Turbulence characterization from forward-looking nacelle-lidar measurements

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UniTTe workshop 2016 – Copenhagen

November 15, 2016

DTU Wind Energy
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Velocity spectra and the spectral velocity tensor

- one point spectra: $F_{ij}(k_1) = \iint \Phi_{ij}(\boldsymbol{k}) dk_2 dk_3$
- Φ_{ij} estimated from the Mann (1994) model ($\alpha\varepsilon^{2/3}$, L, and Γ)
- Normally F_{11}, F_{22}, F_{33}, and F_{13} are computed
- A 2-parameter LUT is created using:

$$F_{ij}(k_1; \alpha\varepsilon^{2/3}, L, \Gamma) = L^{5/3}\alpha\varepsilon^{2/3} F_{ij}(k_1 L; 1, 1, \Gamma) \qquad (1)$$

- The LUT is used to fit the Mann (1994) model parameters to simulated or measured spectra

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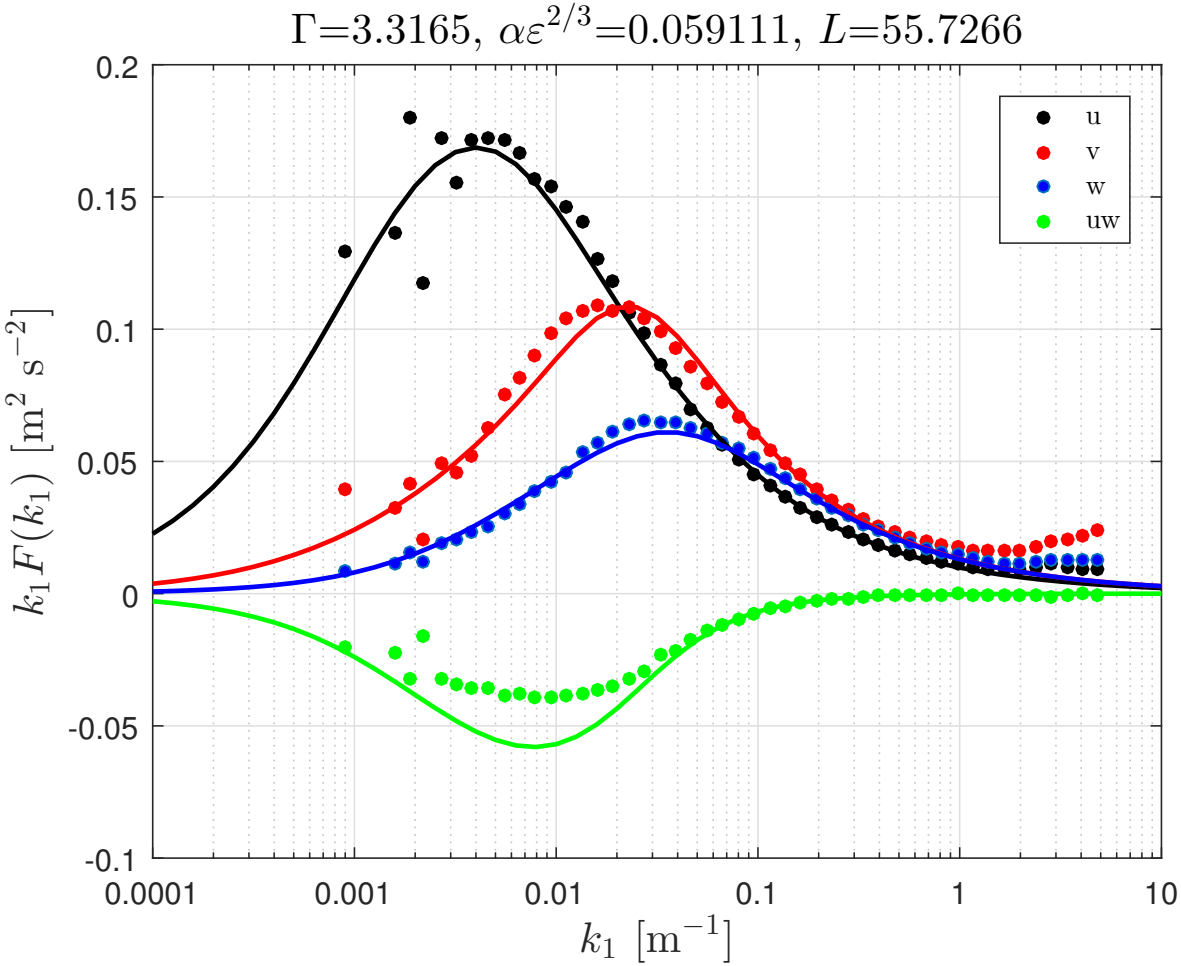
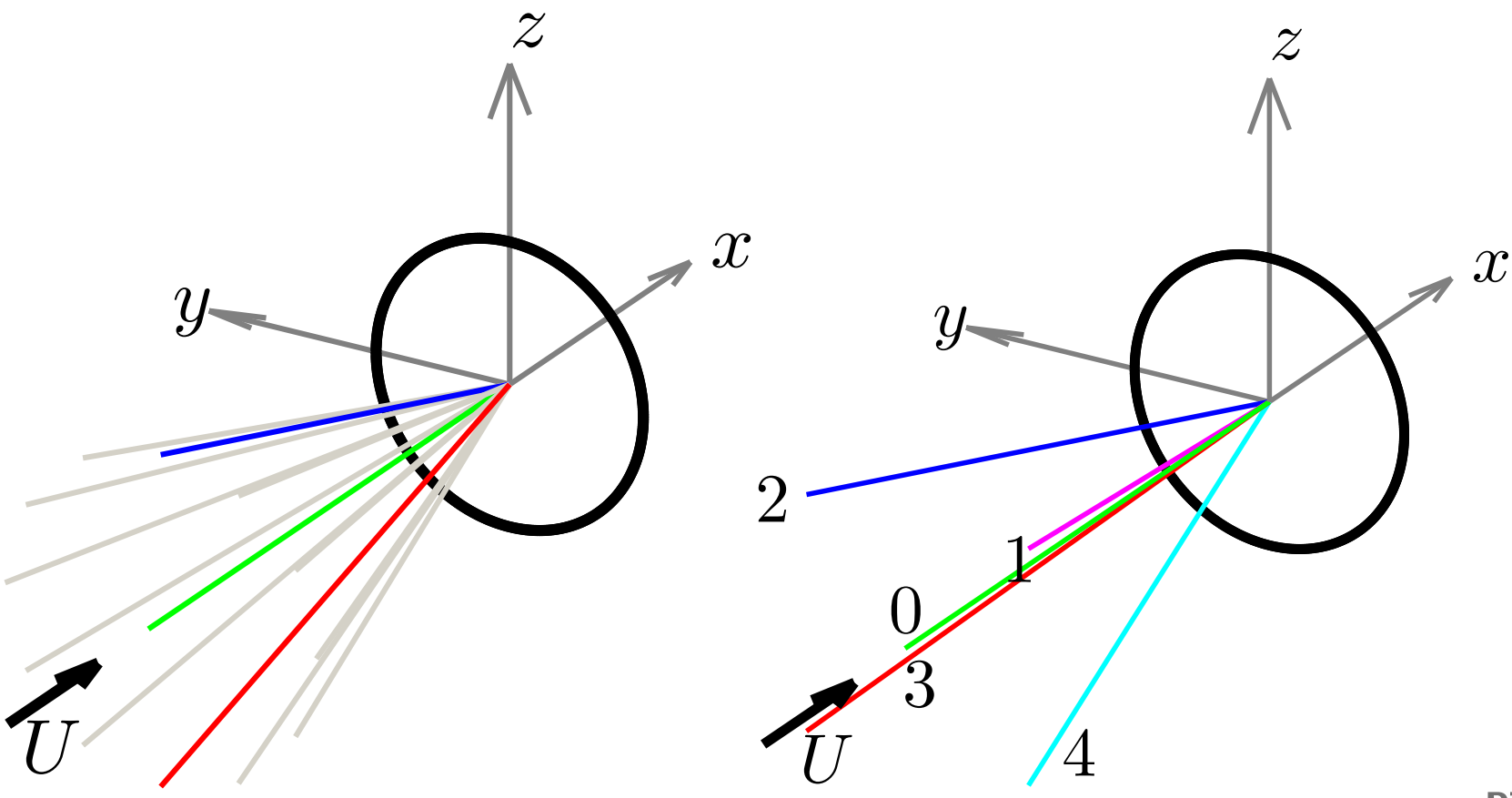
Fitted parameters to 'measured' spectra



Forward-looking nacelle lidars



Radial velocity spectra of lidar measurements

- From Mann et al. (2009):

$$F_v(k_1) = n_i n_j \iint \left|\hat{\phi}(\boldsymbol{k}\cdot\boldsymbol{n})\right|^2 \Phi_{ij}(\boldsymbol{k}) dk_2 dk_3, \tag{2}$$

  where $\boldsymbol{n} = (-\cos\varphi, \sin\varphi\cos\theta, \sin\varphi\sin\theta)$

- Weighting function of CW lidar:

$$\phi(s) = \frac{1}{\pi}\frac{z_R}{z_R^2 + s^2} \Leftrightarrow \hat{\phi}(k_1) = \exp(-|k_1|z_R) \tag{3}$$

- Weigthing function of a pulsed lidar:

$$\phi(s) = \frac{z_R - |s|}{z_R^2} \Leftrightarrow \hat{\phi}(k_1) = \mathrm{sinc}^2(k_1 z_R/2) \tag{4}$$

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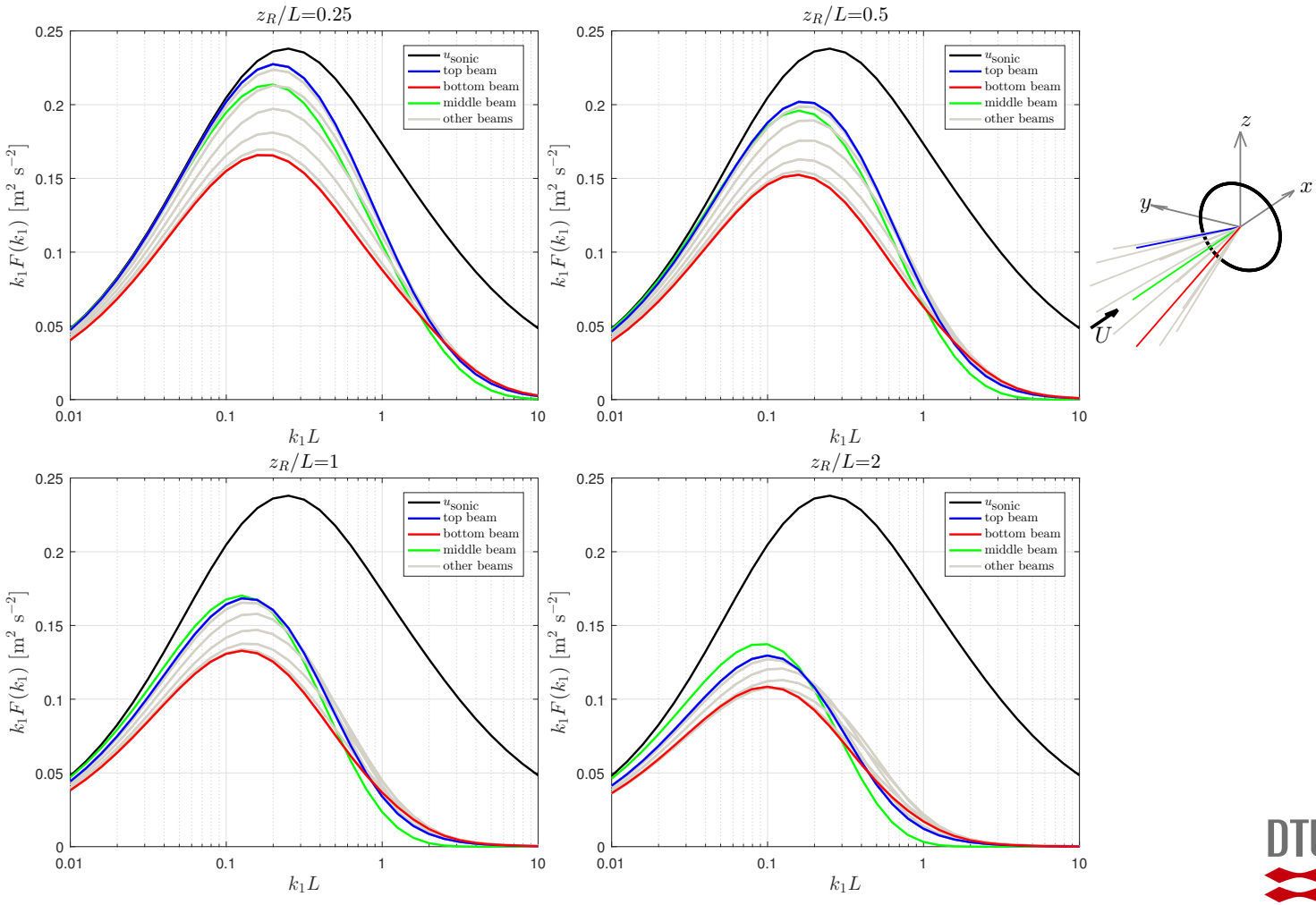
CW lidar, $\Gamma = 3$, $\alpha\varepsilon^{2/3} = 0.1$, $\varphi = 15°$



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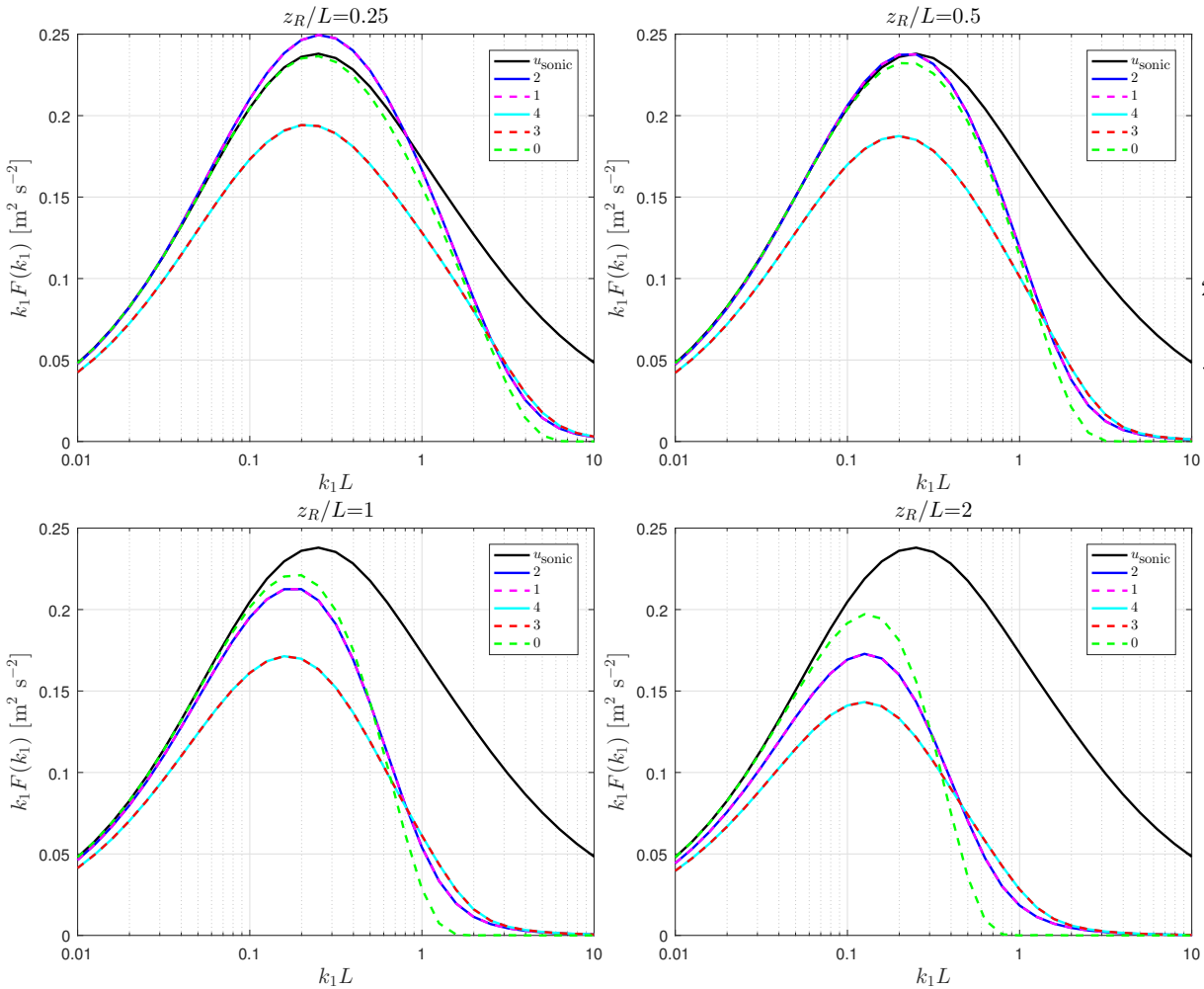
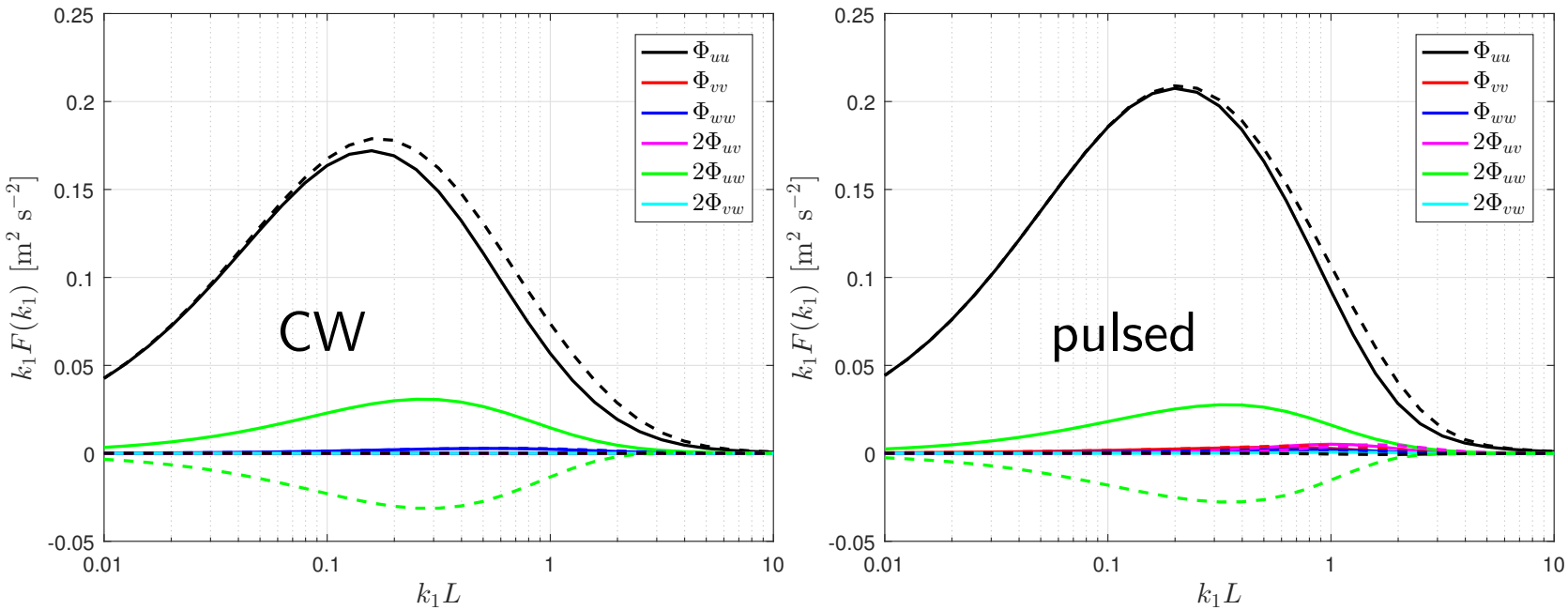


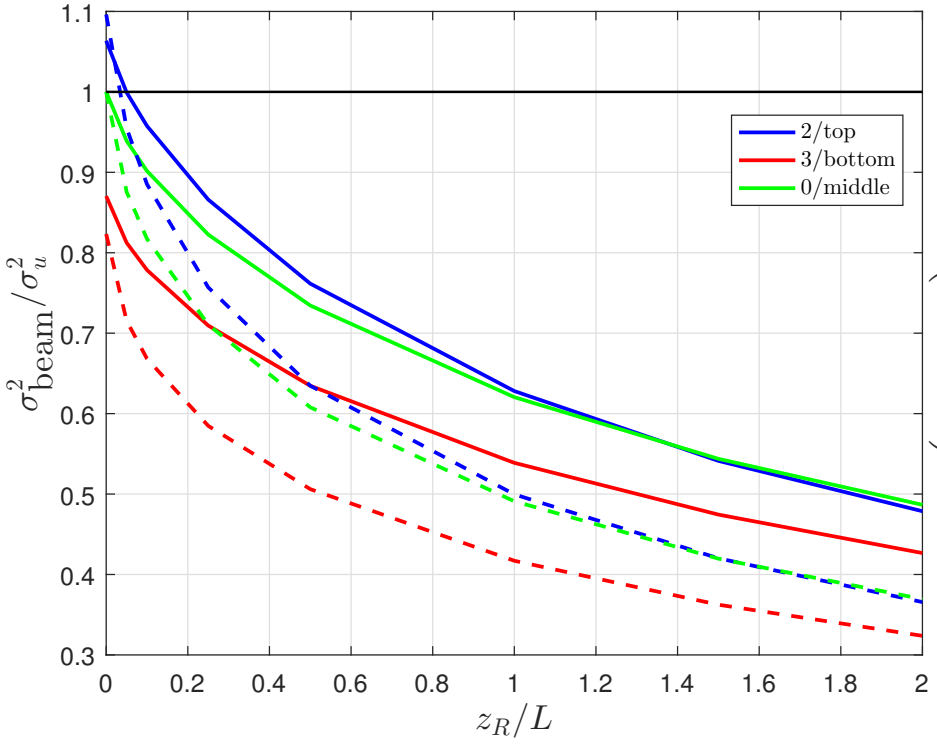
Φ-contributions, $\Gamma = 3$, $\alpha\varepsilon^{2/3} = 0.1$, $z/L = 50$, $\varphi = 15^\circ$

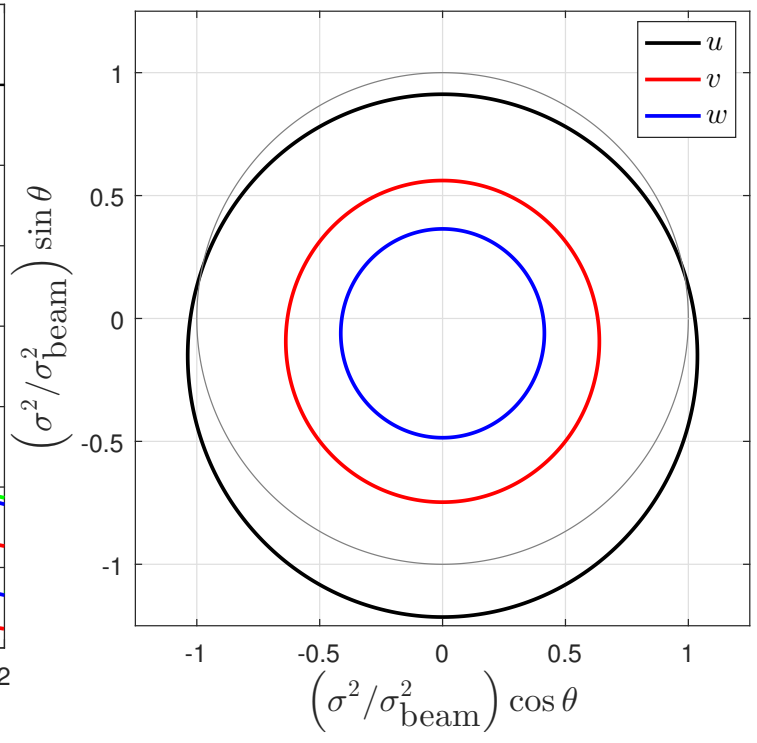
top beams (solid lines), bottom beams (dashed lines)



σ^2_{beam} for $\Gamma = 3$, $\varphi = 15°$

pulsed lidar in solid lines and CW lidar in dashed lines





$$\sigma^2_{\text{beam}_{\text{unf}}}(\theta) = \sigma_u^2 \cos^2\varphi + \sigma_v^2 \sin^2\varphi \cos^2\theta + \sigma_w^2 \sin^2\varphi \sin^2\theta$$
$$-2\langle u'w'\rangle \cos\varphi \sin\varphi \sin\theta \quad \Rightarrow \quad \text{Doppler spectra info!}$$

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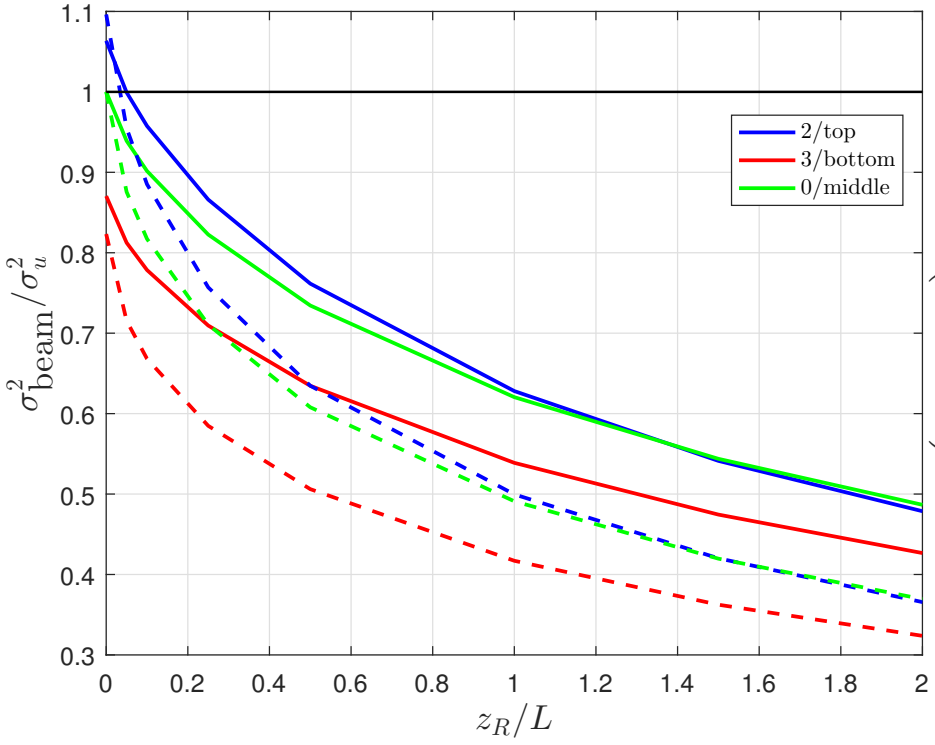

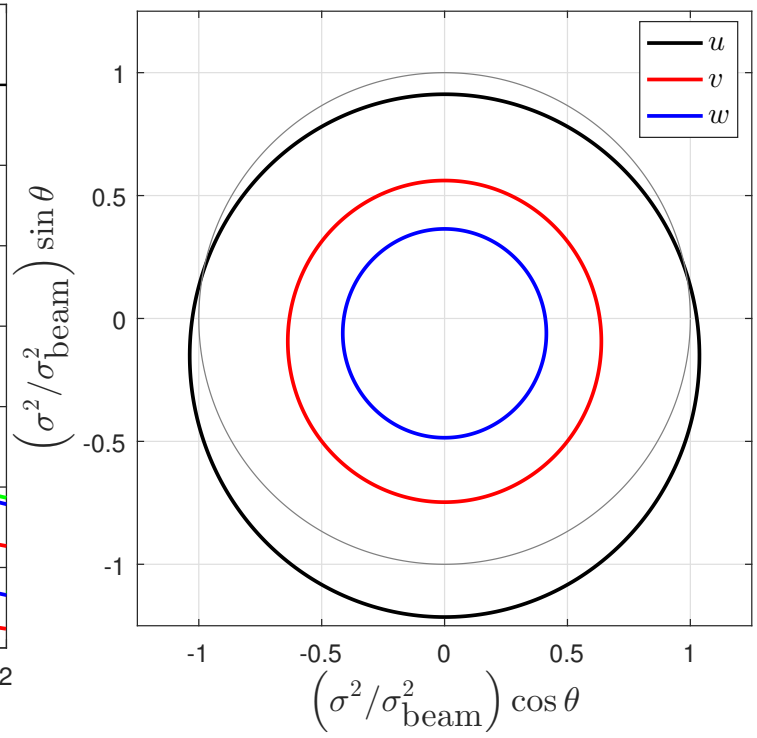

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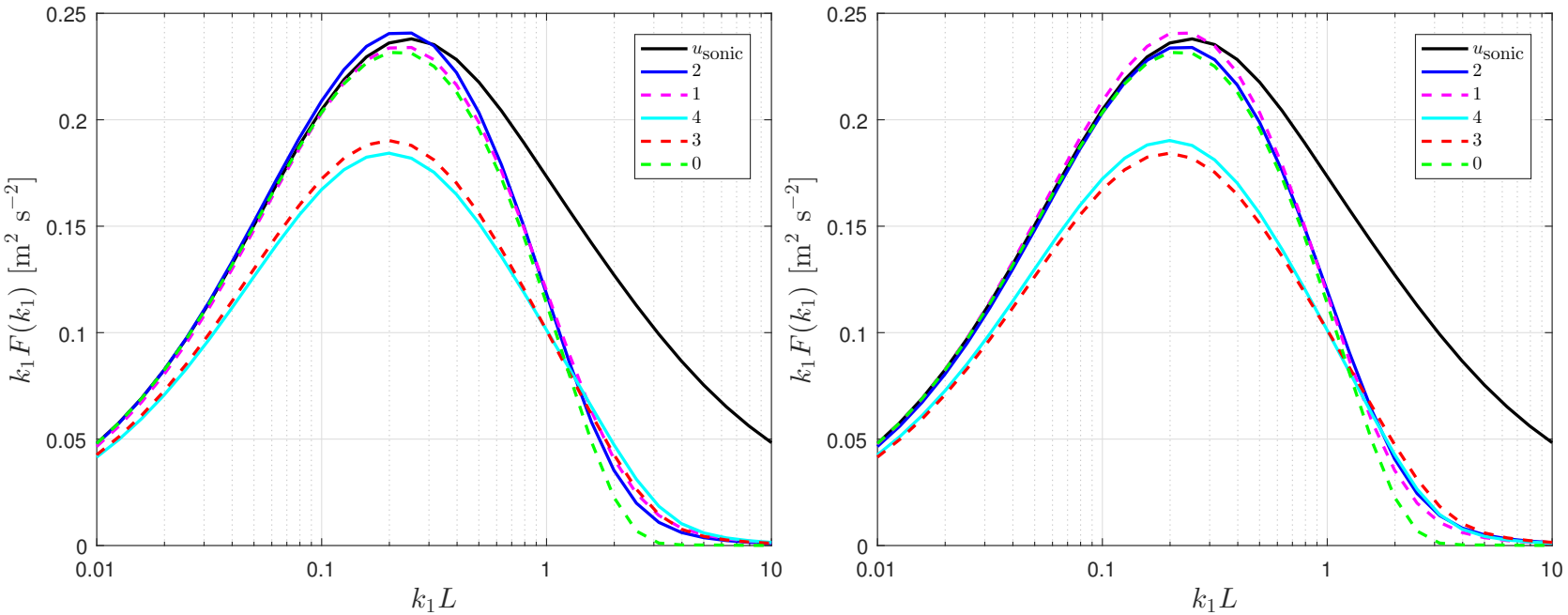
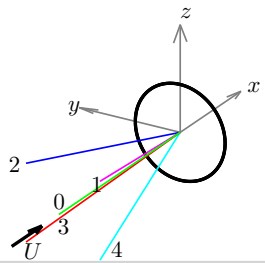
Mann-based LUT of the lidar radial vel. spectra

Due to misalignment, we need 1 more dimension ($\pm 2°$)!, $\Gamma = 3$, $\varepsilon^{2/3} = 0.1$, $z/L = 50$, $\varphi = 15°$





Thank you for the attention!

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