Measurements of Coherent Radiation from picosecond beams
at the
Argonne Wakefield Accelerator
and
SLAC--Final Focus Testbeam

ANL, SLAC, JPL, UCLA

Basic Questions

- Does the 20-30% charge excess predicted by Askaryan really develop?

- Does this excess charge emit 100--2500 MHz as needed by various experiments?

- Can we count on the coherence factors of
  - 10^6 -- 10^{11}

==> Implications for high-energy neutrino detection

Two experiments

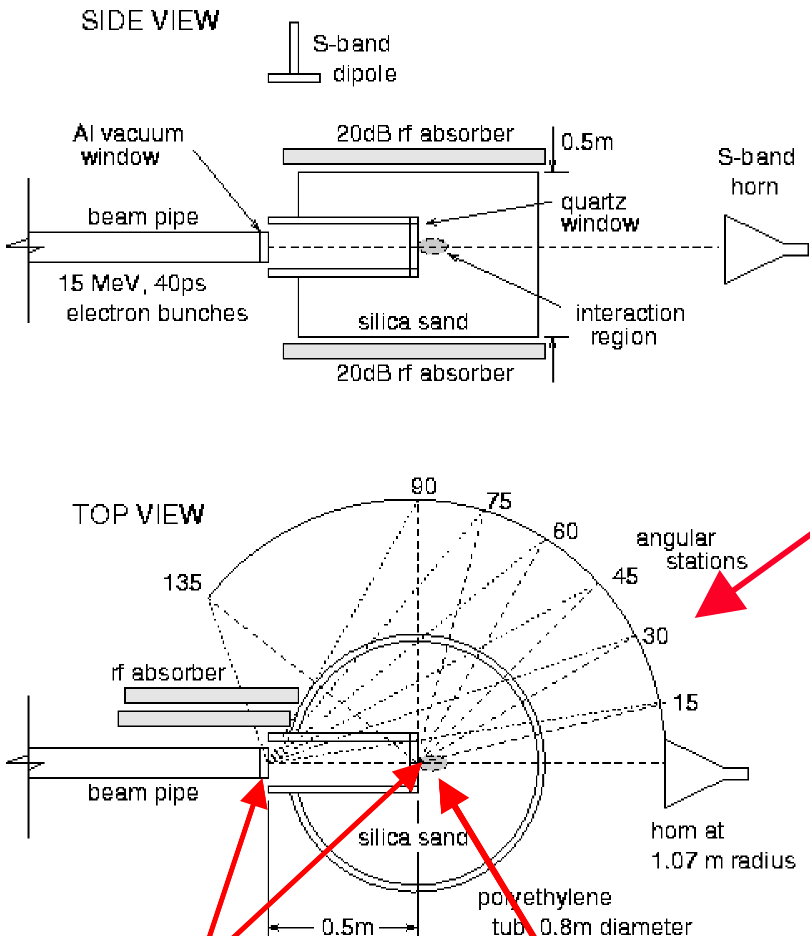
- Lunacee-I: Argonne Wakefield
  - ANL: Paul Schoessow, Wei Gai,
    John Power, Dick Konecny,
    Manuel Conde
  - JPL: Peter Gorham
  - UCLA: David Saltzberg
  - hep-ex/0004007 (Nov. '00 phys. rev. E)

- Lunacee-II: SLAC -FFTB
  - SLAC: Dieter Walz, Al Odian,
    Clive Field, Rick Iverson
  - JPL: Peter Gorham, George Resch
  - UCLA: David Saltzberg, Dawn Williams
  - hep-ex/0011001

Lunacee-I

- Argonne Wakefield Accelerator provides 15.2 MeV electron beam
  - Advantages:
    - ~1mm largest size << λ
    - Intense: ~10^{11} e^- per bunch
  - Disadvantages
    - Assumes charge excess already formed
    - 15 MeV ==> short track length
- Expect two types of radiation
  - Transition Radiation (TR) from beam leaving accelerator through vacuum window
  - Cherenkov Radiation (CR) from beam moving through a sand target.
- September 1999

Argonne setup

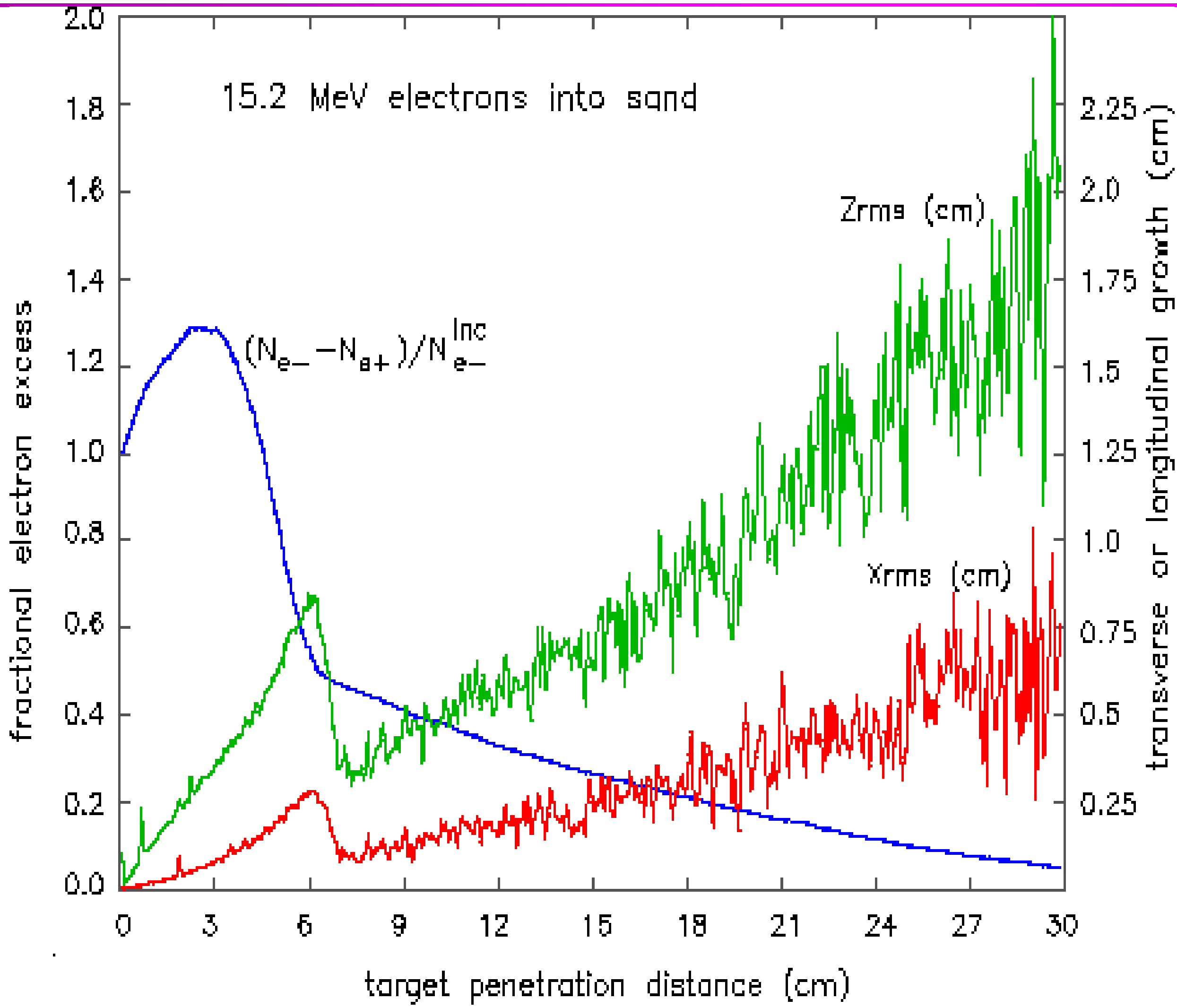


Circular Geometry to measure angle of emission

TR from interfaces

CR from beam in sand

Beam in Target



Stopping distance in sand ~ 6cm

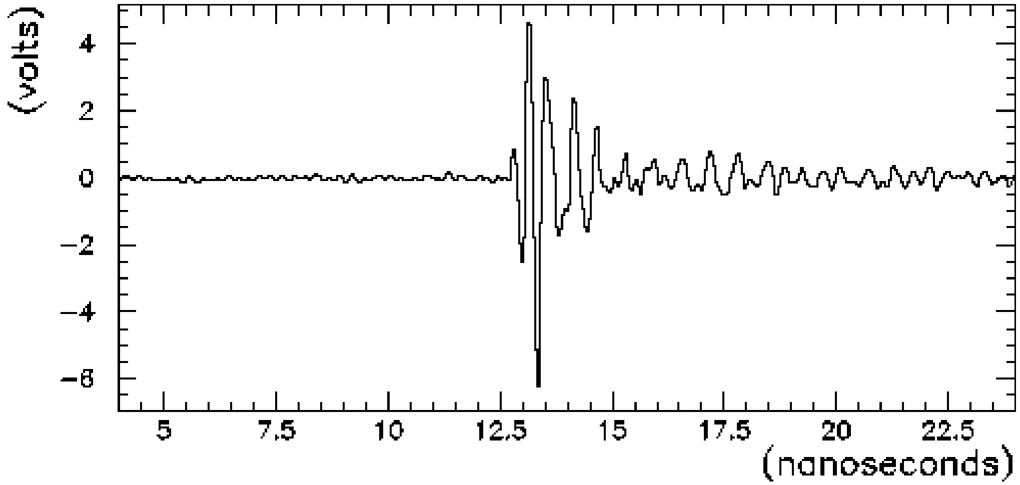
10^{10} -- 10^{11} electrons per bunch

99.8% SiO_2
density=1.58;
n=1.6
tan δ ~ 0.008

Trigger/DAQ

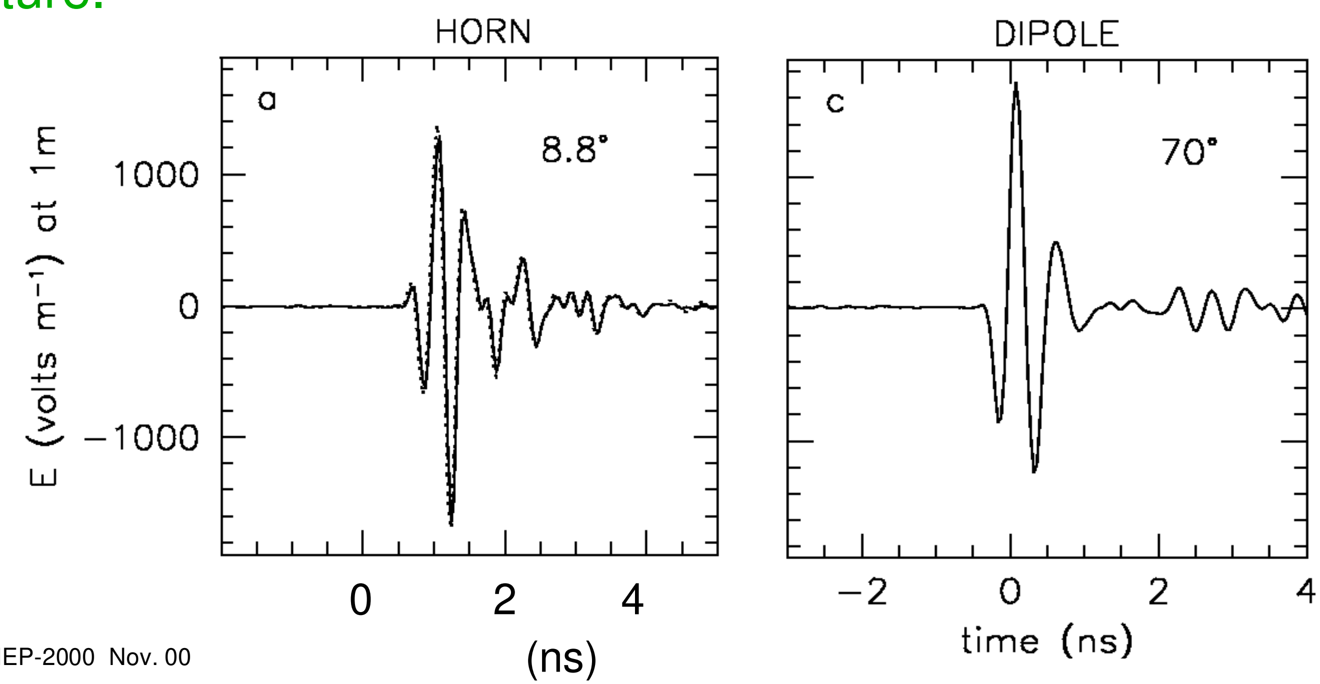
- Trigger from S-band dipole near vacuum window (<<40psec jitter)

- Typical pulses ~10V pk-to-pk ==> No amplifiers, just attenuators. Voltage (ie, field) measured directly by TDS694 -- 3GHz, 10GSa/s oscilloscope

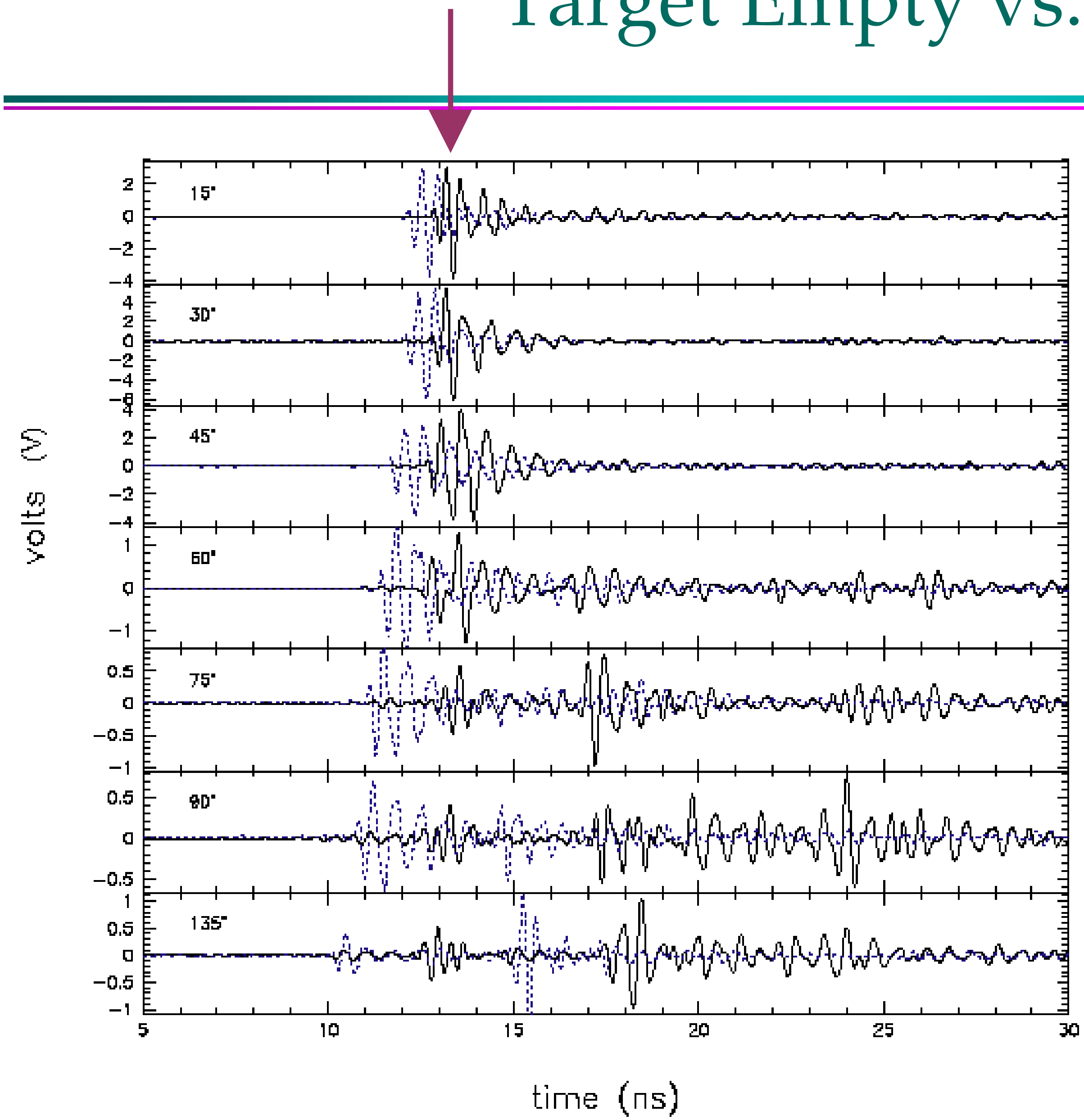


Electric Field & Power Measurements

- Move “standard gain horn” around target
- Tens of volts out of antenna==>attenuators.
- Record voltages directly using 3GHz, 10 GSa/sec oscilloscope.
- Convert voltages to electric fields using antenna “effective height”
- Convert V^2/R over 3 ns to a power measurement using antenna effective aperture.



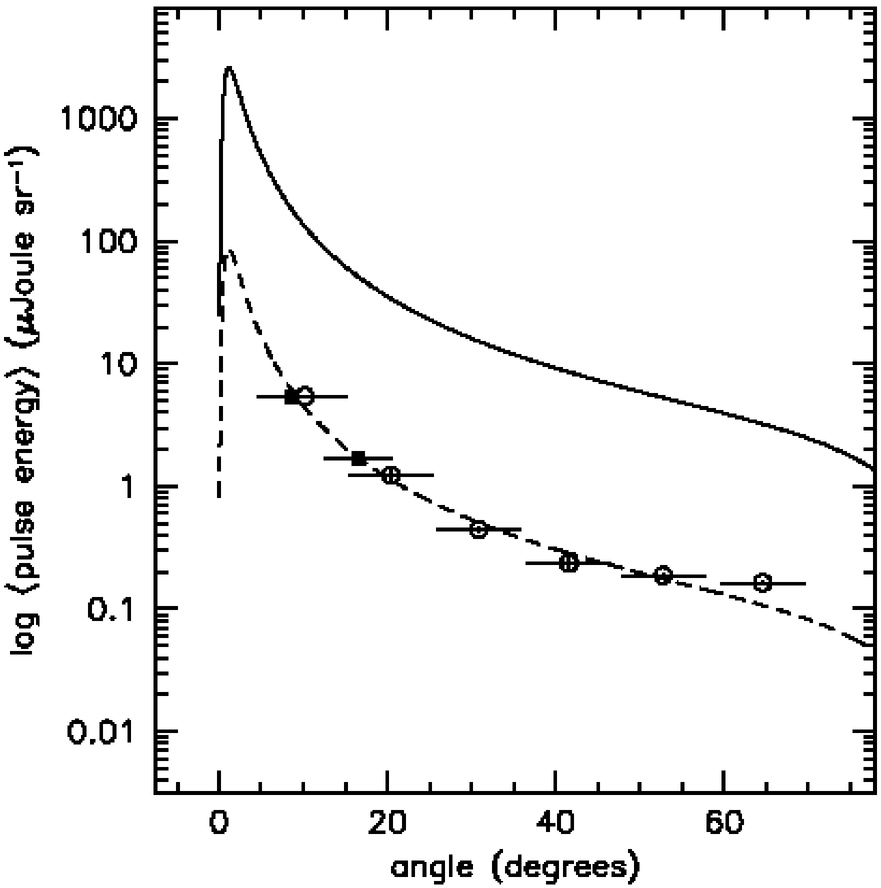
Target Empty vs. Full



dashed=empty
solid=full

All pulses in phase
when full

Target Empty-- Pure TR



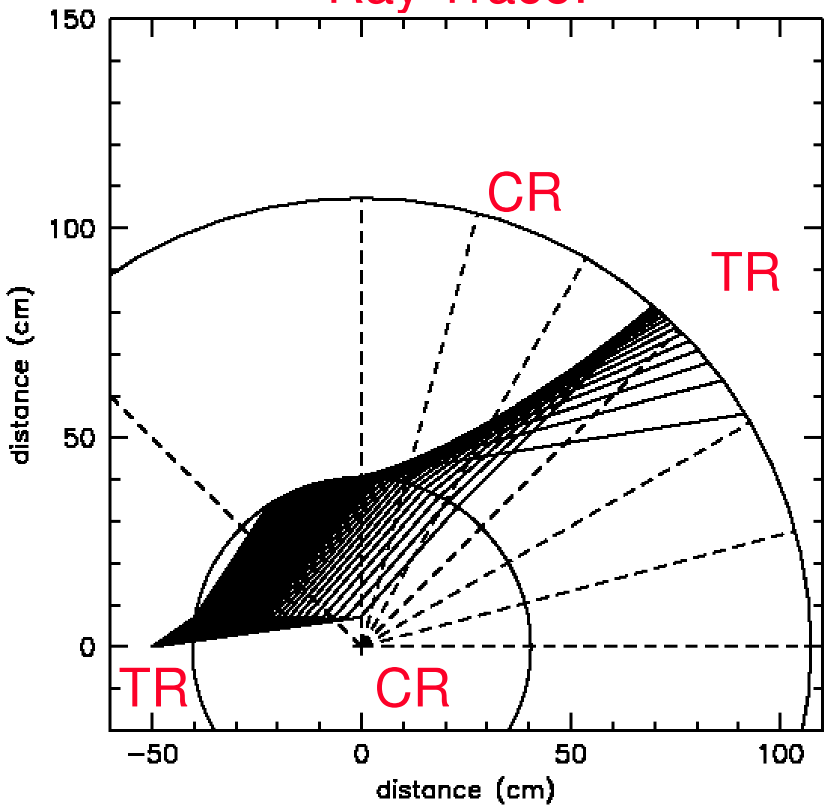
Shape follows TR expectation

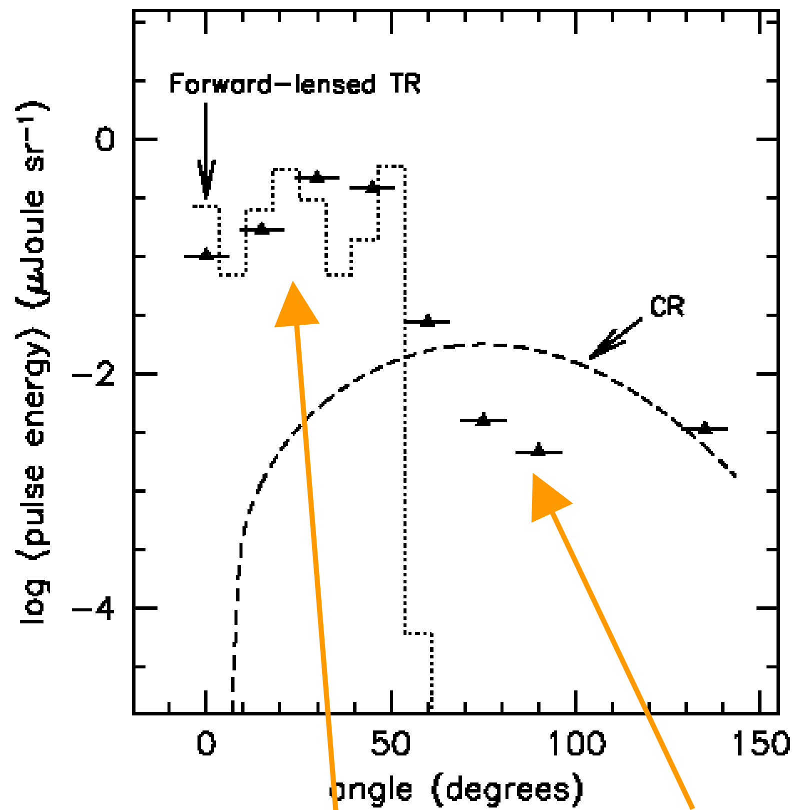
Factor 35 power (6 in E-field) discrepancy -- Not understood

Target Full TR+CR

CR somewhat obscured by presence of Transition Radiation

Ray Trace:





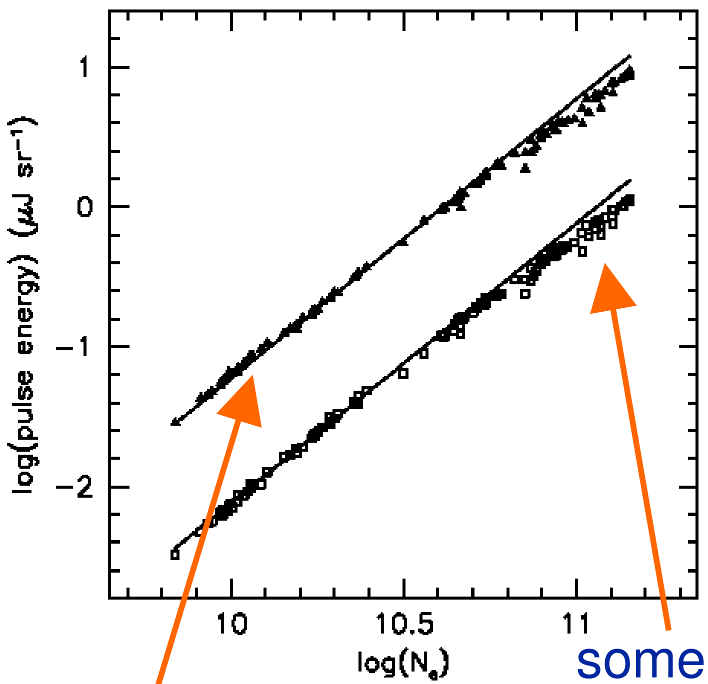
Sand acts as a lens for microwaves

barely polarized

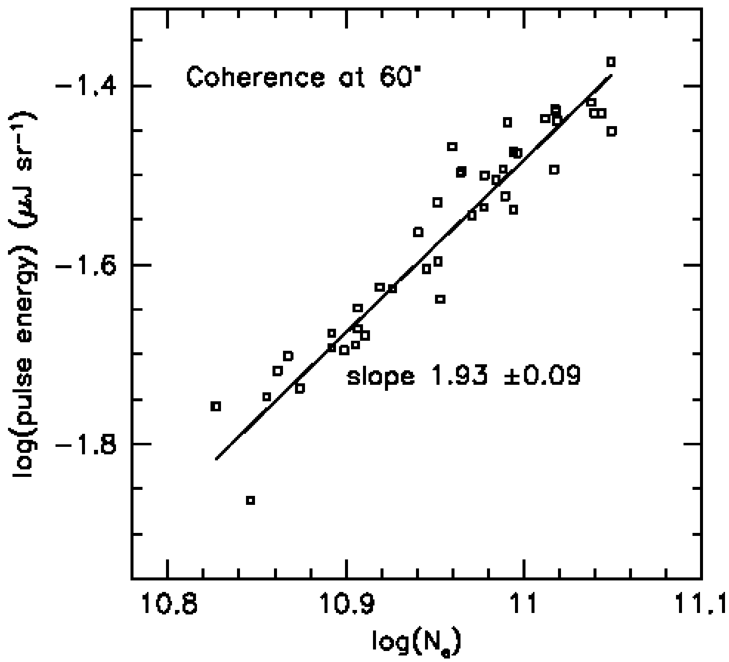
linearly polarized

Coherence:
Expect slope=2

Target Empty



Target Full

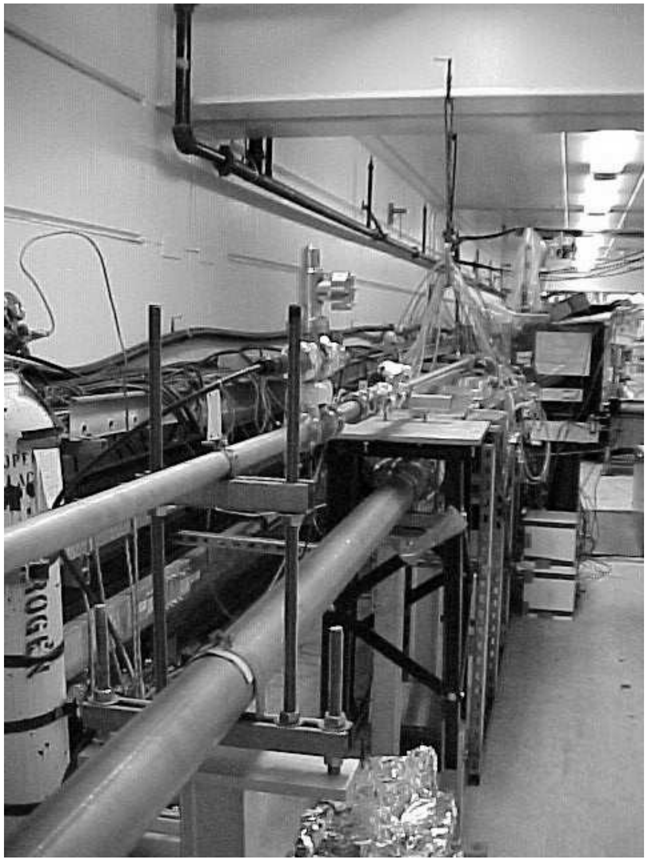


Slope=2.0 drawn

some loss--
possibly space
charge effects

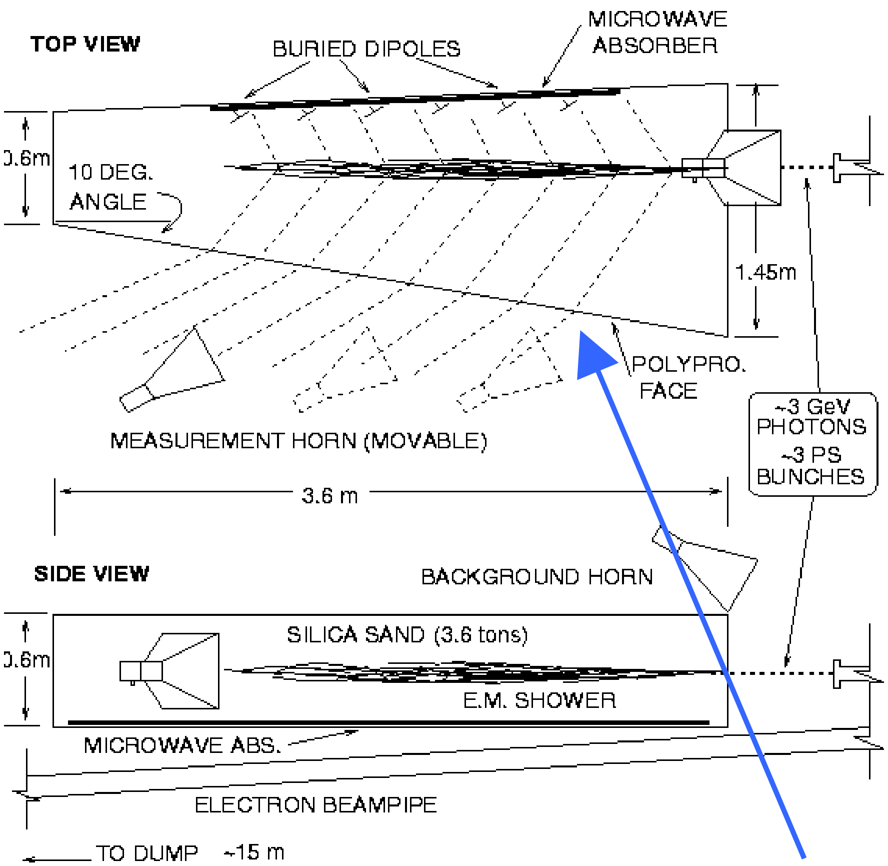
LUNACEE -II -- SLAC-FFTB

- Improvements over Lunacee -I
  - To produce asymmetry prediced by Askaryan==> use a higher energy beam
  - Need a longer shower ==> use a higher energy beam
  - To avoid TR ==> Use photons
- SLAC FFTB
  - 28.5 GeV electrons on 1%,2.7% X0
  - Photon bremsstrahlung beam with <E>~3 GeV
  - Still has tight bunch (<1mm)

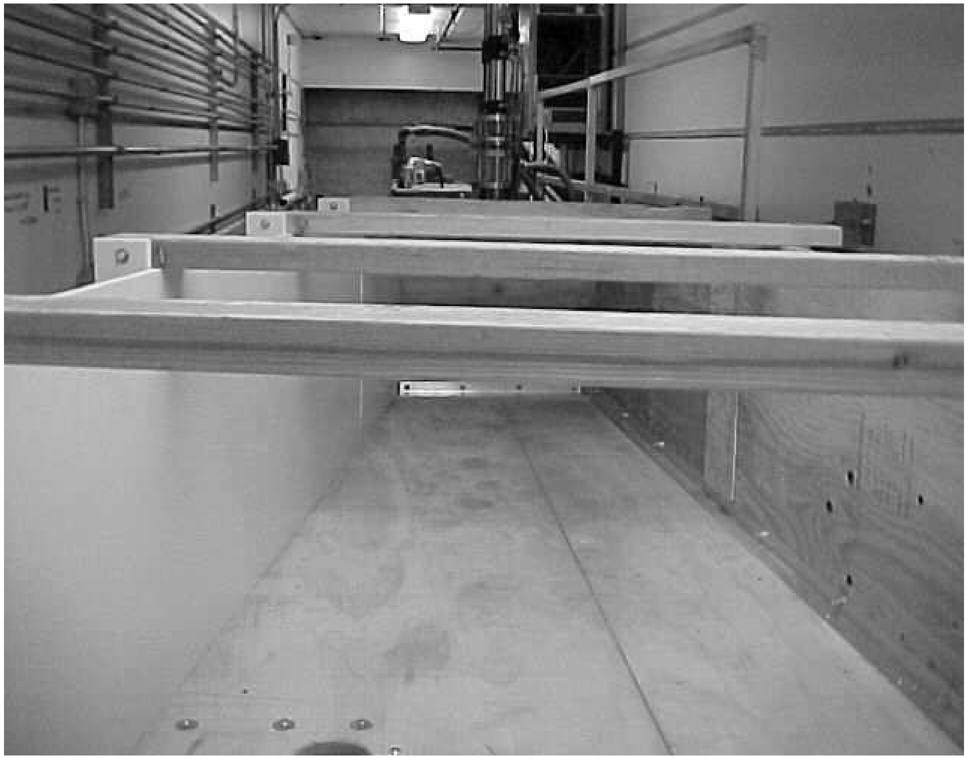


August 2000

Lunacee -II



Angled face to prevent TIR



Target Material

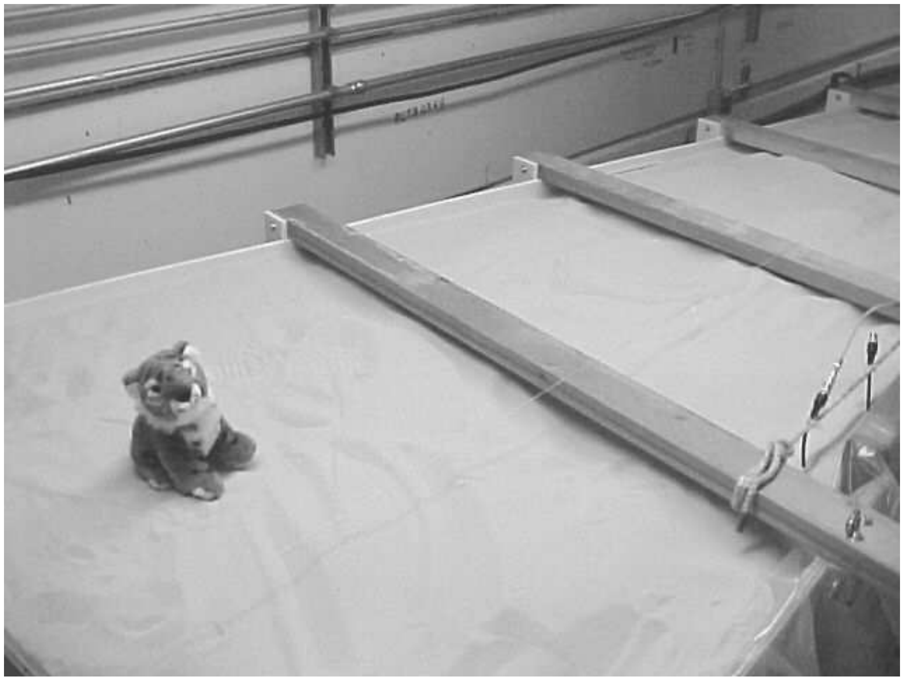
7000 lbs of sand

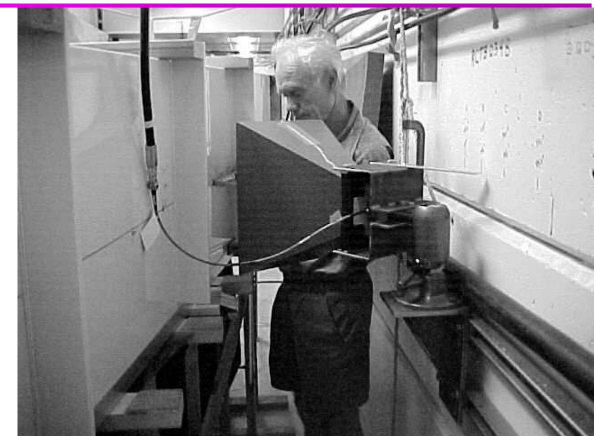
Dry, 99.8% silica sand,
300 micron diameter,
100 pound bags

Loading the box

Great support from SLAC beams & EF depts.

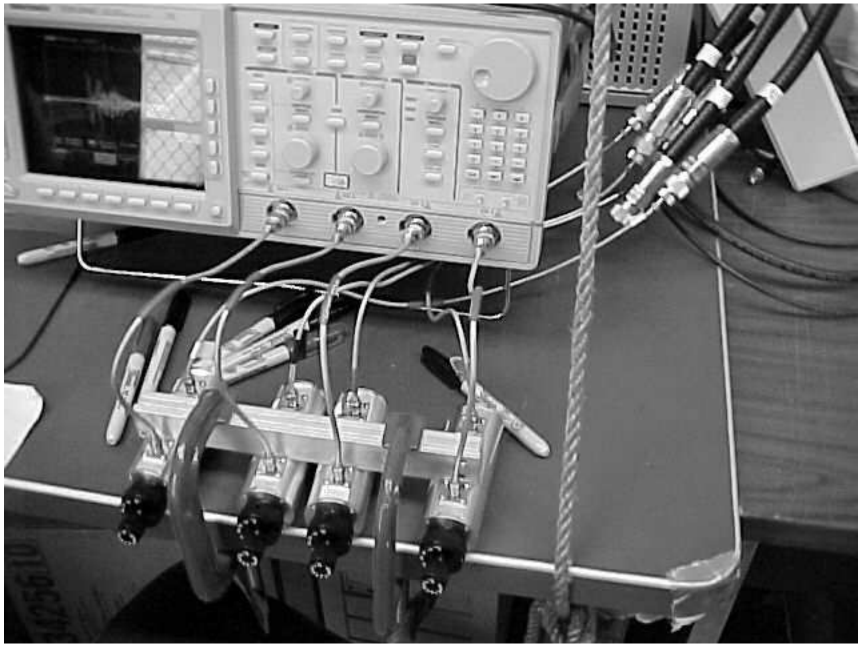
The "Kitty Litter" Experiment





Electric Field Measurements

- Experiment similar to Lunacee-I
- See up to 100V pk-to-pk ==> use attenuators
- Up to S band (2.6 GHz) use real-timeTDS694
- For C band (4.4--5.6 GHz) use a delay& sample scope---OK with stable trigger.
- Unlike Lunacee-I, use peak voltage ==> E field/MHz instead of power measurements.
  - Gives consistent results with power ~10-20%
  - Simpler to use the “linear” variable”
  - less susceptible to reflections



Backgrounds?

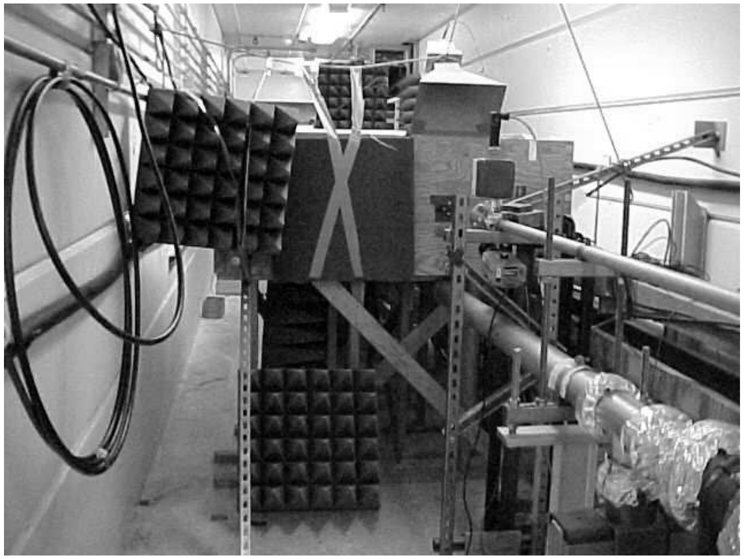
- SLAC is an S-band accelerator---RF background? Electron beam on/ with no radiators (no photon beam)

  ==> ~0.020 V/pk-to-pk

  - Electron beam on/ with 1% radiator

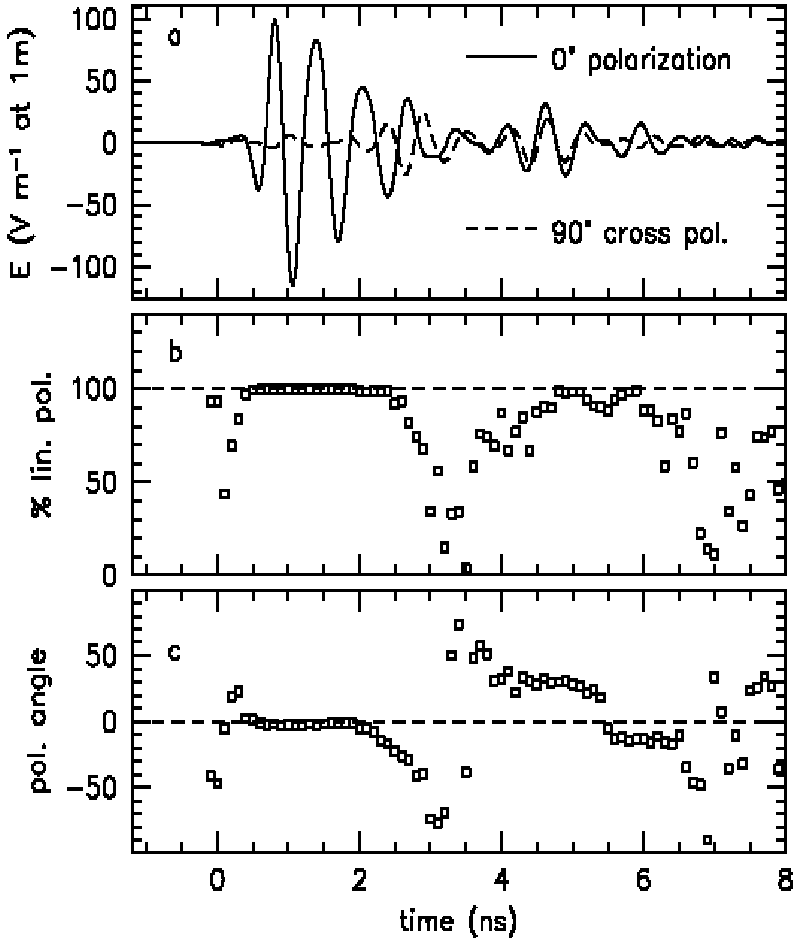
  ==> ~100 V/pk-to-pk

- Monitor potential TR with extra horn



Lunacee II -- Polarization

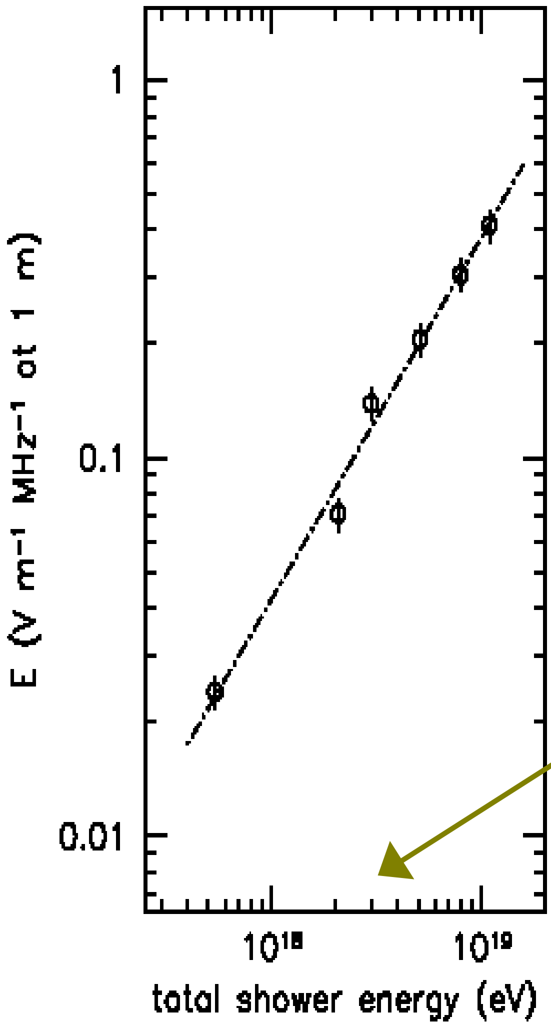
S-band Horn



- Measure polarization using Stokes parameters averaged over 0.5 ns, (assuming no circular)
- Expect linear (radial) polarization (0 deg. in this case)
- Reflections destroy polarization

Coherence:
Expect slope of 1.0 for E-field

S band

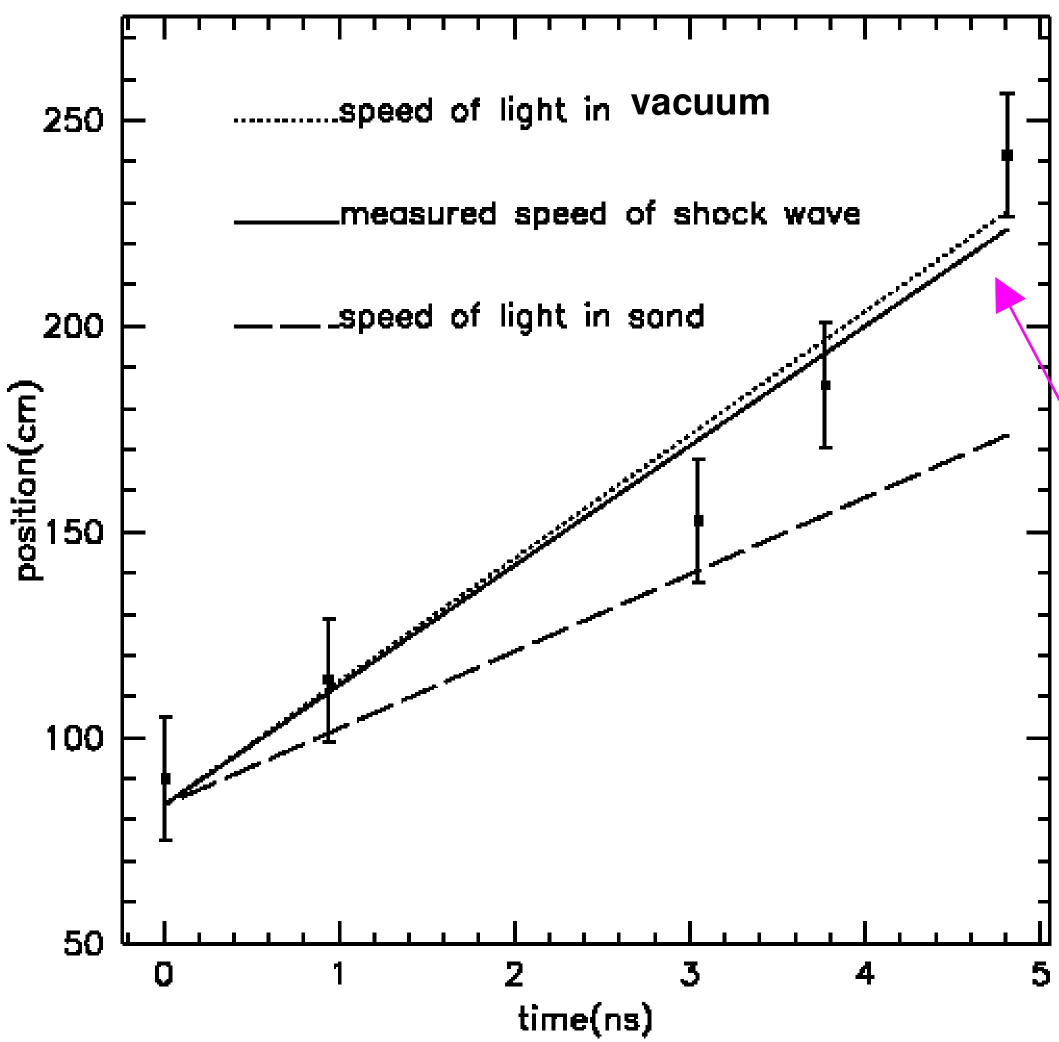


Slope = 0.96 +/- 0.05

Bremsstrahlung beam==> cannot count number of beam particles.

Use total energy deposited instead (allows easier comparison to parameterizations)

Lunacee-II: Shock wave

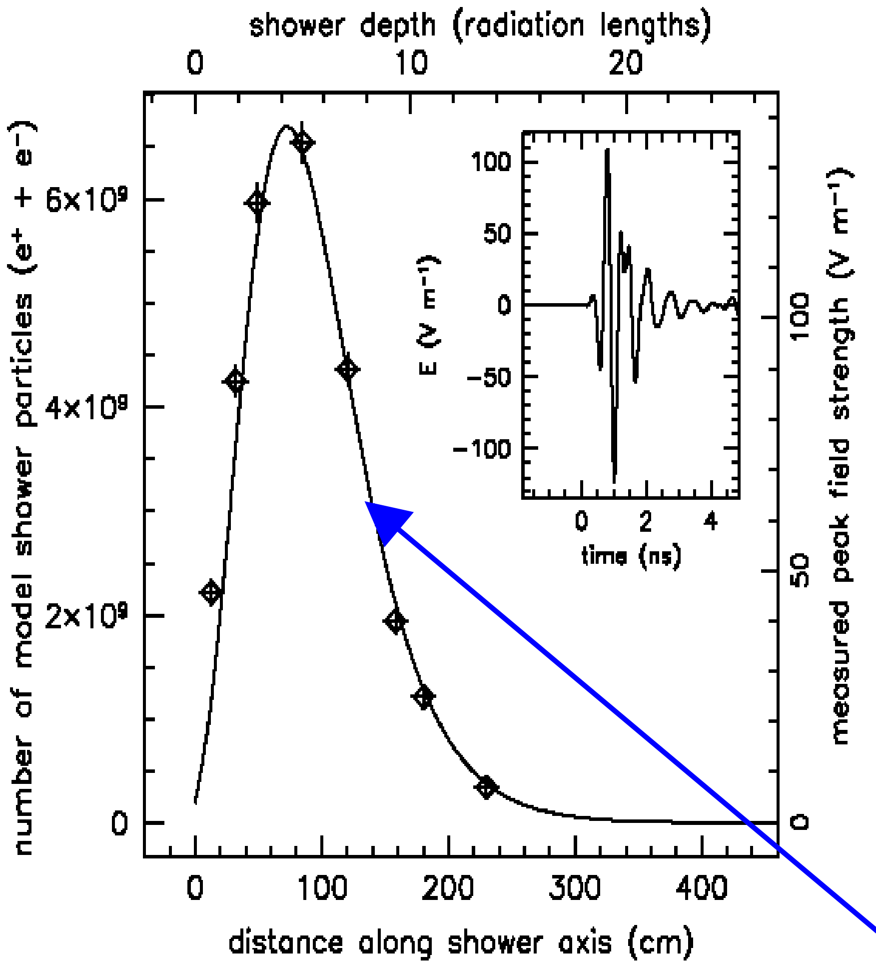


Dipole buried insand along line parallel to beamline

Cherenkov radiation is a shock wave ==> dipoles should “fire” at v=c, not c/n

v/c = 1.0 +/- 0.1

S band profile



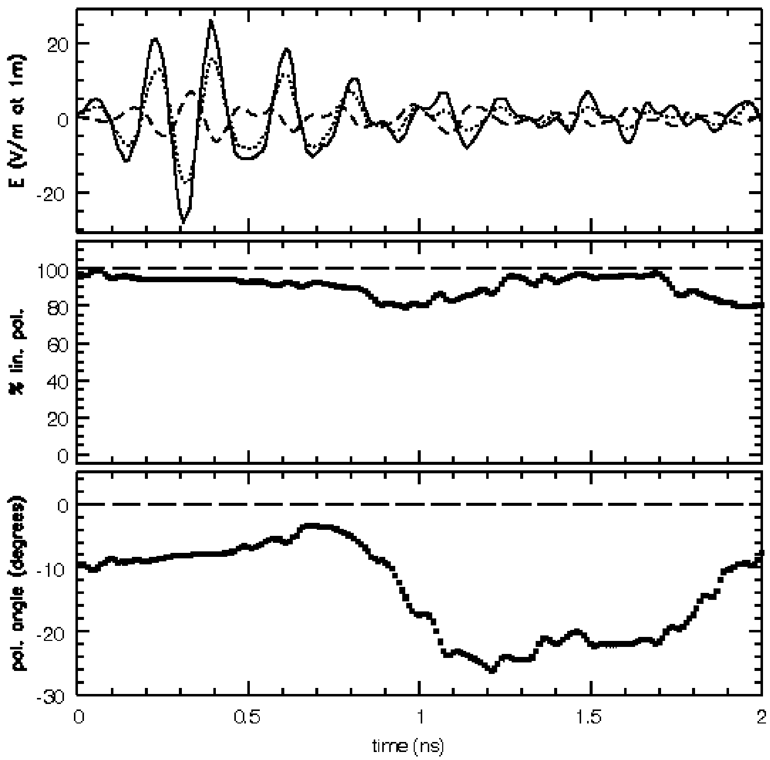
Move S band horn along wall

Peak corresponds ~ shower max. as shower excess approximately does

KNG param.

C Band Horn Data

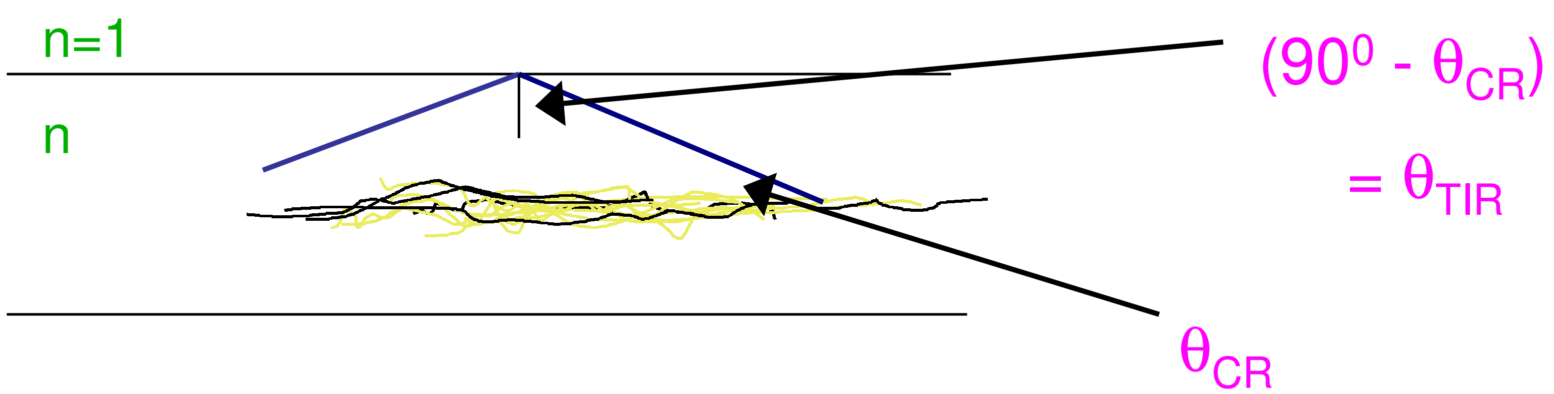
Polarization:



Also have 5 profile points.

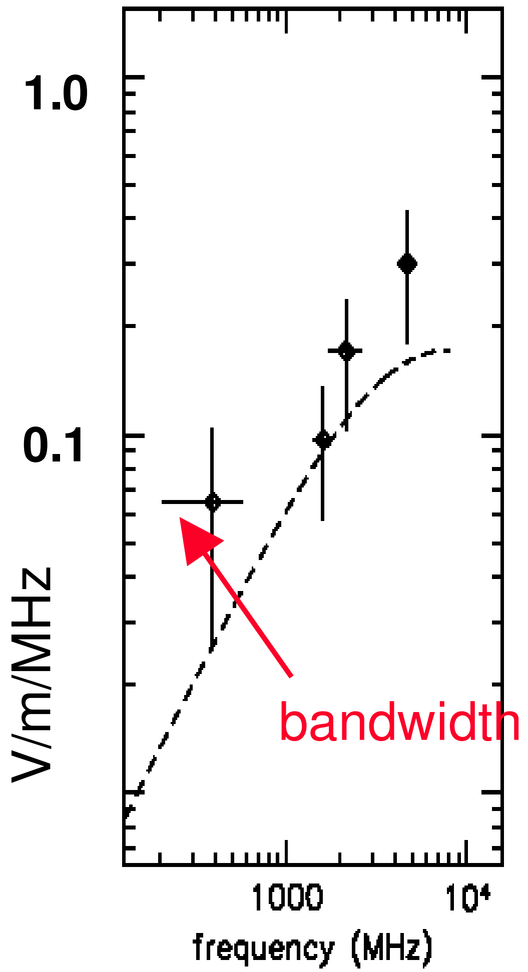
Tests of
Total Internal Reflection

- Compare emission from *inclined* face to *parallel* face.



- Ratio of electric fields ==> at least 50x suppression

“Absolute” field strengths



- Antennas pointing at shower max
  - ~200-800 MHz -- RICE dipole
  - 1.2 - 2.0 GHz -- small dipole
  - 1.7--2.6 GHz -- S band horn
  - 4.4-- 5.6 GHz -- C band horn
- Prediction from Alvarez-Muniz, Vazquez, Zas (2000). [will add Buniy,Ralston (2000)]
  - near-field etc. corrections <~1 dB
  - scaled by 0.5 for partial view
  - scaling from ice to sand
  - Assumes initiated by single particle not beam of lower energy photons

Conclusions

- TR can itself be used for detection of showers crossing an interface:
  - E_{thr} (moon) ~ 5 x 10^{20} eV , possibly 5x lower
- Some theoretical questions
  - odd poles in TR formulas
  - quenching at extremely high energies?
- Askaryan effect is confirmed by absolute intensity, polarization, frequency dependence, coherence
  - E_{thr} (moon) ~ 2 x 10^{19} eV as expected , possibly lower
  - Consistent with thresholds for south pole etc.

Possible Future work?

- Tests of forward & backward TR from interfaces
- Measurement of geomagnetic splitting
- Tests of Radar techniques
- Possible development of new detectors for HEP
- Yerevan, Fermilab?