Review of energy deposition simulations

Marta Sabaté-Gilarte, Francesco Cerutti

WP10

Energy deposition & R2E

12th HL-LHC Collaboration Meeting Uppsala September 20th 2022

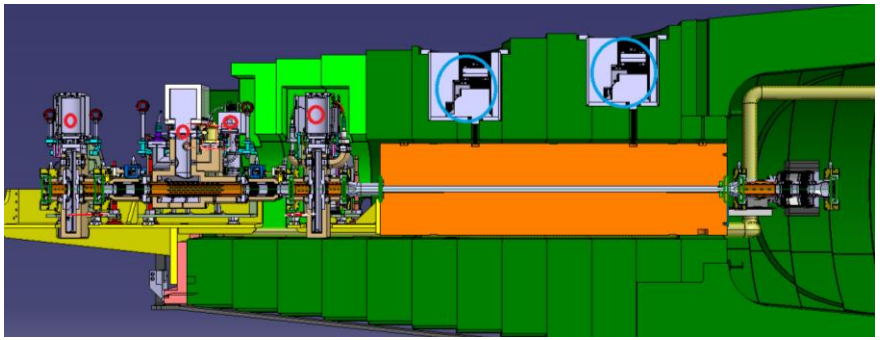
OUTLINE

1. ***Dose evaluation on the TAXS region.***
2. ***Dose distribution in the entire magnets of IT+D1 from cryogenics studies.***
3. ***TCLMB design optimization studies.***
4. ***LSS1:***
    - ***Dose evaluation for vacuum components in the line.***
    - ***Roman Pots in IR1.***
5. ***Background in CMS: beam-gas interaction and beam-halo contribution.***
6. ***Perspectives for HL-LHC optics v1.6: flat optics.***

Dose evaluation on the TAXS region

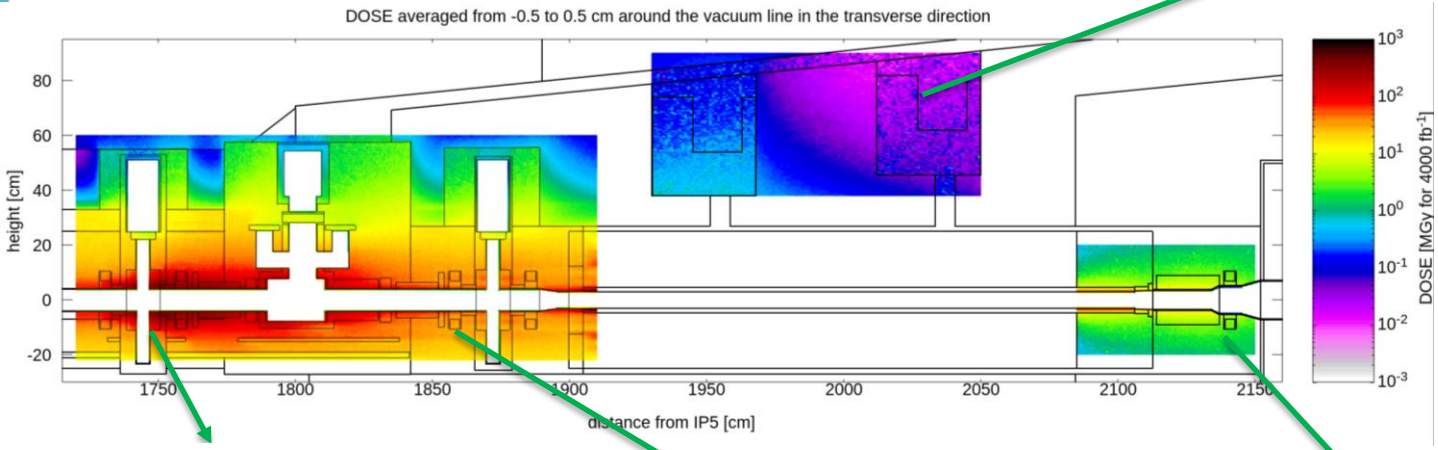
IR1 – horizontal crossing

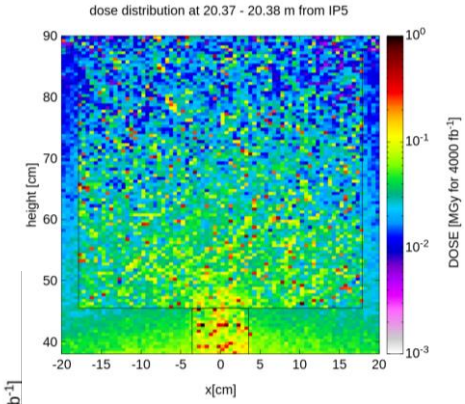
IR5 – vertical crossing (mix polarity)

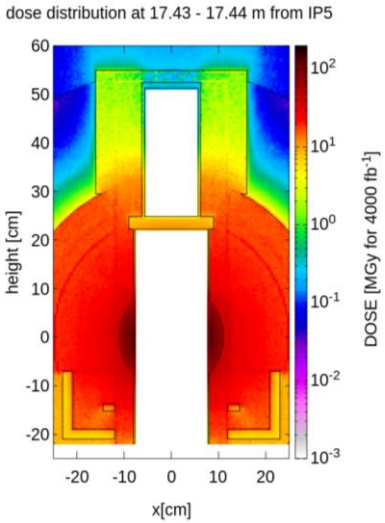


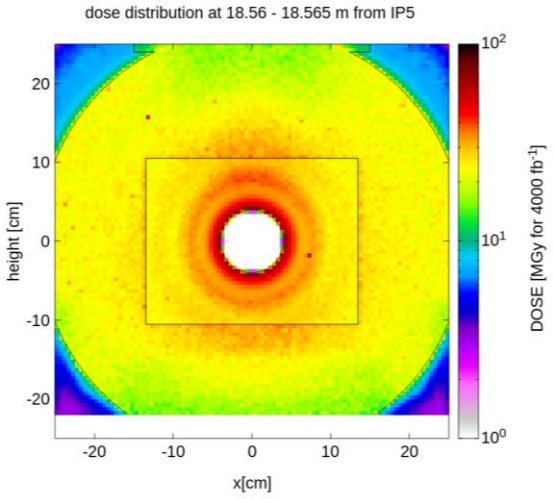
- HL-LHC optics version 1.5 (Nov.19).
- p-p collisions (σ = 85 mb) at 7+7 TeV.
- Horizontal / Vertical crossing with fixed half crossing angle 250 μrad.
- Integrated luminosity: ultimate conditions 4000 fb^{-1}.
  - Dose values scale linearly with the integrated luminosity.

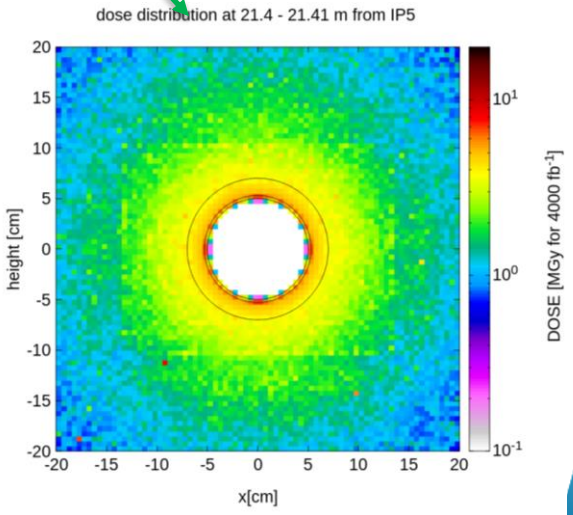
IR5 – vertical crossing (mix polarity)



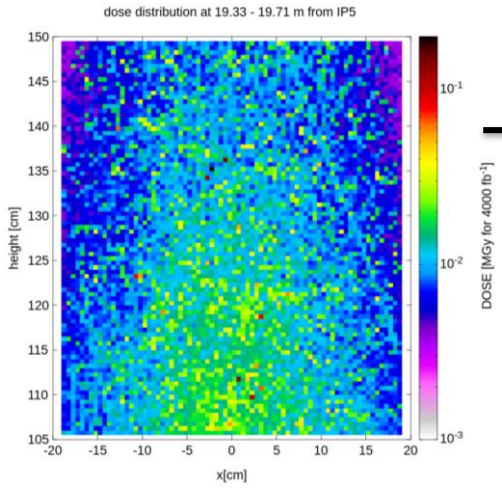


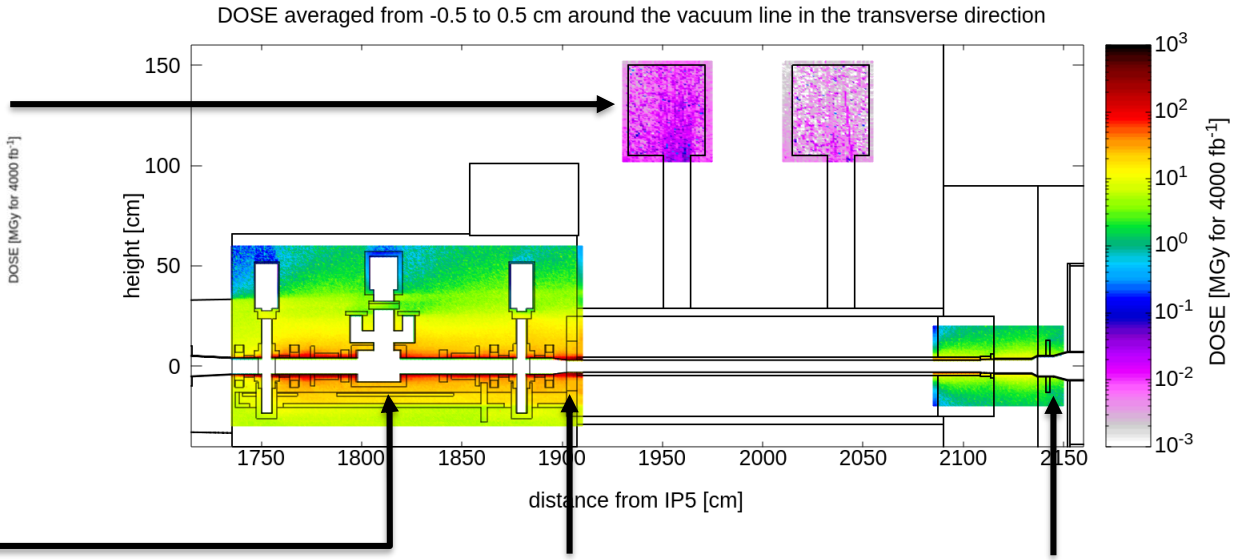


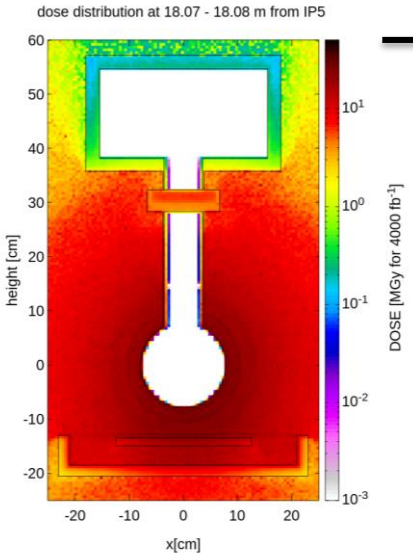


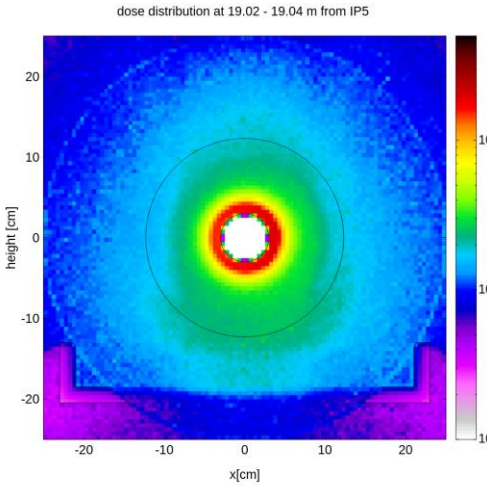


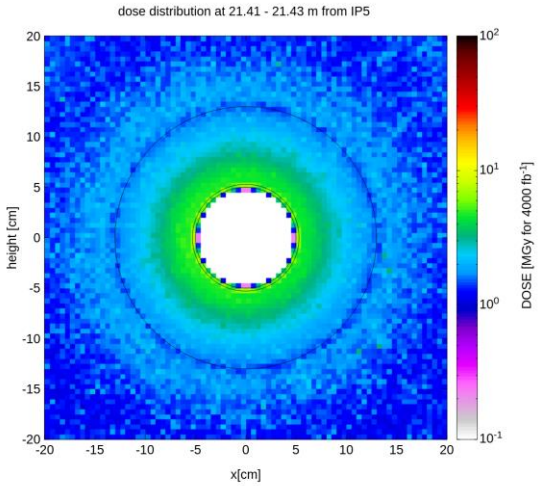
IR1 – horizontal crossing











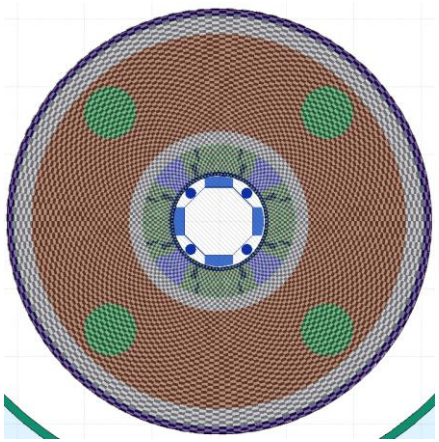
Dose evaluation on the TAXS region

- On the non-IP side of the TAXS the maximum dose in the flanges goes from 300 MGy (right downstream the TAXS) to 6 MGy (the closest to Q1A), depending on the respective aperture.
- Regarding the elements close to the beam line upstream the TAXS, the maximum dose values rises up to 300 - 400 MGy at the entrance of the TAXS.

- For the equipment inside the shielding, the dose values are below 0.5 MGy in IR1 and from 1-2 MGy up to 5 MGy in IR5.
- In the rest of the components, the strong gradient in the dose distribution shows a variation between < 1 MGy and 30 MGy in IR1 or 200 MGy in IR5 depending on the distance to the beam line.

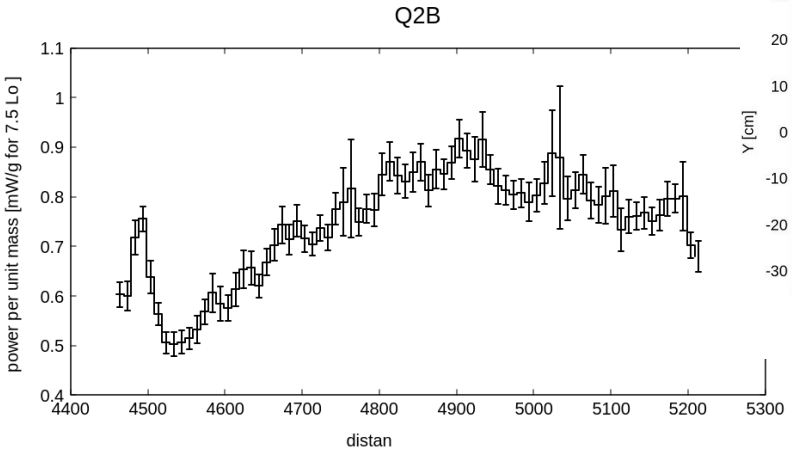
Dose distribution in the entire magnets of the inner triplet and the D1 for cryogenics studies

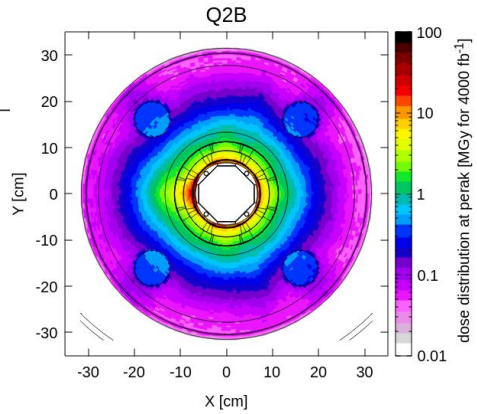
- ***Purpose: input for thermal stability calculations.***



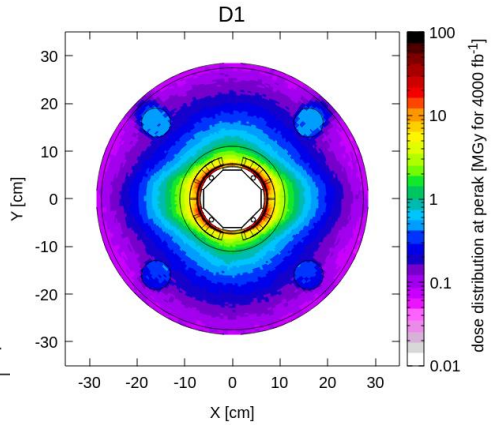
- HL-LHC optics version 1.5 (May/Nov.19).
- Horizontal / Vertical (up) crossing with fixed half crossing angle 250 μrad.
- p-p collisions (σ = 85 mb) at 7+7 TeV.
- Integrated luminosity:
  - Ultimate conditions: 4000 fb^{-1} integrated luminosity and $7.5x10^{34}$ cm^{-2} s^{-1} instantaneous luminosity.
  - These values scale linearly with the luminosity.

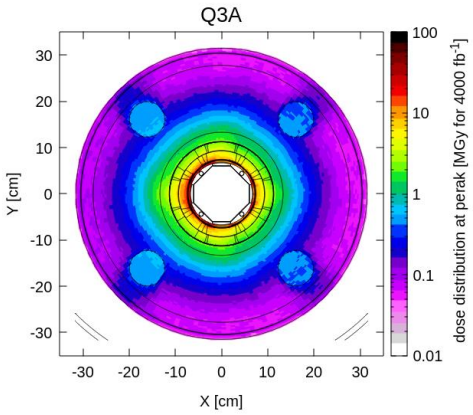
IR1 – horizontal crossing

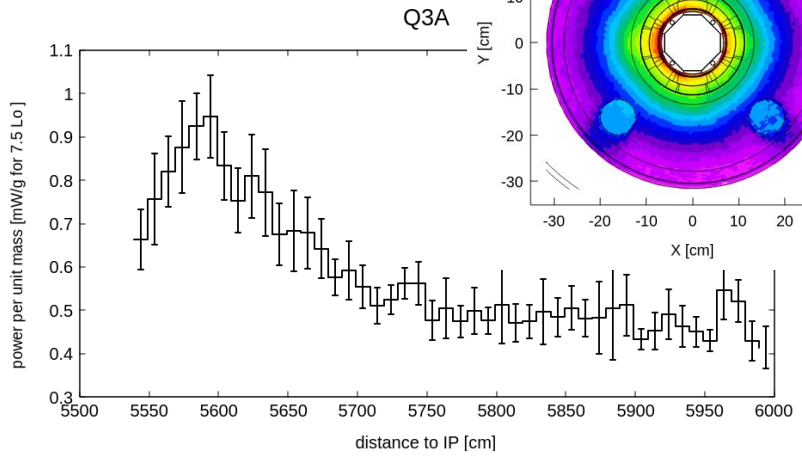


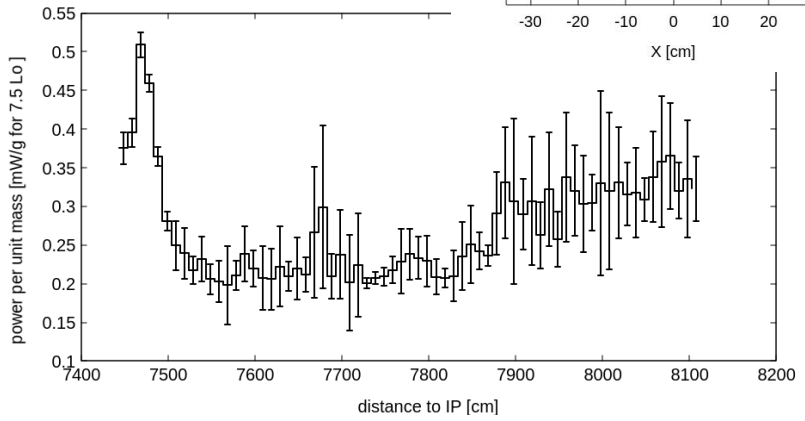


Distribution of the maximum dose value in the cold bore.

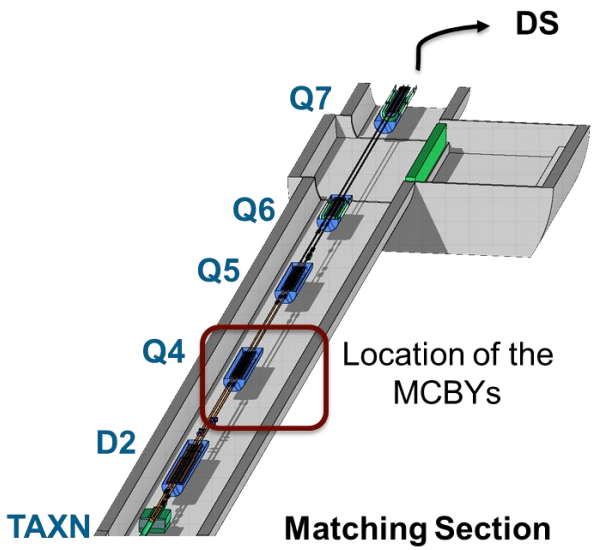






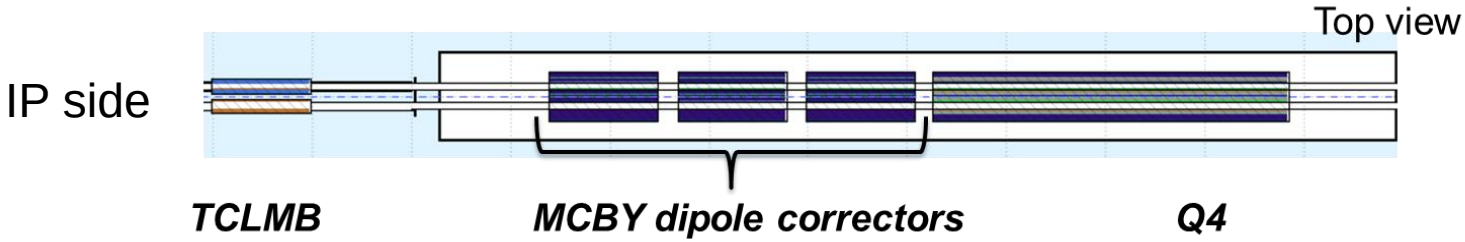


TCLMB design optimization studies



- MCBYs: correctors in Q4-assembly.
- Less radiation resistant than Q4.
- TCLMB mask designed to reduce the radiation due to p-p collision debris.

- HL-LHC optics version 1.5 (Nov.19) for IR1/5.
- Fixed half crossing angle +250 μrad.
- p-p collisions (σ = 85 mb) at 7+7 TeV.
- Integrated luminosity: ultimate conditions 4000 fb^{-1}



https://indico.cern.ch/event/1167566/

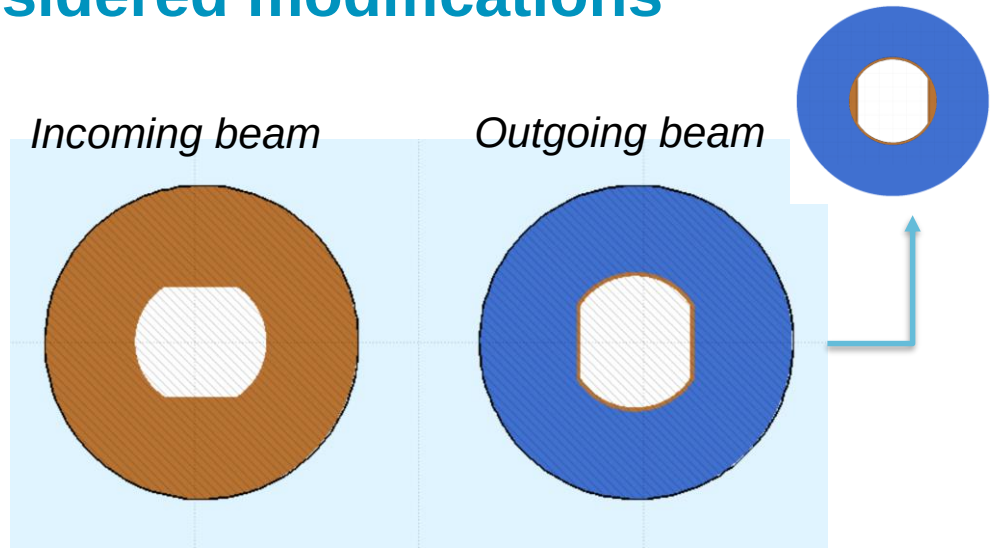
TCLMB model: considered modifications

Baseline

Δx = 5.06 cm

R_{in}= 3.01 cm

Cu pipe thickness pipe = 1 mm



Larger aperture to mimic mechanical tolerances

Δx = 5.22 cm

R_{in}= 3.09 cm

Cu pipe thickness pipe = 1.8 mm

WP2 WP5 WP10

Limit situation of baseline configuration plus mechanical/alignment tolerances

Reduce aperture to better protect the MCBYs

Δx = 4.9 cm

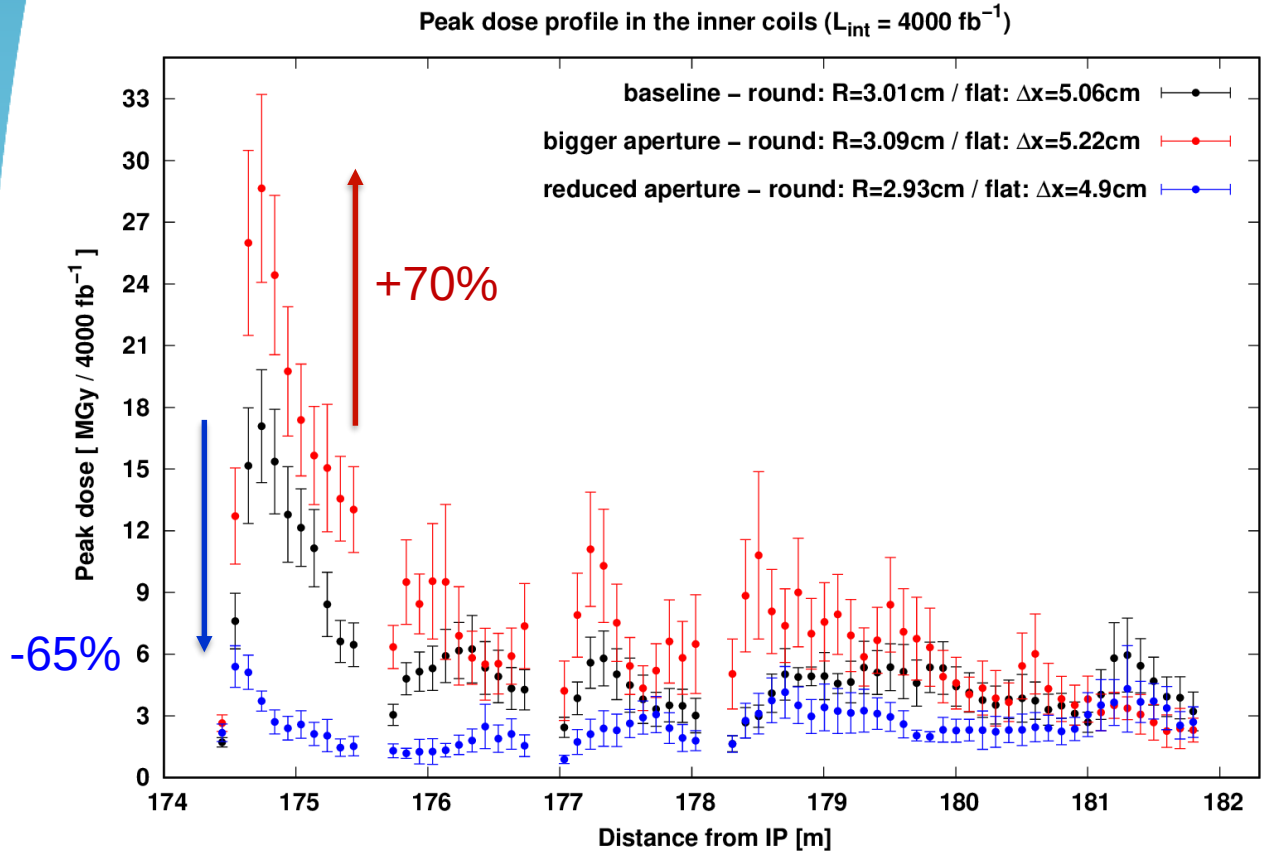
R_{in}= 2.93 cm

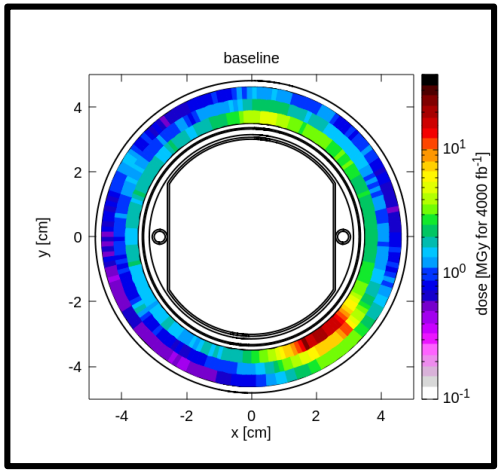
Cu pipe thickness pipe = 1.8 mm

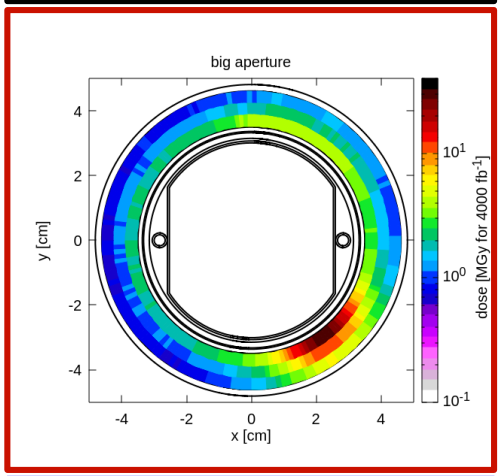
WP2 WP5 WP10

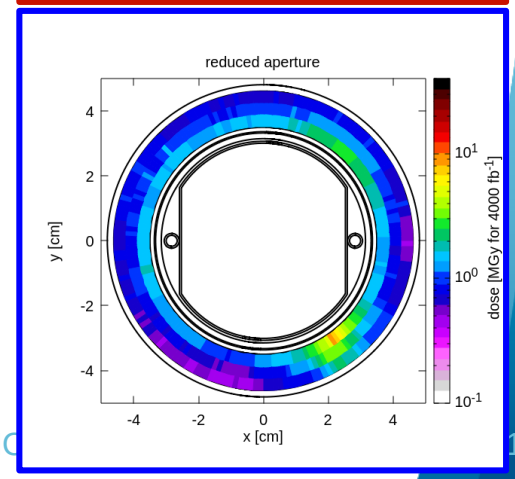
There is room (up to the baseline configuration) to allocate mechanical/alignment tolerances

Peak dose distribution for the different configurations: IR5 – VC with +250 μrad half crossing angle

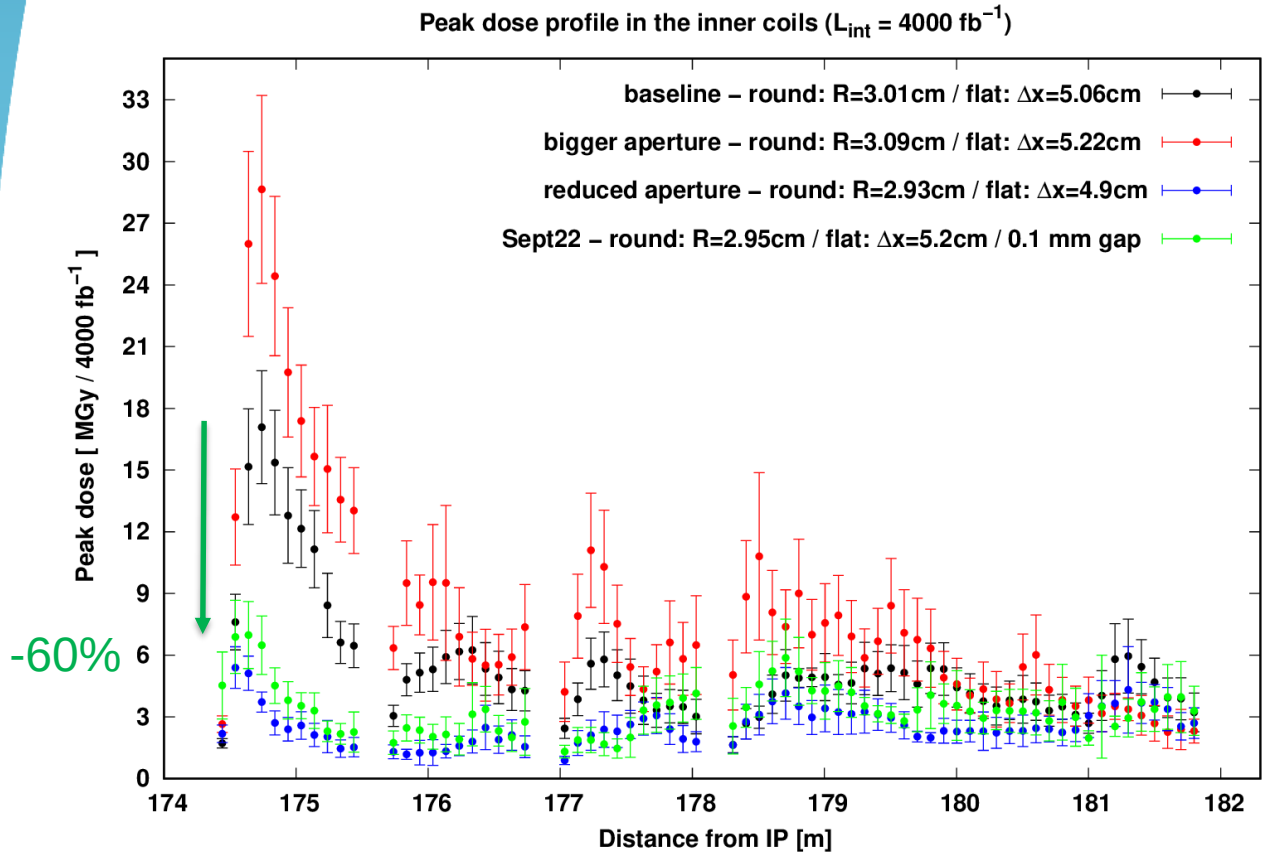




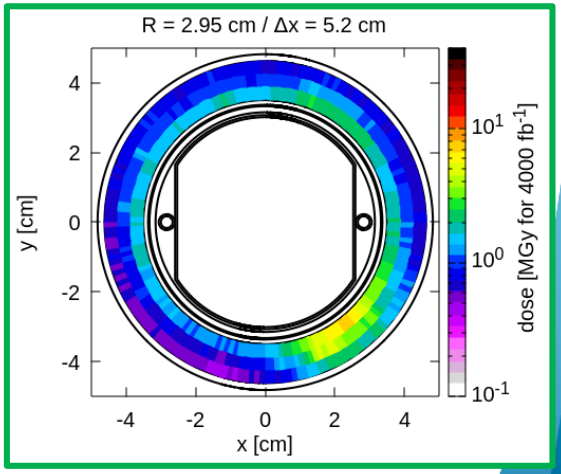




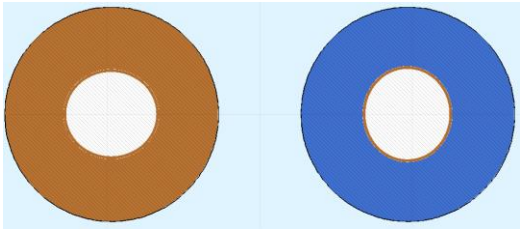
Peak dose distribution for the different configurations: IR5 – VC with +250 μrad half crossing angle

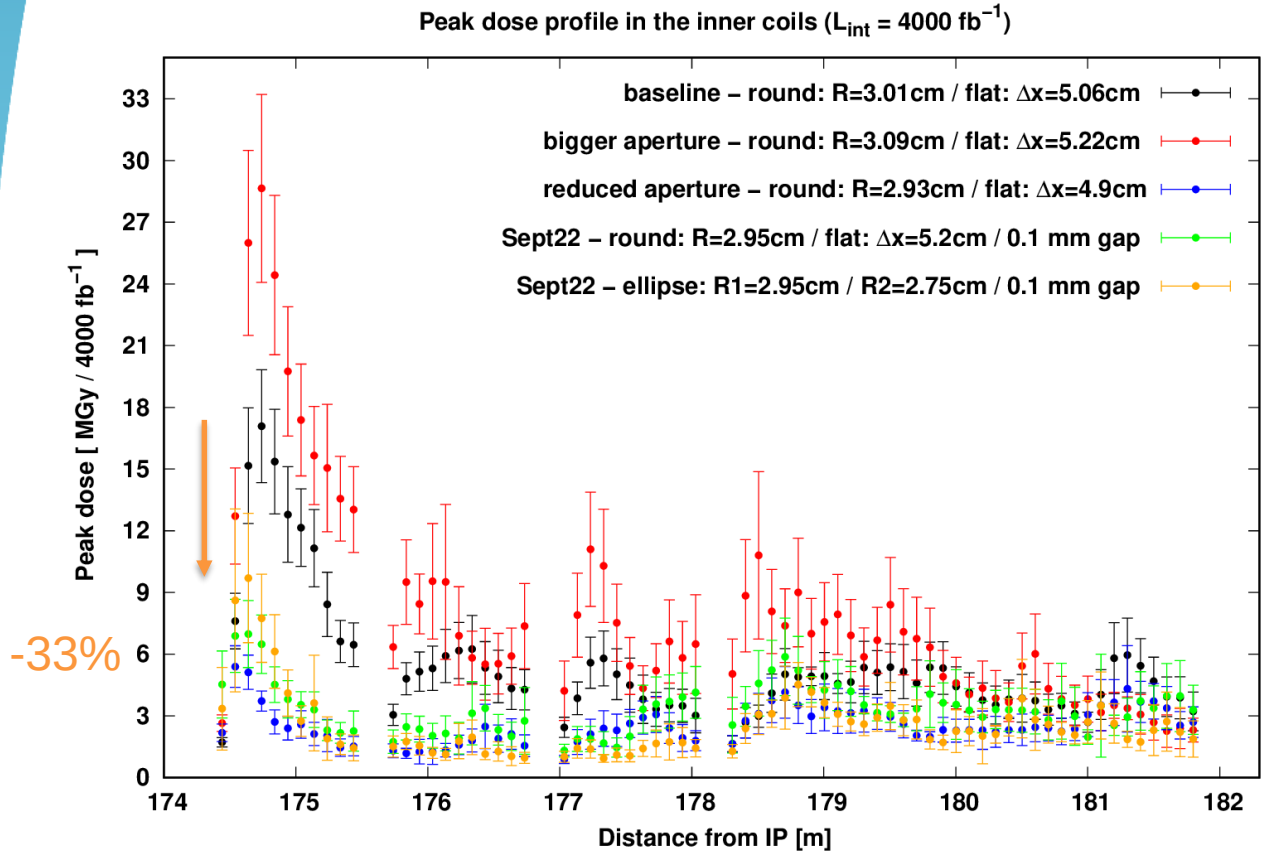


- Increase of the flat part to better allocate the beam from: *Dx = 5.06* to *Dx = 5.2 cm*.
- Reduction of the round part to increase the protection from: *R=3.01* cm to *R = 2.95 cm*.
- Inclusion of the 0.1 mm gap between the Cu-vacuum chamber and the inermet block

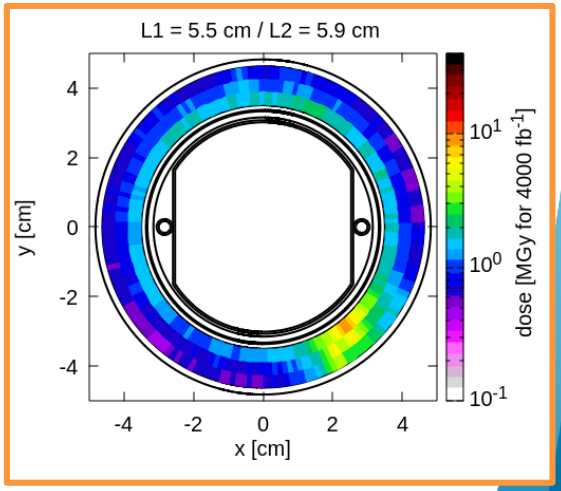


Peak dose distribution for the different configurations: IR5 – VC with +250 μrad half crossing angle

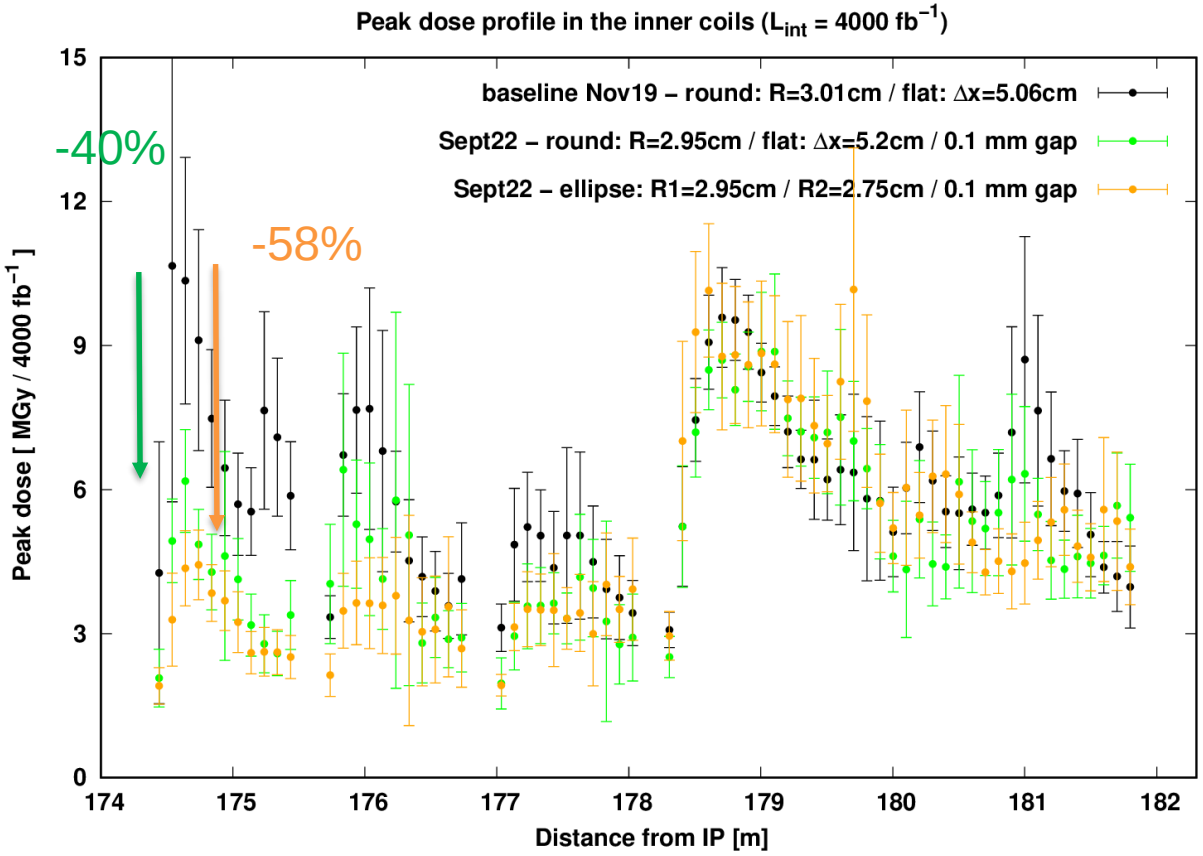


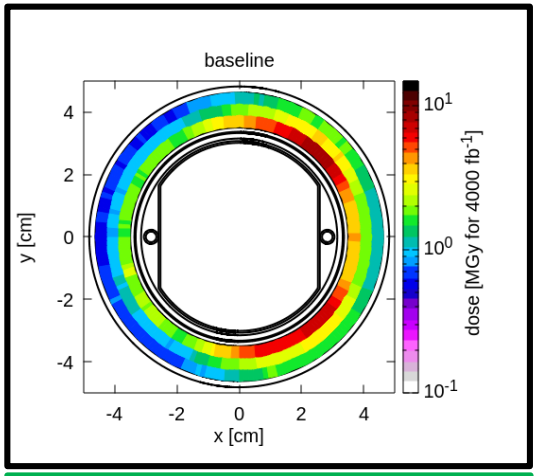


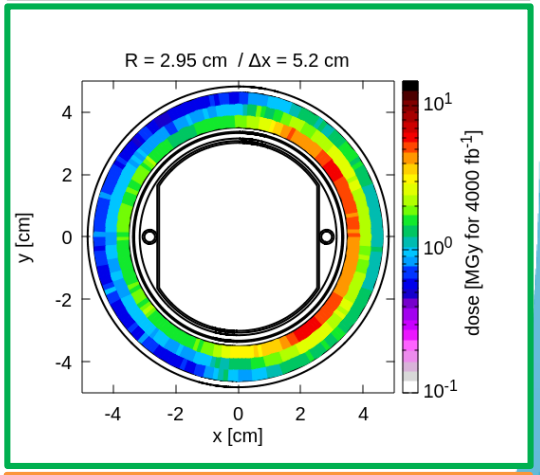
- Replace the rectellipse by an elliptical shape with:
  - *L1 = 5.5 cm*
  - *L2 = 5.9 cm*
- Inclusion of the 0.1 mm gap between the Cu-vacuum chamber and the inermet block

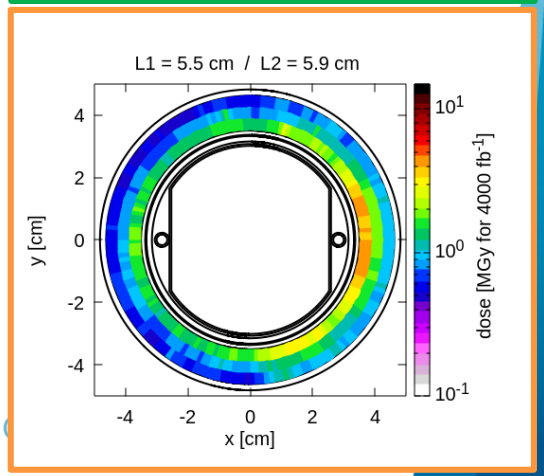


Peak dose distribution for the different configurations: IR1 – HC with 250 μrad half crossing angle









TCLMB design review: conclusions

- Possible new design of the TCLMB increasing the flat part of the aperture and reducing the round part in order to mitigate the impact on the 1st MCBY hot spot. An alternative is to replace the rectellipse by an elliptical shape.
- This calculations include the mechanical tolerances associated to the proposed aperture as well as a 0.1 mm gap between the Cu-vacuum chamber and the inermet block.
- The improvement with respect to the baseline configuration is:

Cumulated dose for 3000 / **4000** fb^{-1}	Baseline Δx = 5.06 cm Φ = 6.02 cm	Rectellipse Δx = 5.2 cm Φ = 5.9 cm	Ellipse L1 = 5.5 cm L2 = 5.9 cm
HC	8.0 / **10.6**	4.7 / **6.2**	3.3 / **4.4**
improvement		**- 40 %**	**- 58 %**
VC Up/Down	6.4 / **8.6**	3.5 / **4.6**	4.3 / **5.7**
Improvement		**- 45 %**	**- 33 %**

LSS1
Dose evaluation in vacuum components
Roman pots in IR1

- HL-LHC optics version 1.5 (Nov.19).
- p-p collisions (σ = 85 mb) at 7+7 TeV.
- Horizontal crossing with fixed half crossing angle 250 μrad.
- Integrated luminosity per year 360 fb^{-1} or for the ultimate HL-LHC scenario: 4000 fb^{-1}.
  - Dose values scale linearly with the integrated luminosity.

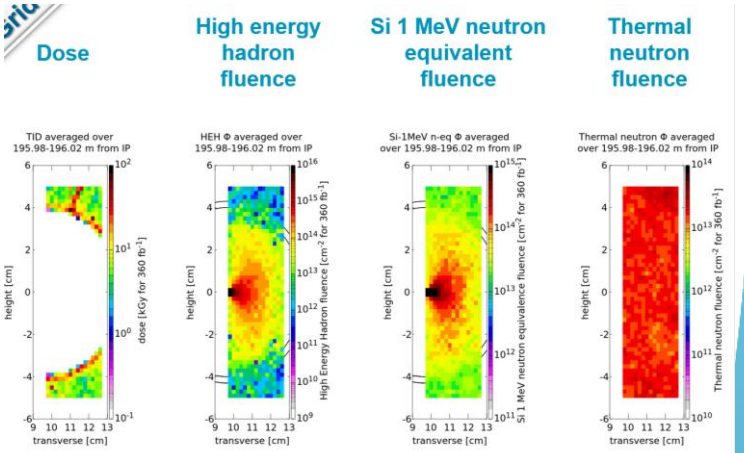
Roman Pots in IR1

- Calculation of the maximum radiation levels in LSS1 at the expected location of the roman pots in the HL-LHC machine.

- In this calculation the model of these elements is not included.

- For 360 fb^{-1} integrated luminosity per year in the vicinity of the outgoing beam vacuum chamber*:

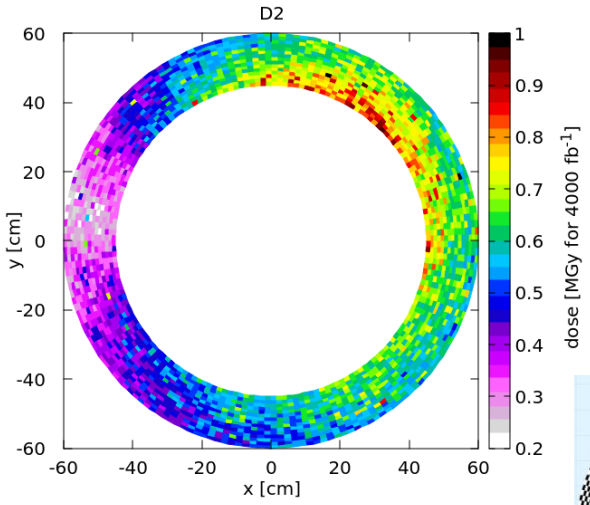
  - Total ionizing dose: 50 kGy.
  - Thermal neutron fluence: $5x10^{13}$ cm^{-2}.
  - High energy hadron fluence: 10^{14} cm^{-2}.
  - Silicon 1 MeV neutron equivalent fluence: $5x10^{13}$ cm^{-2}.

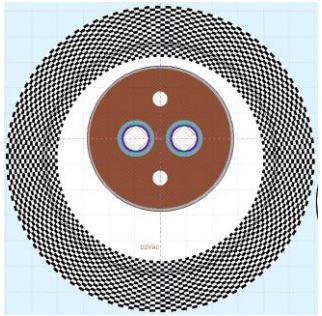


* Since the dose cannot be estimated in a vacuum region, these values are obtained at the vacuum chamber for all quantities.

Dose evaluation in vacuum components

- Maximum dose values in the O-rings of the LSS1 cryostats and various vacuum interconnections.
- Values are given for 4000 fb^{-1} integrated luminosity.



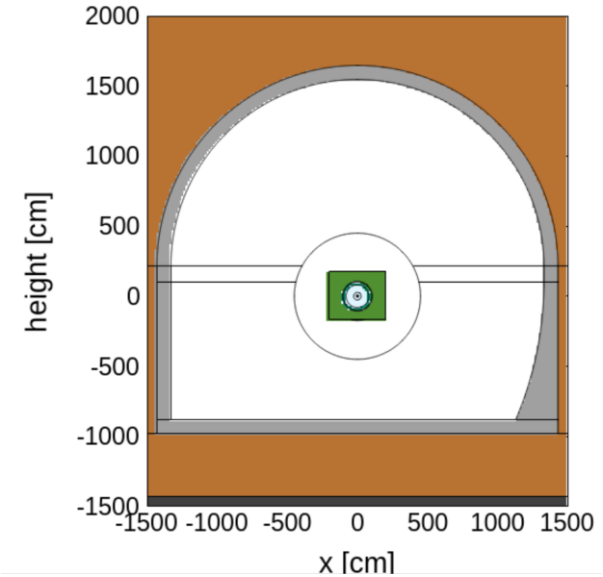


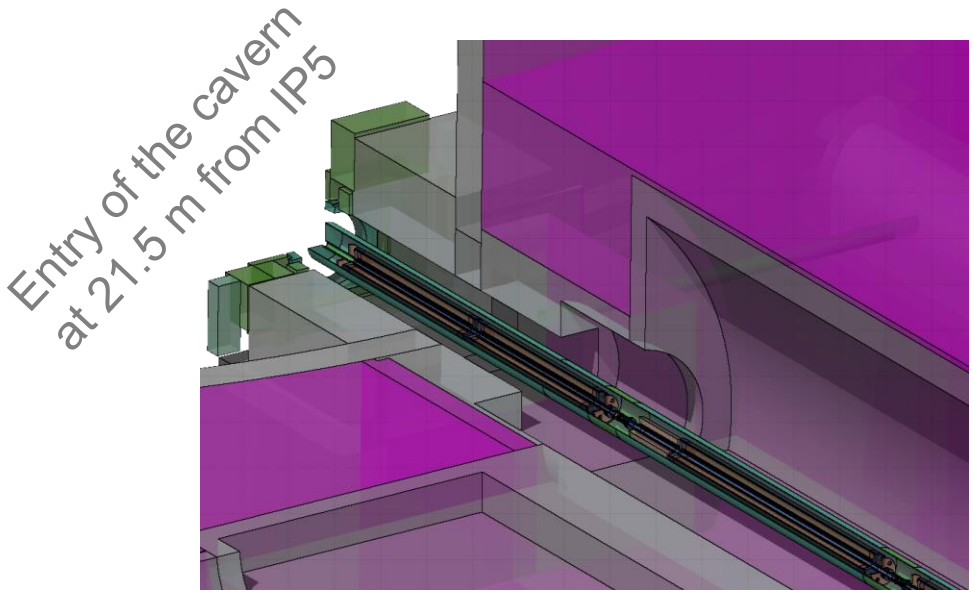
	Distance to IP (m)	Max dose (MGy)
Q1 - IP side	21.4 - 21.5	0.6
Q1B – Q2A inter	33.4 - 33.5	0.5
Q2A – Q2B inter	44.3 – 44.4	0.3
Q2B – Q3A inter	55.1 – 55.2	0.45
Q3B – CP inter	66.85 – 66.95	0.45
CP – D1 inter	74 – 74.1	0.3
D1 – non IP side	82.6 – 82.7	0.5
D2 – IP side	137.3 – 137.4	1
Q4 – IP side	173 – 173.1	0.15
Q5 – IP side	202.6 – 202.7	0.35
Q6 – IP side	223.93 – 224.03	0.15
Q7 – IP side	256.7 – 256.8	< 0.01

IR5: background studies for CMS

Local beam gas interaction

Beam-halo contribution

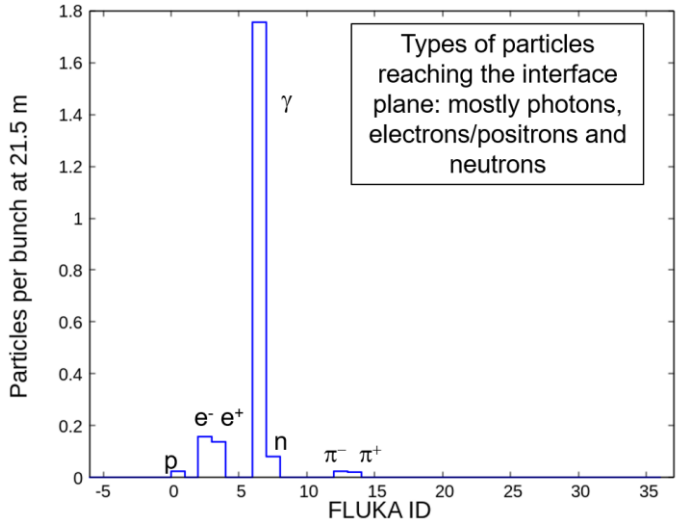


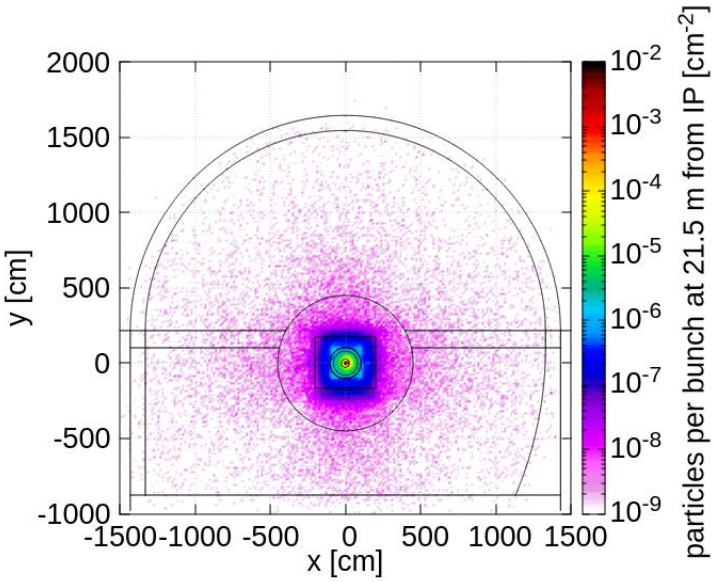


https://indico.cern.ch/event/1145479/ / https://indico.cern.ch/event/1195003/

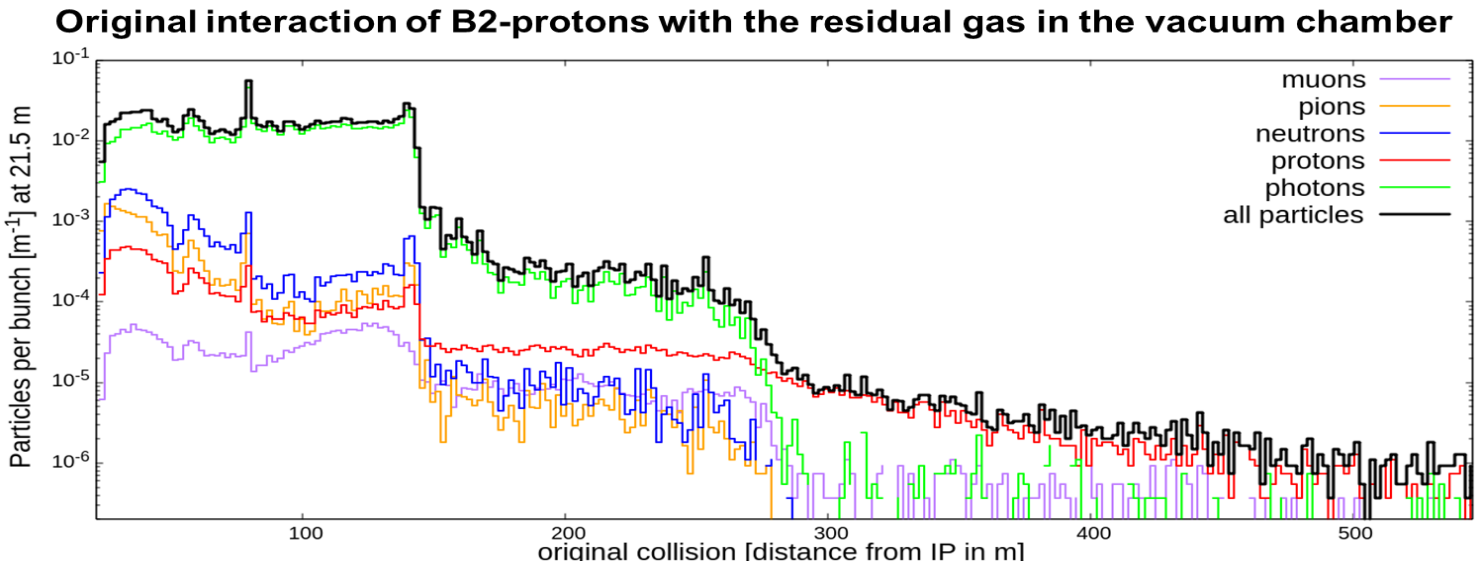
Local beam-gas interaction (I)

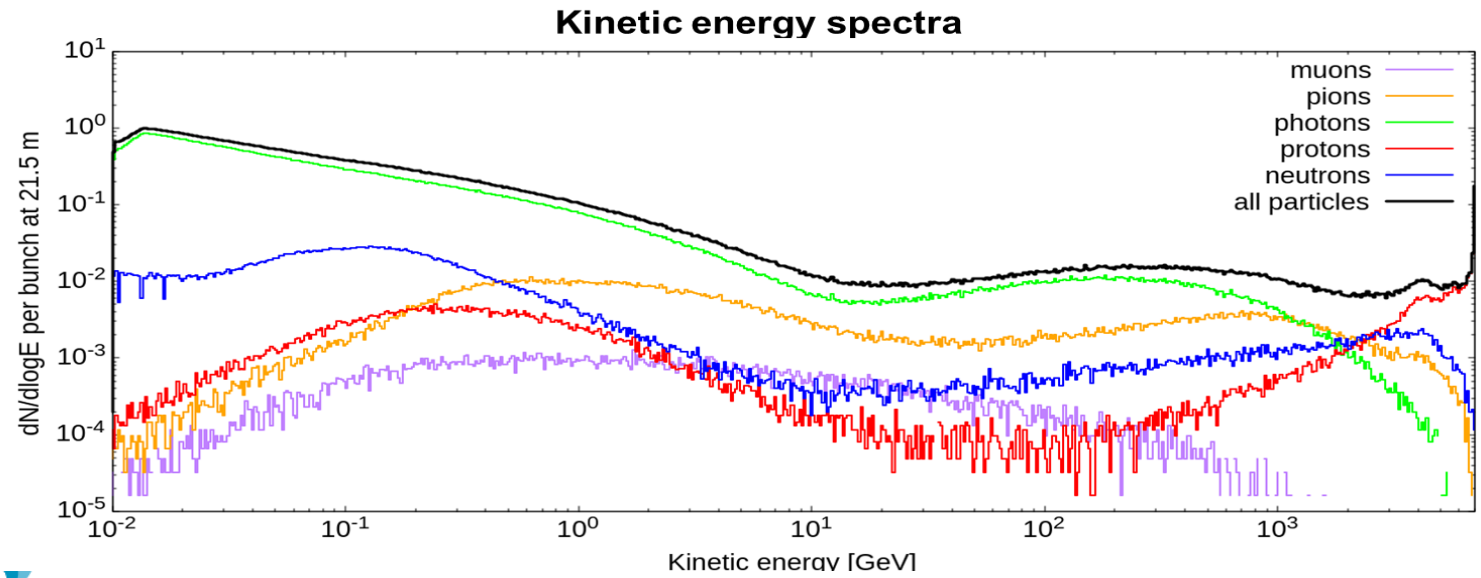
- HL-LHC IR5-CMS right side. Optics v1.5 Nov19.
- Gas composition: pure H_2 assuming an **homogenous** gas density of **10^{14} H_2/m^3**.
- Incoming 7 TeV proton beam. The proton beam size is included in this study.
- A cut of 10 MeV is applied to all types of particles.
- Bunch population 2.2·10^{11} protons per bunch.





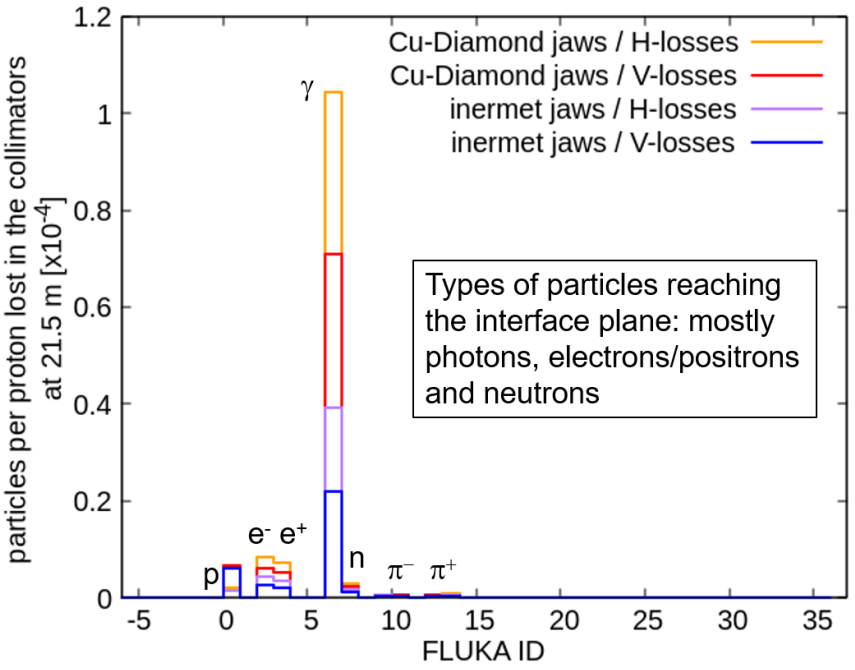
Local beam-gas interaction (II)



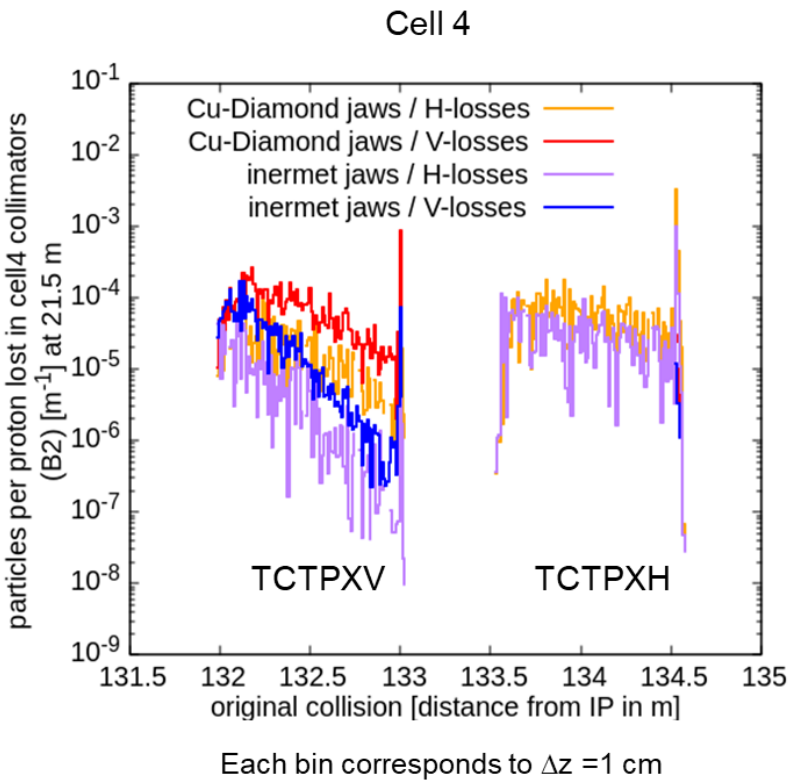


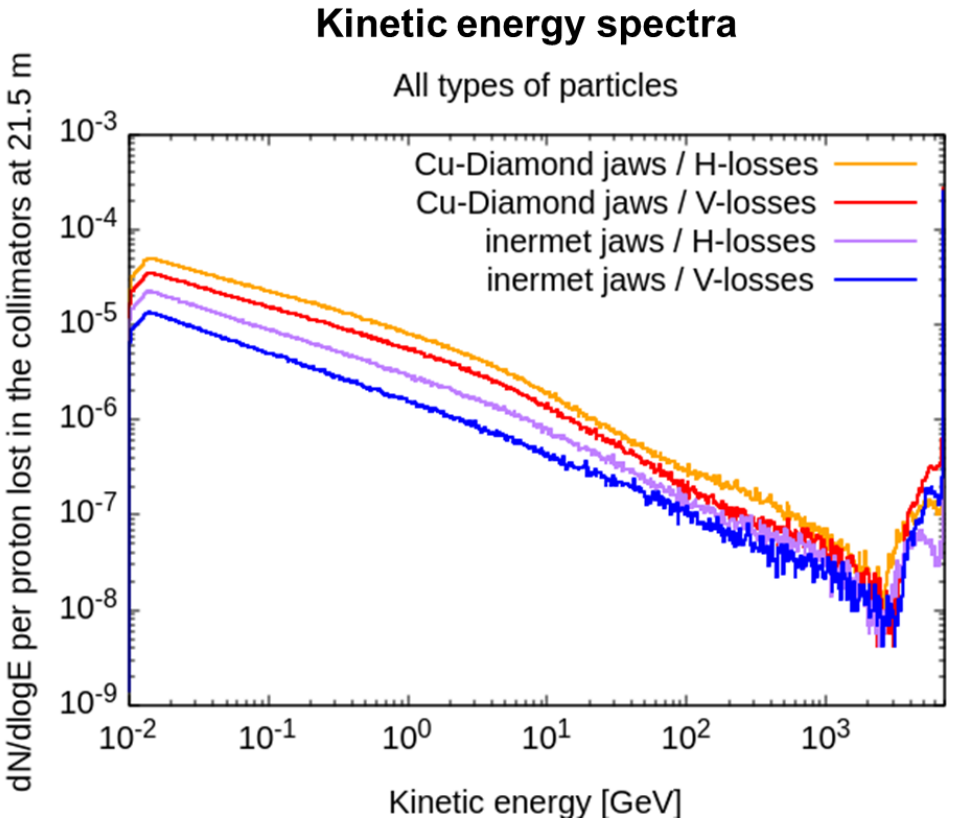
Beam-halo from the betatron collimation in IR7 (I)

- HL-LHC IR5-CMS right side. Optics v1.5 Nov19.
- Energy cut of 10 MeV is applied for all types of particles.
- HL-LHC touches input:
  - Relaxed conditions: new collimator settings with TCPs at 8.5 σ.
  - Losses in the vertical and the horizontal plane.
  - Optics: β^* = 20 cm.
- Two material for the TCTPs jaws:
  - Inermet.
  - Copper-diamond.



Beam-halo from the betatron collimation in IR7 (II)



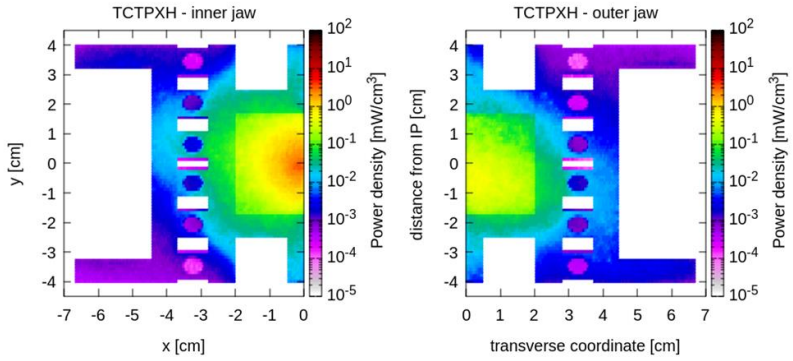


Power deposition in TCTP/Xs

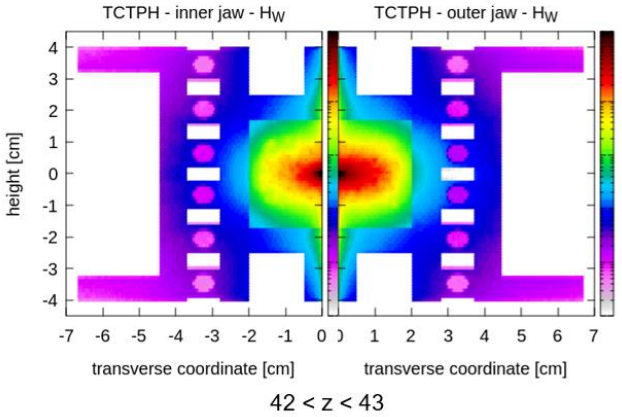
- The thermal loads in the tertiary collimators due to beam-gas interaction (< 100 mW) and beam halo contributions (< 3 W) are negligible compared with the loads due to collision debris in the TCLPX (~230 W in the most exposed jaw for 7.5 Lo).

Power deposition in the most exposed tertiary collimators due to:

beam-gas interaction



beam-halo



Perspectives for HL-LHC optics v1.6

- Implementation of the layout modifications.
- Evaluation of the impact of the new layout in terms of energy deposition and machine protection.
- Inclusion of the Roman Pots: impact of its presence in the rest of the machine.
- Comparison between round and flat optics.

Thank you for your attention

Important input from:

R. De Maria, P. Fessia, R. Longo, P. Tavares,

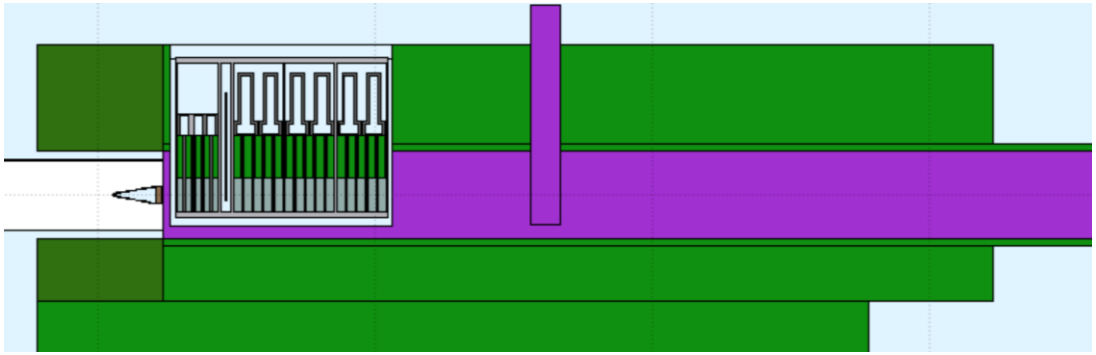
J. Perez Espinos, R. Perez Martinez, F. Sanchez Galan,

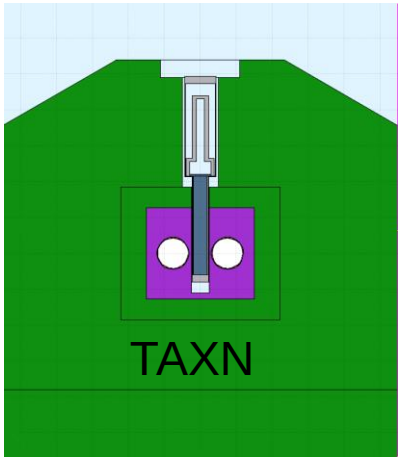
R. Bruce, D. Calzolari, A. Lechner, B. Lindström,

C. Accettura, F. Carra, F-X Nuiry, S. Redaelli

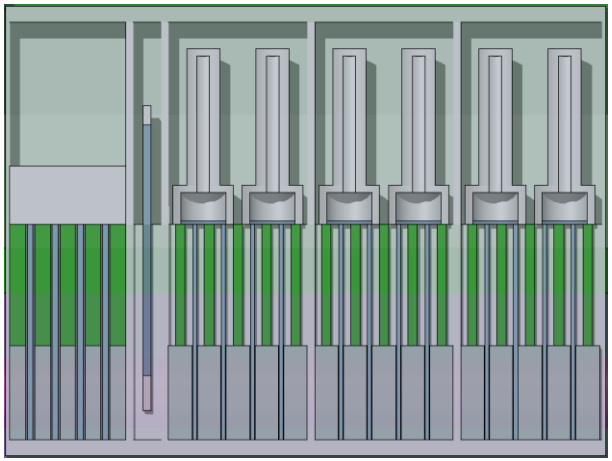
TAXN region:

ZDC experimental conditions



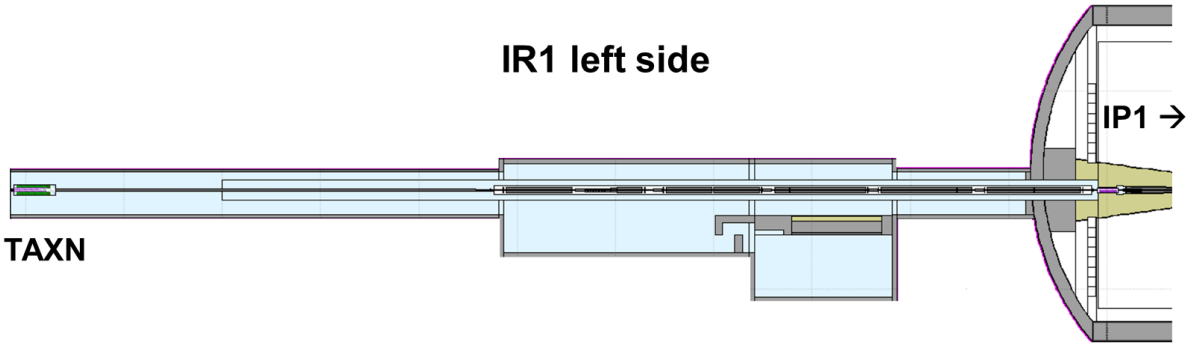


ZDC detector for HL-LHC

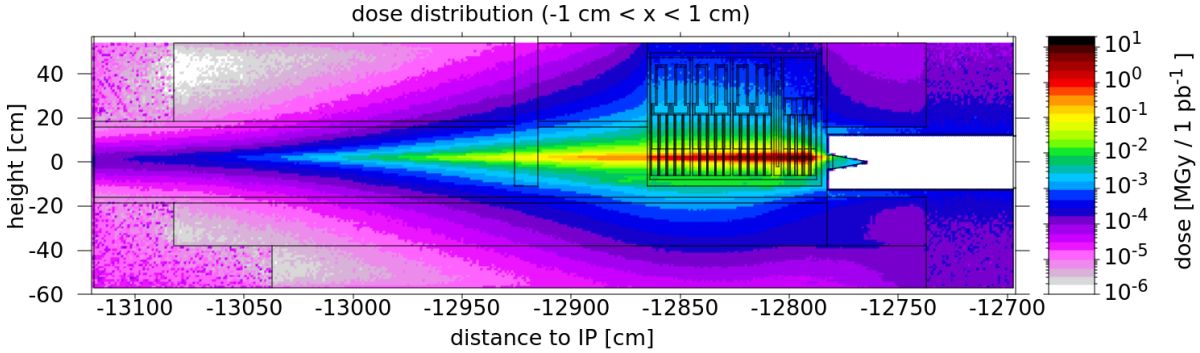


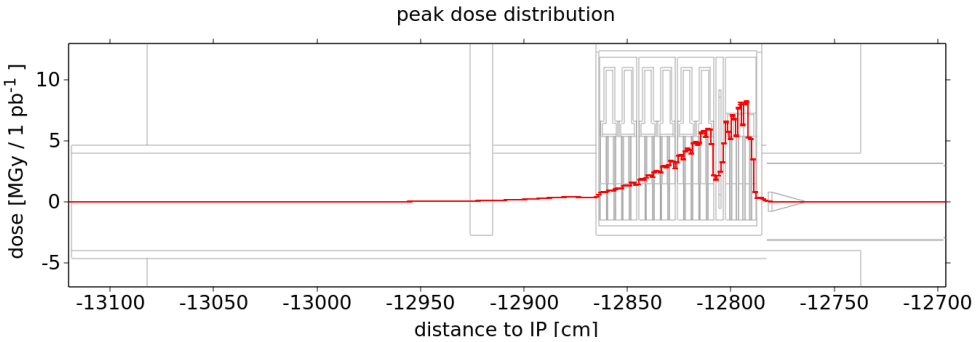
Pb-p collisions : Pb-side

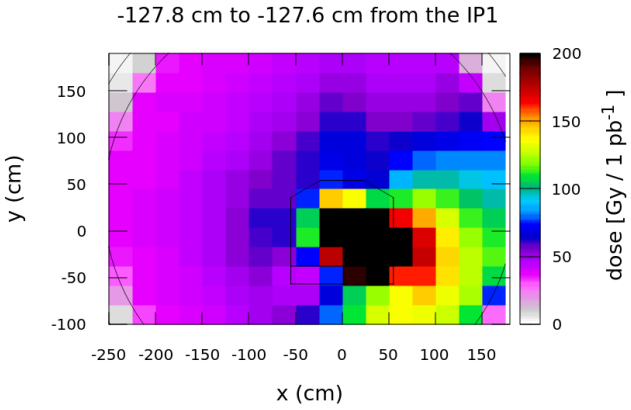
- **HL-LHC** machine. Optics **v1.5** (May 2019). **IR1 – ATLAS**.
- **V**ertical **C**rossing → **+170 μrad** half crossing angle.
- **Left side** of the IP. Results can be extrapolated to IR1-right side.
- β*=15 cm at IP.
- **7 TeV energy per charge per beam: $\sqrt{S_{NN}}$ = 8.8 TeV**.
- **Inelastic Nuclear Interactions** (**2.11 b** Pb-p cross section).
- Integrated luminosity for normalization: **1 pb^{-1}**.
- Instantaneous luminosity for Pb-p run **10^{30} cm^{-2} s^{-1}**.

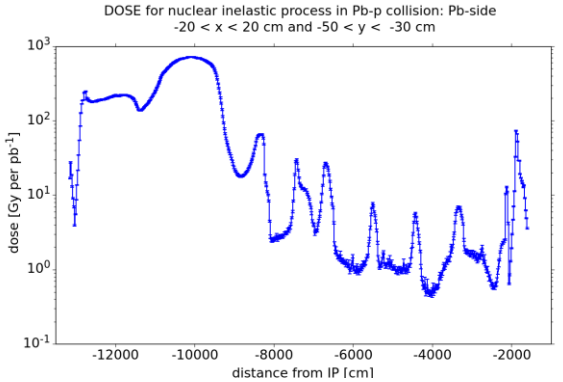


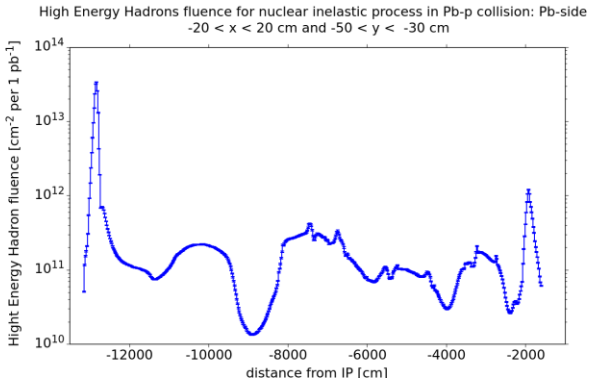
Pb-p collisions : Pb-side

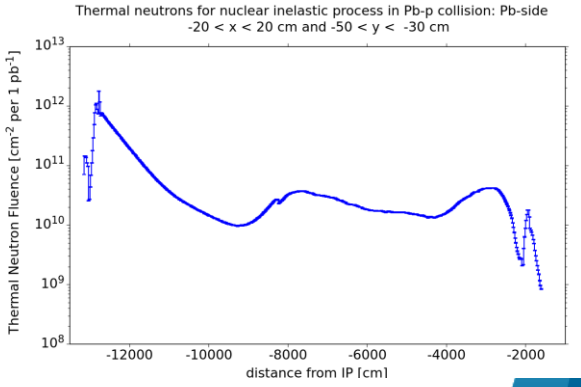






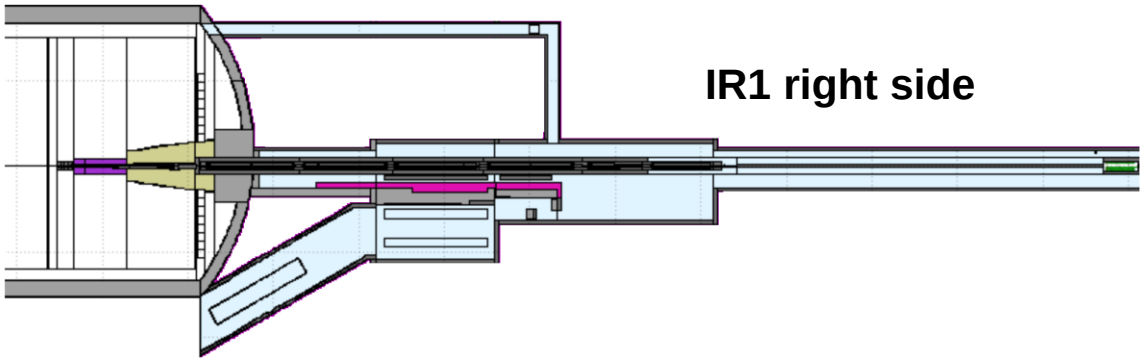




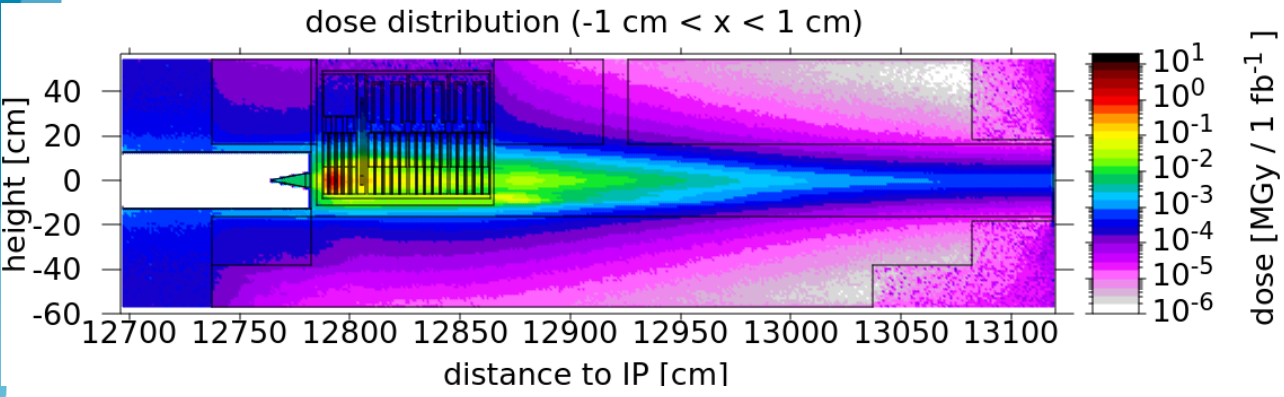


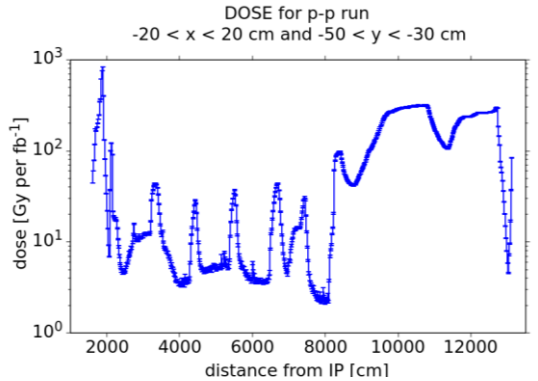
p-p collisions at 14 TeV in IR1

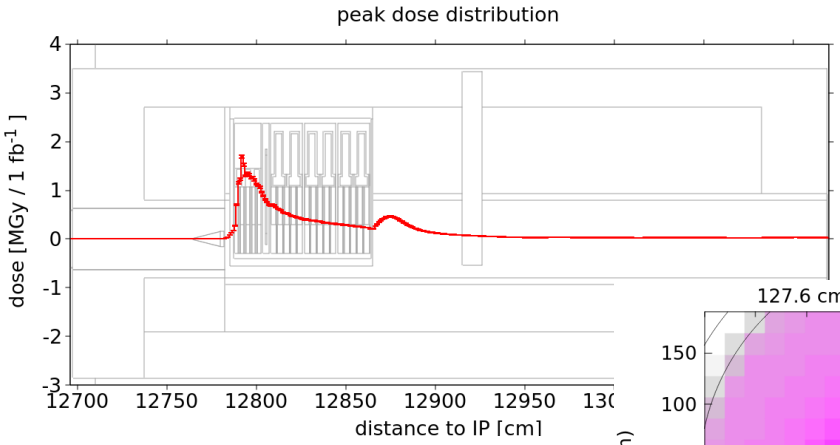
- **p-p collisions**.
- **HL-LHC** machine. Optics **v1.5** (May 2019).
- **IR1 – ATLAS**: right side of the IP1.
- **H**orizontal **C**rossing → **250 μrad** half crossing angle.
- **7 TeV energy per p-beam**.
- Integrated luminosity for normalization: **1 fb^{-1}**.

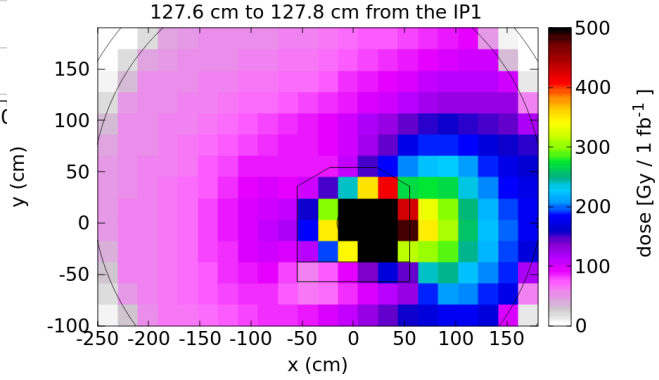


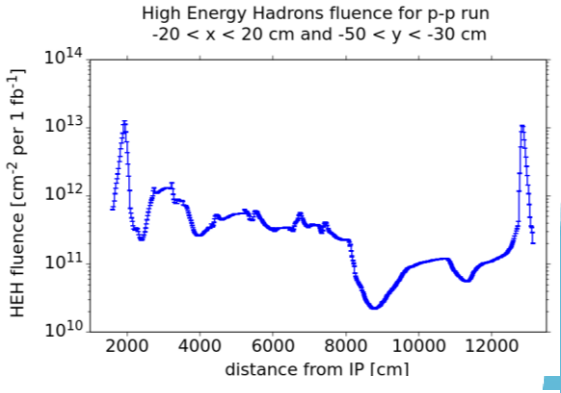
p-p collisions at 14 TeV in IR1

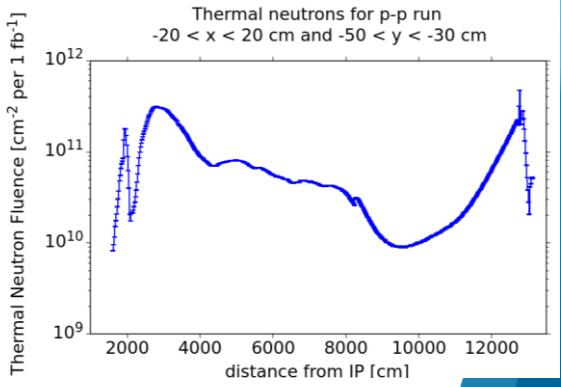






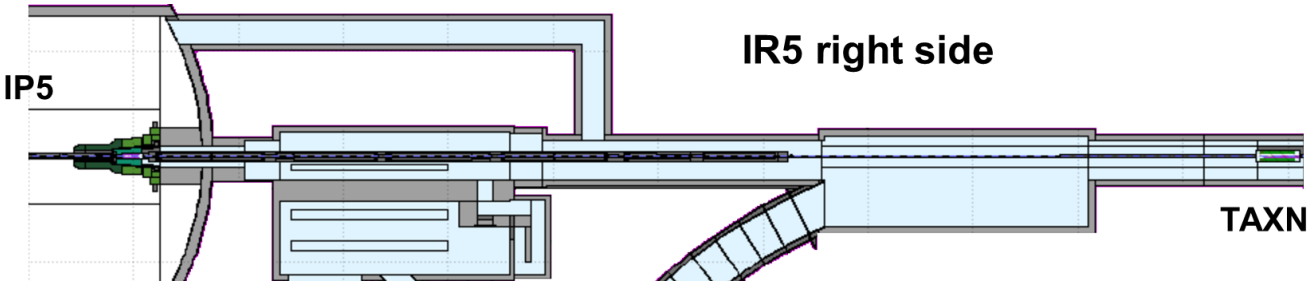






p-p collisions at 11 TeV in IR5

- **p-p collisions**.
- **HL-LHC** machine. Optics **v1.5** (May 2019).
- **IR5 – CMS**: right side of the IP5.
- **V**ertical **C**rossing → **250 μrad** half crossing angle.
- **5.5 TeV energy center of mass** (2.25 TeV per proton beam).
- p-p cross section for 5.5 TeV c.o.m. p-p: **70 mb**.
- Integrated luminosity for normalization: **1 fb^{-1}**.



p-p collisions at 11 TeV in IR5