



# Layout and Performance of Run III System

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2017 HL-LHC Annual Meeting – Madrid (ES) – 13-17 Nov 2017

# Outline

- Introduction
- New TCSPM design: measurements with beam
- Expected performance with TCSPM secondary collimators in Run III
- Removal of MQWA.E5[L,R]7 and possible installation of shielding
- TCLDs
- Conclusions

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# Introduction

- IR7 collimators account for a significant fraction of the LHC Impedance budget, which has impact on beam stability:
  - IR7 hosts the largest fraction of LHC collimators;
  - The vast majority has jaws in graphite: TCPs and TCSGs;
  - Contribution of IR7 carbon collimator jaws to the LHC impedance budget enhanced by small gaps and large number of collimators in the same family;
- With respect to Nominal LHC parameters, HL-LHC foresees to double the bunch population and to reduce the normalised emittance:
  - Increased impact of collimators on impedance;
  - Increased load on collimators for the same beam life time;
- Extensive R&D allowed to converge on:
  - MoGr as jaw material of TCPs and TCSGs – to enhance robustness (with positive effects on impedance);
  - Mo as coating material of TCSs – to improve the impedance;

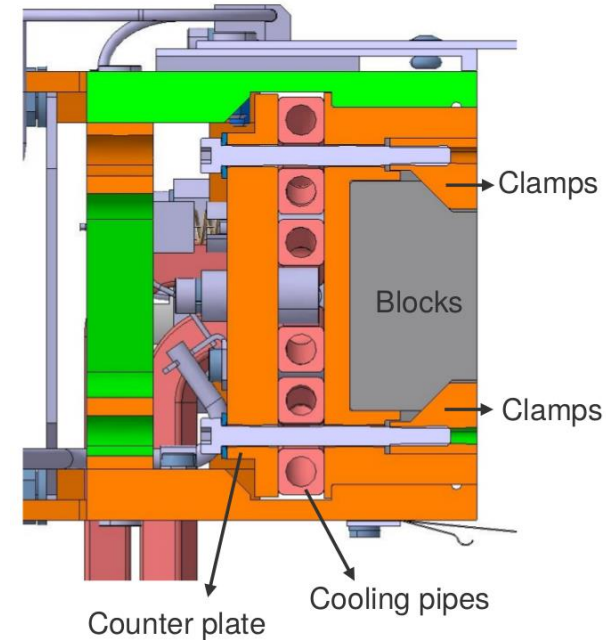


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# TCSPM Design

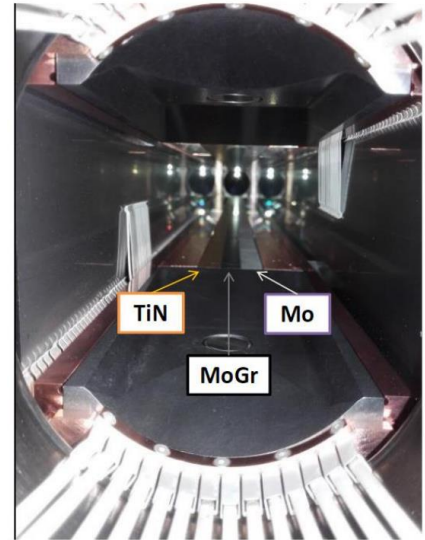
- TCSPM: new design of TCS collimators;
  - “P”: addition of BPM monitors;
  - “M”: “metallic” jaw, i.e. lower impedance;
- Design actually features:
  - MoGr** jaw: better response of material to thermal load:
    - 1MW** in case of 0.2h beam life time over 1-10s (Nominal LHC: 500kW);
    - 200kW** in case of 1h beam life time in steady state (Nominal LHC: 100kW);
  - Mo-coated** jaws: reduce impact on machine impedance budget (spare octupole current);



[Courtesy of F. Carra](#)

# Validation of Design: Installation of TCSPM Prototype

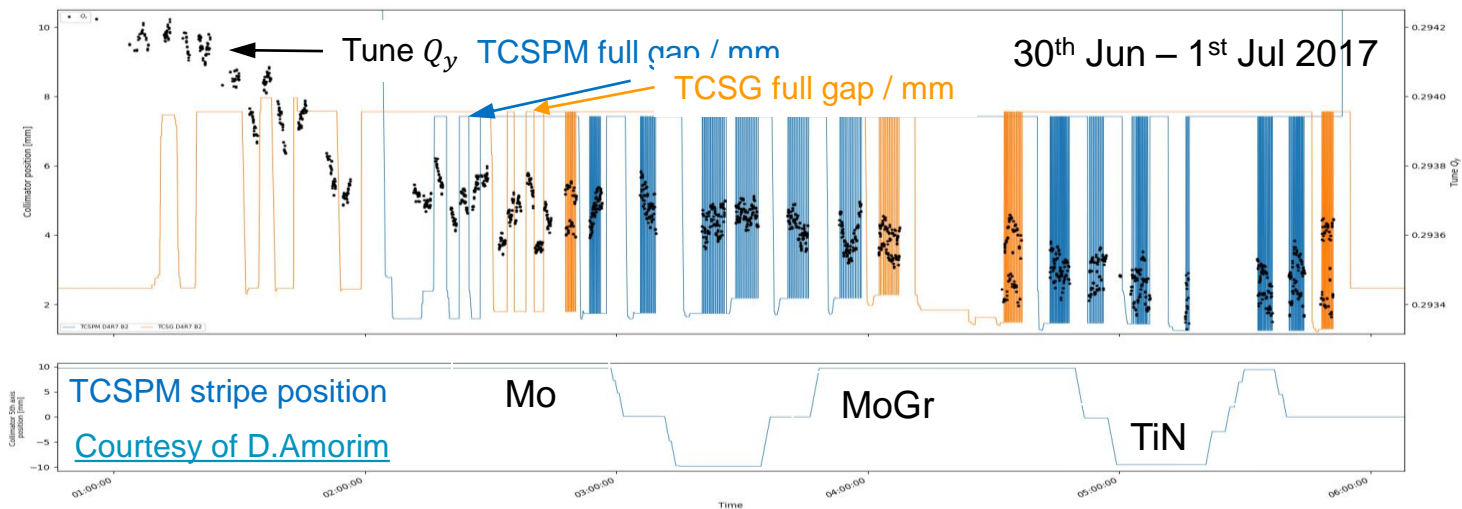
- The finalisation of the TCSPM design required to **verify with beam** the **beneficial effects** of the material choice;
- During YETS 2016, a prototype of TCSPM was installed ([LHC-TC-EC-0006](#)) in slot D4R7.B2 for tests with beam:
  - Slot of vertical secondary collimator:
    - **Smallest beam  $\sigma$**  among the secondary collimators → ideal for **impedance measurements**;
    - Presence of a regular TCS in CFC in same slot → possibility to perform **direct comparisons**;
  - Three **stripes of different materials**, to assess effect of coating on impedance;



During 2017, extensive MD campaign of tune-shift measurements in order to benchmark expectations from impedance models.

# MD2193: Single Stripe Impedance

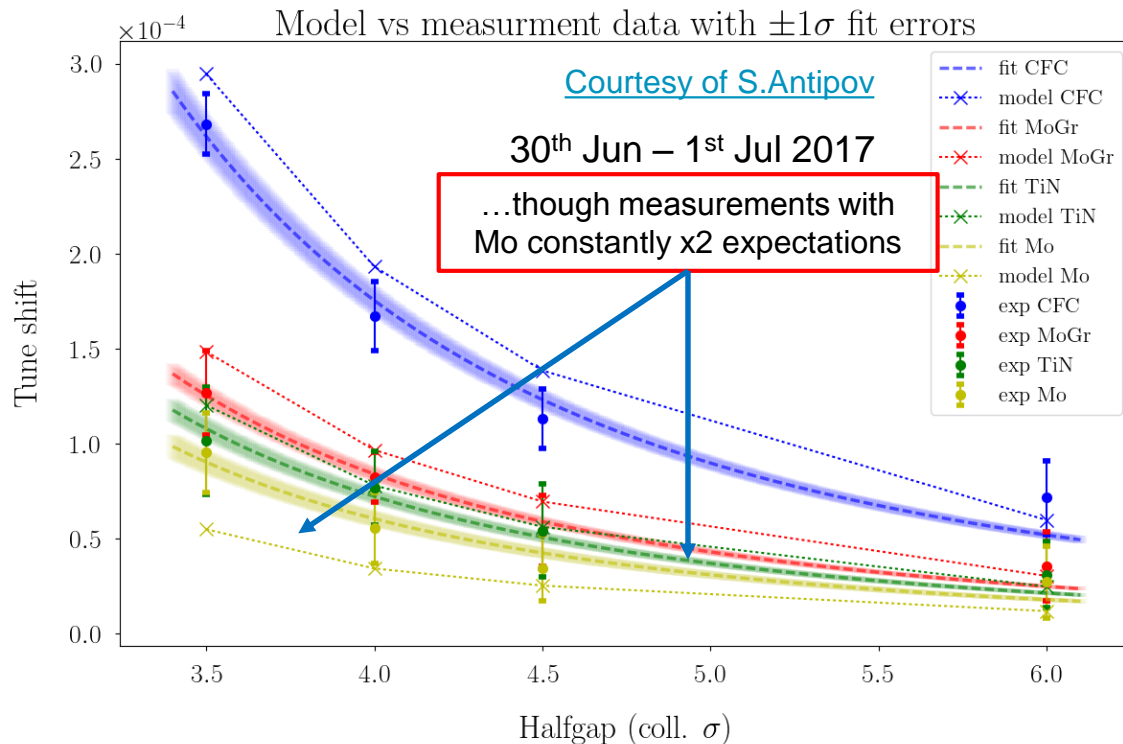
- Aim: to measure the impedance contribution from each TCSPM stripe and compare against the TCSG nearby;
  - Measurements carried out cycling the collimator gap and monitoring the tune signal;
  - Tune measurements obtained kicking the whole bunch and monitoring the damped oscillations



# MD2193: Single Stripe Impedance (II)

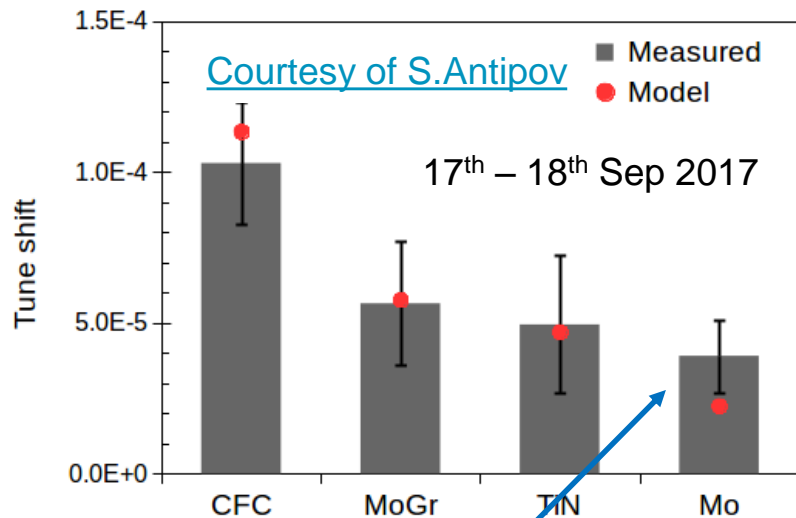
- Good agreement between measurements and expectations (ImpedanceWake2D, resistive wall & geometrical impedances):

Challenging measurements, with sensitivity of  $\Delta Q \sim 2 \cdot 10^{-5}$ !

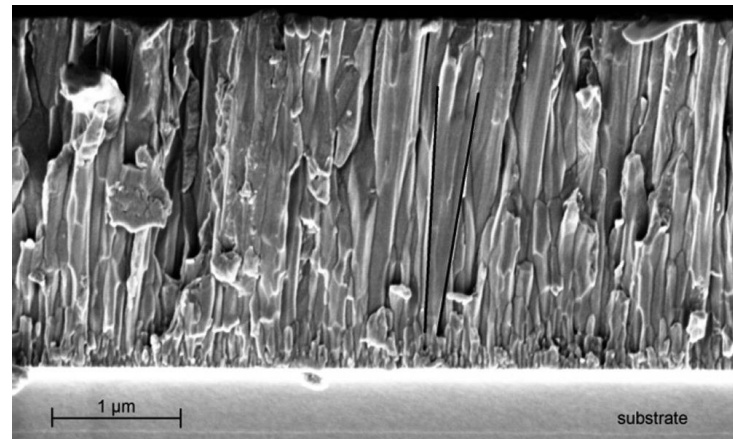


# MD2191: Single Stripe Impedance with HL-LHC-type Bunches

- Same measurements as before, repeated with an HL-LHC-type bunch at  $\sim 1.9 \cdot 10^{11}$  p/bunch;



...measurements with Mo still constantly x2 expectations



...possible explanation: surface roughness / non-regular column structure of Mo coating, with effects on impedance  $\rightarrow$  ongoing investigations (G.Mazzacano, CERN, BE-ABP-HSC)

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# Consolidation of the LHC Collimation System in IR7 – post-LS2 Era

- As part of the consolidation of the LHC collimation system in IR7, it is foreseen to exchange:
  - 2 TCPs (H/V - 60cm) in CFC with TCPPMs in MoGr;
  - 4 TCSGs (1m) in CFC with TCSPM in MoGr, Mo-coated;
- Slots of the 4 TCSPMs still not finalized yet:

More in I.Lamas' presentation on Thu, 16<sup>th</sup> Nov, WP5 Parallel session (afternoon), for production

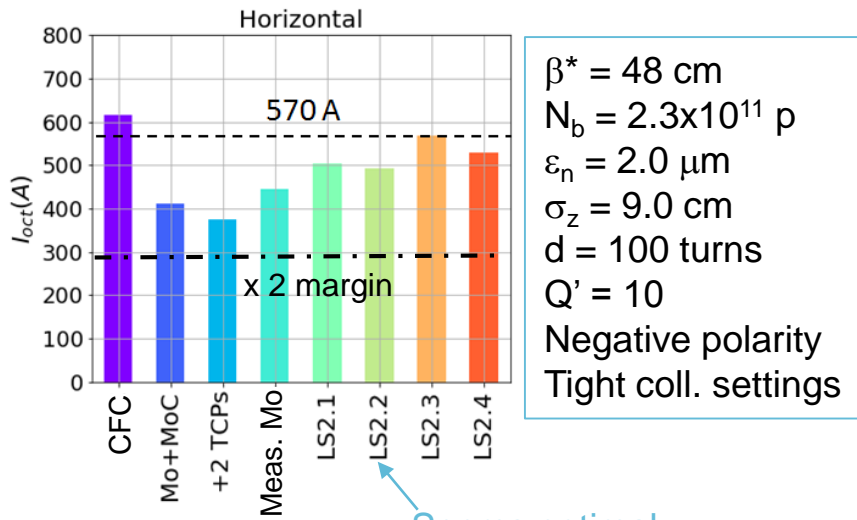
		1	2	3	4
TCSG.A6L7.B1					
TCSG.B5L7.B1					
TCSG.A5L7.B1					
TCSG.D4L7.B1	V				
TCSG.B4L7.B1	H				
TCSG.A4L7.B1					
TCSG.A4R7.B1					
TCSG.B5R7.B1					
TCSG.D5R7.B1					
TCSG.E5R7.B1					
TCSG.6R7.B1	H				

- Configurations being considered:
  - Reduce impedance as much as possible – collimators with largest contribution on both H and V plane);
  - Avoid first two skew collimators – most exposed to steady-state losses;
  - Avoid H and V secondary collimators – protection reasons;
  - Avoid H secondary collimators only – ABD;

Finalization of choice could take advantage of more detailed estimations of impact on impedance and load on coating;

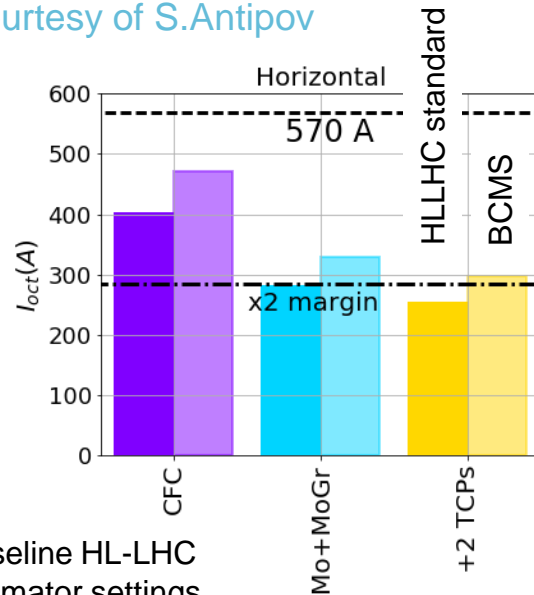
# Impedance Considerations

- Mo coating of IR7 TCSs: octupole currents lowered by 200A if all IR7 TCSs are exchanged with Mo-coated MoGr;
- 50% of the expected impedance reduction can be achieved exchanging only 4 collimators (LS2.2);



Seems optimal  
(largest impact on H plane)

Courtesy of S.Antipov



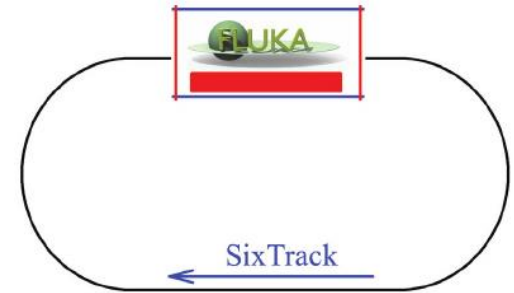
Baseline HL-LHC  
collimator settings

# Load on Coating Layer

- Compare **load** on coating layer for:
  - Different collimator configurations (no TCSPMs / all combos of 4 TCSPMs / all TCSPMs);
  - Optics: regular v1p3 collision optics / newly-developed optics by R. Bruce (no MQWA.5[R,L]7);
- **Too many configurations** to be studied with the usual path for the annual meeting:
  - tracking → endep → thermo-mechanics
- Decided to **narrow-down cases** at **tracking** level;
- Simulations done with Fluka-SixTrack coupling: in addition to usual estimation of cleaning, add an on-line estimation of endep in coating layer, without changing Fluka transport thresholds;
  - **Very rough estimation**: killing EMF + hadron cascade (apart protons  $>1\text{TeV}$ ), leading to local overestimation of values;
  - **Not possible to include contribution to endep from upstream collimators** → relevant, especially for first skew secondary collimators;

# Simulation Settings

- Considered optics:
  - Regular v1p3,  $\beta^*=0.15\text{m}$ , no TCLD (provocative);
  - Flat top,  $\beta^*=6\text{m}$ , one TCLD in cell 8;
  - B1H / B1V only;
  - $2\sigma$ -retractions;

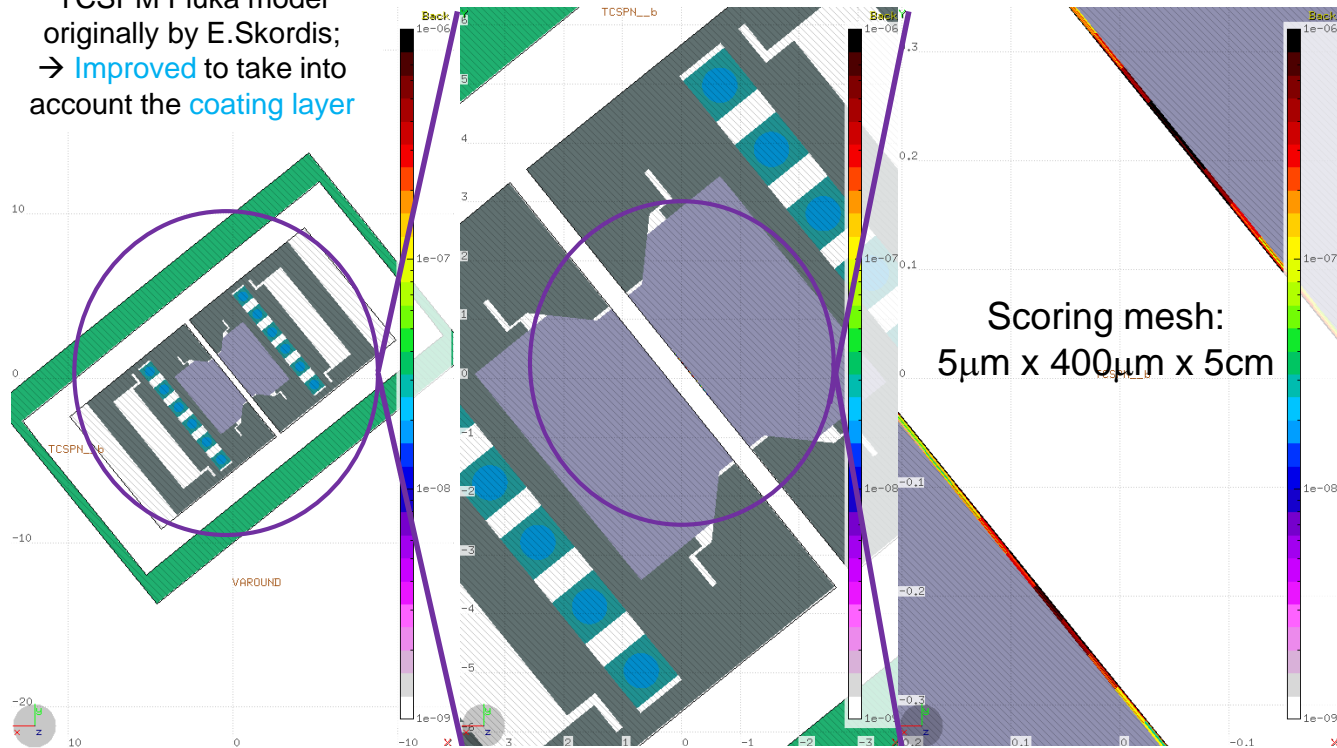


IR	Coll Family	Settings@15cm [ $\epsilon=2.5\mu\text{m}$ ]	Settings@15cm [ $\epsilon=3.5\mu\text{m}$ ]	Settings@6m [ $\epsilon=2.5\mu\text{m}$ ]	Settings@6m [ $\epsilon=3.5\mu\text{m}$ ]
IR7	TCP/TCS/TCLA/TCLD	6.7/9.1/12.7/16.6	5.7/7.7/10.7/out	6.7/9.1/12.7/out	5.7/7.7/10.7/14
IR3	TCP/TCS/TCLA	17.7/21/3/23,7	15/18/20	17.7/21/3/23.7	15/18/20
IR6	TCDQ/TCSP	10.1/10.1	8.5/8.5	12.3/12.3	10.4/10.4
IR1/5	TCT/TCL	10.4/	8.8/12	43.8/out	37/out
IR2	TCT	43.8	37	43.8	37
IR8	TCT	17.7	15	43.8	37

Detailed list of collimator settings in document presented this morning by R.Tomas Garcia

# Example

TCSPM Fluka model originally by E.Skordis;  
→ Improved to take into account the coating layer



Development of cascades interrupted;  
→ Showering from upstream collimators NOT taken into account;

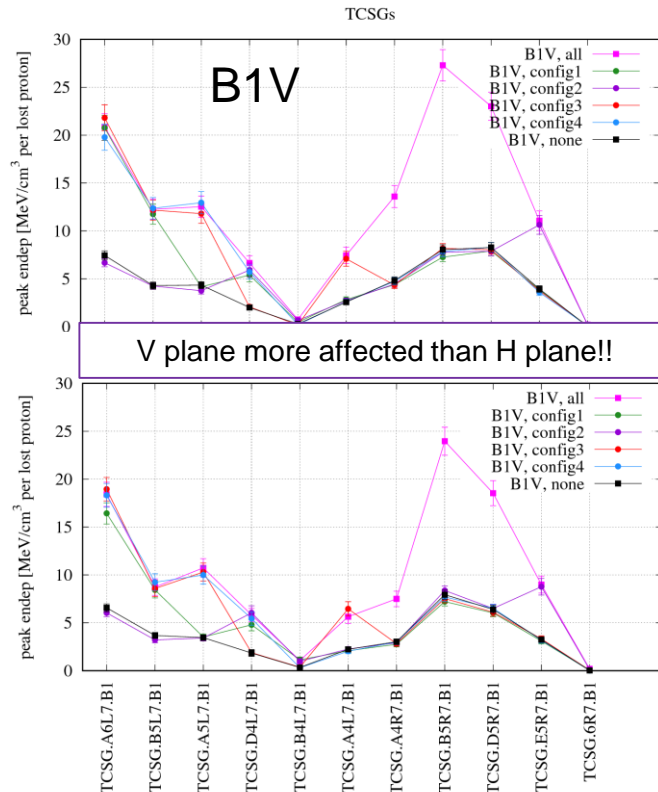
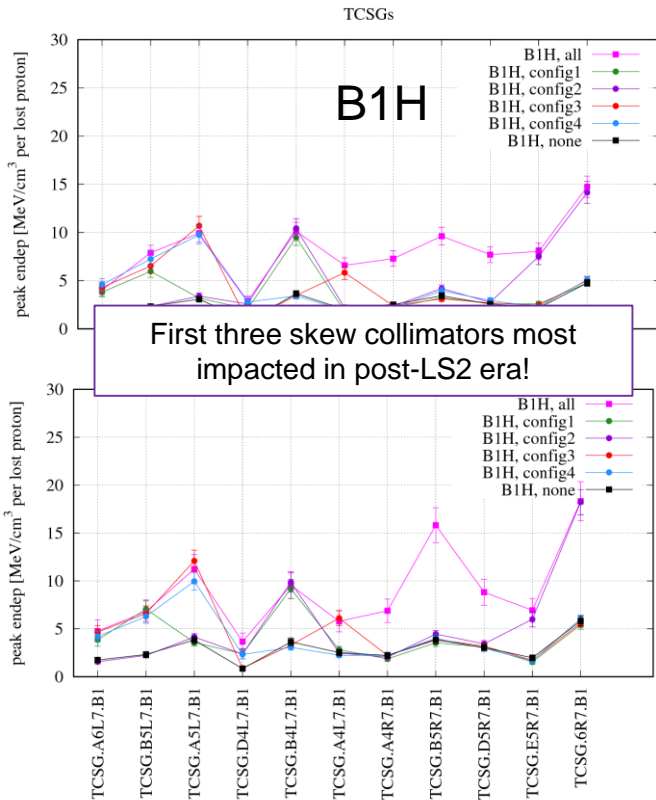
Pre-processing script for automatic generation of Fluka geometry for coupled simulations upgraded to fully exploit LB capabilities (including per-collimator scorings)

# Endep in Coating Layer

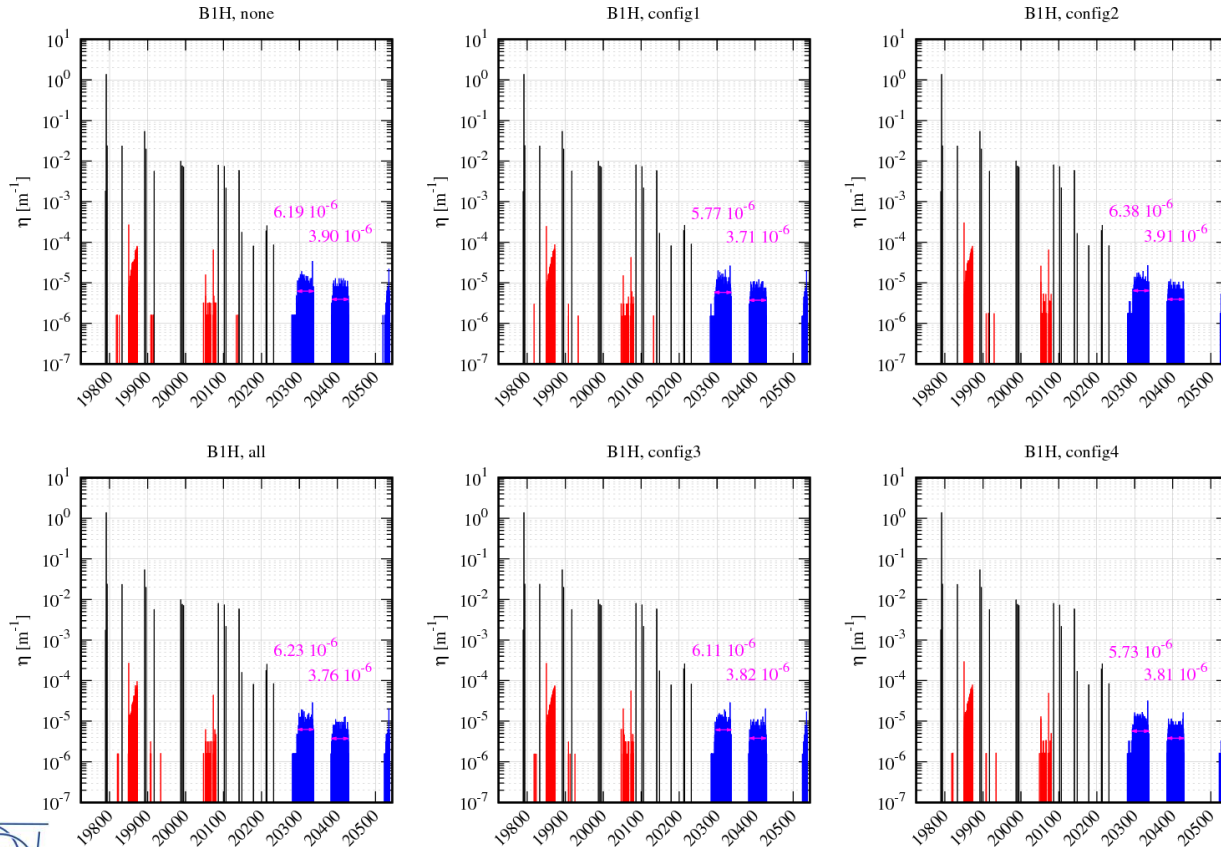
$\beta^* = 15\text{cm}$

FT

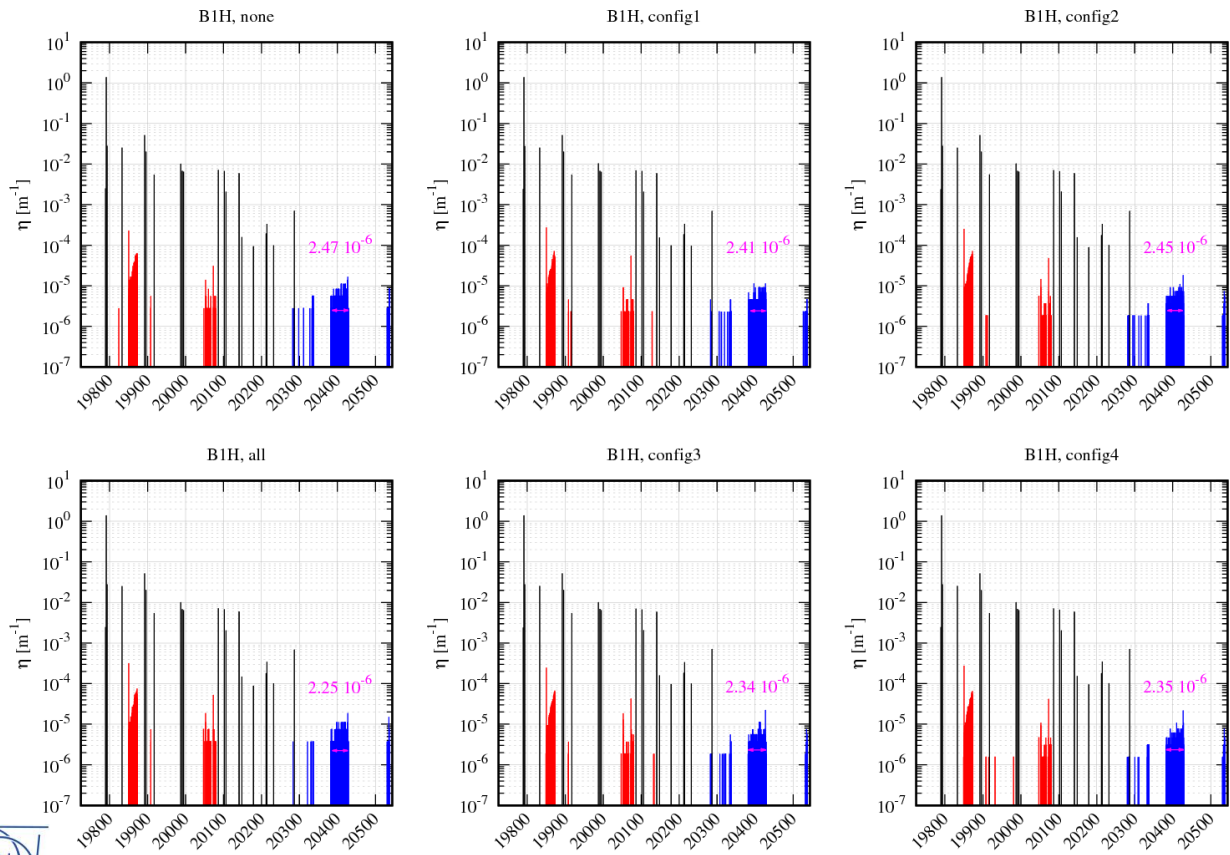
	1	2	3	4
TCSG.A6L7.B1				
TCSG.B5L7.B1	Green			
TCSG.A5L7.B1			Red	Blue
TCSG.D4L7.B1	Green			
TCSG.B4L7.B1	H	Green		
TCSG.A4L7.B1			Red	
TCSG.A4R7.B1				
TCSG.B5R7.B1				
TCSG.D5R7.B1				
TCSG.E5R7.B1				
TCSG.6R7.B1	H			



# B1H Loss Maps – $\beta^*=15\text{cm}$ – IR7



# B1H Loss Maps – $\beta^*=6\text{m}$ – IR7



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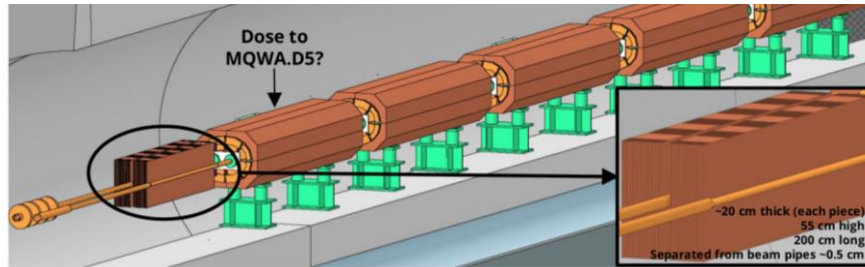
# Removal of MQWA.E5[L,R]7 and Possible Installation of Shielding

- Removal of MQWA.E5[L,R]7:
  - Module subject to highest load from collimation;
  - Measurements and simulation campaign to estimate loads for present LHC and for HL-LHC (F.Cerutti and P.Fessia, [HL-LHC TCC #14](#));
  - Proposal (P.Fessia et al): remove the module and propose solution to limit load on following module;
- Large simulation campaign (C.Bahamonde et al.), to propose shielding solutions – currently: tungsten masks at each magnet + iron shielding;

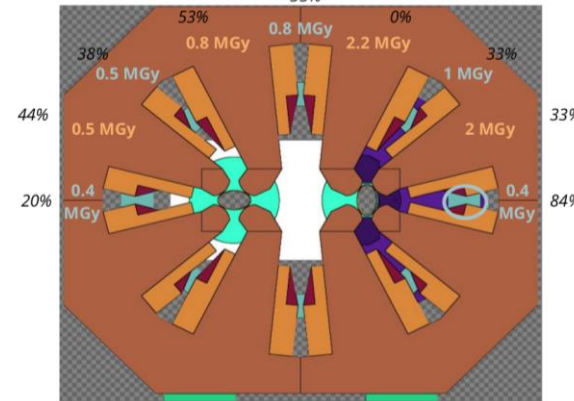
Relevant role of normalization:  $8.4 \times 10^{16}$  protons lost in IR7 for the whole HL-LHC nominal operation

R.Garcia Alia, 27<sup>th</sup> MCWG, 23/05/17

More in C.Bahamonde's presentation on Thu, 16<sup>th</sup> Nov, WP5 Parallel session (afternoon)



■ With shielding  
 ■ % Reduction compared to not having a shielding



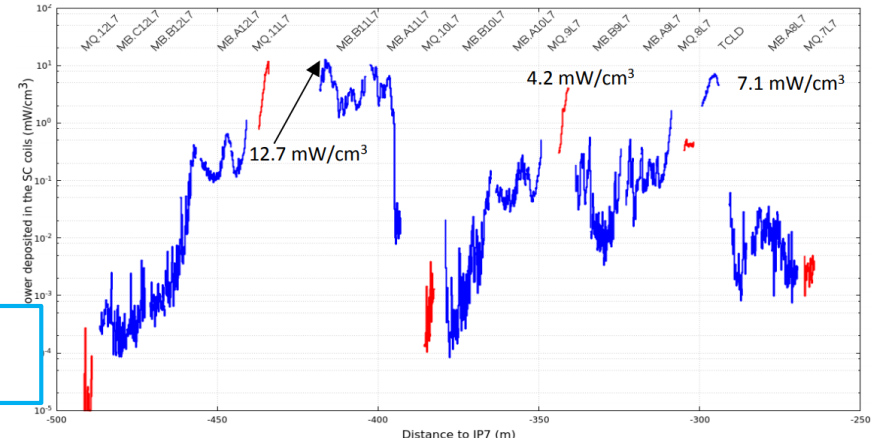
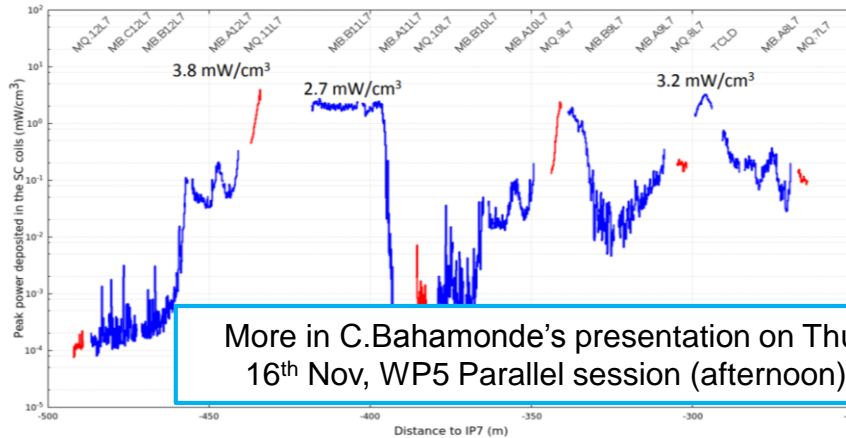
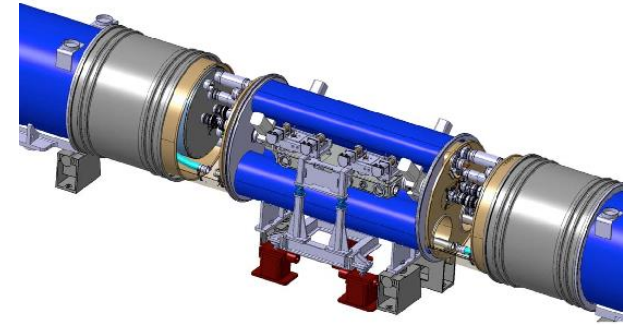
Courtesy of C.Bahamonde

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# TCLDs

- During LS2, it is planned to install a single module MBH(11T)+TCLD(Inermet180)+MBH(11T) in DS downstream of IR7 (protons + ions) and of IR2 (ions only):
  - Position currently considered: MB.B8x7;
- Large simulation campaign (D.Mirarchi, P.D.Hermes, C.Bahamonde et al.), to propose evaluate peak endep in magnets downstream of TCLD collimators;



More in C.Bahamonde's presentation on Thu, 16<sup>th</sup> Nov, WP5 Parallel session (afternoon)

C. Bahamonde - ColUSM #94

7

Courtesy of C.Bahamonde

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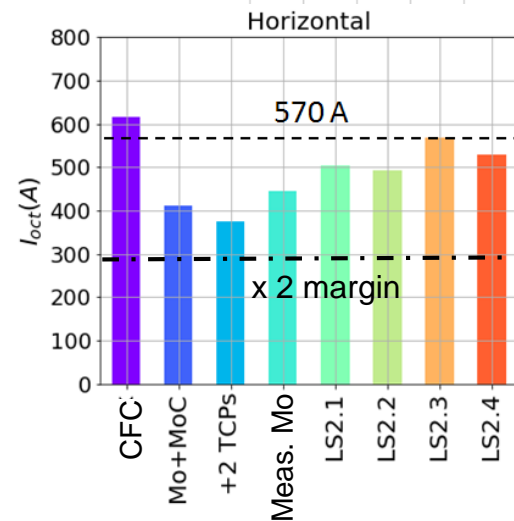
# Conclusions

- **Installation of TCSPM prototype** in slot D4R7 during YETS 2016:
  - Played a **key** role in **verifying** with beam **predictions** of effects on impedance from the IR7 collimator upgrade for HL-LHC;
  - Three **coating stripes** (Mo, MoGr and TiN): **important** to **prove Mo** coating as **best option** impedance-wise, though measurements do not show a performance as good as predicted;
  - **Investigations** on **effects from quality** of Mo-coating layer **on-going**;
- **Consolidation** of IR7 collimation system:
  - Planned to exchange (per beam):
    - 2 TCP (H/V) collimators (60cm, carbon) with TCPMs (60cm, MoGr, un-coated);
    - 4 TCSG collimators (1m, carbon) with TCSPMs (1m, MoGr, Mo-coated) → slots not yet finalized;
  - Installation of a single module MBH(11T)+TCLD+MBH(11T) in IR7 (protons and ions) and IR2 (ions only);

# Conclusions (II)

- From first endep evaluations on coating layer and impedance considerations, one of the **most appealing configuration** is #2, though 3 (out of 4) TCSs are on H/V plane:
  - Largest gain in **impedance**;
  - First skew collimators** are **not involved** in the exchange;
- Cleaning-wise**, no big difference between the different combinations is found;
- Further steps:
  - Perform Fluka simulations for appropriate/accurate endep estimations (B1H scenario, FT optics without MQWA);
  - Explore  $1\sigma$ -retractions;
  - Cross-check with ABD simulation cases;
  - (repeat simulations for B2);

	1	2	3	4
TCSG.A6L7.B1				
TCSG.B5L7.B1				
TCSG.A5L7.B1				
TCSG.D4L7.B1	V			
TCSG.B4L7.B1	H			
TCSG.A4L7.B1				
TCSG.A4R7.B1				
TCSG.B5R7.B1				
TCSG.D5R7.B1				
TCSG.E5R7.B1				
TCSG.6R7.B1	H			





***Thanks a lot!***

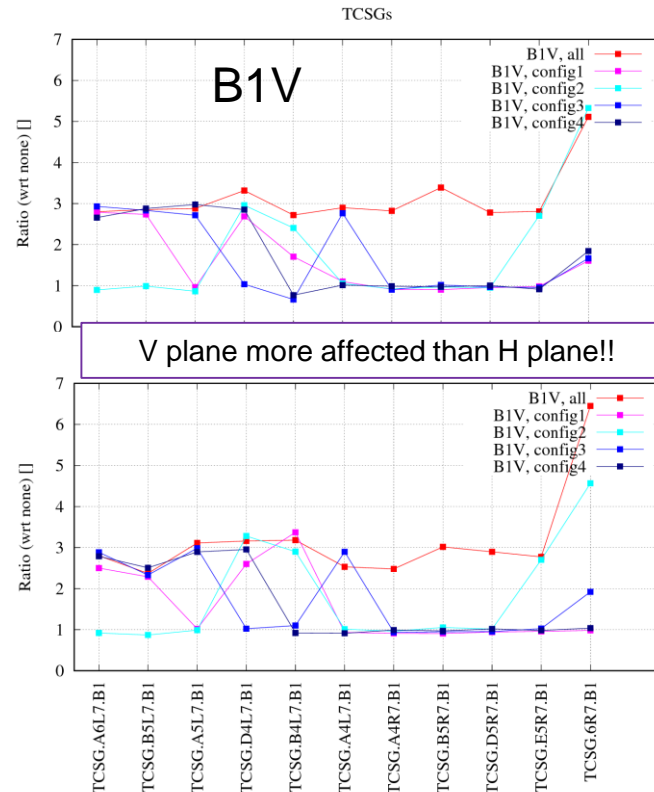
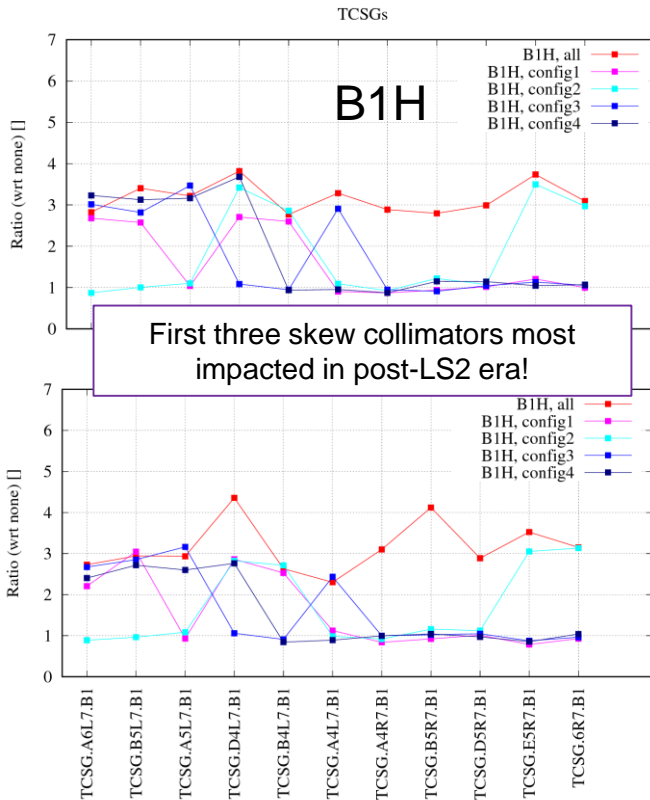


# Endep in Coating Layer – Ratios

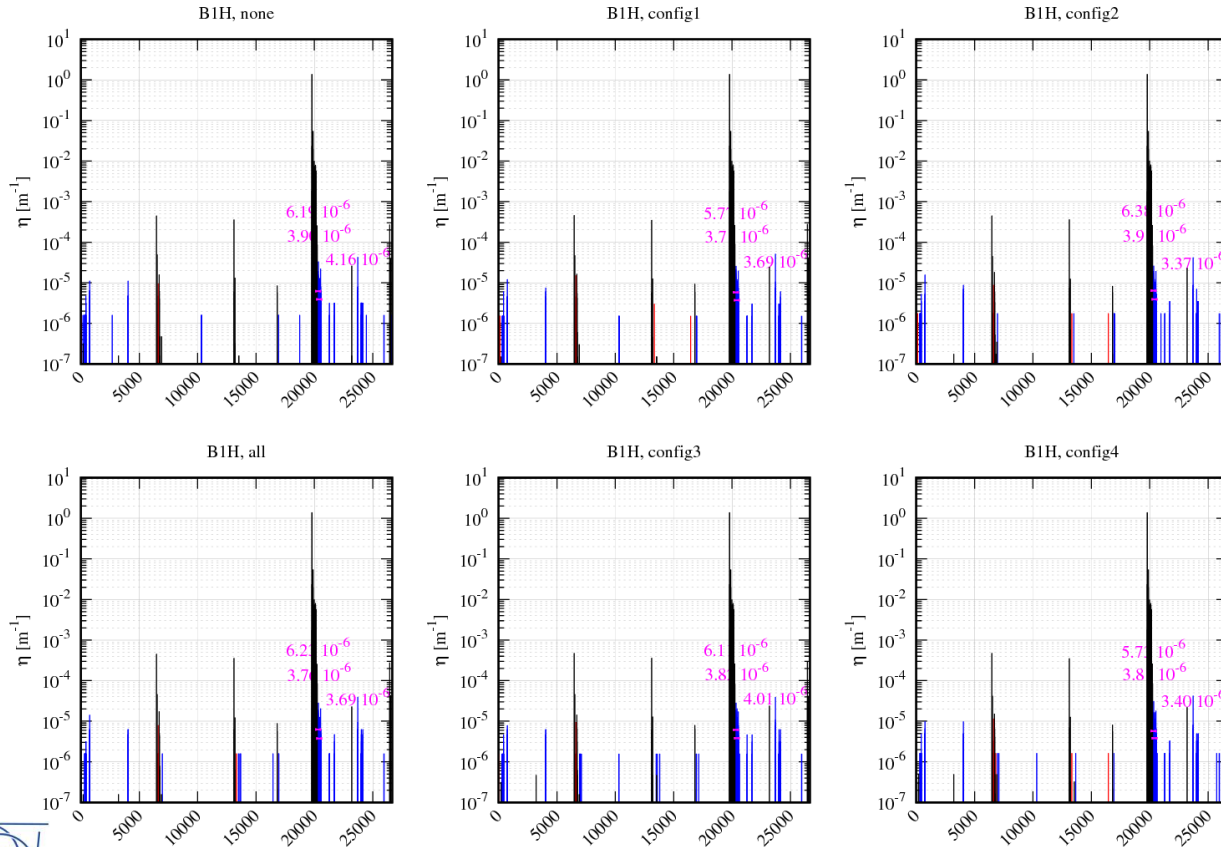
$\beta^* = 15\text{cm}$

	1	2	3	4
TCSG.A6L7.B1				
TCSG.B5L7.B1	■			
TCSG.A5L7.B1			■	
TCSG.D4L7.B1	V			
TCSG.B4L7.B1	H			
TCSG.A4L7.B1				
TCSG.A4R7.B1				
TCSG.B5R7.B1				
TCSG.D5R7.B1				
TCSG.E5R7.B1				
TCSG.6R7.B1	H			

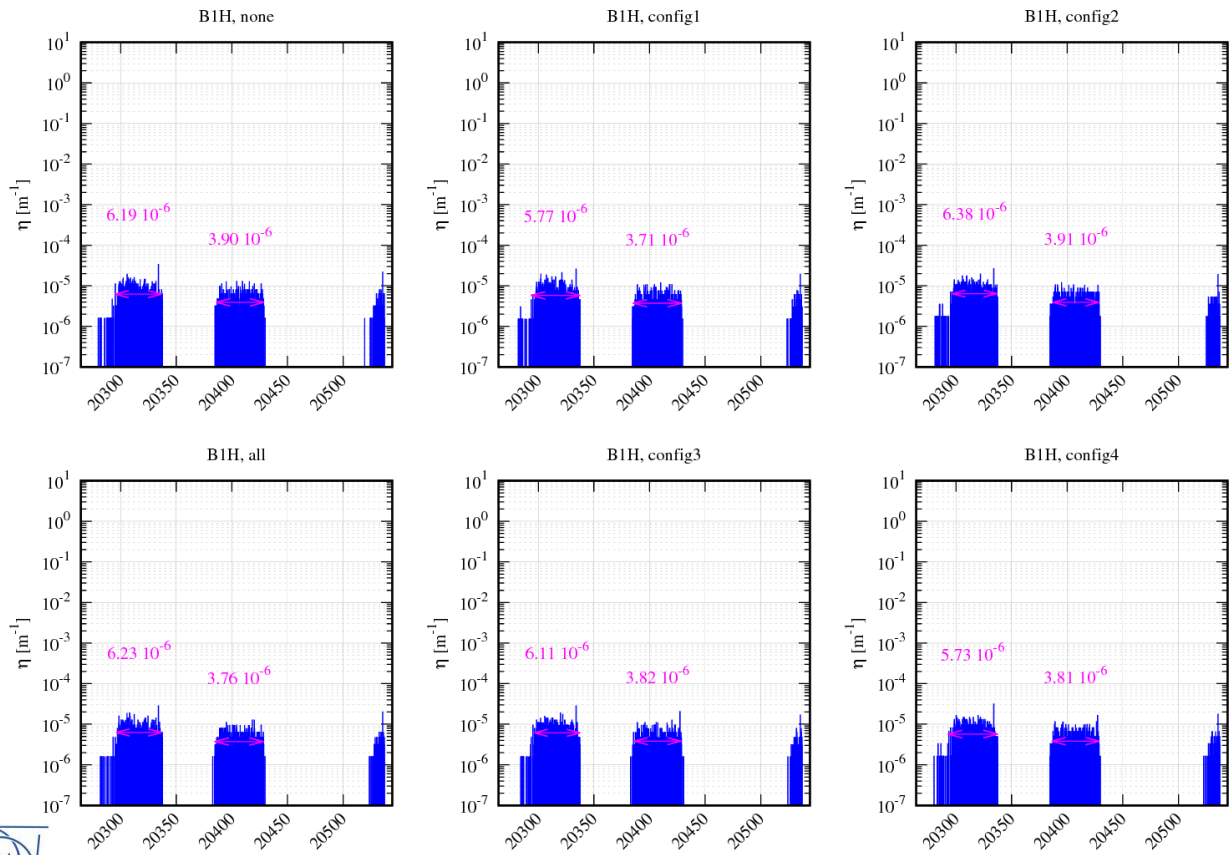
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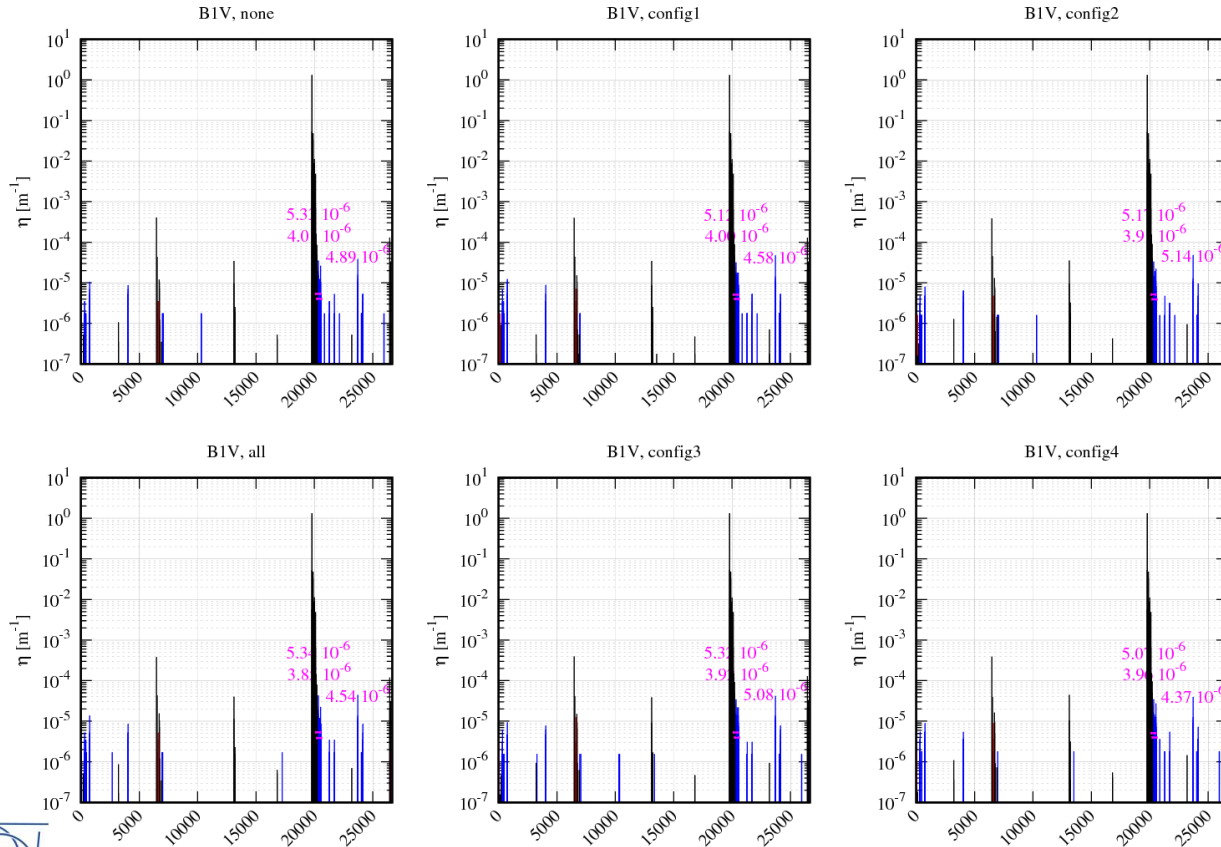
# B1H Loss Maps – $\beta^*=15\text{cm}$ – LHC



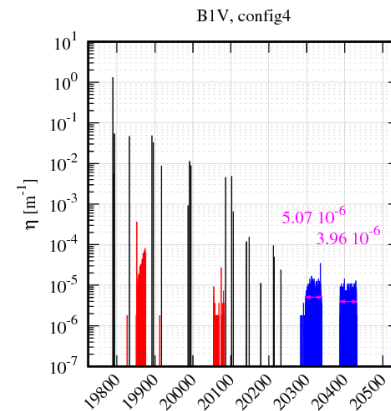
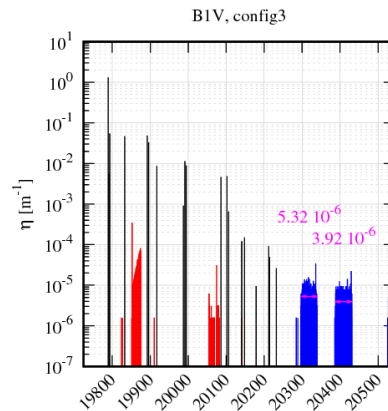
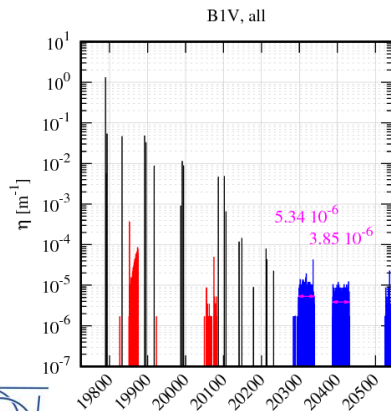
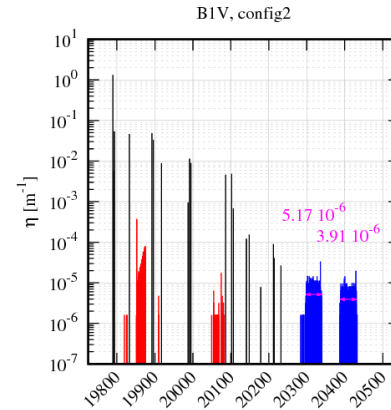
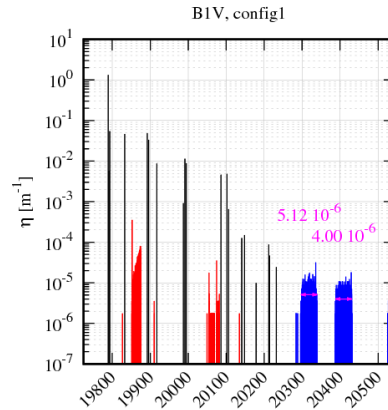
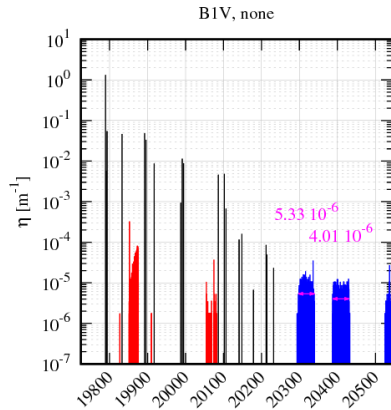
# B1H Loss Maps – $\beta^*=15\text{cm}$ – IR7 DS



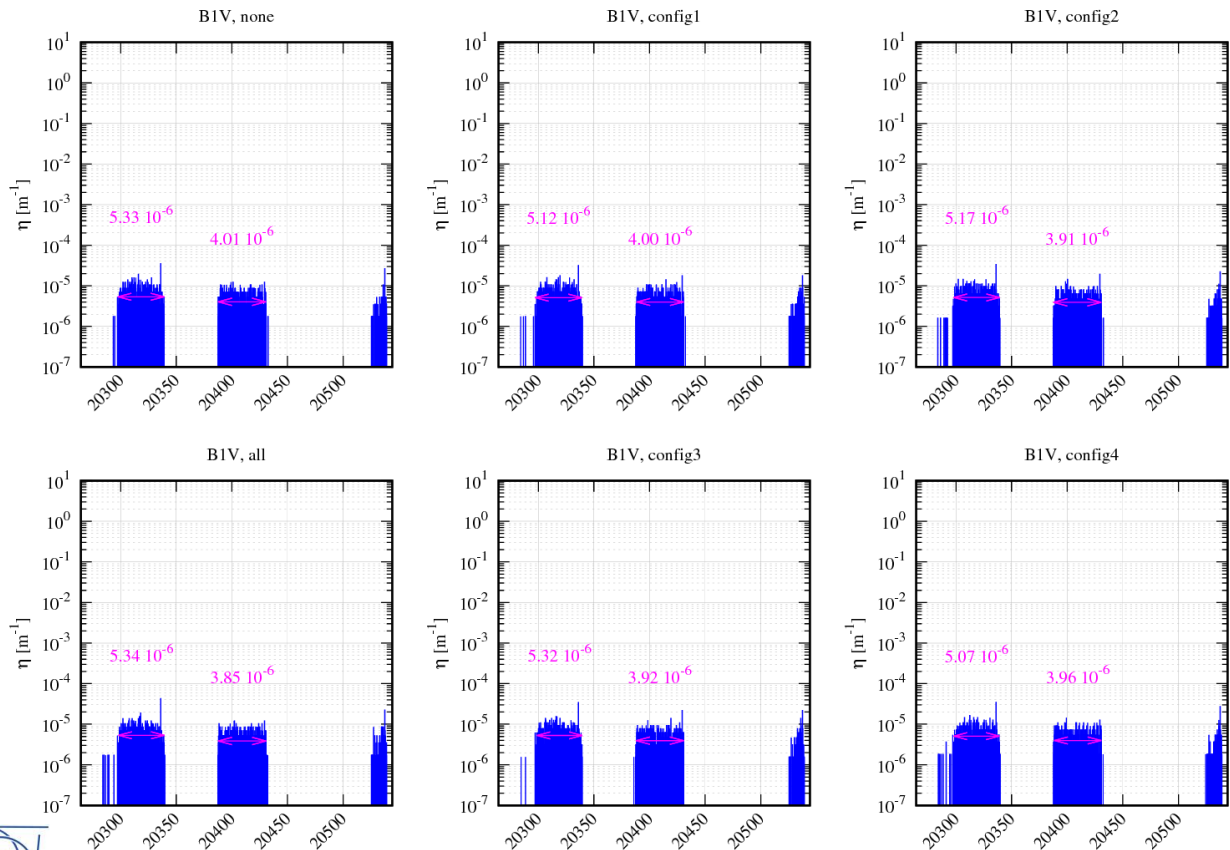
# B1V Loss Maps – $\beta^*=15\text{cm}$ – LHC



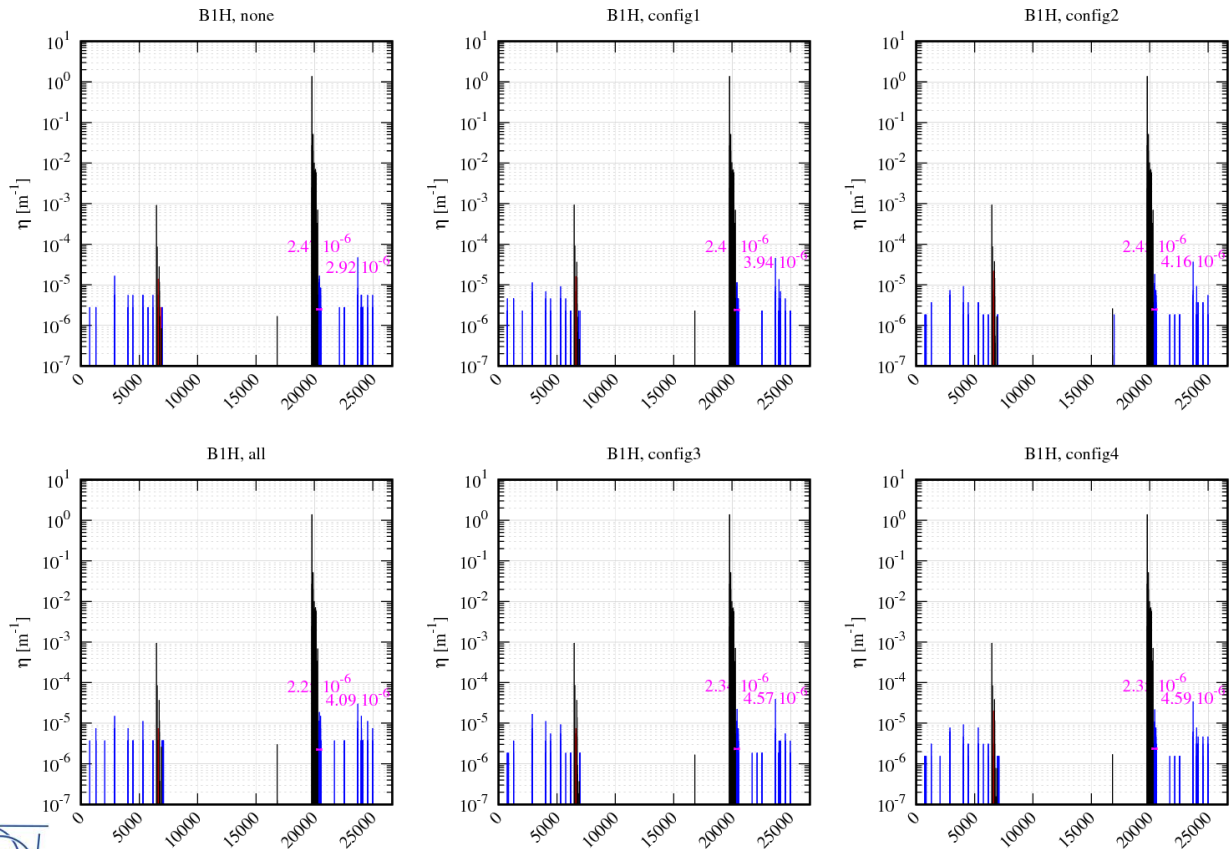
# B1V Loss Maps – $\beta^*=15\text{cm}$ – IR7



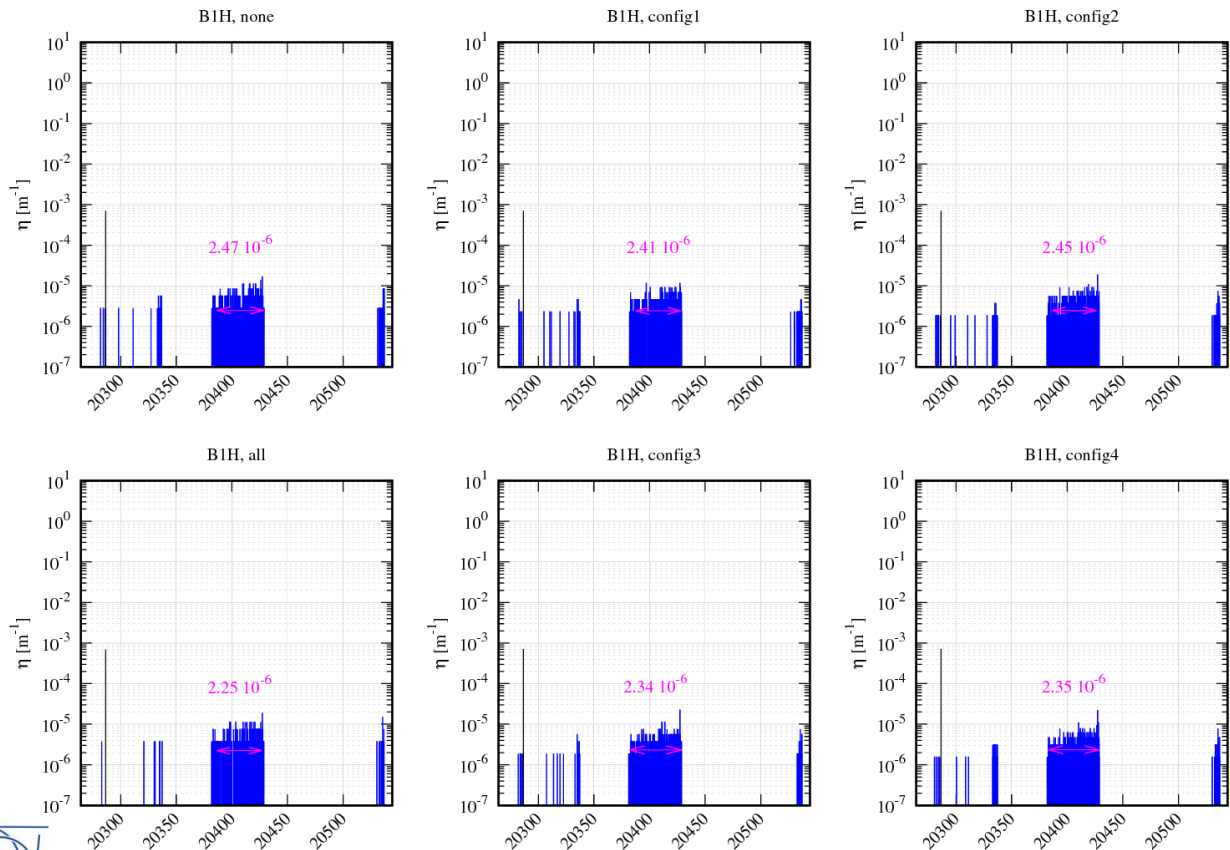
# B1V Loss Maps – $\beta^*=15\text{cm}$ – IR7 DS



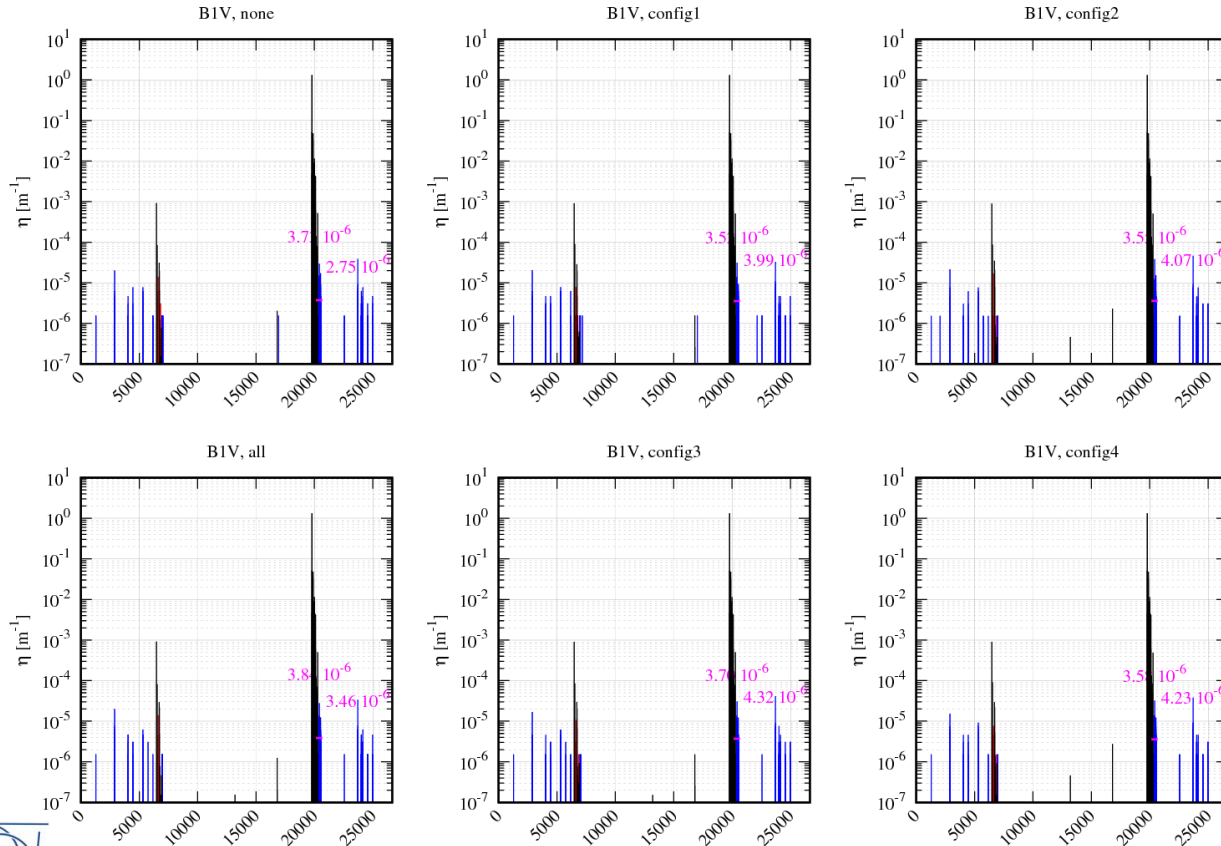
# B1H Loss Maps – $\beta^*=6\text{m}$ – LHC



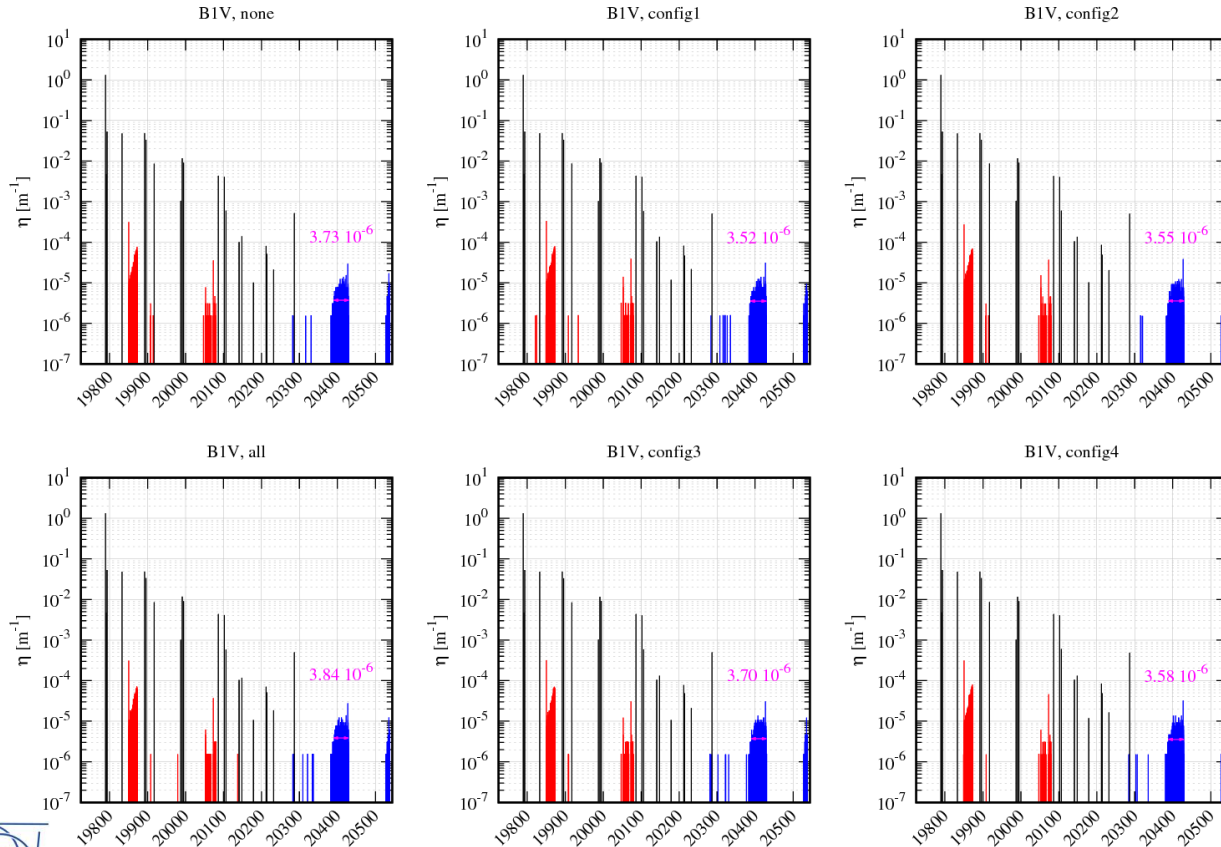
# B1H Loss Maps – $\beta^*=6m$ – IR7 DS



# B1V Loss Maps – $\beta^*=6\text{m}$ – LHC



# B1V Loss Maps – $\beta^*=6m$ – IR7



# B1V Loss Maps – $\beta^*=6\text{m}$ – IR7 DS

