

Design Considerations and Sensitivity Estimates for an Acoustic Neutrino Detector

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bmb+f - Förderschwerpunkt

Astroteilchenphysik

Großgeräte der physikalischen
Grundlagenforschung

- **The Simulation Chain**
- **Influence of Detector Parameters**

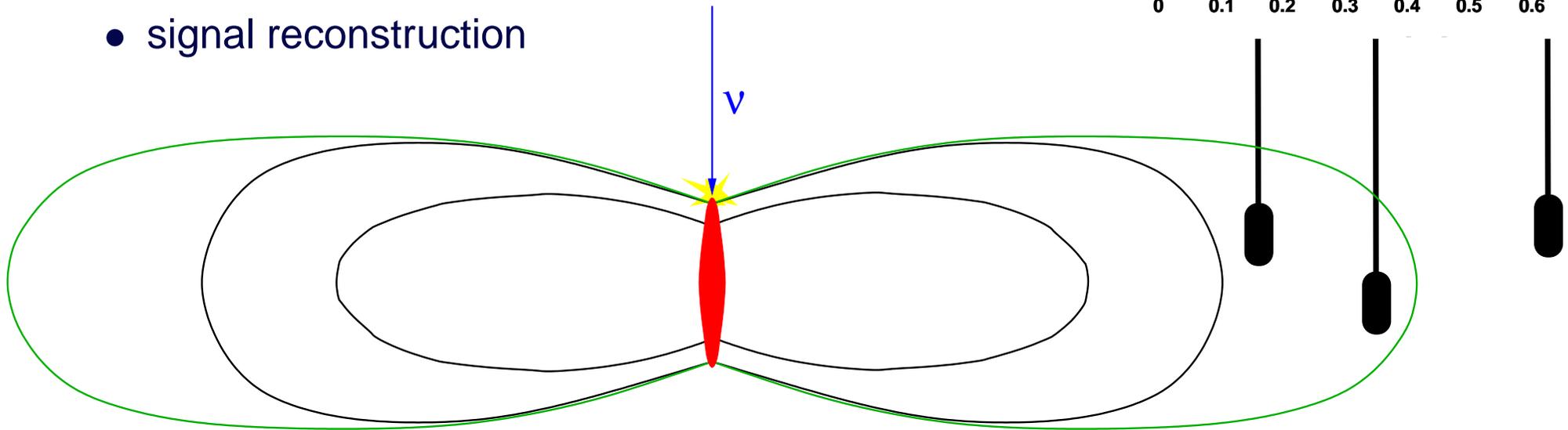
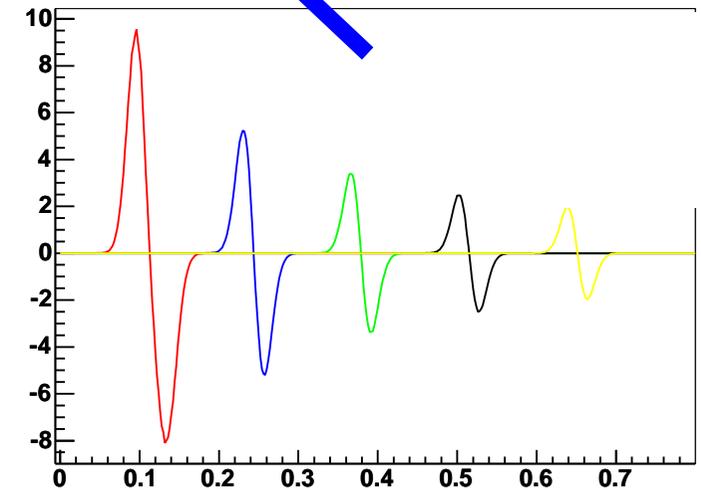
Introduction: Simulation Chain

Design study for an underwater acoustic neutrino telescope for UHE ($E \gtrsim 10^{18}$ eV) neutrinos

Full simulation chain:

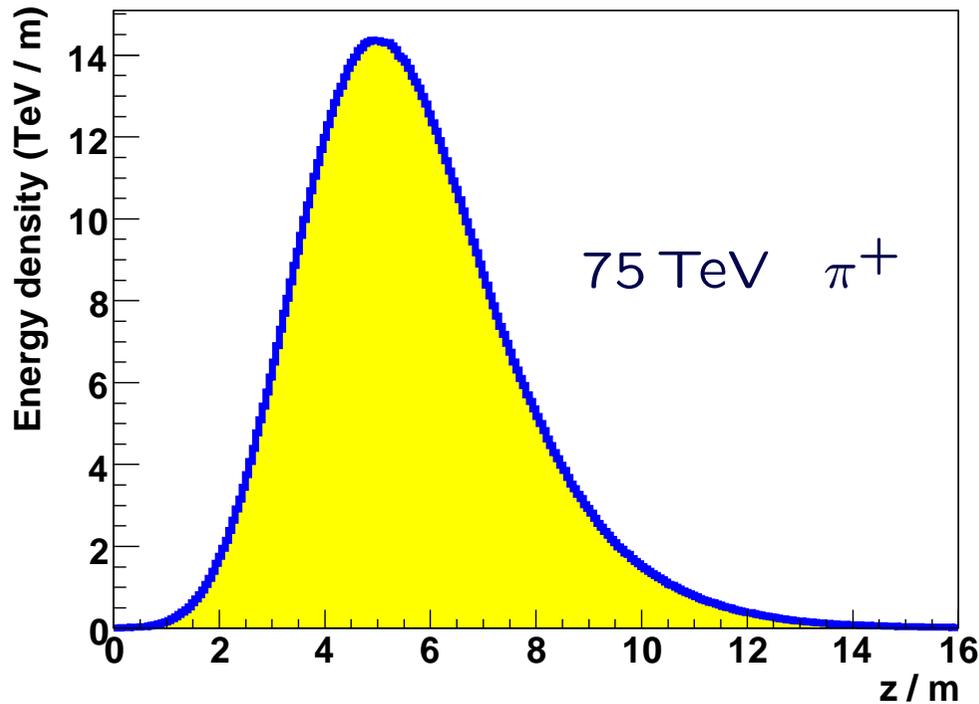
- signal production: hadronic shower
- signal propagation: attenuation
- signal detection and processing: hydrophones
- signal reconstruction

(θ, ϕ, E)

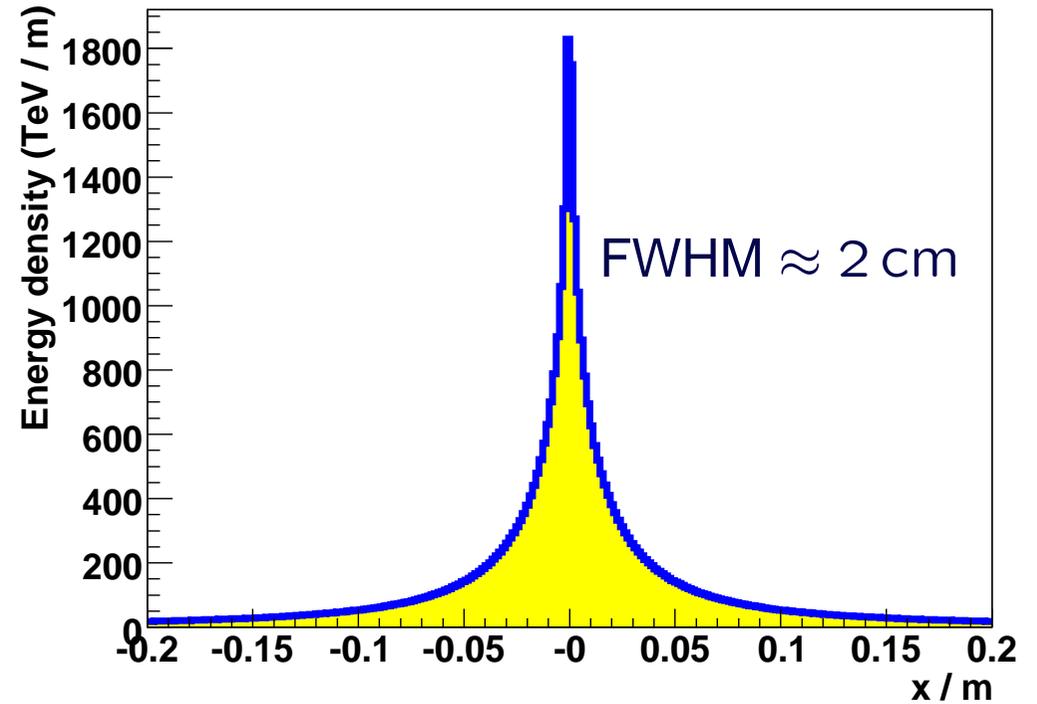


Hadronic Showers

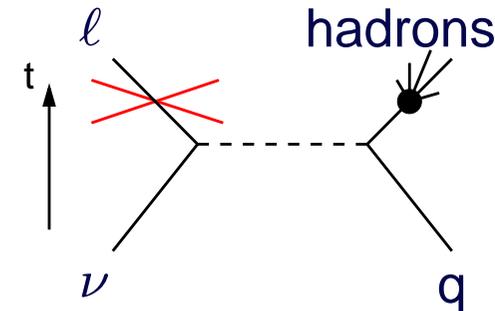
Longitudinal energy deposition



Transversal energy deposition

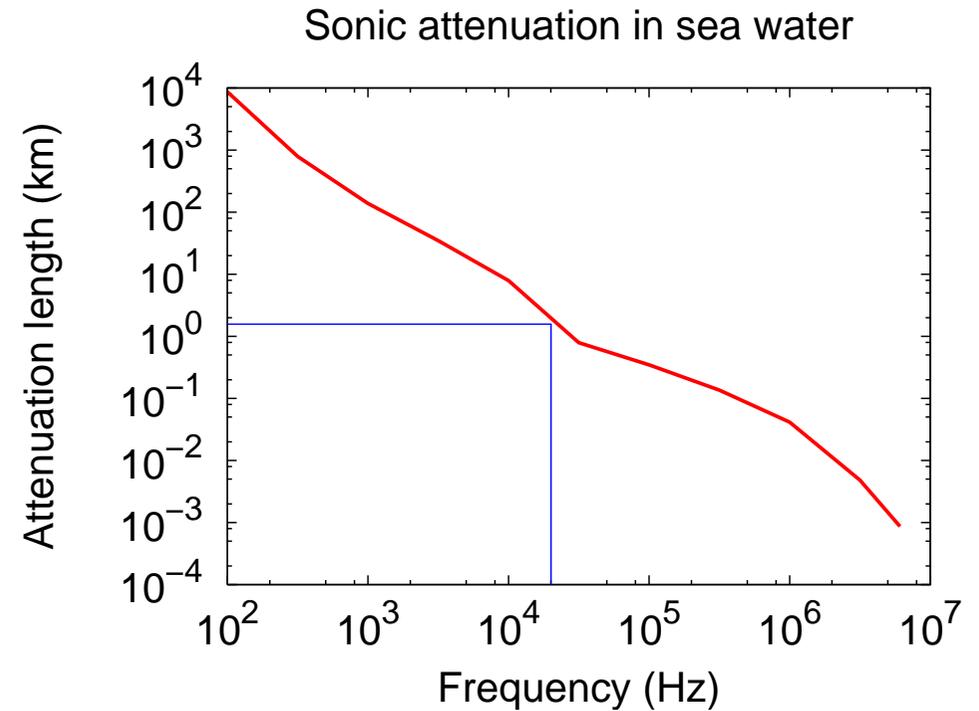
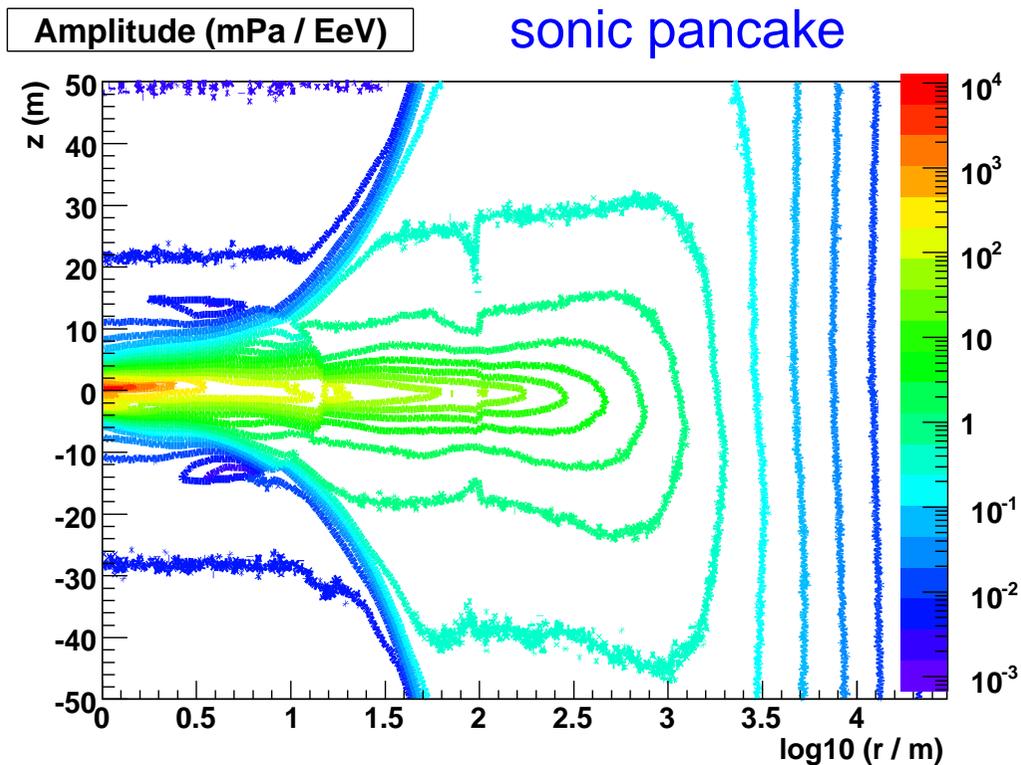


- neglect primary electromagnetic showers due to LPM effect
- full 3D simulation of the energy deposition with GEANT4
 - shower extension (nearly) independent of energy
- ⇒ energy density scales linearly with energy
- numeric integration of energy density gives bipolar acoustic signal $p(\vec{r}, t)$



Signal Propagation

- attenuation length strongly frequency dependent
 - central frequency of signal ≈ 20 kHz
- \Rightarrow **attenuation length ≈ 1 km**



- sonic disc well collimated for distances up to 1 km
- diffraction is neglected (for the moment...)

Signal Detection: Threshold

Example: Threshold estimation for a single hydrophone (from J. Perkin)

- Assumption: the magnitude of the background depends on sea state only
- Use an appropriate bandpass filter for noise reduction
- Trigger on at least five hydrophones in coincidence
- Allow for one false trigger due to noise in 10 years

⇒ Threshold of **35 mPa**

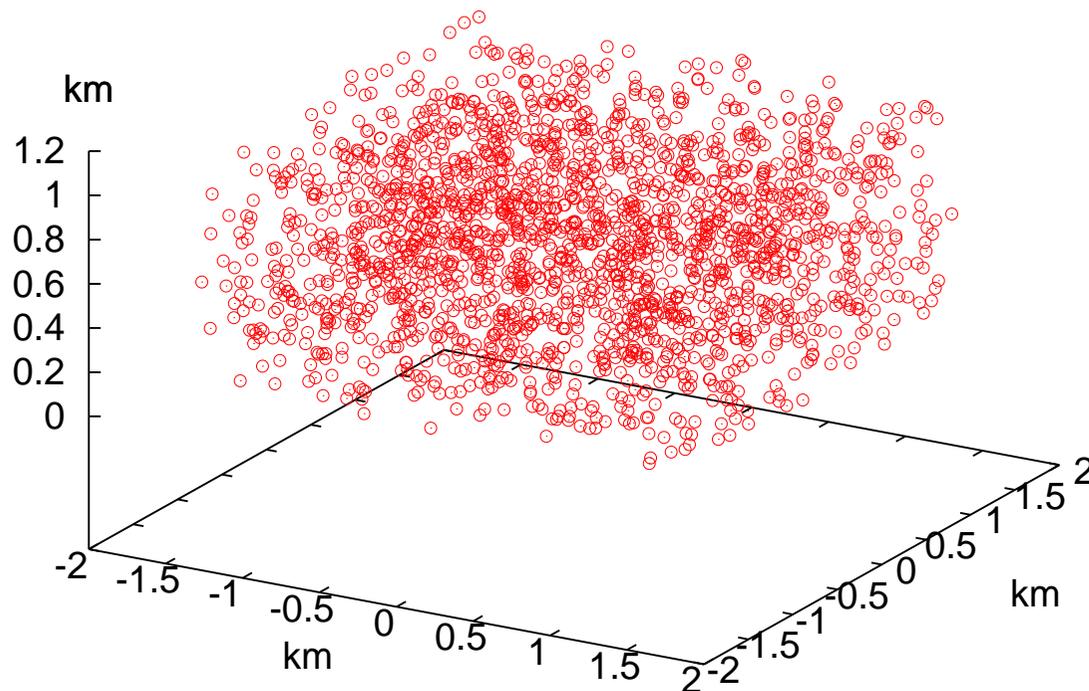
Assuming an uncorrelated background,
and using sophisticated pattern recognition techniques
it should be possible to reduce the threshold to at least **5 mPa**
(under study...)

Acoustic Module (AM):

Local device, which can detect an acoustic neutrino signal
above a given threshold (e.g. antenna of locally correlated hydrophones)

Detector Simulation

- Homogenous, but randomized, AM distribution to avoid geometry effects.
- Generate showers with a given energy spectrum and 2π sr angular distribution inside the can volume.
- Each AM records arrival time and amplitude of signals above a given threshold.
- A trigger in ≥ 4 AMs forms an event.

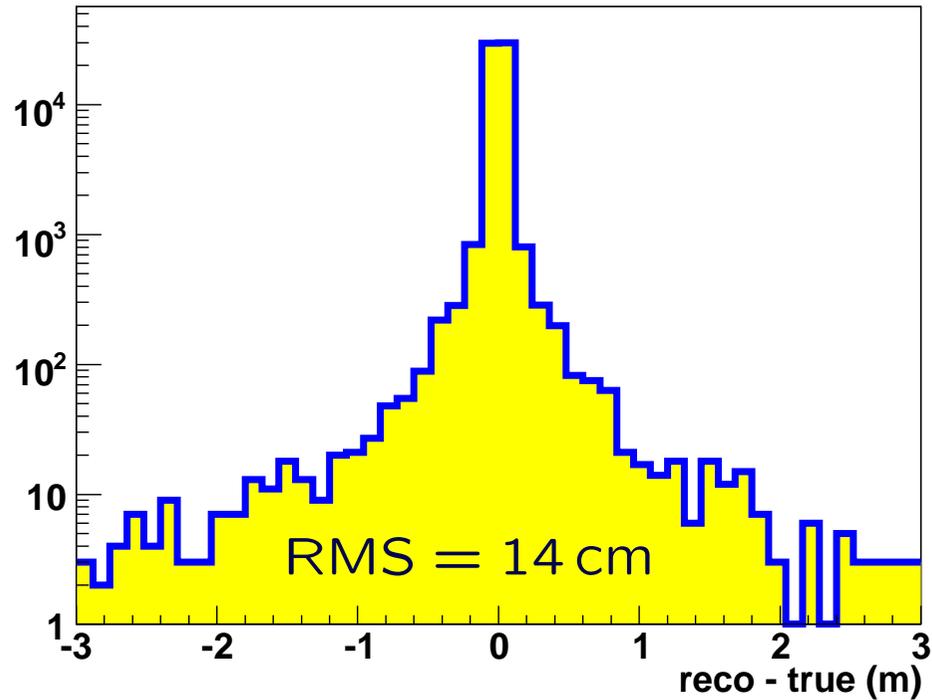


Example detector:

- instrumented volume: 10 km^3
- density: 200 AM/km^3
- precision:
 - AM-position: 10 cm
 - time: $10 \mu\text{s}$
(sampling: 100 kHz)
 - amplitude: 2 mPa

Shower Reconstruction (w/o selection cuts)

Position reconstruction: x

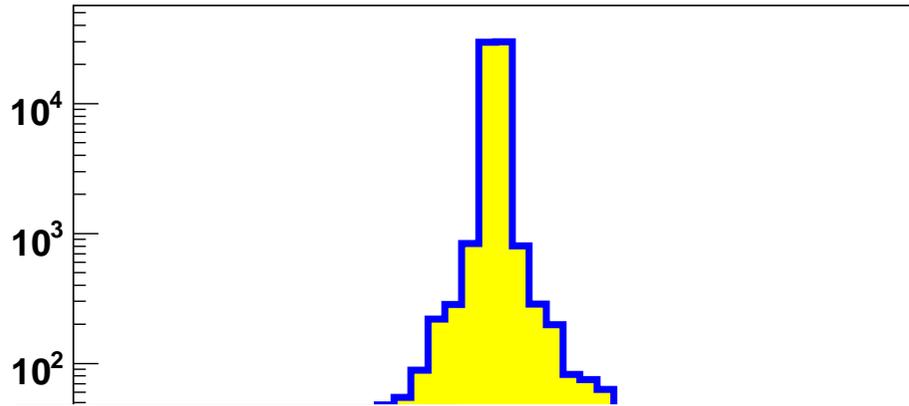


Step 1: Position reconstruction

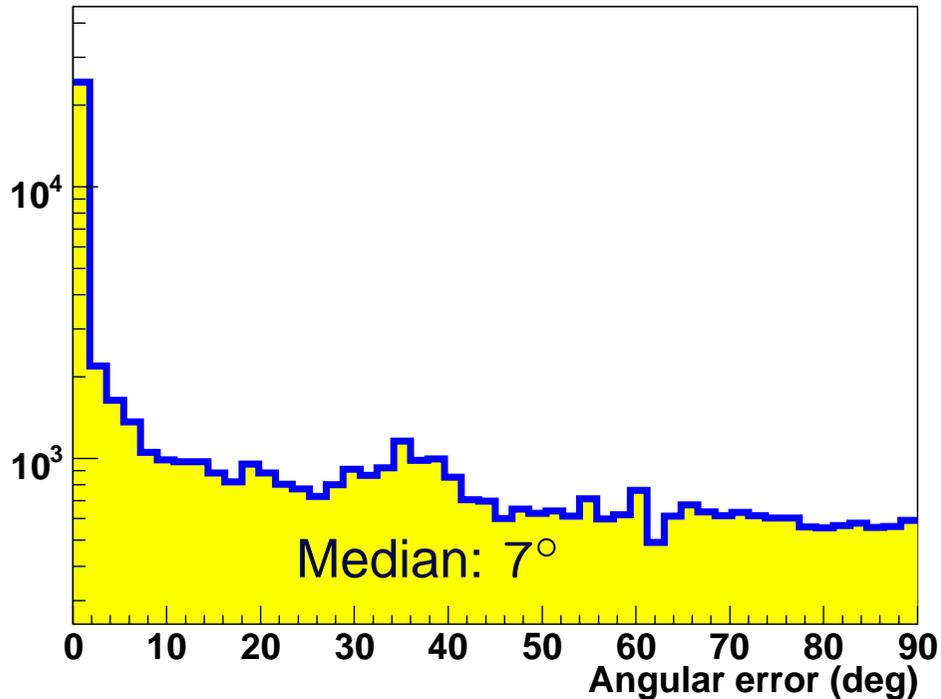
- Good position estimate needed for direction and energy reconstruction
- Assumption: isotropic point source
- Minimise χ^2 of time residuals

Shower Reconstruction (w/o selection cuts)

Position reconstruction: x



Direction reconstruction

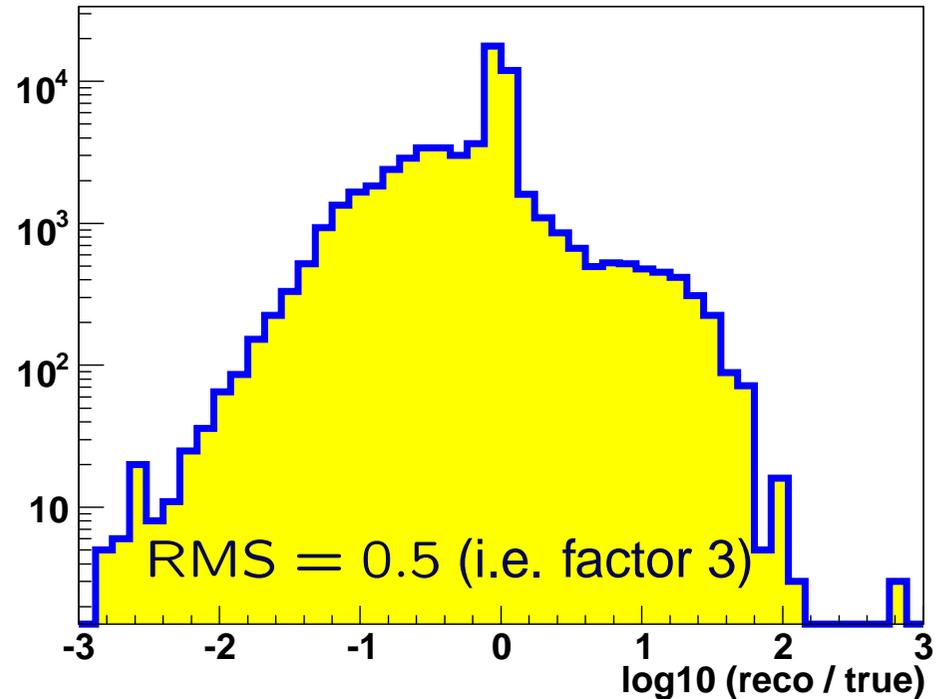


Step 1: Position reconstruction

Step 2: Direction and energy reconstruction

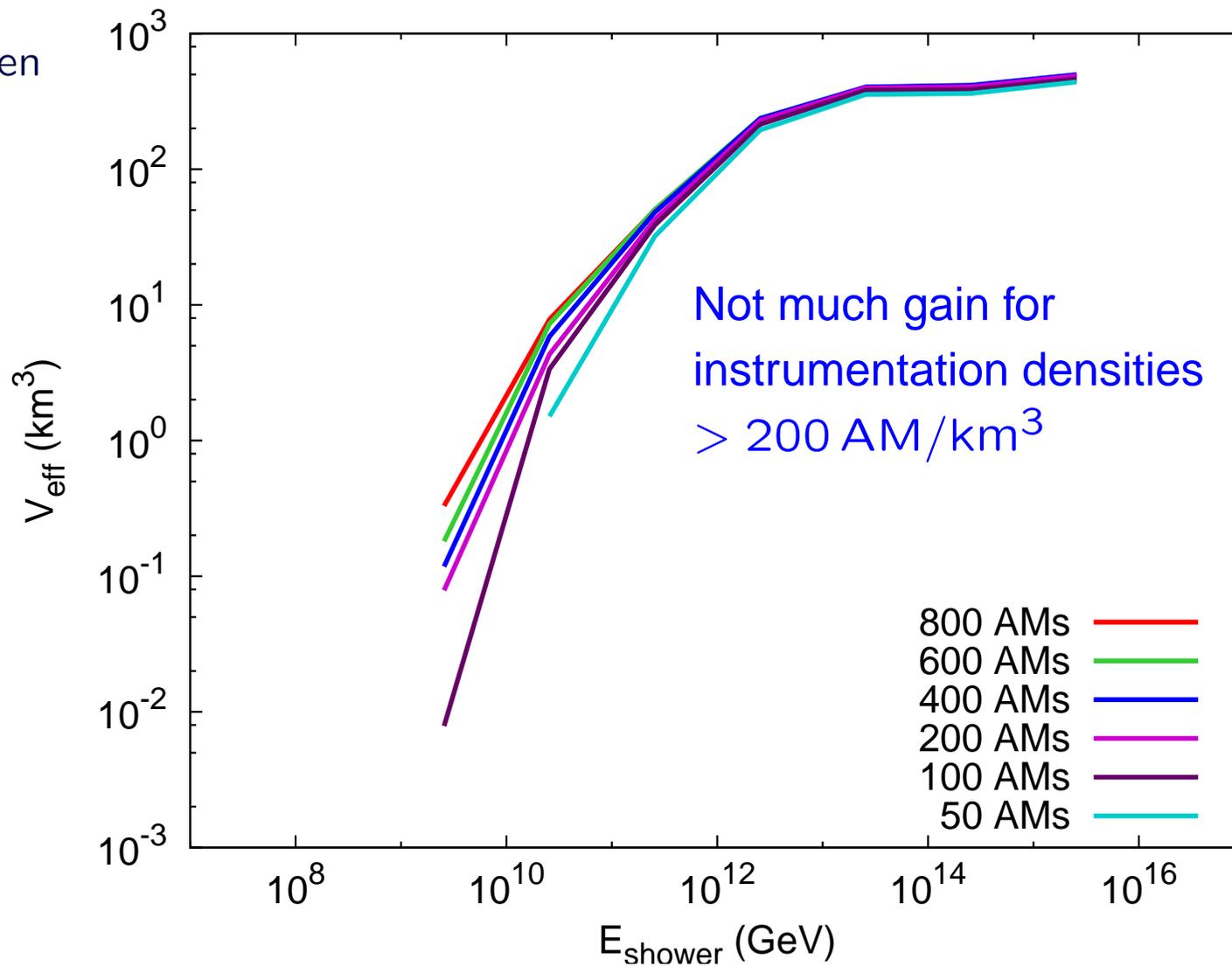
- Use the reconstructed position
- Use the model of the signal amplitudes
- Minimise χ^2 of amplitude residuals

Energy reconstruction



Instrumentation density

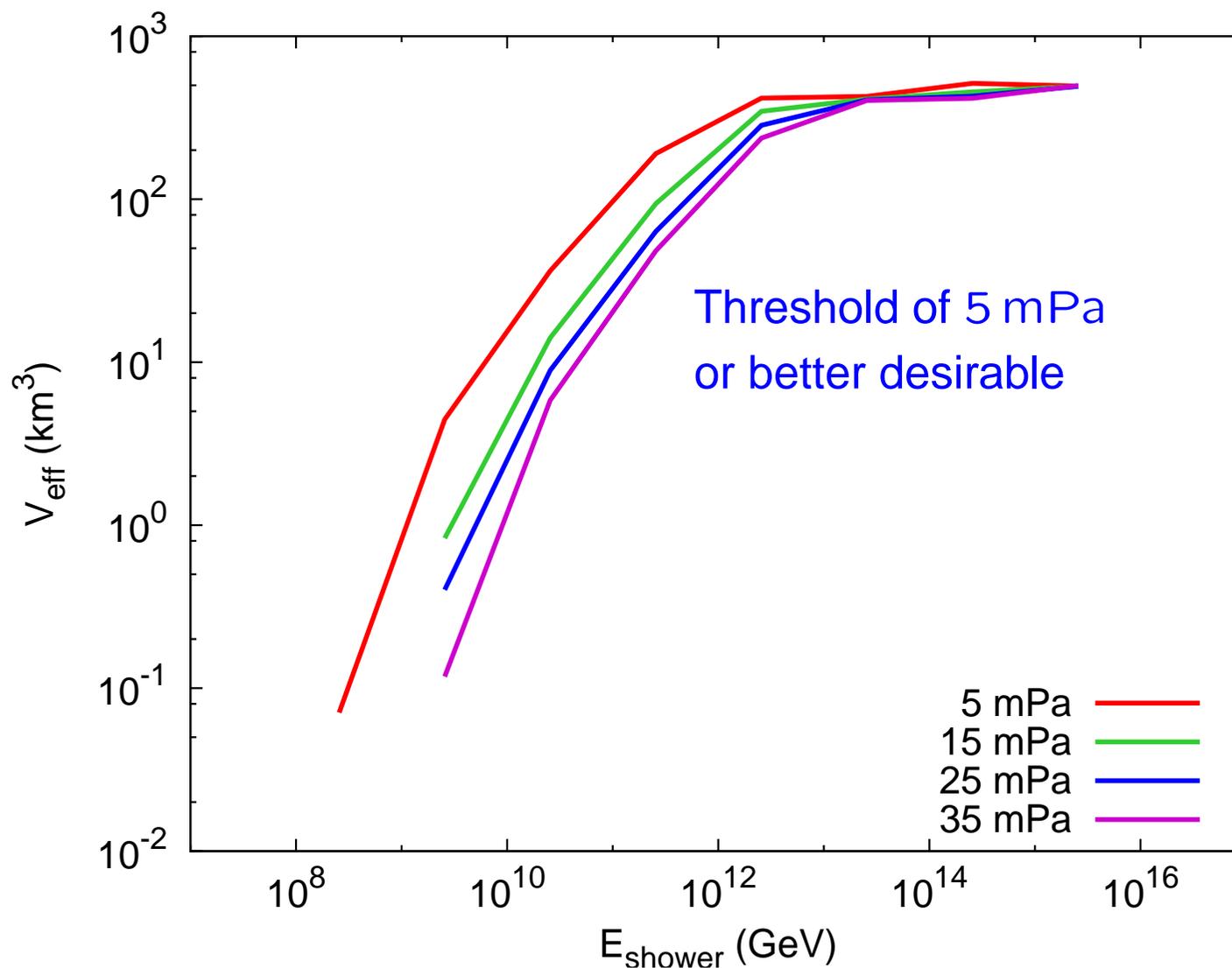
$$V_{\text{eff}} = \frac{N_{\text{det}}}{N_{\text{gen}}} V_{\text{gen}}$$



Instrumented volume: 1 km^3

Threshold: 35 mPa

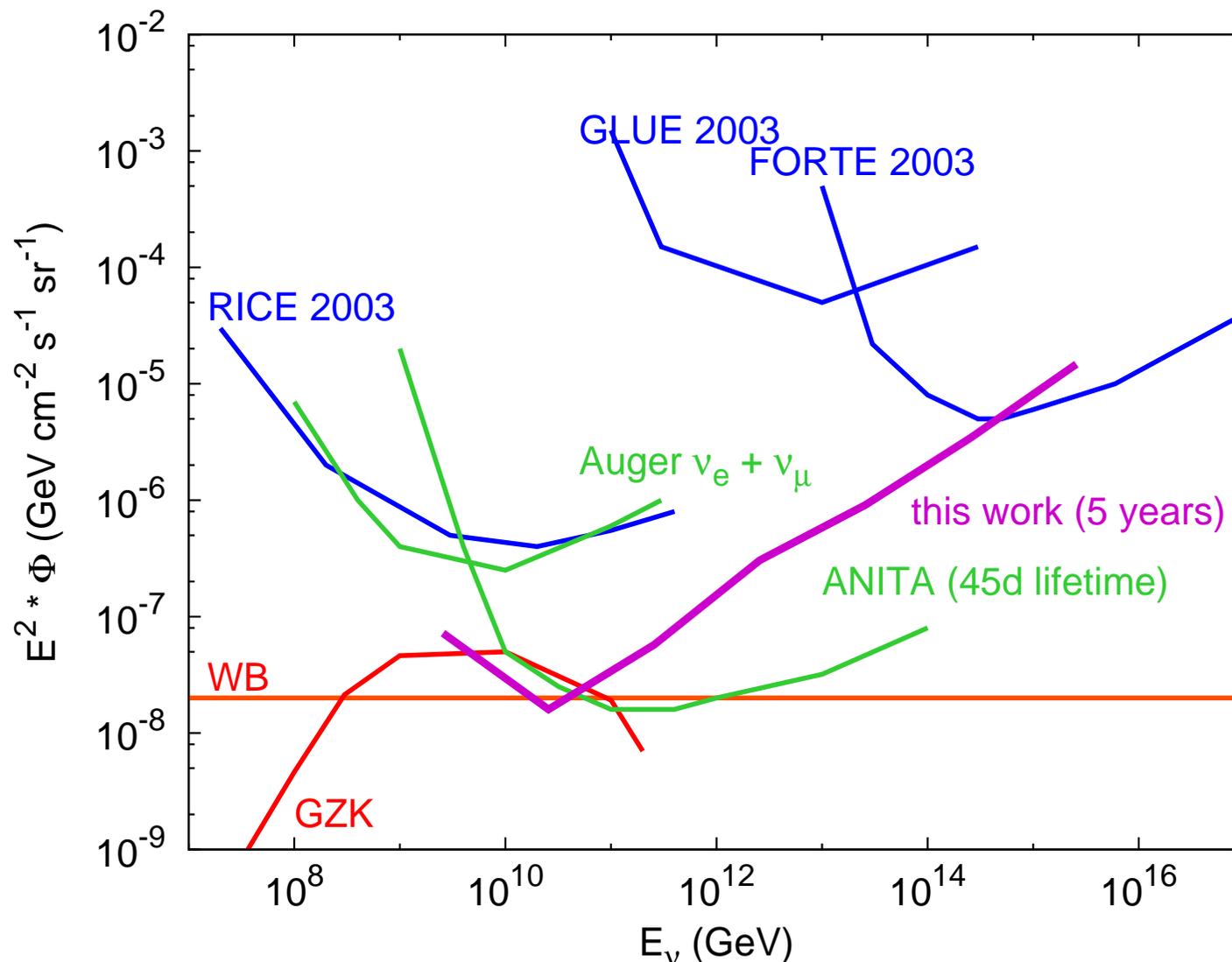
AM threshold



Instrumented volume: 1 km³

Density: 400 AM/km³

Flux Limits



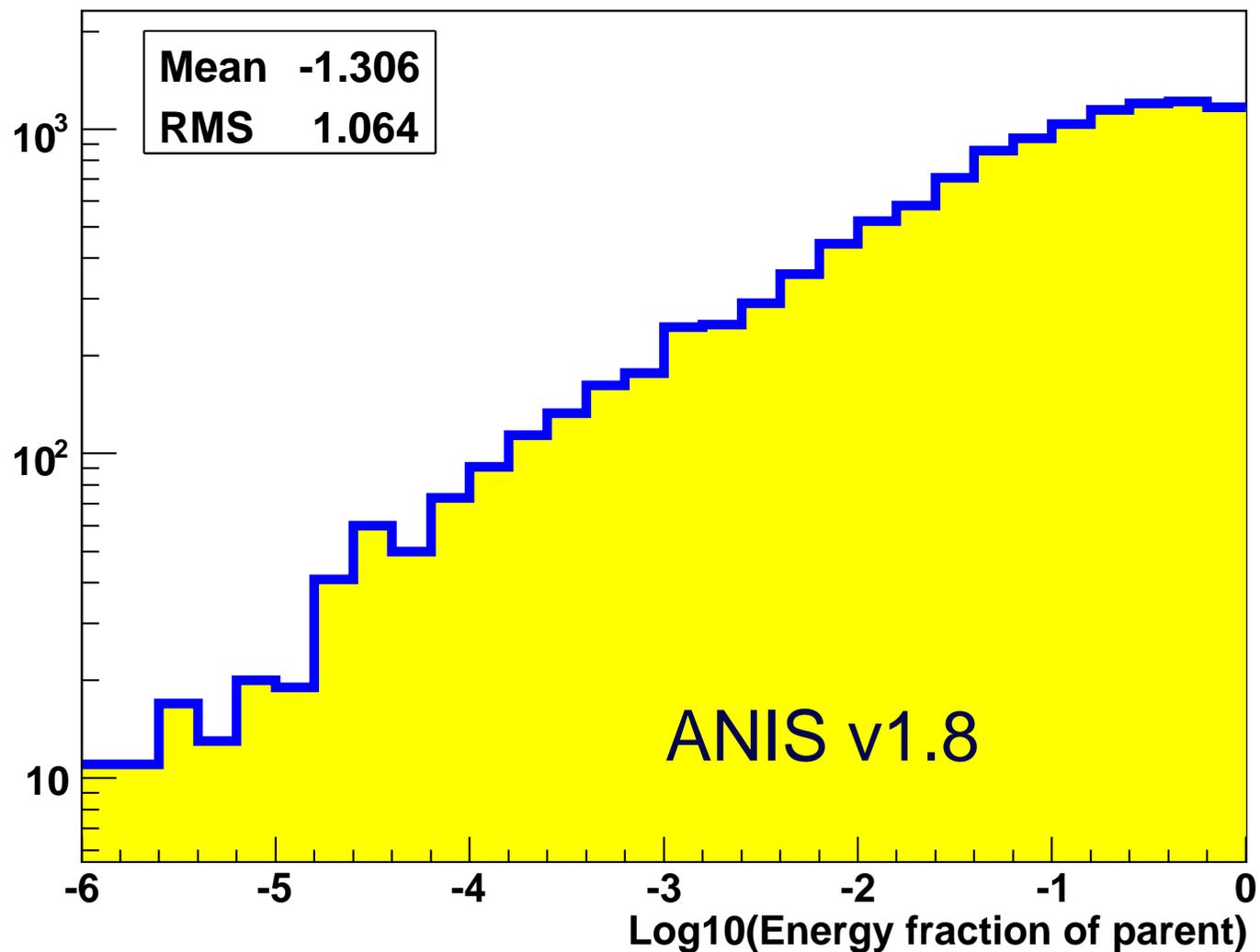
Instrumented volume: $30 \times 50 \times 1 \text{ km}^3$ Density: 200 AM/km^3 Threshold: 5 mPa
 $3 \cdot 10^5$ DAQ channels @ 100 kHz (moderate data rate)

Summary

- A complete simulation chain for an acoustic underwater neutrino detector was developed.
- Very large detector volumes ($10^3 - 10^4 \text{ km}^3$) required to check predictions of theoretical models (e.g. GZK neutrinos).
- An instrumentation density of $100 - 200 \text{ AM/km}^3$ seems sufficient; a detection threshold for bipolar acoustic signals of 5 mPa seems desirable.
- Neutrinos with an energy $E_\nu \geq 10^{18} \text{ eV}$ can be detected and reconstructed.
 - Direction reconstruction: Median 7°
 - Energy reconstruction: **factor 3**

y Distribution

Hadrons



Energy transfer from the neutrino to the hadronic shower