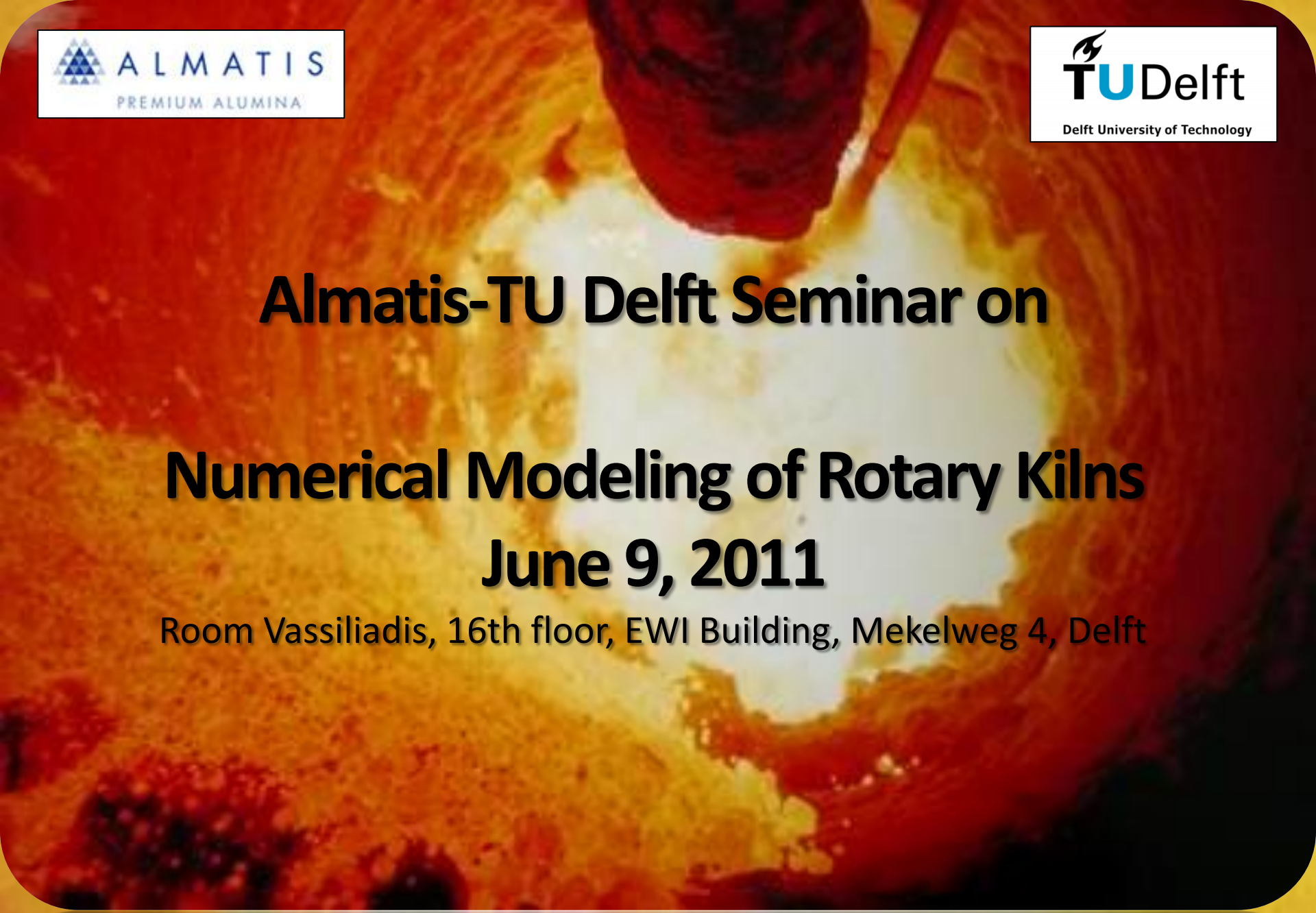


Almatis-TU Delft Seminar on

Numerical Modeling of Rotary Kilns

June 9, 2011

Room Vassiliadis, 16th floor, EWI Building, Mekelweg 4, Delft

Organizers: M. Pisaroni (TU Delft), R. Sadi (Almatis) and D. Lahaye (TU Delft)

GRANULAR DYNAMICS

- Granular flow is a form of two-phase flow consisting of particles and interstitial fluid (Hunt, 1997)

- When sheared, the particulates may either flow in a manner similar to a fluid, or resist the shearing like a solid.
  - **DUAL NATURE**: difficult to analyze.

- In the kiln:
  - COLD ZONE: particles diameters 1/10 to 1 mm
  - HOT ZONE: particles diameters = 5 mm to 1 cm

- Chemical reactions: most important in the hot zone (sintering and ring formation).

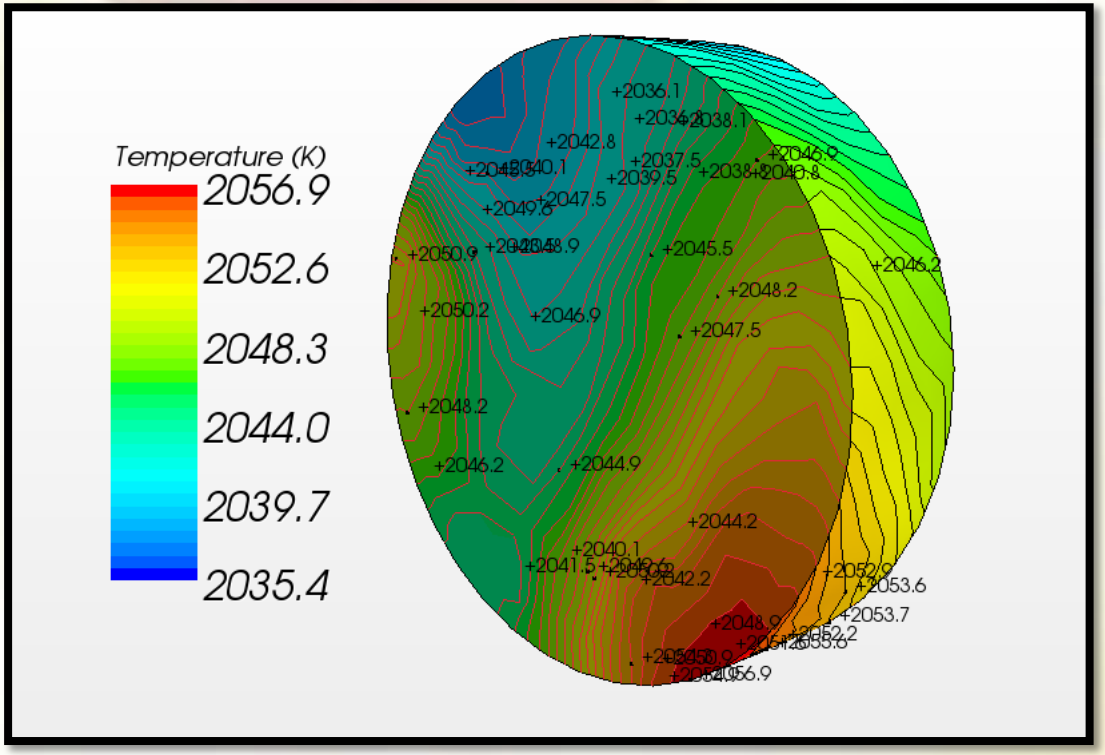
- Heat transfer:
  - Conduction
  - Convection
  - Radiation

- Phase change: small portion liquefy. Interaction with the motion and cause ring formation.

- Different approaches are possible.

MODELING APPROACH:

- **MODEL 2:** Temperature, Velocity, Radiation, Convection, Conduction (Wall), …
- **PARTICLES:** chemical and physical proprieties, particle interaction.
- **WALL :** interaction with the particles, temperature, heat transfer and prescribed rotation, .



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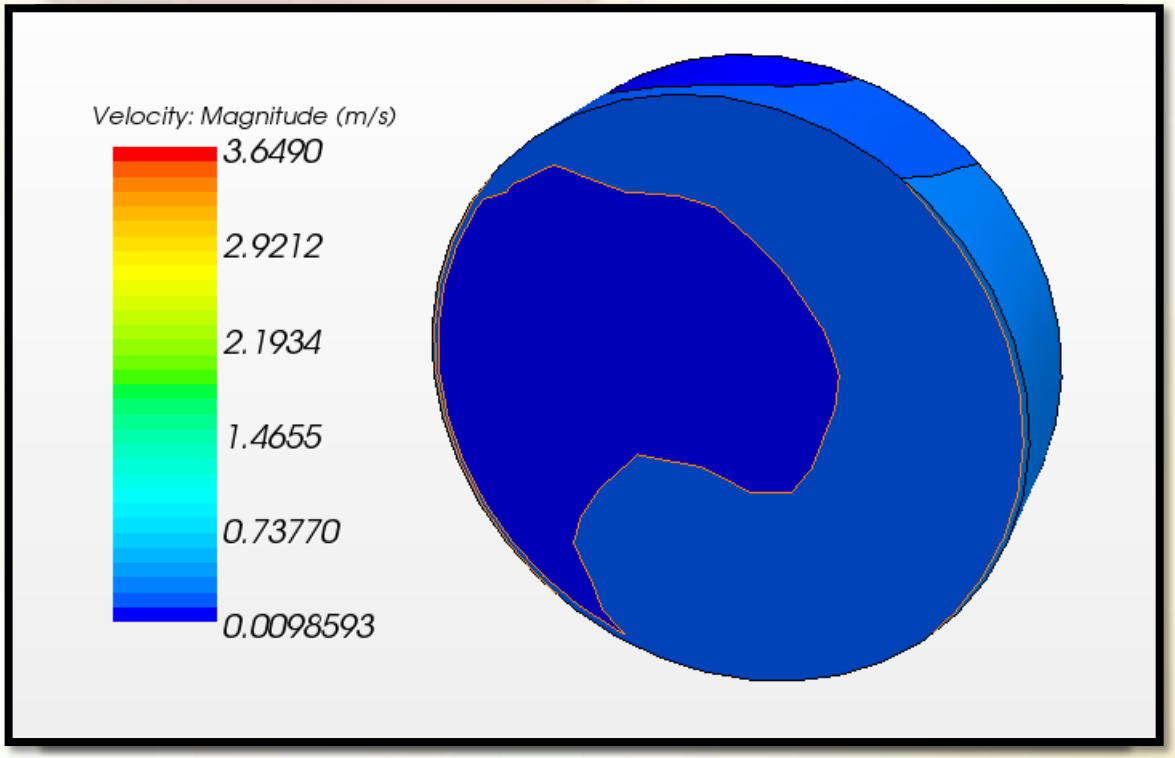

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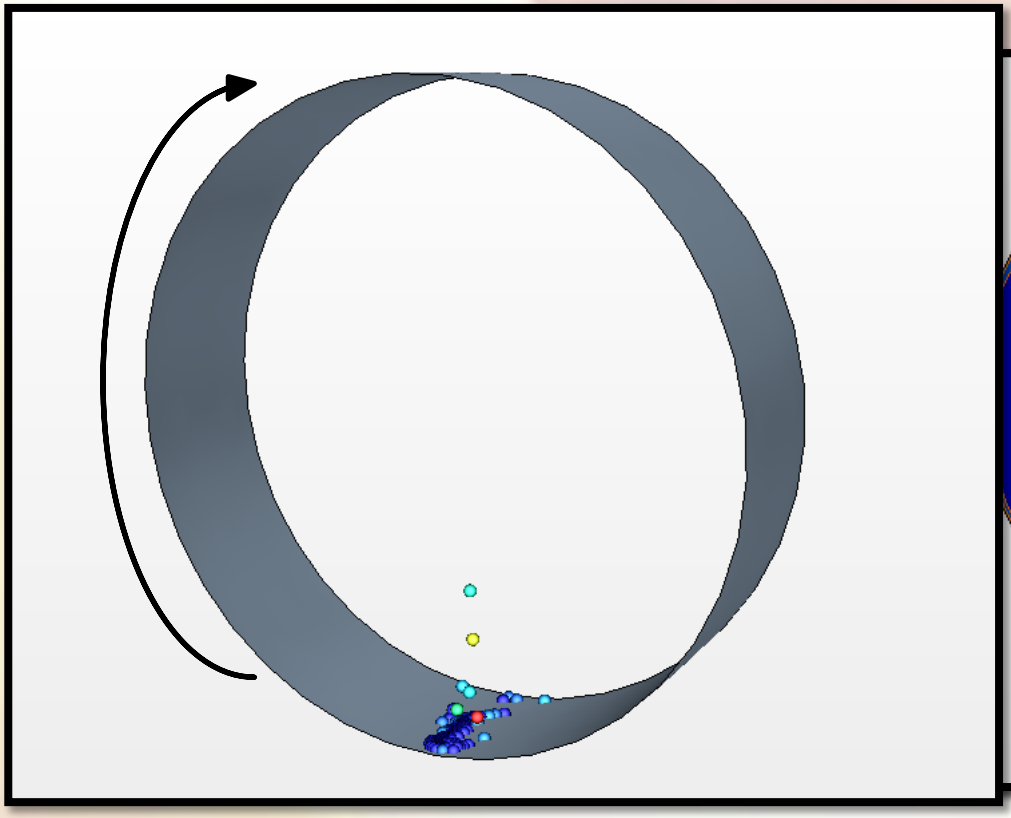
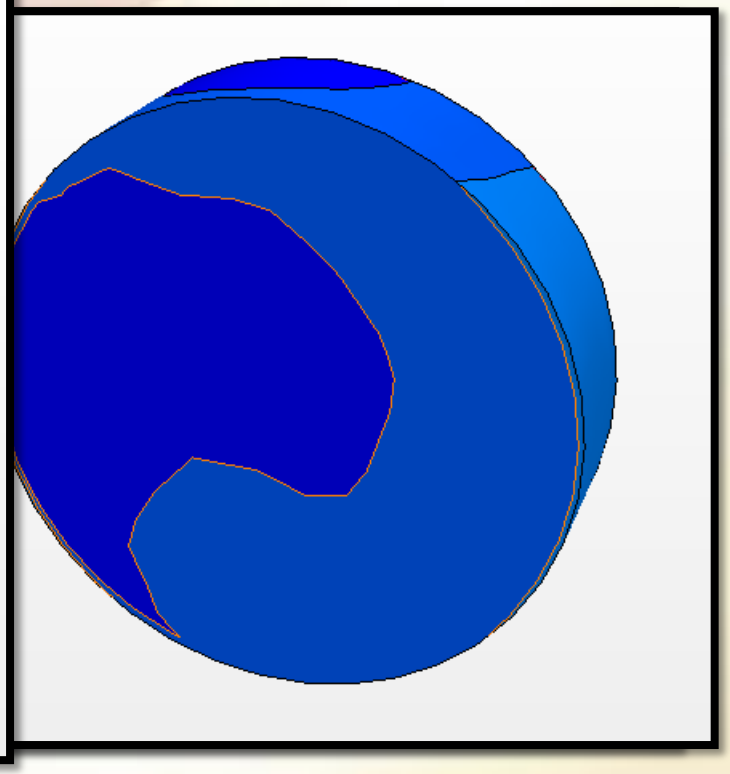




METHOD:

➢The **Discrete Element Method (DEM)** is a numerical method used to simulate motion of a large number of interacting discrete objects.

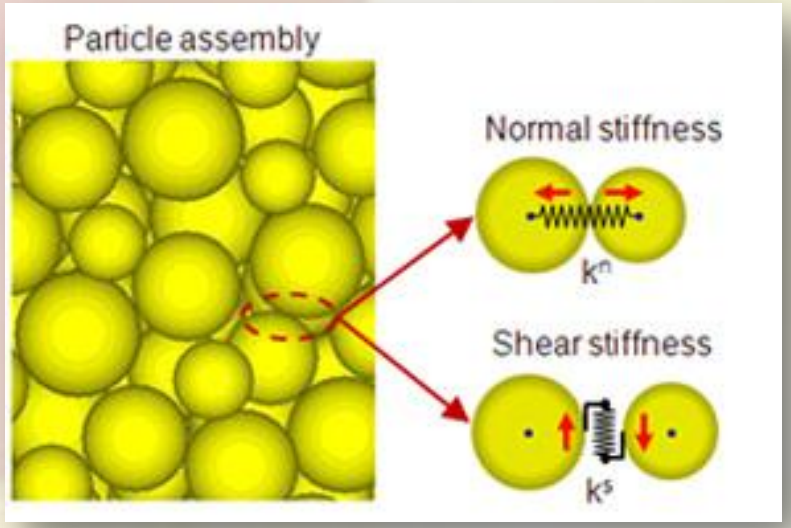
❑ Extension Lagrangian modeling methodology. DEM characteristic is introduction of inter-particle contact forces into equations of motion.

❑Classical mechanics method, based on soft-particle formulation: particles develop and overlap.

❑ Contact force is proportional to the overlap, particle material and geometric properties.

✓ Although DEM modeling demands significant computing power (limits: length of a simulation or the number of particles), it provides detailed resolution other methods cannot achieve.

- DEM simulation three parts:
  - initialization
  - explicit time-stepping
  - post-processing.



- Forces considered in macroscopic simulations:
  - Friction: when two particles touch each other
  - Contact plasticity (recoil): when two particles collide
  - Gravity
  - Volume forces

- All these forces are added up to find the total force acting on each particle.

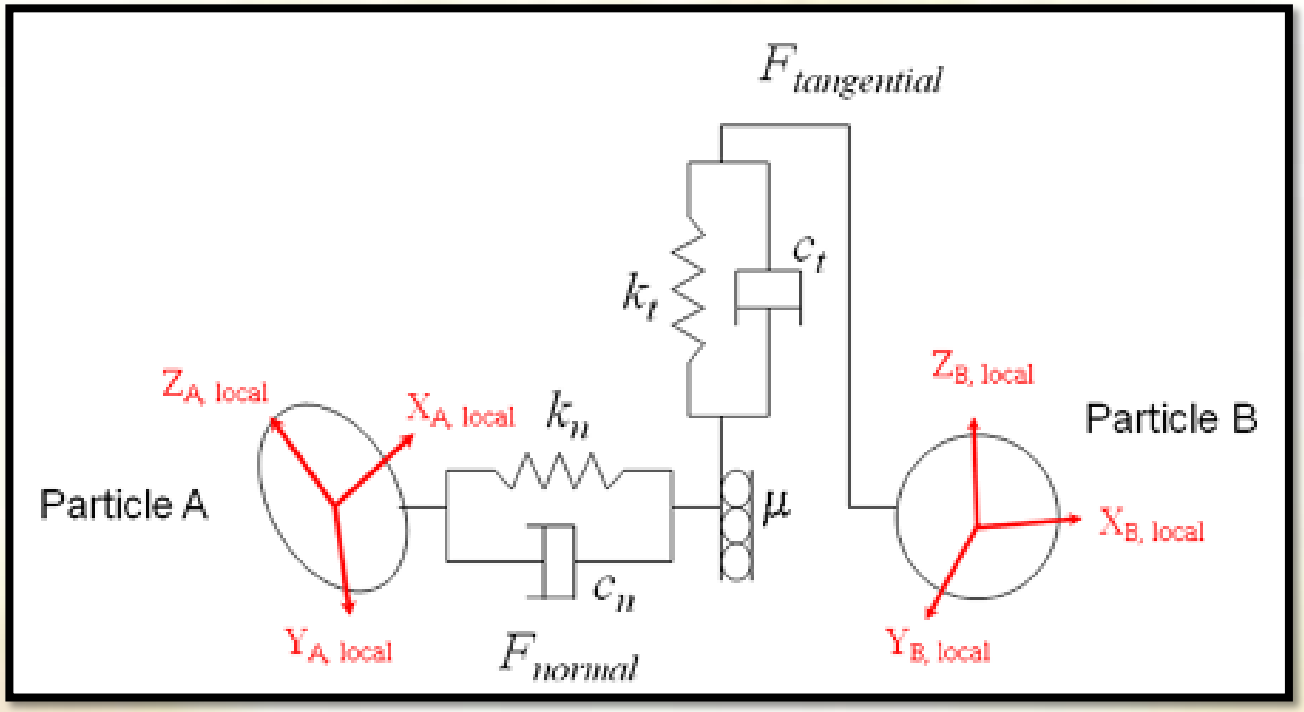
- Integration method is employed to compute the change in the position and the velocity of each particle during a certain time step from Newton's law of motion.
  - new positions are used to compute the forces during the next step, and loop.

CONTACT:

- Contact force formulation in DEM is typically a variant of the spring-dashpotcmodel.
  - •Spring generates repulsive force pushing particles apart
  - • Dashpot represents viscous damping and allows simulation of collision types other than perfectly elastic.

✓The forces at the point of contact are modeled as a pair of spring-dashpot oscillators. One representing the normal direction and the other the tangential direction of force with respect to the contact plane normal vector.

❑ **The Hertz-Mindlin** contact model is a variant of the non-linear spring-dashpot contact model based on the Hertz-Mindlin contact theory. The forces between two spheres, A and B, are described by the following set of equations.



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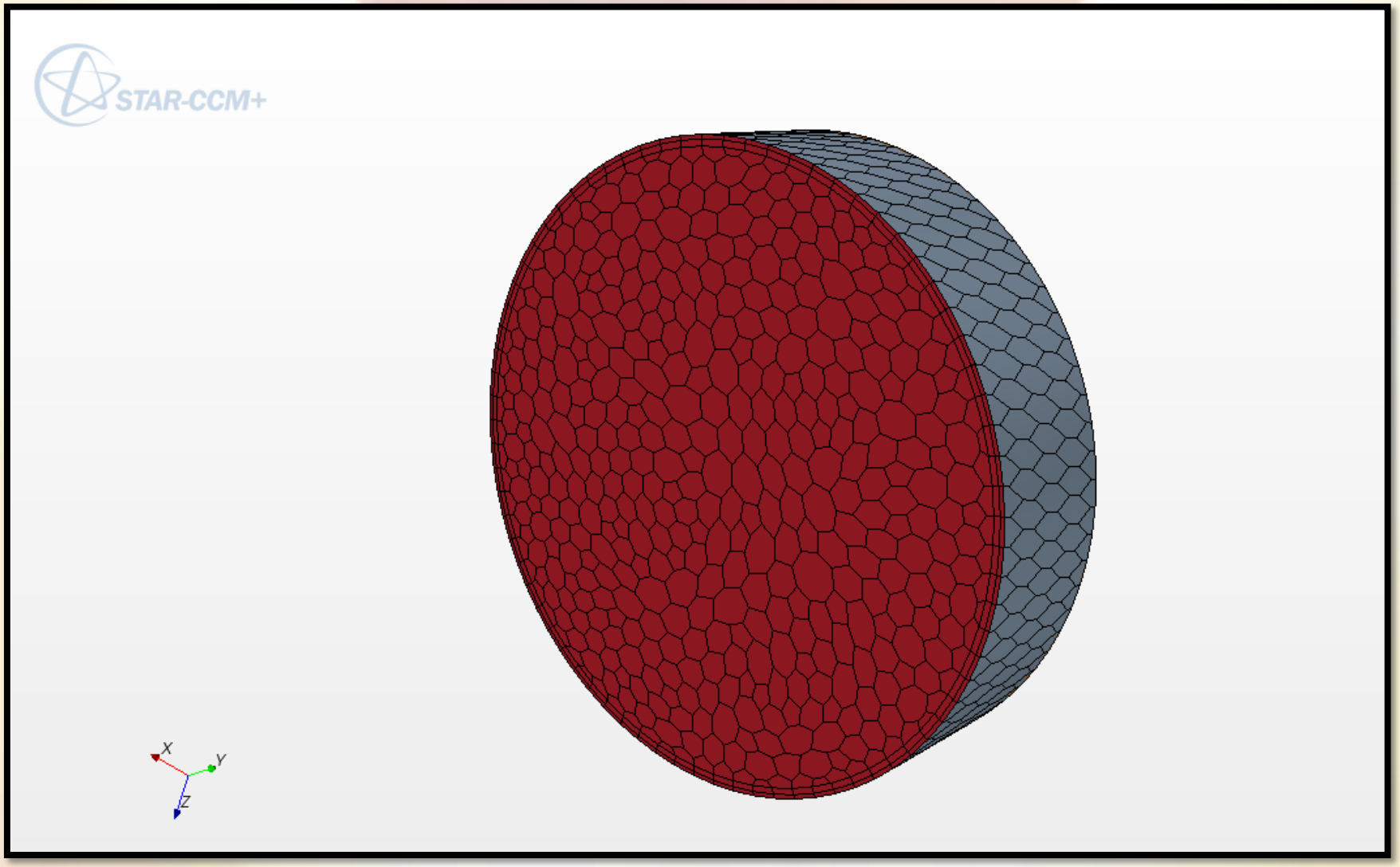
MESH



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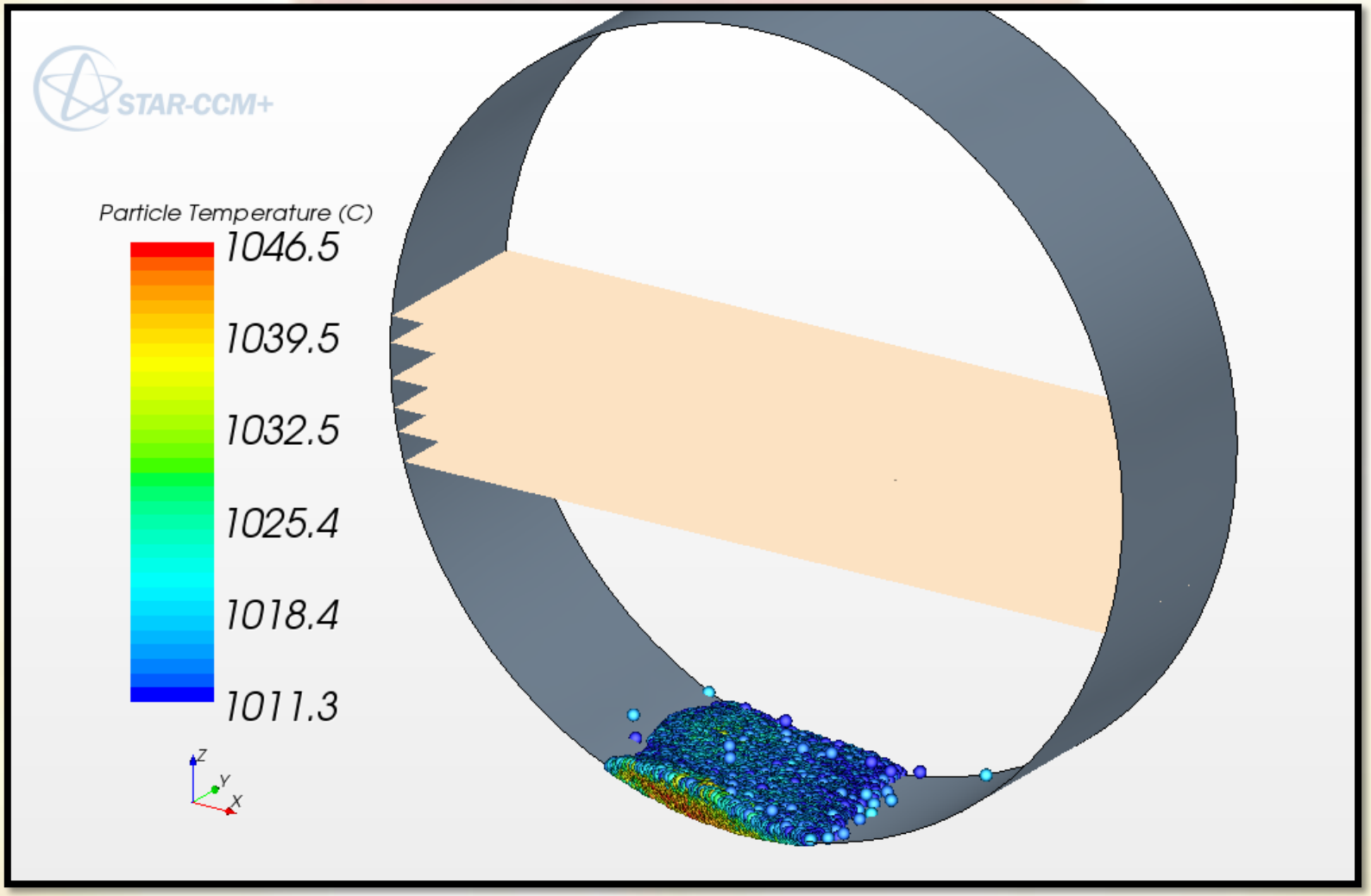

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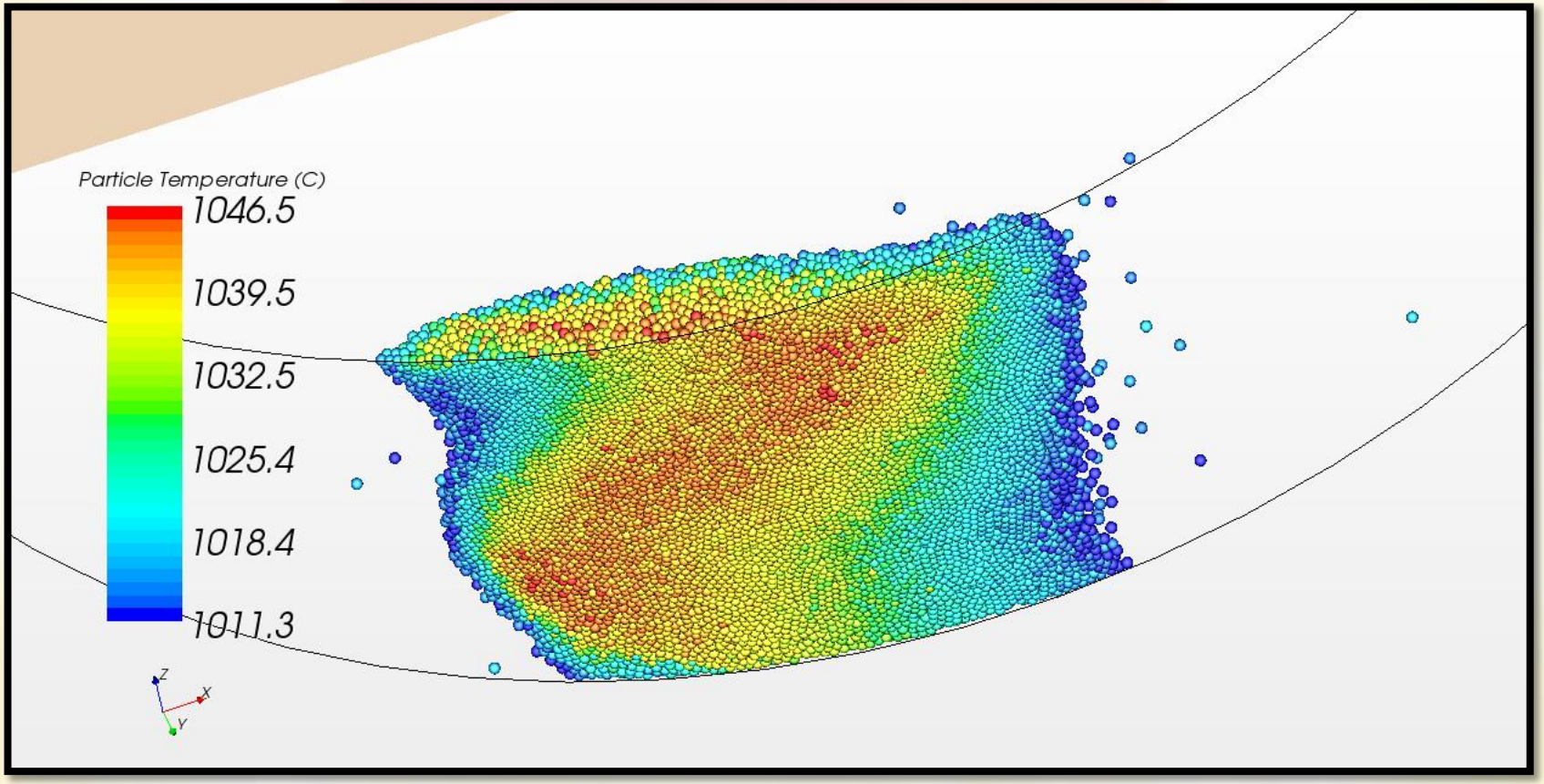

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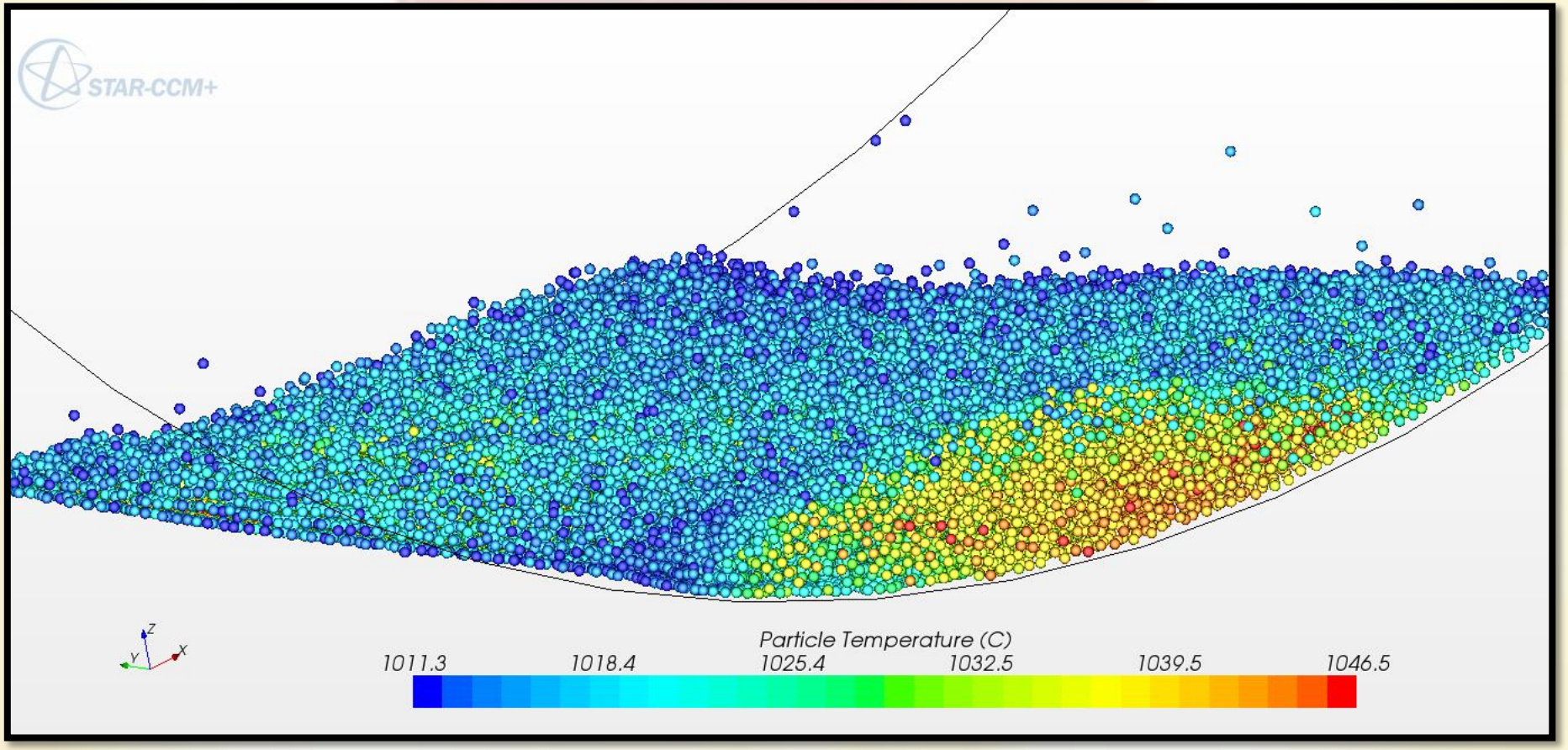

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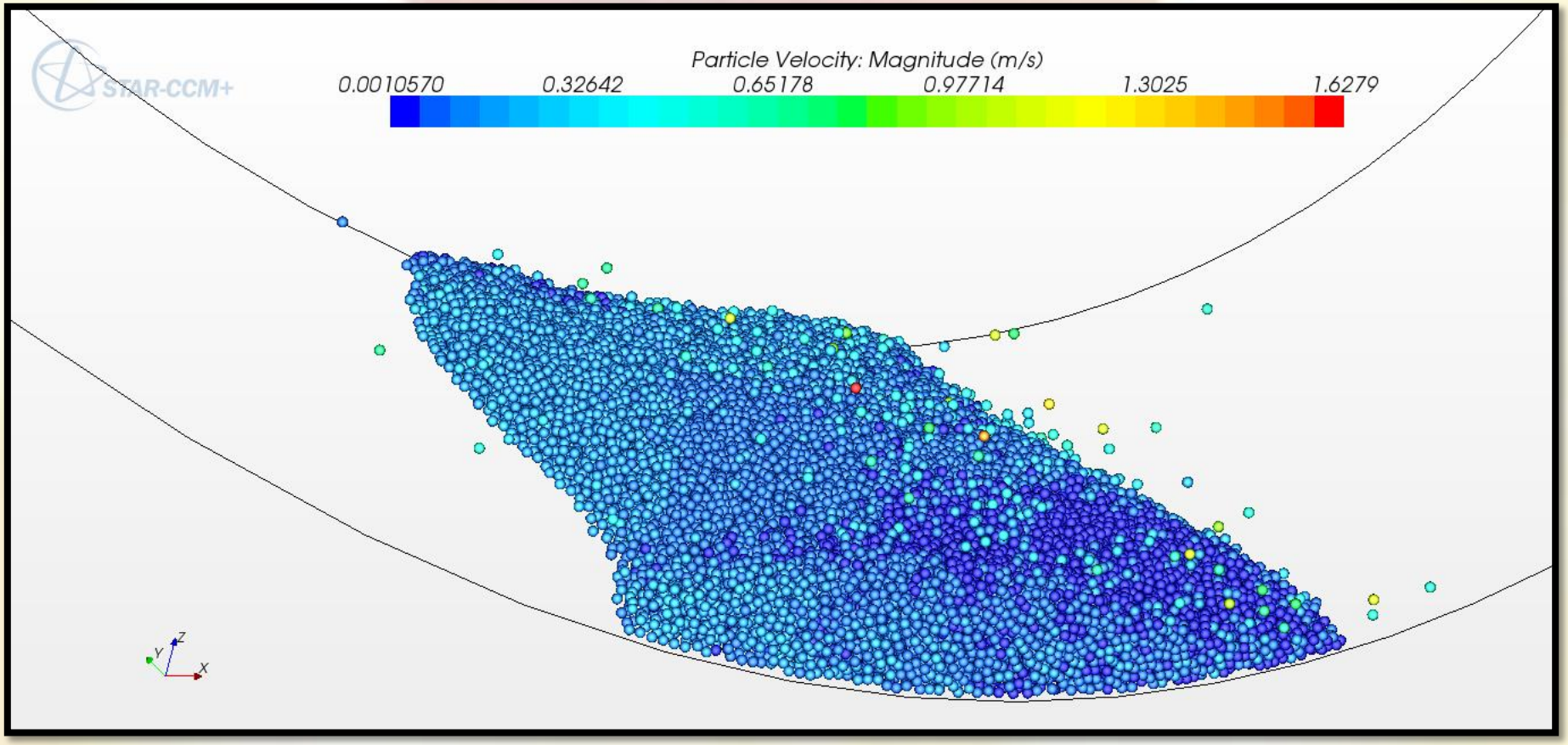

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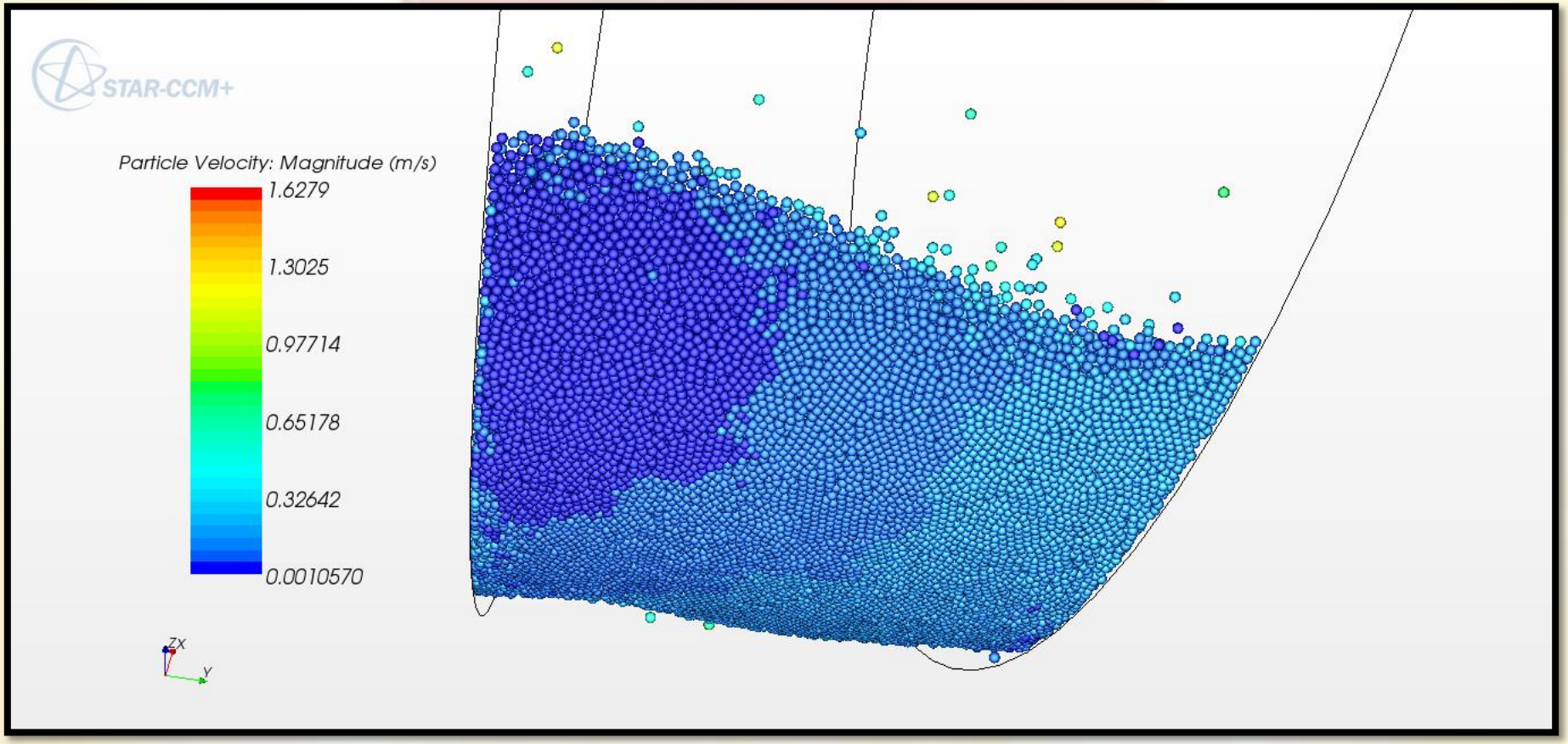

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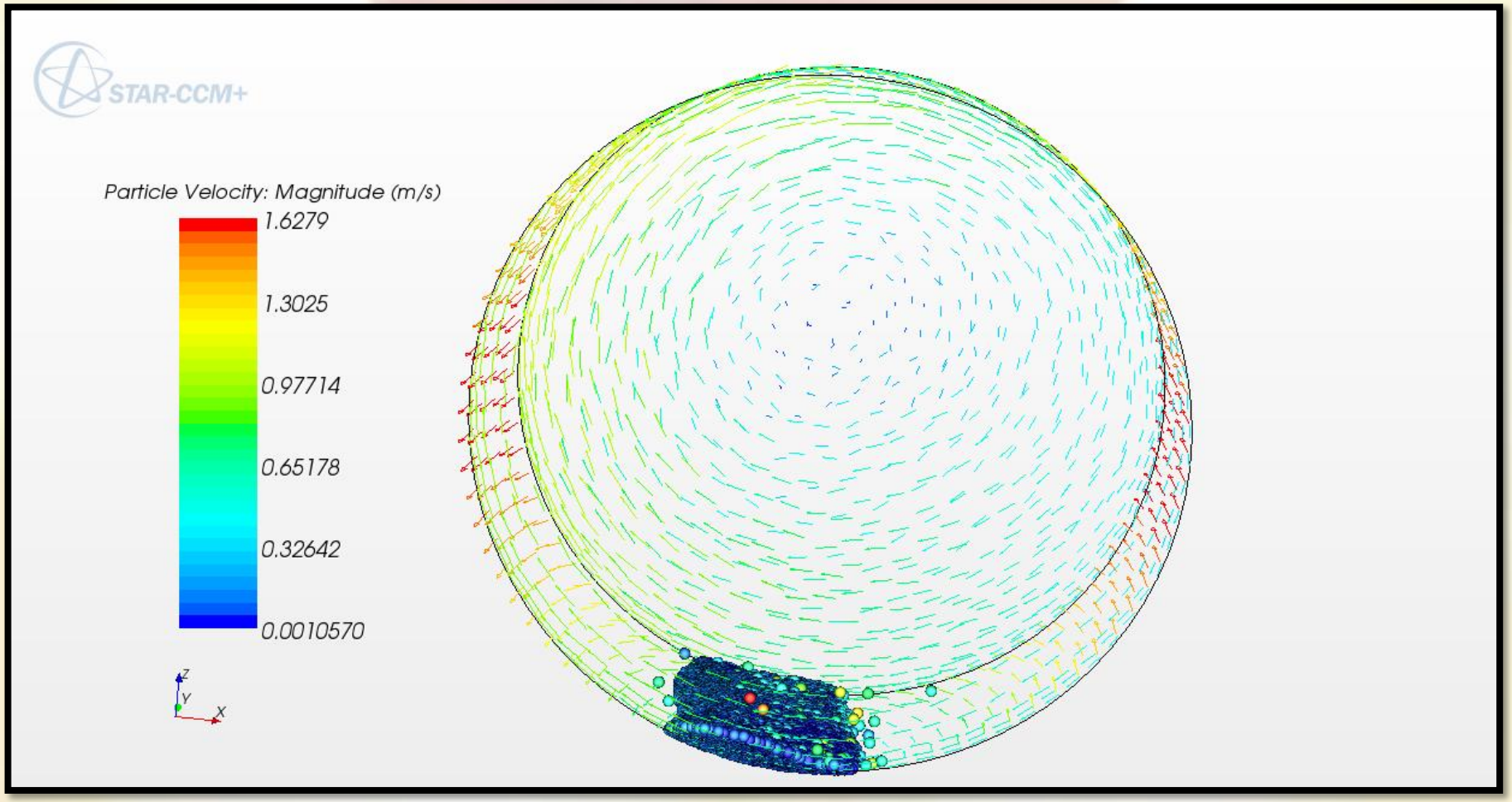

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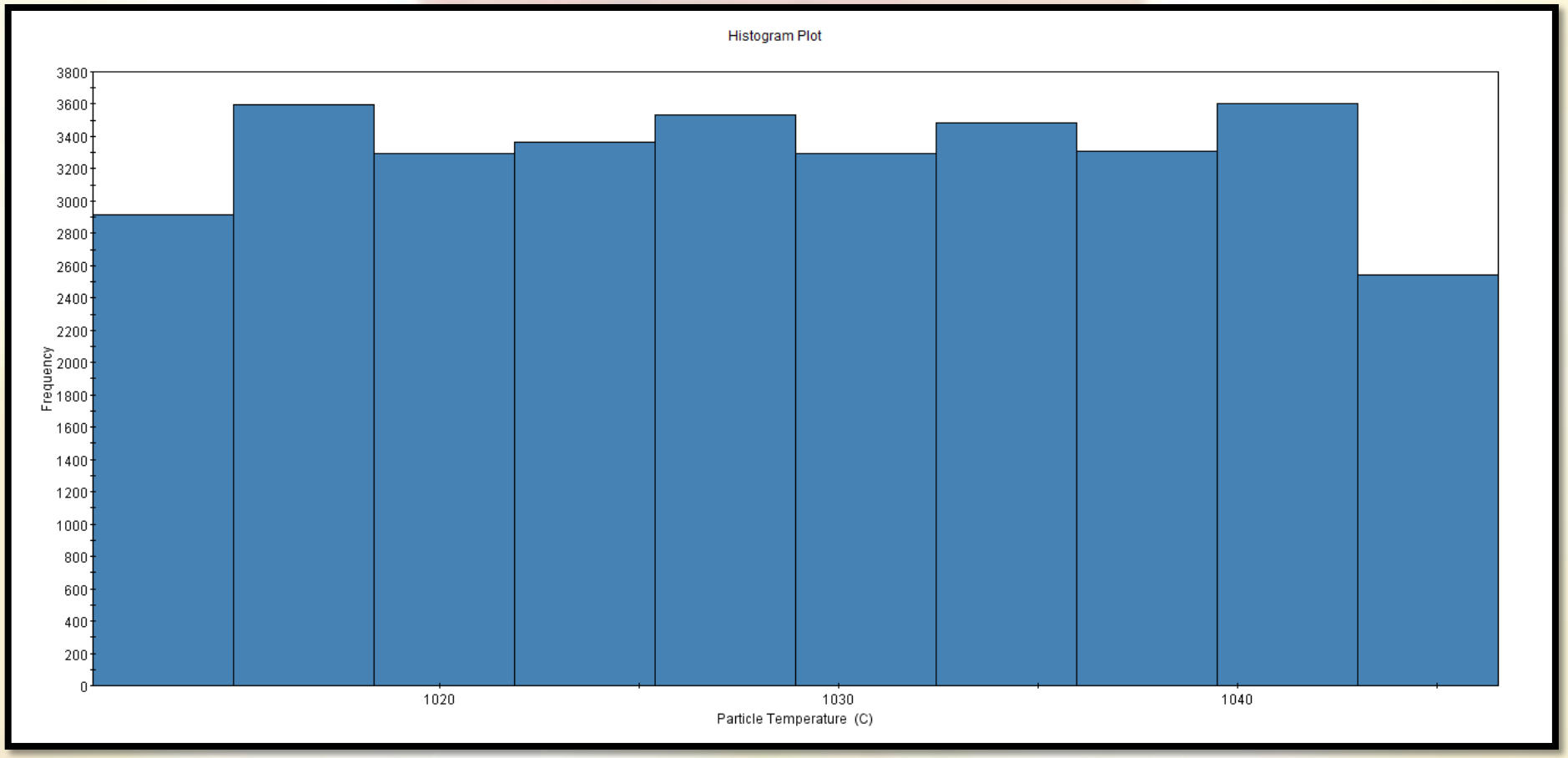

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END OF PART 3