

The Effects of Particle Size Distributions on Riser Hydrodynamics

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Ray Cocco, Roy Hays, John Findlay, Reddy Karri, Ted Knowlton
(Particulate Solid Research, Inc.)

Frank Shaffer

(NETL)

and

Jia-Wei Chew, Christine Hrenya
(University of Colorado)



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

significant role in the design, operation, and troubleshooting of multiphase flow devices in fossil fuel processing plants. These needs include further developments in theory, experiments, computational algorithm and code development and validation. The research needs in the four tracks were then put together in an effort to identify themes that cut across the various tracks. An initial presentation on such integration was prepared by Professors Dimitri Gidaspow and Sankaran Sundaresan. They observed that the workshop identified several issues that cut across the four tracks, which can be grouped into four categories:

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

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 ...

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

- for the micro/meso/macroscale picture that is emerging from studies at these different scales.
6. Develop software framework that allows multiple codes (open-source and commercial) to work together.
7. Solve numerical issues with the treatment of PSD (e.g., DQMOM).

1. Develop continuum descriptions of dense particulate systems (See Table 1.3).
2. Handle the transition from regimes in which the particles are in enduring contact to regimes in which the particles are in collisional contact.
3. Develop methods to model adsorption/desorption and heterogeneous chemical reactions.
4. Determine the significance of electrostatic forces and van der Waals (cohesive) forces on hydrodynamics and develop appropriate models.
5. Develop the theory to model

1. Model particle deposition and re-suspension, which includes the effect of particle size distribution.
2. Model particle attrition and agglomeration, and fragmentation of coal.
3. Account for particle dispersion in solid-fuel injectors and gasifiers. We need to simultaneously account for particle dispersion as well as fluctuating kinetic energy.
4. Determine the significance of gas emanation from particles (via chemical reactions) on overall hydrodynamics and develop appropriate models.

1. simultaneously measure the velocity and volume fraction of different phases. Planar flow field, rather than point-to-point traverses, is required (e.g., measure radial solids concentration in riser using MBI).
3. Develop experimental techniques for gaining information from deep into opaque multiphase mixtures.
4. Measurements of near wall phenomena to establish wall boundary conditions.
5. Small-scale experiments to provide data to check sub-models simultaneously in gas-solids flows and gas and solid
6. Develop standard experiments of simulations (CFD or lattice Boltzmann) combination of a custom drag given powder

Measure spatial variation of PSD

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Workshop on Multiphase Flow Research, June 6-7, 2006

Near-Term (by 2009)	Mid-Term (by 2012)	Long-Term (by 2015)

Train adequate number of graduate students in this area

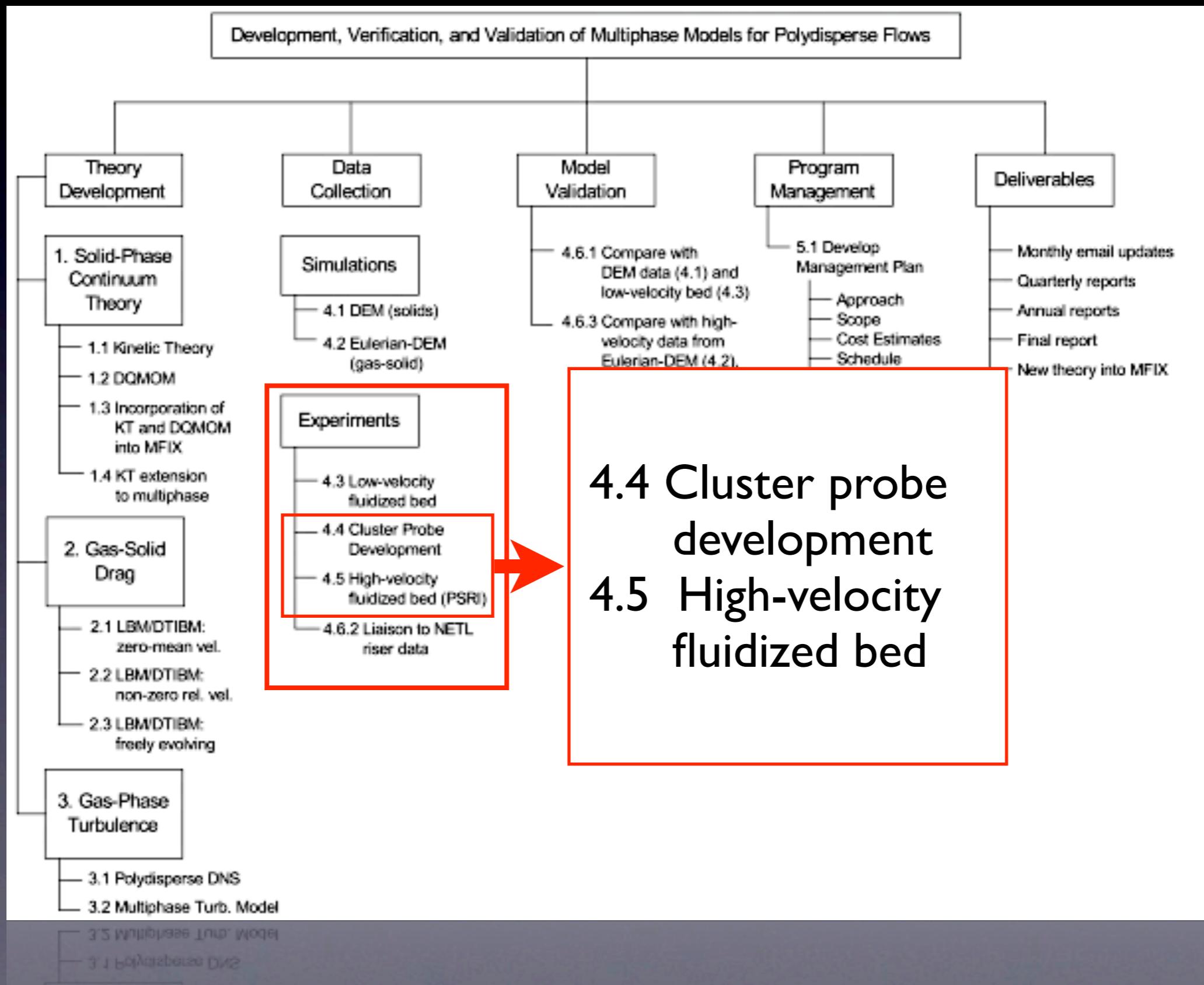
6. Model flow regime transitions in gas-liquid flows; e.g., the transition in a bubble column from "bubbly" to "churn-turbulent" regime.
7. Develop radiation model for particle-particle and particle-wall heat transfer.
8. Develop constitutive models for non-spherical particles.
9. Develop multiphase turbulence models that incorporate fluctuations in the volume fraction.
10. Consider the effect of lubrication forces in particle-particle interactions.

1. Constitute a task force to define benchmark gas-liquid and liquid-solids problems, which will guide CFD model development and experimental work.
2. Establish a communications network for the multiphase research community, which may include newsletter, web page, and regularly scheduled seminars and workshops.
3. Education: Develop curriculum for modular university courses; train adequate number of graduate students in this area; develop on-line instructional modules.

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

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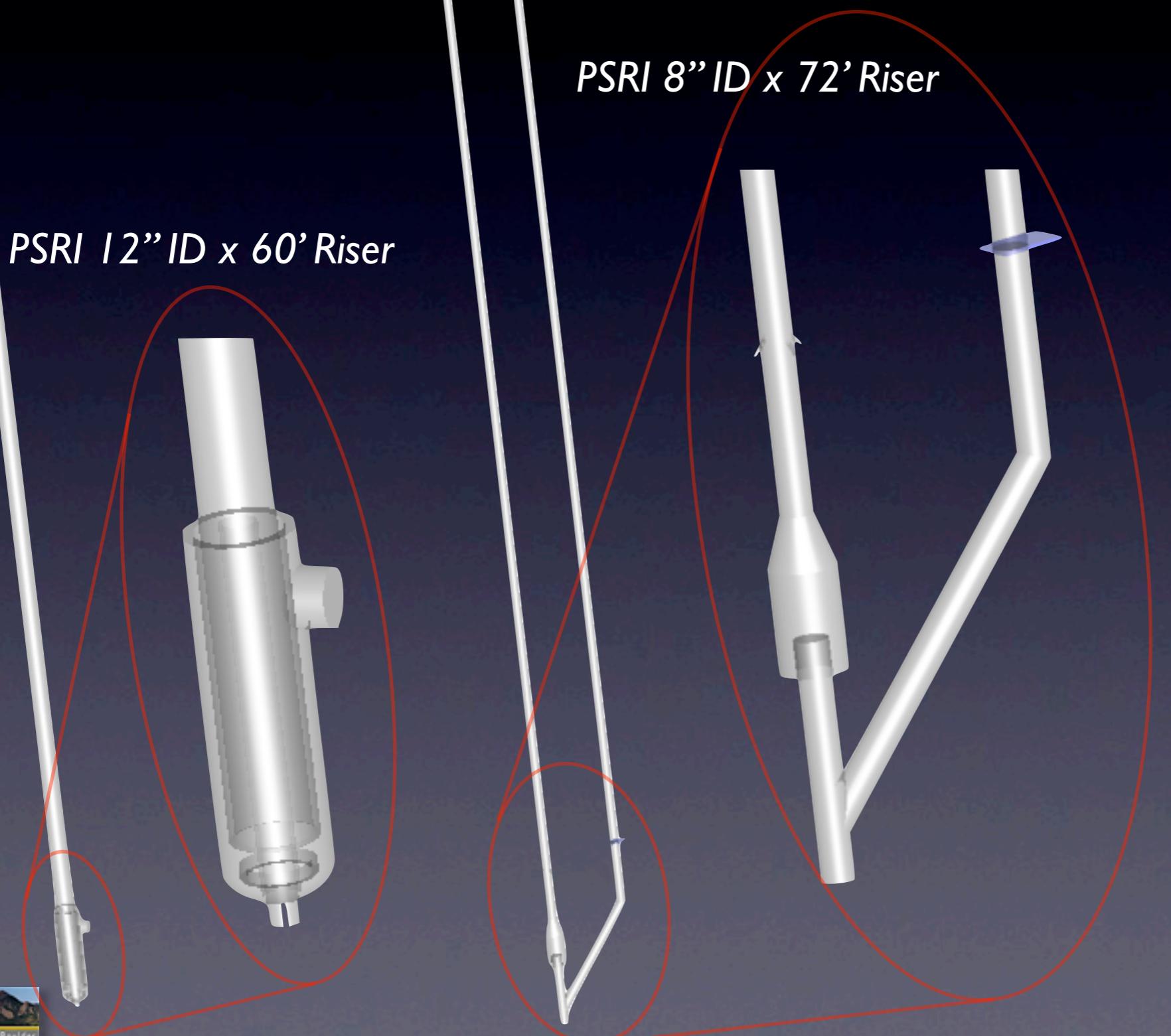
Project Scope



Objectives

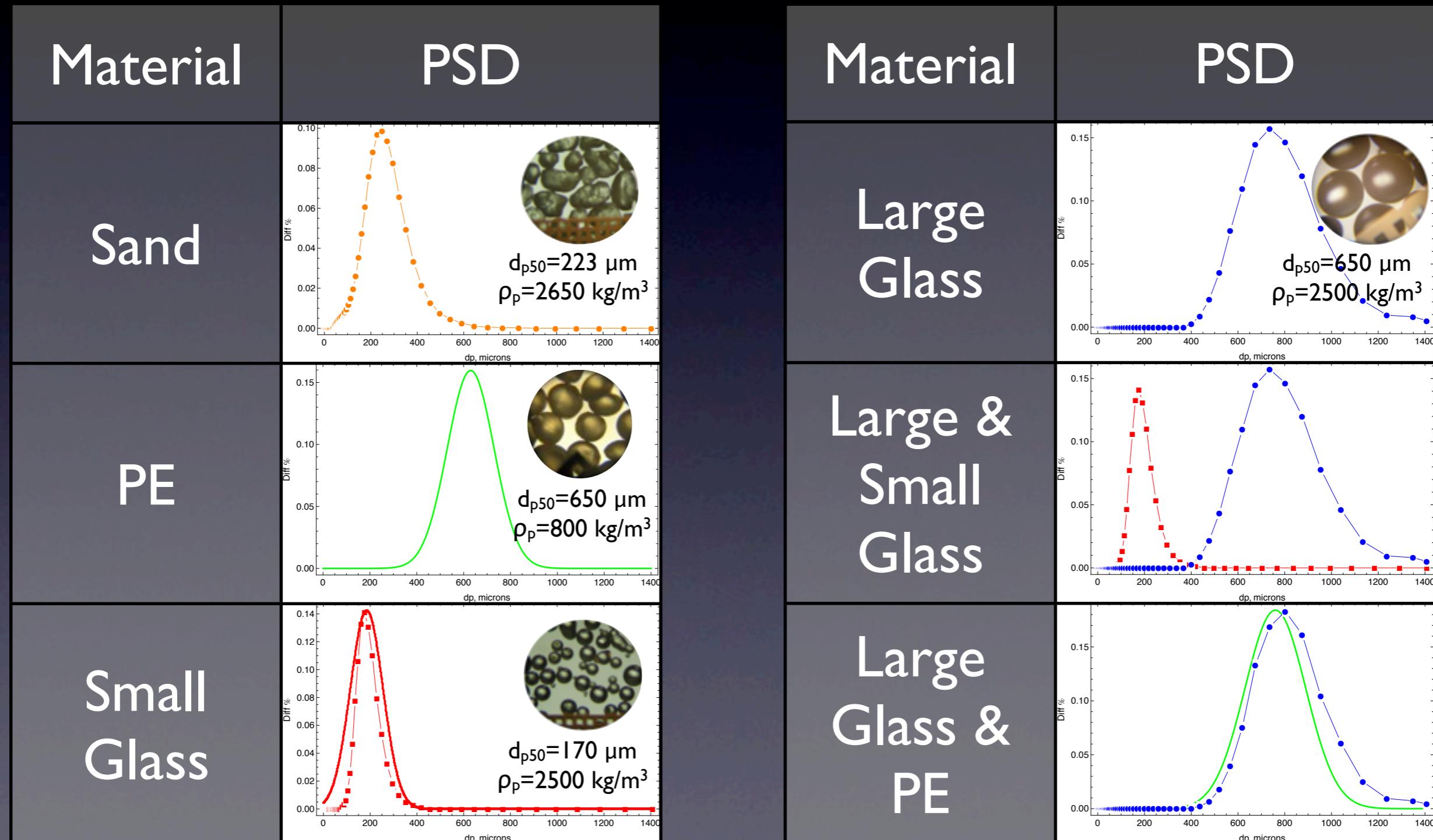
- Provide extensive riser data for on-going modeling efforts
 - PSRI challenge problems (Past)
 - NETL riser data (Past and Present)
 - This effort (Present)
- Examine the role of particle segregation and particle clusters in riser hydrodynamics

Equipment



*Risers have been
designed to provide
symmetric profiles*

Particle Size Distributions



Materials of Interest

HDPE

$$d_{ave} = 650 \text{ } \mu\text{m}$$

$$\rho_p = 900 \text{ kg/m}^3$$

Glass

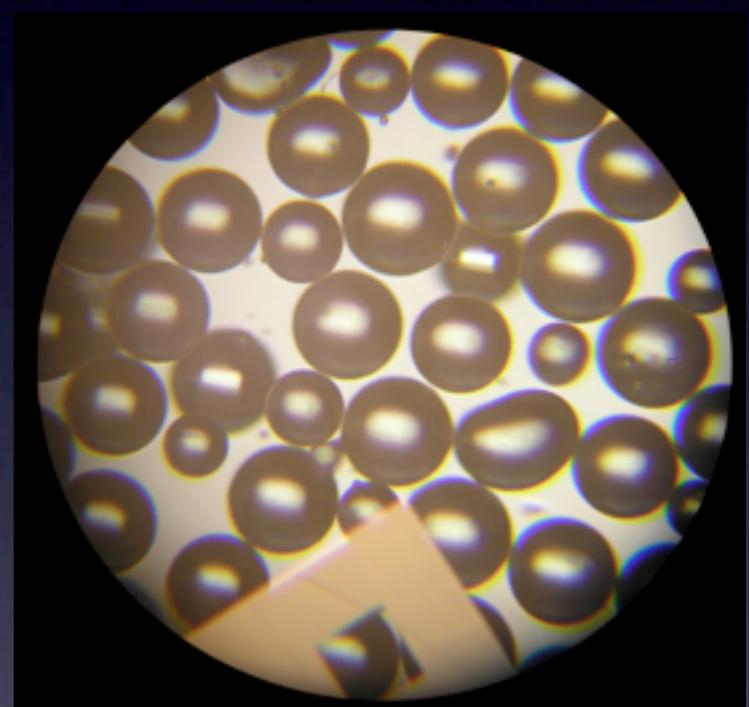
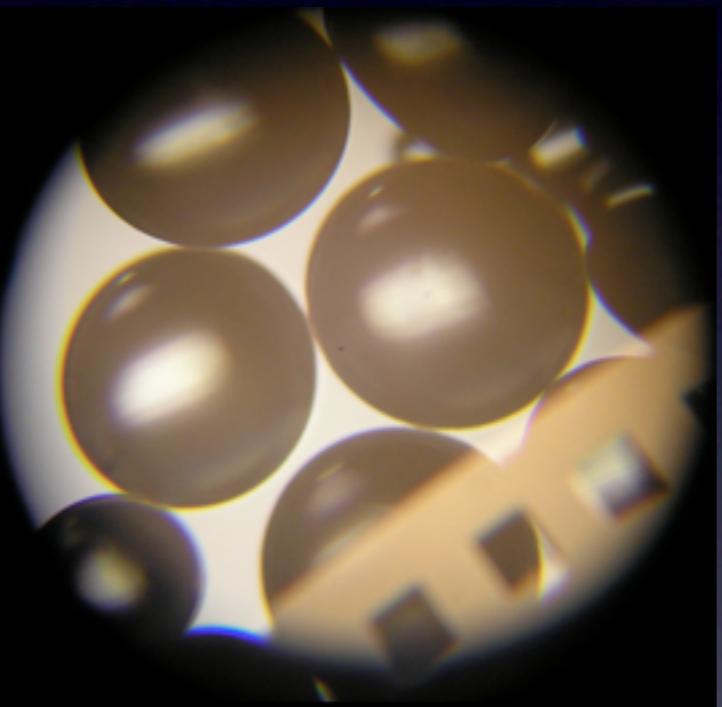
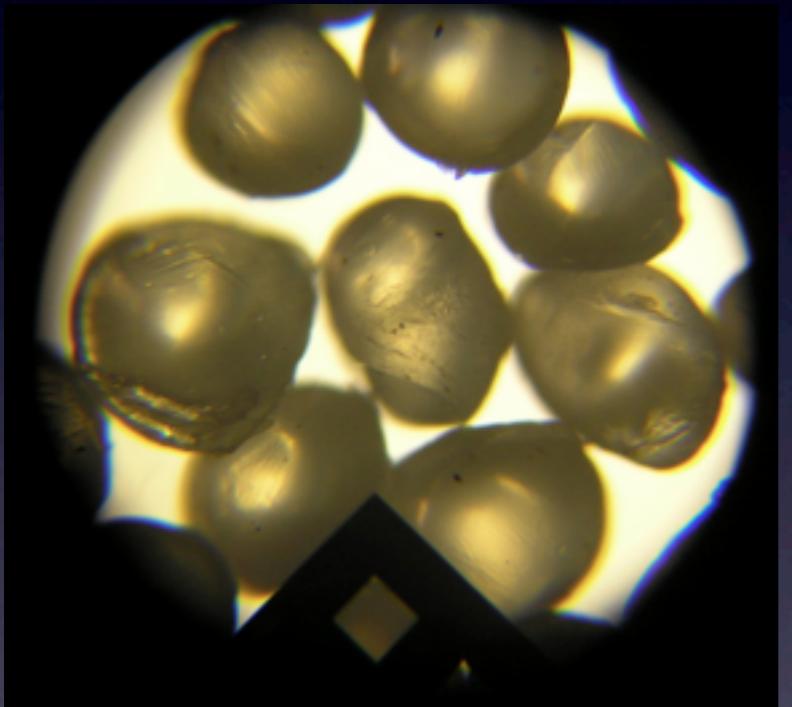
$$d_{ave} = 650 \text{ } \mu\text{m}$$

$$\rho_p = 2500 \text{ kg/m}^3$$

Glass

$$d_{ave} = 170 \text{ } \mu\text{m}$$

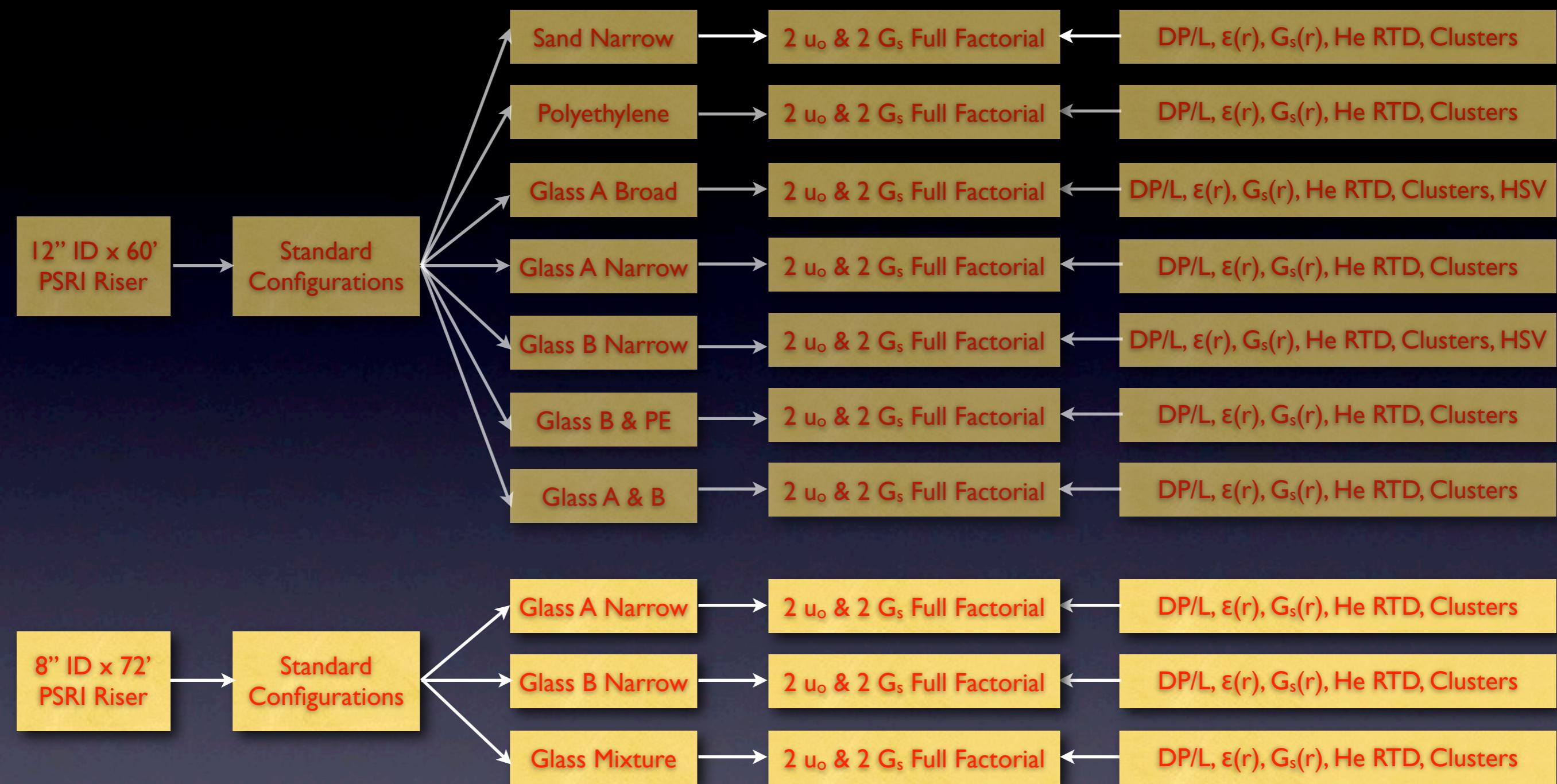
$$\rho_p = 2500 \text{ kg/m}^3$$



Density Effect

Size Effect

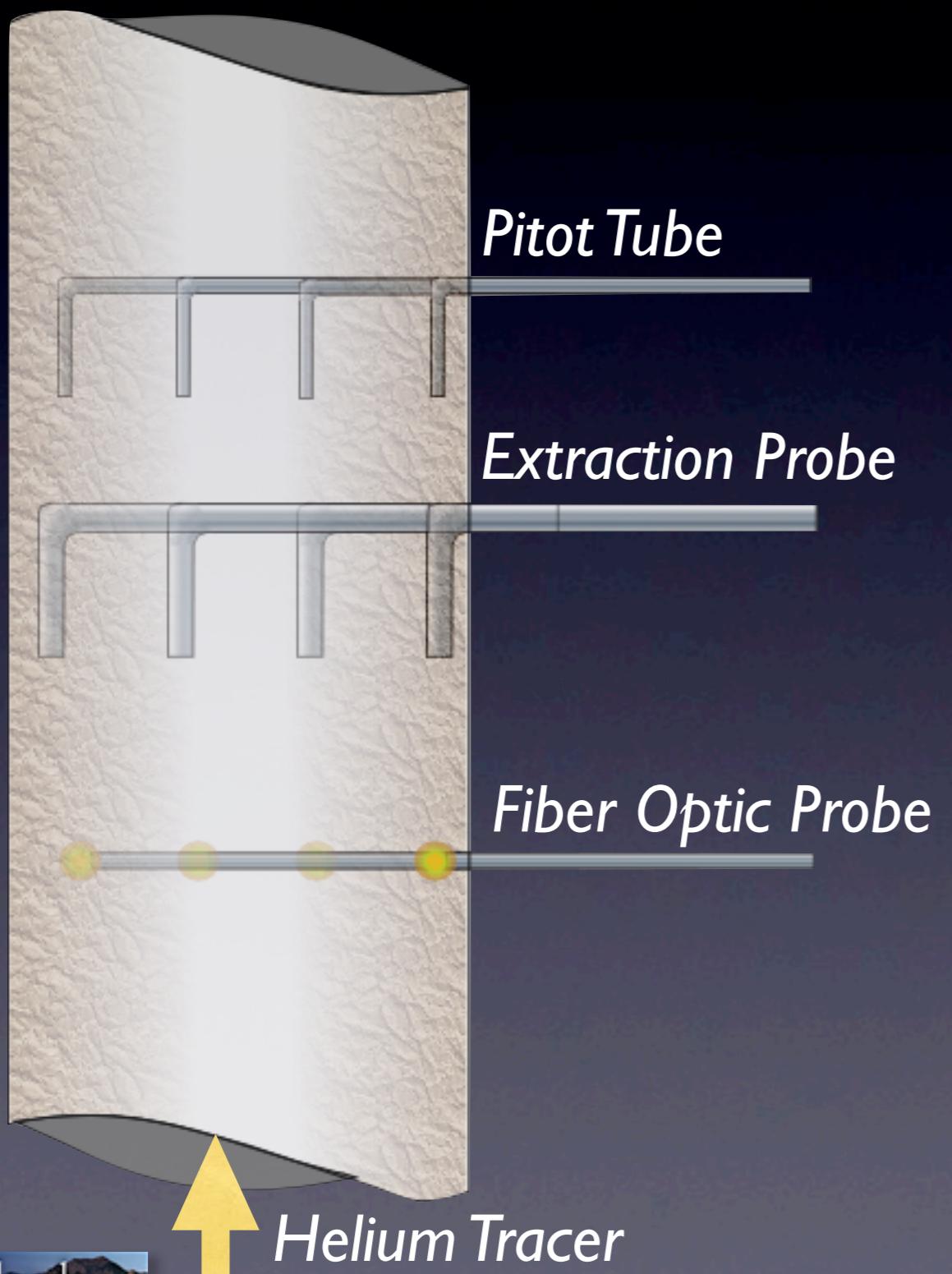
Design of Experiments



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

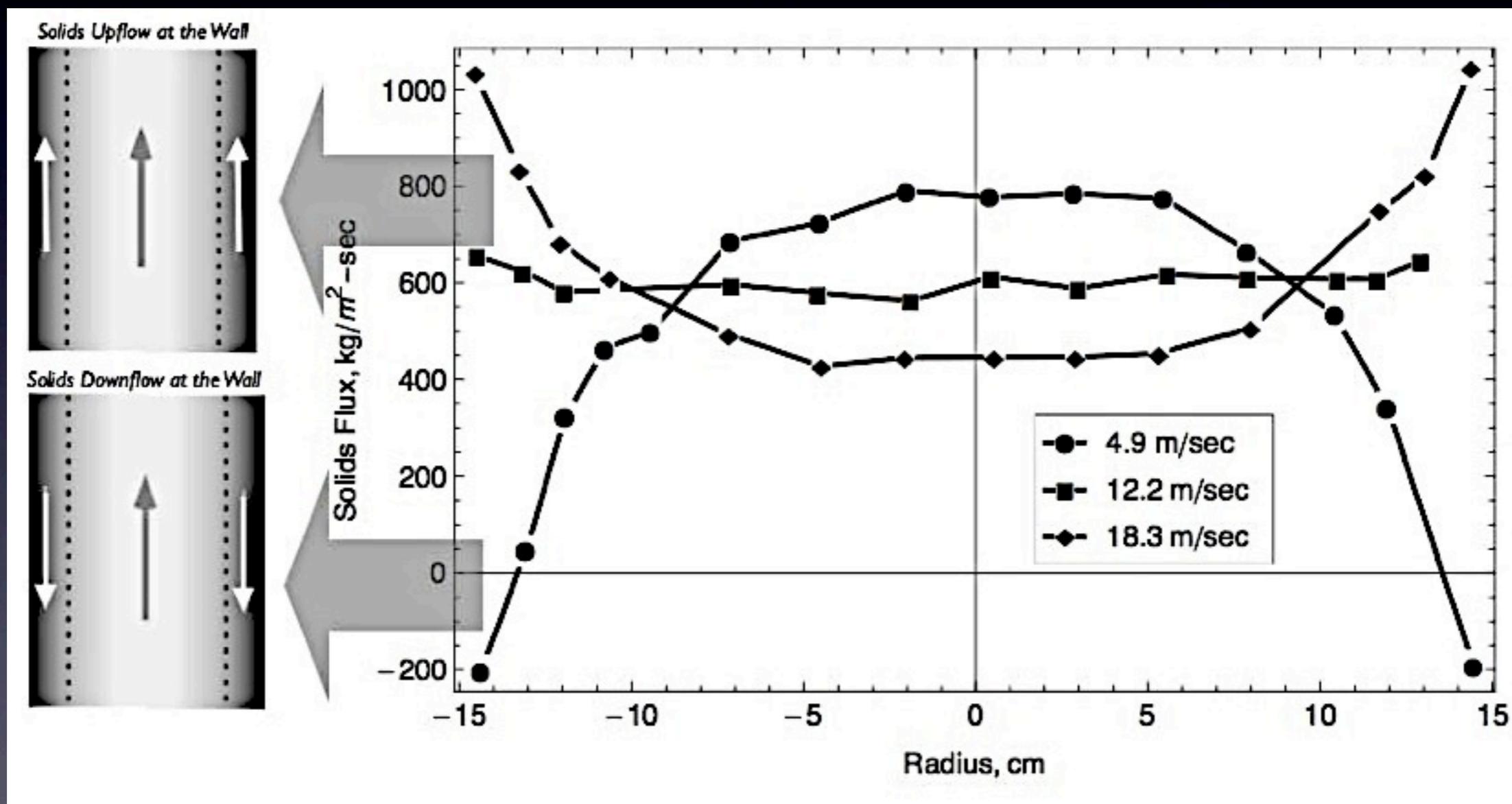
Recent Results

- 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



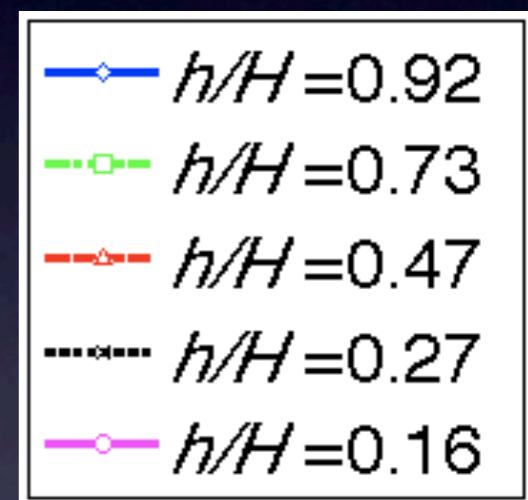
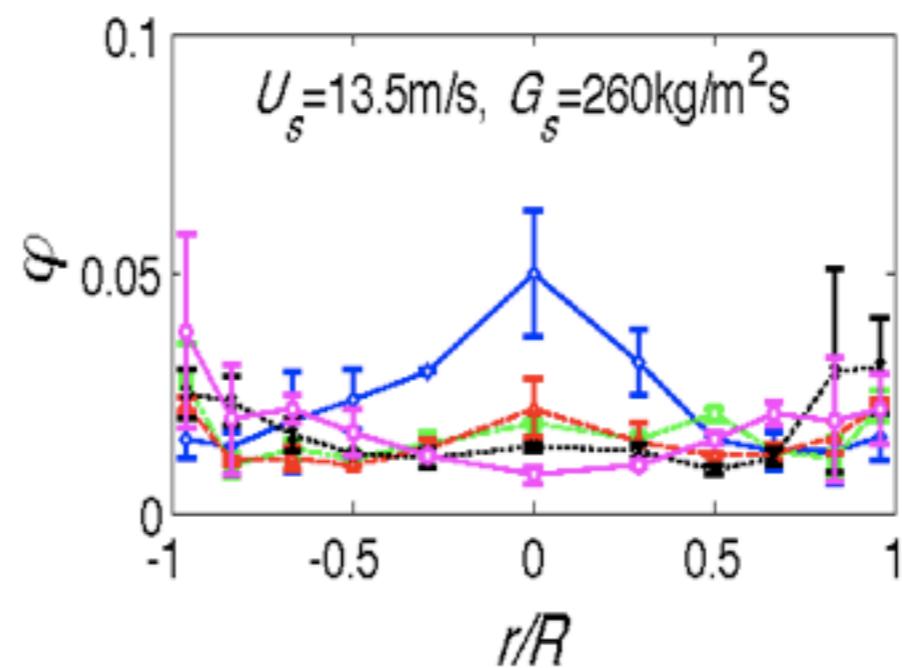
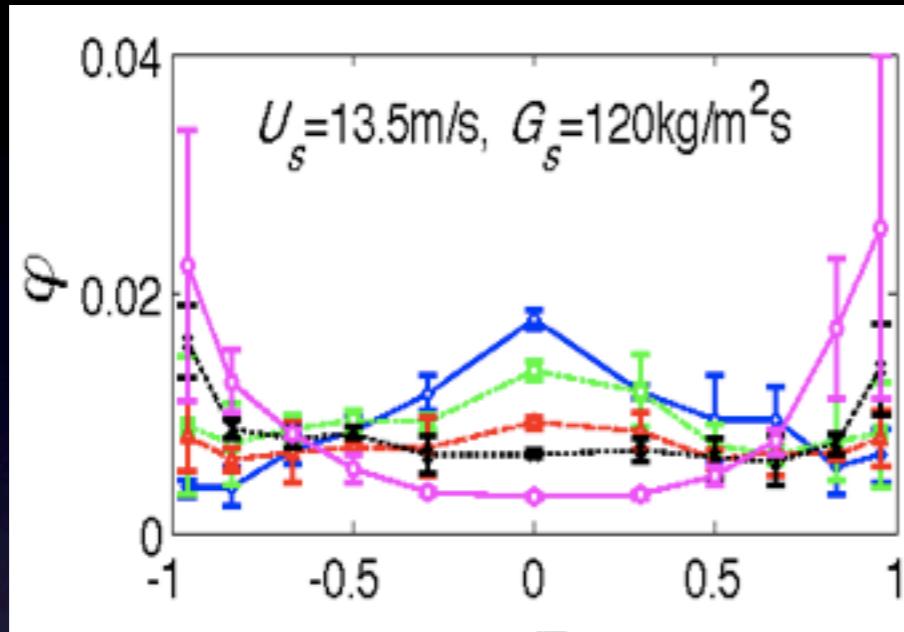
Loading Profiles with 650 μm Glass Beads



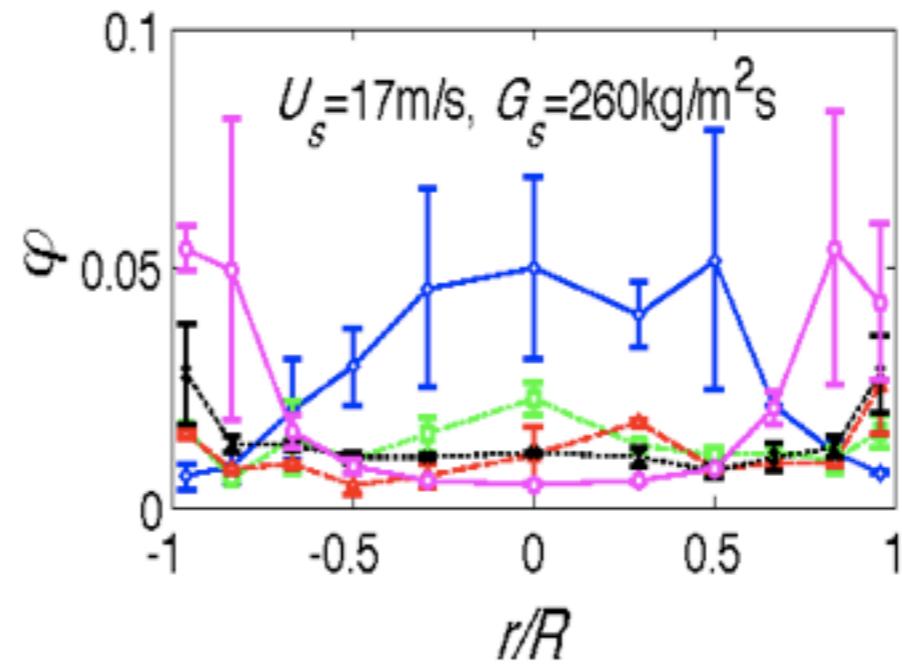
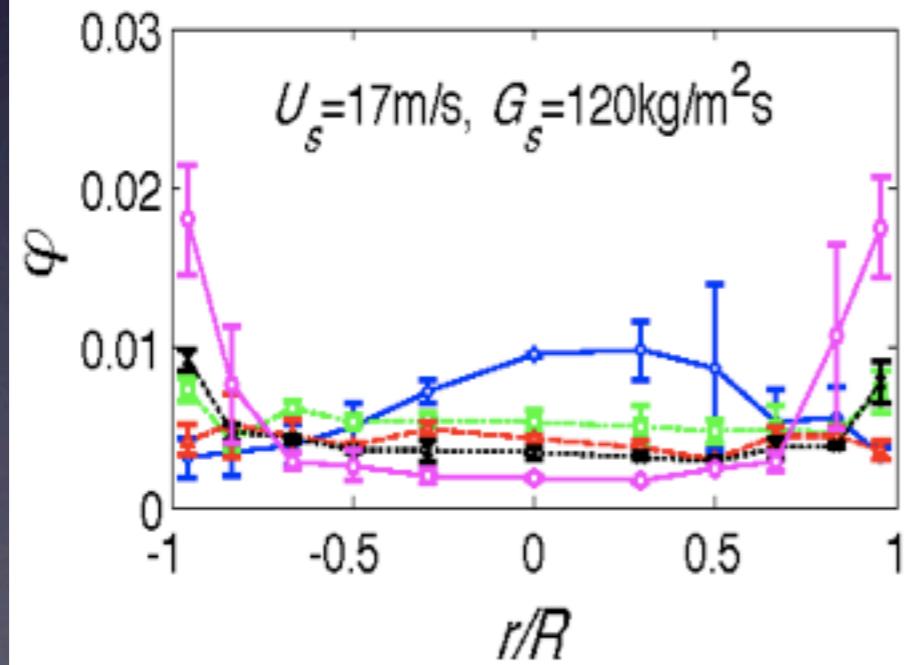
Low U_o

Low G_s

High G_s

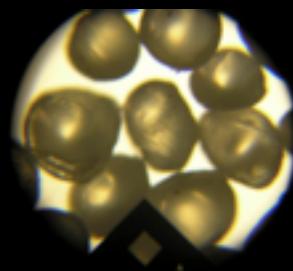


High U_o



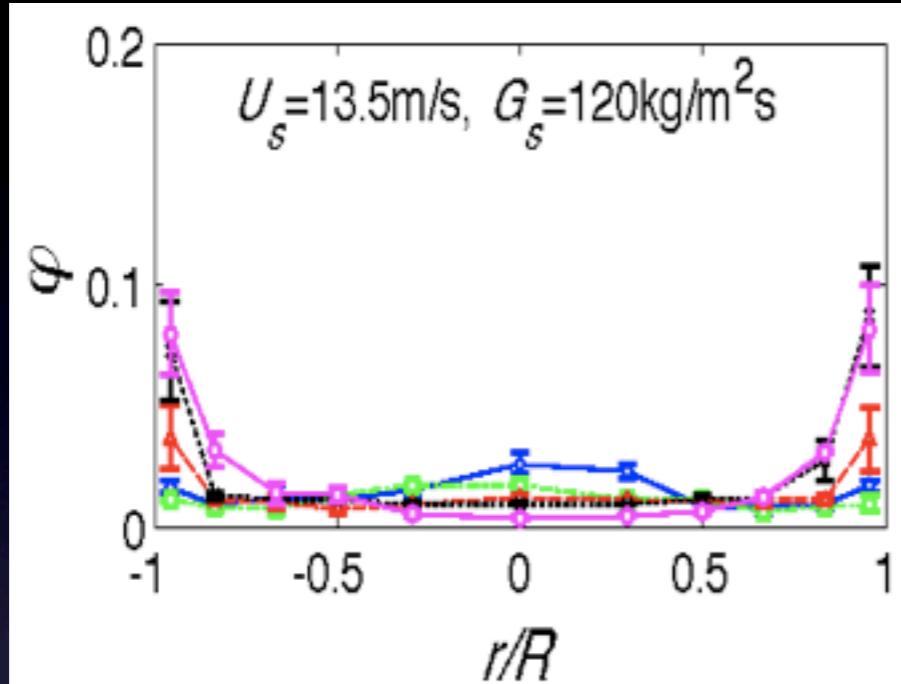
Reverse core-annulus at riser top for all conditions

Loading Profiles with $650 \mu\text{m}$ HDPE

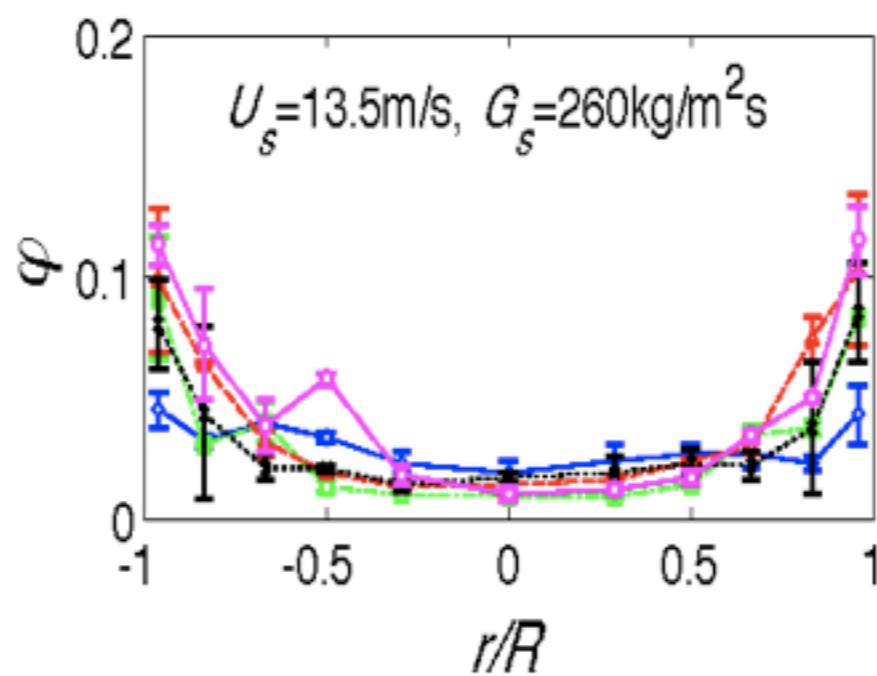


Low U_o

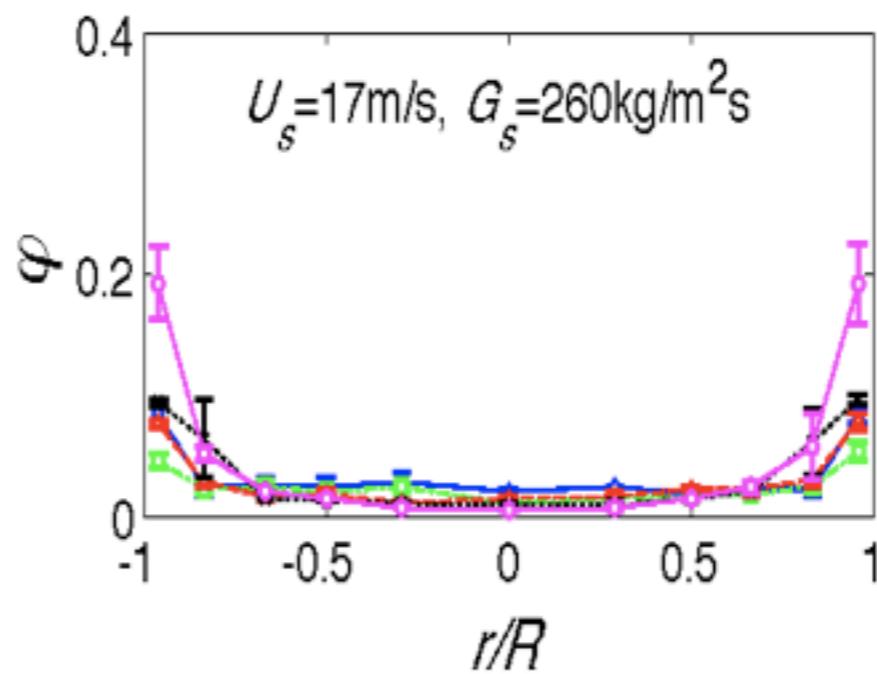
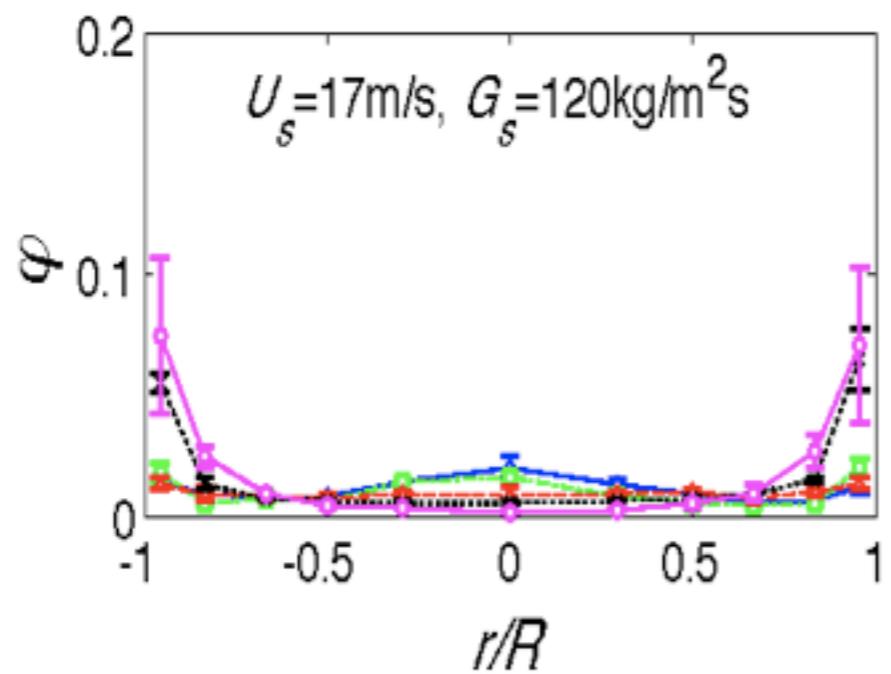
Low G_s



High G_s



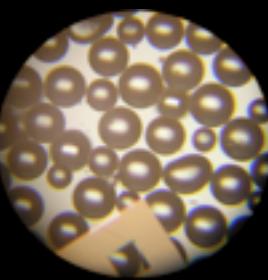
High U_o



- \diamond $h/H = 0.92$
- \square $h/H = 0.73$
- \blacktriangle $h/H = 0.47$
- \cdots $h/H = 0.27$
- \circ $h/H = 0.16$

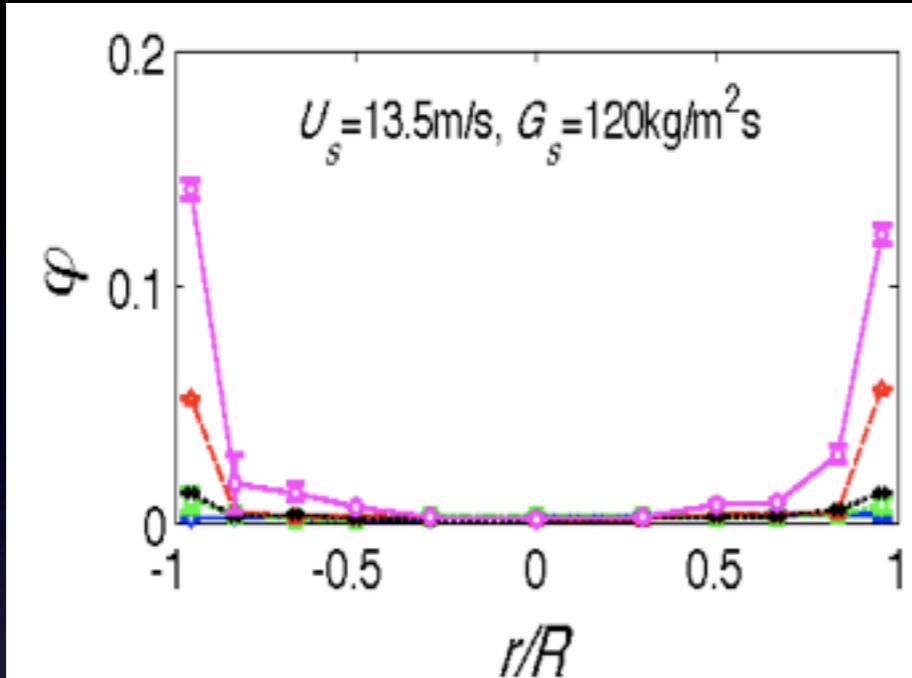
Reverse core-annulus at riser top at low G_s

Loading Profiles with 170 μm Glass Beads

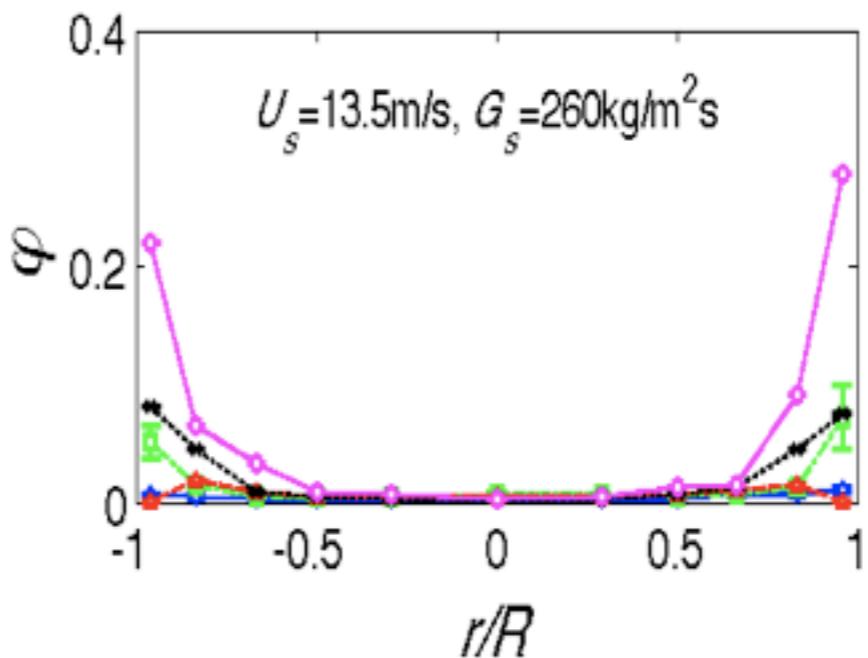


Low U_o

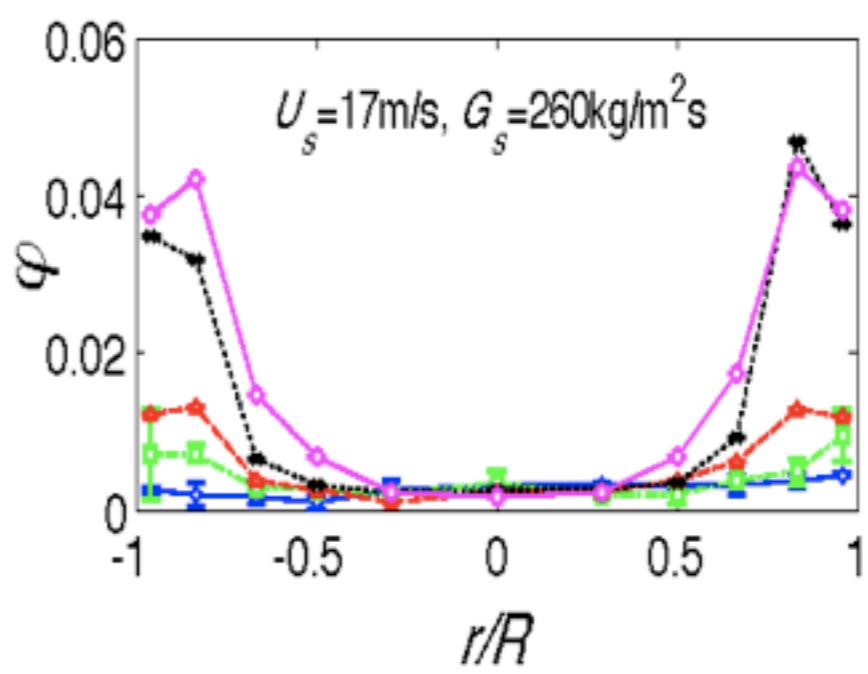
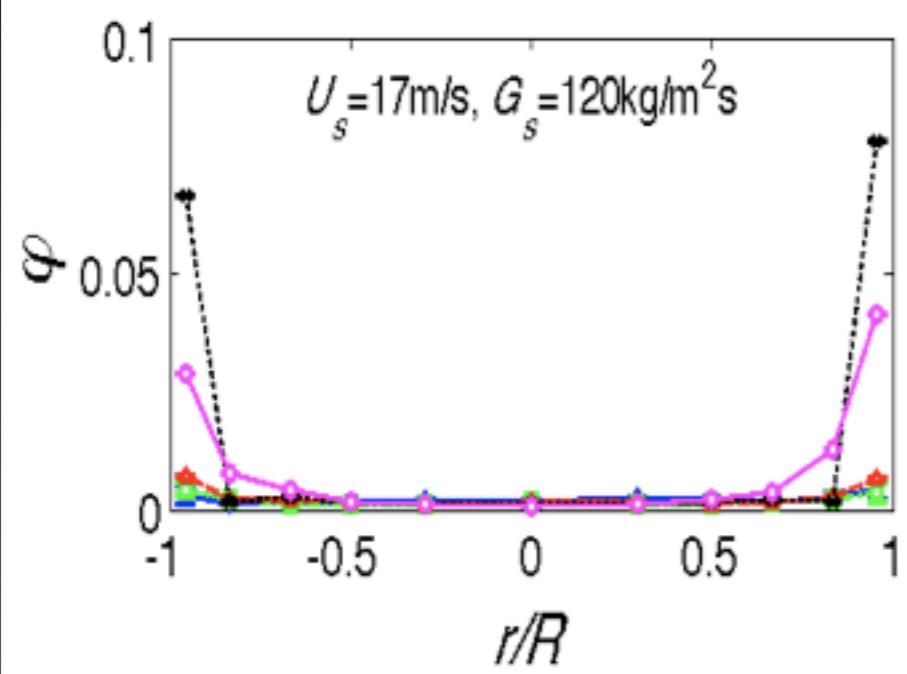
Low G_s



High G_s



High U_o

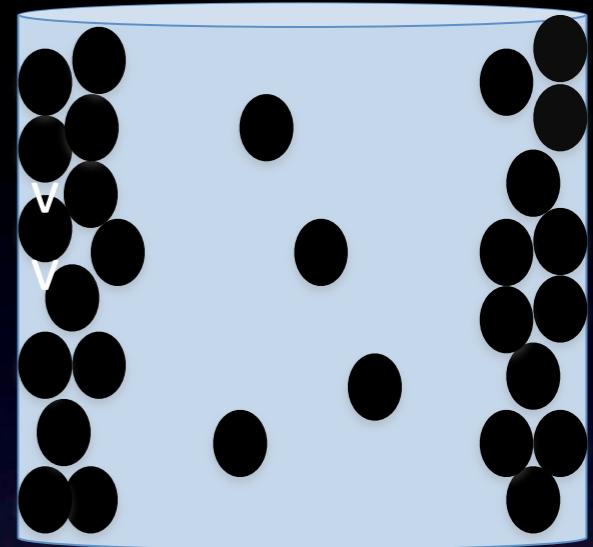


- $h/H = 0.92$
- - $h/H = 0.73$
- ▲ $h/H = 0.47$
- · - $h/H = 0.27$
- ○ - $h/H = 0.16$

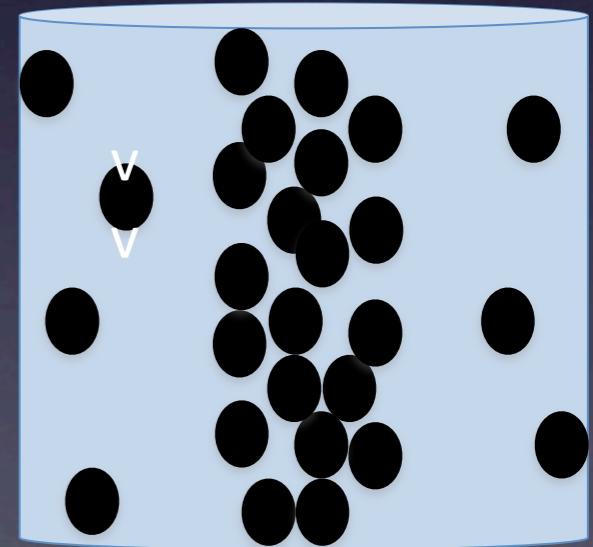
Reverse core-annulus NOT observed

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 G_s
 - 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



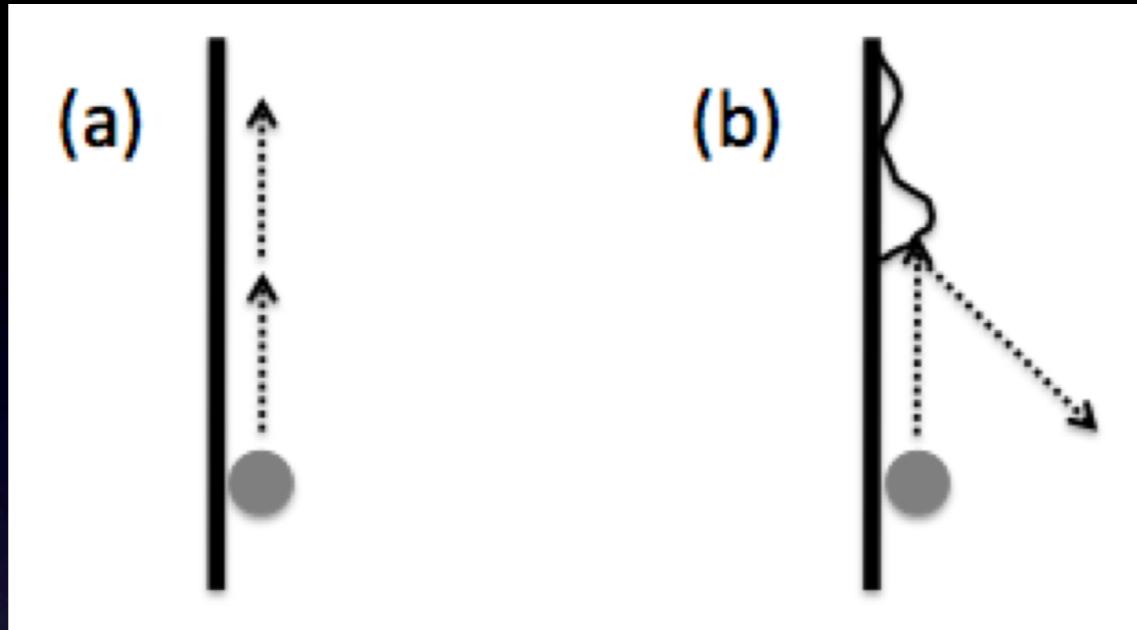
Large Glass Beads & HDPE

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



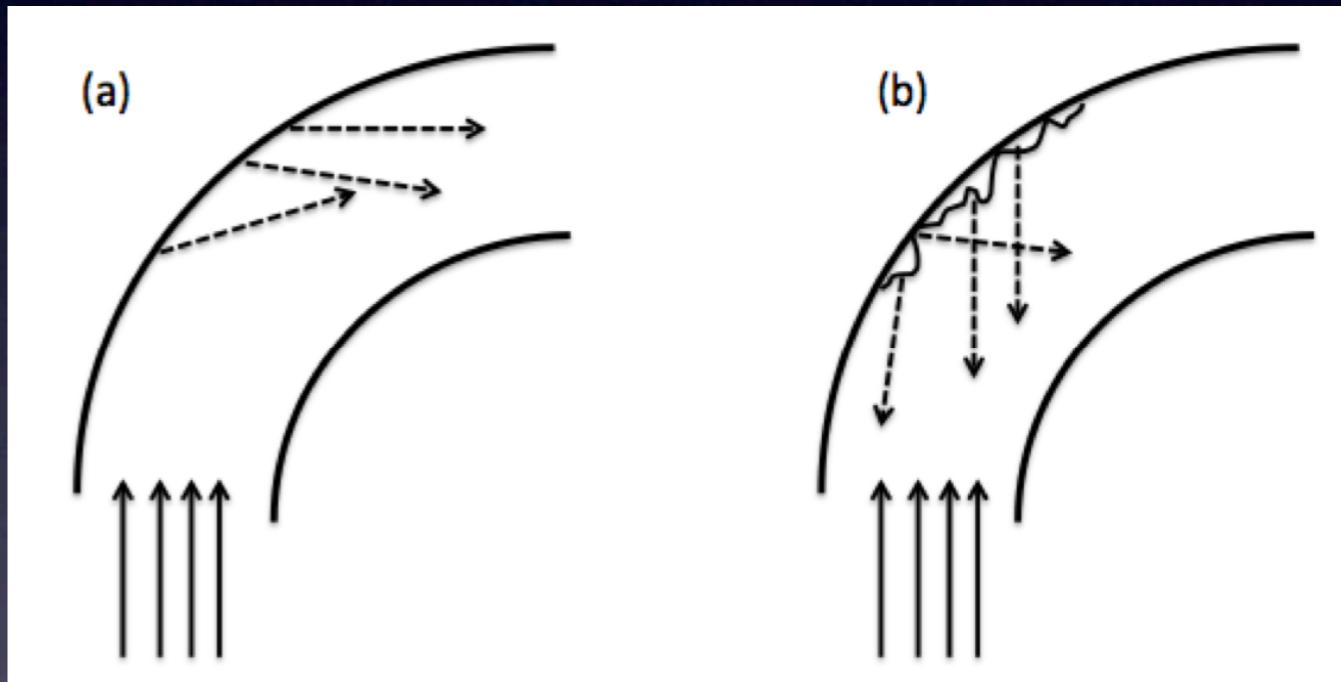
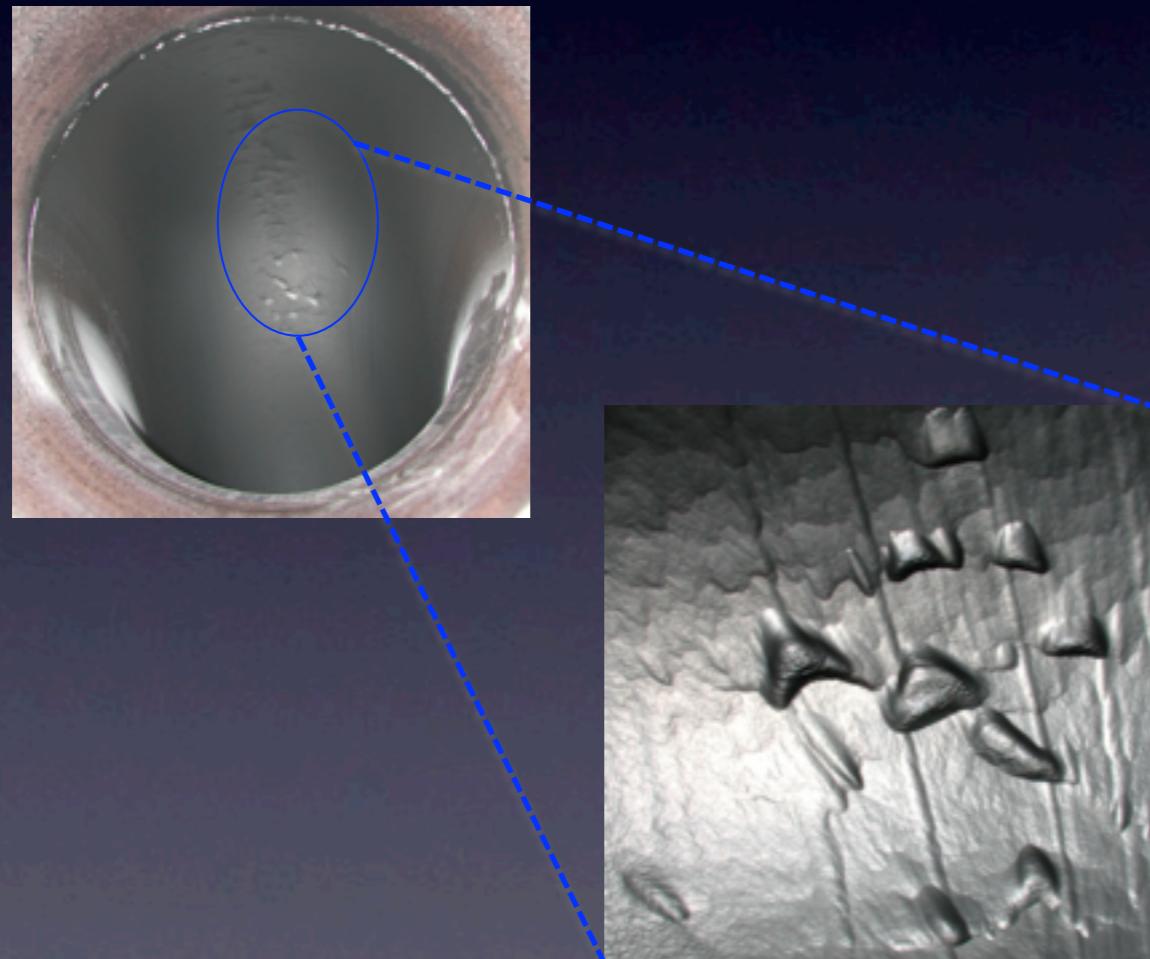
- Simulations and experiments reported
 - As wall roughness increases, loading in riser center increases
 - But, topmost measurement taken at newly-installed Plexiglas™ section → smooth wall?

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

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

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

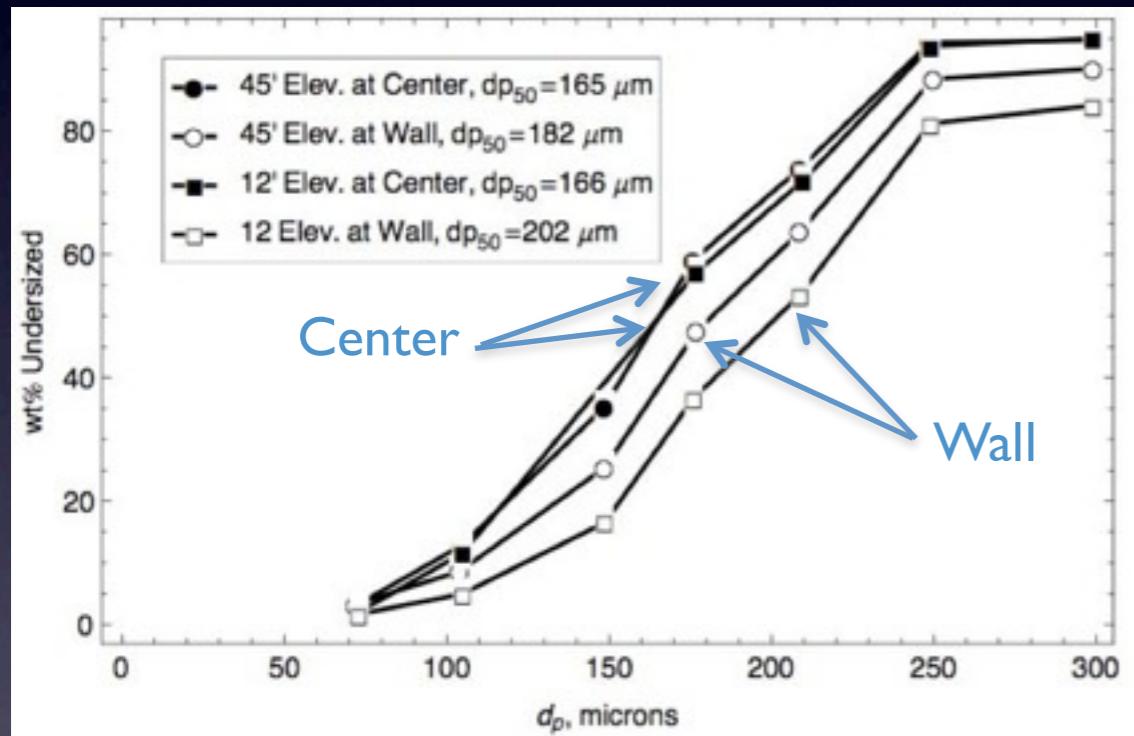
Recent Results

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

Previous Results

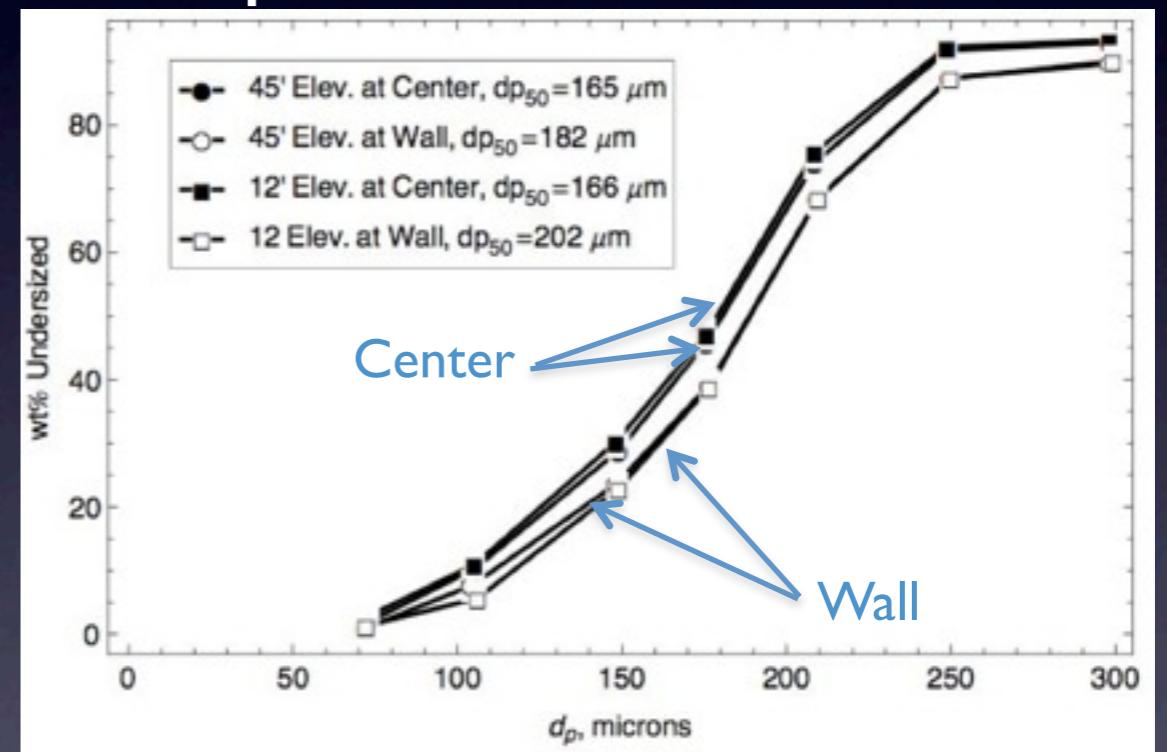
Sand in an 8-Inch Diameter x 72-Foot Tall Riser

Downflow in the Annulus



Larger Particles Segregating to the Wall

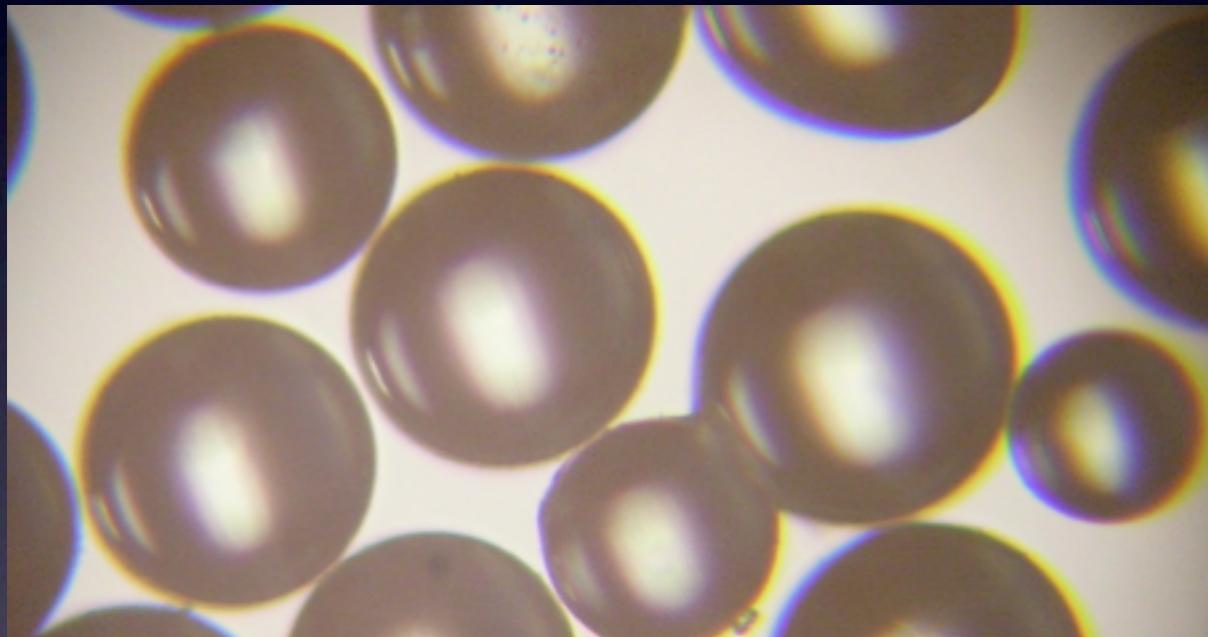
Upflow in the Annulus



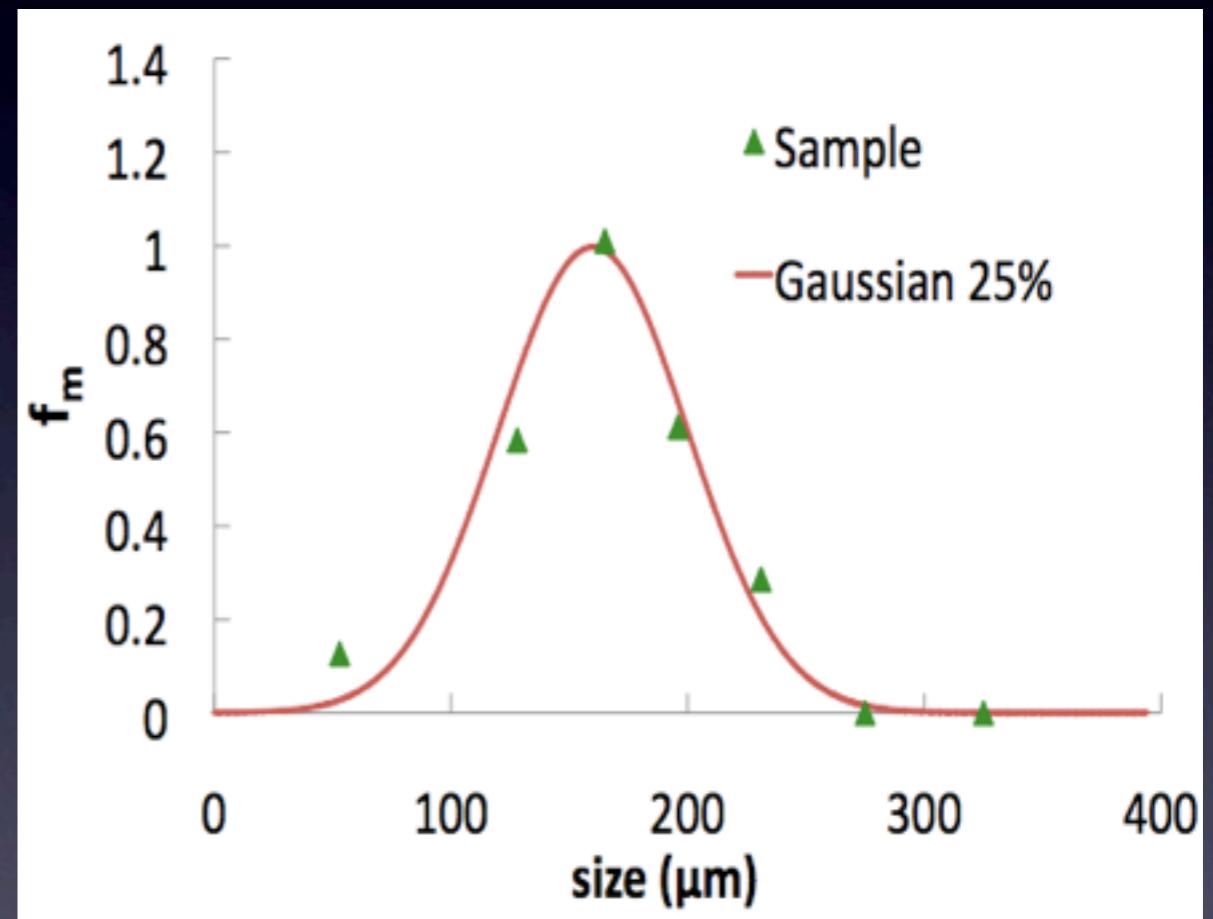
Little Segregation

Material of Interest

$\rho_p = 2500 \text{ kg/m}^3$
Sphericity = 0.95



Gaussian distribution
 $d_{p50} = 170 \mu\text{m}$, $\sigma/d_{p50} = 25\%$

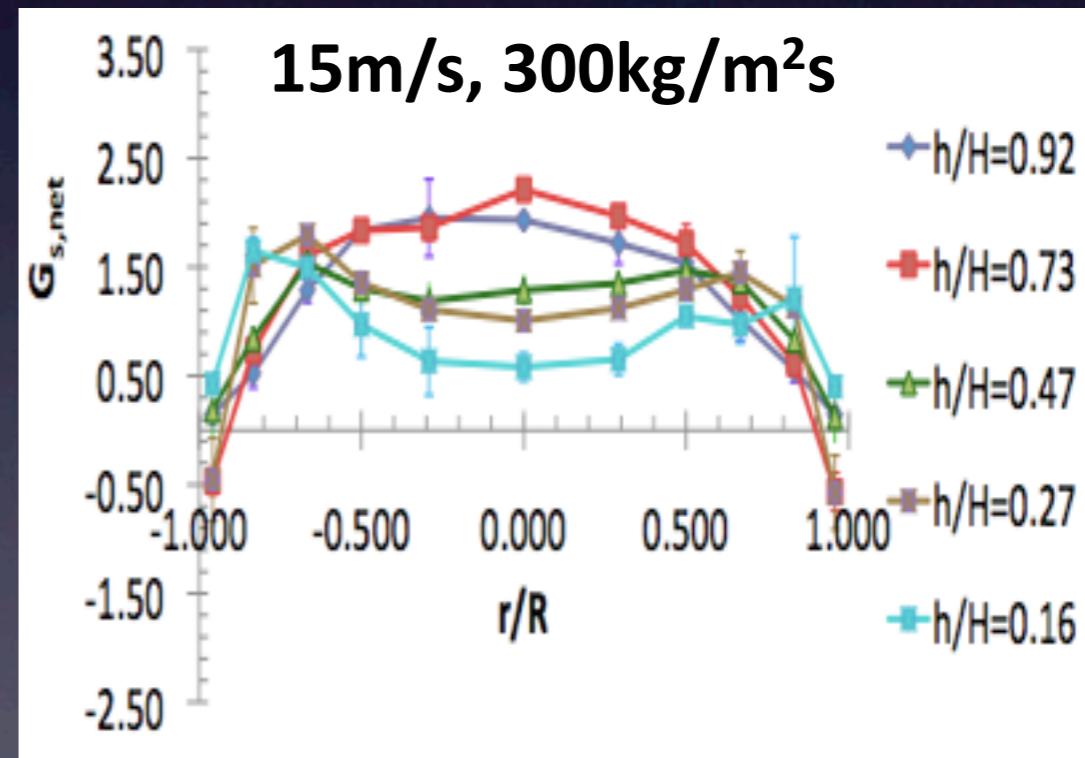
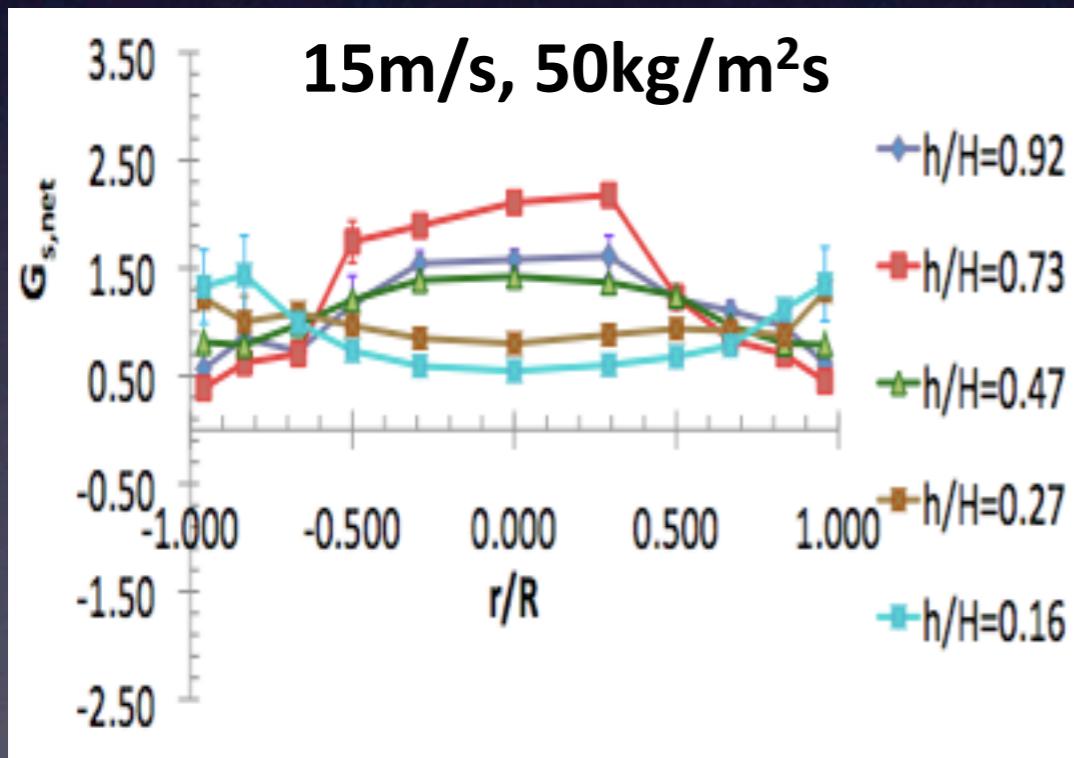
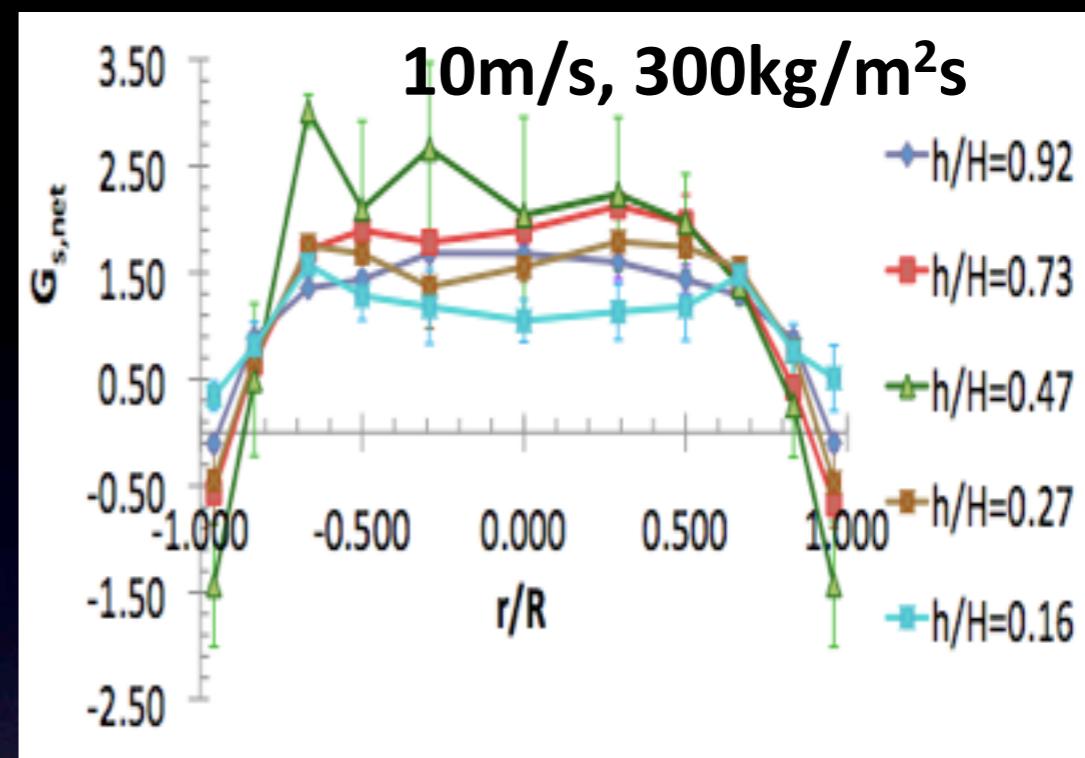
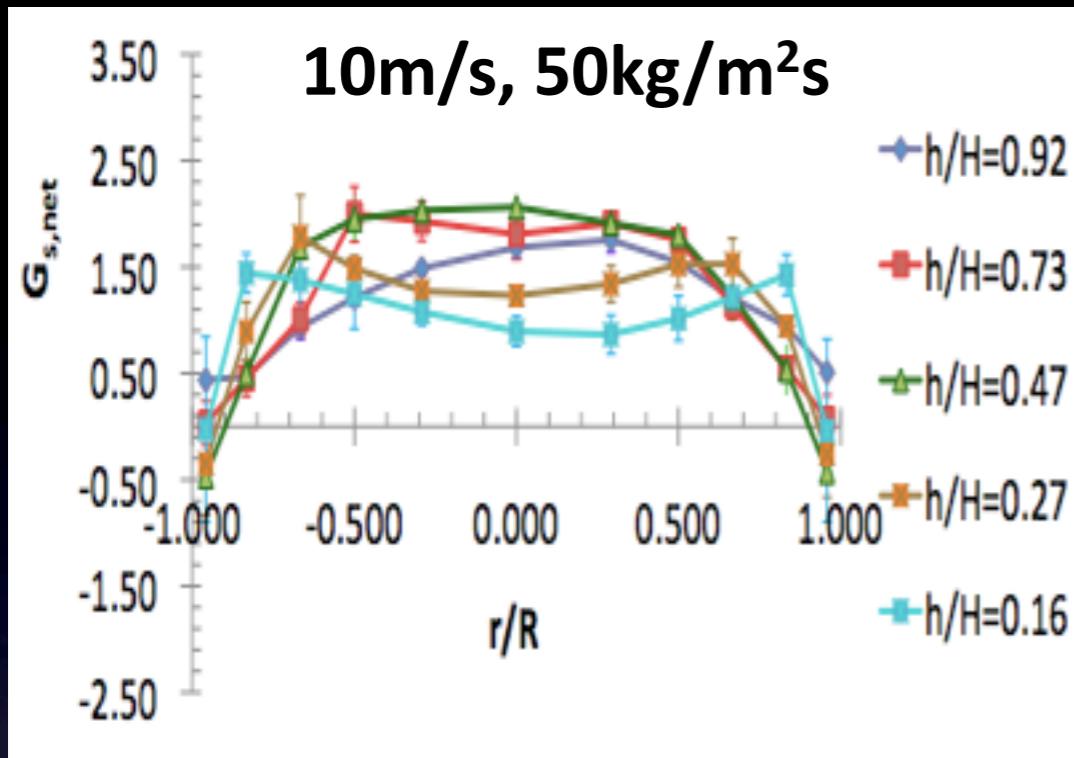


Glass Beads with Broad PSD

Test Conditions

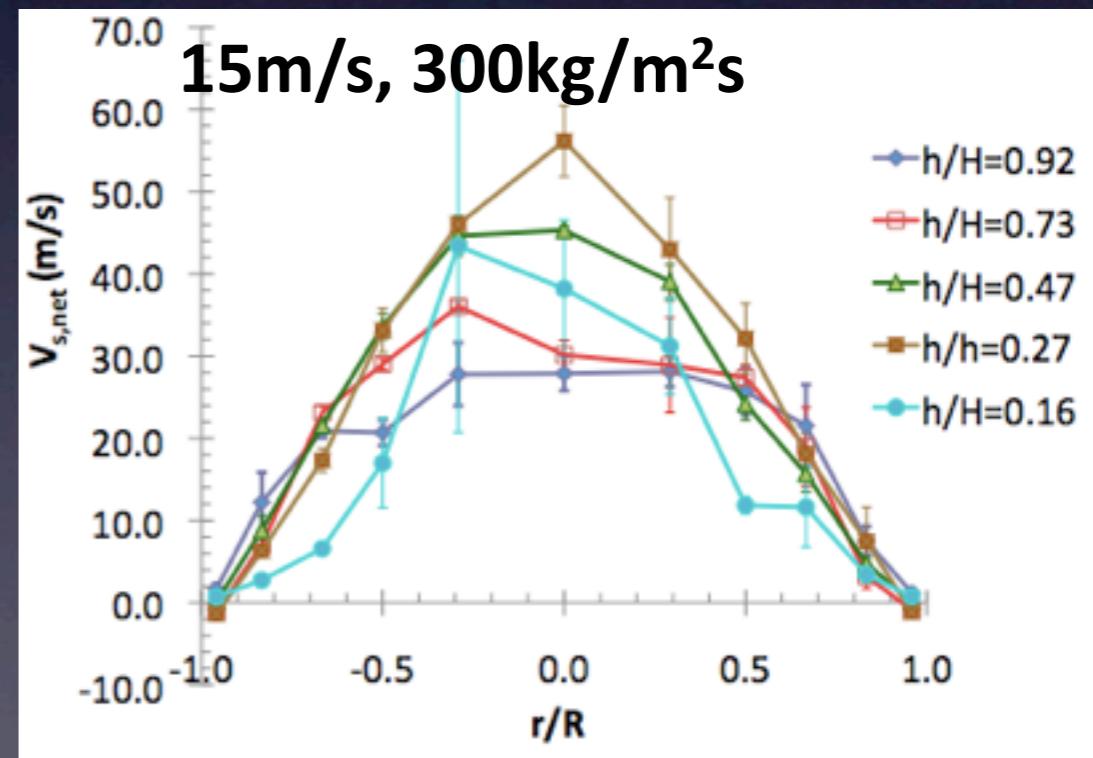
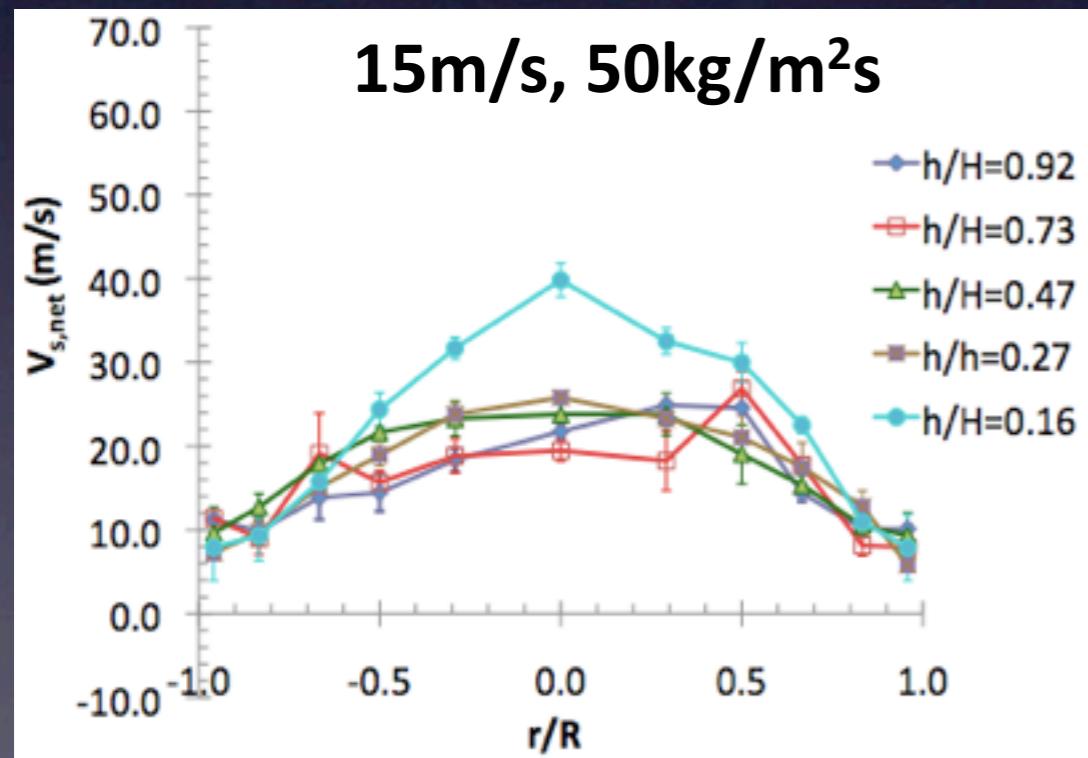
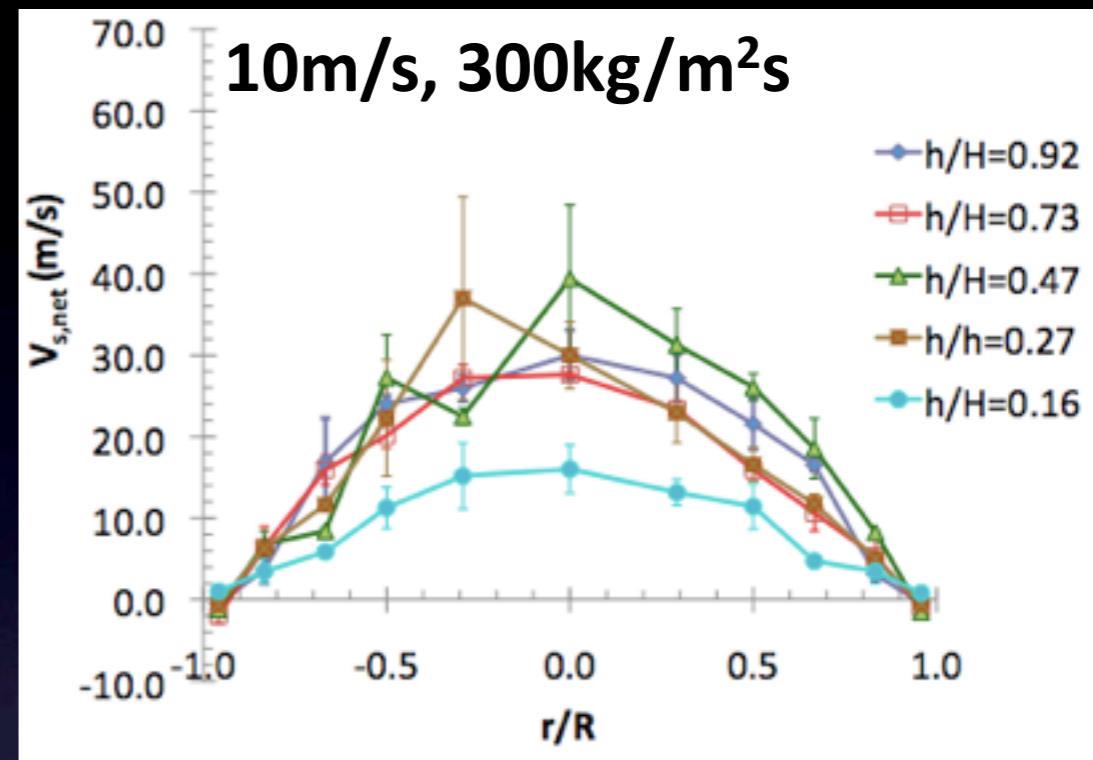
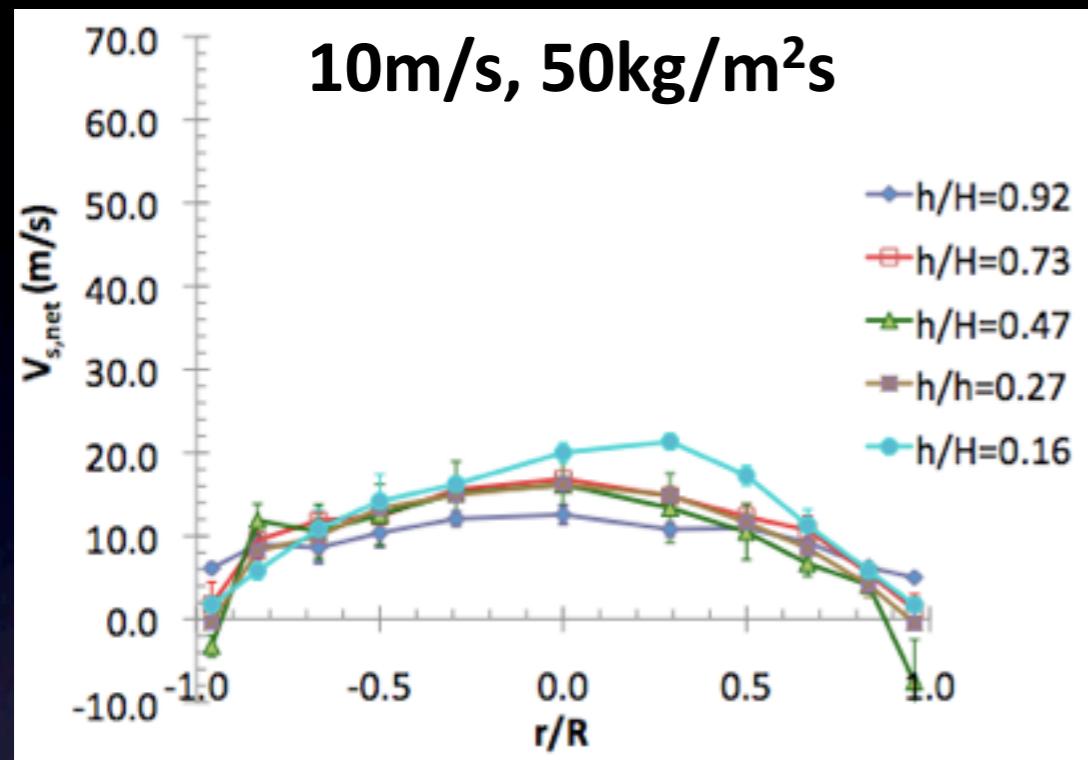
	Low Solids Flux	High Solids Flux
Low Gas Velocity	10 m/sec 50 kg/m ² -sec	10 m/sec 300 kg/m ² -sec
High Gas Velocity	15 m/sec 50 kg/m ² -sec	15 m/sec 300 kg/m ² -sec

Mass Flux Profiles

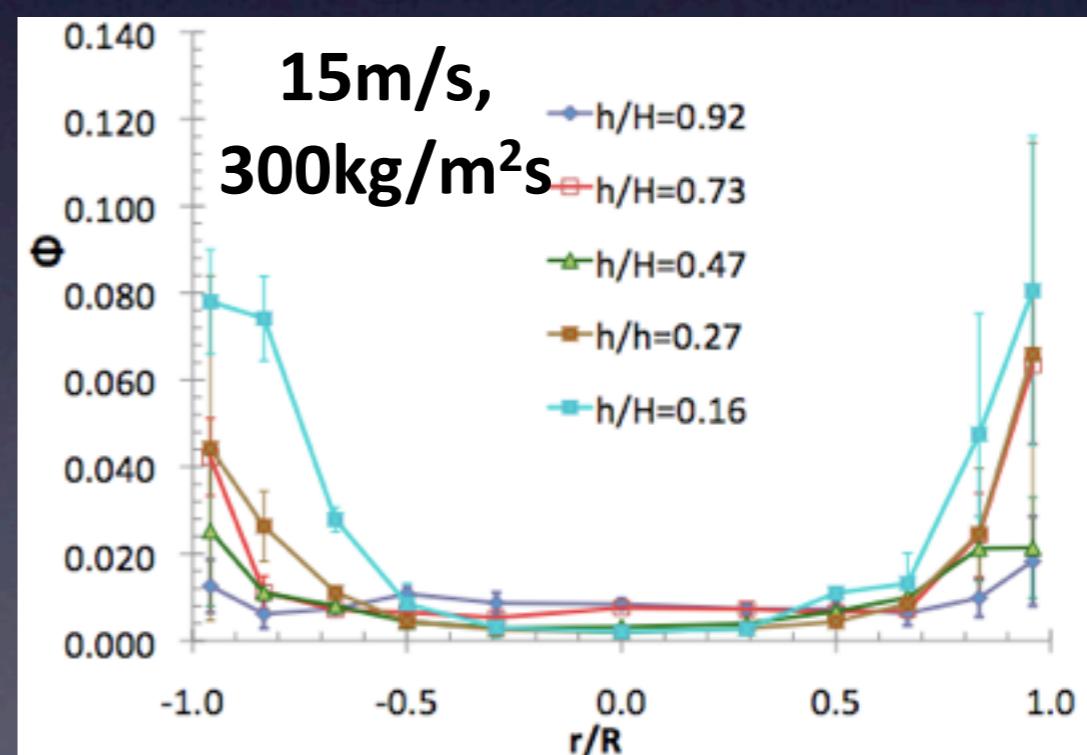
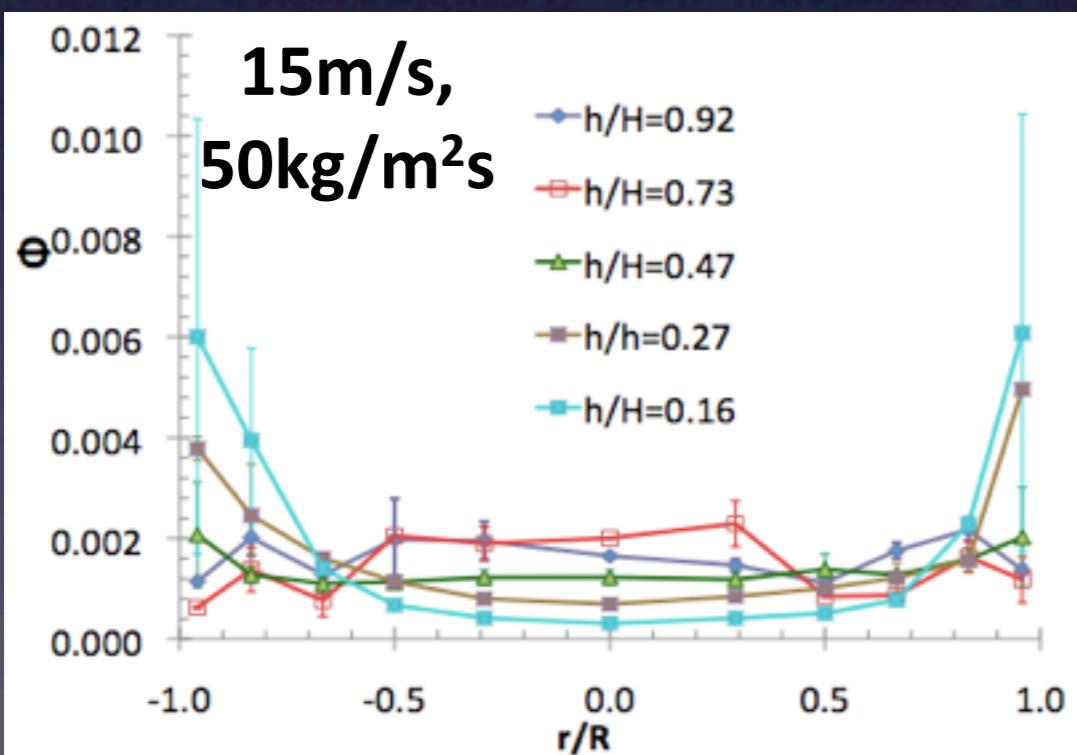
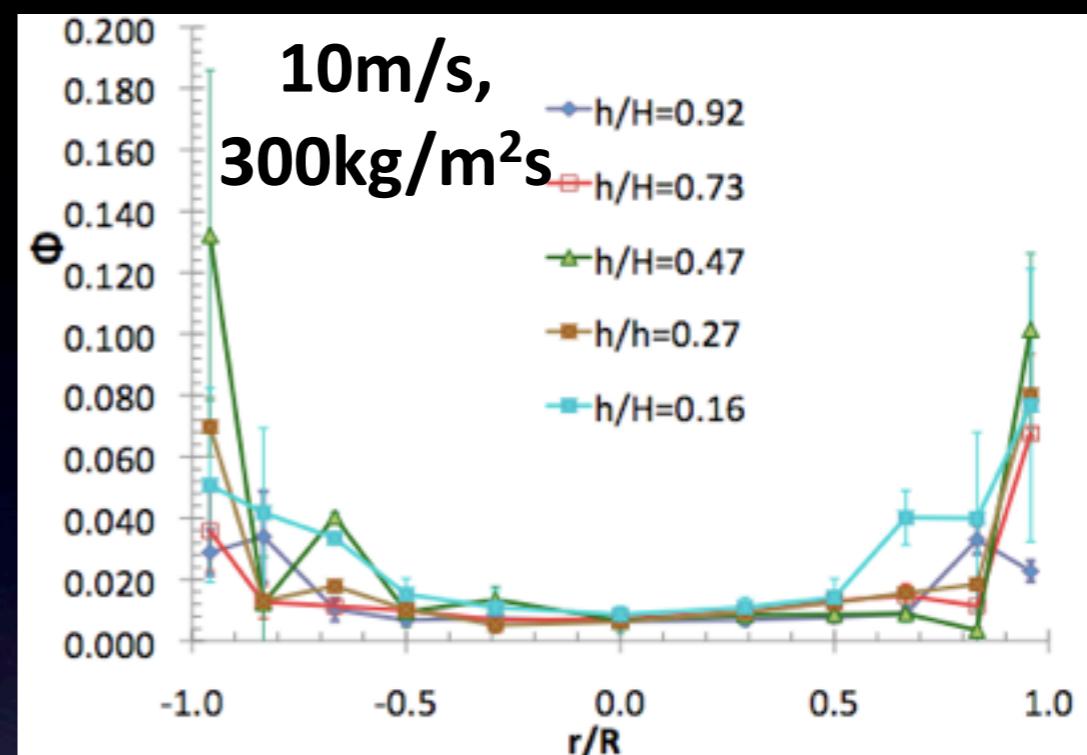
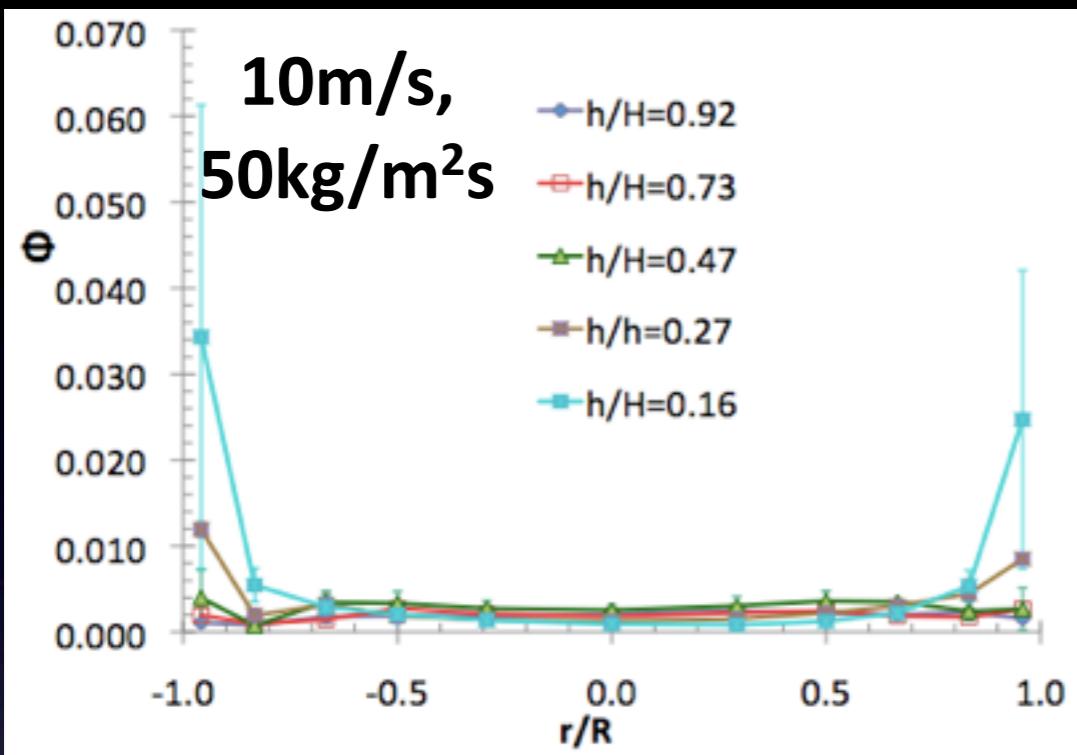


**Upflow and downflow annulus
flat line, M-shaped, inverted U**

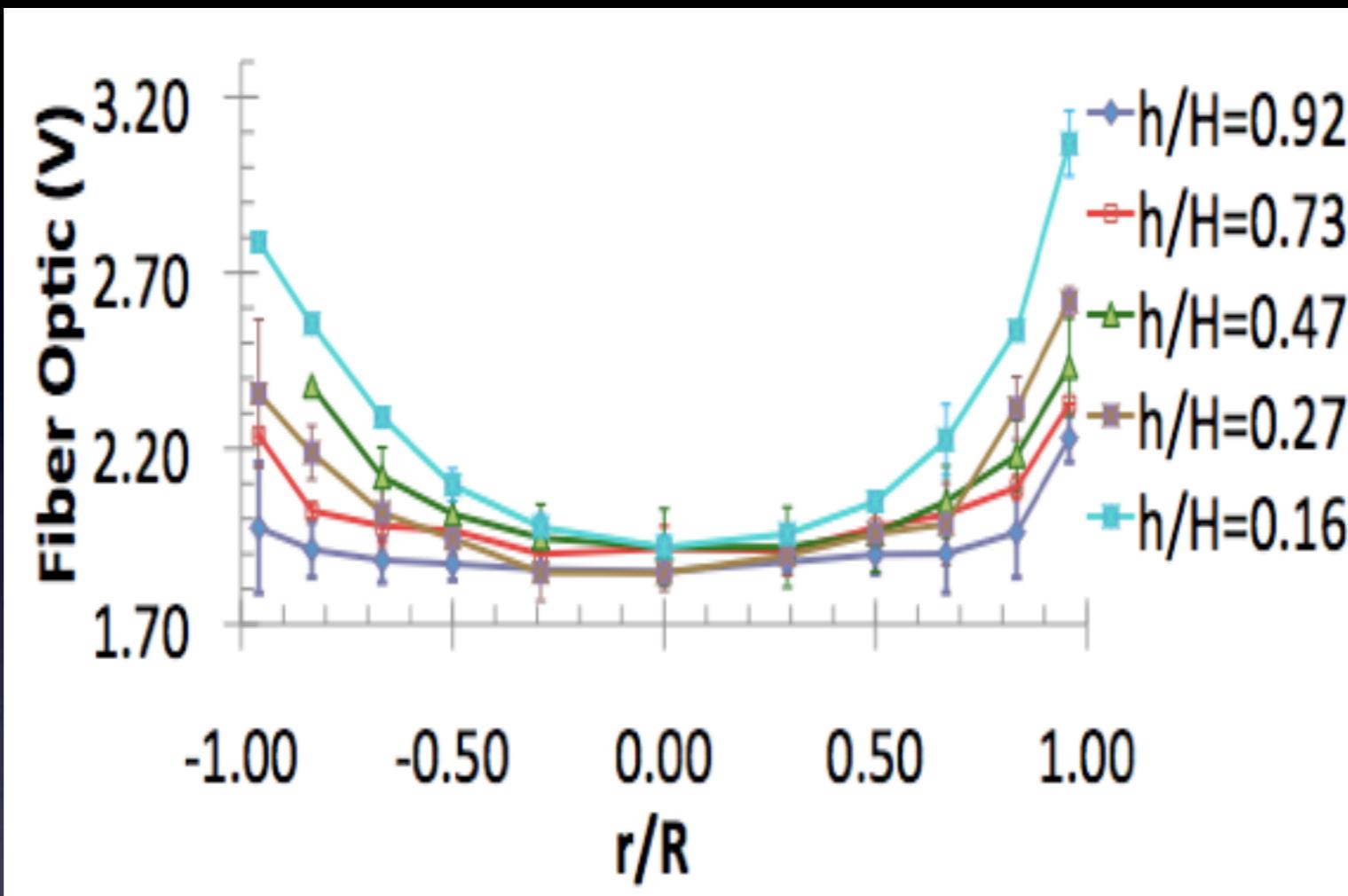
Solids Velocity Profiles



Loading Profiles

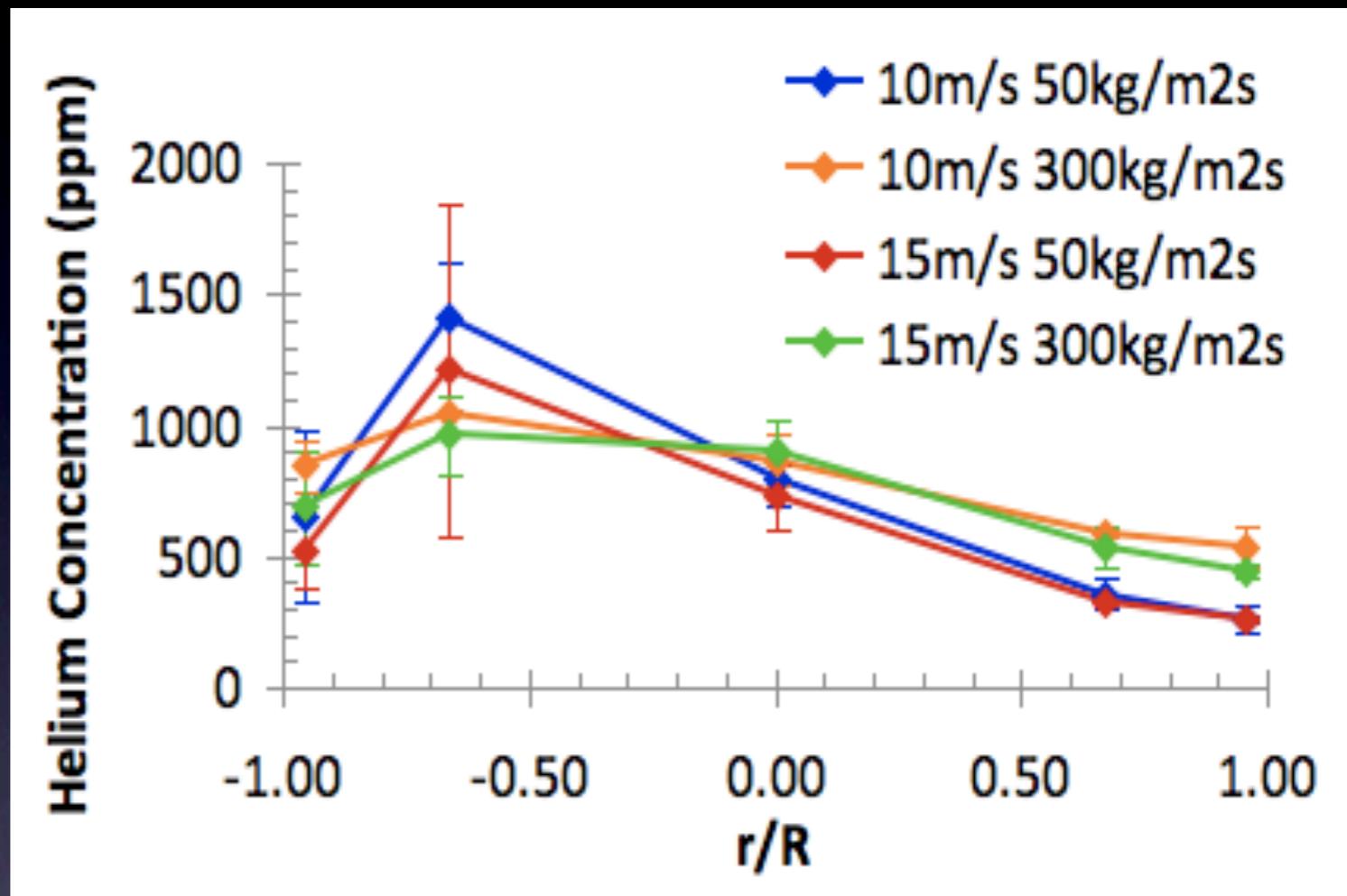
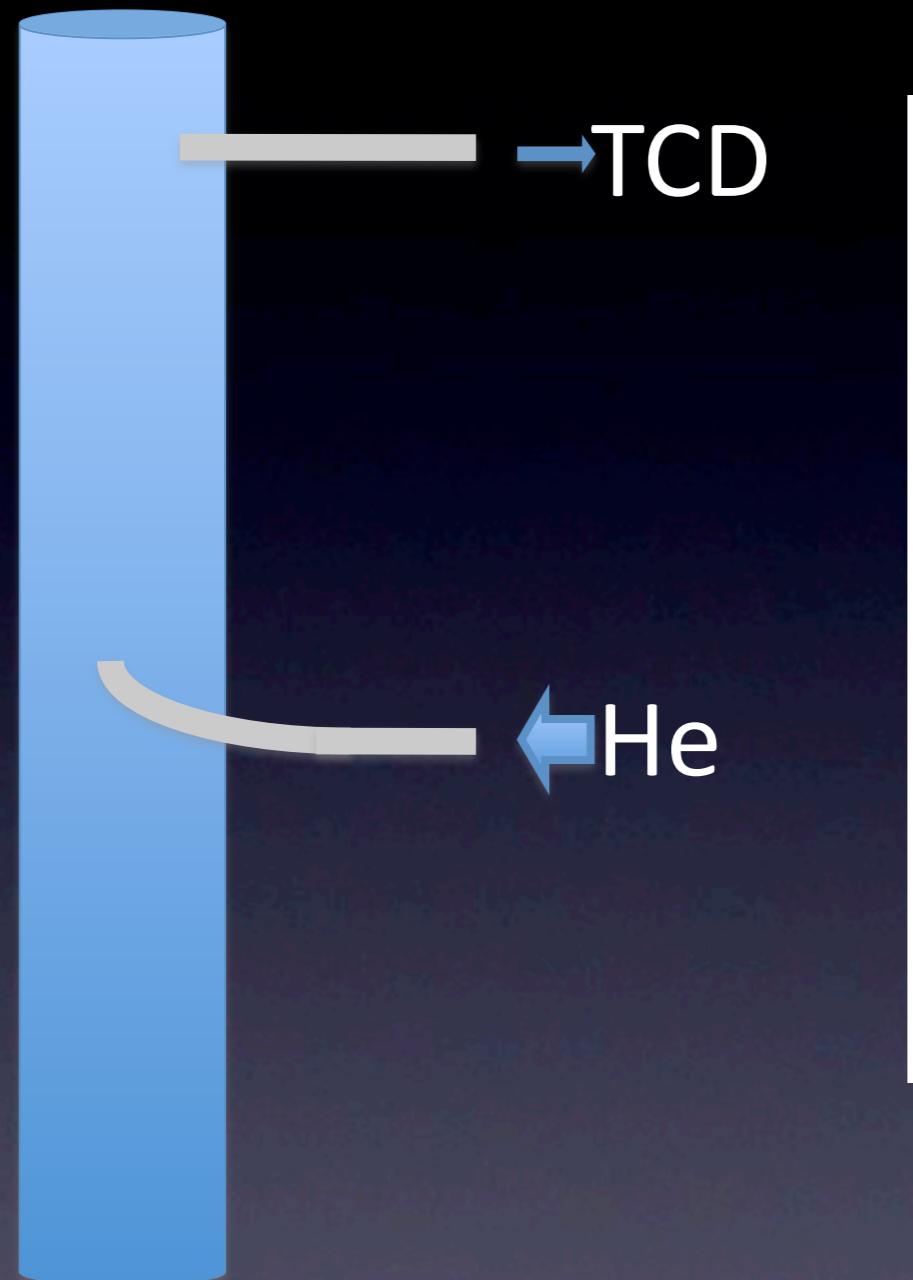


Fiber Optic Voltage Profile



Qualitative solid concentration profile
Cluster analysis via wavelet decomposition

Helium Tracer Profiles

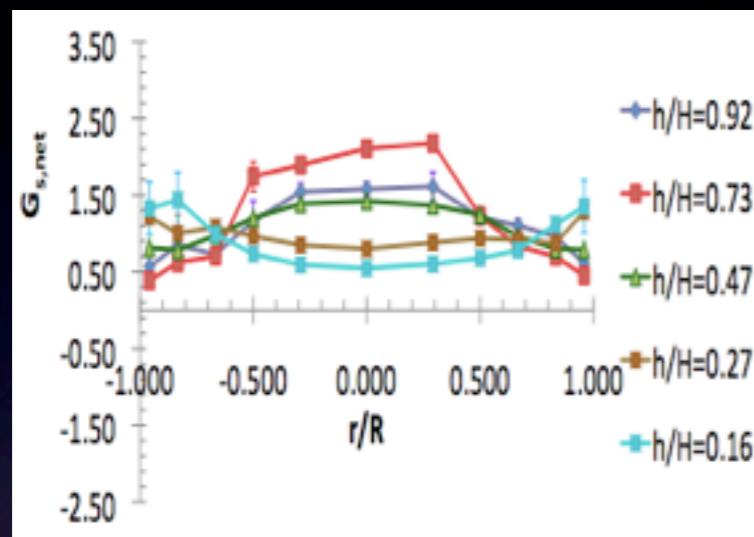


As $G_s \uparrow$, He more uniformly dispersed

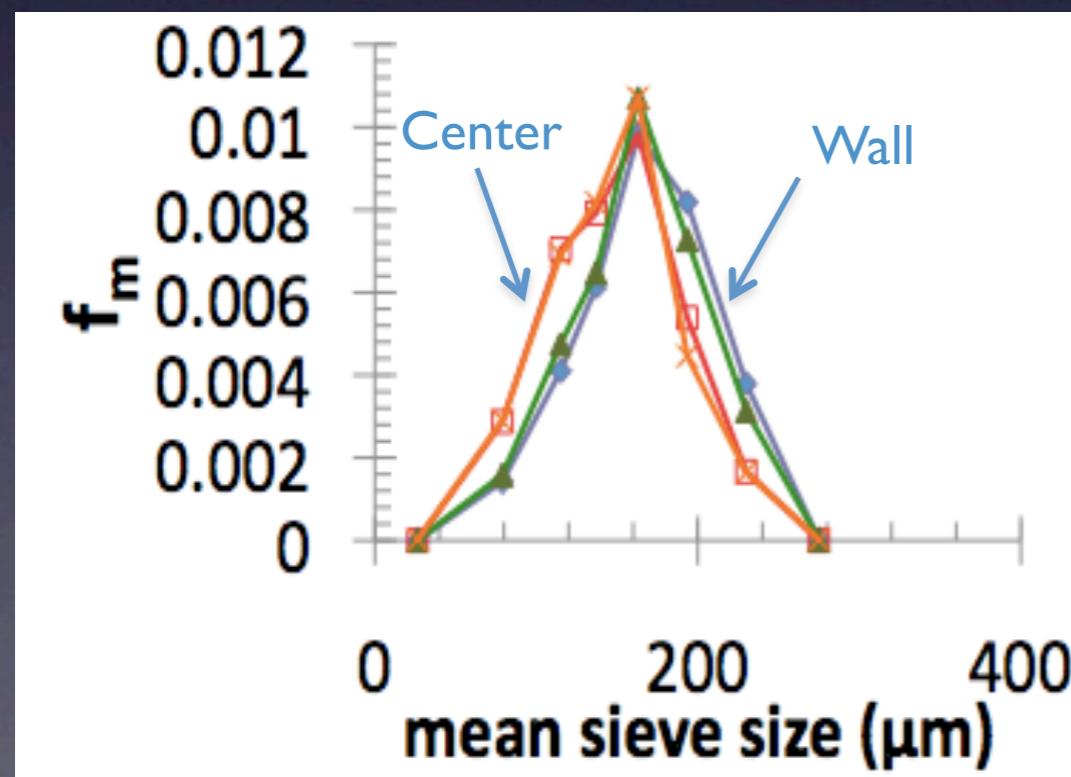
Size Segregation

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

Upflow annulus

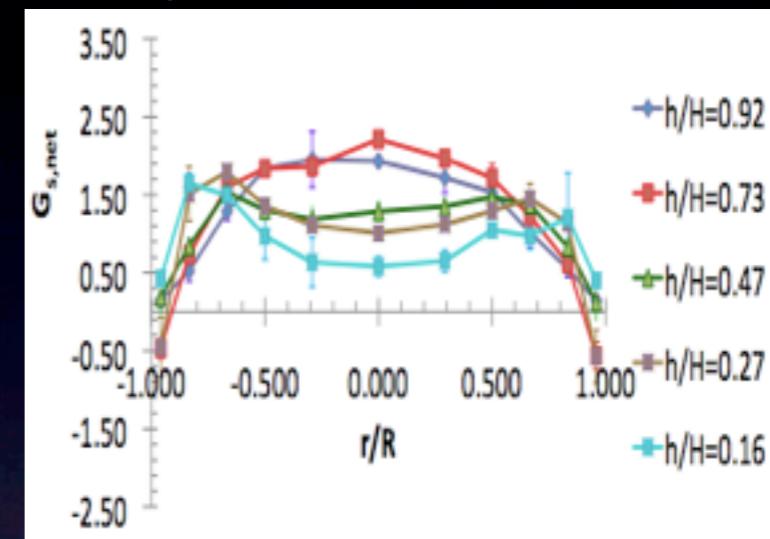


Upflow Annulus, $h/H=0.27$

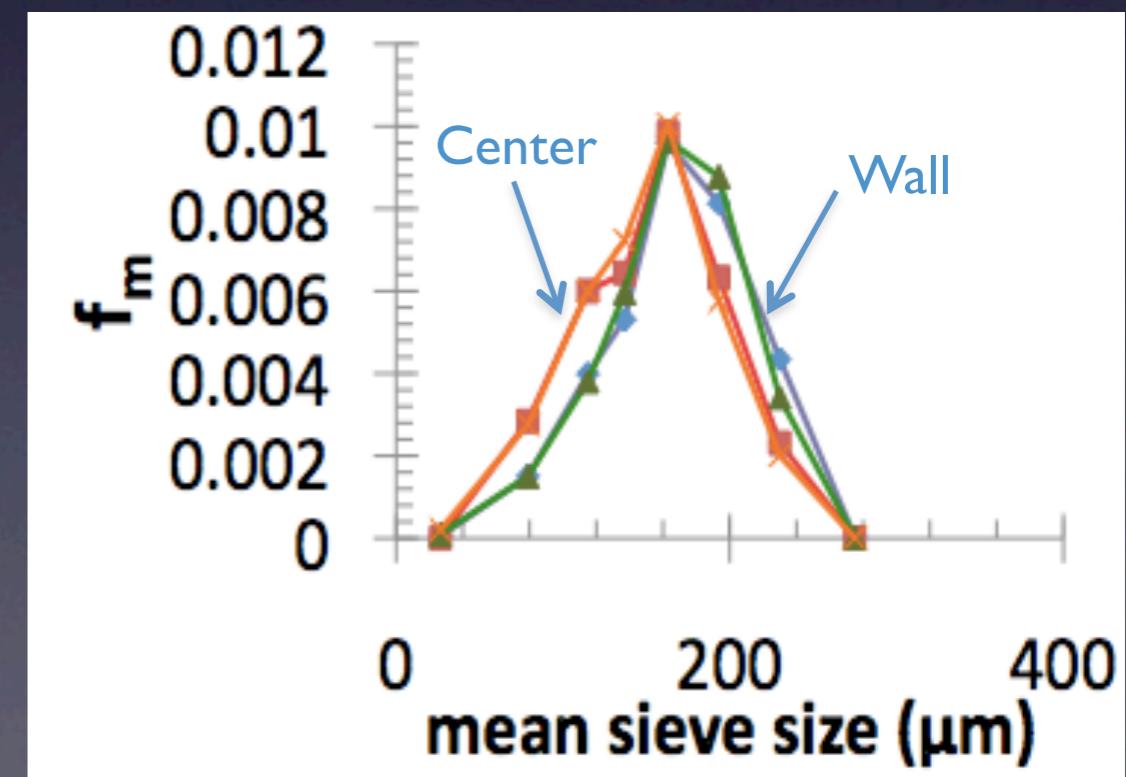


$$U_o = 15 \text{ m/s}, G_s = 300 \text{ kg/m}^2\text{s}$$

Upflow/Downflow annulus



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

- Mike Arrington
- Tracy Foy
- Billy Davis
- Yeook Arrington, Allan Issangya
- Jesus, Bobby, Jason, Gerry, Ralph
- Lucretia, Sharon

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