HIRADMAT TEST OF THE FCC-EE PASSIVE DILUTER PROTOTYPE

Alexander Krainer

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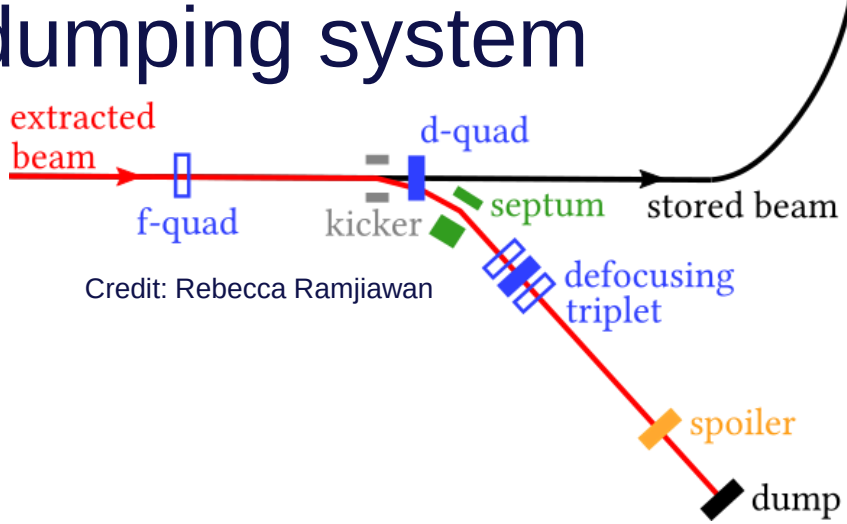
The semi-passive beam dumping system

- Defocusing triplet to increase the beam size
- 3 spoilers to dilute the beam
- Dump block to absorb the beam



Credit: Rebecca Ramjiawan

“A semi-passive beam dilution system for the FCC-ee collider”,
https://doi.org/10.1140/epjti/s40485-022-00078-x

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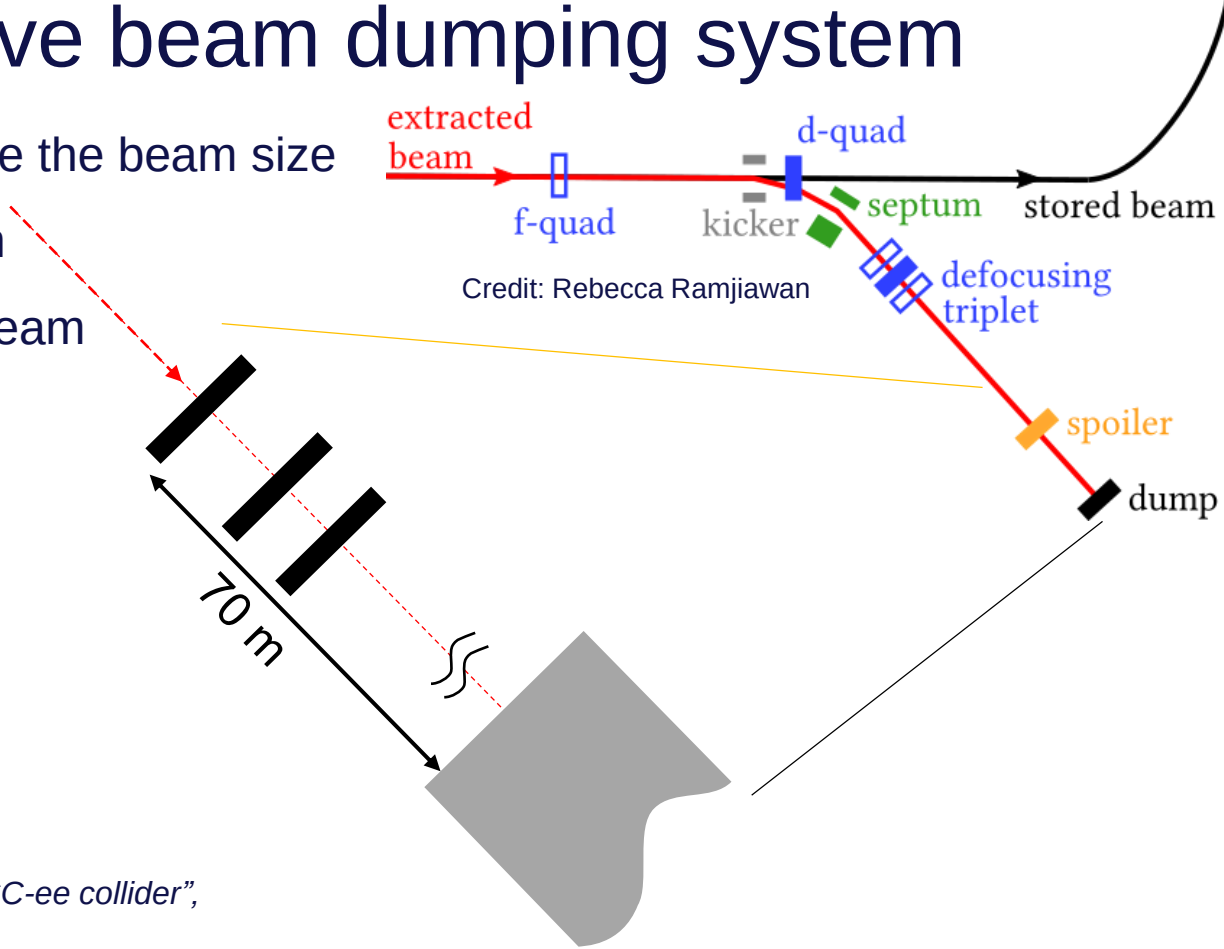

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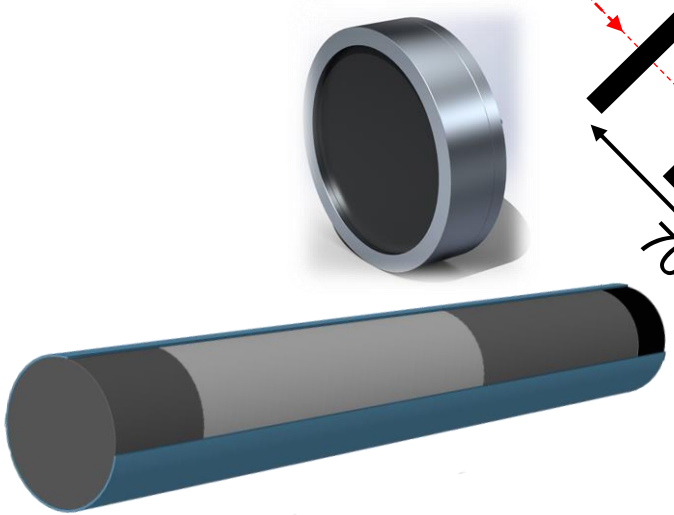

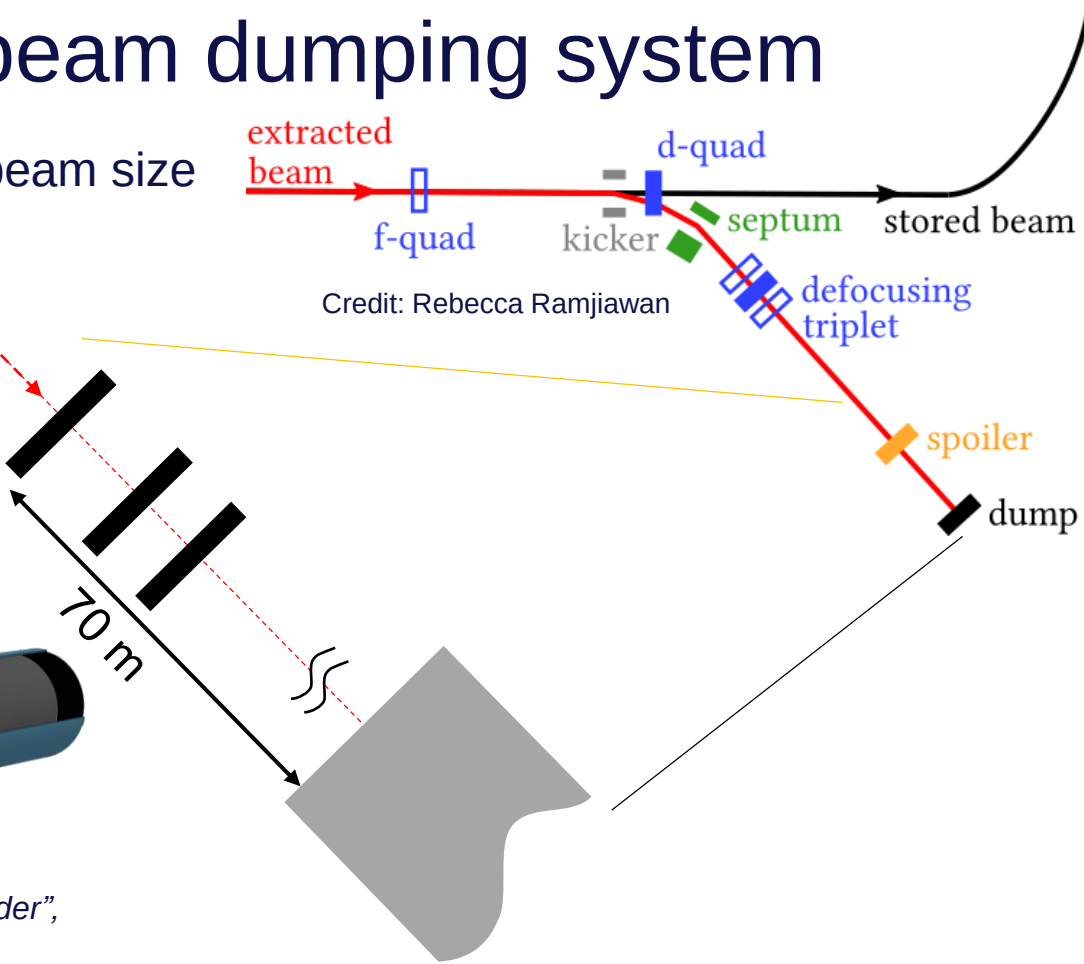

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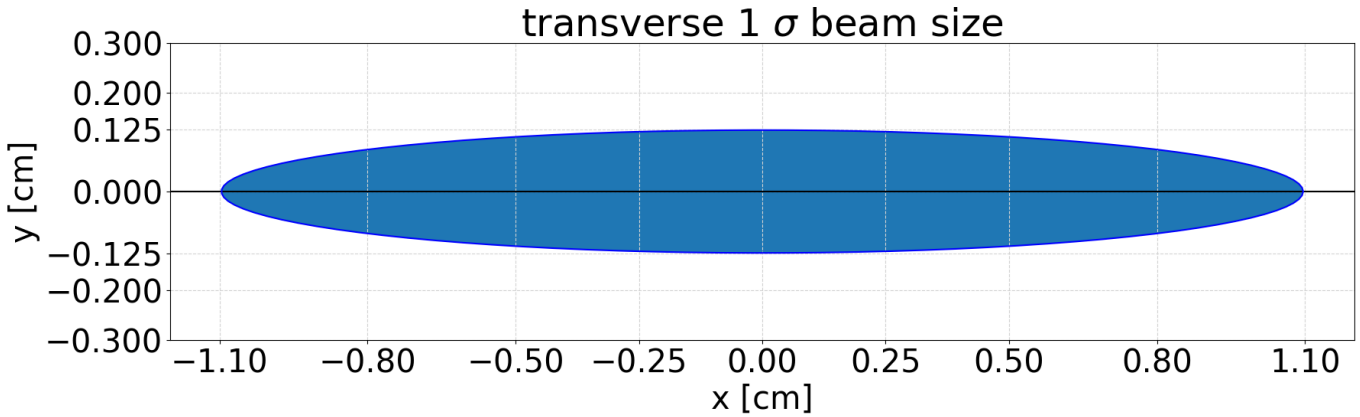
The FCC-ee beam

Z operation: 45.6 GeV, 2.4e15 electrons, ~18 MJ

Beam spot size at the first Spoiler :



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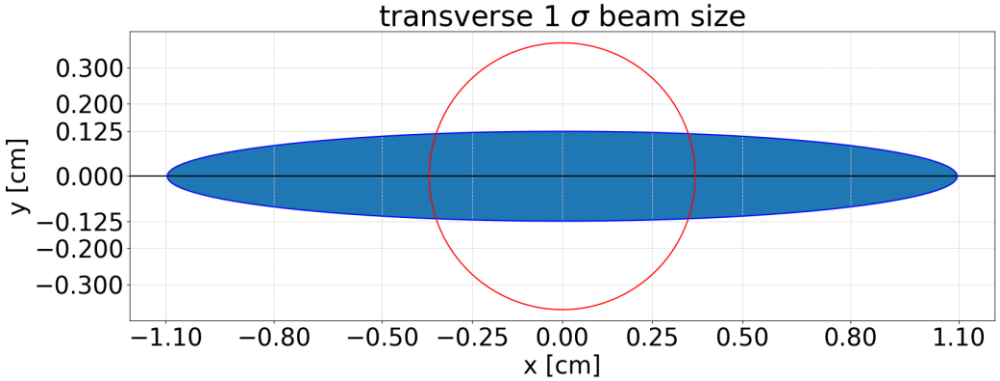

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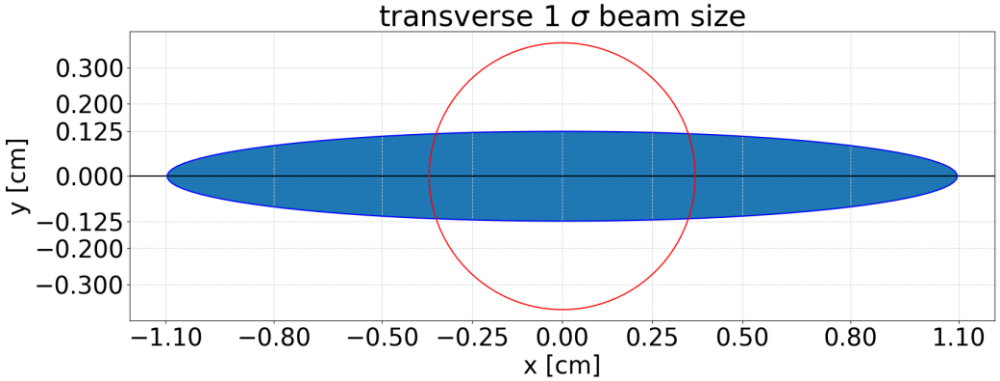

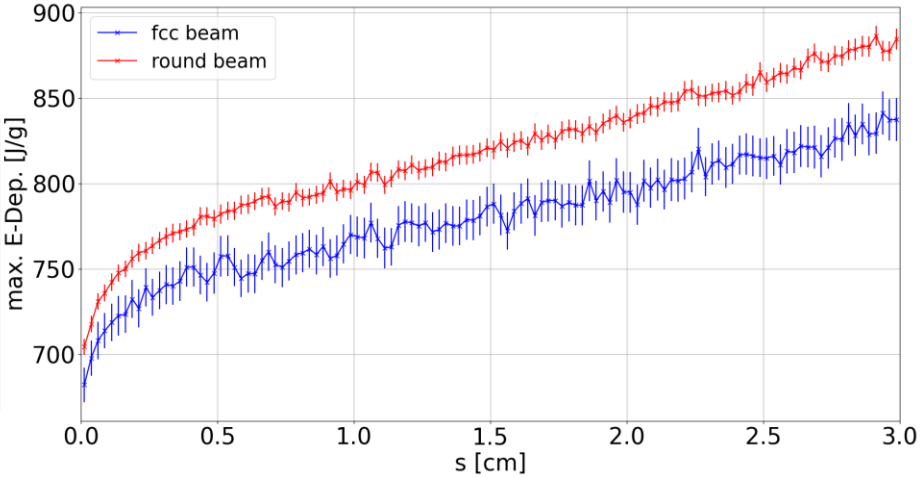

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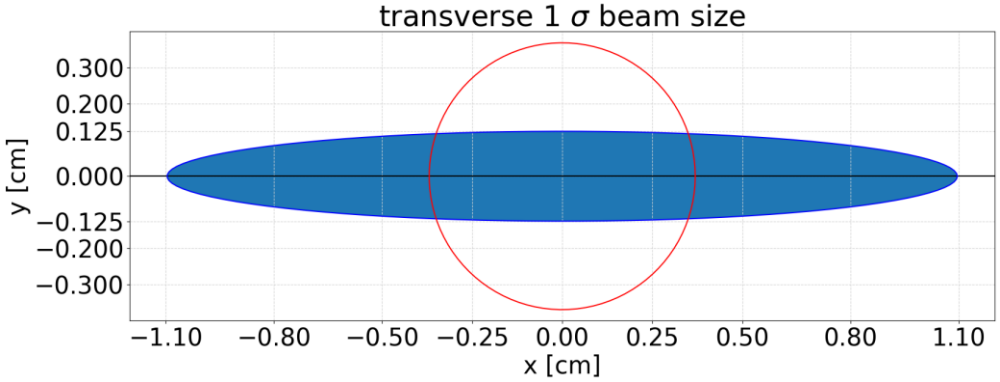

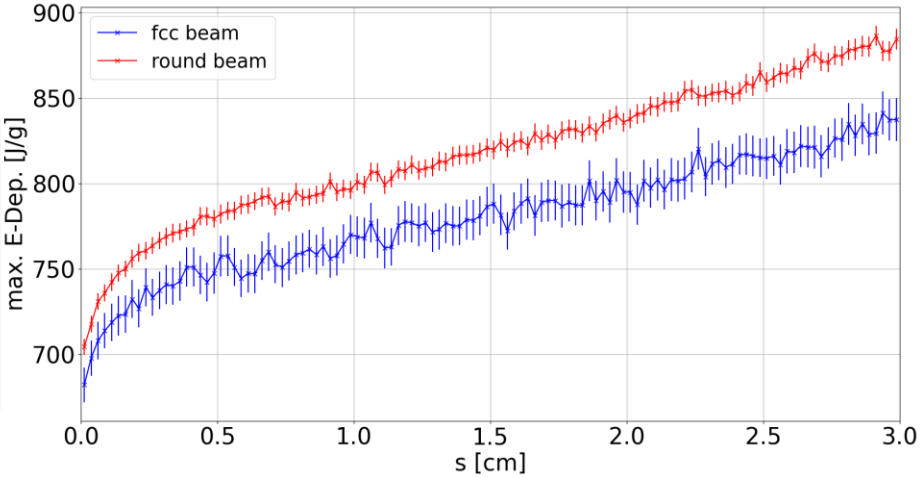

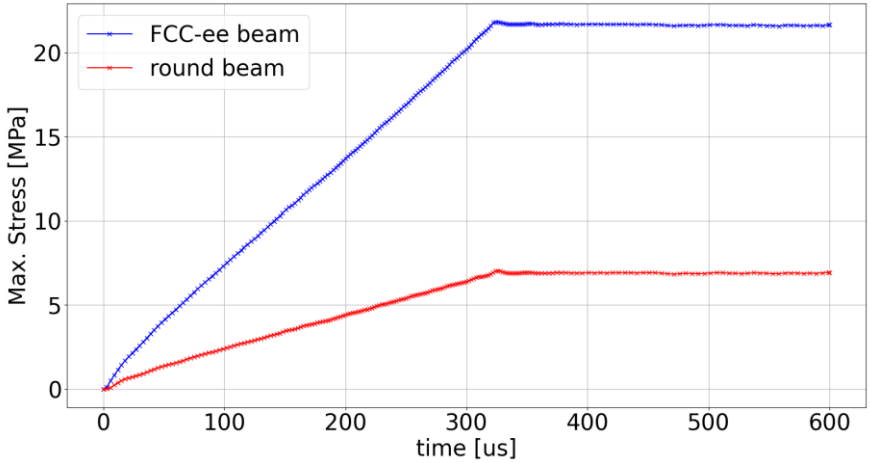

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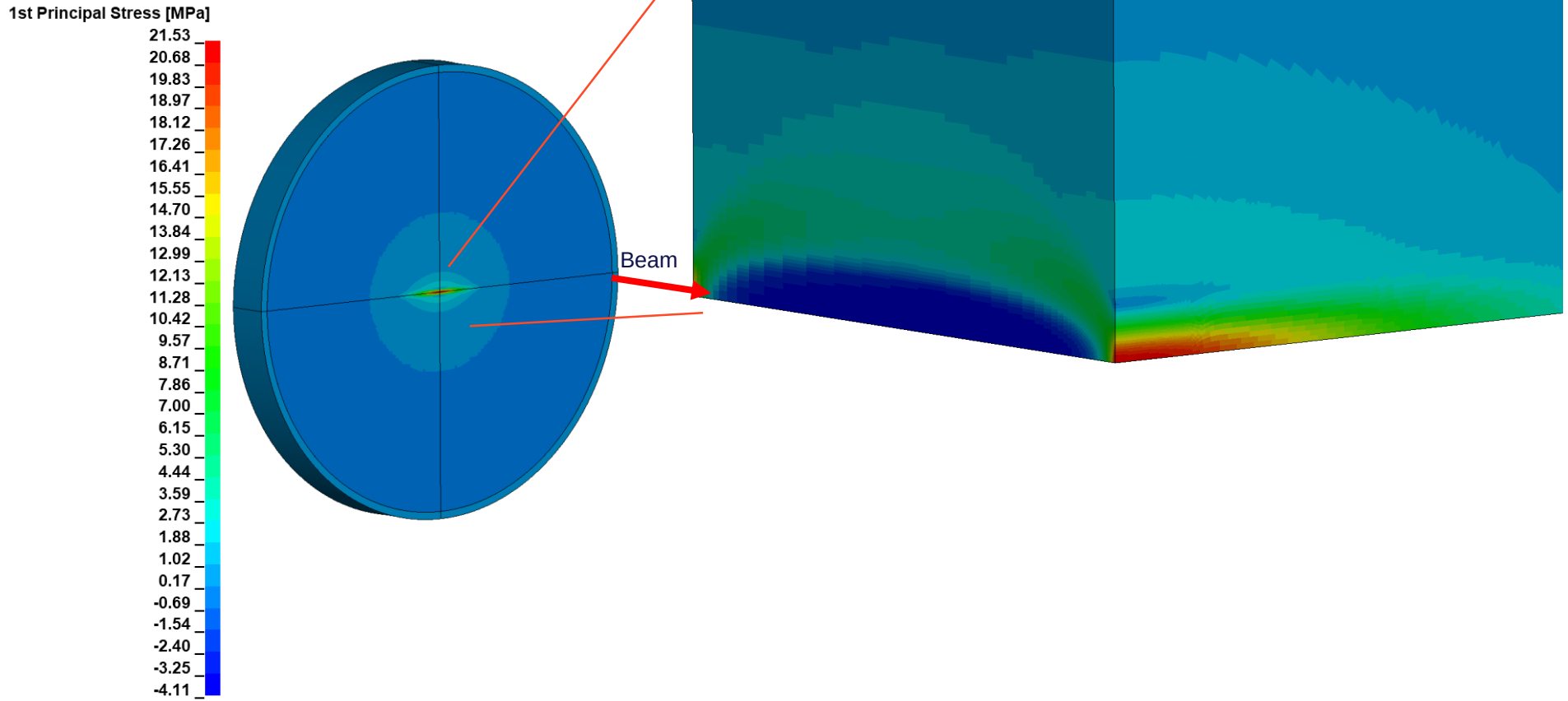


Assessing Material Failure

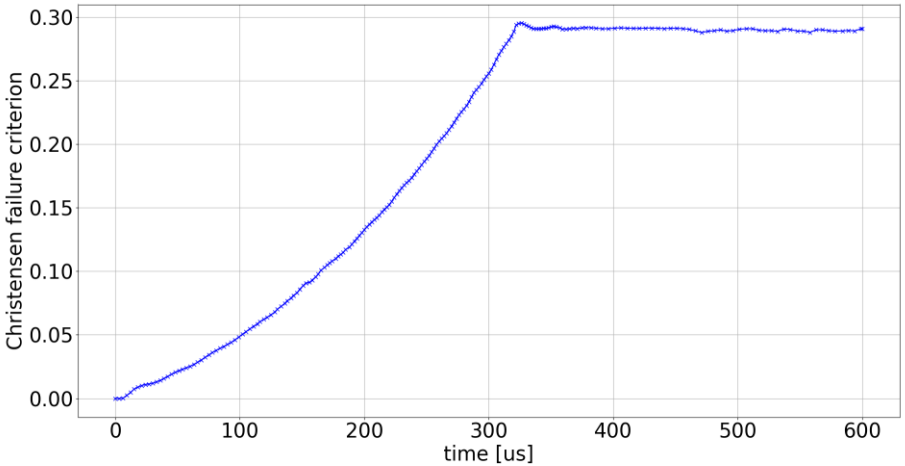
For SGL R7550, isotropic graphite (conservative estimate)
Compressive strength C = 130 MPa
Tensile strength T = 40 MPa

Christensen Failure Criterion:

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

$$\sigma_i < T$$

Values > 1 show material failure



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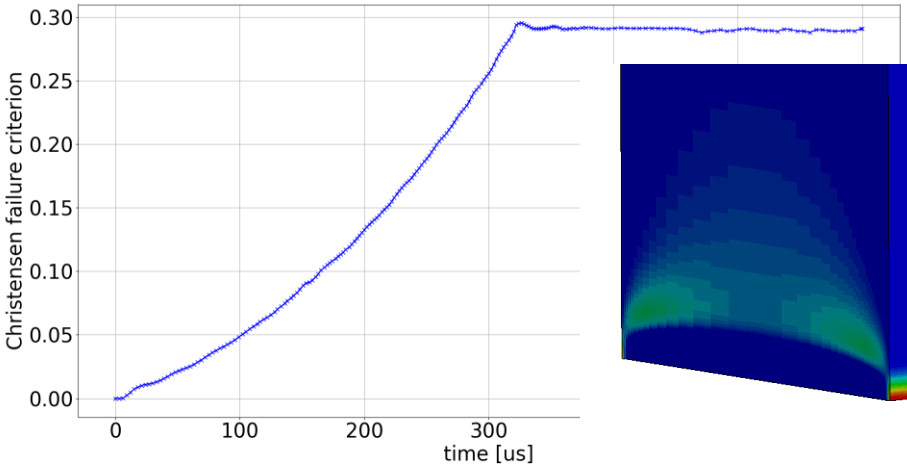

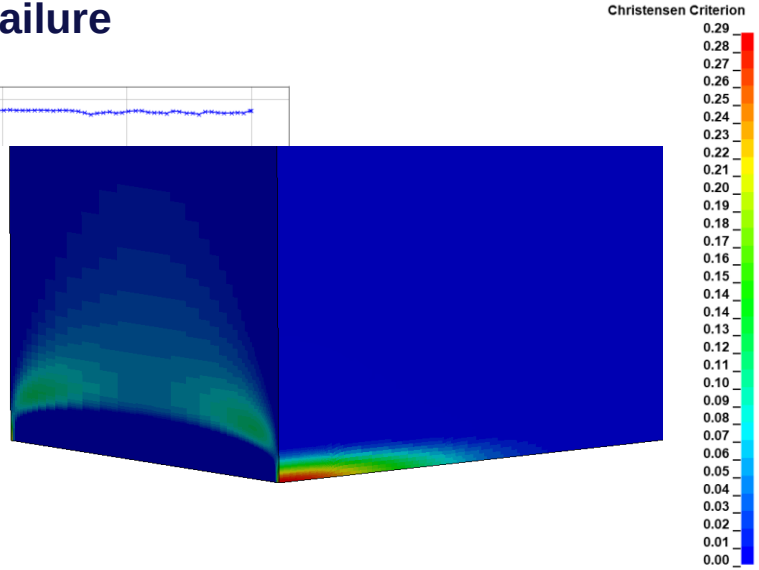

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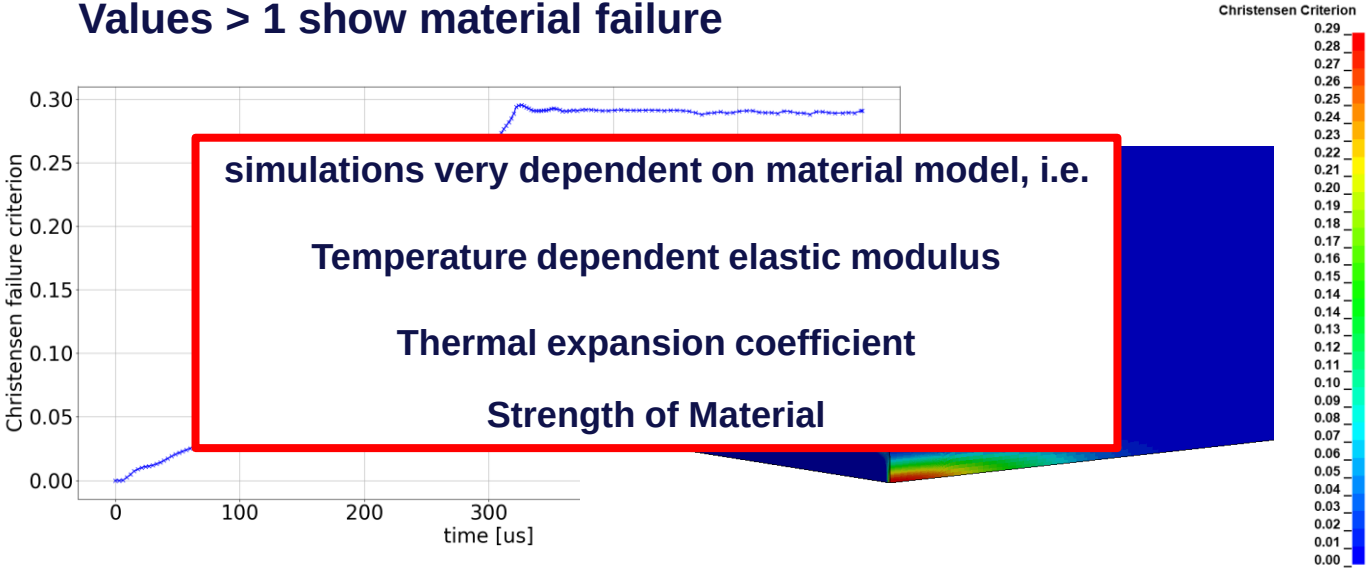


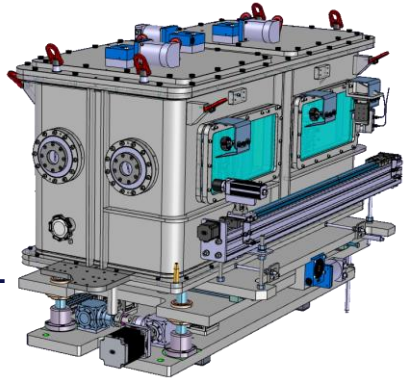
simulations very dependent on material model, i.e.

Temperature dependent elastic modulus

Thermal expansion coefficient

Strength of Material

HiRadMat HRMT56-HED

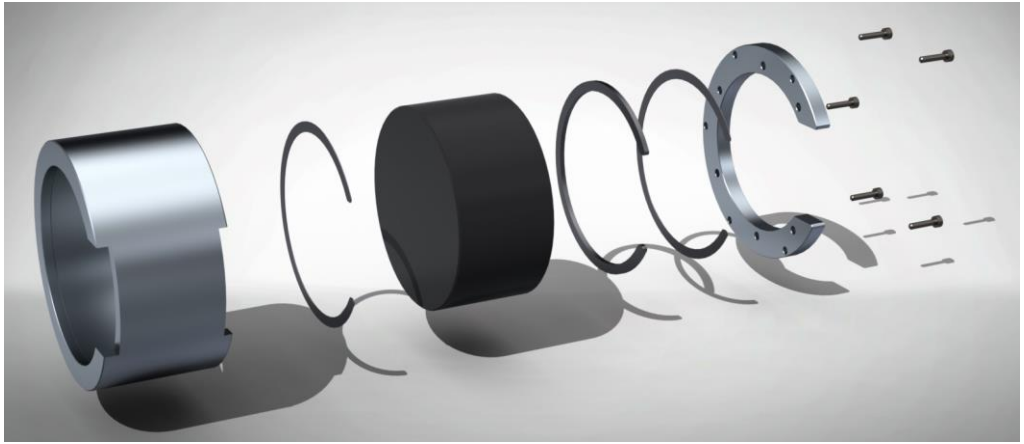


- High Energy Dump experiment
- Finished 1st week of November 2021
- Multiple targets for testing:
  - Sigraflex material of the existing LHC Dump
  - Material candidates for the HL-LHC Dump
  - Materials for the TCDQ and TCDS for the HL-LHC upgrade
  - **Prototype test for the FCC-ee Spoiler**
- In total 35 different targets

HRMT56-HED

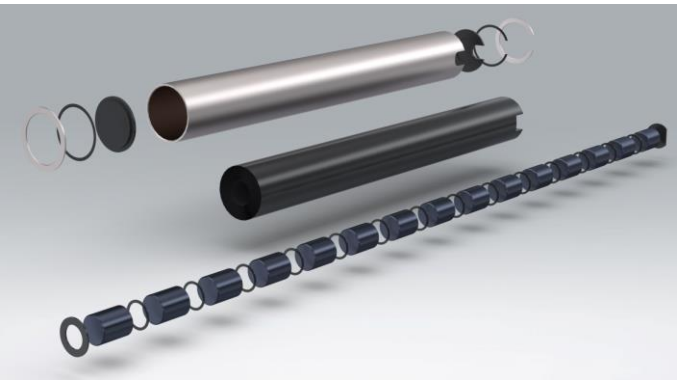
FCC-ee Spoiler Prototype

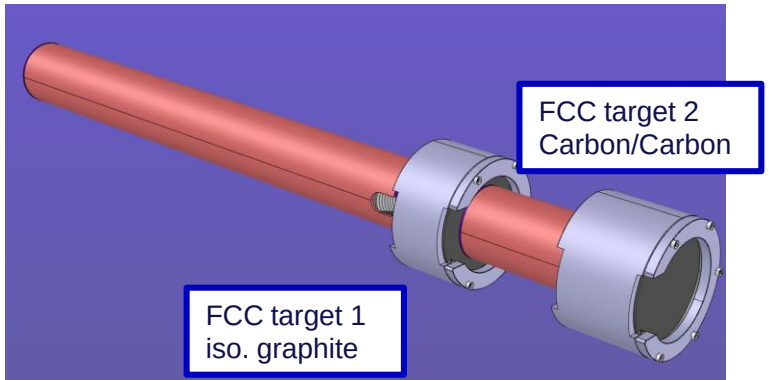
- Scaled Model of the FCC-ee Spoiler design (60 mm diameter, 30 mm length)
- Two Prototypes: Isotropic Graphite and 3D Carbon/Carbon



HRMT56-HED

- SPS proton beam at the CERN HiRadMat facility
  - r.m.s beam sigma up to **5 mm**
  - **440 GeV**, **288 bunches**, **~1.2e11 protons/bunch (~ 2.4 MJ)**
- FCC-ee like beam shape: **σ = 2.2 mm x 0.25 mm**
- Maximizing the deposited energy in the Spoiler prototype
  - Titanium-Carbide pre-target to create secondary shower





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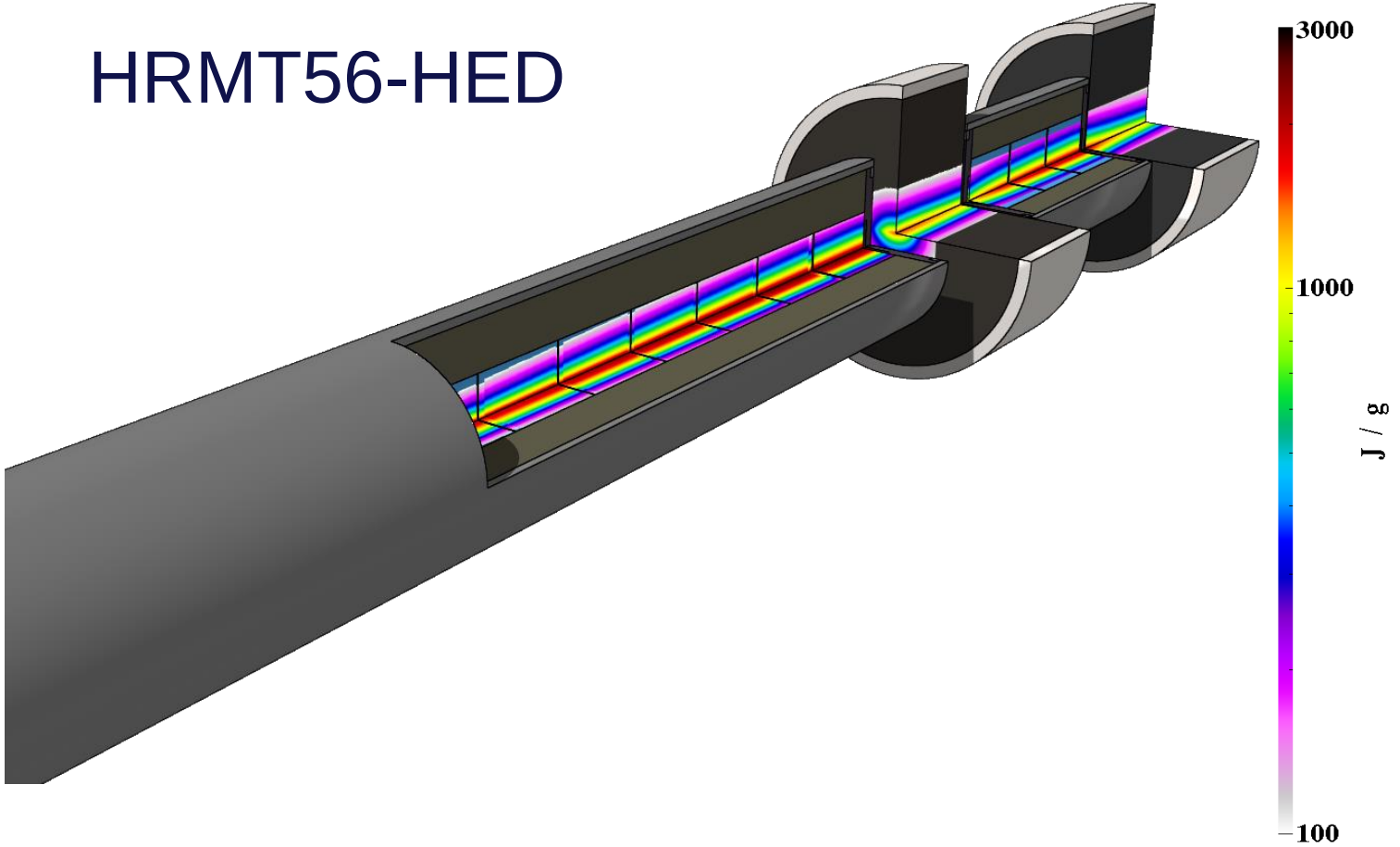

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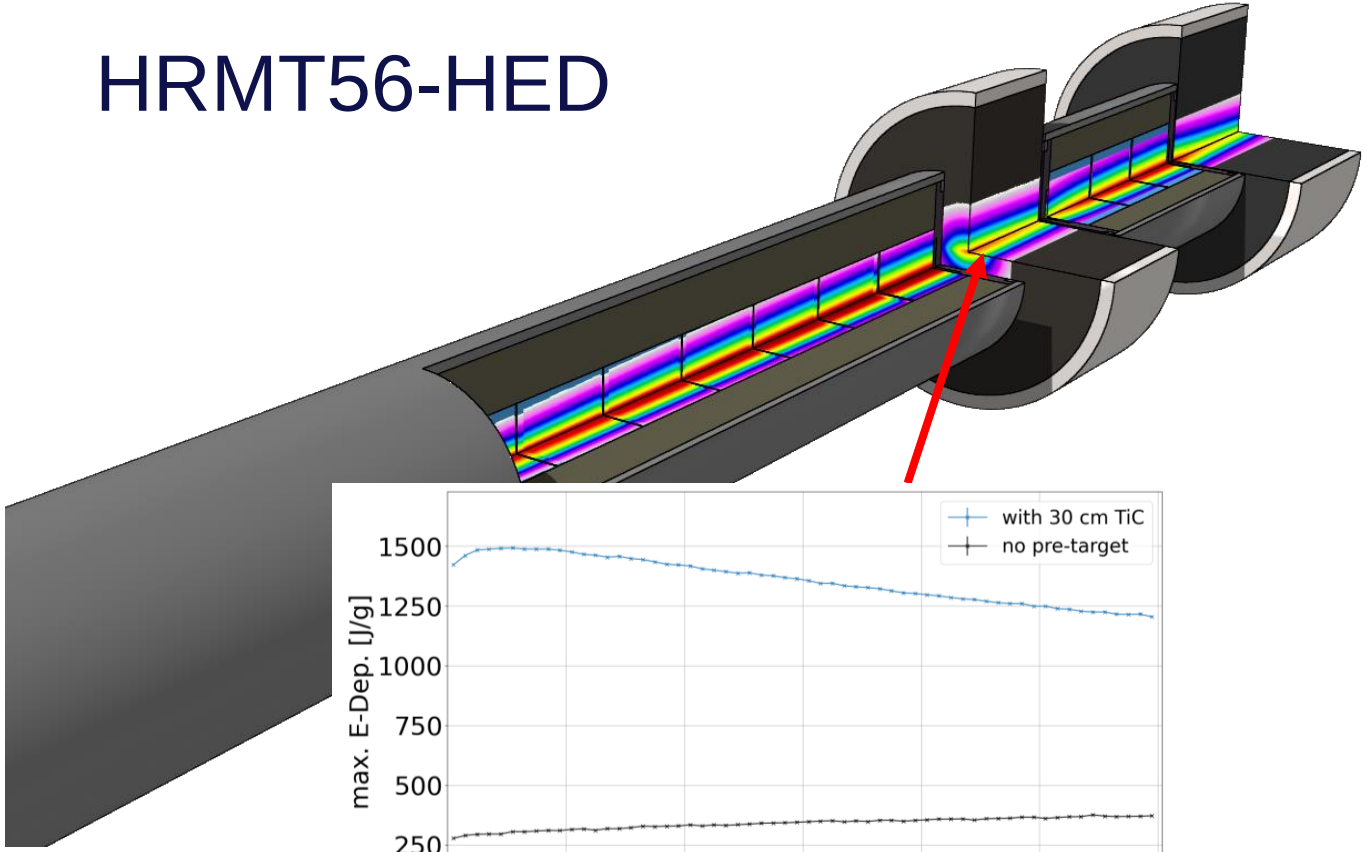
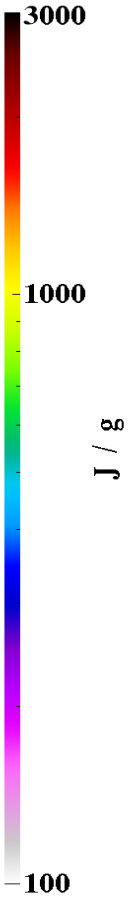
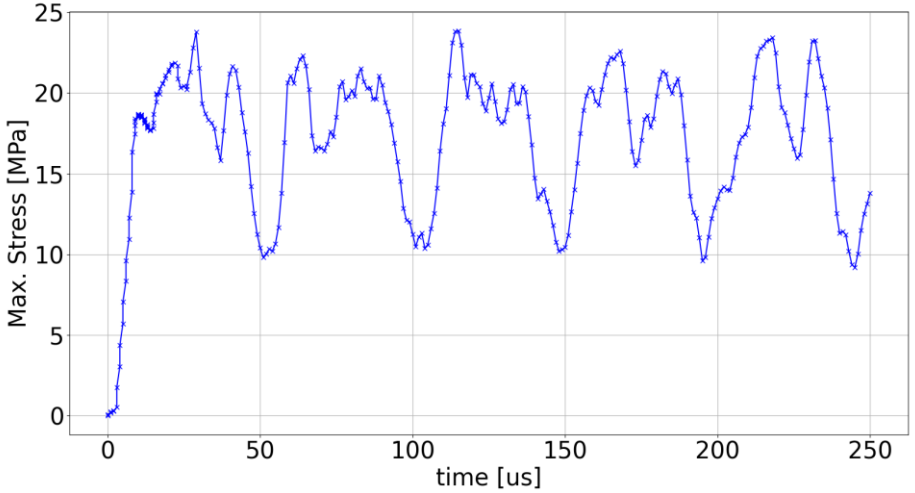
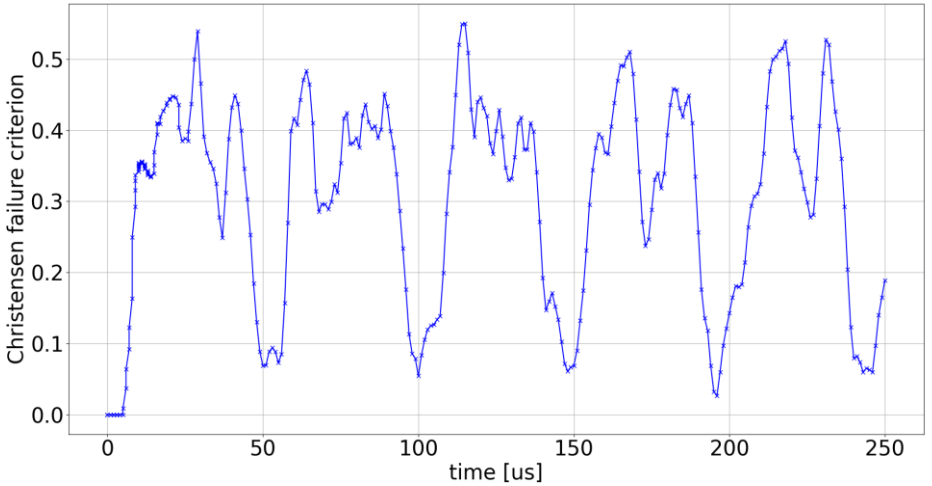


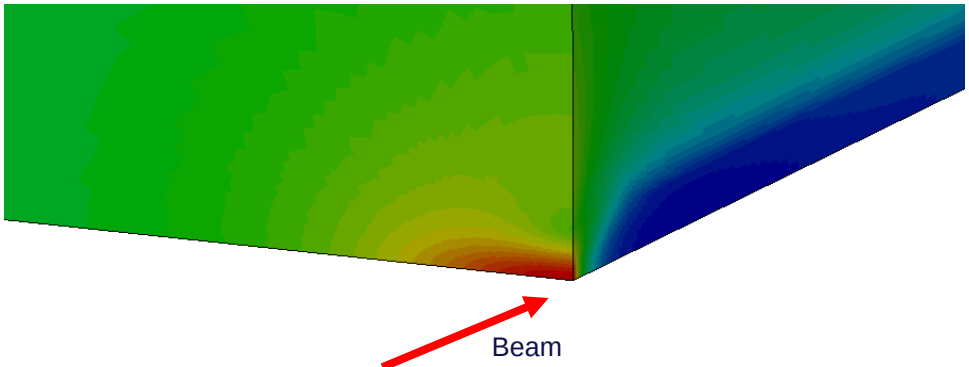
with 30 cm TiC
no pre-target
max. E-Dep. [J/g]
1500
1250
1000
750
500
250
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
s [cm]


3000
1000
100
J / g

HRMT56-HED


Max. Stress [MPa]
time [us]
0
5
10
15
20
25
0
50
100
150
200
250


Christensen failure criterion
time [us]
0.0
0.1
0.2
0.3
0.4
0.5
0
50
100
150
200
250


Beam

HRMT56 Instrumentation

- Stress resulting from out of plane deformation at the beam impact spot
- Strain gauges cannot be placed directly in the beam trajectory.
- With a fibre **Laser Doppler Vibrometer** (LDV) surface velocity and displacement can be measured in real time.
  - Out of plane velocity and displacement are correlated to surface stress
  - Velocity and displacement can be directly compared to simulations

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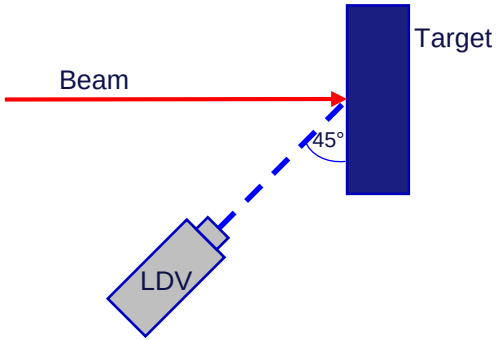

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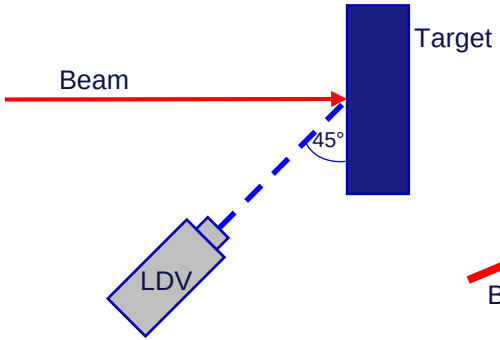

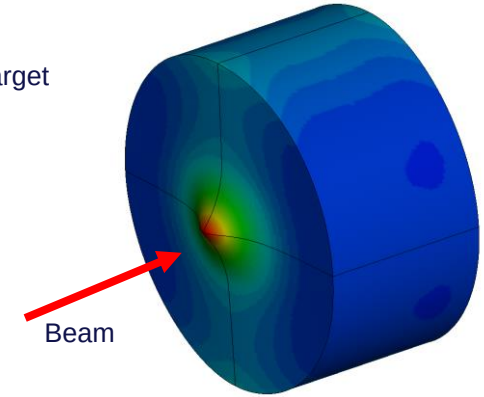

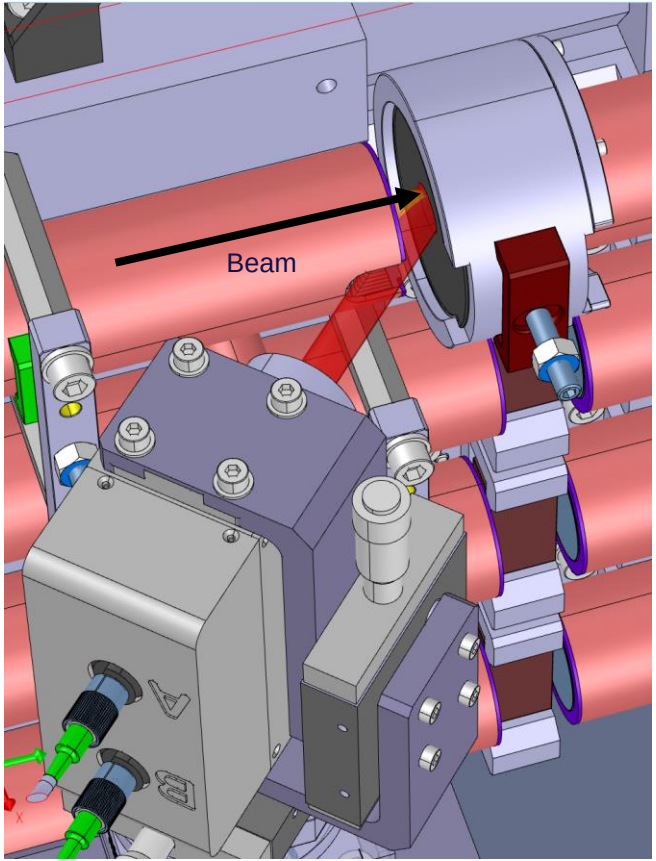
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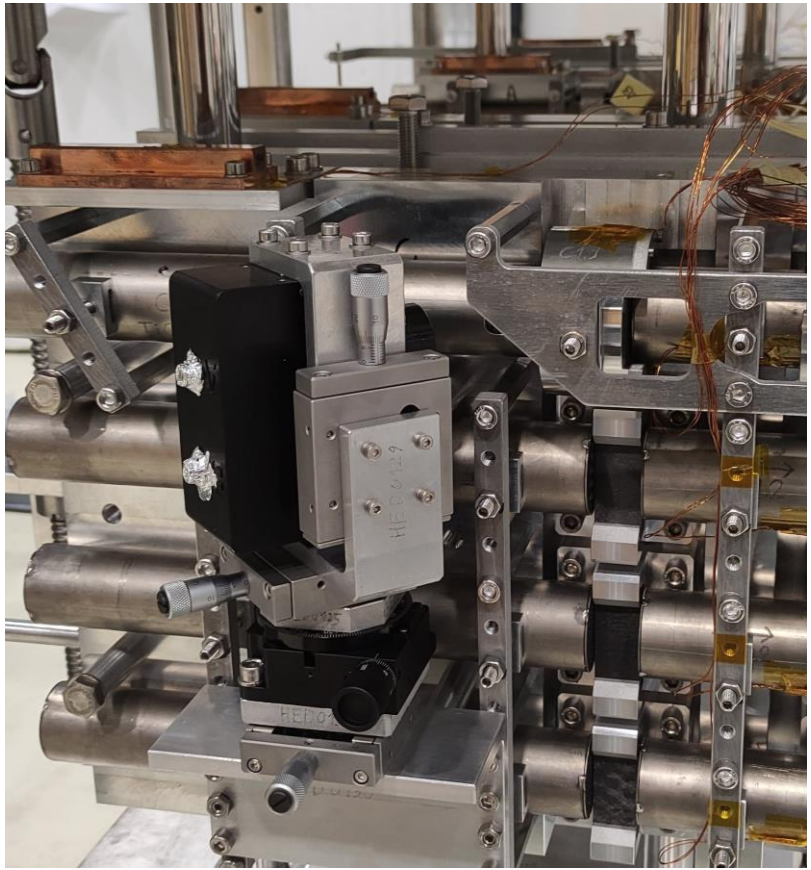

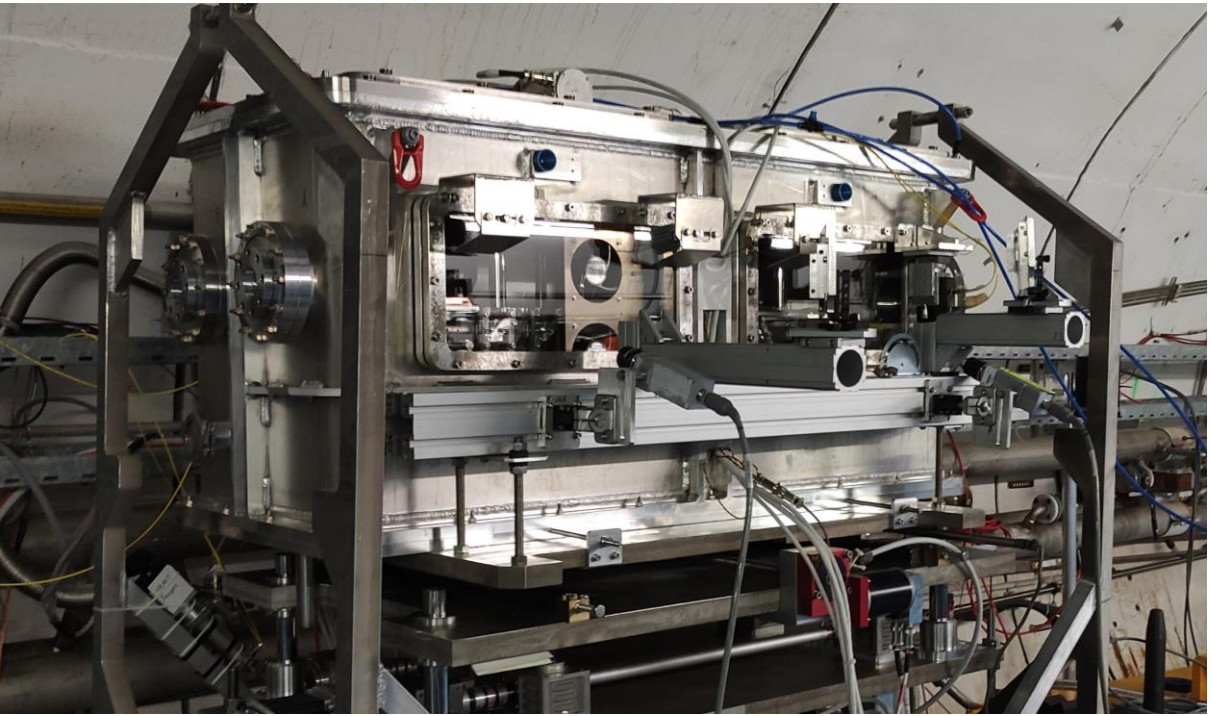

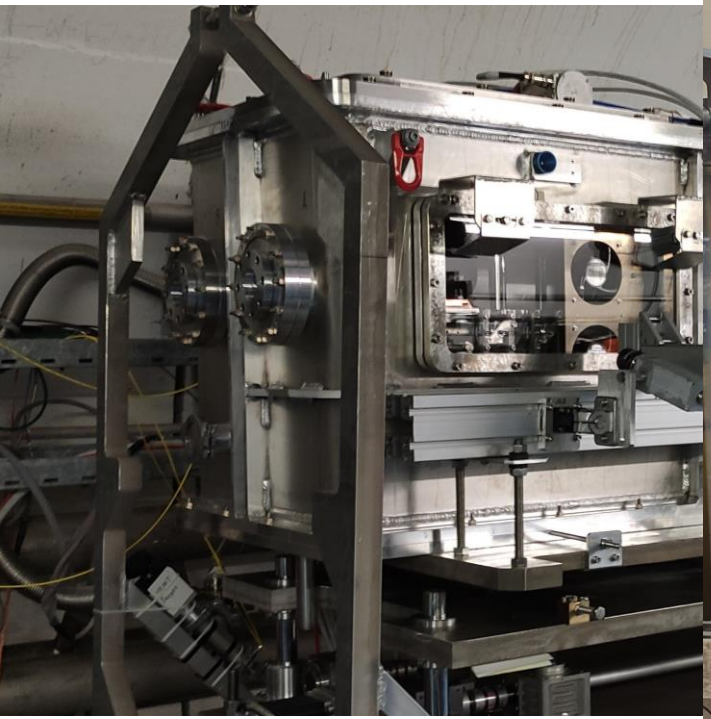

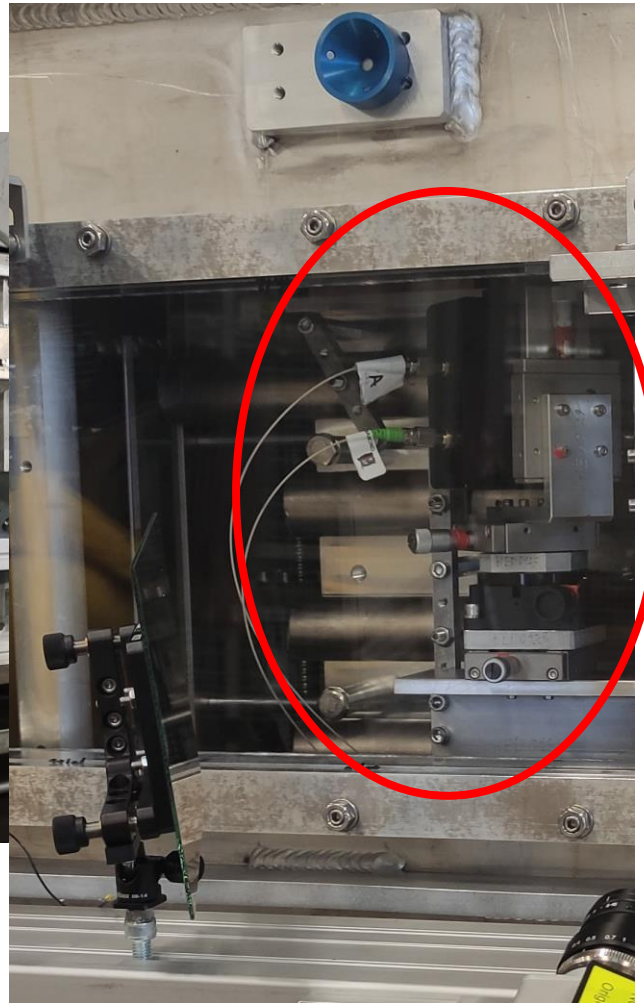

HRMT56 - Experiment

4 shots with full SPS intensity

Intensity: **3.39e13 protons**, Beam Spot Size: **~1.955x0.265 mm**

Intensity: **3.36e13 protons**, Beam Spot Size: **~1.895x0.275 mm**

Intensity: **3.37e13 protons**, Beam Spot Size: **~1.905x0.285 mm**

Intensity: **3.35e13 protons**, Beam Spot Size: **~1.915x0.275 mm**

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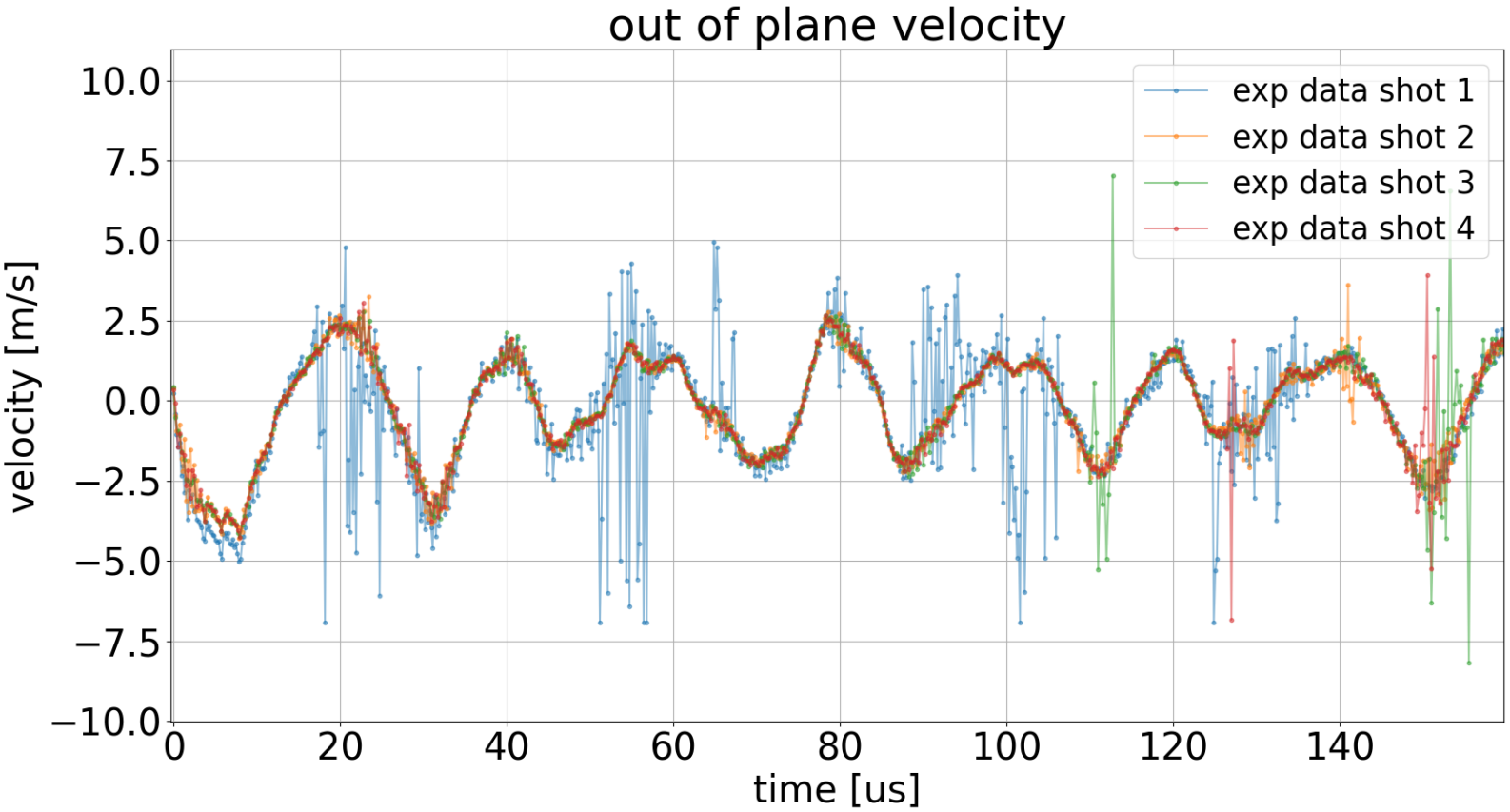

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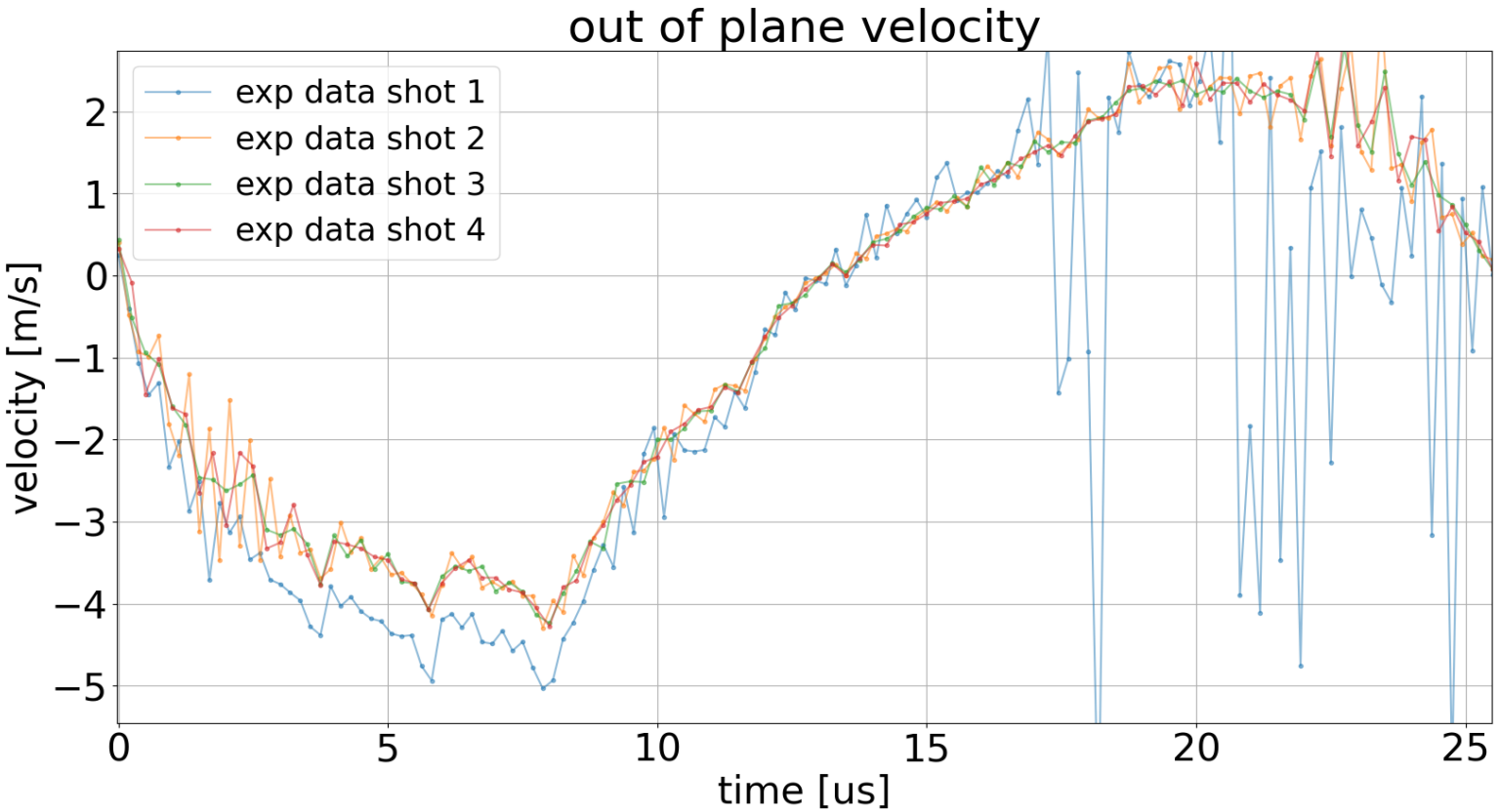

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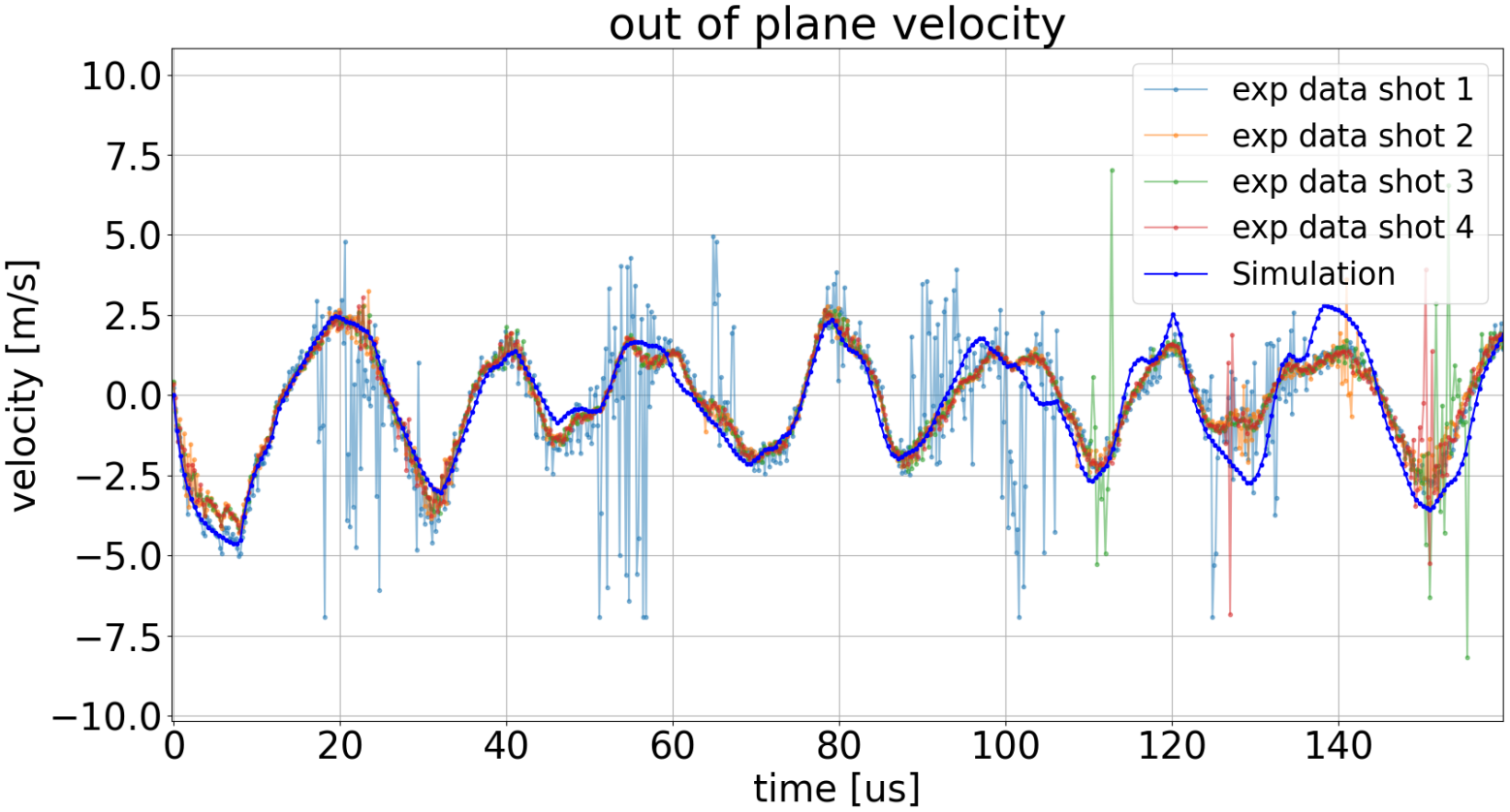

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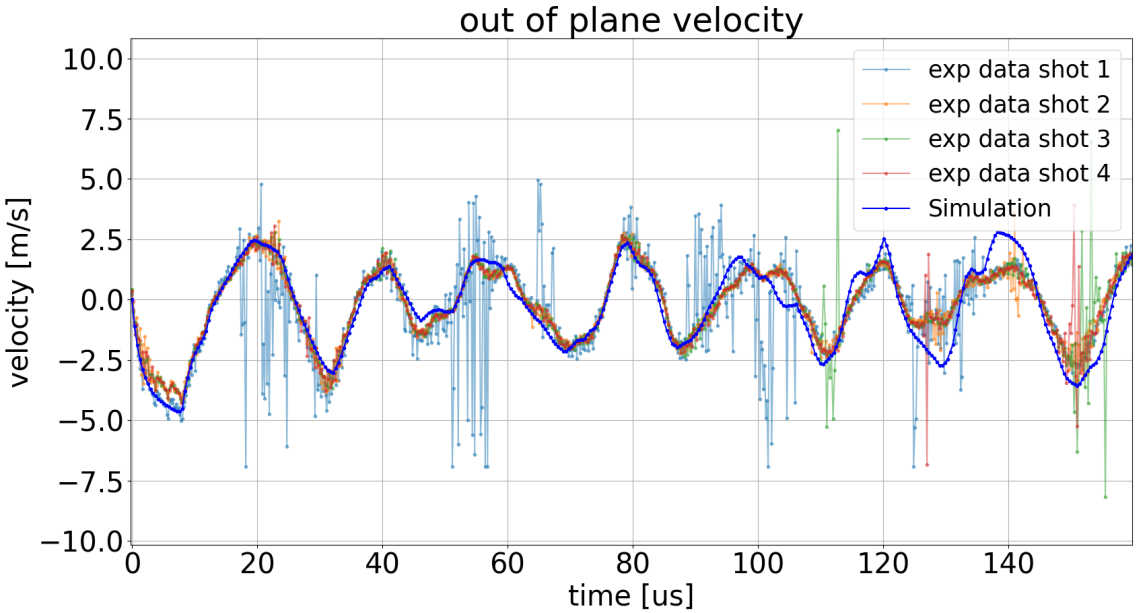
Good agreement with simulations up to 100 us



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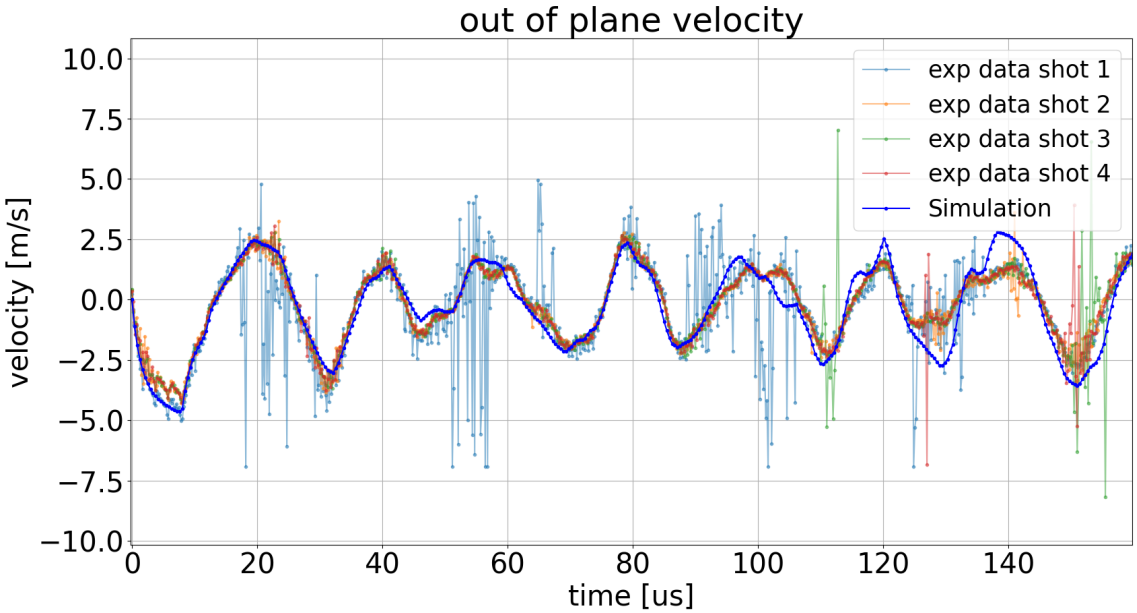
Damping and additional vibrations from support are not simulated



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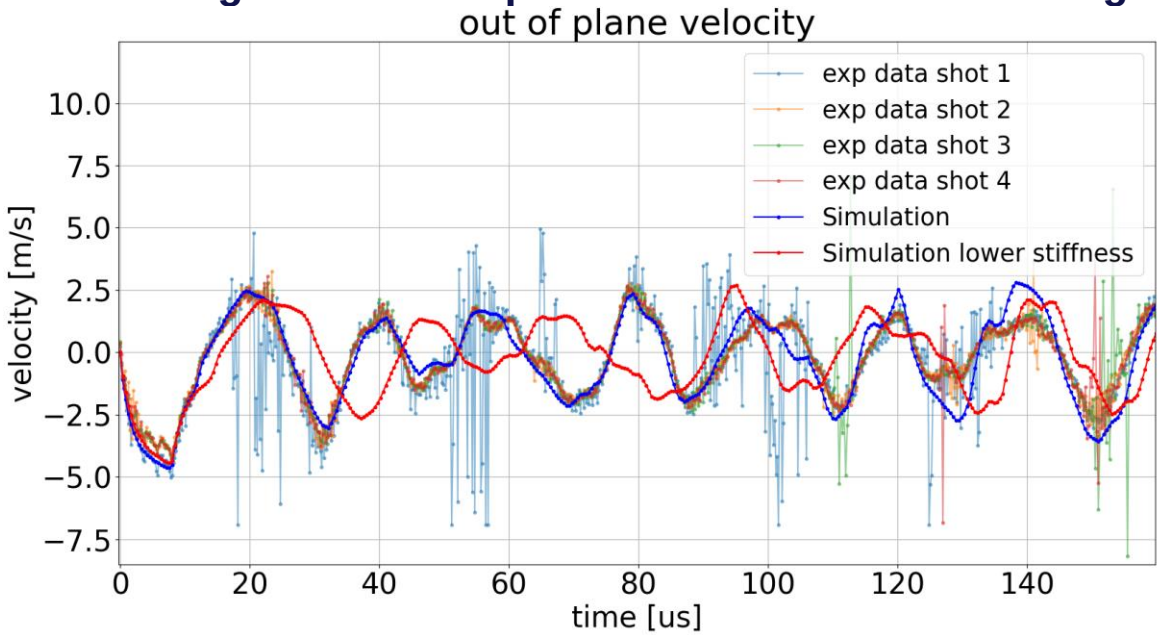
Change in material parameters shows clear change in velocity response



HRMT56 - Experiment

Damage to material:

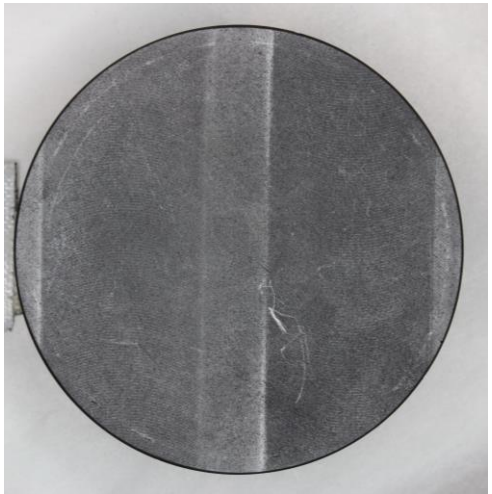
Visual inspection showed no damage to targets

Reproducibility of velocity response is a good indication that no micro damage occurred

Evaluation of post micro-CT scans is ongoing

PRE

POST



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- Out of plane velocity data shows good agreement with the simulations
  - Validates the material model
  - High confidence in stress and failure simulations
- No visible damage was detected
  - Higher failure criterion value reached
  - Good indicator that a Spoiler survives FCC-ee impacts without damage

FUTURE
CIRCULAR
COLLIDER

Thank you
for your attention.

BACKUP