Updates on energy deposition studies

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WP10

Energy deposition & R2E

13th HL-LHC Collaboration Meeting   Vancouver   September 27th 2023

OUTLINE

1. **Dose evaluation in the TAXS region: shielding studies at the VAX**

   https://edms.cern.ch/document/2863478/2

2. ***Inner triplet lifetime: potential quadrupoles polarity inversion***

3. **TCLPX4 settings effect on the matching section of IR1/5**

   Special Joint HiLumi WP2/WP5 meeting: https://indico.cern.ch/event/1320306/

4. ***Peak dose estimation for MCBY up to LS4: LHC and HL-Run4 contributions***

   173th HL-LHC TCC meeting: https://indico.cern.ch/event/1265848/

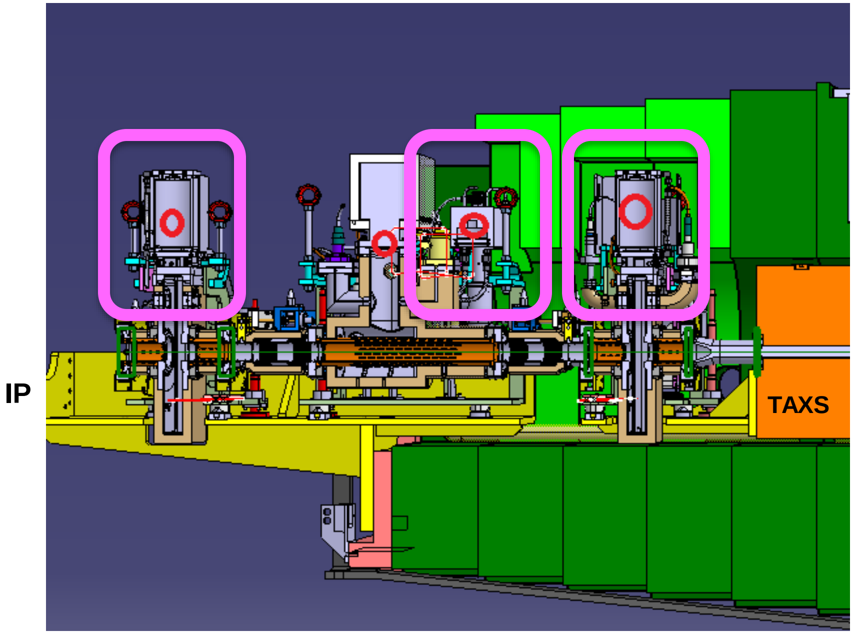
5. **Review of TCLMC5/6 masks effectiveness as a function of mechanical tolerances**

   WP5.2 Technical meeting: https://indico.cern.ch/event/1076813/

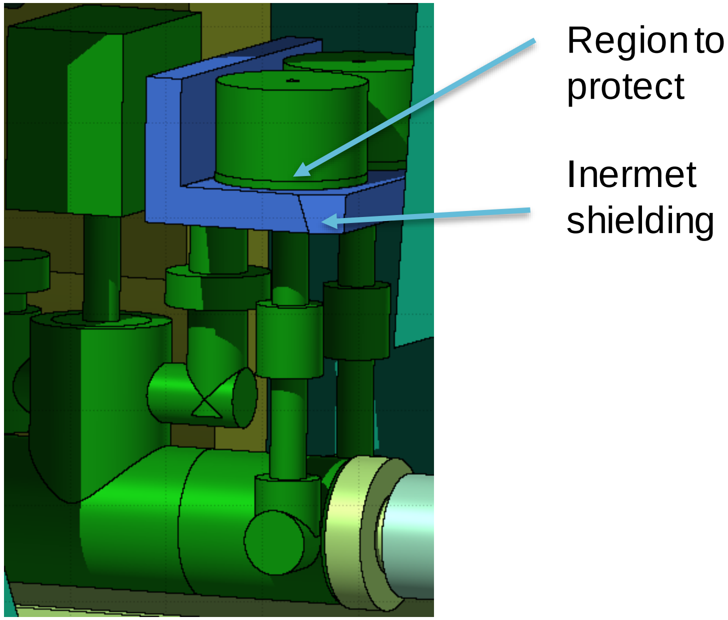
1. Dose evaluation in the TAXS region: shielding studies at the VAX

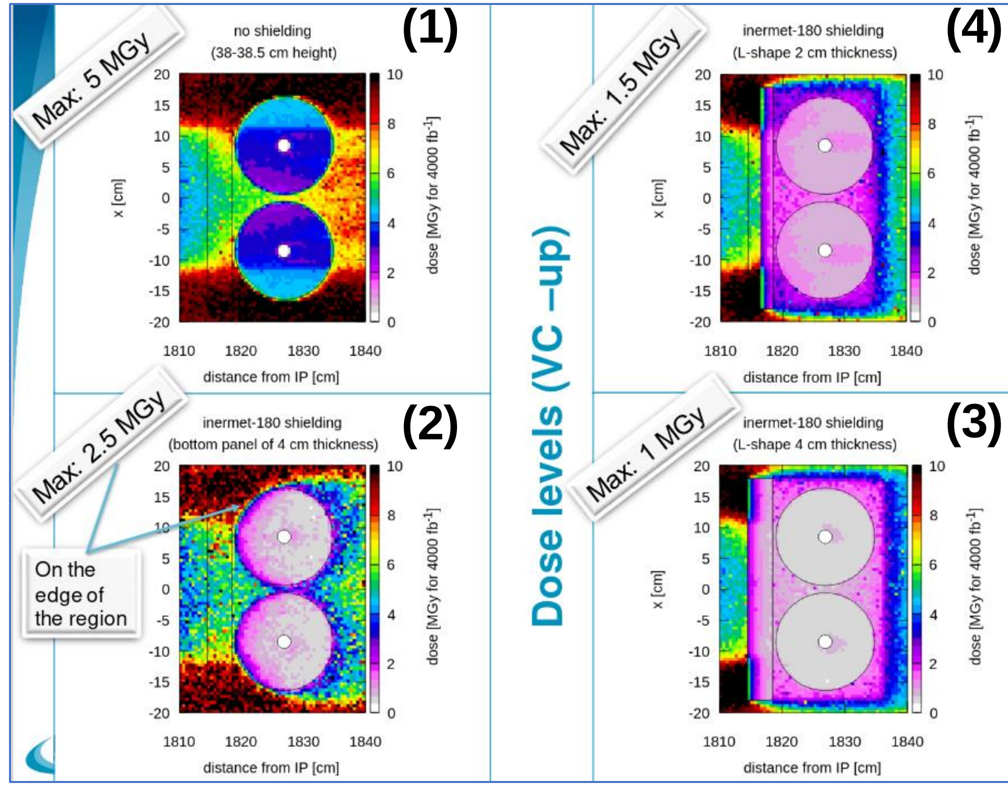
- Aim:
  - *Define the dose level at the actuators of the sector valve and at right-angle valves.*
  - *Explore the effect of possible shielding.*

- FLUKA simulation considering:
  - HL-LHC optics version 1.5 (Nov.19).
  - p-p collisions (σ = 85 mb) at 7+7 TeV.
  - **IR5 – CMS**: vertical crossing with fixed half crossing angle **+250 μrad**. Only **VC-up i**s considered since the elements of interest are above the beam line.
  - Integrated luminosity: ultimate conditions **4000 fb^{-1}**. Dose values scale linearly with the integrated luminosity.



1. Actuators at right-angle valves



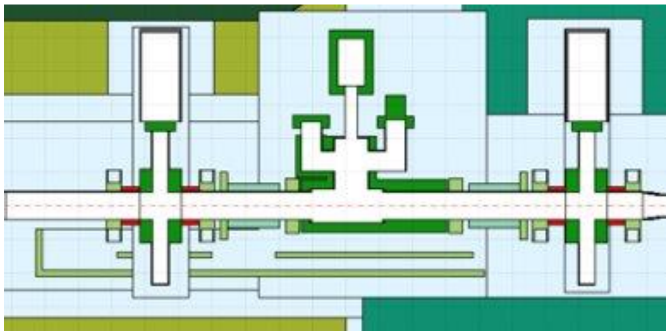


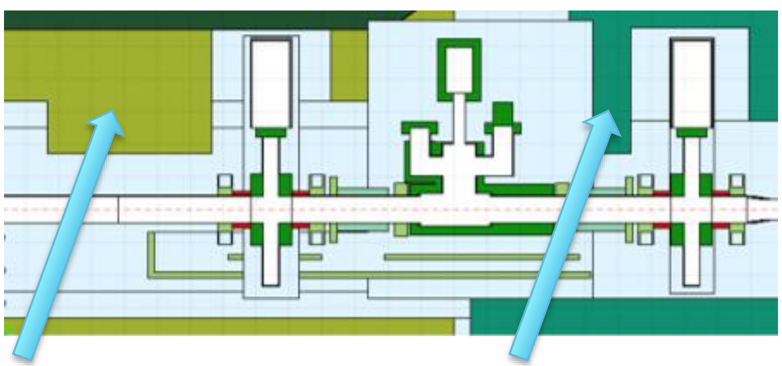
Shielding configuration:

1) No shielding: baseline
2) Bottom panel: 4 cm thickness
3) Bottom + IP-side panels: 4 cm thickness
4) Bottom + IP-side panels: 2 cm thickness

Important improvement in dose levels at the cost of implementing heavy shielding around the actuator.

1. Actuators of the sector valves

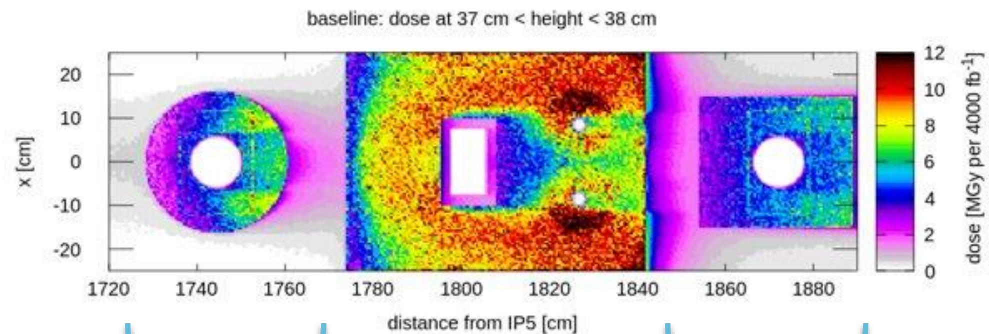




Extension: 16 cm down
Thickness: 50 cm

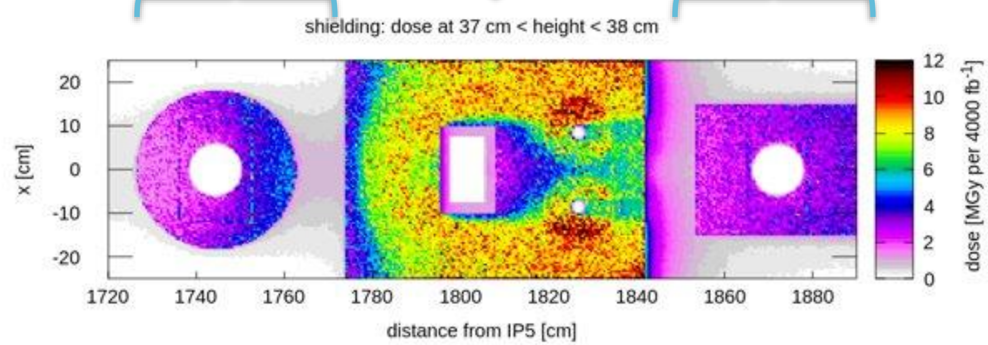
Extension: 10 cm down
Thickness: 11.6 cm

Example of dose levels at a given height from the machine axis



Region of interest

Region of interest



Improvement in dose levels adapting the existing shielding.

2. Inner triplet lifetime: potential quadrupoles polarity inversion

Baseline for HL-LHC

- IR1: HC
- IR5: VC up/down
- Reference case

Crossing plane inversion:

- IR1: VC up/down
- IR5: HC

Reverse quads polarity:

- IR1: HC
- IR5: VC up/down

- *The goal of this study is to explore different combinations of crossing plane and inner triplet quadrupole polarity in order to minimize the peak dose in the inner triplet quads thus increasing their live time.*

- FLUKA simulations:
  - HL-LHC optics version 1.5 (Nov.19).
  - p-p collisions (σ = 85 mb) at 7+7 TeV.
  - Half crossing angle: 250 μrad.
  - Integrated luminosity: ultimate conditions 4000 fb^{-1}.

2. Impact in the inner triplet of inverting the quadrupoles polarity

Baseline for HL-LHC

- IR1: HC
- IR5: VC up/down
- Reference case

Crossing plane inversion:

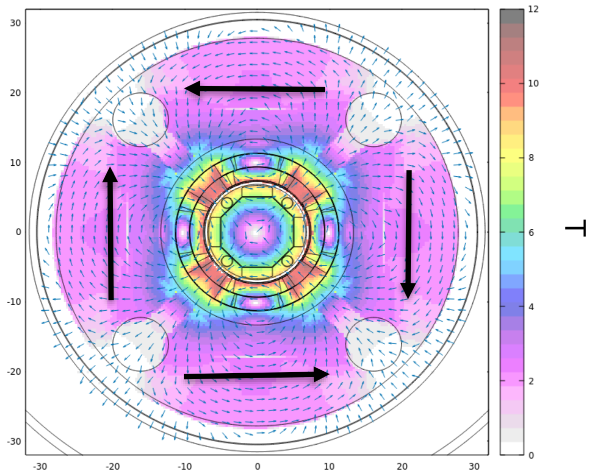
- IR1: VC up/down
- IR5: HC

Reverse quads polarity:

- IR1: HC
- IR5: VC up/down

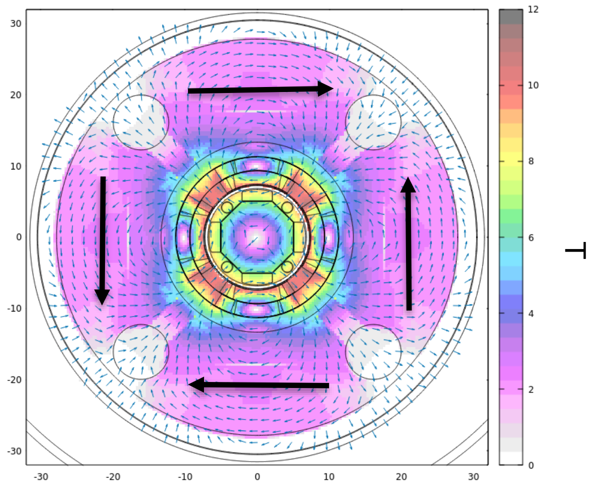
Q1A reference

F – D – F
Q1 Q2 Q3



Q1A reverse polarity

D – F – D
Q1 Q2 Q3

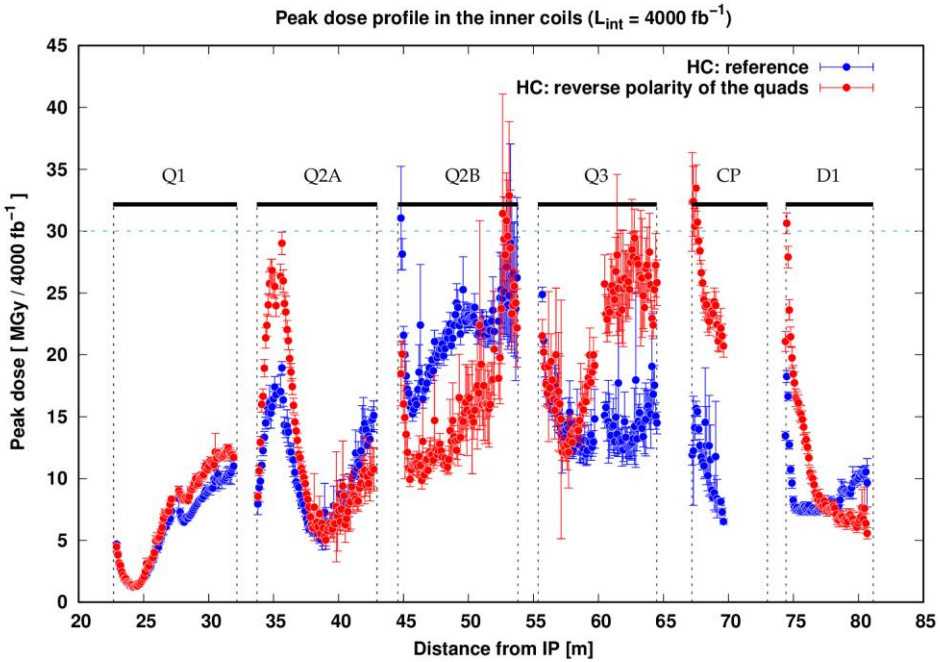


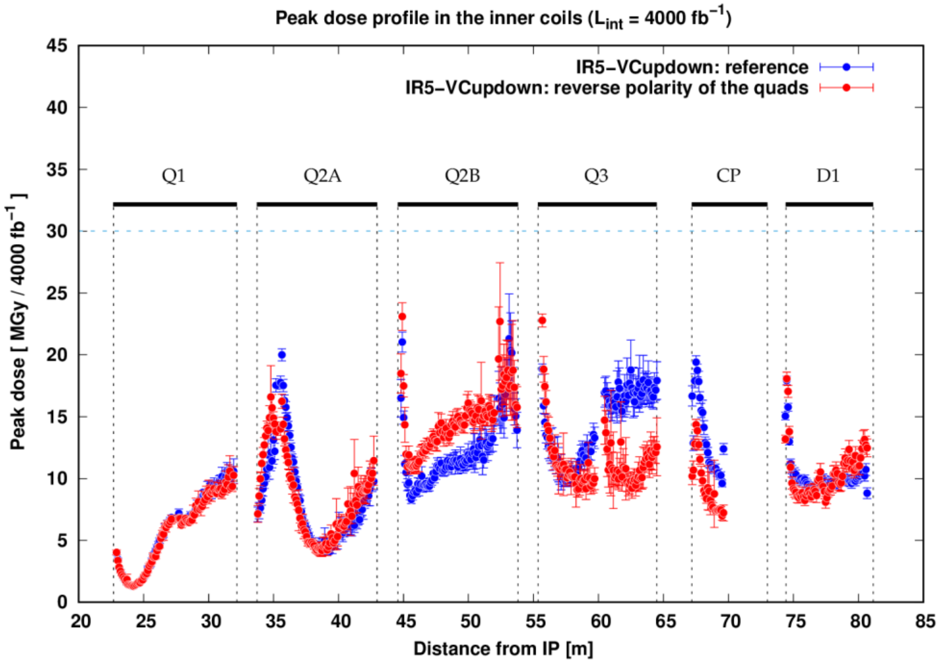
Note: The focusing (F)/defocusing(D) scheme refers to the horizontal plane and to the outgoing beam.

2. Peak dose distribution along the inner triplet + D1

HC

VC up/down

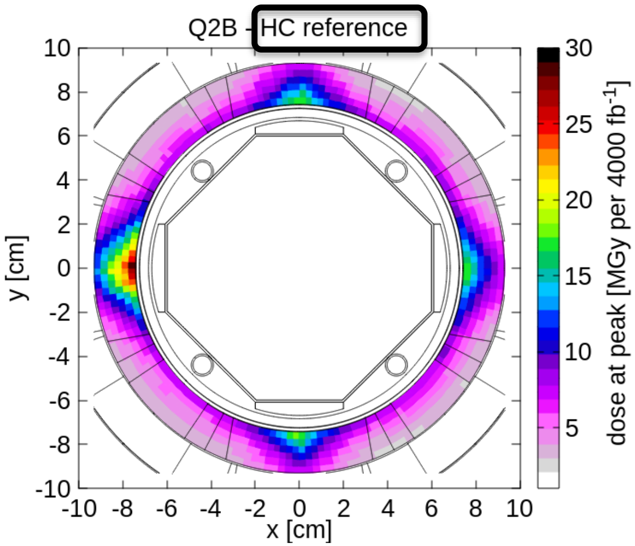




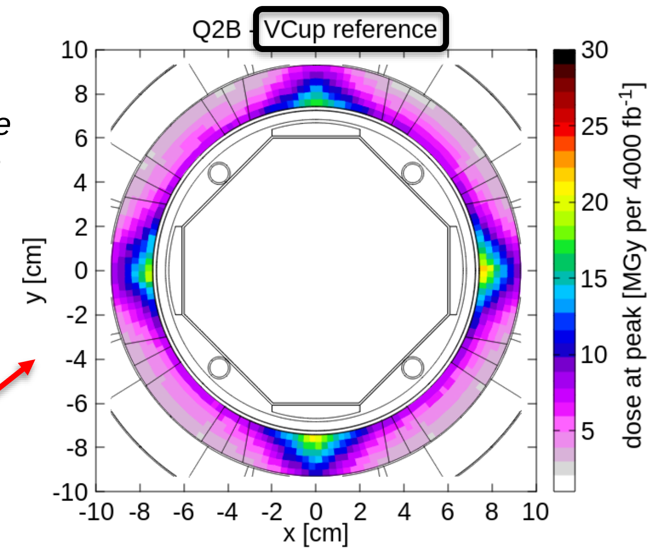
Reference

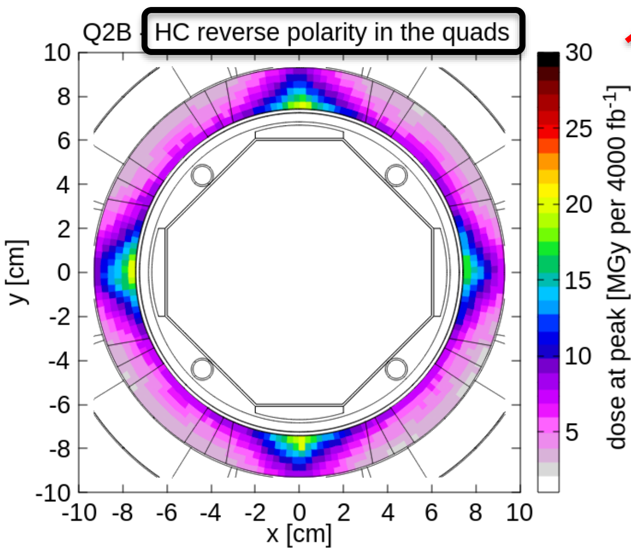
Reverse polarity

2. 2D dose distribution

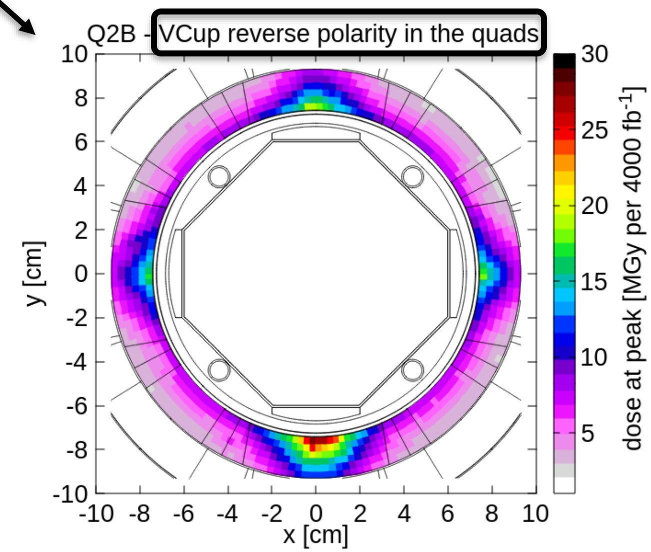


Defocusing in the horizontal plane

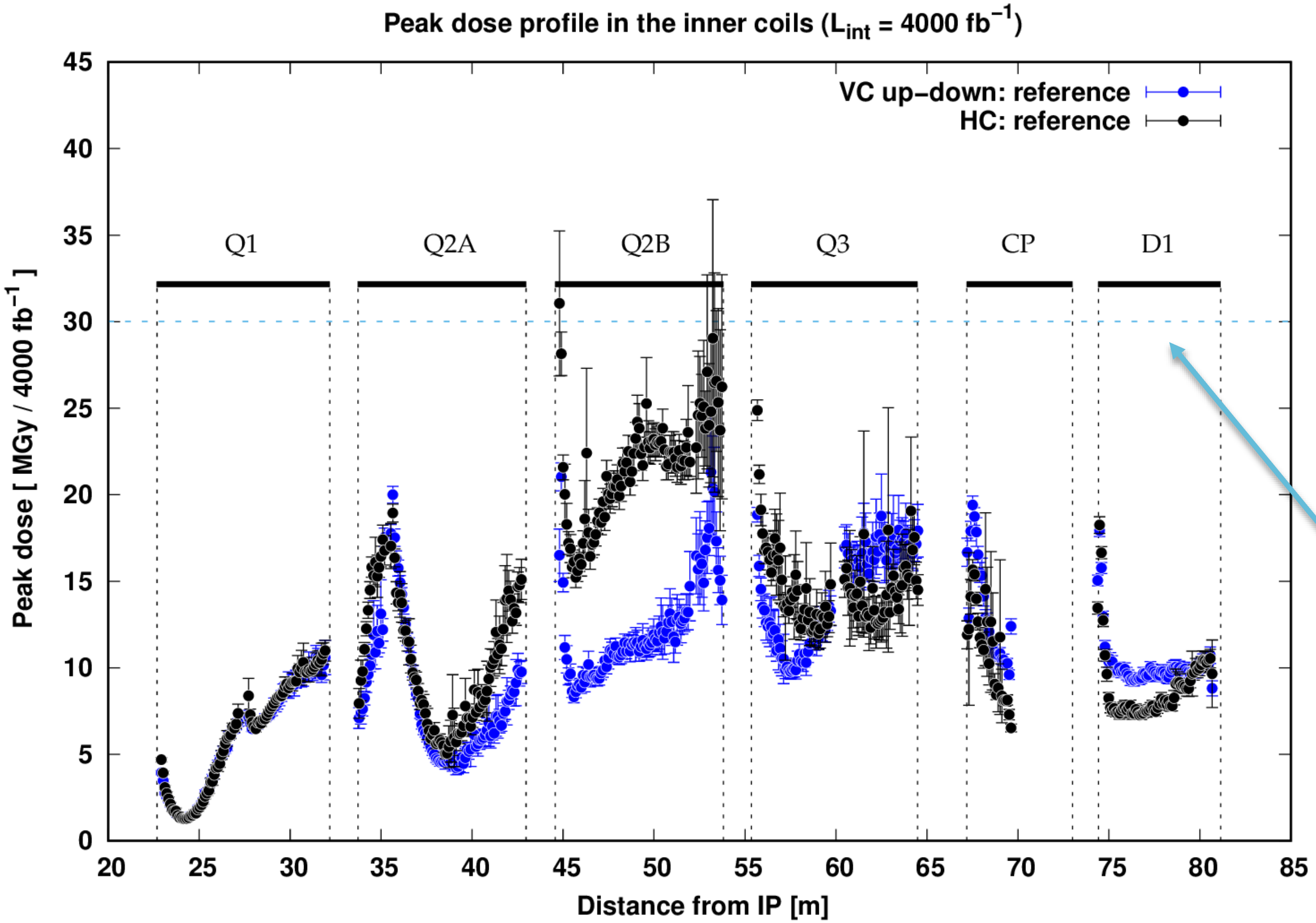




Equivalent dose distribution but rotated 90^0



Focusing in the horizontal plane



HC ref:

100% HC nominal

Max.
> 30 MGy

VC up/down ref:

50% VC-up nominal

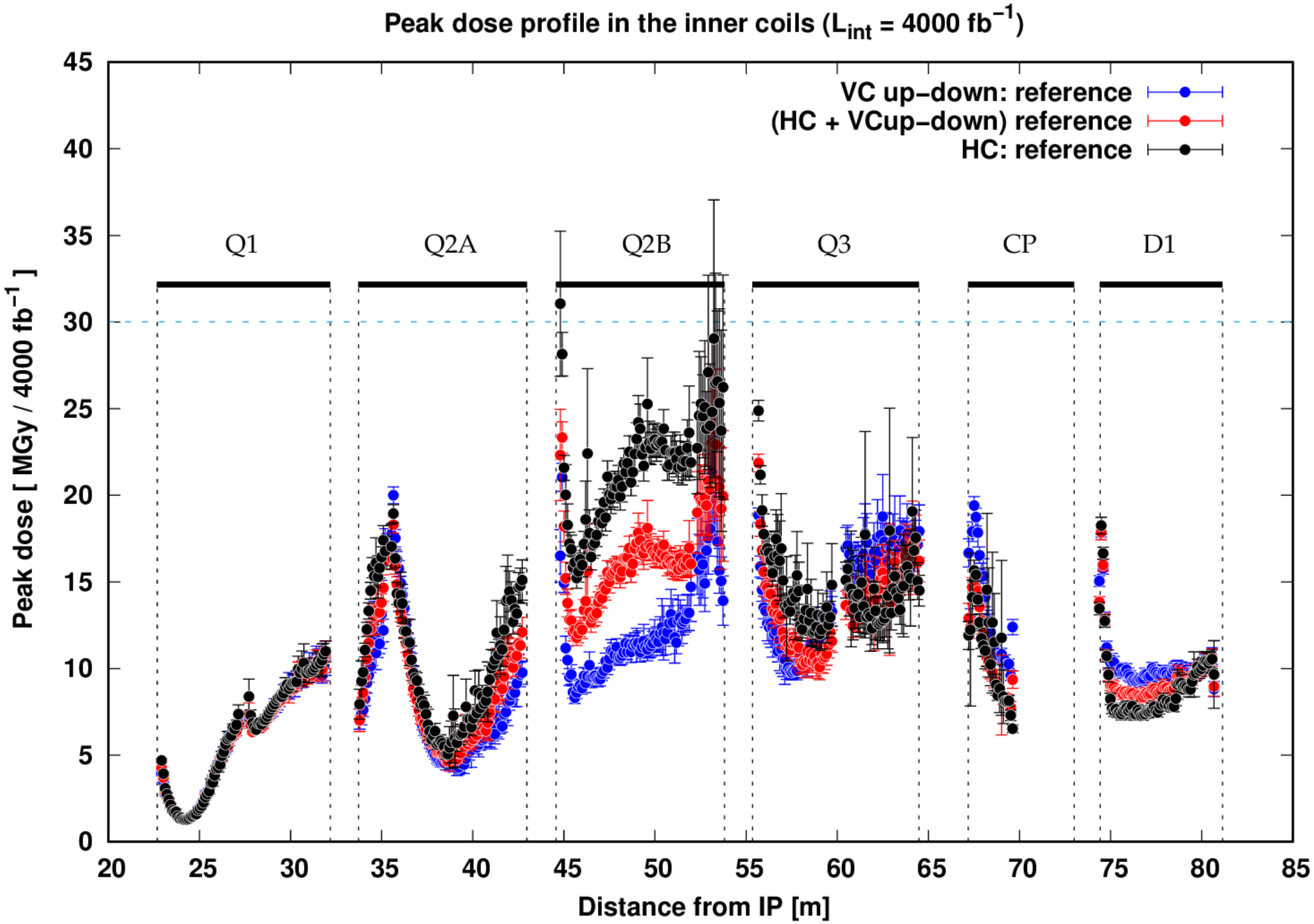
50% VC-down nominal

Max.
21 MGy

**30 MGy is the design limit for 3000 fb^{-1} integrated luminosity.*

Here we focus on the ultimate operation (4000 fb^{-1} integrated luminosity).

% is the HL-LHC operation time



HC ref:

100% HC nominal

Max.
> 30 MGy

VC up/down ref:

50% VC-up nominal

50% VC-down nominal

Max.
21 MGy

(HC + VC up/down) ref:

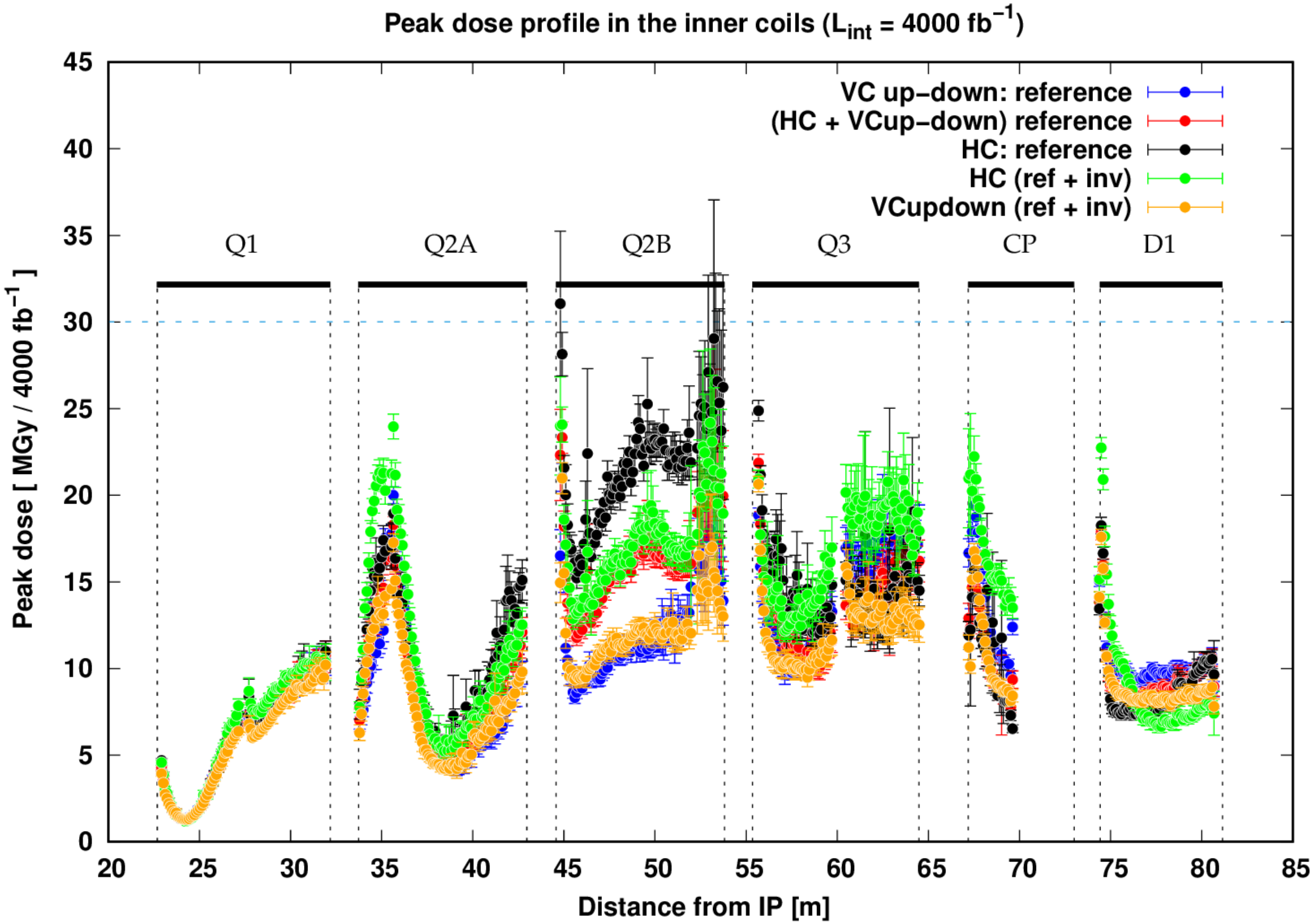
25% VC-up nominal

25% VC-down nominal

50% HC nominal

Max.
23 MGy

% is the HL-LHC operation time



HC ref:

100% HC nominal

Max.
> 30 MGy

VC up/down ref:

50% VC-up nominal

50% VC-down nominal

Max.
21 MGy

(HC + VC up/down) ref:

25% VC-up nominal

25% VC-down nominal

50% HC nominal

Max.
23 MGy

HC (ref+rev):

50% HC nominal

50% HC rev. pol.

Max.
24 MGy

VC up/down (ref+rev):

25% VC-up nominal

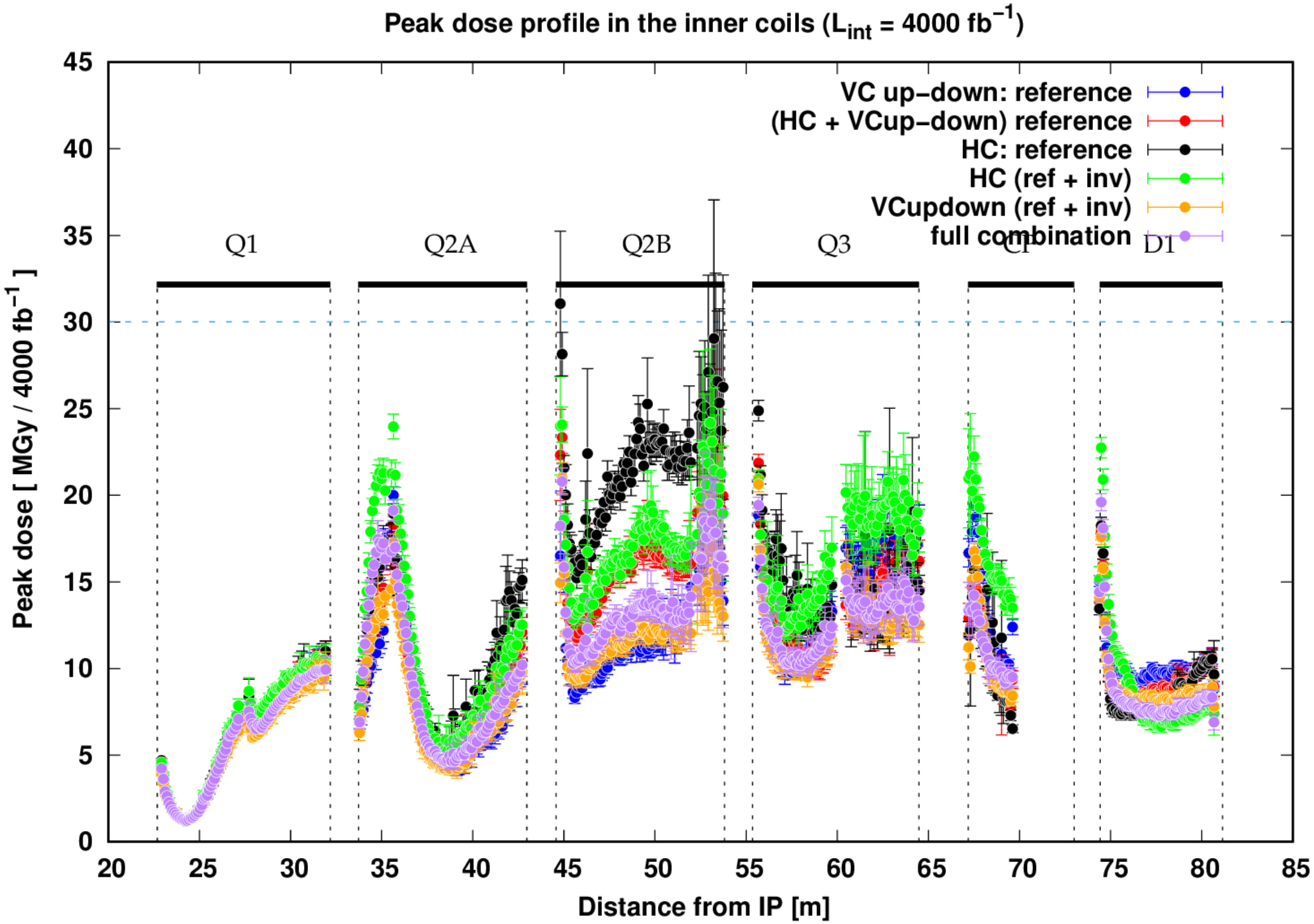
25% VC-up rev. pol.

25% VC-down nominal

25% VC-down rev. pol.

Max.
21 MGy

% is the HL-LHC operation time



HC ref:
100% HC nominal

Max.
> 30 MGy

VC up/down ref:
50% VC-up nominal
50% VC-down nominal

Max.
21 MGy

(HC + VC up/down) ref:
25% VC-up nominal
25% VC-down nominal
50% HC nominal

Max.
23 MGy

HC (ref+rev):
50% HC nominal
50% HC rev. pol.

Max.
24 MGy

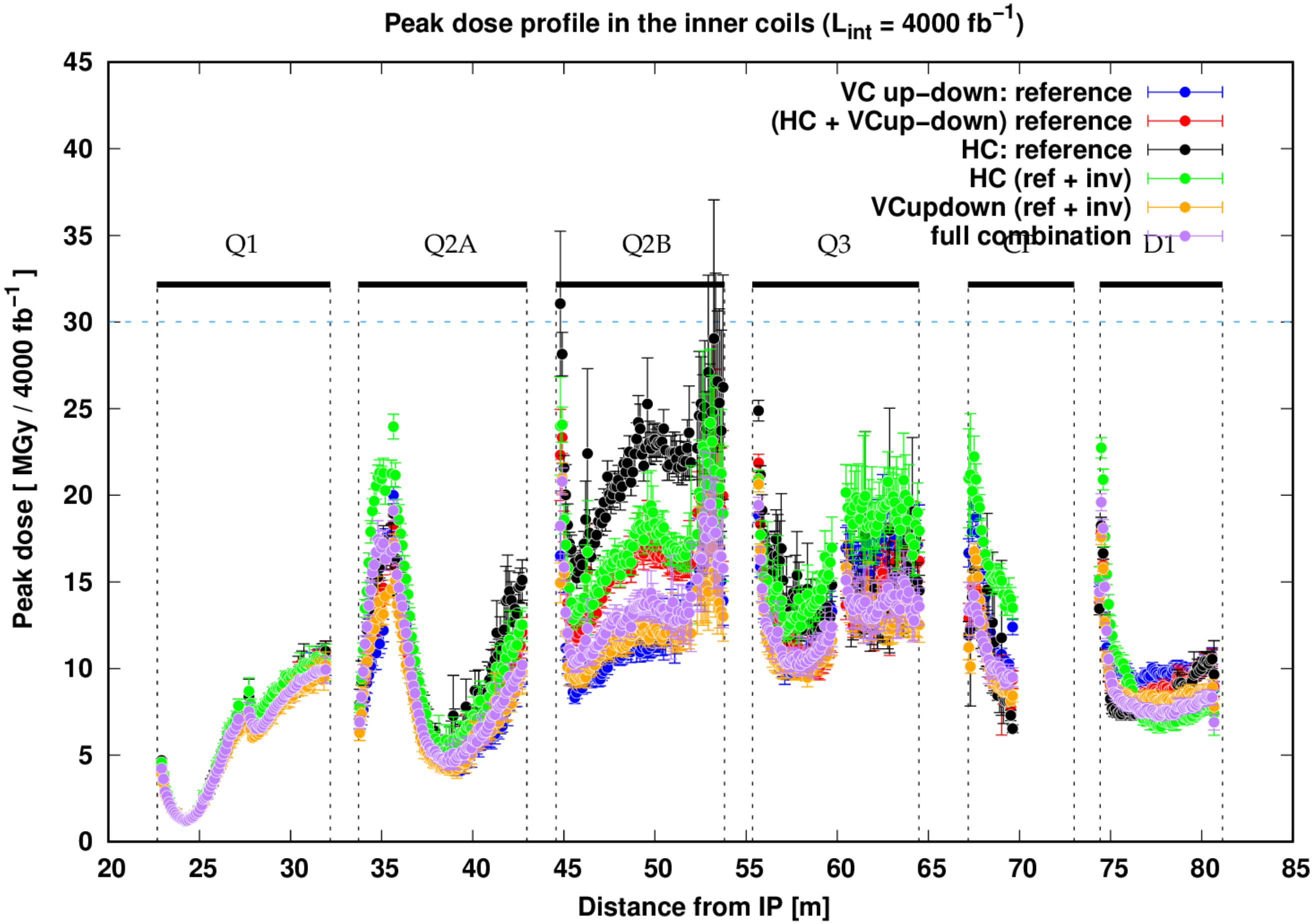
VC up/down (ref+rev):
25% VC-up nominal
25% VC-up rev. pol.
25% VC-down nominal
25% VC-down rev. pol.

Max.
21 MGy

% is the HL-LHC operation time

Full combination:
- 25% HC nominal
- 25% HC reverse polarity
- 12.5% VC-up nominal
- 12.5% VC-up rev. pol.
- 12.5% VC-down nominal
- 12.5% VC-down rev. pol.

Max.
21 MGy



HC ref:

100% HC nominal

Max.
> 30 MGy

VC up/down ref:

50% VC-up nominal

50% VC-down nominal

Max.
21 MGy

(HC + VC up/down) ref:

25% VC-up nominal

25% VC-down nominal

50% HC nominal

Max.
23 MGy

HC (ref+rev):

50% HC nominal

50% HC rev. pol.

Max.
24 MGy

VC up/down (ref+rev):

25% VC-up nominal

25% VC-up rev. pol.

25% VC-down nominal

25% VC-down rev. pol.

Max.
21 MGy

% is the HL-LHC operation time

Full combination:

Max.
21 MGy

- 25% HC nominal
- 25% HC reverse polarity
- 12.5% VC-up nominal
- 12.5% VC-up rev. pol.
- 12.5% VC-down nominal
- 12.5% VC-down rev. pol.

2. Conclusions

- The regular inversion of the crossing angle in the case of VC allows reducing the peak dose in the IT (21 MGy maximum for 4000 fb^{-1}). This is not possible in case of HC (maximum dose above 30 MGy for 4000 fb^{-1}).
- The quadrupole reverse polarity is only beneficial for HC.
- The combination of VC-up/down and HC is a good compromise in terms of peak dose (23 MGy maximum for 4000 fb^{-1}), but better improvement can be achieved. Moreover, the swap of the crossing plane between insertion regions implies the rotation of the crab cavities.
- The combination of VC-up/down and HC for reference operation and reverting the IT quads polarity leads to the maximum reduction of the peak dose in the IT for both insertion regions. A maximum of 21 MGy for 4000 fb^{-1} integrated luminosity was found for this configuration.

3. TCLPX4 settings effect on the matching section of IR1/5

Purpose of the study:

- TCLPX4 aperture needs to be modified to allocate the flat optics. It is also important for PPS2 configuration in IR5.
- Study the impact of the TCLPX4 settings by looking at:
  - Peak dose on D2 and Q4 assemblies.
  - Loads on D2, Q4, TCLPX4 and TCLMB.
  - Radiation levels.
- TCLPX4 half-gap aperture:

FLUKA simulations:

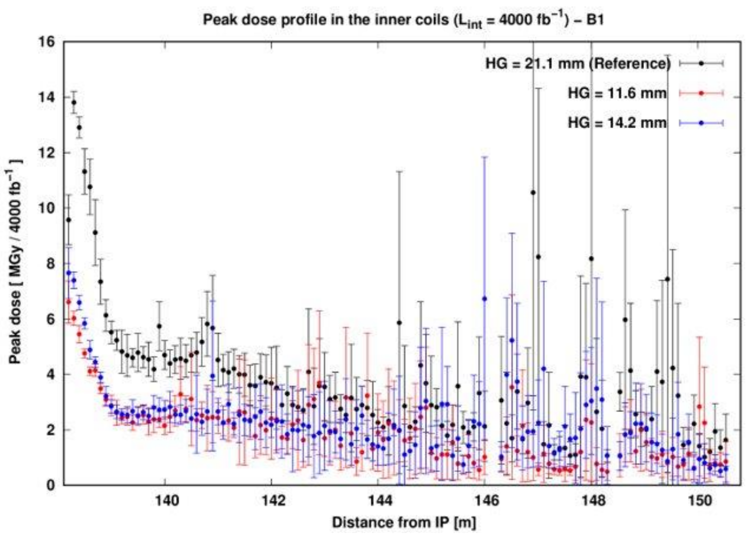
- HL-LHC optics version 1.5 (Nov. 2019 released).
- Right side of the IP1/5.
- p-p collisions at 7 TeV.
- **250 μrad** half crossing angle in the **horizontal/vertical** plane, for the latter the **mix polarity up/down** was adopted.
- Normalization factor:
  - **4000 fb^{-1}** integrated luminosity.
  - **7.5 L_0** instantaneous luminosity.

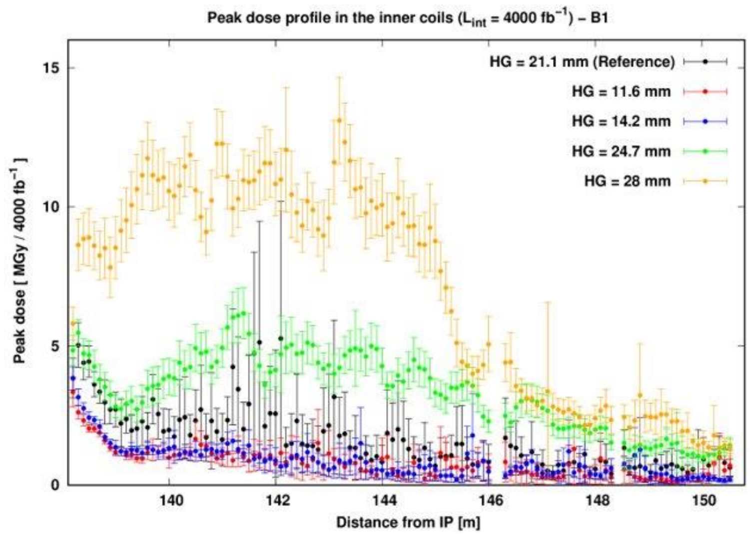
Half-gap	11.6 mm	14.2 mm	21.1 mm	24.7 mm	28 mm
IR1 - **HC**	✓	✓	*ref*		
IR5 - **VC**	✓	✓	*ref*	✓	✓

3. Peak dose distribution

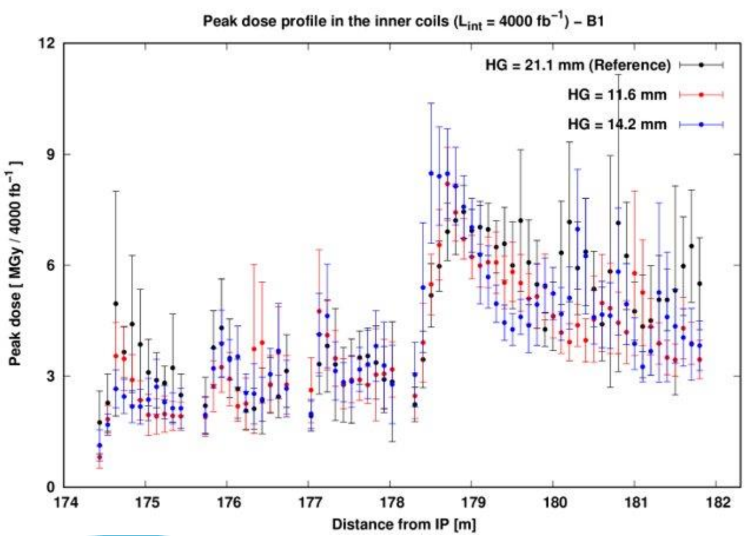
HC

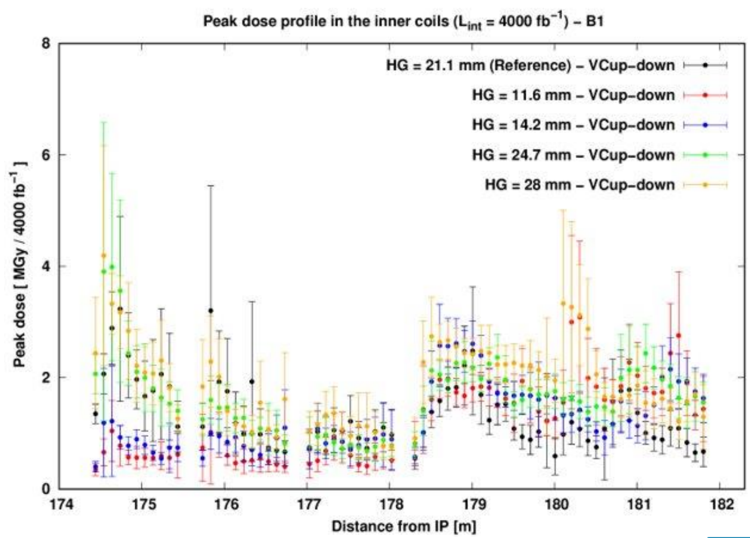
VC up/down





D2 assembly





Q4 assembly

3. Power deposition – total loads (W) for 7.5 L_0: draw backs

HC

Half gap (mm)	TCLPX inner	TCLPX outer
11.6	**303.5**	**288.2**
Ratio	*1.3*	*1.8*
14.2	**277.8**	**256**
Ratio	*1.2*	*1.6*
21.1 - ref	**230.1**	**162.4**

VC up/down

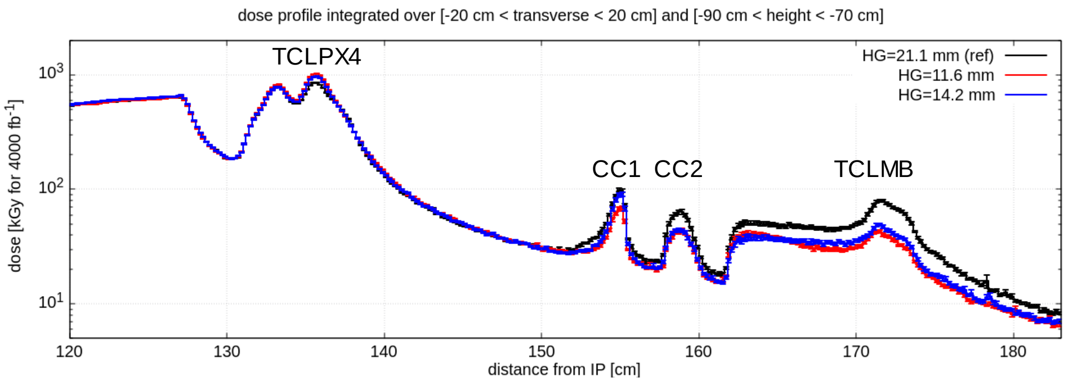
Half gap (mm)	D2	D2 Hcorr	D2 Vcorr	TCLMB B1
21.1 - ref	**18.8**	**1**	**1.2**	**35.7**
24.7	**31.8**	**2.1**	**3.3**	**44.7**
Ratio	*1.7*	*2.2*	*2.7*	*1.3*
28	**54**	**3**	**4.6**	**51.9**
Ratio	*2.9*	*3.1*	*3.8*	*1.5*

The collimator design, including the thermomechanical studies, is based on the loads corresponding to the reference settings.

A factor of 2 increase in the loads on the TCLPX jaws is also observed when closing the collimator. However, the maximum power (170 W) is below the design limits.

3. Radiation levels

HC



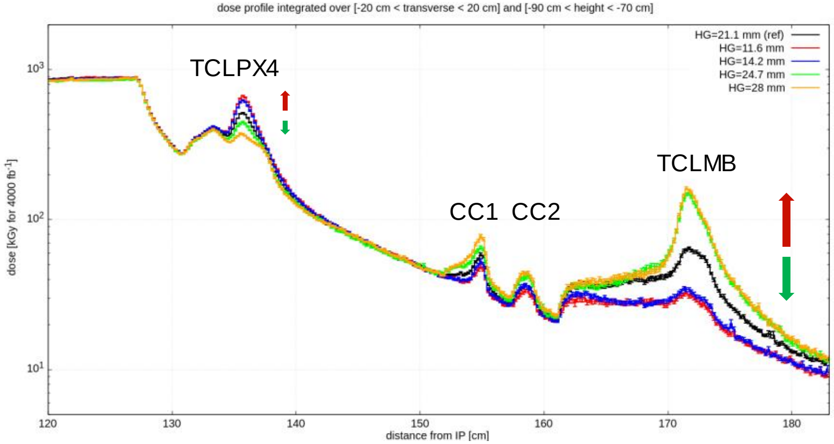
Around TCPLX4

11.6 / 14.2 mm: increased by a factor 1.2

Around Q4-assembly:

11.6 / 14.2 mm: decreased by a factor 0.6

VC-up



Around TCPLX4:

24.7 / 28 mm: decreased by a factor 0.7-0.8

11.6 / 14.2 mm: increased by a factor 1.3

Around Q4-assembly:

24.7 / 28 mm: increased by a factor 2.5

11.6 / 14.2 mm: decreased by a factor 0.5

3. Conclusions

- **Peak dose in D2/Q4 assemblies:**
  - A reduction in the aperture of the TCLPX4 implies a decrease in the peak dose in D2 and Q4-assembly.
  - A larger opening leads to a non-negligible increase in D2 (up to a factor 2, 12 MGy) and Q4-assembly.

- **Total power:**
  - The impact of the TCLPX4 settings highly depends on the half gap and the crossing plane.
  - For horizontal crossing, an aperture of 11.6 mm half-gap implies that the loads in the inner jaw of the TCLPX4 will be < 300 W, 70 W above the values considered in the design.
  - In vertical crossing, when opening the TCLPX4 to 28 mm half-gap, the loads in the D2, Q4 and TCLMB increase by a factor 2.9 (up to 54 W), 1.2 (5.6 W) and 1.5 (52 W) respectively.

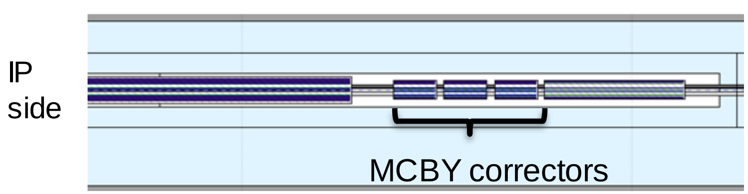
- **Radiation levels:**
  - When opening the collimator there is a decrease by a factor ~0.8 in the surrounding of TCLPX4 and an increase by a factor 2.5 around TCLMB4.
  - When closing the collimator there is an increase by a factor ~1.3 in the surrounding of TCLPX4 and a decrease by a factor ~0.5 around TCLMB4.

- **The combination of all this information should be taken into account in the final decision on the TCLPX4 settings.**

4. Peak dose estimation for MCBY up to LS4: LHC and HL-Run4 contributions

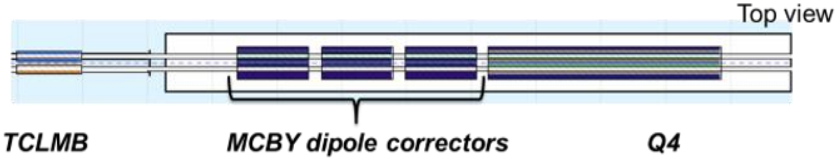
LHC

- **IR1 : VC up/down**
  - Fixed half crossing angle of +/-160 μrad.
  - p-p collisions (σ = 80 mb) at 6.8 TeV.
  - TCL4 half-gap of 11.5 mm.
- **IR5 : HC**
  - Fixed half crossing angle of 160 μrad.
  - p-p collisions (σ = 80 mb) at 6.8 TeV.
  - TCL4 half-gap of 11.5 mm.

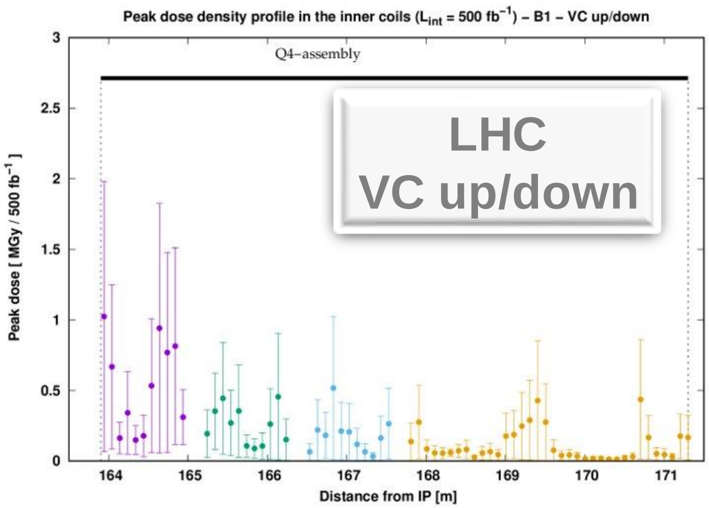


HL-LHC

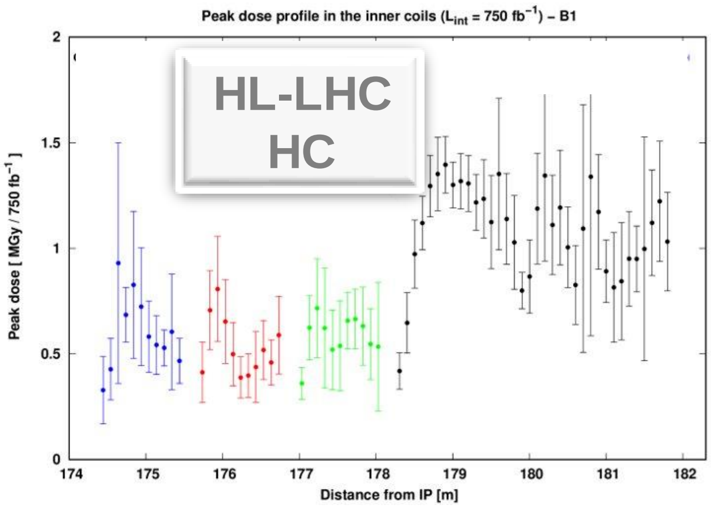
- **MCBY**s: correctors in Q4-assembly.
- After optimization of TCLMB4 design.
- **IR1 - HC** and **IR5 - VC up/down**
  - Round optics version 1.5 (Nov.19).
  - Fixed half crossing angle of 250 μrad.
  - p-p collisions (σ = 85 mb) at 7 TeV.
  - TCL4 half-gap of 21 mm.

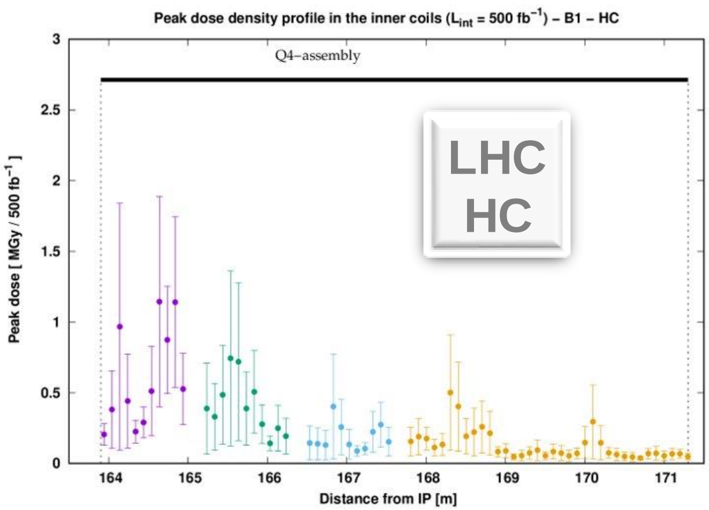


4. Peak dose distribution

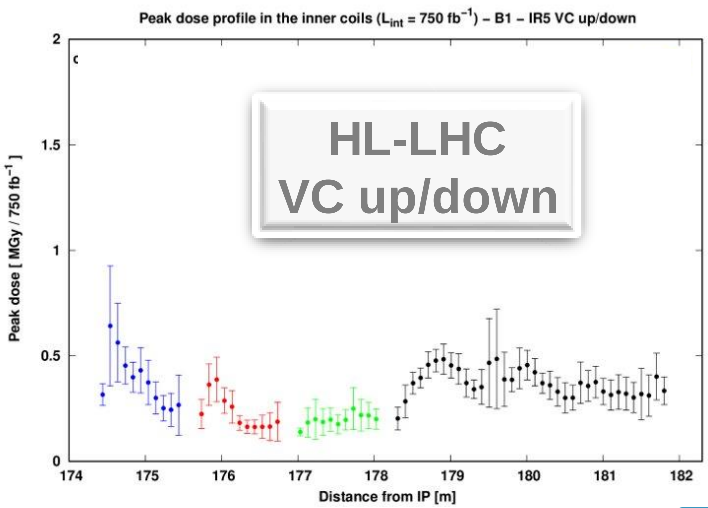


IR1





IR5



4. Conclusions

- A review of the peak dose at the most exposed MCBY in Q4-assembly was carried out for LHC and HL-LHC machine, considering updated values for the expected integrated luminosity to be reached by LS4/5/6.
- Conservative values for the cumulative dose during the LHC operation was taken: 1 MGy for 500 fb^{-1} integrated luminosity. Therefore, the cumulated peak dose up to LS4 for IR1/5 is < 2 MGy.
- The low values for the cumulative dose for the HL-LHC operation are due to the optimization of the TCLMB4 design (shape and aperture).
- ***By the end of the HL-LHC era, the peak dose in the MCBYs is expected to be below 7 MGy.***

Integrated luminosity (MGy)	Up to LS3 500 fb^{-1}	Run4 750 fb^{-1}	Run5 1200 fb^{-1} (300 fb^{-1}/y)	Total – nominal 3000 fb^{-1}	Total – ultimate 4000 fb^{-1}
LHC	1				
HL-LHC	IR1 / IR5	0.9 / 0.7	1.5 / 1.1		
Cumulative dose	Up to LS3 1	Up to LS4 1.9 / 1.7	Up to LS5 3.4 / 2.8	Up to LS6 4 / 3.3	Up to LS6 5.2 / 4.2

5. Review of TCLMC5/6 mask effectiveness as a function of mechanical tolerances

Baseline

Cut-circle

$\Delta x = 37.6$ m

$R_{in} = 47.2$ mm

$R_{out} = 5$ cm

LHC-VSS-ES-0002 v.1.3

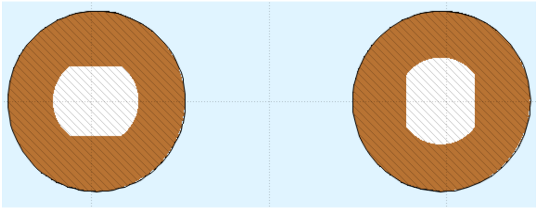
+ 1 mm tolerance

Cut-circle

$\Delta x = 38.6$ m

$R_{in} = 48.2$ mm

$R_{out} = 5$ cm



incoming beam

outgoing beam

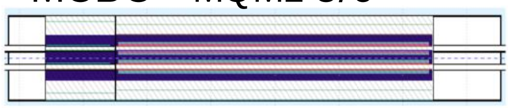
GOAL: check the impact on the MCBC (cell5/6) of including the mechanical tolerances in the design of the TCLMC mask as it was done during the detailed study of the TCLMB4.

FLUKA study:

- HL-LHC v1.5 (Nov.19).
- p-p collisions (σ = 85 mb) at 7+7 TeV.
- Ultimate integrated luminosity: 4000 fb^{-1}.
- **Worst case scenario: IR1-right side, HC 250 μrad.**

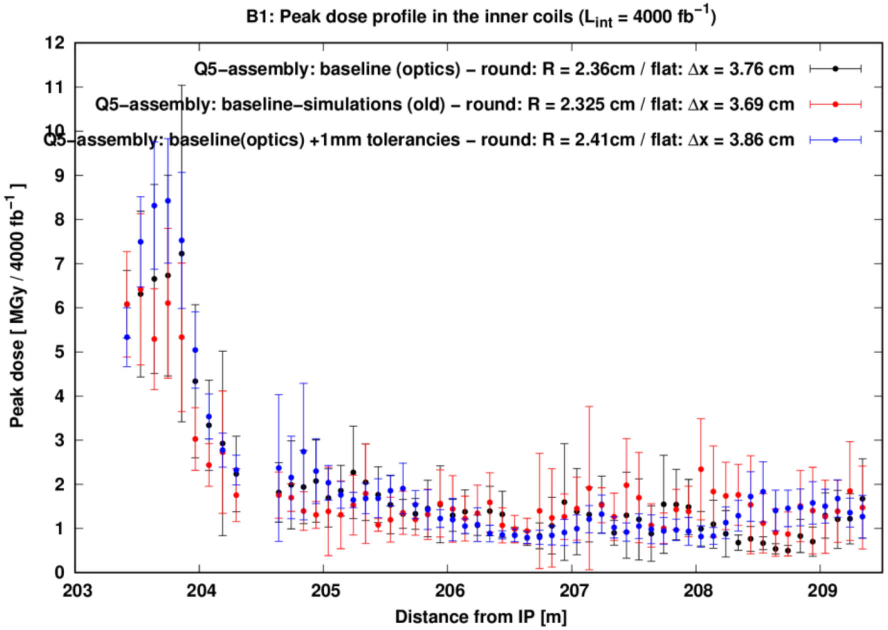
MCBC MQML 5/6

IP1

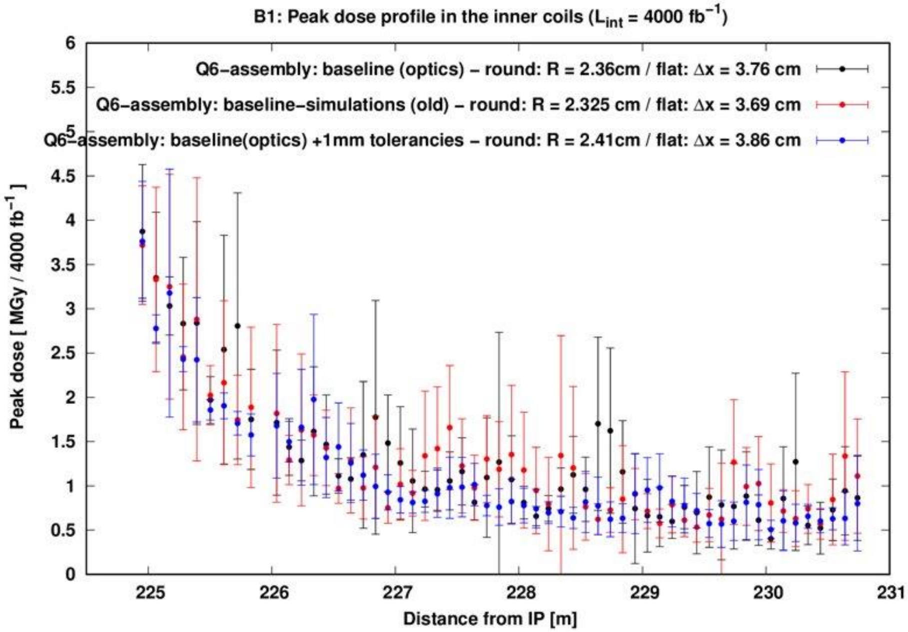


5. Peak dose profile

Cell 5



Cell 6



Reference: **6.7 MGy for 4000 fb^{-1}**

+1mm tolerances: **8.4 MGy for 4000 fb^{-1}**

Increase of +25 % at peak

Compatible within uncertainties

5. Conclusions

- An increase of 25 % in the peak dose at the MCBC5 was found when included the mechanical tolerances of 1 mm (aperture: Δx = 37.6 mm, R_{in}= 47.2 mm + 1mm mechanical tolerances). The dose goes above 7 MGy.

- In view of these results the recommended aperture from machine protection point of view stands for mechanical dimensions:
  - Cut-circle shape.
  - Δx = 36.6 mm
  - Φ = 46.2 mm

Thank you for your attention

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