Radiation Protection: How (radio)active are we going to be?

S. Roesler
(on behalf of DGS-RP)

Chamonix 2011 LHC Performance Workshop
January 24-28, 2011

Outline

1) Run parameters for 2011 and 2012 (M.Lamont)

2) Scaling factors for dose rates and activation
   a) Purely based on run parameters
   b) Obtained with generic simulations with actual irradiation profile

3) Present radiological situation

4) Preview of radiological situation after runs in 2011 and 2012
   a) By scaling of present measurement results
   b) Using generic and/or dedicated simulations for the area of interest

5) Uncertainties and further verification

6) Air activation and related issues

7) Summary and conclusions

Operational scenarios for proton runs

Source: M.Lamont 12/3/2010

	2011	2012
Energy	**4 TeV**	**4 TeV**
Probable bunch spacing	75 ns	50 ns
Maximum number of bunches	**936**	**1400**
Bunch intensity	**1.1e11**	**1.2e11**
Maximum stored beam energy	66 MJ	108 MJ
Beta*	2 m.	2 m.
Emittance	3 microns	2.5 microns
Peak luminosity	**6e32 cm-2s-1**	**2e33 cm-2s-1**
Number of days physics	200	200
Intensity ramp up time	6- 8 weeks	~3 months
Estimated integrated luminosity	**1 - 3 fb-1**	**~5 fb-1**

Derived scaling parameters

→ parameters important for RP estimates:

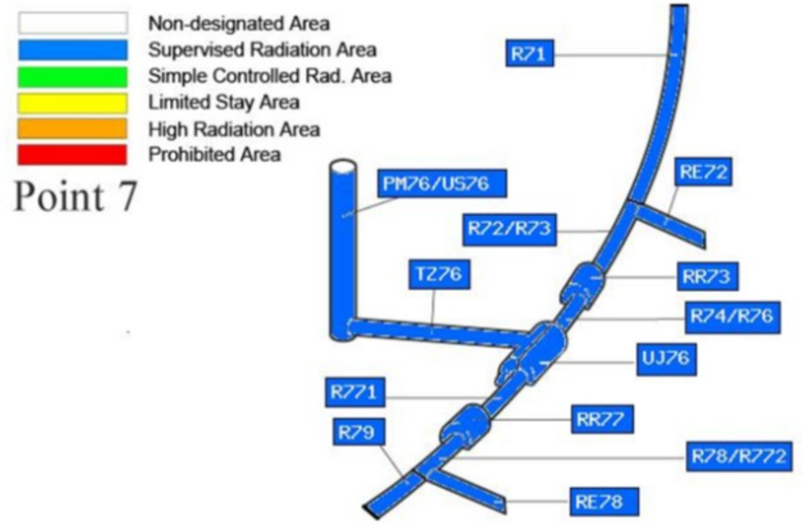
Year of operation	2010	2011	2012	
Energy	3.5 TeV	4.0 TeV	4.0 TeV	
Fraction of nominal beam intensity	13%	32%	53%	
Average luminosity, L_{avg} = ¾ L_{peak}	7.5e31	4.5e32	1.5e33	
Integrated luminosity, L_{int}	0.05 fb-1	1 fb-1	5 fb-1	
Number of days physics	39	129	193	$= 0.2 \times L_{int} / L_{avg}$

→ rough scaling of activation based on above parameters:

(not considering heavy ion run, scrubbing run, *etc.*, assuming linear scaling of losses with beam intensity / luminosity)

	Activation ratios for shutdowns	2012/now	2013/now	2013/2012
beam intensity dependent activation	Short cooling time (scaling w/ beam intensity)	2.5	4.1	1.6
	Long cooling time (scaling w/ total number circulating protons)	9.1	30	3.2
luminosity dependent activation	Short cooling time (scaling w/ average luminosity)	6.0	20	3.3
	Long cooling time (scaling w/ integrated luminosity)	20	100	5.0

Present situation – *IR7*



Dose equivalent rates (μSv/h) on 1/7/2011

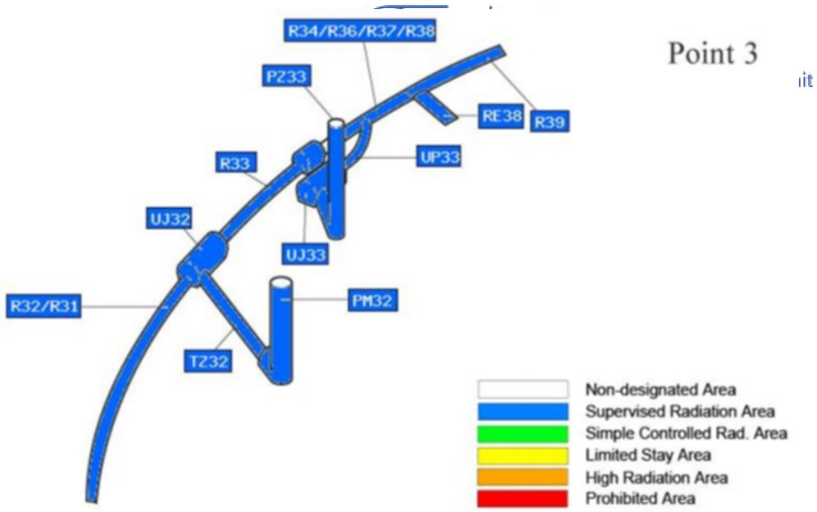
(70 days after proton run, 33 days after ion run)

	IR7-Left (Beam 1, wall side)		IR7-Right (Beam 2, aisle side)	
Element	**Contact**	**Aisle**	**Contact**	**Aisle**
TCP.D6	5.0	0.5	10.0	1.2
TCP.C6	14.0	1.5	18.0	2.5
TCP.B6	31.0	2.6	31.0	3.1
TCAPA	70.0	1.4	70.0	3.0
TCAPB	8.0	0.4	13.0	1.2
TCSG.A6	19.0	2.0	8.0	1.5
TCAPC	45.0	1.2	65.0	2.5

	Area classification	Dose limit	Ambient dose equivalent rate	
			At permant workplaces	In low-occupancy areas
	Non-designated Area	1 mSv / y	< 0.5 μSv h^{-1}	< 2.5 μSv h^{-1}
	Supervised Radiation Area	6 mSv / y	< 3 μSv h^{-1}	< 15 μSv h^{-1}
Controlled Radiation Area	Simple Controlled Radiation Area	20 mSv / y	< 10 μSv h^{-1}	< 50 μSv h^{-1}
	Limited Stay Area			< 2 mSv h^{-1}
	High Radiation Area			<100 mSv h^{-1}
	Prohibited Area			> 100 mSv h^{-1}

nit

Present situation – *IR3*

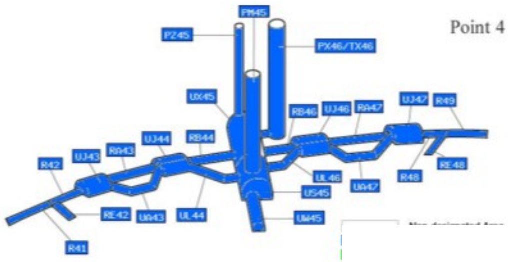


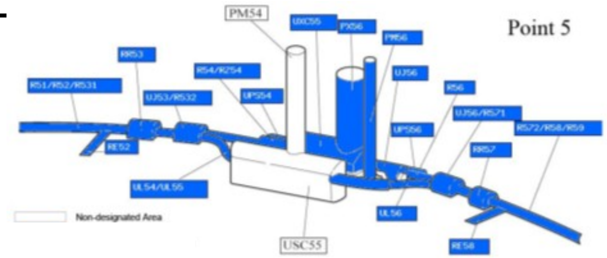
Dose equivalent rates (μSv/h) on 1/10/2011
(73 days after proton run, 36 days after ion run)

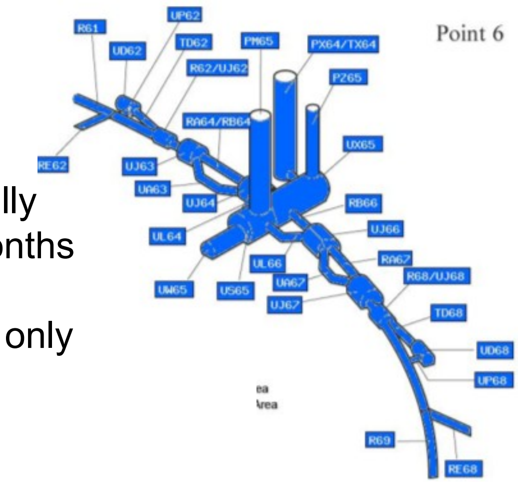
	IR3-Left (Beam 1, aisle side)		IR3-Right (Beam 2, wall side)	
Element	**Contact**	**Aisle**	**Contact**	**Aisle**
TCP	8.0	0.2	13.0	0.3
TCAPA	24.0	0.8	24.0	0.7
D3	10.0		7.0	
MQWA.E	6.0		5.0	
MQWA.D	3.2		4.0	
TCSG.5	4.0	0.2	7.5	0.2
MQWA.C	10.0		9.0	
MQWB	4.0		3.0	
MQWA.B	2.0		1.5	
MQWA.A	1.3		1.4	

	Area classification	Dose limit	Ambient dose equivalent rate	
			At permant workplaces	In low-occupancy areas
	Non-designated Area	1 mSv / y	< 0.5 μSv h^{-1}	< 2.5 μSv h^{-1}
	Supervised Radiation Area	6 mSv / y	< 3 μSv h^{-1}	< 15 μSv h^{-1}
Controlled Radiation Area	Simple Controlled Radiation Area	20 mSv / y	< 10 μSv h^{-1}	< 50 μSv h^{-1}
	Limited Stay Area			< 2 mSv h^{-1}
	High Radiation Area			<100 mSv h^{-1}
	Prohibited Area			> 100 mSv h^{-1}

Present situation – *Other areas*



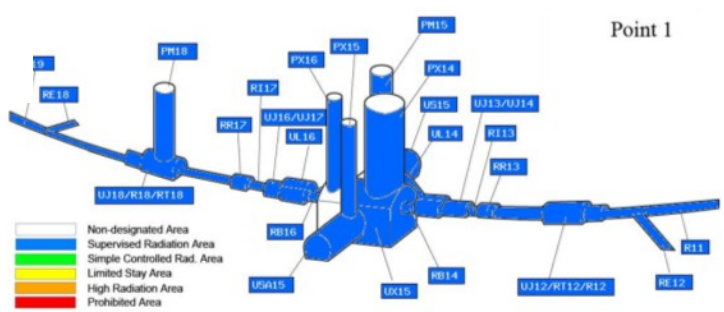


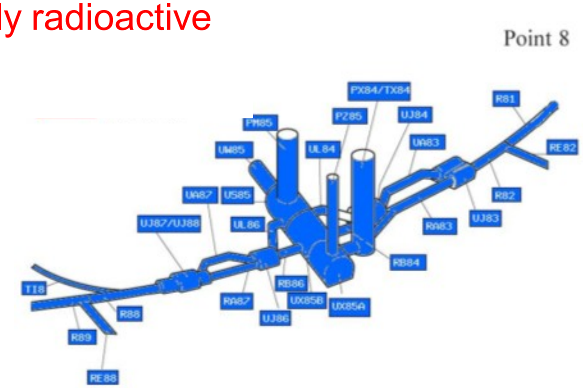


- All other areas (except USC55) classified as Supervised Radiation Areas
- Dose equivalent rates on accessible components generally very low / background (situation January 2011, i.e. ~2 months after proton run)
- Dose rate values above background on few components only

  TAS (IR1,5 machine side) : 0.5 μSv/h
  TCT (IR1,5) : 0.2 μSv/h
  dumps (front entrance) : 30 μSv/h

- No contamination found
- Nevertheless, components close to beam potentially radioactive already now





Generic study – *Geometry*

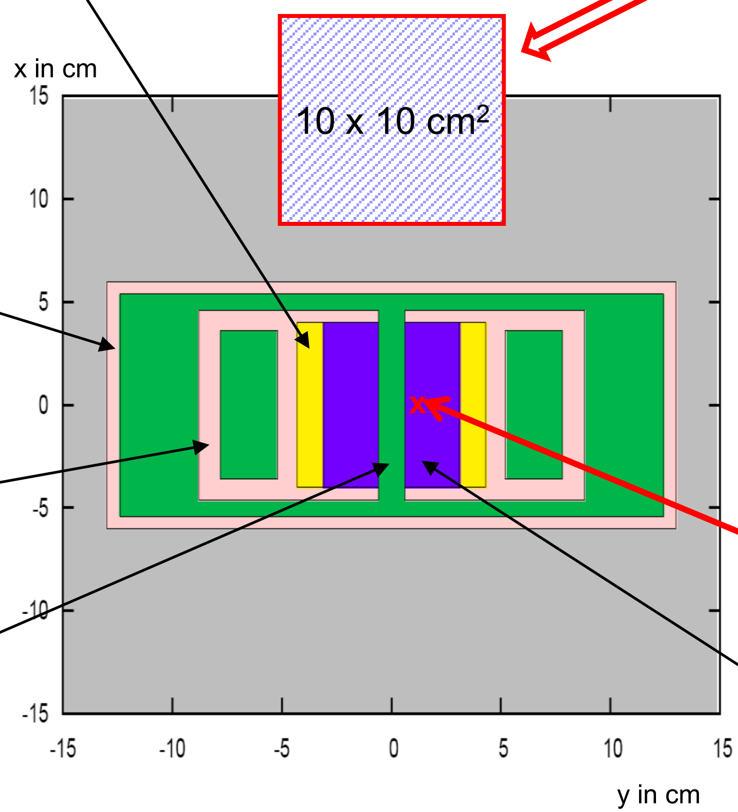
"Collimator" (length: 120 cm)

Cooling system
Copper (scaled density)
15 x 80 mm^2

Tank
Stainless Steel
Thickness: 6 mm

Structure
Stainless Steel
Thickness: 6/10 mm

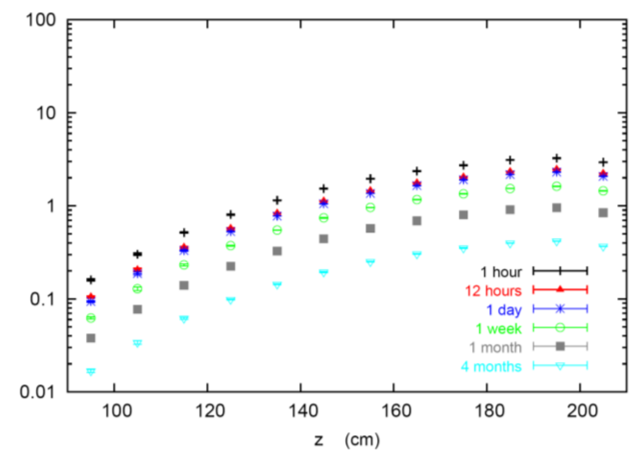
Gap
Full width: 12mm



Jaws
graphite
25 x 80 mm^2

4 TeV protons

Scoring of residual ambient dose equivalent rate at different cooling times:



Generic study – *Derived scaling parameters*

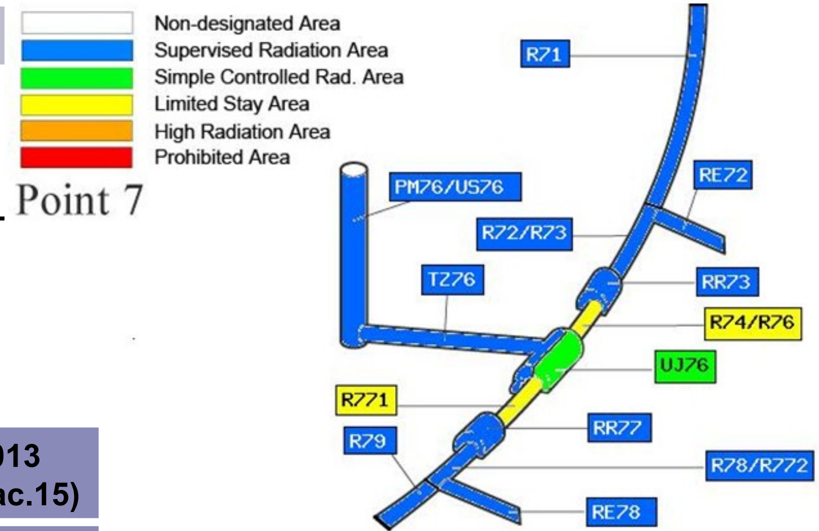
Evolution of residual dose equivalent rates until 2013
(for areas where activation is related to the beam intensity, *e.g.*, IR3/7)

Dose rate ratios for shutdowns	2012/now	2013/now	2013/2012
Short cooling time (scaling w/ beam intensity)	2.5	4.1	1.6
One week cooling	3.9	7.4	1.9
One month cooling	4.9	10.0	2.0
Four months cooling	6.6	15.0	2.3
Long cooling time (scaling w/ total number circulating protons)	9.1	30	3.2

Dependence on cooling time

Dose rate relative to one month cooling	2011	2012	2013
One week cooling	2.3	1.9	1.7
One month cooling	1.0	1.0	1.0
Four months cooling	0.3	0.4	0.4

Future situation – *IR7*



Dose equivalent rates (μSv/h) (about two months cooling)

IR7-Right	January 2011 (measurement)		January 2012 (Jan.2011 x fac.6.6)		January 2013 (Jan.2011 x fac.15)	
Element	Contact	Aisle	Contact	Aisle	Contact	Aisle
TCP.D6	10.0	1.2	66.0	8.0	150.0	18.0
TCP.C6	18.0	2.5	120.0	17.0	270.0	38.0
TCP.B6	31.0	3.1	205.0	21.0	465.0	47.0
TCAPA	70.0	3.0	460.0	20.0	1050.0	45.0
TCAPB	13.0	1.2	86.0	8.0	195.0	18.0
TCSG.A6	8.0	1.5	53.0	10.0	120.0	23.0
TCAPC	65.0	2.5	430.0	17.0	975.0	38.0

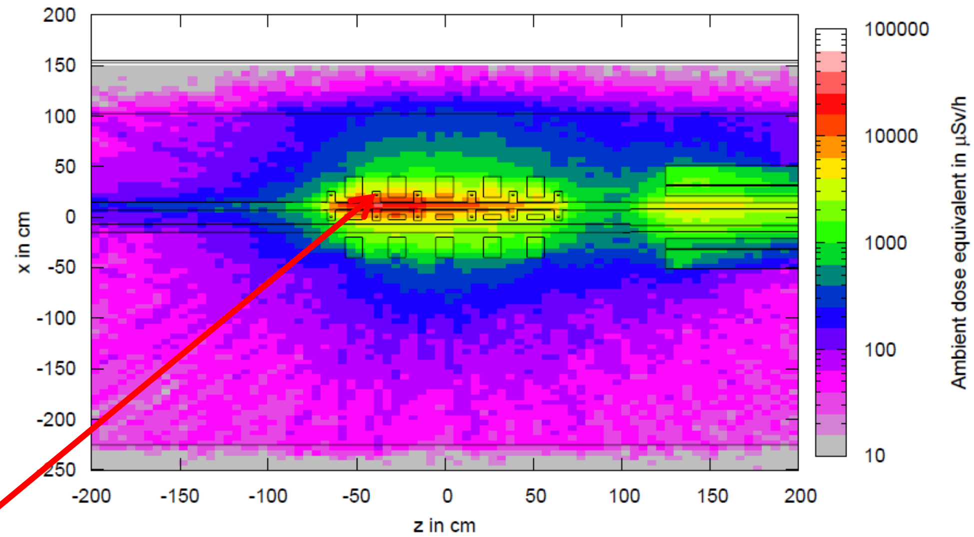
	Area classification	Dose limit	Ambient dose equivalent rate	
			At permant workplaces	In low-occupancy areas
	Non-designated Area	1 mSv / y	$< 0.5\ \mu Sv\ h^{-1}$	$< 2.5\ \mu Sv\ h^{-1}$
	Supervised Radiation Area	6 mSv / y	$< 3\ \mu Sv\ h^{-1}$	$< 15\ \mu Sv\ h^{-1}$
Controlled Radiation Area	Simple Controlled Radiation Area	20 mSv / y	$< 10\ \mu Sv\ h^{-1}$	$< 50\ \mu Sv\ h^{-1}$
	Limited Stay Area			$< 2\ mSv\ h^{-1}$
	High Radiation Area			$<100\ mSv\ h^{-1}$
	Prohibited Area			$> 100\ mSv\ h^{-1}$

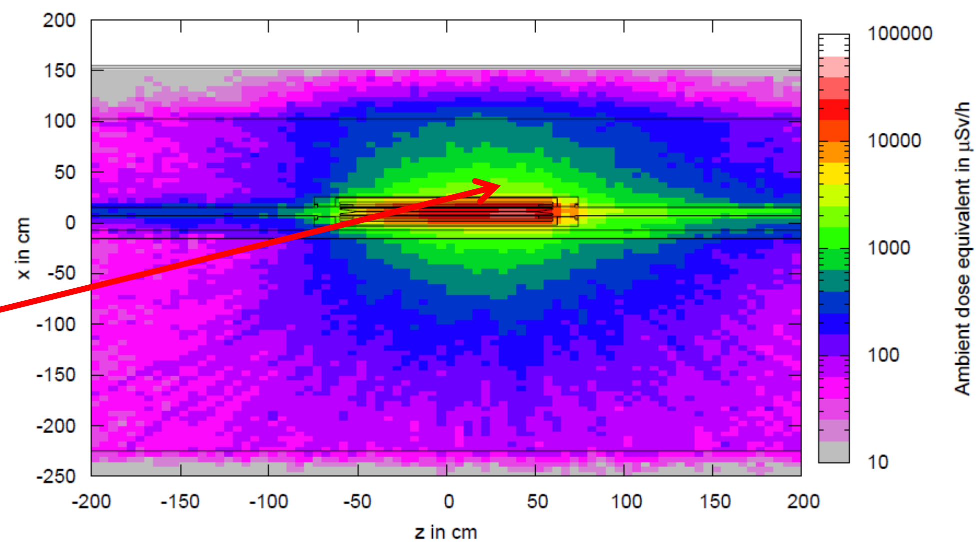
Future situation – *IR7*

Dose equivalent rates (µSv/h)
(about two months cooling)

IR7-Right	January 2013		Nominal (Jan.2013 x factor 3)	
Element	**Contact**	**Aisle**	**Contact**	**Aisle**
TCP.D6	150.0	18.0	450.0	54.0
TCP.C6	270.0	38.0	810.0	114.0
TCP.B6	465.0	47.0	1400.0	141.0
TCAPA	1050.0	45.0	3150.0	135.0
TCAPB	195.0	18.0	580.0	54.0
TCSG.A6	120.0	23.0	360.0	70.0
TCAPC	975.0	38.0	3000.0	114.0

S.Roesler et al., EDMS 863919





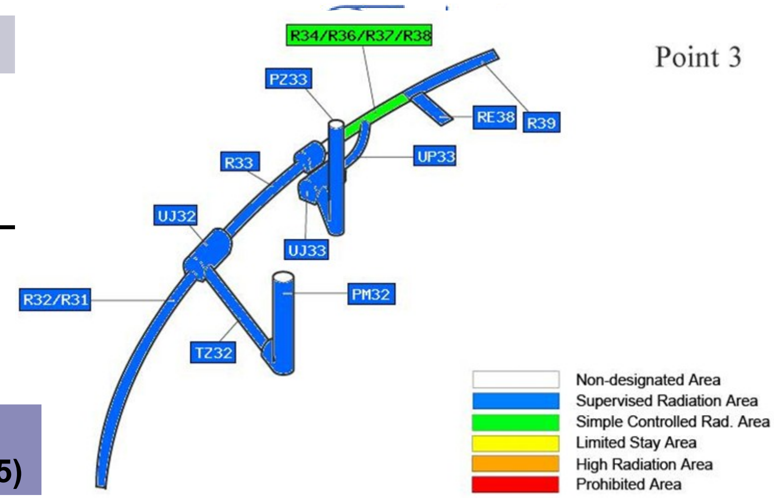
- reasonable agreement for passive absorber
- dose rate somewhat lower than predicted for first secondary collimator (due to initial settings?)

Future situation – *IR3*

Dose equivalent rates (µSv/h) (about two months cooling)

IR3-Right	January 2011 (measurement)		January 2012 (Jan.2011 x fac.6.6)		January 2013 (Jan.2011 x fac.15)	
Element	**Contact**	**Aisle**	**Contact**	**Aisle**	**Contact**	**Aisle**
TCP	13.0	0.3	86.0	2.0	195.0	4.5
TCAPA	24.0	0.7	158.0	5.0	360.0	11.0
D3	7.0		46.0		105.0	
TCSG.5	7.5	0.2	50.0	1.3	113.0	3.0
MQWA.C	9.0		60.0		135.0	

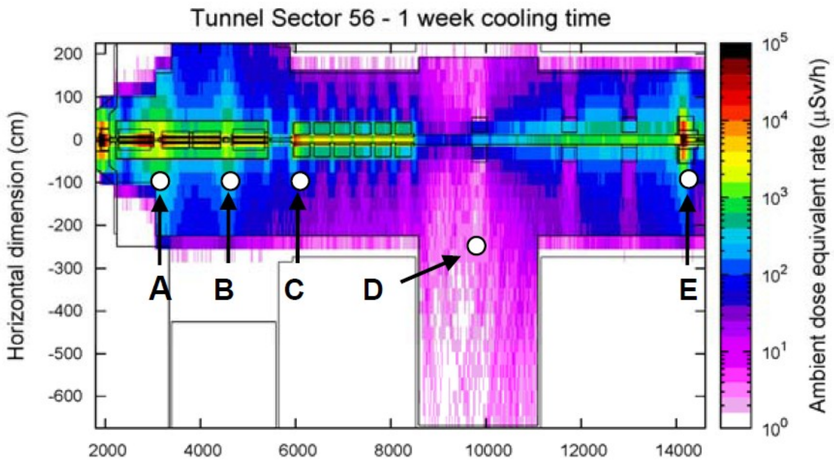
- Scaling assumes the IR7/3 loss ratio of the 2010 run
- Contribution from beam-gas interactions not included



	Area classification	Dose limit	Ambient dose equivalent rate: At permanent workplaces	Ambient dose equivalent rate: In low-occupancy areas
	Non-designated Area	1 mSv / y	< 0.5 µSv h^{-1}	< 2.5 µSv h^{-1}
	Supervised Radiation Area	6 mSv / y	< 3 µSv h^{-1}	< 15 µSv h^{-1}
Controlled Radiation Area	Simple Controlled Radiation Area	20 mSv / y	< 10 µSv h^{-1}	< 50 µSv h^{-1}
	Limited Stay Area			< 2 mSv h^{-1}
	High Radiation Area			<100 mSv h^{-1}
	Prohibited Area			> 100 mSv h^{-1}

Future situation – *Inner triplets*

M.Fürstner et al., EDMS 1006918



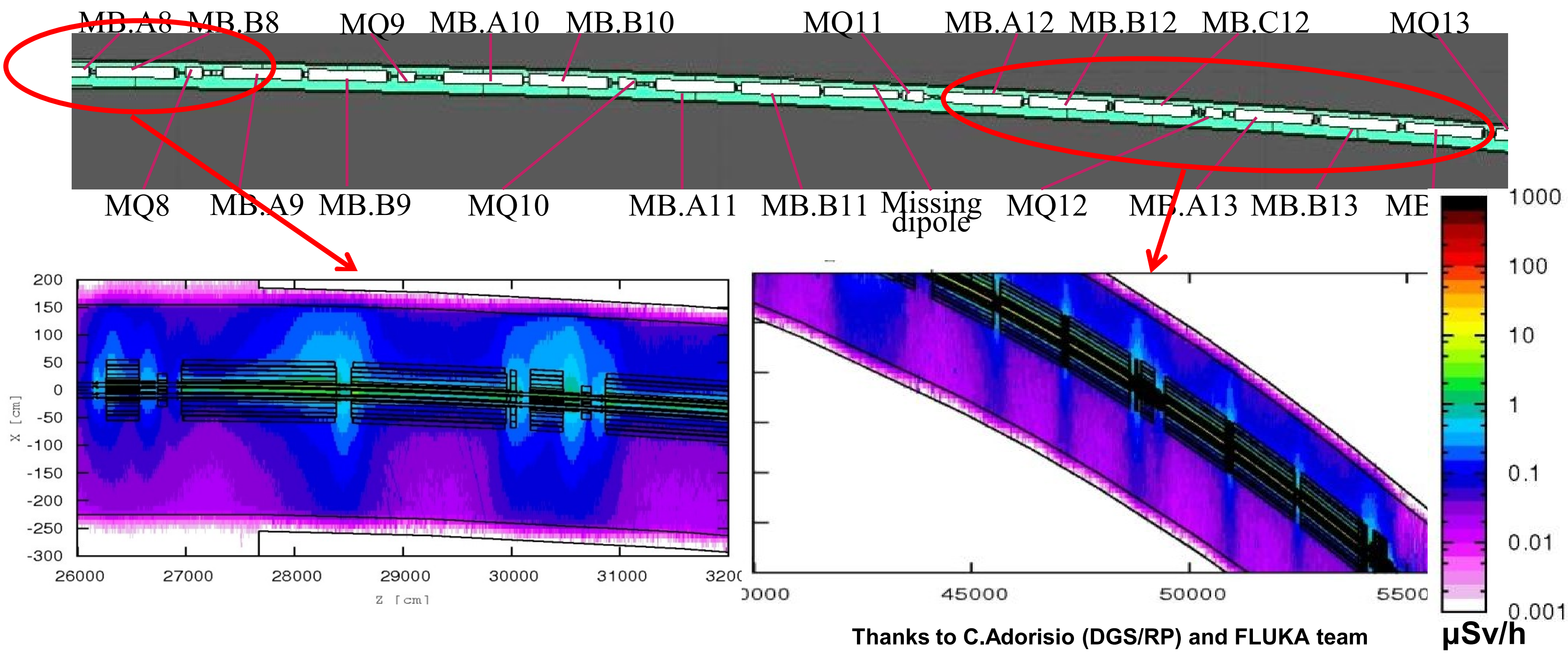
Assumption:
10^9 7TeV-pp/s for 180 days = 180 /fb

Pos.	Distance to IP5 (cm)	Ambient dose equivalent rate in µSv/h for the cooling time											
		1 hour		8 hours		1 day		1 week		1 month		4 months	
A	3045	1819	±2%	872	±2%	603	±3%	315	±3%	167	±3%	78	±4%
B	4515	702	±3%	423	±5%	323	±5%	198	±5%	117	±5%	56	±5%
C	6015	660	±3%	264	±5%	155	±6%	59	±9%	30	±8%	16	±10%
D	9825	21	±12%	8	±21%	6	±26%	3	±36%	2	±43%	0.7	±41%
E	14145	972	±2%	526	±3%	392	±3%	239	±3%	155	±3%	64	±4%

2013: values lower by factor of 8 for short cooling times (dominated by average luminosity)
30 for very long cooling times (dominated by integrated luminosity)

e.g., 1 day cooling: < 100 µSv/h at positions A-E
4 months cooling: < 10 µSv/h at positions A-E

Future situation – *DS and Arcs* *(here: IR7-right / Sector 78)*

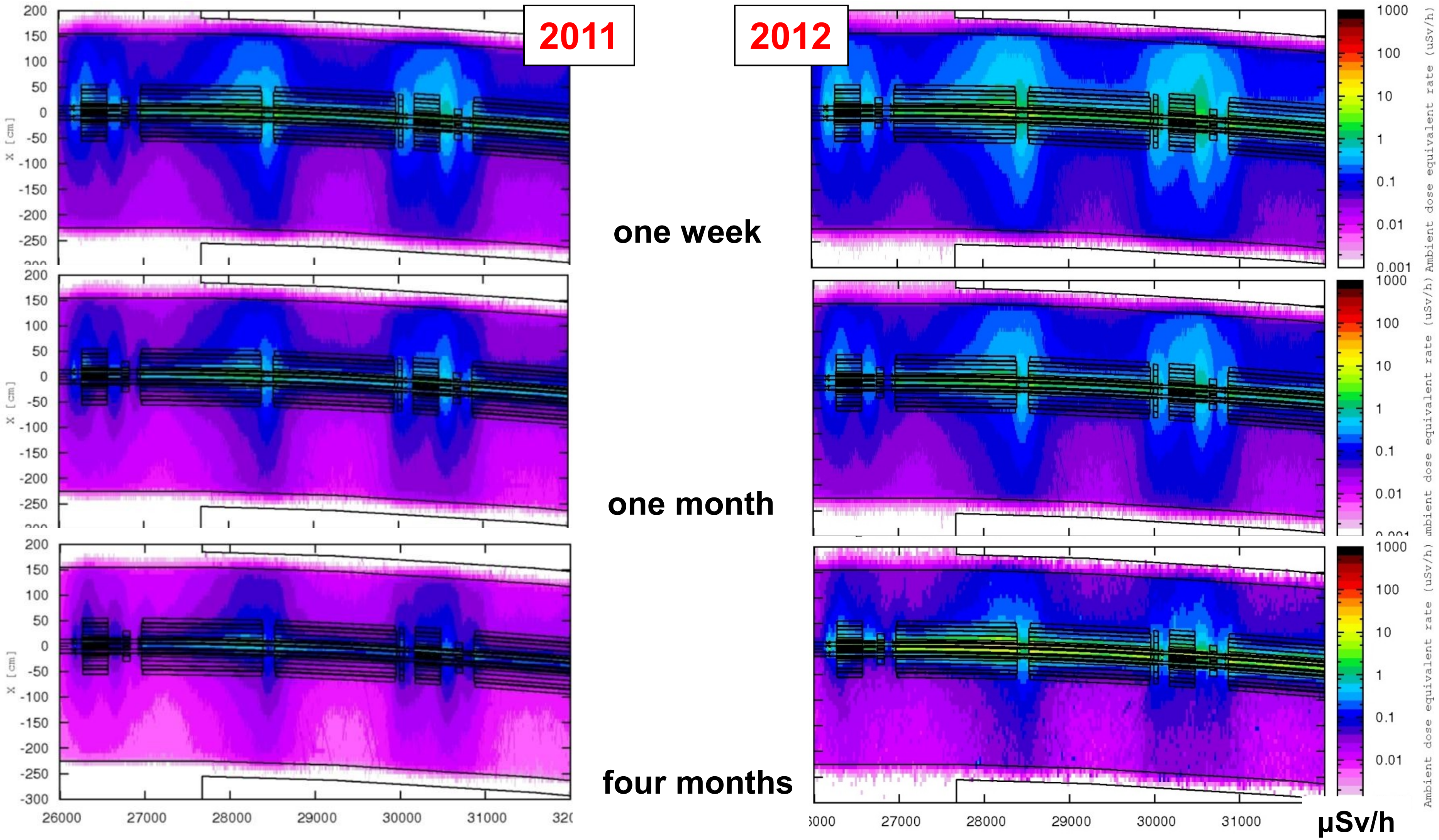


Thanks to C.Adorisio (DGS/RP) and FLUKA team

- above plots are for ***January 2013*** (~one month cooling) and ***beam gas interactions*** (beam 1) only (1×10^{15} H_2eq/m^3)
- dose rates close to background in the aisle, few µSv/h on contact to beam pipe
- known from other calculations that dose rates from losses due to leakage on collimators lead to localized spots with dose rates on contact of the order of 10 µSv/h
- thus, risks due to external irradiation should be in general very low

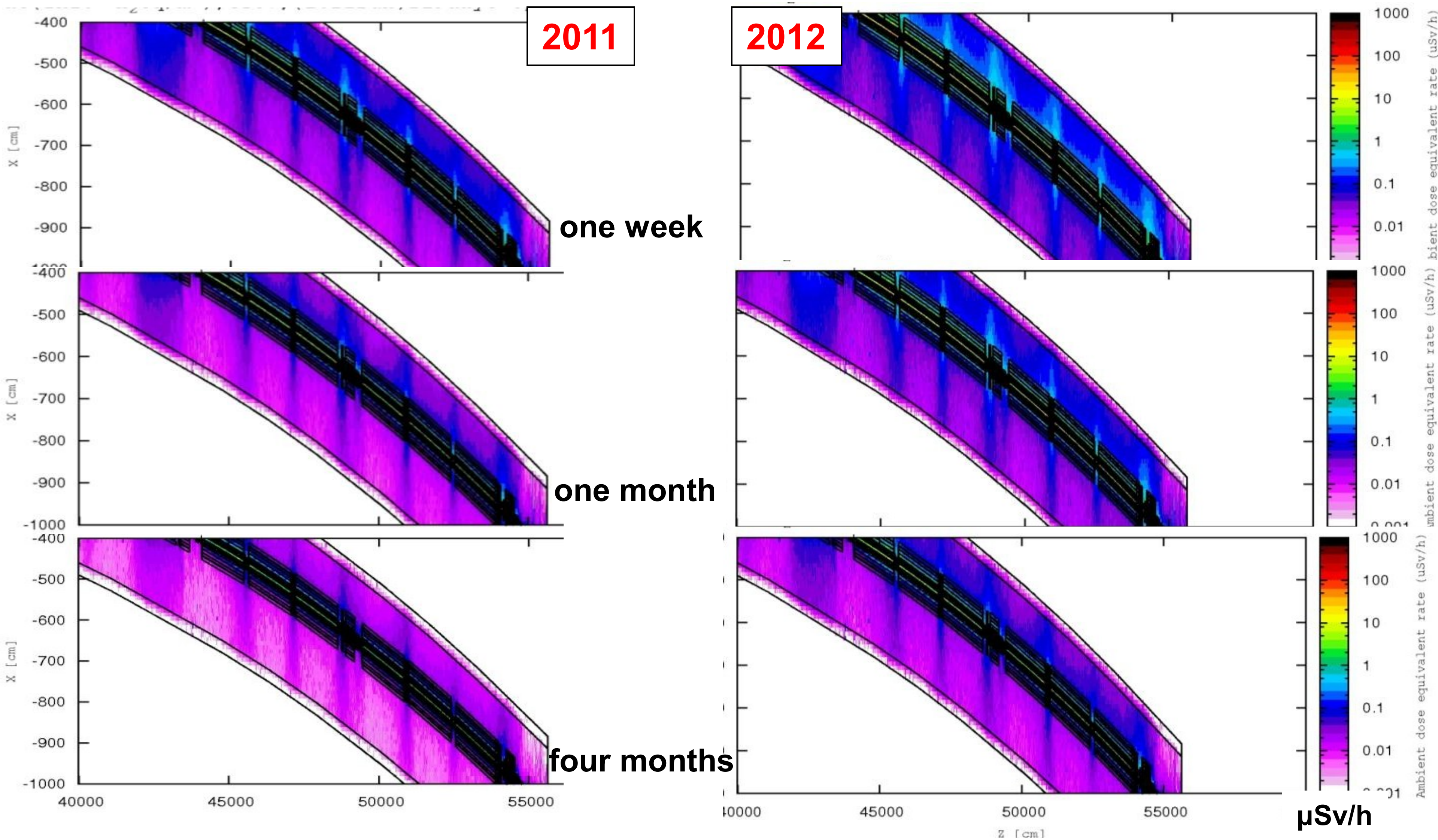
Future situation – *DS* *(here: IR7-right)*

Thanks to C.Adorisio (DGS/RP) and FLUKA team

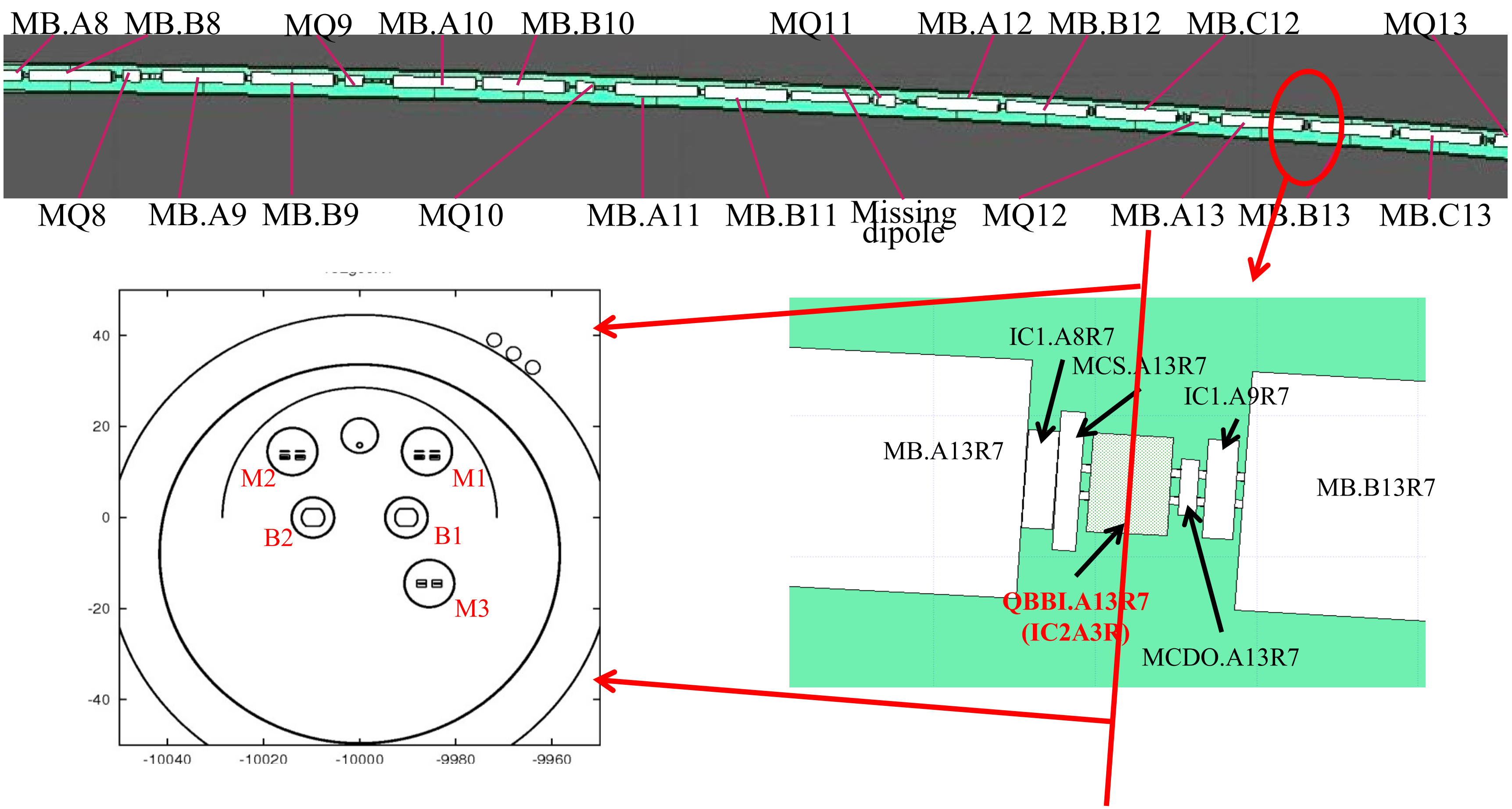


Future situation – *Arcs* *(here: Sector 78)*

Thanks to C.Adorisio (DGS/RP) and FLUKA team



Interconnects consolidation - *induced radioactivity*



- ***detailed FLUKA implementation of interconnect*** considering actual material compositions for M-pipes flanges, bus bars, *etc*.
- calculation for ***beam-gas interactions only*** ($1x10^{15}$ H_2eq/m^3)

Interconnects consolidation - *induced radioactivity*

Radioactive = specific ***and*** total activities exceed LE
or dose rate at 10cm distance >10 μSv/h

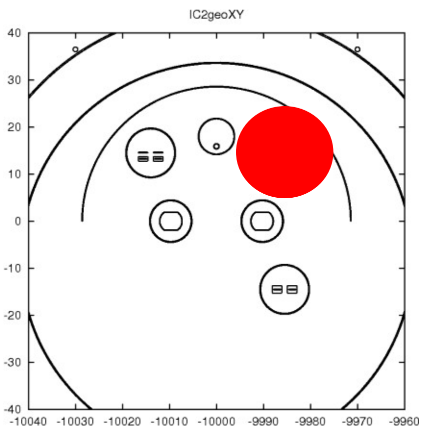
Mixture of nuclides: $$\sum_{i=1}^{n} \frac{a_i}{LE_i} > 1$$

LE values:
ingestion of activity LE leads to a dose of 10 μSv

					Grandeurs d'appréciation			Limite d'exemption	Limite d'autorisation	Valeurs directrices		
Nucléide	Période	Type de désintégration/ de rayonnement	e_{inh} Sv/Bq	e_{ing} Sv/Bq	h_{10} (mSv/h)/GBq à 1 m de distance	$h_{0,07}$ (mSv/h)/GBq à 10 cm de distance	$h_{c0,07}$ (mSv/h)/(kBq/cm²)	LE Bq/kg ou LE_{abs} Bq	Bq	CA Bq/m³	CS Bq/cm²	Nucléide de filiation instable
1	2	3	4	5	6	7	8	9	10	11	12	13
Co-55	17.54 h	ε, β⁺, γ	8.3 E-10	1.1 E-09	0.302	1000	1.4	9 E+03	6 E+06	1 E+04	3	-> Fe-55
Co-56	78.76 d	ε, β⁺, γ	4.9 E-09	2.5 E-09	0.485	300	0.6	4 E+03	1 E+06	2 E+03	10	
Co-57	270.9 d	ε, γ	6.0 E-10	2.1 E-10	0.021	100	0.1	5 E+04	8 E+06	1 E+04	100	
Co-58	70.80 d	ε, β⁺, γ	1.7 E-09	7.4 E-10	0.147	300	0.3	1 E+04	3 E+06	5 E+03	30	
Co-58m	9.15 h	γ	1.7 E-11	2.4 E-11	<0.001	10	<0.1	4 E+05	3 E+08	5 E+05	1000	-> Co-58 [6]
Co-60	5.271 a	β⁻, γ	1.7 E-08	3.4 E-09	0.366	1000	1.1	1 E+03[157]	9 E+04	5 E+02	3	
Co-60m	10.47 m	β⁻, γ	1.2 E-12	1.7 E-12	0.001	20	<0.1	6 E+06	4 E+09	7 E+06	300	-> Co-60 [6]
Co-61	1.65 h	β⁻, γ	7.5 E-11	7.4 E-11	0.017	1000	1.6	1 E+05	7 E+07	1 E+05	3	
Co-62m	13.91 m	β⁻, γ	3.7 E-11	4.7 E-11	0.436	1000	1.8	2 E+05	1 E+08	2 E+05	3	
Ni-56	6.10 d	ε, γ	9.6 E-10	8.6 E-10	0.260	60	0.1	1 E+04	5 E+06	9 E+03	30	-> Co-56 [6]
Ni-57	36.08 h	ε, β⁺, γ	7.6 E-10	8.7 E-10	0.278	700	0.8	1 E+04	7 E+06	1 E+04	10	-> Co-57
Ni-59	7.5 E4 a	ε	2.2 E-10	6.3 E-11	<0.001	10	<0.1	2 E+05	2 E+07	4 E+04	1000	
Ni-63	96 a	β⁻	5.2 E-10	1.5 E-10	<0.001	<1	<0.1	7 E+04	1 E+07	2 E+04	1000	
Ni-65	2.520 h	β⁻, γ	1.3 E-10	1.8 E-10	0.081	1000	1.6	6 E+04	4 E+07	6 E+04	3	
Ni-66 / Cu-66	54.6 h	β⁻, γ	1.9 E-09	3.0 E-09	0.039	2000	2.2	3 E+03	3 E+06	4 E+03	3	
Cu-60	23.2 m	ε, β⁺, γ	6.2 E-11	7.0 E-11	0.596	1000	1.8	1 E+05	8 E+07	1 E+05	3	
Cu-61	3.408 h	ε, β⁺, γ	1.2 E-10	1.2 E-10	0.128	900	1.1	8 E+04	4 E+07	7 E+04	3	
Cu-64	12.701 h	ε, β⁺, β⁻, γ	1.5 E-10	1.2 E-10	0.030	900	0.8	8 E+04	3 E+07	6 E+04	10	
Cu-67	61.86 h	β⁻, γ	5.8 E-10	3.4 E-10	0.018	1000	1.4	3 E+04	9 E+06	1 E+04	3	
Zn-62 / Cu-62	9.26 h	ε, β⁺, γ	6.6 E-10	9.4 E-10	0.319	1000	1.9	1 E+04	8 E+06	1 E+04	3	
Zn-63	38.1 m	ε, β⁺, γ	6.1 E-11	7.9 E-11	0.175	1000	1.6	1 E+05	8 E+07	1 E+05	3	
Zn-65	243.9 d	ε, β⁺, γ	2.8 E-09	3.9 E-09	0.086	40	0.1	3 E+03	2 E+06	3 E+03	30	
Zn-69	57 m	β⁻, γ	4.3 E-11	3.1 E-11	<0.001	1000	1.6	3 E+05	1 E+08	2 E+05	3	

Source: **ORaP, Swiss legislation**

Interconnects consolidation - *induced radioactivity*



(Shutdown 2012/13, one month cooling, beam-gas interactions only)

Main elements / materials (specific activity):

$$R = \sum_{i=1}^{n} \frac{a_i}{LE_i} \quad \begin{array}{ll} = 0.3\ (\pm 9\%) & \text{pipe (stainless steel)} \\ = 0.3\ (\pm 26\%) & \text{SCC (copper)} \end{array}$$

Minor / trace elements (*e.g.*, solder):

- assessment of risk from activation relative to copper with generic calculations
- for example: the ratio *R* for silver is up to 20 times higher for radiation fields around the interconnects; however, the amounts of silver are very small

⟶ Preliminary conclusions and advise

- very low activation of majority of bus-bars (those, where beam-gas interactions dominate activation)
- good margin for areas where point losses dominate
- consequently low risk of contamination and internal exposure
- nevertheless, precautions necessary (ALARA): use methods which do not produce small particles/dust, contain any small particles/dust (vacuum cleaner, plastic foils), *etc.*

Uncertainties and verification

Numerous sources of ***uncertainties***:

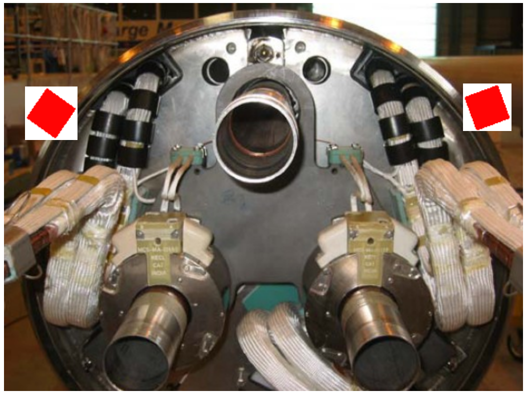
- actual beam-gas pressure
- activation by scrubbing runs
- loss assumptions (IR3 vs. IR7, losses in heavy ion runs)
- differences between actual and simulated geometry (collimator settings, imperfections, *etc.*)
- FLUKA models (e.g., for prediction of activation) and simulations (statistical uncertainties)
- ...

→ **Verification by measurements essential**

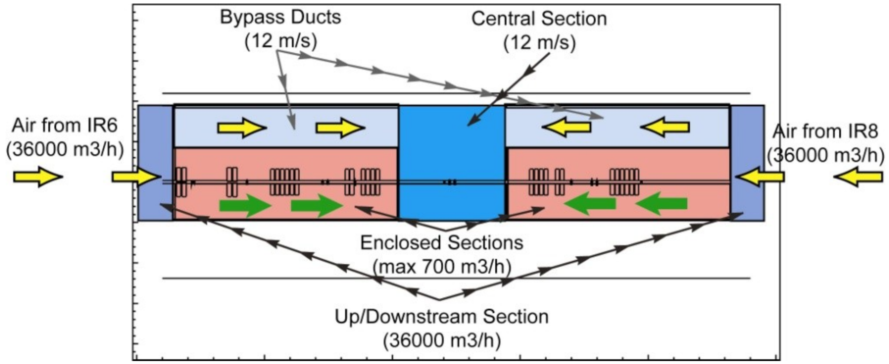
- survey measurements during technical stops to monitor evolution of residual dose rates
- integrated BLM readings to identify loss points and provide "relative" information
- material samples, especially of materials on which destructive work is foreseen (*e.g.*, civil engineering, soldering)

<u>*Example*</u>*:* **interconnect consolidation**

- fix samples of typical materials (copper, SS, Sn, Ag) outside of typical and worst interconnects
- measure activation during stops/shutdown periods
- use FLUKA calculations to obtain scaling factor for location of same material inside interconnect



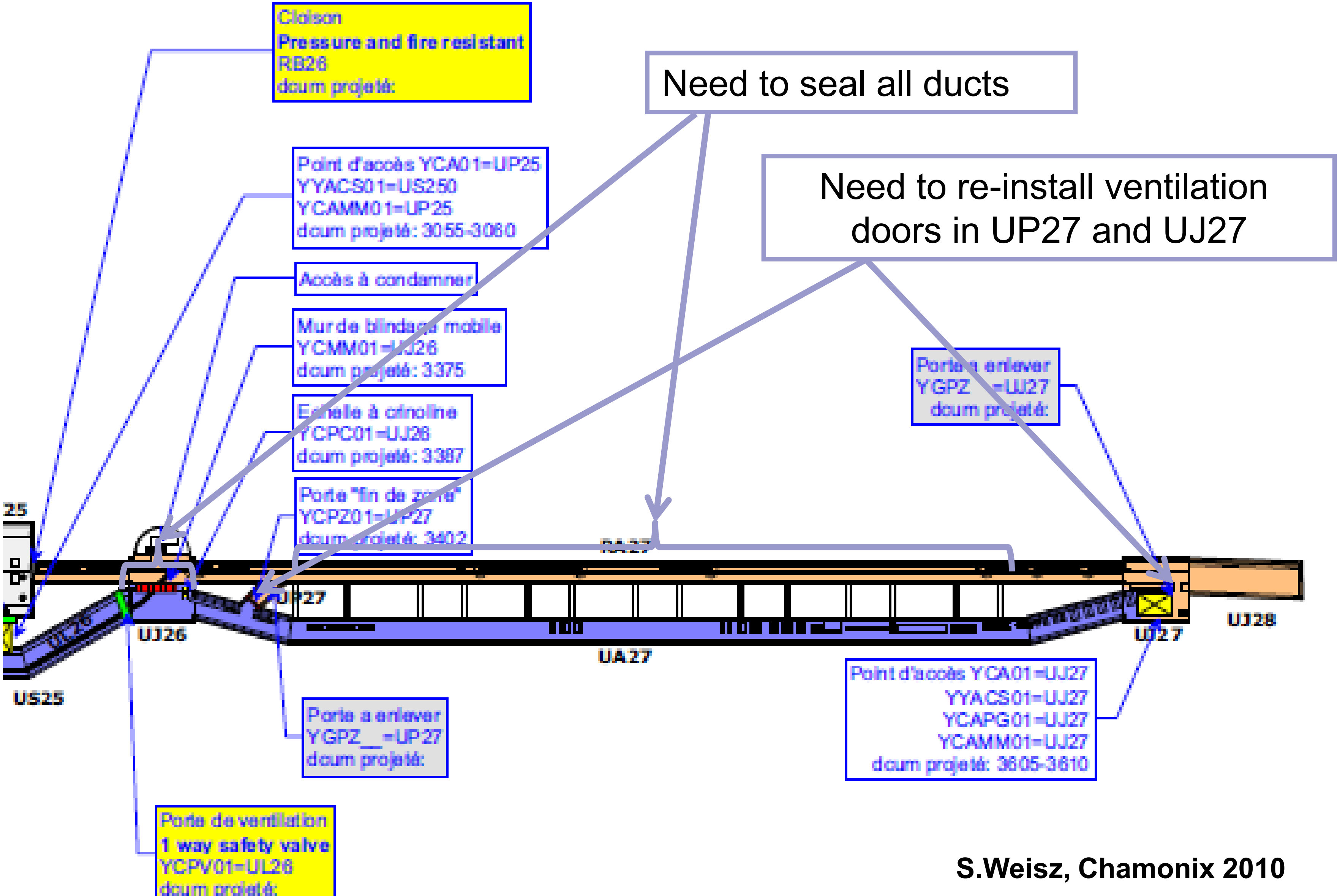
Air activation and related issues – *IR7 ventilation doors*



M. Brugger *et al*, Chamonix 2006:
...
Therefore, keeping in mind the target value (10 µSv/year) and the fact that the ventilation ducts in TZ76 will be removed as from start-up onwards, it can be concluded that the full functionality of the air bypass duct would only be required as soon as half-nominal intensities are reached. However, it shall be noted that due to the significant residual activation in the respective collimation region all civil engineering and the technical implementation must be performed before start-up in order to avoid excessive doses to personnel.
...

- installation of doors required latest by 2013
- review status of implementation and prepare as early as possible (frames, fixations, *etc.*)

Air activation and related issues – *service galleries*



S.Weisz, Chamonix 2010

Air activation and related issues – *service galleries*

S.Weisz, Chamonix 2010:

The present situation has two main drawbacks:

- The air from the tunnel can mix freely with the air of the service galleries at the even points: this limits the control of the underground ventilation flows and does not insure best practice for radio-protection, ODH and fire hazard mitigation;

...

The sealing of the LHC tunnel towards other underground areas must be pursued with first priority during the next long shut down. The study of alternate release paths from the LHC tunnel to the surface will continue...

...

Achieved so far:

- separation of air volumes UA / US by ventilation doors in UL galleries and verification of closure during operation
- caps on all PX pits
- new monitoring stations for released activity at PX45/65

Further actions:

- sealing of tunnels towards service areas (ducts, re-installation of ventilation doors, *etc.*) in next long shutdown

Summary and conclusions – *Evolution of activation*

- Based on the operational scenarios for runs in 2011/12, beam intensity-dependent activation and residual dose rates will increase by about a factor of 4-7 during the 2011 run and by another factor of 2 during 2012 (assuming that losses scale approx. linearly with intensity, scrubbing *etc.* not considered). Thus, *RP constraints and recommendations for shutdowns in 2012 and 2013 are quite similar.*

- Luminosity-dependent activation (mainly detectors and inner triplets) will increase by a factor of 6-20 during the 2011 run and by another factor of 3-5 during 2012.

- By operating at nominal conditions after 2013 activation will increase further by factors of about 3 (beam intensity-dependent activation) and >5 (luminosity-dependent activation).

- Presently the entire LHC is classified as Supervised Radiation Area with low activation and dose rate levels (maximum dose rate in the aisle: 3 μSv/h, on contact to a component: 70 μSv/h (passive absorber, IR7).

- In 2012 and 2013 a few limited areas (*e.g.*, IR3/7) will have to be classified as Controlled Radiation Areas where job and dose planning is obligatory (maximum dose rates in the aisle: 10-50 μSv/h, few mSv/h on contact [mainly collimators and absorbers])

Summary and conclusions – *Splices and DS collimators*

- Residual dose rates in the arcs after the 2012 run are estimated to be very low (no limitation in duration of work). A few localised areas in the DS regions (loss points of protons or HI "leaking" from straight section) might show measurable residual dose rates (<10 μSv/h).

- Despite low residual dose rates in these areas, components might become "radioactive" according to CERN regulations and dissipation or incorporation of this radioactivity must be prevented (ALARA principle).
  Thus, use methods which avoid creation of small particles or dust, *e.g.*, (if possible) avoid grinding and similar methods, contain any radioactivity, *e.g.*, by using special vacuum cleaners, by protecting work site with plastic foils, *etc*.

- Due to significant uncertainties it is important to continuously monitor the evolution of activation (*e.g.*, survey measurements, material samples) to be able to further optimise work plans and schedules. In areas where civil engineering will be required (*e.g.*, DS regions in IR3) place concrete samples (available from RP) in order to demonstrate absence of activation.

- Avoid or limit the passage along collimators and absorbers (if possible). Consider the use of temporary shielding in front of such elements.

Summary and conclusions – *Air monitoring*

- The full functionality of the ventilation bypass in IR7 has to be established in the next long shutdown.
- The separation of the LHC tunnel and service area air volumes has been improved and additional monitoring at Point 4 and 6 is being added. Full sealing has to be established in the next long shutdown.