The Effects of Particle Size Distributions on Riser Hydrodynamics

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Outline

- Objective
- Background
- Proposed work and techniques
- Recent results
- Summary

Develop a plan for generating validation test cases, identify fundamental experiments and identify computational challenge problems

Develop experimental techniques for gaining information from deep into opaque multiphase mixtures

Understand the cause and effects of particle clustering. The effect of particle clustering on drag, collisions and gas-phase turbulence modulation are needed

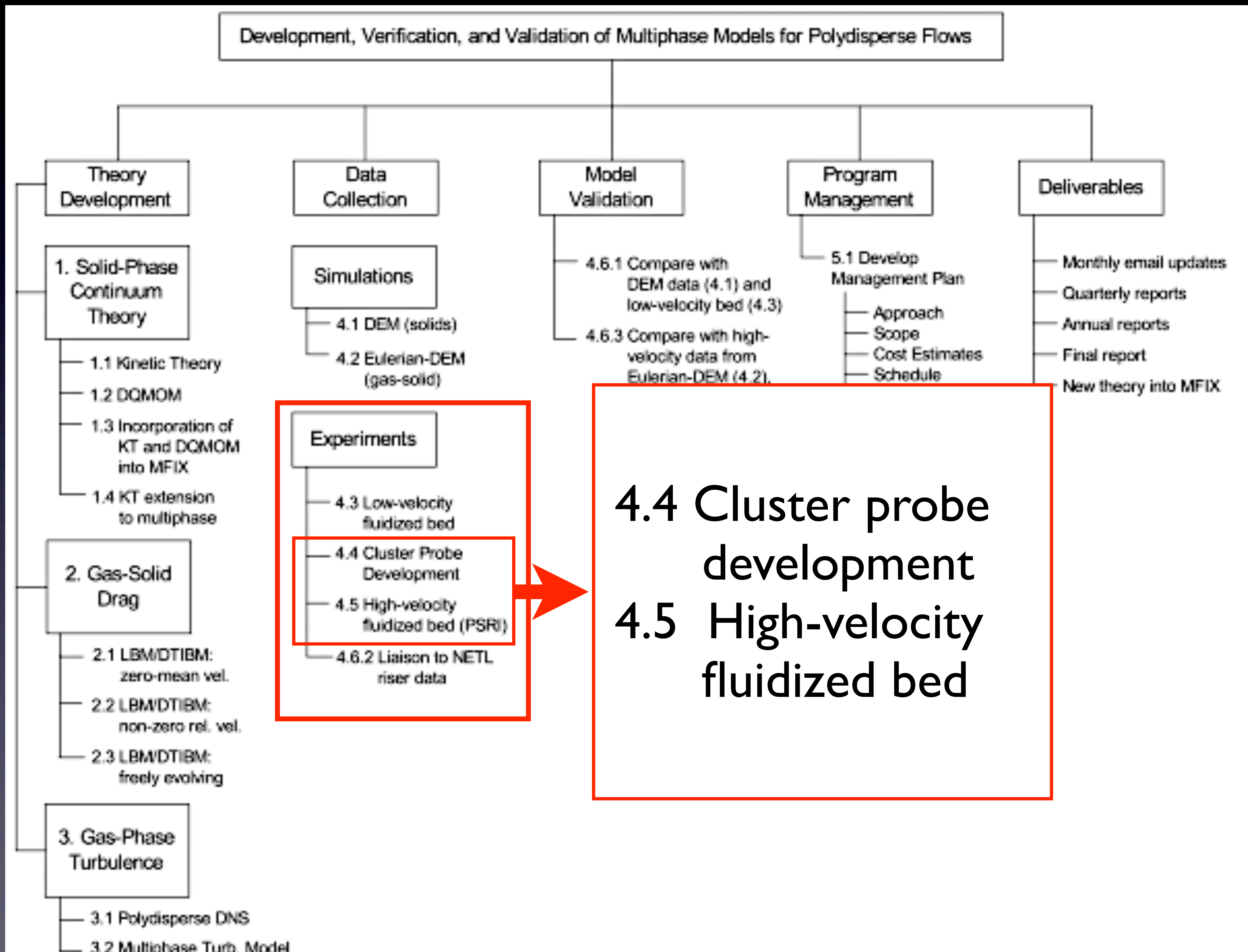
Measure spatial variation of PSD

Train adequate number of graduate students in this area

Provide detailed CFB data on at least two scales. The experiments must have well-defined entrance, exit and boundary conditions. Should report detailed data for local pressure, velocities ...

Use large flow facilities to elucidate the effect of particle size distribution on flow. Determine lateral distribution of wall or internals by particle impact

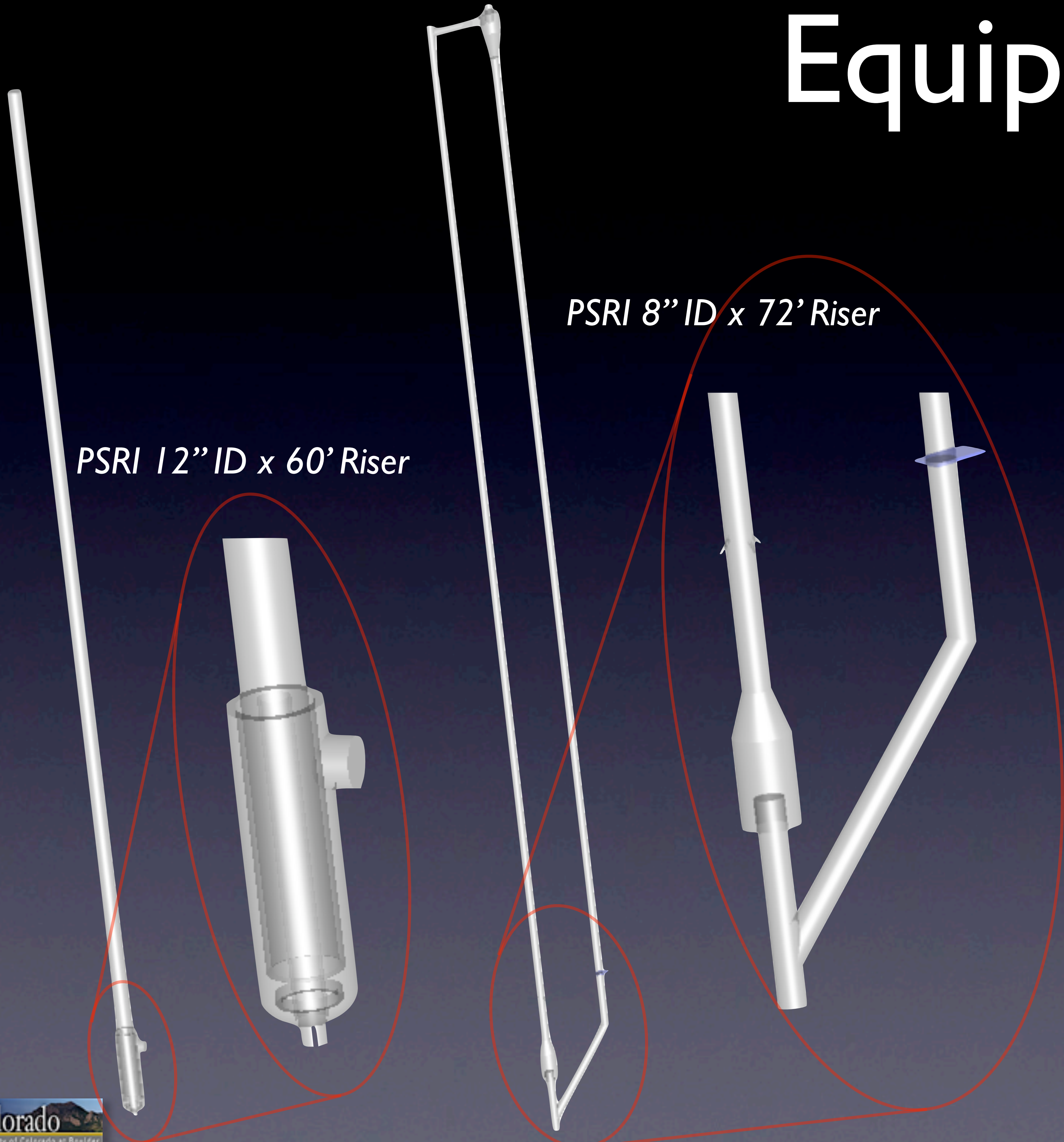
Project Scope



Objectives

- Provide extensive riser data for on-going modeling efforts
  - PSRI challenge problems (Past)
  - NETL riser data (Past and Present)
  - This effort (Present)
- Examine the role of particle segregation and particle clusters in riser hydrodynamics

Equipment



Risers have been designed to provide symmetric profiles

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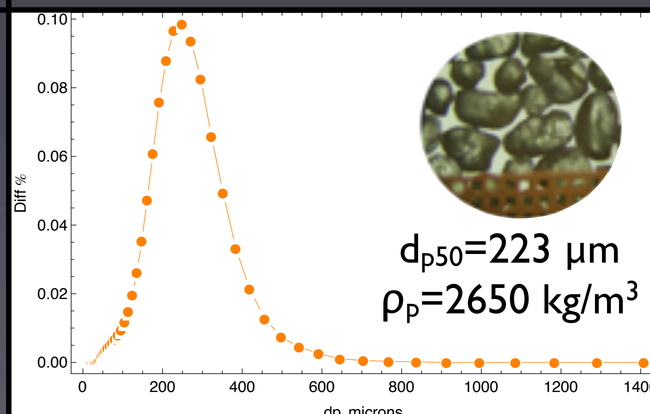
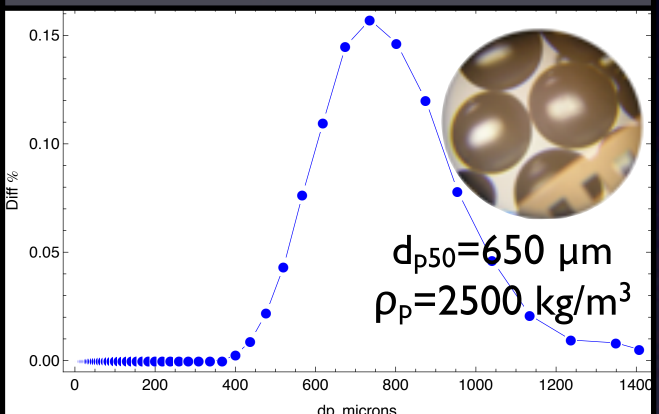
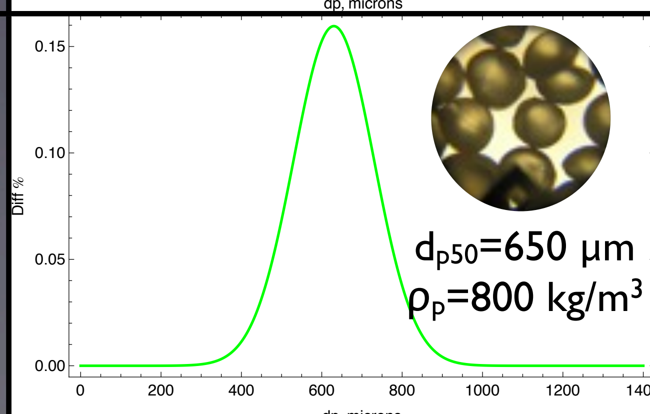
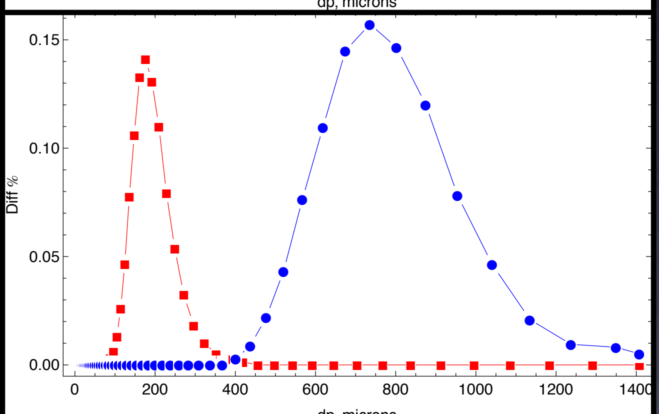
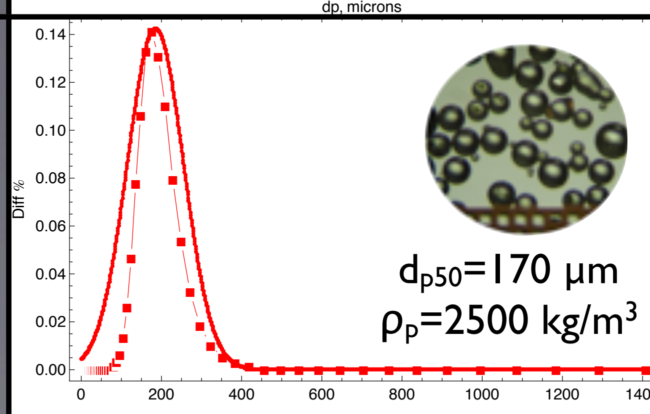
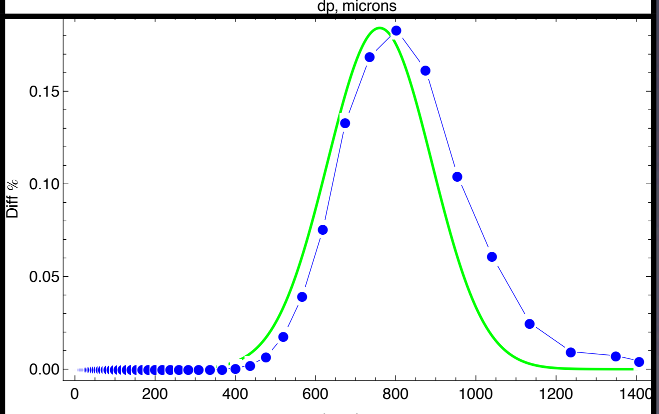
Particle Size Distributions

<table>
<tr><th>Material</th><th>PSD</th><th>Material</th><th>PSD</th></tr>
<tr><td>Sand</td><td></td><td>Large Glass</td><td></td></tr>
<tr><td>PE</td><td></td><td>Large & Small Glass</td><td></td></tr>
<tr><td>Small Glass</td><td></td><td>Large Glass & PE</td><td></td></tr>
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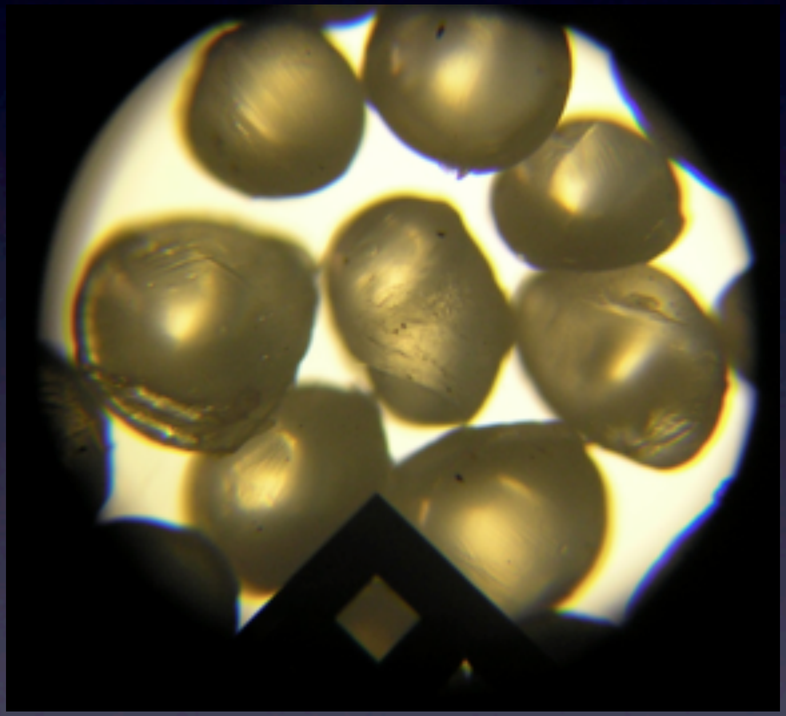
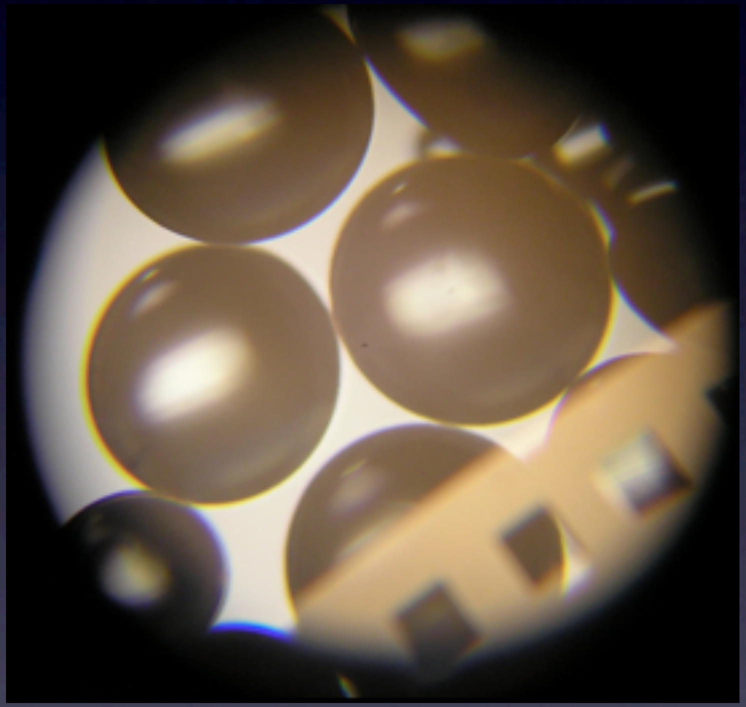
Materials of Interest

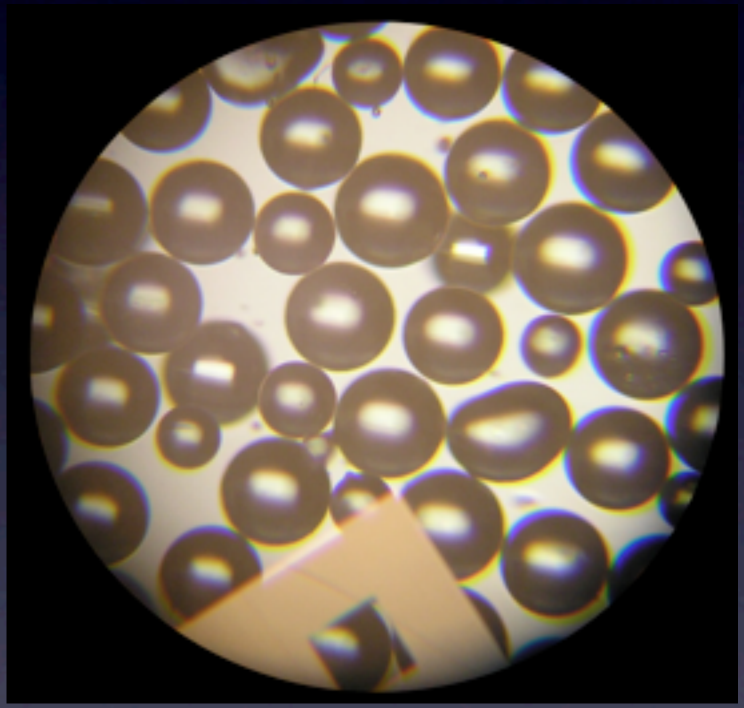
HDPE
d_{ave} = 650 µm
ρ_p = 900 kg/m^3



Glass
d_{ave} = 650 µm
ρ_p = 2500 kg/m^3



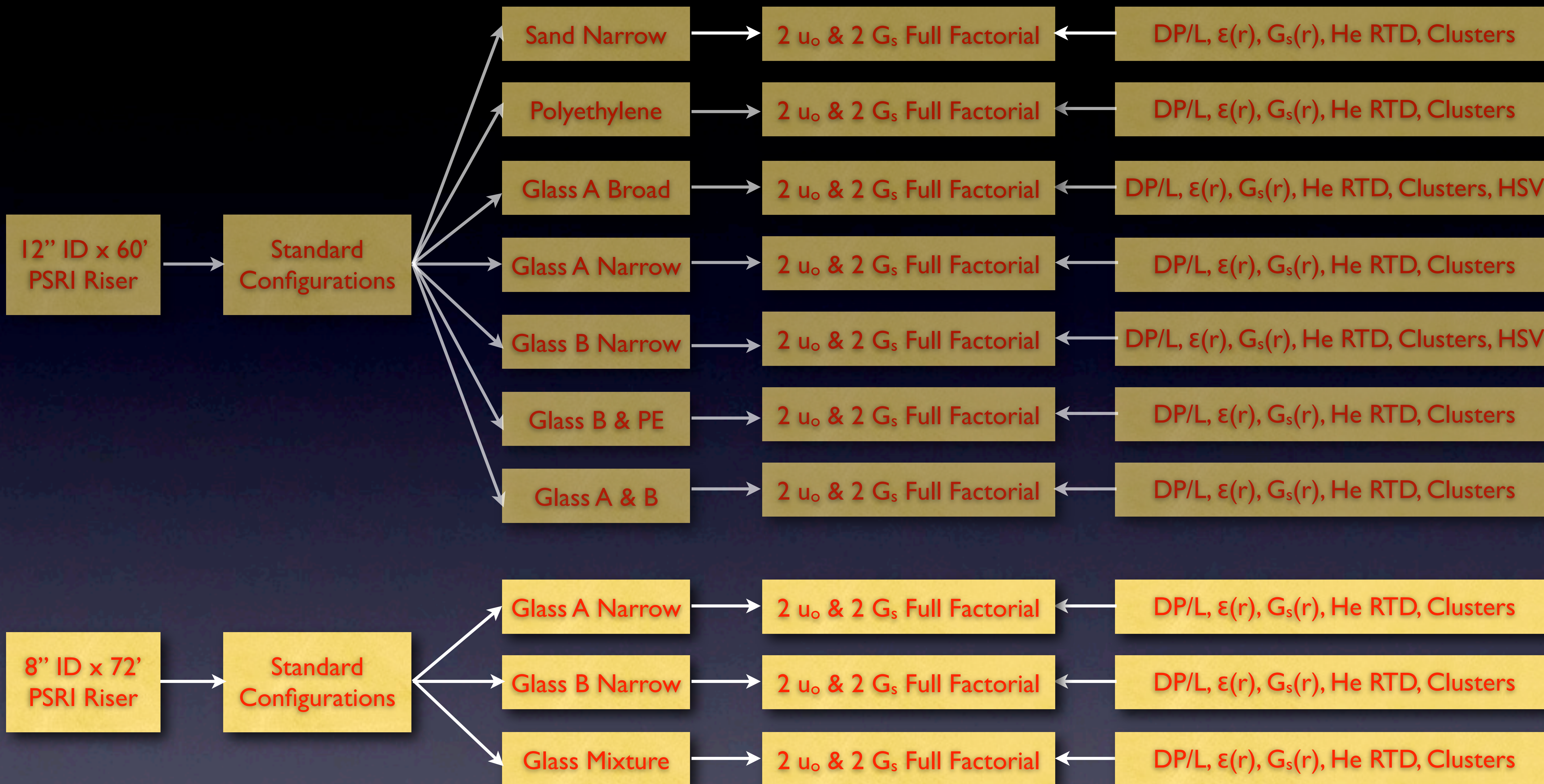
Glass
d_{ave} = 170 µm
ρ_p = 2500 kg/m^3



Density Effect

Size Effect

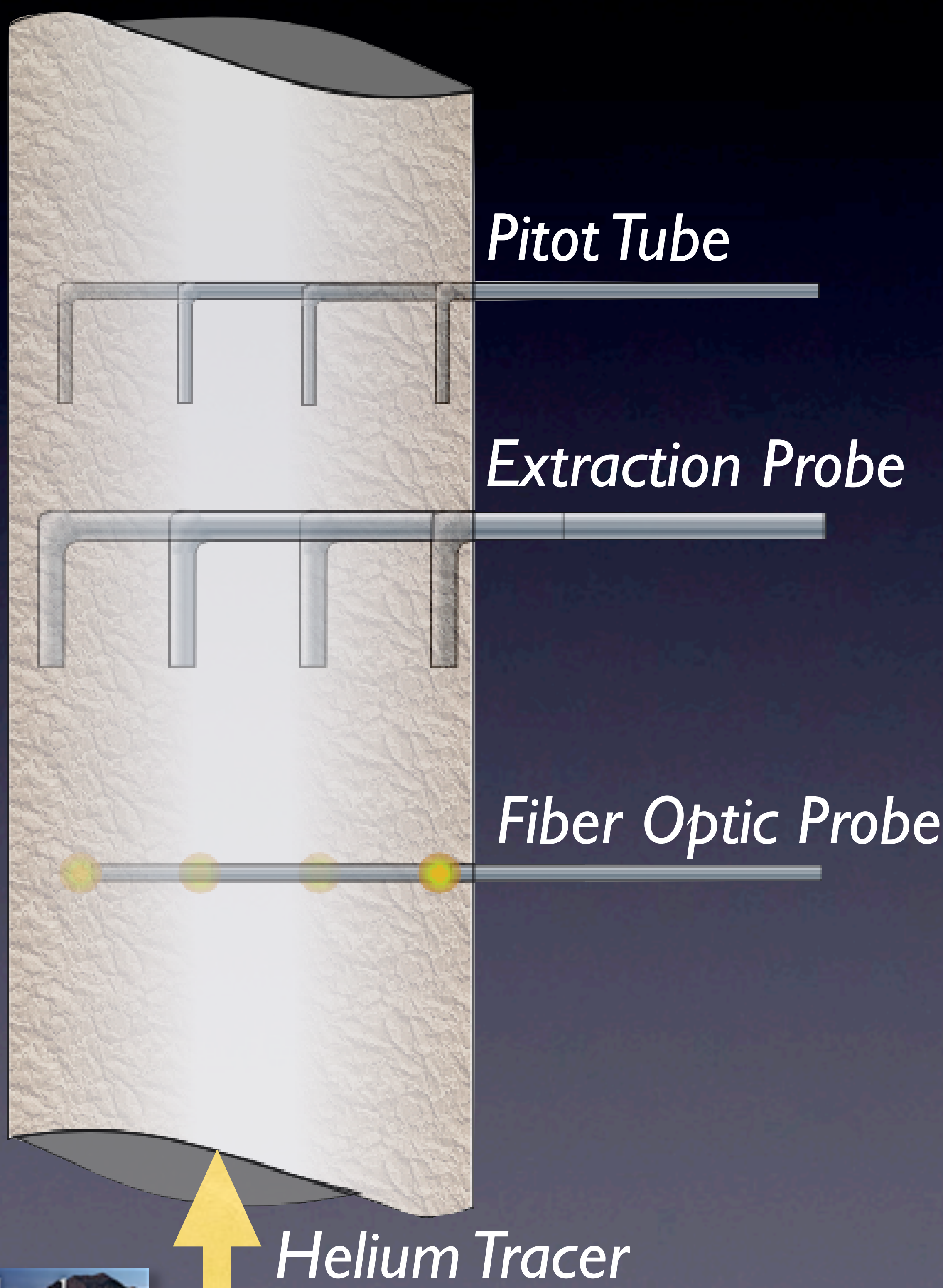
Design of Experiments



Unit	Configurations	Materials	Conditions	No. of Exp.
12" ID x 60'	1	7	4	28
8" ID x 72'	1	3	4	12

Standard Techniques

5 axial positions by 11 radial positions (NS & EW)



- Pitot tube
  - Dynamic pressure corresponds to particle velocity
- Extraction probe
  - Solids flux via mass flow rate corrected for cylindrical effects
  - Local solids concentration can be obtained with particle velocity measurements
  - Samples will be used for segregation study
- Fiber optical probe
  - Local solids concentration
  - Cluster size
    - Wavelet decomposition
      - Guenther & Breault
      - Yang & Leu
- Helium tracer
  - Gas residence time distribution
    - Dispersion

Guenther and Breault.. Powder Technology (2007) vol. 173 (3) pp. 163-173; Yang and Leu., AIChE Journal (2009) vol. 55 (3)

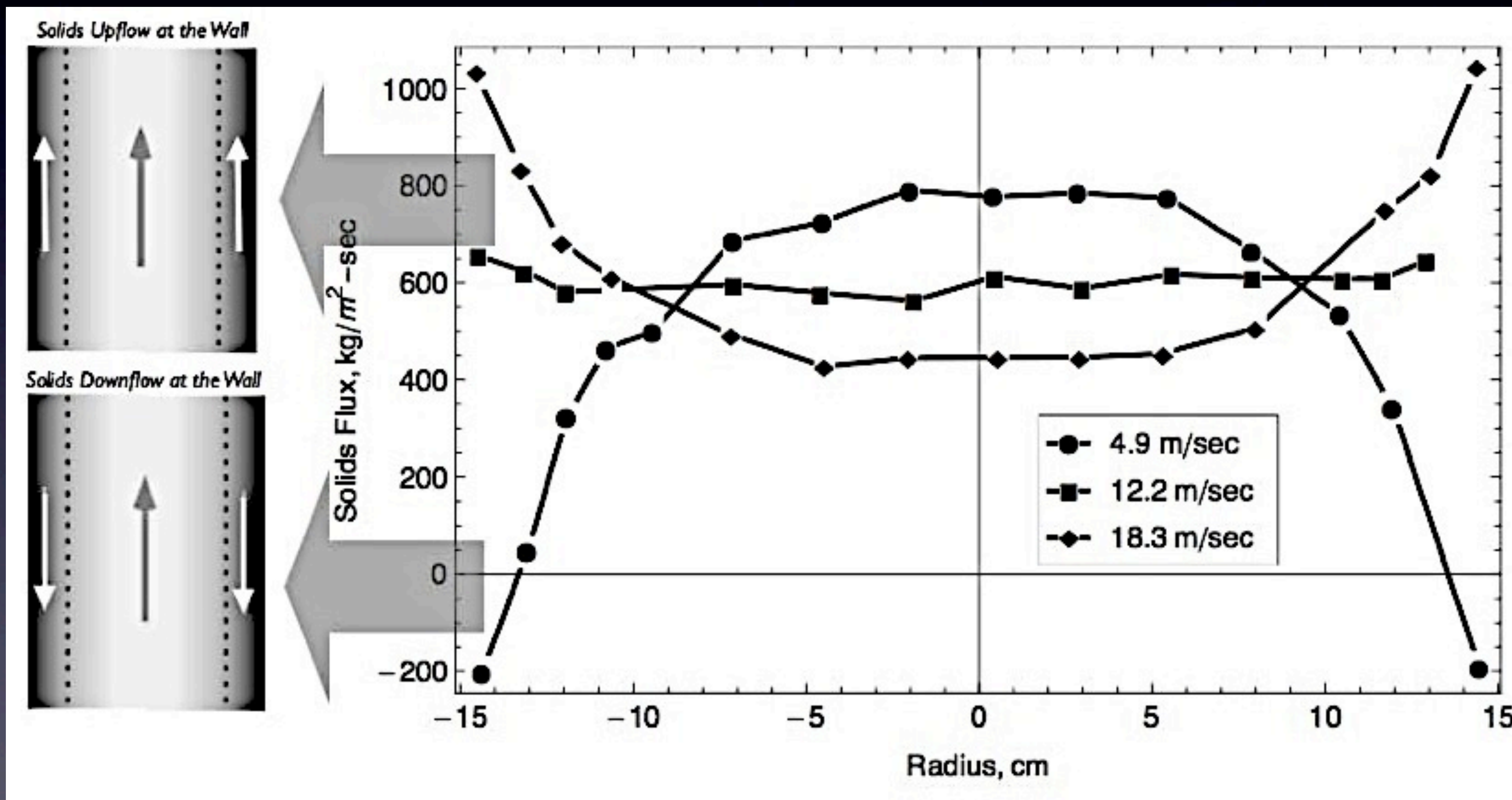
Recent Results

- Reverse core-annulus behavior near the top of the riser for some materials
- Particle segregation in a riser

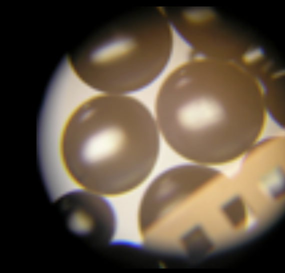
Test Conditions

	Low Solids Flux	High Solids Flux
Low Gas Velocity	13.5 m/sec 120 kg/m^2-sec	13.5 m/sec 260 kg/m^2-sec
High Gas Velocity	17 m/sec 120 kg/m^2-sec	17 m/sec 260 kg/m^2-sec

Core-Annulus Behavior



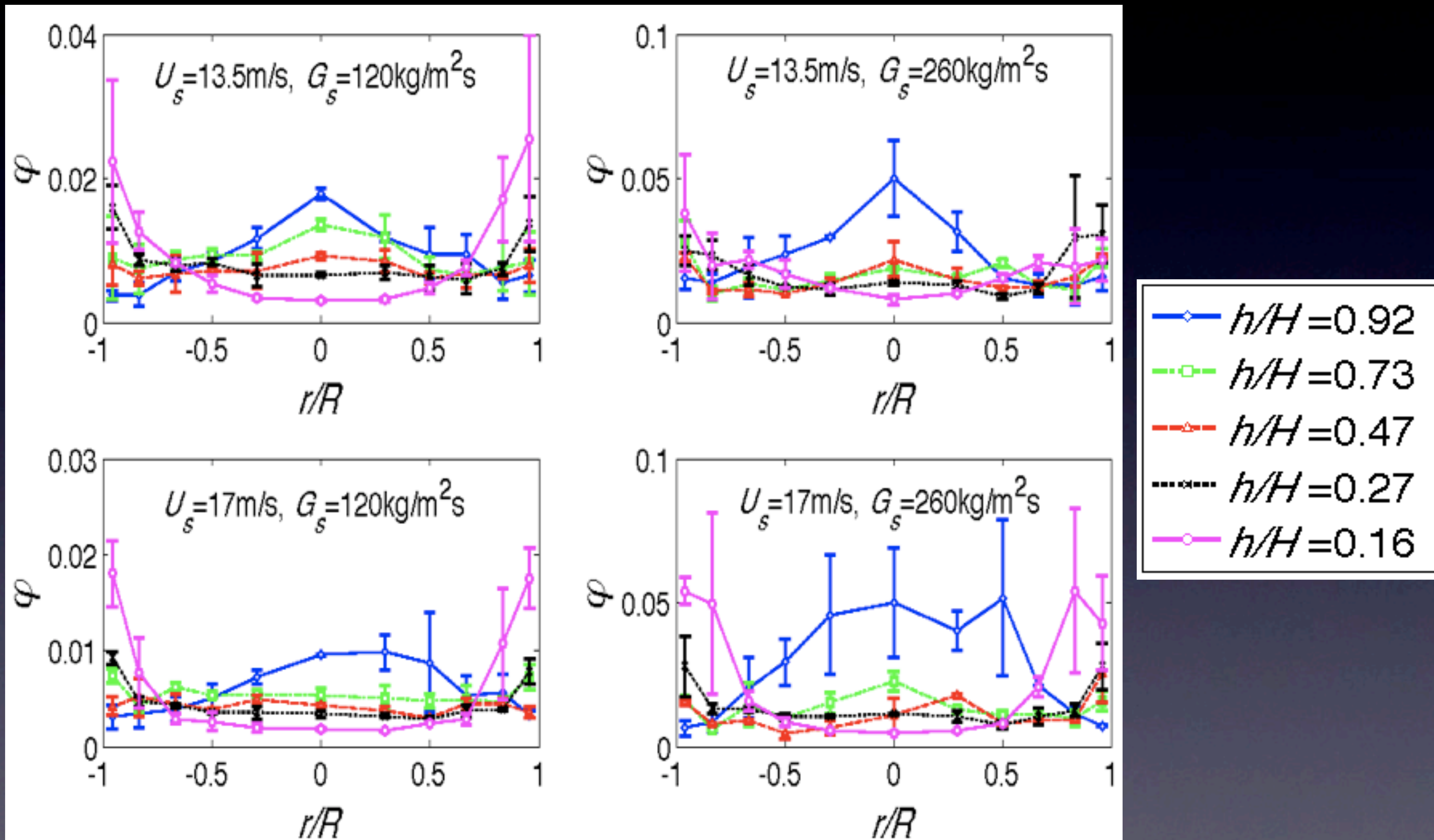
Loading Profiles with 650 µm Glass Beads



Low G_s | High G_s

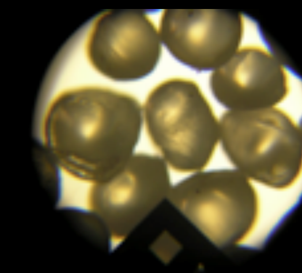
Low U_o

High U_o



Reverse core-annulus at riser top for all conditions

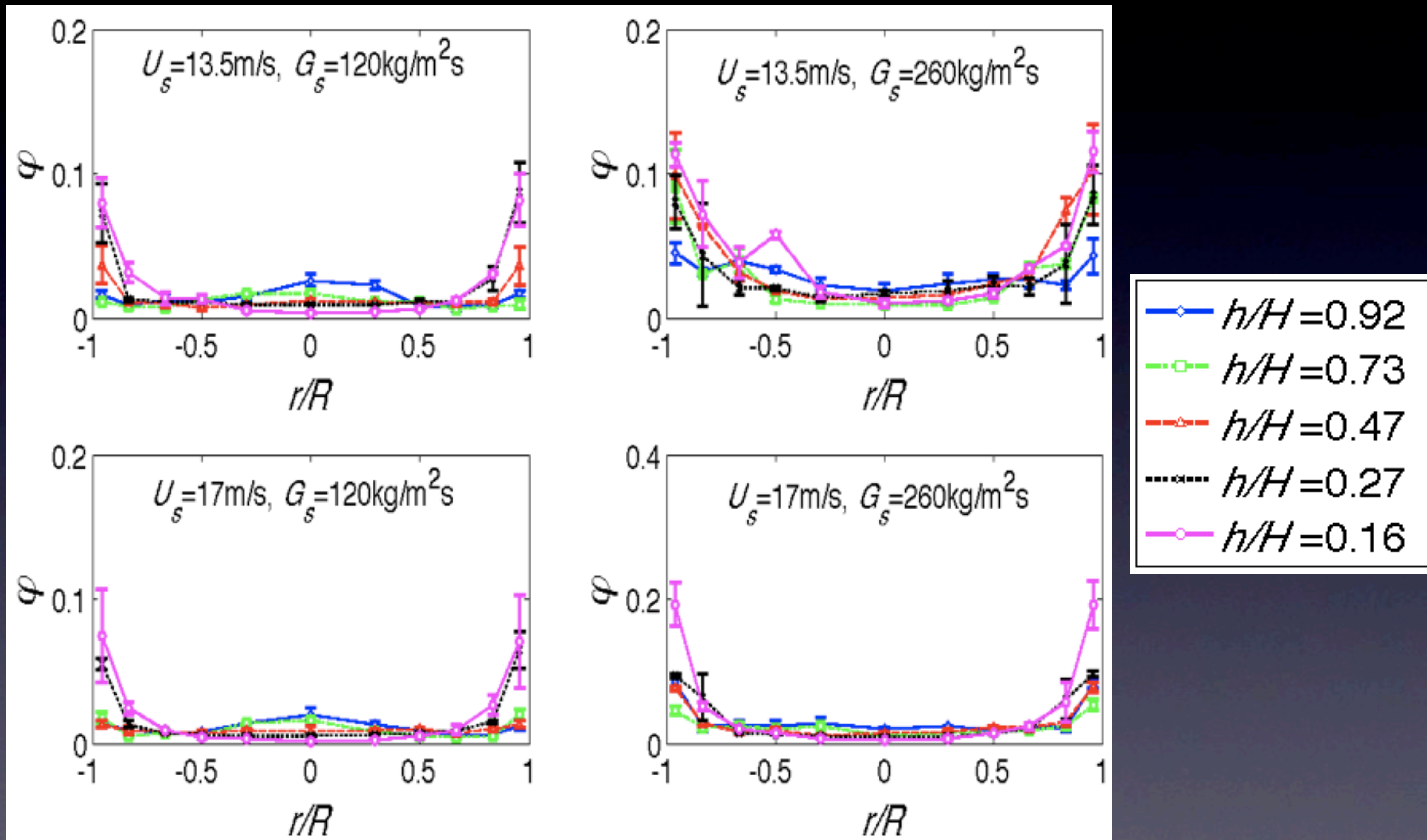
Loading Profiles with 650 μm HDPE



Low G_s | High G_s

Low U_o

High U_o



Reverse core-annulus at riser top at low G_s

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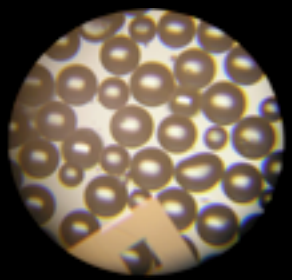
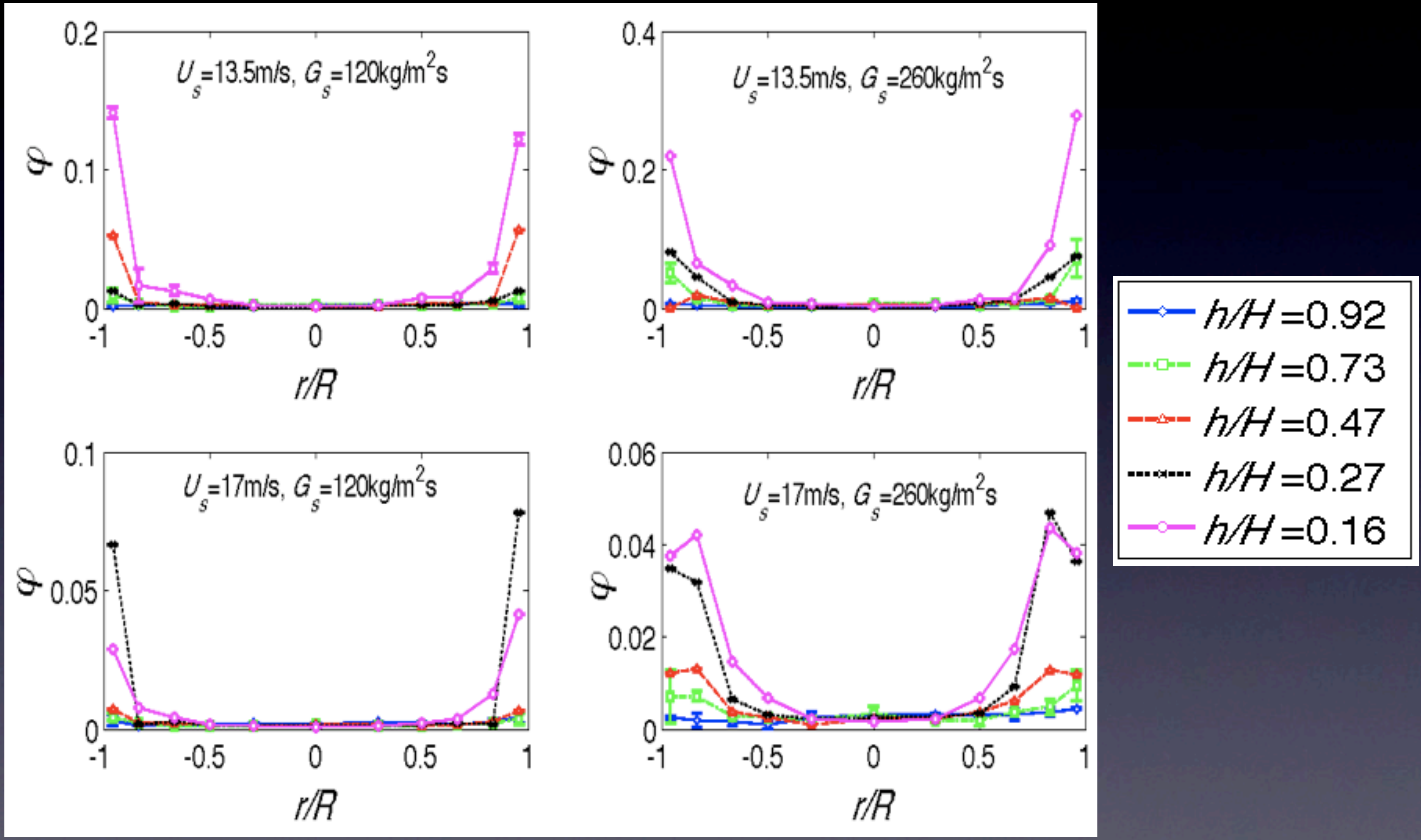
Loading Profiles with 170 µm Glass Beads



Low G_s | High G_s

Low U_o

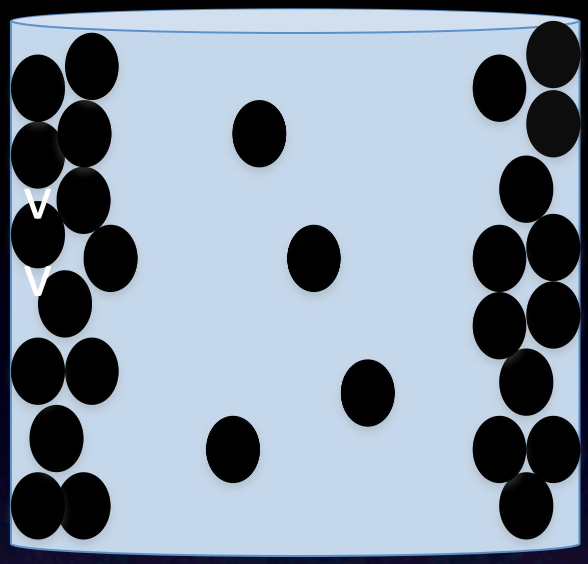
High U_o



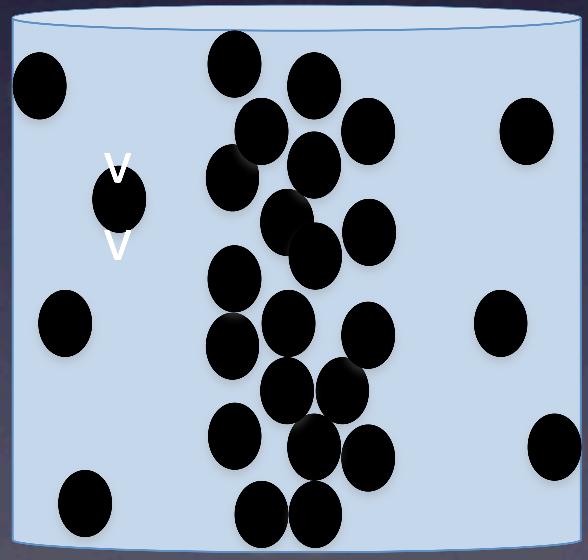
Reverse core-annulus NOT observed

Questions

- In general
  - Core-annulus profiles are reported
    - Solids density is highest at the wall
- Deviation observed for 2 of the 3 materials at the top of the riser
  - 650 µm Glass Beads: All conditions
  - 650 µm HDPE: Only at low Gs
  - 170 µm Glass Beads: Not observed
- What causes reverse core-annulus?
  - Turbulence
    - It is more dilute at the top
  - Rough wall effect
  - Exit effect
    - It is only at the top
- Why only for some materials and/or condition?



Small Glass Beads



Large Glass Beads & HDPE

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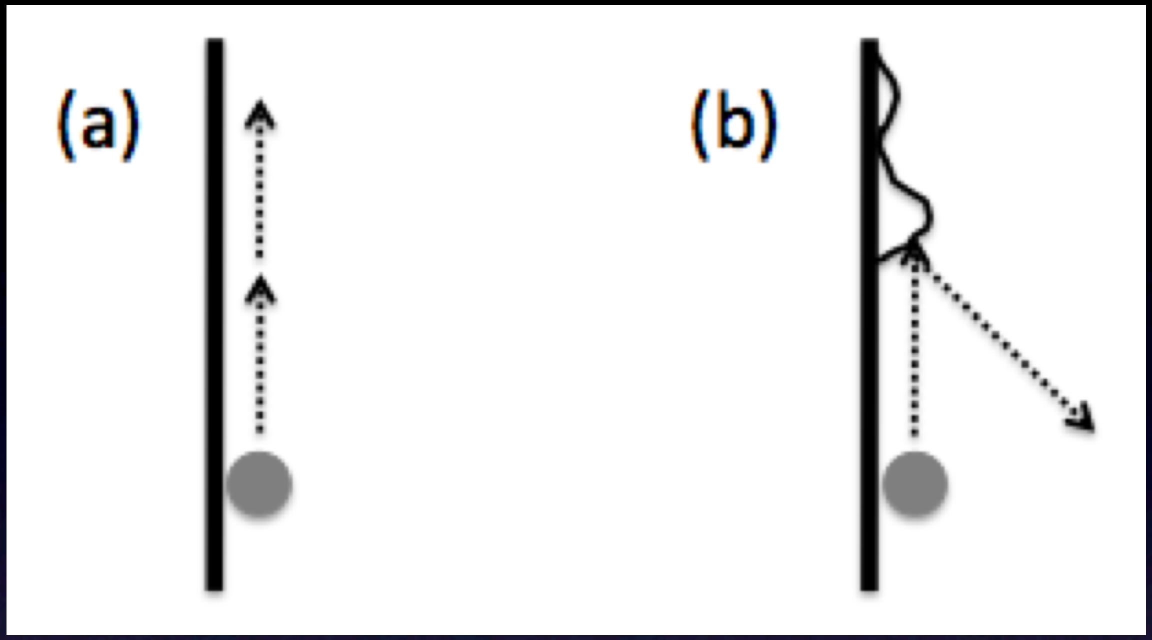
Turbulence Effect

- Simulations and experiments reported
  - As dilution increases, turbulence increases, loading at the riser center increases
- Deviation reported at max solids loading of 0.006
  - But, reverse core-annulus persists at average solids loadings of 0.02 in this work
- Deviation reported NOT as exaggerated as this work

Simulations: Tanaka and Tsuji (1991), Bolio and Sinclair (1995),
Experiments: Tsuji et al. (1984), Tanaka et al. (1989)

Rough Wall Effect

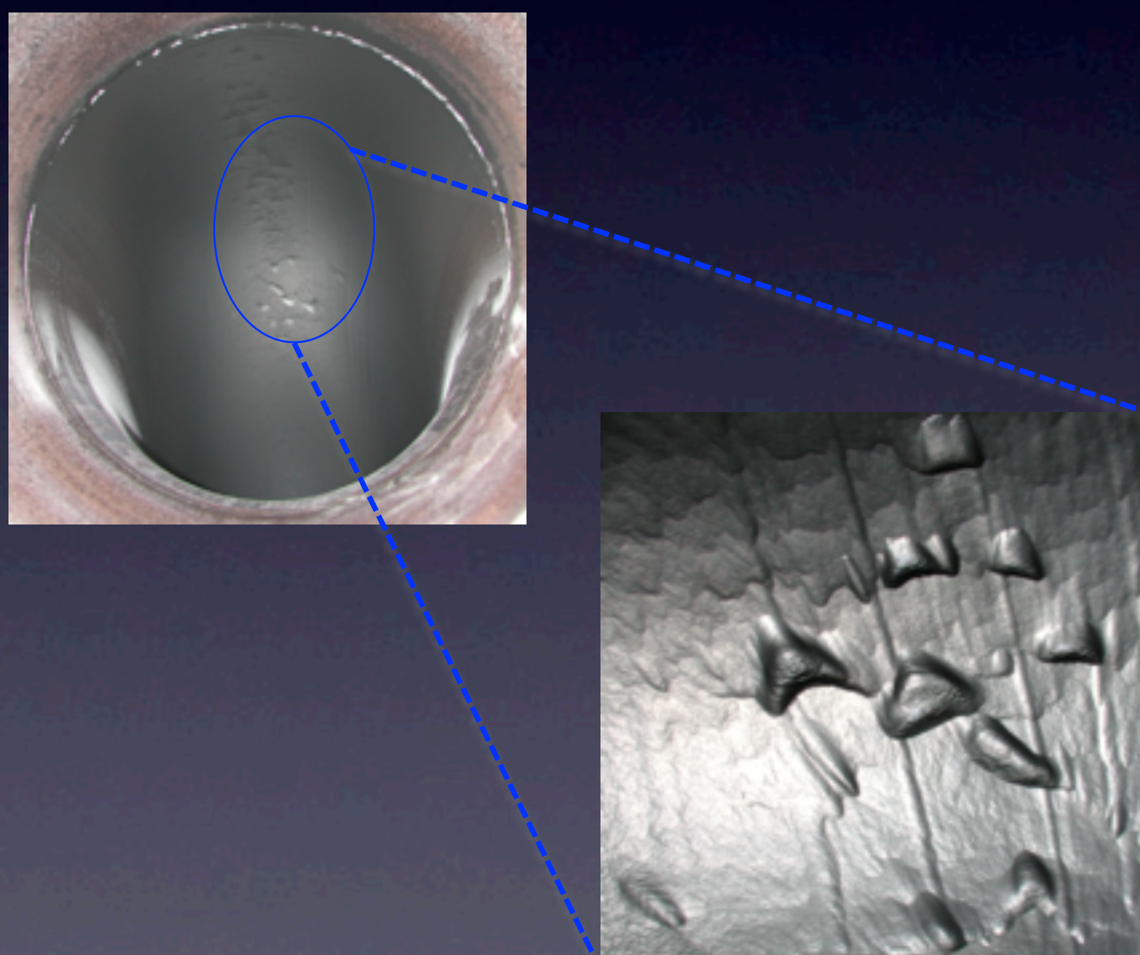


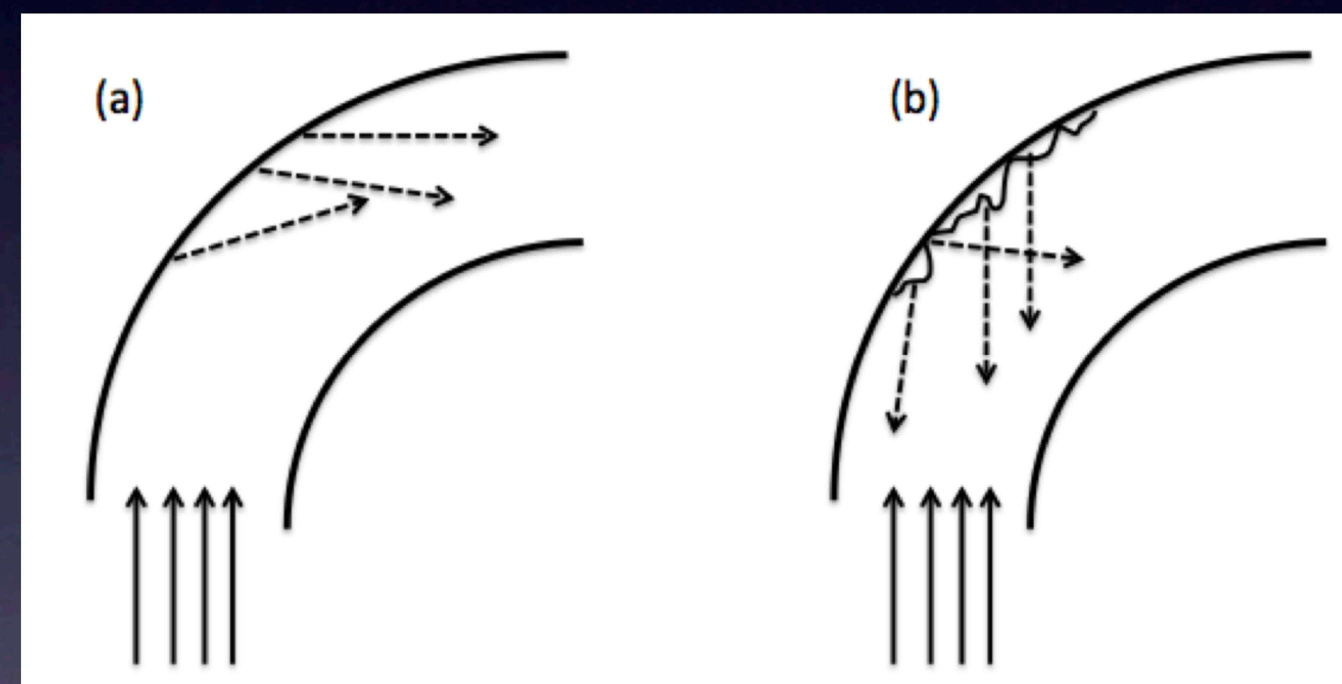
- Simulations and experiments reported
  - As wall roughness increases, loading in riser center increases
    - But, topmost measurement taken at newly-installed Plexiglas™ section → smooth wall?

Simulations: Jenkins and Louge (1997), Benyahia et al. (2005), Benyahia et al. (2007), Experiments: Zhou et al. (1996), Jasti and Higgs (2008)

Exit Effects

- Particle bombardment → roughening of inner walls of elbow-exit





Rough Wall + Exit-geometry = Reverse core-annulus

Stokes Number and Likelihood of Reverse Core-Annulus

$$St = \frac{inertia}{viscous} = \frac{\rho_p d_p (u-v)}{\mu} = \frac{\rho_p d_p v_t}{\mu}$$

Material	d_{p50}, µm	Particle Density, kg/m^3	Reverse Core-Annulus?	Stokes Number
Large Glass Beads	650	2500	All Conditions	8.3/µ
Large HDPE	650	900	Only at Low G_s	1.6/µ
Small Glass Beads	170	2500	Not Observed	0.5/µ

- As Stokes Number increase, the likelihood of reverse core-annulus increases in rough bends

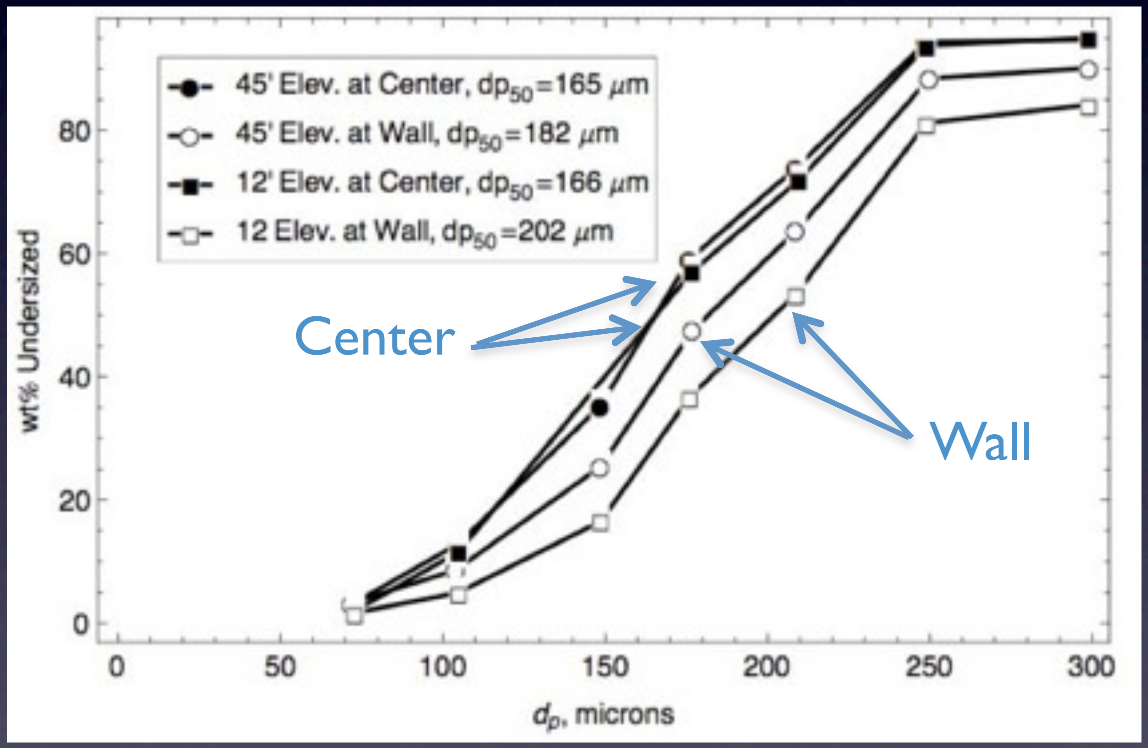
Recent Results

- Reverse core-annulus behavior near the top of the riser for some materials
- Particle segregation in a riser

Previous Results

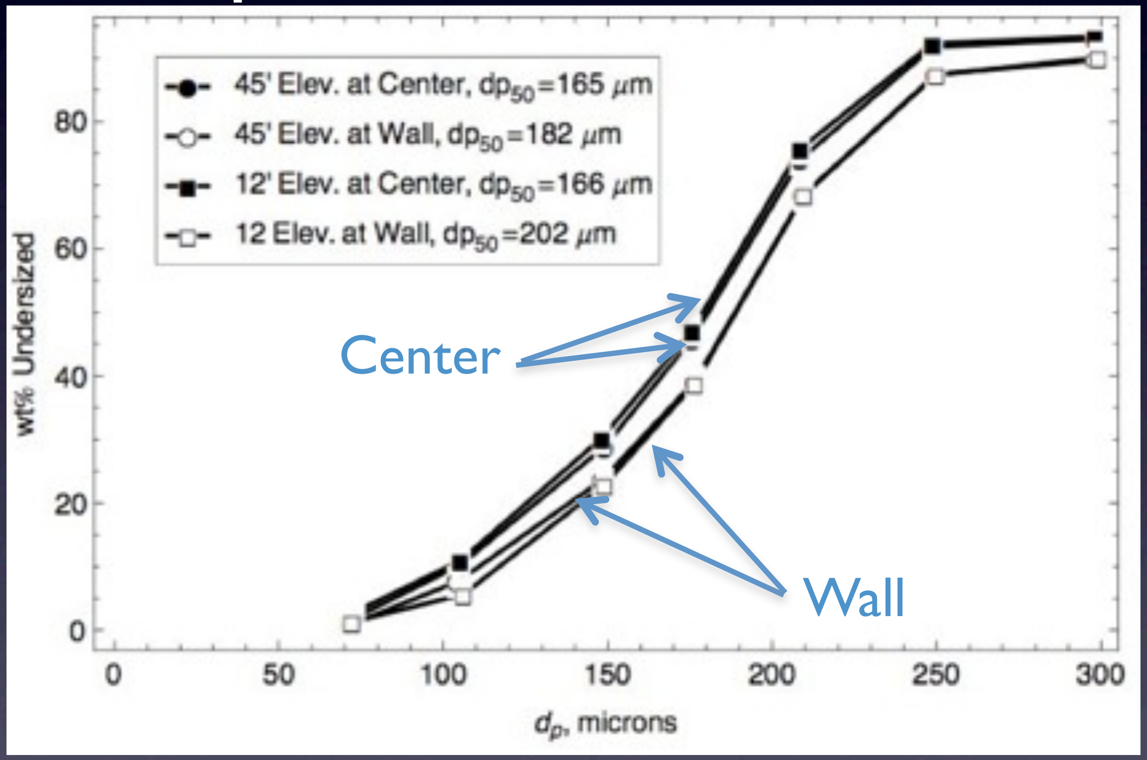
Sand in an 8-Inch Diameter x 72-Foot Tall Riser

Downflow in the Annulus



Larger Particles Segregating to the Wall

Upflow in the Annulus



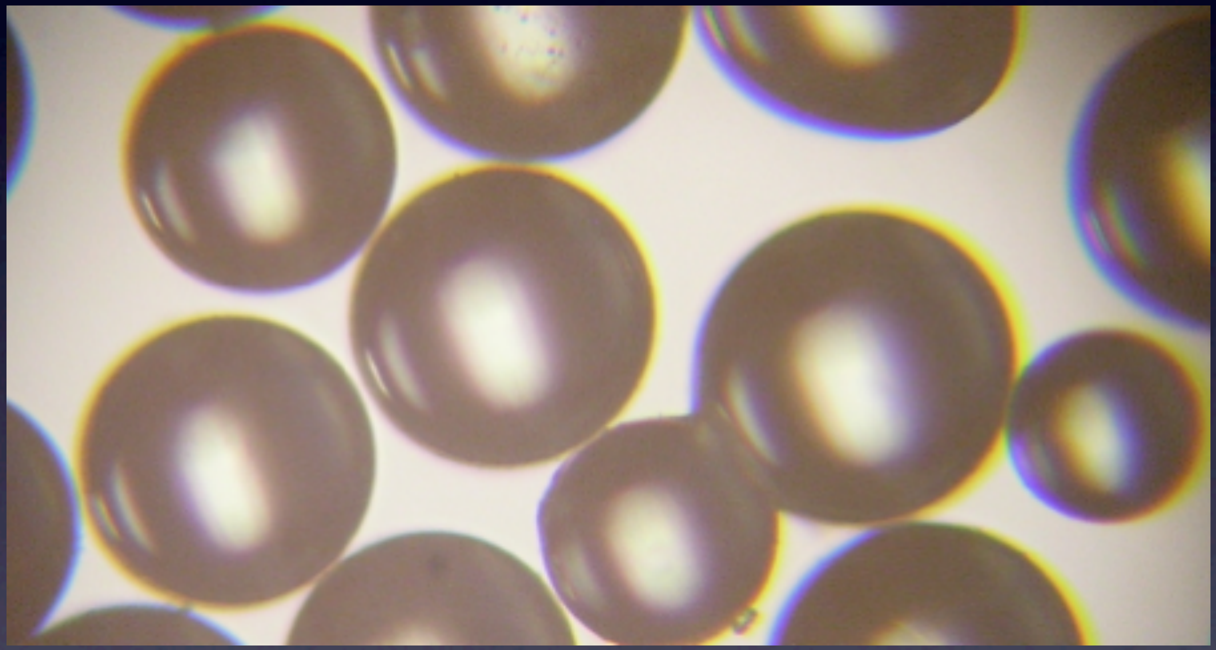
Little Segregation

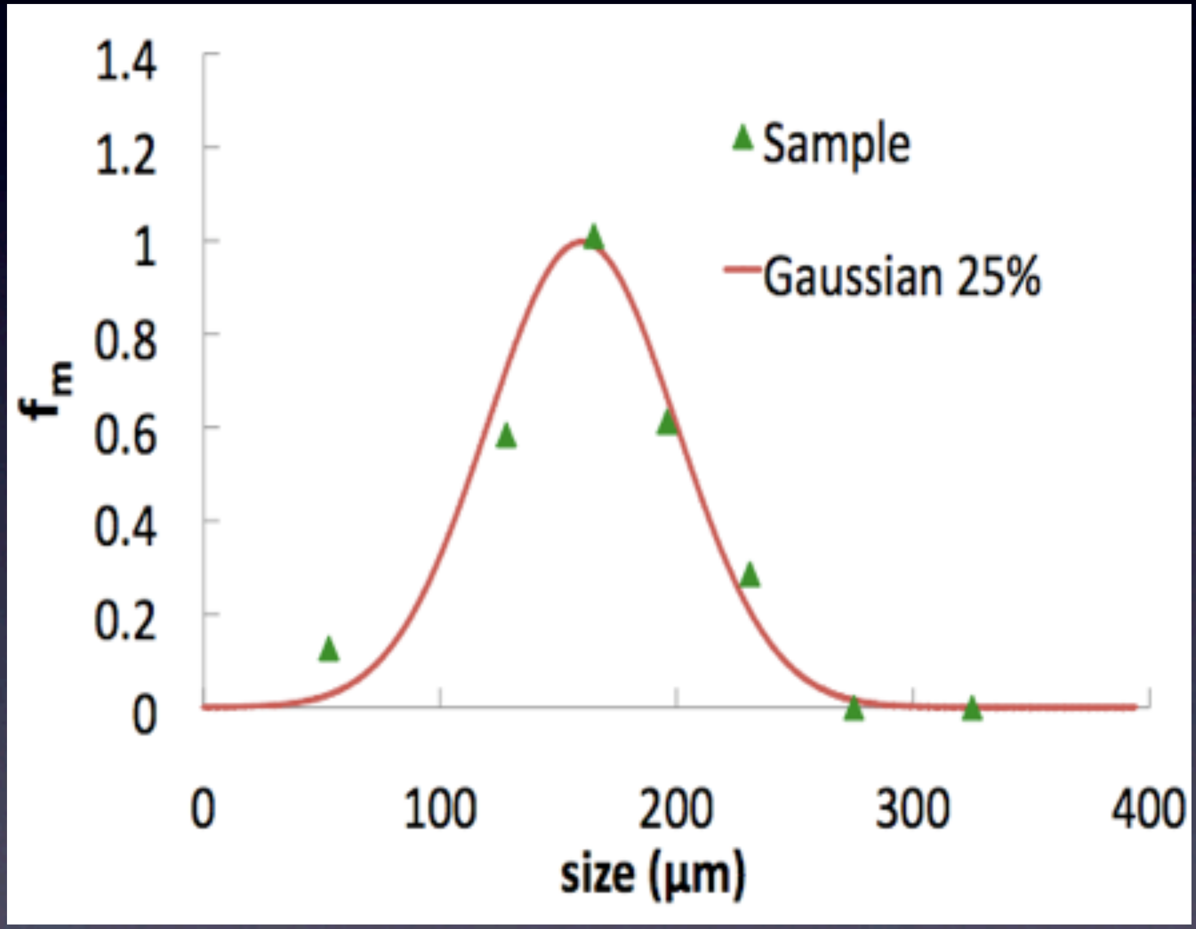
Karri, S.B.R., & Knowlton, T.M. (1998). Flow Direction and Size Segregation of Annulus Solids in a Riser. In L-S. Fan, T.M. Knowlton (Eds.), *Fluidization IX* (pp. 189-195) New York: Engineering Foundation.

Material of Interest

ρ_p=2500kg/m^3
Sphericity = 0.95

Gaussian distribution
d_{p50} = 170µm , σ/d_{p50} = 25%





Glass Beads with Broad PSD

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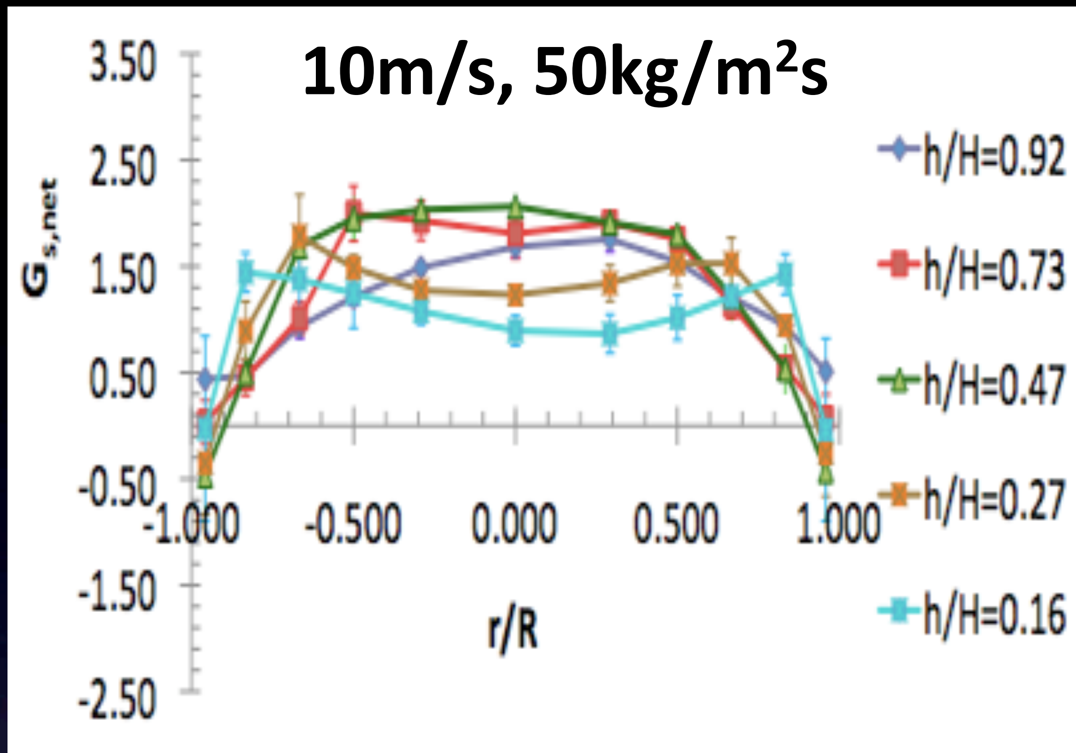
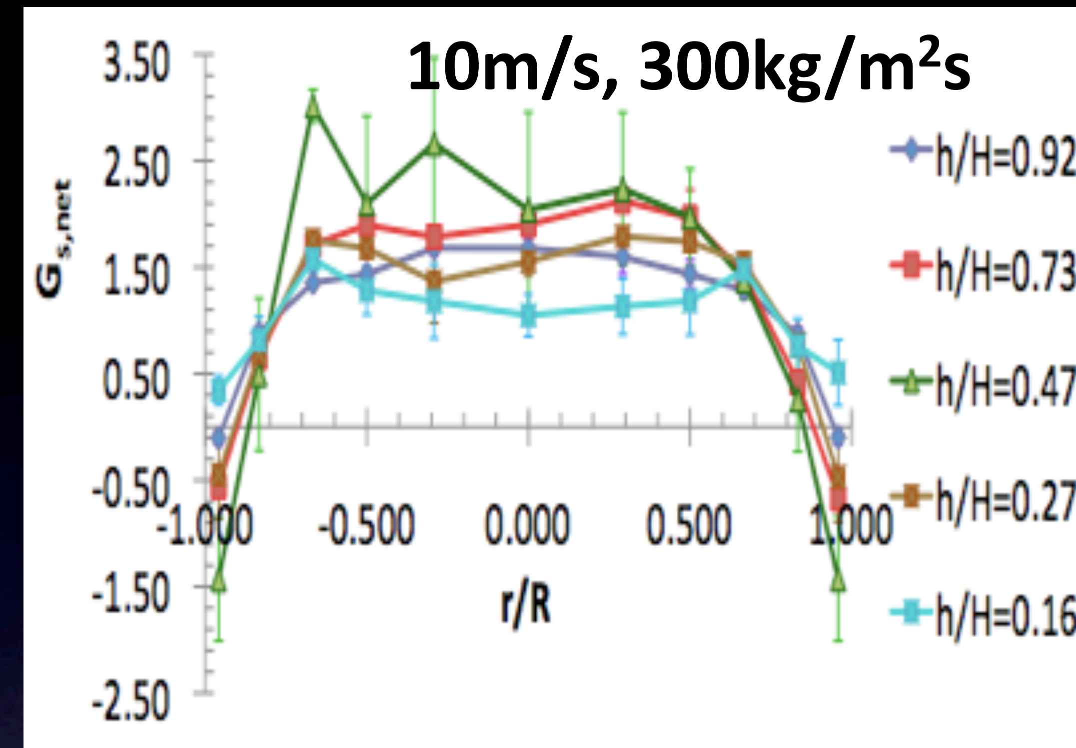
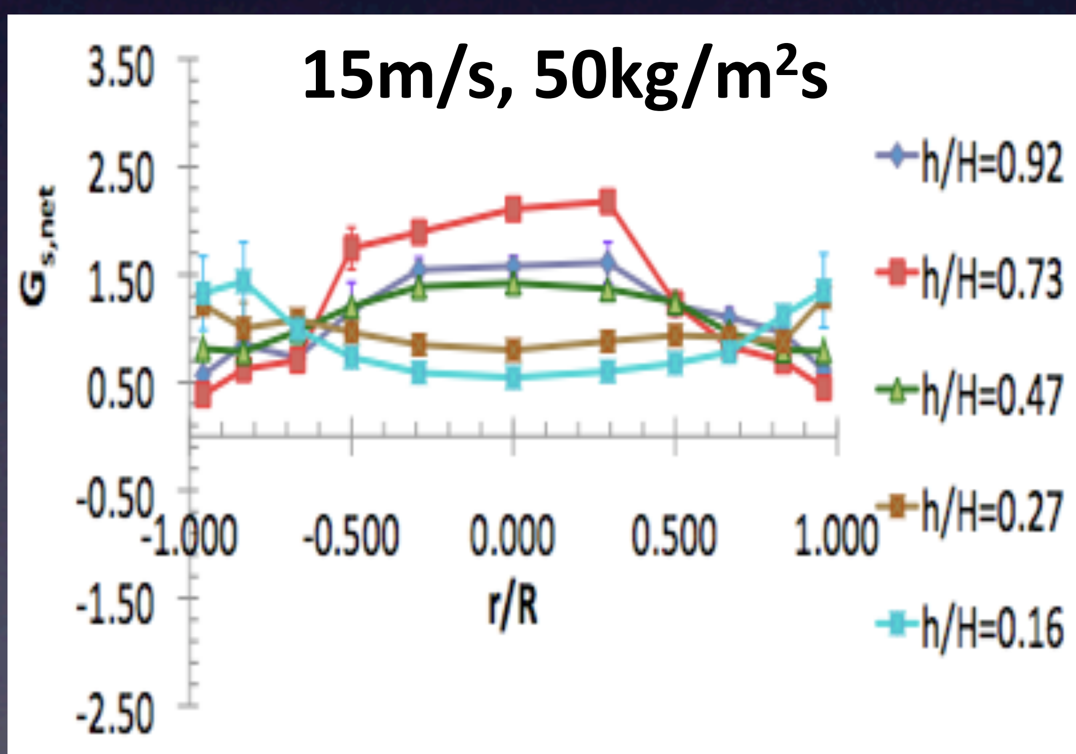
Test Conditions

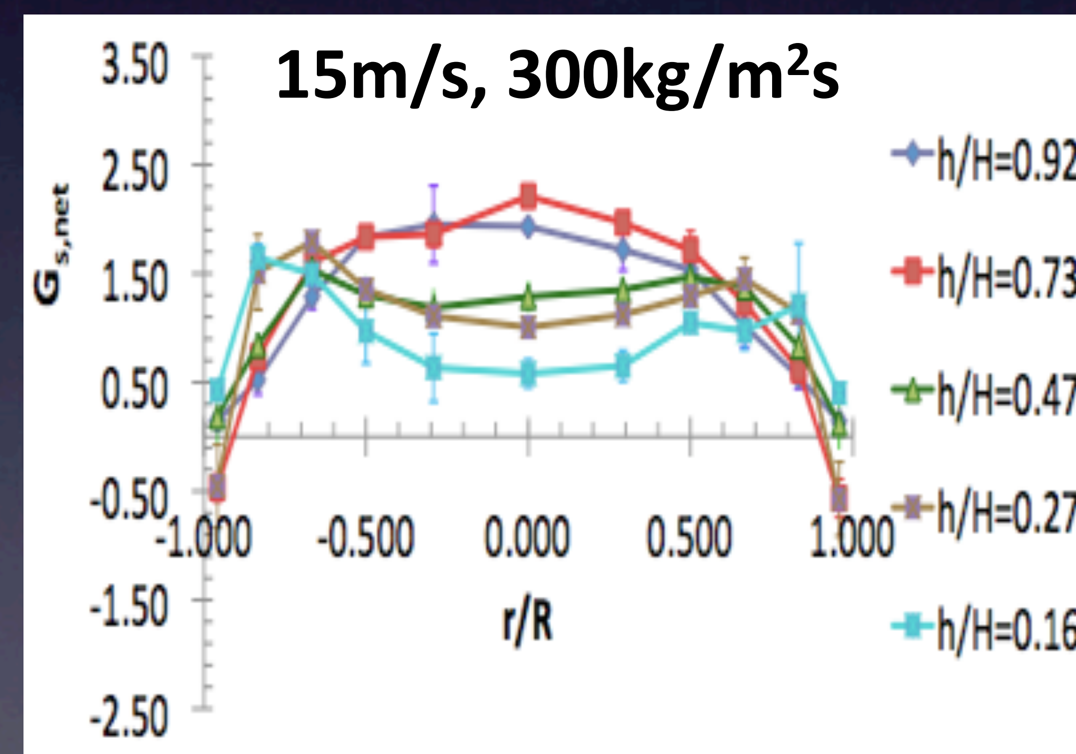
	Low Solids Flux	High Solids Flux
Low Gas Velocity	10 m/sec 50 kg/m^2-sec	10 m/sec 300 kg/m^2-sec
High Gas Velocity	15 m/sec 50 kg/m^2-sec	15 m/sec 300 kg/m^2-sec

Mass Flux Profiles









Upflow and downflow annulus
flat line, M-shaped, inverted U

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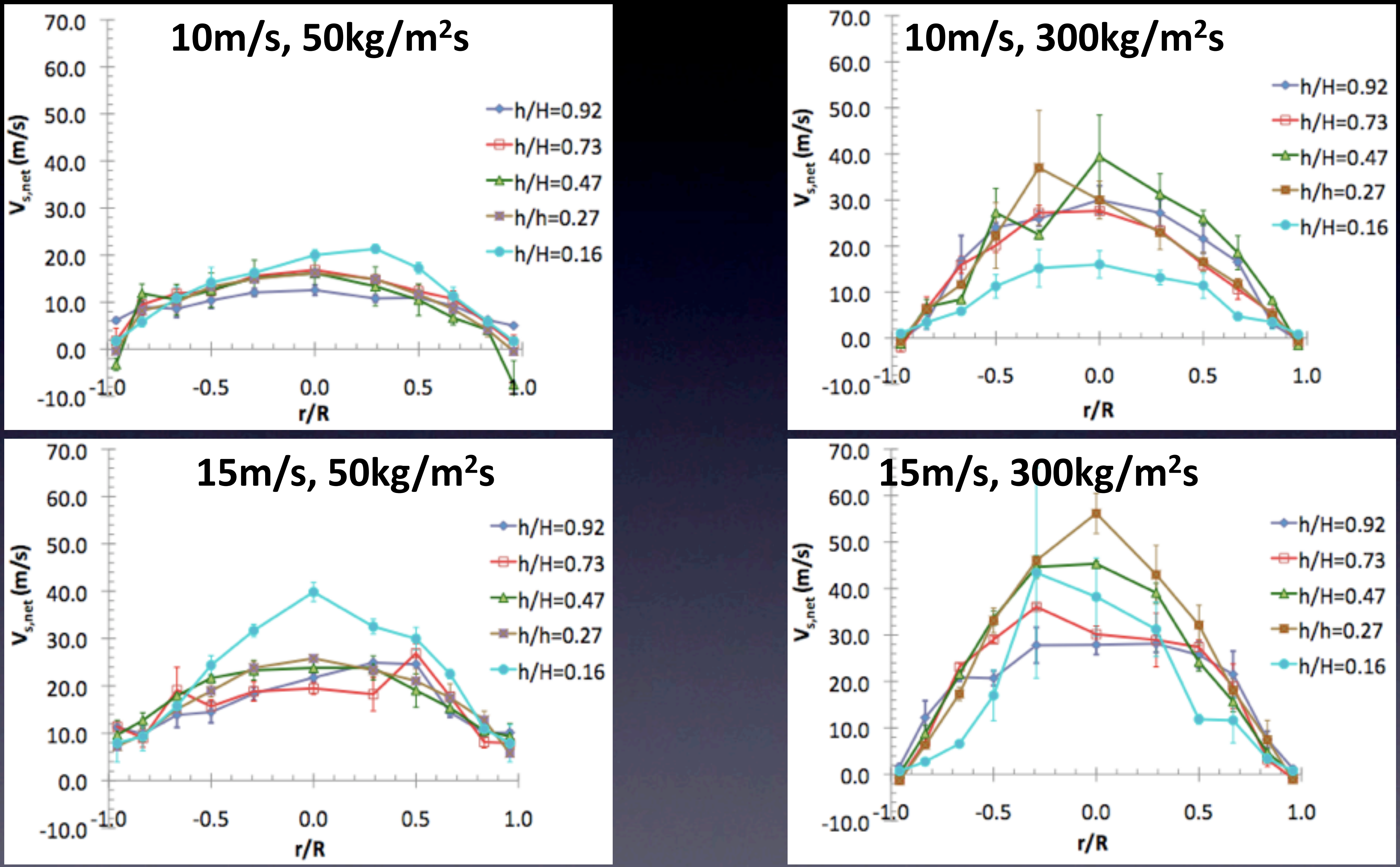
Solids Velocity Profiles



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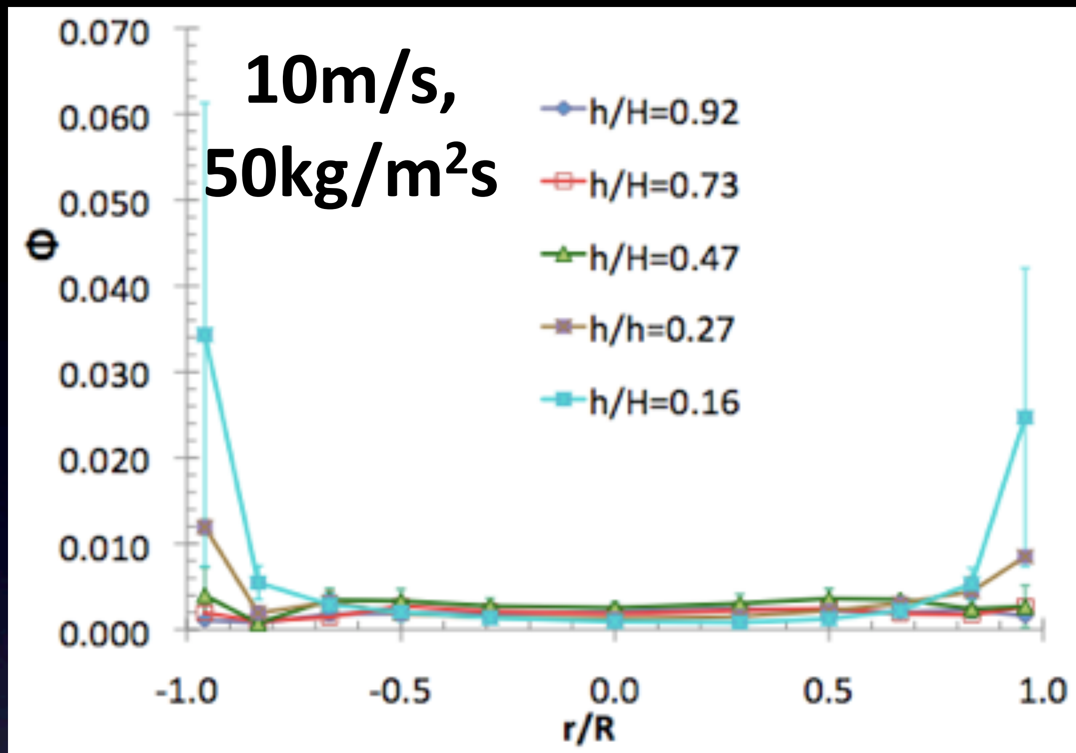
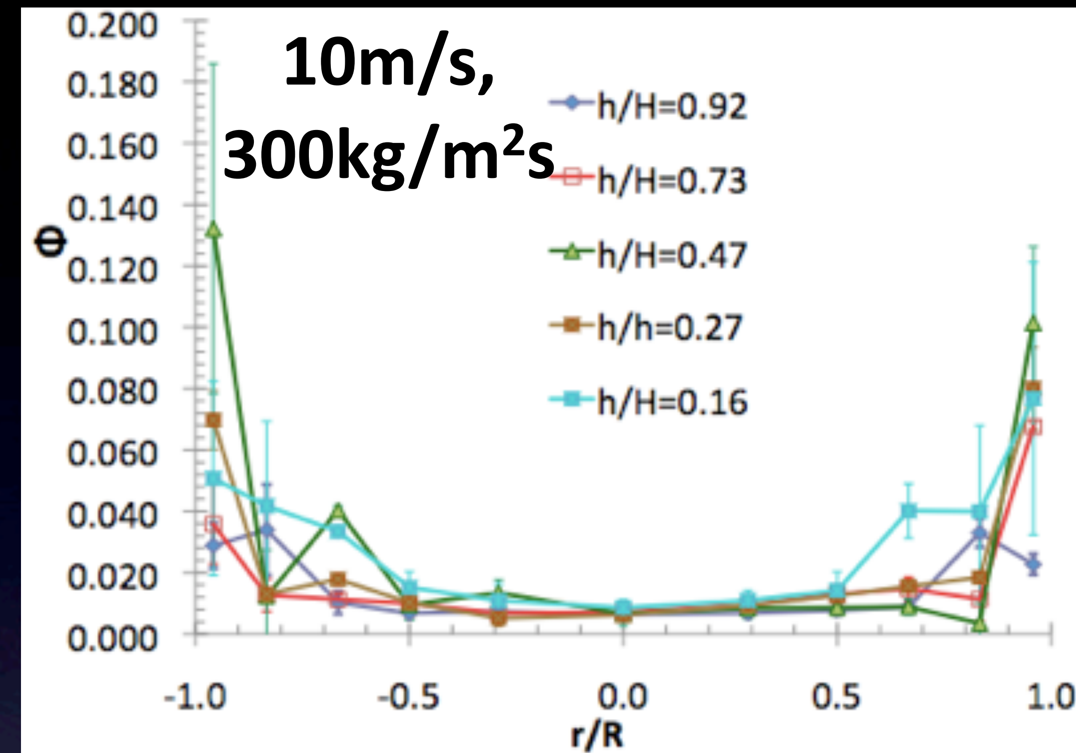
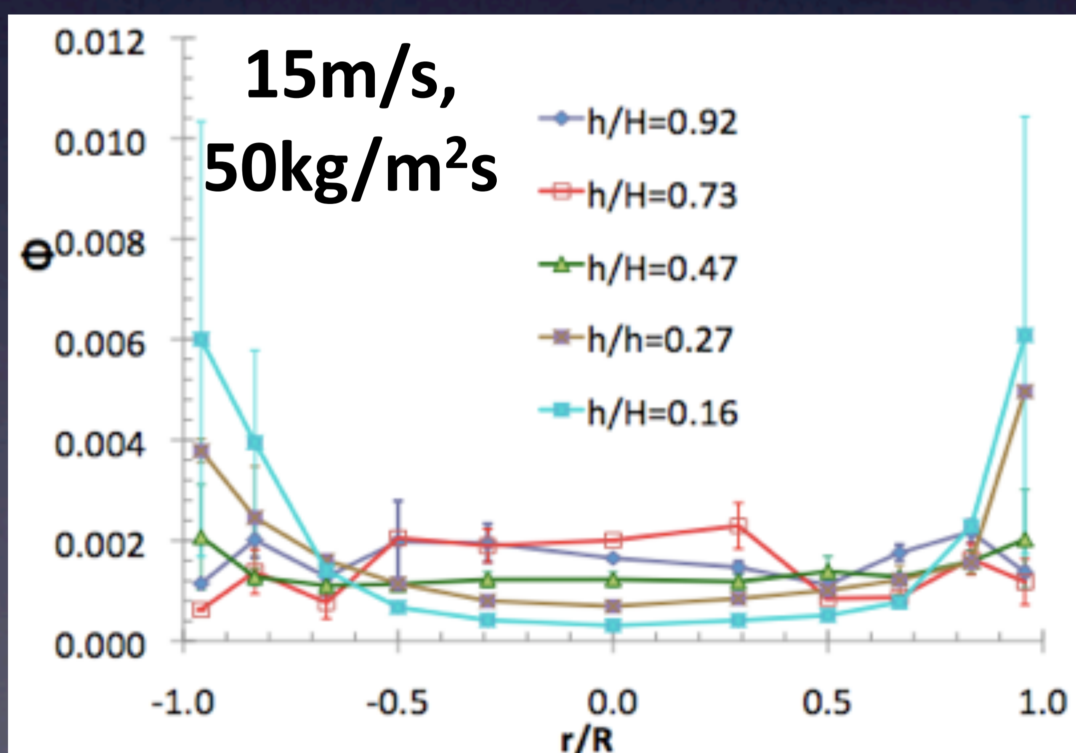
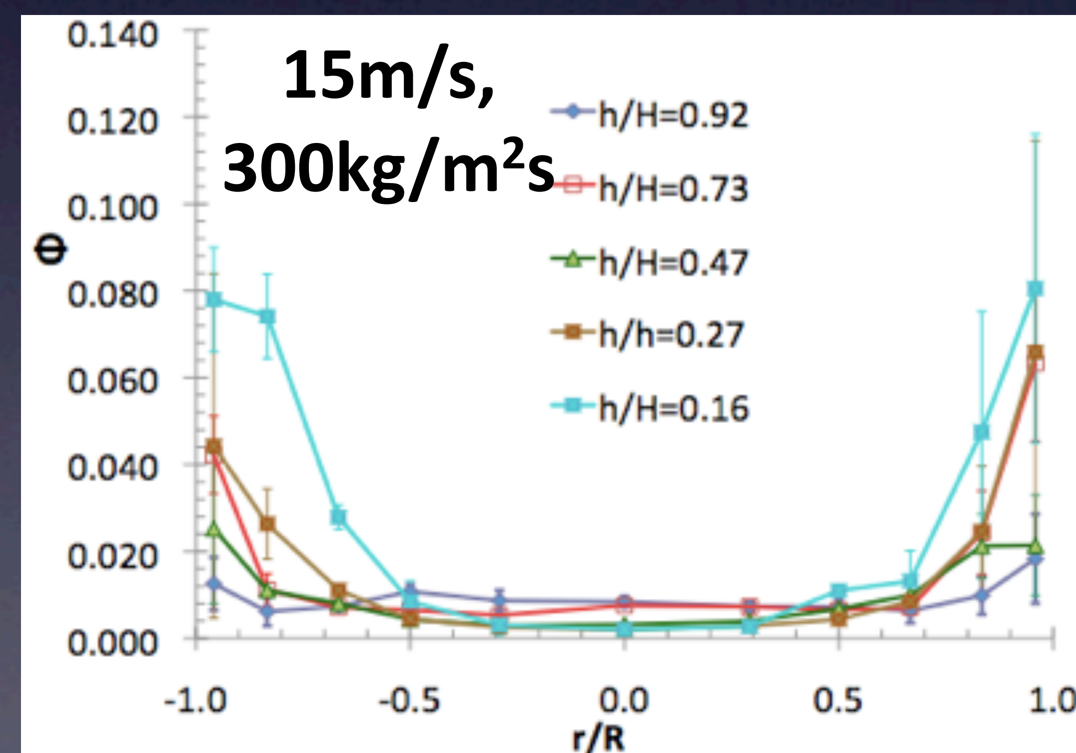
Loading Profiles

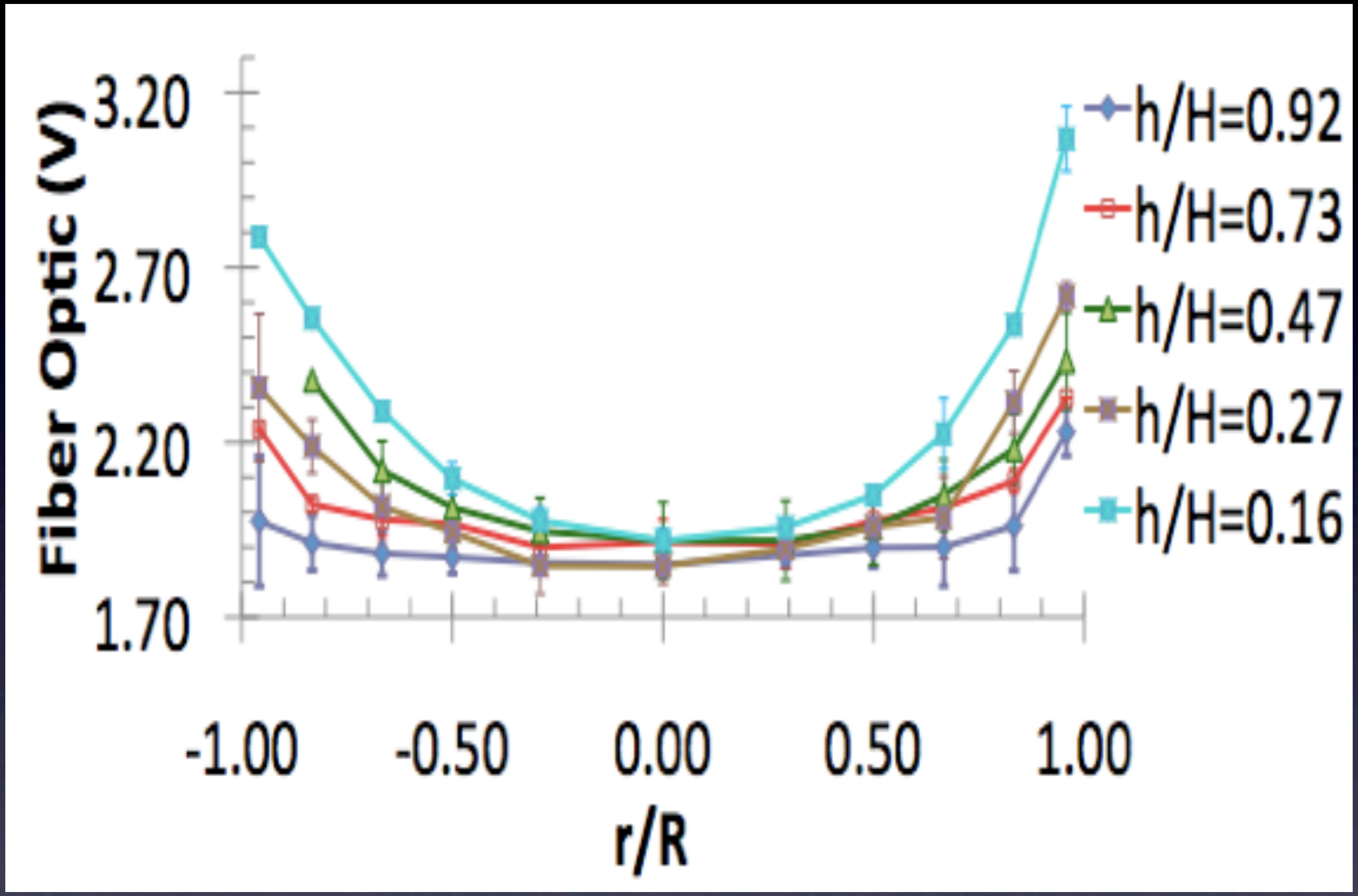








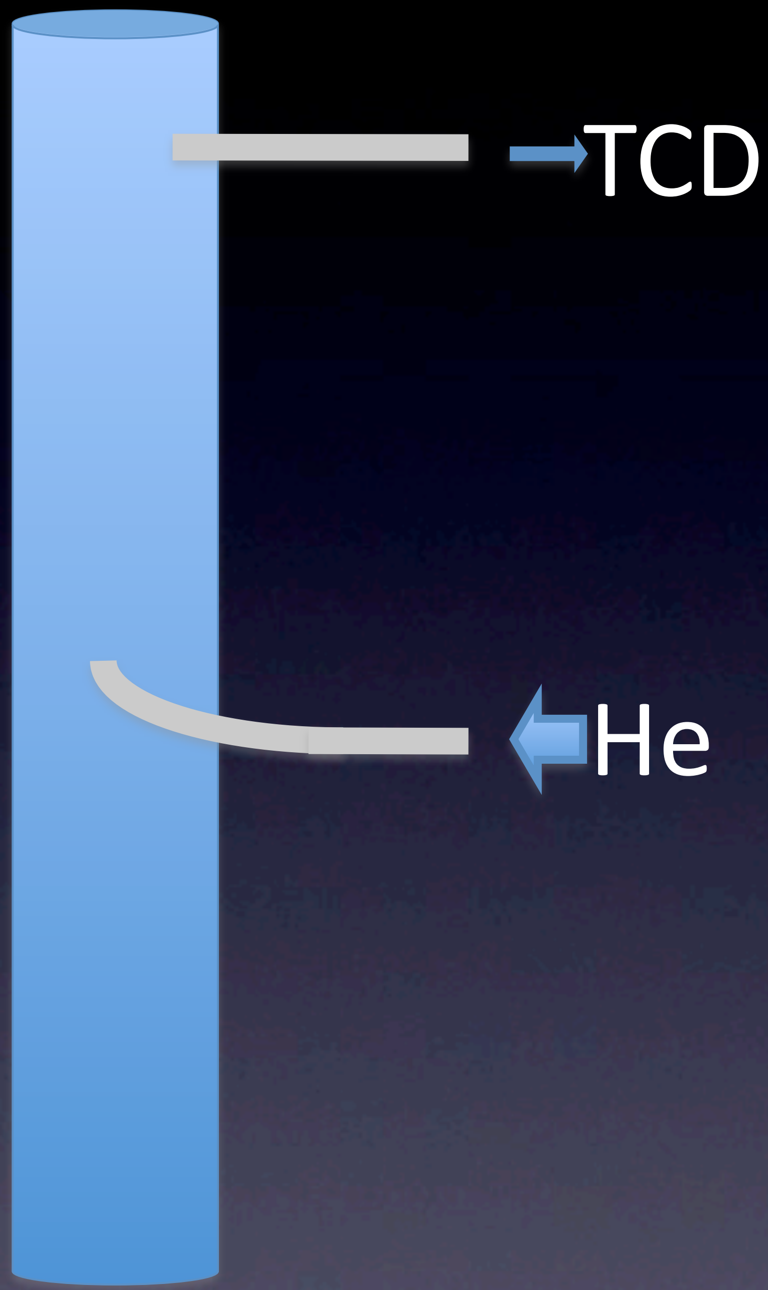
Fiber Optic Voltage Profile

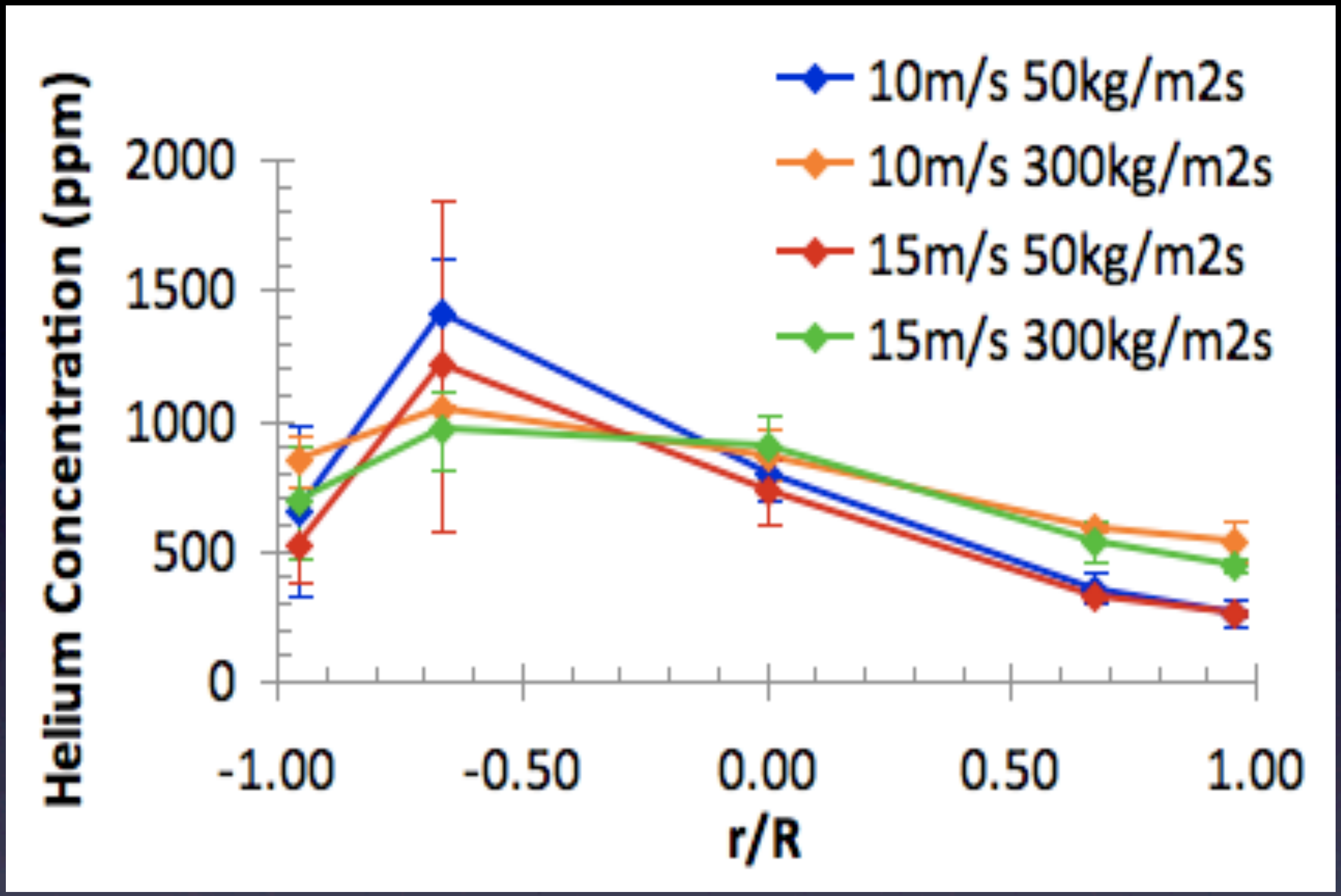


Qualitative solid concentration profile

Cluster analysis via wavelet decomposition

Helium Tracer Profiles





Asymmetrical

As G_s ↑ , He more uniformly dispersed

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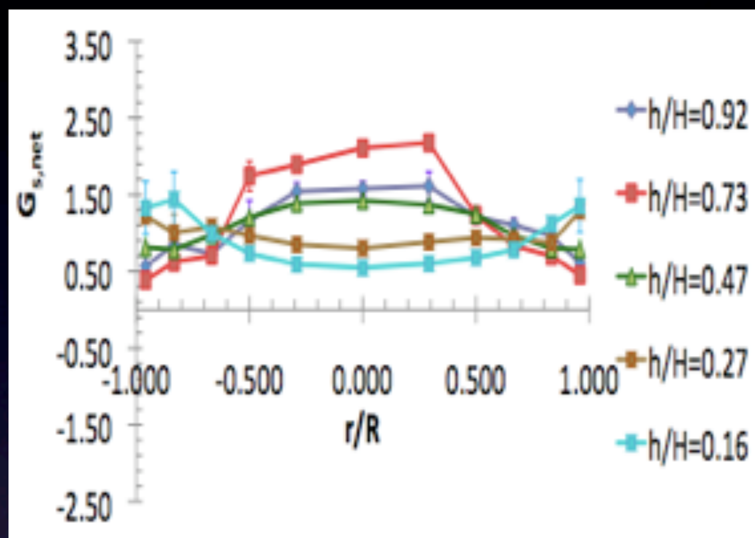
Size Segregation

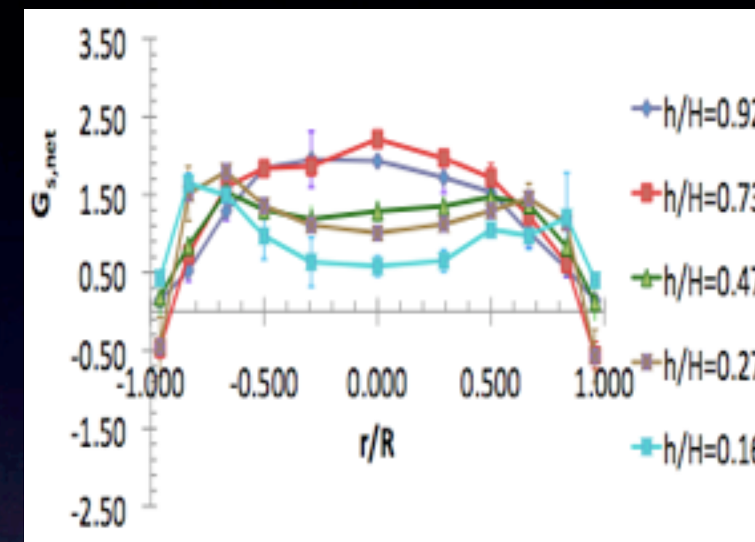
U_o=15m/s, G_s=50kg/m^{2}s

Upflow annulus

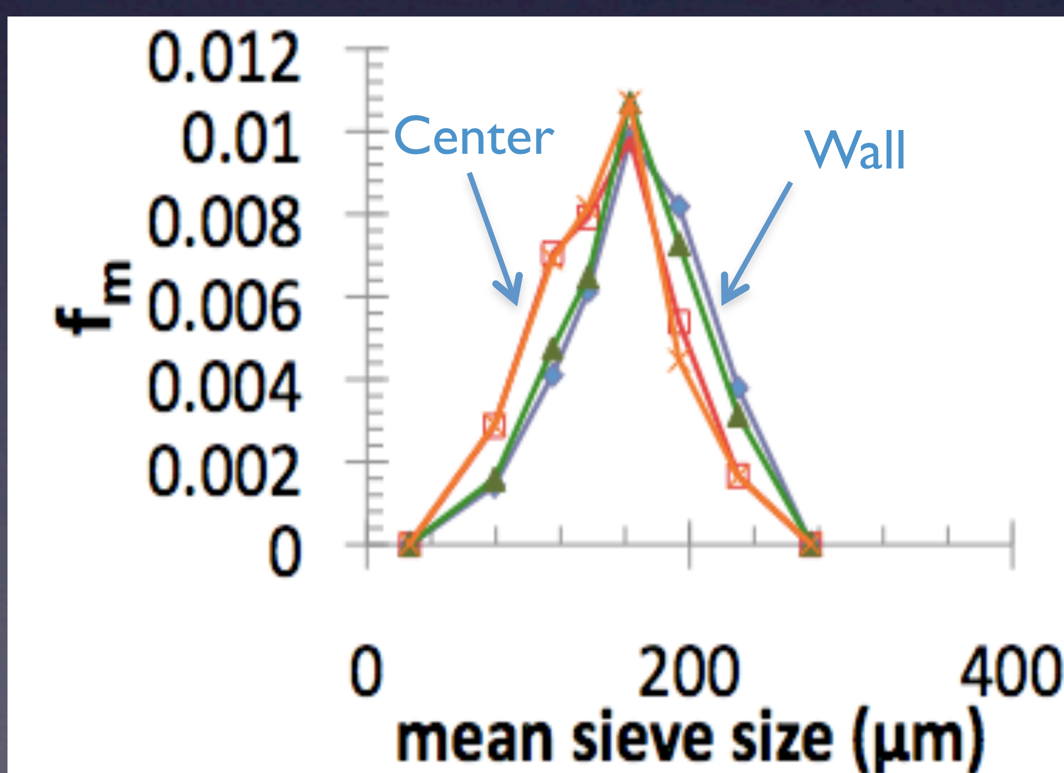


U_o=15m/s, G_s=300kg/m^{2}s

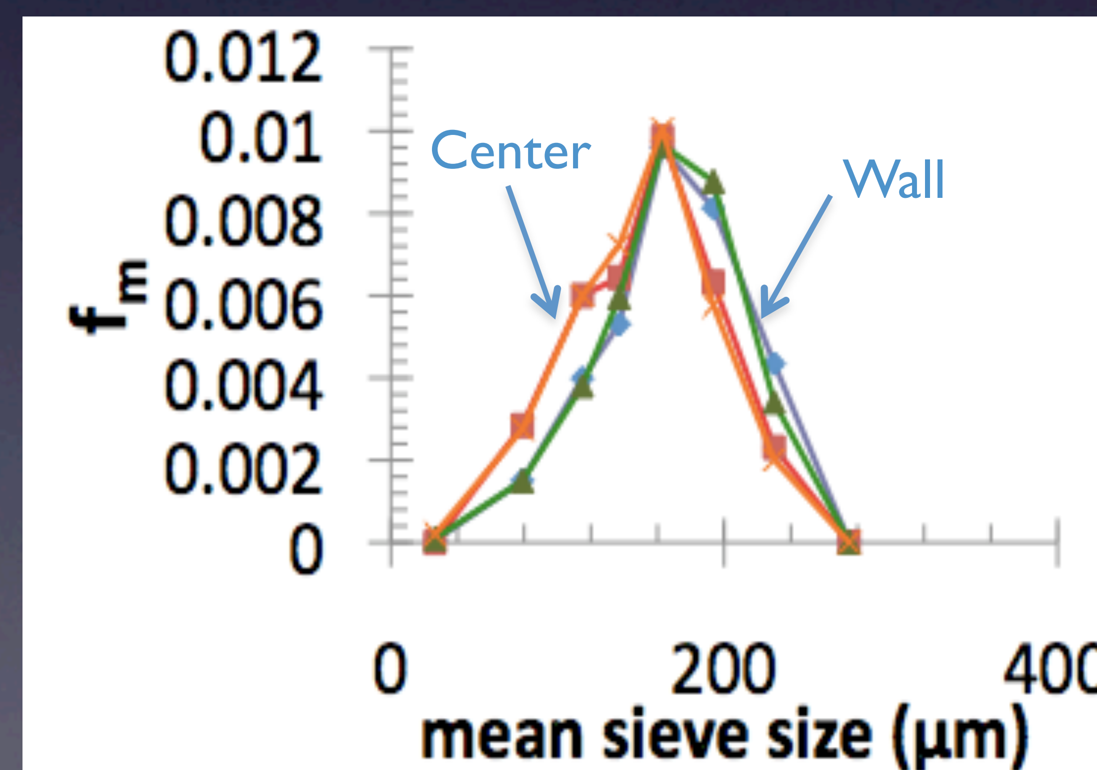
Upflow/Downflow annulus



Upflow Annulus, h/H=0.27



Downflow Annulus, h/H=0.73



Overview

- Downflow (dilute core-dense annulus)
  - Radial segregation of larger particles to the wall
  - In agreement with previous results
- Upflow (dilute core-dense annulus)
  - Radial segregation of larger particles to the wall
  - Not in agreement with previous results
    - Radial segregation consistently observed

Conclusions

- Work on the 12-inch diameter x 60-foot tall riser is completed
  - Data analysis still underway
  - Work on the 8-inch diameter x 72-foot tall riser to start in July 2010
- A reverse core-annulus profile was measured near the top of the riser for the larger/denser particles
  - May be due to exit effects with the long radius bed and rough wall surfaces
- Large particles were observed to segregate towards the wall for both the upflow and downflow in the annular region

Future Work

- Design of experiment for the 8-inch diameter x 72-foot tall riser
- Cluster analysis for existing data sets
- High speed video analysis with existing data
- Upload data sets with the 12-inch diameter x 60-foot riser to web

Acknowledgement

PSRI Staff

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- Jesus, Bobby, Jason, Gerry, Ralph
- Lucretia, Sharon

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