CERN Academic Training
FCC7: Civil Engineering and Technical Infrastructure

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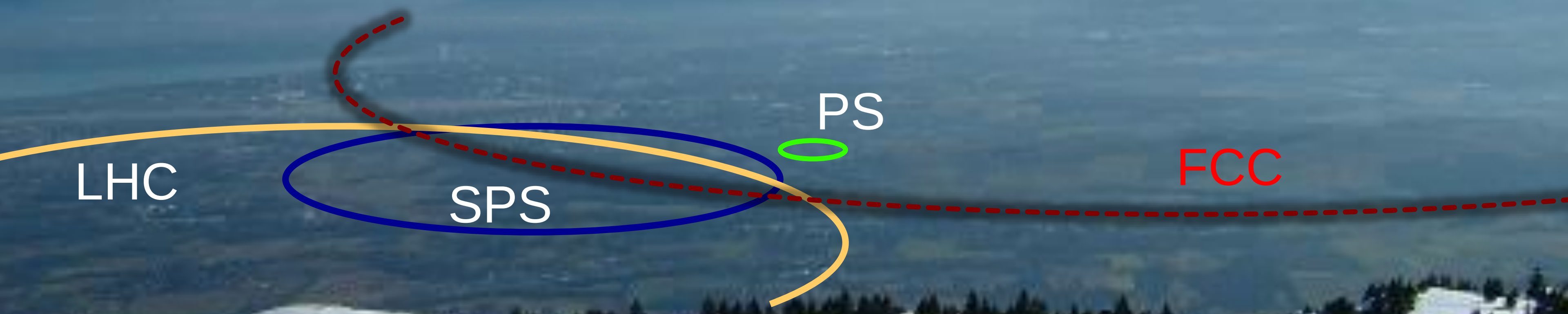
on behalf of the
FCC Infrastructure and Operation Working Group*

5 February 2016



http://cern.ch/fcc

Acknowledgements for material to: D. Bozzini, Ch. Cook, A. Henriques, Ph. Lebrun, A. Niemi,
K. Oide, J. Osborne, I. Ruehl, P. Sollander, L. Tavian, R. Trant and M. Widorski

Scope

- The physics, detector and accelerator physics & technology parts of the FCC conceptual design are essentially site-independent.
- They are to be complemented by a study of the implantation and infrastructure for the 80 km to 100 km perimeter ring in the neighbourhood of CERN.
- This would permit optimal re-use of the existing infrastructure, a strong asset of a CERN-based FCC.
- The study should also address integration, installation, computing and control, as well as operational aspects including reliability/availability, power/energy consumption and safety.
- Together with the detector and accelerator parts of the FCC conceptual design, the infrastructure study is an essential input to the cost, schedule and risk assessments, as well as to the future environmental impact assessment.

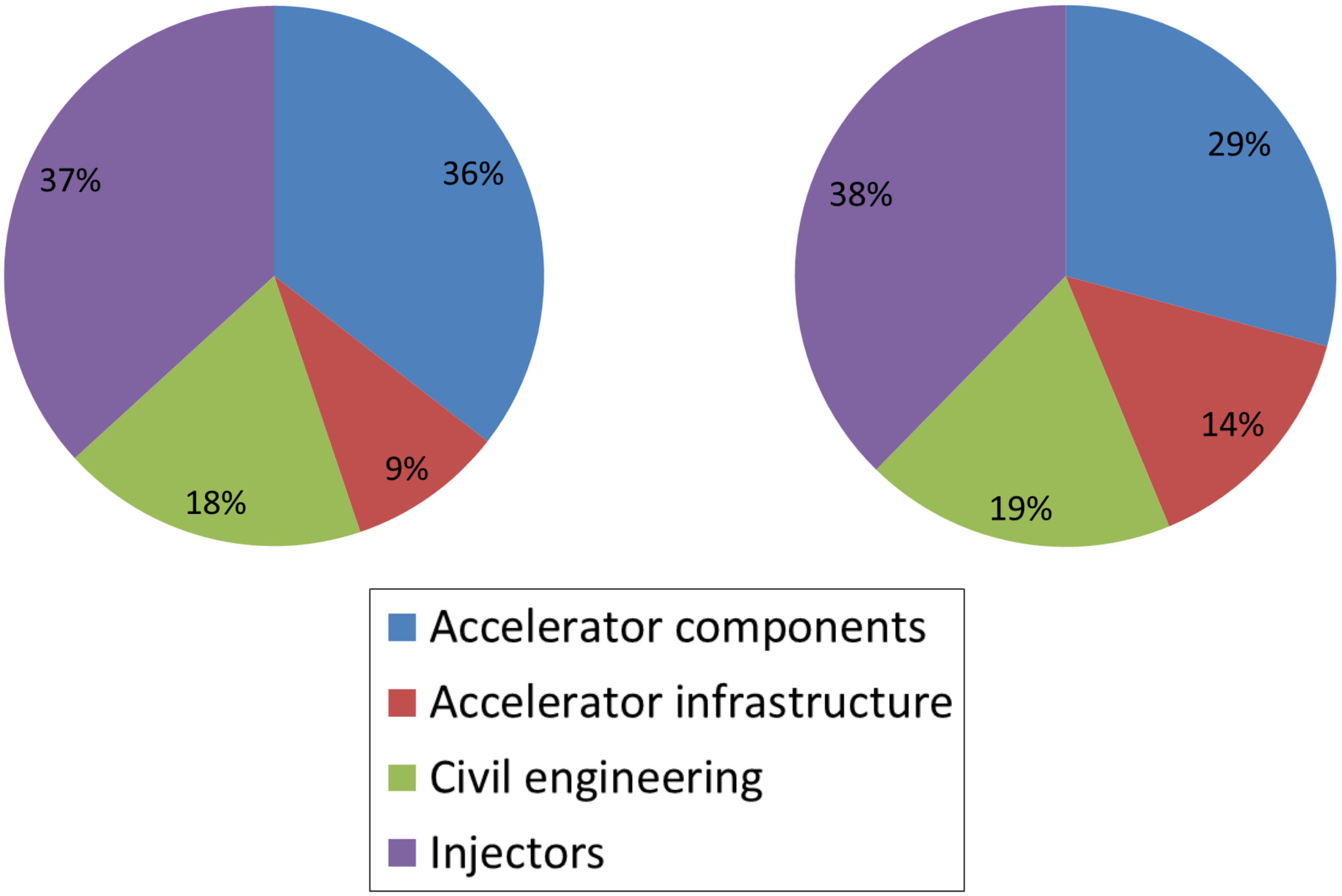
Infrastructure & Operation topics

- ☆ Geology & civil engineering
- ☆ Electrical distribution
- ☆ Cryogenics
- Cooling & ventilation
- ☆ Transport & handling
- Integration
- Installation
- Planning & coordination
- Survey & alignment
- Controls
- Power/energy consumption
- Energy efficiency
- ☆ Availability & reliability
- ☆ General safety
- ☆ Radiation protection
- Environmental protection
- ...

IOWG

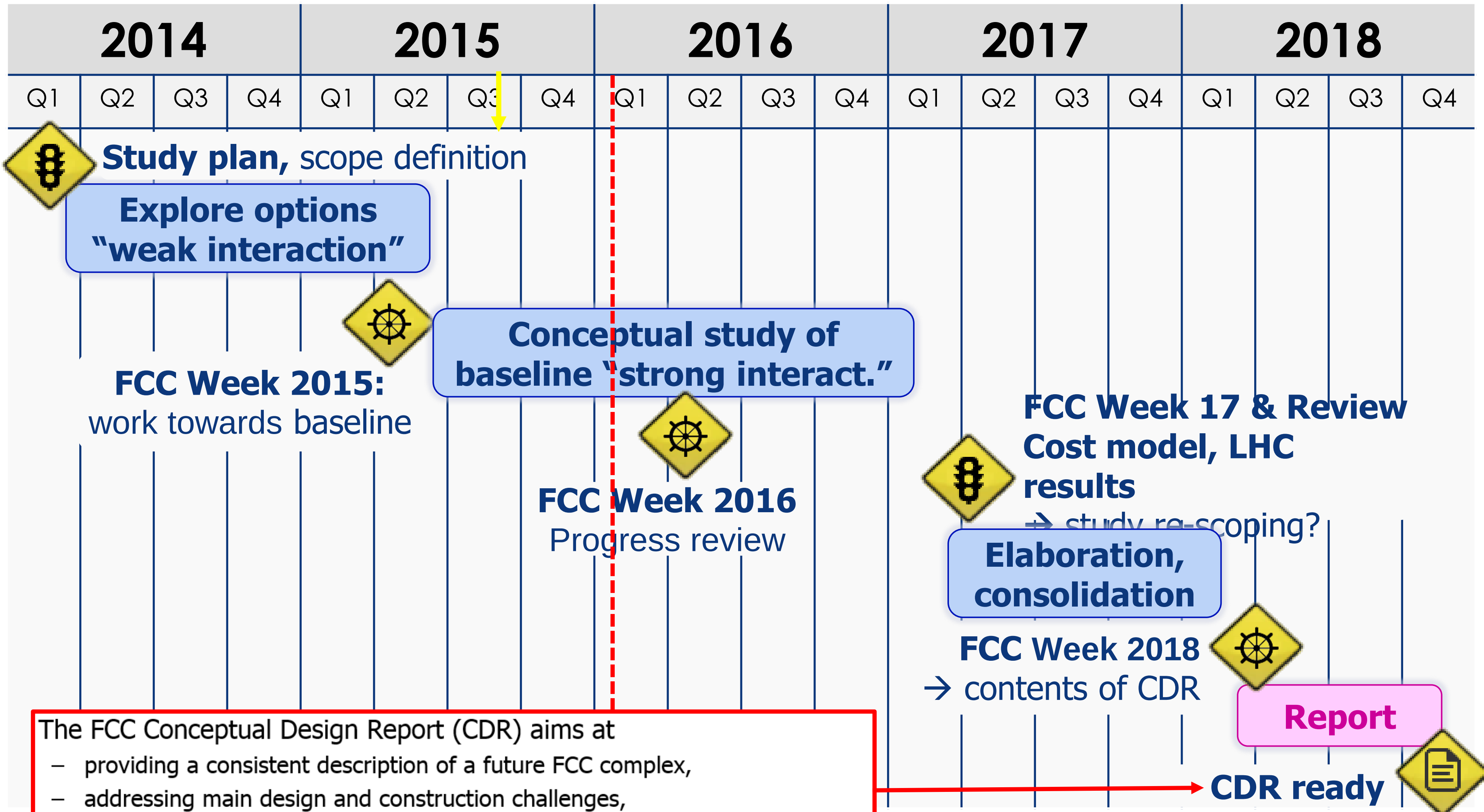
Infrastructure as cost driver
Cost structure of high-energy accelerators

LHC "green field" (reconstructed) | CLIC 500 ≡ "green field"



Timeline of the study

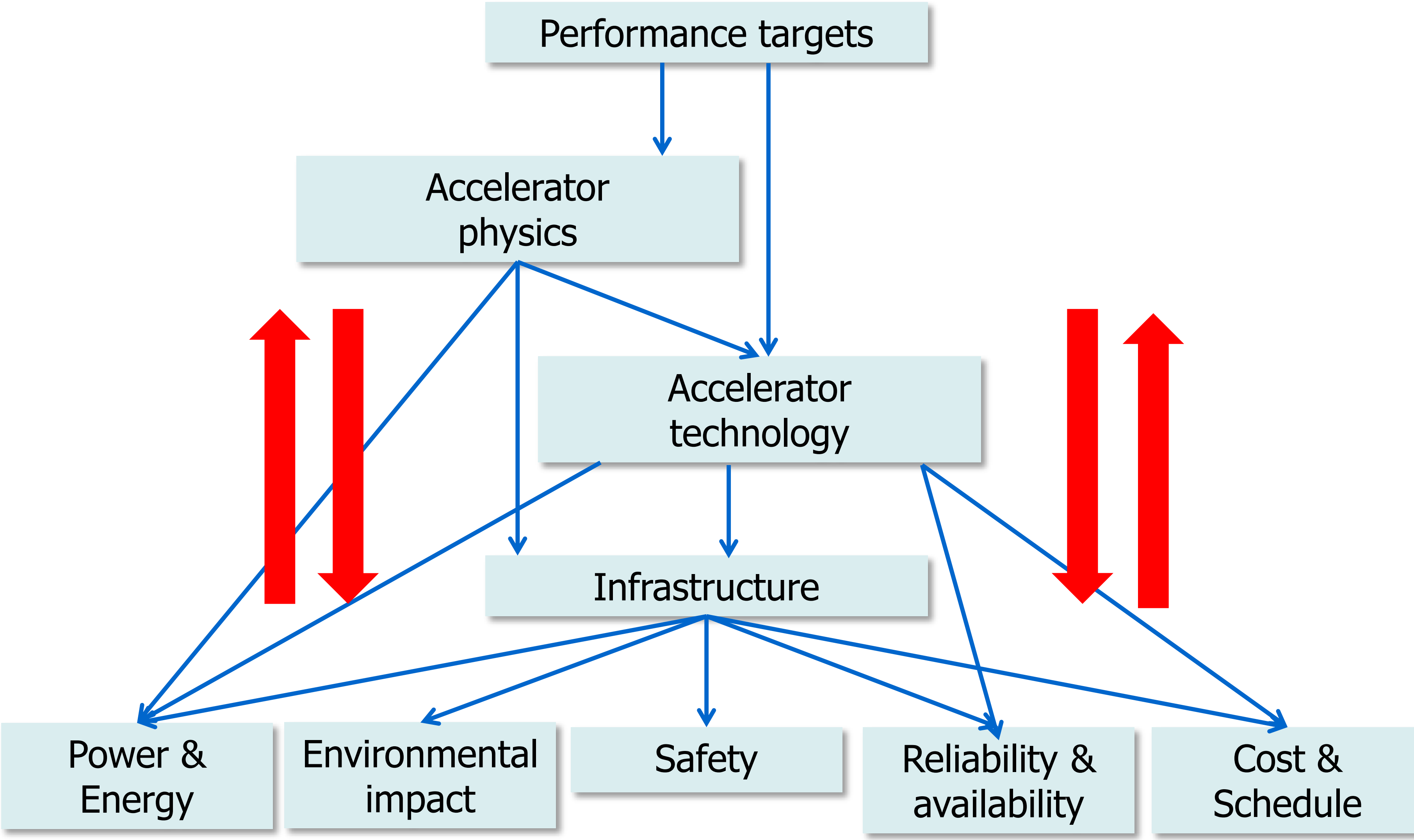
M. Benedikt, Tuesday



The FCC Conceptual Design Report (CDR) aims at

- providing a consistent description of a future FCC complex,
- addressing main design and construction challenges,
- presenting possible – if not optimized – configurations, with a level of detail sufficient to perform quantity, schedule and cost estimates

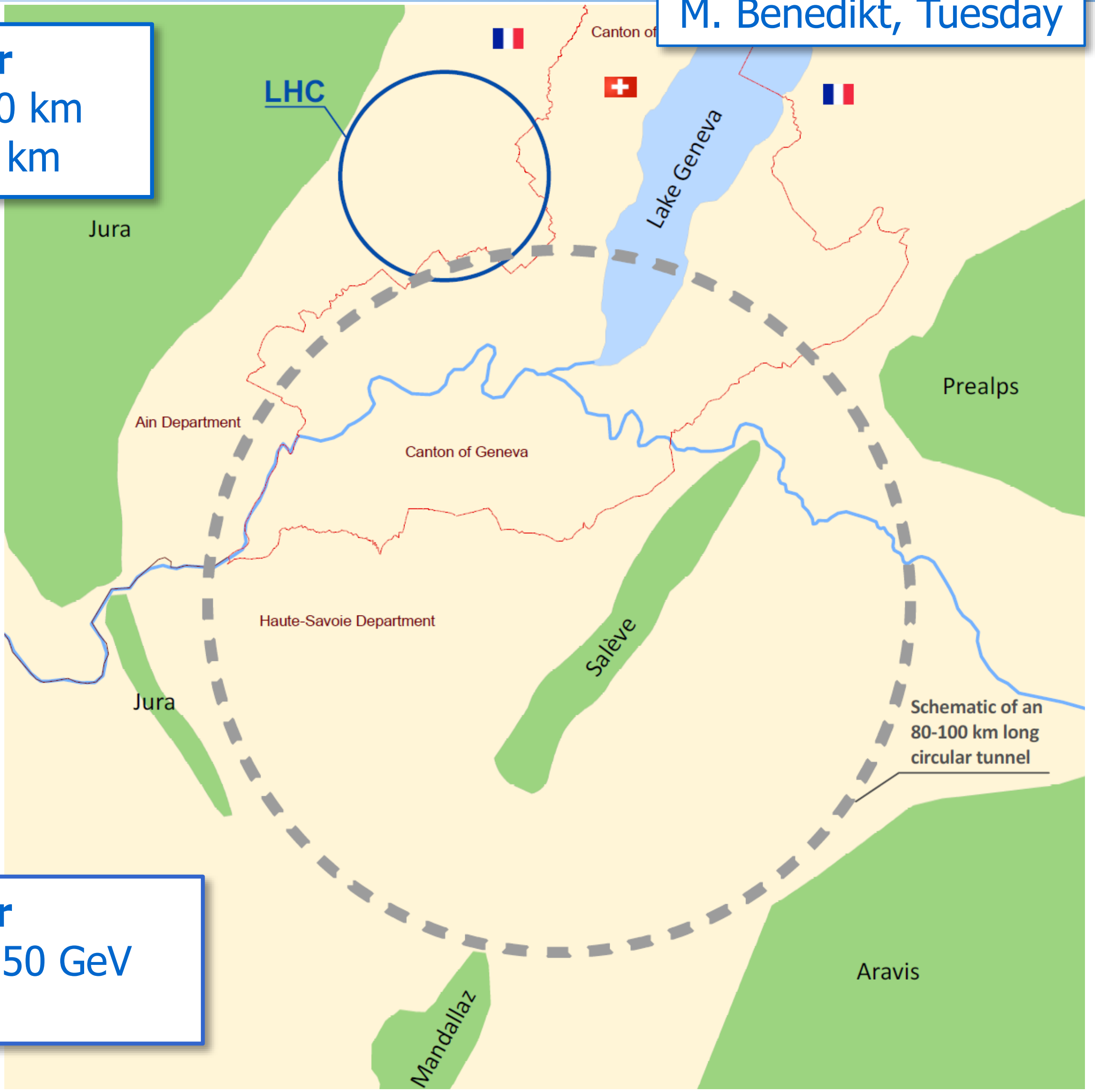
Accelerator design roadmap
“Waterfall” vs “concurrent” engineering



Basic input to FCC Infrastructure & Operation
Quasi-circular tunnel of 80 to 100 km perimeter

M. Benedikt, Tuesday

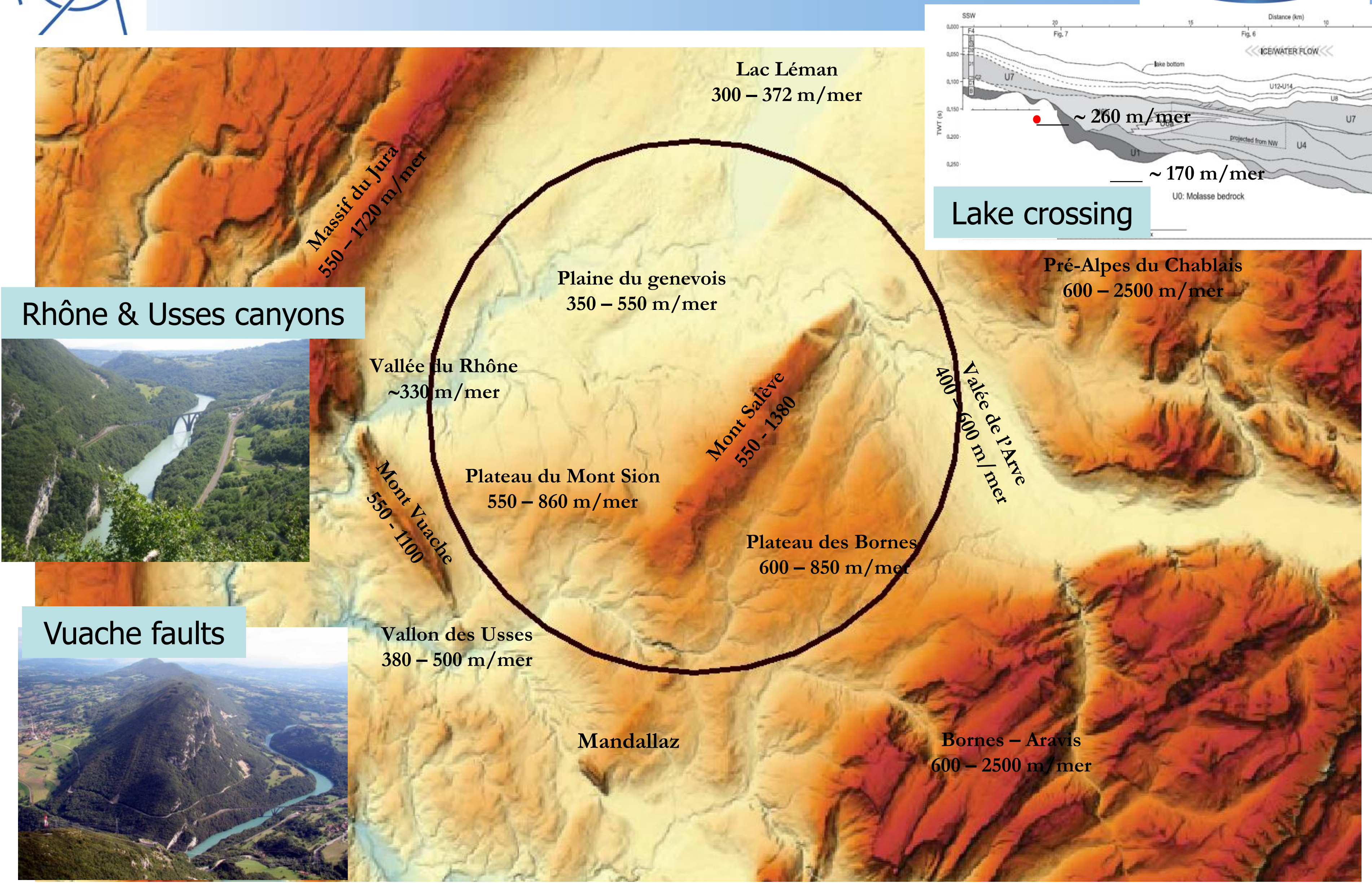
Hadron collider
16 T $\Rightarrow$ 100 TeV for 100 km
20 T $\Rightarrow$ 100 TeV for 80 km



e+e- collider
Collision energy 90 to 350 GeV
Very high luminosity

GEOLOGY and CIVIL ENGINEERING

Topographical constraints, critical areas



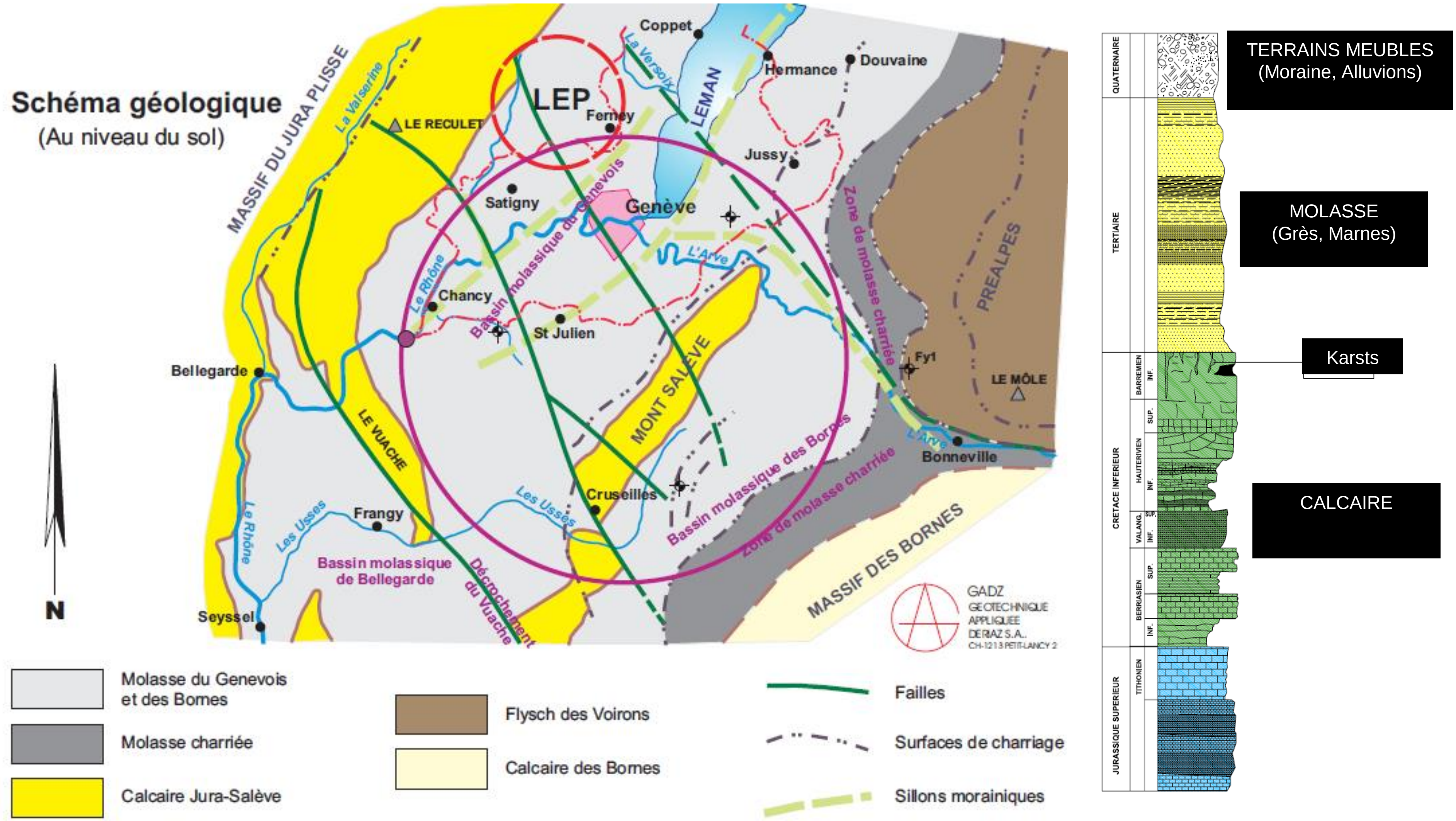
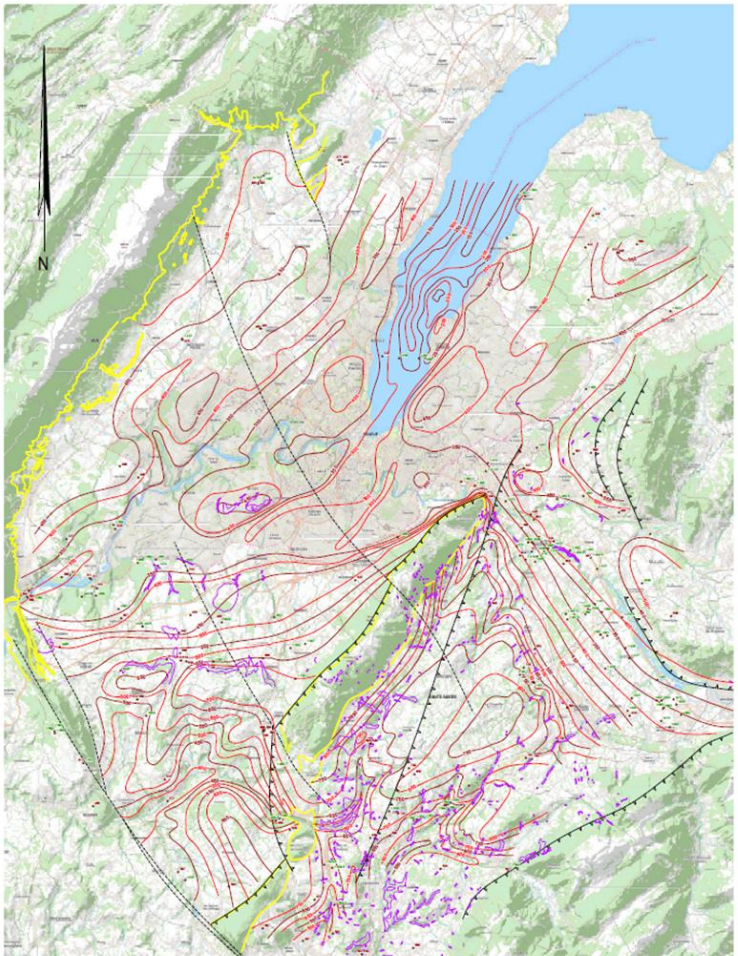


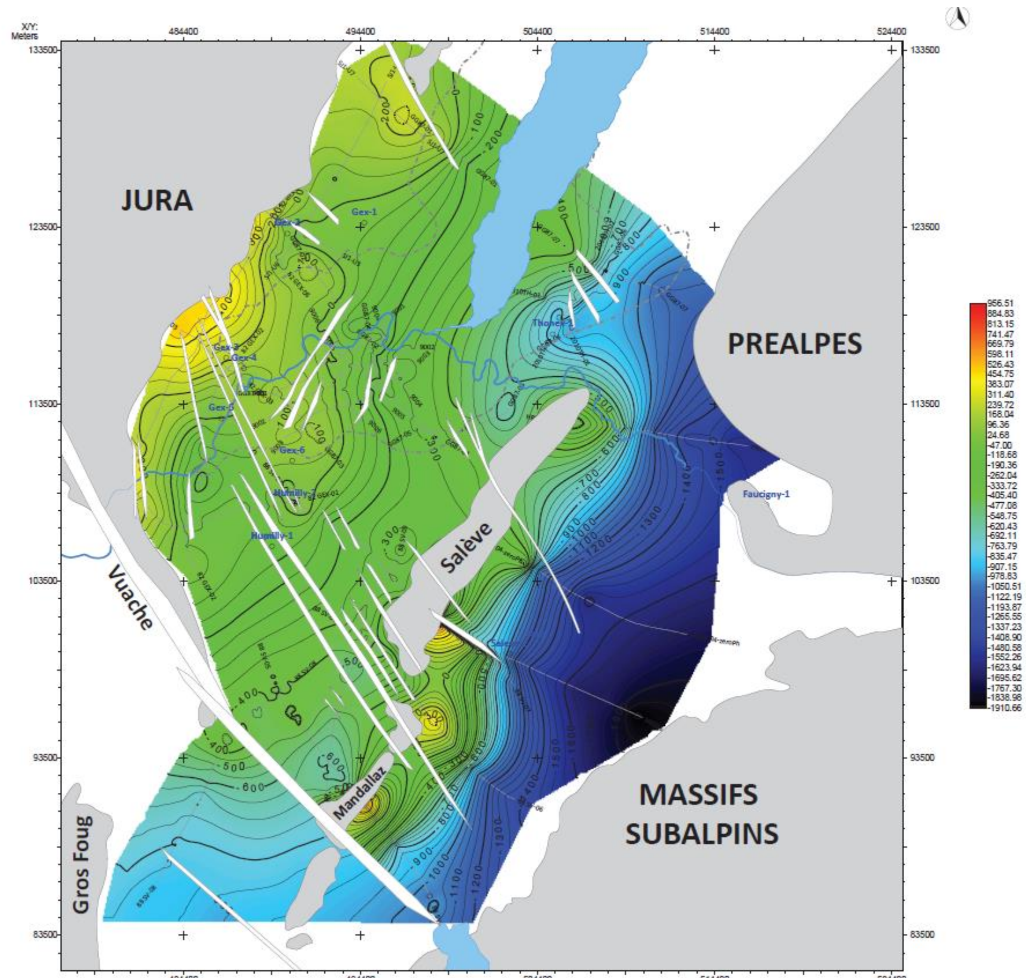
Schéma géologique
(Au niveau du sol)
MASSIF DU JURA PLISSE
La Valserine
LE RECULET
LEP
Coppet
La Versoix
LEMAN
Hermance
Douvaine
Ferney
Jussy
Satigny
Genève
Bassin molassique du Genevois
L'Arve
Zone de molasse charriée
PREALPES
Le Rhône
Chancy
St Julien
Bellegarde
MONT SALEVE
Fy1
LE MÔLE
LE VUACHE
Bonneville
Cruseilles
Bassin molassique des Bornes
Zone de molasse charriée
MASSIF DES BORNES
Le Rhône
Les Usses
Frangy
Les Usses
Bassin molassique de Bellegarde
Décrochement du Vuache
Seyssel
N
GADZ
GEOTECHNIQUE APPLIQUEE DERIAZ S.A.
Molasse du Genevois et des Bornes
Molasse charriée
Calcaire Jura-Salève
Flysch des Voirons
Calcaire des Bornes
Failles
Surfaces de charriage
Sillons morainiques
QUATERNAIRE
TERTIAIRE
CRETACE INFERIEUR
JURASSIQUE SUPERIEUR
BARREMIEN
HAUTERIVIEN
VALANG.
BERRIASIEN
TITHONIEN
TERRAINS MEUBLES
(Moraine, Alluvions)
MOLASSE
(Grès, Marnes)
Karsts
CALCAIRE

Updated model of molasse layer
(from test drillings and seismic logs)

Tertiary-quaternary interface (top of molasse layer)



Cretaceous-tertiary interface (bottom of molasse layer)

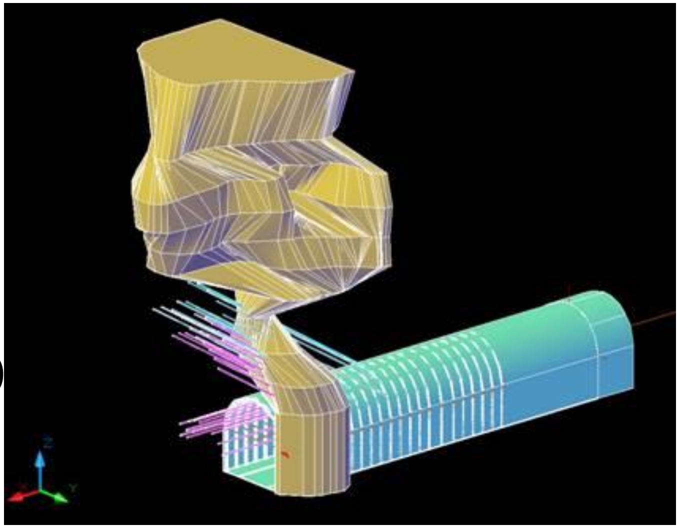


Geological considerations
Rock properties

Moraines
- Glacial deposits comprising gravel, sands, silt and clay
- Water bearing unit
- Low strength

Molasse
- Mixture of sandstones, marls and formations of intermediate composition
- Considered good excavation rock
- Relatively dry and stable
- Relatively soft rock
- However, some risk involved
- Weak marl horizons between stronger layers are zones of weakness
- Faulting due to the redistribution of ground stresses
- Structural instability (swelling, creep, squeezing)

Limestone
- Hard rock
- Normally considered as sound tunneling rock
- In this region fractures and karsts encountered
- Risk of tunnel collapse
- High inflow rates measured during LEP construction (600 l/s)
- Clay-silt sediments in water
- Rockmass instabilities



Model of tunnel collapse caused by Karsts

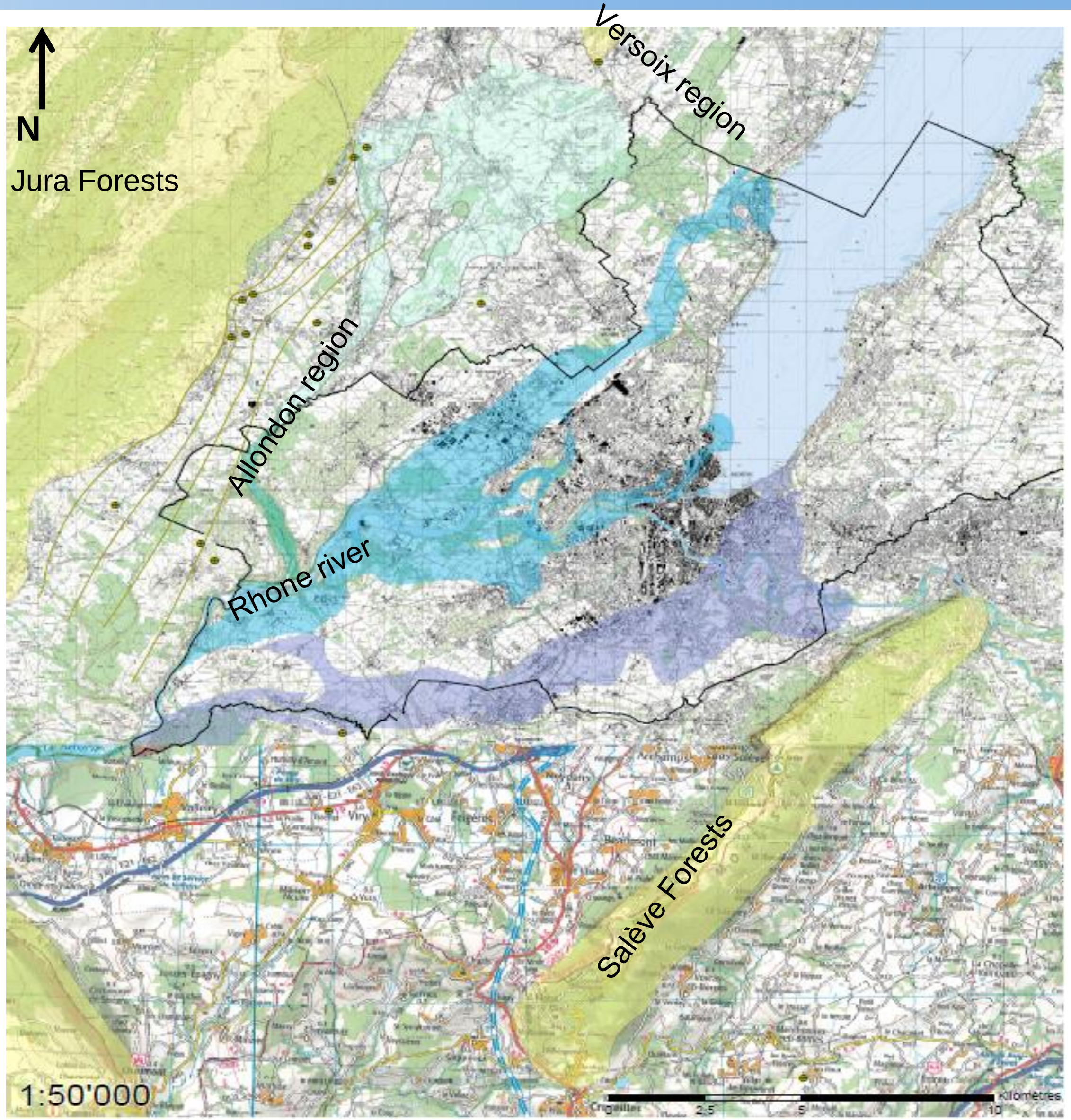
Karst networks

…more or less plugged off!

Environmental considerations

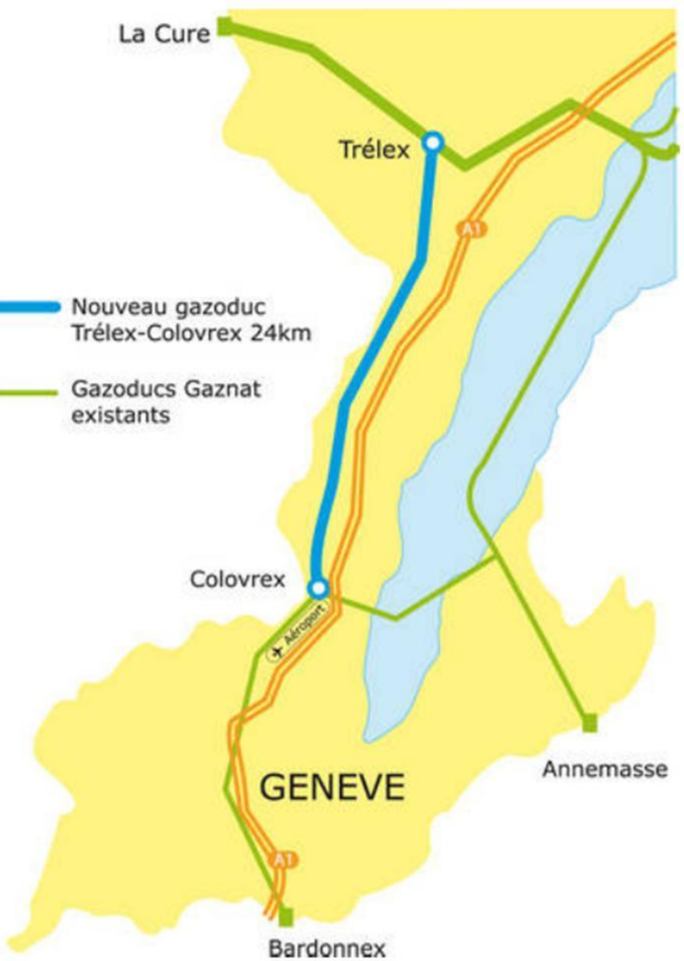
Environmentally sensitive areas :

- Urban
- Natural parks
- Protected water sources
- Groundwater
- …

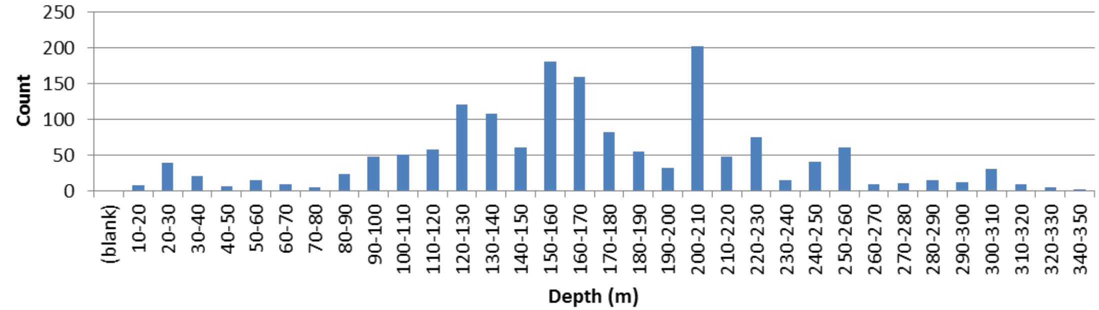


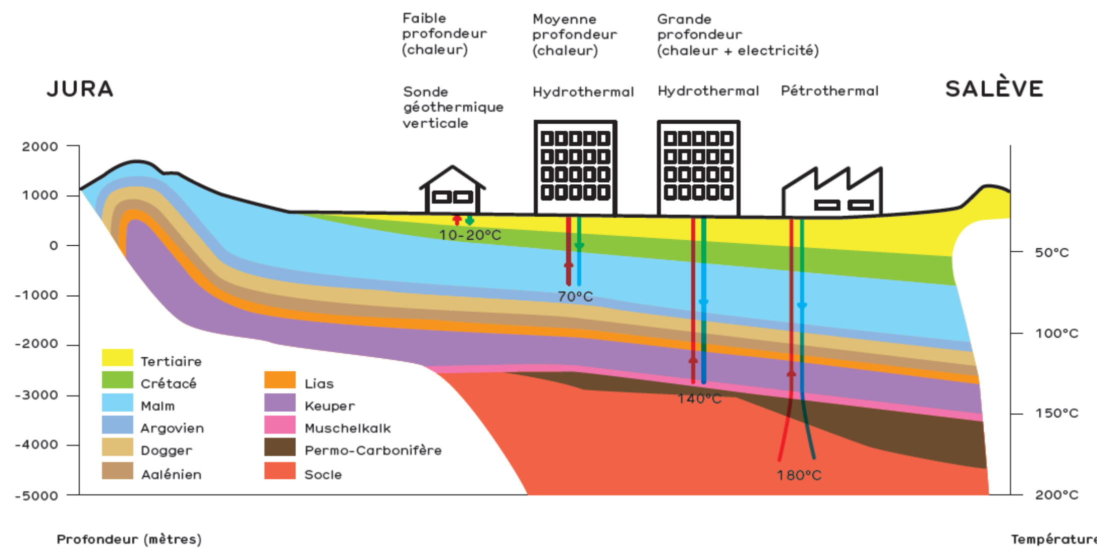
Man-made hazards

Gas pipelines

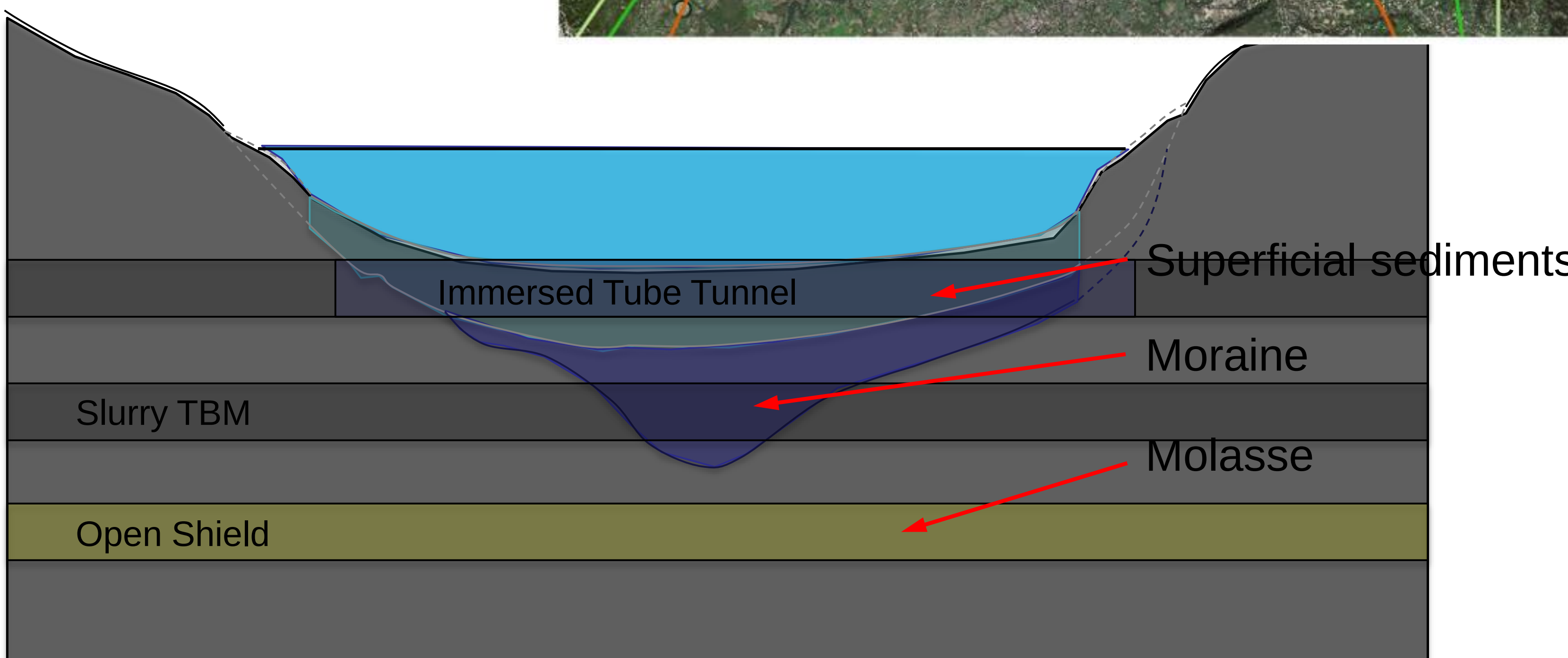


Geothermal boreholes Canton de Geneve - Depth Distribution





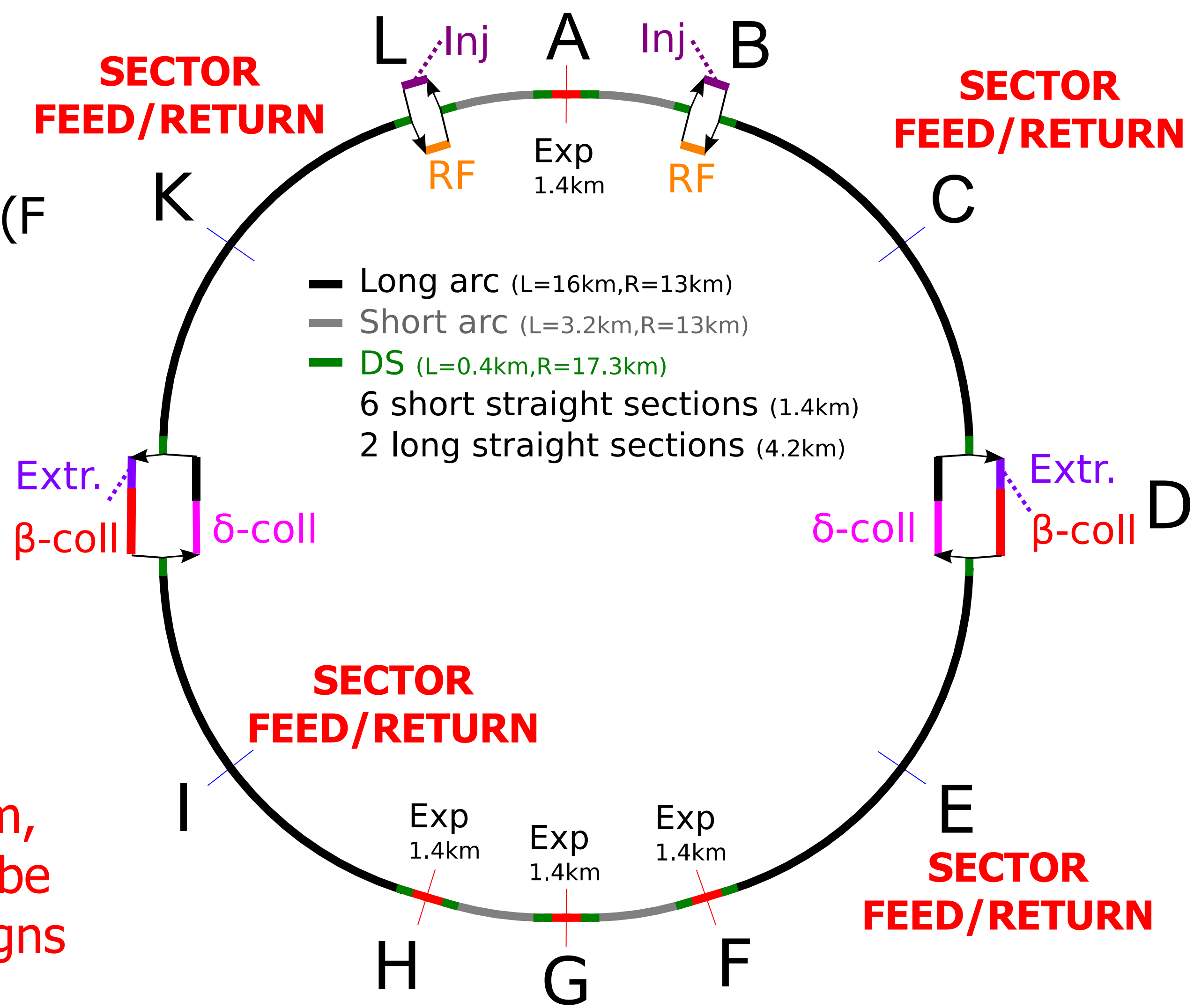
Lake crossing
Tunneling considerations



Preliminary FCC-hh tunnel layout

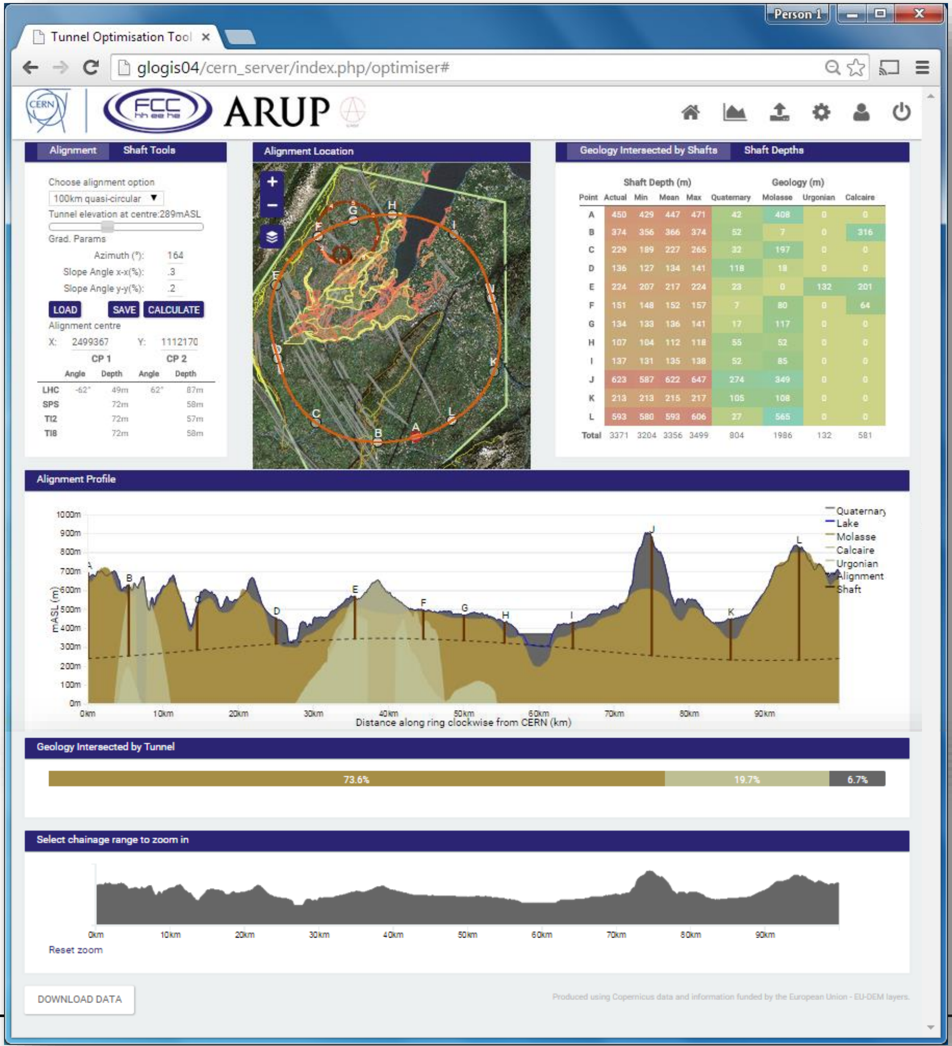
D. Schulte, Thursday

- Two high-luminosity experiments (A and G)
- Two other experiments (F and H)
- Two collimation and extraction insertions
  - Exact layout being developed
- Two injection insertions
- Insertion lengths (1.4km, 4.2km for J and D) will be reviewed as optics designs are optimised



The Digital Approach
ARUP & the Tunnel Optimisation Tool (TOT)

- ARUP (UK) mandated to produce a 3D geological model to analyse various layouts
- Streamlines the conventional approach which is broadly linear and manual
- All data in one tool
- Visual decision aid
- Clash detection



User Inputs

- Initially 6 Alignments Options
- Interactive alignment location on map
- Alter Shaft locations - slidebar
- Select Tunnel Depth - slidebar
- Select Tunnel Gradient - slidebar

Outputs

Dynamic Chart:

- Profile surface elevation and geology
- Profile of tunnel
- Shaft Locations
- Warnings when tunnel above ground level

Dynamic Tables:

- Depth to tunnel (mASL)
- Shaft Length intersecting geology layer
- % age of tunnel intersecting geology

FCC 100 km – "intersecting"
Possible siting

Alignment | Shafts | Query

Choose alignment option
100km quasi-circular
Tunnel elevation at centre:261mASL
Grad. Params

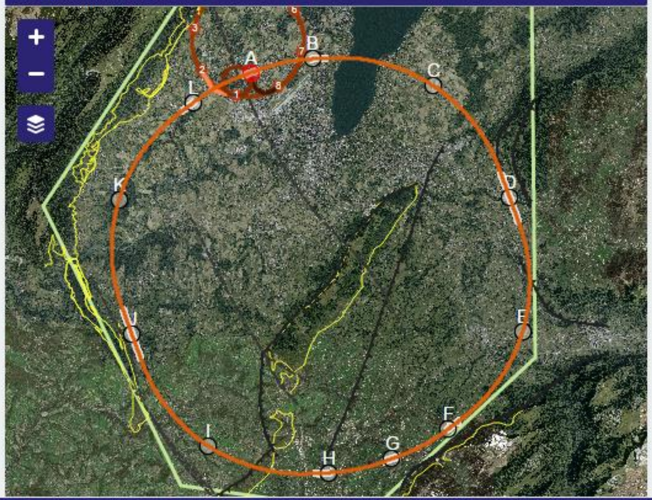
Azimuth (°):	-20
Slope Angle x-x(%):	0.65
Slope Angle y-y(%):	0

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

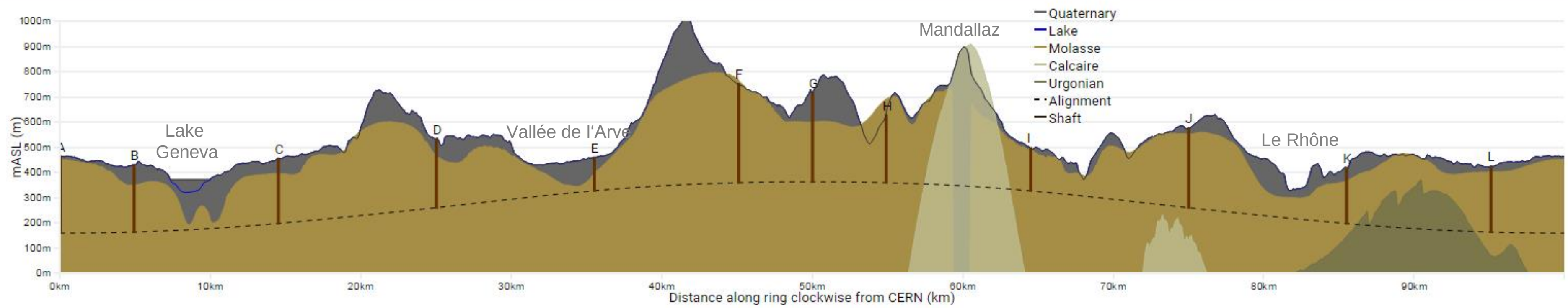
Alignment Location



Geology Intersected by Shafts | Shaft Depths

Shaft Depth (m)		Geology (m)			
Point	Actual	Quaternary	Molasse	Urgonian	Calcaire
A	304	12	292	0	0
B	266	80	186	0	0
C	257	58	199	0	0
D	272	64	208	0	0
E	132	64	68	0	0
F	392	0	392	0	0
G	354	116	237	0	0
H	268	0	268	0	0
I	170	12	158	0	0
J	315	22	293	0	0
K	221	52	169	0	0
L	260	21	239	0	0
Total	3211	501	2710	0	0

Alignment Profile



Geology Intersected by Tunnel | Geology Intersected by Section

86.5% | 7.8% | 5.7%

- 7.8 km tunnelling through Jura limestone
- 13.5 % in total in limestone
- Max. 0.65 km overburden

FCC 100 km – "non-intersecting"
Possible siting

Alignment | Shafts | Query

Choose alignment option: 100km quasi-circular
Tunnel elevation at centre:291mASL

Grad. Params

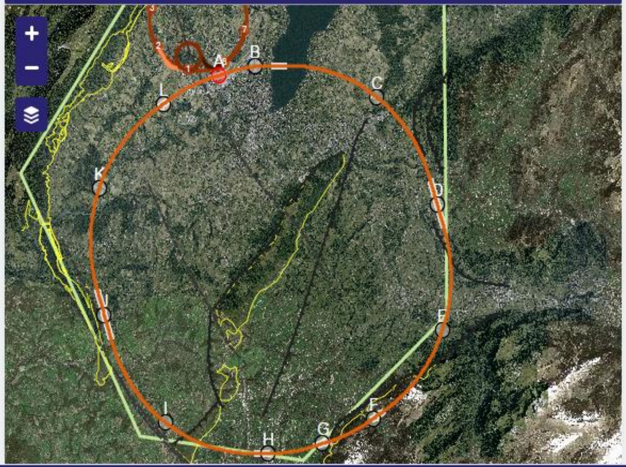
Azimuth (°): -17
Slope Angle x-x(%): 0.48
Slope Angle y-y(%): 0

LOAD SAVE CALCULATE

Alignment centre
X: 2500583 Y: 1105970

	CP 1		CP 2	
	Angle	Depth	Angle	Depth
LHC		122m		122m
SPS		187m		187m
TI2		187m		187m
TI8		139m		137m

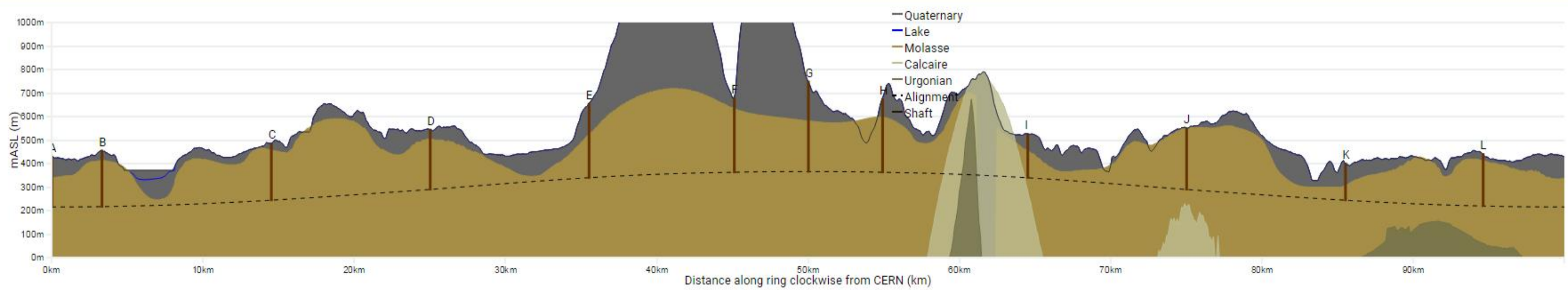
Alignment Location



Geology Intersected by Shafts | Shaft Depths

Shaft Depth (m)		Geology (m)			
Point	Actual	Quaternary	Molasse	Urgonian	Calcaire
A	214	93	122	0	0
B	238	42	196	0	0
C	241	26	215	0	0
D	254	42	212	0	0
E	315	131	184	0	0
F	316	44	273	0	0
G	383	166	216	0	0
H	311	77	235	0	0
I	186	70	116	0	0
J	260	0	260	0	0
K	156	93	63	0	0
L	221	28	193	0	0
Total	3095	812	2282	0	0

Alignment Profile



Geology Intersected by Tunnel | Geology Intersected by Section

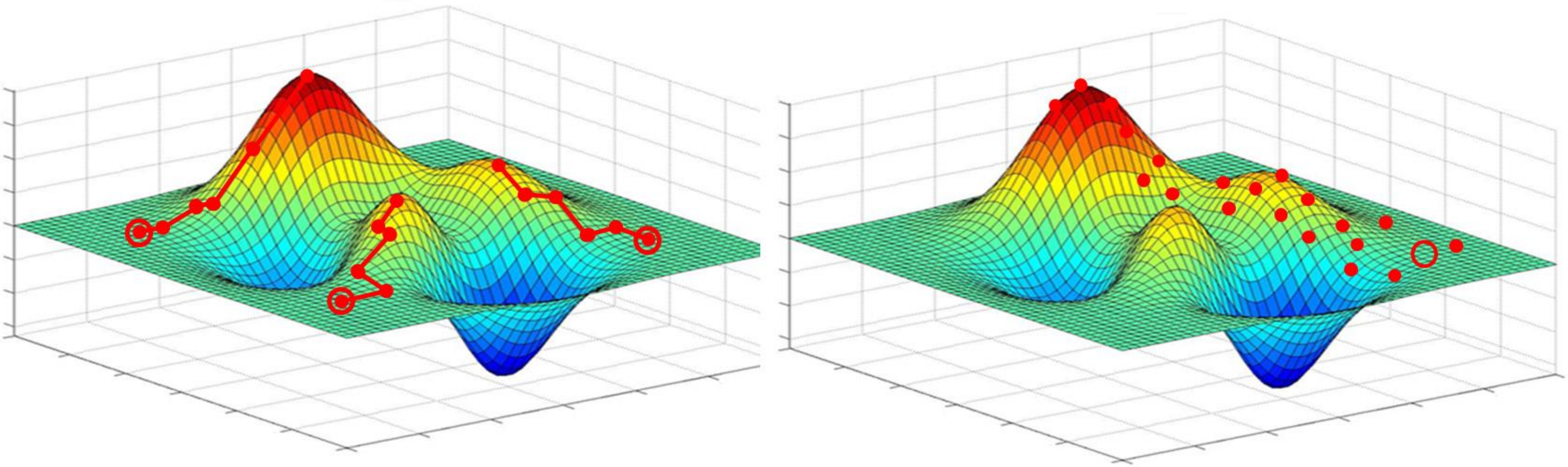
94.6% | 1.0 | 4.4%

- 4.4 % of tunnel in limestone (none in Jura)
- Max. 1.35 km overburden (for tunnel)
- More fractured geology under Pre-Alps

Automatic optimisation

Can the optimal position for the FCC be found automatically?

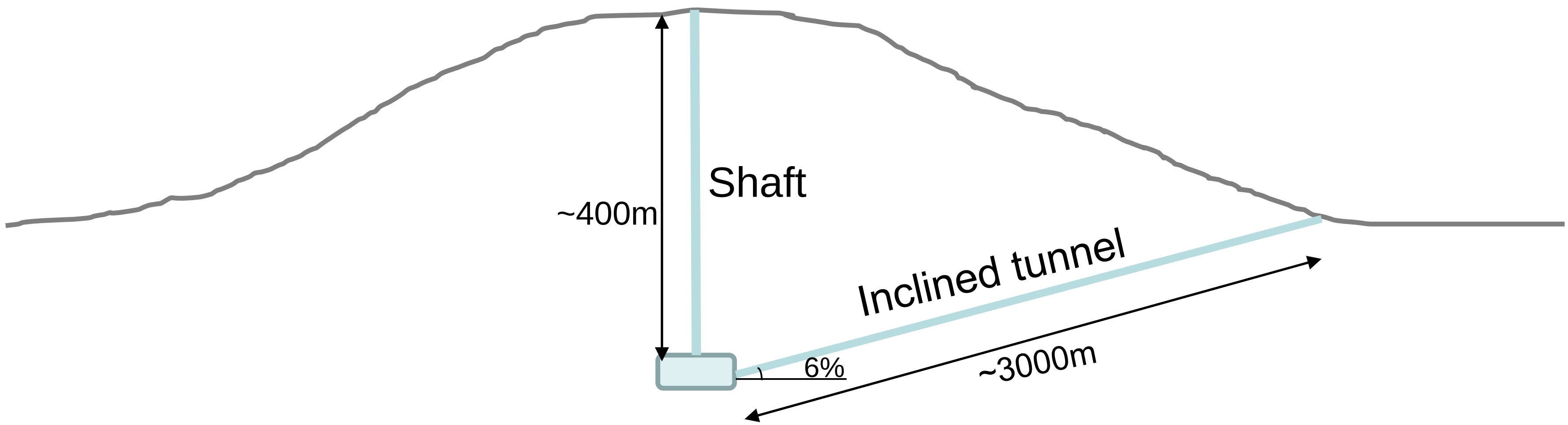
- Previous application of optimisation algorithms for magnet design at CERN
- Deterministic or genetic algorithm could find the optimal solution
- Currently working with ARUP and CERN specialists to investigate feasibility of pairing the optimisation algorithm with TOT



Deterministic method   Genetic method

Detector cavern access

Vertical shaft vs. inclined tunnel ?



Many aspects and considerations:

- Topography
- Surface use (rural, village, ...)
- Access roads
- Transport (and dump) of excavated material
- Integration into the landscape
- Which services at the surface
- Cost comparison
- ...

Excavation methods – experimental shafts

Moraine layer
If moraine is firm, cohesive or consolidated → conventional excavation.
Support:
- Lattice girder rings
- Shotcrete
- Steel mesh.

If loose or below water table
→ pile walls up to 25 m deep,
diaphragm walls > 25 m.

Molasse layer
Drill & blast recommended.

Support similar to moraines but less required.

Figure 28: London crossrail shaft, diameter 30 m, depth 45 m

Figure 27: Shaft Brunnenhof of SBB Zürich cross line, 23 m in diameter, 42 m depth, in Moraine and Molasse (out of this shaft started a shielded multi-mode TBM with 13 m diameter)

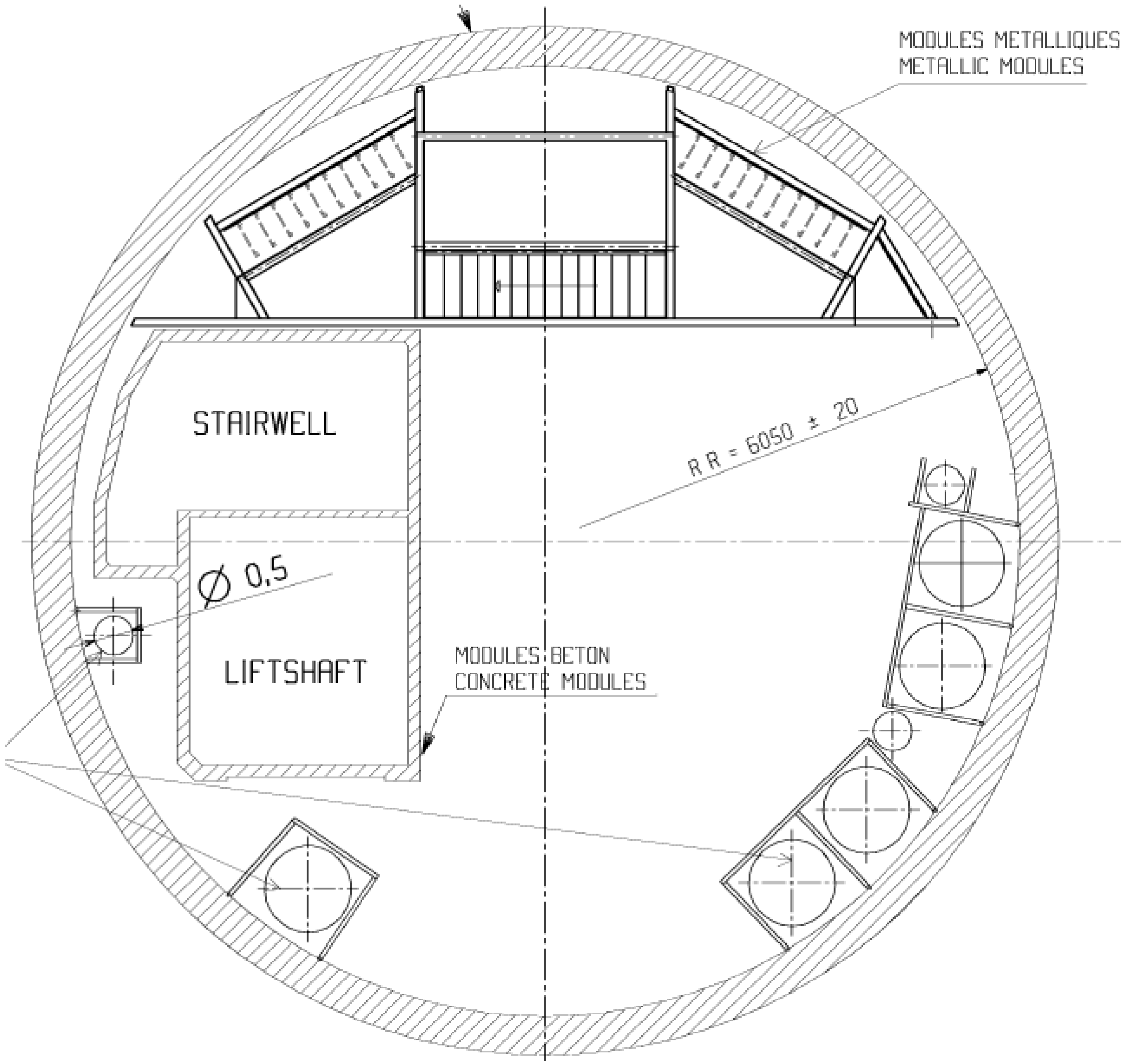
Moraine layer
Like for experimental shaft.

Molasse layer
Shaft boring machines or drill & blast are possible
(which may prove the less risky choice).


Figure 31: Shaft sinking drill rigs, Nant de Drance (CH)

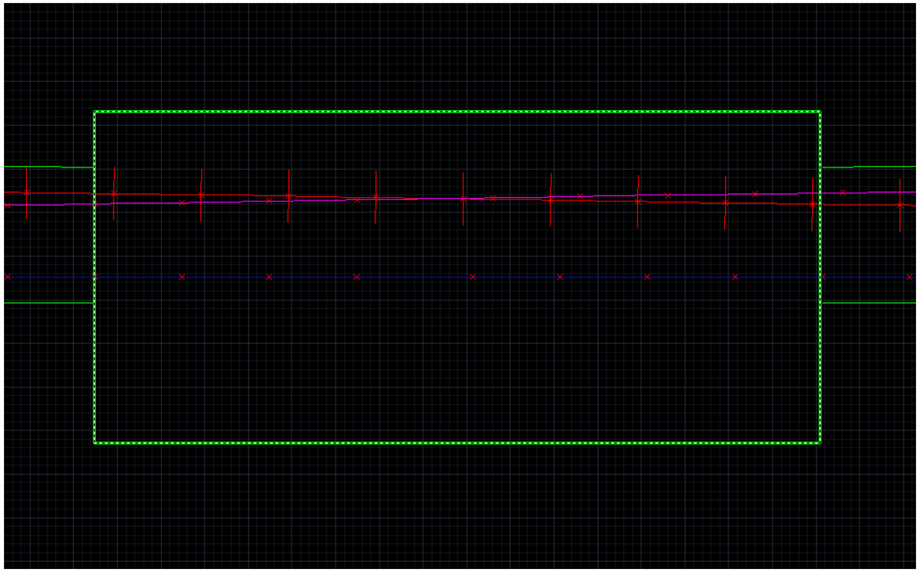

Figure 30: Case study of a shaft sinking machine (Herrenknecht)

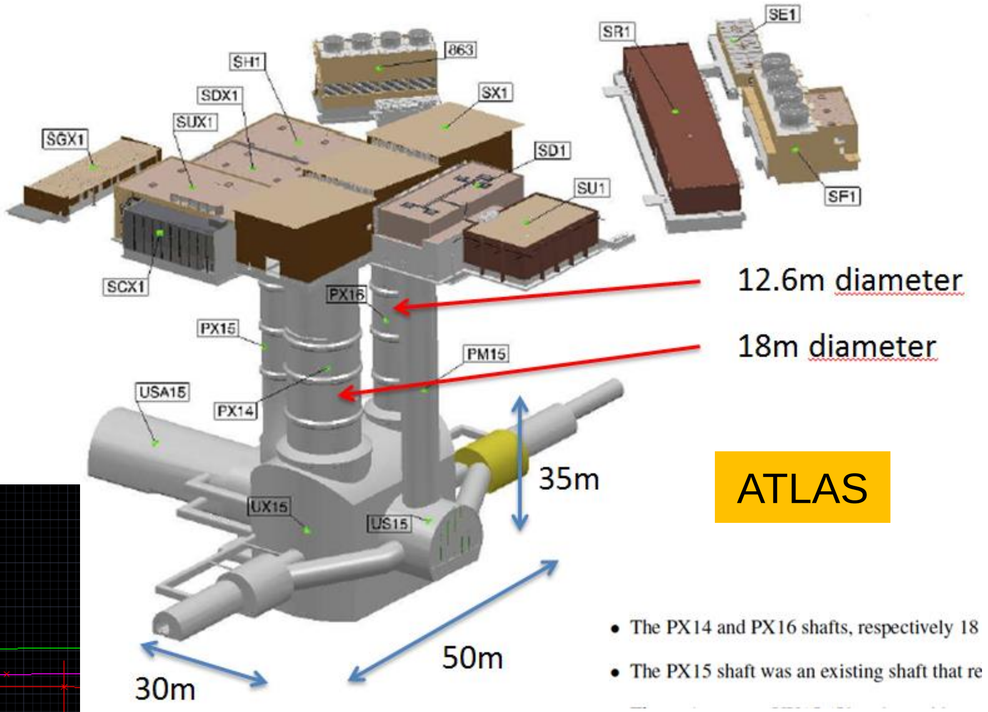
Equipment to fit into access shaft (LHC PM54 example)



Detector cavern considerations

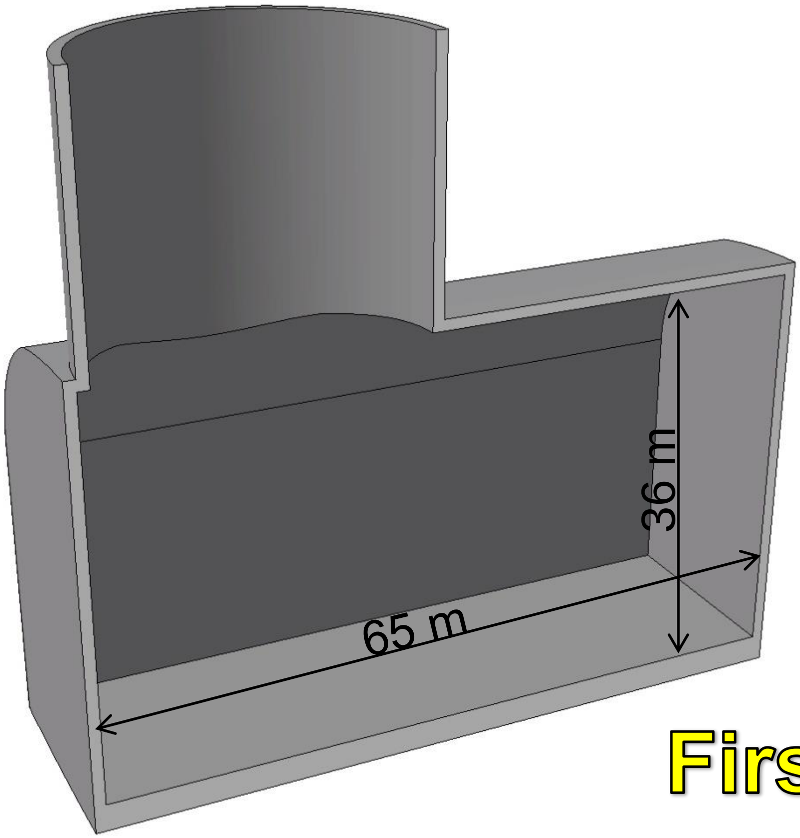
- Deep Underground experimental caverns (F, G & H)
- Shafts currently 300-400 m deep
- High CE challenges
  - Risk of rock 'squeezing'
  - Hydrostatic risk
- High construction cost
- Impact on detector design

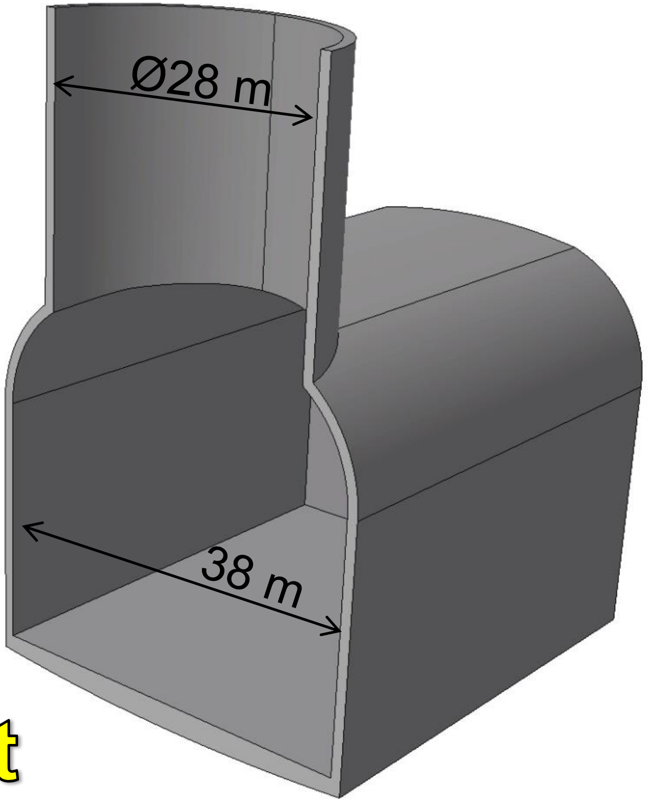




Twin solenoid detector cavern with shaft

Cavern Option	Access solution	Shaft/tunnel diameter [m]	Detector design	Required dimensions for installation [m]	Width of metallic structures [m]	Cavern dimensions (LxWxH) [m]	Span [m]
Option 1	Shaft	28	Twin Solenoid	65x30x36	8	65x38x36	38
Option 2	Inclined tunnel	14	Toroid	86x36x42	8	86x44x42	44



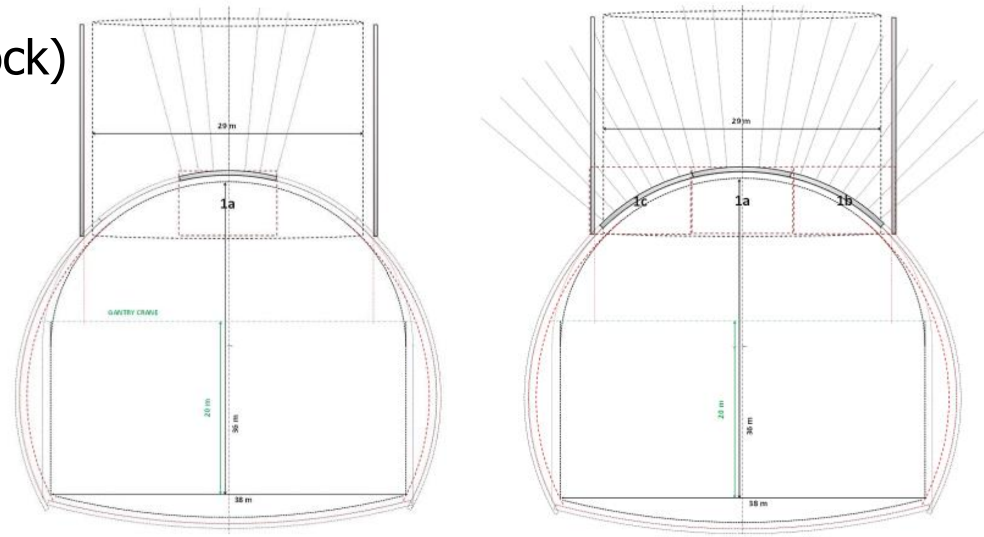


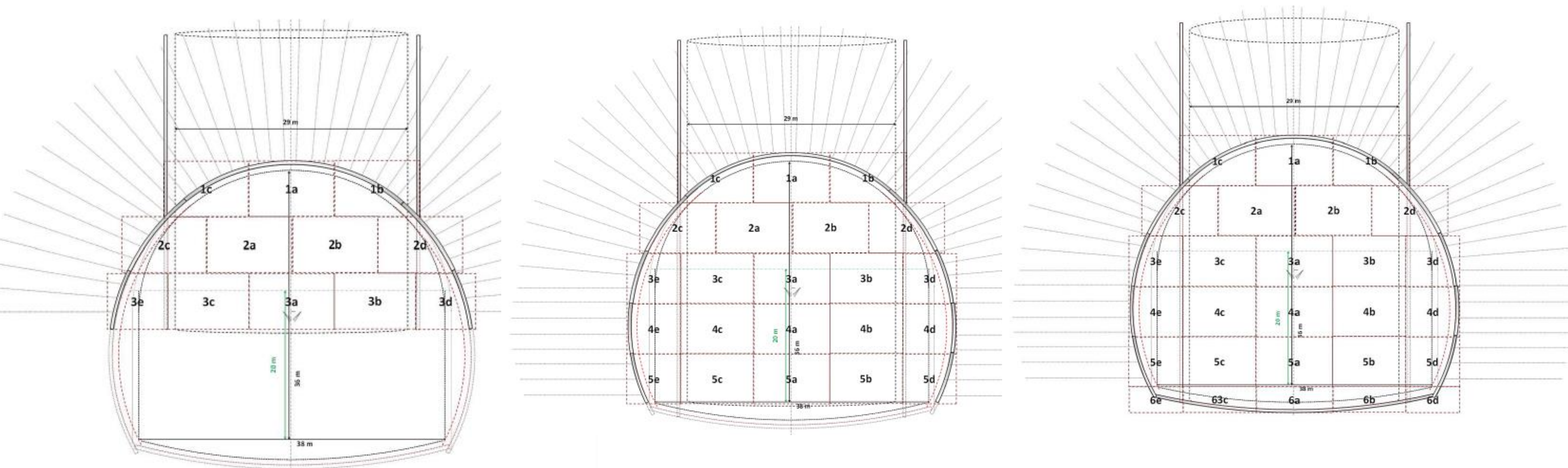
First Draft

Excavation methods – experimental caverns

‘Good’ geological conditions (stable rock)

Support:
- rock bolts
- lattice girders
- reinforced shotcrete

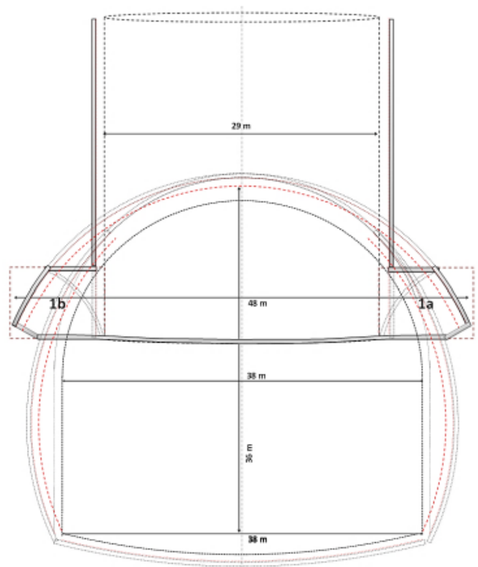


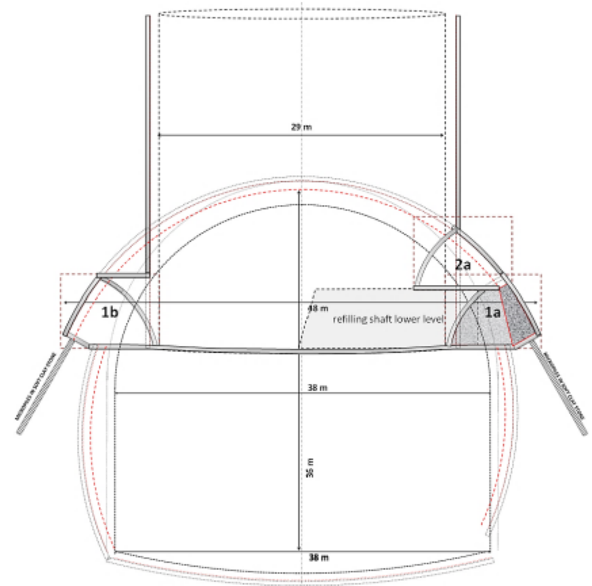


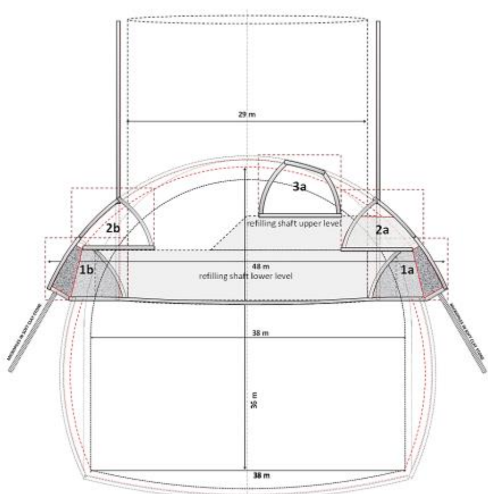
Excavation methods – experimental caverns

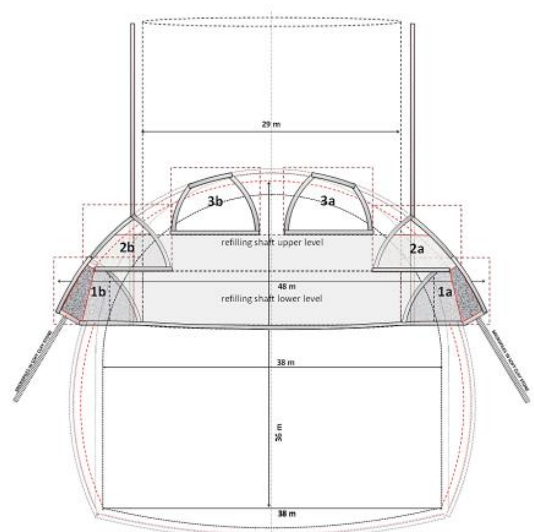
‘Moderate’ geological conditions
(Flysch and soft clay rock)

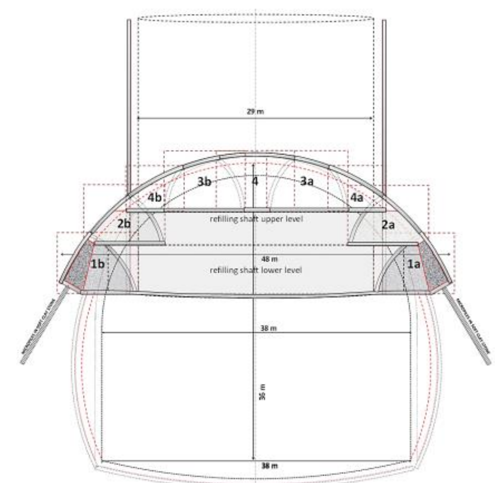
Support:
micro piles
rock bolts
lattice girders
reinforced shotcrete







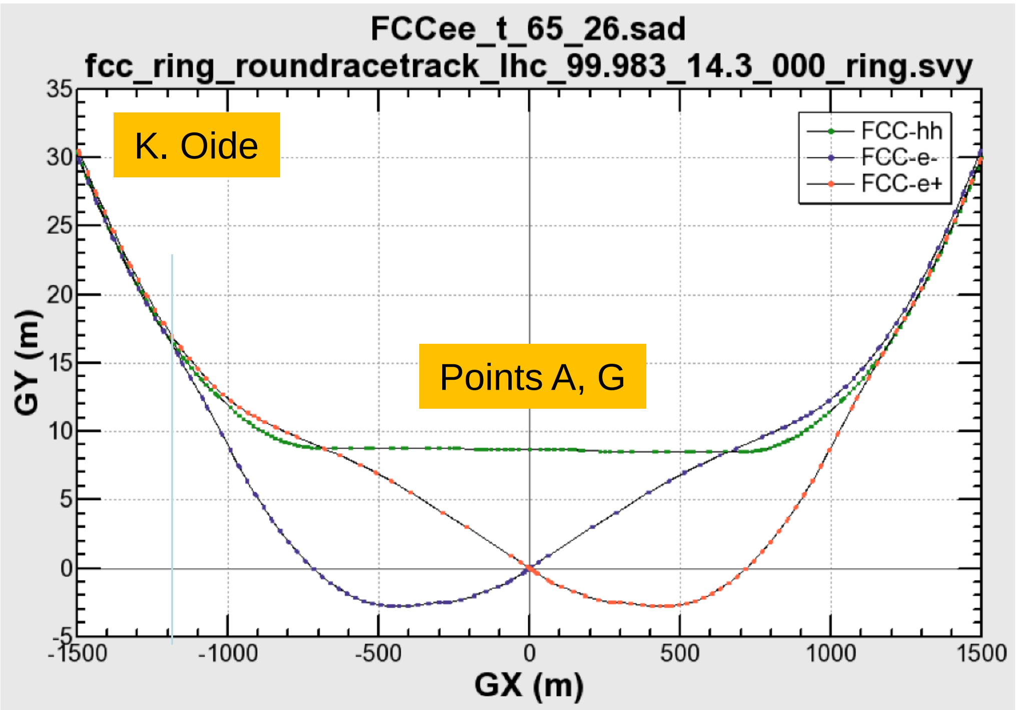


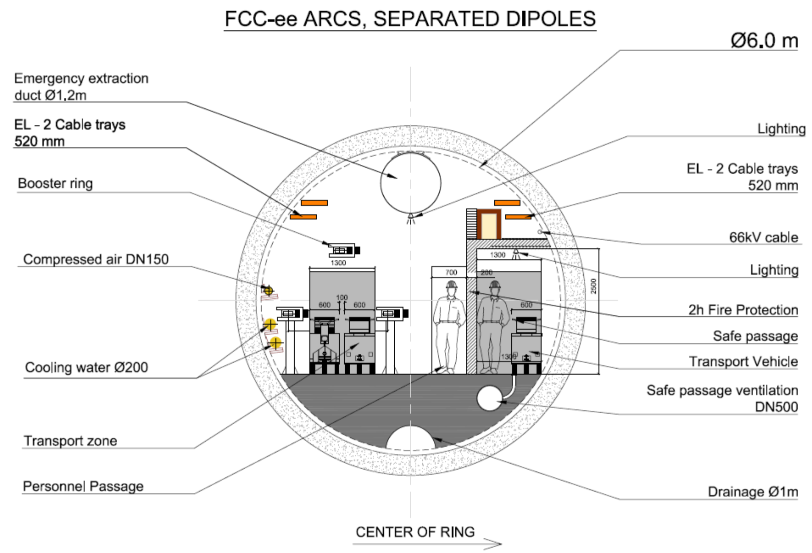


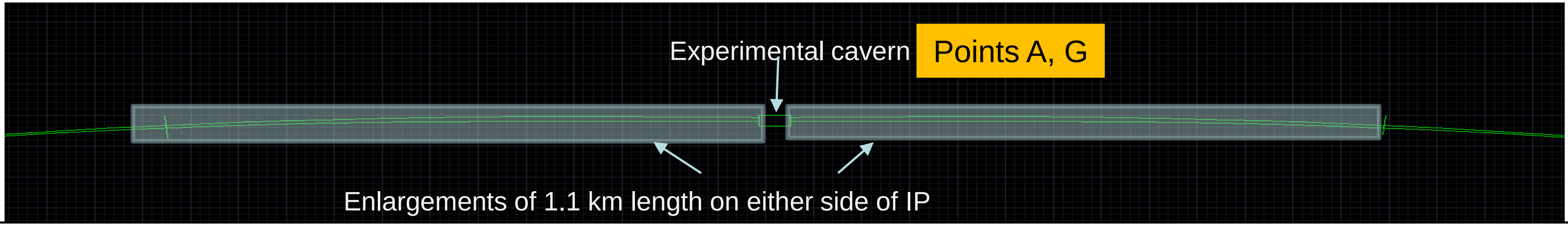
Tunnel enlargements around points A + G

Beam line of FCC-ee will sweep across tunnel and depart from FCC-hh by up to 12 m (optics of FCC-ee being further optimized to minimize this).

4 * ca 1.1 km where ee beams cannot both be contained in a 6 m tunnel.



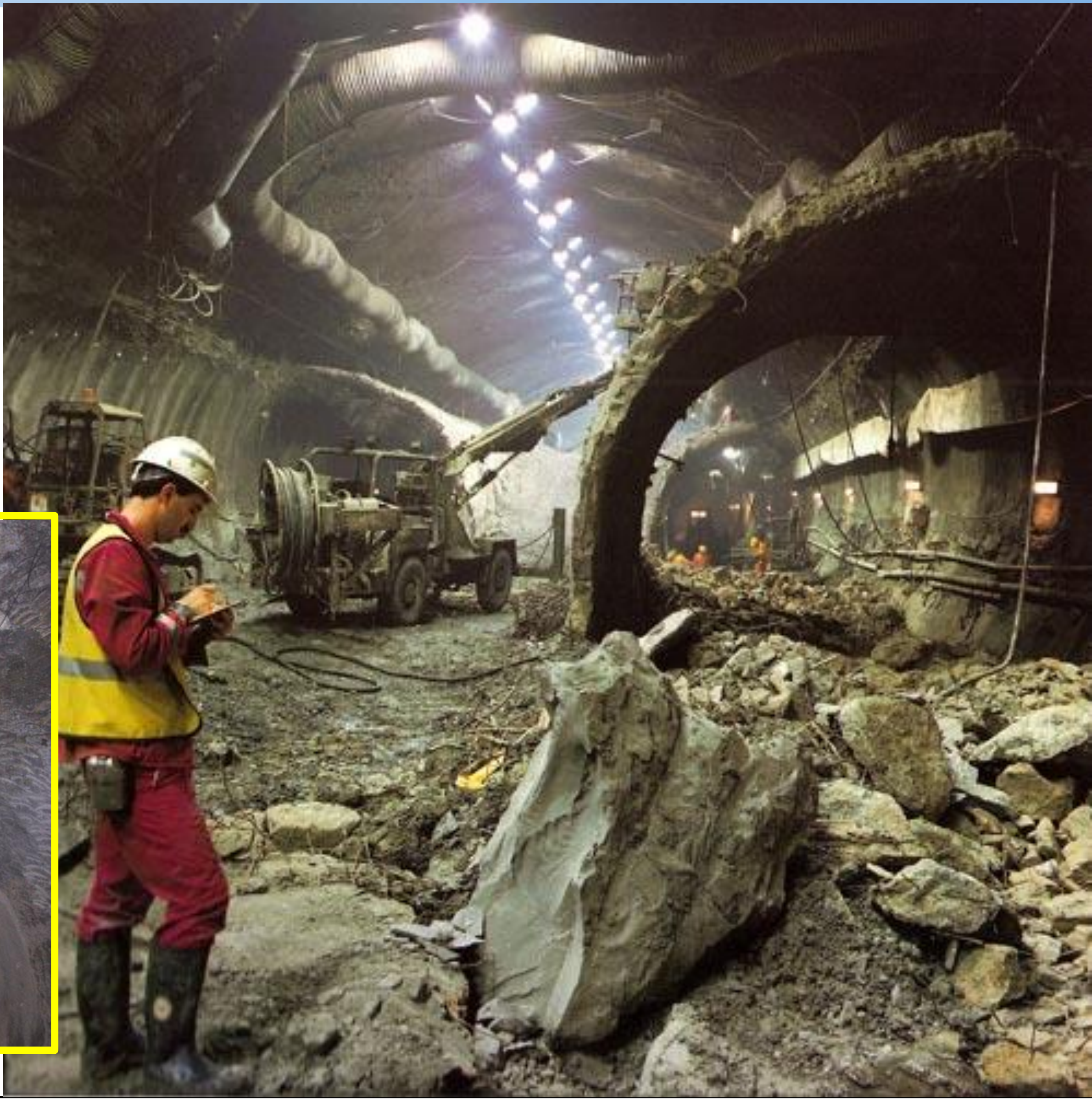




Tunnel enlargements around points A + G

Enlargements to be excavated with a road header
(regular tunnel with TBMs).

Options could be twin tunnels as long as the gap between them gets not too small, otherwise junction caverns.



Road header

Tunnel cross sections

Under discussion; recently intensified.

- Many implications, not only civil engineering (thus mainly cost) ...
- ... safety, transport, ventilation, accessibility/maintainbility, ...
- Important decision; all aspects to be throrougly considered.

FUNCTIONALITY MATRIX

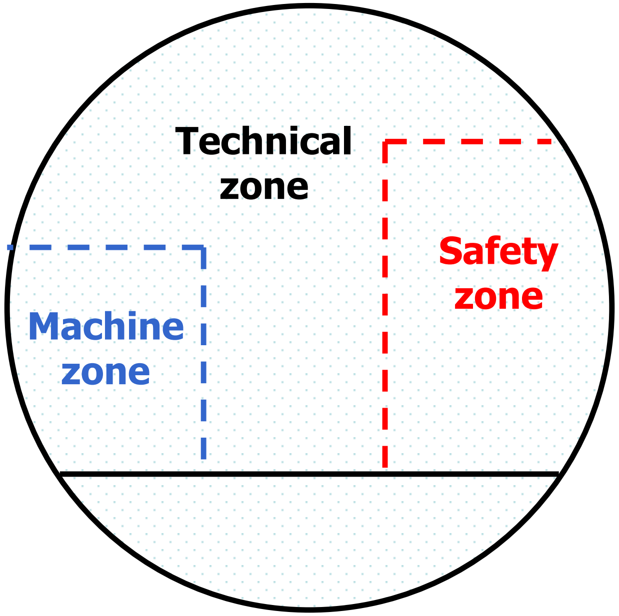
Functions	Machine zone	Technical zone	Safety zone
House accelerator(s)	X		
Install accelerator(s)	X	X	
Maintain accelerator(s)			
Transport accelerator components			
Align accelerator components			
Drain water ingress			
Distribute raw water			
Distribute cooling water (demineral			
Distribute chilled water			
Distribute fire-fighting media			
Distribute compressed air			
Distribute cryogenic fluids			
Distribute HV electrical power			
Distribute MV/LV electrical power			
Ventilate: normal & emergency			
Allow personnel normal access/eg			
Transport personnel from/to acces			
Allow emergency egress			
Ensure general safety of perso			
Ensure radiation protectio			
Ensure general saf			
Ensure radiation prot			
House accelerator prote			
House magnet power conv		X	
House magnet protection equ		X	
House RF powering equipment		local	
House vacuum powering equipment		X	
House geodetic monuments	X	?	
House cooling equipment		X	
House ventilation equipment		X	
House electronic & control equipment	?	X	
House power cables	X	X	
House signal cables	X	X	
House optical fibers	?	X	
House wireless communication equipment	?	X	X
House public address equipment	?	?	?
House safety detection & warning equipment	X	X	X

ACCESSIBILITY MATRIX

Operation mode	Machine zone	Technical zone	Safety zone
Long shutdown	Y	Y	Y
Individual system tests	strictions	Y	Y
Cooldown/Warmup	estrictions	Y	Y
Technical stop	Y	Y	Y
Cold chec	Y	Y	Y
Cold	N	Y	Y
ems on	Y	Y	Y
ne powered	N	Y	Y
g, pilot beams	N	N	N
beam	N	N	N

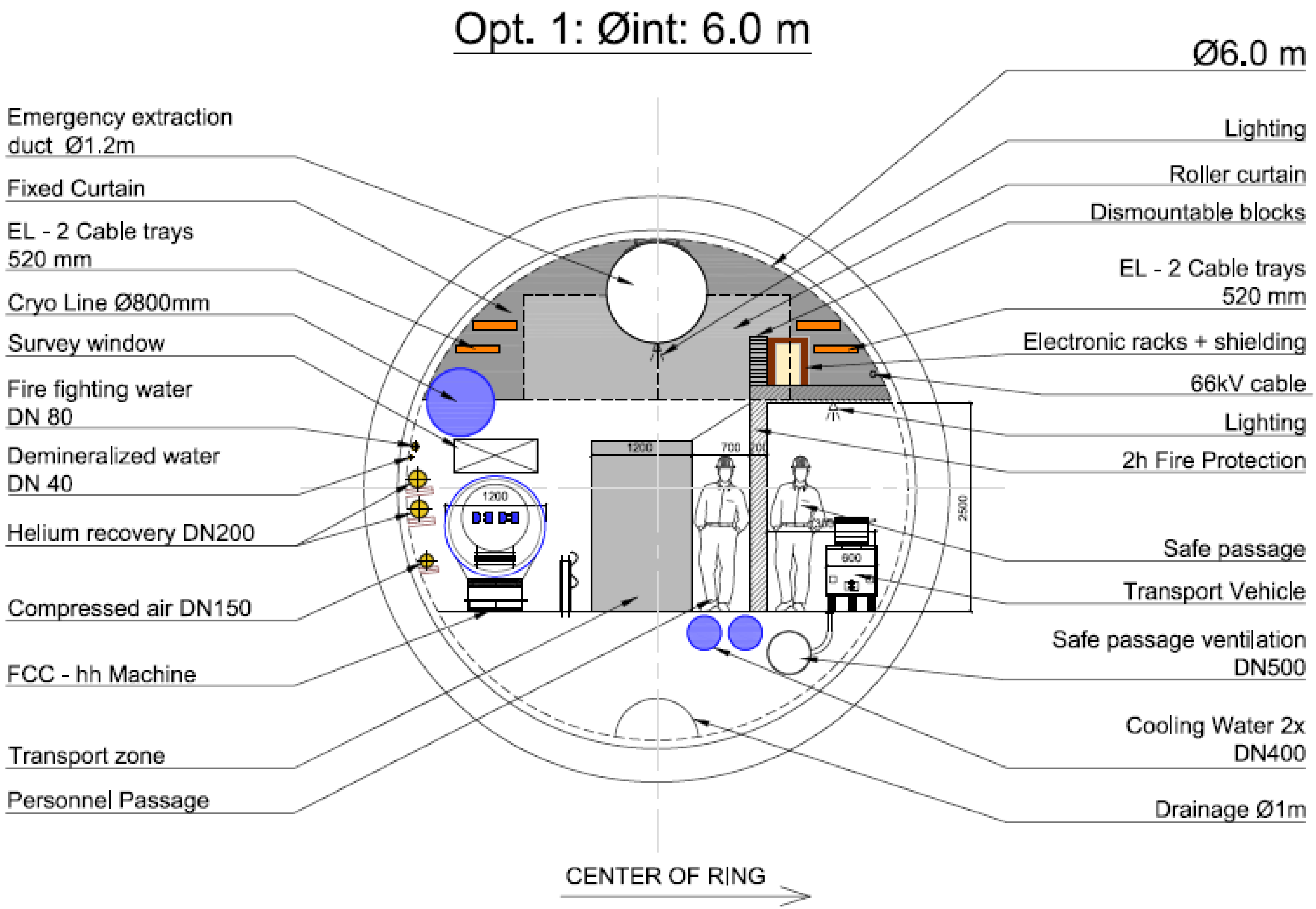
preliminary

defining 3 functional + accessibility zones

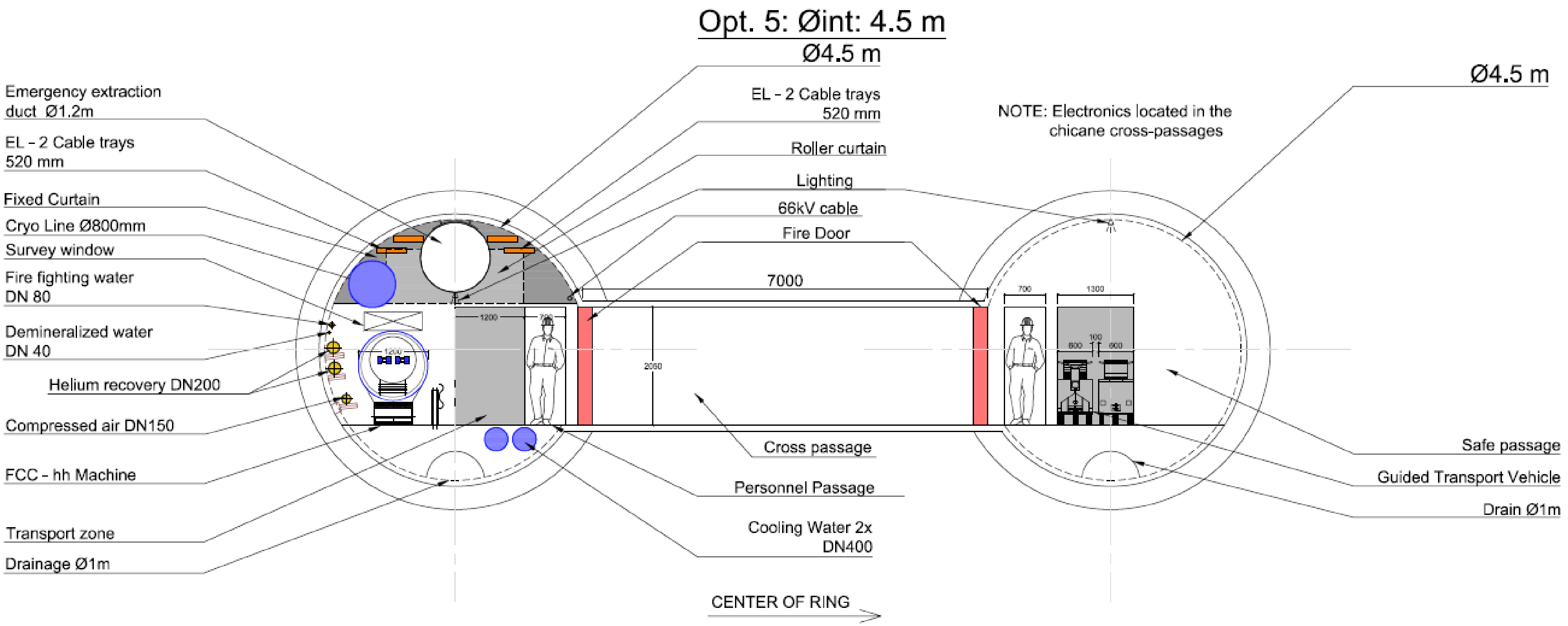


Early cross sections (single tunnel, FCC-hh, longitudinal ventilation)

all drawings to trigger basic discussions; not about details and not „for engineering“



Early cross sections (double tunnel, FCC-hh, long. ventilation)



Brief summary of where CE stands today (recommendations)

„Footprint review" June 2015:

For FCC-hh 100 TeV collision energy, about 82 km of arcs with 16 T dipoles at 80 % filling factor
Considering present number + length of LSS + ESS → total perimeter of **100 km** required.
Bypass tunnels needed at high radiation locations (collimators).

FCC-ee (in FCC-hh tunnel) needs enlargements over x.x km on both sides of collisison points A, G.
Klystron galleries needed (meanwhile decided to lump at points D, J).

Adopt **planar** geometry (no „kink", V-shape).
Cross lake in **molasse** layer.
Preserve present symmetry (quasi-racetrack, experiments, injections/extraction, ...)

Preliminary outcome of CE consultant study „cautiously optimistic":

- Foreseen caverns + shafts possible to excavate under given geological circumstances.
- Neither engineering nor logistics limits met ...
- Further geological and geotechnical investigations strongly recommended.
- Available data indicate „intersecting" variant as better choice.
- Molasse best with TBM, limestone per „drill & blast".

Study points

Better understand and confirm geology; refine studies and evaluate risks
(ground water, tunneling in moraines, karsts, hydrocarbons, rock squeezing, ..., excavation methods, risk mitigation).

Optimise optics and systems design (positioning, lengths).

Iterate on and optimise position of 100 km variant; choose btw „intersecting“ or „non-intersecting“.

Define:

- Transfer tunnels
- Dimensions of caverns and enlargements
- Dimensions of technical caverns and galleries

  (consolidate options, conceptual design, investigate further for depth and span)
- Tunnel option (single vs. double)
- Access topology (shaft vs ramps)
- Number, size and outfit of shafts
- Siting of shafts, access roads
- Surface area and buildings (requirements/functional analysis, conceptual design/preliminary layout drawings)

Impact assessment:

- Removal and deposit of spoil.
- Radiation assessment – risk of activation of groundwater and geothermal boreholes.

Prepare cost and schedule estimates (for CDR 2018).

TRANSPORT and HANDLING

Transport and handling
General issues

Need to consider all transport and handling phases:

- Delivery of components
- Assembly
- Test
- Storage (just on time?)
- Transfer to shaft (road transport)
- **Surface ⟷ Underground transfer (crane or lift)**
- Loading underground
- **Transport along tunnel**
- Unloading / Transfer onto supports
- Removal for repair

➢ Integrate transport and handling design requirements into equipment and infrastructure design as early as possible.

Shaft lifts

Safety Factor (SF): ratio strength of rope / working load

(only a guide)

- Miscellaneous Hoisting Equipment 5 to 6
- LIFTS 12 (US + JP 10)
- Mine Shafts 8.0 for depths to 500 ft.
  - *7.0 for depths 500-1000 ft.*
  - *6.0 for depths 1000-2000 ft.*
  - *5.0 for depths 2000-3000 ft.*
  - *4.0 for depths 3000 ft. and more*

SF not only dependent on load (also speed, acceleration, length, ...).

Lift travel of ca. 500 m so far considered as maximum due to SF 12.

The 400 m at FCC could still be handled with steel ropes

(special requirements: greater pit depth, larger top clearance, larger machine room, ...).

Now KONE Ultra Rope™ (carbon fibre).

First time commercialized in 2014. Lift travel of 1000 m and more.

Lower mass = lower wear, energy saving, higher speed (16 m/s); bending radius > 1 m.

By the time of FCC construction carbon fibre ropes for lifts should be standard.

Lifting heights of > 3000 m currently in use (offshore and mining industry).

The RL-K 7500 Heavetronic® with knuckle boom and AHC (Active Heave Compensation) for subsea operations can lift up to 270 t above the surface of the water and handle loads down to a depth of 3,600 m. As a heavy lift crane (without subsea functionality) lifting capacities up to 300 t are possible.

Technical Key Facts:

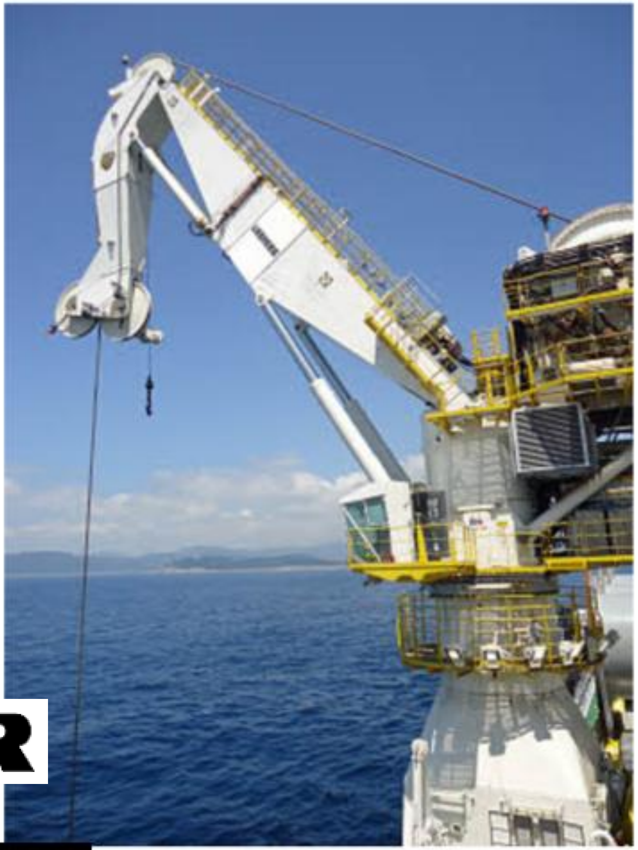
- 75000 kNm - maximum dynamic overturning moment
- Modular boom system
- Continuous outreach from max. 35 m up to max 55 m on customer specification
- Possible to hoist and lower of full capacity
- Optimized boom geometry
- Optimized rope guidance for increase rope life
- Modular hoisting gear system

Technical data | Images | Downloads

Lifting capacity	up to 300 t
Radius	35 - 55 m

Top | Print preview

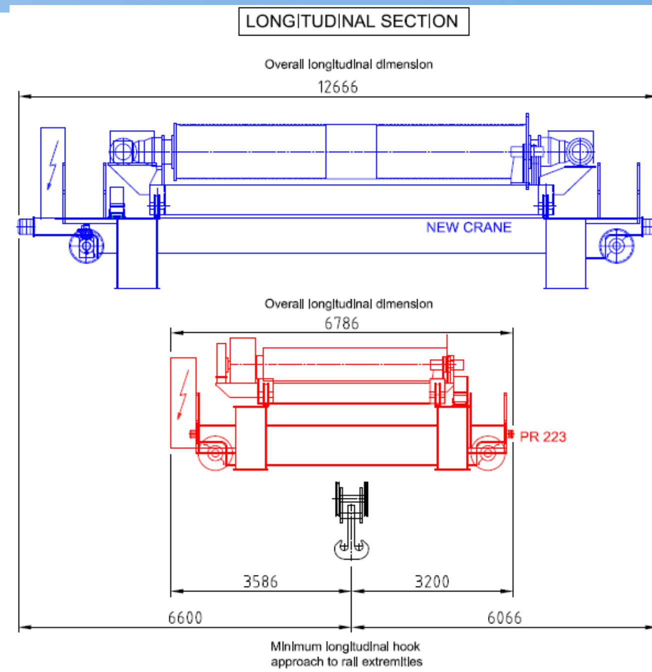
LIEBHERR

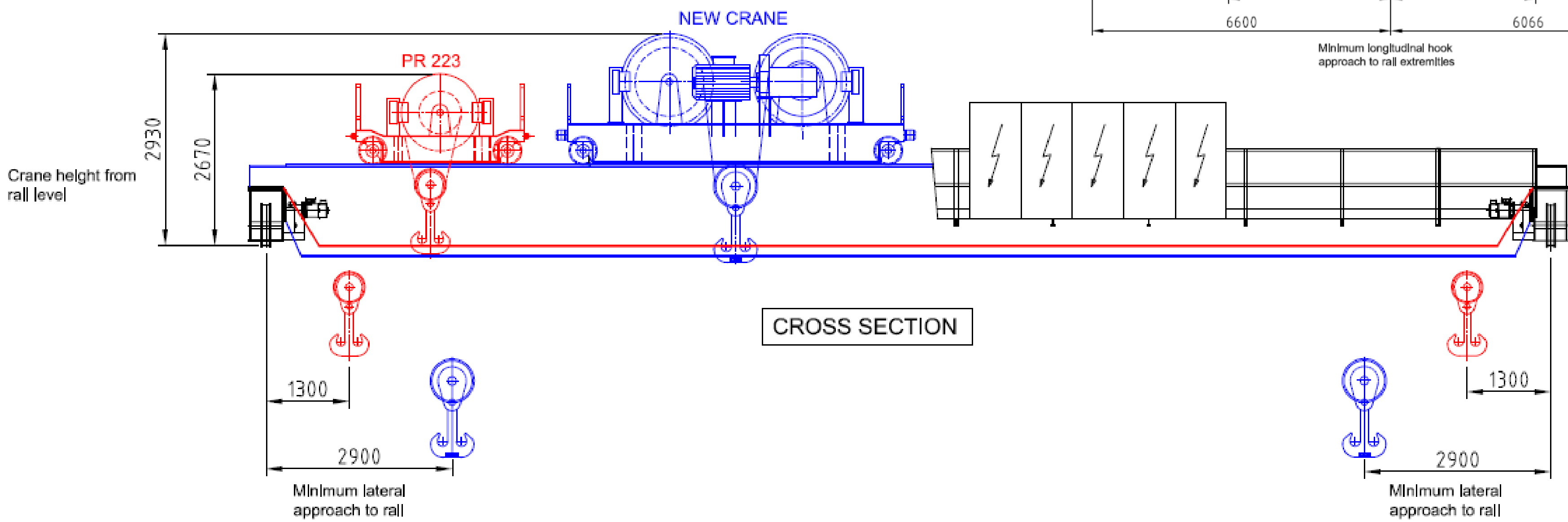


Subsea Crane RL-K 7500 Heavetronic®

Lifting height of 400 m in itself not a problem but problematic with EOT cranes (twin rope drum system → major impact on building height and width, …).

CRANE	PR 223 (SMI2 CRANE)	New crane
CAPACITY	40 TON	40 TON
SPAN	19,76 m	20 m
LIFTING HEIGHT	52,5 m	300 m
HOIST CONCEPTION	Single rope drum with emergency brake	Two rope drums operating simultaneously (no mechanical connection) ; emergency brake on both drums
DRUM DIAMETER/LENGTH	660 mm / 3800 mm	1070 mm / 7000 mm
LIFTING MOTOR POWER	90 kW	2 x 75 kW
LIFTING SPEED	10 m/min (100% load) / 20 m/min (25% load)	10 m/min (100% load) / 20 m/min (25% load)
CROSS TRAVEL SPEED	20 m/min	10 m/min
LONG TRAVEL SPEED	16 m/min	20 m/min
TOTAL WEIGHT	30,500 kg	~ 48,000 kg

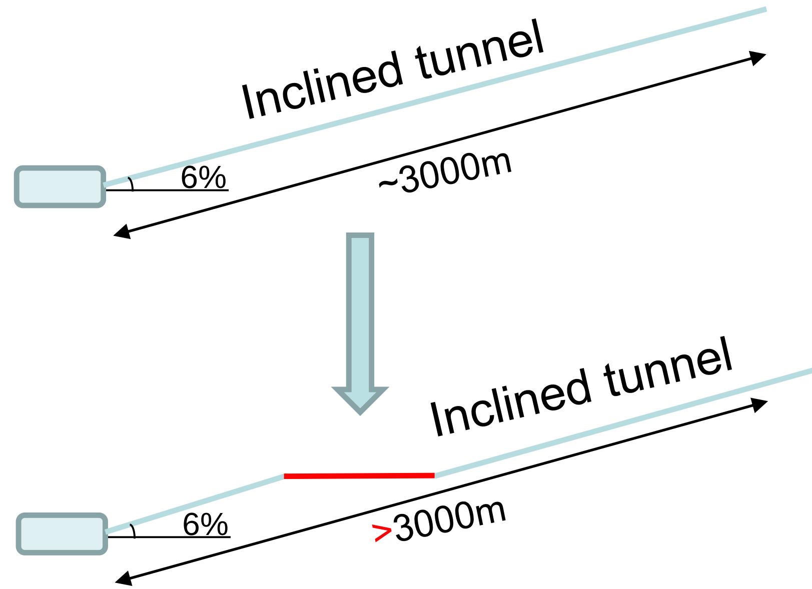




Detector cavern access (shaft vs ramp)

Shaft ⌀ = biggest component
+ Transport equipment
+ Safety clearance(s)
+ Tunnel infrastructure (ventilation ducts etc.)

Need of flat 'parking' station(s) (escape lane(s)) somewhere along an inclined tunnel!

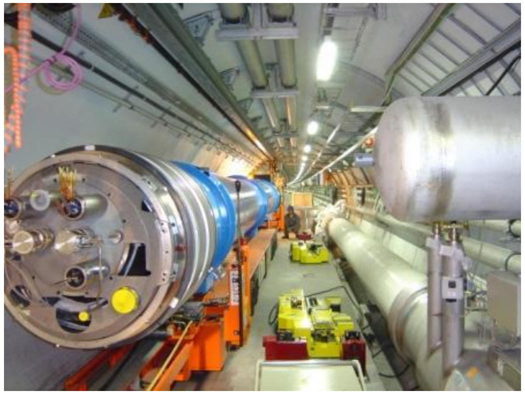


Increasing slope ←→ reduced load capacity

Example:
Towing tractor nominal capacity 20 t at 10 km/h.
On 7 % slope towing capacity 6 t at 3.5 km/h.

Tunnel Transport & Handling Equipment

CERN LHC conventional-magnet installation
Capacity: 9 t per buggy
Eq. height: 560 mm



CERN LHC cryo-magnet installation
Capacity: 35t/20t
Eq. height: 500mm (TES 300mm)

The **4** red framed solutions provide longitudinal transport and lateral transfer!

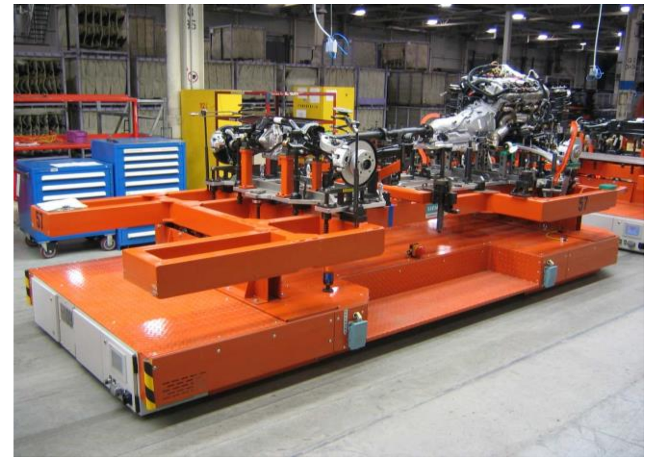
Boundary condition:
Sufficient clearance under the accelerator components !

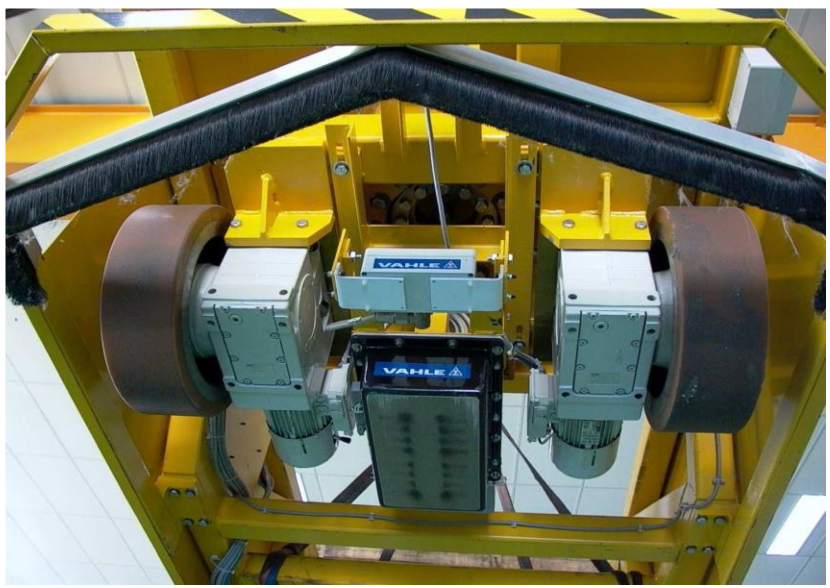
CERN SPS conventional-magnet installation
Capacity: 20 t
Eq. height: 800 mm

DESY XFEL installation
Capacity: 6.t per lifting platform
Lifting height: 2.4m

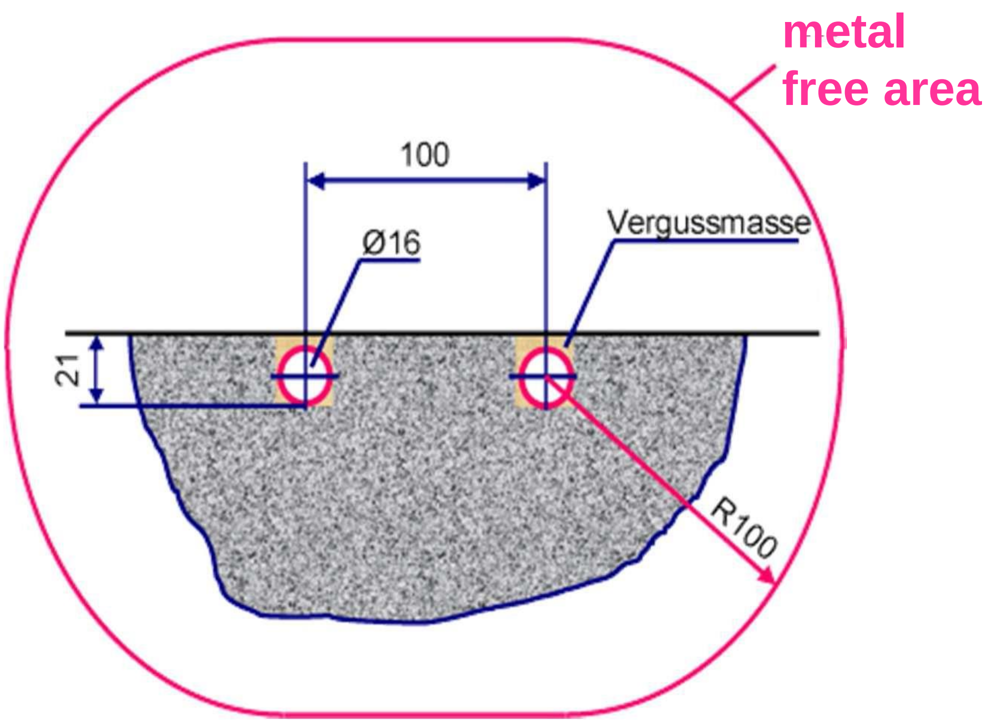
DESY conventional-magnet installation
Capacity: ???
Eq. height: ???

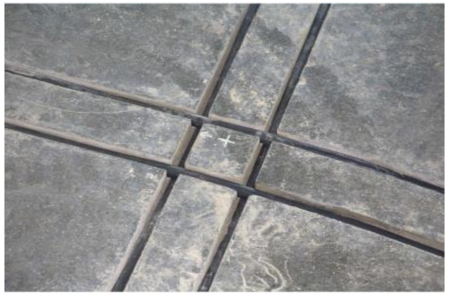
Automated Guided Vehicles using Contactless Power System (CPS^{TM})





Under floor primary cable installation (for inductive powering)





Min. clearance of 100 mm to surrounding steel

Compatibility between machine and inductive powering and guiding system to be checked.

Horizontal transport with on-board energy storage

If inducting guiding alone is not compatible with transport needs, then

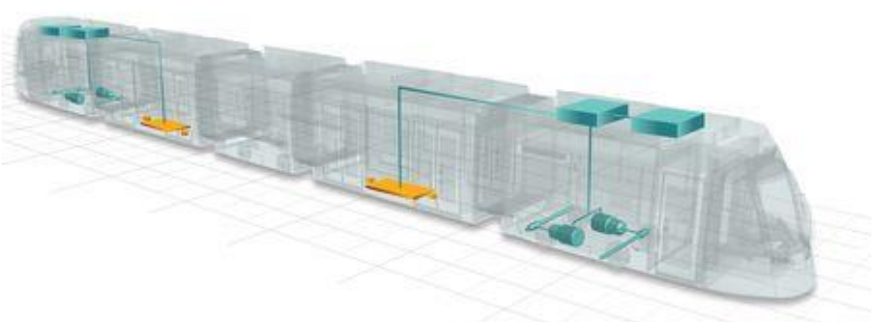
inductive guiding system

plus

defined charging stations,

which requires important energy storage capacities for the AGVs.

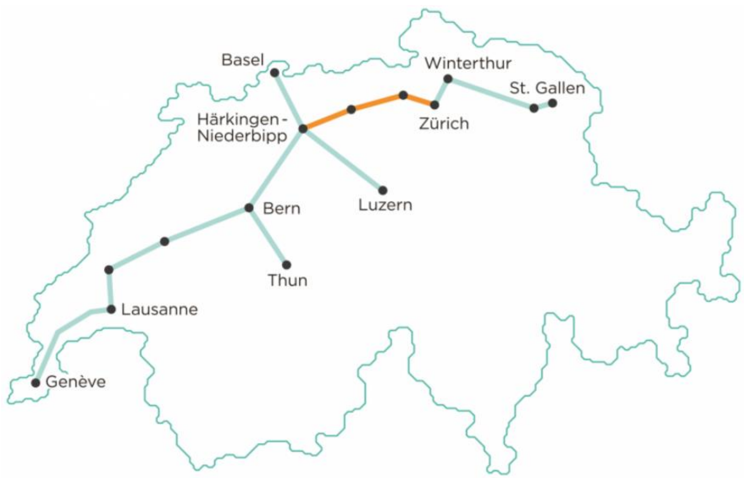
Battery charge at parking

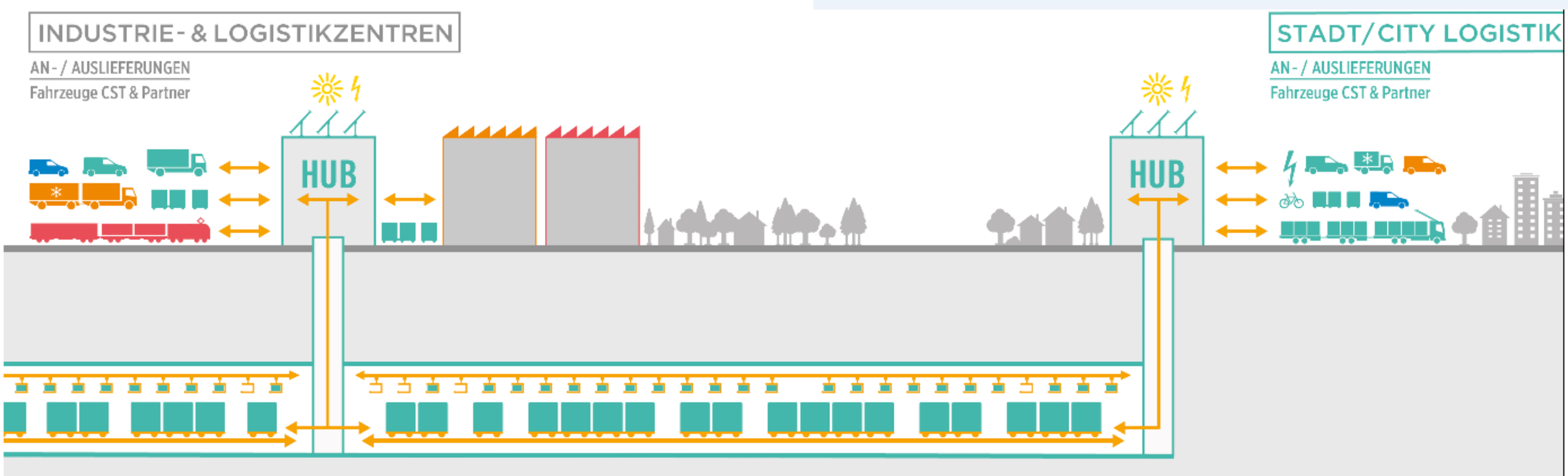


Supercapacitor recharge at periodic stops

Feasibility study for goods transport across CH (concluded in 2015)

First step: ca. 70 km of 6 m tunnel; induction powered + automatically guided vehicles.
http://www.cargosousterrain.ch/fr (de); featured recently in various newspapers.





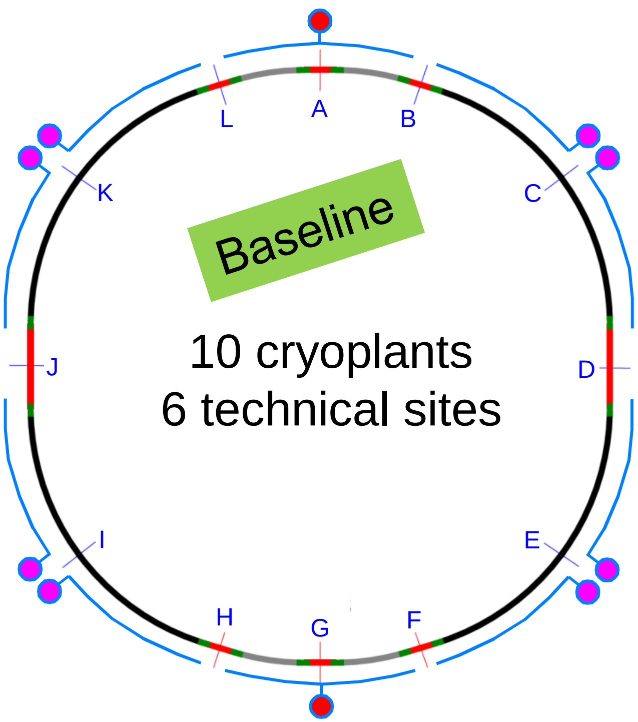
Feasibility study for goods transport across CH (concluded in 2015)

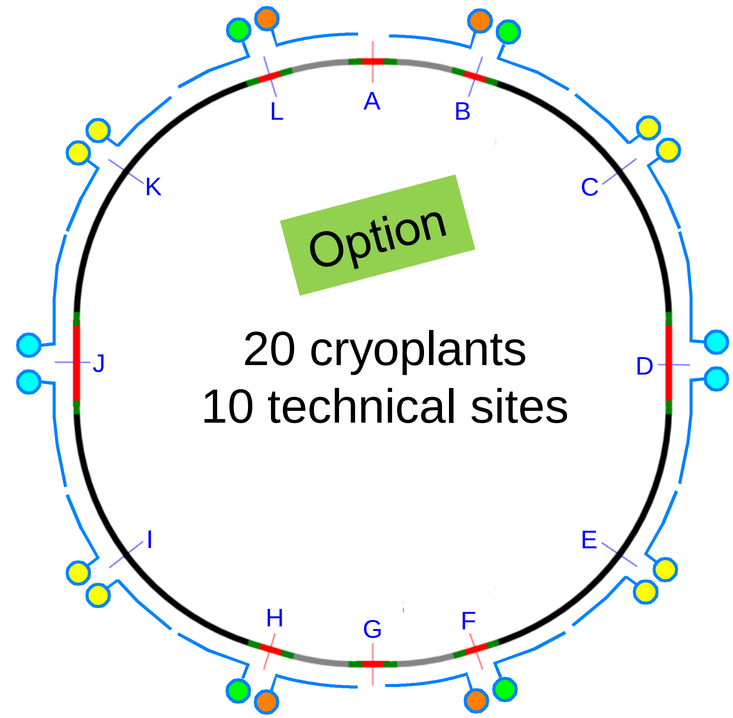
Study points

- Design options for elevators and cranes with large lifting heights
- Consultancy for proposed layouts of shafts, tunnels and galleries
- “Technology watch” on contactless guiding and powering of electrical vehicles
- Study of “high”-velocity people mover in safe area of tunnel
- Vertical/horizontal traffic & duty cycle optimization for access and installation phases
- Remote/automated intervention systems (diagnostics, repair)
- Robotics/remote handling for radiation-hot areas

CRYOGENICS

FCC-hh cryogenic layout





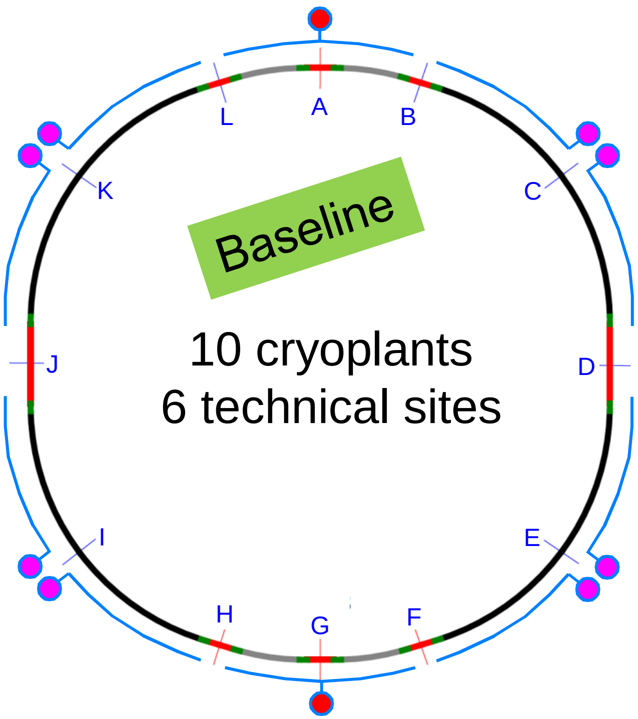
Cryoplant	L Arc+DS [km]	L distribution [km]
●	2 x 4 = 8	2 x 4.7 = 9.4
●	8.4	8.4

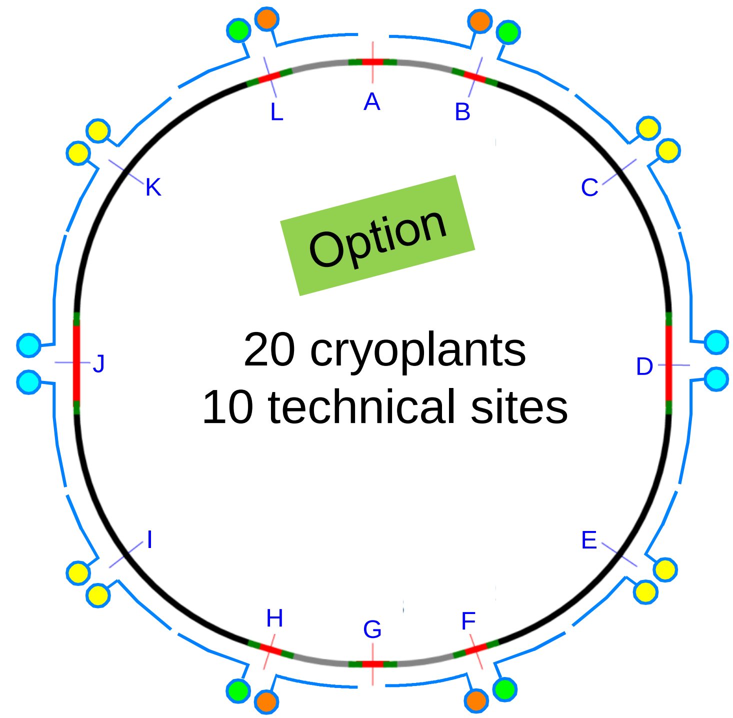
No cryoplant redundancy at Point A and G

No cryo-distribution in ESS (8.4 km)

Cryoplant	L Arc+DS [km]	L distribution [km]
●	4	4.7
●	4.4	5.1
●	4	4
●	4.4	6.5

FCC-hh cryogenic capacity



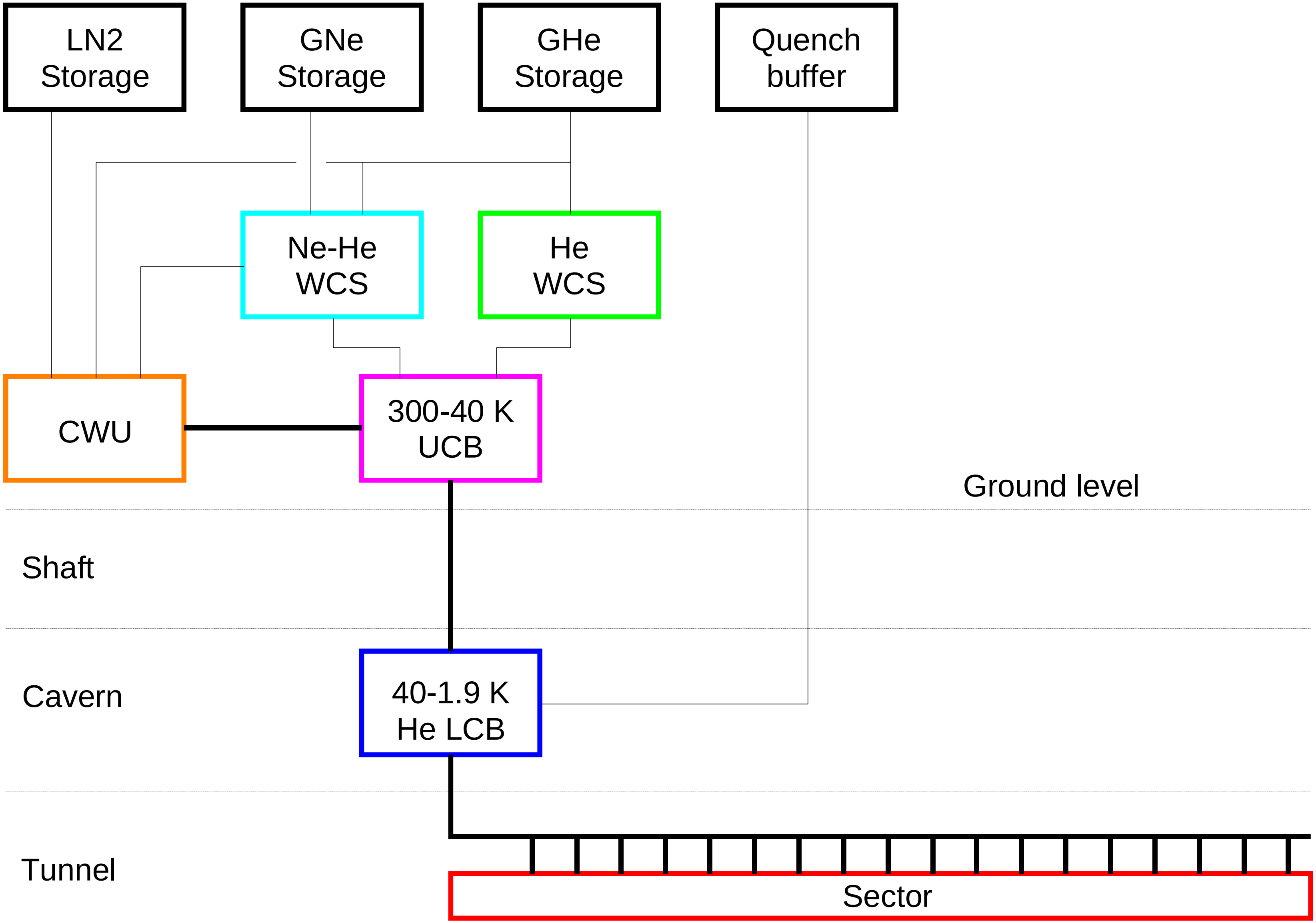


Cryo-plant	40-60 K [kW]	Tcm [kW]	40-300 K [g/s]
🔴	592	11	135
🟣	616	12	99

Without operational margin !

Cryo-plant	40-60 K [kW]	Tcm [kW]	40-300 K [g/s]
🟠	296	5.7	67
🟢	325	6.2	67
🟡	293	5.6	67
🔵	331	6.4	67

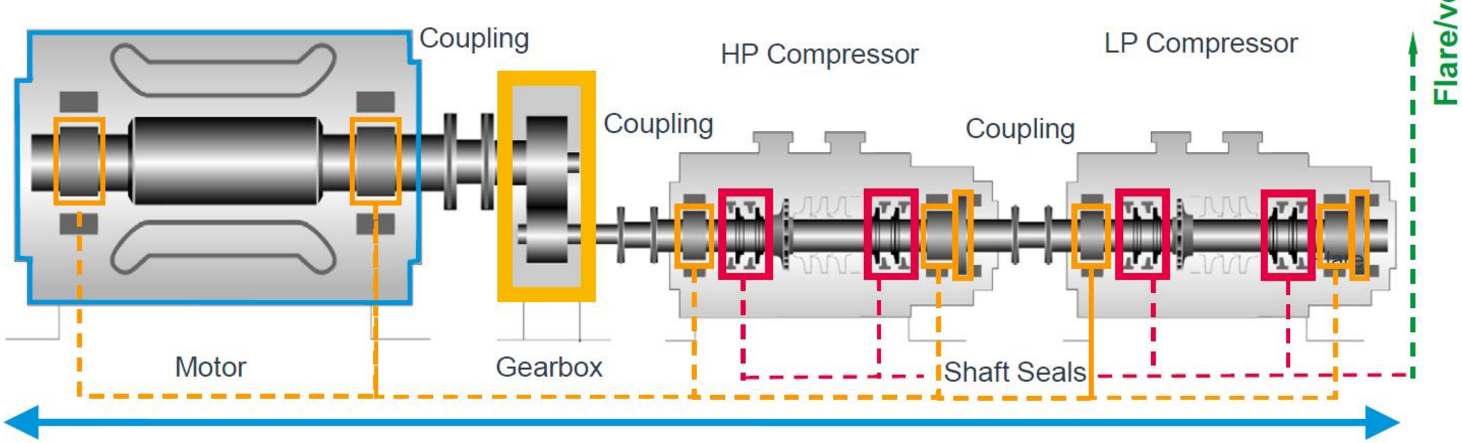
Cryogenics architecture



New type of Nelium compressors

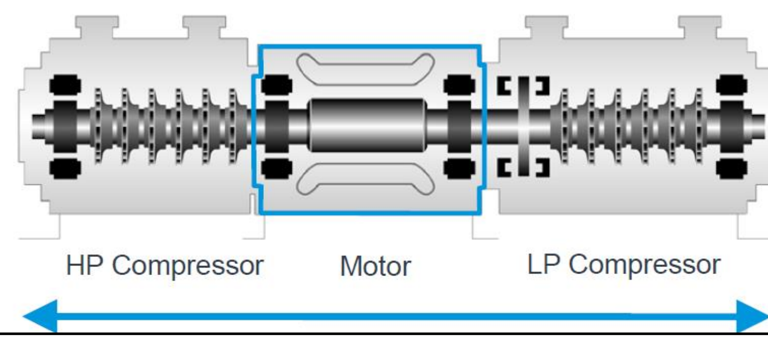
Elimination of Traditional Components

Conventional train configuration



+ No gearbox, no Vorecon
+ No lube oil system
+ No shaft seals, no seal system
+ No emissions
+ Reduced footprint / smaller motor

MOPICO® / HOFIM™

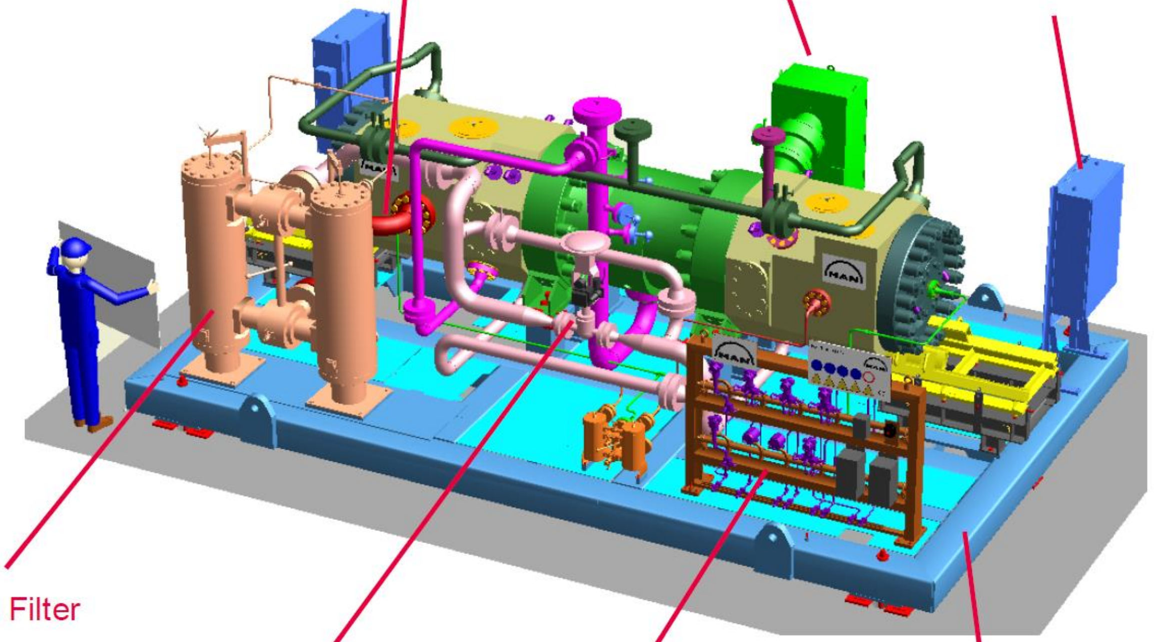


New type of Nelium compressors

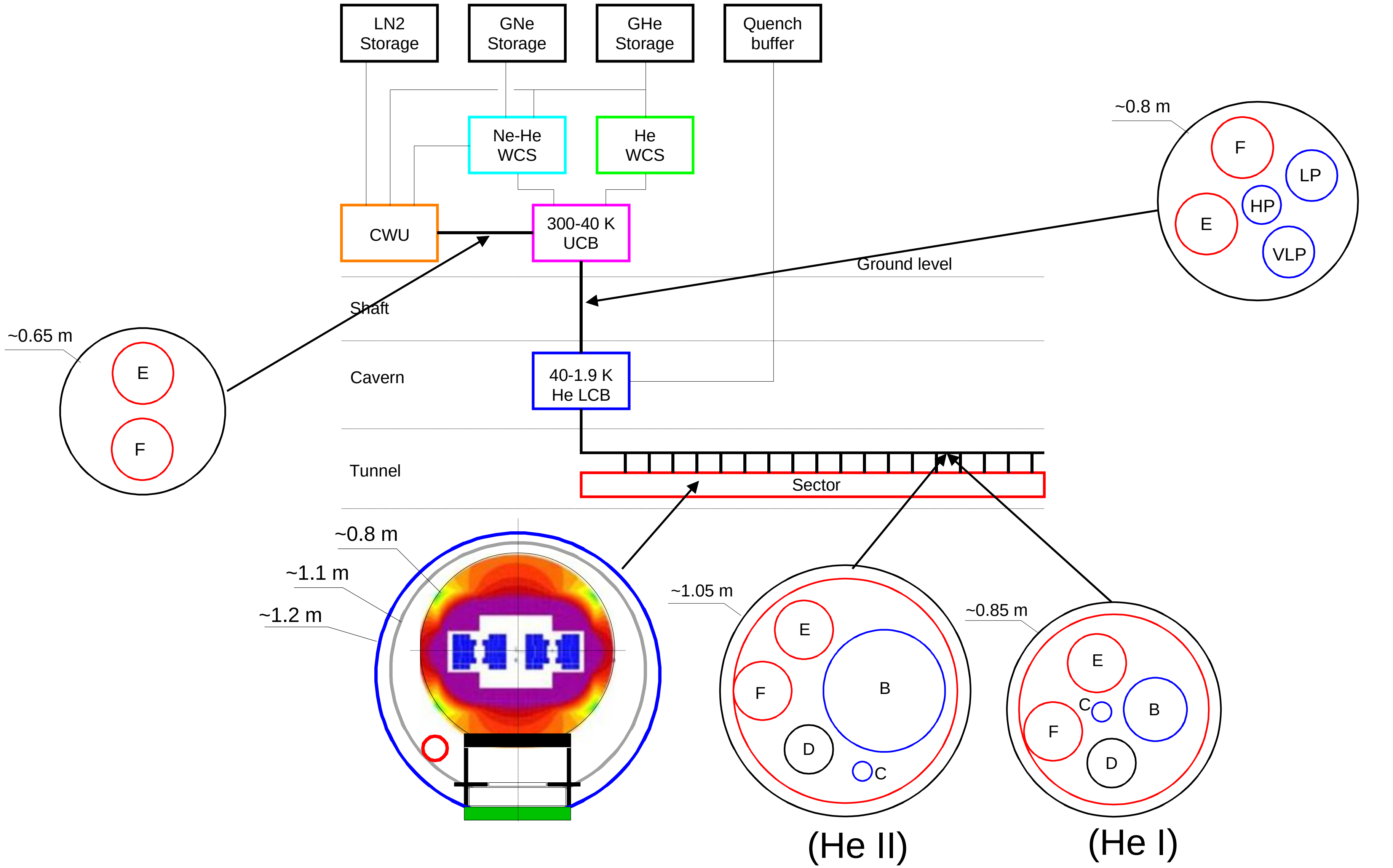
HOFIM™ General Arrangement

General Arrangement

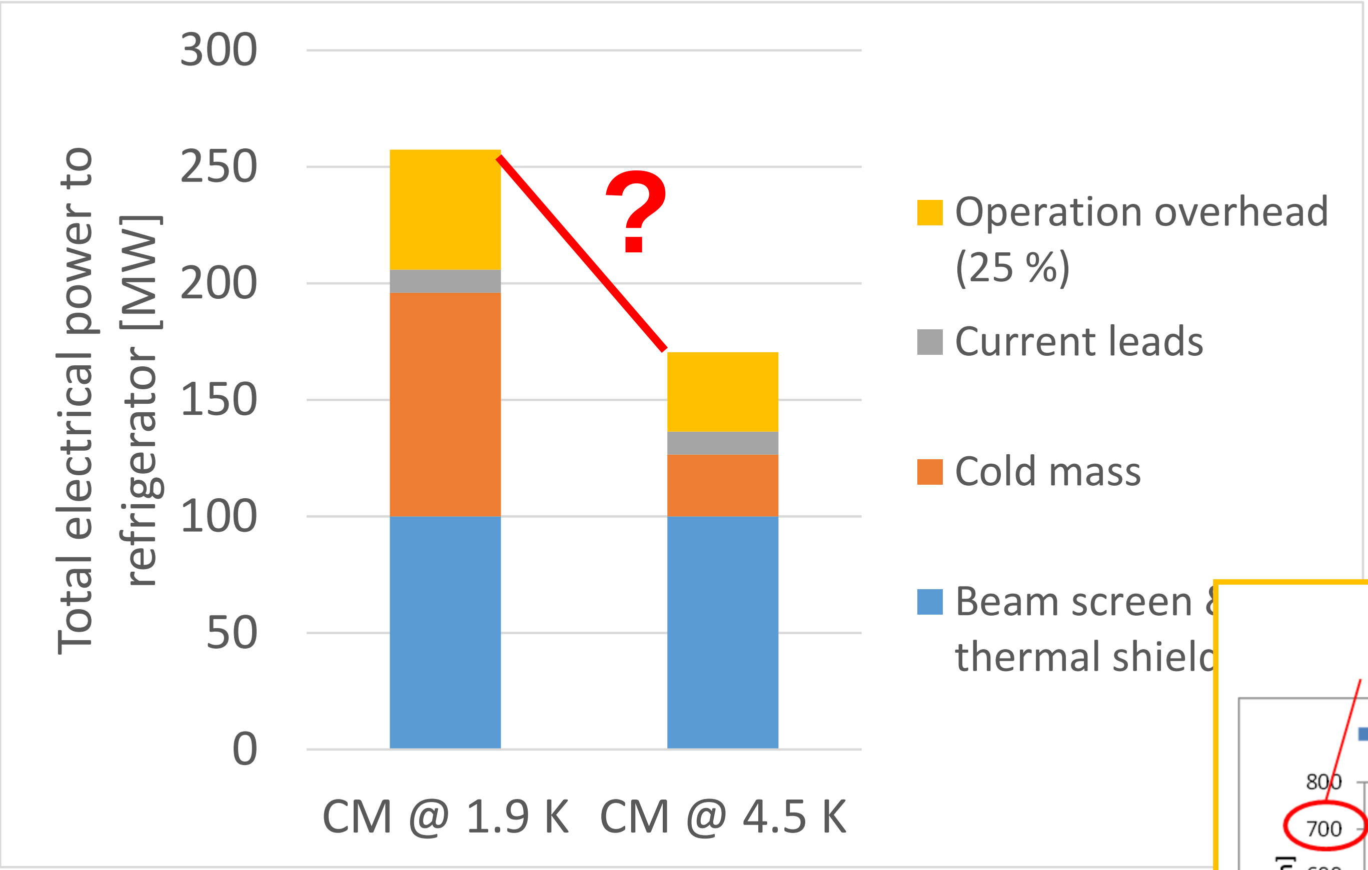
- Standardized base frame design
- Serial or parallel operation
- Minimum space requirement
- High power density → reduced weight
- Only small foundation required
- Integrated AMB inter-mediate junction box



Main cryogenic transfer lines

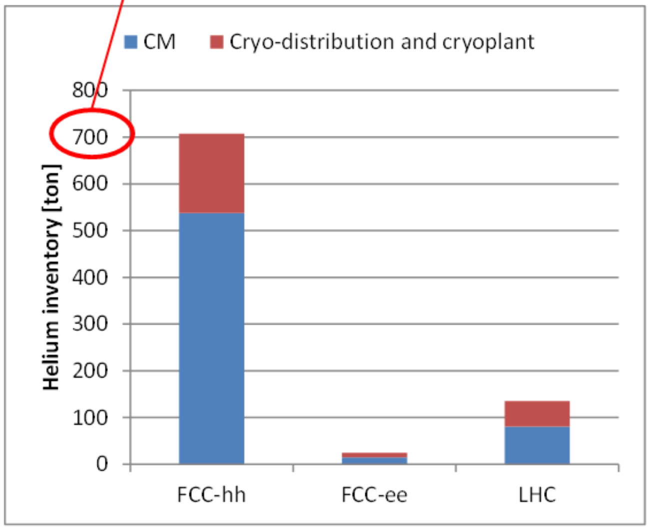


Electrical power to the refrigerators

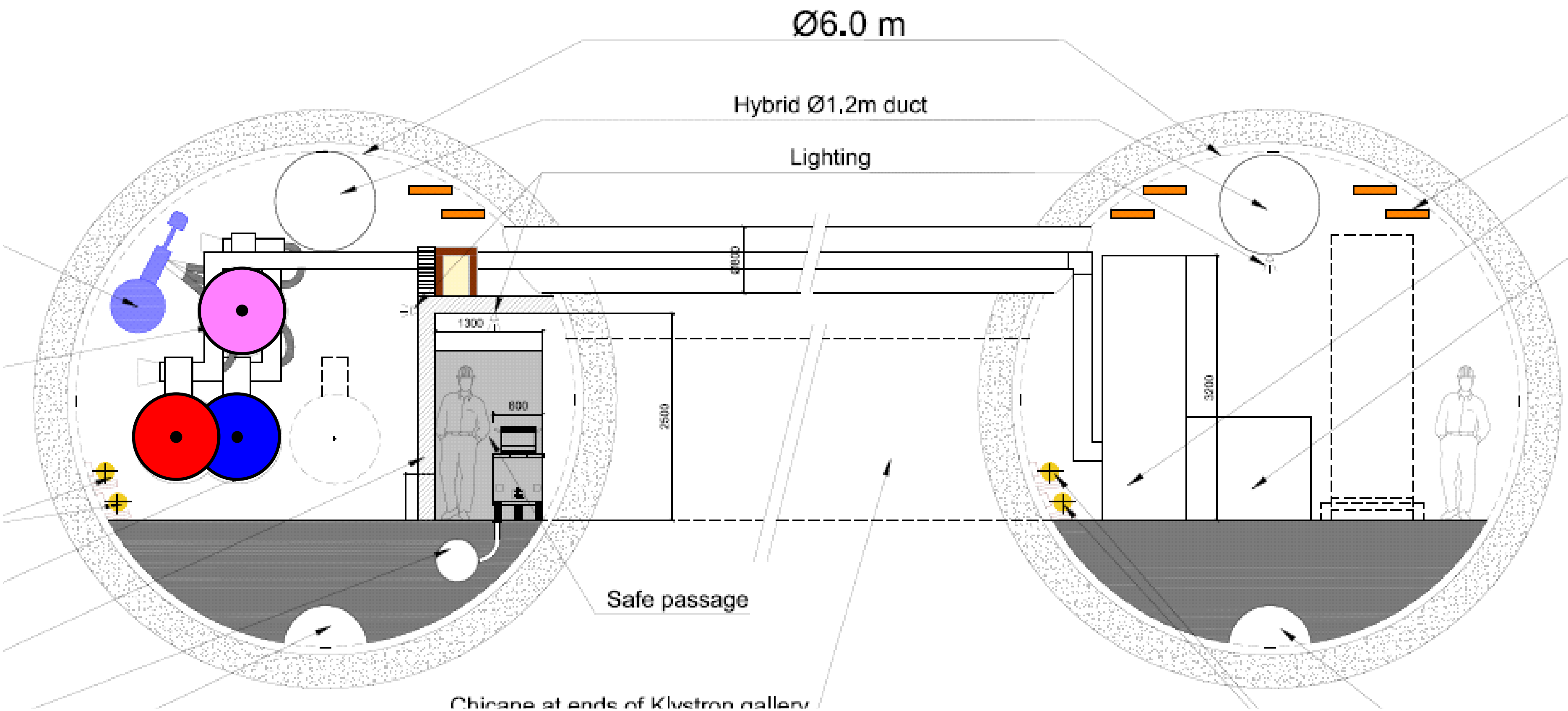


He inventory

~ 12 % of EU annual market
~ 2.5 % of annual world market

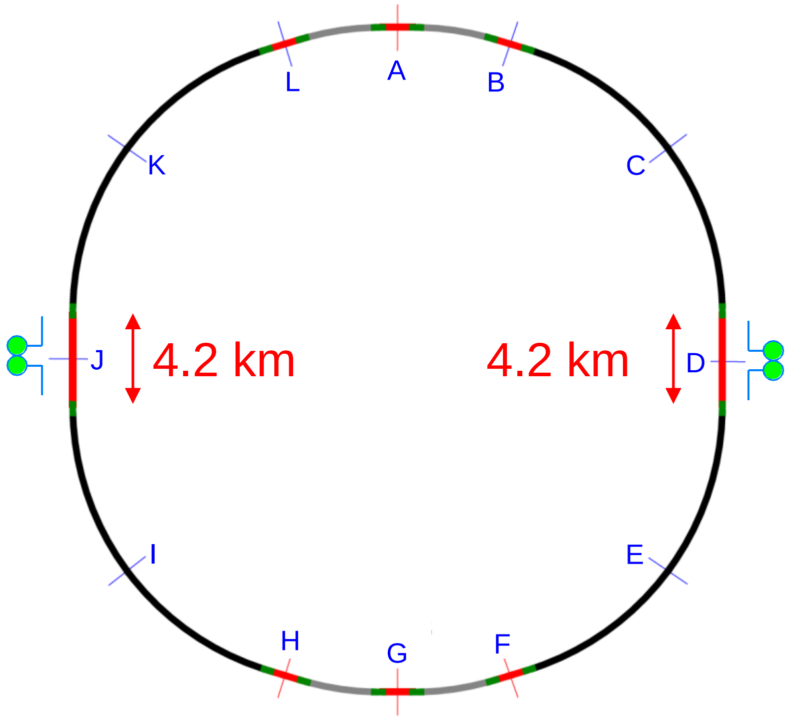


FCC-ee RF straight section



2 main-ring and 1 booster-ring RF module strings

FCC-ee cryogenic capacity (2 main + 1 booster rings)

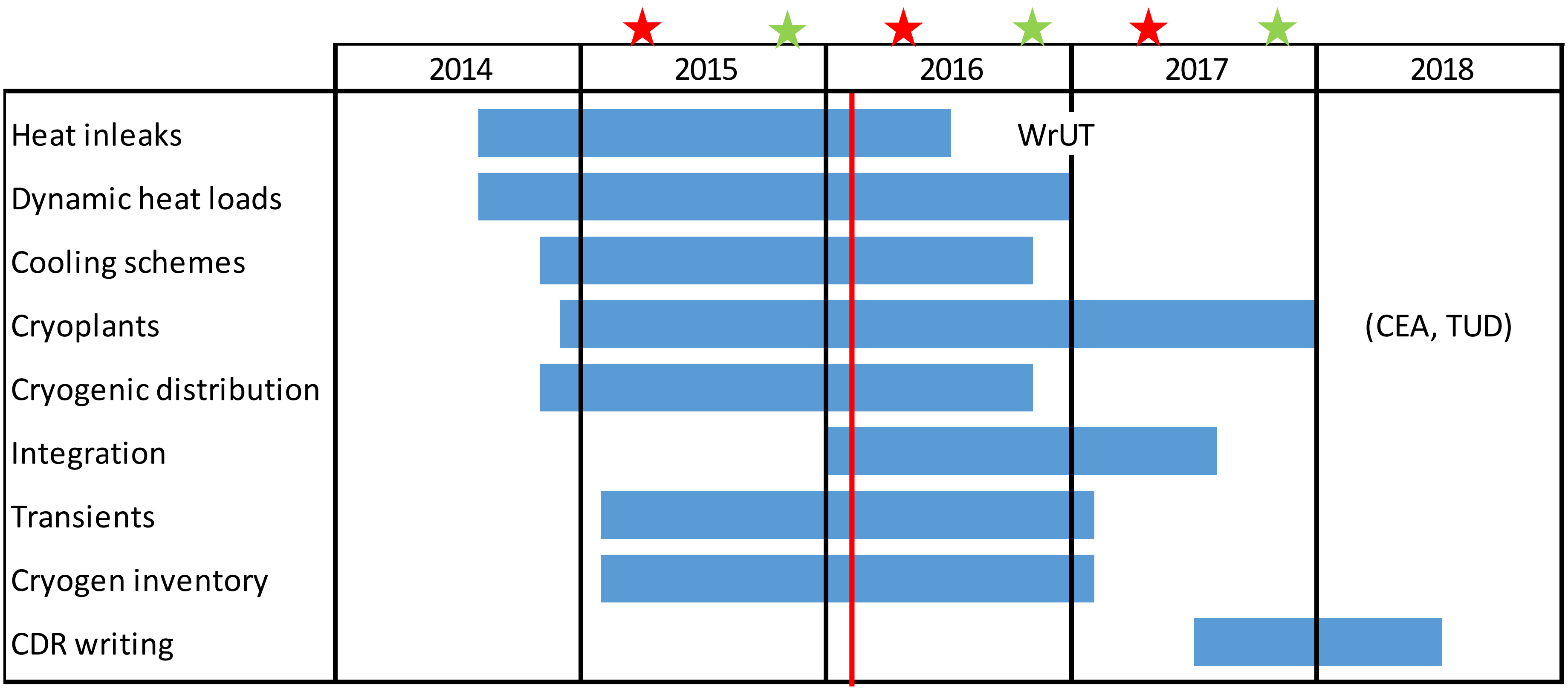


- RF-cavity modules installed in the long straight sections (J, D)
- Operating temperature still to be optimized (4 K, 2 K, 1.8 K, 1.6 K)

Magnetic refrigeration?

Cryoplant	Q stat [kW]	Q dyn [kW]	Qtot [kW]
	5	45	50
Total FCC-ee	20	180	200

FCC cryogenics study point + schedule

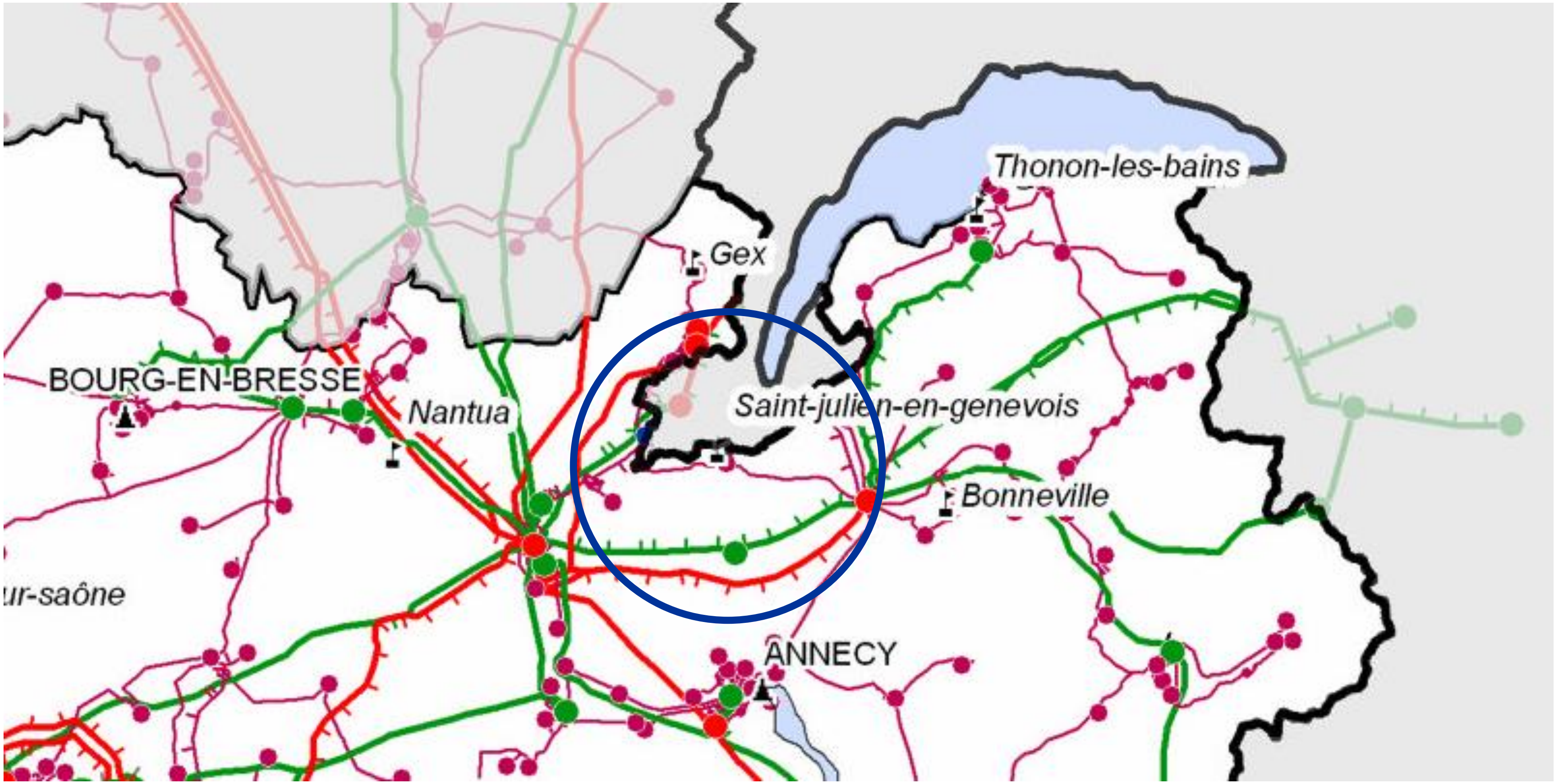


★ FCC weeks (Next in Rome 11-15 April 2016)

★ FCC cryogenics days (Next in October 2016)

ELECTRICAL
SUPPY and DISTRIBUTION

HV networks (Source: RTE)

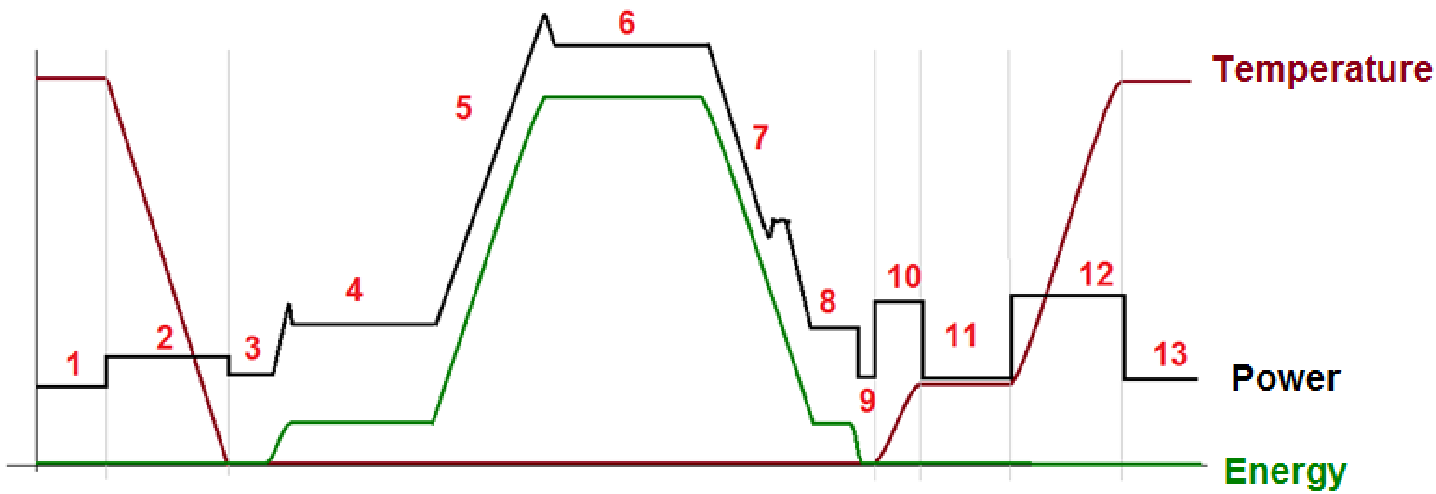


400kV	225kV	150kV	90kV	63kV

Study points

- Following two approaches
  - Scaling from existing installations: adapted to obtain a first estimate, must choose reference project(s) (FCC-hh: LHC, FCC-ee: LEP, LEP2, recent developments in SC RF) and scaling laws
  - Analytical from user demands/estimates: proper when PBS/WBS is known, from elementary values to aggregates by system to complete facility
- Electrical network quite complex – make users aware; trigger discussions.
- Collect requirements for normal, emergency and no-break power for the different systems; explore on-site and off-site distribution options (staging of voltages, network architecture including redundancy, location of substations, routing of lines)
- From power to energy
  - Investigate partial operation and standby modes
  - Explore options for energy efficiency and energy management
- Provide coherent, feasible and optimised network proposal(s) for CDR
- Avoid oversizing

FCC complete cycle (tentative)



Warm (1)
Cold down (2)
TS (3,9)
Injection (4,8)
Ramp up (5)
Steady state (6)
Ramp down (7)
Cryo warm up (10)
TS flowting (11)
Cryo warm up (12)

Who

How much

When

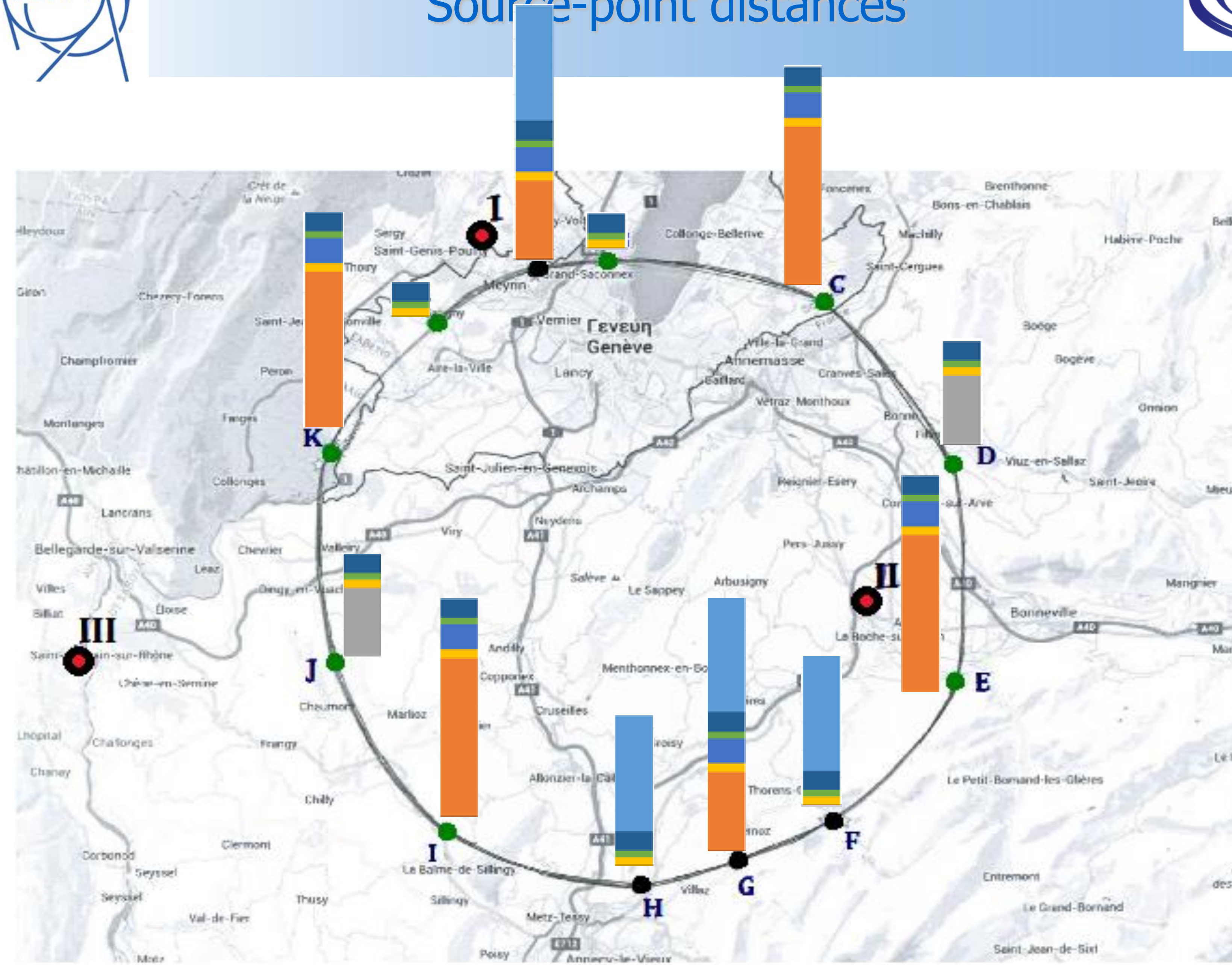
Where

How

Objectives

- Provide mapping of requirements according to different systems layouts
- Sizing with good precision
- Verify feasibility considering the existing grid
- Energy efficient network
- Redundancy

Source-point distances



I

L=5km
A=3km
B=6.4km

II

D=8km
E=6km
F=11.4km
G=14.7km
H=17.9km

III

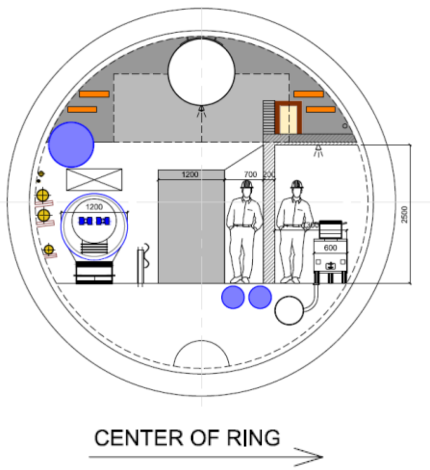
H=29km
I=20km
J=12.5km
K=16.4km
L=24.2km
A=29.6km

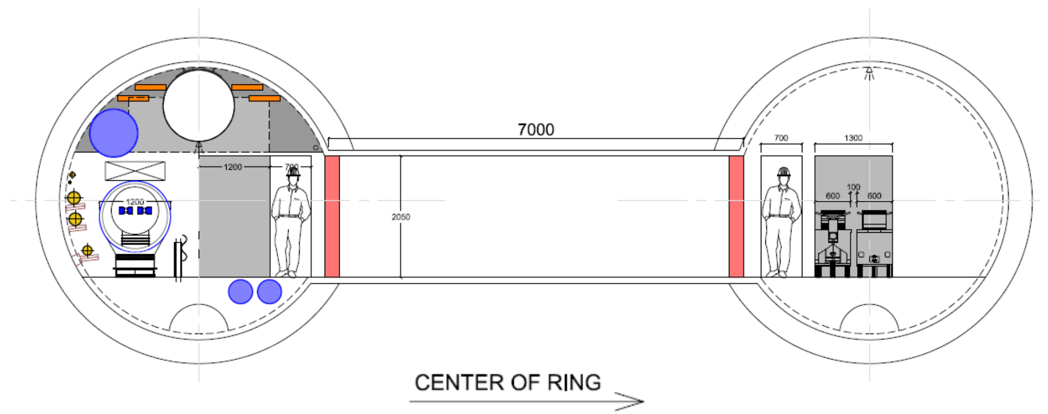
SAFETY

Conventional safety
Radiation protection

Conventional safety studies

- Focus on studies for conventional Safety aspects:
  1. Air management
  2. Evacuation
  (3. Cryogenic safety)
- Studies focused on two main tunnel cross-sections FCC-hh:
  - 6 m Ø single tunnel
  - 4.5 m Ø double tunnel



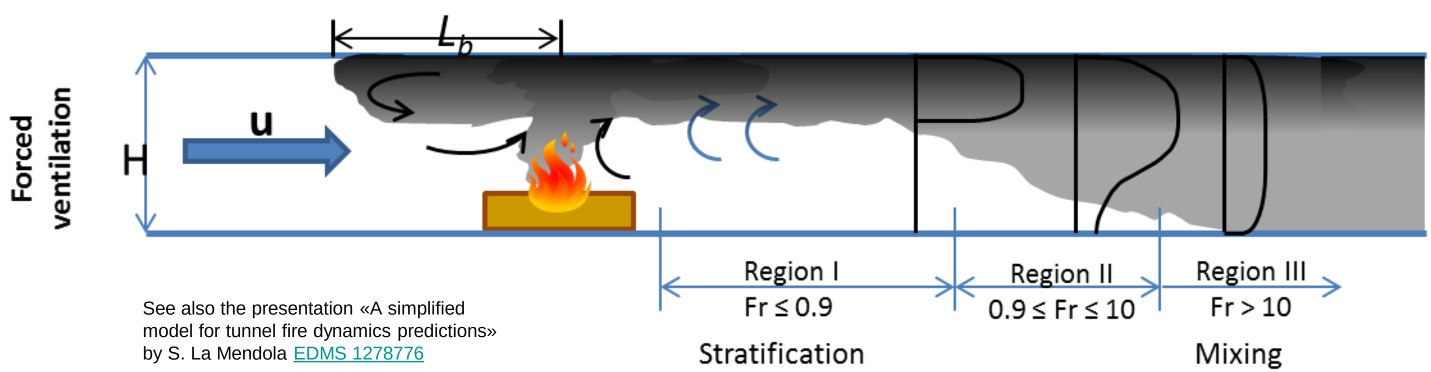


- Outcome is in line with RP constraints

Longitudinal ventilation (LV):

Main Advantages, w.r.t. conventional Safety	**Main Disadvantages**, w.r.t. conventional Safety
• Provides fresh air for occupants during access • Regulate air speed in the tunnel	- Propagation and contamination of smoke to others volumes of the tunnel - Even if the ventilation is stopped , the smoke still propagates

Smoke propagation in LV:



See also the presentation «A simplified model for tunnel fire dynamics predictions» by S. La Mendola EDMS 1278776

The **back layering length** (L_b) is limited to a few tens of meters upstream the fire at worst

Fr = Froude number: ratio between flow inertia and buoyancy

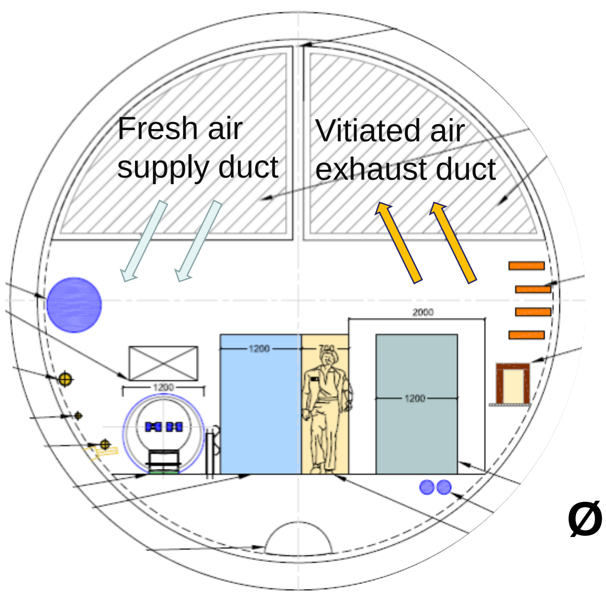
Courtesy S. La Mendola

Air management concepts

Transverse ventilation (TV):

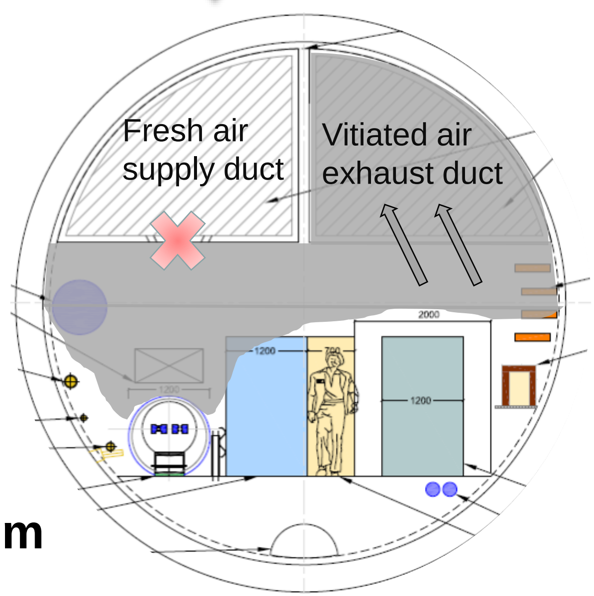
Main Advantages, w.r.to conventional Safety	**Main Disadvantages**, w.r.to feasibility of the system
- Limit the propagation and contamination of smoke to others volumes of the tunnel - Provide dynamic confinement localized near the fire	- Large ducts are needed → occupy ~50 % of the tunnel volume - Larger tunnel needed

Smoke propagation in TV:



Normal operation

Ø 7.5 m



Fire conditions

D = 7.5 m → A_{total} = 44 m^2

→ A_{useful} = 34 m^2

A_{ducts} = 14 m^2 →

41 % of the useful area

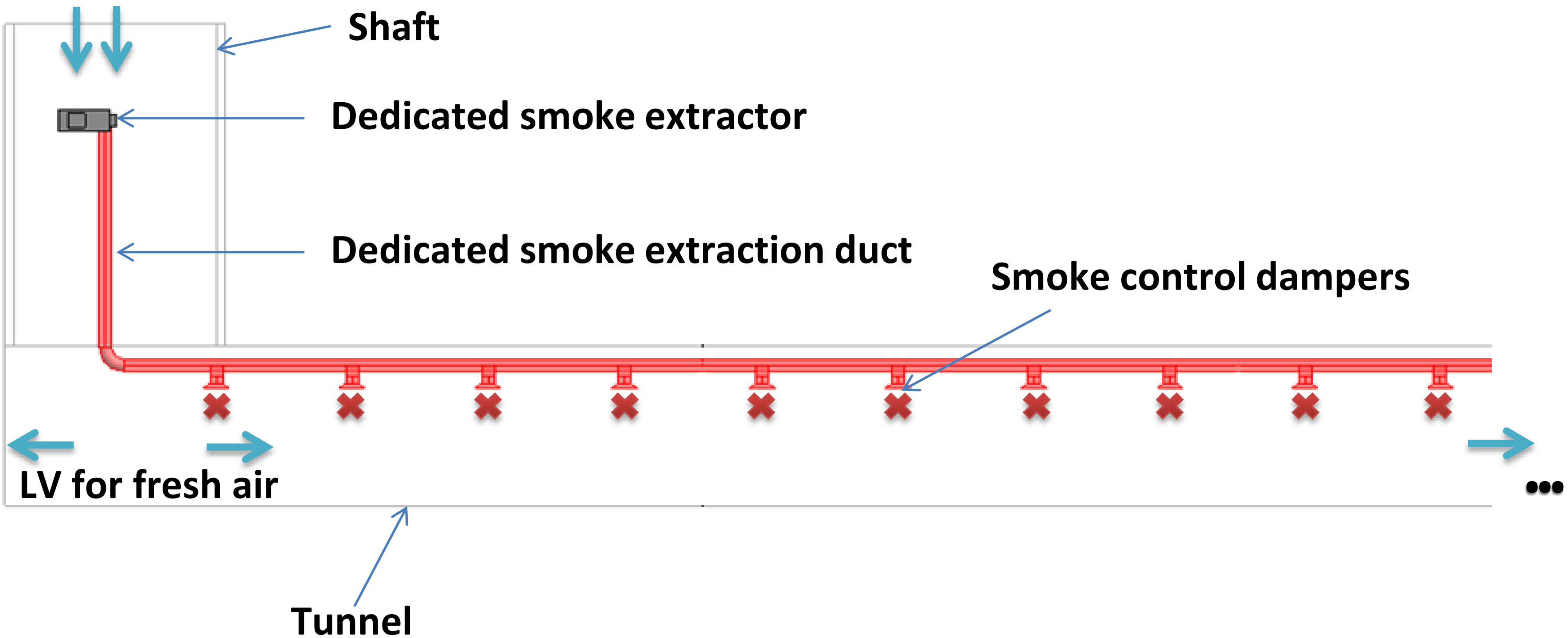
Air management concepts

"Optimised" solution:

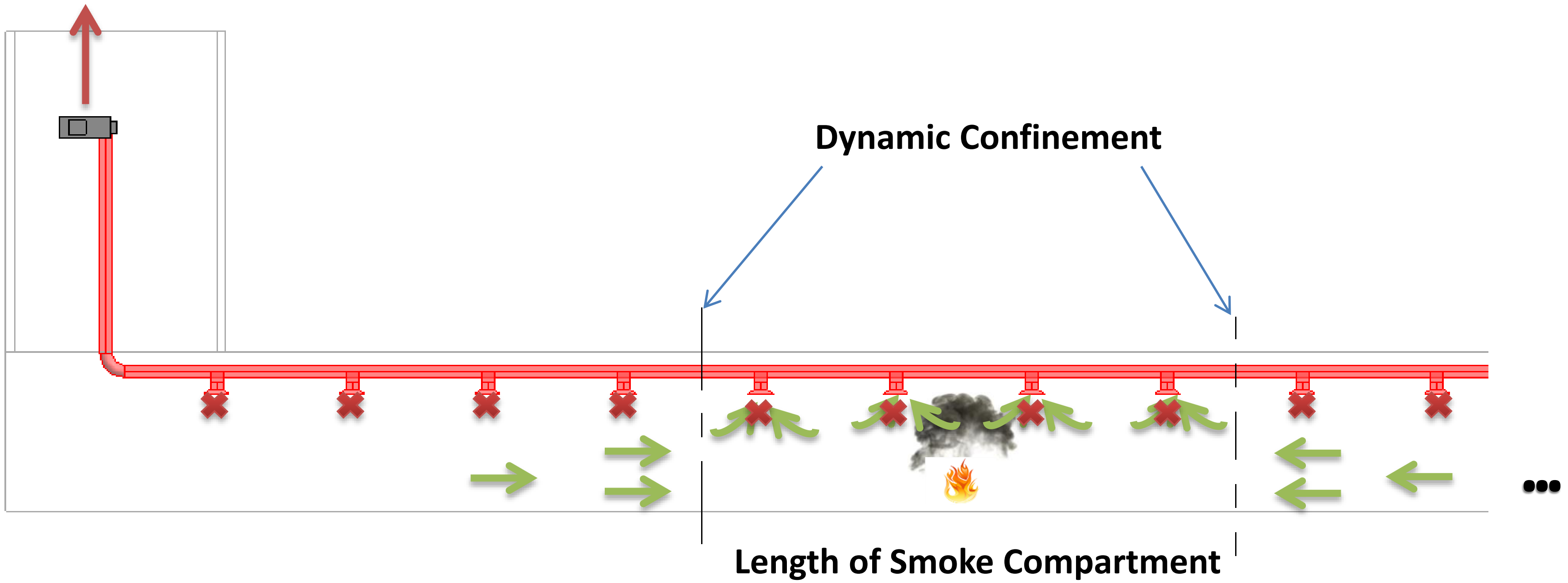
- Longitudinal Ventilation for normal operations
  - Provide the requirements for occupational health (fresh air)

- Dedicated smoke extraction system
  - Limit propagation and contamination of smoke to others volumes of the tunnel
  - Provide the dynamic confinement
  - Reduced cross section of the smoke extraction duct

- Example of a section of the FCC tunnel:
  - Nominal conditions



- # Example of a section of the FCC tunnel:
  - Accidental scenario – e.g. fire
  - Longitudinal ventilation is stopped

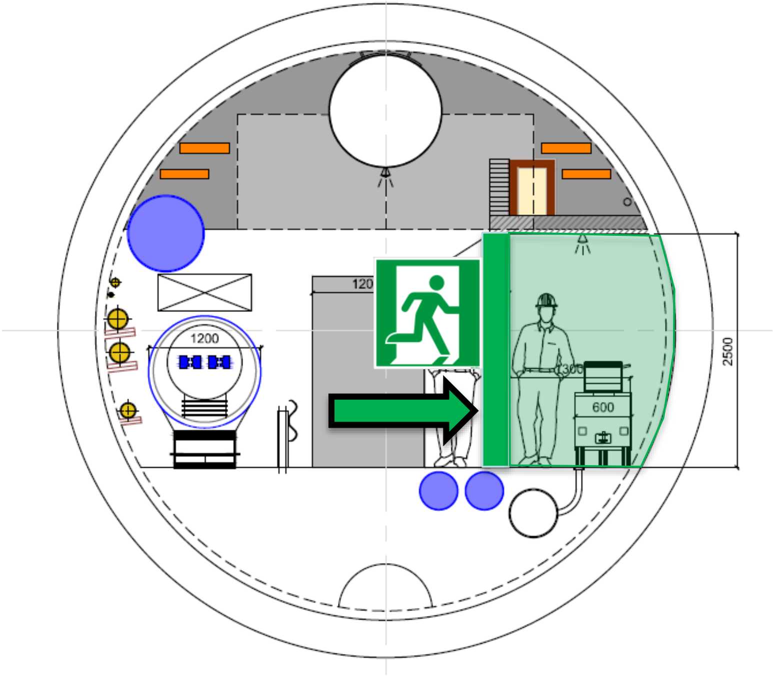


Evacuation

6 m Ø Single Tunnel

Evacuate through a door leading to a "Safe Zone":

- Fire resistant
- Air tight in case of cryogen release
- Overpressure, w.r.t. machine zone
- Personnel transportation for evacuation



Safe zone with limited amount of combustible material

Radiation protection principles

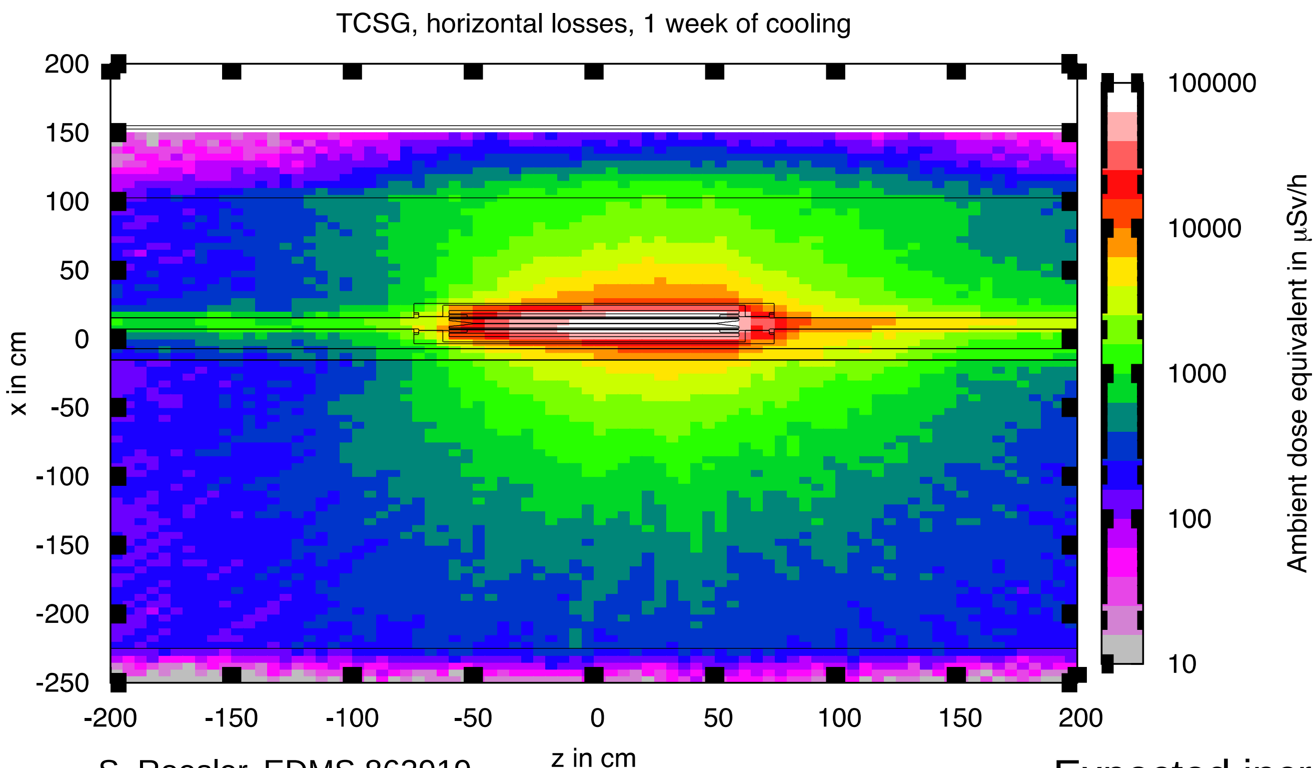
Justification

Limitation

<u>Optimization</u>

- Already during the concept & design phase
- To be considered at this stage for CE layout choices:
  - Minimize production and release of radioactivity which could have a potential environmental impact
  - Optimal access and working conditions
- Important for machine and equipment design:
  - Limitation of installed material
  - Material choice to reduce residual does and minimize rad. waste
  - Optimised handling to reduce personnel exposure to radiation

Residual dose rate



S. Roesler, EDMS 863919

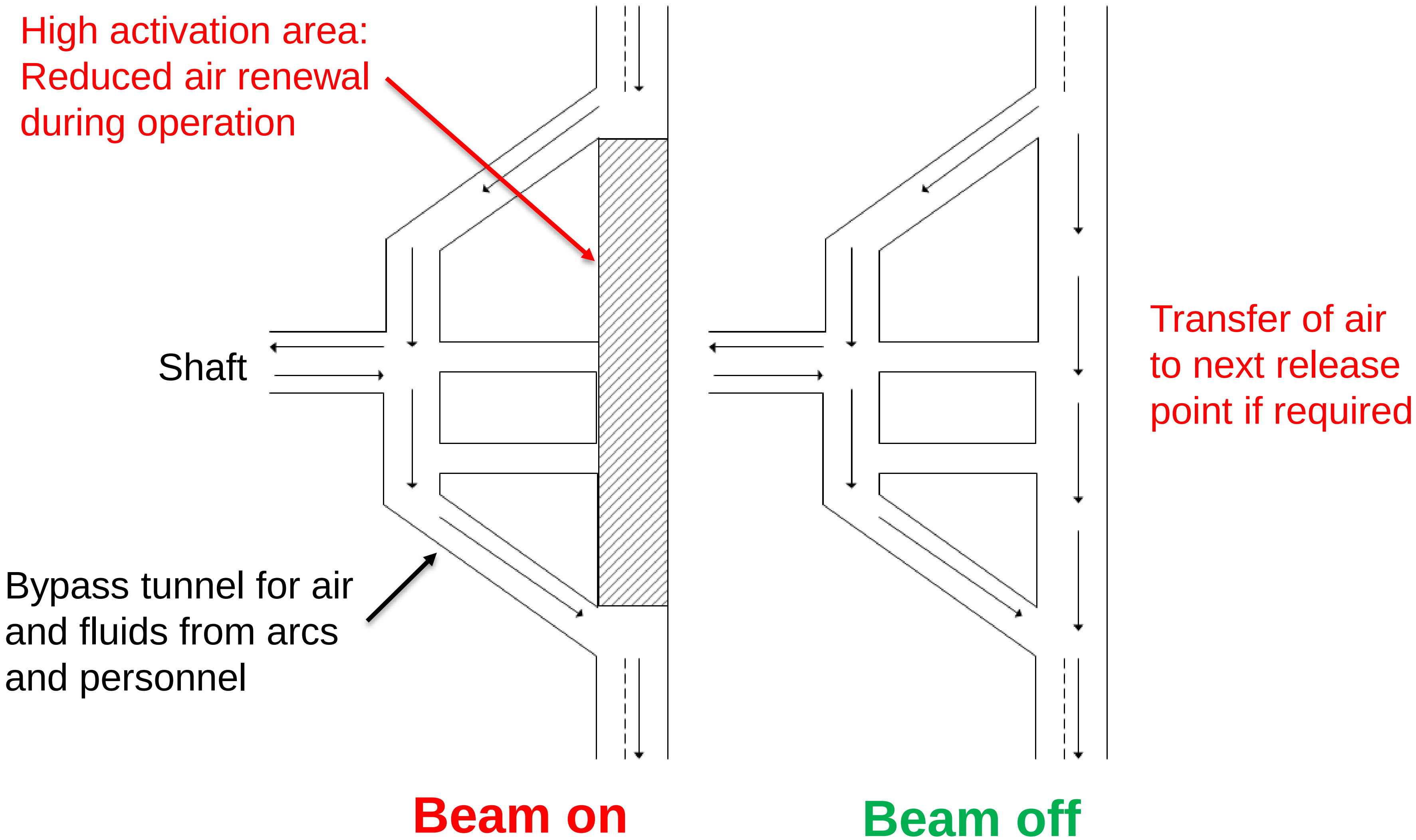
LHC collimator activation studies → validated by measurements at the beginning of LS1

Expected for LHC nominal: ~ 4 mSv/h range after 1 week cool-down

Expected increase factor to FCC nominal: 6 (energy) x 5 (luminosity, bunches) = 30

Extrapolated from LHC, dose rates of several tens of mSv/h expected for the FCChh !

Air activation



Study points

- Evaluation and optimisation of proposed layouts and tunnel cross sections

(frequency of connection tunnels/doors, chicanes, experimental and service caverns, shaft positions, constraints for combustible material in “safe zones”)

- Safety studies in underground areas

(MCA, fire containment, smoke/helium extraction, ODH, emergency access & egress, sizing of safe zones in front of lifts, horizontal and vertical transport)

- Ventilation concept
- Environment protection, radiological & conventional
- Prepare environmental impact study
- Radiation maps in and around tunnel(s) for personnel and equipment safety

(zoning, exclusion zones)

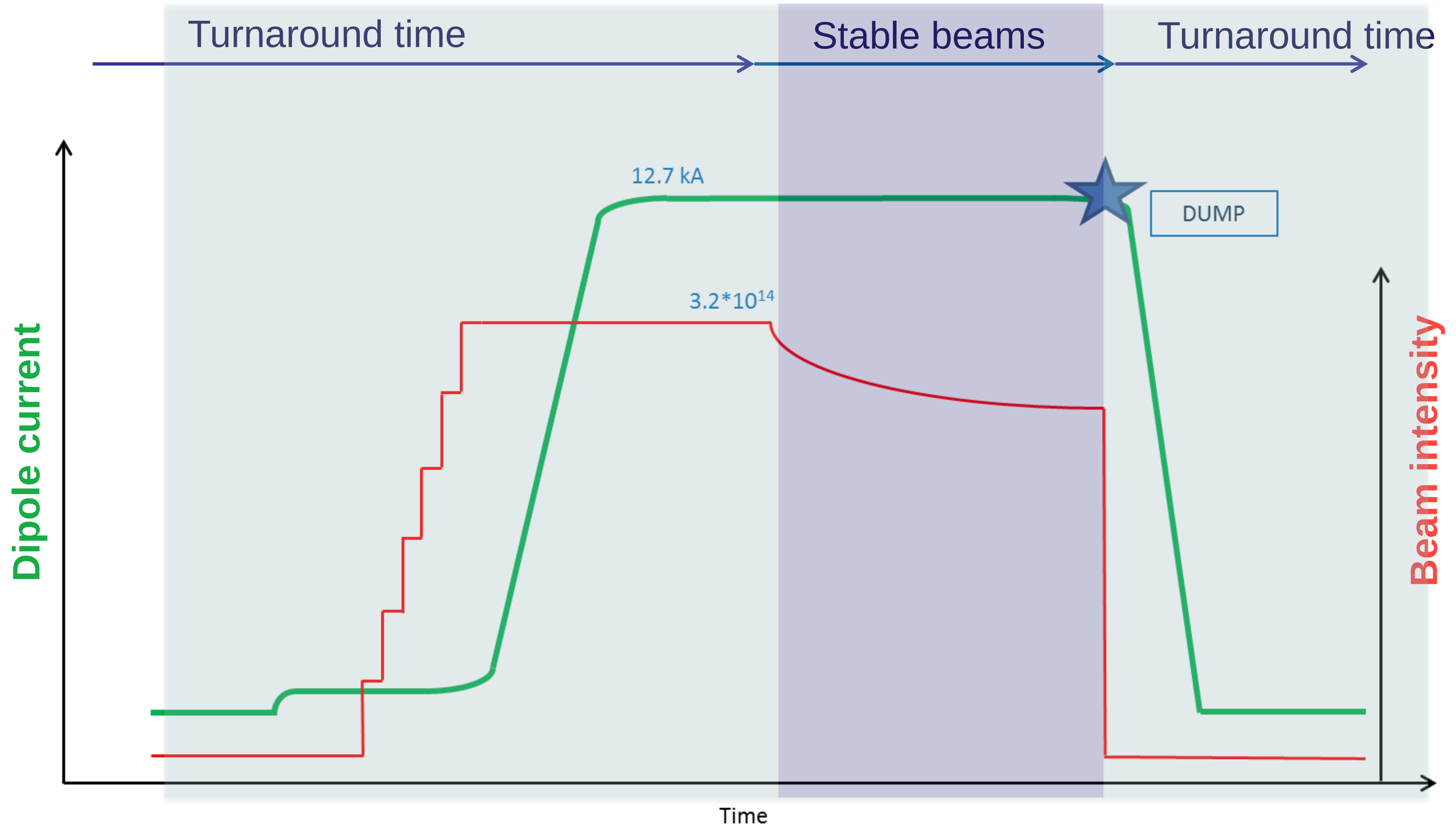
- Pressure build-up in case of major He release (no access)
- Expected activations levels in collimator and IT regions
- Activation levels and residual dose rates in the arc from beam-gas interaction
- Synchrotron radiation as activation source (FCC-ee)
- Layout of RF regions (ducts and shielding configurations ←→ cross-over with FCC-hh design)
- Activation of fluids (cryogens for beam screens and magnets, water cooling)
- Material optimization
- Radiological implications of the transition to “LHC as FCC injector”

(equipment removal, reinstallation, potential schedule impact)

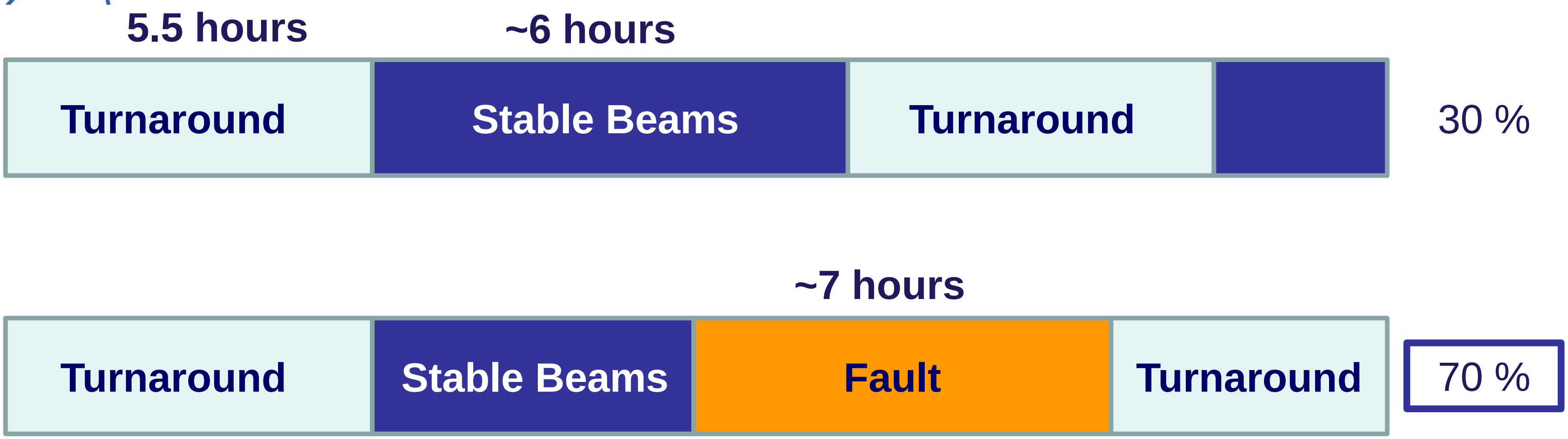
- Radiological impact of running LHC as FCC injector (compared to (HL-)LHC)

AVAILABILITY and RELIABILITY

Collider operation is stable beams + turn-around time

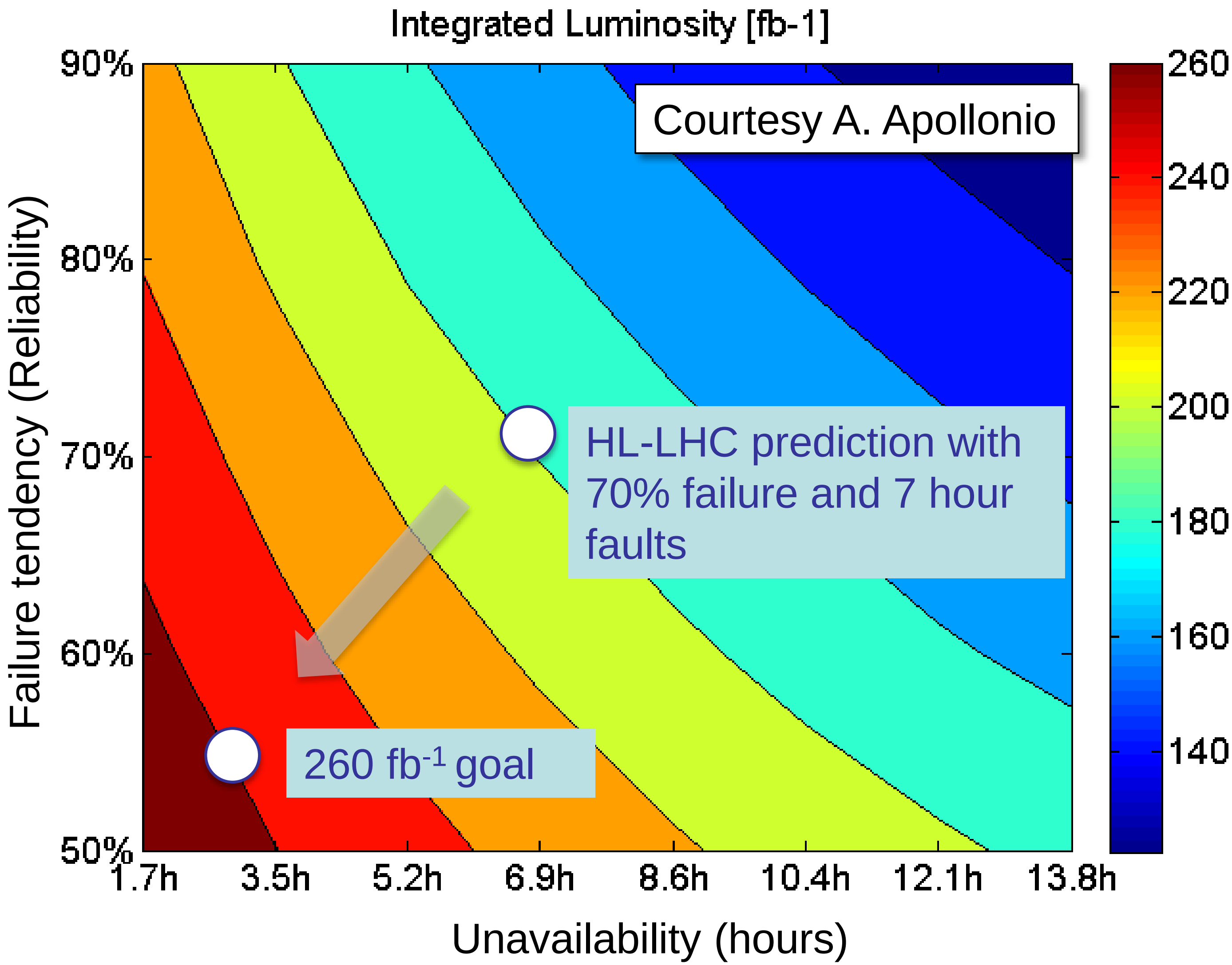


Faults increase turn-around time



- **LHC example 2012**
  - **Failure tendency** – 70% of fills dumped prematurely
  - **Average unavailability caused by fault** – 7 hours
    - Mean Time To Repair plus
    - Localization, Diagnostics, Logistics

Performance can be increased by reducing failure tendency and unavailability



Localization + Diagnostics + Logistics + Repair

Reliability, Availability, Maintainability, Safety

RAMS study being performed; see whether industrial method applicable to accelerators (model lumi. prod. based on accelerator schedule, performance, turn-around time and fault number + duration).

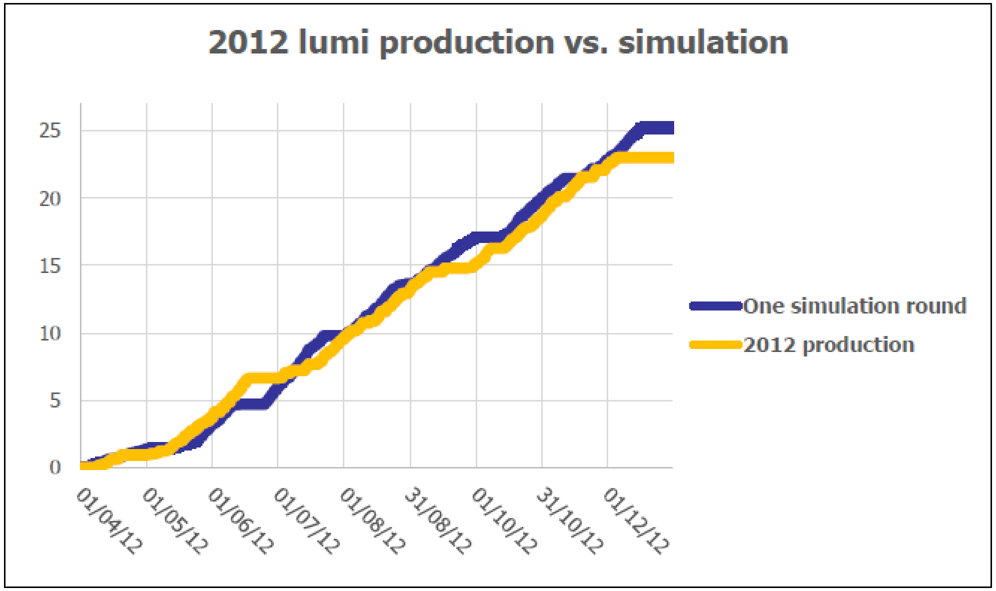
MC model created w commercial S/W ELMAS by Ramentor Oy in collab. w TU Tampere.

Model benchmarked on the LHC 2012 run, with remarkable agreement.

Evaluating possibility to extrapolate to HL-LHC and FCC.

Allows (in principle) to simulate different scenarios on all levels (operation, fault prob).

Accuracy of modeling and and level of detail of analyses depends on quality of operation and subsystem data.



Features likely to play an important role in increasing the availability:

Redundancy (automatic fail-over) of sub-systems, electronics cards, radiation hardness (if electronics cannot be placed away), automatic test procedures, automatic and remote failure analyses and reset, remote replacement of faulty components, ...

Concluding remarks

- „Infrastructure and Operation" for FCC is a wide and diverse field.
- Work areas interlinked in many ways, and impacting each other.
- Intensive studies underway on a large front, with already substantial progress.
- Concurrent with developments in accelerator design and technology.
- Several collaborations established (cryogenics, realibility and safety).
- FCC CE and infrastructure pose great challenges.
- Experience from LHC helpful but will not work everywhere.
- Dimensions + requested performance demand novel concepts + real breakthroughs.

Further reading

- FCC Week 2015 (under Thursday)
  http://indico.cern.ch/event/340703/
- FCC Week 2016 (under Thursday)
  http://fccw2016.web.cern.ch/fccw2016/
- FCC Infrastructure and Operation Working Group
  http://indico.cern.ch/category/5398/

www.cern.ch