Effect of RADAR azimuthal rotation speed on Doppler velocity and direction estimation

- Tworit Kumar Dash

- Promoter (TU Delft): Prof. Dr. Alexander Yarovoy (Chairman, Ms3)
- Supervisor (TU Delft): Dr. Oleg Krasnov

TU Delft

Challenge

- When the radar beam on azimuth rotates very fast, the time on target at one direction in space is too low.
- The faster the radar rotates, the smaller are the time samples at one direction of space.

$$T_d = \frac{BW[rad]}{\Omega[rad\,.\,s^{-1}]}$$

Beamwidth

Rotation speed in radian/second

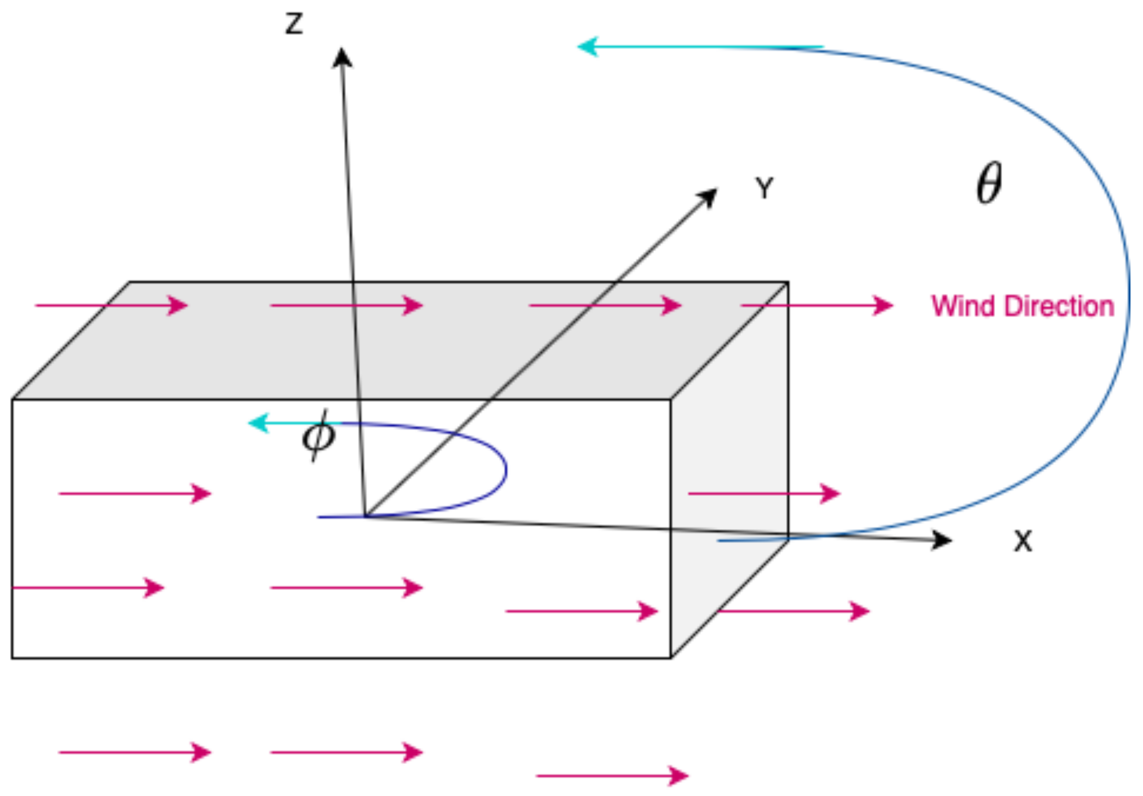
Time spent in one single Beamwidth in space

TUDelft

Model of Homogeneous wind

- Wind is considered homogeneous
- The elevation of the radar beam is fixed
- The wind velocity spectrum for ground truth is considered as a Gaussian shaped spectrum.

$$S(v) = \frac{1}{\sqrt{2\pi\sigma_v^2}} e^{\frac{-(v-\mu_v)^2}{2v_{\sigma_v}^2}}$$



Radar forward model

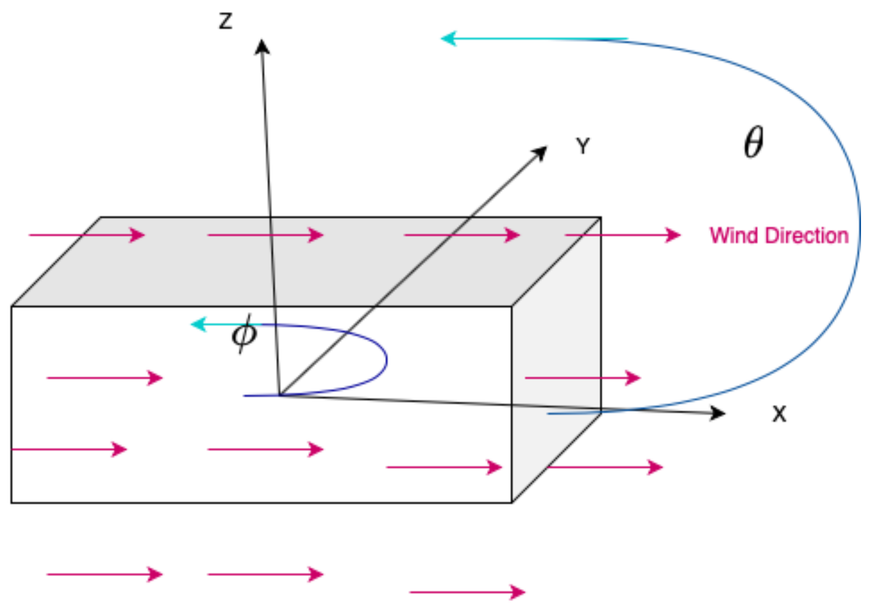
- The time domain signal is sampled based on the time on target direction.
- The phase is modified based on the observation direction

$$s_\Omega(t) = A(t)e^{j\Psi(t)\cos(\phi_{wind}-\phi(t))}$$

$$\phi(t) = \phi_0 + \Omega t$$

TU Delft

Ideas to simulate the slow-time domain signal (1)



1. Direction independent high definition spectrum

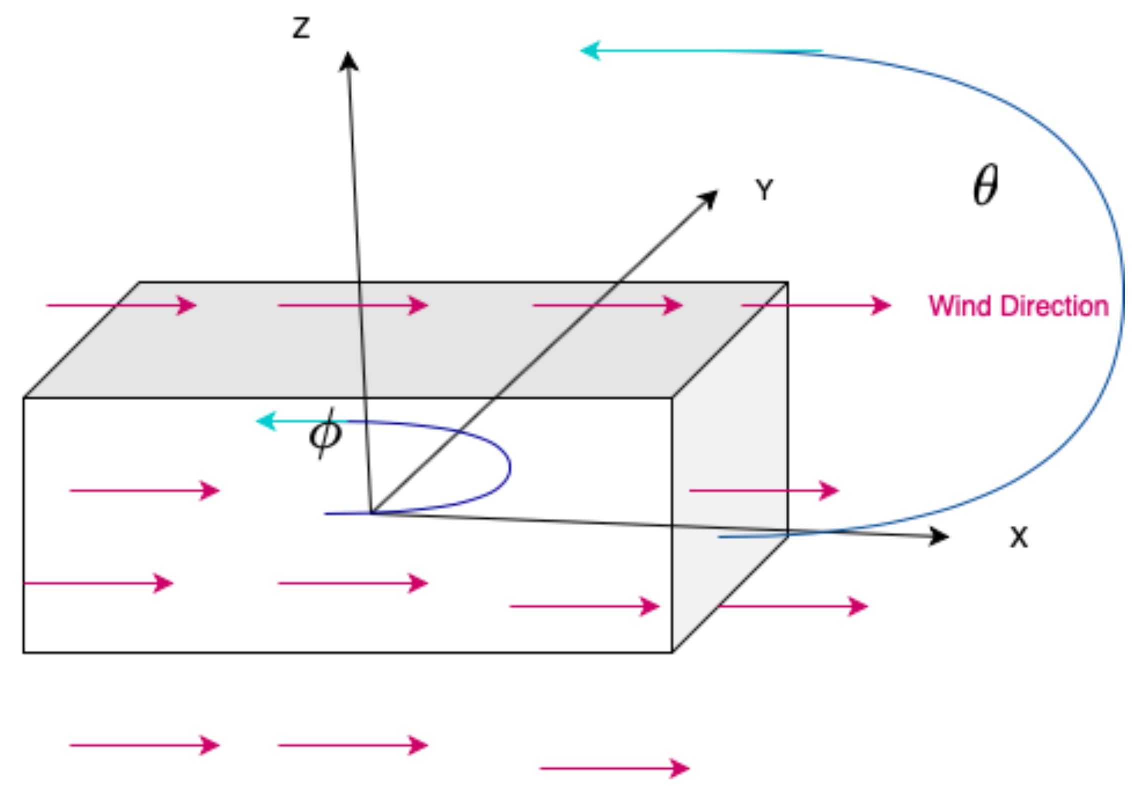
$$S(v) = \frac{1}{\sqrt{2\pi\sigma_v^2}} e^{\frac{-(v-\mu_v)^2}{2v_{\sigma_v}^2}}$$

2. Convert to Time Domain $s(t) = A(t)e^{j\Psi(t)}$
3. Use direction information in time domain and sample it based on time on target Ω, T_d

$$s_\Omega(t) = A(t)e^{j\Psi(t)\cos(\phi_{wind} - \phi(t))} \qquad \phi(t) = \phi_0 + \Omega t$$

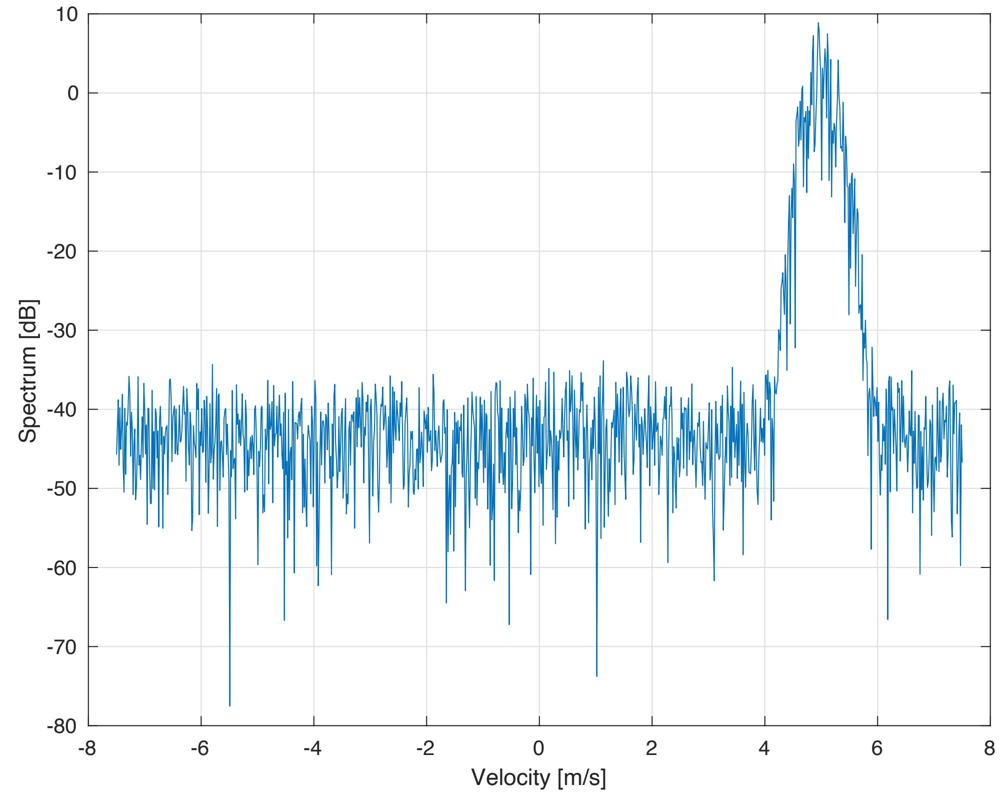
Result of (1)

Ground Truth: $\mu = 5[m/s]$ $\sigma = 0.2[m/s]$ $\phi_{wind} = 0$



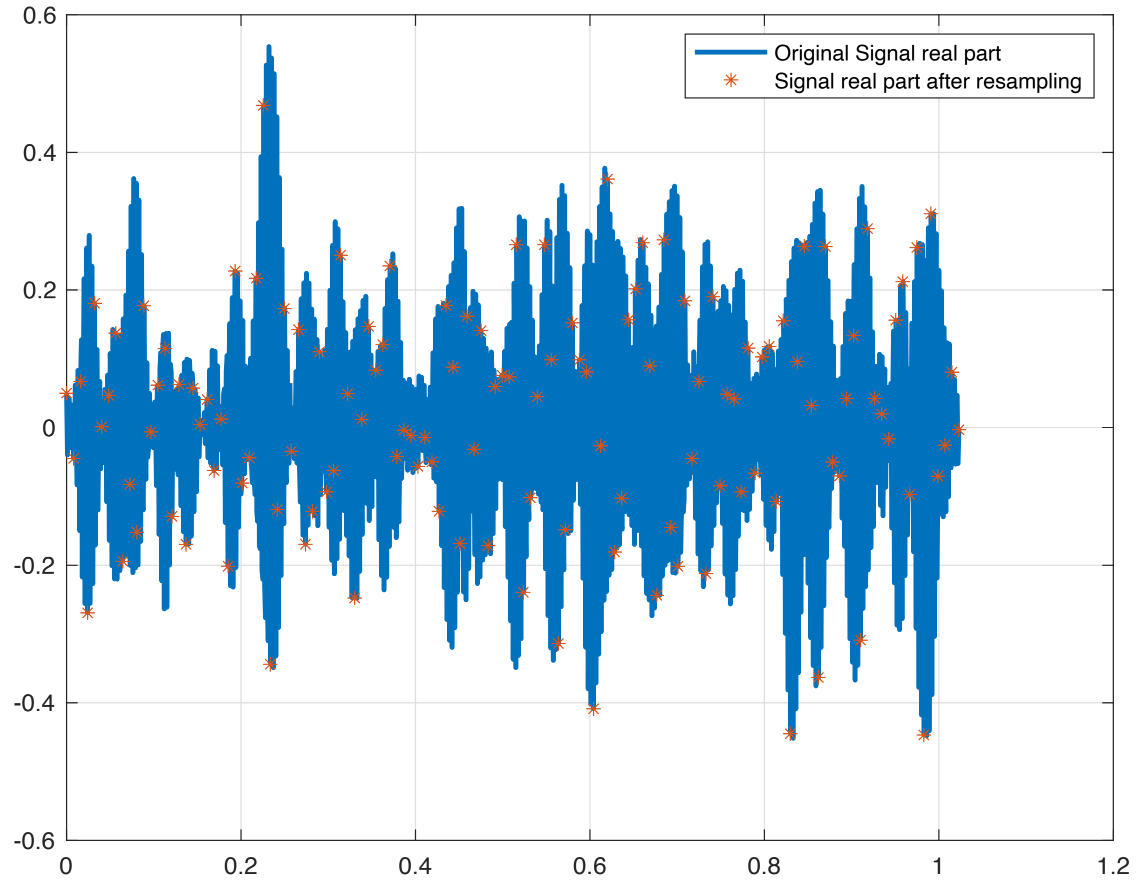
$\Omega[RPM]$	N_{bursts}	Samples for FFT processing
HD		1024
1	167	128

1



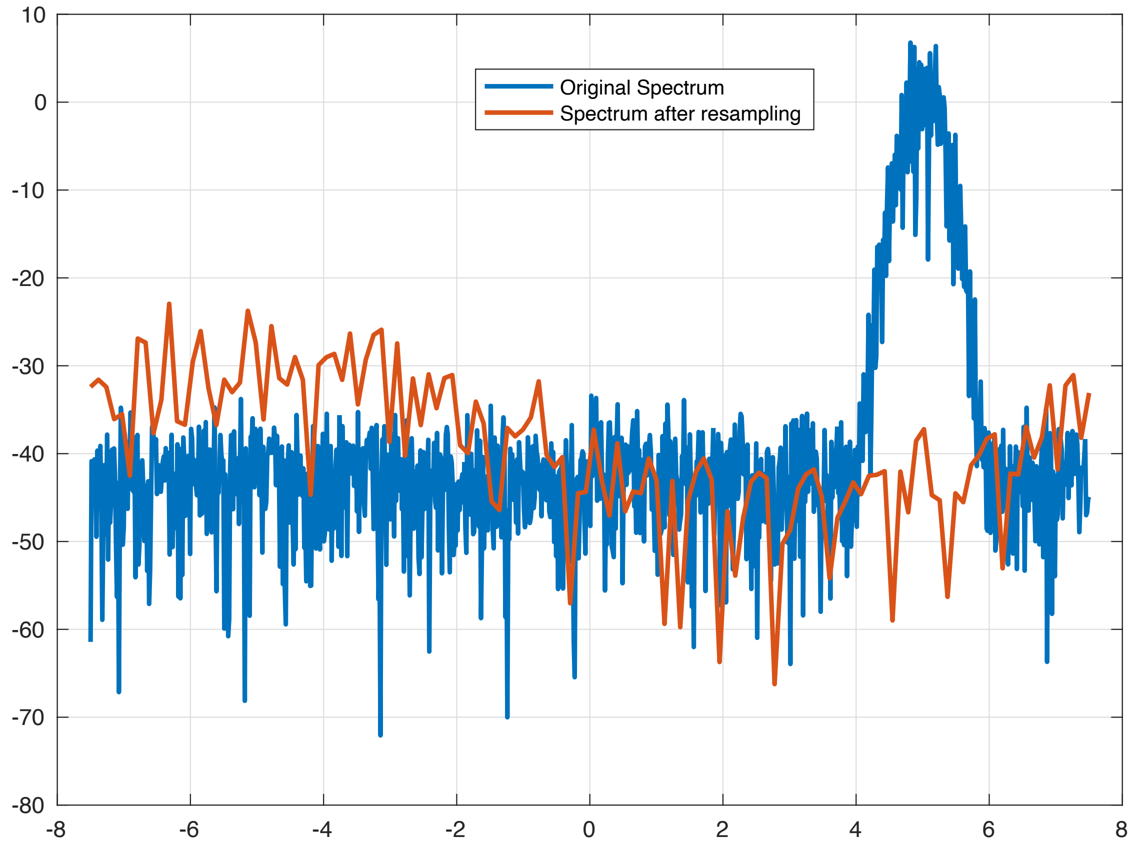
Original HD spectrum

2



Time domain sampling

3

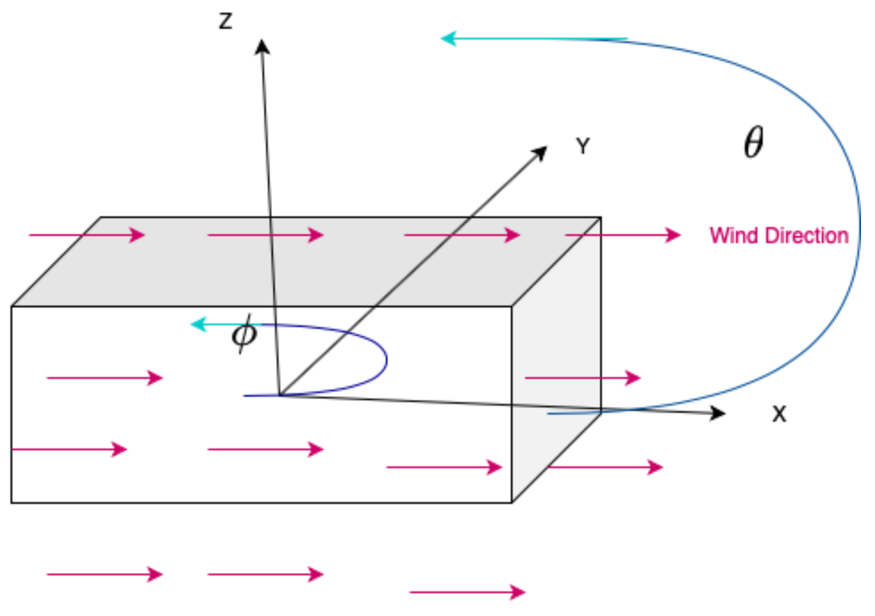


Spectrum reconstruction

Time domain sampling was too coarse and didn't produce the spectrum well.
Didn't go with this approach.

TUDelft

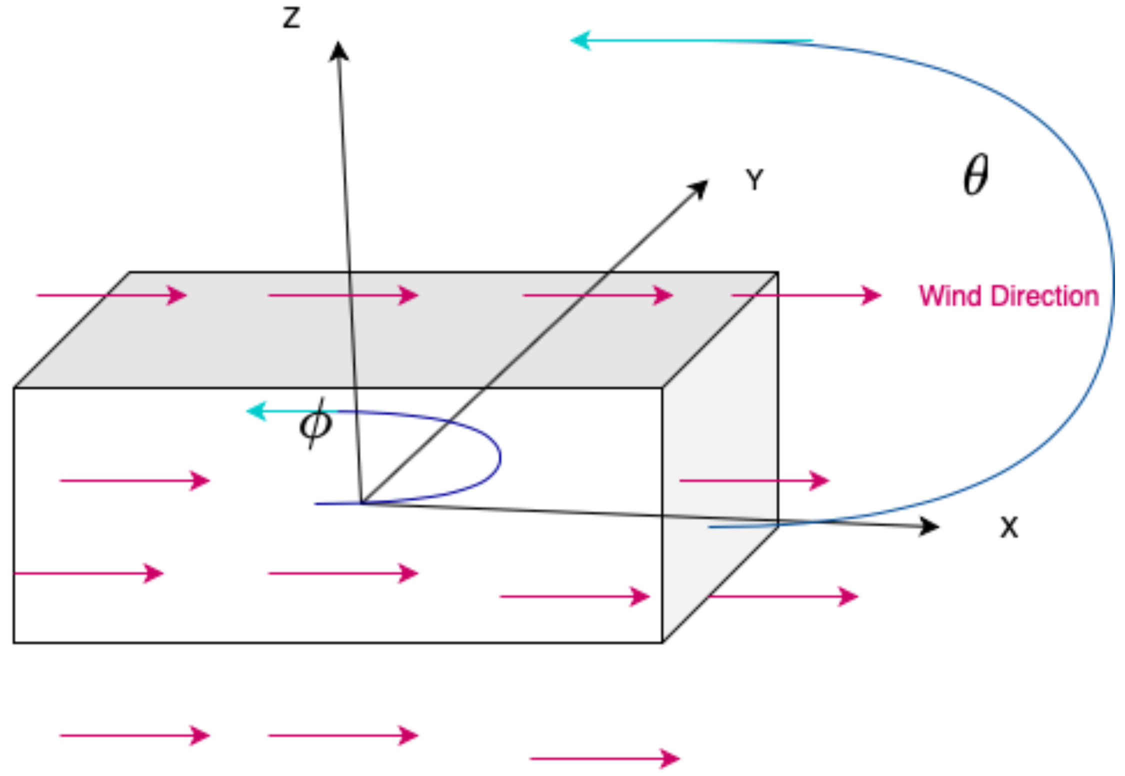
Ideas to simulate the slow-time domain signal (2)



1. Direction independent low definition spectrum
$$S(v) = \frac{1}{\sqrt{2\pi\sigma_v^2}} e^{\frac{-(v-\mu_v)^2}{2v_{\sigma_v}^2}}$$
2. Determined by area under the curve of the high definition spectrum with limited number of samples
3. Convert to Time Domain $s(t) = A(t)e^{j\Psi(t)}$
4. Use direction information in time domain and sample it based on time on target Ω, T_d

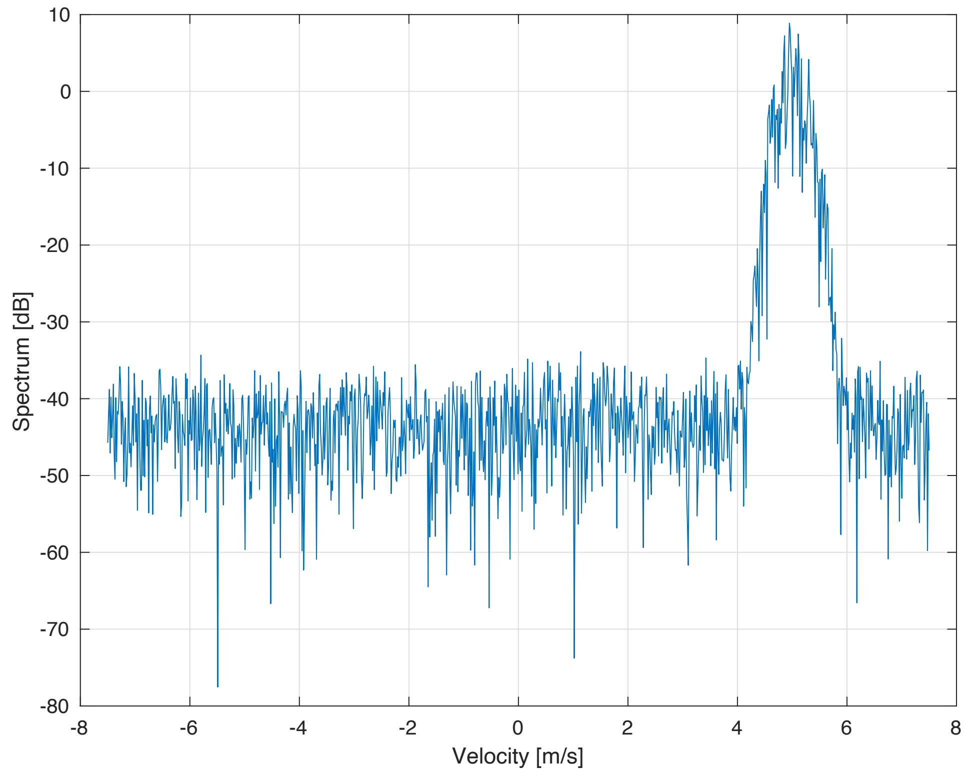
$$s_\Omega(t) = A(t)e^{j\Psi(t)\cos(\phi_{wind} - \phi(t))} \qquad \phi(t) = \phi_0 + \Omega t$$

Result of (2)



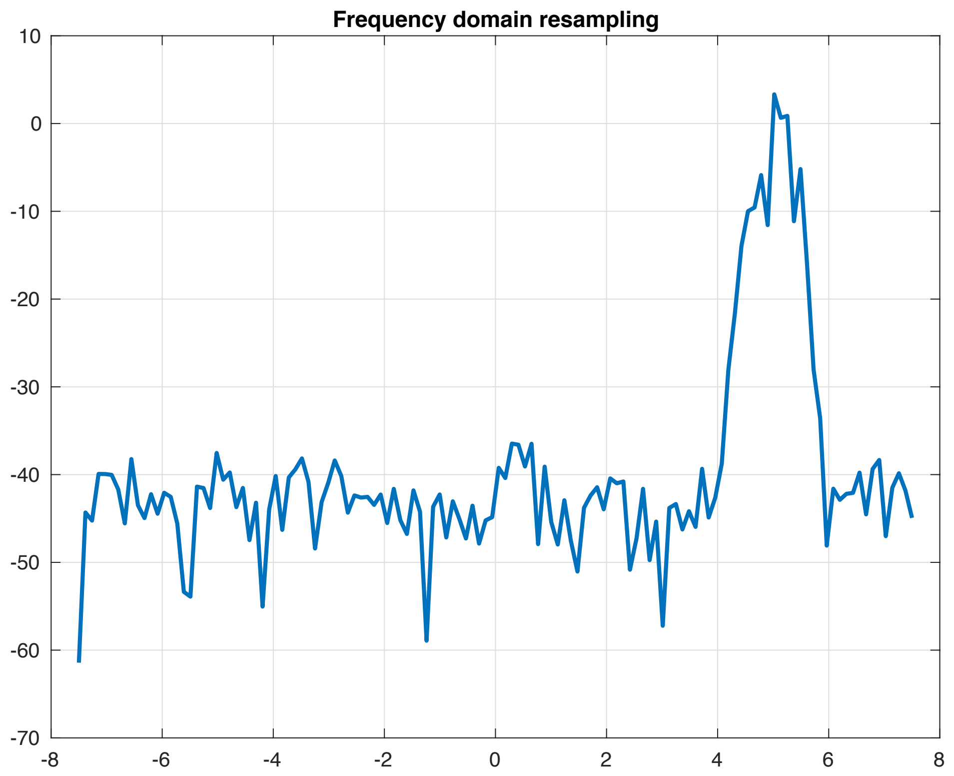
Ground Truth: $\mu = 5[m/s]$ $\sigma = 0.2[m/s]$ $\phi_{wind} = 0$

1



Original HD spectrum

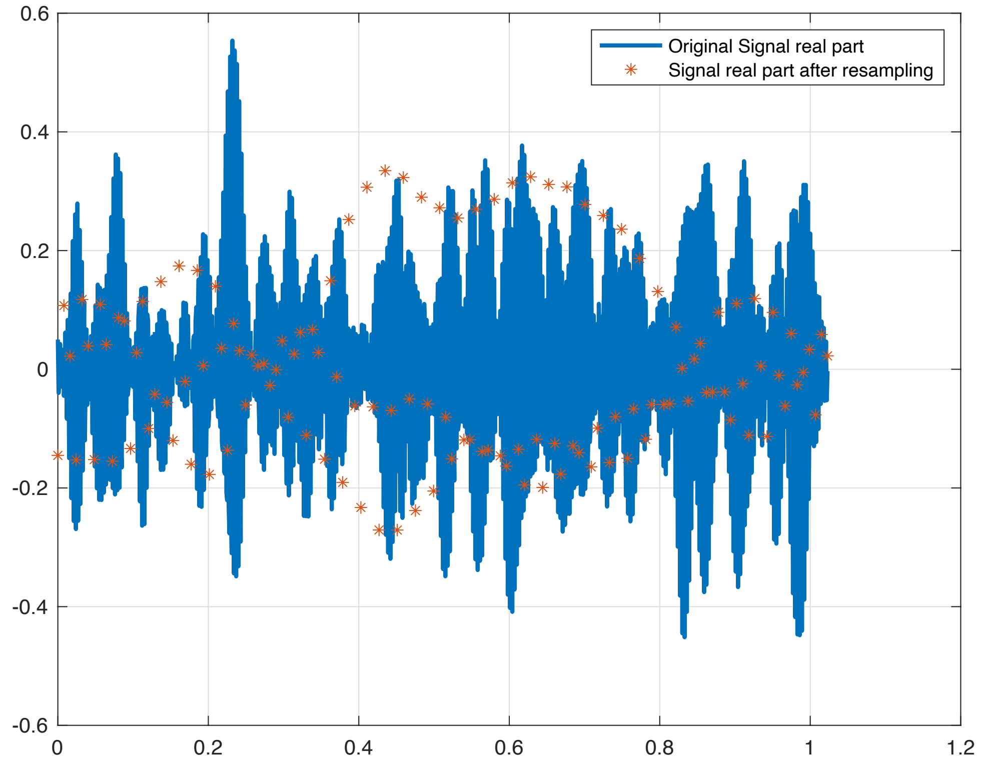
2



Frequency domain sampling based on area under the curve

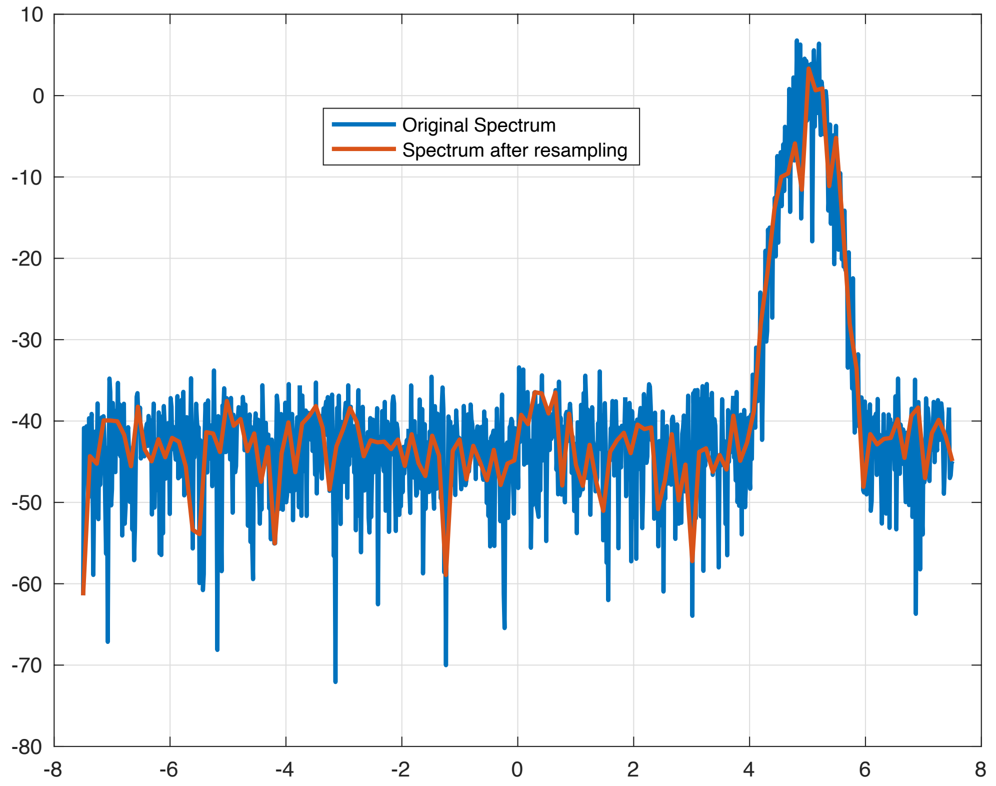
$\Omega[RPM]$	N_{bursts}	Samples for FFT processing
HD		1024
1	167	128

3



Time domain equivalent

4

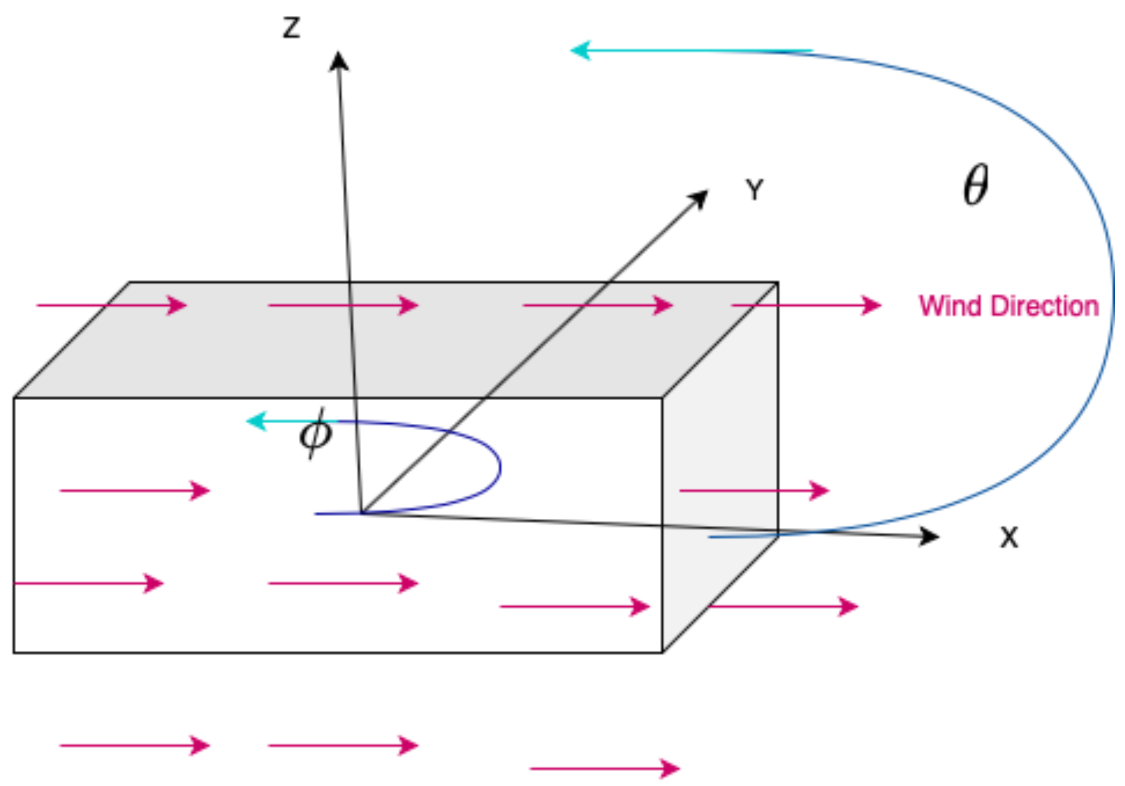


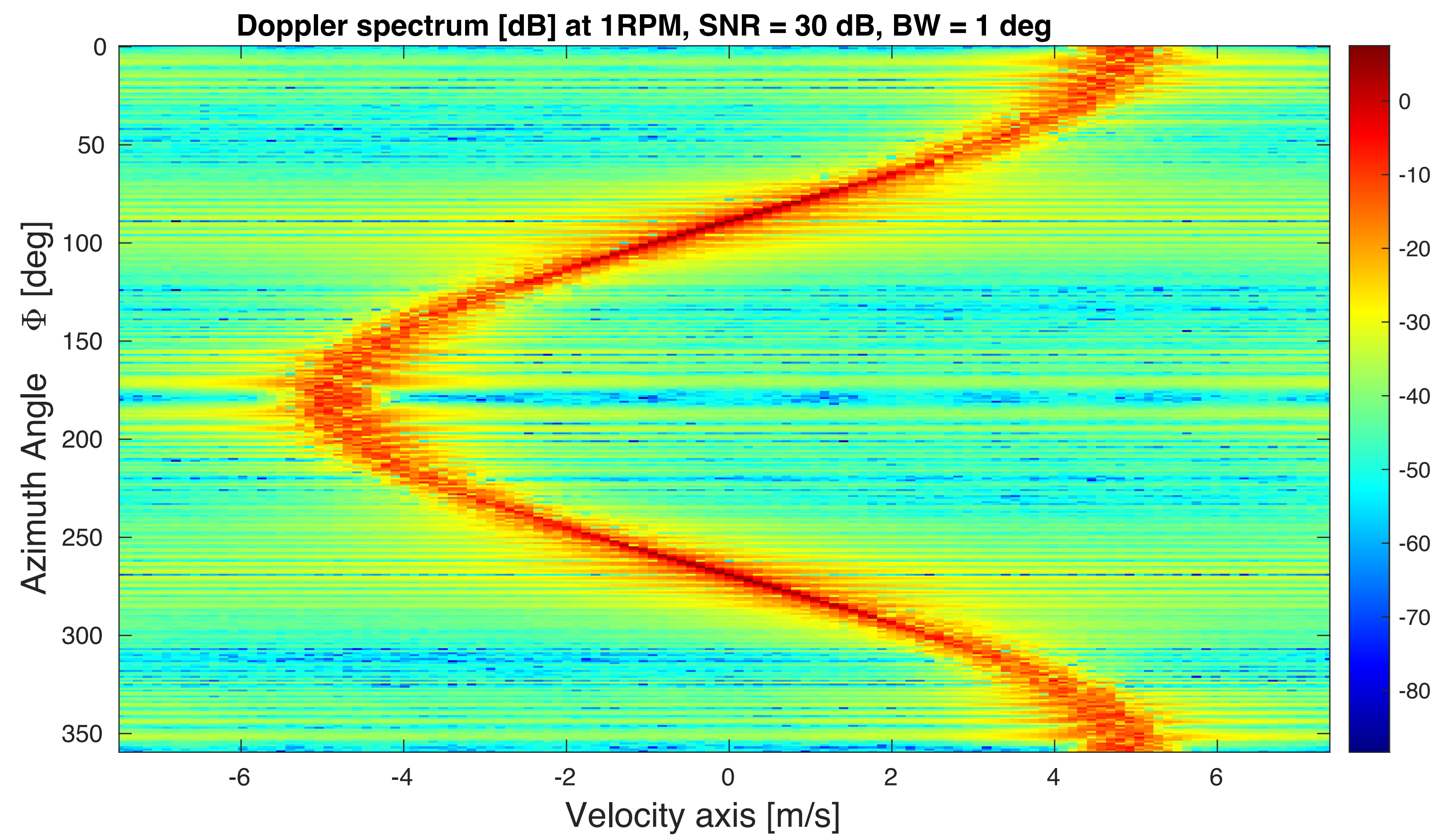
Reconstruction of spectrum

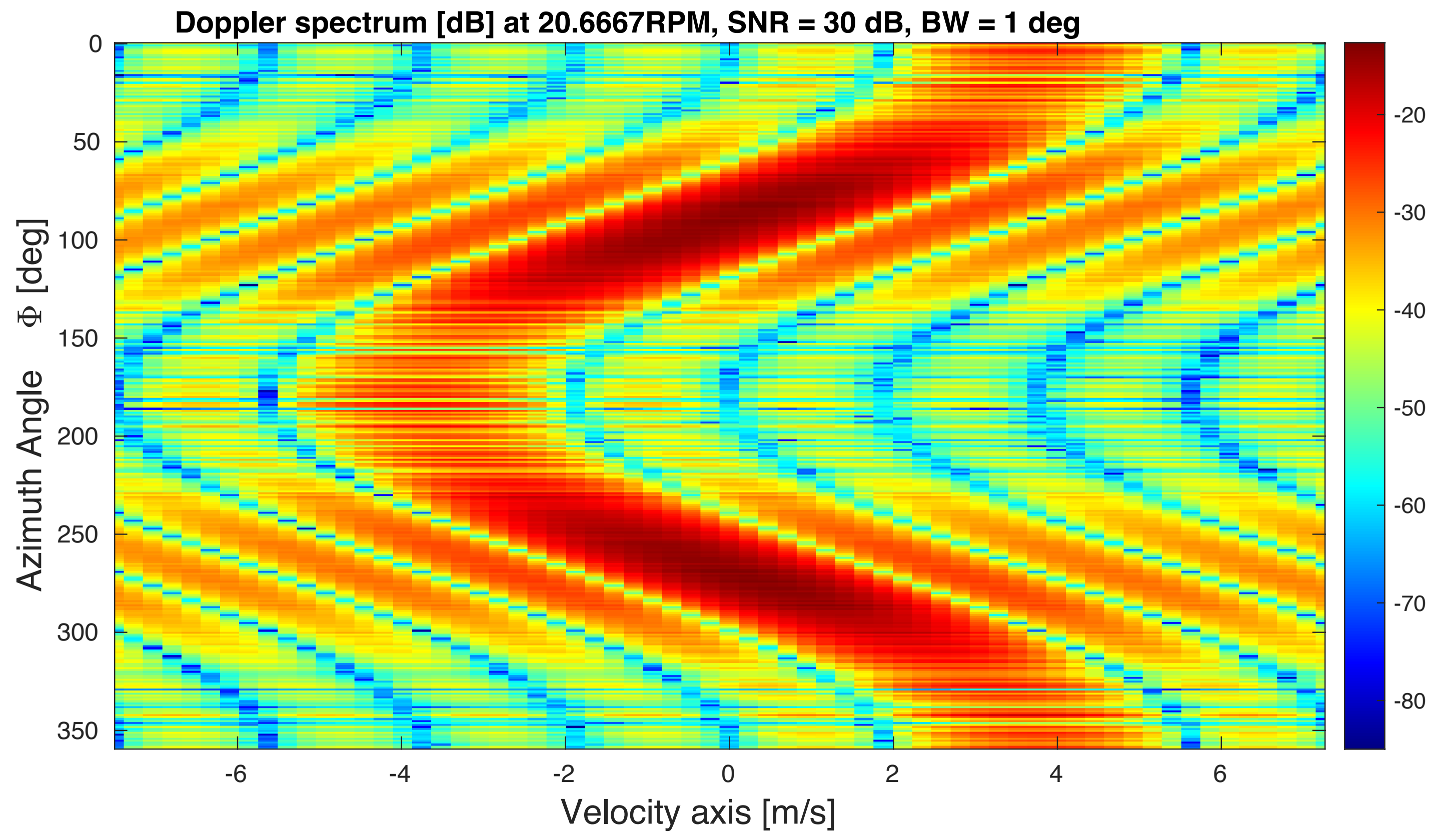
Went ahead with this approach

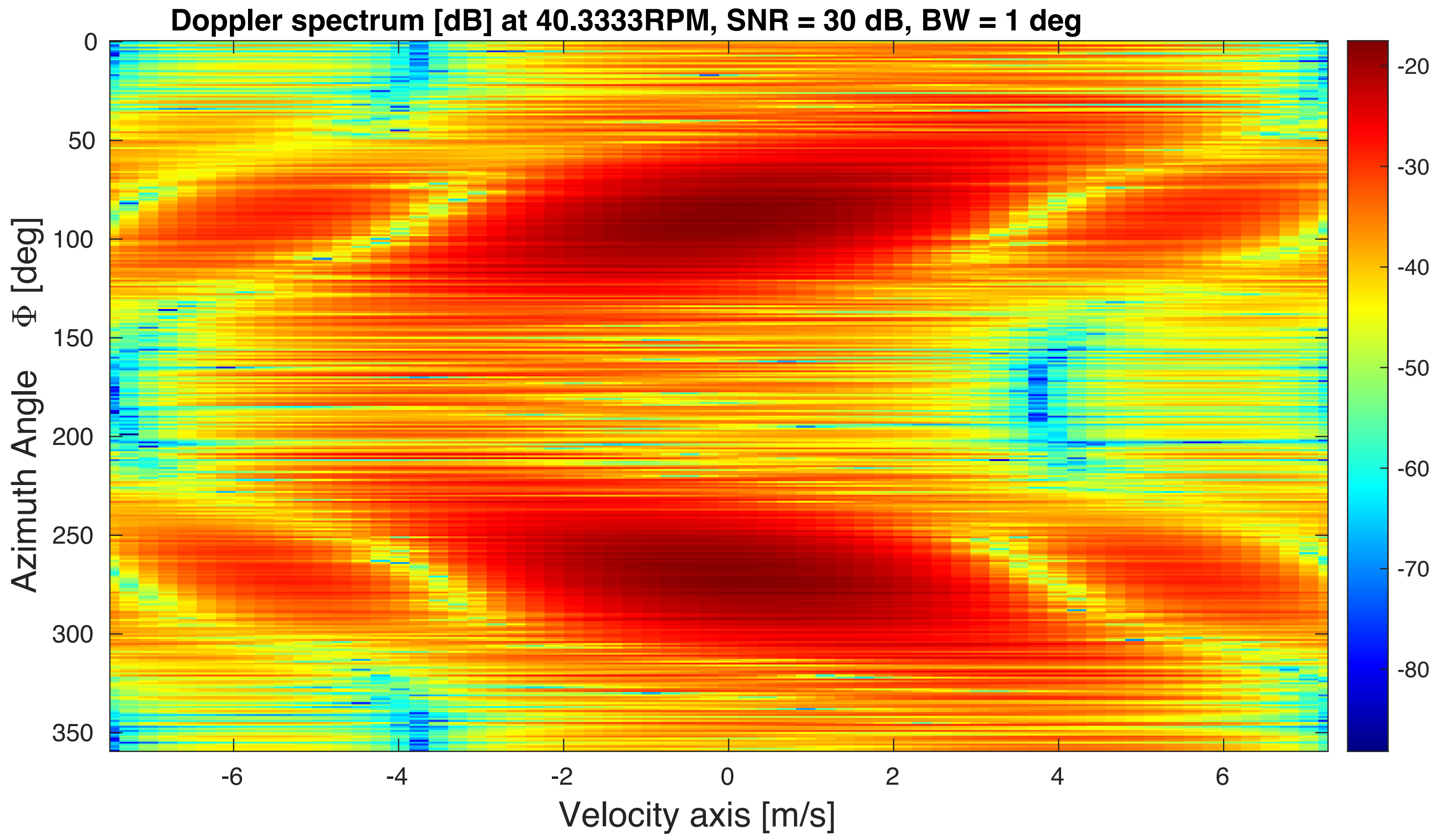
Preliminary Results

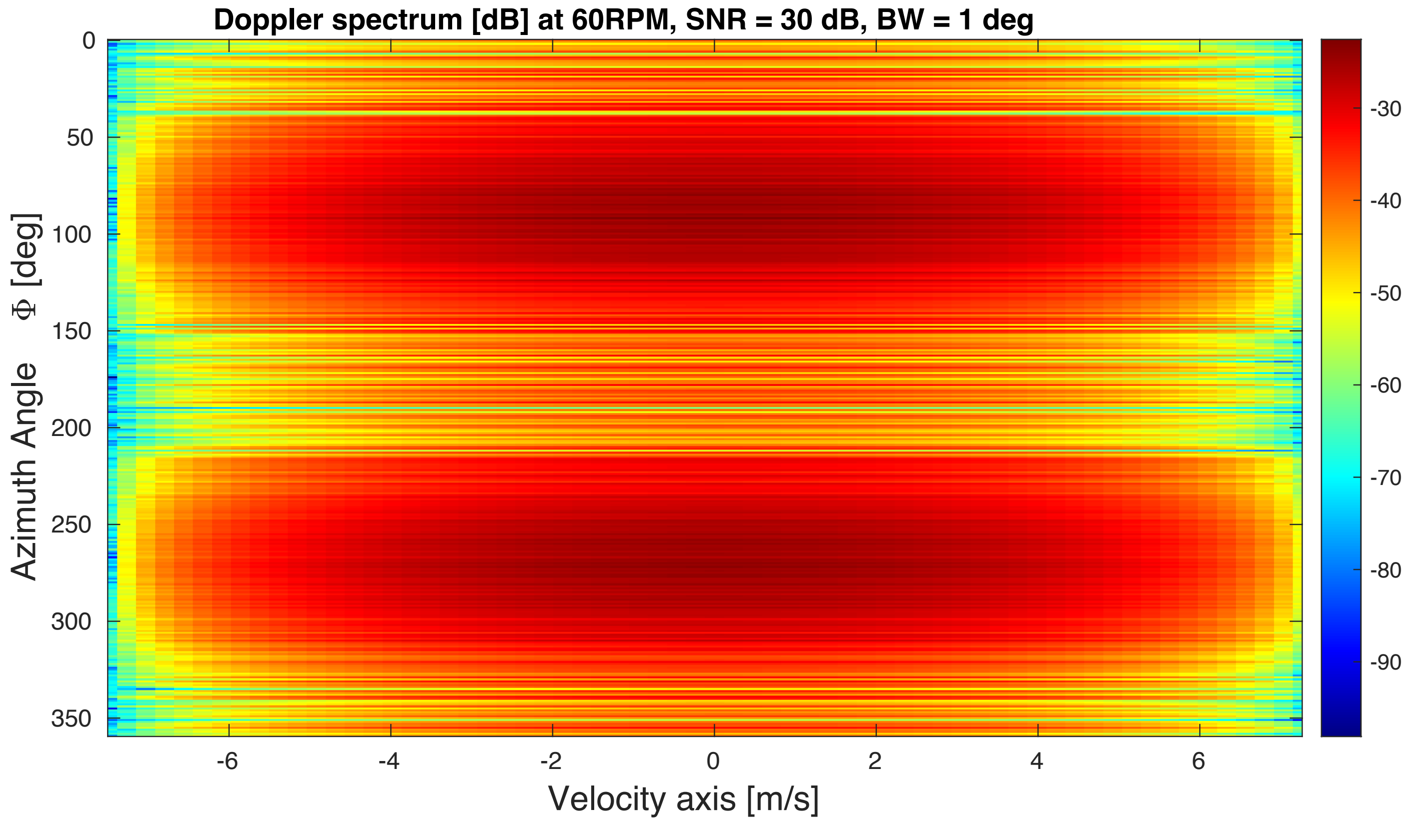
Ground Truth: $\mu = 5[m/s] \quad \sigma = 0.2[m/s] \quad \phi_{wind} = 0$







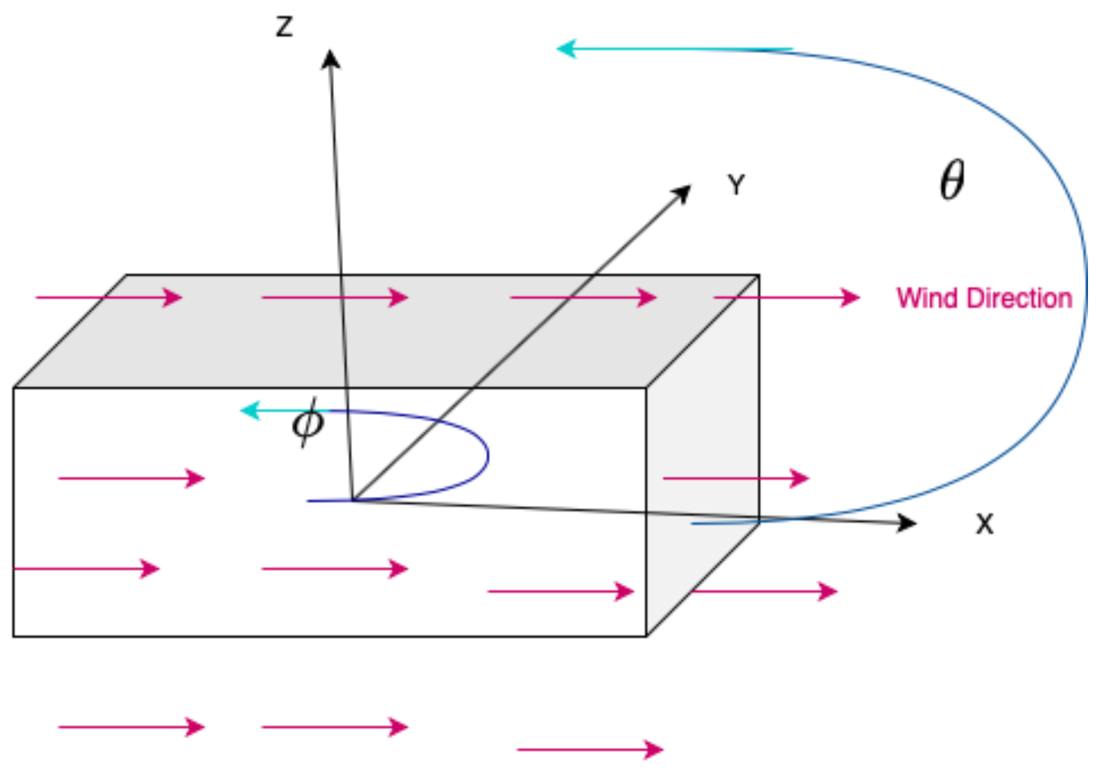




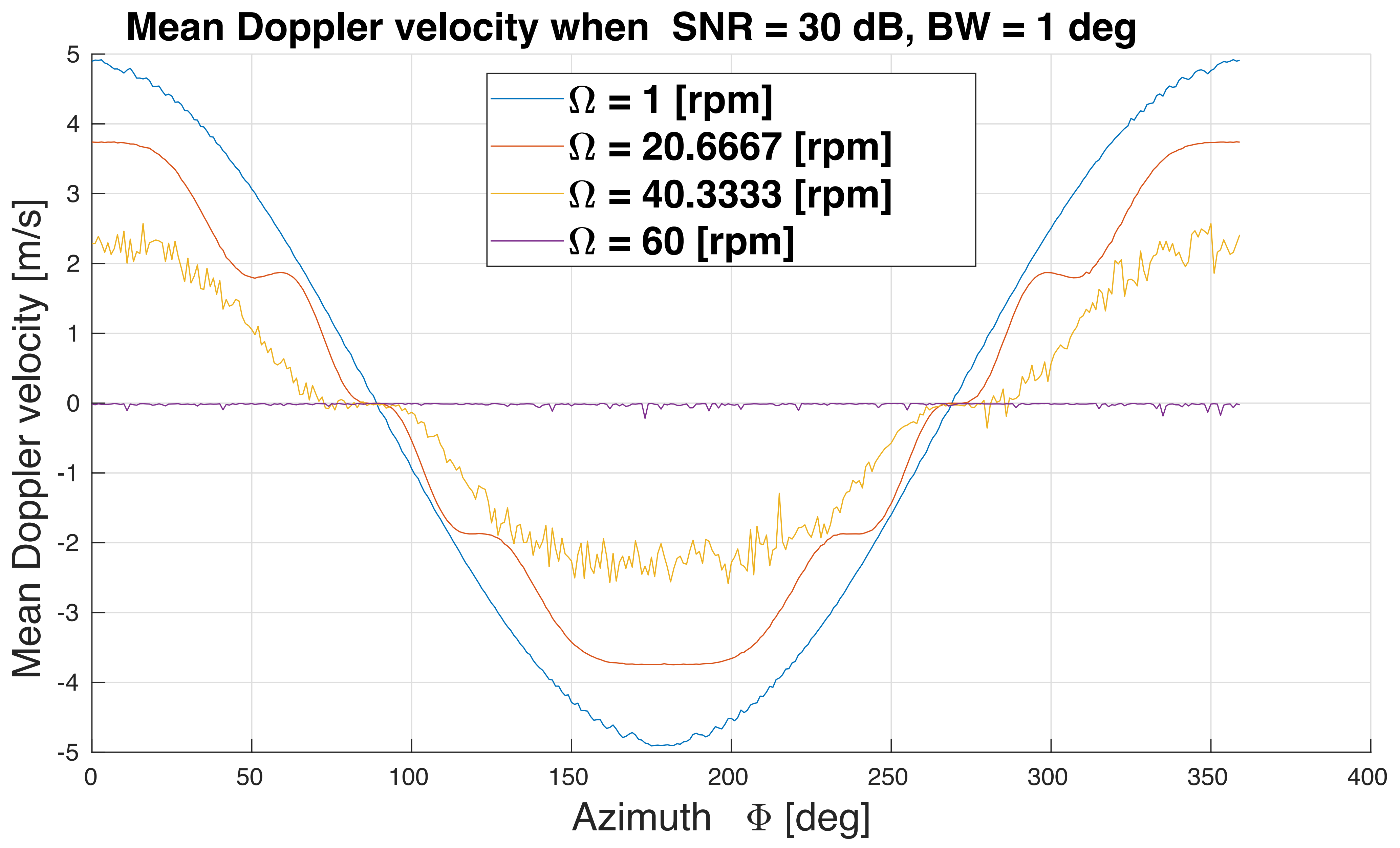
$\Omega[RPM]$	N_{bursts}	Samples for FFT processing
1	167	128
20	9	8 - zero padded till 64
40	5	4 - zero padded till 64
60	3	2 - zero padded till 64

TU Delft

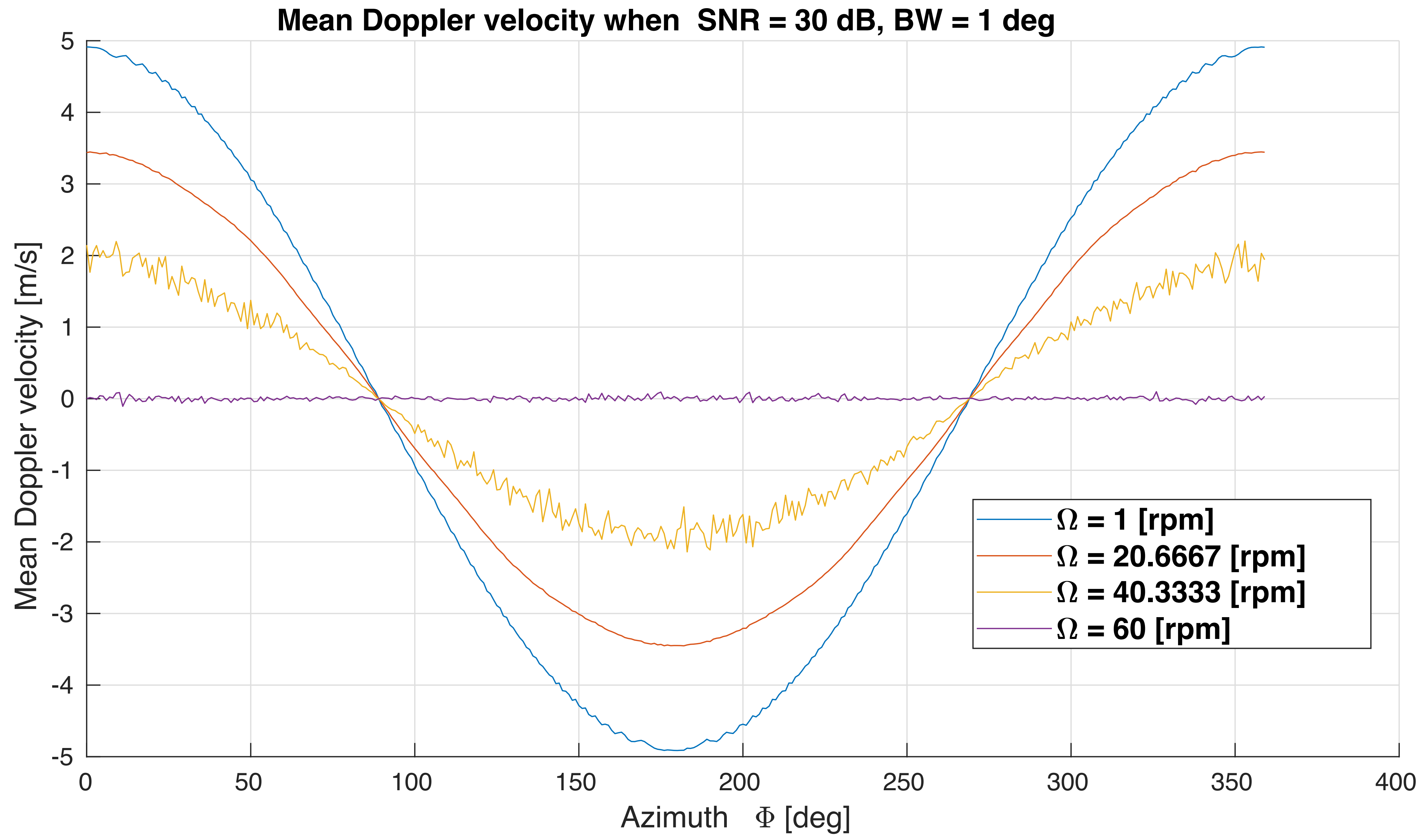
Preliminary Results (Mean Velocity)



Ground Truth: $\mu = 5[m/s]$ $\sigma = 0.2[m/s]$ $\phi_{wind} = 0$



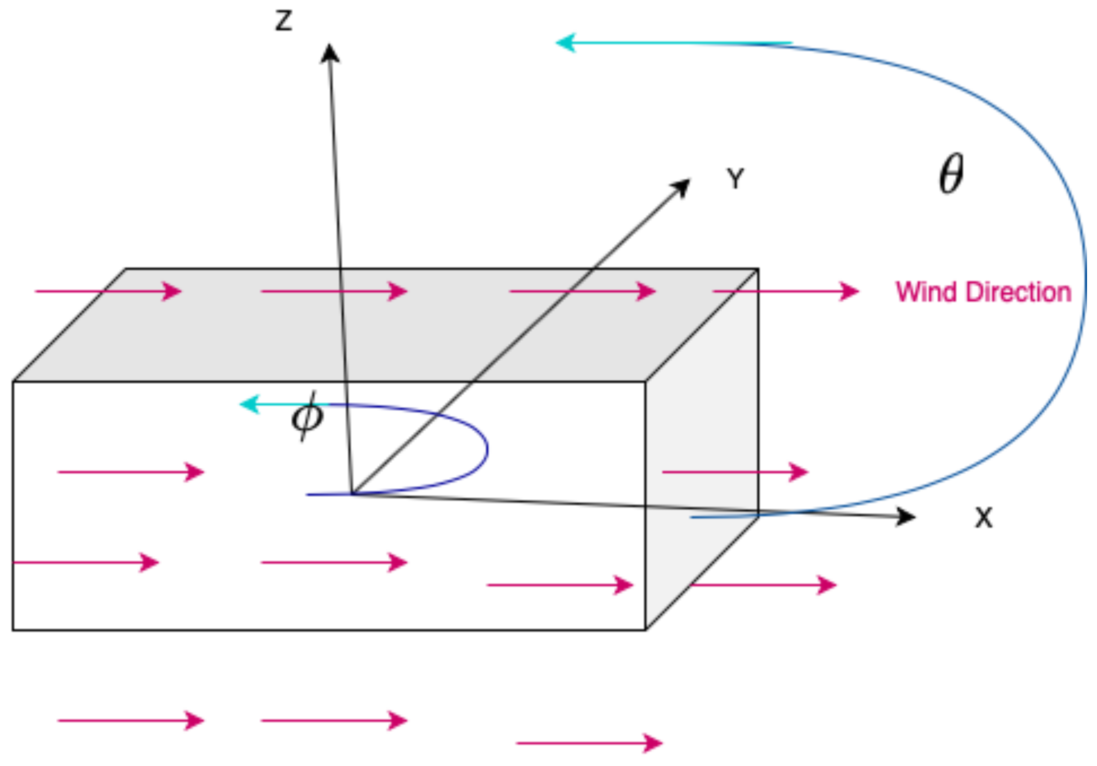
Without zero padding



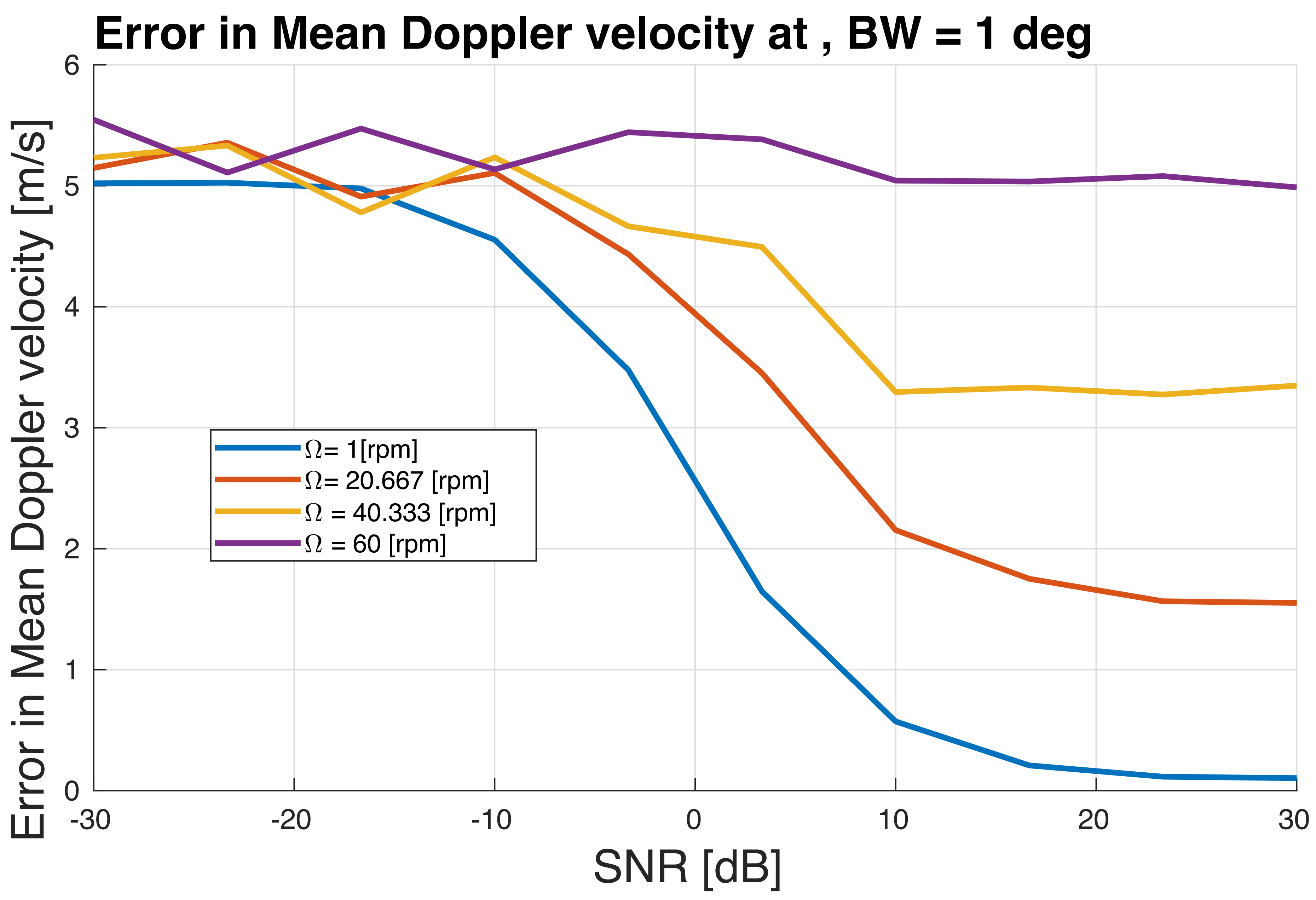
With zero padding

TU Delft

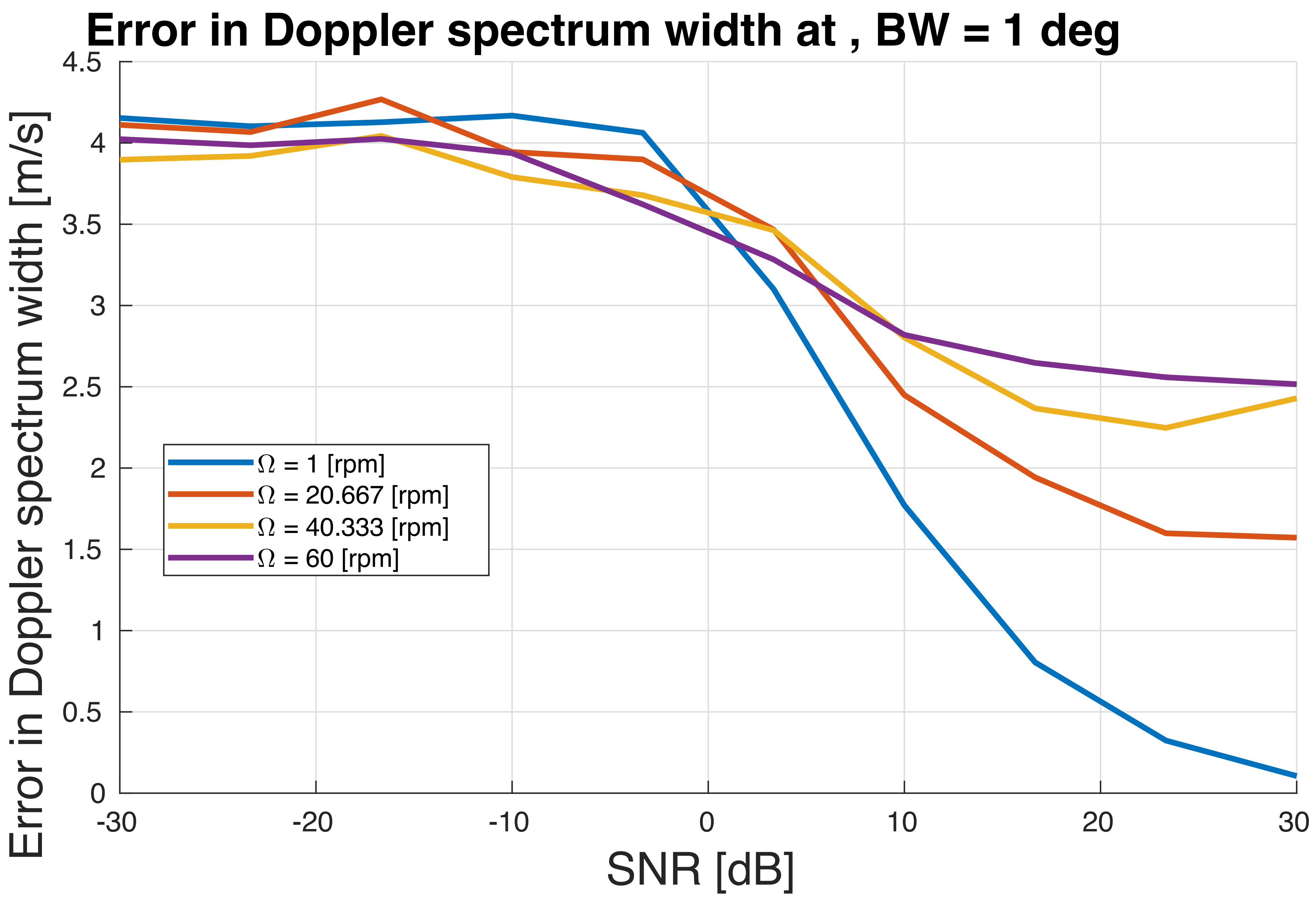
Preliminary Results (Velocity error with SNR)



Ground Truth: $\mu = 5[m/s] \quad \sigma = 0.2[m/s] \quad \phi_{wind} = 0$



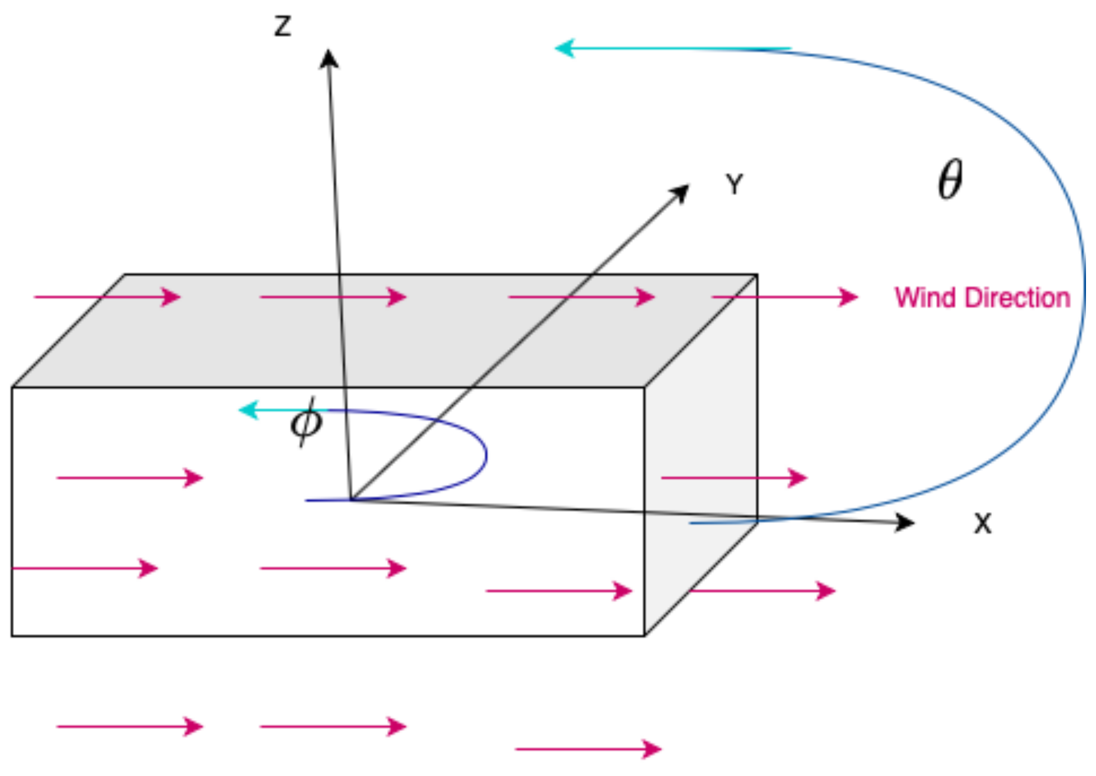
RMSE of Mean Doppler velocity



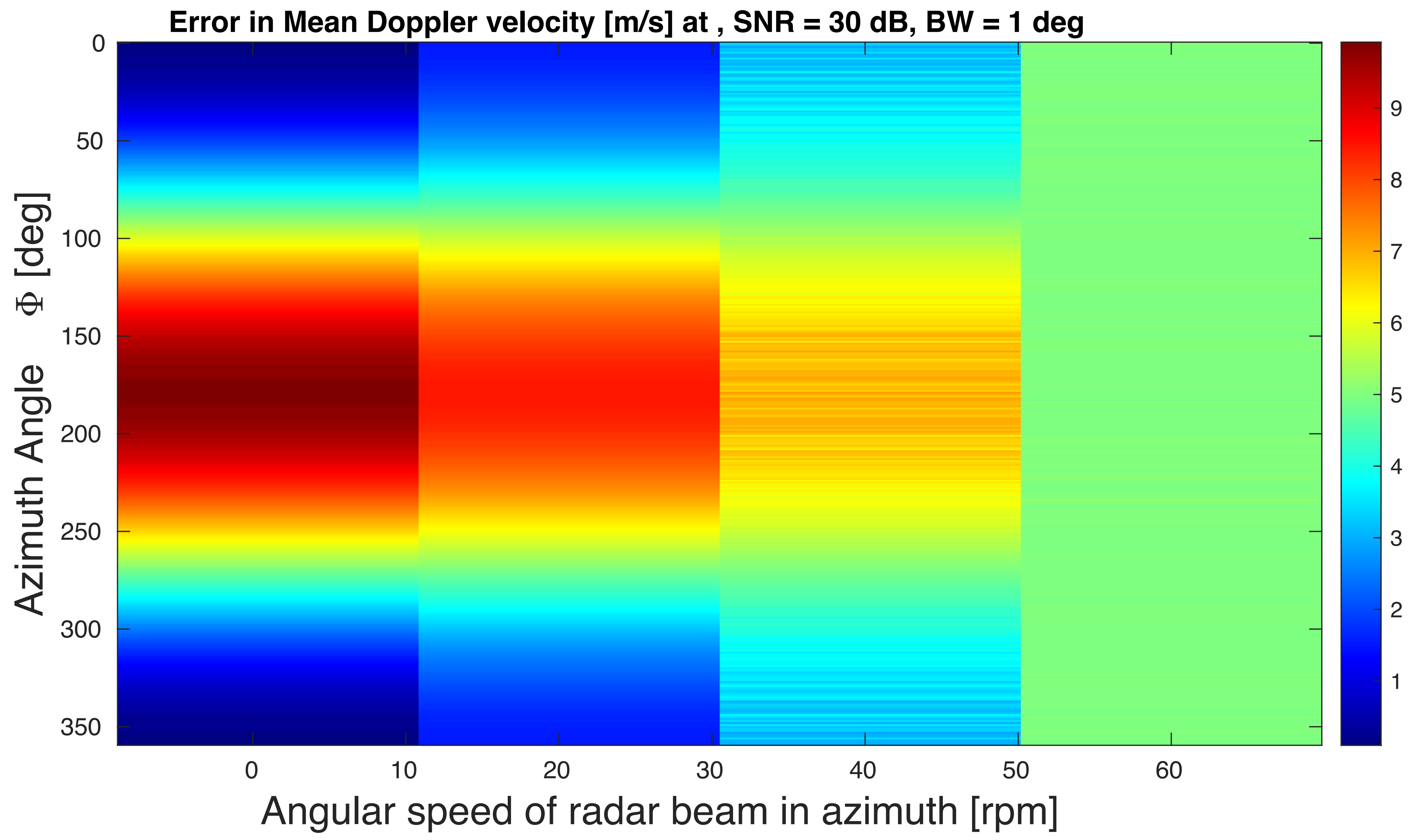
RMSE of Doppler spectrum Width

TU Delft

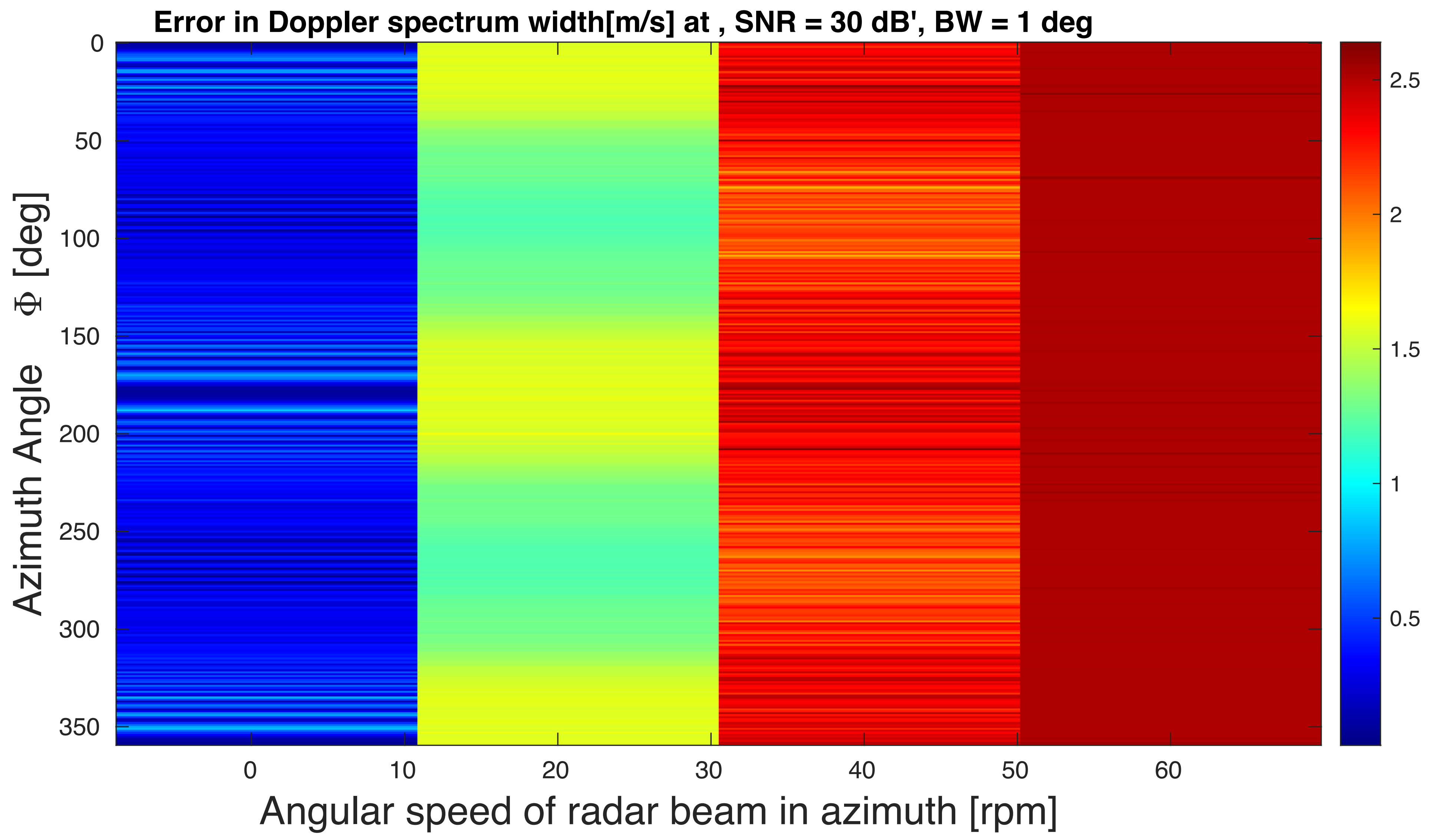
Preliminary Results (Velocity error with Ω)



Ground Truth: $\mu = 5[m/s]$ $\sigma = 0.2[m/s]$ $\phi_{wind} = 0$



RMSE of Mean Doppler velocity

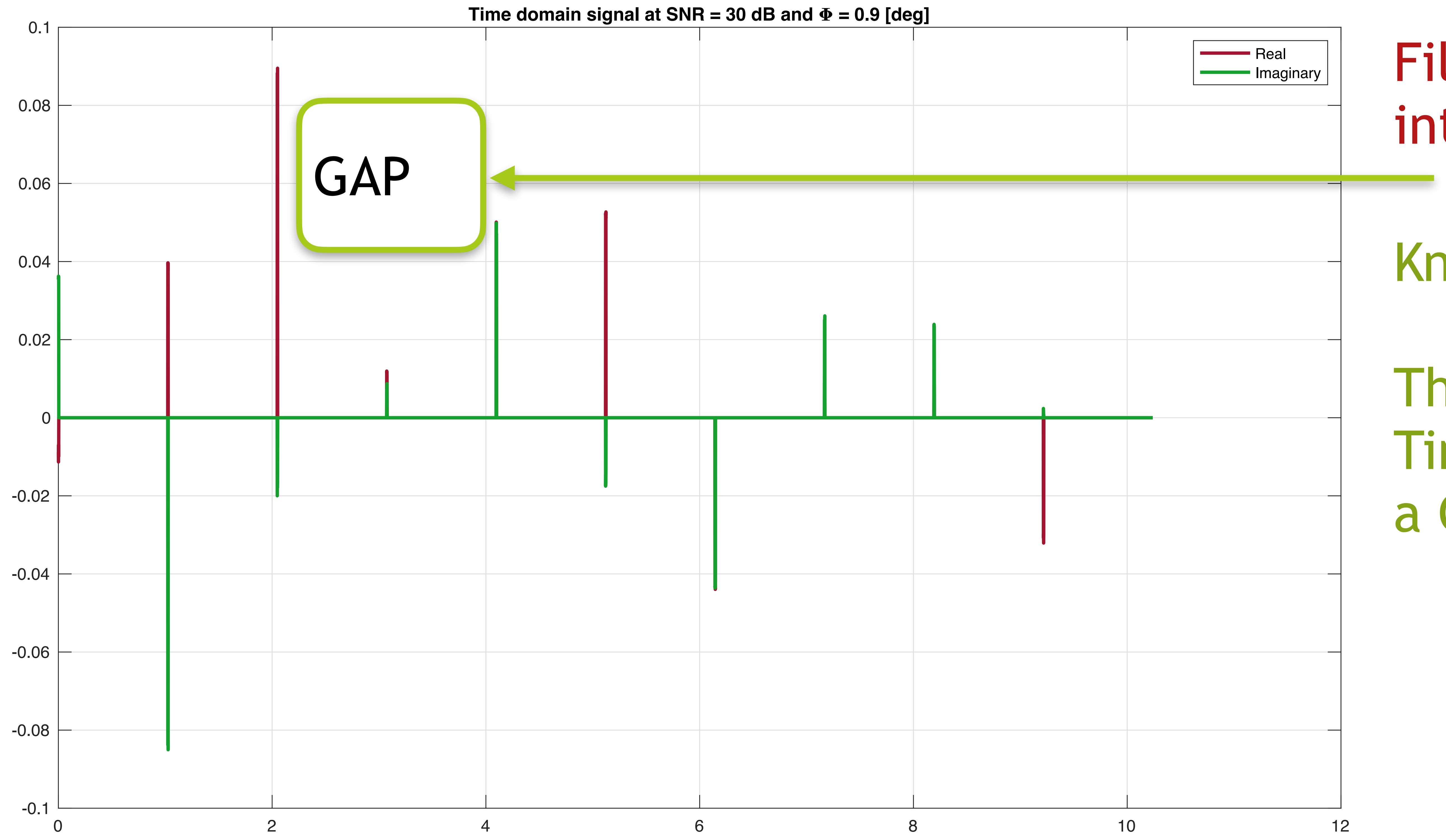


RMSE of Doppler spectrum Width

TU Delft

Ideas for multiple rotations

- Time domain signal for multiple rotations in one single direction



Fill the Gap using interpolation

Known Information:

The spectrum of this Time Domain signal is a Gaussian Spectrum

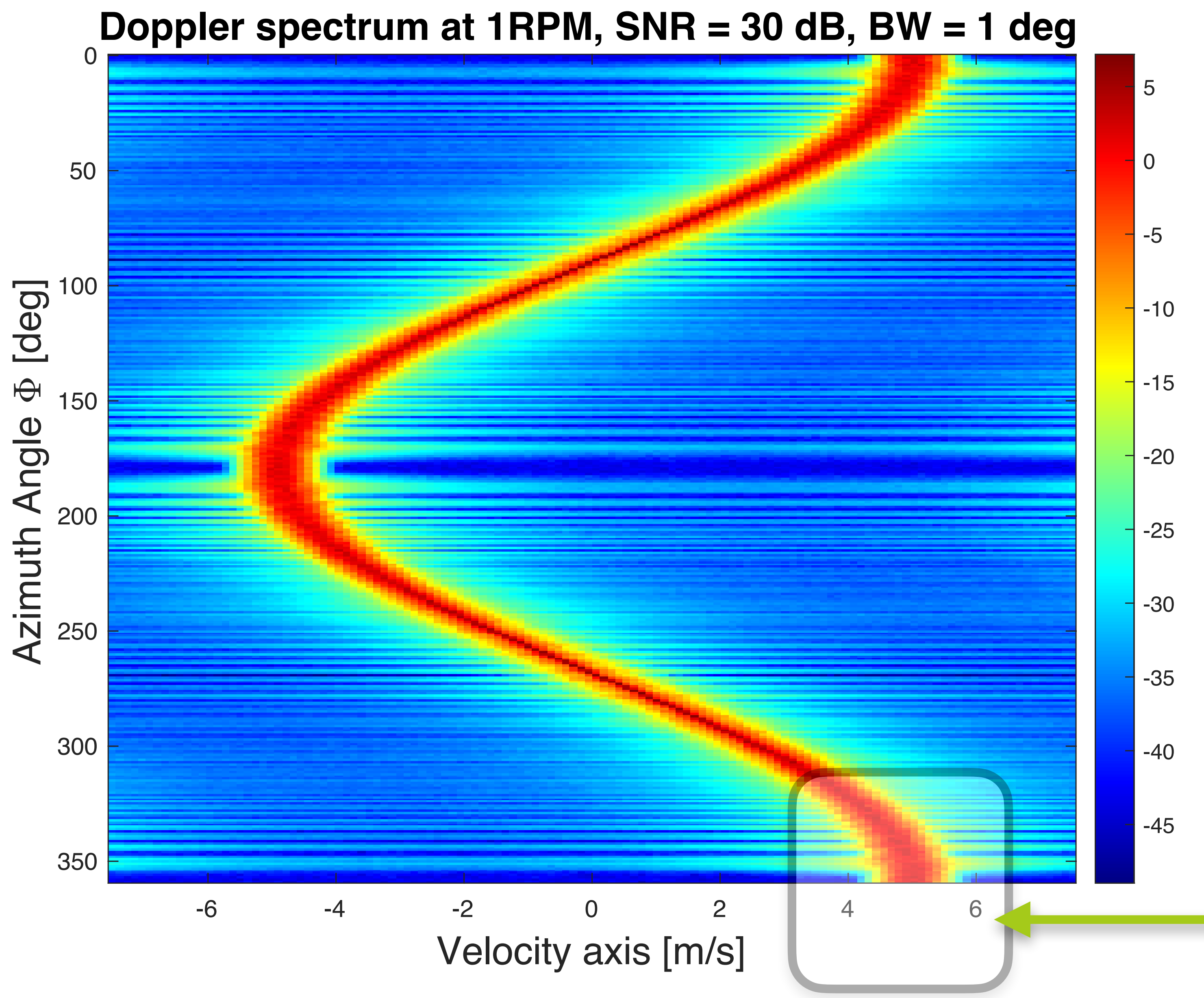
Need to determine the pattern of the time domain signal analytically to understand how to interpolate it

Use the data from different directions in space using cosine compensation technique

Ideas for direction of wind estimation

Find the angle at which the cosine dependence has a maximum

If there is a vortex or unusual directions of wind all over the space, a Fourier transform along the angle axis would give some ideas of which harmonics are present - Far Fetched idea



Direction of wind