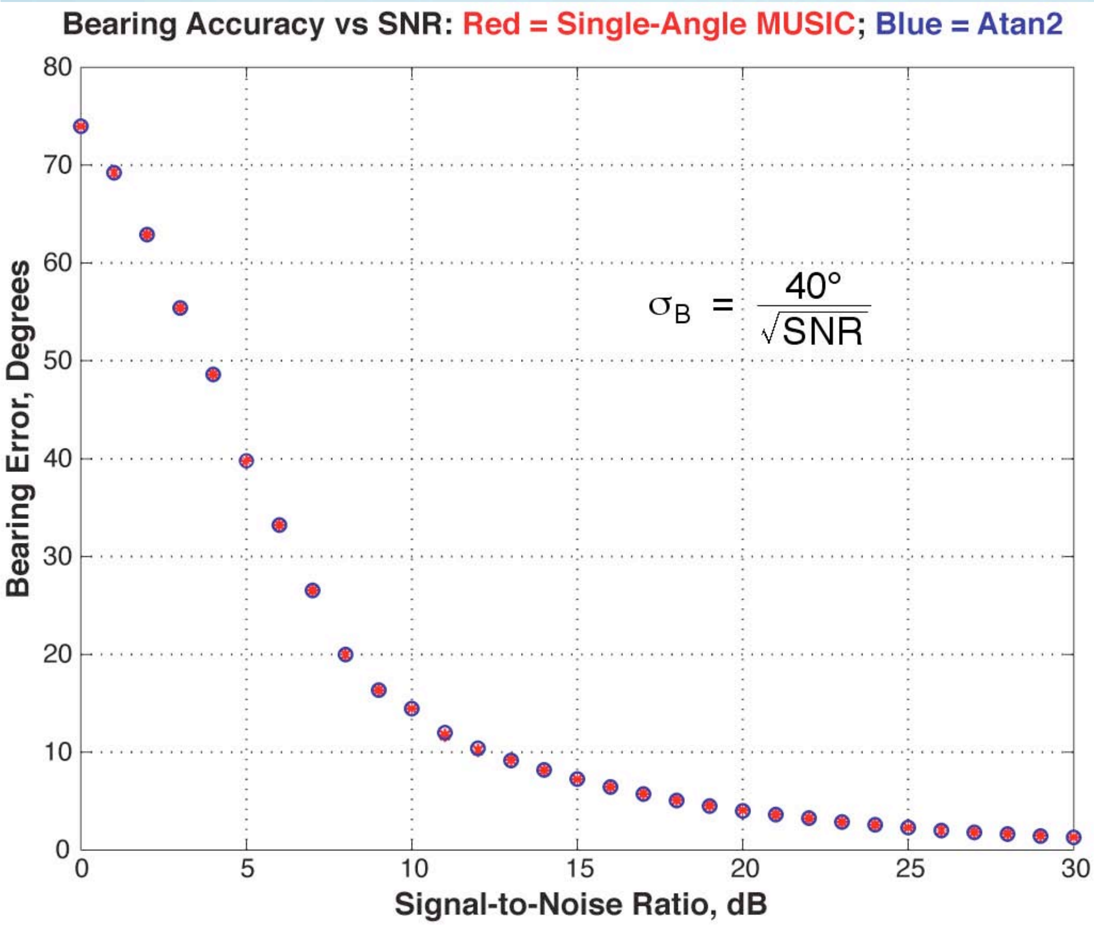
New Result -- Bearing Accuracy with SeaSonde DF Established



- Theoretical formula derived based on Atan2 algorithm
- Monte-Carlo simulations show same relationship as theory for:
  - Single-angle MUSIC - red x
  - Atan2: blue o
- Experimental data follow theory and simulations with added offset when antenna patterns are not do not reflect reality
- Question: Why not use Atan2 rather than MUSIC if results are identical?
- Answer: Because Atan2 does not work with general antenna patterns (only sine, cosine)

The CODAR SeaSonde Ship Detection Processing Provides Files Inputted to AMI Kalman-Filter Tracker

CODAR OCEAN SENSORS

- **Detection is done after range/Doppler processing**
- **Peaks from two loop and monopole antenna signals identified before bearing determination (DF)**
- **Constant false alarm rate (CFAR) -- peaks on 2 out of 3 antennas must fall above threshhold with respect to background -- 7-10 dB seems best**
- **Two types of background investigated:**
  - **Average of noise floor backward in time (IIR filter) -- this is best**
  - **Median of noise floor**
- **Simultaneous multiple FFT spectral processing gives best SNR for unknown maneuvering target -- 128 seconds appears best**
- **Bearing determined on peaks exceeding threshhold**
- **Estimates of uncertainties made for range, bearing, radial speed**
- **Information stored in ASCII 'Detection File' for tracker**

Next Year Project: Getting Higher SNR for Detection by Combining 3-Antenna Signals -- Concept Demonstration with Ideal SeaSonde Antenna Patterns

CODAR OCEAN SENSORS

- **The Issue: Must now select ship peak from three possible antenna signals**
- **The Goal: Combine three signals to increase detectable signal power**
- **Ideal Crossed-Loop-Monopole Antenna Patterns:**

$$s_1 \propto \cos\theta; \quad s_2 \propto \sin\theta; \quad s_3 \propto 1$$

- **Point Cardioid beam to direction θ_o by software signal weighting & summing**

$$V = s_1\cos\theta_o + s_2\sin\theta_o + s_3$$

$$V = \cos\theta\cos\theta_o + \sin\theta\sin\theta_o + 1 \qquad V = 1 + \cos\left(\theta - \theta_o\right)$$

$$V = 2\cos\left(\frac{\theta - \theta_o}{2}\right)^2$$

- **At and near direction θ_o :**
  - **Original signal amplitudes s < 1**
  - **Combined beam signal ~ 2**
  - **3-4 dB peak enhancement with respect to noise**

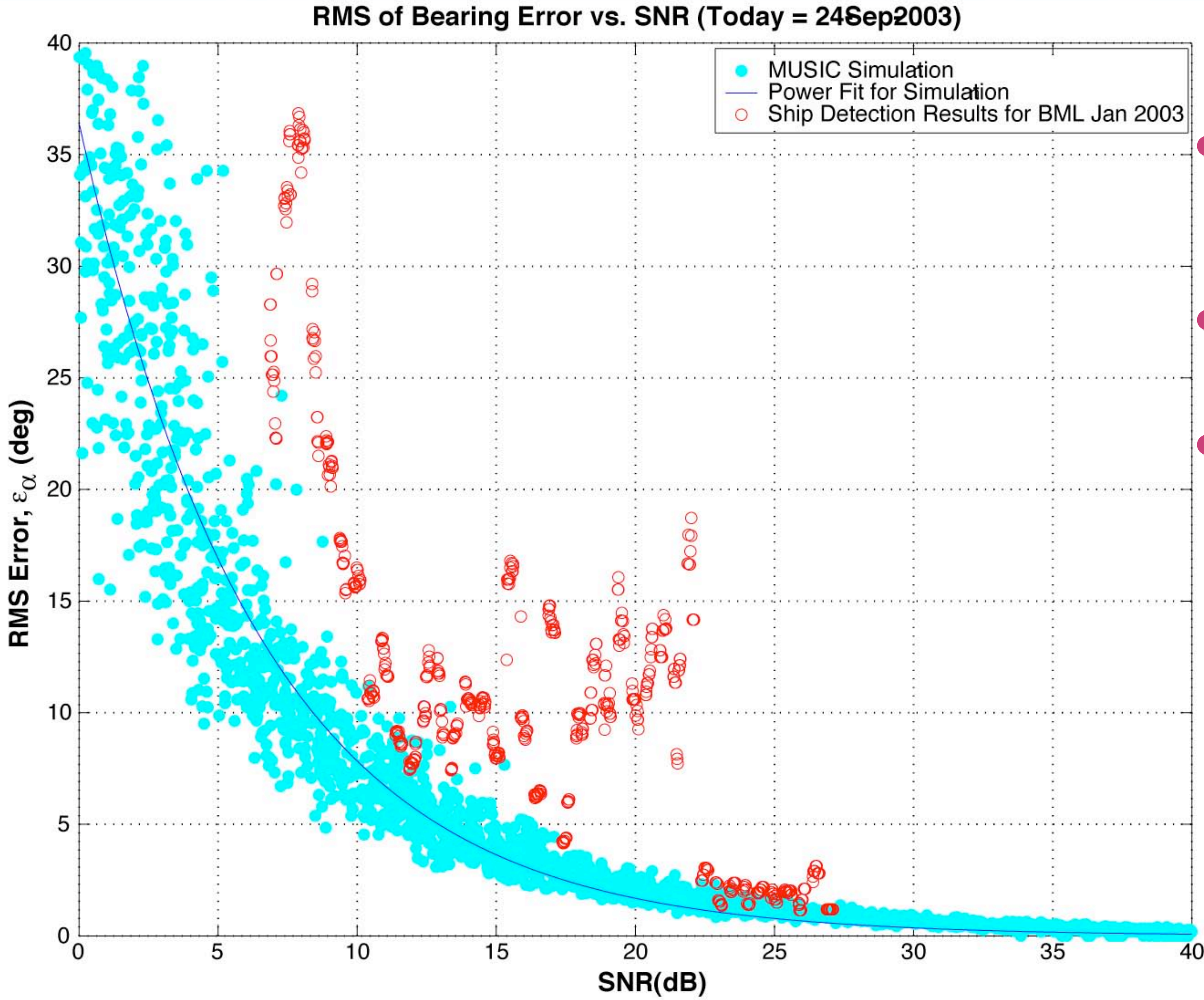
- **A 3-4 dB SNR increase for detection with no hardware change is worth $$$**

Next Year Project: Getting Higher SNR for Detection by Combining 3-Antenna Signals -- Dealing with Measured Distorted Antenna Patterns

CODAR OCEAN SENSORS

- Antenna patterns measured with transponder on boat are not ideal
- Pattern can be measured on horizon plane only -- not over upper hemisphere of space where gain is normally defined
- Pattern is measured only on part of 360° sector over sea
- Planned Solution/Analysis
  - Construct covariance matrix of three measured antenna signals
  - Perform eigenfunction analysis of signal covariance matrix to optimize gain pattern at several bearing directions
  - Solve for the required software antenna signal weights (amplitudes/phases)
  - Store these for use in detection algorithm
- We will deal with single range/Doppler peak spectrum rather than three
- Several such spectra represent 3 or 4 cardioid broad-beam patterns
- Each gives peaks 3-4 dB higher SNR
- Test new methodology with ship echoes vis-à-vis present method

Simulated Bearing Error with Distorted, Measured Antenna Patterns Compared with Real Ship Bearing Data



- **Simulated points follow power law:**

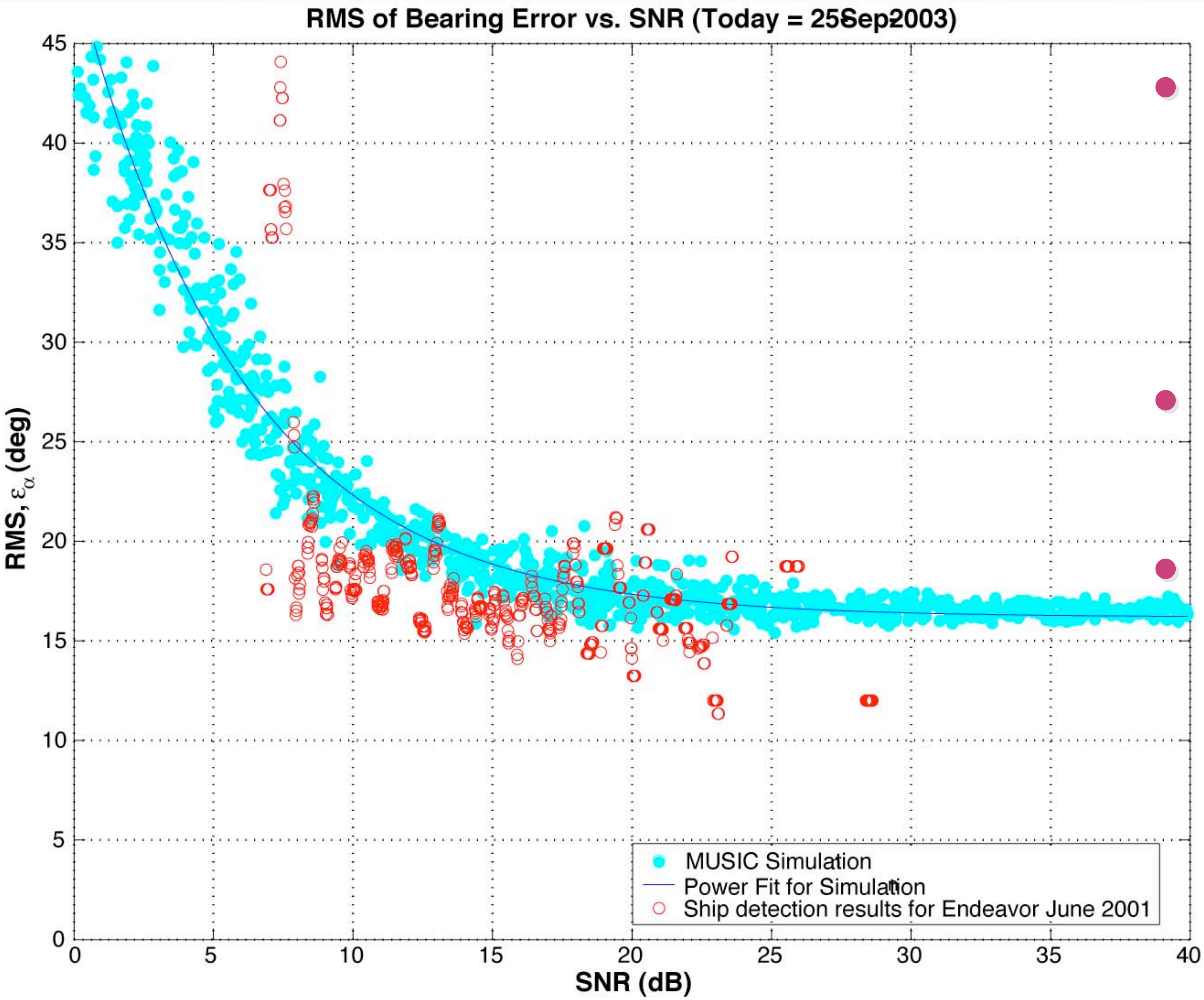
$$\epsilon_B = \frac{36.4}{SNR^{0.67}}$$

- **Compared to:**

$$\epsilon_B = \frac{40}{SNR^{0.5}}$$

- **Ship detections at lower SNRs may differ because:**
  - **Noise peaks are mis-identified as ships**
  - **"Noise" near peak contains ship signal, i.e., it is too high**

Simulated Bearing Error with Added Bias from Improper Antenna Pattern Compared with Real Ship Bearing Data



- **For Simulation:**
  - **Measured distorted pattern inputted**
  - **Ideal pattern used to recover echo**
- **Expected power-law fit is offset by 16°**
- **Ship is also offset when inappropriate ideal pattern is used**