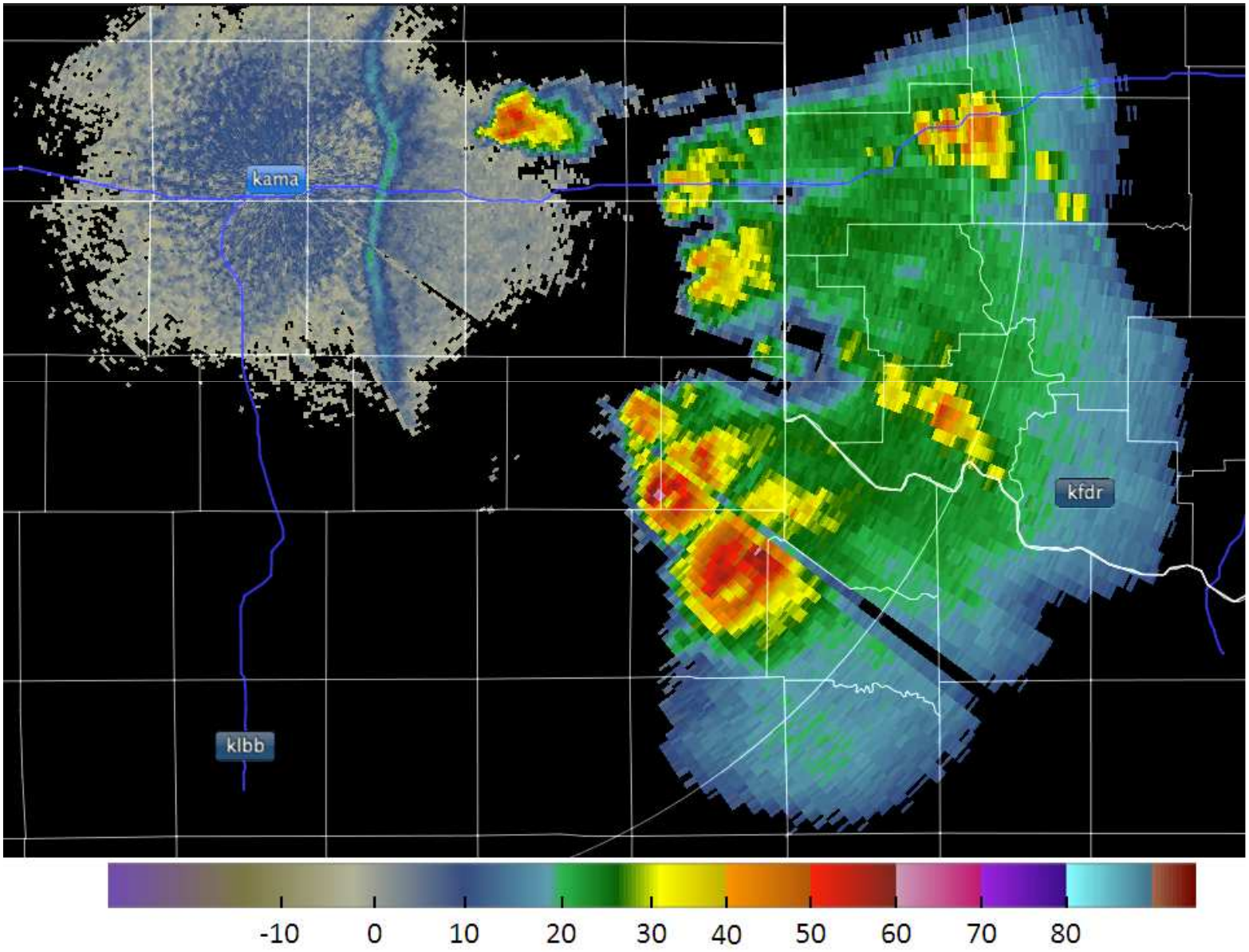
# Rapid scanning with phased array radars – issues and potential resolution

Dusan S. Zrnic, V.M.Melnikov, and R.J.Doviak

# Z field, Amarillo 05/30/2012

r=200 km

El = 1.3°

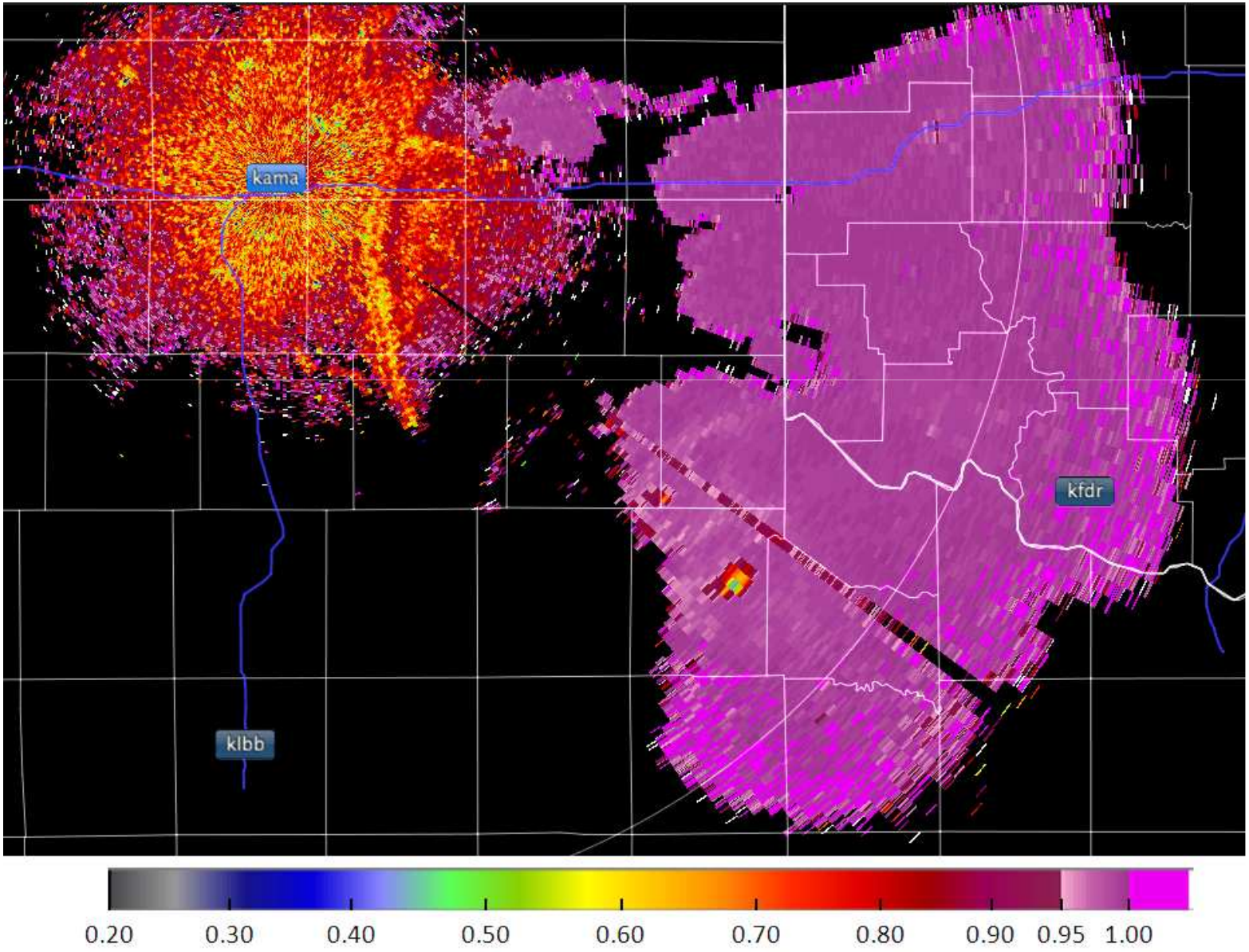



From Kumjian

# $\rho_{hv}$ field, Amarillo 05/30/2012

r=200 km

El = 1.3°



# WSR-88D

- Signal sequences are designed to
  - Obtain accurate estimates
  - Provide polarimetric variables
  - Resolve significant weather features
  - Mitigate Ambiguities in Range and Velocity
  - Cancel ground clutter

| Challenges | Possibilities |
| --- | --- |
| Rapid Scan | Automatic adaptive;<br>Pulse compression |
| R/V Ambiguity Mitigation | Adaptive beam to beam dwell;<br>Signal design, Beam multiplex |
| Ground Clutter | Point null of antenna pattern at clutter;<br>Sidelobe blanking arrays |

Dual Polarization:

- Dependence on beam pointing
- Depolarization
- Choice of sequence (i.e.)

HHVHHHVHHV?

# Field lines of two E dipoles and E&M dipoles

$PAR_{EE}$

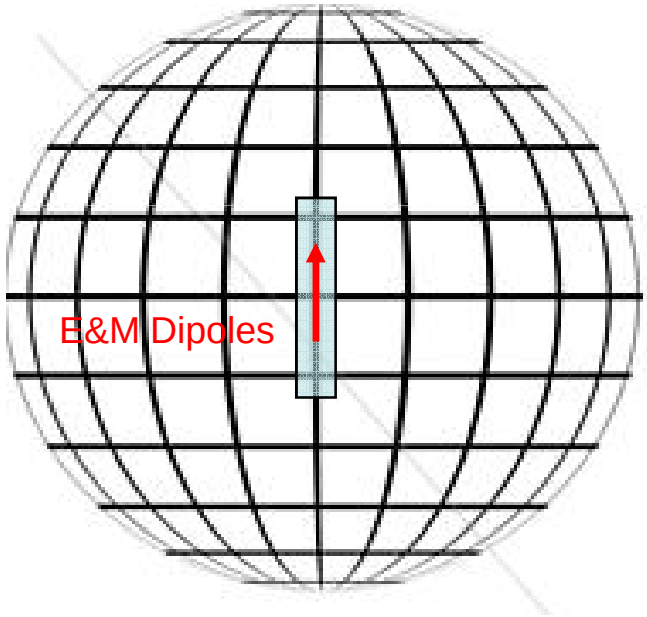
**Two E Dipoles**

The E fields of two Electric dipoles are orthogonal only in principal planes


$PAR_{EM}$

**E&M Dipoles**

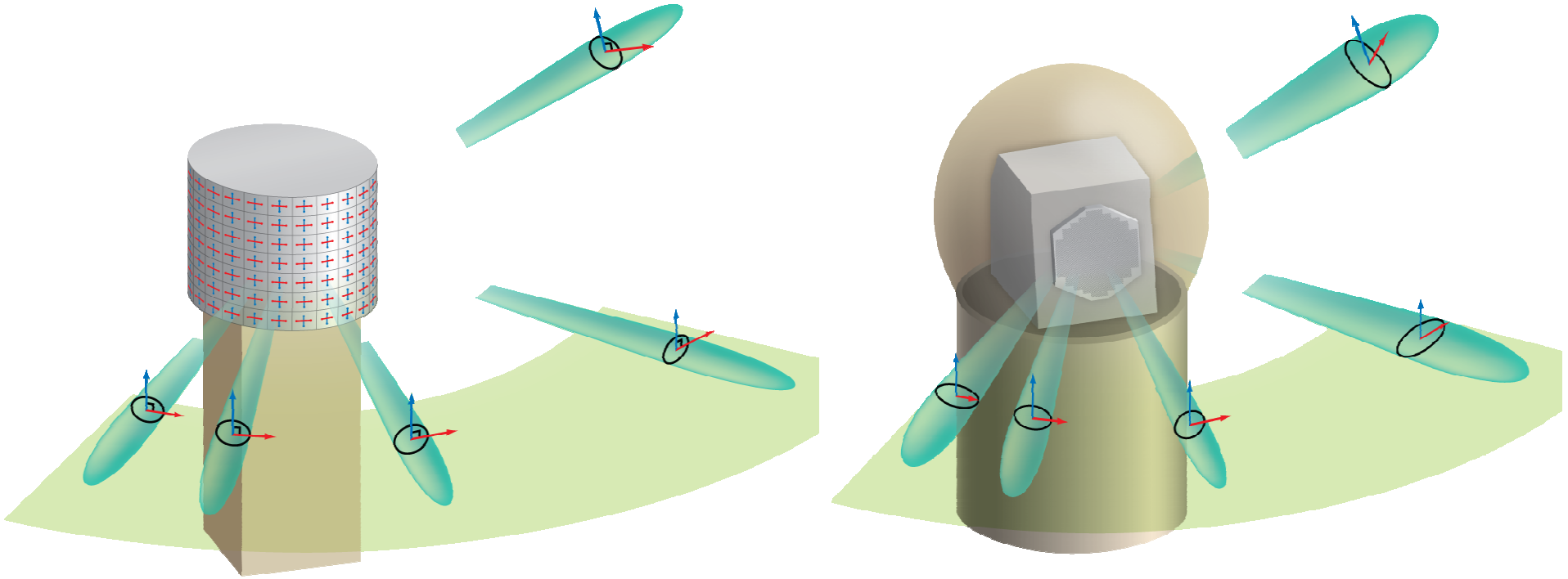
The E fields of Electric and magnetic dipole are orthogonal everywhere




The E & M dipoles are collinear

Ongoing development by: Lockheed Martin, BCI, and NSSL

# ANOTHER SOLUTION
# Cylindrical Phased Array $PAR_{CYL}$



- There is no dependence of polarization on direction. Therefore the $PAR_{CYL}$ radar is equivalent to a conventional radar

- System Study is Ongoing (at University of Oklahoma and NSSL) – scanning strategy, multiple beams, frequencies, beamwidth, waveforms, .....

# Error in Estimates Depend on

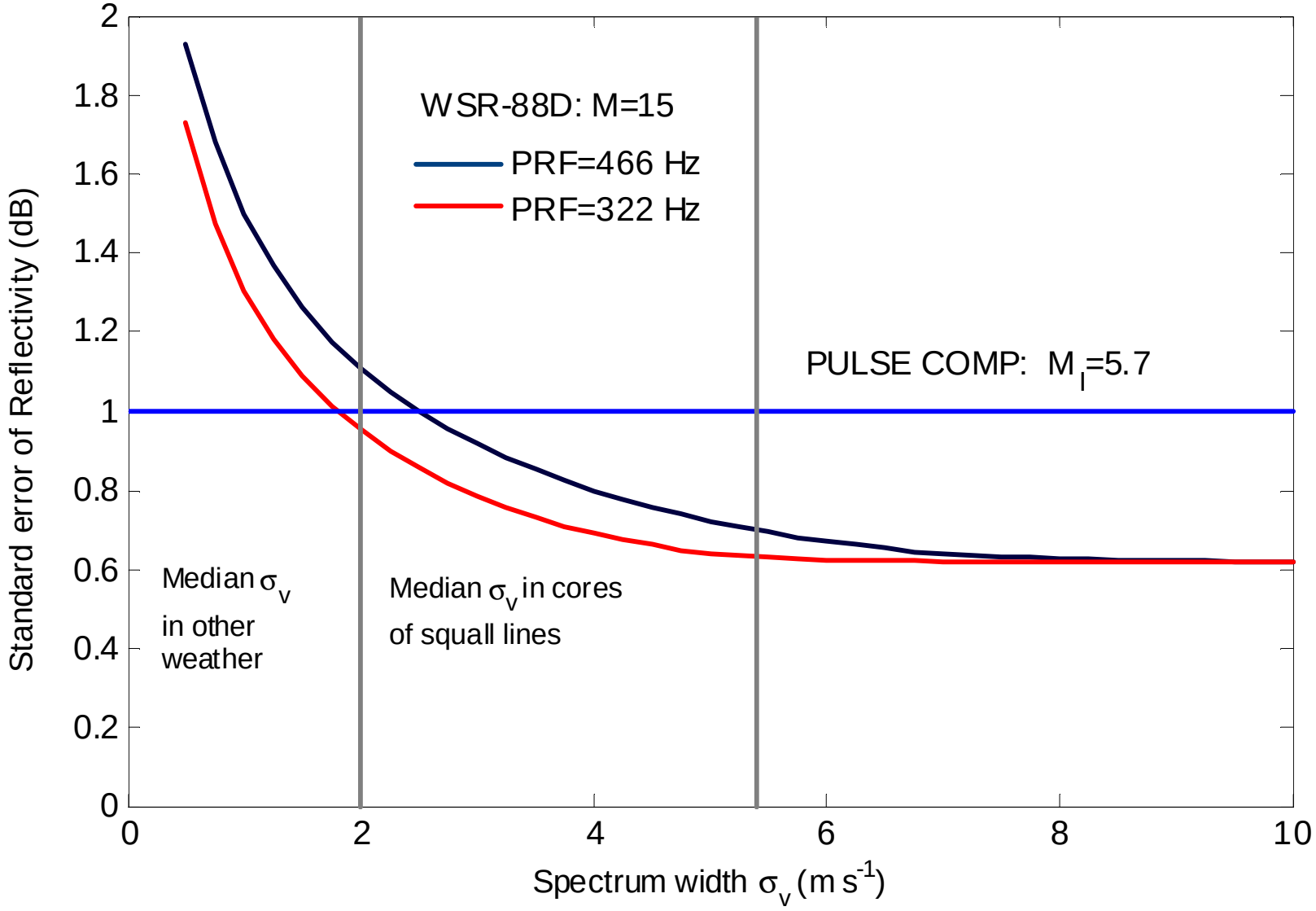
- Transmitted signal attributes
  - Power, Duration, Bandwidth, Polarization
- Receiver attributes
  - Sensitivity, Bandwidth, Polarization
- Dwell time
  - The shortest equals
    - one PRT for Reflectivity estimation
    - two PRTs for Velocity estimation

# BEST POSSIBLE FROM SINGLE PULSE (for Z) and Single Pair (for Vel)

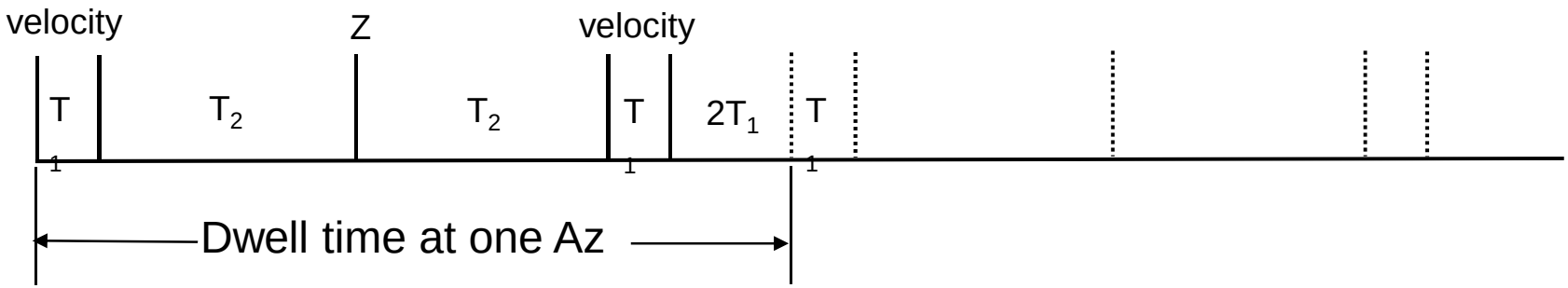
(Simultaneous HV mode = SHV)

- SIM (SHV) mode: can pulse compression and averaging provide accuracy of Z and Velocity as on the WSR-88D?
- WSR-88D:
  - Z: Surveillance scans No of samples M=15. Need $M_I$=5.7 independent samples
  - V: Doppler scan No of samples M=40 (PRT=1ms) Need $M_I$=10 independent pairs

# Standard error of Z estimates on WSR-88D and on PAR with Pulse Compression



# Hypothetical signal timing in the SIM (SHV) mode single beam




Ground Clutter Mitigation for this sequence must be equivalent to the mitigation on the Legacy WSR-88D surveillance and Doppler scans

# Minimum Time for a 360 deg scan compared to the WSR-88D scan time (beam spacing 1 deg single beam PAR)

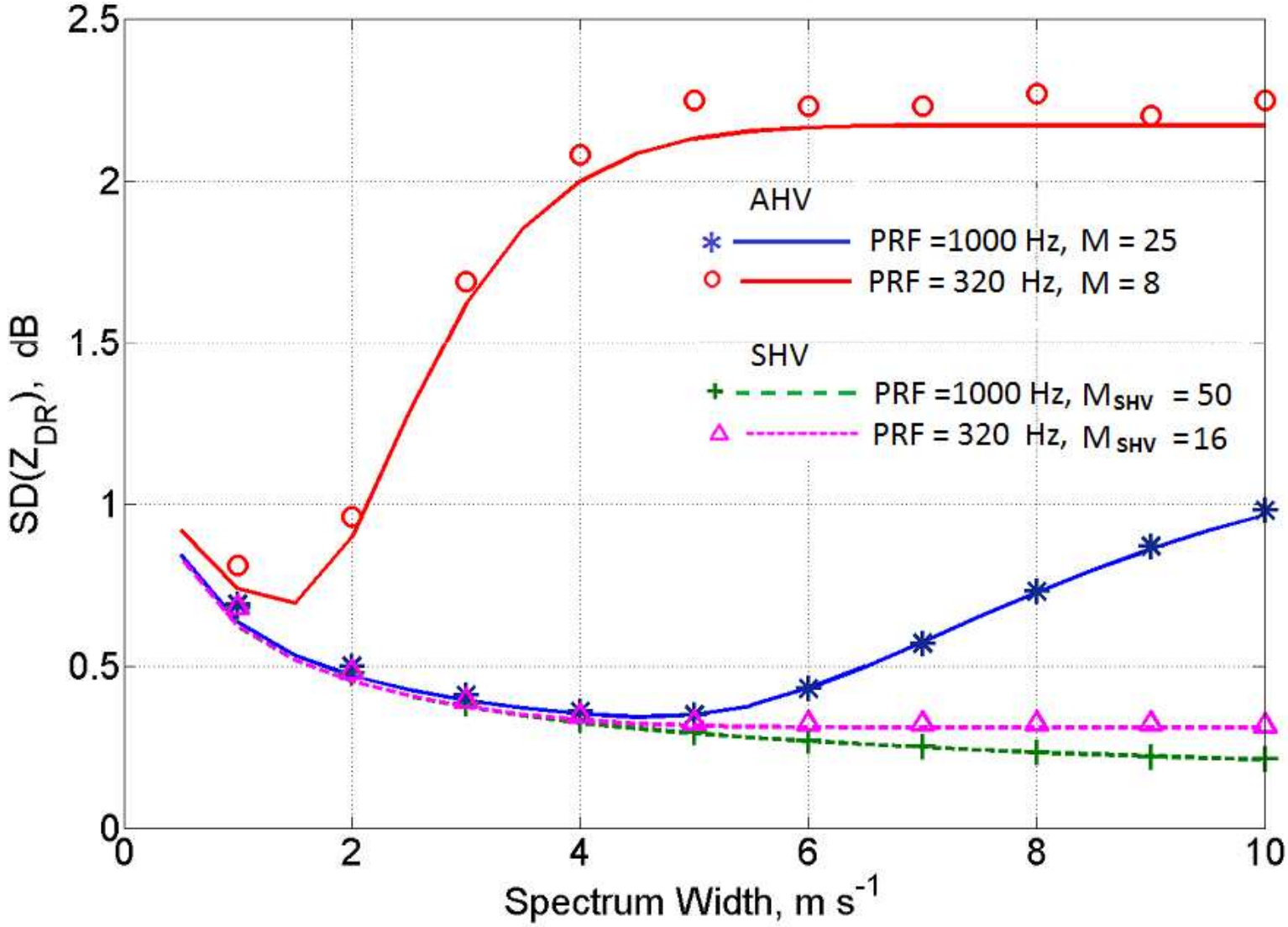
| Scan | WSR-88D time (s) | Min time (s) |
|---|---|---|
| For Z | 16 | 1.65 |
| For v | 14 | 1.4 |
| Total | 30 | 3.05 |

# Alternate (ALT) mode

## Relaxes Cross-polar isolation requirement

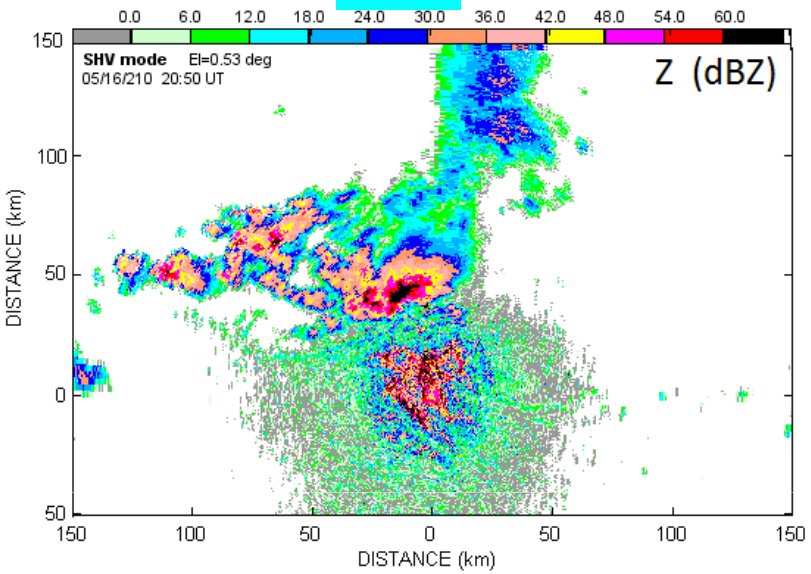
- Dwell time is two or more times longer than in the SIM mode
- Doppler and differential phase $\Phi_{DP}$ are coupled
- Processing of $\Phi_{DP}$ requires use of continuity in range to extend the principal phase over a 360 deg interval
- Errors in polarimetric variables are larger

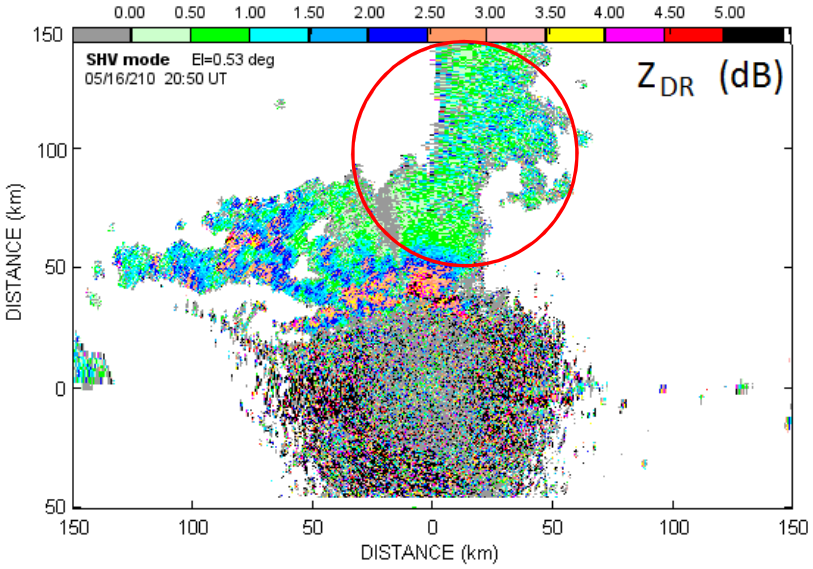
# Errors in $Z_{DR}$ for the ALT (AHV solid) and SIM (SHV dash) modes



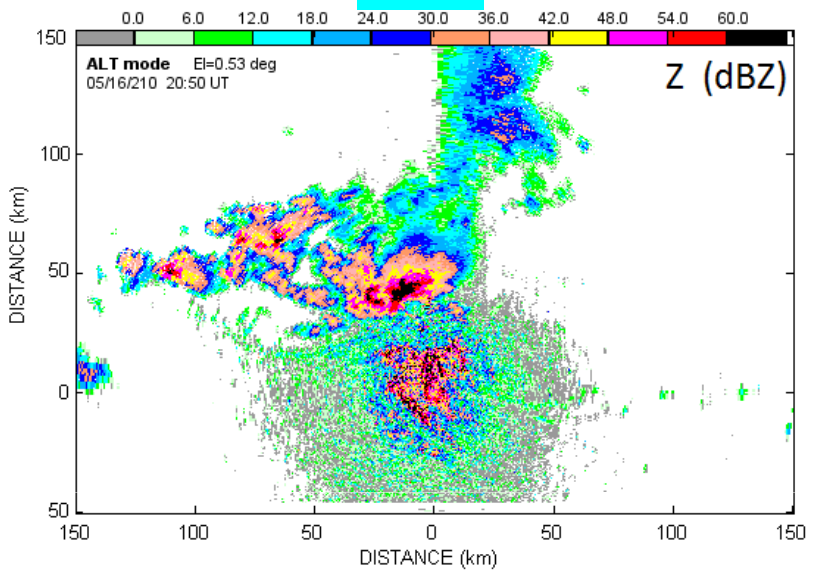
# Z and $Z_{DR}$ processes as in SIM(16) and as in ALT(8+8)

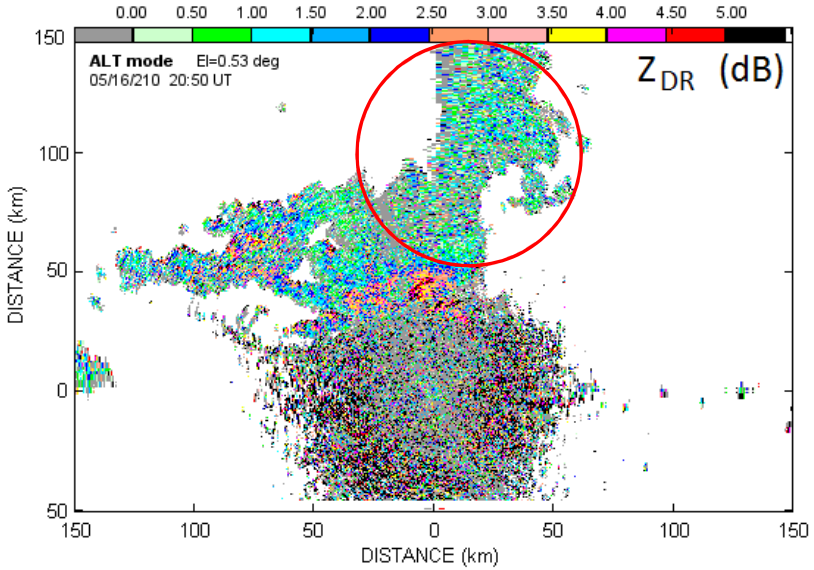
SIM



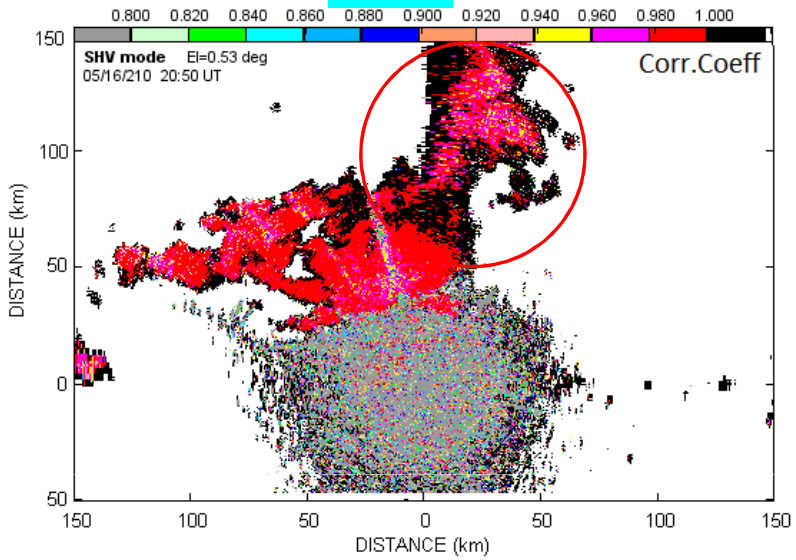

ALT

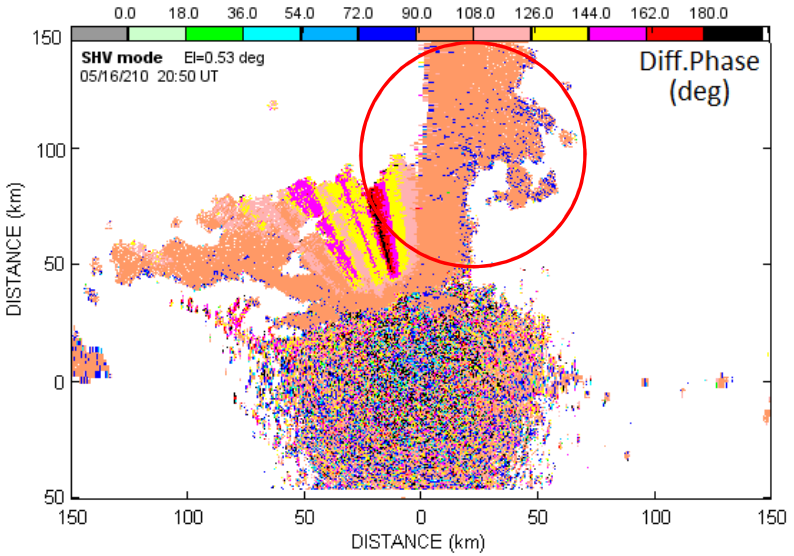


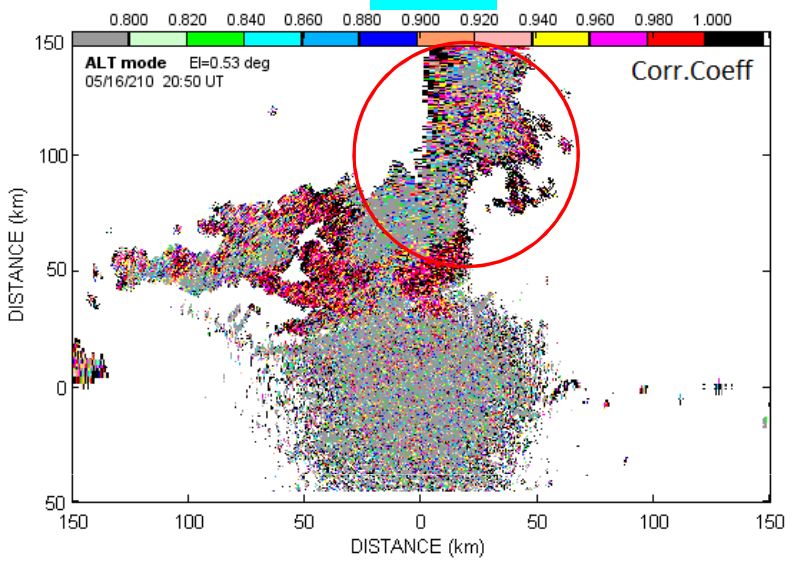
# $\rho_{hv}$ and $\Phi_{DP}$ processes as in SIM(16) and as in ALT(8+8)

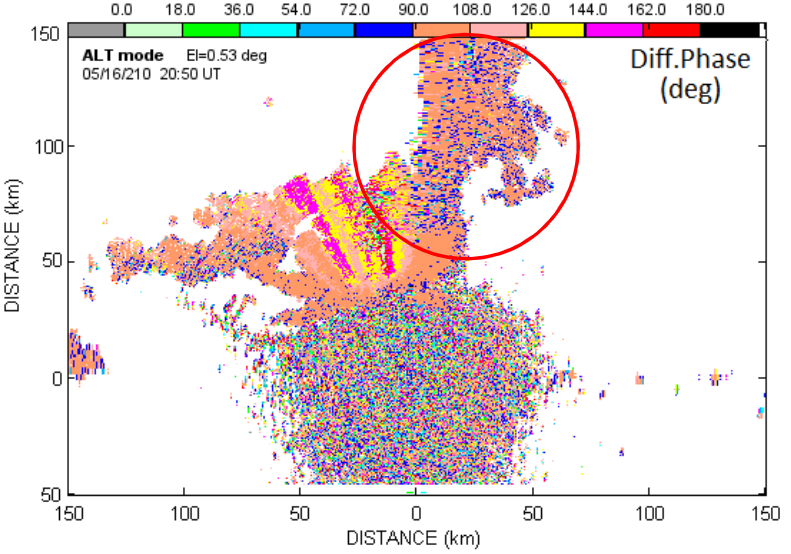
SIM




ALT



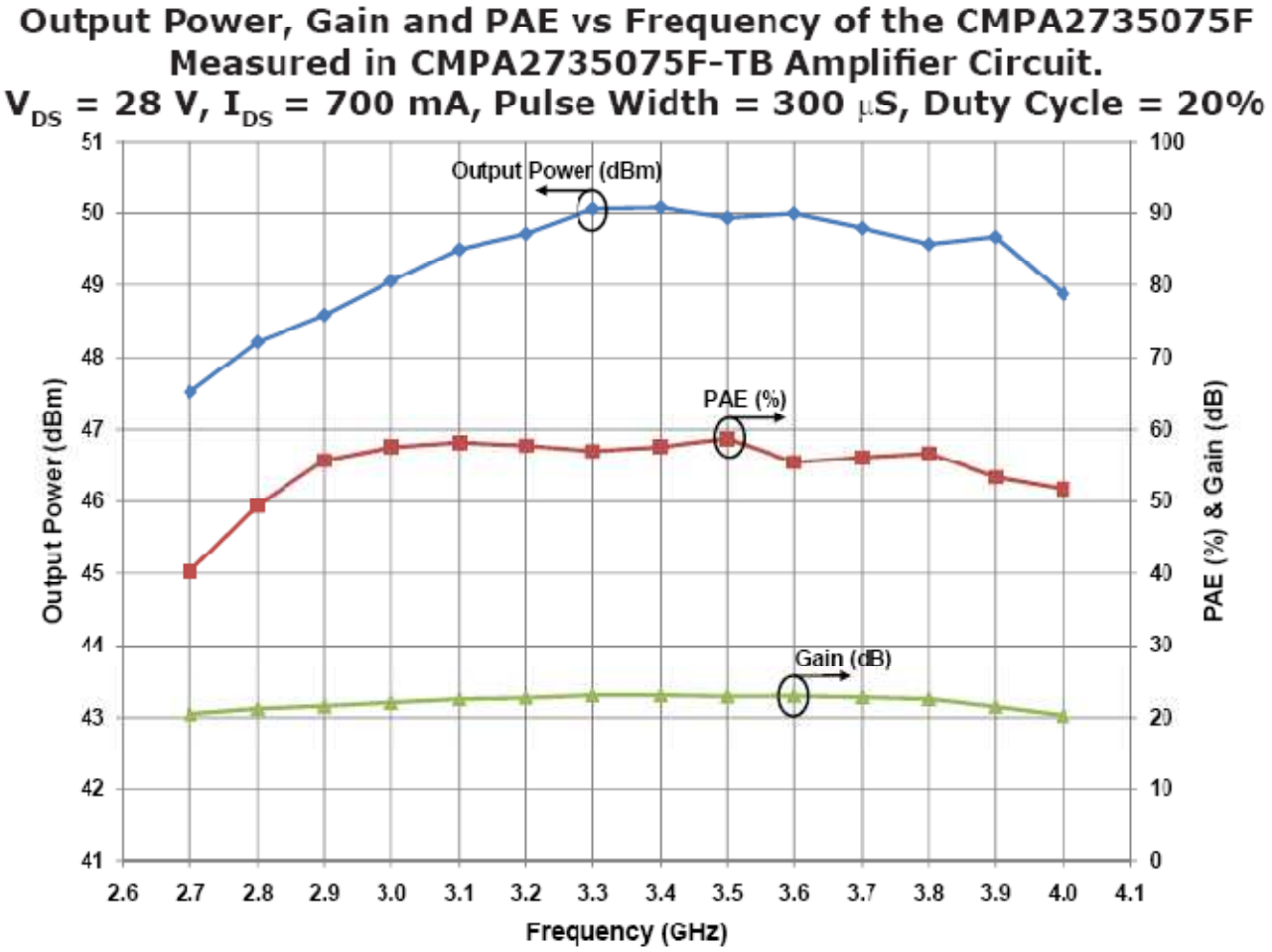



# Conclusions

- Theory suggests that
  - $PAR_{ME}$ and $PAR_{CYL}$ can operate in the SIM polarimetric mode
  - $PAR_{EE}$ could operate in SIM mode but with H and V encoded with orthogonal codes

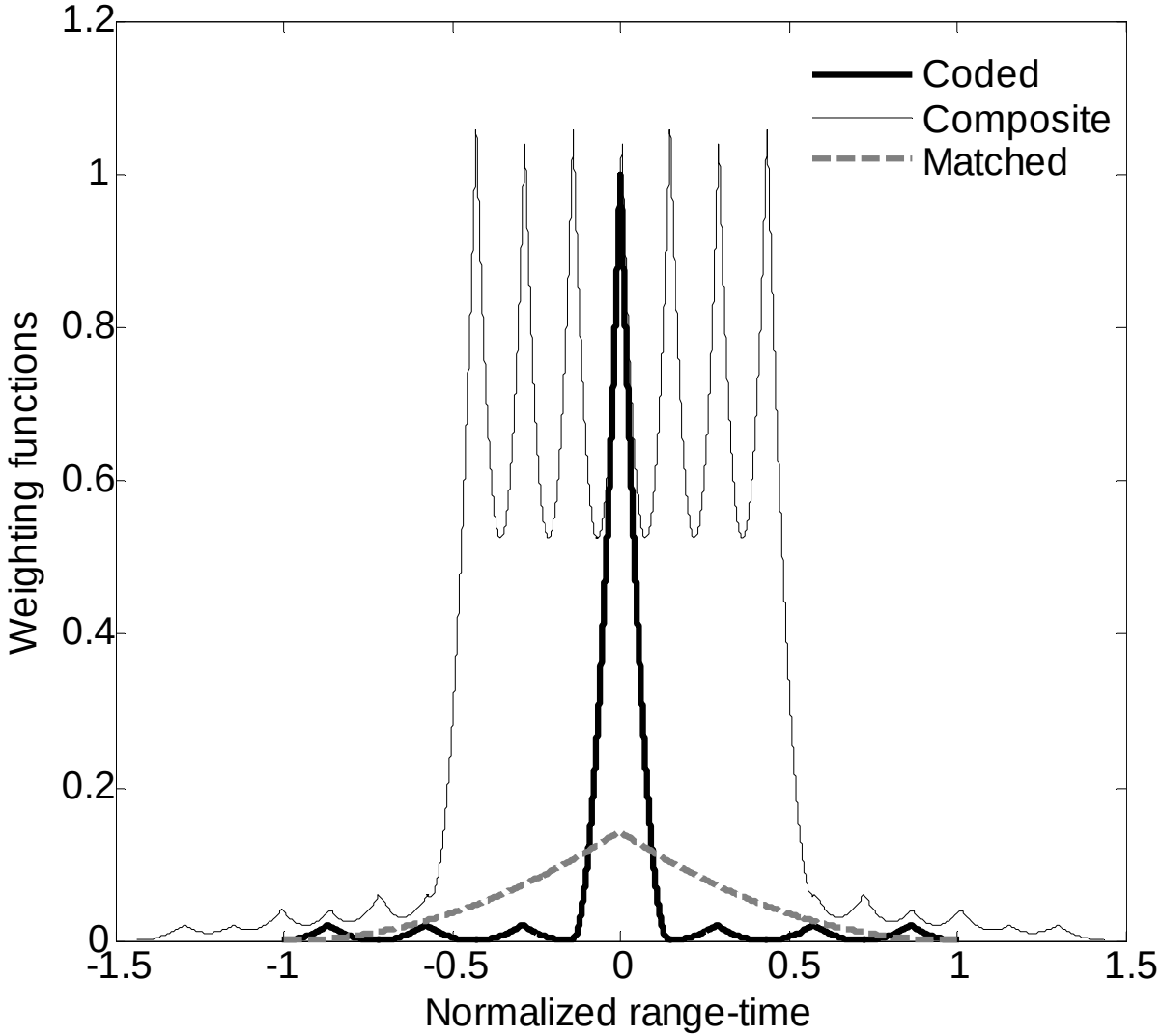
    Neither of these have been tested
- Choice of the Polarimetric mode (SIM or ALT) influences
  - Schemes to estimate polarimetric variables
  - Schemes to mitigate range/velocity ambiguities
  - Schemes to filter ground clutter
- Without Clutter Filter but with pulse compression
  - SIM mode: volume scans can be ~ 10 times faster than standard WSR-88D scans
  - ALT mode: volume scans
    - DOPPLER MODE ~ 10 time faster than WSR-88D
    - SURVEILLANCE MODE requires larger compression ratio and bandwidth to equal WSR-88D scan time for polarimetric measurements
    - Therefore special POLARIMETRIC MODE needs to be designed
- Time domain clutter filter increases dwell time
  - Space-Time Adaptive Processing applied to filtering ground clutter at each range location might meet the WSR-88D requirements?

# Solid State Amplifier



# Pulse Compression: Range Weighting Functions

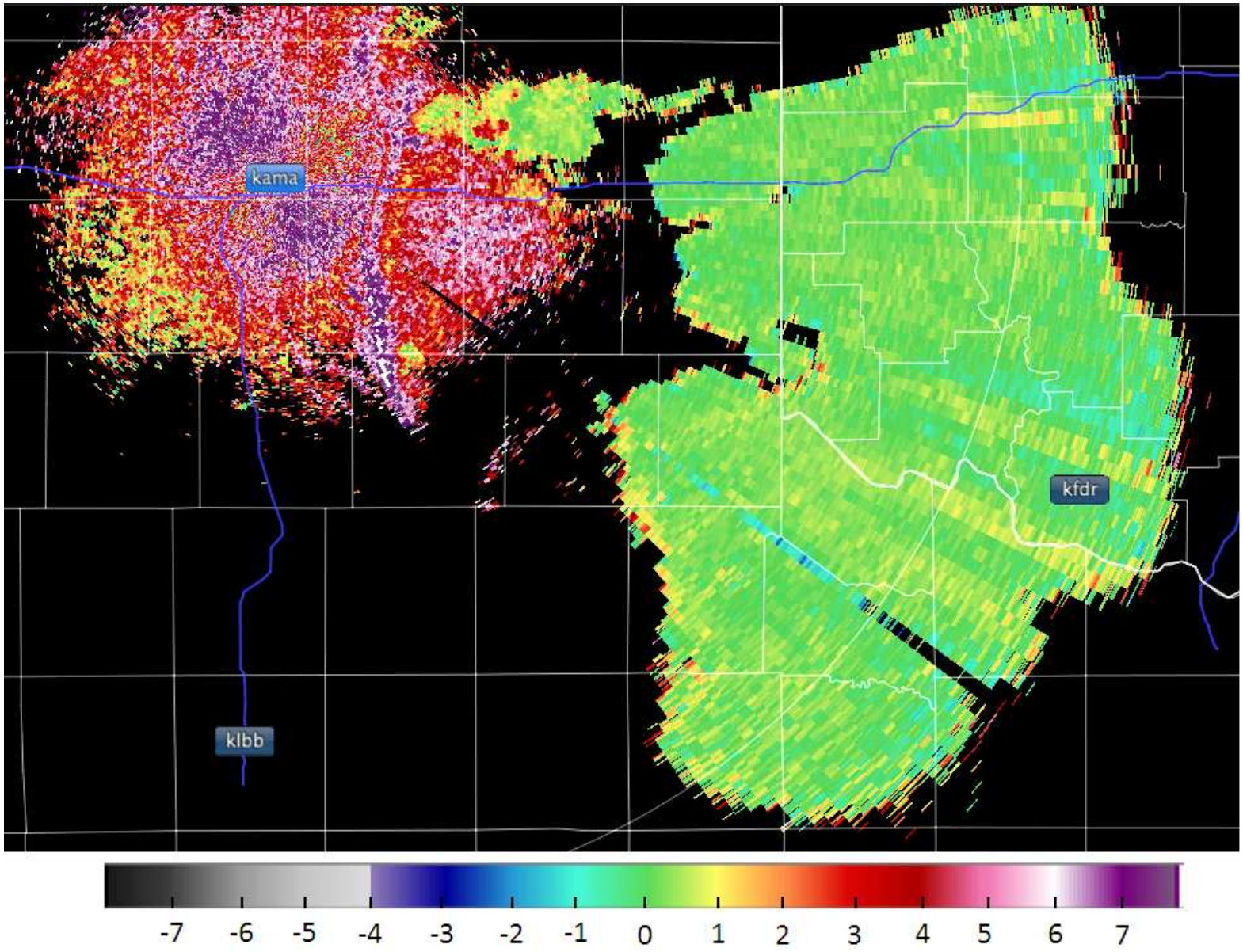
(Notional example: Barker 7 code)



# $Z_{DR}$ field, Amarillo 05/30/2012

r=200 km

El = 1.3°



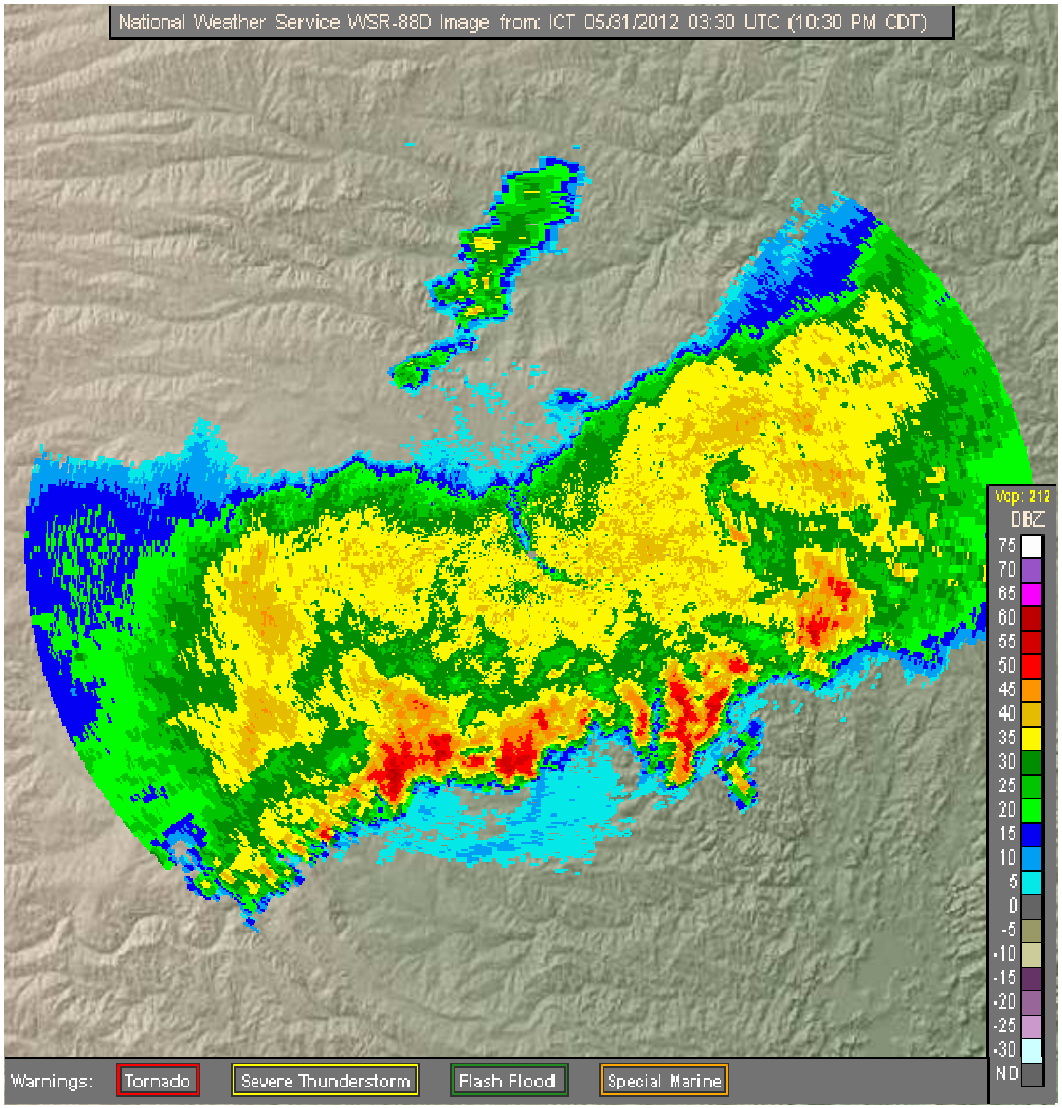
# Challenges for PAR (to observe Weather)

A) Obtaining Polarimetric Variables with satisfactory precision in Simultaneous H,V mode

B) Ground clutter canceling

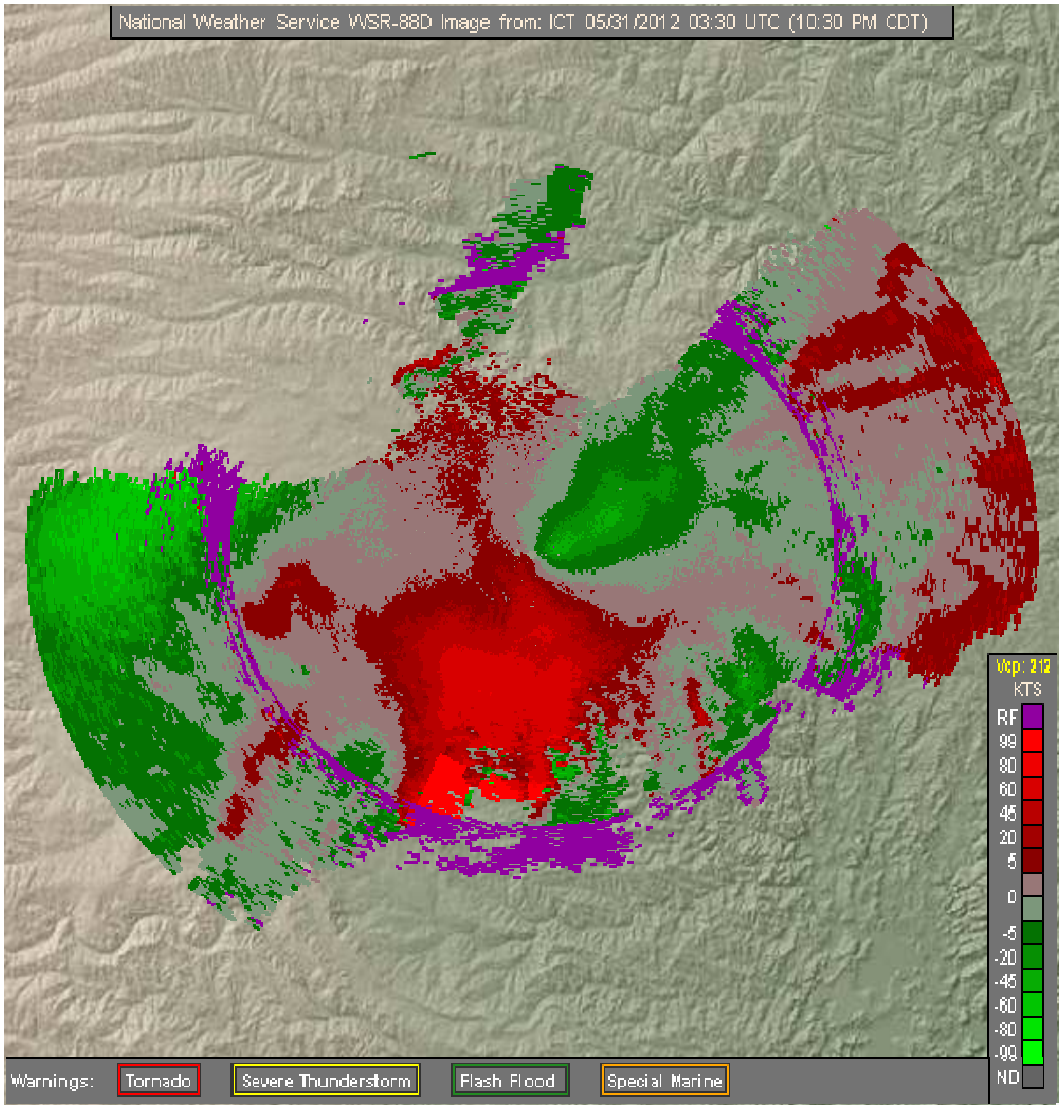
C) Scanning very rapidly

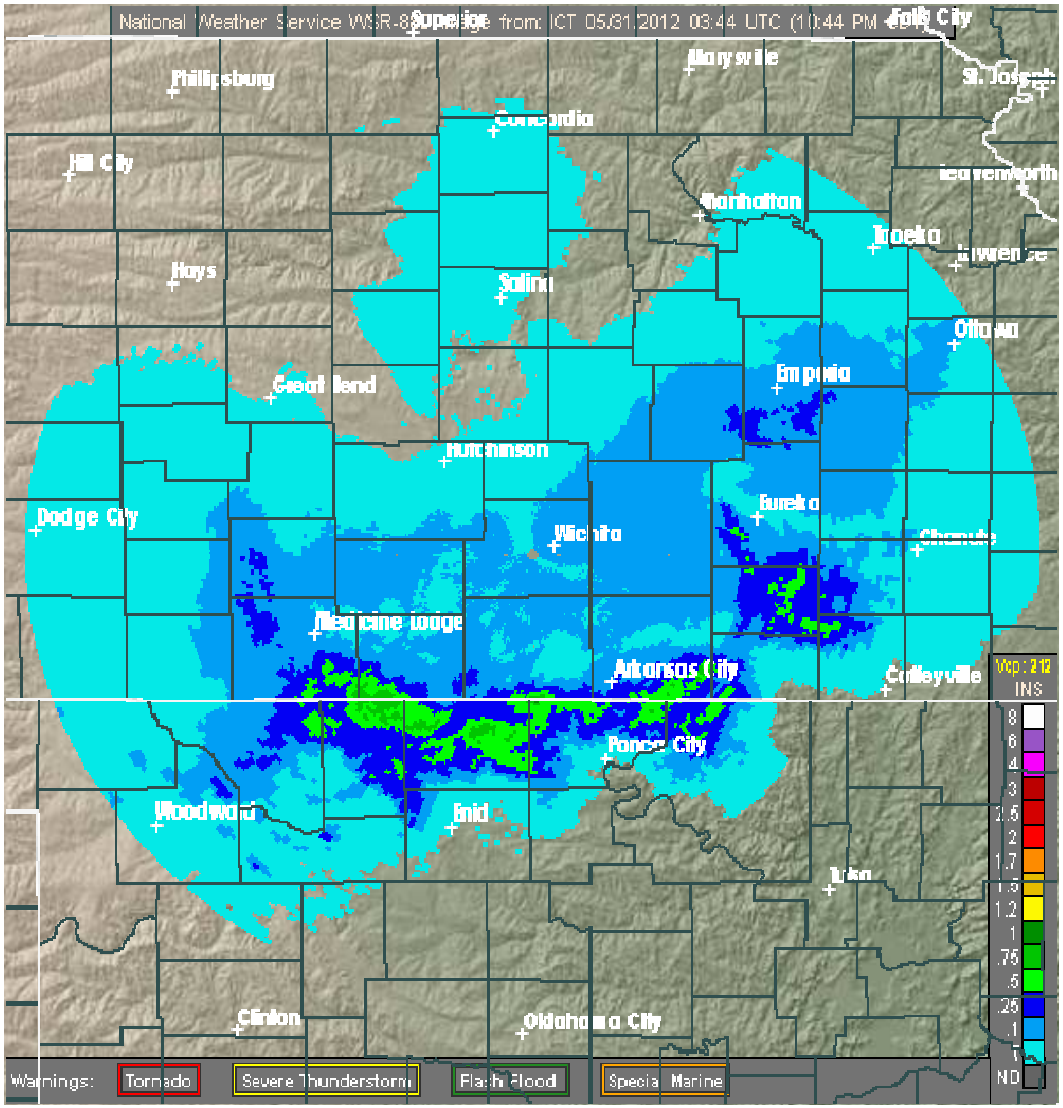
Wichita Kansas radar



One hour rain accumulation

Wichita Kansas radar




National Weather Service WSR-88D Radar from: ICT 05/31/2012 03:44 UTC (10:44 PM
Phillipsburg
Concordia
Manhattan
Topeka
Hays
Salina
Ottawa
Great Bend
Emporia
Hutchinson
Dodge City
Wichita
Eureka
Medicine Lodge
Arkansas City
Coffeyville
Ponca City
Woodward
Enid
Clinton
Oklahoma City
Top: 212
INS
8
6
4
3
2.5
2
1.7
1.5
1.2
1
.75
.5
.25
.1
0
ND
Warnings:
Tornado
Severe Thunderstorm
Flash Flood
Special Marine

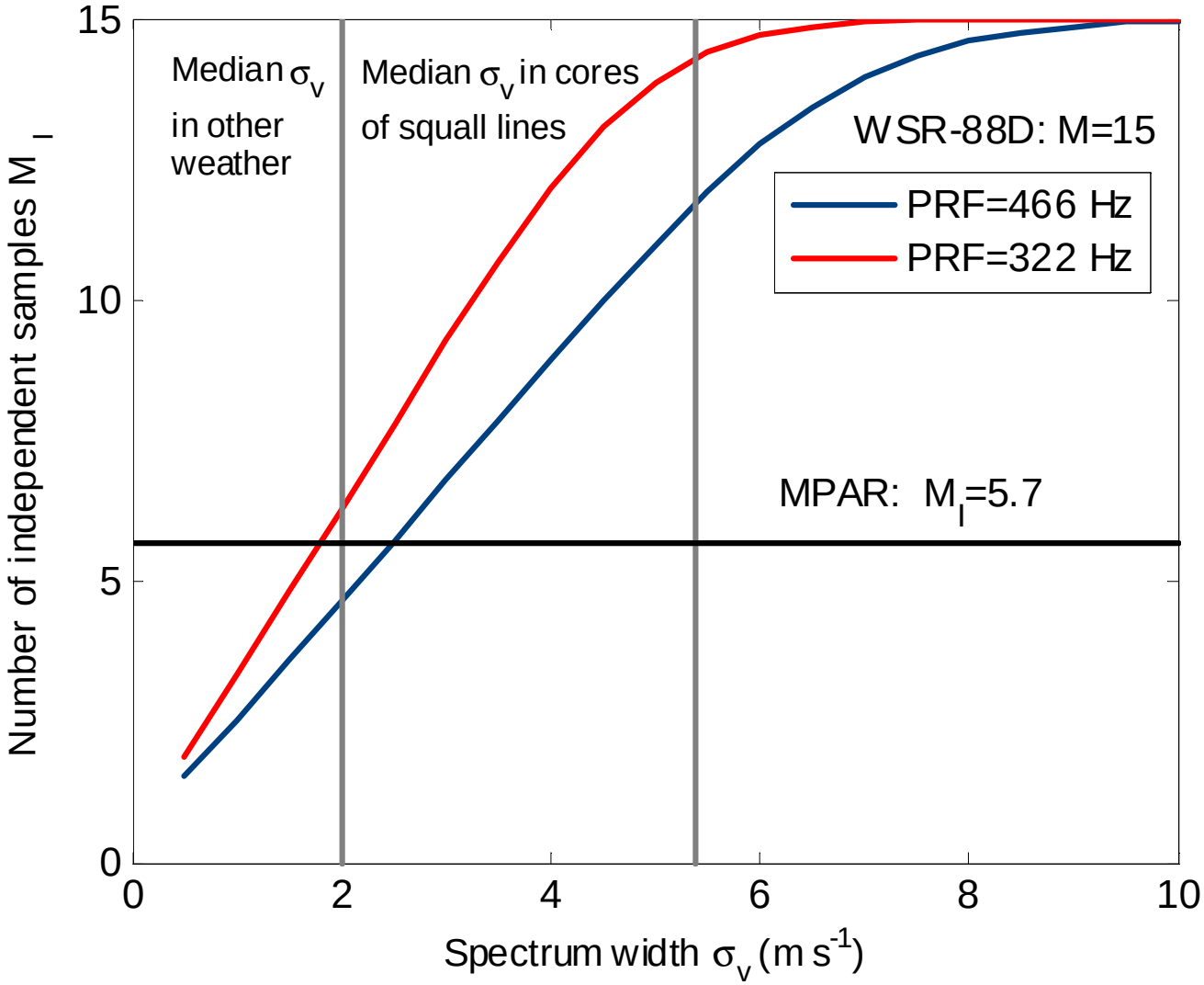
# MPAR's Capabilities for Weather Observation

- The capabilities of the WSR-88D have increased substantially since its deployment
- Its potency will continue to improve
- Therefore the MPAR should match or exceed the WSR-88D capabilities which will exist at the time of replacement

# Polarization Modes and Compensation for Inherent Change

- Alternate (ALT separate) transmission of two polarization states with compensation on
  - Transmission and Reception
  - Reception
- Transmission of SAME polarization state and separate reception of each with compensation on
  - Transmission and Reception
  - Reception
- Compensation on Transmission is done on each transmitted pulse and depends on the pointing direction
- Compensation on Reception can be done on each returned sample or on estimates of powers and correlations

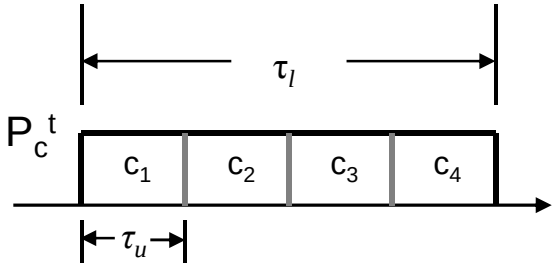
# No of independent samples $M_I$ in surveillance scans on the WSR-88D and $M_I$=5.7 on an MPAR



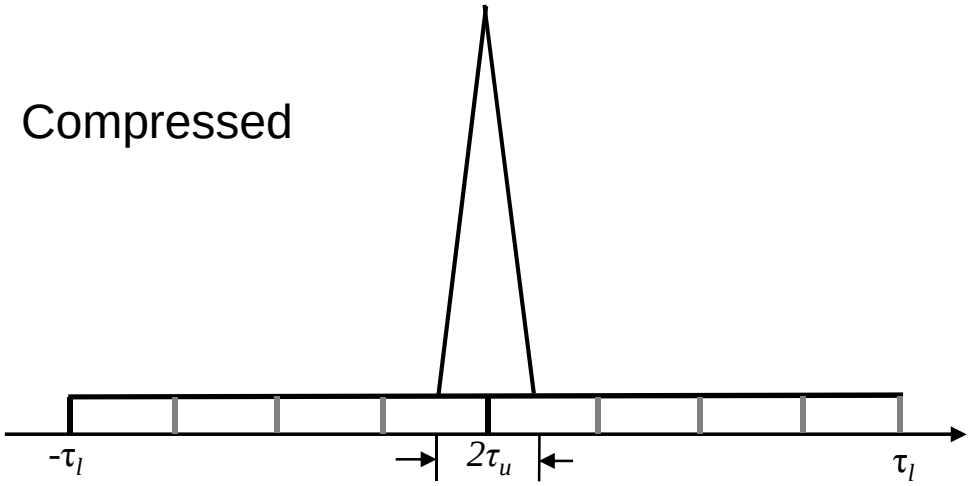
# Dwell Time Extenders

- Canceling Clutter imposes lower limit on dwell time:
  - Can combined spatial filter and temporal filter reduce the dwell time compared to sole use of temporal filter?
- ALT (AHV) mode requires longer dwell times compared to SIMULTANEOUS (SHV) mode
- Mitigation of range a velocity ambiguities
  - Two PRTs (one for Z the other for v)
  - Staggered PRT

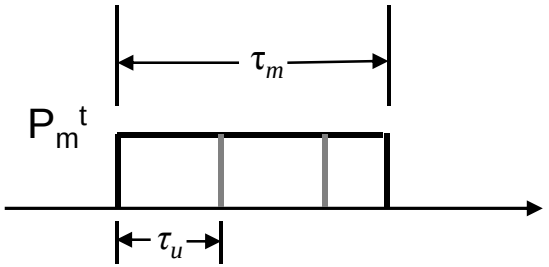
Long pulse



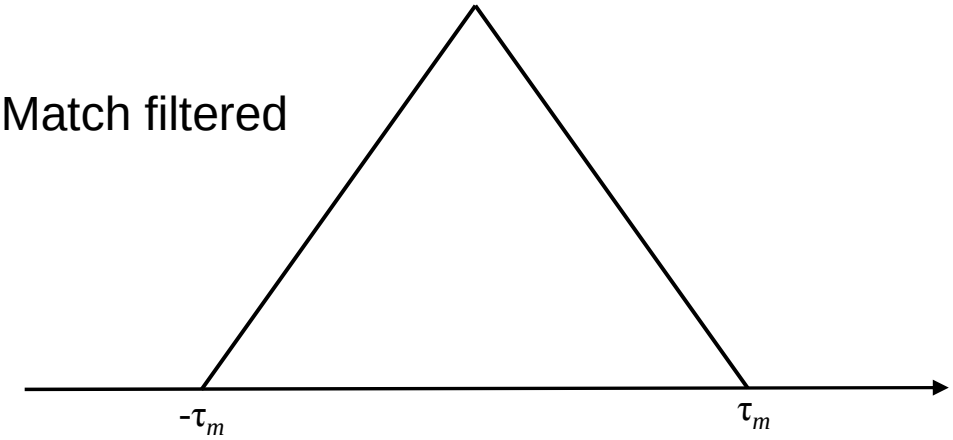

Compressed




Matched pulse



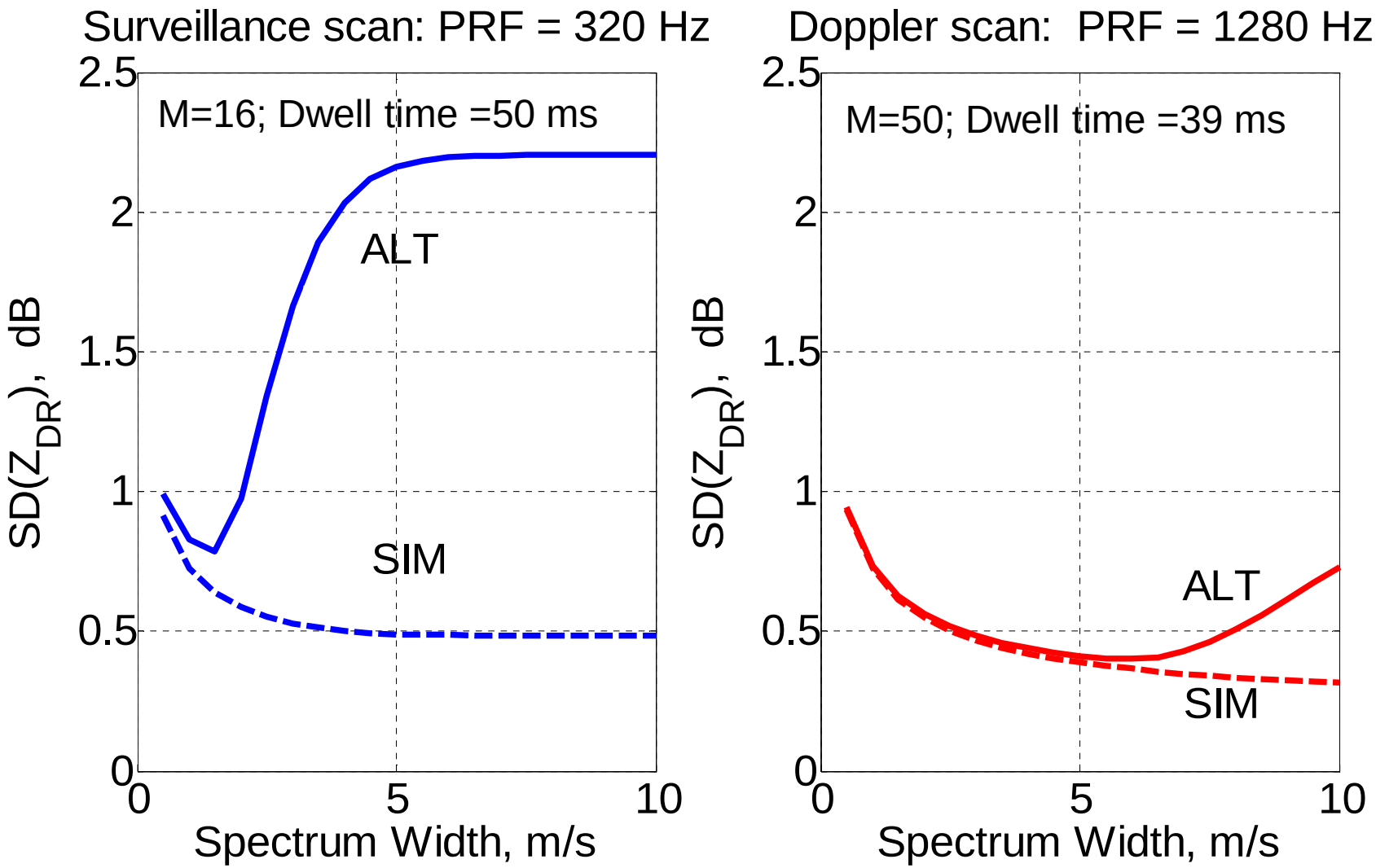

Match filtered



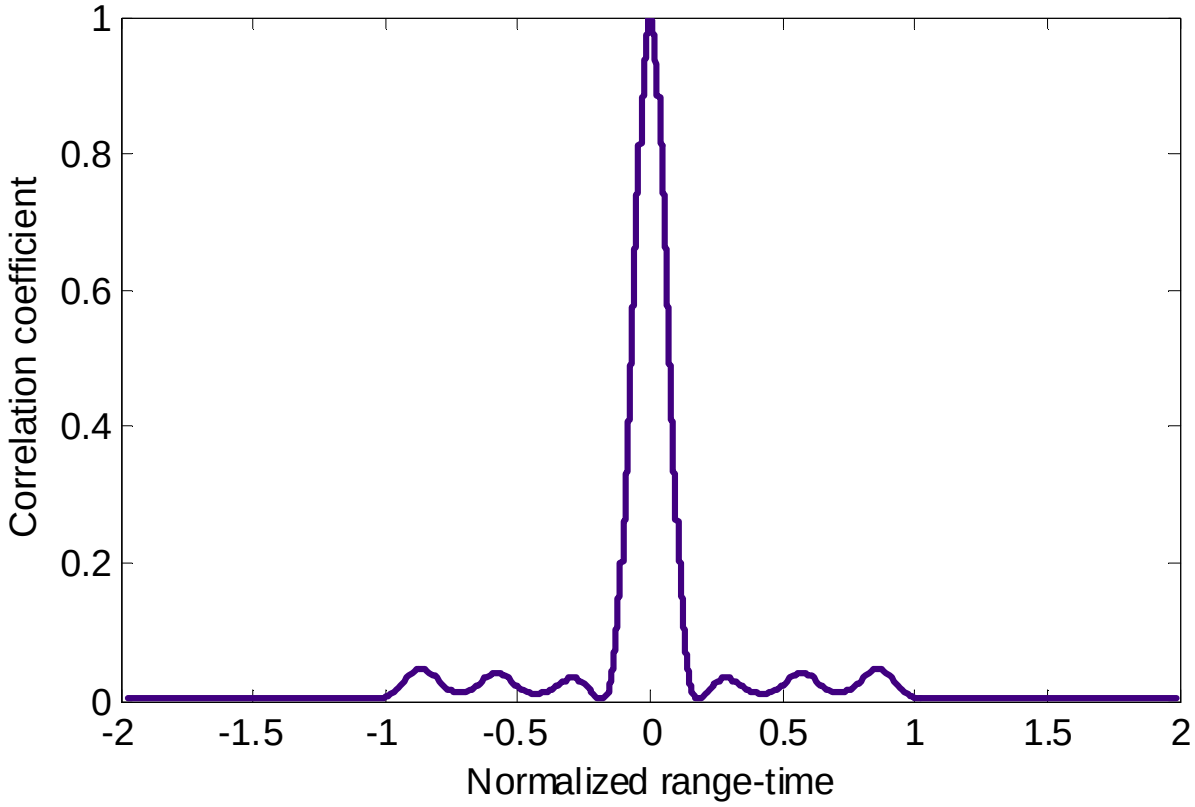

$$\frac{SNR_{\mathrm{m}}}{SNR_{\mathrm{c}}} = \frac{P_{\mathrm{m}}^{\mathrm{t}}}{P_{\mathrm{c}}^{\mathrm{t}}}\left(\frac{\tau_m^2}{\tau_l \tau_u}\right)$$

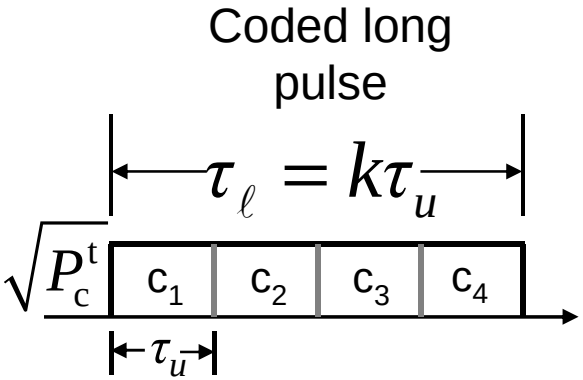
take $\tau_l = k\tau_m$ then $\tau_u = \tau_m / k$

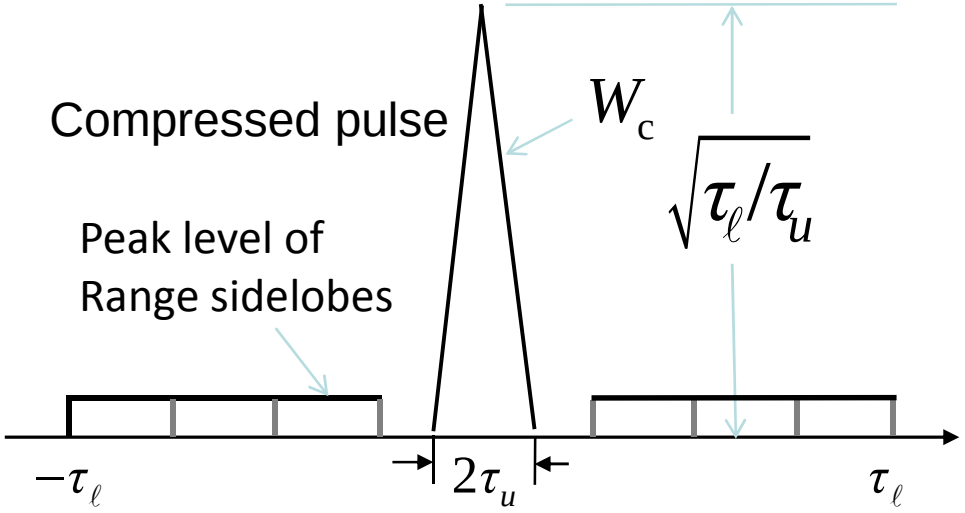
compression ratio $= k^2 = \tau_l / \tau_u$

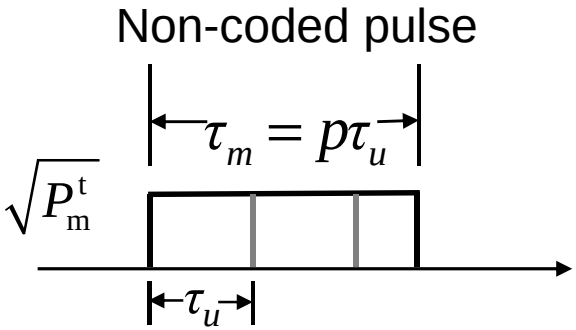

Surveillance scan: PRF = 320 Hz
M=16; Dwell time =50 ms
ALT
SIM
SD(Z_DR), dB
Spectrum Width, m/s
0
0.5
1
1.5
2
2.5
0
5
10
Doppler scan: PRF = 1280 Hz
M=50; Dwell time =39 ms
ALT
SIM
SD(Z_DR), dB
Spectrum Width, m/s

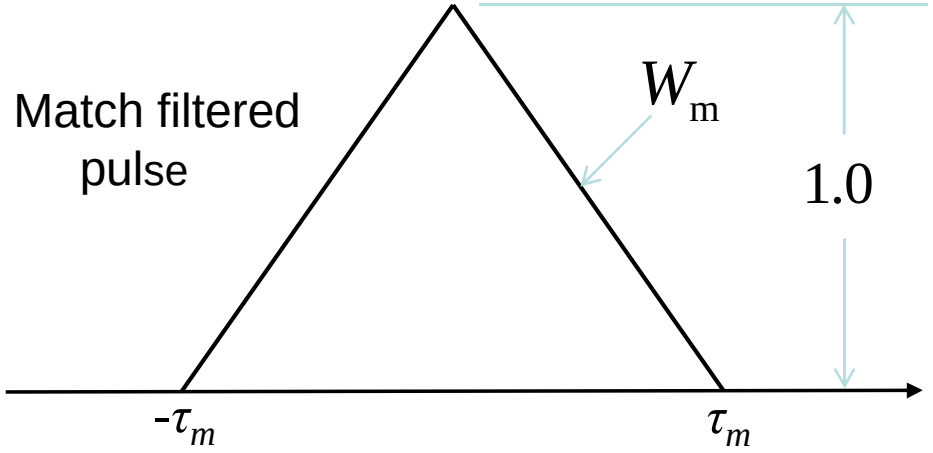
# Correlation along Range-Time
# Code: Barker 7






$$\frac{SNR_m}{SNR_c} = \frac{P_m^t}{P_c^t}\left(\frac{\tau_m^2}{\tau_l \tau_u}\right)$$

take $\tau_l = k\tau_m$ then $\tau_u = \tau_m / k$

compression ratio $= k^2 = \tau_l / \tau_u$

# Dwell Time Reducers

- Pulse over-compression followed by averaging in range
  - Currently available transmit modules deliver 30 to 75 W of power with high efficiency
  - Required sensitivity can be achieved without compressing the pulse
  - Compression followed by range averaging can increase the number of independent estimates and thus reduce errors of estimates
- Oversampling and whitening of samples in range
- Adaptive scanning

# Pulse Compression Issues

- Bandwidth allowance?
- Range time sidelobes
- Effects of Doppler shift