Upgrade studies for the TCDS in IR6

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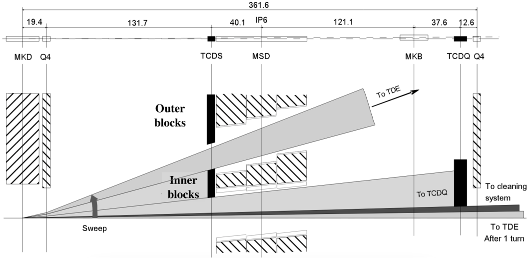
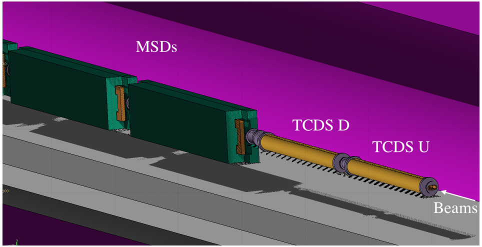
TCDS Purpose

Beam extraction: horizontal beams separation (MKD) + vertical kick (MSD) towards the beam dump

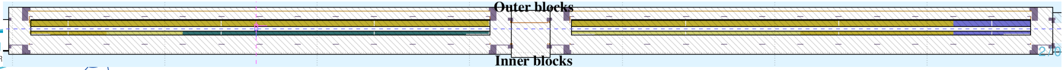
TCDS

- Protection of the extraction septa in case of
  - asynchronous beam dump
  - higher-than-normal kick angles
- 2 rows of diluting blocks (2 x 3.3 m) and interconnecting bellows
- In each vacuum tank: 2 rows of absorber blocks





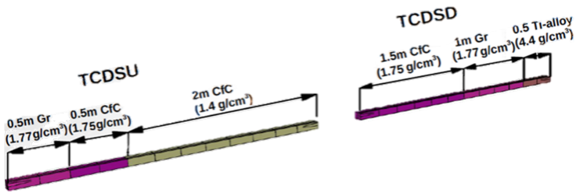
Upstream module: Downstream module:



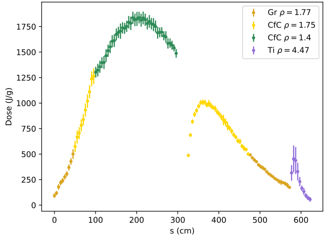
Current absorbers configuration

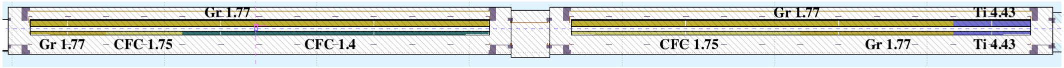
The inner blocks consist of a series of:

- High density isostatic graphite (C2020) blocks
- Carbon-Fiber-Reinforced-Carbon (CFC) blocks: two types with different densities; placed at the shower maximum, to limit energy deposition and temperature increase
- Last 2 blocks made of a Ti alloy (Ti-6Al-4V, grade 5), enhancing the energy absorption of the TCDS



Peak dose profile:



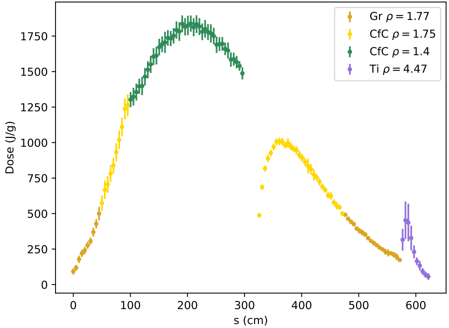


Energy deposition in the TCDS inner blocks with HL beams

HL beam settings:
asynchronous beam dump,
7 TeV, $\varepsilon_n = 1.37\,\mu\text{m.rad}$, 2.3×10^{11} ppb
No emittance growth nor intensity loss in ramp

HL beams lead to higher energy densities:

- Graphite blocks already foreseen to be changed due to fracturing risk
- Risk of cyclic plastic deformation of Ti blocks
- CFC blocks shown the be capable to withstand HL doses (HRMT-56: P. Andreu Muñoz et al., THE CERN HiRadMat-56-HED EXPERIMENT, IPAC 2022)

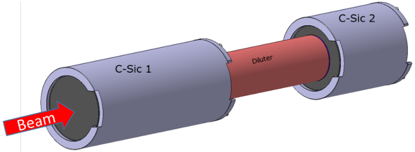


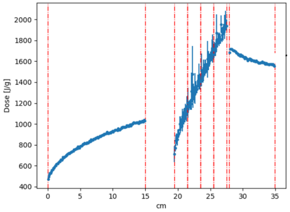
C-SiC material candidate

Carbon / Silicon Carbide (C-SiC):

- CFC infiltrated with silicon at 1400 deg C
- Higher density (2.5g/cm3) ⇒ increased energy absorption capabilities
- Tested in HRMT-56: no sign of structural degradation when exposed to up to 1700 $J\,g^{-1}$
- Exhibit higher outgassing rates than the currently used materials, which can be mitigated with adding additional vacuum pumps

HiRadMat-56[1] CSiC target:





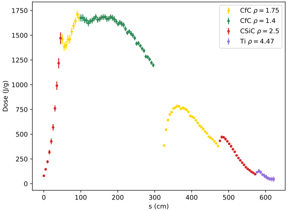
[1] P. Andreu Muñoz et al., IRRADIATION OF LOW-Z CARBON-BASED MATERIALS WITH 440 GeV/c PROTON BEAM FOR HIGH ENERGY & INTENSITY BEAM ABSORBERS: THE CERN HiRadMat-56-HED EXPERIMENT, IPAC 2022

Simulated configurations: IG → C-SiC?

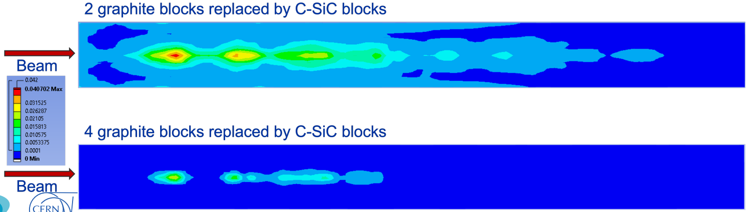
Several configurations were considered, with replacing up to 6 of the IG blocks with C-SiC:

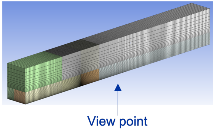
- C-SiC can't be used for the two first blocks, where it would be exposed to very high doses
- C-SiC tested for the downstream module graphite blocks: either replacing 2 or 4 of them, and keeping the 2 last Ti blocks
  - Peak dose in the first Ti block still high
  - Based on Based on structural FEA, the risk of plastic deformation in the upstream Ti block can't be excluded, if the TCDS were to experience multipl a.b.d

2 C-SiC upstream +
4 C-SiC downstream:



Accumulated plastic strain in the first Ti block (80 µs), bottom view *(C. Sharp, T. Calvet)*





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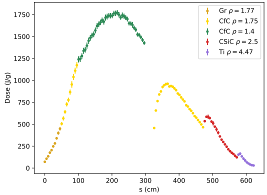
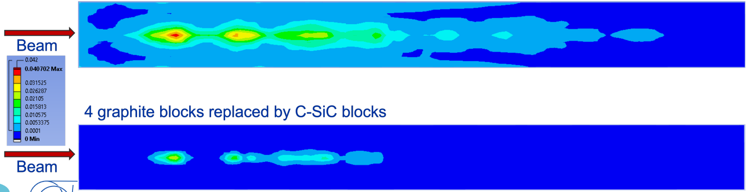
4 C-SiC downstream:

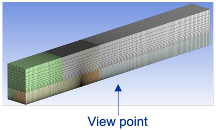


Accumulated plastic strain in the first Ti block (80 µs), bottom view *(C. sharp, T. Calvet)*

2 graphite blocks replaced by C-SiC blocks

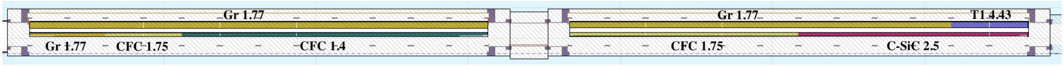


4 graphite blocks replaced by C-SiC blocks

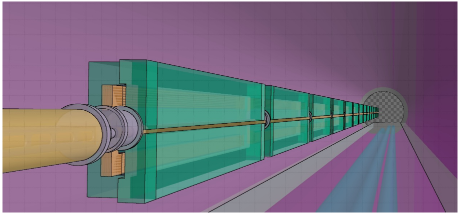


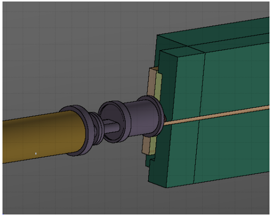
View point

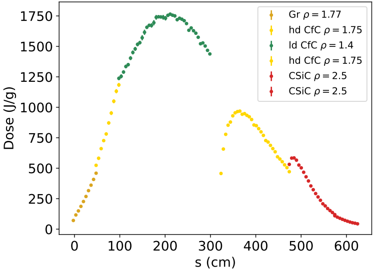
Proposed configuration



- 6 final blocks made with C-SiC, including previous Ti blocks
- No more peak in the final blocks
- Do these modules grant a sufficient protection for downstream elements?

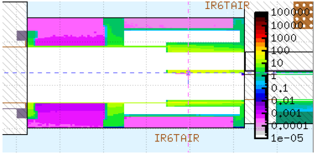


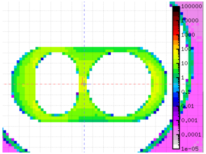


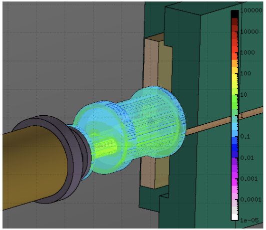


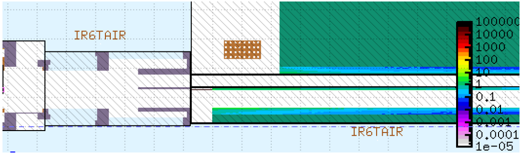
Energy deposition in downstream elements

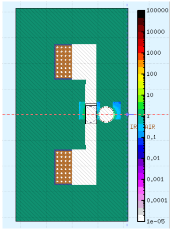
Energy densities for the interconnects ($\leq 60\,\mathrm{J\,g^{-1}}$), all MSD pieces (coils, yoke, etc. $\leq 40\,\mathrm{J\,g^{-1}}$) and beam chambers ($\leq 40\,\mathrm{J\,g^{-1}}$) are found to be very similar as for the configuration with Ti blocks, where they were found acceptable by TE-VSC and TE-MSC:









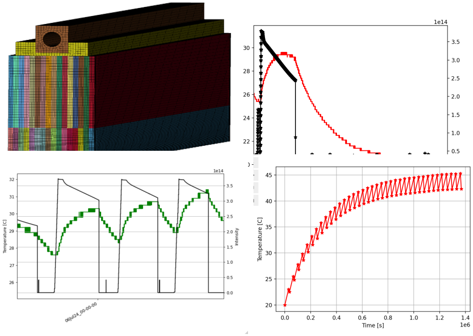


Conclusion: Configuration selected, with vacuum pumps to be added, to compensate for the increased outgassing rate of C-SiC blocks.

Cooling

The TCDS are water-cooled to prevent beam-induced heating.
Studies showed that, with HL intensities, there could potentially be a risk that the rapid evaporation of water can damage the cooling circuit
$\rightarrow$ Do we need water cooling?

- Tests were made this year with no water cooling on one TCDS
- Heat accumulation and temperature increase over successive fills
- Measurement of the exponential time decay constant and numerical estimate of the worst case heat accumulation scenario (8h fills separated by 2h)
- Numerical estimate of worst case heat accumulation between successive fills
  $\Rightarrow$ Plateau at 100 deg C, with assuming a doubled beam intensity leads to twice the measured temperature



(C. Bracco)

$\Rightarrow$ Decision to remove water cooling on HL devices

Conclusion

In view of the increased beam intensity, some concerns were raised regarding the risk of failure of the TCDS absorbing blocks, in case of asynchronous beam dump.

- Several material block configurations were evaluated, simulating beam energy deposition maps and performing structural analysis simulations
- New configuration for the HL-LHC TCDS, with 6 blocks made of C-SiC, supported by previous HiRadMat tests:
  - Offers sufficient absorption capacity to ensure MSDs protection
  - Within the blocks, the max. energy densities in the blocks are considered acceptable
- Water cooling will be removed on the HL devices

Thank you for your attention