FUTURE
CIRCULAR
COLLIDER

DESIGN STUDIES AND HIRADMAT TEST FOR THE FCC-EE BEAM DUMP SYSTEM

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FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

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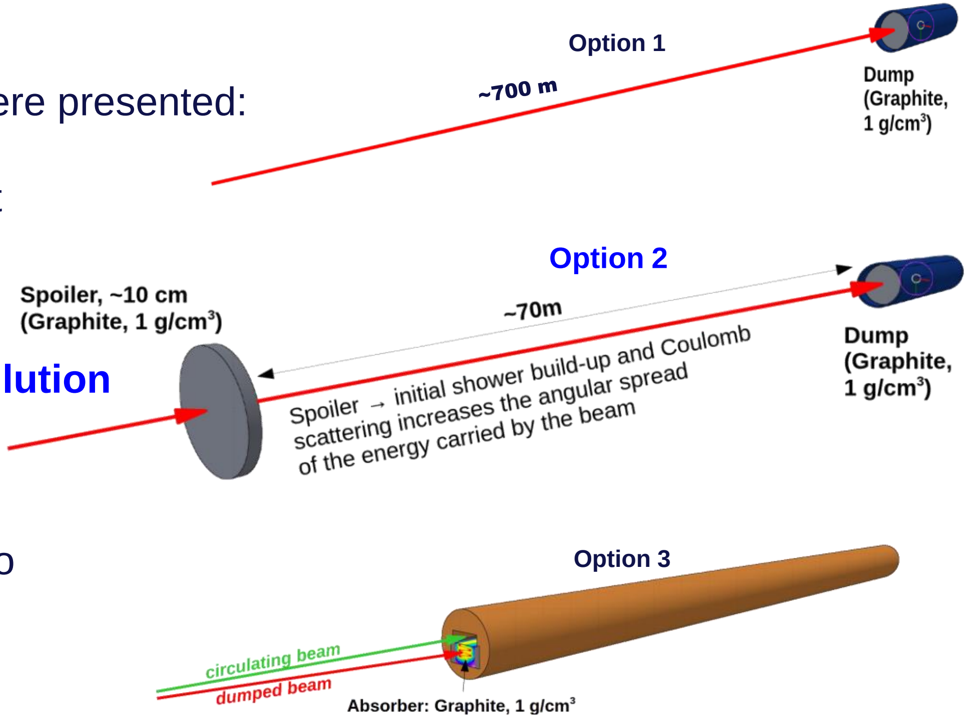
FCC-Week 2019

At FCC-Week 2019, 3 alternatives to the CDR were presented:

- Option 1: Blow up beam with defocusing triplet
  and ~700 m of drift space.
  (β-function ~5000 km at Dump)

- **Option 2: Use a Spoiler for passive beam dilution**
  and ~70 m of drift space.
  (β-function ~400 km at Spoiler)

- Option 3: Use an internal beam dump similar to
  the SPS with active dilution system.



FCC-Week 2019:
https://indico.cern.ch/event/727555/contributions/3452829/

Challenges concerning the FCC-ee beam

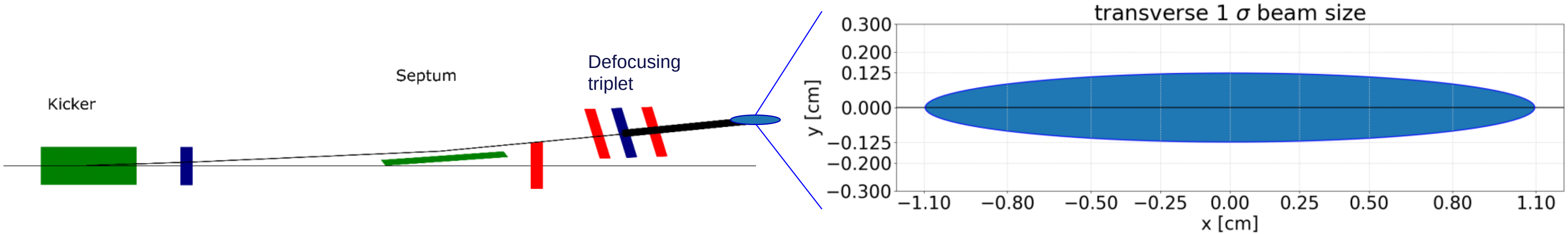
	Z	WW	ZH	$t\bar{t}$	
Beam Energy [GeV/pp]	45.6	80	120	175	182.5
Bunch population [10^{11}]	1.7			2.2	2.3
Bunches / beam	16640				
Stored energy / beam [MJ]	20.6				
Average bunch spacing [ns]	19.6				
Horizontal emittance ε_x [nm] Vertical emittance ε_y [pm]	0.27 1.0				
Horizontal β_x^* [m] Vertical β_y^* [mm]	0.15 0.8	0.2 1.0	0.3 1.0	1.0 1.6	

Beam spot @ IP:
$\sigma_x \approx 6$ µm
$\sigma_y \approx 28$ nm

Energy Density @ IP:
40 MJ / µm²

Compared to LHC:
$\sigma_{x,y} \approx 20$ µm

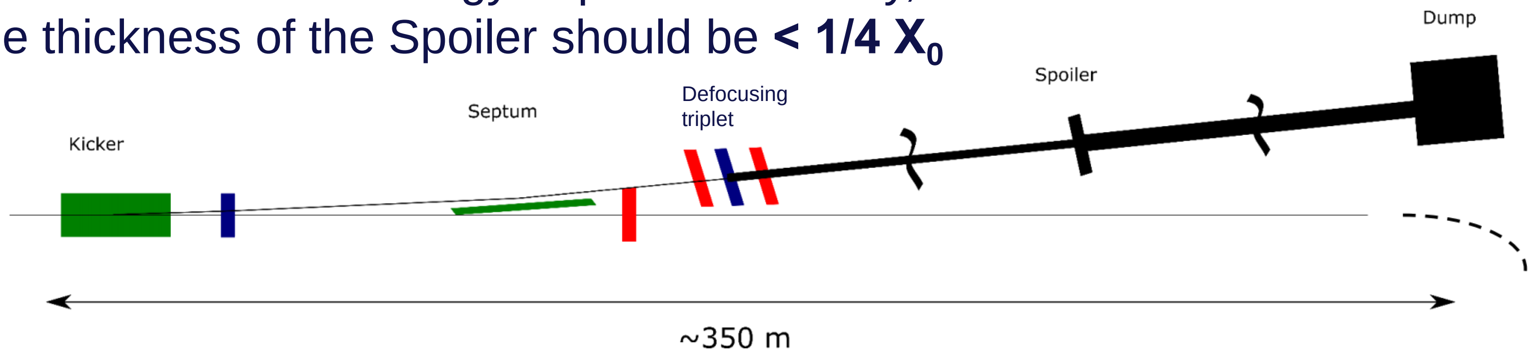
~0.3 MJ / µm²



Optimization together with Wolfgang Bartmann and Salim Ogur from CERN / ABT-BTP

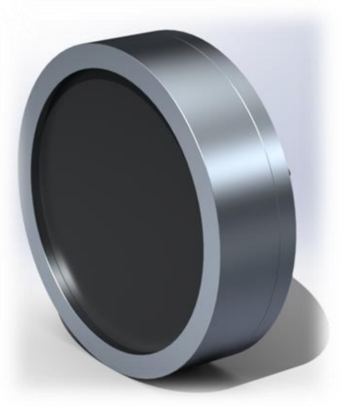
Passive Beam Diluter Concept

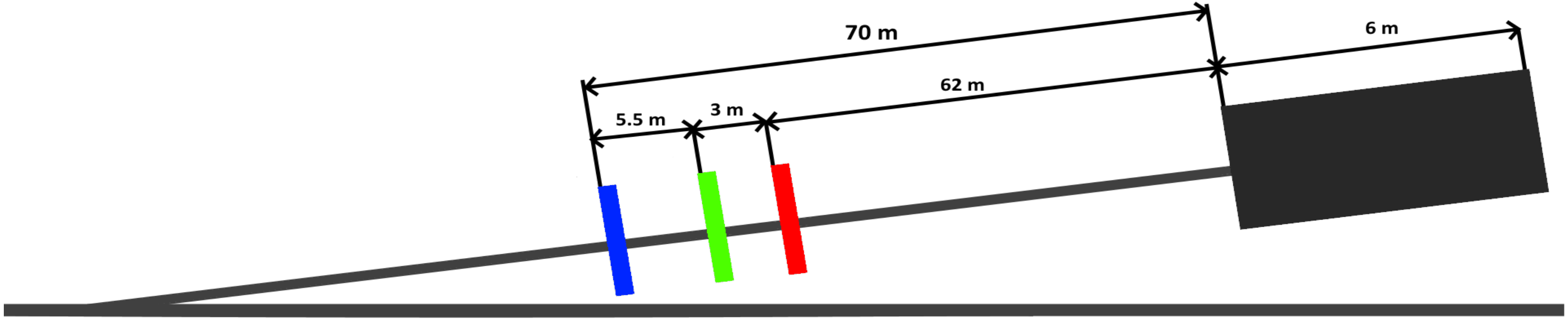
- Dilution of the beam due to elastic scattering (multiple coulomb scattering) and shower build-up (bremsstrahlung, ionization losses)
- All of these mechanisms are related to the radiation length X_0
- Bremsstrahlung and ionization losses contribute to energy deposition in the Spoiler.
- To avoid too much energy deposition density, the thickness of the Spoiler should be **< 1/4 X_0**



Design study with 3 consecutive spoilers

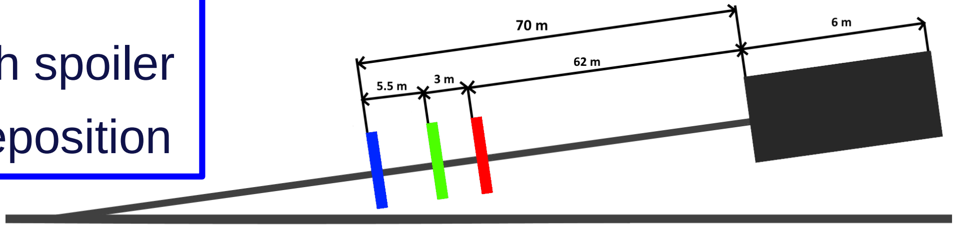
- High density (1.7-1.8 g/cm³) graphite
- 3 cm thick
- 15 cm diameter
    - Corresponding to > 7σ horizontally
- Aluminium support

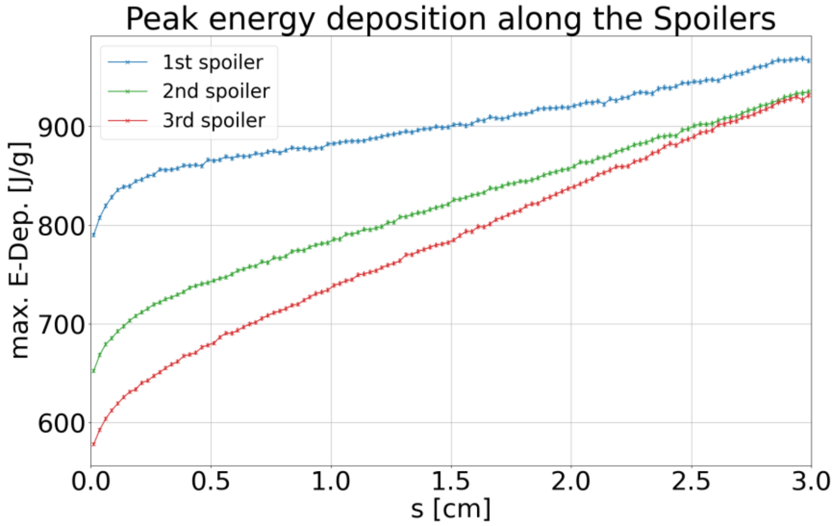


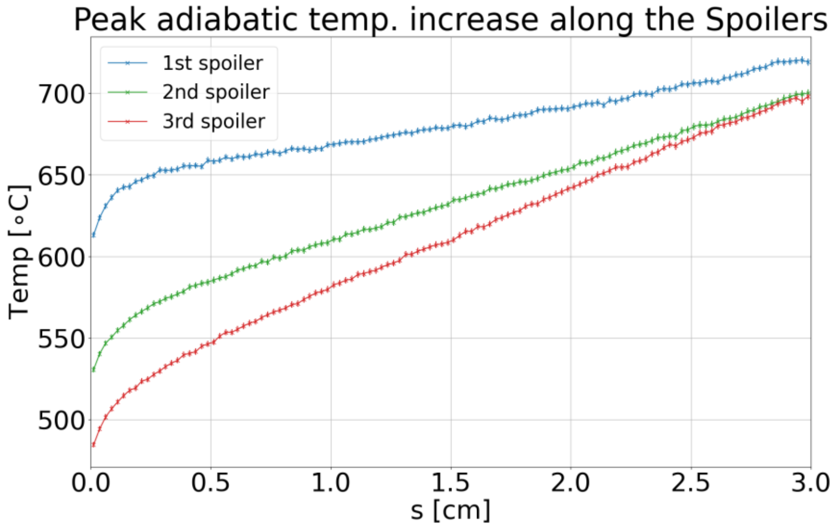


Design study with 3 consecutive spoilers

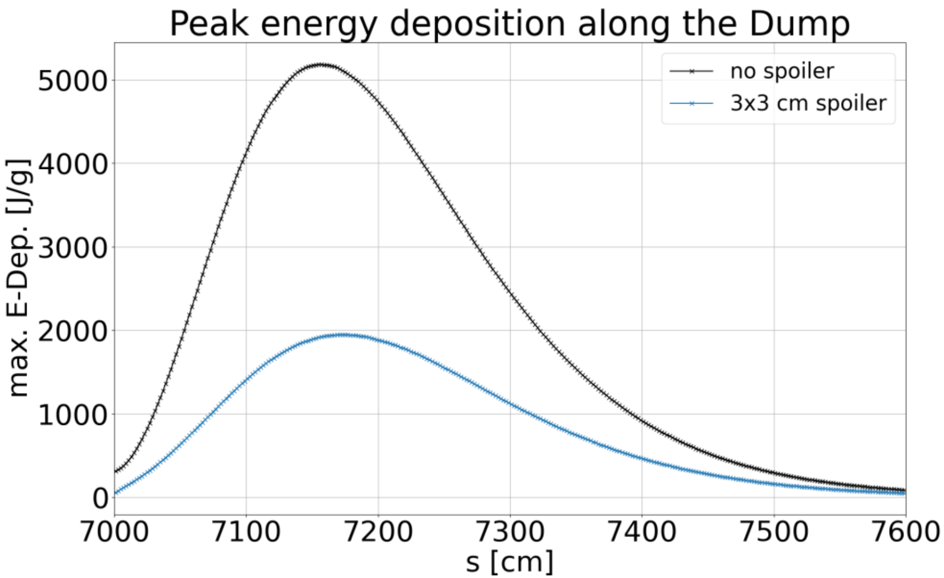
- 3 consecutive 3 cm thick spoilers
- Reduced energy deposition in each spoiler
- Spacing for similar peak energy deposition

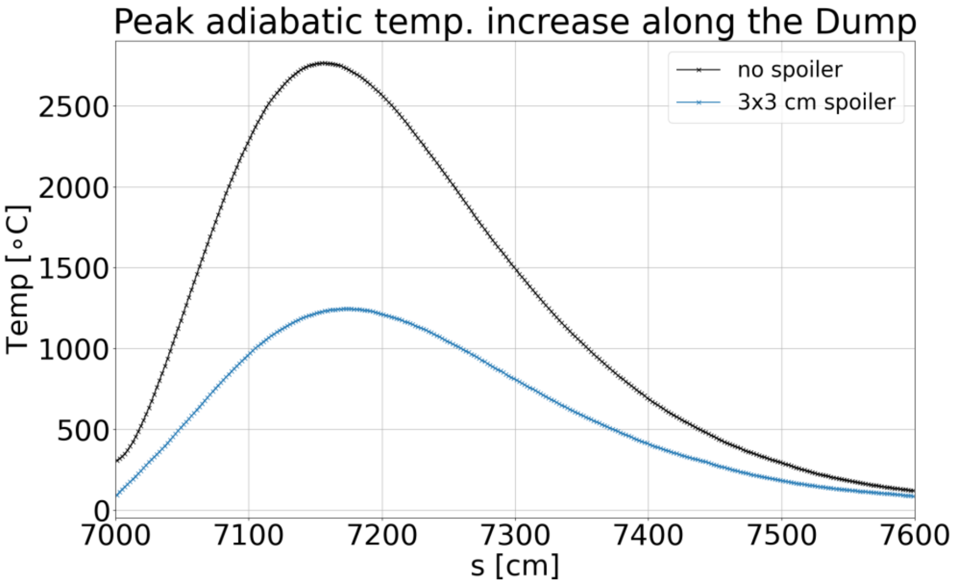






Design study with 3 consecutive spoilers

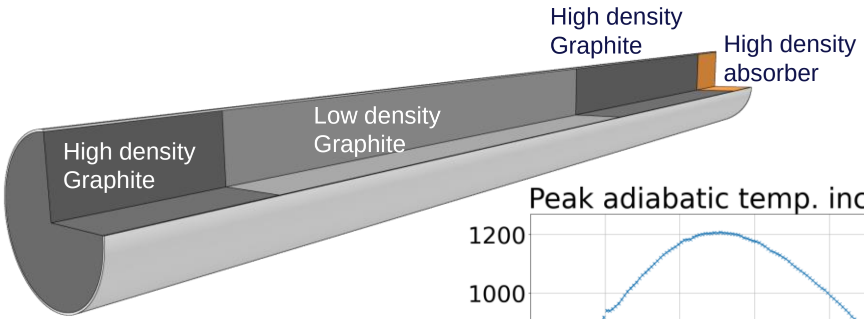


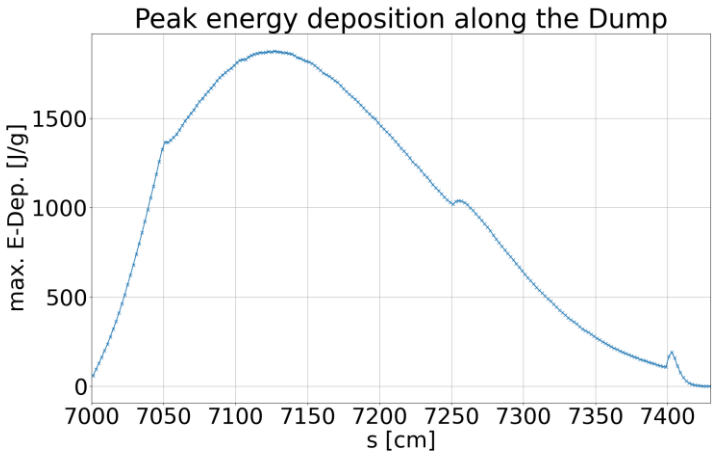


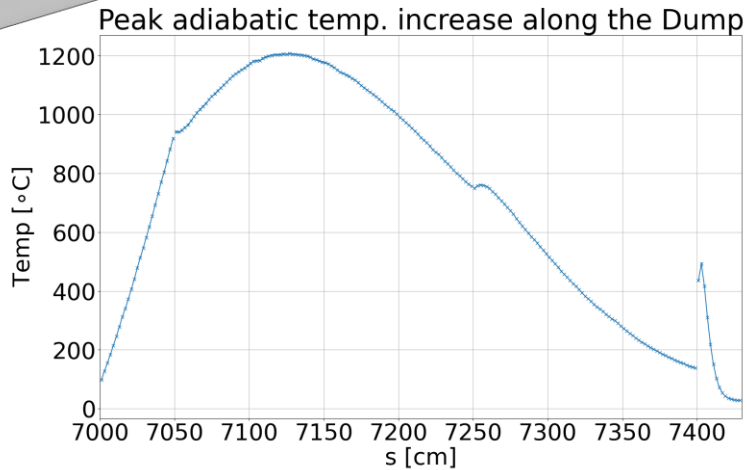
assuming a 6 m long low density graphite block

The FCC-ee Beam Dump Core

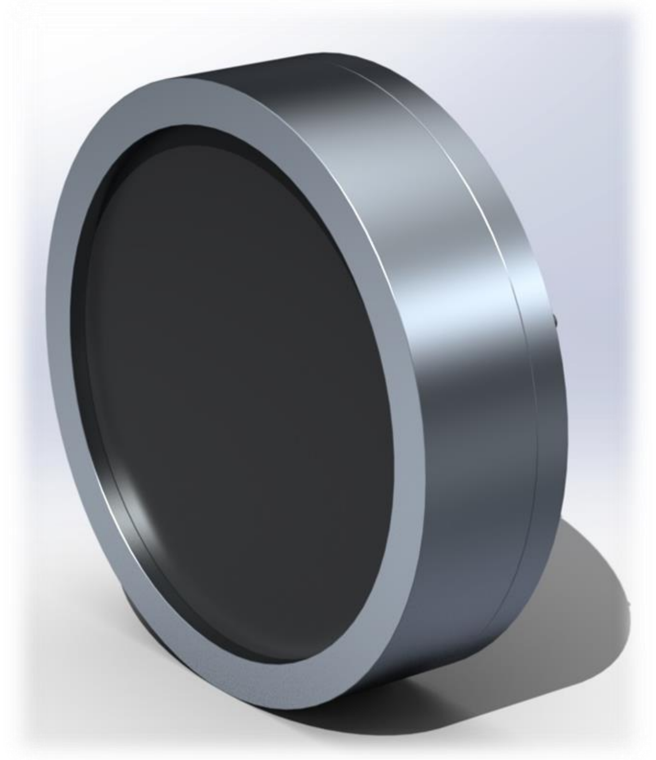
- Similar approach as the LHC Dump
- Multiple sections with different densities for the Dump core
- Exact choice of materials will also rely on findings for the Hi-Lumi Dump upgrade







The Spoiler Design



Choice of material

Requirements

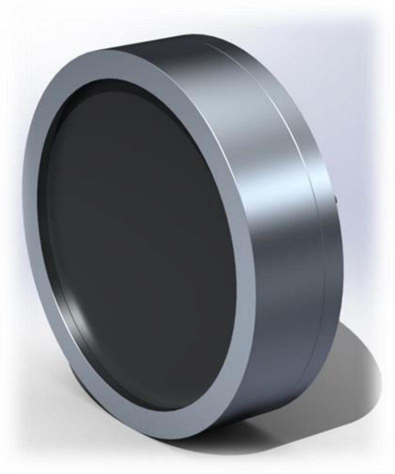
- Low Z material
- High melting point
- High specific heat
  - Over a wide temperature range
- Mechanical strength

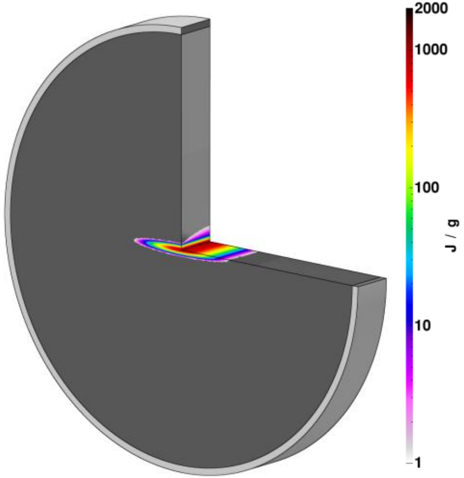
Isotropic Graphite

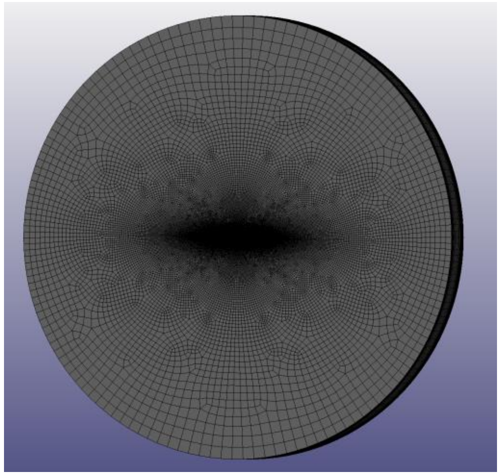
Carbon/Carbon Composites

Thermomechanical simulations

- Energy deposition from FLUKA
- Finite Element Analysis
- ANSYS and LS-Dyna are used for thermomechanical simulation
- Detailed material model with all relevant properties







Thermomechanical simulations

The Christensen Failure Criterion

- For brittle materials, the von-mises stress is not a good indicator for material failure.
- Here the Christensen criterion is a much better representation for likelihood of material failure.
(The Theory of Materials Failure, Richard M. Christensen)

$$\left(\frac{1}{T}-\frac{1}{C}\right)(\sigma_1+\sigma_2+\sigma_3)+\frac{1}{2TC}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]\leq 1$$

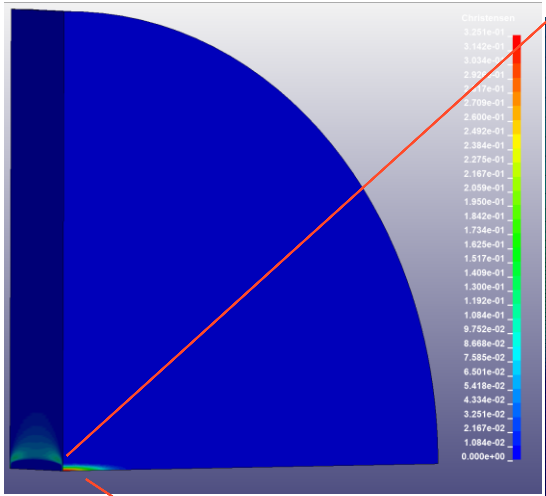
$$\sigma_i < T$$

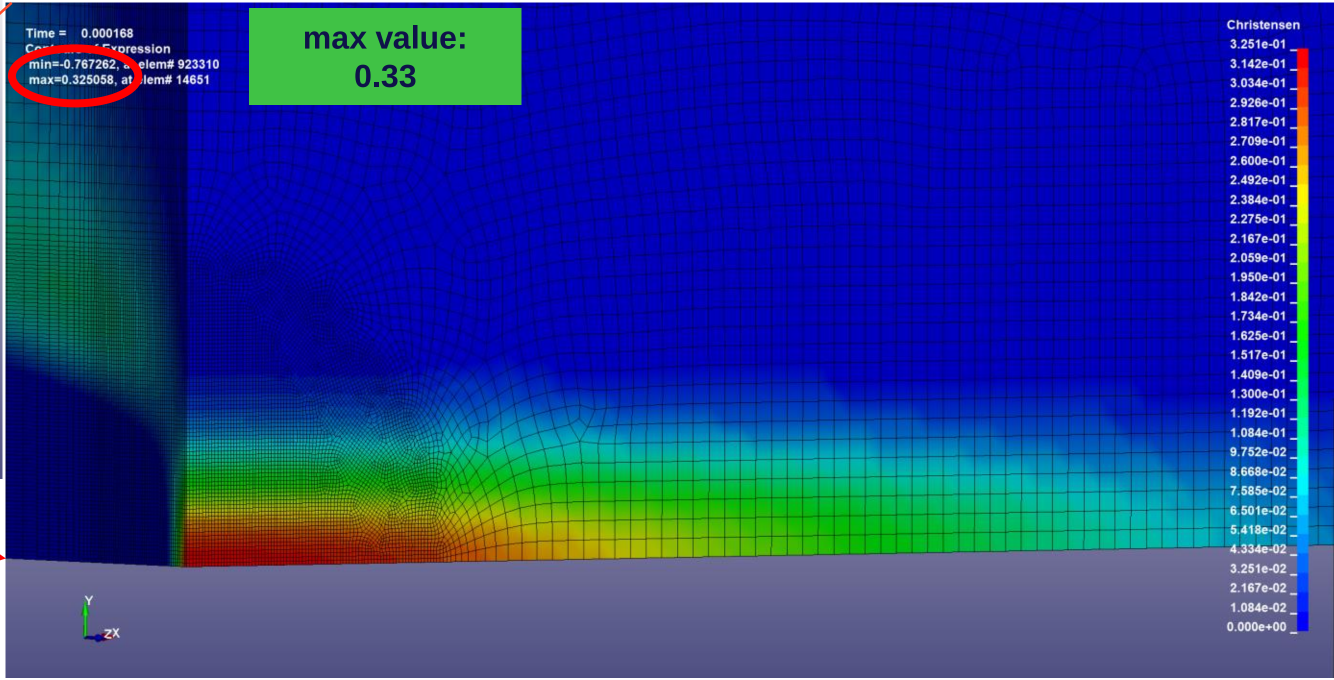
For isotropic graphite
(conservative estimate)
C = 120 MPa
T = 40 MPa

Where **C** is the maximum compressive strength
and **T** is the maximum tensile strength
Values > 1 show material failure

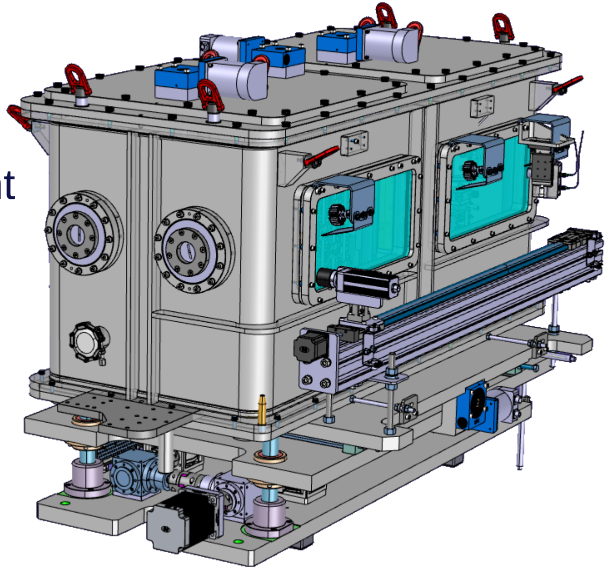
Thermomechanical simulations

Christensen Failure Criterion in LS-Dyna





HiRadMat HRMT56-HED



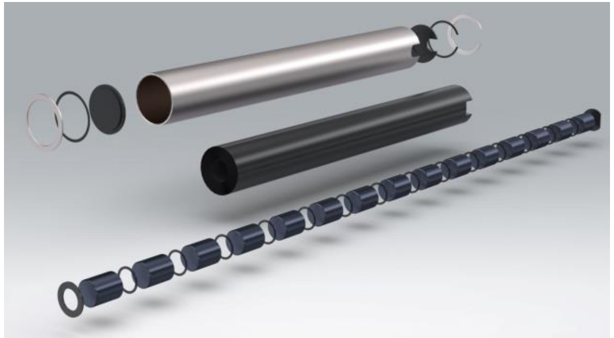
- November 2021
- High Radiation to Material – High Energy Dump experiment
- Multiple targets for testing:
  - Design of the existing LHC Dump
  - Materials for the HL-LHC Dump
  - Materials for the TCDQ and TCDS for the HL-LHC upgrade
  - **Test for the FCC-ee Spoiler**
- In total 35 different targets
- Key experiment for insights into high energy impacts on graphite materials.

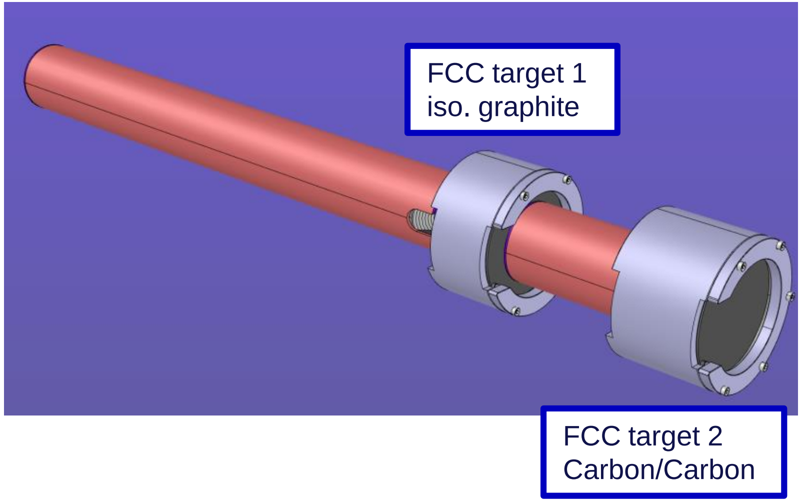
HRMT56 FCC-ee setup

- HRMT56 experiment to verify the validity of the simulations.
  - Especially important since testing with an FCC-ee style beam is not possible.
- HiRadMat beam parameters are chosen to reproduce the mechanical stresses expected from an impact with the FCC-ee beam.
  - A 450 GeV proton beam of **σ = 2.2 mm x 0.25 mm** is used for the experiment.
- To increase the deposited energy in the target, a pre-target material is used to create shower build-up.
- This material needs higher density than the target as well as a high melting point to survive the beam impact.

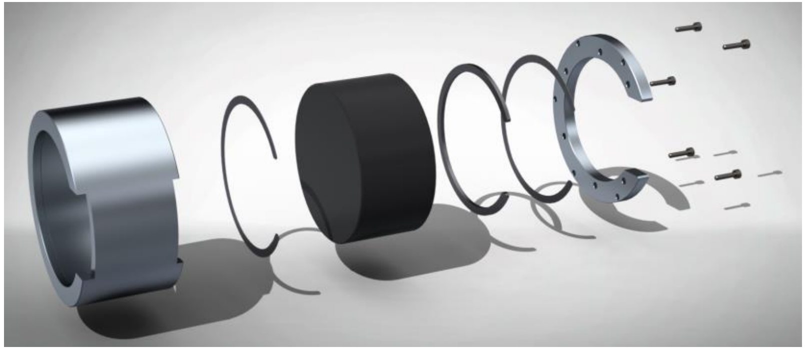
HRMT56 FCC targets

Pre-Target
Titanium-Carbide (TiC)
Density of ~4.84 g/cm^3
Melting point of ~3100 °C



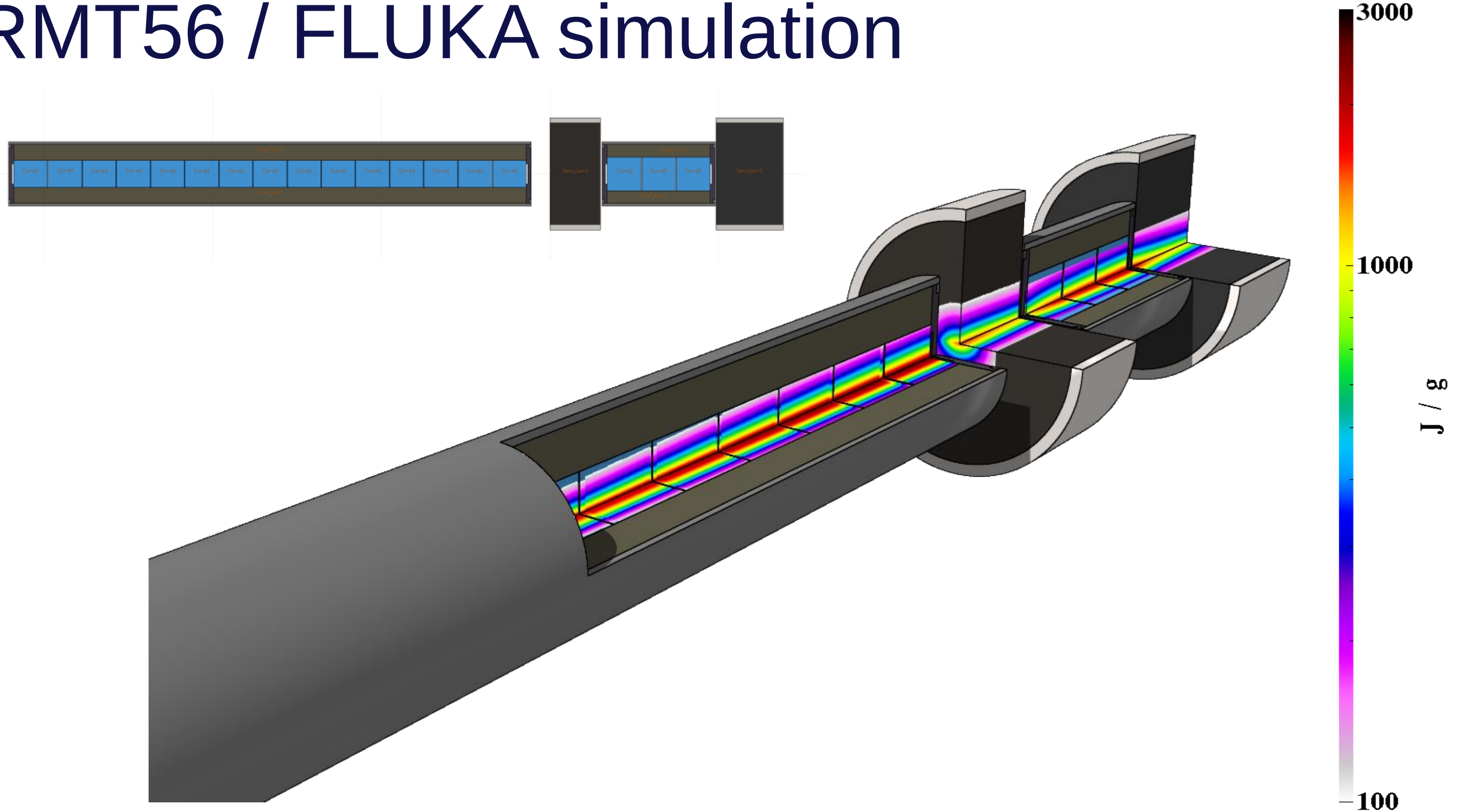


Targets
Scaled Model of the FCC-ee Spoiler design
Isotropic Graphite and Carbon/Carbon are tested

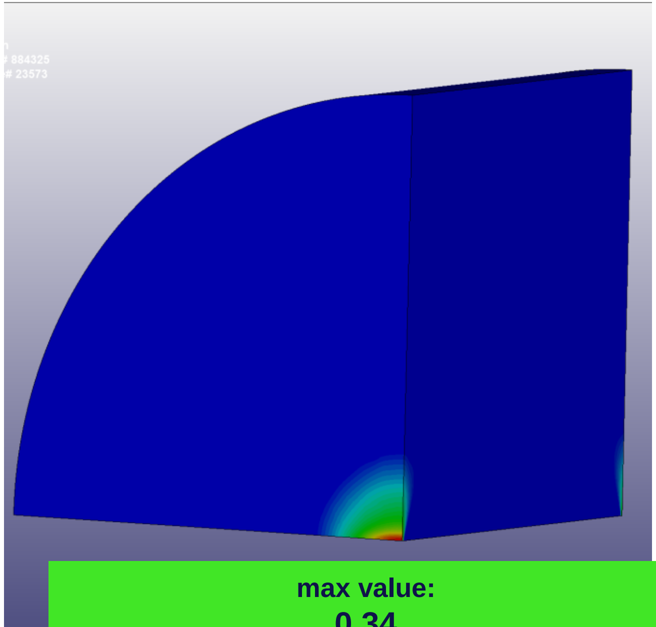


HRMT56 / FLUKA simulation

Beam



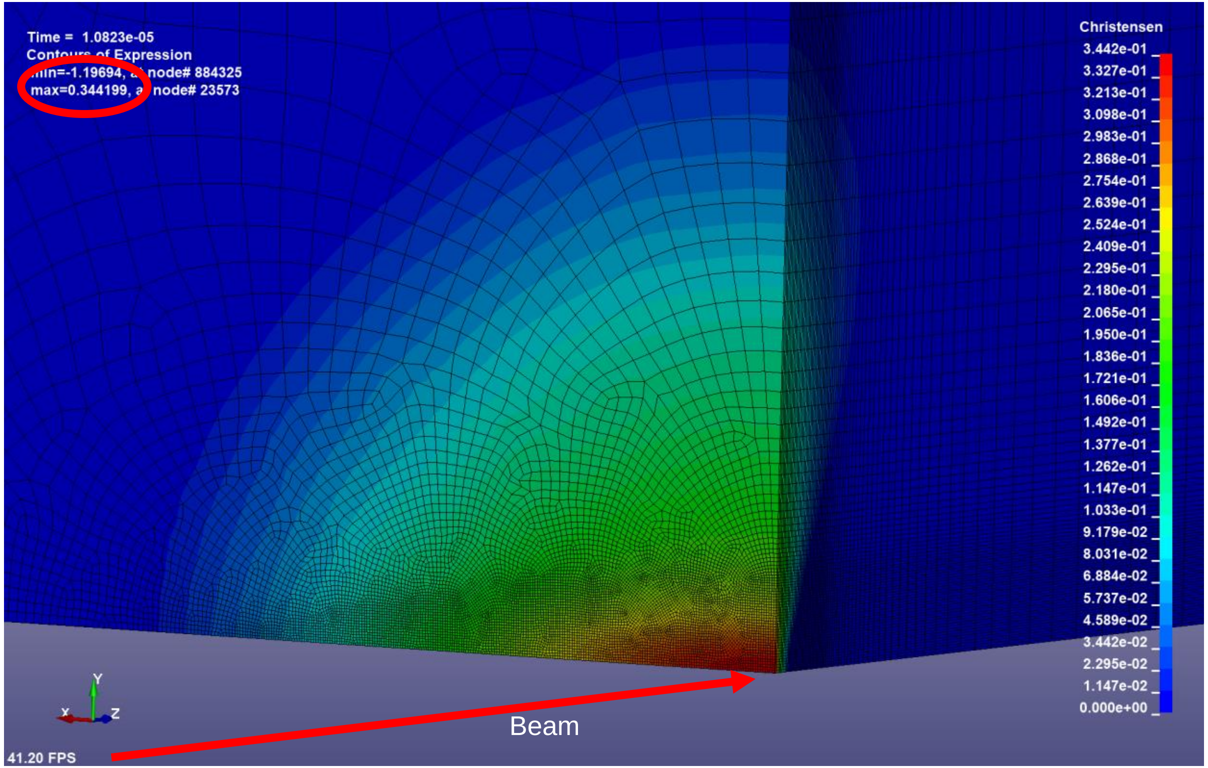
HRMT56 / LS-Dyna simulation



max value:

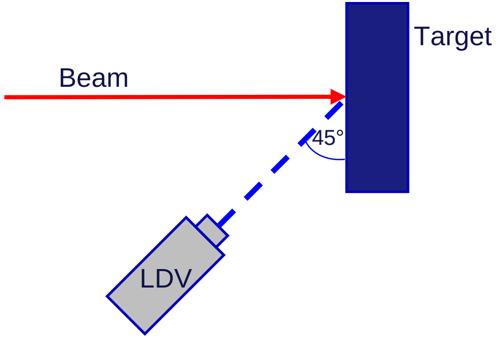
0.34

Similar to the FCC-ee Spoiler simulation

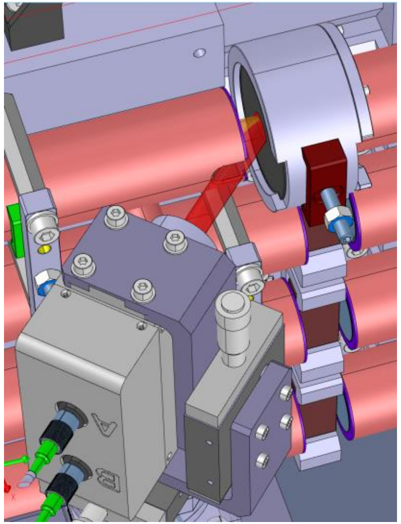


Instrumentation for HRMT56

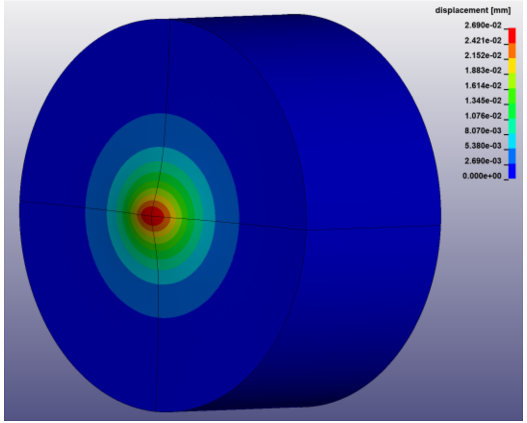
- To verify that the simulations correctly reproduce the thermal expansion and resulting stresses on the surface of the target, special instrumentation is needed.
- Strain gauges do not have a good enough resolution and cannot be placed directly in the beam trajectory.
- To measure this during and after the beam impact directly at the impact spot is possible by using a **Laser Doppler Vibrometer** (LDV).
- The LDV can measure with a time resolution of 0.4 us (2.5 MHz) and a displacement resolution of less than 1 nm.



Instrumentation for the FCC target



- Displacement is correlated to strain
- Surface displacement and velocity are simulated and can be directly compared
- Gives good indication if material model and simulations are correct
- Pre and Post irradiation examinations will be done as well (i.e. micro tomograpy, raman spectroscopy, etc.)
    - To see if there are micro cracks or other material defects



Summary

- Because of the challenging beam parameters even a relatively low energy electron beam needs a sophisticated dumping system.
- Passive dilution is possible with spoilers made from graphite.
  - Spoilers experience high surface stresses.
- To mitigate stresses in the spoiler optimizations have been carried out.
  - The beam profile has been adapted in the extraction line.
  - Multiple thin spoilers show better stress behavior than one big spoiler.
- No long extraction tunnel needed.
- No active high frequency dilution needed.

Summary

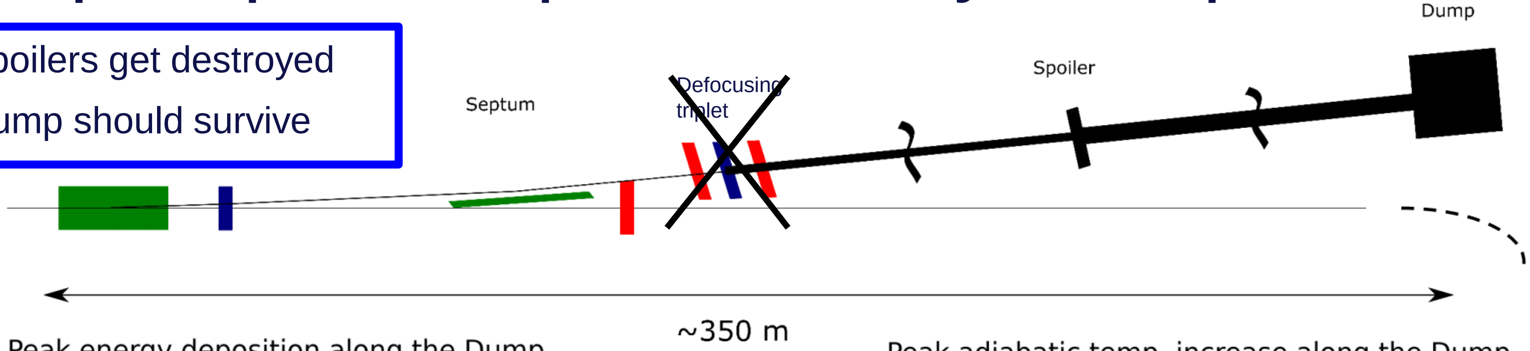
- Experimental study of a passive beam diluter for FCC-ee is ongoing
- HRMT56-HED should provide enough data to verify the simulations and give an estimate on the safety factor for the Spoiler
- This should also provide insights into the possibility of testing FCC-ee components in the HiRadMat facility.

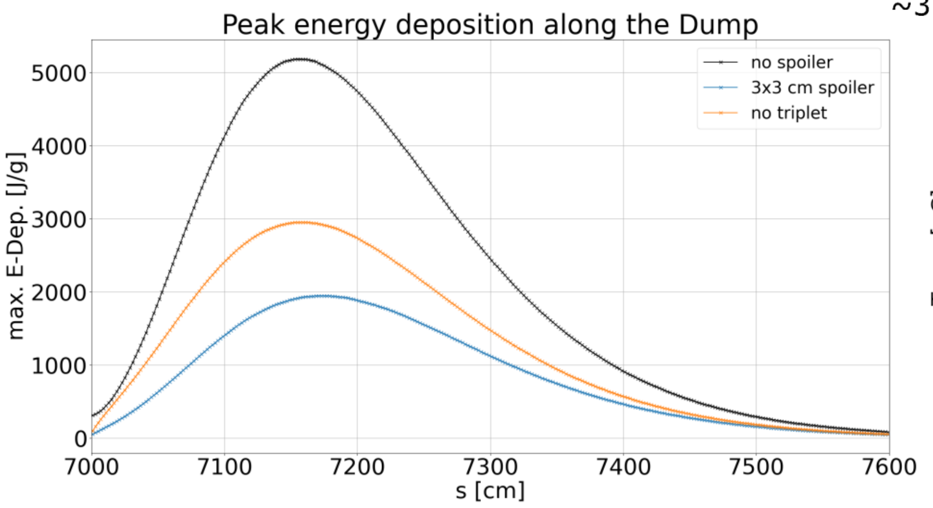
Thank you
for your attention.

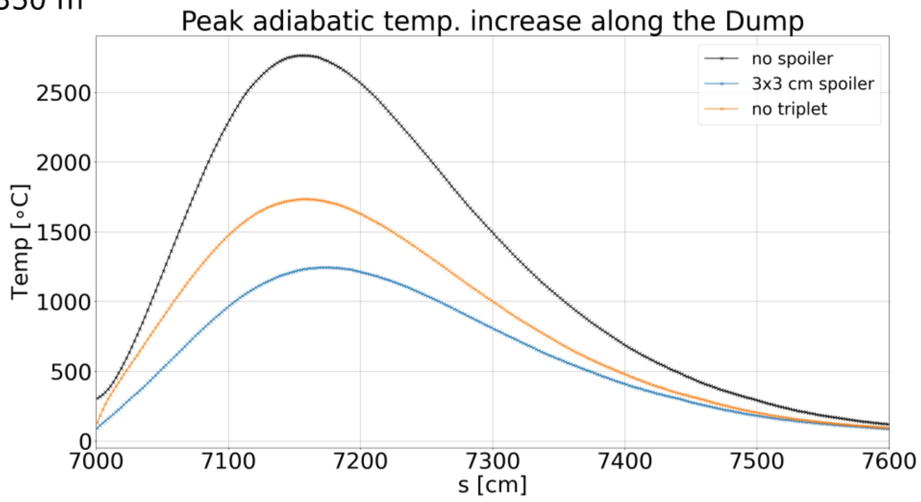
BACKUP

No triplet, passive protection by the Spoiler

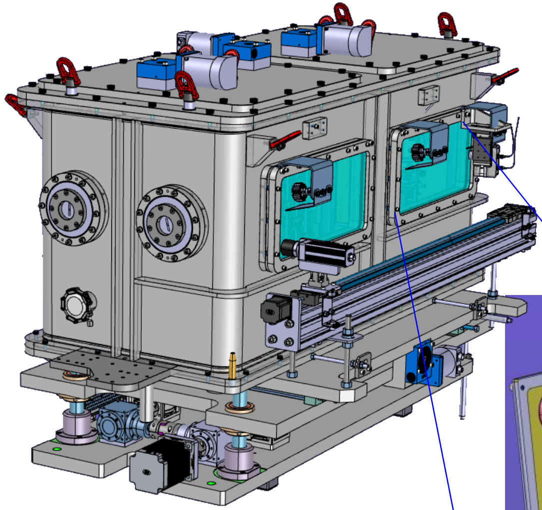
- Spoilers get destroyed
- Dump should survive

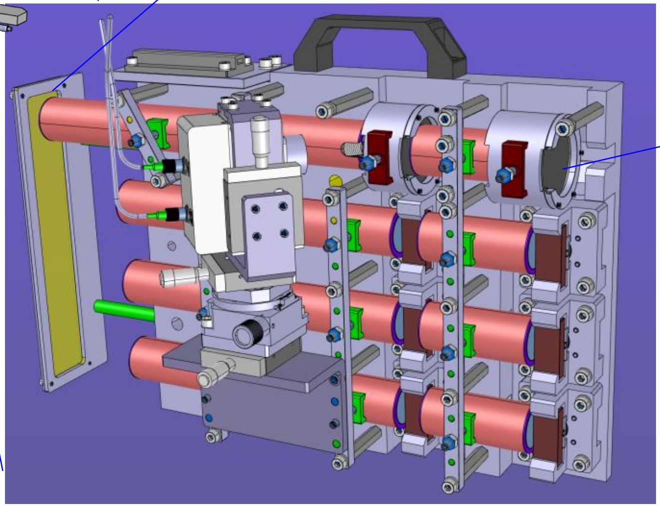


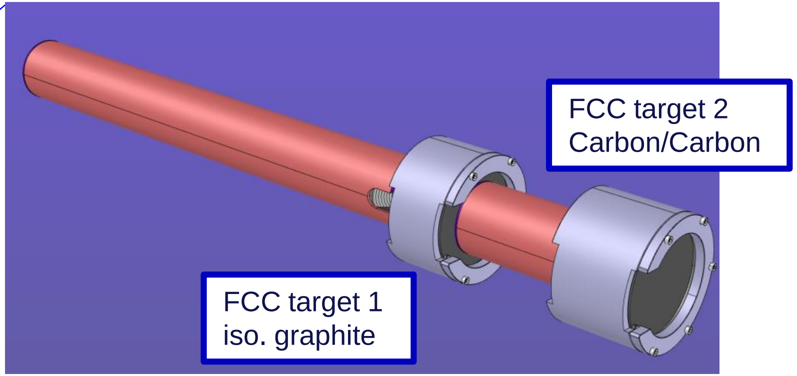




HiRadMat HRMT-56







Outlook

- Determine the exact design and placement of the Dump and the integration in the straight section.
- Determine access requirements for the area surrounding the Dump and estimate shielding requirements.