# Liquid and Particle Dynamics in Fluidized Beds

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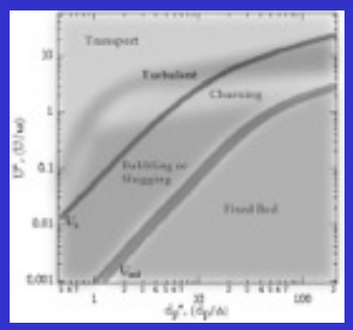
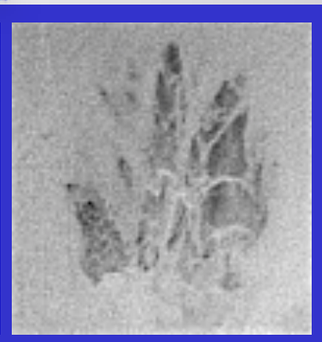
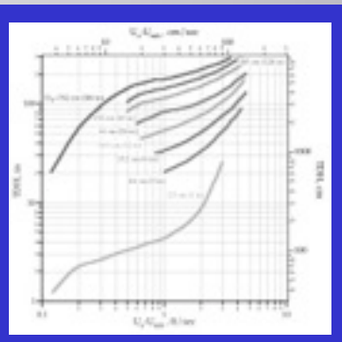
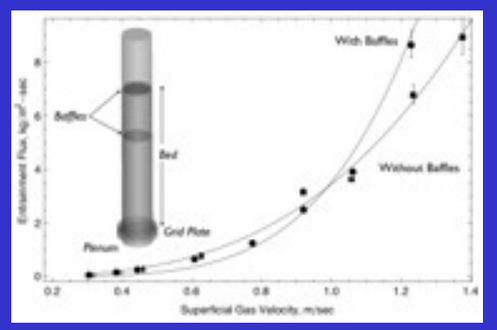
PSRI Particulate Solid Research, Inc.

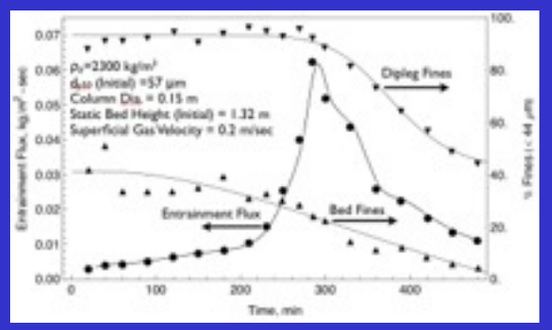
*Applying the Fundamentals*







# Outline

- Gas jets in fluidized beds
    - Data and simulations
- Gas solid jets in fluidized beds
- Gas liquid jets in fluidized beds
    - Visualization beyond the wall
- Conclusions

# Particulate Solid Research, Inc.



- PSRI is an international consortium of companies, each of which pay a yearly membership fee to fund applied research in the fluidization, solids transport, and other fluid-particle areas.
- PSRI focuses its research on large-scale equipment and bridges the gap between fundamental and application based research in fluidized unit operations.
  - Risers up to 3 feet (0.91 meter) ID and 90 feet (27 meters) in height
  - Fluidized beds with diameters up to 5 feet (1.5 meters)
    - High temperature and pressure (3500 KPa, 800°C)
  - Cyclones
  - Pneumatic conveying lines
  - Attrition testing
    - Jet cup, immersed jet and jet impact
  - Speciality probes
    - γ-ray, fiber optics, gas and solid tracers, acoustics

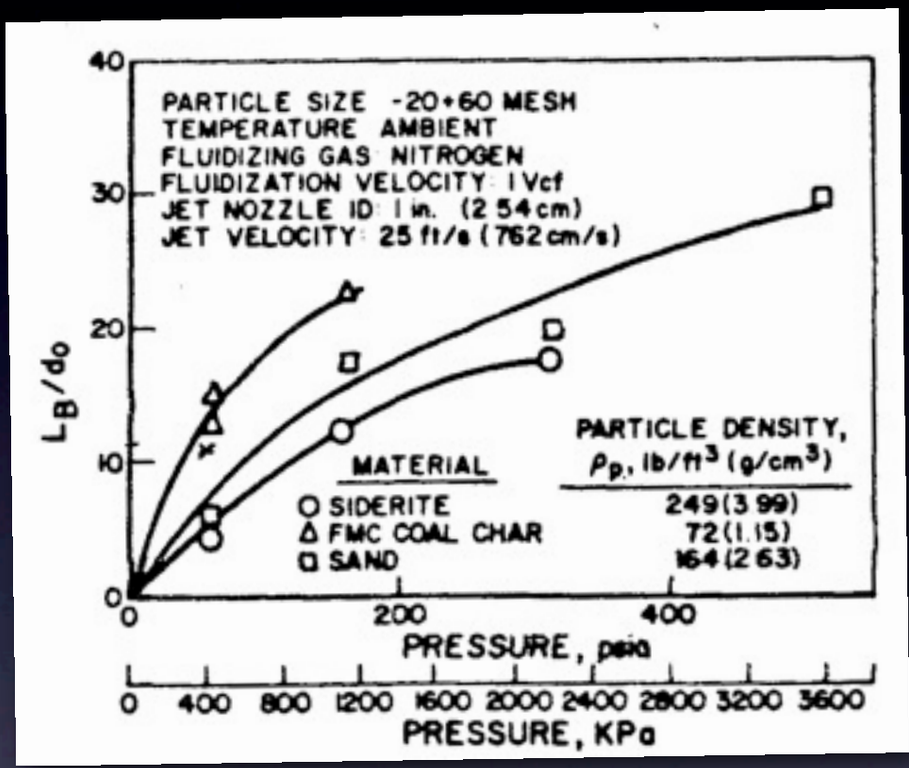
# Gas Jets

- Most fluidized beds have gas jets
  - Grid plates and spargers
- High pressure gas jets
  - Effects of pressure on bed and jet hydrodynamics

# Jet Penetration at High Pressures

- From Knowlton, T.M. and Hirsan, I., "The Effect of Pressure on Jet Penetration in Semi-Cylindrical Gas Fluidized Beds", in "Fluidization", Grace and Matsen, Eds., p. 315, Plenum Press, New York. 1980.
- Three materials
  - Siderite
  - Coal char
  - Ottawa sand
- Jet velocity = 7.6 m/sec for all cases
- Superficial gas velocity = complete fluidization velocity
  - This changes with pressure

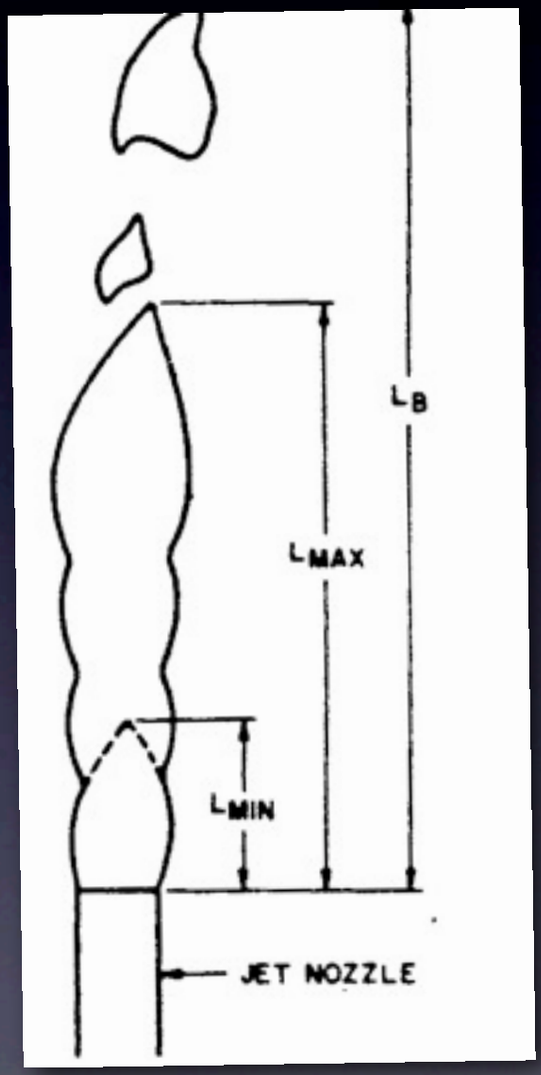
*Freeboard/Disengagement*


| Material | Particle Density, kg/m$^3$ |
|---|---|
| FMC Char | 2629 |
| Ottawa Sand | 1158 |
| Siderite | 3988 |

# Measuring Upward Jet Penetration

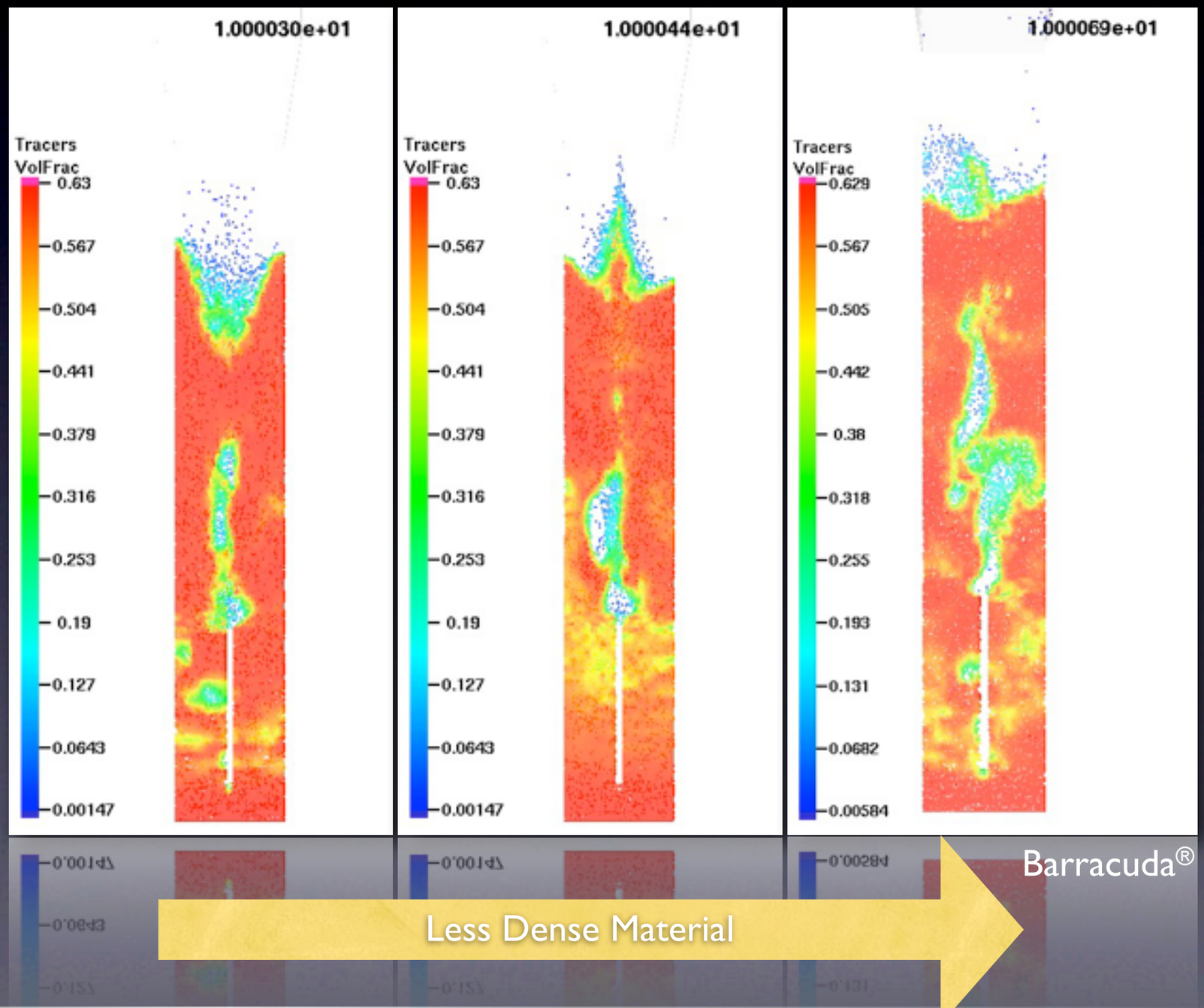
- Jet penetration is the length of the jet as the first bubble sheds off ($L_B$)
- Measurement of jet penetration in the simulations was subjective
  - Defining the boundary of a jet
  - Defining the point where a bubble sheds off
  - Defining the cycle at which bubbles shed off
  - Defining when bubbles from other parts of the bed are not interacting with the jet



# Simulations: Particle Density Effects

| Material | Particle Density, kg/m$^3$ |
|---|---|
| FMC Char | 2629 |
| Ottawa Sand | 1158 |
| Siderite | 3988 |

*Siderite* *Char* *Sand*

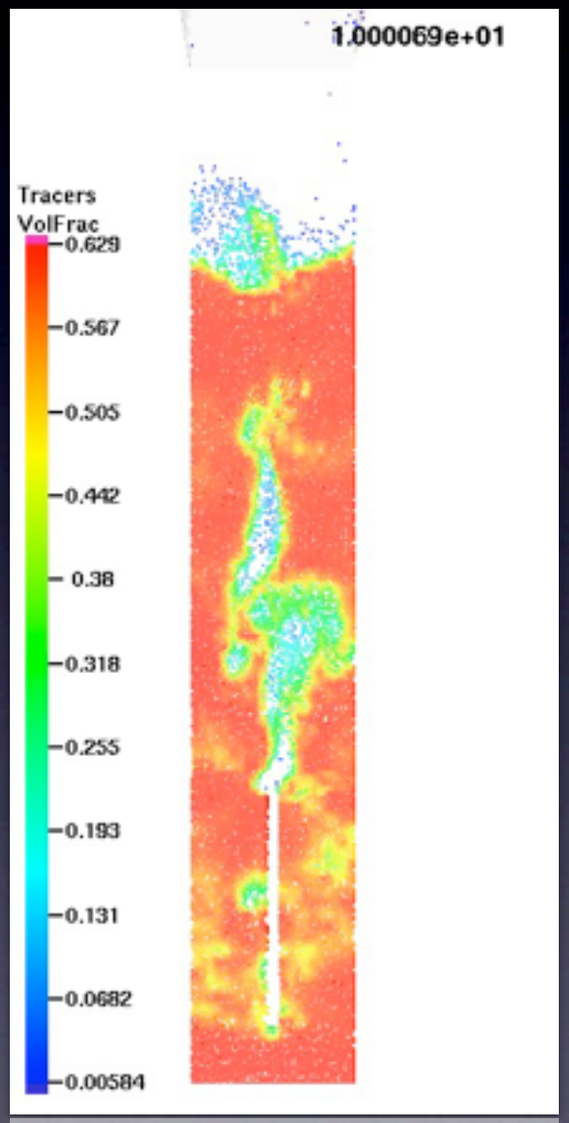



Barracuda®

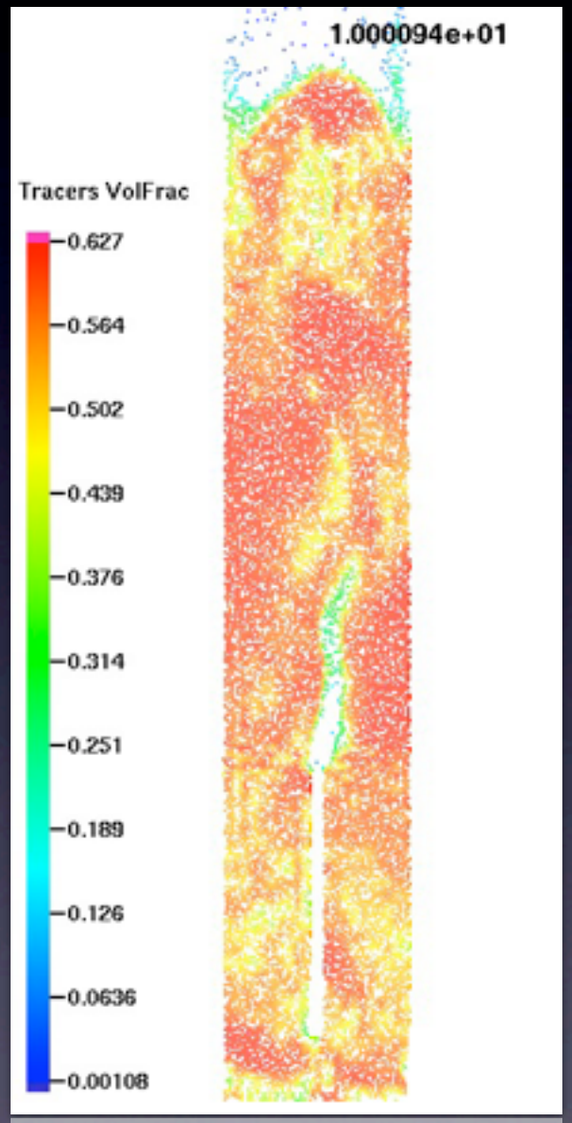
Less Dense Material

# Pressure Effects With Sand

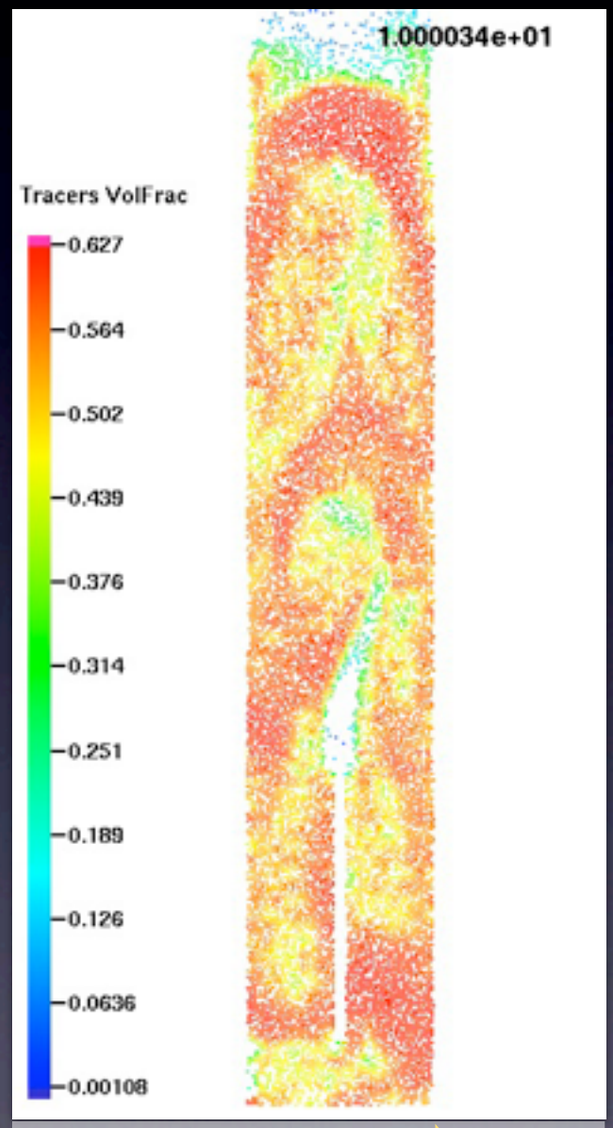
*424.7 KPa*



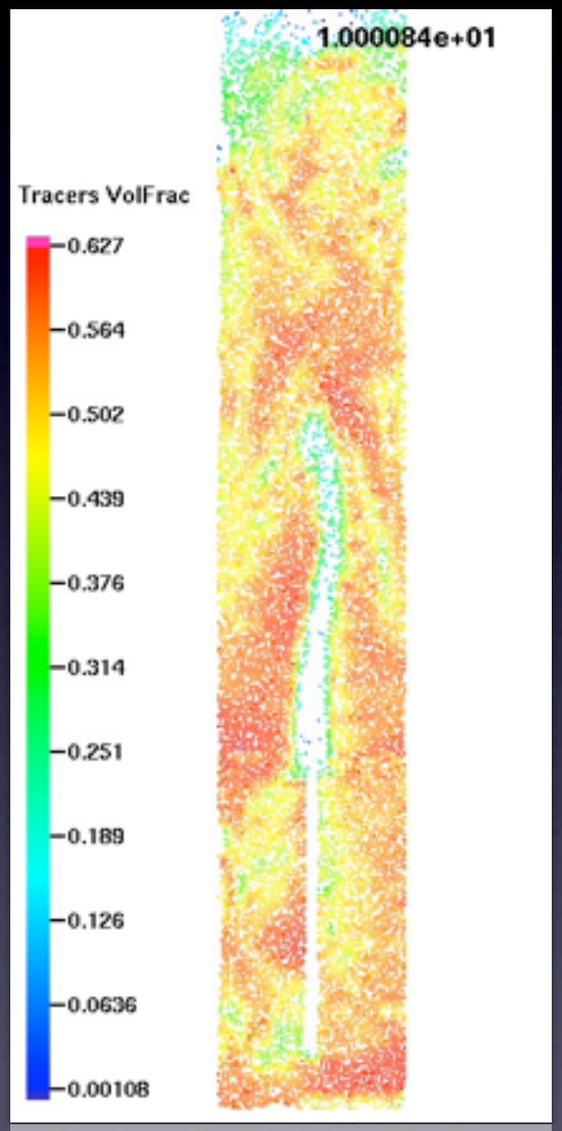

*1111.8 KPa*




*3509.2 KPa*




*5296.7 KPa*




Higher Pressures

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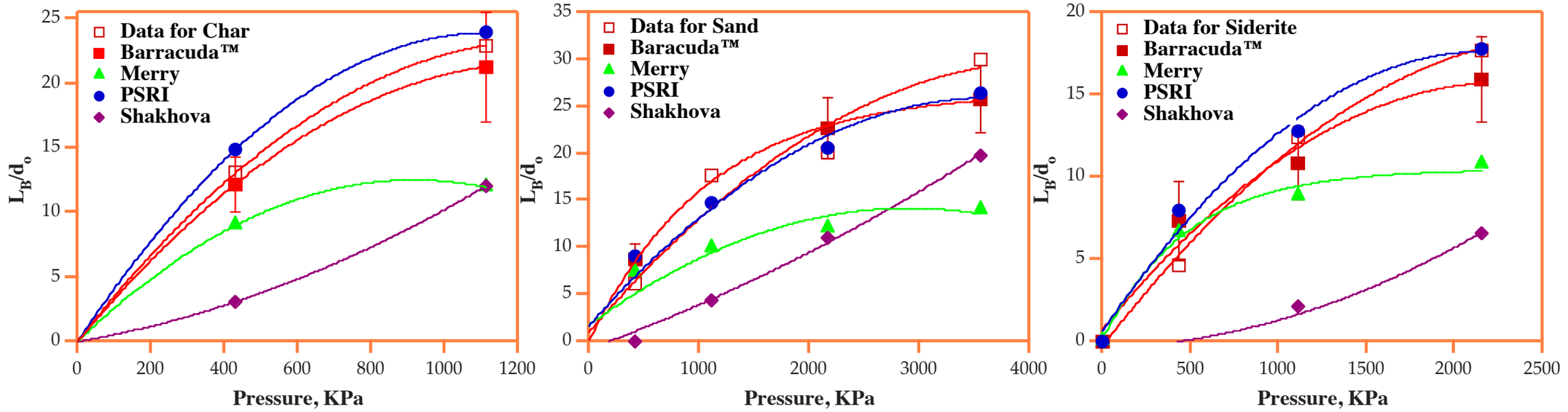
# Jet Penetration Correlations

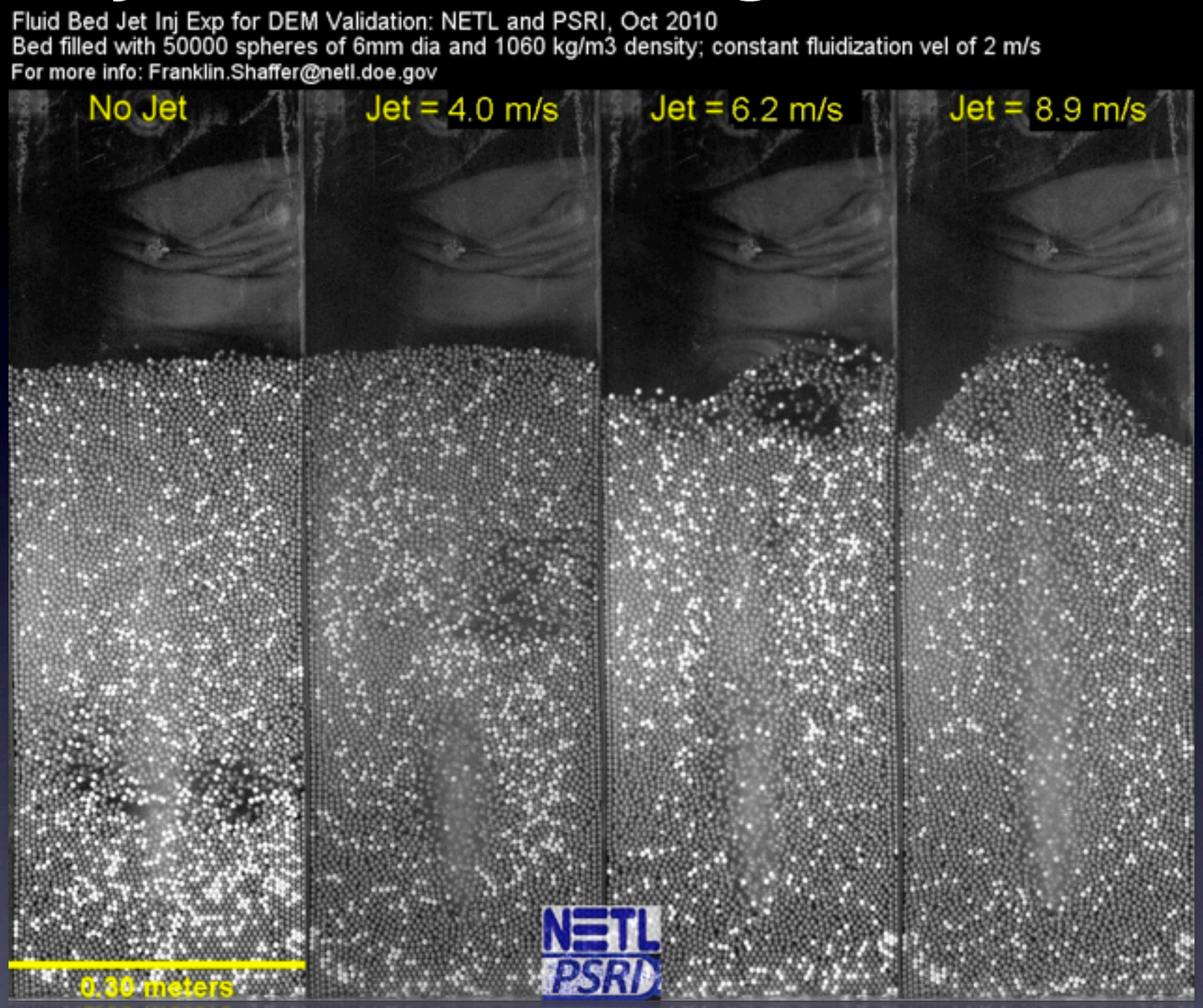



- Both Barracuda® and PSRI correlations do well for all three materials at all pressures
- Merry and Shakhova did not fare well


Merry, J.M.D., AIChE J., 21 (1975) 507

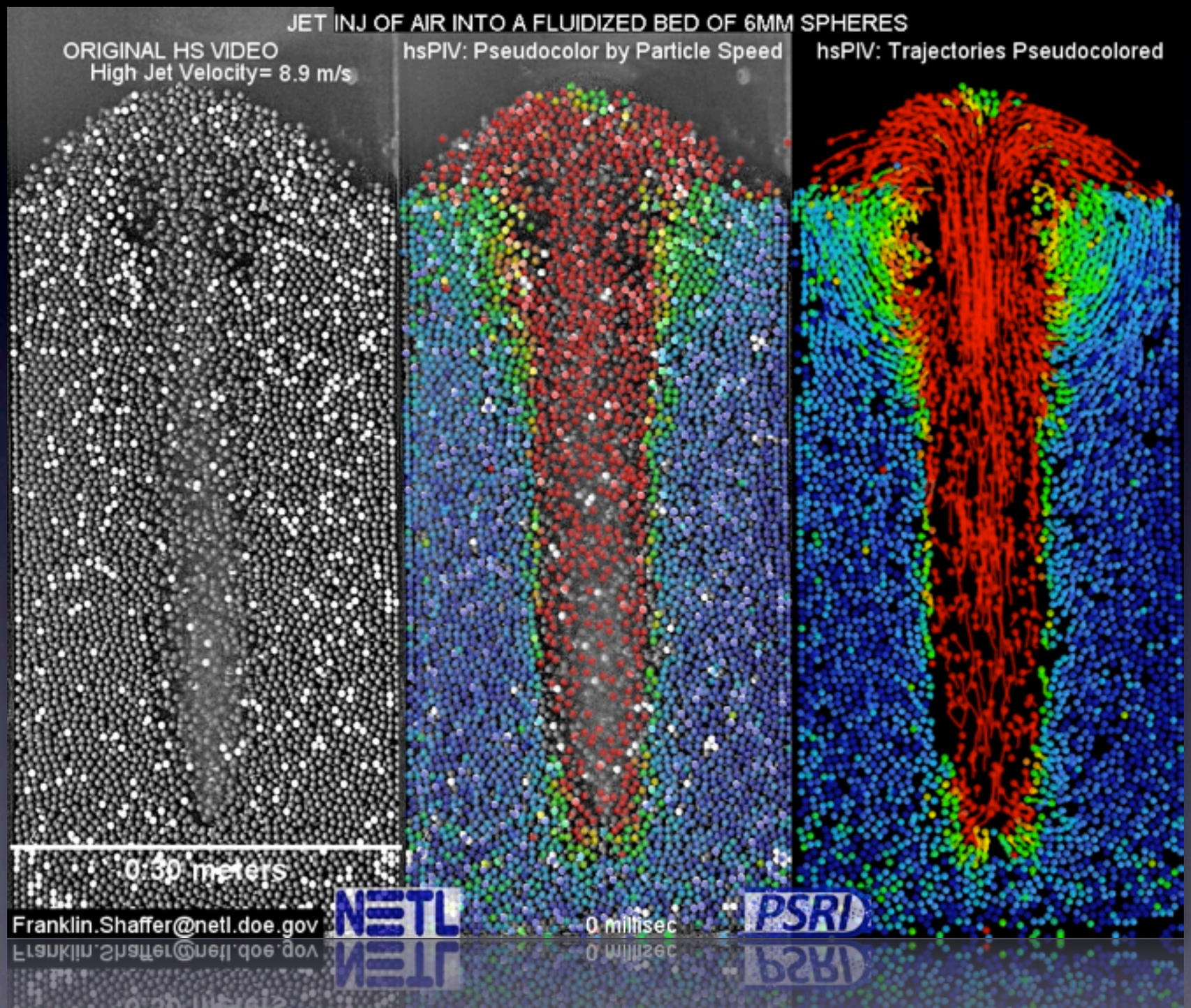
Shakhova, N.A. Inzh. Fiz. Zh., 14 (1968) 61

# Gas Jets with Large PE Beads




- 6 mm PE beads and gas jet with increasing velocity

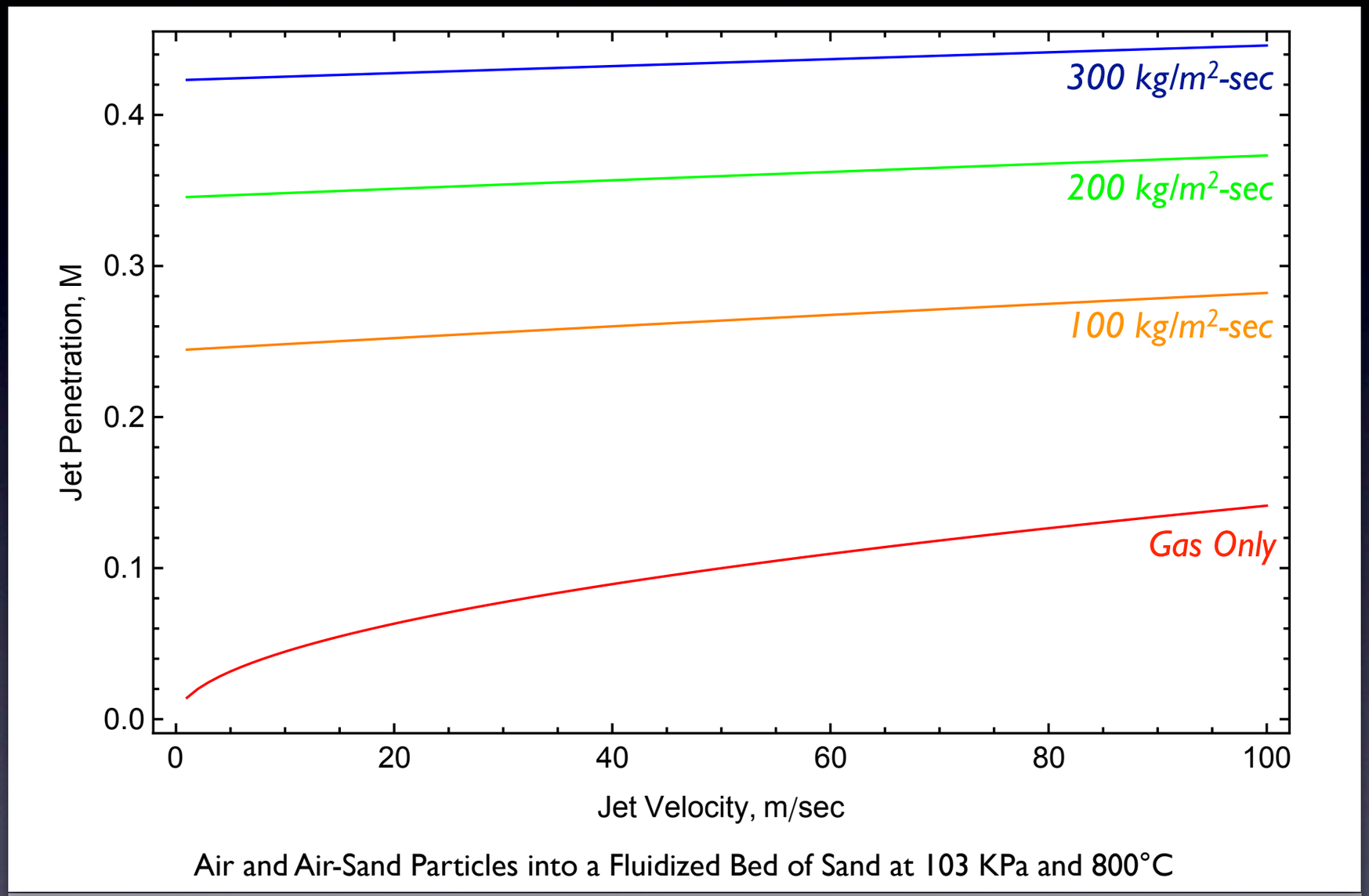
# Tracking the Particles in Jets



# Gas and Gas Solid Jets

- Important with
  - Solids feeds in gasifiers, combustors and pyrolysis units
    - Cokers
    - FCC regenerators
- Solids penetration
- Jets in gasifiers simulation

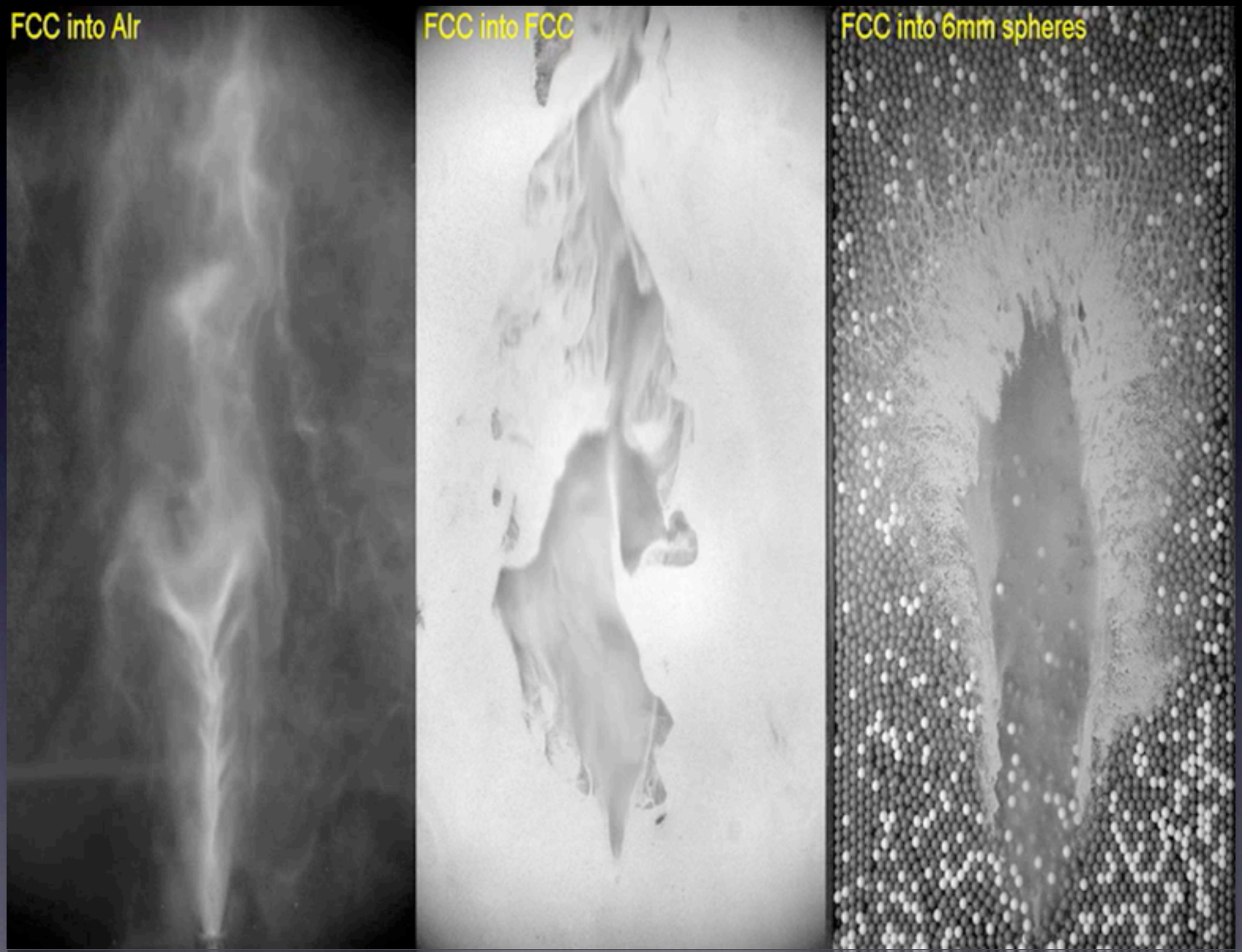
# Particle Laden Jets via PSRI Jet Penetration Correlation




Air and Air-Sand Particles into a Fluidized Bed of Sand at 103 KPa and 800°C

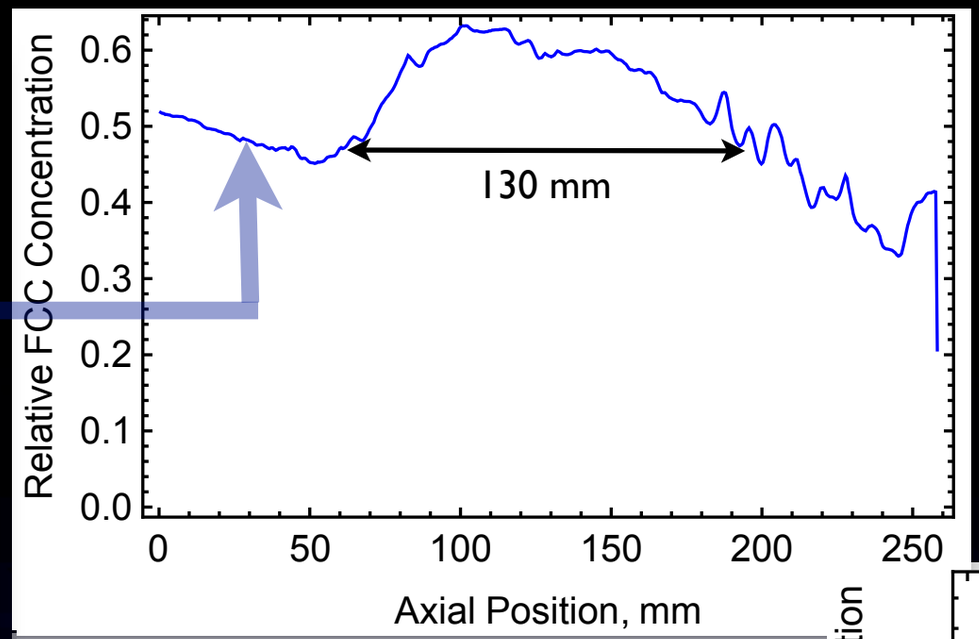
- Particle momentum form a jet significantly increase the jet penetration length

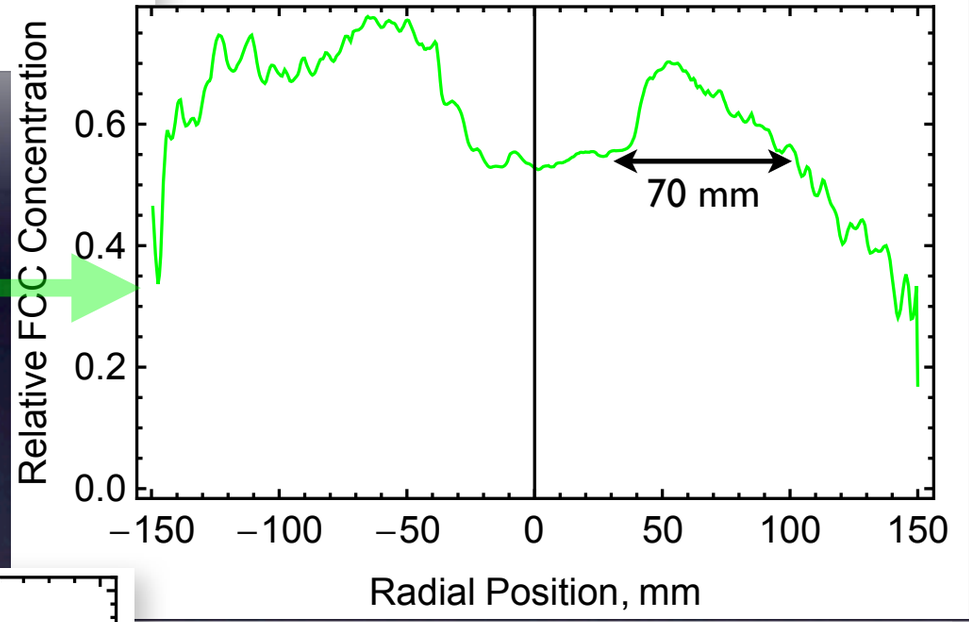
# FCC/Fines Penetration in Jets

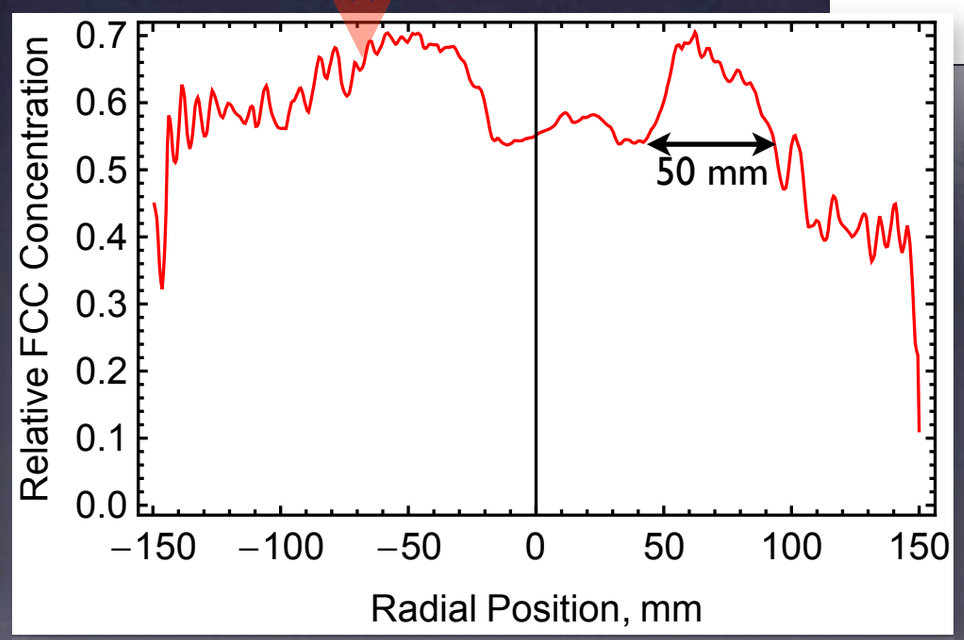



# FCC/Fines Penetration in Jets

- Large particles entrained mostly near the jet orifice
- FCC particle penetrate deep into bed of 6 mm spheres

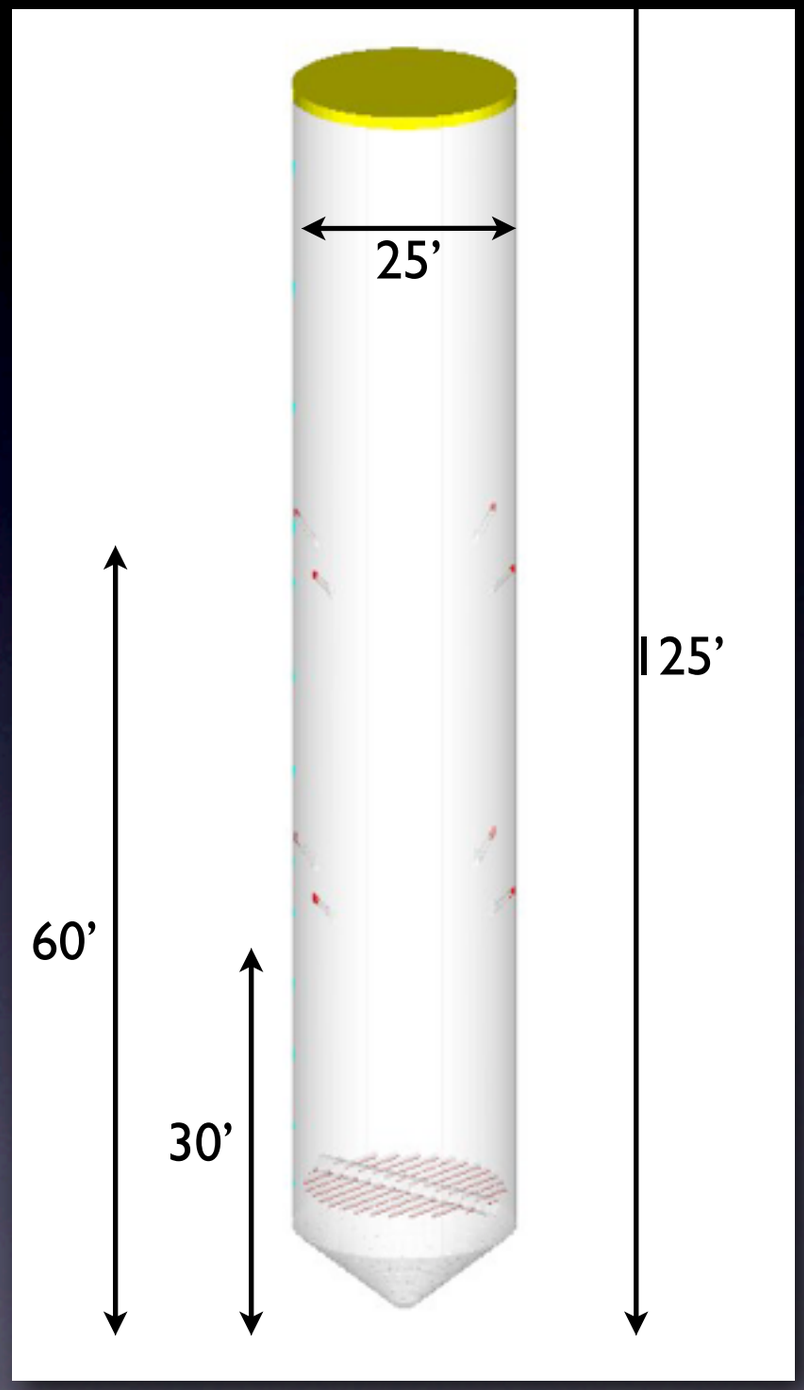




# Fines Penetration

# Injecting Solids Into a Fluidized Bed



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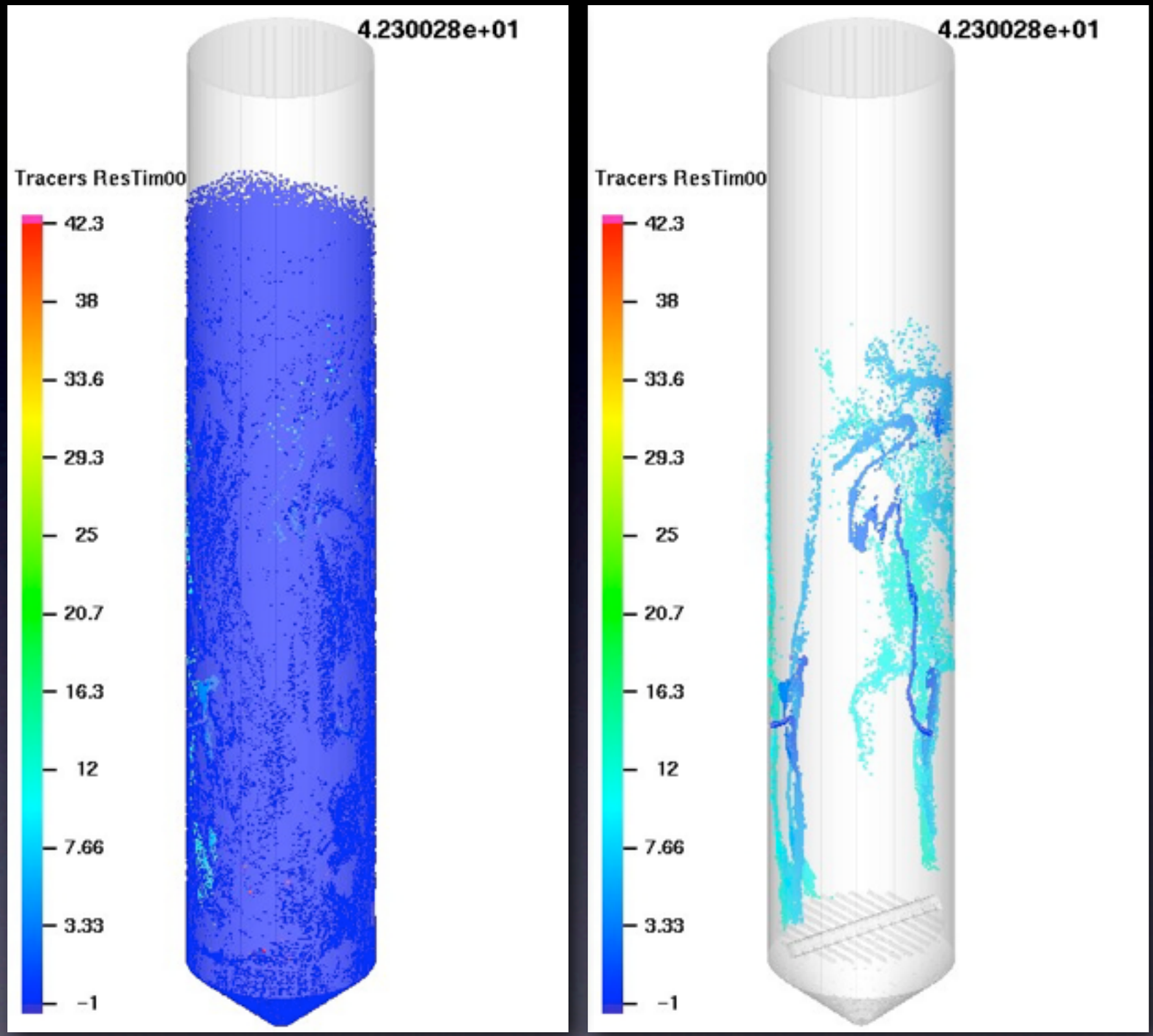
- Vessel dimensions
  - 25-feet vessel diameter
  - 125-feet vessel height
    - 110-feet from sparger
- Coal feed positions
  - First row is 30-feet from sparger
  - Second row is 60-feet from sparger
  - Feed angle is 45° with no protrusion beyond the wall
- Sparger
  - 15-feet from bottom
  - 24-inch diameter main manifold
  - 8-inch diameter feeder manifolds
  - Superficial gas velocity is 1 ft/sec

# Simulating Where the Particles Go

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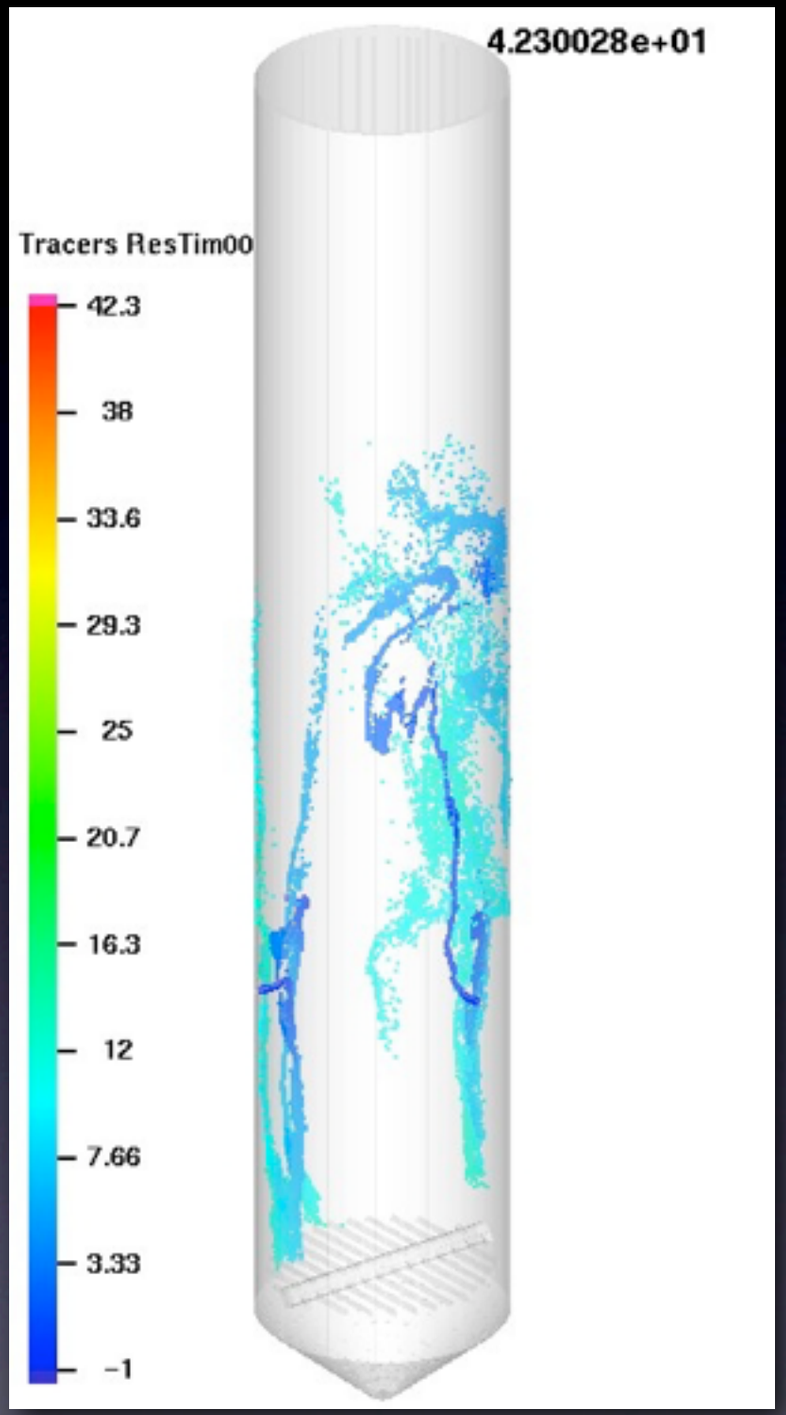
# Simulating Where The Particles Go

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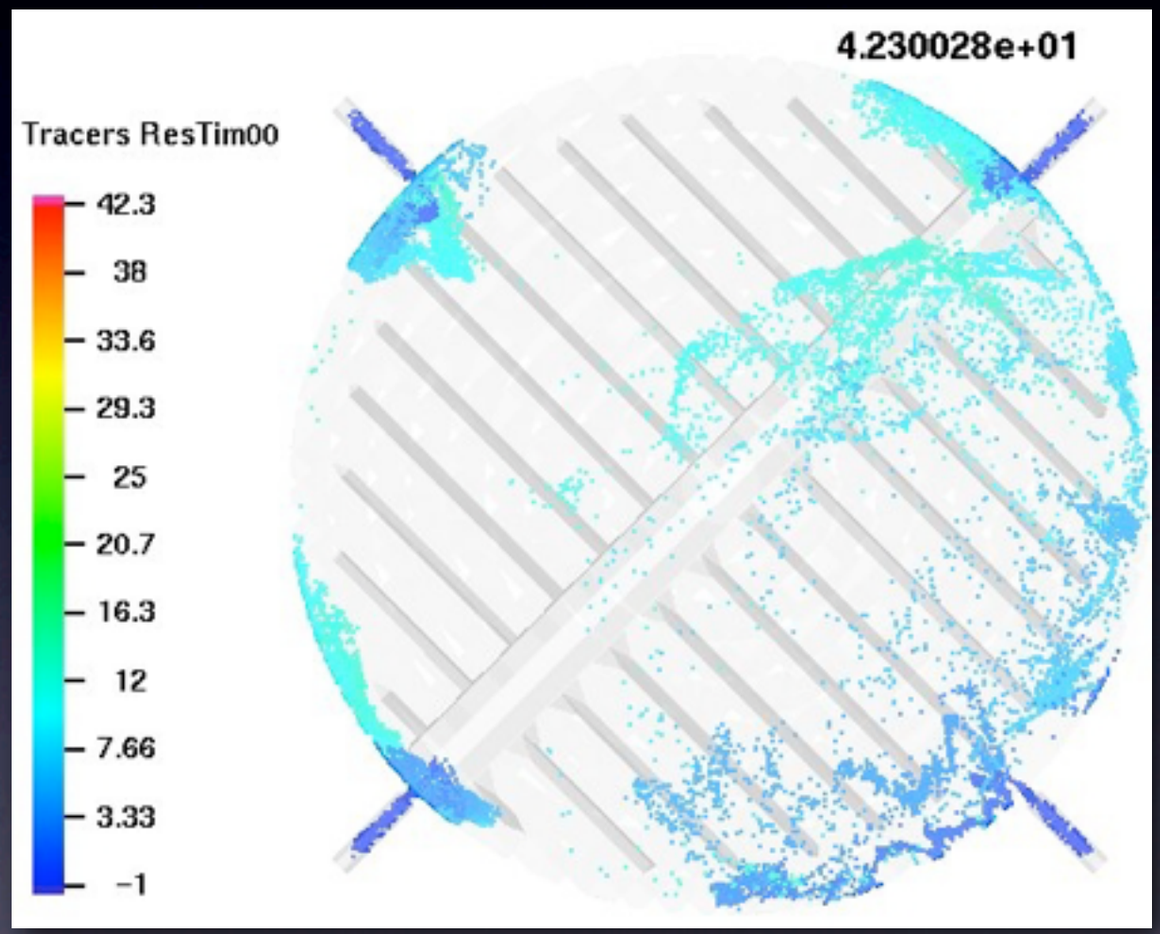


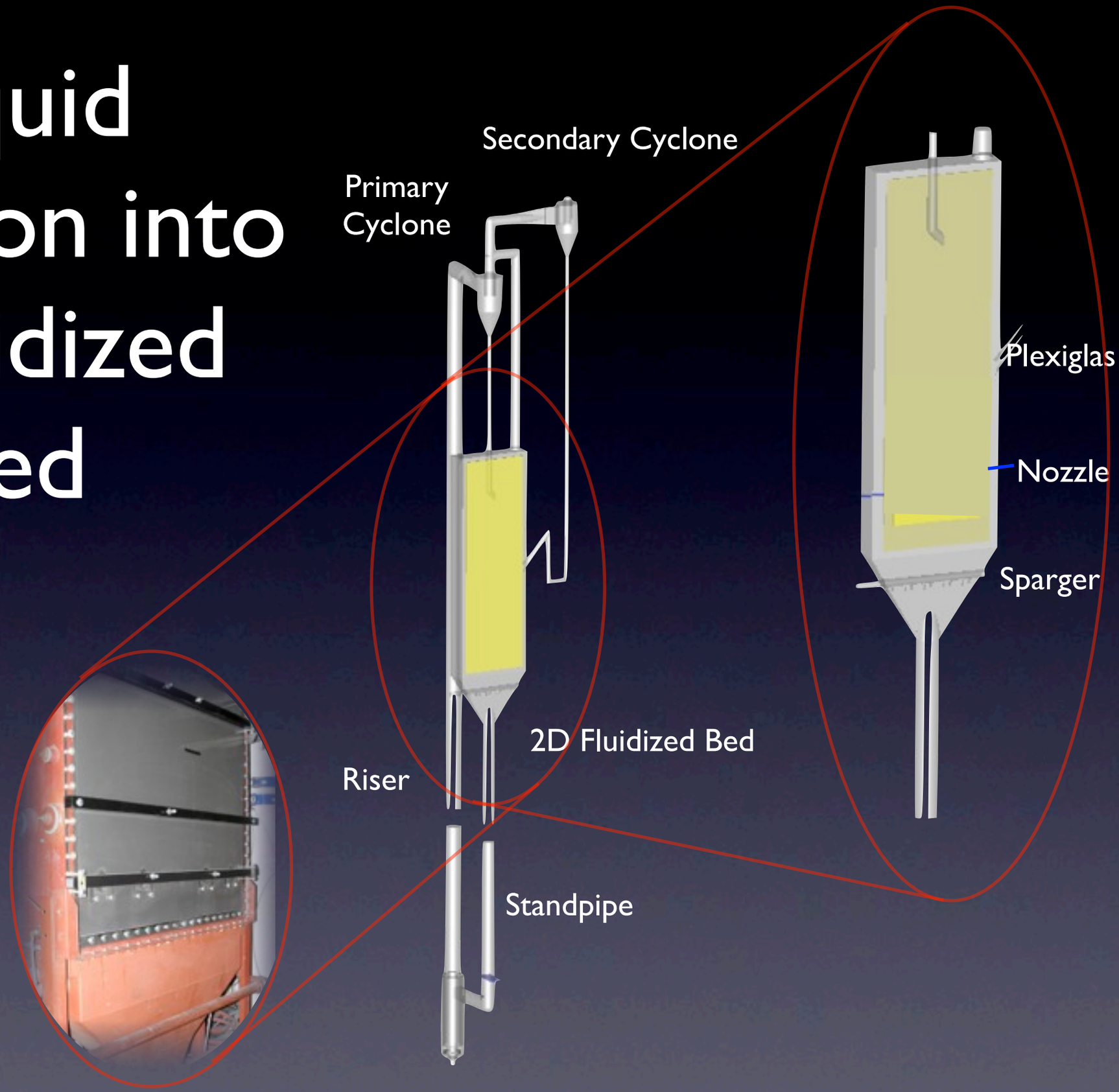

Barracuda®

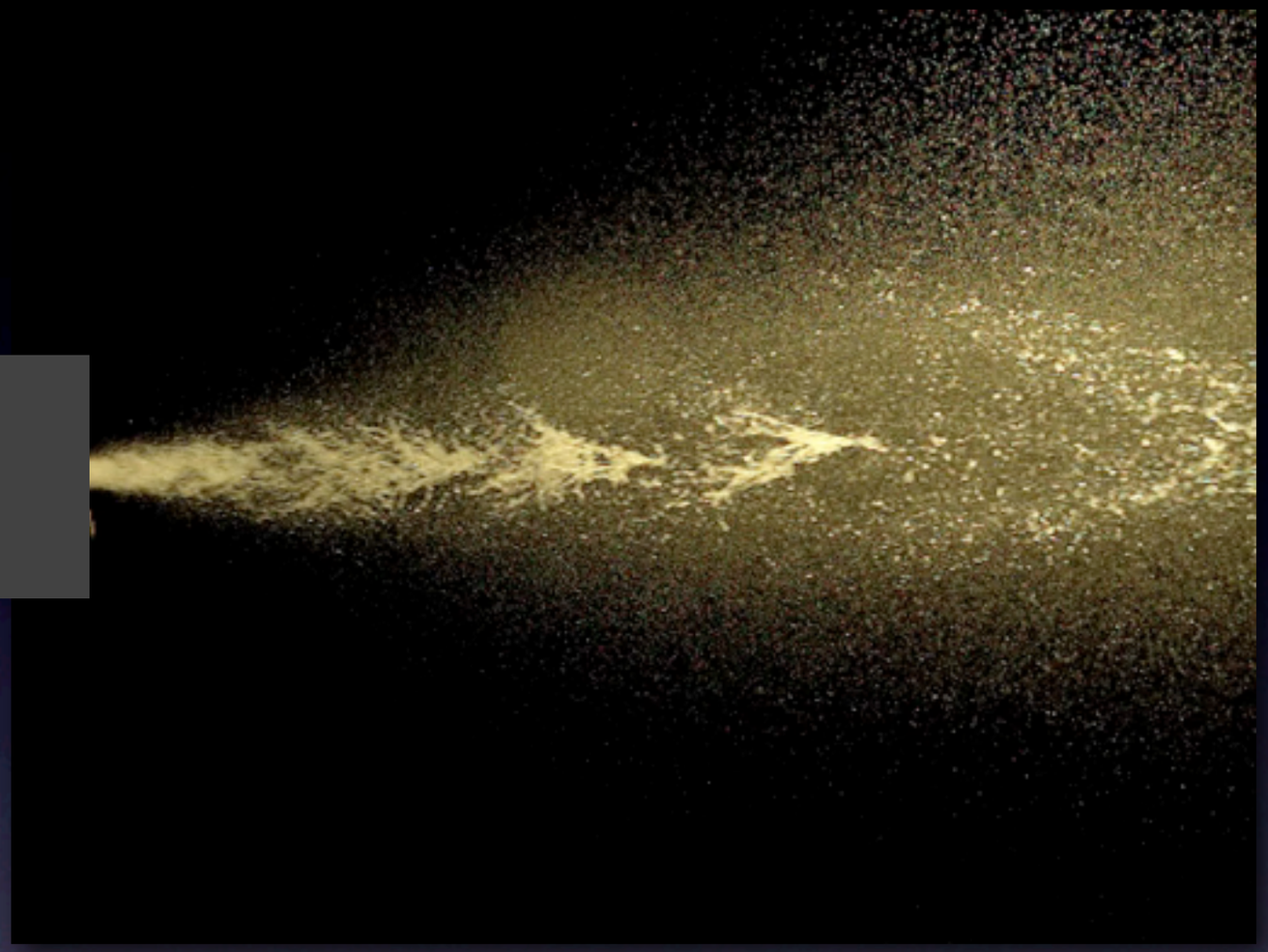
- Four nozzles start at 30 seconds

# Gas-Liquid Jets

- Atomized liquid injection into a fluidized bed
- Mechanism for dispersion and agglomeration

# Liquid Injection into a Fluidized Bed





# Liquid Injection in Air

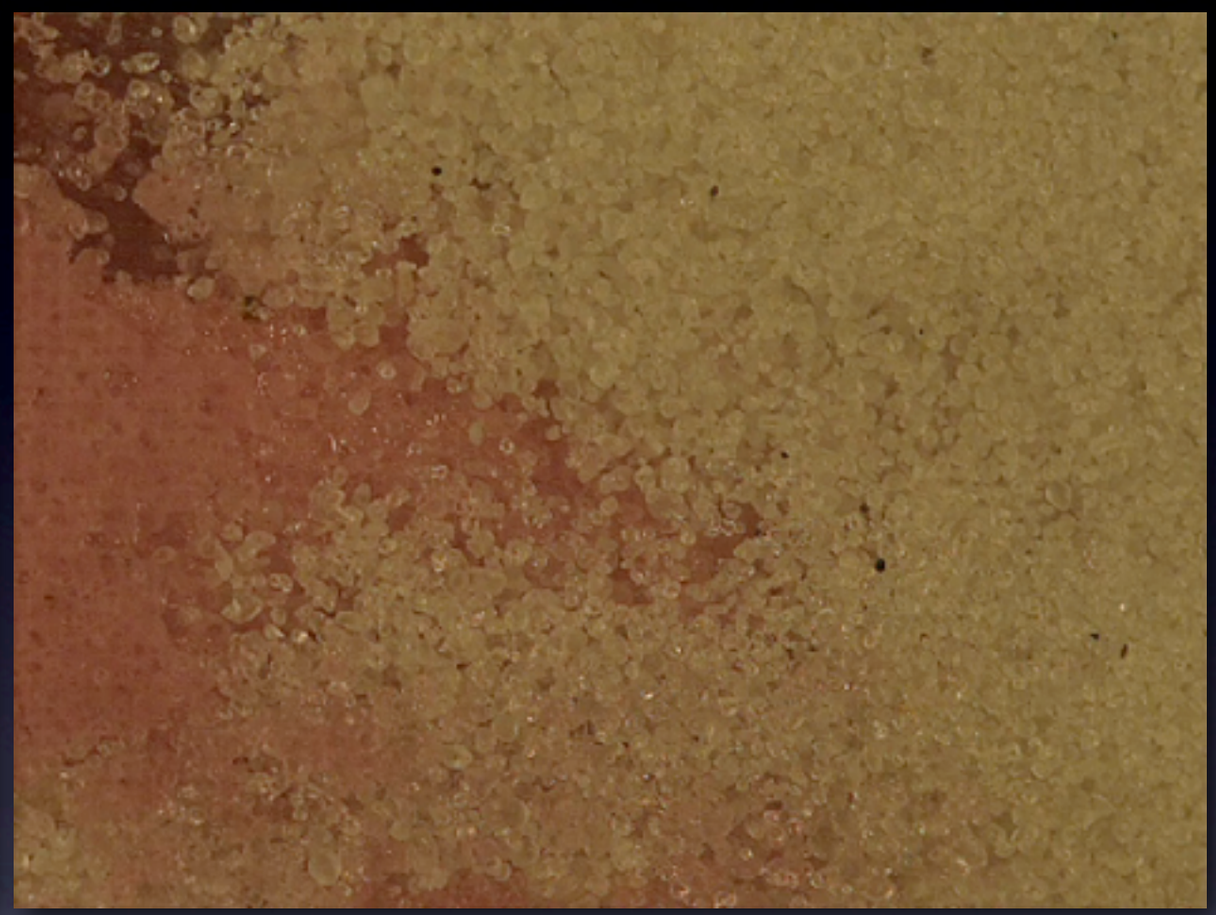
- High-speed video camera at 5000 fps with 30 microsecond shutter speed
- Wide droplet size distribution
- Liquid slugs

# Liquid Injection into a Fluidized Bed


- Phantom VII Color High-Speed Video Camera
  - 9900 fps at 20 microsecond shutter speed
  - Red dye in liquid to enhance contrast

# Liquid Injection into a Fluidized Bed

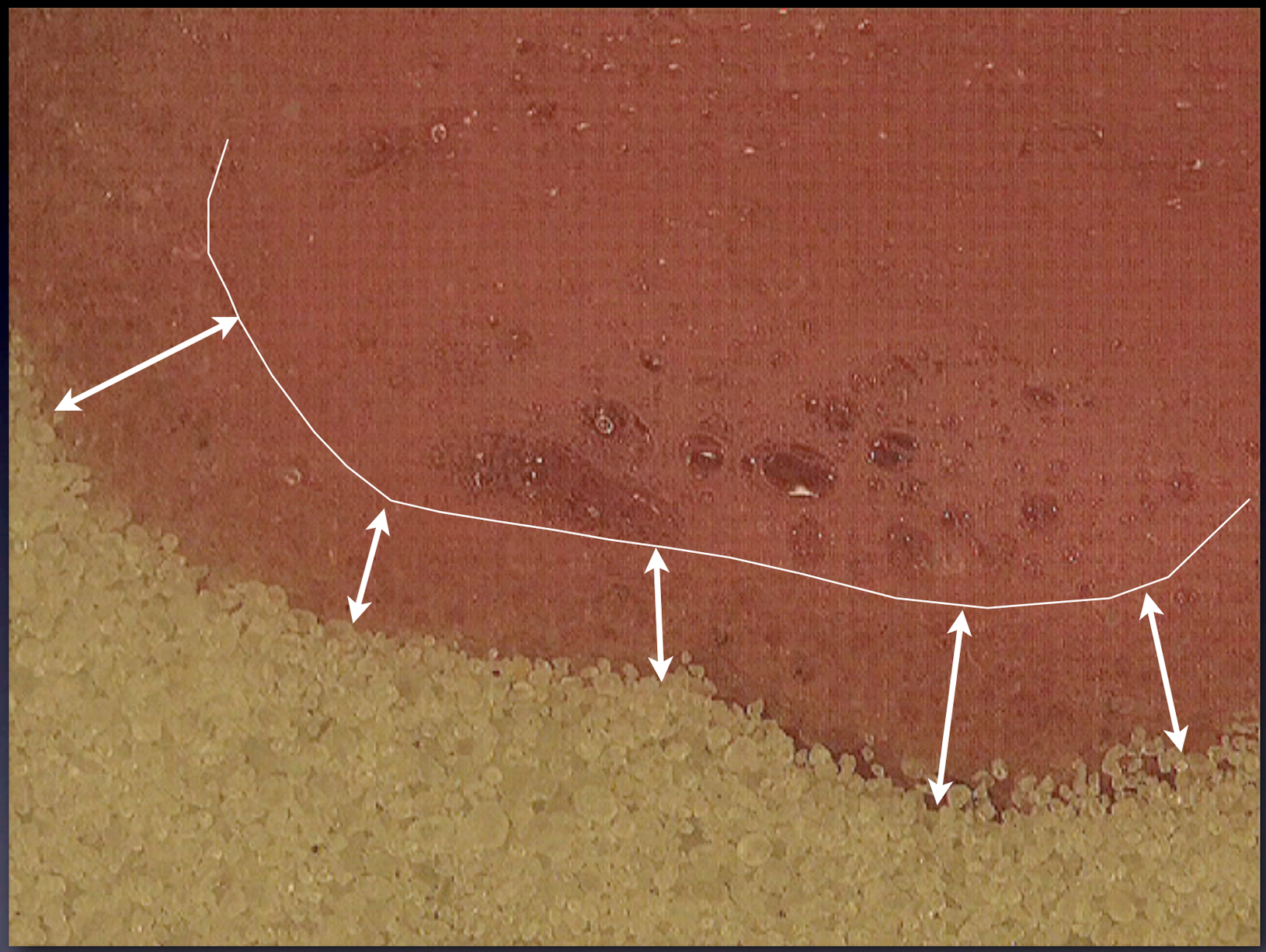

8-inches (20 cm) from injector face



2-inches (5 cm) from injector face

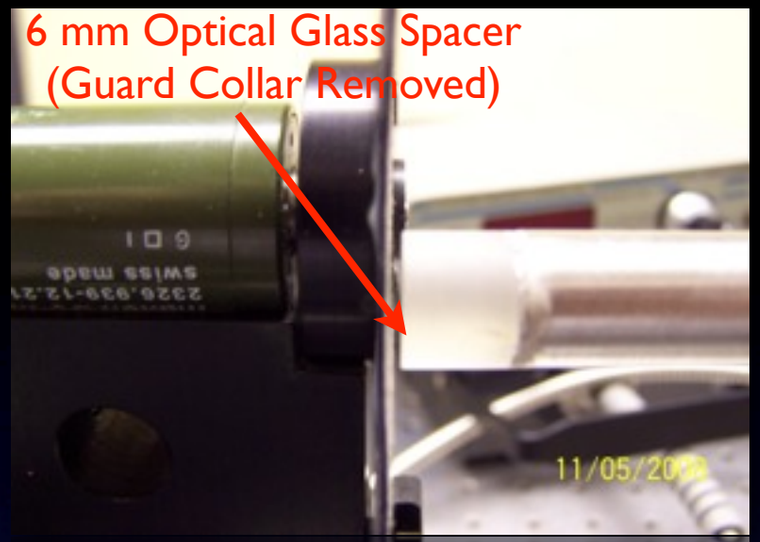
- Phantom VII Color High-Speed Video Camera
  - 9900 fps at 20 microsecond shutter speed
  - With liquid dye for contrast

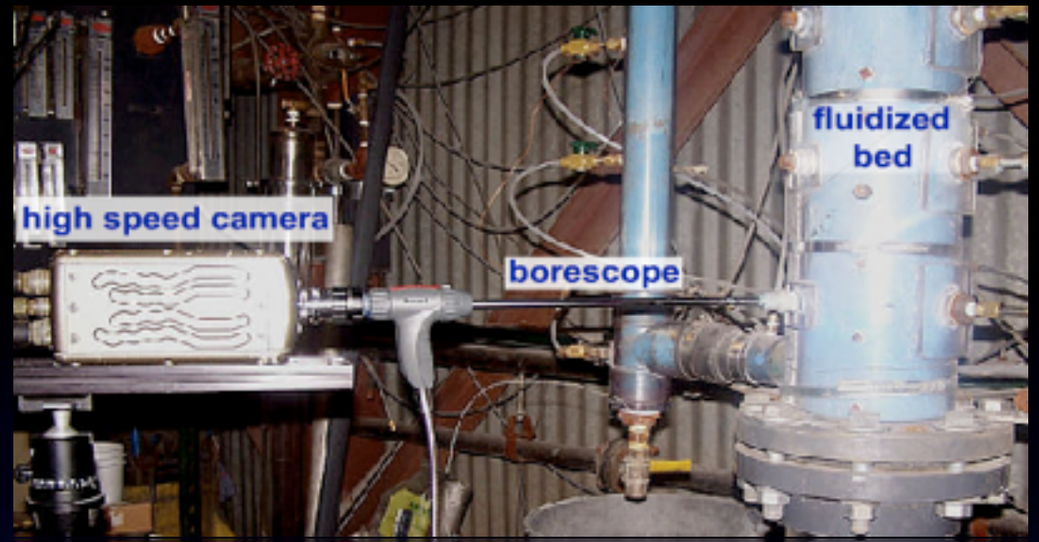
# Jet - Fluidized Bed Boundary Layer



- Little liquid jet penetration after initial wetting of particles
- Little particle exchange between wetted particles and dry particles beyond boundary
- Boundary layer estimated at 0.18 ± 0.04 cm
- Clusters in the center of the jet are about 1/3 the speed of particles and consist of 10 to 20 particles
- Particles are traveling at similar velocities as the liquid

# Looking Beyond the Walls

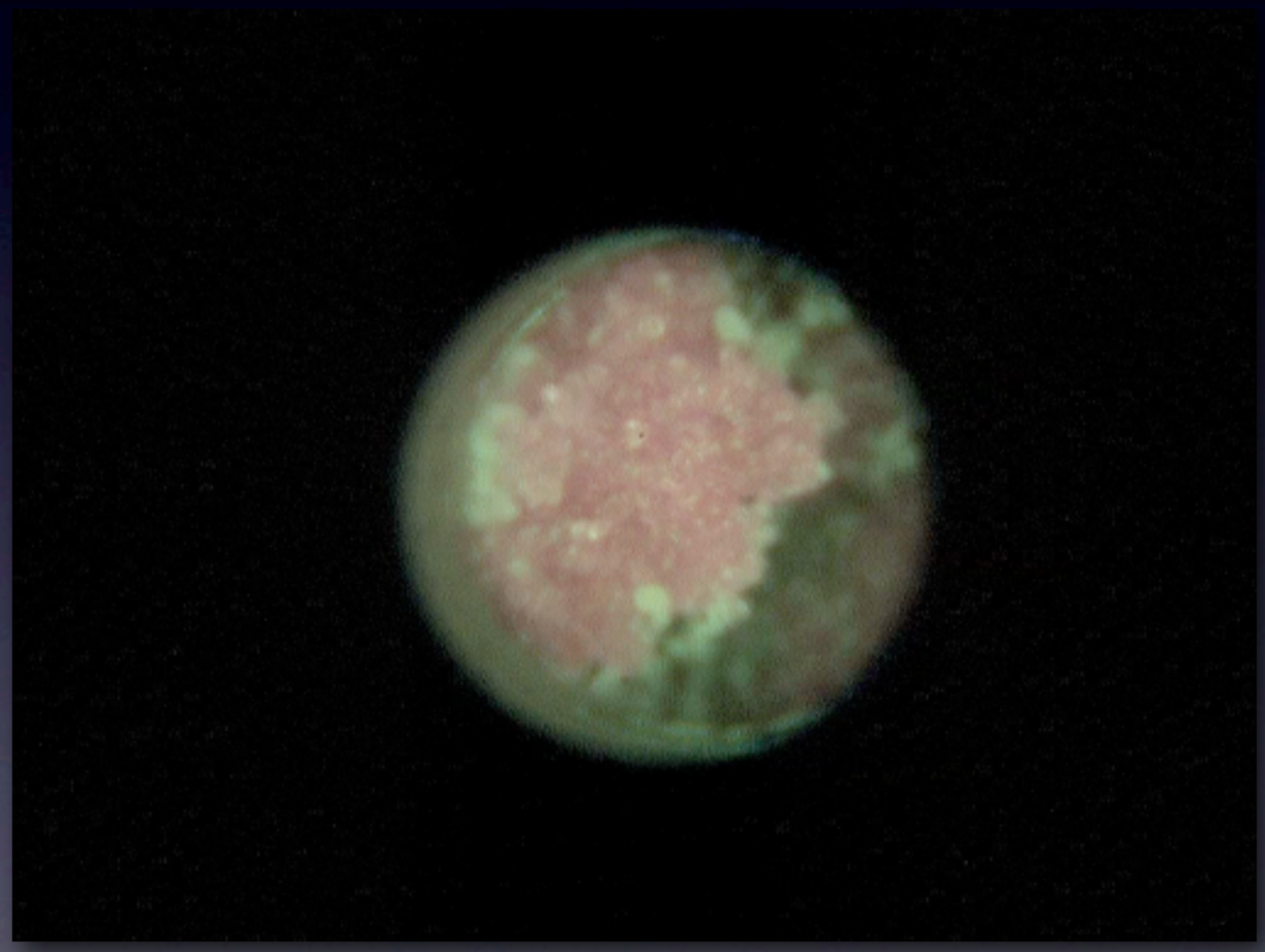



- Olympus R100-038-000-50 Industrial Rigid Borescope
  - 38 cm effective length
  - 50° field of view
  - Short depth of field
- 6 mm Optical Glass Spacer
  - With stainless steel Guard Collar (not shown)
- Liquid Filled Light Guide
- External lighting
- High speed camera ready

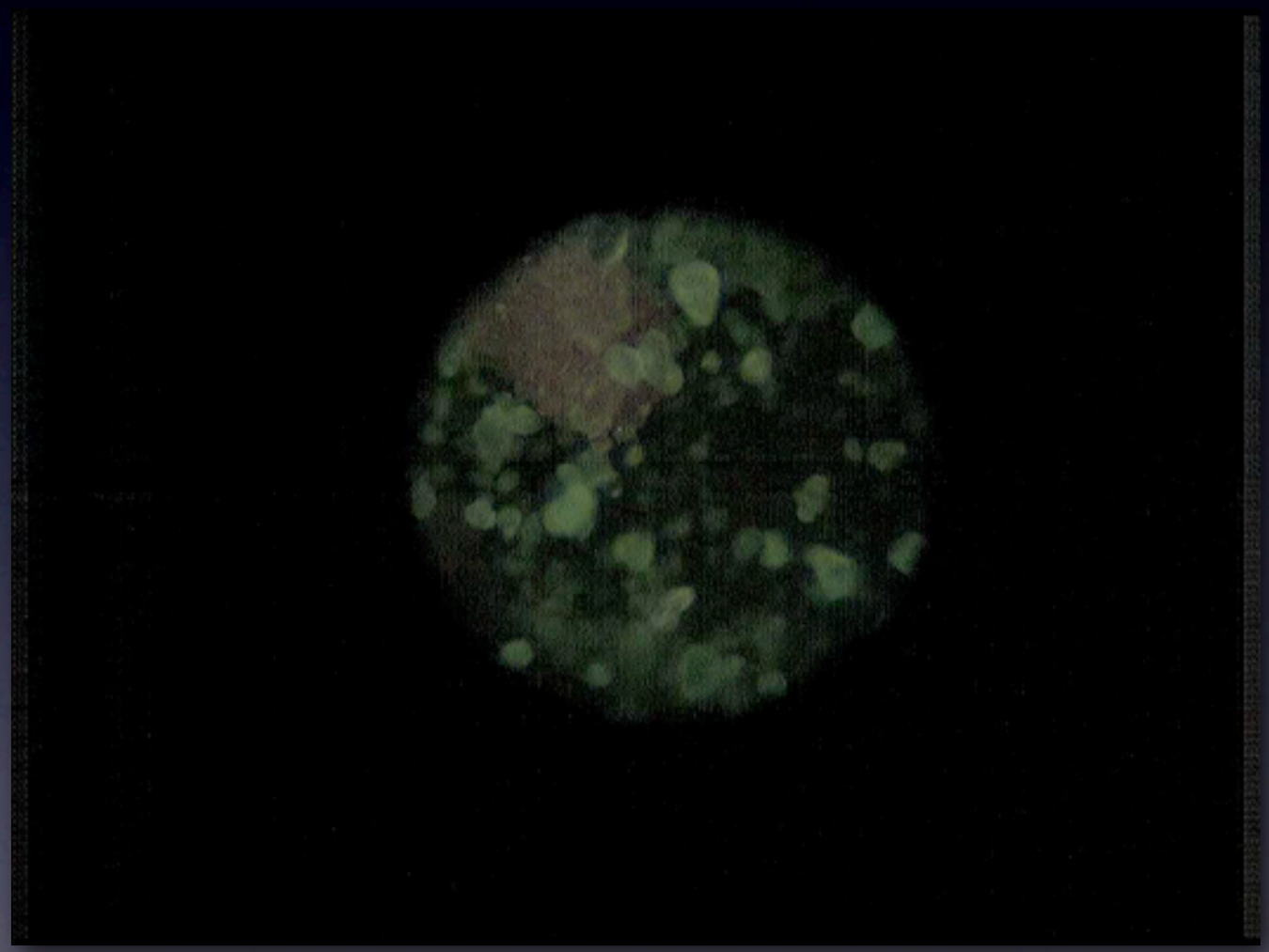
# Liquid-Particle Interactions in a Fluidized Bed

- 1000 fps at 990 microsecond shutter speed
- 5-inches (12.7-cm) from nozzle face
- 1.5-inches (3.8-cm) from face plate (wall)
  - Estimated to be within the of jet
- 20 SCFH (0.6 SCMH) sweeping gas
- Liquid injection contains dye
- Small particles coating liquid droplets
- Cluster look bigger than that observed from the faceplate



# Liquid-Particle Interactions in a Fluidized Bed

- 1000 fps at 990 microsecond shutter speed
- **9-inches (23-cm) from nozzle face**
- **1.0-inches (2.5-cm) from face plate (wall)**
  - Estimated to be at the boundary  of the jet
- 5 SCFH (0.15 SCMH) sweeping gas
- Liquid injection contains dye
- Bigger particles coating droplets



# Conclusions

- Particles appear to only be picked up near the entrance region of a jet
- For gas and gas-solids jets, solids (sum of particles) momentum and bed density are the controlling factors in jet penetration
  - Gas only jet
  - Gas-solid jets
- For gas-liquid jets, surface tension may also be a factor
  - More solids in this region could reduce this problem