Modulator and Wiggler simulations

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Beam parameters

- Electron Beam

  Bunch length = 3e-3m, RMS bunch width = 6.83e-4m, number density (lab) = $5.59e+17/m^3$
- Ion Beam

  Bunch length = 6e-1m, bunch width = 5e-4m, number density (lab) = $3.32e+14/m^3$
- Kappa2 velocity distribution in beam frame

  $\beta_x = \beta_y = 2e+6m/s, \beta_z = 3e+5m/s$
- Transversal Debye length (lab) : 3e-4m
- Longitudinal Debye length (lab) : 1e-6m

Numerical setting

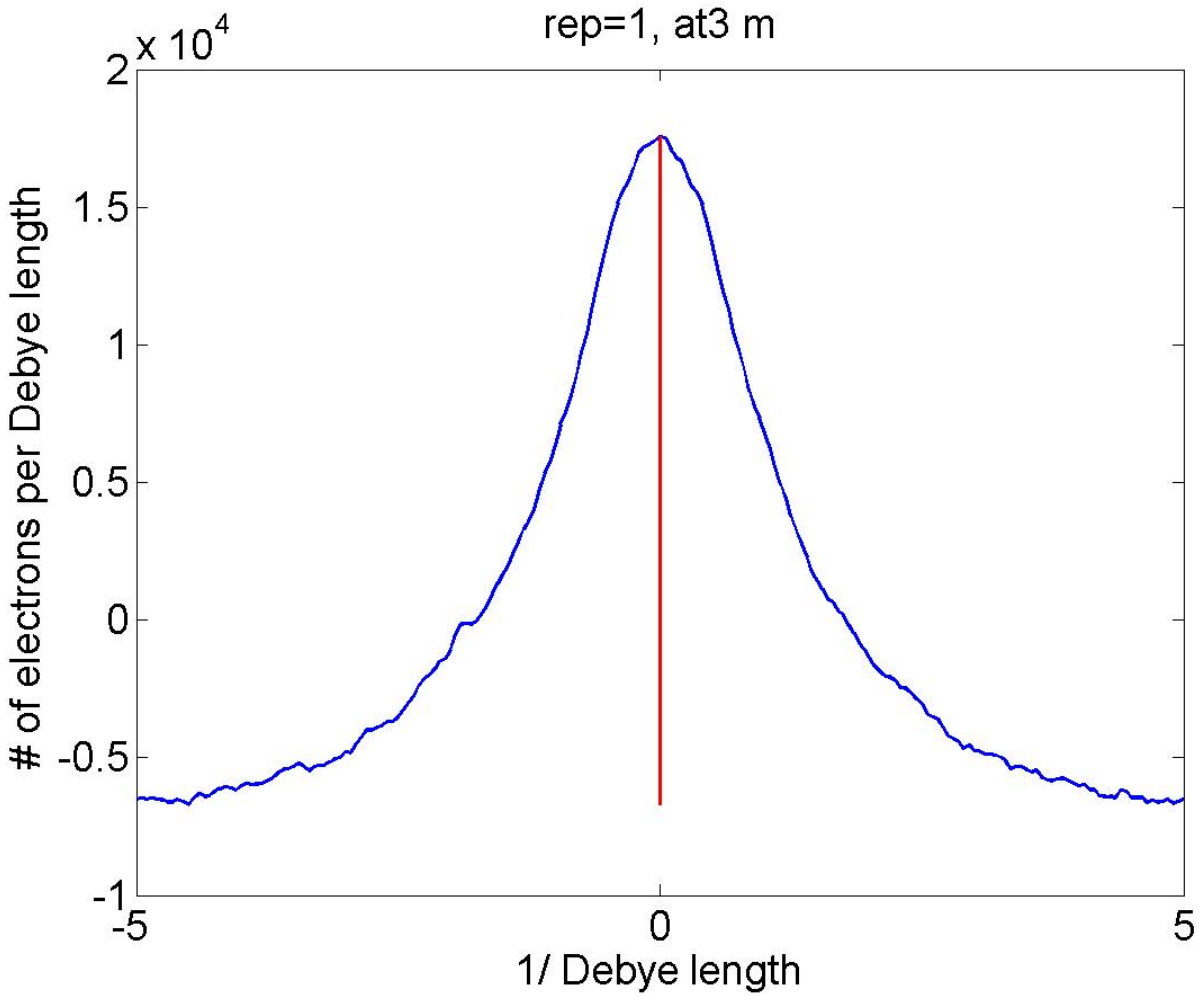
- Domain size
  - Transversal : 2.4e-3m ($8 \times$ *Debyelength*)
  - Longitudinal : 1e-5m ($10 \times$ *Debyelength*)
- Grid number : 20 / 5 per Debye length
- Electron
  - number of computational particles : 3e+7 / 3e+5
  - representing number : 1 / 1e+2
- Ion
  - number of computational particles : 1
  - representing number : 1e+3

Verification

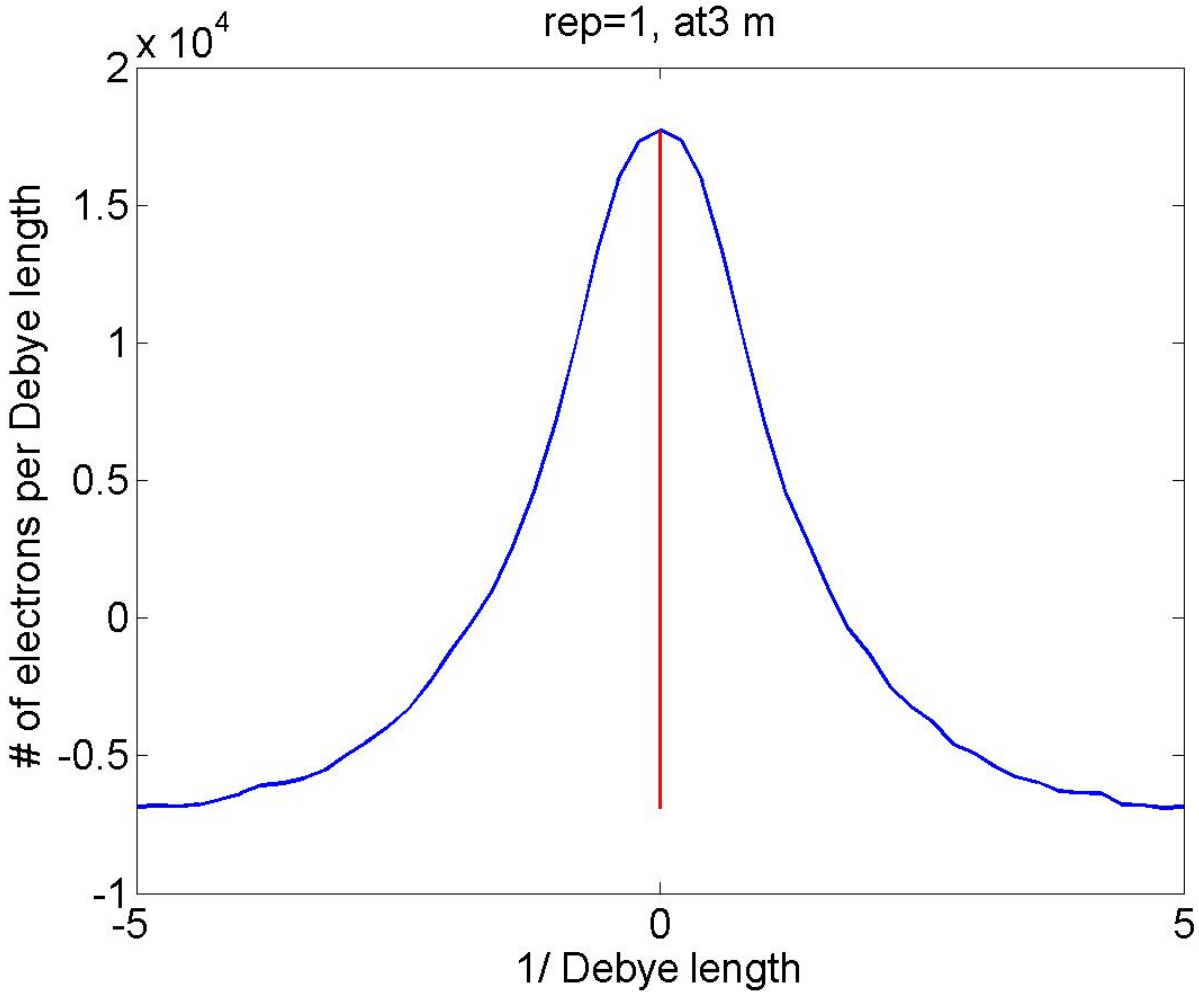
Ion representing number = 1e+3

- 20 grids per Debye length, number of macro electrons = 3e+7, representing number = 1
- 5 grids per Debye length, number of macro electrons = 3e+7, representing number = 1
- 5 grids per Debye length, number of macro electrons = 3e+5, representing number = 1e+2

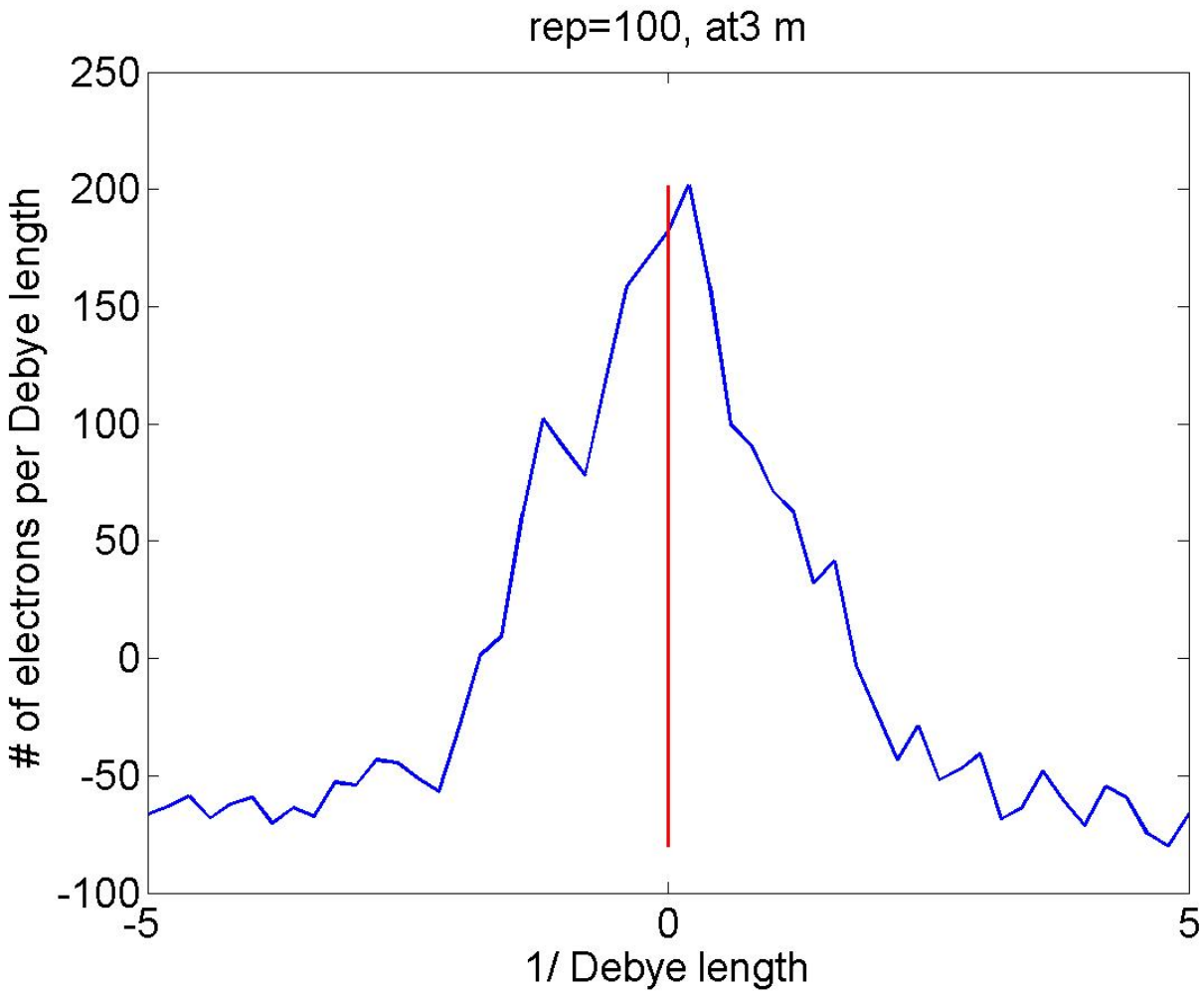
Fine mesh


rep=1, at3 m
x 10^4
2
1.5
1
0.5
0
-0.5
-1
# of electrons per Debye length
-5
0
5
1/ Debye length

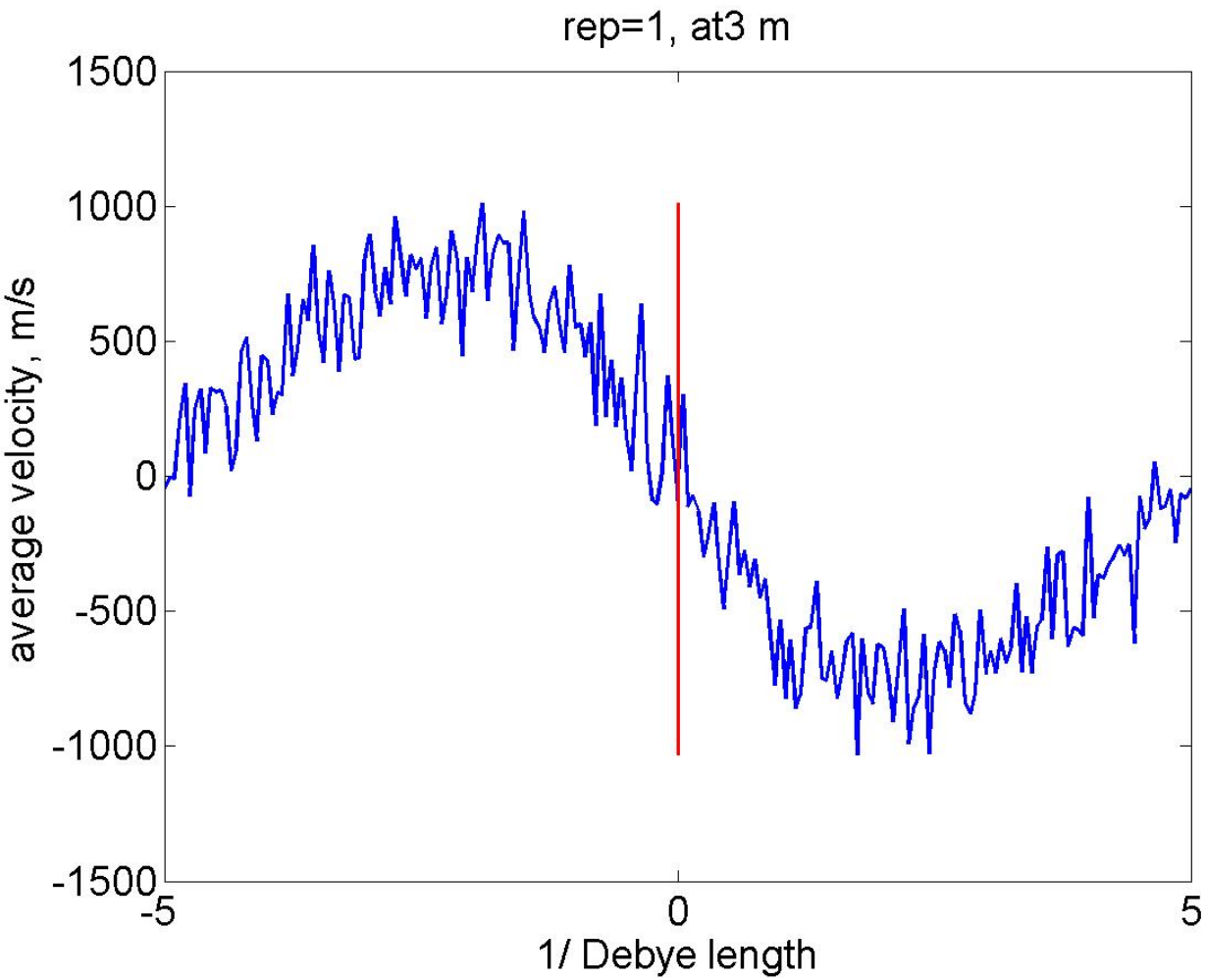
Coarse mesh


rep=1, at3 m
x 10^4
2
1.5
1
0.5
0
-0.5
-1
# of electrons per Debye length
-5
0
5
1/ Debye length

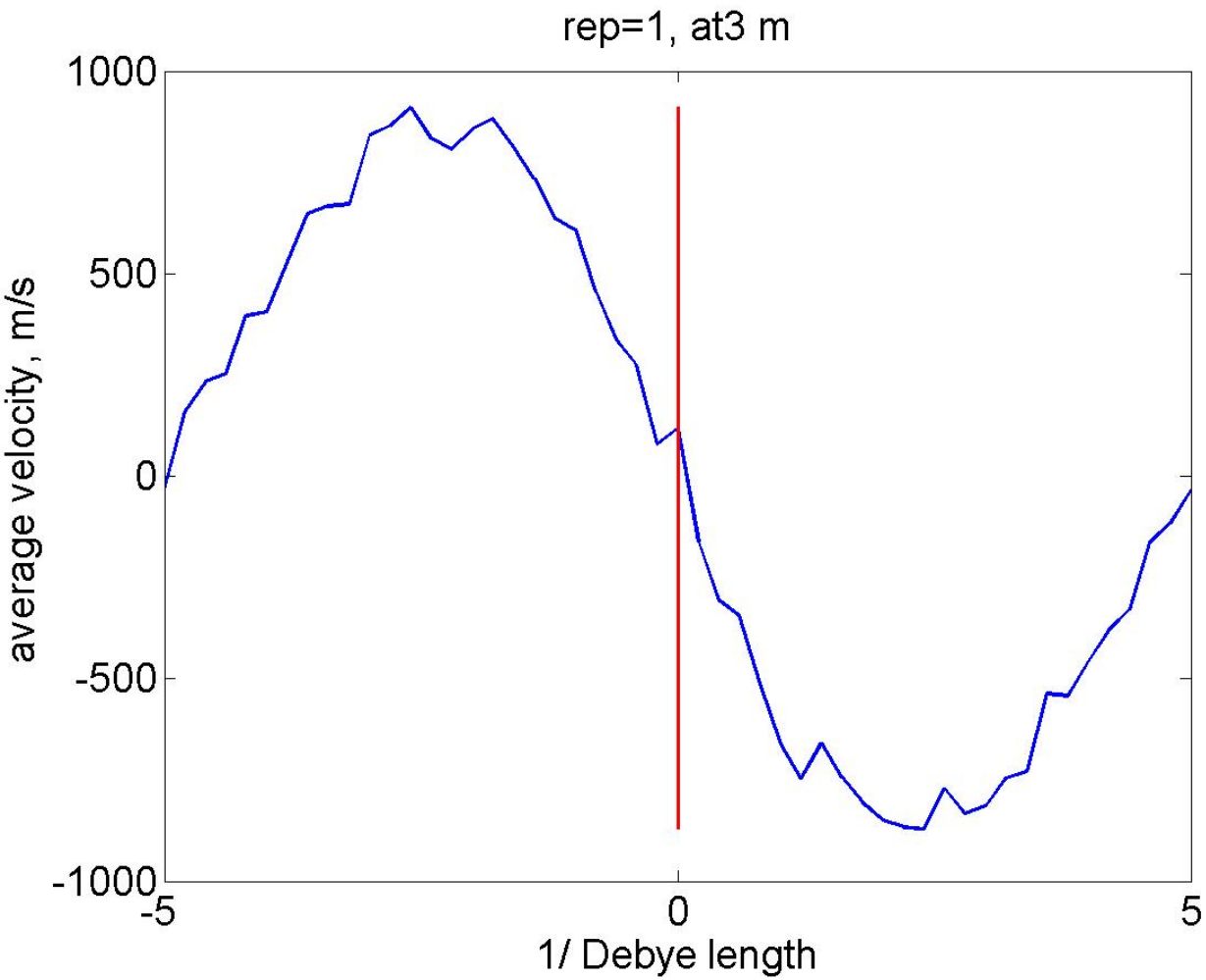
Coarse mesh, less macro electrons



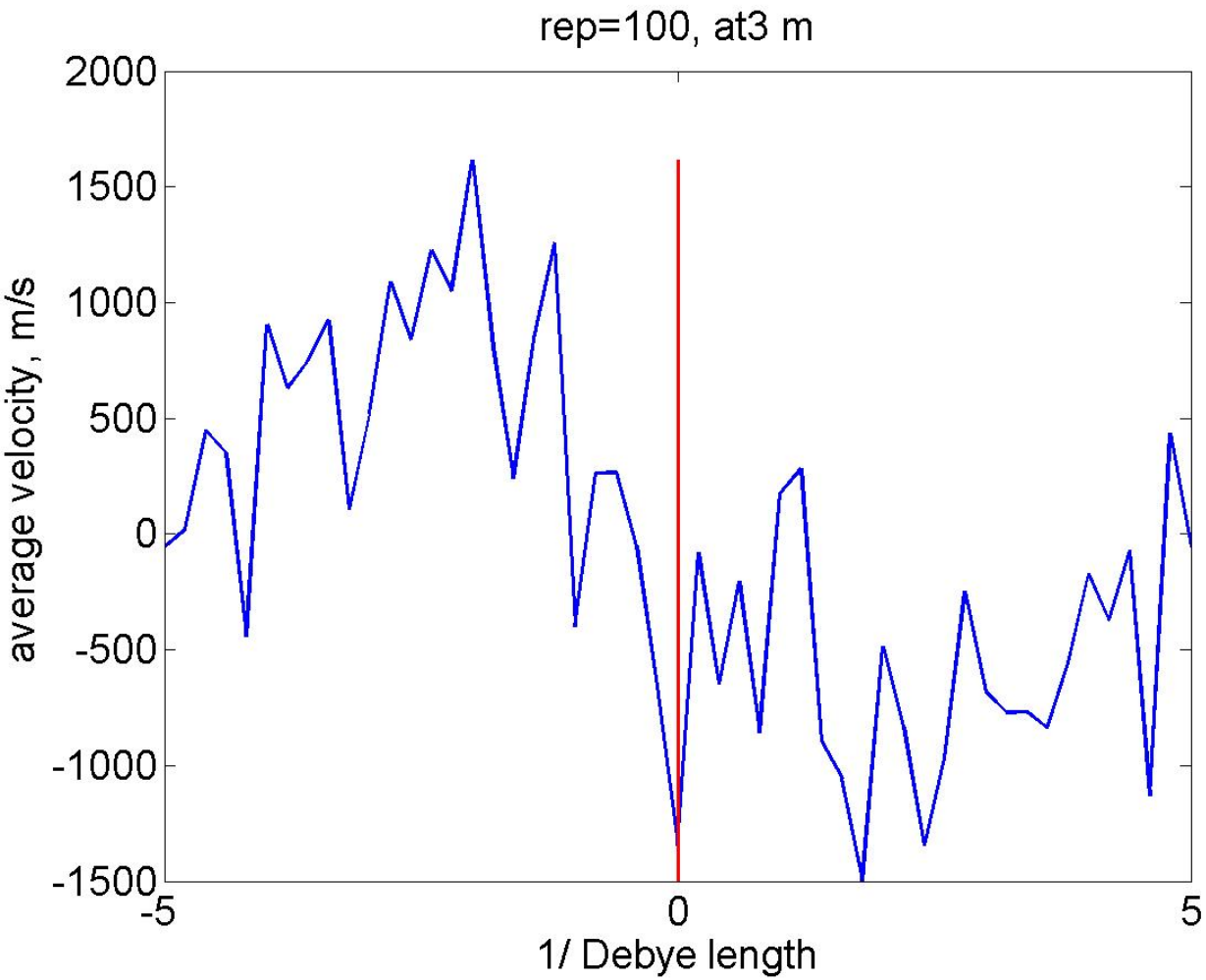
Fine mesh


rep=1, at3 m
1500
1000
500
0
-500
-1000
-1500
average velocity, m/s
-5
0
5
1/ Debye length

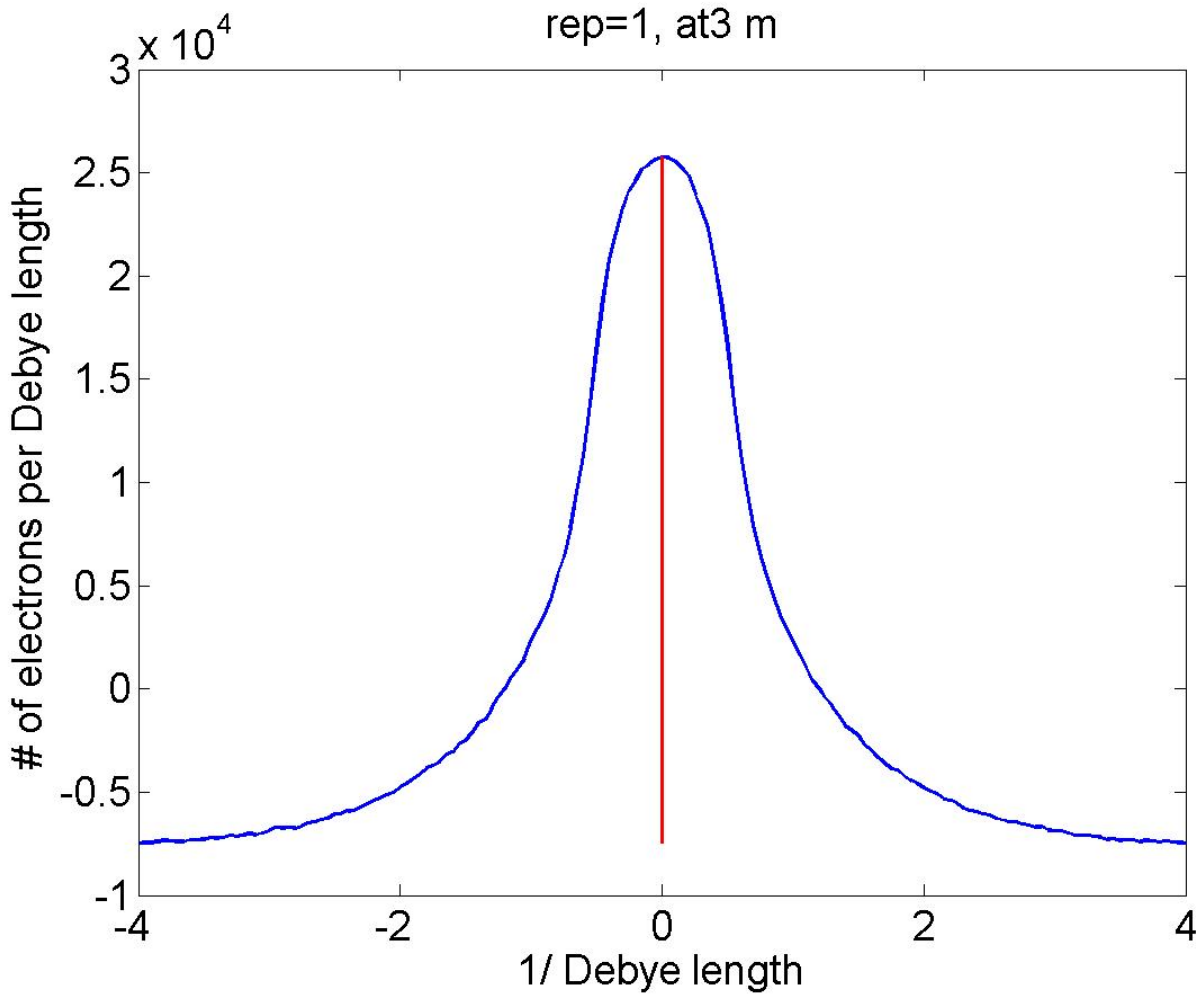
Coarse mesh


rep=1, at3 m
1000
500
0
-500
-1000
average velocity, m/s
-5
0
5
1/ Debye length

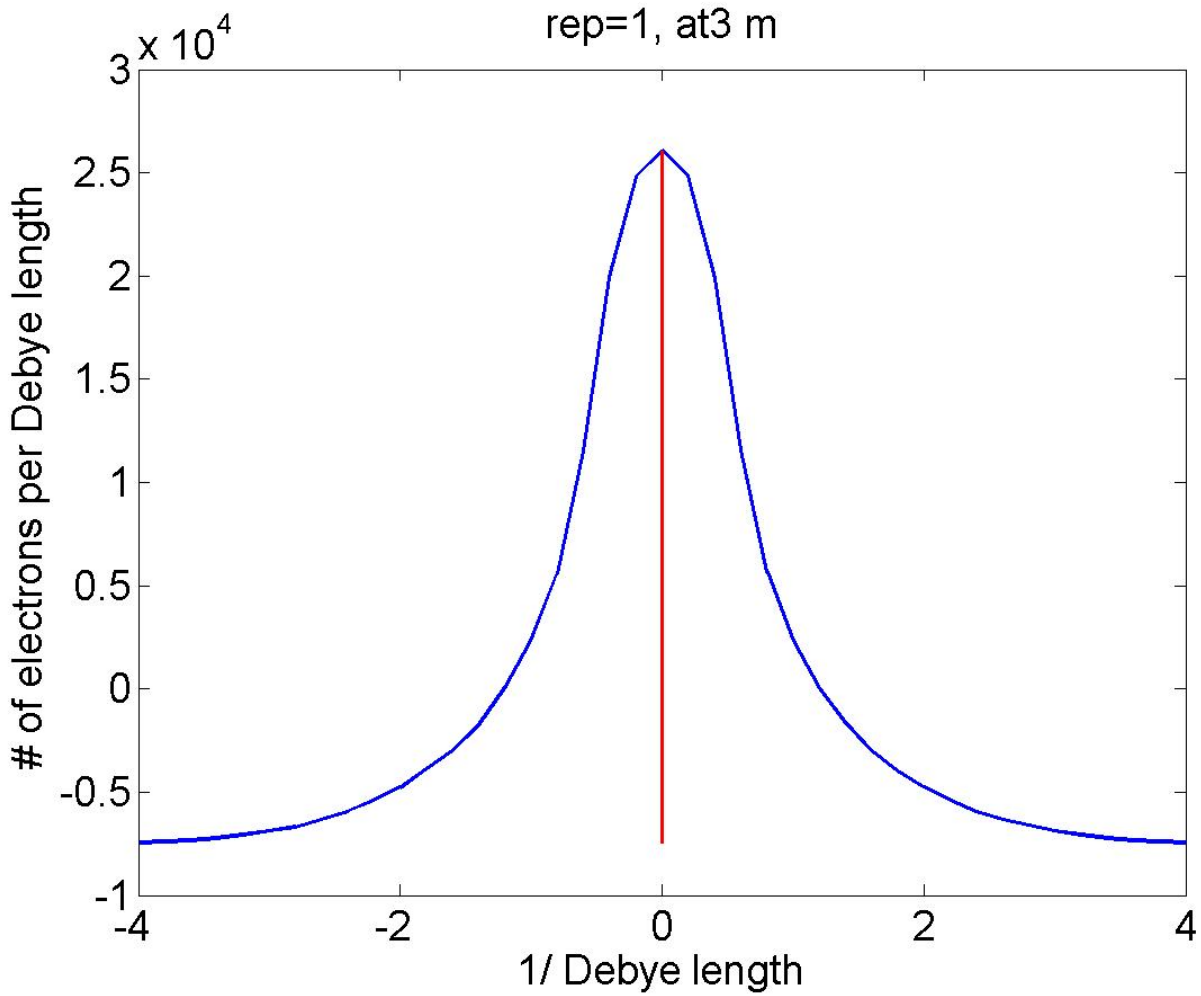
Coarse mesh, less macro electrons



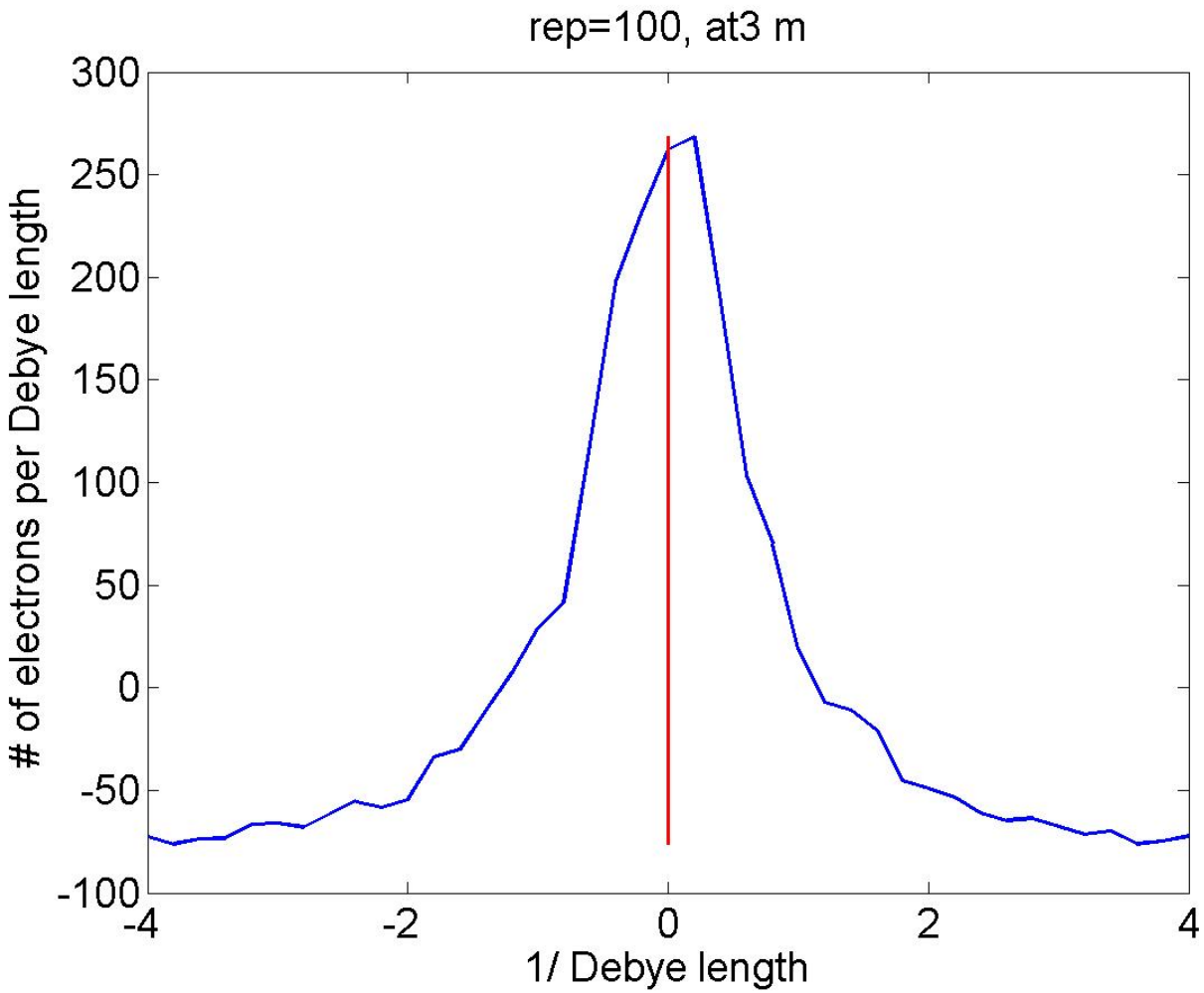
Fine mesh


rep=1, at3 m
x 10^4
3
2.5
2
1.5
1
0.5
0
-0.5
-1
# of electrons per Debye length
-4
-2
0
2
4
1/ Debye length

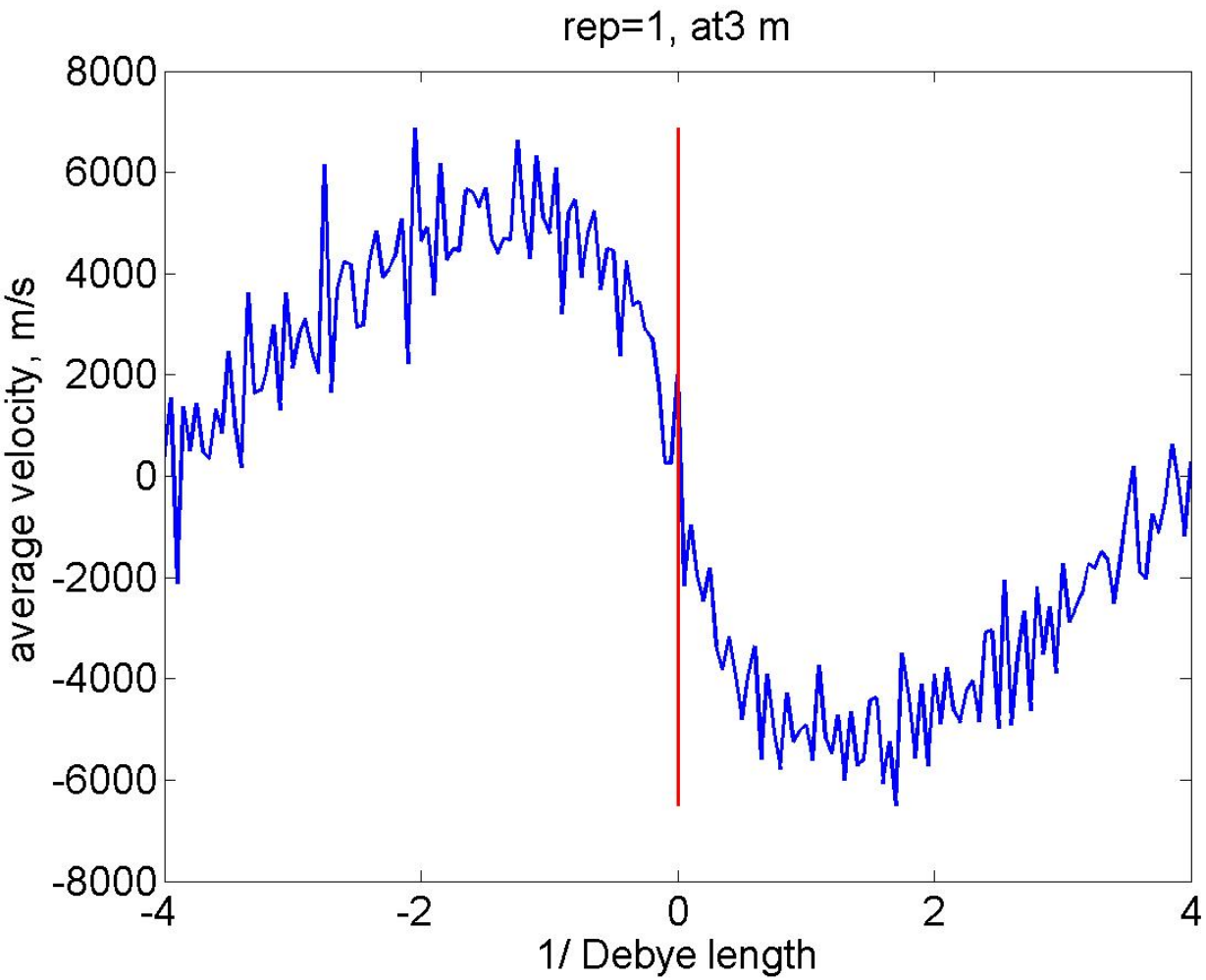
Coarse mesh


rep=1, at3 m
x 10^4
3
2.5
2
1.5
1
0.5
0
-0.5
-1
# of electrons per Debye length
-4
-2
0
2
4
1/ Debye length

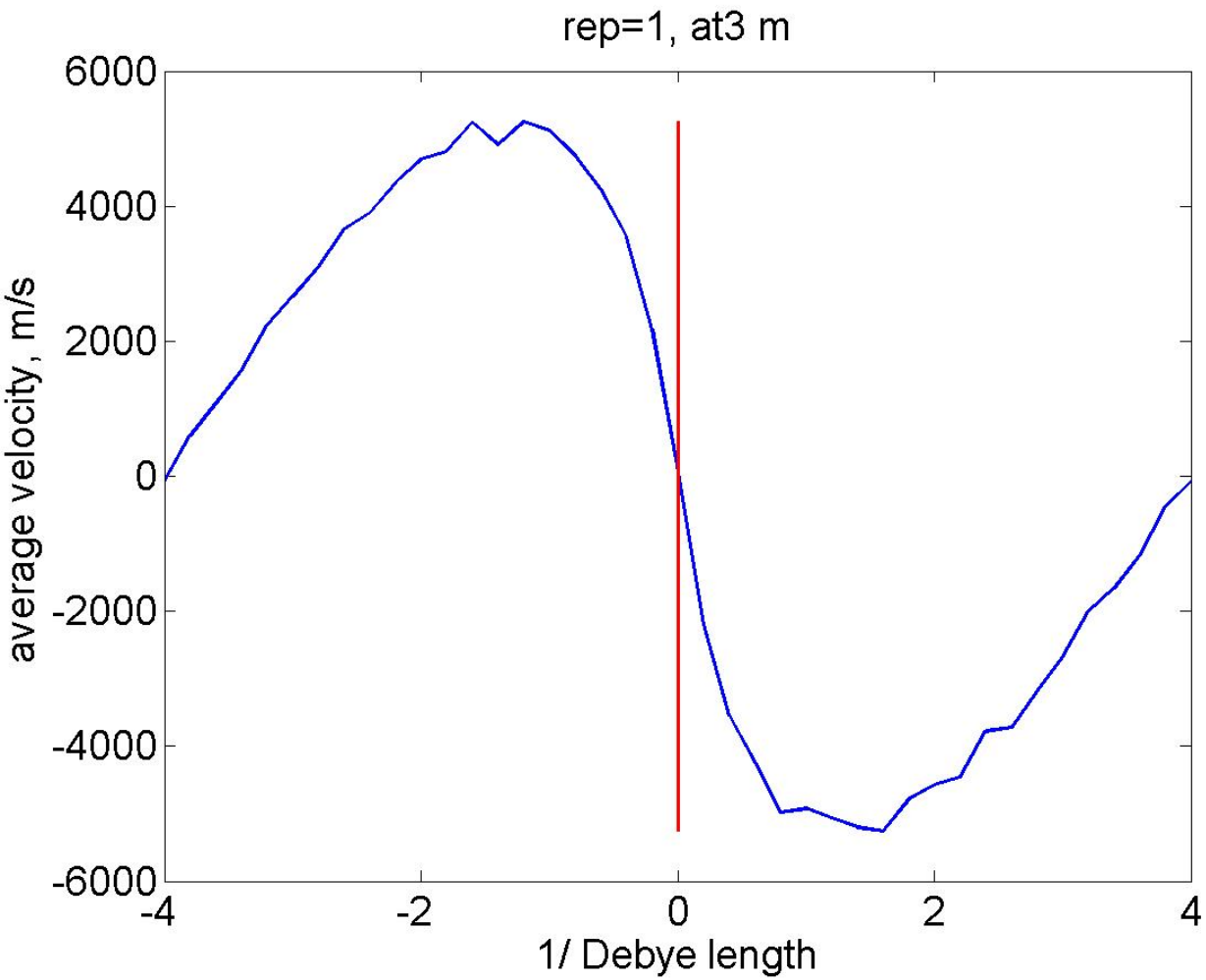
Coarse mesh, less macro electrons



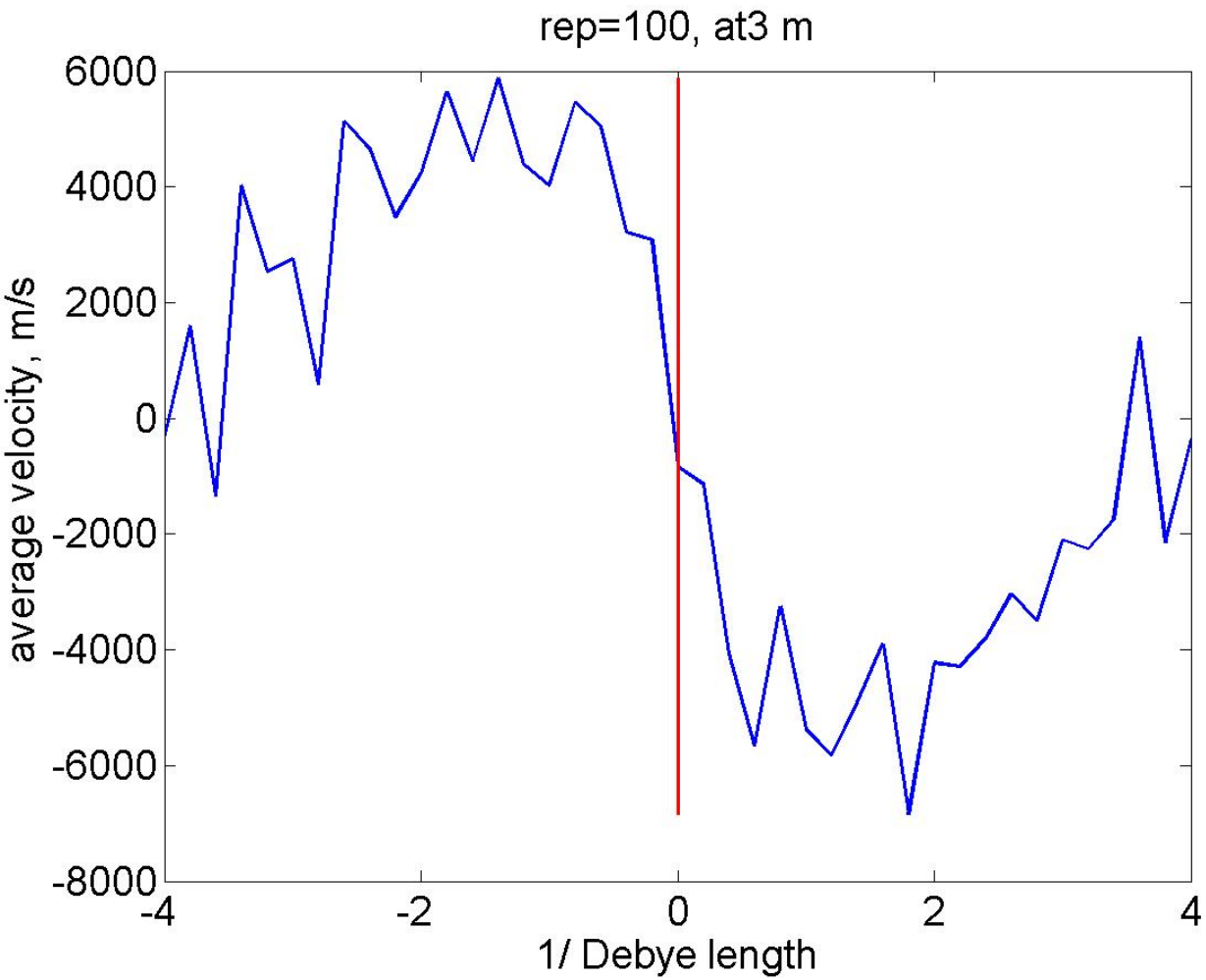
Fine mesh


rep=1, at3 m
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
average velocity, m/s
-4
-2
0
2
4
1/ Debye length

Coarse mesh

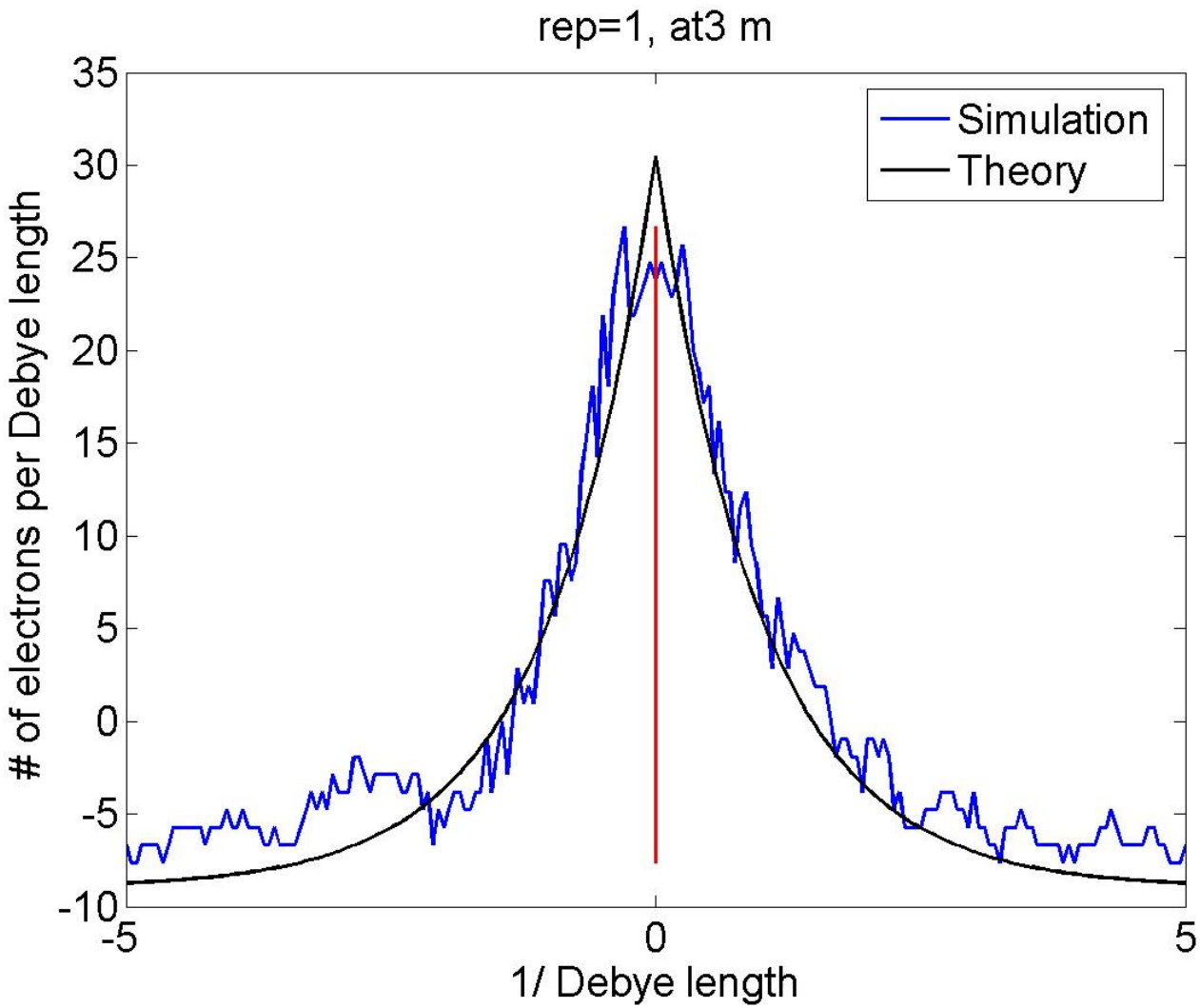

rep=1, at3 m
6000
4000
2000
0
-2000
-4000
-6000
average velocity, m/s
-4
-2
0
2
4
1/ Debye length

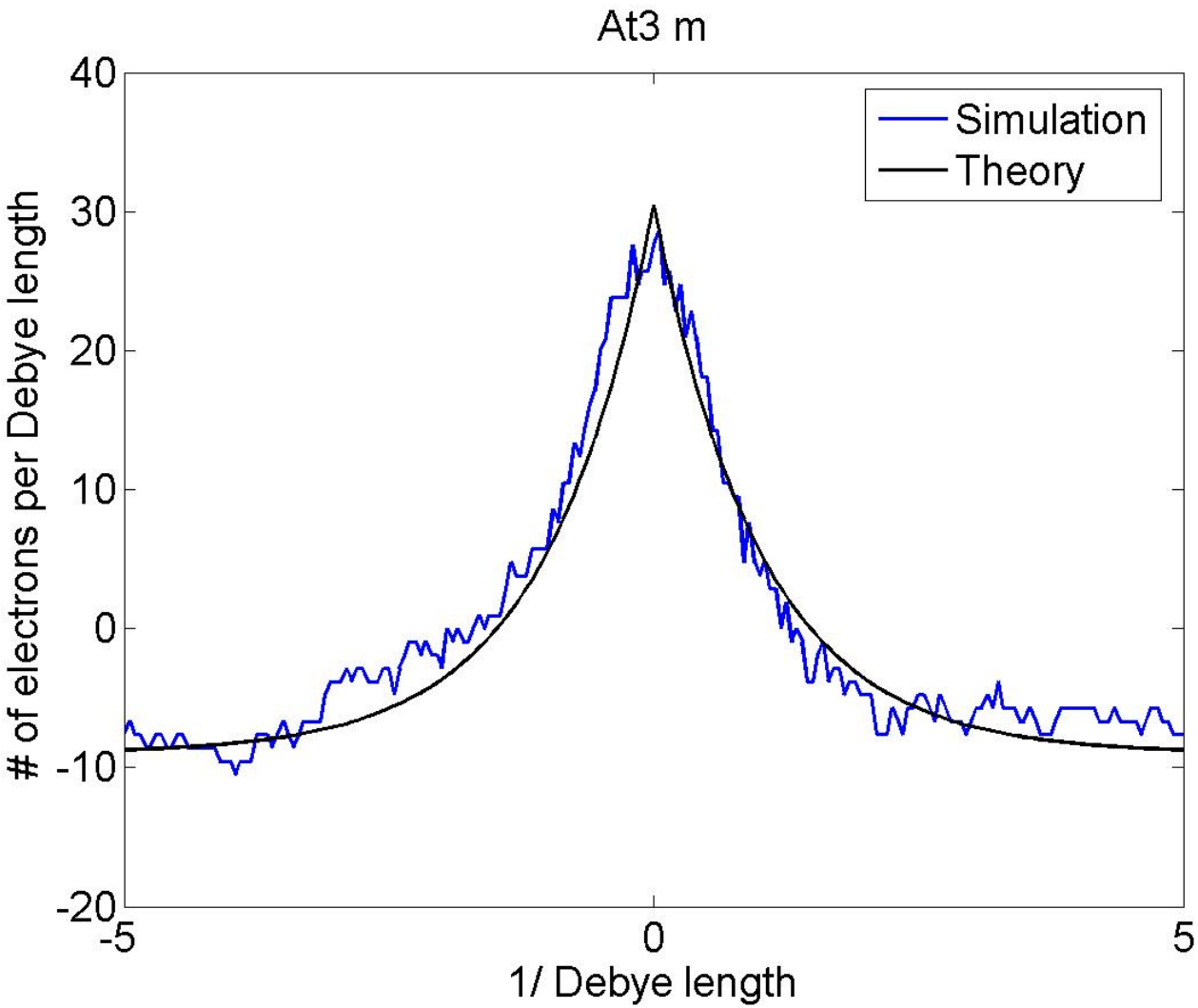
Coarse mesh, less macro electrons



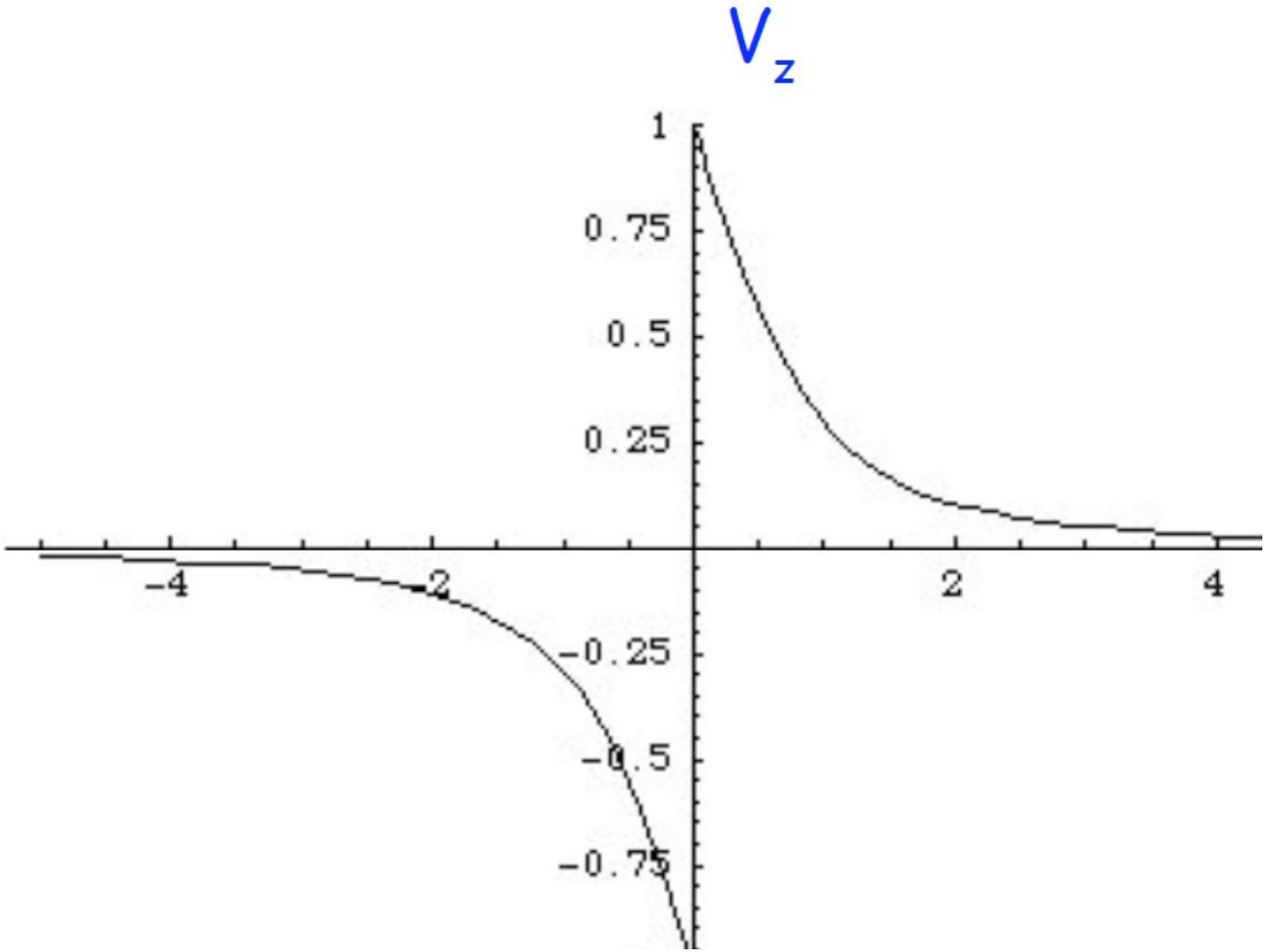
$$\tilde{n}_1(x) = \frac{Z_i \omega_p}{2\beta} exp\left(-\frac{\omega_p |x|}{\beta}\right)$$

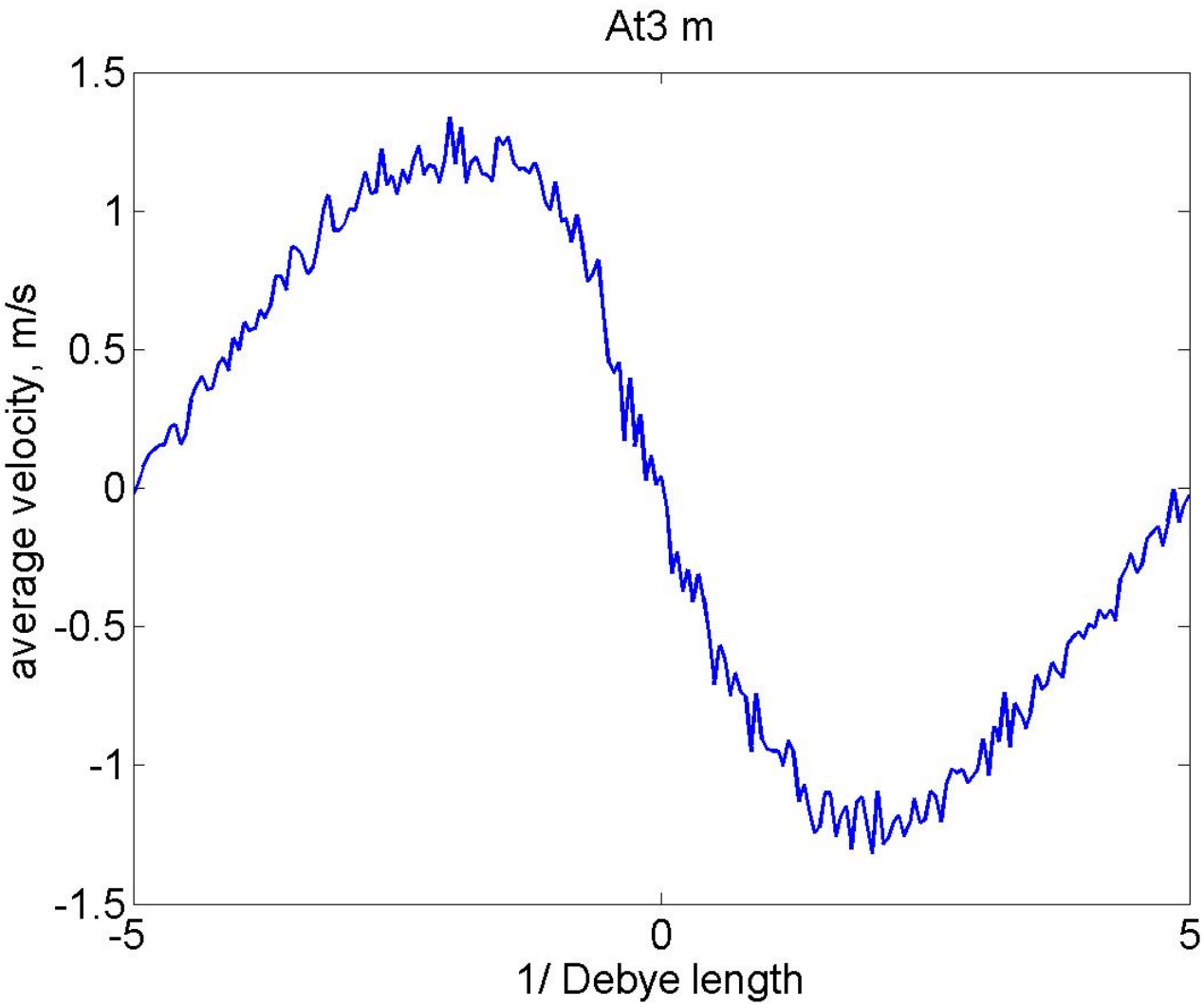
G. Bell et al., VLASOV AND PIC SIMULATIONS OF A MODULATOR SECTION FOR COHERENT ELECTRON COOLING, Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA, MOP067.


rep=1, at3 m
Simulation
Theory
# of electrons per Debye length
1/ Debye length
35
30
25
20
15
10
5
0
-5
-10
-5
0
5


At3 m
Simulation
Theory
# of electrons per Debye length
1/ Debye length
40
30
20
10
0
-10
-20
-5
0
5

V. N. Litvinenko and Y. S. Derbenev, Free Electron Lasers and High-Energy Electron Cooling, Proceedings of the FEL07(29th International Free Electron Laser Conference) Budker INP, Novosibirsk, Russia, BNL-79509-2007-CP

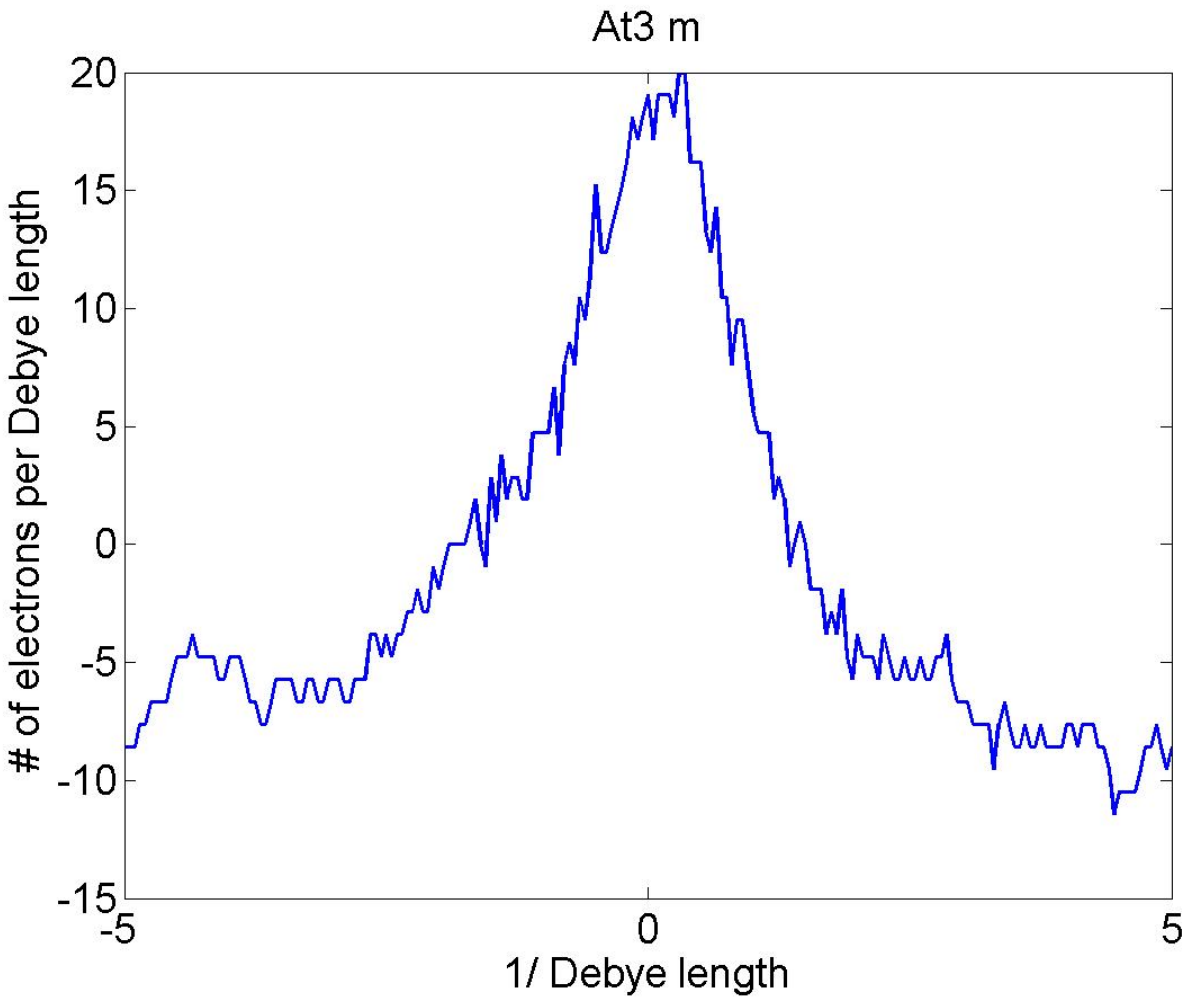

V_z
1
0.75
0.5
0.25
-4
-2
2
4
-0.25
-0.5
-0.75


At3 m
average velocity, m/s
1/ Debye length
1.5
1
0.5
0
-0.5
-1
-1.5
-5
0
5

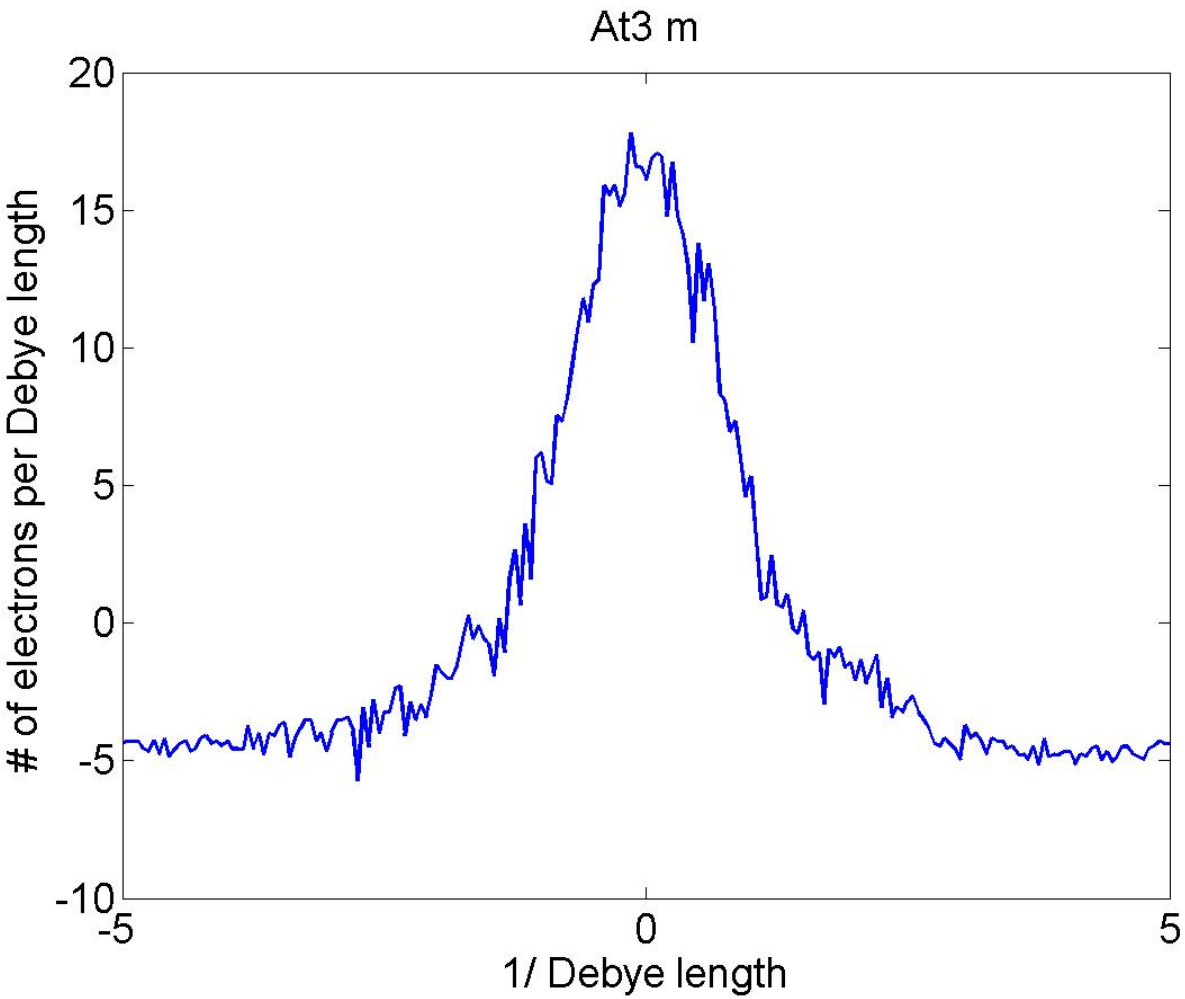
Assume normal distribution for electron bunch, and σ is the standard deviation.

- At 0, peak density
- At 0.5 σ, 88% of peak density
- At 1.0 σ, 60% of peak density
- At 1.5 σ, 32% of peak density
- At 2.0 σ, 13% of peak density

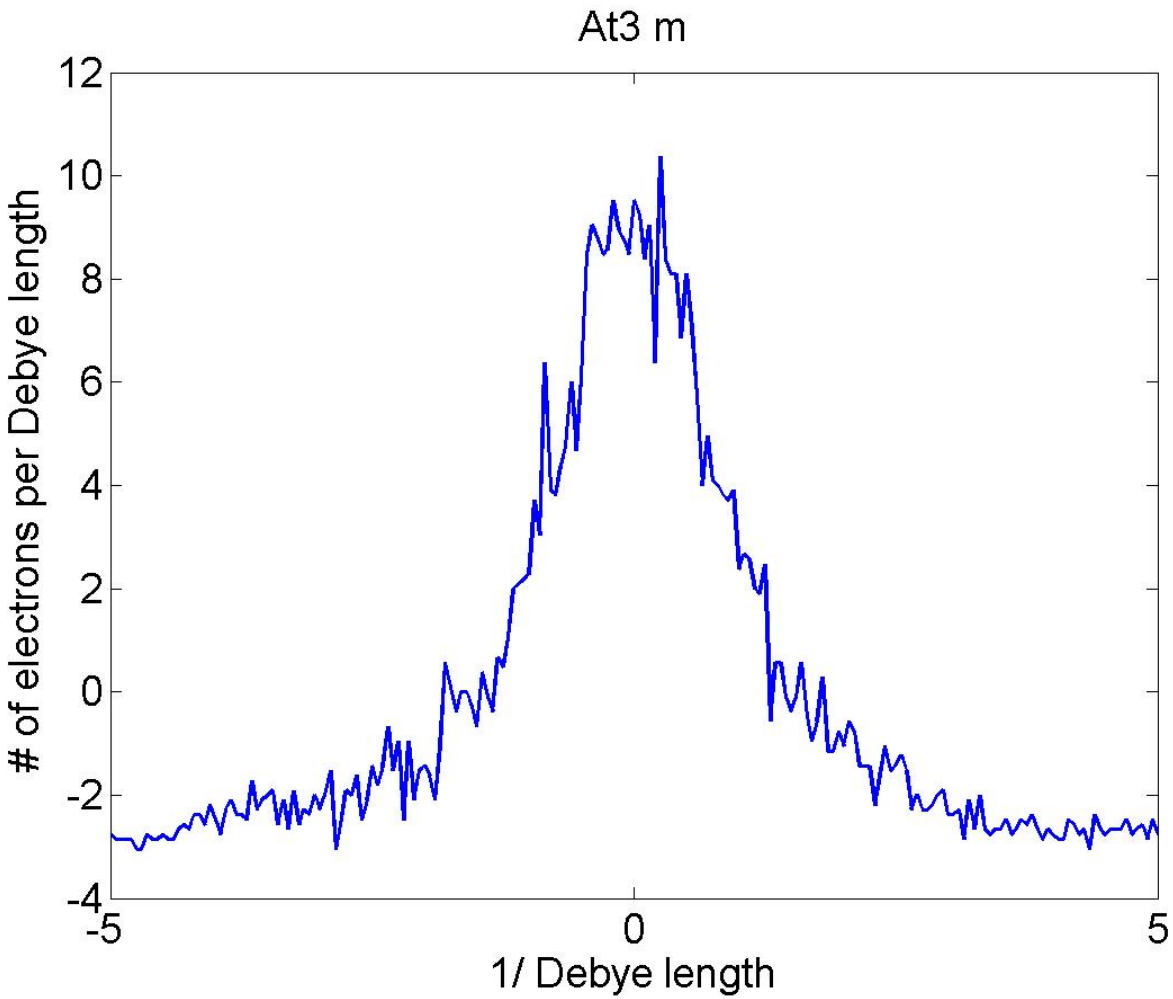
At 0.5 σ, 88% of peak density



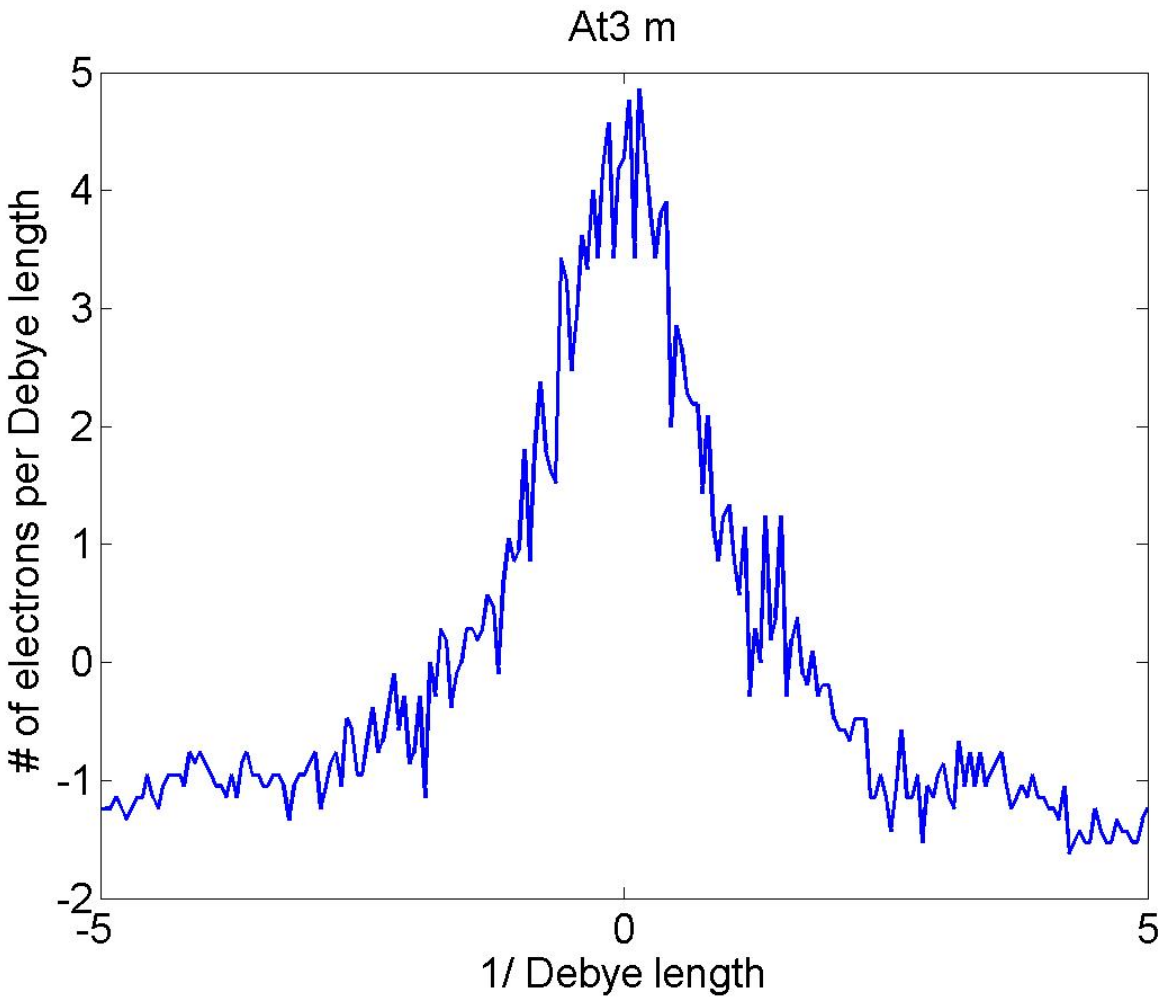
At 1.0 σ, 60% of peak density



At 1.5 σ, 32% of peak density



At 2.0 σ, 13% of peak density



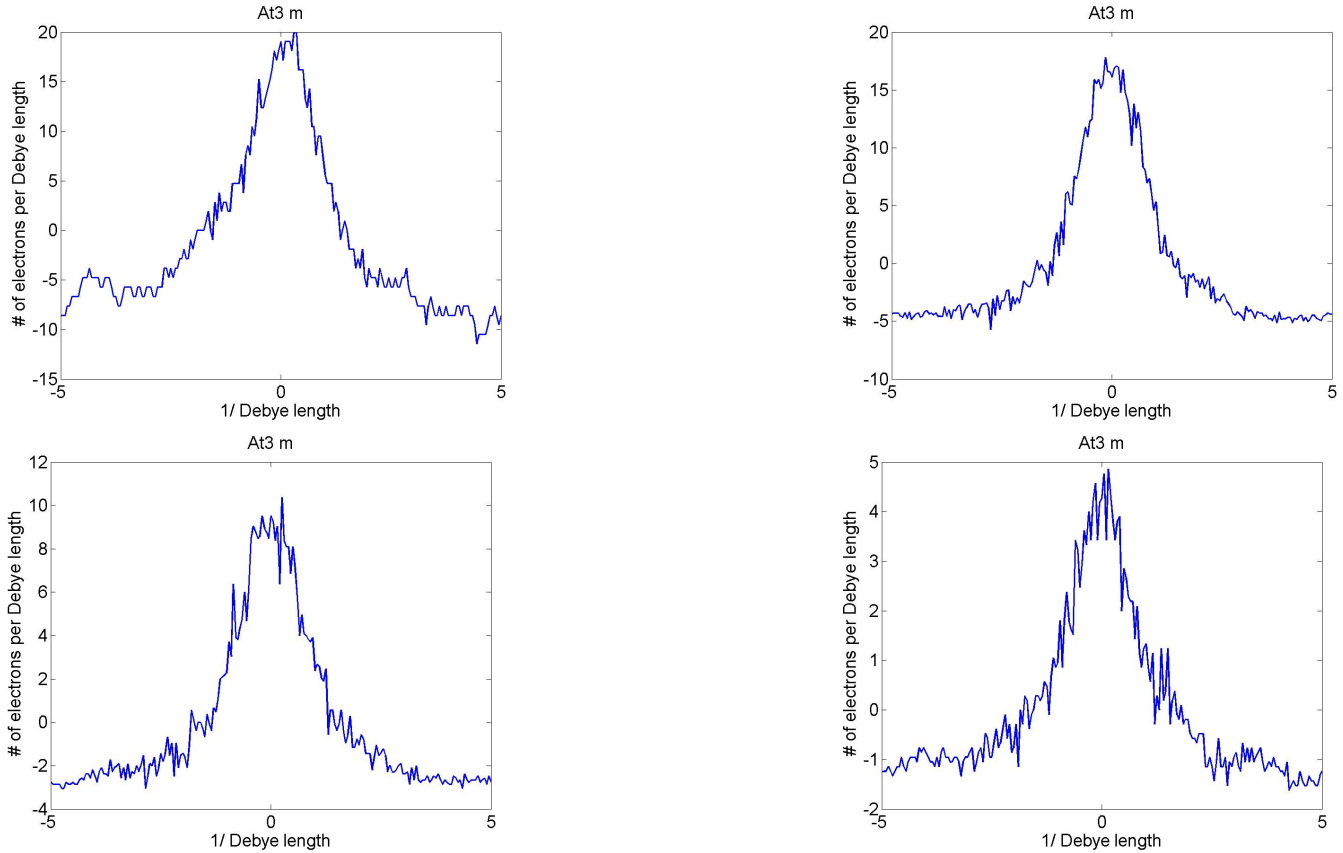
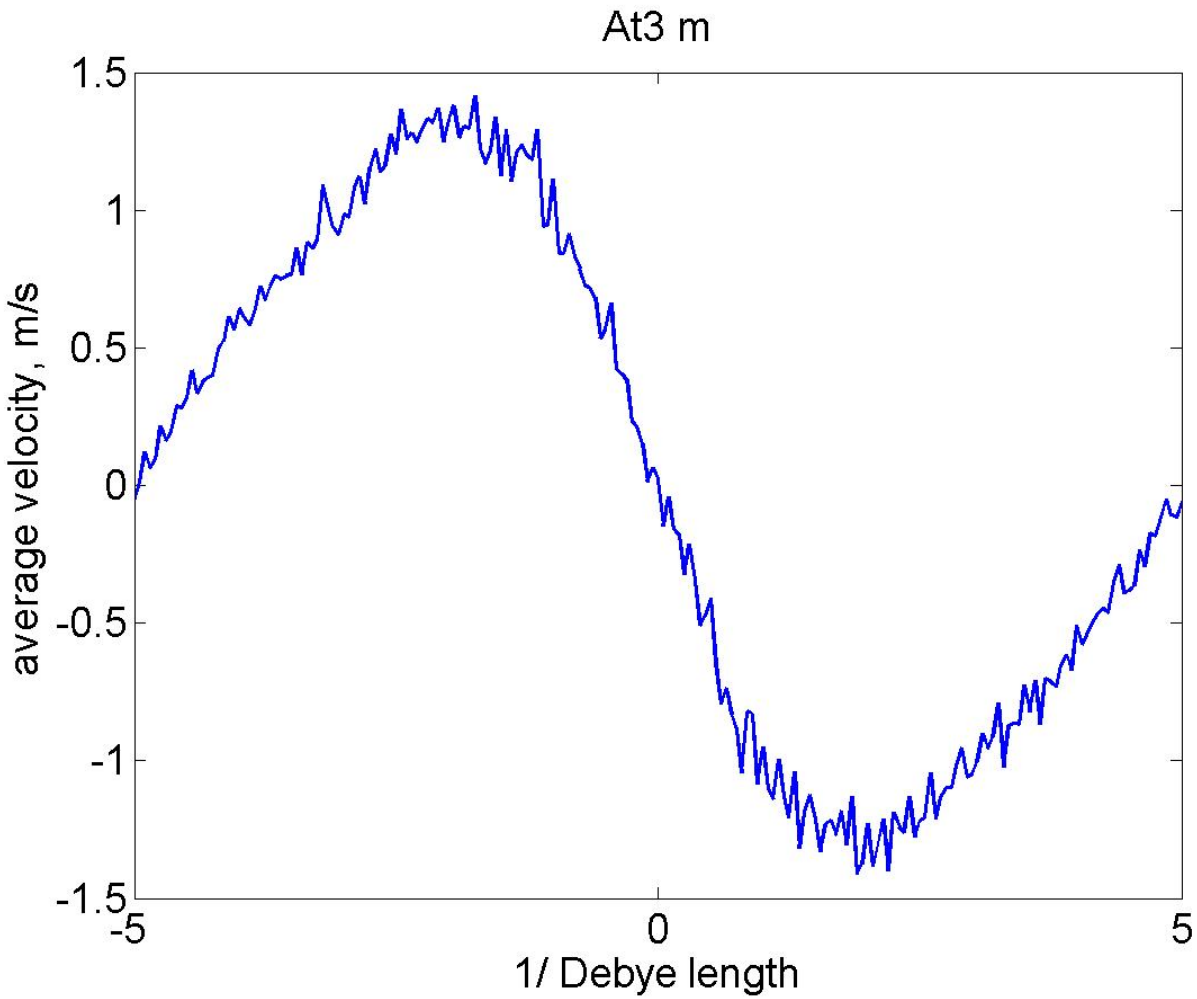
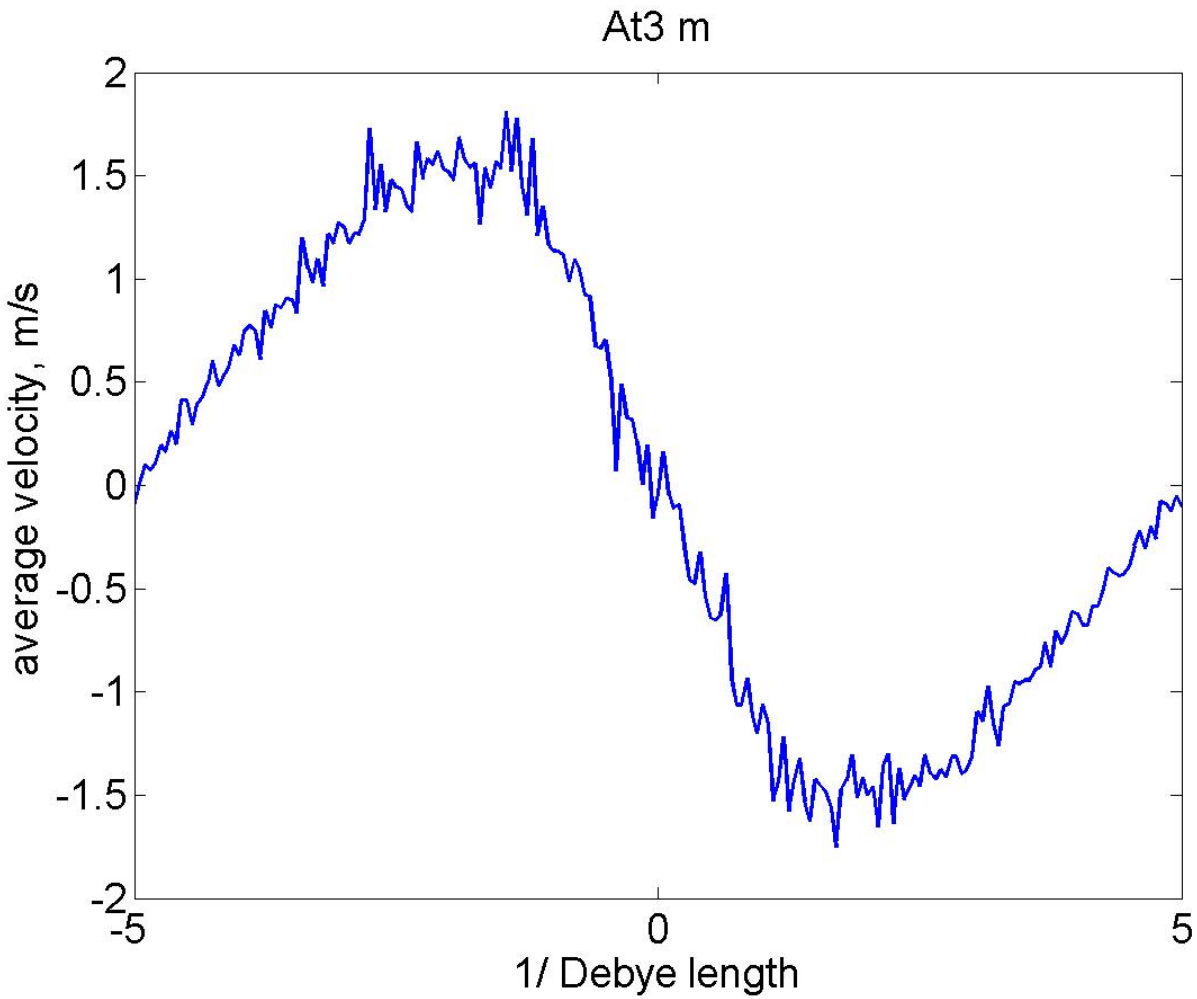


Figure: Electron density at 0.5σ (upper left), 1.0σ (upper right), 1.5σ (lower left), 2.0σ (lower right)

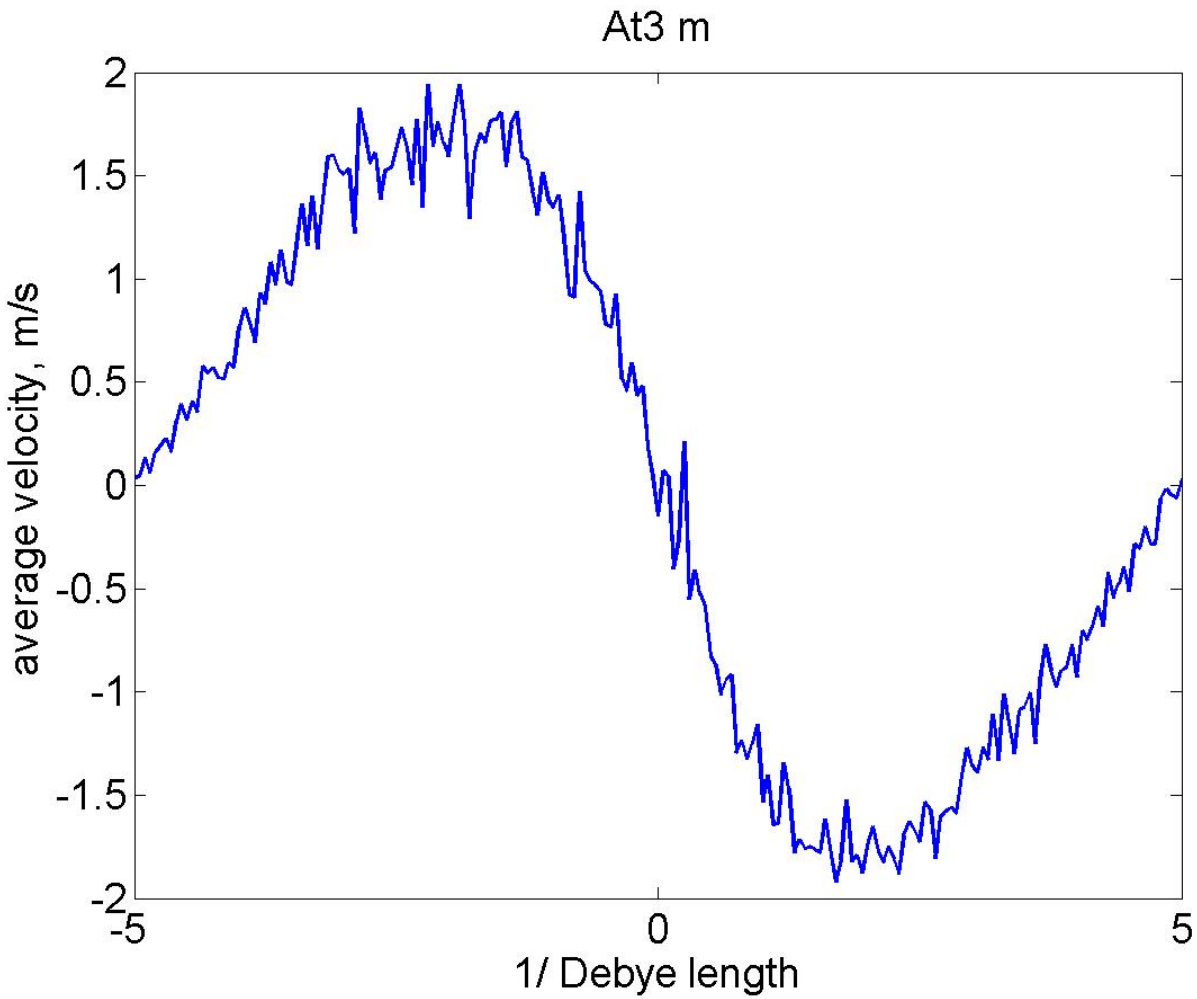
At 0.5 σ, 88% of peak density



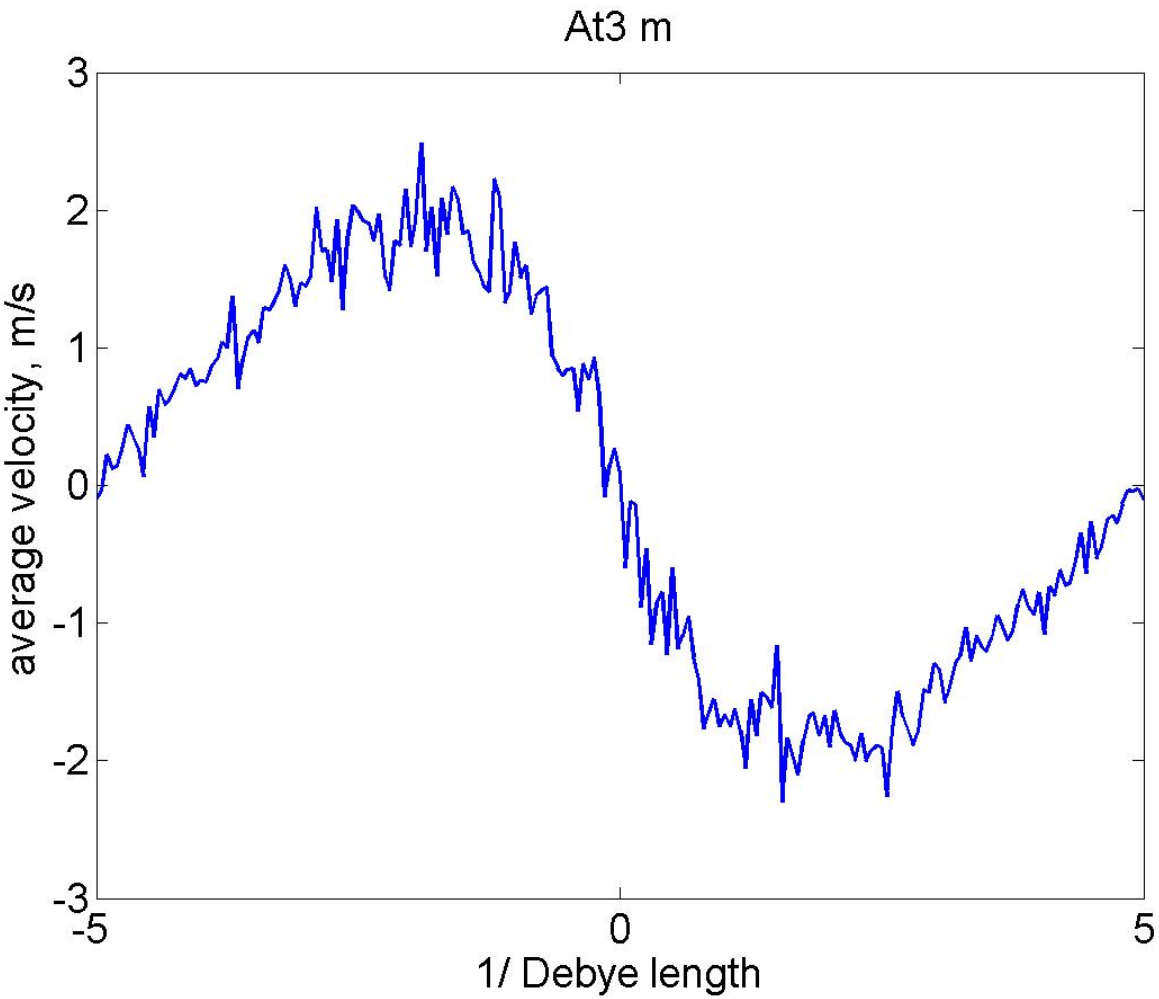
At 1.0 σ, 60% of peak density



At 1.5 σ, 32% of peak density



At 2.0 σ, 13% of peak density



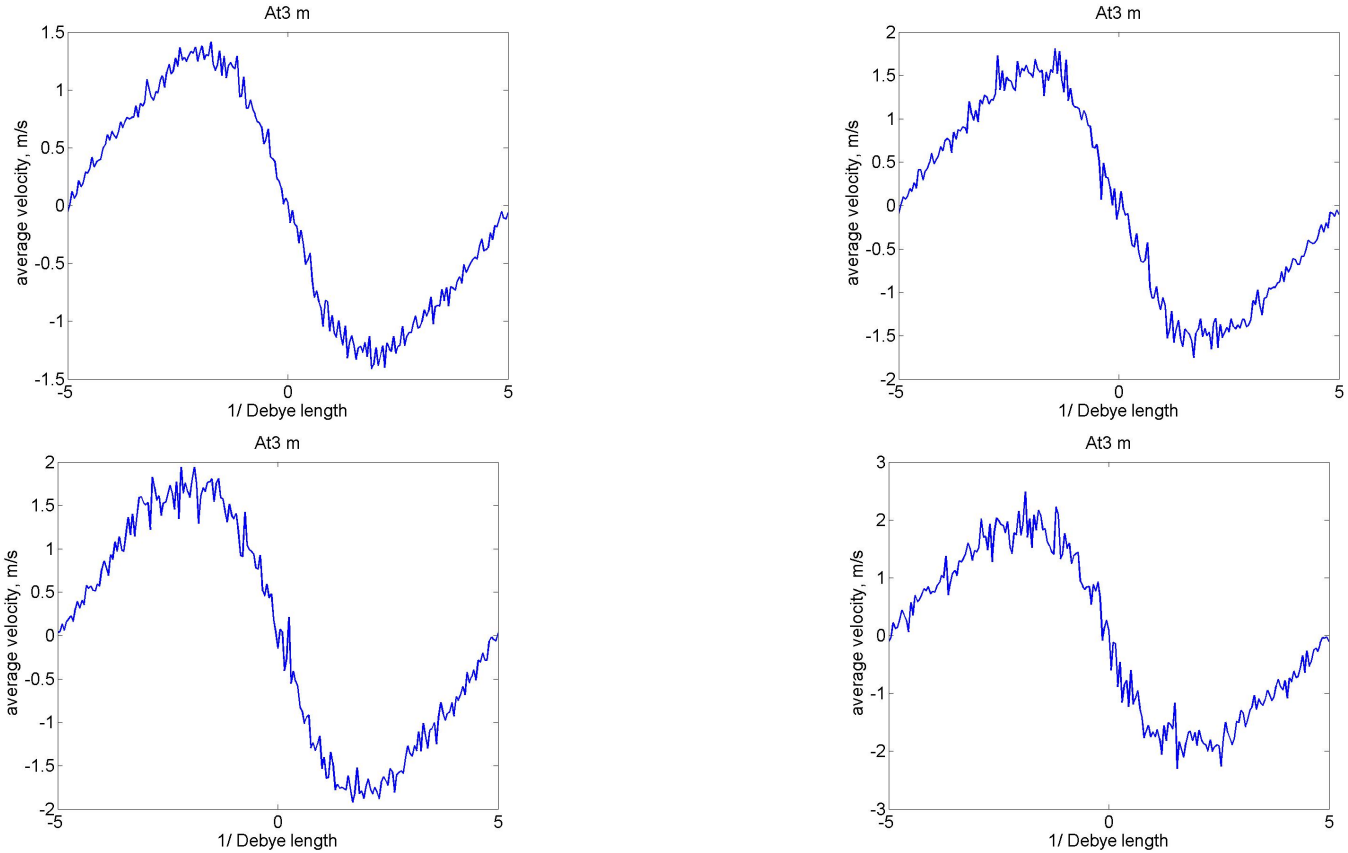
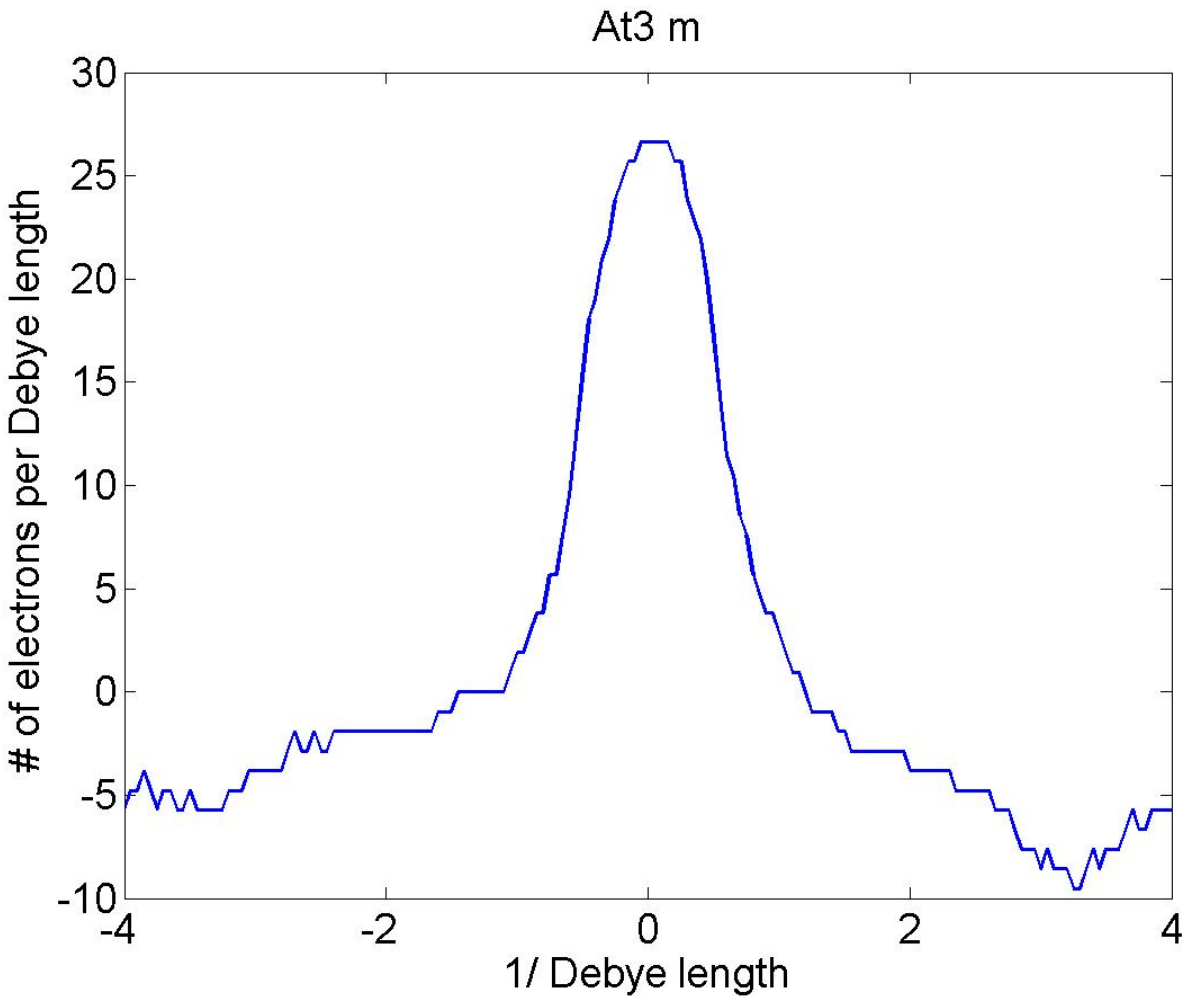
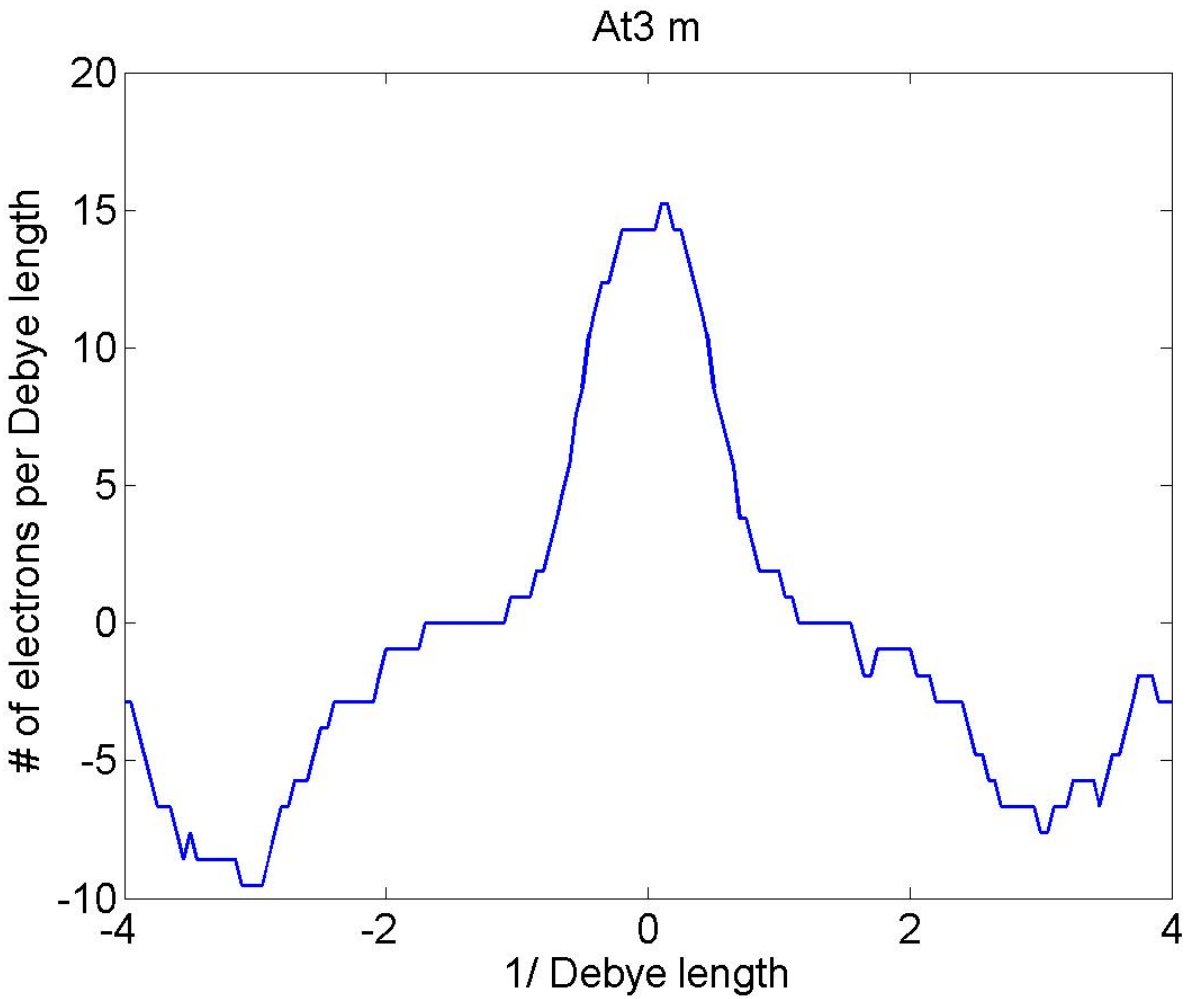


Figure: Electron density at 0.5σ (upper left), 1.0σ (upper right), 1.5σ (lower left), 2.0σ (lower right)

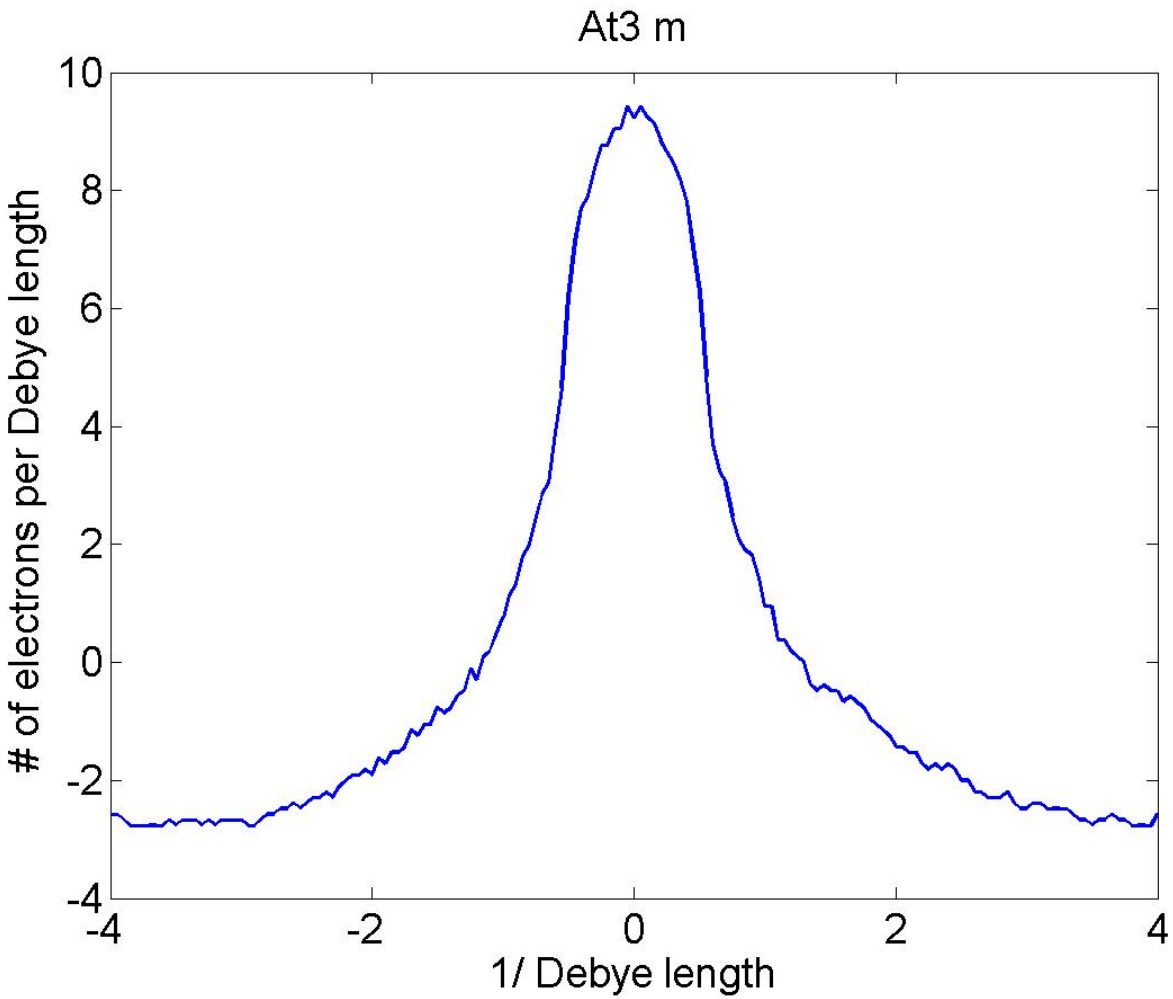
At 0.5 σ, 88% of peak density



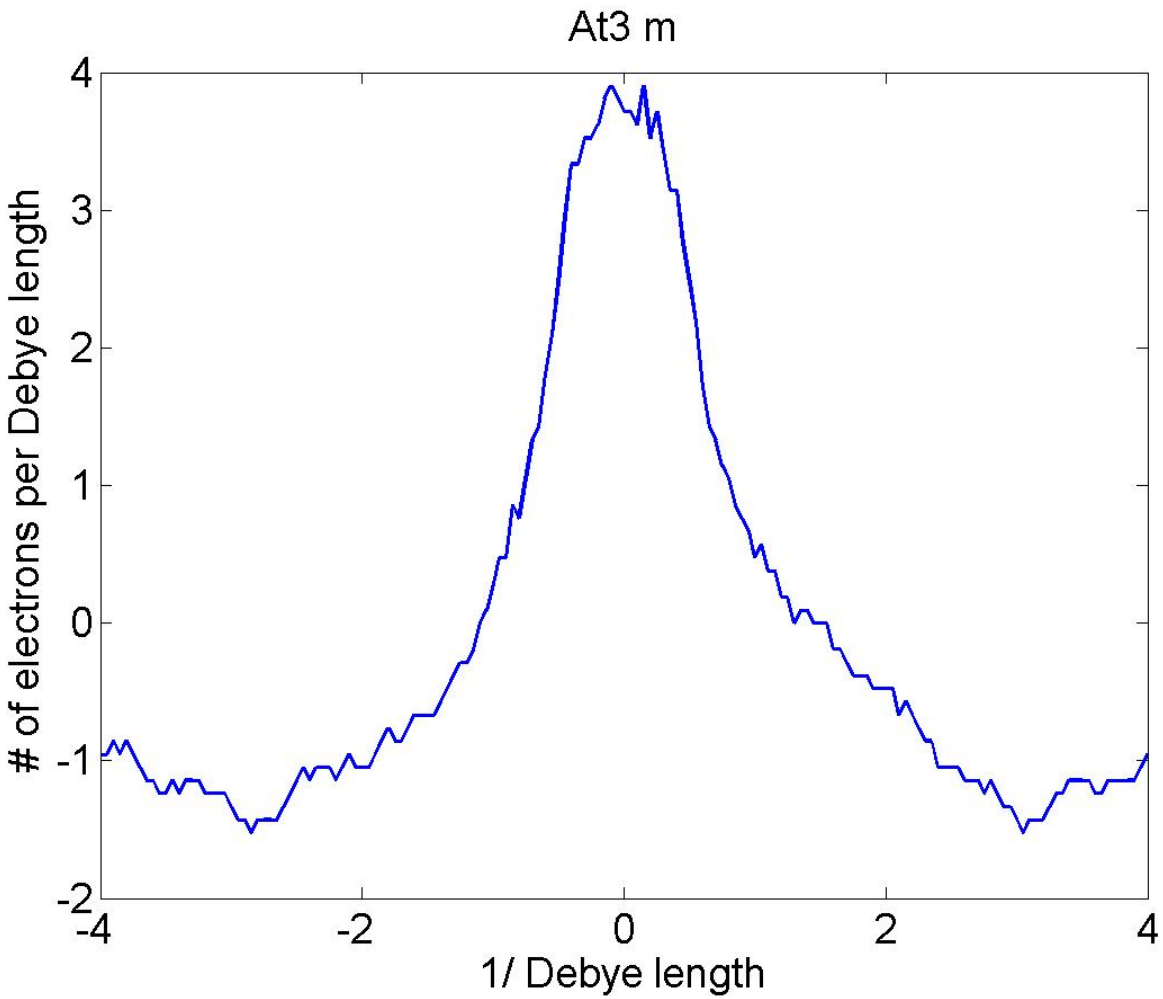
At 1.0 σ, 60% of peak density



At 1.5 σ, 32% of peak density



At 2.0 σ, 13% of peak density



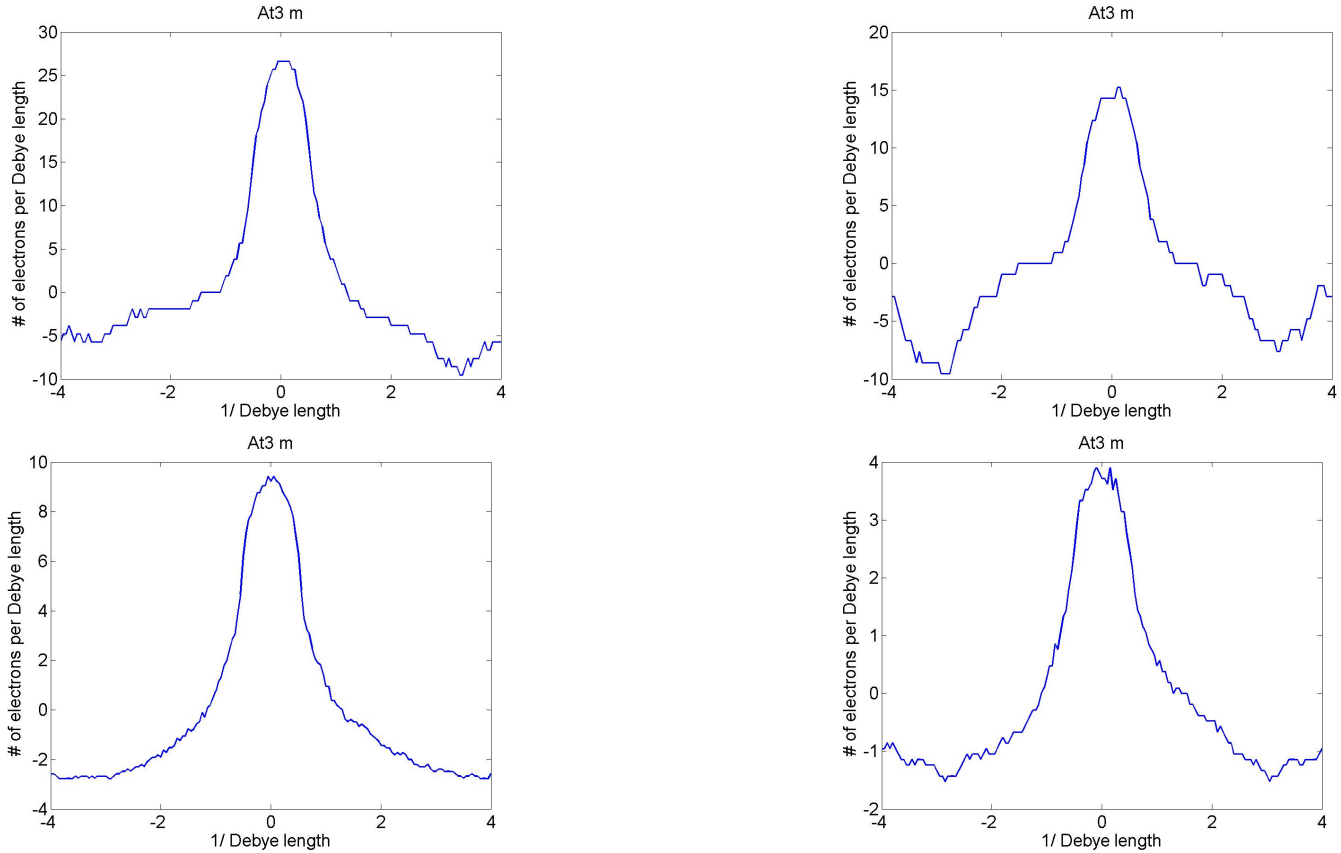
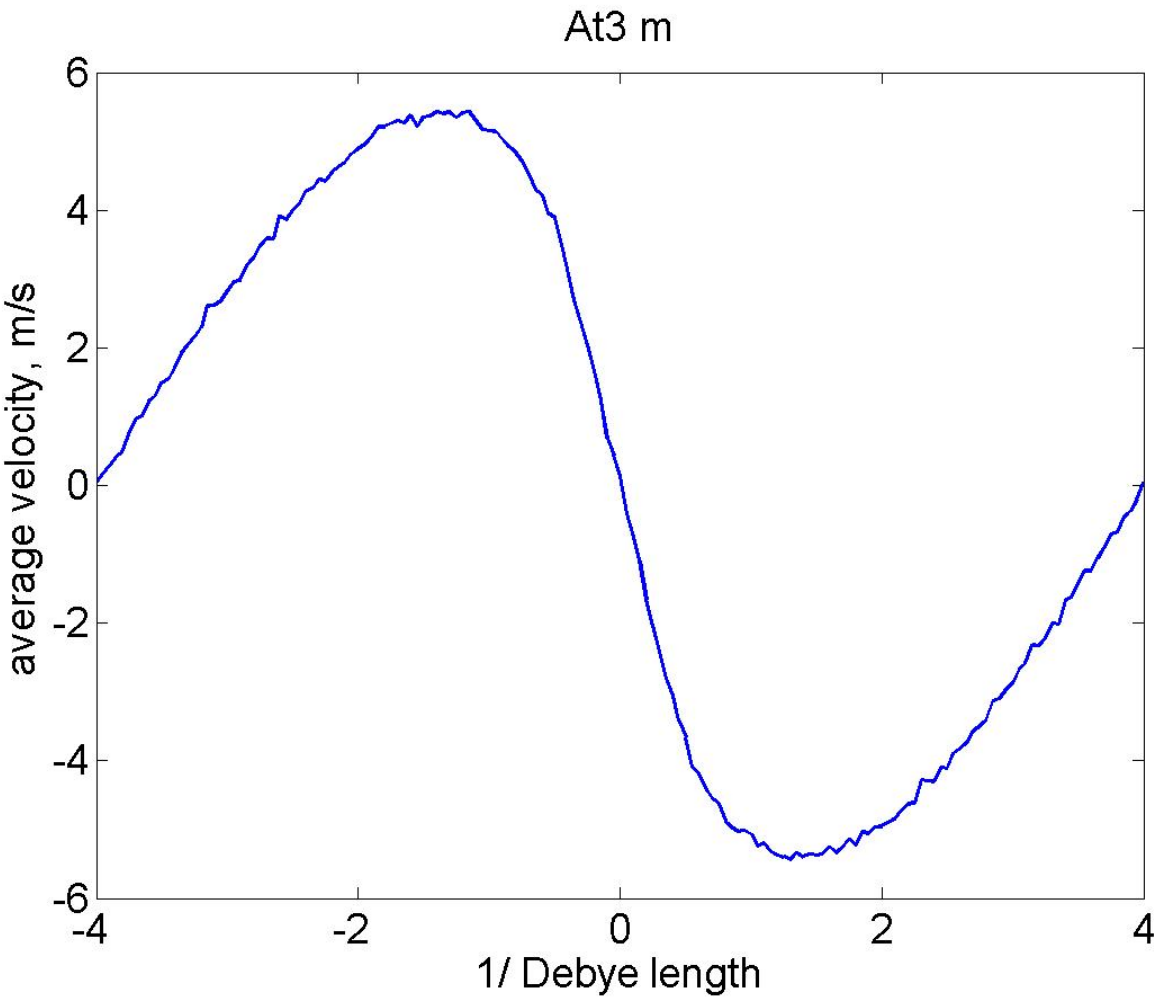
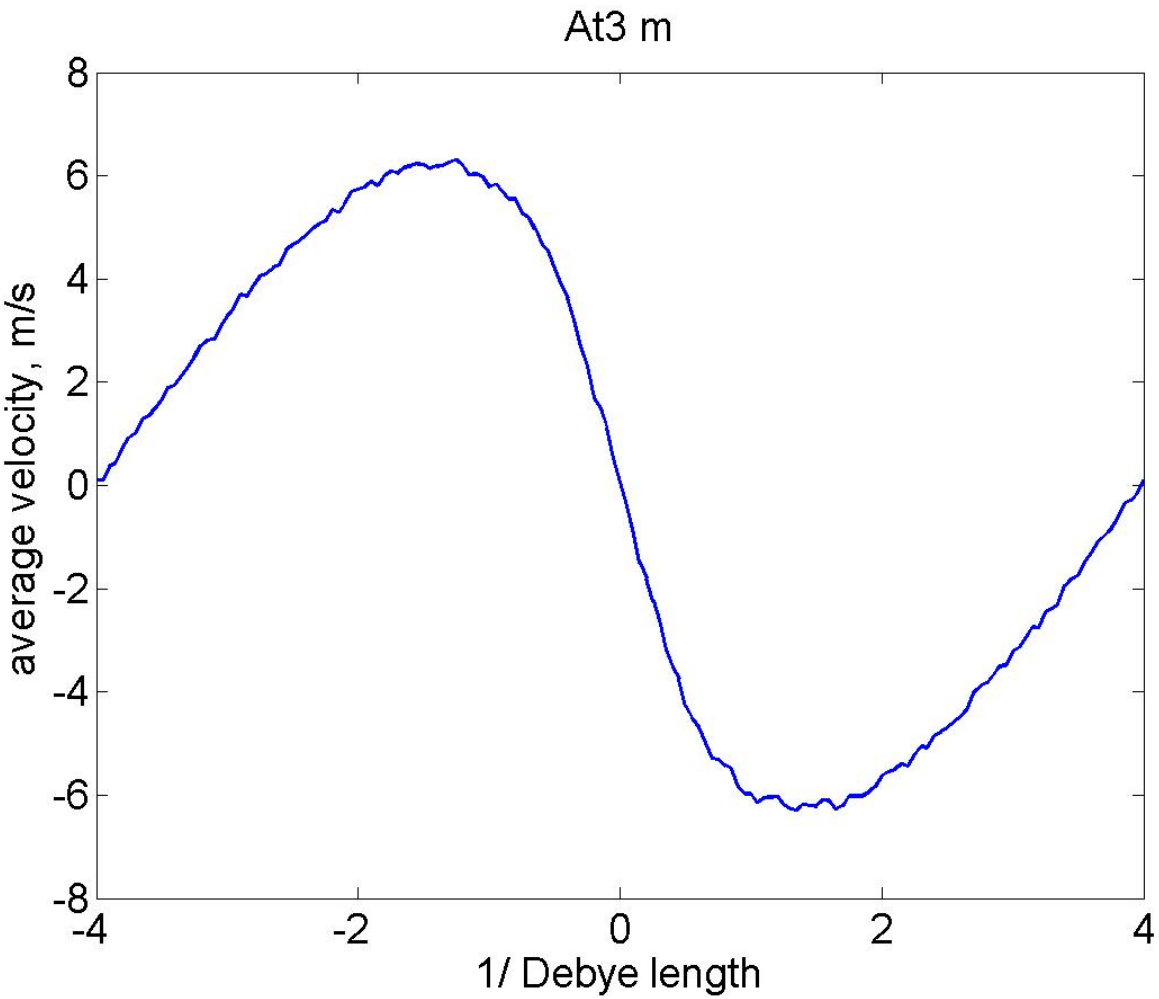


Figure: Electron density at 0.5σ (upper left), 1.0σ (upper right), 1.5σ (lower left), 2.0σ (lower right)

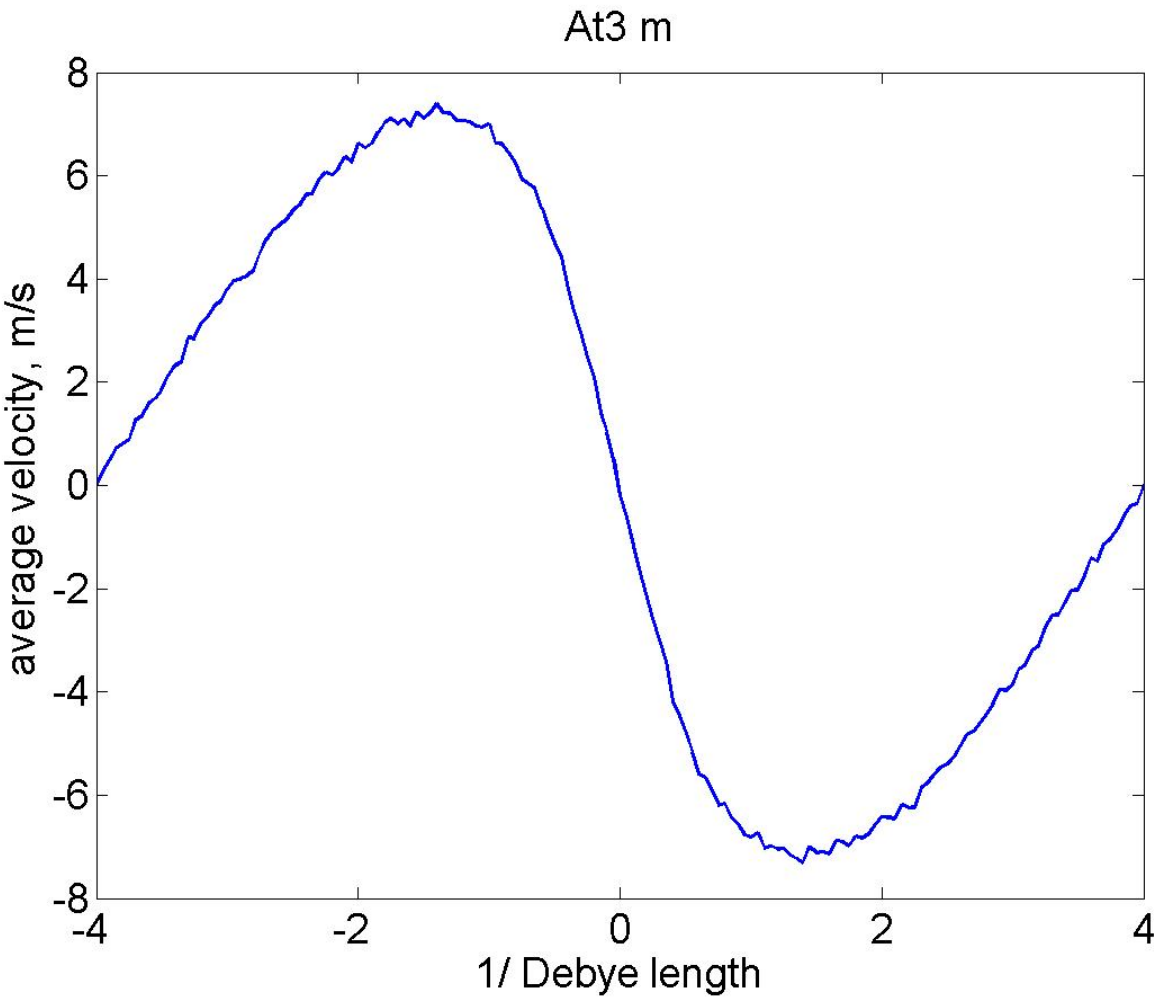
At 0.5 σ, 88% of peak density



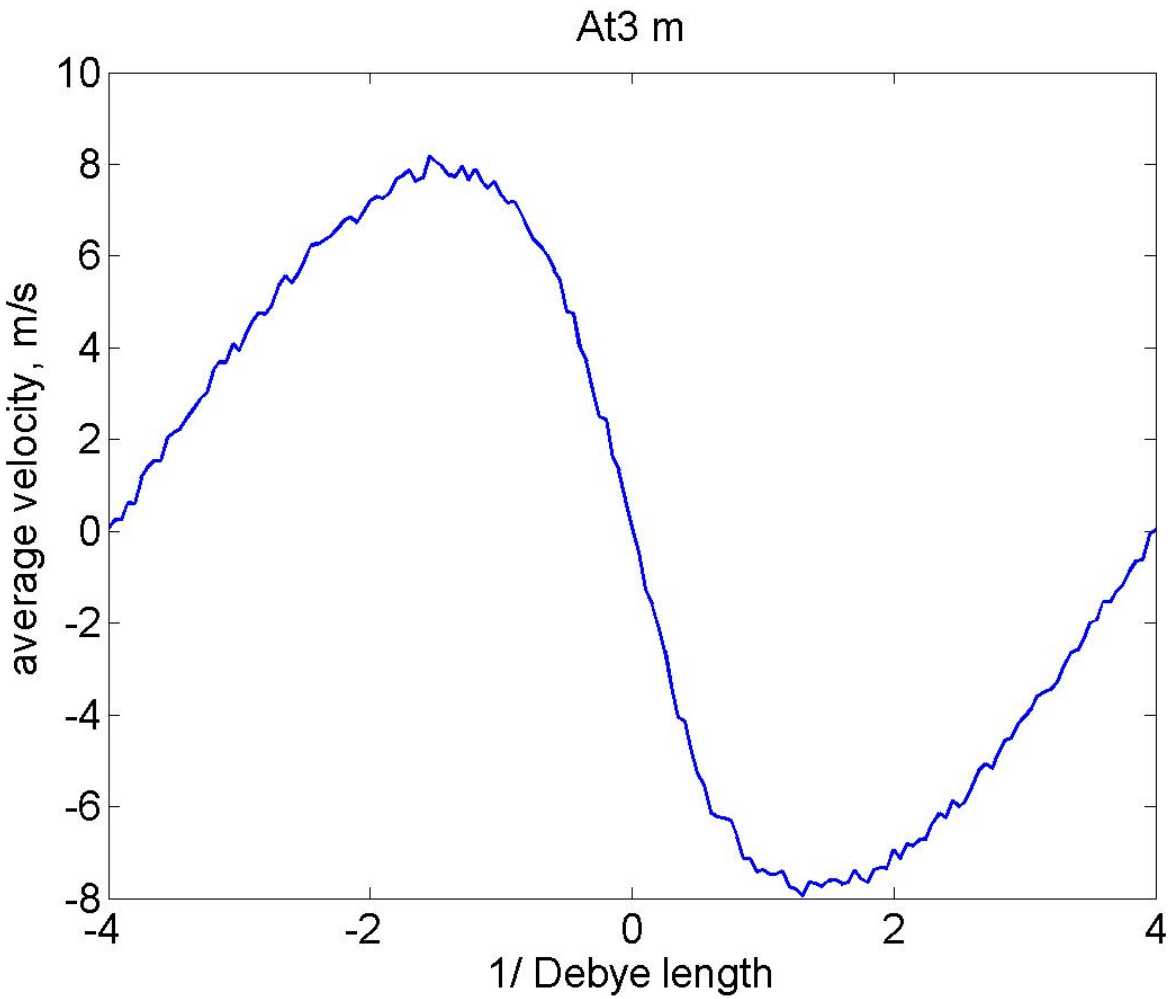
At 1.0 σ, 60% of peak density



At 1.5 σ, 32% of peak density



At 2.0 σ, 13% of peak density



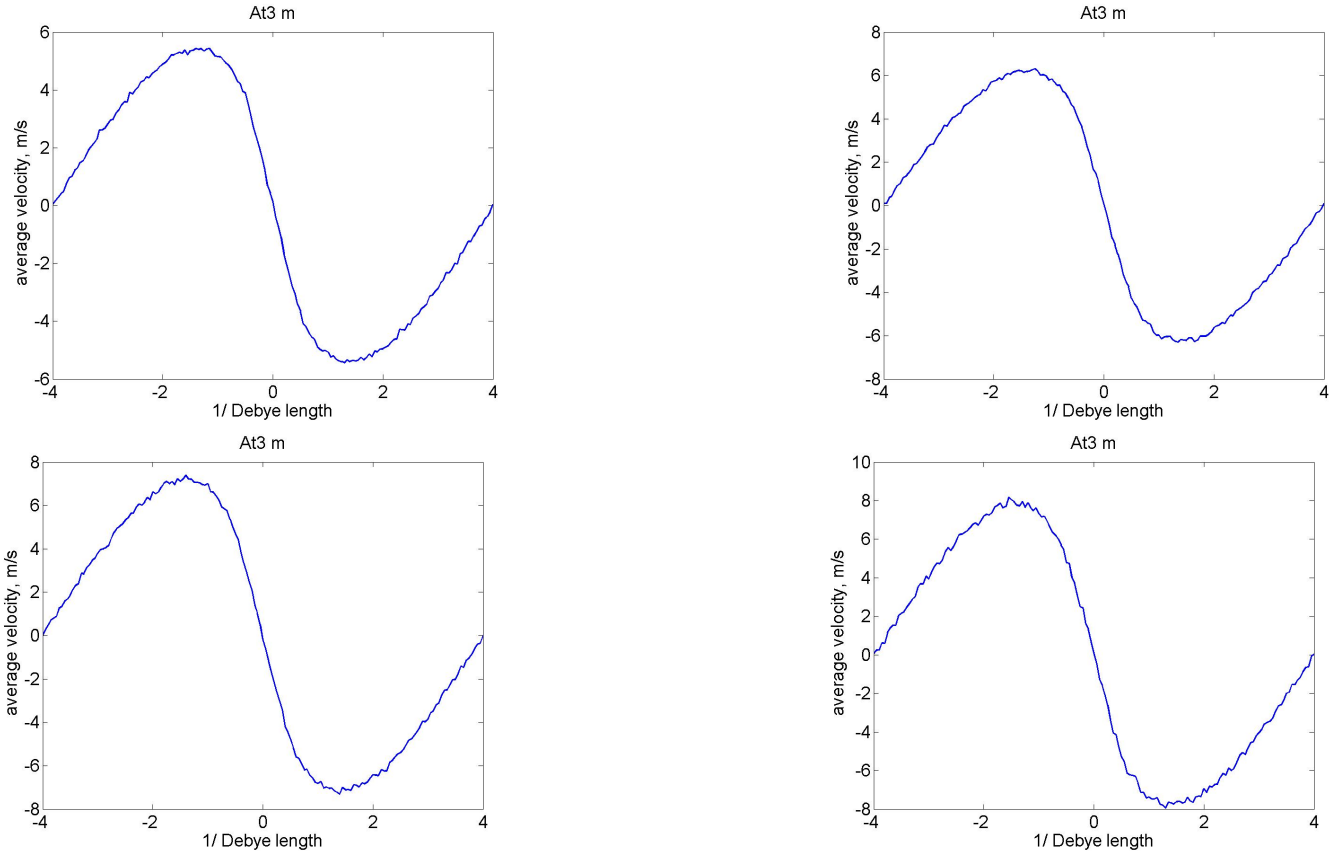
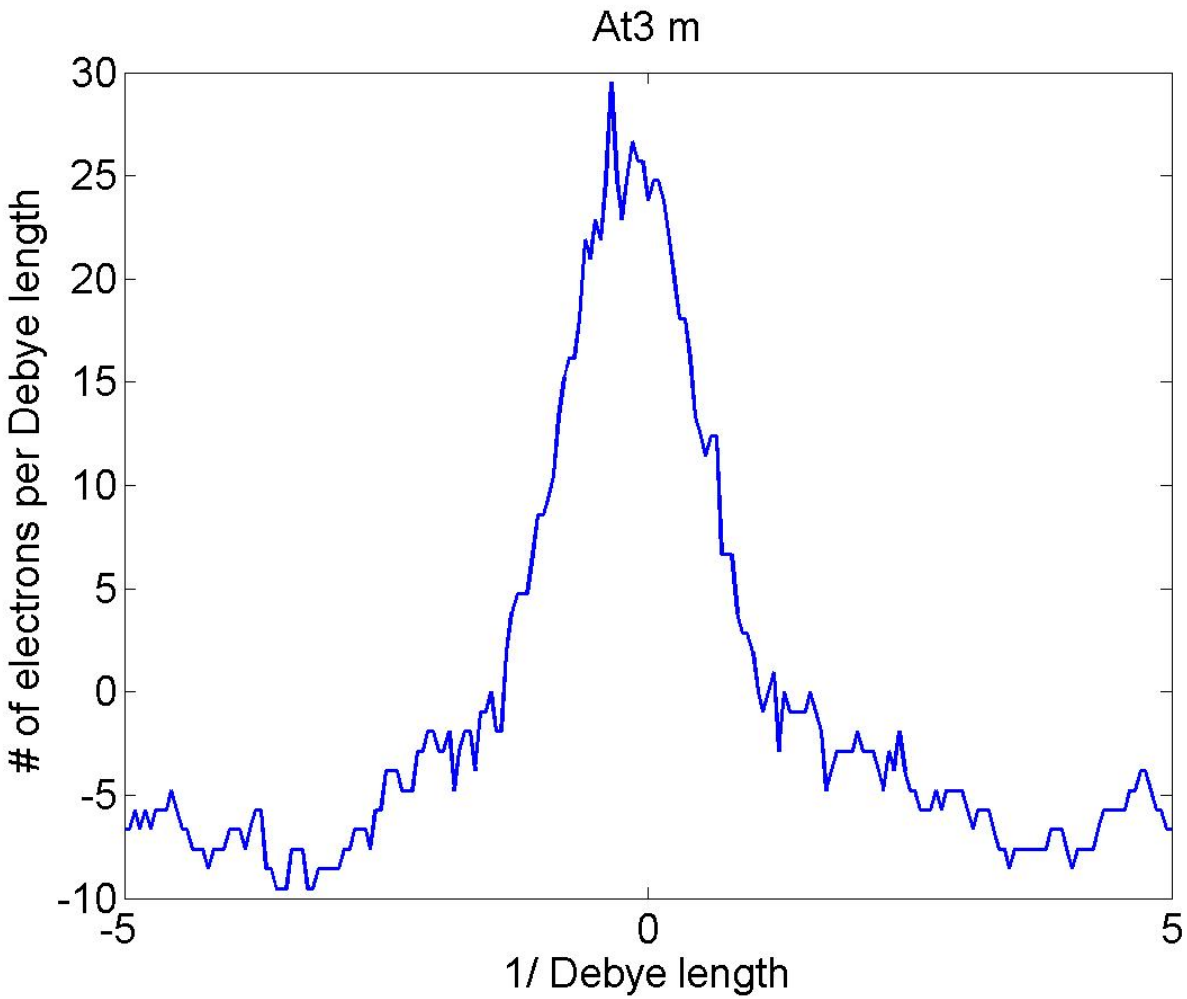


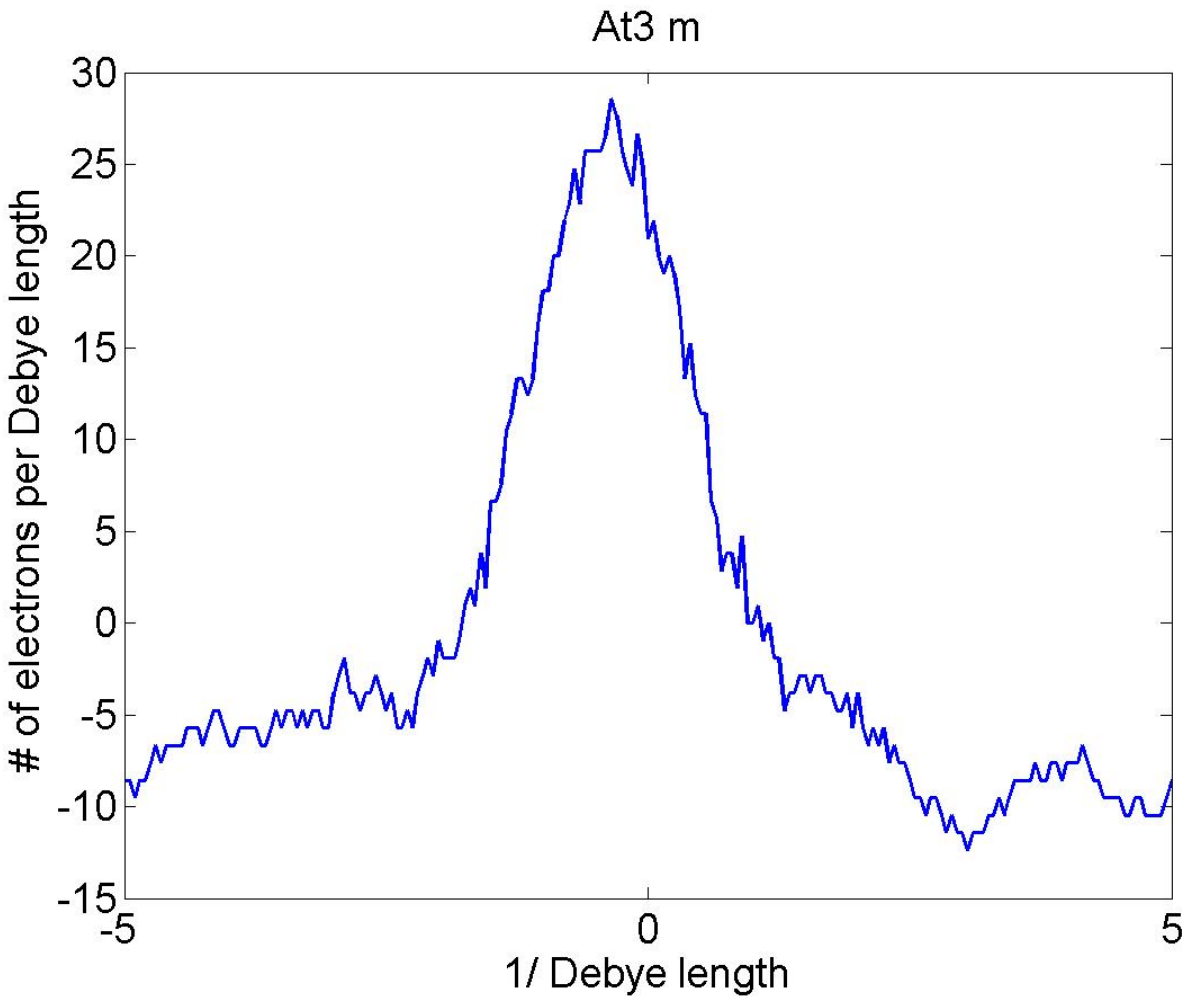
Figure: Electron density at 0.5σ (upper left), 1.0σ (upper right), 1.5σ (lower left), 2.0σ (lower right)

- Ion moves along longitudinal direction with velocity
  - 0.25 β_z
  - 0.50 β_z
  - 0.75 β_z
  - 1.00 β_z
- $\beta_z = 3\text{e+}5$ m/s
- In simulation, ion stays in the center of moving frame, electrons move instead.

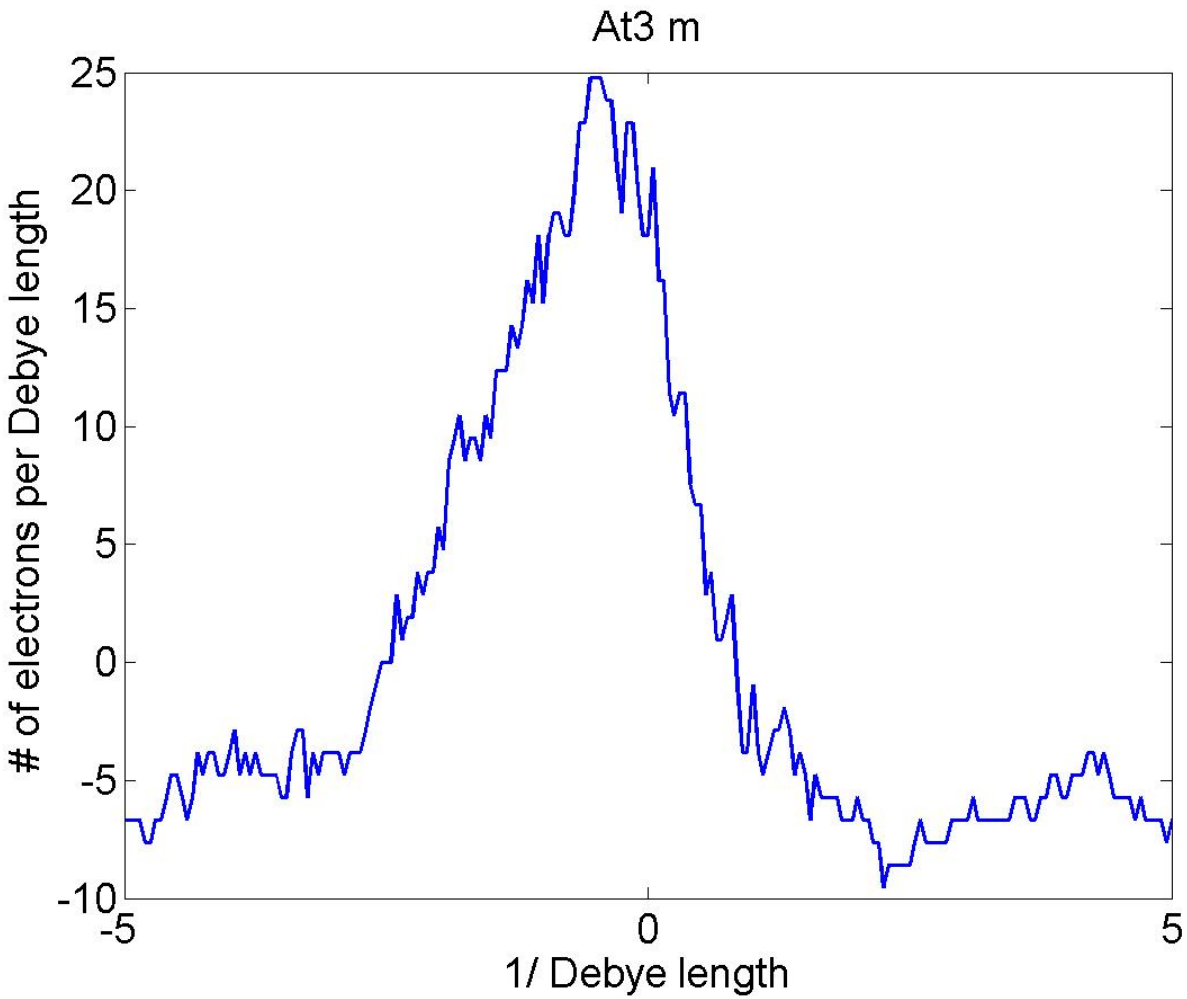
0.25 β_z


At3 m
# of electrons per Debye length
1/ Debye length
30
25
20
15
10
5
0
-5
-10
-5
0
5

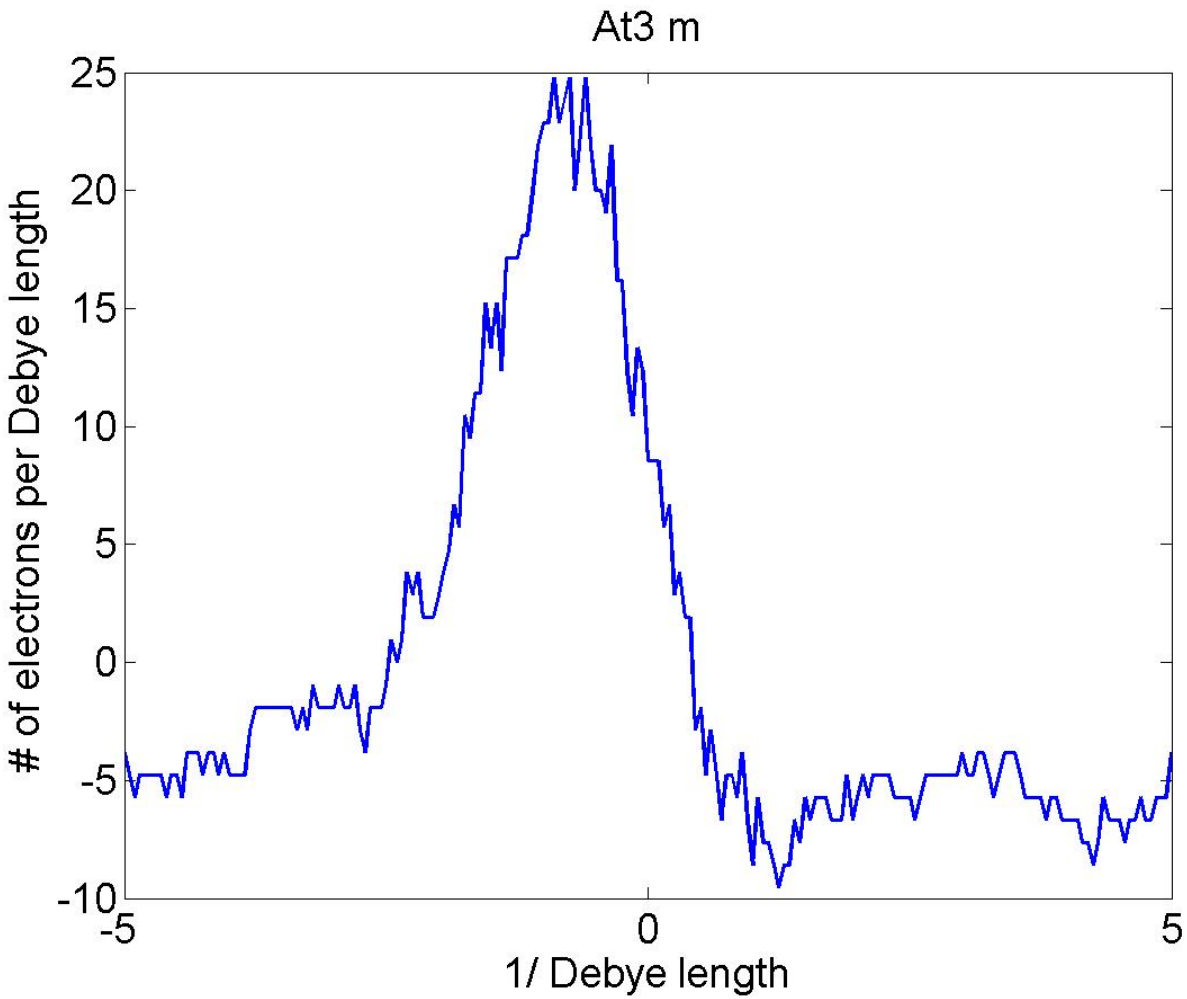
0.50 β_z


At3 m
# of electrons per Debye length
1/ Debye length
30
25
20
15
10
5
0
-5
-10
-15
-5
0
5

0.75 β_z


At3 m
# of electrons per Debye length
1/ Debye length
25
20
15
10
5
0
-5
-10
-5
0
5

1.00 β_z


At3 m
# of electrons per Debye length
1/ Debye length
25
20
15
10
5
0
-5
-10
-5
0
5

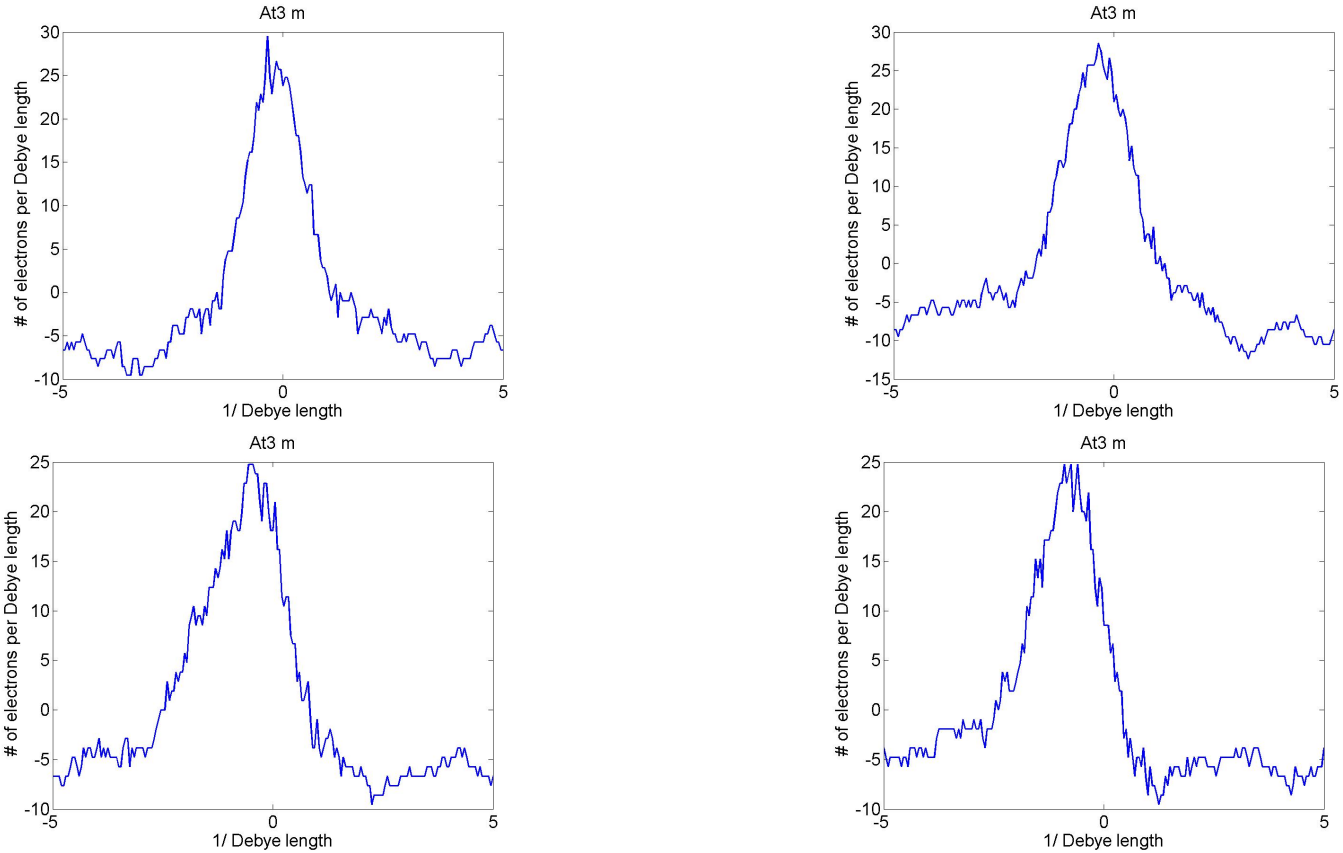
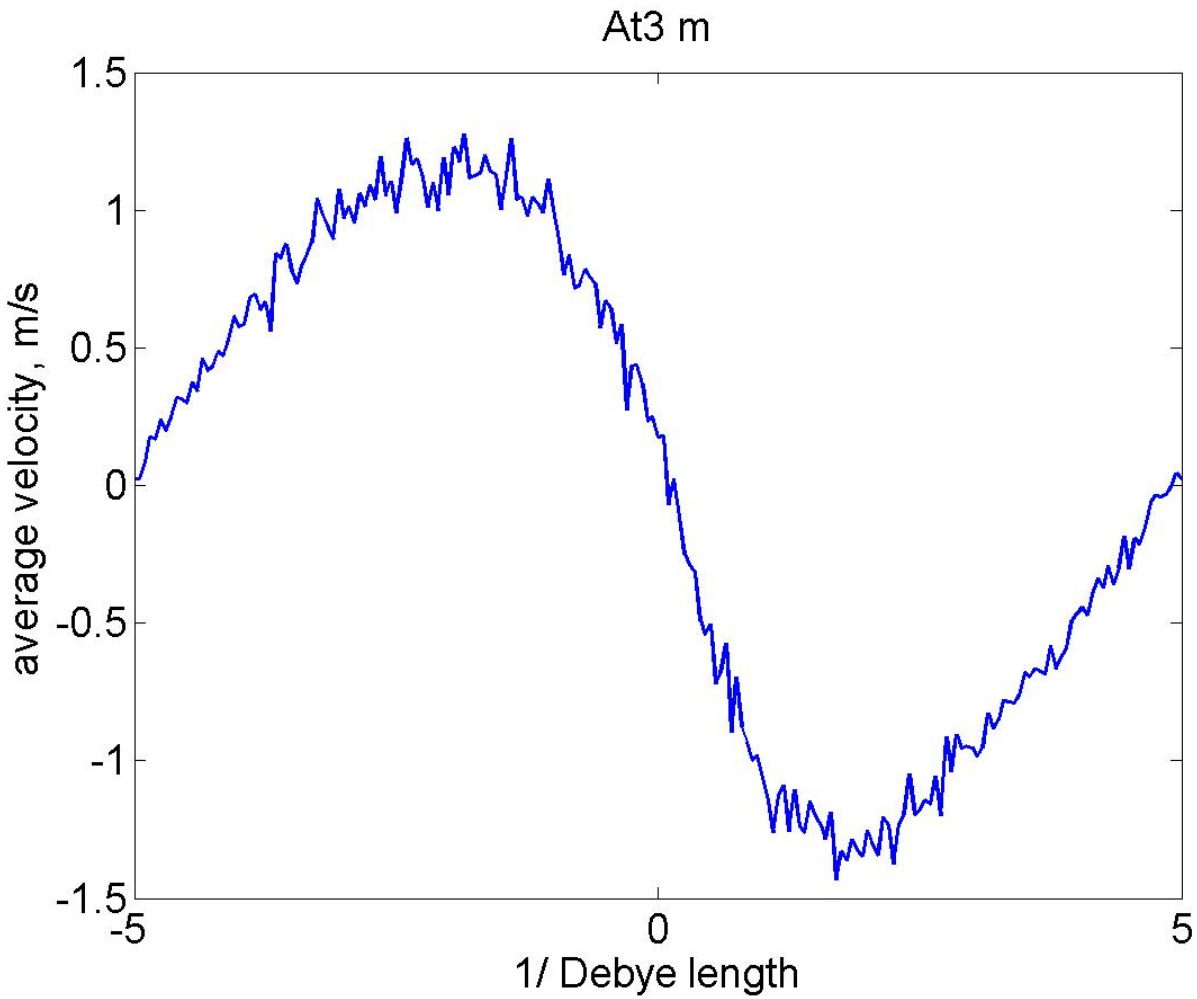
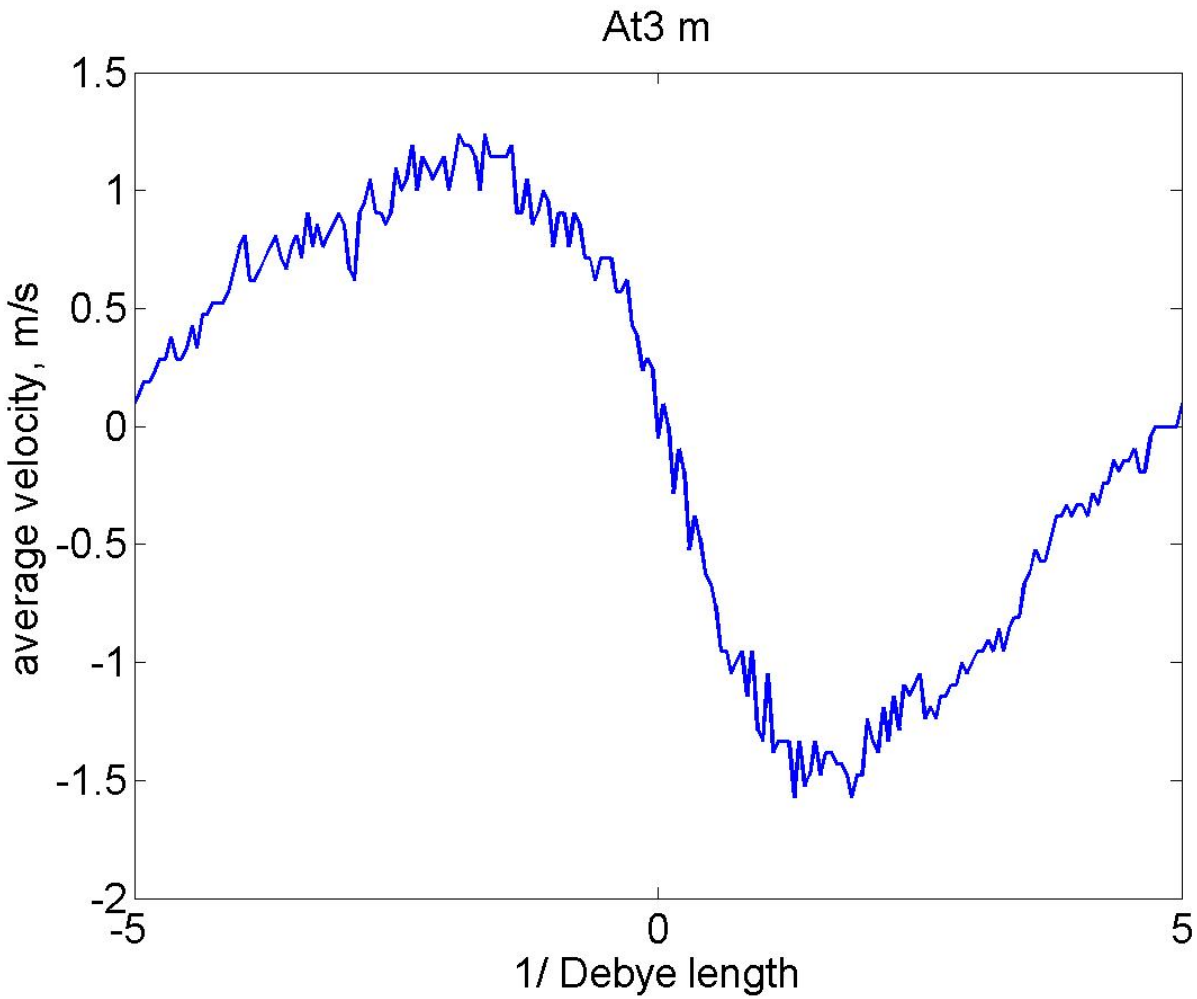


Figure: Electron velocity $0.25\beta_z$ (upper left), $0.50\beta_z$ (upper right), $0.75\beta_z$ (lower left), $1.00\beta_z$ (lower right)

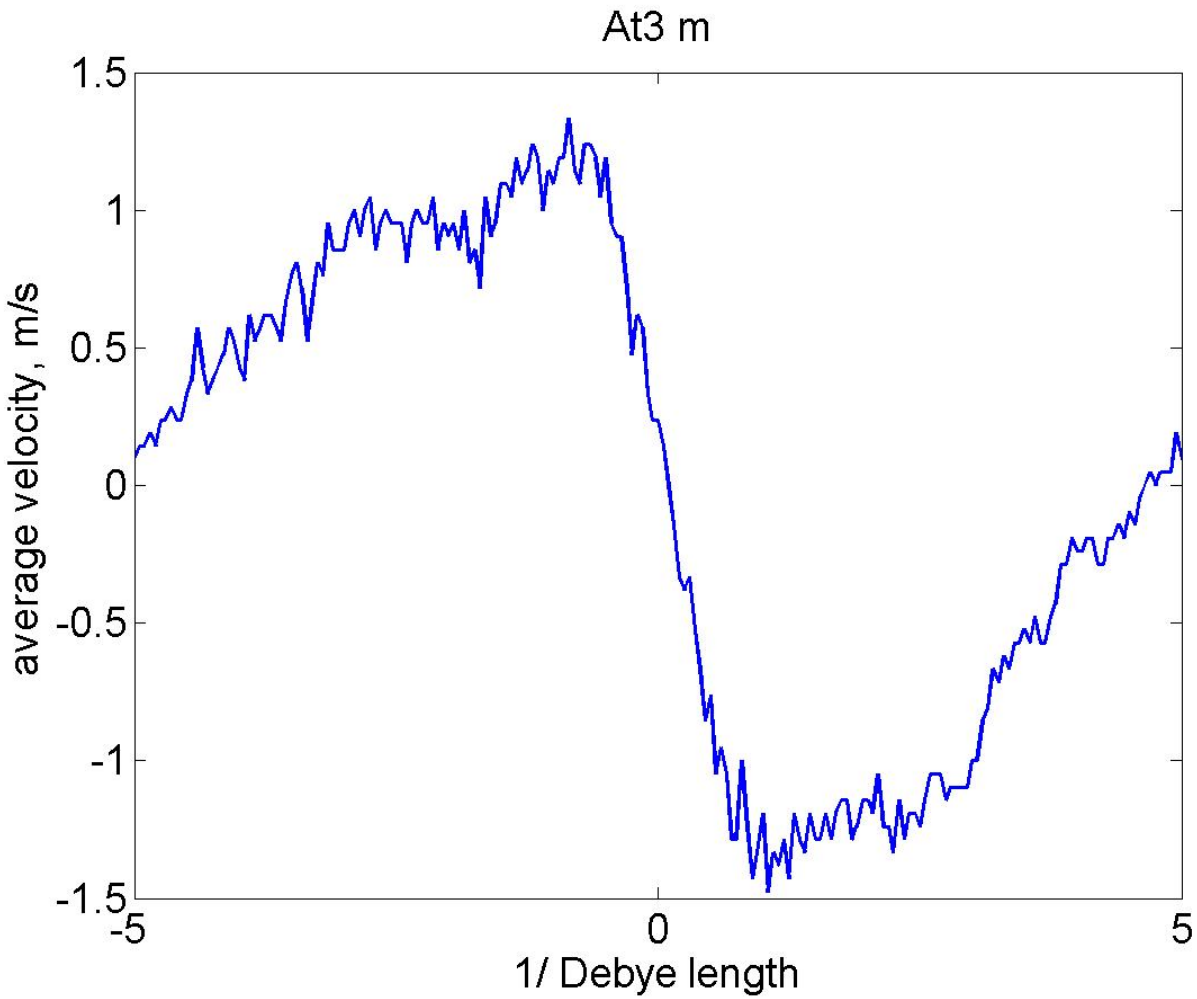
0.25 β_z



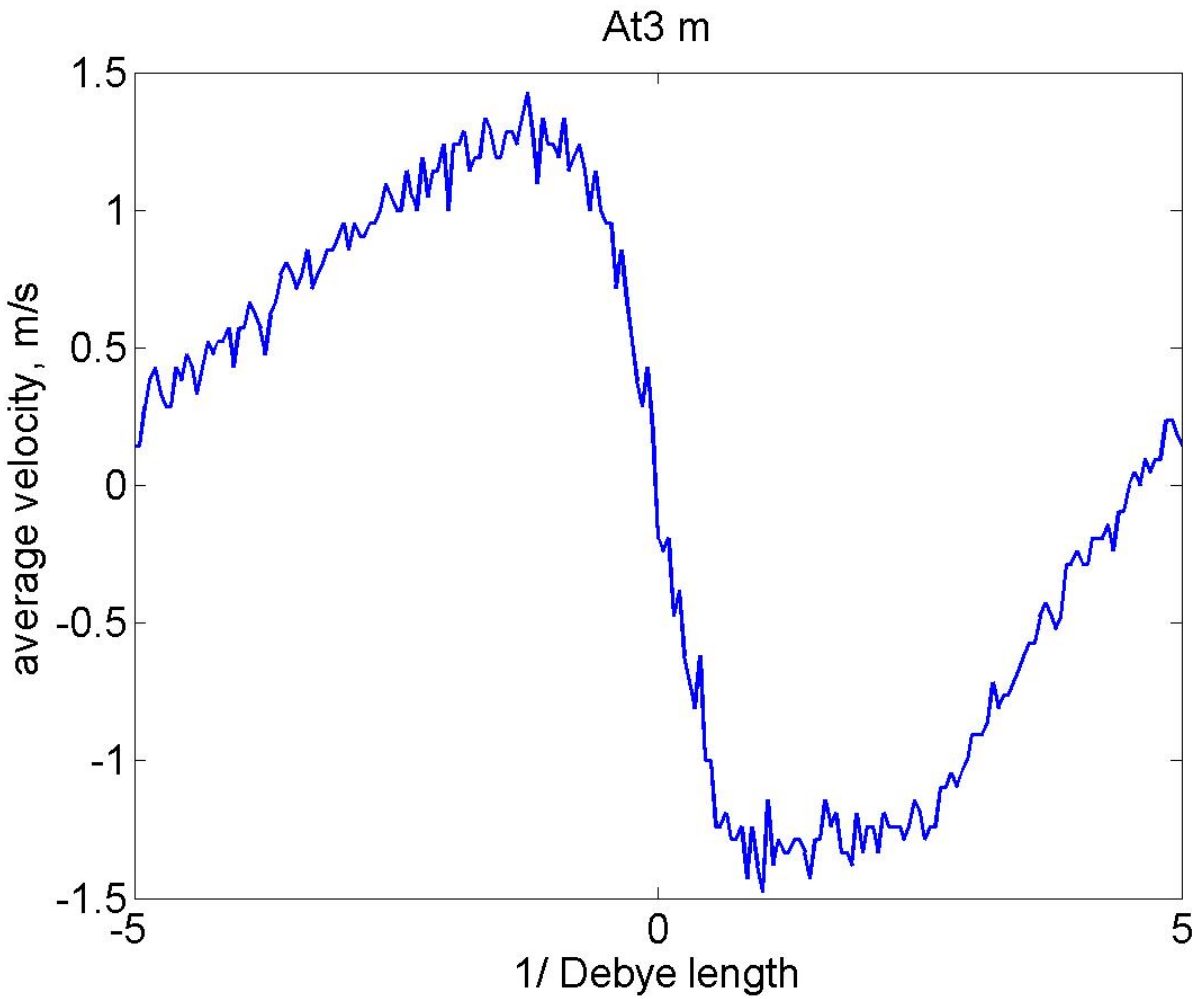
0.50 β_z



0.75 β_z



1.00 β_z



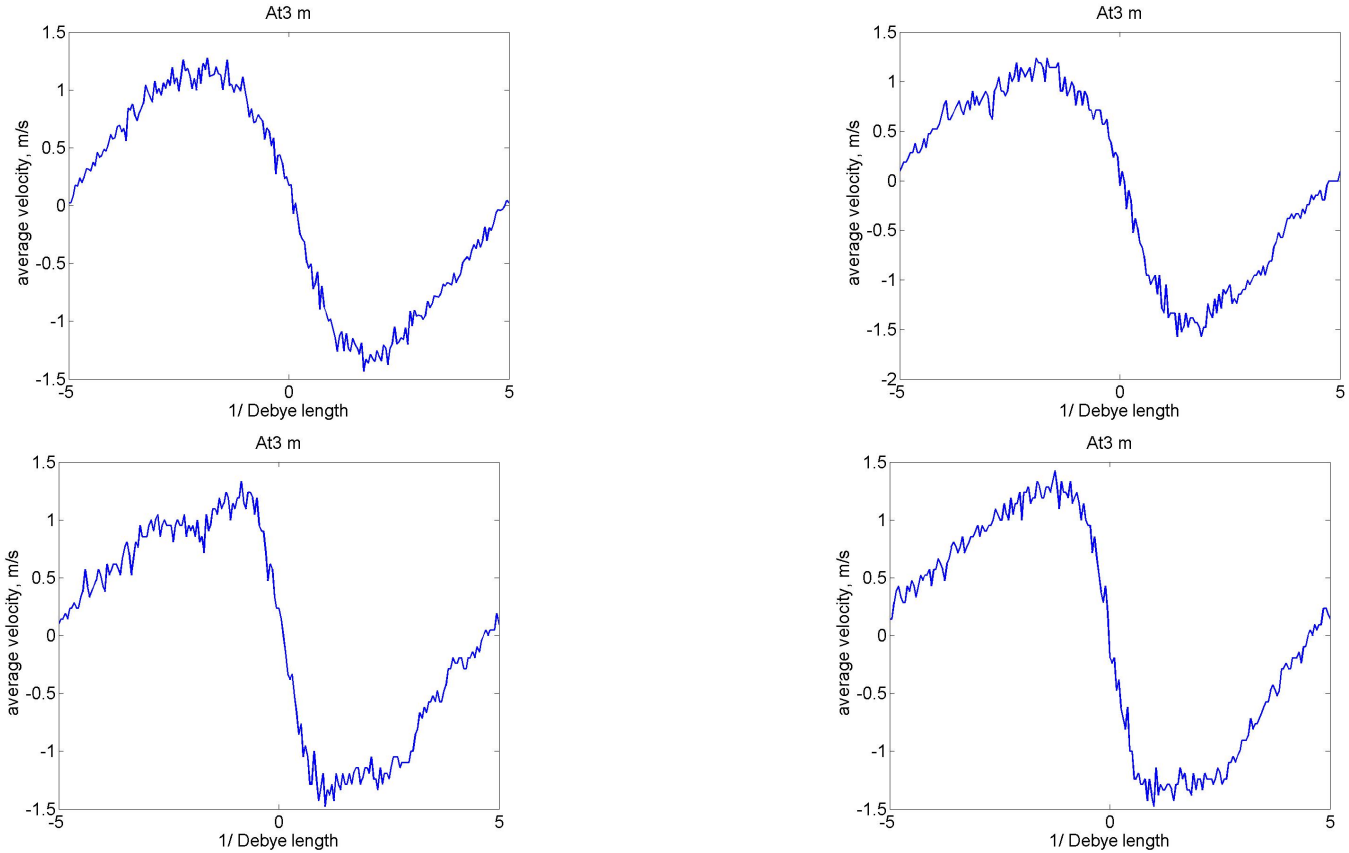
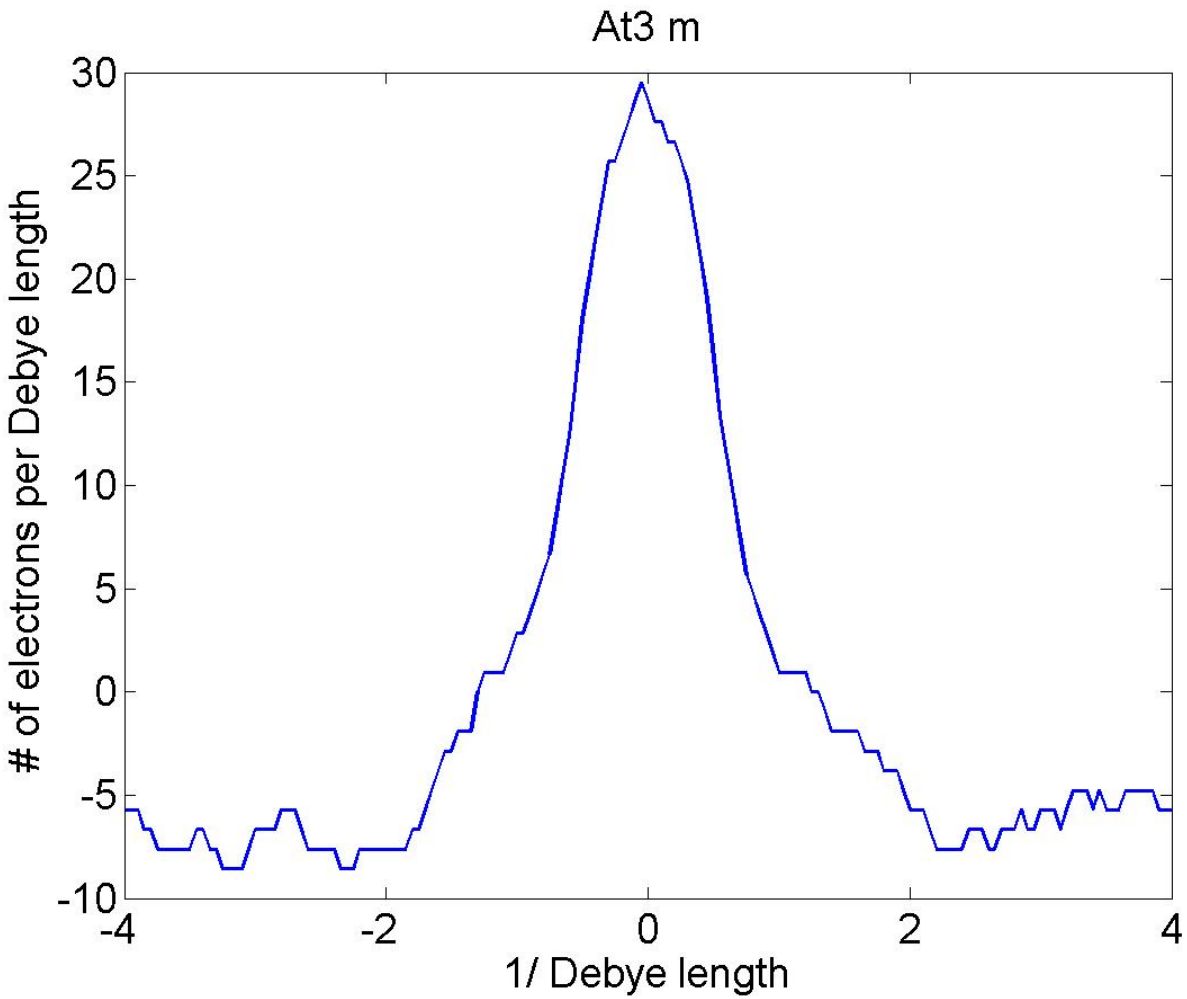
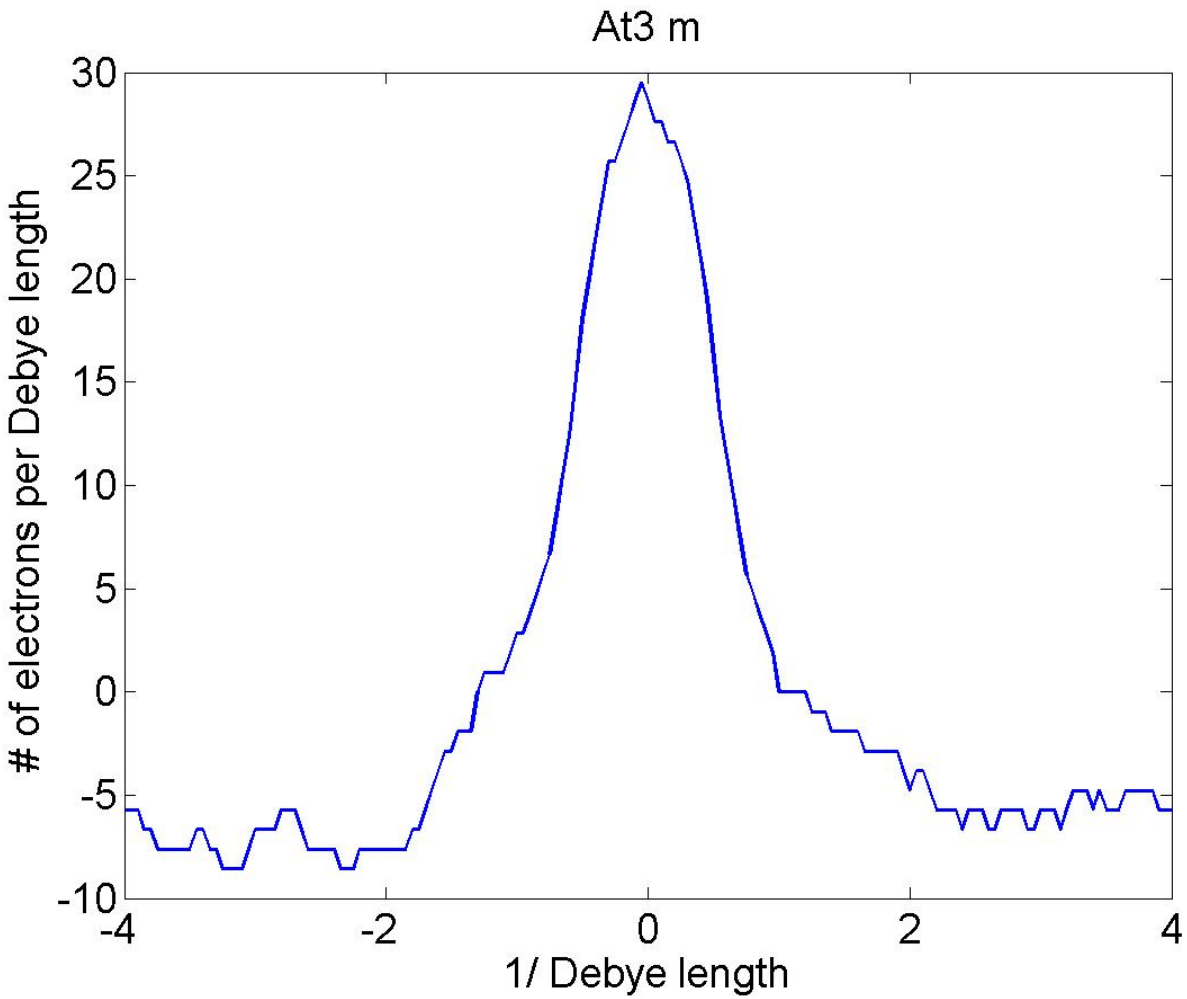


Figure: Electron velocity $0.25\beta_z$ (upper left), $0.50\beta_z$ (upper right), $0.75\beta_z$ (lower left), $1.00\beta_z$ (lower right)

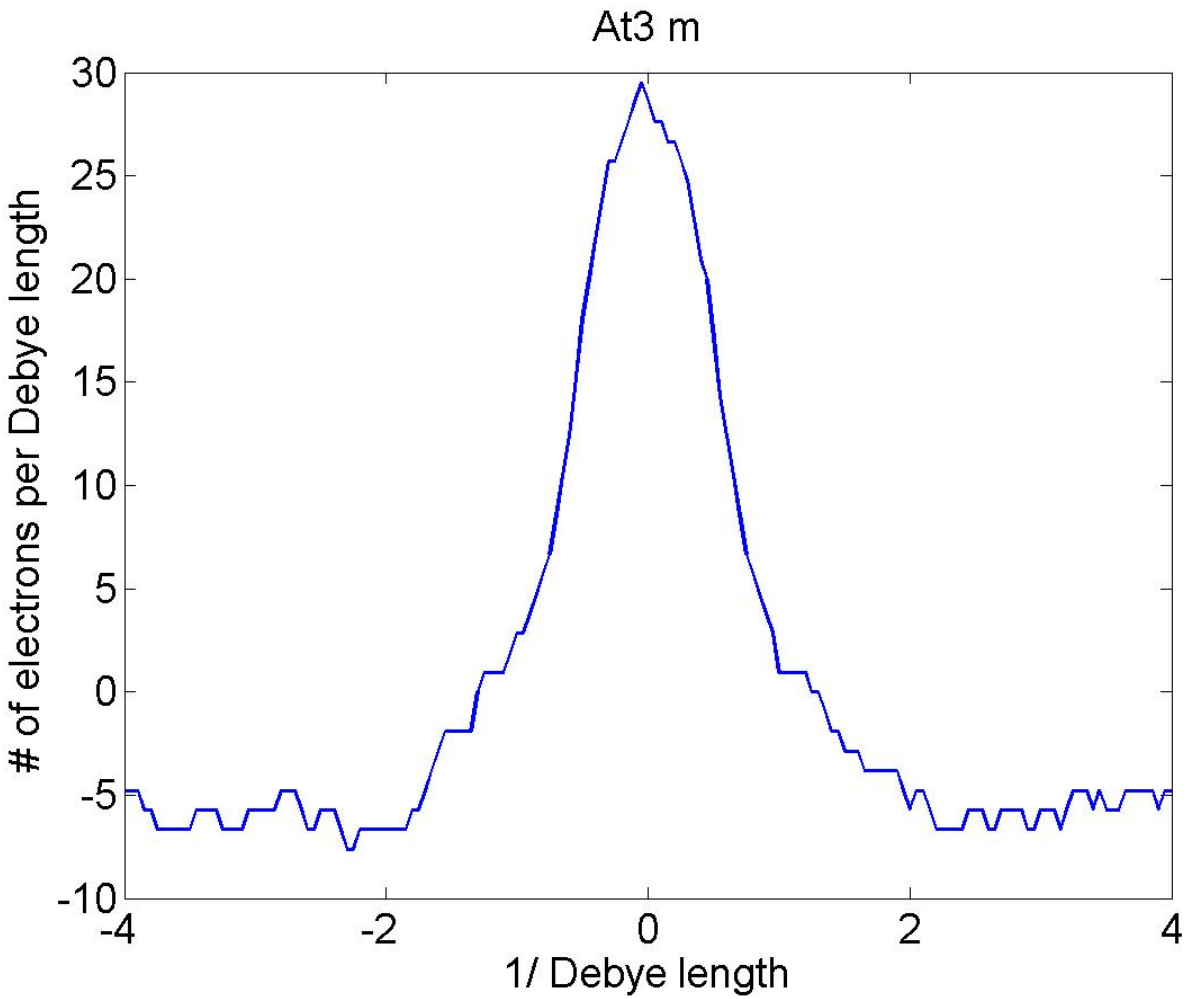
0.25 β_z


At3 m
# of electrons per Debye length
1/ Debye length
30
25
20
15
10
5
0
-5
-10
-4
-2
0
2
4

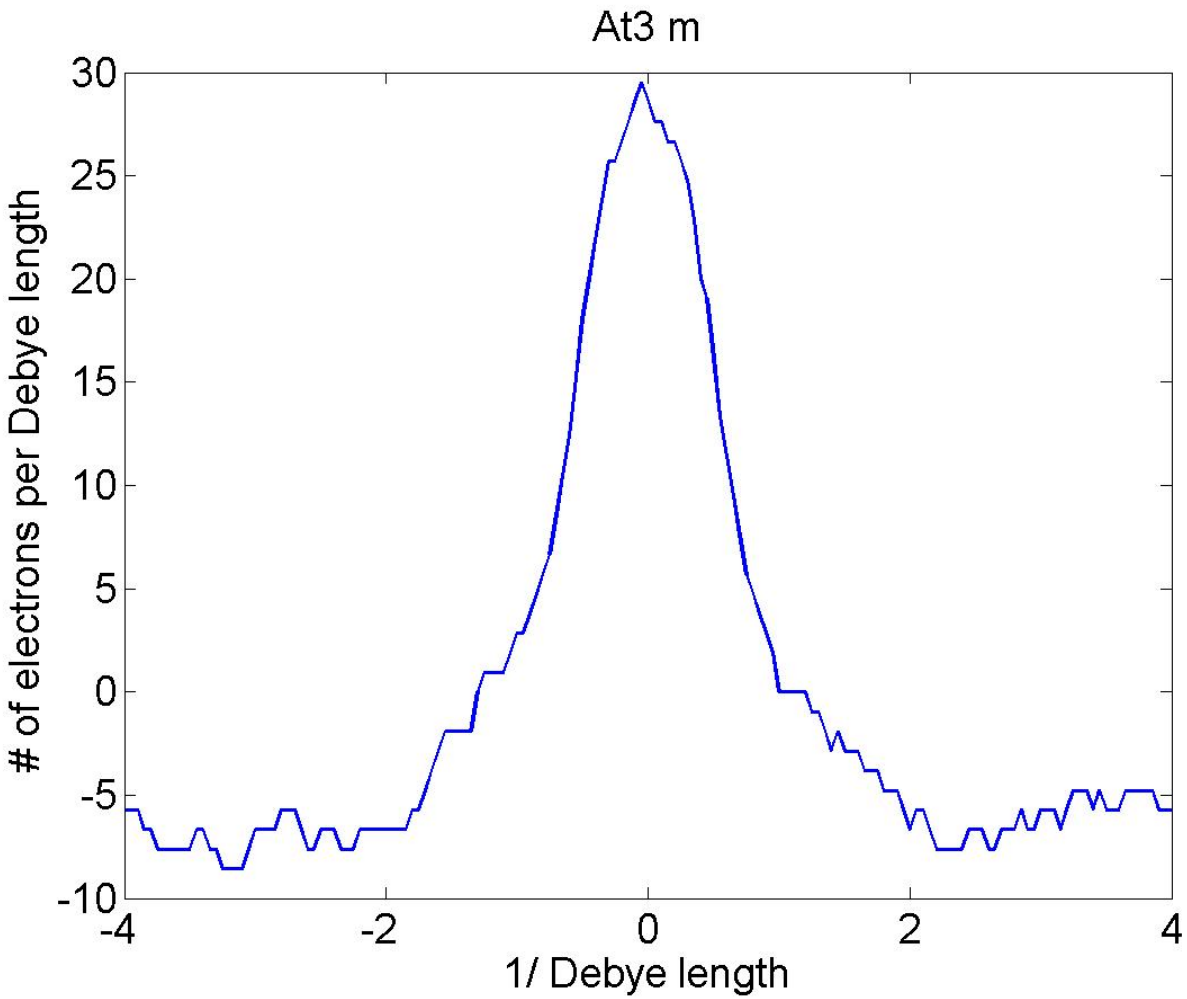
0.50 β_z


At3 m
# of electrons per Debye length
1/ Debye length
30
25
20
15
10
5
0
-5
-10
-4
-2
0
2
4

0.75 β_z


At3 m
# of electrons per Debye length
1/ Debye length
30
25
20
15
10
5
0
-5
-10
-4
-2
0
2
4

1.00 β_z


At3 m
# of electrons per Debye length
1/ Debye length
30
25
20
15
10
5
0
-5
-10
-4
-2
0
2
4

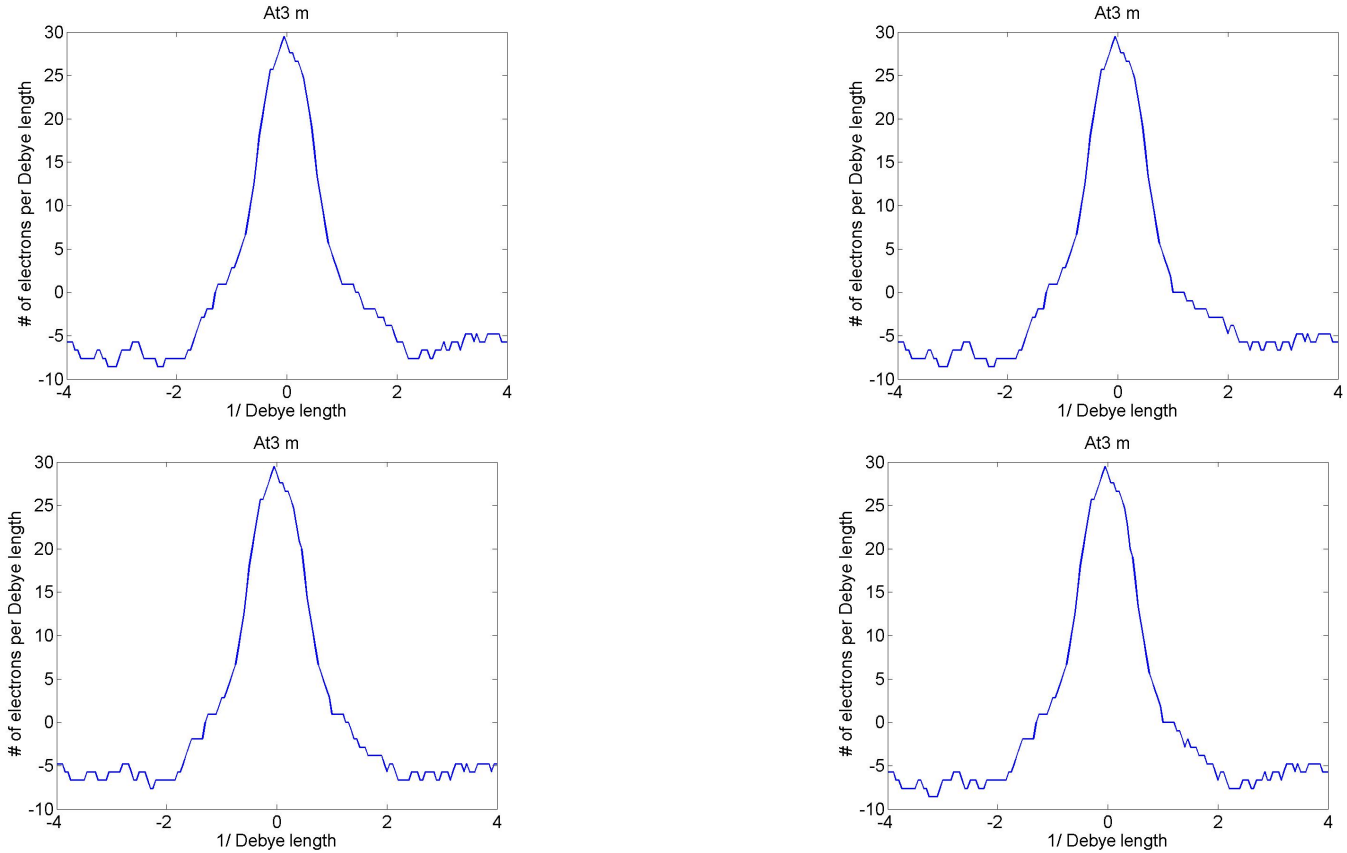
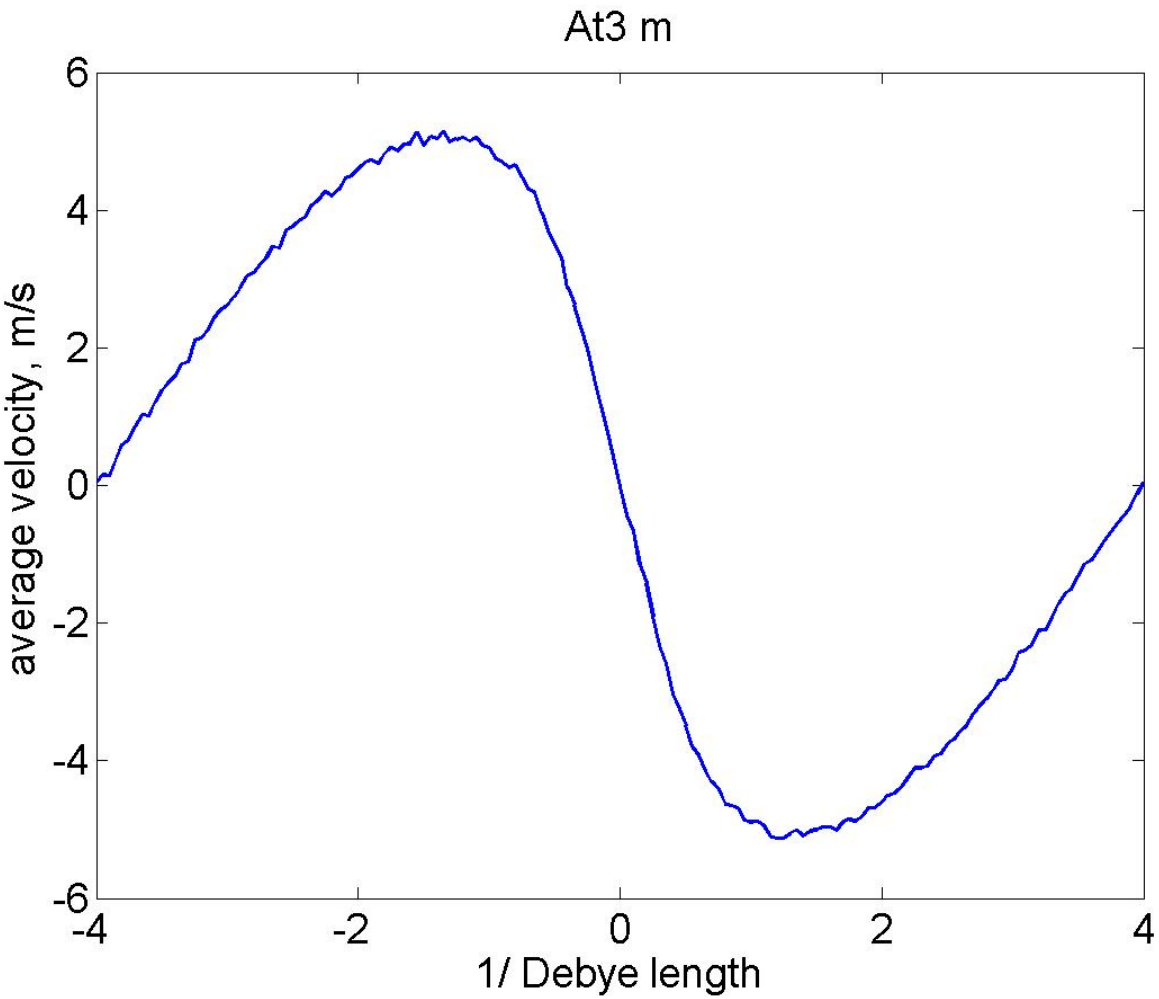
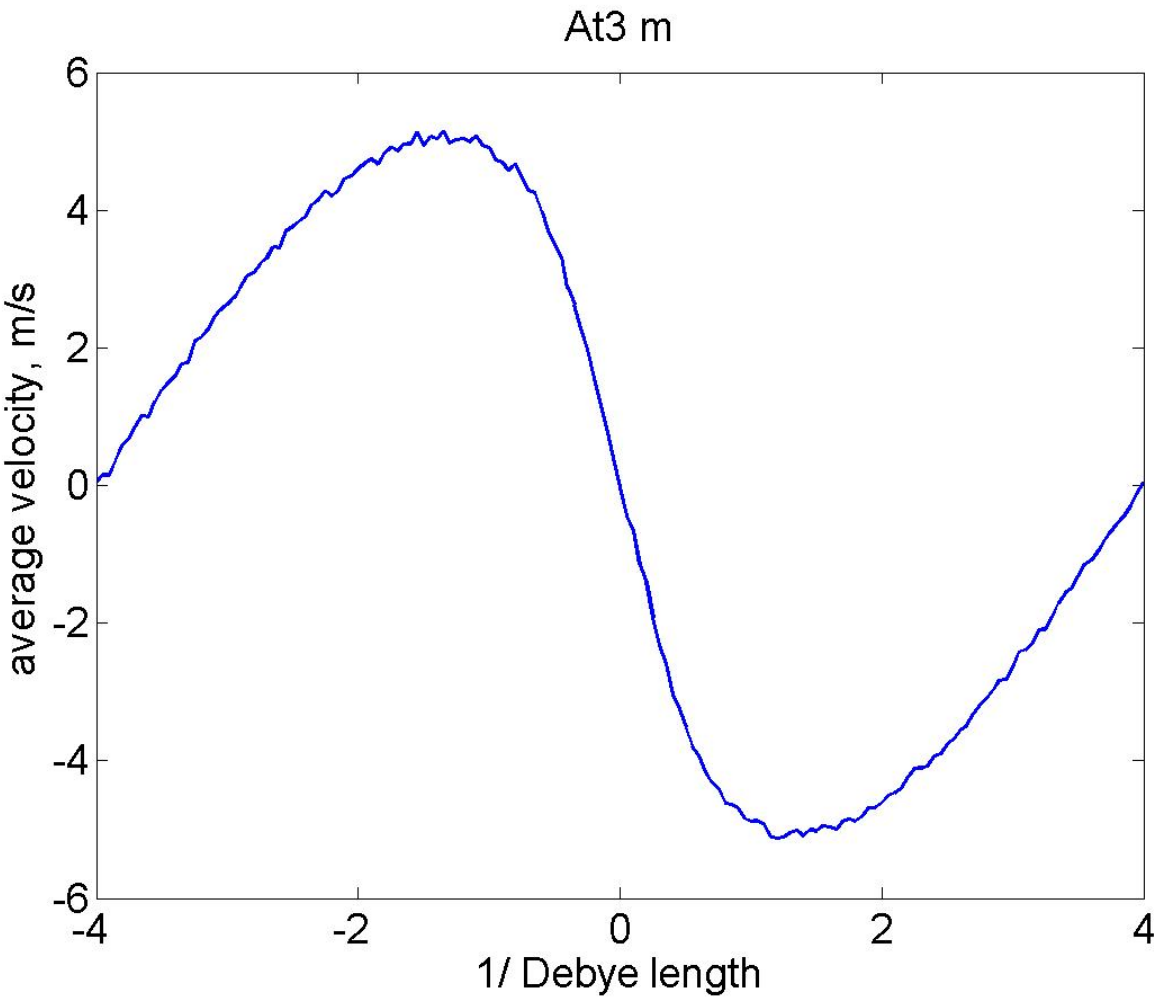


Figure: Electron velocity $0.25\beta_z$ (upper left), $0.50\beta_z$ (upper right), $0.75\beta_z$ (lower left), $1.00\beta_z$ (lower right)

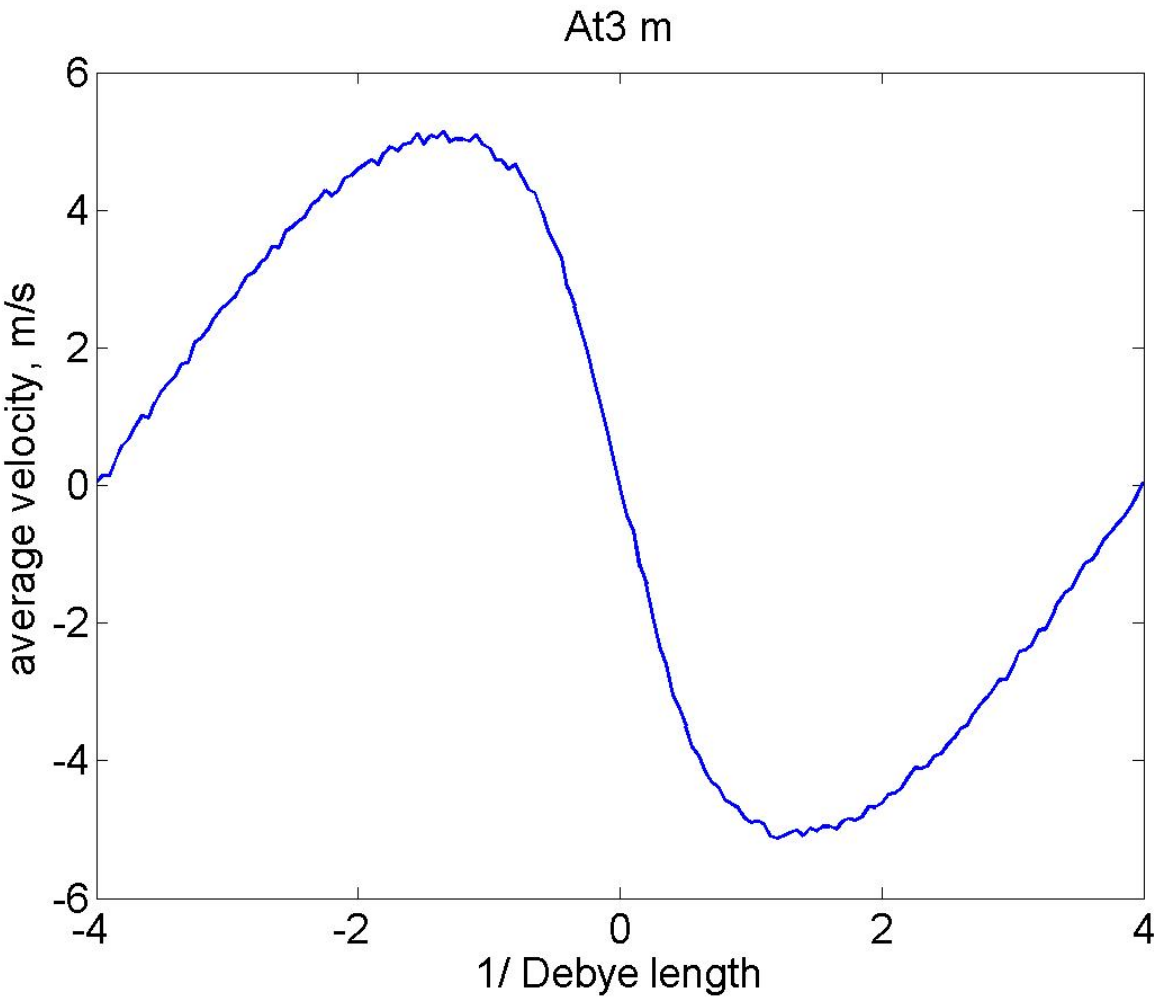
0.25 β_z



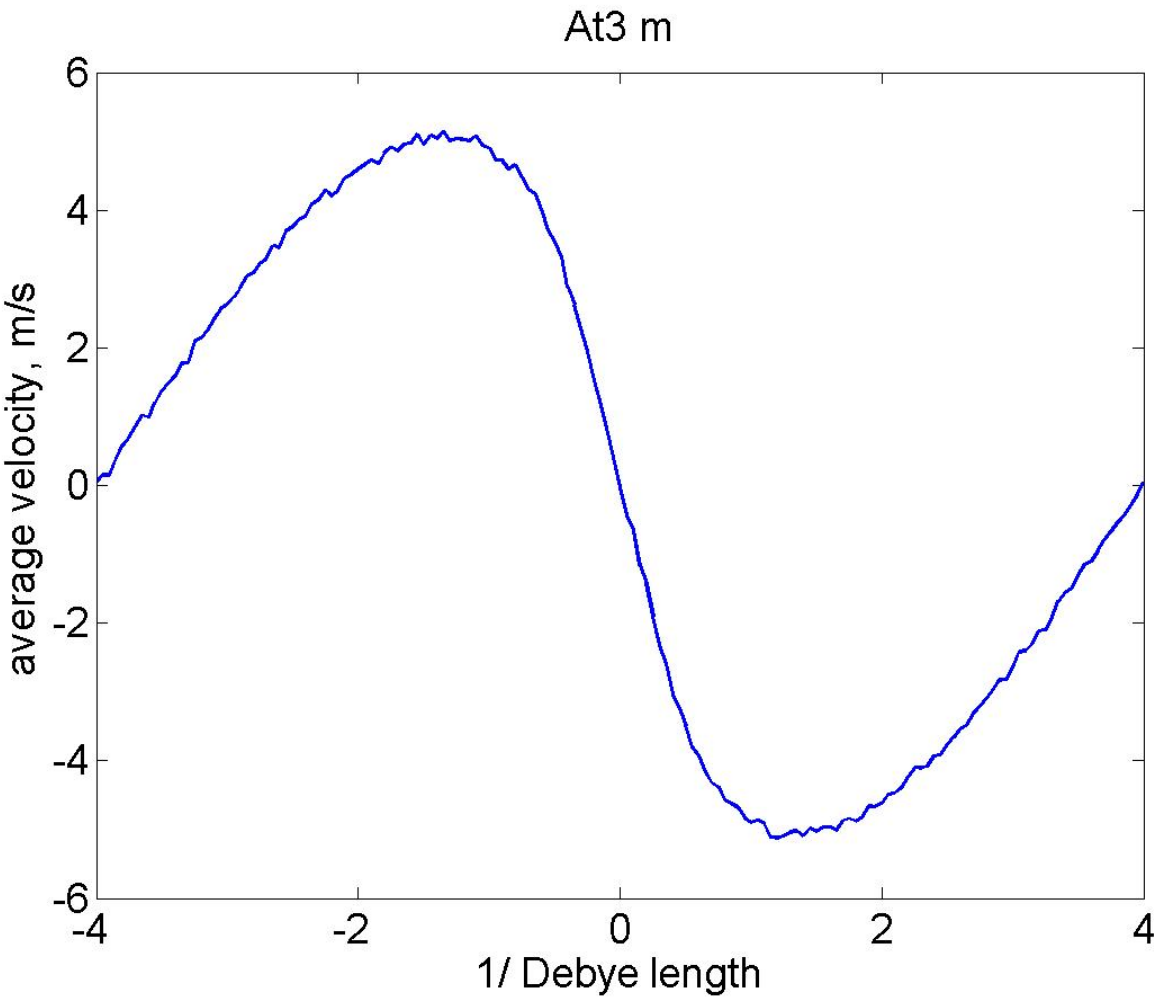
0.50 β_z



0.75 β_z



1.00 β_z



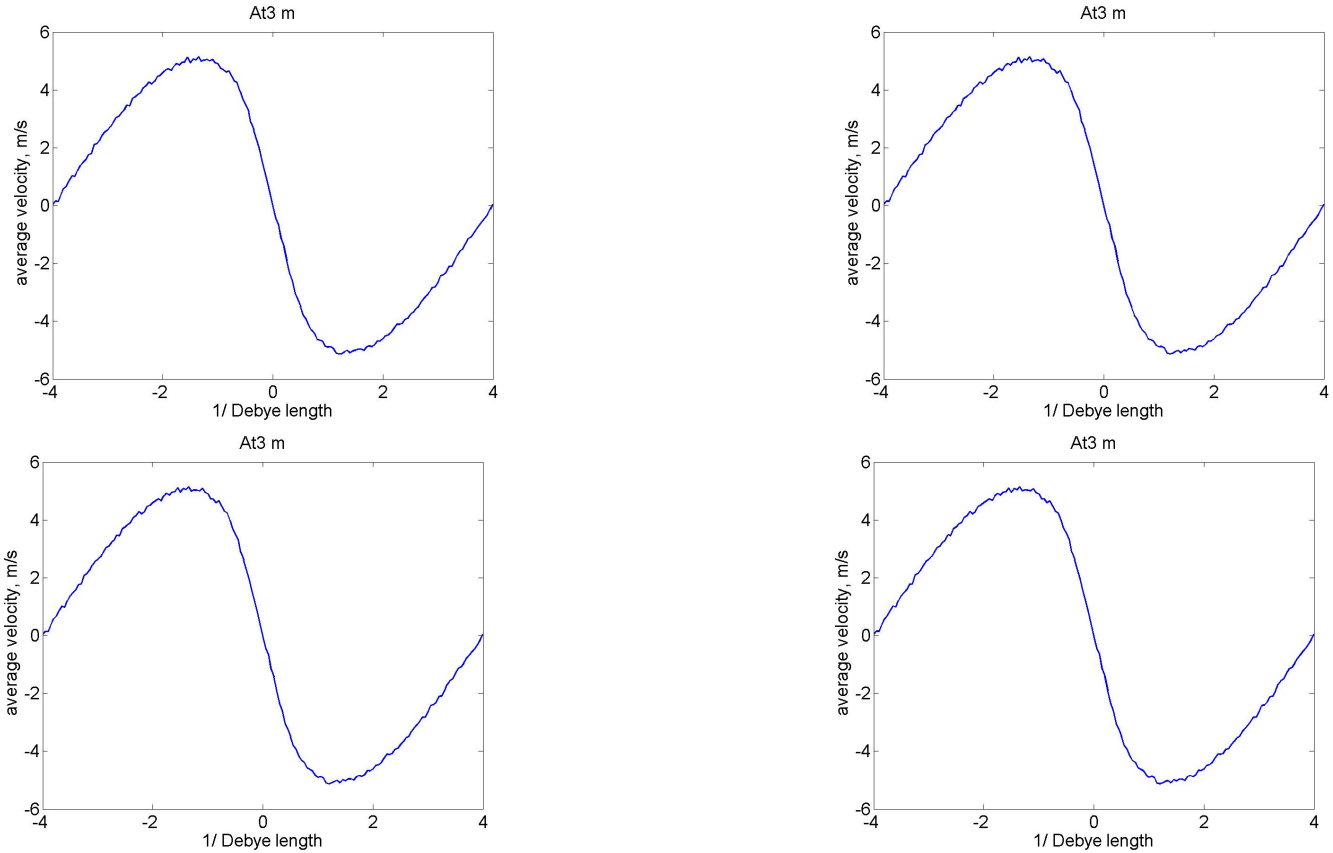
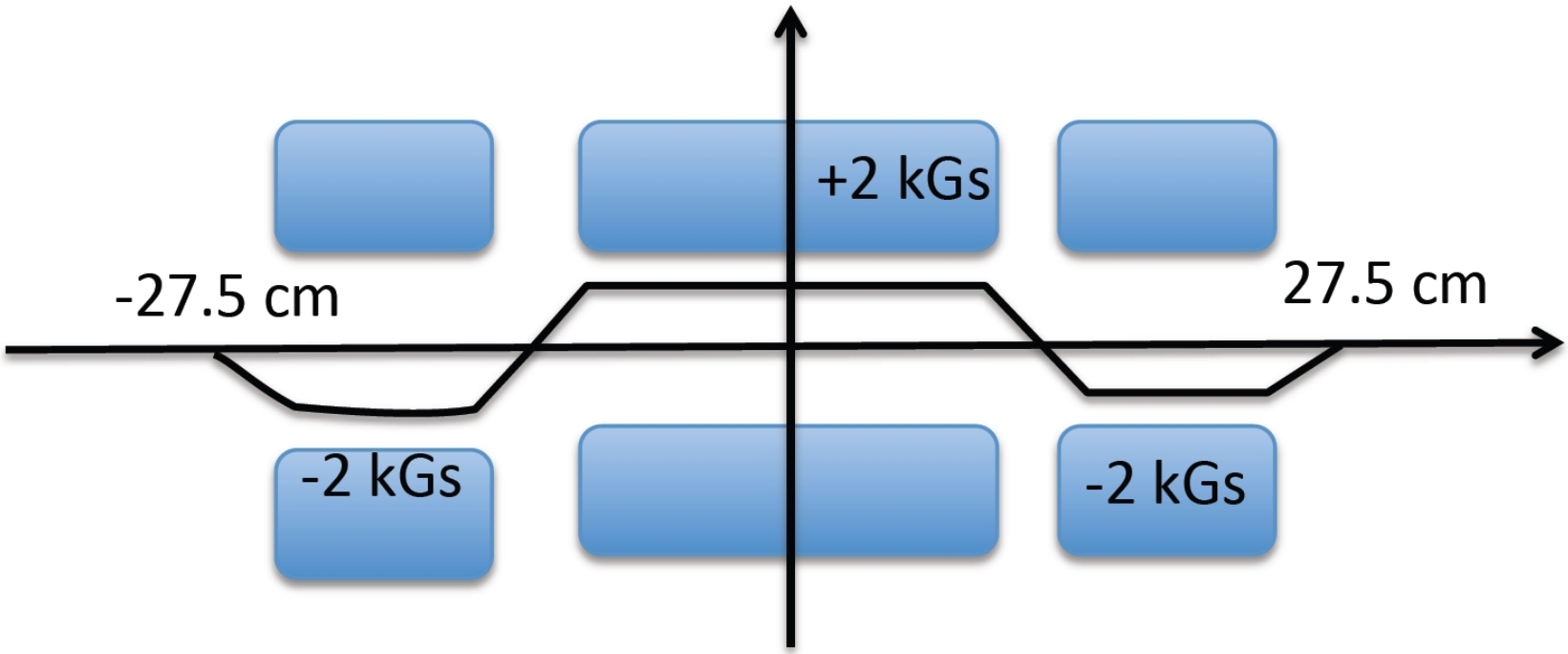
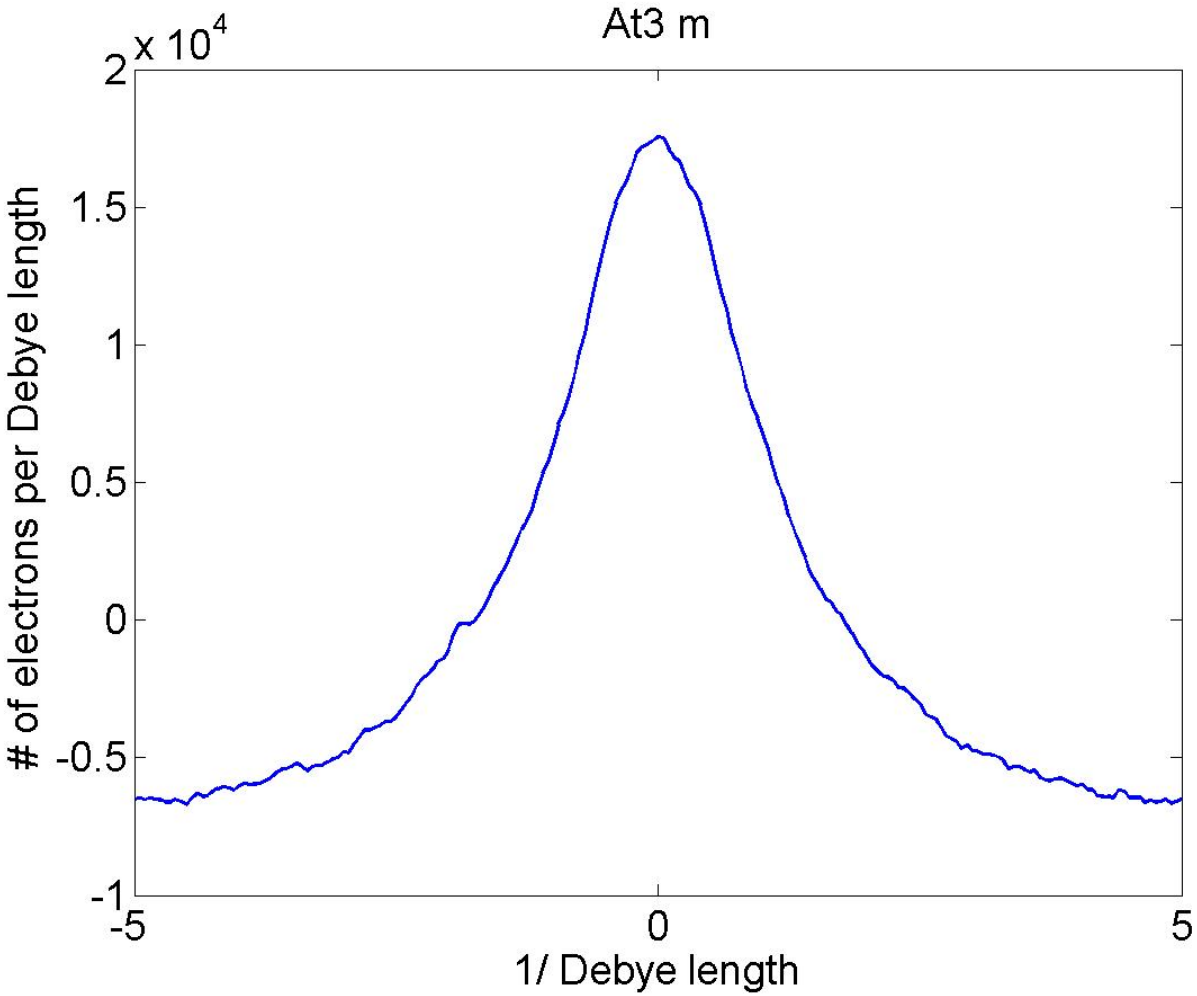


Figure: Electron velocity $0.25\beta_z$ (upper left), $0.50\beta_z$ (upper right), $0.75\beta_z$ (lower left), $1.00\beta_z$ (lower right)

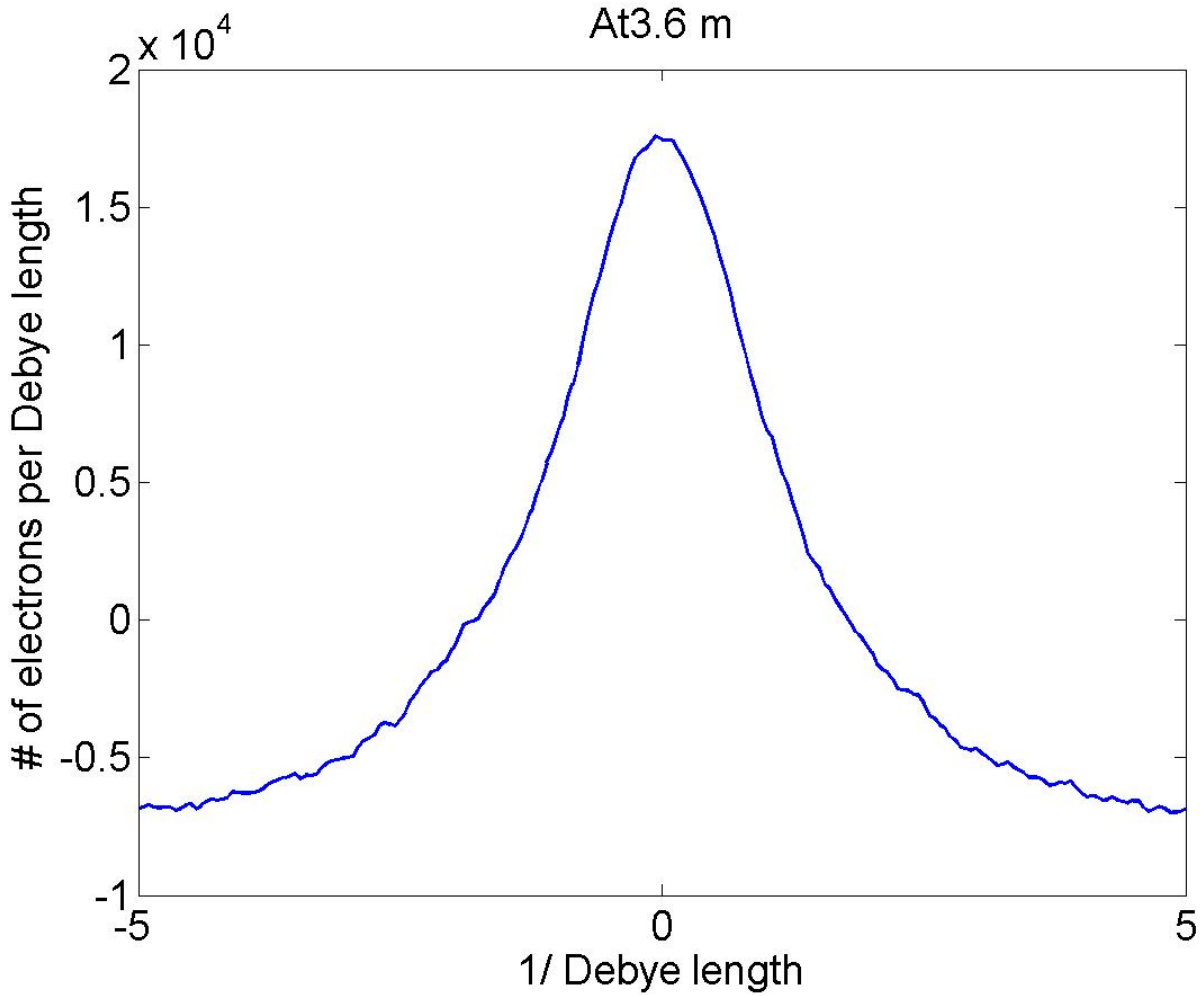
Wiggler structure



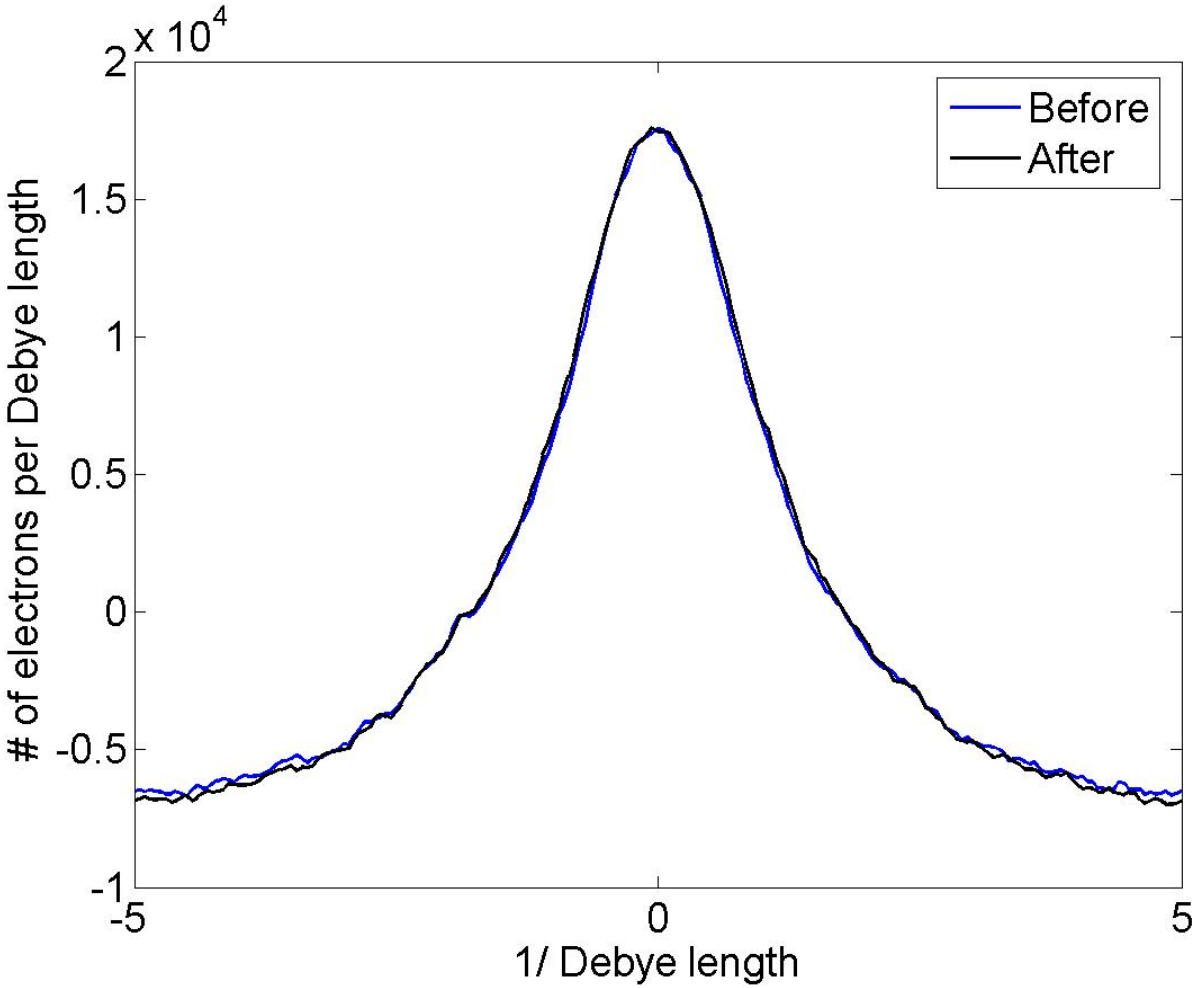
Before wiggler



After wiggler



Compare before and after



Difference between before and after