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Energy deposition in the Betatron Cleaning Insertion of **HE-LHC** machine

M. Varasteh and F. Cerutti

Tracking input from BE-ABP:
M. Crouch, J. Molson, R. Bruce, A. Mereghetti

Acknowledgments: C. Bahamonde, M.I. Besana, E. Skordis, other colleagues in BMI & FLU

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Outline

- **Challenges for the HE-LHC collimation system**
- **Power density on the collimators and warm magnets**
- **Energy deposition in the cold section, IR7**
- **Impact of the dog-leg removal**

Parameters / challenges

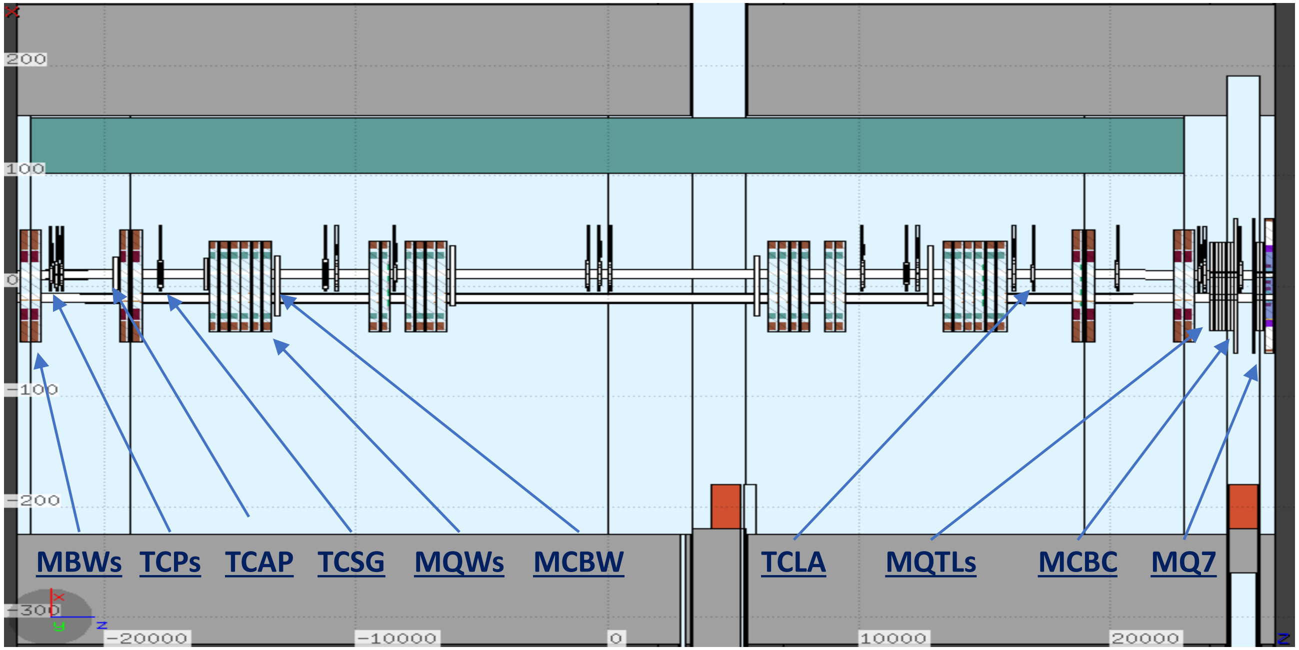
	unit	FCC-hh	HE-LHC	HL-LHC	LHC
center-of-mass energy	TeV	100	27	14	14
arc dipole field	T	16	16	8.33	8.33
bunch population [10^{11}]	ppb	1	2.2	2.2	1.15
number of bunches		10600	2808	2760	2808
stored beam energy	GJ	8.4	1.4	0.7	0.36
total power loss for 12 min BLT	MW	11.8	1.9	0.95	0.5

Main challenge is due to the restrictions caused by the geometry of the *existing Tunnel*

As the first stage, the same collimation design as LHC machine is used

- **Vertical halo scenario was studied**
- **Considering high loss scenario of 0.2h beam life time (BLT)**

HE-LHC IR7, warm section



- **8 warm dipoles (MBW)**
- **24 warm quadrupoles (MQW)**
- **Beam-Beam separation (bbs):**
  - *204 mm in the arc* (194 mm for LHC*)*
  - *224 mm within the doglegs* (same as LHC*)*
- **3 Passive absorbers (TCAP) (1 m, 20 cm, 60 cm)**

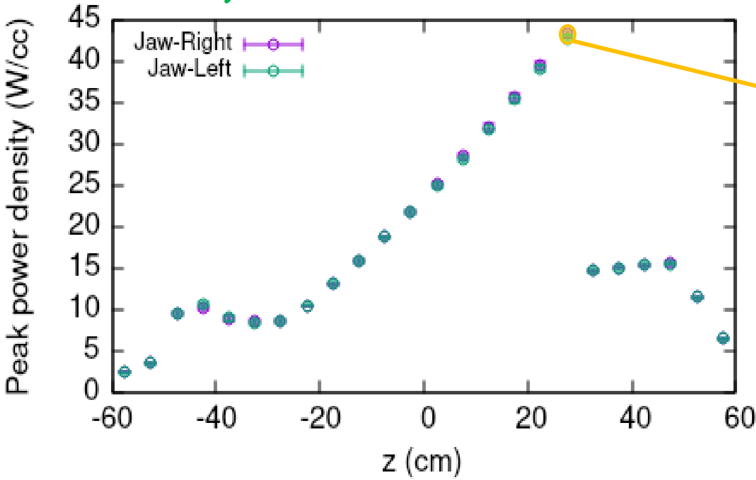
	HE-LHC	LHC	Comments
MBW	3.4 m	3.4 m	different return coils
MQW	3.5 m	3.1 m	different length
Collimators			the same
MQTLH/I	1.3 m	1.3 m	different bbs, beam screen, material
MCBCH/V	0.9 m	0.9 m	different bbs, beam screen, material
MQ7	3.5 m	3.1 m	different length, material

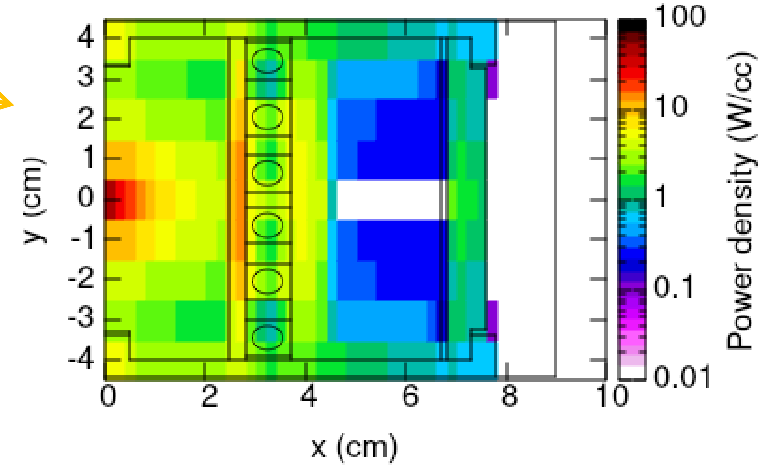
Collimators	Length (cm)	Aperture (σ)	Material	Number
Primary	*60*	*6.7*	*CFC*	*3*
Secondary	*100*	*9.1*	*CFC*	*11*
Active absorbers	*100*	*11.5*	*tungsten*	*5*

about 30 m longer w.r.t. LHC

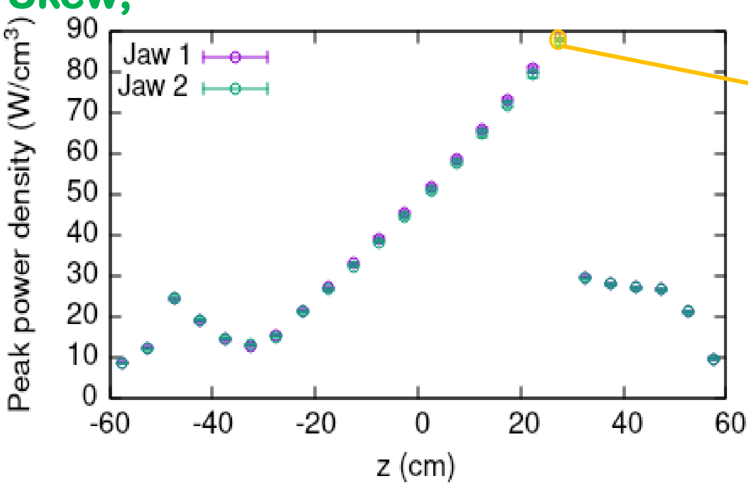
Horizontal and Skew primary collimators

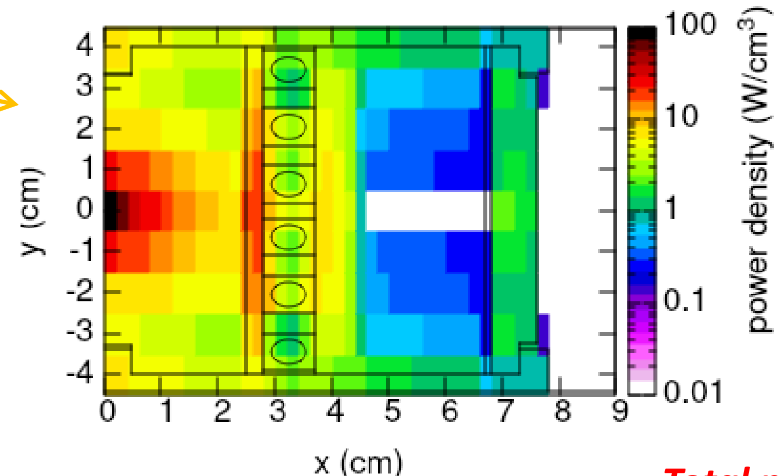
Horizontal;





Skew;





x-y-z resolution: *0.2cm, 1cm, and 5cm*

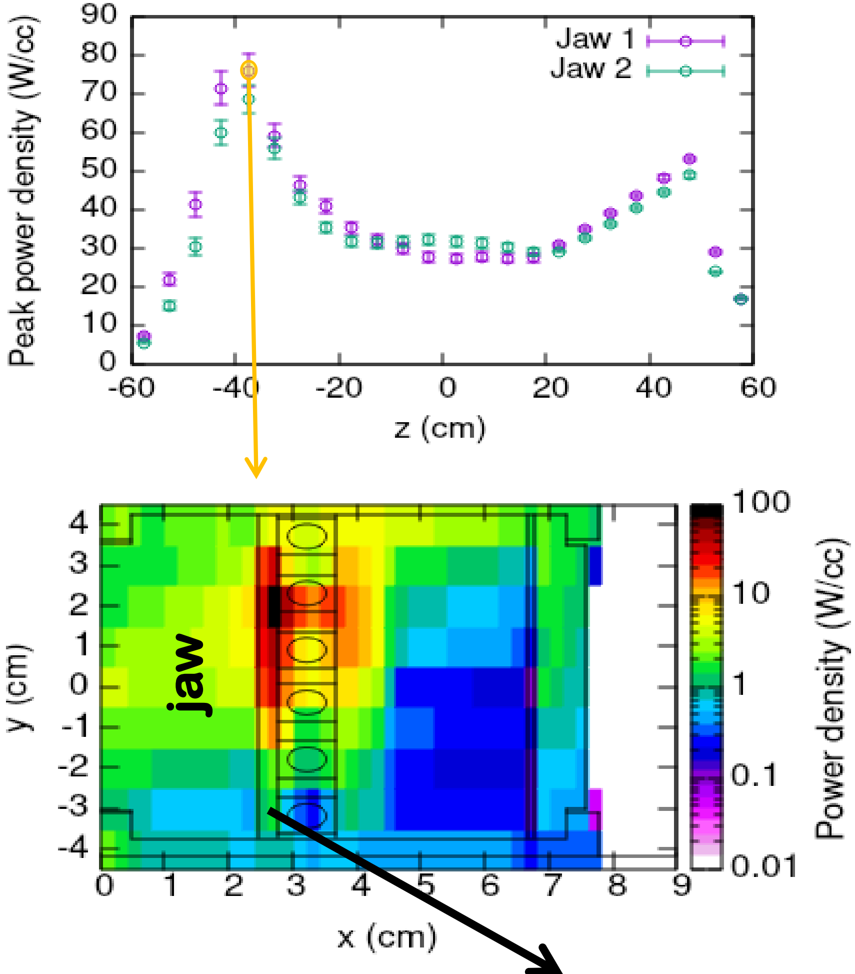
most loaded primary collimator

Total power (kW)

Vertical	*3.7*
Horizontal	*29.5*
Skew	*53.1*

Secondary collimators

most loaded secondary collimator (1st TCSG)



❖ the maximum is on the metallic support! **New design with thicker jaws is mandatory…**

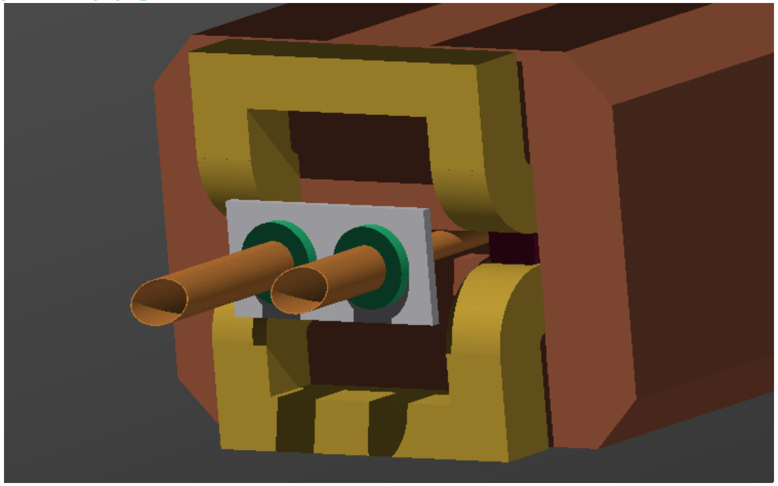
Total power (kW)	
Secondary Collimators	
TCSG.A6L	***56.1***
TCSG.B5L	*12.6*
TCSG.A5L	*37.3*
TCSG.D4L	*6.9*
TCSG.B4L	*3.7*
TCSG.A4L	*4.9*
TCSG.A4R	*5.3*
TCSG.B5R	*0.5*
TCSG.D5R	*1.2*
TCSG.E5R	*1.9*
TCSG.6R	*0.2*

For LHC at 6.5TeV, the max load is about 15 kW

x-y-z resolution: *0.2cm, 1cm, and 10cm*

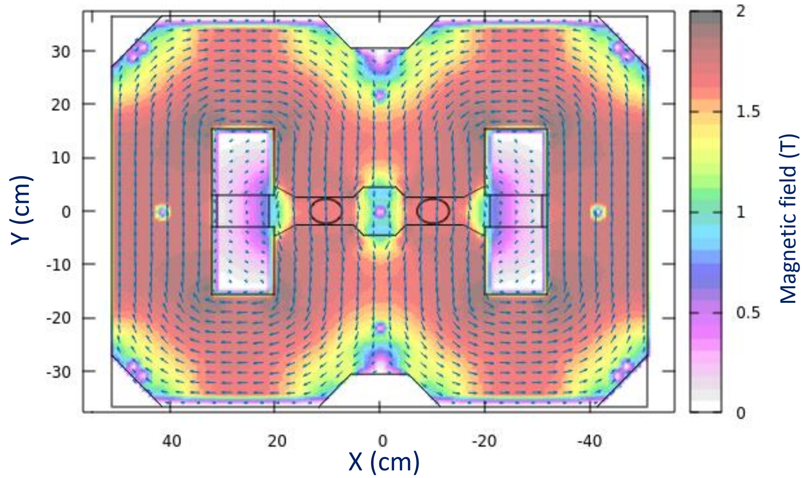
Warm dipole's return coil (MBW)

HE-LHC

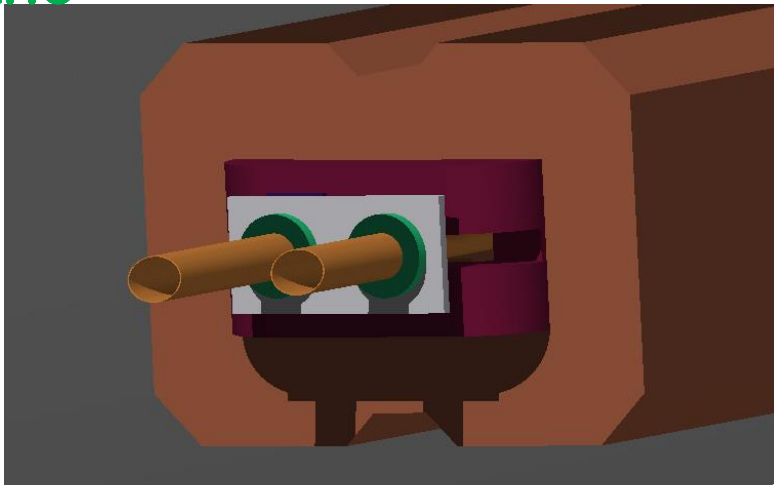


Magnetic field map in FLUKA simulation

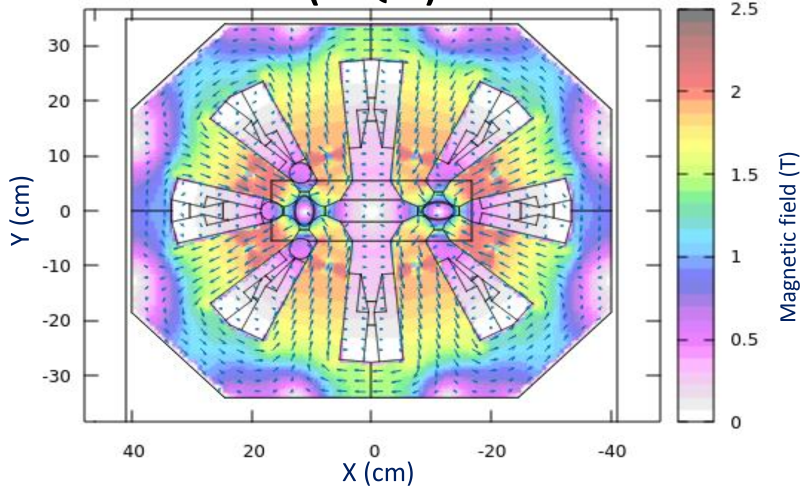
(MBW)



LHC



(MQW)

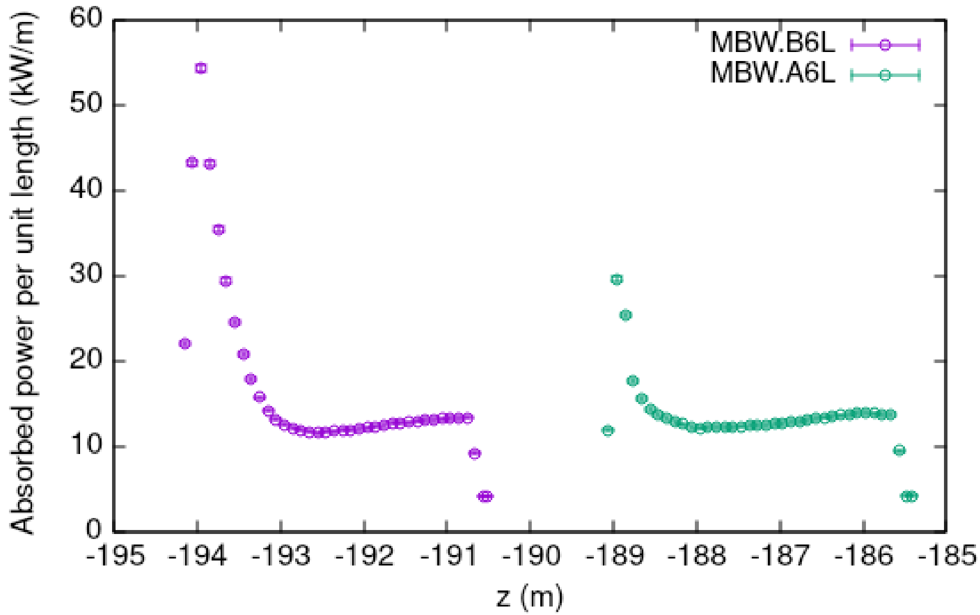


Warm dipoles

Total power (kW) over warm dipoles	
MBW.B6L	*66.36*
MBW.A6L	*53.57*

- **Two MBWs downstream the TCPs take more than 99% of the total power on the warm dipoles!**

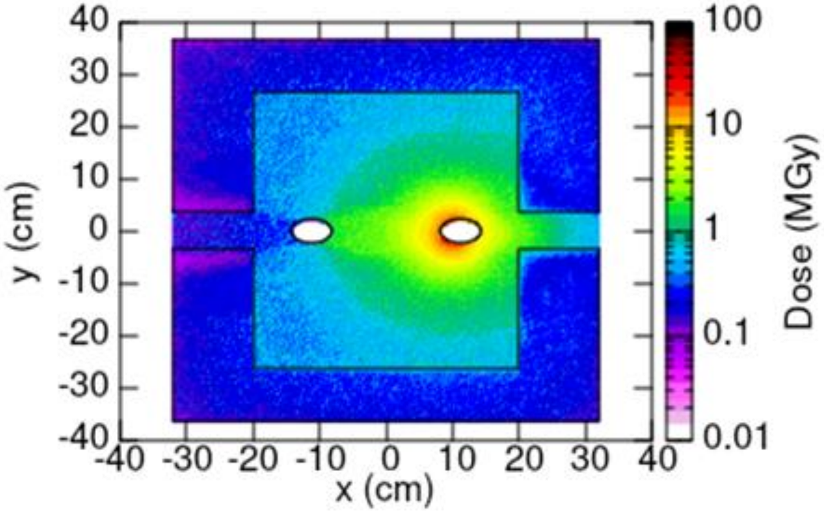
at LHC the maximum is about 22 kW



Maximum power per unit length → 55 kW/m
(bulk is below 14 kW/m)

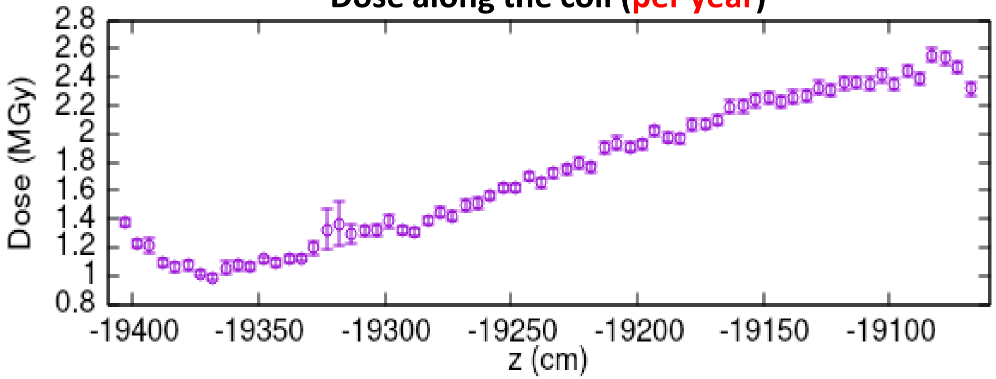
Coils in the most loaded warm dipole

MBW.B6L's front face



> ➢ **moving away from the beam pipe, a factor of 10 less dose on the return coil…**

Dose along the coil (per year)

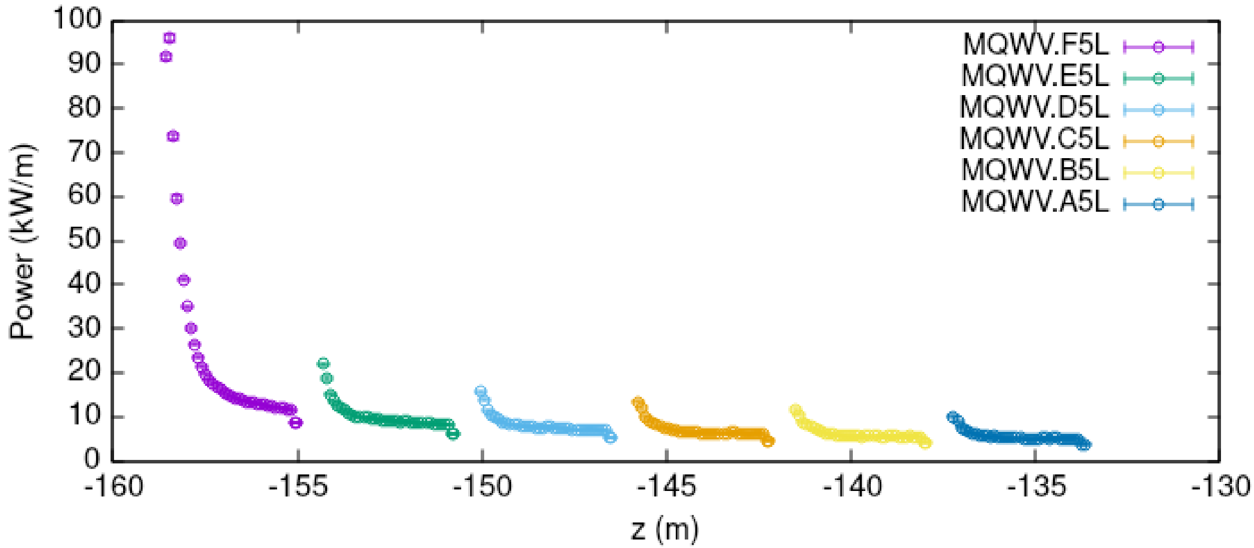


In total, the coil insulator can stand about 30 MGy

*****considering 1e16 proton lost per year*****

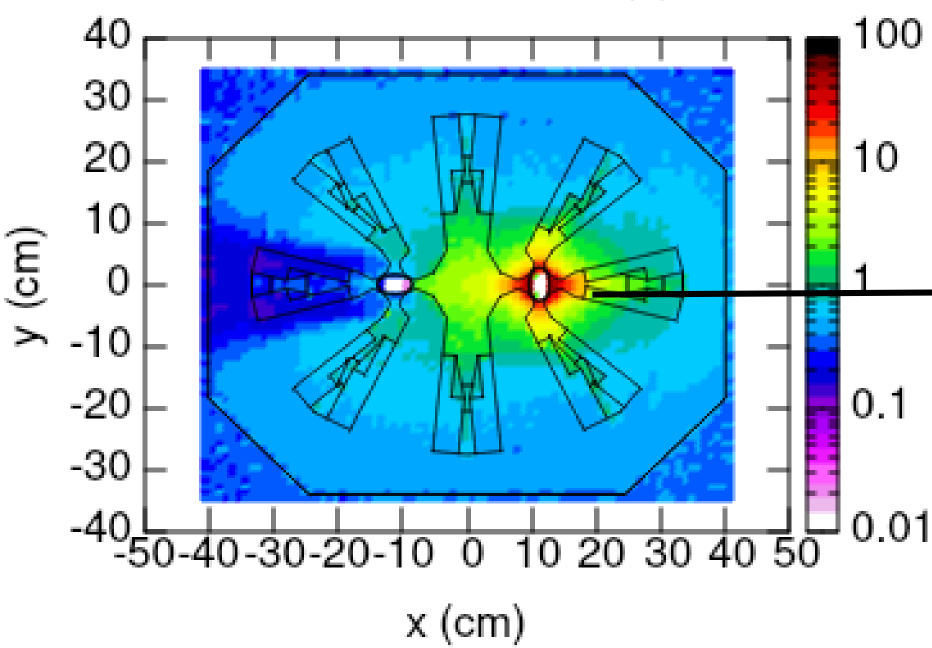
0.25cm, 0.25cm, 5cm (x-y-z resolution)

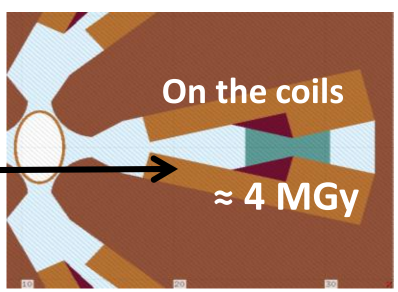
Warm quadrupoles (MQWs)



Total power (kW)

MQWVF5L	***95.1***
MQWVE5L	***39.0***
MQWVD5L	***31.1***
MQWVC5L	***26.8***
MQWVB5L	***23.5***
MQWVA5L	***21.1***



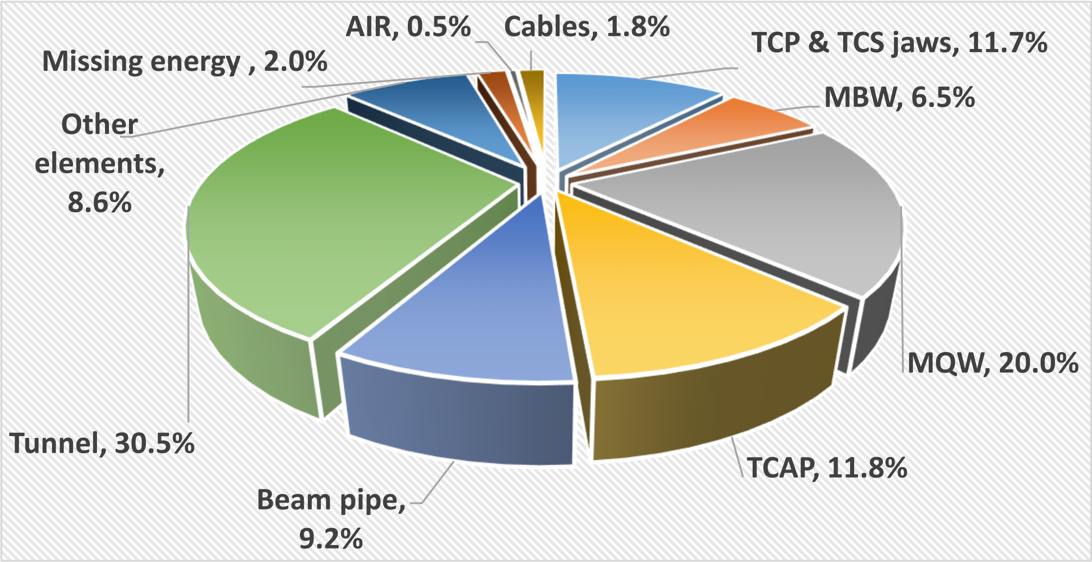


Material dose limits is 50 MGy for the coils and 10 MGy for the spacers!

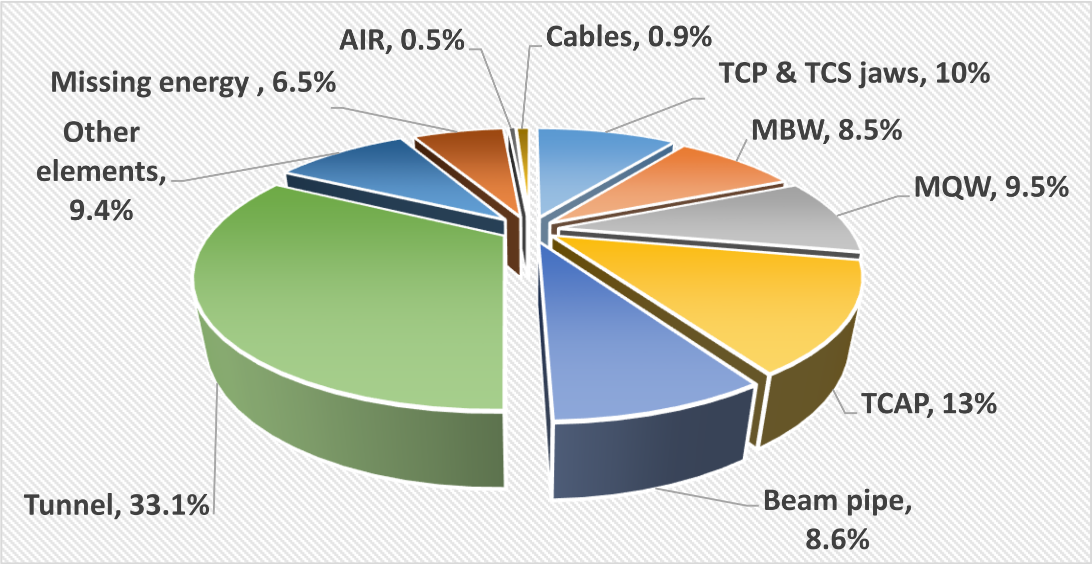
***At LHC, internal shield is used**

Power fraction on different elements at IR7

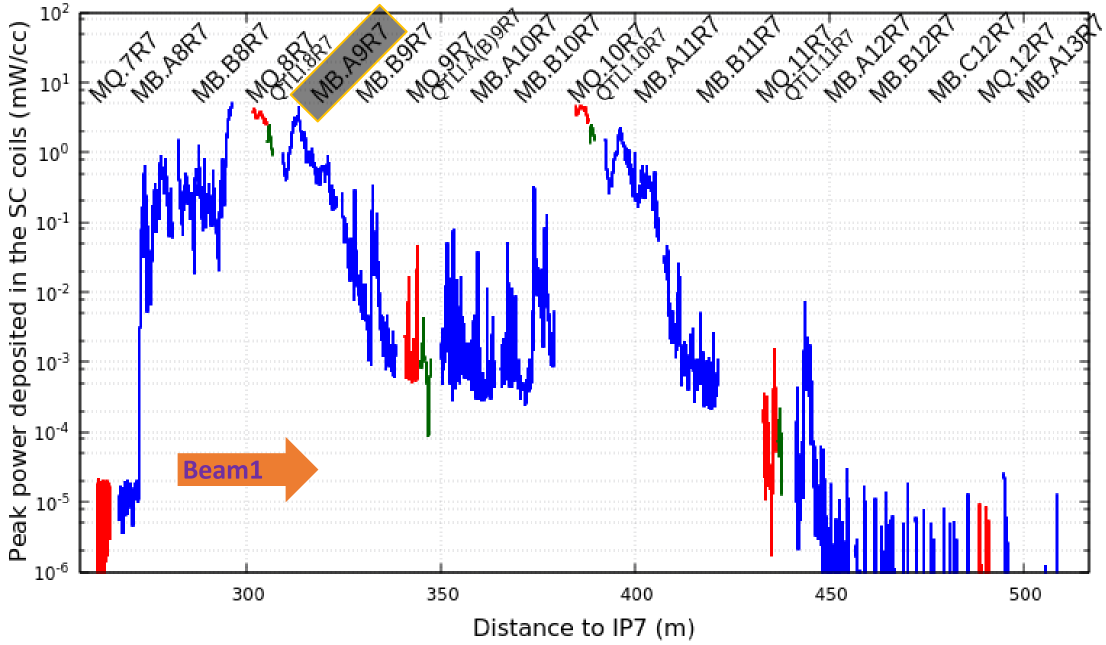
HE-LHC @ 13.5 TeV

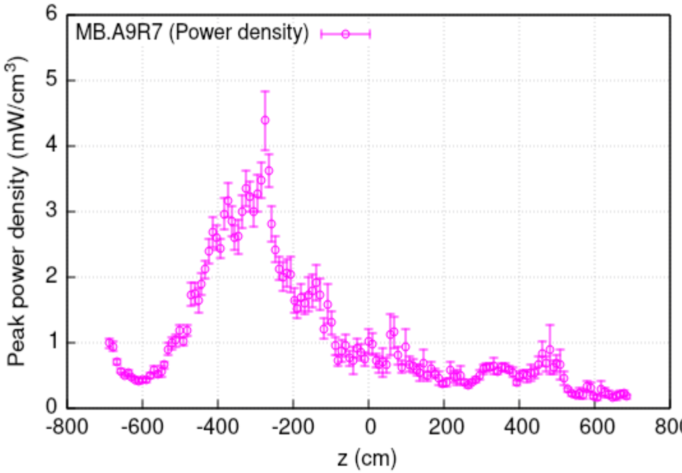


LHC @ 7 TeV



Cold section





With two collimators (TCLDs) in the cold section, before MQ8 and MQ10, the maximum peak power density is about 5 mW/cc

r-φ-z resolution: 1.86cm, 2°, 10cm

(three radial bins of 1.86cm)

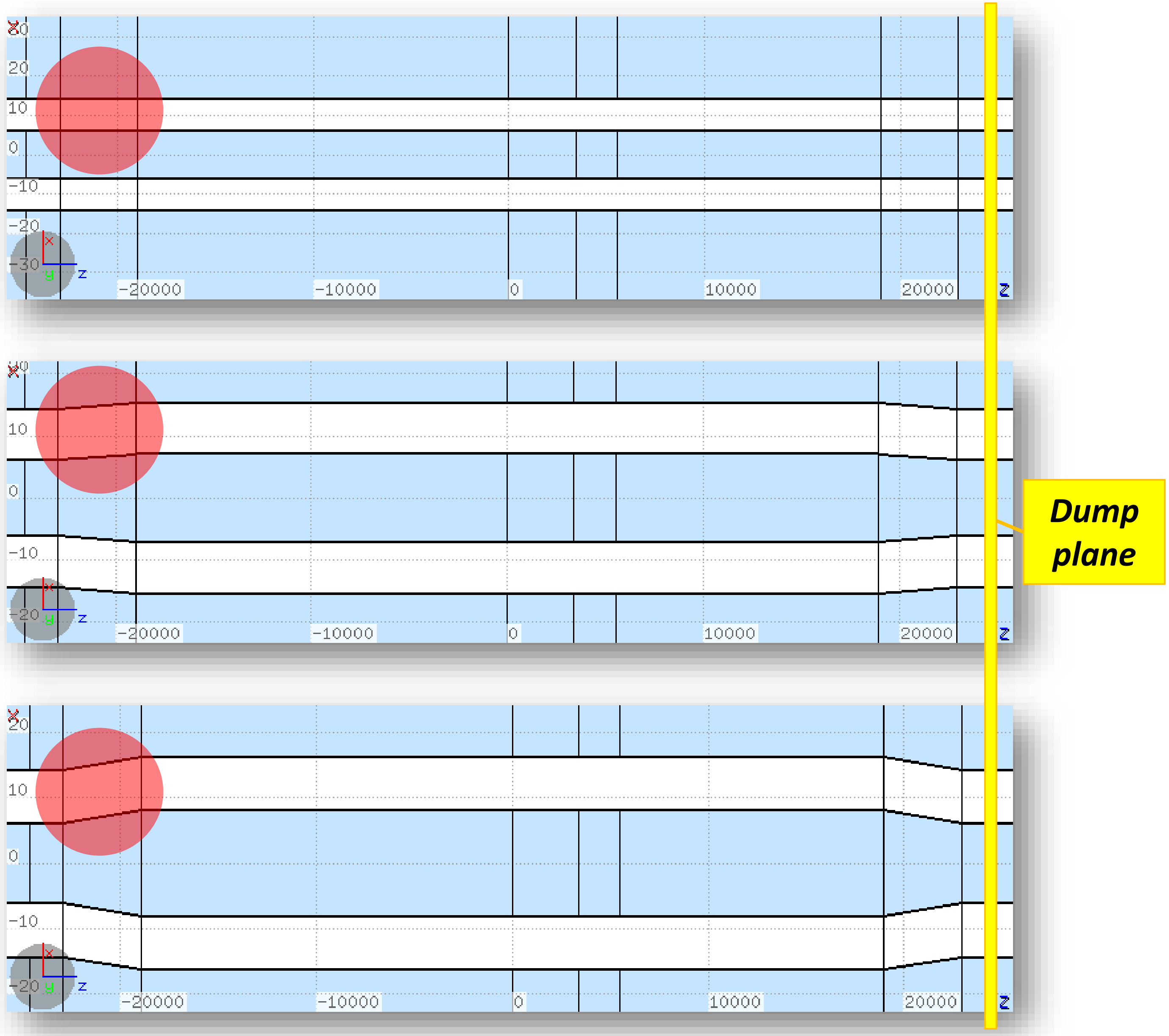
Values are for the 12 min BLT !

Impact of the dogleg removal - I

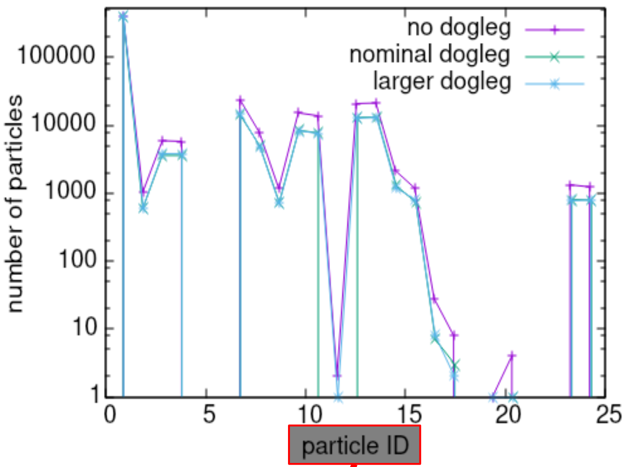
204mm bbs (no dogleg) →

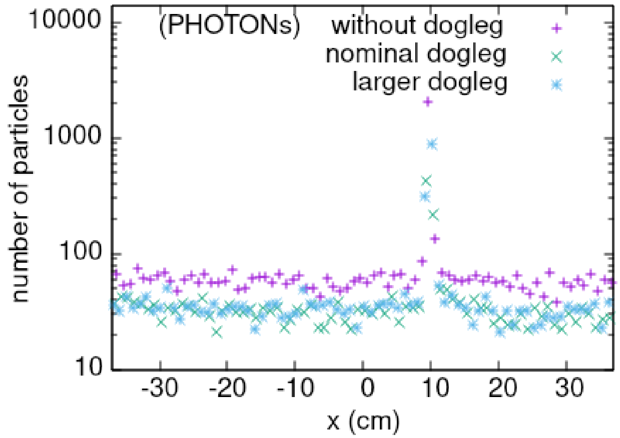
224mm bbs (nominal dogleg) →

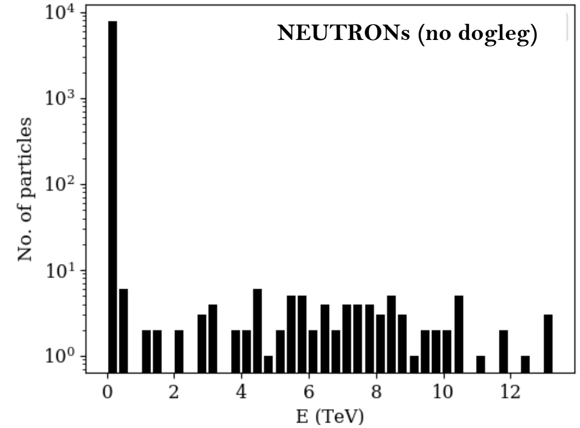
244mm bbs (larger dogleg) →



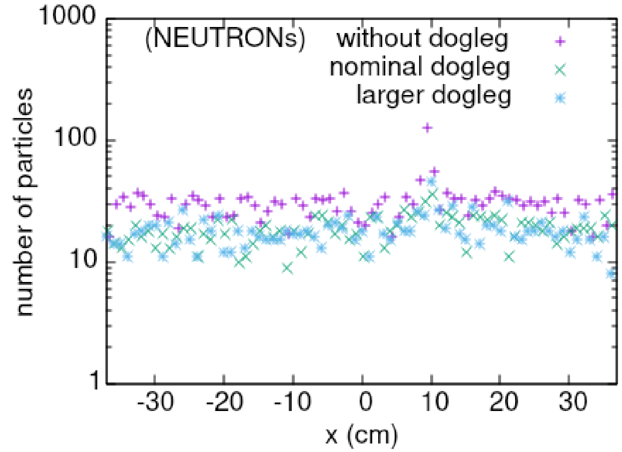
Impact of the dogleg removal - II

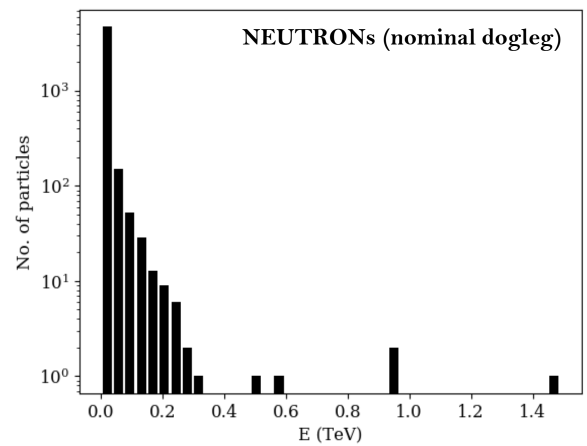






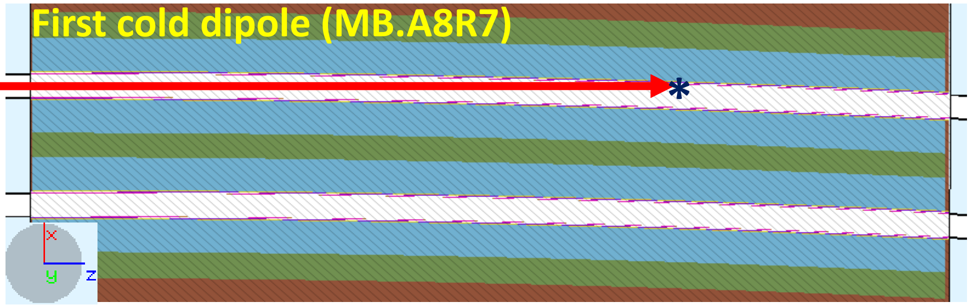
1 Proton
7 Photon
8 Neutron
9 ANeutron
13 Pion+
14 Pion-





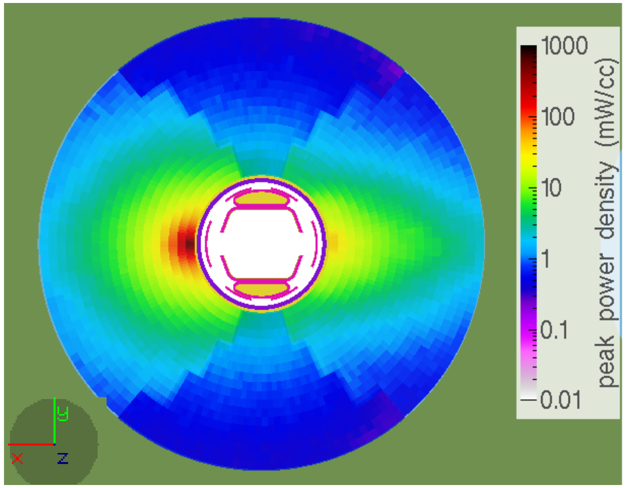
Impact of the dogleg removal - III

If no dogleg:

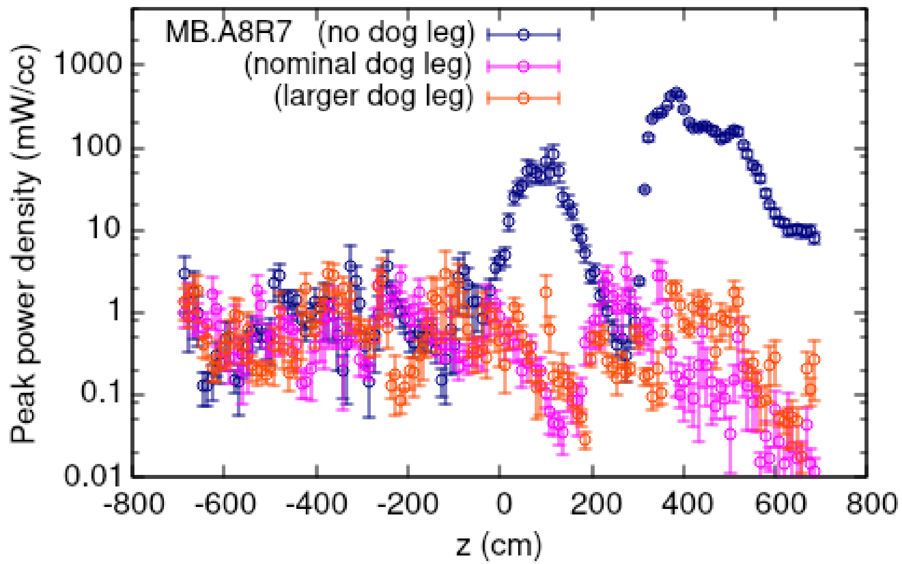


	w/o dogleg	dogleg
PHOTON	***4E-3***	***4E-5***
NEUTRON	***3E-4***	**-**

(per proton lost)



Total power (W)		
beam separation in warm section	**MQ7**	**MBA8**
204mm (no dogleg)	***7.1***	***419.3***
224mm (nominal)	***5.9***	***12.7***
244mm (larger dogleg)	***4.8***	***12.1***



(r-ϕ-z resolution: 1.86cm, 2^{o}, 10cm)

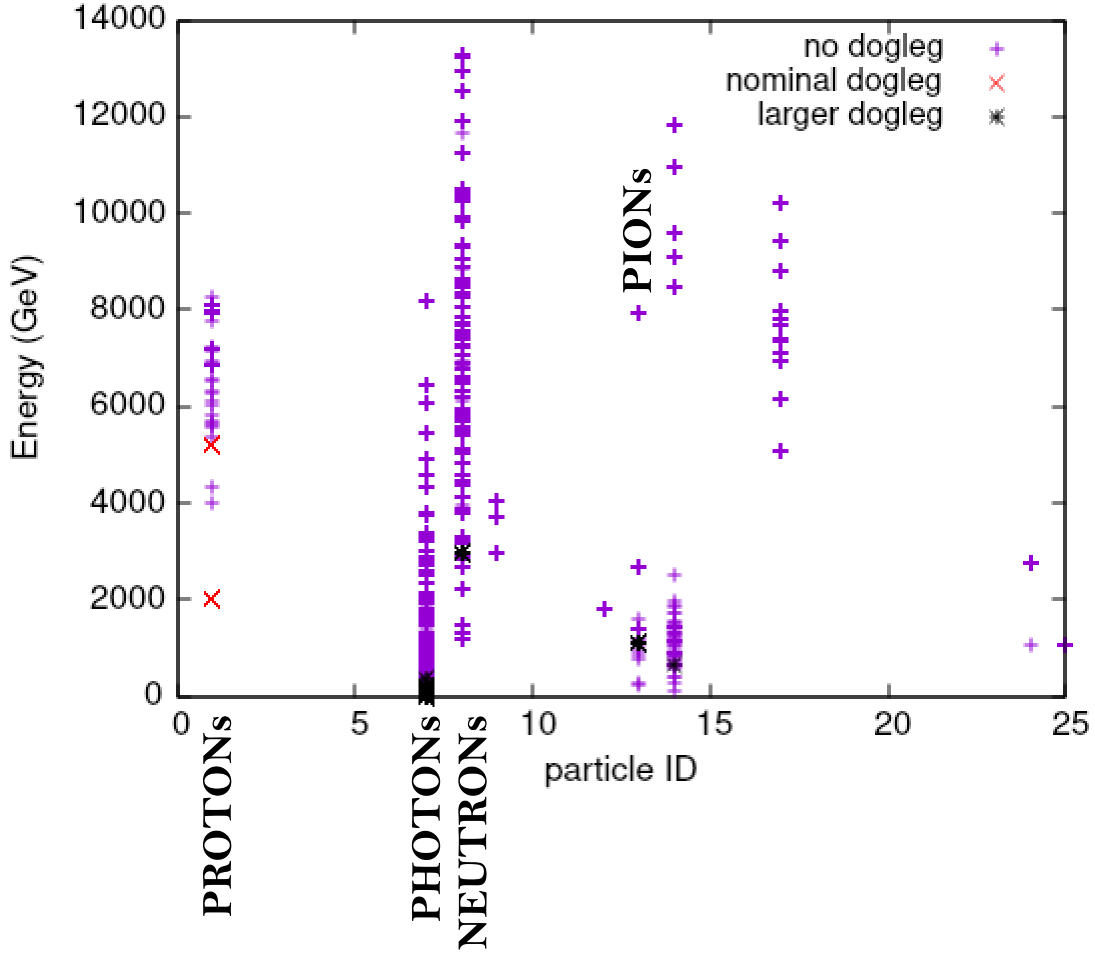
Messages from FLUKA simulation of HE-LHC machine

- **The maximum power collected by a collimator is below 60 kW (for 0.2h BLT)**
- **For the first TCSG, the max power density is NOT on the Jaw! A new design would address the issue…**
- **Thanks to the TCLD collimators, Energy deposition in the cold section is NOT hazardous**
- **No apparent showstopper was seen**
- **Dogleg removal results in a dramatically higher impact of the neutral particles in the first cold dipole**

Mohammad Varasteh

CERN / EN-STI-BMI
m.varasteh @ cern.ch

Backup Slides



14000
12000
10000
8000
6000
4000
2000
0
Energy (GeV)
0
5
10
15
20
25
particle ID
no dogleg
nominal dogleg
larger dogleg
PIONs
PROTONs
PHOTONs
NEUTRONs

MBA8

	w/o dogleg	dogleg
PHOTON	***48088***	***1085***
NEUTRON	***3187***	***-***

Active absorbers	**Total power (kW)**
TCLA.A6R (CLAA6R1i & j)	*3.0*
TCLA.B6R (CLAB6R1i & j)	*0.3*
TCLA.C6R (CLAC6R1i & j)	*0.1*
TCLA.D6R (CLAD6R1i & j)	*0.1*
TCLA.A7R (CLAD6R1i & j)	*0.03*
Passive absorbers	
TCAPA.6L (CAPA6L1)	*59.8*
TCAPB.6L (CAPB6L1)	*8.0*
TCAPC.6L (CAPC6L1)	*150.3*

MAX !
In front of most exposed MQW

ELEMENTS	**HE-LHC**	**LHC**
TCP & TCS jaws	*11.7%*	*10%*
MBW	*6.5%*	*8.5%*
MQW	*20.0%*	*9.5%*
TCAP	*11.8%*	*13%*
Beam pipe	*9.2%*	*8.6%*
Tunnel	*30.5%*	*33.1%*
Other elements	*8.6%*	*9.4%*
Missing energy	*2.0%*	*6.5%*
AIR	*0.5%*	*0.5%*
Cables	*1.8%*	*0.9%*