Infrastructure and Operation Summary

John Osborne, CERN

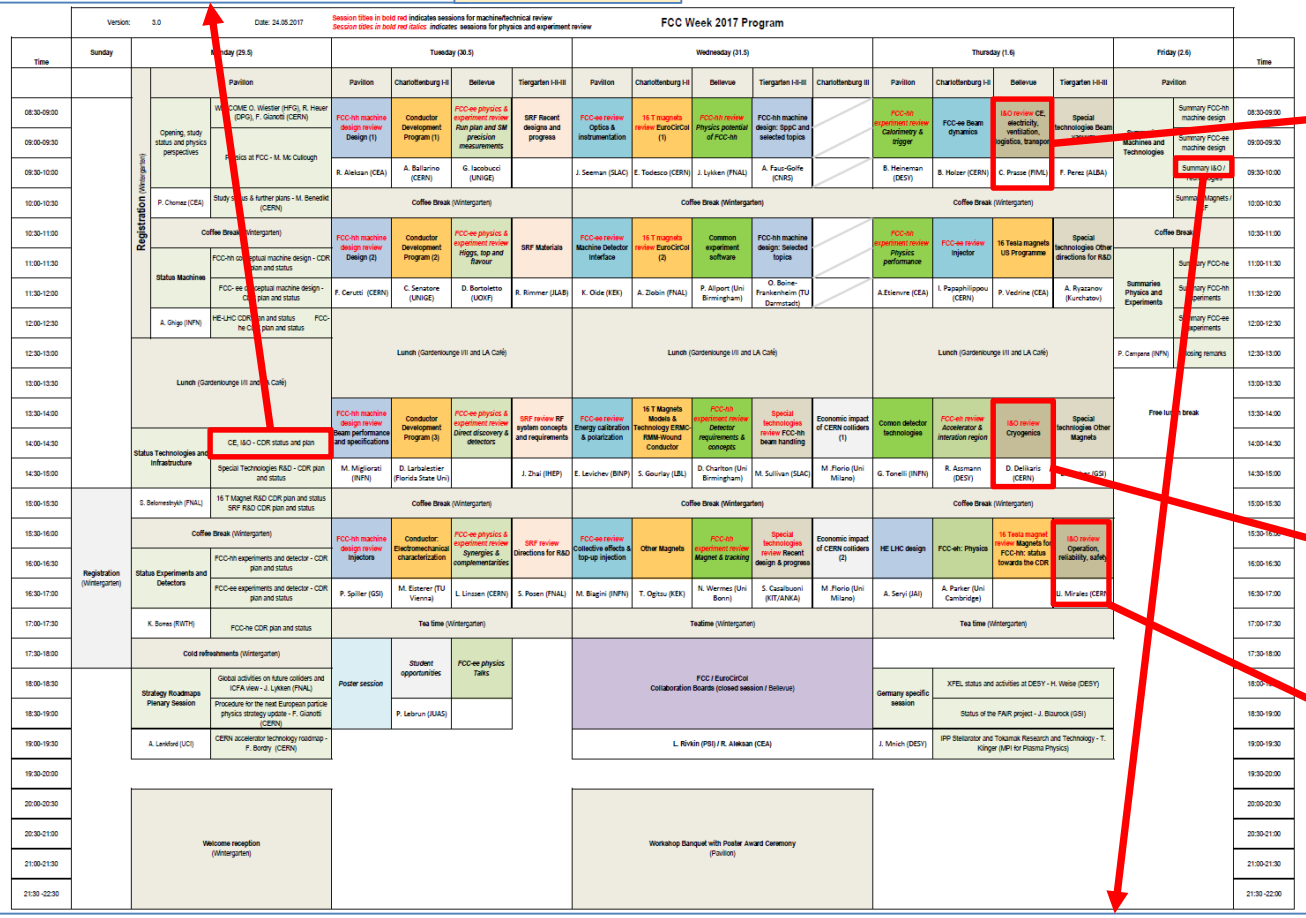
Report on behalf of FCC Infrastructure and Operation WG,
all FCC study teams
Special thanks to Volker Mertens

FCC Week 2017
Berlin, 2 June 2017

Infrastructure and Operation related programme

Overview (V. Mertens, 25‘+5‘)

Monday



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‘)

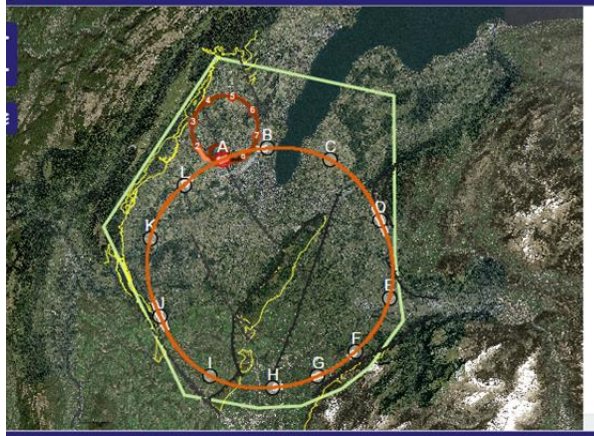
Friday

Poster listed in V.Mertens Monday presentation

“Berlin” baseline 97.75km

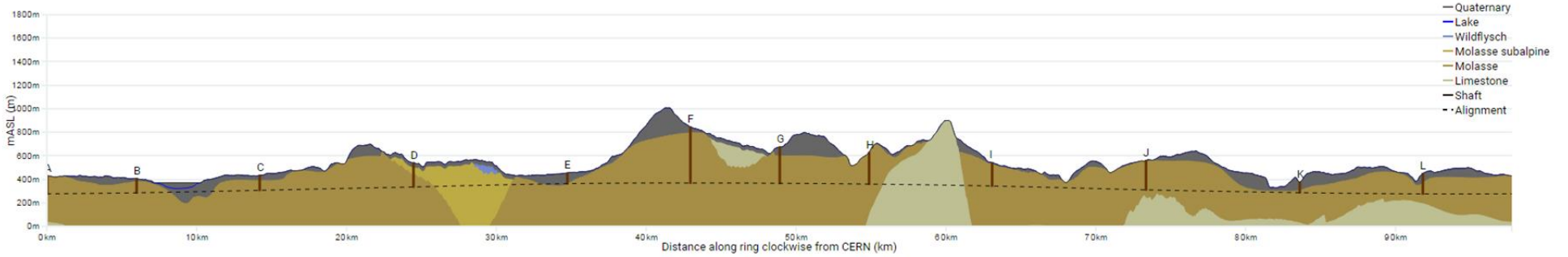
Highlights:

- Avoids Jura and Pre-Alps limestone.
- Only one sector containing limestone.
- Significantly reduced total shaft length.
- Experimental Site at Point A on existing CERN land.
- Avoids extremely large overburden.



Geology Intersected by Shafts | Shaft Depths

Point	Actual	Molasse SA	Wildflysch	Quaternary	Molasse	Urgonian	Limestone
	Shaft Depth (m)			Geology (m)			
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



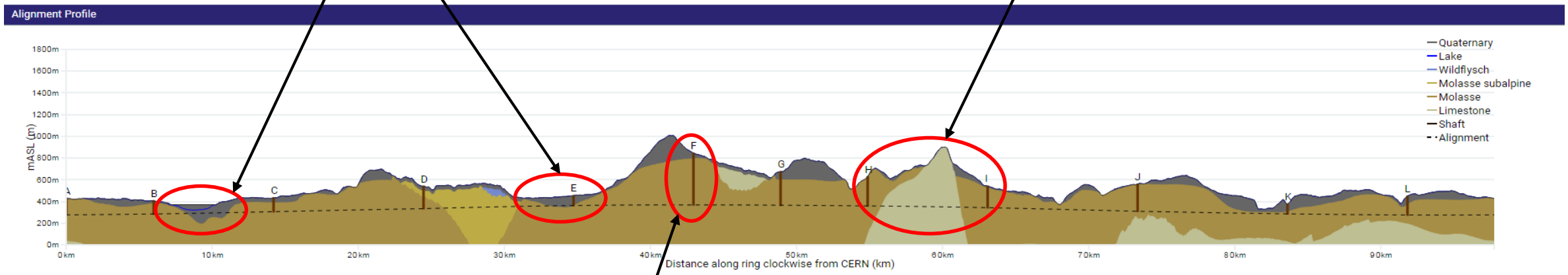
Geology Intersected by Tunnel | Geology Intersected by Section

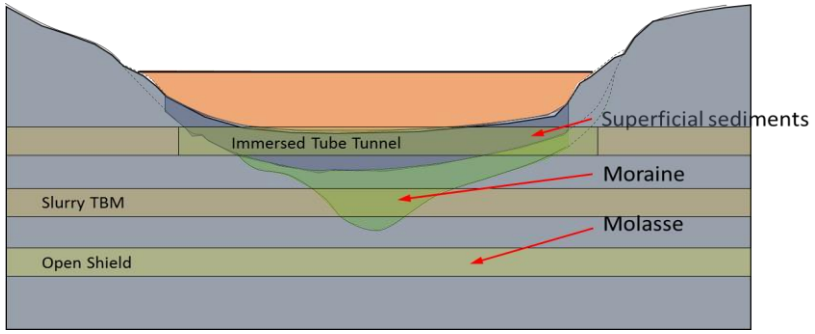
Civil engineering optimisation and design development (J. L. Stanyard)

Key CE issues and possible solutions

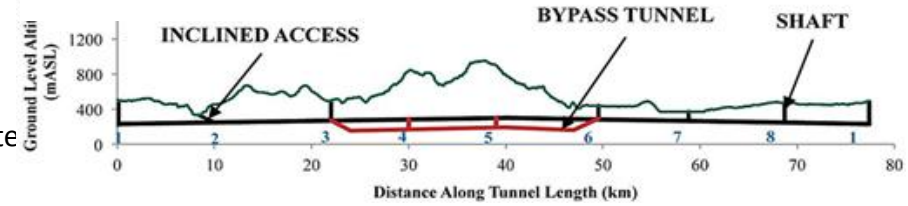
Issue: Tunnel excavation through water bearing moraines
Possible Solutions:
a) Excavation using a multi-mode earth pressure balanced TBM.
b) Employ a double-lining method for waterproofing.

Issue: Unavoidable Mandallaz Limestone formation
Possible Solutions:
a) Drill & Blast excavation method
b) Systematic exploration ahead of excavation





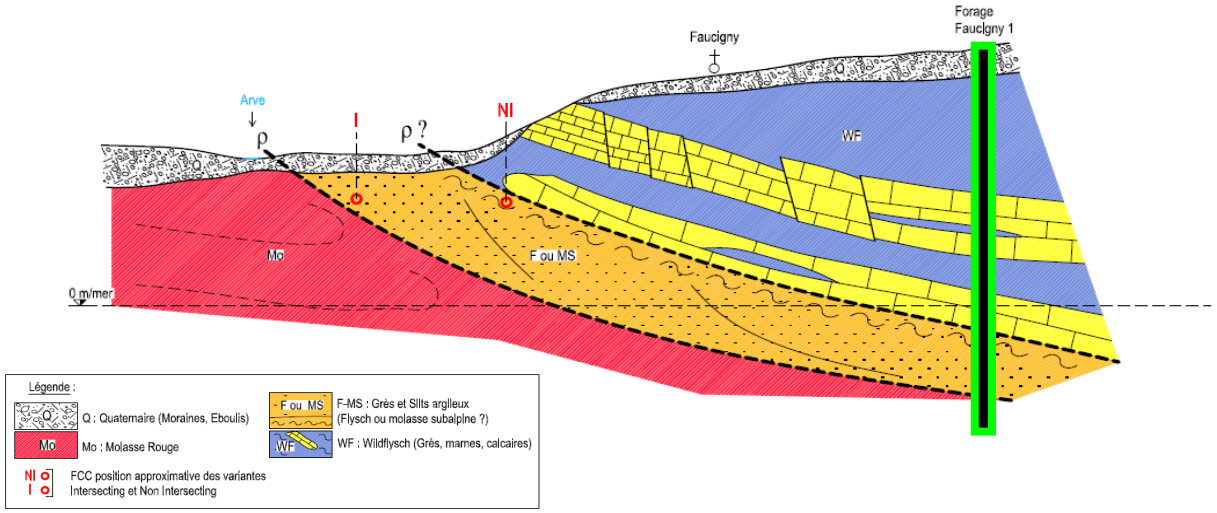
Issue: Exceptionally deep shaft at point F
Possible Solutions:
a) Remove shaft
b) Replace with a shaft of a smaller diamete
c) Replace with an inclined access tunnel

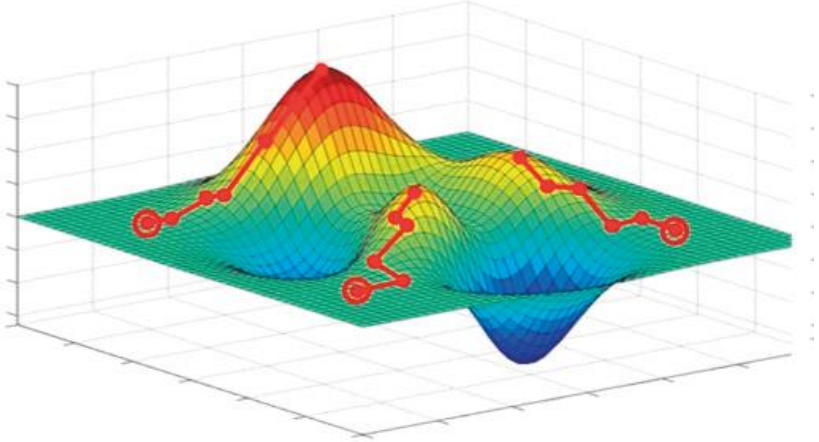


Tunnel Optimistation Tool capabilities and limitations

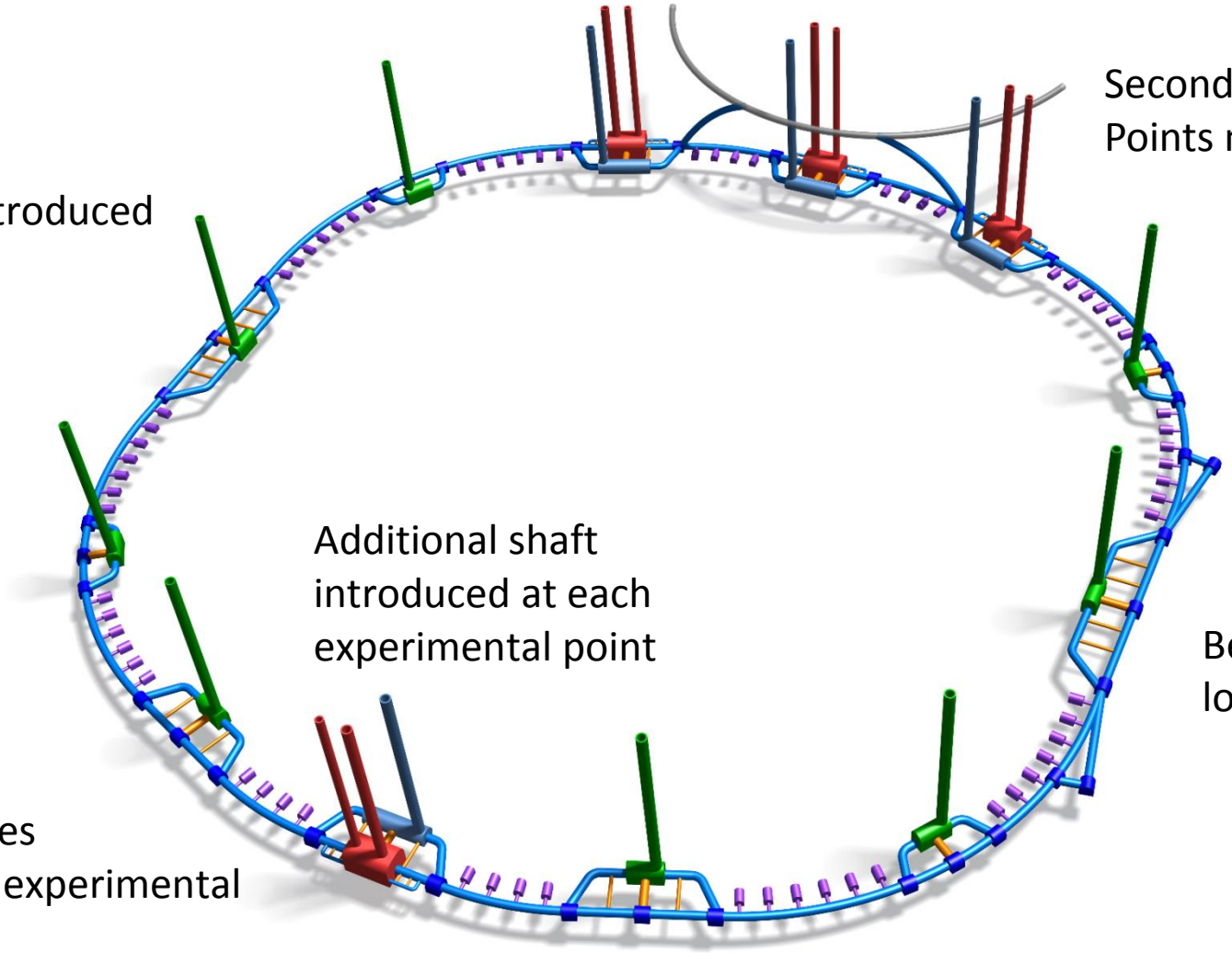
- TOT is only as powerful as the data behind it.
  - Topographical data is very accurate
  - Certain areas of geological data more accurate than others.
  - Interpreted data from existing maps and boreholes.
  - Site Investigation is required to significantly improve understanding.

- Automation of the tool is a possibility but challenging.
  - Optimisation algorithm such as ROXIE (previously used at CERN for magnet design optimisation) could be used.
  - The challenge is the large number of variables.
  - Not all variables are easily quantified.
  - Potential for automating certain features such as shaft positions once the layout and siting are fixed.





Berlin Schematic – Single Tunnel



Secondary experimental Points moved to B & L

Electrical alcoves introduced at 1.5 km spacing

Additional shaft introduced at each experimental point

Beam Dumps both located at Point D

Survey Galleries introduced at experimental points

CE Cost and Schedule Studies

- Cost & Schedule Study launched in September 2016
- Two sets of consultants engaged to work independently.

ILF CONSULTING ENGINEERS

GEOCONSULT

synaxis BAUINGENIEURE SIA/USIC

Phase 1

Cost & Schedule estimate for "baseline" single tunnel design.*

Phase 2

Cost & Schedule implications of variations considered:

- Double tunnel design
- Shallow option
- Alternative tunnel diameters
- Alternative shaft diameters
- Alternative cavern dimensions
- ee machine requirements
- Alternative schedule + Inclined access tunnels

Phase 3

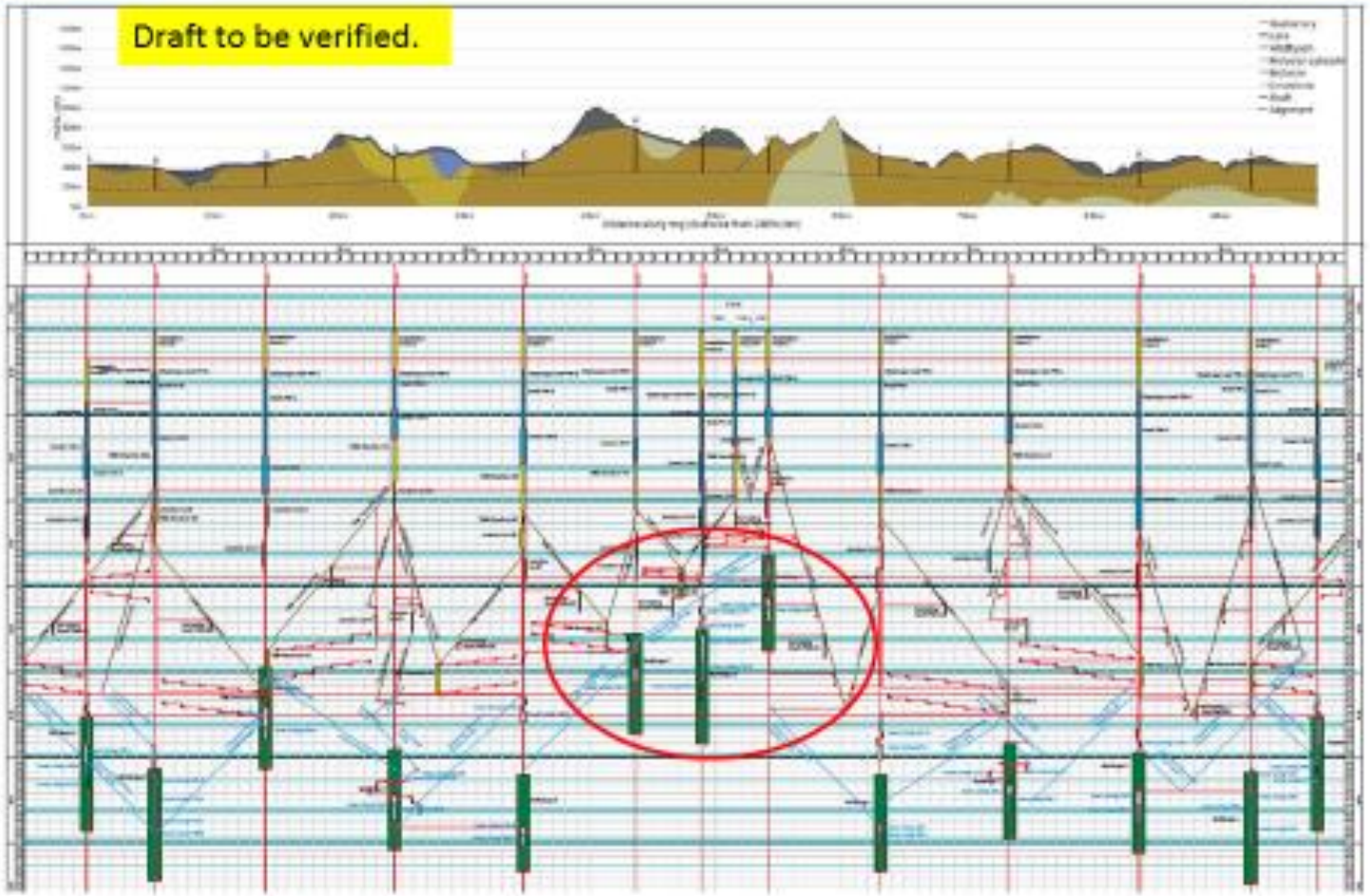
Refinement of results from Phases 1 and 2:

- Review to include updates made to baselined design.
- Incorporate desirable variations from Phase 2.

*Some changes have been made since the study was launched including raising the profile and introduction of third shaft at experimental points.

CE Schedule Studies

Early schedule results – Accelerated schedule (2)

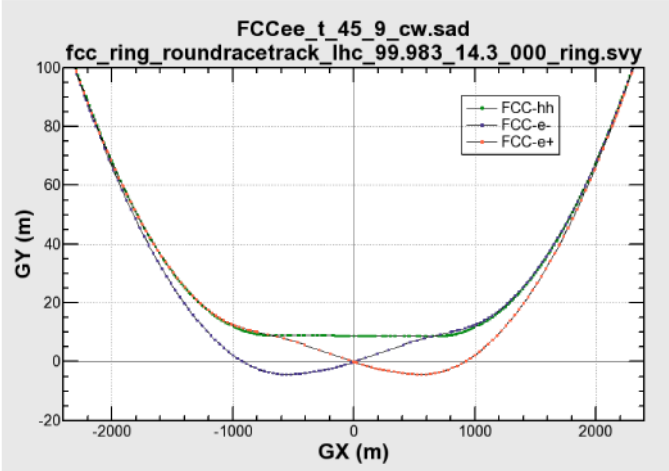


- First two sectors complete in 4 years, 11 months.
- Construction complete in 6 years, 5 months.

Close co-ordination with Julie Coupard

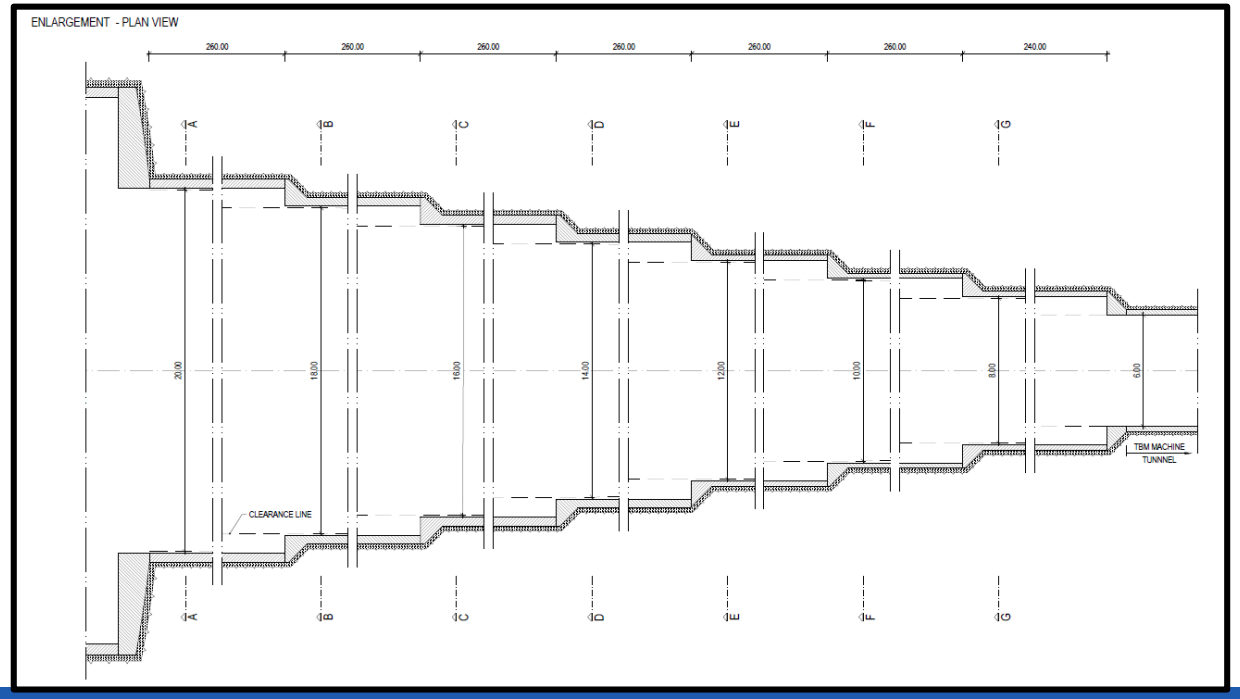
ee machine CE requirements

- Tunnel widening required around points A & G to accommodate ee lattice.
- Design is not fully developed: potential for a combination of double tunnel and enlargement caverns to accommodate lattice.
- For Cost & Schedule study: 1.8 km of tunnel widening on either side of IPs at A and G considered.



*not the latest ee plot, but the one that was used for initial costing exercise

IP

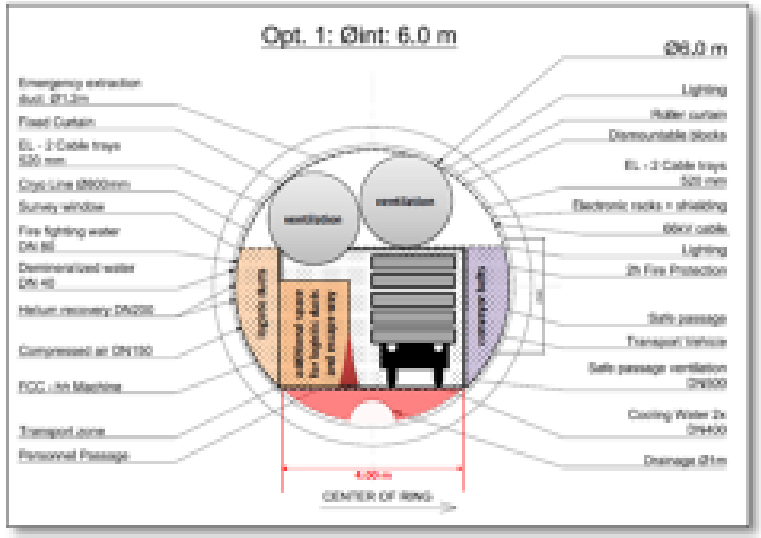


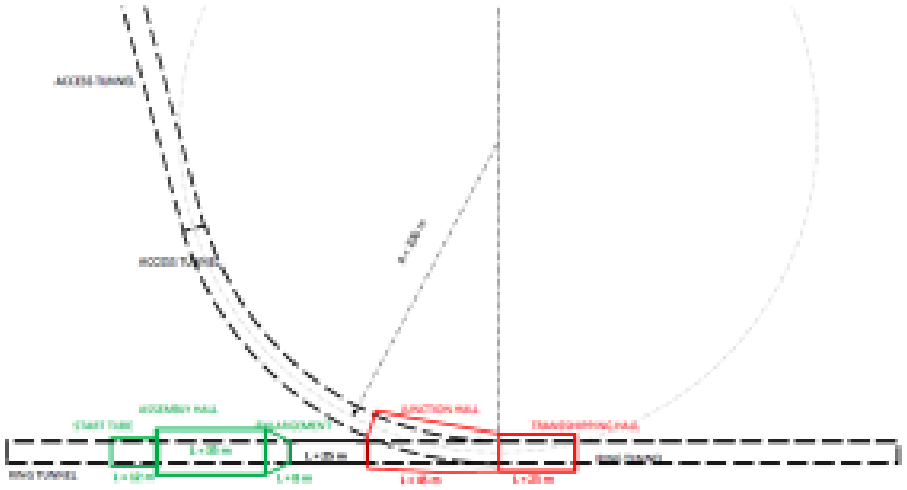
Inclined tunnel possibilities (instead of vertical shafts)

AMBERG ENGINEERING

Inclined Access Study

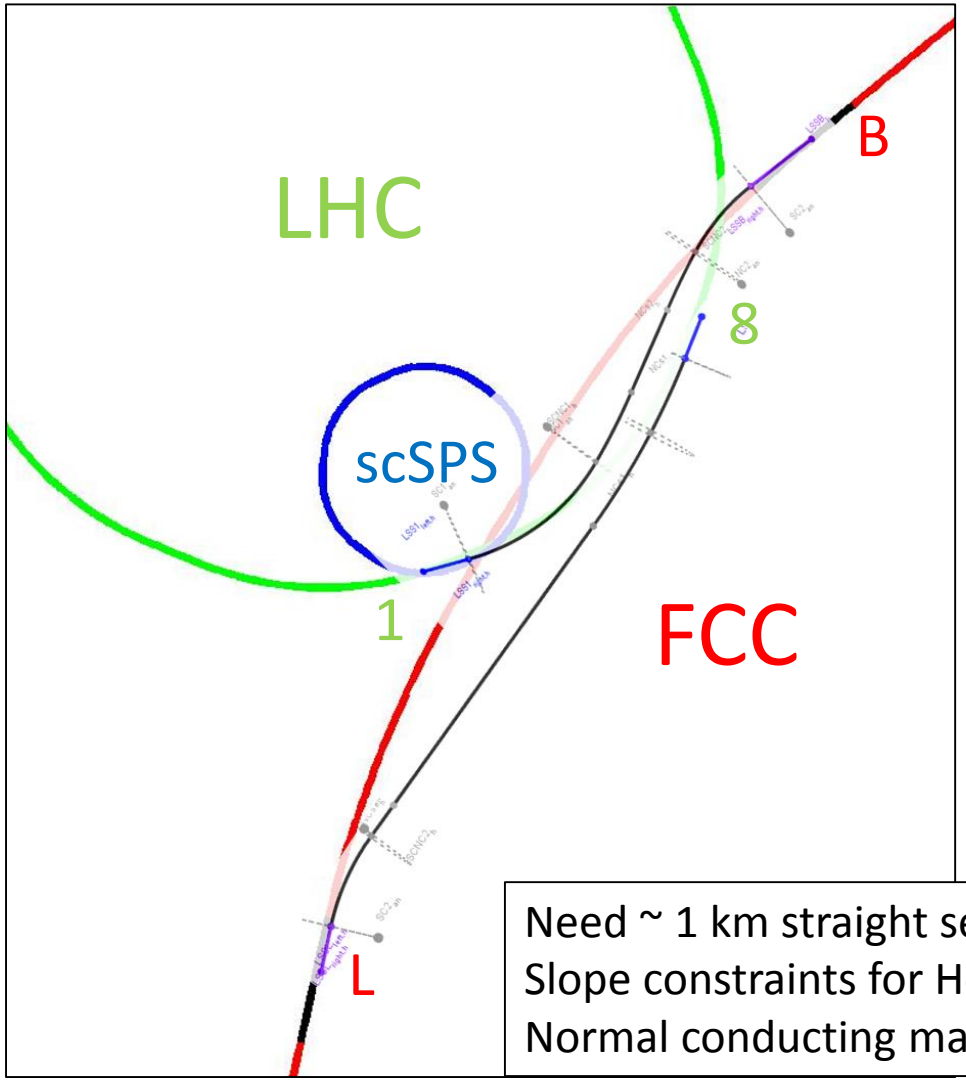
- Study launched with Amberg Engineering following FCC week 2016 to verify feasibility of inclined access tunnels.
- Main questions:
  - Can a shaft be replaced with a 6.0 m diameter tunnel and a TBM be launched from the bottom?
  - What is the estimate for possible time saving?

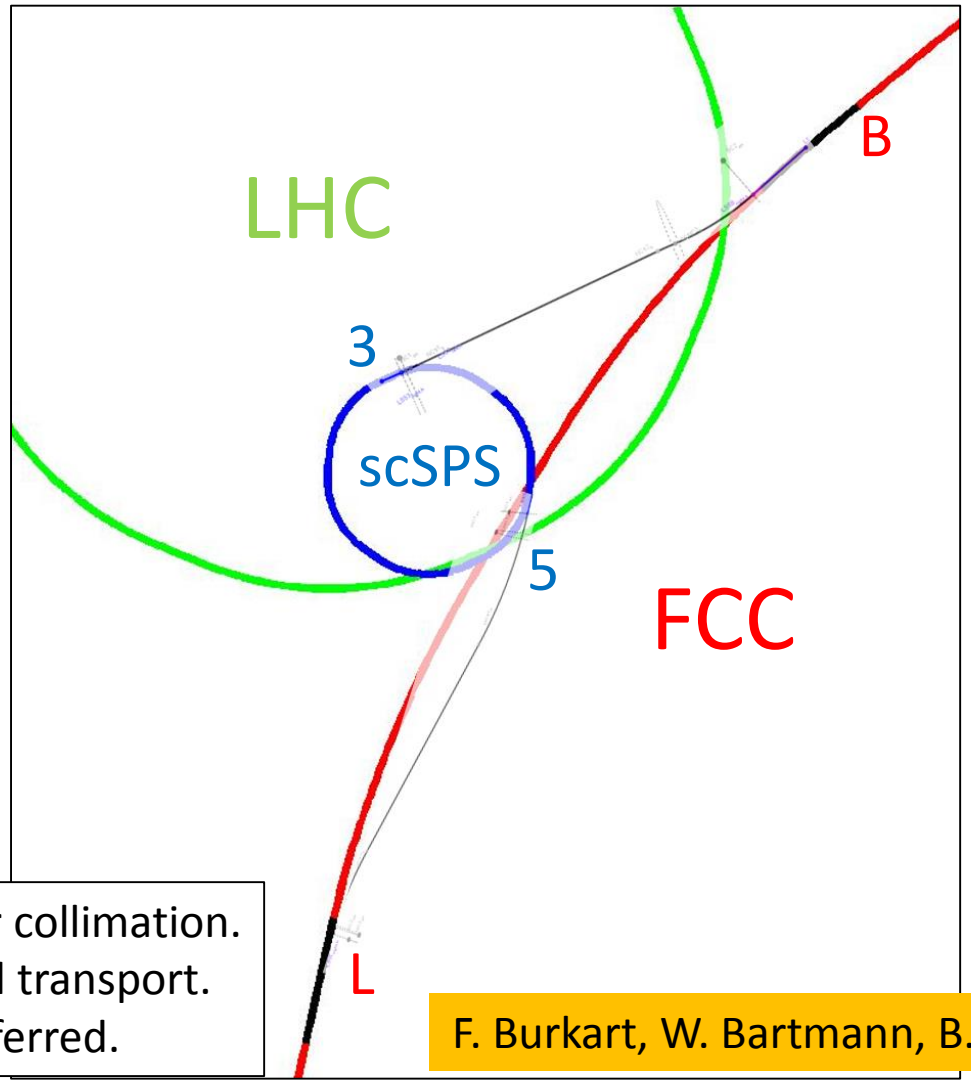




- Feasibility of logistics confirmed.
- Confirmed that some time reductions are possible – construction of inclined access can start during procurement of TBM.

Beam Transfer from LHC or SPS





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)

he civil engineering studies : preferred location

Why is experimental point L preferred?

Positives:

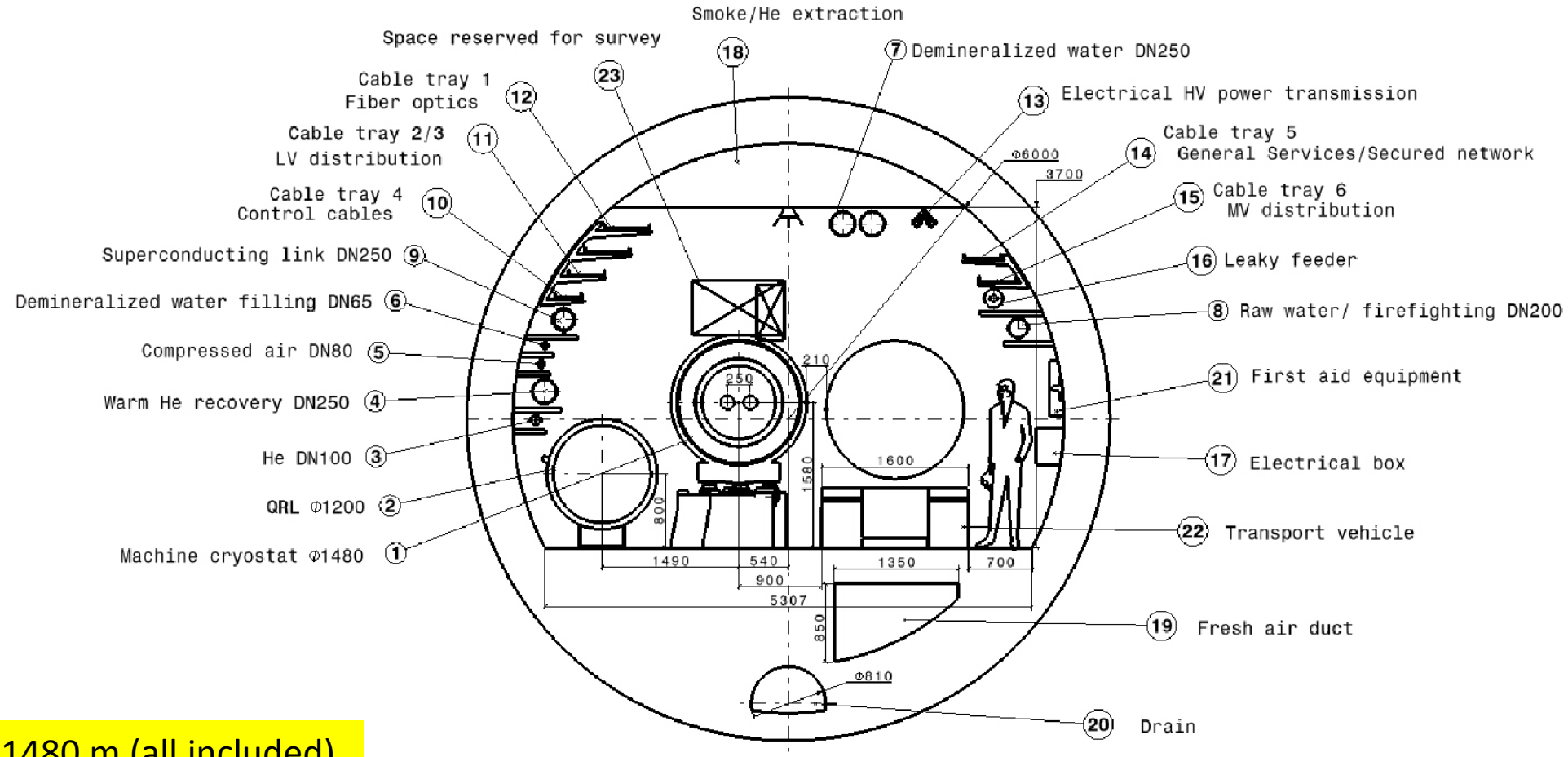
- Low geological risk compared to other locations, anticipated tunnelling in molasse only.
- Close to current CERN site.
- FCC ring relatively shallow at this point, therefore shallower shafts.

Remaining problems:

- Potential clash with injection lines needs to be studied.
- Located inside the FCC ring so integration with other structures to be studied.
- Depth below Rhone to be evaluated.

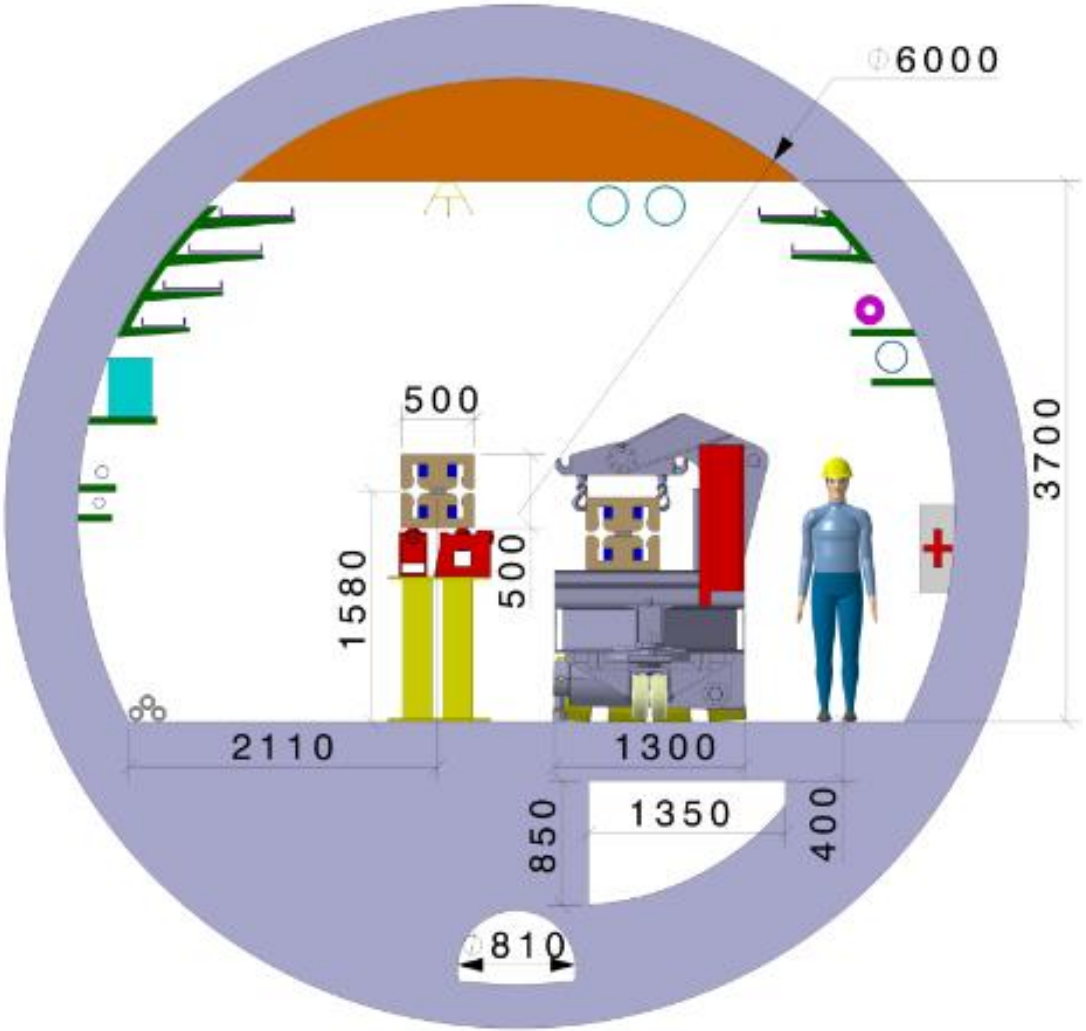
Civil engineering optimisation for FCC-he (J. L. Stanyard)

Tunnel cross section, FCC-hh



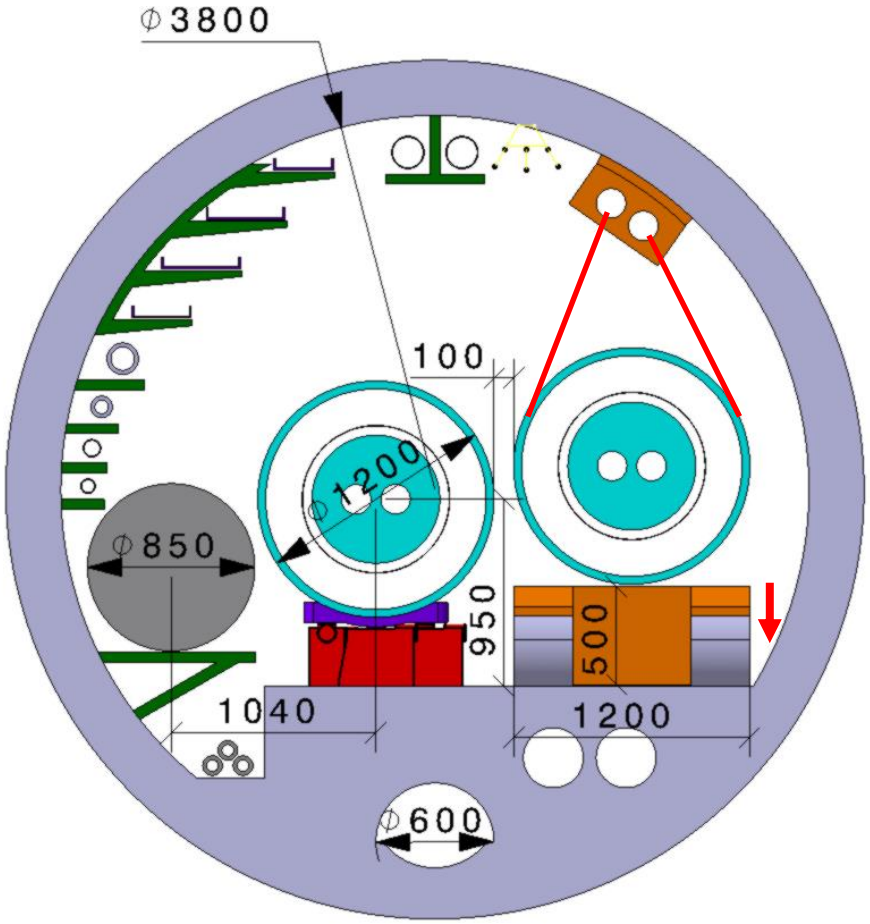
Magnets OD 1480 m (all included)
QRL OD 1200 mm (all included)

Tunnel cross section, FCC-ee



F. Valchkova-Georgieva
Magnet model: A. Milanese

Tunnel cross section, HE-LHC



Limited 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

Today: 16 T magnet R&D (D. Tommasini) and other presentations

F. Valchkova-Georgieva

Supply and Distribution of Electrical Energy

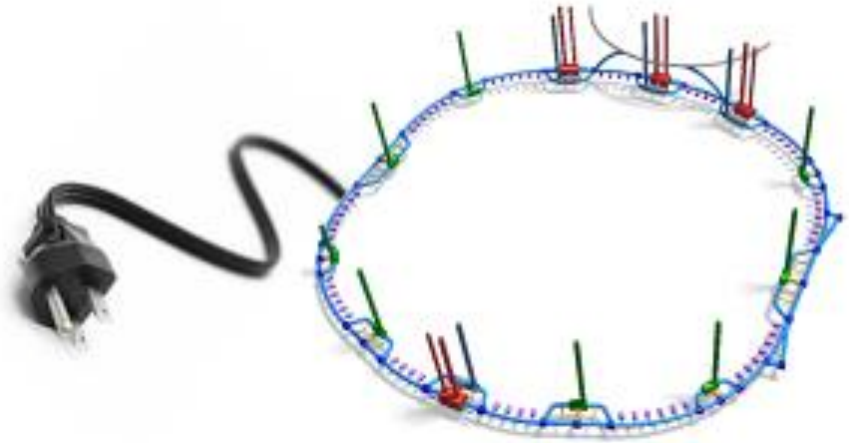
Supply and Distribution of Electrical Energy

FCC week 2017, Berlin

Davide Bozzini - CERN

With the contribution of the FCC Infrastructure & Operation Working Group and CERN Electrical Group members

ENGINEERING DEPARTMENT

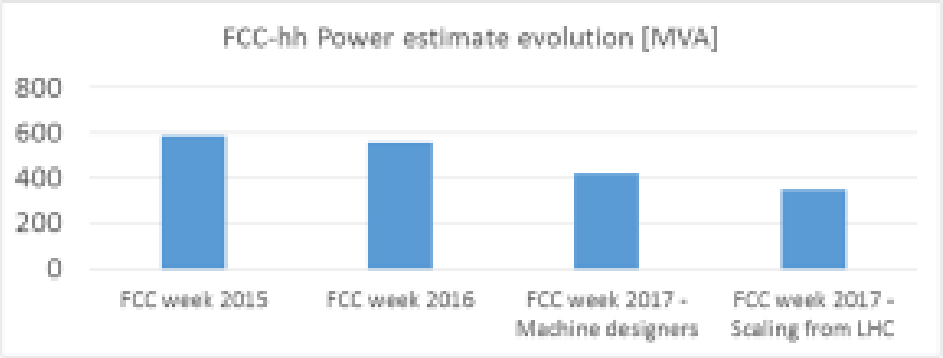


Power Consumption Estimate FCC-hh

- **FCC week 2015**
  - First estimate for FCC-hh scaled on 4 x LHC design report and systems estimate when available
- **FCC week 2016**
  - Definition of maximum target power consumption for FCC-hh at 555 MVA
- **FCC week 2017**
  - Two approaches for FCC-hh
    - Input from machine/ system designers
    - Scaled from LHC real consumption

System	FCC week 2015	FCC week 2016	FCC week 2017	
			Machine designers	Scaling from LHC
FCC-hh	585	555	423	347
Injectors			122	
Data centers			7	

Values expressed in MVA – Considered Power Factor = 0.9



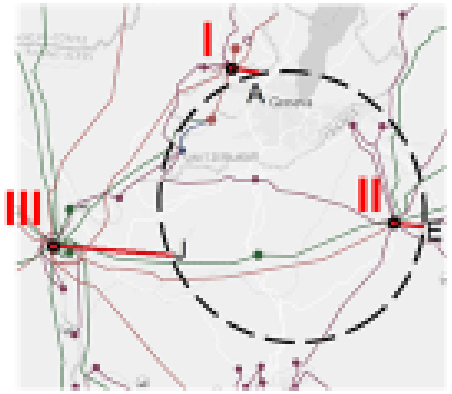
Injectors requirements and data centres not included

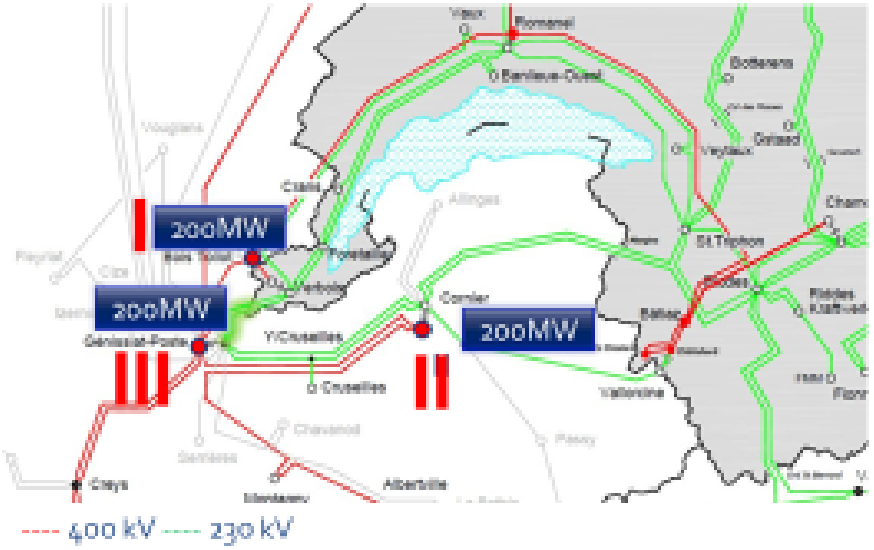
-Two approaches adopted
-Estimates are coming down

Supply and Distribution of Electrical Energy

Availability of power at European grid level

- Based on mid long term plan (2030) of the network operator
- Additional **200 MW are available** simultaneously at each 400 kV source (I,II, III)
- Total power higher than 600 MW will require **major hardware changes** at the European grid level
- Maximum available power in case of N-1 availability of the sources might **impact the transit of power at grid level**
- Power availability on existing sources operated at lower voltages (230 kV and 132 kV) is **included in the same budget** (3 x 200 MW)



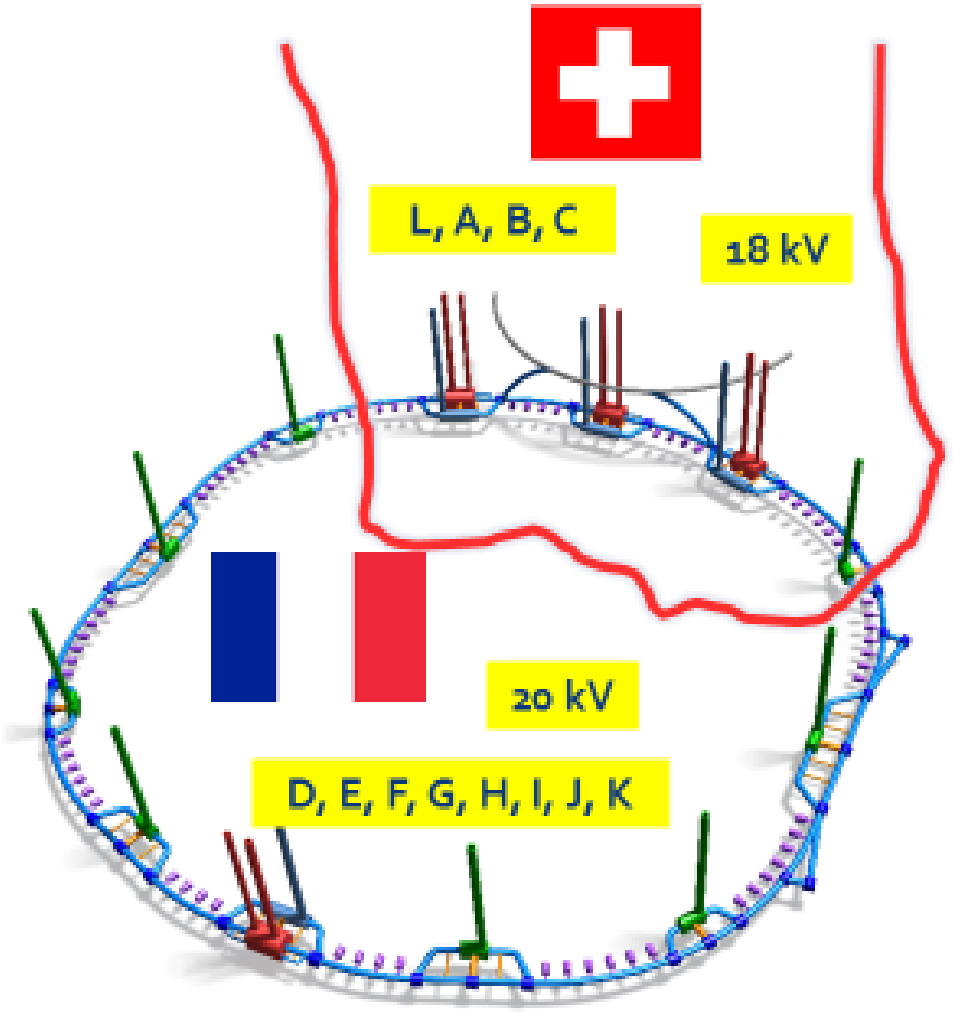


-3 sources exist
-network capabable

Supply and Distribution of Electrical Energy

Geneva Based Related Aspects

- Current civil engineering baseline includes **4 access points on Swiss and 8 access points on French** territory
- The three **main sources are located in France**
- Swiss and French local (second) sources are **operated respectively at the following different voltage** levels 18 kV and20 kV
- Access points are located in **urbanised and agricultural areas**



-Surface impacts to be evaluated

Electrical Conclusions

Conclusions

With respect to the CDR …

- Powering of the FCC-hh and FCC-ee from the European grid - **Feaseble**
- Baseline transmission and distribution layout for FCC-hh - **Available**
- Functional concept for the electrical distribution in the arcs for the FCC-hh - **Available**
- The same exercise for FCC-ee and HE-LHC – **To be initiated**
- Inputs for an FCC-hh electrical infrastructure cost and schedule review based on the proposed baseline - **Available**

… and from a conceptual design study point of view

- Comparative study for the transmission line between points - **To be completed**
- Power consumption estimates and location - **To be continued**

Ventilation Systems

A ventilation system for the FCC tunnel

M. Nonis, G. Peon – CERN EN Department / CV Group

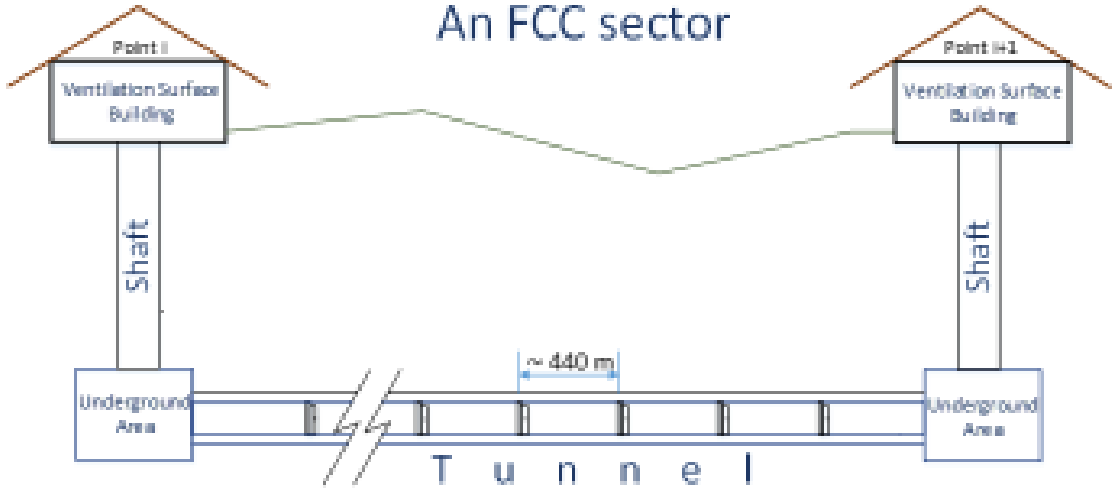
FCC Week, 1st June 2017

Ventilation Systems

Main Input Parameters: Geometry

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

Compartment Input data	
Number of Compartments	24
Compartment length	440 m
Volume Compartment	7788 m^3



-main parameters better understood

Ventilation Systems

Main Input Parameters: Estimated Loads in the Sectors to the Air

SECTOR	FROM MAGNETS (kW)	TRANSMISSION LINE (kW) (normal conditions)	OTHERS (kW)	TOTAL (kW)
A-B	60	13	39	112
B-C	110	21	65	196
C-D	140	24	75	239
D-E	120	24	75	219
E-F	110	21	65	196
F-G	50	12	39	101
G-H	50	12	39	101
H-I	110	21	65	196
I-J	120	24	75	219
J-K	140	24	75	239
K-L	110	21	65	196
L-A	60	12	39	111

Approx. Maximum 240 KW from magnets/transmission lines other equipment

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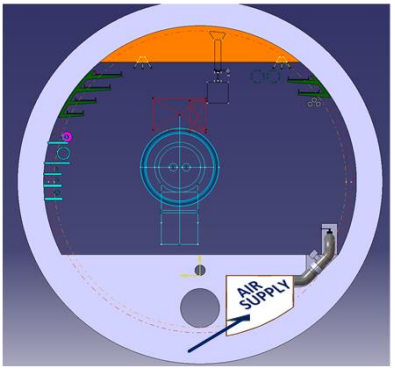
Ventilation Systems

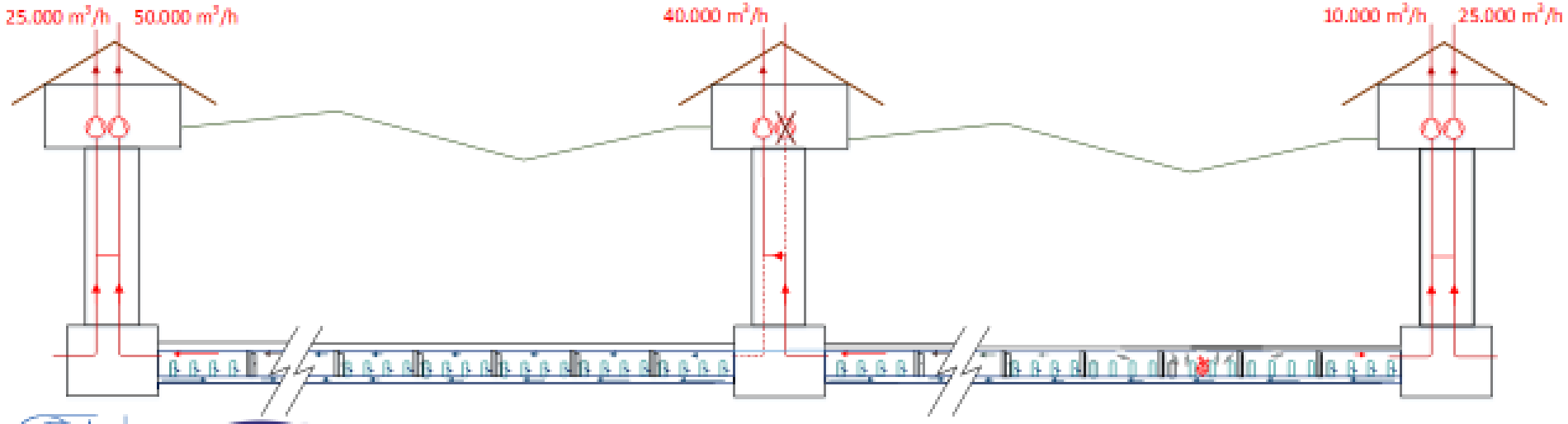
-Many scenarios simulated

Smoke/He Extraction



Ventilation in degraded conditions: worst case scenario

- Combination of previous scenarios:
  - Extraction AHU breaks down;
  - During an emergency situation (smoke or helium release);
- Interaction between extraction units of two adjacent sectors
- Assuming nom. flow 25000 m³/h and max. flow 50000 m³/h



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Ventilation studies : next steps

Conclusions and further steps

- The design of the ventilation system is adapted to the new configuration (compartmentalised);
- Estimated heat loads to the air of the tunnel can be cooled by the air without any additional cooling
  - Though tunnel wall temperature needs further study
  - Heat load estimations need validation
- The ventilation system ensures the required functionality during normal and degraded conditions;
- The foreseen pressure differential cascade and airlocks to prevent less activated zones to be exposed to air from more activated areas has also been addressed;
- The singularities in each type of point have been addressed.
- Next steps: validation of the concept and more detailed design

Logistics

100%
LOGISTICS

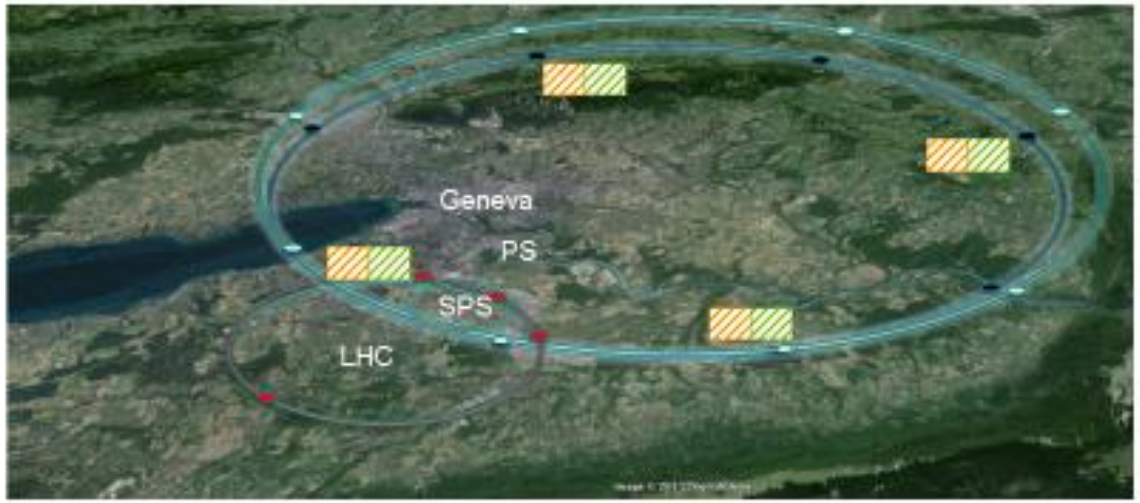
Fraunhofer
IML

Thursday 9:35: Logistics : Ingo Ruehl, Matti Tiirakari and Fraunhofer Institute

Logistics

Several Logistics scenarios being studied

Alternative 2: Decentral Assembly and Testing Facilities with several shafts



Test Cryo-Unit

Assembly Cryo-Unit

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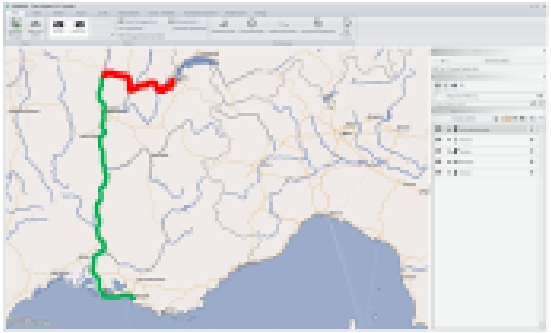
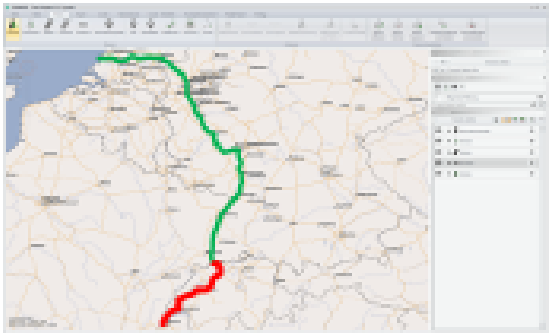
Different Routes to CERN and Transport Modes



Marseille: -> CERN

- Using barge/road transport:
  - Seaship to Marseille:
  - Barge to Mâcon
  - Road transport to CERN
- Using only road transport:
  - Seaship to Marseille
  - Road transport to CERN



Rotterdam<-> CERN

- Using barge/road transport:
  - Seaship to Rotterdam
  - Barge to Basel
  - Road transport to CERN
- Using only road transport:
  - Seaship to Rotterdam
  - Road transport to CERN

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Cryogenics

FCC Week 2017, Berlin

Towards a conceptual design for FCC cryogenics

Laurent Tavian,
CERN, ATS-DO

On behalf of the FCC cryogenics study collaboration

1st June 2017

Cryogenics

Towards a conceptual design for FCC cryogenics

"Bellevue"

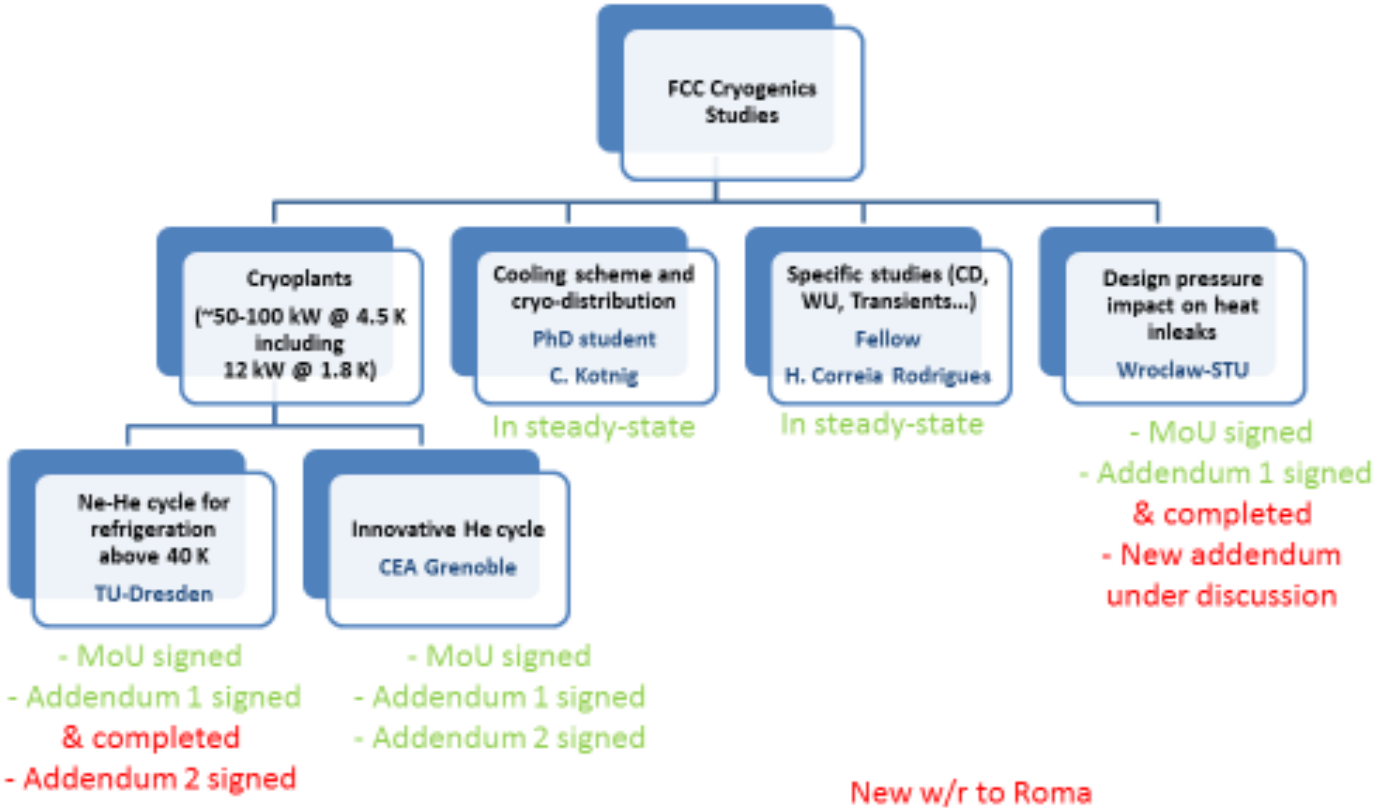
Cryogenic refrigeration with neon-helium mixtures fo... *Steffen Kloeppel*

Technical specifications for industry studies on the FCC cryogenic system *Francois Millet*

Cryogenic distribution fo... *Paweł Duda*

D. Delikaris

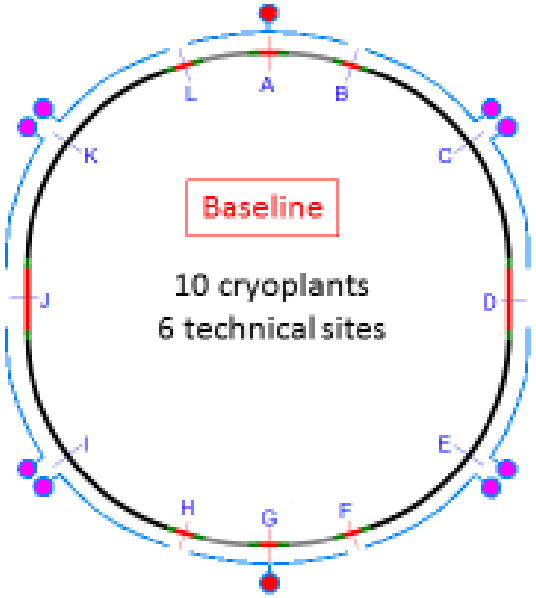
FCC cryogenics studies



Cryogenics

FCC cryogenic layout and architecture

10 Cryo plants at 6 sites.
Each plant approx. 10km supply

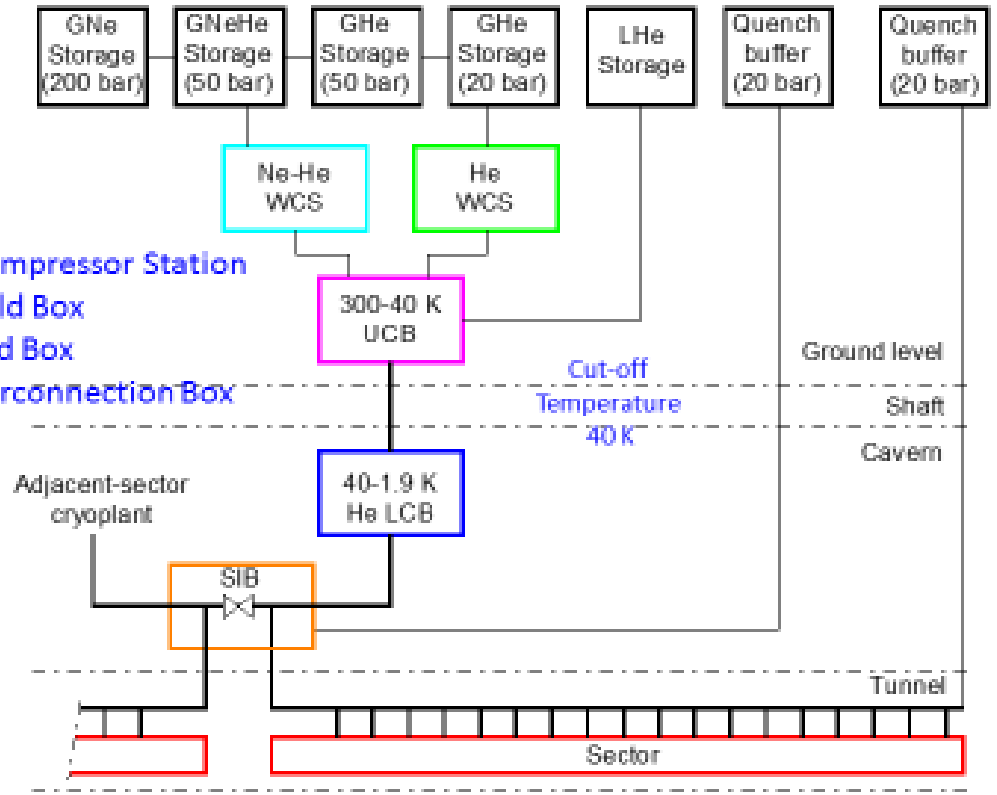


Cryoplant	40-60 K [kW]	1.9 K [kW]	40-300 K [g/s]
●	592	11*	85
●	618	12*	85

Without operational margin !

*: Outside State-of-the-Art

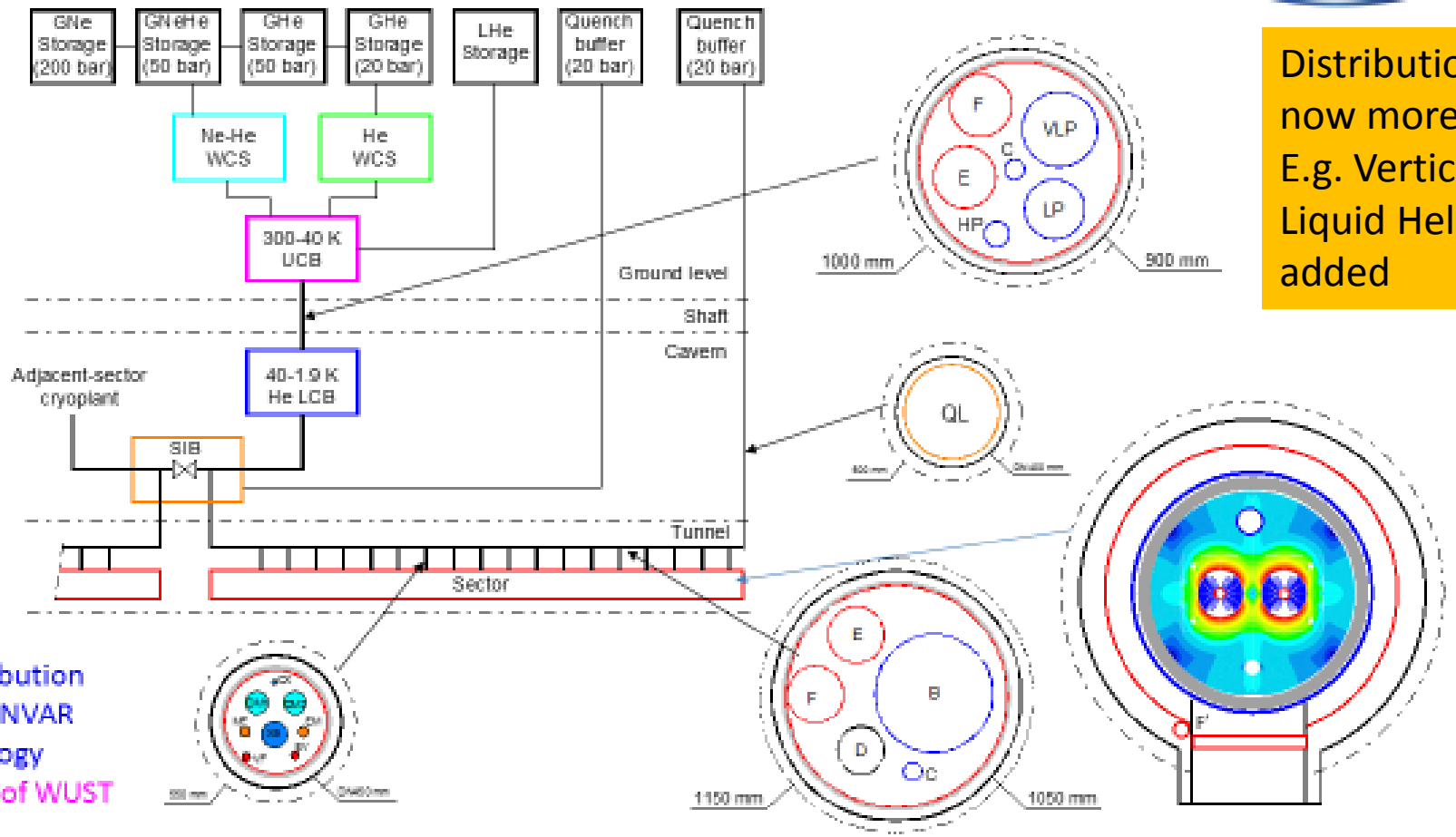
WSC: Warm Compressor Station
UCB: Upper Cold Box
LCB: Lower Cold Box
SIB: Sector Interconnection Box



Cryogenics

Main cryogenic distribution

	DN mm
B	500
C	80
D	200
E	250
F	250
F'	50
HP	100
LP	250
VLP	300
QL	400



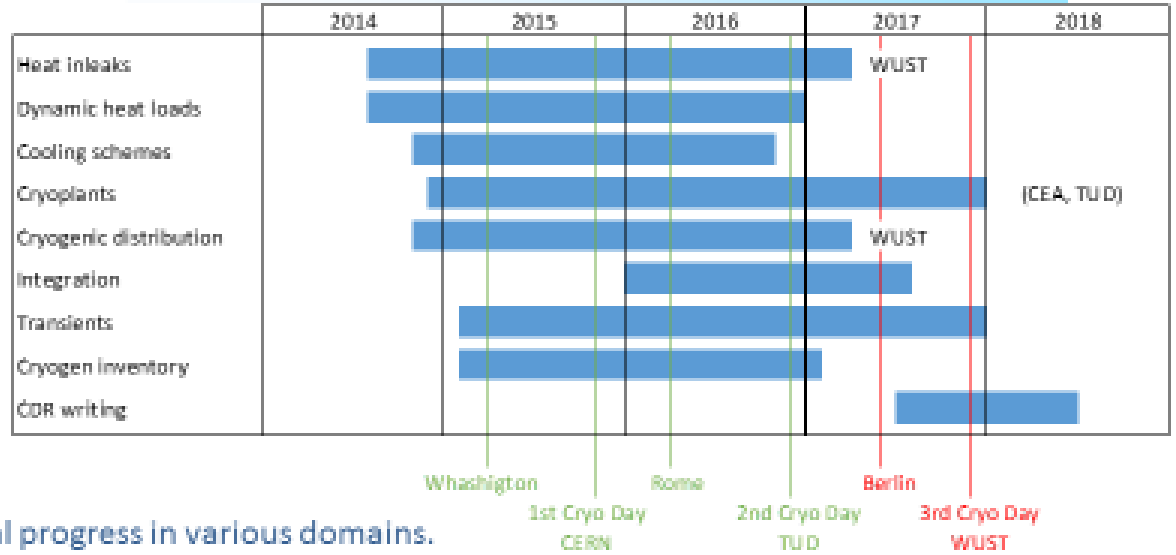
Main distribution based on INVAR technology

Contribution of WUST

Distribution systems now more defined E.g. Vertical Line C for Liquid Helium transfer added

Cryogenics

Conclusion: schedule



2017 studies:
- Cyroplants
- Transient operation Mode

Substantial progress in various domains.

Next important steps:

- FCC-hh: Complete the engineering studies with our industrial partners (Air Liquide and Linde)
- FCC-hh & HE-LHC: Cryogenic transients during resistive transitions → impact on quench valve size & number and on cold-mass design pressure.
- FCC-hh & HE-LHC: Energy buffering during magnet current ramp-up and fast ramp-down → impact on helium inventory (is 33 l/m (400 t) sufficient ?)
- FCC-ee: Refine the staging scenario with 400 MHz (4.5 K) and/or 800 MHz (2 K).
- All: Operational margin discussion/definition → impact on capital and operation cost

FCC-hh operation schedule and turn-around cycle

Initial operation schedule

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

3.5yrs of operations in 5yr cycle is current goal but there is a large potential to extend the time between shutdowns.

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)

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)

FCC Availability Studies

Andrea Apollonio – CERN TE-MPE
Arto Niemi – CERN BE-ICS

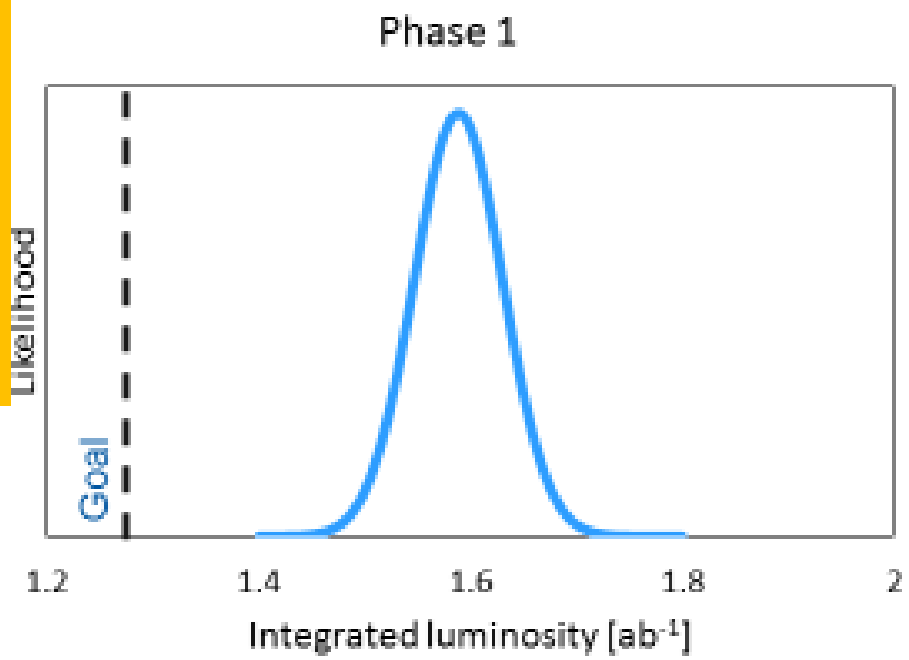
FCC Week – Berlin 2017

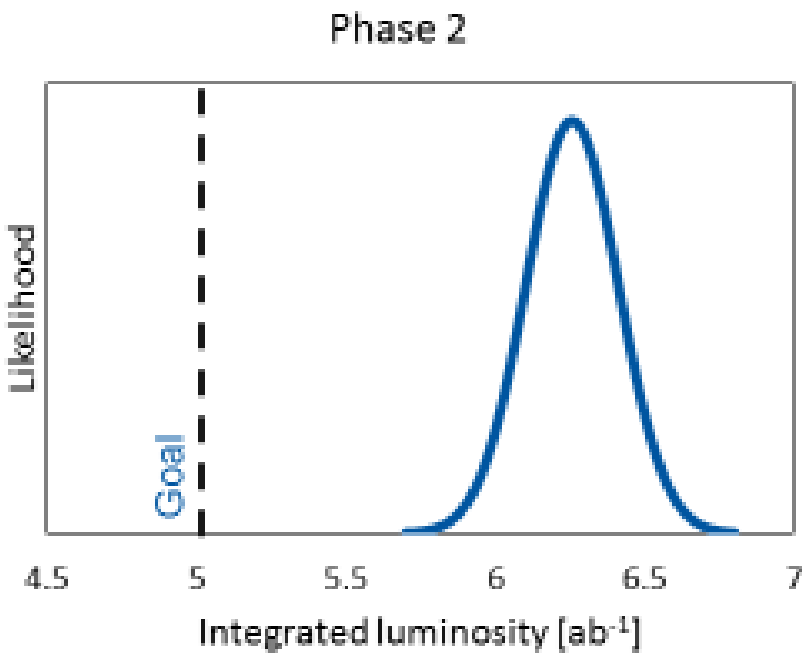
Acknowledgements: R. Alemany, M. Benedikt, F. Burkart, J. Gutleber, V. Mertens, J.-P. Penttinen, D. Schulte, L. Ponce.

Availability and Integrated Luminosity Studies

FCC Luminosity Production for LHC-like Availability

Luminosity goals very challenging but appear achievable
Phase 1 : 1.25
Phase 2 : 5





IF the FCC will exhibit the same overall LHC availability, the production goals can be achieved (NB: despite the increased number of systems and higher energies)

Availability and Integrated Luminosity Studies

Injection from Superconducting SPS seems promising from availability point of view

Injector Options - Assumptions

Scenario 1

Upgraded LHC:

- Present day LHC failure rates
- No experiments
- No failures due to high energies (UFOs, training quenches)

Scenario 2

Superconducting SPS

- SC-magnets
- Quench protection
- Power converters
- 3 Cryogenic plants

IMPORTANT: Availability is not the only parameter to be considered when comparing injector options. This study does not include considerations on costs, electricity consumption, magnets' field quality, constraints on transfer lines design, work required to replace existing accelerator systems, project schedule, etc.)

Safety Strategy for CDR, T.Otto

Hazard Register

Systematic collection of Hazards, ordered by:

- **Technology**
  - S.c. magnets
  - N.c. magnets
  - Cryogenics
  - Vacuum
  - Powering
  - Transport
  - … others
- **Project Phase**
  - Construction
  - Service Installation
  - Accelerator installation
  - Commissioning
  - Operation
  - Technical Stop
  - Long Shut-down
  - Dismantling
- **Location in the facility**
  - Surface
  - Shaft
  - Long Straight Section
  - Arc Tunnel
  - Caverns
  - … others

Potential of a substance, activity or process to cause harm

Standard best practices where available to try and render hazards inoffensive

Future Circular Collider Study
Thomas Otto
FCC Week, Berlin, 1 June 2017

FCC Safety Strategy for the CDR

1

Safety Strategy for CDR

Example :
Typical chain between technology and the hazard

Safety Strategy for CDR

If Standard best practice not applicable, this risk assessment method will be adopted

Peformance-based Safety Design

Objective	In case of fire, no loss of human life
Performance Criterion	Nobody exposed to dangerous CO conc.
Test Fire	location ignition source, combustible material, heat release power
Trial Design	building structure, occupation frequency, safety devices (alarms)
Evaluate	Does trial design meet performance criteria ? Yes: adopt trial design No: Improve trial design

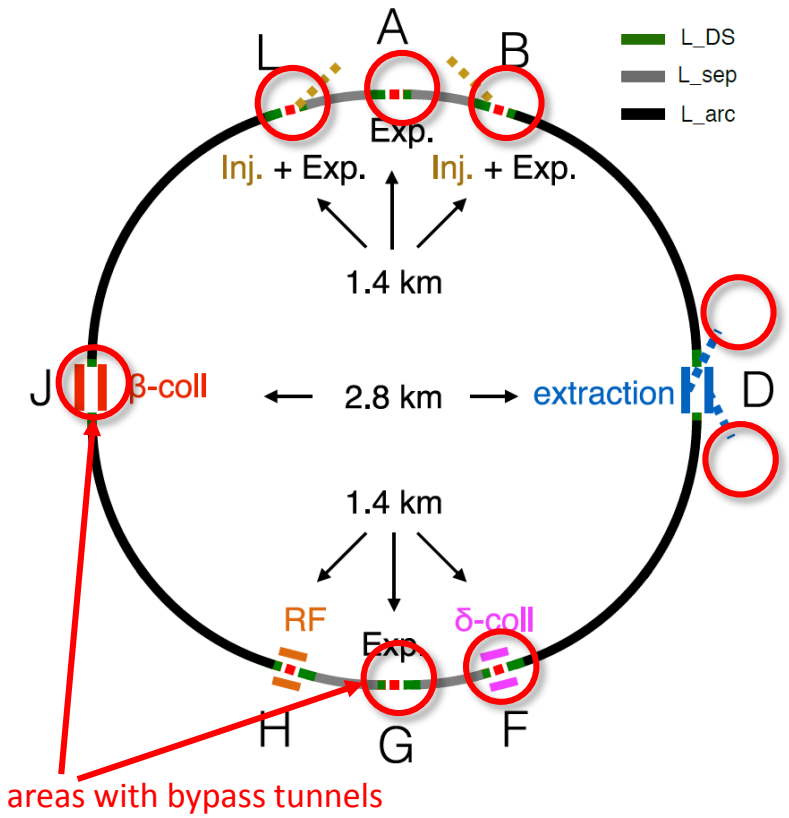
Future Circular Collider Study
Thomas Otto
FCC Week, Berlin, 1 June 2017

FCC Safety Strategy for the CDR

3

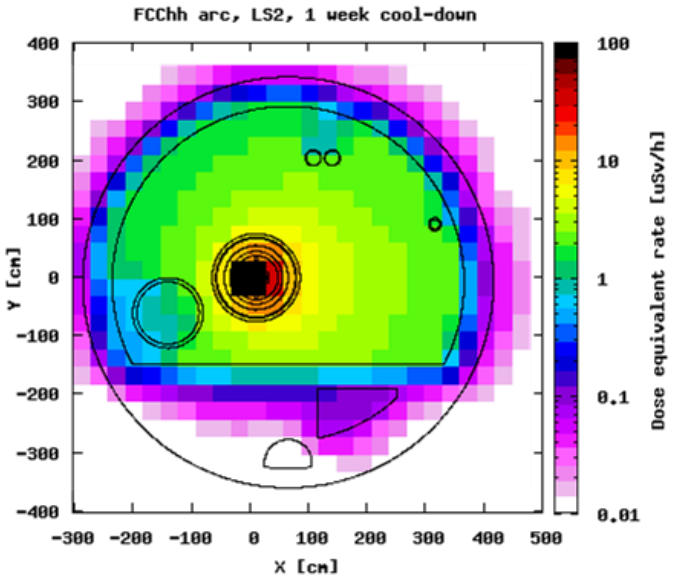
Radioprotection matters

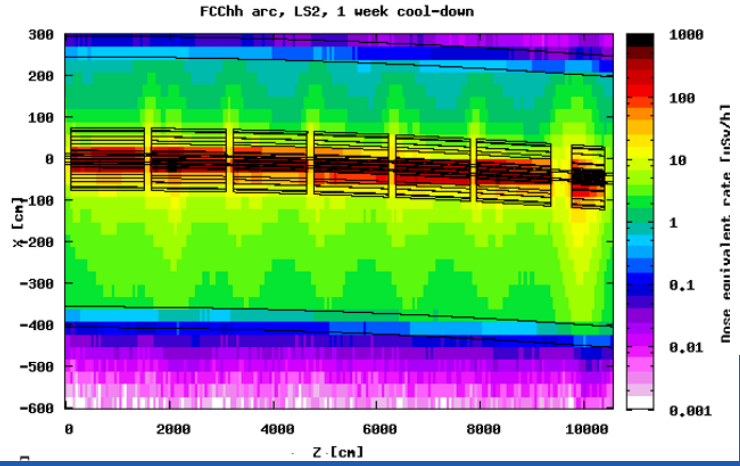
High-radiation areas



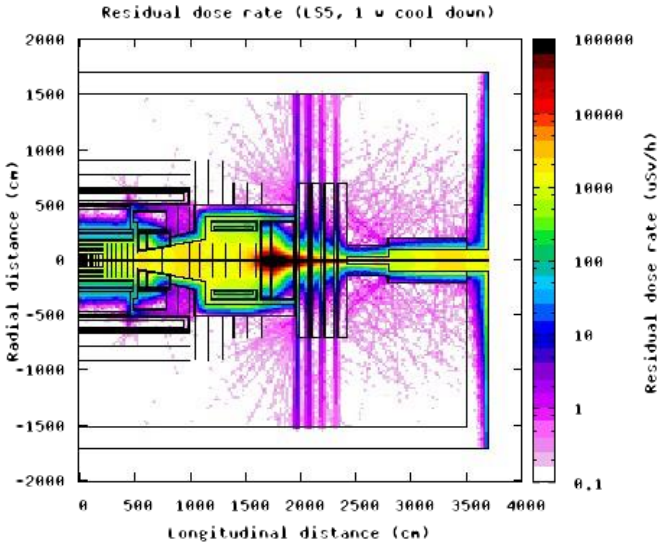
Radiation hazards lists (prompt stray radiation, activated air, X-rays ...

FCC-hh arc residual dose rate





FCC-hh detector residual dose rate



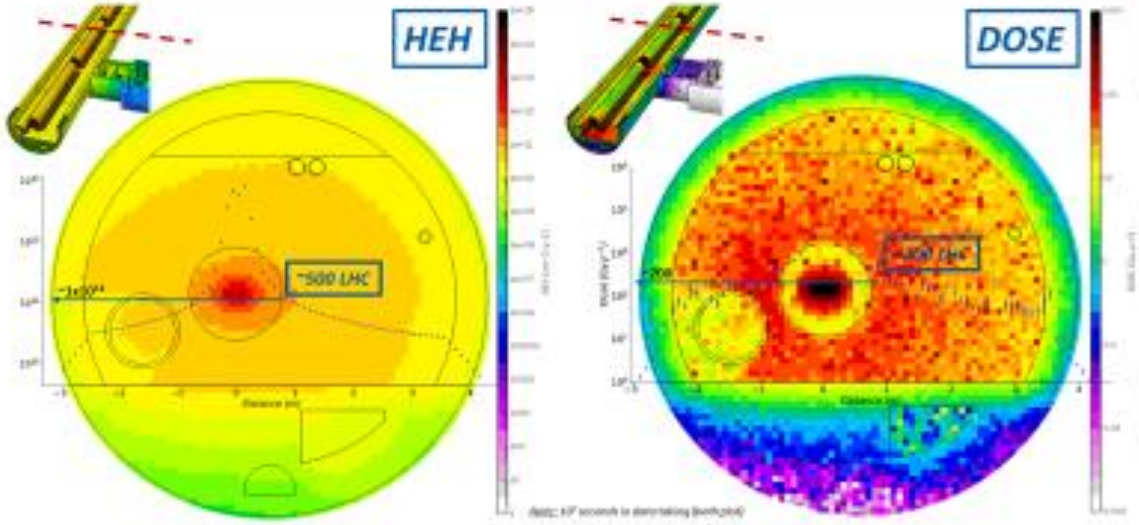
RP simulations advanced well since room Rome in machine and detector areas

Radioprotection matters (M. Widorski)

Radiation Levels, Angelo Infantino

FLUKA simulations advancing for new layout. Possible extra shielding needed at alcoves.

R2E: Radiation Levels in the FCC Tunnel



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:

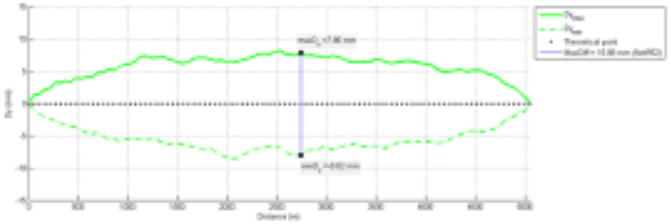
- ✓ *Strong interaction* across many areas of expertise (I&O, Magnets, Vacuum…)
- ✓ *R2E*: assessment of the radiation levels in *critical areas* for electronics (e.g. power converters): *HEH ~500* and *DOSE ~200* LHC.
- ✓ Taking into account the radiation levels in the tunnel, the *qualification requirements* (procedures, test facilities,…) already beyond current availability.

A. Infantino | *FLUKA Monte Carlo modelling of the FCC arc cell: radiation environment and energy deposition due to beam-gas interaction*
FCC Week 2017, 29 May 2017 - 2 June 2017, Berlin, Germany

Surveying and Alignment, Dominique Missiaen, Mark Jones and Nerea Ibarrola Subiza

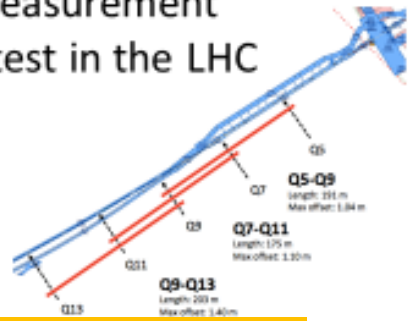
Surveying and Alignment

- Geodesy
  - GPS measurement campaign of the CERN Geodetic Network
    - To redeterminate the transformation parameters between Cern Coordinates System and International one
  - Simulation of the underground network accuracy depending on distance between shafts (5/10 km)



Surveying and Alignment (2)

- Geodesy (ctd)
  - Calculation of a new geoid on the whole FCC area (Swiss topo with data from french IGN) on going
- Alignment
  - Application of the wire offset measurement technique with wires of 200m, test in the LHC (Poster)



-GPS measurements in CERN area planned for 2017.
-First indications suggest that the 5km intermediate shafts might not be required, but to be confirmed.
-Wire tests in LHC P8 area provided some interesting results.

Conceptual Design Report for I&O matters

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

Concluding remarks

- Impressive progress by Infrastructure and Operation working group
- Need to conclude by end of the summer on a Baseline Layout, Cross Sections etc. to allow more in-depth studies which are in accordance with the Performance Based Safety Criteria
- Cost and Schedule studies to be further developed
- Intensive effort will be required over the coming months to complete the CDR in 2018.

Big thanks to presenters, chairpersons and organisers

THANK YOU FOR YOUR ATTENTION

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