The FRIB High Power Production Target Development

High Power Targetry Workshop
May 3rd , 2011

W.Mittig

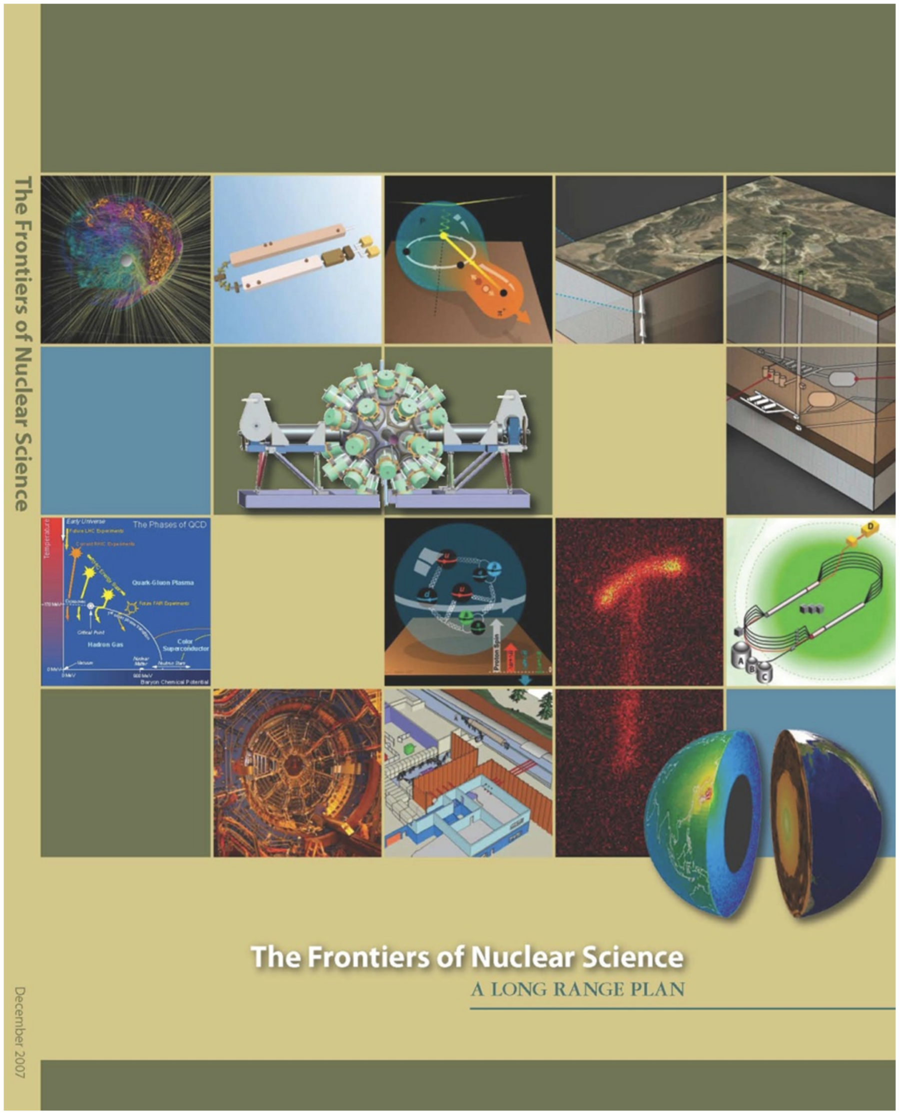
MSU-NSCL

MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

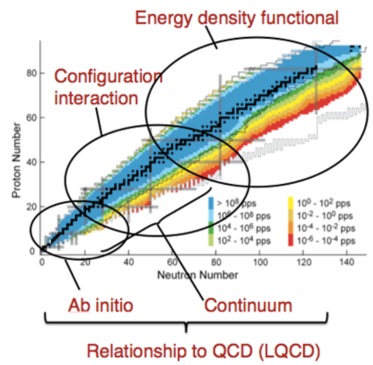
FRIB in the Context of the 2007 LRP

- Recommendation II
  - “We recommend construction of the Facility for Rare Isotope Beams (FRIB), a world-leading facility for the study of nuclear structure, reactions, and astrophysics. Experiments with the new isotopes produced at FRIB will lead to a comprehensive description of nuclei, elucidate the origin of the elements in the cosmos, provide an understanding of matter in the crust of neutron stars, and establish the scientific foundation for innovative applications of nuclear science to society.”

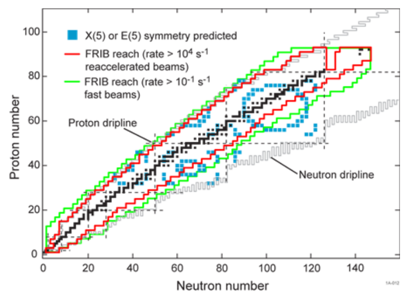


Scientific Aims of FRIB

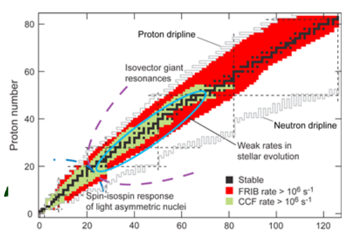
- What is the Nature of the Nuclear Force that Binds Protons and Neutrons?



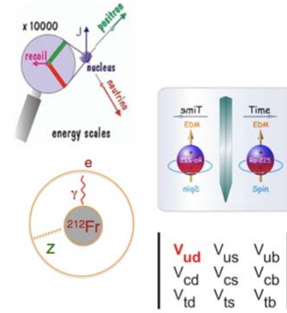
- What is the Origin of Simple Patterns in Complex Nuclei?



- What are the Nuclear Reactions that Drive Stars and Stellar Explosions?

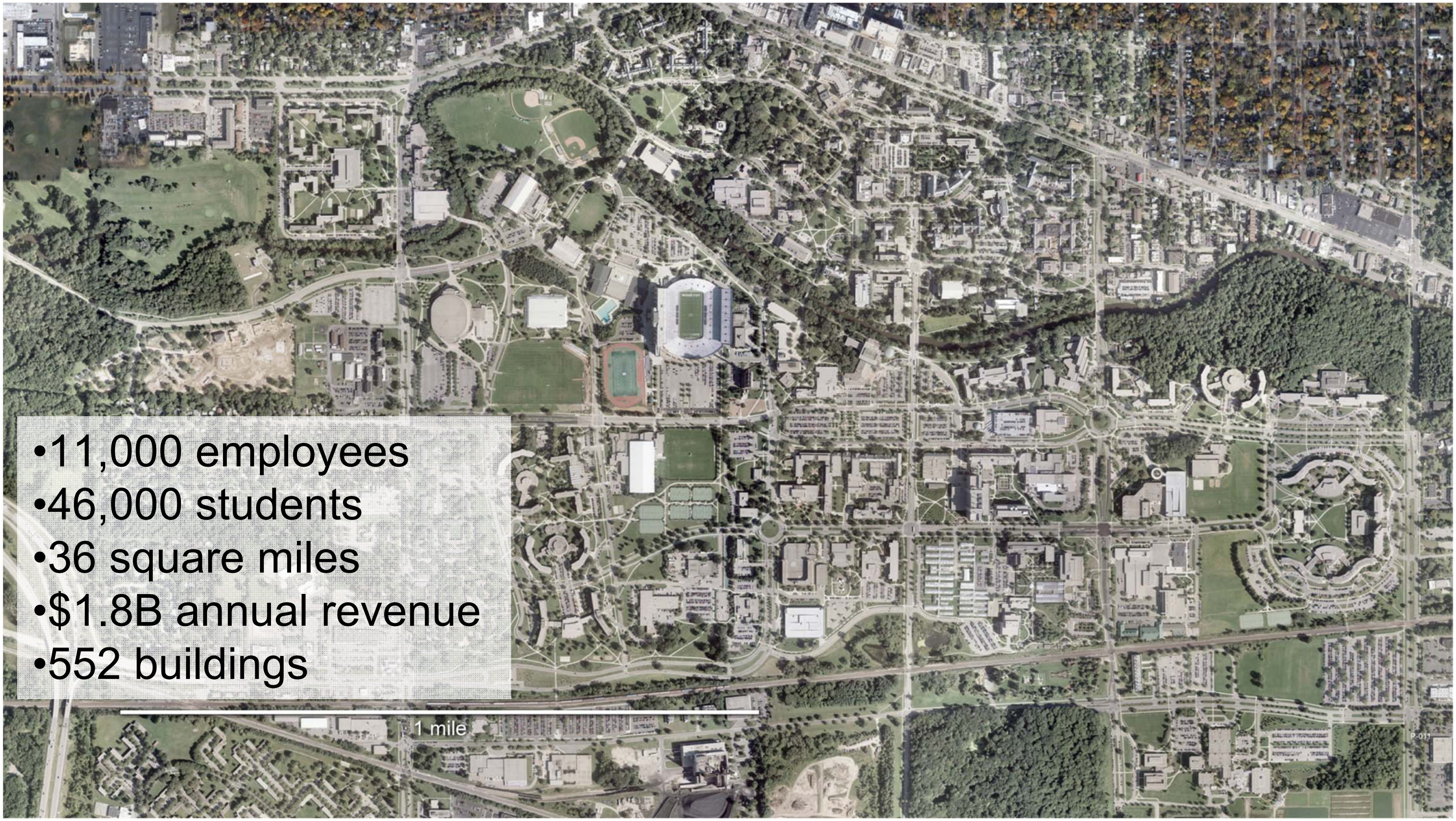


- Tests of Nature's Fundamental Symmetries



- Applications to Societal Needs

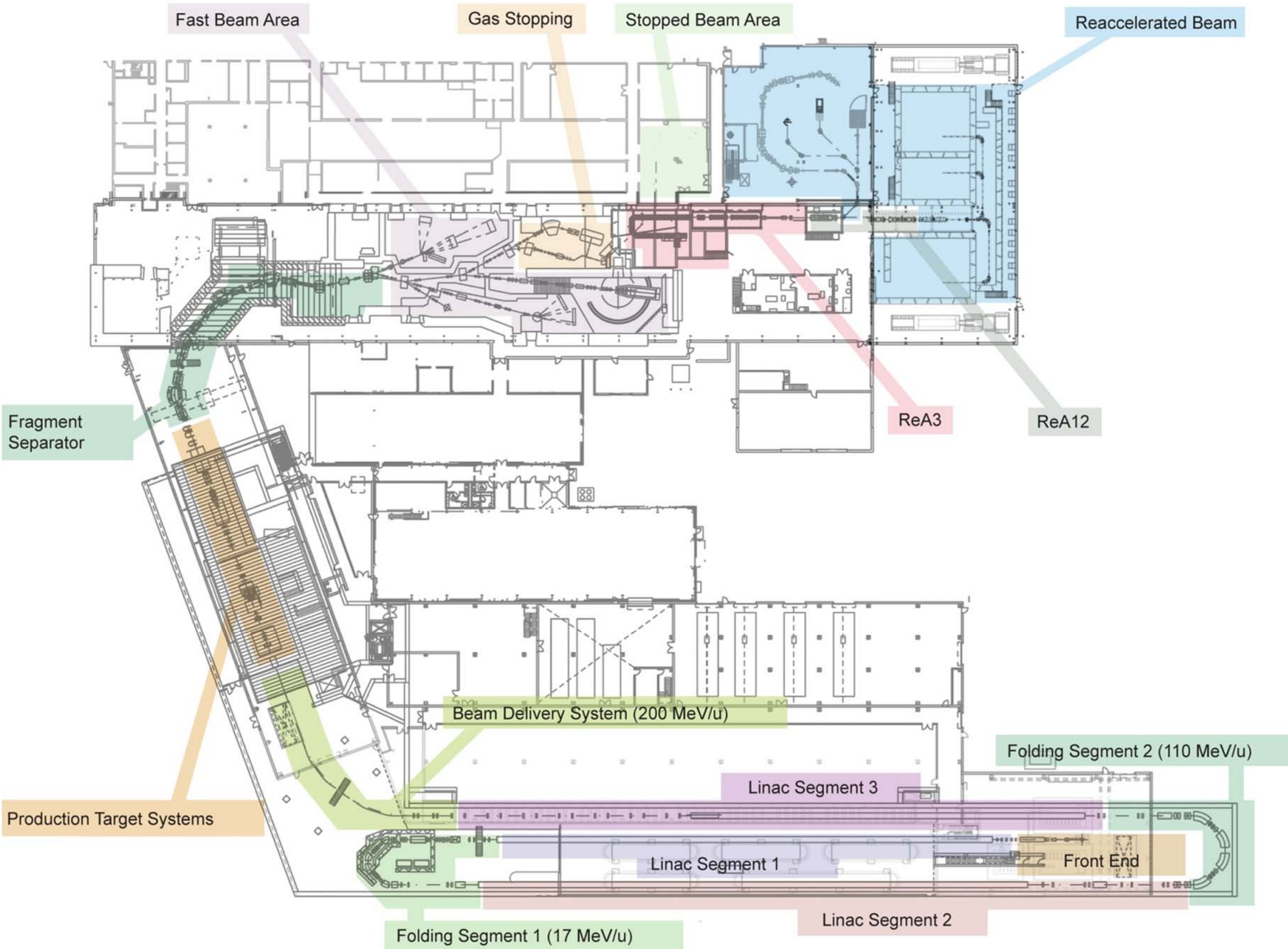
DOE signs Cooperative Agreement with MSU (June 10)



FRIB Key Performance Requirements

- superconducting heavy ion driver linac ≥ 200 MeV/u, 400 kW
- Initial capabilities should include fragmentation of fast heavy ion beams combined with gas stopping and reacceleration
- Capable of world-class scientific research program at start of operation
- Accommodate 100 users at a time, 400-500 per year
- Funding profile constraints

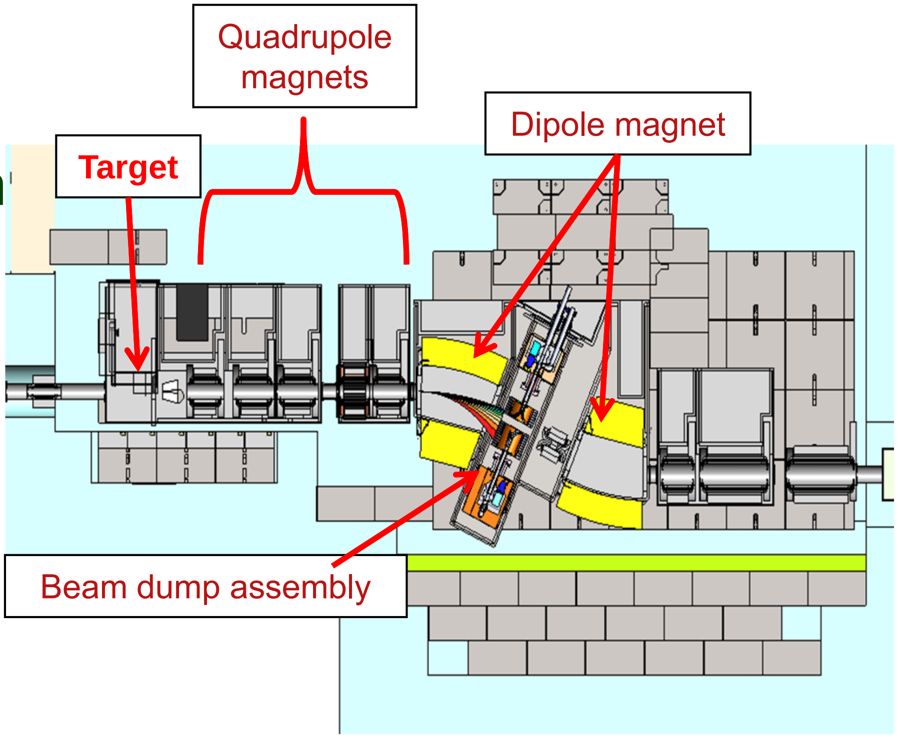
FRIB CD-1 Conceptual Design



Scope and Technical Requirements

Rare isotope beam production with beam power of 400 kW at 200 MeV/u from C to U

- Up to 200 kW in a ~ 0.6 - 8 g/cm^2 target for projectile fragmentation
- Optics requirements: 1 mm diameter beam spot; max. extension in beam direction ~ 25 mm
- High reliability – lifetime: 2 weeks
- Ideally one target concept for all primary beams + fragmentation products

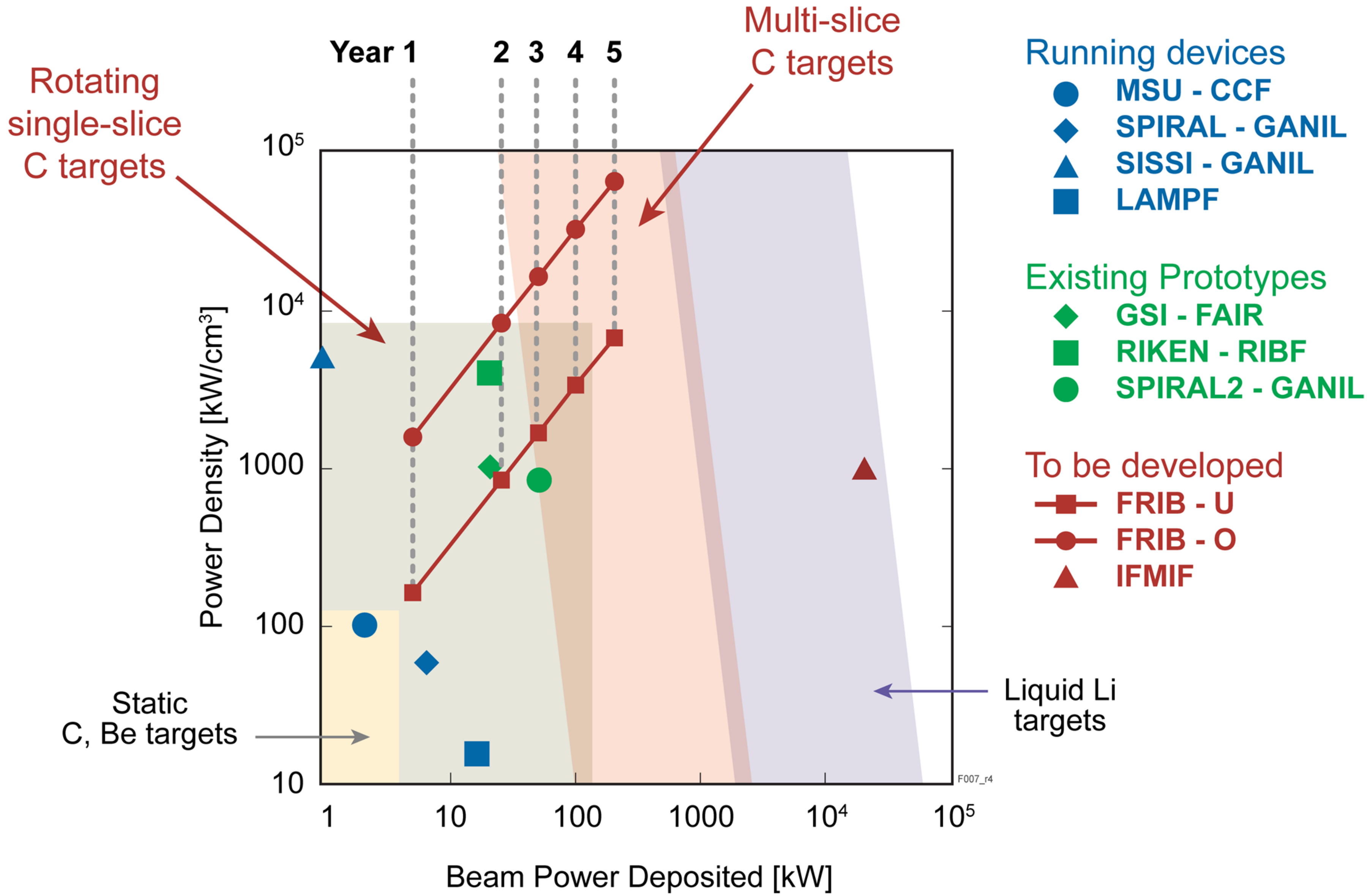


Technical Risk:

- High power density: ~ 20 - 60 MW/cm^3

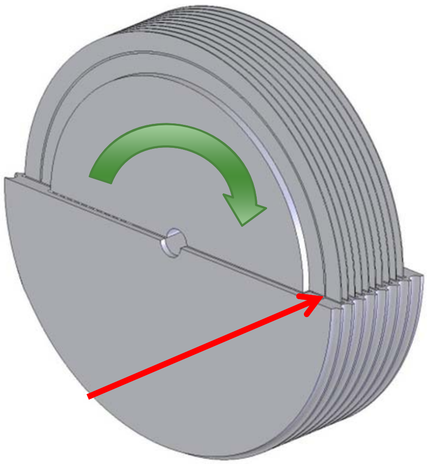
SISSI at GANIL: 5 MW/cm^3
Spiral2 200 kW: ~1 MW/cm^3

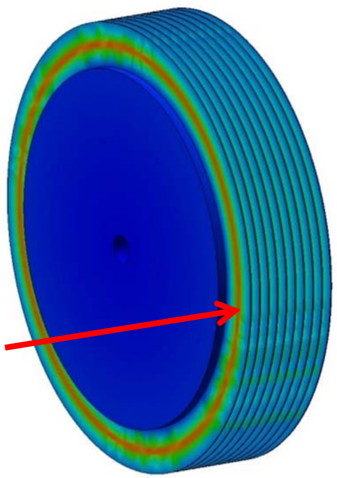
High Power Target Technology



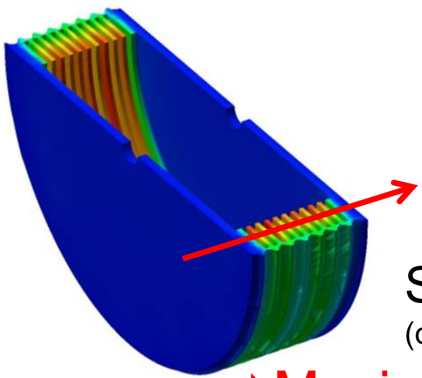
Chosen: Multi-Slice Target Concept

- Concept: radiation-cooled rotating solid-graphite target
- Increasing the radiating area by using multi-slice target

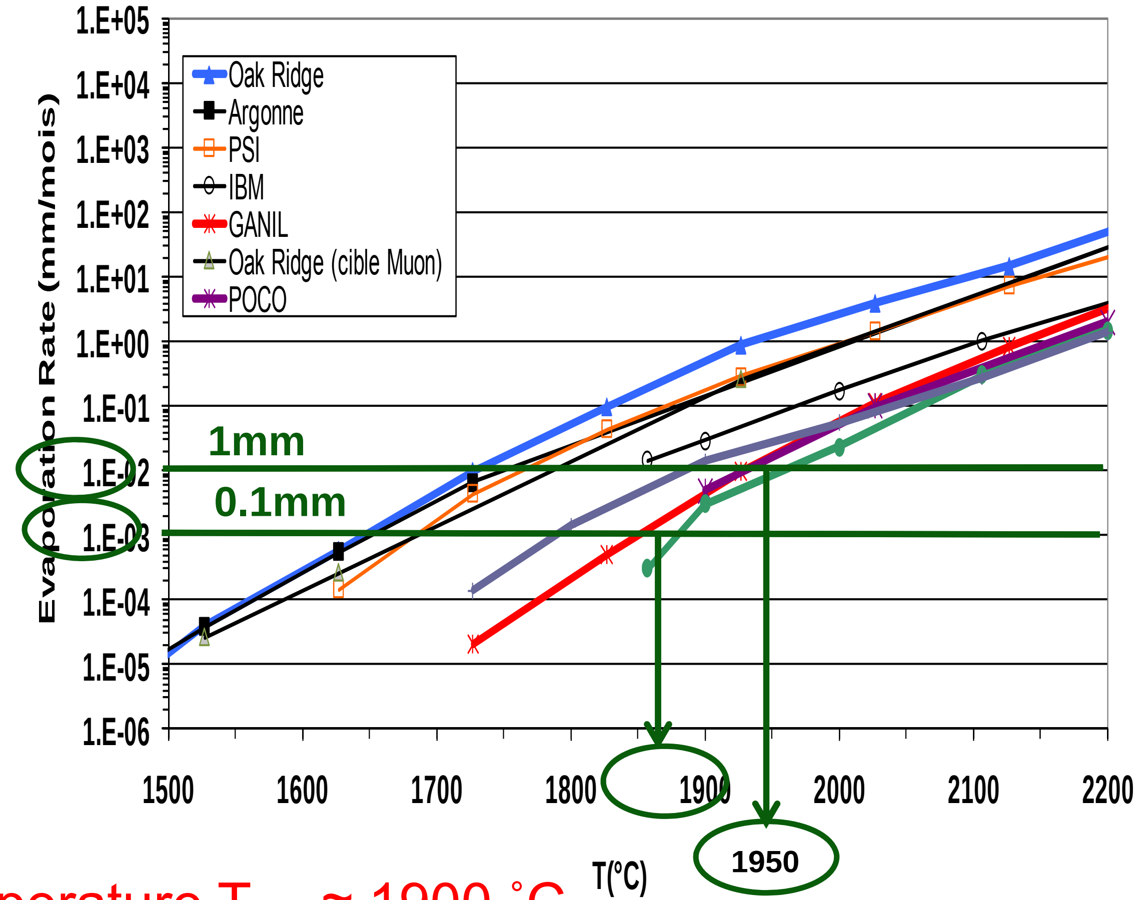




Rotating wheel



Static heat sink
(only lower half shown)



⇨Maximum allowable temperature T_{max}≈ 1900 ˚C

⇨For ΔT~100-200°C ~5000rpm for 30cm wheel

Number of Slices: P_{max} versus Thickness

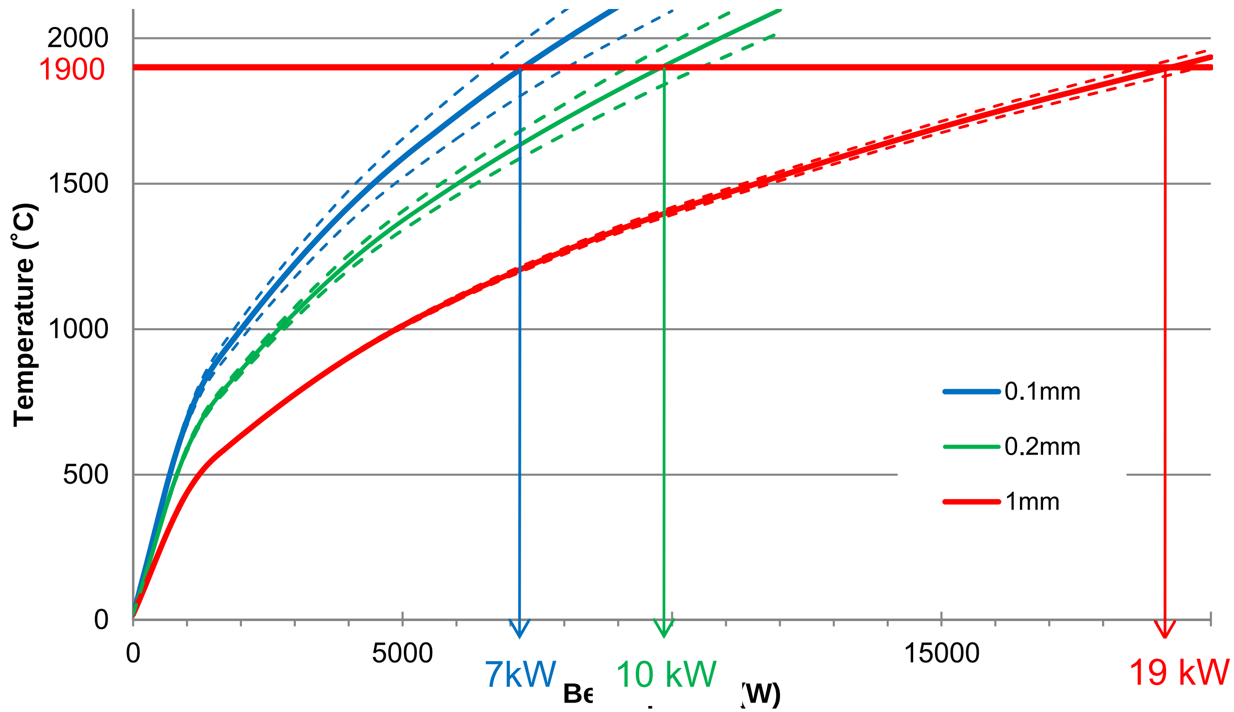
Beam Power = 400 kW; C target density (ρ=1.8 g/cm^3)
Desired maximum extension of target in beam direction ~25 mm

Beam	Target thickness mm for 30 % of range	Number of slices 1 mm thick	Power loss/slice [kW]	Number of slices 0.2 mm thick	Power loss/slice [kW]	Number of slices 0.1 mm thick	Power loss/slice [kW]
C	16	16	4.35				
U	1.68	2	52.3	9	10.38	17	5.17

Target wheel diameter: 30 cm

Maximum power deposition per slice:
P_{max} = 7 kW for 0.1 mm
P_{max} = 10 kW for 0.2 mm
P_{max} = 19 kW for 1 mm

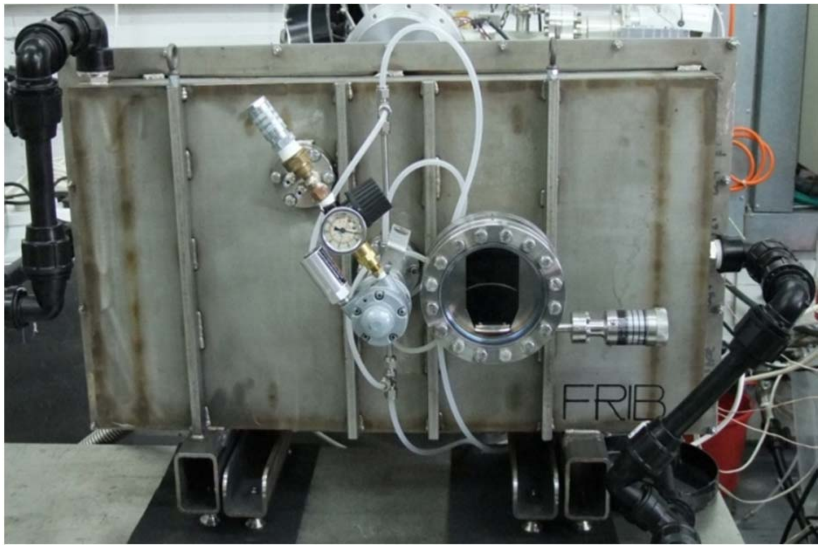
⇨ **Values confirmed in Soreq and Sandia experiments**

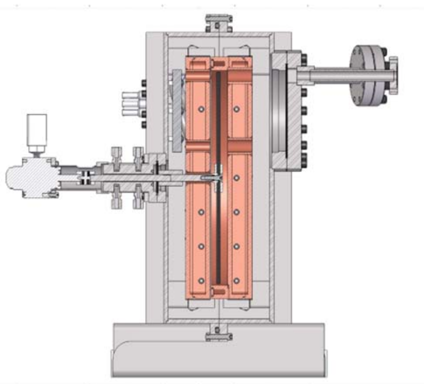


3 Step R&D Program (started in Oct. 2009)

1. Single slice Test Device (~10kW)
2. Multi-slice   Test Device (~5*10kW)
3. Final design

Electron Beam Tests at Soreq (Israel)





- Conditions
  - Spot size: ~3 mm FWHM (limited by electron gun)
  - Power: <20 kW at 20 keV (range ~5.4 μm)
- Targets tested
  - Border thicknesses: 0.1, 1 mm
  - Border width: 15 mm
  - Diameter: 10 cm and 30 cm

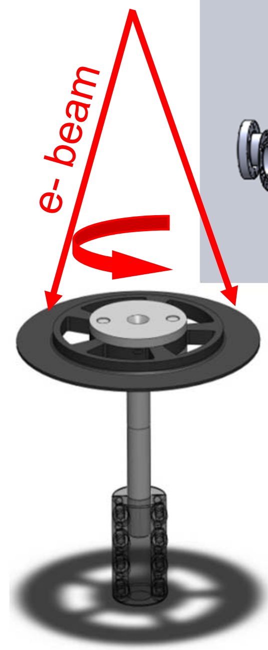
    (10 cm target requires only 25% of power for similar thermal conditions as for a 30 cm target)
- Example:
  - 30 cm diameter, border thickness 0.1 mm
    - » Graphitech, 5 μm grain size: $1500
    - » Carbone of America, 3 μm grain size: $2300

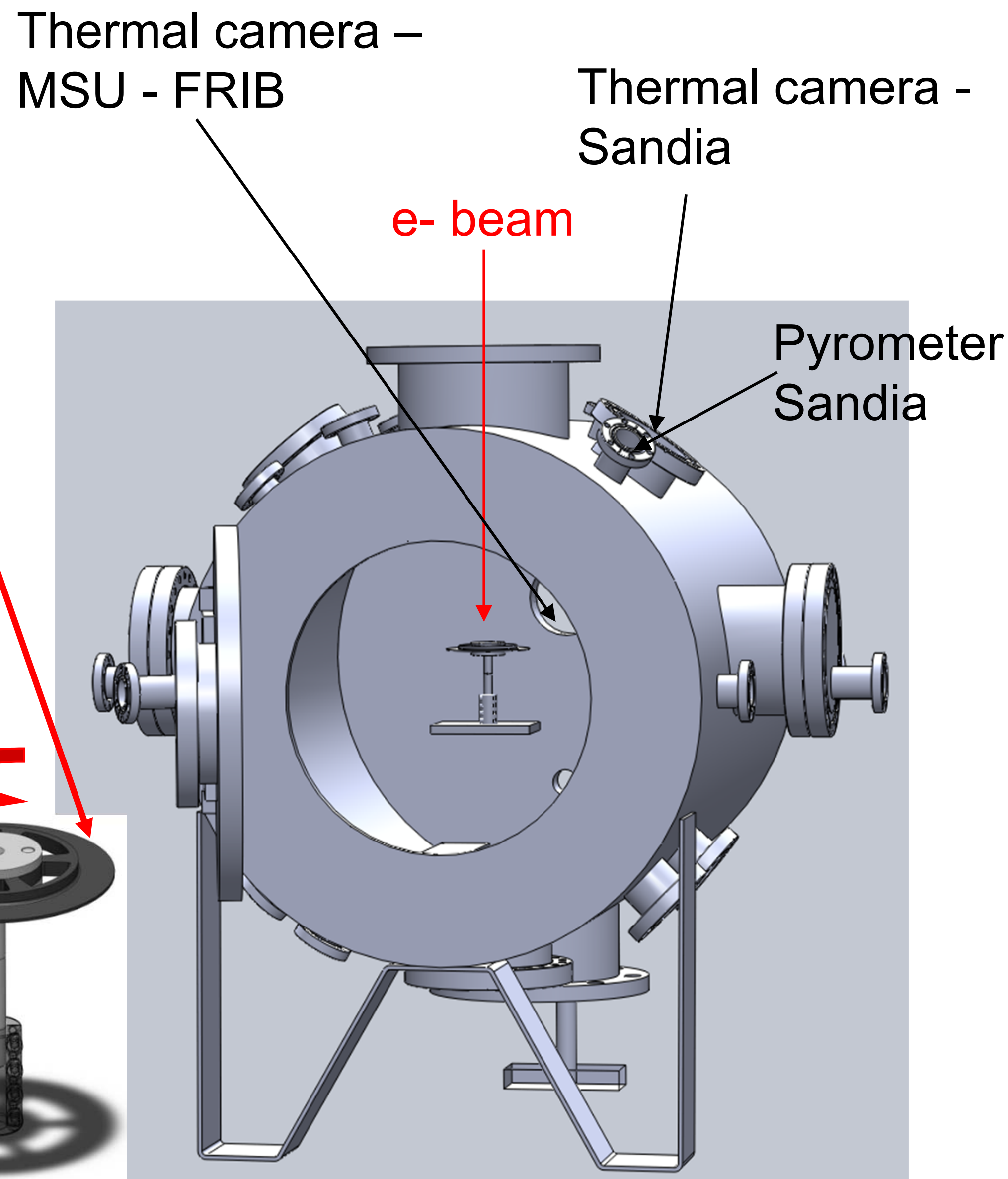
Design: J.Oliva, D.Ippel, T.Xu, W. Mittig, F. Pellemoine   Tests: J. Lenz, W. Mittig, F. Pellemoine, Soreq Team

30cm Target 0.1mm border

Electron Beam Tests at Sandia, NM USA

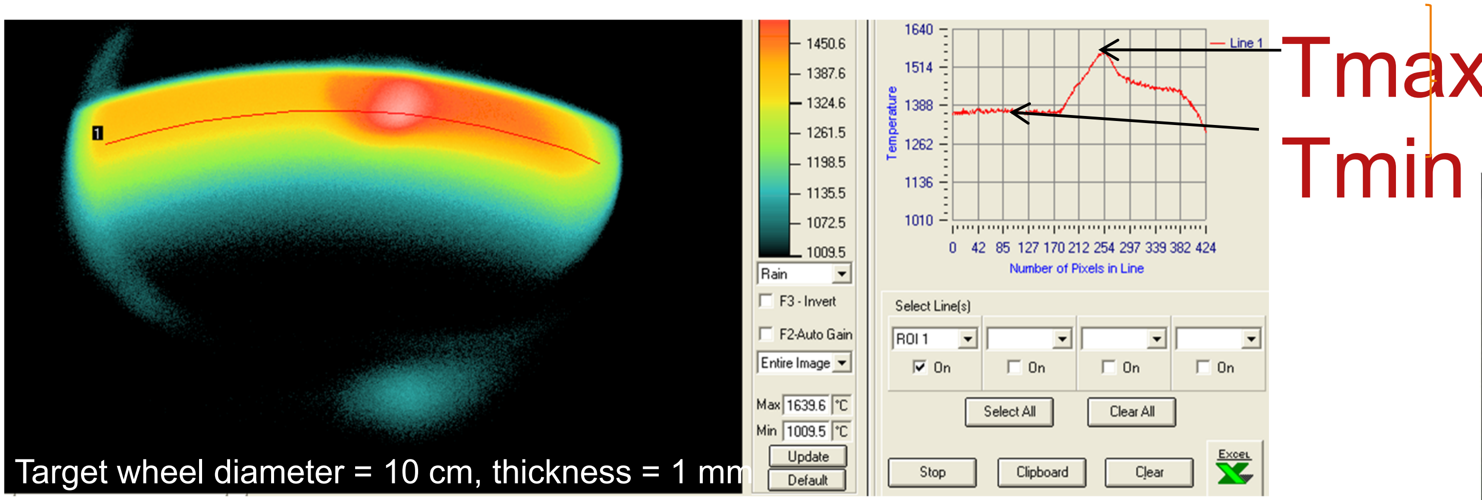
- **Purpose**
  - Static target and rotating beam to study deformations of the border (high temperature and rotation)
- **Targets tested**
  - Border thicknesses: 0.1, 0.3, 1 mm
  - Diameter: 10 cm
- **Conditions**
  - Spot size ~ 2 mm FWHM
  - Power < 20 kW at 22 keV
  - Range ~ 6 μm

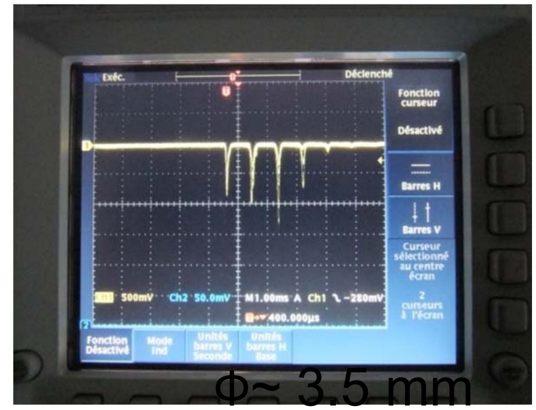


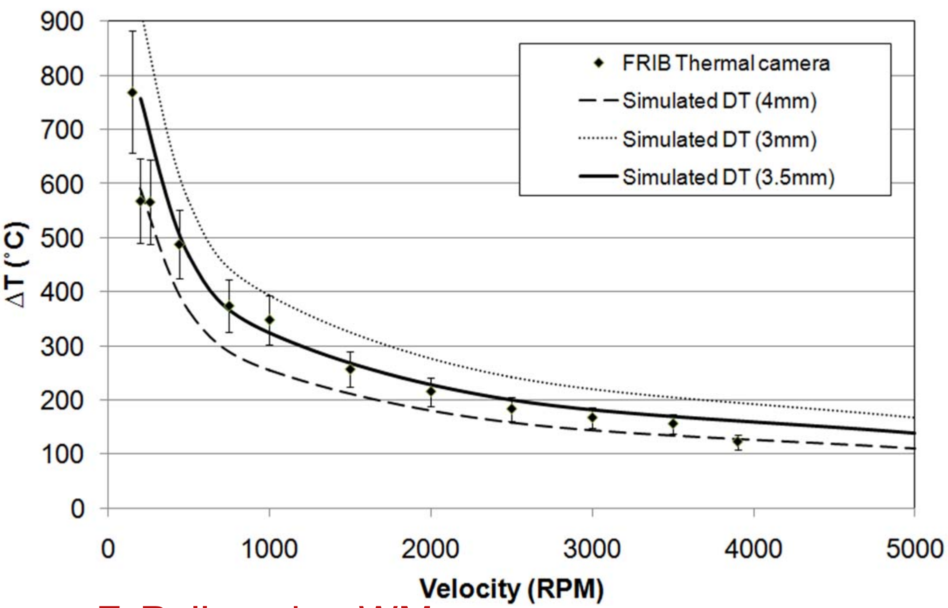


F. Pellemoine, W. Mittig, Sandia Team

Comparison of Experiment to Simulation : temperature variation





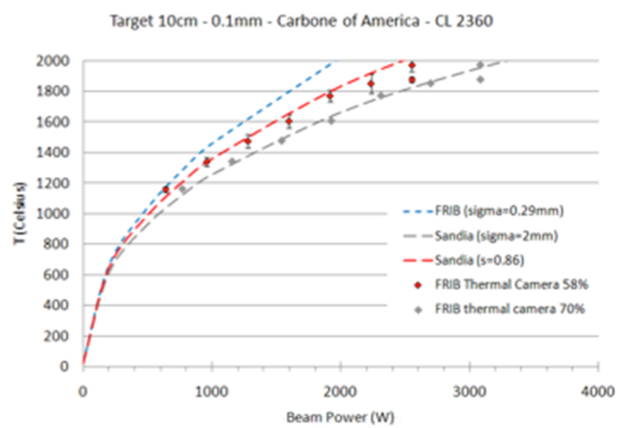


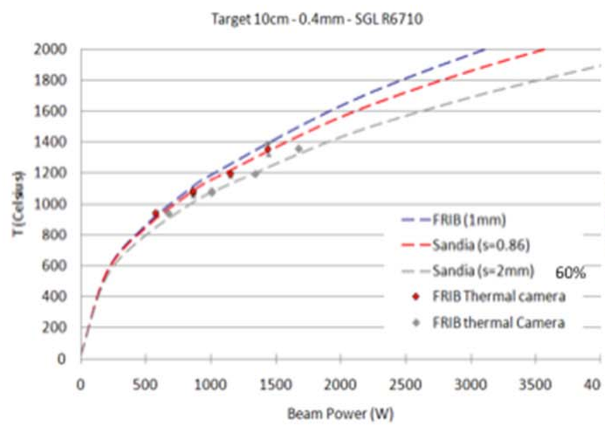
F. Pellemoine,WM

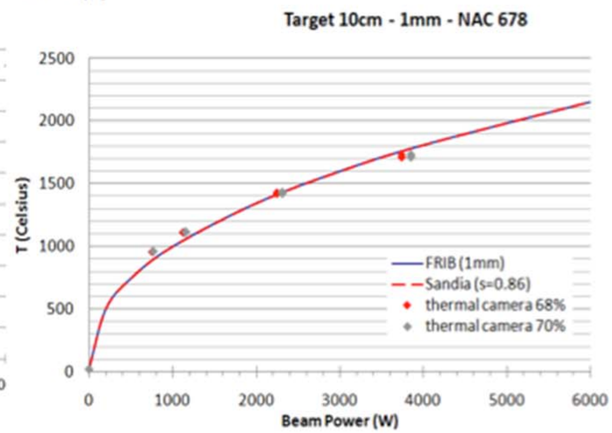
- SOREQ Beam
  - ΔT max measured = 750° C
- FRIB Beam
  - σ = 0.26 mm
  - 10kW/slice
  - ΔT simulated = 310° C for thickness = 0.2 mm
  - ΔT simulated = 60° C for thickness = 1 mm

Comparison of Experiment to Simulation: using power fraction of e-beam power absorbed

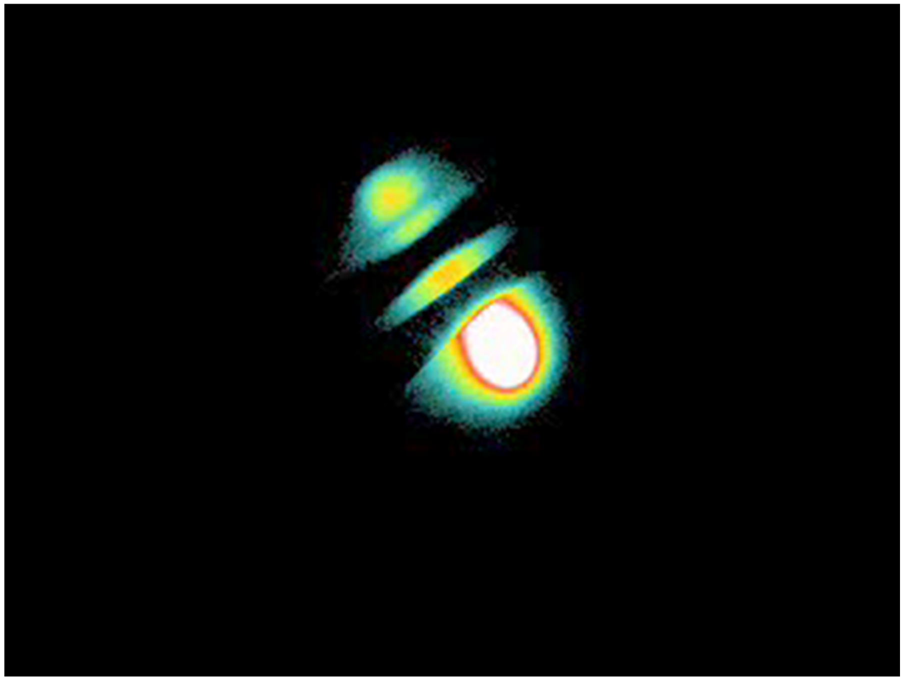
- Sandia condition: 10 cm / 0.1 mm target, $P_{max} \approx 2.9$ kW
  - Corresponds to ~11.6 kW for a 30 cm / 0.1 mm target for FRIB beam profile (1 mm diameter)
- Comparable to FRIB condition for 400 kW U beam: $P_{max} = 5.2$ kW / slice



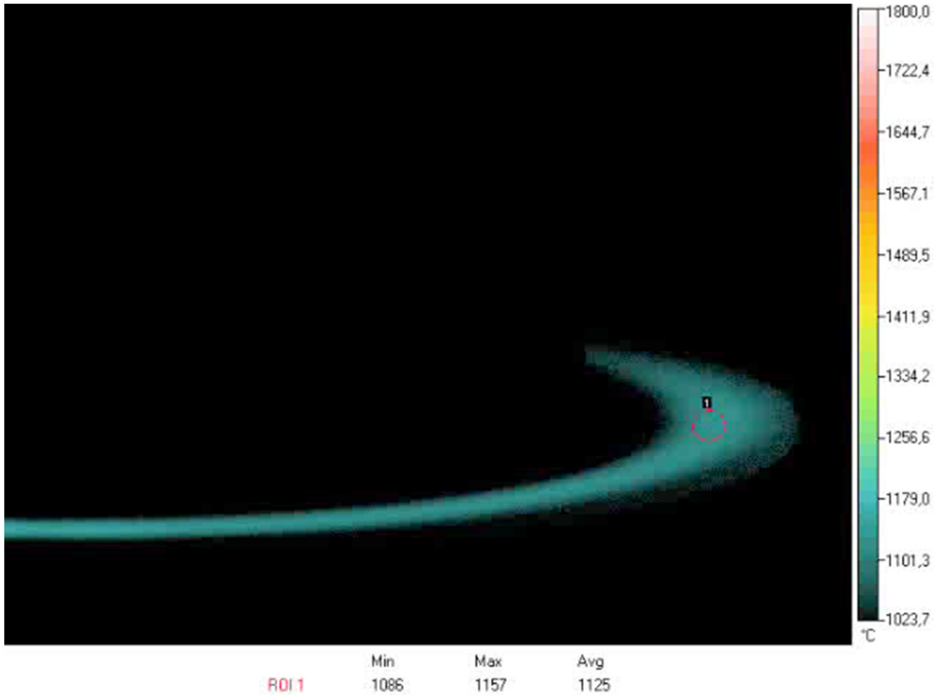




Destructive tests

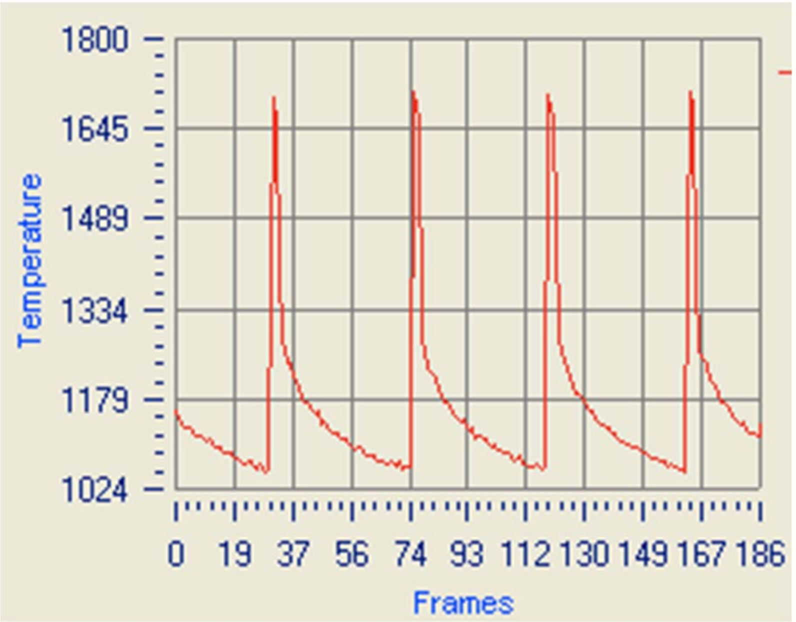


Soreq 2kW, 1mm, stopped

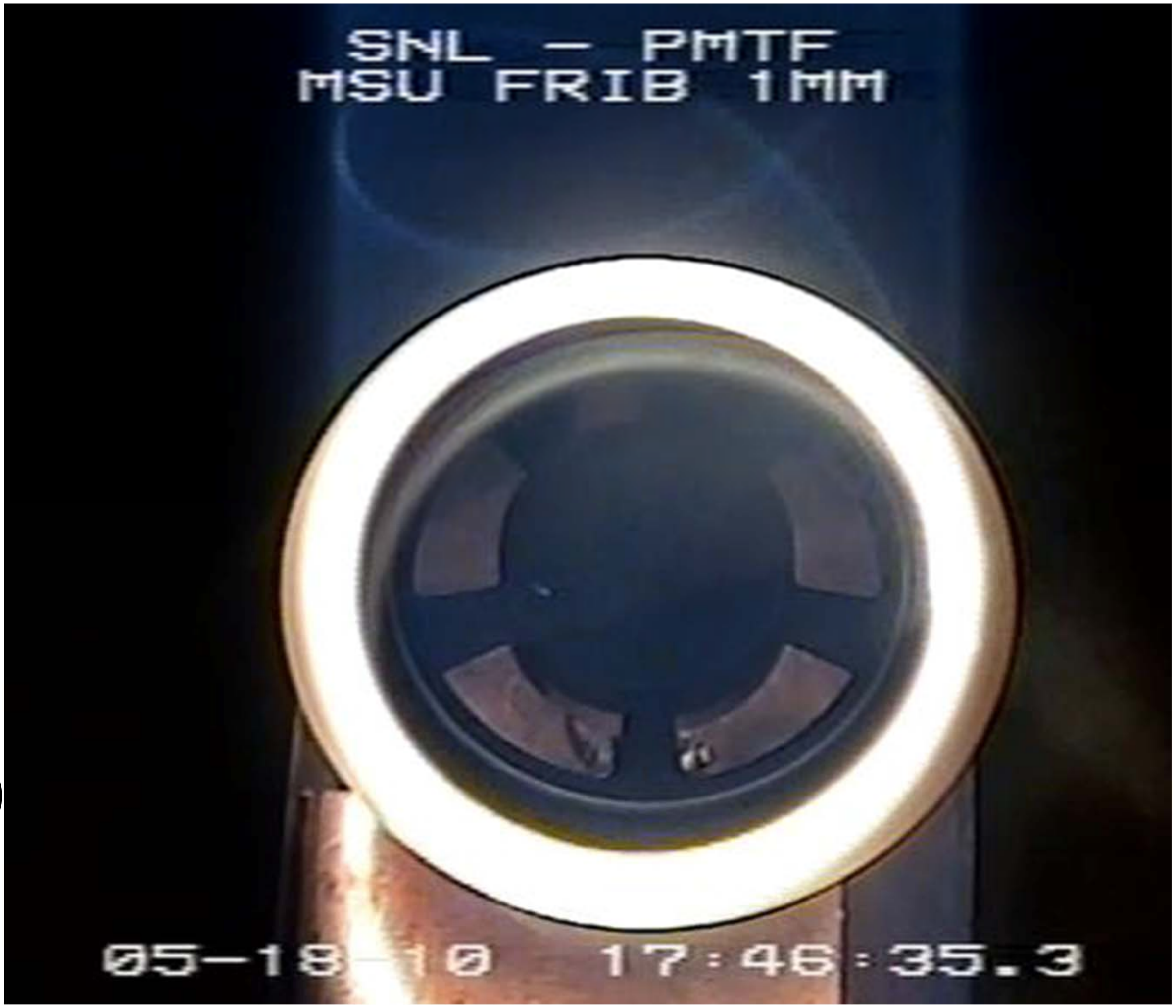


Sandia 2kW, 1mm, Beam 1 rot/s

Extreme Conditions at 1Hz (target 10cm-1mm)

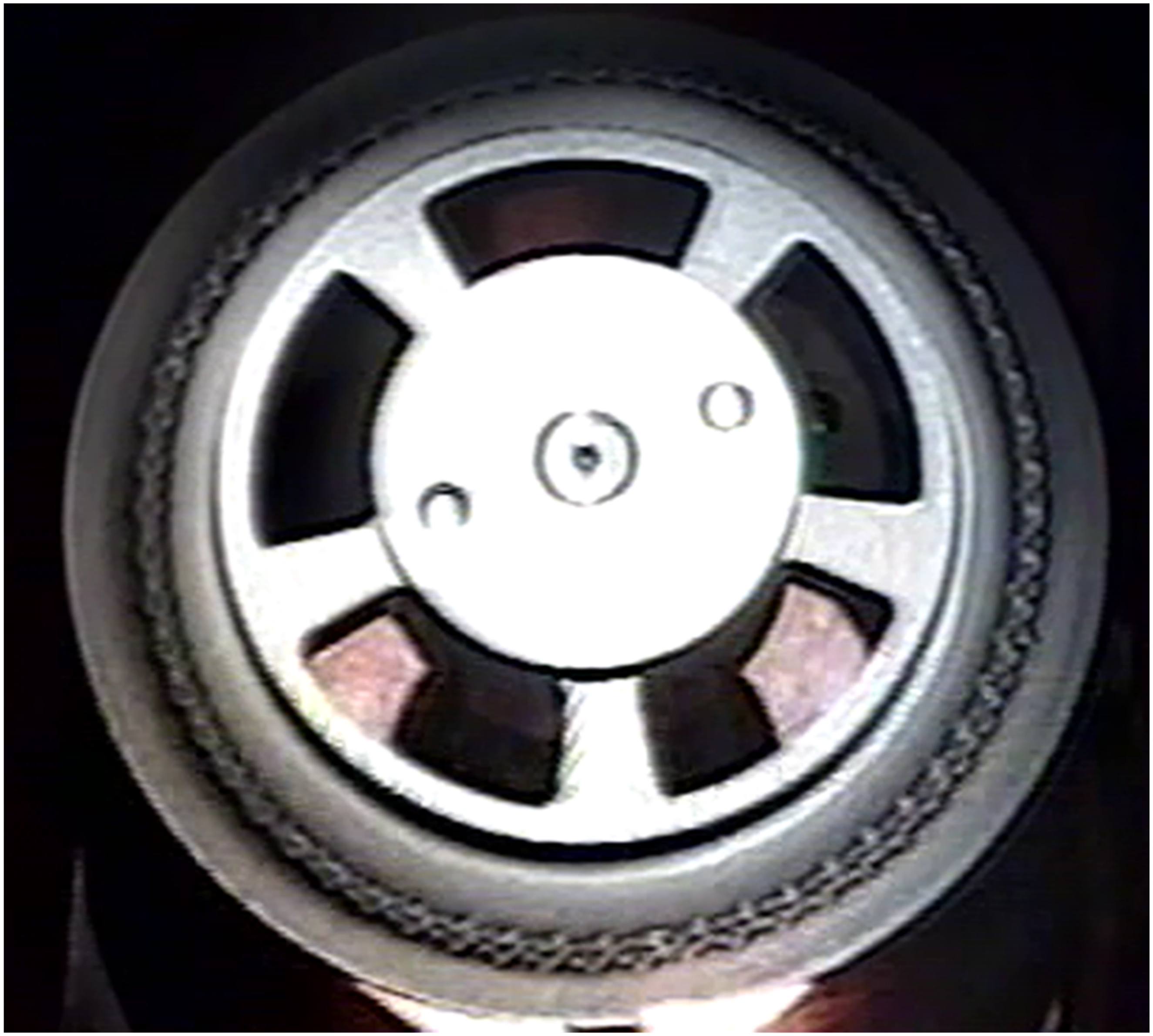


1.65kW ΔT 640 deg
(estimated DT=780deg)
3.3 kW ΔT 1800 deg



Plasma Effect (3.3kW)

Extreme Conditions



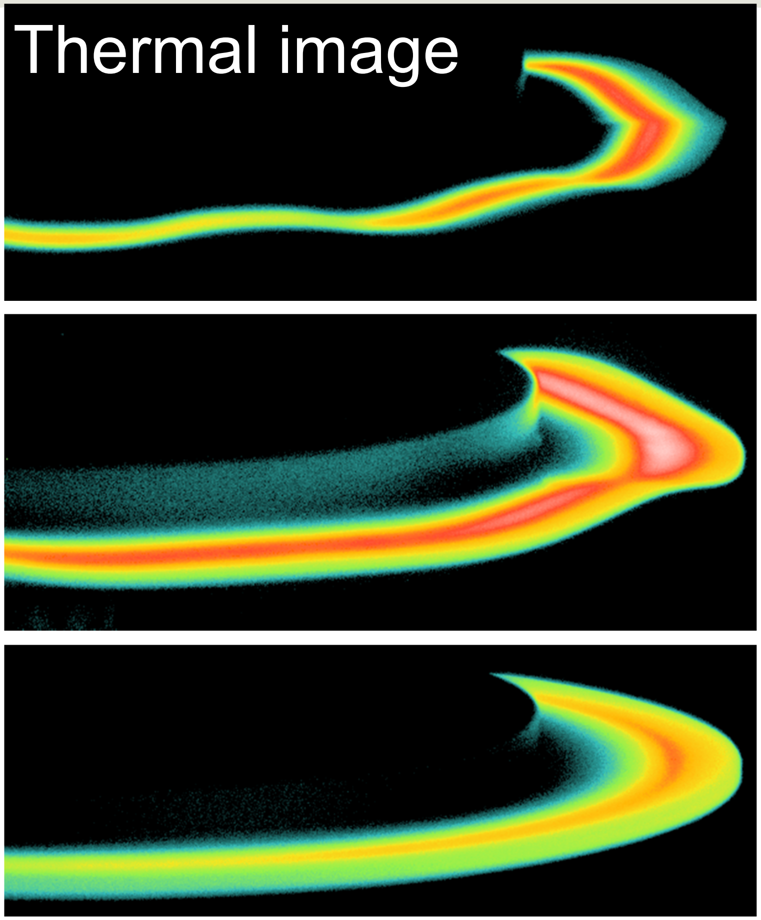
Destructive tests: conclusion

Rescaled to a 30cm diameter target:

With standard precautions (rounding of corners, avoid thermal shocks,…) there is no thermo-mechanical failure at the level of ~10kW power absorbed, as well for thin (0.1-0.3mm) as well for thick (0.5-1mm) targets

We reached a power density of ~ 60MW/cm3 with the 30cm diameter 0.1mm thick target

Observation of Deformations

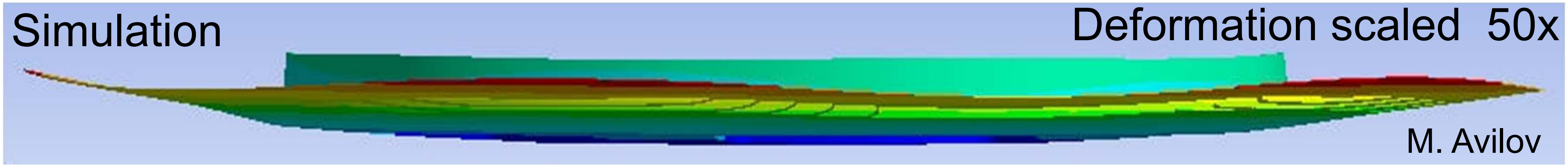


Target 0.1 mm at 1200 ° C (P = 1100 W)
Carbone of America

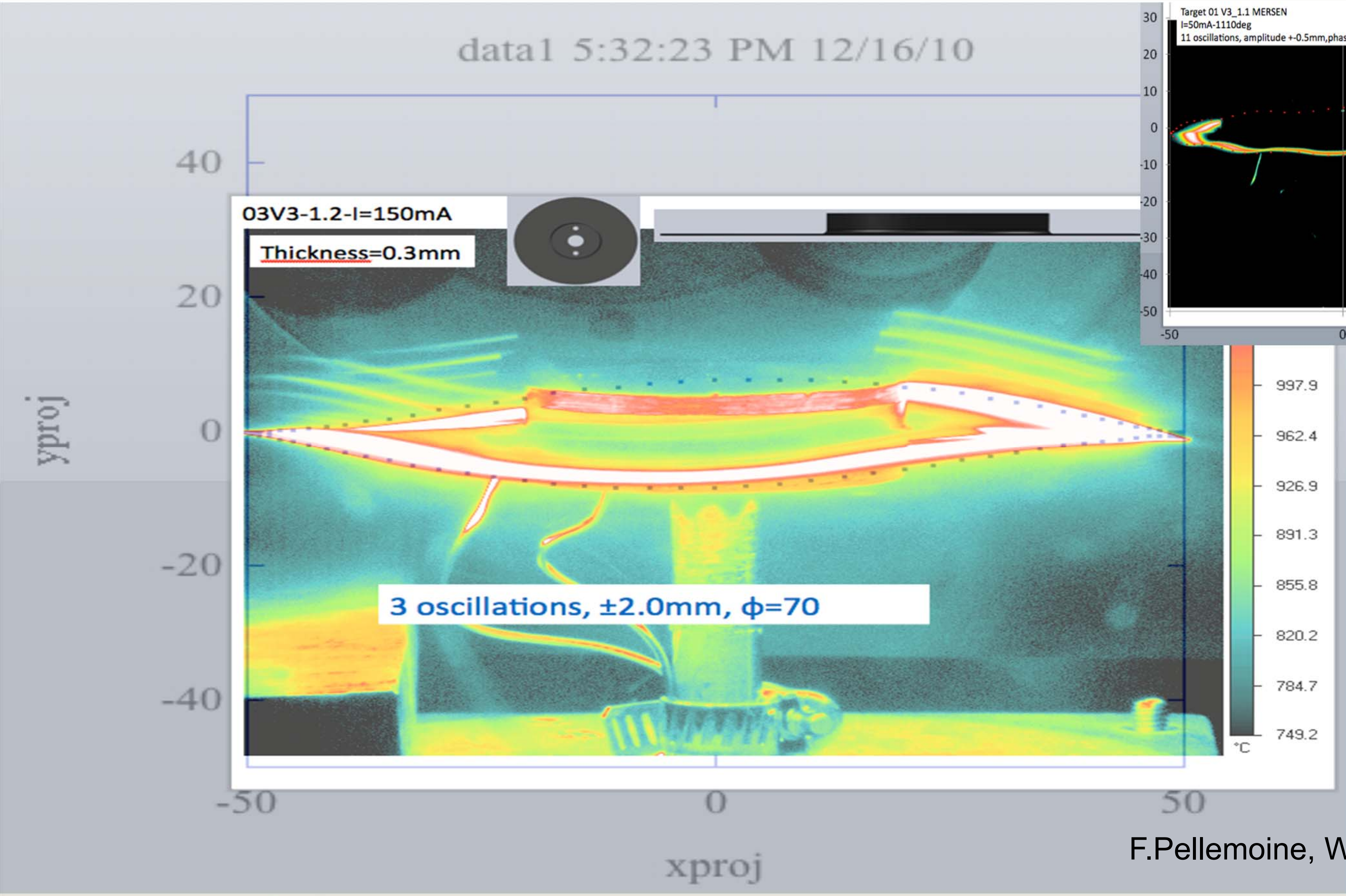
Target 0.3 mm at 1200 ° C (P = 1760 W)
Graphitech

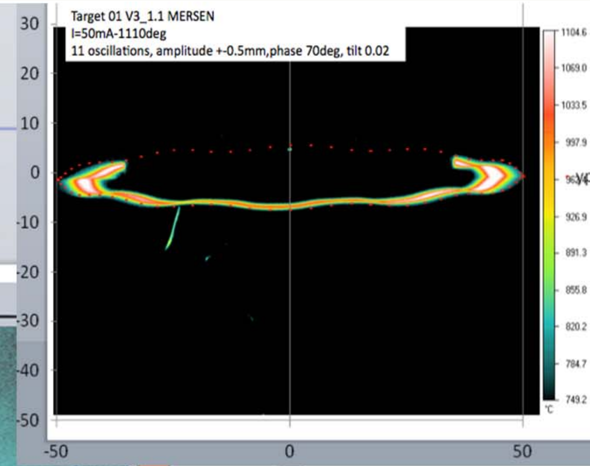
Target 1 mm at 1200 ° C (P = 2420 W)
GMI

F.Pellemoine, W.Mittig,+Sandia



Deformation analysis





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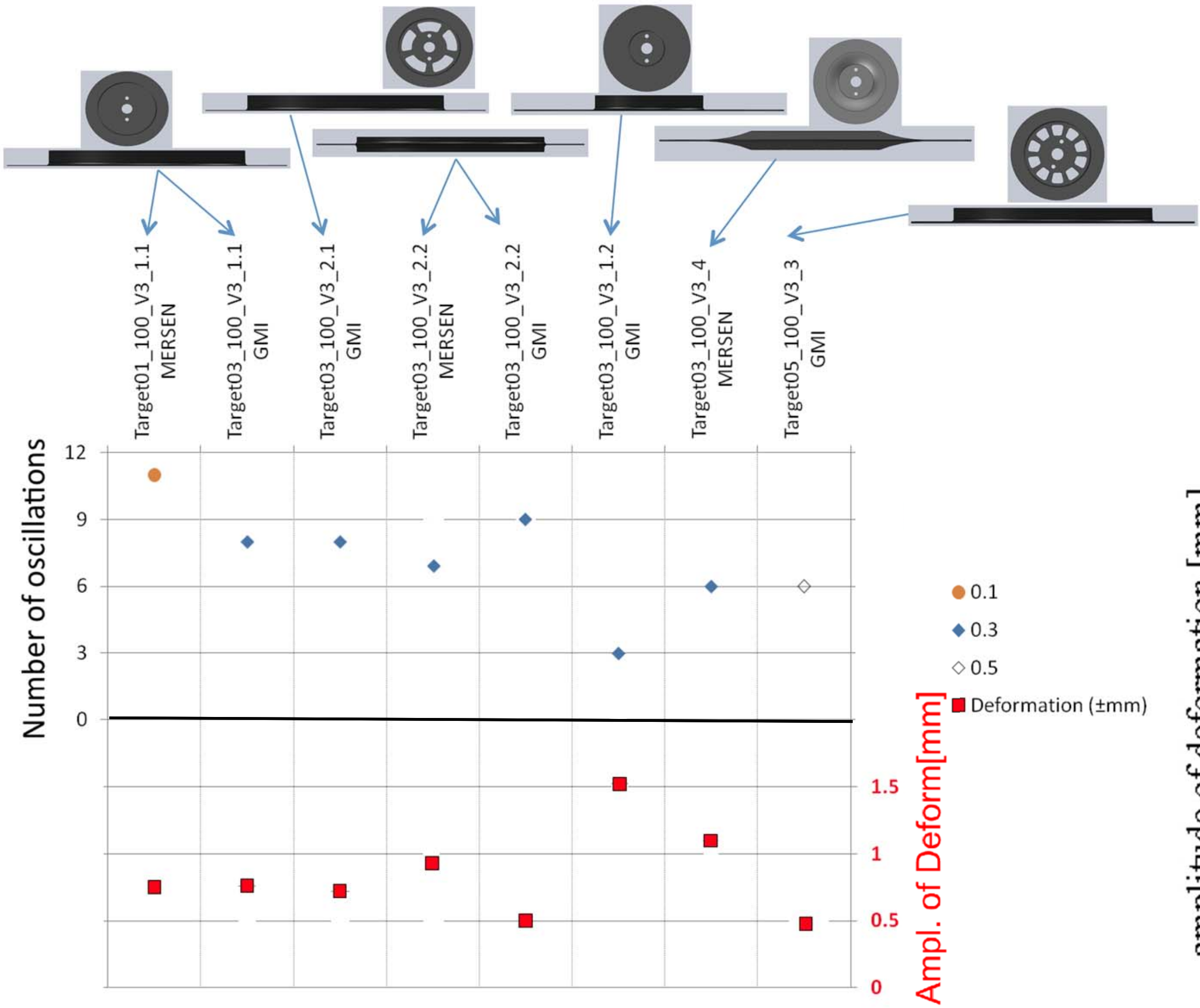
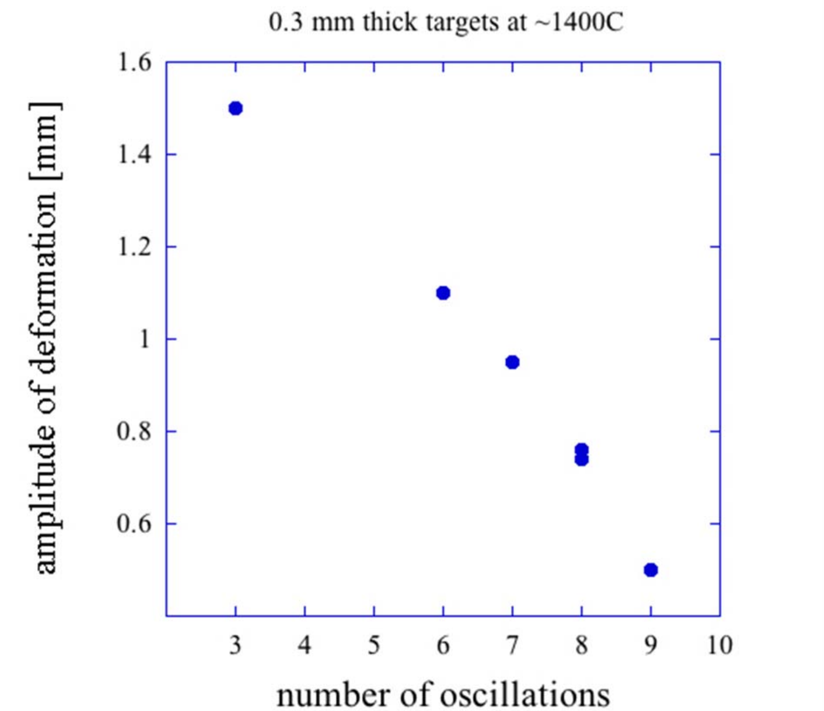
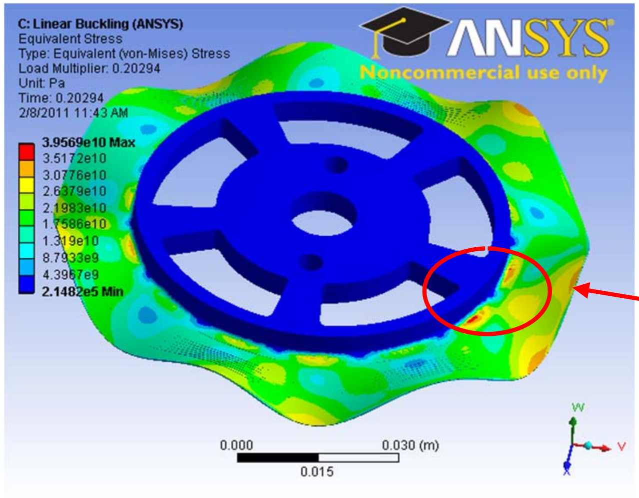
Deformation: analysis results

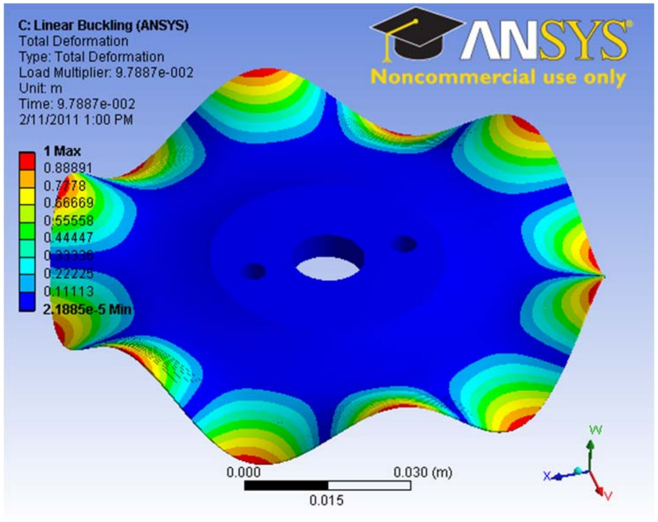


-Does not depend on the geometry of the spokes!
-Nosc*amplitude=const



Buckling



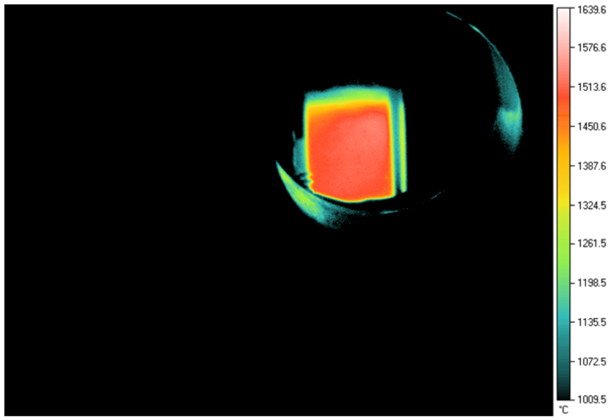


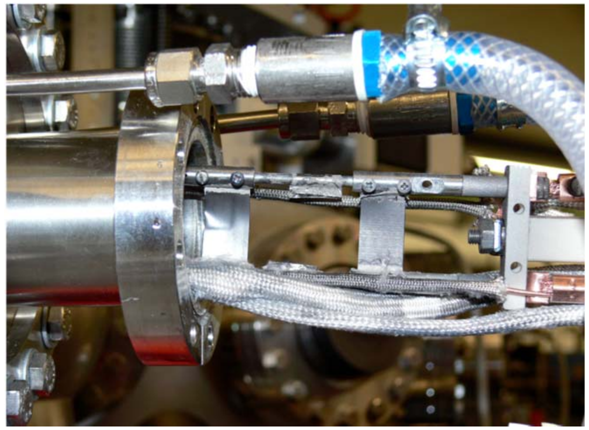
Thermal shocks:
Beam on-off

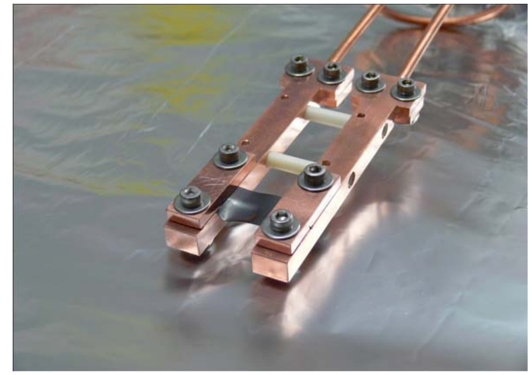
Deformation: Conclusion

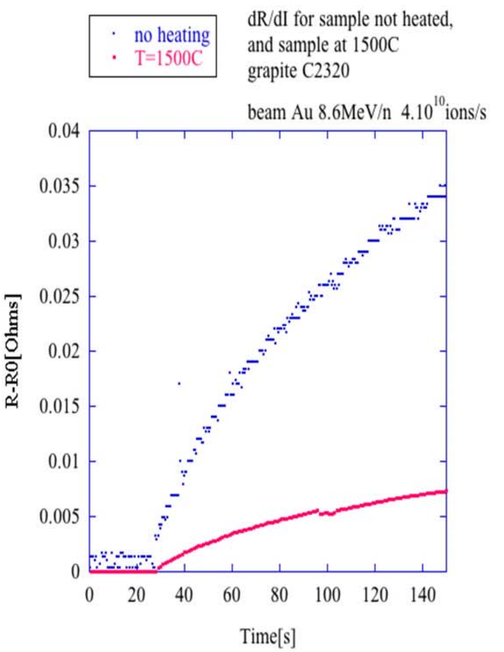
- Significant thermo-mechanical deformations were observed for the thin targets (0.1-0.3mm)
- The deformation does not depend on the geometry of the spokes; the product of N_{osc}*A=const
- Simulations with pre-deformation of small amplitude and the observed period reproduce the observed amplitude and the temperature dependence; buckling calculations give the correct number of oscillations
- The amplitude is limited to ±1mm, so there is enough space between the cooling fins for the multi-slice target (available=+-2.5mm); for thicker targets (~≥1mm) no deformation effect observed

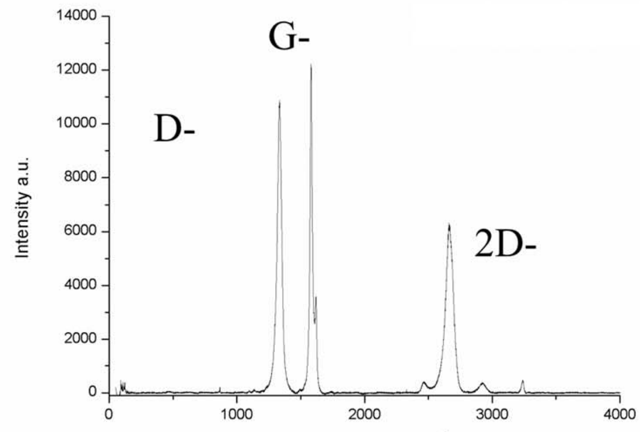
Radiation Resistance and Annealing: GSI

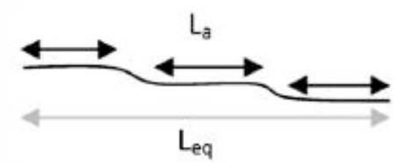












	Pristine	Only Beam heating~600 °C 10^{14} i/cm²	900 °C; 10^{14} i/cm²	1500 °C; 10^{14} i/cm²	1500 °C; 10^{15} i/cm²
L_a	4.3	2.9	4.2	5.5	4.6
L_{eq}	11.0	4.0	8.3	8.6	14.5

Summary of Tests with Single-slice Targets Performed

- Power deposition capability of a single slice as needed for FRIB for 200 MeV/u 400 kW beams up to U demonstrated
  - Based on a number of test with different targets (diameters 10 cm and 30 cm, thicknesses from 0.1 – 1mm, different graphite target material)
- Annealing of heavy-ion radiation damage on graphite at high temperature demonstrated (see M.Tomut, Thursday)
  - First experiment of this kind
  - Promises sufficient lifetime for FRIB beam production targets
- Next step: development of 50 kW prototype

Multislice prototype Target (5*10kW)

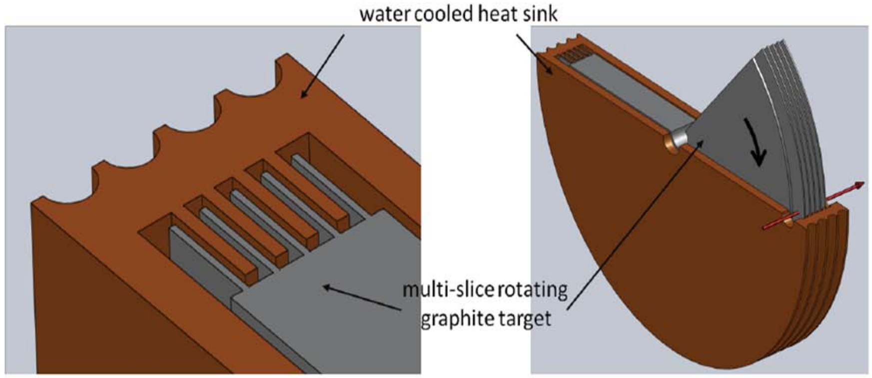
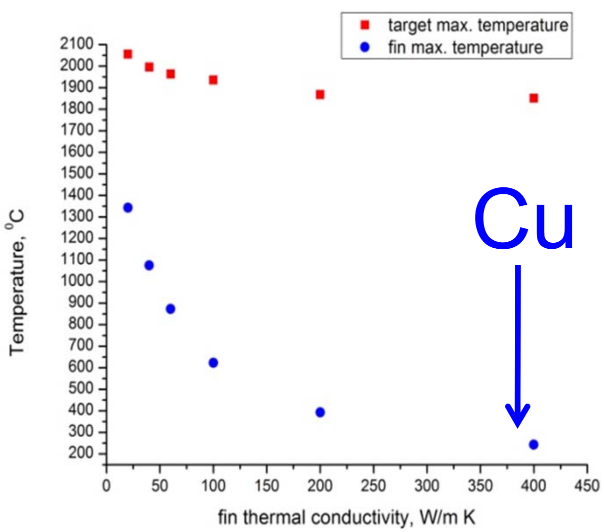
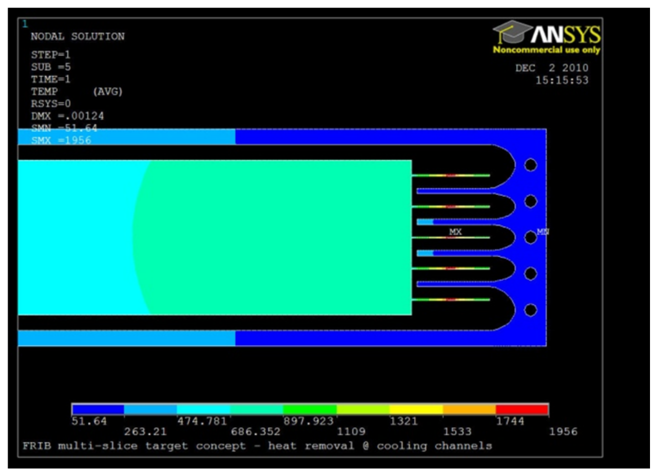
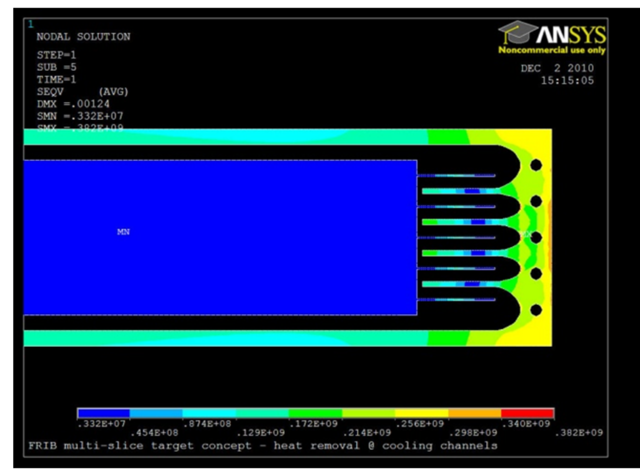


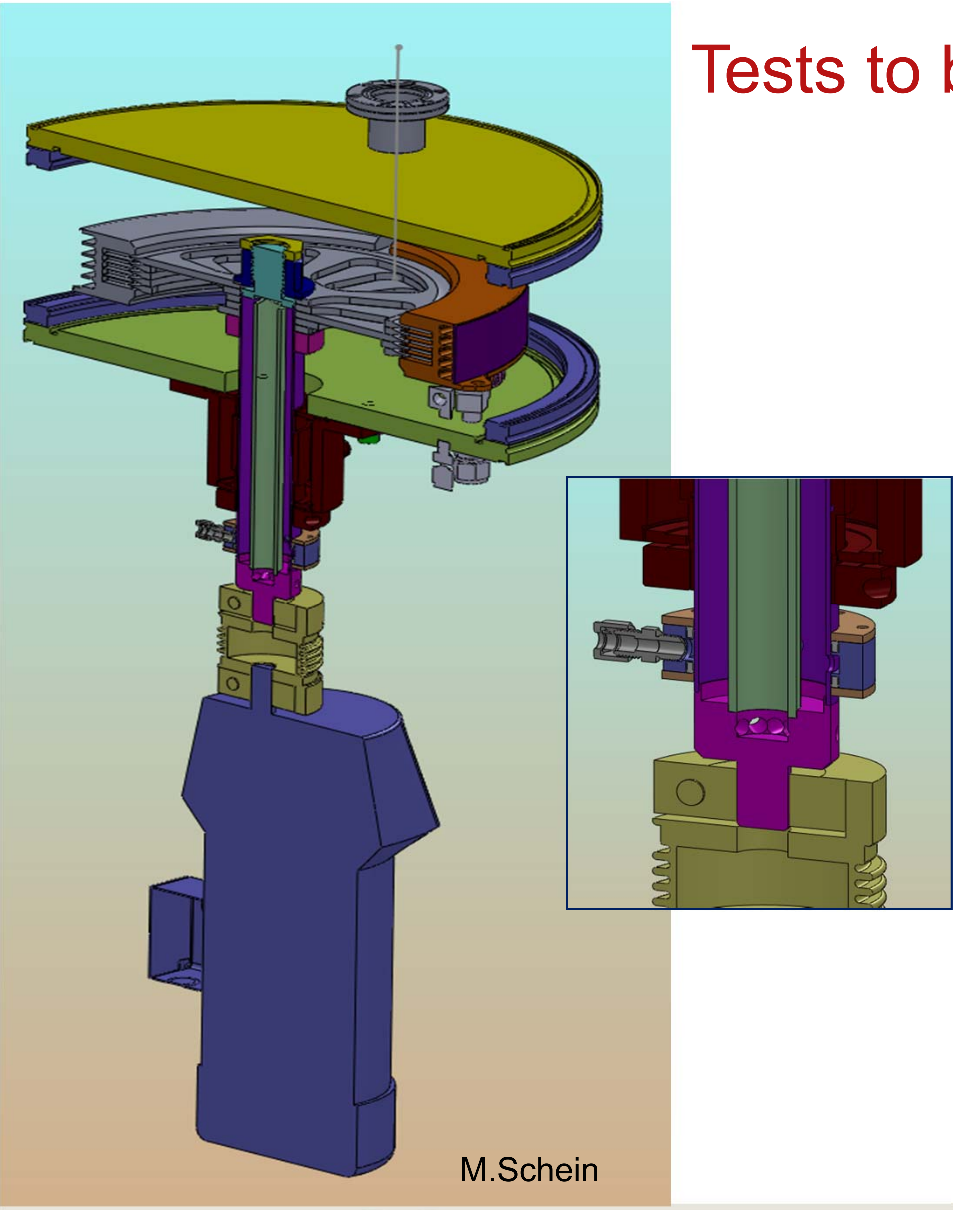
Figure 3 - Concept of solid multi-slice rotating graphite target. A water cooled heat sink with fins between each slice will absorb and remove the heat from the target (only the lower half of the heat sink is shown).







50kW multi-slice Target

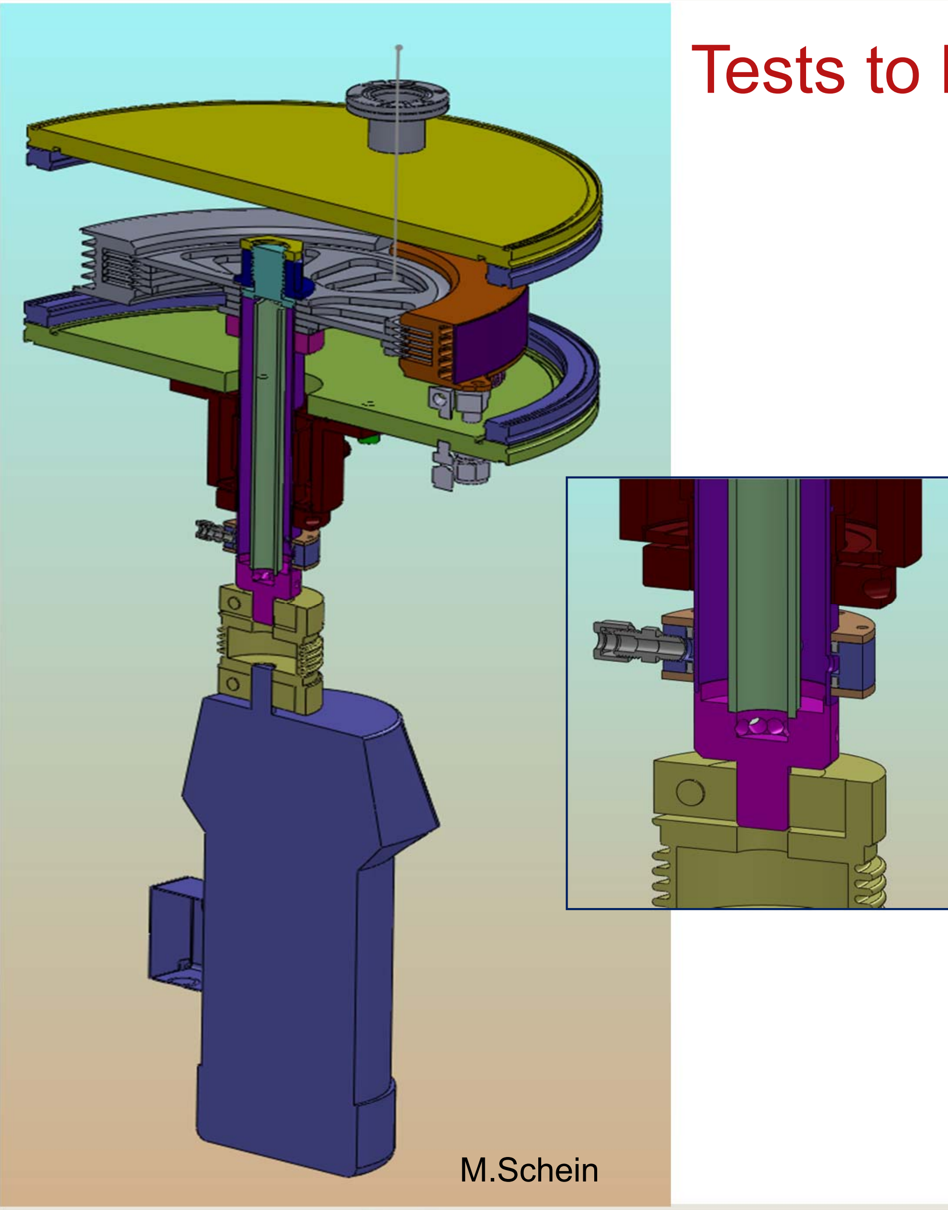


Tests to be done: ~1MeV electrons 50kW

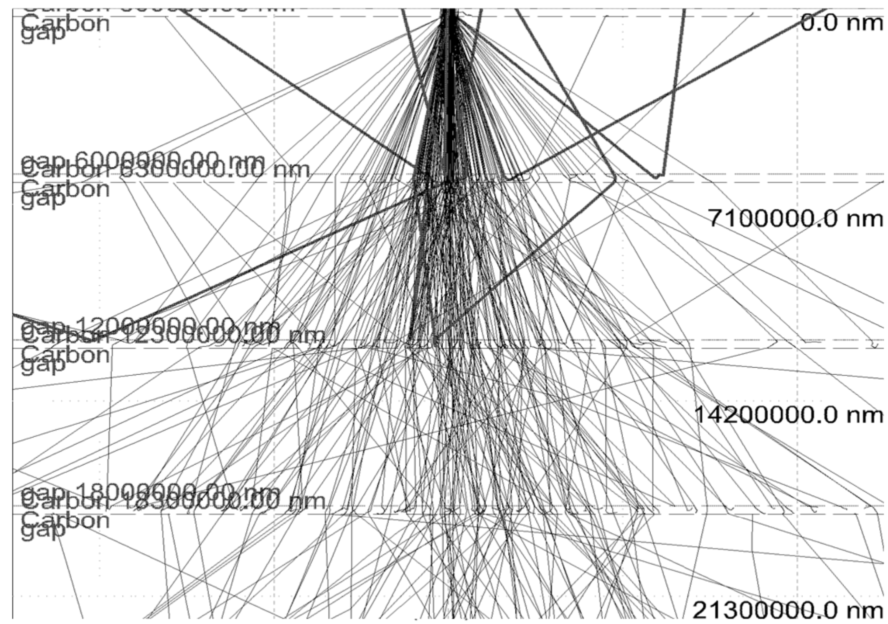
Conclusion ?

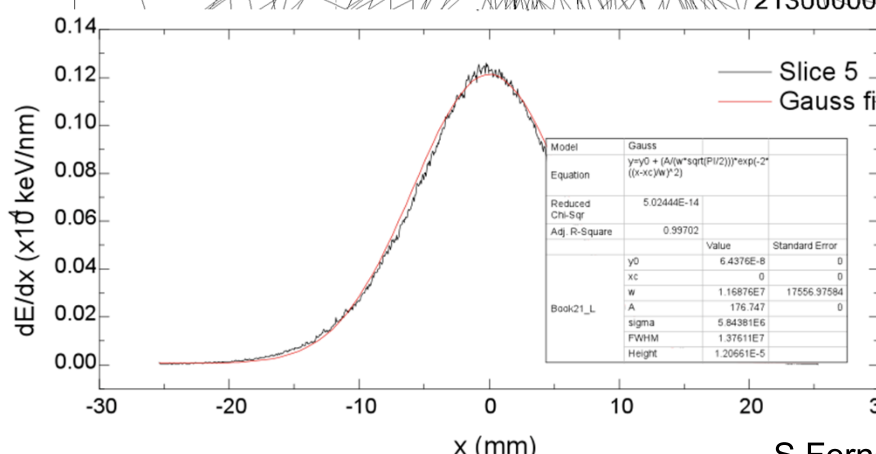
Wait for the results of the multi-slice target

50kW multi-slice Target



Tests to be done: ~1MeV electrons 50kW

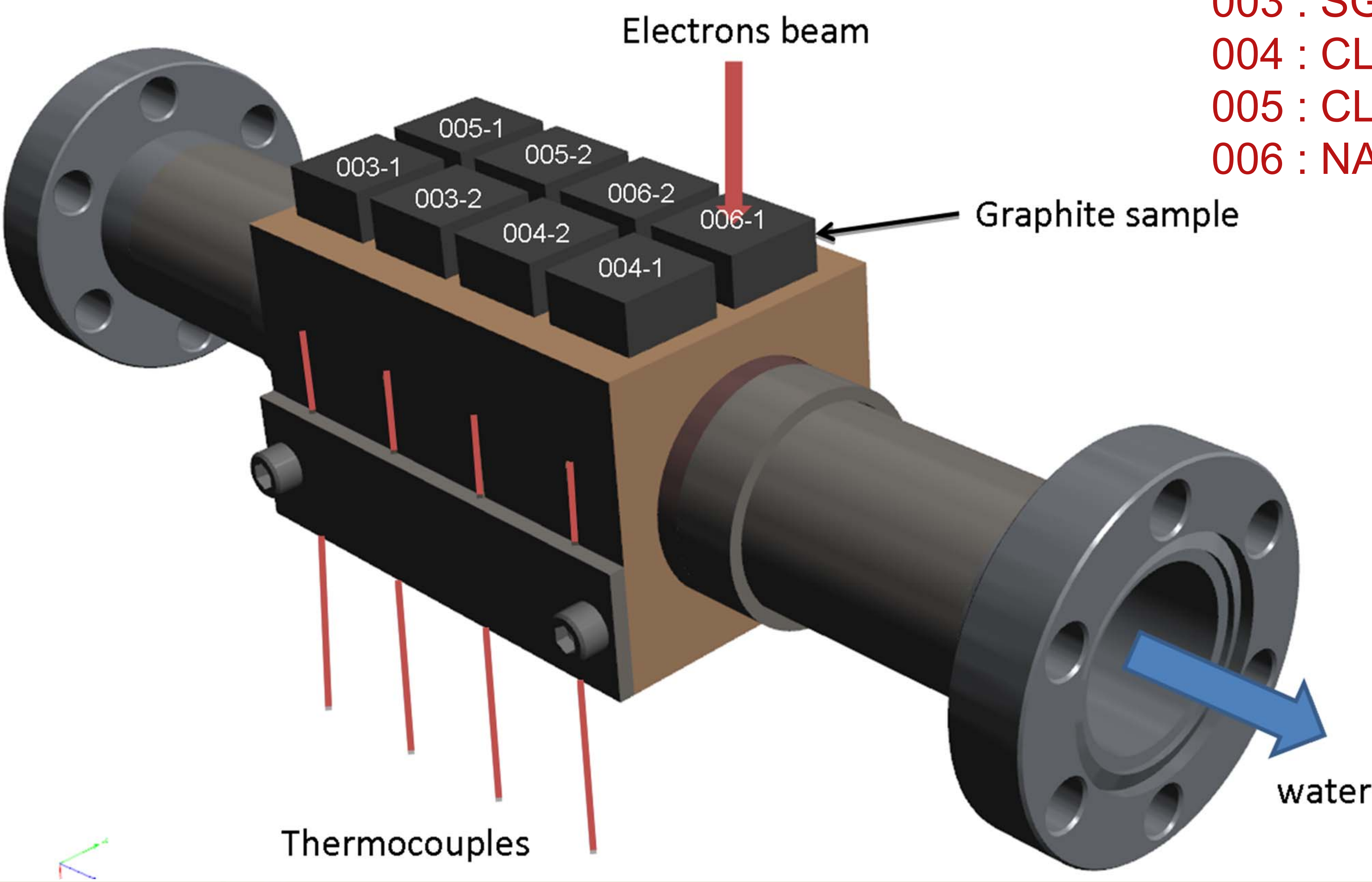




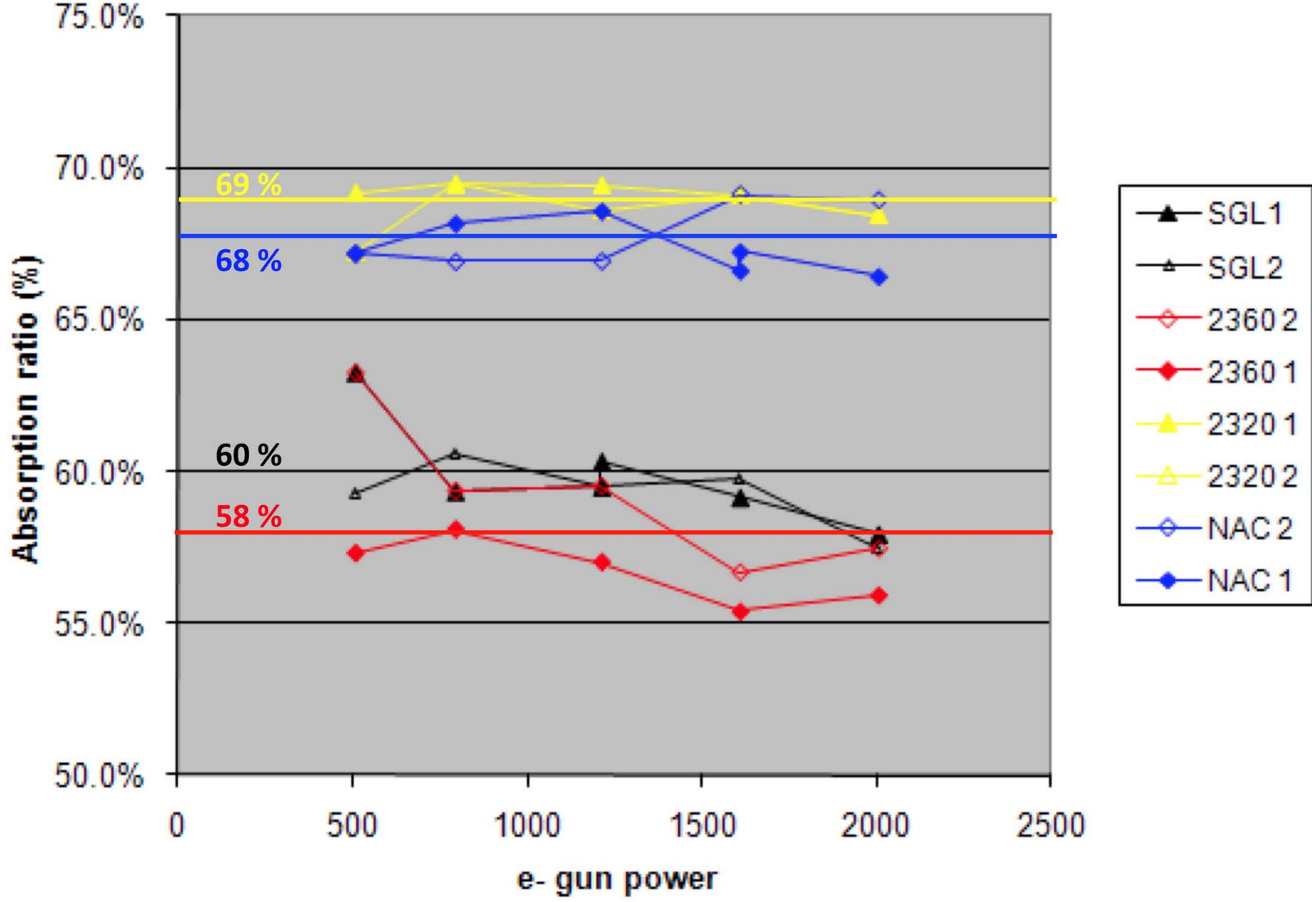
S.Fernandes, WM

Comparison of Results to Simulation: power fraction of e-beam absorbed

003 : SGL R6710
004 : CL2360
005 : CL 2320
006 : NAC 678

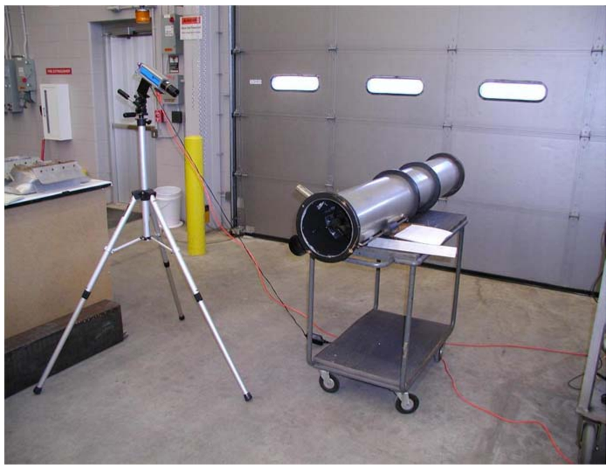


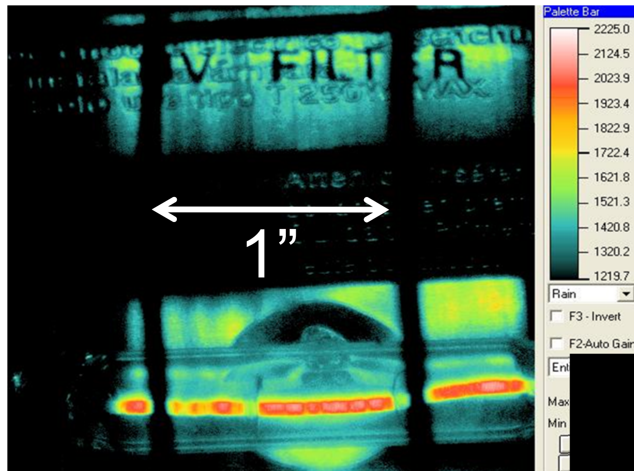
Fraction of e-beam power absorbed



Diagnostic of Temperature

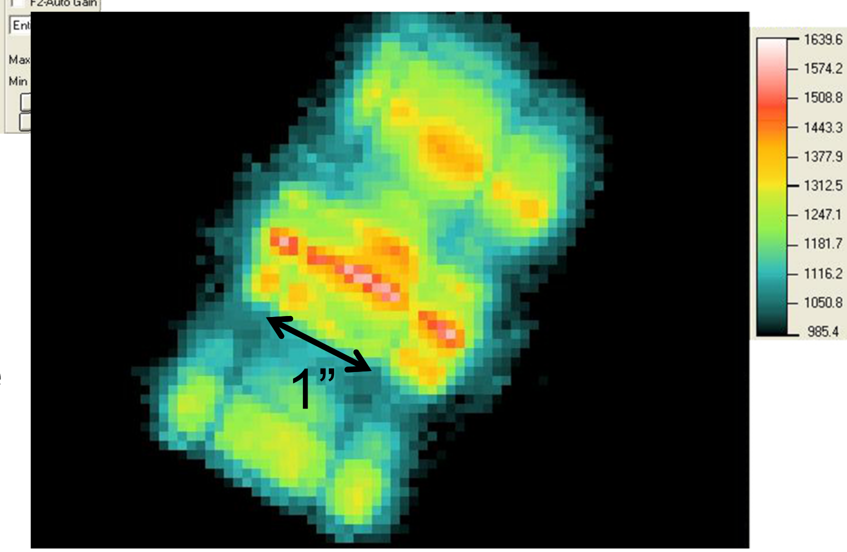
- Monitoring of beam spot on target critical
  - Temperature measurement with thermal camera
  - Requirement: measurement from distance far from high radiation





Direct measurement
Distance = 0.7 m
Res. ~0.1mm

Measurement through a telescope
Distance = 50 m
Res~1.5mm



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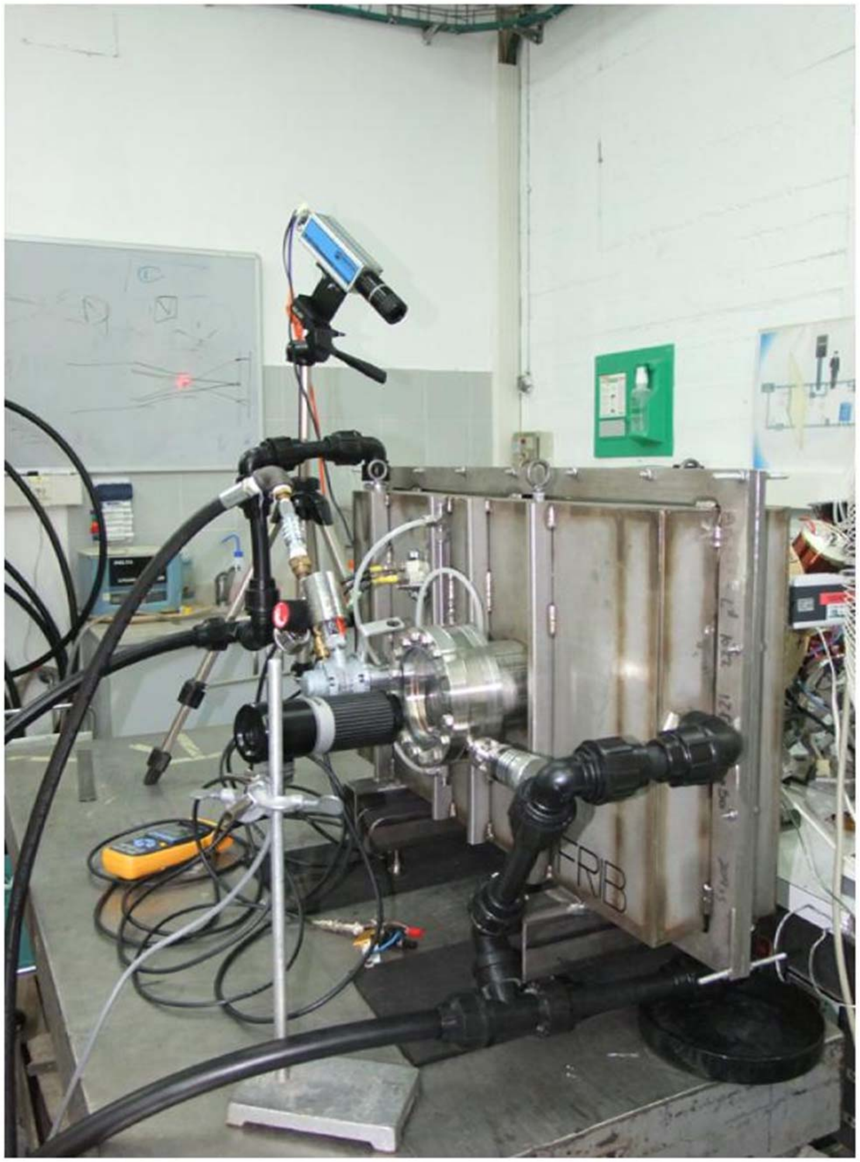
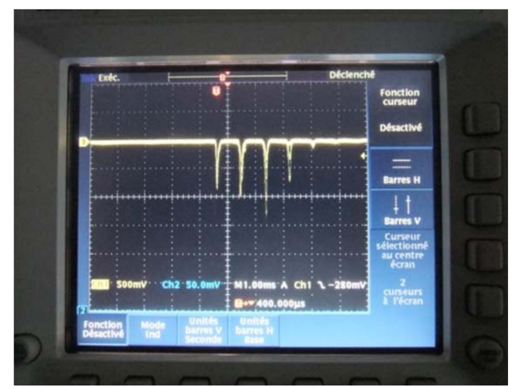
Equipment Used at Soreq



Thermal paint

Pin-hole beam profiling



Φ~ 3.5 mm