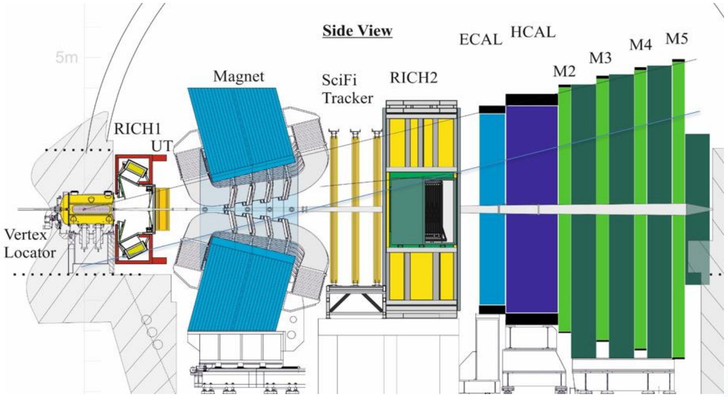

Accelerator configuration and modification for LHCb at high luminosity

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8^{th} HL-LHC Collaboration Meeting – October 16, 2018

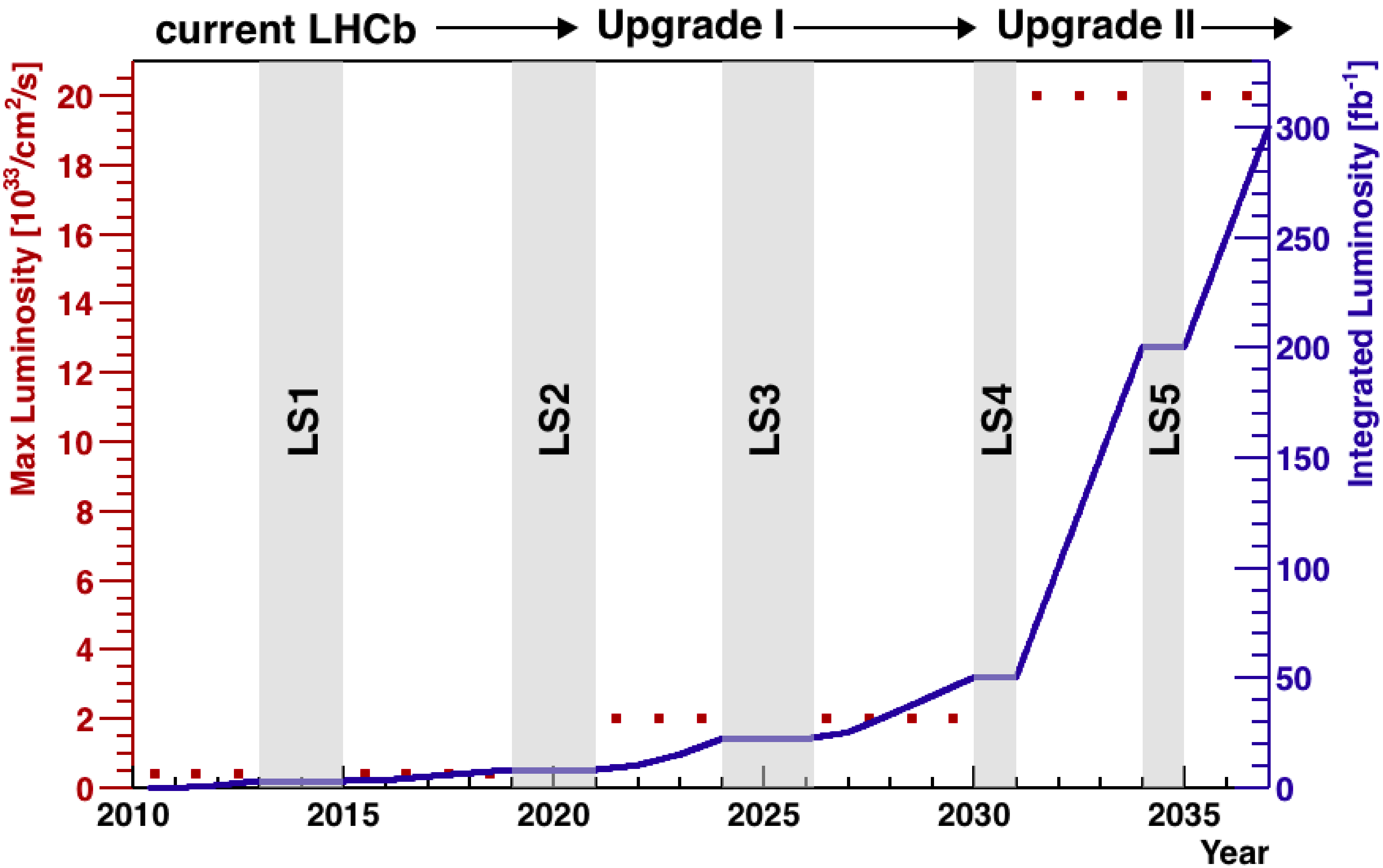
LHCb Upgrade II – operation at high luminosity

- Modifications to allow the experiment to collect 50 fb^{-1} every year if able to work at

$$\mathcal{L} = 1 \text{ to } 2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$$

- Major ingredients :
  - adapting the beam optics, operation scenarios
  - increasing the protections for both LHC machine elements and detectors experimental cavern to the new environment

LHCb - Luminosity upgrade summary



Status of the studies

- Accelerator Note **CERN-ACC-NOTE-2018-0038** released
  - Overview of design studies and possible operational scenarios
  - Outline of issues to allow operations at high luminosity and possible mitigation solutions

- Full costing not yet completed
  - In the coming months a more detailed costing will be discussed with the CERN groups involved
  - Need to enter into details:
    - Update of energy deposition effects
    - Integration studies
    - Experimental areas aspects

CERN-ACC-NOTE-2018-0038

2018-08-29

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LHCb Upgrades and operation at 10^{34} cm^{-2} s^{-1} luminosity –A first study

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Keywords: LHC, HL-LHC, HiLumi LHC, LHCb, https://indico.cern.ch/event/400665

Abstract

Presently, the LHCb experiment at IP8 operates at reduced luminosity (~4.0 10^{32} cm^{-2}s^{-1}) compared to ATLAS and CMS experiments. The LHCb collaboration is proposing an Upgrade II during HL-LHC operation, where the beams at IP8 will collide at high-luminosity (~1-2 10^{34} cm^{-2} s^{-1}), comparable to the present high-luminosity regions IP1&IP5. The LHCb experiment aims to collect more than 300 fb^{-1} by the end of the HL-LHC operation. A feasibility study of operating IP8 at high-luminosity whilst preserving the performance at IP1 and IP5 and on the impact to the LHC machine and experimental cavern was done. Optics studies shows that solutions allowing to reach an integrated luminosity of 40 to 50 fb^{-1} per year to LHCb/IP8 at the cost of a reduction of about 5% in the integrated luminosity of the main experiments ATLAS and CMS, under the assumption that there are no lifetime limitations besides burn-off, are feasible. Aspects like beam-beam effects that could have an impact on the beam lifetime and on the overall estimates of the integrated luminosities for LHCb and ATLAS and CMS need to be further studied. Energy deposition in the machine elements of the IR straight section 8 and LHC infrastructure and possible mitigation options were evaluated, revealing the challenges involved but also showing possible mitigation solutions. This is a first study with preliminary findings on the key aspects and a range of potential solutions for operating LHCb Upgrade II at a luminosity up to 2 10^{34} cm^{-2} s^{-1}, permitting the collection of 300 fb^{-1} or more at IP8 during the envisaged lifetime of the LHC. Further studies are needed to fully validate the proposed options.

Peak luminosity

$$L = \frac{N_b^2 f_{rev} k_b}{4\pi\epsilon\sqrt{\beta_\times^* \beta_\parallel^*}} \cdot \frac{1}{\sqrt{1+\Phi_p^2}}$$

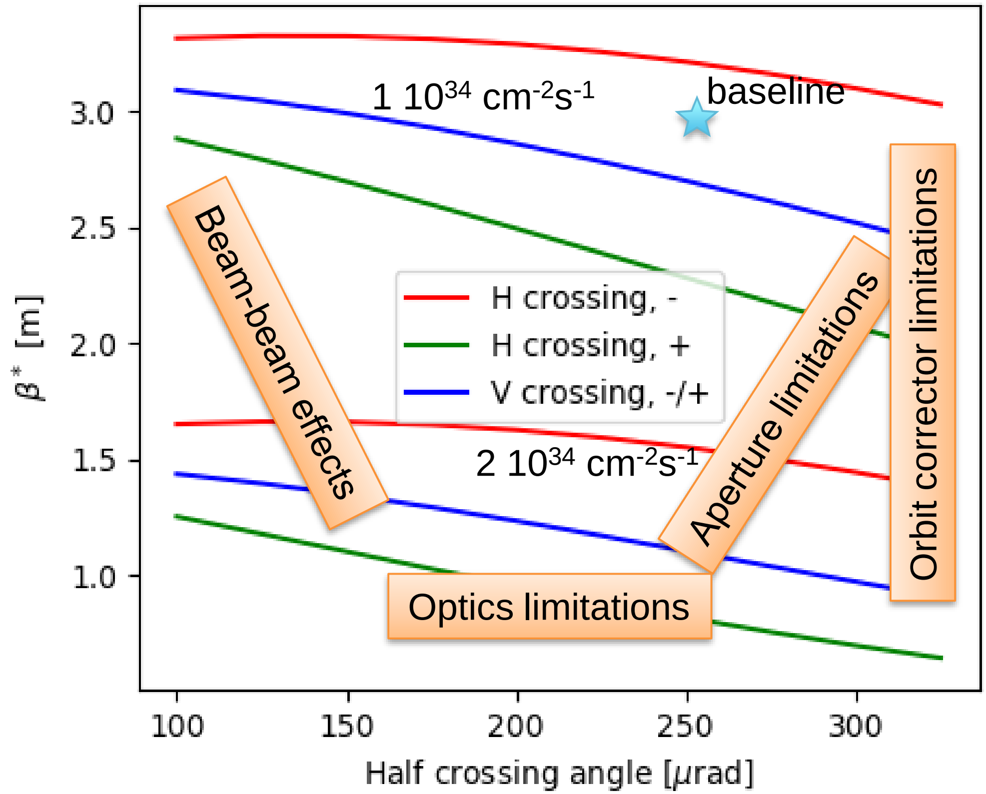
$$\Phi_p = \frac{\sigma_s}{\sigma_\times} \cdot \frac{\theta_\times}{2} = \frac{\sigma_s}{\beta_\times^*} \cdot \frac{\mathrm{bb_{sep}}}{2}$$

$$\theta_\times = \theta_{\mathrm{external}} \pm \theta_{\mathrm{spectrometer}} \cos \alpha_{\mathrm{plane}}$$

Protons per bunch	N_b	2.2 10^{11}
Number of Bunches	k_b	2572(2374)
R.M.S. bunch length	σ_s	7.61(9.0) cm
+/- Polarity		B_y<0 / B_y>0

- Minimum β* is constrained by optics flexibility.
- Maximum crossing angle limited by orbit corrector strength
- For a given β*:
  - Aperture constrains maximum crossing angle.
  - Beam-beam effects (i.e. beam lifetime) constrains minimum crossing angle.

$\theta_{\mathrm{external}}$, β^* at constant luminosity



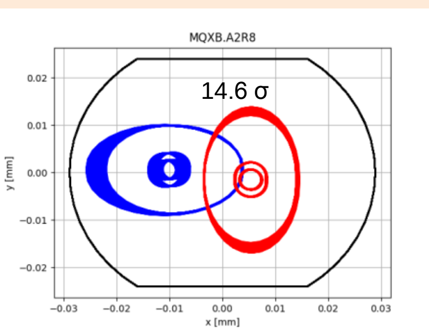
Aperture limitations in collision

Maximum half external crossing angle as function of β*

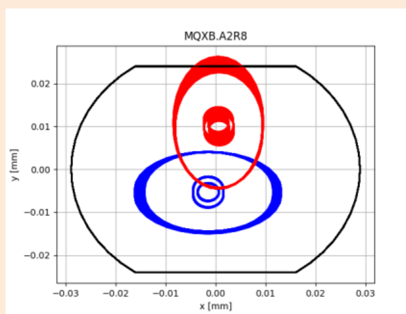
β* [m]	H[1] [µrad]	H[2] [µrad]	V[3] [µrad]	V[1,4] [µrad]
1	-165	-220	±115	±220
1.5	-225	-275	±165	±235
2	-265	-310	±205	±270
3	-310	-310	±250	±310

[1] with present TCDDM
[2] without present TCDDM
[3] crossing plane can be rotated during the ramp (difficult to setup)
[4] if beam screen is rotated, introducing strong limitations during the ramp

Aperture in the triplet is not symmetric (H=57.8 mm, V=48 mm) and cannot be rotated easily.

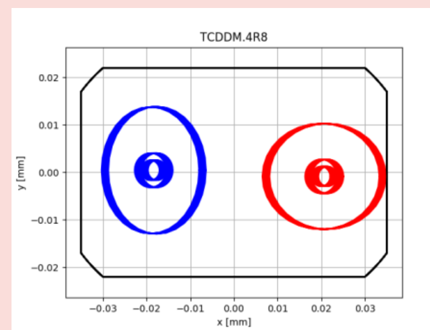


H crossing

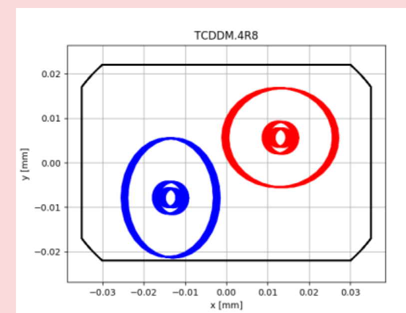


V crossing

TCDDM needed for D1 protection
Present aperture bottleneck for B2H and B1V.



H crossing



V crossing

- Solutions possible with some aperture margin for $\beta^*_{//}$.
- Beam screen rotation not needed so far in V-crossing
  - Rotating the beam screens would introduce issues at injection

Can parameters be found to make the dream real? Yes

Parameter	**Unit**	**Lumi Scenario**						
Target Leveled Lumi	$10^{34}cm^{-2}s^{-1}$	**0.2**	**1.0**			**2.0**		
β^*	m	3.0	1.5					
Crossing Plane		H	H		V	H		V
Magnet Polarity		$-$	$-$	$+$	$\pm$	$-$	$+$	$\pm$
External x-ing angle	μrad	500	400	300	320	400	300	320
Full x-ing angle at IP	μrad	230	130	570	419	130	570	419
Virtual (Peak) Luminosity	$10^{34}cm^{-2}s^{-1}$	1.07	2.16	1.57	1.79	2.16	1.57	1.79
Leveled pile-up	1	5.6	28	28	28	56	44.2	50.3
RMS luminous region (start)	mm	52.2	52.7	39.5	44.7	52.7	39.5	44.7
Peak line Pile-up density (start)	mm^{-1}	0.04	0.20	0.28	0.25	0.41	0.44	0.44
eff. line Pile-up density (start)	mm^{-1}	0.03	0.13	0.17	0.15	0.20	0.20	0.20
Fill duration	h	8.5	8.0	8.0	8.0	7.7	8.0	7.9
leveling time	h	>8.5	4.7	3.1	3.6	0.6	n.a.	n.a.
Yearly integ. lumi. at IP8	fb^{-1}/y	10.7	**46.3**	**40.9**	**42.5**	**61.7**	**46.2**	**51.0**
Yearly integ. lumi. at IP1/5	fb^{-1}/y	261.5	257.1	257.7	257.5	255.1	257.0	256.4

Unavoidable impact on ATLAS and CMS is limited to 2-3% (best estimation)

Can parameters be found to make the dream real? Yes

Parameter	Unit	Base. nom.	130H 1e34	130H 2e34	570H 1e34	570H 2e34	419V 1e34	419V 2e34
IP1&5								
Min. β*	cm	15/15	15/15	15/15	15/15	15/15	15/15	15/15
Full x-sing angle	μrad	496	496	496	496	496	496	496
Norm. BBLR sep. at min. β*	σ	10.5	10.5	10.5	10.5	10.5	10.5	10.5
Virtual luminosity	10^{34} cm^{-2} s^{-1}	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Virtual pile-up	1	444	444	444	444	444	444	444
Virtual loss factor	1	0.716	0.716	0.716	0.716	0.716	0.716	0.716
Levelled luminosity	10^{34} cm^{-2} s^{-1}	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Levelled pile-up	1	131	131	131	131	131	131	131
β* (start)	cm	64/64	64/64	64/64	64/64	64/64	64/64	64/64
Norm. BBLR separation (start)	σ	21.8	21.8	21.8	21.8	21.8	21.8	21.8
RMS luminous region (start)	mm	49.0	49.0	49.0	49.0	49.0	49.0	49.0
Peak line PU density (end of lev.)	mm^{-1}	1.28	1.29	1.29	1.29	1.29	1.29	1.29
Effective line pile-up dens.	mm^{-1}	0.79	0.79	0.8	0.79	0.8	0.79	0.8
Levelling time	h	7.3	6.8	6.5	6.8	6.7	6.8	6.7
Integrated luminosity per fill	fb^{-1}	1.49	1.39	1.35	1.4	1.39	1.4	1.38
IP8								
External x-sing angle	μrad	500	400	400	300	300	320	320
Spectrometer Polarity	sign	-	-	-	+	+	-/+	-/+
Full x-sing angle at the IP	μrad	230	130	130	570	570	419	419
β*	m	3.0/3.0	1.5/1.5	1.5/1.5	1.5/1.5	1.5/1.5	1.5/1.5	1.5/1.5
Virtual luminosity	10^{33} cm^{-2} s^{-1}	10.68	21.62	21.62	15.77	15.77	17.98	17.98
Virtual pile-up	1	30	61	61	44	44	50	50
Virtual loss factor	1	0.96	0.98	0.98	0.71	0.71	0.81	0.81
Levelled luminosity	10^{33} cm^{-2} s^{-1}	2.0	10.0	20.0	10.0	20.0	10.0	20.0
Levelled pile-up	1	5.6	28	56	28	44.2	28	50.3
Full parallel sep. (start)	um	82.1	39.4	12.5	30.3	0.0	34.3	0.0
RMS luminous region (start)	mm	52.2	52.7	52.7	39.5	39.5	44.7	44.7
Peak line PU density (start)	mm^{-1}	0.04	0.2	0.41	0.28	0.44	0.25	0.44
Effective line pile-up dens.	mm^{-1}	0.03	0.13	0.2	0.17.0	0.2	0.15	0.2
Levelling time	h	[1]	4.7	0.6	3.1	[2]	3.6	[2]
Integrated luminosity per fill	fb^{-1}	0.06	0.25	0.33	0.22	0.25	0.23	0.27
Yearly integrated performance								
Fill duration [3]	h	8.5	8	7.7	8	8	8	7.9
xsec for pile-up / burn-off	mb	81/111	81/111	81/111	81/111	81/111	81/111	81/111
Efficiency	%	50	50	50	50	50	50	50
Turn-around time	min	145	145	145	145	145	145	145
Yearly integ. luminosity at IP1&5	fb^{-1}/year	261.5	257.1	255.1	257.7	257	257.5	256.4
Yearly integ. luminosity at IP8	fb^{-1}/year	10.7	46.3	61.7	40.9	46.2	42.5	51

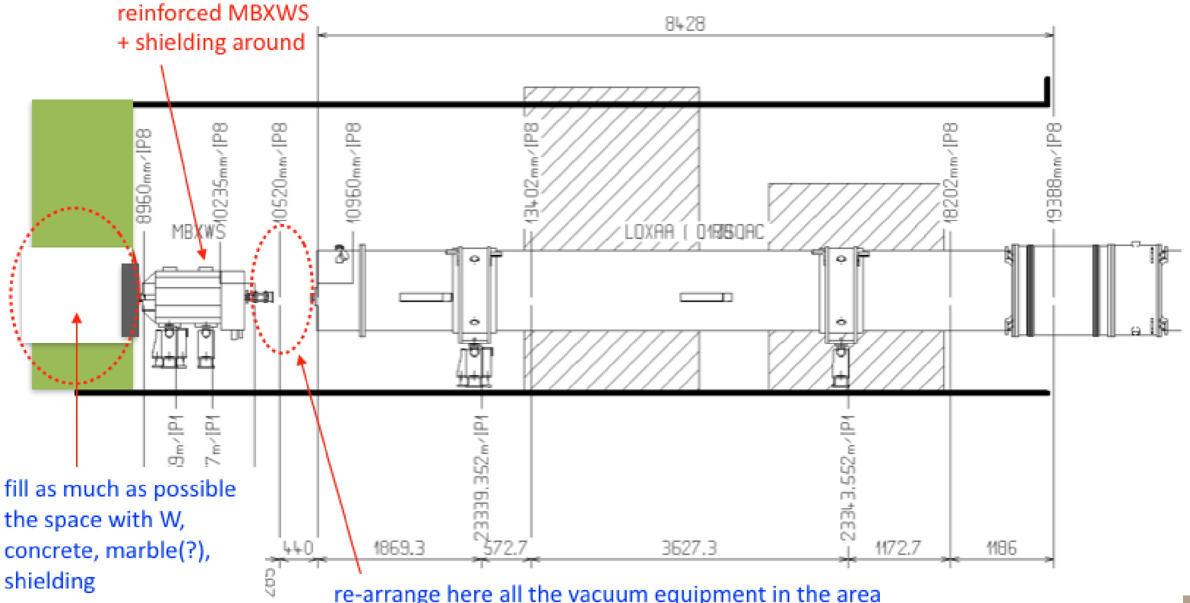
Unavoidable impact on ATLAS and CMS is limited to 2-3% (best estimation)

Other beam dynamic aspects

- More studies needed for beam-beam effects
  - First look at dynamic aperture is ok provided the crossing angle is kept above 200 μrad
- For the option with x-sing plane rotation during ramp more studies would be required
  - It would need verification and operational experience in HL-LHC conditions
- More understanding on β^* optimizations in IP1 and IP8 to be gained
  - Constraints from the HL-LHC baseline optics and the telescopic squeeze that links IP1 and IP8

Modifications RB86

TAS
reinforced MBXWS
+ shielding around



fill as much as possible the space with W, concrete, marble(?), shielding

re-arrange here all the vacuum equipment in the area
- challenging task for the vacuum team, but need to look into the details…

Modifications RB84

Wall to be reinforced

Services to be rearranged: easier than on the RB86 side

Energy deposition aspects

- Implementation of protections that haven't been considered before
  - A TAS-like based on filling with tungsten bars the MBXWS magnets or normal TAS
  - Possibly a longer TAN than currently planned to be installed during LS2 for Upgrade I
  - Prolongation of the shielding to Q1 interconnect (a reinforcement as in HL-LHC)
  - TCL collimators for Q5 protection
  - Better definition of the TCDDM mask in front of the D1 magnet

- Magnets ageing or robustness
  - Inner Triplets should be ok up to 300 fb^{-1}
    - Exchanged magnets from IR1 and IR5 could be considered as spares
  - There is a need of more investigations on the D1 magnets
    - If new magnets have to be built this would have a cost impact
  - The ageing and servicing of the "instrumented" MBXWS have to be assessed

Energy Deposition Studies

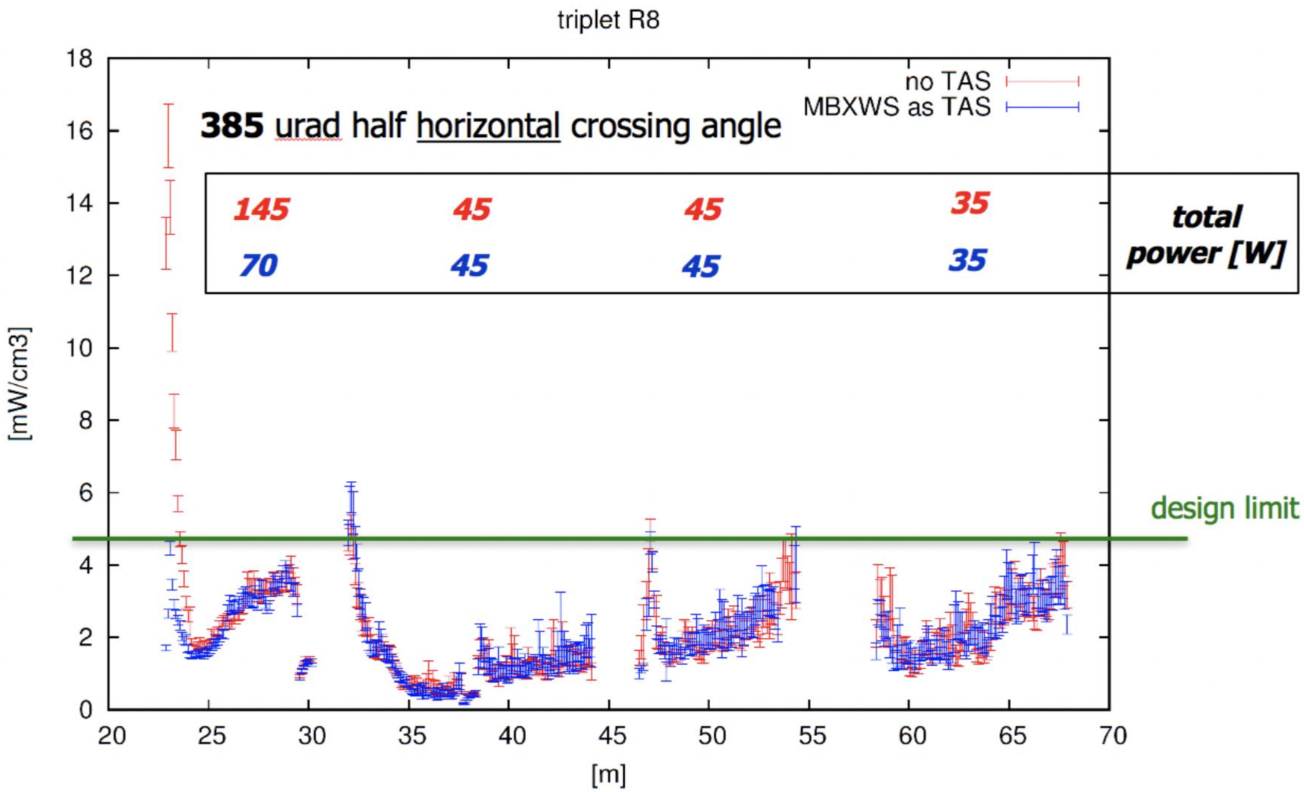


Figure 11 – Peak power density profile in the triplet and D1 superconducting coils on the right of IP8 for an instantaneous luminosity of 10^{34} cm^{-2} $s^{-1}$and a half crossing angle of 385 μrad at the collision point on the horizontal plane. Total power values in Q1, Q2, Q3 and D1 are also indicated. Vertical bars give the statistical error. Red points and numbers refer to the present layout, while blue ones refer to a case where the MBXWS integrates a tungsten absorber. The LHC design limit is shown.

Other aspects not yet studied

- Possible impact in cryogenics to be still evaluated
  - Protection of the remaining(?) electronics and installations
  - Higher heat load on the system and impact on higher heat on QRL
- Impact in ventilation system, R2E for proximity electronics and services, increasing wall thickness and density on one side
- Vacuum equipment displacement from hot and constrained regions around the inner triplets to be evaluated

Cost evaluation

- Absorbers TAS and TAN: quite some amount of tungsten
- Two collimators (all included, cables, controls)
- Cryogenics
- Civil engineering and additional shielding
- Experimental area aspects
- Ventilation
- D1 magnets rebuild?

First guess 10-30 MCHF with still high uncertainty

(20 MCHF would be the cost of new D1 magnets)

Next steps

- A more refined costing is being prepared to reduce uncertainty
  - Preliminary figure soon with higher precision
    - It might need few more months or end of LS2

- Integration studies need to be done.
  - On the right side IP8 is complicated by beam 2 injection elements
  - Space for TAN, TCL, other possible absorbers is very limited

- If LHCb is given green light to TDR, a similar level of documentation and refinement will be done on the accelerator side
  - Need of setting up a small project

Summary

- Scenarios for operating LHCb after Upgrade II at high luminosity have been worked out that match the expectations from the experiment
  - Impact to IP1/IP5 performance within acceptable levels

- First study on required modifications in the IP8 region for machine components, experimental cavern and infrastructure completed and published.

- A rough cost estimate on major cost drivers completed

- No major showstoppers, but lot of work is required to finalize and validate the proposed solutions

Thanks LHCb for the challenge!!! – it would be a fun project to work on if good physics is to be found!