Shutdown Constraints and Radiation and Activation effects

ECFA - Aix Les Bains

02.10.2013

O. Beltramello, H. Vincke, G. Corti on behalf of the Working Group

The first step ... Understand the amplitude of the radiations problem due to material activation ...

1. Scale factor between the doses measured at LS1 and LS3/LS4/LS5 shutdowns ...

Estimations were performed using the present detectors configuration and two different assumptions of luminosity profile (from 2011/2012):

ATLAS (minimum target lumi)
CMS (optimistic * 1.5)

		2015	2016	2017	LS2	2019	2020	2021	LS3
ATLAS	L_{int} (fb^{-1})	52	41	41		83	83	83	
	L_{peak} ($cm^{-2}s^{-1}$)	1.0×10^{34}	1.0×10^{34}	1.0×10^{34}		2.0×10^{34}	2.0×10^{34}	2.0×10^{34}	
CMS	L_{int} (fb^{-1})	50	80	100		150	150	150	
	L_{peak} ($cm^{-2}s^{-1}$)	1.2×10^{34}	2.3×10^{34}	2.5×10^{34}		3.5×10^{34}	3.5×10^{34}	3.5×10^{34}	

After LS3:

ATLAS detector current configuration

$5 \cdot 10^{34}$ peak luminosity per year
300 fb^{-1} integrated luminosity per year

Total integrated luminosity in 2036 **≈ 3000 fb^{-1}**

Estimation of scaling factors (H. Vincke, S. Roesler, C. Urscheler, K. Zabrzycki)

In general :

Short cooling times are dominated by short-lived radio nuclides

➔ dose rate reflects the interaction rate (peak luminosity)

Long cooling times are dominated by longer-lived radio nuclides

➔ dose rate reflects roughly the integrated luminosity

For both cases, it depends strongly on the material and therefore on the produced radionuclides

Between LS1 and LS2 / LS3 shutdowns – cooling time 4 months:

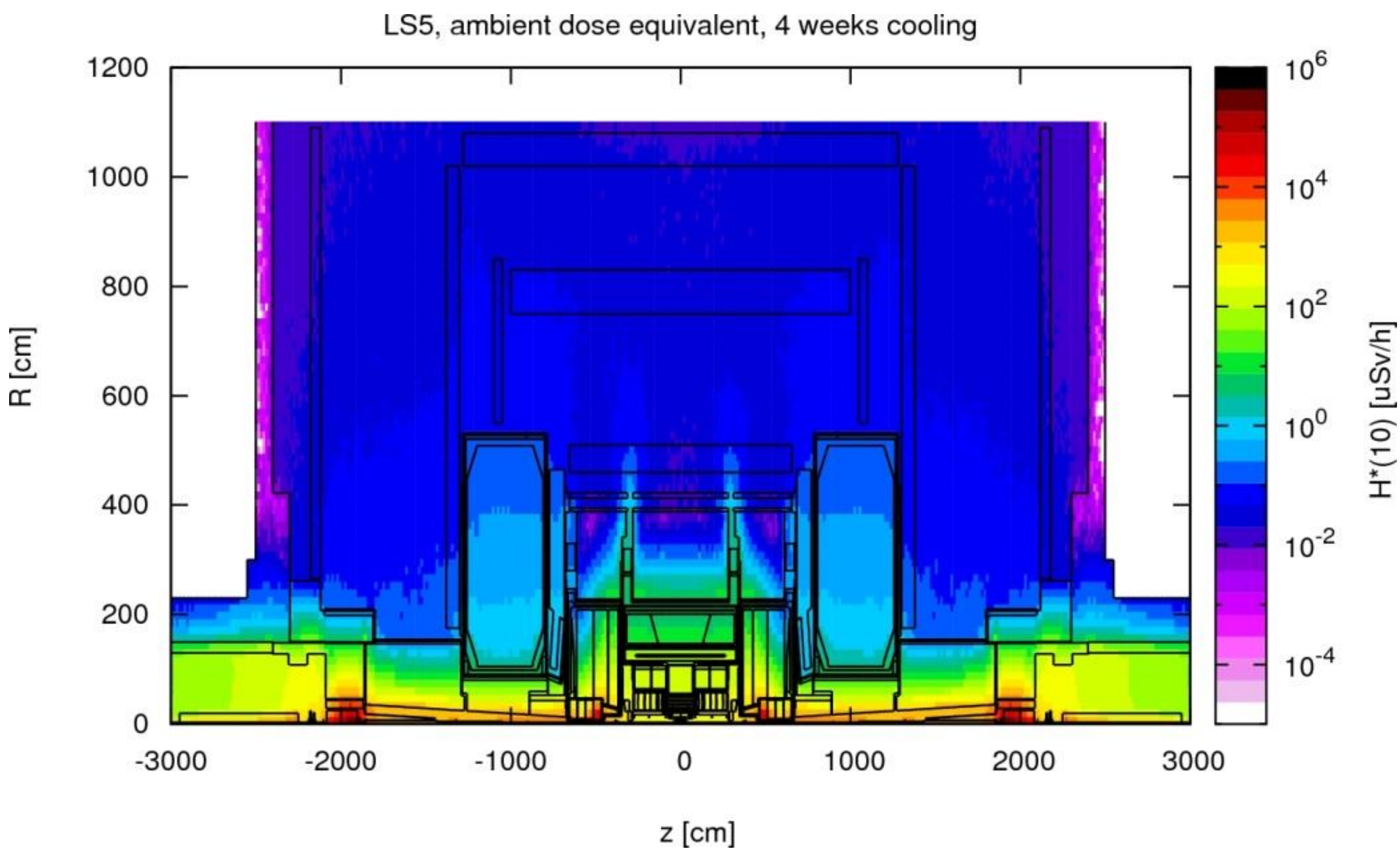
t_{cool} = 4 months	ATLAS	CMS
LS2 / LS1	4.1	9.0
LS3 / LS1	8.5	16.0

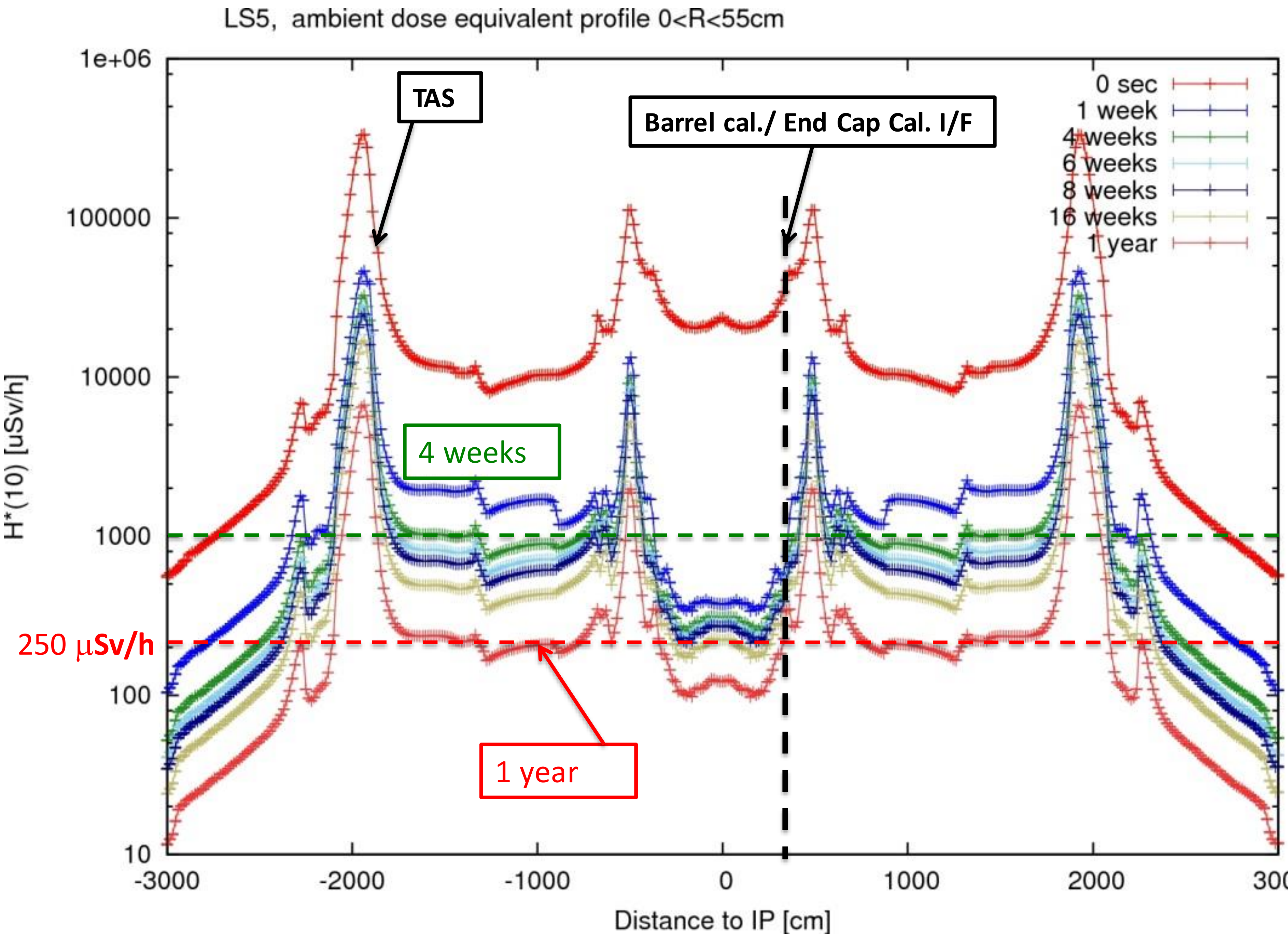
For a longer cooling time, the scaling factor is increasing

Between LS1 and LS4 / LS5 shutdowns :

New calculations performed recently (H. Vincke, K. Zabrzycki, C. Strabel)

ATLAS detector current configuration





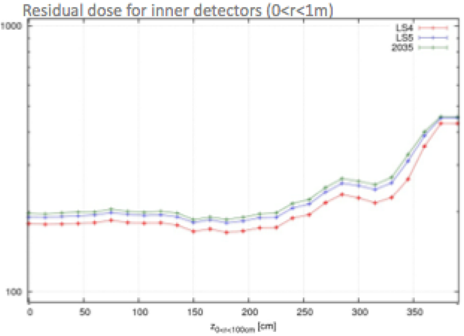
LS5, ambient dose equivalent profile 0<R<55cm
1e+06
100000
10000
1000
100
10
-3000
-2000
-1000
0
1000
2000
300
H*(10) [uSv/h]
Distance to IP [cm]
0 sec
1 week
4 weeks
6 weeks
8 weeks
16 weeks
1 year
TAS
Barrel cal./ End Cap Cal. I/F
4 weeks
250 μSv/h
1 year

Scaling factors for inner detectors –

4 weeks cooling

LS4 vs. LS5 vs. 2035, 4 weeks cooling

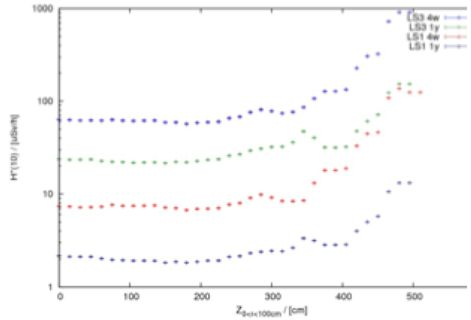
Residual dose for inner detectors (0<r<1m)



Average residual dose (z<255cm) [µSv/h]	
LS4	178
LS5	191
2035	197

LS1 vs. LS3[1]

Residual dose for inner detectors (0<r<1m)



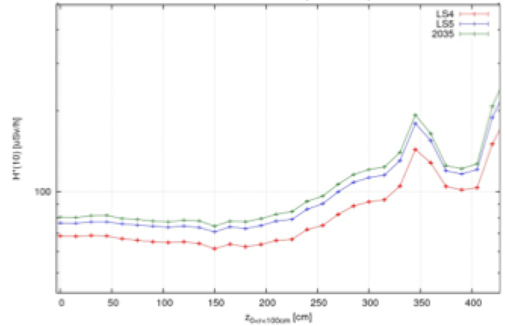
X (z<255cm)	X/LS1	X/LS3
LS4	24.5	2.9
LS5	26.3	3.1
2035	27.1	3.2

Scaling factors for inner detectors

1 year cooling

LS4 vs. LS5 vs. 2035, 1 year cooling

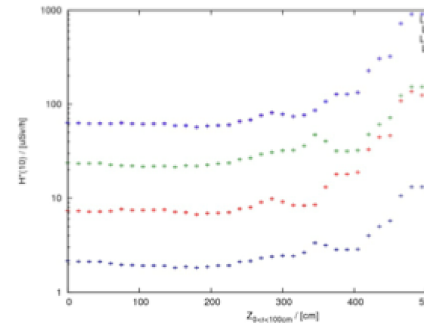
Residual dose for inner detectors (0<r<1m)



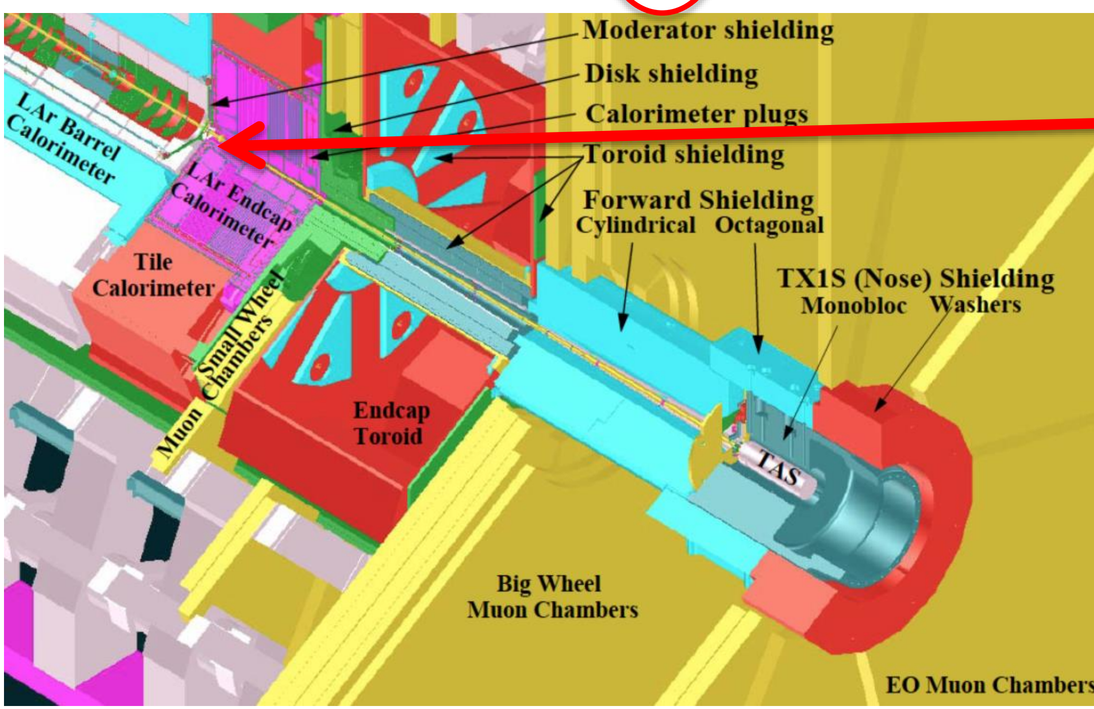
Average residual dose (z<255cm) [µSv/h]	
LS4	66
LS5	76
2035	80

LS1 vs. LS3[1]

Residual dose for inner detectors (0<r<1m)



X	X/LS1	X/LS3
LS4	33.5	2.9
LS5	38.5	3.3
2035	40.7	3.5



Inner Detector region:

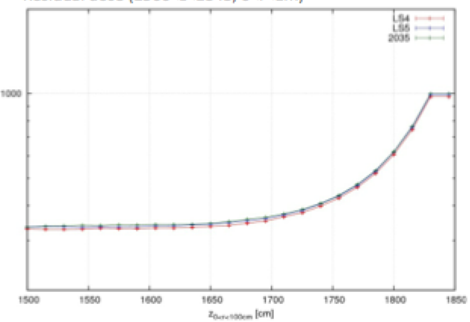
Scaling factor between **25 to 40**

The scaling factor increases for **long-lived radio nuclides**.

Scaling factors for 1500<z<1845 – 4 weeks cooling

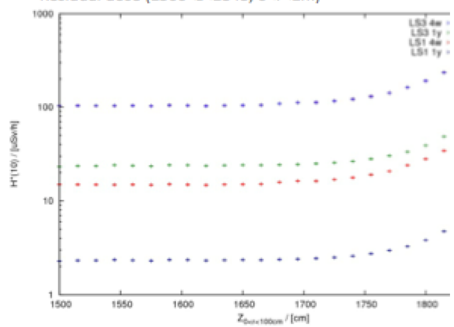
LS4 vs. LS5 vs. 2035, 4 weeks cooling

Residual dose (1500<z<1845, 0<r<1m)



LS1 vs. LS3[1]

Residual dose (1500<z<1845, 0<r<1m)



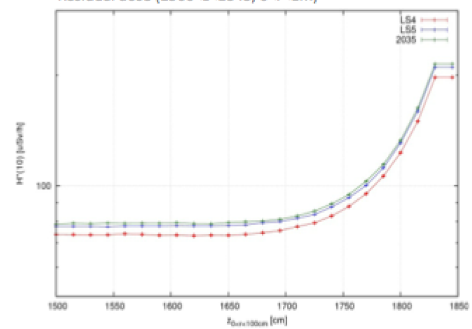
Average residual dose [uSv/h]	
LS4	439
LS5	447
2035	451

X	X/LS1	X/LS3
LS4	22.0	3.2
LS5	22.5	3.3
2035	22.6	3.3

Scaling factors for 1500<z<1845 – 1 year cooling

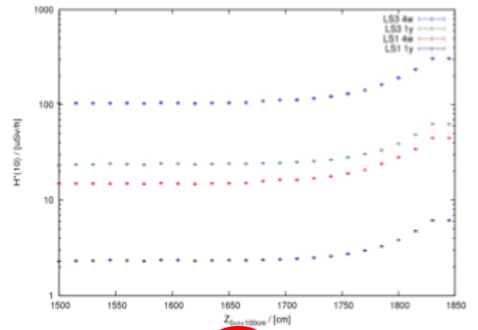
LS4 vs. LS5 vs. 2035, 1 year cooling

Residual dose (1500<z<1845, 0<r<1m)



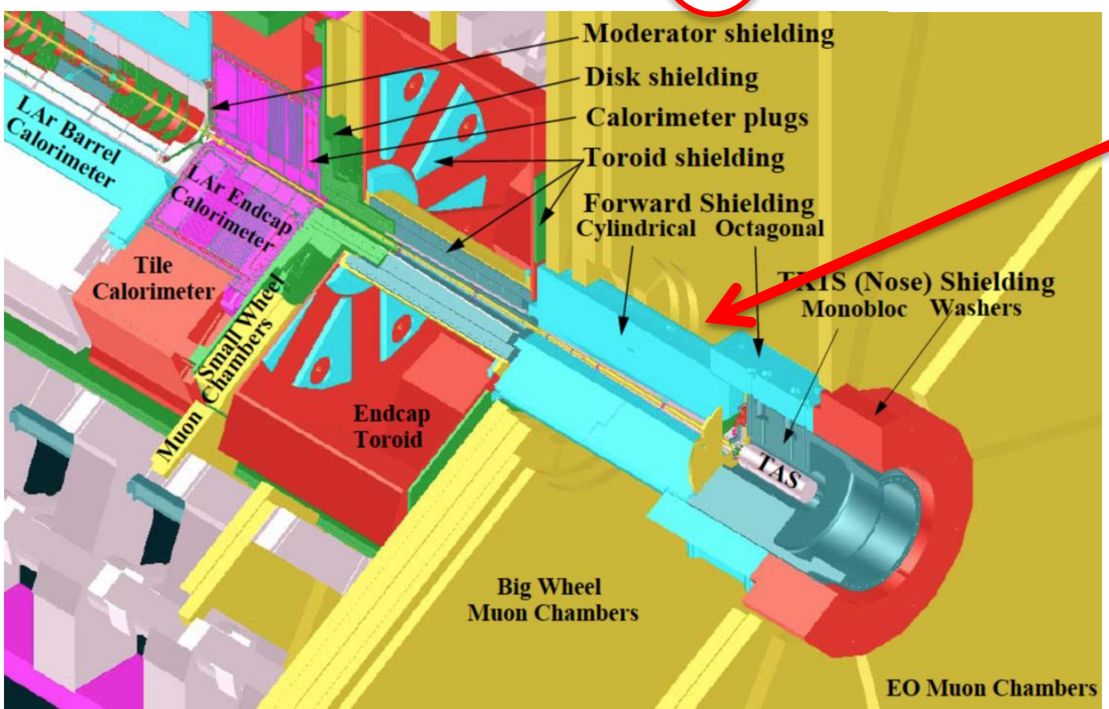
LS1 vs. LS3[1]

Residual dose (1500<z<1845, 0<r<1m)



Average residual dose [uSv/h]	
LS4	93
LS5	98
2035	100

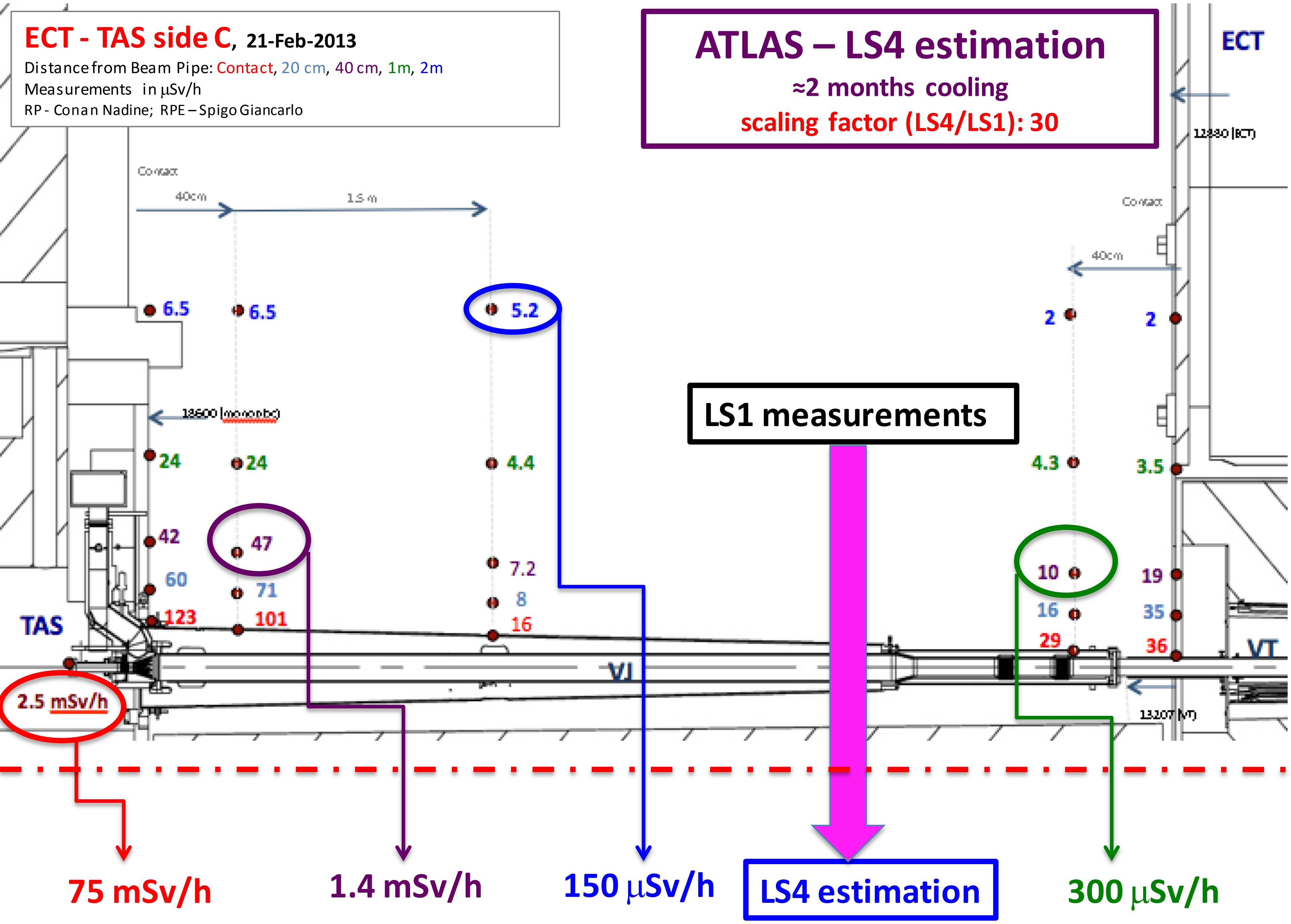
X	X/LS1	X/LS3
LS4	31.9	3.1
LS5	33.7	3.3
2035	34.4	3.4



TAS region:

Scaling factor between **25 to 35**

The scaling factor increases for **long-lived radio nuclides**.



ECT - TAS side C, 21-Feb-2013
Distance from Beam Pipe: Contact, 20 cm, 40 cm, 1m, 2m
Measurements in µSv/h
RP - Conan Nadine; RPE – Spigo Giancarlo
ATLAS – LS4 estimation
≈2 months cooling
scaling factor (LS4/LS1): 30
ECT
Contact
40cm
1.5 m
6.5
6.5
5.2
2
2
LS1 measurements
24
24
4.4
4.3
3.5
42
47
7.2
10
19
60
71
8
16
35
TAS
123
101
16
29
36
VJ
VT
2.5 mSv/h
75 mSv/h
1.4 mSv/h
150 µSv/h
LS4 estimation
300 µSv/h

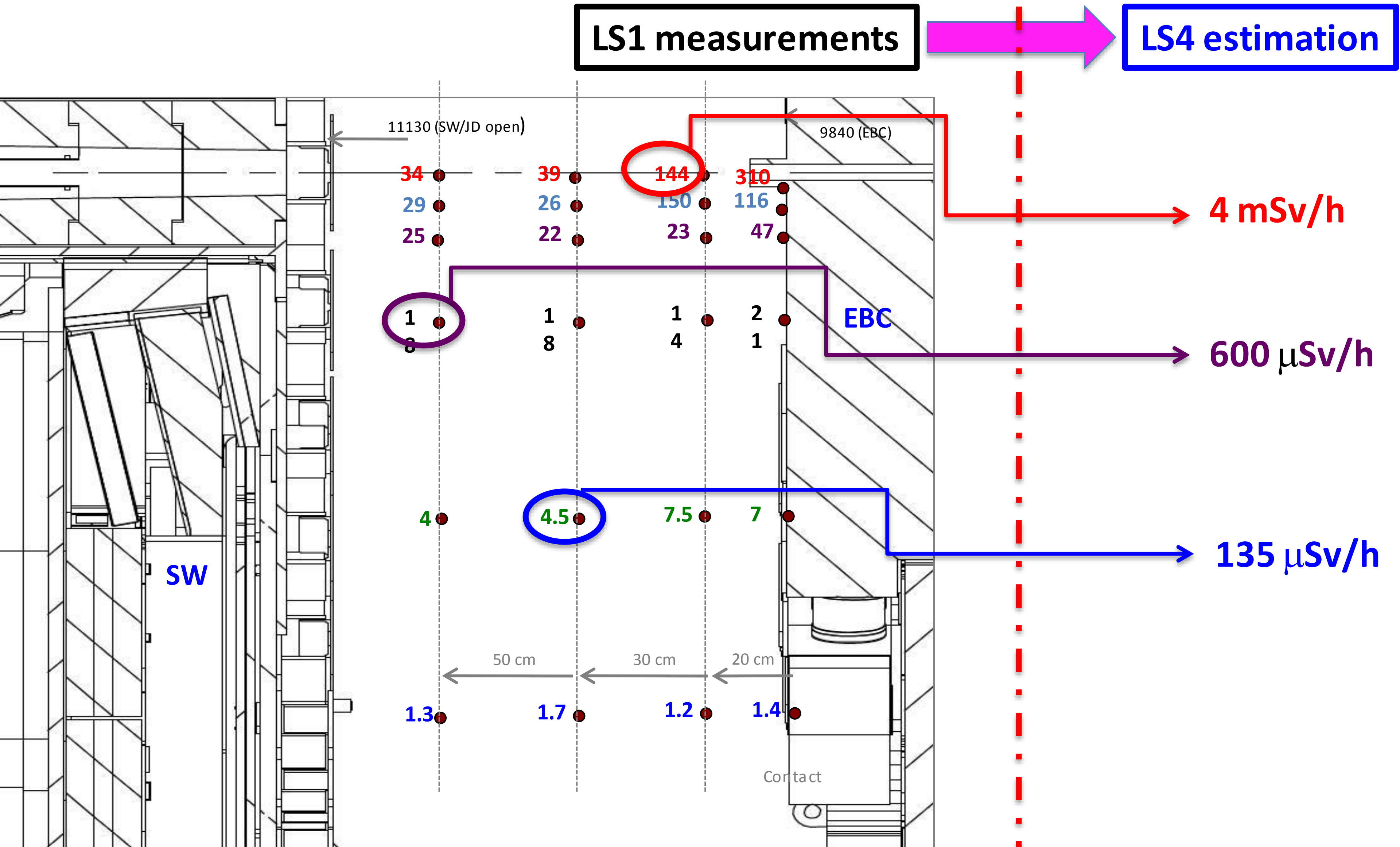
SW/JD - EBC side C, 8-Mar-2013

SW/JD(open), EBA (open) ,VA (steel), VT (removed)
Distance from Beam-pipe: Contact, 10 cm, 20 cm, 40 cm, 1 m, 2m
Measurements in μSv/h
RPE – Spigo Giancarlo

ATLAS – LS4 estimation

≈2 months cooling

scaling factor (LS4/LS1): 30



Barrel Calo – EBA side A , 11-Mar-2013

ECAL(open), VA(steel)

Distance from Beam Pipe: Contact, 10cm, 20cm, 40 cm, 1 m, 2m

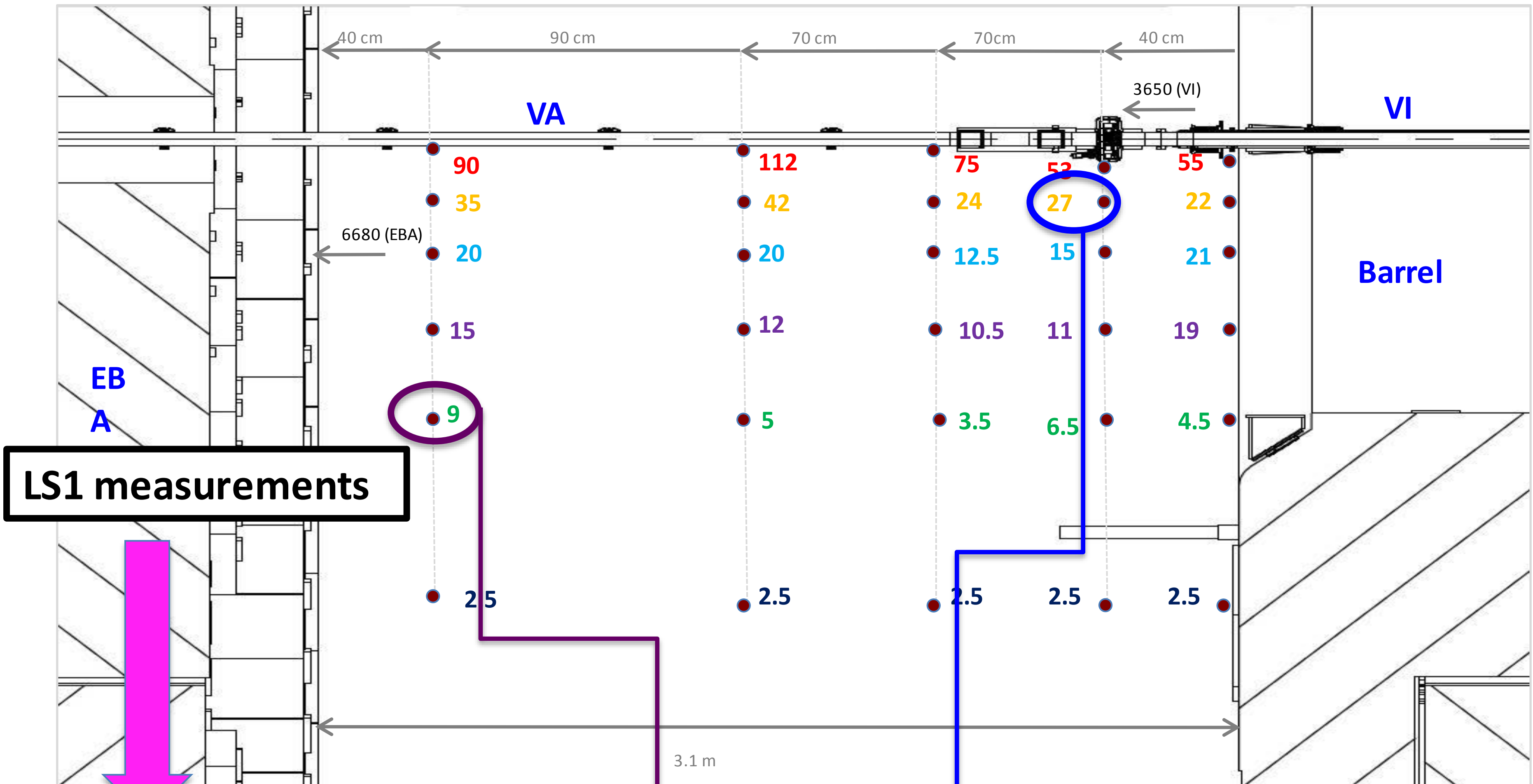
Measurements in µSv/h

RP: Nadine Conan, RPE: Giancarlo Spigo

ATLAS – LS4 estimation

≈2 months cooling

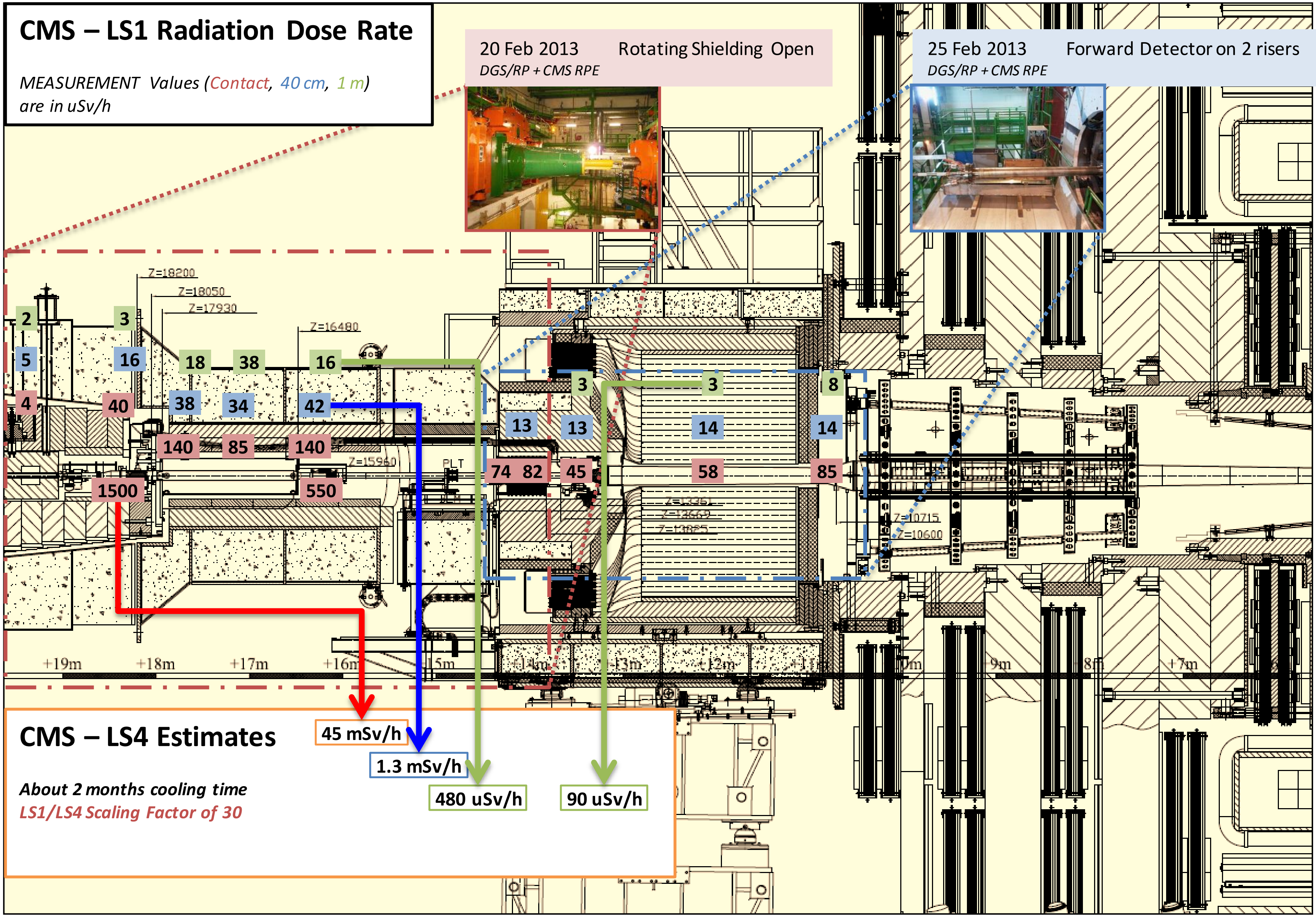
scaling factor (LS4/LS1): 30



LS4 estimation

300 µSv/h

900 µSv/h


CMS – LS1 Radiation Dose Rate
MEASUREMENT Values (Contact, 40 cm, 1 m) are in uSv/h
20 Feb 2013 Rotating Shielding Open
DGS/RP + CMS RPE
25 Feb 2013 Forward Detector on 2 risers
DGS/RP + CMS RPE
Z=18200
Z=18050
Z=17930
Z=16480
Z=15960
PLT
Z=10715
Z=10600
2
3
5
16
18
38
16
4
40
38
34
42
140
85
140
1500
550
3
3
8
13
13
14
14
74 82
45
58
85
+19m
+18m
+17m
+16m
+15m
+14m
+13m
+12m
+11m
+9m
+7m
CMS – LS4 Estimates
About 2 months cooling time
LS1/LS4 Scaling Factor of 30
45 mSv/h
1.3 mSv/h
480 uSv/h
90 uSv/h

ALICE :

The HI program for Run3 and Run4 foresees a delivered PbPb luminosity of >$10nb^{-1}$.
The radiation load of $10nb^{-1}$ of PbPb collisions @5.5TeV/nn corresponds to the radiation load of <$100pb^{-1}$ of pp collisions@14TeV.

Activation is a small issue for a few elements very close to the beampipe in ALICE.

LHCb :

	2011	2012	LS1	2015	2016	2017	LS2	2019	2020	2021	LS3
E_{beam} (TeV)	3.5	4		6.5	6.5	6.5		7	7	7	
L_{int} (fb^{-1})	1.2	2.2		1.5	1.5	2.0		5	5	5	
L_{ave} ($cm^{-2}s^{-1}$)	3.6×10^{32}	4×10^{32}		4×10^{32}	4×10^{32}	4×10^{32} 6×10^{32}		1×10^{33} 2×10^{33}	2×10^{33}	2×10^{33}	

New calculations are being carried out for LS2 when major LHCb detector upgrade will take place.

If needed, access close to the beam pipe in the area of the VErtex LOcator is possible very shortly after beam dump, hence it is important for LHCb to also consider activation after short cool down times.
Based on measurement done in 2012, simple scaling for energy and luminosity expect **~230 uSv/h at 40 cm from beam pipe after 2-3 h for Run 3** (the same after LS3).

3. Reminder of the CERN regulations and strategy:

➔ CERN regulation – **Safety code F**

✓ **Any practice leading to an effective dose exceeding 100µSv per year** for individuals working on the CERN site or 10µSv for members of the general public **must be justified.**

✓ It is obligatory to **optimize radiation protection** according to the As Low As Reasonably Achievable (ALARA) principle. Optimization can be considered as respected if the **annual** dose of a practice is below 100µSv for persons exposed because of their professional activity and 10µSv for members of the general public.

✓ The effective dose in any consecutive 12-months period is limited to:

- **20mSv = Category A Radiation Workers**
- **6mSv = Category B Radiation Workers**
- 1mSv for not occupationally exposed personnel (the effective annual dose to any person outside of the CERN site boundaries must not exceed 300µSv).

And ... we must declare to Swiss Federal Office of Public Health if one person exceed 2 mSv/ month !

➔ Design constraints for new or upgraded facilities
(HILUMI LHC - CERN-ACC-2013-018 - S. Roesler – Nov. 2012 and in Chamonix Workshop 2005)

The exposure of persons working on the CERN sites, the public and the environment will remain below the dose limits under normal as well as abnormal conditions of operation and that the optimization principle is implemented.

In particular, the following design constraints apply:

Design of new components and equipment must be optimized such that installation, maintenance, repair and dismantling work does not lead to **an effective dose exceeding 2mSv per person and per intervention.**
The design is to be revised if the dose estimate exceeds this value for cooling times compatible with operational scenarios.

Selection of construction material must consider activation properties to **optimize dose to personnel** and to **minimize the production of radioactive waste.**
The web-based code **ActiWiz** is available for CERN accelerators

3. ALARA Strategy

Optimization is a legal requirement if the accumulated dose exceeds 100 µSv (ALARA) per person. Optimization includes:

- design
- material choice (ActiWiz)
- work coordination
- work procedures
- tools
- follow up

ALARA Committee

ALARA criteria – EDMS

Individual dose equivalent	**Level I**	100 µSv	**Level II**	1 mSv	**Level III**
Collective dose equivalent		500 µSv		5 mSv	

Group 1 criteria: determine ALARA Level classification

Ambient dose equivalent rate	**Level I**	50 µSv/hr	**Level II**	2 mSv/hr	**Level III**
Airborne activity in CA		5 CA		200 CA	
Surface contamination in CS		10 CS		100 CS	

Group 2 criteria: can be used by RP to increase (or eventually decrease) classification

ALARA Strategy

The following personal dose objectives apply at CERN (for any consecutive 12-months period)
(HILUMI LHC - CERN-ACC-2013-018 - S. Roesler – Nov. 2012)

- **Personal dose < 2mSv for Winter Shutdowns and operational period**
- **Personal dose < 3mSv for Long shutdowns**

Some collected statistics - courtesy of the CERN Dosimetry Service

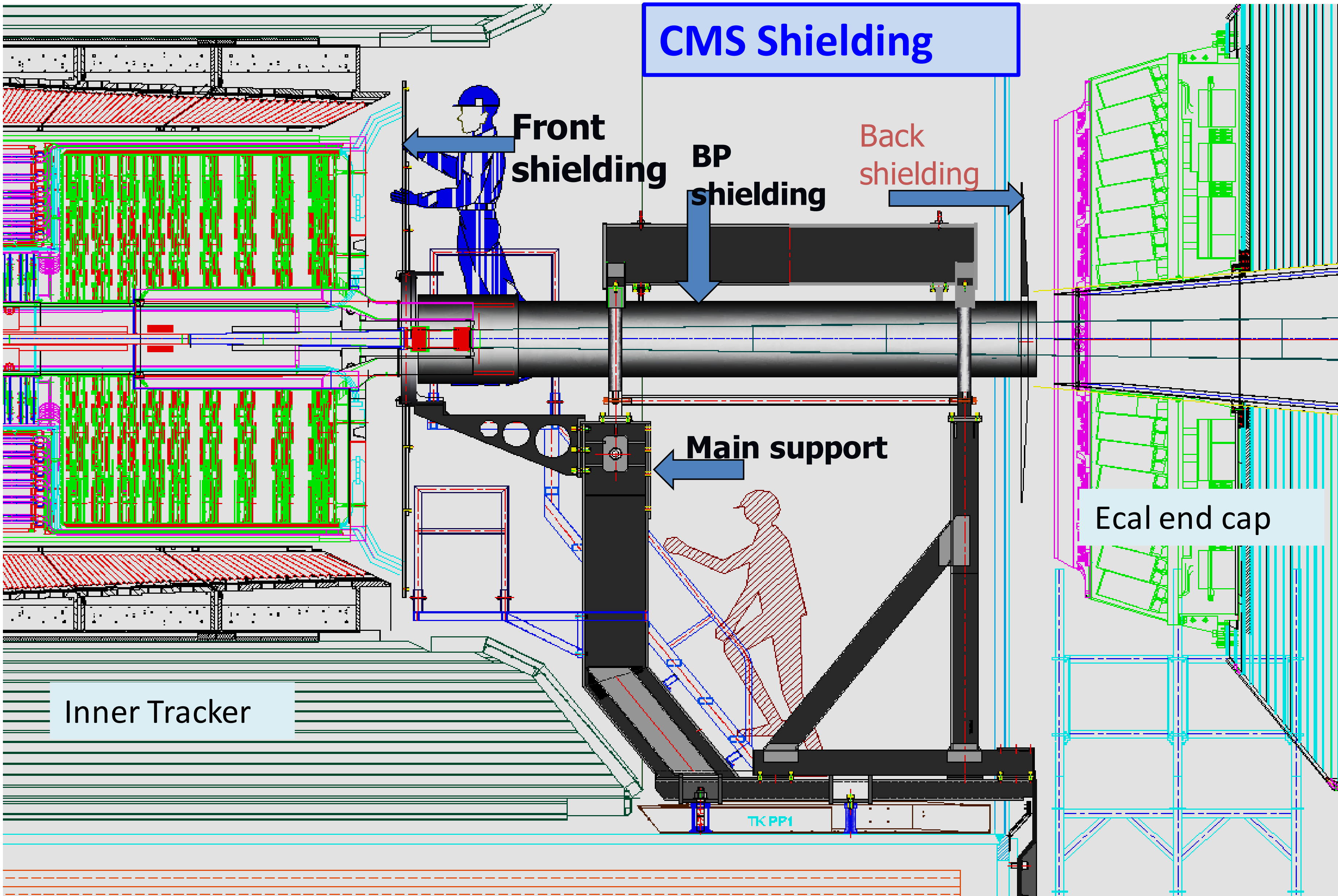
Dose interval (mSv)	Persons Concerned (2005)	Persons Concerned (2006)	Persons Concerned (2007)	Persons Concerned (2008)	Persons Concerned (2009)	Persons Concerned (2010)	Persons Concerned (2011)	Persons Concerned (2012)
0.0	3074	4192	5131	5143	5042	5418	5325	6002
0.1-0.9	1522	1738	898	1020	1219	1514	1994	2030
1.0-1.9	53	37	33	40	39	31	43	29
2.0-2.9	9	17	2	3	13	6	6	-
3.0-3.9	3	4	1	1	2	-	-	-
4.0-4.9	4	2	1	1	-	-	-	-
5.0-5.9	1	-	-	-	-	-	-	-
> 6.0	-	-	-	-	-	-	-	-

Distribution of personal annual dose equivalent from 2005 onwards.
The majority of monitored persons did not receive any personal dose.

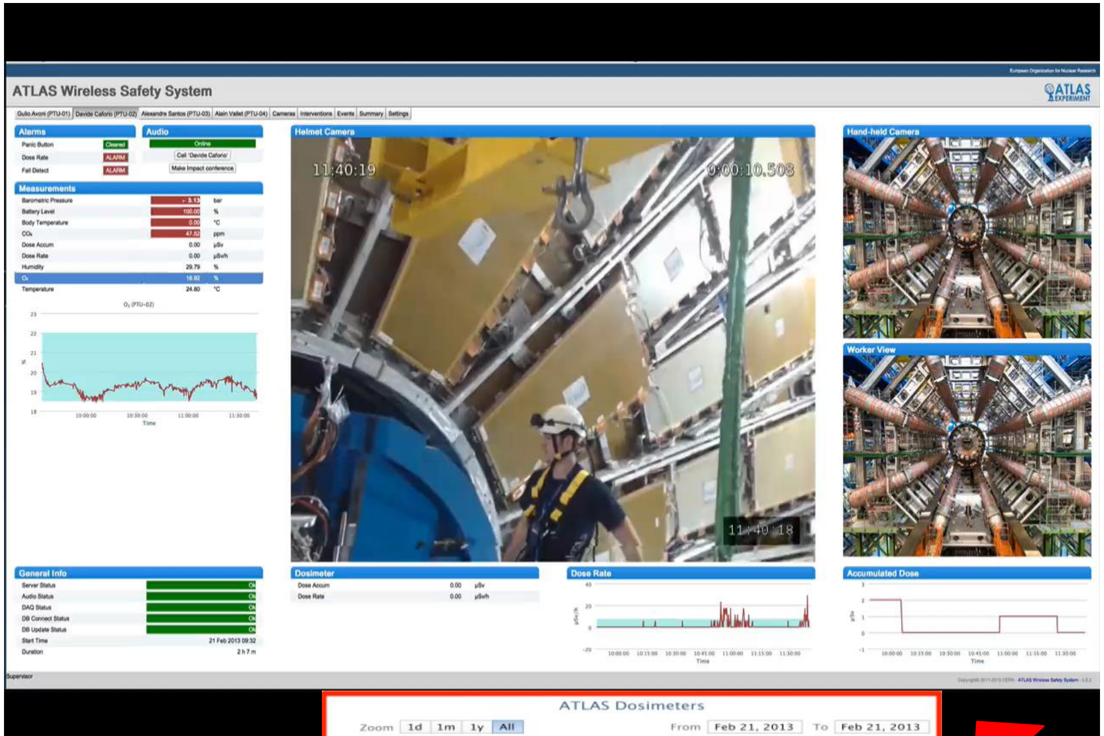
In 2012, only 29 persons exceeded an annual dose of 1 mSv!

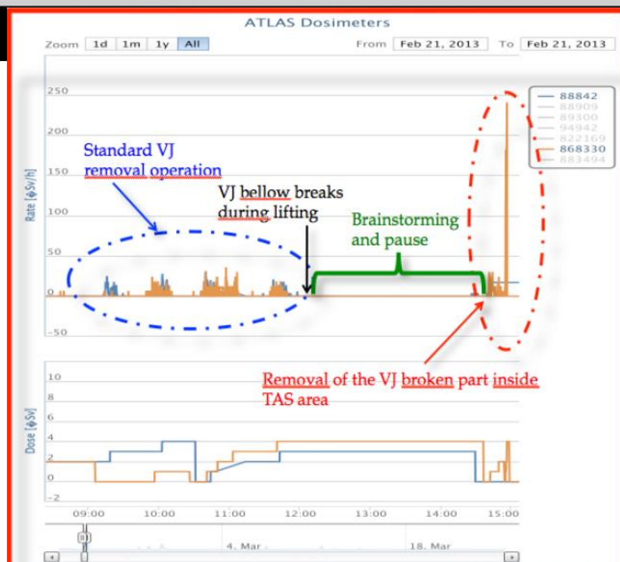
Means envisage by the experiments to lower the dose rates

1. Shielding:



2. Devices to supervise and assist personnel in radiation areas





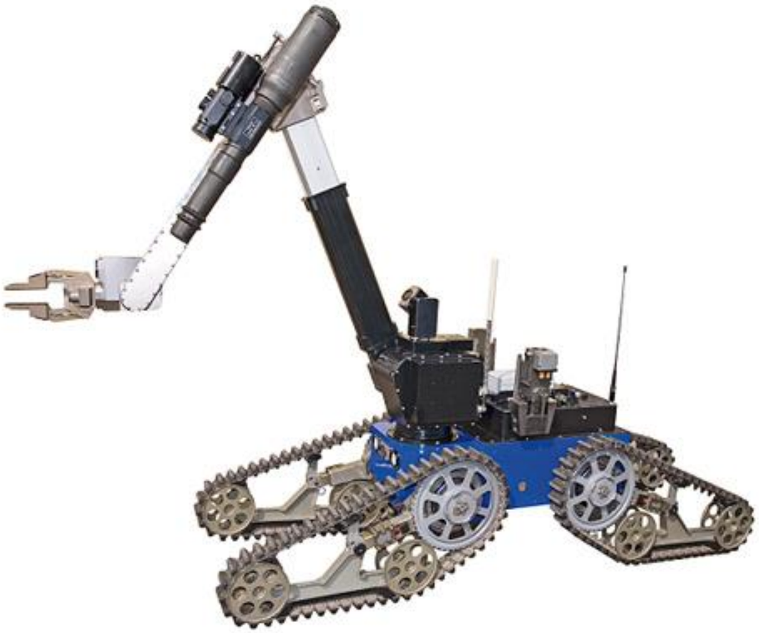
ATLAS Personal Supervision System

ATWPSS already in use for LS1

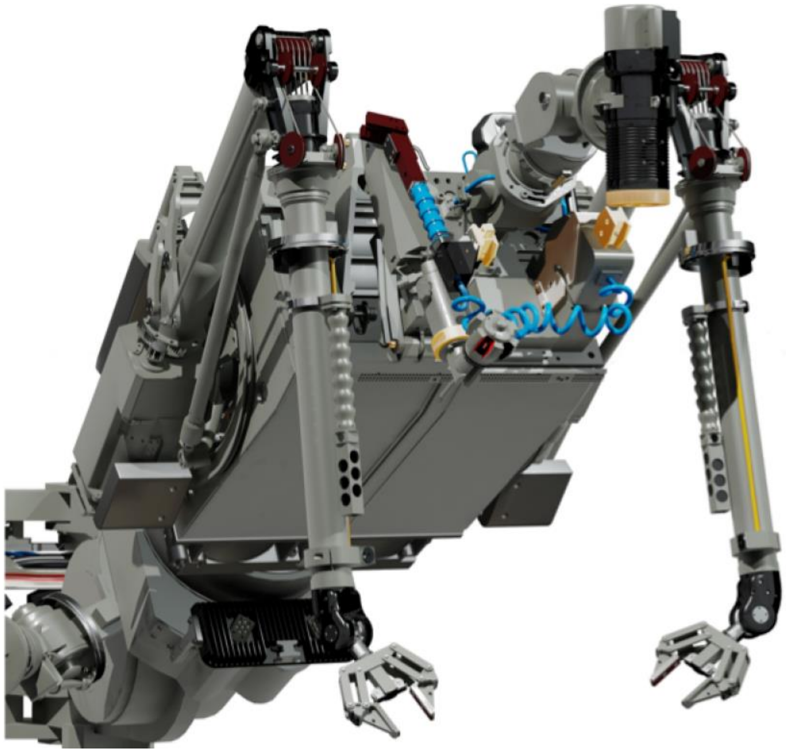
Removal of VJ Beam Pipe

3. Remote Handling Manipulations

We are currently investigating what are the most appropriate technologies



TELEMAX



MASCOT

Impact of Air Activation on Access conditions and environment...

1. An estimation of the activation at LS4/LS5 shutdowns ...

CMS, ATLAS and LHCb air activation have been calculated CERN-SC-2008-067-RP-TN.V2 (2008)

COOLING TIME	Effective dose CMS [μSv]	Effective dose LHCb [μSv]	Effective dose ATLAS [μSv]
0 MIN	1.81	0.05[μSv	1.46
1 H	0.54	0.02	0.32
2 H	0.43	0.01	0.26
6 H	0.34	0.01	0.23
½ DAY	0.31	<<0.01	0.22
DAY	0.30	<<0.01	0.21

CERN Guideline: effective dose due to inhalation < 1 μSv per hour of presence

CMS: **~10^{34} cm-2 s-1**
~10^{9} proton-proton collisions per second

LHCb: **2.10^{32} cm-2 s-1**
1.6 x 10^{7} proton-proton collisions per second
Beam energy 14 TeV

Waiting time for LS1 is 15 min.

A scaling is performed assuming proportionality with peak luminosity:

After 1 day, effective dose in ATLAS and CMS ~ 1 μSv/h at 5.10^{34}

We need to run more accurate calculations.

Impact of Air Activation on Access conditions and environment...

2. Possible impact on environment and ventilation system:

The consequences on environment has to be carefully analyzed and **eventually modifications of the ventilation system** at some LHC locations.

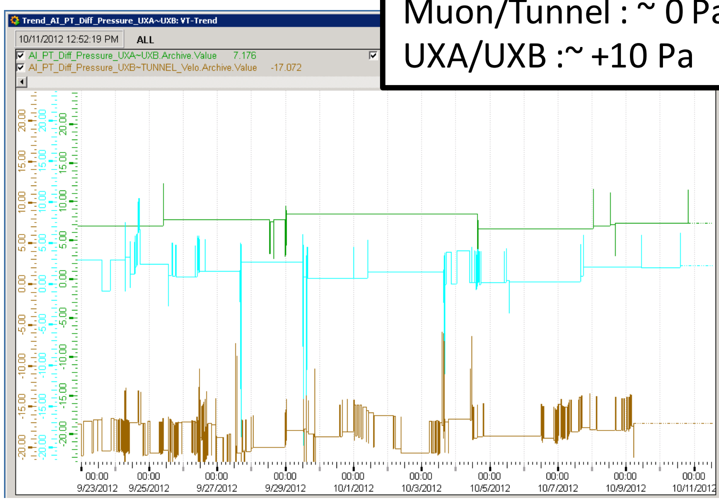
Can we still survive with the current ventilation system ?

- ATLAS , CMS – 80 % recirculation
- LHCb – no recirculation

For some of the experiments, the tightness between the experimental caverns, the services caverns and the LHC machine has to be consolidated

Example: **LHCb**

Velo/Tunnel : ~ -20 Pa
Muon/Tunnel : ~ 0 Pa
UXA/UXB :~ +10 Pa



Measurements Oct 2012 show that air activation in the tunnel upstream of LHCb is about twice that of the area of the VErtex Locator close by.

For the current situation dose to personnel from air leaking into LHCb is negligible.

Re-assessment for LHCb upgrade is recommended

Impact of radiations in the services caverns during Beam ...

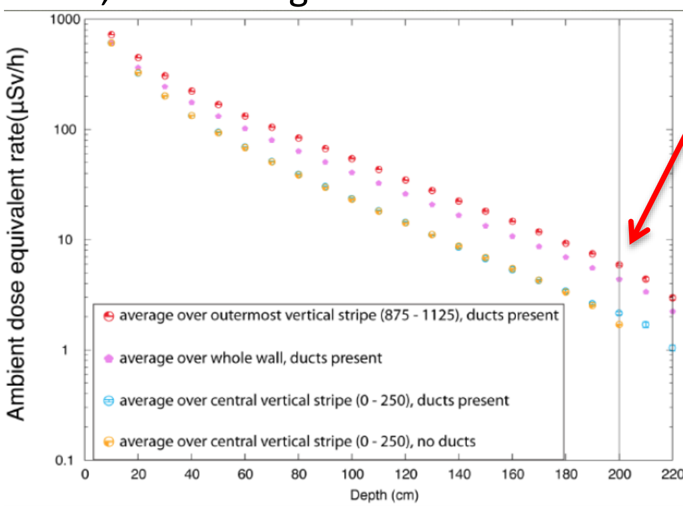
1. An estimation of the neutrons in the service caverns areas and surface buildings to be estimated .

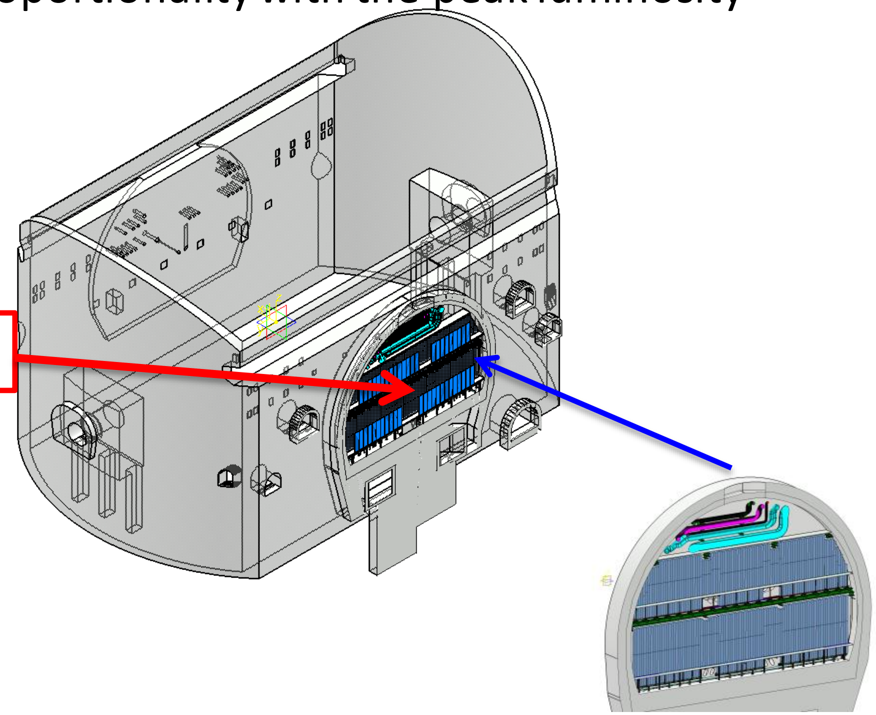
A first estimation is performed with a simple proportionality with the peak luminosity

Example: ATLAS

Ref: Radiation in the USA15 cavern in ATLAS

I. Dawson, V. Hedberg 2004 ATL-TECH-2004-001





USA15 Service cavern - Just behind the wall between UX15 and USA15

Dose rate due to neutrons at 10^{34} ➔ ≈ 6 µSv/h

Dose rate due to neutrons at 5.10^{34} ➔ ≈ 30 µSv/h

We need to shield the UX15/USA15 wall to remain a supervised radiation area

(we target an attenuation factor 2 to 3)

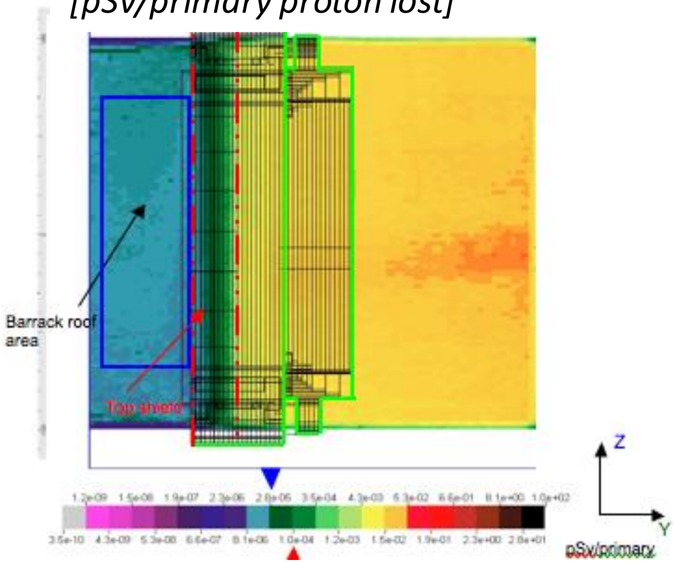
LHCb

Calculation for the as-built shielding wall between the UX85A accessible side of the cavern and UX85B, where the detector sits done in 2008 for nominal LHC and nominal LHCb (C. Theis et al., EDMS no. 847155).

Radiation levels for **UX85A well within a Supervised area classification** when scaling to LHCb upgrade luminosity

Average ambient dose equivalent **0.56 uSv/h ± 2% << 15 uSv/h**
→ No issues for LHCb upgrade Luminosity for normal operation.

Ambient-dose-equivalent on D3 [pSv/primary proton lost]



Radiation levels in UX85A also to comply with limit of 20 mSv ambient-dose-equivalent in case of a **full beam loss.**

Average dose values in counting rooms are ~4 mSv for a full beam loss of one 7 TeV beam of 4.7 x 10^{14} protons, BUT on 4th floor dose levels are above 20 mSv (blue box) hence access is restricted.

→May be an issue with increase of beam intensity in HL-LHC

Contamination ...

1. Estimation of the contamination problem amplitude

✓ **Fluid activation calculations** are to be updated for the 4 experiments with the HL-LHC conditions to determine the **risks of contamination and impact on environment**.

✓ **Regularly analyze contamination** and follow up history to quantify the issue for the HL-LHC.
Note that **corrosion of metallic structure** might highly increase the dust contamination

2. Possibly anticipate solutions ...

- ✓ follow up carefully the history where possible by **taking samples**
- ✓ use double containers
- ✓ **replace the type of fluids** with less problematic ones
  for example C3F8 by CO2
  (already on going for some fluids because of green house gases effects)

3. Determine the real impact of contamination on activities

- ✓ Required infrastructure
- ✓ Training for personnel
- ✓ Scheduling impact can be huge
- ✓ ... and also the cost impact ...

Material activation ...

Revision of the **radioactive zoning for the 4 experiments** taking into account:

- ✓ the irradiation scenario of the HL_LHC
- ✓ **New detectors layout**
- ✓ **Exemption limits** (in Bq/kg) are **under revision presently in Europe** and might be enforced soon (in Switzerland probably in 2015). These LE values will be sometimes significant lower then nowadays.

The main dominating isotope for **Copper and Stainless Steel** is **Mn-54**
for 1 month and 1 year cooling time
For Mn-54, the **threshold is divided by 100 !**

We need to assess

- ✓ **the quantity of radioactive material in the experiments**
- ✓ **characterisation of radioactive waste (nuclide inventory)**
- ✓ **an estimation of the required of cool down areas and storage space**
- ✓ **radioactive workshops**
- ✓ **associated costs**

Conclusions ...

- We have a first idea of the issues related to radiations and activation for the HL-LHC.

- Clearly we will have to face very high residual doses in CMS and ATLAS

- Air activation, contamination will probably also be an issue.

- The radioactive waste will also increase by a significant amount.

- Associated to this, we will have to face schedule and costs impacts.

- We need to understand in more details where and when will appear these issues.

- Some calculations have started and need to be continued in close collaboration with the CERN RP group.

- In parallel, LHC Experiments are investigating already ways to mitigate the radiation and activation problems for the access periods.