Summary of October 3-4
FCC CE and TI Requirements Review

FCC-EIC Joint & MDI Workshop 2022

27 October, 2022

Mogens Dam, Niels Bohr Institute

Presentations

09:00 **Introduction**
Speakers: Andy Parker (University of Cambridge (GB)), Michael Benedikt (CERN)

09:10 **FCC-hh detector concepts and requirements**
Speaker: Werner Riegler (CERN)

09:40 **FCC-ee detector concepts and requirements**
Speaker: Mogens Dam (University of Copenhagen (DK))

10:10 **CE and TI requirements from the FCC-hh and FCC-ee detectors**
Speaker: Werner Riegler (CERN)

10:30 **Break**

11:00 **Civil engineering aspects and constraints**
Speaker: Timothy Paul Watson (CERN)

11:30 **Technical infrastructure aspects and constraints**
Speaker: Klaus Hanke (CERN)

Review committee

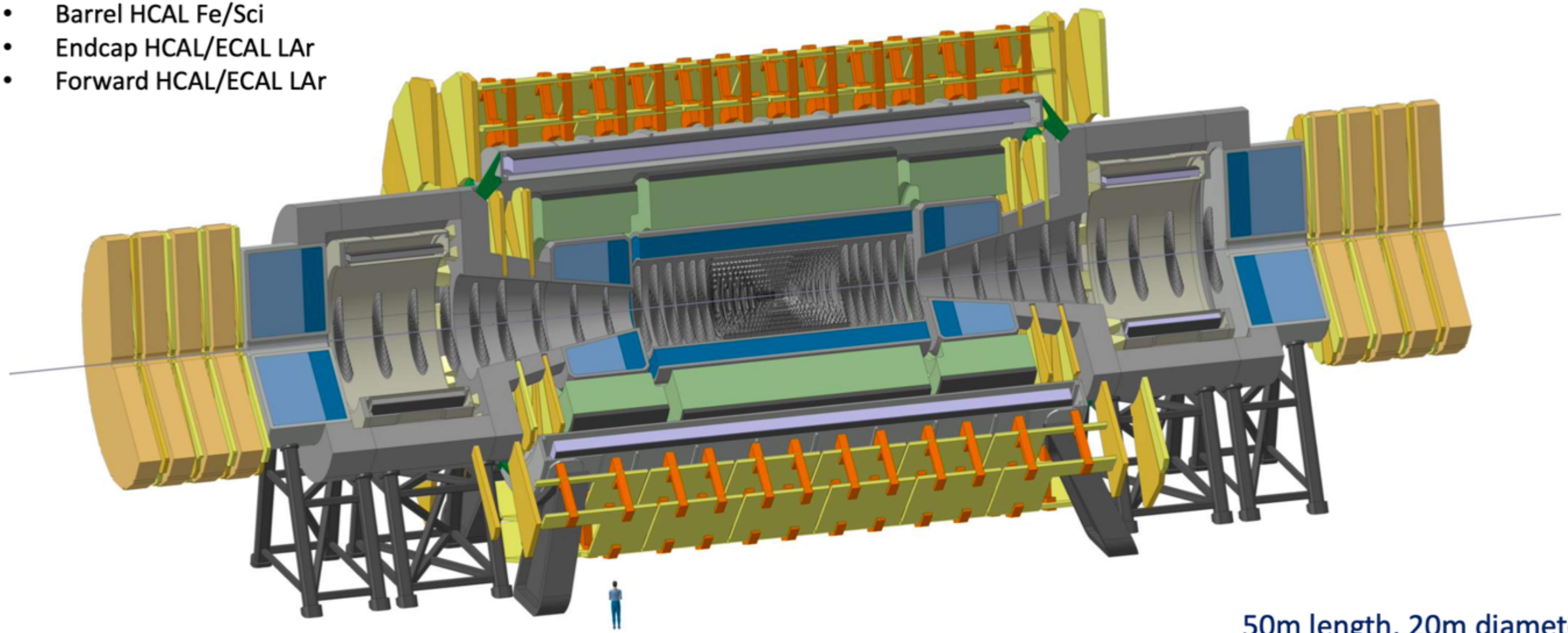
- **Composition**
  - Austin Ball (STFC),
  - Alain Chabert (SFTRF),
  - Peter Krizan (Jozef Stefan Institute),
  - Rolf Lindner (CERN),
  - Andrew Parker (University of Cambridge – Chairperson),
  - Roberto Tenchini (INFN Sezione di Pisa),
  - Frank Zimmermann (CERN – Secretary).

FCC-hh Reference Detector

Werner Riegler

- 4T, 10m solenoid, unshielded
- Forward solenoids, unshielded
- Silicon tracker
- Barrel ECAL LAr
- Barrel HCAL Fe/Sci
- Endcap HCAL/ECAL LAr
- Forward HCAL/ECAL LAr

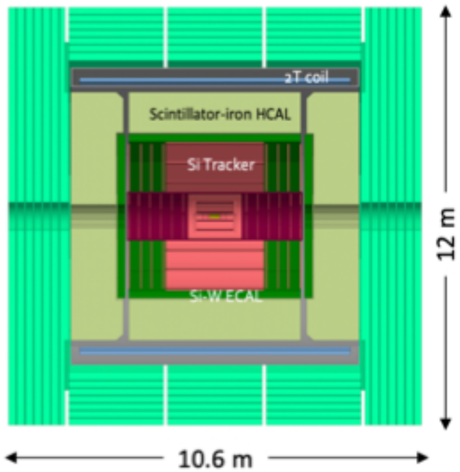
The cost and weight of a yoke that returns the magnetic flux is considered excessive.



50m length, 20m diameter
similar to size of ATLAS

Developing Landscape of FCC-ee Detector Concepts

CLD

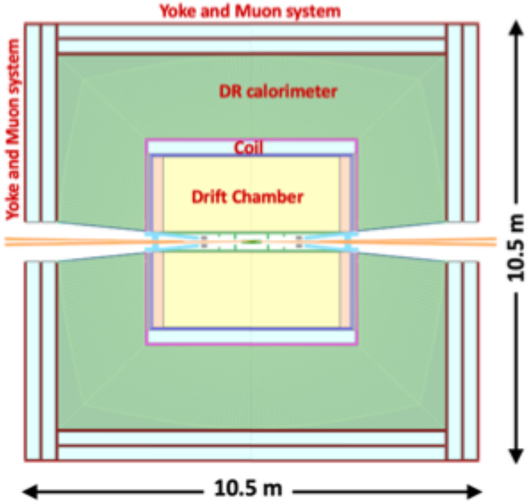


- Full Silicon vertex detector + tracker;
- Very high granularity, CALICE-like calorimetry;
- Muon system
- Large coil outside calorimeter system;

- Possible optimization for
  - Improved momentum and energy resolutions
  - PID capabilities

CDR

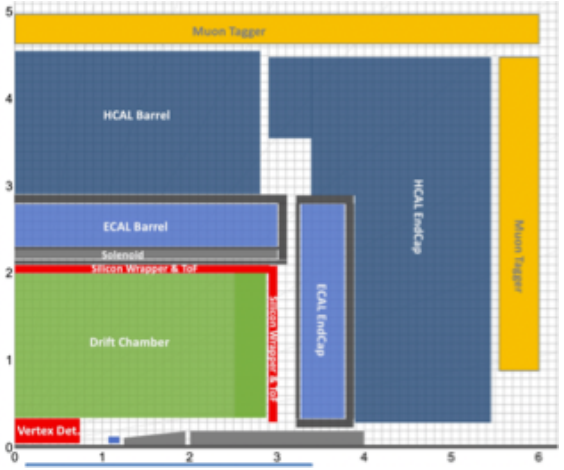
IDEA



- Si vertex detector;
- Ultra light drift chamber w. powerfull PID;
- Monolitic dual readout calorimeter;
- Muon system;
- Compact, light coil inside calorimeter;

- Possibly augmented by crystal ECAL in front of coil;

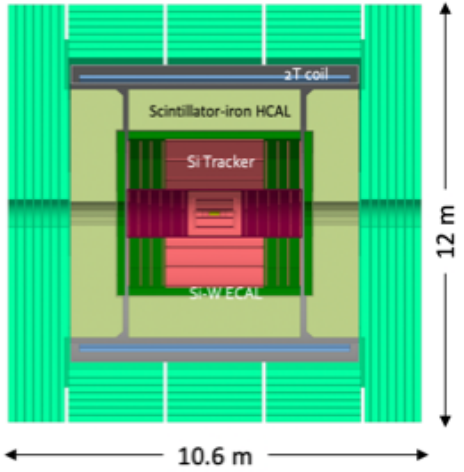
Noble Liquid ECAL based



new

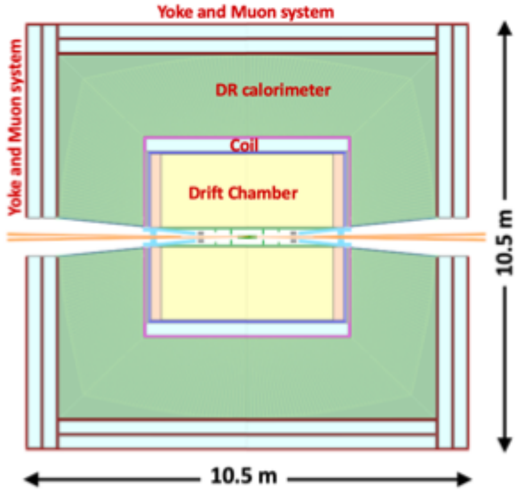
- High granularity Noble Liquid ECAL as core;
  - PB+LAr (or denser W+LCr)
- Drift chamber (or Si) tracking;
- CALICE-like HCAL;
- Muon system;
- Coil inside same cryostat as LAr, possibly outside ECAL.

CLD



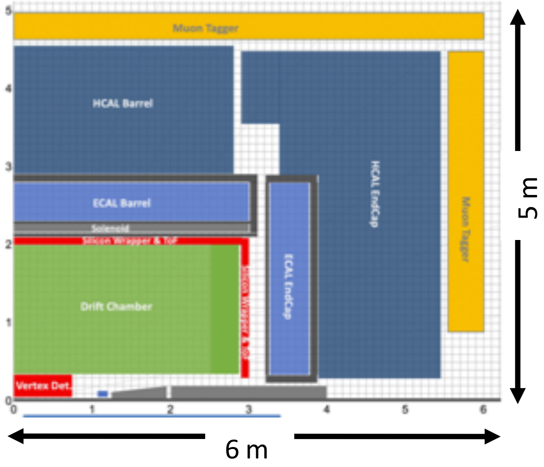
Cryostat:
- Outer diameter: 8.55 m
- Length : 7.4 m

IDEA



Cryostat:
- Outer diameter: 4.8 m
- Length : 6.0 m

Noble Liquid ECAL based



Cryostat:
- Outer diameter: ~6 m
- Length : ~6 m

- All concepts fit inside 12x12 m envelope
- Tentatively, assume that largest single piece (undismountable) is coil/cryostat
- Assume that coil/cryostat dimensions allow remote production with transportation to site
  - CLD has the largest coil/cryostat with dimensions similar to that of CMS:
    - length x outer diameter = 7.4m x 8.55m [CMS: 12.5m x 7.2m]

Detectors at LEP

Typical design: Aleph, Delphi, Opal

Dimensions similar to FCC-ee detector concepts

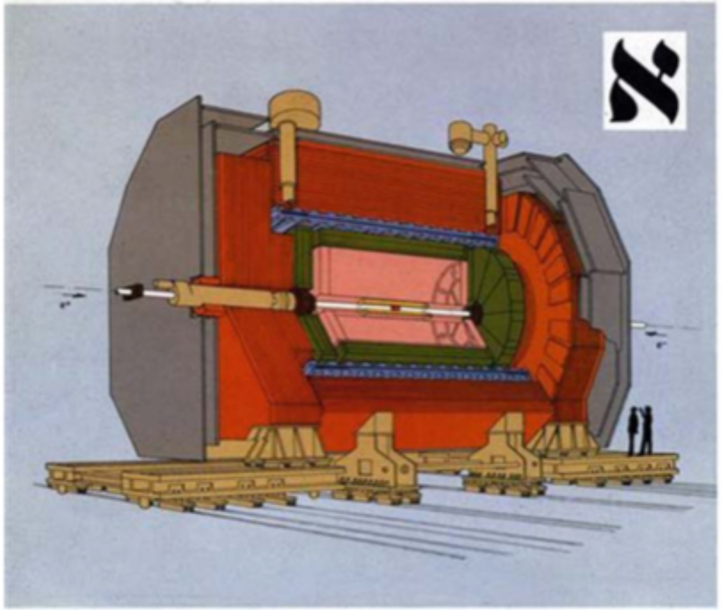
Assembled underground.

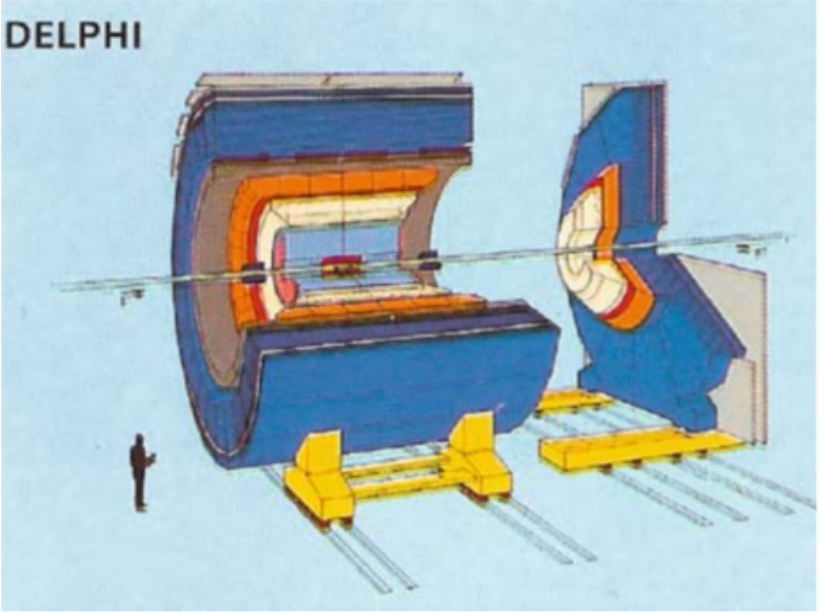
Largest components to lower into cavern:

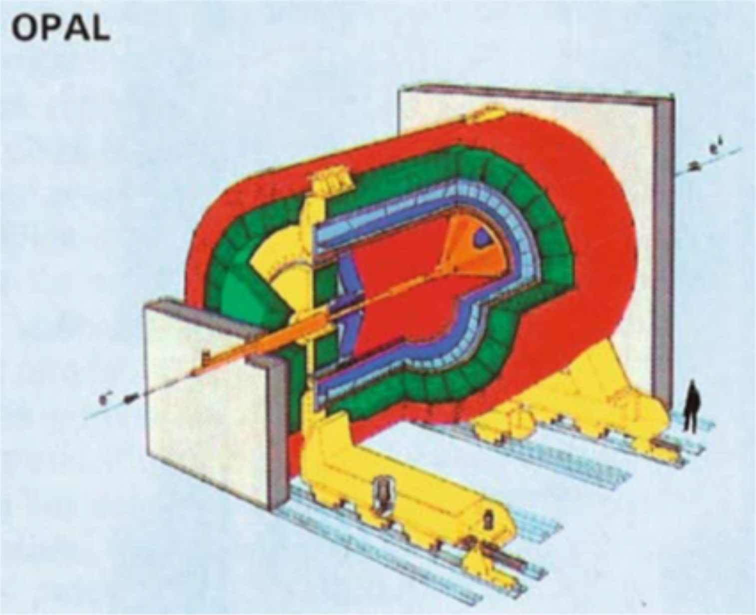
- Coil: max dimension 7.4 m length x 6.2 m diameter (DELPHI)
- HCAL modules: 10 m long x 1 m width

In terms of size, FCC-ee detector concepts have many similarities with typical LEP detectors.

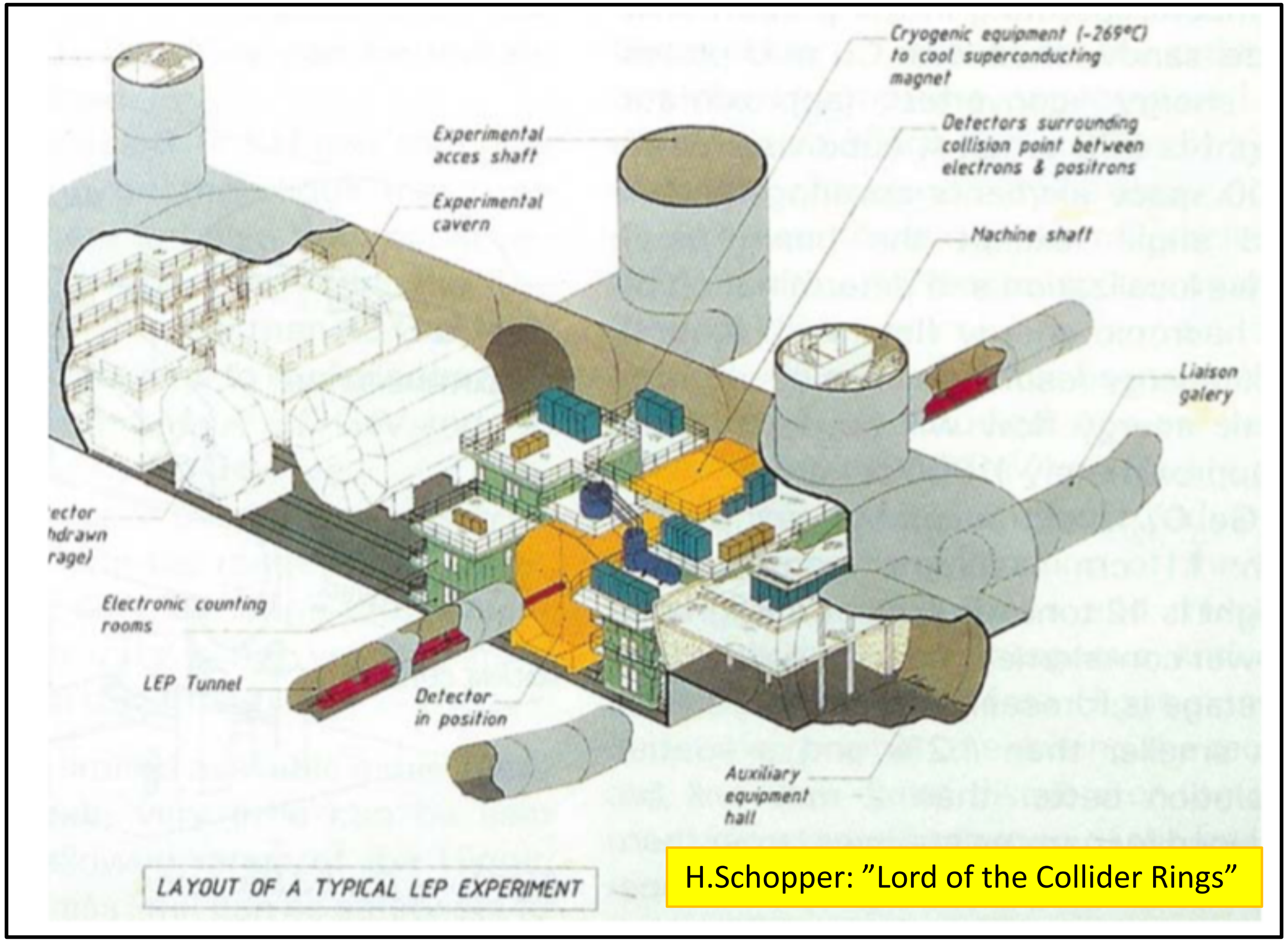
- Exception: CLD's larger diameter coil of 7.4m x 8.55m







LEP Cavern Layout of the three typical Detectors



H.Schopper: "Lord of the Collider Rings"

Baseline is that FCC-ee detetors will be assembled under ground as at LEP.

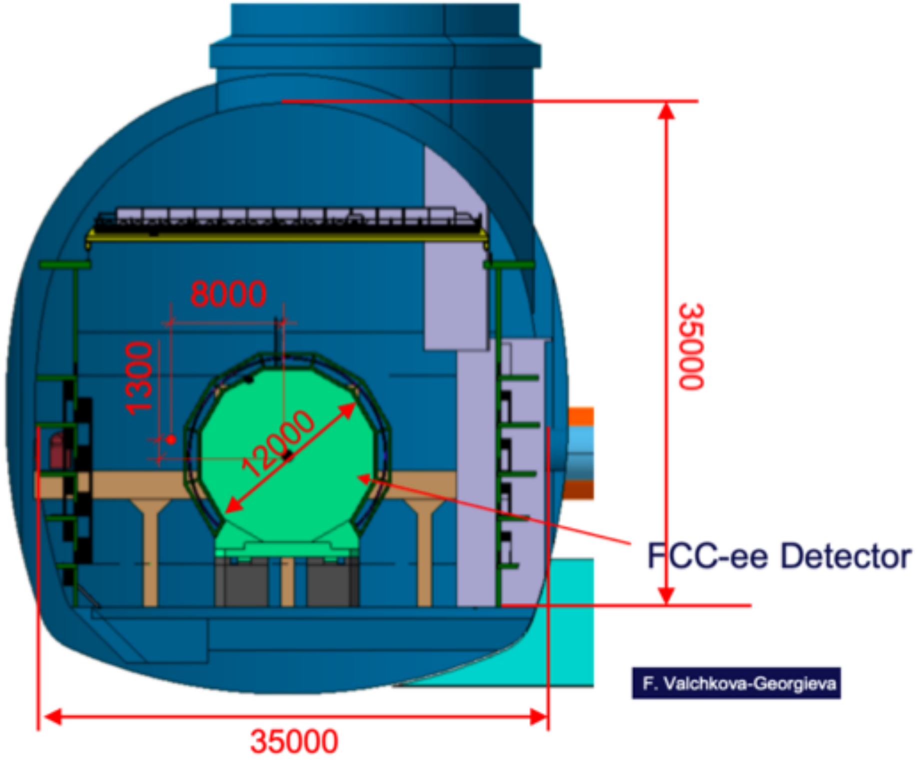
With similar sizes, FCC-ee detectors would fit into a typical LEP underground area

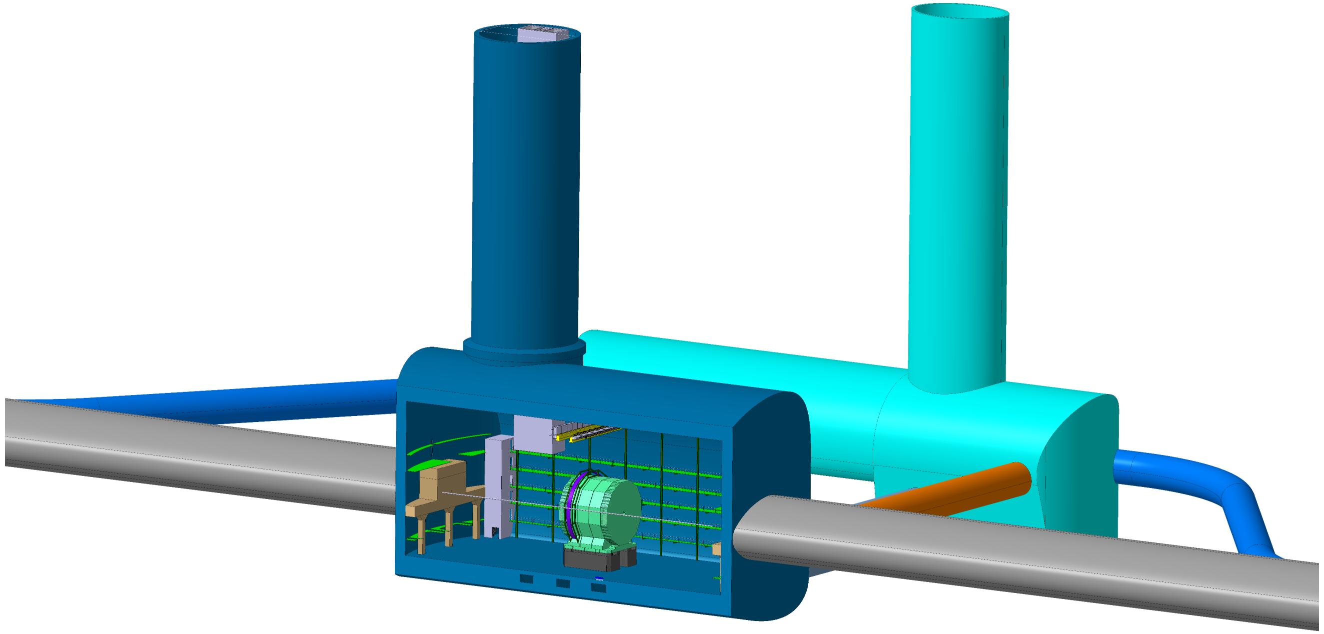
- Cavern: 70m long, 17m wide, 18.5 m high
- A single shaft of 10.1 m diameter
- Main cavern with enough space for detector, including barracks for electronics, cryogenics, services, and even empty space to move the detector into garage position (never used)
- No service cavern used by experiments
- Length direction perpendicular to beam direction

FCC-hh Experiment Underground Structure

With FCC-ee detectors being considerably smaller than FCC-hh detectors, a baseline FCC-hh cavern works perfectly for the housing of a FCC-ee detector including all services

- cooling plants, cryo cold box, gas systems, electronics barracks





A FCC-ee detector would also fit well inside a somewhat smaller CMS-like cavern of size 53x25x25 m^3.
A shaft of 10m diamater is sufficient

Radiation level in the Main Cavern

- Radiation levels are estimated to be low enough to allow cohabitation of detector and services (incl. electronics and people) in the main cavern

  - Example: LHCb readout electronics is located in the detector cavern behind a brick wall
    - 2-3 orders higher collision rate than Tera-Z and with higher particle multiplicity

  - Detailed simulation studies of FCC-ee cavern backgrund conditions are ongoing
    - Preliminary results show that the fluence from Tera-Z operation can be kept at close to the normal background radioactivity level

Conclusion: No a priori need of a service cavern

The case for four Interaction Points

One of the many advantgages of circular colliders: can serve several IPs

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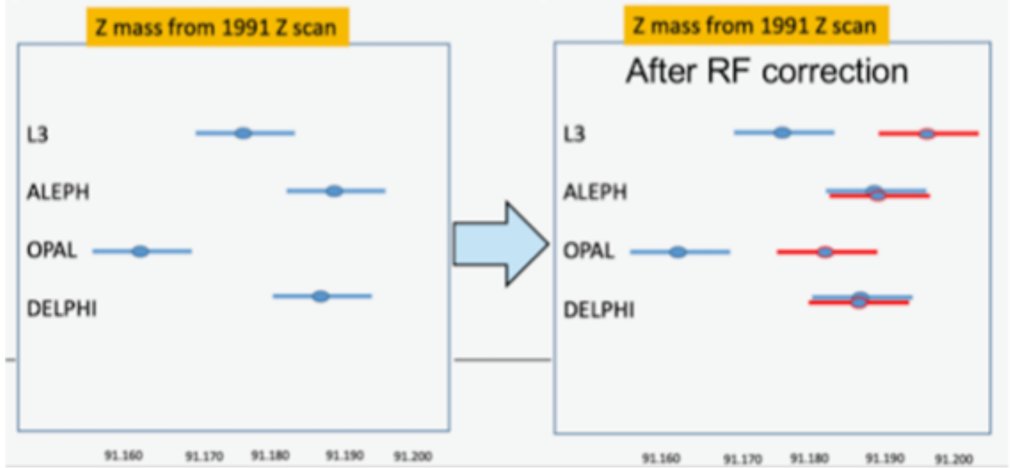
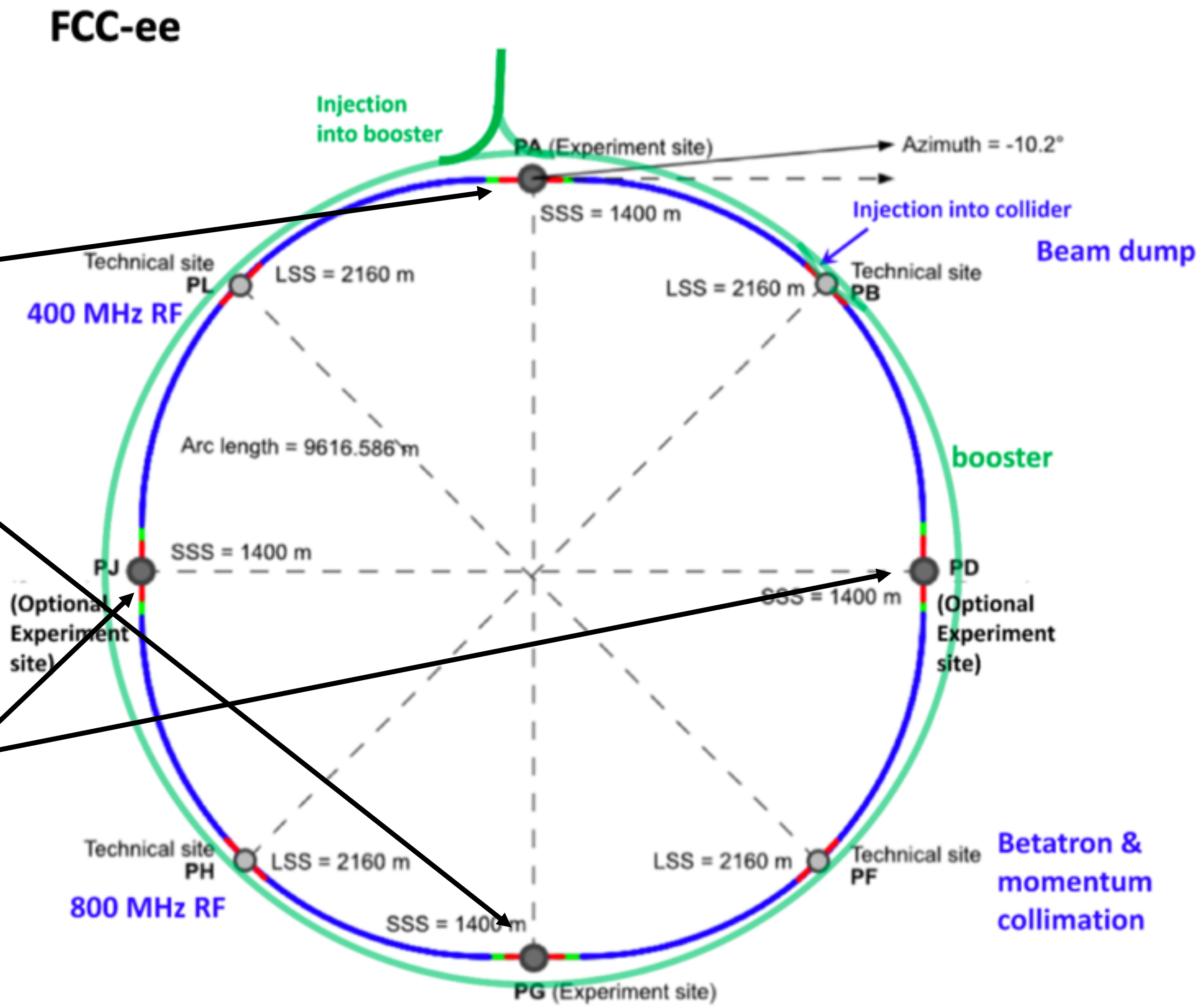
- Overall gain in luminosity, in luminosity/MW, and importantly in luminosity/kg CO_2 equiv
  - Many measurements are statistics limited – some are tantalizingly close with only 2 IPs
    - E.g., Higgs self-coupling, search for Heavy Neutral Leptons, Flavour anomalies, Electron Yukawa coupling, etc.
- Variety of detector requirements may not be satisfied by one or even two detectors
  - E.g., high precision, high granularity, high stability, geometric accuracy, PID
    - Having four IPs allows for a range of detector solutions to cover all FCC-ee opportunities
- Four IPs provide an attractive challenge for all skills in the field of particle physics
- Redundancy is invaluable in uncovering hidden systematic biases or conspiracy of errors
  - E.g., m_z discrepancy at LEP in 1991
    - Found to be an effect of RF phases and voltages
      - Correction of ~+19 MeV for L3 and OPAL
  - Could have remained unnoticed for ever with
    - only ALEPH and DELPHI, or
    - only L3 and OPAL



The four experiental sites



PA and PG are the ”main” sites

- FCC-hh size caverns

PD and PJ are the ”additional” sites

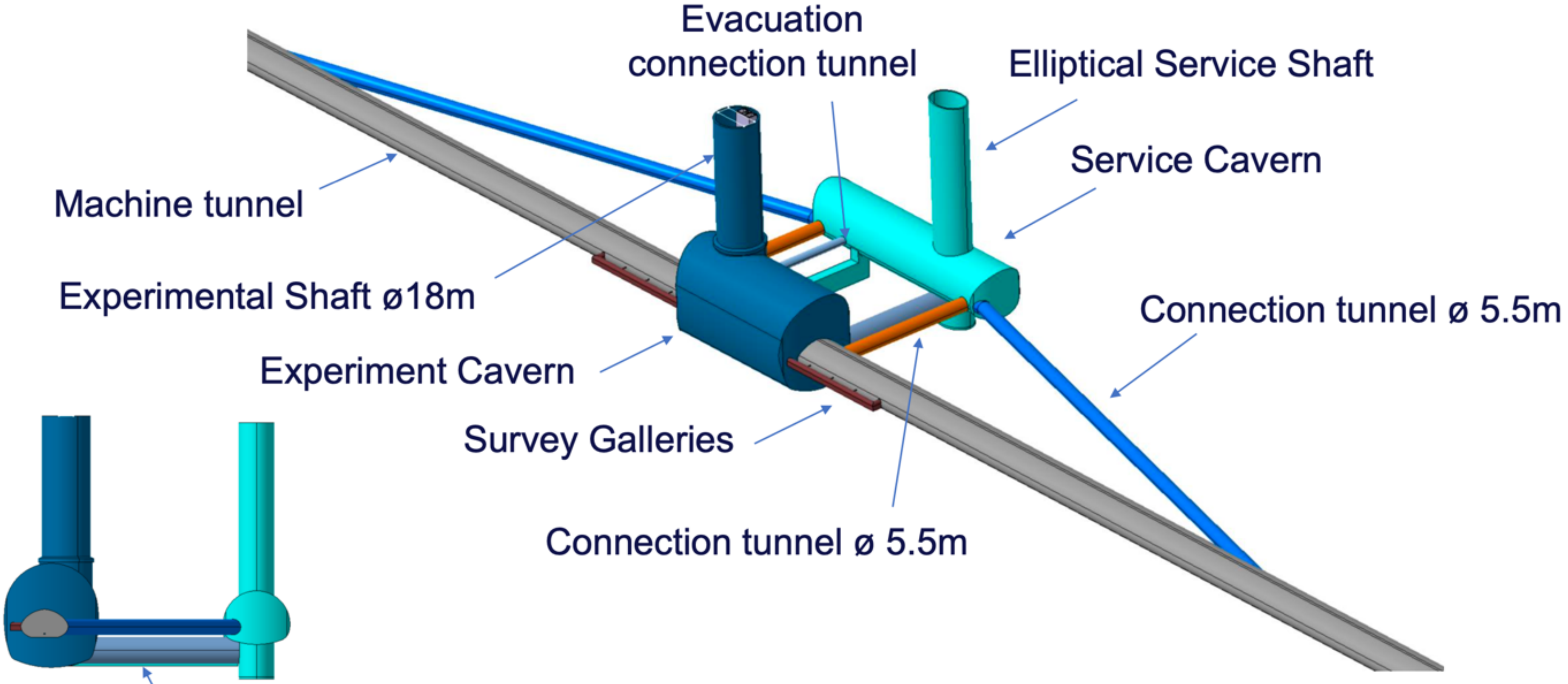
- Possibly with somewhat smaller caverns

Surface building needs

- Detector pre-assembly and storage
  - As at LEP, need ~1000 m^2
- Computing system:
  - Experience from ALICE with a comparable event rate as FCC-ee Tera-Z, but much higher particle multiplicity, is that space needs for computing are small
  - No specific consequences on CE and TI
- Offices:
  - Experimental sites are away from CERN; people need places to work

Proposed Layout

Werner Riegler



Evacuation connection tunnel

Elliptical Service Shaft

Service Cavern

Machine tunnel

Experimental Shaft ø18m

Connection tunnel ø 5.5m

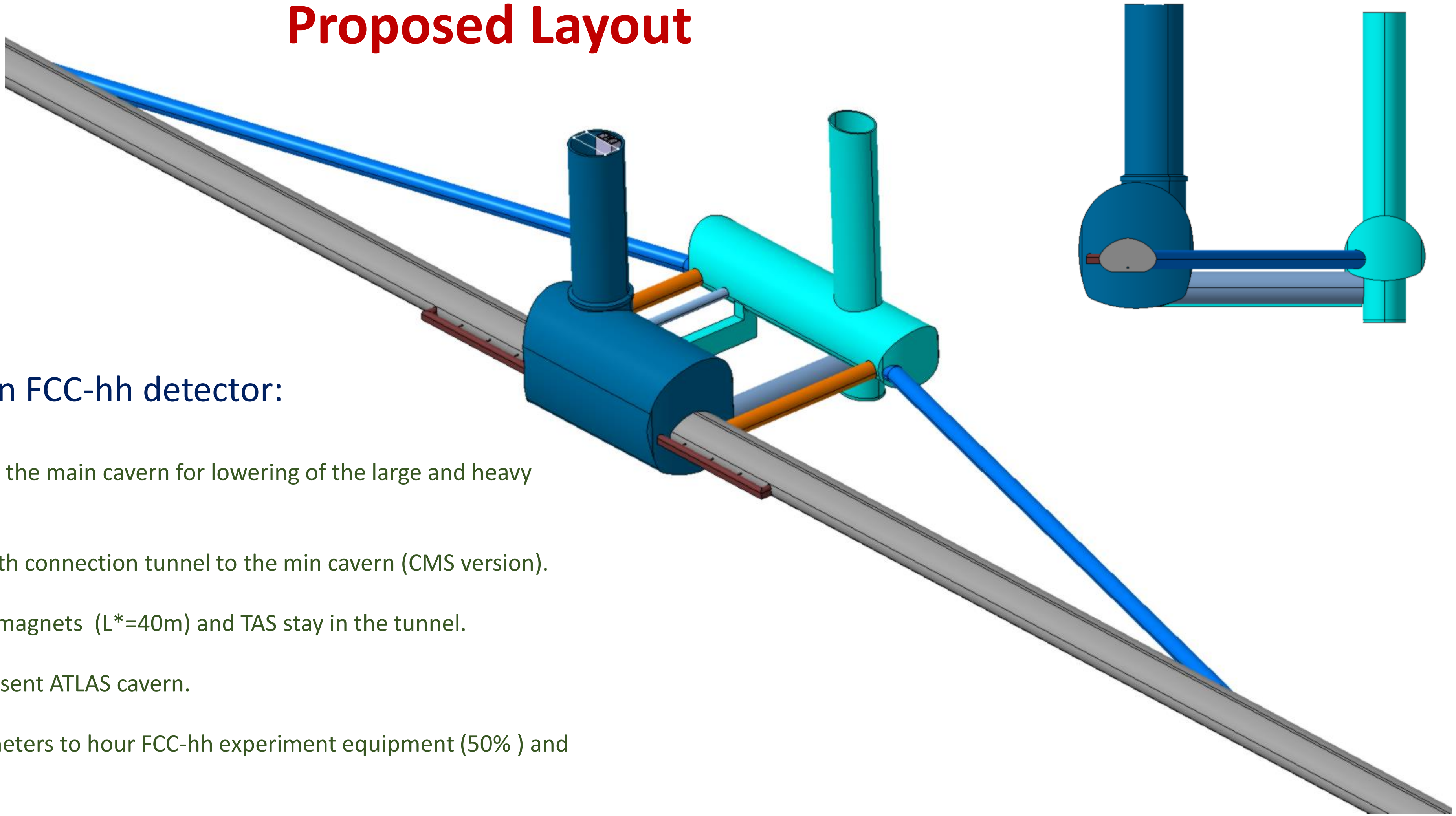
Experiment Cavern

Survey Galleries

Connection tunnel ø 5.5m

Connection tunnel ø 10m

Proposed Layout



Fulfils the requirements for an FCC-hh detector:

One large shaft (15m free bore diameter) to the main cavern for lowering of the large and heavy detector components.

Second shaft (10m) to the service cavern with connection tunnel to the min cavern (CMS version).

Cavern length of 66m to ensure that triplet magnets (L*=40m) and TAS stay in the tunnel.

Cavern height and width 35m, similar to present ATLAS cavern.

Service cavern of 90m length and 20 x 20 meters to hour FCC-hh experiment equipment (50%) and FCC-hh magnet cryogenics (50%).

Distance of 50m between main cavern and service cavern to ensure

- Magnetic field below 5mT for unshielded geometry (could be closer of a detector with a yoke is used)
- Ensure sufficient radiation shielding (10m would be sufficient)

- Ensure 'independent' Civil engineering situation.

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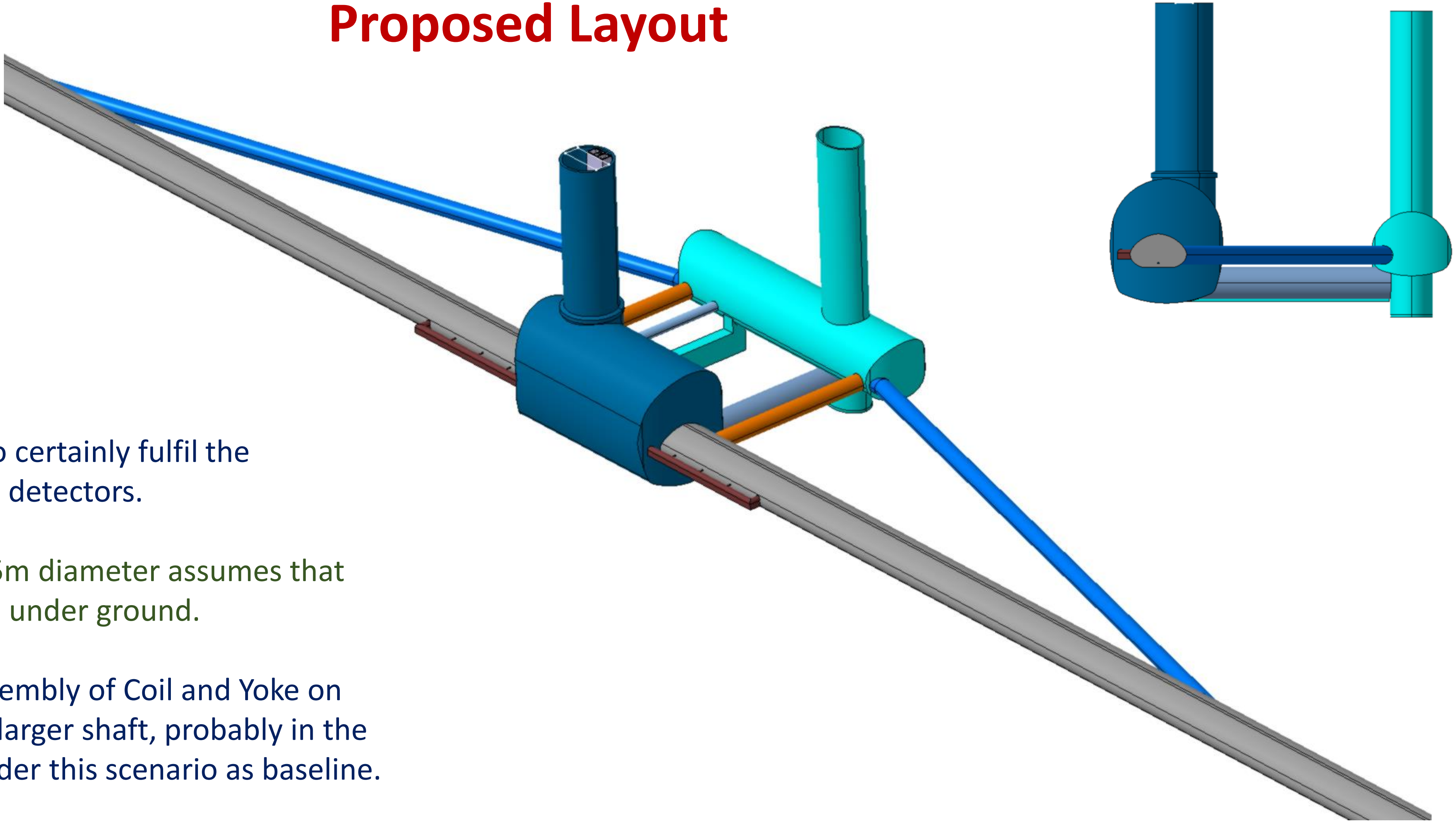
Proposed Layout



This FCC-hh requirements do certainly fulfil the requirements for the FCC-ee detectors.

The specified shaft size of 15m diameter assumes that the detectors are assembled under ground.

CMS type scenarios with assembly of Coil and Yoke on the surface would require a larger shaft, probably in the 20m range. We do not consider this scenario as baseline.

Werner Riegler

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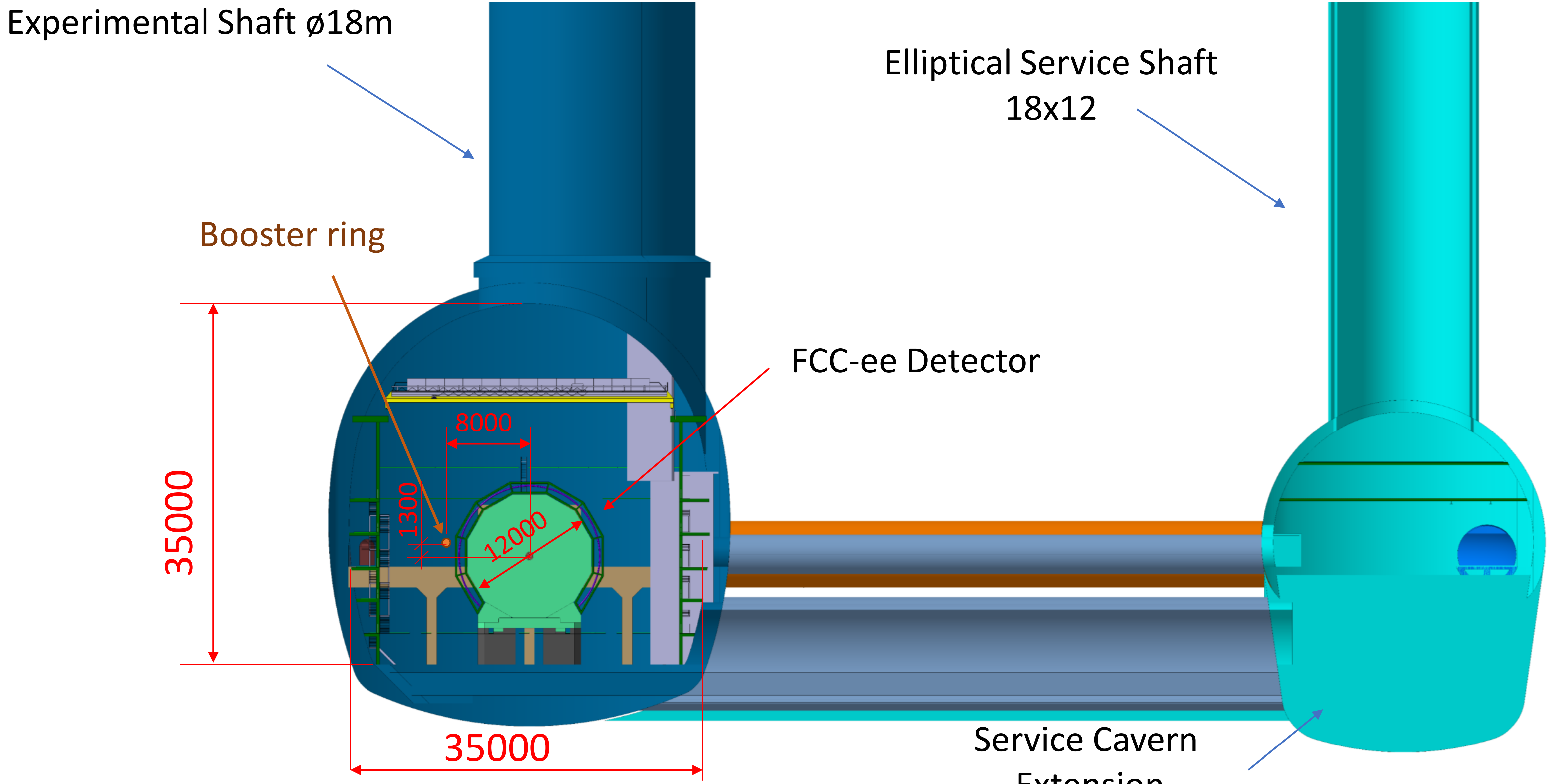
FCC Experiment Underground Structure version 2022



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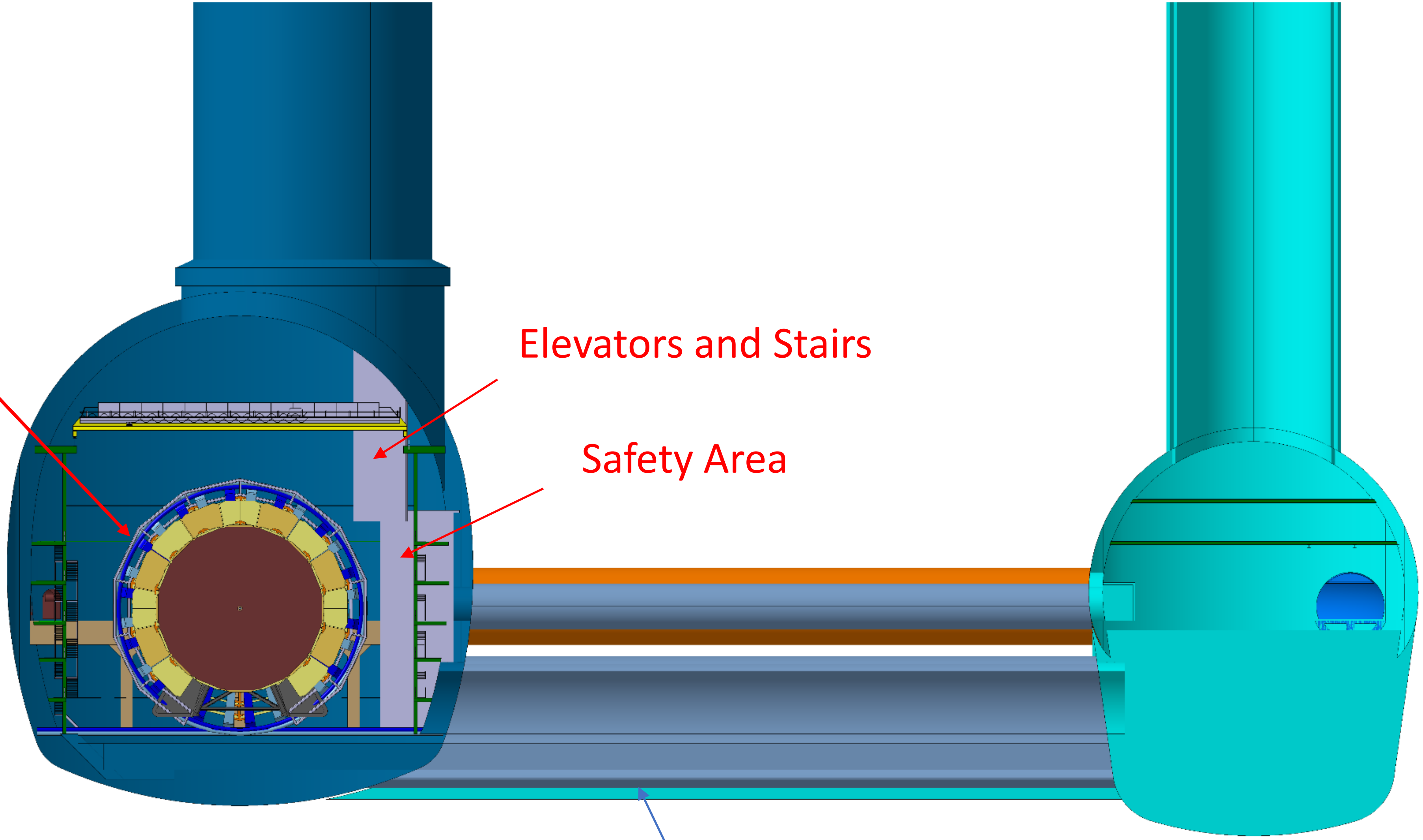
FCC Experiment Underground Structure version 2022



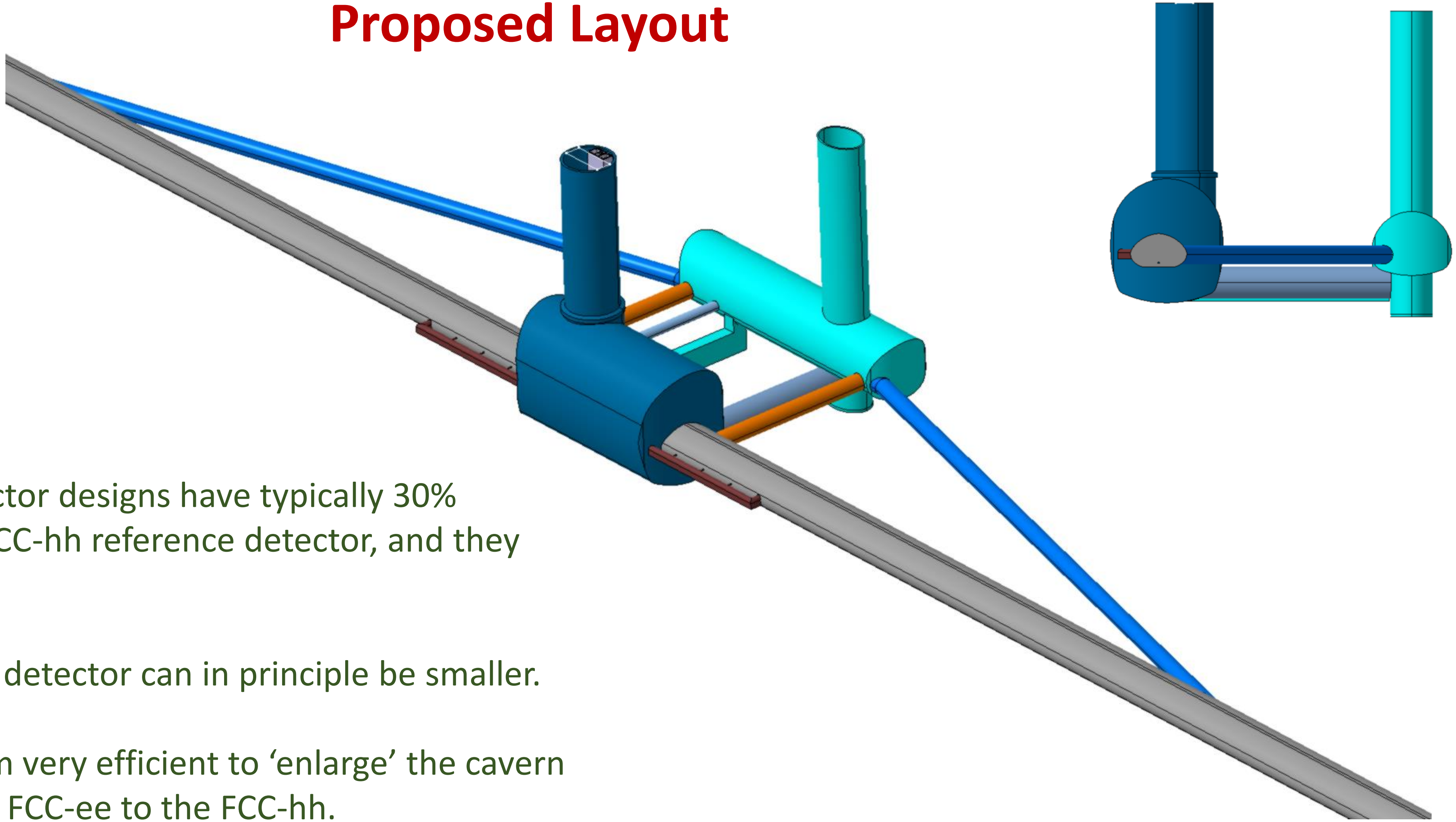
FCC-hh Detector

Elevators and Stairs

Safety Area

Connection tunnel , two levels

Proposed Layout



Staging possibilities ?

The present FCC-ee detector designs have typically 30% smaller radius than the FCC-hh reference detector, and they are significantly ‘shorter’.

The cavern for an FCC-ee detector can in principle be smaller.

However it does not seem very efficient to ‘enlarge’ the cavern size when going from the FCC-ee to the FCC-hh.

Cost, Construction activity close to communities, etc.

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FCC Experiment Underground Structure version 2022

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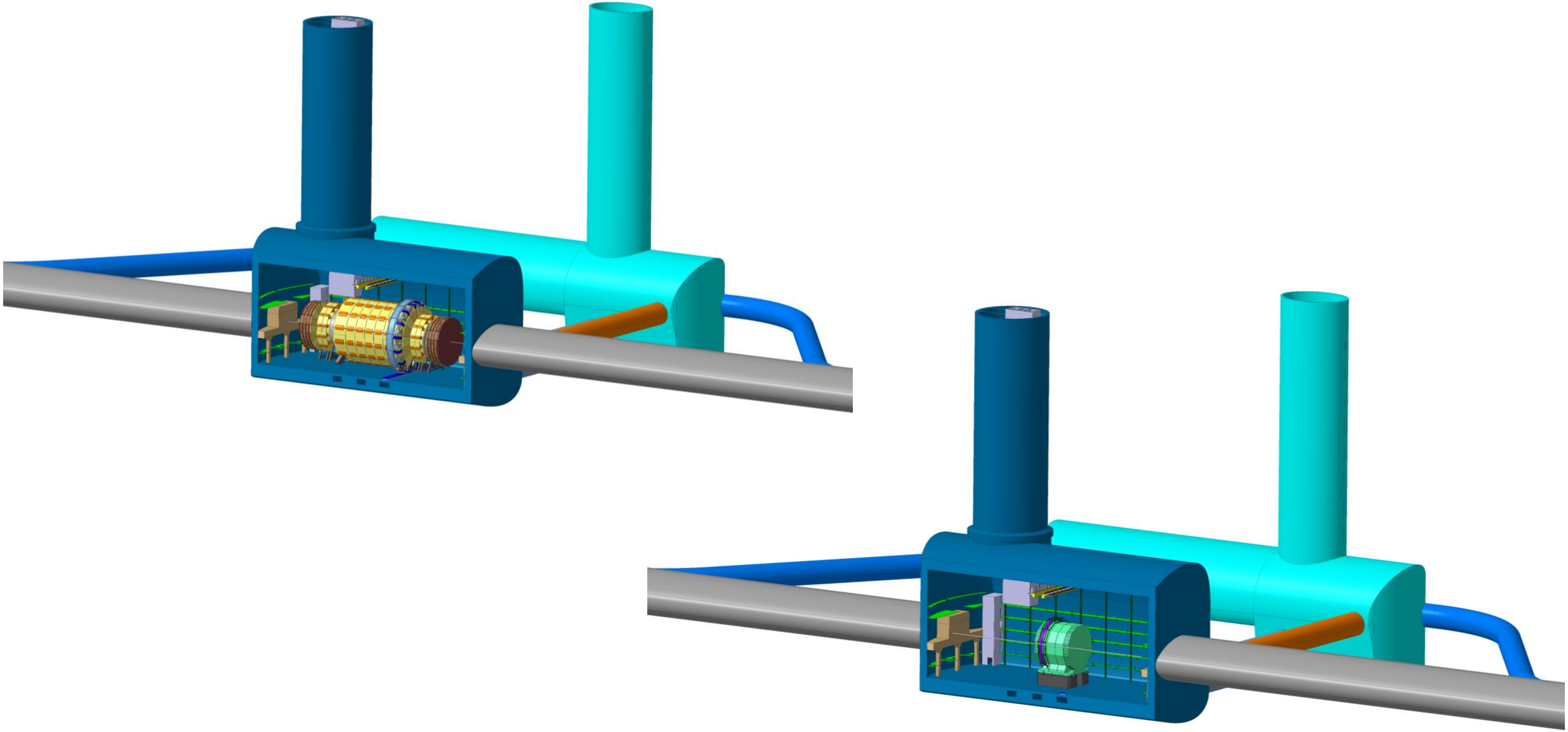
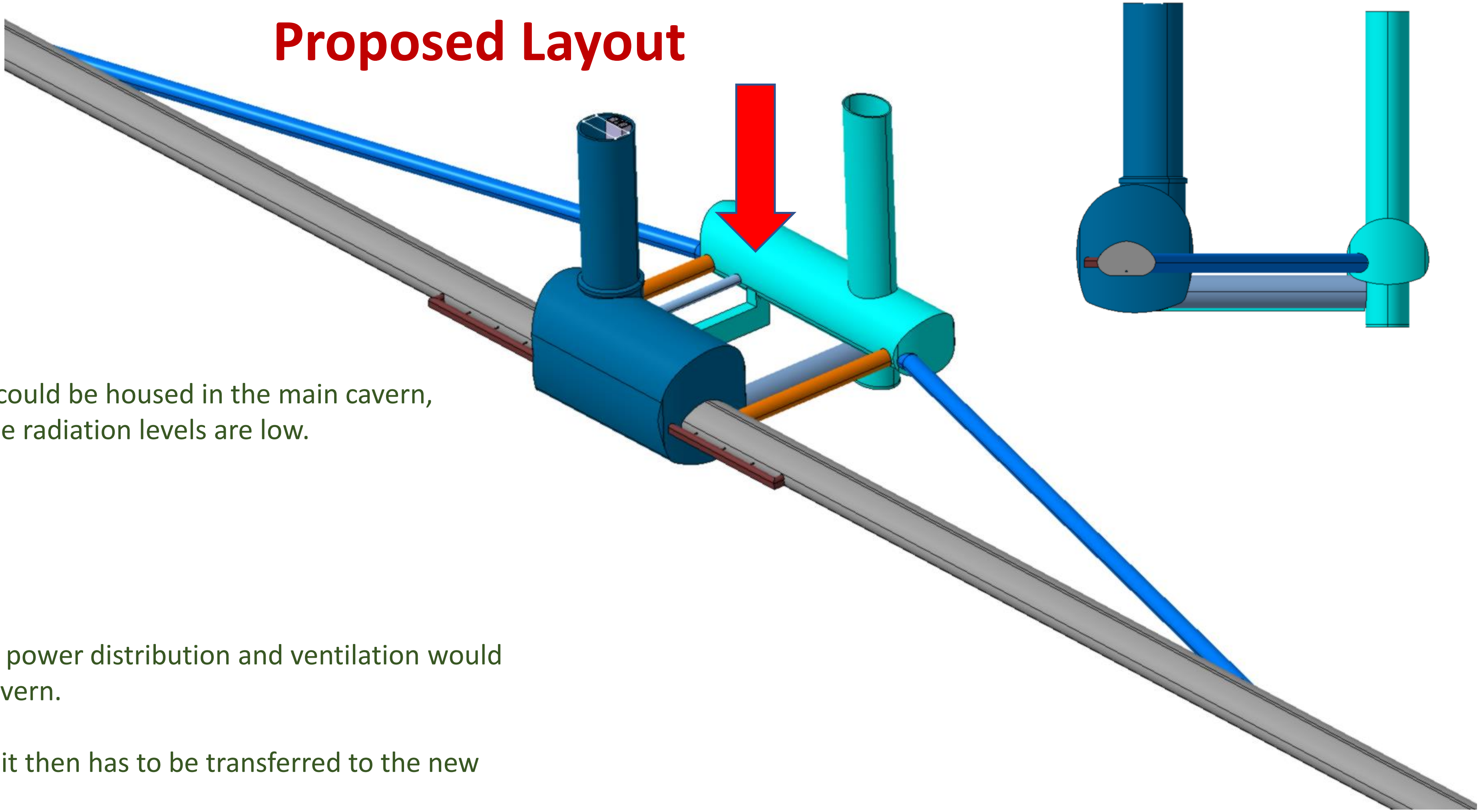


Proposed Layout



Staging possibilities ?

For the FCC-ee detector, the services could be housed in the main cavern, because there is enough space and the radiation levels are low.

Permanent access can be established.

However:

The entire technical infrastructure for power distribution and ventilation would also have to be housed in the main cavern.

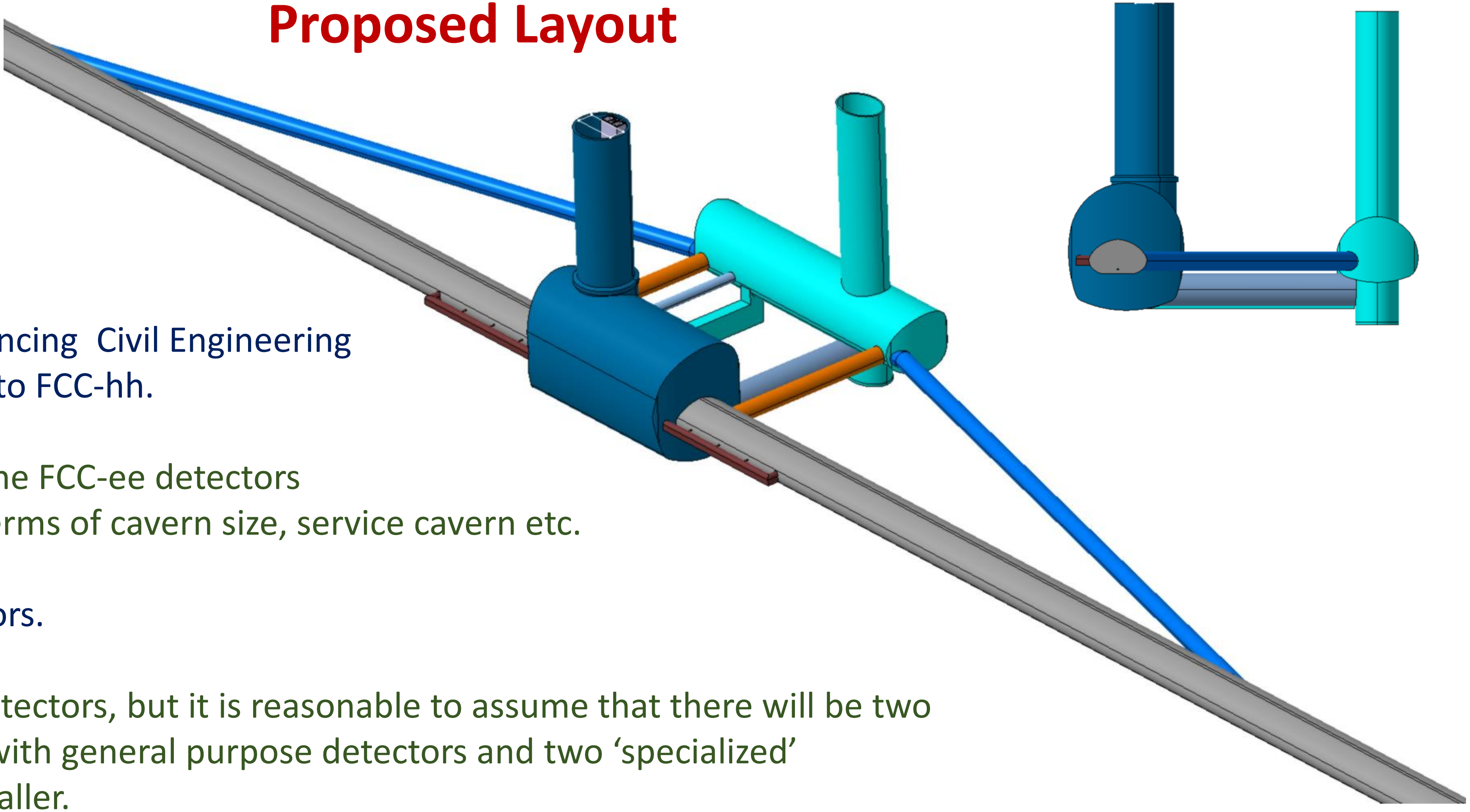
When moving from FCC-ee to FCC-hh it then has to be transferred to the new service cavern.

We understand that the service shaft and the bypass tunnels have to be there in any case.

We understand that the cost of the service cavern is at the level of 20-30% of the cost of the service shaft.

Werner Riegler

Proposed Layout



We could not identify a convincing Civil Engineering staging scenario from FCC-ee to FCC-hh.

Still, due to the smaller size, the FCC-ee detectors have significant flexibility in terms of cavern size, service cavern etc.

There will be 4 FCC-ee detectors.

There will also be 4 FCC-hh detectors, but it is reasonable to assume that there will be two high luminosity experiments with general purpose detectors and two ‘specialized’ experiments that could be smaller.

Strategic question:
We could have point A and D with the proposed CE infrastructure and the other two points with a cavern size and service cavern similar to CMS.

Werner Riegler

LEP/LHC/FCC Summary

Werner Riegler

Point	Cavern L x W x H (m)	Cavern Volume (m^3)	Service cavern L x W x H (m)	Service Cavern Volume (m^3)	Shaft 1 diameter/depth (m)	Shaft2 diameter/depth (m)	Shaft3 diameter/depth (m)	Shaft4 diameter/depth (m)
P2	53.5 x 15.5 x 22.7	21,667	21.4 x 16.2 x 13.4	4,635	PX24: 23/29	PM25: 9.1/32	PGC2: 12/46	
P4	70 x 16.6 x 18.5	23,170	16.5 x 20.7 x 13.4	3,897	PX46: 10.1/133	PZ45: 5.1/124	PM45: 9.1/125	
P6	70 x 16.5 x 18.6	23,170	16.2 x 20.7 x 13.4	3,828	PX64: 10.1/91	PZ65: 5.1/82	PM65 9.1/81	
P8	70 x 16.5 x 18.6	23,170	16.5 x 20.7 x 13.4	3,899	PX84: 10.1/93	PZ85: 5.1/85	PM85: 9.1/86	
P1	53 x 30 x 35	47,213	62 x 19.3 x 12.6	14,900	PX14: 18/57	PX15: 9.1/70	PX16: 12.6/56	PM15: 9.1/69
P5	53 x 24.3 x 24.5	32,373	84 x 13.7 x 13.3	17,400	PX56: 20.5/70	PM54: 12.1/73	PM56: 7.1/85	
FCC	66 x 35 x 35	80,850	90 x 20 x 20	36,000	PX: 15/200-300	PM: 10/200-300		

Power

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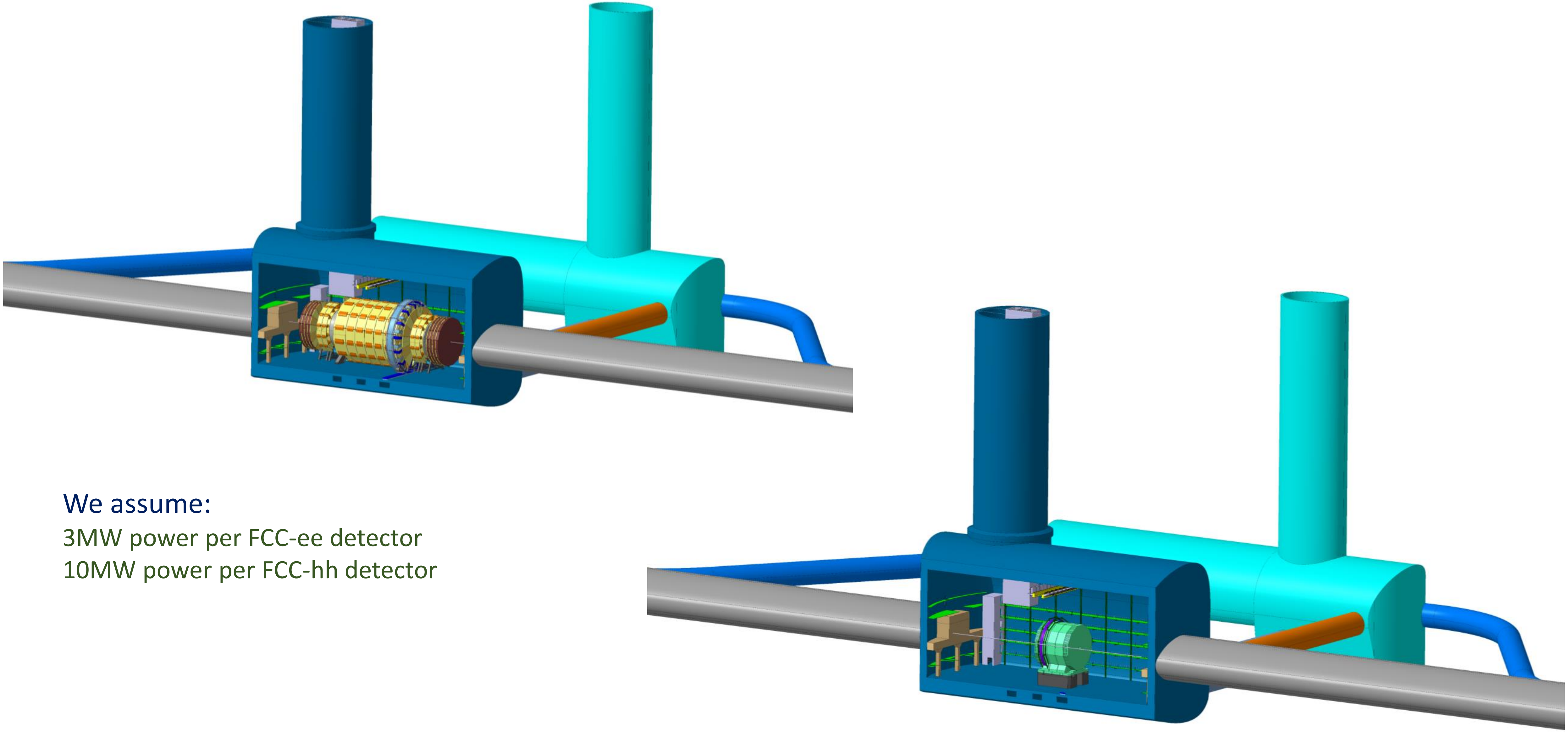


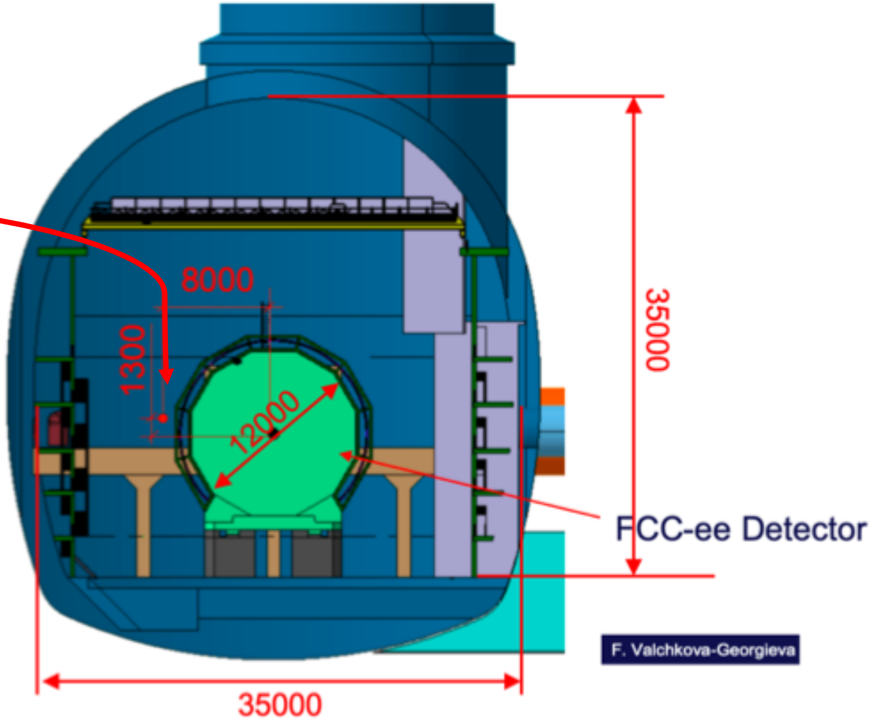
We assume:

3MW power per FCC-ee detector

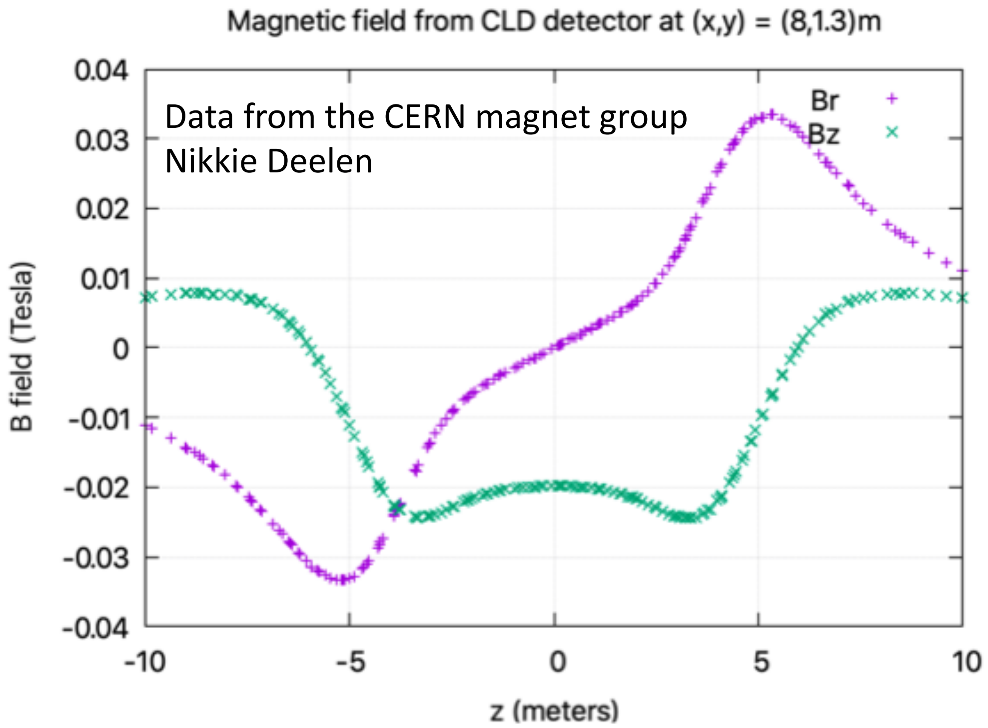
10MW power per FCC-hh detector

A side issue: Position of the booster ring

- Booster position may have consequences on the tunnel layout around the IP
- For this study, booster ring passes through cavern outside detector volume at [x, y]= [8.0, 1.3]m
- Detector stray field at the booster location is up to ten times stronger than the 3 mT dipole field strength at injection
    - Needs to be corrected for



F. Valchkova-Georgieva



Data from the CERN magnet group
Nikkie Deelen

A solution for shielding and/or correction has to be developed

- The booster location must be such that there is at least 1 m free space around the detector envelope with the shielding/compensation in place
- The shielding/compensation must not sizeably affect the magnetic field of the detector.

Extras

In comparison: ILC Underground Hall

- Large underground hall with push-pull of two detectors
  - ILD: 15.6 m high, 13.2 m long
  - SiD: 12.4 m high, 11.6 m long
- Detectors planned to be assembled at surface and lowered down in main parts (CMS style)
  - Supposedly saving 4 years of scheduling time with detector assembly and cavern construction running in parallel
  - Cost of 3500 m^2 assembly hall per experiment (in addition to 4000 m^2 for pre-assembly)
  - Requires large shaft of 18 m diameter