UNIVERSITY OF CAMBRIDGE

Pixel-based Beamforming for Ultrasound Imaging

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Outline

- Introduction of Ultrasound Imaging
- Image Formation and Beamforming
- New Time-delay Calculation
- Results
- Conclusions

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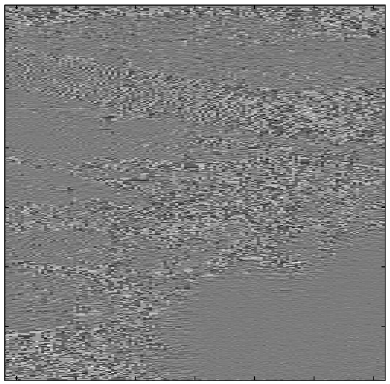
Ultrasound Imaging

US scanning

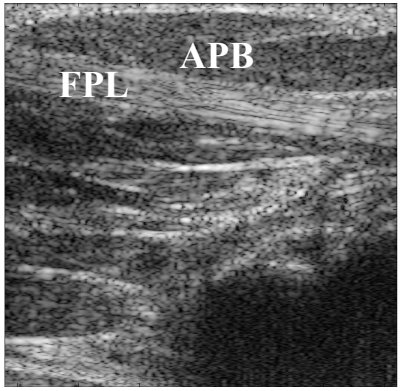
Acquisition →

Imaging (RF) data



Demodulation →

B-mode



FPL = Flexor Pollicis Longus tendon
APB = Abductor Pollicis Brevis muscle

Scanning flexor tendon using ultrasound

- Pulse-echo Imaging, using acoustic wave/pressure to form images
- Frequency range: 1 - 40 MHz
- Many applications imaging soft tissue in clinical medicine (not good for air or bone)

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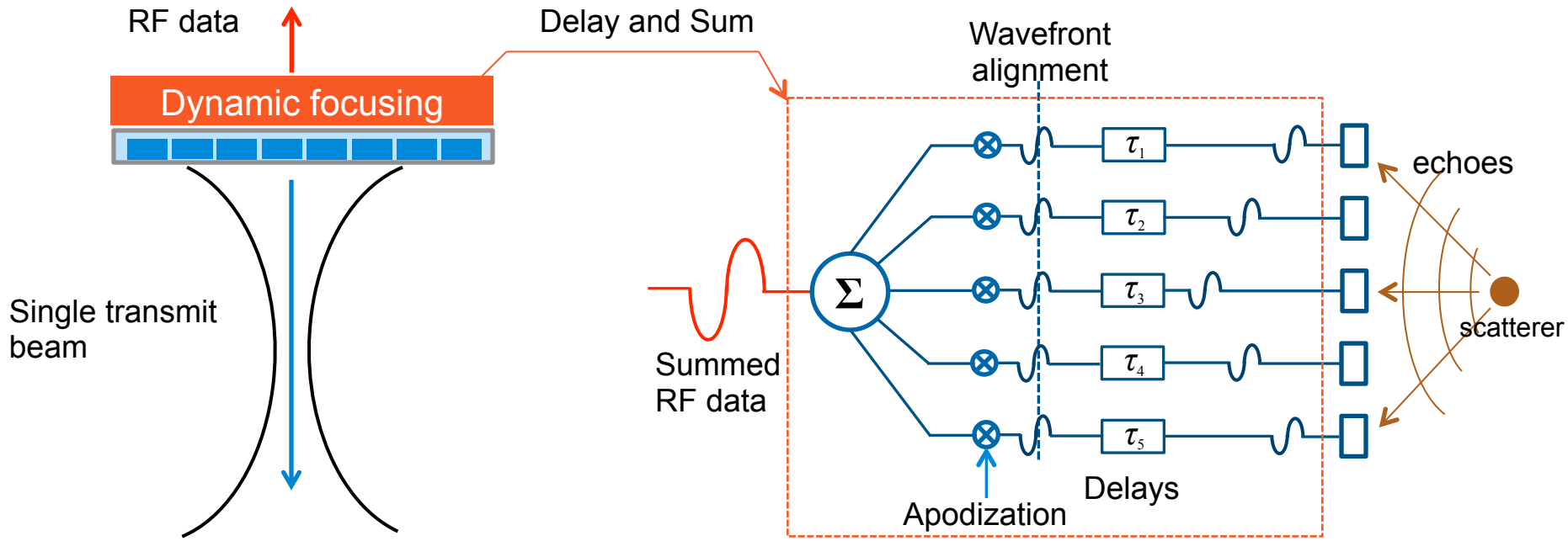
Image Formation: Dynamic Focusing



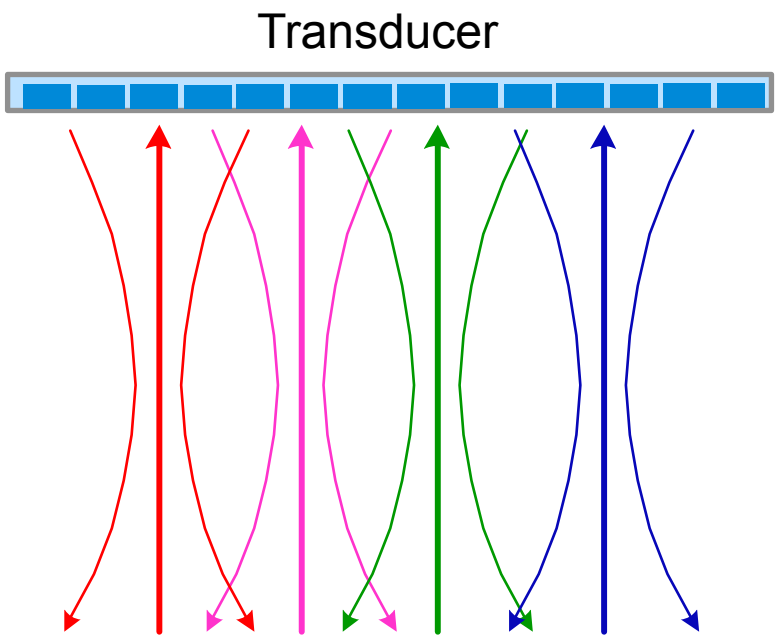
- Image is generated line-by-line using fixed focused transmit and dynamic receive focusing → image resolution is only optimal around focal depth, (transmit focal depth problem).

- Synthetic scan-lines are interpolated between actual scan-lines, (interpolation problem).

Beamforming

Store the raw received data from all the transmitted beams.

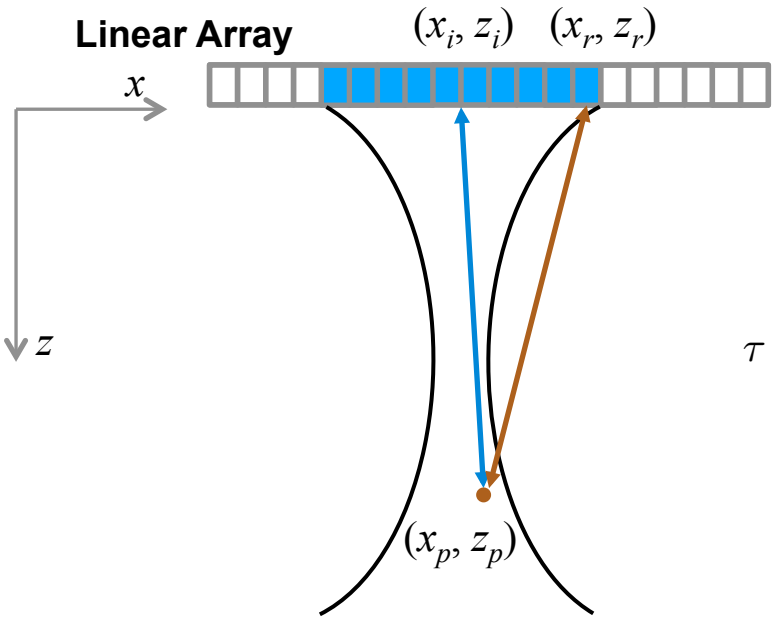
This enables us to solve both problems:



- **Fix interpolation problem:** perform individual focus calculations for each pixel.
- **Fix the single transmit focal depth problem:** combine information from several beams to improve the focussing away from the focal depth.

To focus using data away from the centreline we need the travel times for these points.

Time-Delay Calculation: Conventional Approach



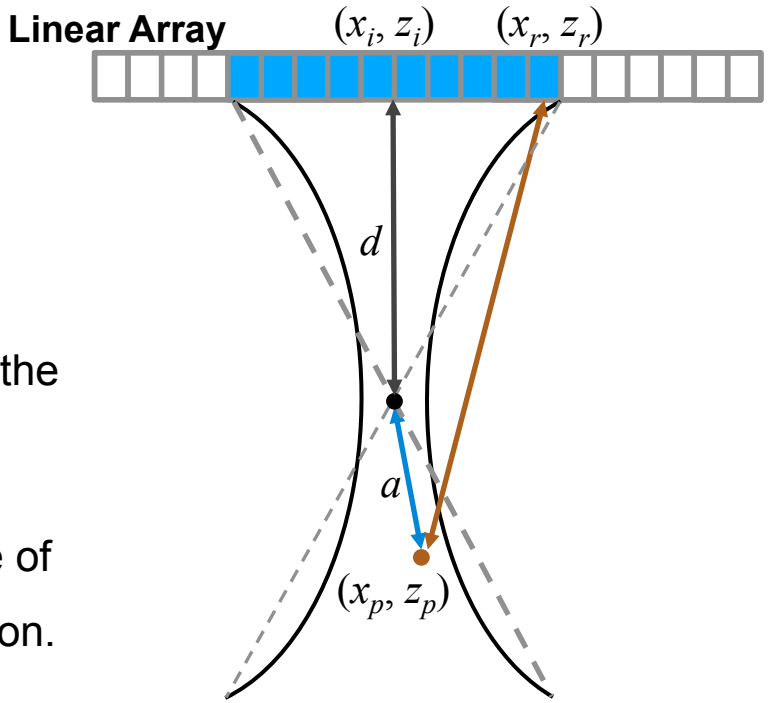
$$\tau = \frac{\sqrt{(x_p - x_i)^2 + (z_p - z_i)^2}}{c} + \frac{\sqrt{(x_p - x_r)^2 + (z_p - z_r)^2}}{c}$$

c – Sound speed

- Using *geometrical optics approximations*
- Assuming that the transmitted pressure field is spherical and generated from the center of the active aperture
- Used in convex array systems with data compounding limited to two transmit beams (Lee et al., *IEEE Trans. UFFC*, 59(3):573-582, 2012.)

Time-Delay Calculation: Virtual Source Approach

- A virtual source is assumed at the focal point. This generates a spherical wave.
- The assumption is valid only within a limited angle (shown by the dotted lines). Imaging data outside the angle is currently discarded.
- Creates artefacts around the focal depths because of the discontinuity in the spherical wave approximation.
- Transmit beams can be made more broad with the focal depth outside the imaging region (**SA-BiPBF**: Kim et al., IEEE TBE, 60(10):2716-2724, 2013.)



$$\tau_i = \frac{d \pm a}{c} + \frac{\sqrt{(x_p - x_r)^2 + (z_p - z_r)^2}}{c}$$

d – focal length

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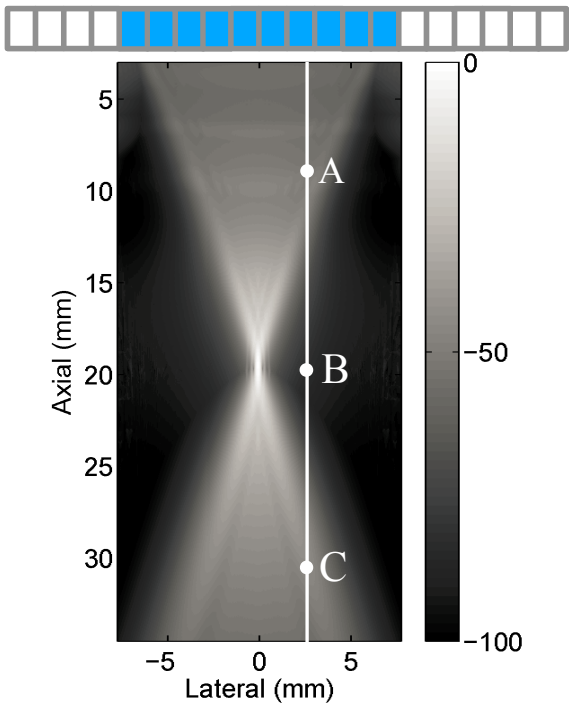
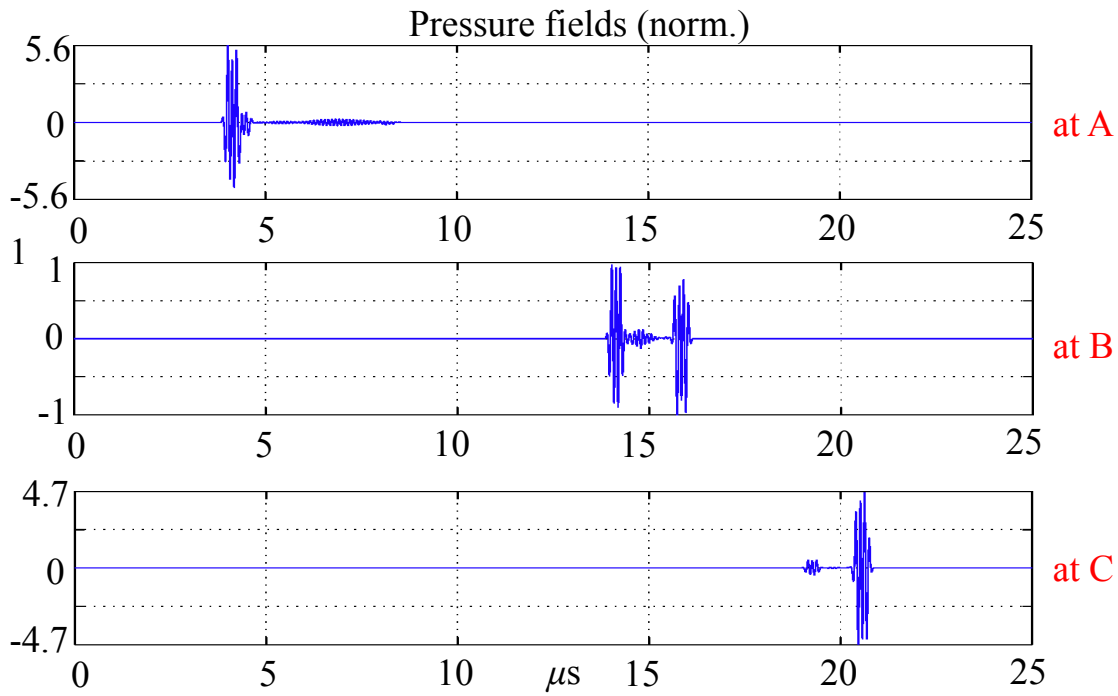
Simulated Pressure Waveforms

- **Goal:** Maximize data compounding at individual pixels.

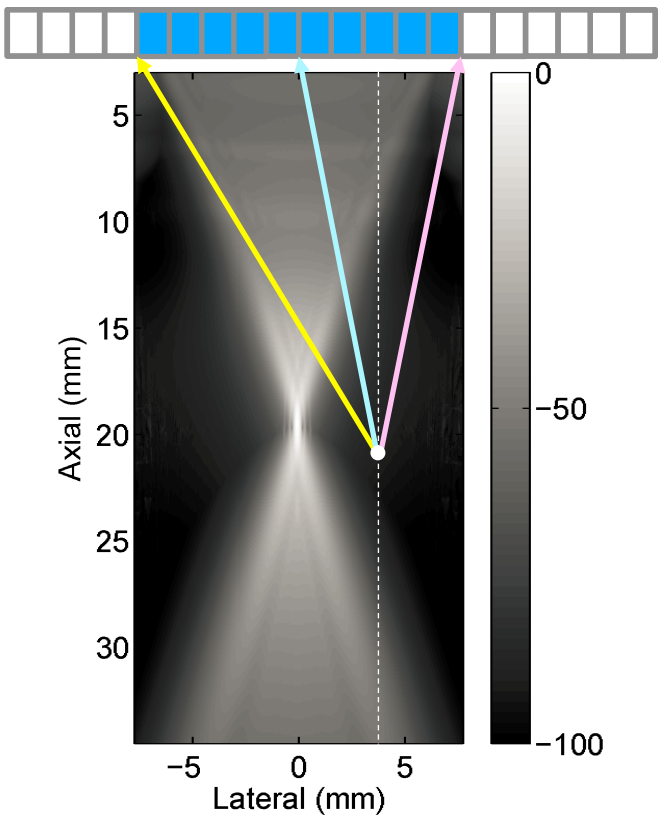


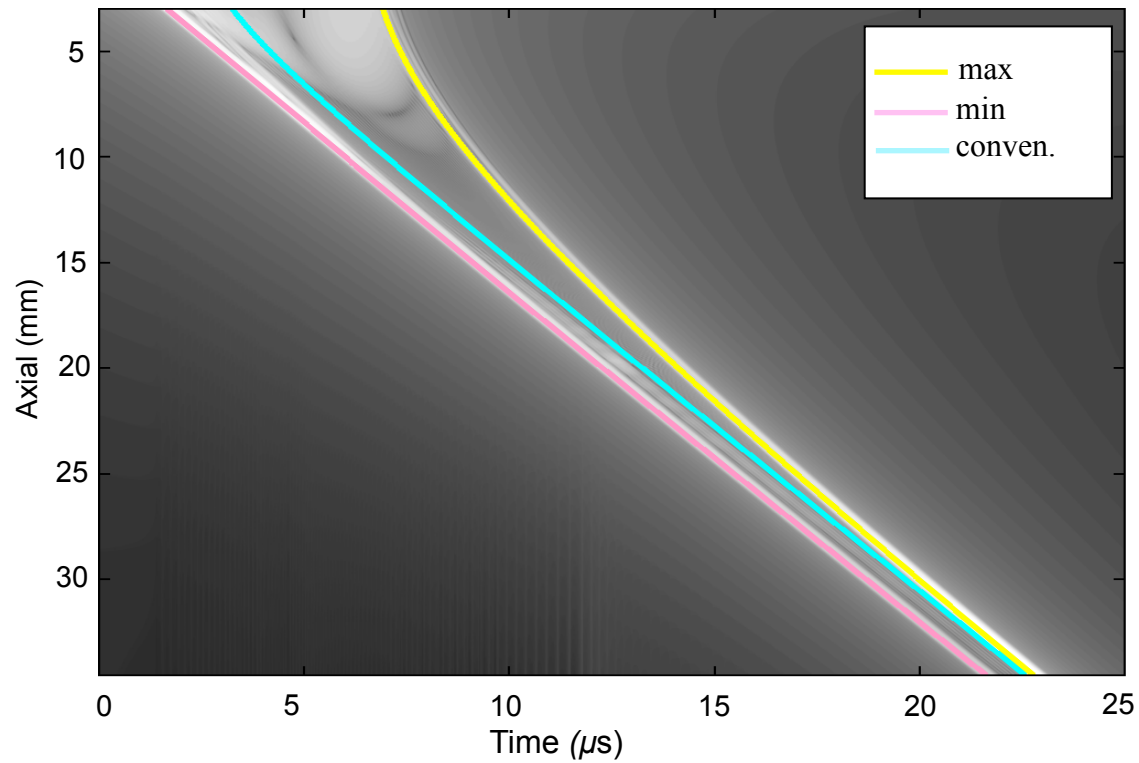


- The virtual source approach is only valid in some places.
- A better approximation is to describe the beam at each point in terms of two pulses of varying amplitude.

Field Pattern Analysis

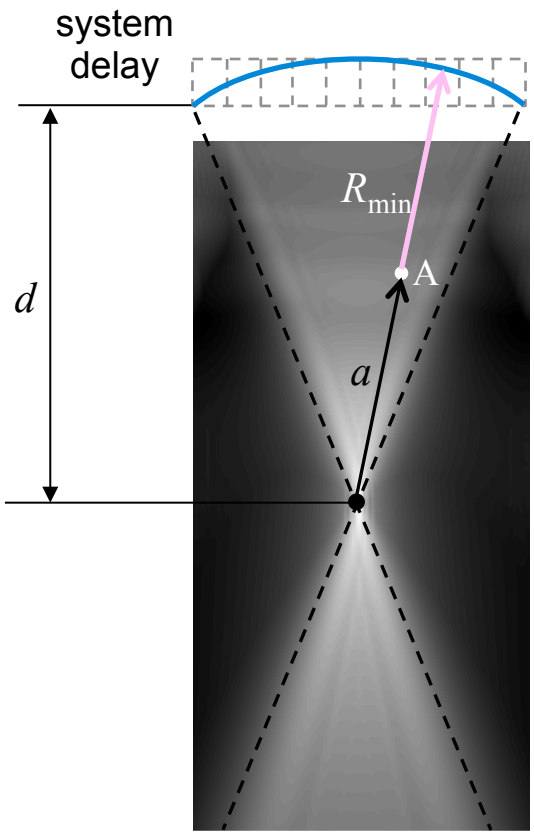
Linear Array

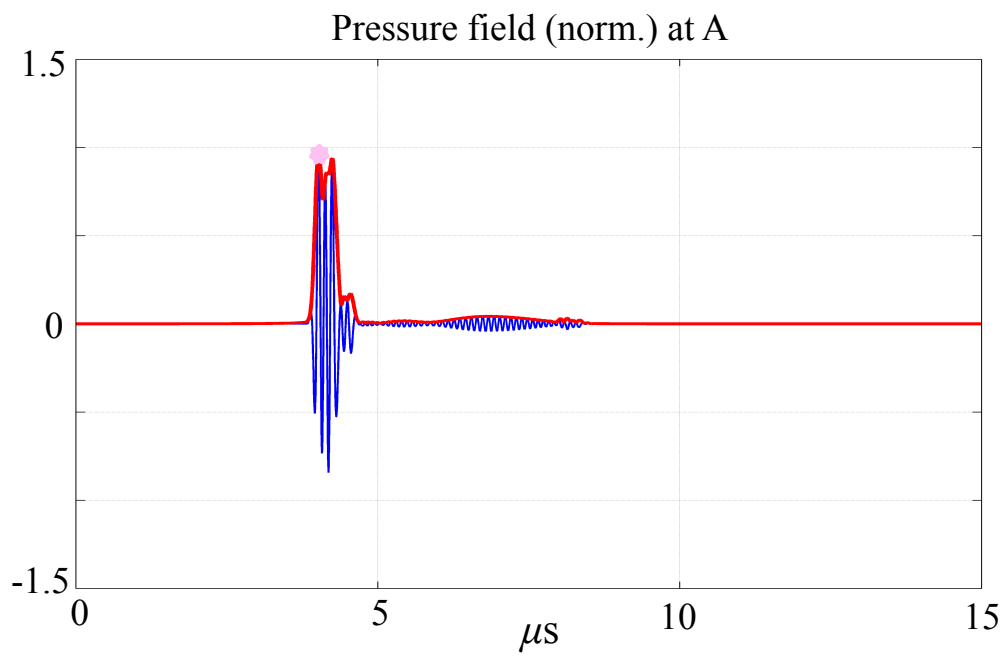




Nguyen and Prager, "High-resolution ultrasound imaging with unified pixel-based beamforming", *submitted to IEEE TMI (*May 2015*)*.

New Time-Delay Calculation (I)

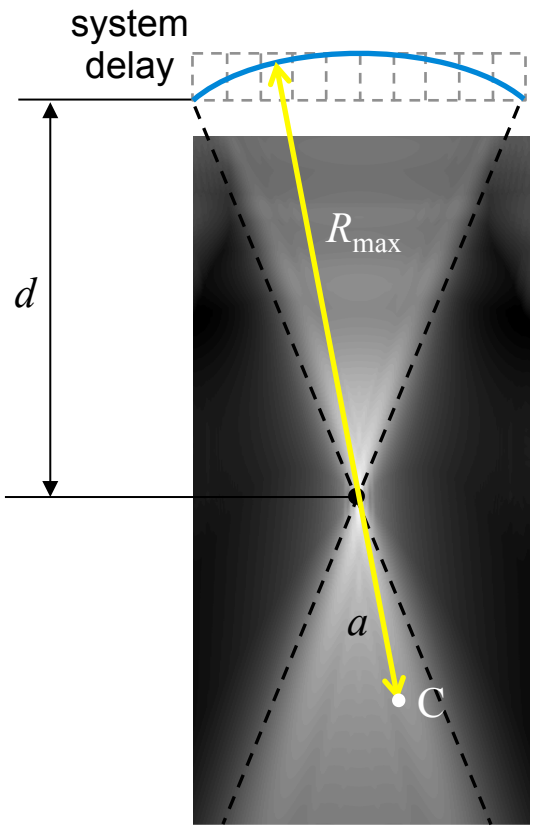


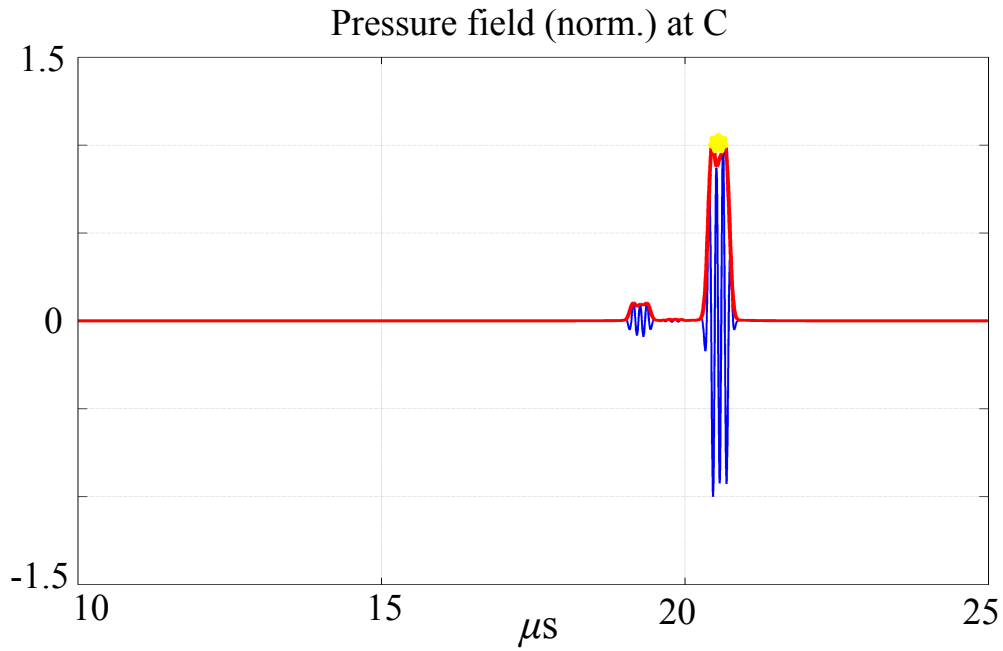


$$\tau_{\text{trans}} = \frac{R_{\text{min}}}{c} - \tau_0$$
$$= \frac{d-a}{c}$$

τ_0 – delay between the transmit time at the edge and centre of the active aperture.

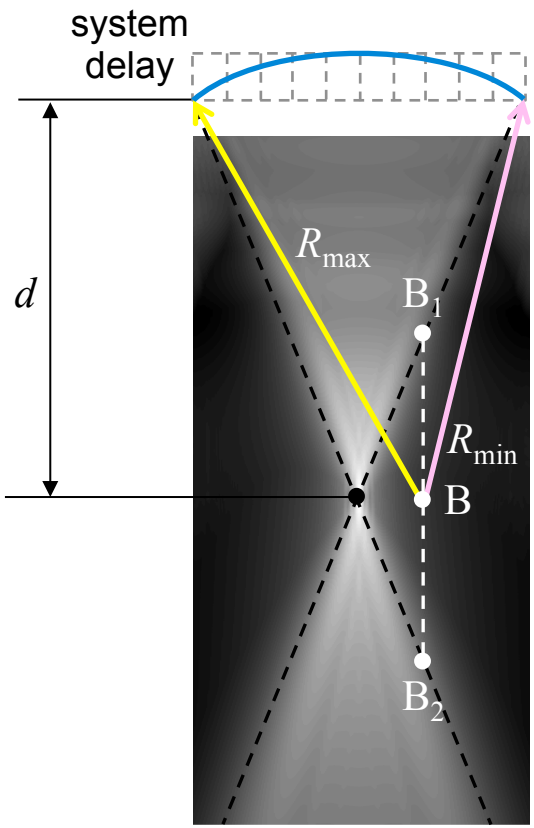
New Time-Delay Calculation (II)

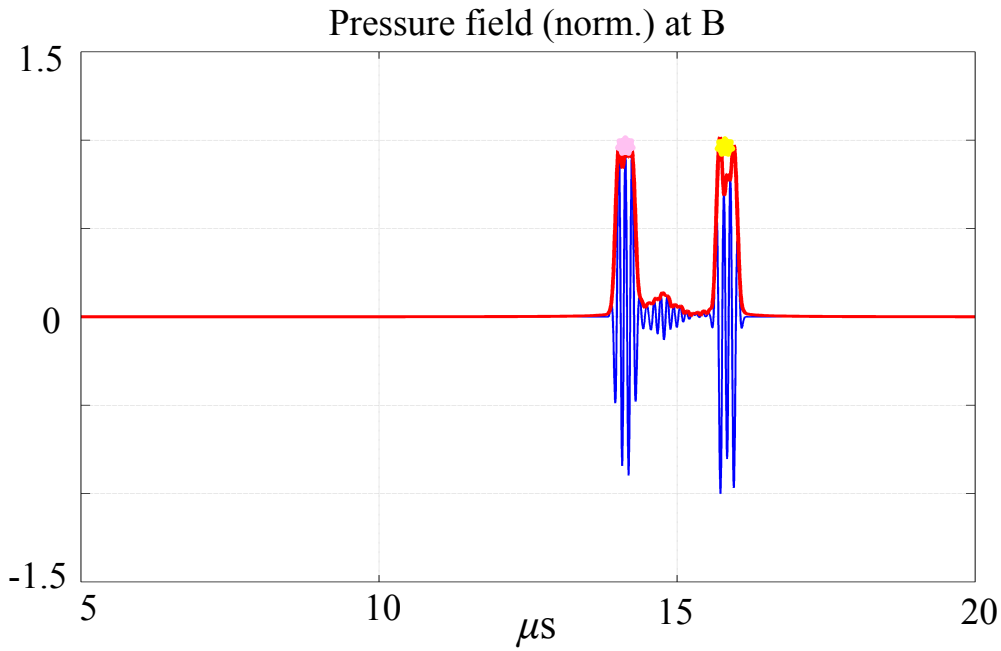




$$\tau_{\text{trans}} = \frac{R_{\max}}{c} - \tau_0$$
$$= \frac{d+a}{c}$$

New Time-Delay Calculation (III)





$$\tau_{\min} = \frac{R_{\min}}{c} - \tau_0 \quad \text{and} \quad \tau_{\max} = \frac{R_{\max}}{c} - \tau_0$$

$$\tau_{\text{trans}} = \frac{\text{dist}(B_2, B)}{\text{dist}(B_2, B_1)}\tau_{\min} + \frac{\text{dist}(B_1, B)}{\text{dist}(B_2, B_1)}\tau_{\max}$$

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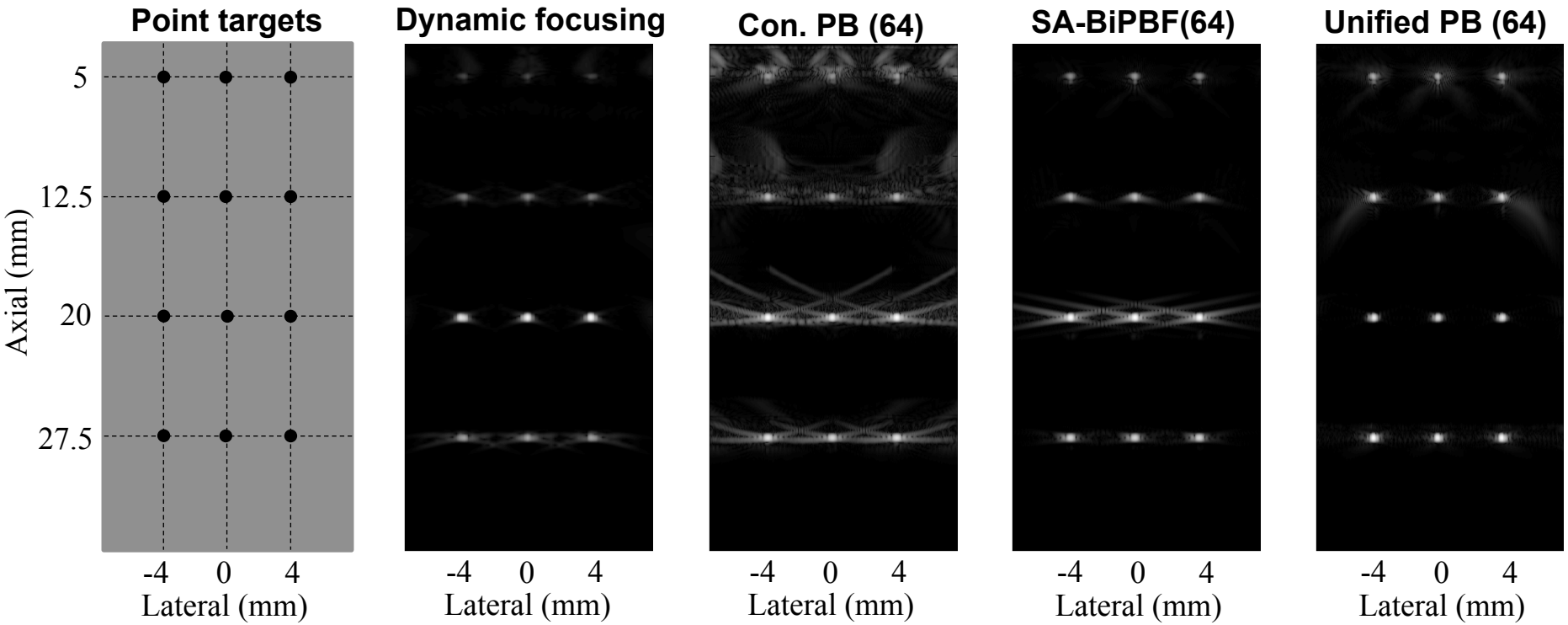
Demonstration

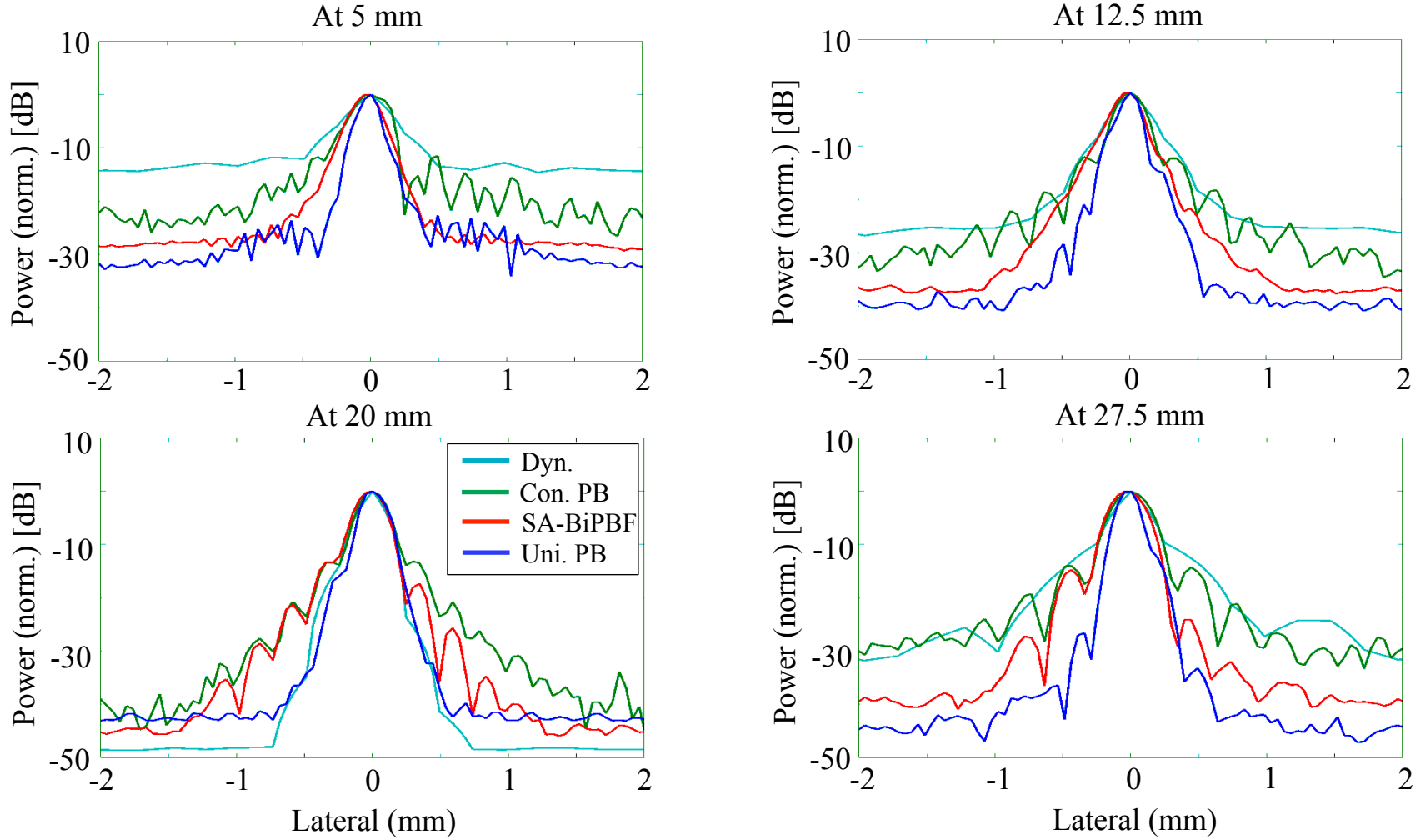
Beamformers	Focal depth	No. of beams per scanline
Dynamic Focusing	20 mm	1
Conventional Pixel-based	20 mm	64 and 8
SA-BiPBF	40 mm	64
Unified Pixel-based (*proposed method*)	20 mm	64

All images have a depth range from 3 mm to 34 mm

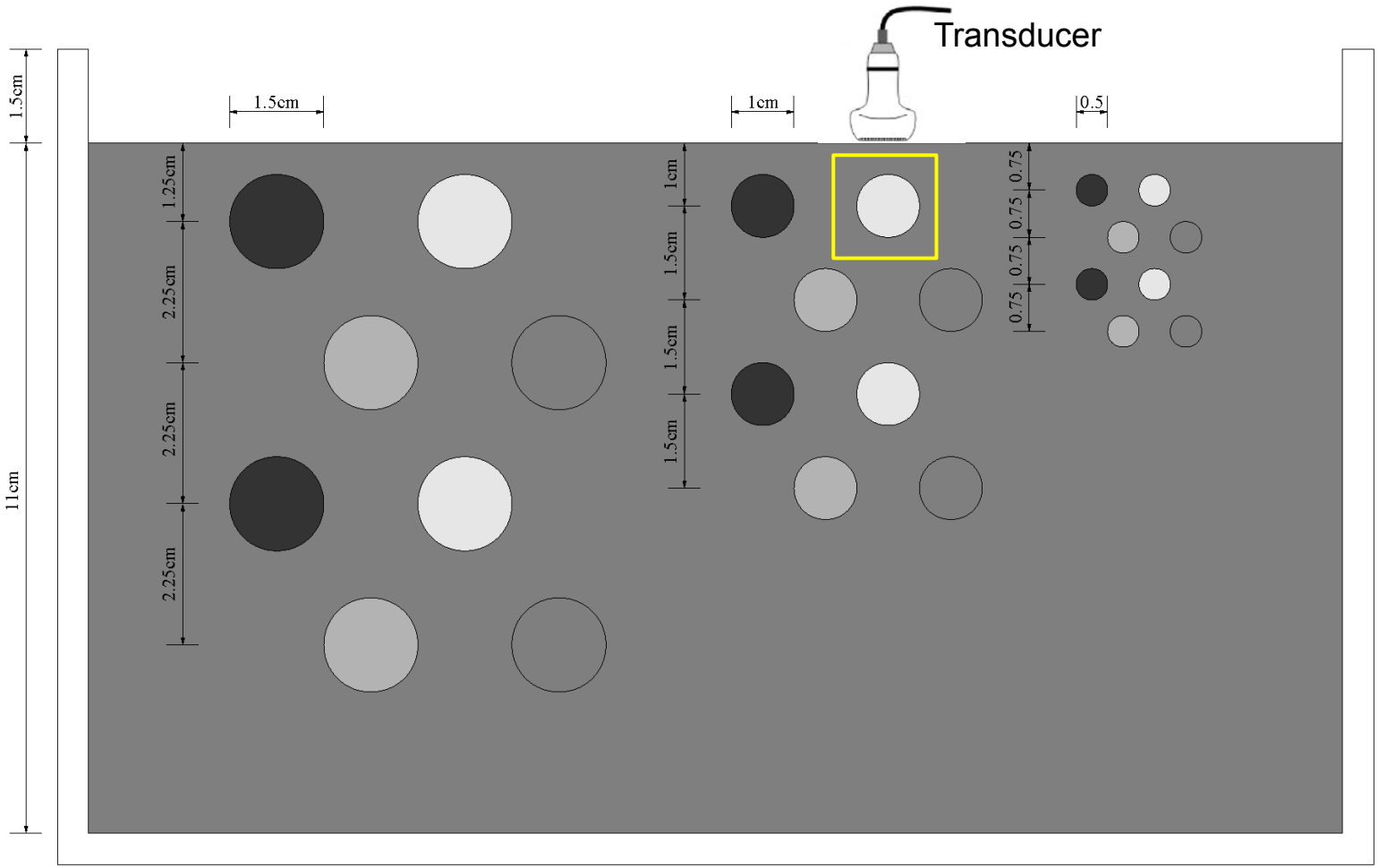
Simulated Results



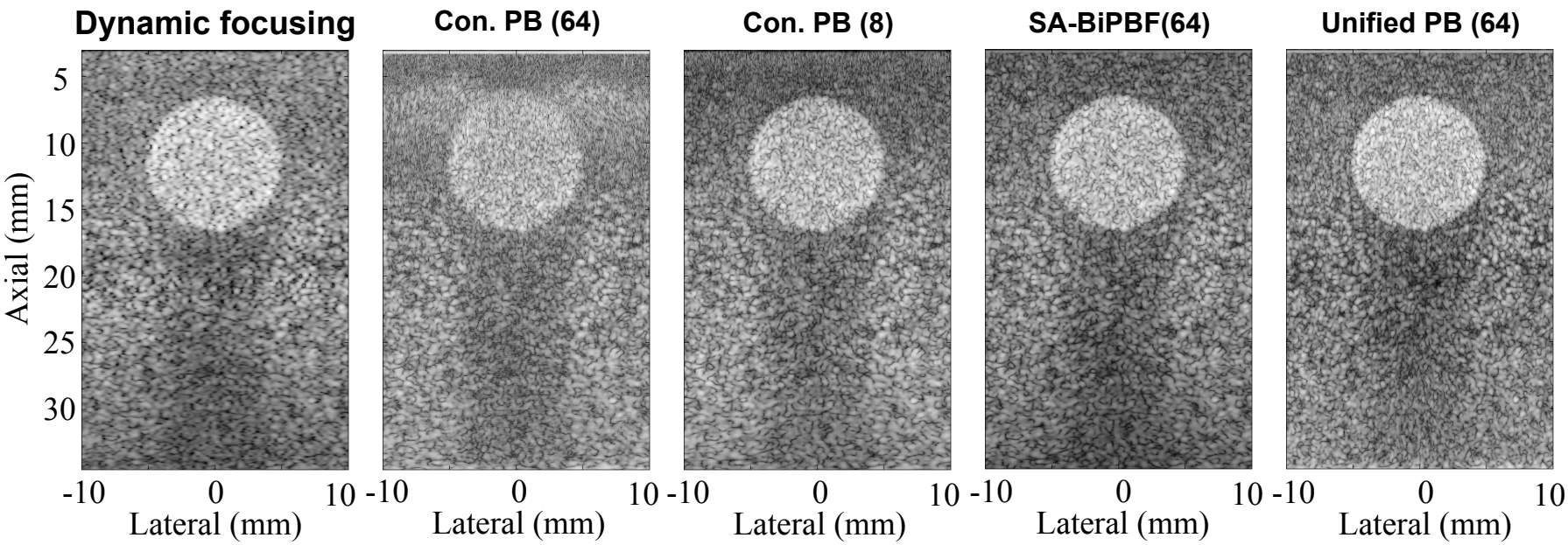
Lateral Profiles



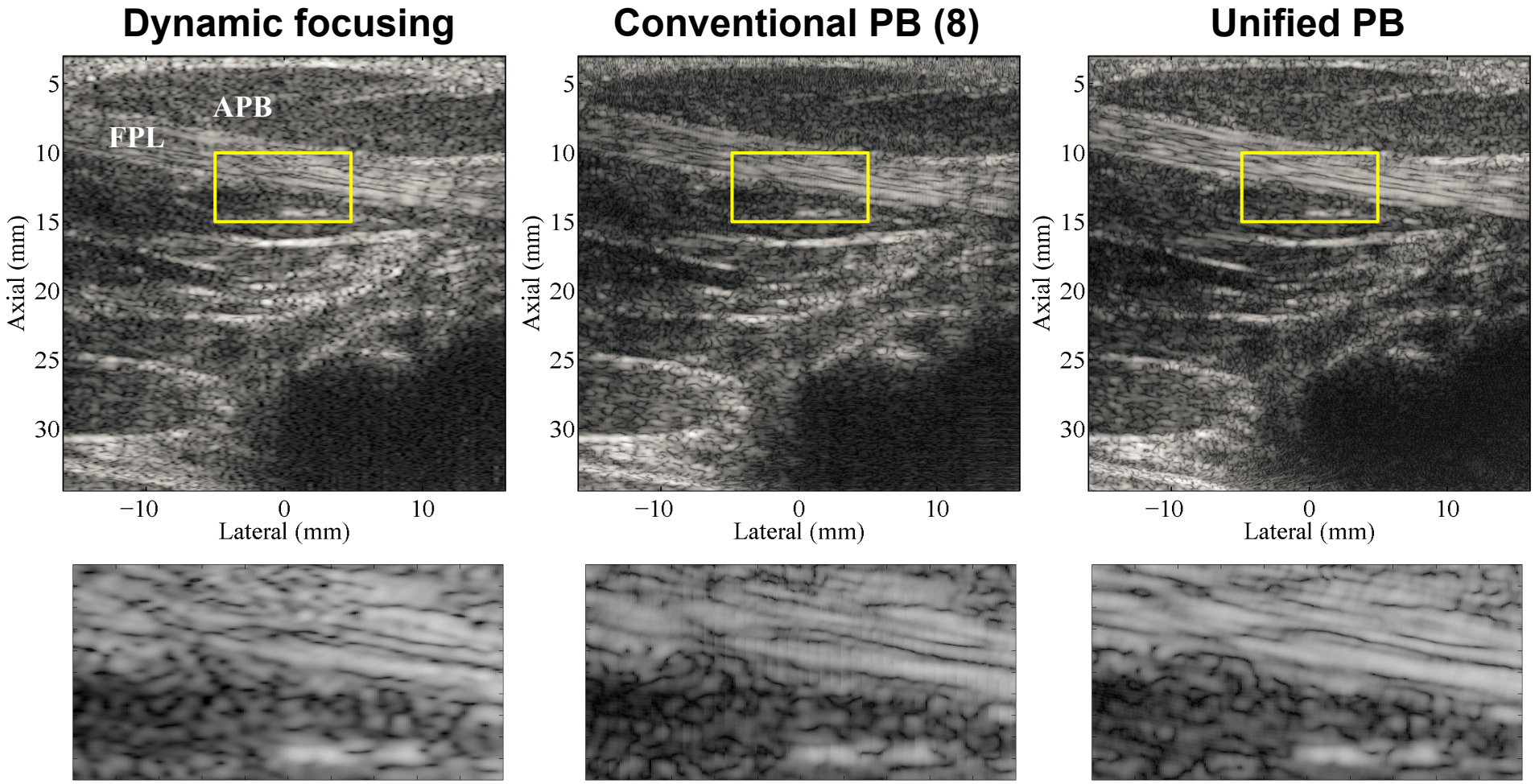
Phantom scanning



Phantom results



In vivo results



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Conclusions

- Good performance of the proposed unified PB beamforming comes from the highly focused beam on transmit and dynamic time delay calculations on receive.
- The time-delay calculation still uses the geometric optics approximation which makes for simple implementation but limits us to the use of only one data point per received waveform.
- The method leads to enhancements in image quality in both phantom and *in vivo* studies.

Acknowledgements: Dr Laurence Berman for performing and interpreting the in vivo scans.