Radio Signals from Photon Beams in Sand and Salt

Dawn Williams
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UHE Neutrino Astronomy

- From 10^{15} to ~10^{21} eV, neutrinos are the messenger
  - Photons interact with cosmic IR background
  - Cosmic ray protons bend in IG magnetic field
- "Guaranteed" GZK neutrino flux around 10^{18} eV
- Predicted neutrino fluxes are very low
  - Cubic kilometer scale detectors required
- Optical neutrino detectors: ice, water
  - Scattering limits effective volume
- Another method: radio

The Askar'yan Effect

- Proposed by G. Askar'yan, 1962
  - High-energy neutrino interacts in a solid dielectric
  - Net charge excess develops in electron-γ shower
  - Charge excess moving at speed of light in vaccuum → Cherenkov radiation results
- The key: Cherenkov radiation is *coherent* for wavelengths larger than shower bunch size
  - For sand, salt and ice, coherent at freq. < 1-10 GHz
  - Power scales *quadratically* with particle energy
  - Most energy in radio at >PeV energies

The targets: sand, salt and ice

- Salt, sand and ice transparent in radio
- Ice: Antarctic icecap (RICE, ANITA), Greenland
  - Possible co-detection with IceCube
  - Large volume seen with ANITA
- Sand: lunar regolith (GLUE, others)
  - Showers visible from radio telescopes at > 10 EeV
- Salt: salt domes in Gulf Coast region (SALSA)
  - Easily accessible
  - No terrestrial radio interference

Measuring the Askar'yan Effect

- Air showers
  - Complicated by geomagnetic effects
- RICE, lunar regolith
  - Not enough volume/livetime
- Argonne electron beamtest
  - Sand target
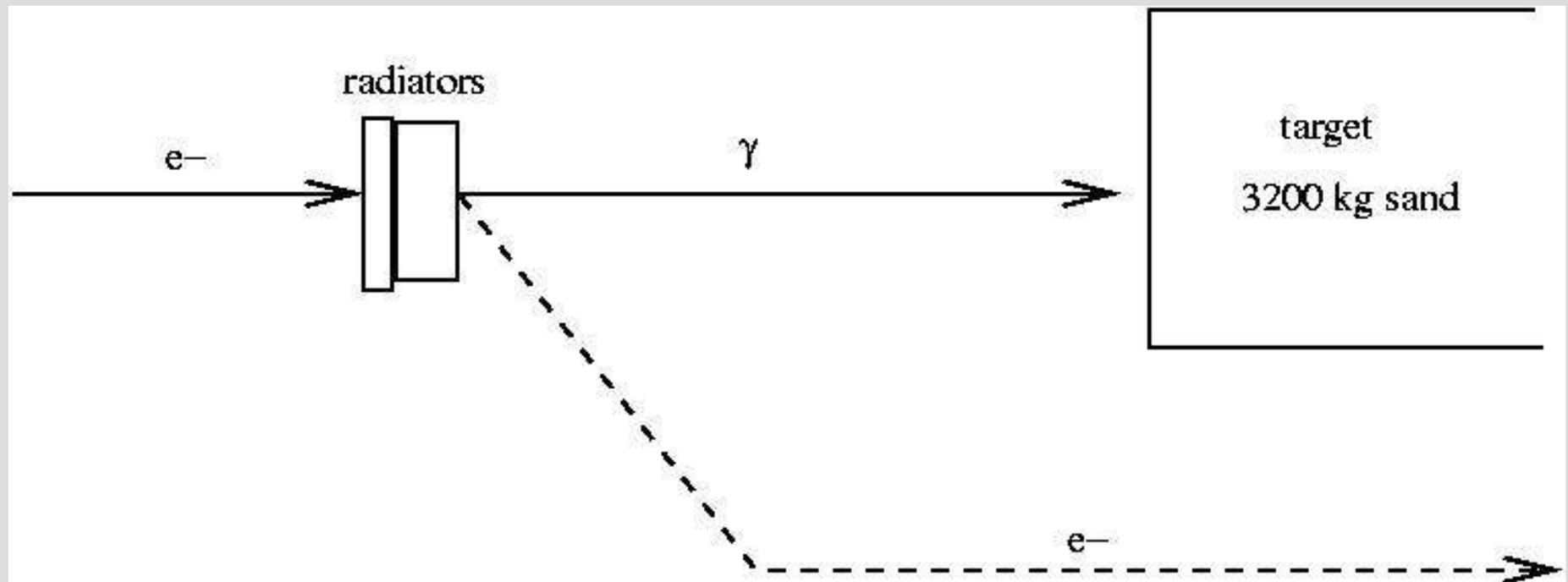 - Transition radiation obscures Cherenkov

Argonne pulse
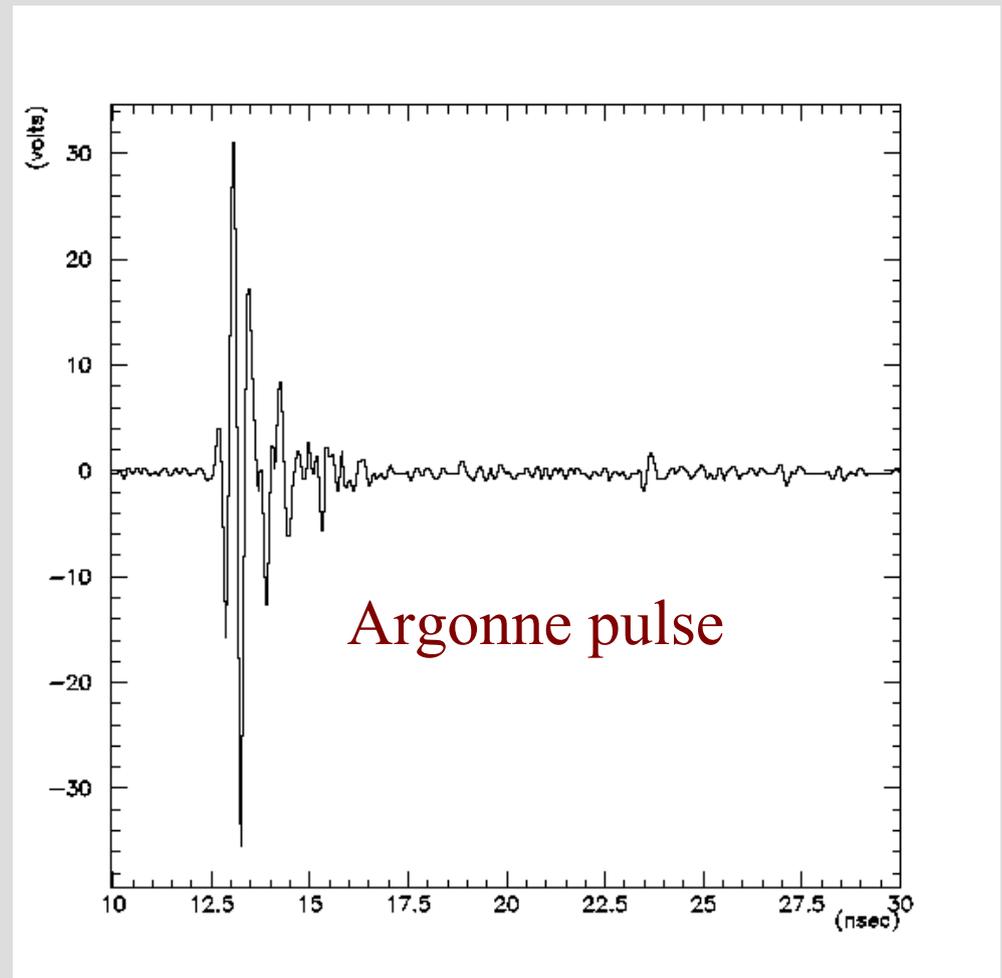
The SLAC beamtests

- ## 2000: sand target
  - Argonne: P. Schoessow
  - JPL: P. Gorham, G. Resch
  - SLAC: C. Field, R. Iverson,
    A. Odian, D. Walz
  - UCLA: D. Saltzberg, D. Williams
- ## 2002: salt target
  - SLAC: C. Field, D. Walz
  - UCLA: D. Saltzberg, D. Williams
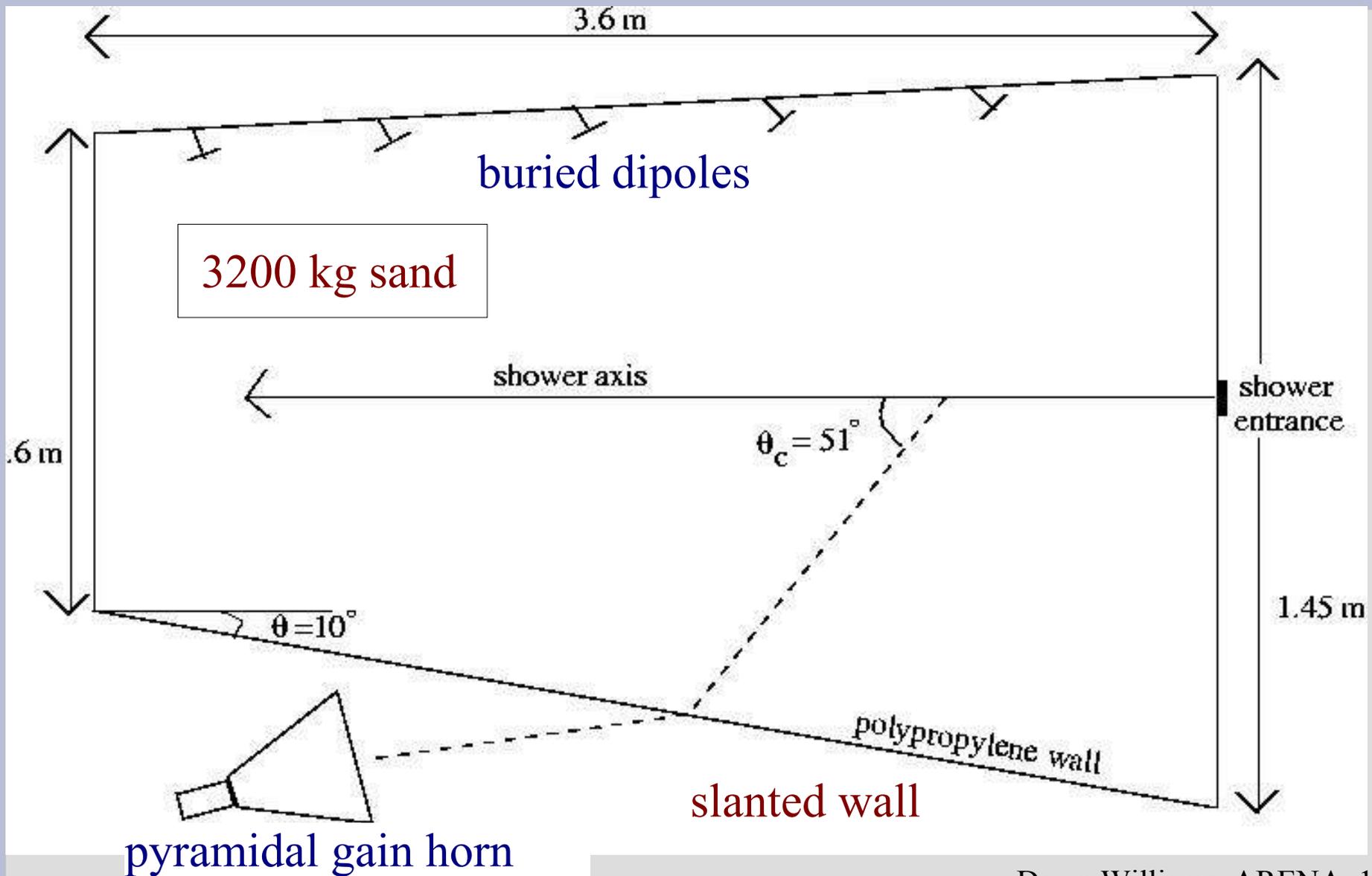 - UH Manoa: P. Gorham,
    E. Guillian,
    R. Milincic

The SLAC Photon Beam

- Photon beam into target
  - No TR at interface.... all radiation from shower
- Variable radiators/beamcurrent
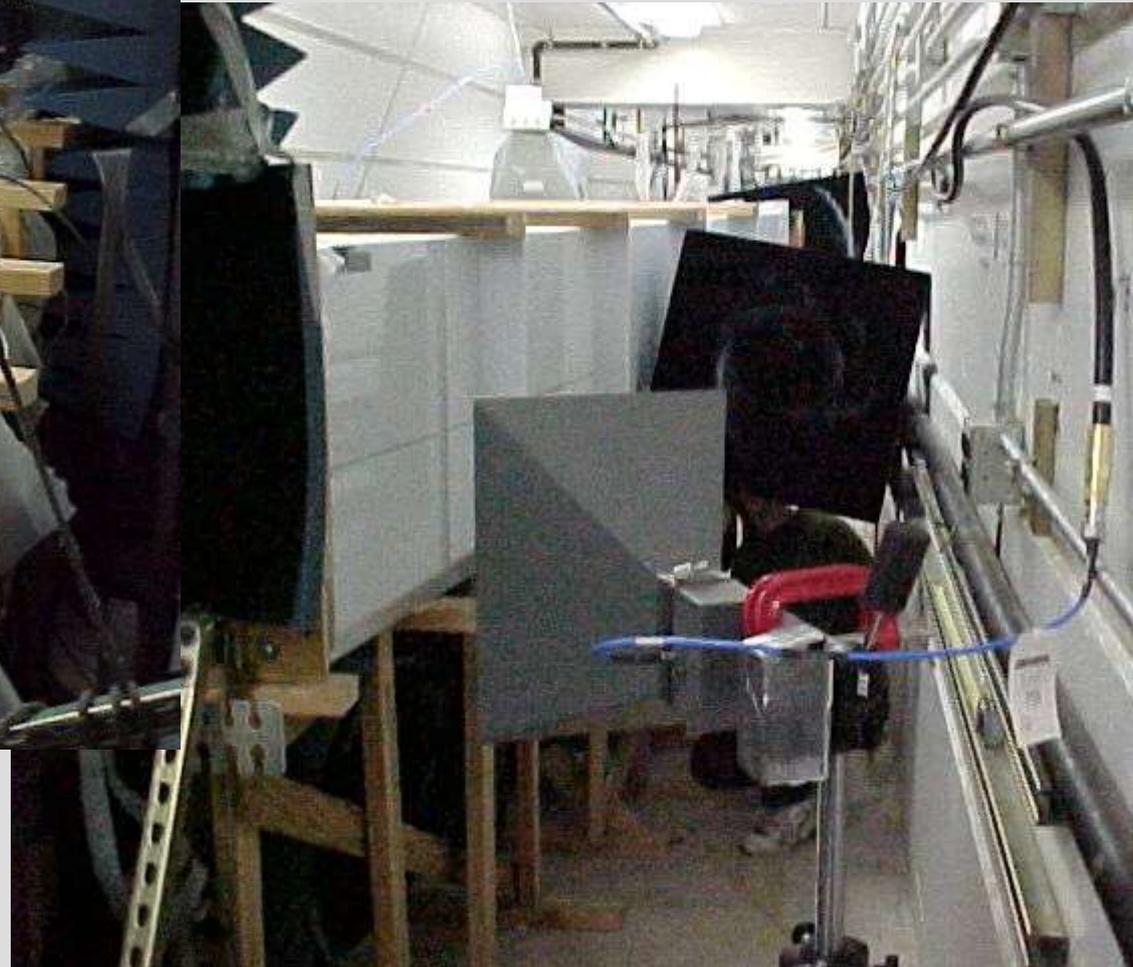 - equivalent bunch energy from 10^{15} to 10^{19} eV
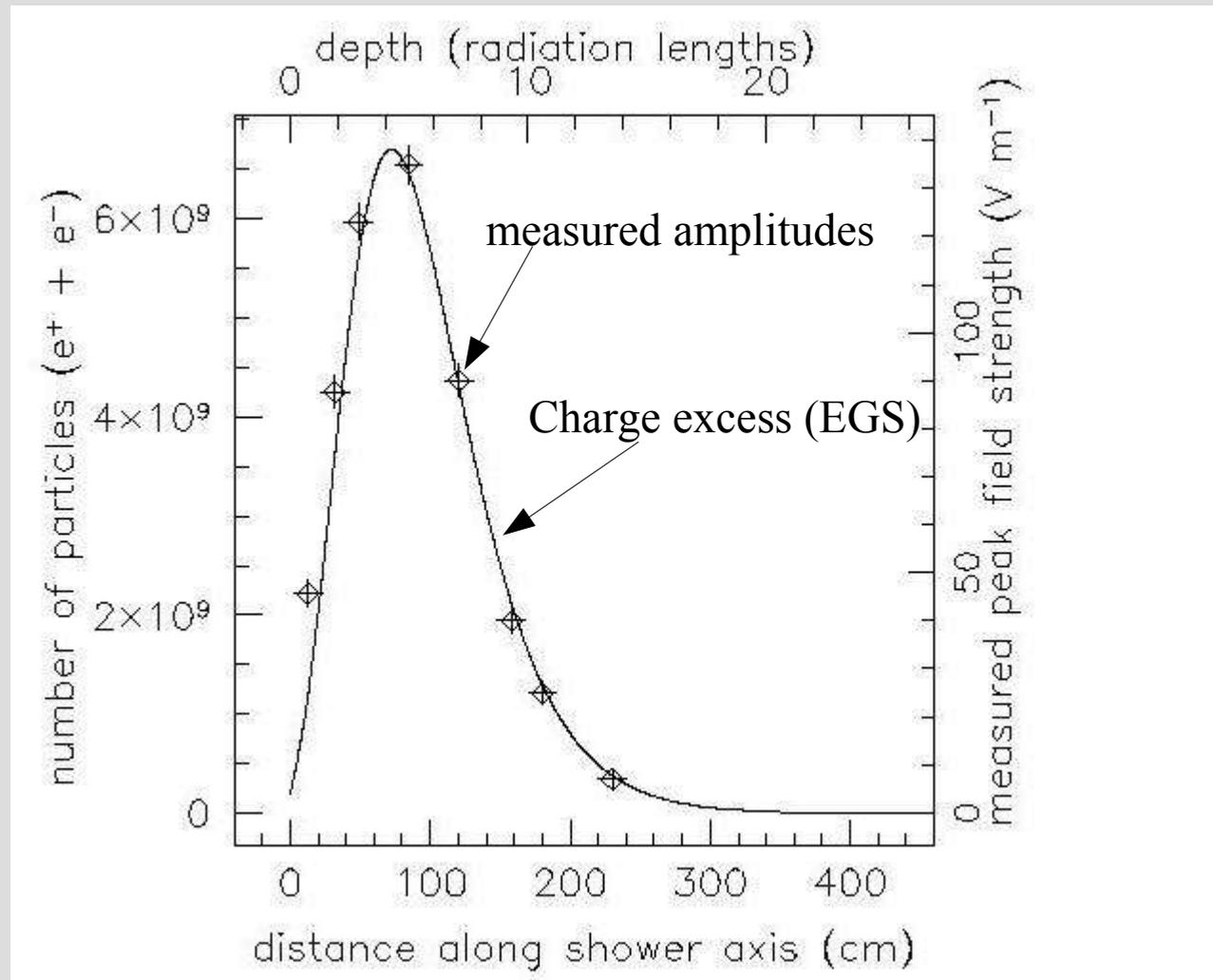
SLAC 2000: Sand target

3.6 m

buried dipoles

3200 kg sand

shower axis

$\theta_c = 51°$

shower entrance

.6 m

1.45 m

$\theta = 10°$

polypropylene wall

slanted wall

pyramidal gain horn
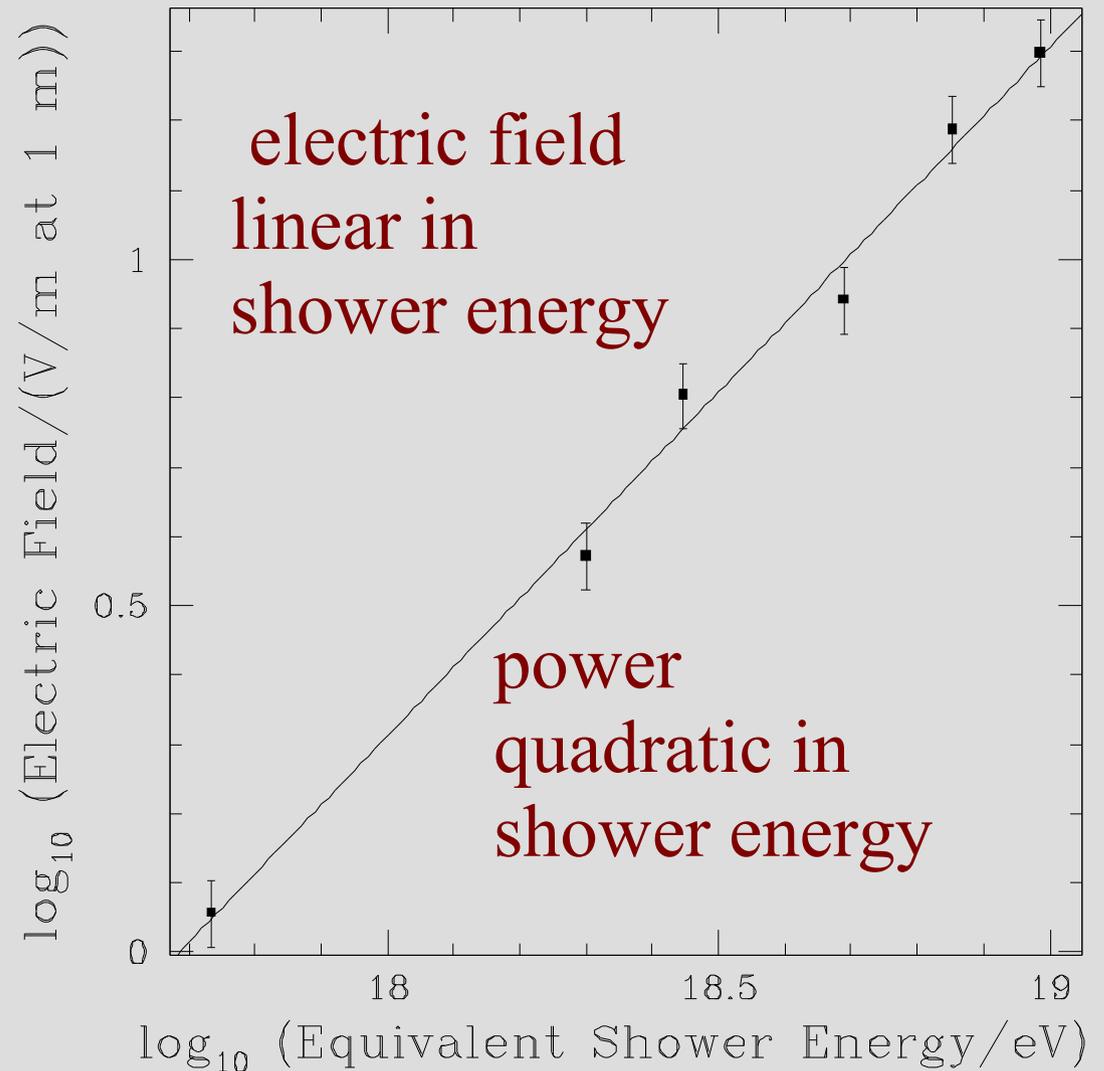
The "Kitty Litter" Experiment

downstream view

upstream view

SLAC 2000: Longitudinal Shower Profile
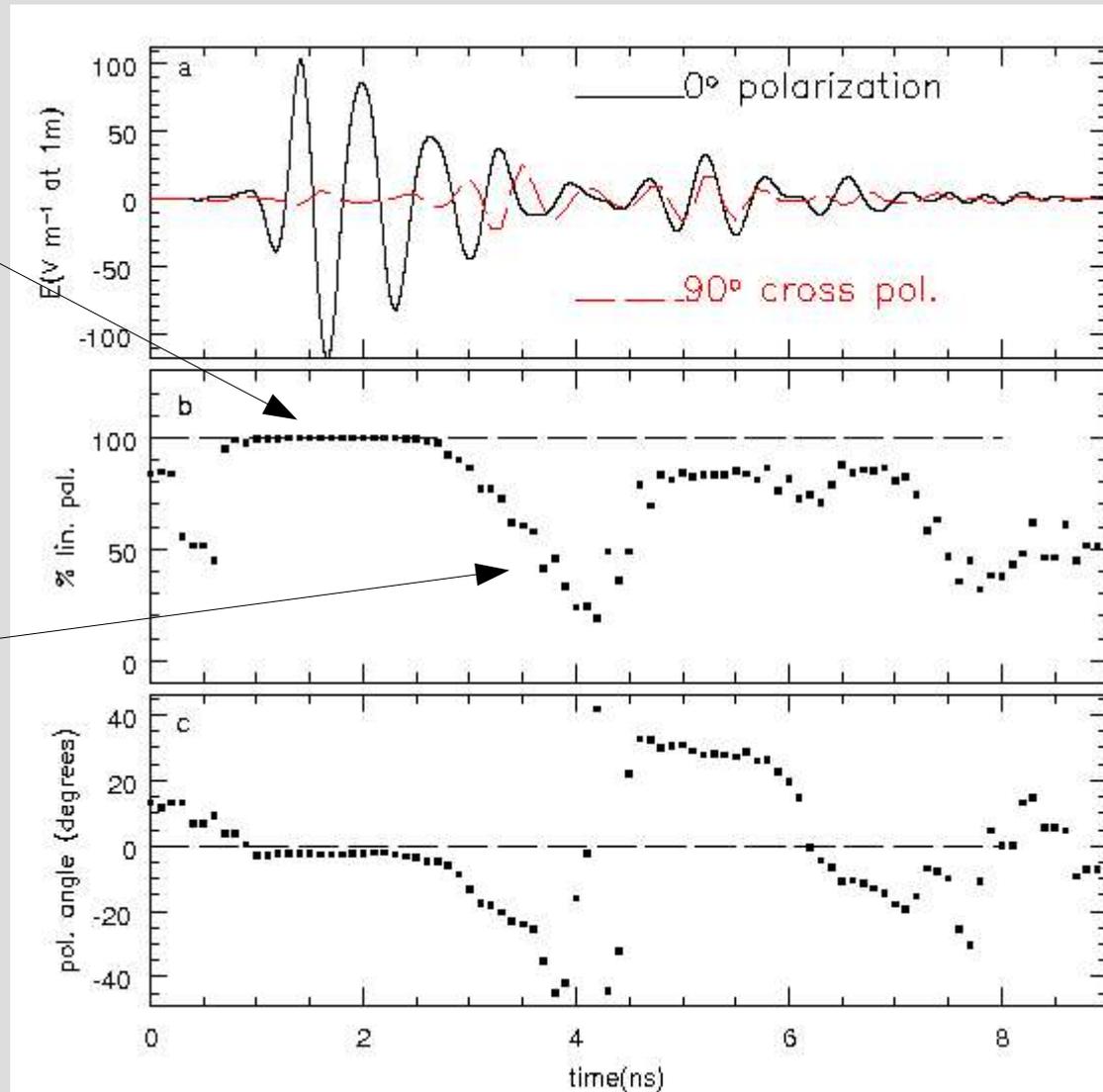

Also seen in salt

SLAC 2000: Coherence

Measured over 1.5
decades in energy

electric field
linear in
shower energy

power
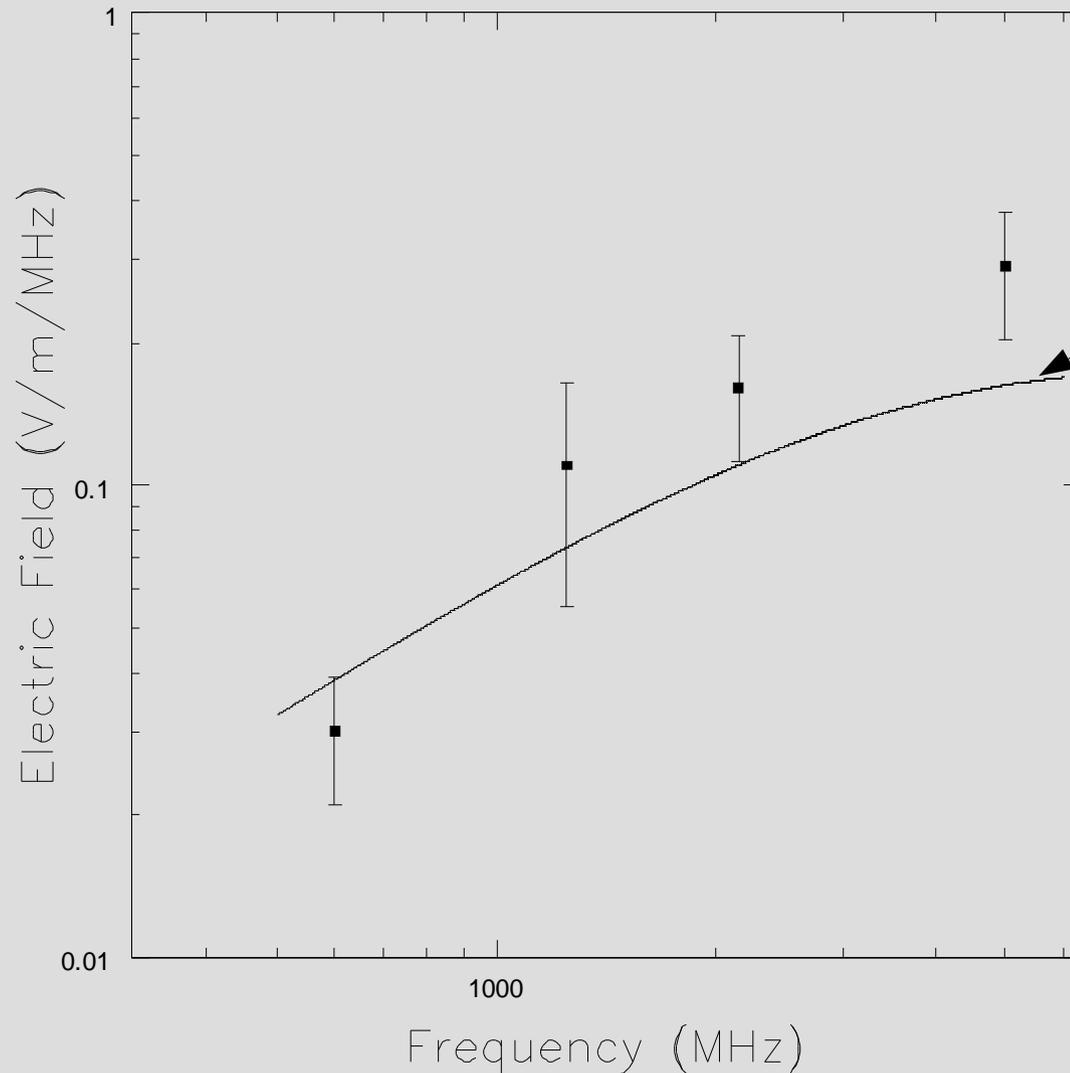quadratic in
shower energy

SLAC 2000: Polarization

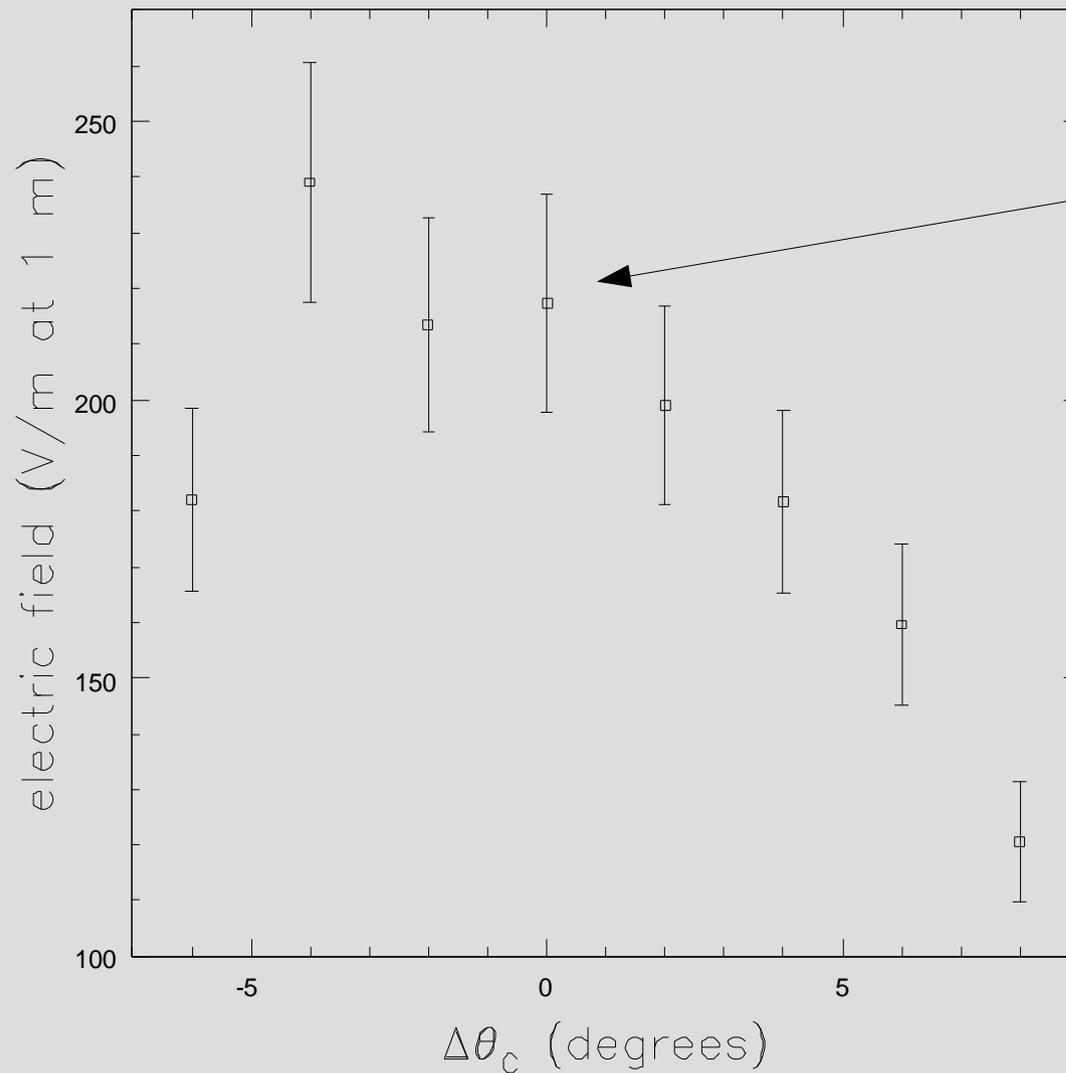100% linear polarization

reflections

SLAC 2000: Field Strength

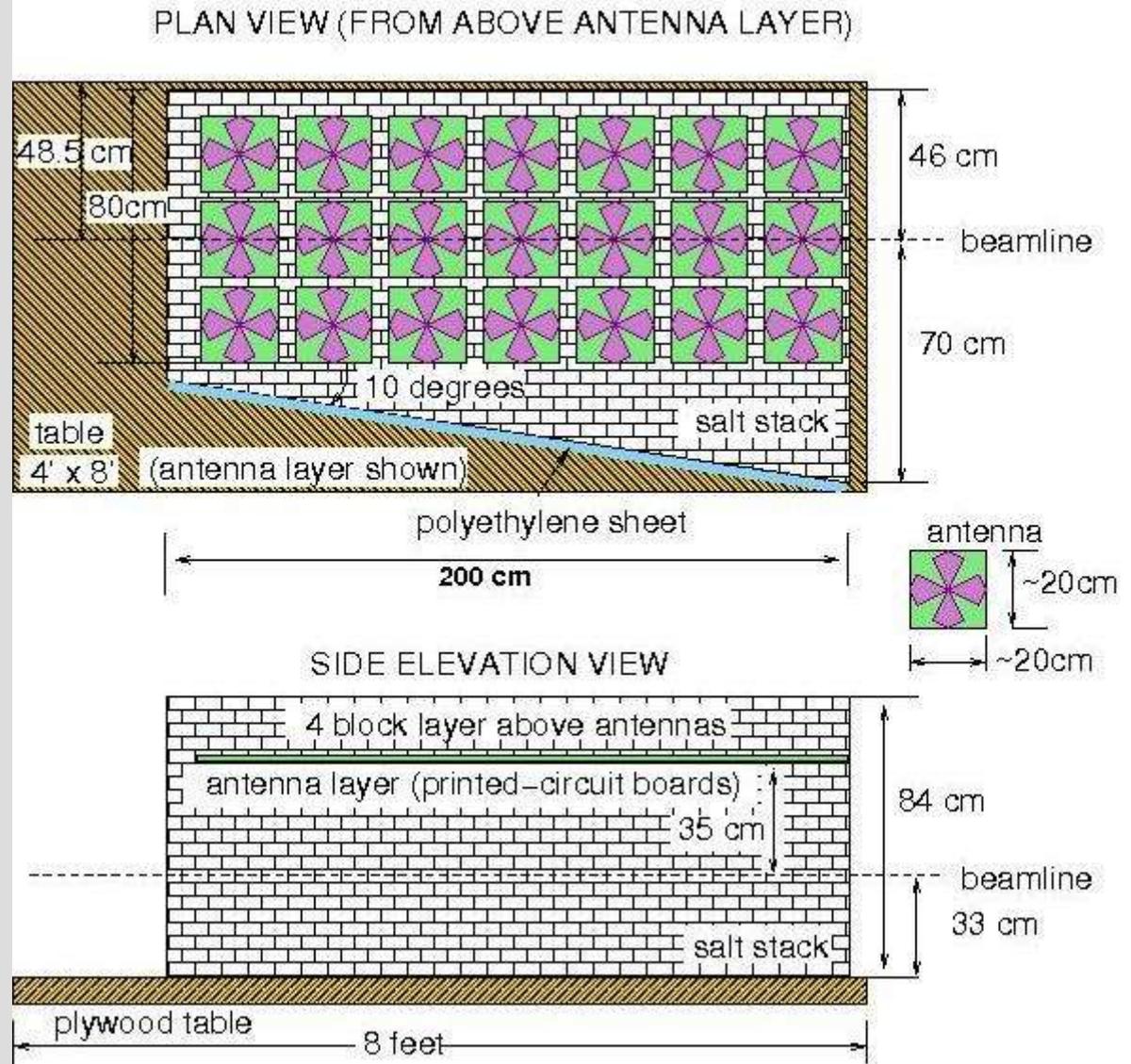Parameterization by Alvarez-Muniz, Vasquez and Zas

SLAC 2000: Cherenkov Angle

Peak at 0° offset from Cherenkov angle

SLAC 2002: Salt Target

- Target: 4 tons salt bricks
- Same geometry as sandbox
- Antennas:
  - External horns
  - Buried bowtie antennas
  - Log periodic dipole

PLAN VIEW (FROM ABOVE ANTENNA LAYER)

48.5 cm
80 cm
46 cm
beamline
70 cm
10 degrees
salt stack
table
4' x 8' (antenna layer shown)
polyethylene sheet
200 cm

antenna
~20 cm
~20 cm

SIDE ELEVATION VIEW

4 block layer above antennas
antenna layer (printed-circuit boards)
84 cm
35 cm
beamline
33 cm
salt stack
plywood table
8 feet

SLAC 2002 photos

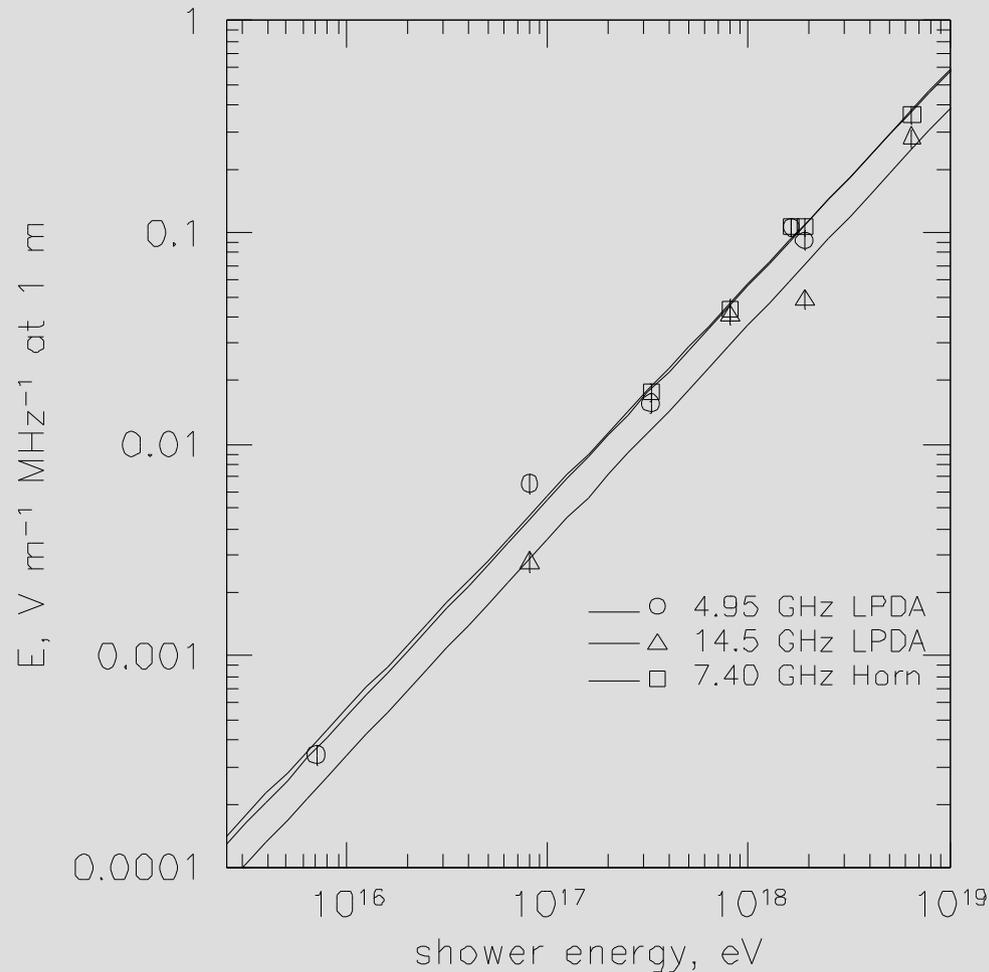Target: bowtie antennas being buried

beam exit

downstream shower core still very compact

SLAC 2002 coherence

Coherence measured over two more decades in energy than SLAC 2000
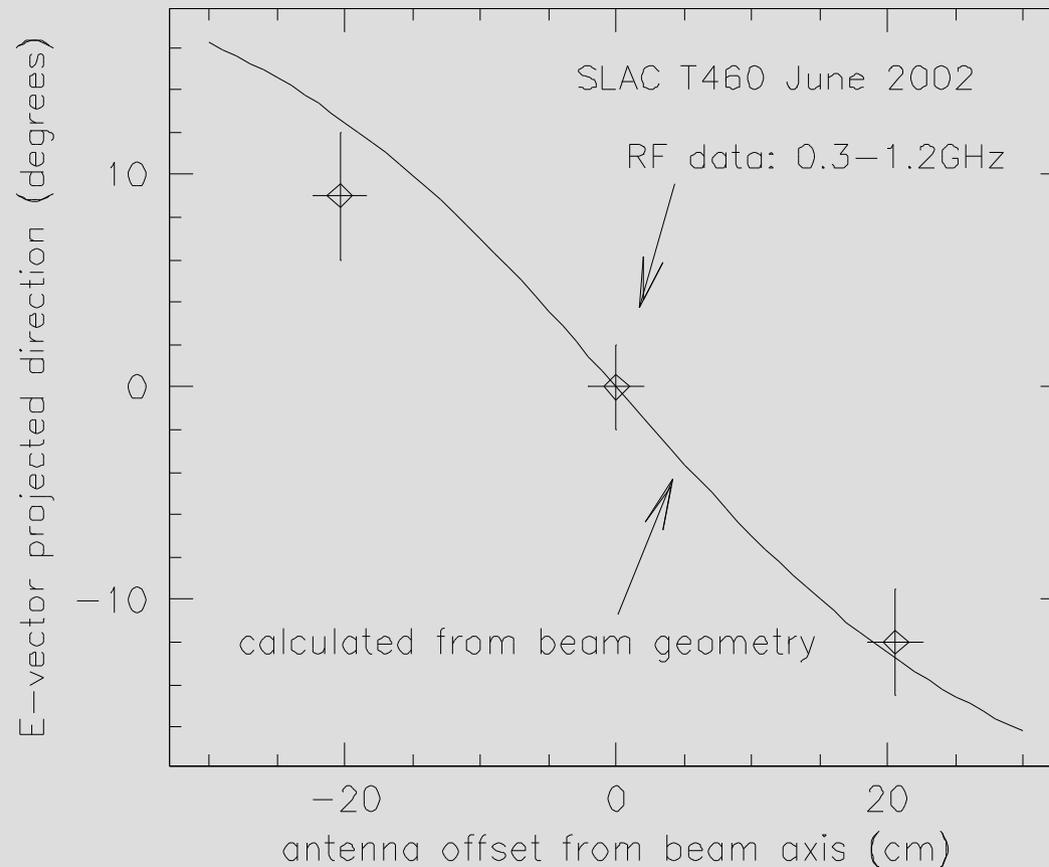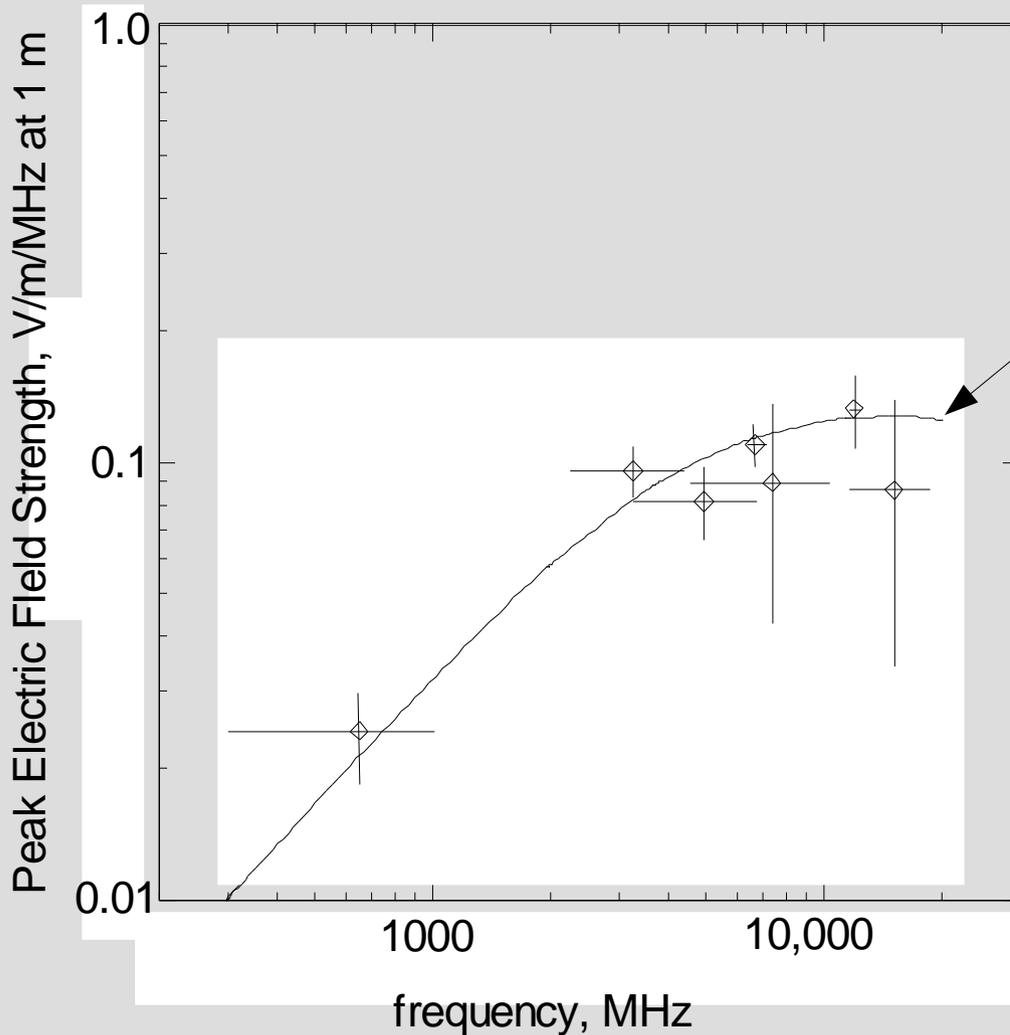

3 frequency ranges

up to 14 GHz

SLAC 2002: Polarization Tracking

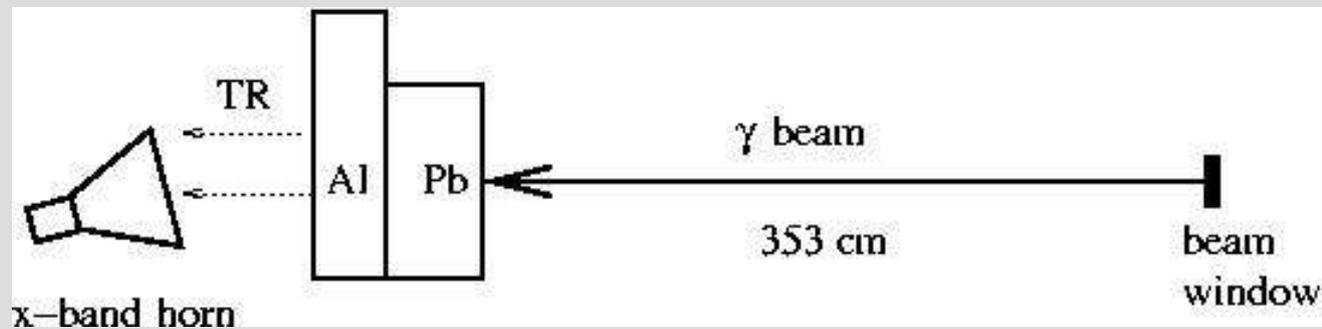Directional
information
from
polarization

SLAC 2002: Field Strength in Salt

SLAC 2002:Transition Radiation

- Shower formed in Pb/Al target upstream of salt
- TR measured as charge excess exits , in agreement with predicted strength
- New avenue of detection?

Summary

- Askar'yan effect has been observed directly in sand and salt: first direct observation

- Coherence observed over many decades in energy, frequencies from ~0.5 to 14 GHz

- 100% linear polarization observed, may be used to track shower direction

- Absolute field strength agrees w/parameterization

- TR signal from Askar'yan charge excess also observed