Energy deposition in optics v1.5 and possible layout optimizations

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WP10

Energy deposition & R2E

9th HL-LHC Collaboration Meeting Fermilab Oct 15th, 2019

OUTLINE

Updates in the layout v1.5 with respect to v1.3:

Impact in the triplet+D1 and the TAXN-Q4 regions

Energy deposition for vertical and horizontal crossing

Diverse studies in optics v1.5:

TAXN twin aperture considerations (85 vs 80 mm)

TAXN absorber length reduction

Possible rotation of Q4-assembly

D1 intentional misalignment

CONTEXT

Point 1 and 5 for HL-LHC machine

Horizontal and Vertical crossing of 250 μrad

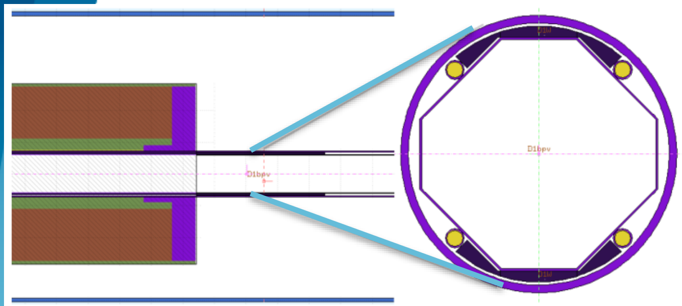
HL-LHC optics version 1.5 (end of May 2019)

Mention of version 1.3 only for comparison reasons

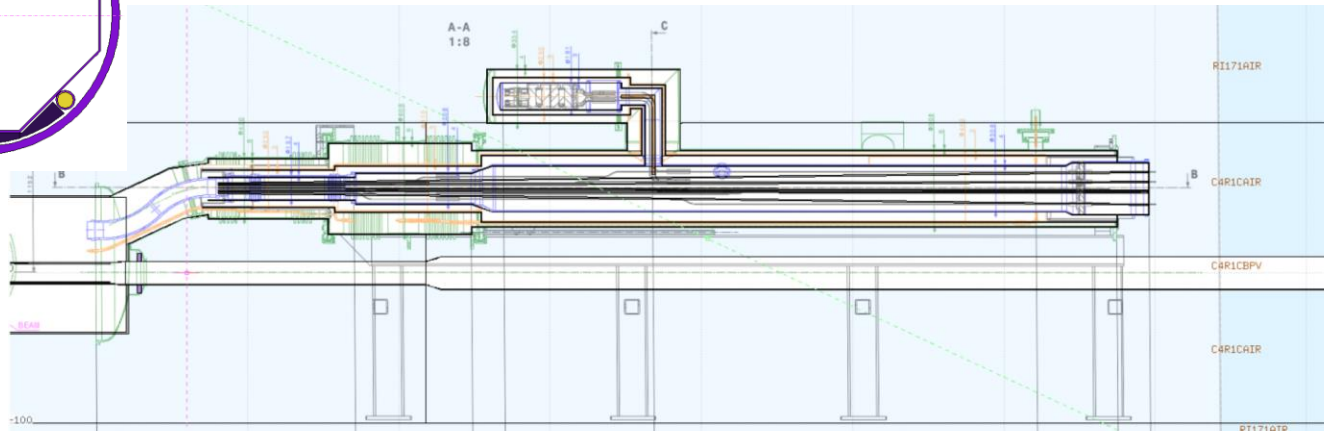
Updates in the layout since v1.3

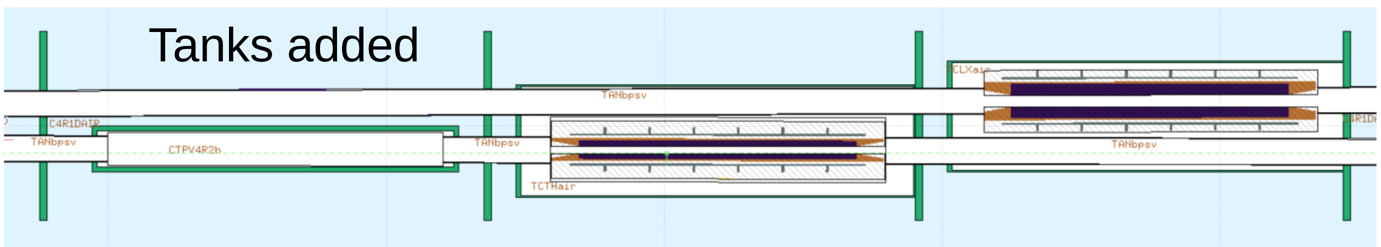
Updates in the layout since v1.3 for HL-LHC

- Revision of the **vacuum layout from TAXS to Q7**.
- Update on the triplet-D1 **IC** model.
- Inclusion of **end covers** of the thermal shield in the triplet+D1 and D2 cryostats.
- Update of the **CP** magnetic and mechanical lengths.
- **D1 beam screen extension**:
  - Prolongation of the BS: modification of the inermet shielding and the horizontal aperture.
- Inclusion in the geometry of the **Cold Diode at the end of D1**.
- Increase **TAXN beam separation** from 148 mm-158 mm to 151 mm-161 mm.
- Implementation of the full model of the **Crab Cavities Cryomodule.**
- Extended dose evaluation for R2E/R2M considerations.

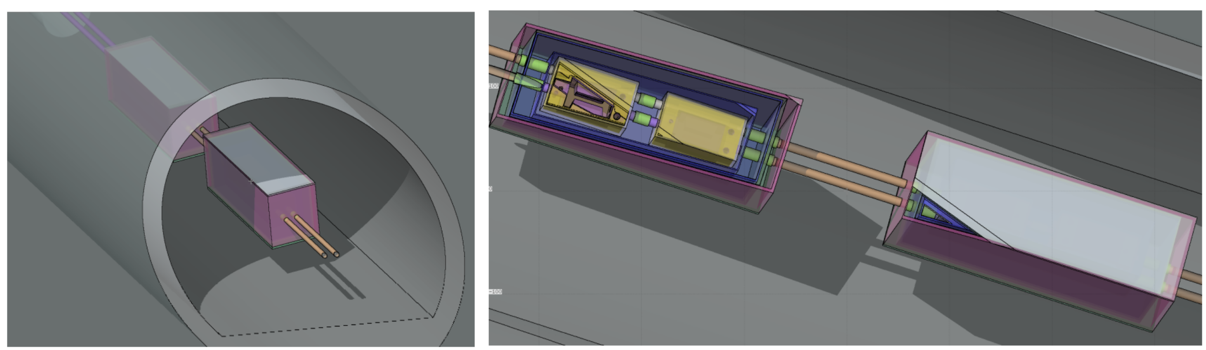


D1 beam screen extension and cold diode





FLUKA model of the collimators region between TAXN and D2.



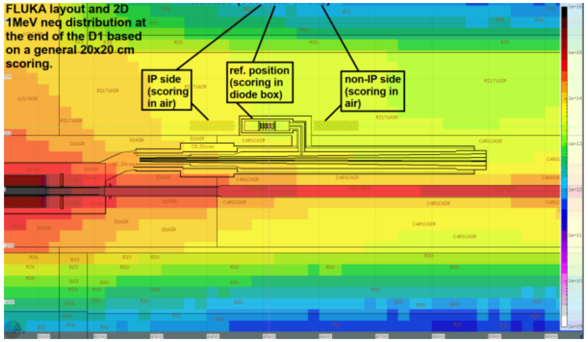
FLUKA prototype for the full crab cavities in the tunnel.

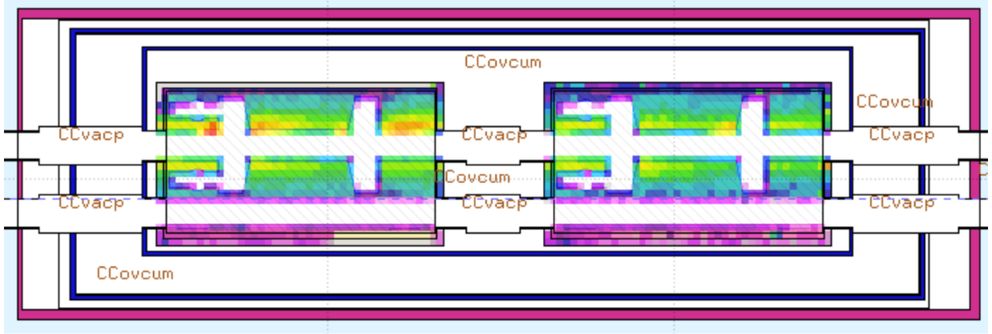
Extended dose evaluation for R2E/R2M considerations

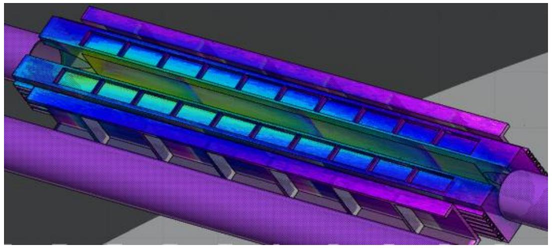
New dedicated scoring implemented for energy deposition studies in specific equipment:

- Crab Cavities.
- Collimator engines for TCTPXV-TCTPXH-TCLPX.
- TCLX4 collimator.
- Cold diode after the D1:

  https://edms.cern.ch/ui/#!master/navigator/document?D:100424717:100424717:subDocs



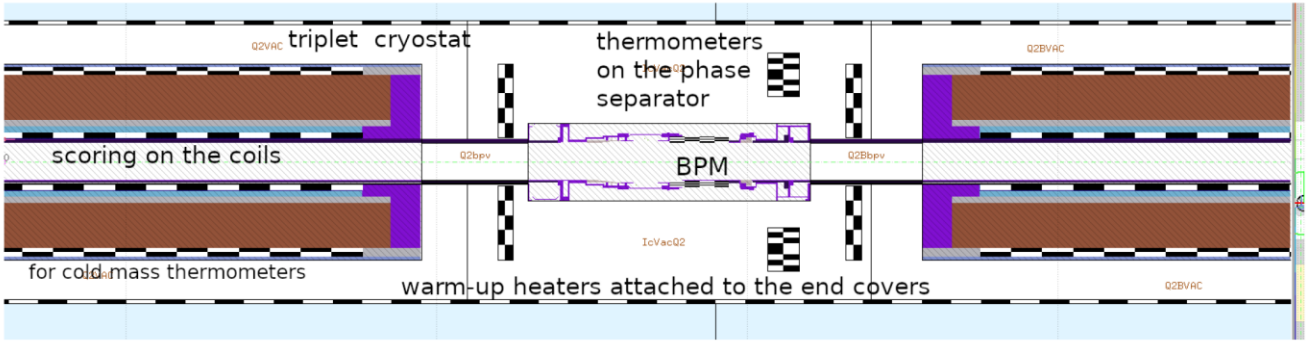




See G. Lerner contribution:
https://indico.cern.ch/event/806637/contributions/3574371/

Extended dose evaluation for R2E/R2M considerations

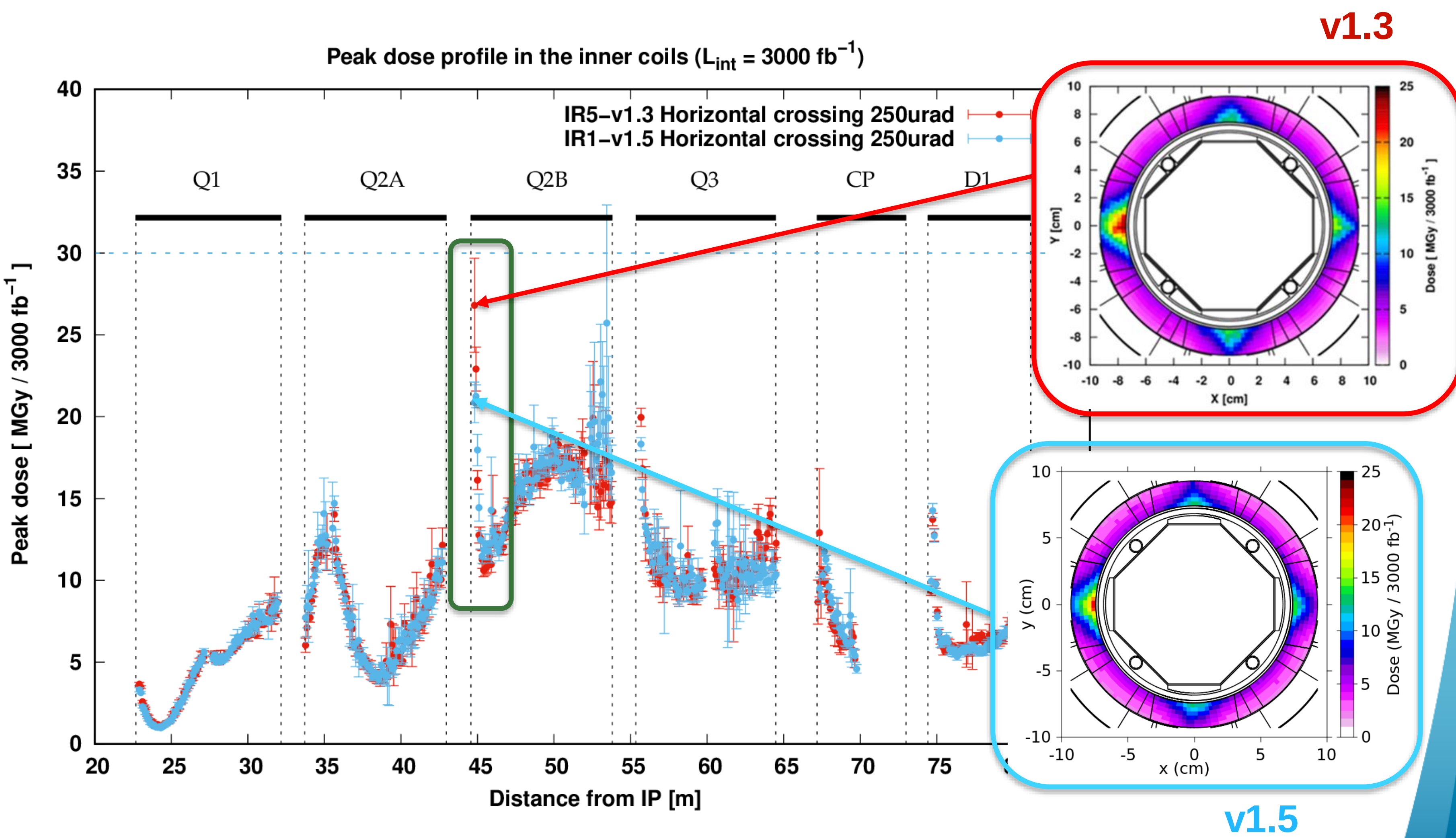
New dedicated scoring implemented for energy deposition studies in specific equipment:



- Cryogenics equipment
  - IT/D2 cold mass thermometers in Q1, Q2, Q3, CP, D1 and D2.
  - IT/D2 warm heaters: placed on the end covers of the thermal shield.
  - IT thermometers on the phase separator.
  - IT/D2 beam screen heaters and thermometer inlet side.
  - https://edms.cern.ch/ui/#!master/navigator/document?D:100451746:100451746:subDocs

See G. Lerner contribution:
https://indico.cern.ch/event/806637/contributions/3574371/

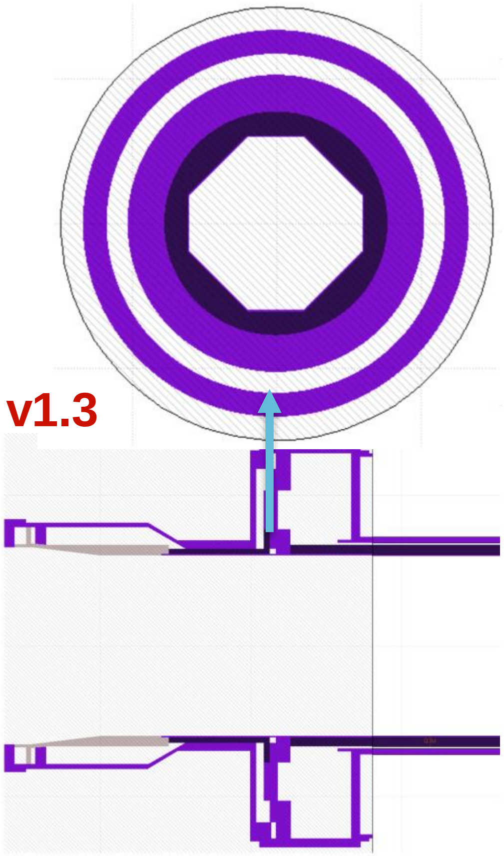
Impact in the triplet+D1 region: horizontal crossing



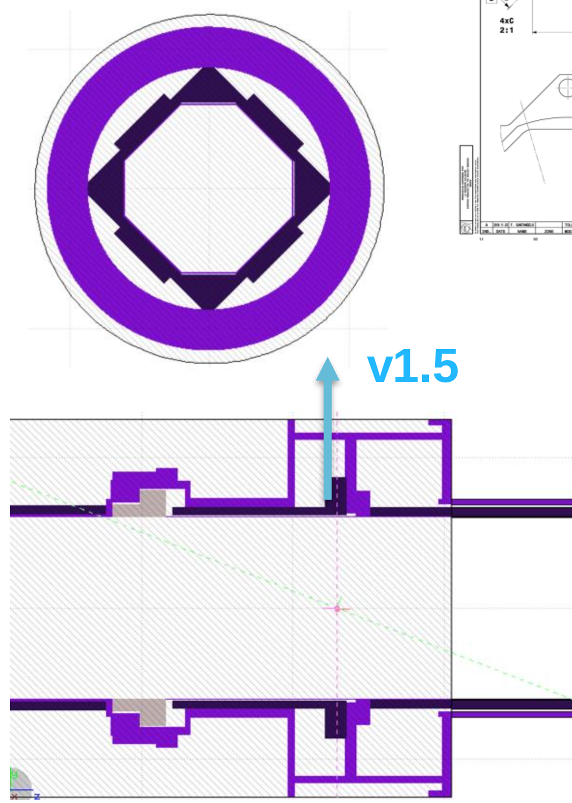
Changes in the design of the triplet IC

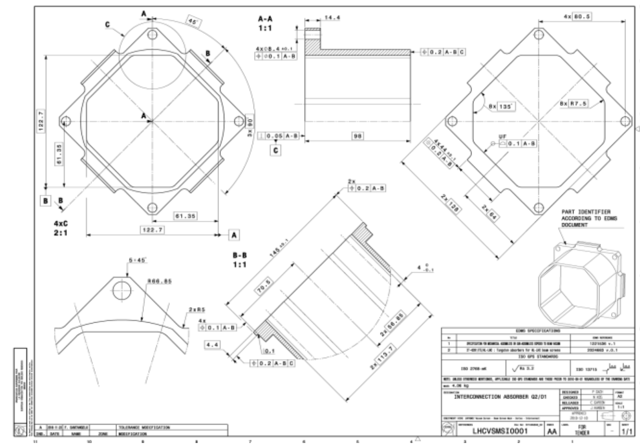
- The 11.5cm inermet block on the non-IP side of the IC is as follow:

v1.3

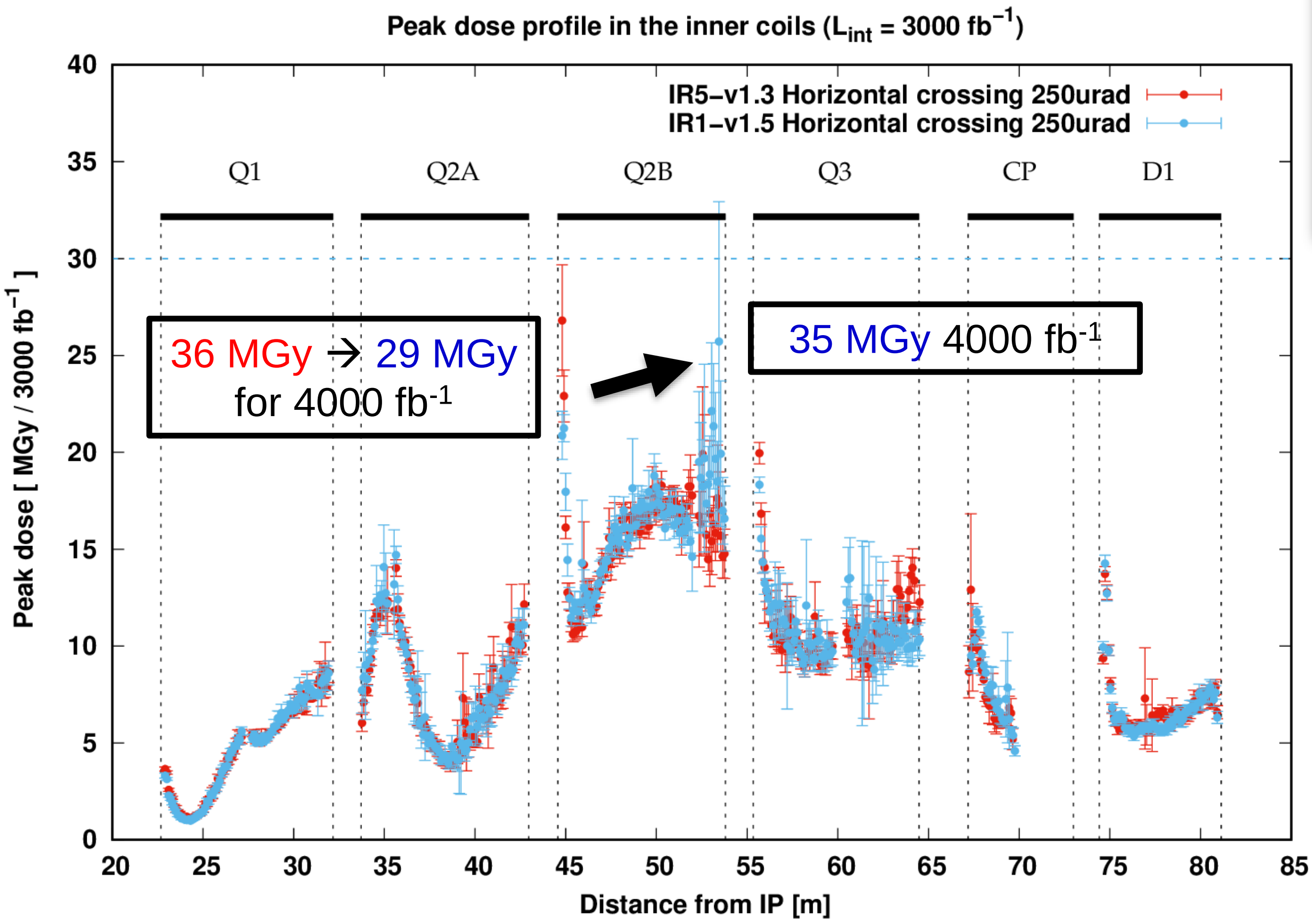


v1.5





Impact in the triplet+D1 region: horizontal crossing



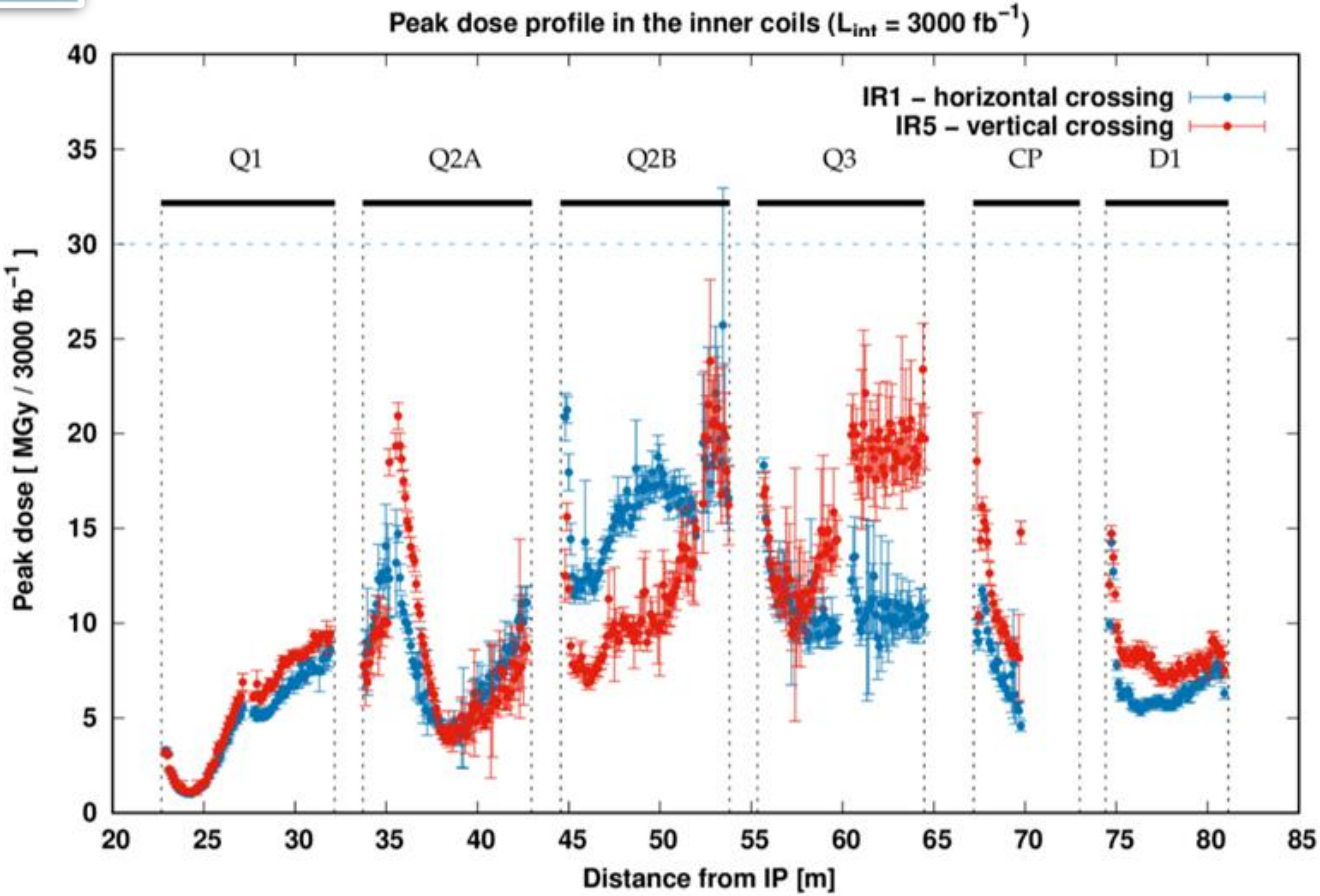
Now the hottest point lies on the Q2B-corrector instead on the quadrupole itself.

v1.3 Horizontal crossing in IP5

v1.5 Horizontal crossing in IP1

Peak dose distribution along the IT
Horizontal vs. Vertical crossing

v1.5



Energy deposition in the IT

Ultimate operation: L_{int}=7.5·10^{34} (cm^{-2} s^{-1})

Maximum dose

- The front face of Q2B was the most exposed point in the IT for horizontal crossing with a maximum dose of 36 MGy for ultimate conditions in v1.3. The inclusion of the latest design of the IC shows a reduction of few MGy in Q2B being now the Q2B-corrector the most exposed region (35 MGy).
- In case of vertical crossing, the hottest spot was at the beginning of the orbit corrector in the CP and now is moved to the Q2B-corrector with a maximum dose of 33 MGy.

Max. power density

- The maximum power density in the triple-D1 string is ~3 mW/cm^3 in the Q2B orbit corrector, for vertical and horizontal crossing.

	HC	Cold mass	Beam screen	VC	Cold mass	Beam screen
Total power in IT		861 W	734 W		926 W	786 W

Matching section

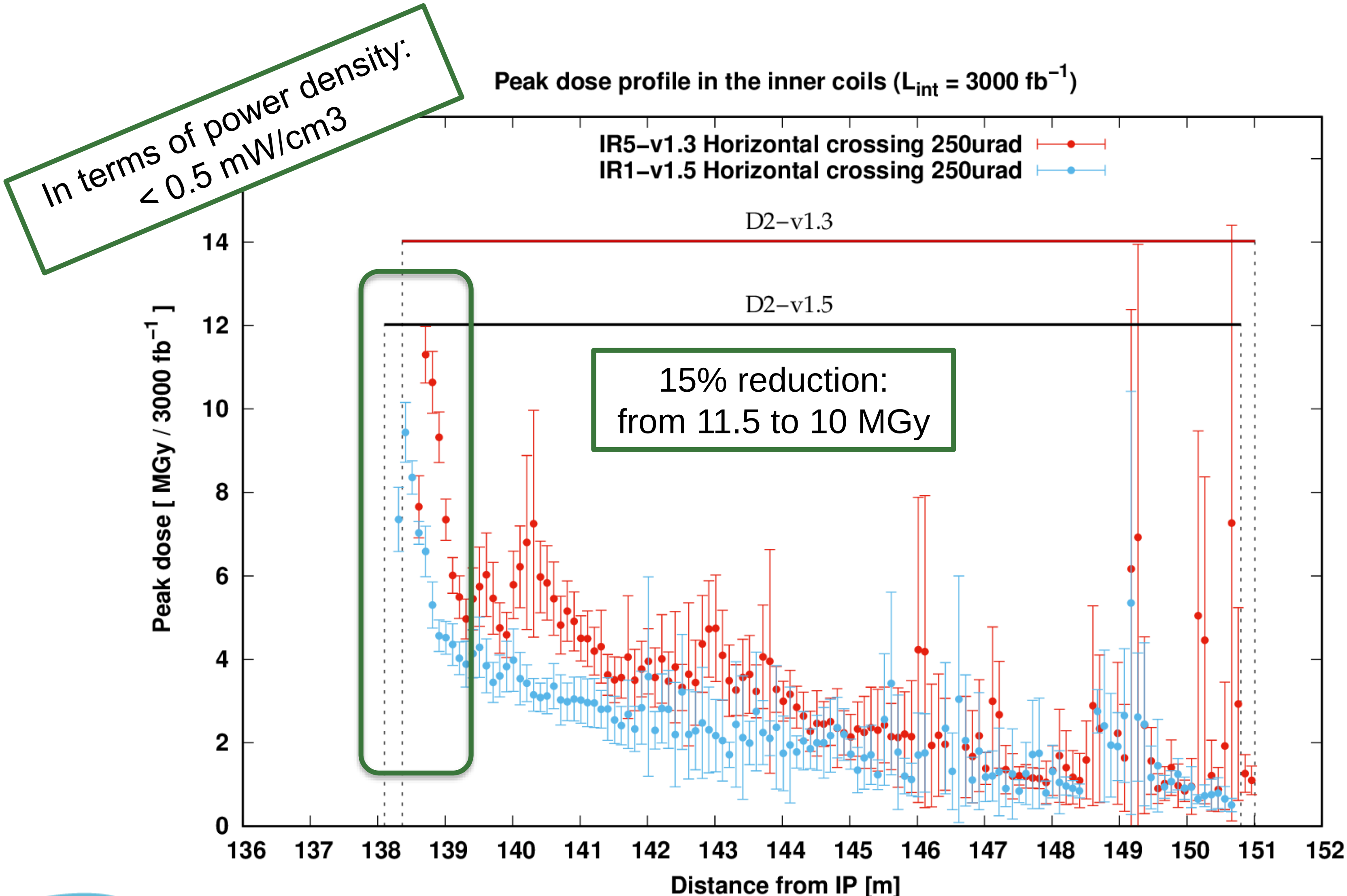
v1.3 vs. v1.5: Total Power

Power in W	Horizontal crossing		Vertical crossing	
	v1.3	v1.5	v1.3	v1.5
TAXN	819	930	1087	1178
TCLX4 int/ext	156 / 89	147 / 102	25 / 53	25 / 54
D2-assembly	33	24	17	12
TCLM4	20	20	20	22
Q4-assembly	8	8	7	6

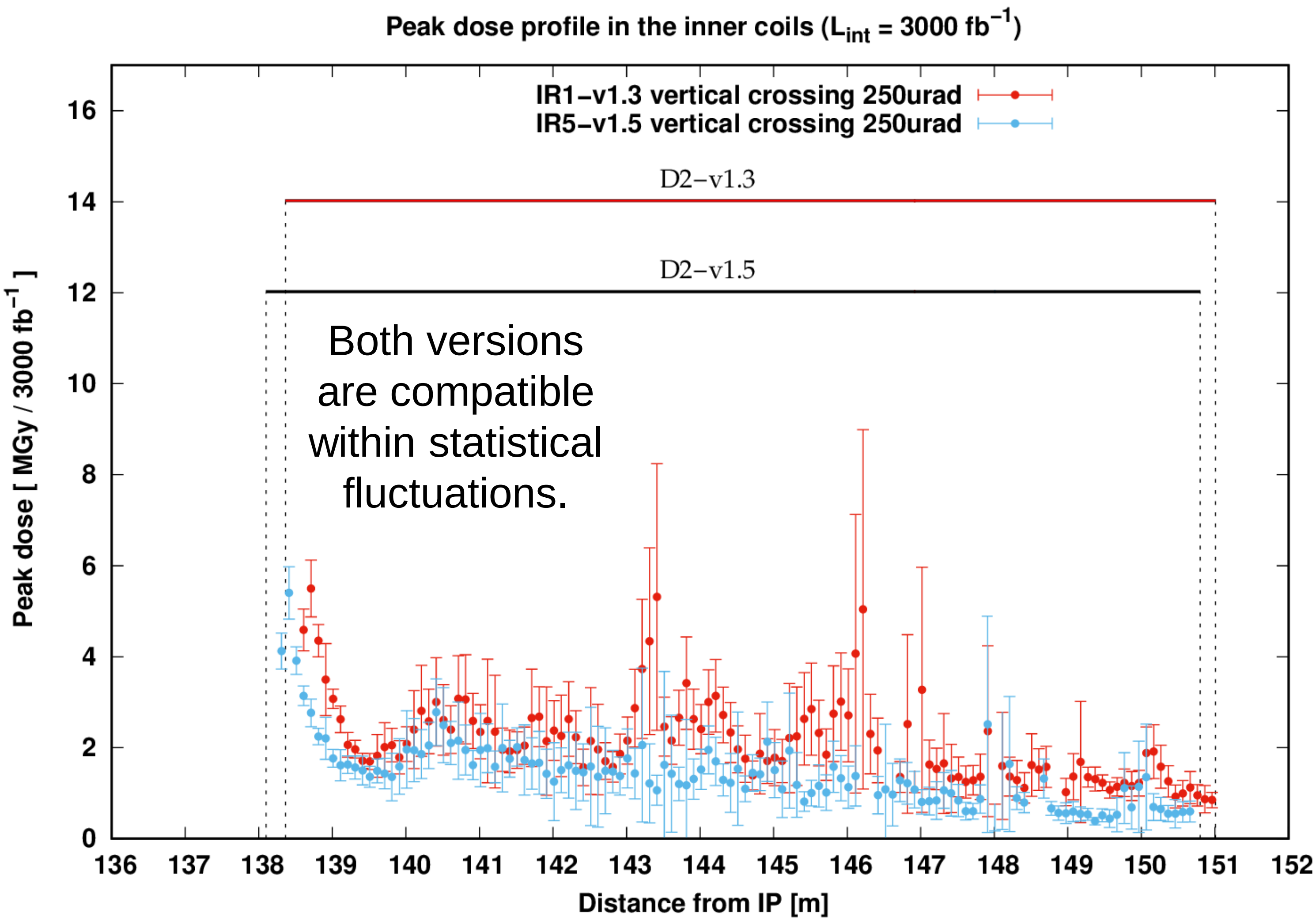
Beam separation: **148mm-158mm** (v1.3) **151mm-161mm** (v1.5)

$L_{int}=5\cdot10^{34}$ ($cm^{-2}\ s^{-1}$) and σ(p-p collision) = 85 (mb)

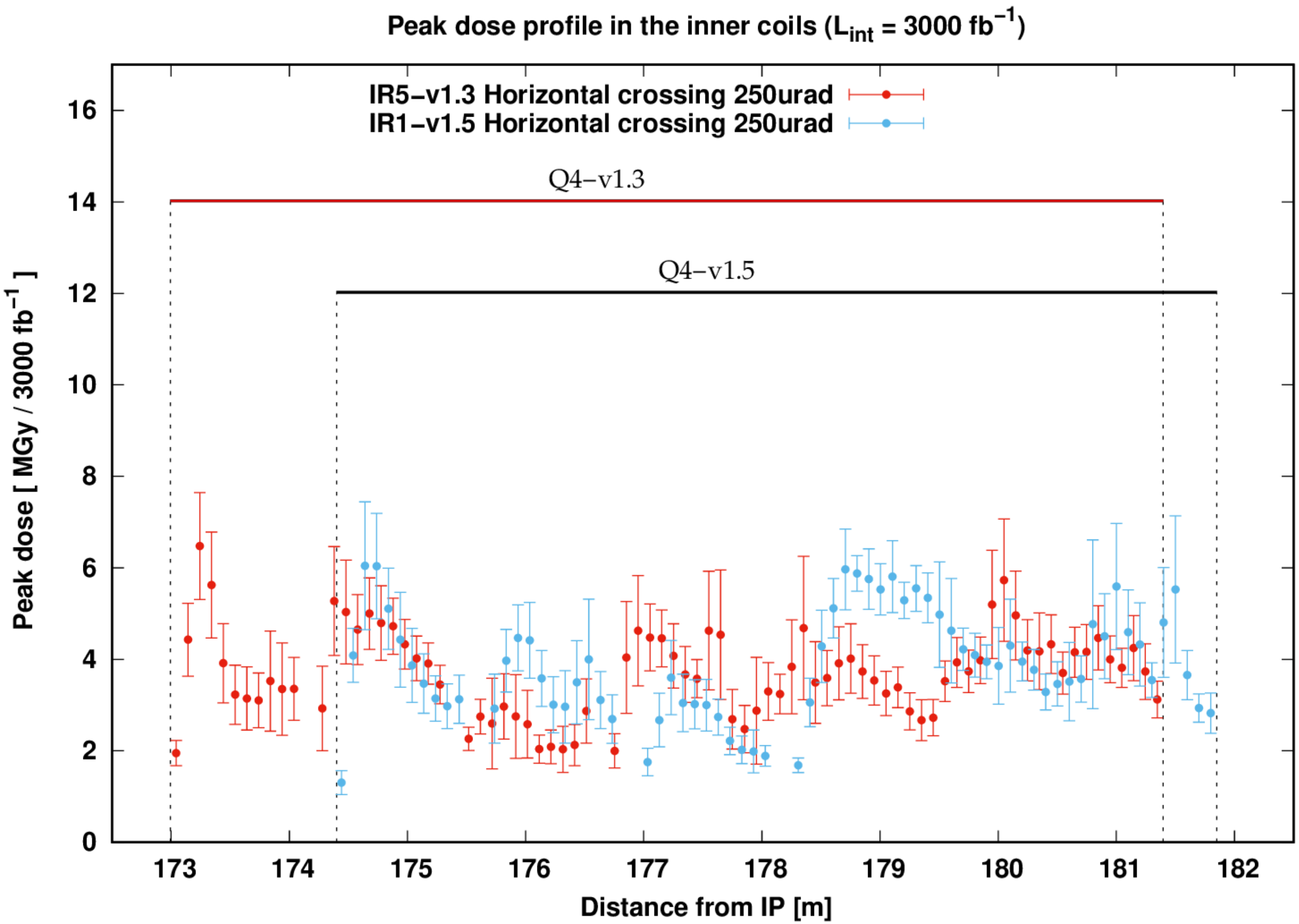
v1.3 vs. v1.5 for horizontal crossing: effect on D2



v1.3 vs. v1.5 for vertical crossing: effect on D2

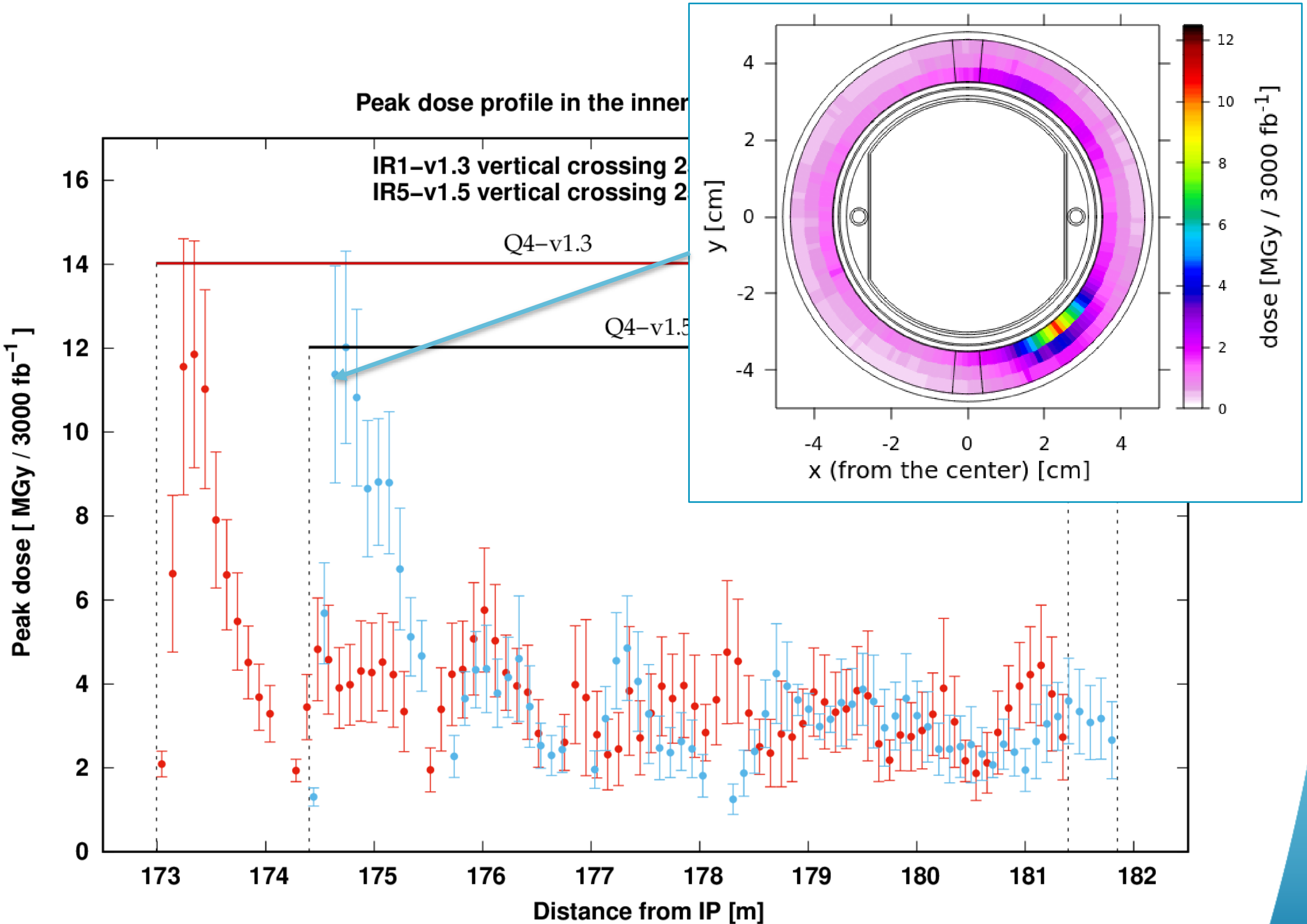


v1.3 vs. v1.5 for horizontal crossing: effect on Q4



Note:
4-corr.
in v1.3
vs.
3-corr.
in v1.5

v1.3 vs. v1.5 for vertical crossing: effect on Q4



Note:
4-corr.
in v1.3
vs.
3-corr.
in v1.5

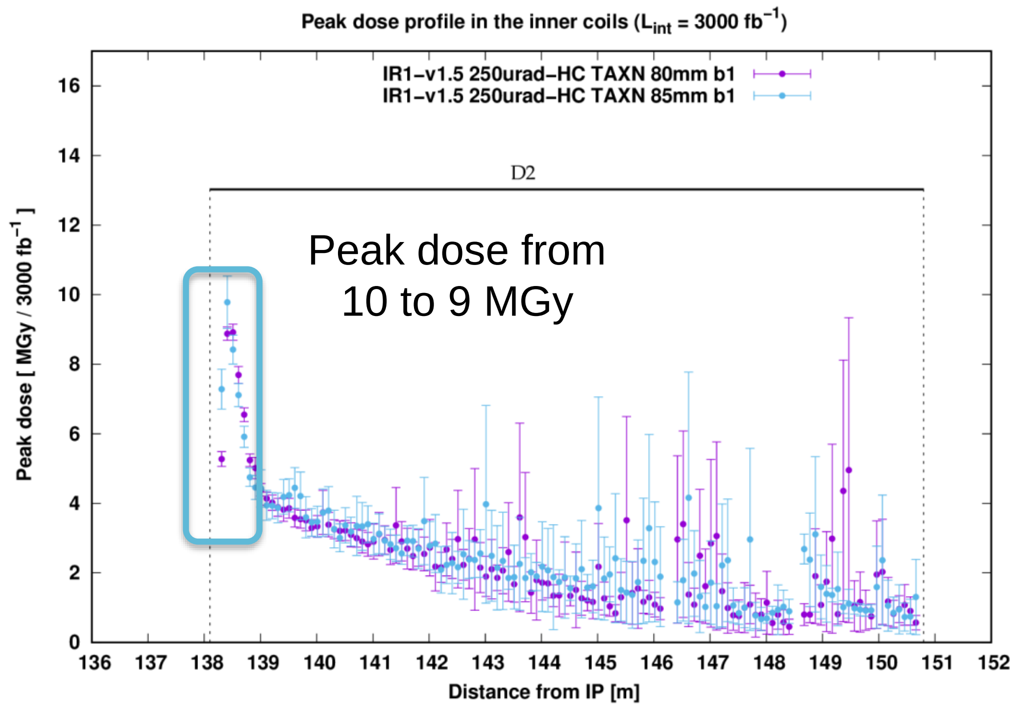
Various studies in optics v1.5 for horizontal crossing (IP1)

TAXN twin aperture considerations: 85 vs. 80 mm

- Twin apertures of the TAXN Y-chamber.
- Horizontal crossing of 250 μrad (IP1 v1.5).
- The vacuum layout between TAXN and D2 depends on the TAXN twin aperture: ID=90 mm in case of 85 mm or ID=80 mm in case of 80 mm.
- Study the impact on the D2 when reducing the TAXN aperture from 85 mm down to 80 mm.

A minor gain

Total power (W)	85mm	80mm
TAXN	930	997
TCLX4-int	147	97
TCLX4-ext	102	89
D2-assembly	24	22

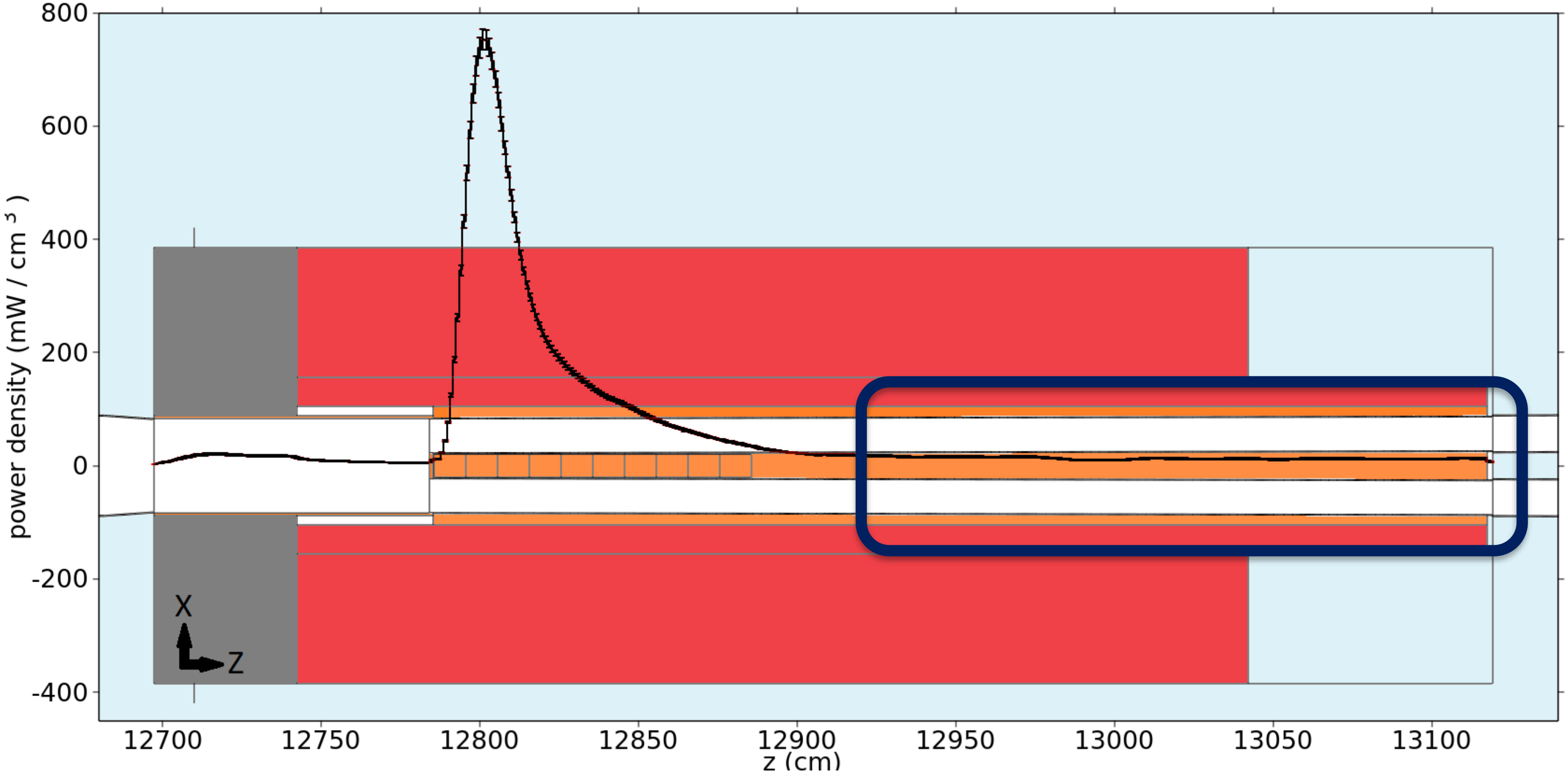


- Around ~65 W taken by the TAXN and removed from the TCLX4 jaws.
- 10% reduction on the D2.
- No effect on Q4 nor in the MCBYs correctors.

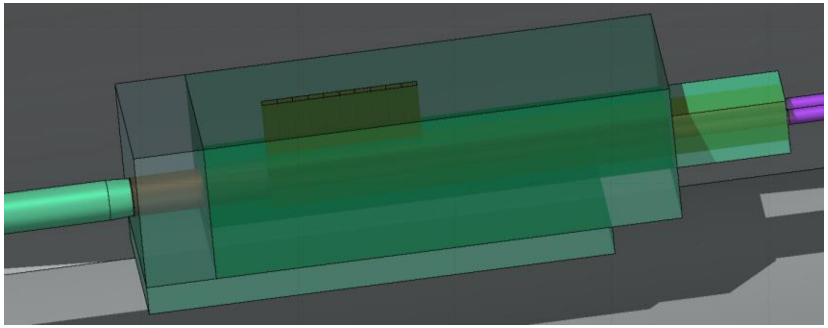
TAXN absorber lenght reduction

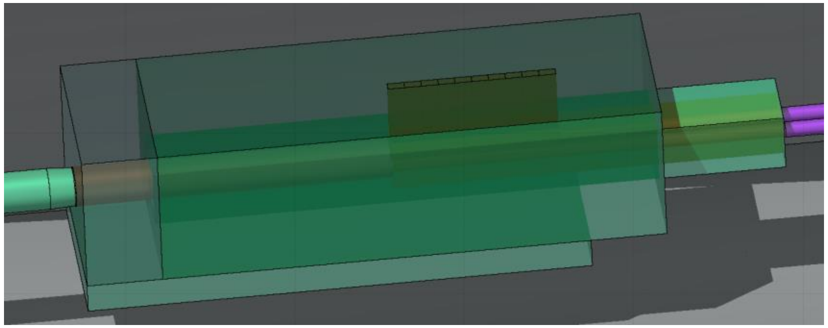
- Energy deposition studies show that the maximum of the power density delivered to the internal copper shielding in the TAXN occurs at 15 cm in depth with the present absorber, going down rapidly.
- There is the possibility to reduce the length of the copper in order to save material in the design and gain space.
- Action: study the effect of reducing by 1 m the absorber length.

Energy deposition profile along the TAXN



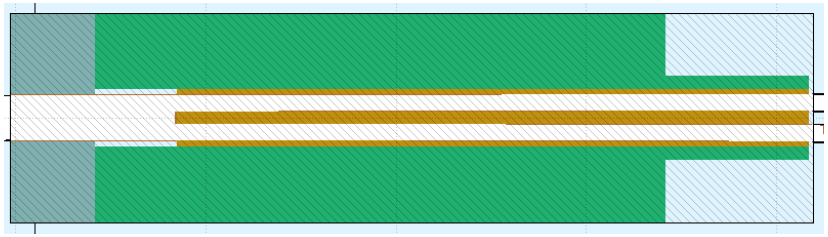
FLUKA model adjustment

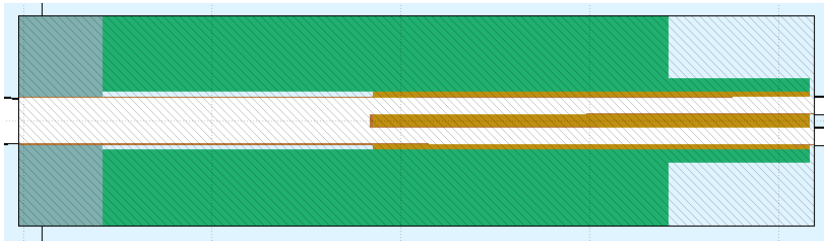




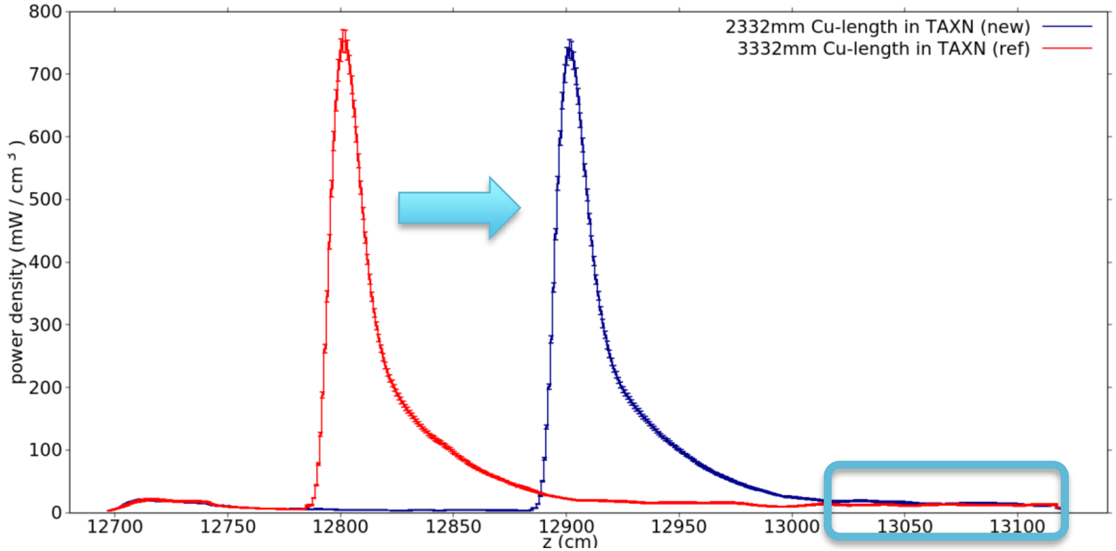
Reference case: 332 cm

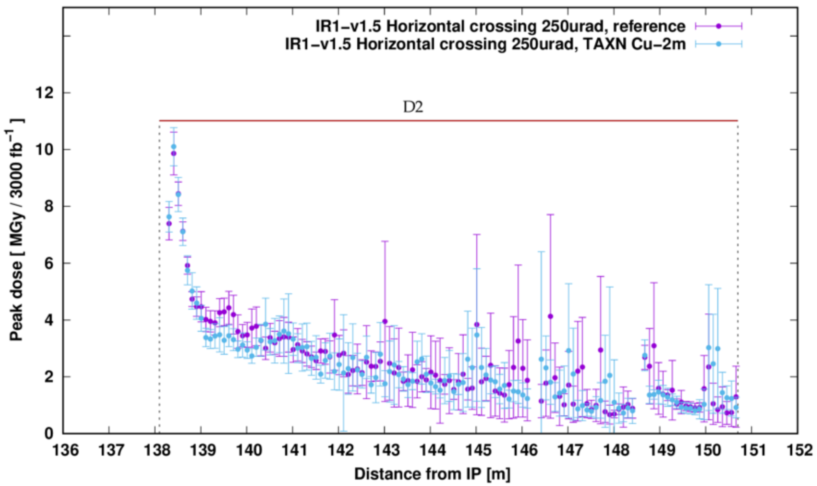
Cu-block reduced in length: 232 cm





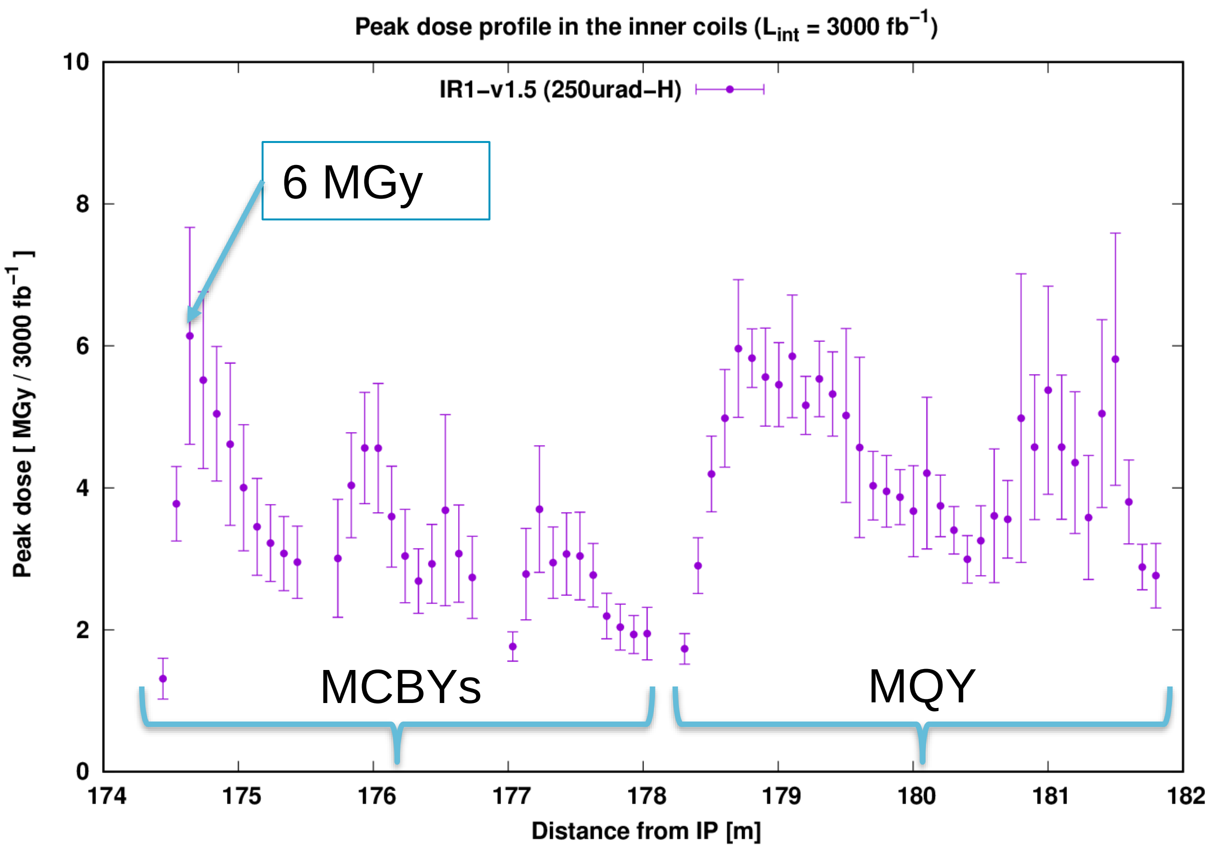
Effect of reducing the length of the absorber





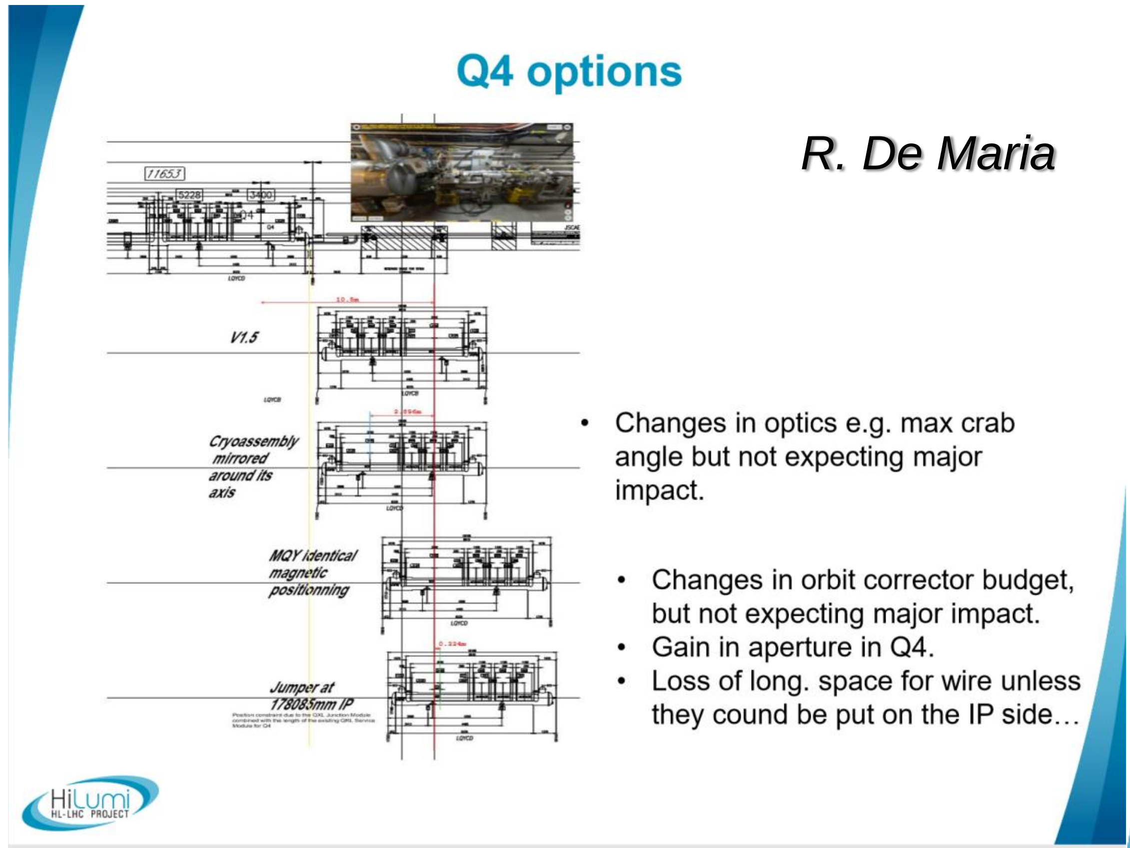
Power in W	Cu reduction	ref
TAXN	933	930
D2-assembly	25	24

- **Problem of the Dose to the Q4 MCBY correctors: possible rotation of Q4-assembly**



Q4-assembly rotation

- The MQY does not move.
- This change could help to protect the MCBYs.

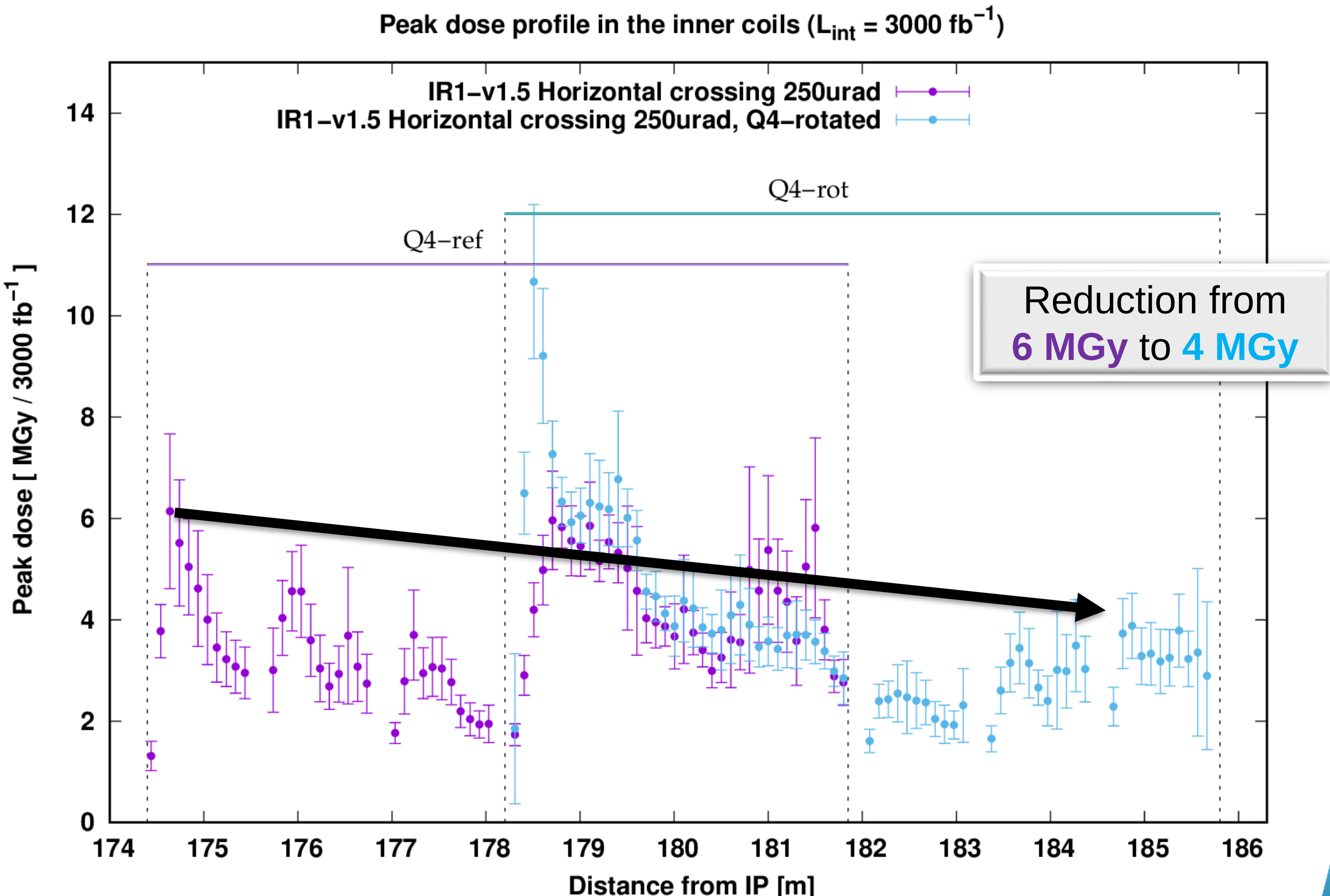


Total Power

Power in W	Horizontal	crossing
	Q4-rotated	**ref**
TCLM4 (B1+B2)	21	20
Q4-correctors	3	4
Q4	5	4
Q4-assembly	8	8

$L_{int}=5\cdot10^{34}$ (cm^{-2} s^{-1}) and σ(p-p collision) = 85 (mb)

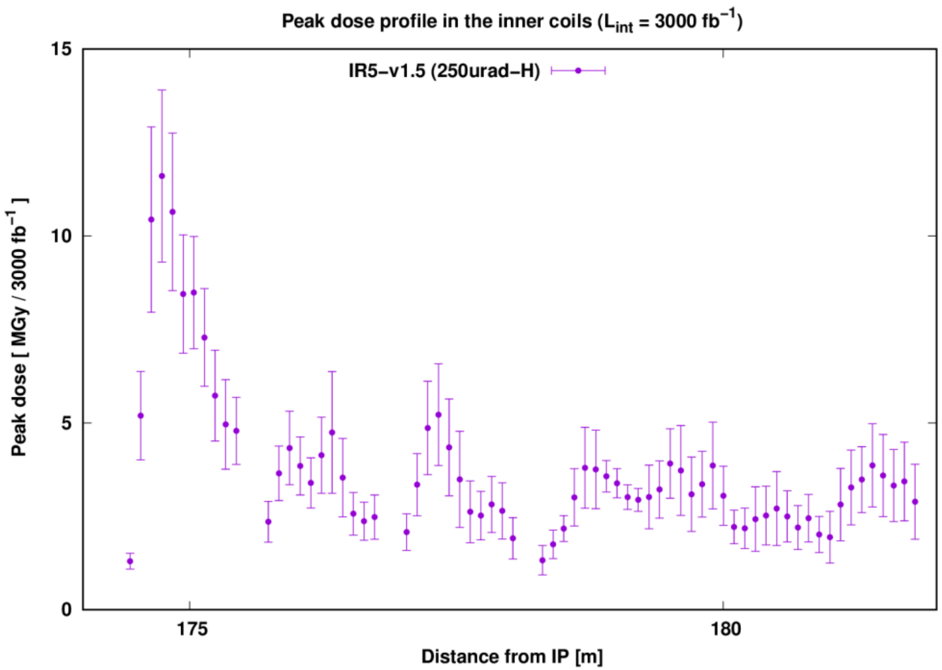
Peak dose distribution in the Q4-assembly

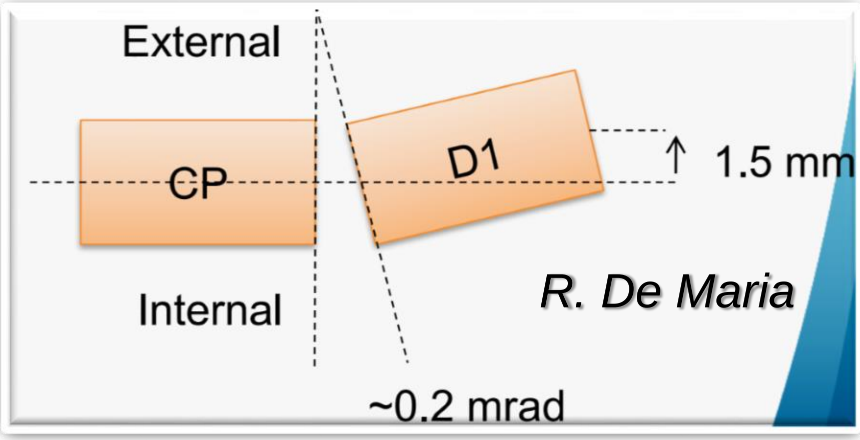


Peak dose distribution in the Q4-assembly

Vertical crossing

- The situation for vertical crossing is worse than for horizontal crossing because the maximum dose at the MCBY front face is above 10 MGy instead of 6 MGy.
- A dedicated study on the Q4-assembly rotation for vertical crossing is on-going.
- The rotation, potentially, can represent an important reduction in the MCBY.

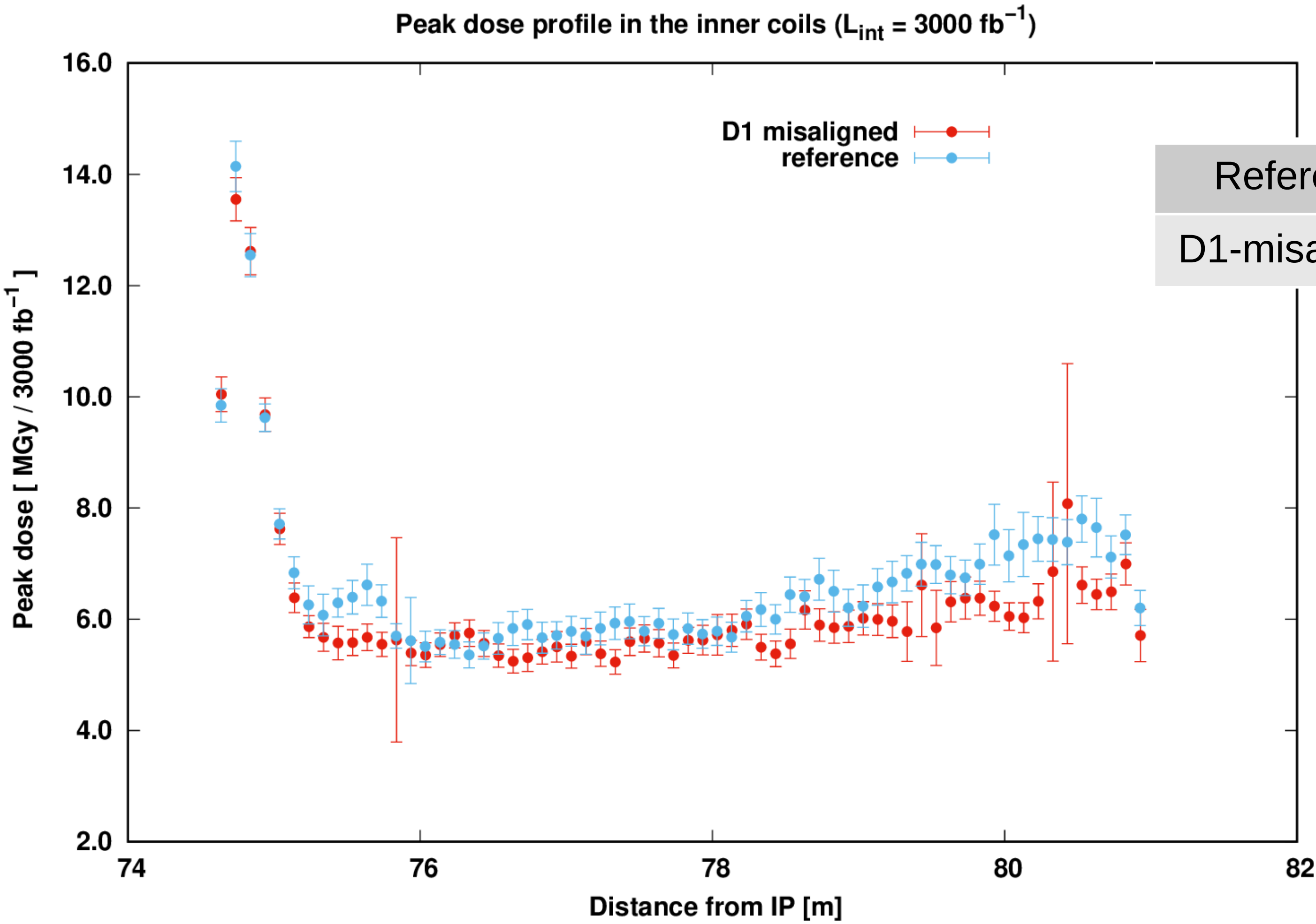




Intentional misalignment of the D1

- Improve D1 aperture by means of tilting the magnet.
- A shift of 1.5 mm towards the external side is considered for D1 as shown in the plot.

Energy deposition along D1
peak dose profile and total power



	Total power (W)
Reference	67
D1-misaligned	64

No significant impact in D1 from energy deposition point of view.

Summary and Conclusions

Updates in v1.5 with respect to v1.3

Horizontal crossing

- The inclusion of the most updated model of the IC in the triplet-D1 region shows an improvement in the dose at the entrance of Q2B, where a reduction of few MGy has moved the most exposed point in the IT to the Q2B-corrector.
- The increase of the beam separation in the TAXN for v1.5 with respect to v1.3 entails a rise in the total power taken by the TAXN (110 W more) together with a reduction of the D2 load (max dose down to 10 MGy and 25% less power).

Vertical crossing

- The radiation levels at the entrance of the Q2B and the OC of the CP is been reduced thanks to the last IC model. Therefore, in v1.5, the most exposed region becomes the Q2B-corrector.
- With respect to HC, the cryogenic load on the triplet-D1 string is larger while the impact on the matching section is less, but for the Q4 assembly front face.

TAXN aperture studies in optics v1.5 for HC

- Possible reduction from 85 mm to 80 mm in the twin aperture of the TAXN Y-chamber was considered.
- For 80 mm, the total power in the TAXN increases by 65 W which are removed from the TCLX4.
- A minor beneficial effect on D2 was found. Both, the maximum dose and the total power in the dipole is reduced by 10% to 9 MGy and 22 W compared to the 10 MGy and 24 W for 85 mm.
- Regarding the energy deposition, there is no strong argument to support the aperture reduction.

TAXN absorber length reduction in optics v1.5 for HC

- The peak of the energy deposition in the internal absorber of the TAXN occurs around 15 cm in depth. In the implemented FLUKA model a length of 332 cm is assumed.
- In order to optimize the TAXN design, an alternative model of the absorber with 232 cm length was considered, keeping the same beam separation at the end of the TAXN.
- Simulations show no effect on the D2 nor in the TAXN itself, meaning that the length of the copper absorber can be safely reduced.

Possible rotation of Q4-assembly in optics v1.5 for HC

- The technology of the MCBYs is not as radiation resistant as the one for the MQY.

- The proposed rotation of the Q4-assembly can protect the MCBYs.

- **Horizontal crossing**: the maximum dose goes down from 6 MGy to 4 MGy.
- **Vertical crossing**: the starting level is 10 MGy. The on-going study will provide the new levels after the rotation.

- Internal shielding would be needed to further reduce the dose level below few MGy. In that case, a fraction of the 70 mm aperture must be sacrificed.

D1 intentional misalignment in optics v1.5 for HC

- The improvement of the D1 aperture requires a misalignment of the magnet.
- A shift of 1.5 mm towards the external side, keeping the IP side on axis, is under consideration.
- Therefore, a dedicated energy deposition study was performed to see the effect on the D1.
- No significant impact in the D1 was observed.

Thank you for your attention

v1.3 vs. v1.5: Total Power on the cold mass

Power in W	Horizontal crossing IP5 v1.3	Horizontal crossing IP1 v1.5	Vertical crossing IP1 v1.3	Vertical crossing IP5 v1.5
Q1A + Q1B	113	110	114	112
Q2A + corr.	99	98	101	101
Q2B + corr.	136	135	126	125
Q3A + Q3B	119	119	134	137
CP	42	45	54	63
D1	67	67	79	79
Total in the IT	576	574	608	617

- Values consistent within uncertainty fluctuations.
- The differences in the CP are due to the changes in the layout.

The loads on the IC is not included in the totals.

$L_{int} = 5 \cdot 10^{34}$ (cm^{-2} s^{-1}) and σ(p-p collision) = 85 (mb)