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Radiation protection at the FCChh
- Status update -

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Outline

1. Design criteria and beam loss scenarios for RP studies
2. Evaluation of proposed ventilation schemes
3. Single and double tunnel layout and connection tunnel design
4. Service cavern and shafts layout
5. Experimental cavern and shaft – first results of prompt dose rate and residual dose rate studies

Design criteria for RP (on site)

Prompt radiation in areas accessible during operation

Singular losses (accident event)

- < 6 mSv: designated area
- < 1 mSv: non-designated area

Continuous losses (nominal operation)

- < 10 µSv/h: controlled radiation area
- < 3 µSv/h: supervised radiation area
- < 0.5 µSv/h: non-designated

Residual activity

Activation zones

- machine tunnel including safe zone, experimental caverns, attached unshielded galleries and alcoves
- → **Radiation levels will determine the intervention scenarios** (waiting times, requirement for remote maintenance)

Non-activation zones

- all other zones
- **Below specific activity limits for radiological control**; installed equipment to be considered as non-radioactive

Beam loss scenarios for RP studies (1)

All loss scenarios based on LHC and HL-LHC approach (EDMS 687553), scaled to FCChh parameters:

Accident event (*maximum loss scenario*)

- Single beam loss of 1E15 protons at 50 TeV (FCC parameters)
- Collimator-like bulk target, no hydrodynamic tunneling considered
- ”Worst failure case” → not realistic, but provides a simple upper limit
- Standard scenario for LHC and HL-LHC design; well accepted by authorities
- Radiological impact: Exposure to prompt radiation
- ***More realistic scenario to be developed where a substantial cost impact is expected and to be justified (maximum credible loss scenario)***

Continuous beam loss (beam cleaning, nominal operation)

- 20 % of all protons are lost in beam cleaning, distributed over collimation regions (at LHC)
- Instantaneous loss rate (hour average) can be a factor 5 higher compared to the annual average (at LHC)
- Radiological impact:
  - Exposure to prompt radiation in service tunnel (if accessible)
  - Exposure to residual radiation in access mode
  - Activation of object, fluids and gases
- ***Loss distribution and intensities in collimation region required***

Beam loss scenarios for RP studies (2)

Beam gas interactions (arcs, nominal operation)

- ~ 5% of total number of protons lost through beam gas interactions (at LHC)
- In FCC this would result in a similar linear loss rate as in LHC
- Radiological impact:
  - Exposure to prompt radiation in service tunnel (if accessible)
  - Exposure to residual radiation in access mode
  - Activation of objects, fluids and gases

pp-collisions (experiments & focusing regions, nominal operation)

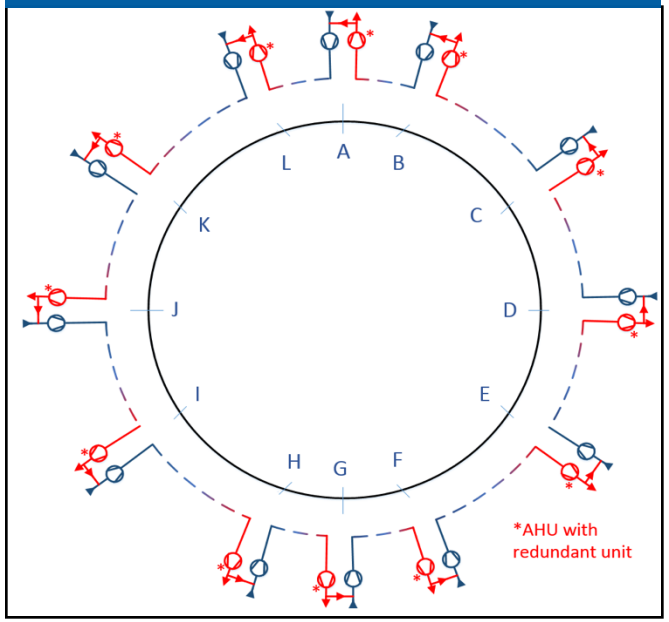
- Based on FCChh baseline and ultimate peak and integrated luminosity
- Radiological impact:
  - Exposure to prompt radiation in adjacent service cavern and tunnels (if accessible)
  - Exposure to residual radiation in experimental cavern and focusing regions
  - Activation of objects, fluids and gases

Beam dump (nominal operation)

- Total number of protons dumped
- Radiological impact:
  - Exposure to residual radiation in the dump cavern
  - Activation of objects, fluids and gases

Ventilation of machine tunnel and safe zone

Machine & Safe Zone



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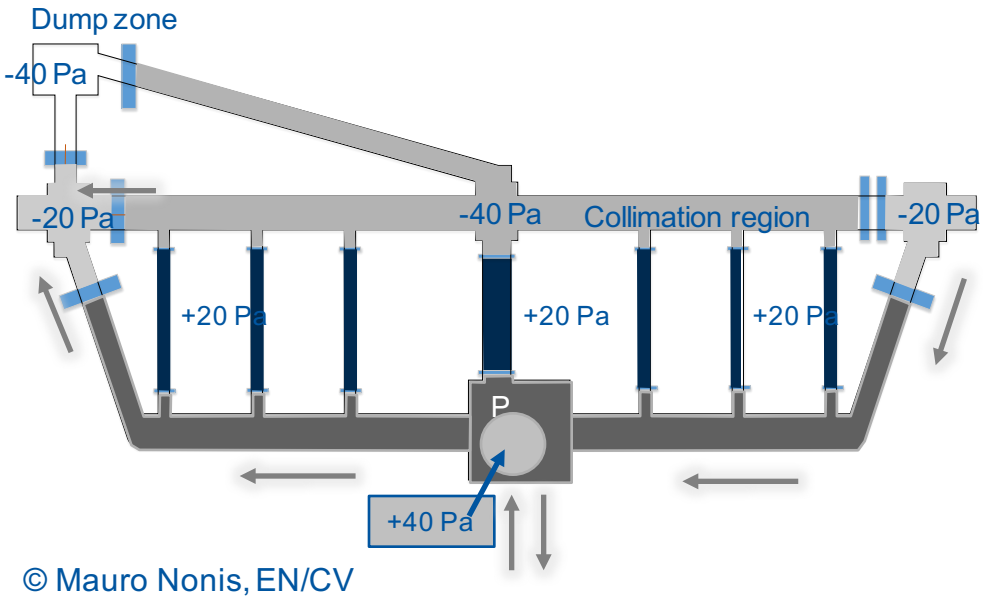
Proposed approach is in line with RP requirements:

- Recycling scheme for activation areas
  - Assures air conditioning while maintaining ability to limit radioactive releases
  - Releases can be modulated from (almost) 0 to 100%
  - Release points could be (almost) 'freely chosen'
  - Technical design to demonstrate the limitations to the above points

Ventilation of high activation areas



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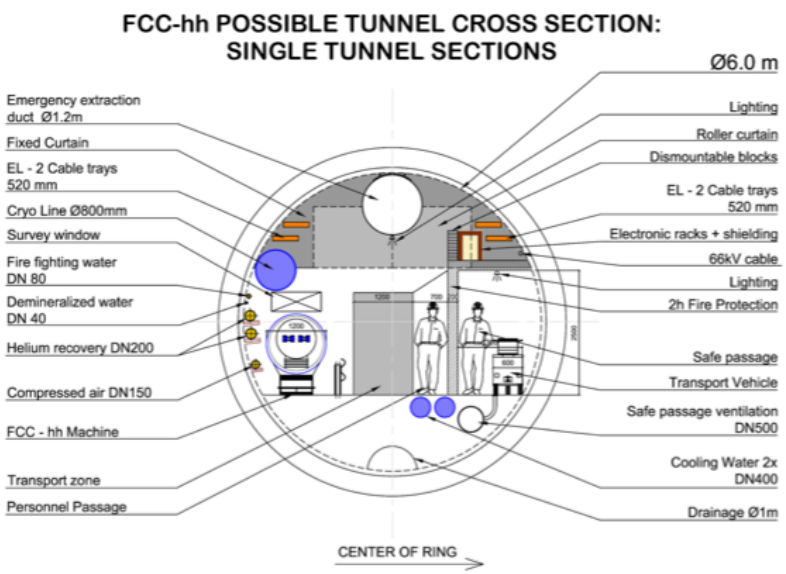
Proposed approach in line with RP requirements:

- Recycling scheme to assure air conditioning while maintaining a (variable) closed circuit operation
- Air volume separation between high activation areas and low/no activation areas by air locks and a pressure cascade
- Extracted air will mix and decay with machine tunnel air before release

To be clarified:

- Extracted volumes to maintain pressure cascade → Can we keep them low enough ?

Single tunnel



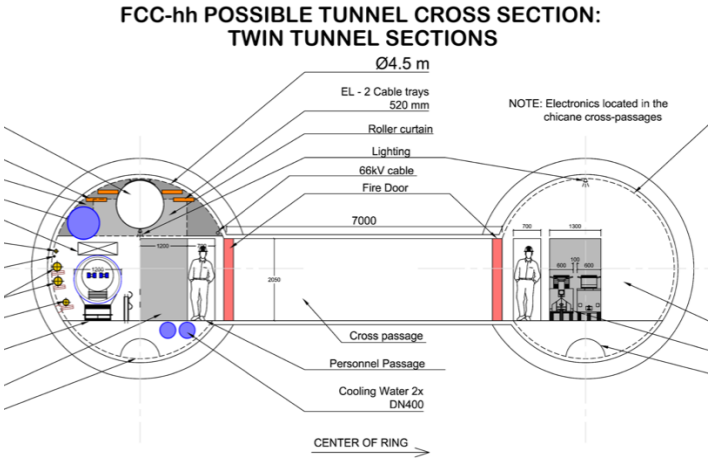
Excluded in high activation regions

- High residual dose rates → **no passage**
- Safe zone walls provide insufficient shielding to avoid activation of air → flush before access
- Safe zone: Material activation and residual dose rates remain high.

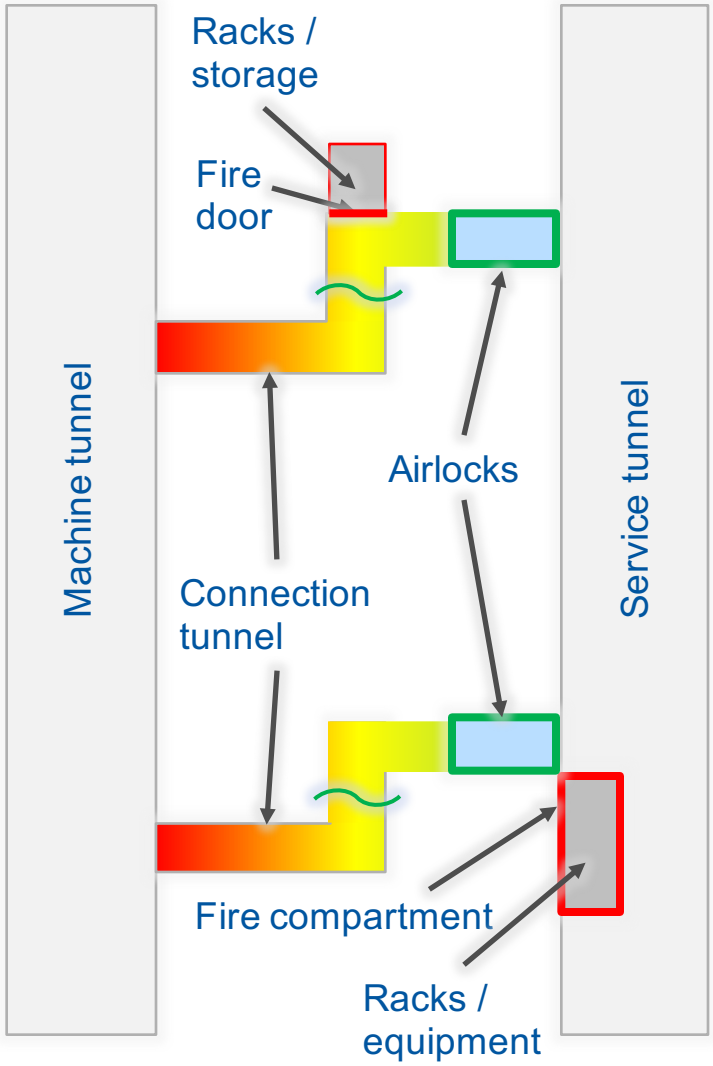
In arcs and low activation straight sections

- Air activation: Safe zone air must be treated during operation as the machine zone air
- Air renewal required before access is granted to safe zone or machine zone
- Activation expected in the whole tunnel volume including safe zone
- Equipment may need to be placed in specific alcoves for R2E issues → t.b.c. by EN/STI

Double tunnel

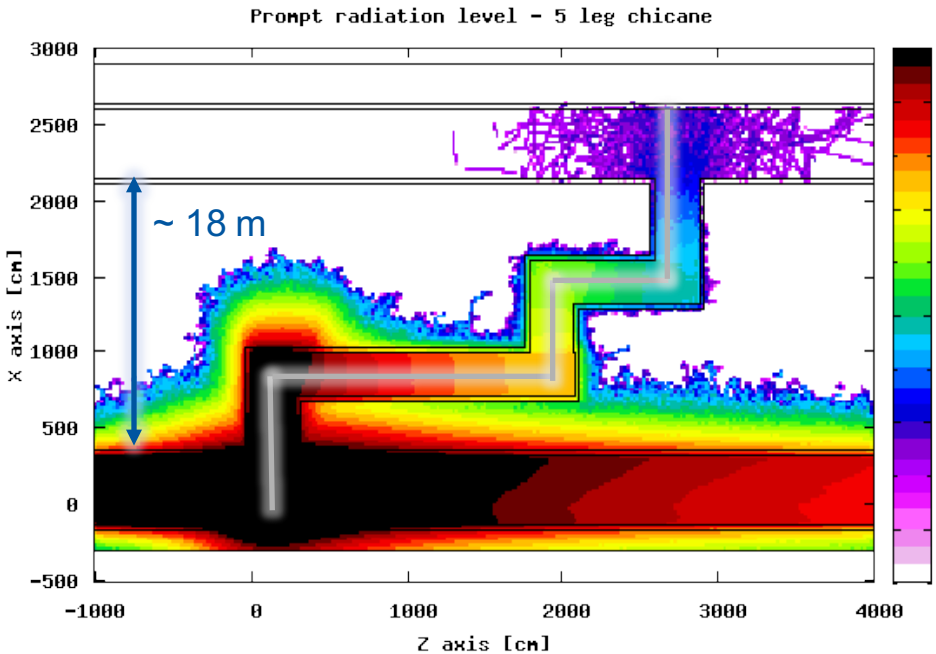


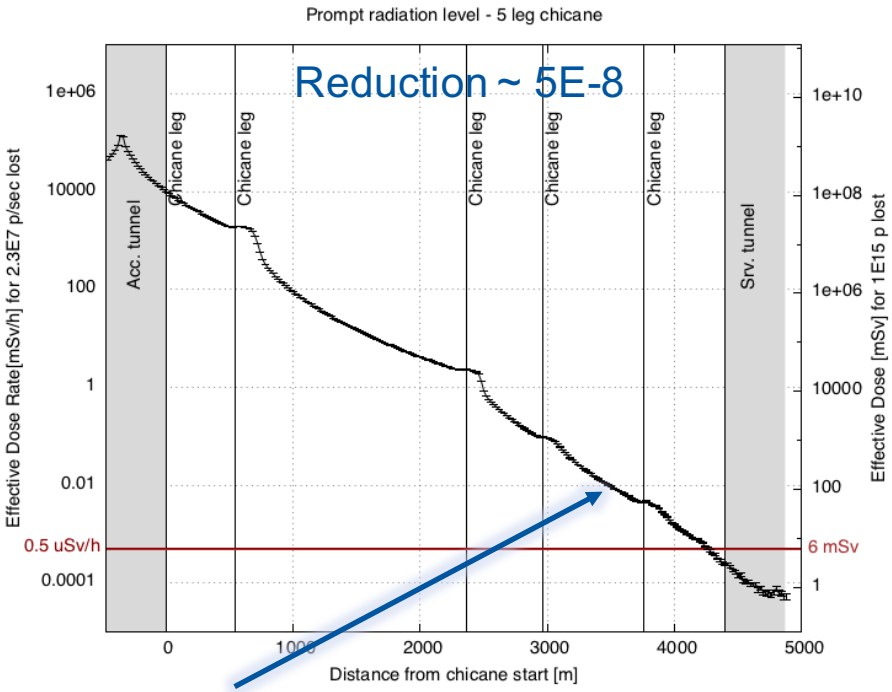
- Mandatory for high activation regions:
  - Collimation regions incl. beam dumps (2 x 4.2 km)
  - Focusing regions (4 x 1 km)
- Advantages:
  - Service tunnel should be designed as non-activation area
  - Equipment located in service tunnel→ Maintenance in a radiation-free environment
  - Cooling water supply in the service tunnel runs in a non-activation environment
  - Access to work places mainly through radiation-free service tunnel; passage in activated areas is limited to a minimum
  - Connection tunnels can be designed to allow access to service tunnel during operation



- Installation of radiation sensitive equipment possible in chicane or service tunnel
- Chicane to be designed such to prevent activation in rack area and service tunnel
- Airlock installed on the service tunnel side and entirely in non-activation area
- Ventilation of connection tunnel must be guaranteed during access mode
- Service tunnel could be ventilated in any scheme as required by other constraints
- Activation limitation criteria are generally respected for air lock and service tunnel, when the chicane is designed to allow access to the service tunnel during operation.

Chicane design for accessible service tunnel



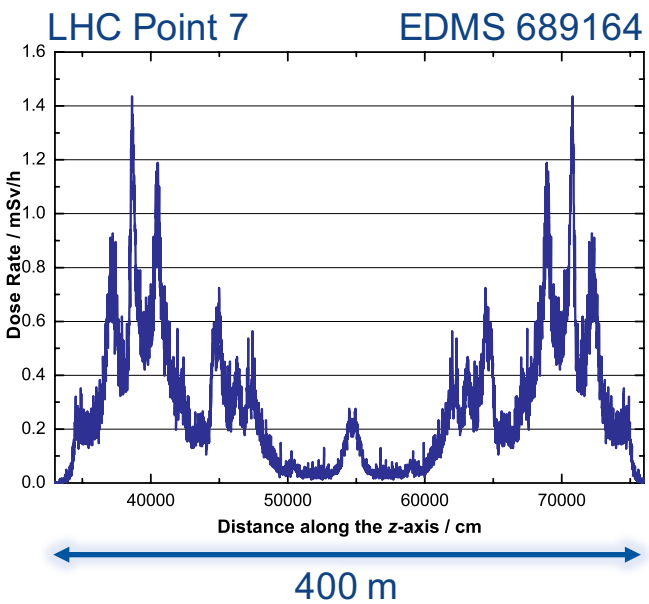


Factor 10 reduction for ~5-10 m distance (end of chicane)

- Tunnel distance: about 2x required rock shielding to compensate for a chicane
- Maximum loss scenario dominating: 5 leg chicane length of ~ 43m; a more credible loss scenario would shorten the chicane

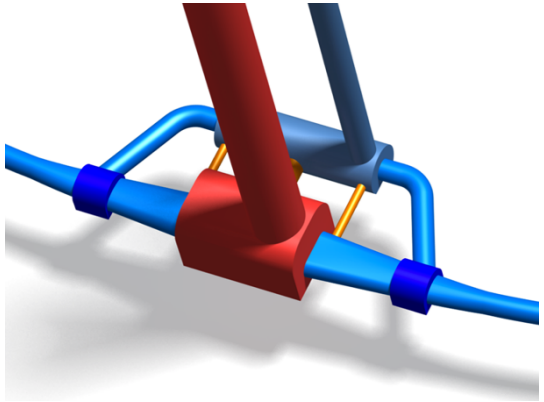
- Collimation section: permanent loss rate might become dominant, depending on adopted maximum credible loss scenario
- Arc section: always dominated by maximum (credible) loss scenario

Collimation region bypass

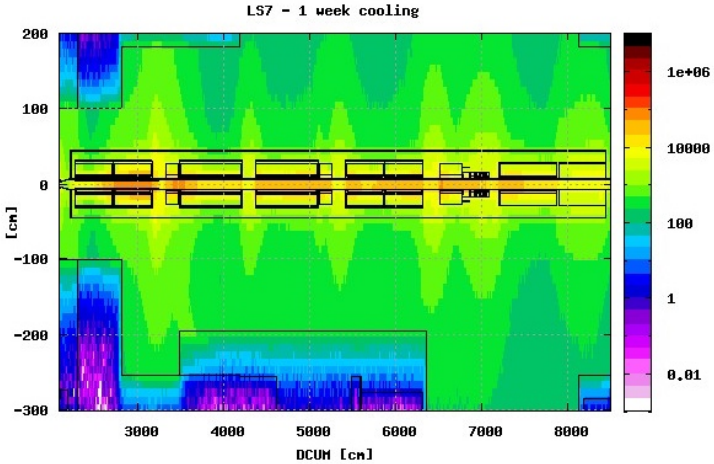


- **Connection tunnels** approx. spaced by 500m along the insertion of 4.2 km length
  → ~ 5-7 connection tunnels per point
- Applicable for both collimation points D and J
- Connection galleries placed inbetween primary, secondary collimators and absorbers
- Optimal location and number of connections depending on the layout of the collimation insertions and the expected loss distribution
- ***Input required:***
  - ***collimation insertion layout***
  - ***loss distribution***

Focusing region bypass



LHC Point 1



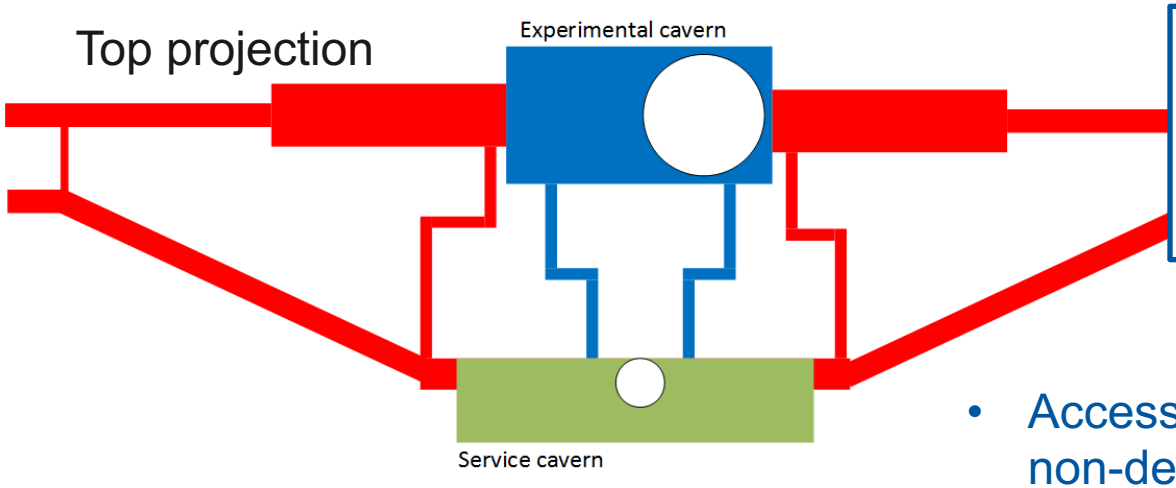
60 m

- Bypass will join the service cavern
- On both sides of the interaction points
- On ~ 1000 m distance, **1-2 connection tunnels** to allow proximity access

→ optimal number and location of connections to be determined by residual dose rate distribution

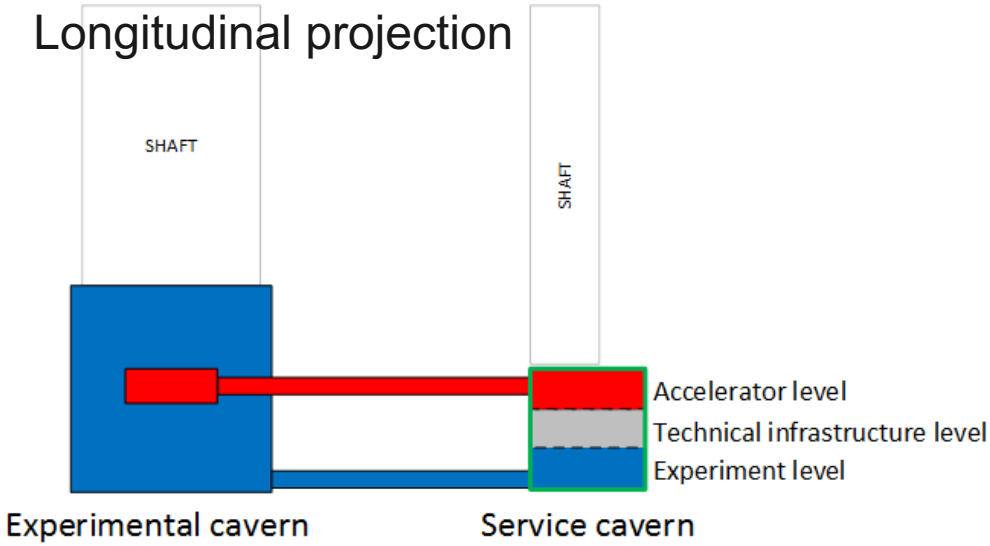
Experimental and service cavern

Top projection



Considerations:
- Area classification
- Personnel flow
- Material flow

Longitudinal projection



- Access shaft + Service cavern: non-designated areas
- Access control to accelerator and experiment underground
- Buffer areas for accelerator and experiment underground

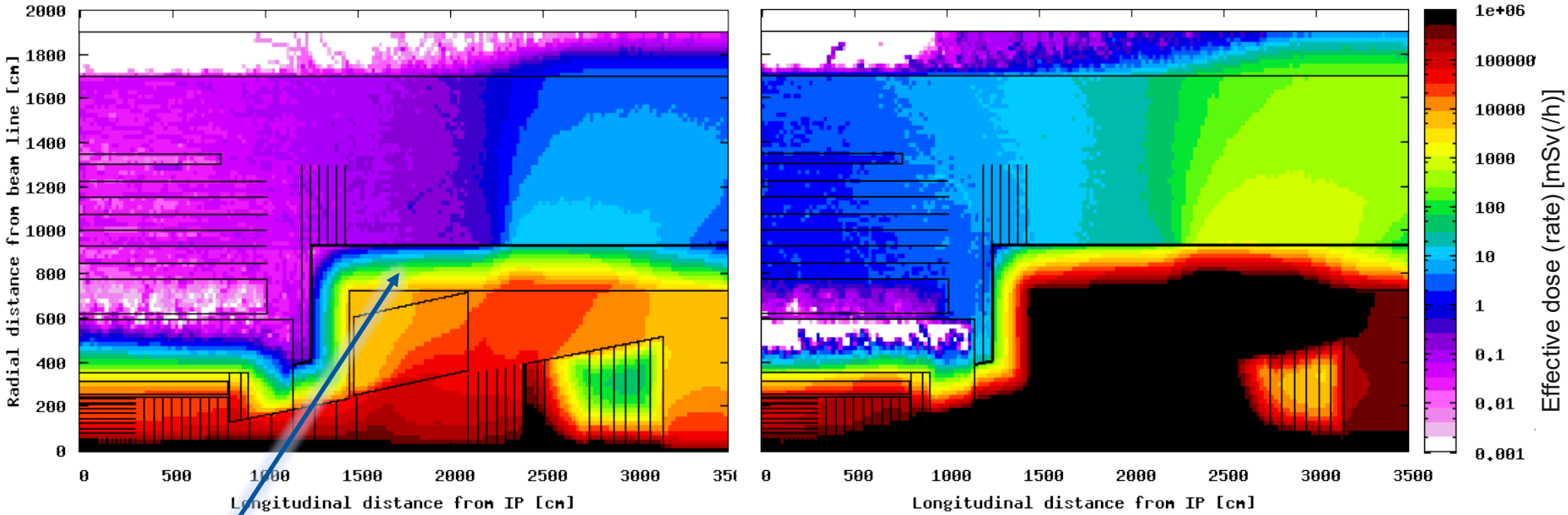
Functional separation of levels in service cavern

Experimental cavern - prompt radiation

Horizontal plane

FCChh Ultimate collisions

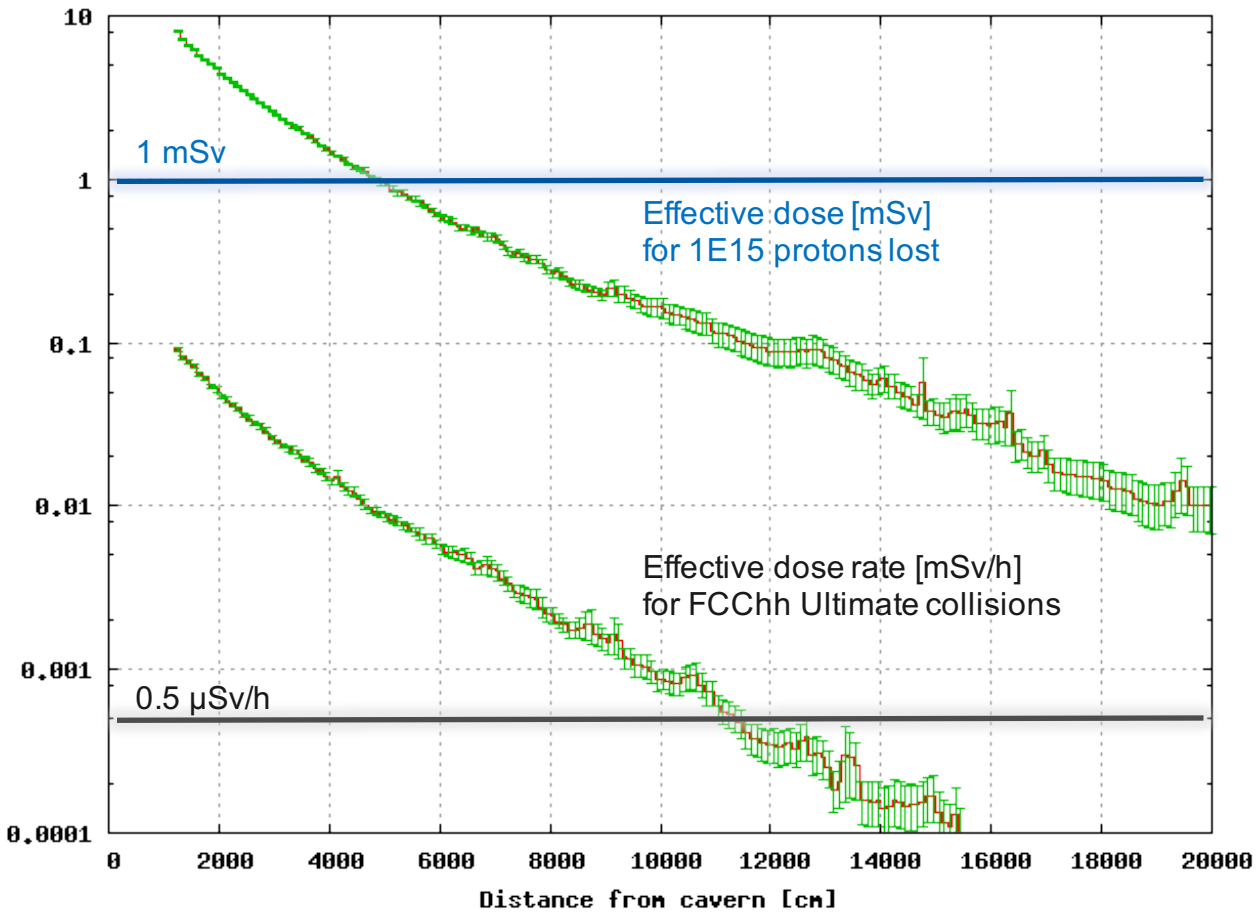
Full beam loss



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

Detector layout as of 01/2016
Input provided by I. Besana, EN/STI

Experimental cavern shaft – prompt radiation

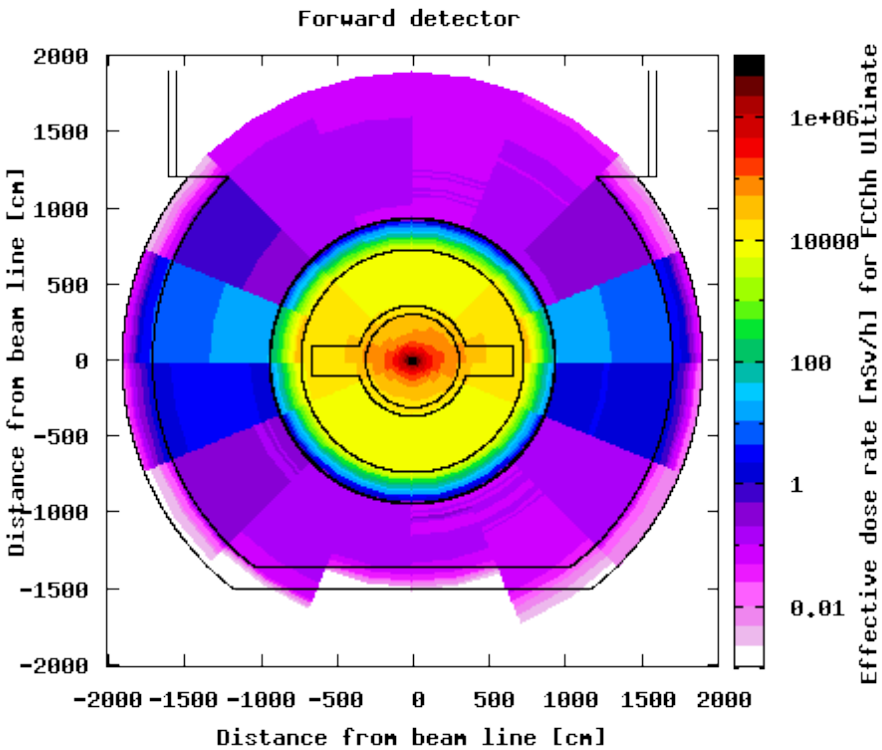


For both scenarios: Full beam loss and FCChh Ultimate operation

Dose rate levels limits on top of shaft far below limits

Experimental cavern - prompt radiation

Longitudinal projection along forward detector

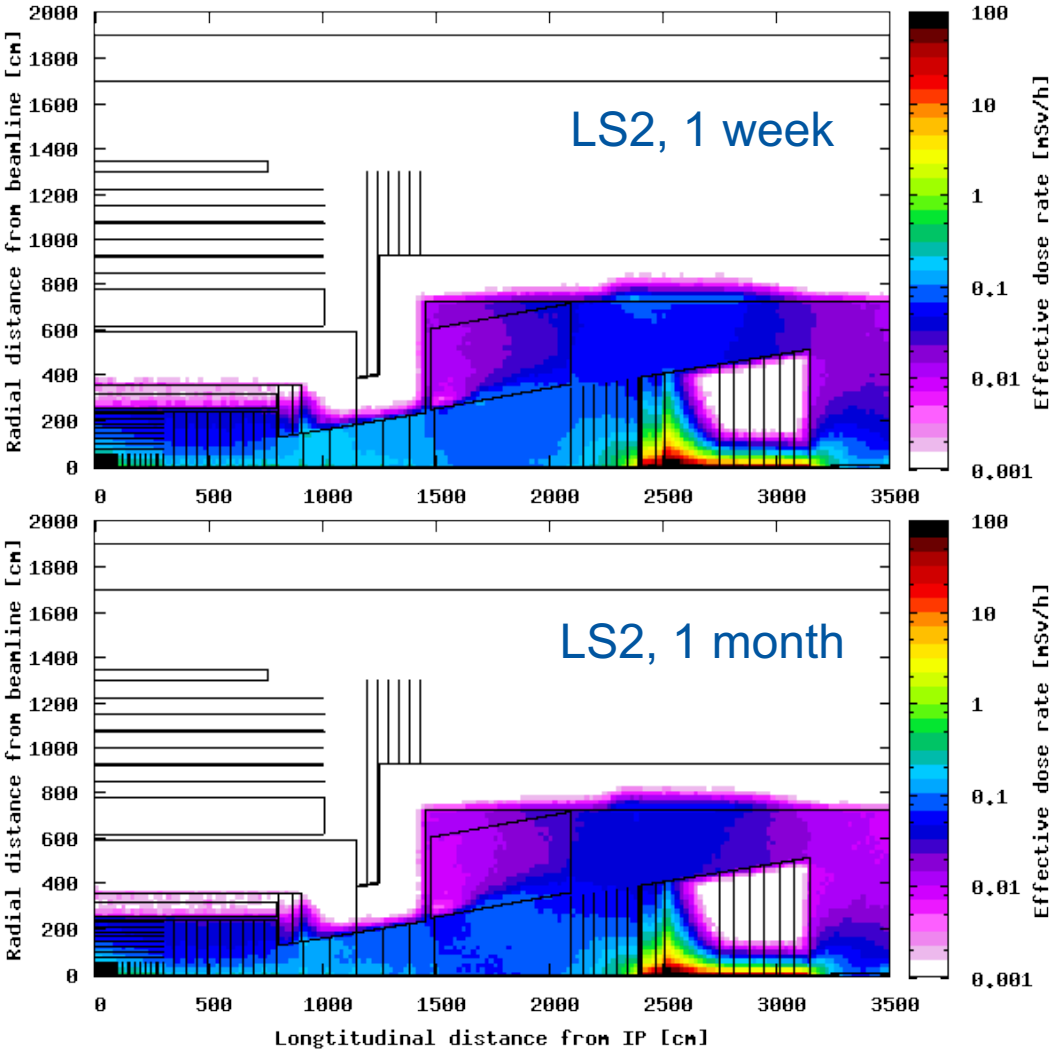


Higher dose rates in horizontal plane at forward detectors, due to the dipole

→ Access tunnels preferably located :

- above/below beam line
- not at very end of the experimental cavern

Detector activation – residual dose rates (1)

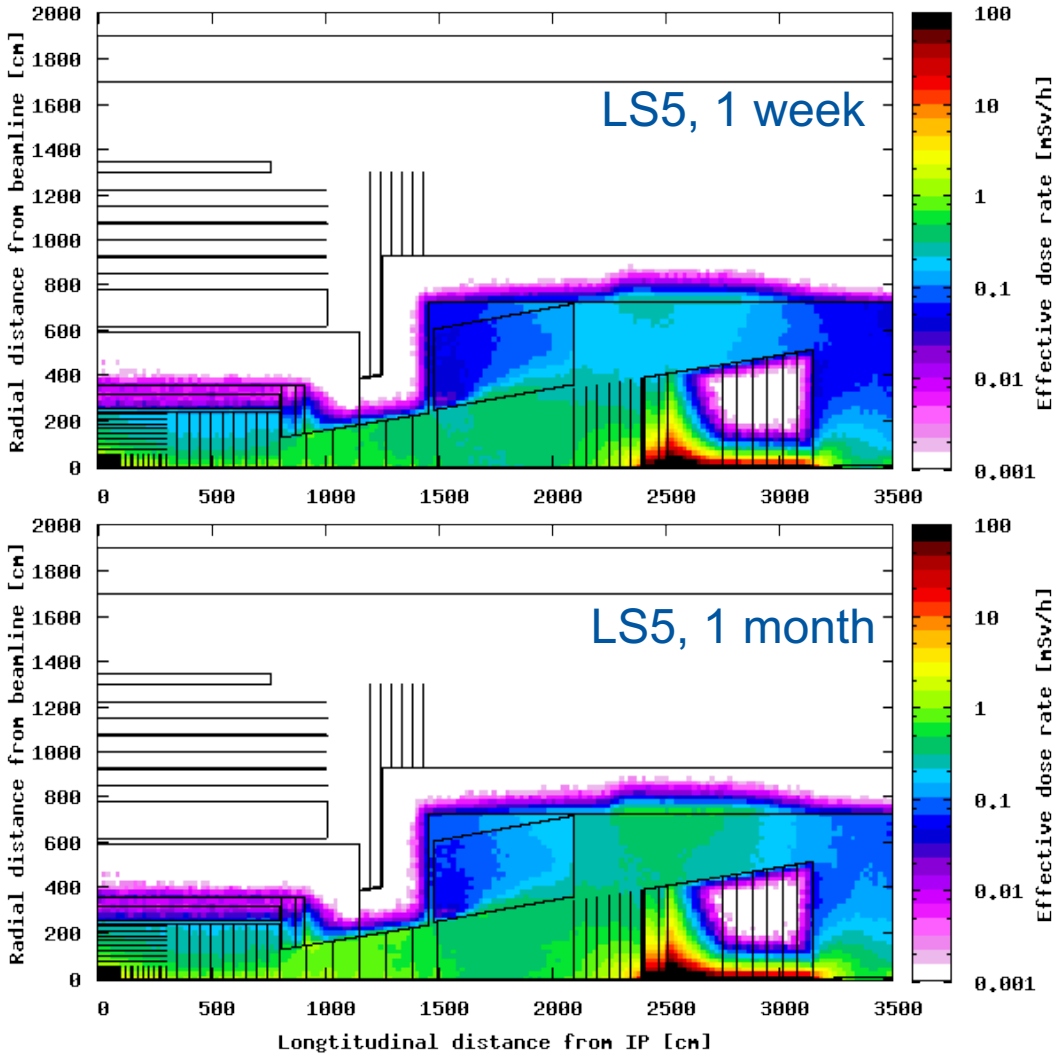


FCChh baseline operation
Residual dose rate at the start of LS2 (after 2500 fb^{-1})

→ ~ 0.2 mSv/h within a week
→ High levels in the forward detector hadron calorimeter

Detector layout as of 01/2016
Input provided by M.I. Besana, EN/STI

Detector activation – residual dose rates (2)



FCChh Ultimate
Residual dose rate after 5 FCChh run periods and 17.5 ab^{-1}

→ Below 1 mSv/h within a week
→ High levels in the forward detector hadron calorimeter

Detector layout as of 01/2016
Input provided by M.I. Besana, EN/STI

What next ?

- Further refinement of RP recommendations as the design converges in civil engineering and accelerator development
- First residual dose rate calculations for arcs and the focusing regions
- FCCee: evaluation of the radiological impact
- HTS beam screen coating study → material optimisation

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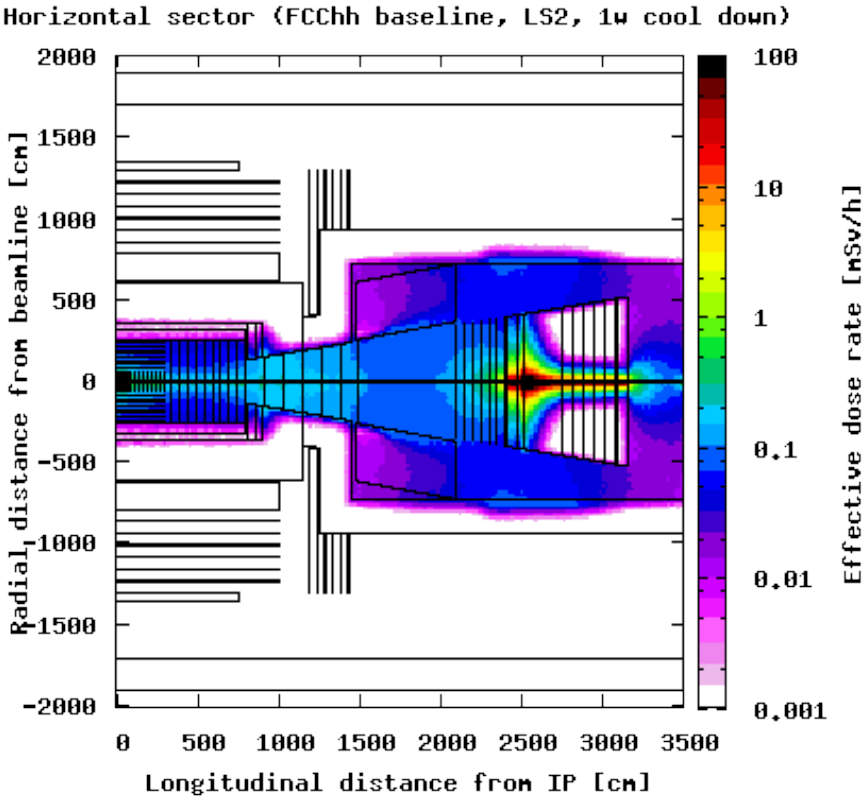
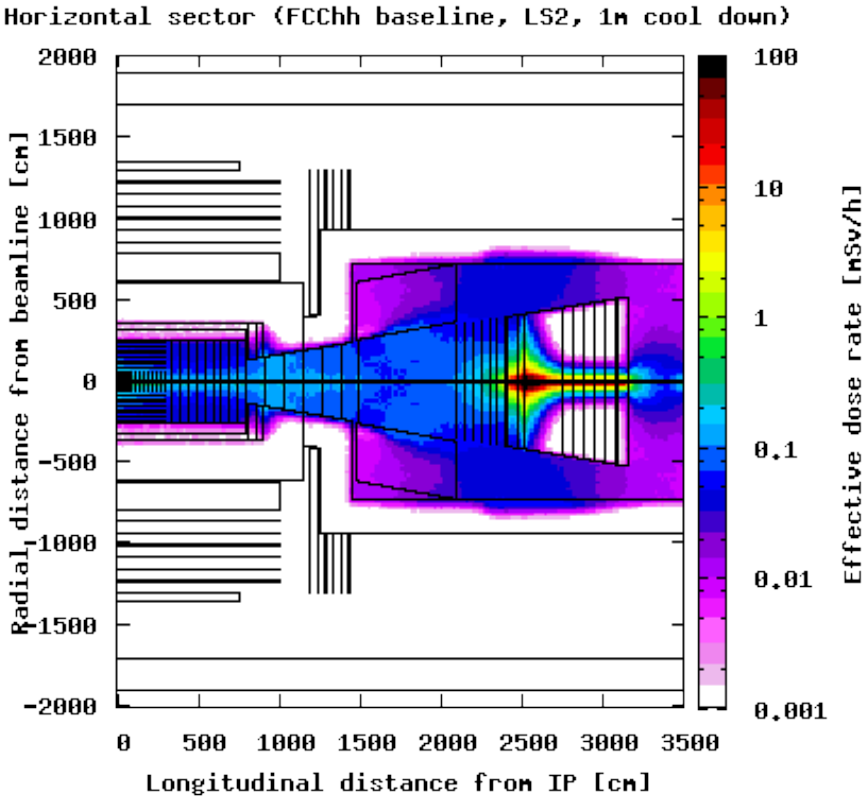

Horizontal sector (FCChh baseline, LS2, 1w cool down)
Radial distance from beamline [cm]
2000
1500
1000
500
0
-500
-1000
-1500
-2000
0
500
1000
1500
2000
2500
3000
3500
Longitudinal distance from IP [cm]
100
10
1
0.1
0.01
0.001
Effective dose rate [mSv/h]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Radial distance from beamline [cm]
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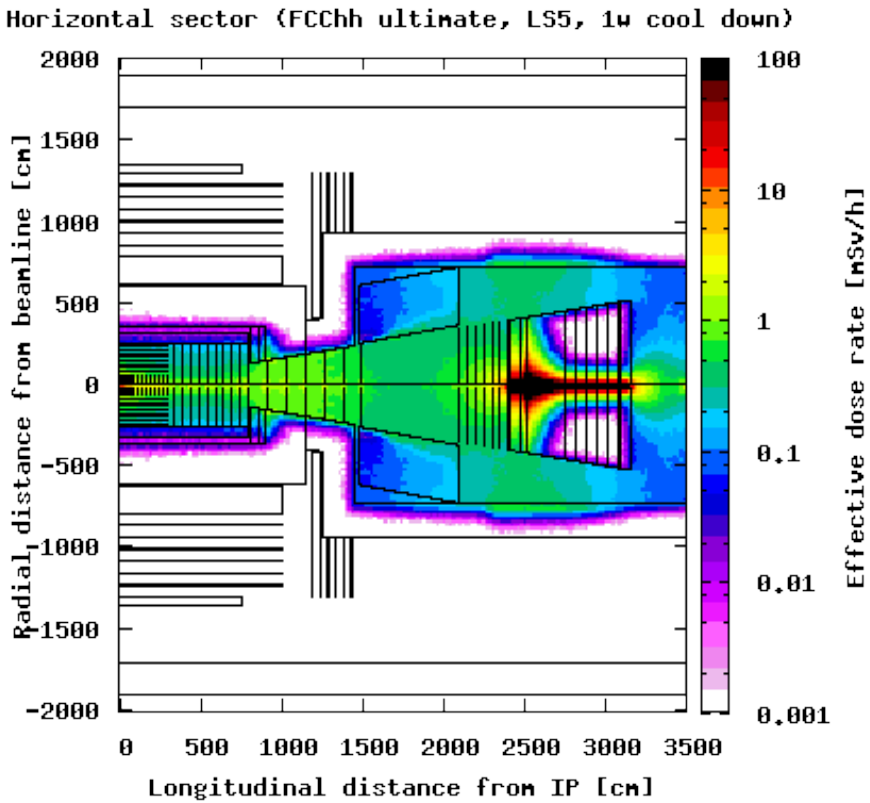
2000
2500
3000
3500
Longitudinal distance from IP [cm]
100
10
1
0.1
0.01
0.001
Effective dose rate [mSv/h]


Horizontal sector (FCChh ultimate, LS5, 1w cool down)
Radial distance from beamline [cm]
Longitudinal distance from IP [cm]
Effective dose rate [mSv/h]
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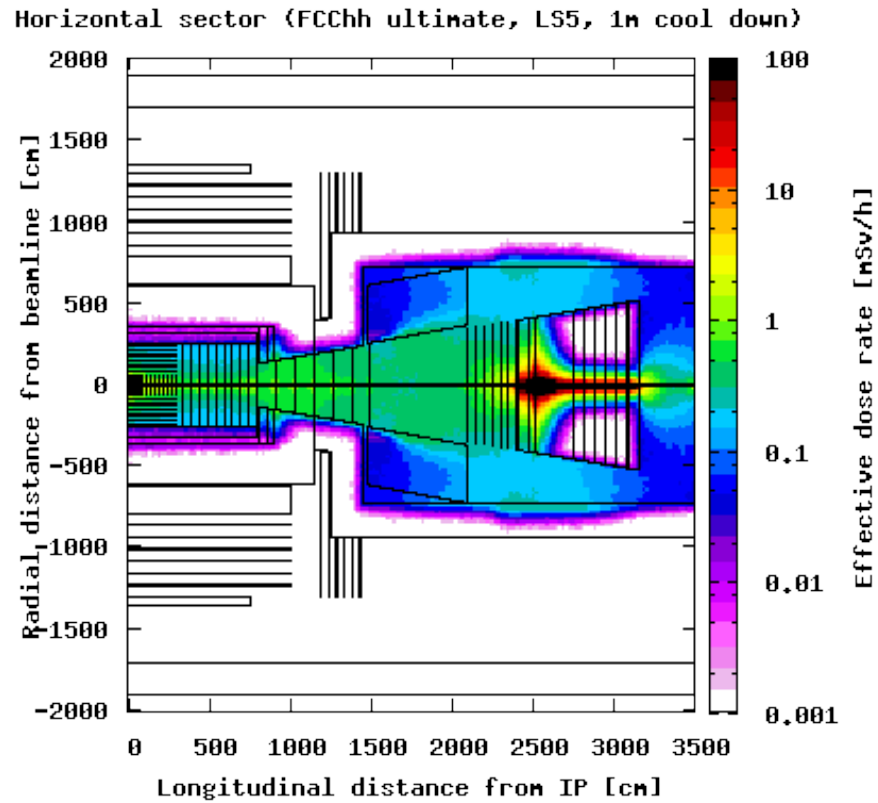
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Radial distance from beamline [cm]
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