Multi-Resolution Signal Processing Techniques for Airborne Radar

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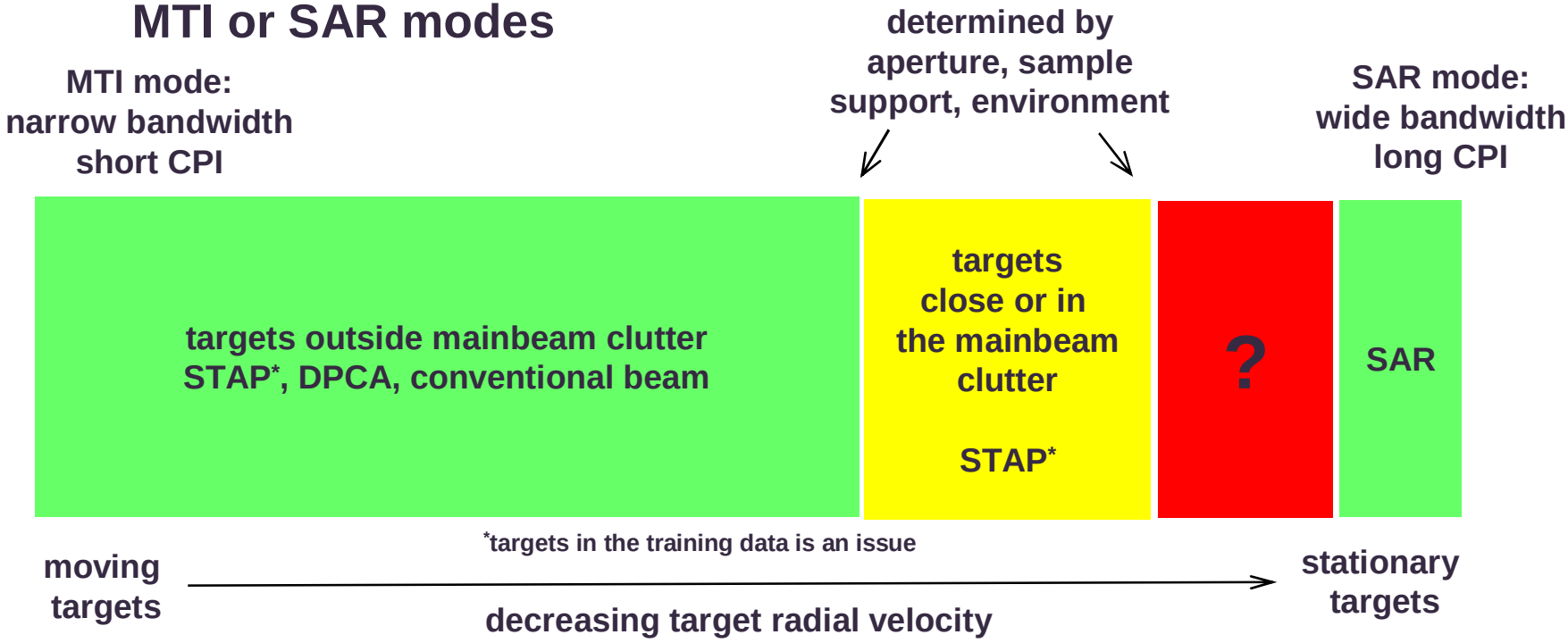
Outline

- **Background and Objectives**
- **Simulations**
- **Ideal Covariance Analysis**
- **Adaptive Processing Techniques**
- **Summary**

Background

- **Airborne radar processing has typically focused on either MTI or SAR modes**



- **Suggests that it may be advantageous to vary the CPI length (and bandwidth?) as a function of the assumed radial velocity**
- **This presentation addresses longer CPIs for detecting *very* slow moving targets (e.g., GMTI radar)**

Objectives

- **Understand the theoretical advantages of long CPIs**
- **Investigate ways to exploit the long CPI to improve STAP performance**
- **Begin to answer the fundamental question: what should we do with all those pulses?**
- **Generate a long CPI covariance matrix and data samples for use in analyzing the problem**

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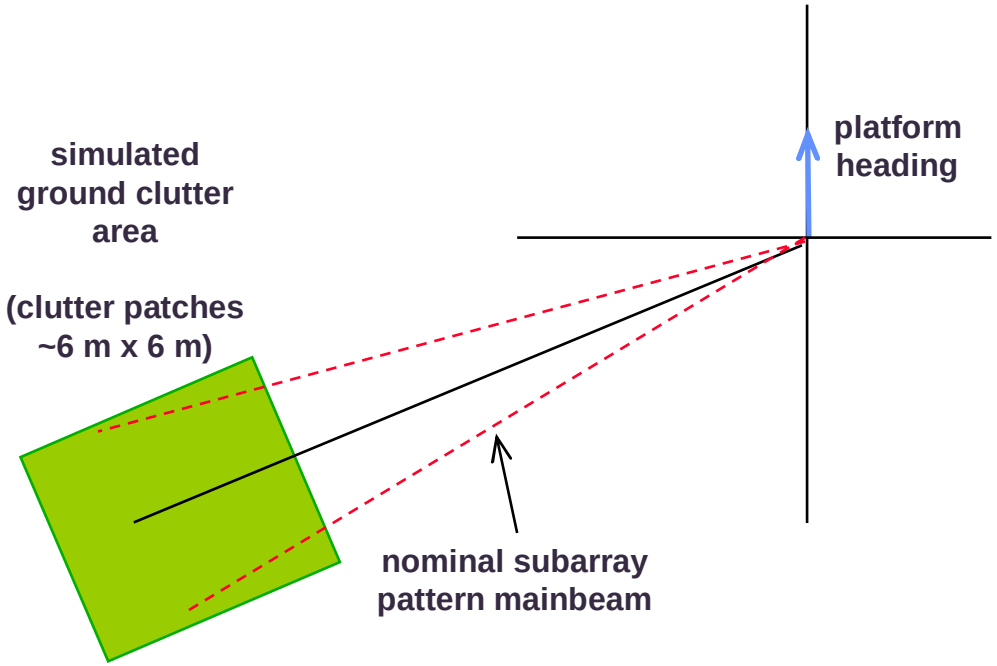
Simulation Parameters



Parameters

Frequency	X-band
Bandwidth	10 MHz
PRF	1 kHz
Pulses	512
Antenna	3.5 m x 0.3 m
Subarrays	6 (50% overlap)
CNR	40 dB element/pulse

- **Simulated clutter patches in the mainbeam only**
- **bald Earth, Gaussian clutter**
- **Look direction is ~17° off broadside**
- **Platform**
  - speed: 125 m/s
  - height: 11 km
  - slant range: 38 km
- **Billingsley ICM (15 mph winds)**
- **No scintillation**

Simulation Issues

- **True path range from pulse to pulse is required instead of linear phase based on Doppler shift for a single platform location**
- **Must account for “range walk”**
- **Computing the ideal covariance for 512 pulses and 6 spatial channels is computationally and memory intensive**

- **5 range bins were simulated**
- **Ideal covariance was computed for the center range bin**

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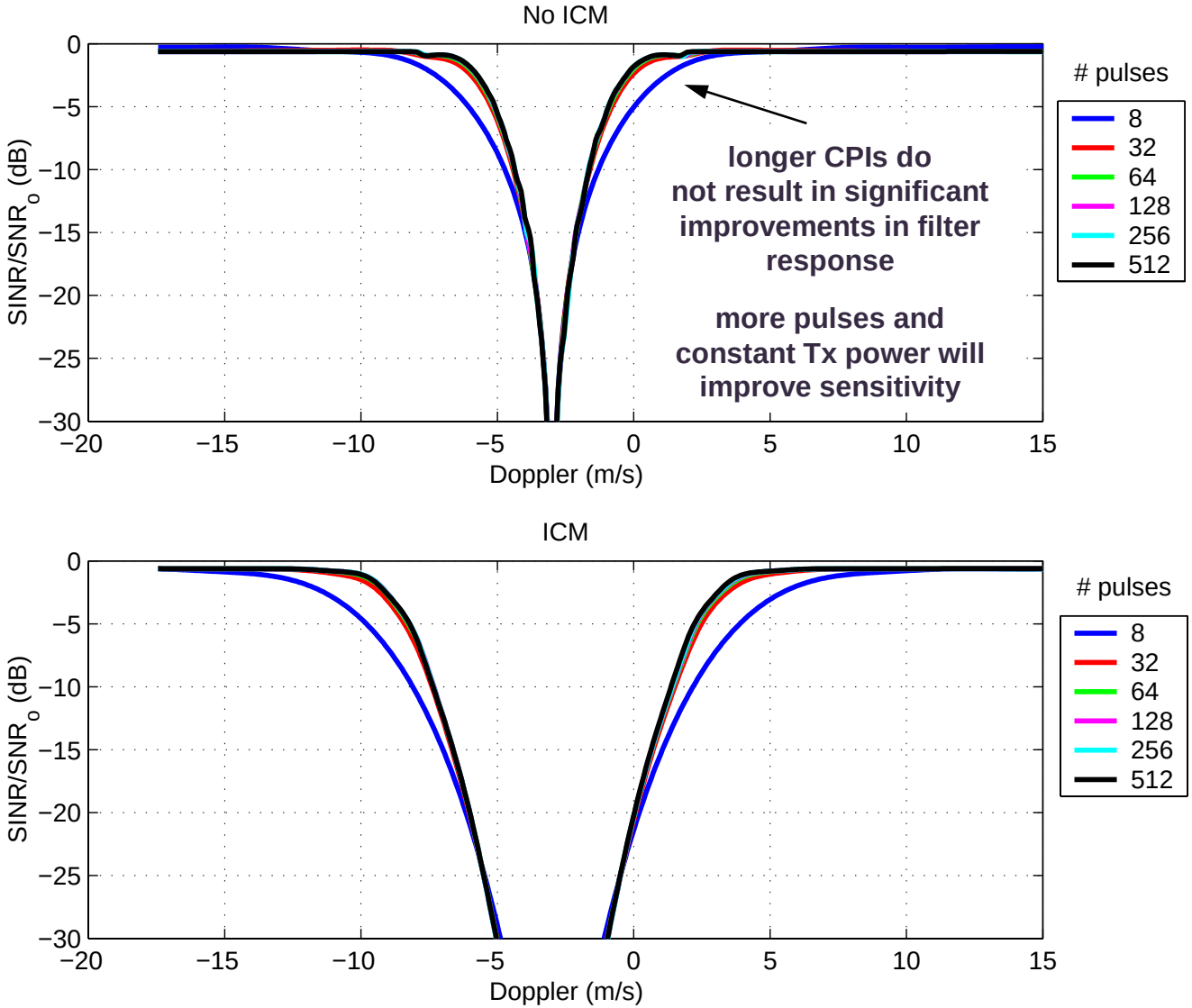
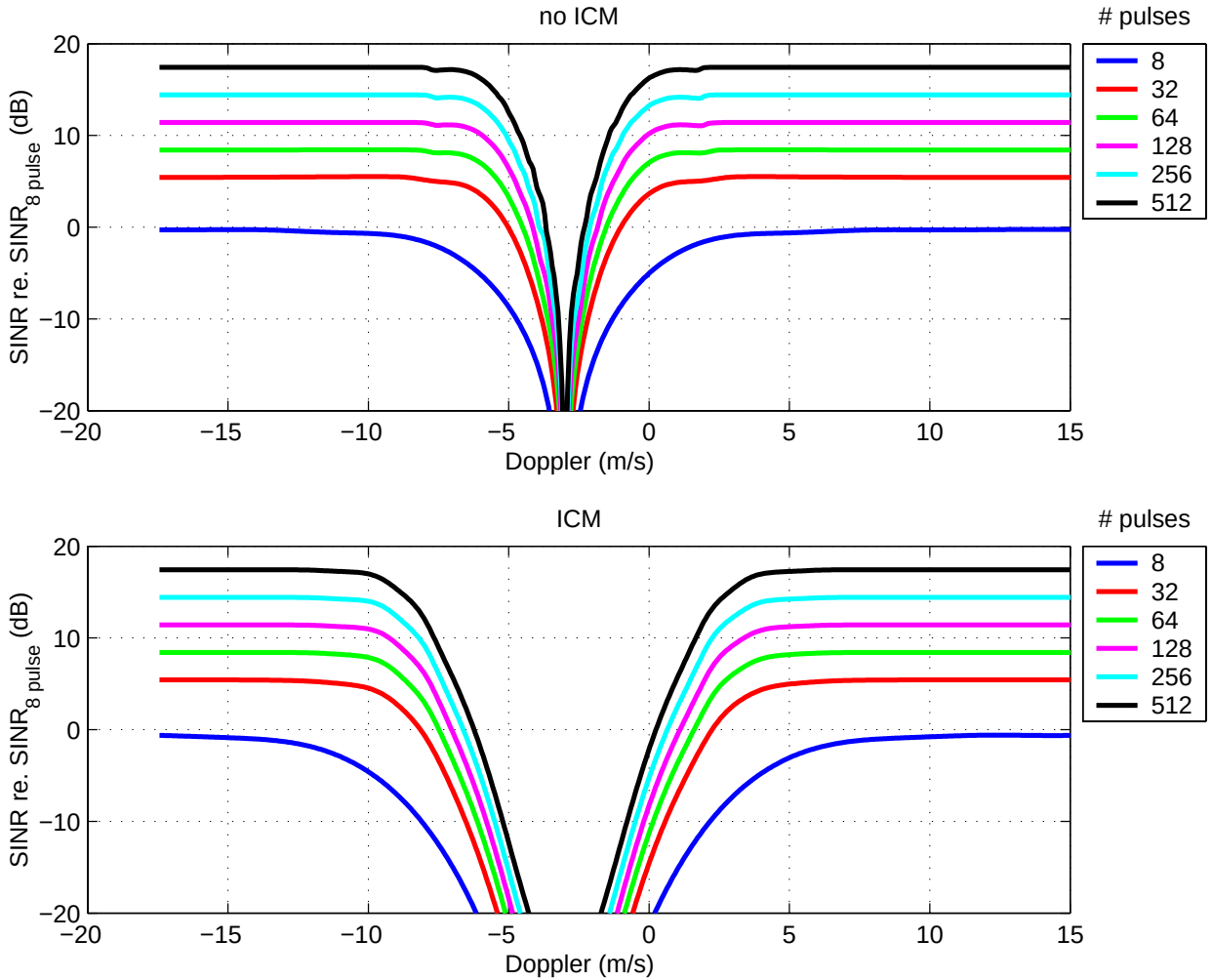
Ideal Covariance SINR loss



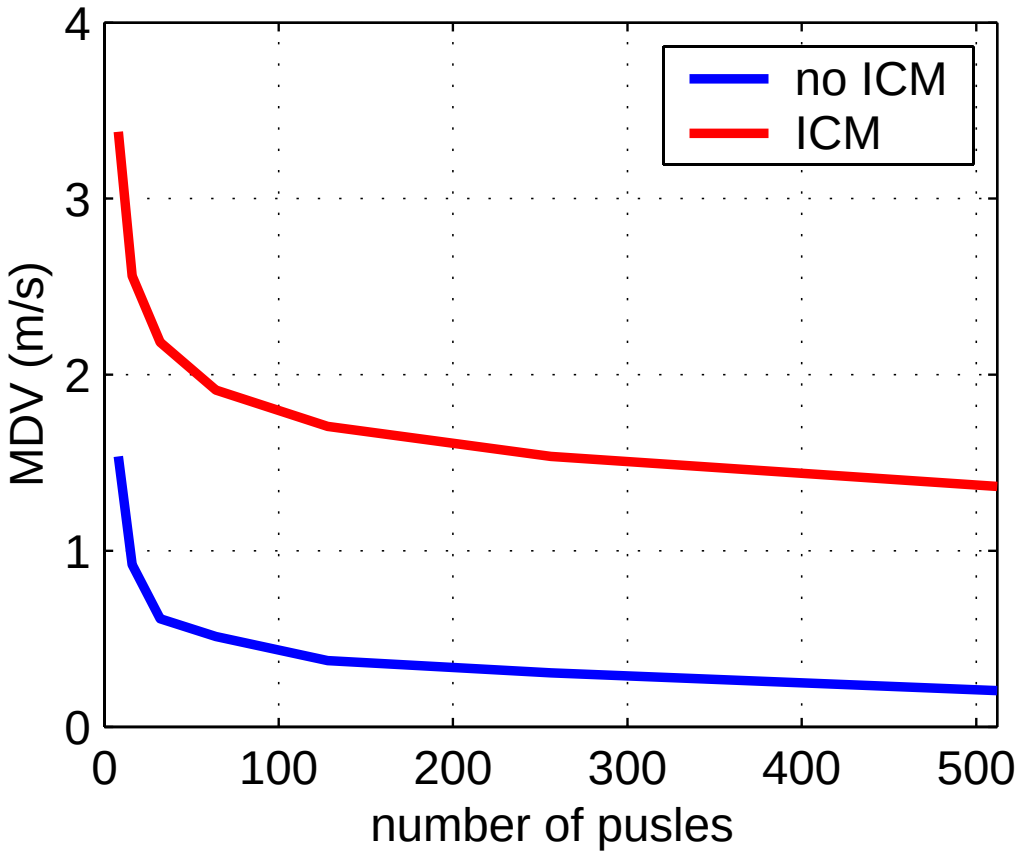
- **Post-Doppler element space**
  - 6 spatial
  - 7 adjacent bins
  - No Doppler taper
- **Including more bins results in negligible improvement in filter response**
- **Results shown for different CPI lengths**

Ideal Covariance Relative SINR



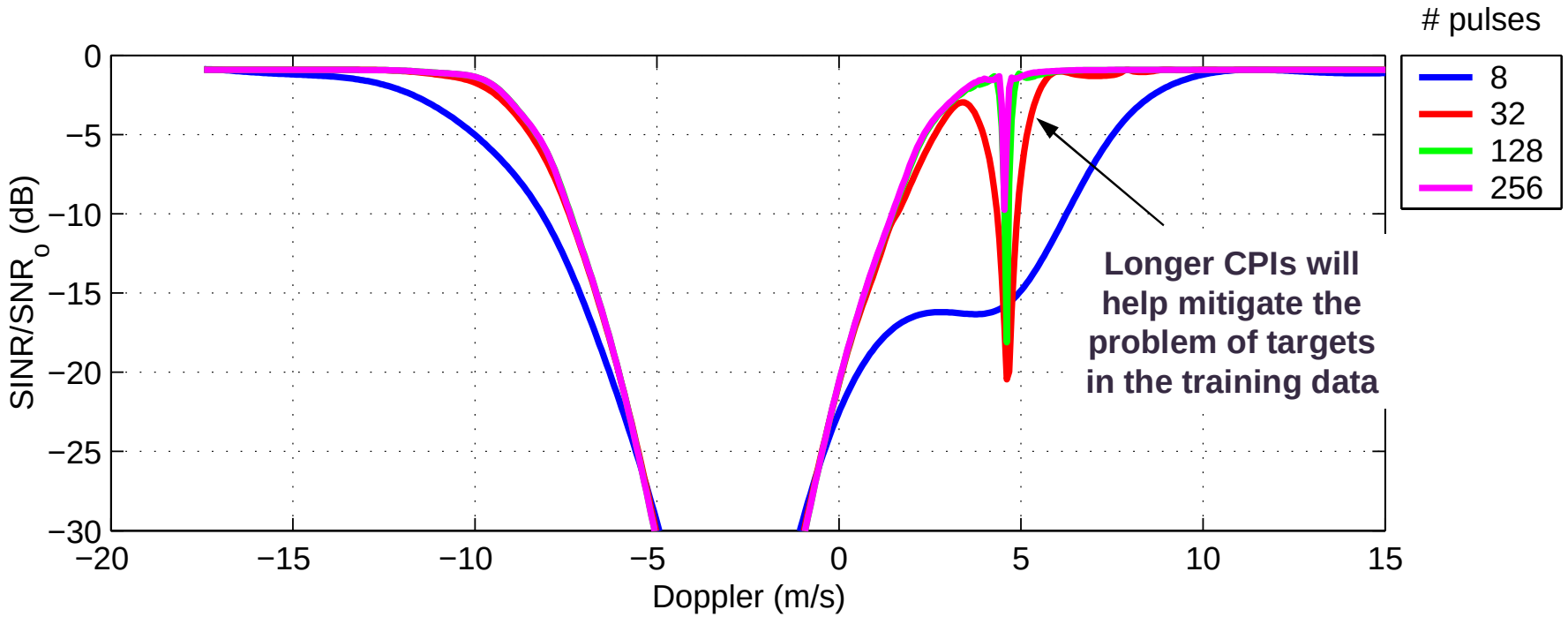
- **SINR re. the 8 pulse case is shown**
- **Assumes Tx power is constant**
- **Post-Doppler element space**
  - 6 spatial
  - 7 adjacent bins
  - No Doppler taper
- **Improvement gains in MDV falls off with Increasing numbers of pulses**

Minimum Detectable Velocity (MDV)



- **For this analysis MDV is defined as the radial velocity where SINR is -5 dB relative to optimal for 8 pulse case**
- **Results assume that in a noise limited environment a target is detectable with ~5 dB margin with an 8 pulse CPI**
- **This MDV calculation is optimistic since it does not include:**
  - heterogeneous clutter
  - sample effects
- **Illustrates that improvements to *optimal* MDV for CPIs longer than ~150 ms are minimal**

Ideal Covariance Results
"Targets in the Training Data"



- **Post-Doppler element space (5 bins)**
- **Ideal target covariance added to the ideal clutter covariance**
- **Target SNR is 0 dB (pre-integration)**

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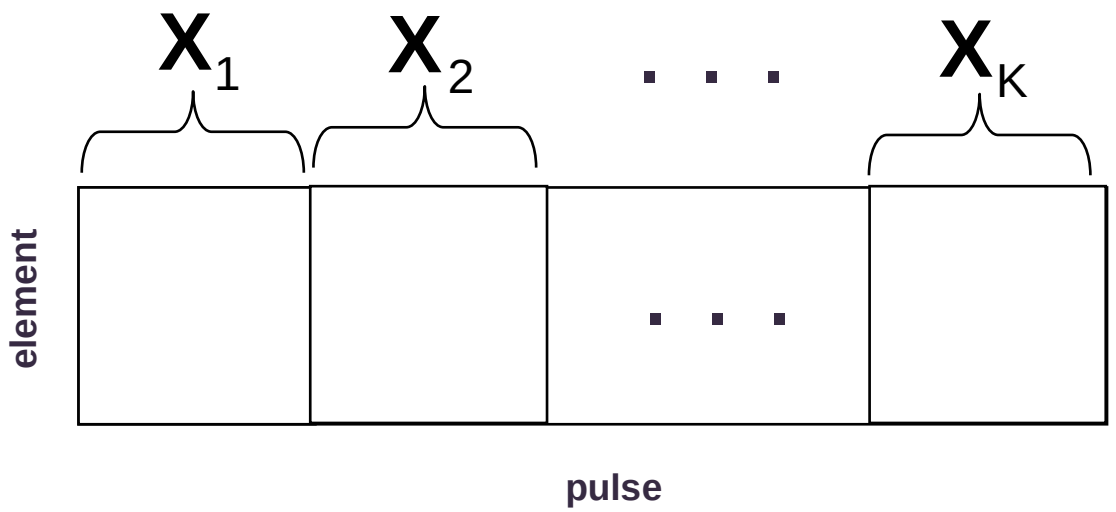
Adaptive Processing

- **Previous results were for ideal covariance processing**
- **Ideal covariance is optimistic in real-world where covariance must be estimated:**
  - Heterogeneous clutter
  - Mainbeam clutter nulling
- **More samples will generally improve the mainbeam clutter nulling problem**
- **More samples usually require larger training regions which may not be desirable if clutter is heterogeneous**
- **Do longer CPIs address this trade-off?**

Adaptive Algorithm: Approach #1



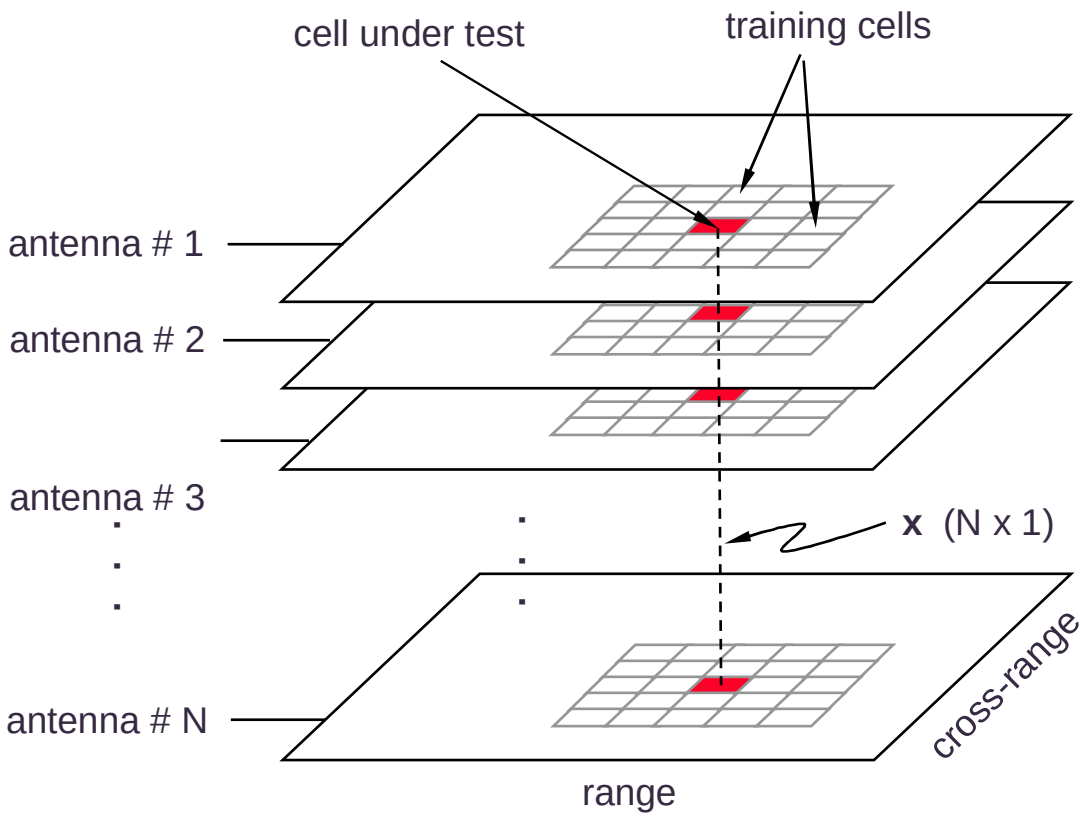
$$\mathbf{X} = \left[\mathbf{X}_1(:) \quad \mathbf{X}_2(:) \quad \ldots \quad \mathbf{X}_K(:)\right]$$

$$\hat{\mathbf{R}} = \frac{1}{K}\mathbf{X}\mathbf{X}^H$$

NOTE: graphic shows only a single range bin

- **Break the long CPI into sub-CPIs for use in training**
- **Possibly apply the weights to each sub-CPI and coherently or incoherently average (area for future work)**
- **Training data versus range may also be included in the usual way**
- **May still want to remove test bin from the training set**

Adaptive Algorithm: Approach #2



- **Each plane is a SAR image (range-Doppler map) formed from the output of a single antenna (note: it is complex)**
- **The cell under test is processed with a spatial filter:**

$$\mathbf{x}_w = \mathbf{R}_s^{-1/2}\mathbf{x}$$

- **Where R_s is computed using the spatial vectors from surrounding cells in both range and cross-range**
- **Detection statistic:**
  - Calibrated array

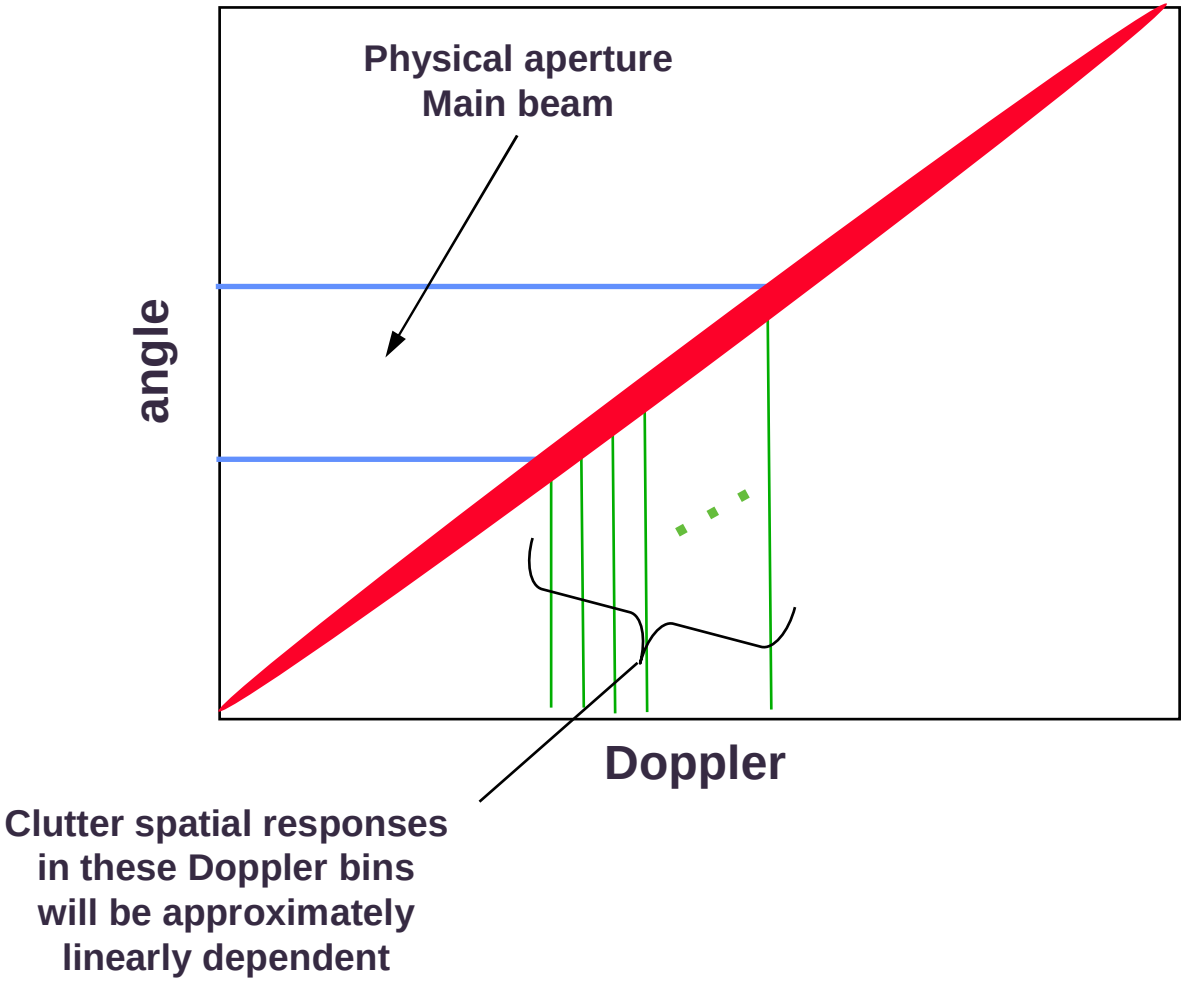
$$\gamma = \left|\mathbf{v}_w^H \mathbf{x}_w\right|^2$$

  - Uncalibrated array

$$\gamma = \mathbf{x}_w^H \mathbf{x}_w$$

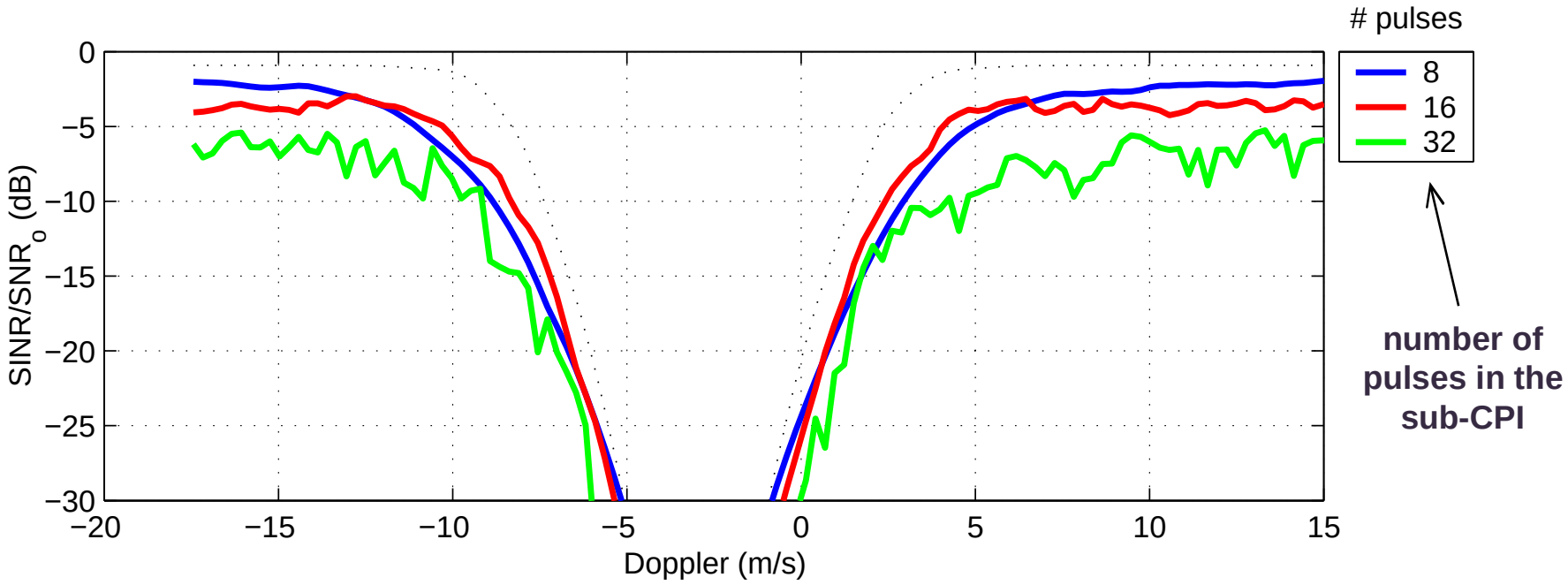
1. **This is Ali Yegulalp's technique.**
2. **Multiple cross-range bins can be used (multi-bin post-Doppler) and multiple range bins (fast time-taps)**
3. **Training in cross-range is possible because of high resolution re. spatial resolution of physical aperture (see next slide)**

Spatial Covariance Training Using Adjacent Cross-range (Doppler) Bins



- Graphic illustrates why training using data from adjacent Doppler bins is possible
- Takes advantage of high Doppler resolution re. angular resolution of physical aperture
- Longer CPI results in more samples

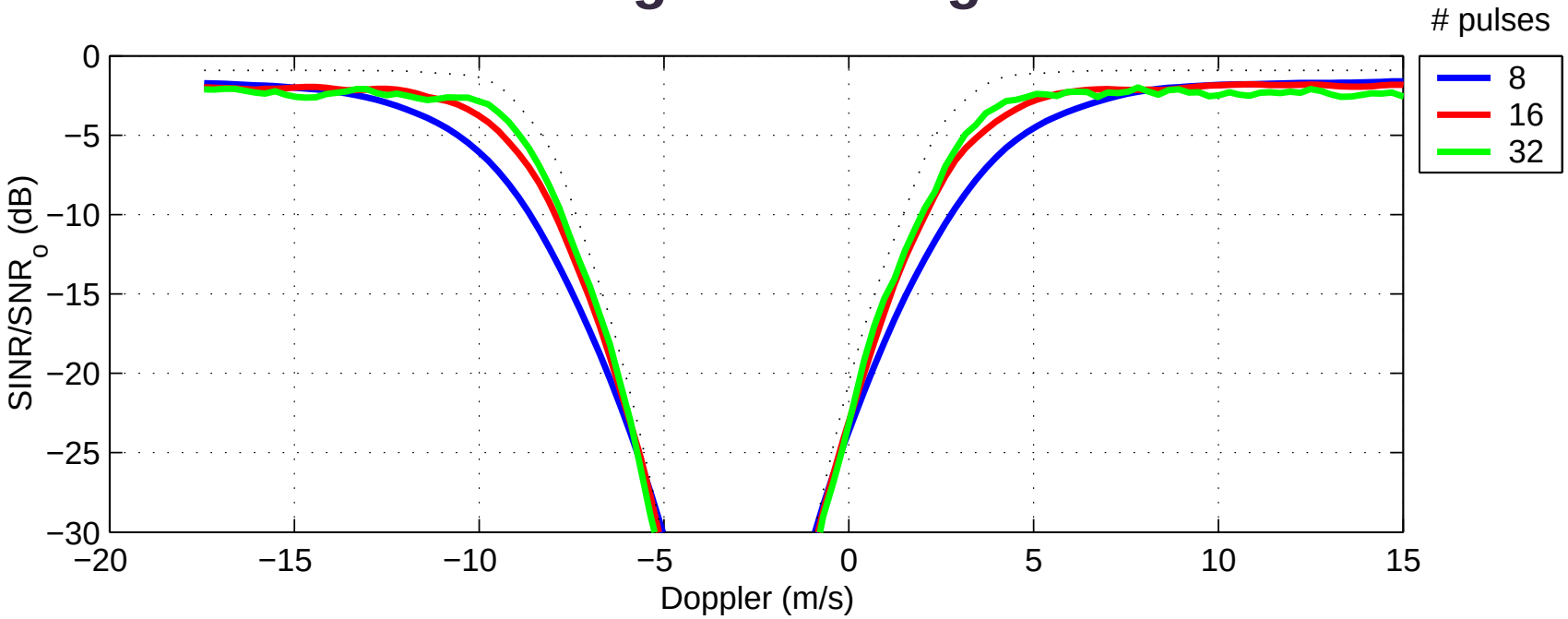
Sub-CPI Training
training set: single range bin



- **3 bin post-Doppler element space (0 dB diagonal loading)**
- **Training over sub-cpis in a single range bin**
- **Number of samples:**

$$\frac{512}{M} = \frac{\text{total \# pulses}}{\text{\# pulses in sub-CPI}}$$

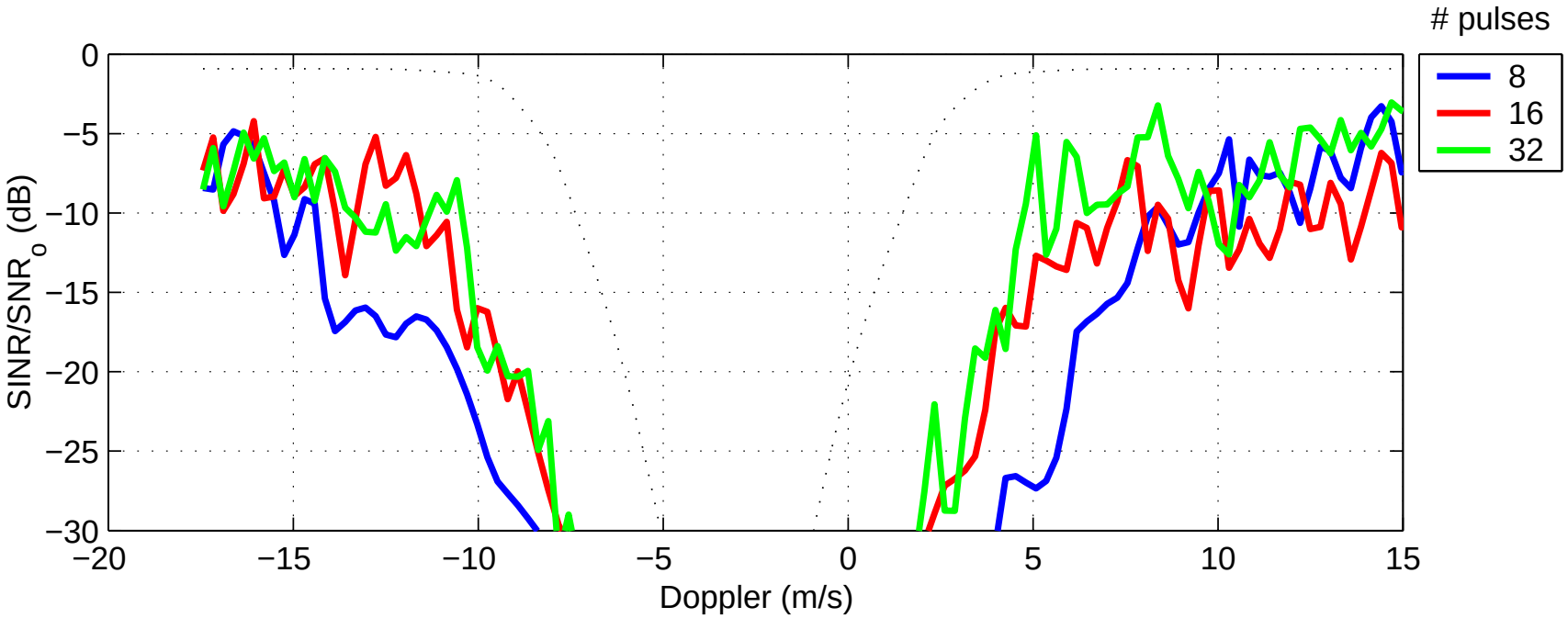
Sub-CPI Training
training set: 5 range bins



- **3 bin post-Doppler element space (0 dB diagonal loading)**
- **Training over sub-cpis in 5 range bins**
- **Number of samples:**

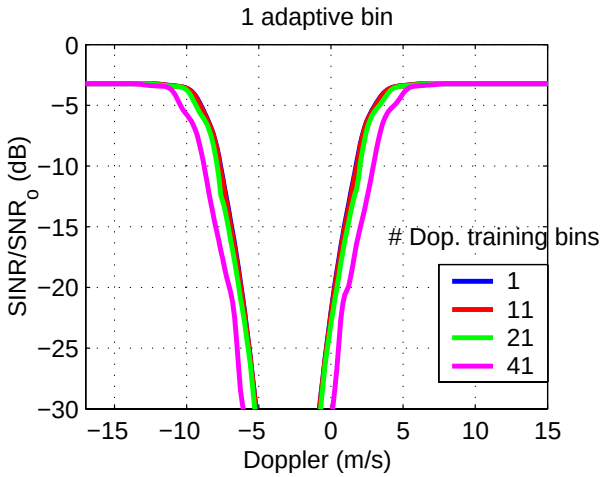
$$5\left(\frac{512}{M}\right) = \#\,\text{range bins} \cdot \frac{\text{total}\,\#\,\text{pulses}}{\#\,\text{pulses in sub-CPI}}$$

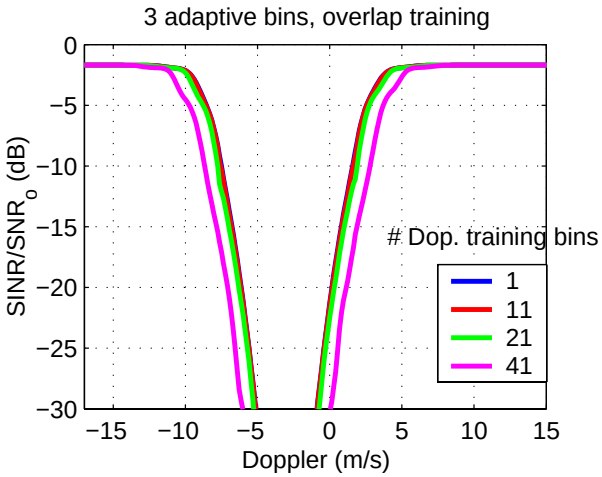
Range-only Training
training set: 5 range bins

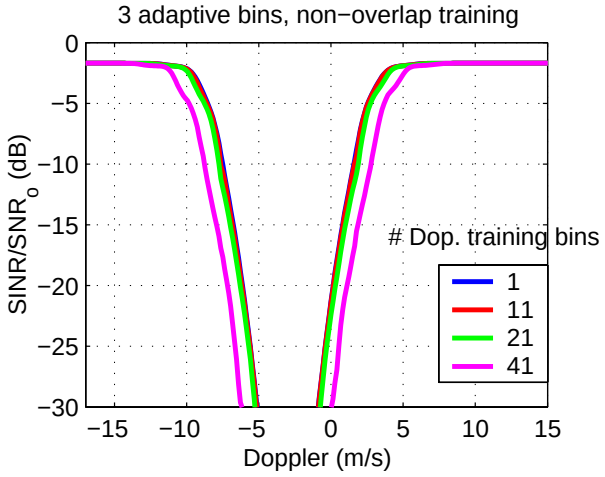


- **3 bin post-Doppler element space (0 dB diagonal loading)**
- **5 range bins used for training (i.e., 5 samples)**
- **This result is shown for comparison purposes**

Post-Doppler Processing
Ideal Covariance







"Angular" resolution in Doppler:

$$\delta_d = \frac{\lambda}{2L_{eff}} = \frac{\lambda f_p}{2v_p M}$$

Antenna angular resolution:

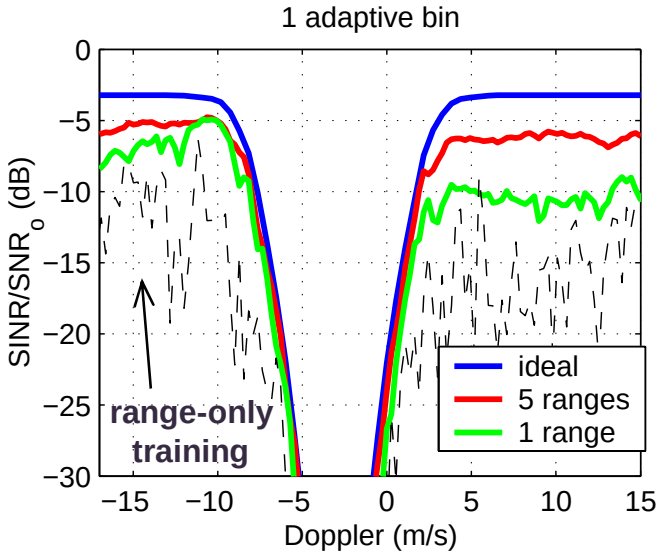
$$\delta_a = \lambda / L$$

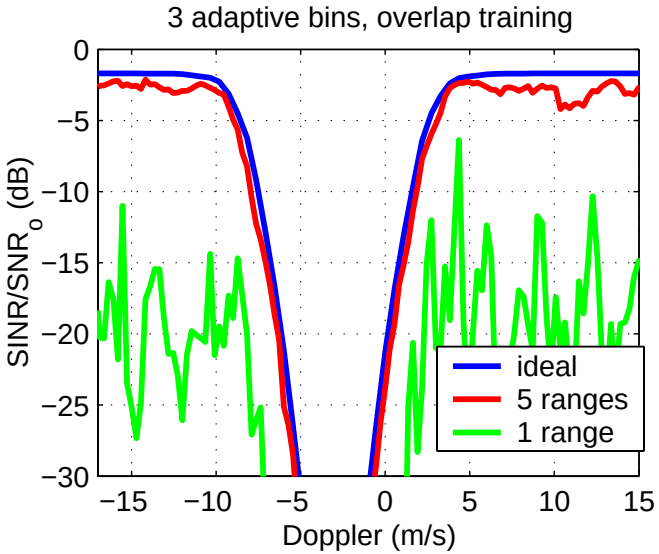
Resolution ratio:

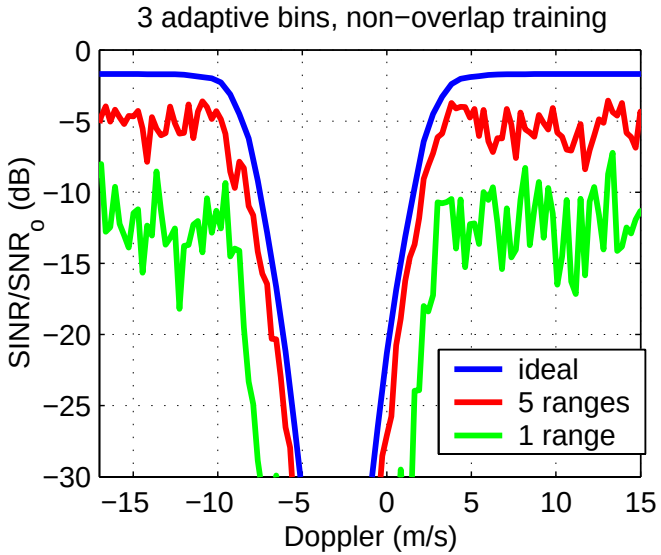
$$f_{res} \approx \frac{\delta_a}{\delta_d} = \frac{2v_p M}{L f_p}$$

- **Demonstrates the effect of using adjacent Doppler bins for training**
- **Beamformer computed using average of ideal covariances from the adjacent Doppler bins**
- **Overlapping and non-overlapping training cases shown for the multi-bin (multi-pixel) processing case**
- **Performance degrades for large window**
- **All results are for 256 pulse CPI (f_{res} = 18.7)**
- **1 adaptive bin result uses 65 dB Cheb. Doppler taper**

Post-Doppler Processing
Sample Covariance







- **Sample covariance computed using adjacent Doppler and range bins**
- **21 adjacent Doppler bins used for training**
- **0 dB diagonal loading**
- **All results are for 512 pulse CPI (f_{res} = 37.4)**

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- **Concept of varying the CPI length (and bandwidth?) may offer a technique for tracking targets over a continuum of radial velocities: moving → stationary**
- **Longer CPIs combined with traditional GMTI processing techniques do not lead to significant improvements in *optimal* MDV**
- **Longer CPIs may help reduce the problem of targets in the training data**
- **Two techniques that exploit longer CPIs to improve the performance of *adaptive* processing algorithms by increasing sample support without increasing physical dimensions of the training regions were explored**
- **Longer CPIs may allow the *adaptive* techniques to more closely approach *optimal* performance**
- **Future work will include: testing the algorithms using site-specific data sets and exploring other algorithms for detecting very slow moving targets**