CERN

Energy Deposition in the FCC-hh Betatron Cleaning Insertion

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FUTURE CIRCULAR COLLIDER
CONFERENCE
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Introduction

- **Cleaning insertion is in charge of protecting the machine from losses by concentrating them in the specific areas**

- **Stored beam energy is 8.4 GJ (≈ 20 times of LHC)**

- **Collimation system must stand a high loss scenarios of 0.2h BLT at 50 TeV**
  - *total beam loss power of 11.8 MW (24 times as high as LHC) is a real challenge for robustness of the collimators and other exposed elements*

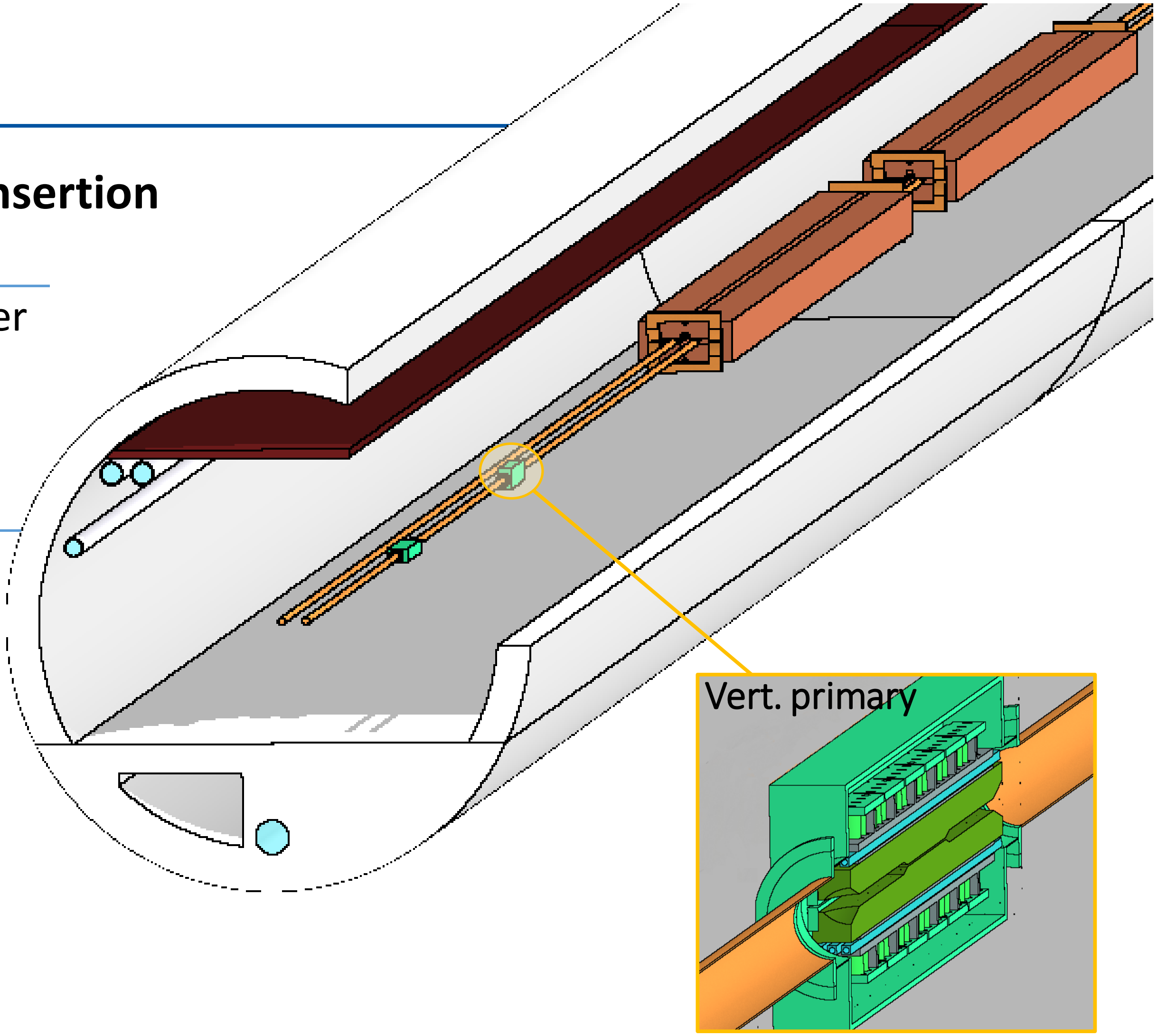
- **A multi-stage collimation system is considered**
  - *scaled-up version of the LHC cleaning system*

Betatron collimation insertion

➢ **Length of 2.7 km ≈ 5 times of LHC Betatron Cleaning Insertion**

Collimators	Length (m)	Aperture (σ)	Material	Number
Primary	**0.3**	**7.6**	**CFC**	**2**
Secondary	**1.0**	**8.8**	**CFC**	**11**
Active Absorbers	**1.0**	**12.6**	**tungsten**	**4**

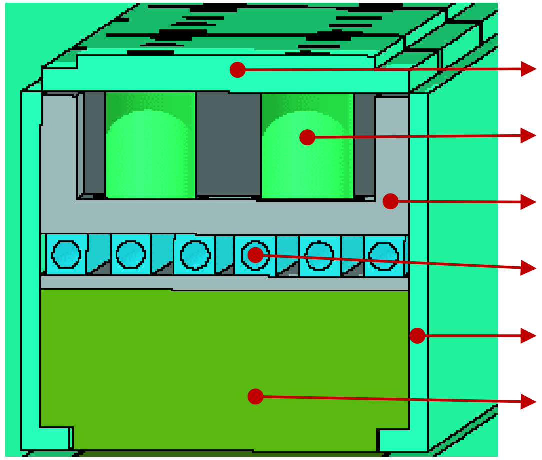
Passive absorbers:
- TCAPA.6L (1.5m long) *in front of MBW.B6L*
- TCAPB.6L (0.4m long) *in front of MBW.A6L*
- TCAPC.6L (1m long) *in front of MQWA.E5L*



- **8 warm dipoles**
  - *17 m long and 1.85 T magnetic field*
  - *design of the return coil was changed to protect them from the radiation (A. Milanese)*
  - *beam-beam separation is 204 mm in the arc and 400 mm in the center of the insertion*
  - *beam-pipe aperture is 29.5mm x 22mm*

- **24 warm quadrupoles**
  - *15.5 m long*
  - *simplified design with 400 mm beam-beam separation*
  - *beam-pipe aperture of 15.26mm x 26.14mm*

Save the collimators

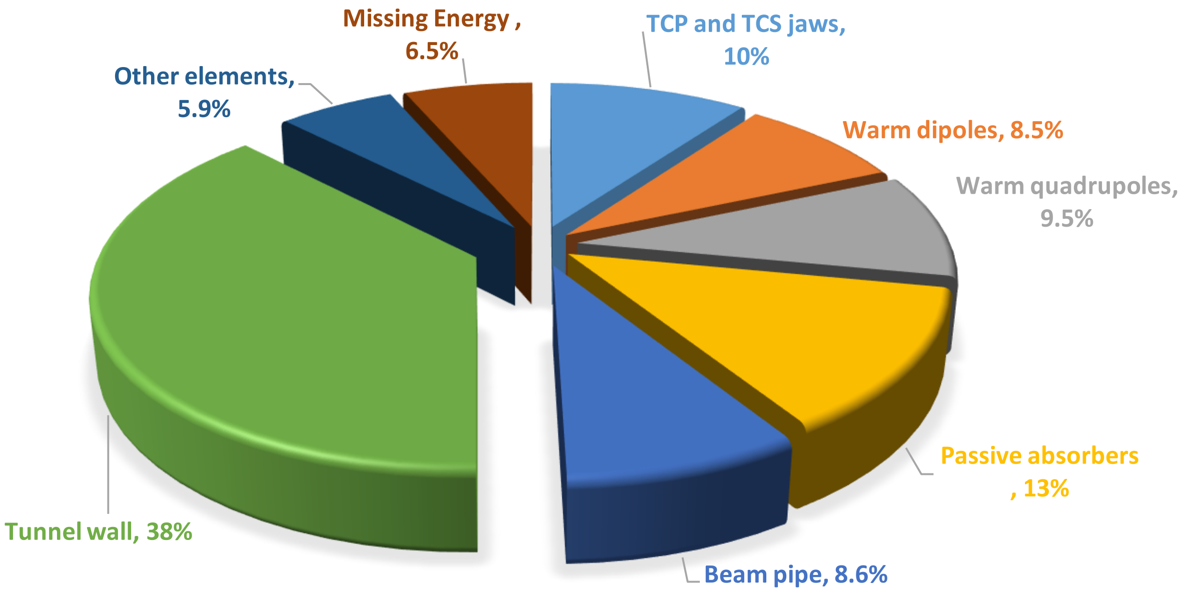


- ***30 cm TCP*** ***was proposed to reduce the shower development inside the primary collimators***
- ***Thicker jaw*** ***was implemented in order to avoid the highest power density in the metallic structure***
  - TCPs jaws → 3.5cm (instead of 2.5cm)
  - TCSGs jaws → 4.5cm (instead of 2.5cm)
- ***Skew TCP*** ***with total power above 260 kW was removed from the layout***

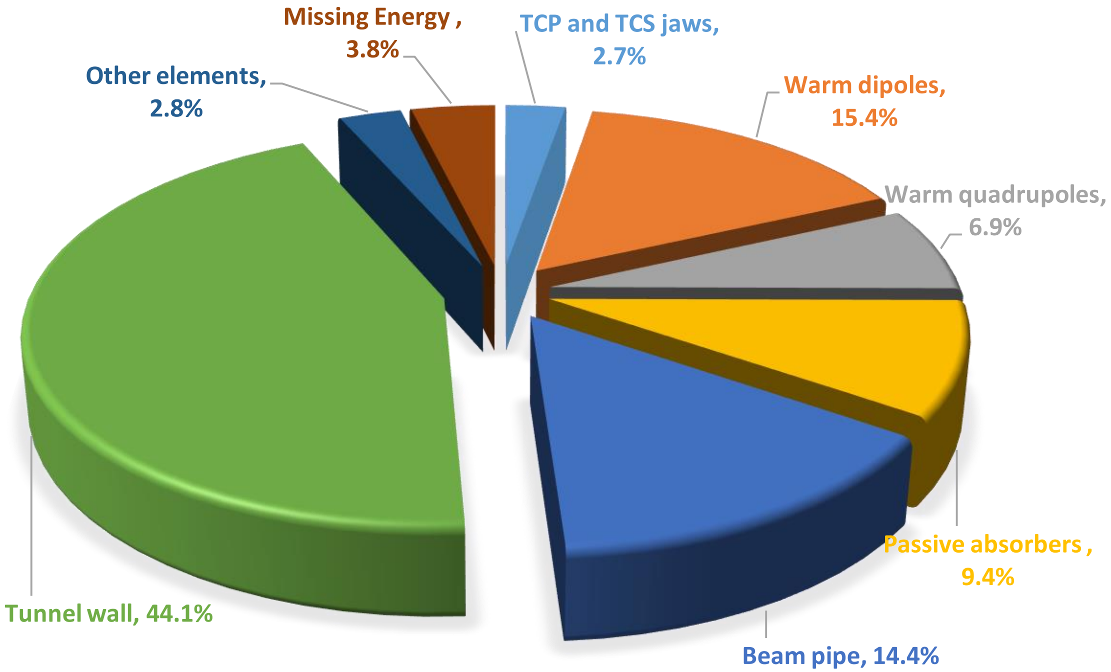
- **FLUKA showering calculation takes the touch distribution from SixTrack-FLUKA coupling.**
- **SixTrack-FLUKA coupling → for 30 cm TCP, on average 2.11** $\left(\frac{\#\text{touch}}{\#\text{loss}}\right)$
- **Values are for the 12 minutes beam lifetime !**

Power fraction on different elements

LHC collimation system



FCC collimation system



Power on collimators & absorbers

Collimator Jaws	TCP 60cm	TCP 30cm	TCP 30cm Thicker Jaw, w/o TCPB	
Primaries (kW)				
TCP.D6L	14.7	7.7	6.5	-56%▼
TCP.C6L	158.7	99.2	79.7	-50%▼
TCP.B6L	260.8	153.7	NA	
Secondaries (kW)				
TCSG.A6L	220.9	226.6	92.4	-58%▼
TCSG.B5L	10.6	13.9	9.8	-8%▼
TCSG.A5L	40.8	51.2	41.2	1%▲
TCSG.D4L	33	43.5	32.9	0%
TCSG.B4L	8.2	11.7	6.4	-22%▼
TCSG.A4L	10.8	14.1	11.6	7%▲
TCSG.A4R	13.7	18.2	13.6	-1%▼
TCSG.B5R	3.9	5	3.3	-16%▼
TCSG.D5R	6.7	9.4	7.2	7%▲
TCSG.E5R	10.9	14.6	12.5	14%▲
TCSG.6R	1.8	2.4	2.3	28%▲

w.r.t the first design

about a factor of 15 higher than LHC

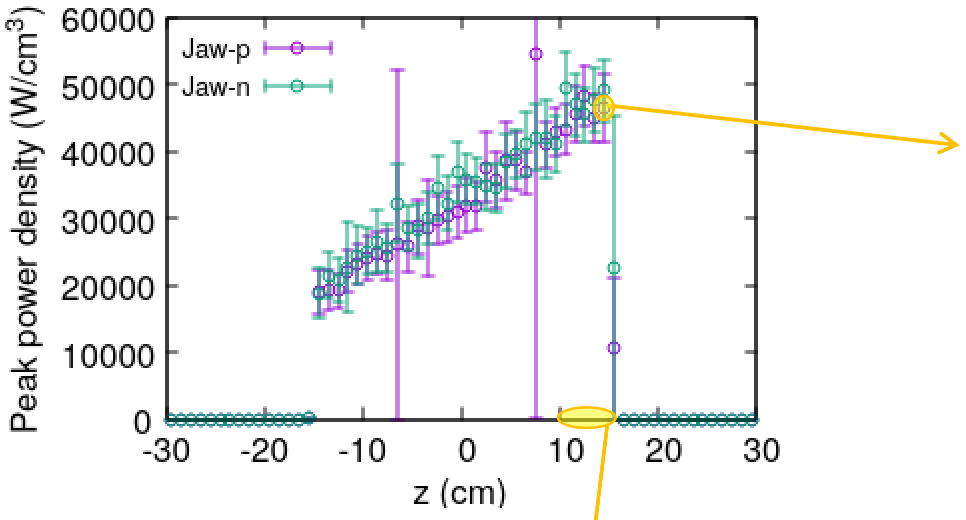
about a factor of 3 higher w.r.t. LHC

	TCP 60cm	TCP 30cm	TCP 30cm Thicker Jaw, w/o TCPB	
Active absorbers (kW)				
TCLA.A6R	23	37.7	36.5	59%▲
TCLA.B6R	1.6	2.7	2	25%▲
TCLA.C6R	1.75	2.34	2.2	26%▲
TCLA.D6R	0.46	1.7	1.6	248%▲
Passive absorbers (kW)				
TCAPA.6L	450.8	501.9	545.1	21%▲
TCAPB.6L	73.4	74.8	78.2	7%▲
TCAPC.6L	404.7	455.96	484.3	20%▲

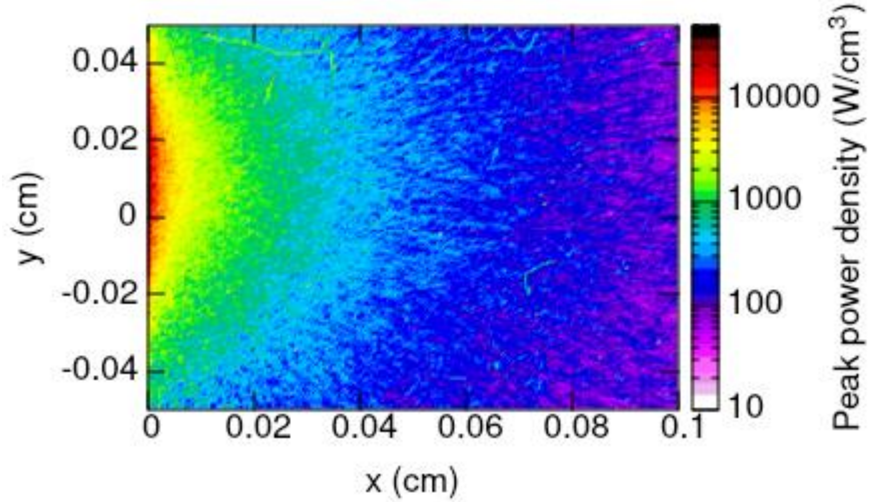
- *Power on the most loaded primary collimator has been reduced from 260 kW to 80 kW by halving the primaries' active length as well as removing the skew primary.*
- *Power on the most loaded secondary decreases for 60% by making the Jaws thicker.*

Peak power density on Vertical Primary

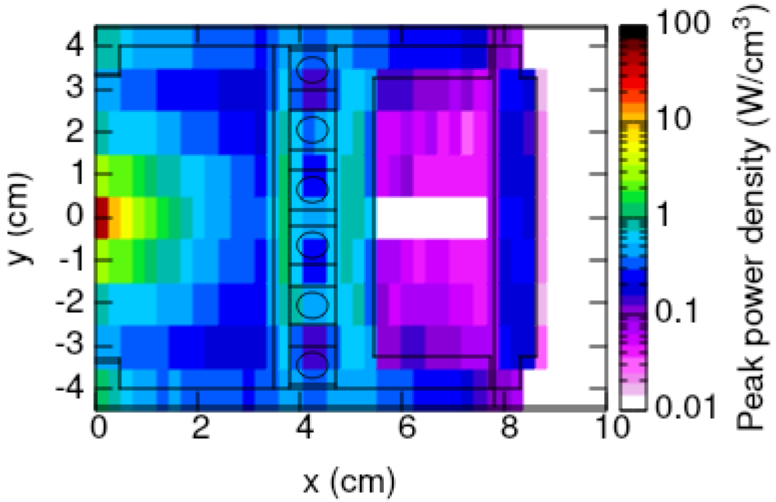
x-y-z resolution: *5μm, 5μm, and 1cm*



x-y-z resolution: *5μm, 5μm, and 1cm*



x-y-z resolution: *0.24cm, 1cm, and 5cm*

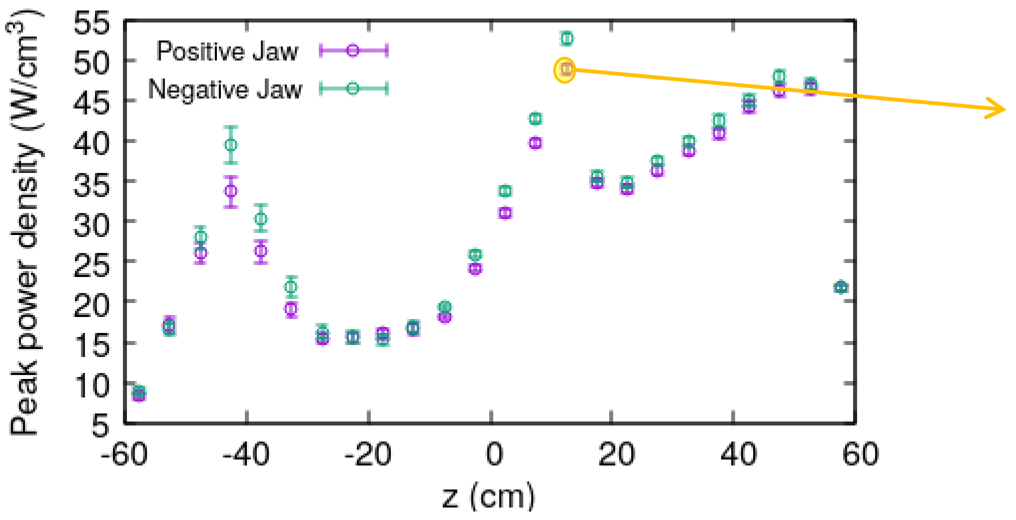


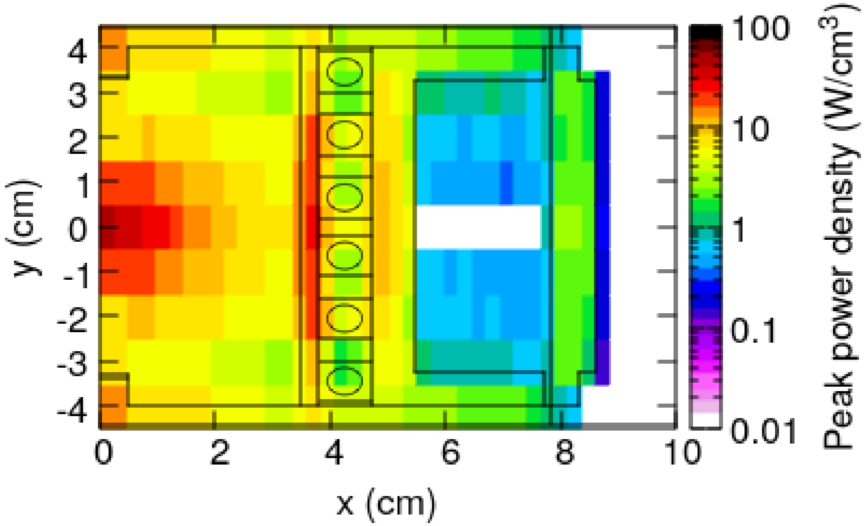
The most exposed collimator in terms of peak power density receives a total power which is more than a factor of 10 less than the Horizontal Primary.

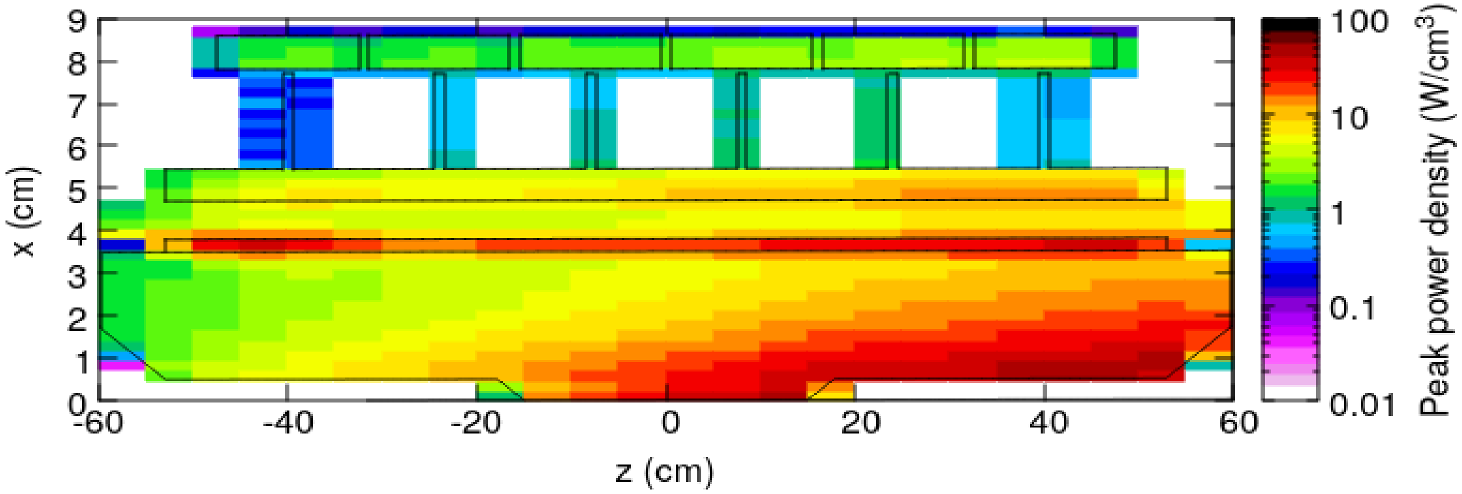
For the long term damage, DPA calculation is relevant (under study)!

Peak power density on Horizontal Primary

x-y-z resolution: *0.24cm, 1cm, and 5cm*

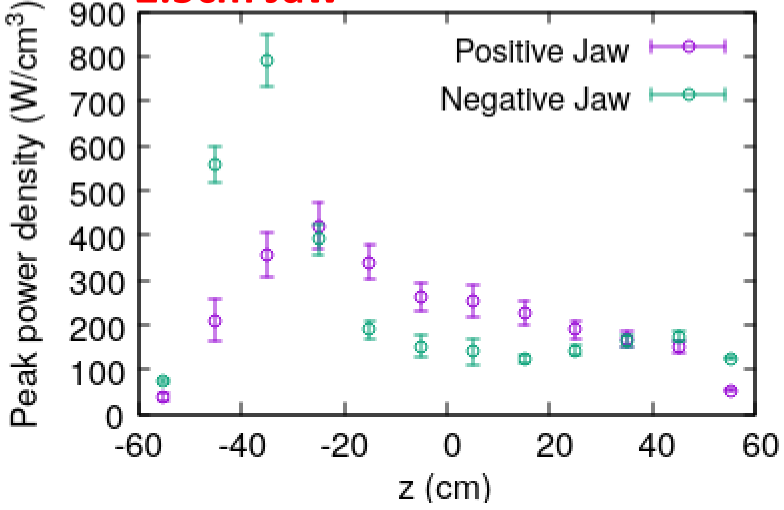


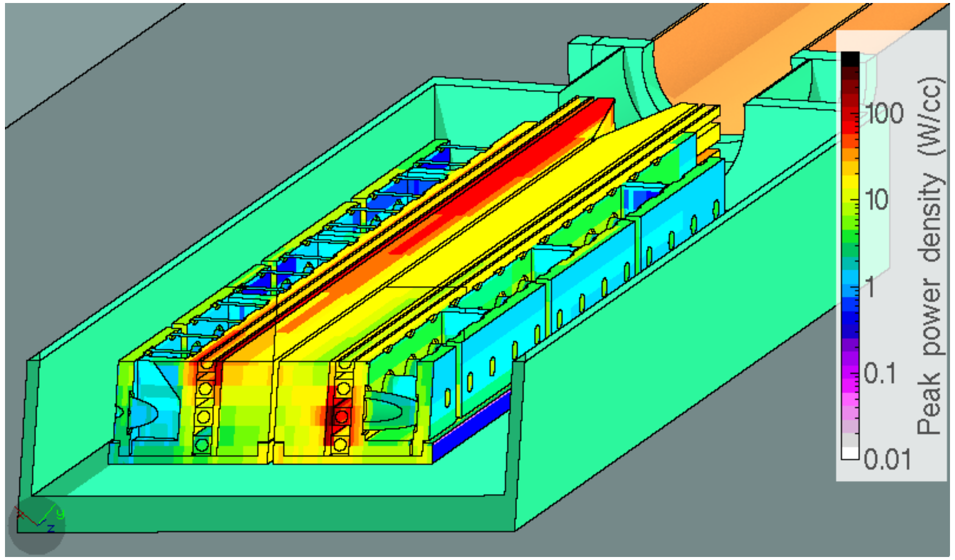




Power density on the First Secondary

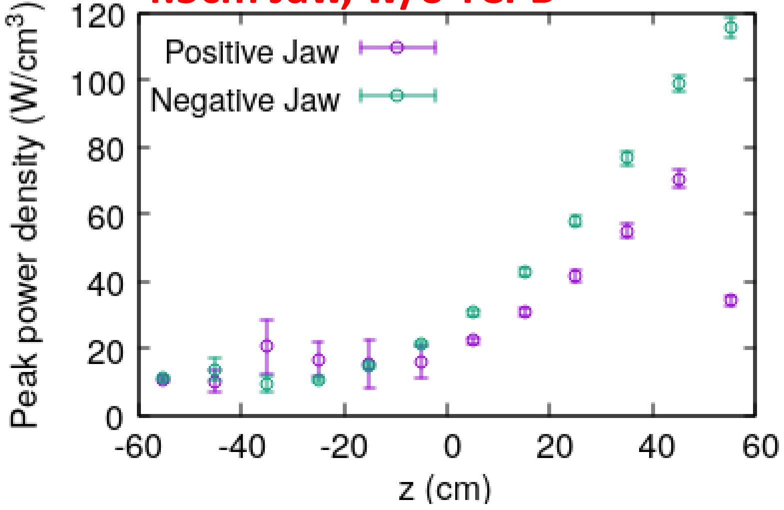
2.5cm Jaw

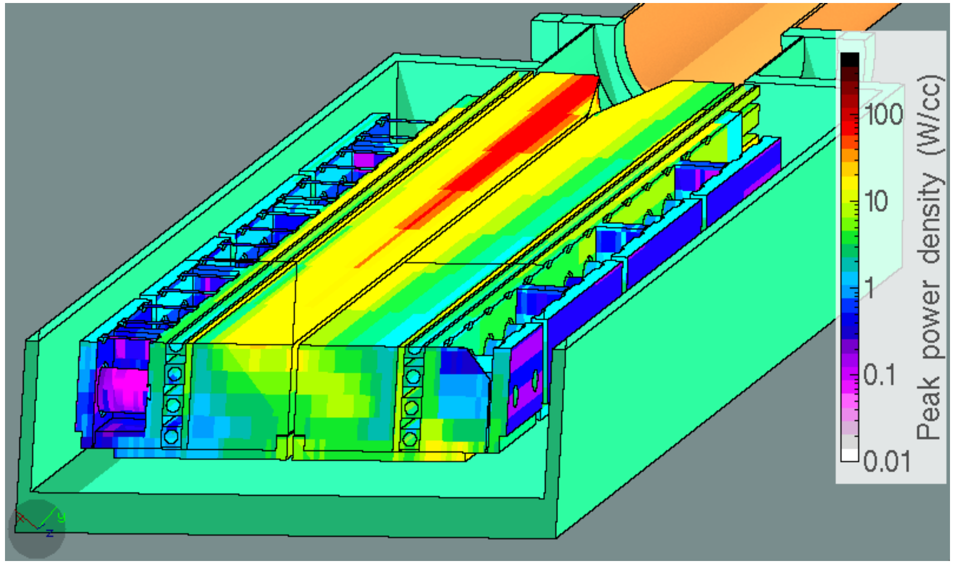




- **TCSG.A6L → 800 Wcm^{-3}**
- TCSG.A5L → 90 Wcm^{-3}
- TCSG.D4L → 33 Wcm^{-3}

4.5cm Jaw, w/o TCPB





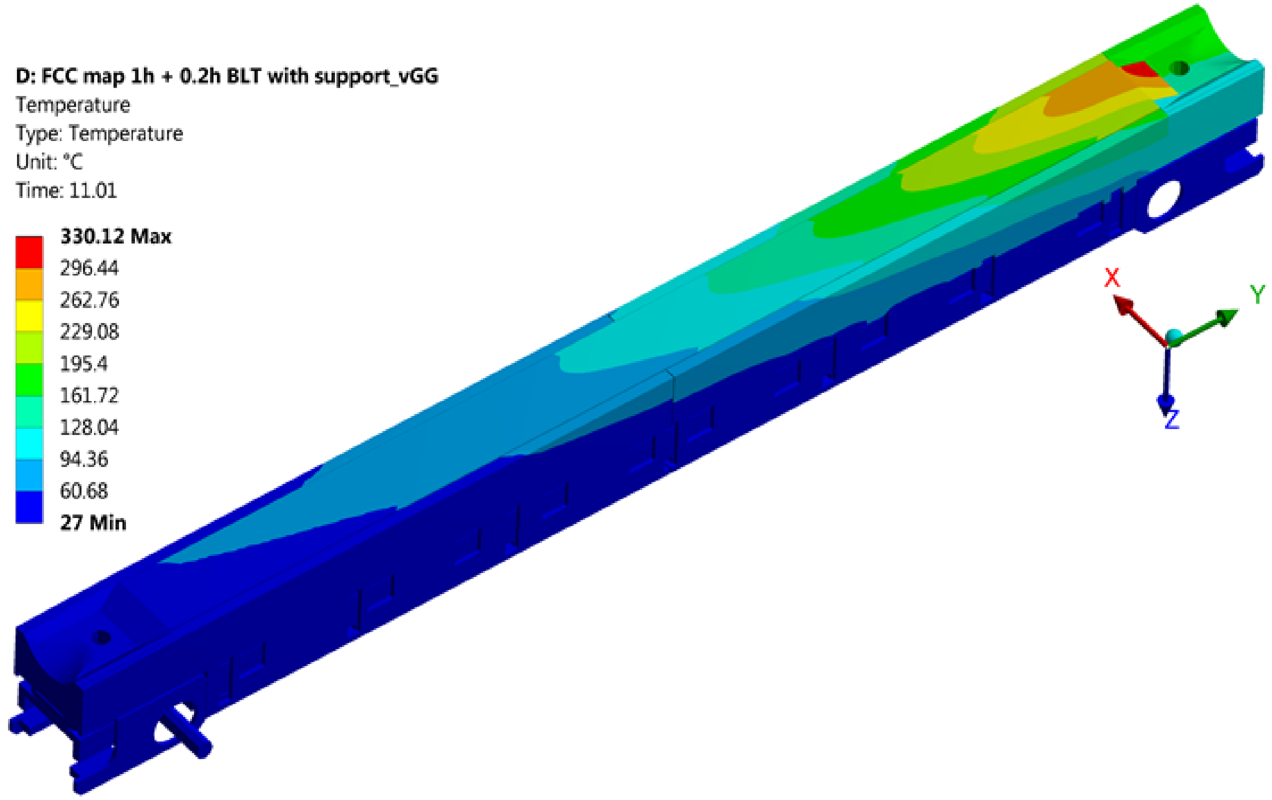
- **TCSG.A6L → 115 Wcm^{-3}**
- TCSG.A5L → 85 Wcm^{-3}
- TCSG.D4L → 30 Wcm^{-3}

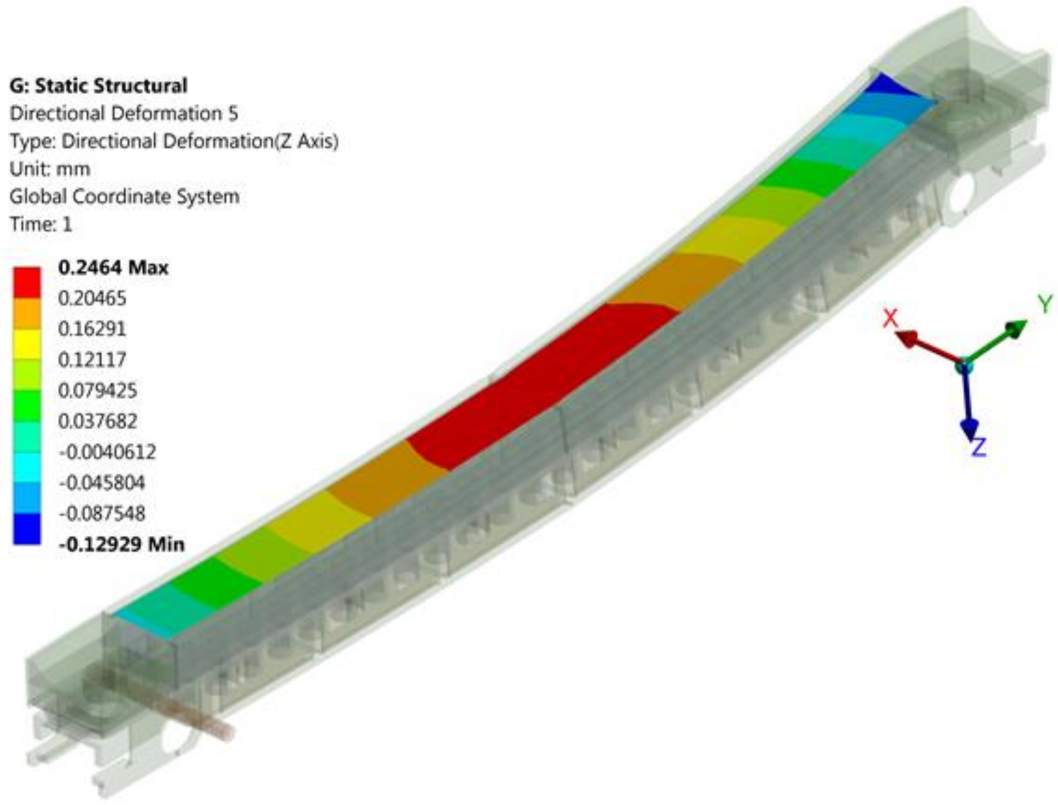
LHC → 10 Wcm^{-3} (1st Secondary)

0.24cm, 1cm, and 10cm
(x-y-z resolution)

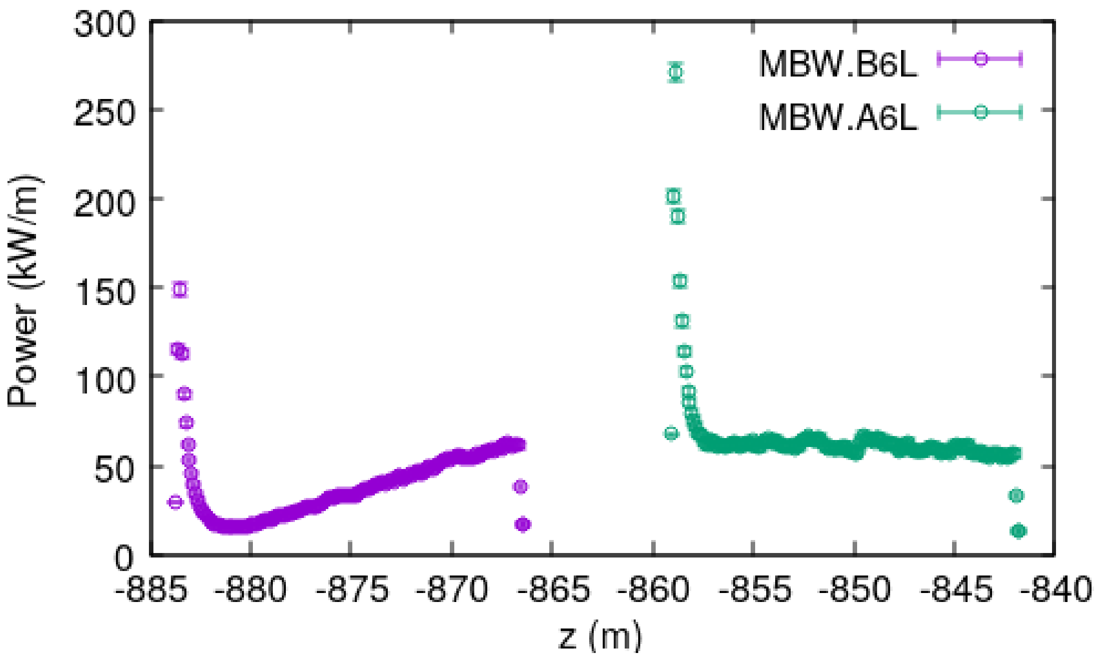
Thermomechanical study (G. Gobbi, F. Carra and A. Bertarelli, EN-MME)

- Max temperature → 330 ^{o}C for 4.5 cm jaw vs 393 ^{o}C for 2.5 cm jaw (cooling water at 27 ^{o}C)
- Thermal induced deflection → 375 µm vs 1174 µm for 4.5 and 2.5 cm jaws, respectively
- Plasticity on the cooling pipes is reduced and the remained might be addressed by a different material for the cooling pipes

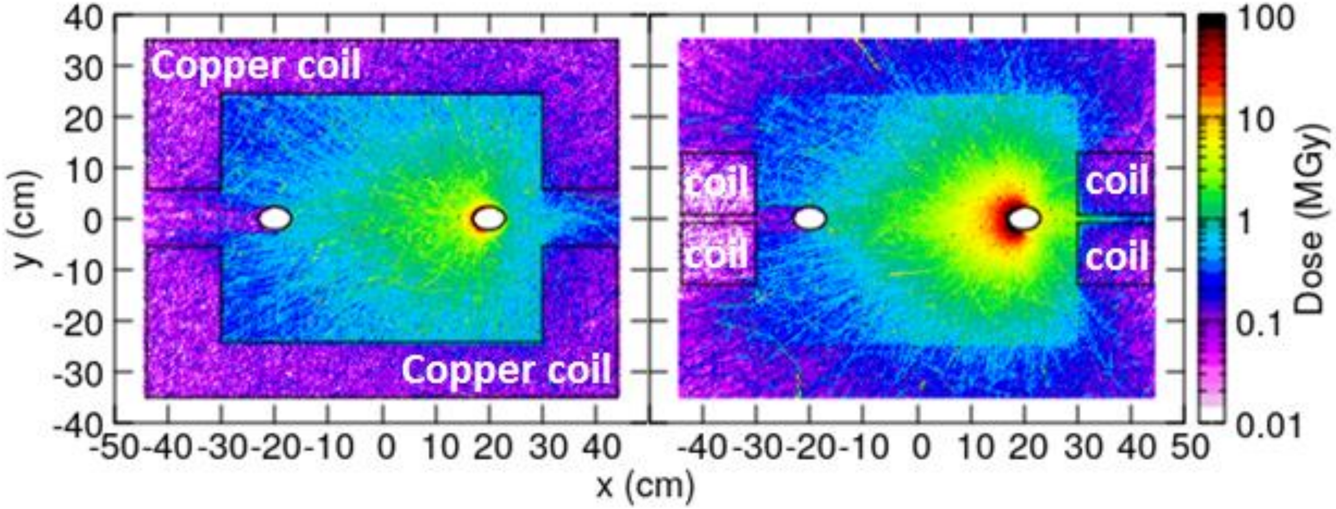




Dipole modules after primary collimators



MBW.B6L upstream (for 1e16 proton lost per year)

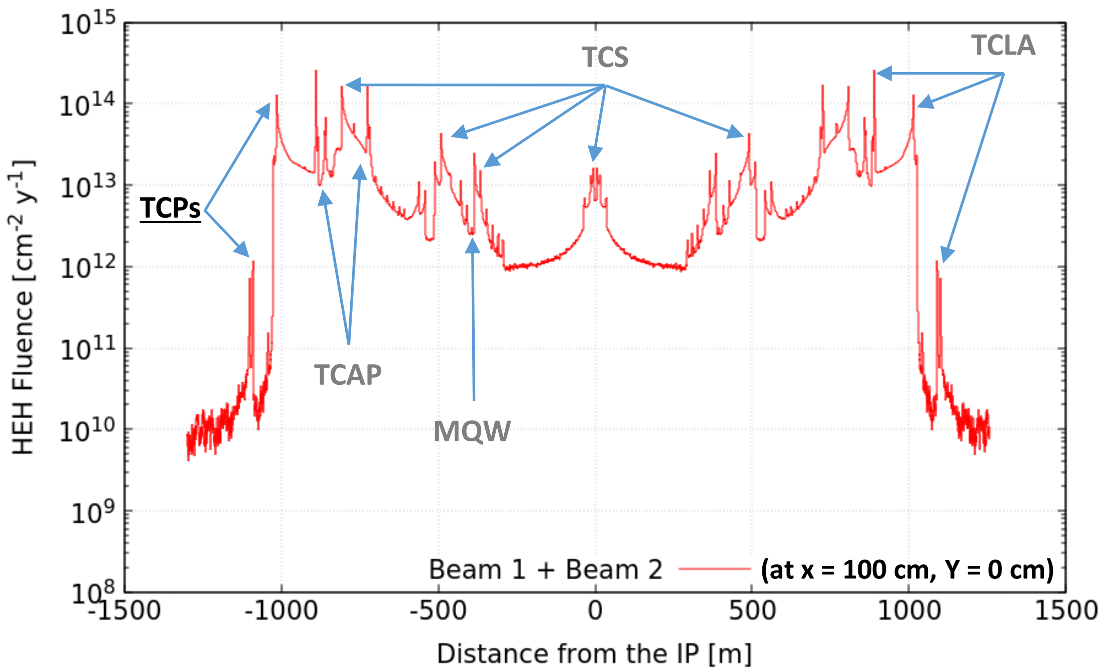


➢ **Moving away from the beam pipe, a factor of 10 less dose on the return coil**

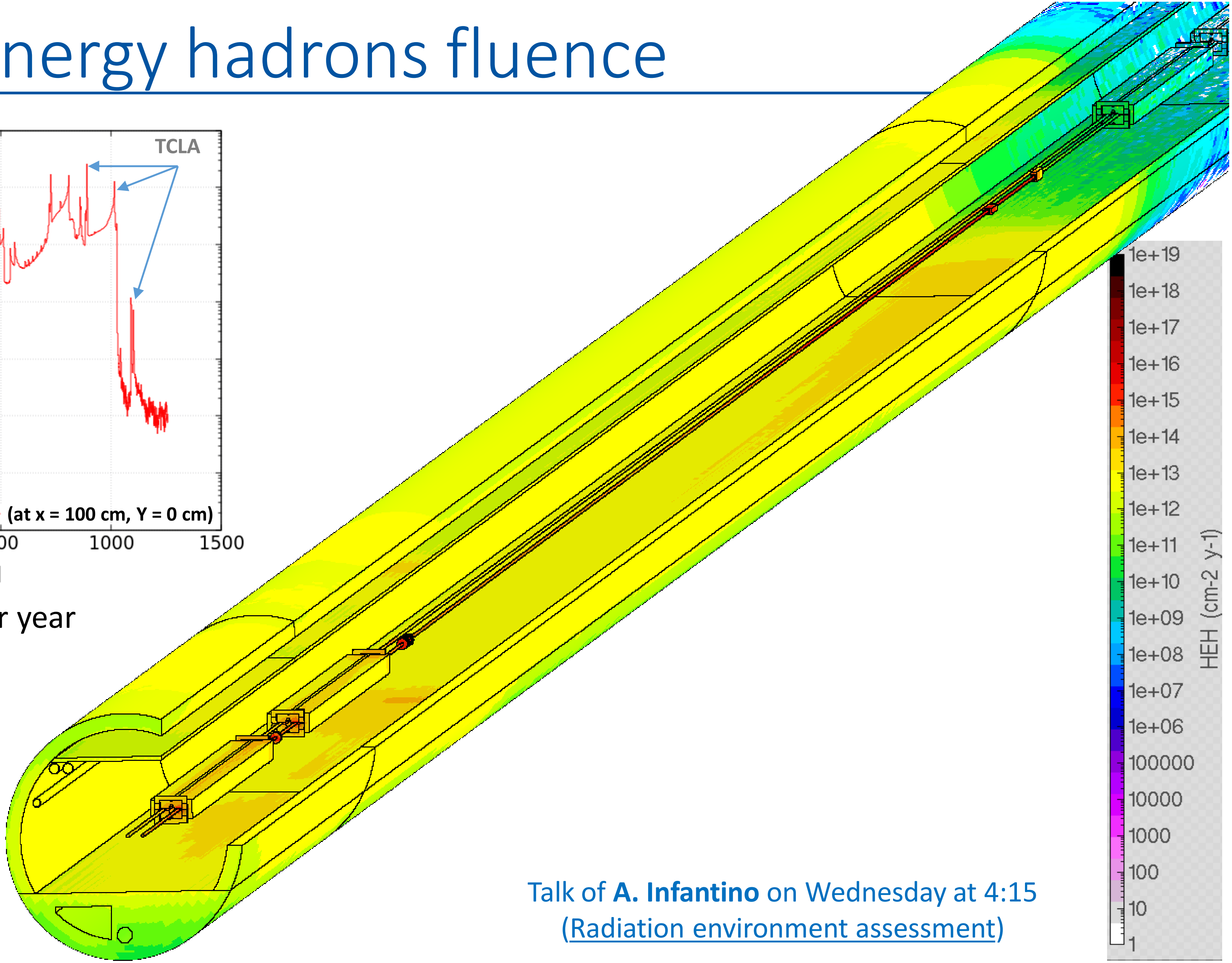
	Total power	Hottest segment	Removable power
MBW.B6L	0.68 (MW) -1% ▼	64 (cm) **4%** of total length	57 (kW) **9%**
MBW.A6L	1.1 (MW) 18% ▲	124 (cm) **7%** of total length	156 (kW) **14%**

- **Maximum power per meter is 270 kW/m but the bulk is about 60 kW/m**
- **Maximum power on dipoles → 1.1 MW (22 kW for LHC)**

R2E study: high energy hadrons fluence



- Considering 1e16 protons lost per year



Talk of **A. Infantino** on Wednesday at 4:15
(Radiation environment assessment)

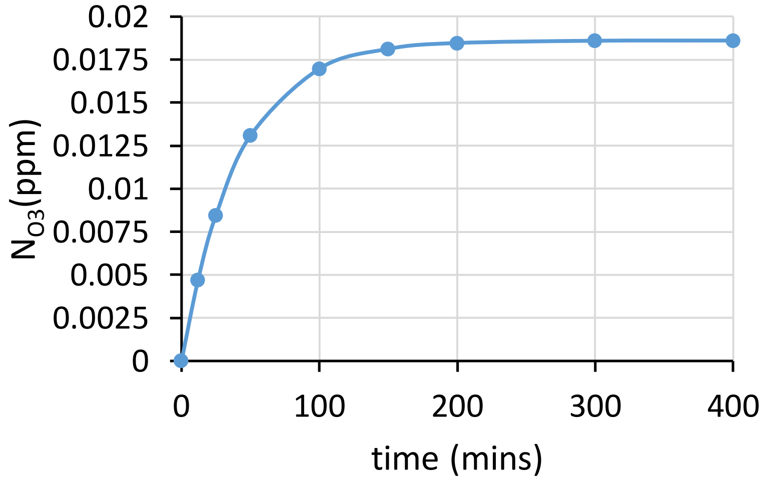
Ozone production (dose in air)

$$N_{O_3}(ppm) = 9.28 \times 10^{-15} \times G(eV^{-1}) \frac{P_{eV}(eV/s)\tau(s)}{V(cc)} [1 - e^{\frac{-t}{\tau}}]$$

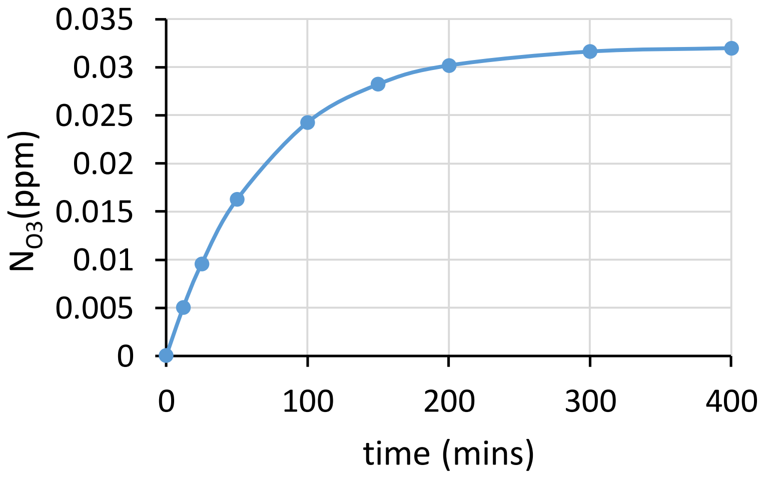
- $\mathrm{G} = 0.06$ to 0.074 (number of produced O_3 molecules per eV)
- $\tau(\mathrm{s}) = 1/(\alpha + 1/\tau_{\mathrm{vent}} + \mathrm{kP_{eV}/V})$
  - $\alpha(1/s) = 2.3\mathrm{e}-4$ (dissociation constant of O_3)
  - $\mathrm{k(eV^{-1}cm^3)} = 1.4 \times 10^{-16}$ (decomposition constant)

- 2 x 1e16 loss per 4800 beam-hours
- Assumed all energy loss in air is ionizing
- Power in air = 102 W
- Air Volume = 58000 m^3

Ventilation rate: 36000 $m^3 h^{-1}$, τ_{vent} = 1.6 h
→ $N_{O_3}(ppm)$ = **1.9E-2 a factor of 20 higher than LHC**



Ventilation rate: 700 $m^3 h^{-1}$, τ_{vent} = 82.8 h
→ $N_{O_3}(ppm)$ = **3.2E-2**



Summary

- With shorter (and less) primaries and thicker jaws, the maximum power collected by a collimator for a 12 min BLT is below 100 kW
- In the surface layers of the directly impacted collimator, a power density of tens of kW/cc is reached → calling for thermomechanical assessment
- Peak power density on the 1st secondary collimator is reduced by a factor of 7, thanks to the increase in the jaws' thickness
- The dogleg warm dipoles, 17 m long, are subject to about 200 kW for a 1h BLT → requiring a suitable cooling system

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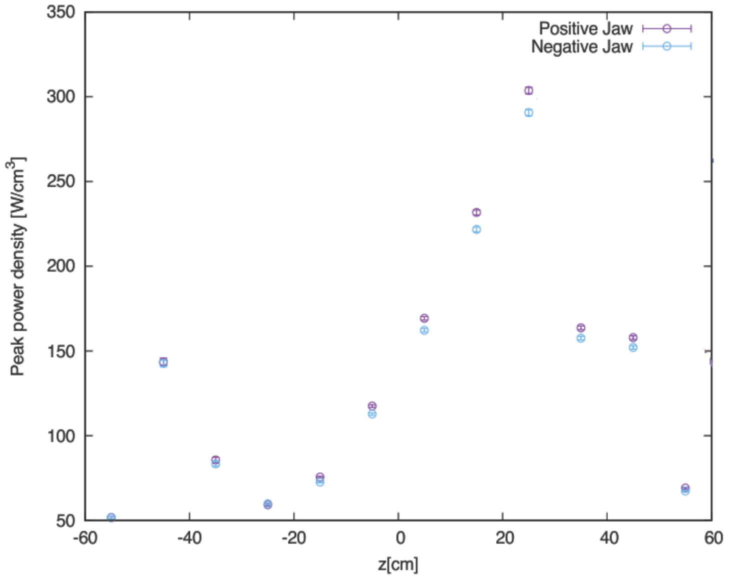
Backup Slides

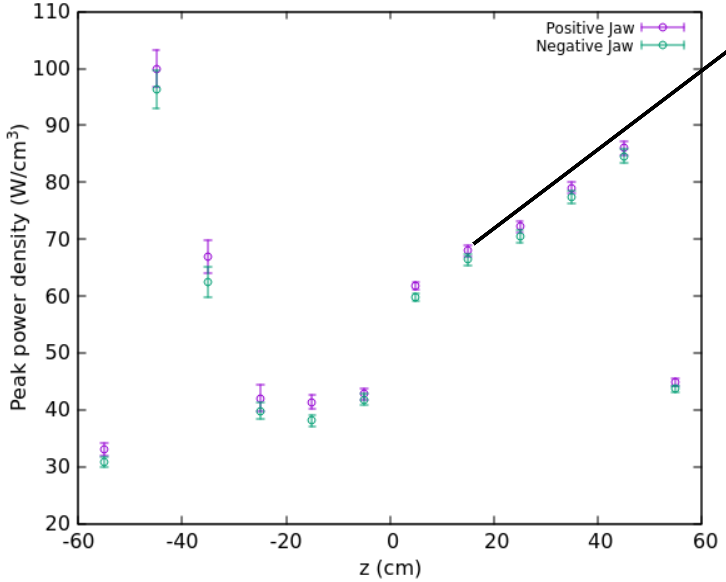
Power density (60cm vs 30cm) → Skew TCP

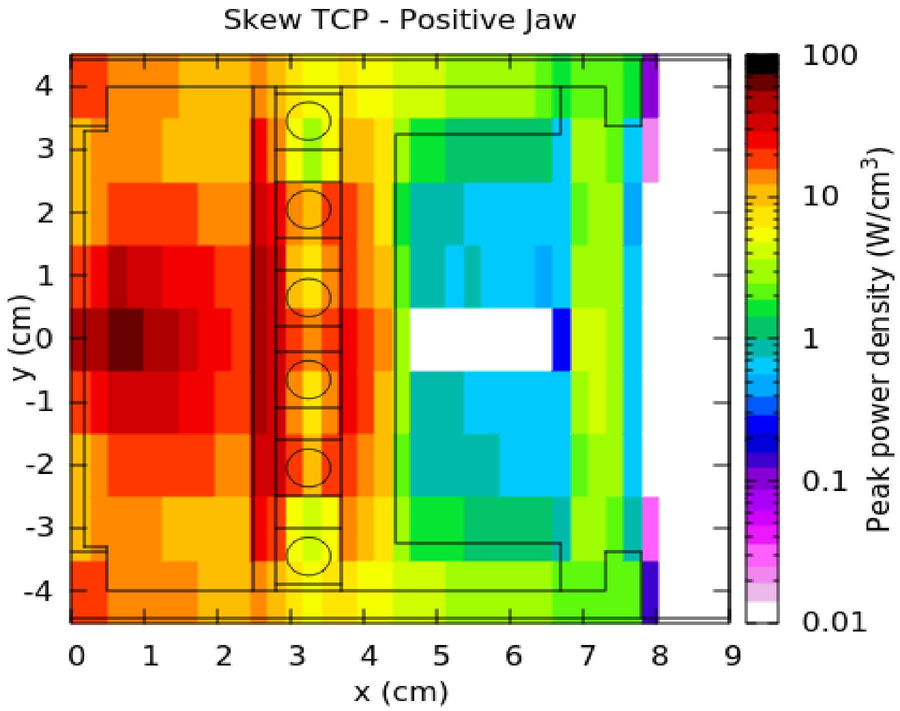
(60cm TCP)



Max peak power density on the skew TCP

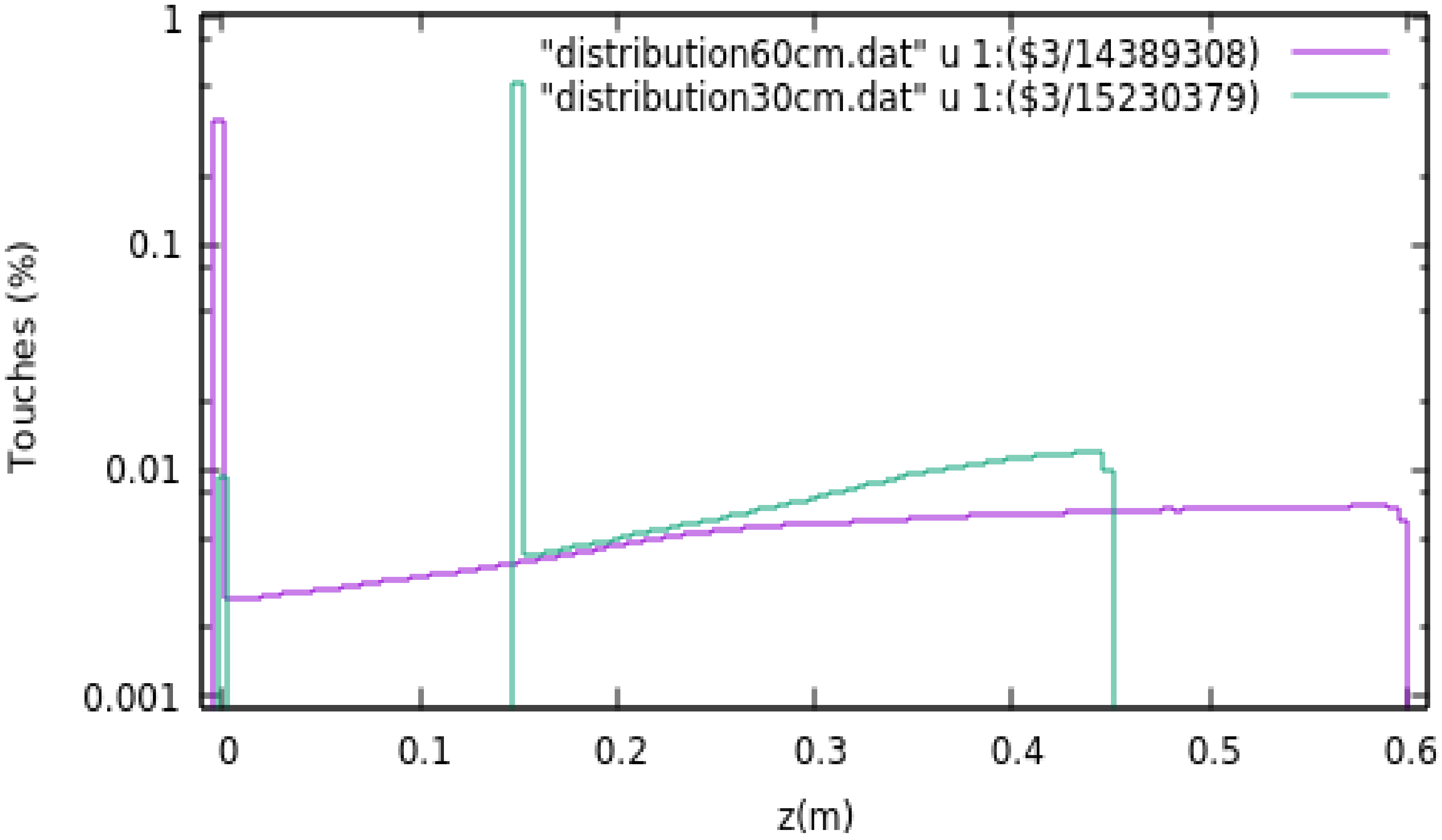
(30cm TCP)





resolution → 0.24cm, 1cm, 10cm

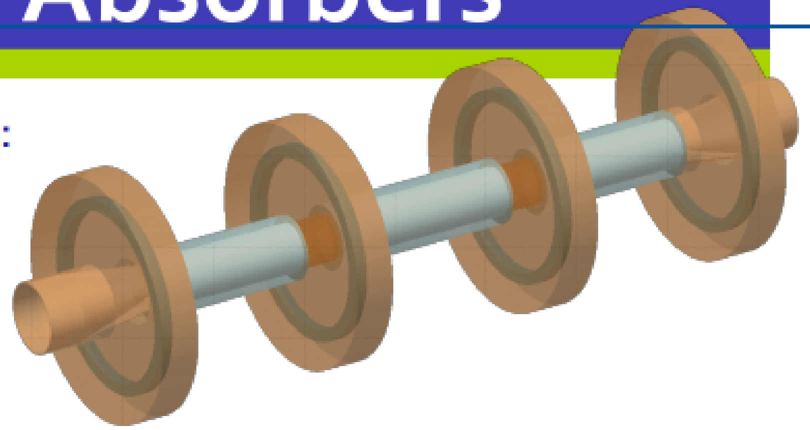
Distribution of touches (60 cm vs 30 cm)



Impact of Passive Absorbers

60 cm TCP

- Passive absorbers put in front of the magnets:
  - design not optimized: LHC models
    - TCAPA.6L in front of MBW.B6L (1.5 m long)
    - TCAPB.6L in front of MBW.A6L (0.4 m long)
    - TCAPC.6L (1 m long)



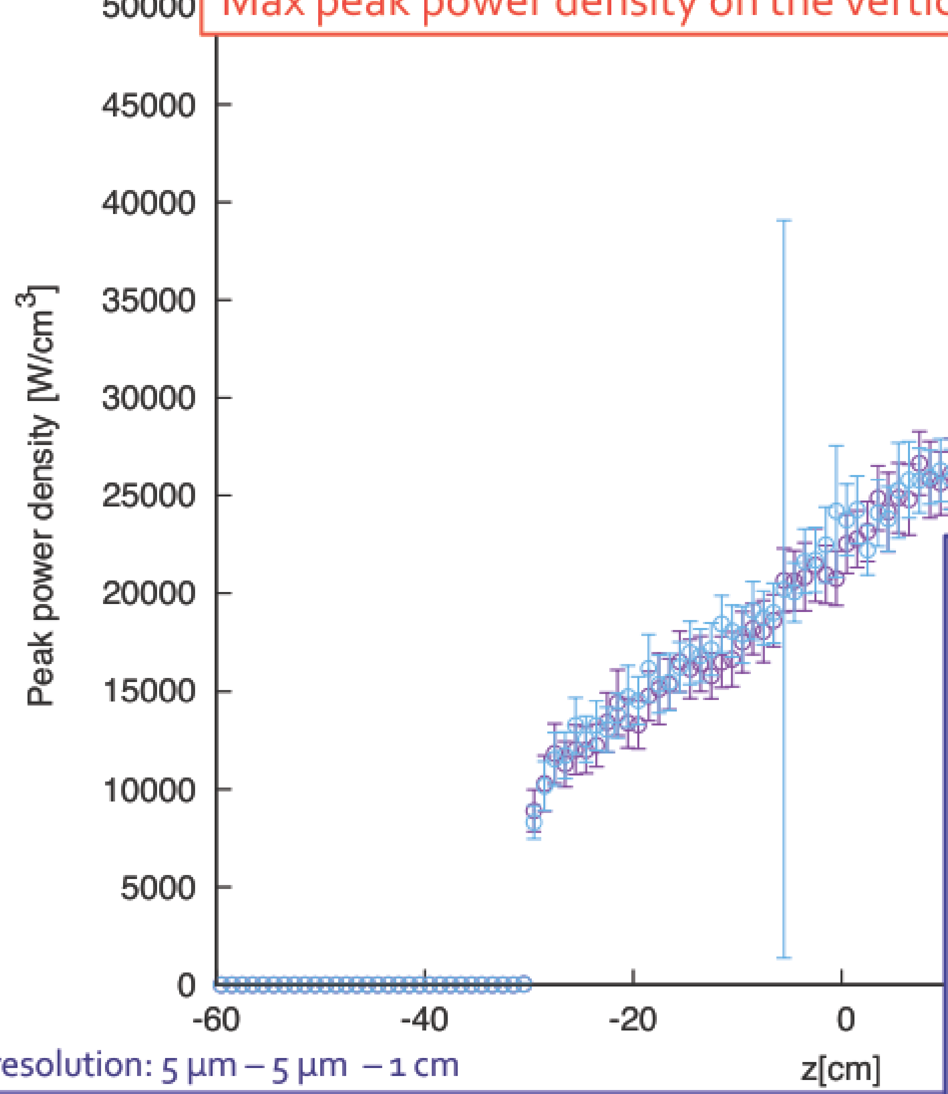
Power Fraction	FCC w/o TCAP	FCC w TCAP
Power Loss for 12 minutes beam life-time	**11.8 MW**	**11.8 MW**
Passive absorbers (TCAP)	-	8.6%
Warm dipoles	20.3%	16%
Warm quadrupoles	6.6%	4.6%
TCP and TCS jaws	5.5%	5.1%
Tunnel wall	44.4%	44%
Beam pipe	15%	14%

- Max power on a dipole (MBW.A6L): ~1 MW
  - 22 kW at LHC (6.5 TeV)

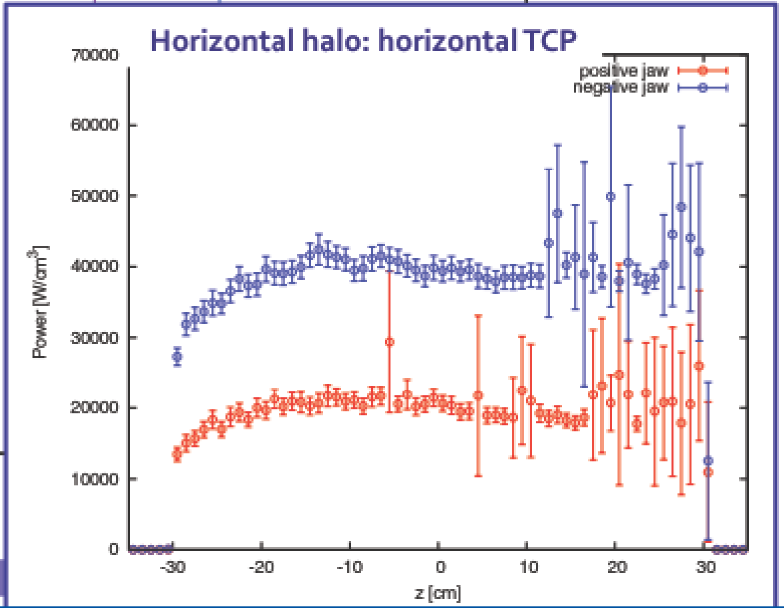
Maria Ilaria Besana

Vertical TCP

Max peak power density on the vertical TCP



x-y-z resolution: 5 µm – 5 µm – 1 cm



Maria Ilaria Besana

FCC Power Sharing

FLUKA showering calculation taking as initial condition the touches distribution by the SixTrack+FLUKA coupling

Power Fraction	FCC (50 TeV)	LHC (6.5 TeV)
Power Loss for 12 minutes beam life-time	**11.8 MW**	**0.5 MW**
Warm dipoles	16 %	8.5 %
Warm quadrupoles	4.6 %	9.5 %
TCP and TCS jaws	5.1 %	10.5 %
Passive absorbers (TCAP)	8.6 %	13.5 %
Beam pipe	14.2 %	8.6 %
Tunnel wall & Other elements	47.5 %	42.3 %
Neutrinos/E —> m	4 %	6.5 %

higher fraction at the FCC wrt to LHC
—> FCC dipoles are 5 times longer & upstream collimators and absorbers are identical to LHC

the FCC longer quadrupoles are less impacted, thanks to the protection of upstream dipoles

courtesy of I. Besana

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