Collimator failure losses for various HL-LHC configurations

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Thanks to C. Bracco and B. Goddard

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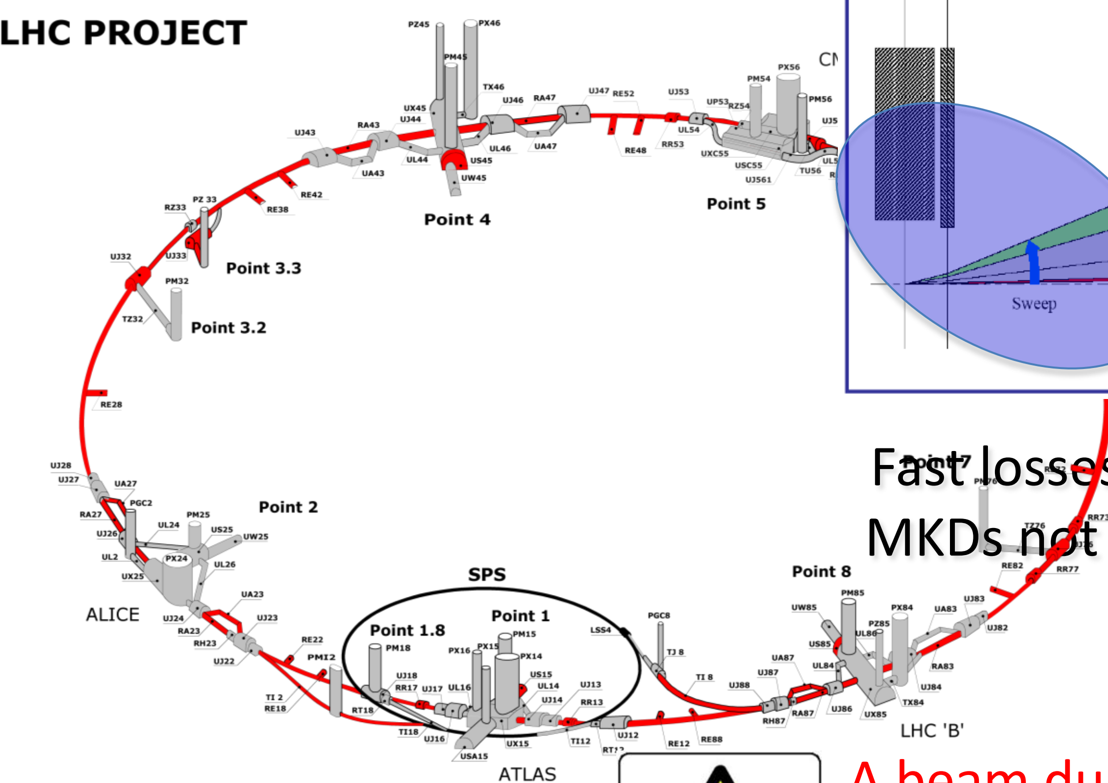
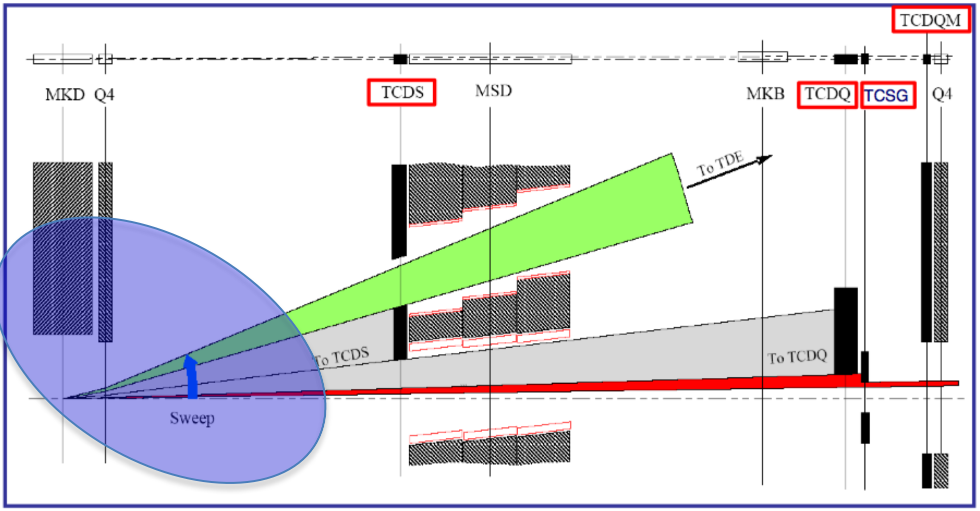
Outline

- Asynchronous dump: what is it?
- Tools used in the simulations
- Validation of the simulation set-up
- Risks by using the HiLumi optics with 2 different collimation settings:
  - *Beam1*
  - *Beam2 + including optics errors*
- Conclusions

Asynchronous dump: what is it?





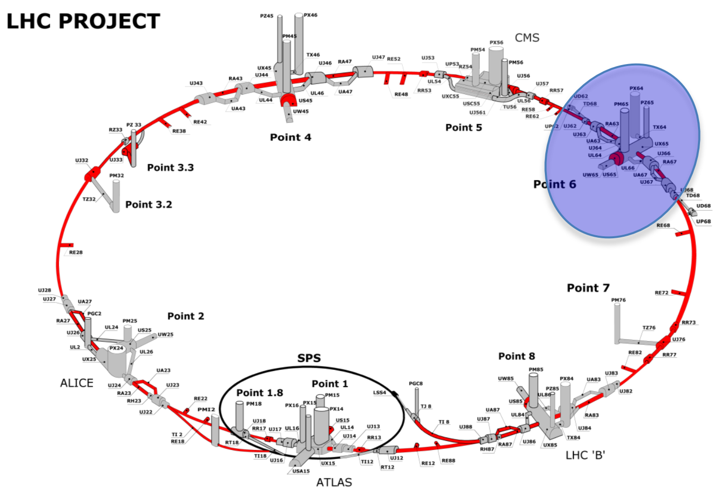
Fast losses happens when one or all of MKDs not synchronously fired with the abort gap.

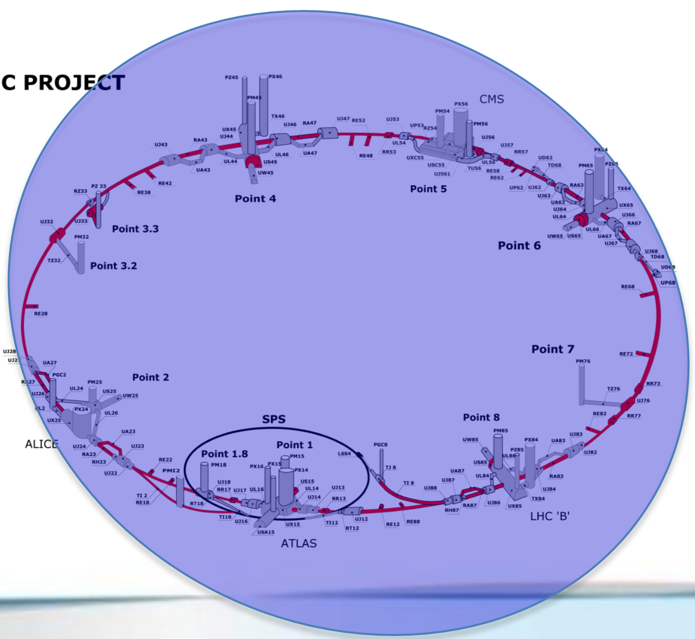
A beam dump system fault could lead to severe damage on LHC machine components.

Scope of the study…

…is to understand the beam loads in different collimators in case of asynchronous beam dump, in order to improve the LHC collimation system design by understanding realistic loss cases.

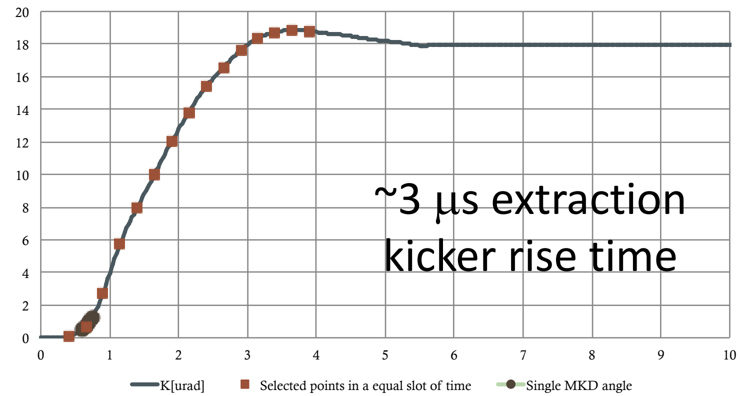
Not looking at that from the beam dump point of view,
but from the whole LHC collimation system point of view!





Tools used in the simulations

A **modified SixTrack collimation routine** to allow studies of asynchronous dump with the whole collimation system in place, including **different errors**.

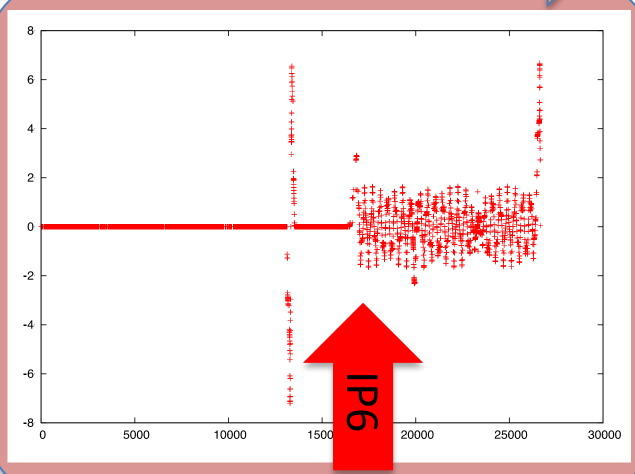


MKD pulse form - Courtesy B. Goddard

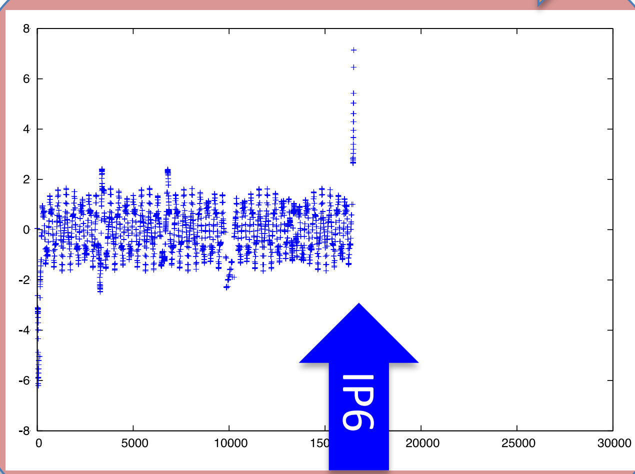
1st turn

The collimator are put in place with respect to the optics scenario under study

IP1 2nd turn IP8



IP1 3rd turn IP8



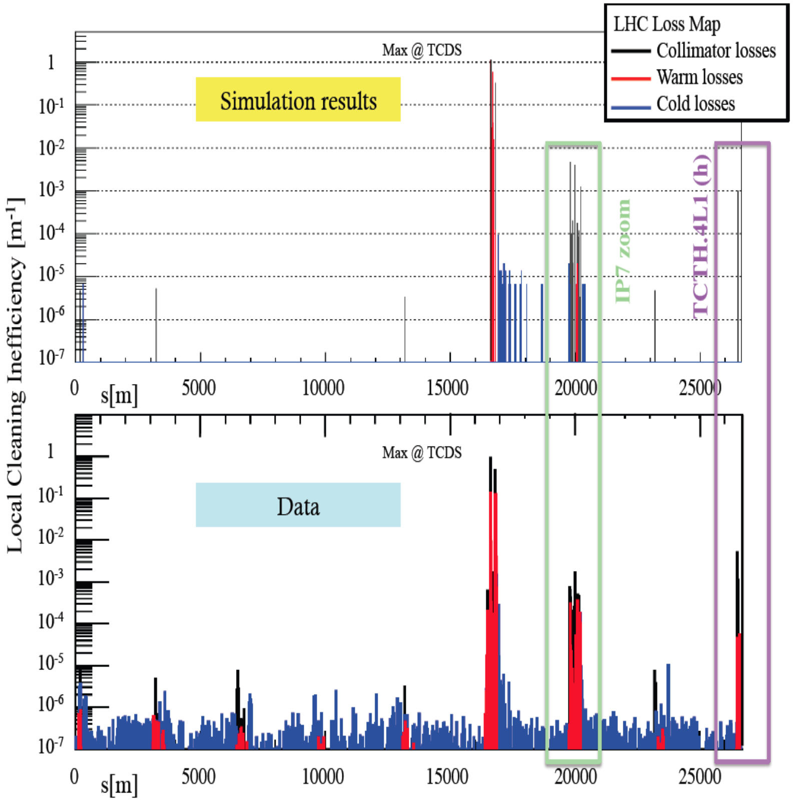
Validation of the simulation set-up

June 2012

4TeV nom. Optics + out 1.5 mm @IP6

+ 1 mm out 3 TCSG +1 TCLA @IP7

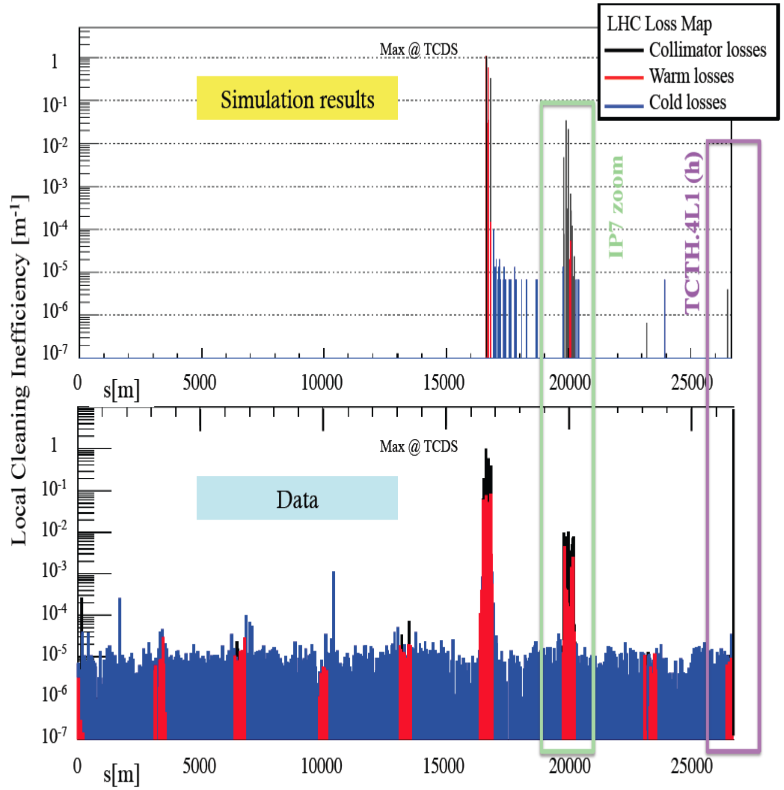
+1σ in the most exposed TCT @IP1



November 2012

4TeV nom. Optics + out 1.5 mm @IP6

+1σ in the most exposed TCT @IP1



[REF: L.Lari et al. *Simulations and Measurements of Beam Losses on LHC Collimators during Beam Abort Failures*, IPAC13, Shanghai, China]

Thin lens → optics 'as-built' V6.503 : /afs/cern.ch/eng/lhc/optics/V6.503/V6.5.thin.seq
/afs/cern.ch/eng/lhc/optics/V6.503/V6.5.thin.coll_special.4.0TeV_0.6m3m0.6m3m.str

Configuration 1 : /afs/cern.ch/eng/lhc/optics/V6.503/job.sample.4.0TeV.madx

Past & **new** studies: an overview

[REF: L.Lari et al. *Studies of Thermal Loads on Collimators for HL-LHC Optics in case of Fast losses*, IPAC13, Shanghai, China]

Beam1

1. 7 TeV nom optics → Physics run with 0.55 m β* in IP1/IP5

   Thin lens → optics 'as-built' V6.503 : /afs/cern.ch/eng/lhc/optics/V6.503/V6.5.thin.seq; /afs/cern.ch/eng/lhc/optics/V6.503/V6.5.thin.coll.str

2. Achromatic Telescopic Squeeze (ATS) 7 TeV → Physics run with **0.15 m** β* in IP1/IP5

   Thin lens → optics SLHCV3.1b :/afs/cern.ch/eng/lhc/optics/SLHCV3.1b/slhc_sequence.madx; /afs/cern.ch/eng/lhc/optics/SLHCV3.1b/slhc_sequence.madx/opt_0150_0150thin.madx

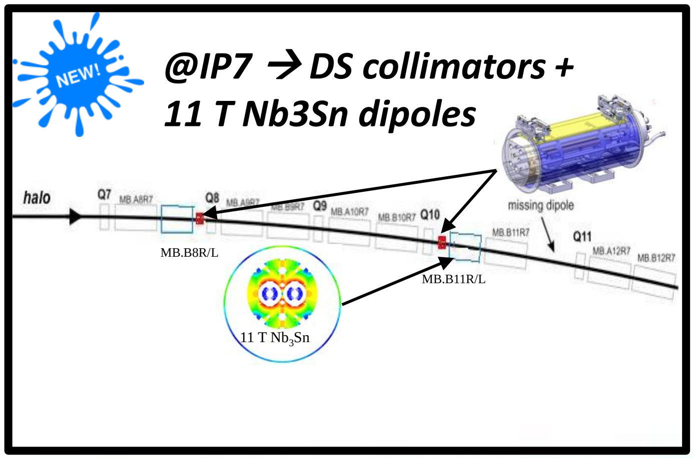
NEW!

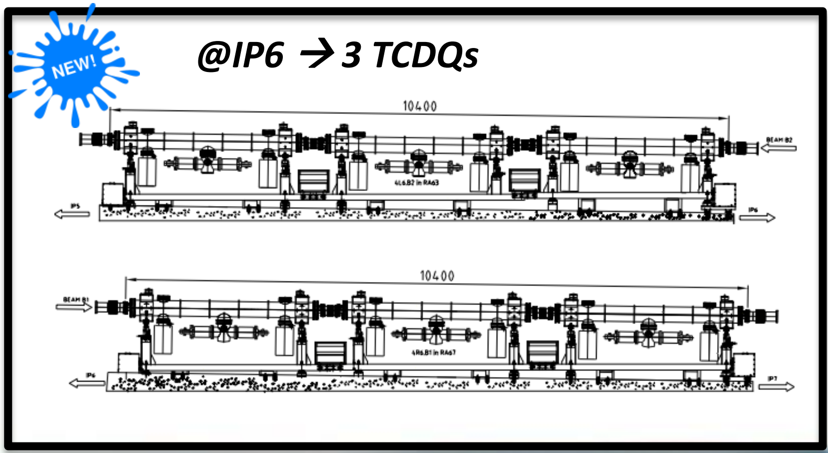
3. ATS 7TeV improved version → Physics run with **0.15 m** β* in IP1/IP5

   Thin lens → optics HLLHCV1.0 :system,"ln -fns /afs/cern.ch/eng/lhc/optics/HLLHCV1.0/hllhc_sequence.madx;

Beam2

1. + 2. + 3. optics → using "Beam4" sequence.





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Phase advance

Calculated from the MKD.4O6
(the furthest away form TCDQs)

	7TeV nominal → 55 cm	SLHC_3.1b → 15 cm	HL-LHC v1.0 → 15 cm
Beam1			
TCTH.4L1.B1	55.8	97.2 ☹	208.8
TCTH.4L2.B1	257.3	182.8	265.7
TCTH.4L5.B1	47.3	145.6	244.6
TCTH.4L8.B1	335.7	166.5	213.1
Beam2			
TCTH.4R1.B2	198.1	303.2	139.6
TCTH.4R2.B2	170.4	184.7	230.9
TCTH.4R5.B2	175.8	220.4	103.5
TCTH.4R8.B2	18.7	225.2	215.2

[See also R.Bruce et al. *Collimation requirements for the IR1/5 layout and on-going WP5 studies*, 8th HL-LHC Extended Steering Committee meeting, 13/08/2013, CERN]

Collimation setting considered

For **Beam1** and **Beam2**

Updated ATS optics for Hi-Lumi
(i.e. HL-LHC v1.0 optics)

NEW!

= Tungsten

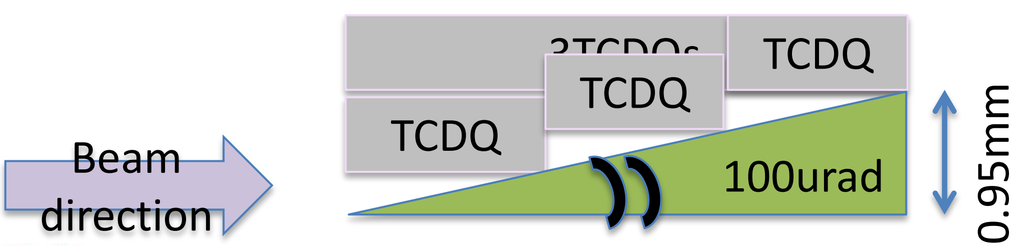
	Nom. setting	**2σ retraction**
TCP.IP7	**6**	**5.7**
TCSG.IP7	**7**	**7.7**
TCLA.IP7	**10**	**10.7**
2*80cm W DS @IP7	**10**	**10.7**
TCP.IP3	15	15
TCSG.IP3	18	18
TCLA.IP3	20	20
TCT.IP1/IP5	**8.3**	**10.5**
TCT.IP2/IP8	30	30
TCL.IP1/IP5 (2 Cu +1 W)	15	15
TCLI/TDI.IP2	Tot opened	Tot opened
TCDQ.IP6	**8**	**9**
TCSG.IP6	**7.5**	**8.5**

Different scenarios studied

For **Beam1** and **Beam2** → ***Setting*** and ***Orbit*** and ***Optics*** errors considered

1. Perfect machine;
2. + Retraction of 1.2 mm @IP6 ;
3. + Retraction of 1mm of 3 or 4 of the most critical coll. @ IP7
   + TCTHs @IP1 and @IP5 in of 1 σ more;
4. Optics error (for the most critical Beam2) for the scenario number 3.;
5. TCDQs misalignment (precision in alignment = 100urad → max offset of ~0.95 mm (2 preliminary cases studied);

[See: W. Wetering, B.Goddard. ECR: *Upgrade of TCDQ Collimator*, LHC-TCDQ-EC-0003 ver 1.1, CERN]



Note that this errors correspond pessimistically to a scenario that could be achieved with the present configuration of interlocks

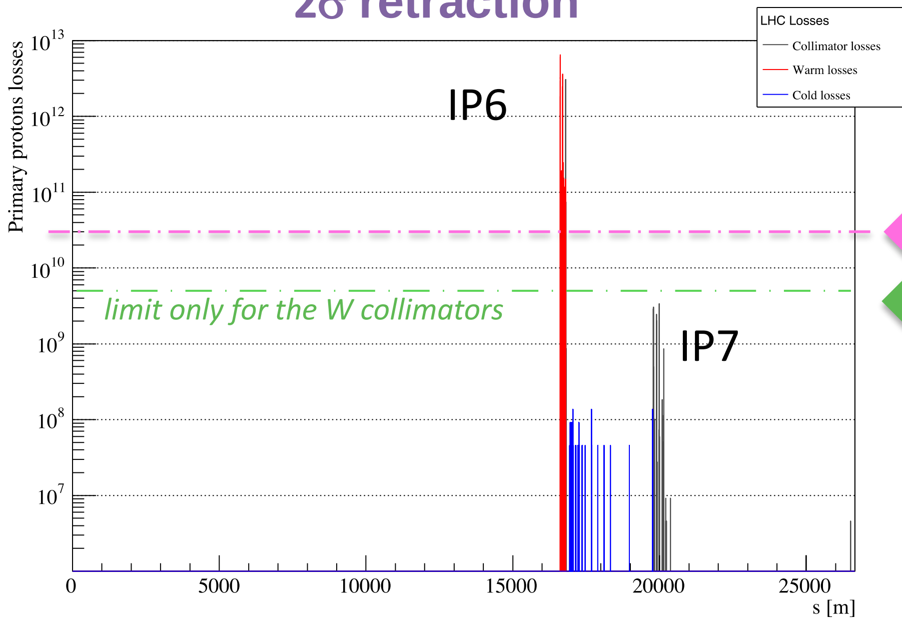
HL-LHC v1.0

1. Perfect machine

Results are normalized to 2.2×10^{11} p+ (25 ns)

Beam1

2σ retraction



[REF: A. Bertarelli et al. *Updated robustness limits for collimator material*, LHC Machine Protection Workshop, Annecy, France]

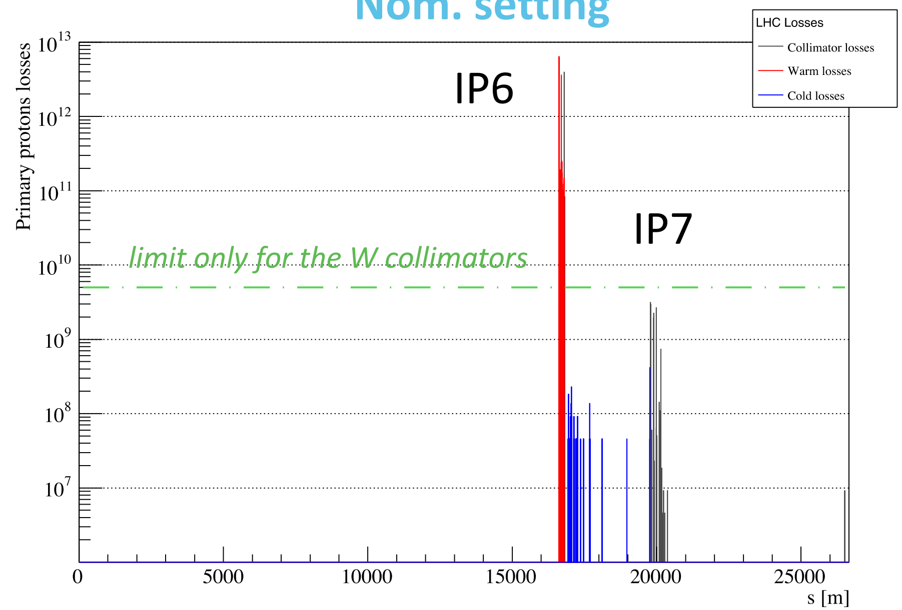
Limit for fragment ejection: 2×10^{10} p+

Onset of plastic damage on Tungsten collimators : 5×10^{9} p+

Beam 1

As for the 7 TeV nom optics → no problem in case of asynchronous dump in perfect machine conditions

Nom. setting



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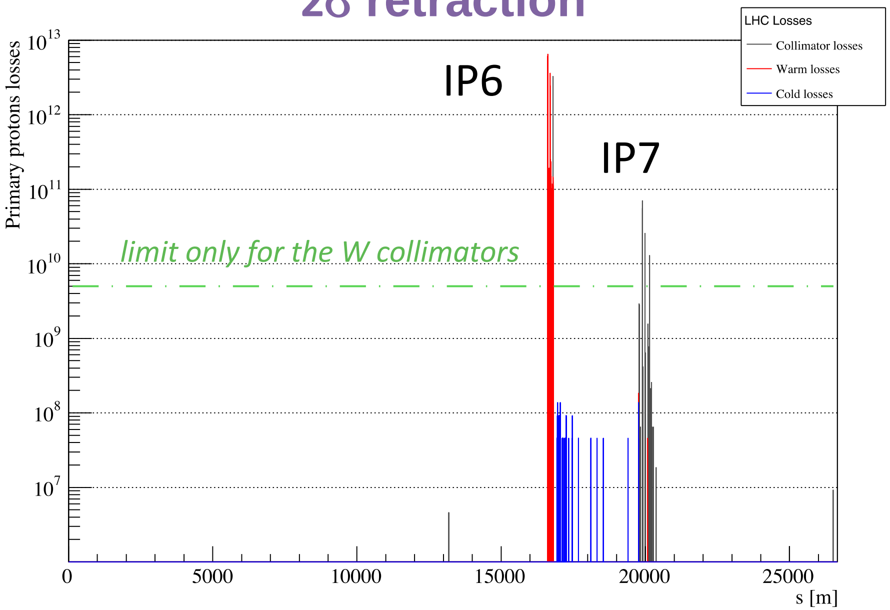
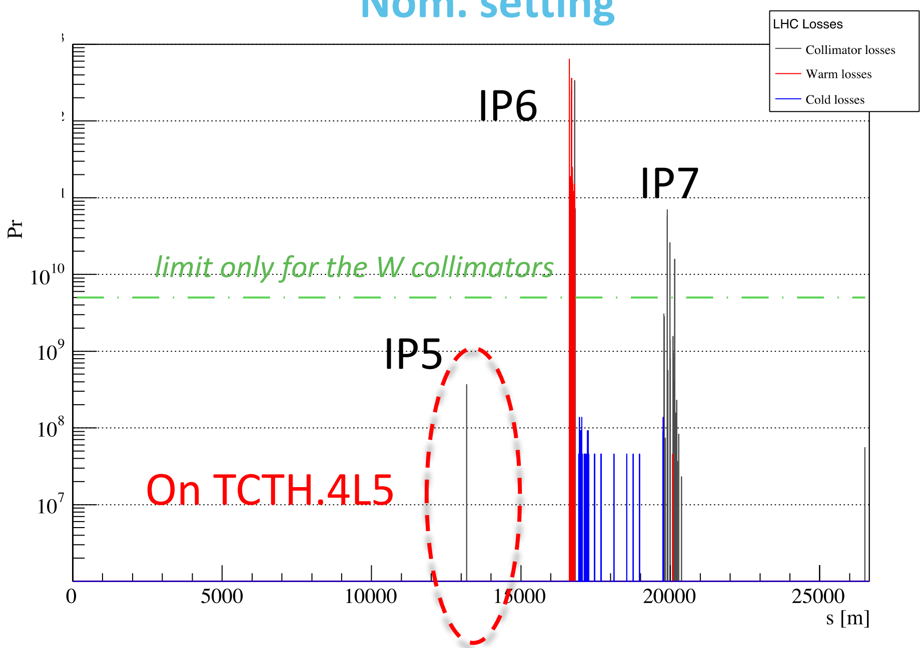
Beam1

2. + Retraction of 1.2 mm @IP6

2σ retraction



Nom. setting



NB: no problem for the CFC collimators in IP7 since the damage limit is *significantly* higher!

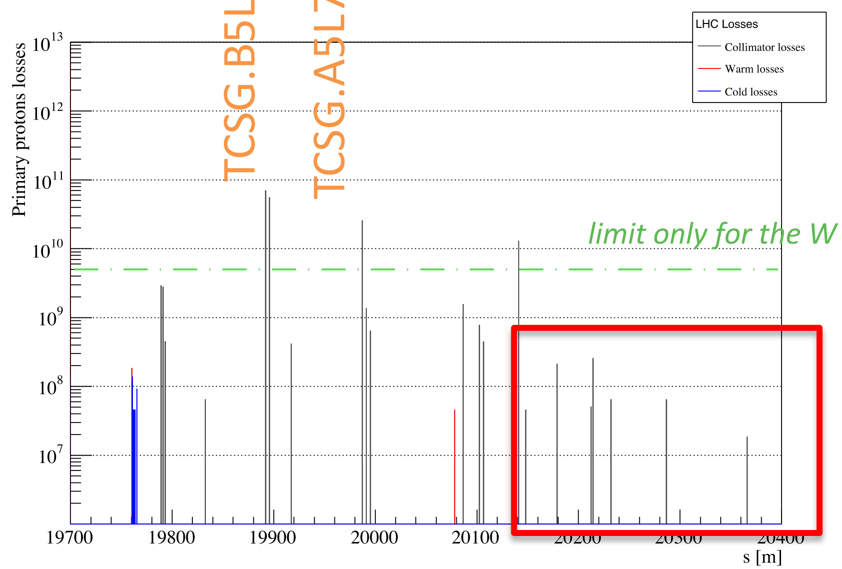
Beam1

2. + Retraction of 1.2 mm @IP6

2σ retraction (& Nom. Setting)

TCSG.B5L7.B1 (s)

TCSG.A5L7.B1 (s)

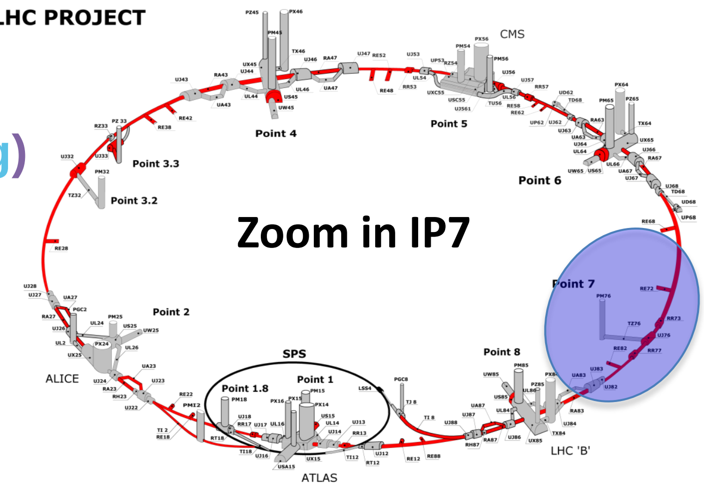


limit only for the W collimators

TCLAs and DS coll.

TCSG.B4L7.B1 (h)

TCSG.6R7.B1 (h)



No damage risks for Tungsten collimator @ IP7!

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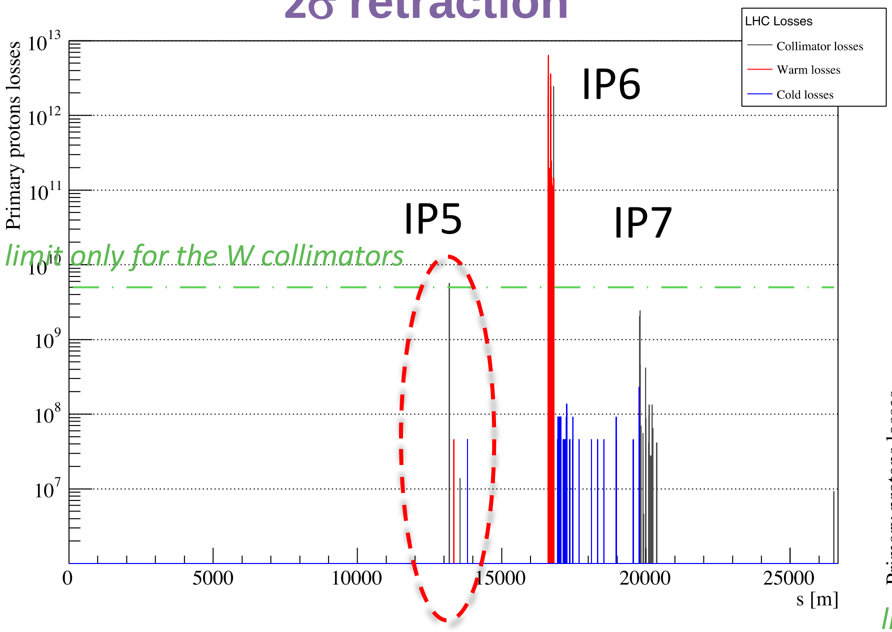
HL-LHC v1.0

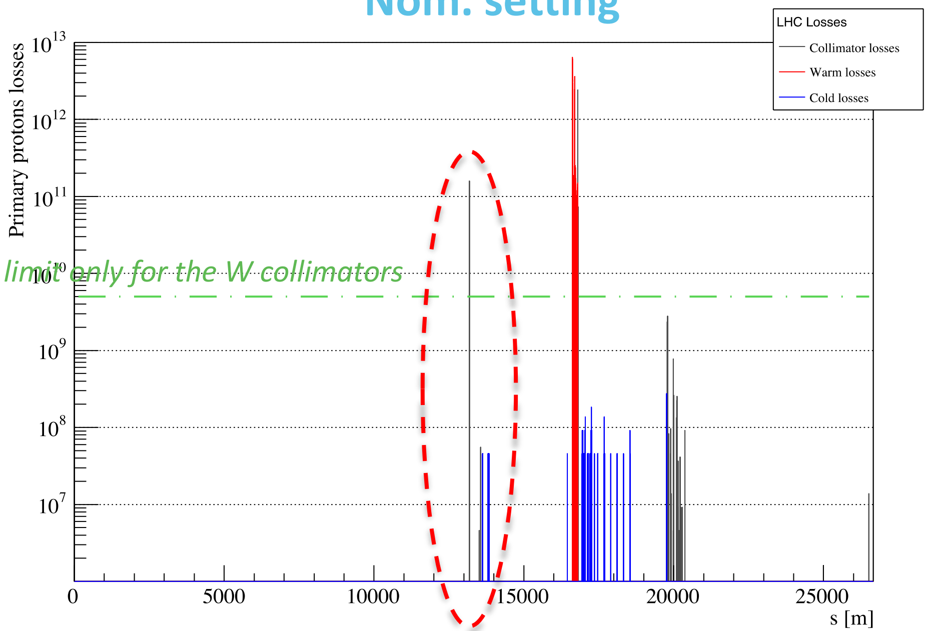
Beam1

3. + Retraction of 1mm @IP7
+ TCTHs @IP1 and @IP5 in of 1 σ.

2σ retraction



Nom. setting



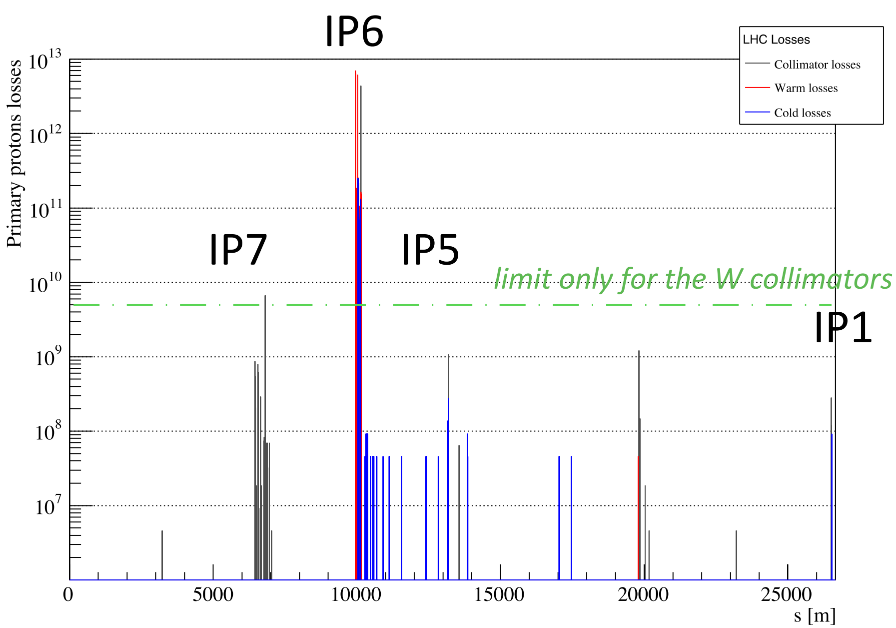
The limit of plastic deformation for W is reached in TCTH @IP5!

HL-LHC v1.0

Beam2

1. Perfect machine

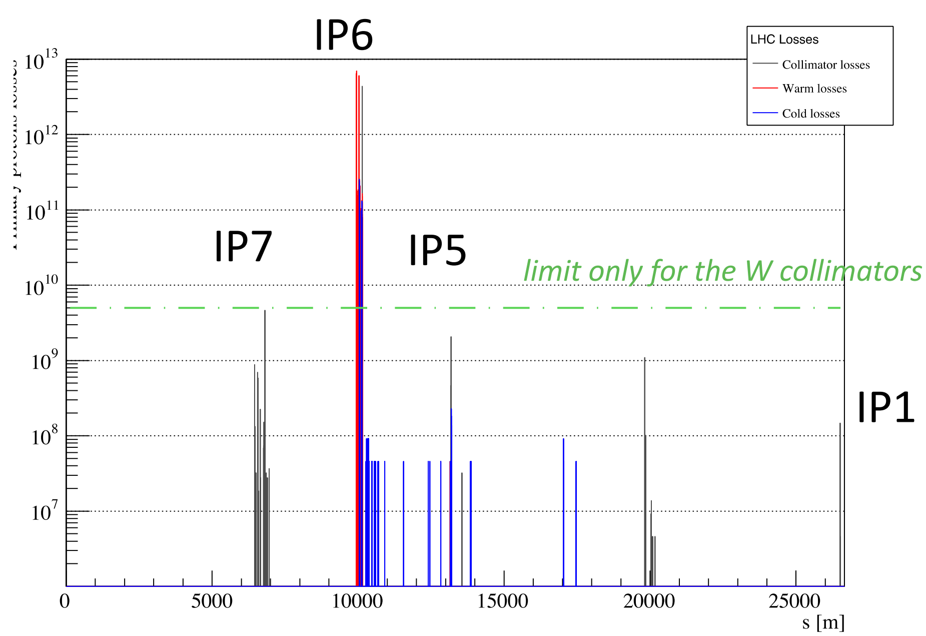
2σ retraction



Beam 2

As for the 7 TeV nom optics → no problem in case of asynchronous dump in perfect machine conditions

Nom. setting



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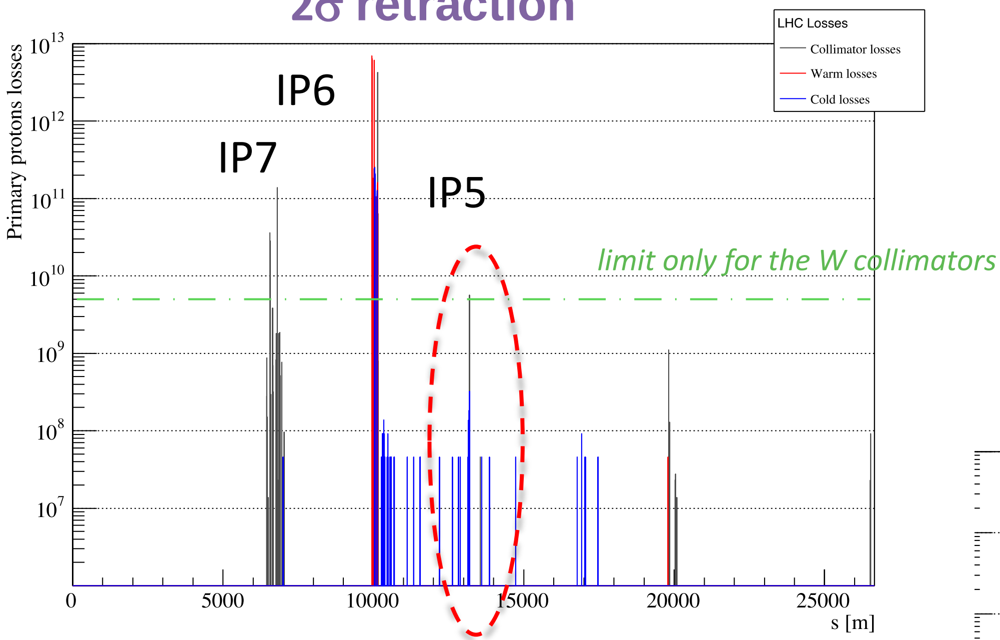
Beam2

2. + Retraction of 1.2 mm @IP6

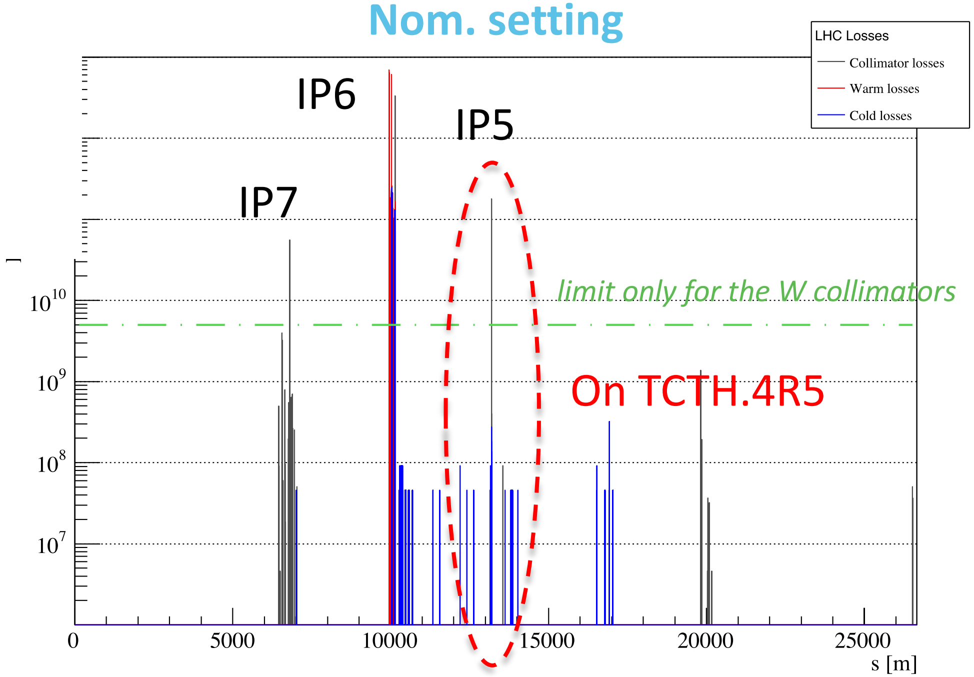
2σ retraction



On TCTH.4R5

The limit of plastic deformation for W is reached in TCTH @IP5!

Nom. setting



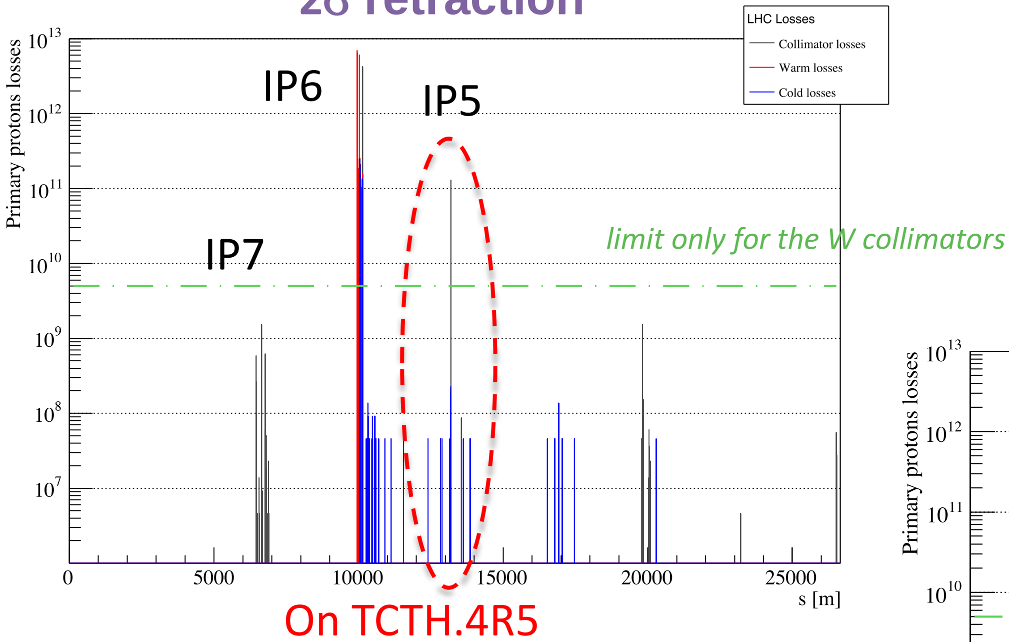
HL-LHC v1.0

Beam2

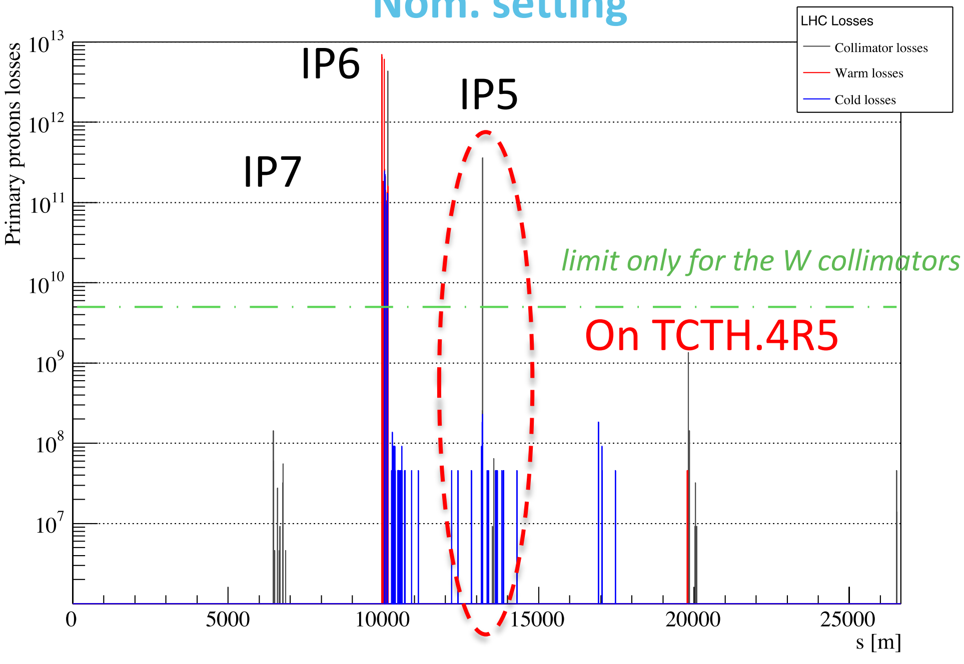
3. + Retraction of 1mm @IP7 + TCTHs @IP1 and @IP5 in of 1 σ.

The limit of plastic deformation for W is reached in TCTH @IP5!

2σ retraction



Nom. setting



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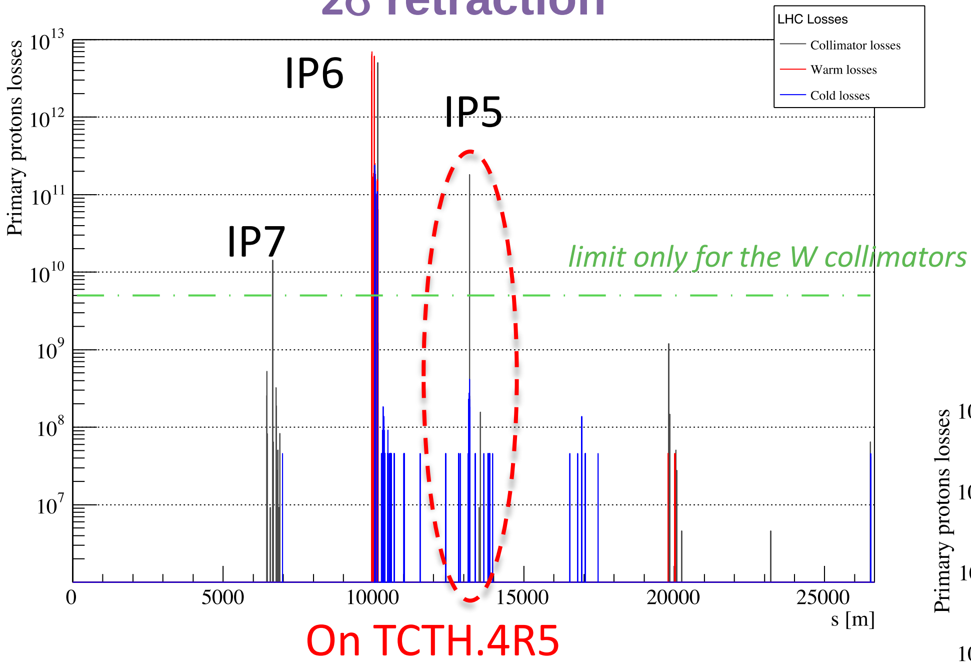
Beam2

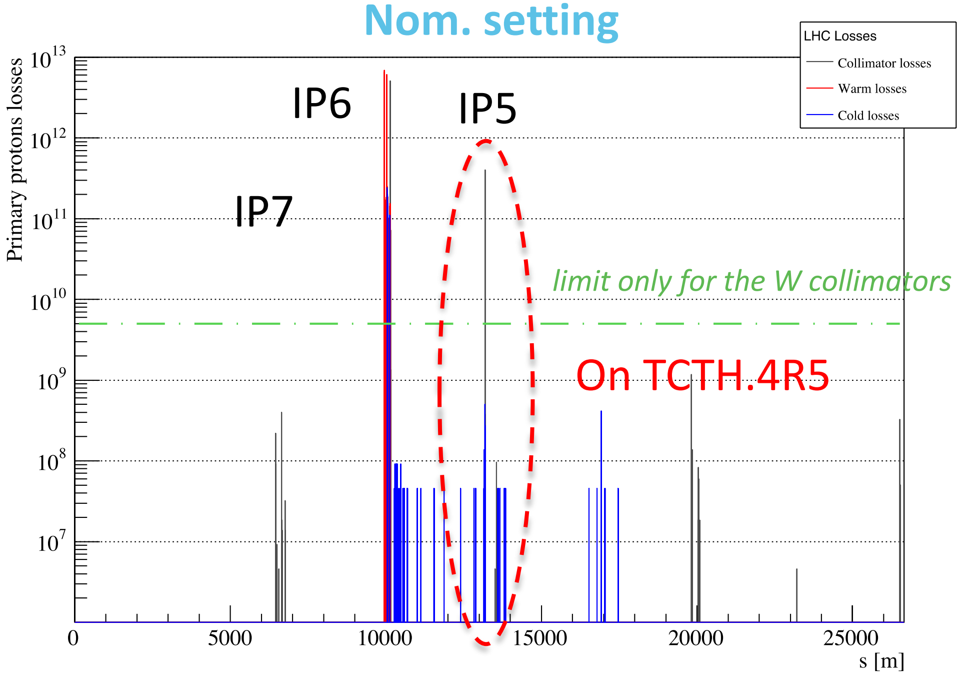
4. Optics errors

2σ retraction



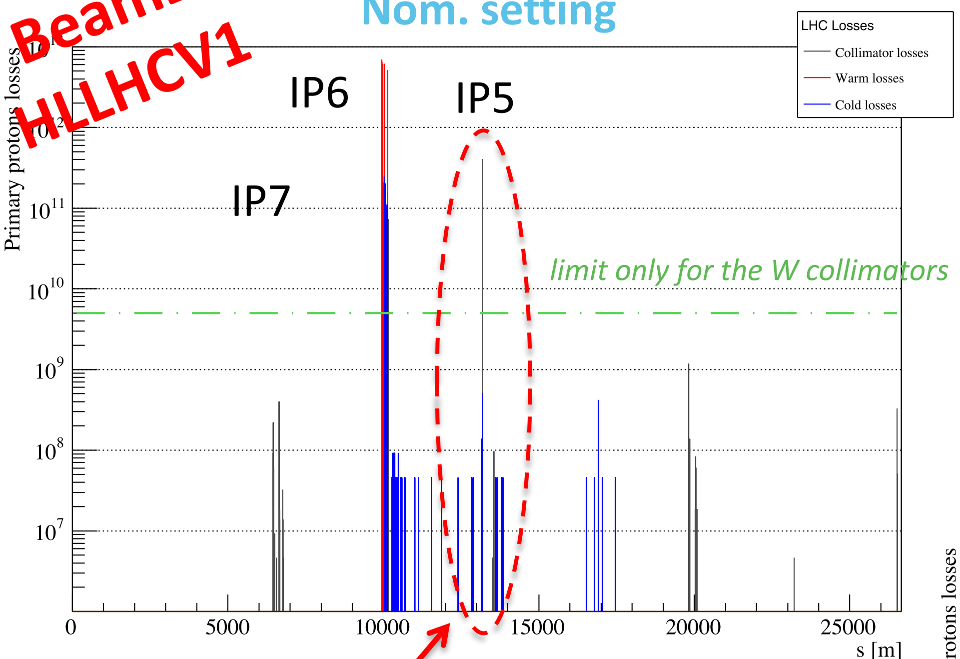
The limit of plastic deformation for W is reached in TCTH @IP5!

Nom. setting



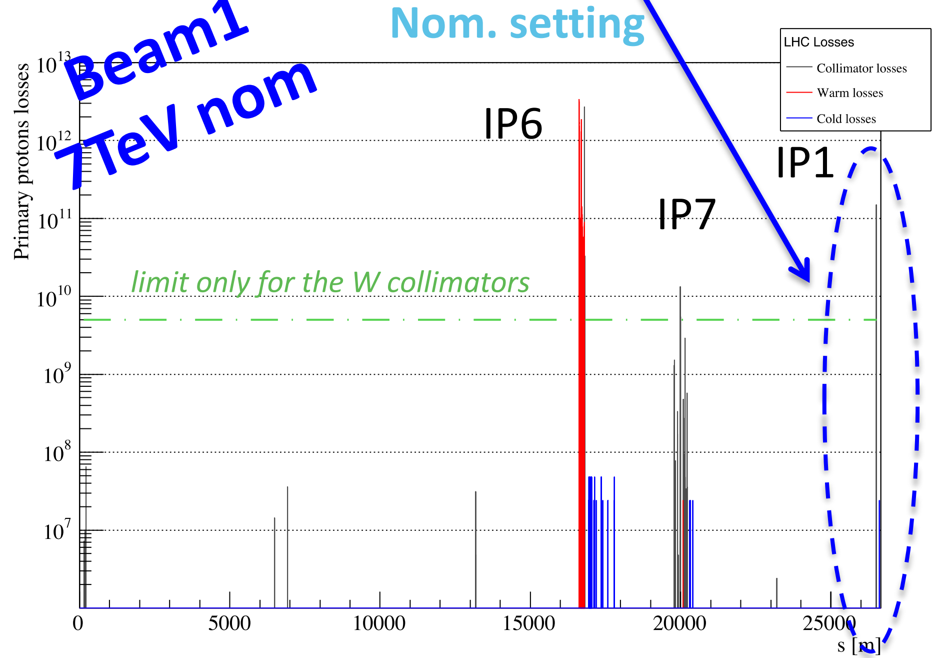
NB: Results refer to the worst case out of 1000 optics configuration with random errors [R. Bruce]

4. Optics errors HL-LHCv1.0 vs 7TeV nom



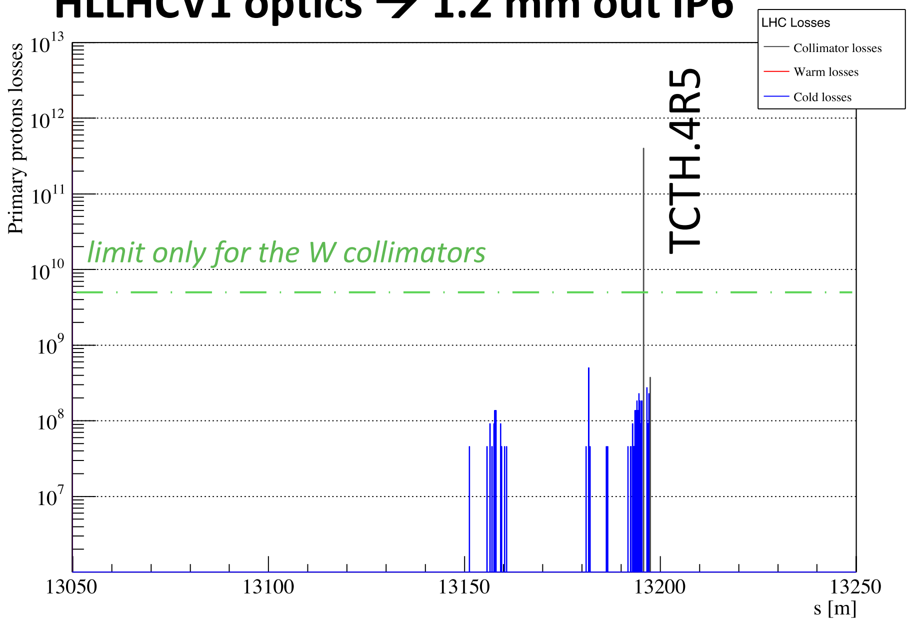
On TCTH.4R5
Max @ **4e+11** p+
(results normalized @ 2.2e+11)

On TCTH.4L1
Max @ **1.5e+11** p+
(results normalized @ 1.15e+11)



4. Optics errors HL-LHCv1.0 vs 7TeV nom

HLLHCV1 optics → 1.2 mm out IP6

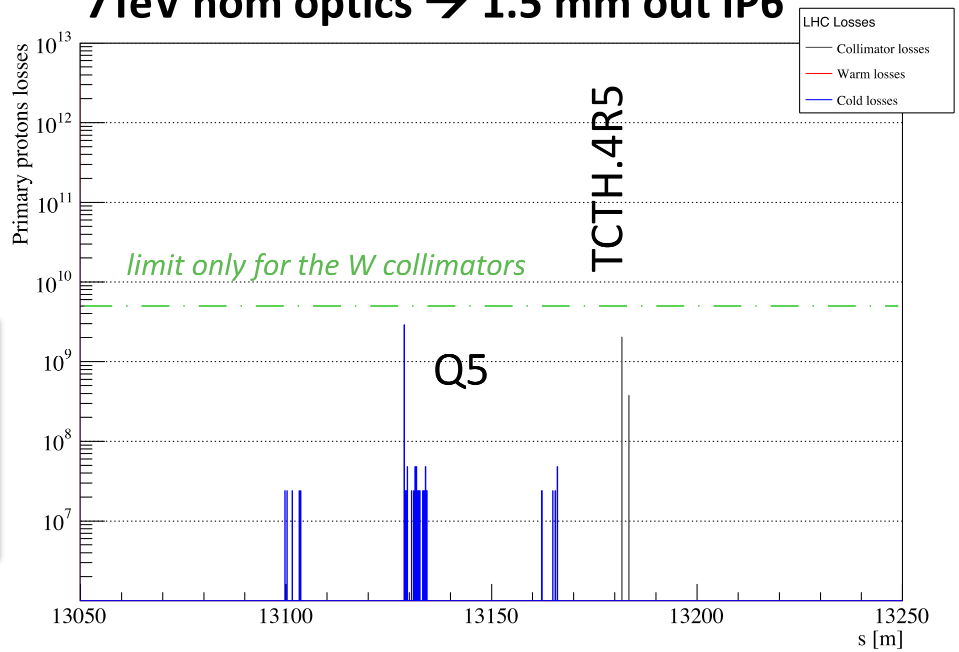


Beam2

Nom. setting

A look to IP5

7TeV nom optics → 1.5 mm out IP6

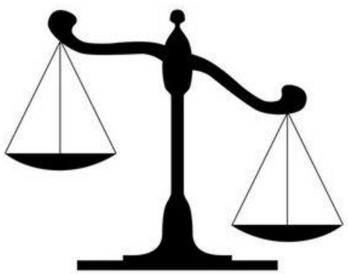


NB: Aperture at Q4 and Q5 locations is bigger for the HLLHCV1 optics !!!!

(hor. plane ~ 10mm difference)

4. Optics errors HL-LHCv1.0 vs 7TeV nom

Some conclusions



- For the HL-LHC v1.0 optics the plastic deformation limit is reached by retracting 1.2 mm the protections @IP6, while for the 7 TeV nom optics more optics and imperfections errors are needed to reach the limit.

- Note that the combination of all errors @IP6, @IP7, @TCTs and worst case optics is extremely unlikely.

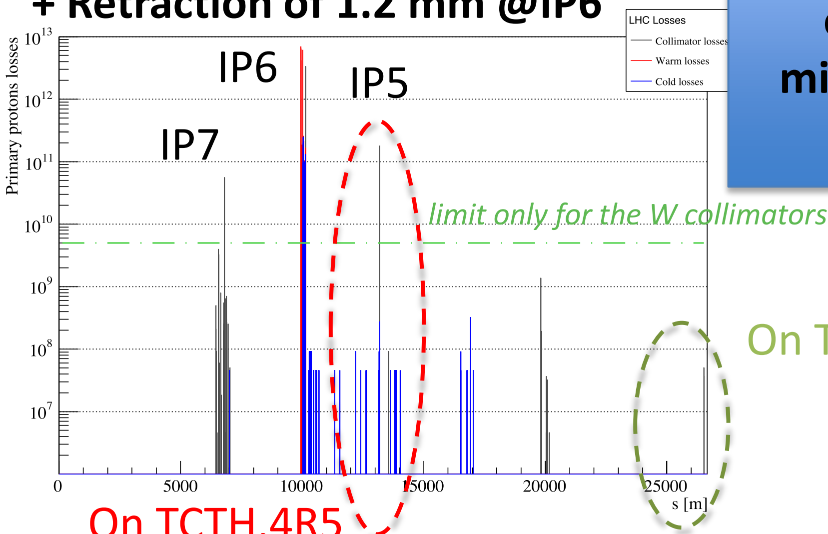
HL-LHC v1.0

5. TCDQs misalignment

Nom. setting

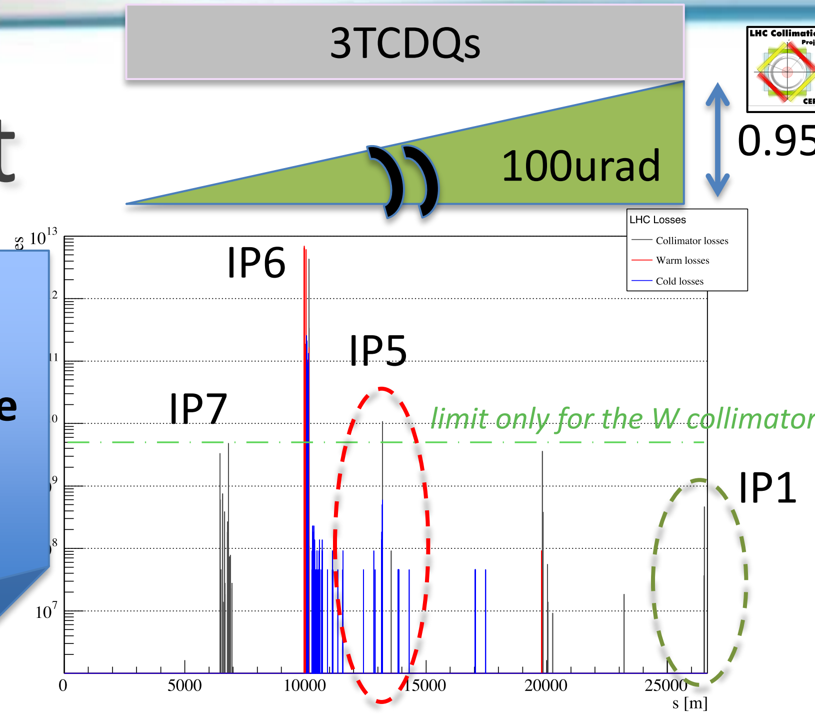
Beam2

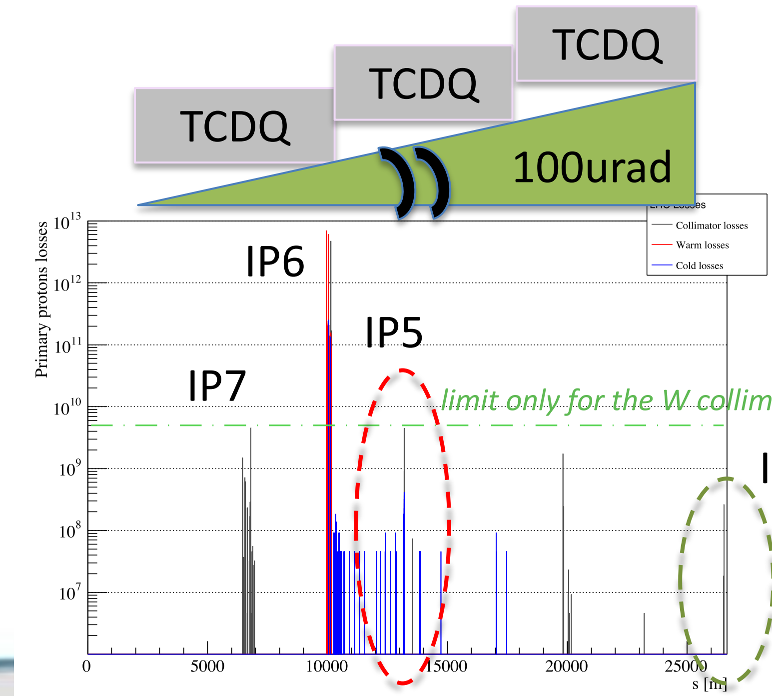
+ Retraction of 1.2 mm @IP6



Beam 2

NB: the TCSG @IP6 is NOT retracted in case of TCDQs misalignment studies





Secondary losses from TCSG @IP6 play an important role on load the TCTH @ IP5 and IP1

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Conclusions

- For the HL-LHCv1.0 optics, different realistic failure scenarios were presented.
- As shown, the TCTH@IP5 is the most exposed location for both beams → in particular the plastic deformation limit exceed for **Beam2** already in case of partially retraction of the TCDQs in IP6. The importance of secondary vs. primary halo was also shown.
- For the optics errors case, the SixTrack outputs are available for future FLUKA and structural analysis study on actual W TCTs.
- In terms of protection from an asynchronous dump accident, the 2 σ retraction collimation settings is found better than the nominal one, including setting, orbit and optics error scenarios.
- A comparison with the 7TeV nom optics worst case shows a factor 3 of difference on the TCTH peak.
- Possible mitigation actions such as new collimation materials for TCT jaws with higher limit damage could be the subject of future work.

Thank You!

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