Characterizing Cluster Behaviour Using Instantaneous Particle Concentration Signals from Multiple Optical Fiber Probes

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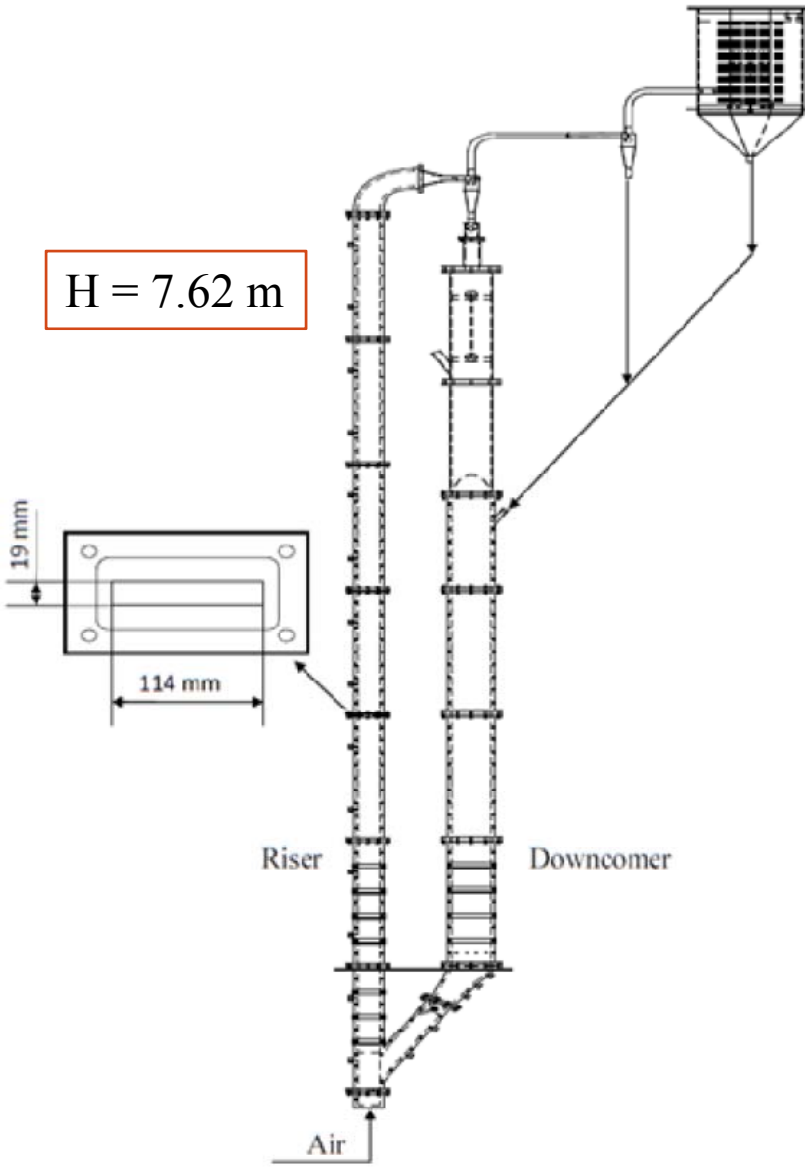
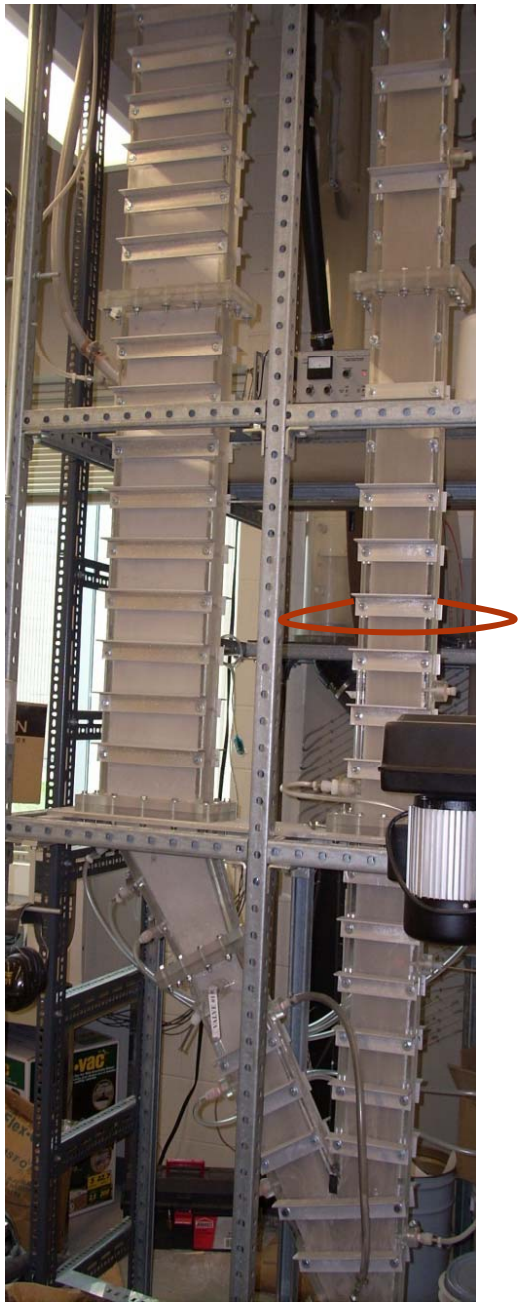
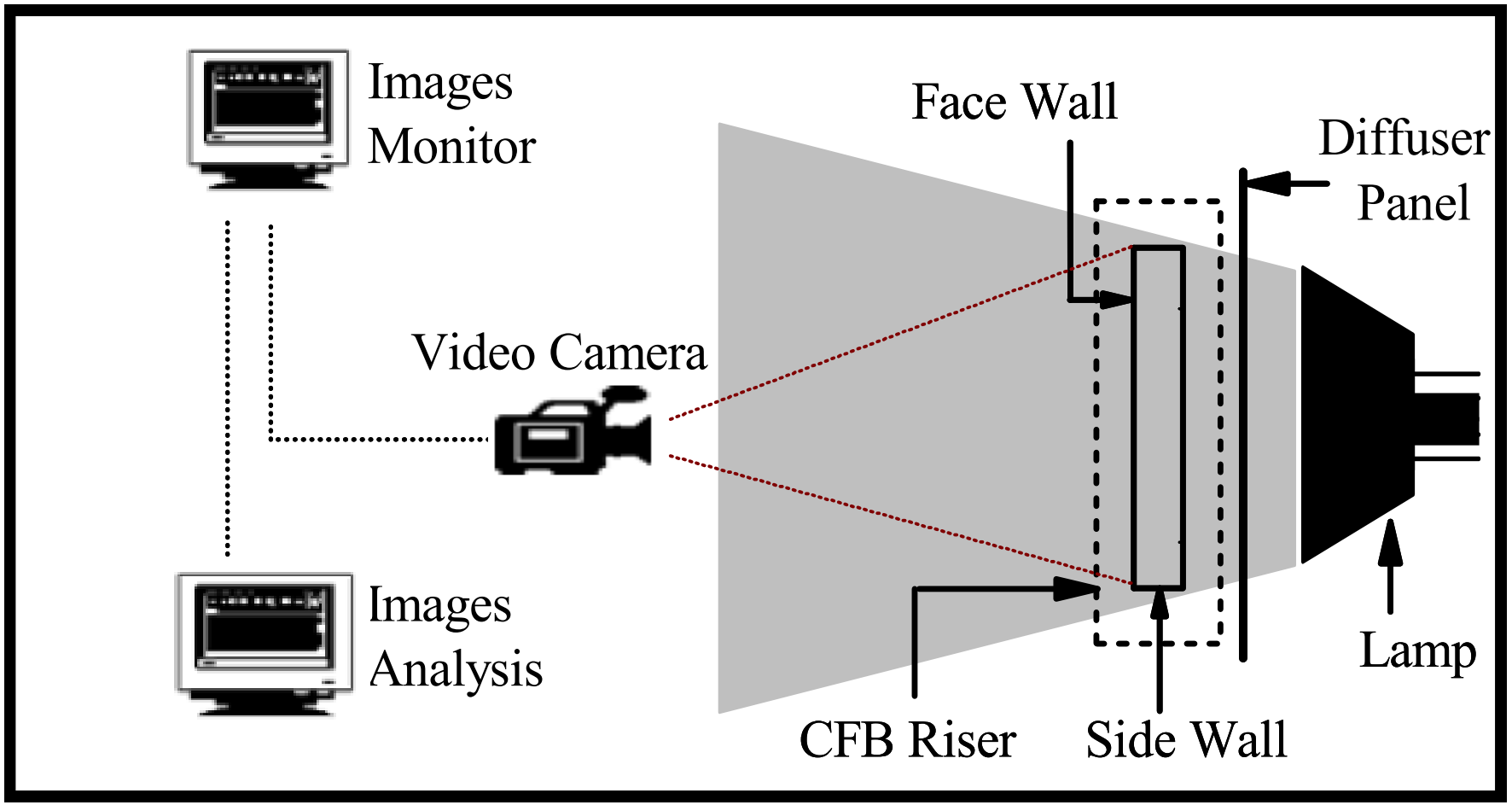
Schematic of 2-D CFB

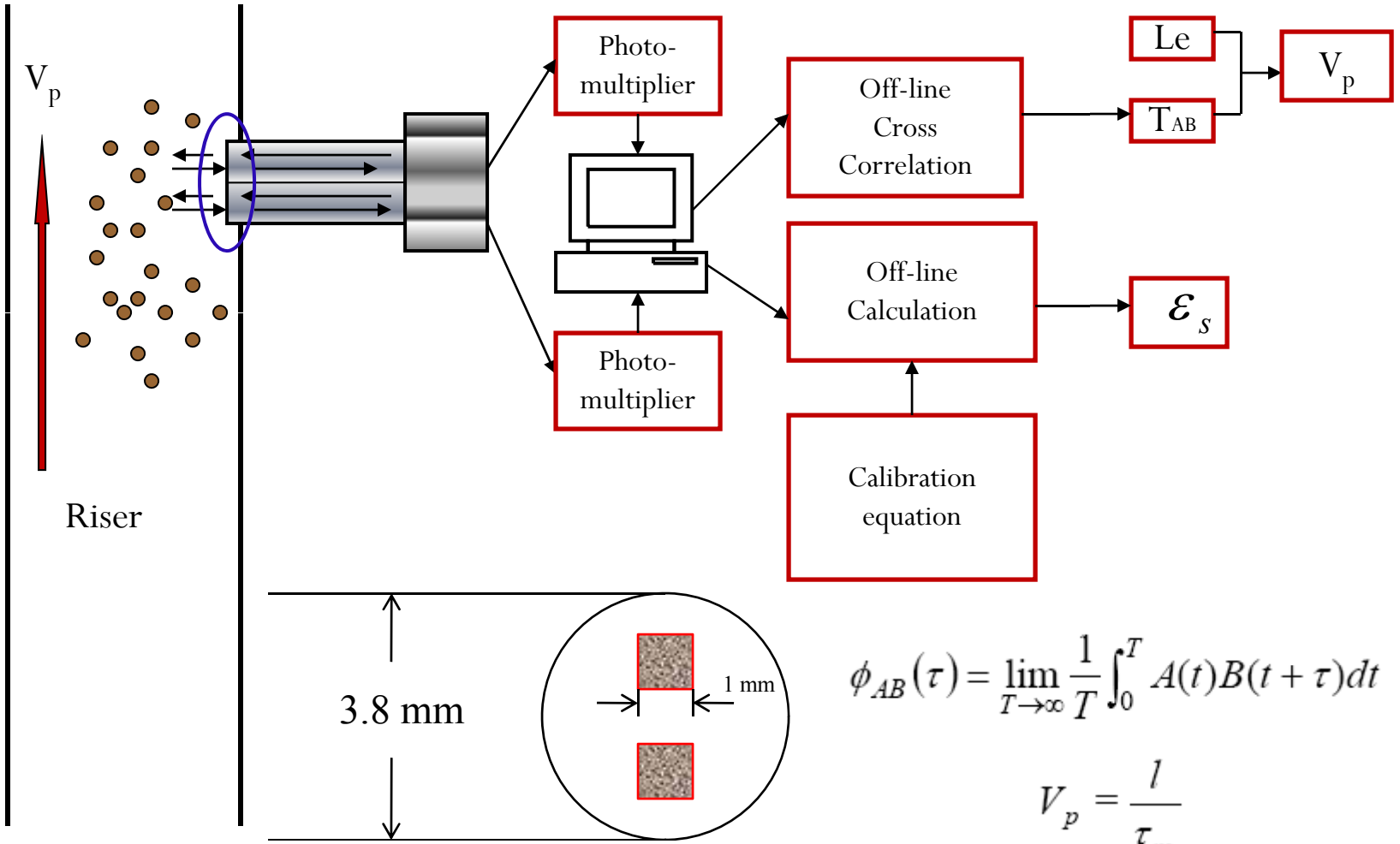




High Speed Digital Image System



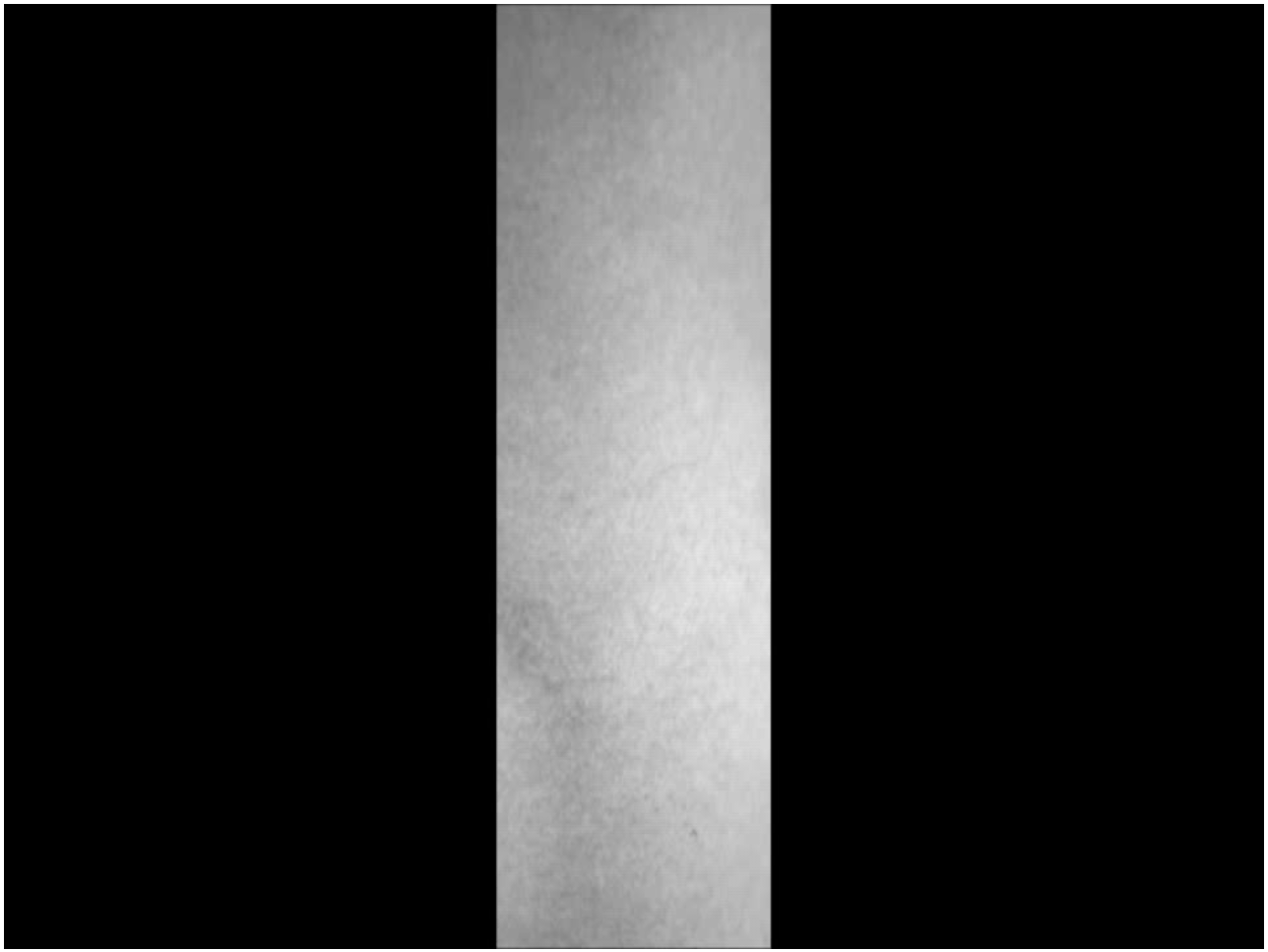
Multiple Optical Fiber Probe



$$\phi_{AB}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T A(t)B(t+\tau)dt$$

$$V_p = \frac{l}{\tau_m}$$

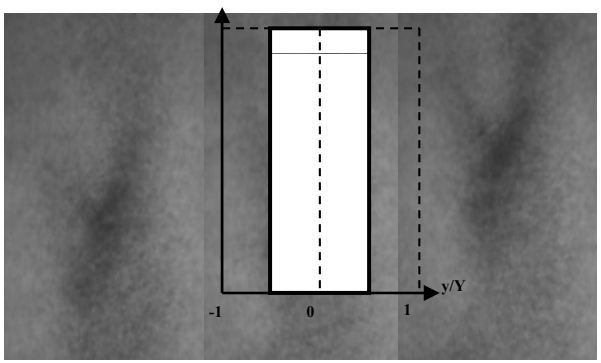
Observation of clusters

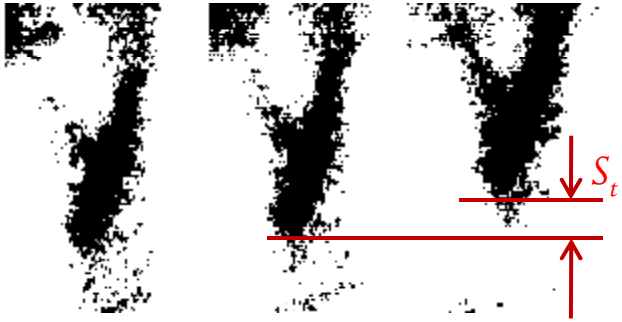


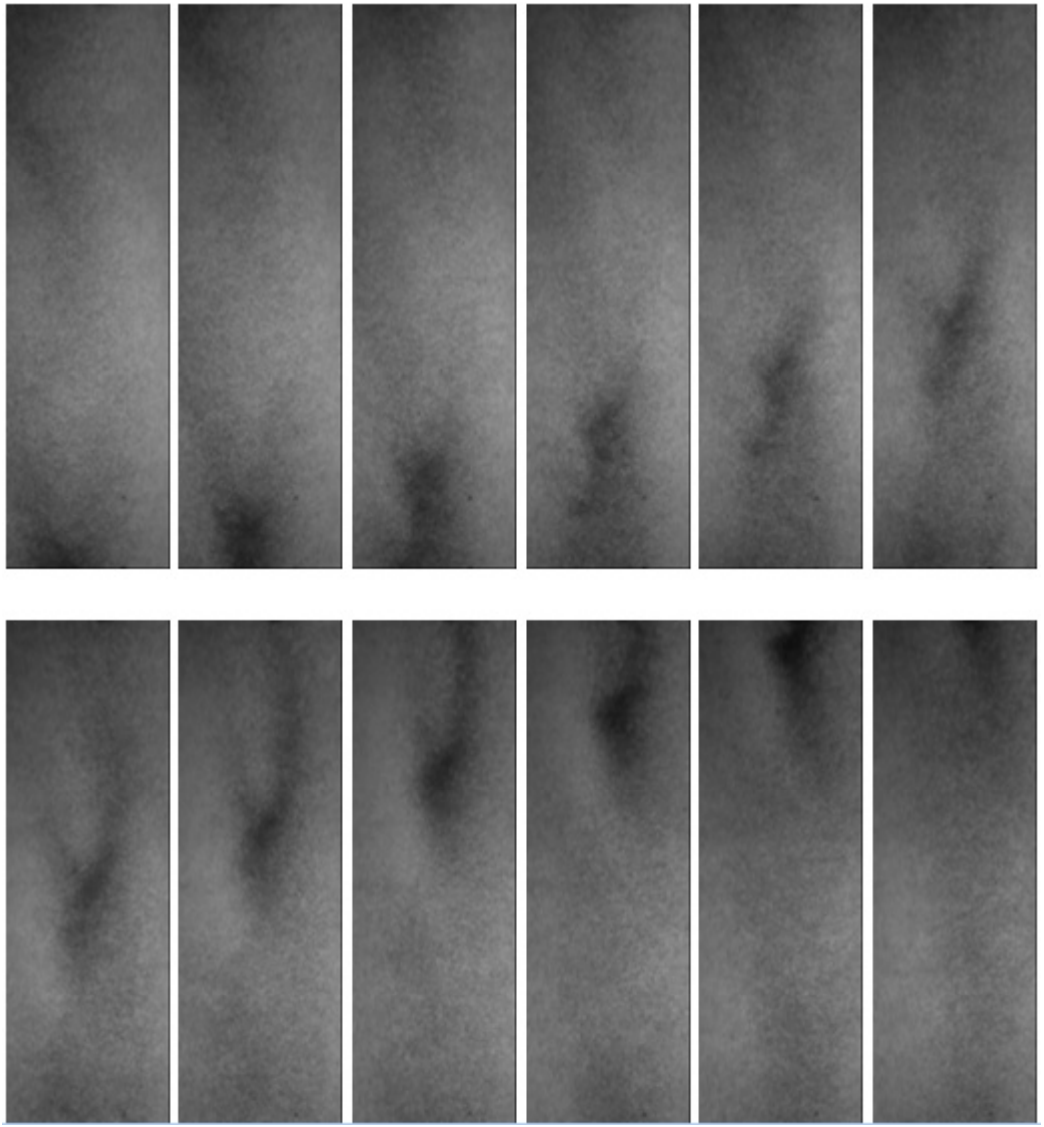
A typical U-shape cluster

Time interval =10ms, window size: 46.6×13.5 mm^2, bed height Z = 7.5 m, lateral position y/Y = 0, superficial gas velocity U_g = 5.5 m/s, solids circulation rate G_s = 100 kg/m^2·s). The particle is Glassbead #3, d_p = 288 μm, ρ_p = 2498 kg/m3, Φ_s = ~ 1.

$$V_c = S_t / T$$







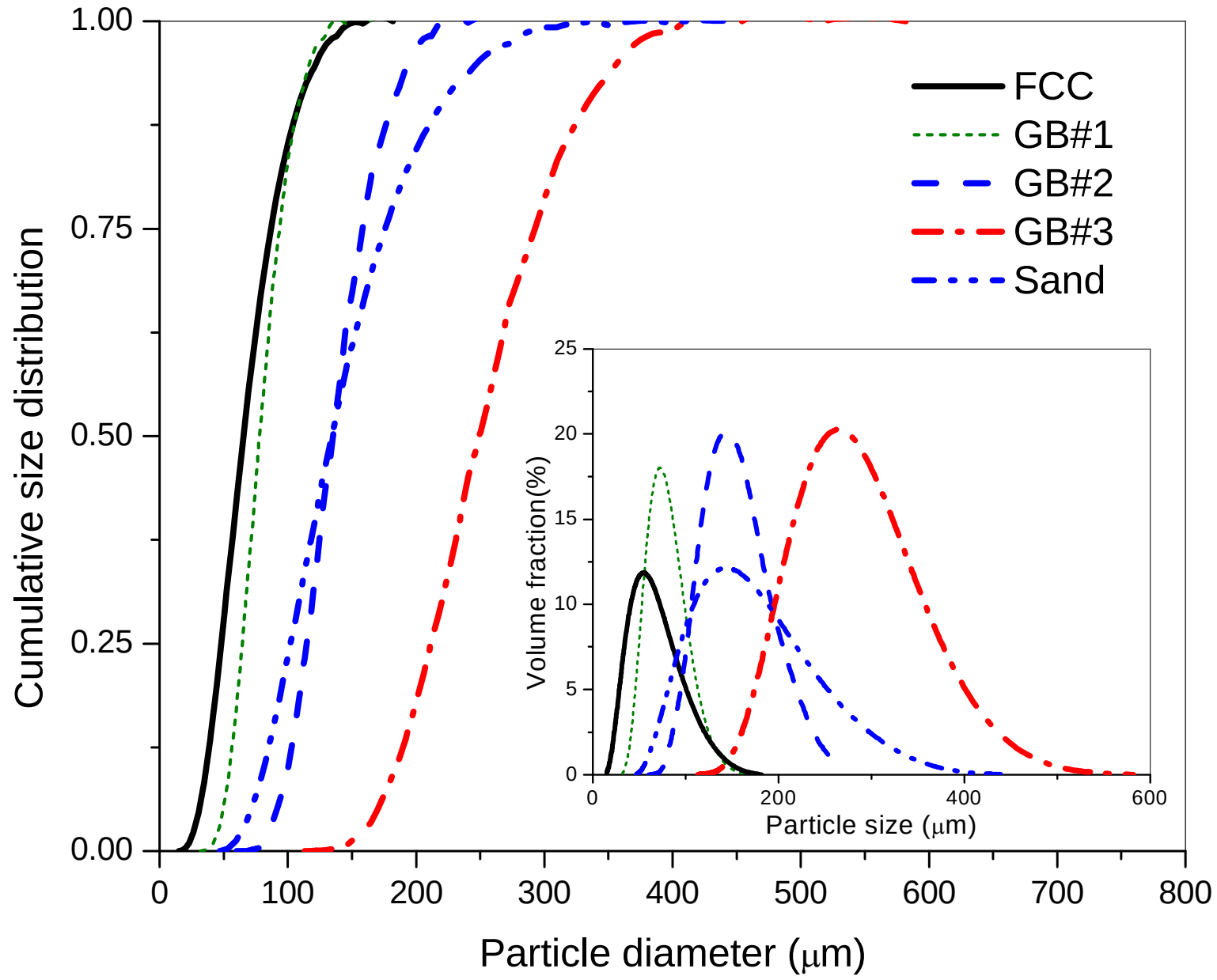
Particles used

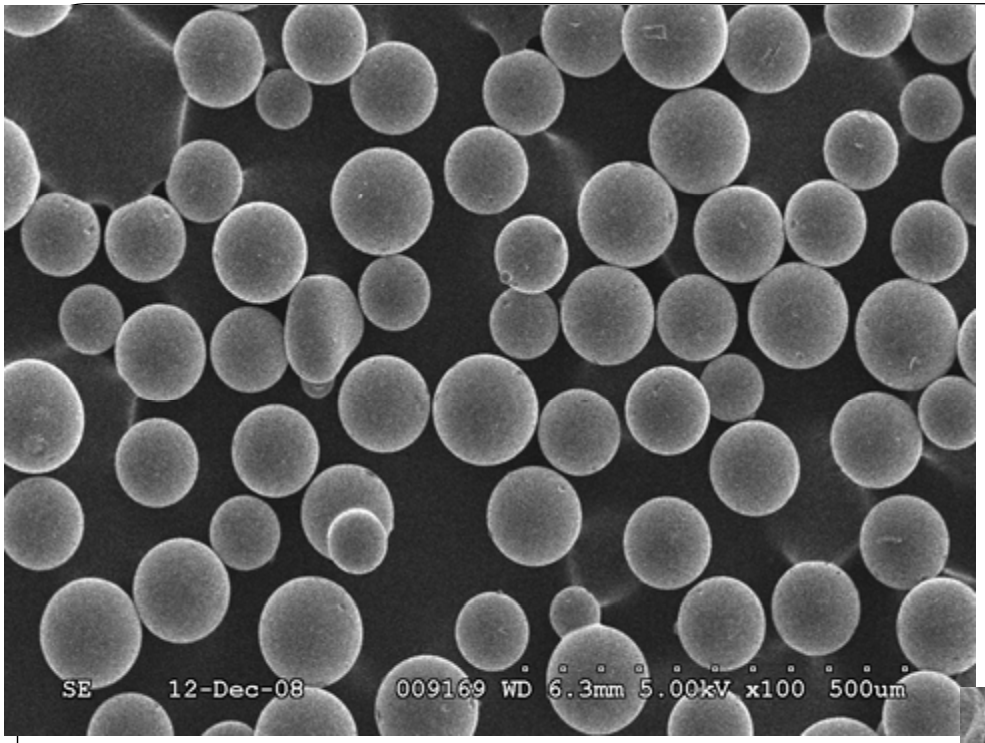
Particles	FCC	Glassbeads #1	Glassbeads #2	Glassbeads #3	Sand
Particle Sauter mean diameter, μm	67	76	138	288	134
Partcle density, kg/m^3	1877	2453	2403	2498	2467
Bulk density, kg/m^3	1125	1434	1421	1475	1453
Sphericity, -	0.95	~1	~1	~1	0.554~0.628
Particle terminal velocity, m/s	0.26	0.42	1.19	3.73	1.56

Operating conditions selected:

U_g = 3.5~8 m/s

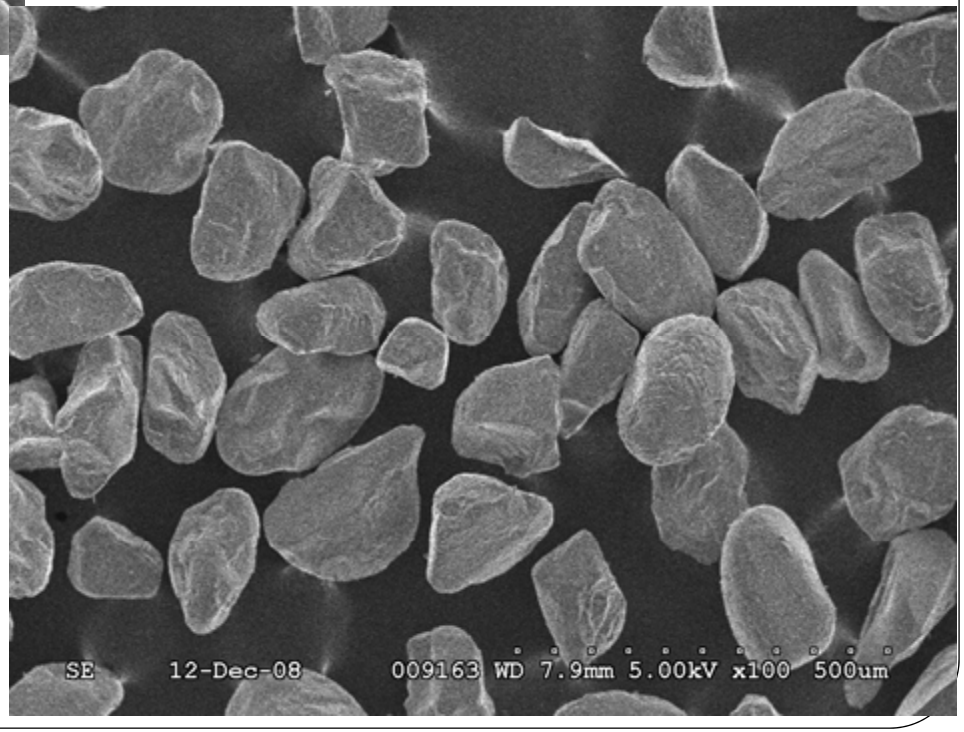
G_s = 50~300 kg/m^2 s

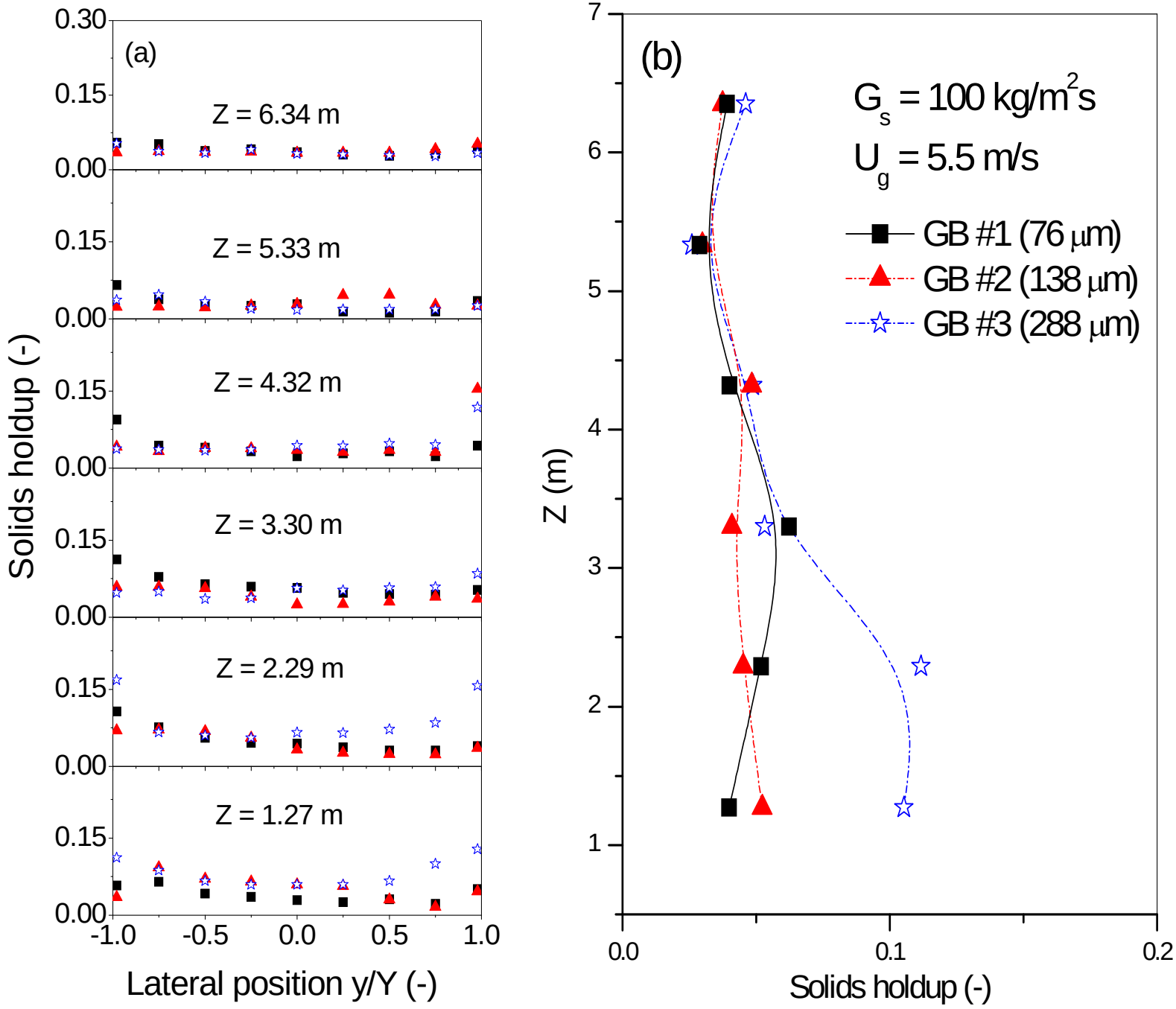

Cumulative size distribution
1.00
0.75
0.50
0.25
0.00
0
100
200
300
400
500
600
700
800
Particle diameter (μm)
FCC
GB#1
GB#2
GB#3
Sand
Volume fraction(%)
25
20
15
10
5
0
0
200
400
600
Particle size (μm)

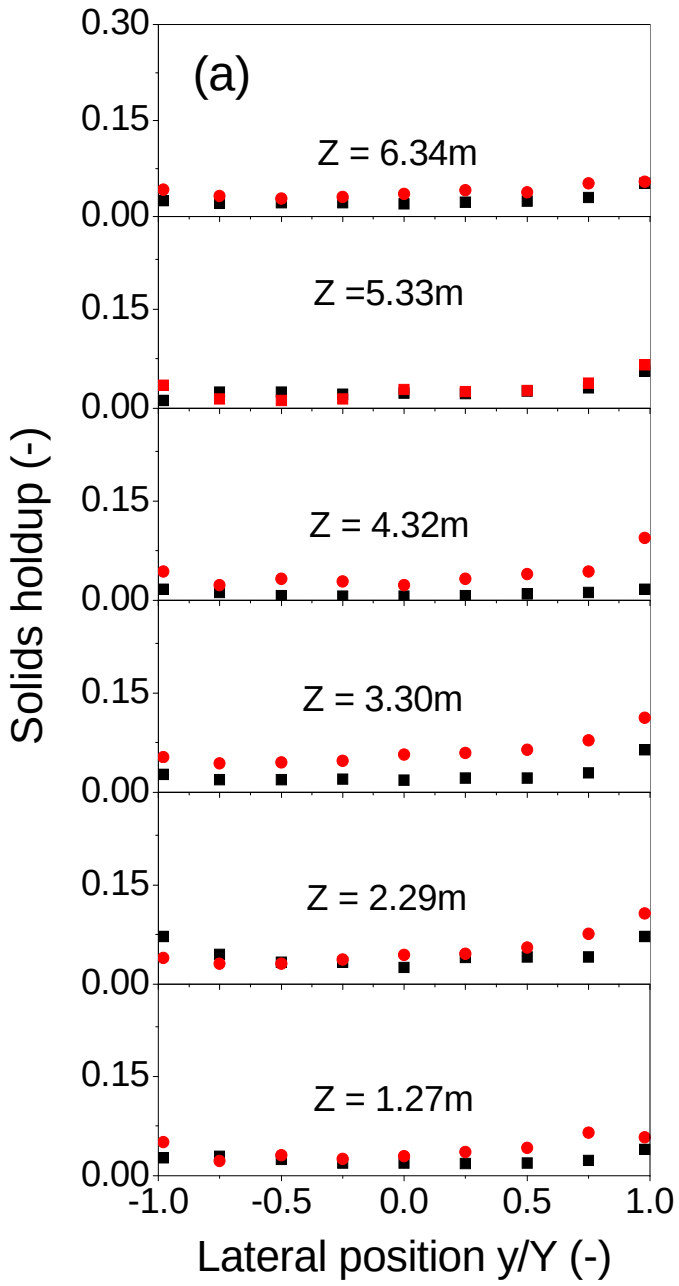


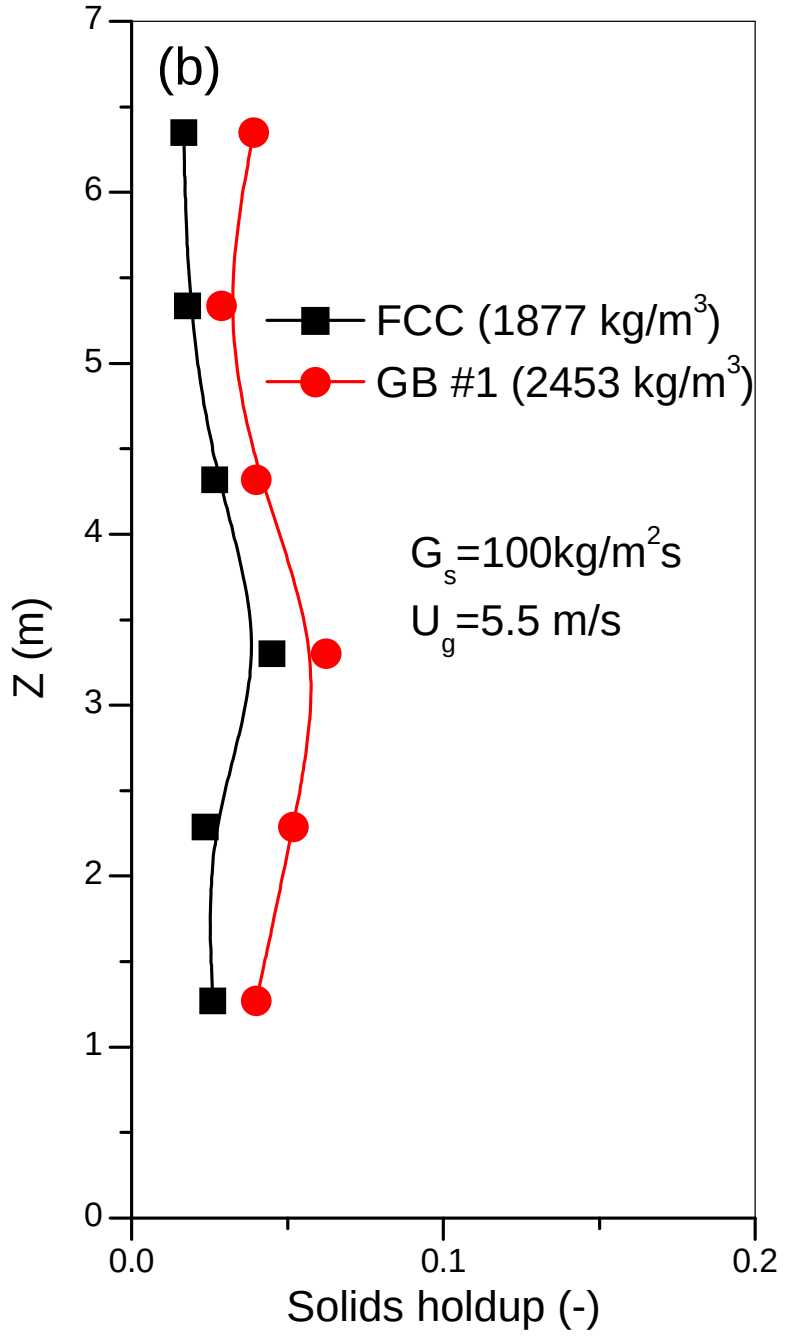
Sand Particles

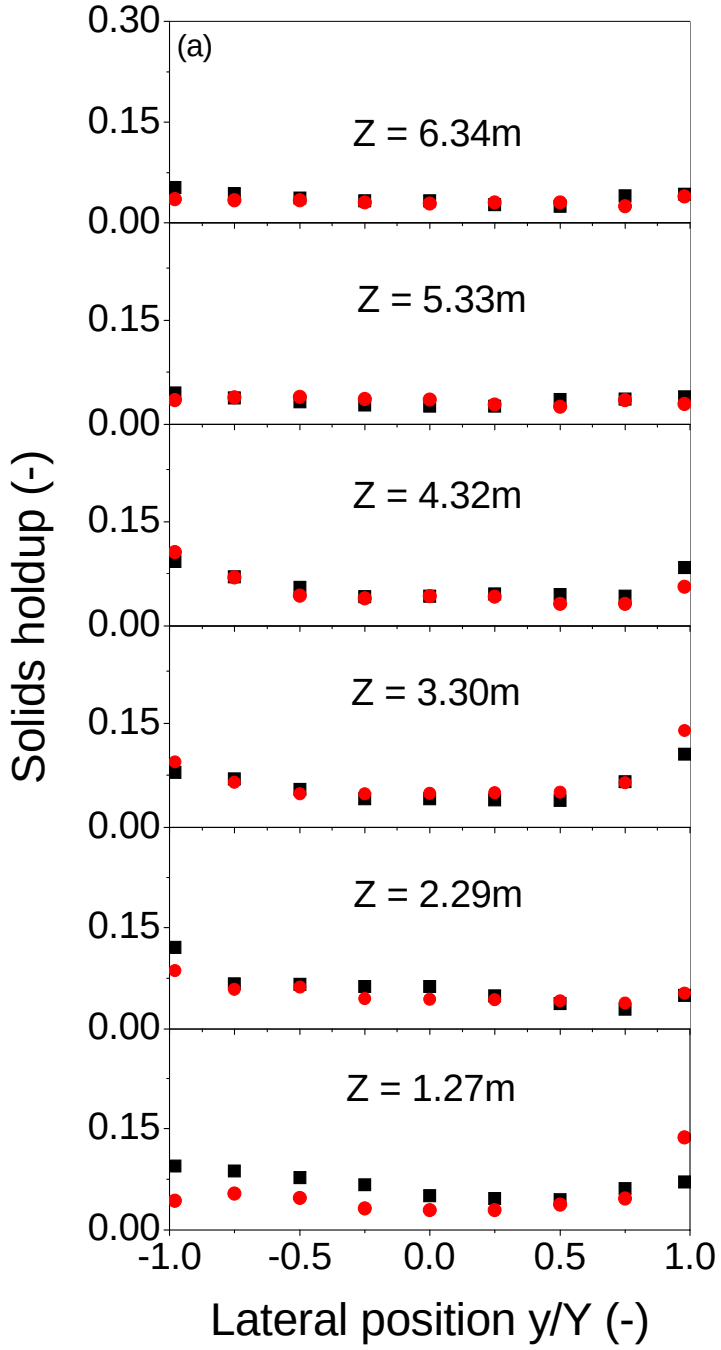
FCC Particles

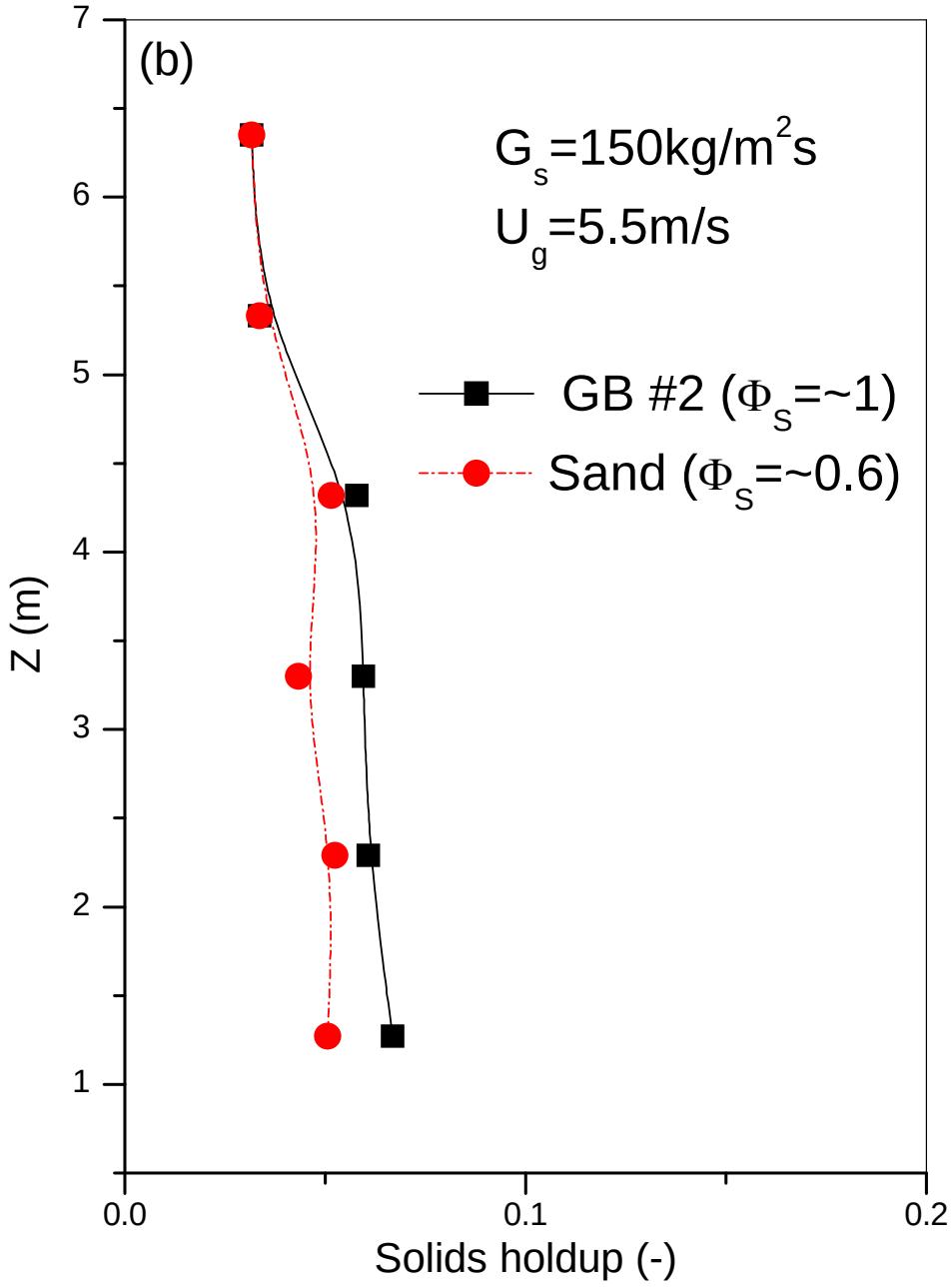



(a)
Z = 6.34 m
Z = 5.33 m
Z = 4.32 m
Z = 3.30 m
Z = 2.29 m
Z = 1.27 m
Solids holdup (-)
Lateral position y/Y (-)
0.30
0.15
0.00
-1.0
-0.5
0.0
0.5
1.0
(b)
G_s = 100 kg/m^{2}s
U_g = 5.5 m/s
GB #1 (76 μm)
GB #2 (138 μm)
GB #3 (288 μm)
Z (m)
Solids holdup (-)
1
2
3
4
5
6
7
0.0
0.1
0.2

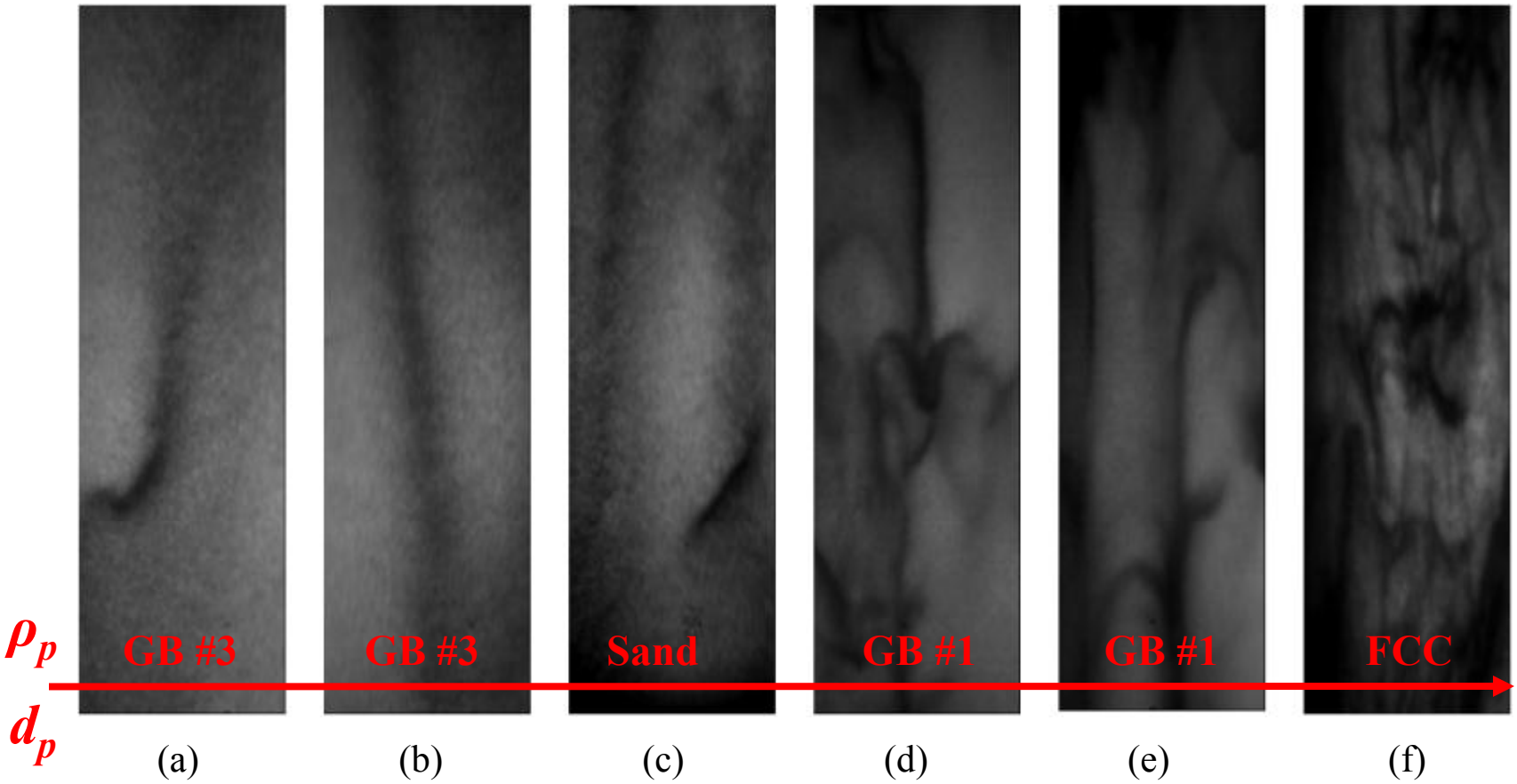

(a)
Z = 6.34m
Z =5.33m
Z = 4.32m
Z = 3.30m
Z = 2.29m
Z = 1.27m
0.30
0.15
0.00
-1.0
-0.5
0.0
0.5
1.0
Solids holdup (-)
Lateral position y/Y (-)


(b)
FCC (1877 kg/m3)
GB #1 (2453 kg/m3)
Gs=100kg/m2s
Ug=5.5 m/s
Z (m)
0
1
2
3
4
5
6
7
0.0
0.1
0.2
Solids holdup (-)


(a)
Z = 6.34m
Z = 5.33m
Z = 4.32m
Z = 3.30m
Z = 2.29m
Z = 1.27m
0.30
0.15
0.00
-1.0
-0.5
0.0
0.5
1.0
Solids holdup (-)
Lateral position y/Y (-)

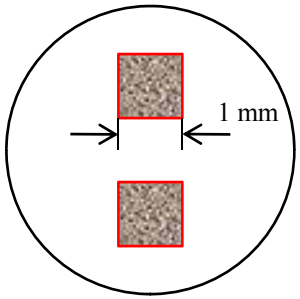

(b)
G_s=150kg/m^2s
U_g=5.5m/s
GB #2 (Φ_S=~1)
Sand (Φ_S=~0.6)
Z (m)
7
6
5
4
3
2
1
0.0
0.1
0.2
Solids holdup (-)

Particle properties effects on aggregations

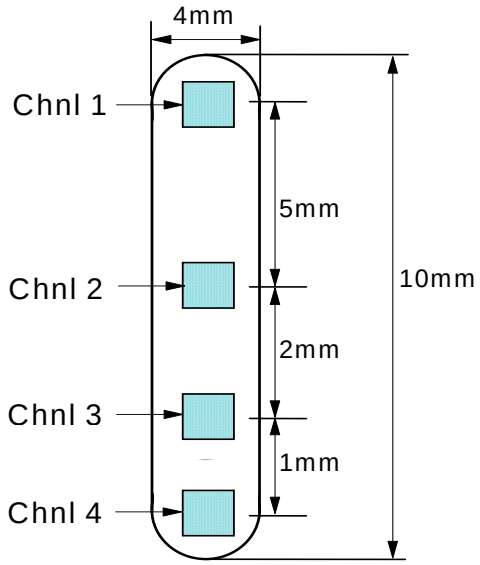


Cluster structures observed in the riser center under different operating conditions: (a) Glassbead #3, d_p = 288 μm, ρ_p = 2498 kg/m^3, Φ_s = ~ 1, G_s = 100 kg/m^2·s, U_g = 5 m/s; (b) Glassbead #3, G_s = 100 kg/m^2·s, U_g = 8 m/s; (c) Sand, d_p = 134 μm, ρ_p = 2467 kg/m^3, Φ_s = ~ 0.6, G_s = 100 kg/m^2·s, U_g = 5 m/s; (d) Glassbead #1, d_p = 76 μm, ρ_p = 2453 kg/m^3, Φ_s = ~ 1, G_s = 100 kg/m^2·s, U_g = 5 m/s; (e) Glassbead #1, G_s = 150 kg/m^2·s, U_g = 5 m/s; (f) FCC, d_p = 67 μm, ρ_p = 1877 kg/m^3, Φ_s = 0.95, G_s = 100 kg/m^2·s, U_g = 5 m/s

Criteria for clusters



2-Channel

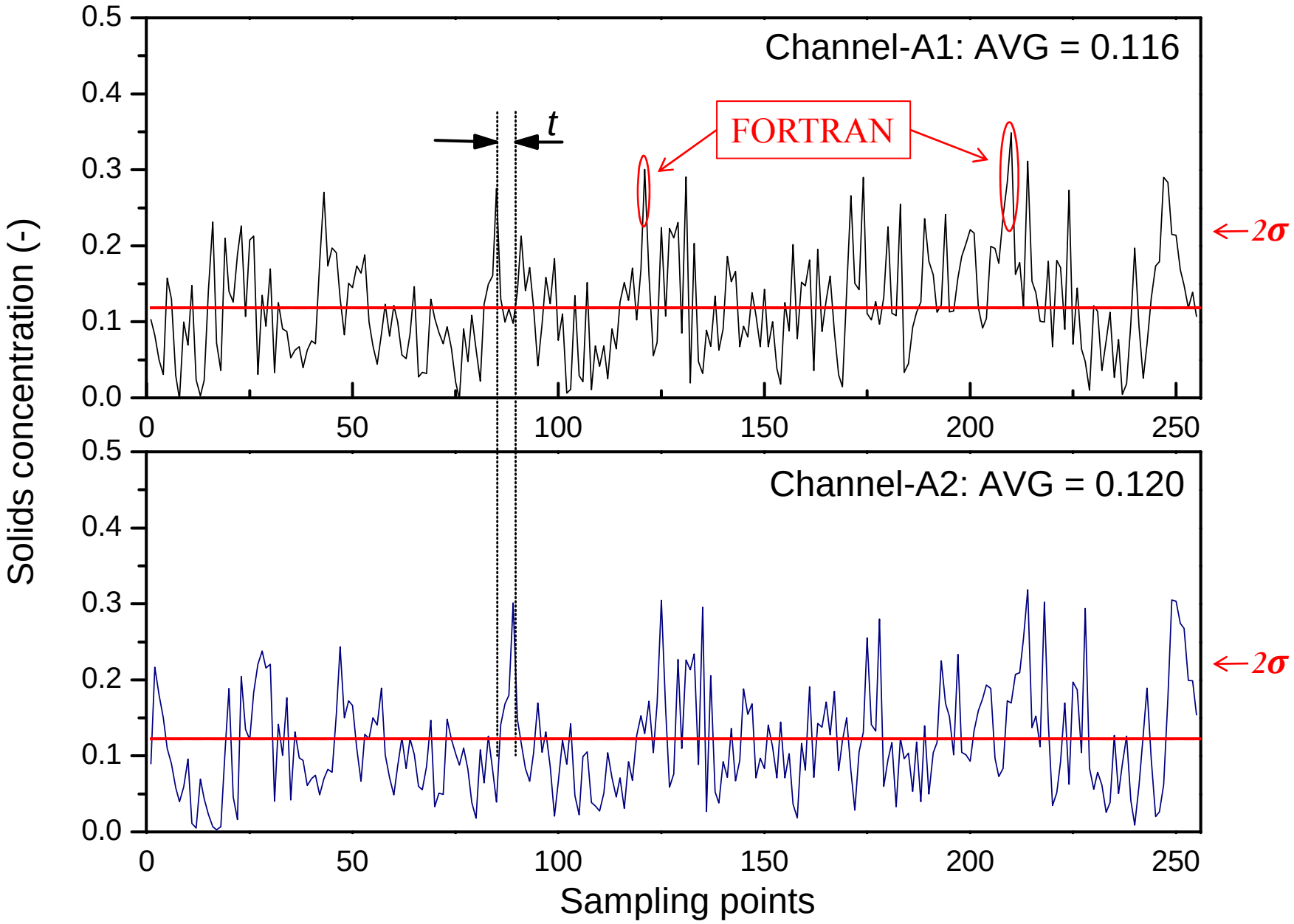


4-Channel

(1) Critical solids concentration: must be over *n*-times the standard deviation of the sampled signal

(2) N_s: Number of consecutive samples above the critical solids concentration. Set to determine the minimum time interval for the perturbation caused by a cluster

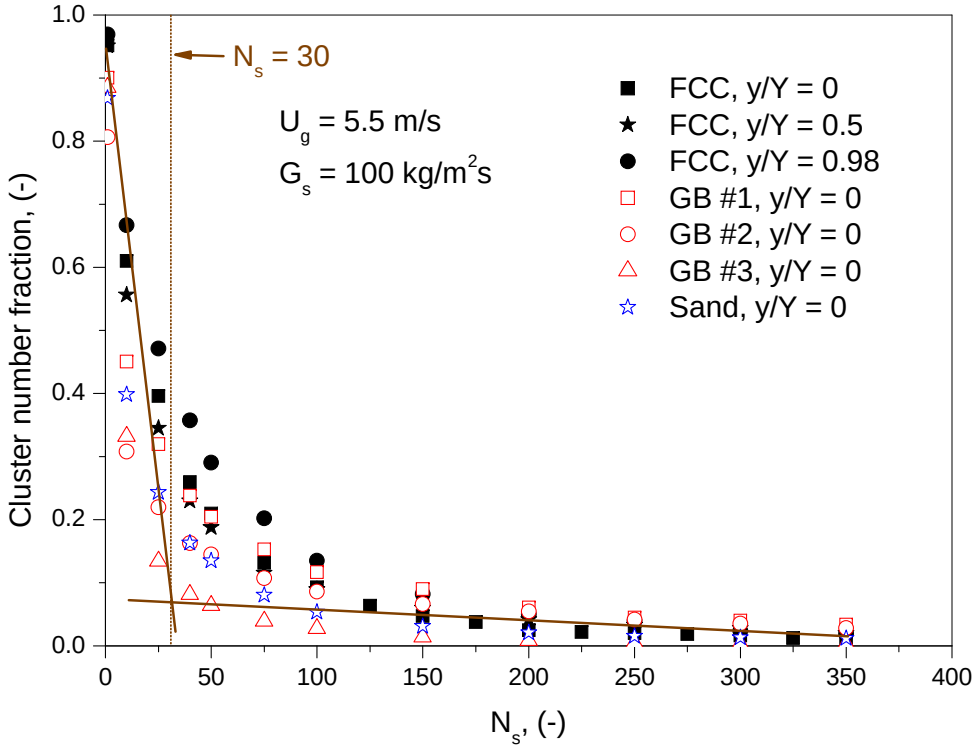
(3) The sampling volume must be greater than one to two orders of particle diameter


Channel-A1: AVG = 0.116
FORTRAN
t
2σ
Channel-A2: AVG = 0.120
2σ
Solids concentration (-)
Sampling points
0.0
0.1
0.2
0.3
0.4
0.5
0
50
100
150
200
250

A New aggregation characteristic (Cluster Number Fraction, F_{lc})

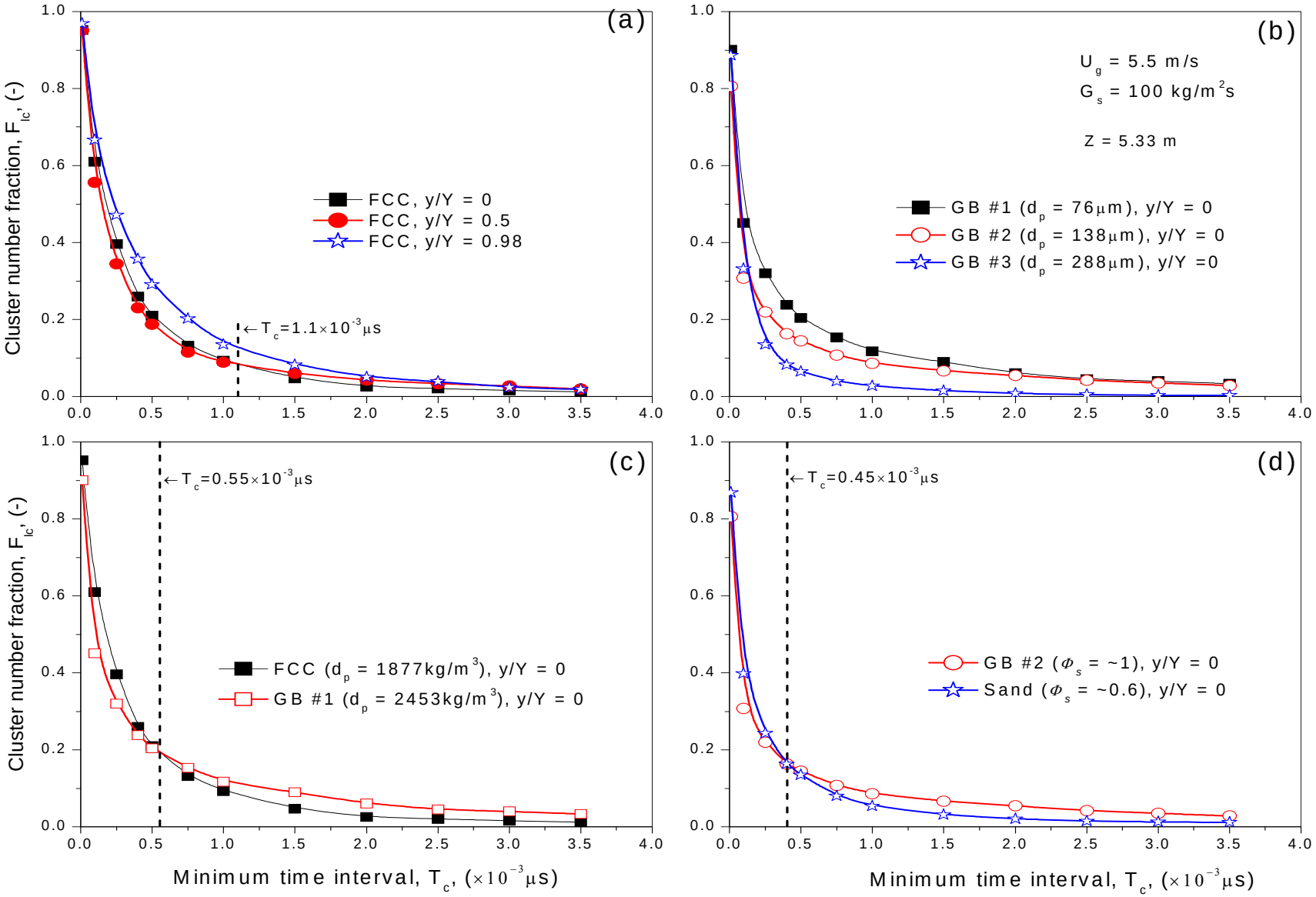
$$F_{lc} = N_{lc} / N_c$$

- N_c is the total number of the clusters (without minimum time interval limitation).
- N_{lc} is the number of clusters with N_s consecutive samples (minimum time interval) above the critical solids concentration



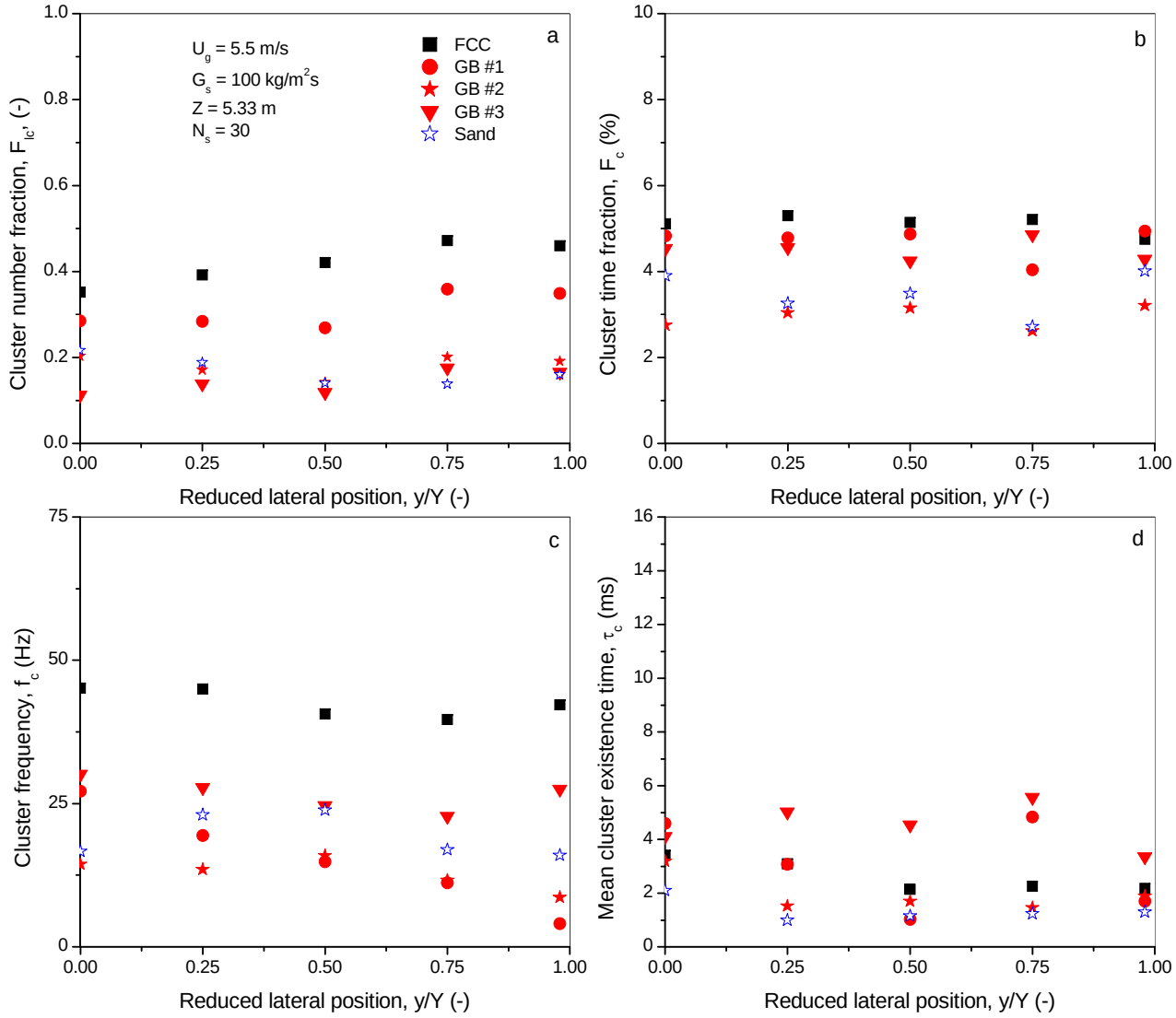
- An increase/decrease of N_s would lower/raise the fraction of clusters with existence time longer than N_s sampling time interval

Cluster number fraction with particle properties influences



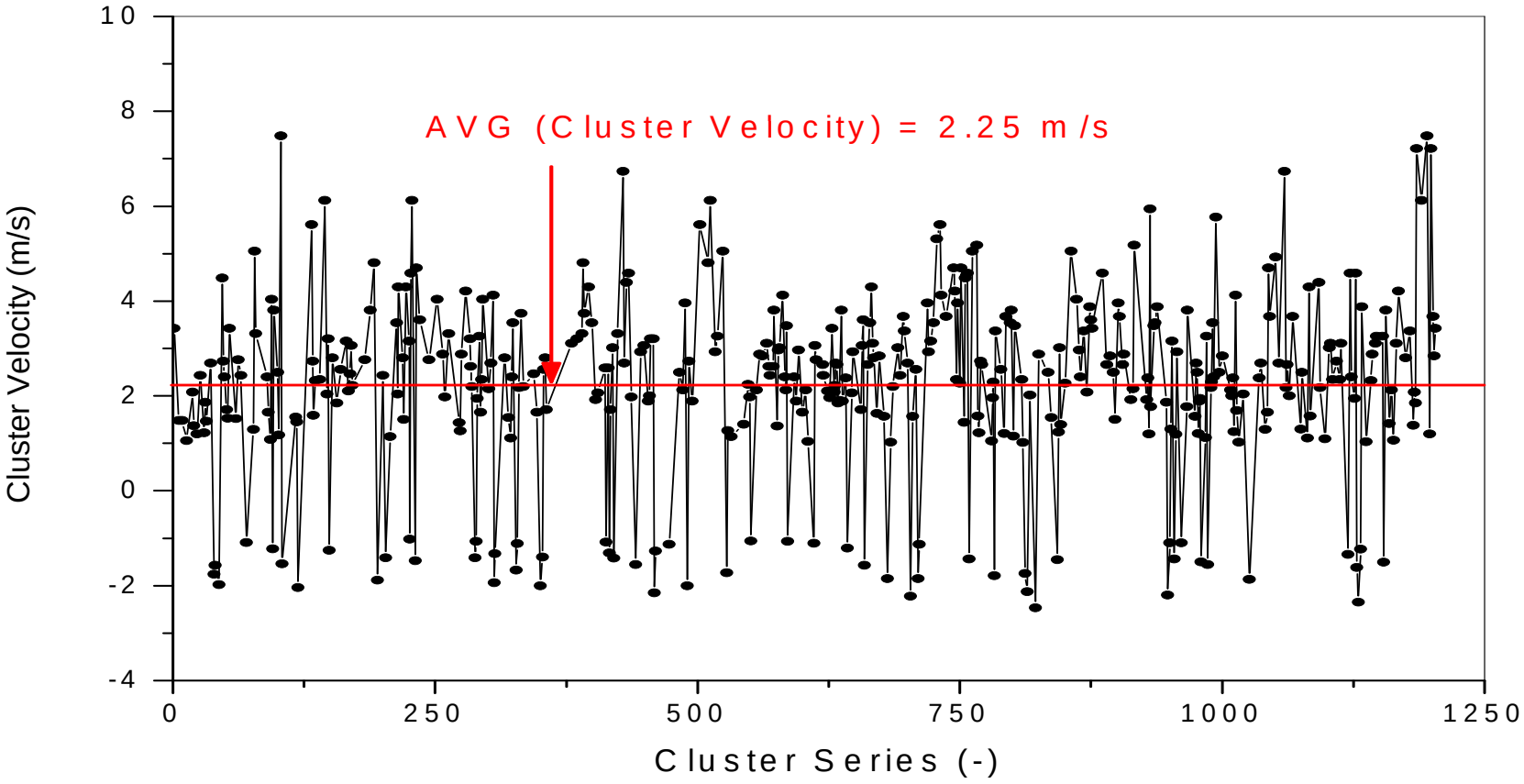
Characteristics of aggregates

- Cluster number fraction, F_{lc}
- *Cluster time fraction,* F_c
- Cluster frequency, *fc*
- Mean cluster existence time, τ_c



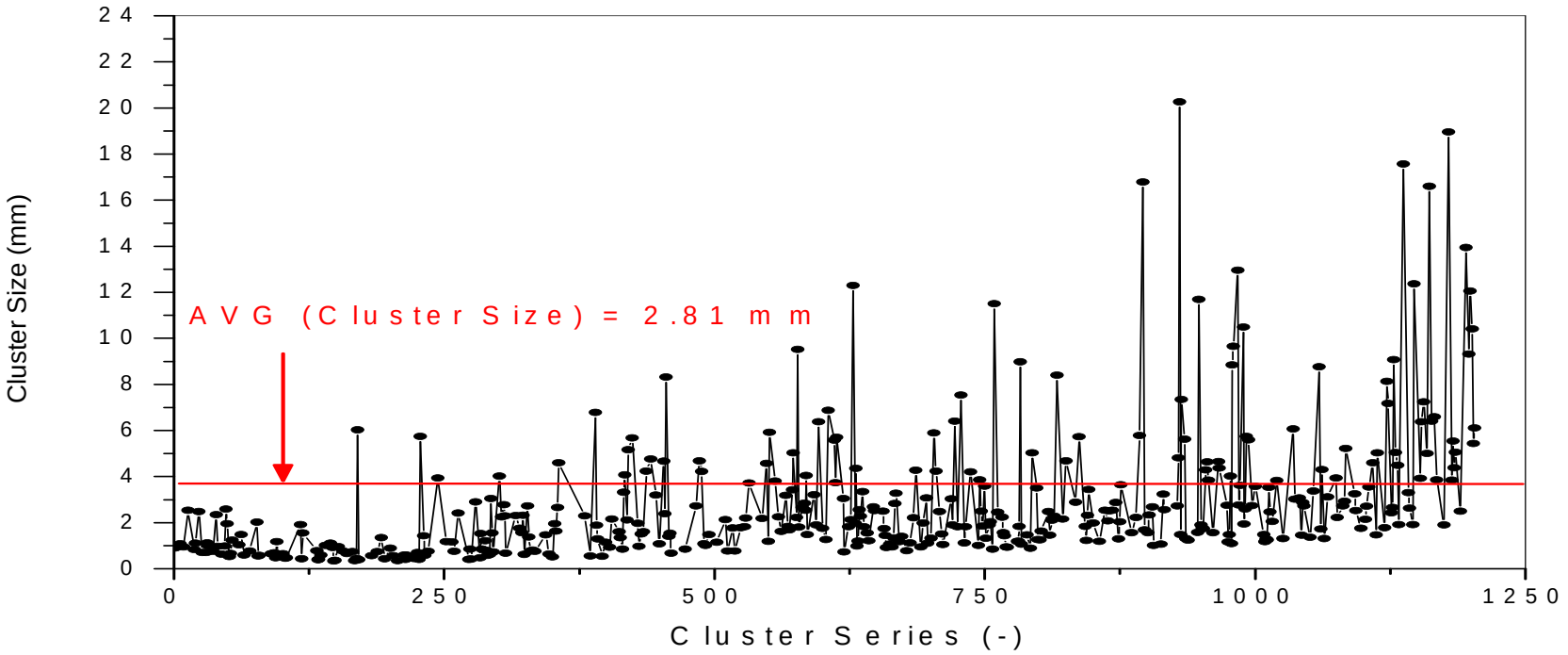
Instantaneous cluster velocity

- FORTRAN: Cluster detection
- Cross-correlation use

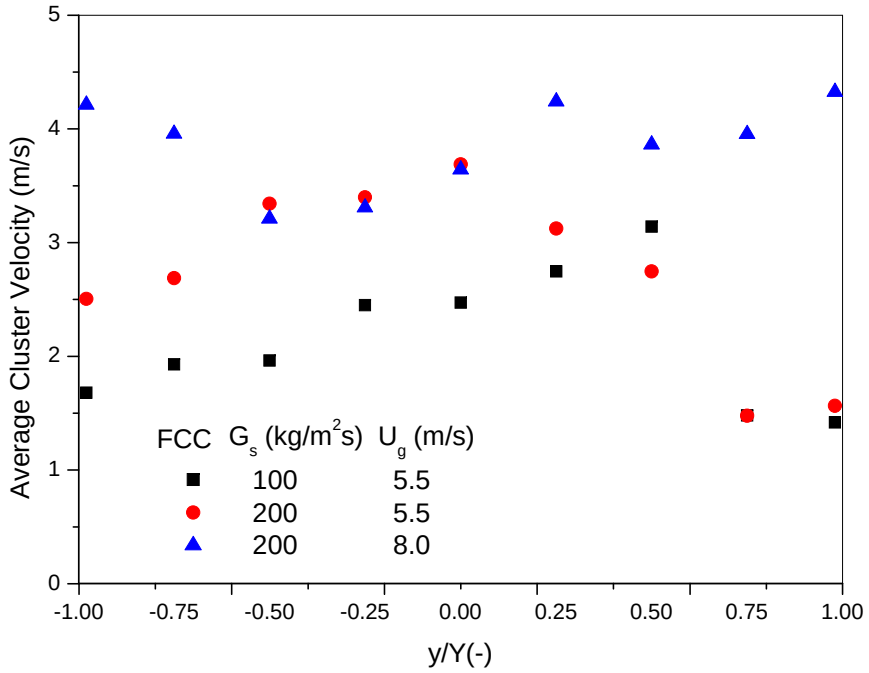


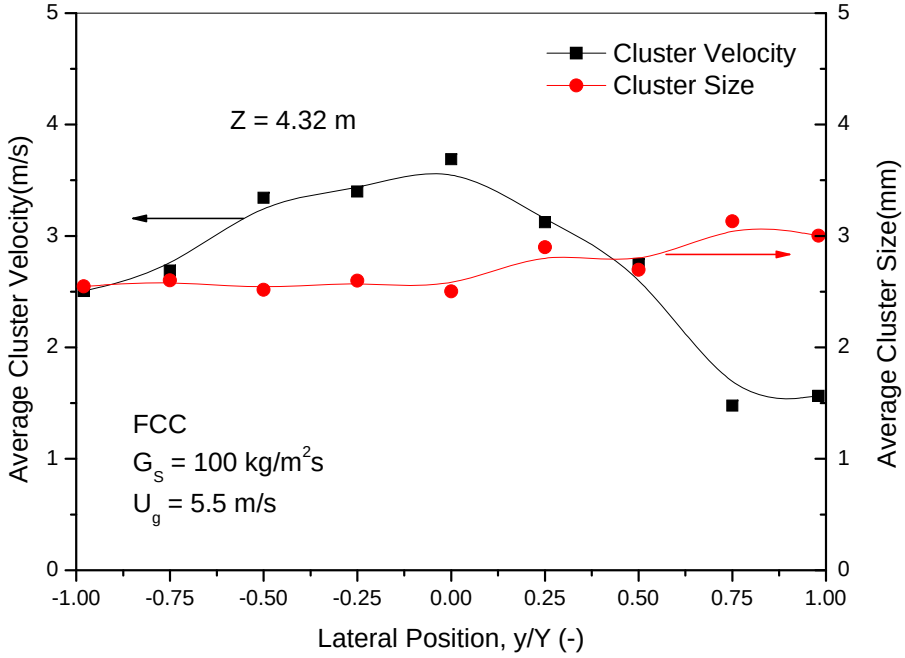
Instantaneous cluster size

- Cluster vertical length
- $d_{cl} = V_c \times T$, V_c is cluster velocity, T is the transit time for each cluster



Average cluster velocity & size





Increase *Ug* and *Gs*
Increase cluster velocity

Cluster velocity high/low
Cluster size small/large

Summary

- Observation: cluster shape, size and velocity, influence from particle properties
- Quantified analyses: cluster properties F_{lc} , F_c , f_c , τ_c vs. U_g , G_s , d_p , ρ_p , Φ_s
- A new method to determine the cluster velocity and size V_c vs. d_{lc}

Thank you!