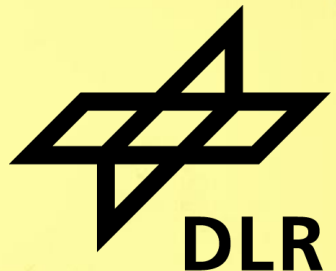


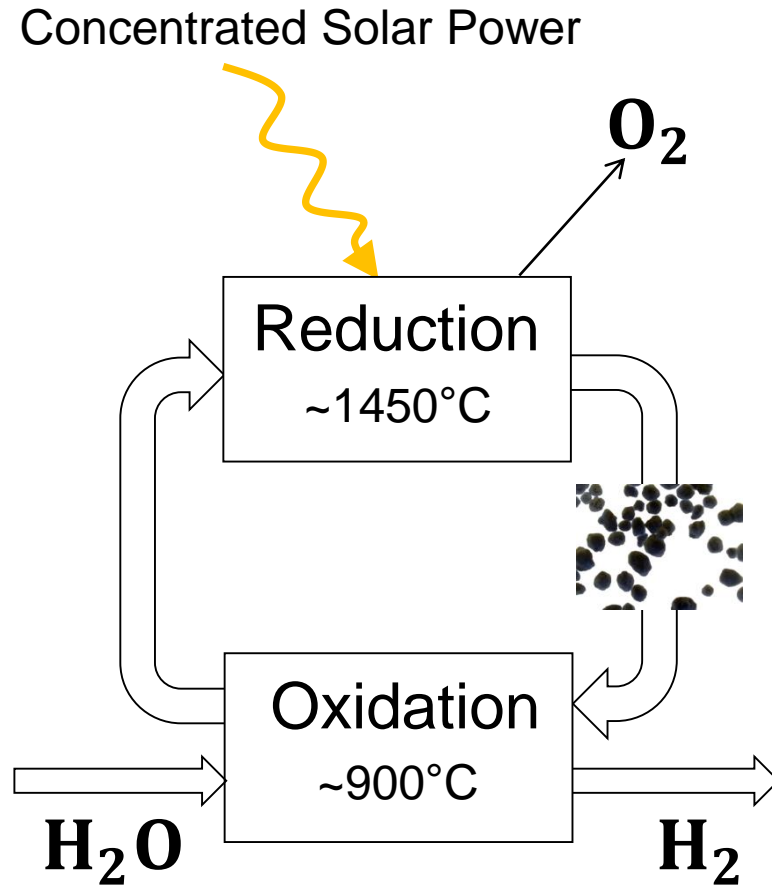
EXPERIMENTAL INVESTIGATION OF A SYSTEM OF TWO VACUUM SOLAR RECEIVERS FOR THE CONTINUOUS REDUCTION OF CERIA PARTICLES

**Johannes Grobbel, Anthony McDaniel, Ante Giljanovic, Clarisse Lorreyte,
Jan Hendrik Müller, Dennis Thomey, Christian Sattler**

Institute of Future Fuels, German Aerospace Center (DLR), Germany

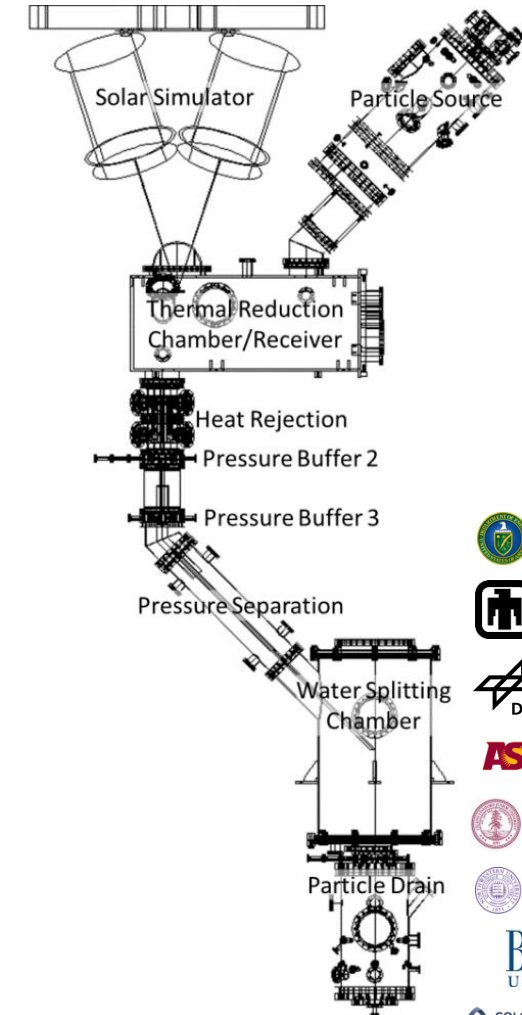


Solar Thermochemical Hydrogen Production with Ceria

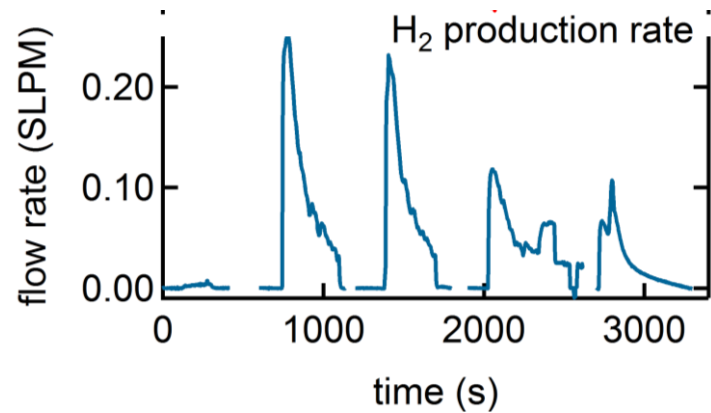
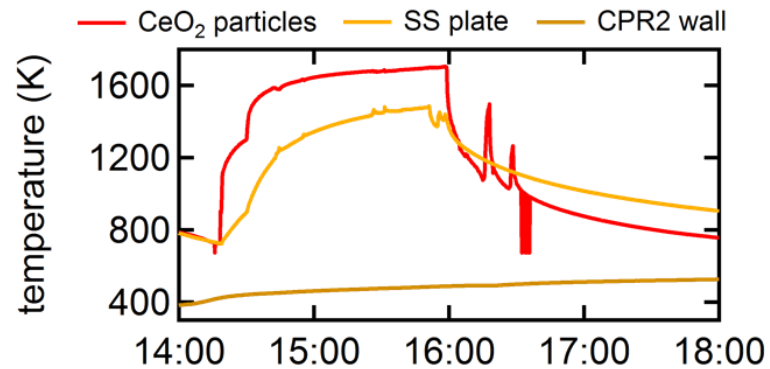


Ceria (CeO_2) Particles

- Sauter diameter 277 μm
- Density 6.6 g/cm^3

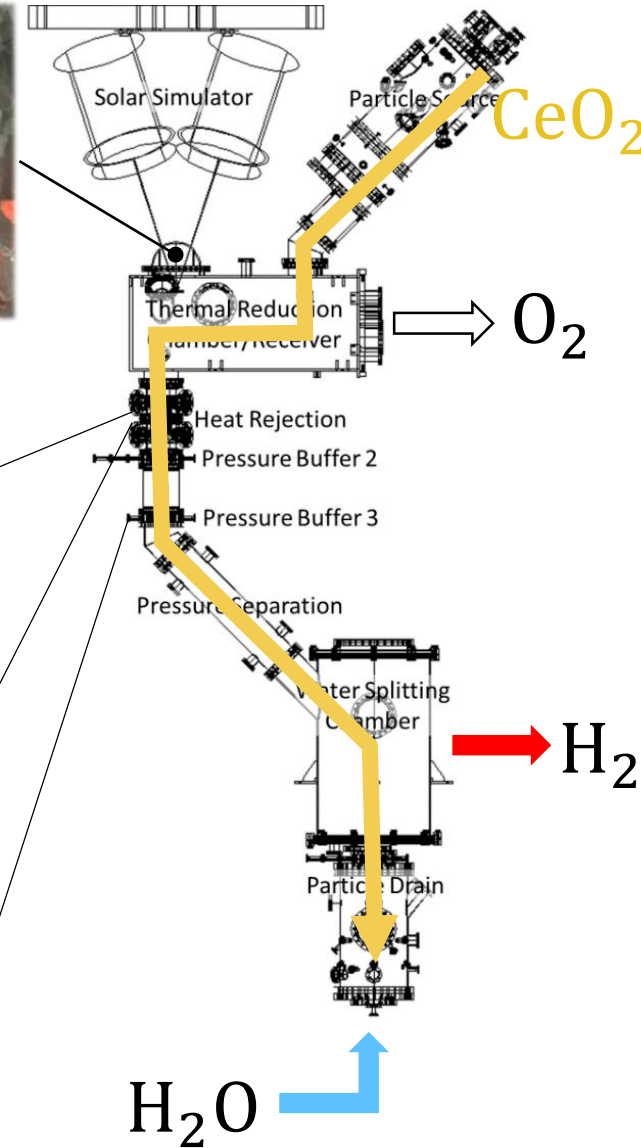
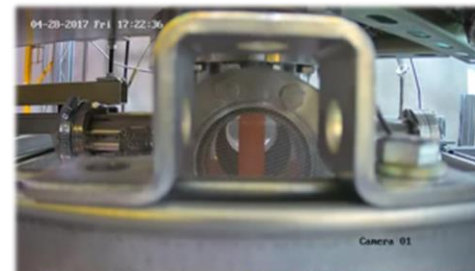


DOE-STCH Project (2015-2017): Tests in Albuquerque



- Particles heated to 1700 K
- 0.25 SLPM peak H₂ rate

Aperture, $T \approx 1700$ K

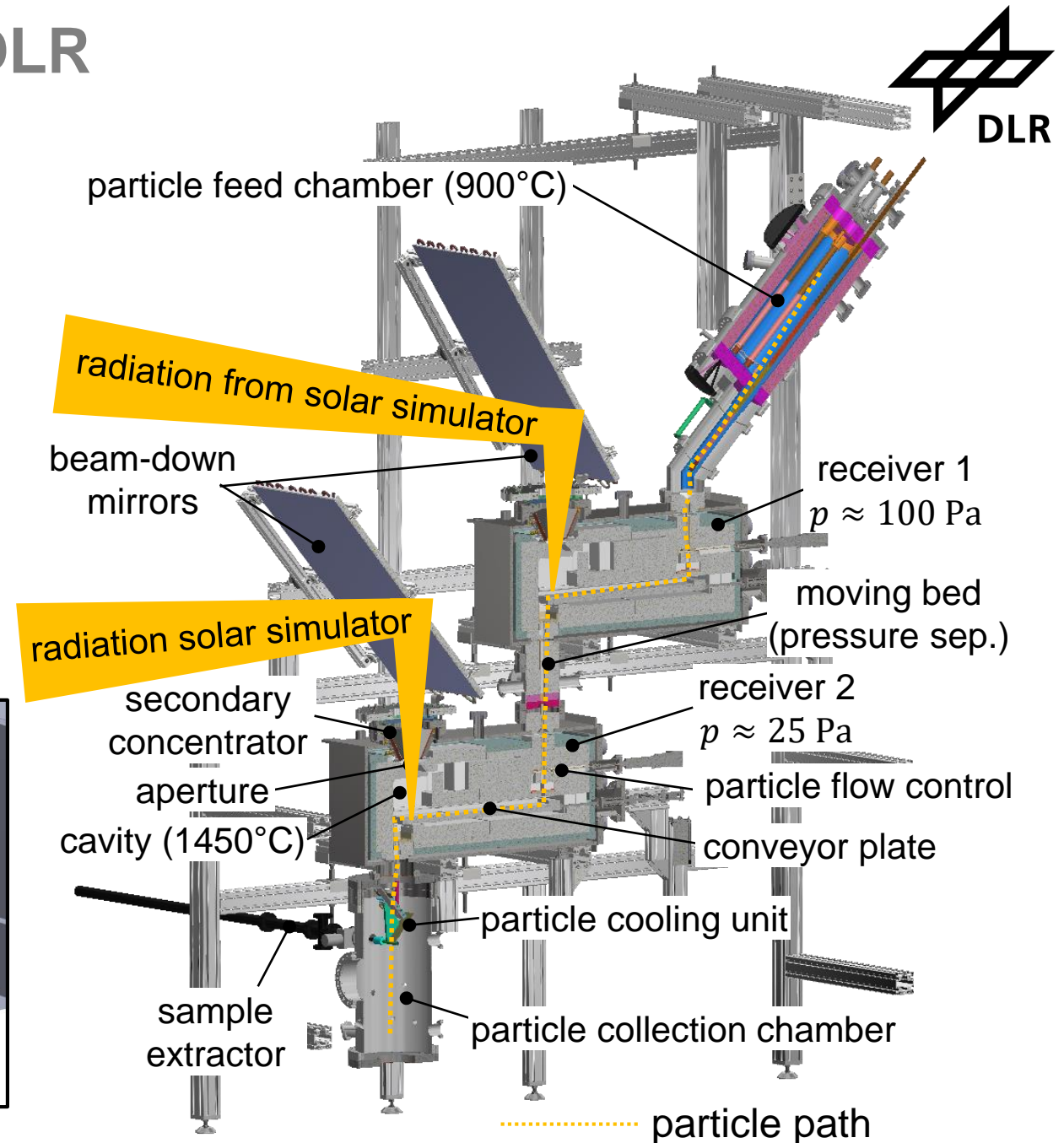
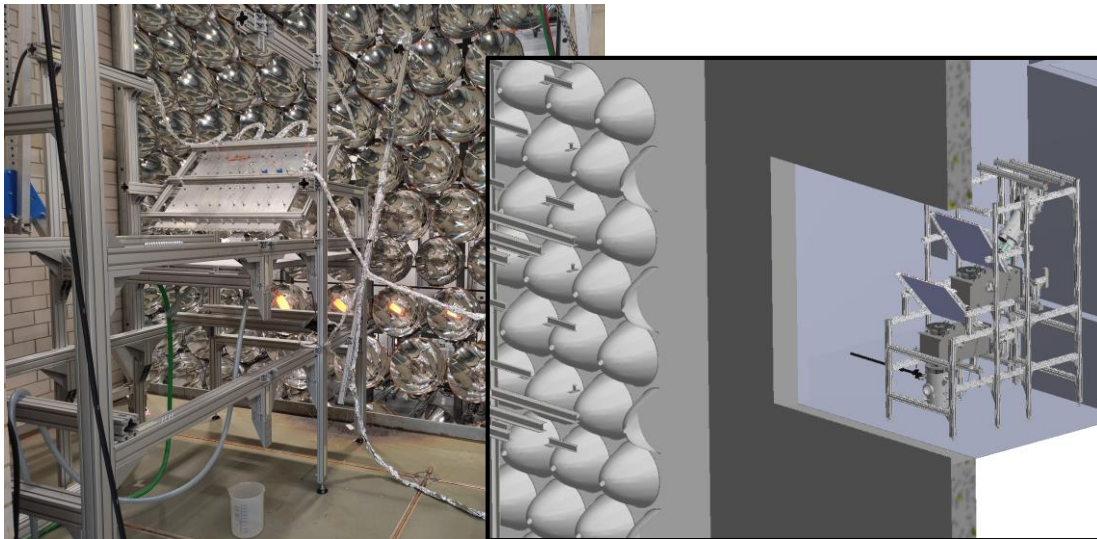


15 ft = 4.65 m

Ongoing Work of Sandia and DLR

Main goals:

- Improve vacuum receiver-reactors
- Demonstrate pressure separation between two receivers in Synlight®
- Collect more operational data



Outline

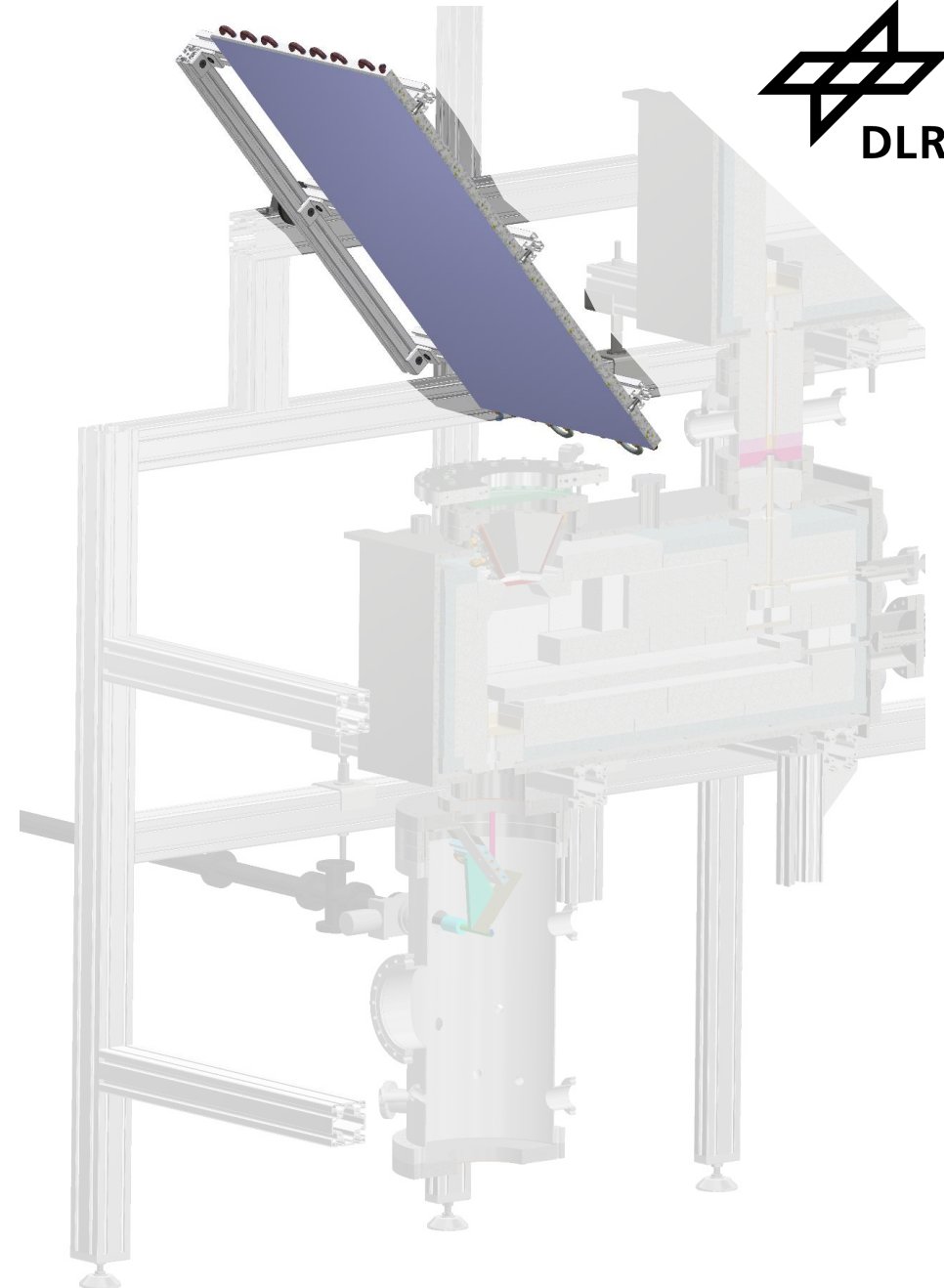


1. Beam-down mirror
2. Secondary concentrator
3. Particle conveying plate
4. Particle quenching and sample collection

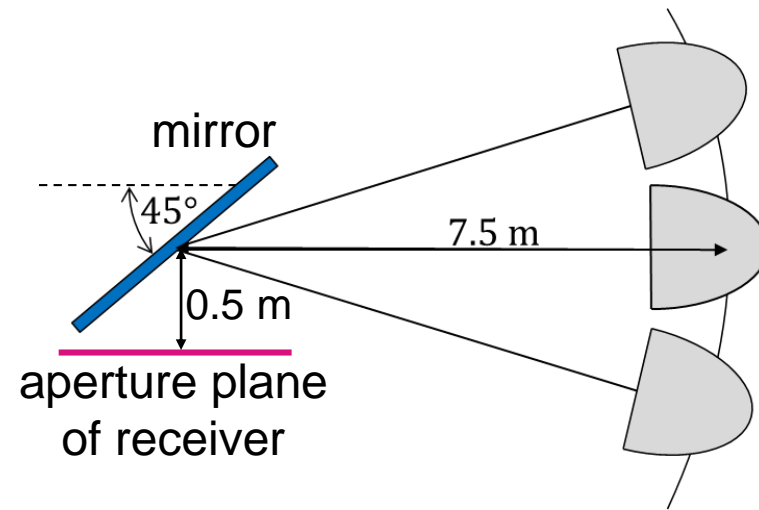
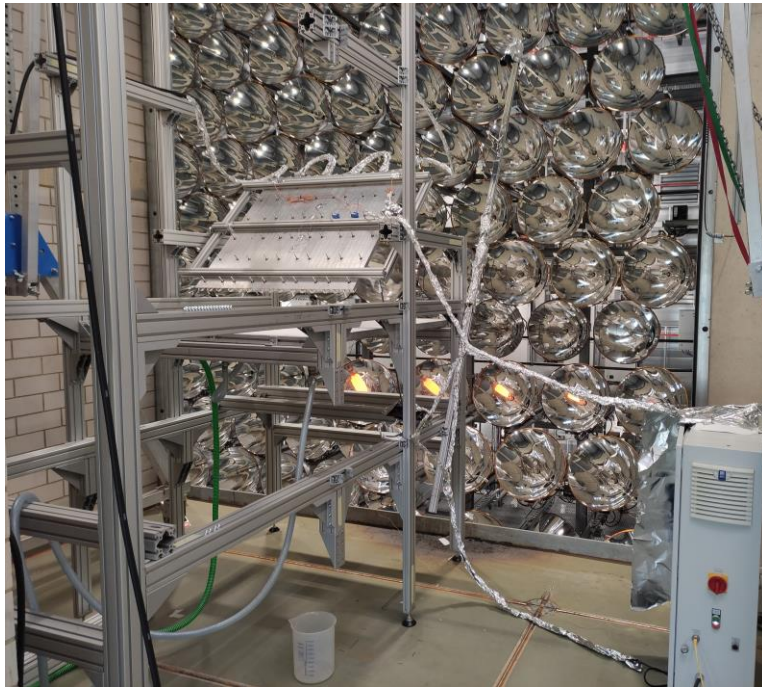
Outline



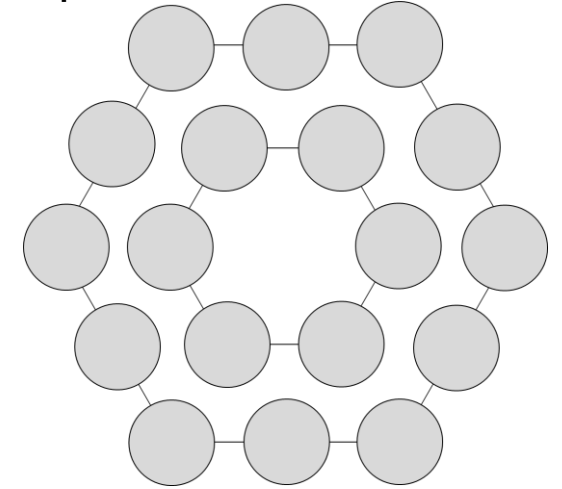
1. **Beam-down mirror**
2. Secondary concentrator
3. Particle conveying plate
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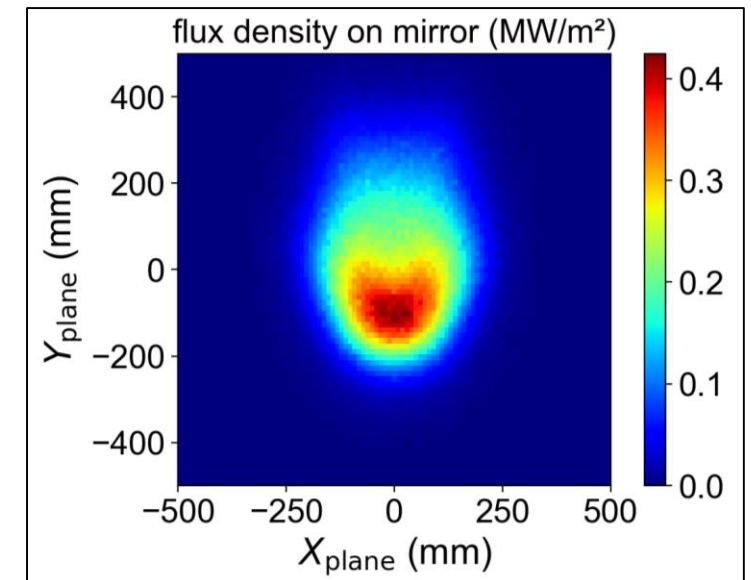
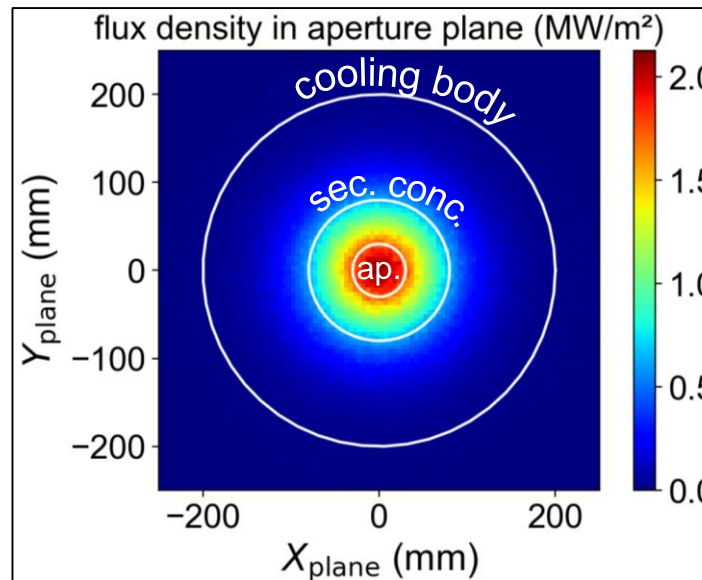
Raytracing



18 lamps

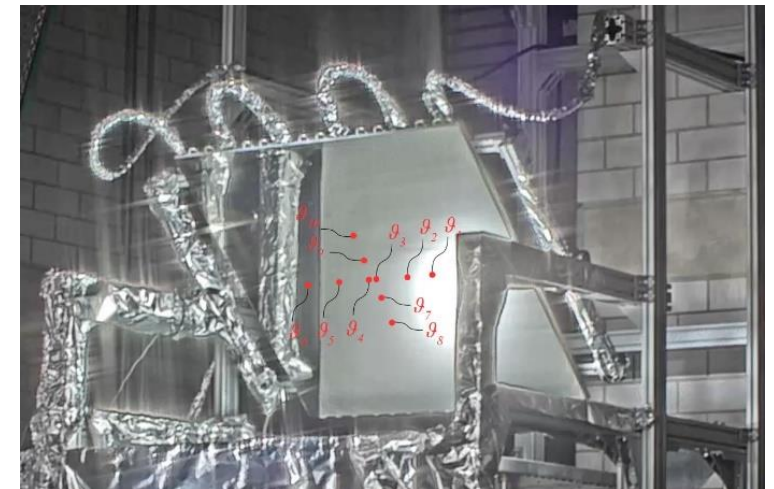
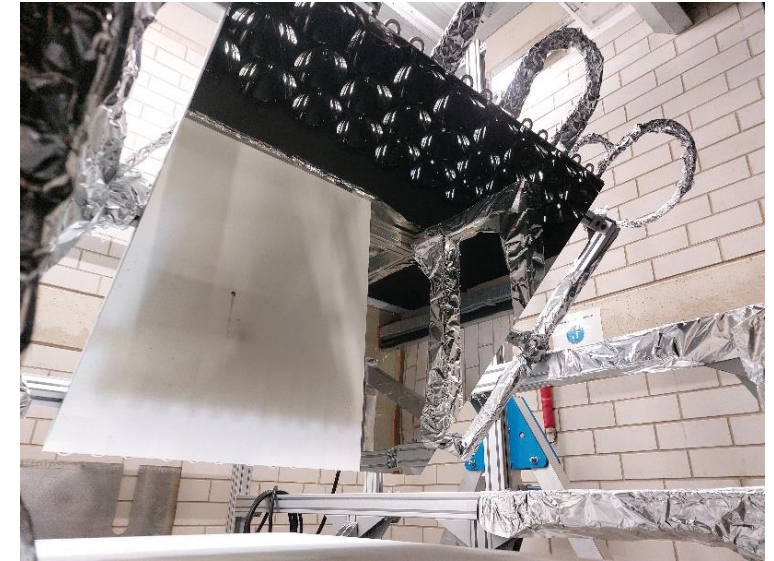
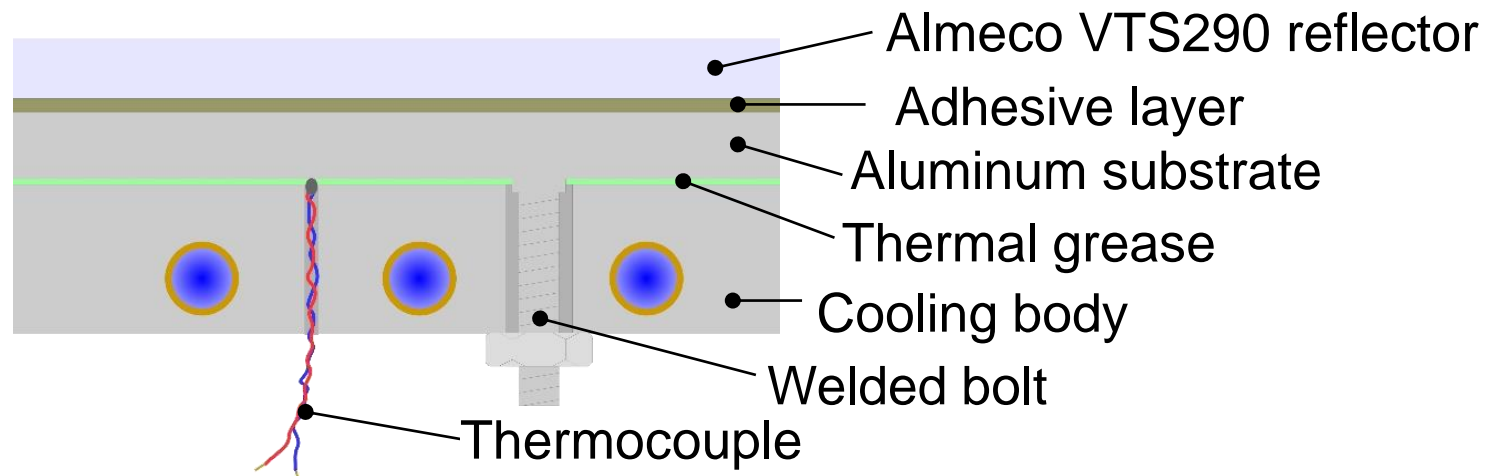


- Flux on mirror: $\approx 50\text{ kW}$ total, peak flux density $\approx 400\text{ kW/m}^2$
- Secondary concentrator reduces required # of lamps to 9 instead of 18 to reach 5 kW in aperture



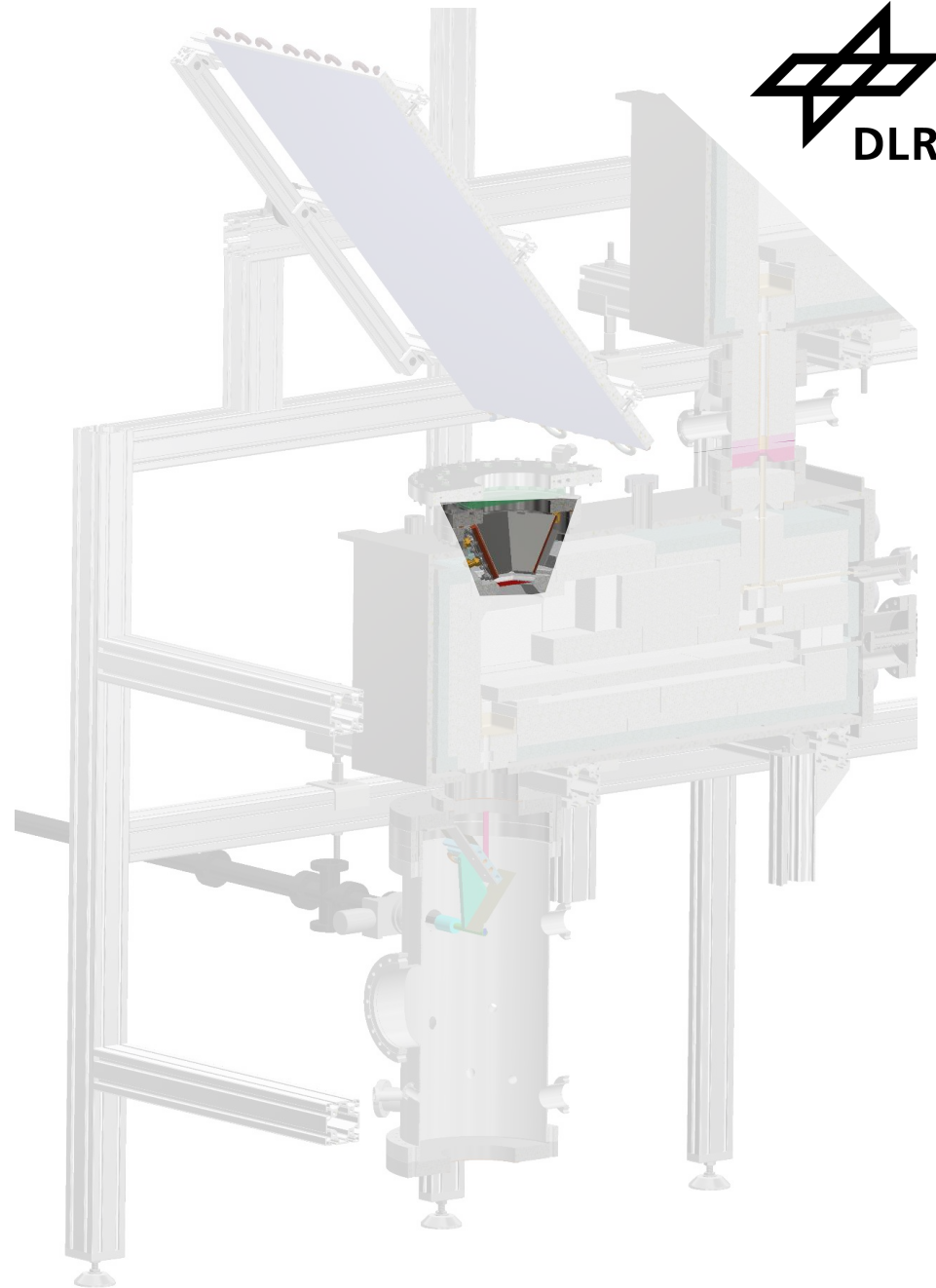
Beam-Down Mirrors

- 1m x 1m, solar reflectivity $\approx 90\%$, water cooled
- 2-hour test with 18 lamps
(≈ 50 kW total, peak flux density ≈ 400 kW/m²)
- Reflector front peak temperature $\approx 104^\circ\text{C}$
- No visible damage or deformation



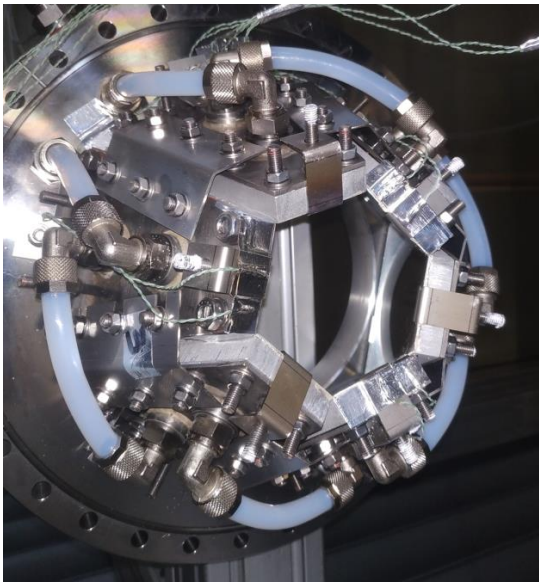
Outline

1. Beam-down mirror
2. **Secondary concentrator**
3. Particle conveying plate
4. Particle quenching and sample collection

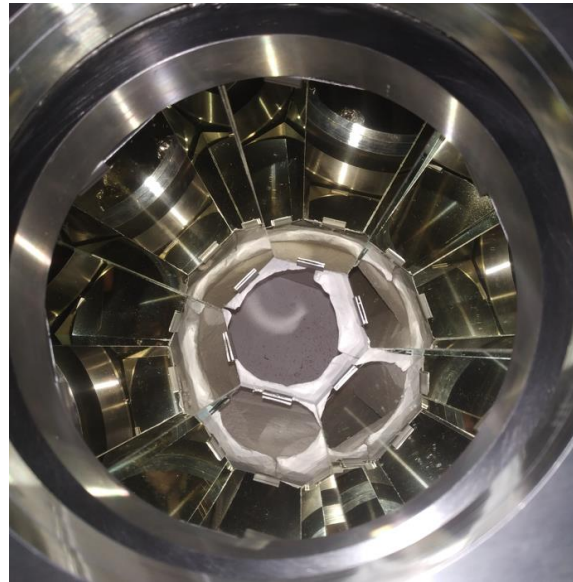


Secondary Concentrator

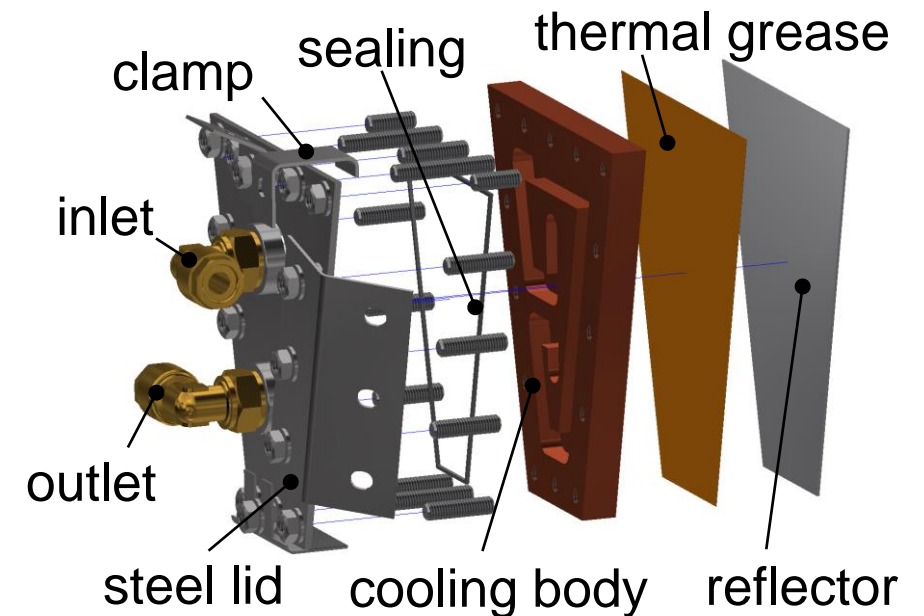
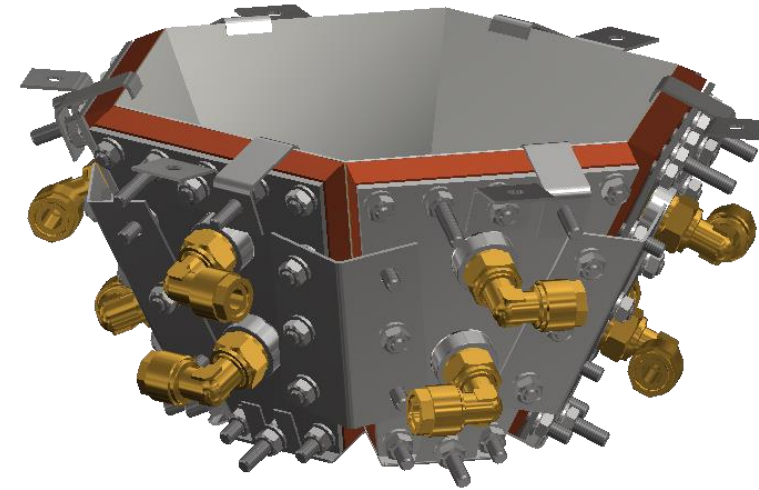
- Six trapezoidal, flat elements
- Hexagonal radiation entrance and exit



Exiting aperture

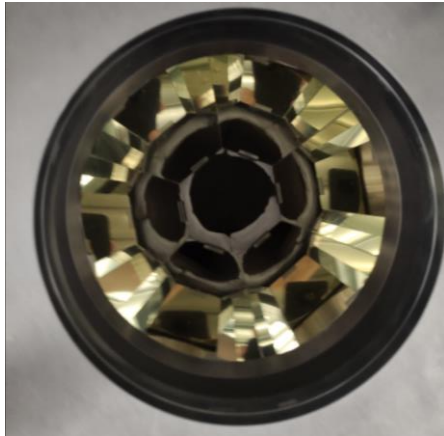


Entrance aperture

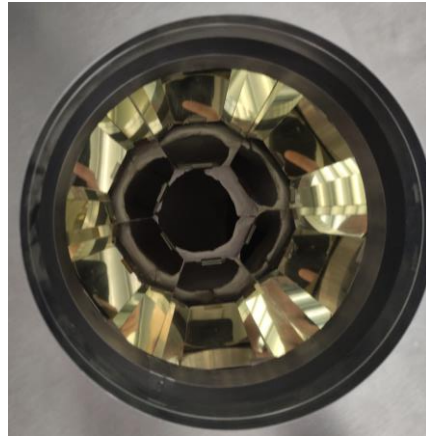


Secondary Concentrator: Tests

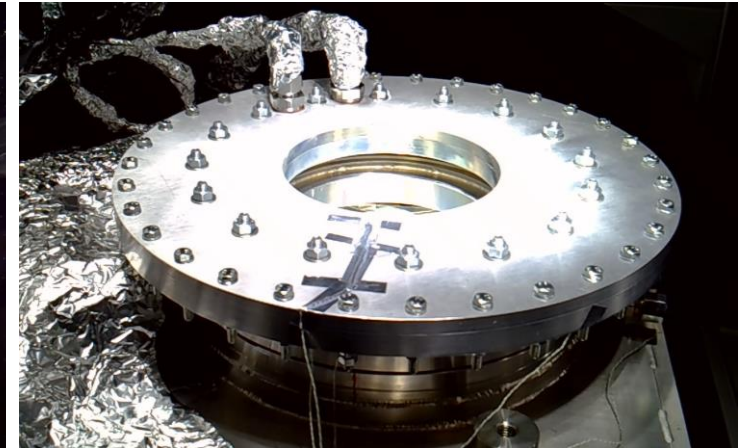
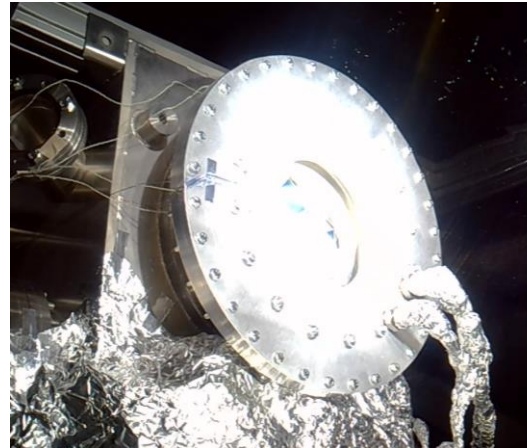
- First test with 8 kW successful



Before test



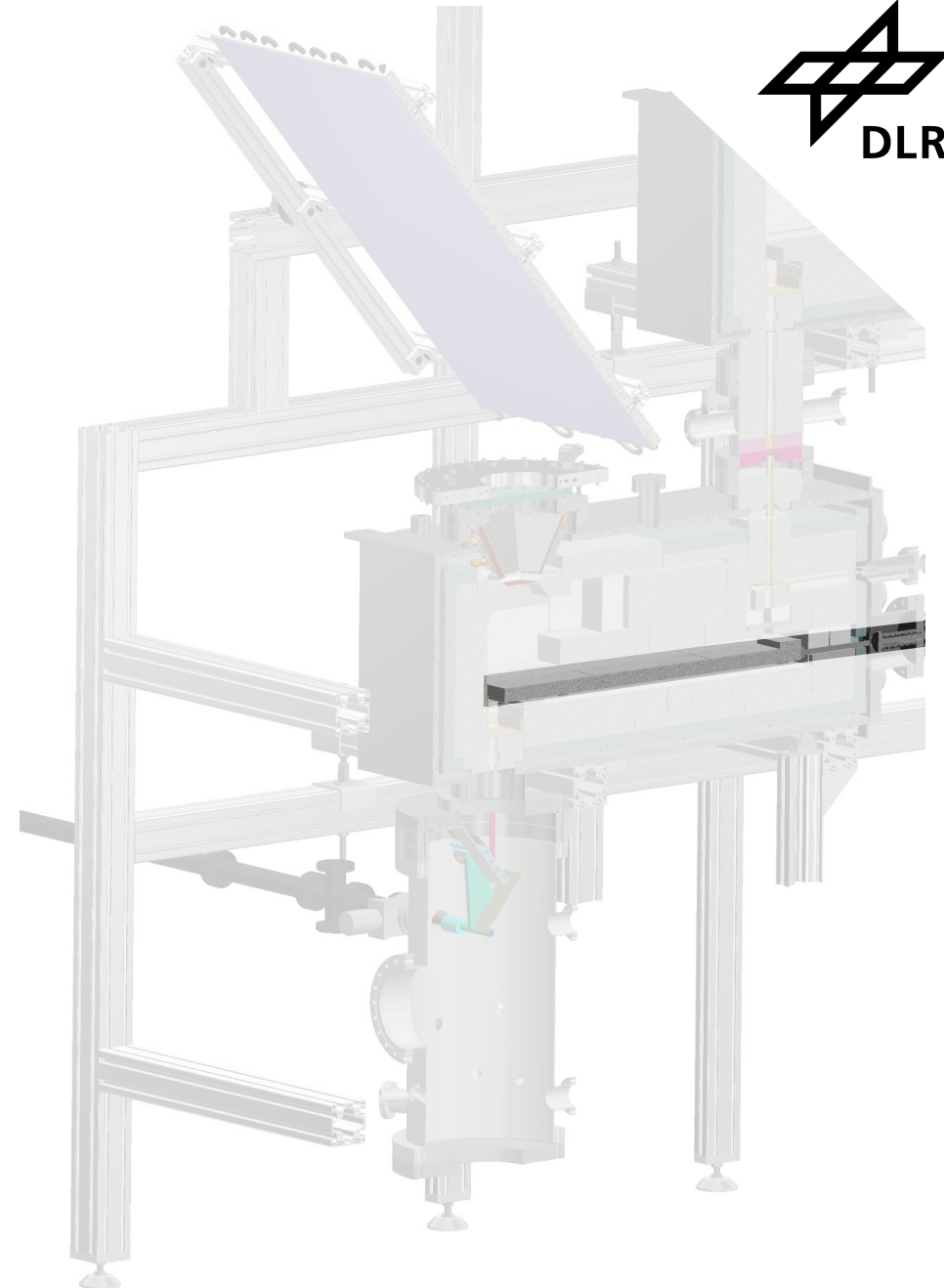
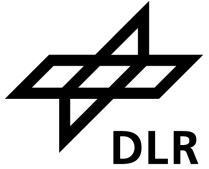
After test



- Tests took place at ambient pressure
- Further tests with higher power planned, but in vacuum conditions

Outline

1. Beam-down mirror
2. Secondary concentrator
3. **Particle conveying plate**
4. Particle quenching and sample collection



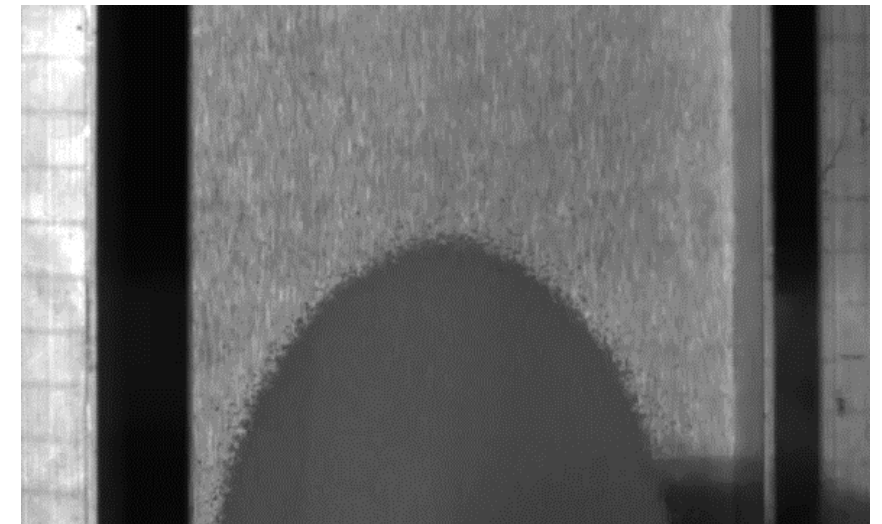
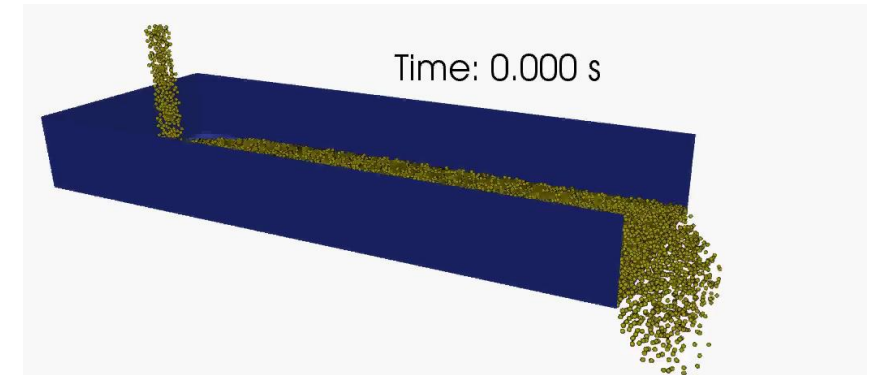
Horizontal Conveyor Plate

Plate motion:

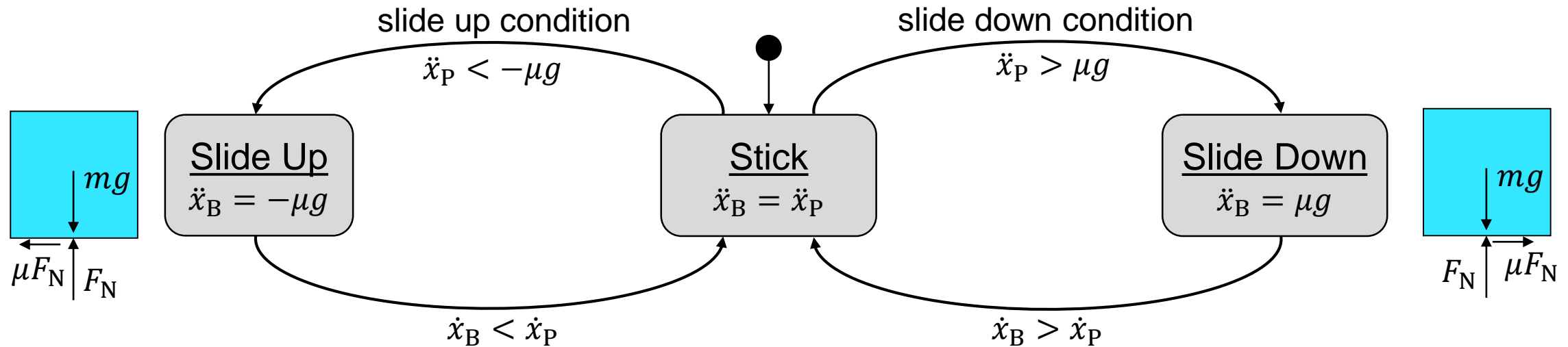
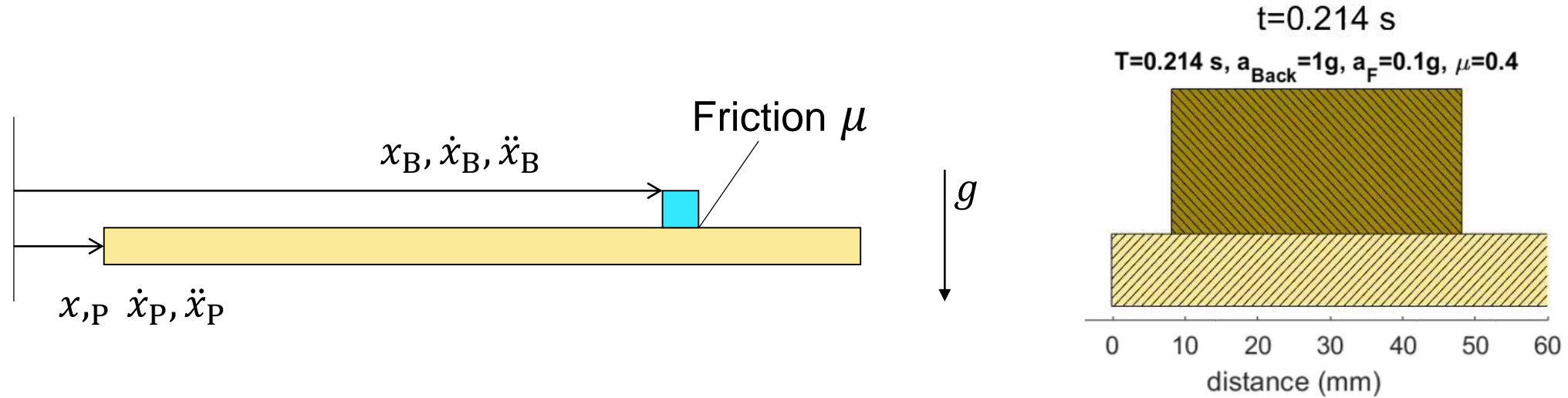
- Low forward acceleration
 - particles stick to plate, move forward with it
- High backward acceleration
 - particles slide on plate
 - plate moves back, but particles not so much

Advantages:

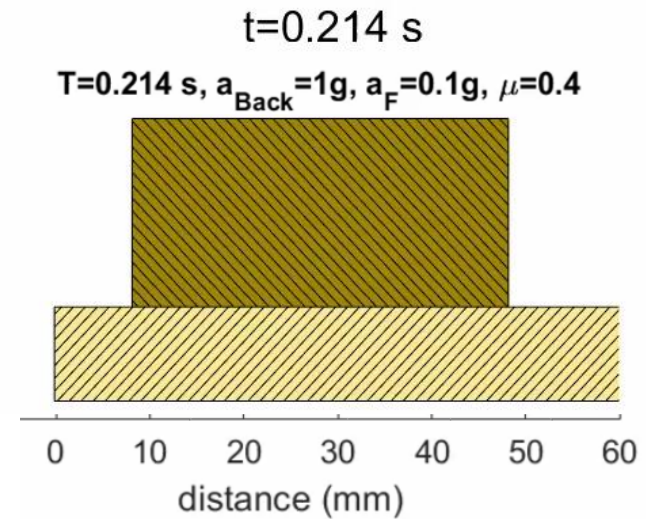
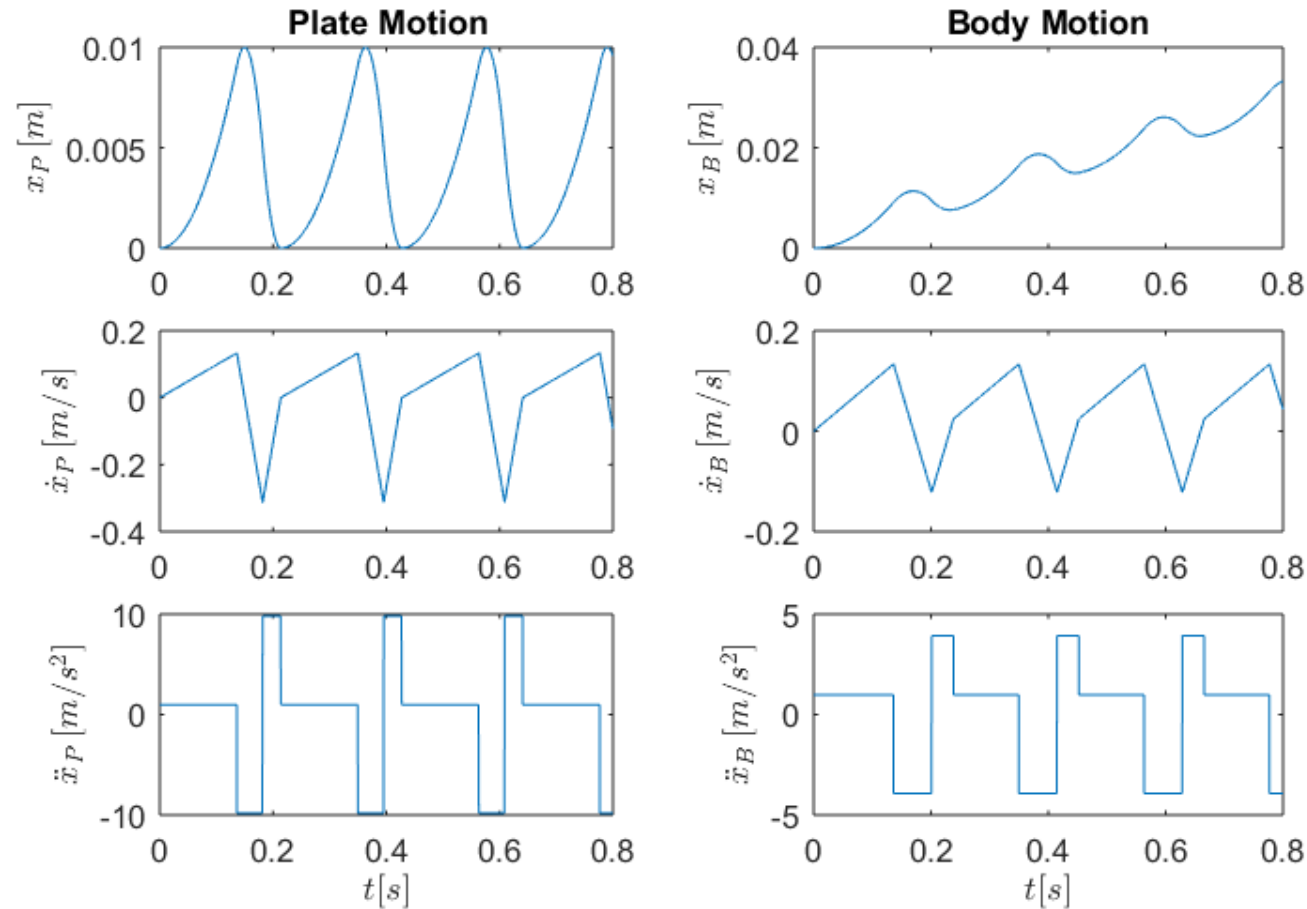
- Adjustable transport speed
- Thin layer of particles



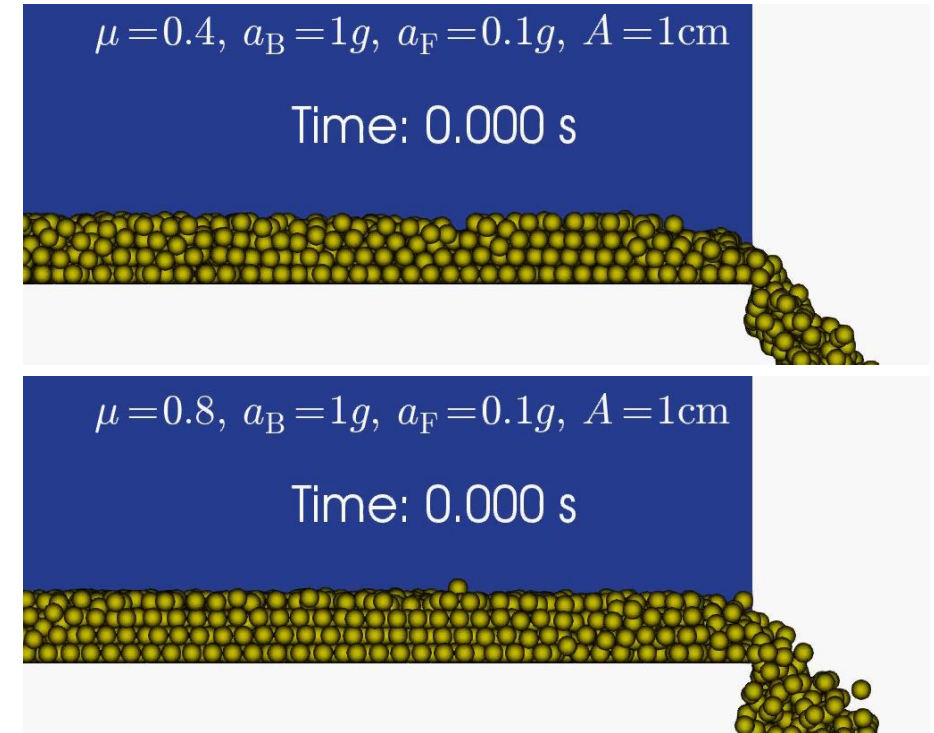
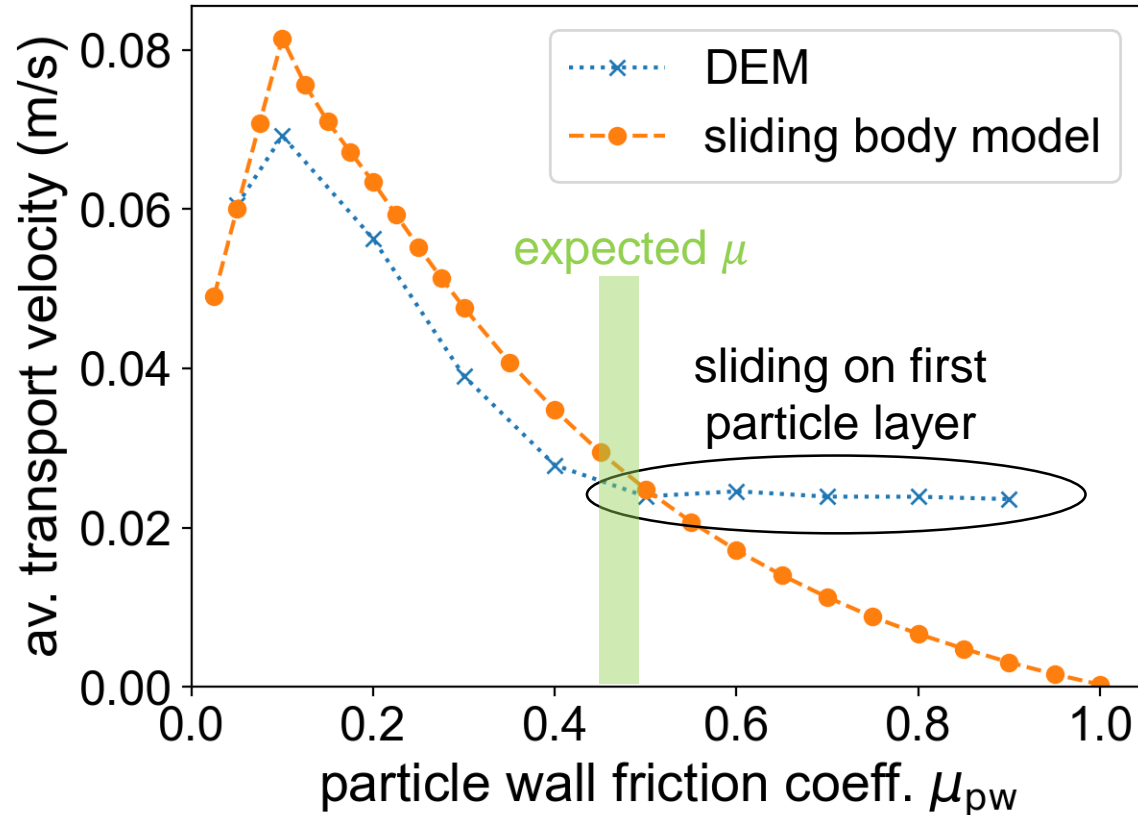
Model for Particle Transport Speed on Plate



Horizontal Conveyor Plate



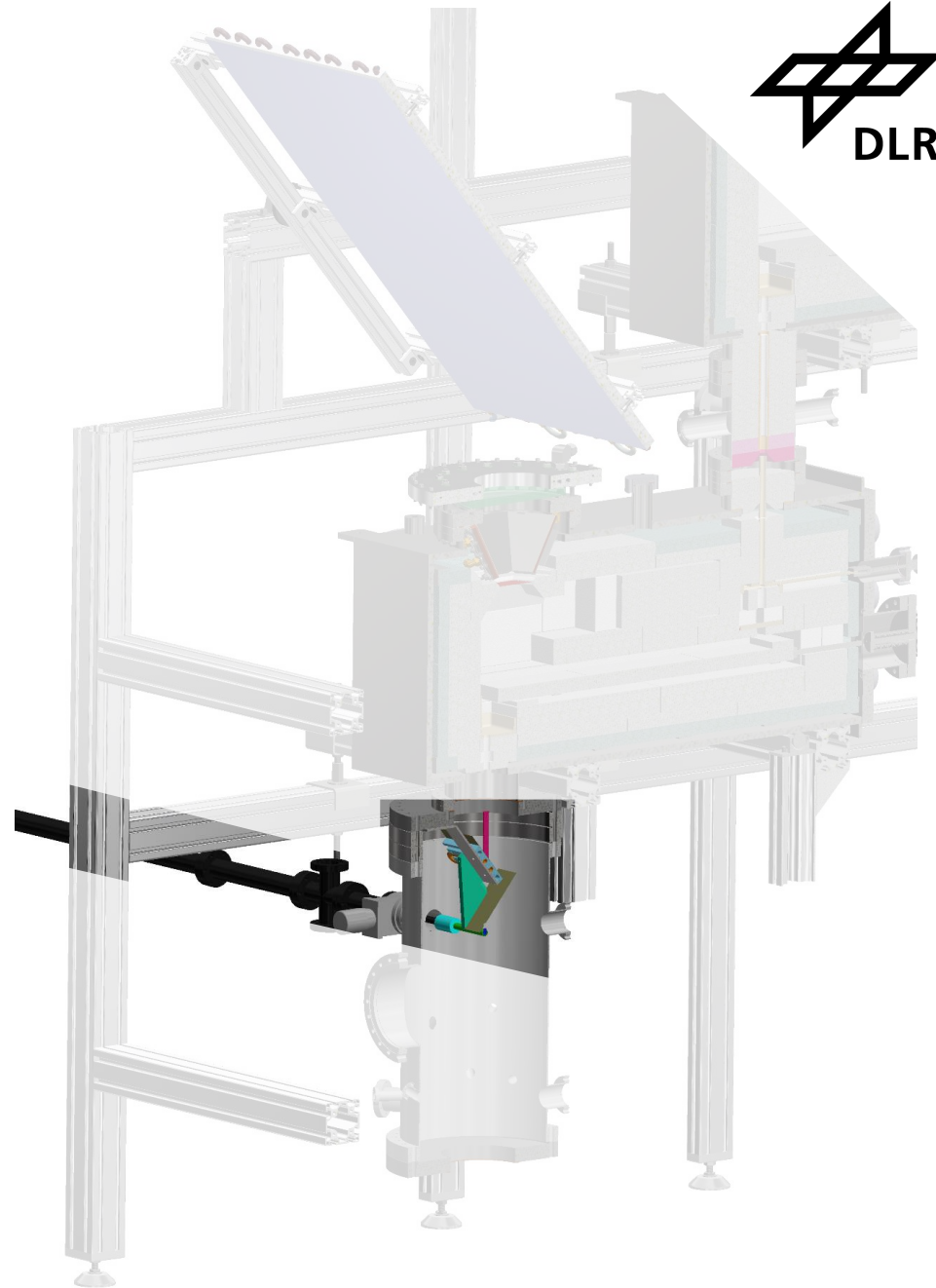
Comparison with Discrete Element Method (DEM)



- DEM itself calibrated to experiments [1]
- Sliding body model sufficiently accurate for design calculations

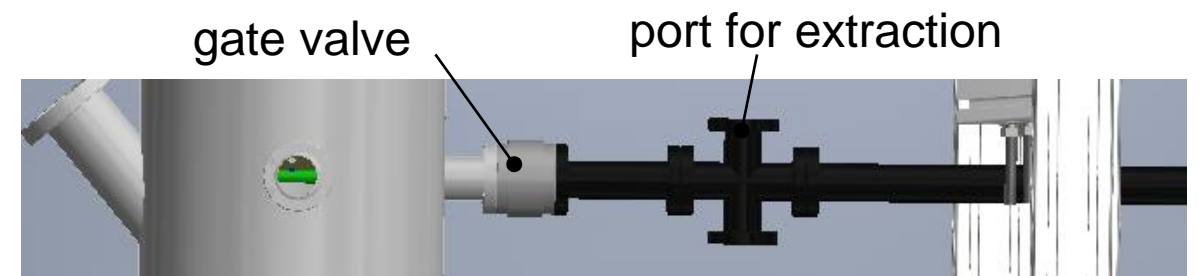
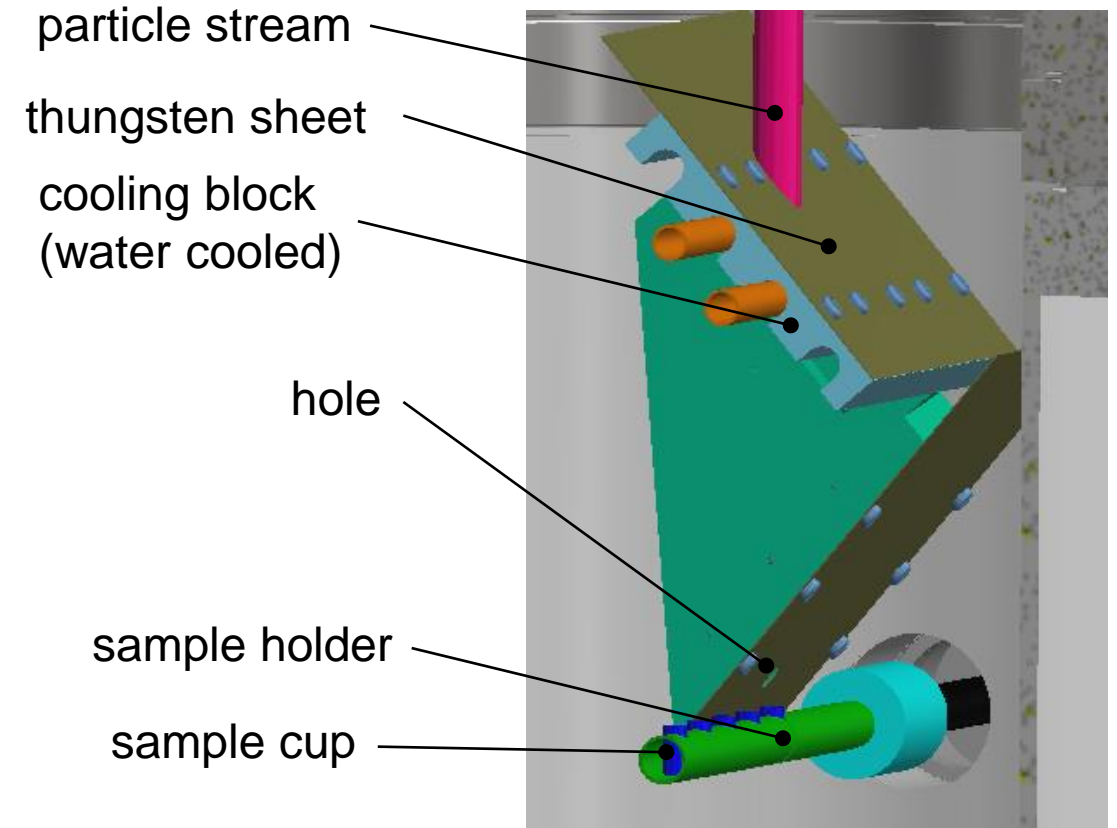
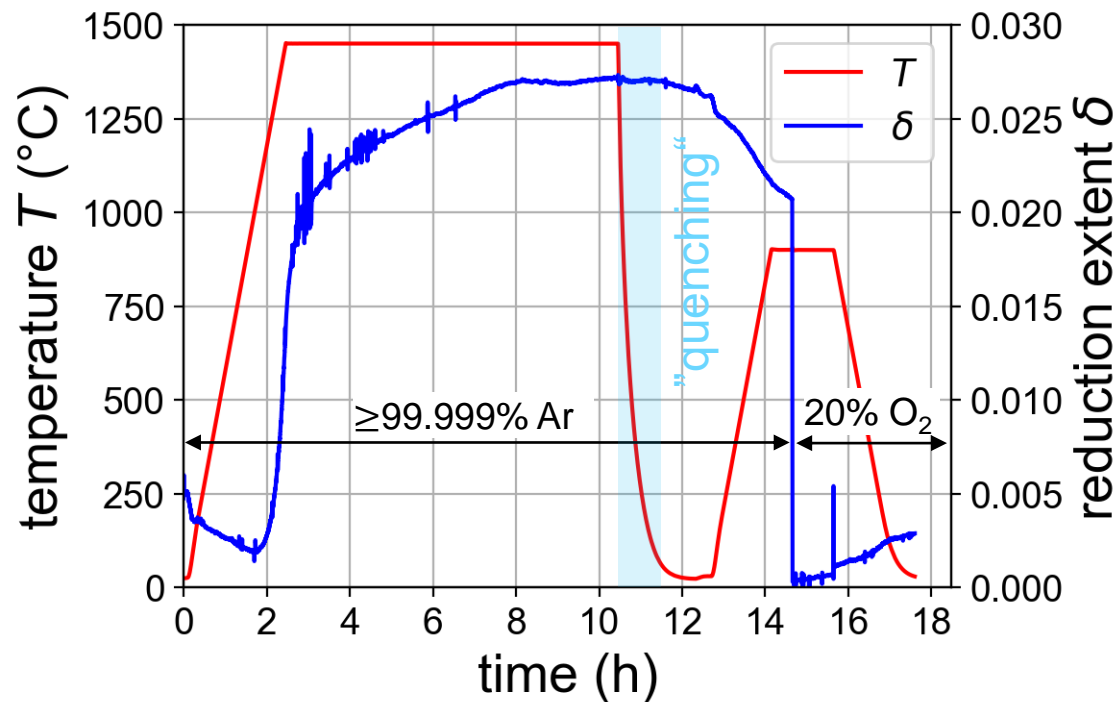
Outline

1. Beam-down mirror
2. Secondary concentrator
3. Particle conveying plate
4. **Particle quenching and sample collection**



Particle Collection and Analysis

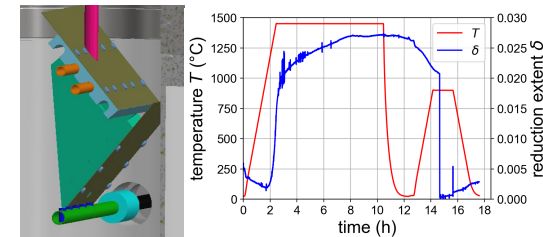
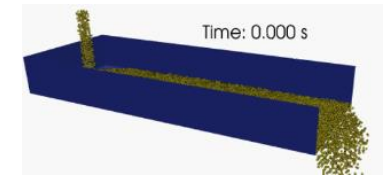
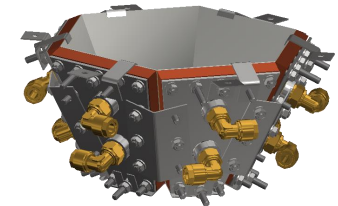
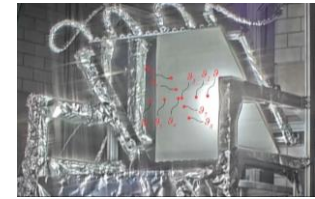
- Mimicked quenching in TGA experiment
- Sample mass 0.67g



Summary



- Two beam-down mirrors were erected and successfully tested
- With the secondary concentrators the spillage is reduced significantly, tests at part load indicate no problems with them so far
- Particle transport on conveyor works and can be well described by a fast rigid body model, which was validated with the DEM
- TGA tests indicate that quenching of the particles is fast enough to freeze their reduction state for later analysis
- **Many lessons learned about particle handling, vacuum systems, concentrating optics and high temperature reactors**



- Upcoming full system tests (2022):
 - Vacuum tests
 - Pressure separation tests
 - Particle reduction tests
- The work inspired the development of other, innovative particle based concepts for solar chemical production, which should be investigated in the future

Support by the DOE Hydrogen and Fuel Cells Technologies Office and the DOE Office of Technology Transitions was greatly appreciated.

Special thanks for discussions and experimental support go to...

Nate Siegel, Christian Willsch, Dmitrij Laaber, Kangjae Lee, Lamark de Oliveira and the workshop team at DLR in Jülich

