FCC Civil Engineering Optimisation and Design Development

John Osborne & Joanna Stanyard (SMB - Site Engineering - FAS Section)

With acknowledgements to I&O and all FCC study teams
Outline

• Brief history of previous layouts and positions

• Layout & siting progress since Rome 2016

• Design development of structures

• Cost & Schedule study

• Future steps
Brief History of Previous Layouts and Positions

- **European Strategy, Krakow 2012: 80km Options**
  During pre-feasibility an 80 km layout was considered with 2 distinct positions: Jura mountains v lakeside.

- **Kick-off meeting, Geneva 2014**
  The two 80 km options were reviewed in addition to a 47 km option.

- **Washington 2015: Multiples of LHC Considered in 80 km, 87 km, 93 km, 100 km**
  In addition to the 80 km option, other multiples of the LHC were considered: 87 km, 93 km, 100 km.

- **Rome 2016: Intersecting v non-intersecting 100 km options considered**

- **August 2016: 97.75 km options introduced in comparison to Intersecting option (V1)**
  A variety of options were considered to identify the optimal layout for the machine whilst fitting within the geological constraints.
Comparison Criteria

1. Geology along alignment:
   - Maximum proportion of tunnel in molasse.
   - Avoid limestone formations wherever possible due to associate risk of water ingress and karsts.
   - Avoid water bearing moraines wherever possible due to risk of water ingress and potential contamination of water sources.
   - Minimise overburden.

2. Shaft length:
   - Minimise total shaft length.
   - Avoid individual very deep shafts, particularly at experimental points where there are multiple shafts.

3. Geology of shafts and caverns
   - The greater the depth of the moraine before reaching the molasse layer, the more costly/time consuming the construction.
   - Cavern construction requires good ground conditions.

4. Environmental Constraints
   - Avoid protected water sources.

5. Shaft Surface Locations
   - Initial assessment to avoid clashes with buildings, natural features or protected zones.
   - Followed by a more refined assessment of feasibility including potential access to the site.

6. Injection Line Length
   + Additional ‘softer criteria’
The round of optimisation undertaken in August 2016 led to the selection of the current 97.75 km layout.

In early 2017 small variations on this layout were assessed that incorporated increased $L_{\text{sep}}$.

- Reduced straight sections at points J & D enabled the tunnel to fit between Jura and Pre-Alps limestone.
- Introduced potential for significant shaft depth savings.
Selected Baseline – Berlin97.75

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.

John Osborne, Joanna Stanyard (SMB-SE-FAS)

FCC Week, Berlin 2017
Key Issues and Possible Solutions – Berlin97.75

**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 diameter
- c) Replace with an inclined access tunnel
TOT capabilities & Limitations

- **TOT is a bespoke, web-based geological tool.**

- **Datasets imbedded:**
  - Interpreted geological data, simplified to major types of geology.
  - Topography
  - Hydrological Information
  - Protected areas
  - Existing Boreholes and Geothermal farms

- **Very powerful tool for early stage feasibility**
  - Quickly assess different layout options.
  - Clear visual outputs for communicating results
• 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.
Underground Schematic

- Electrical alcoves introduced at 1.5 km spacing
- Additional shaft introduced at each experimental point
- Beam Dumps both located at Point D
- Secondary experimental Points moved to B & L
- Survey Galleries introduced at experimental points
Concept based on LHC and Hi-Lumi reference structures.
Some scaling where deemed appropriate.
John Osborne, Joanna Stanyard (CERN - SMB - SE)

Cost and Schedule Study

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

**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.
ee machine 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.
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.
1) **Replacing shafts with inclined access tunnels:**
   - Shaft F

2) **Inclined access between shafts to accelerate program:**
   - Option a: between I & J and J & K
   - Option b: between G & H

Option b is favourable as it is desirable for the installation schedule for 2 of the shorter sectors to be delivered first.
Draft to be verified.

Construction complete in 6 years, 5 months.
Early schedule results – Baseline

- Construction commences with site installation and diaphragm wall construction.
- PM-B excavated first followed by US-B, TBM launched from this cavern for sectors R-AB and R-LA.
- PX-B and UX-B excavated in parallel but have a longer duration due to their larger dimensions.
- Second TBM launched following completion of both caverns.
- Transfer tunnel excavated using Drill & Blast or roadheader.
- Alcoves excavated behind tunnel excavation front and lined during TBM removal.
- Lining of tunnels and caverns completes underground construction.
First two sectors complete in 4 years, 8 months.

Construction complete in 6 years, 5 months.

Draft to be verified.
Early schedule results – Accelerated schedule (2)

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

Draft to be verified.
Future steps for Cost & Schedule study

- Work to refine a cost estimate to an accuracy of +/- 30%.

- Design updates to be incorporated into Phase 3:
  - Additional shaft at each experimental point.
  - New layout and position.
  - New cross-section.

- Fix inclined access positions and incorporate results into study.

- More closely study the schedule implications of the connection to the LHC or SPS.

- Scope for optimising the whole schedule once design and schedule constraints fixed.

- Iterative process of integrating the CE schedule into the full installation schedule.
Civil Engineering for FCC-eh IR – J.L Stanyard Thursday 14:25
High Energy LHC Civil Engineering

- If it is concluded High Energy LHC cannot fit into the current LHC envelope, a technical and cost and study will be launched to evaluate an option to enlarge the cross-section of the existing tunnel.
Future Steps

• Continue to evaluate new layout and position:
  ▪ Confirm shaft and inclined access tunnel locations.
  ▪ Evaluate the risk of construction in the moraines under the lake.

• Confirm civil engineering requirements for ee machine.

• Evaluate cavern and shaft construction methods.

• Develop TOT, potentially working towards automating some features.

• Environmental impact and spoil management study.

• Develop High Energy LHC and FCC-eh studies.

• Site investigation planning.