Time Domain Analysis of Askaryan pulses

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Outline

- SLAC ‘02 data collection
- RF calibration and pulse extraction
- Analysis and results
- Summary

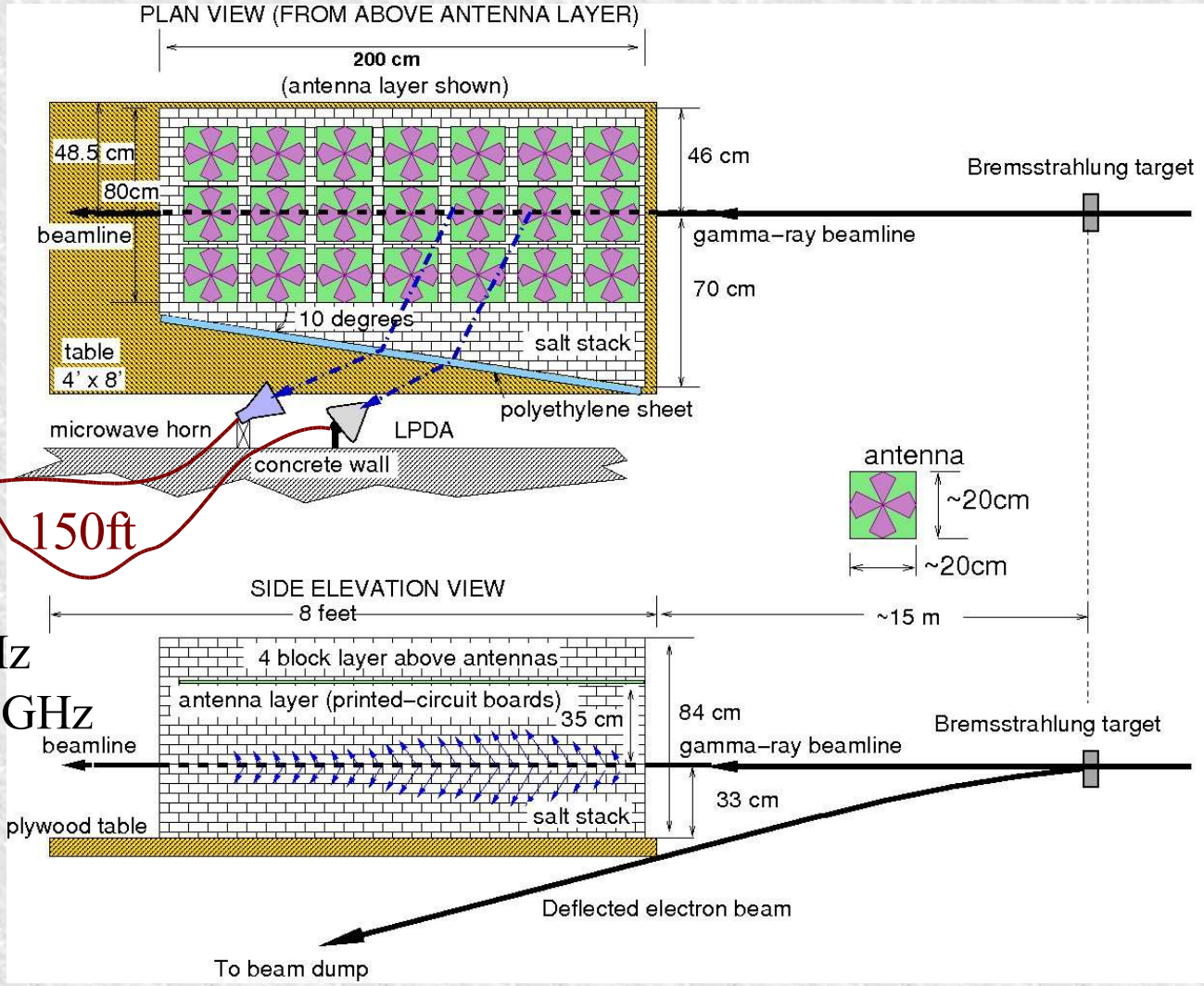
Data taking setup

Digitizing scope

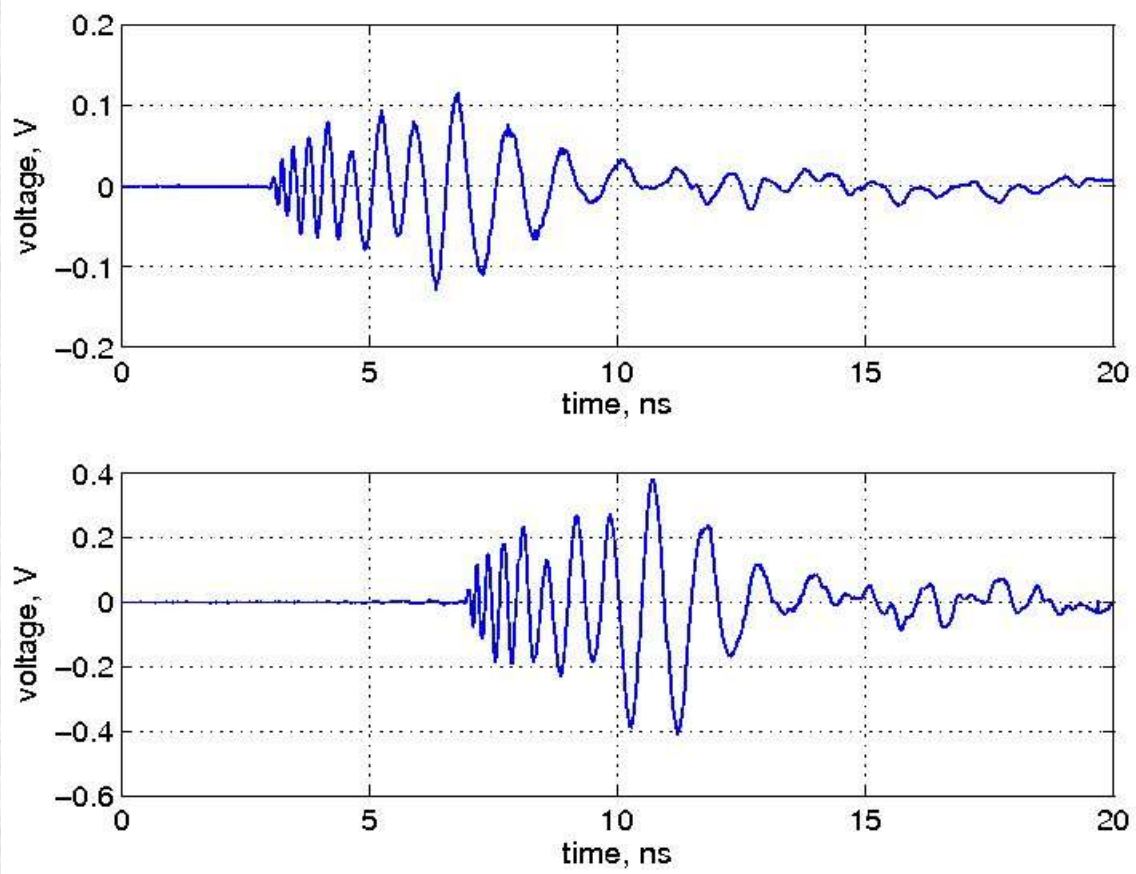
CSA8000

150ft

LPDA
Nominal BW; 1-18 GHz
Measured BW; 0.8-20 GHz
Gain; ~ 4-7 dB



Raw Askaryan pulse data



Two runs available:

I. Sampled at 50 GS/sec
   no filter
   20 dB attenuator
   $E_{sh} \sim 1.9$ EeV

II. Sampled at 100 GS/sec
   no filter
   no attenuator
   $E_{sh} \sim 0.66$ EeV

Raw pulse formation

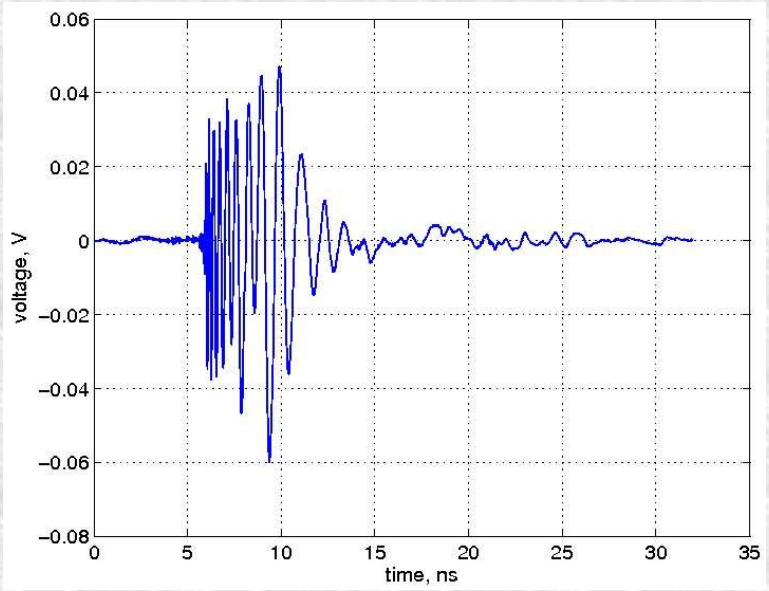
- True pulse is distorted by the antenna and the cable

$$V_{raw} = E_{Ask} \circ h_{LPDA} \circ R_{cable}$$

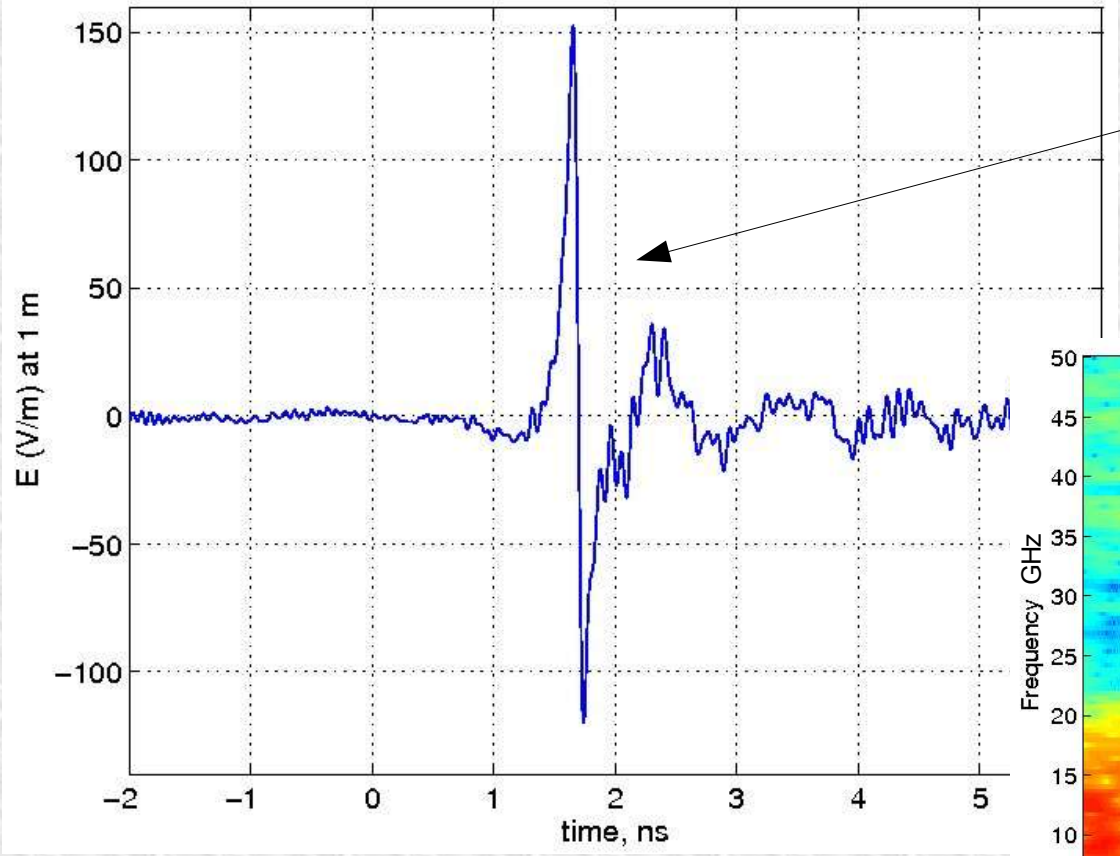
- Fourier Domain construction; each element can be treated in terms of a transfer function

$$H_{raw} = H_{Ask} \cdot H_{LPDA} \cdot H_{cable}$$

- Extracting the original Askaryan pulse requires the knowledge of antenna and cable complex responses
- Time domain deconvolution can be done through;
  - complex division in Fourier space
  - Weiner algorithm with noise reduction


0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
voltage, V
0
5
10
15
20
25
30
35
time, ns

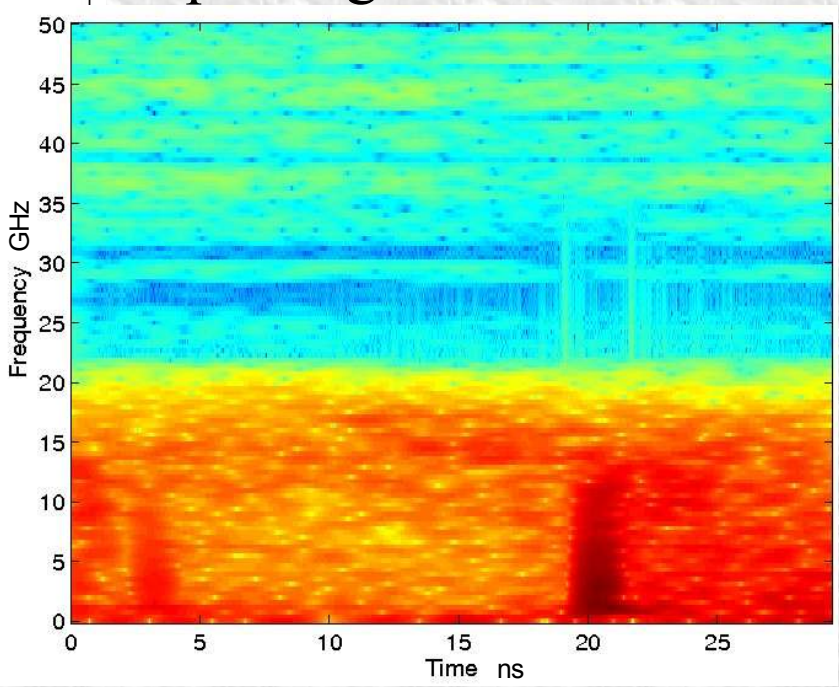
Measured Askaryan pulse



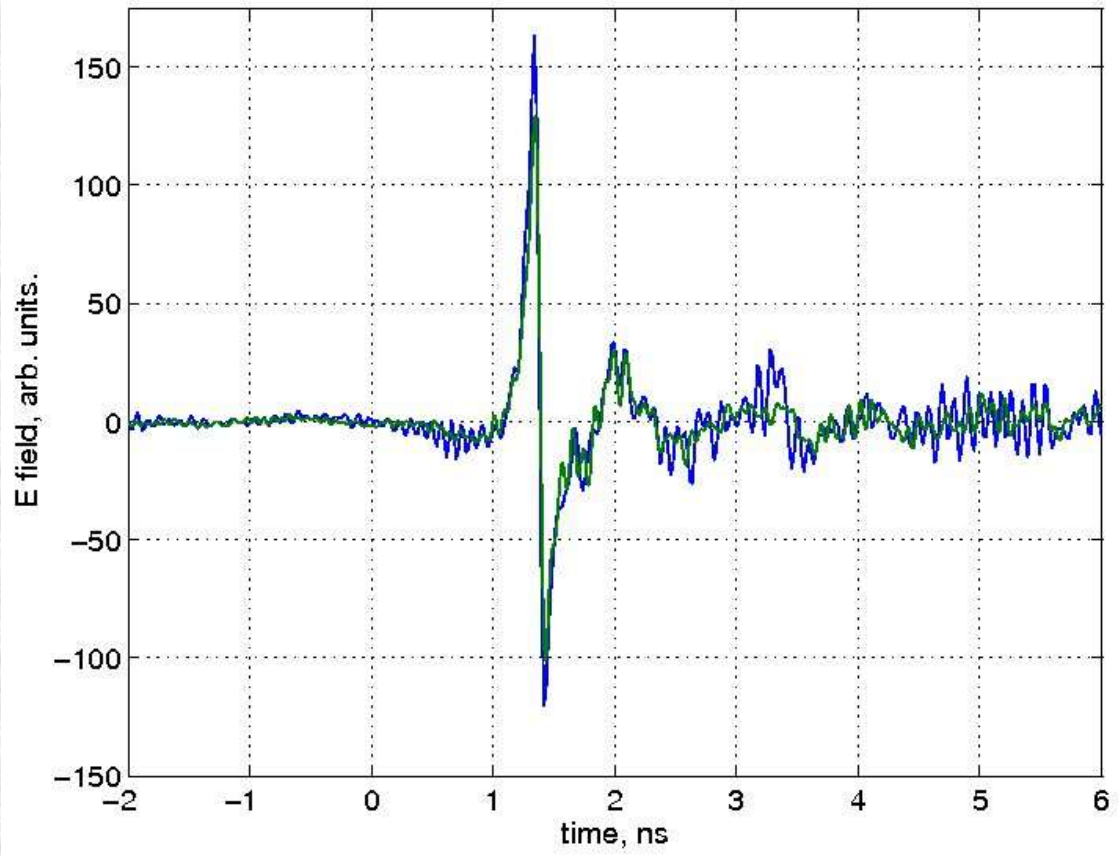
Electric field at antenna

Broadband measure:
SNR>1 in 0.5-11.5 GHz

spectrogram of E-field

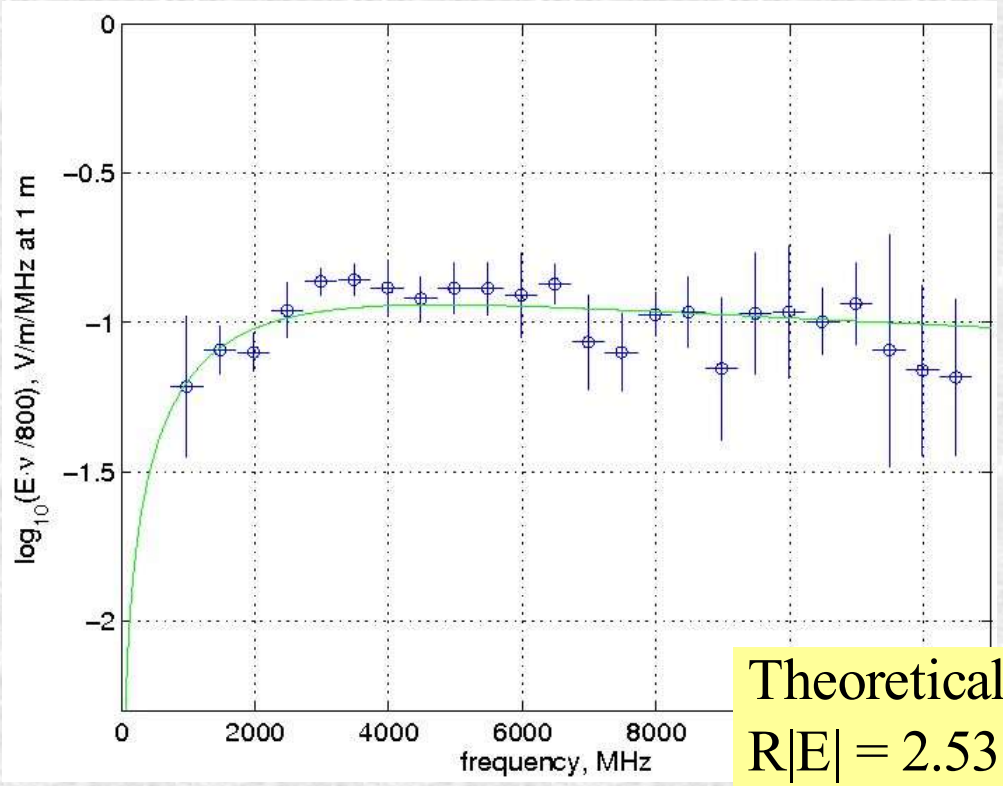


Comparison of runs



- Pulses rescaled by estimated energy of showers (estimate good to about 20%)
- Askaryan pulse is reproducible, since any shower to shower variations are averaged during a run
- blue trace is noisier due to 20dB attenuator

Spectral power distribution



Data corrected for dispersion at salt/air interface and for near-field effects:

- Antenna is in the far-field for $\nu < 800$ MHz; in the near-field the shower coherence region as seen by the antenna scales inversely with frequency
- Thus, the field strength correction
  $E \rightarrow E \cdot \nu/800$

Theoretical expectation:

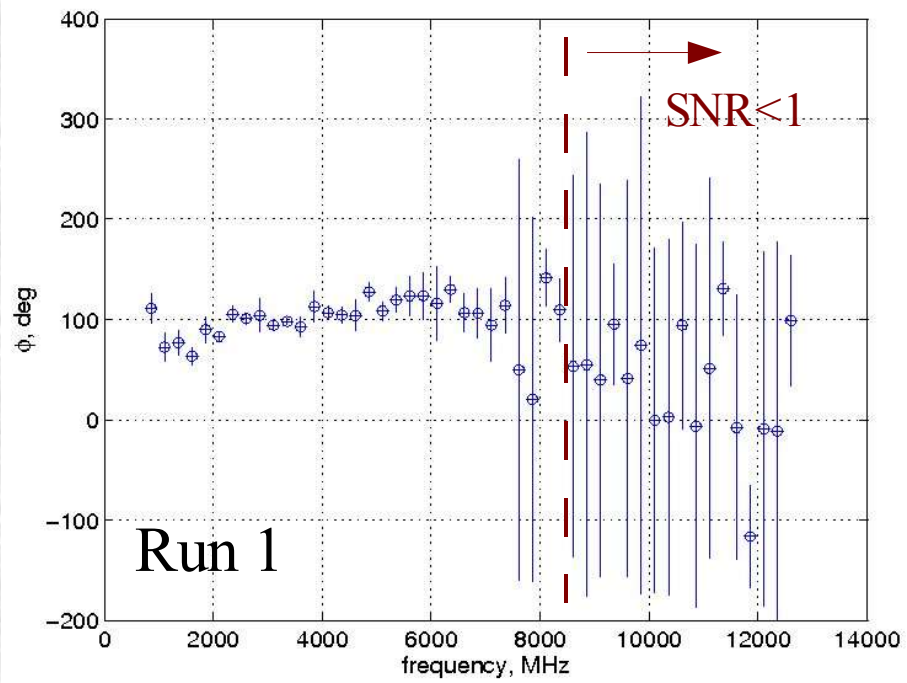
$R|E| = 2.53 \cdot 10^{-7} \cdot E_{sh} \cdot 0.52 \cdot \nu/\nu_0 \cdot (1+(\nu/\nu_1)^{1.44})^{-1}$

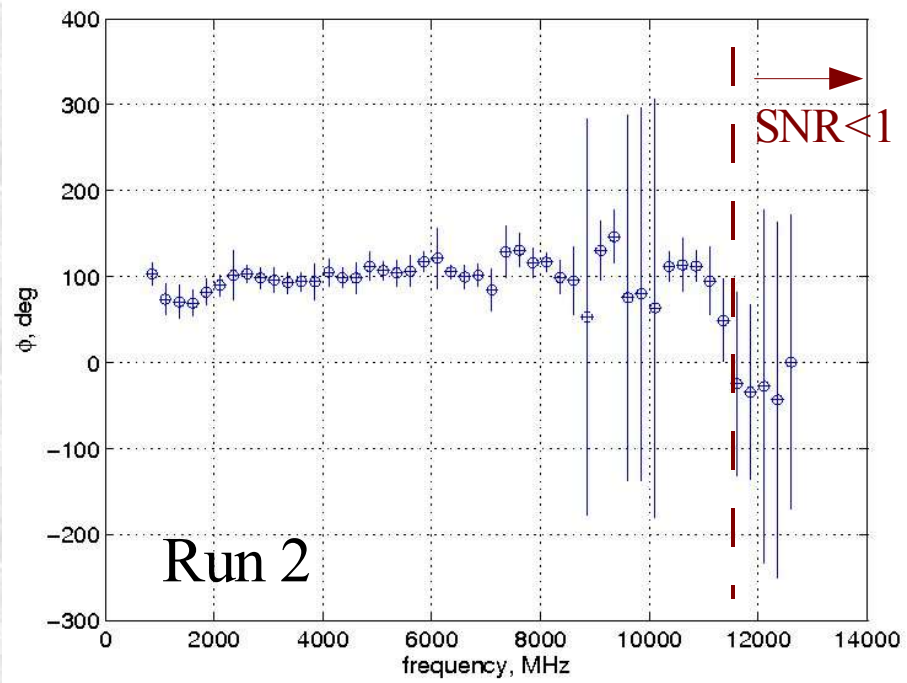
$E_{sh}=6.6 \cdot 10^5$ TeV

$\nu_0=1150$ MHz (reference frequency)

$\nu_1=2860$ MHz (decoherence frequency, salt)

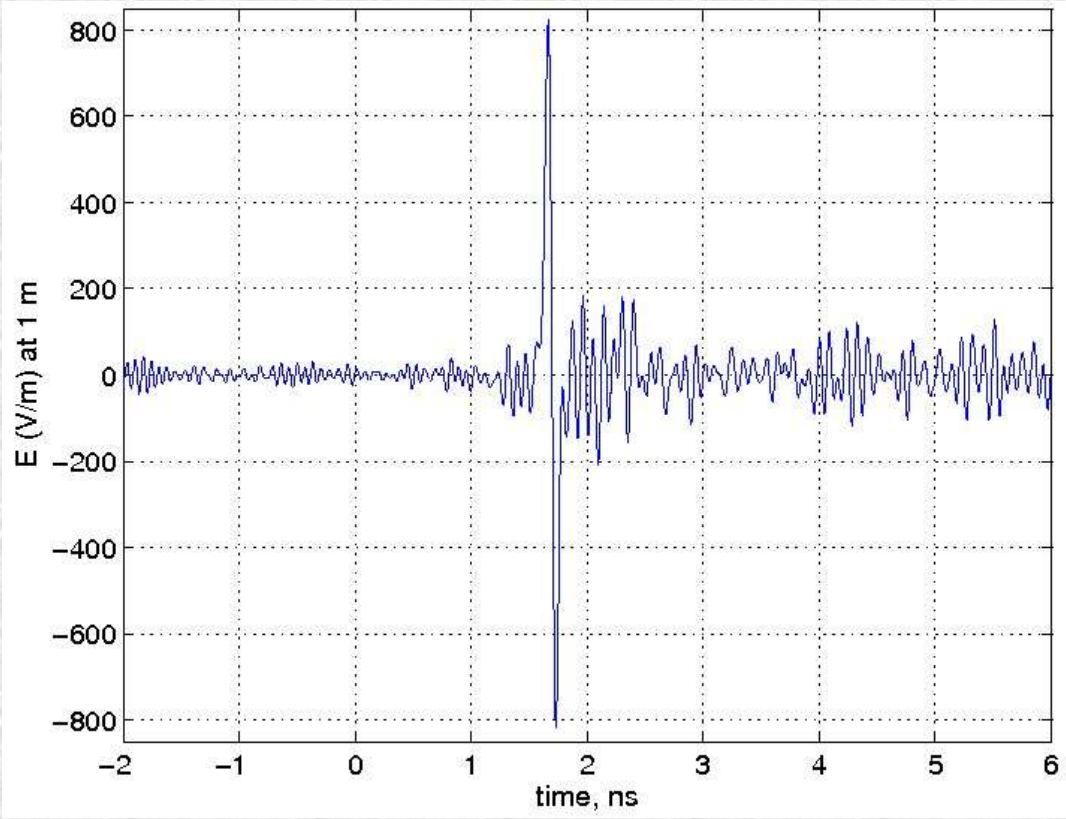
Phase characteristics





- Phase reference at the pulse mid-point (zero crossing)
- No evidence that phase is running with frequency

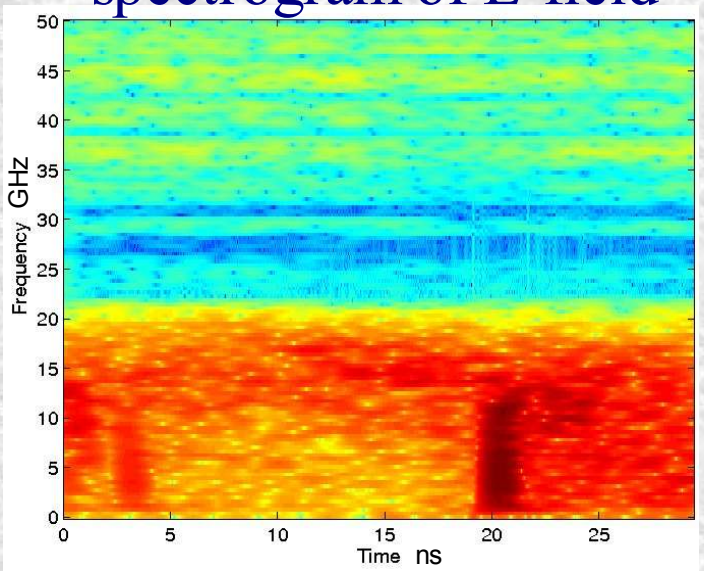
Askaryan pulse in far-field



E-field at far-field antenna

- Time domain representation of Askaryan pulse with near-field spectral correction
- Pulse appears very symmetric

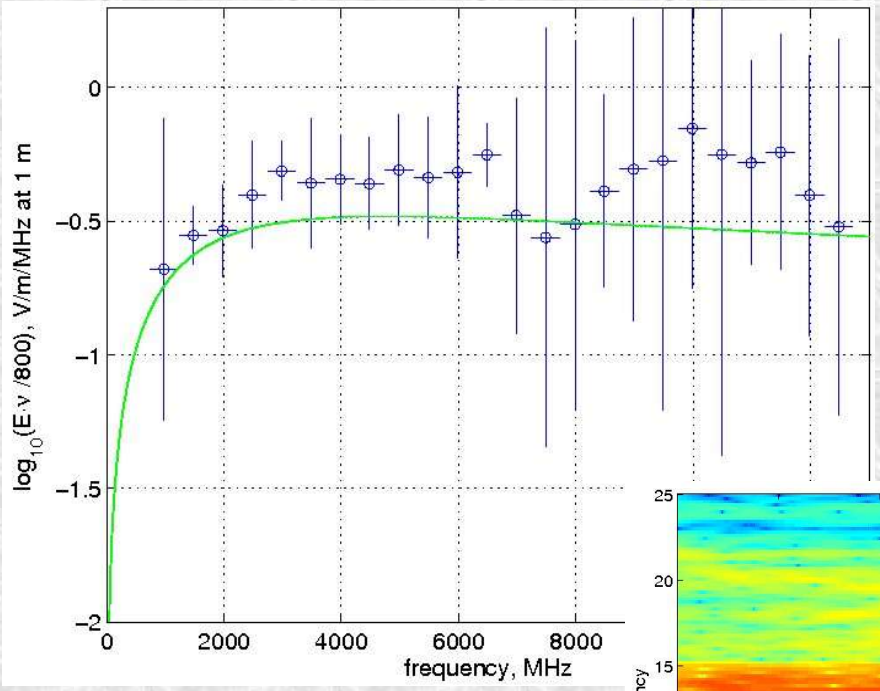
spectrogram of E-field

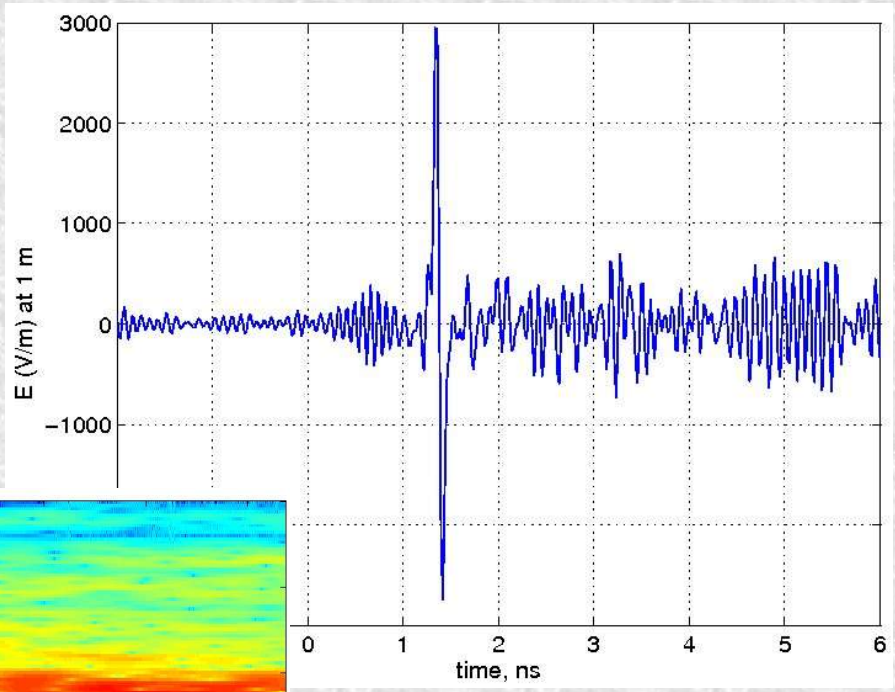


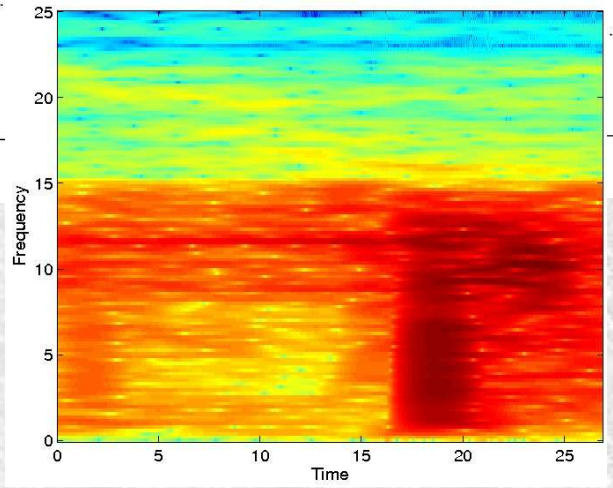
Summary

- First broadband, time-domain measurement of an Askaryan pulse is reported
- The absolute RF power per frequency agrees well with theoretical expectations
- Pulse phase characteristics disagree with (the only!) published theoretical result; ZHS '92
  - predictions of pulse phase behavior are very important for maximizing analysis efficiency of RF neutrino experiments
- More accelerator based measurements should be taken to verify time-domain characteristics of Askaryan pulses in different media and over wider energy range

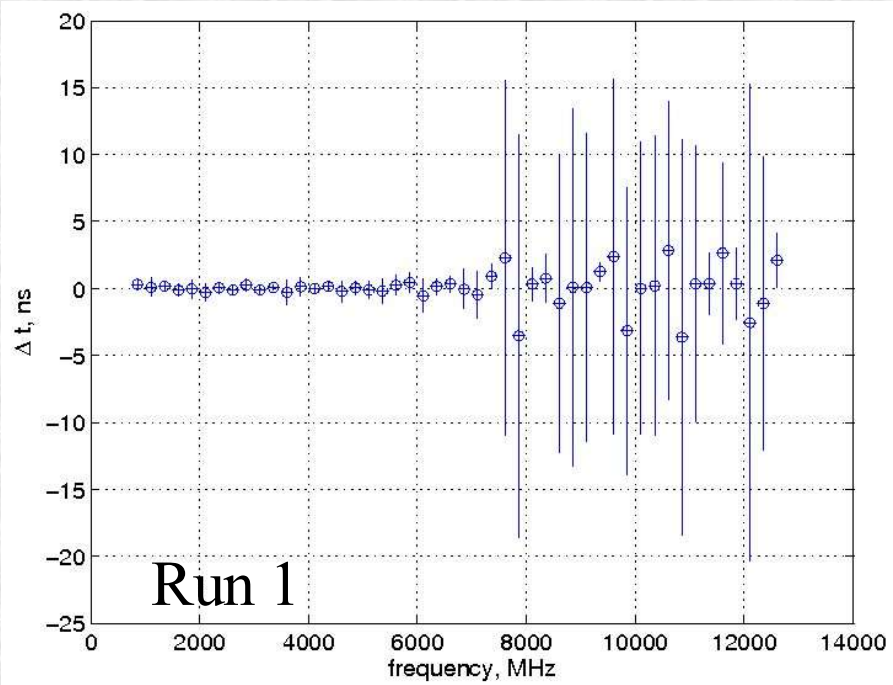
Run 109 spectrum and "far-field" pulse

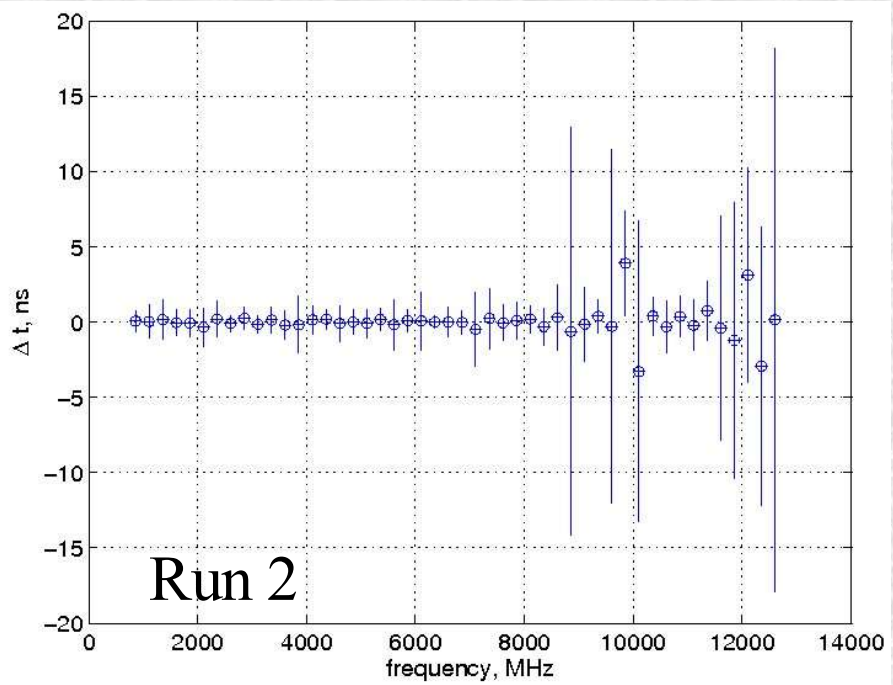




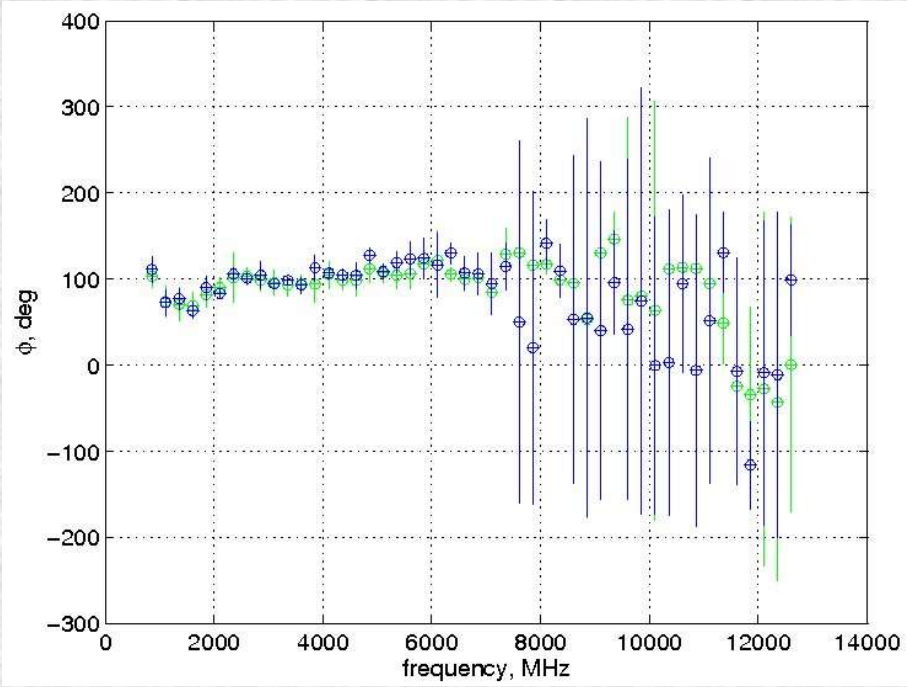
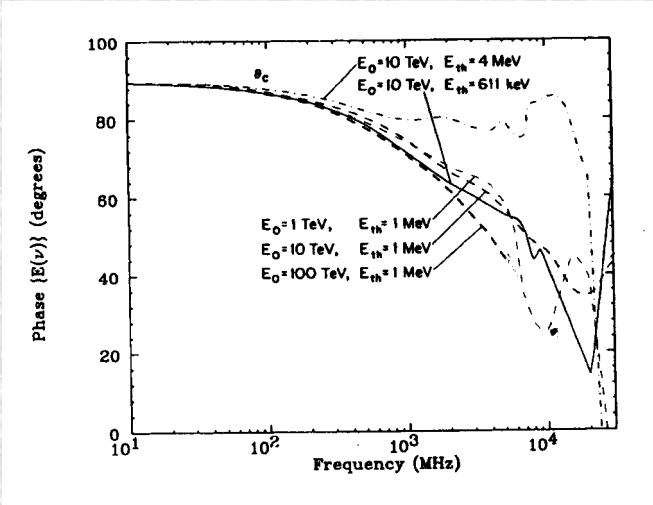


Group delays





Phase comparison



Phase ZHS ‘92