

What's next :
Includes CO2e emissions by systems to evaluate the carbon footprint of each solution



R&D sustainable accelerators power grids

HORIZON - RESEARCH FACILITY 2.0:
TOWARDS A MORE ENERGY-EFFICIENT AND SUSTAINABLE PATH

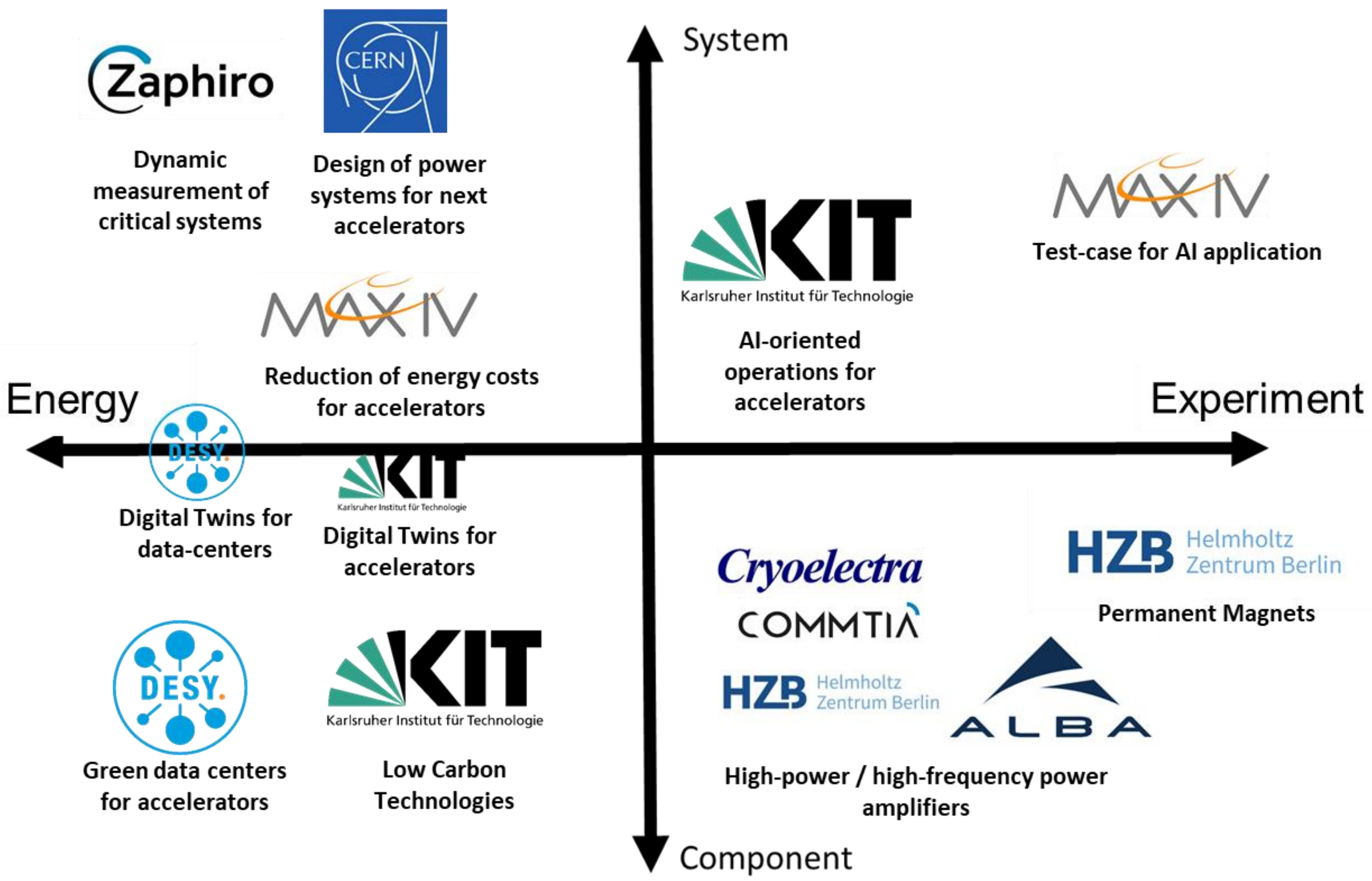
Presented ESSRI24 by . Sapountzoglou

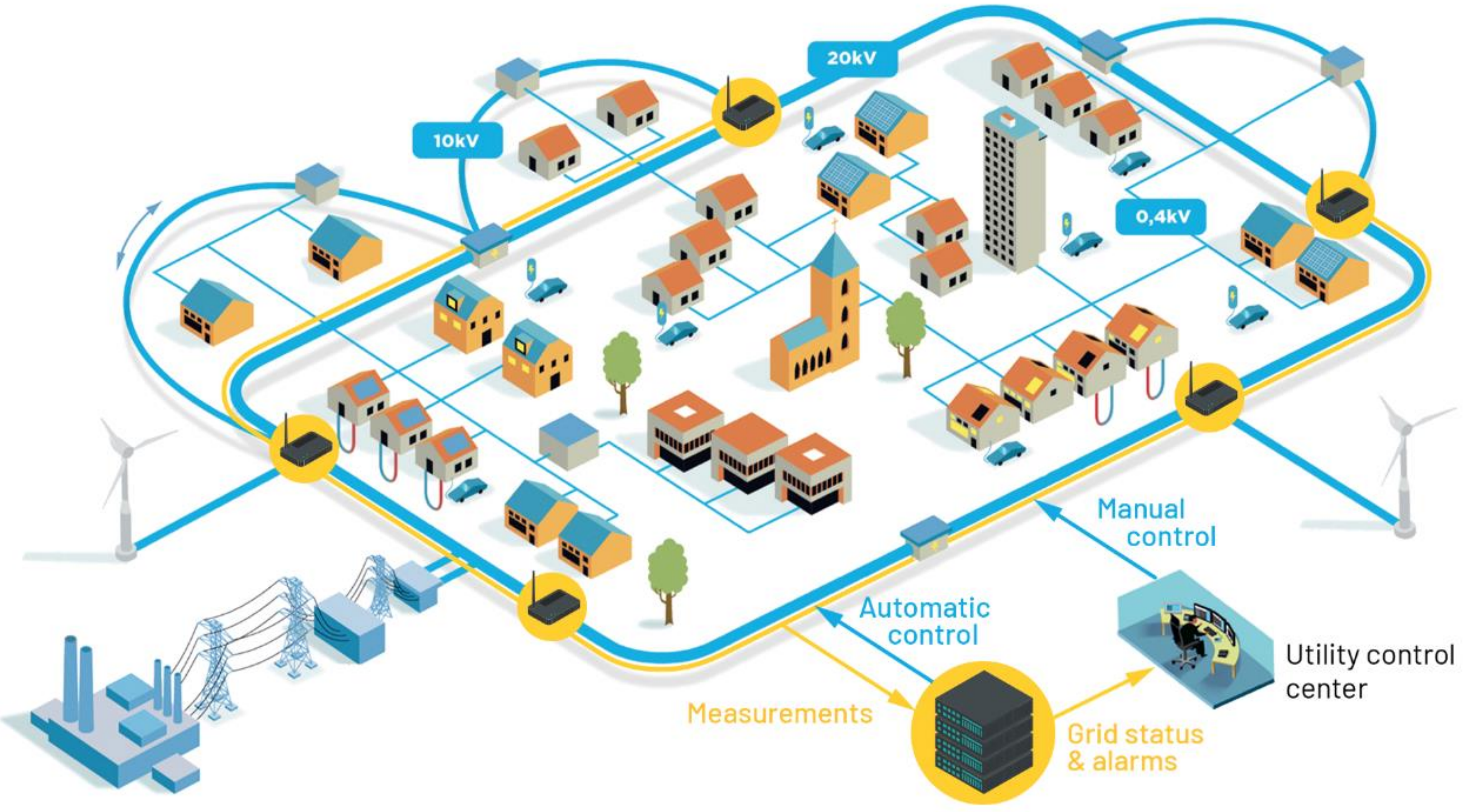
- Equip LHC with grid monitoring and automation system that leverages high-speed and time-synchronized measurements (Zaphiro)
- Built a digital twin of a large accelerator based on LHC measurement (KIT)
- Design an FCC electrical network able to integrate renewable energy and energy storage (CERN)

Zaphiro

TT.-Prof. Dr.-Ing. Giovanni De Carne
Head of „Real Time System Integration“ group
Helmholtz young investigator group leader

Karlsruhe Institute of Technology
Institute for Technical Physics (ITEP)





Summary

- Sustainability is a key aspect of the project
- All designs and R&D are focused on carbon footprint optimisation
  - Energy savings to reduce the power demand and energy consumption
  - Reduction of material needed
- Pre-TDR phase needs to be clarified on the deliverables
- Work package description to be written to help project organisation

Toward sustainable accelerators

Thank you
for your attention