Measurements of the GHz emission by a 3 MeV electron beam

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Kavli Institute
for Cosmological Physics
at The University of Chicago

Introduction

Several activities on GHz detection of cosmic rays based on the Gorham et al. measurements at SLAC

Our objective is to cross-check the SLAC measurement adding information about the spectral characteristics of the signal, that was not measured at SLAC

Use a different electron beam. In particular the use of a low energy Van der Graaff allows us to stay below the Cherenkov threshold in air.

MAYBE Collaboration

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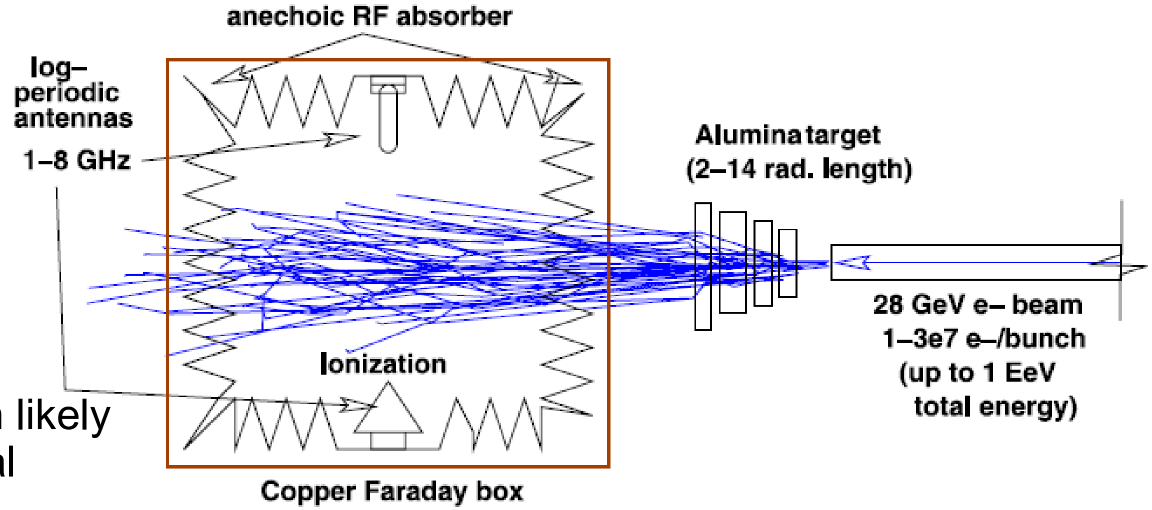
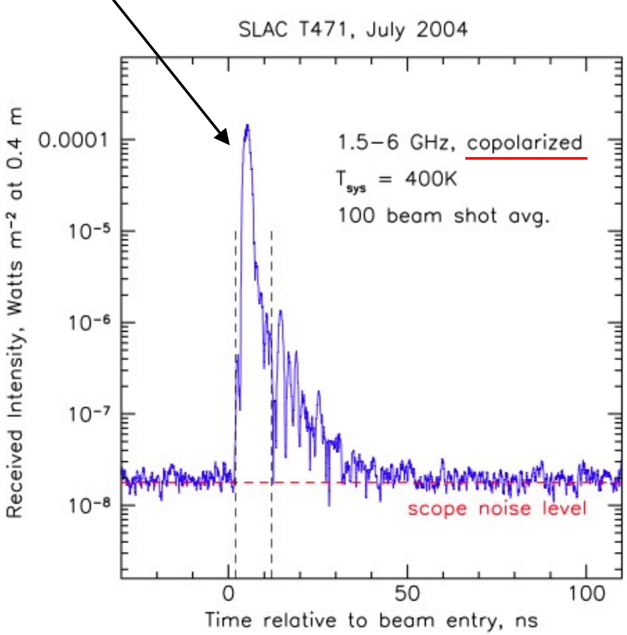
Previous Beam Measurements

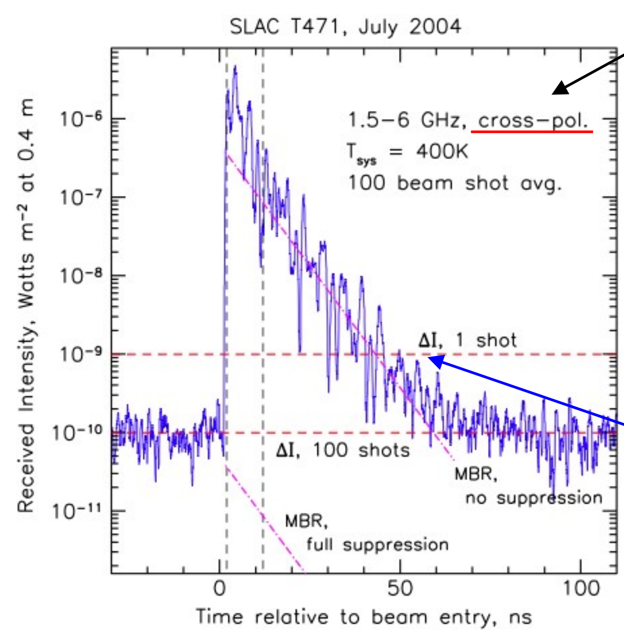
SLAC T471 experiment



Prompt emission likely Cherenkov signal

Insensitive to Cherenkov





10 ns decay constant, compatible with plasma cooling.

P.W. Gorham et al., “Observations of microwave continuum emission from air shower plasmas”, Phys. Rev .D. 78, 032007 (2008)

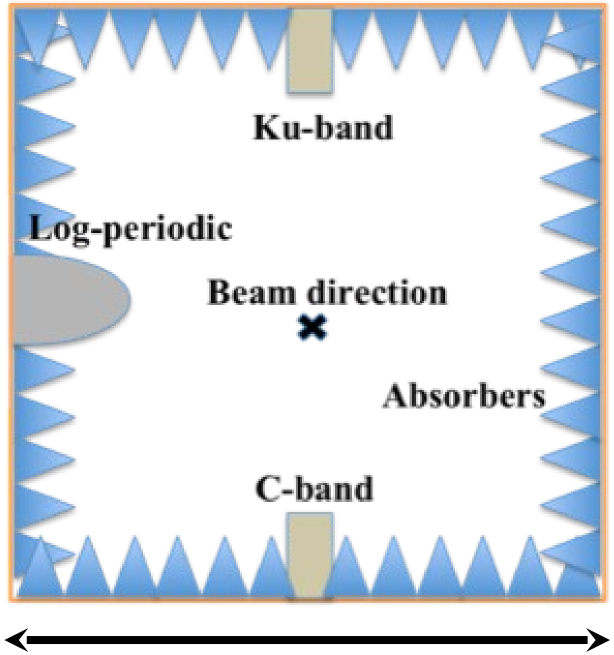
Quadratic scaling w/ beam intensity, isotropic, unpolarized

MAYBE Test Set-up

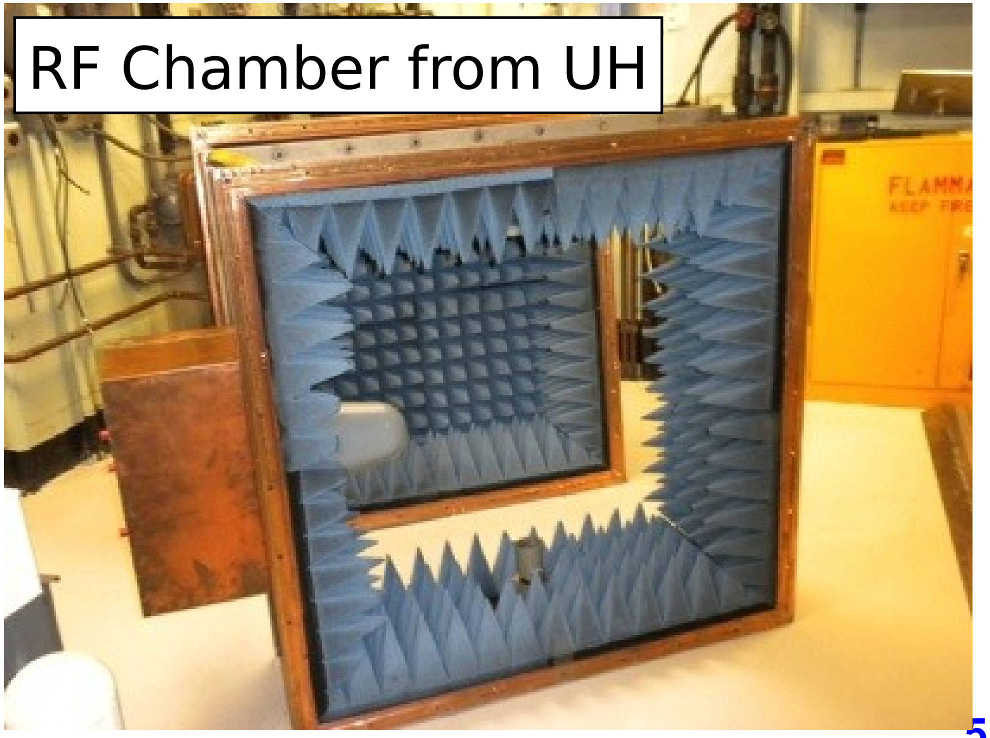
1 m^3 RF anechoic chamber, attenuation >30 dB above 1 GHz

Instrumented with three feed horns:

- Dual polarized commercial C-Band LNBF
- Circular polarized commercial Ku-Band LNBF
- 850 MHz to 26.5 GHz R&S Log Periodic Antenna, 3 Miteq amplifiers 1-2, 4-8, 8-12 GHz. Both polarization accessible through physical rotation of antenna

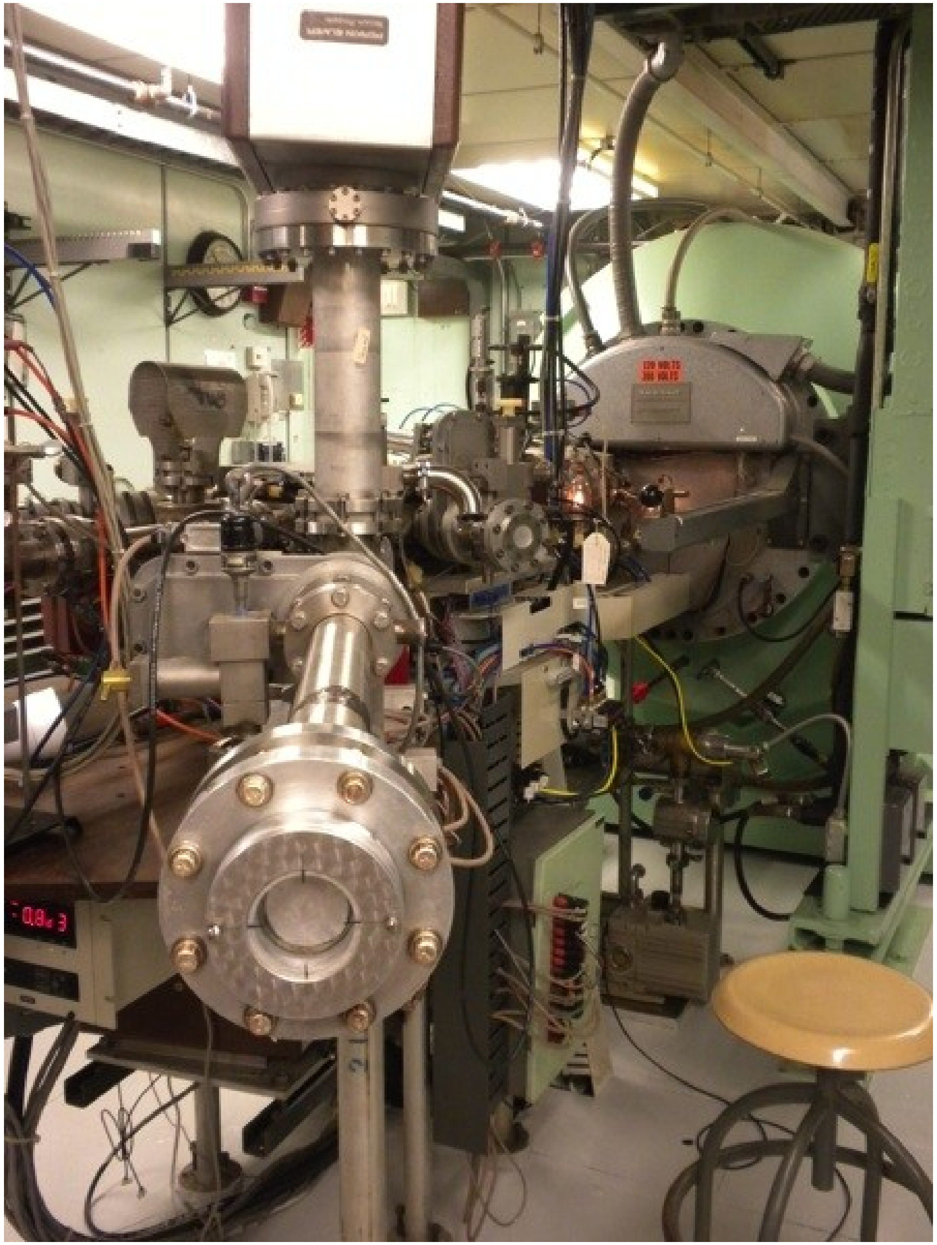


1 m

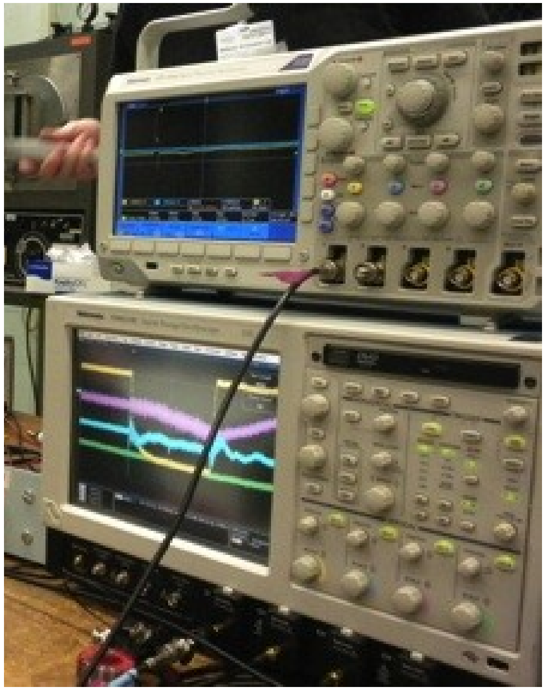


Accelerator

- 3 MeV Van de Graaff at Argonne National Lab, Chemistry Division.
- **Electrons are below Cherenkov threshold.**
- Pulse length 5 ns to 1 ms (1 μs for most of data taking)

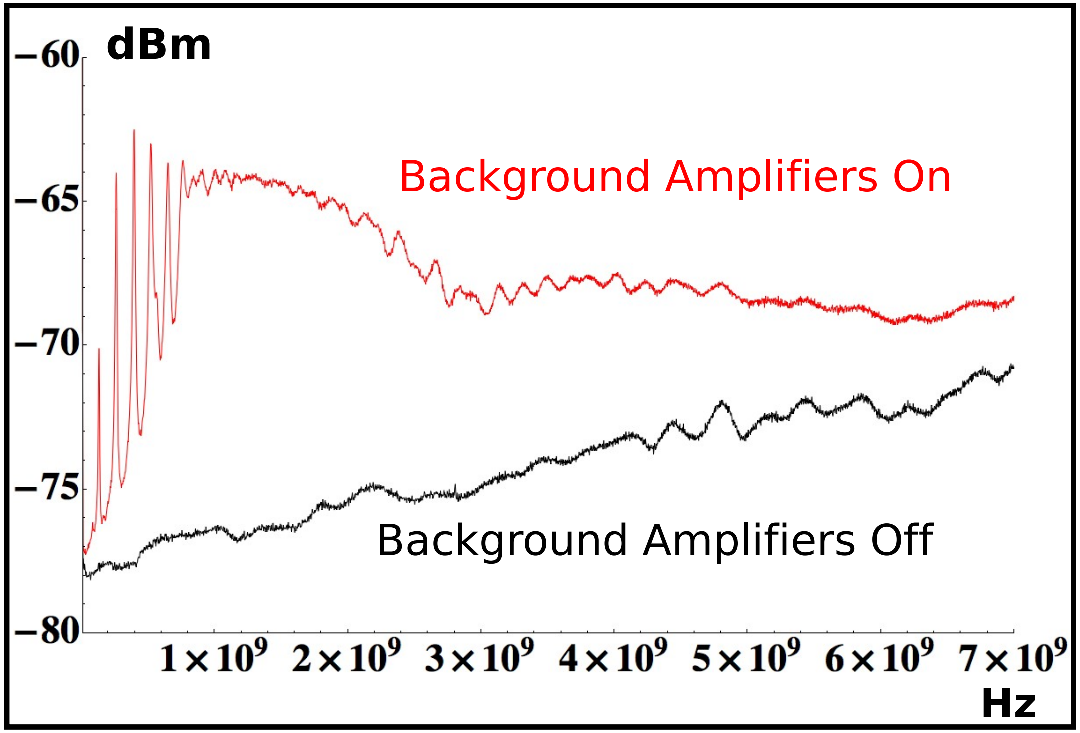


Data Acquisition



Time domain

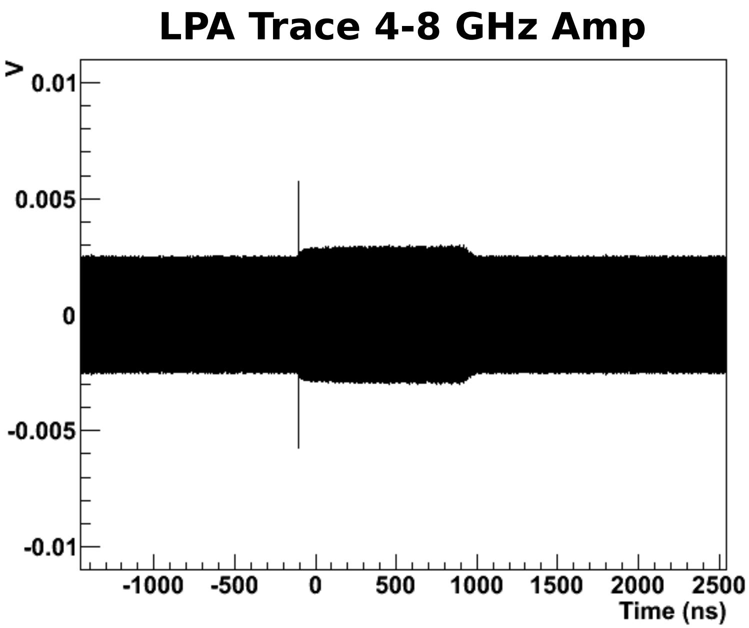
- Trace capture with Tektronix TDS6154C
- 40 GS/s with 15 GHz analog bandwidth

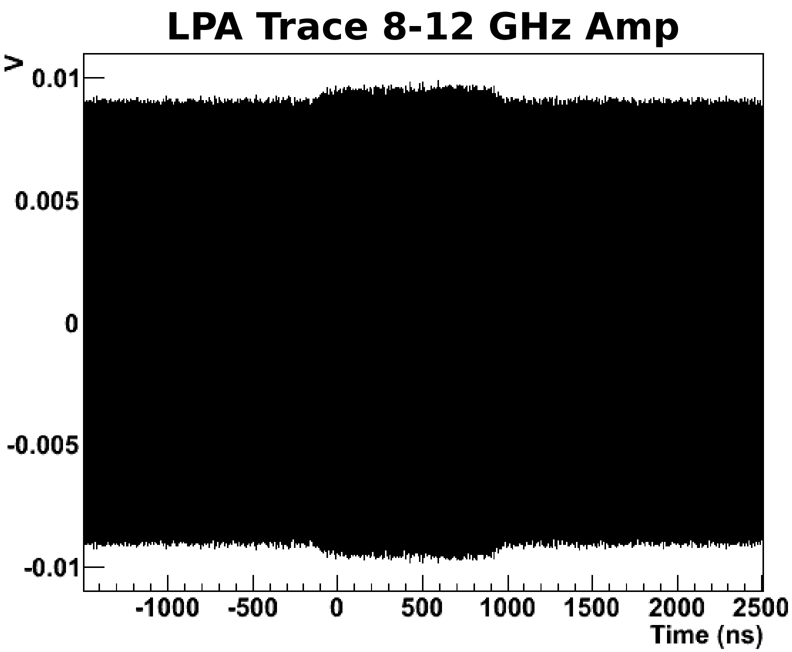


Frequency domain

- Spectrum analyzer R&S FSV 30 (30 GHz maximum frequency)
- 1 GHz to 7 GHz Using gated trigger window (higher freq: VdG pulse not stable enough)
- Noise floor dominated by amplifiers

Power - Time Domain Signal





Traces have 40 GS/s time sampling

First filter trace with FFT to select frequency band to calculate power

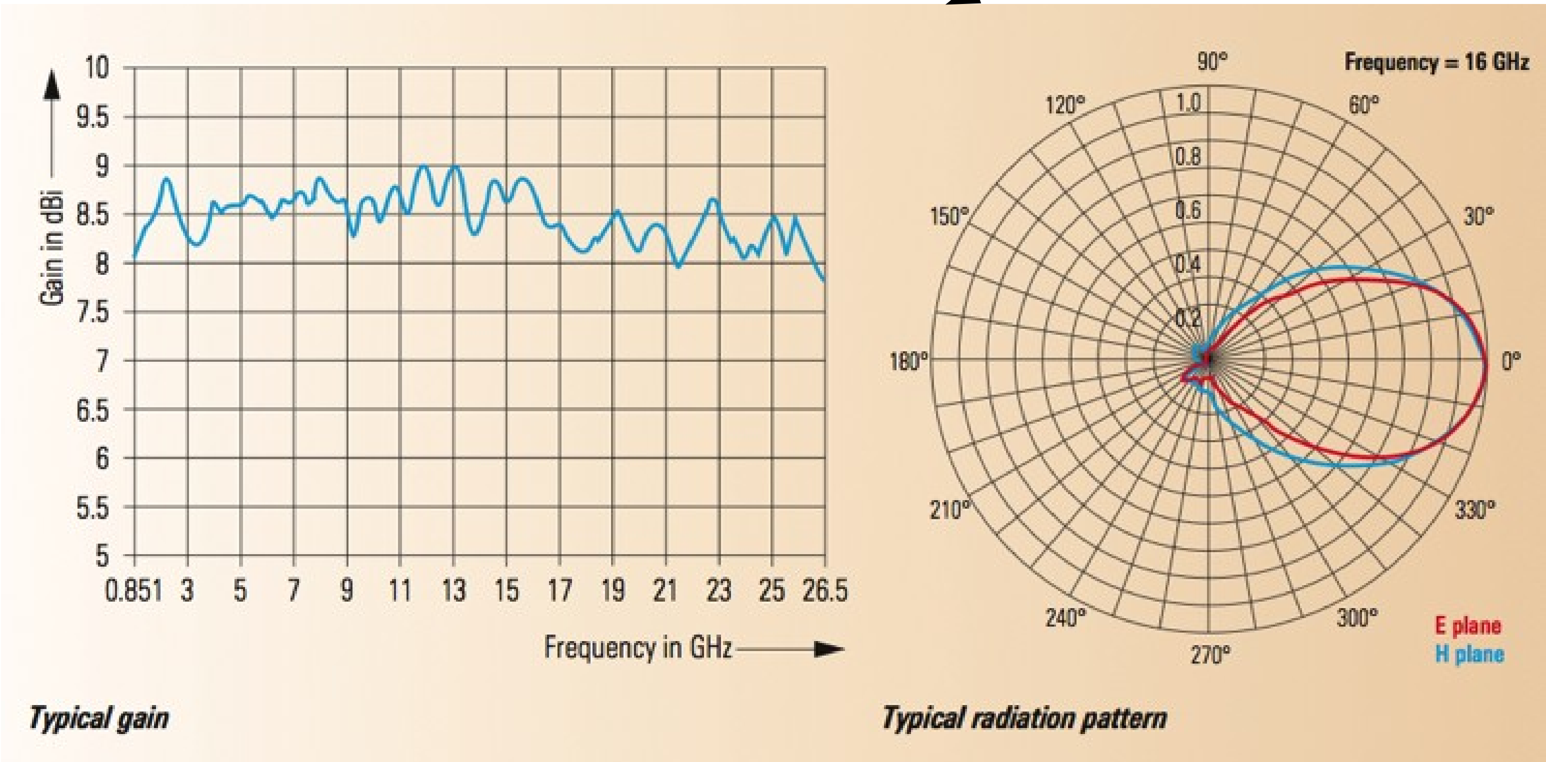
$$P_{signal} = \left(\frac{\langle V_{rms}\rangle^2}{R}\right)_{sig+bkg} - \left(\frac{\langle V_{rms}\rangle^2}{R}\right)_{bkg}$$

Flux Signal

$$I_f = \frac{P_{signal}}{A_{eff}\Delta\nu} \qquad A_{eff} = \left(\frac{c}{\nu}\right)^2 \frac{G}{4\pi}$$

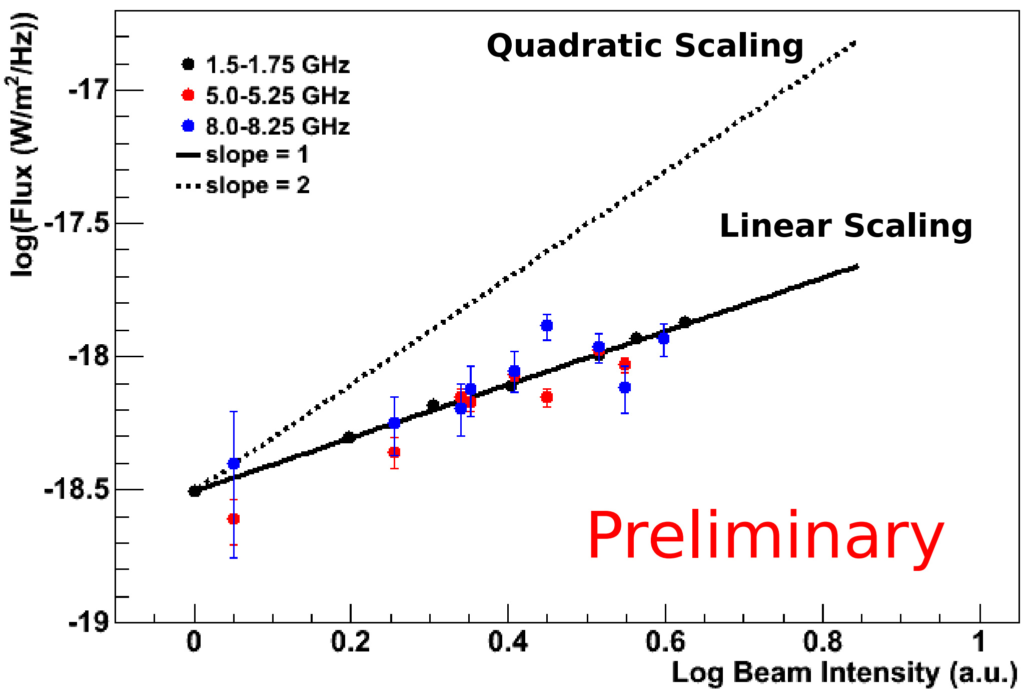
From trace

From manufacturer

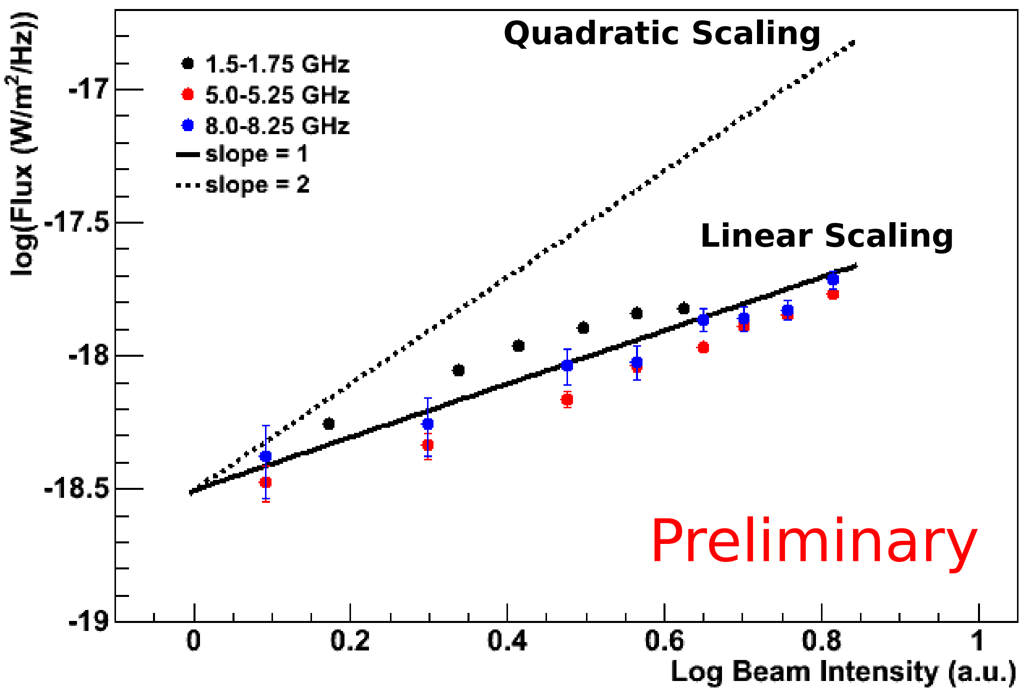


Scaling with the beam intensity

Cross-Polarized



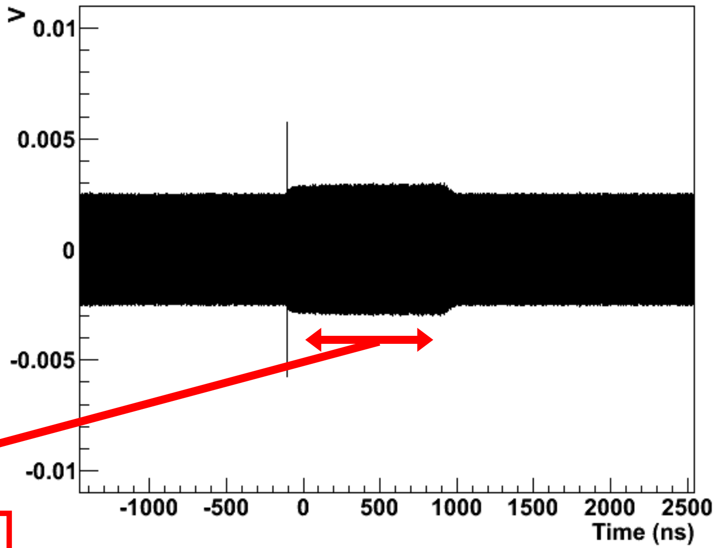
Co-Polarized



- Average flux from 1000s of traces
- Possible noise contamination in 1-2 GHz traces creating systematic shift

Measurement consistent with linear scaling

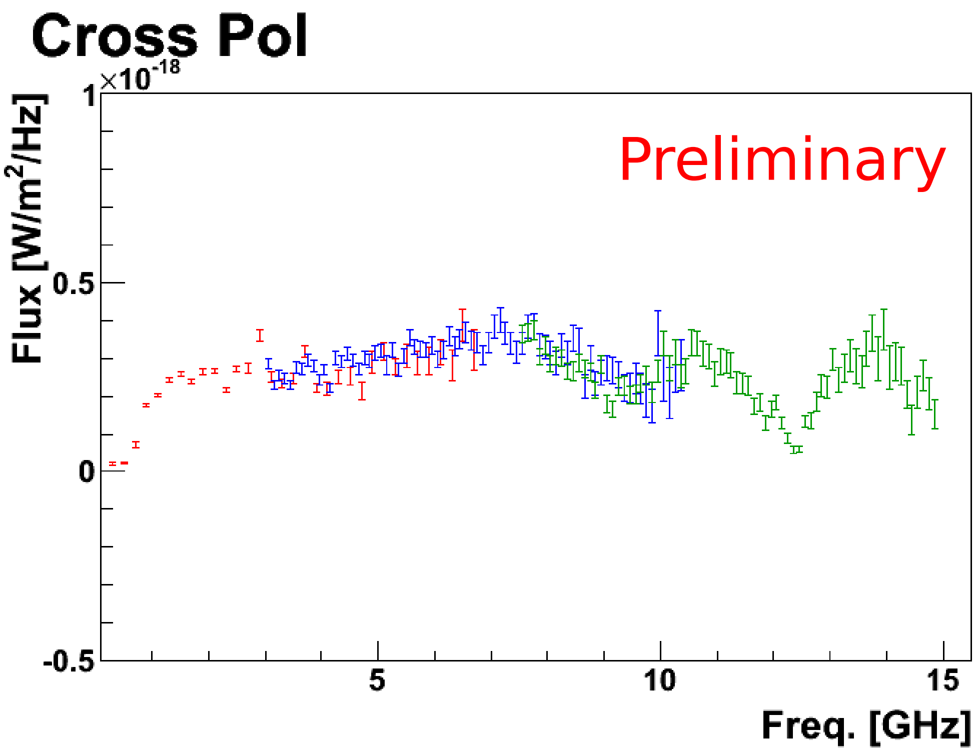
Spectrum

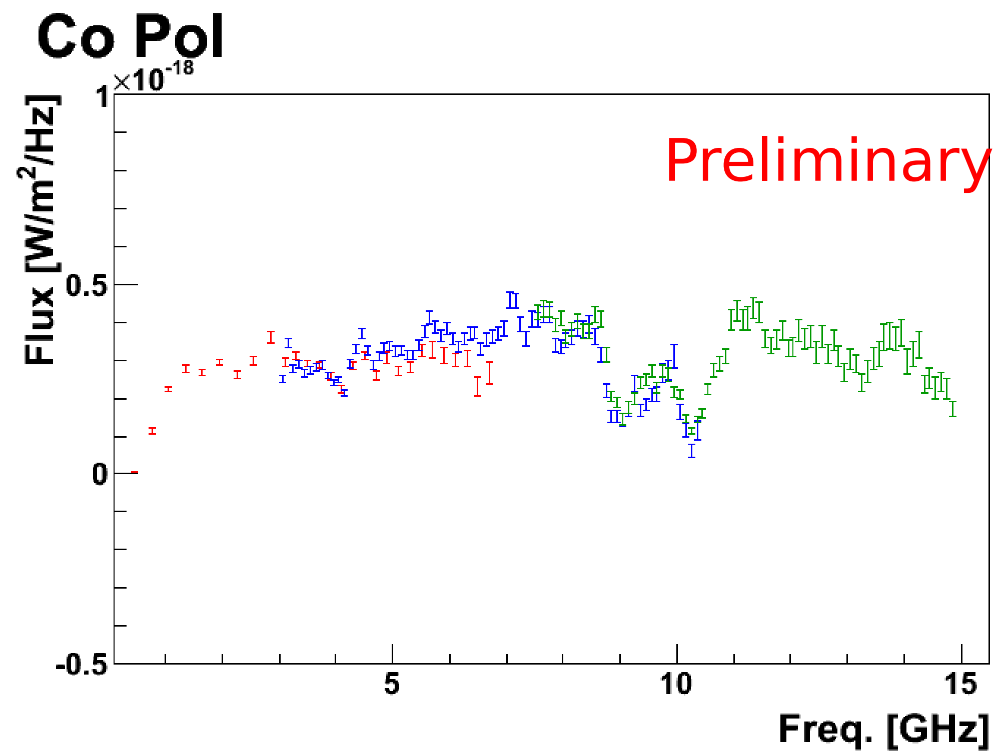


Use beam pick-up coil for trigger, create time gate for signal portion of pulse

- Spectrum analyzer traces built of 10,000s of pulses over hour time scales
- Beam stability monitored with pick-up coil
- Both polarizations taken by physically turning antenna in anechoic chamber

Spectrum

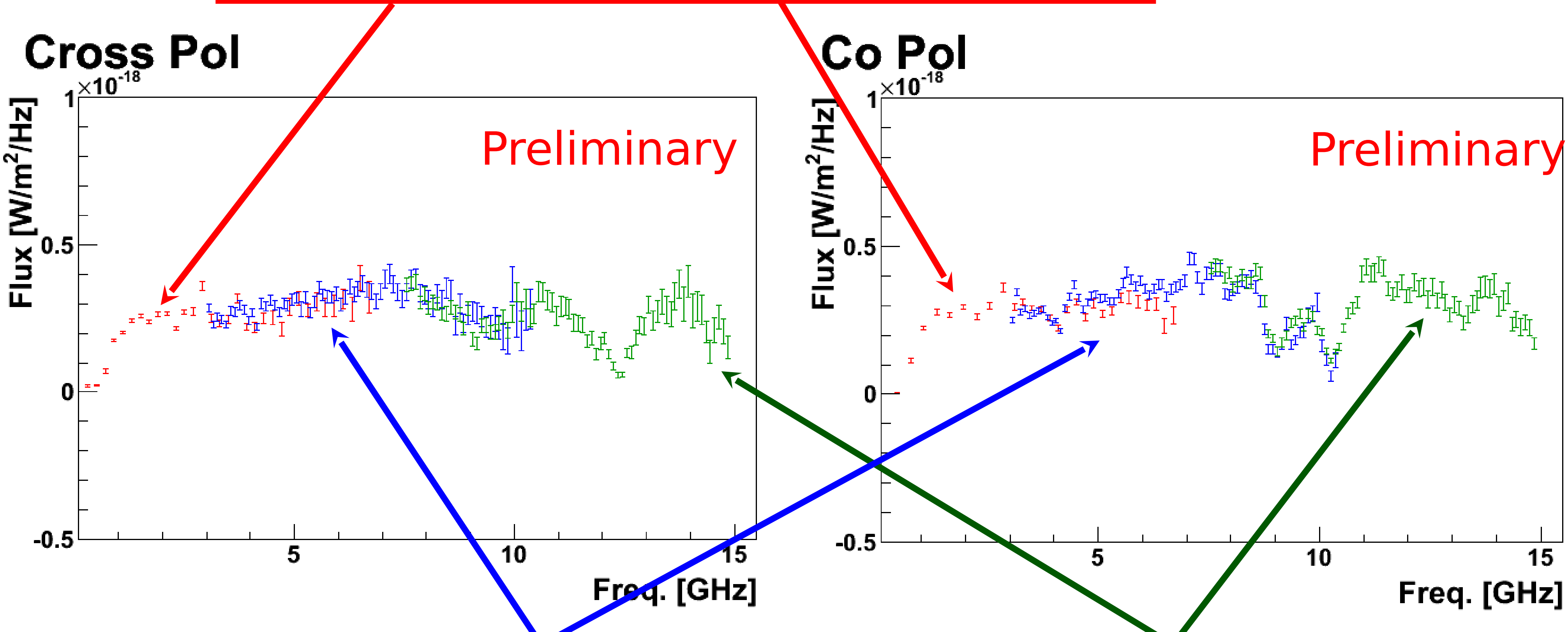




- Measured signal flux correcting for varying beam intensity between data runs

Spectrum

1-2 GHz Amp and 4-8 GHz Amp, Flux recorded by spectrum analyzer



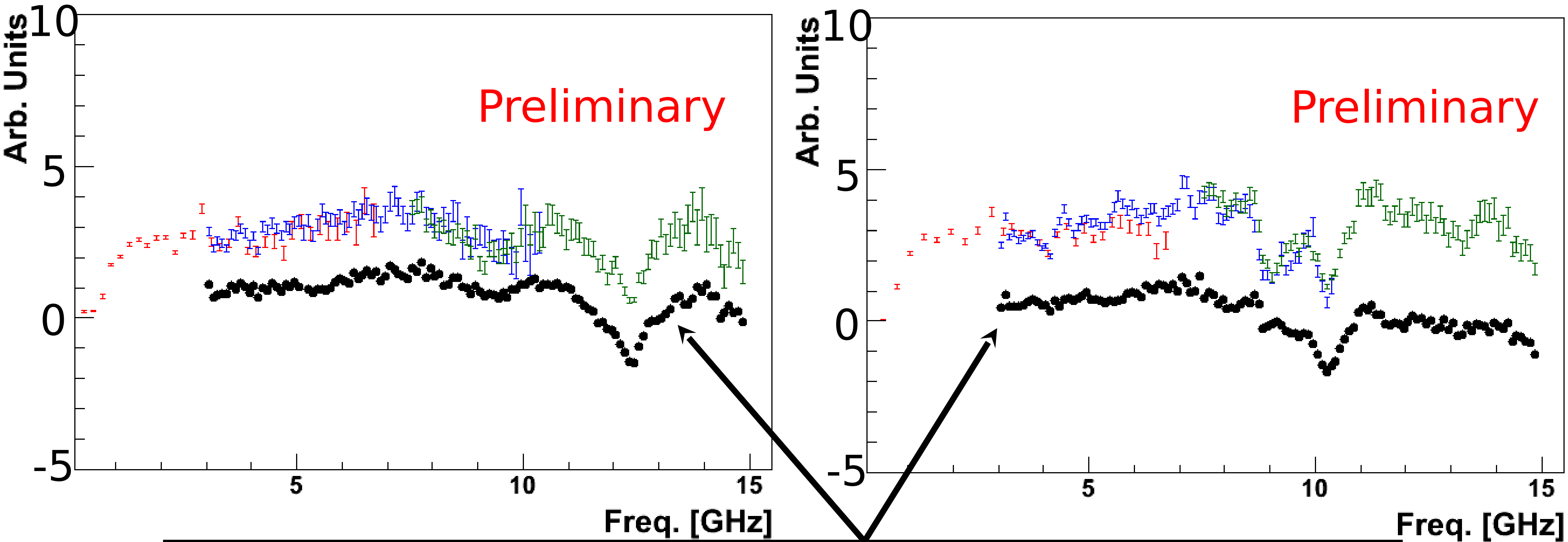
4-8 GHz Amp, Flux from scope using 100 MHz bins

8-12 GHz Amp, Flux from scope using 100 MHz bins

Spectrum

Cross Pol

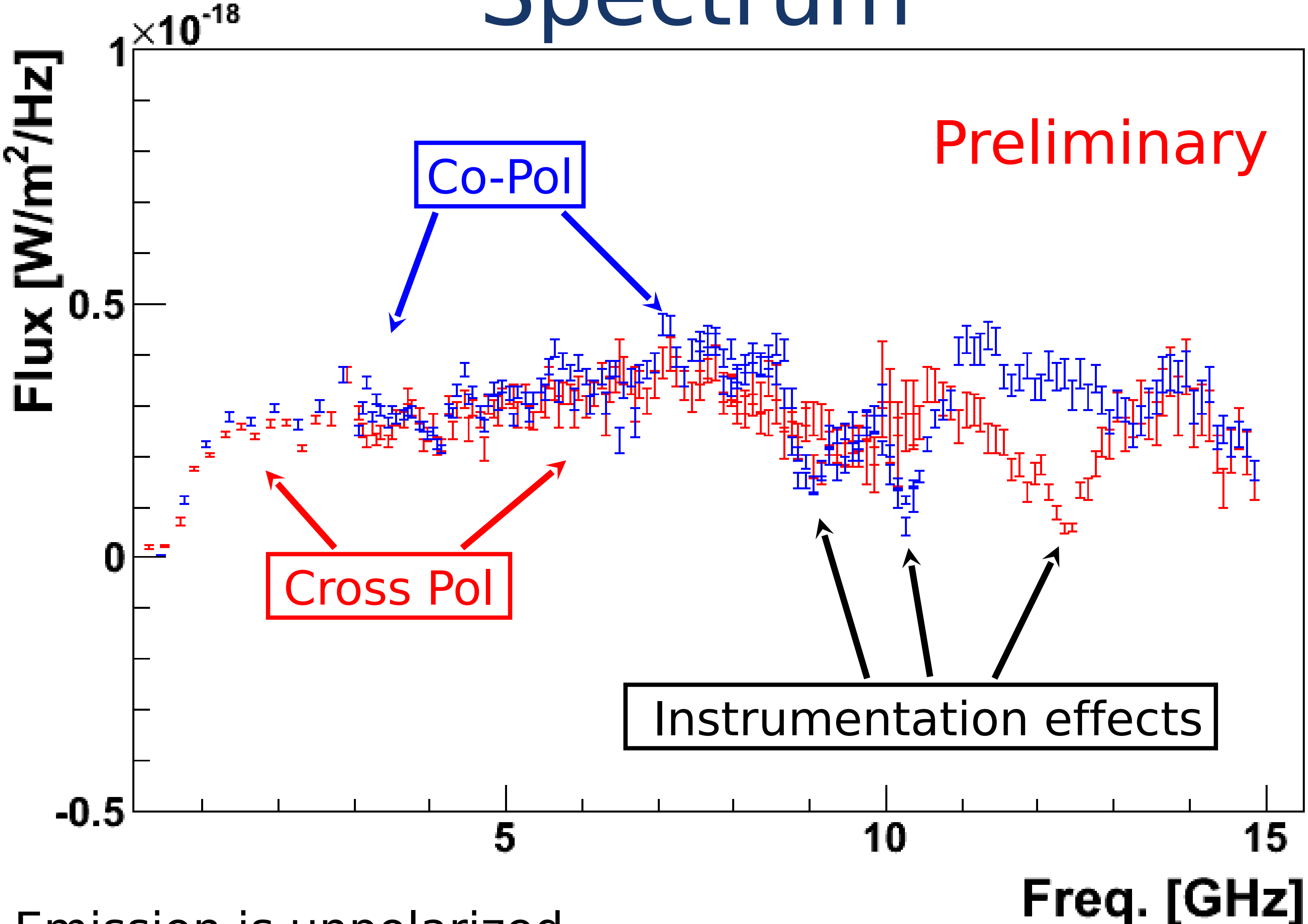
Co Pol



Background power measured from time traces in corresponding amps, scaled to signal level

- Spectral shape of background suggests additional systematics explain high frequency features in signal spectrum
- Ongoing calibration work to understand this

Spectrum

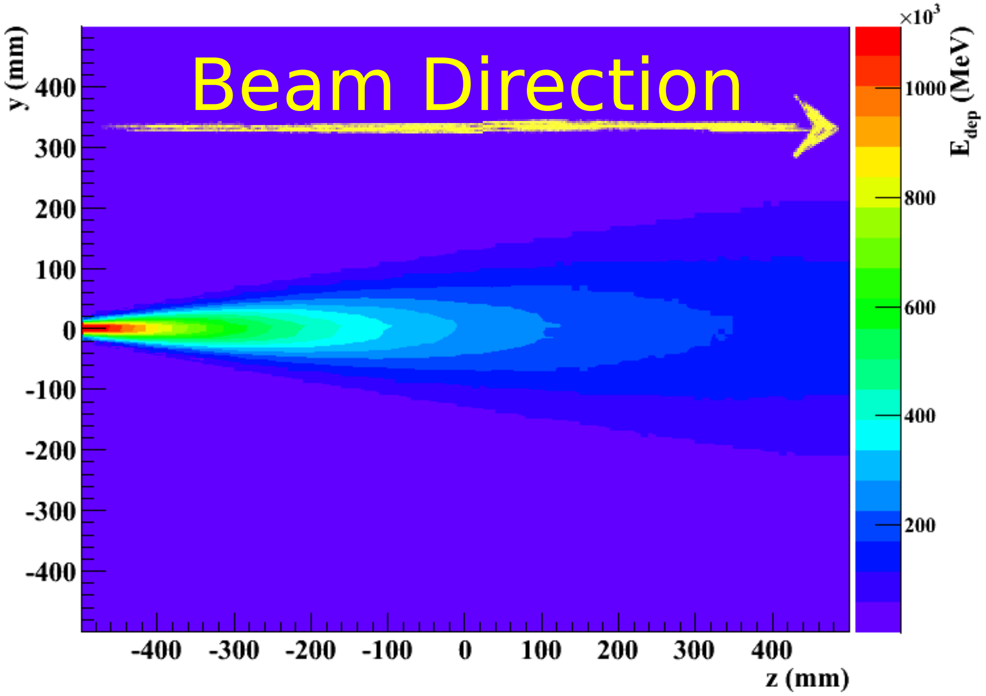


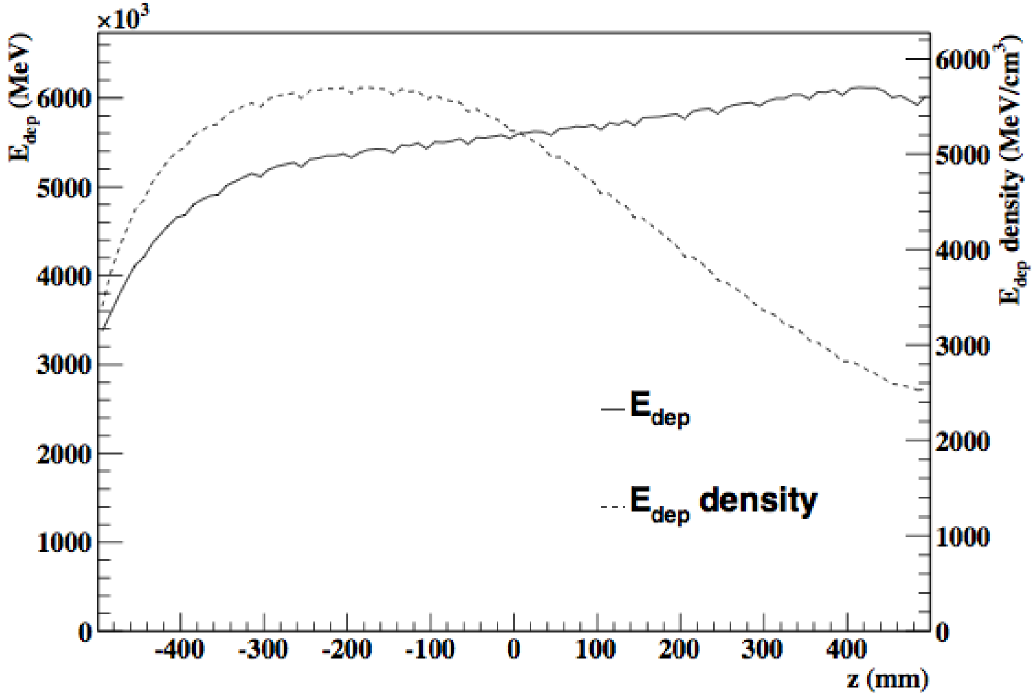
- Emission is unpolarized
- Flat spectrum over range 1 - 15 GHz

Consistent with expectations for molecular bremsstrahlung

GEANT 4 Simulation

Simulations for 3×10^9 3 MeV electrons (number of e$^-$ within 3ns for a typical pulse)





The RMS of the energy deposit cone goes from a few mm to about 15 cm.

Total E deposit in the chamber typically: 10^{14}-10^{15} eV (equivalent to the energy deposit at Xmax by a p shower of 10^{18}-10^{19} eV).

Edep density: 10^7-10^8 e$^-$/cm^3 (assuming all the energy deposit is invested in ionization)

EAS Scaling

For an air shower of 3×10^{17} eV, assuming linear scaling, emission at maximum:

Preliminary: Flux approximately Few$\times10^{-20}$ W/m^2/Hz

- This value is much lower than previous measurements [4×10^{-16} W/m^2/Hz, Gorham et al.]
- Beam very different between experiments (timing, electron energy, ...)

Caveats:

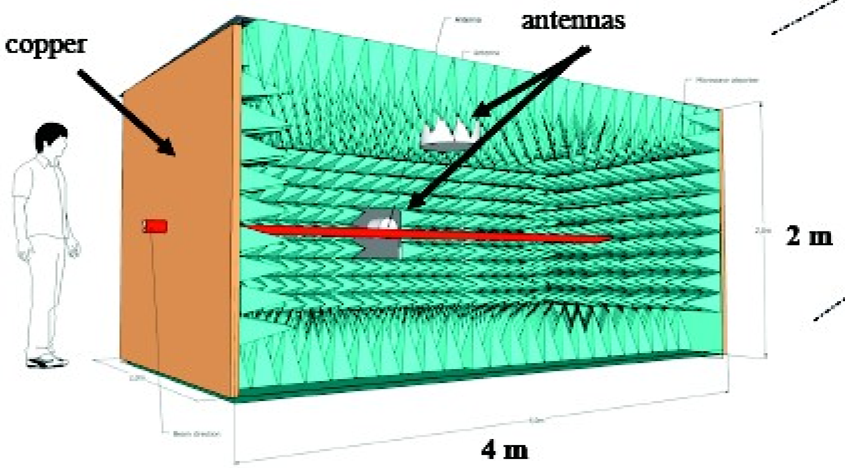
- The plasma created by the beam is different from the one created by air showers (eg. electron spectrum)
- Energy deposit in shower larger than test beam conditions

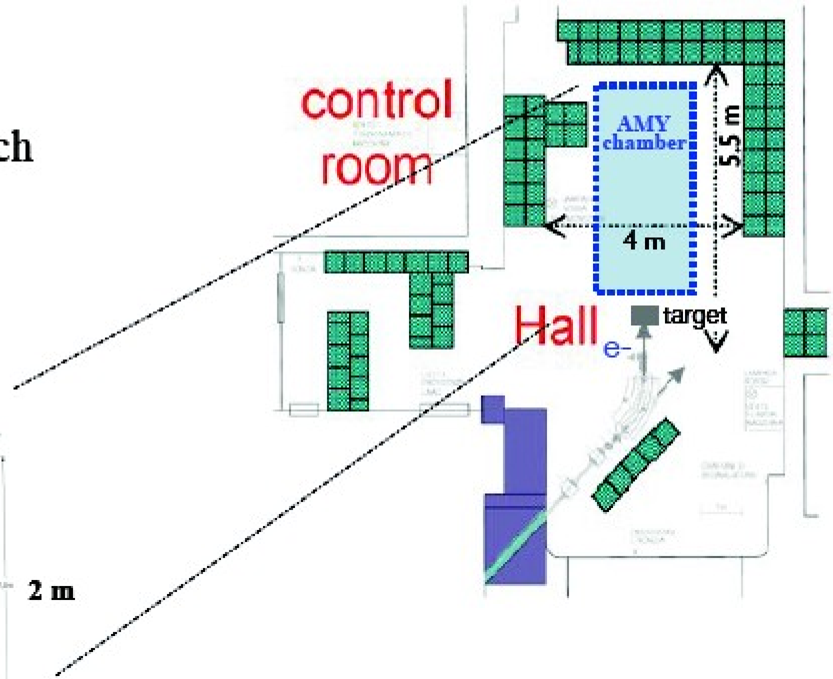
AMY: Air Microwave Yield

Beam extracted from the LINAC of DAFNE

electrons 510 MeV
up to 5 10^{10} particles/bunch

Anechoic Faraday chamber





The aim is to make a **precise measurement of the MBR power and frequency spectrum** repeating a test similar to the one of P.W. Gorham et al.

TWO TEST BEAM

21/11/2011 – 04/12/2011
14/05/2012 – 27/05/2012

AMY COLLABORATION

Roma ToV	C. Di Giulio, G. R. Fernandez, G. Salina, V. Verzi
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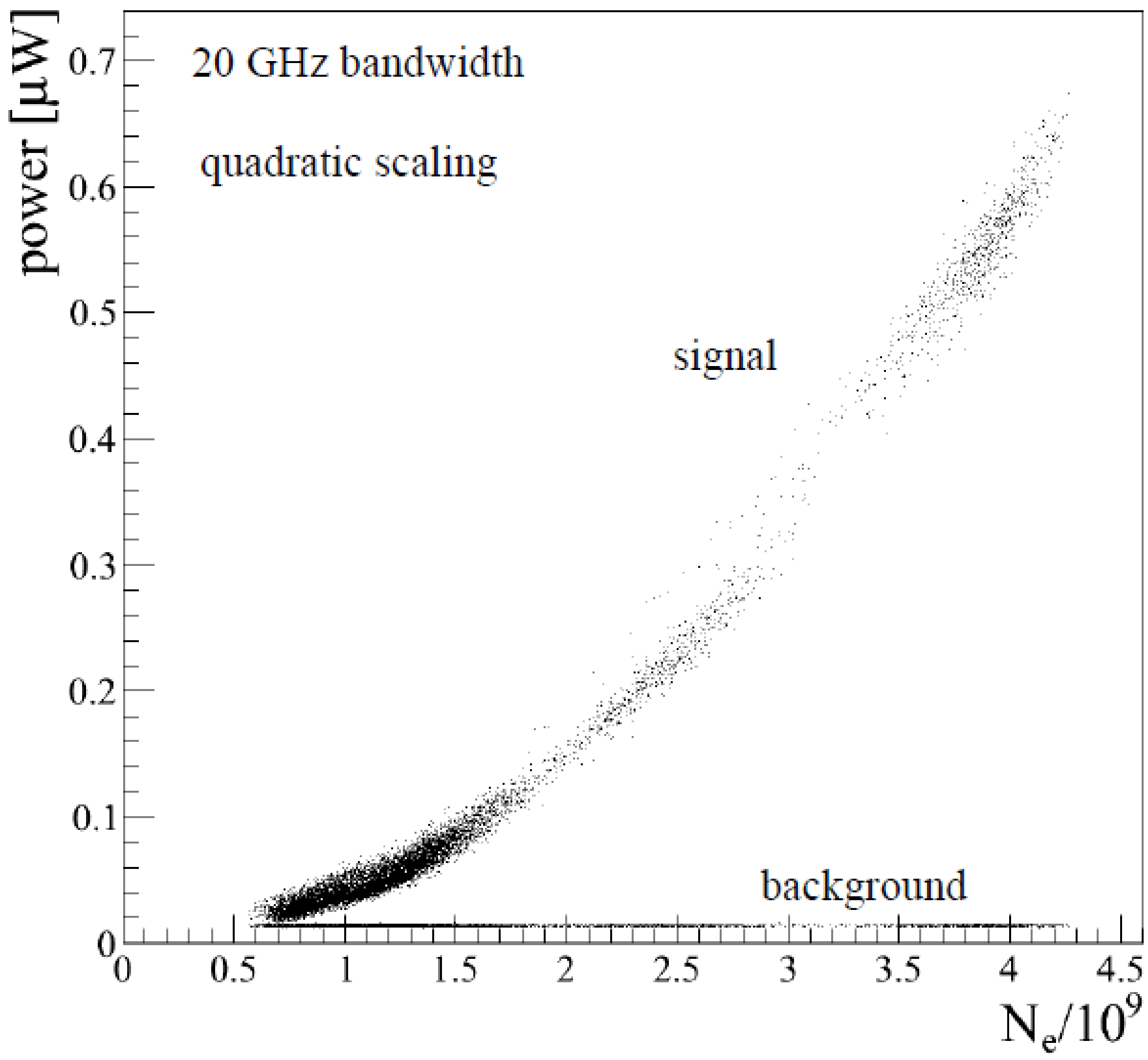
Karlsruhe	R. Engel, M. Riegel, R. Smida, F. Werner

SIGNAL IN THE FULL BANDWIDTH



Preliminary

Includes Cherenkov

Data analysis from the first two test beams ongoing.

A third data test beam planned for the end of 2012

Conclusions & Outlook

- Measured RF emission consistent with expectations from molecular bremsstrahlung:
  - Flat spectrum (between 1 – 15 GHz)
  - Unpolarized

- Measured linear scaling with beam intensity.

- Preliminary signal lower that in previous experiment. Some work still needed to understand antenna systematics.

- Uncertainties on how to scale the accelerator measurements to air shower conditions.

- AMY: complementary measurements with different beam charactristics.

- The final answer will likely come from the combination of test beam and air shower measurements.