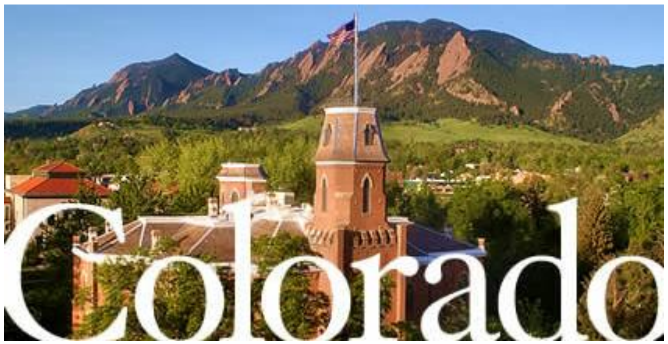
Polydispersity Model Development & Validation: Report on Findings



Jia-Wei Chew
Aaron Murray
Christine Hrenya

Ray Cocco
John Findlay
Roy Hays
SB Reddy Karri
Ted Knowlton

Particulate Solid Research Inc.

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

Sofiane Benyahia
Larry Shadle

NETL 2011 Workshop on Multiphase Flow Science
16 August 2011
Pittsburgh, PA

Project Goals & 2006 Technology Roadmap

Theme: Particle Size Distribution (PSD)

Relevant Tracks in 2006 Technology Roadmap

1. Continuum Theory for the Solid Phase
2. Improved Gas-Particle Drag Laws
3. Gas-Phase Instabilities: Turbulence Models

} Theory and Model Development

4. Data Collection and Model Validation

} Physical and Computational Experiments

5. Project Management

} Communication, Collaboration, and Education

Colorado

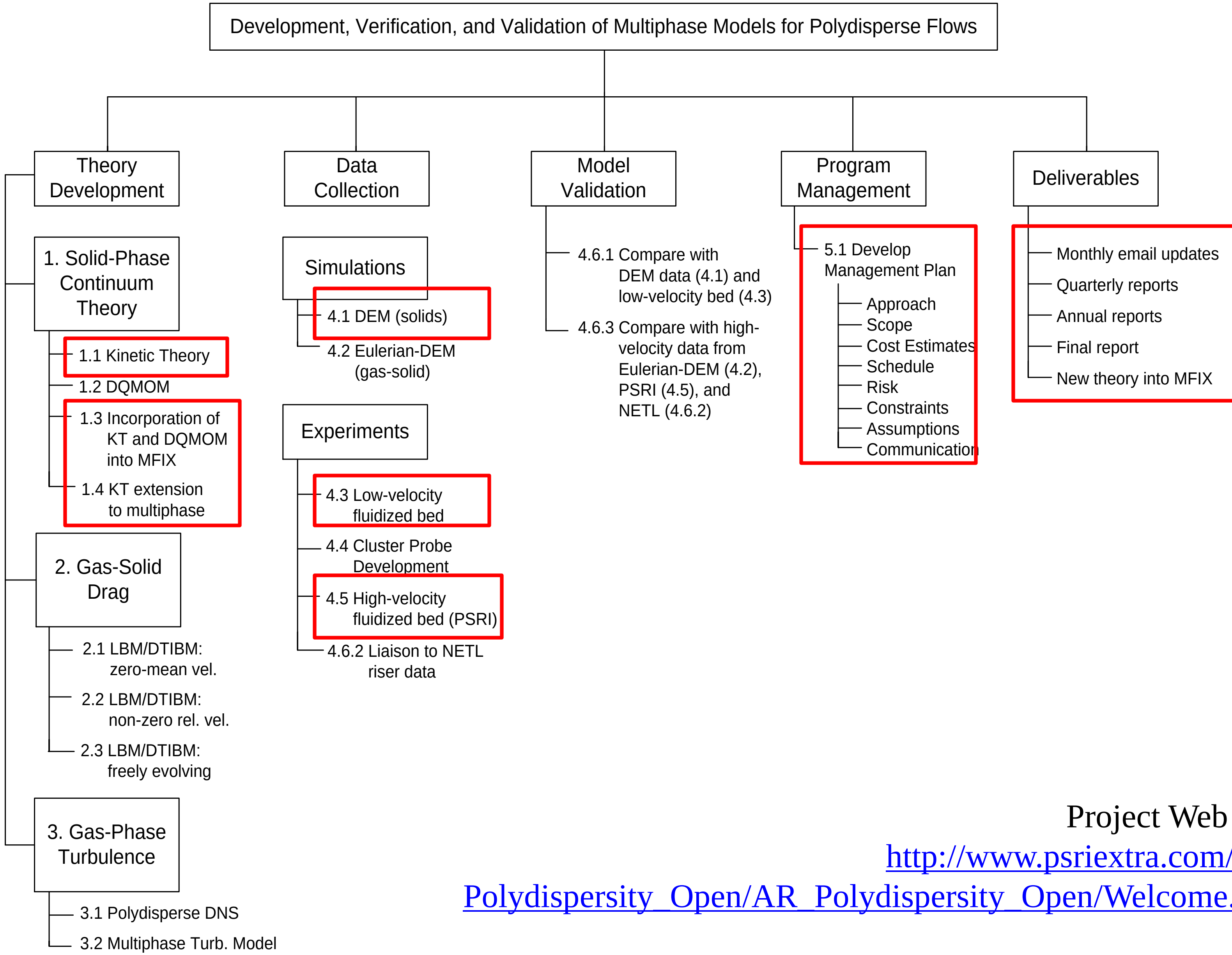
NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

Iowa State

PRINCETON UNIVERSITY

Particulate Solid Research Inc.

Project Scope: Work Breakdown Structure

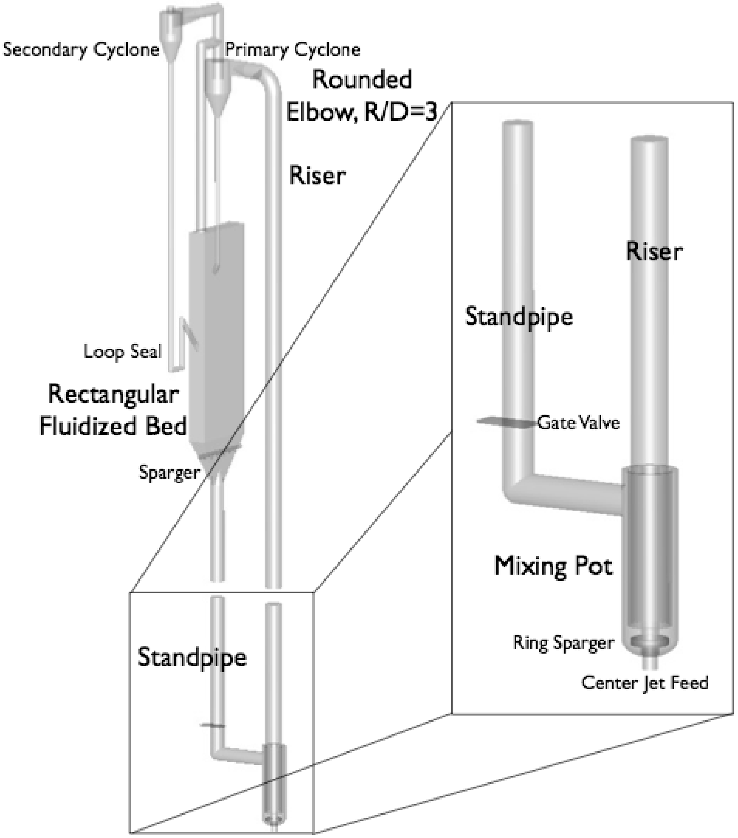


Project Web Site:
http://www.psriextra.com/AR_Polydispersity_Open/AR_Polydispersity_Open/Welcome.html

Experimental Setups

Colorado Bubbling Bed / “Dilute” CFB

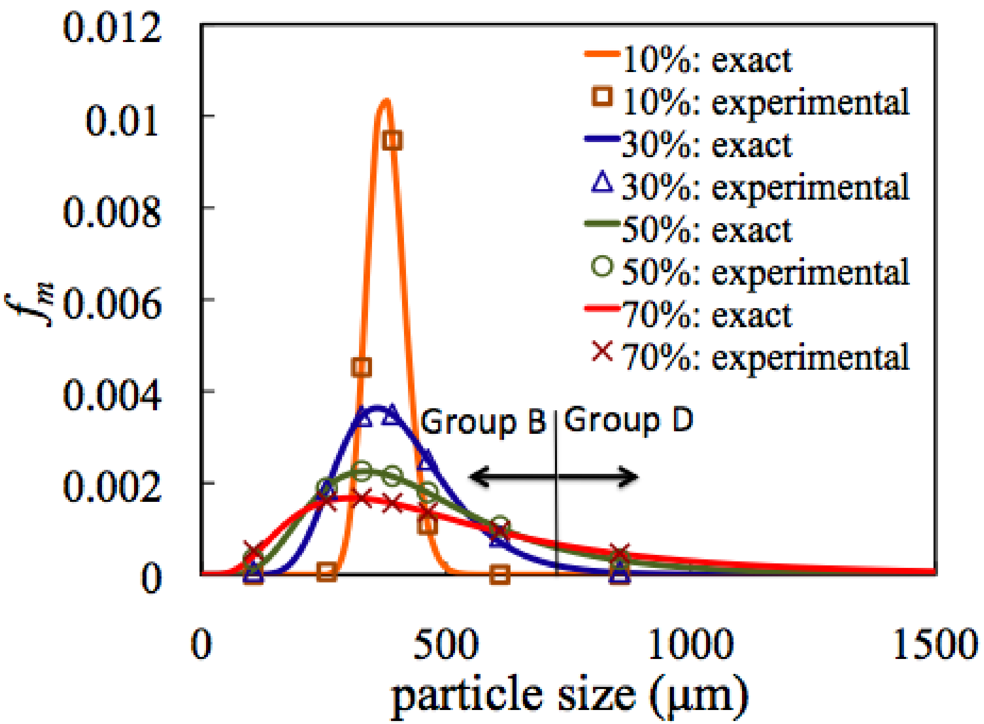
PSRI “Dense” CFB

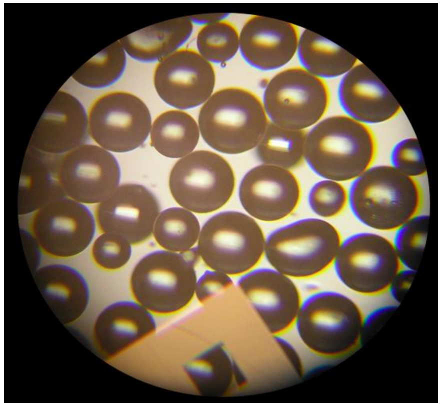


Particles

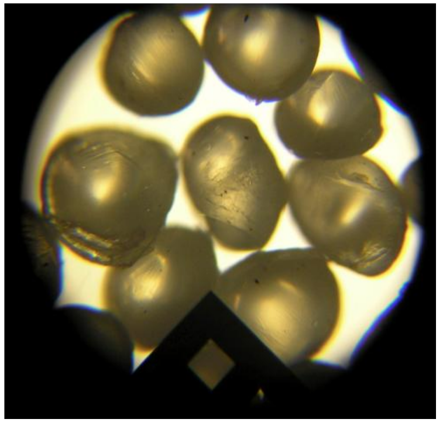
Colorado: sand
PSRI: glass beads and HDPE pellets

- Group B
- monodisperse, binary & continuous PSD's

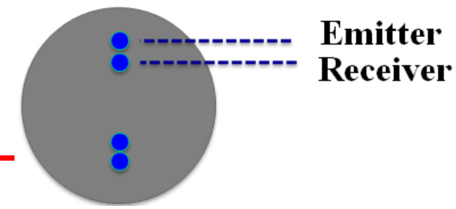




Glass
d_{ave} = 170 μm
ρ_p = 2500 kg/m^3



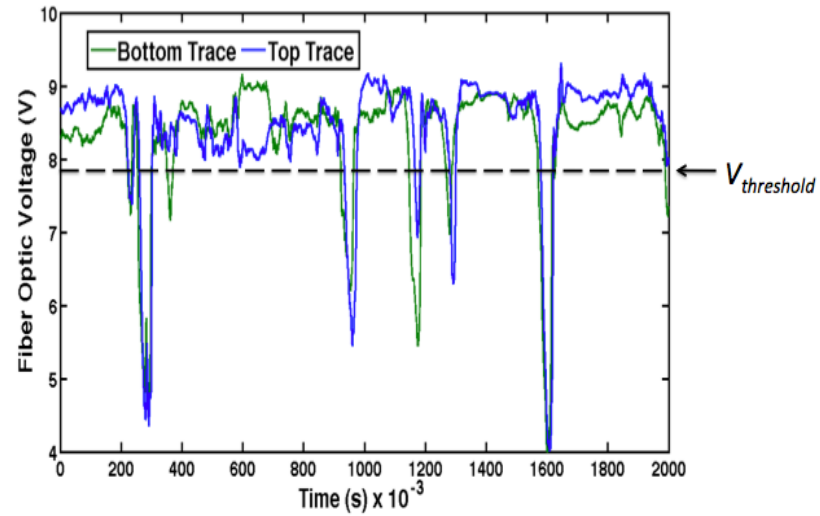
HDPE
d_{ave}= 650 μm
ρ_p = 900 kg/m^3

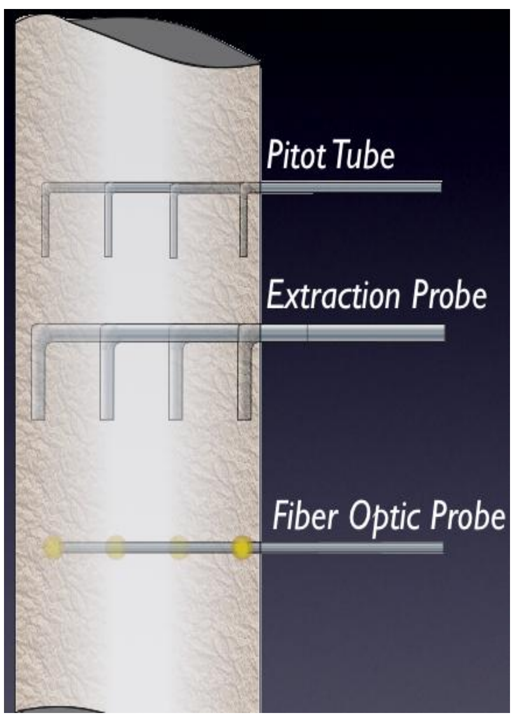


Experimental Measurements

Bubbling Bed (Colorado)

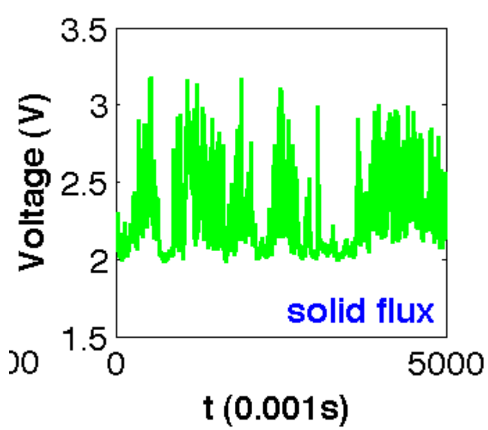
- Axial segregation:
  vacuum slice, sieve, and weigh
- Bubble frequency, velocity & size:
  optical dual-fiber probe

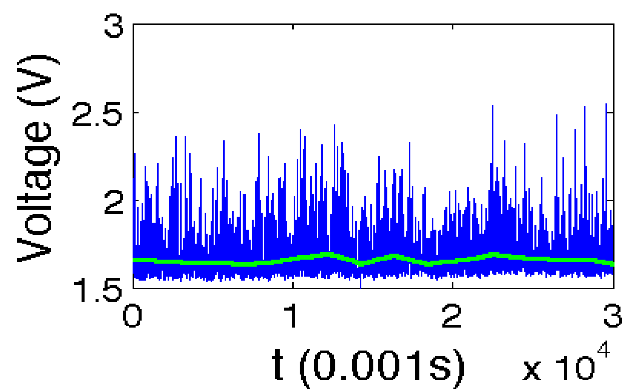




CFB (Colorado & PSRI)

- Species flux: extraction probe
- Cluster freq., duration, & appear. prob.: optical fiber probe

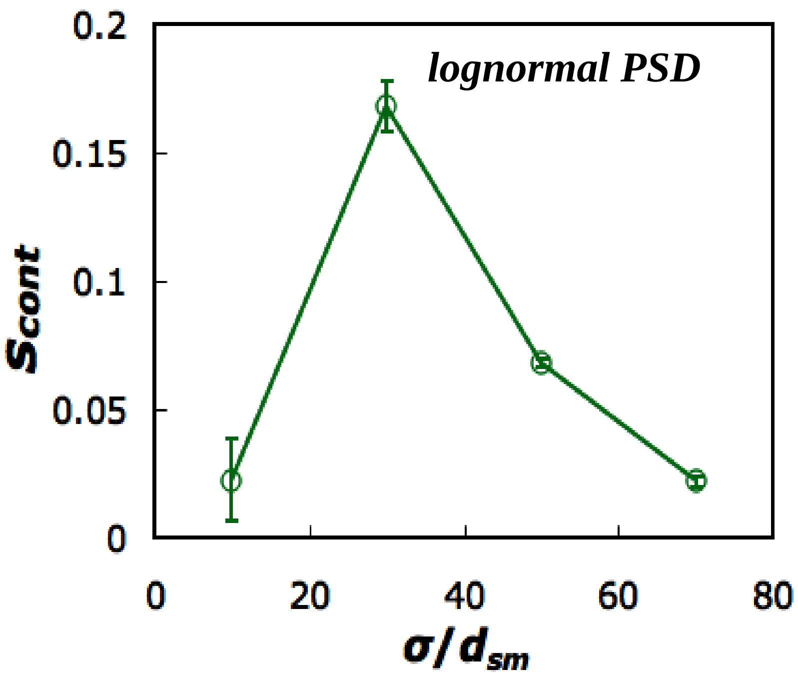




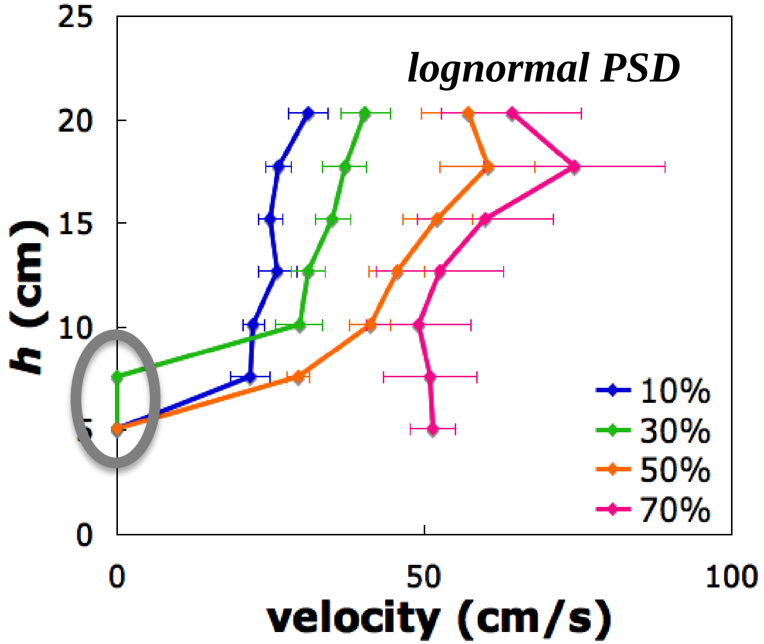
Comprehensive set of polydisperse data…

1. Chew, J. W., D. M. Parker, R. A. Cocco and C. M. Hrenya, "Cluster characteristics of continuous size distributions and binary mixtures of Group B particles in dilute riser flow," ***Chemical Engineering Journal***, submitted.
2. Chew, J. W., R. Hays, J. G. Findlay, T. M. Knowlton, S. B. R. Karri, R. A. Cocco and C. M. Hrenya, "Cluster characteristics of Geldart Group B particles in a pilot-scale CFB riser. I. Monodisperse systems," ***Chemical Engineering Science***, submitted.
3. Chew, J. W., R. Hays, J. G. Findlay, T. M. Knowlton, S. B. R. Karri, R. A. Cocco and C. M. Hrenya, "Cluster characteristics of Geldart Group B particles in a pilot-scale CFB riser. II. Polydisperse systems," ***Chemical Engineering Science***, submitted.
4. Chew, J.W., D. M. Parker, and C. M. Hrenya, "Elutriation and species segregation characteristics of polydisperse mixtures of Group B particles in a dilute CFB riser," ***AIChE Journal***, submitted.
5. Chew, J. W., R. Hays, J. G. Findlay, T. M. Knowlton, S. B. R. Karri, R. A. Cocco and C. M. Hrenya, "Reverse Core-Annular Flow of Geldart Group B Particles in Risers," ***Powder Technology***, submitted.
6. Chew, J. W., R. Hays, J. G. Findlay, T. M. Knowlton, S. B. R. Karri, R. A. Cocco and C. M. Hrenya, "Impact of material property and operating conditions on mass flux profiles of monodisperse and polydisperse Group B particles in a CFB riser," ***Powder Technology***, in press.
7. Chew, J. W., R. Hays, J. G. Findlay, T. M. Knowlton, S. B. R. Karri, R. A. Cocco and C. M. Hrenya, "Species segregation of binary mixtures and a continuous size distribution of Group B particles in riser flow," ***Chemical Engineering Science***, in press.
8. Chew, J. W. and C. M. Hrenya, "Link between bubbling and segregation patterns in gas-fluidized beds with continuous size distributions," ***AIChE Journal***, in press.
9. Chew, J. W., J. Wolz, and C. M. Hrenya, "Axial segregation in bubbling gas-fluidized beds with Gaussian and lognormal Distributions of Geldart group B particles," ***AIChE Journal***, 56, 3049-3061 (2010).

Bubbling Bed: Segregation and Bubbling

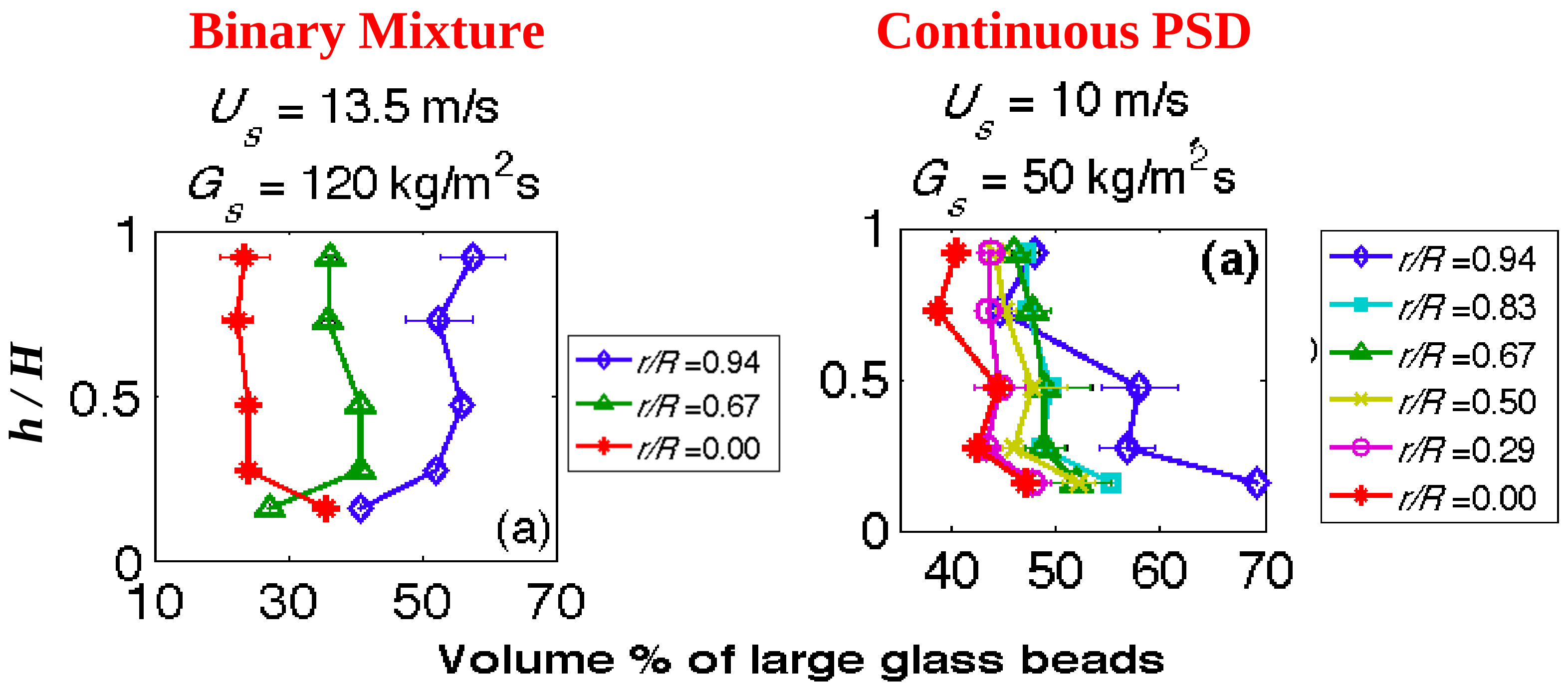


s_{cont}= 1 ➔ perfect segregation
s_{cont}= 0 ➔ perfect mixing



- As distribution width ↑ , segregation ↑ then ↓ (binary: monotonic ↑)
- As distribution width ↑ , all bubble characteristics ↑
- Explanation: segregation level tied to thickness of bubble-less layer

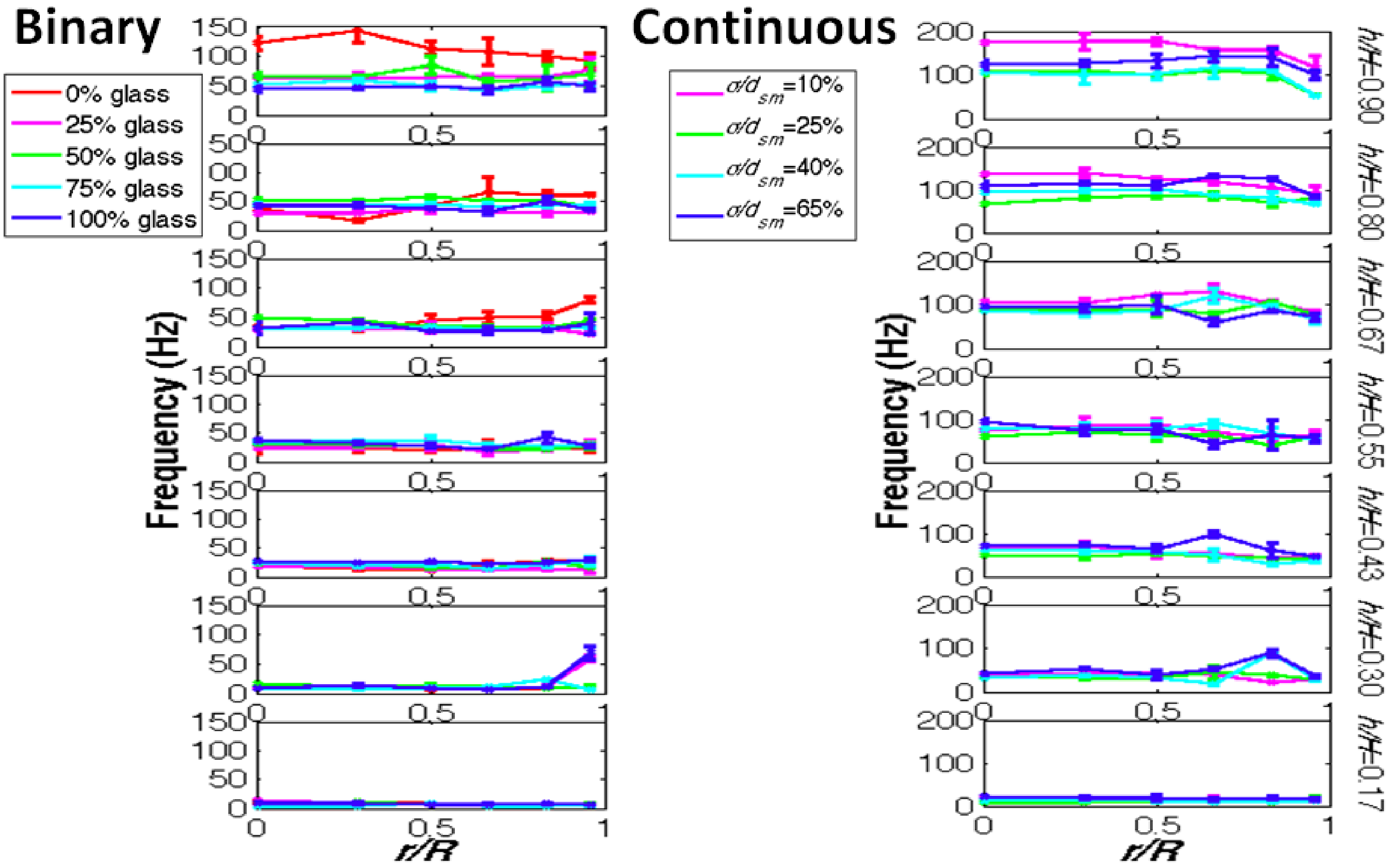
CFB: Axial Segregation



Binary: As height ↑, % of massive ↑ at some locations

Continuous: As height ↑, % of massive ↓ at all locations

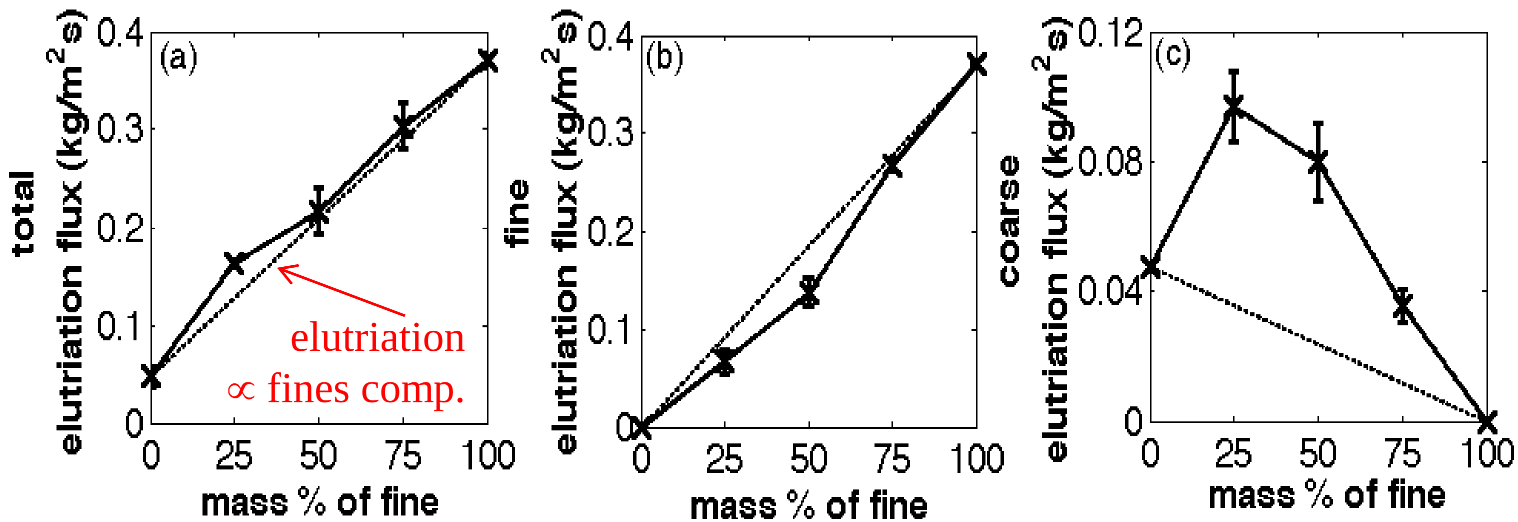
CFB: Cluster Frequency



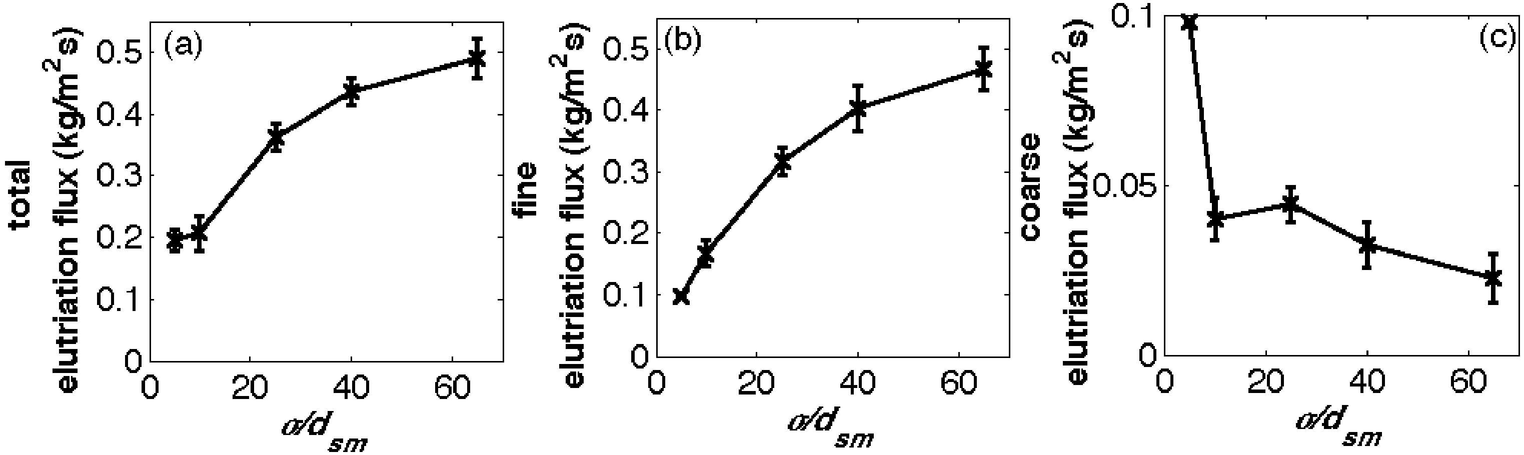
- Axial position has large influence on profile
- Binary composition and continuous PSD width have impact at high *h*/*H*

CFB: Elutriation

Binary Mixture

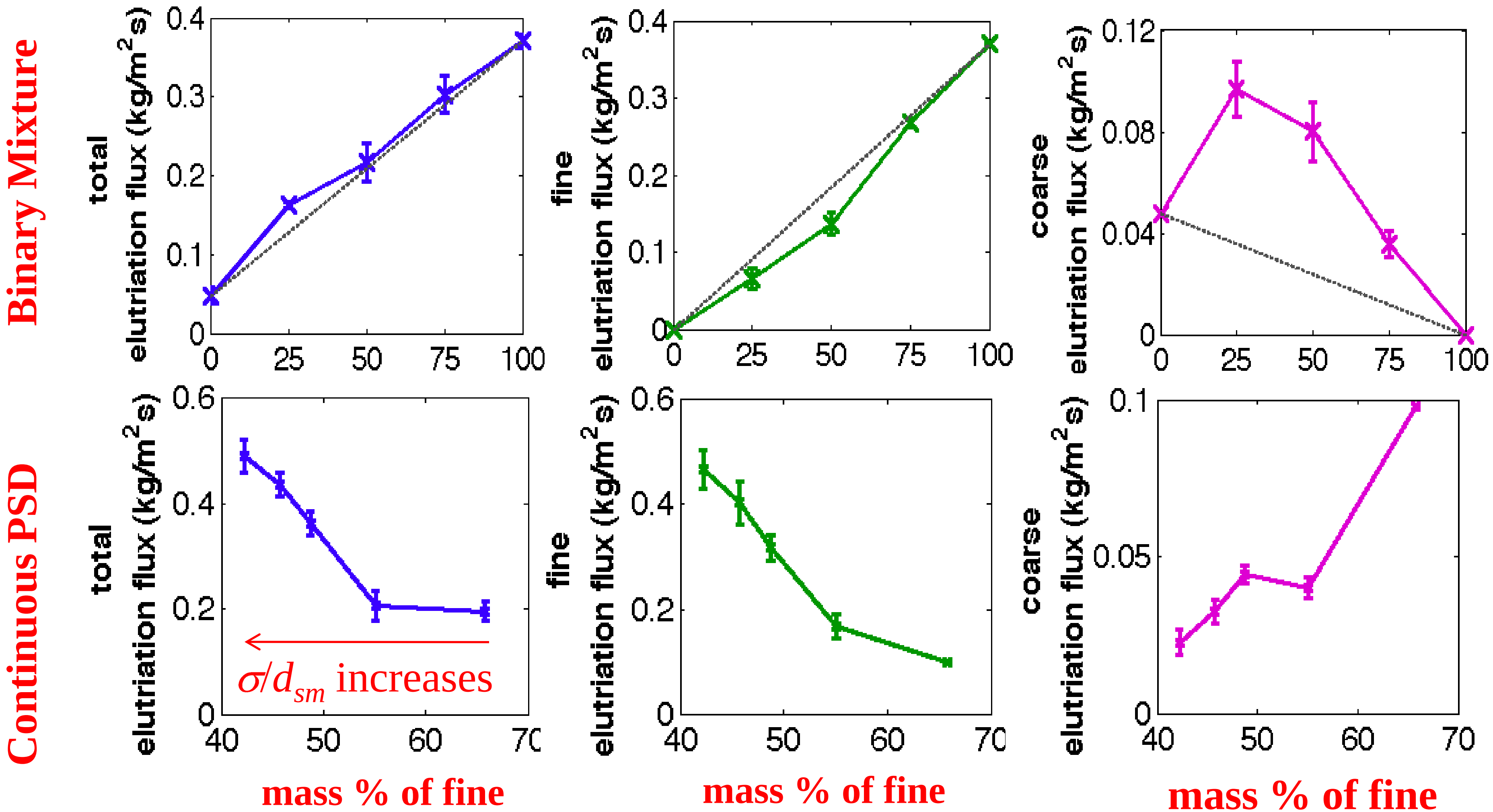


Continuous PSD



Trends of binary and continuous appear similar, but x-axes are different…

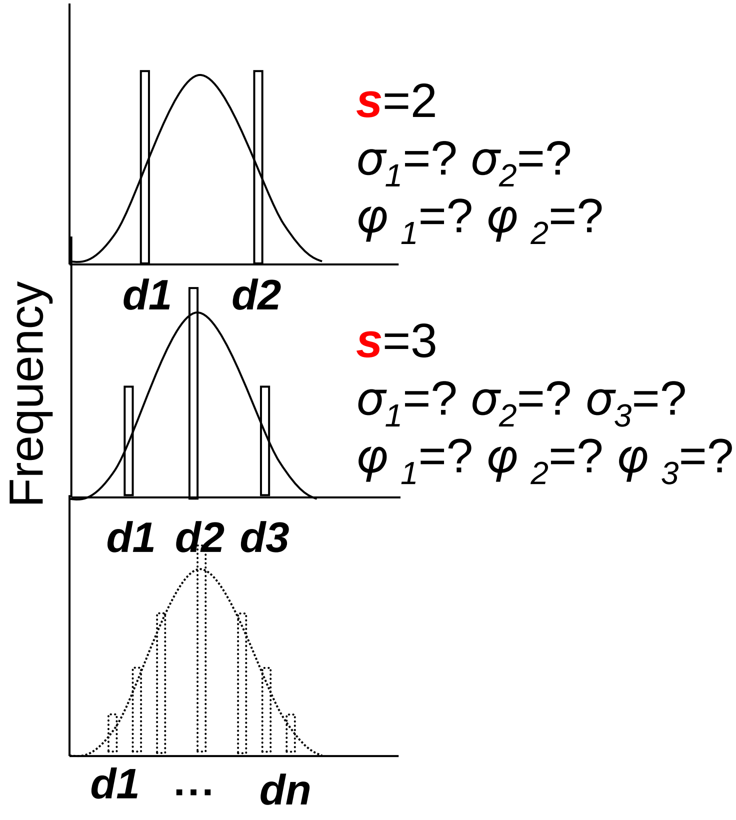
CFB: Elutriation w/ same x-axes



- Elutriation trends of binary and continuous PSD's are in stark contrast
- Explanation: as continuous width ↑ (mass % of fines ↓), d_{fine}↓ and elutriation easier

Aside: How well do kinetic theories predict *continuous* PSD's?

Basic Idea: **How to accurately represent a continuous PSD using the transport coefficients for '*s*' discrete species.**



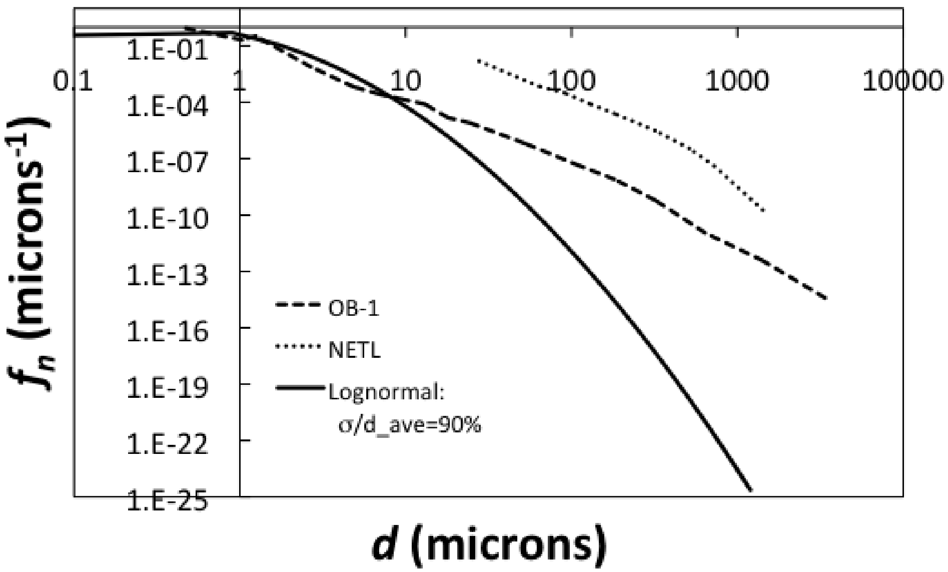
Q1: What ***method*** do we choose to find σ's and φ_i's for given φ?

A1: moment-based method

Q2: What ***value*** of '***s***' is required for '*accurate*' representation of continuous PSD?

A2: "collapsing" of transport coefficients from new kinetic theory (Garzo, Hrenya & Dufty, *PRE*, 2007)

Preliminary Answer…

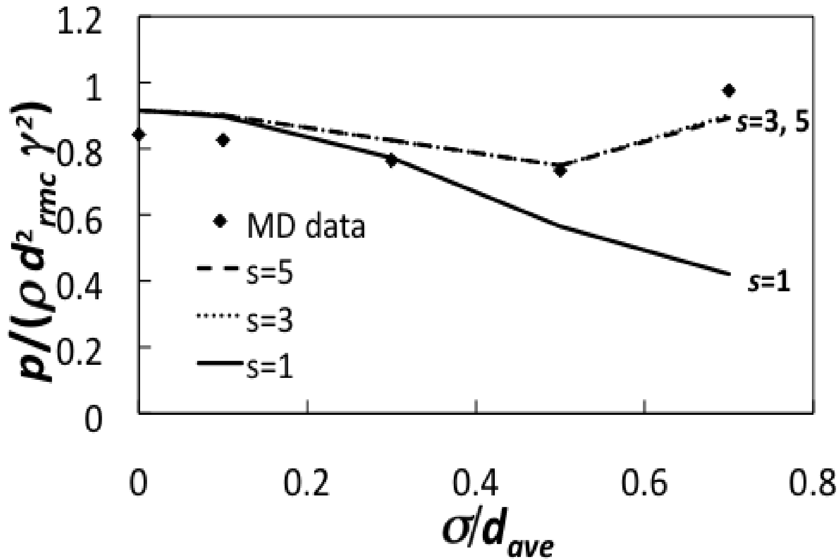


Distributions investigated

- Lognormal (σ/d_{ave} = 90%)
- NETL coal
- NASA lunar simulant (OB-1)

Comparison with MD data of Dahl et al (Powder Tech, 2003)

- Simple shear flow
- Discrete approximation with 3 particles (s=3) provides similar accuracy as monodisperse theory



Summary

- Binary and continuous PSD's display different qualitative trends
  - bubbling bed: axial segregation
  - CFB: axial segregation, elutriation

- Preliminary work indicates *discrete* kinetic theory can approximate well a *continuous* PSD with a fairly small number of size species