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CFI simulation in Field II

Color Flow Imaging

- Color encoded image of blood flow
  - Axial mean velocity and direction
- Velocity is found from the mean frequency (shift) estimated in each spatial point
- Several pulses must be emitted for each beam direction, e.g. N = 8 -12 → slow time signal

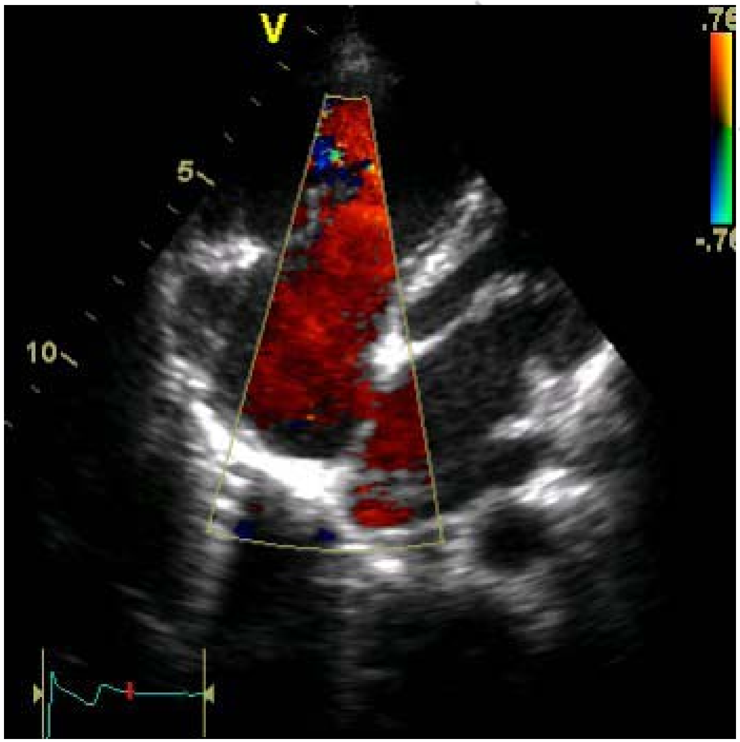

Image borrowed from Lasse's presentation on dynamic imaging

Parameter estimation

- The acquisition leads to a complex (slow time) signal for each spatial position
- Sum from many scatterers - complex Gaussian random process (stationary)
- For such a process, the autocorrelation function is related to the frequency spectrum (power spectral density) through the Wiener-Khinchin theorem

$$\boxed{R(m) = \frac{1}{2\pi}\int_{-\pi}^{\pi} G(\omega)\, e^{i\omega m}\, d\omega}$$

$$R(0) = \frac{1}{2\pi}\int_{-\pi}^{\pi} G(\omega) d\omega$$

$$R(1) = \frac{1}{2\pi}\int_{-\pi}^{\pi} G(\omega)\, e^{i\omega} d\omega = \frac{e^{i\varpi}}{2\pi}\int_{-\pi}^{\pi} G(\omega)\, e^{i(\omega-\varpi)} d\omega$$

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The estimators

$$\hat{P} = \hat{R}(0) = \frac{1}{N}\sum_{n=0}^{N-1} z(n)z(n)^* = \frac{1}{N}\sum_{n=0}^{N-1} \left|z(n)\right|^2$$

$$\hat{f}_d = \frac{\angle \hat{R}(1)}{2\pi} = \frac{1}{2\pi}\angle\left[\frac{1}{N-1}\sum_{n=0}^{N-1} z(n)^* z(n+1)\right] \qquad -0.5 \leq \hat{f}_d \leq 0.5$$

From the mean frequency, the velocity in each point is found by

$$v_z = \frac{\hat{f}_d\, c\, PRF}{2 f_0}$$

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Scan setup in Field II

- Assignment: CFI simulation of parabolic flow in a blood vessel
- A linear scan was simulated, firing K pulses in each beam direction, with 64 of 192 elements active
- The physical array parameters were similar to the GE 7L probe
- Focus direction with reference point on transducer surface is set by using xdc_center_focus() and xdc_focus
- Hamming apodization was used on tx and rx

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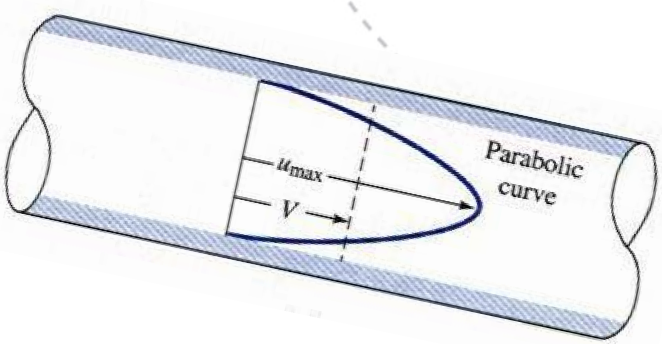
2D phantom

- Consists of many point scatterers with equal scattering amplitude.
- Initial positions are randomly distributed in a vessel shaped area, positioned at some angle to the beam direction
- In each timestep the positions are updated according to a parabolic velocity profile (Poiseuille flow)
- Include enough scatterers to get a gaussian distributed backscattered signal



$$v(r) = v_{\max}\left(1 - \left(\frac{r}{R}\right)^2\right)^2$$

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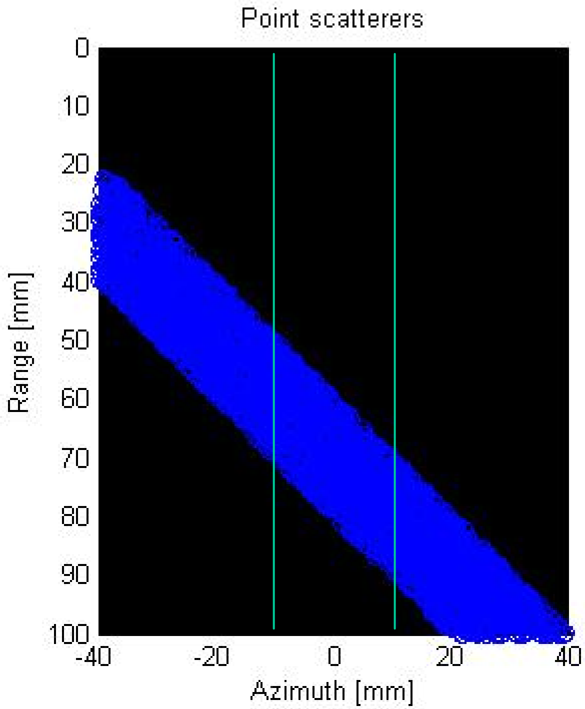
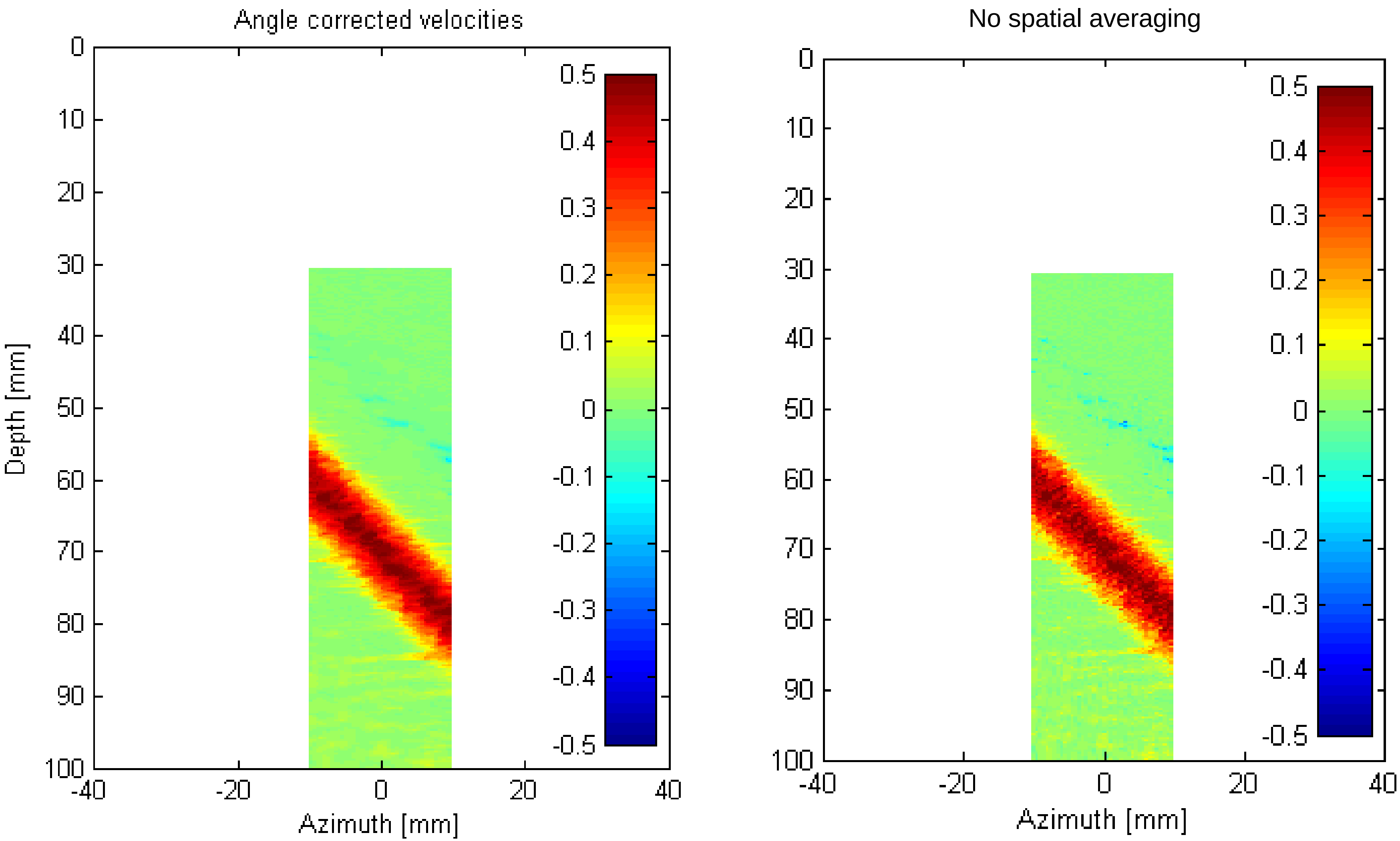
CFI setup

- v_{max} = 0.5 m/s
- Parabolic velocity profile
- Vessel radius = 7 mm
- PRF = 6000 Hz
- Packetsize = 8
- dx = 0.5 mm



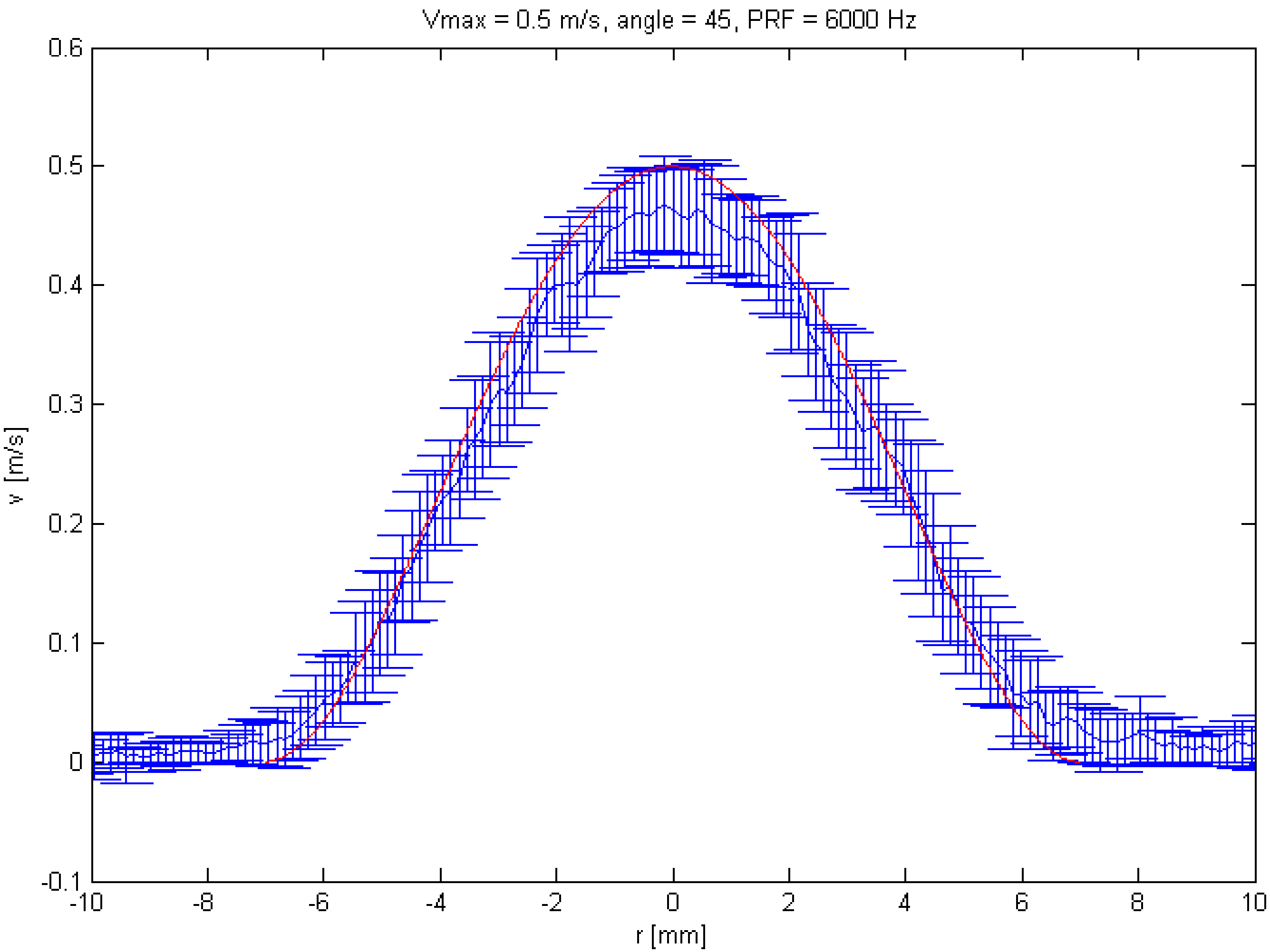
- Did not include dynamic focusing or dynamic aperture
- Did not include stationary scatterers (clutter)



- Seems to give the right velocity profile
- Can investigate the velocity profile in more detail by using only one image line

Estimator performance

- The performance of the velocity estimator was assessed by repeatedly imaging only the center line.
- The image lines were aligned in depth, and a mean velocity profile calculated
- The velocity profile was then compared to the equation for Poiseuille flow, which was used to move the scatterers.


Vmax = 0.5 m/s, angle = 45, PRF = 6000 Hz
v [m/s]
r [mm]
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-10
-8
-6
-4
-2
0
2
4
6
8
10

Estimator performance

Aliasing effects:

- Is not the problem here,
  v_{nyq}= 0.65 m/s

Averaging effects:

- Underestimation of high central velocities
  - The sidelobes of the PSF pick up lower velocities from more peripheral sites
- Overestimation of low peripheral velocities
  - The sidelobes of the PSF pick up higher velocities from within the vessel.

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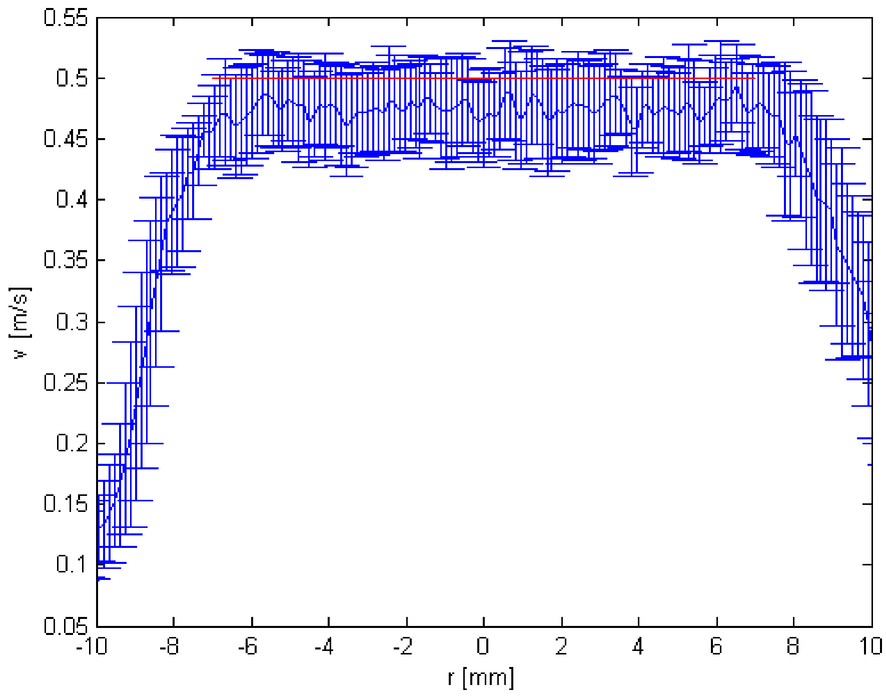
Estimator performance

- Problem: The high velocities are also underestimated if the velocity profile is uniform



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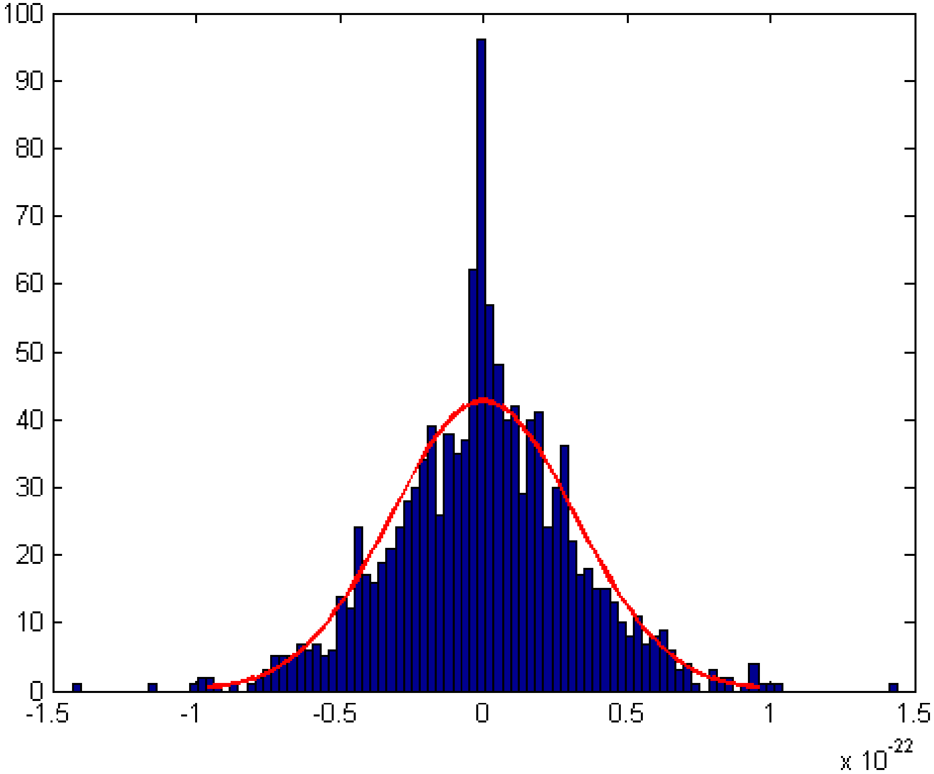
Estimator properties – questions….

Asymmetric frequency spectrum?

- The autocorrelation estimator is an approximation
- The approximation is poor if the frequency spectrum is asymmetric
- Poor approximation can lead to bias in velocity estimation

Estimator properties – questions…

- Signal not Gaussian enough?



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