Infrastructure and Operation
Summary of parallel sessions

Volker Mertens, CERN

on behalf of the FCC Infrastructure & Operation Working Group
and the collaborating partners

FCC Week 2016
Rome, 11-15 April 2016

Big thanks to presenters, chairpersons, organisers !!!

Session overview

Infrastructure and Operation overview (V. Mertens, 10‘)
Civil engineering (John A. Osborne, 20‘)

Monday

Thursday

Room: **Costantino**

11:00	**Cryogenics** *Jaroslaw Polinski (TU Wroclaw)*
12:00	
13:00	
14:00	**Implementation, Electricity, Cooling and Ventilation** *Philippe Lebrun (CERN)*
15:00	**Coffee Break** *Winter Garden, Crowne Plaza*
16:00	**Safety, Availability, Controls** *Ralf Trant (CERN)*

Friday

Summary of parallel Infrastructure and Operation sessions (V. Mertens, 15‘)

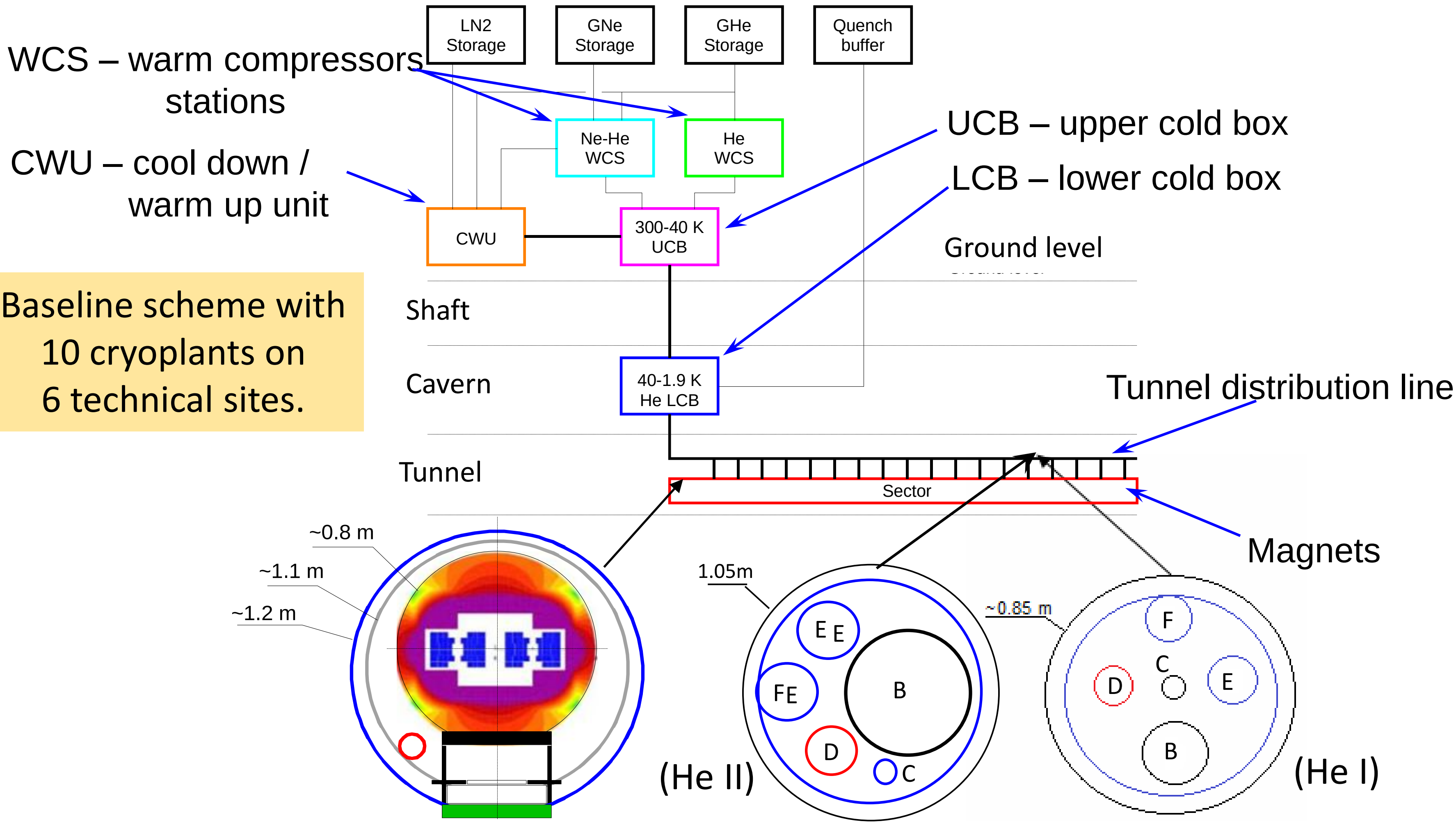
Parallel session I

Thursday, 10:30-12:10

Cryogenics – chair: Jaroslaw Polinski / TU Wroclaw

- Cryogenics overview (Laurent Tavian)
- Ne-He cycle refrigeration above 40 K (Steffen Klöppel / TU Dresden)
- Innovative He cycle (François Millet, CEA Grenoble)
- Cool-down and warm-up studies of a FCC sector, Hugo Correia Rodrigues
- Impact of high design pressures on heat inleaks, Pawel Duda / TU Wroclaw

L. Tavian: Cryogenics overview



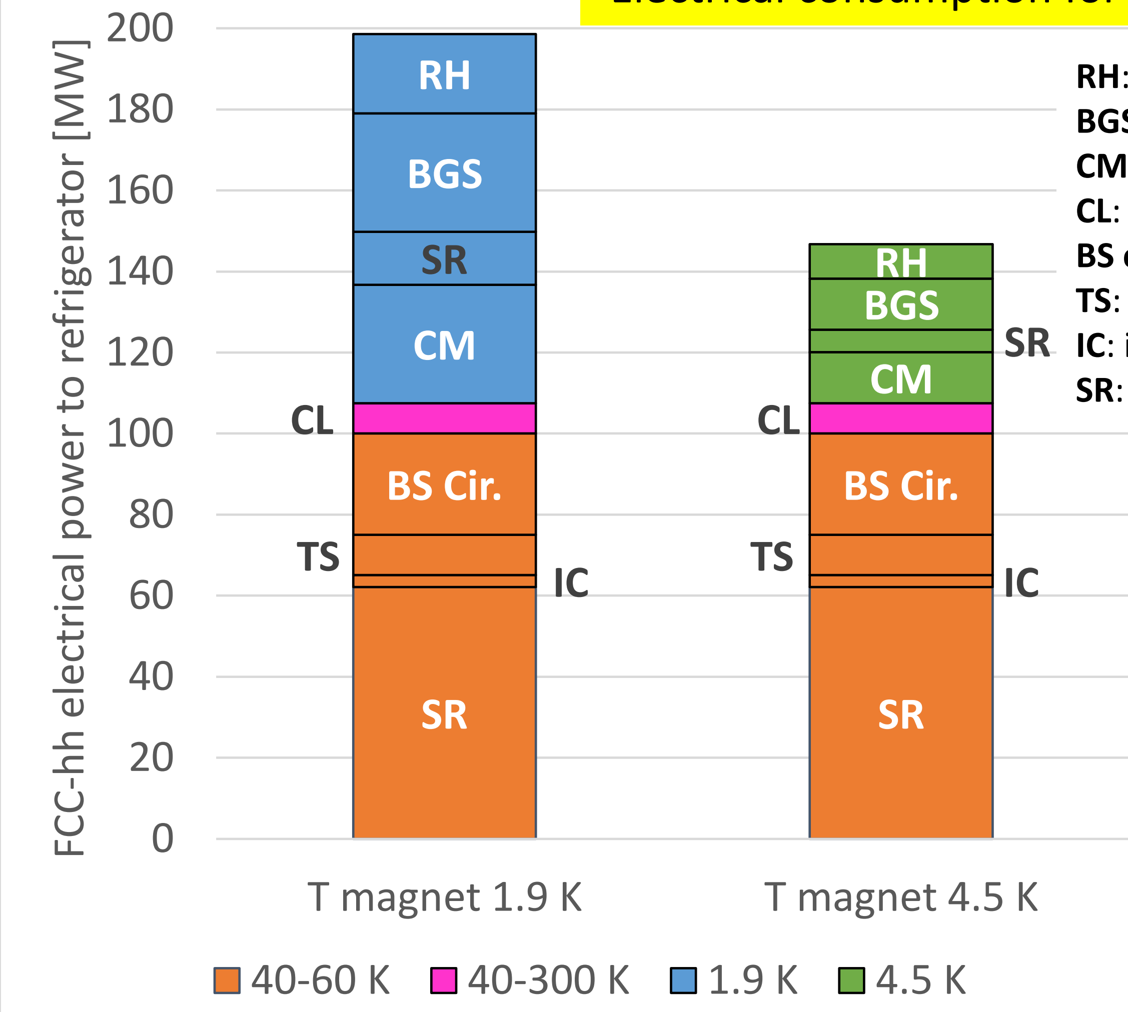
Baseline scheme with 10 cryoplants on 6 technical sites.

Cross section of the magnet

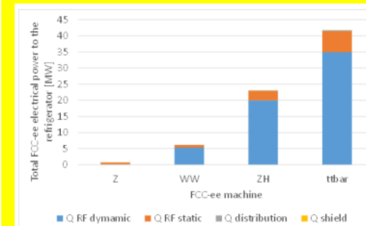
Cross section of the tunnel distribution line

L. Tavian: Cryogenics overview

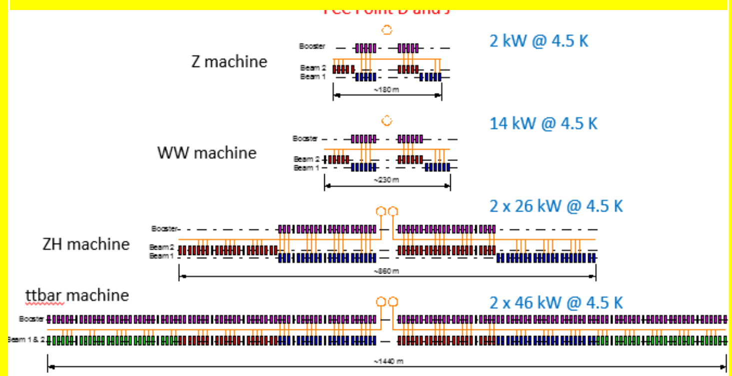
Electrical consumption for FCC-hh



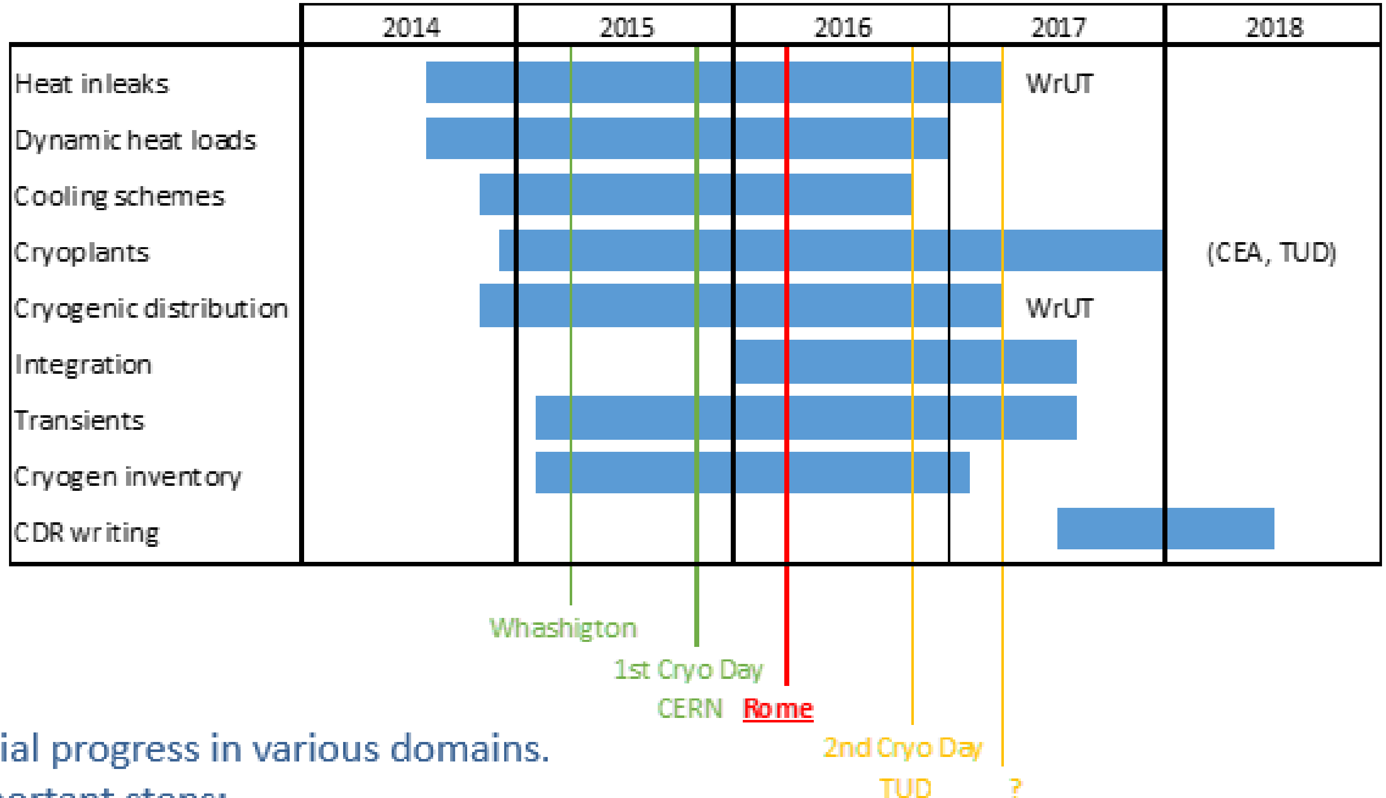
RH: resistive heating
BGS: beam-gas scattering
CM: cold mass heat-inleaks
CL: current lead
BS cir.: Beam screen circulator
TS: thermal shield
IC: image current
SR: synchrotron radiation



Electrical consumption for FCC-ee



L. Tavian: Cryogenics overview



Substantial progress in various domains.

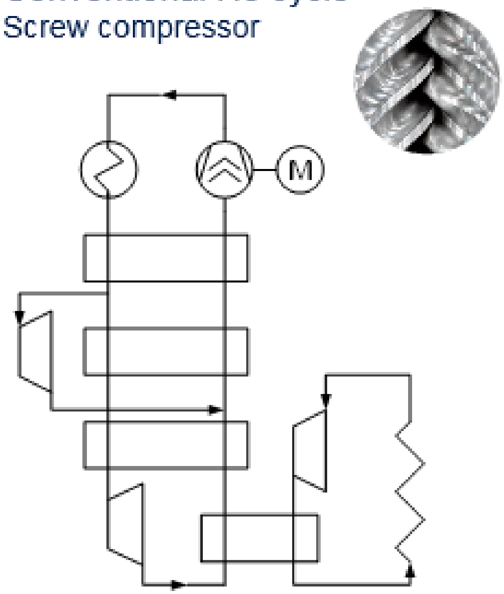
Next important steps:

- Cryoplant studies by industrial partners (Air Liquide & Linde)
- Beam-screen transient → local and global controls strategy
- Quench discharge and recovery (impact on CM design pressure and # of quench valves)
- Distribution system (heat inleaks, INVAR option)
- Freezing of magnet operating temperature

S. Klöppel: Cryogenics refrigeration with Ne-He mixtures for FCC beam screens

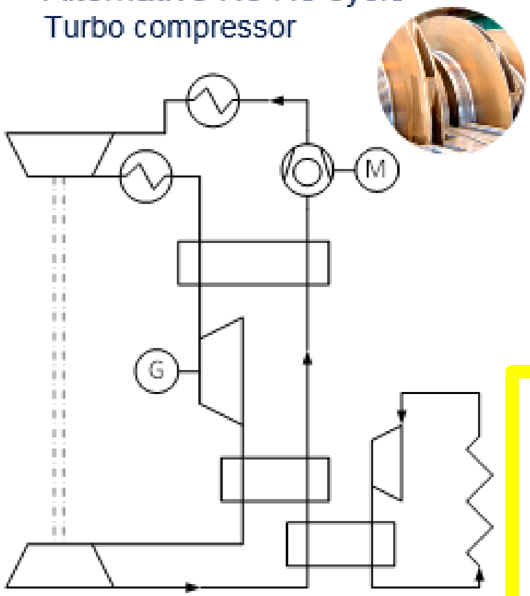
High cooling power needed for beam screen and thermal shield (new for accelerators).
Special effort needed to develop an efficient and flexible cycle 300 – 40 K.

Conventional He cycle
Screw compressor



≈30 % of Carnot efficiency
➔ 13 MW input power

Alternative Ne He cycle
Turbo compressor



≈45 % of Carnot efficiency
➔ 8.7 MW input power

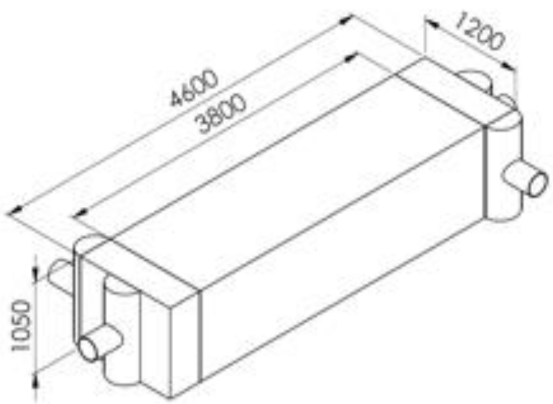
Required pressure ratios in the cycles: ≈ 7

Achievable pressure ratios per stage:
Pure He: 1.05 ➔ 39 stages
Pure Ne: 1.27 ➔ 8 stages, but large HXs

Compromise:
20 mol-% Ne + 80 mol-% He,
Pressure ratio per stage: 1.1 ➔ 20 stages

S. Klöppel: Cryogenics refrigeration with Ne-He mixtures for FCC beam screens

Design for 20 % neon



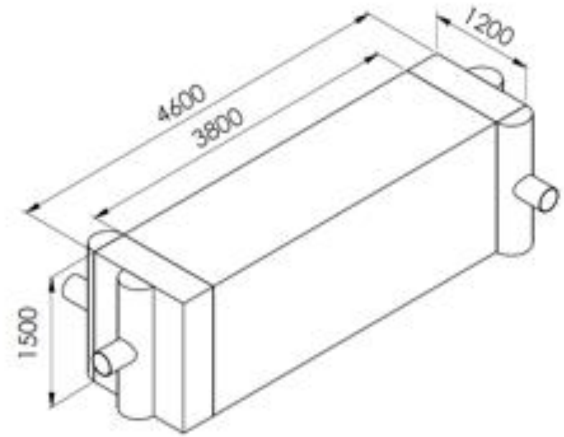
Compressor: 19 stages

Optimal system is defined by lowest cost

CAPEX:
- Compressor
- HX
- Coldbox

OPEX:
- Input Power
- Neon losses

Design for 40 % neon

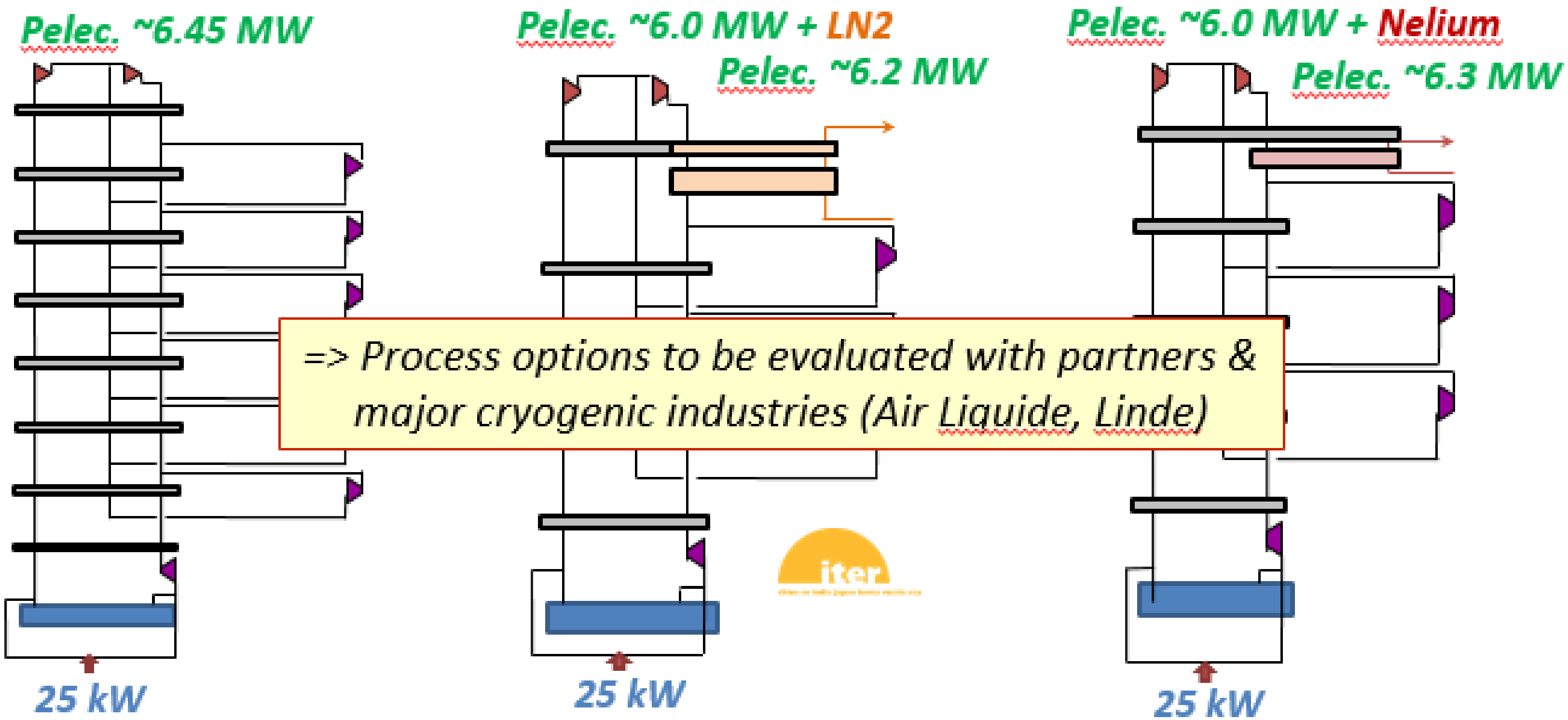


Compressor: 12 stages

Next steps: develop model, optimise cost of compressor, heat exchanger and refrigerant.

Innovative He cycle

No pre-cooling & 7 expanders | **LN2 pre-cooling & 4 expanders** | **Nelium pre-cooling & 4 expanders**



=> Process options to be evaluated with partners & major cryogenic industries (Air Liquide, Linde)

No pre-cooling & 7 expanders:
- Autonomous
- Less efficient ?

LN2 pre-cooling & 4 expanders:
- Dependent of LN2 supply
- Selected when LN2 plant present on site (ITER)

Nelium pre-cooling & 4 expanders:
- Dependent of Ne-He plant

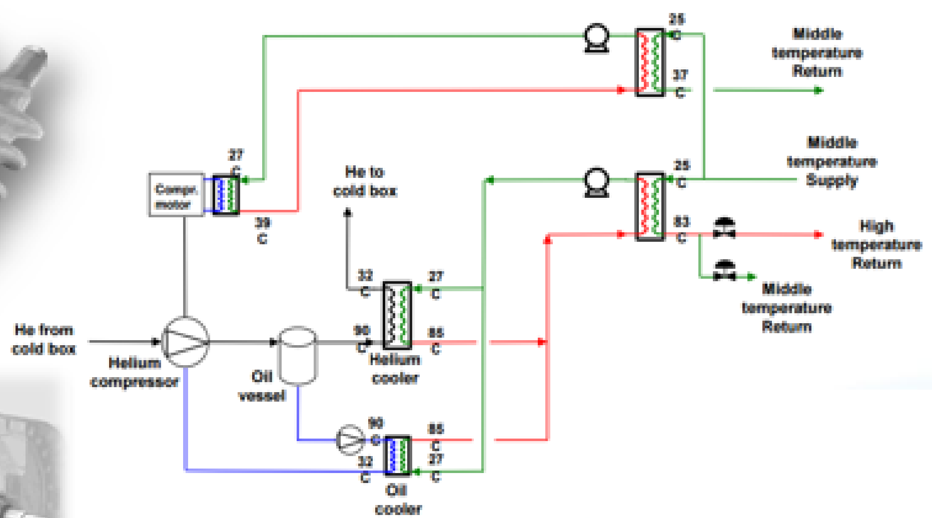
Studying different He cycle options to optimise efficiency (e.g. expanders vs. pre-cooling)

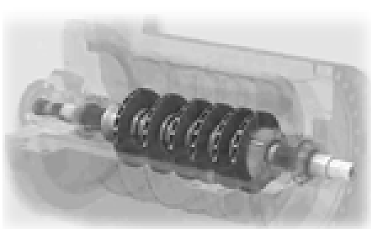
F. Millet: Innovative He cycle

- **Warm compression generates huge gas heating (150 to 200 MW) and requires large water cooled heat exchangers and cooling towers**

  Gas heating will be function of gas nature and compressor technology

=> Heat Recovery System (in addition to HVAC system) to optimise global energy management on FCC site





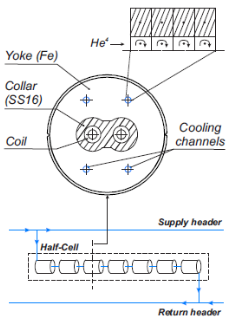
Office building heating

City heating

Industry studies to be started in 2016.

H. Rodrigues: Sector cool-down and warm-up studies

Magnet design and half-cell layout



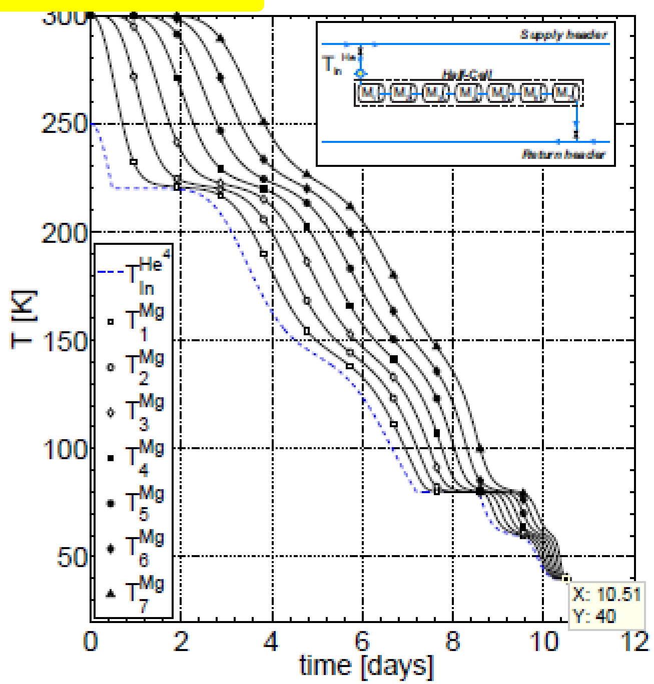
$$M \cdot c_p\,(T^M) \cdot \frac{\partial T^M}{\partial t} = -\alpha \cdot (T^M - T^{He})$$

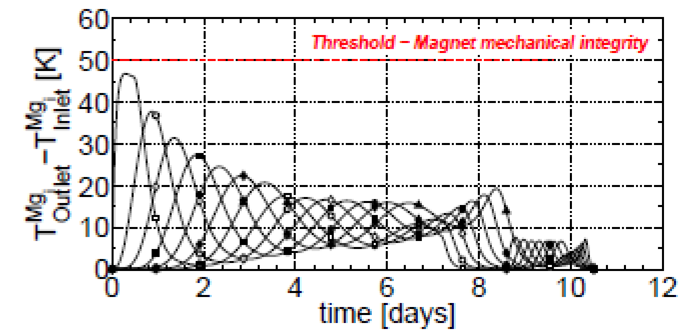
$$\underbrace{\frac{\partial h}{\partial t}}_{\mathcal{T}} + \underbrace{u\frac{\partial h}{\partial x}}_{\mathcal{P}} = \underbrace{\frac{1}{\rho A} \cdot \alpha \cdot (T^M - T^{He})}_{\mathcal{Q}}$$

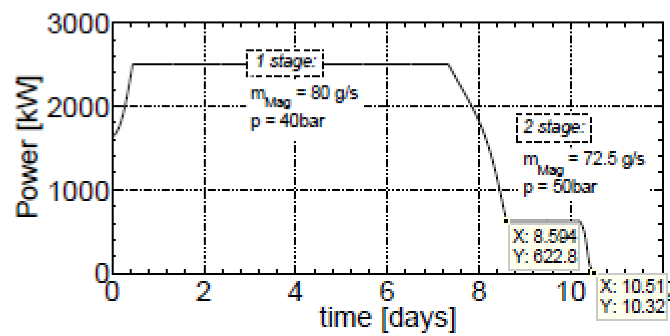
$\mathcal{T}$: Net rate of heat added to the fluid element
$\mathcal{P}$: Convective transport
$\mathcal{Q}$: Source term (heat exchange with the magnet)

- **Numerical method:** Finite-differences
- **Materials:** 70% Iron (Fe) and 30% Stainless steel 316 (SS16)
- **Maximum thermal gradient:** 50 K (over the magnet length)

Half-cell cool-down times 300 – 40 K.







H. Rodrigues: Sector cool-down and warm-up studies

Cool-down and warm-up timescales are comparable to those of the (LHC).

	FCC	LHC[1]
Cool-down:		
300 - 4.5 K	10.9 days	11.0 days
Warm-up:		
4.5 - 300 K	12.0 days	9.5 days

1) L. Liu et al., *"Numerical analysis of cooldown and warmup for the Large Hadron Collider"*, Cryogenics, Vol. 43-6, p. 359-367, 2003.

N_2 consumption (10 sectors):

44500 t = 5.89E7 litres (12 trucks/hr)

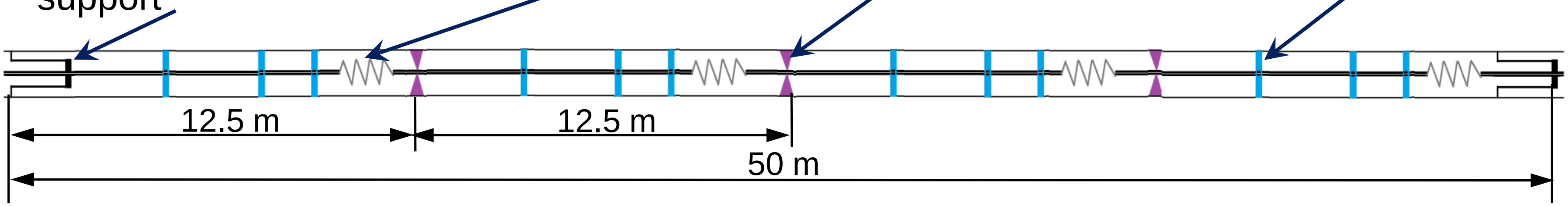
5.7 x

The Globe of Science and Innovation Geneva

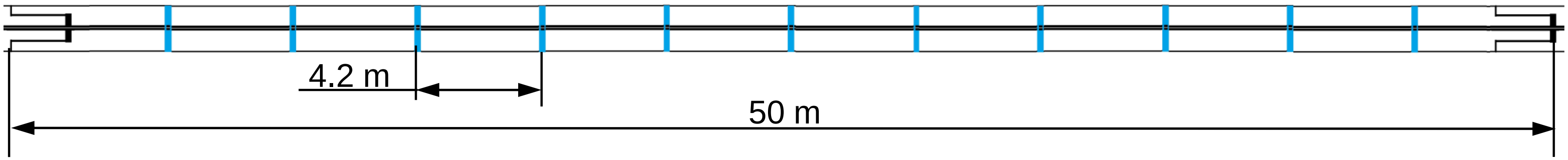
The temperature gradients over the half-cell length comply with the established requirements (50 K).

P. Duda: Impact of high design pressures of the cryogenic transfer lines on heat inleaks

Steel



Invar



	T	Q_{STEEL} 20 bar	Q_{STEEL} 50 bar	Q_{INVAR}
	K	W	W	W
DN80	4.6	4.57	4.59	4.01
DN200	40	3.22	3.66	2.75
DN240 F	40	3.48	4.92	2.99
DN240 R	60	145.6	157.5	109.9
DN250	4	6.8	7.44	4.98

P. Duda: Impact of high design pressures of the cryogenic transfer lines on heat inleaks

Invar	Stainless steel
• Less types and numbers of supports • Lower heat fluxes • No compensation bellows • Lower numbers of welds • Lower forces on the vacuum barriers • Lower probability of failure	• Conventional design • Well-known welding method • Pipes commonly available

Using Invar process pipes seems to be a very attractive alternative for FCC.

Parallel session II

Thursday, 13:30-15:00

Implementation, Electricity, Cooling and Ventilation – chair: Philippe Lebrun

- ❑ FCC civil engineering – tunnel optimisation (Charles Cook)
- ❑ Large scale metrology for the FCC work package (Mark Jones)
- ❑ Design considerations for the FCC electrical network architecture (Davide Bozzini)
- ❑ FCC electrical power requirements –
- ❑ methodology for data collection and geographical mapping (Maria Mylona)
- ❑ Cooling plants and ventilation systems (Mauro Nonis)

C. Cook:
FCC civil engineering

For the time being advancing with the 100 km ‘Intersecting’ option.

Choose alignment option: 100km quasi-circular

Tunnel elevation at centre:261mASL

Grad. Params

Azimuth (°): -20

Slope Angle x-x(%): 0.65

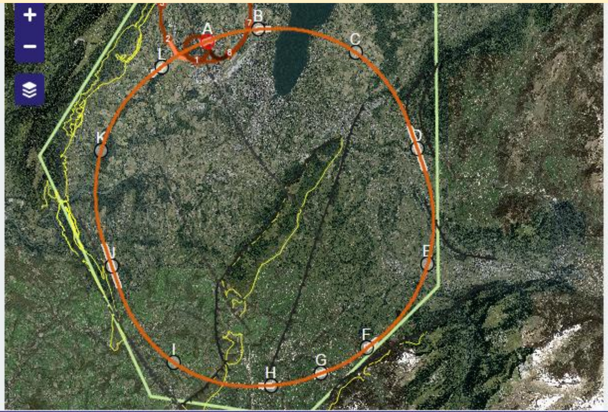
Slope Angle y-y(%): 0

LOAD | SAVE | CALCULATE

Alignment centre

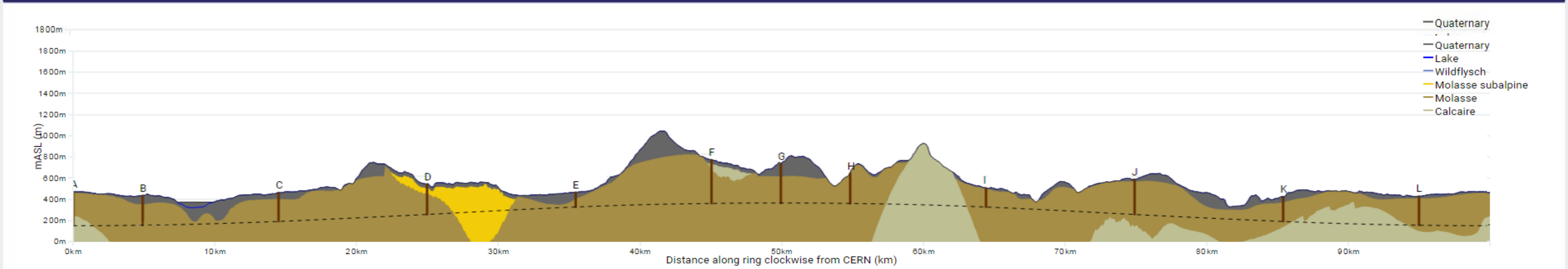
X: 2499731 Y: 1108403

	CP 1		CP 2	
	Angle	Depth	Angle	Depth
LHC	-64°	220m	64°	172m
SPS		242m		241m
TI2		235m		241m
TI8		242m		170m



	Shaft Depth (m)			Geology (m)			
Point	Actual	Molasse SA	Wildflysch	Quaternary	Molasse	Urgonian	Calcaire
A	304	0	0	12	213	0	79
B	266	0	0	80	156	0	30
C	257	0	0	58	199	0	0
D	272	52	0	40	181	0	0
E	132	0	0	64	68	0	0
F	392	0	0	40	296	0	56
G	354	0	0	116	237	0	0
H	268	0	0	0	268	0	0
I	170	0	0	12	158	0	0
J	315	0	0	22	293	0	0
K	221	0	0	52	169	0	0
L	260	0	0	21	239	0	0
Total	3211	52	0	517	2478	0	109

Alignment Profile

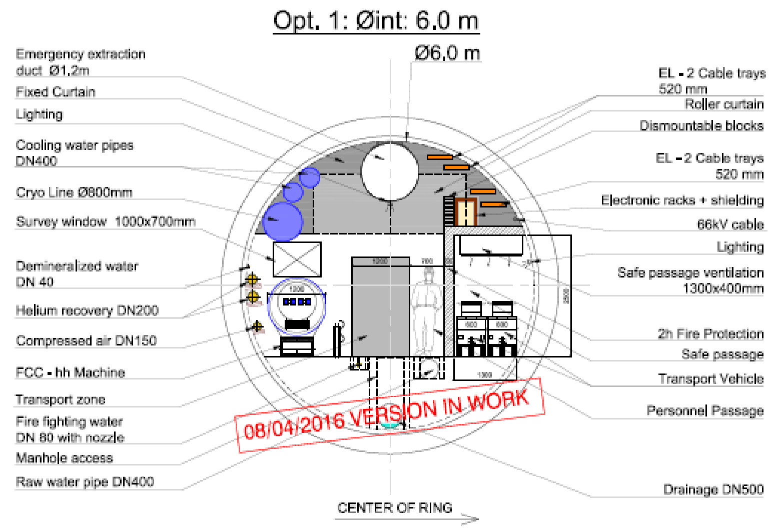


- Limestone region: **Jura**
- Max overburden: **650 m**
- Deepest shaft: **392 m**
- % of tunnel in limestone: **13.5 %**
- Total shaft depths: **3211 m**

Challenges:

- 7.8 km tunnelling through Jura limestone
- Up to 300 - 400 m deep shafts + caverns in molasse

Future steps



- Official FCC Naming Convention
- CE Environmental Impact Assessment
- First order cost estimates
- First full (high-level) schedule forecast
- Update & development of tunnel cross-sections
- Single vs. double tunnel cost & schedule (ongoing)
- Study of surface building requirements
- Experiment gantry crane study (with MDI WG)
- Closer look at cavern construction

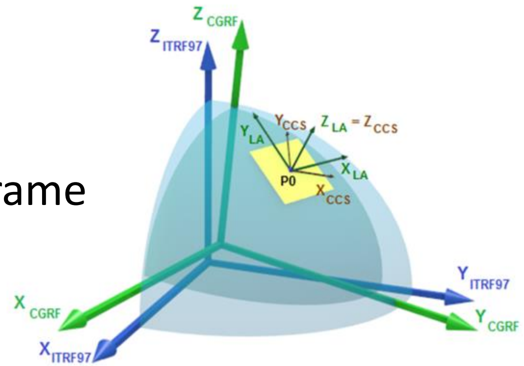
M. Jones: FCC - large scale metrology

Different activities (geodesy, data management/processing, accelerator alignment, sensors for permanent monitoring of critical components, as-built surveys (laser scanning)).

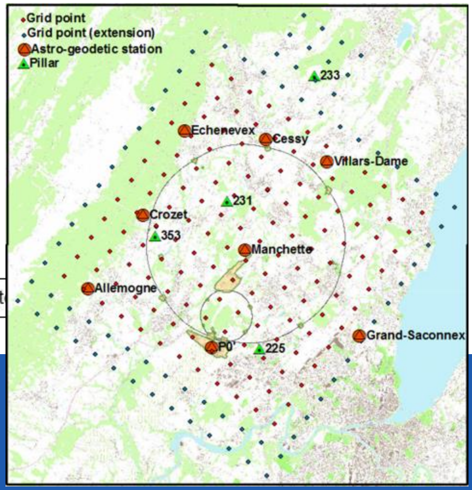
Specifications needed (relative precision, global requirements to be broken down into: manufacturing, component assembly, final alignment, ...).

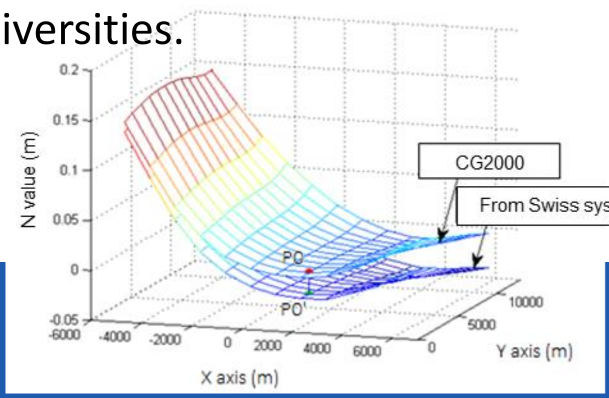
Access restrictions (radiation hazard, magnetic fields, space limits).

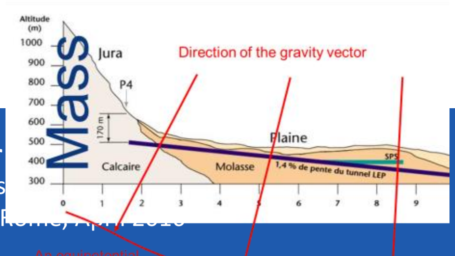
CERN coordinate system vs. connection to CH / F / global reference frame (some parameters to be modified)



Geoid model – some inconsistencies
New model needed, combining CH and F data
Analyses underway, with support from „swisstopo".
Looking for input from IGN and some universities.

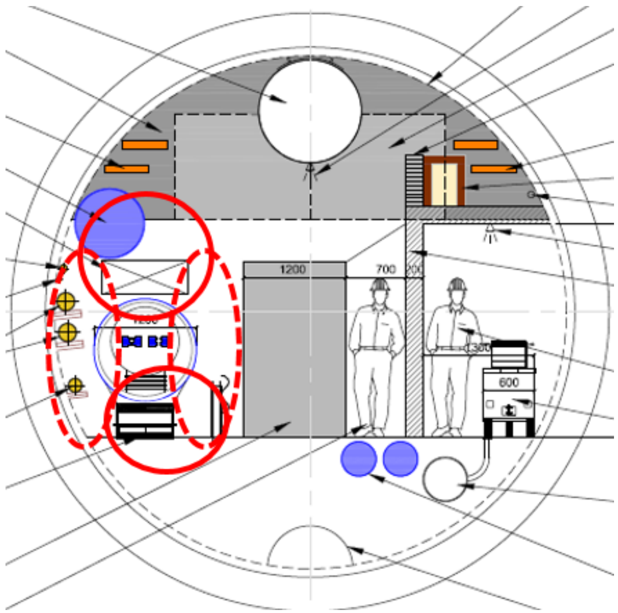


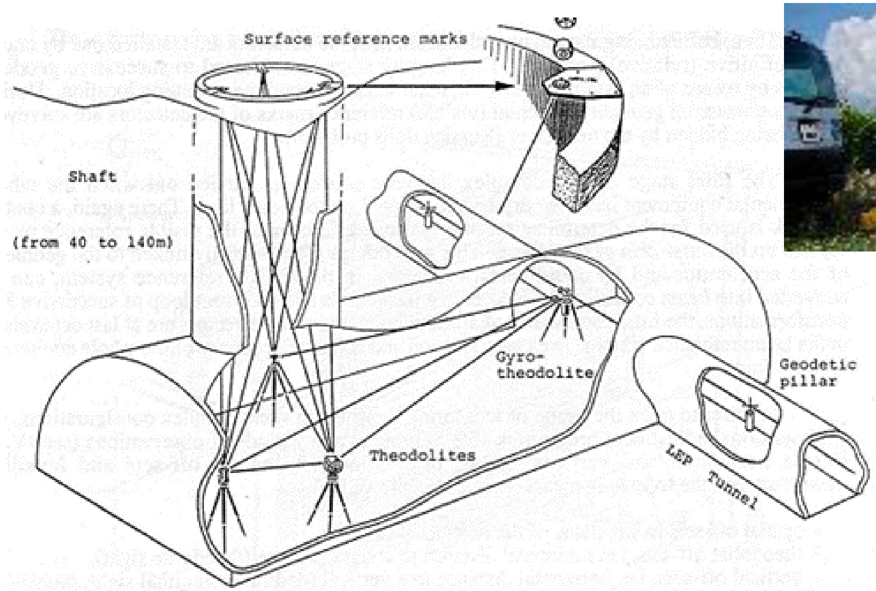




M. Jones: FCC - large scale metrology

Looking into space reserved for survey, and methods how to bring down the reference system.



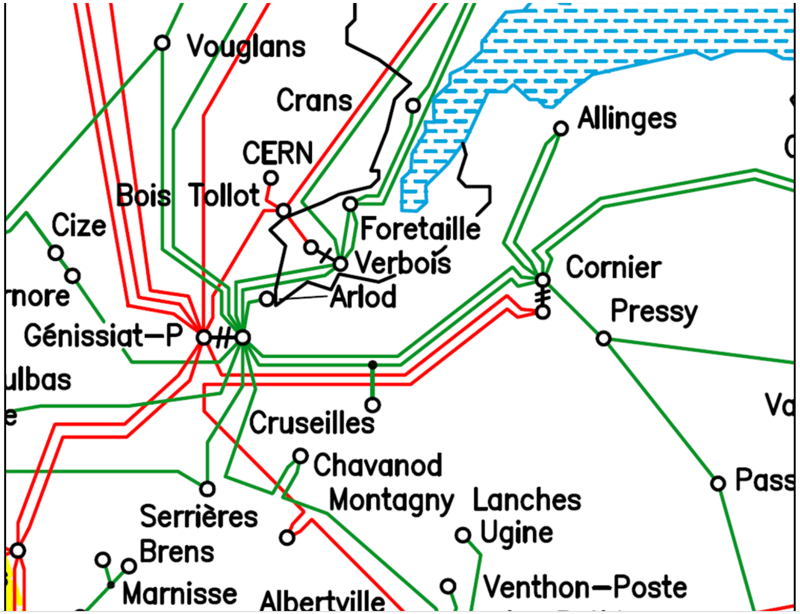


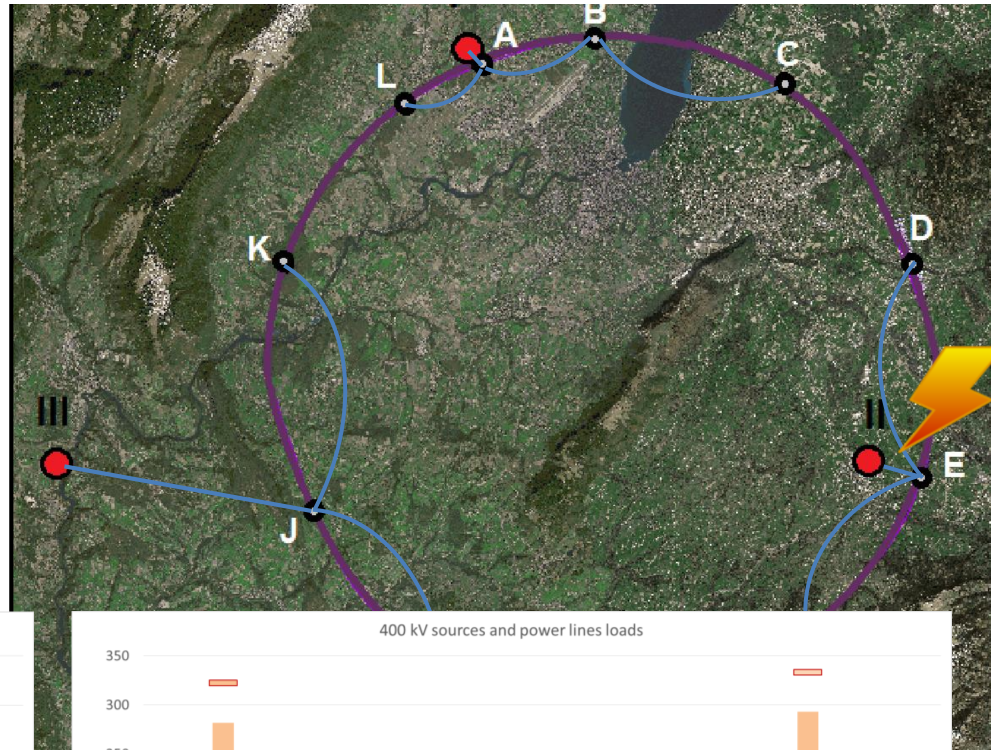
Continuing to work on: geoid model, geodetic network simulations, instruments + math. models

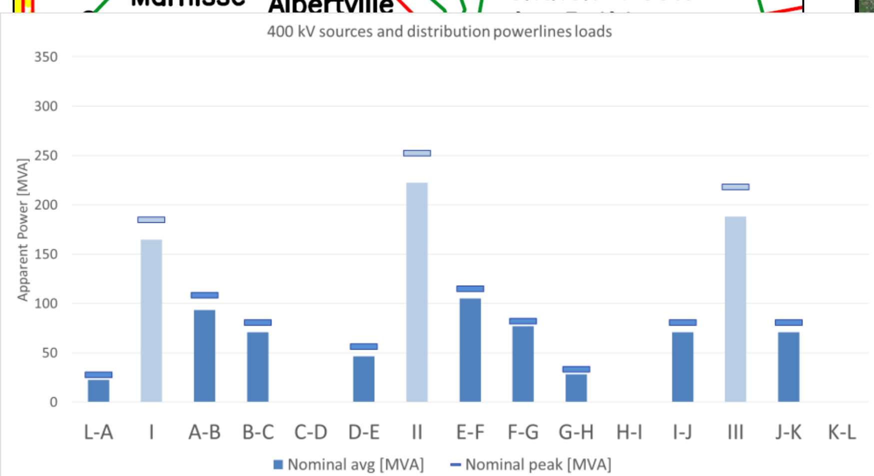
Specifications needed for FCC-hh, FCC-ee, transfer lines, experiments.
These will define alignment, monitoring
and control system technology (could imply R&D).

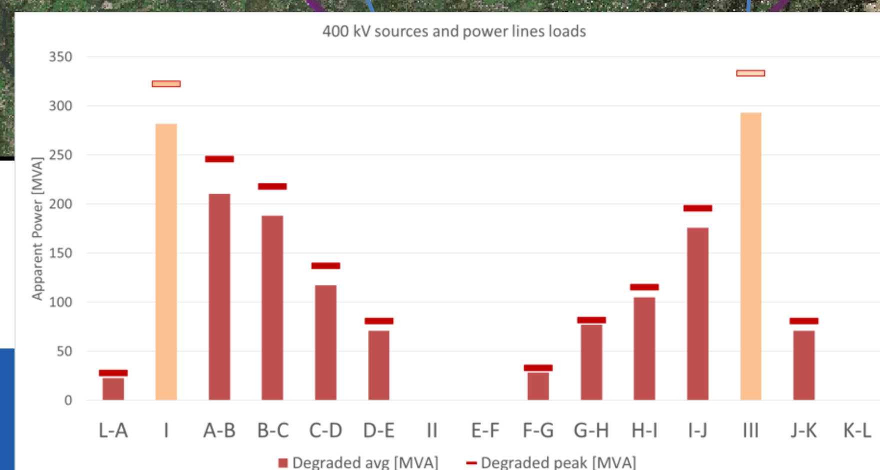
D. Bozzini: Design cosiderations for the FCC electrical network architecture

Studying supply of neighbouring FCC points from 3 400 kV feeds, in normal + degraded mode.
Based on first input from system designers (target values: FCC-hh 500 MW, FCC-ee 400 MW)





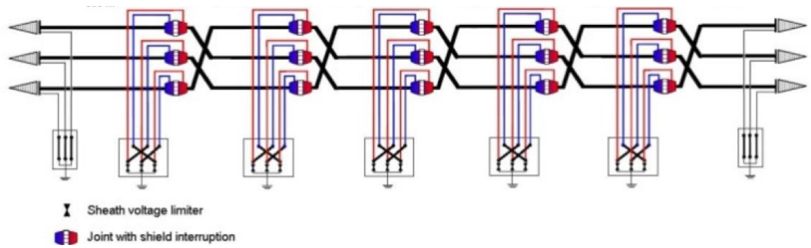


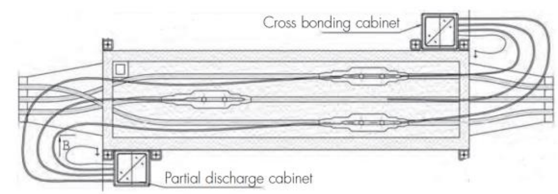


D. Bozzini: Design cosiderations for the FCC electrical network architecture

Present conceptual design foresees overhead line from nearest 400 kV point and underground distribution (study case 132 kV; to be refined).

Cross bonding required to limit sheath induced longitudinal voltages and currents circulating in sheath.

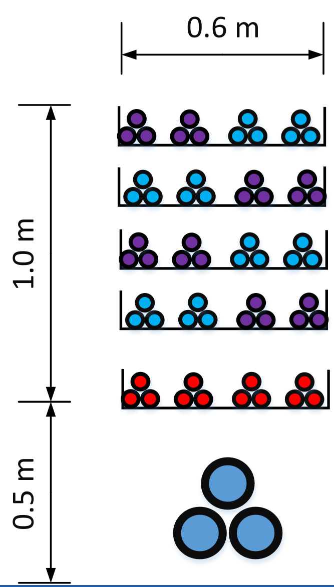


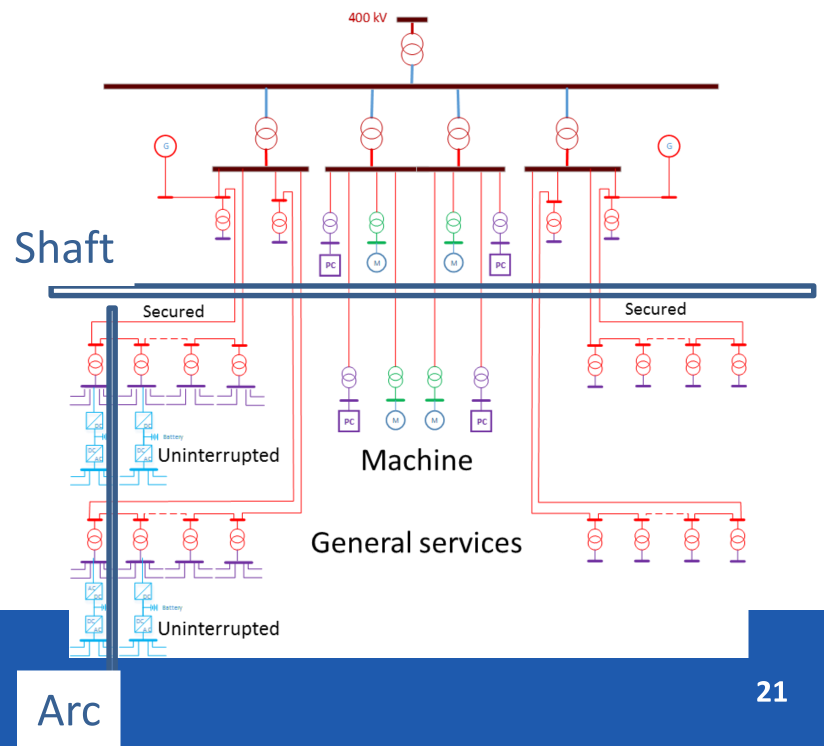


Maximum transportable length of cable will determine # of pits for cable joints and cross bonding (ca 500-800 m).

Distribution network to be integrated into cross section.

Dimensioning depends on system requirements and capability to run in degraded mode.

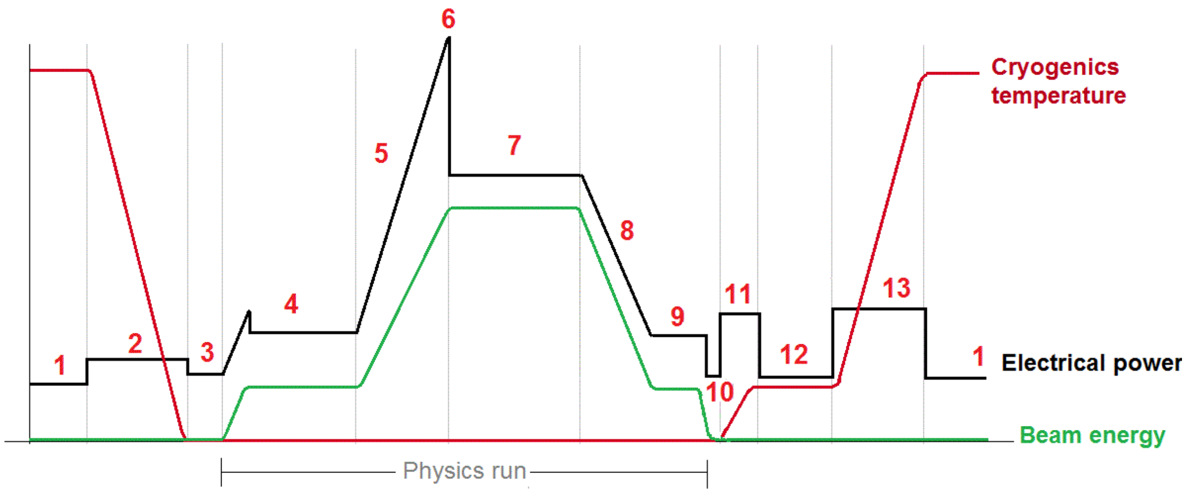


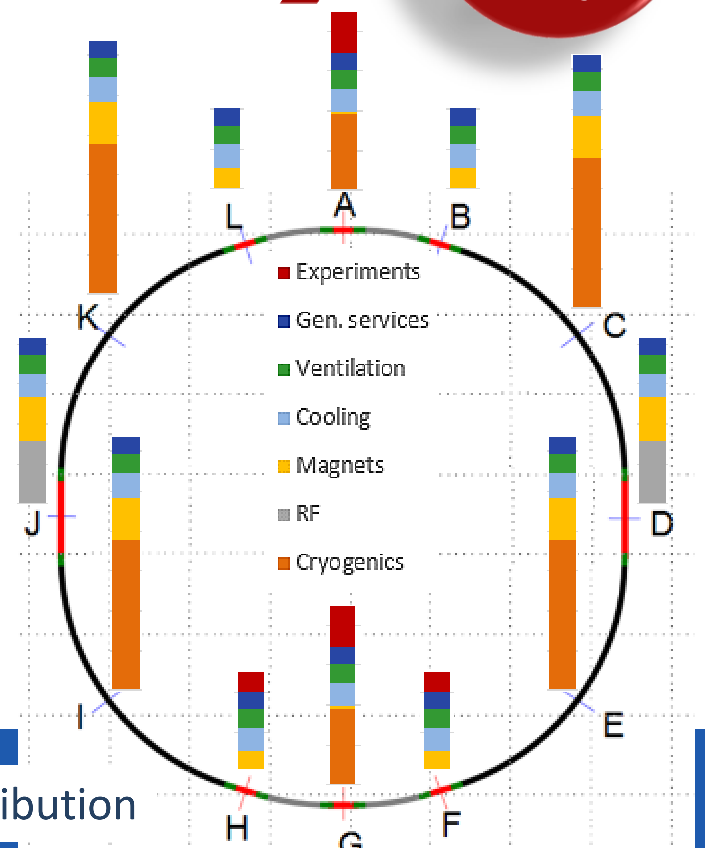


M. Mylona: FCC power requirements – methodology for data collection

who	when	where	how	
Users	Operating cycle	Power location (mapping)	Classification (network, voltage)	FCC network design

Method being set up. Data needed from users for various phases and different machines.





Average power distribution

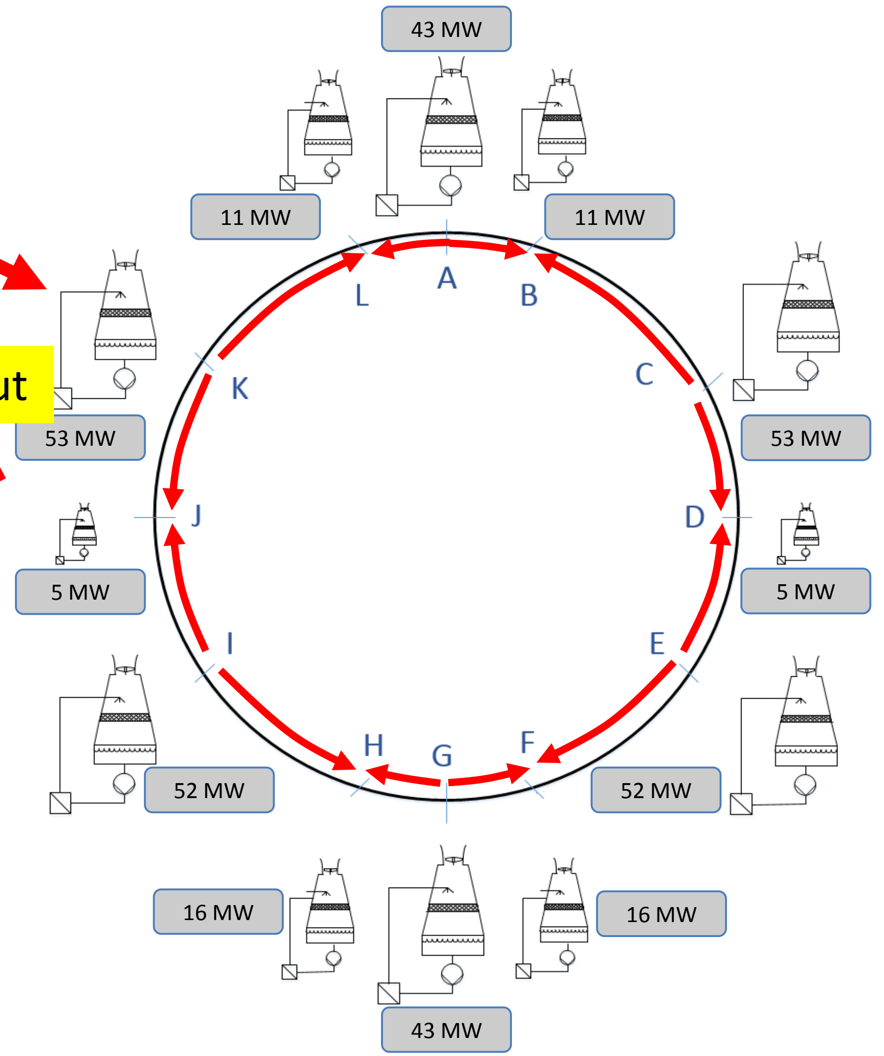
M. Nonis:
Cooling and ventilation plants

FCC-hh: heat loads cooling circuits [MW]

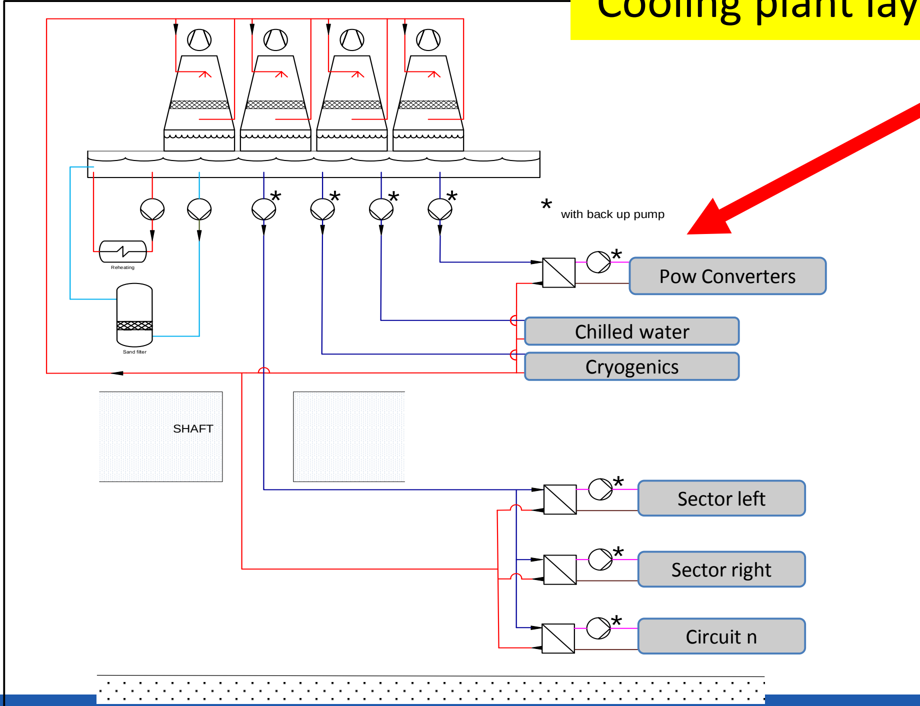
MW	L-A	As	Au	A-B	Bs	Bu	B-C	Cs	Cu	C-D	Ds	Du	E-D	Es	Eu	E-F
Cryo		20	1.2					41	2.6					41	2.6	

MW	Fs	Fu	F-G	Gs	Gu	G-H	Hs	Hu	H-I	Is	Iu	I-J	Js	Ju	J-K	Ks	Ku	K-L	Ls	Lu
Cryo				2	1.3															
RF																				
Exper	7.3	2		10.5	2.7															
Gen services	2			2																
Magnets			0.5																	
Pow converters	0.1			0.1																
Chilled water	3			5.4																
Total	12.4	2	0.5	38	4															
Total point	**14.4**			**43**																

POINT A	Power kW	ΔT K	Q m3/h	ND mm	H bar
Primary	43,000	15	2,470	550	1.2
Primary (shaft)	3,700	15	213	200	2.0
Cryogenics S	20,000	15	1,149	400	1.3
Experiments S	10,500	15	603	300	1.6
Gen services	2,000	15	115	150	2.7
Chilled water	5,400	6	775	350	1.4
Power converters	100	15	6	50	1.7
Cryogenics U	1,300	15	75	125	1.4
Tunnel circuit L-A	500	15	29	125	4.6
Tunnel circuit A-B	500	15	29	125	4.6
Experiments U	2,700	15	155	150	2.2
make up water (5%)			124	150	1.0

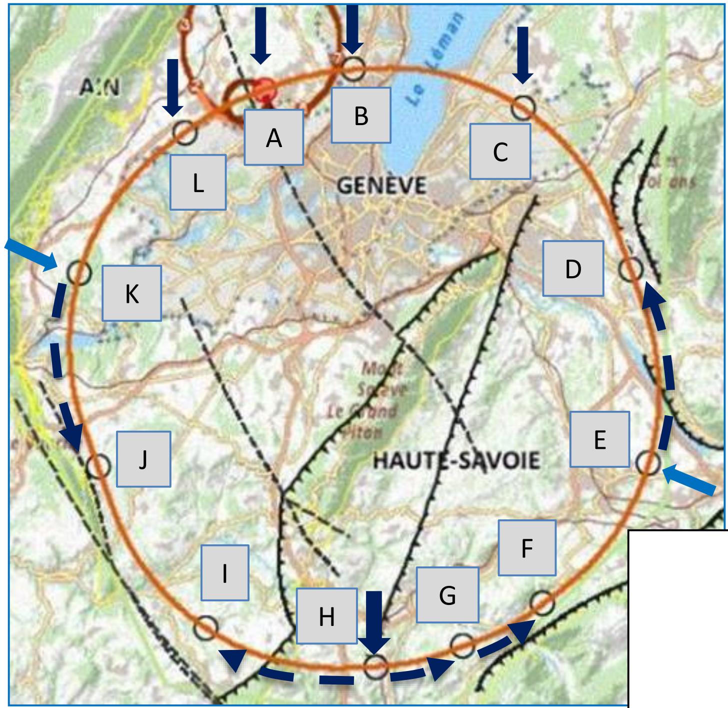


Cooling plant layout



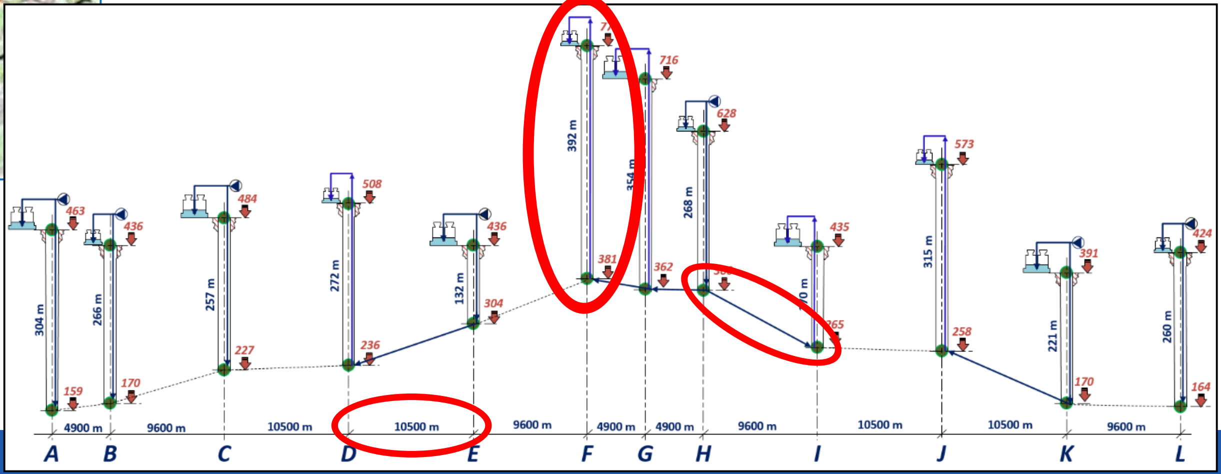
M. Nonis: Cooling and ventilation plants

Primary water supply



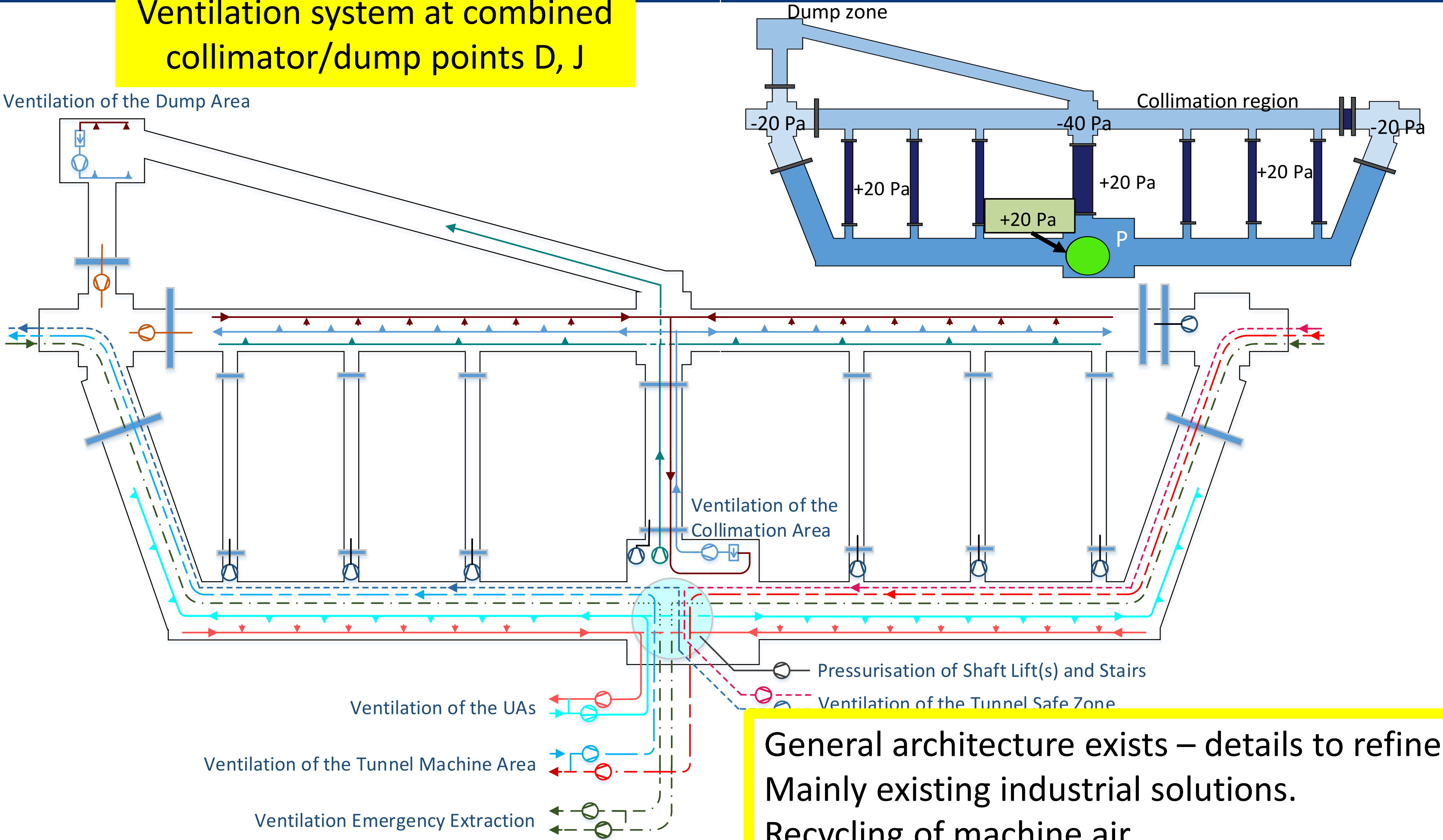
Various constraints from topology

Depth
Sector length
Altitude variation



M. Nonis: Cooling and ventilation plants

Ventilation system at combined collimator/dump points D, J



General architecture exists – details to refine.
Mainly existing industrial solutions.
Recycling of machine air.
To come: environmental impact, overall efficiency, valorisation of waste heat, ...

Parallel session III

Thursday, 15:30-17:00

Safety, Availability, Controls – chair: Ralf Trant

FCC collaboration “Fire safety” (Saverio La Mendola)
Conventional safety (André Henriques)
Radiation protection (Markus Widorski)
First results from availability studies (Andrea Apollonia)
Controls architecture challenges for beam dump kickers (Pieter van Trappen)

S. La Mendola: FCC collaboration "fire safety"

Starting from ITSF (International Technical Safety Forum).
Realising that same issues get explored (smoke propagation, evacuation, air management, ...).

On initiative of ESS and CERN

Workshop on Fire Protection at Research Facilities

21-22 January 2015
Tunavägen 24
Europe/Stockholm timezone

Lund January 2015

Main topic	Sub-topic
Hazard characterization	Burning behavior of commonly present items
	Fire simulations
	Oxygen Deficiency Hazard
	Flammable gases
Passive fire protection	
Active fire protection systems	Fire detection
	Fire extinction
	Smoke extraction and ventilation
Intervention of rescue teams	
Life safety in underground facilities	Evacuation of occupants
Fire risk methodologies and tools	Collection, analysis and use of statistics
	RAMS aspects

FCC as framework for more direct (thus effective) collaboration between labs → synergy.

Consistency of assumptions and tools is key for reliable results.

S. La Mendola: FCC collaboration “fire safety”

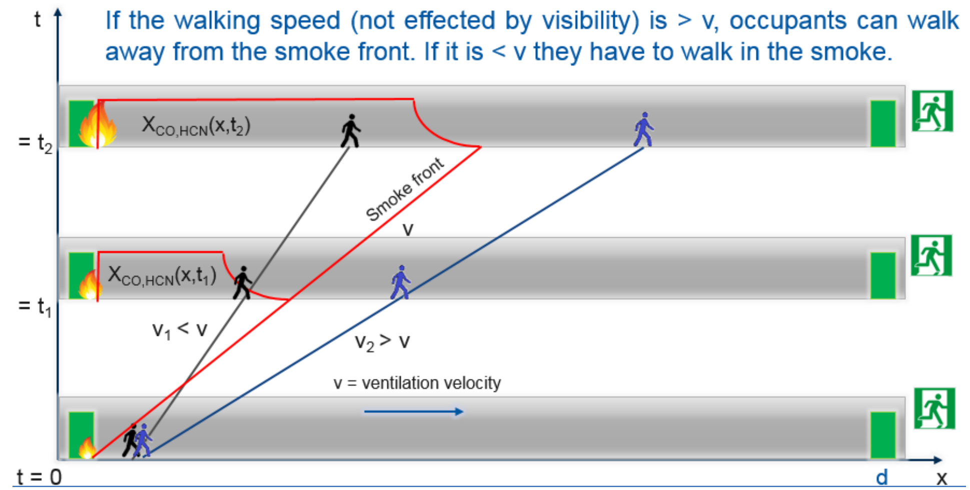
Welcoming additional partners.

Fire protection workshop at CERN October 2015

Presenting first results at next ITSF

A. Henriques: General safety studies + considerations for FCC

Smoke propagation studies ongoing ... (standard arc)



... leading to indications about the maximum distance between connections between the machine area and the „safe zone“ (single or double tunnel).

Ventilation speed [m/s]	**Maximum distance** (mean value Monte Carlo sim.) **[km]***
1	2.0
1.5	0.73
2	0.61
	*preliminary results

1 km baseline value validated
Optimisation once ventilation speed is fixed

A. Henriques: General safety studies + considerations for FCC

Other studies, with concrete recommendations coming up:

General points on safe zone
- Minimum fire risk/load

Evacuation modeling
- Smoke compartmentalisation, personnel transport means along 10 km arc, alarms, ...

# of shafts + lifts
- 1 shaft per point is acceptable, at least 2 lifts, lift time = LHC, protected area at bottom

Air management
- Overpressurised safe zone (resp. pressurised airlock between double tunnel)

He release + extraction during access mode
- Smoke extraction system to cope with 1 kg/s He. Temperature vs mech. properties.

Connections experimental/service caverns
- Zoning, flow of people/material. Access to service caverns with beam on.

Magnetic field in experimental caverns
- Hazards mainly of technical nature.

Verification and optimisation to continue with definitive values, e.g. of ventilation speed, number of people present during different phases (installation, operation, ...), electrical network, cryogenic system, ...

M. Widorski: Radiation protection at FCC-hh – status update

Assessment of ventilation of machine tunnel and safe zone.

Proposal for „recycling“ machine air in line with RP requirements.

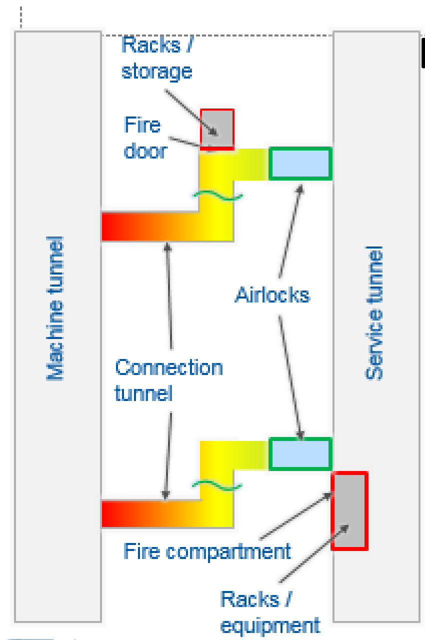
Air in safe zone needs to be flushed before access (single tunnel variant).

Double (bypass) tunnel needed in collimator/beam dump regions (2 x 4.2 km)

and focusing regions (8 x 1 km)

# of connection tunnels per high-radiation point (4.2 km): ca 5-7 → ca every 500 m.

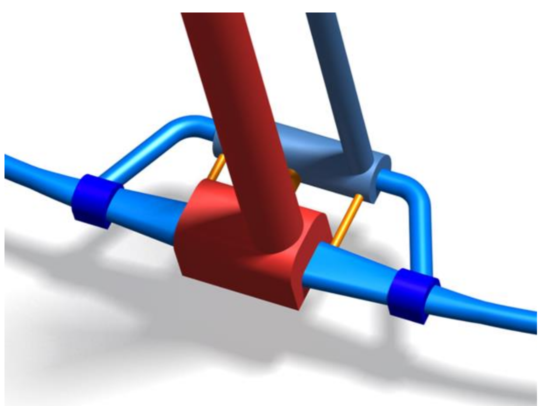
Optimisation when collimator layout and loss distribution are known.



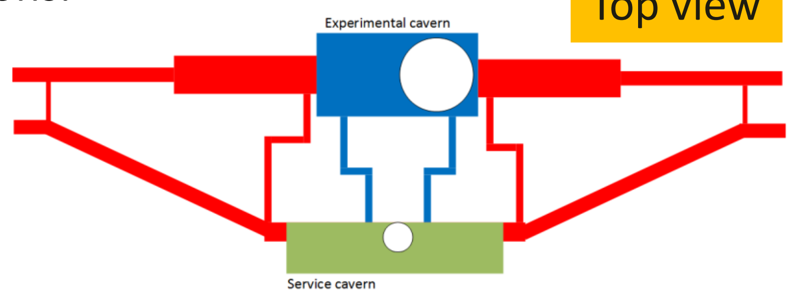
Bypass to join (near) the service cavern.

Ca 1-2 connections in focusing regions.

No dead ends.

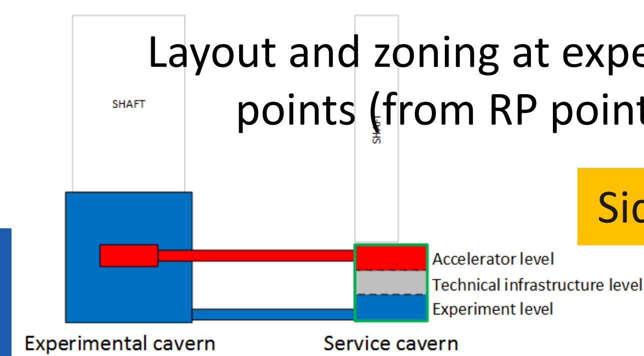


Top view



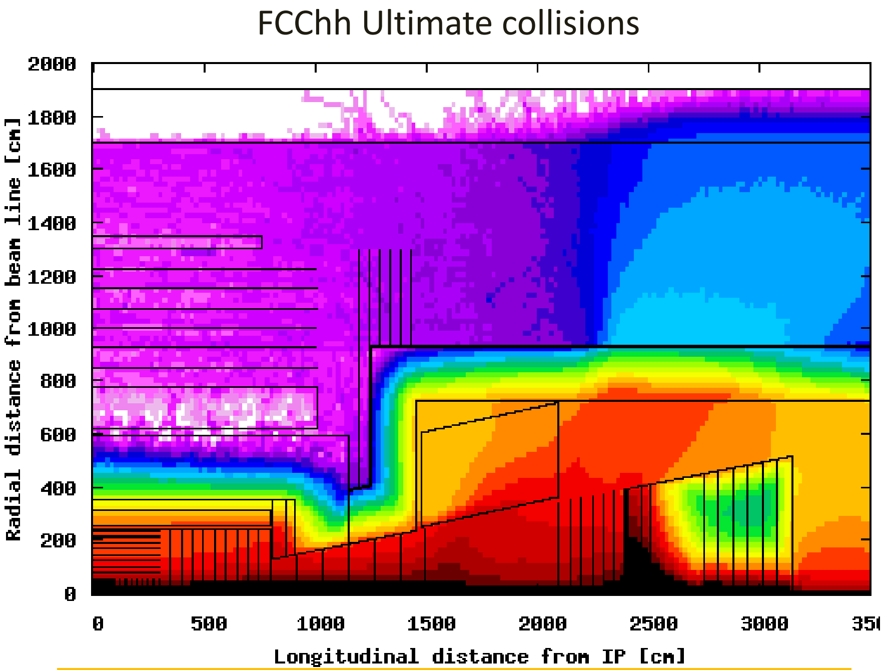
Layout and zoning at experimental points (from RP point of view)

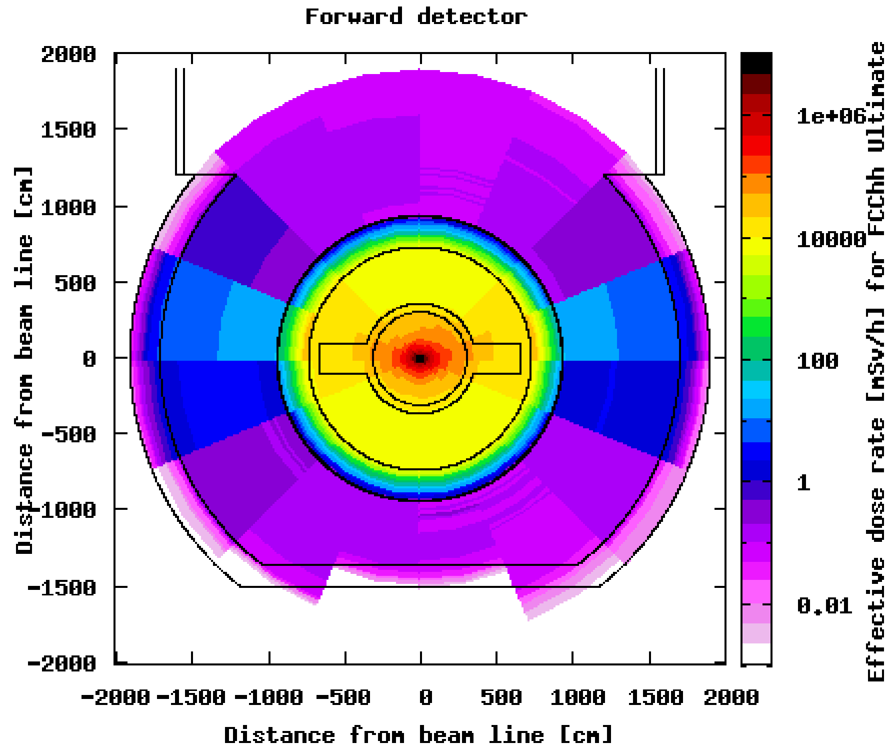
Side view



M. Widorski: Radiation protection at FCC-hh – status update

Studies for experimental caverns/shafts.





Massive 2 m iron shielding around forward detector → still under study

Higher dose rate in horizontal plane gives recommend's for layout of access paths.

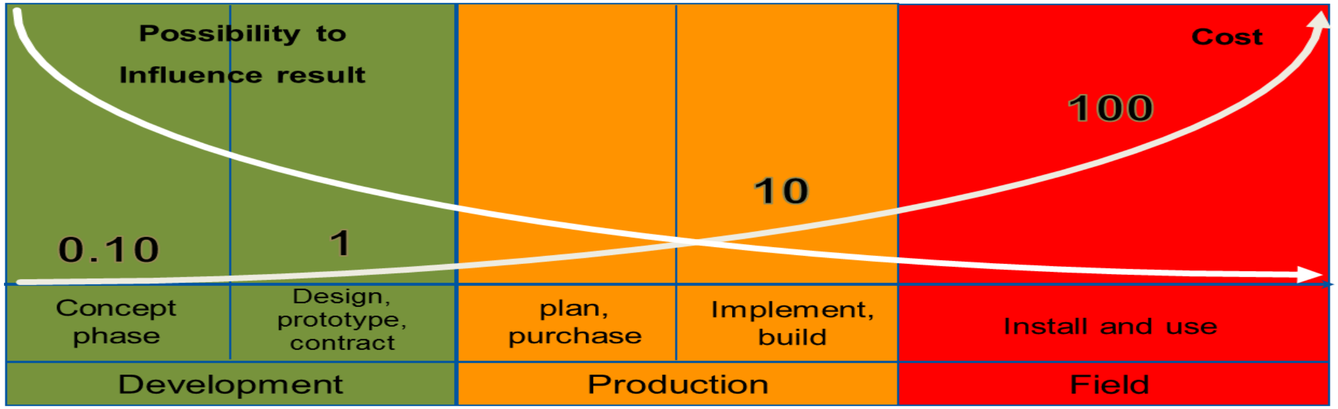
No RP issues at top of experimental shafts, neither for ultimate operation nor full beam loss.

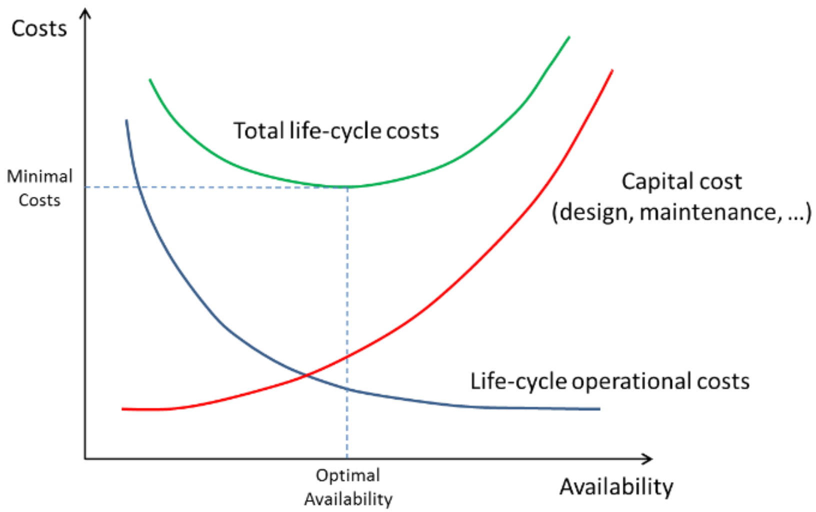
Residual dose rates after operation being investigated (forward detector).

Next: refinement as design proceeds, FCC-ee evaluation, HTS beam screen coating material (?).

A. Apollonio: FCC availability studies

Important to address from the outset (and further throughout whole accelerator lifetime), to maximise performance within technological and financial boundaries.





Scope:

- Evaluate suitability of industrial availability methods to partile accelerators.
- Identify and analyse possible design and operation scenarios for FCC-hh.
- Identify key impact factors for availability and luminosity production.

Not:

- Specific guidelines for individual system designs.

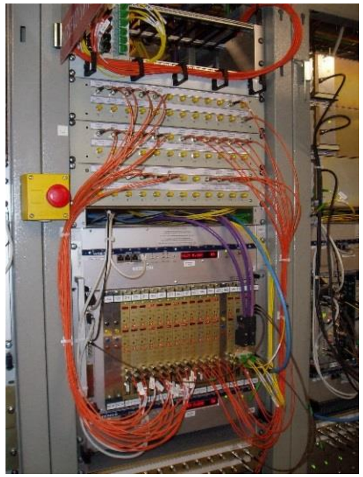
Conclusions & Outlook

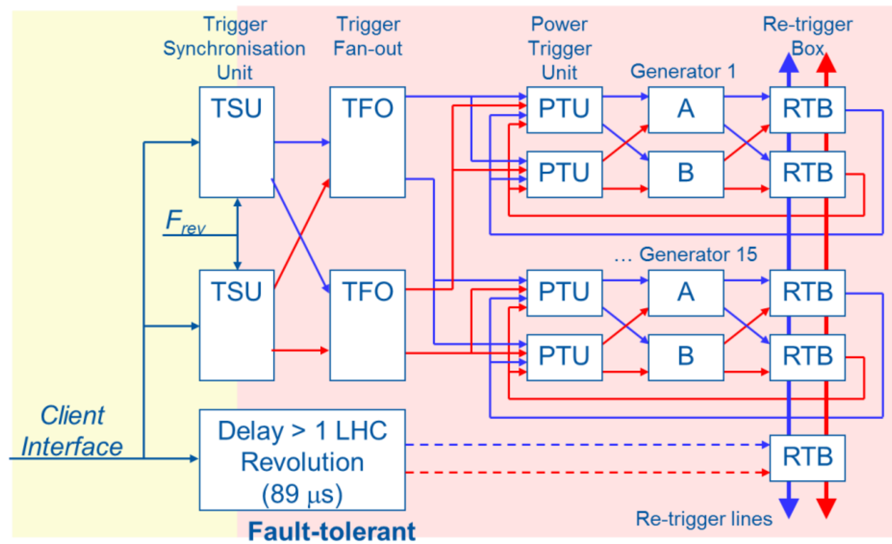
- Estimates of the **achievable availability** of the FCC-hh will be one of the main factors for the assessment of its **feasibility**
- LHC Availability model implemented (better than 1 % acc.), ready for extrapolation to FCC
- Future studies should focus on:
  - Definition of a FCC **cycle duration** (also influencing system design)
  - Analysis of different **injector options** (also influencing cycle duration)
  - Identify strategy for **scaling** number of components (e.g. number of power converters, redundancy in cryogenic system,…)
  - **Data quality** management (RAMS Database)
- Possibility: extend the study to the FCC-ee?
  - Requires expertise (and data) on lepton machines

Join us in the FCC RAMS study !
FCC-RAMS@cern.ch

P. van Trappen: Controls architecture challenges for beam dump kickers

In LHC LBDS is already a mission-critical system with specific design features (kicker granularity, redundant HV switches, redundant trigger paths, avoidance of common-mode failures, ...).





FCC (8 GJ beam energy, distances/access, performance demand) requires another approach:

- Perform **qualitative reliability analysis** for each part from the design phase on.
- Implement **system redundancy**: hot swappable HV pulse generators.
- Apply **Triple Modular Redundancy (TMR)** to critical parts.
- Accept operation in **degraded mode** where non-critical redundant paths are lost.
- Meticulously plan **preventive maintenance** during Technical Stops by leveraging advanced data monitoring.

RAMS aspects from the outset

P. van Trappen: Controls architecture challenges for beam dump kickers

FBDS plans to use 300 extraction kickers of ca. 30 cm (+ dilution kickers).
Need to fit HV generators and switches, controls electronics, ... in these 100 m.

More custom-made electronics (yet allowing design re-use); rad-hardness to be „designed in“.
Minature controllers, decentralisation, less cables and connections, combined HW/SW (SoC).

Investigating to place the HV generator and controls close to the beam
to shorten the transmission line and reduce field rise time
(depends on dose and SEE rate).

Triggering and retriggering
Looking whether delayed synchronous dump is possible when 1/300 kickers fires erratically.
(several about gaps of 1 us ?).
Laser-püumped thryristor triggering ?

Huge amount of channels to supervise, waveforms to check to make sure that next dump is OK.
LHC: post-operational checks. FCC: Artificial Intelligence (?)

Concluding remarks

Huge amount of activity going on – „IO train running at full steam“.

Concepts for several systems elaborated, using approximate data and estimates
(civil engineering, cryogenics, electrical distribution, cooling & ventilation, ...).
Machine(s) requirements are needed to narrow down, become more specific and quantitative,
resp. know about need for R&D efforts (survey, ...).

New level of challenges – for full eploitation FCC cannot just be extrapolation of LHC „methods“.

Use momentum and develop new methods – some of them mentioned at this workshop
(superconducting power transmission, laser alignment, possibility to run
in degraded mode, AI for data mining, high degree of automatisation, ...).

Such developments can have useful spin-off also for other applications.

Great occasion for (further) collaborations.

Grazie per l‘attenzione !

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