Radiation Protection Issues After 20 Years of LHC Operation

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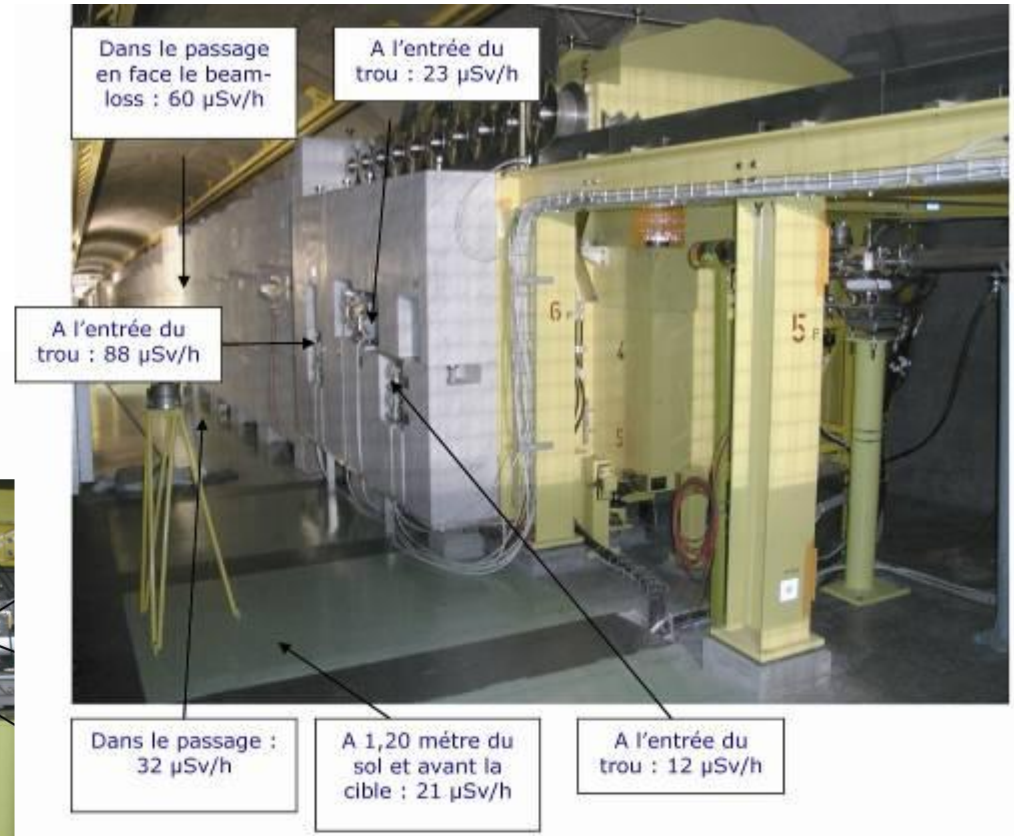
HE-LHC from RP’s Point of View

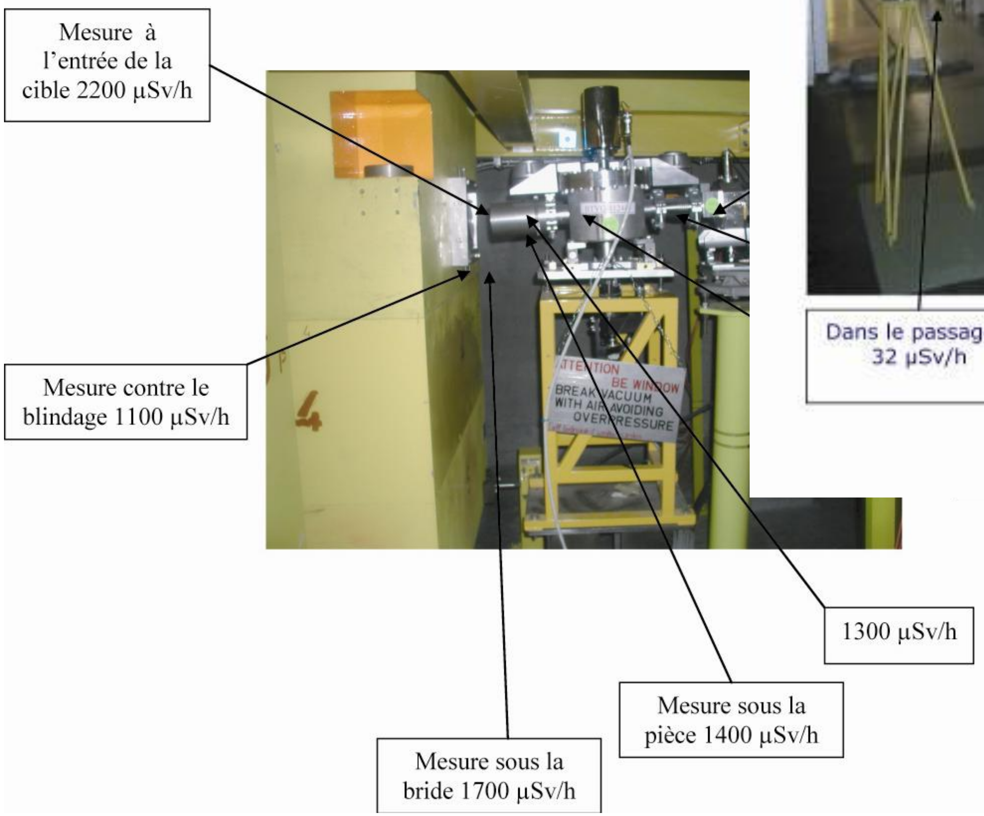
To convert LHC/HL-LHC into HE-LHC after 20 years of operation implies:

- exposure of workers to ionizing radiation
  - removal of dipoles
  - removal of inner triplets (?)
  - removal of collimators (?)
  - modification of beam dumps (?)
  - LHC experiment modifications/upgrades
  - installation of new components
- radioactive waste
  - production
  - conditioning
  - interim storage
  - final disposal

Risk Analysis

..based on measurements





Optimisation – Based on Outcome of Risk Analysis

special devices

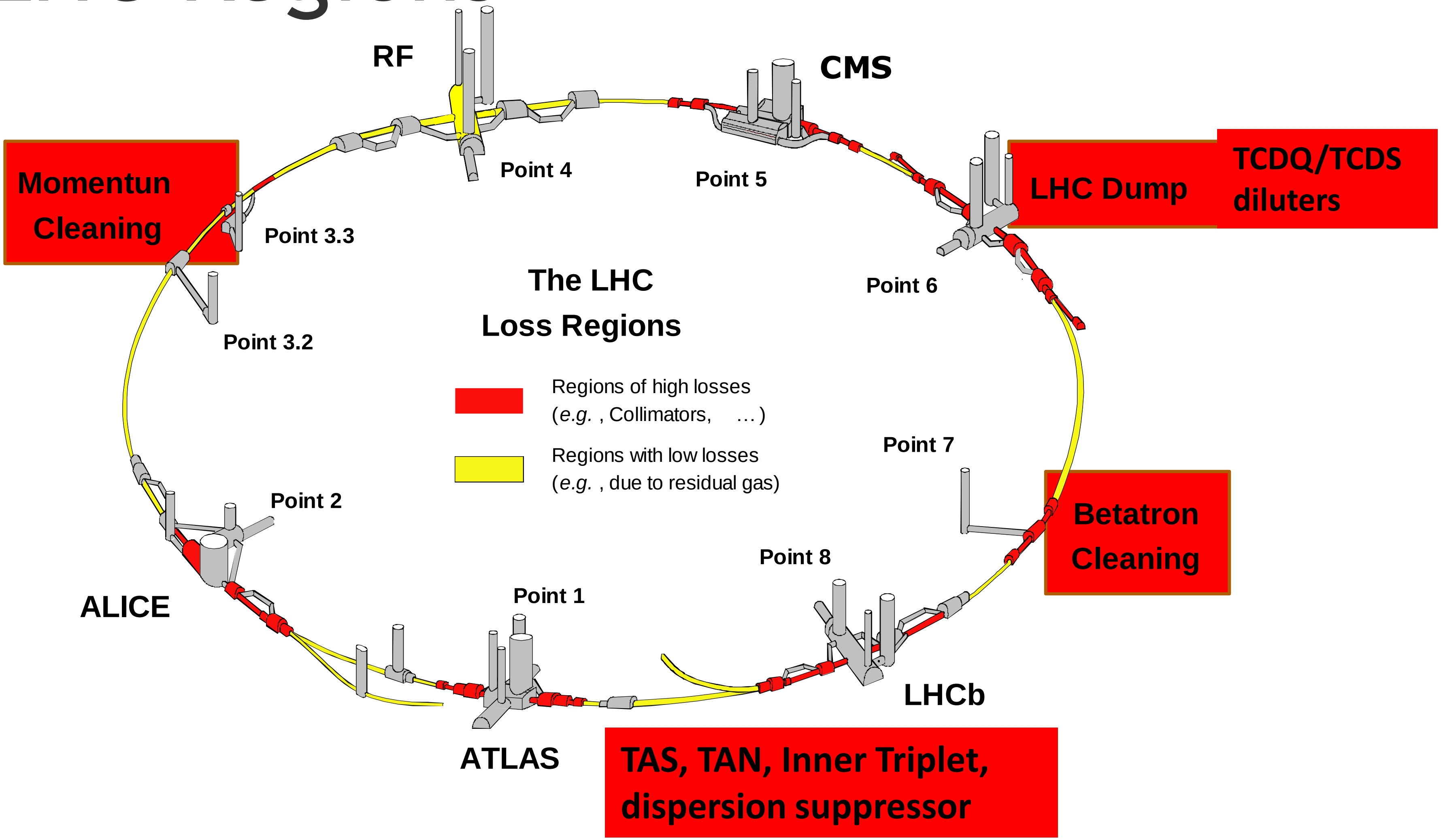
dry-runs

remote handling

accomplishment

Critical LHC Regions

LHC: forecasts on ambient dose equivalent rates can be only based on Monte Carlo simulations – comparison with measurements only later (LHC not yet very radioactive)



Extrapolation of FLUKA results for nominal and 180 d of operation to 20 years of operation (including ultimate and HL-LHC)

Fluka study

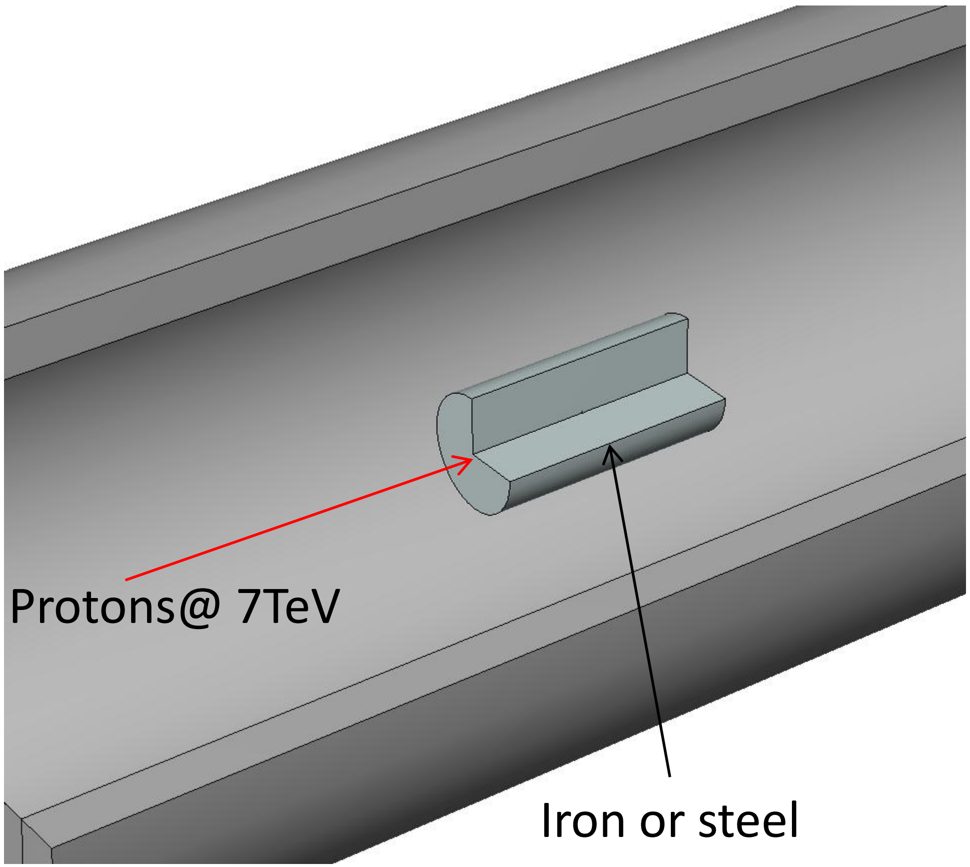
Irradiation times: *180d, 5y, 20y*

Cooling times: *1d, 1w, 1m, 4m*

Materials of Cylinder:

Iron (r= 7.874 g/cm³)

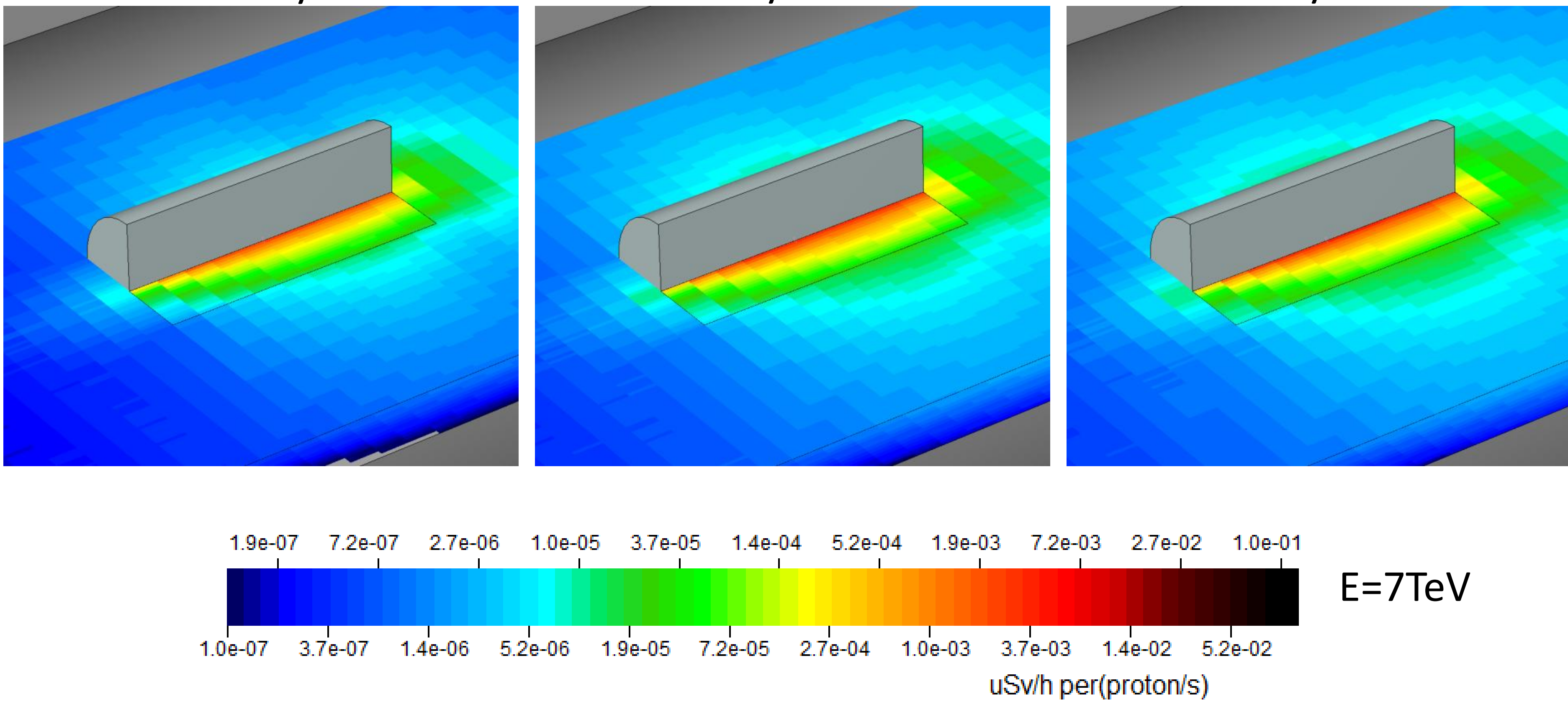
Steel (r= 7.252 g/cm³)



Steel composition				
Element	wt-%		Element	wt-%
IRON	63.09		SULFUR	0.00
CHROMIUM	17.79		COPPER	0.09
NICKEL	6.50		OXYGEN	0.00
MANGANES	11.43		TITANIUM	0.01
SILICON	0.38		VANADIUM	0.07
NITROGEN	0.31		COBALT	0.11
PHOSPHOR	0.02		NIOBIUM	0.01
MOLYBDEN	0.09		TUNGSTEN	0.01
CARBON	0.10			

Steel magnet, various irradiation times and 4 months cooling

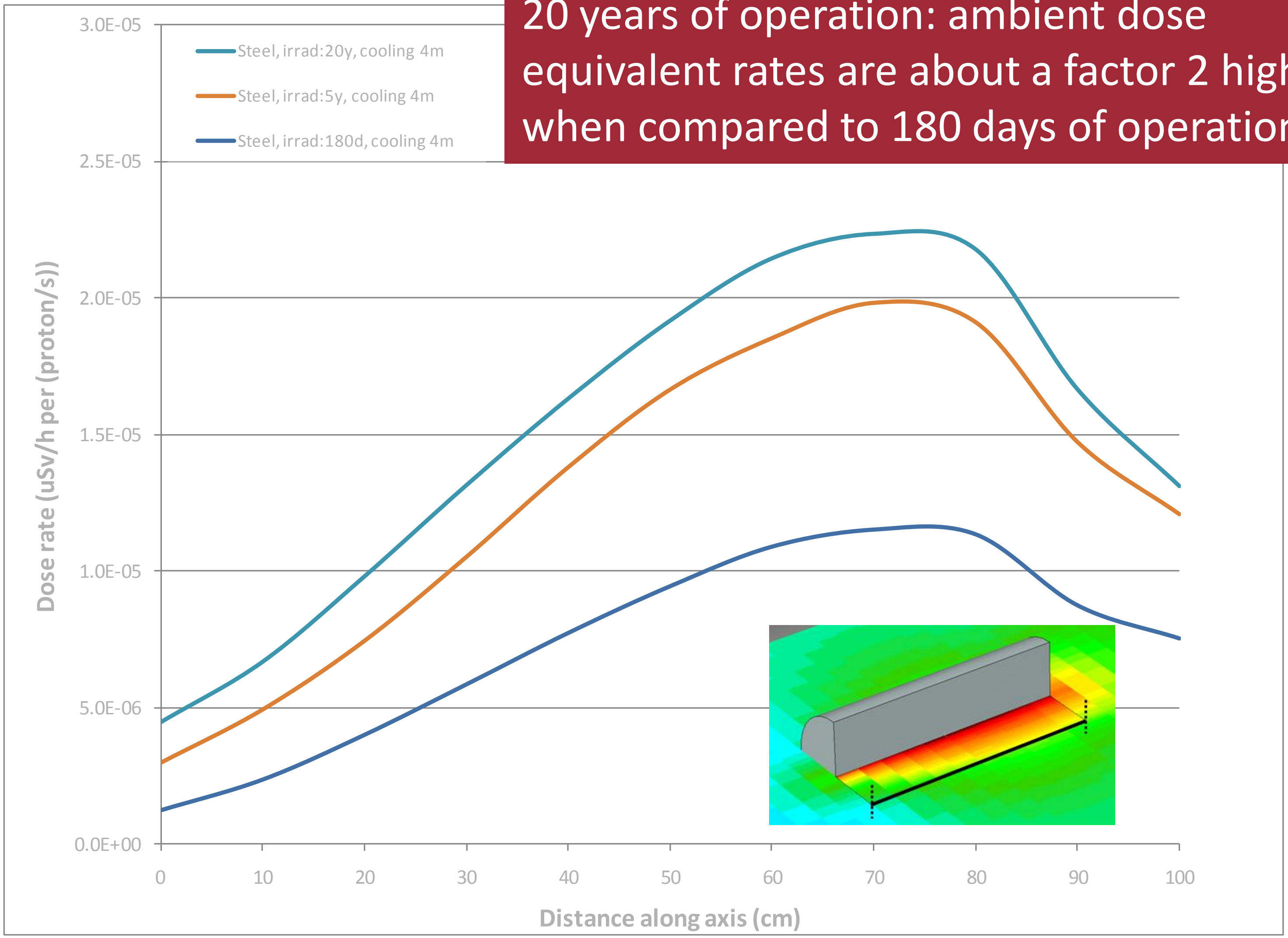
Irradiation time: 180 days | Irradiation time: 5 years | Irradiation time: 20 years



Assumption good enough for a reasonable extrapolation of ambient dose equivalent rates:

- 20 years = 20 x 180 days irradiation, 185 days shutdown
- removal of LHC accelerator components starts 4 months after beam stop

Ambient dose equivalent rates along a steel magnet



20 years of operation: ambient dose equivalent rates are about a factor 2 higher when compared to 180 days of operation

RP relevant LHC Parameters

LHC Phase	energy (TeV)	beam intensity (protons/beam)	luminosity (cm-2s-1)	year
Commissioning	3.5	$5.1\cdot10^{13}$	$2\cdot10^{32}$	2010
“	3.5	$1.5\cdot10^{14}$	$1\cdot10^{33}$	2011
nominal	7	$3.2\cdot10^{14}$	$1\cdot10^{34}$	2013
ultimate	7	$4.7\cdot10^{14}$	$2.3\cdot10^{34}$	2017
HL-LHC	7	$4.7\cdot10^{14}$	$5\cdot10^{34}$	2021
HE-LHC	16.5	$2.5\cdot10^{14}$	$2\cdot10^{34}$	>2030

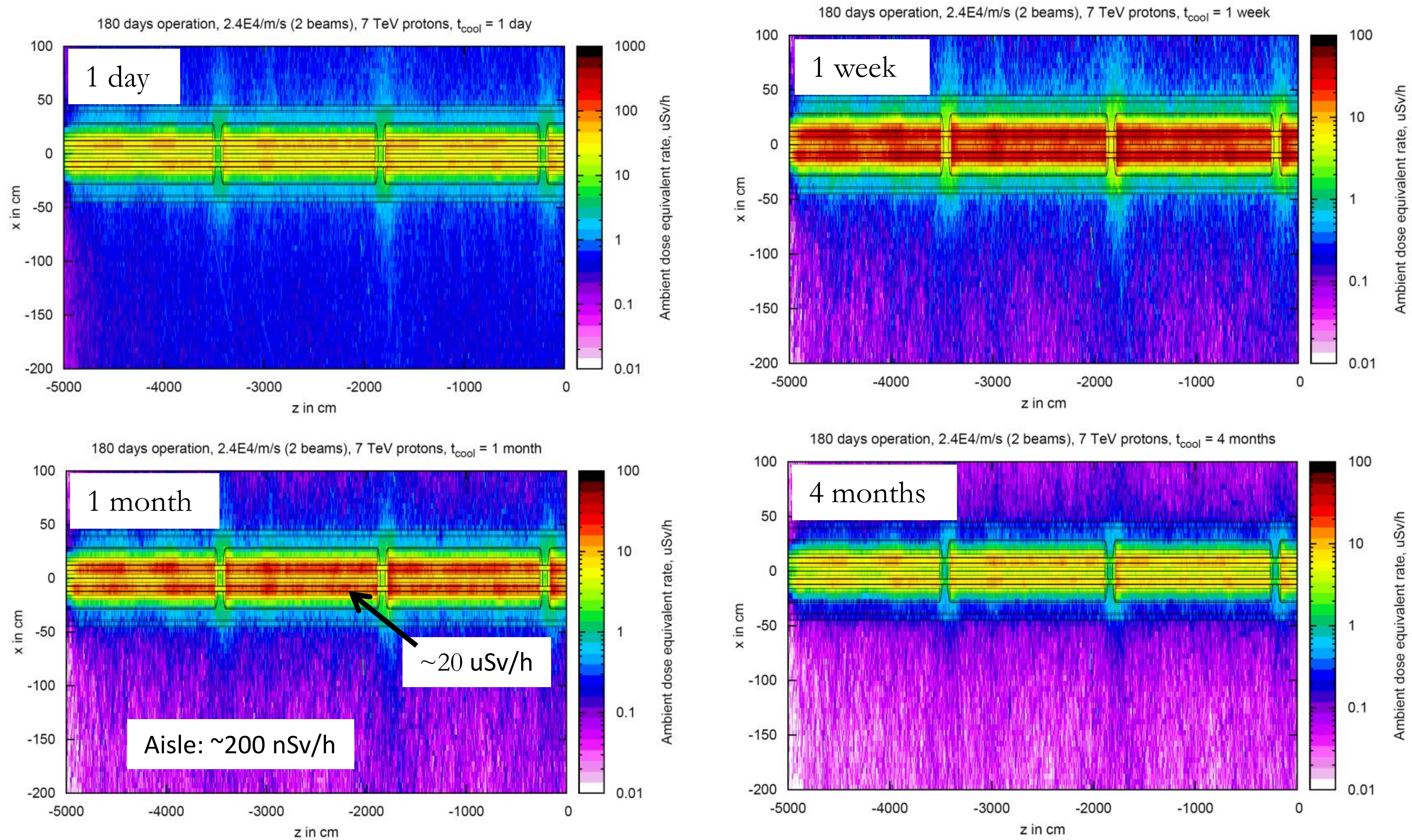
Assumption:
no technical modification of LHC installations and no change of beam loss pattern
-> ambient dose equivalent rates scale with beam energy ($E^{0.8}$), with luminosity (experiments, Inner Triplet), beam intensity (arcs, collimators) and total number of protons

Activation of Arcs

Assumption:

2.4 10^4 protons/m/s (both beams), 7TeV, lost for 180 days continuously
(corresponds to an H_2-equivalent beam gas density of 4.5 10^{14} /m^3)

nominal

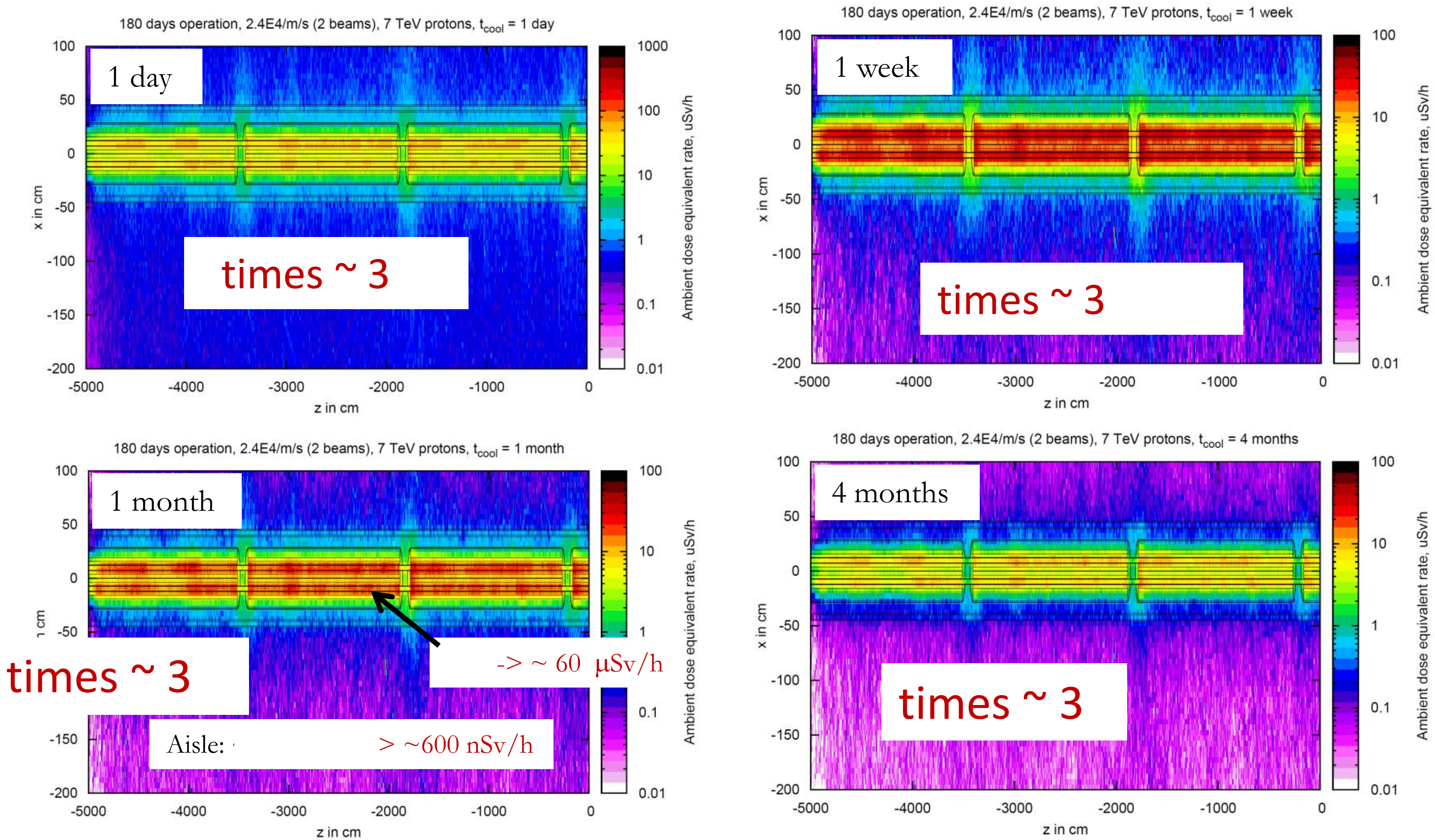


Activation of Arcs

2030 - after HL-LHC

Assumption:

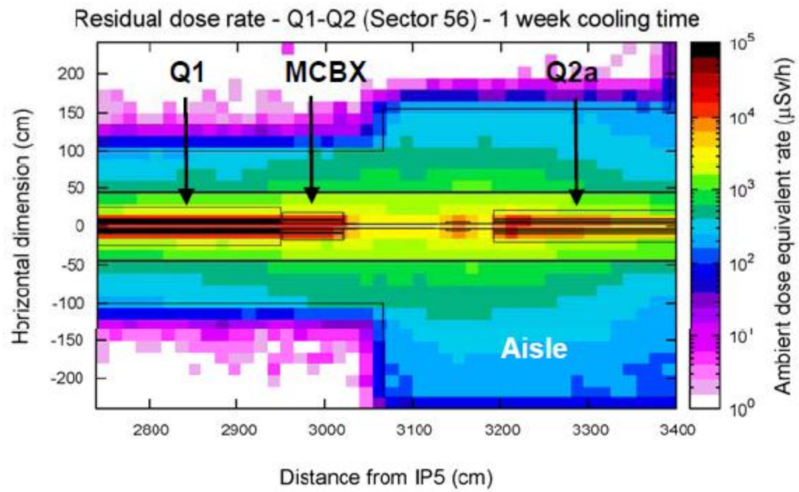
2.4 10^4 x ~1.5 protons/m/s (both beams), 7TeV, lost for 20 years operation
(corresponds to an H_2-equivalent beam gas density of 4.5 10^{14} /m^3)

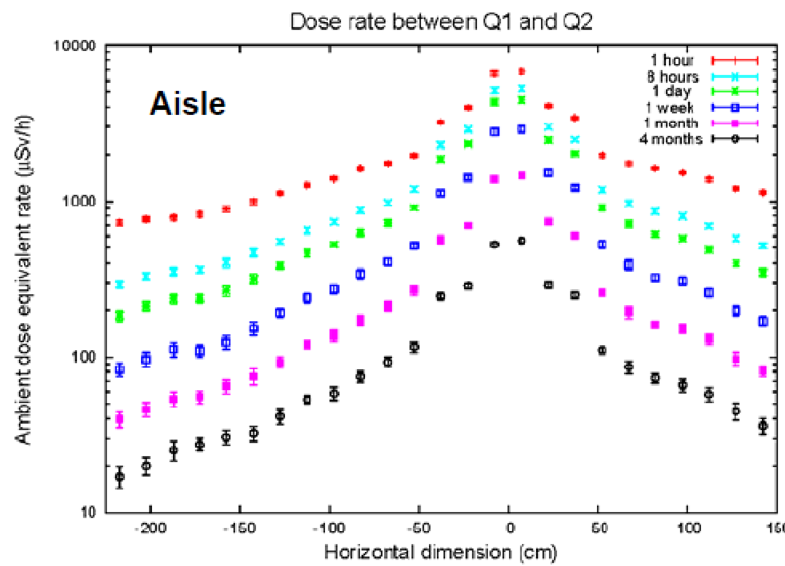


Inner Triplet

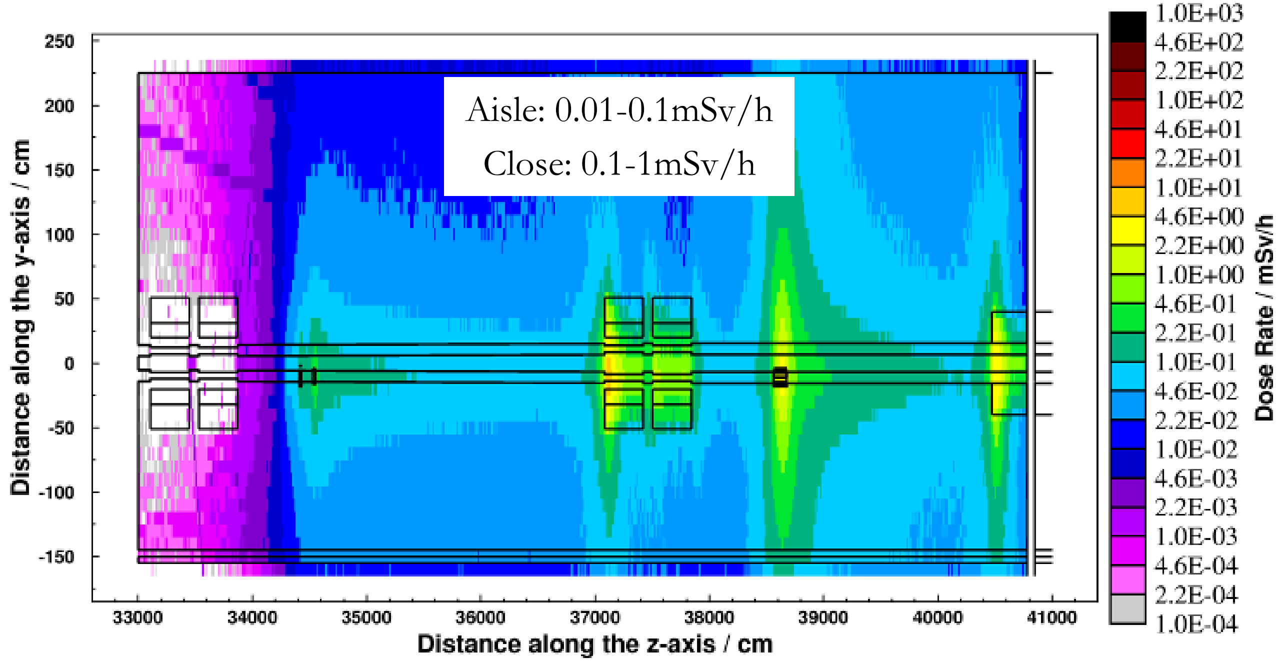
LHC mode	Duration	Ambient dose equivalent rate
nominal	5 y	up to 600 uSv/h
HL-LHC	10 y	up to 1 mSv/h

Monte Carlo results for 180 days at nominal luminosity





Collimators



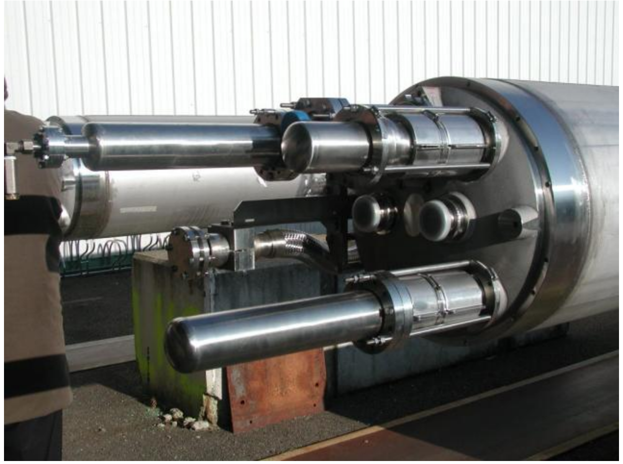
Monte Carlo results for 180 days of nominal operation, 4 months cooling

2030 – after HL-LHC:
Aisle: 0.03 – 0.3 mSv/h
Close 0.3 – 3 mSv/h

Removal of Dipoles

- Removal of dipoles implies destructive work (cutting beam pipes, splices, etc.) and such risk of contamination. Adequate technique will be developed during splice exercise in 2012.

- Dose to workers during dismantling and transport needs to be optimised:
  - avoiding Point 7 and Point 3
    - dipoles out at Point 2 and Point 6?
    - new side galleries (?)
  - shielded vehicles
  - remote controlled vehicles (?)



Removal of Inner Triplet

- Dismanling implies destructive work – experience will be gained from the the first triplet exchange in some few years

- The dose rates may reach 500 uSv/h to 1 mSv/h after four months of cooling: major optimisation has to be done with respect to design, installation, removal and transport – valid already for the next Triplet generation and optimised design is imperative
    - material choice,
    - fast flange connection instead of welding ?
    - adequate handling means to be developed

Removal of Collimators, Warm Magnets, etc.

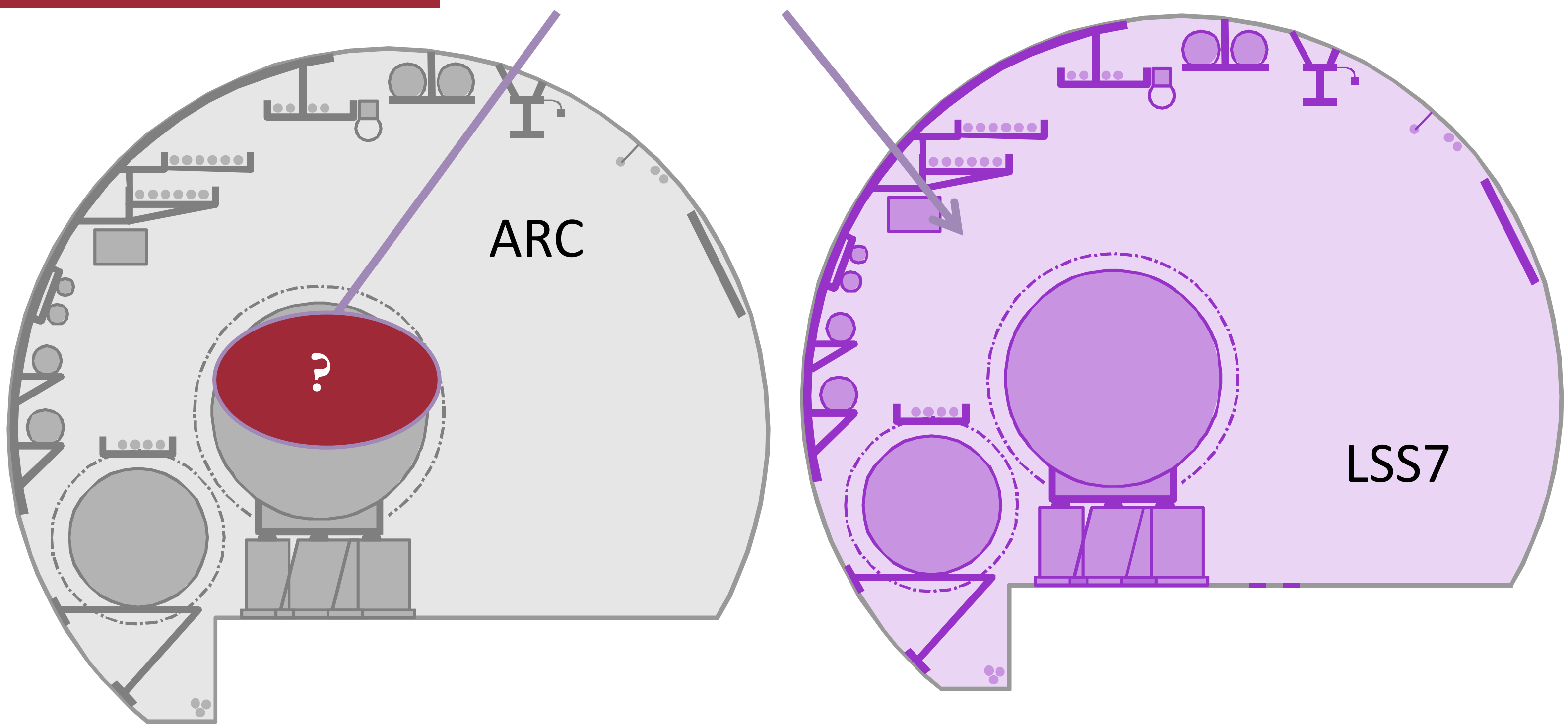
Ambient dose equivalent rates will be in the order of some few 100 uSv/h to mSv/h - even after 4 months of cooling

- Dismanling of collimators had been studied and optimised – development of remote handling tool is ongoing
- Dismantling of warm magnets and passive absorbers needs to be prepared and optimised – remote handling tools and special transport vehicles need to be developed *(already required for the next years of LHC operation)*
- Installing equipment in addition to the already existing, radioactive material in Point 3 and Point 7 seems extremely difficult if not impossible

Waste Production

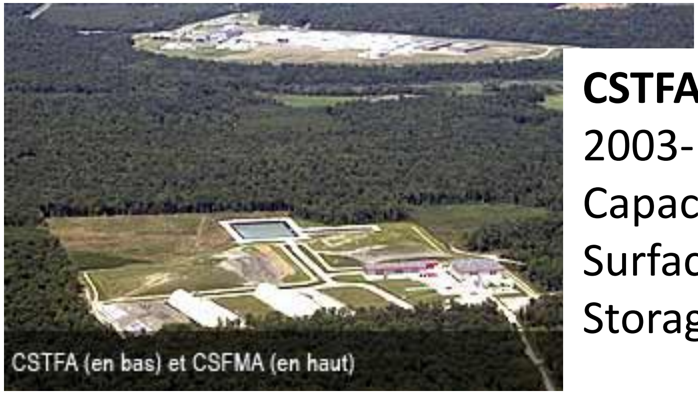
2030: LH-LHC, lower release limits

Radioactive after 10 years of LHC nominal operation and 4 months of cooling

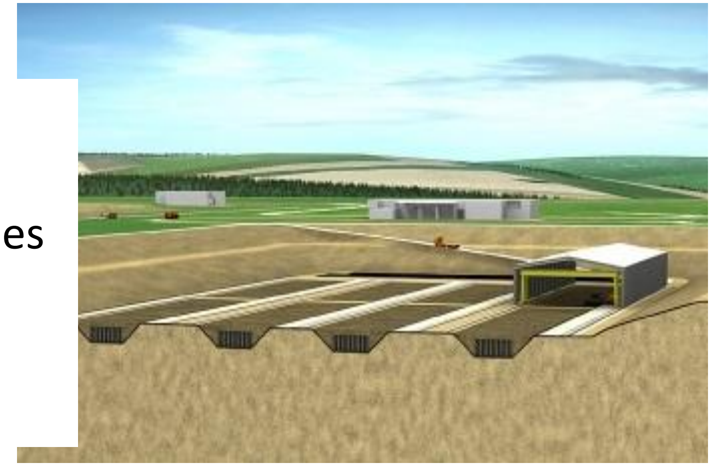


Waste Storage and Disposal

- CERN's present interim storage for radioactive waste is not adapted to store LHC dipoles (cranes limited to 8 t).
- « Light storage solutions for dipoles» need to be studied
- Radioactive waste others than dipoles need to be stored in shielded areas equipped with proper handling means
- Waste study to define the elimination pathway for dipoles (possible final repository CSTFA in Aube, today about 1000 Euros/m3)
- The rest risks to stay at CERN waiting for final repository in France or Switzerland. Waste disposal techniques and regulation might evolve until 2030.



CSTFA
2003- 2033
Capacity: 750 000 tonnes
Surface 48 h
Storage 28,5 h



Summary

RP issues of HE-LHC are challenging

- Exposure to workers during dismantling:
  - Much experience in removing components (dipoles, triplet, collimators) will be gained in the next few years, optimised dismantling will be required within the next years
  - Design of any new generation of components (like Inner Triplet) need to be optimised before being installed

  -> preparation for HE-LHC

- Operation of HE-LHC will not increase the radiological risk to workers and public when compared to LHC-ultimate and HL-LHC *(based on best present knowledge)*

Summary

- Radioactive waste production, storage and disposal – needs to be addressed today as even small quantities of radioactive waste from LHC risk to pose a problem.
- Moving from LHC to HE-LHC will double the amount of radioactive LHC waste , more options should be studied:
  - recycling of dipoles
  - “Magnet Disassembly Facility” to separate radioactive from non-radioactive material *(if at all possible)*