Characterization of Particle Flow in a Free-Falling Solar Particle Receiver

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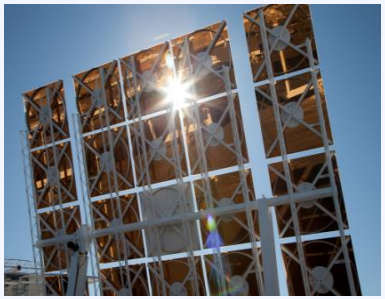

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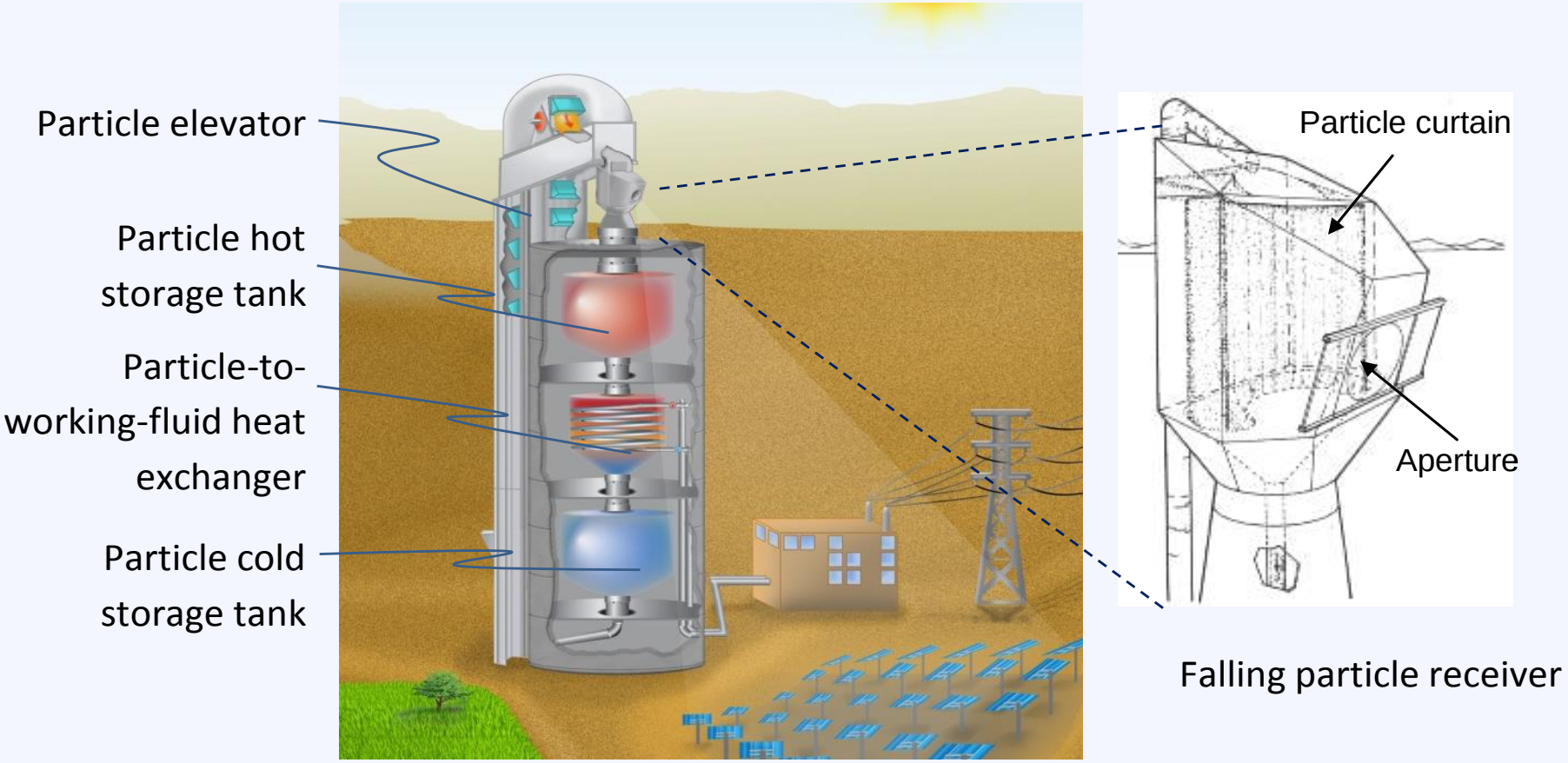
Presentation Overview

- Introduction and Objectives
- Particle Flow Characterization
  - Mass flow rates
  - Velocities
  - Curtain properties
- Future Work

Technology Description

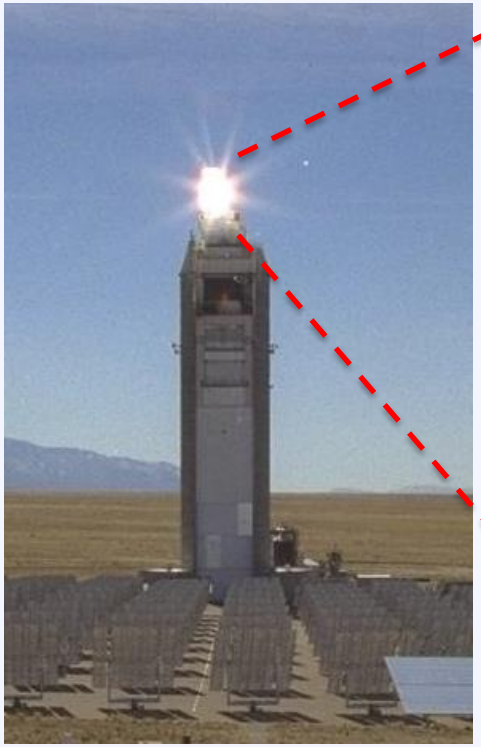


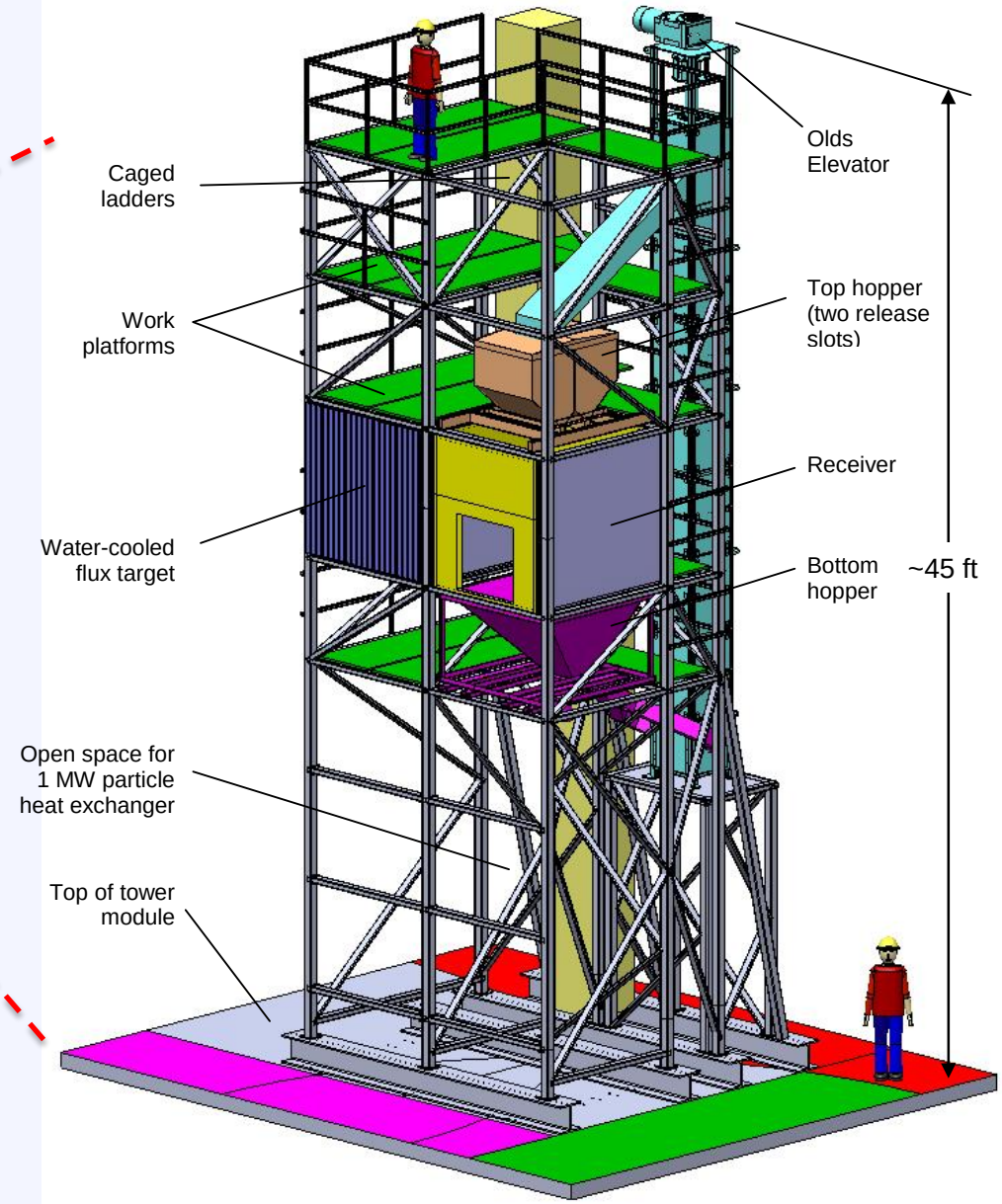
Falling Particle Receiver Technology

Particle Receiver Advantages

- High temperatures (> 600 C)
  - Enables higher efficiency power cycles
- Increased fluxes and concentration ratios
  - Increased thermal efficiencies
- Direct storage

Project Objectives





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Project Objectives

- Characterize particle flow behavior prior to on-sun testing
  - Particle mass flow through elevator
  - Particle mass flow through discharge plate
  - Particle velocities
  - Particle curtain properties

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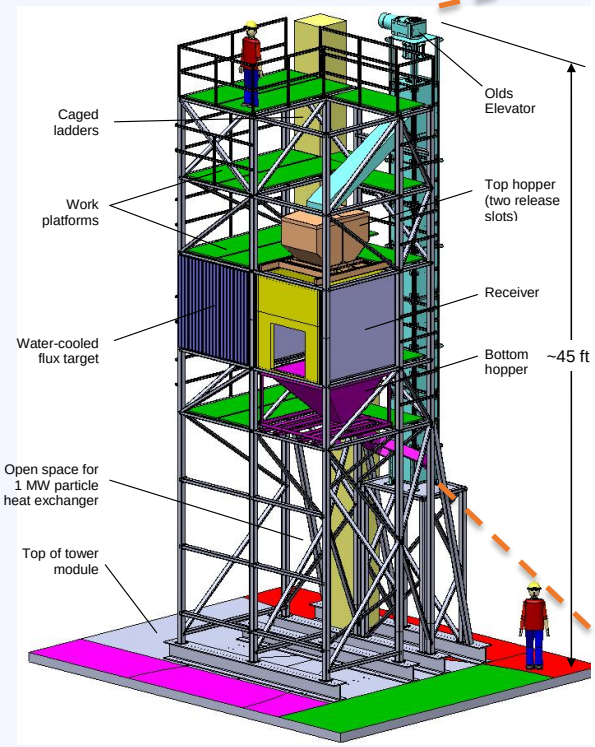
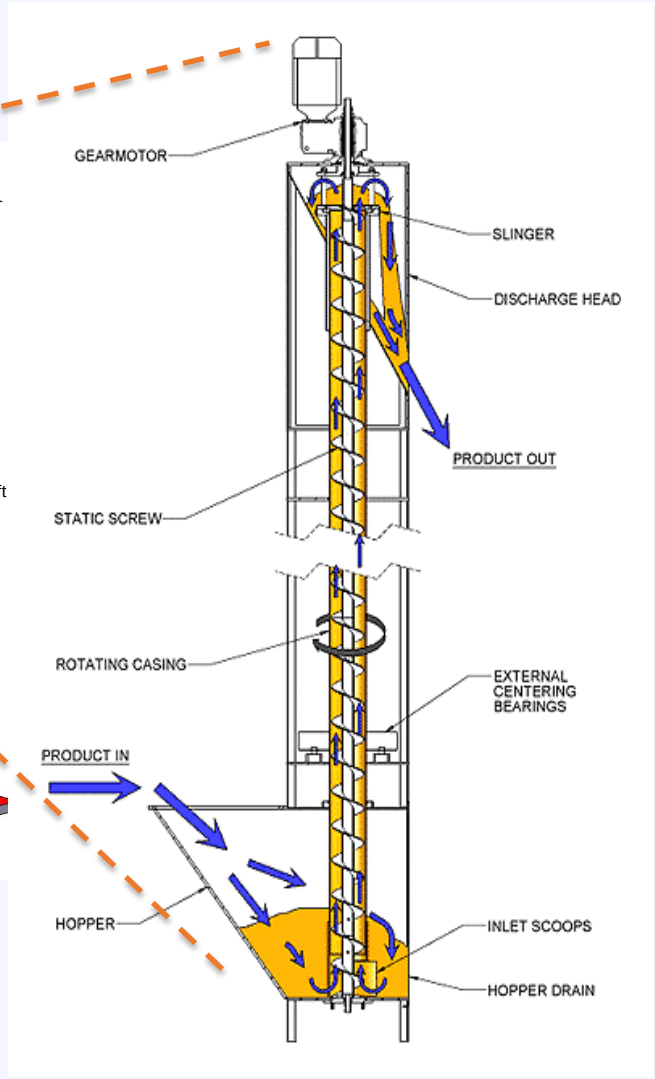
Particle properties

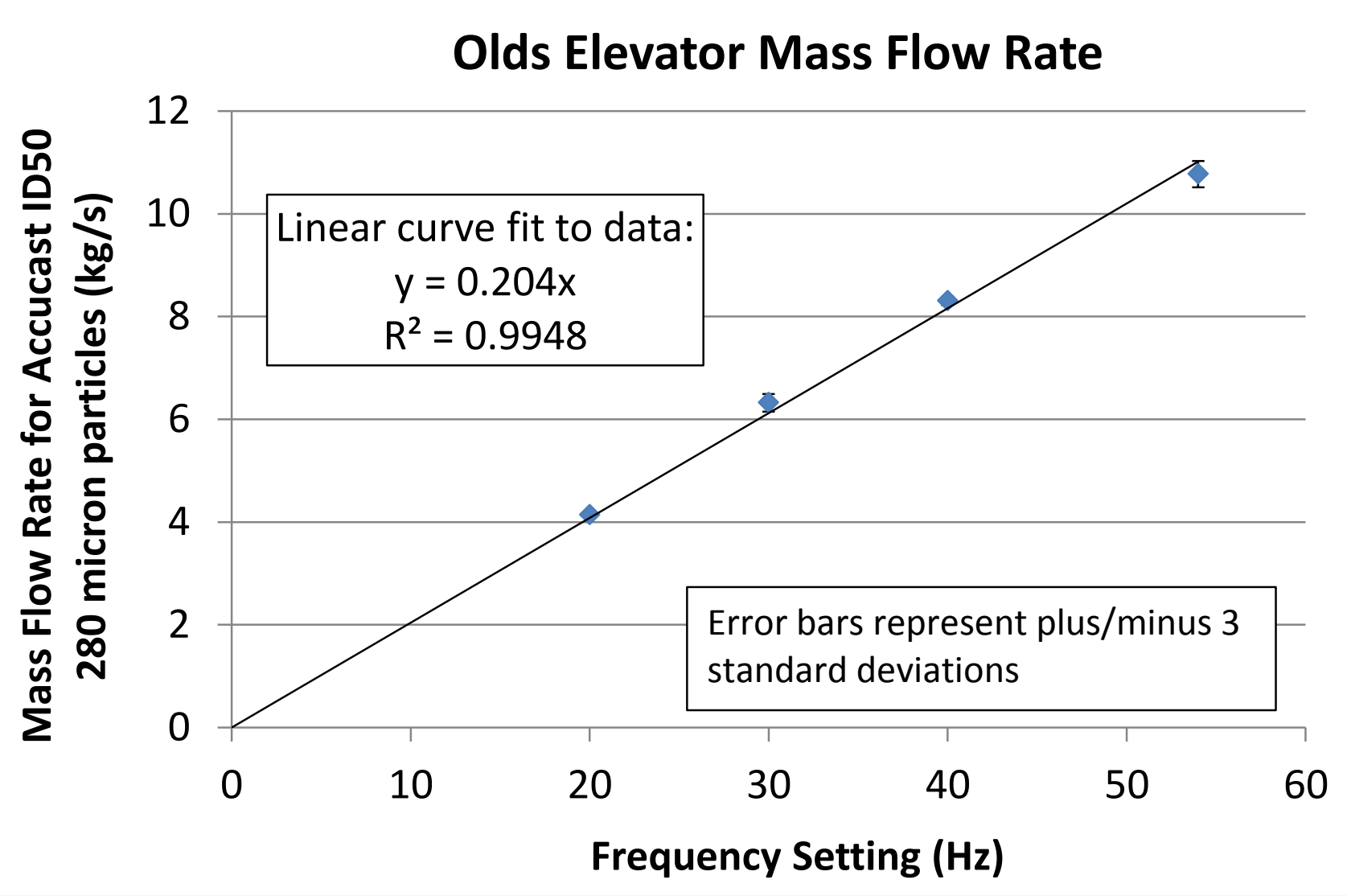
- Ceramic proppants (CARBO Ceramics)
  - 75% Al_2O_3, 11% SiO_2, 9% Fe_2O_3, 3% TiO_2
- Properties
  - 280 micron nominal diameter
  - ~90% solar absorptance

Olds Particle Elevator



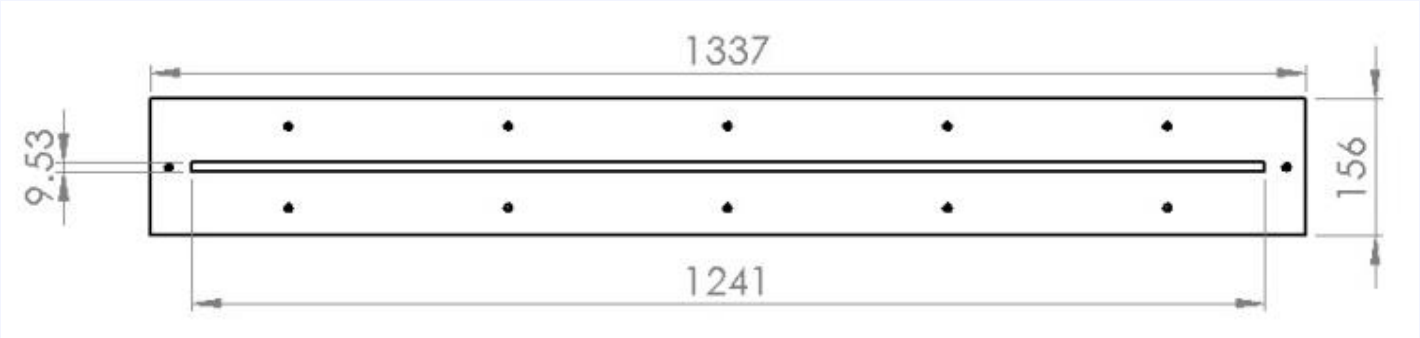


Olds Elevator Mass Flow Measurements

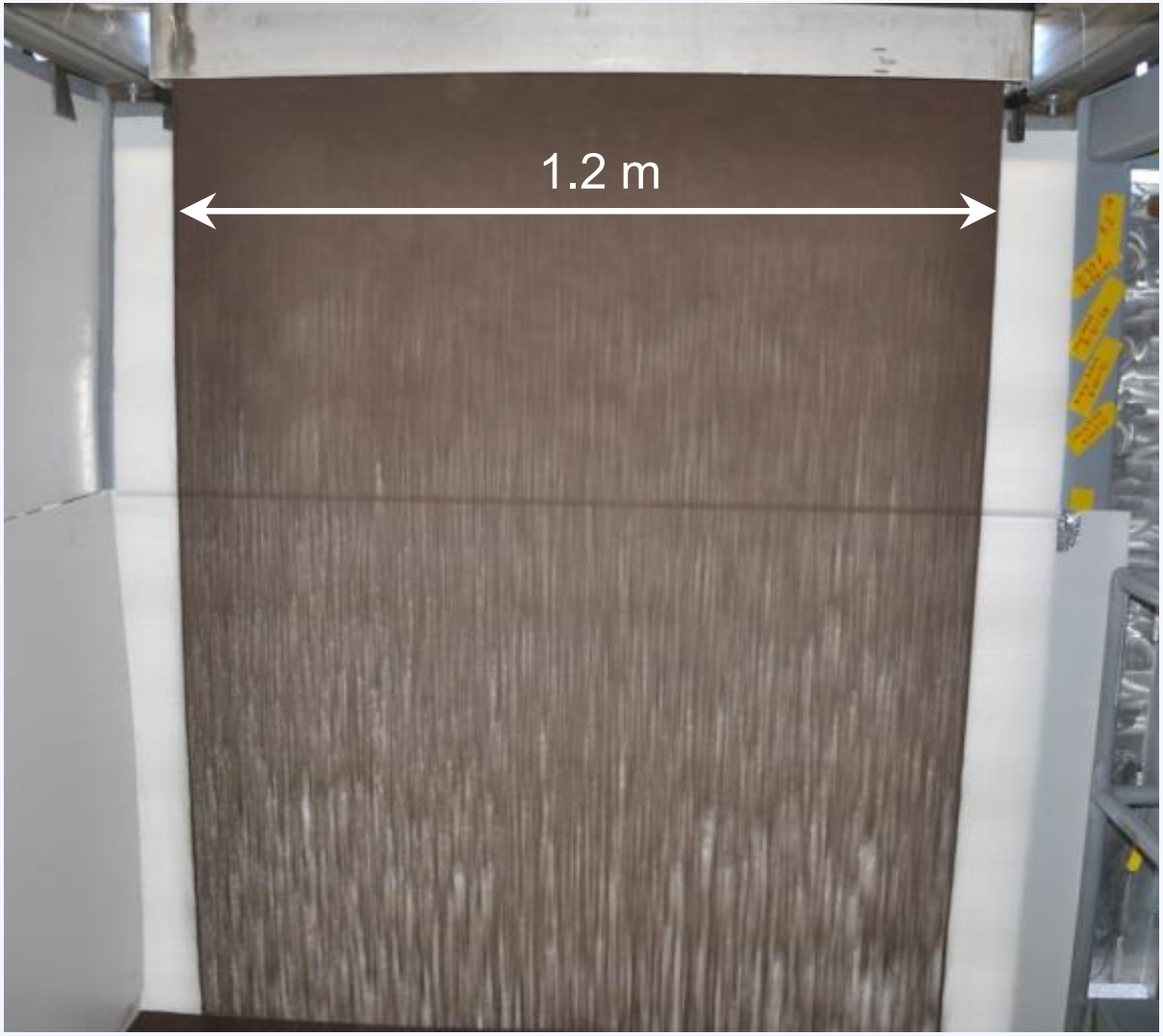


Mass Flow through Discharge Plates

- Discharge plates of different aperture sizes were tested
  - 6.35 mm (1/4 inch)
  - 9.53 mm (3/8 inch)
  - 11.1 mm (7/16 inch)
  - 12.7 mm (1/2 inch)



Sample Particle Curtain



11.1 mm slot aperture

Modified Beverloo Equation

$$\dot{m} = C_1 \rho_b \sqrt{g} \left(D - C_2 d \right)^{n+0.5} \qquad (1)$$

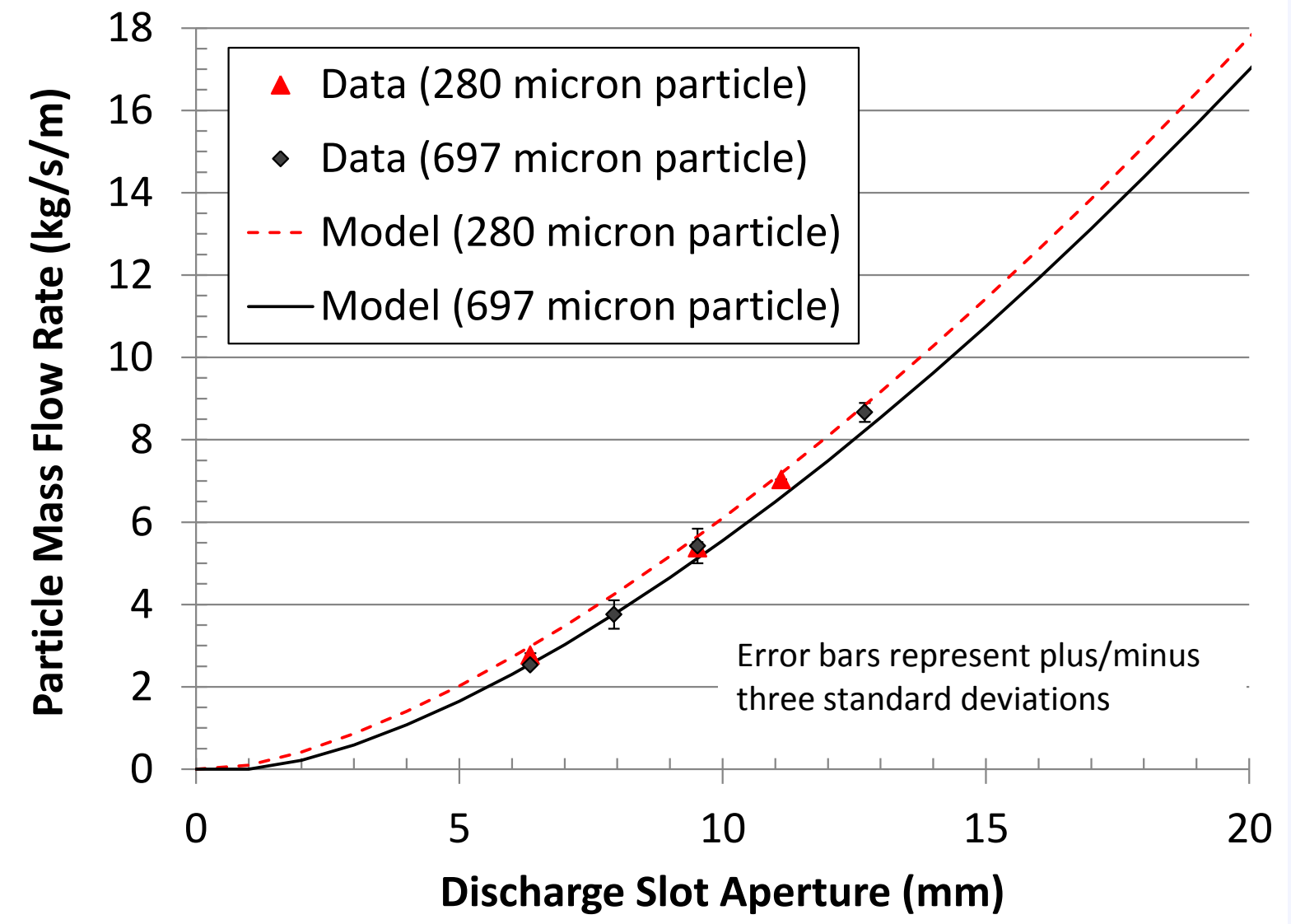
where

$\dot{m}$ = Mass flow rate (kg/s for 3D or kg/s/m for 2D)
C_1 = Dimensionless constant related to material properties
ρ_b = Bulk density of particles above the aperture (kg/m^3)
g = Gravitational constant (9.81 m/s^2)
D = Aperture size (m)
C_2= Geometrical factor accounting for the effective outpouring section being smaller than the aperture
d = Particle size (m)
n = "1" for 2D and "2" for 3D

Beverloo, W.A., H.A. Leniger, and J. Vandevelde, 1961, The Flow of Granular Solids through Orifices, *Chemical Engineering Science*, **15**(3-4), p. 260

Janda, A., I. Zuriguel, and D. Maza, 2012, Flow Rate of Particles through Apertures Obtained from Self-Similar Density and Velocity Profiles (vol 108, 248001, 2012), *Physical Review Letters*, **109**(18).

Mass Flow Rates through Discharge Plates



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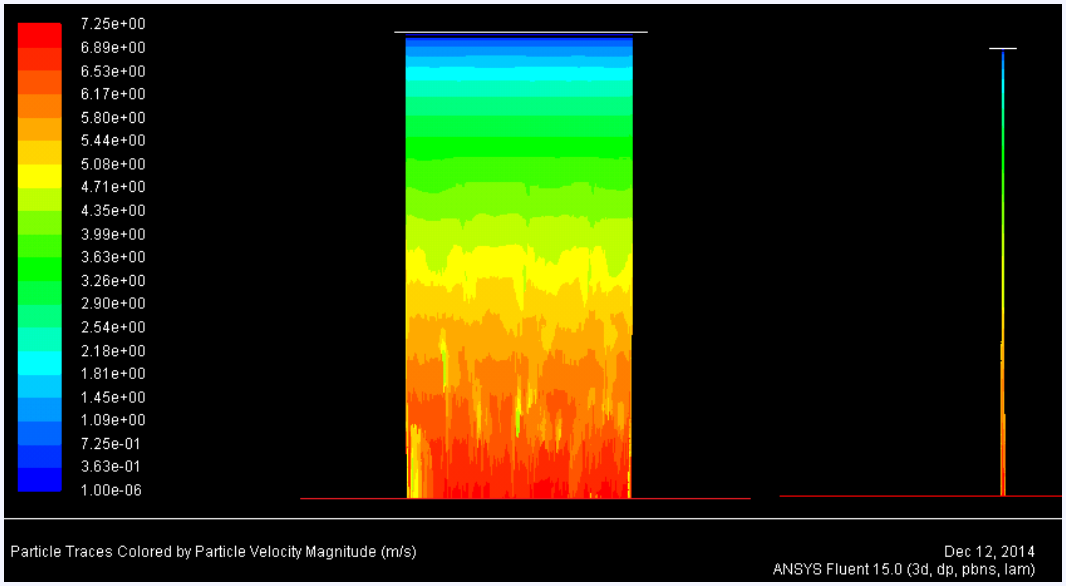
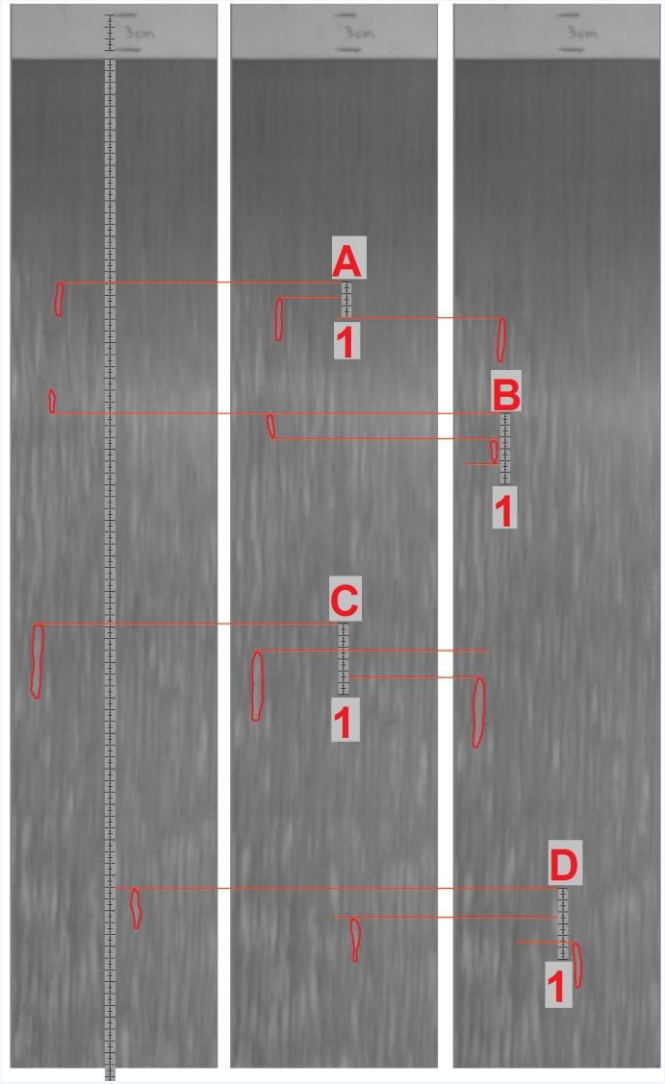
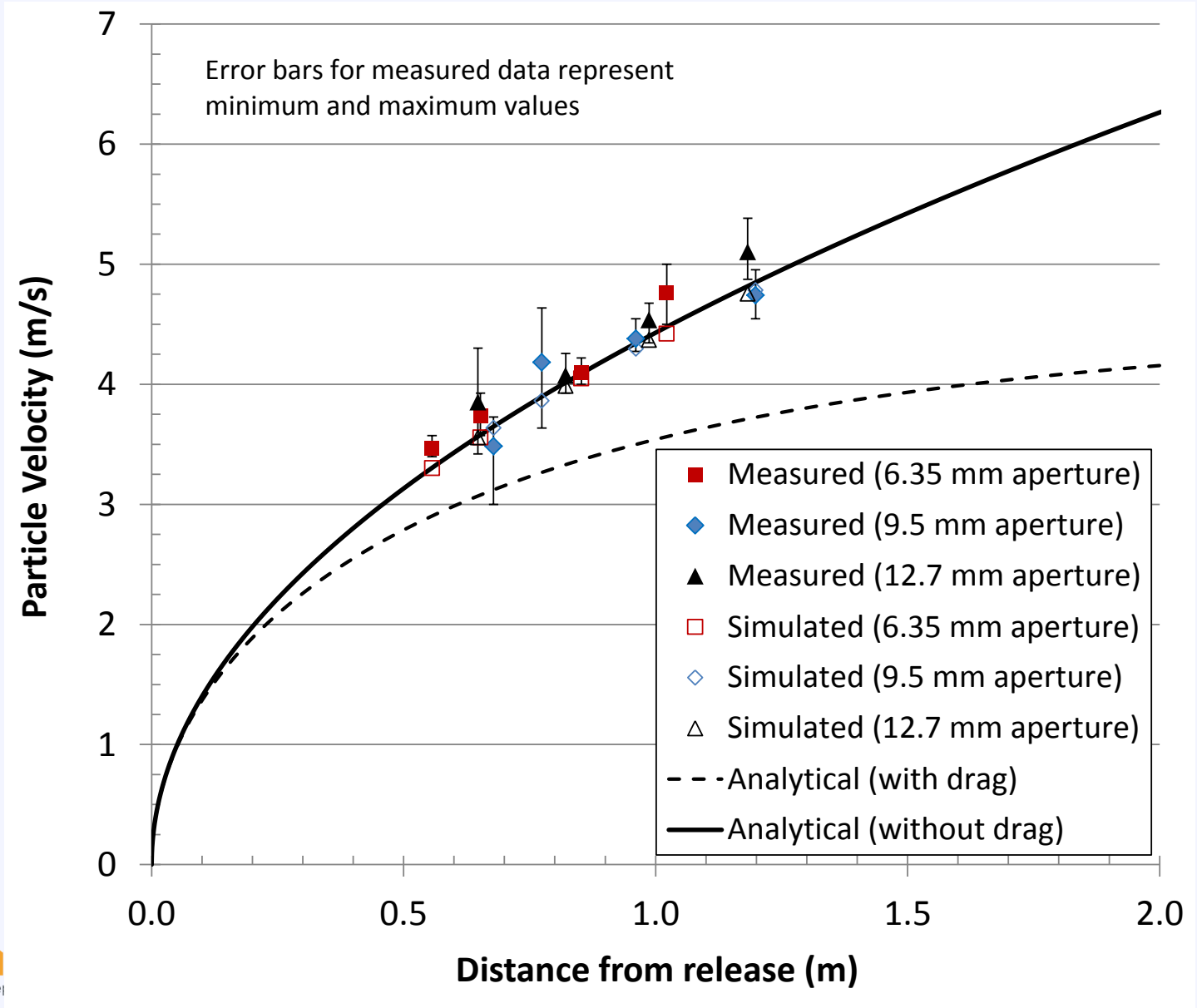
Particle Velocity

- Analytical solutions (with and without drag)
- Numerical Simulation
- Empirical (high-speed photography)





Particle Velocity



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Particle Curtain Thickness

6.35 mm

9.53 mm

11.1 mm

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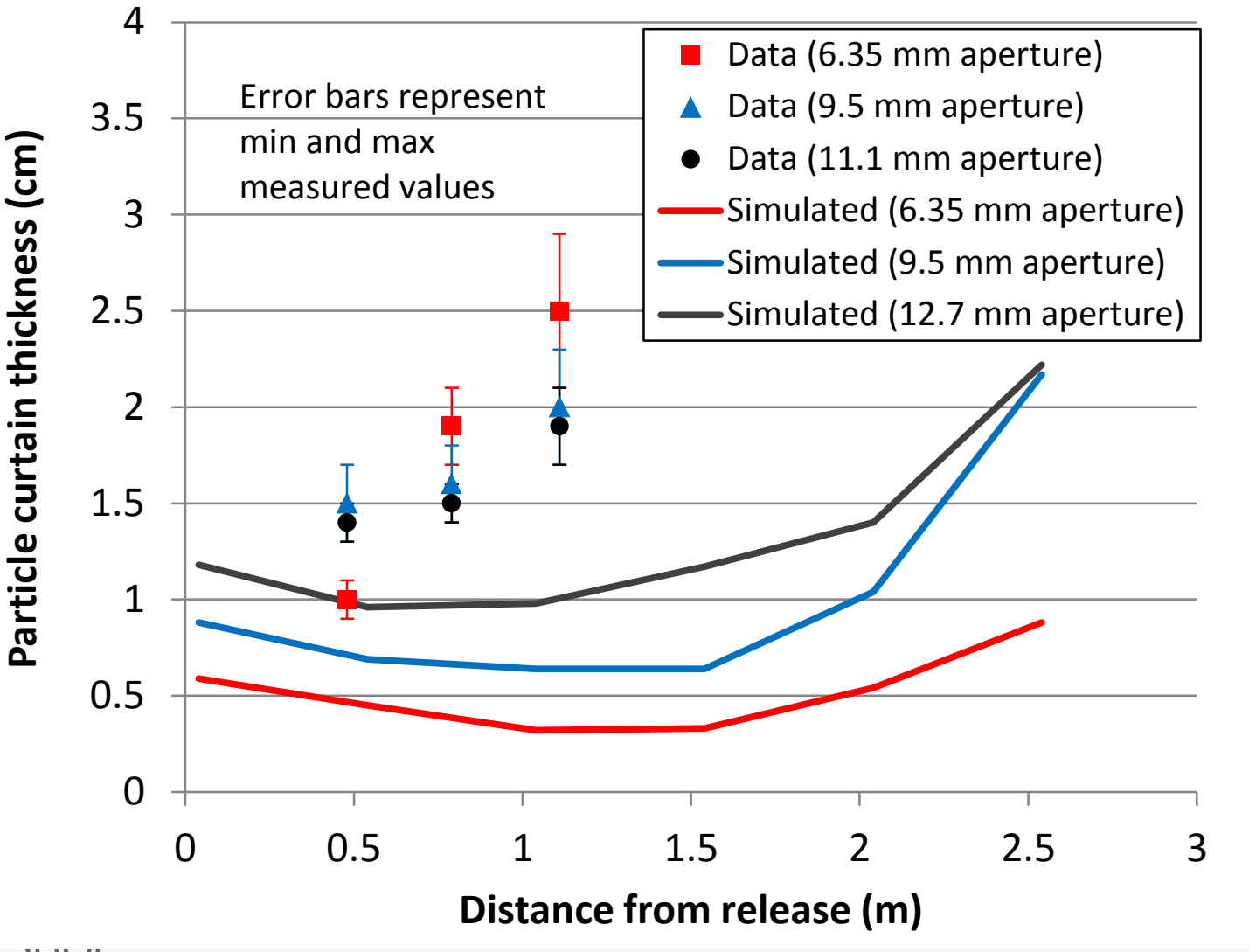
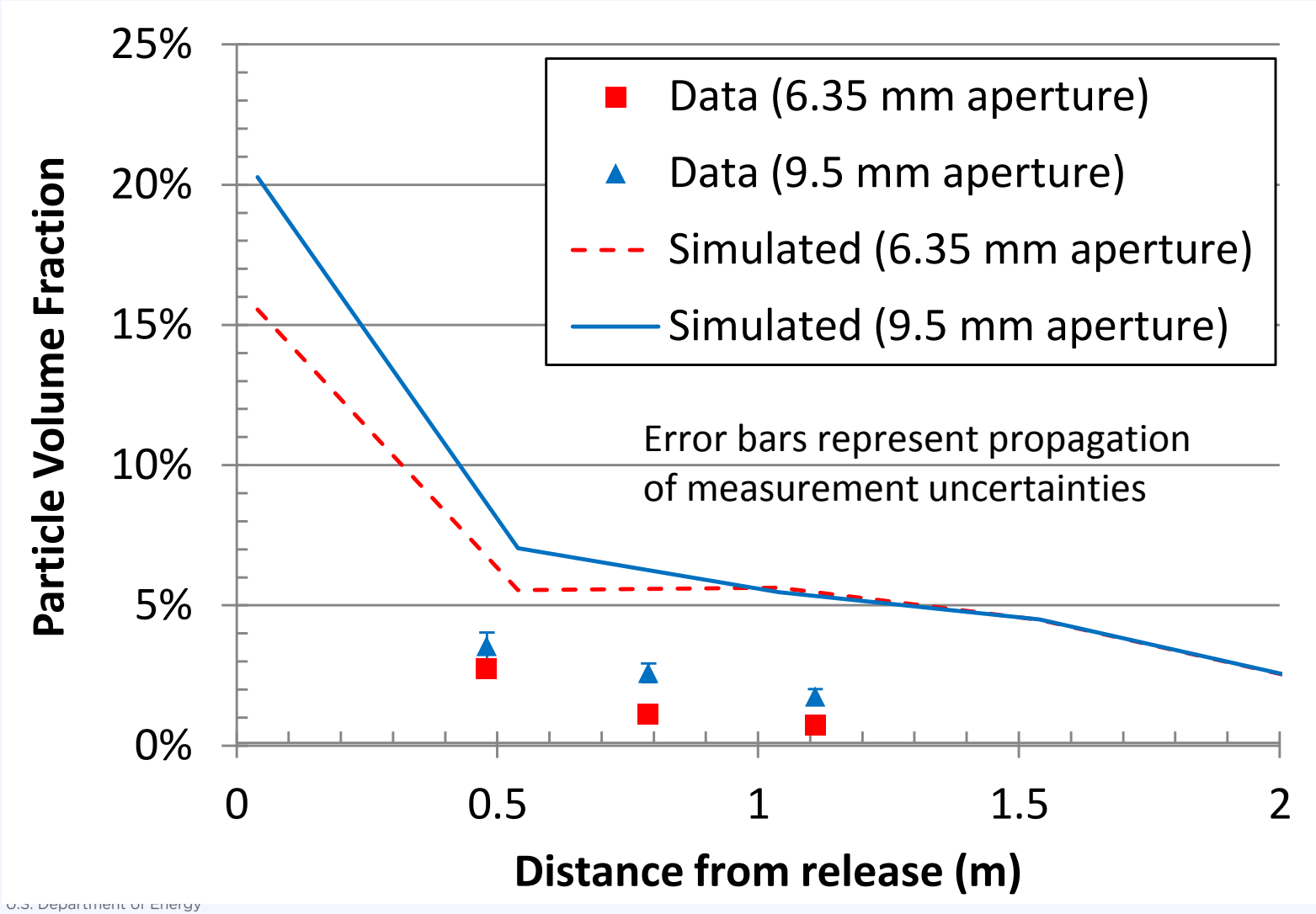
Particle Curtain Thickness

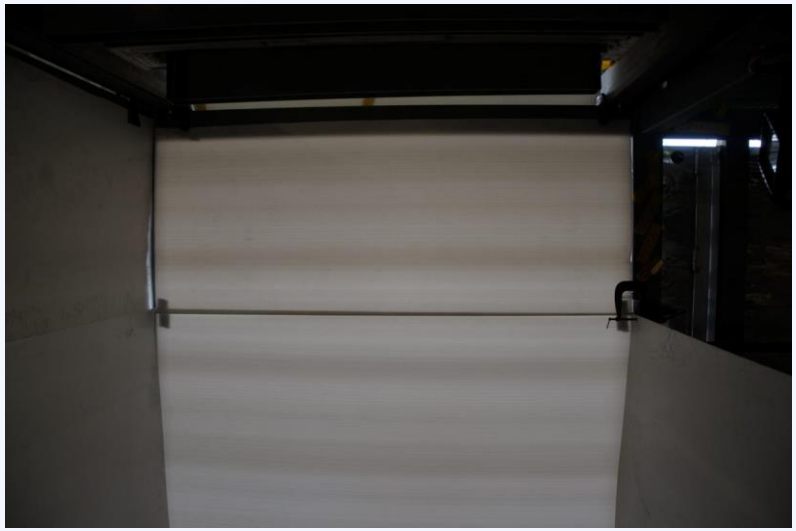


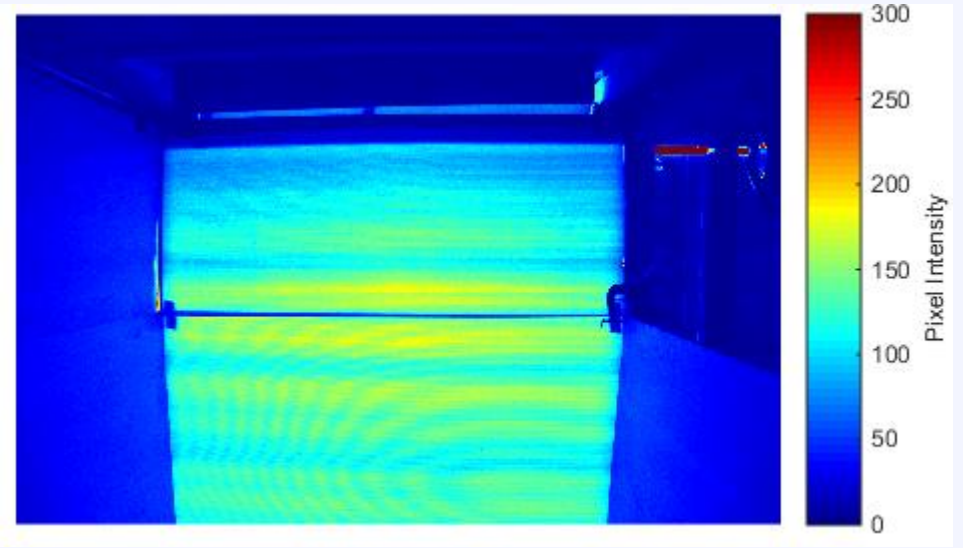
Particle Volume Fraction

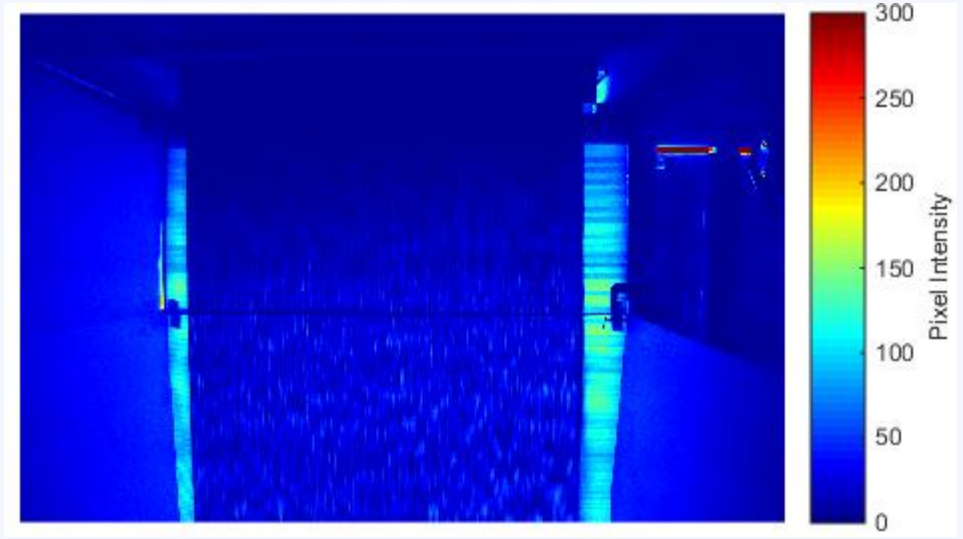
$$\rho_{b,f}(y) = \frac{\dot{m}}{v(y)A(y)}$$



Particle Curtain Transmittance

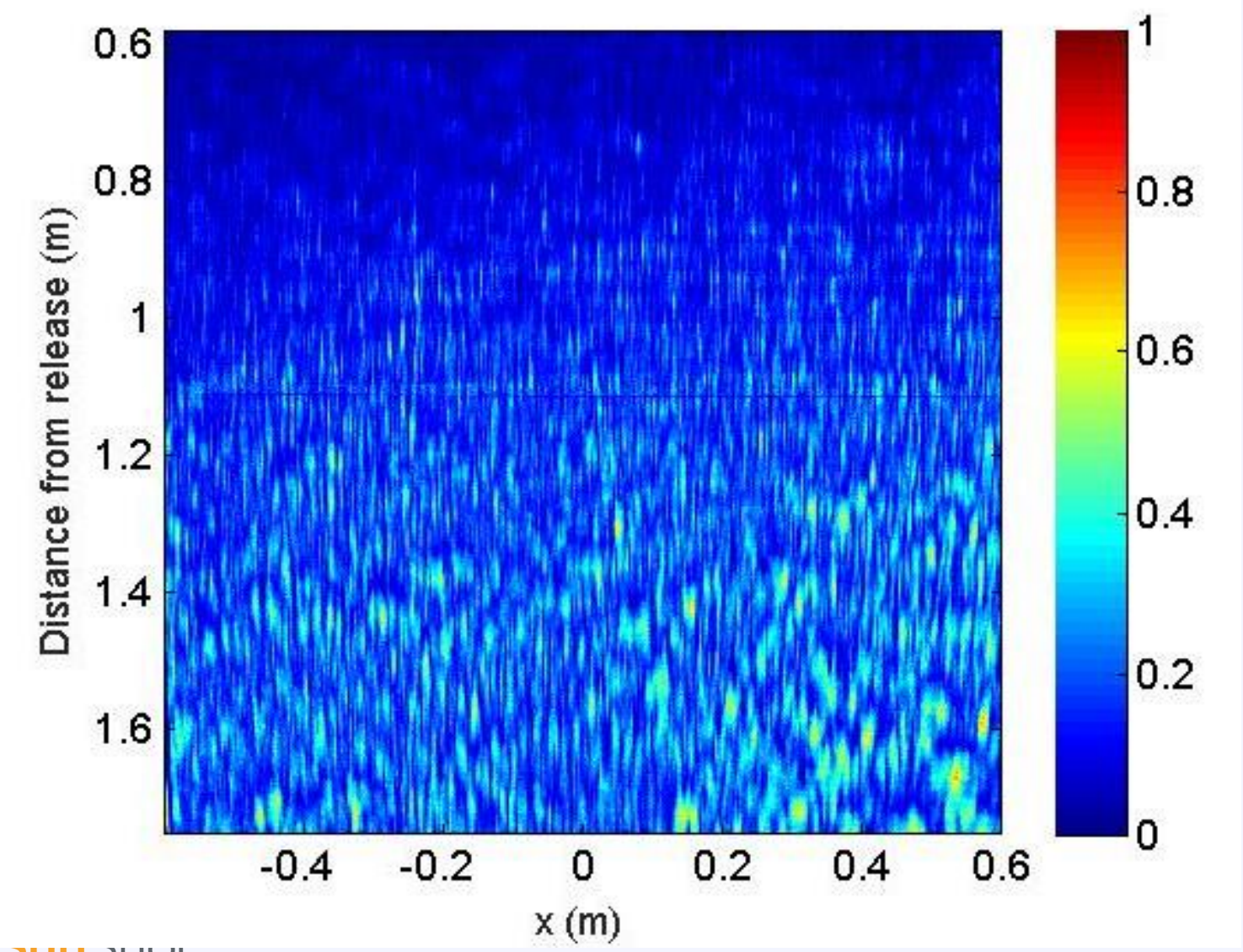




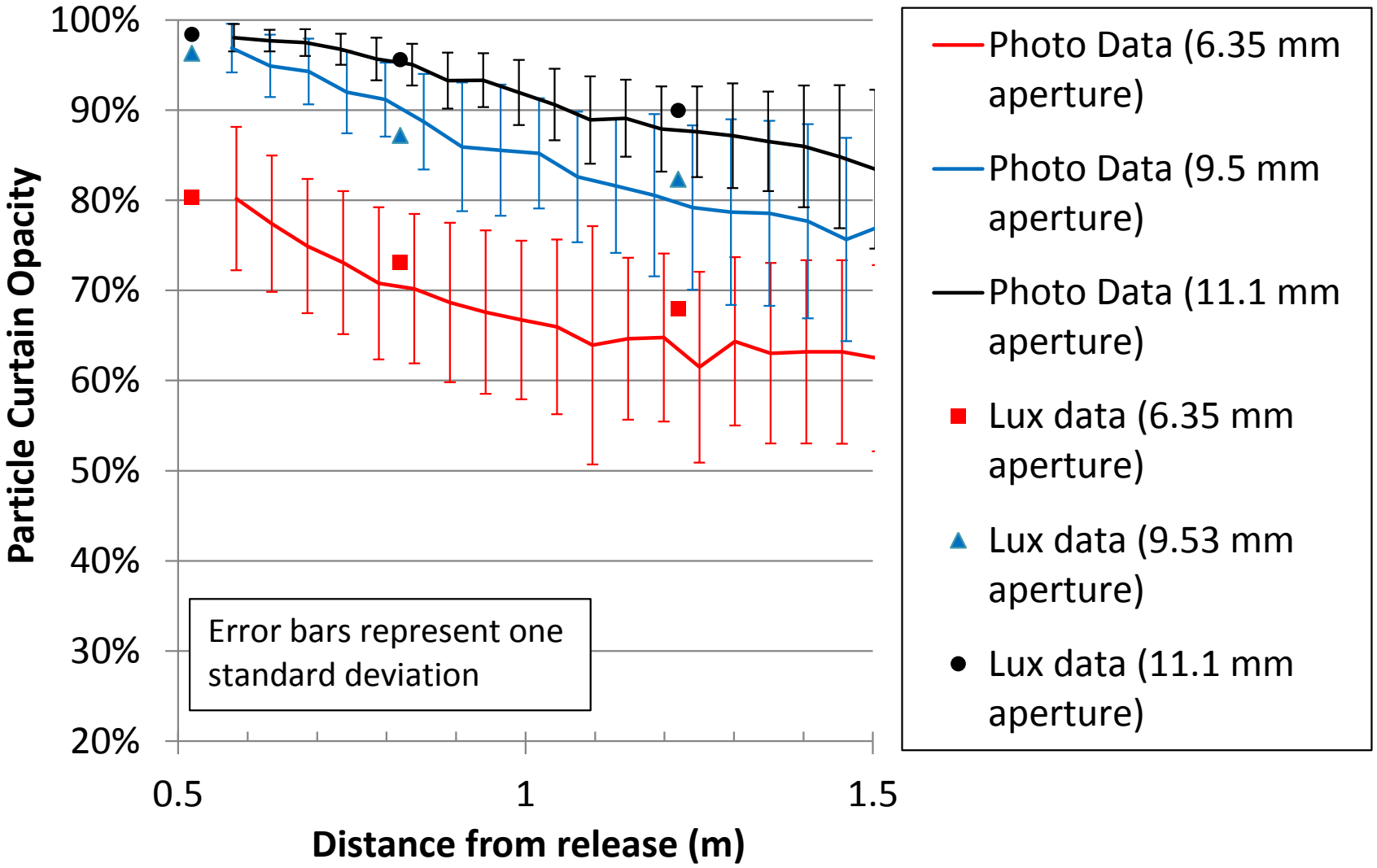


9.53 mm aperture

Particle Curtain Transmittance



Particle Curtain Transmittance



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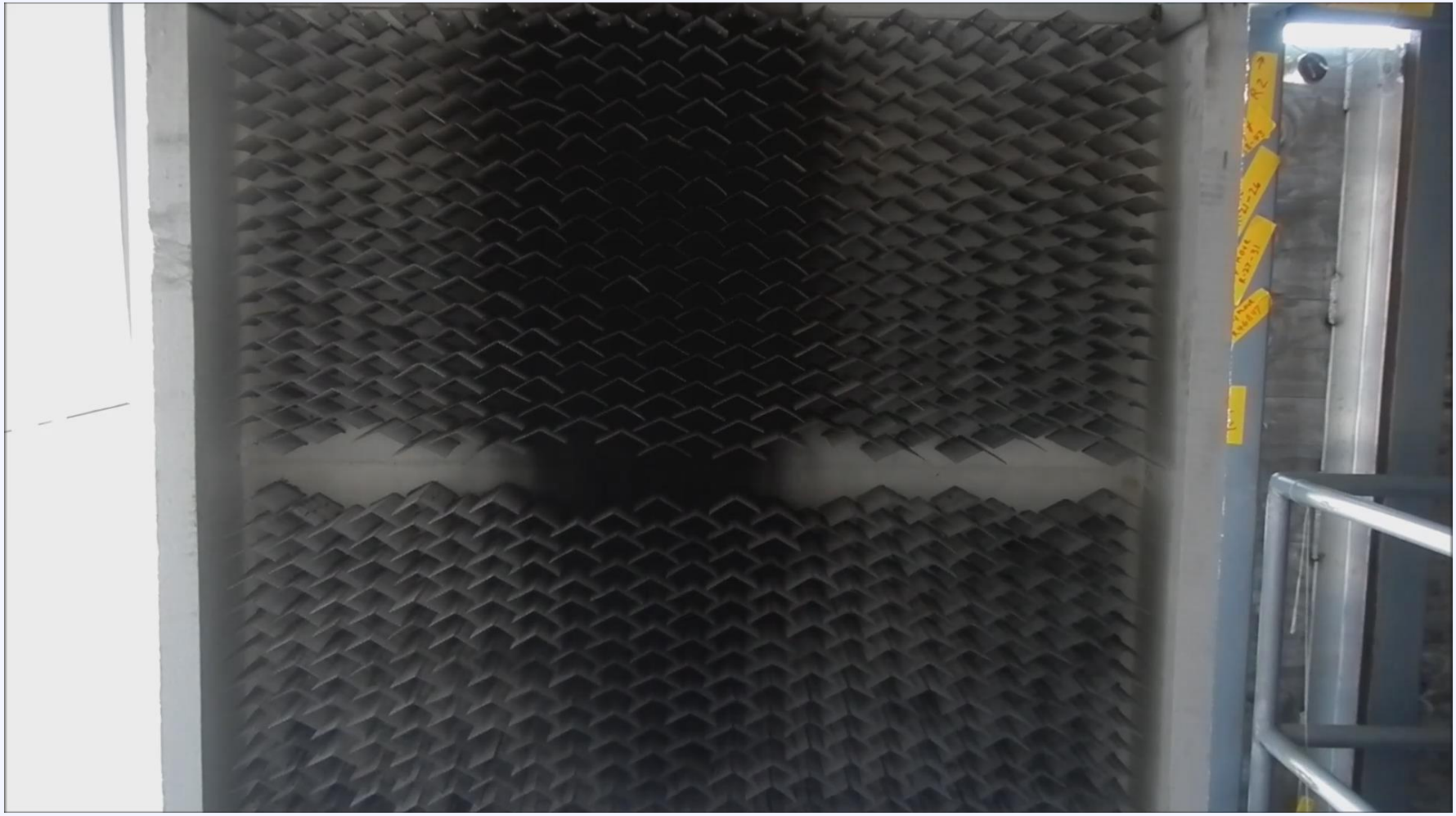
Conclusions

- Particle mass flow rates measured
  - Olds elevator
  - Discharge slots
    - Data matched well with modified Beverloo equation
- Particle velocities
  - Measured and simulated velocities matched analytical free-fall model with no drag
- Particle curtain properties
  - Particle volume fractions decrease from 60% to less than 10% within 0.5 m
  - Curtain opacity decreased with increasing distance

Next Steps

Particle flow tests over chevron screens



~0.61 m/s

On-Sun Tower Testing

Over 300 suns on receiver
(June 25, 2015)

Acknowledgments

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Questions?

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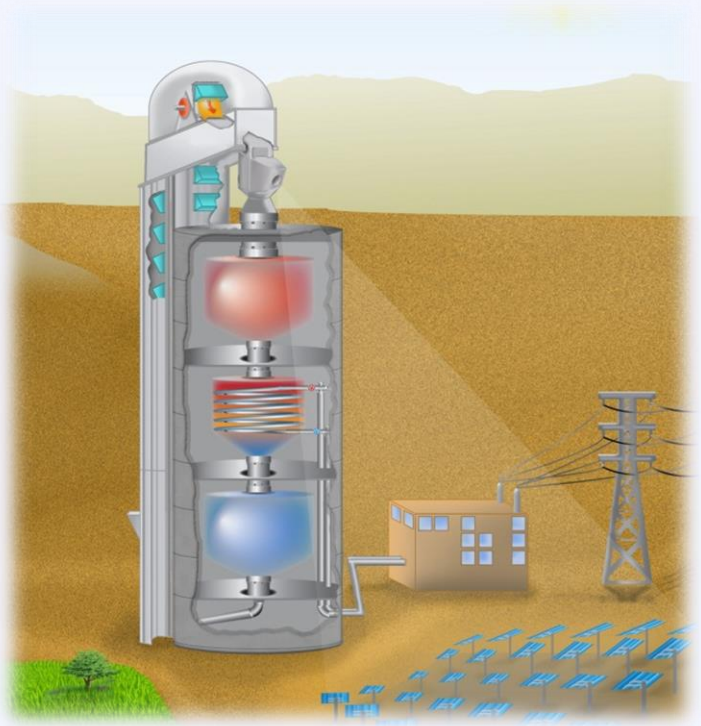

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