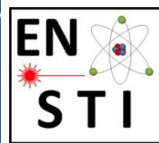




RECAP OF ENERGY DEPOSITION AND RADIATION DAMAGE

Francesco Cerutti, Andrea Tsinganis



WP10

Energy deposition & R2E



essential input from many contributors and WPs:

***R. De Maria, S. Fartoukh, Y. Papaphilippou, D. Pellegrini, G. Arduini,
A. Musso, E. Todesco,
R. Bruce, A. Lechner, S. Redaelli,
K. Brodzinski, G. Ferlin,
L.S. Esposito,
R. Fernandez Gomez, C. Garion, P. Santos Diaz, V. Baglin,
D. Draskovic, T. Lefevre, R. Jones,
P. Fessia***

OUTLINE

Triplet – D1

Collision debris figures and features

The LHC picture, dose mitigation strategy

HL-LHC: the v1.3 picture,

weak point and hardware/optics mitigation options

margin for improvement

crossing angle prospects

IP displacement

Matching Section

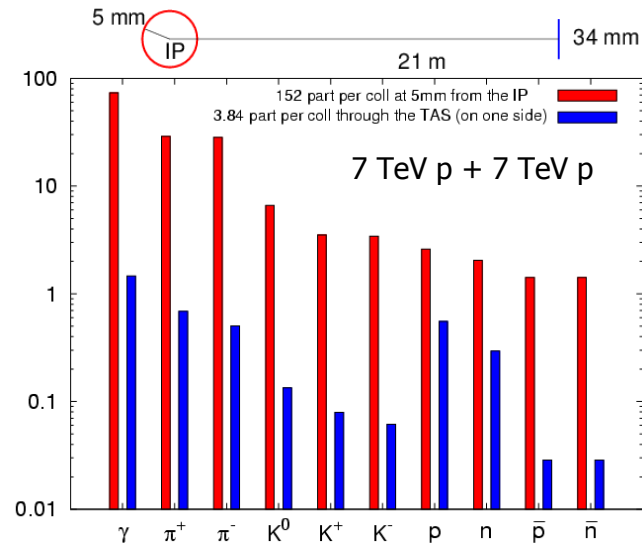
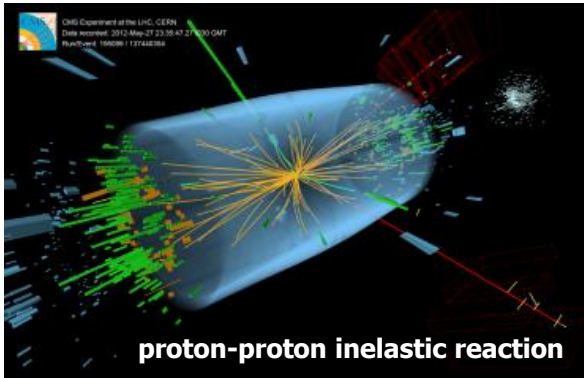
An overview

A taste of imperfection sensitivity (Q4 mask aperture)

Dispersion Suppressor

The first exploration

THE COLLISION DEBRIS



with $7.5 \cdot 10^{10}$ Higgs bosons

@ $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, i.e. $8.5 \cdot 10^8 \text{ s}^{-1}$ inelastic collision rate

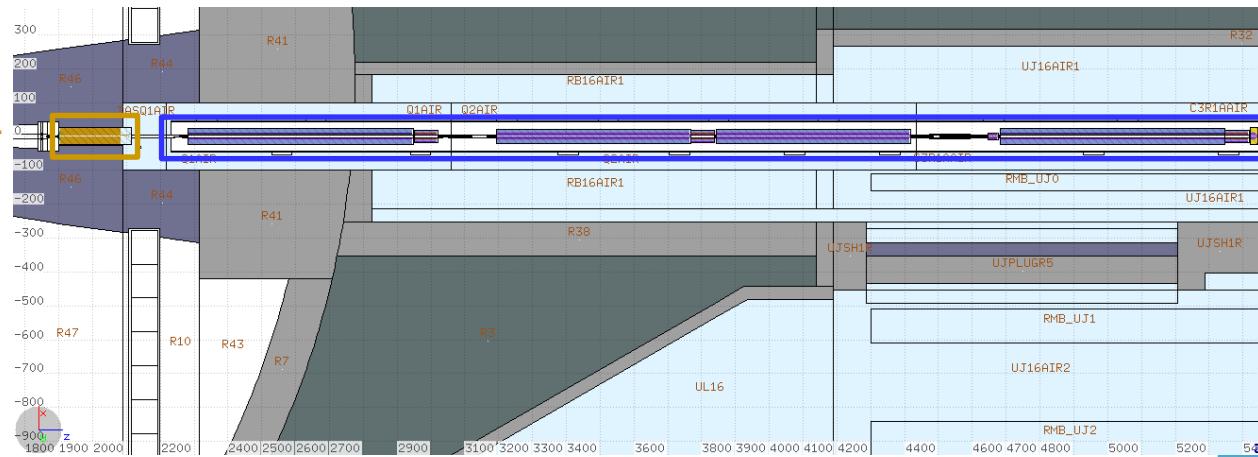
950 W towards each (L&R) side

150 W absorbed in the TAS absorber

650 W going through the TAS

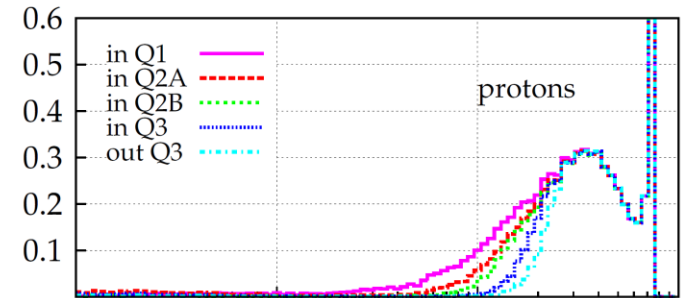
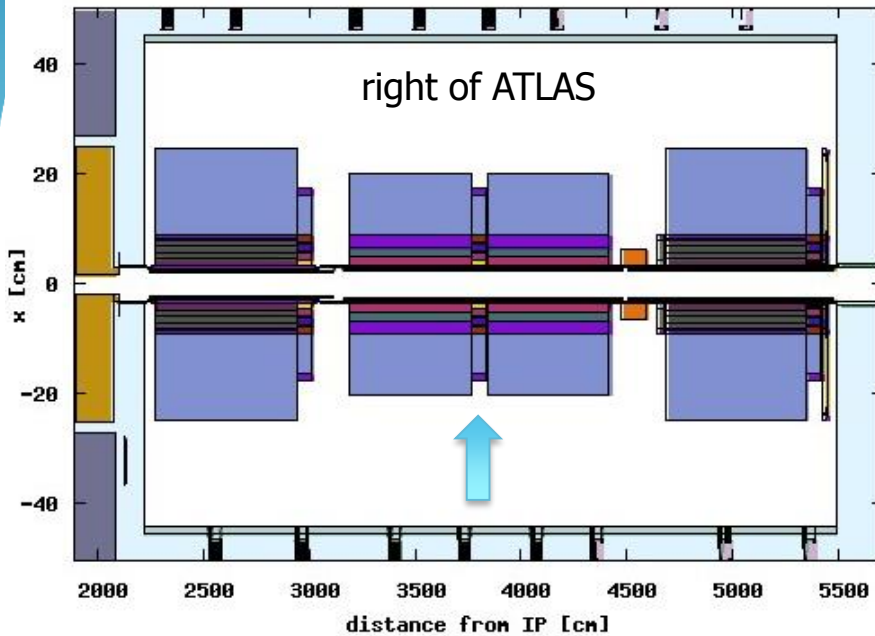
of which

150 W absorbed in the triplet cold magnets

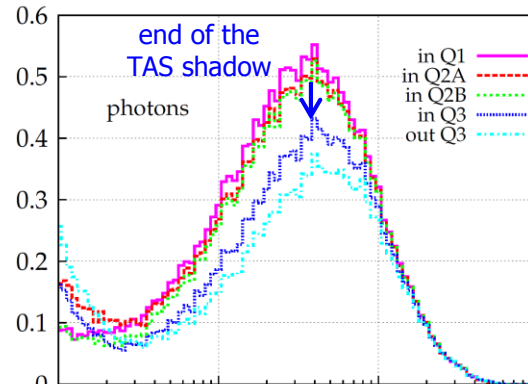
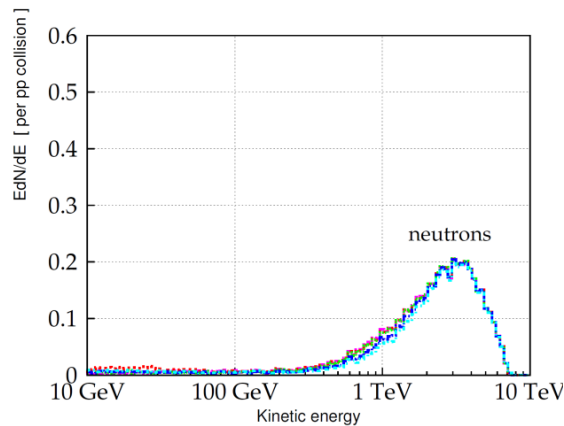
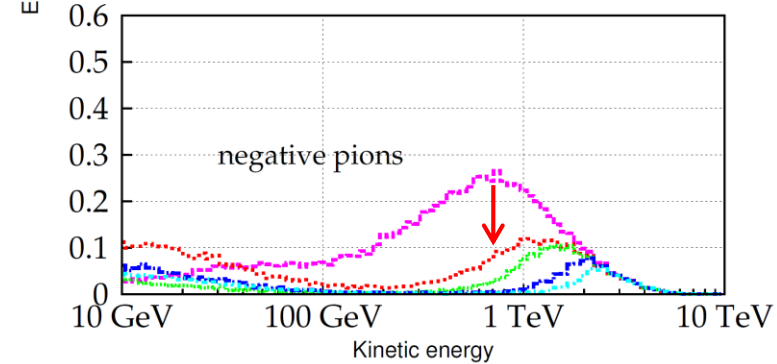
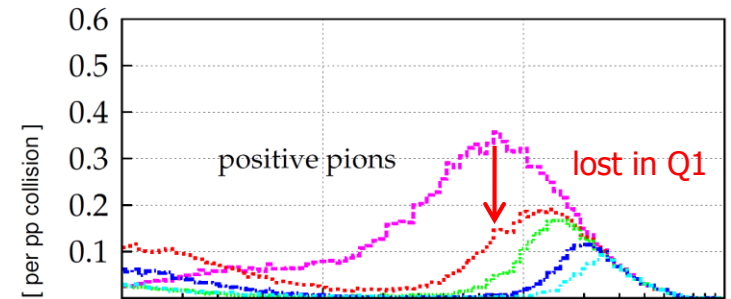


with 6.5 TeV beams (80mb) $\sim 125 \text{ W}$ (magnet end uncertainties) prediction at $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
vs $115\text{-}135 \text{ W}$ measurements (TE-CRG-OP) in the triplet cold mass

DEBRIS CAPTURE IN THE TRIPLET

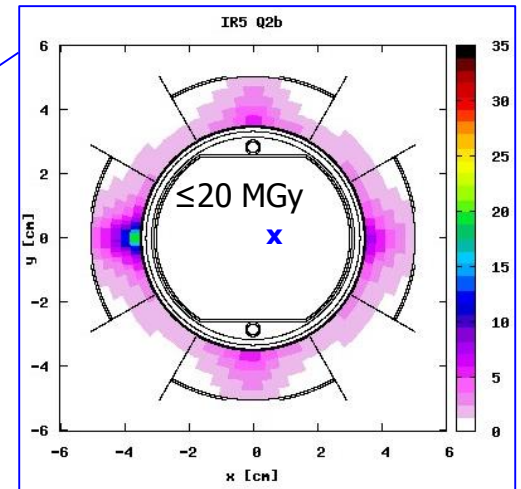
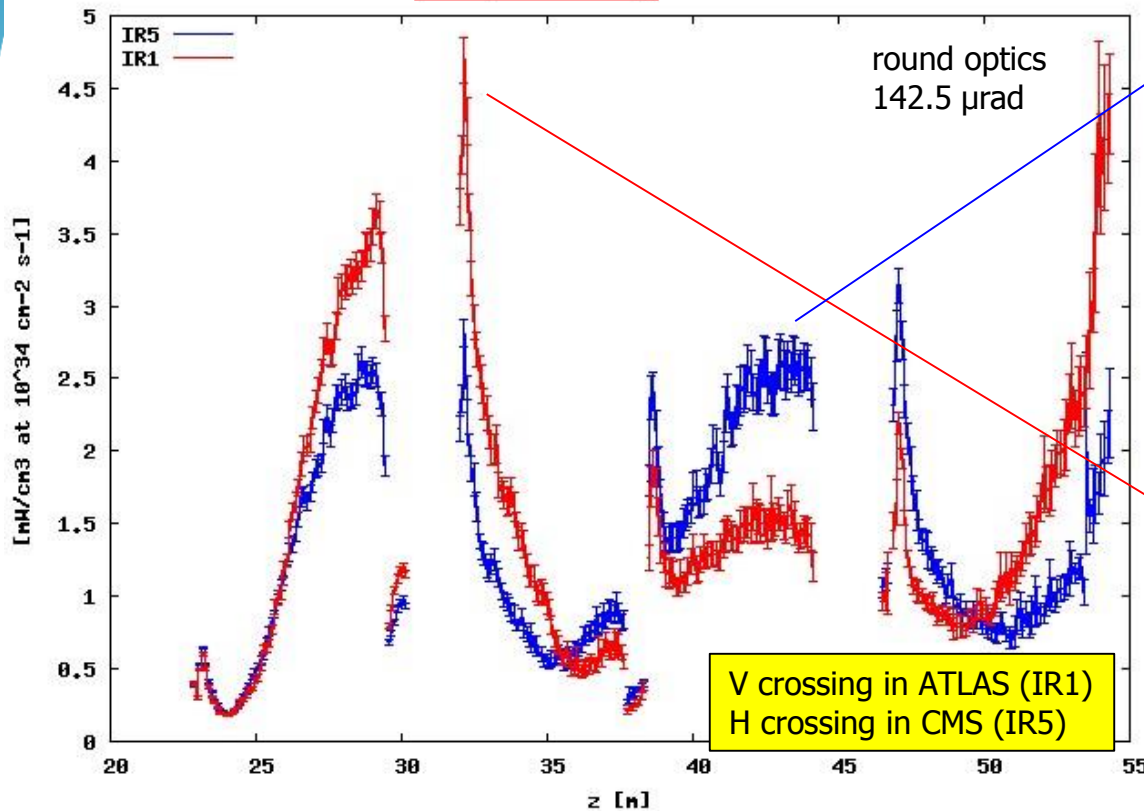


high energy spectra are depopulated by *charge particle (especially pion)* interception in the successive quadrupoles due to magnetic field bending

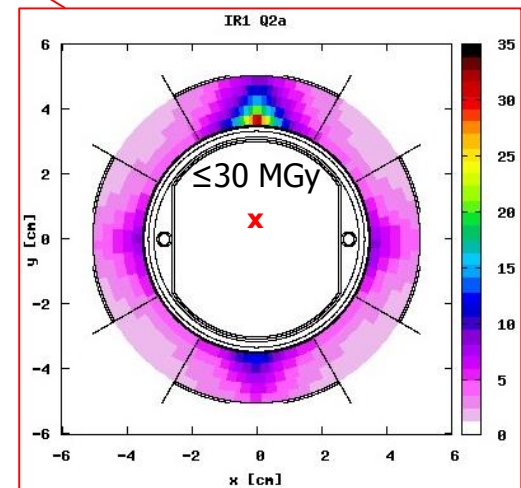


MARGIN TO QUENCH AND LIFETIME

peak power density in the coils

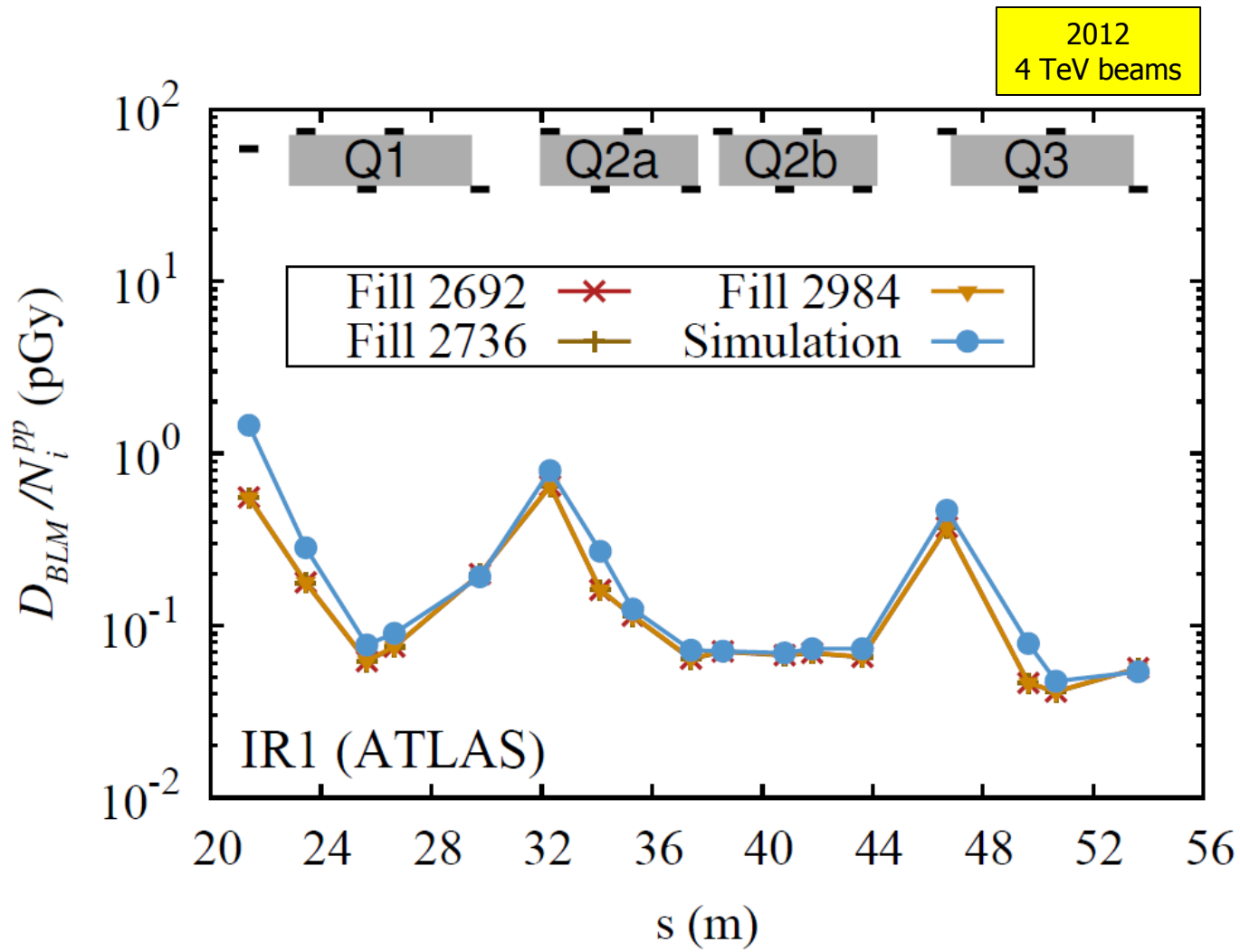


peak dose [MGy] after 300 fb⁻¹, relevant for triplet (i.e. coil insulator) lifetime



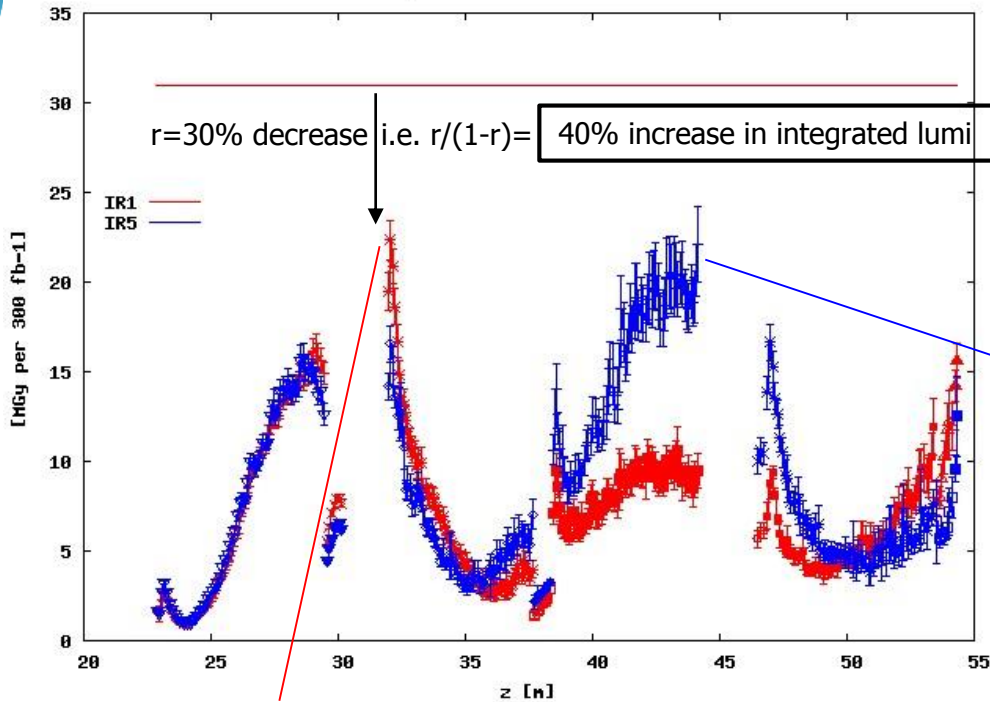
- different behavior reflecting the crossing plane variation for the same magnetic configuration of the triplet (FDF in the horizontal plane for positively charged particles coming from the IP)
- IR1 triplet (Q2a) approaches the design limit at nominal luminosity

BLM BENCHMARKING



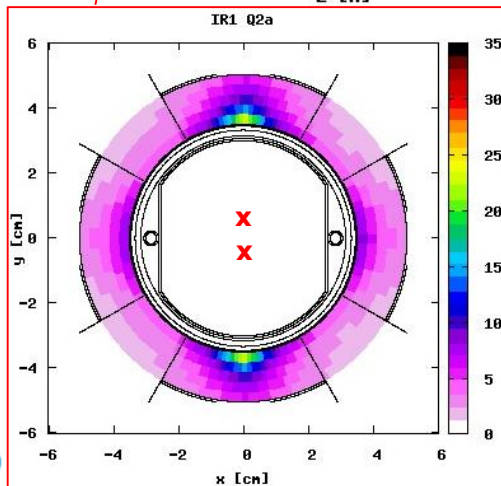
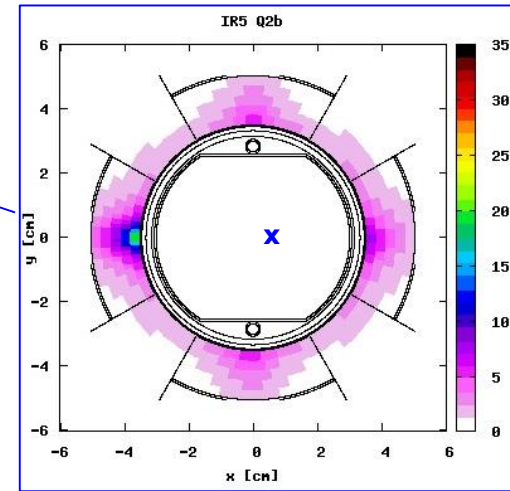
MITIGATION GYMNASTICS

peak dose in the coils



round optics
142.5 μ rad

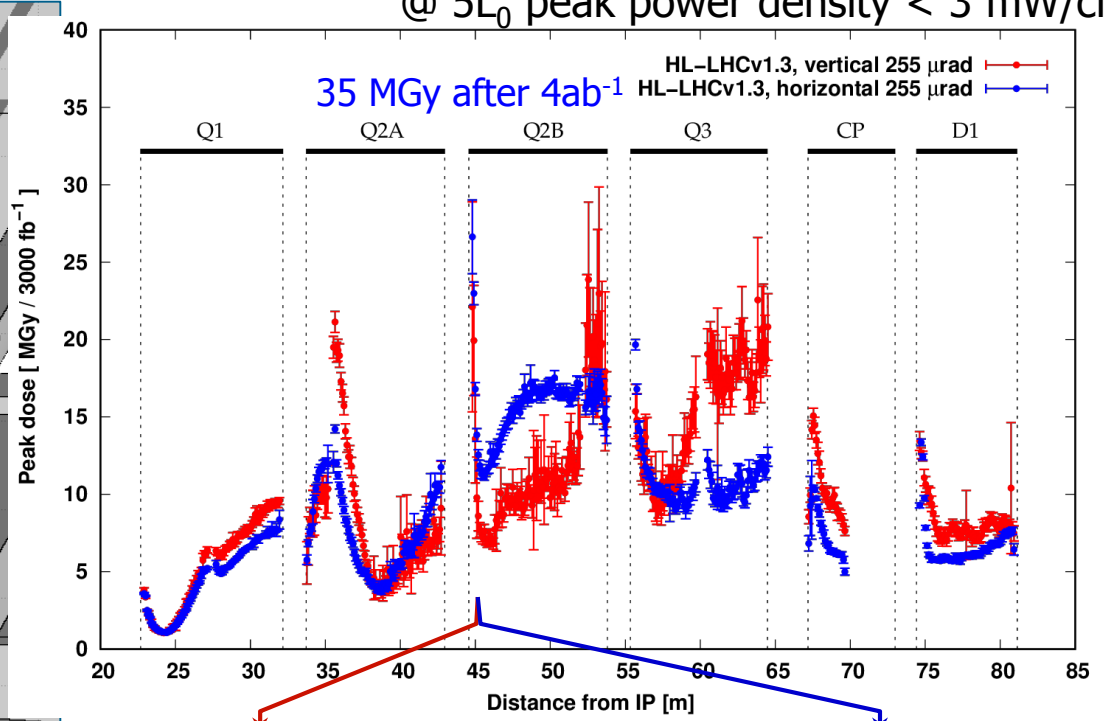
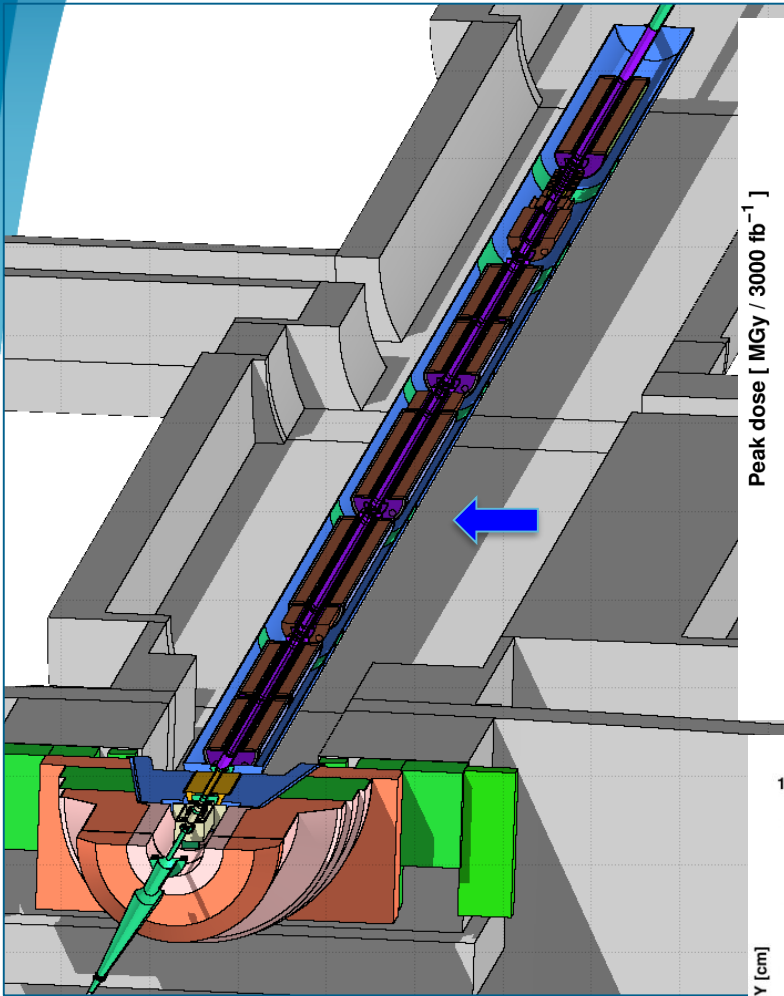
50% +V & 50% -V crossing in ATLAS (IR1)
100% H crossing in CMS (IR5)



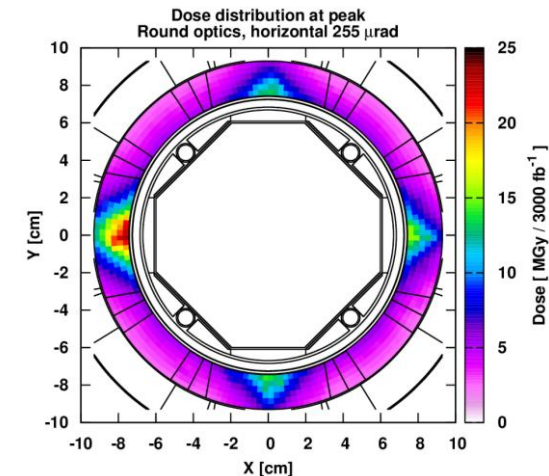
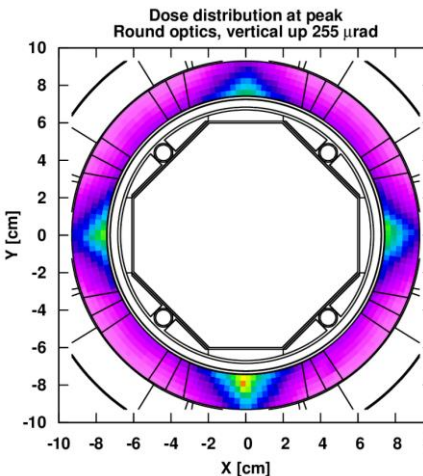
similar max dose level in IR1 and IR5

HL-LHC v1.3

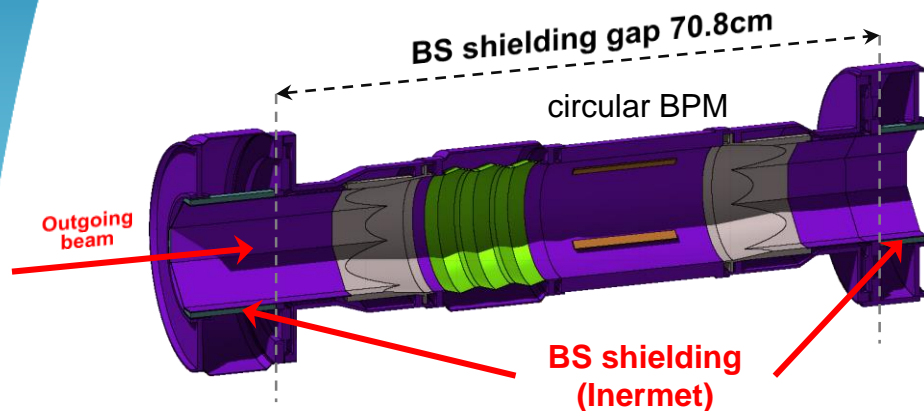
@ $5L_0$ peak power density < 3 mW/cm³



@ $5L_0$
 630 (V) 595 (H) W in the cold mass
 595 (V) 555 (H) W in the beam screen



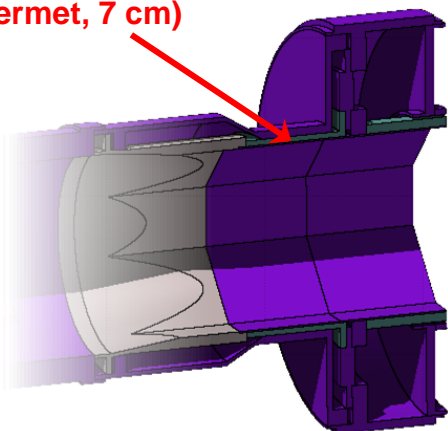
HARDWARE MITIGATION



The interruption of the Inermet BS shielding in the interconnect was the cause of the localised 36 MGy per 3000 fb⁻¹ dose peak at the IP end of Q2B in IR5

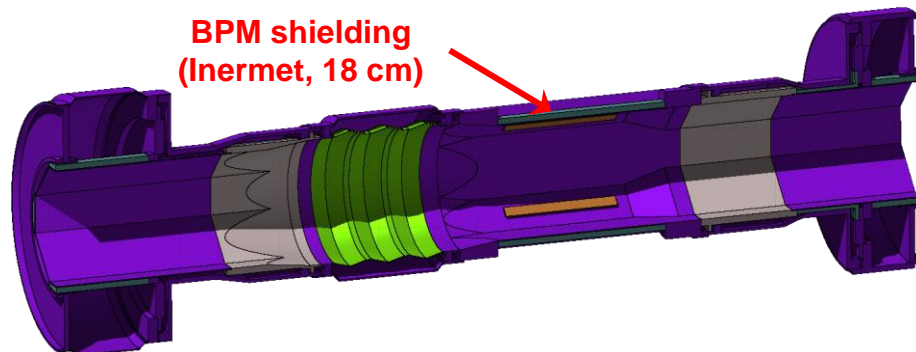
Shielding improvements:

Additional shielding on non-IP side (Inermet, 7 cm)



octagonal BPM with incorporated Inermet pieces on the mid-planes

BPM shielding (Inermet, 18 cm)

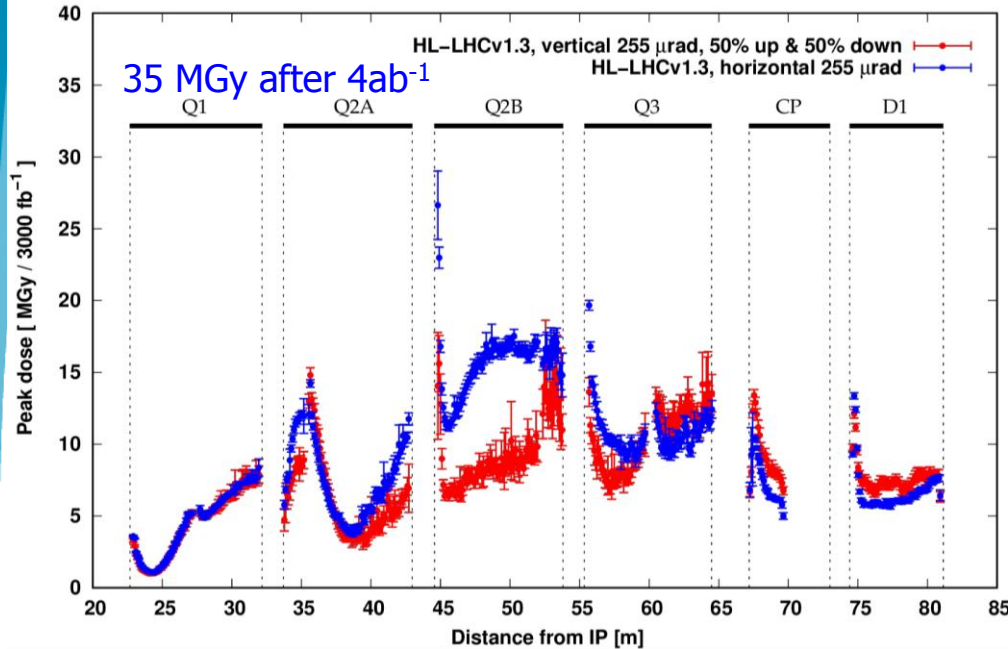


- Peak value reduction by ~15% (down to 31 MGy)

- Further ~15% reduction (down to 26-27 MGy as in the previous slide, retaining the 7 cm prolongation)

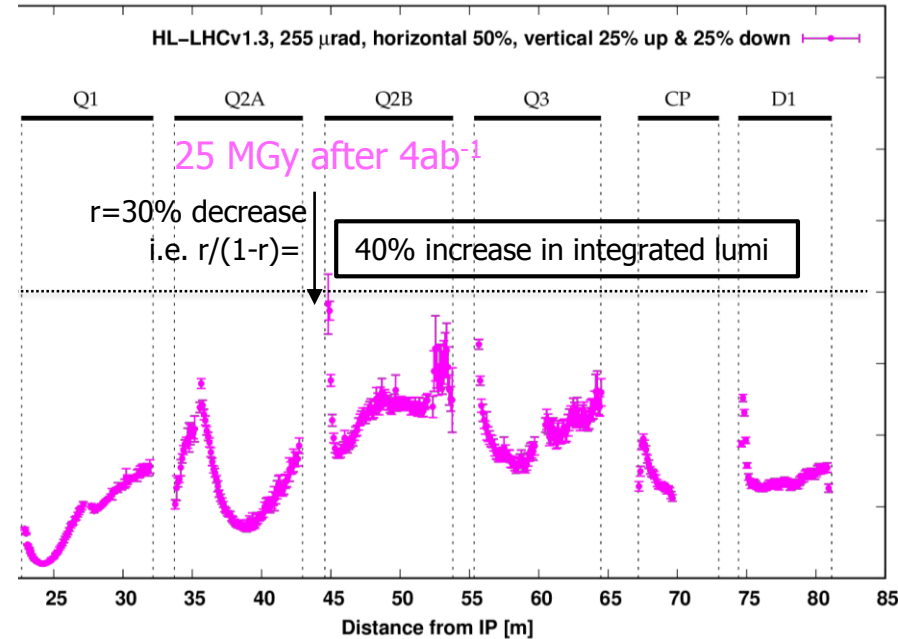
OPTICS MITIGATION

50% +V & 50% -V crossing in one insertion
100% H crossing in the other



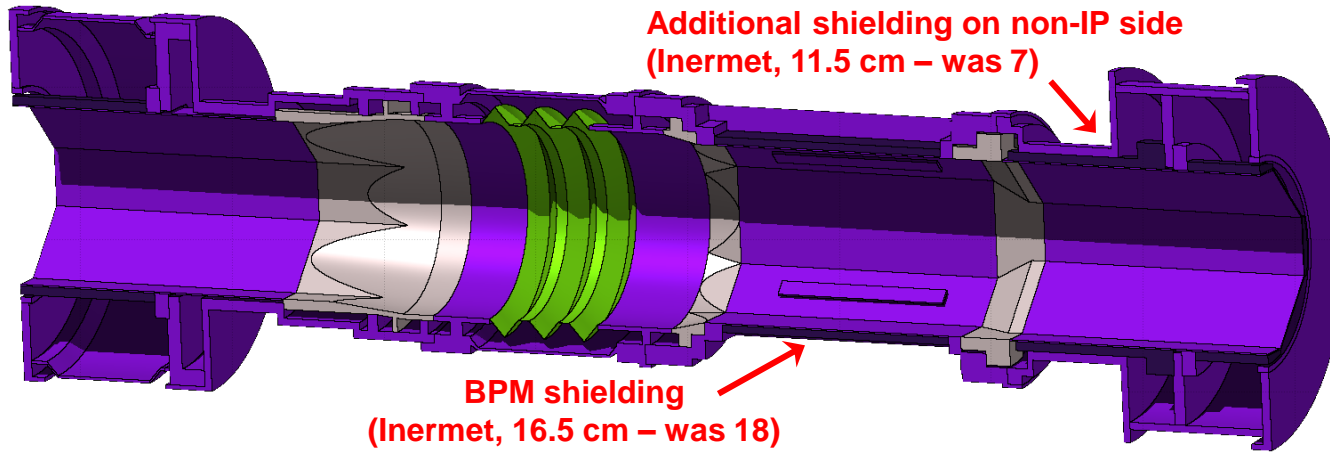
the limiting peak is obviously unmodified

25% +V & 25% -V & 50% H crossing in each insertion

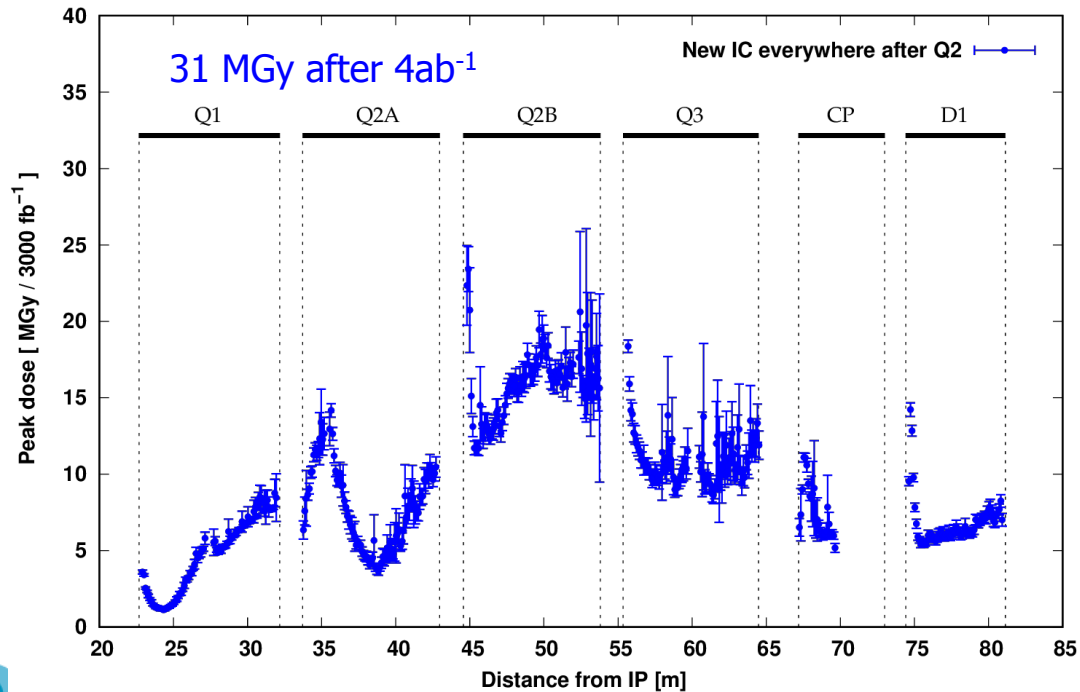


the gain is there,
but it requires a quite challenging hardware flexibility
with optics drawbacks

BETTER SHIELDING

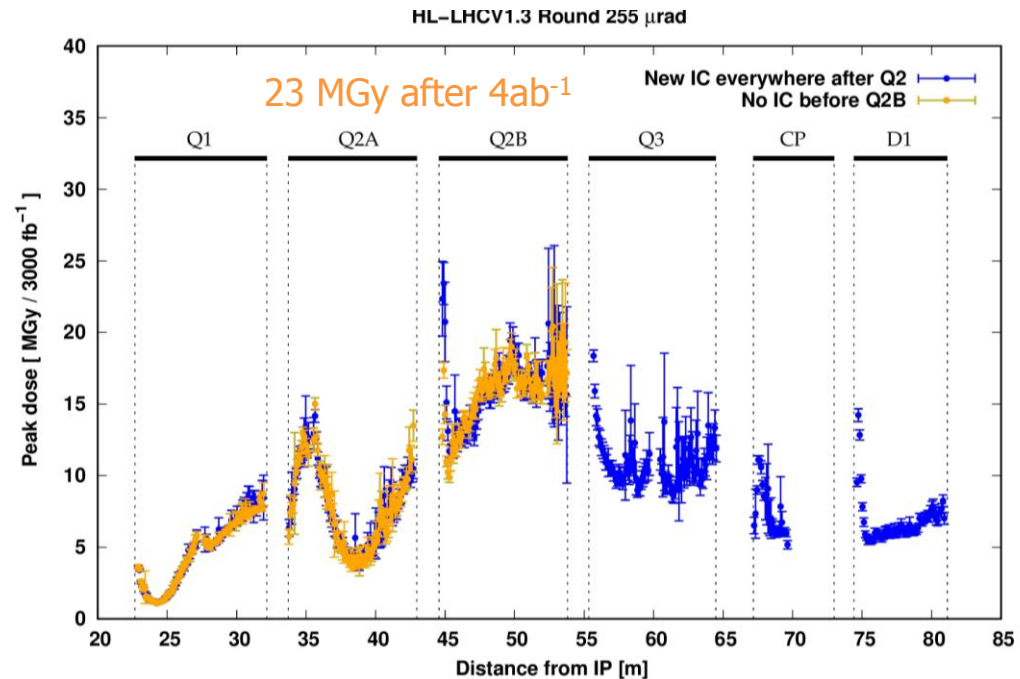


HL-LHC V1.3 Round 255 μ rad



IDEAL SHIELDING

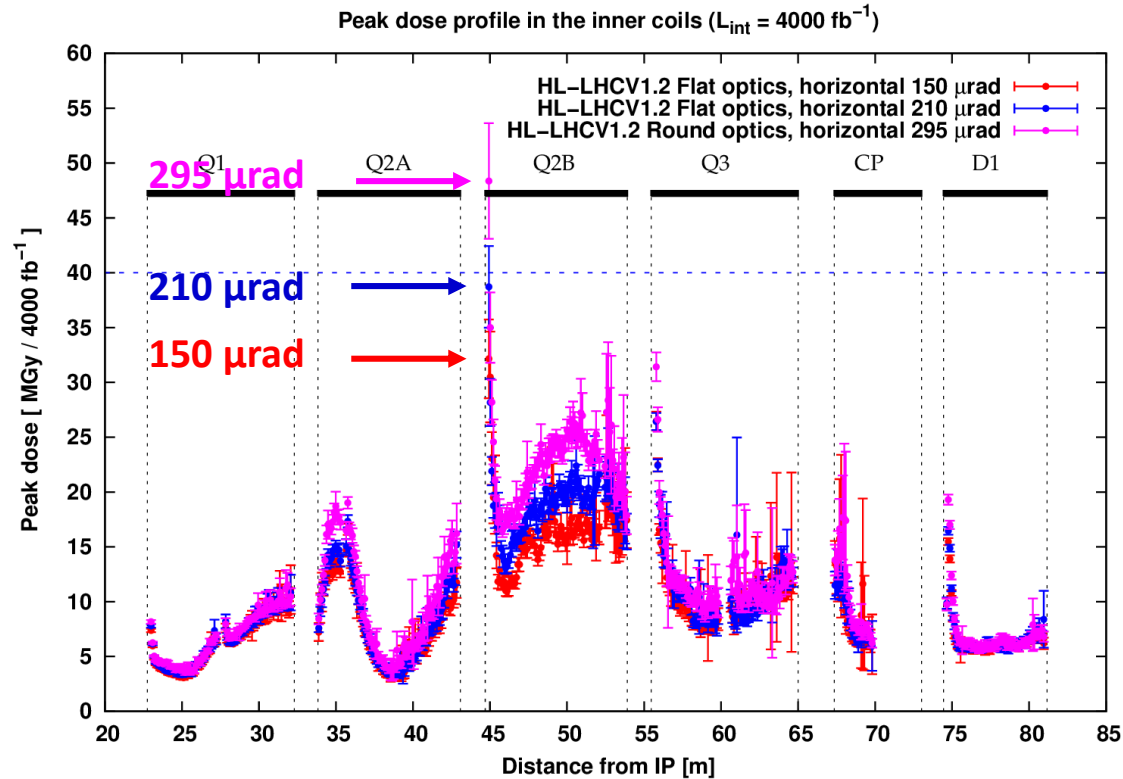
Assuming a continuous beam screen and cold bore between Q2A and Q2B



the weak point at the Q2B IP end ceases to be limiting

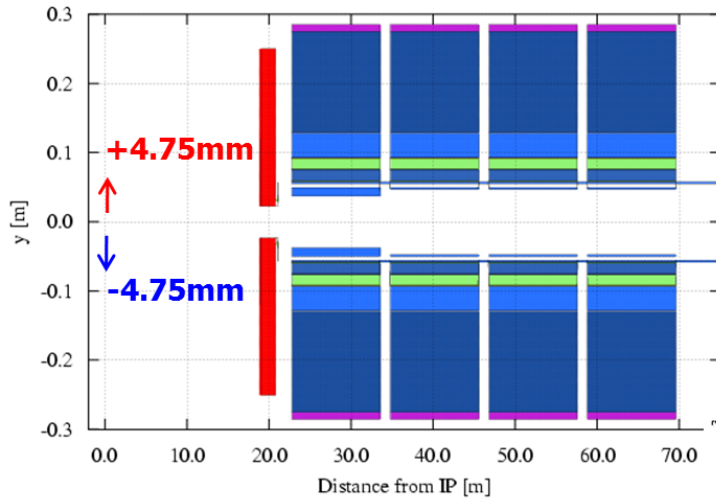
DEPENDENCE ON CROSSING ANGLE

Looking back at v1.2 (for 4 ab^{-1}) without IC improvement:



Effect of crossing angle variation along the fill over the 160-240 μrad interval to be explored in the updated conditions

IP DISPLACEMENT



in the crossing plane

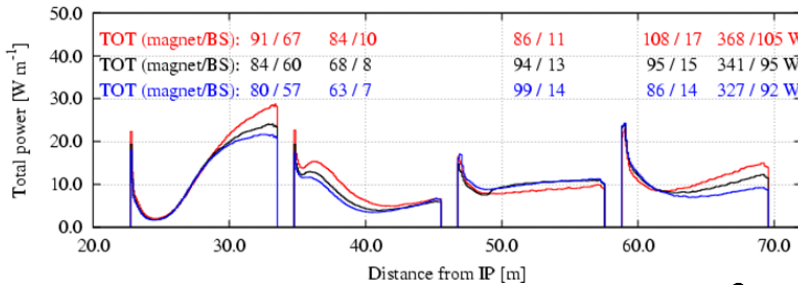
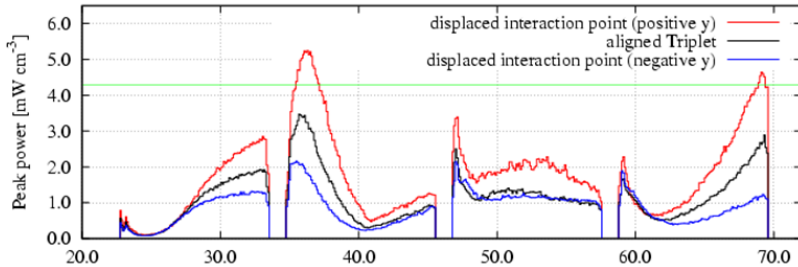
vertical crossing
(+225 urad half crossing angle)

↑
vertical axis

+50% for peaks

+10% for totals

when the debris cone is moved to a higher field region at the triplet entrance



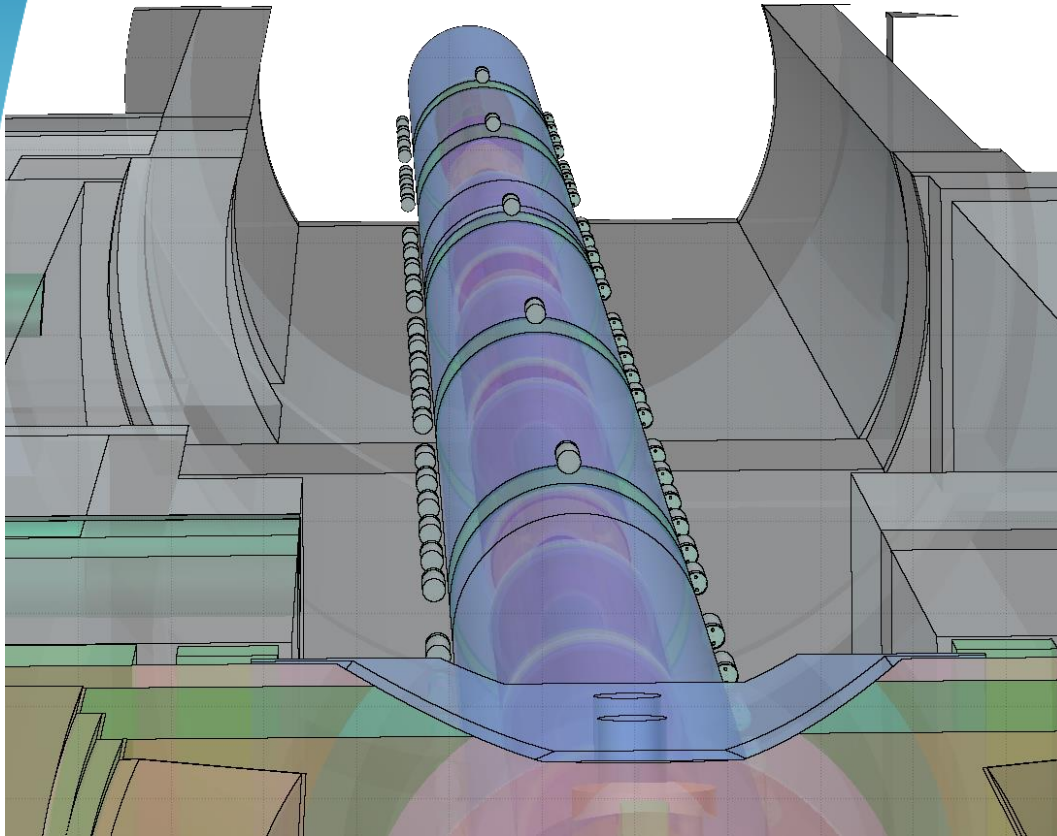
SLHC-IRP1, TDG Meeting, June 4th 2009

F.Cerutti

3

Effect to be evaluated for realistic conditions

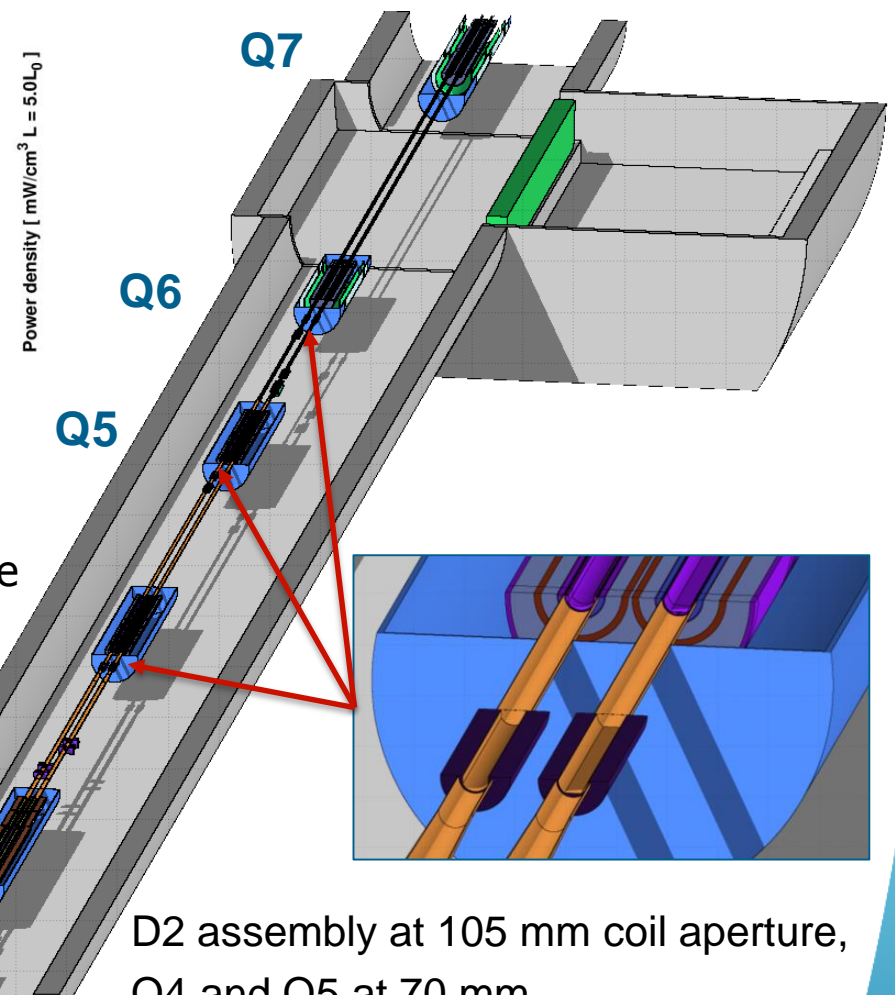
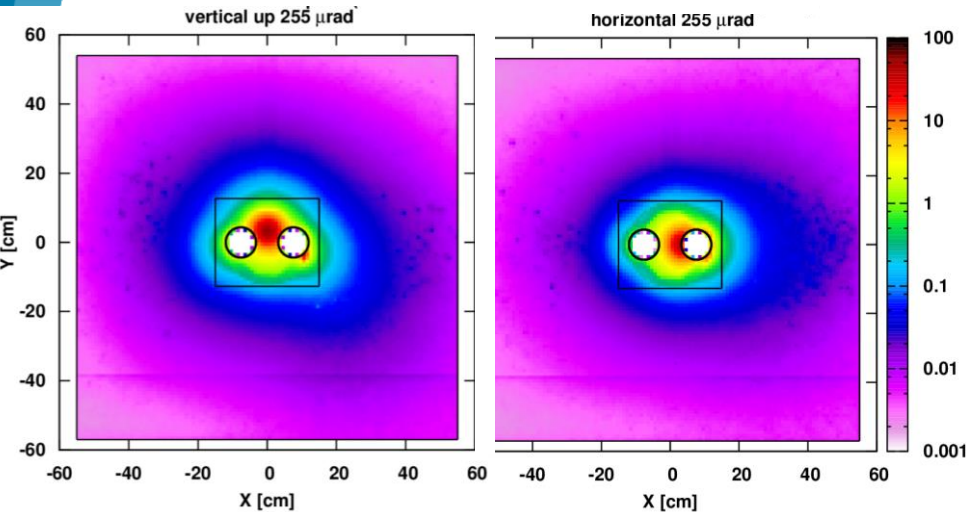
LOSS DETECTION



disentangling *abnormal triplet losses* from regular debris

talk on **Losses and cryogenic BLM** on Wed PM
WP7/10/13/15 session

MATCHING SECTION



@ $5L_0$ peak power density < 1 mW/cm³ everywhere
 and 33 W in the **D2** cold mass for **hor** crossing,
 155 W in the most exposed **TCL4** jaw
 and 20 W in the **TCLM4**;
TAXN
 up to 12 MGy after 3 ab⁻¹ on the D2 IP end coils

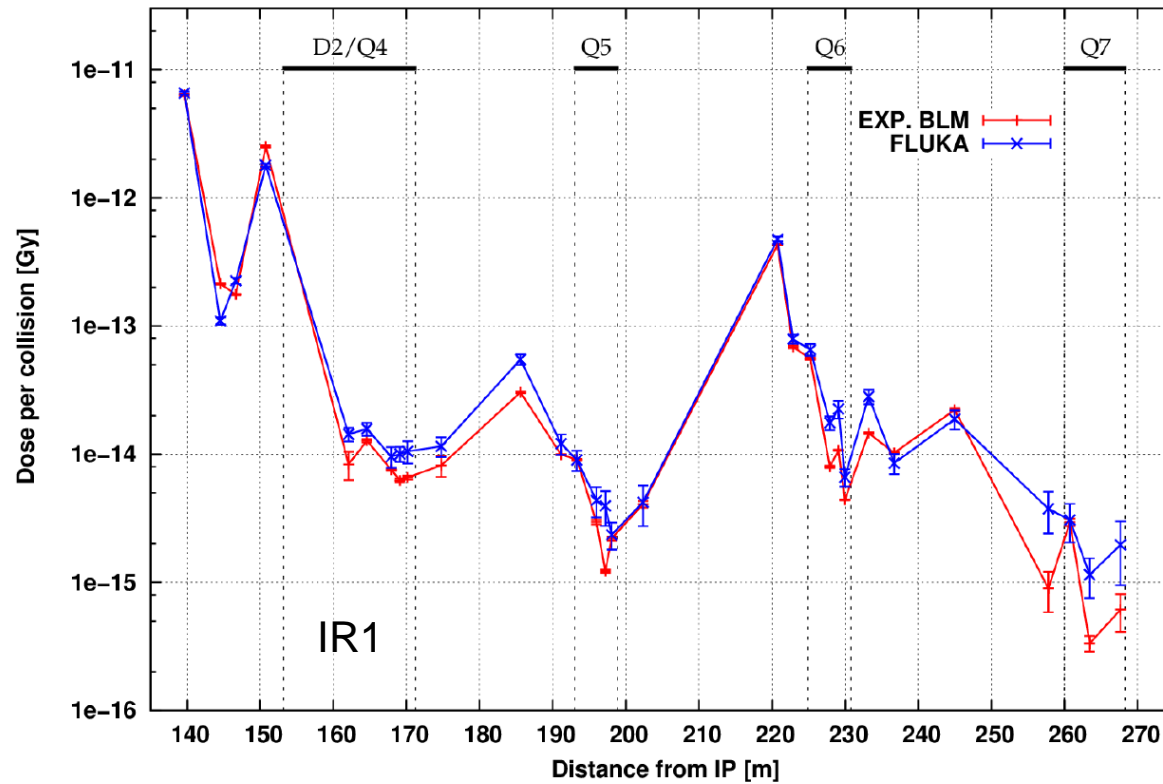
Q5 at 56 mm to be studied

D2 assembly at 105 mm coil aperture,
 Q4 and Q5 at 70 mm
 Masks in front of Q4, Q5 and Q6
 3 TCLs @ 13.5σ and 4 TCTs @ 12σ

BLM BENCHMARKING

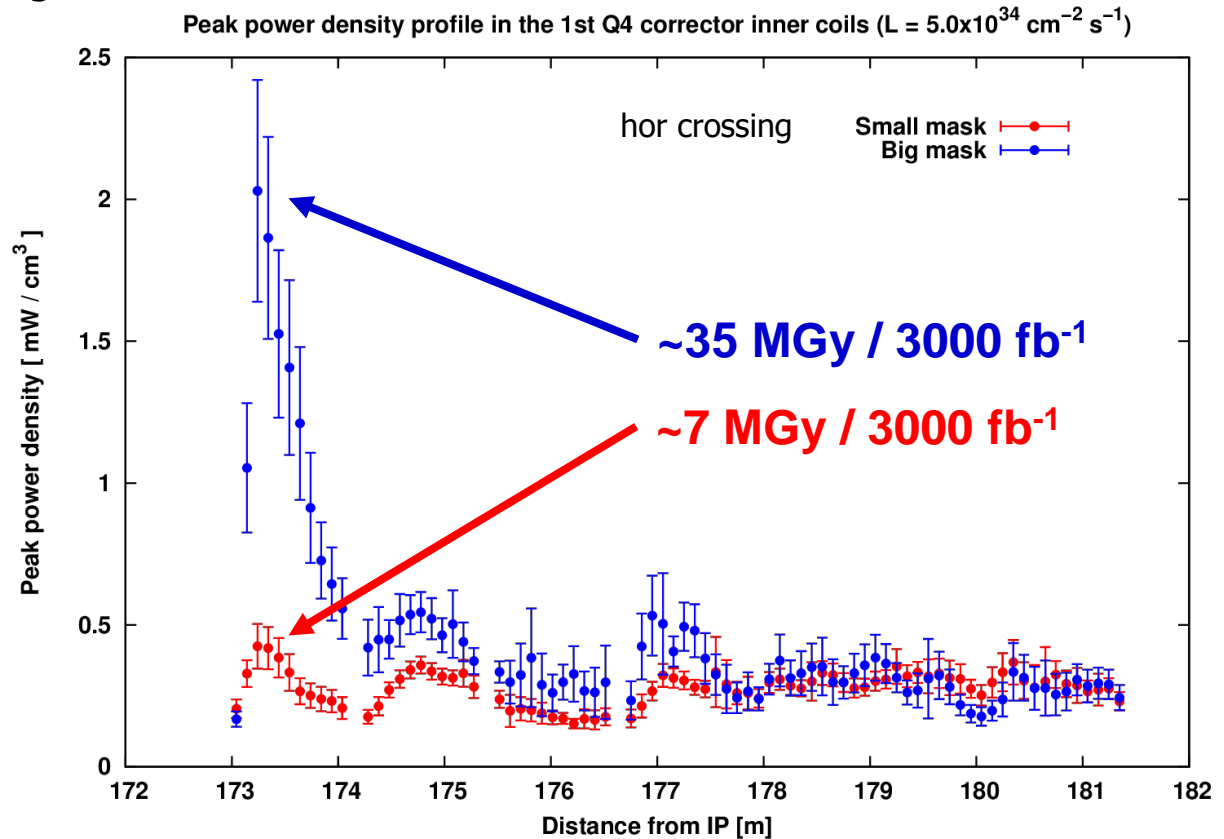
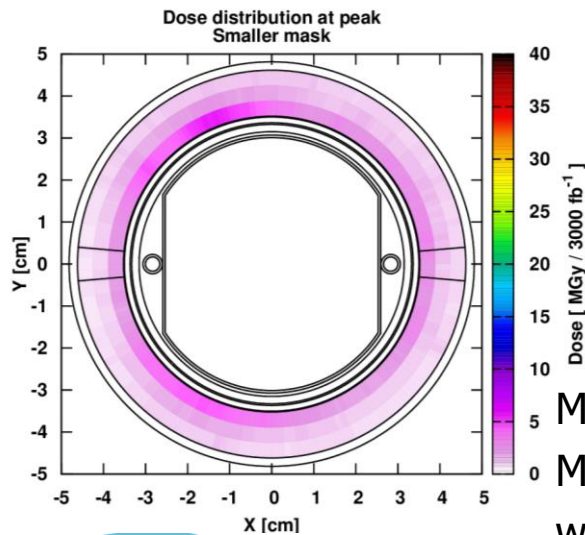
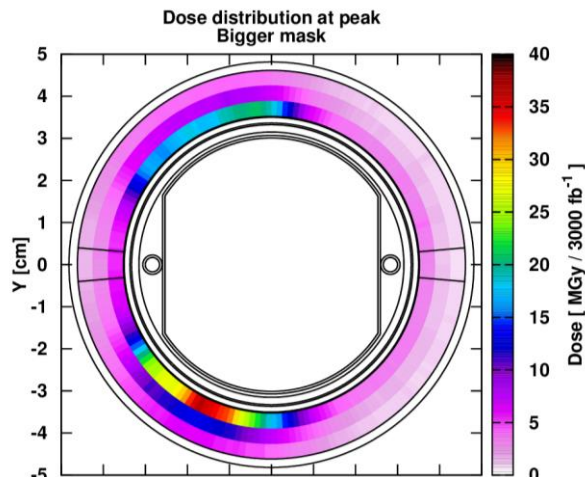
6.5 TeV beams

- Fill #4919 (May 2016) Experimental BLM data vs. FLUKA – TCL6 closed



SENSITIVITY TO MASK APERTURE/MISALIGNMENT

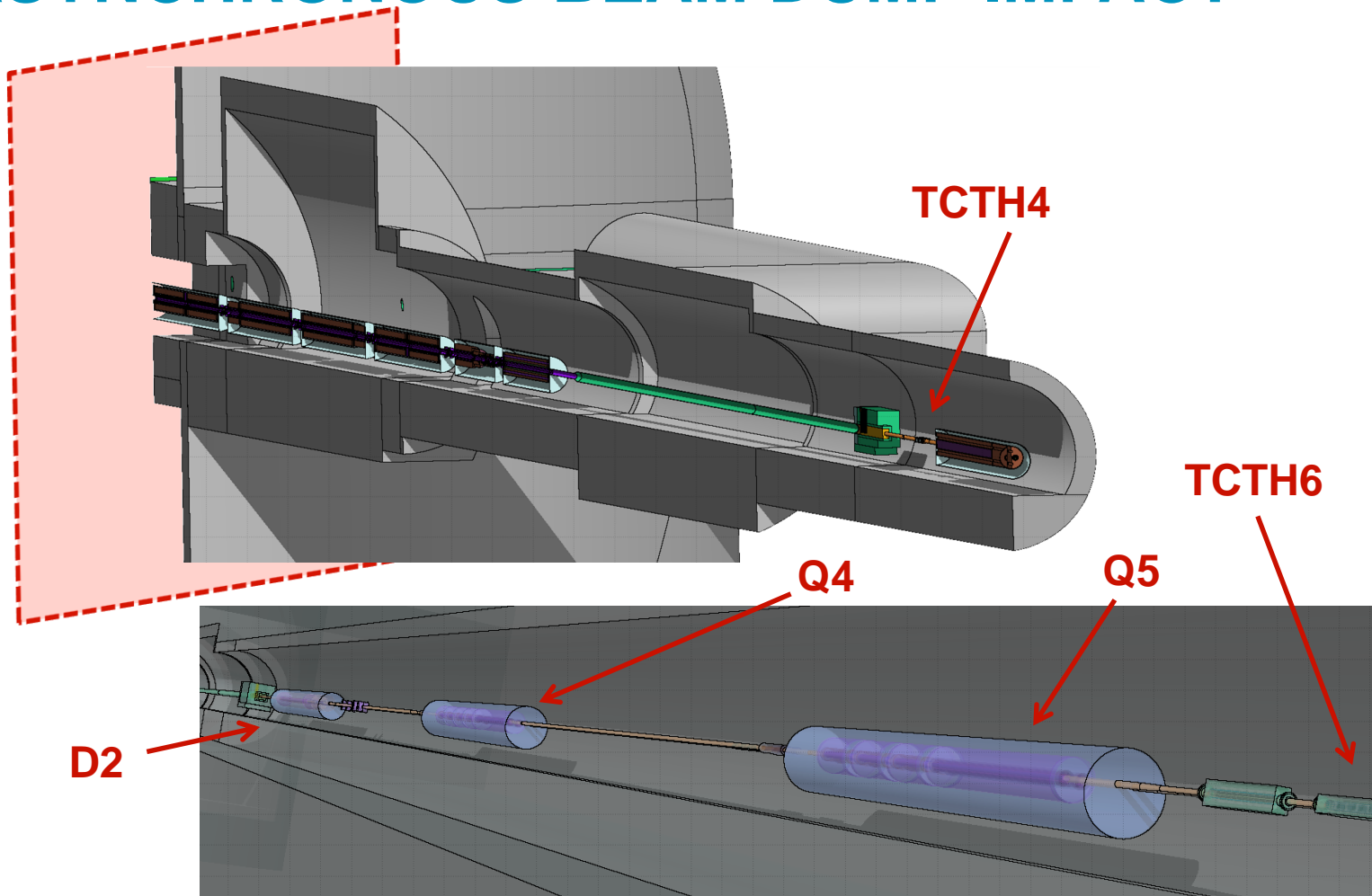
The warm masks are designed to match the beam screen aperture of the respective magnet
Assuming a 2 mm radial enlargement:



Major increase of the peak dose on the IP face of the first Q4 MCBYV
Max power density value of 2 mW/cm³ @5L₀ still acceptable,
with small impact on the total heat load

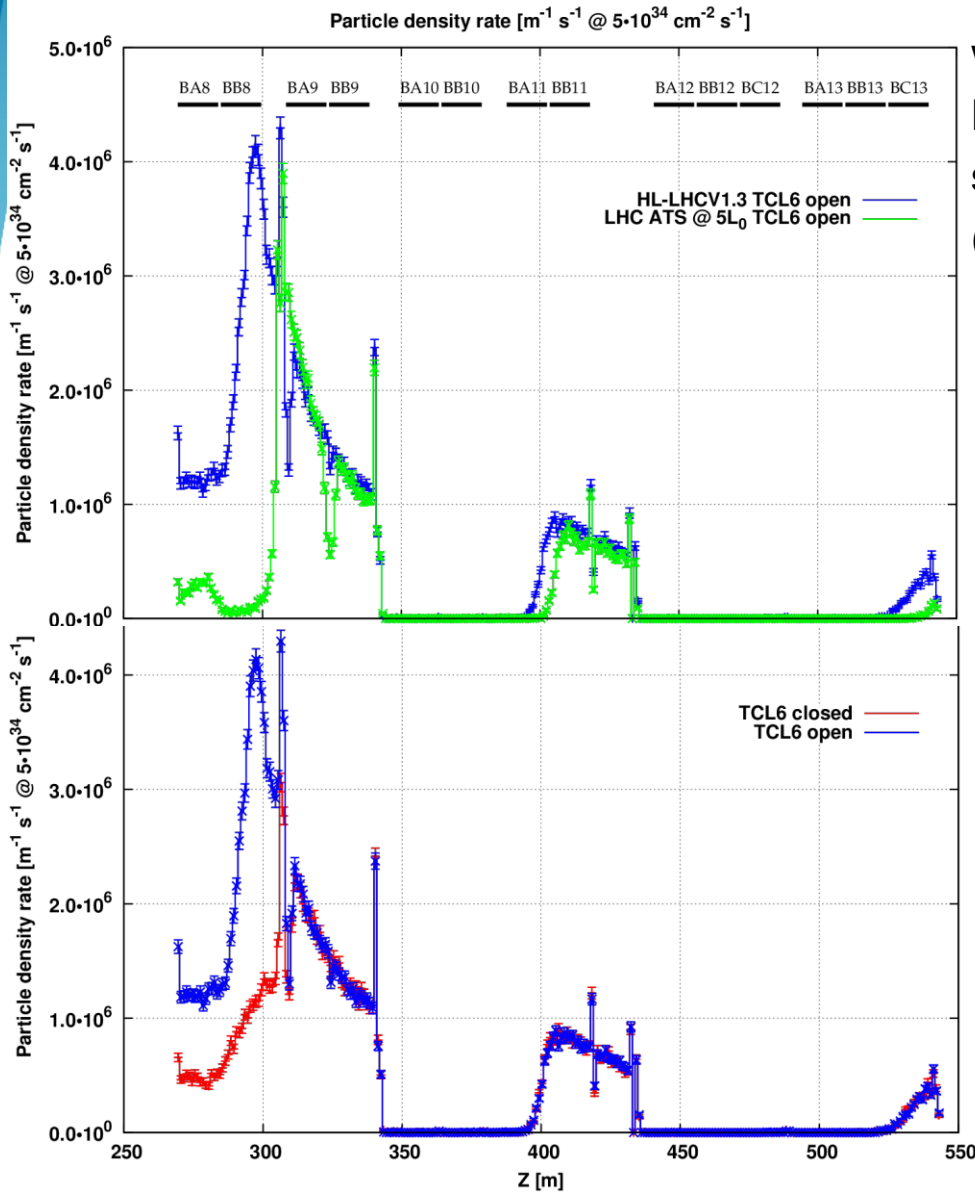
ASYNCHRONOUS BEAM DUMP IMPACT

Interface
plane at
22.6m

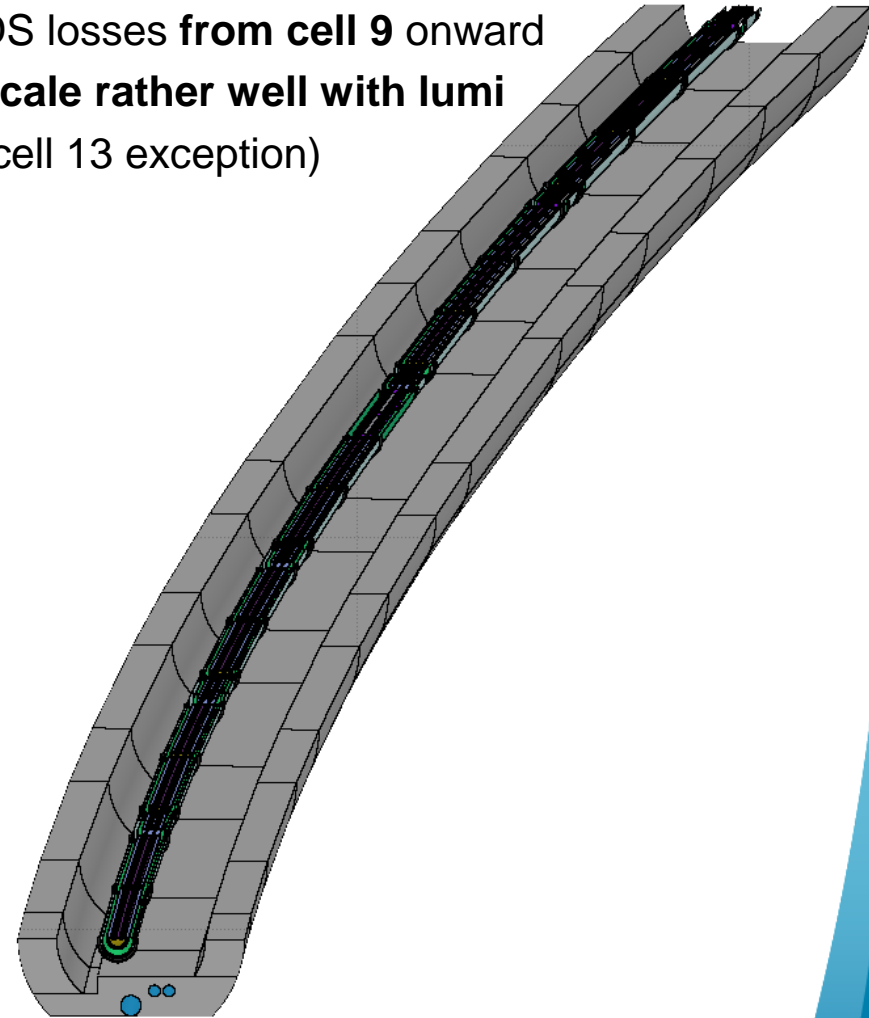


talks on **TCT** on Wed PM
WP5/7/10/14 session

DISPERSION SUPPRESSOR



wrt present LHC ATS optics,
 DS losses from cell 9 onward
 scale rather well with lumi
 (cell 13 exception)



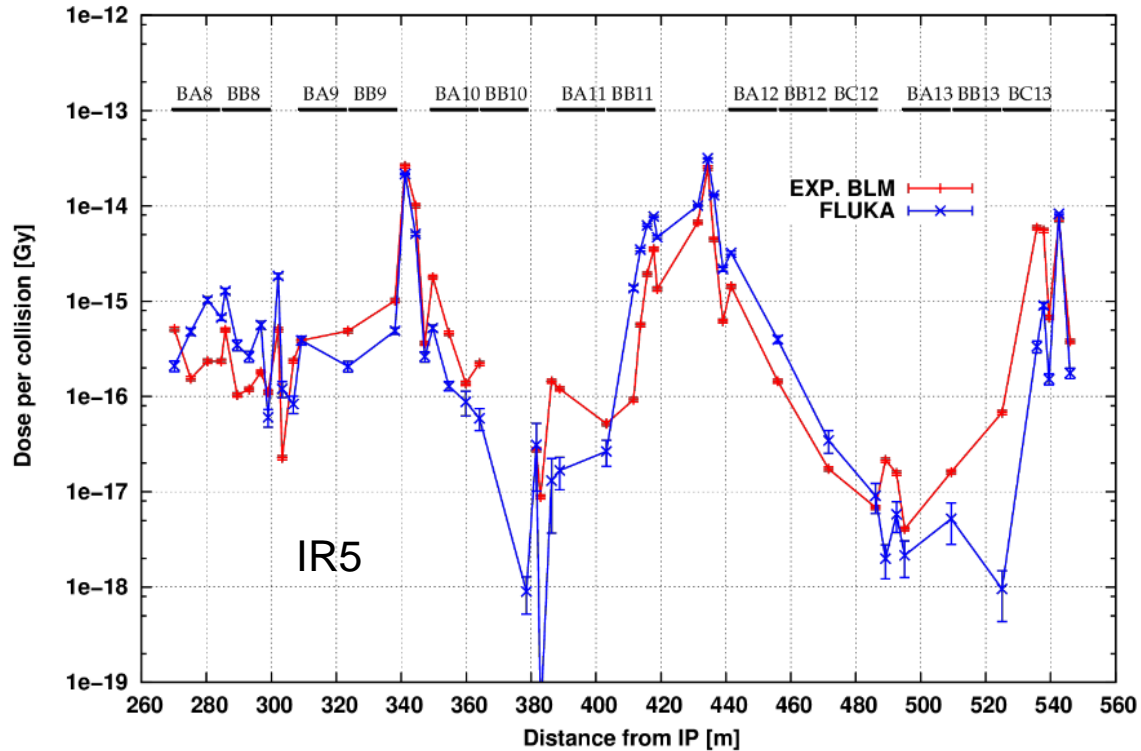
TCL6 has a noticeable impact
 only up to cell 8

BLM BENCHMARKING

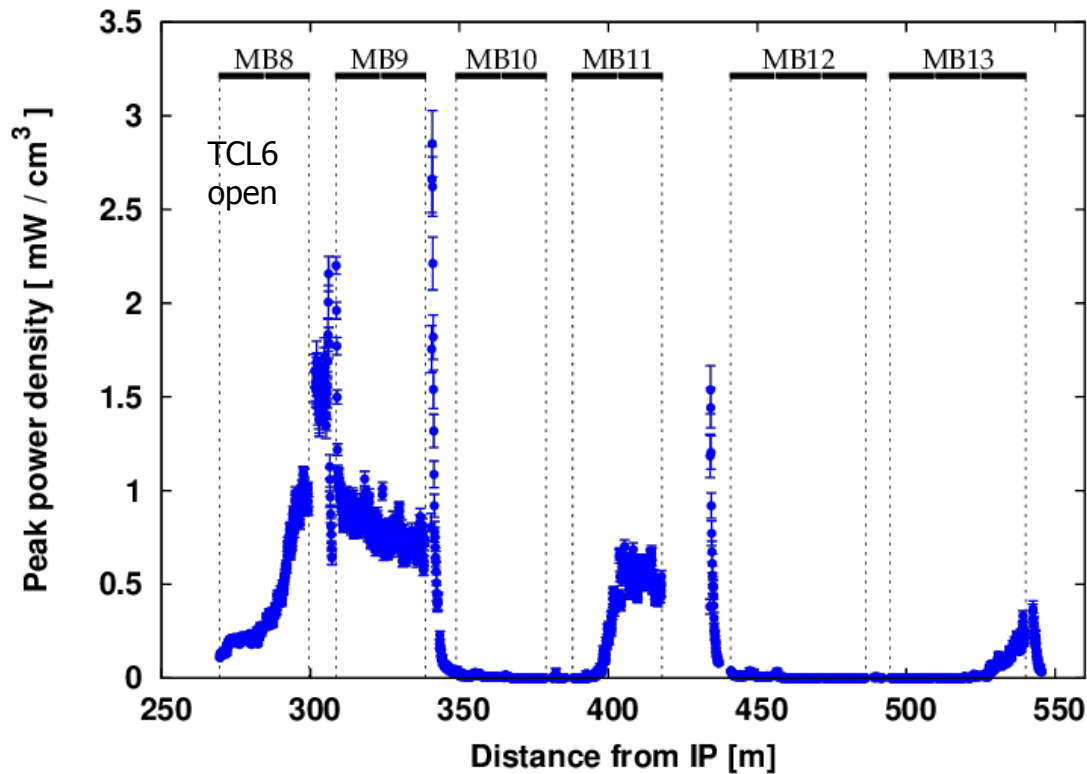
Fill #5401 (October 2016)
TCLs @ 15-35-20 sigma

6.5 TeV beams

Experimental BLM data vs. FLUKA – TCL6 closed



DS COILS IN THE HL-LHC ERA



Maximum peak power density values in the coils around 2-3 mW/cm³ @ 5L₀
Maximum dose values could be challenging in cell 9 (up to 40 MGy per 3 ab⁻¹
in MQMC, but very localized peaks are sensitive to aperture imperfections)

CONCLUSIONS

The structural Q2B weak point is brought to slightly exceed 30 MGy after 4 ab⁻¹, with a clear asymmetry between the hor and ver crossing insertions.

The crossing plane flexibility is capable to provide a valuable benefit but has heavy implications.

On the other hand, the crossing angle variation along the fill can offer a further gain, to be quantified, as a substantial fraction of the integrated luminosity could in principle be produced at lower crossing angle, both at the beginning of the fill (at larger β^*) and in the end of the fill (at minimum β^* but lower intensity).

Despite the weaker TAXN effectiveness, collimators and masks can offer a reasonable protection to the matching section.

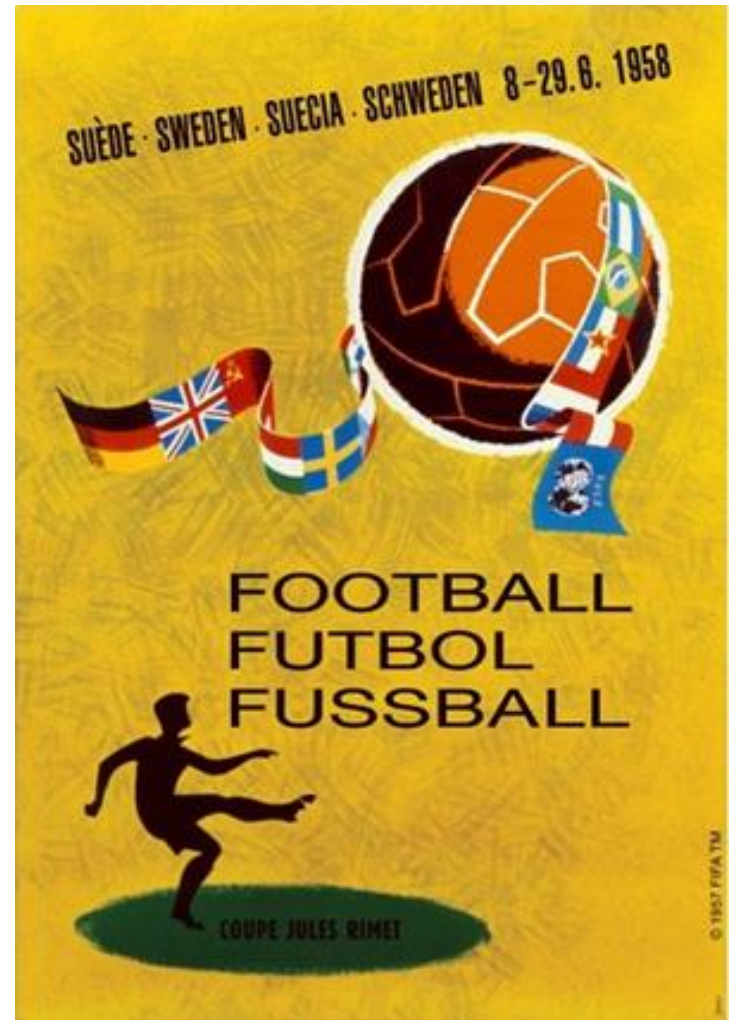
The Q5 aperture reduction needs to be studied.

Dispersion suppressor losses are expected to mainly display the expected lumi scaling, with a localized cell 9 hot spot challenging the MQMC lifetime.

THANKS FOR THE WEATHER



ESPAÑA 82



PEAK VALUES IN THE MATCHING SECTION

Magnet assemblies	Horizontal crossing	
	power density [mW/cm ³ @ 5L ₀]	dose [MGy after 3 ab ⁻¹]
D2	0.8	12
Q4	0.5	7
Q5 (70mm)	0.2	3
Q6	0.2	3
Q7	0.5	7