# ALERT: Awareness and Localization of Explosives-Related Threats

Northeastern

ALERT
AWARENESS AND LOCALIZATION OF EXPLOSIVES-RELATED THREATS

# Challenges and Opportunities for Improved Mm-Wave Whole Body AIT Threat Discrimination


**Carey Rappaport**
**Northeastern University**
**Boston, MA**



**ADSA09, October 2013**

# Conclusions

- Mm-wave nearfield imaging is effective but can be improved
- Bandwidth is important – range resolution
- Aperture is important – cross range resolution
- Illumination direction is important – spectral reflection

**MUST CONSIDER BOTH WAVES AND RAYS**

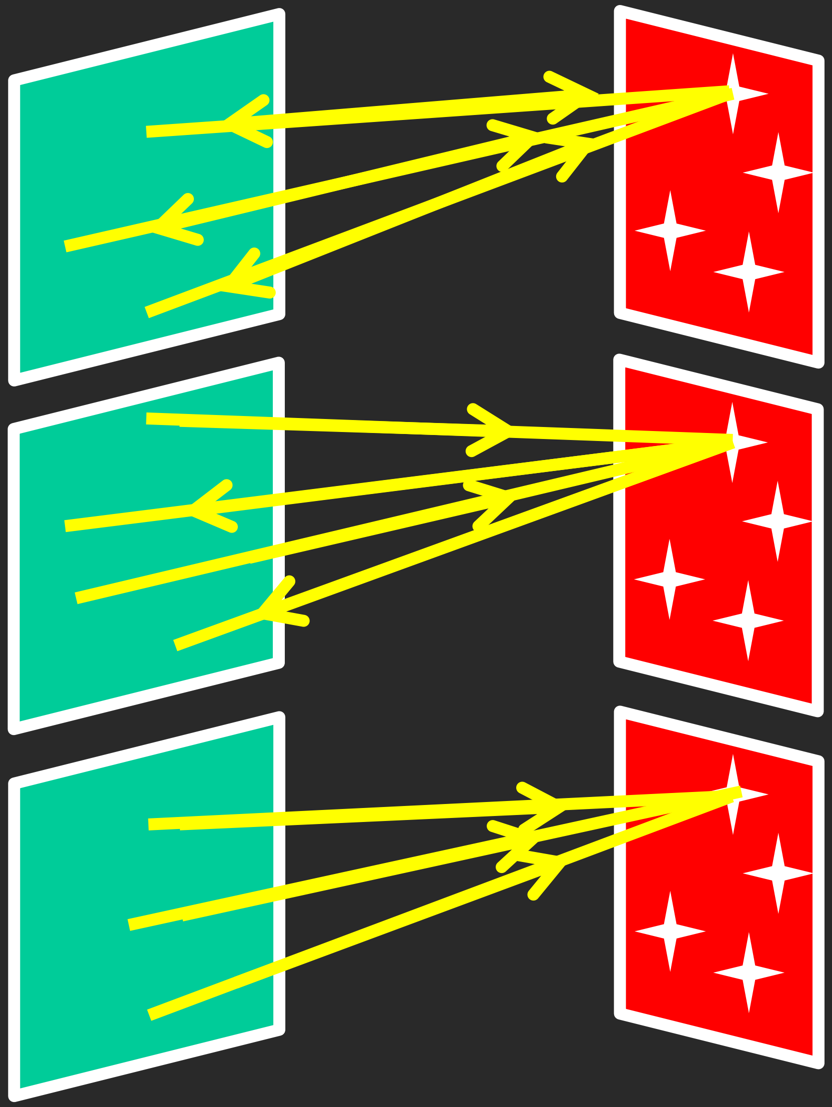
- Multistatic sensing is important
  - Multiple rays scattering from same target point
  - Opportunity to observe non-specular rays
- Array thinning is useful and efficient
- Multi-modal fusion with mm-waves radar offers advantages

# Portal-Based Mm-Wave Security Screening (AIT)

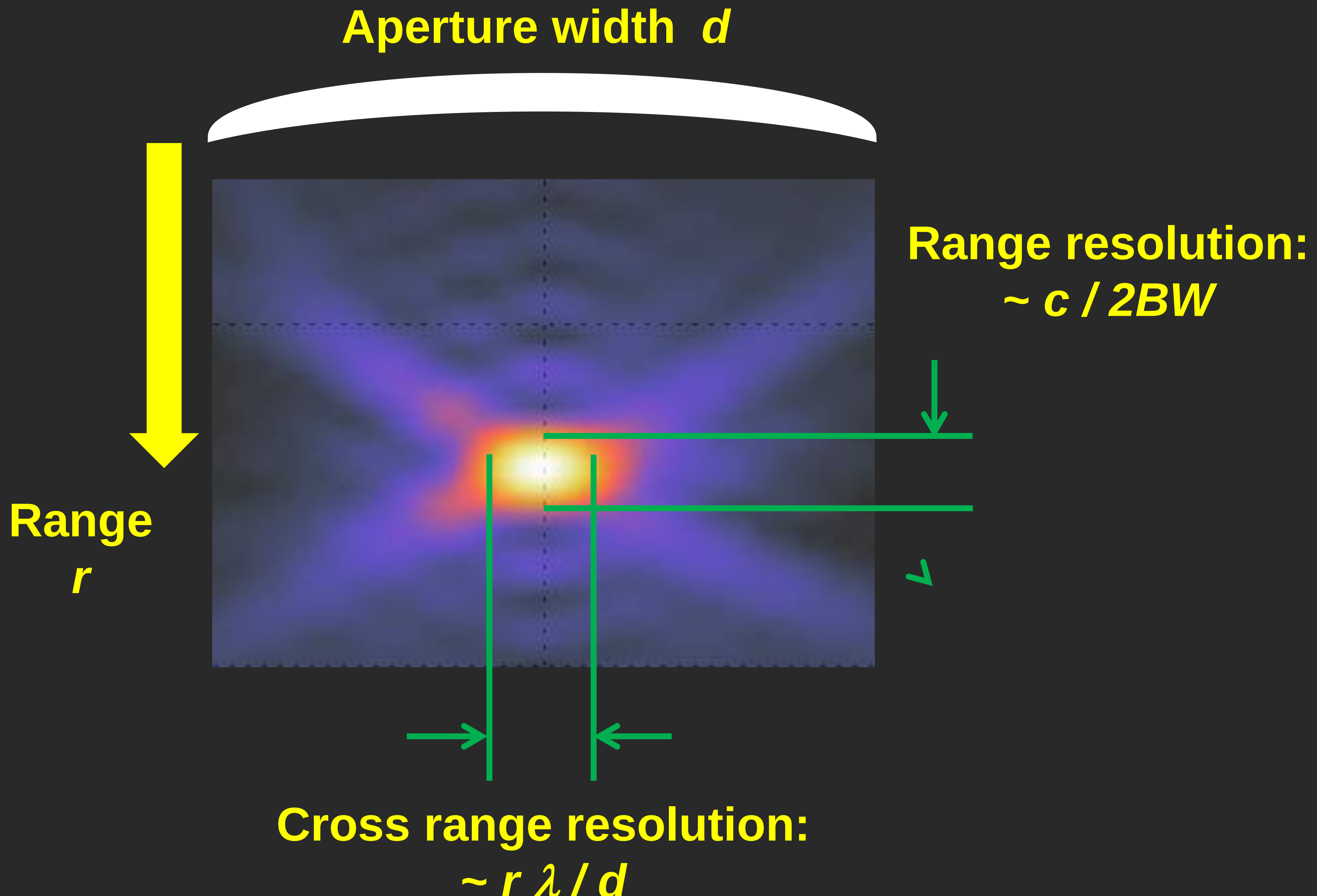
- Goal: Detect concealed man-made objects under clothing
- Portal-based broadband mm-wave radar
  - 26-33 GHz (15-45 GHz)
  - 56-64 GHz
  - 70-77 GHz
  - 91-98 GHz
- Advantages:
  - Non-ionizing, eye-safe
  - Reasonable resolution ~ 0.25-2.5 cm
  - Sensitive to metal and low-permittivity explosives
  - Commercially available RF modules
  - Many algorithms for shape reconstruction
- Disadvanages
  - Huge amounts of data
  - No chemical information
  - Limited time to acquire / process
  - Poor non-specular focusing / SAR imaging

# Monostatic / Multistatic Radar

- Monostatic
  - Multi-monostatic
- Bistatic
  - Multi-bistatic
- Multistatic

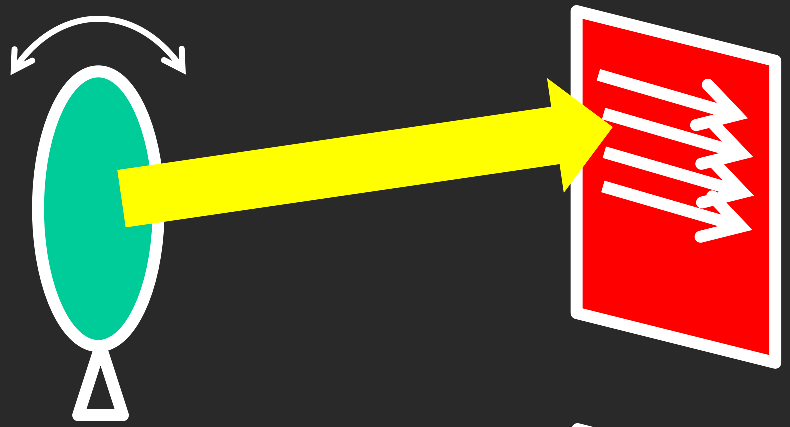


# Radar Focusing Resolution –Point Spread Function

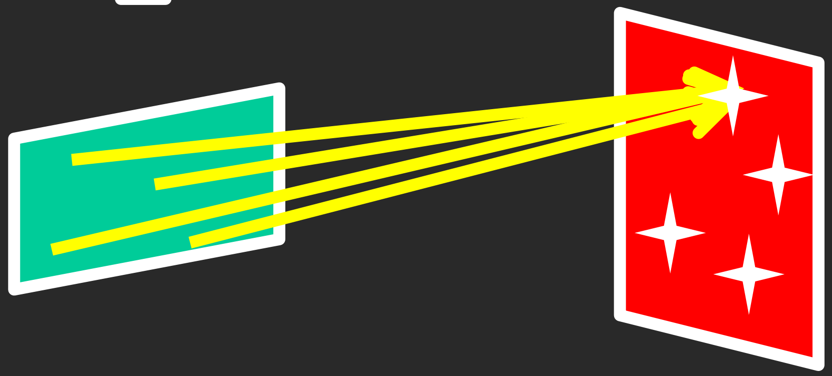


# Imaging with Mm-Wave Radar

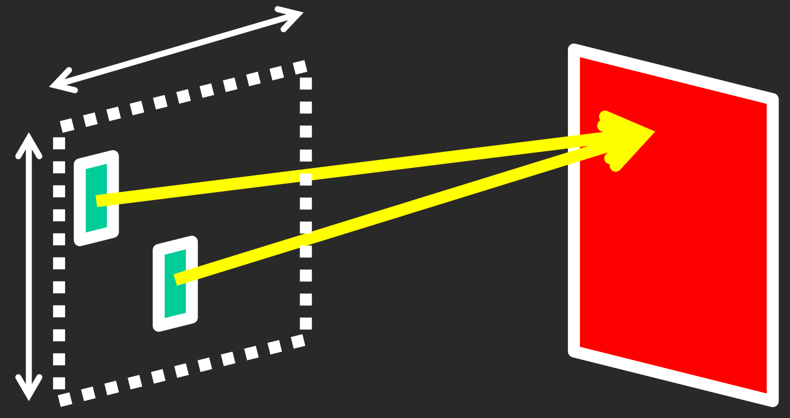
- Raster scanned focused point



- Electronically scanned phased array



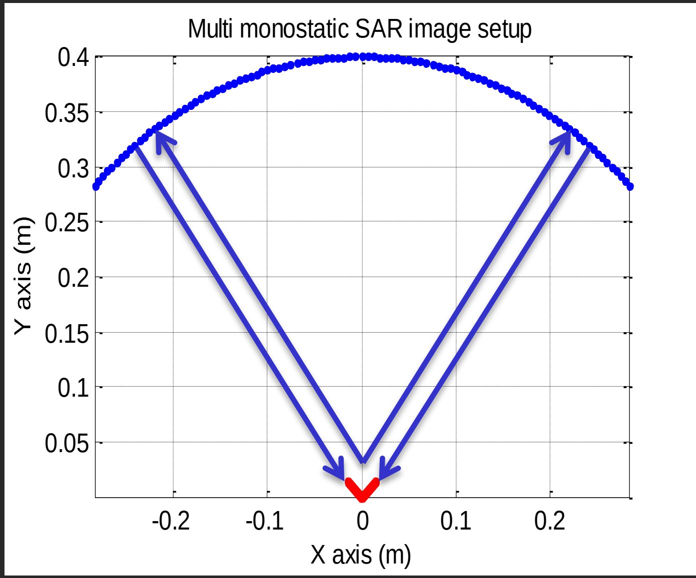
- Synthetic aperture radar

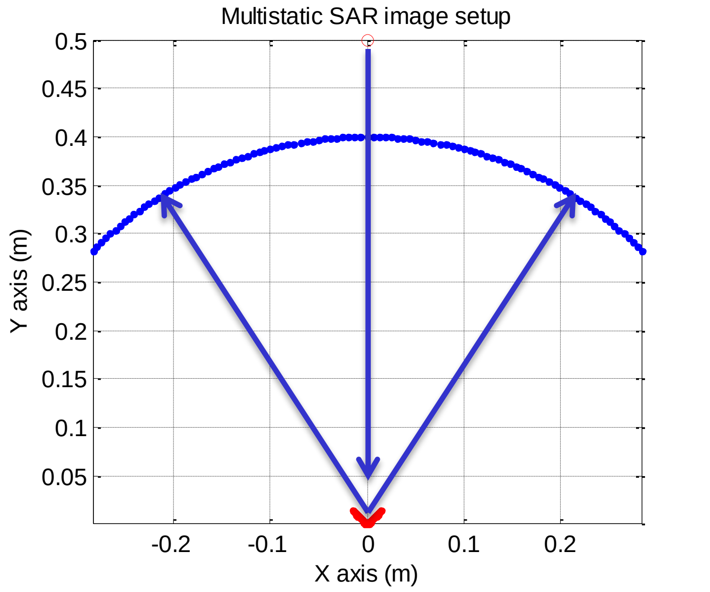


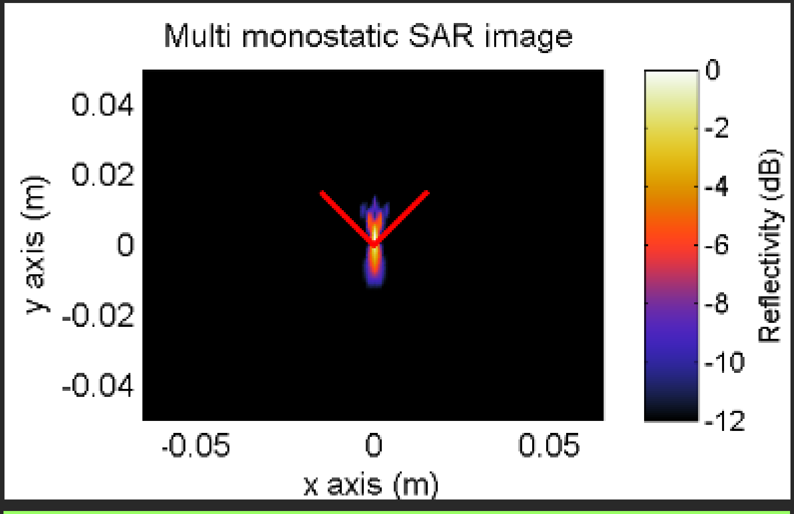
# AIT Systems

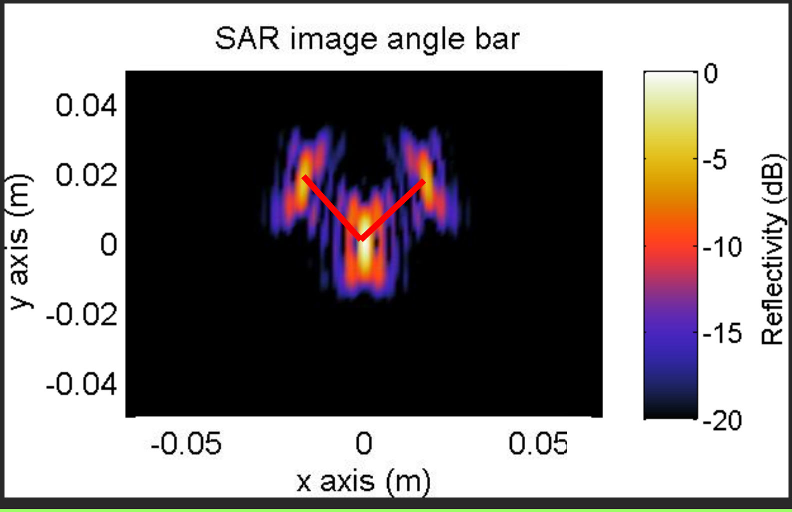
| Raster scanned focused point | Cost | Perf. | Developer |
| --- | --- | --- | --- |
| Moving antenna / mirror | $$ | ★★ | JPL, PNNL |
| Electronically scanned reflect-array | $ | ★ | Smiths |
| **Electronically scanned phased array** | | | |
| Multi-monostatic | $$$ | ★★★ | |
| Multi-bistatic | $$$$ | ★★★★ | |
| Multistatic | $$$$ | ★★★★ | Rohde & Schwarz |
| **Synthetic aperture radar** | | | |
| Moving mast of multiple monostatic | $ | ★★ | L3 |
| Moving focusing multistatic system | $ | ★★★ | NEU |

# Monostatic vs. multistatic



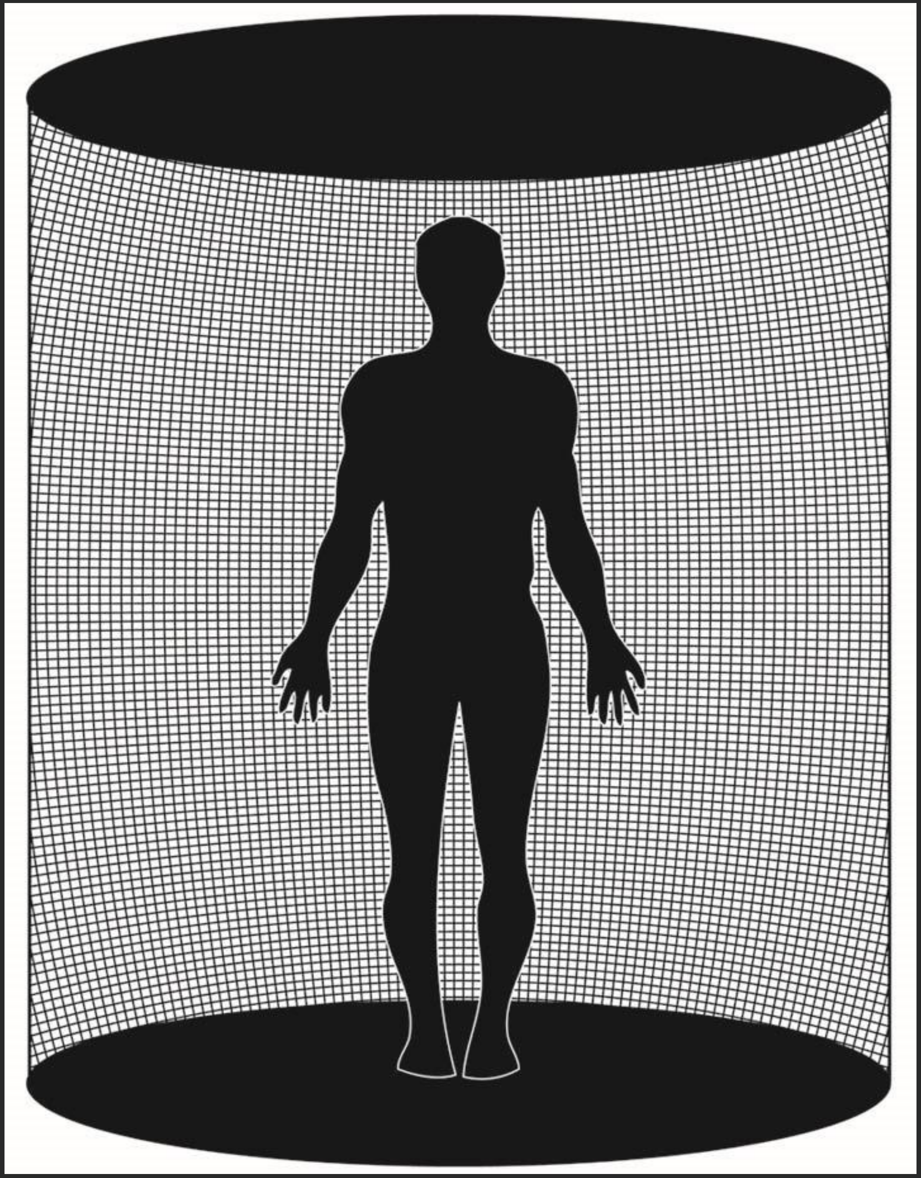




**Monostatic:** Dihedral images to a point

**Multistatic:** Dihedral images to correct corner scatterer

# Portal Provides the Possibility for Full Aperture Sensing



**Huge 360 deg. Aperture**

- Almost perfect body surface reconstruction
- No motion artifacts

**However:**

- Very expensive
- Long acquisition time
- Long computation time and massive storage

$(200 \times 300)^2$ Tx/Rx
10,000 ($cm^2$) body pts.
= $3.6\ 10^{13}$ focusing calculations

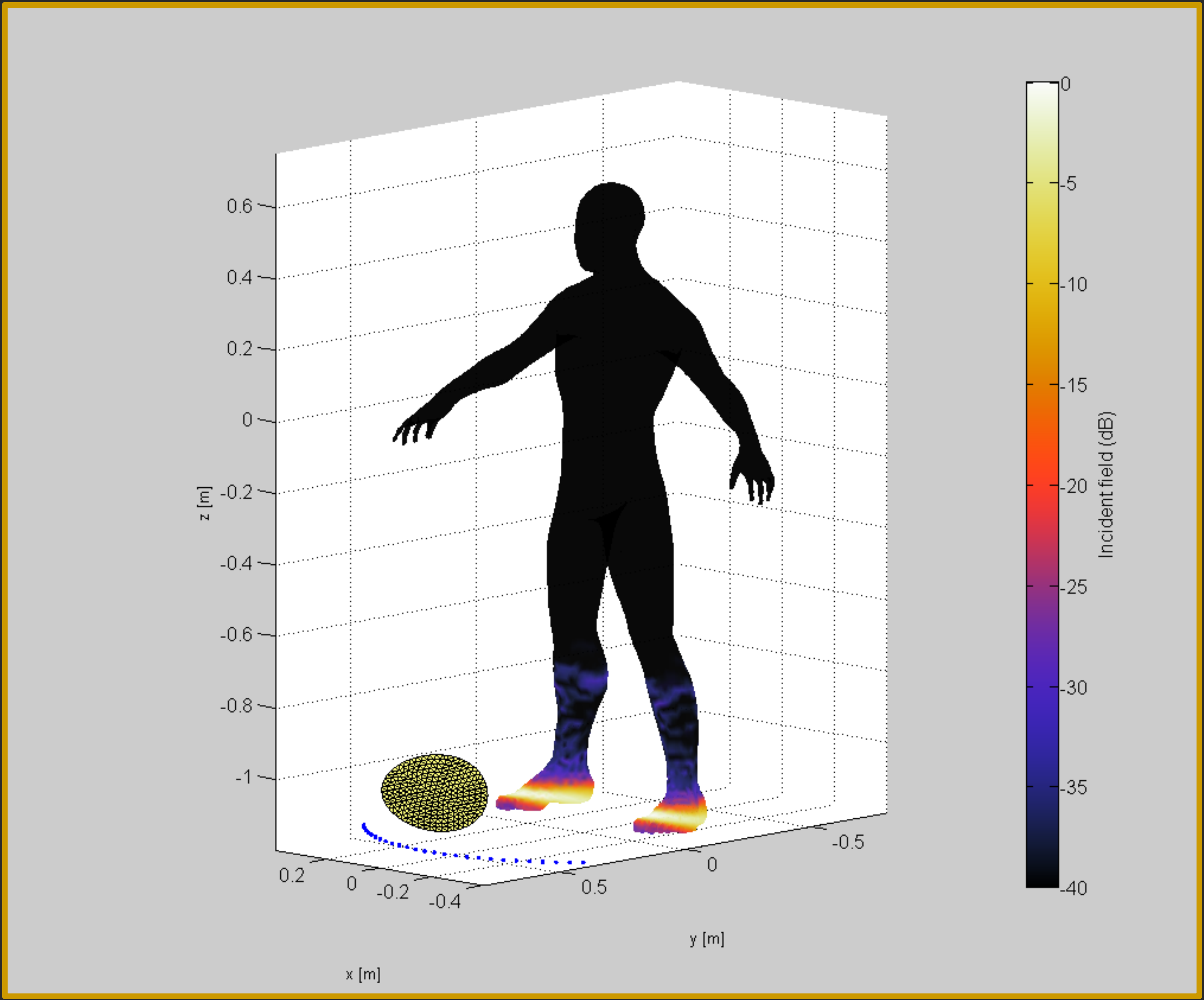
# Current State-of-the-Practice Example: L3 ProVision Mm-Wave Imager

- TSA qualified AIT system
- Detects many types of materials based on shape (metallic and non-metallic): liquids, gels, plastics, metals, ceramics
- Uses two linear antenna arrays, scans through 240 degrees
- Quick acquisition, processing
- Mm-wave Limitations
  - Poor non-spectral imaging
  - Limited views
  - No spectroscopic info
  - Poor penetration through wet or metallic clothing
  - No penetration through skin or into body cavities

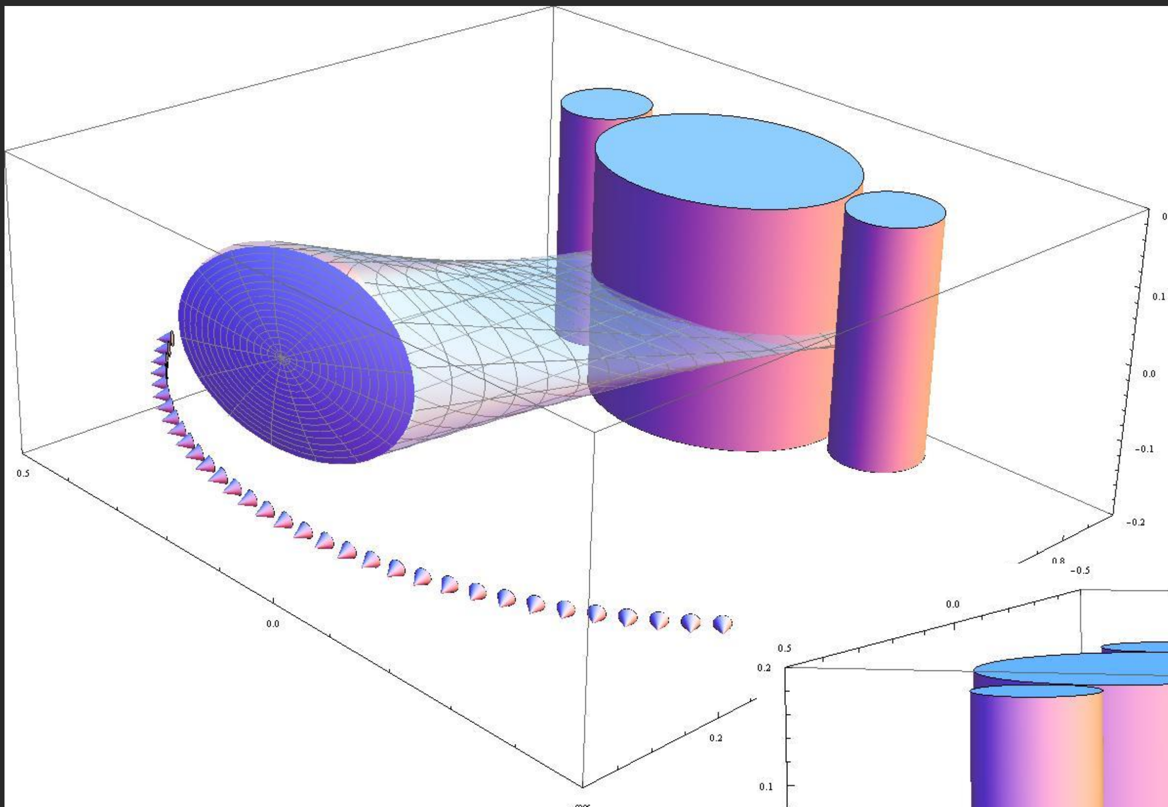
# Current State-of-the-Practice Example: Smiths eqo Mm-Wave Imager

- ECAC Std. 2 qualified AIT system
- CW – 26 GHz
- Detects shape anomalies
- Uses reflect-array with single antenna:  45 deg. view (360 deg. with subject rotation)
- Extremely quick acquisition, processing (> 10 frames/s)
- Mm-wave Limitations
  - Requires subject rotation

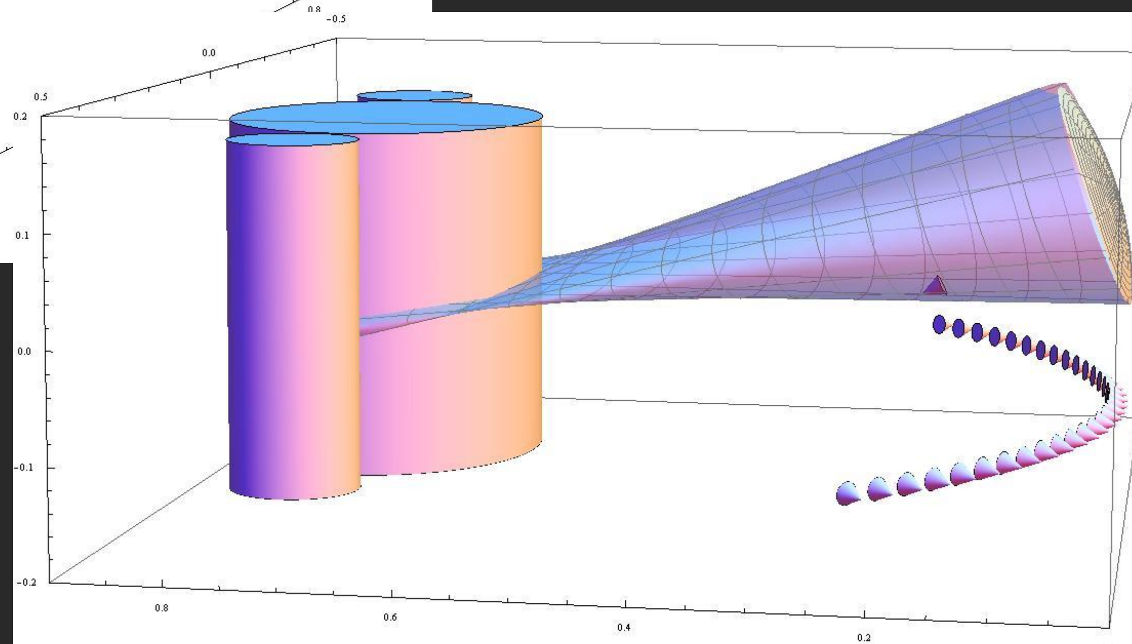
# NEU System Simulated Scanning Protocol



# Specially Designed Elliptical Parabolic Reflector Focuses to a Thin Slice on Body

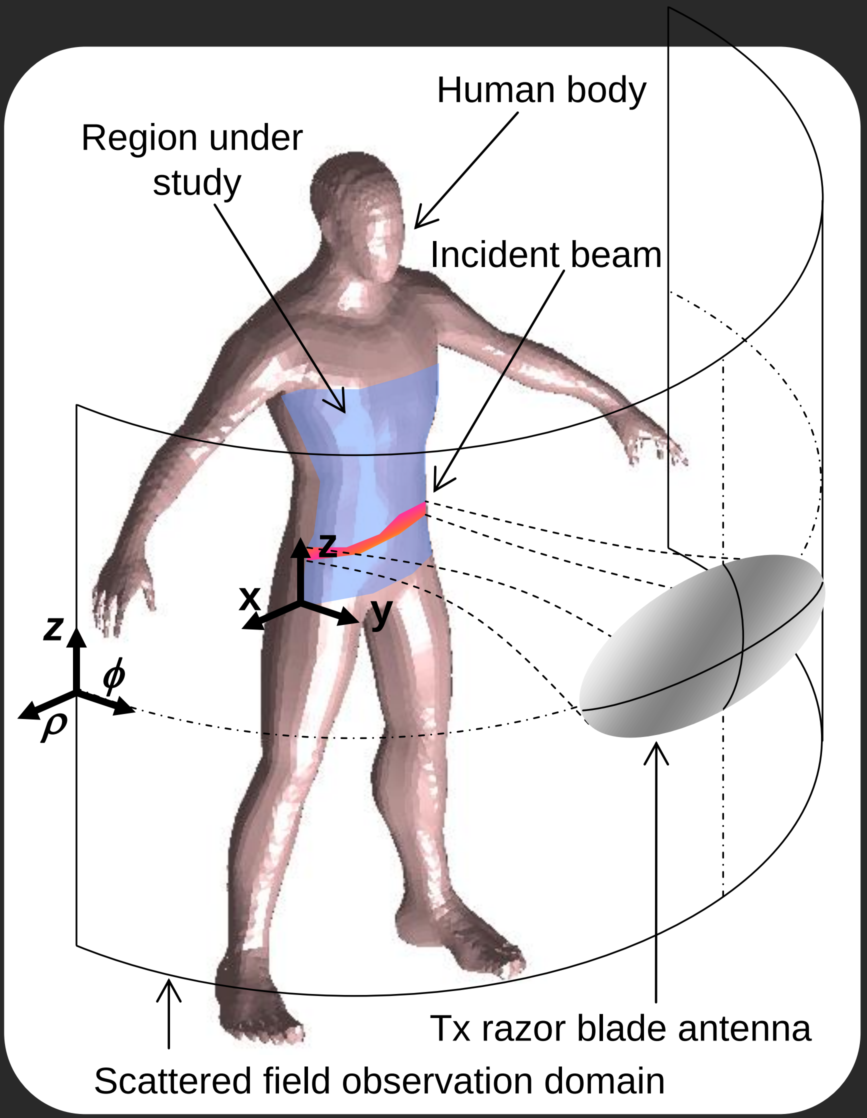


**Parabolic in azimuth**
- Gives wide beam
- Parallel incident rays

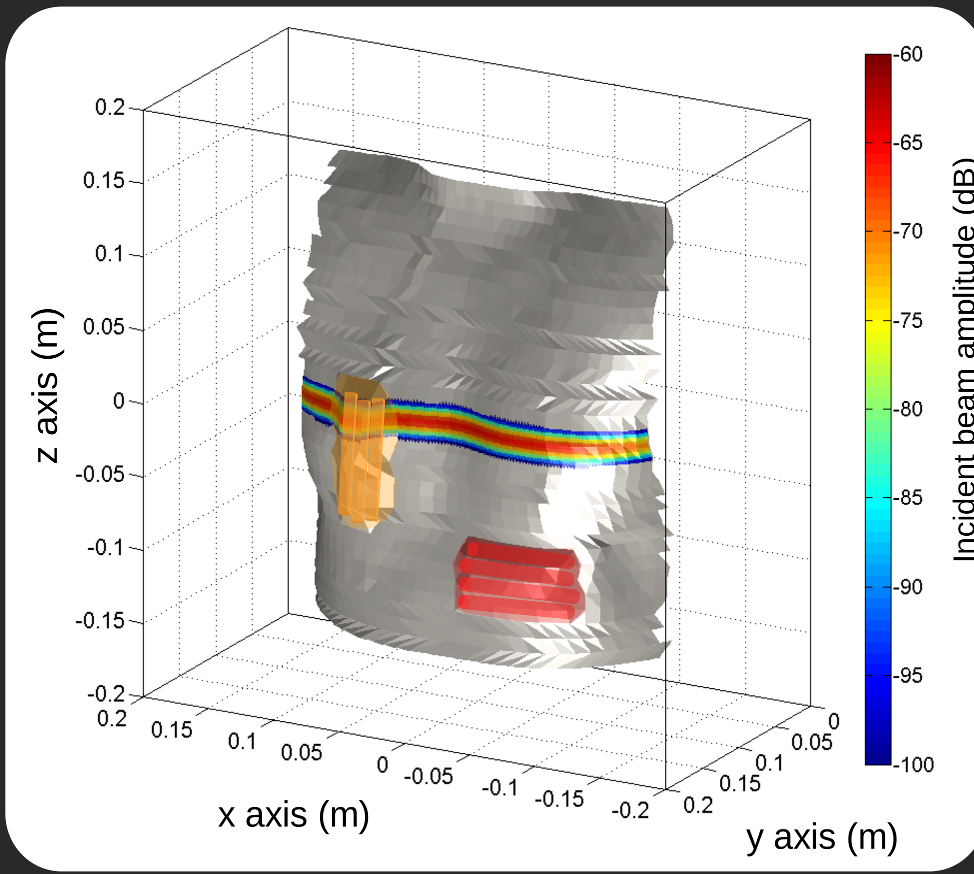


**Elliptical in elevation**
- Gives tight “Blade Focus”
- Illuminates narrow slice

# Specific 3D Human Modeling Geometry

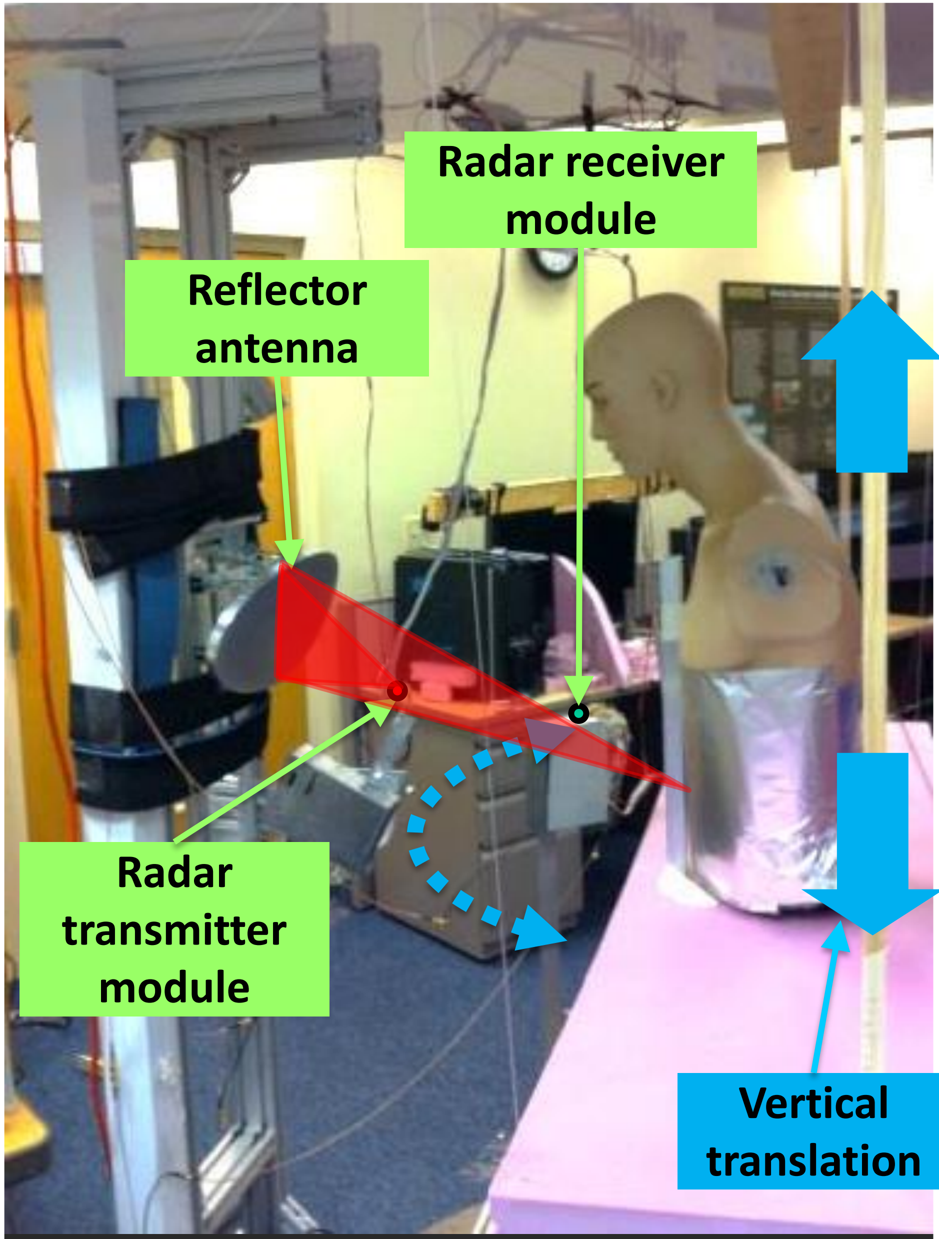



## Resulting computed illumination on torso with foreign objects



# NEU Portal Security System Concept – Multistatic, Narrow Slice Illumination

- Lab prototype AIT system
- 56-63 GHz
- Detects shape anomalies
- Uses blade beam and 120 deg. receiver arc
- Second transmitter necessary for more than +/- 30 deg. field of view
- Quick acquisition, processing
- Mm-wave Limitations



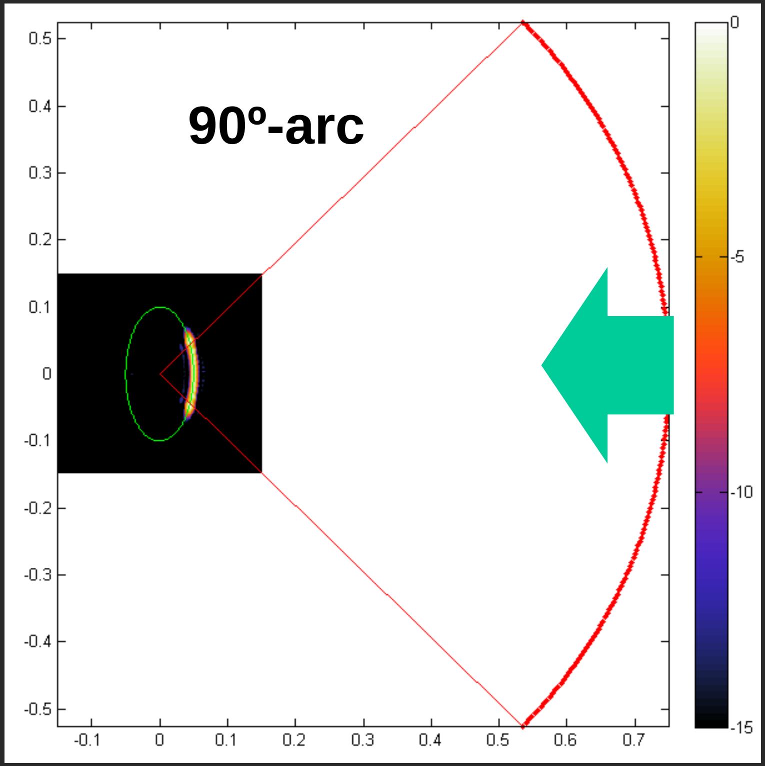
# Importance of Large Aperture

- Electrically large aperture provides narrow beam and high resolution (wave effect)
- As center frequency increases, for same physical aperture, resolution increases
- As distance to target increases, resolution decreases
- For given aperture, higher frequency demands more elements, more closely spaced
  - Grating lobes for uniform sparse aperture
  - Non-uniform element spacing avoids lobes

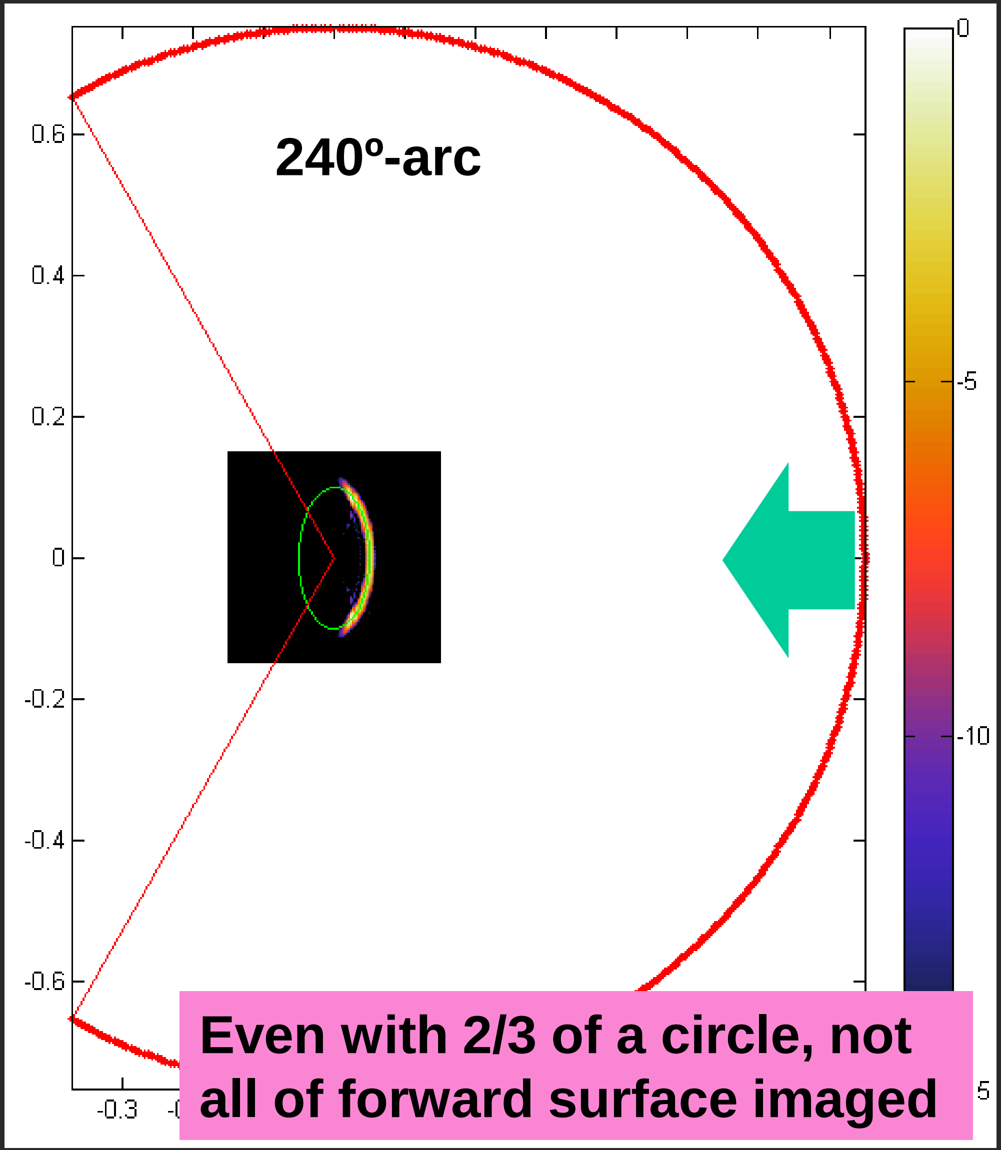
# Importance of Specular Sensing

- At high frequencies, waves behave like rays
- Rays reflect from piecewise planar boundaries specularly
- Extreme focusing or ultra large bandwidth cannot compensate for specular reflection
- If reflected rays leave subject away from source, the detector must be on the other side of the subject from the source
- Ray analysis is often overlooked, but crucial for effective design

# With Single Plane Wave Illumination, Receiving Array Must be Oversized (NEU)

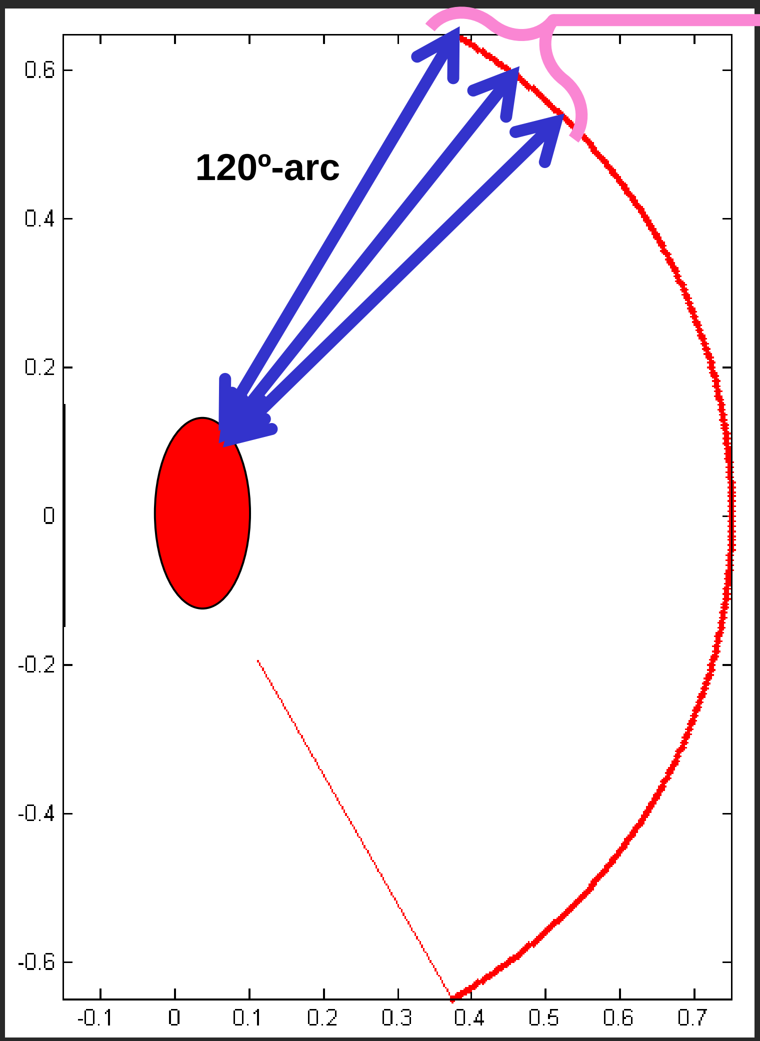



Only front surface (normals < 22.5 deg.) imaged



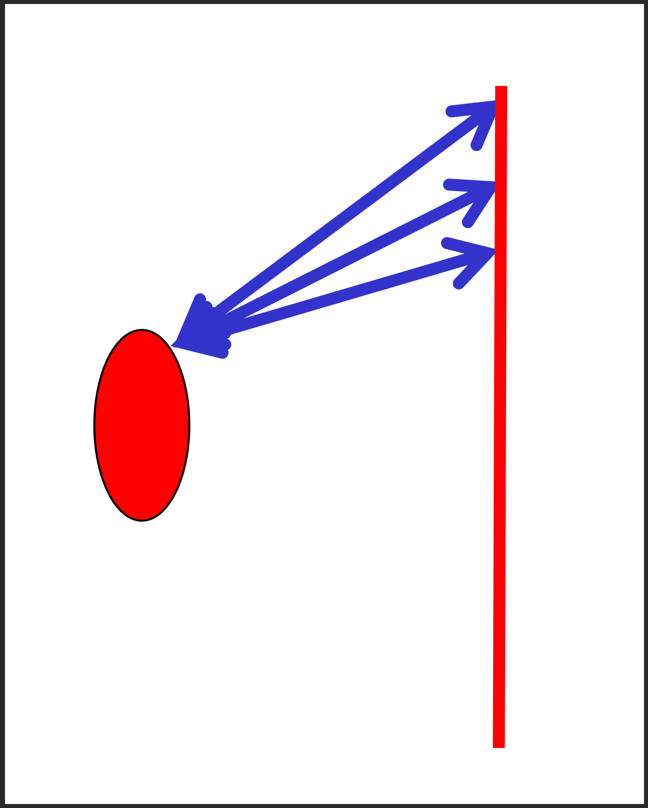

Even with 2/3 of a circle, not all of forward surface imaged

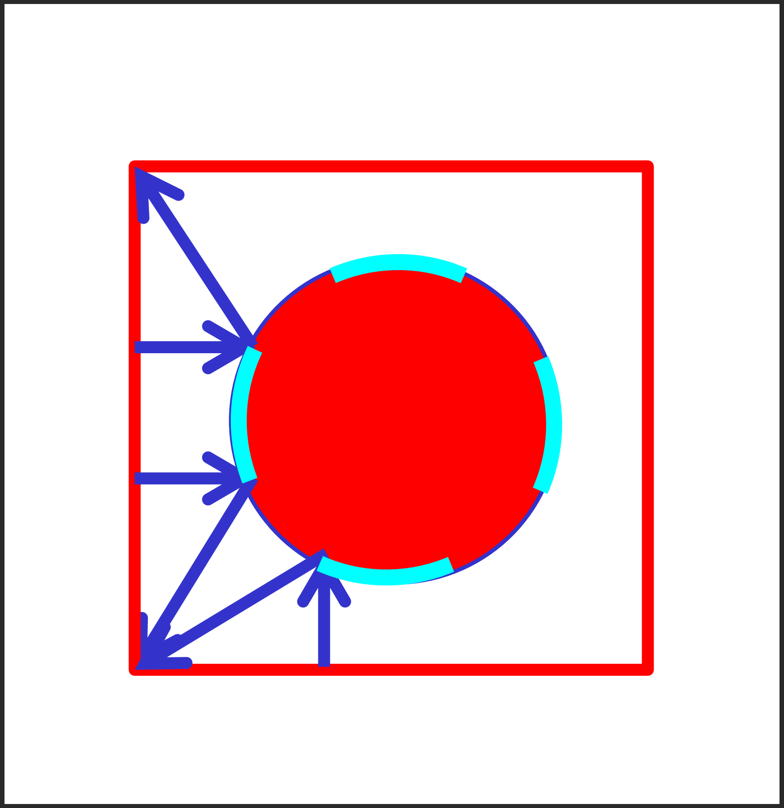
# With Multi-Monostatic, Either Aperture Shrinks or Specular Rays Miss Receiver (L3)




**Reduced usable aperture at edges:**
**Reduced resolution at extremes**

# For Planar Apertures, Specular Reflection at Edge Points Limits Imaging (Smiths, R&S)



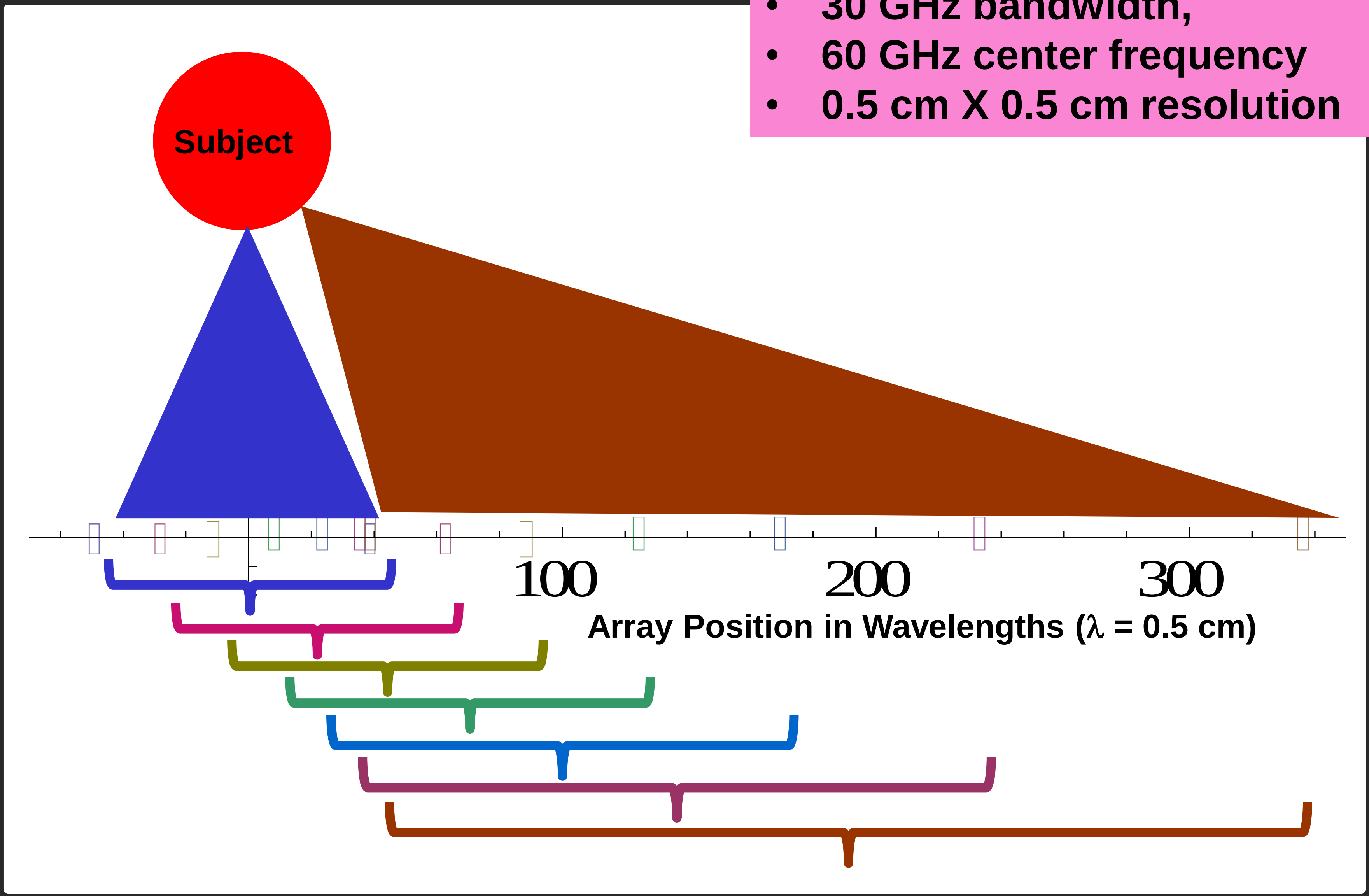


- Only scattering points with normals pointing to array can be imaged.
- Extreme points have aperture reduced to single element

- Even with four independent multistatic planar arrays, only ~50% of the subject can be imaged

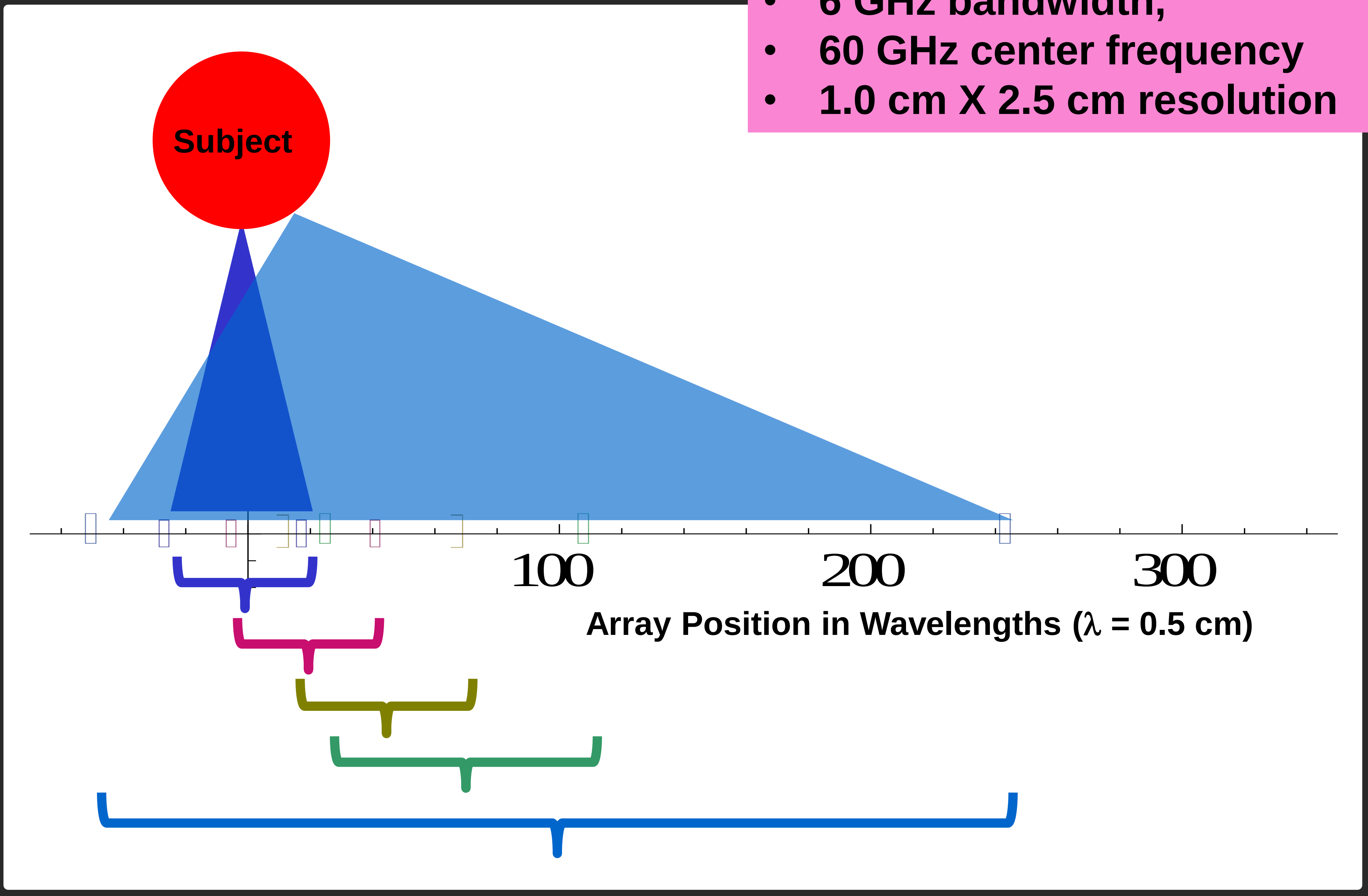
# Planar Array Requires Wider Aperture for Comparable Resolution – Large BW Case

- 30 GHz bandwidth,
- 60 GHz center frequency
- 0.5 cm X 0.5 cm resolution



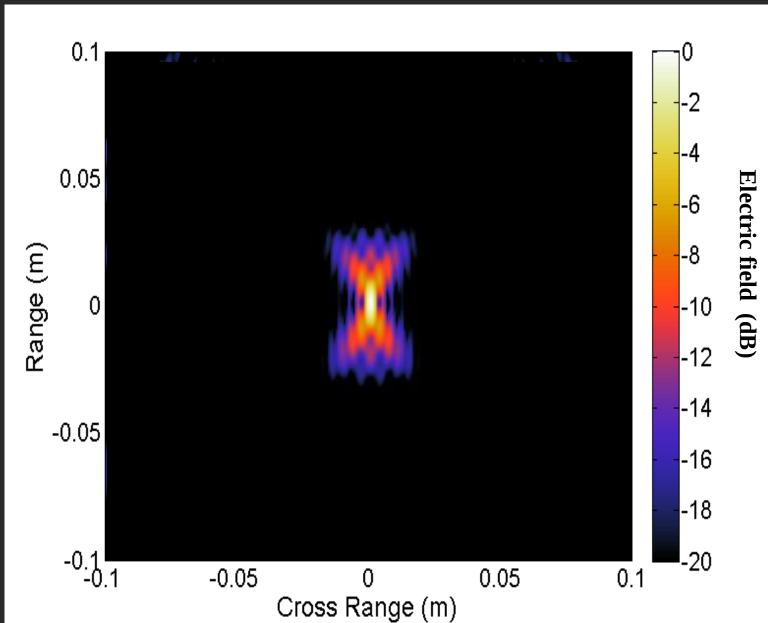
# Planar Array Requires Wider Aperture for Comparable Resolution – Typical BW Case

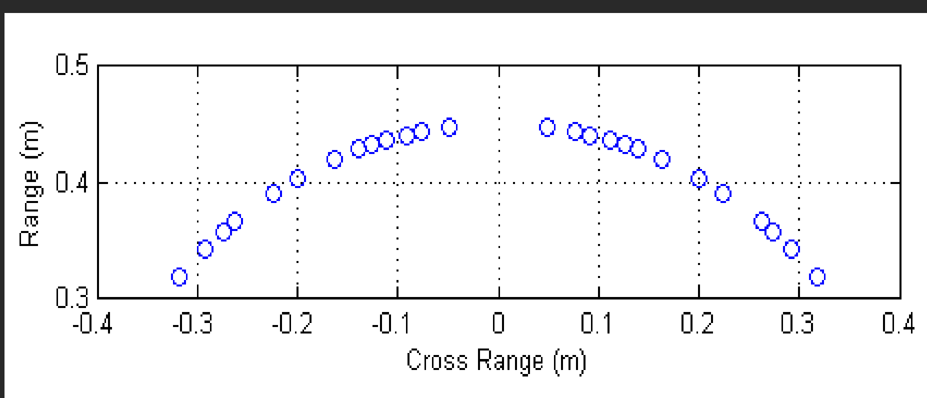
- 6 GHz bandwidth,
- 60 GHz center frequency
- 1.0 cm X 2.5 cm resolution



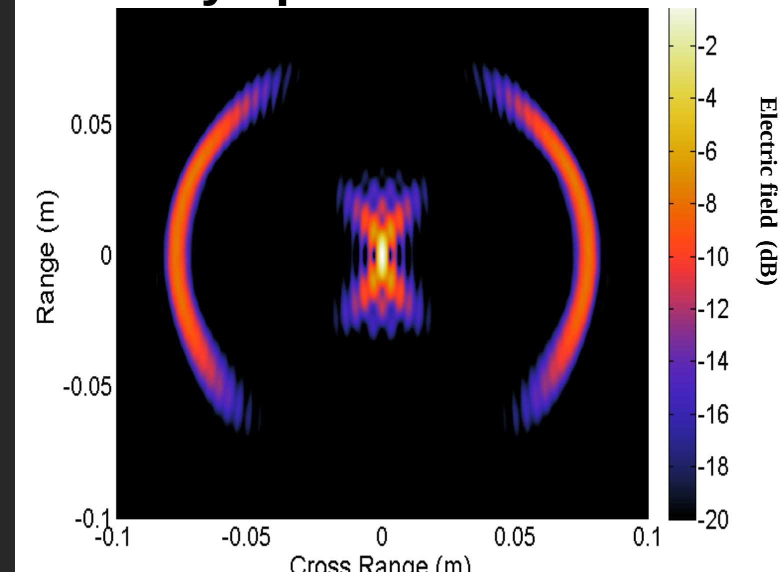
# Effect of 83% Element Thinning and Optimization

## Full 151 element array

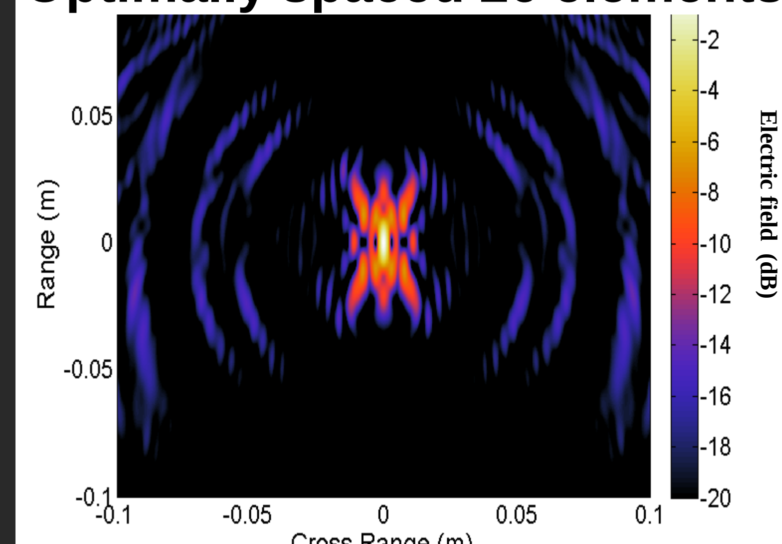



## Evenly spaced 26 elements




## Optimally spaced 26 elements



# Considerations for Fusing Technologies with Mm-Wave Sensing

- Compensate for deficiencies of mm-wave sensing
  - Low resolution
  - No skin penetration
  - Limited material identification
  - Heavy computation burden
- Establish minimum desired sensing requirements
  - Resolution
  - Material classification
- Consider completely orthogonal sensor
  - No joint inversion – simple union of sensor info
- Consider front-end fusion – joint inversion
  - Initial guess
  - Regions of particular interest

# Conclusions

- Mm-wave nearfield imaging is effective but can be improved
- Bandwidth is important – range resolution
- Aperture is important – cross range resolution
- Illumination direction is important – spectral reflection

**MUST CONSIDER BOTH WAVES AND RAYS**

- Multistatic sensing is important
  - Multiple rays scattering from same target point
  - Opportunity to observe non-specular rays
- Array thinning is useful and efficient
- Multi-modal fusion with mm-waves radar offers advantages

# People Who Actually Did the Work…

Prof. Jose Martinez
Prof. Yuri Alvarez
Dr. Borja Gonzalez Valdes
Spiros Mantzavinos
Kathryn Williams
Galia Ghazi
Luis Tirado
Dan Busioc
James Rooney
Nathan Dunn
Matt Nickerson
Jenna Czeck
Greg Allan
Nigil Lee
Richard Moore