Energy deposition in the HL-LHC experimental IRs (v1.3)

A. Tsinganis, F. Cerutti (EN/STI/FDA)

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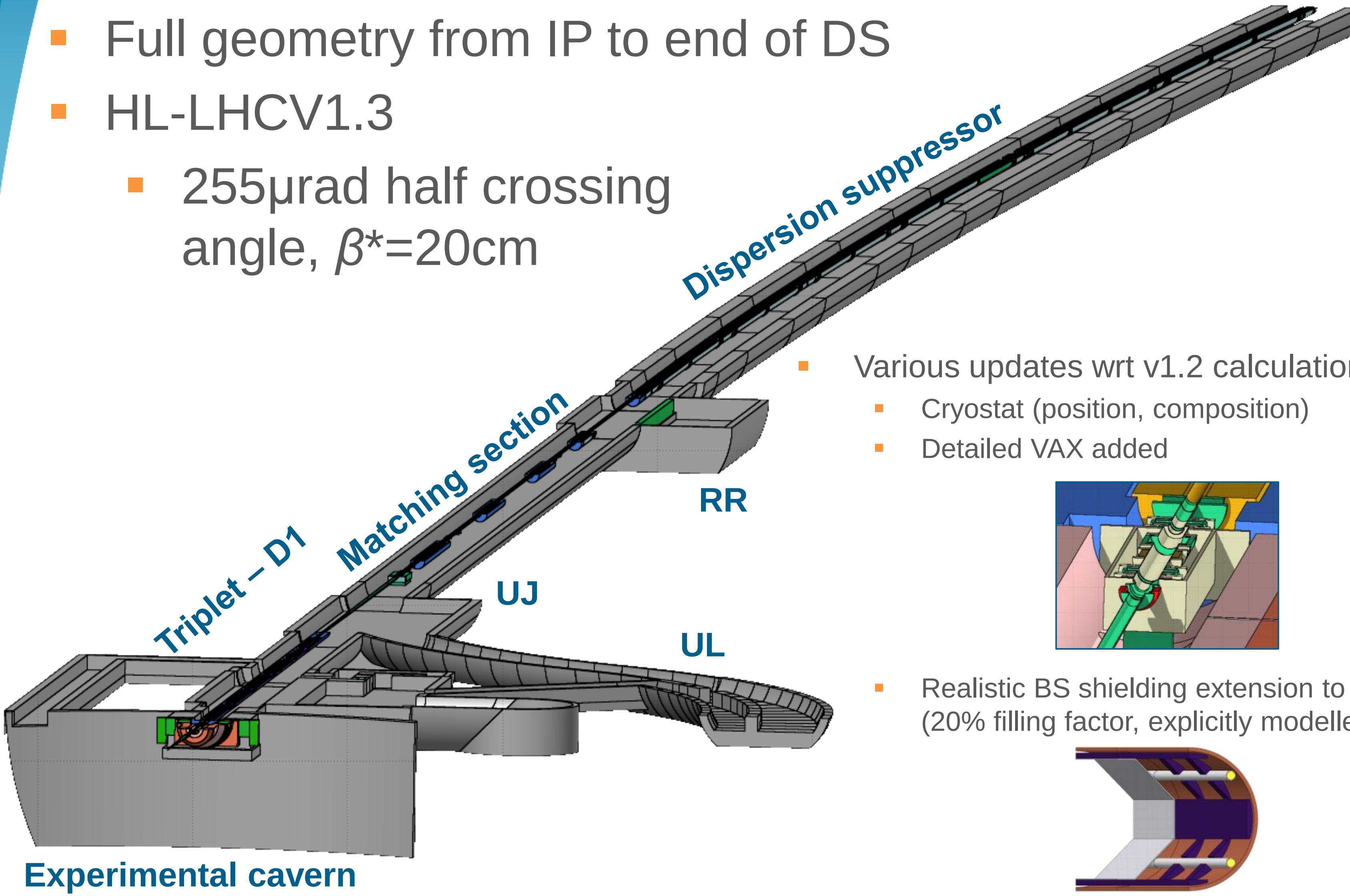
Outline

- Layout and optics
- Results for v.1.3
  - Total power, peak dose, peak power density, losses
  - Triplet-D1
  - Matching section
  - Dispersion suppressor
- Summary

Layout and optics

Simulated geometry

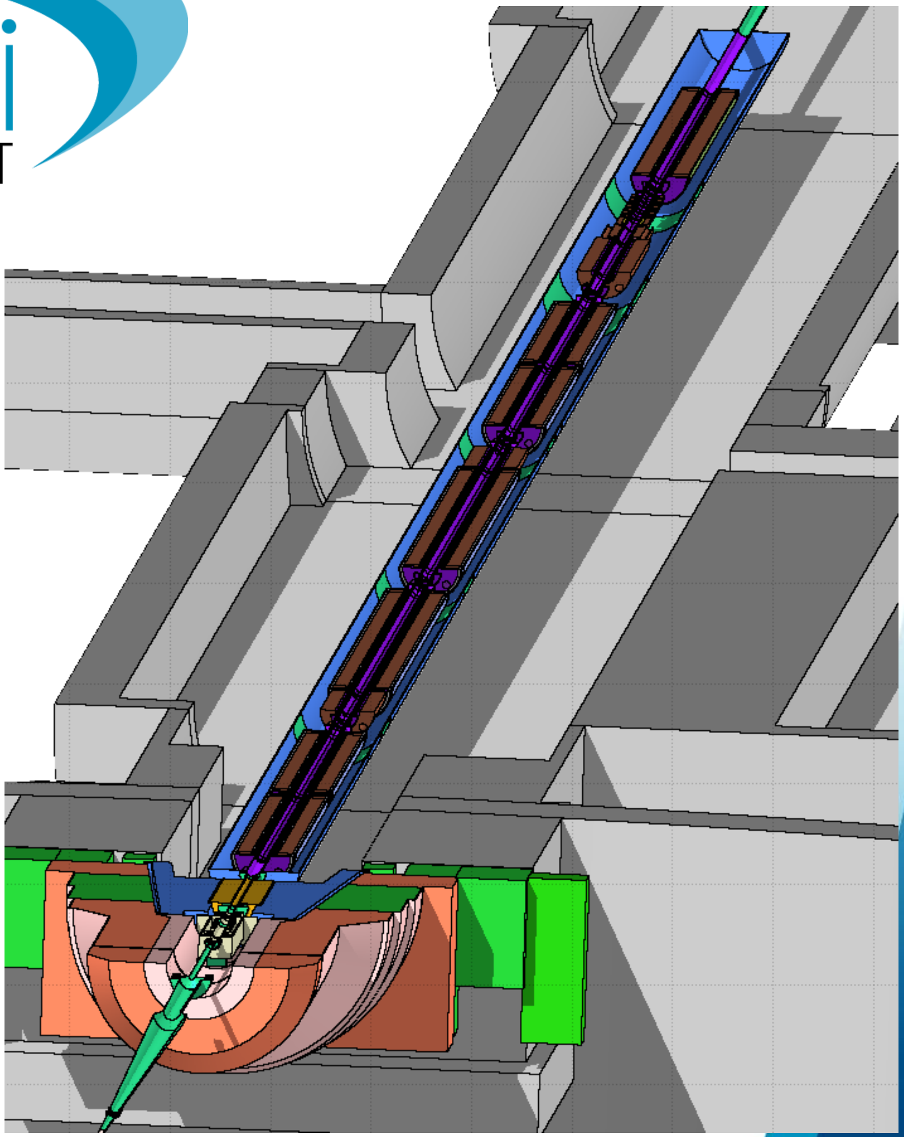
- Full geometry from IP to end of DS
- HL-LHCV1.3
  - 255μrad half crossing angle, β^*=20cm



- Various updates wrt v1.2 calculations:
  - Cryostat (position, composition)
  - Detailed VAX added
  - Realistic BS shielding extension to 45^{o} (20% filling factor, explicitly modelled)
  - **Triplet interconnects** (see later slides)

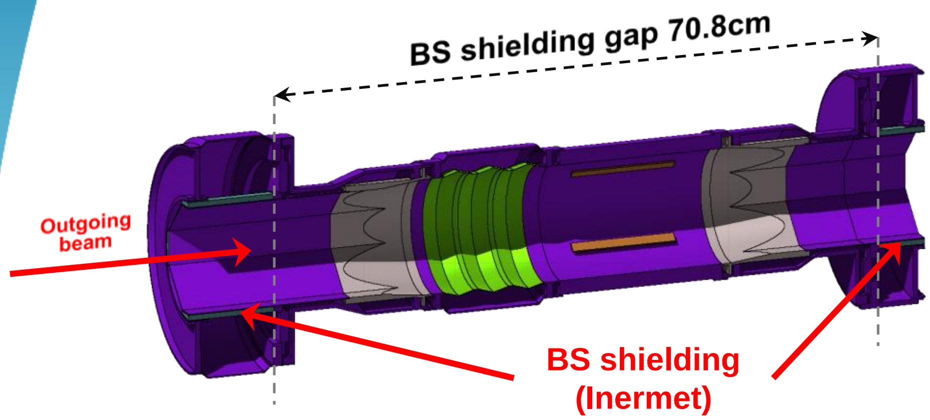
HiLumi HL-LHC PROJECT

Triplet-D1



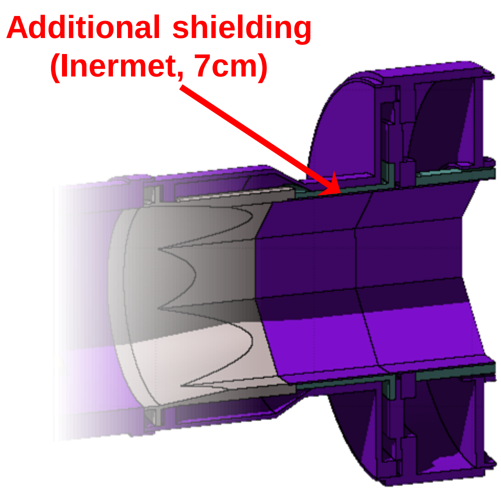
Triplet interconnects and BPMs

with T. Lefevre, R. Jones, D. Draskovic (BE/BI)
C. Garion, R. Kersevan, R. Fernandez-Gomez (TE/VSC)



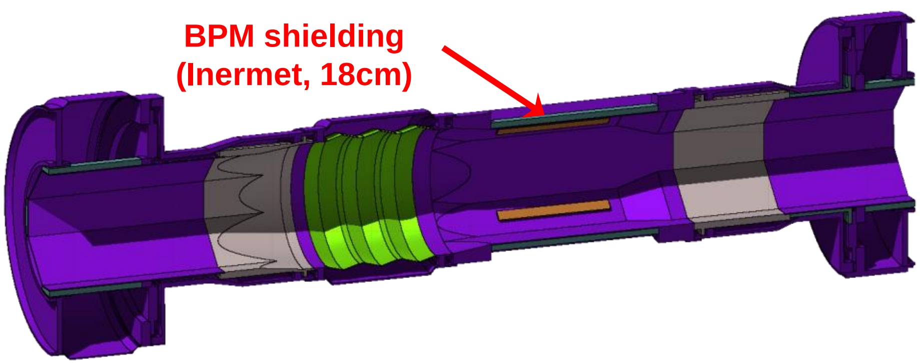
- The interruption of the Inermet BS shielding in the interconnect was the primary cause of the localised 36MGy/3000fb^{-1} dose peak at the IP face of Q2B in IR5
- Shielding improvements:

- “Circular” BPM
- Addition of 7cm Inermet insert on non-IP side



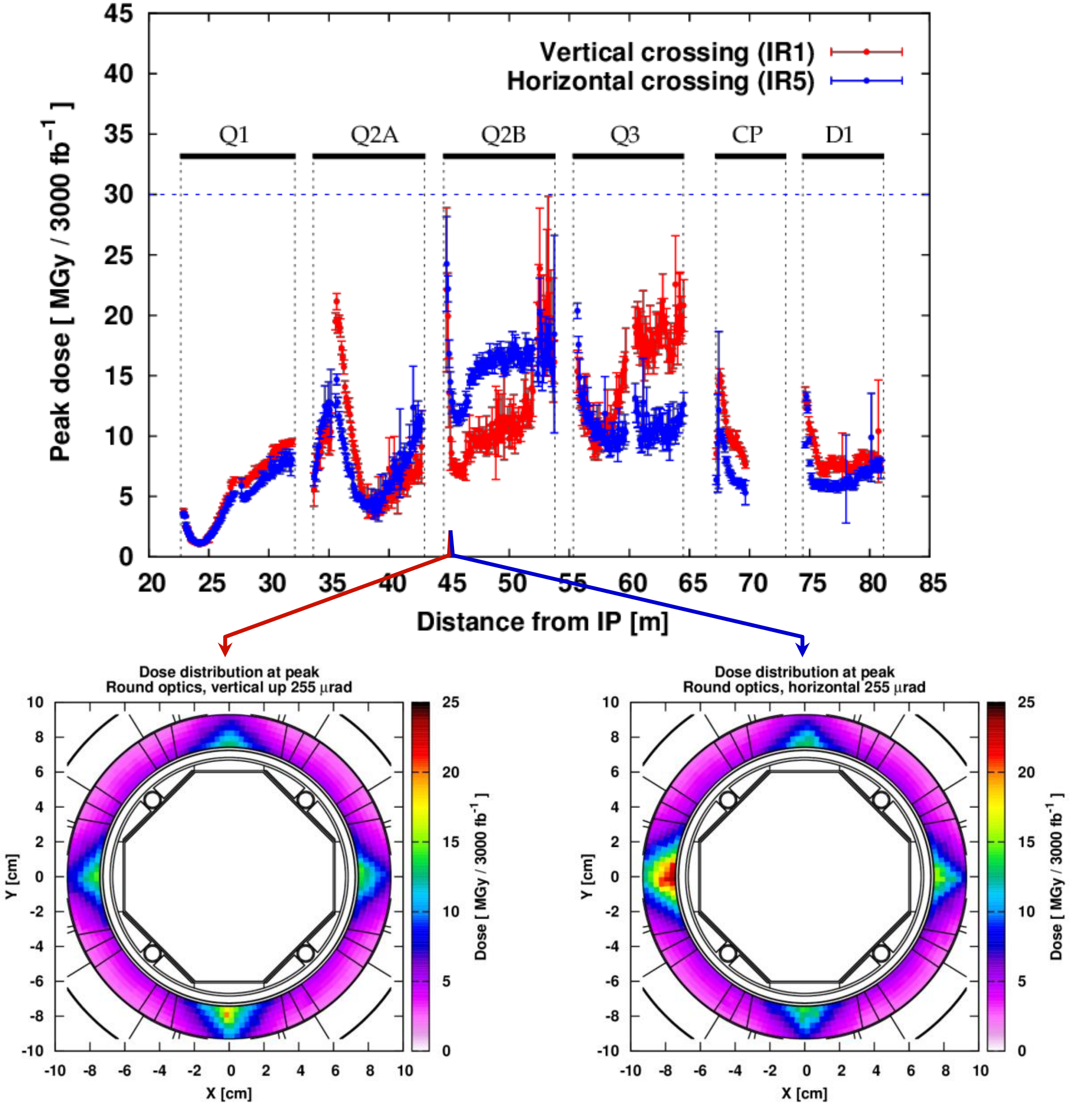
- Peak value reduction by ~15% (30MGy)

- “Octagonal” BPM with incorporated 18cm Inermet pieces on the mid-planes (retaining 7cm insert)

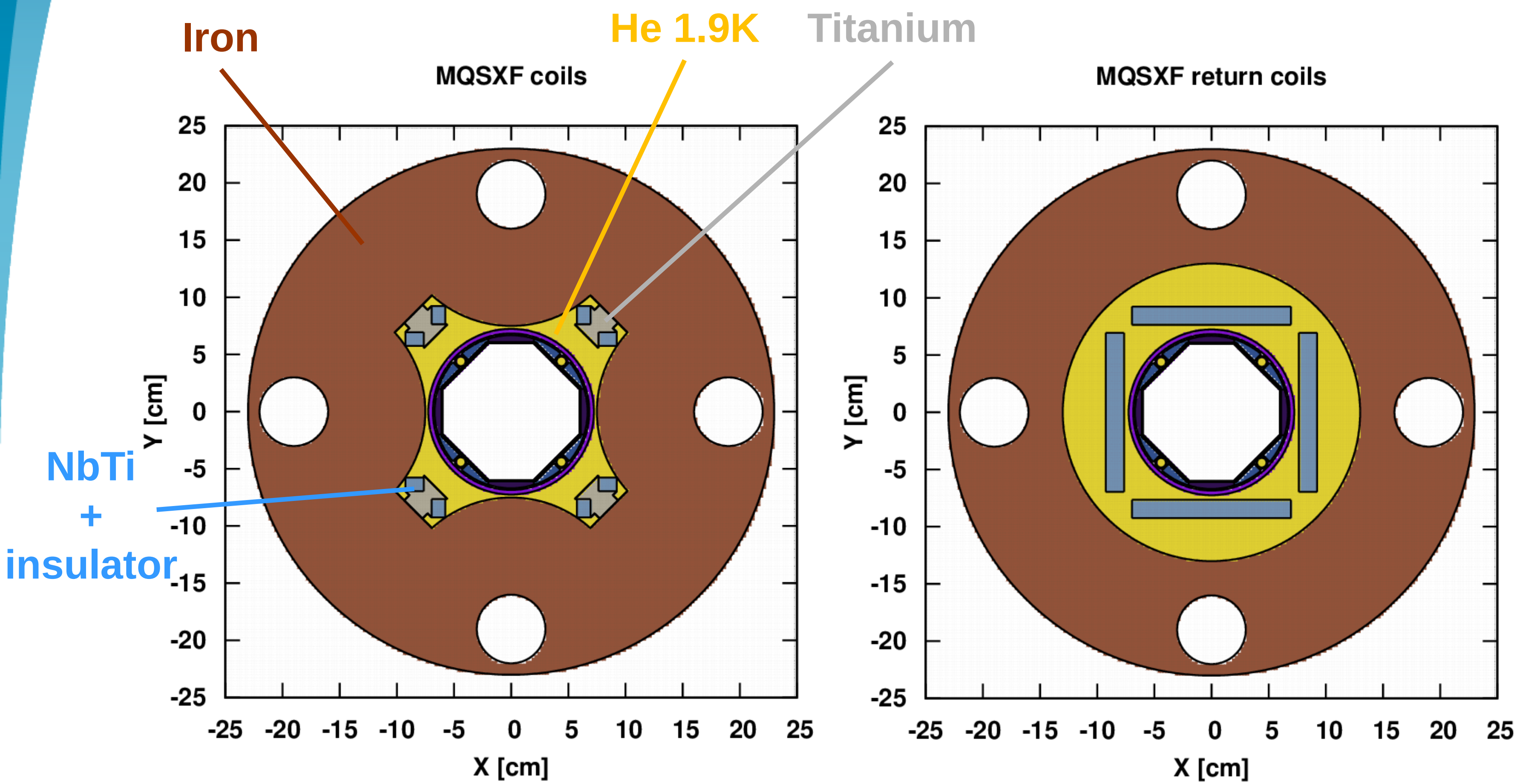


- Further ~15% reduction (26MGy)
- Only in front of Q2B (for now)

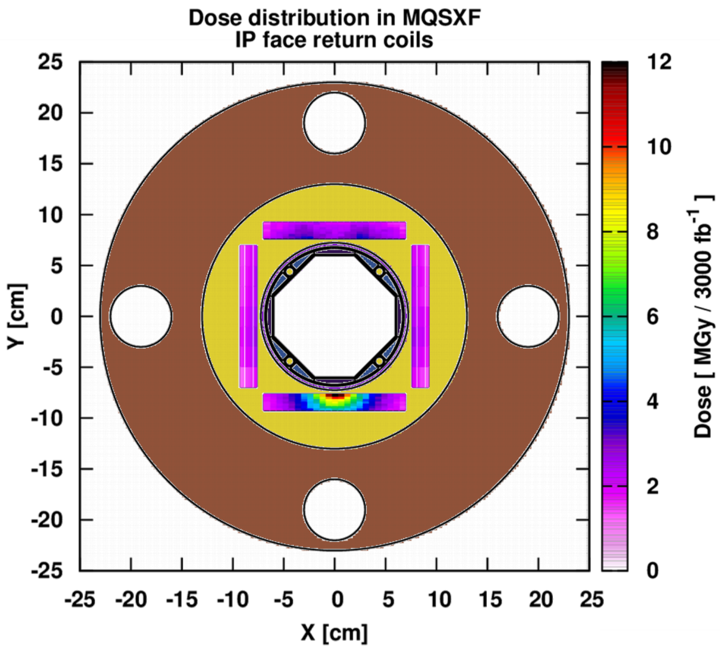
Triplet-D1: Peak dose profile

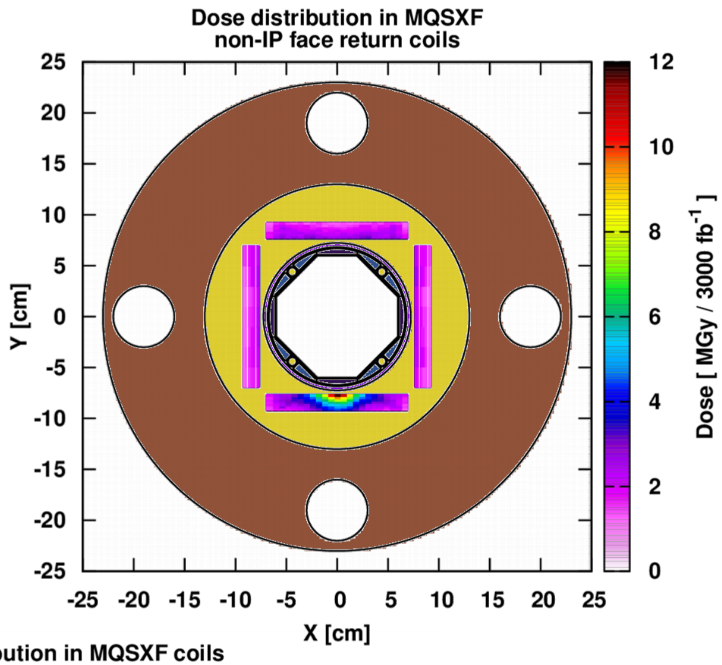


Skew quadrupole (MQSXF)
FLUKA model cross-sections

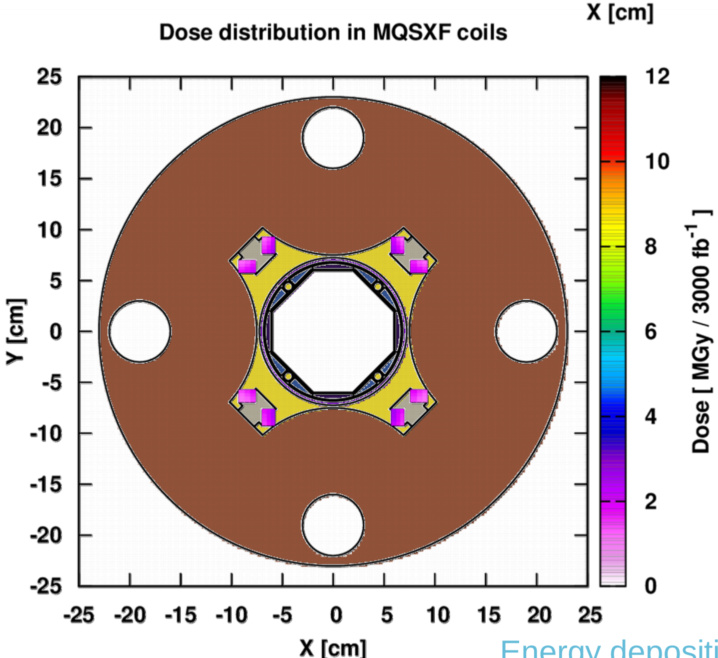


Dose profile in IR1 MQSXF (L_{int}=3000 fb^{-1})

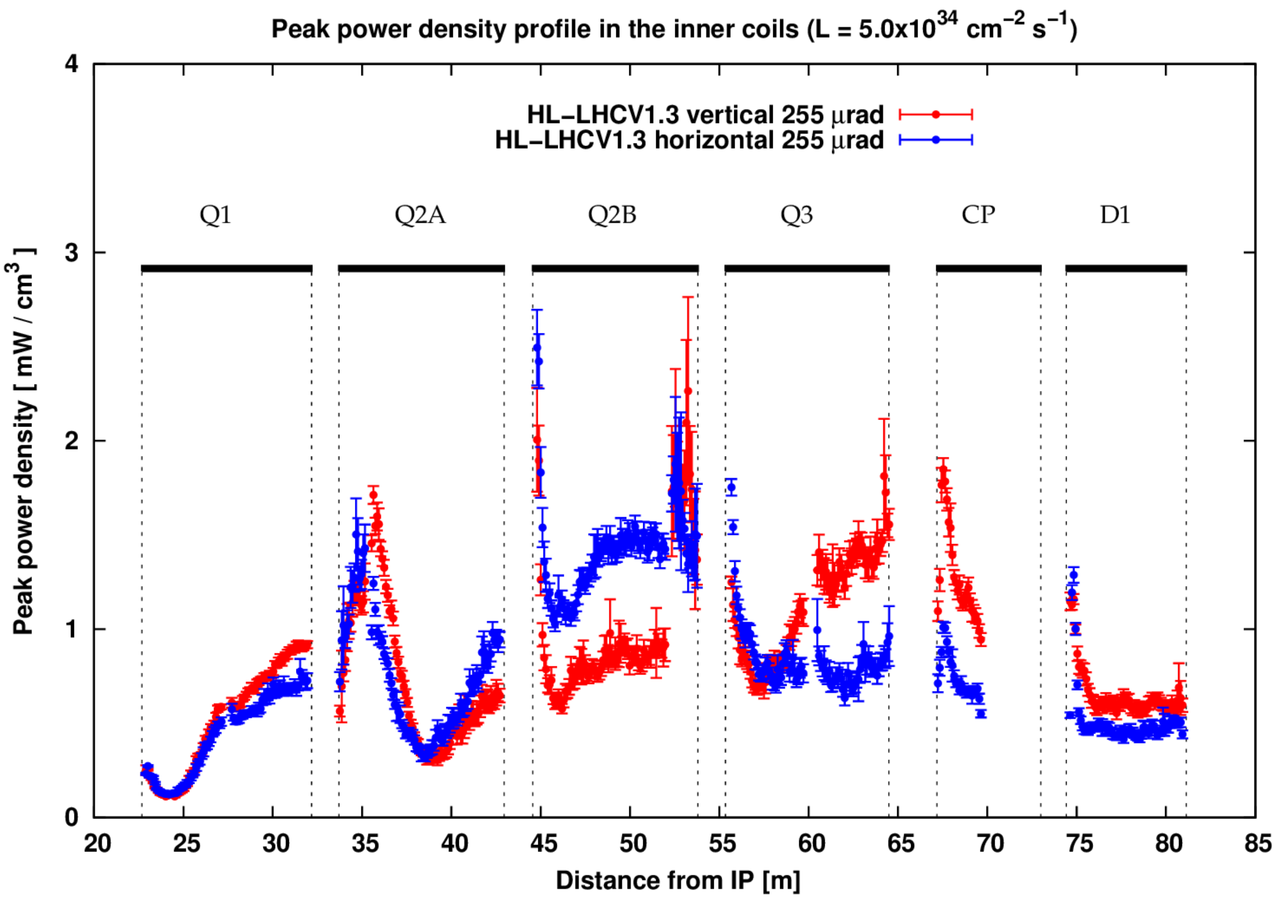




- Dose values up to 12MGy in return coils and up to 3MGy elsewhere
- Overall, a maximum value of 15 MGy is expected in the CP coils



Triplet-D1: Peak power density profile ($L=5.0x10^{34}$ cm^{-2} s^{-1})

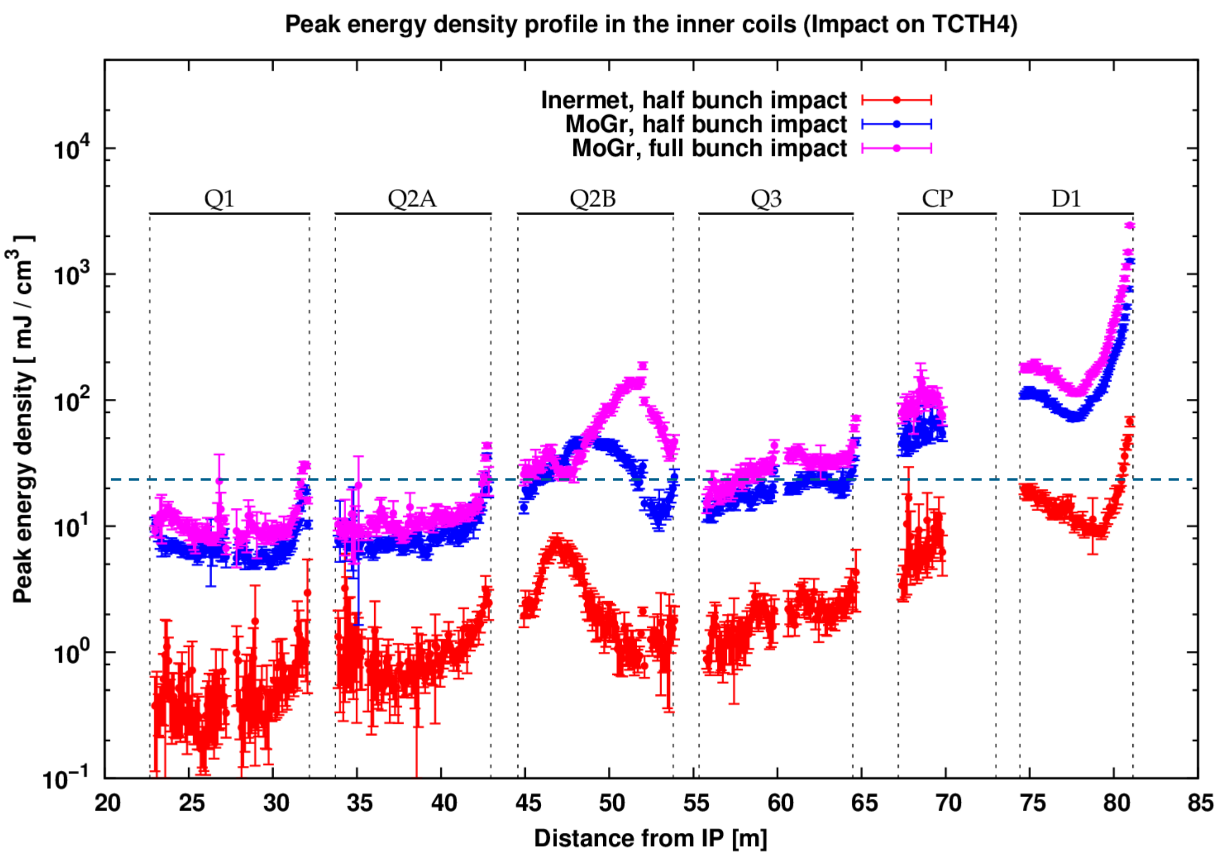


- Peak power density values below $3mW/cm^3$ everywhere

Total power (triplet-D1) ($L=5.0x10^{34}$ cm^{-2} s^{-1})

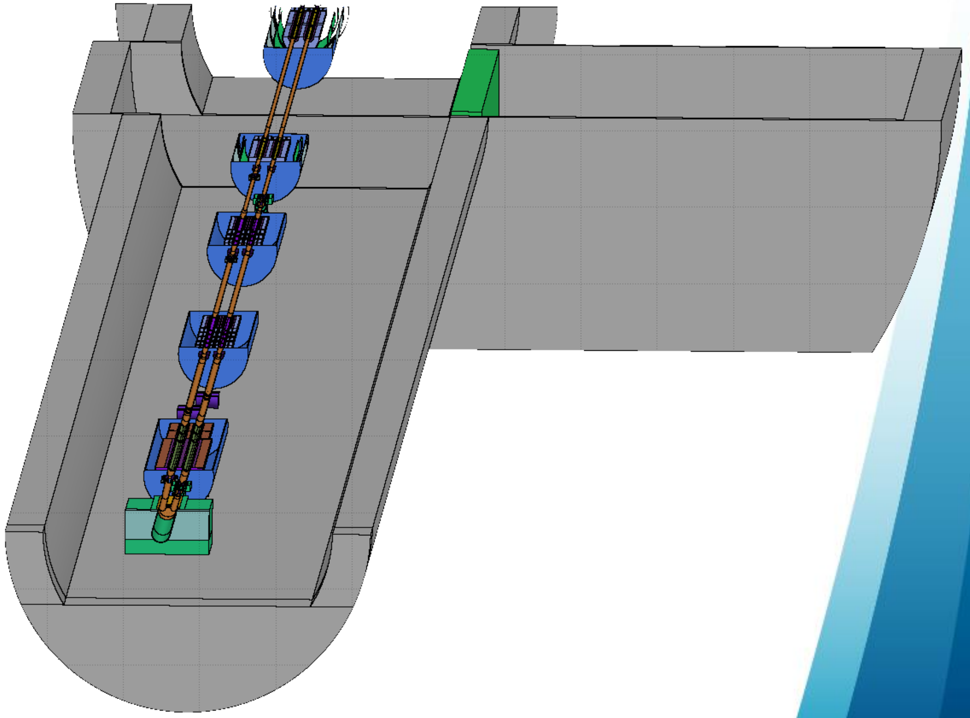
	Vertical		Horizontal	
Magnets	**Magnet cold mass**	**Beam screen**	**Magnet cold mass**	**Beam screen**
	Power [W]			
Q1A + Q1B	114	170	113	168
Q2A + corr.	101	68	96	62
Q2B + corr.	126	87	137	98
Q3A + Q3B	134	80	118	68
CP	54	62	45	49
D1	79	56	67	46
Beam pipe extensions	21	72	19	64
TOTAL	**629**	**595**	**595**	**554**

Asynchronous beam dump Impact on TCTH4.R5



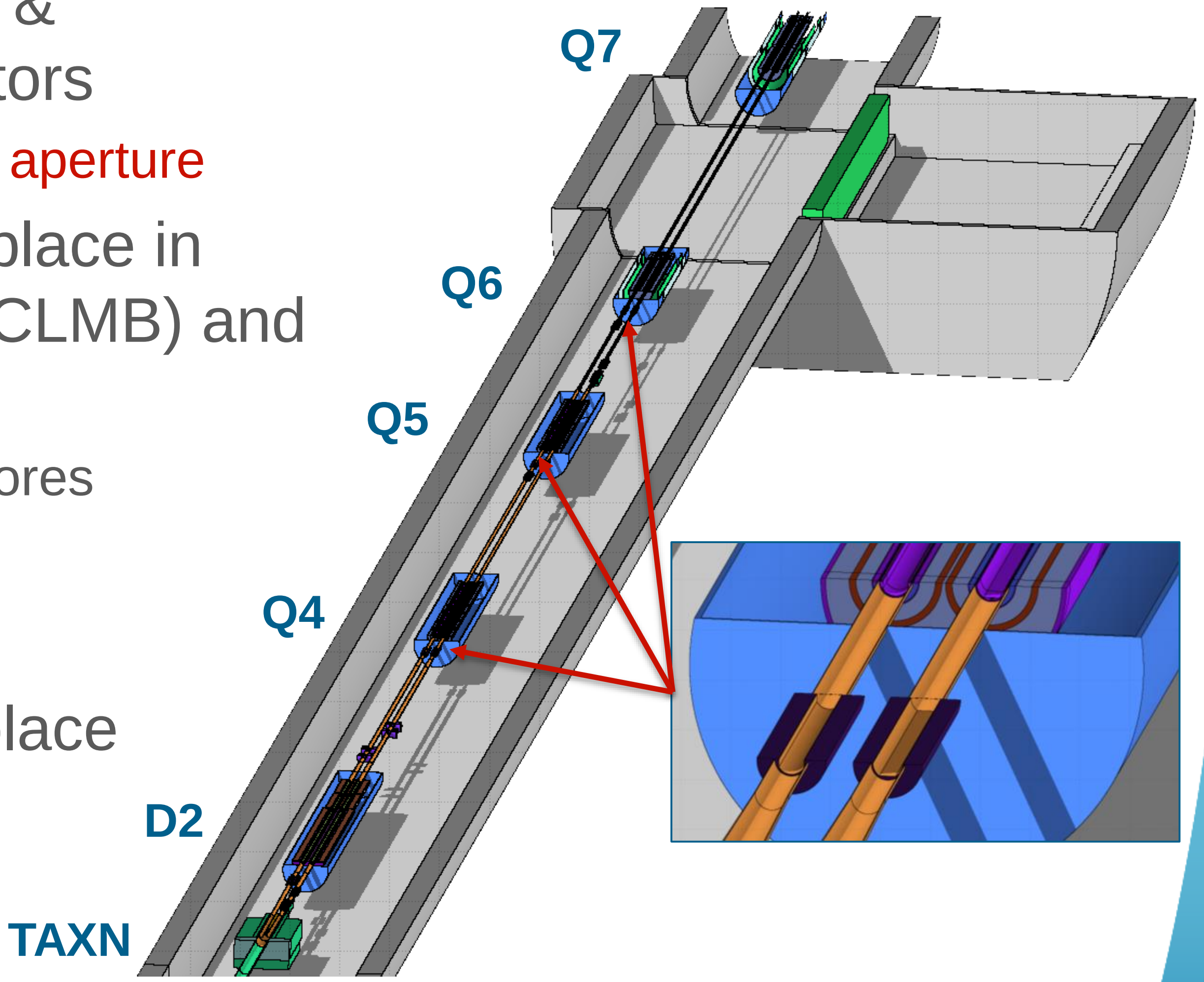
- All values well below damage limit (~100J/cm^3)
- Only D1 would quench in the Inermet / half bunch scenario
- Values higher by at least a factor of 10 in MoGr case

Matching section

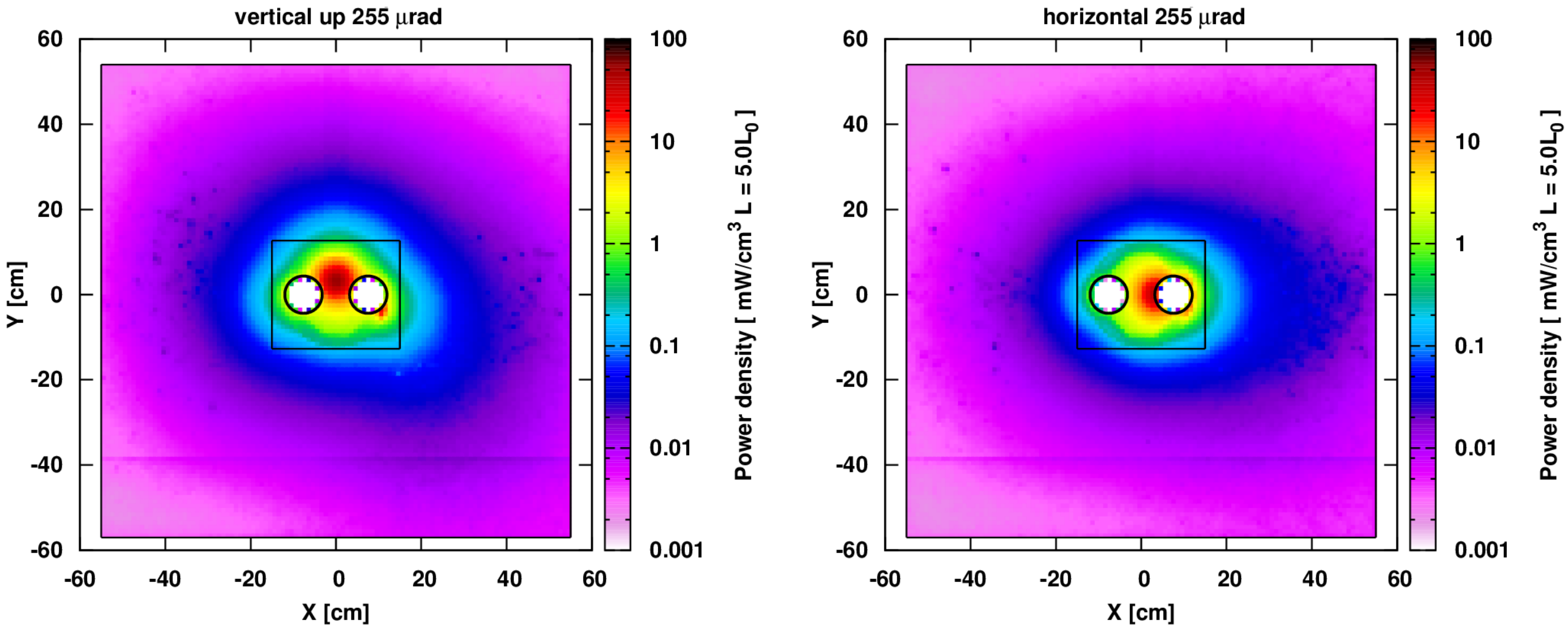


Simulated geometry (matching section)

- Major change: Q4 & associated correctors
  - Now at 70mm coil aperture
- Masks already in place in front of Q4, Q5 (TCLMB) and Q6 (TCLMC)
  - Present on both bores
- Updated RR shielding
- All collimators in place
  - TCLs @ 13.5σ (instead of 12σ)
  - TCTs @ 12σ (instead of 10.9σ)



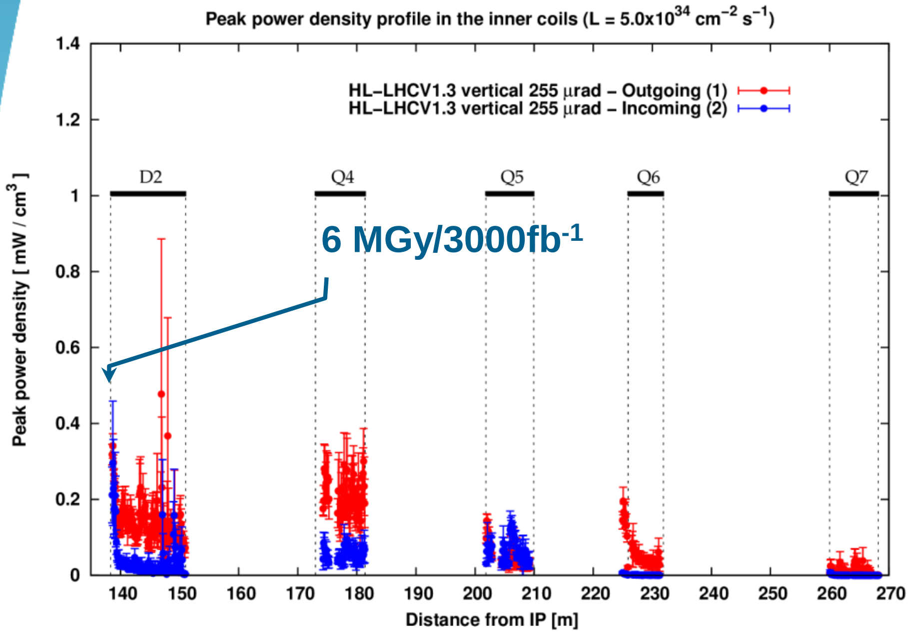
TAXN effectiveness



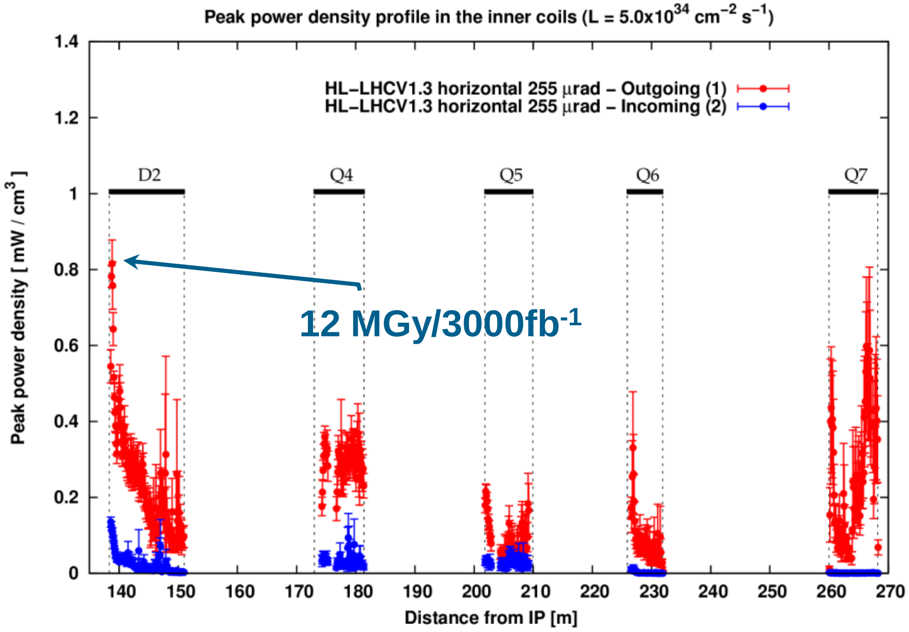
- Greater leakage in the horizontal case, hence the lower power on the TAN itself and higher radiation in the matching section

Matching section: peak power density profile ($L=5.0x10^{34}\ cm^{-2}\ s^{-1}$)

Vertical crossing



Horizontal crossing



- Peak power density values well below 1mW/cm^3 in the matching section
- Dose values /3000fb^{-1} up to 12MGy in front face of D2 (for horizontal crossing)
- CRITICAL POINT: the overall good result (despite the significant restriction of the Q4 aperture) is largely due to the beneficial presence of the masks on the outgoing beam bore (especially before Q4), as well as the TCLs and the TCTs on the incoming beam bore

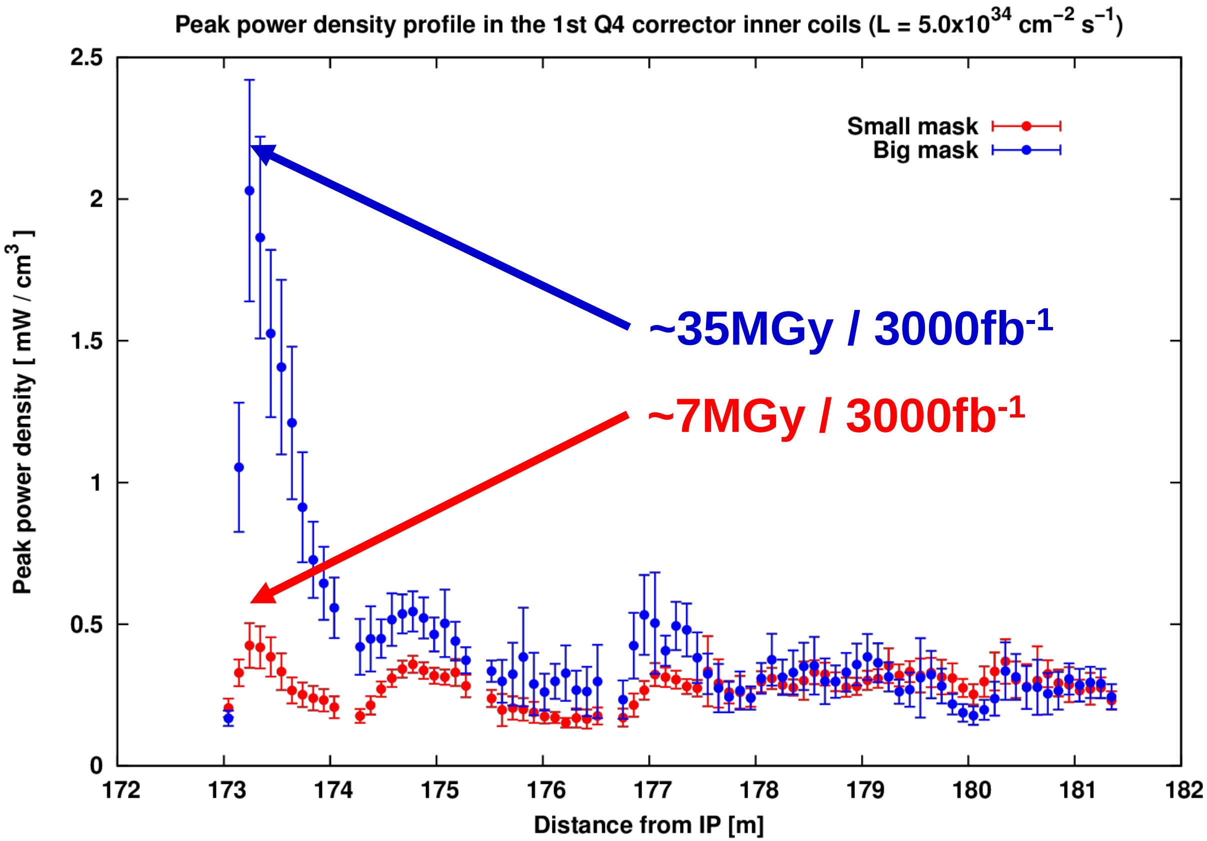
Total power (matching section) (1/2) ($L=5.0x10^{34}\ cm^{-2}\ s^{-1}$)

	Vertical		Horizontal	
Magnets	Magnet cold mass	Beam screen	Magnet cold mass	Beam screen
	Power [W]			
D2 + corr.	17	1.1	33	1.9
Q4 + corr.	6.8	0.2	8.2	0.4
Q5 + corr.	0.9	<1mW	0.9	0.04
Q6 + corr.	0.9	0.03	2.3	<1mW
Q7 + corr.	0.1	<1mW	0.7	0.1

Total power (matching section) (2/2)

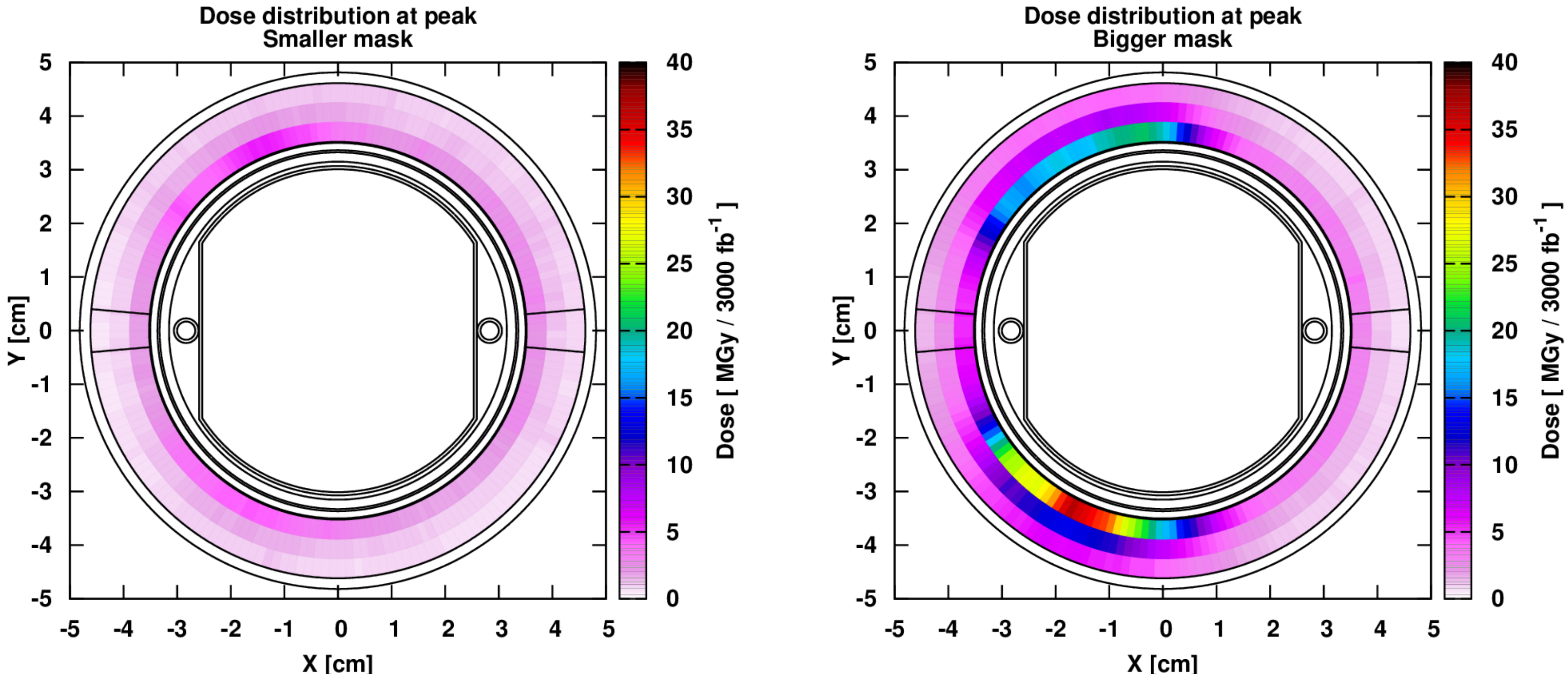
	Vertical		Horizontal	
Collimators	Inner/ upper jaw	Outer/ lower jaw	Inner/ upper jaw	Outer/ lower jaw
	Power [W]			
TCLX4.B1	25	53	156	89
TCTPV4.B2	11	6	4.2	3.6
TCTPH4.B2	5	19	1.6	8.6
TCL5.B1	7	45	13	83
TCL6.B1	10	32	12	27
TCTV6.B2	0.9	0.9	0.3	0.4
TCTH6.B2	0.4	0.05	0.3	0.03
Masks	Beam 1	Beam 2	Beam 1	Beam 2
TCLM4	**19**	1.3	**19**	0.7
TCLM5	2.6	1.3	3.6	0.8
TCLM6	0.7	0.06	1.5	0.05

Peak power density profile (Q4+corr.) with larger mask aperture (+2mm)



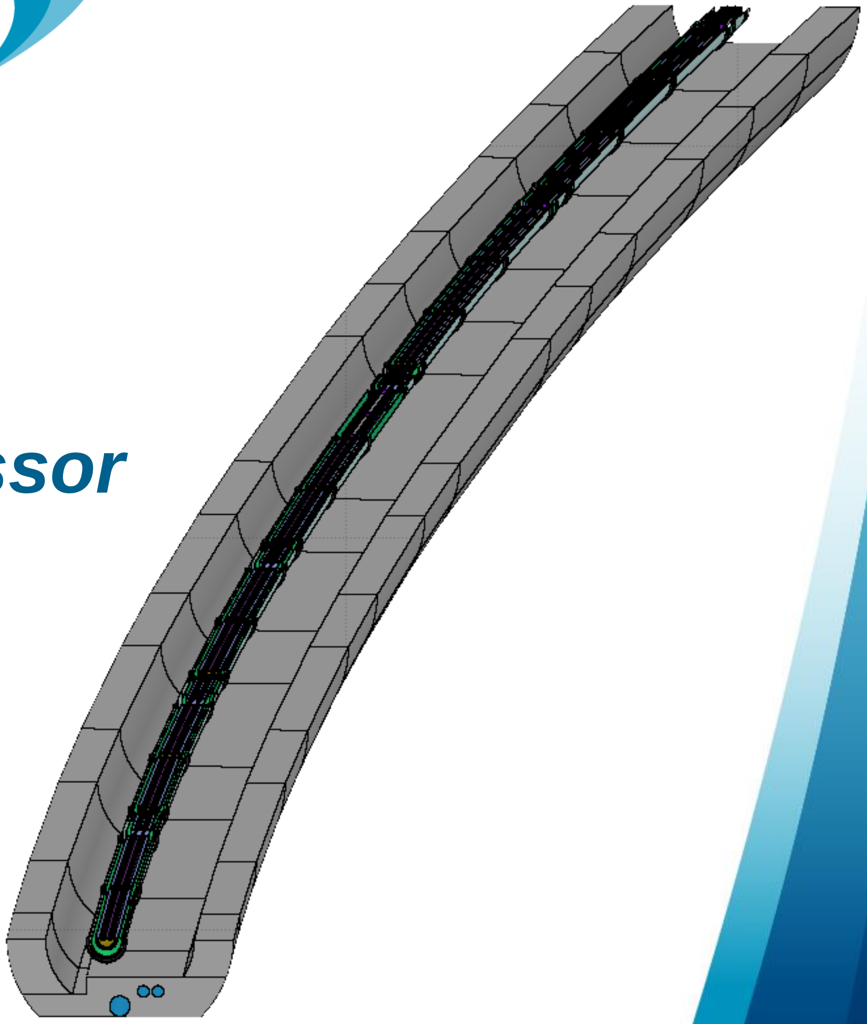
- Increasing the mask aperture by 2mm:
  - Significant increase on the IP-face of the first Q4 corrector (MCBYV)
  - Max. value of 2mW/cm^3 still within operational limits, while the impact on the total heat load is small
  - **However, the local increase in the accumulated dose becomes worrisome**

2D dose distribution at peak on Q4 corr. (3000 fb^{-1}) with larger mask aperture (+2mm)

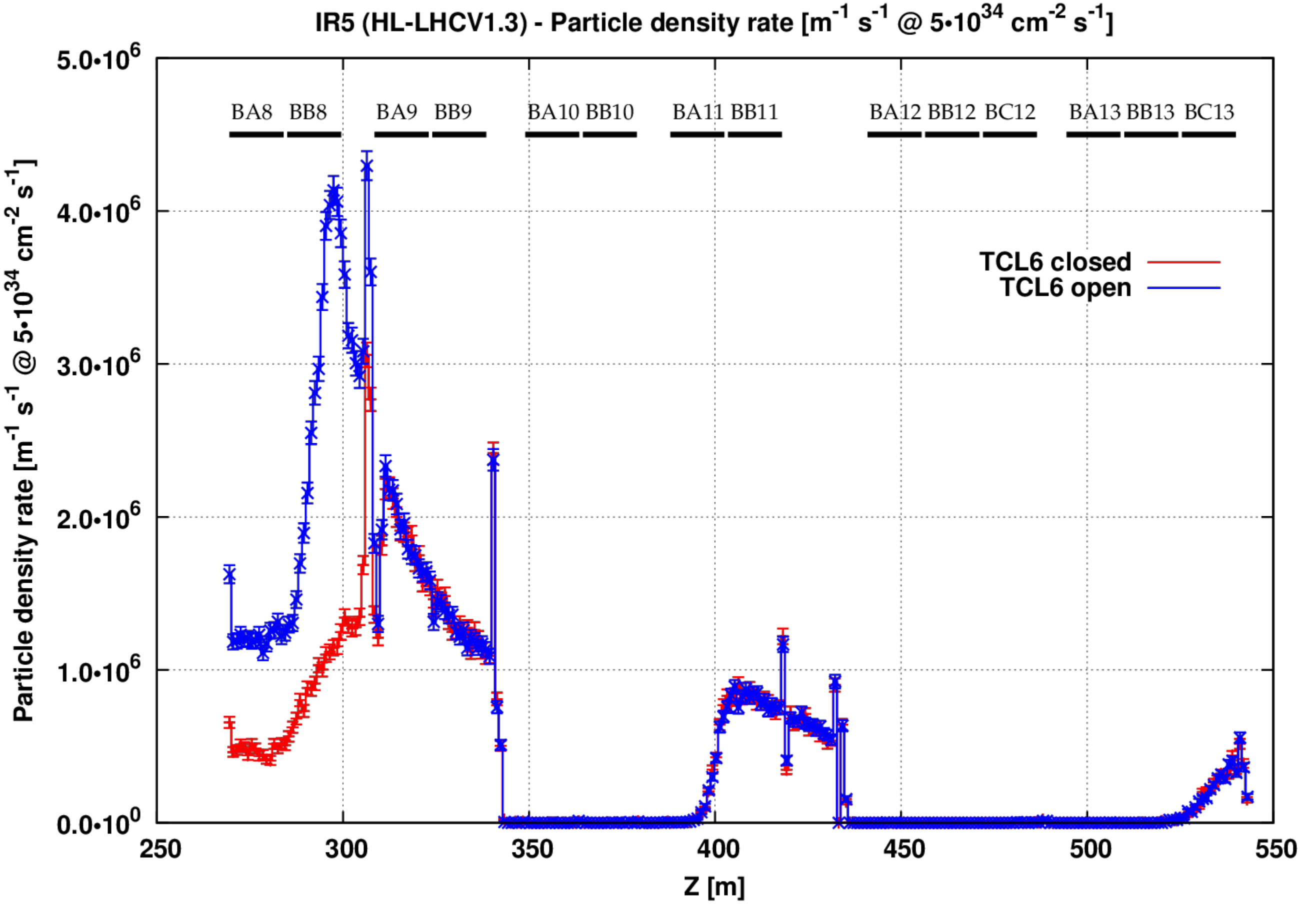


- Regardless of possible misalignments, the aperture increase of the mask exposes the front face of the first Q4 corrector to an accumulated dose of ~35MGy for 3000fb^{-1}
- In Q5 (which already benefits from the presence of TCL5), the aperture change moves the dose peak from the horizontal plane to the vertical, but without leading to worrying values

Dispersion suppressor

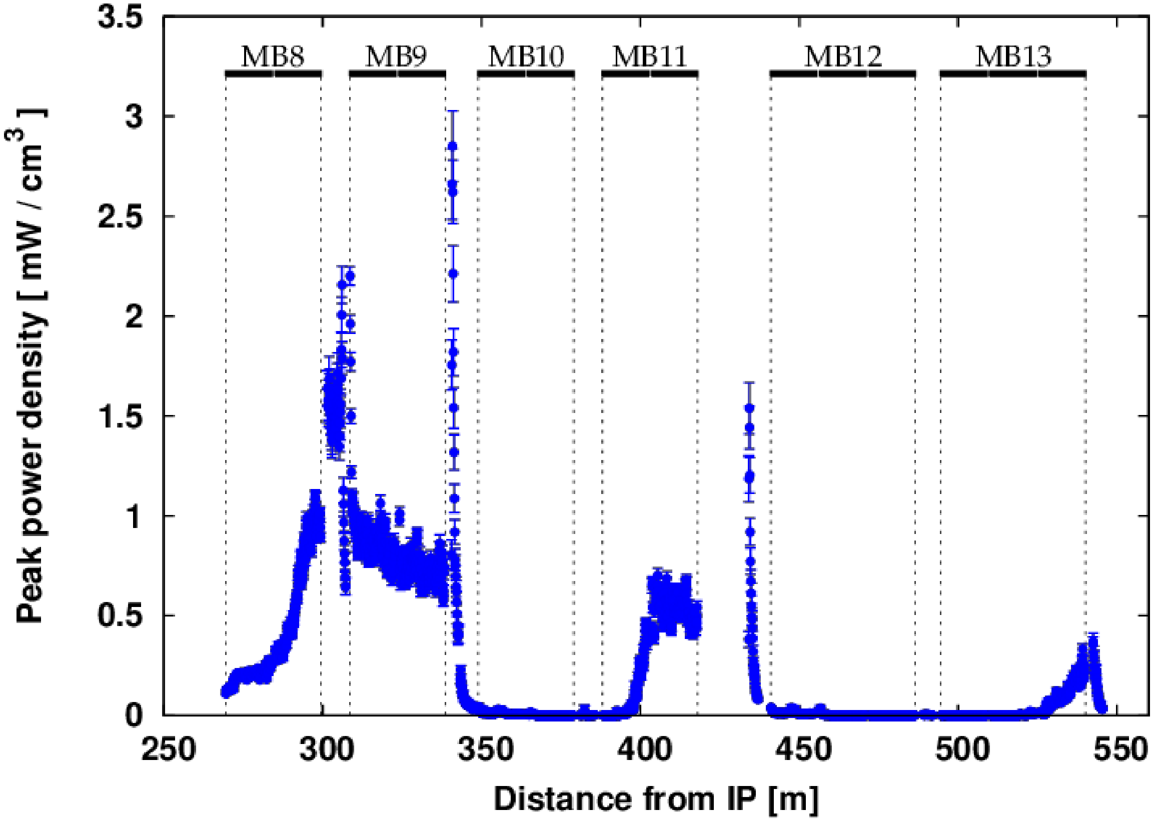


Losses in the HL-LHC DS



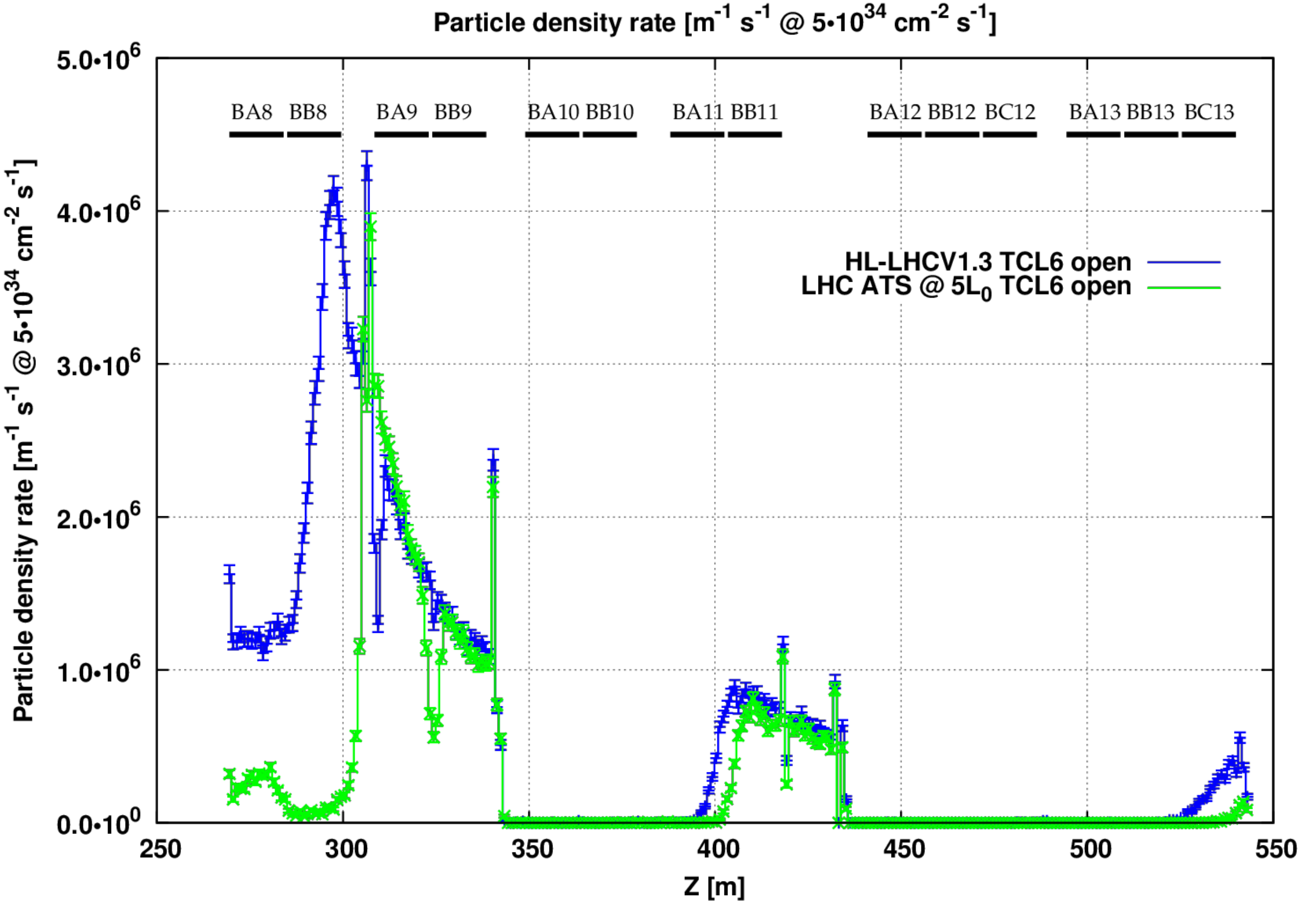
- Losses dominated by off-momentum protons
- Two cases: 1) TCLs at 12σ, 2) TCL6 open (25mm halfgap)
- Opening TCL6 has a noticeable impact only up to cell 8

Impact on the HL-LHC DS coils



- Maximum peak power density values in the coils around 2-3mW/cm^3
- Maximum dose values in the coils could be challenging between cells 8 & 9 (up to 40MGy locally, especially in MQMC in cell 9)

Losses in the HL-LHC DS

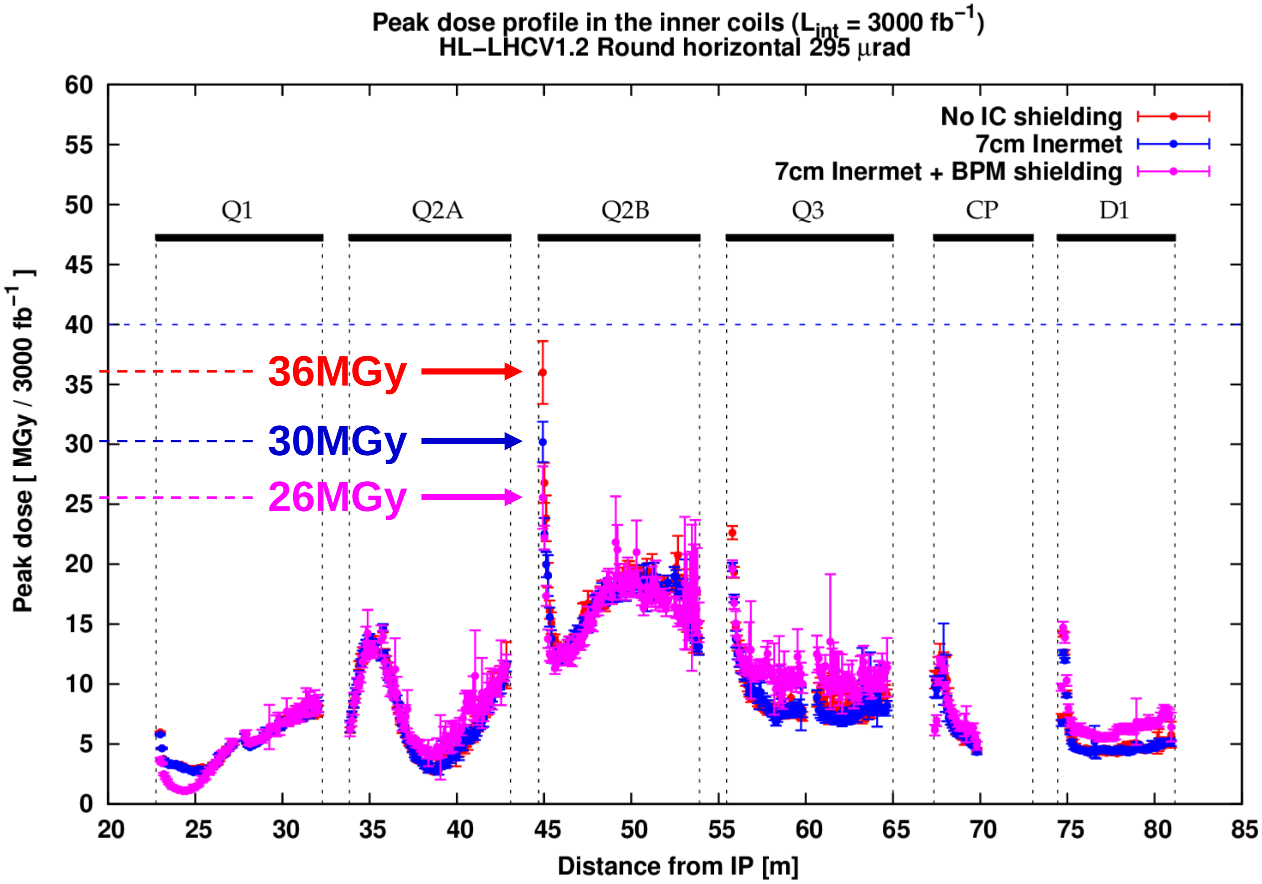


- Comparing to present LHC ATS optics (scaled to HL luminosity) it is clear that losses from cell 9 onward rise purely with the luminosity
- However, contrary to LHC, in HL-LHC cell 8 is more exposed without TCL6

Summary

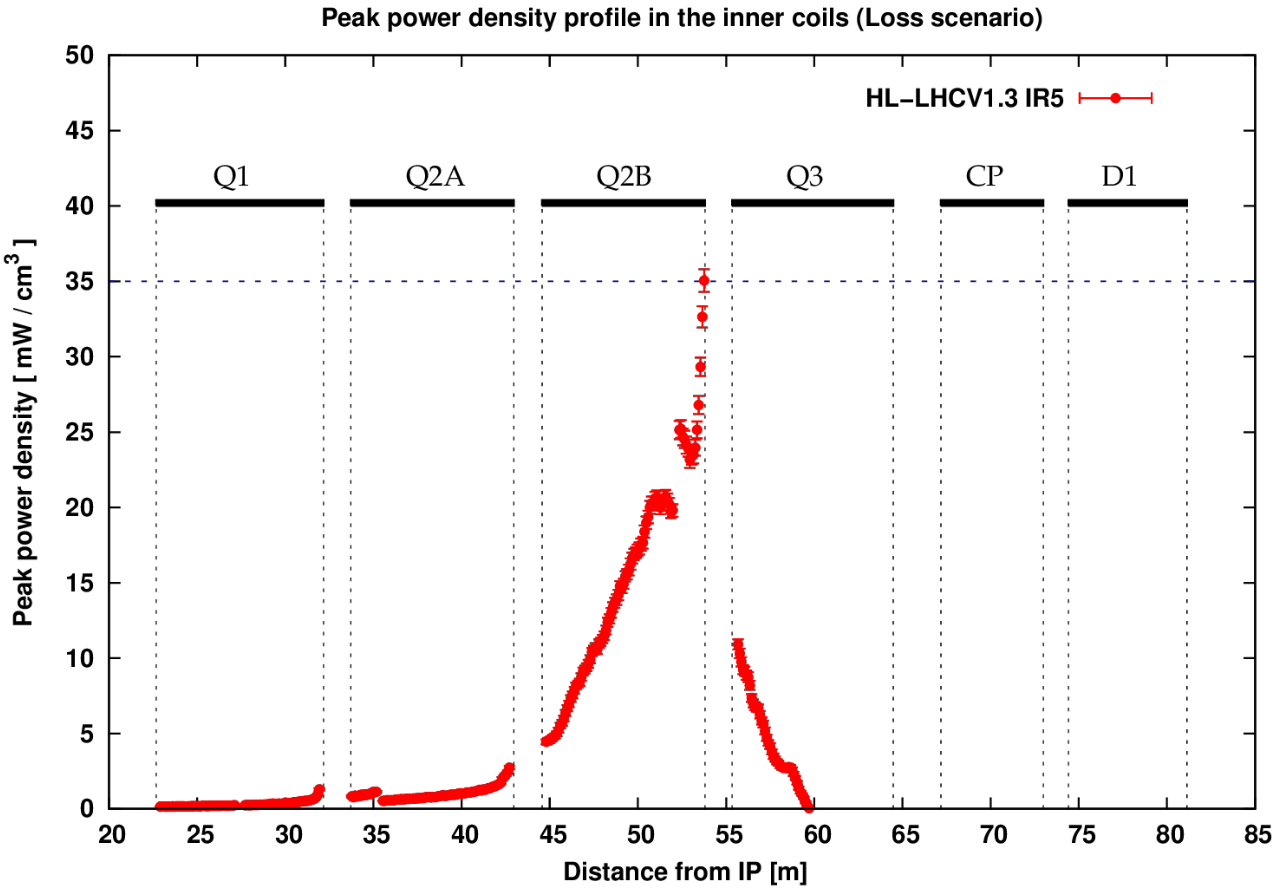
- Situation in the triplet-D1 region remains largely unchanged in v.1.3 (no major changes in the layout)
  - Use of shielded BPM in interconnect before Q2B is important
- Despite reduced Q4 aperture, peak dose and peak power density values in the matching section remain acceptable, largely due to the presence of masks on the outgoing beam (especially before Q4), as well as TCLs and TCTs
- Peak power density in DS up to 3mW/cm^3, but local dose peaks could be challenging

Summary of results



- TCC decision (used for v.1.3 calculations):
  - Interconnect with shielded BPM only before Q2B (for now)
  - Interconnect with 7cm insert kept elsewhere

Triplet-D1: Peak power density profile (Losses, normalised to 35*mW/cm³ quench limit)

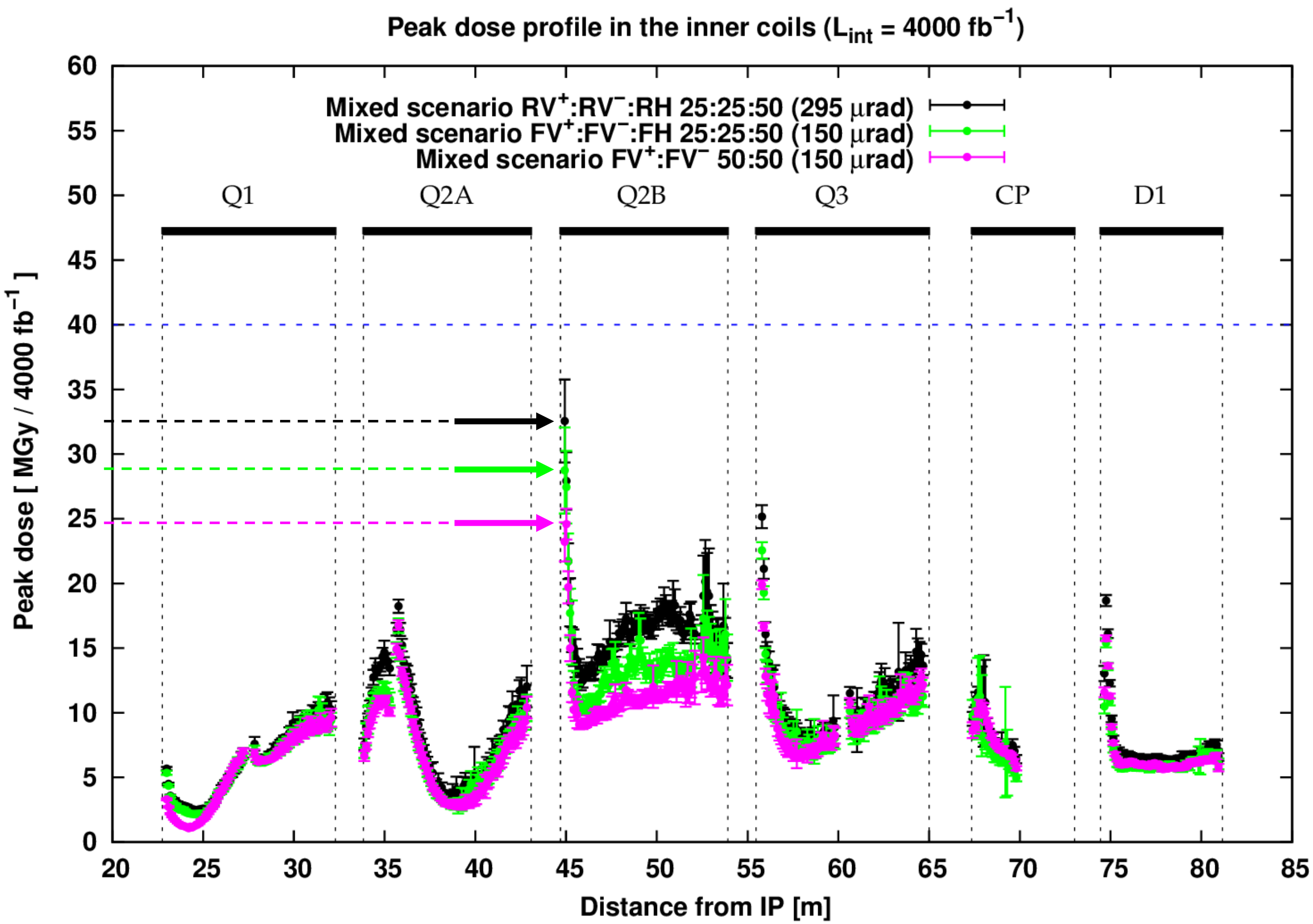


*
To be checked for the MCBX corrector!

- Corresponds to 4.1×10^9 p/s lost locally ➔ 7.36×10^{13} p/s global loss rate
- A few seconds of beam life-time
- ~80 MW of power lost

Peak dose minimisation scenarios

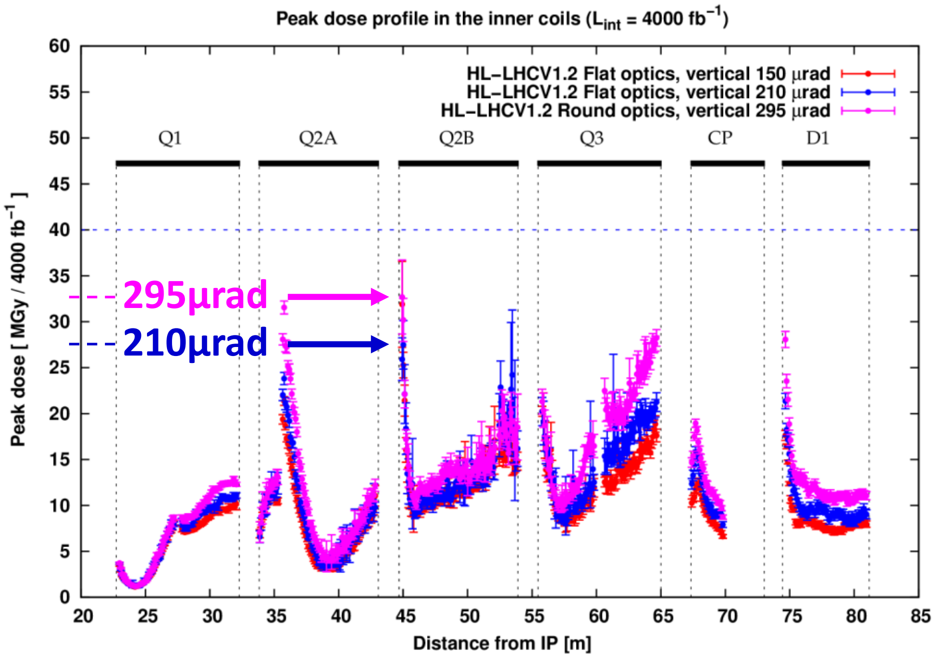
- Comparison of three mixed scenarios:



Further studies: flat optics

- Two flat optics scenarios were also studied for both vertical and horizontal crossing
  - 150µrad half-crossing angle, $\beta^*_x / \beta^*_y = 40 / 10$ cm
  - 210µrad half-crossing angle, $\beta^*_x / \beta^*_y = 40 / 10$ cm
- Sensitivity of results to changes in bunch length and beam divergence is limited
- On the contrary, the crossing angle plays an important role
  - Lower dose for lower crossing angle

Vertical crossing



Horizontal crossing