FUTURE CIRCULAR COLLIDER

THE FCC-EE BEAM DUMPING SYSTEM

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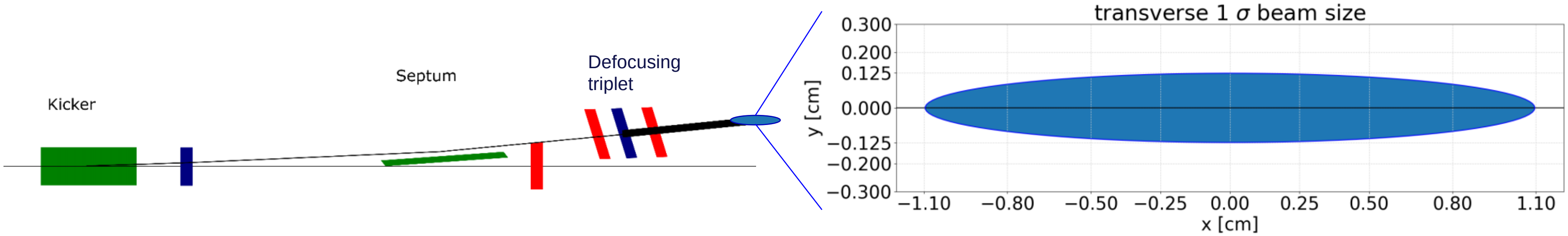
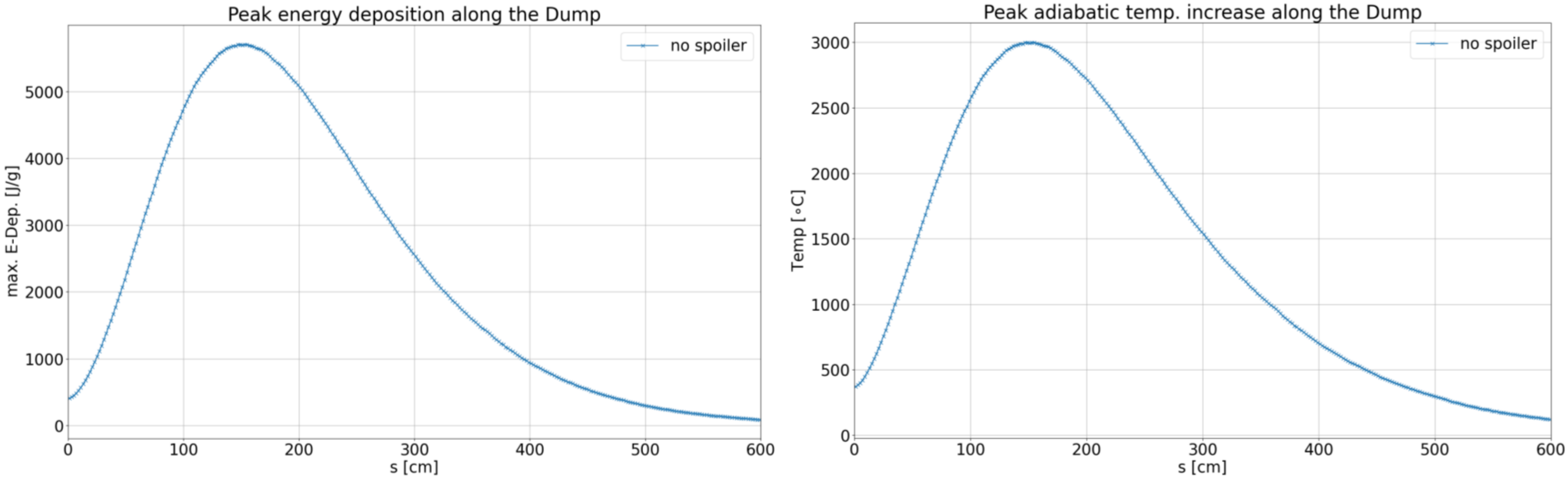
Challenges concerning the FCC-ee beam

	Z	Z, New Layout (4 IPs)	ZH	$t\bar{t}$	
Beam Energy [GeV/pp]	45.6	**45**	120	175	182.5
Bunch population [10^{11}]	1.7	**2.76**	1.8	2.2	2.3
Bunches / beam	16640	**8800**	328	59	48
Stored energy / beam [MJ]	20.6	**17.5**	1.13	0.36	0.32
Horizontal emittance ε_x [nm] Vertical emittance ε_y [pm]	0.27 1.0	**0.71** **1.42**	0.63 1.3	1.34 2.7	1.46 2.9



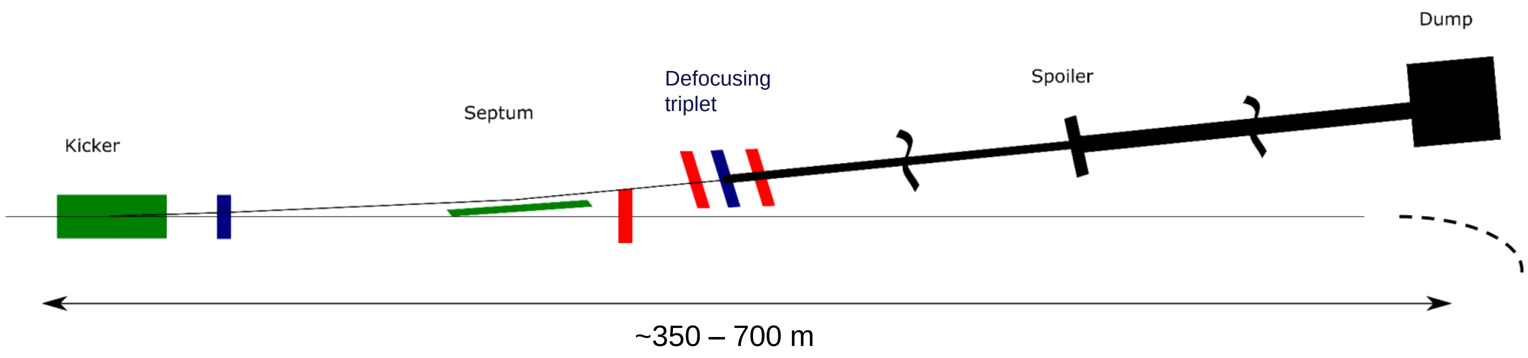
Peak Energy Deposition, with triplet, no dilution



assuming a 6 m long 1.0 g/cm^3 graphite block

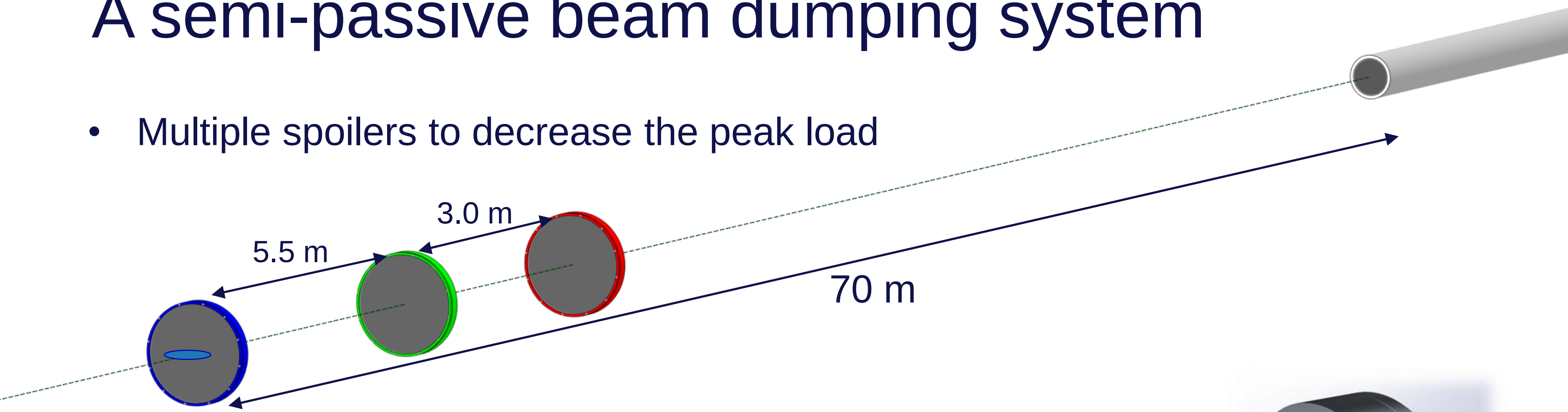
Passive Beam Diluter Concept

- Dilution of the beam by multiple coulomb scattering and Bremsstrahlung energy losses
- Bremsstrahlung-induced shower build-up contributes to the energy deposition in the Spoiler.

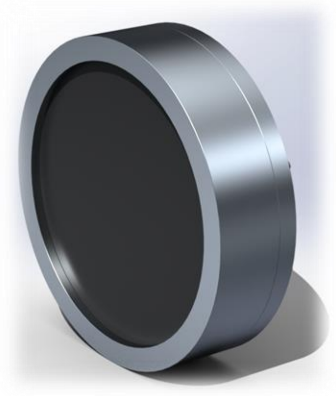


A semi-passive beam dumping system

- Multiple spoilers to decrease the peak load

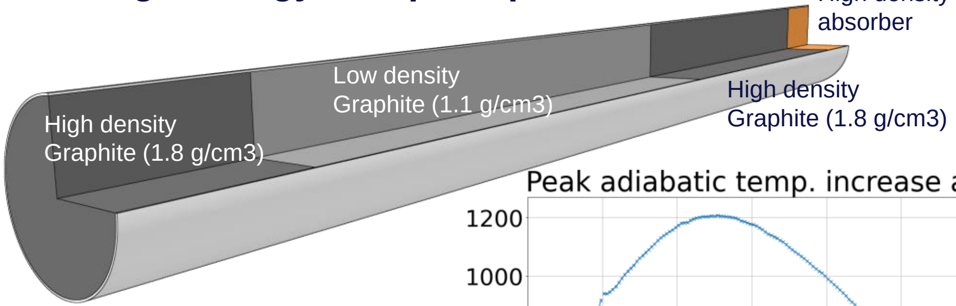


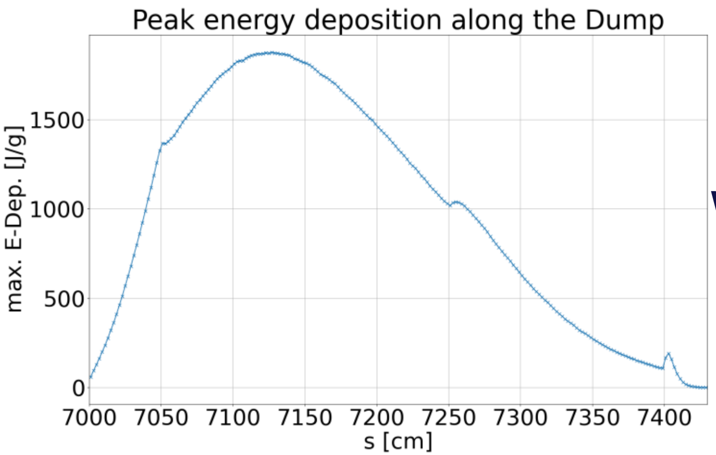
- High density (1.7-1.8 g/cm^3) graphite
- 3 cm thick
- 30 cm diameter
  - Corresponding to ~15 σ horizontally
- Aluminium support



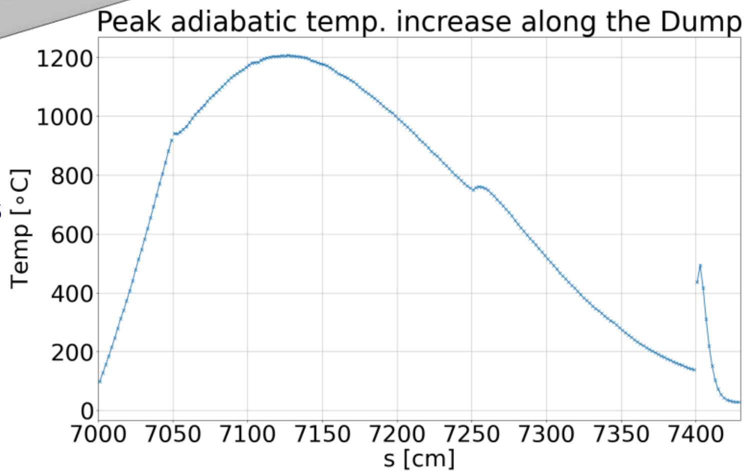
The FCC-ee Beam Dump Core

- Similar approach as the current LHC Dump
- Multiple sections with different densities for the Dump core
- **Design and material choice to be optimized following the findings of the HiRadMat High Energy Dumps Experiment**



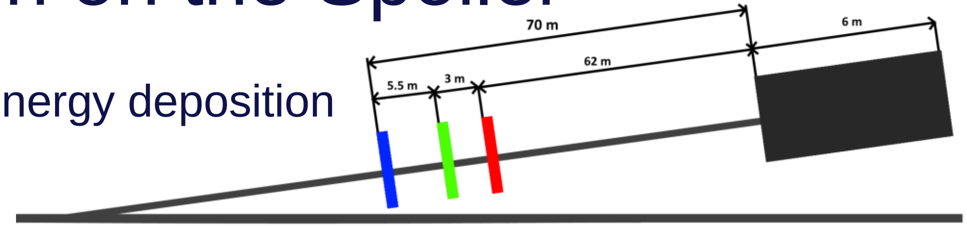


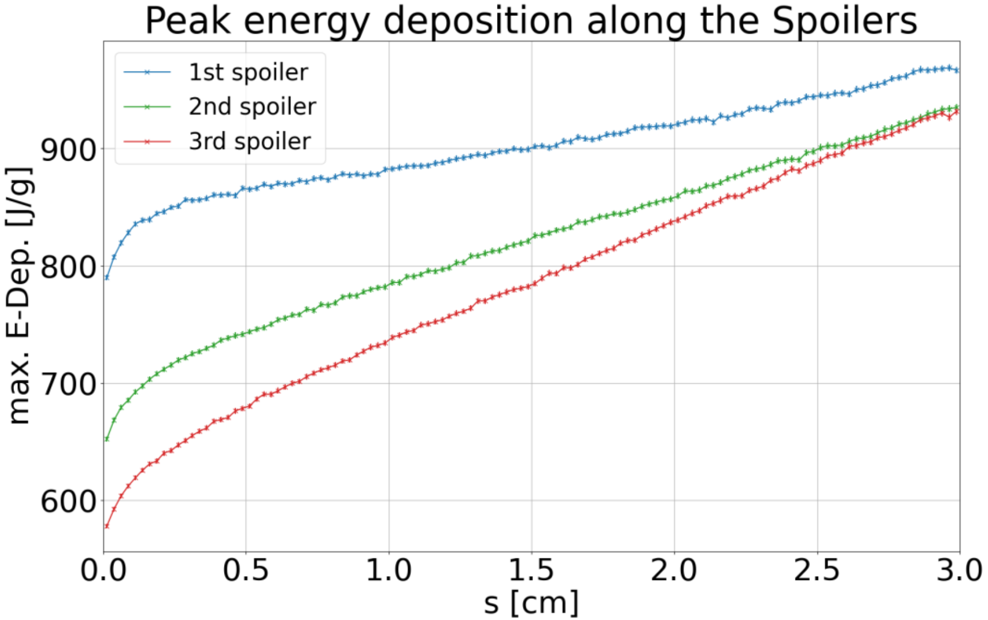
with triplet and 3 spoilers

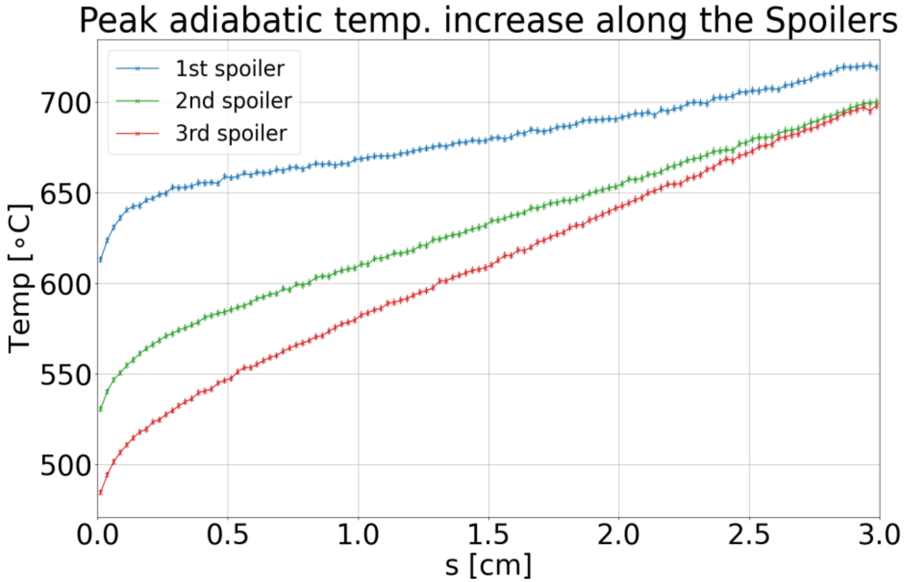


Peak energy deposition on the Spoiler

- Spoiler spacing to reach similar peak energy deposition

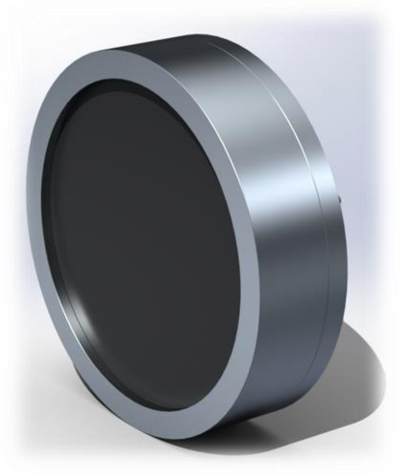


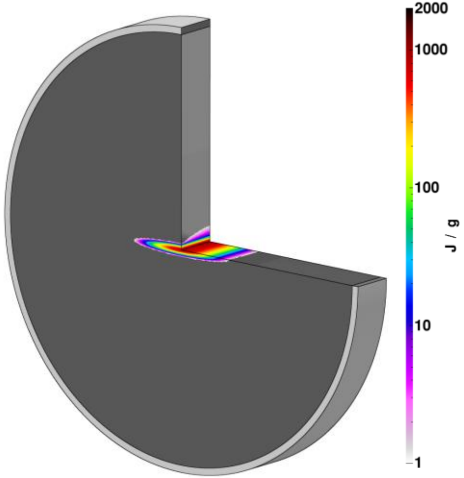


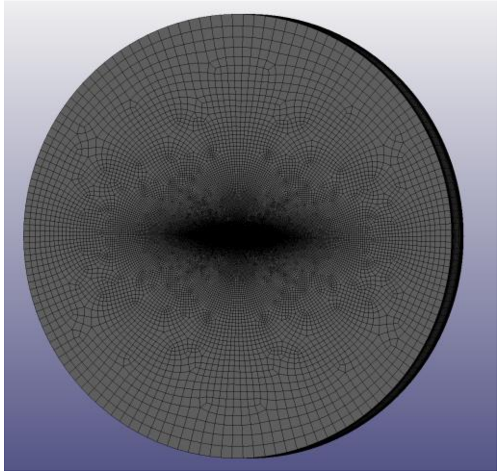


Thermomechanical simulations

- Energy deposition from FLUKA
- Finite Element Analysis
- LS-Dyna tight-coupled thermomechanical simulations
- 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)

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

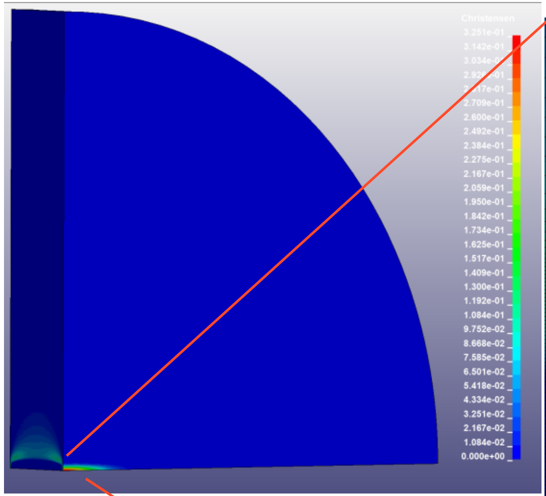
$$\sigma_i < T$$

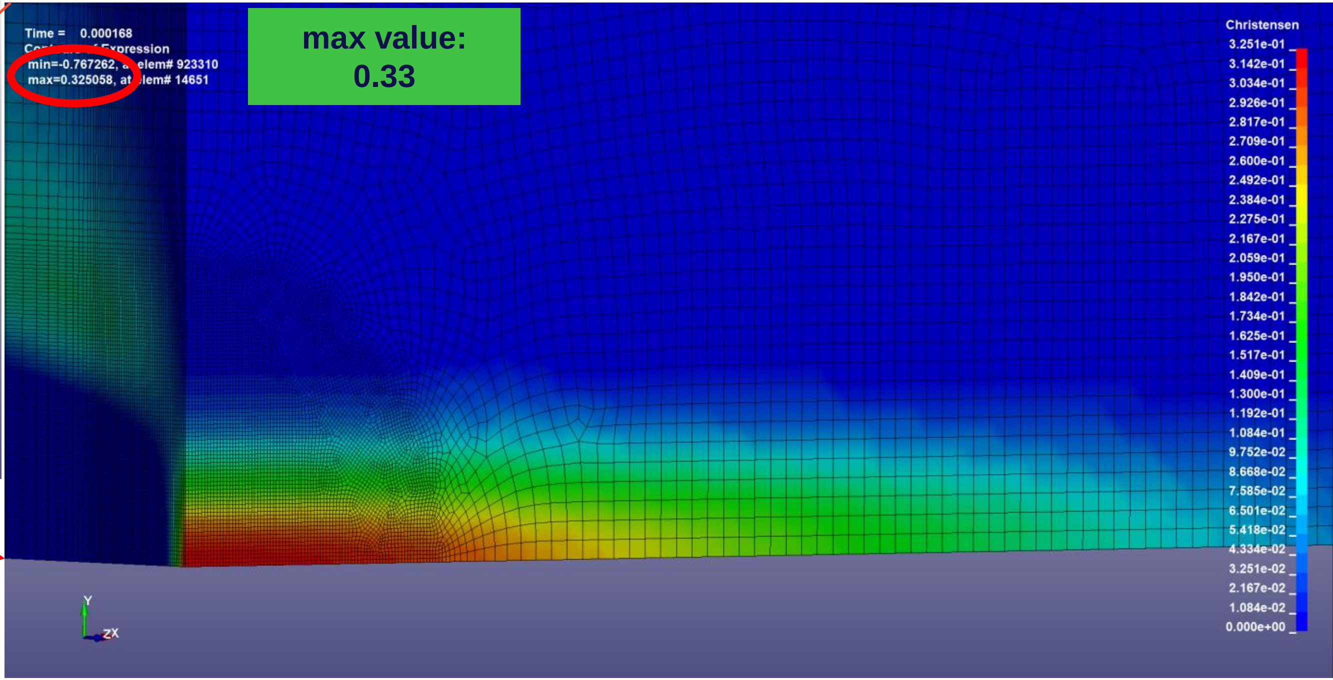
For SGL R7550, isotropic graphite (conservative estimate)
C = 120 MPa
T = 40 MPa

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

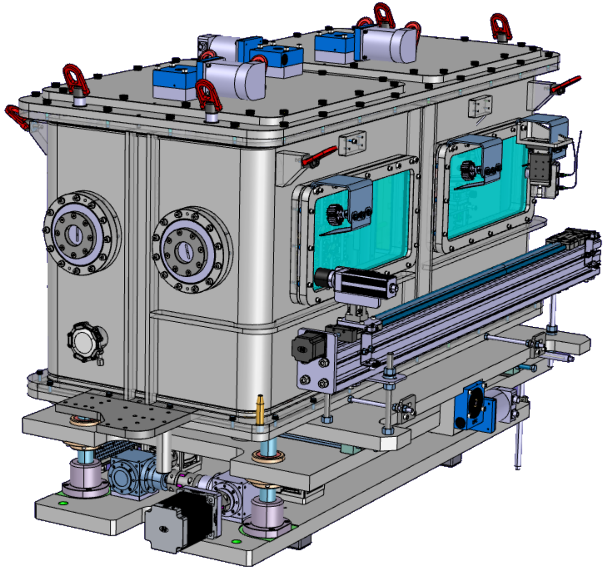
Thermomechanical simulations

Christensen Failure Criterion in LS-Dyna





HiRadMat HRMT56-HED

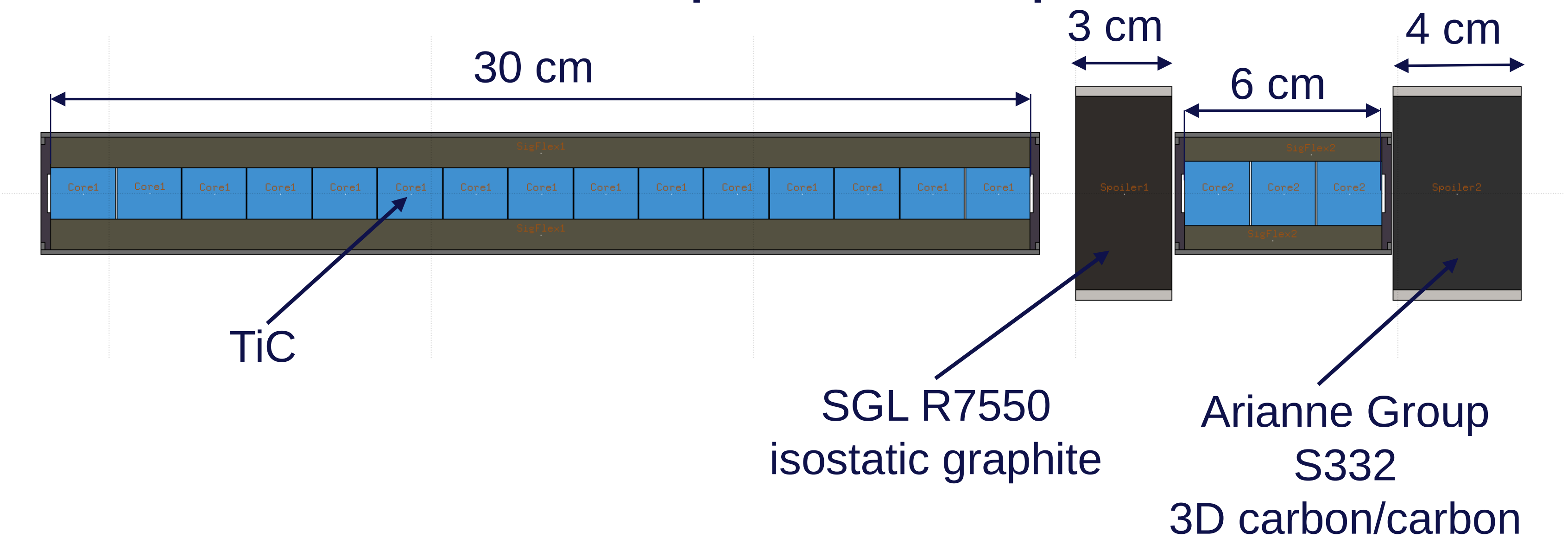


- High Energy Dumps experiment
- Finished 1st week of November 2021
- Multiple targets for testing:
  - Sigraflex material of the existing LHC Dump
  - Material candidates for the HL-LHC Dump
  - Materials for the TCDQ and TCDS for the HL-LHC upgrade
  - **Material test for the FCC-ee Spoiler**
- In total 35 different targets
- Key experiment for insights into high energy impacts on graphite materials.

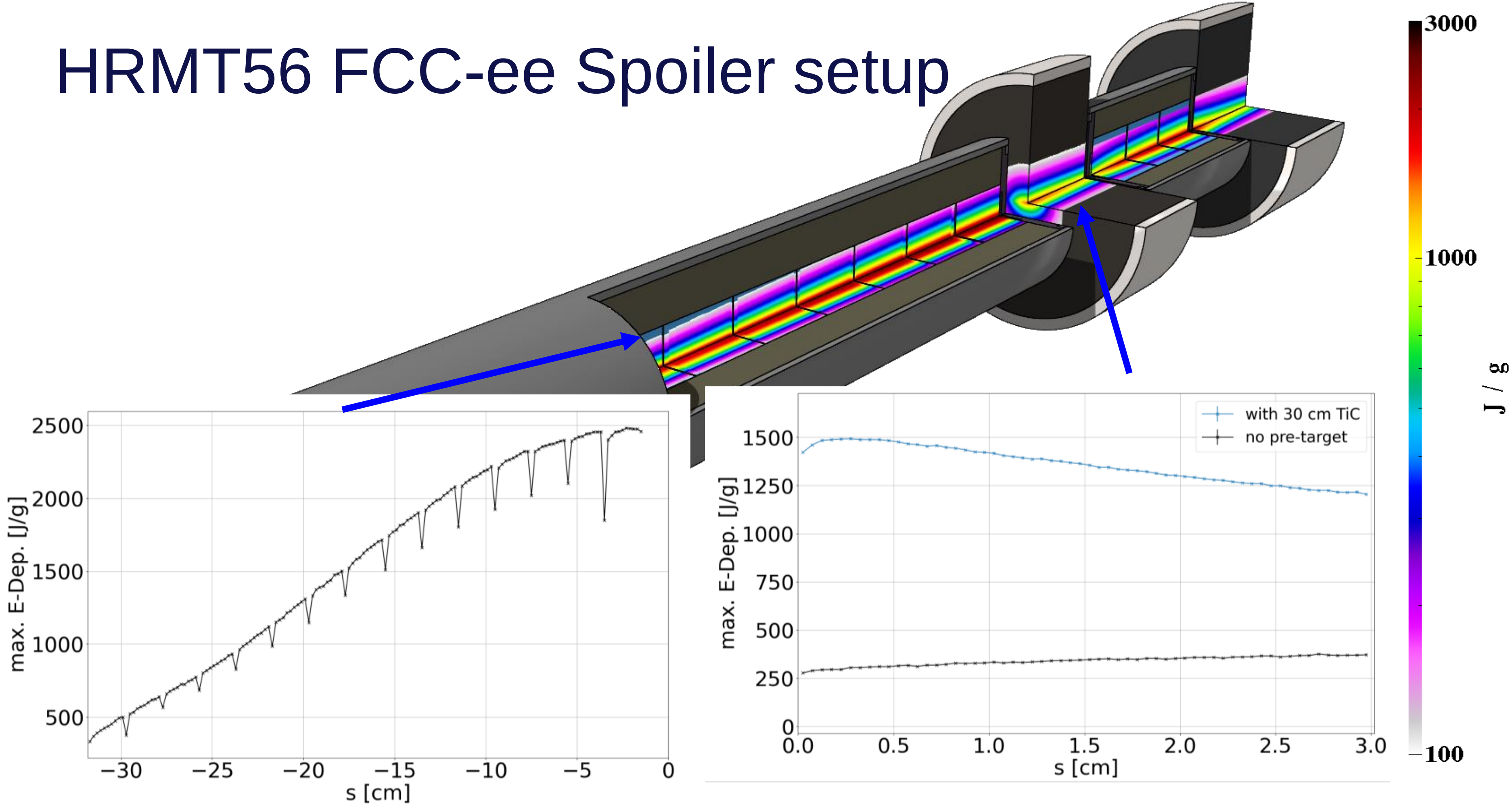
HRMT56 FCC-ee Spoiler setup

- Experimental verification of the validity of the simulations.
  - Especially important since testing with an FCC-ee style beam is not possible.
- HiRadMat beam parameters were chosen to reproduce the mechanical stresses expected from an impact with the FCC-ee beam.
  - A proton beam of **σ = 2.2 mm x 0.25 mm** was used for the experiment.
  - 450 GeV, 288 bunches, ~1.2e11 protons/bunch
- 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.
  - Titanium – Carbide (TiC) and Titanium-Diboride (TiB2) proved to be the best options

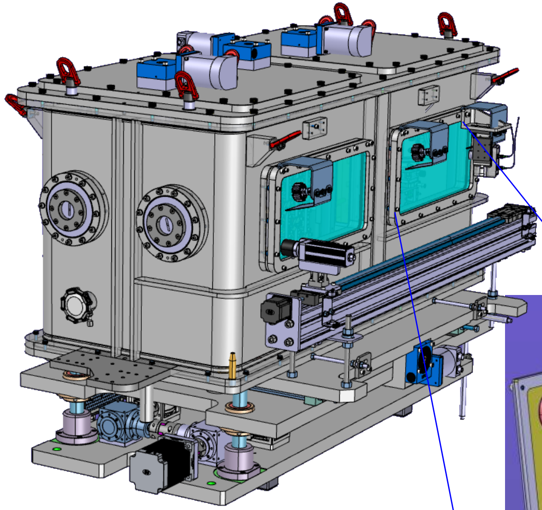
HRMT56 FCC-ee Spoiler setup

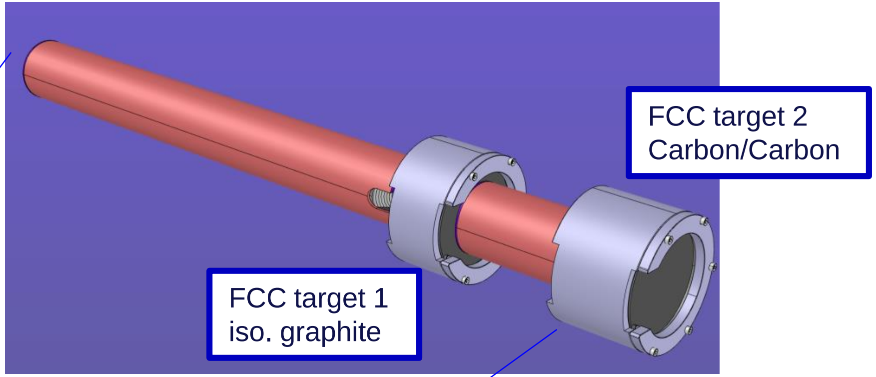


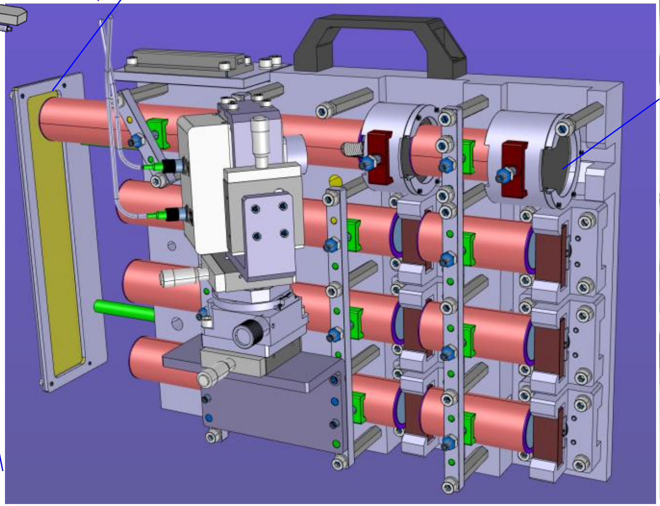
HRMT56 FCC-ee Spoiler setup

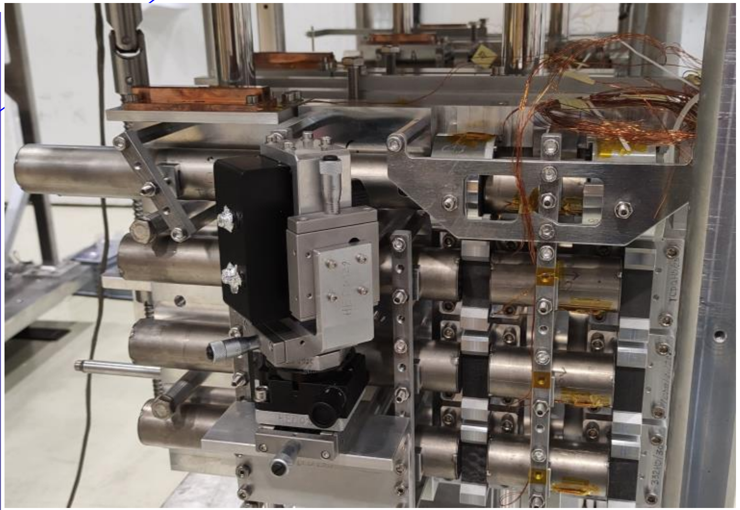


HiRadMat HRMT-56









FCC-ee Spoiler material candidates

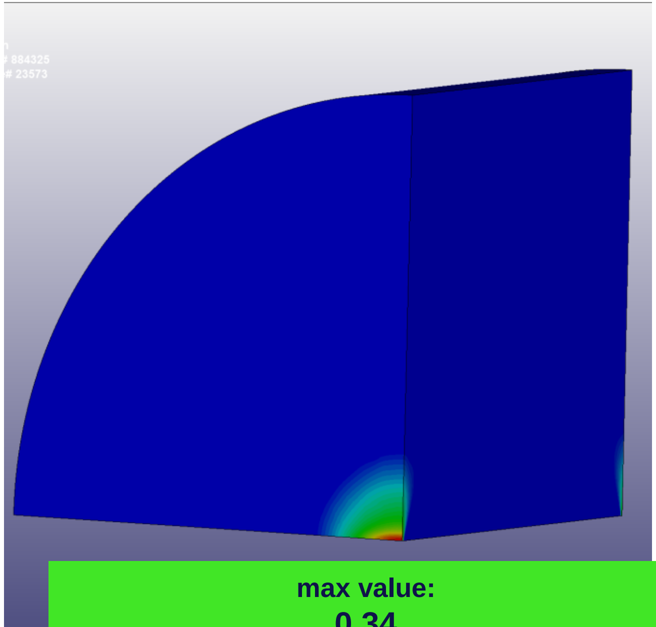
Requirements

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

Isotropic Graphite
(SGL R7550)

Carbon/Carbon Composites
(AG S332)

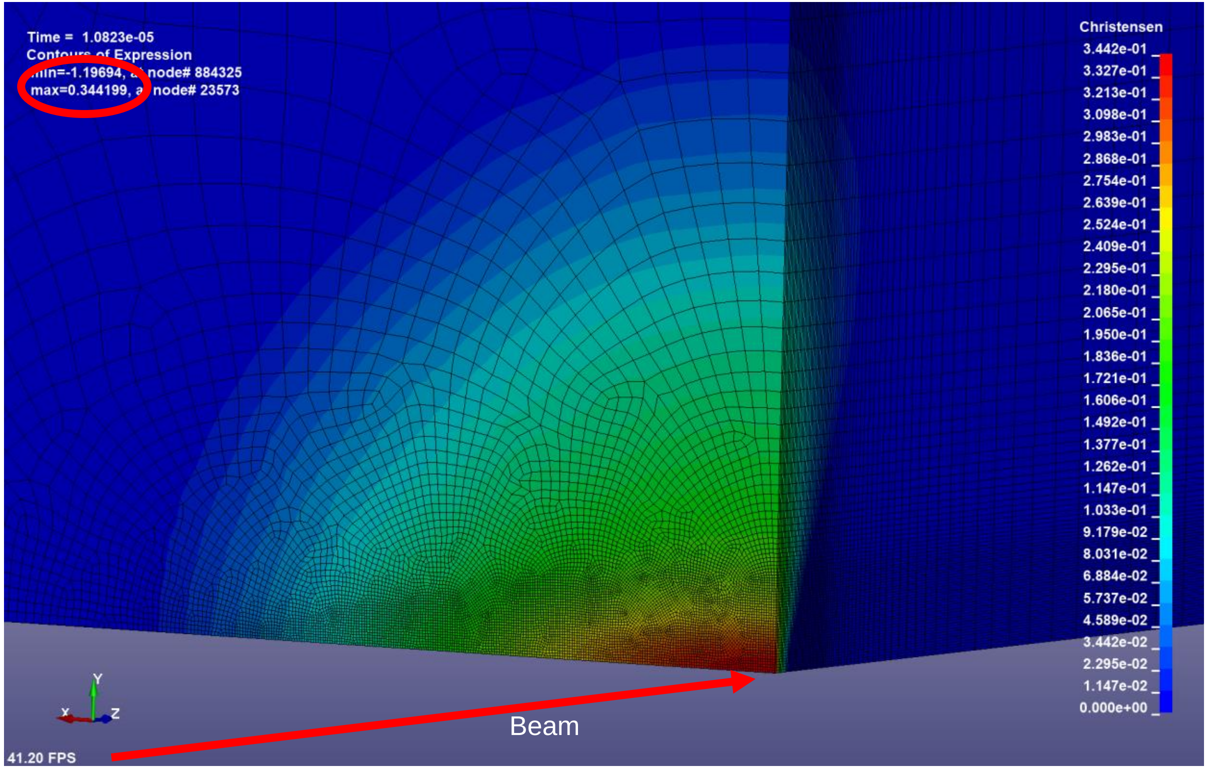
HRMT56 / LS-Dyna simulation



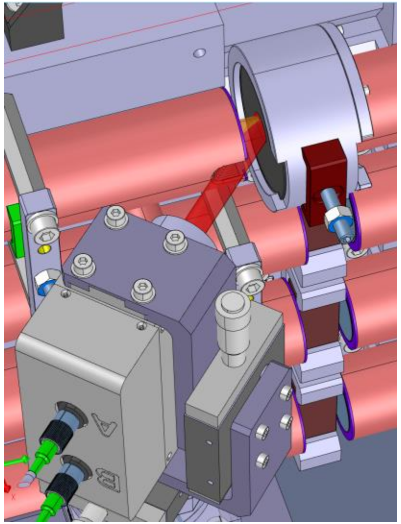
max value:

0.34

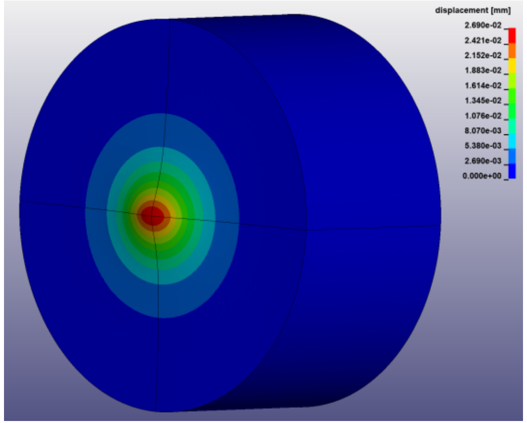
Similar to the FCC-ee Spoiler simulation



Instrumentation for the FCC target



- Out of plane displacement is correlated to strain
- Laser Doppler Vibrometer for live surface velocity measurement
- Surface displacement and velocity are simulated and can be directly compared
- Gives good indication if material model and simulations are correct
- Post irradiation examination to verify material survival
  (i.e. micro tomograpy, raman spectroscopy, etc.)



Current Status

- Dump beamline ~70 m from Spoilers to Beam Dump.
- Overall extraction line length depends mainly on requirements for separation from the main ring.
- Extraction does not need a dedicated external tunnel.
- Dilution and beam dumping can be done with a (semi) passive system

Next steps and open questions

- **Specify location in the lattice**
- Evaluate radiation field around spoilers and dump
  - Determine the required separation of dump and main ring
  - Access requirements and shielding requirements
- Post irradiation examination of HRMT56-HED
  - Optimize spoiler design
  - Optimize dump absorber design
- What about injection/extraction protection?
  - Booster beam abort system?
  - Extraction protection like in the LHC?

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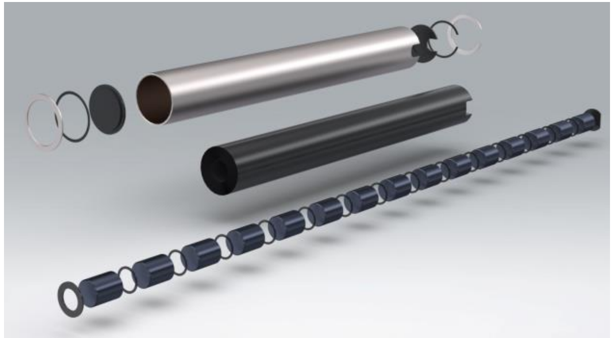
Thank you for your attention.

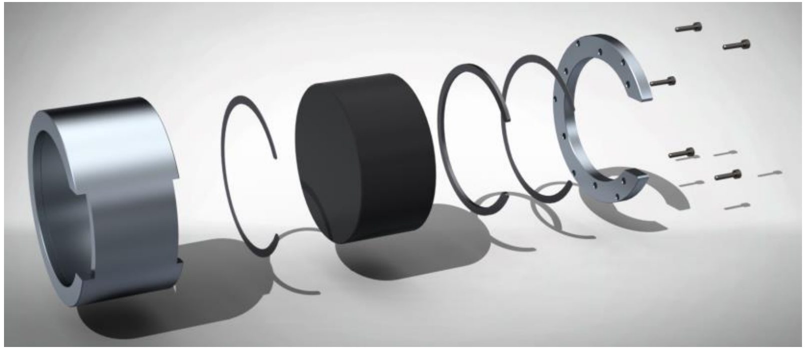
BACKUP

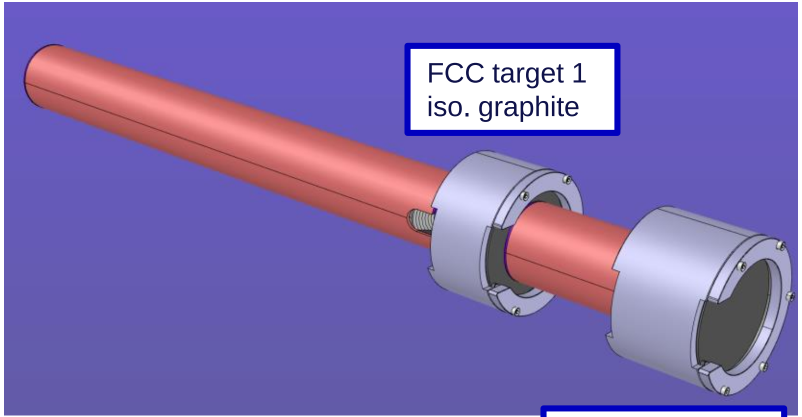
HRMT56 FCC targets

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



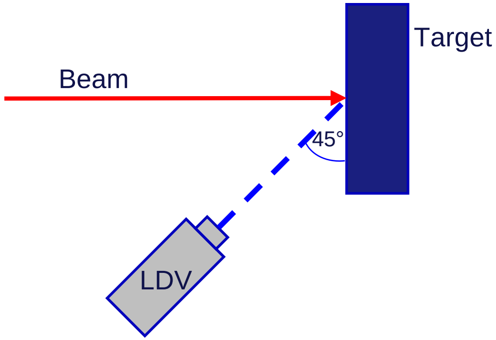
Targets
Scaled Model of the FCC-ee Spoiler design
Isotropic Graphite and Carbon/Carbon are tested





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.



No triplet, passive protection by the Spoiler

- Spoilers get destroyed
- Dump should survive
- Hydrodynamic tunneling not considered