Civil engineering, Infrastructure and Operation – CDR status and plan

Volker Mertens, CERN

gratefully acknowledging the contributions of
the FCC Infrastructure and Operation WG,
all FCC study teams and
the collaborating partners (list in annex)

FCC Week 2017
Berlin, 29 May 2017

Infrastructure and Operation topics

- Geology & civil engineering
- Integration
- Electricity distribution
- Cryogenics
- Cooling & ventilation
- Transport & handling
- Installation
- Planning & coordination
- Survey & alignment
- Controls
- Computing
- Communications & networks
- General safety
- Access control
- Radiation protection
- Environmental protection
- Power/energy consumption
- Energy efficiency
- Operation & maintenance concepts
- Availability & reliability
- ...

Full structure in https://fcc.web.cern.ch/Documents/Organisation/WBS.pdf, heading "3".

Only presenting material with substantial evolution since Rome.

Infrastructure and Operation related programme

Overview (V. Mertens, 25‘+5‘) **Monday**

Version: 3.0 Date: 24.05.2017

Session titles in bold red indicates sessions for machine/technical review
Session titles in bold red italics indicates sessions for physics and experiment review

FCC Week 2017 Program

Time	Sunday	Monday (29.5)			Tuesday (30.5)				Wednesday (31.5)					Thursday (1.6)				Friday (2.6)		Time
			Pavilion		Pavilion	Charlottenburg I-II	Bellevue	Tiergarten I-II-III	Pavilion	Charlottenburg I-II	Bellevue	Tiergarten I-II-III	Charlottenburg III	Pavilion	Charlottenburg I-II	Bellevue	Tiergarten I-II-III	Pavilion		
08:30-09:00		Registration (Wintergarten)	Opening, study status and physics perspectives	WELCOME O. Wiestler (HFG), R. Heuer (DPG), F. Gianotti (CERN)	FCC-hh machine design review Design (1)	Conductor Development Program (1)	*FCC-ee physics & experiment review Run plan and SM precision measurements*	SRF Recent designs and progress	FCC-ee review Optics & instrumentation	16 T magnets review EuroCirCol (1)	*FCC-hh review Physics potential of FCC-hh*	FCC-hh machine design: SppC and selected topics		*FCC-hh experiment review Calorimetry & trigger*	FCC-ee Beam dynamics	I&O review CE, electricity, ventilation, logistics, transpor	Special technologies Beam [illegible]	[illegible] Machines and Technologies	Summary FCC-hh machine design	08:30-09:00
09:00-09:30				Physics at FCC - M. Mc Cullough															Summary FCC-ee machine design	09:00-09:30
09:30-10:00					R. Aleksan (CEA)	A. Ballarino (CERN)	G. Iacobucci (UNIGE)		J. Seeman (SLAC)	E. Todesco (CERN)	J. Lykken (FNAL)	A. Faus-Golfe (CNRS)		B. Heineman (DESY)	B. Holzer (CERN)	C. Prasse (FIML)	F. Perez (ALBA)		Summary I&O / [illegible]	09:30-10:00
10:00-10:30			P. Chomaz (CEA)	Study status & further plans - M. Benedikt (CERN)	Coffee Break (Wintergarten)				Coffee Break (Wintergarten)					Coffee Break (Wintergarten)					Summa[illegible] Magnets / [illegible]	10:00-10:30
10:30-11:00			Coffee Break (Wintergarten)		FCC-hh machine design review Design (2)	Conductor Development Program (2)	*FCC-ee physics & experiment review Higgs, top and flavour*	SRF Materials	FCC-ee review Machine Detector Interface	16 T magnets review EuroCirCol (2)	Common experiment software	FCC-hh machine design: Selected topics		*FCC-hh experiment review Physics performance*	FCC-ee review Injector	16 Tesla magnets US Programme	Special technologies Other directions for R&D	Coffee Break		10:30-11:00
11:00-11:30			Status Machines	FCC-hh conceptual machine design - CDR plan and status														Summaries Physics and Experiments	Summary FCC-he	11:00-11:30
11:30-12:00				FCC- ee conceptual machine design - CDR plan and status	F. Cerutti (CERN)	C. Senatore (UNIGE)	D. Bortoletto (UOXF)	R. Rimmer (JLAB)	K. Oide (KEK)	A. Zlobin (FNAL)	P. Allport (Uni Birmingham)	O. Boine-Frankenheim (TU Darmstadt)		A.Etienvre (CEA)	I. Papaphilippou (CERN)	P. Vedrine (CEA)	A. Ryazanov (Kurchatov)		Summary FCC-hh experiments	11:30-12:00
12:00-12:30			A. Ghigo (INFN)	HE-LHC CDR plan and status FCC-he CDR plan and status	Lunch (Gardenlounge I/II and LA Café)				Lunch (Gardenlounge I/II and LA Café)					Lunch (Gardenlounge I/II and LA Café)					Summary FCC-ee experiments	12:00-12:30
12:30-13:00			Lunch (Gardenlounge I/II and LA Café)															P. Campana (INFN)	Closing remarks	12:30-13:00
13:00-13:30																		Free lunch break		13:00-13:30
13:30-14:00					FCC-hh machine design review Beam performance and specifications	Conductor Development Program (3)	*FCC-ee physics & experiment review Direct discovery & detectors*	SRF review RF system concepts and requirements	FCC-ee review Energy calibration & polarization	16 T Magnets Models & Technology ERMC-RMM-Wound Conductor	*FCC-hh experiment review Detector requirements & concepts*	Special technologies review FCC-hh beam handling	Economic impact of CERN colliders (1)	Comon detector technologies	*FCC-eh review Accelerator & interation region*	I&O review Cryogenics	Special technlogies Other Magnets			13:30-14:00
14:00-14:30			Status Technologies and Infrastructure	CE, I&O - CDR status and plan																14:00-14:30
14:30-15:00				Special Technologies R&D - CDR plan and status	M. Migliorati (INFN)	D. Larbalestier (Florida State Uni)		J. Zhai (IHEP)	E. Levichev (BINP)	S. Gourlay (LBL)	D. Charlton (Uni Birmingham)	M. Sullivan (SLAC)	M .Florio (Uni Milano)	G. Tonelli (INFN)	R. Assmann (DESY)	D. Delikaris (CERN)	[illegible] (GSI)			14:30-15:00
15:00-15:30	Registration (Wintergarten)		S. Belomestnykh (FNAL)	16 T Magnet R&D CDR plan and status SRF R&D CDR plan and status	Coffee Break (Wintergarten)				Coffee Break (Wintergarten)					Coffee Break (Wintergarten)						15:00-15:30
15:30-16:00			Coffee Break (Wintergarten)		FCC-hh machine design review Injectors	Conductor: Electromechanical characterization	*FCC-ee physics & experiment review Synergies & complementarities*	SRF review Directions for R&D	FCC-ee review Collective effects & top-up injection	Other Magnets	*FCC-hh experiment review Magnet & tracking*	Special technologies review Recent design & progress	Economic impact of CERN colliders (2)	HE LHC design	FCC-eh: Physics	16 Tesla magnet review Magnets for FCC-hh: status towards the CDR	I&O review Operation, reliability, safety			15:30-16:00
16:00-16:30			Status Experiments and Detectors	FCC-hh experiments and detector - CDR plan and status																16:00-16:30
16:30-17:00				FCC-ee experiments and detector - CDR plan and status	P. Spiller (GSI)	M. Eisterer (TU Vienna)	L. Linssen (CERN)	S. Posen (FNAL)	M. Biagini (INFN)	T. Ogitsu (KEK)	N. Wermes (Uni Bonn)	S. Casalbuoni (KIT/ANKA)	M .Florio (Uni Milano)	A. Seryi (JAI)	A. Parker (Uni Cambridge)		Ll. Mirales (CERN)			16:30-17:00
17:00-17:30			K. Borras (RWTH)	FCC-he CDR plan and status	Tea time (Wintergarten)				Teatime (Wintergarten)					Tea time (Wintergarten)						17:00-17:30
17:30-18:00			Cold refreshments (Wintergarten)		*Poster session*	*Student opportunities*	*FCC-ee physics Talks*		FCC / EuroCirCol Collaboration Boards (closed session / Bellevue)											17:30-18:00
18:00-18:30			Strategy Roadmaps Plenary Session	Global activities on future colliders and ICFA view - J. Lykken (FNAL)										Germany specific session	XFEL status and activities at DESY - H. Weise (DESY)					18:00-18:30
18:30-19:00				Procedure for the next European particle physics strategy update - F. Gianotti (CERN)		P. Lebrun (JUAS)									Status of the FAIR project - J. Blaurock (GSI)					18:30-19:00
19:00-19:30			A. Lankford (UCI)	CERN accelerator technology roadmap - F. Bordry (CERN)					L. Rivkin (PSI) / R. Aleksan (CEA)					J. Mnich (DESY)	IPP Stellarator and Tokamak Research and Technology - T. Klinger (MPI for Plasma Physics)						19:00-19:30
19:30-20:00																				19:30-20:00
20:00-20:30			Welcome reception (Wintergarten)						Workshop Banquet with Poster Award Ceremony (Pavilon)											20:00-20:30
20:30-21:00																				20:30-21:00
21:00-21:30																				21:00-21:30
21:30 -22:30																				21:30 -22:00

Ch. Prasse/FIML

- civil engineering
- electricity
- ventilation
- logistics
- transport

All sessions as input for review

D. Delikaris

- cryogenics

Ll. Miralles

- operation
- reliability
- safety

Summary of IO related parallel sessions and posters (J. Osborne, 15‘) **Friday**

Poster list in annex.

Conceptual Design Report

1 – PHYSICS

Physics opportunities across all scenarios

2 Hadron Collider Summary

3 – Hadron Collider Comprehensive

- Accelerator
- Injectors
- Technologies
- Infrastructure
- Operation
- Experiment
- eh

4 Lepton Collider Summary

5 – Lepton Collider Comprehensive

- Accelerator
- Injectors
- Technologies
- Infrastructure
- Operation
- Experiment

6 High Energy LHC Summary

7 – High Energy LHC Comprehensive

- Accelerator
- Injectors
- Infrastructure

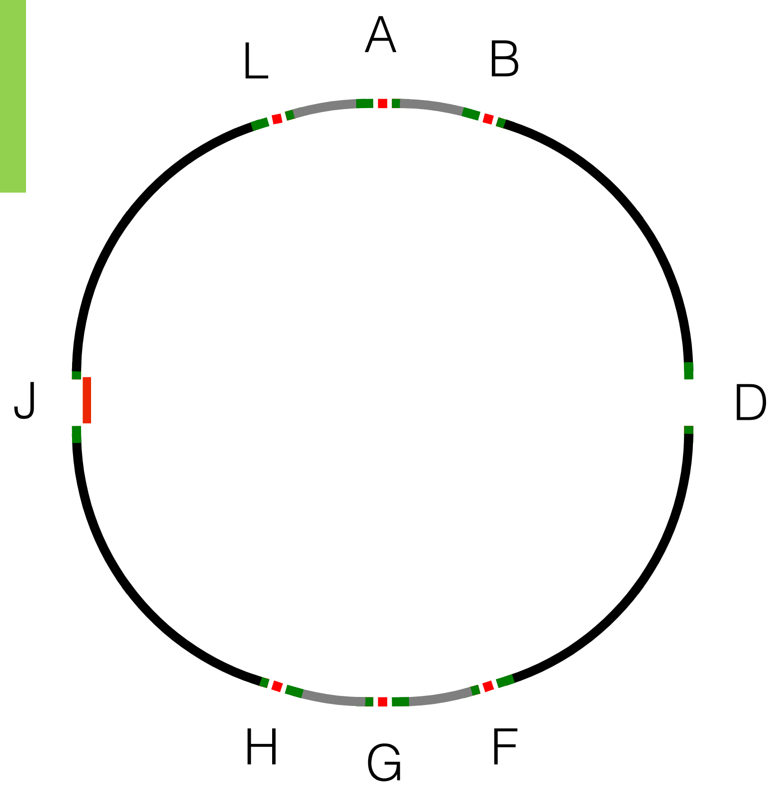
Refs to FCC-hh, HL-LHC, LHeC

- Documents the performed studies
- Material to support the baseline concepts
- A basis for the next phase
- Highlights remaining work
- Lists alternatives
- …

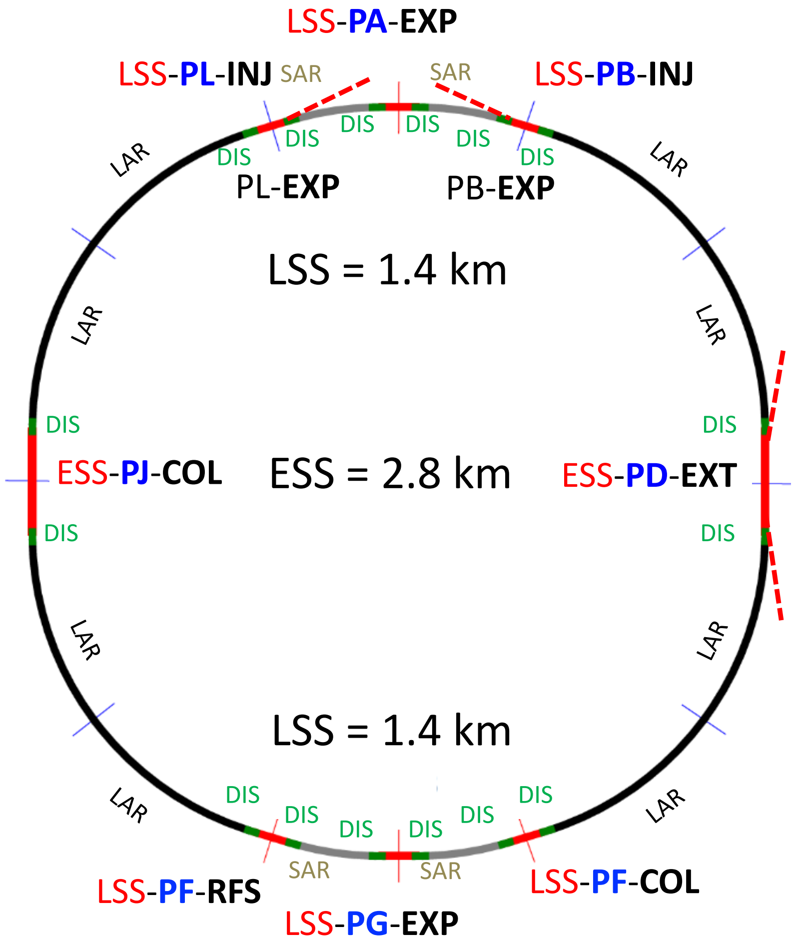
Concise description of main concepts and key points

New layout baseline

New features include:
Overall length 97.75 km
Injections upstream side experiments
Larger distances A-B, L-A (F-G, G-H)
(altered footprint choices)



A. Langner, D. Schulte



J. Gutleber

Taking this layout as fixed
(for CDR preparation)

New footprint baseline

CERN | FCC hh ee he | ARUP

Alignment | Shafts | Query

Choose alignment option

V4variation_v2017-2

Tunnel elevation at centre:322mASL

Grad. Params

Azimuth (°): -23.5

Slope Angle x-x(%): 0.3

Slope Angle y-y(%): 0.08

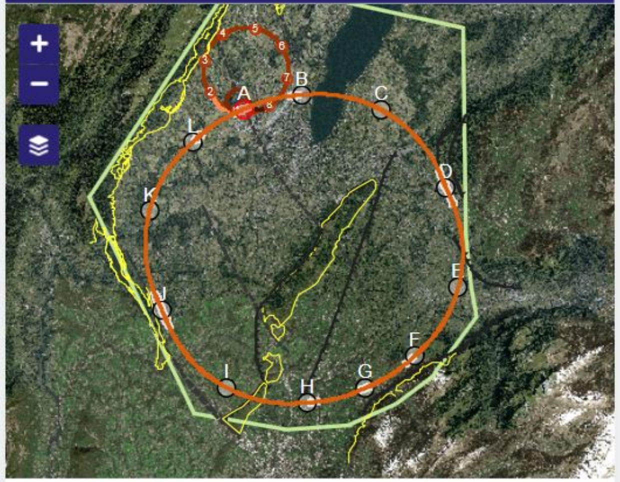
LOAD | SAVE | CALCULATE

Alignment centre

X: 2499941 Y: 1107760

	CP 1		CP 2	
	Angle	Depth	Angle	Depth
LHC	37°	49m	-40°	83m
SPS		121m		126m
TI2		121m		126m
TI8		51m		118m

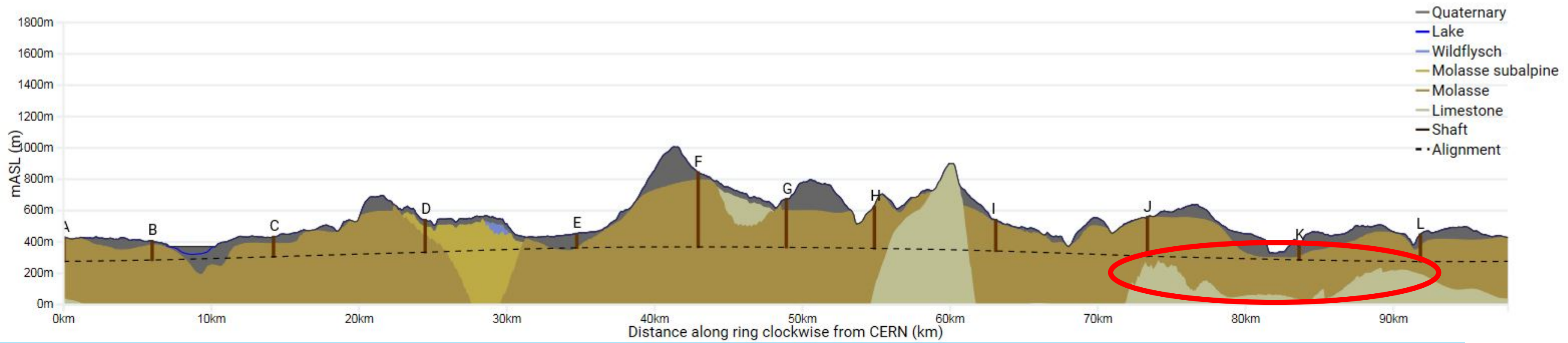
Alignment Location



Geology Intersected by Shafts | Shaft Depths

	Shaft Depth (m)				Geology (m)		
Point	Actual	Molasse SA	Wildflysch	Quaternary	Molasse	Urgonian	Limestone
A	152	0	0	0	152	0	0
B	121	0	0	26	95	0	0
C	127	0	0	44	83	0	0
D	205	66	0	40	100	0	0
E	89	0	0	89	0	0	0
F	476	0	0	49	427	0	0
G	307	0	0	73	234	0	0
H	266	0	0	0	266	0	0
I	198	0	0	11	187	0	0
J	248	0	0	1	247	0	0
K	88	0	0	70	18	0	0
L	172	0	0	89	83	0	0
Total	2449	66	0	492	1892	0	0

Alignment Profile

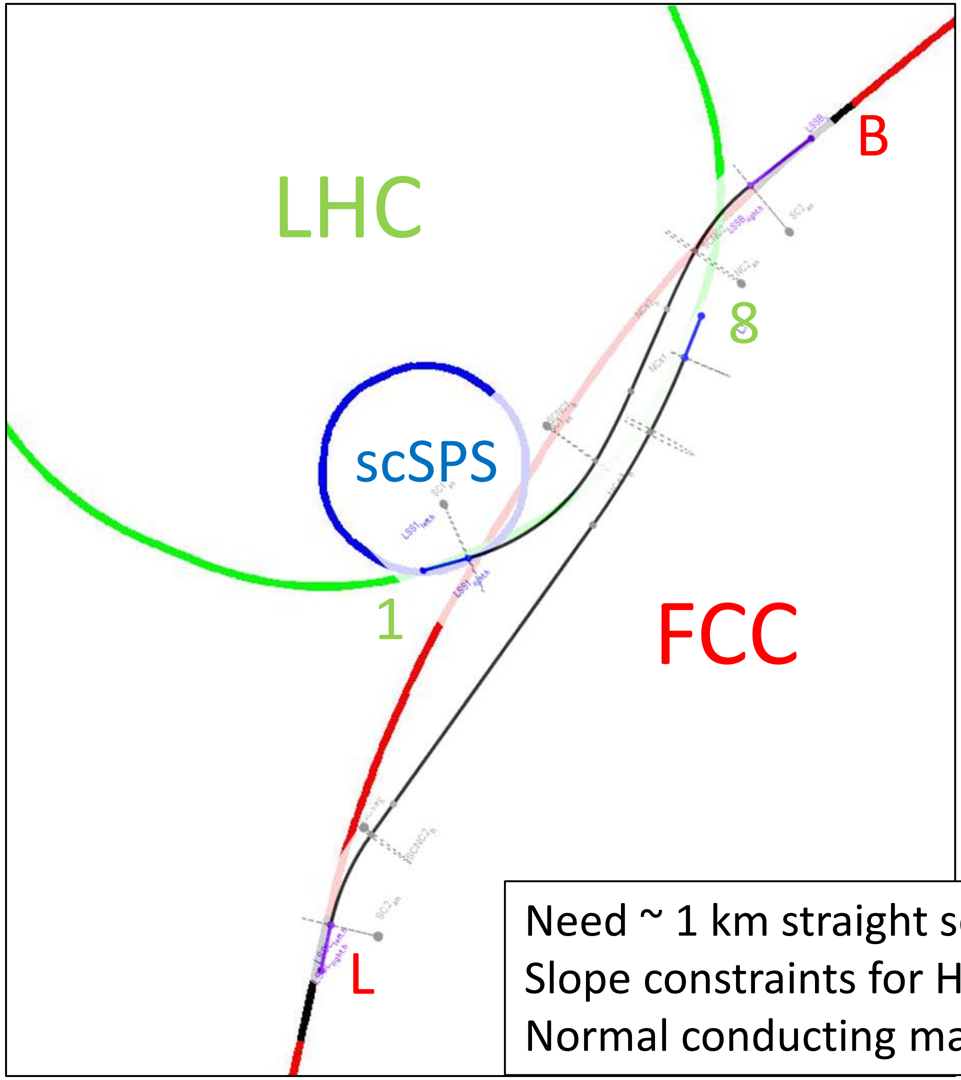


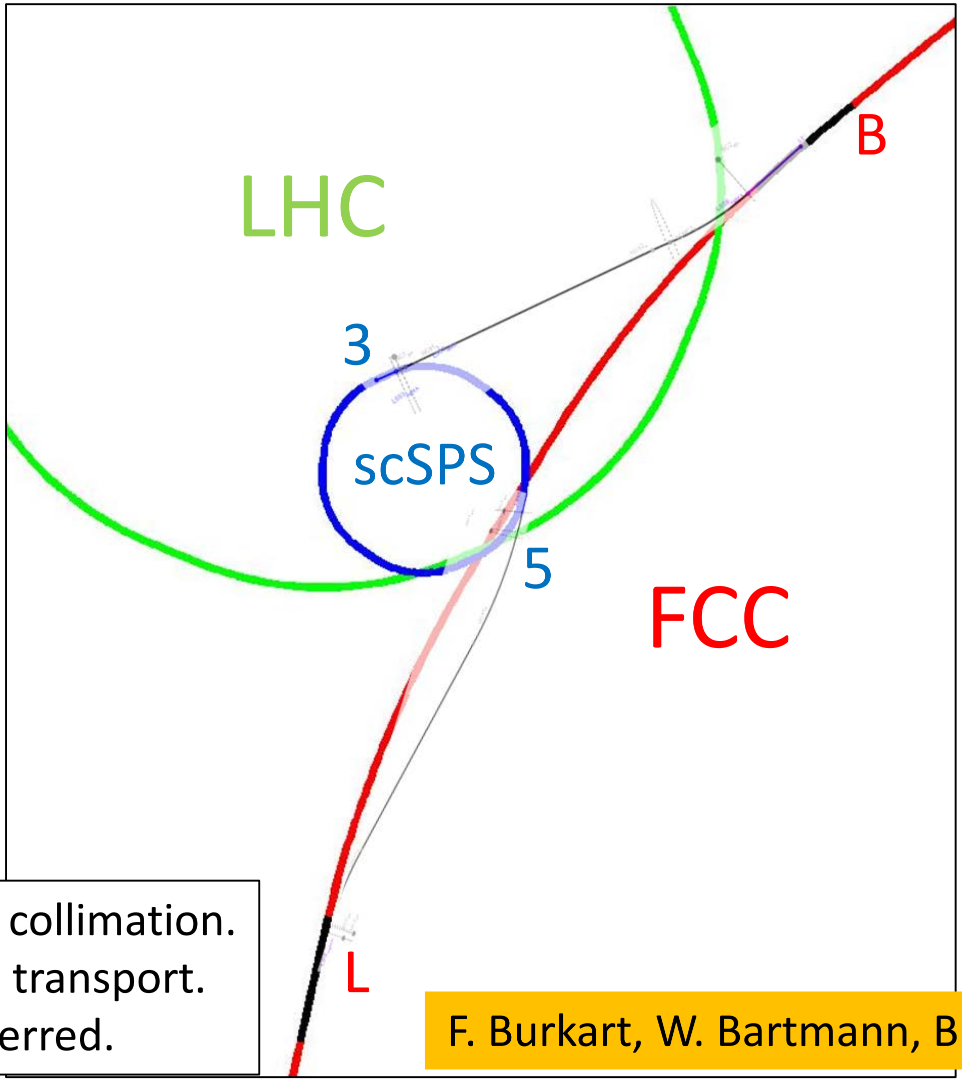
J. L. Stanyard

Thursday 8:30: Civil engineering optimisation and design development (J. L. Stanyard)

84.6% | 5.2% | 5.5% | 4.7%

Beam Transfer from LHC and scSPS





Need ~ 1 km straight sections for collimation.
Slope constraints for He flow and transport.
Normal conducting magnets preferred.

F. Burkart, W. Bartmann, B. Goddard

Tuesday, 9:35: Injection and extraction insertions and dump lines (F. Burkart)

Main implementation characteristics

FCC tunnel	2017 values	2016 values**)
Sum of depths at all points [m]	2449*)	3211
Deepest shaft [m]	476 (F)	392 (F)
Limestone [%]	5.5	13.5
Moraine [%]	4.7	-

*) Based on a „shallow" option, crossing Lake Geneva in moraine (positive indications on feasibility and cost efficiency; water exchange in layers surrounding the tunnel (radiation impact) yet to be studied.

**) Former 100 km intersecting version („option 2a")

Beam transfer [km]	SC part (6 T)	NC part (2 T)	Straight	Total length
LHC_1 → FCC_B	2.4	1.4	0.9	4.7
LHC_8 → FCC_L	1.1	2.4	3.6	7.1
scSPS_3 → FCC_B	-	1.3	3.0	4.3
scSPS_5 → FCC_L	-	2.5	2.8	5.3

Annotations on footprint baseline

It conceptually works (limestone, shaft depths, surface locations, beam transfer).

Explore potential from inclined access tunnels, of displacing or suppressing specific shafts, or to use different techniques for lots to be delivered at different times.

Need to collect more information

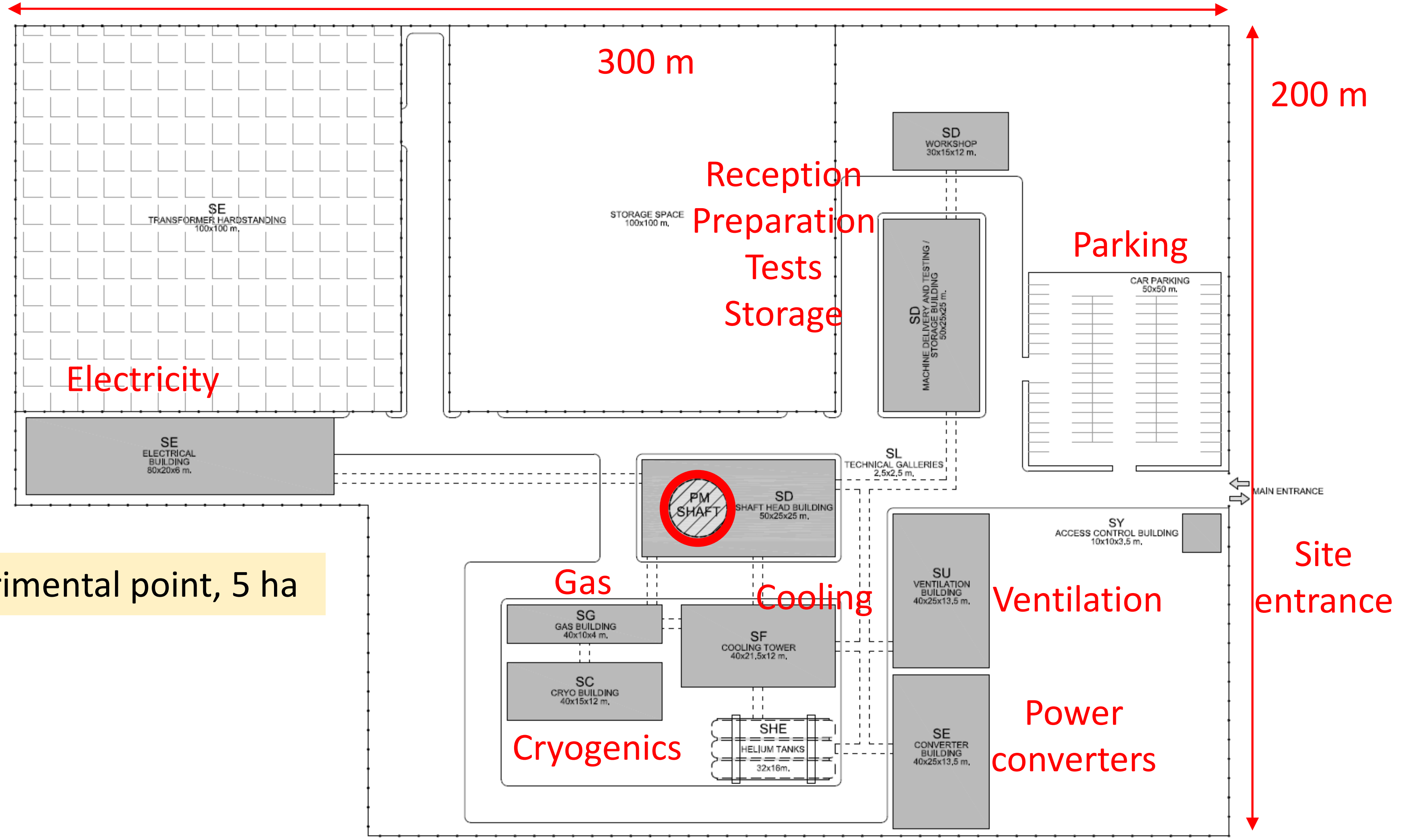
- on geological conditions (extend data area, in-situ exploration);
- up-to-date status of areas (constructed, protected) and their evolution;
- legal requirements and constraints (proximity, noise, integration);
- cost of elements (tunnels, shafts, roads, ...).

Many constraints in a densely populated area, with interesting geology and topology.
Many design criteria (partly contradicting) – looking for „optimum".
Geological design tool helps enormously – still time-intensive process.

Great interest to have more automated tool which optimises footprint to chosen criteria.

Still much work for civil engineering, to elaborate options and methods and check details.

Surface buildings



Non-experimental point, 5 ha

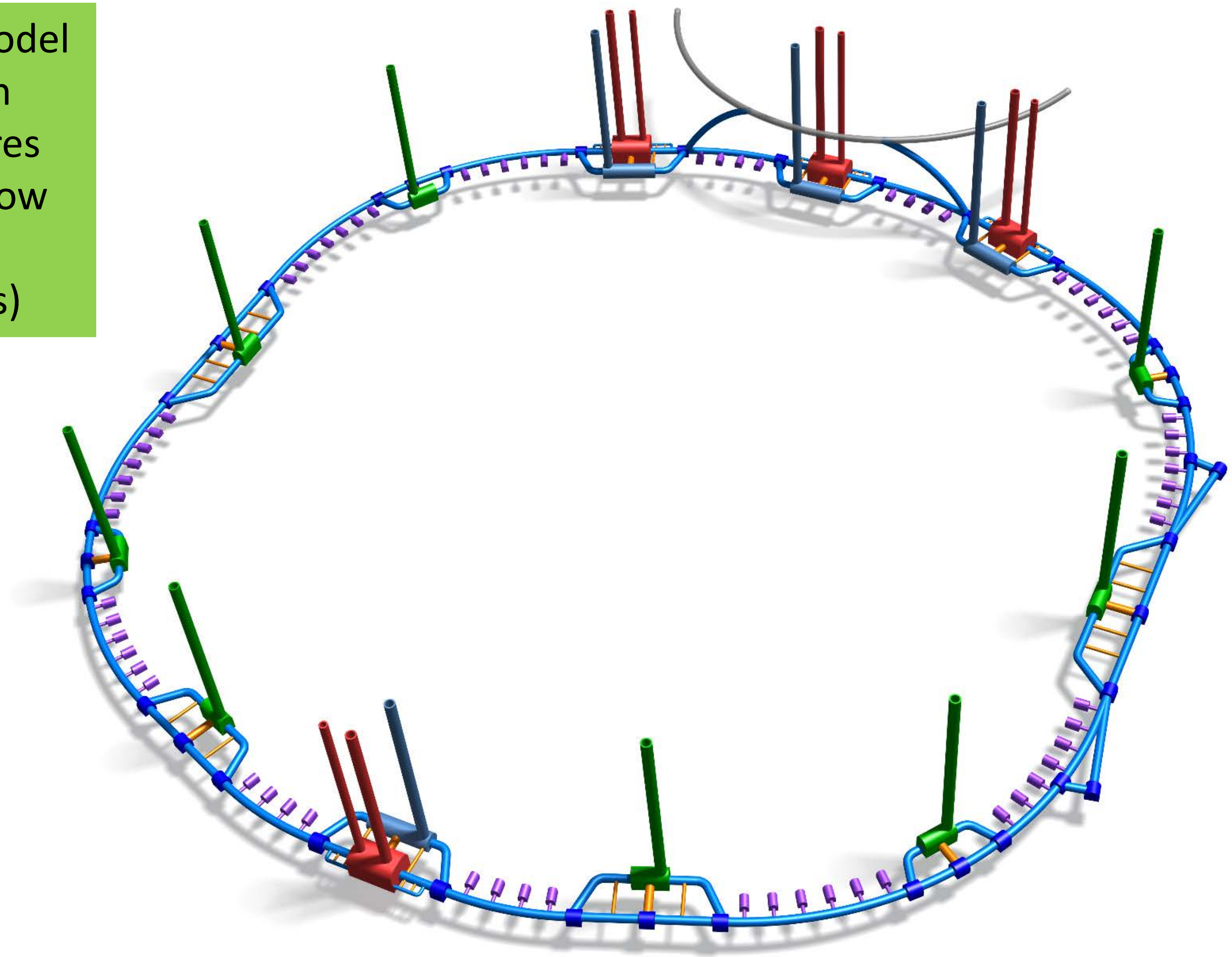
„Generic layout“, modelled after LHC (partly scaled).
Detailed requirements to be elaborated.

C. Navas, J. L. Stanyard

Overall schematic 3D view

not to scale

Single tunnel model updated with all main features known up to now (w/o FCC-ee enlargements)

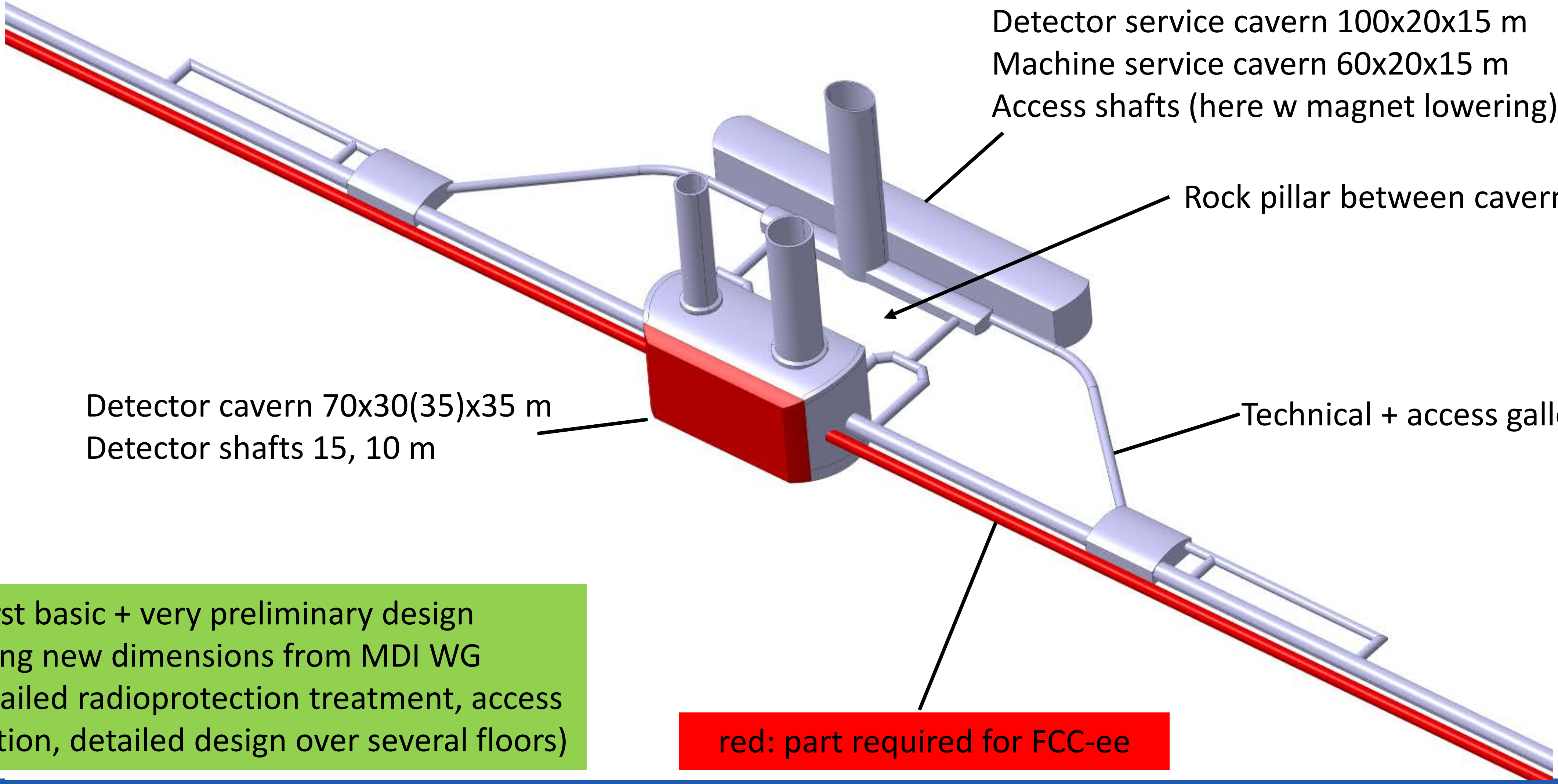


Colour code:

- Machine tunnels + bypass galleries
- Detector caverns + shafts
- Service caverns + access shafts
- Electrical alcoves
- Connection tunnels

A. Navascues Cornago

Underground structures



Detector service cavern 100x20x15 m
Machine service cavern 60x20x15 m
Access shafts (here w magnet lowering) 18 m

Rock pillar between caverns 45 m

Detector cavern 70x30(35)x35 m
Detector shafts 15, 10 m

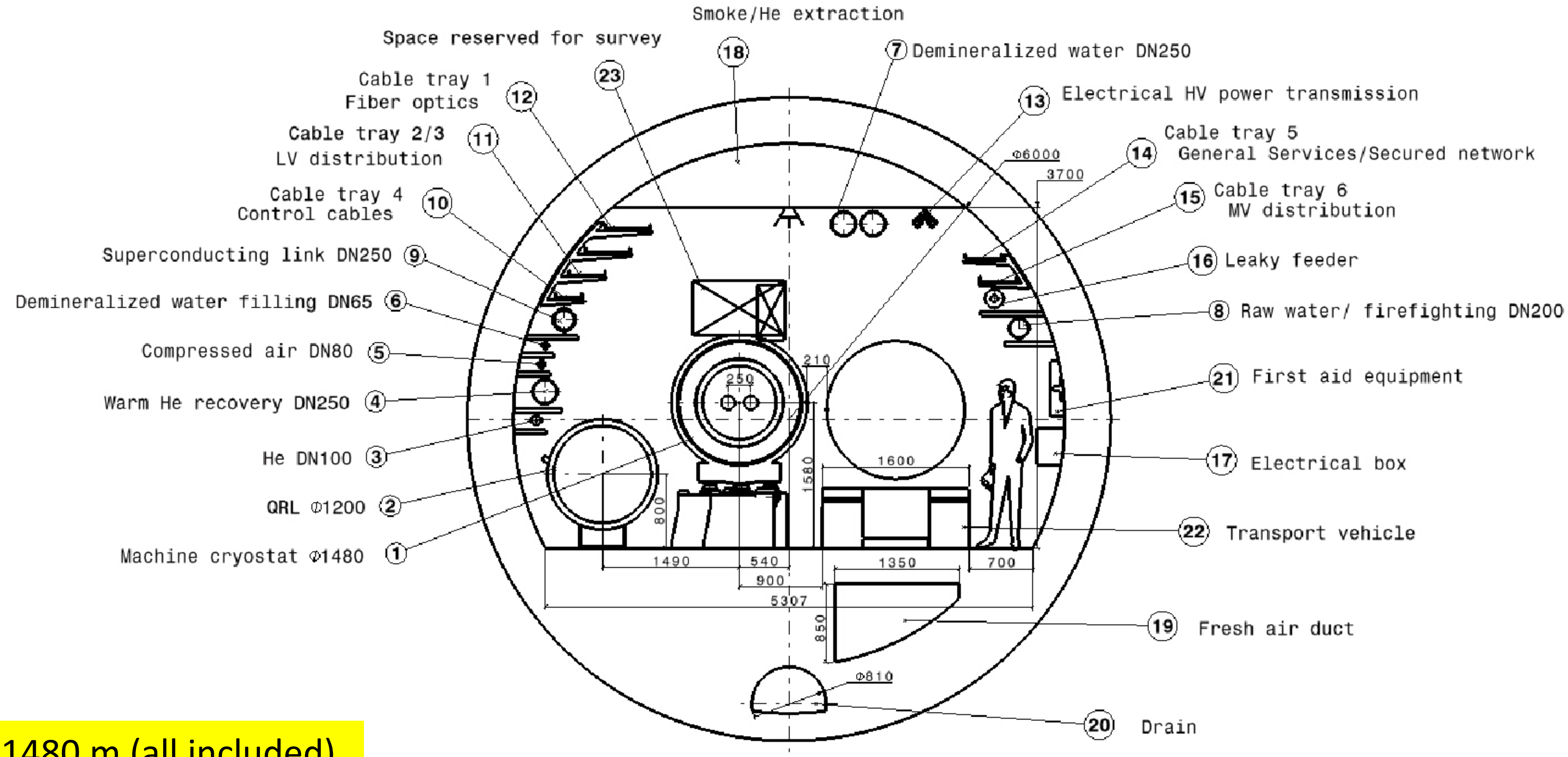
Technical + access galleries

First basic + very preliminary design
using new dimensions from MDI WG
(w/o detailed radioprotection treatment, access optimisation, detailed design over several floors)

red: part required for FCC-ee

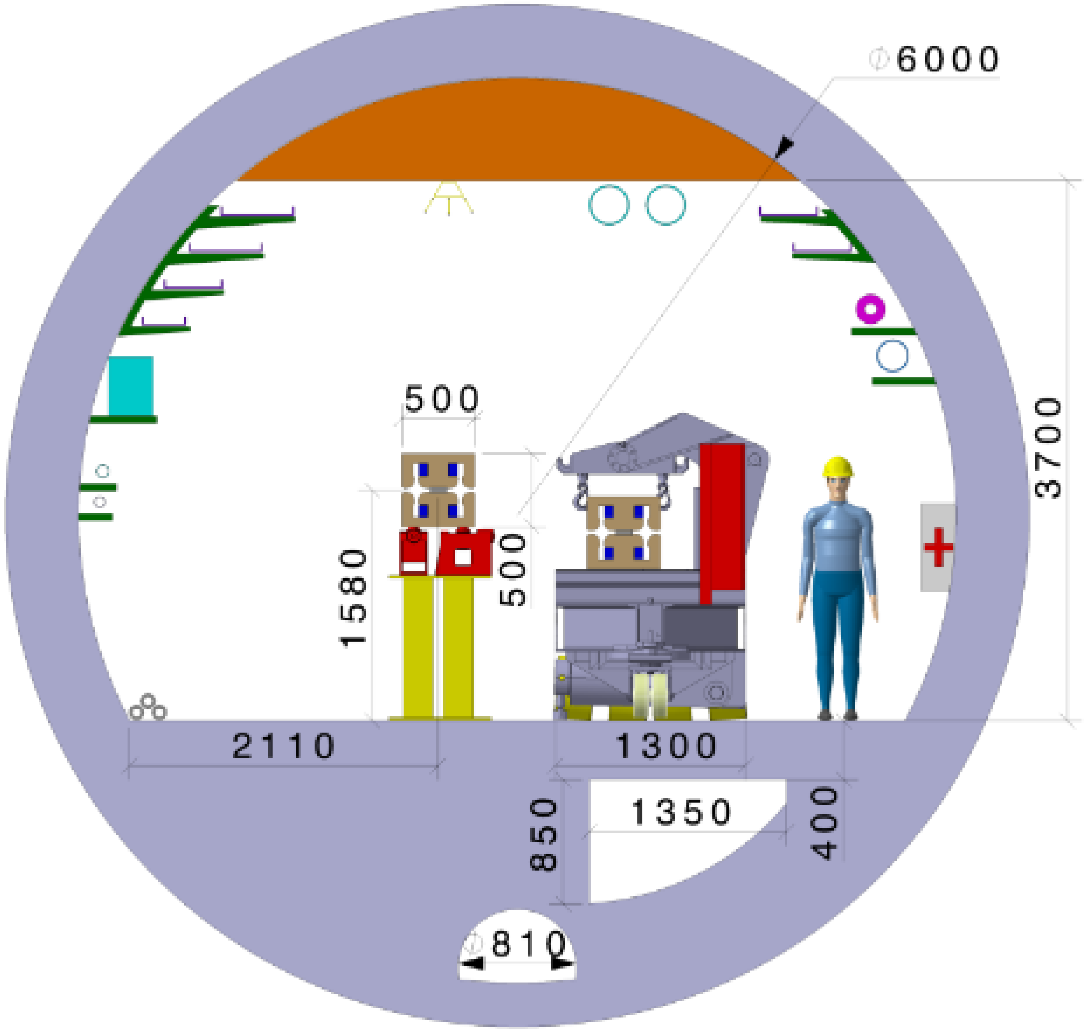
F. Valchkova-Georgieva

Tunnel cross section, FCC-hh



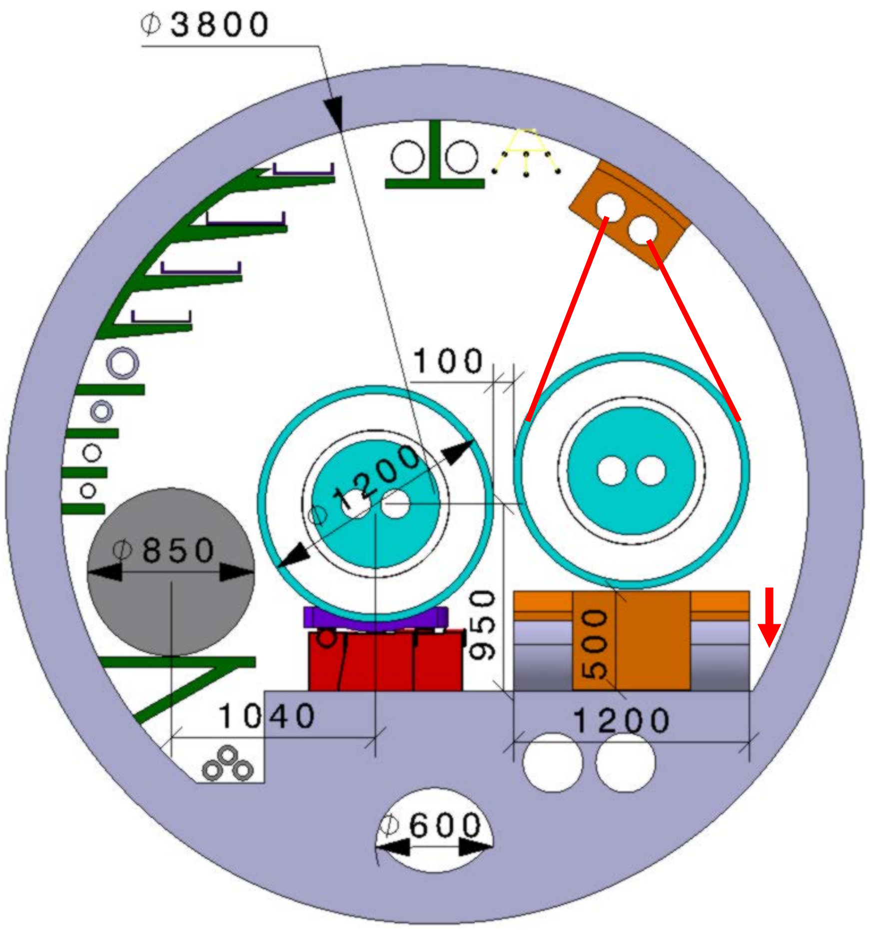
Magnets OD 1480 m (all included)
QRL OD 1200 mm (all included)

Tunnel cross section, FCC-ee



F. Valchkova-Georgieva
Magnet model: A. Milanese

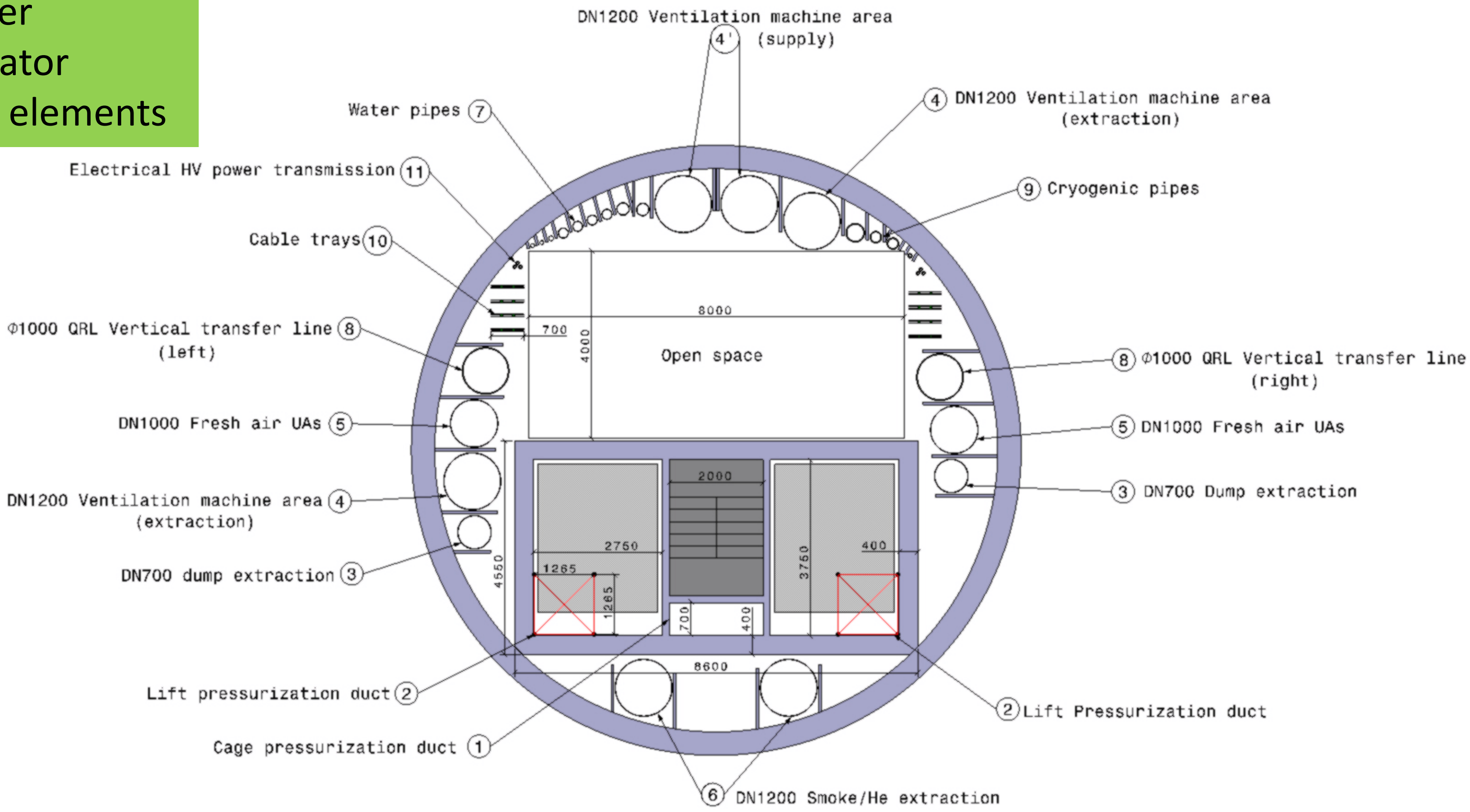
Tunnel cross section, HE-LHC



No civil engineering
Same beam height as LHC
→ Magnets OD ca. 1200 m (all included) – study in //
QRL (sector shorter than at FCC) OD ca. 850 mm (all included)
Re-routing of services abeam the cryogenics service module not yet studied
Magnet suspended during „handover“ from transport vehicle to installation transfer table

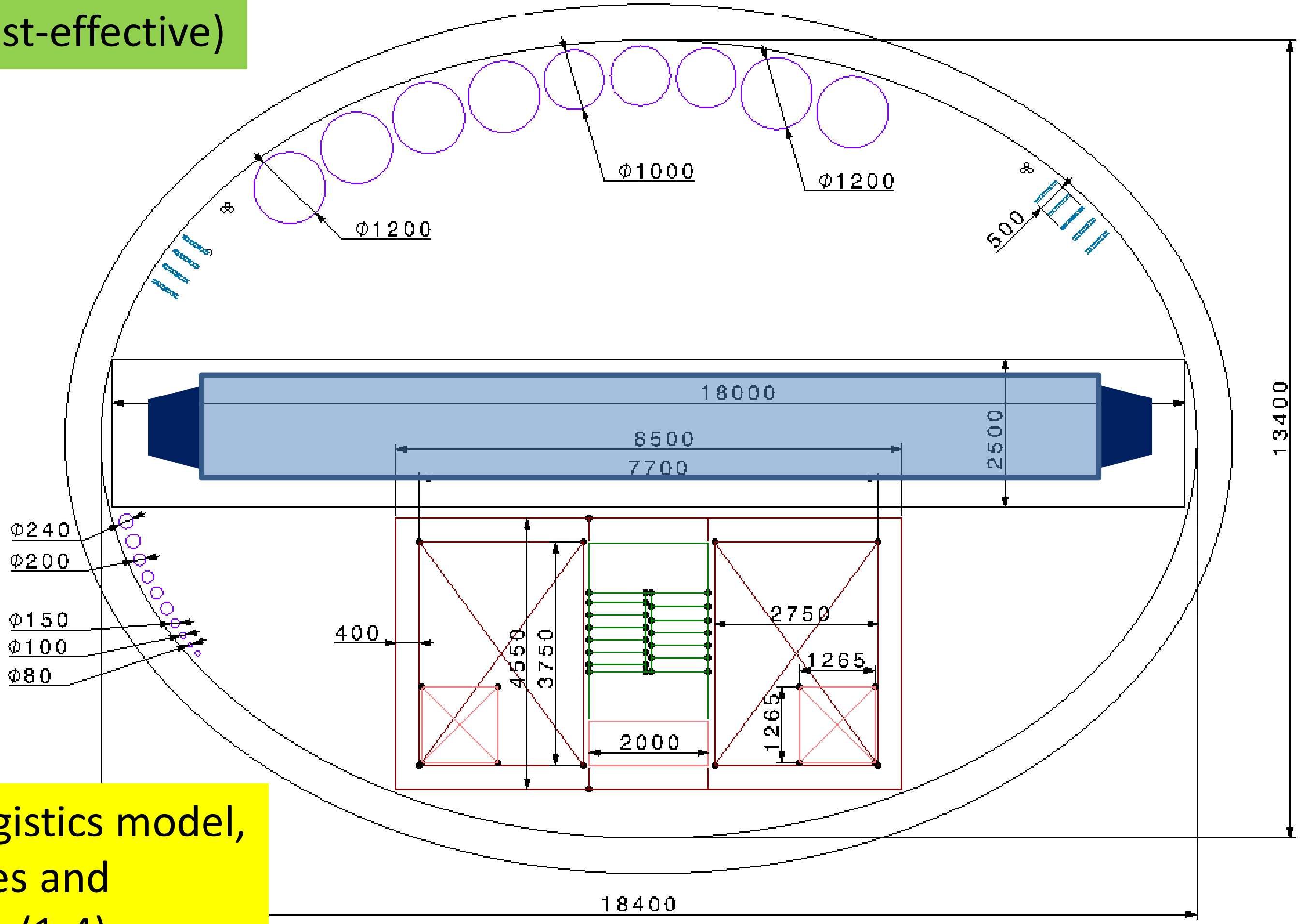
Shafts

Single access shaft per point
12 m diameter
double 3 t elevator
all requested service elements



Shafts (allowing magnet lowering)

18 m elliptical or round
(whichever will be more cost-effective)

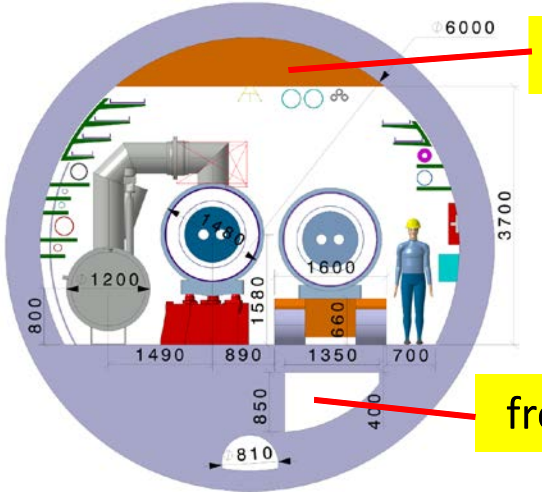


As many as indicated by logistics model, transport capabilities and installation schedule (1-4).

F. Valchkova-Georgieva

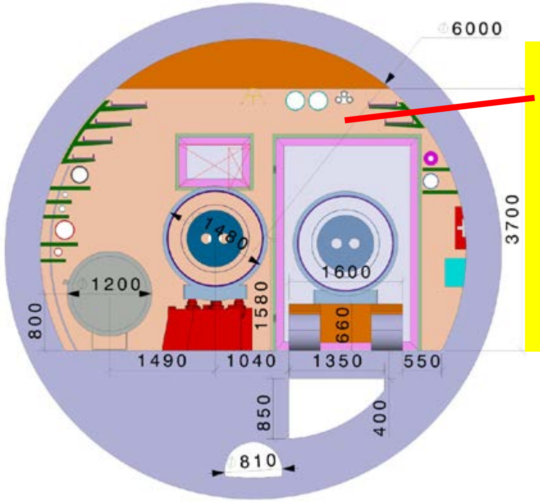
Arc ventilation
(working hypothesis for safety concept)

Abnormal conditions considered;
redundant AHUs
(also for smoke/He extraction)

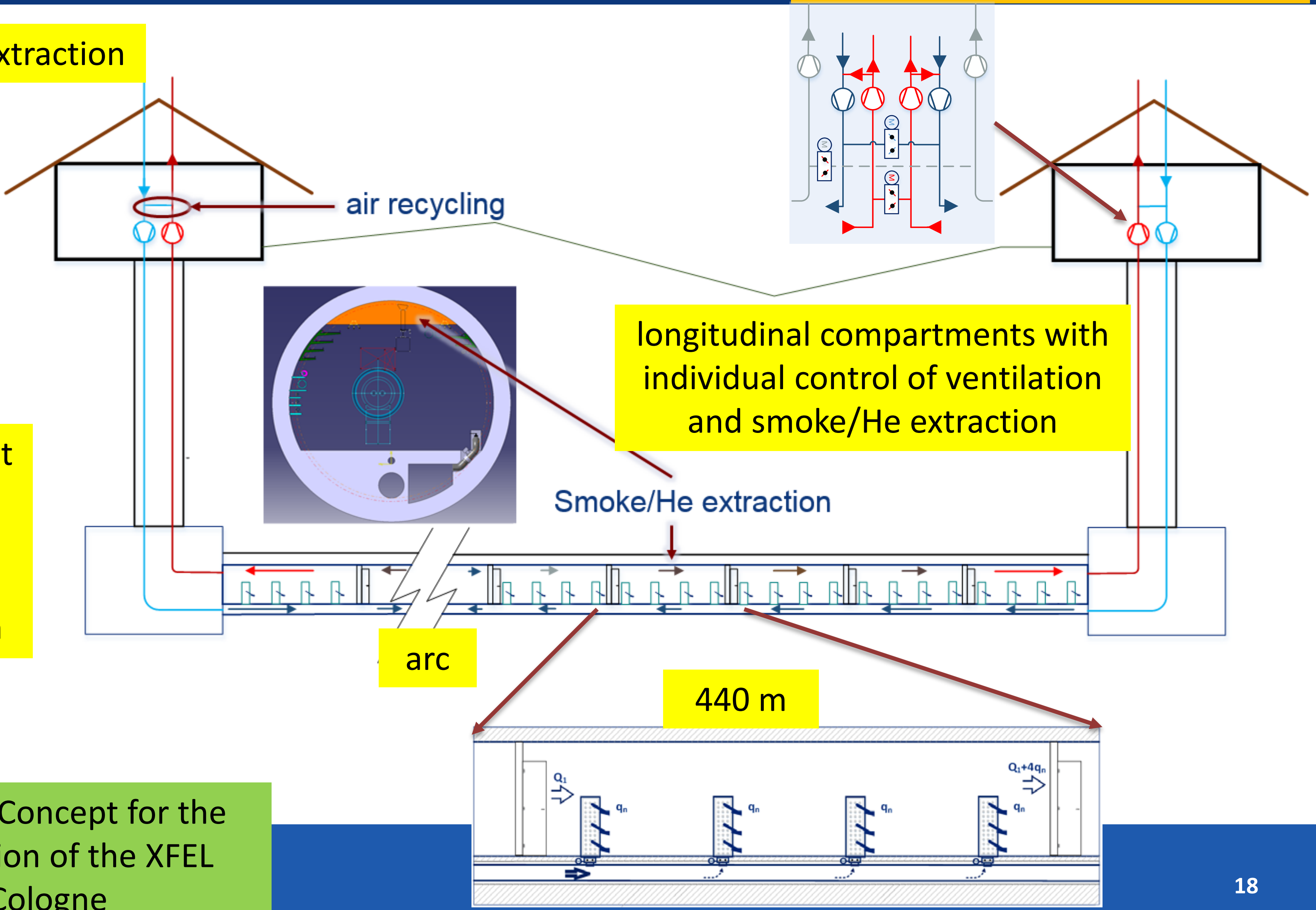


smoke/He extraction

fresh air duct



compartment with automated fire doors every 440 m



longitudinal compartments with individual control of ventilation and smoke/He extraction

arc

440 m

Ref to: Security and Workplace Safety Concept for the Construction, Installation and Operation of the XFEL Research Facility, STUVA e.V., Cologne

Ventilation parameters

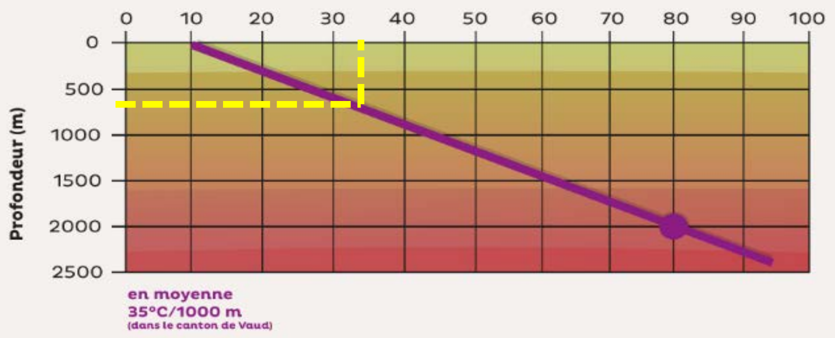
Thursday, 9:15: A ventilation system for the FCC (G. Peon)

General input data	
Cross section area	17.7 m^2
Max. sector length	10.5 km
Maximum Temperature (running conditions)	32 °C (tbc)
Maximum dew point	12 °C (tbc)

Compartment input data	
Number of compartments	24
Compartment length	440 m
Volume Compartment	7788 m^3

Ventilation figures	
Normal air flow	2 x 25,000 m^3/h
Flushing air flow	2 x 50,000 m^3/h
Air supply points per compartment	4
Air flow per supply point (normal)	520 m^3/h
Air flow per supply point (flushing)	1041 m^3/h
Time for complete air renewal	1.8 h
Maximum air speed	0.78 m/s
Cooling capacity in normal operation, ΔT=15K	250 kW
Estimated head loss (supply in flushing)	3300 Pa

Peak tunnel wall temperature (Pre-Alps)



Evolution de la température dans le sous-sol dans les conditions du Plateau suisse. Source S. Catin CREGE

Peak tunnel wall temperature (Pre-Alps)

Estimated heat load to tunnel air (min. 101, ave 177., max. 239 kW/sector) can be cooled by air flow w/o additional cooling. Tunnel wall temperature needs further study (sector average < peak).

Safety accompanies development

CDR

- **Conceptual Safety Study**
- Hazard Register
  - Standard best practice – directives, standards, guidelines
  - Identify cases for risk assessment
- Proposal of conceptual approaches for risk-control

TDR

- **Technical Safety Study**
- Specific Risk Assessments
  - Prescriptive solutions: strictly rule-based
  - Performance-based: tailor-made solutions to meet safety objectives
- Proposal of detailed technical solutions for risk-control

Thursday, 16:15: FCC safety strategy for the CDR (Th. Otto)

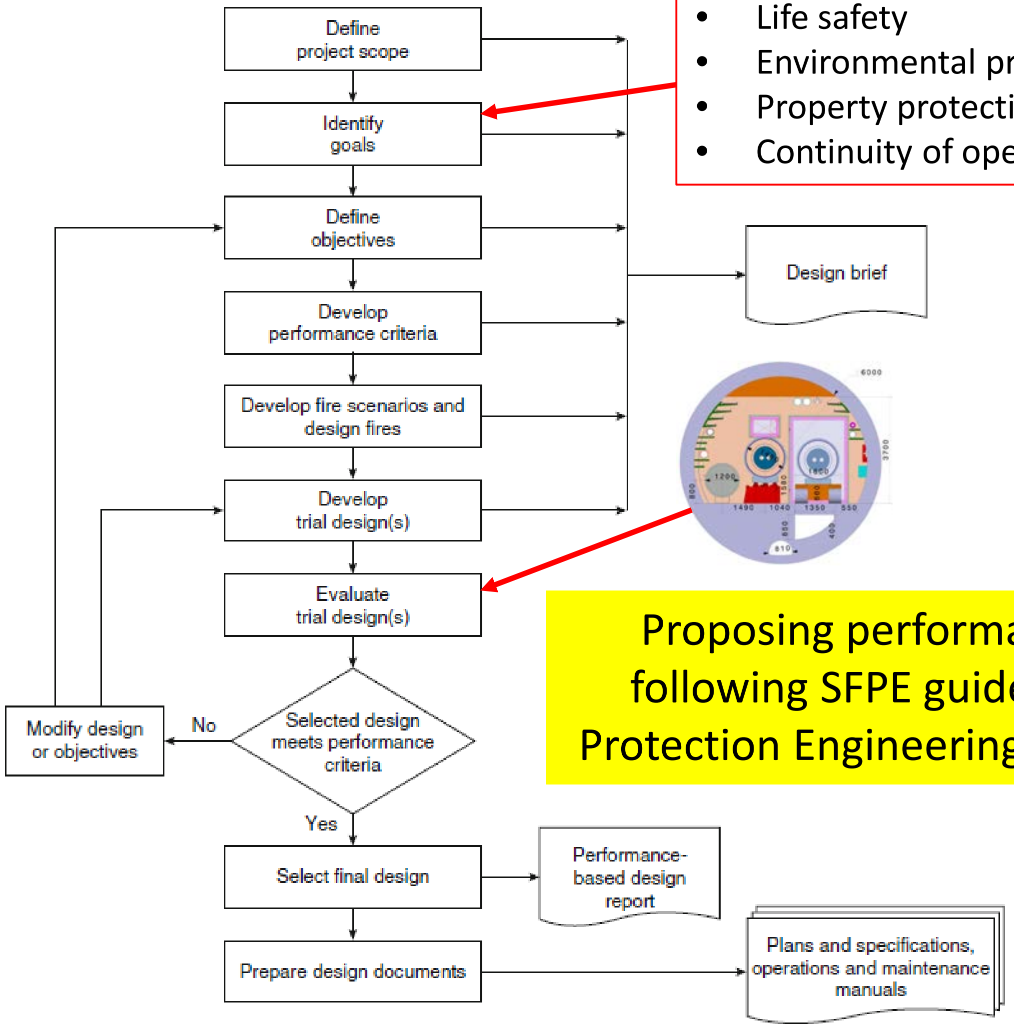
Hazard register

Systematic, ordered collection

Technology
- SC magnets
- Cryogenics
- …

- Location in the facility
  - Surface
  - Tunnel
  - Cavern
  - …
- Project Phase
  - Installation
  - Operation
  - Shutdown
  - …

Other safety studies



- Life safety
- Environmental protection
- Property protection
- Continuity of operation

Proposing performance-based analysis, following SFPE guideline - Society of Fire Protection Engineering (not only for fire risks)

Fire safety engineering collaboration

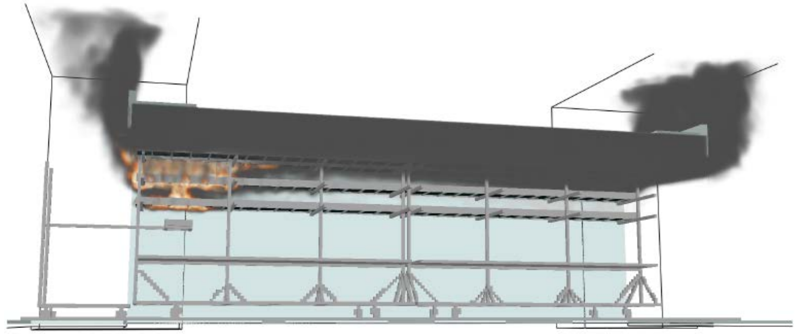
Active on:

WP1 – fire statistics
→ fire losses and cost

WP2 – fire detection and extinguishing
→ fire response (human and robotic)

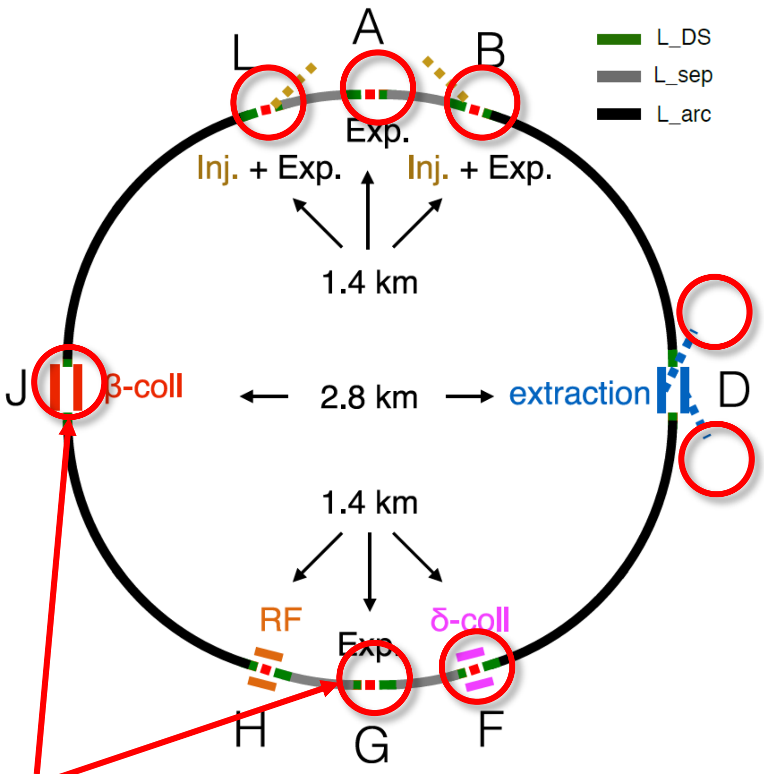
WP3 – fire propagation and its limitation
→ cable fire test @Lund
→ modeling cable tray fires

WP4 – evacuation
→ mono-dimensional evacuation model



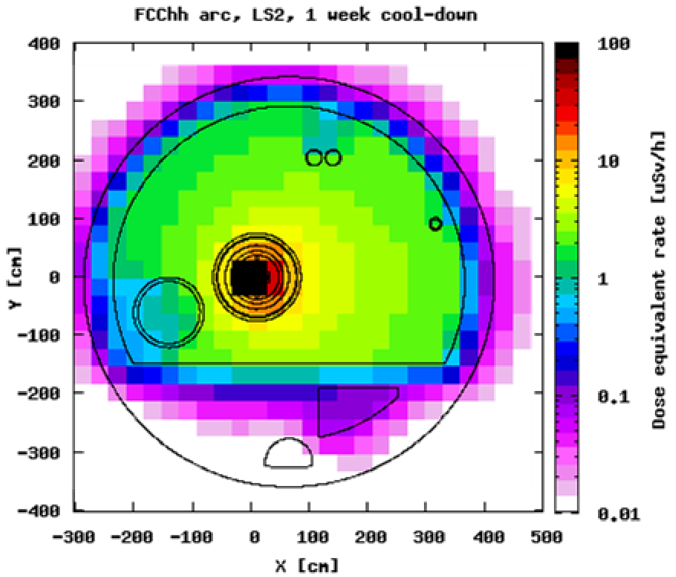
Radioprotection matters

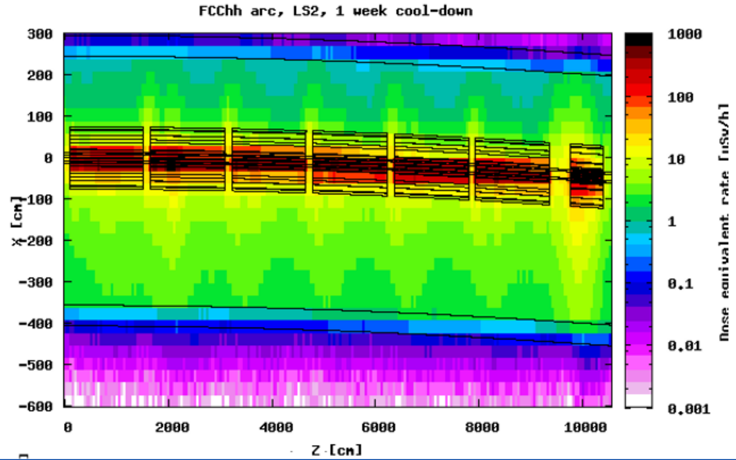
High-radiation areas



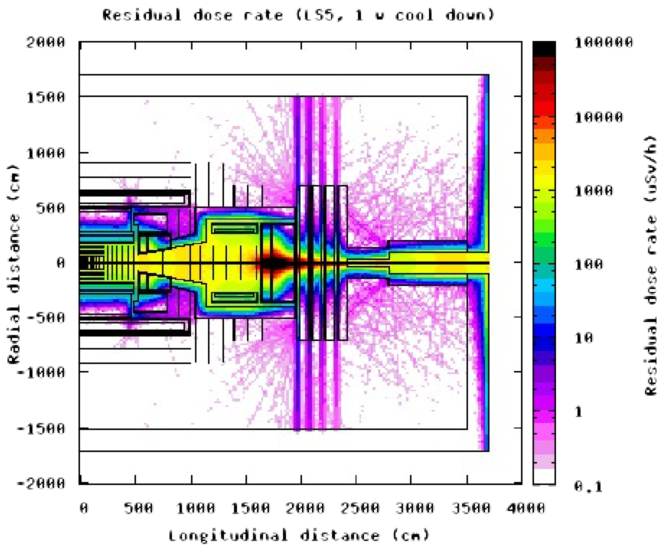
Radiation hazards lists (prompt stray radiation, activated air, X-rays ...

FCC-hh arc residual dose rate





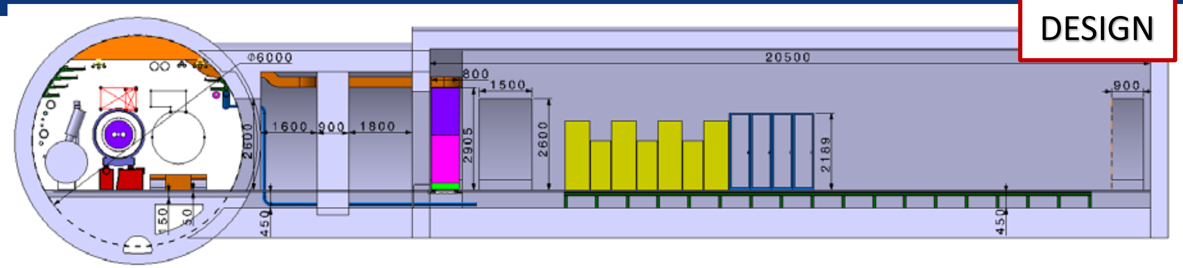
FCC-hh detector residual dose rate

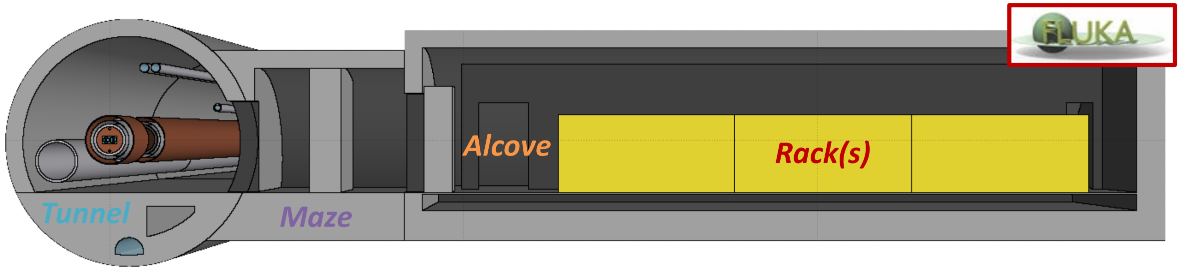


Ultimate, after 5 runs (17.5 ab^{-1})
1 mSv/h after 1 wk
High levels in forward HC

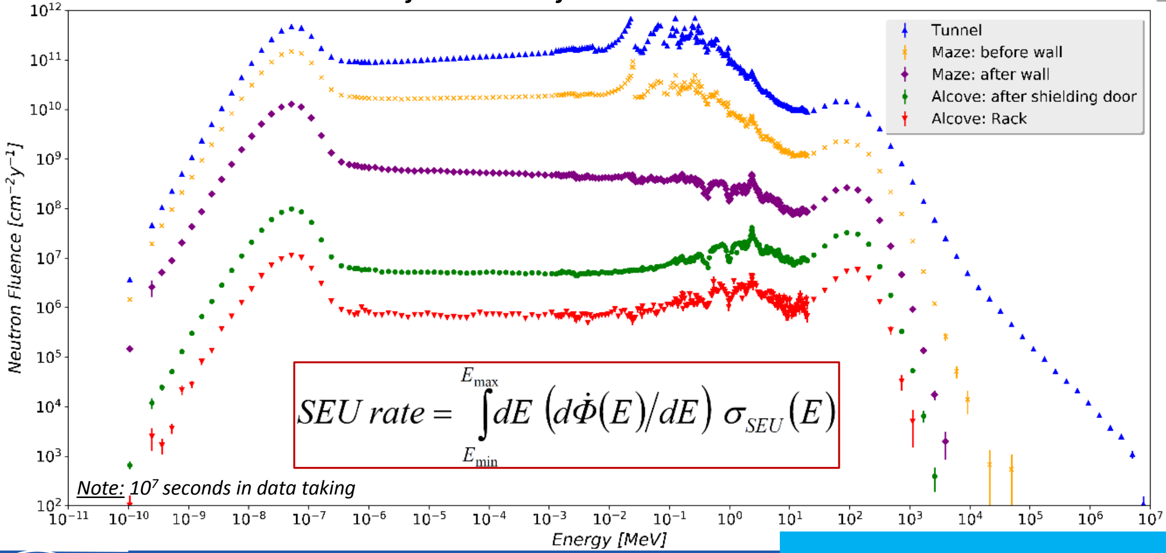
Thursday, 16:40: Radioprotection matters (M. Widorski)

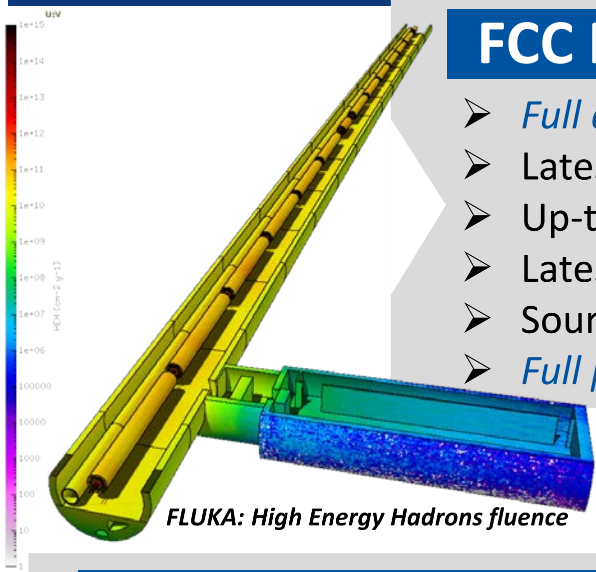
Radiation levels in FCC tunnel and alcoves (R2E)





FLUKA assessment of the neutron fluence within the FCC Tunnel and Alcove





FLUKA: High Energy Hadrons fluence

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*

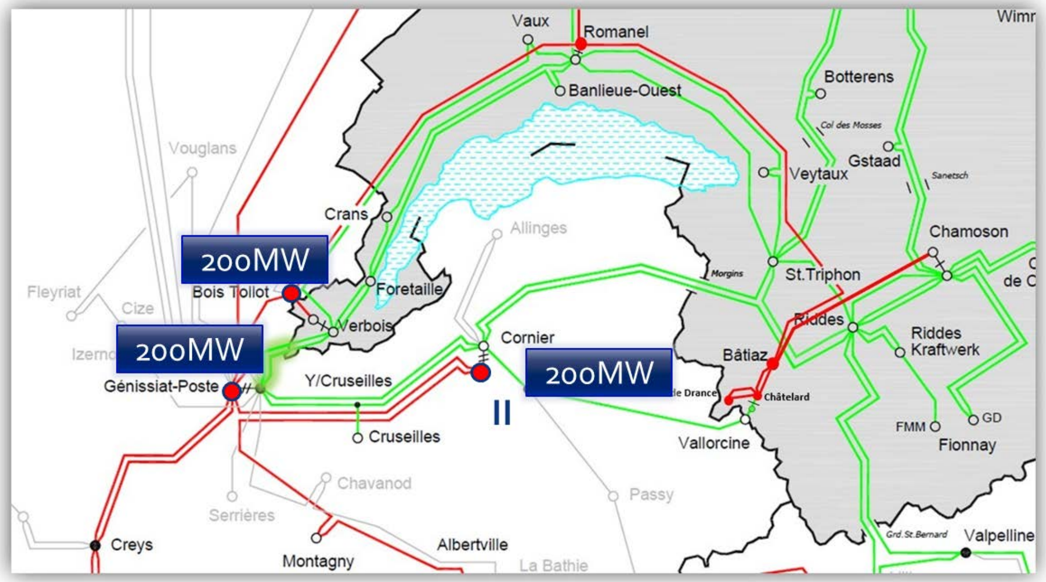
Main achievements:

- ✓ *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 factor *~3-4* LHC RE areas
- ✓ *Qualification requirements* already beyond current availability

Thursday, 11:10: FLUKA Monte-Carlo modelling of the FCC arc cell: radiation environment and energy deposition due to beam-gas interactions (A. Infantino)

Supply and distribution of electrical energy

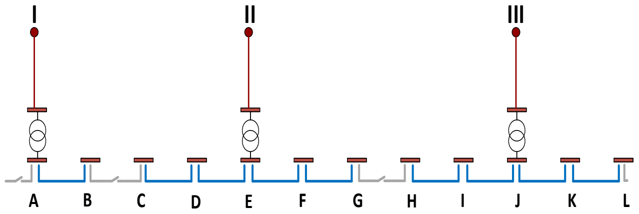
Power available at grid level at horizon 2030



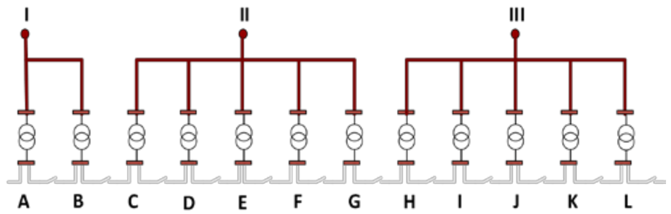
---- 400 kV *Réseau autour du Lac Léman, base case 2022* ---- 230 kV

- Power estimates are being updated and appear not to exceed the available power.
- „FCC service level“ to be defined (full availability, degraded modes, redundancy).
- Local energy buffers could cover short (100 ms) network interruptions and increase availability.

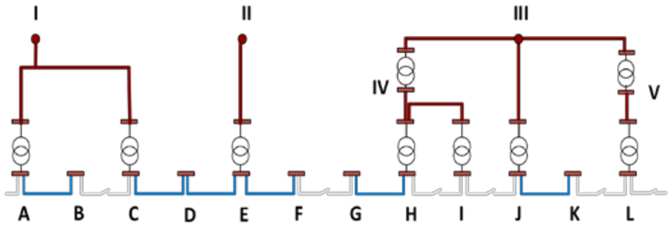
Transmission alternatives



400 kV to nearest FCC point and underground transmission ring

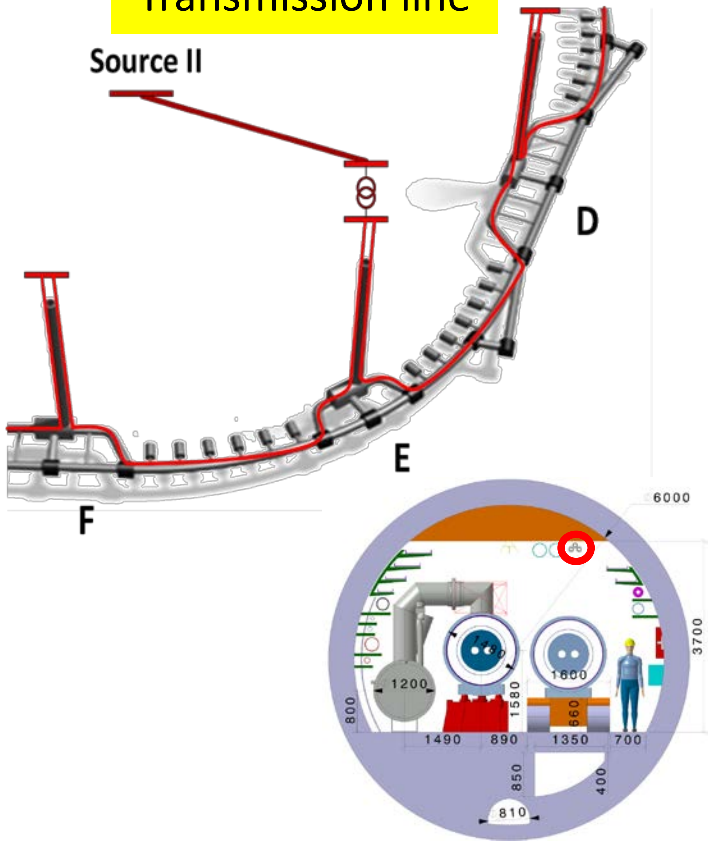


Radial feeding from existing sources



Powering by zones

Transmission line

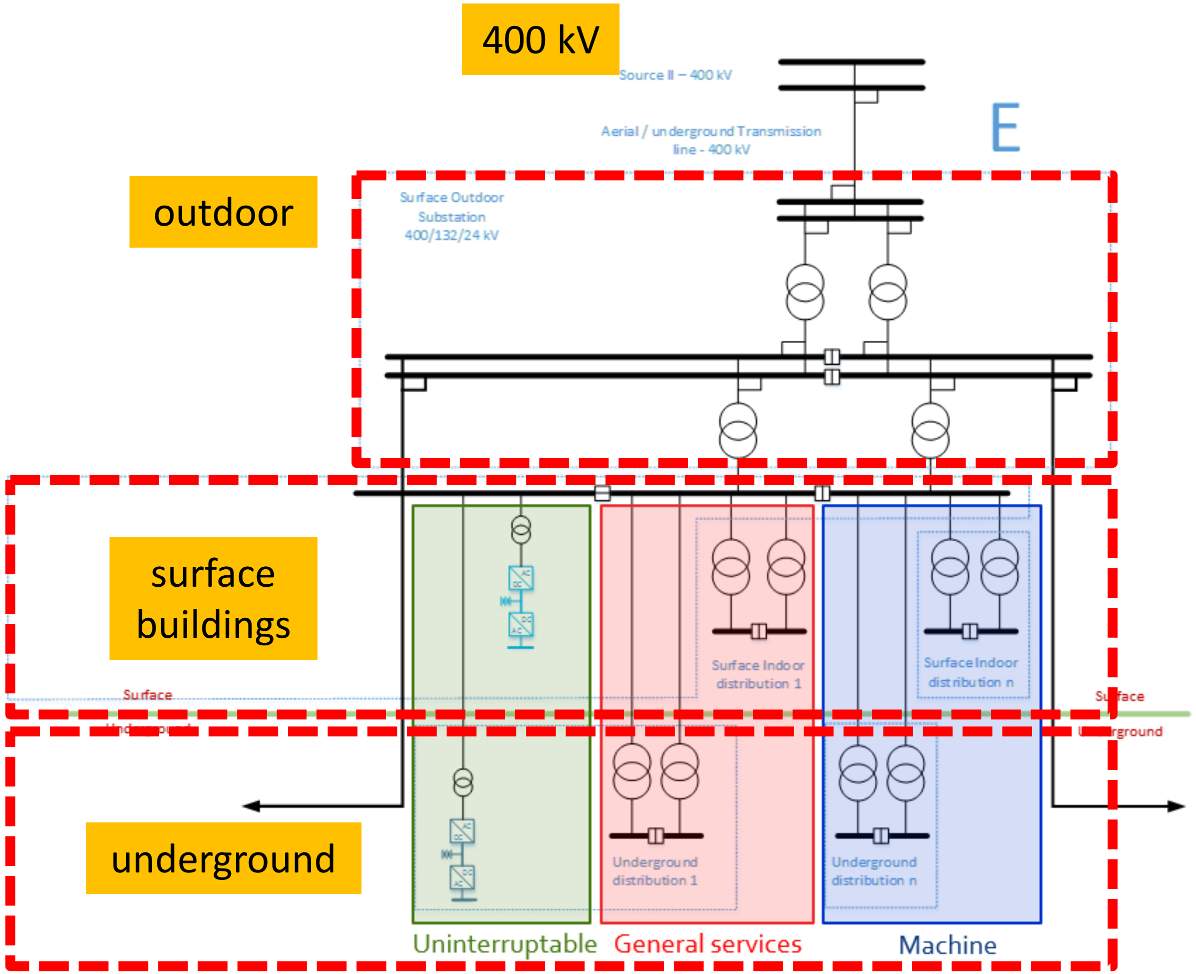


Study ongoing with cable company
Comparative study NC/SC foreseen.

Thursday, 8:50: Supply and distribution of electrical energy (D. Bozzini)

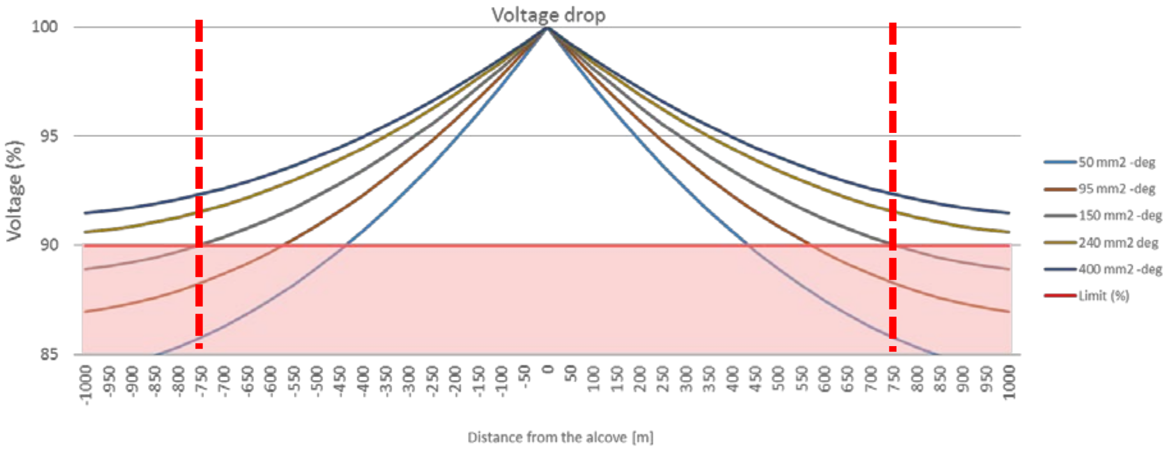
Supply and distribution of electrical energy

Nominal supply configuration

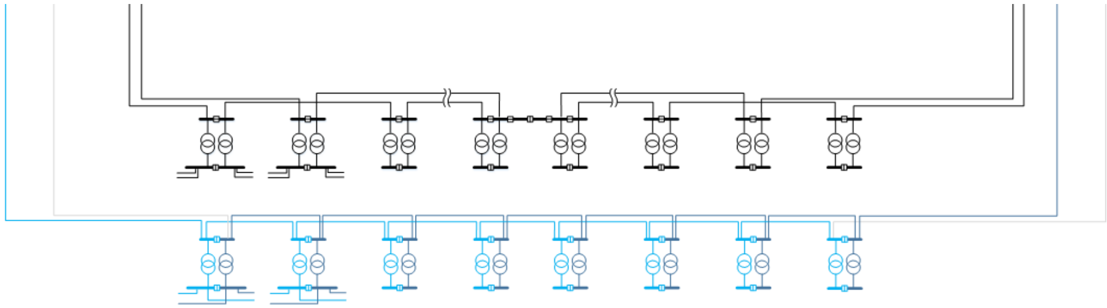


All networks supplied by transmission network.
All points have at least two transmission sources.

Voltage drop along arcs and need for alcoves



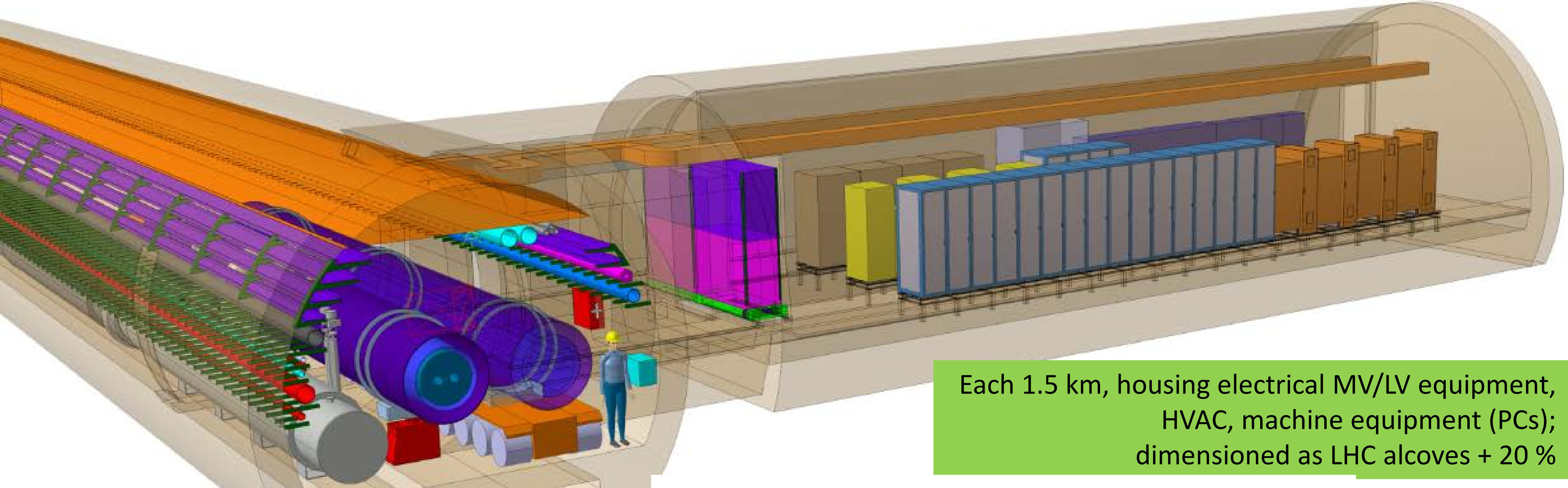
Long arc electrical distribution scheme



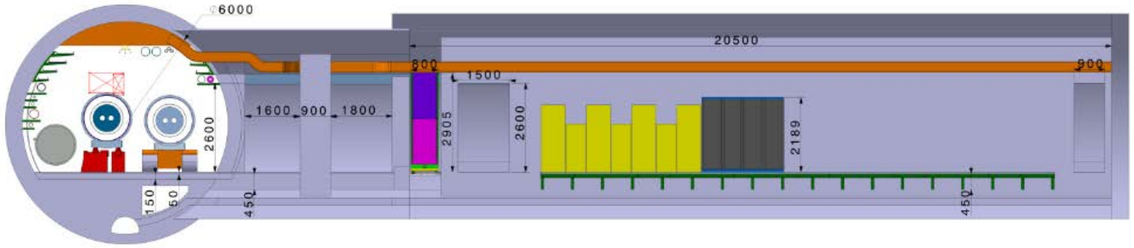
Other design principles:

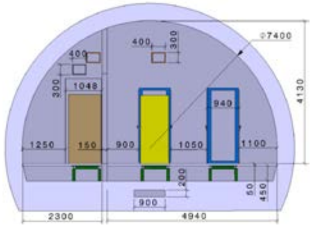
- Redundancy at all levels and on each equipment
- Limit underground installation of active components

Alcoves



Each 1.5 km, housing electrical MV/LV equipment, HVAC, machine equipment (PCs); dimensioned as LHC alcoves + 20 %





Logistics and transport

New collaboration with Fraunhofer Institute for material flow and logistics (FIML, Dortmund) Fraunhofer IML

on several work packages:

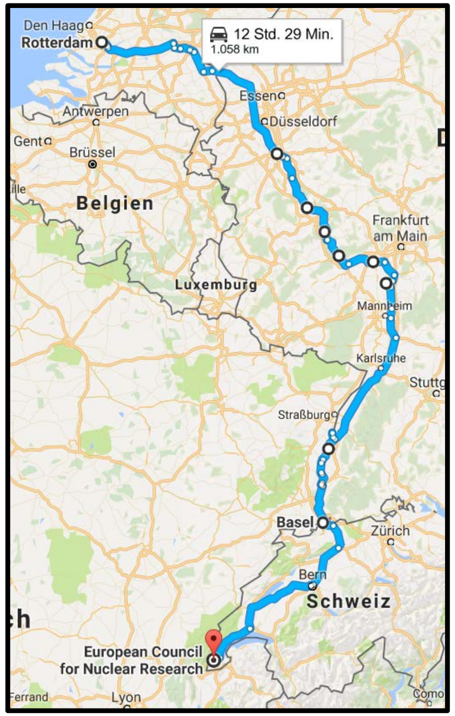
1) Design and evaluation of global supply chains for large and heavy components.
2) Logistics concept for storage, assembly, testing and handling of cryomagnets.
3) Vehicle concept for underground transportation and handling of cryomagnets.

1) Supply chain – investigating and assessing ...

- Transport options (seaship, barge/truck, ...)
- Constraints (road size, maximum weight, road blockage)
- Transport enclosures (non-standard containers, special handling equipment)
- Maximum tolerable g-forces during transport and loading, maximum tilt angles

3) Vehicle

- Rail vs wheel-based
- Track guidance (optical/wire/marker) vs sensor based free navigation
- Ideally covering/compatible with other transport needs
  (other equipment, personnel, remote reconnaissance/interventions)



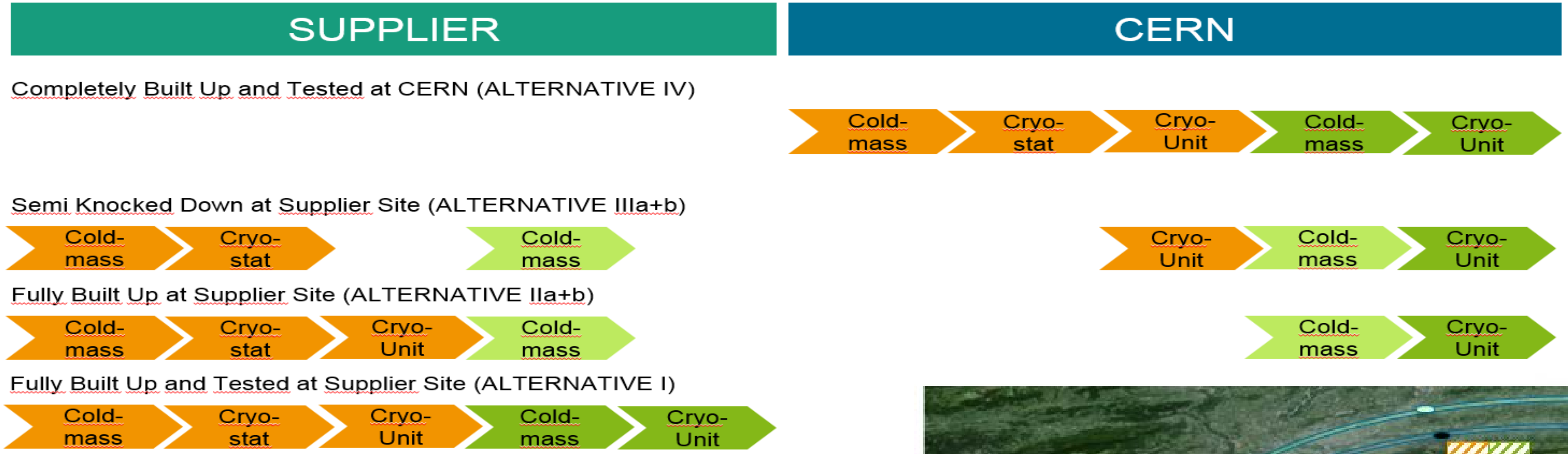
Thursday, 9:35: Cryomagnet logistics and transport (A. Nettsträter/FIML)

FIML, M. Tiirakari, I. Rühl

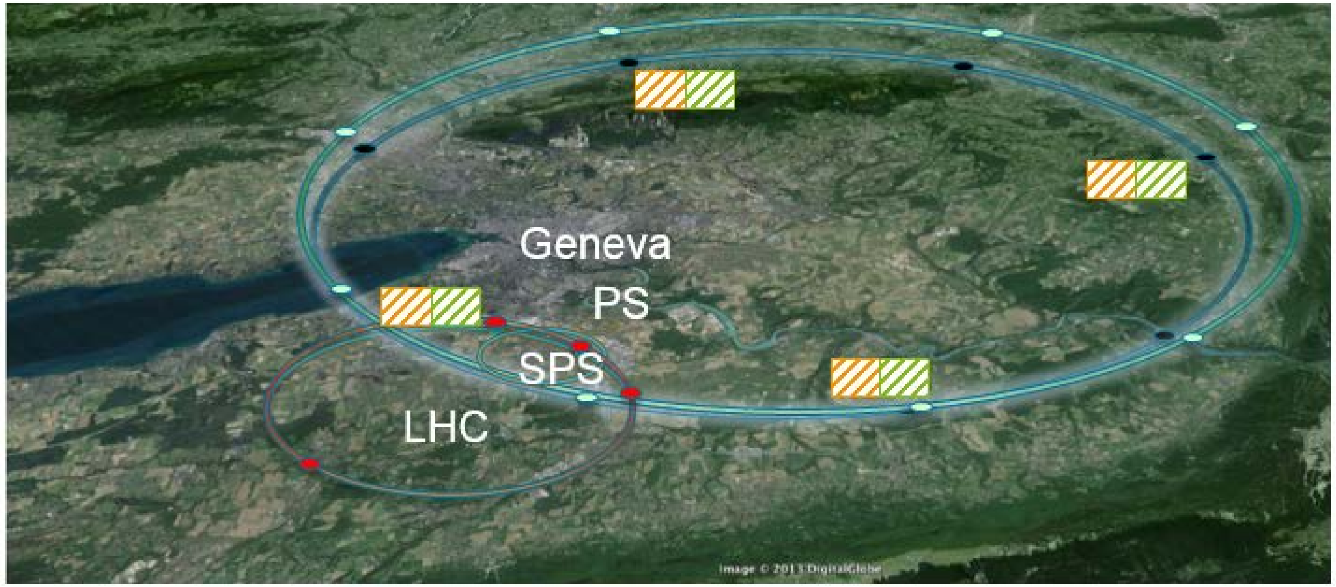
Logistics and transport

2) Assembly concept

- Assess benefits and drawbacks of various scenarios



- Study required number of assembly and testing sites
  (amount of personnel, traffic,
  transport means, quality assurance, ...)

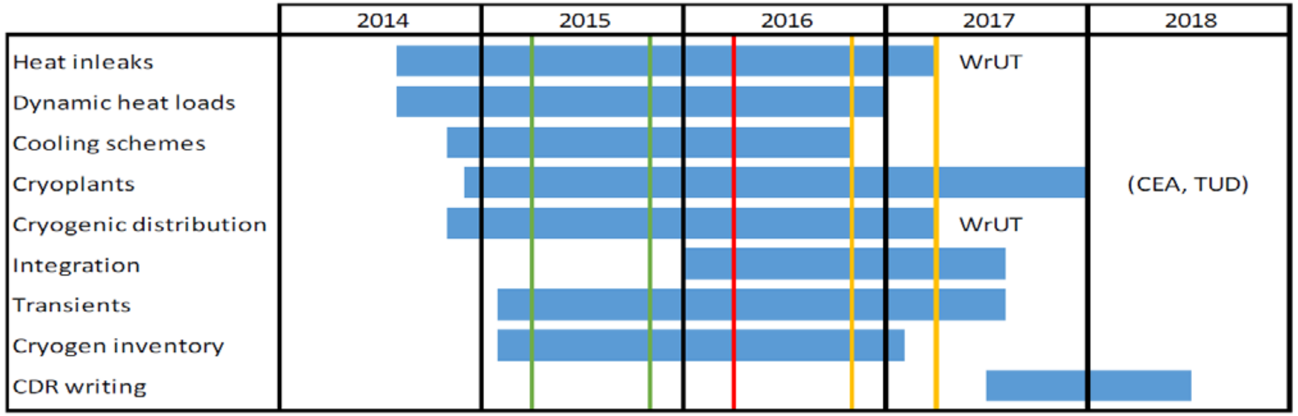


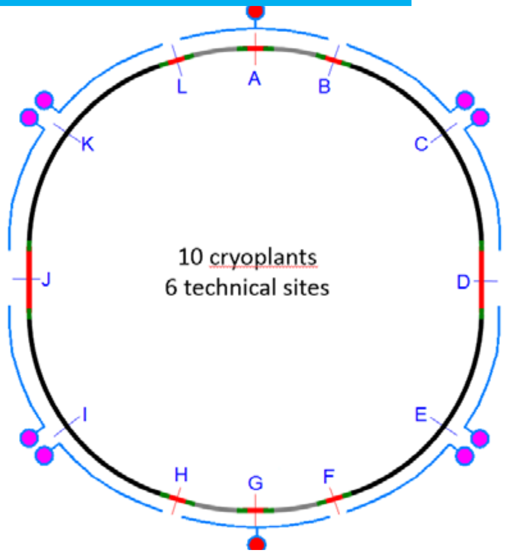
FIML, M. Tiirakari, I. Rühl

Cryogenics

Thursday:
13:30: Towards a conceptual design for FCC cryogenics (L. Tavian)
14:00: Cryogenic refrigeration w neon-helium mixtures for the FCC-hh (S. Klöppel/TU Dresden)
14:20: Technical specifications for industry studies on the FCC cryogenic system (F. Millet/CEA Grenoble)
14:40: Cryogenic distribution for FCC-hh (P. Duda/Wroclaw UT)

Good progress across the board - globally well on track to conclude for CDR.
Timeline shown in Rome:



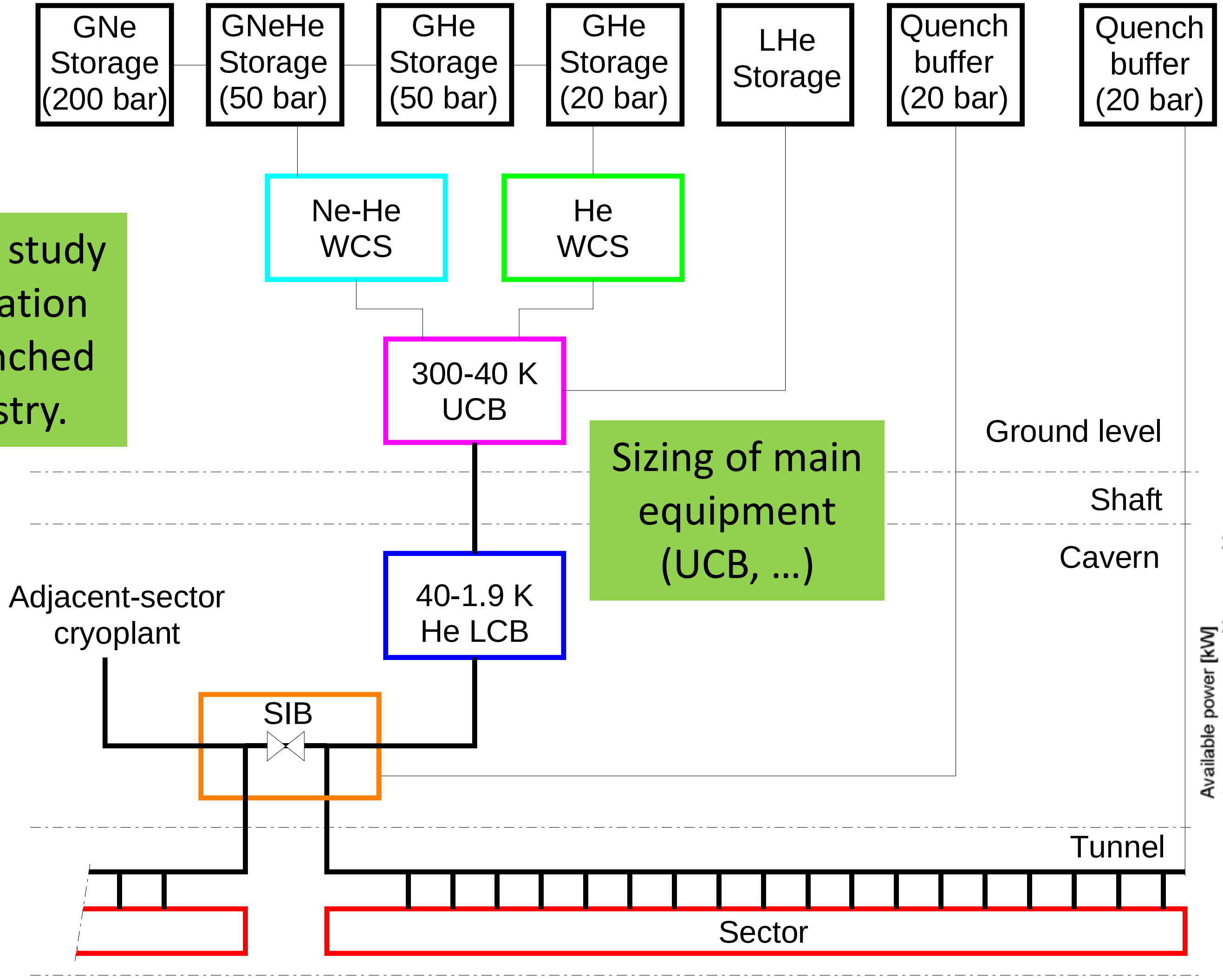


Baseline layout confirmed (FCC-hh: 10 plants, 6 sites).
Magnet operating temperature confirmed (1.9 K).
Refinement, simplications, dimensioning, ... (for FCC-hh and FCC-ee).

Cryoplant	40-60 K [kW]	1.9 K [kW]	40-300 K [g/s]
● (red)	592	11	85
● (magenta)	616	12	85

w/o operation margin !

FCC-hh cryogenics architecture



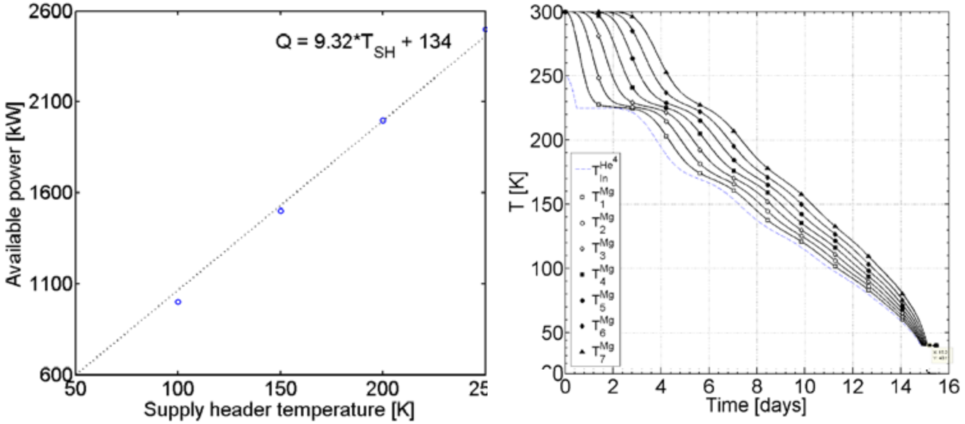
Engineering study for refrigeration system launched with industry.

Sizing of main equipment (UCB, …)

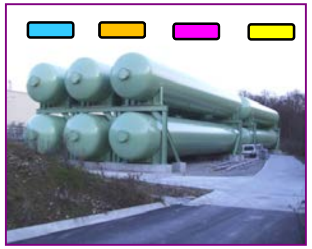
Possibility to couple adjacent sectors

Study of cool-down using the Ne-He turbo-Brayton refrigeration cycle (suppression of the LN_2 cool-down unit and associated huge storage and delivery logistics)

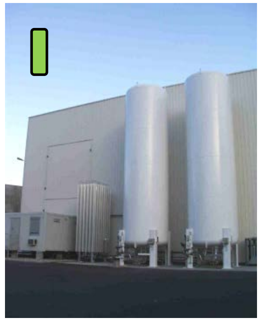
Cool-down time goes from 10 to 15 days-

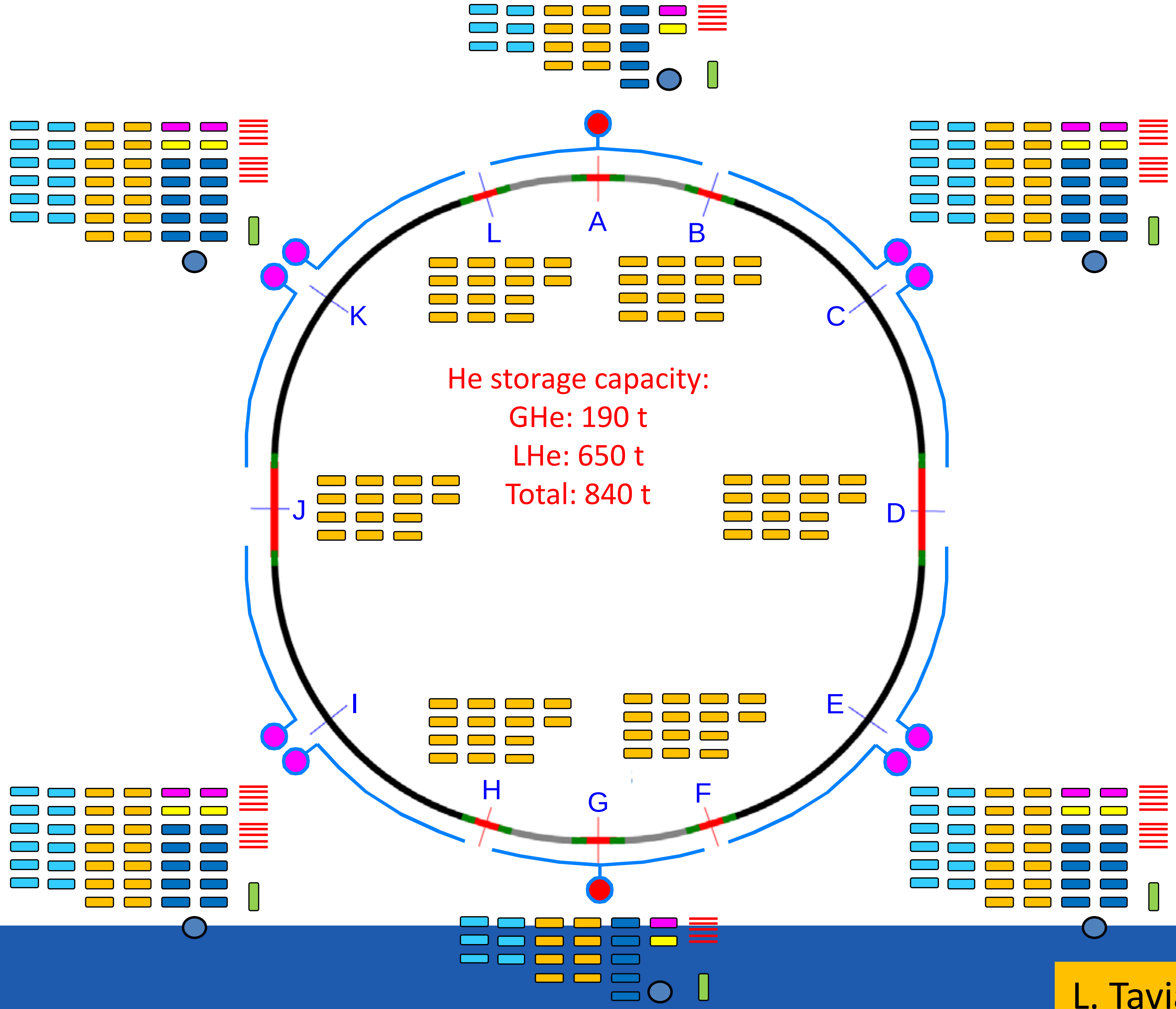


Cryogenics storage architecture



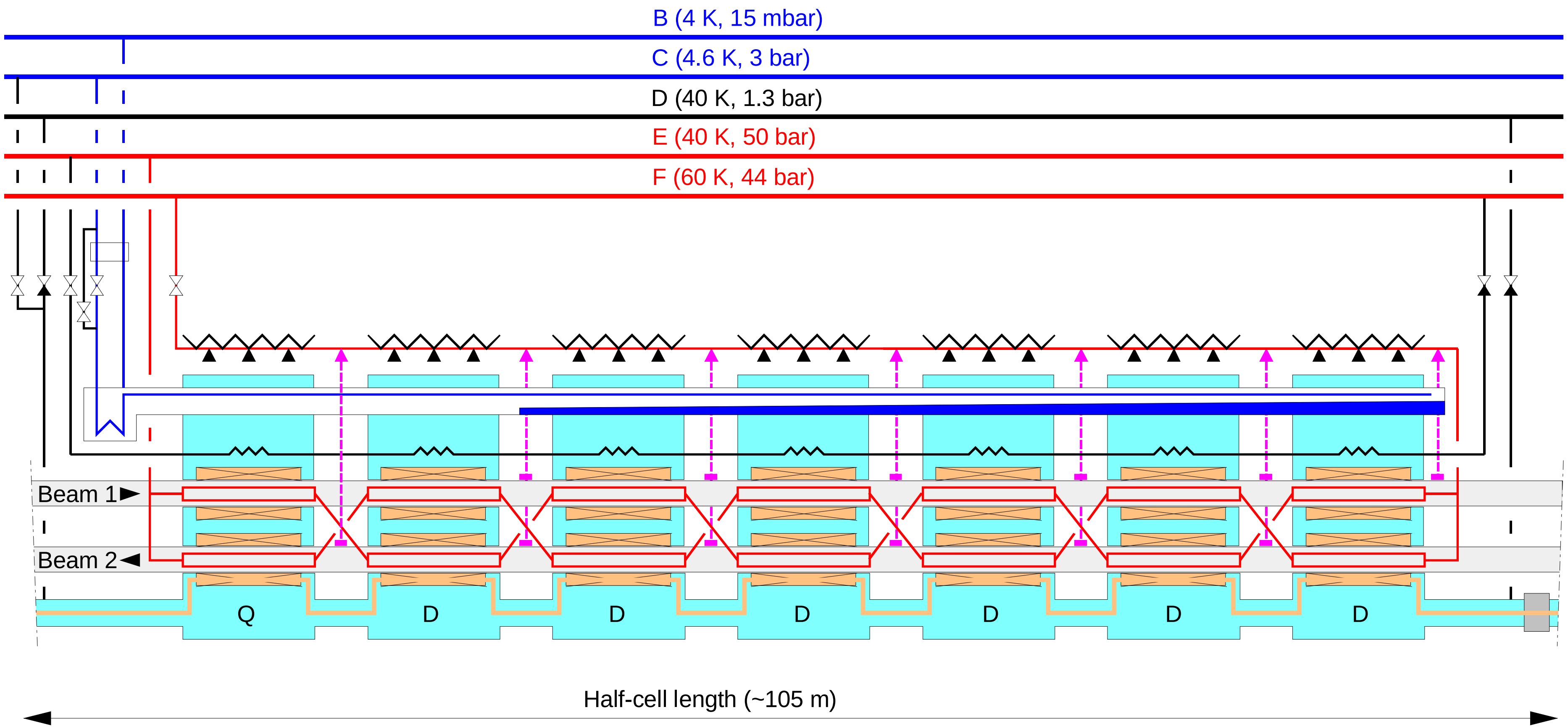
- GHe storage (250 m3, 20 bar)
- Quench buffer (250 m3, 20 bar)
- GHe storage (250 m3, 50 bar)
- Ne-He storage (250 m3, 50 bar)
- GNe cylinders (200 bar)
- LHe storage (120 m3)
- LHe boil-off liquefier (150 to 300 l/h)
- LN2 storage (50 m3)





FCC-hh half-cell cooling loop

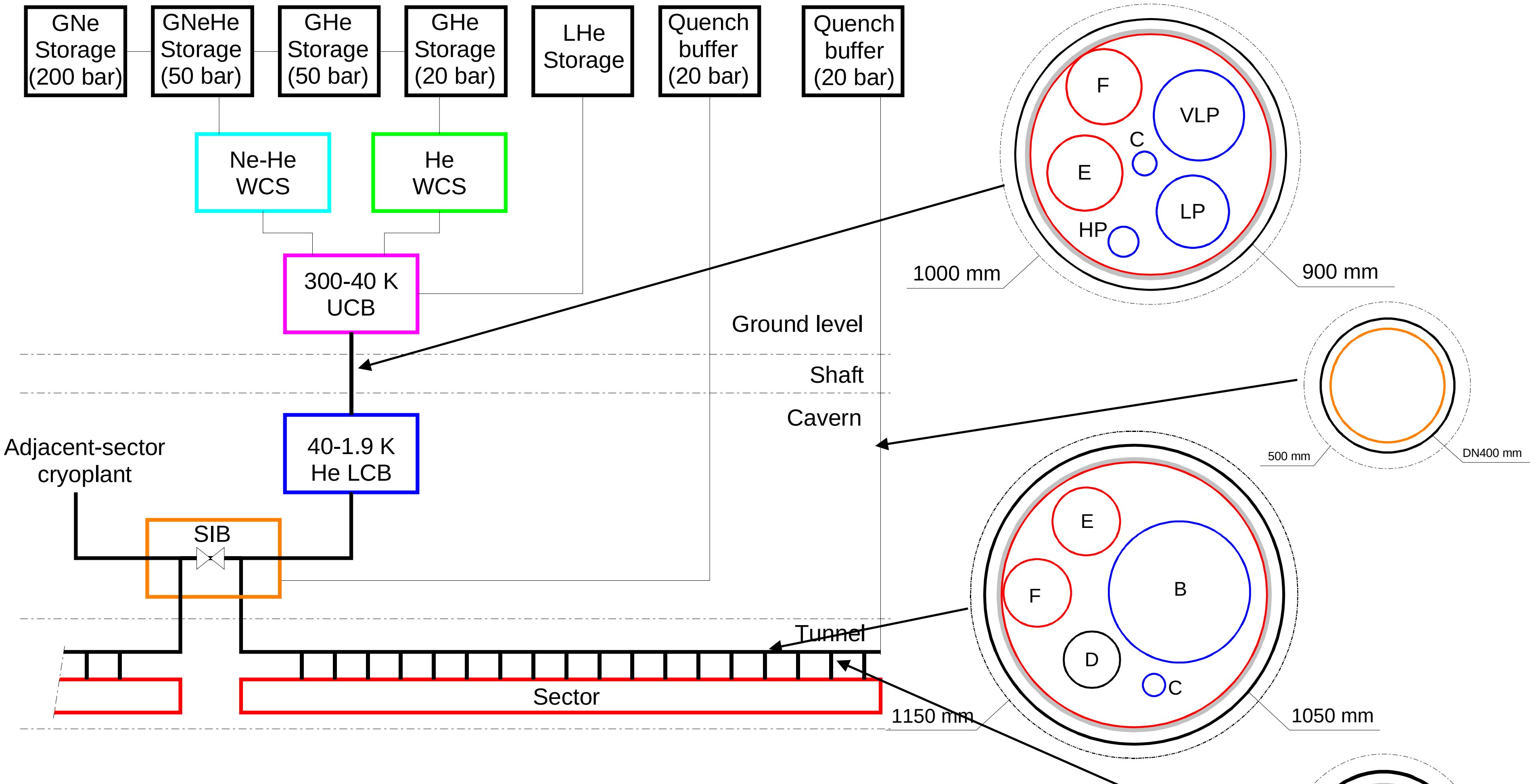
Superfluid He cooling “à la LHC”

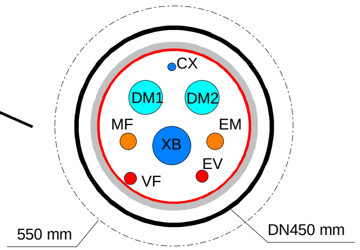


Study of the cold-mass cooling below 2 K. Definition of the cryogenic requirements (bayonet HX, free cross-section area, …).
Update of the beam-screen cooling with SR absorbers at magnet interconnect.
Completion of the cryo-distribution study based on INVAR technology.

L. Tavian

Main cryogenic transfer lines





Re-check/refinement of dimensioning; addition of pipes.
Completion of cryo-distribution study based on INVAR technology.

Operation

Initial operation schedule

Total of 162 m of physics (p + ions)
6 x 1 wk MD + 1 wk stop per 5-yr cycle

Comparison of turn-around times

Phase	FCC th.	LHC th.	LHC 2015	LHC 2016
Setup	10	10	222.7	158.5
Injection	40*)	38	58.1	51.6
Pre-ramp	5	4	5.4	4.2
Ramp	20	20	20.4	20.4
Flattop	5	5	4.8	4.2
Squeeze	3	18	13.1	18.0
Adjust	5	10	12.5	14.1
Ramp down	20	31	41.0	41.0
Total	108 min (1.8 h)	132 min (2.2 h)	378 min (6.3 h)	312 min (5.2 h)

Stops need radiation cool-down and recommissioning → reduce ? Injector chain and detectors must sustain long maintenance-free periods and radiation levels.

Long setup times mainly due to system failures → FCC to be designed for utmost availability (fault tolerance or quick repair between runs). Injection time depends on injector chain availability and beam quality control.

Thursday 15:30: FCC-hh operation schedule and turnaround (A. Niemi/Tampere UT)

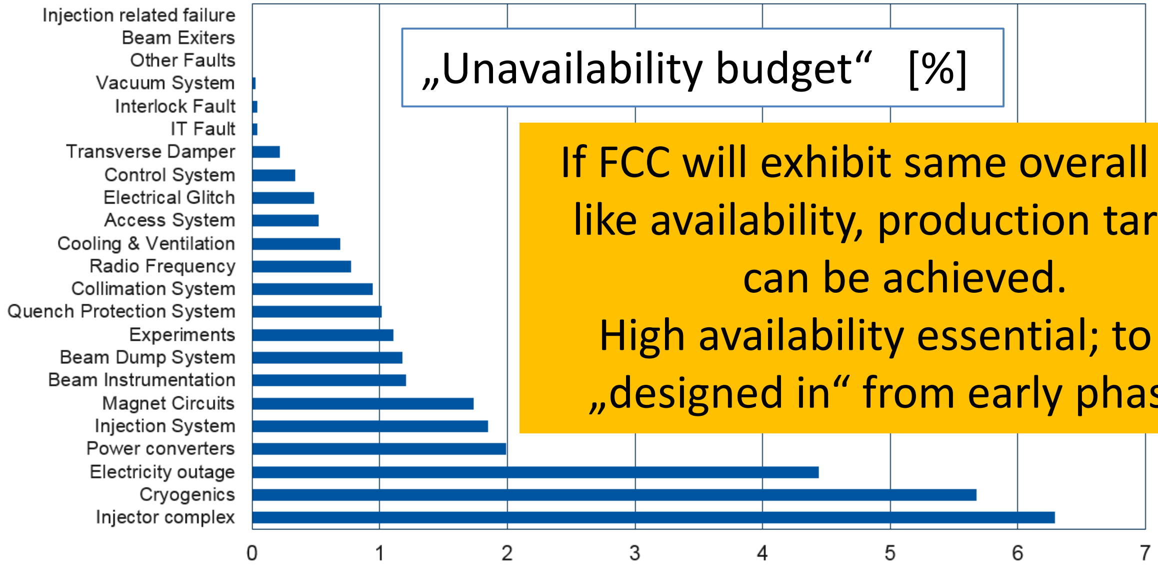
Availability considerations

Demonstrate that FCC luminosity goals are achievable

Approach:

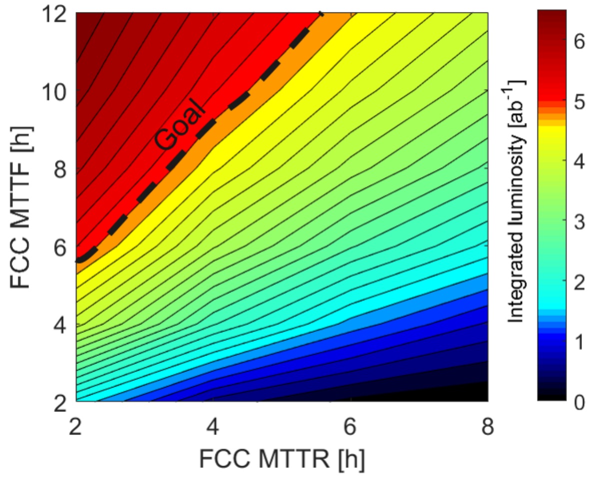
- Monte-Carlo model of accelerator operation (cycles, injections, luminosity production)
- Fault-tree model of system reliability (failures rates, repair times)

(benchmarked on LHC 2015 and 2016 results)

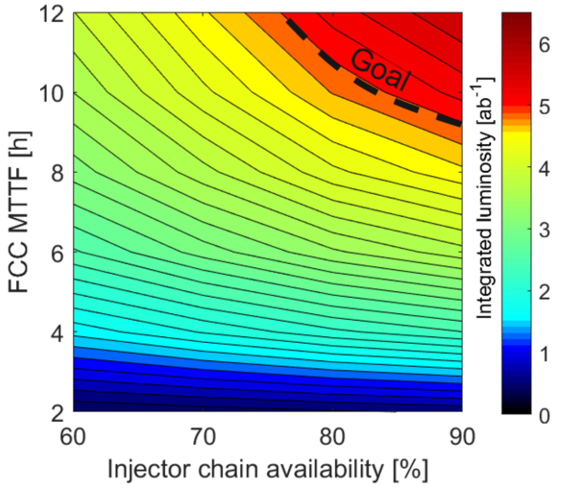


If FCC will exhibit same overall LHC-like availability, production targets can be achieved.
High availability essential; to be „designed in" from early phases.

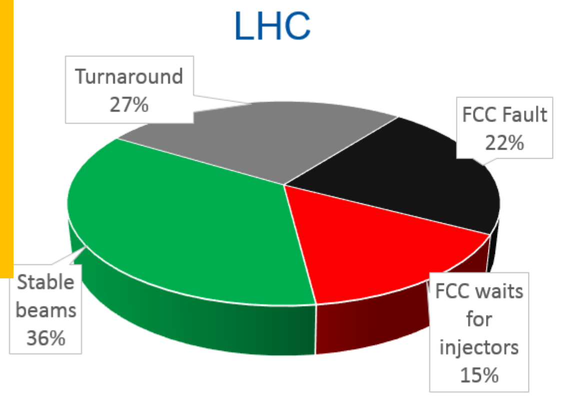
Sensitivity analysis

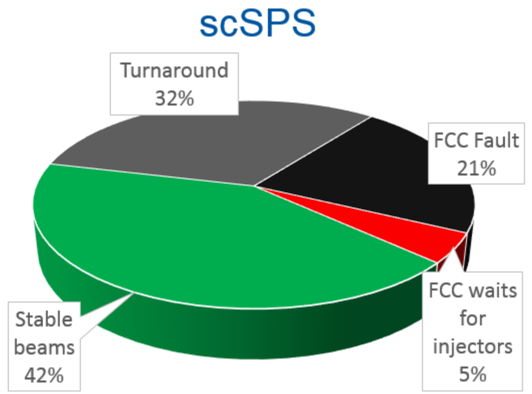


Effect of injector chain



Comparison of injector options





Redundance/fault tolerance, „maintenance-free", limit radiation effects, advanced diagnostics/anticipate failures

Thursday 15:50: FCC availability studies (A. Apollonio)

Concluding remarks

„Infrastructure and operation“ team continues to be very active.

Major steps made towards CDR in key areas,
with safety, performance, cost efficiency, impact, reliability aspects in mind.

Many topics to be elaborated further – iterative process.
Some of the assumptions need still to be validated/consolidated.
Certain „IO“ related matters need still to be addressed.

Will produce TO DO list of items to have for CDR after FCC Week.

FCC exiting in terms of size, logistics, system demands, reliability, ...
Advancement in methods and technologies is expected to help in many ways.

Maintaining the intensive effort will keep us well on track to round off in 2018.

THANK YOU FOR YOUR ATTENTION

www.cern.ch

LOOKING FORWARD TO
INTERESTING PRESENTATIONS
AND STIMULATING DISCUSSIONS

Annex

Collaborations, I

Cryogenics

- TU Wroclaw – Design pressure impact of the FCC-hh cryogenic distribution system and superconducting magnet cryostats on the heat inleaks at different temperature levels
- CEA Grenoble – New architectures and technologies for innovative helium refrigeration above 4.5 K and in superfluid helium at 1.8 K and 1.6 K including magnetic refrigeration
- TU Dresden – Ne-He cycle producing large refrigeration capacity above 40 K for the cooling of the FCC beam screens, thermal shields and HTS current leads

Safety (fire safety engineering, FCC-FSEC)

- ESS – Ignition probabilities of materials and equipment; intervention procedures for classified accelerator areas
- FNAL – Tunnel fire dynamics and egress studies based on a broad range of different US underground installations
- DESY
- JRC Jülich Research Centre / University of Wuppertal – Optimisation of Computational Fluid Dynamics tools for fire safety related calculations
- Lund University – Fire and egress scenarios typical for accelerator facilities and their special geometries, including fire testing and virtual reality
- MAX IV – Knowledge transfer on fire statistics for physics laboratories

Collaborations, II

Reliability, availability

- TU Tampere – RAMS design methods and tools to be applied to particle accelerators
- TU Delft – RAMS modeling of LHC cryogenic system
- Univ. Stuttgart – Reliability engineering training

Transport & Logistics

- FIML Dortmund – Transport and logistics modeling and consulting

Plus direct or indirect support from industrial and informal support from institutional partners (referenced in the respective presentations).

IO related posters, I

Integration:

- 3D study and integration of FCC-hh underground structures (F. Valchkova-Georgieva)

Survey, alignment:

- Application of the wire offset measurements technique in the FCC alignment (N. Ibarrola Subiza, D. Missiaen)

Electrical distribution:

- Power transmission network studies (M. Mylona, D. Bozzini)

Transport, handling:

- Lift layout (D. Lafarge, I. Rühl, Schindler SA)
- Optimisation of equipment design for handling and maintenance in radiation areas (K. Kershaw)

IO related posters, II

Cryogenics:

- Impact of large beam-induced heat loads on the transient operation of the beam screens and cryogenic plants of the Future Circular Collider (H. R. Correira Rodrigues, L. Tavian)
- Adaption of the LHC Cold Mass Cooling System to the requirements of the Future Circular Collider (C. Kotnig, G. Brenn / TU Graz, L. Tavian)
- Pneumatic free valve actuators (F. Holdener, A. Hegglin / Shirokuma GmbH, Ch. Haberstroh, S. Klöppel, H. Quack / TU Dresden)

Reliability:

- Software for reliability modelling (Ramentor Oy)
- Kicker pulse generator anomaly detection for realibility improvements through advanced machine learning (P. van Trappen)

Safety:

- FCC Fire safety engineering collaboration (M. Plagge et al.)
- FCC performance-based safety design (S. La Mendola, S. Baird, A. Henriques)