CLIC collimator survival

IWLC 2010

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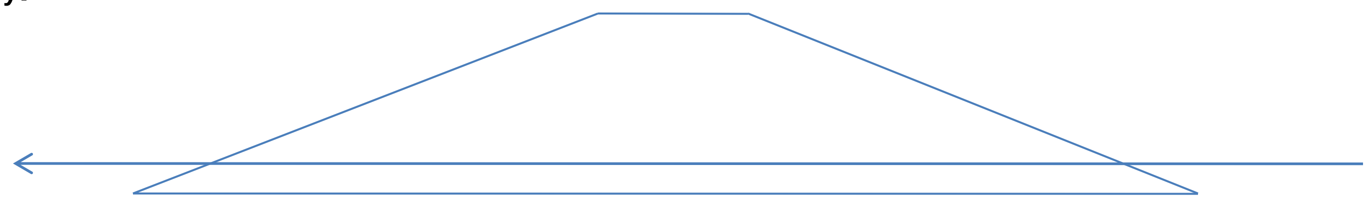
The collimator mission is to clean the beam halo from e- or e+ off orbit which could damage the equipment and mainly to stop the photons generated during the bending of the beam towards the Interaction Point. These photons, if not removed, would generate a noise background that would not allow the detectors to work properly.

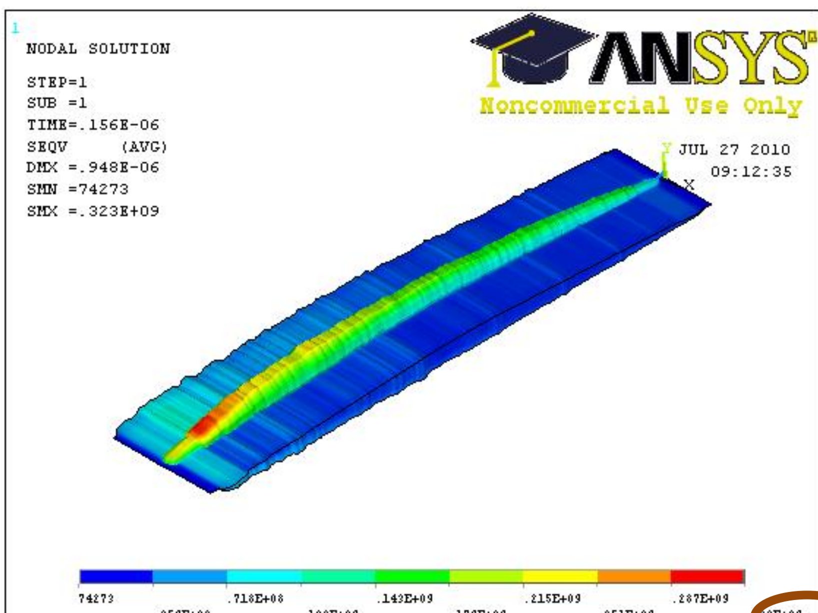
The spoiler serves as protection for the main collimator body as it will disperse the beam, reducing the beam energy density by multiple Coulomb scattering, in case of a direct bunch hit avoiding severe radiation damage.

	Energy spoilers	Betatron spoilers
Energy	1500 GeV	250/500 GeV
Bunches it has to resist	312	2/1
Particles per bunch	3.72E9	2E10
σ_x in the spoiler position	779.6 μm	5.064 μm/7.792 μm
σ_y in the spoiler position	21.9 μm	1.814 μm/0.831 μm
Material length needed to spoil beam	0.05 Xo	0.2 Xo

At IPAC 2010 I showed the resulting stress (using FLUKA and ANSYS) right after a CLIC bunch train has hit the spoiler at 0.2 mm from its bottom (or 4.29 mm from its top). Being the normal orbit of the beam at 8 mm from the bottom of the spoiler (3.51 from the top) that represents a deviation from normal orbit of **356σ_y**.

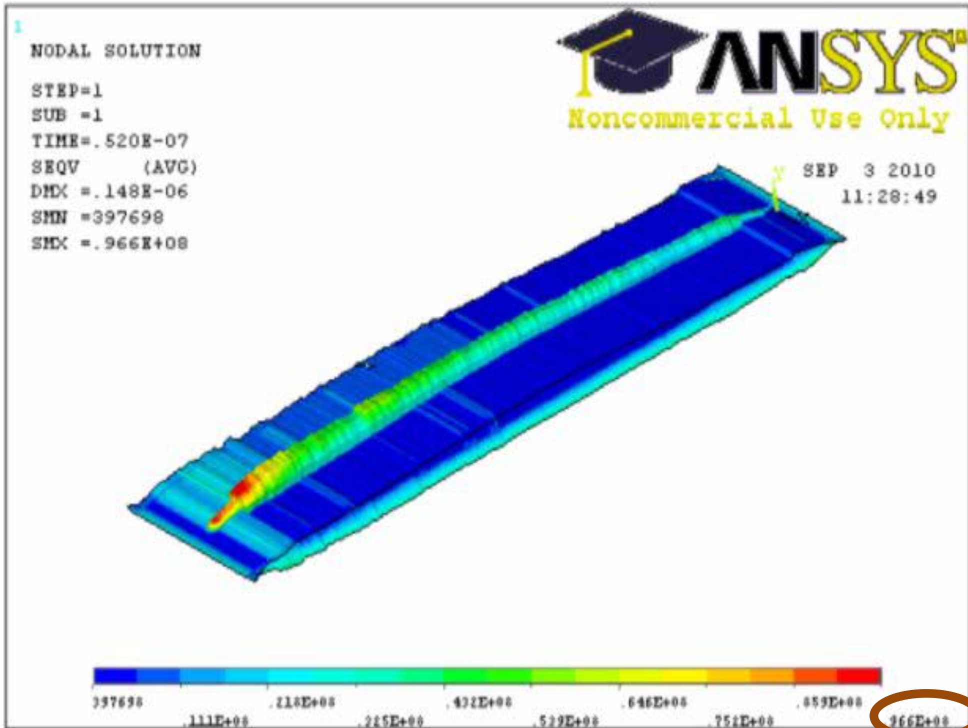


The results right after the time the bunch train has hit the spoiler, 156 ns, showed that there would be permanent deformation but not fracture.



~325MPa compressive stress

T_{melt} [K]	1560
Y [10^5 MPa]	2.87
α_T [10^{-6} K^{-1}]	11.3
σ_{UTS} [MPa]	370
ΔT_{fr} [K]	228
Yield Tensile Strength [MPa]	240
Yield Compressive Strength [MPa]	270
Specific Heat Capacity [J/g°C]	1.925
Density [g/cm^3]	1.844



I added then that I needed to let the ANSYS calculation go on, after the beam has hit the spoiler, to see if there would be any stress build up that could reach fracture levels. And…

…it kind of does.

950MPa, and tensile, which is way above tensile strength limit.

$$\sigma_{eq} = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}$$

T_{melt} [K]	1560
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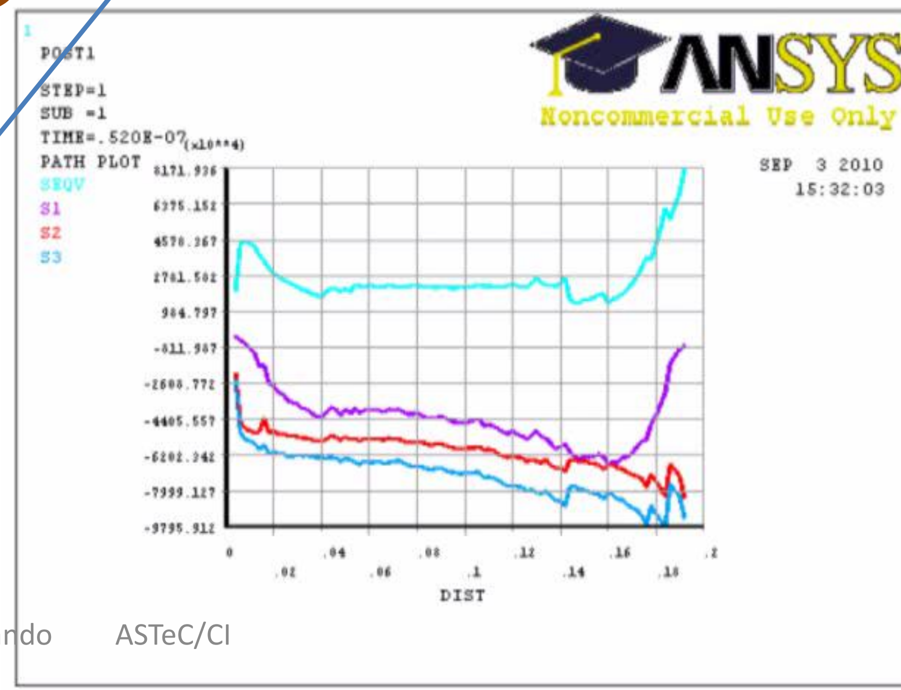
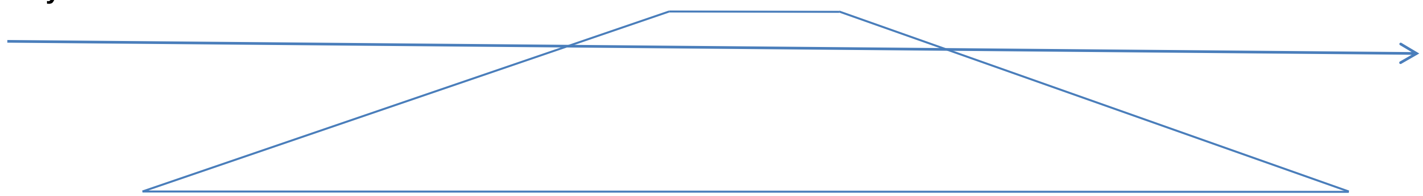
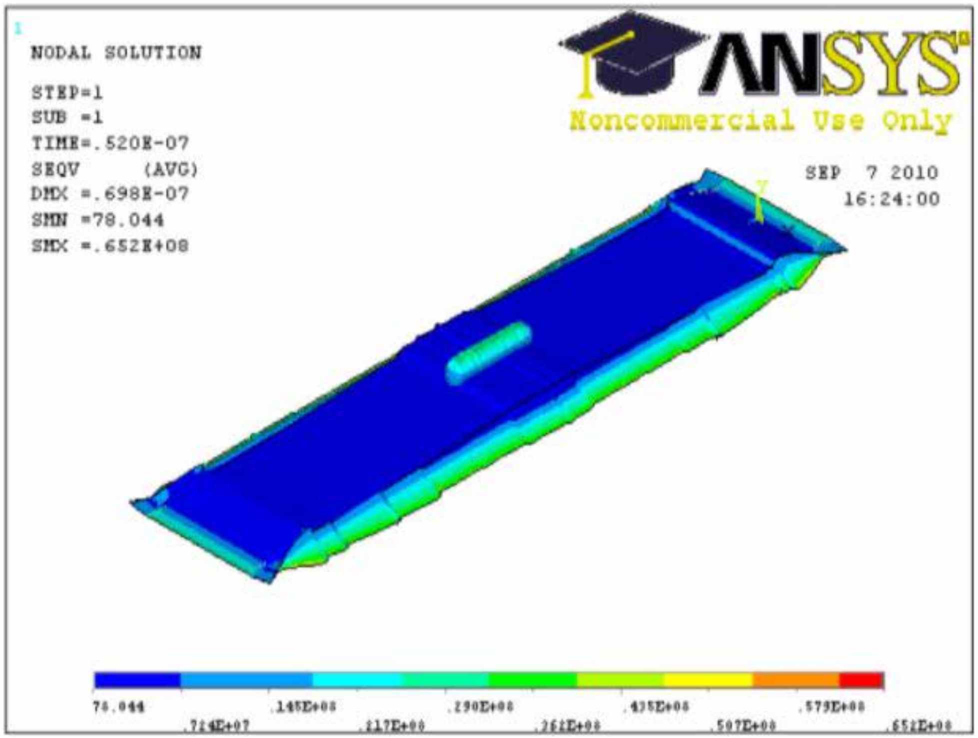


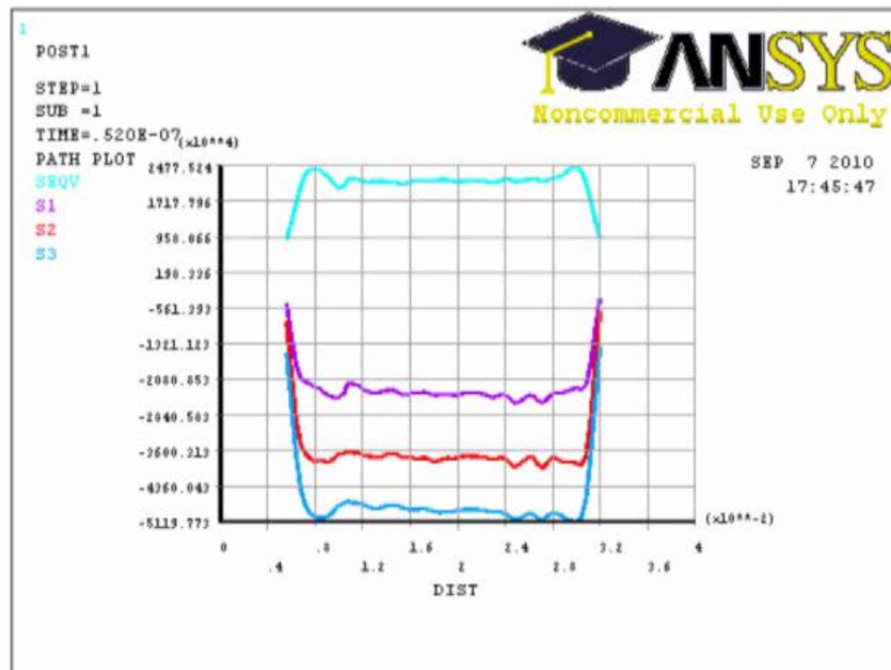
But… is a deviation of 356 sigmas even possible?

I have also calculated the stresses when the bunch train hits 0.2mm from the top instead of 4.29 mm (or 4.29 mm from the bottom instead of 0.2). Which means a deviation of “just” **169σ_y.**



The top value of stress is ~340MPa and compressive. Meaning that **there will not be fracture** but **there will be a permanent deformation**, and in this case it is a vertical deformation of 5 µm, which represents **a 0.1% of the half gap**. Can we live with that?

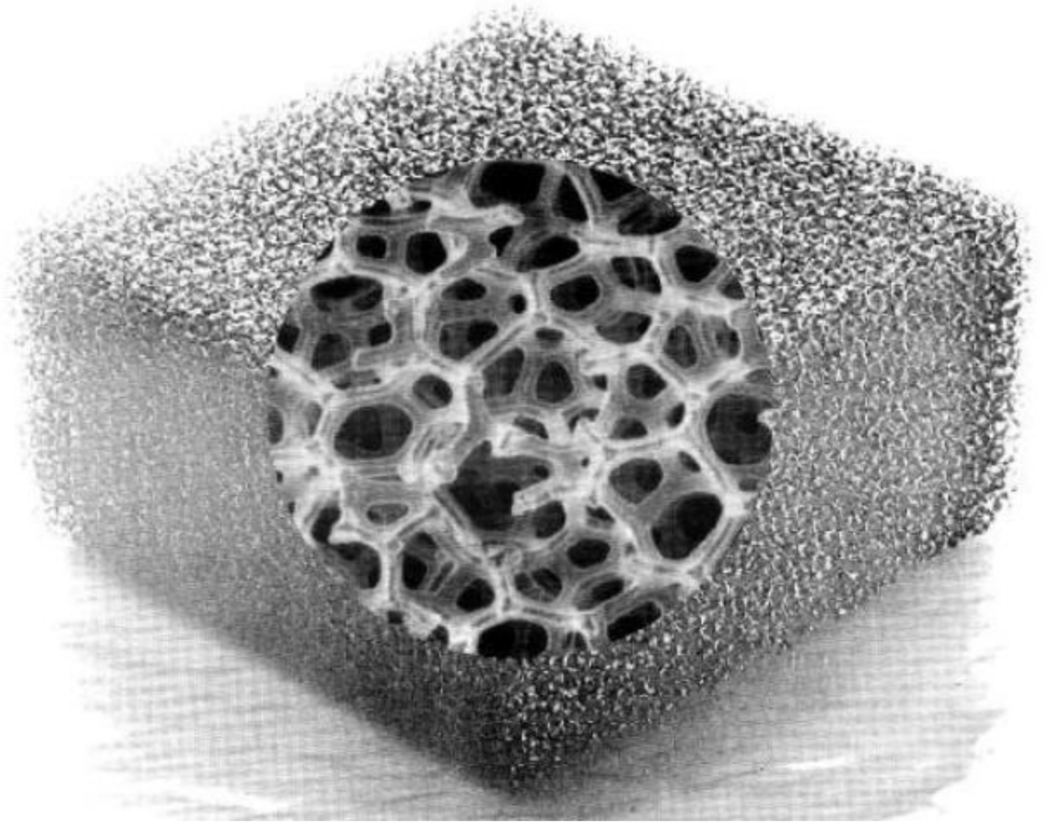




Silicon carbide (SiC) foam

SiC is a material with good thermomechanical properties. Used for LHC collimation phase 2, in F1 brakes, and aerospace applications.

It can be used as core material for CLIC spoilers, coated with metal (Be, Cu...)



Material	Radiation length Xo [cm]
Copper	1.44
Ti alloy	3.56
Beryllium	35.3
SiC (solid)	8.1
SiC (foam 8%)	337

Very long radiation length of the foam at 8% of nominal density allows for low energy deposition of the particle beam.

Pros and cons for using SiC foam as core material in CLIC energy spoilers covered by 0.05Xo (in the z direction) of beryllium:

Pros:

- It will not matter the depth the beam hits as it will always see 0.05Xo of beryllium (the contribution of the SiC foam can be negligible).

- Save some beryllium.

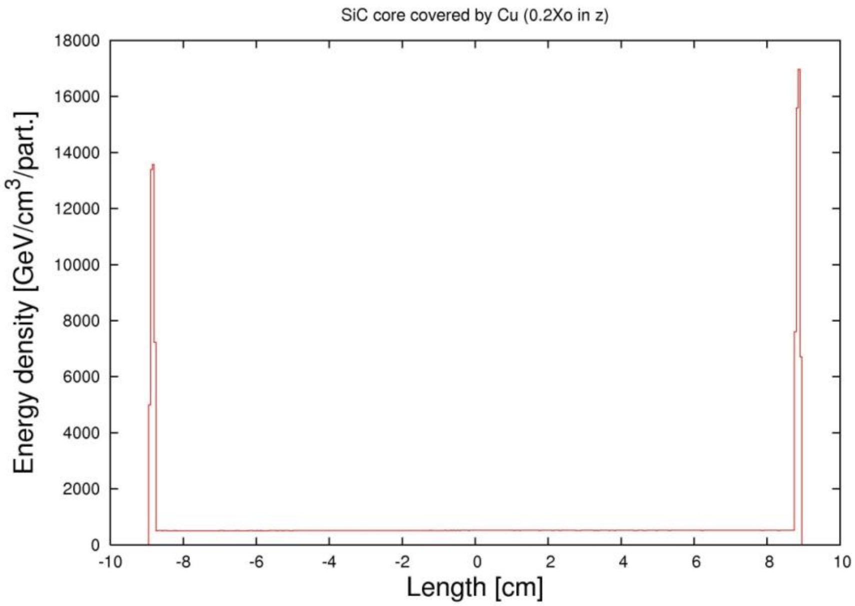
Cons:

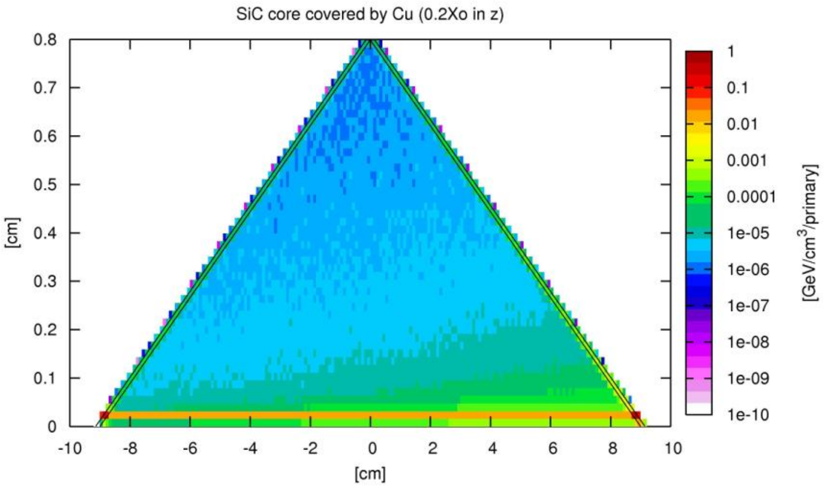
- The junction of two different materials is a complicate thing, mechanically speaking. The different thermal properties can lead to dislocation or fracture of the junction when the bunch train hits. A single material spoiler is more “whole” in that aspect.

The foam though, is a good option for **betatron spoilers** to reduce the radiation length budget as much as possible.

Betatron spoilers do not have to be survivable. Notice the much smaller beam sizes in their position compared to the energy spoilers ones (a factor ~100 in σ_x and ~20 in σ_y , and the fact that they need at least 0.2Xo of material to spoil the beam safely for the absorber (instead of 0.05Xo).

Any bunch train hit implies obliteration of the spoiler material. Therefore beryllium, due to its toxic nature, is discarded as spoiling material. The most obvious candidate would be **copper**.





Conclusions for the energy spoilers:

It would be very important to identify the failure modes and accident scenarios to know by how much the bunch train can be deviated from orbit as the energy spoiler design could perfectly withstand the worse case scenario… or not.

Studies on how to attach the spoiler to its mount are required to avoid concentration of tensions in the attached points.

Studies of using a SiC foam core would give us the maximum stress in the material junction and therefore tell us if it would survive a bunch train hit at any depth position.

If studies of accident scenarios reveal that the beam orbit cannot be deviated by more than ~170 σ's (could be more) then the full beryllium body would survive the impact of a bunch train.

Outlook for the energy spoilers:

Apart from the already mentioned: mechanical support, cooling and activation studies.

Conclusions for the betatron spoilers:

The small half gap, of 100 µm, makes the design very challenging.

There are studies of rotatable spoilers but as I see it any deformation generated by the bunch train could block the gap and avoid the rotation.

Also, circular spoilers do not insure 0.2Xo of material at any given depth.

The mechanical stability of the support system has to be flawless.

What happens with the melted material blown into the vacuum vessel?

Outlook for the betatron spoilers:

Imagine options. Nobody wants to be a CLIC betatron spoiler...