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A proposed experiment to detect air showers with the Jicamarca radar system

first look at the expected results and potential problems

Overview

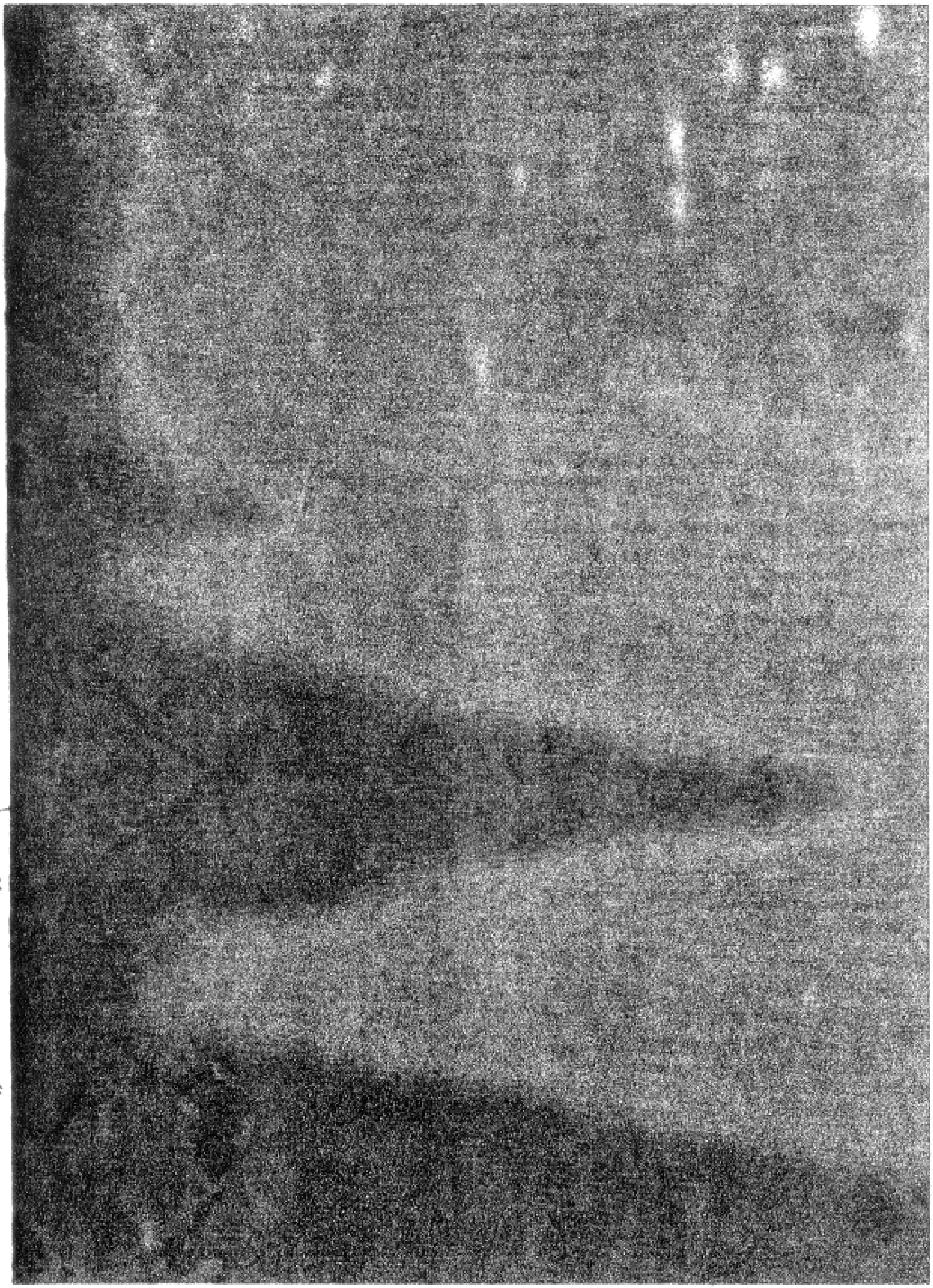
- Jicamarca RADAR Observatory - proposed site for CRS detection with radar
- Detection technique
- Detector geometry
- Expected results (experiment normalization aspects, number of expected events, very first estimations..)

Jicamarca Radar Observatory

- The Observatory is the scientific facility for studying the equatorial ionosphere. It has a 2-MW transmitter and a main antenna with 18,432 dipoles covering an area of nearly 85,000 square meters.
- It is located at a geographic latitude of 11.95° south and a longitude of 76.87° west (Peru, South America). The altitude of the Observatory is about 500 m ASL.
- The Jicamarca Radio Observatory was built in 1960, the first incoherent scatter measurements at Jicamarca were made in late 1961.

- The 49.92 MHz incoherent scatter radar is the principal facility of the Observatory. The radar antenna consists of a large square array of 18,432 half-wave dipoles arranged into 64 separate modules of 12 x 12 crossed half-wave dipoles. Each linear polarization of each module can be separately phased (by hand, changing cable lengths), and the modules can be fed separately or connected in almost any desired fashion.
- each of these new modules can deliver a peak power of ~1.5 MW, with a maximum duty cycle of 6%, and pulses as short as 0.8-1.0 μs. Pulses as long as 2 ms show little power droop; considerably longer pulses are possible.

- There are 3 additional 50 MHz "mattress" array antennas steerable to +/-70° zenith angles in the E-W direction only. Each consists of 4 x 2 half-wave dipoles mounted a quarter wavelength above a ground screen. Two of these arrays can handle high powers.



"mattress"

Basic concept of the Jicamarca CRS detection

- Extensive air showers resulting from primary cosmic-ray particles of E>10^18 eV produce an ionization trail which is compatible of that of micro-meteors; this trail can be described in terms of effective radar backscatter cross section (RCS) for a given choice of radar frequency.
- Radiation is emitted from an antenna with peak transmitted power Pt and directivity gain of antenna G , $G = G(\theta, \varphi)$
- Radar return power :

$$P_r = P_t \sigma_t \eta \frac{G^2 \lambda^2}{(4\pi)^3 R^4}$$

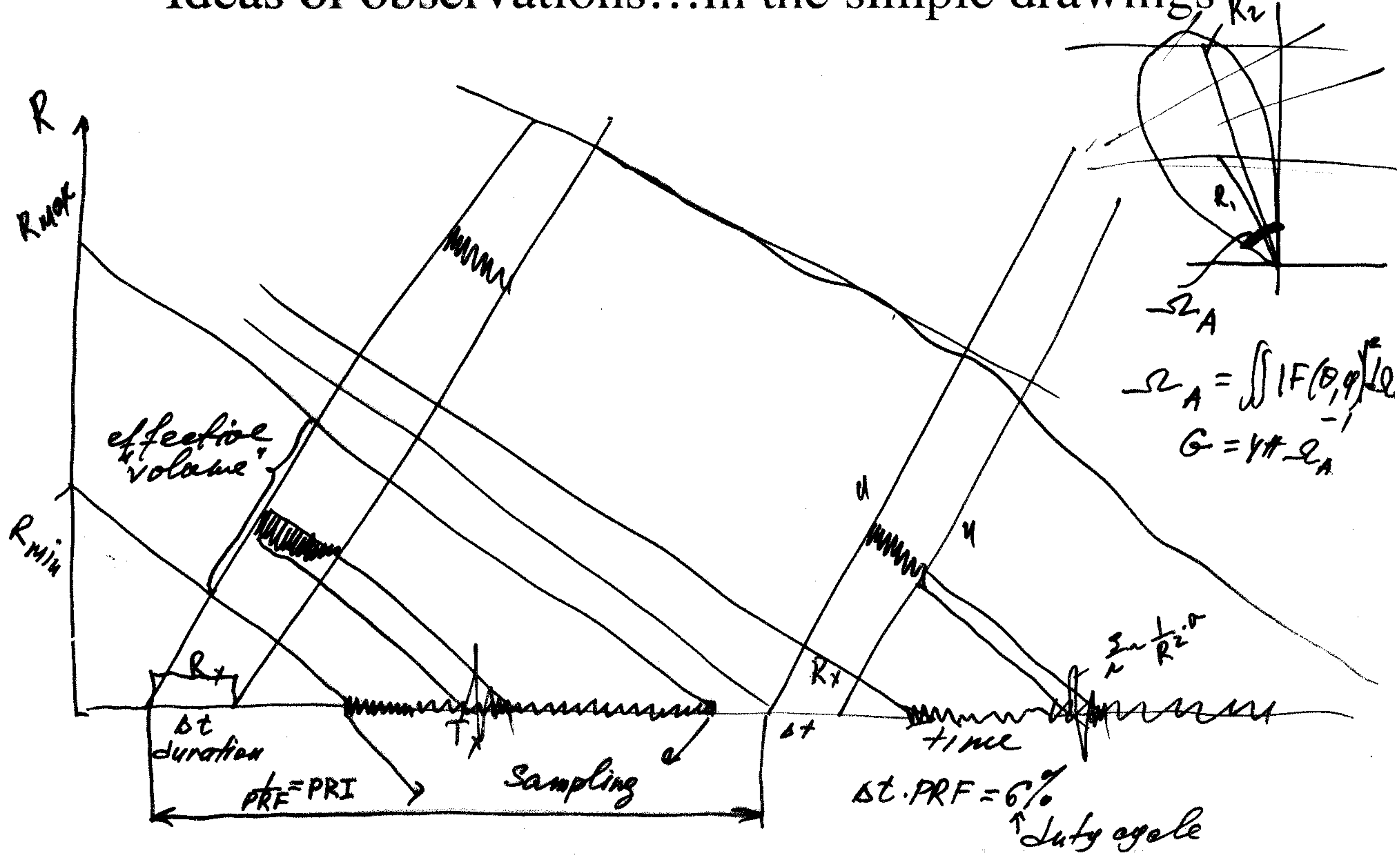
efficiency

$$P_N = kT_{sys} \Delta f \sim \frac{1}{\delta t}$$

$$S / N = 33\left(\frac{\sigma}{1m^2}\right)\left(\frac{P}{10kW}\right)\left(\frac{\eta}{0.1}\right)\left(\frac{G}{10}\right)^2\left(\frac{\lambda}{3m}\right)^2\left(\frac{R}{10^4 m}\right)^{-4}\left(\frac{T_{sys}}{10^3 K}\right)^{-1}\left(\frac{\Delta t}{10 \mu c}\right)$$

$\sigma = \sigma(E, R)$ fixed one can measure one can tune

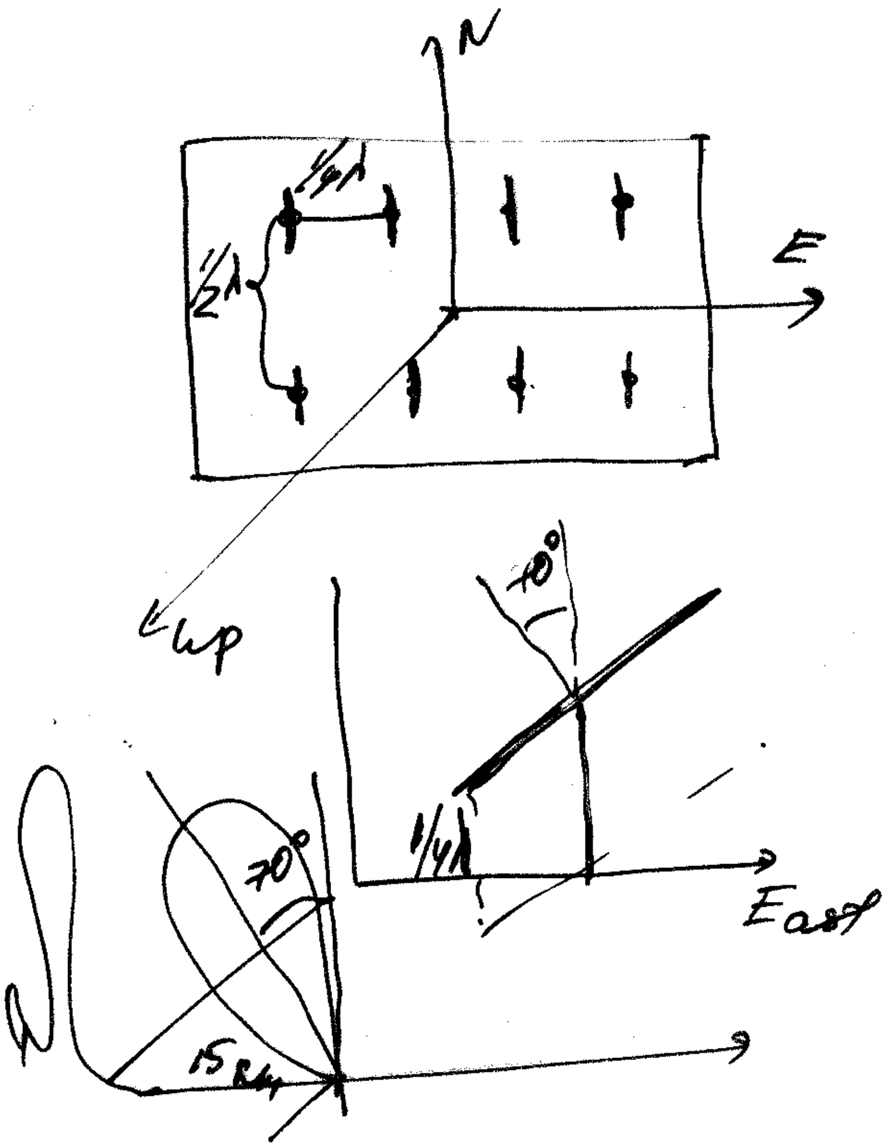
Ideas of observations…in the simple drawings

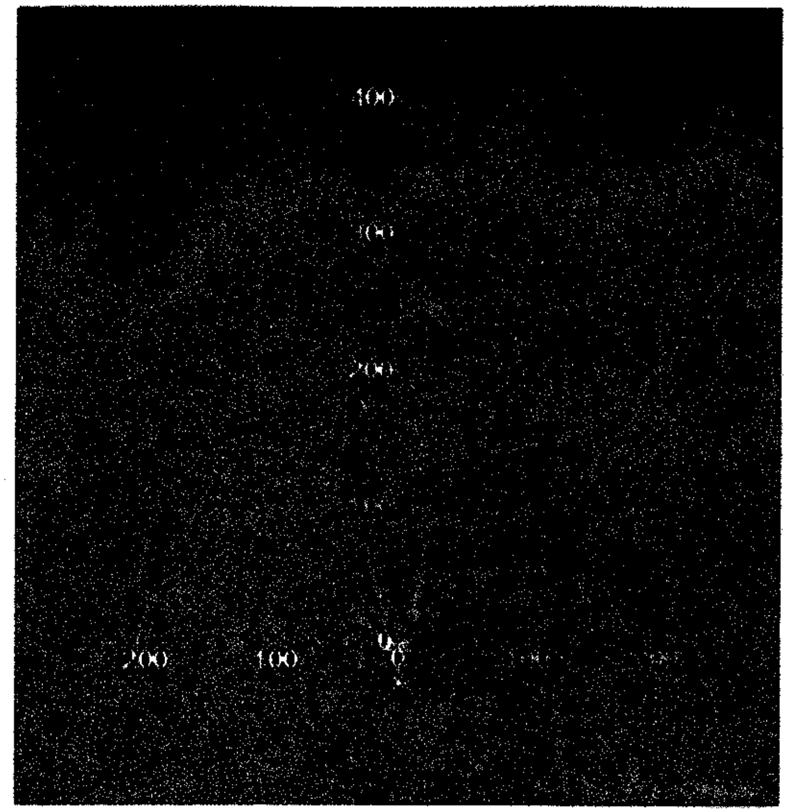


Parameters of the Jicamarca system

Transmitted pulse power	1.5 MW →
Efficiency after losses	0.1 → estim.
Wavelength	6 m →
Main beam lobe diameter	~ 0.5 Rad → calculated
Antenna gain	~ 20.0 → calculated
System temperature Tsys	~ 1000 K → calibration
Pulse duration	10^-6 – 10^-3 s → tune
Duty cycle	6 % - fixed
PRI	needs to be tuned
Effective BW	1 MHz
Number of pulses	N choose
Received signal power	<u>need to estimate RCS</u>

Antenna array of the 4x2 half-wave dipoles mounted a quarter wavelength above the ground screen





η and radiation pattern can be calibrated with Radio stars

How does ~~RCS~~ signal looks for Jicamarca in terms RCS (Radar Cross Section)?

- For Radar detection of ionization column we need to consider two regimes: under- and over-dense.
- They can be distinguished based on the ratio of radar frequency to plasma frequency of ionized region.
- Over-dense portion of the is the region where the electron density is high enough and and the plasma frequency exceeds the radar frequency -> radar signal is reflected
- Under-dense columns have electron densities such that the local plasma frequency is below the frequency of incoming radar, which can penetrate the region and will scatter with partial coherence
- Empirical parameterizations for two cases at a given frequency for 10 km altitude used are:

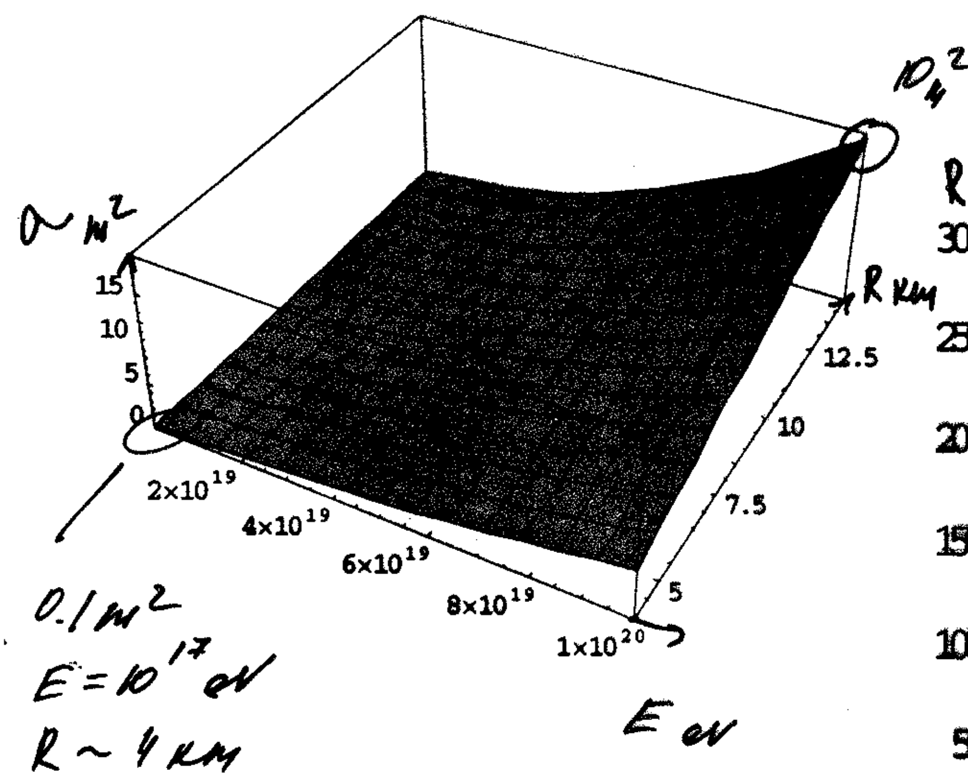
$$\sigma_b^{od} = 2.6 * 10^4 (f / 30\,MHz)^{-1.45} (E / 10^{20})^{0.44} (R / 10\,km)\,m^2$$

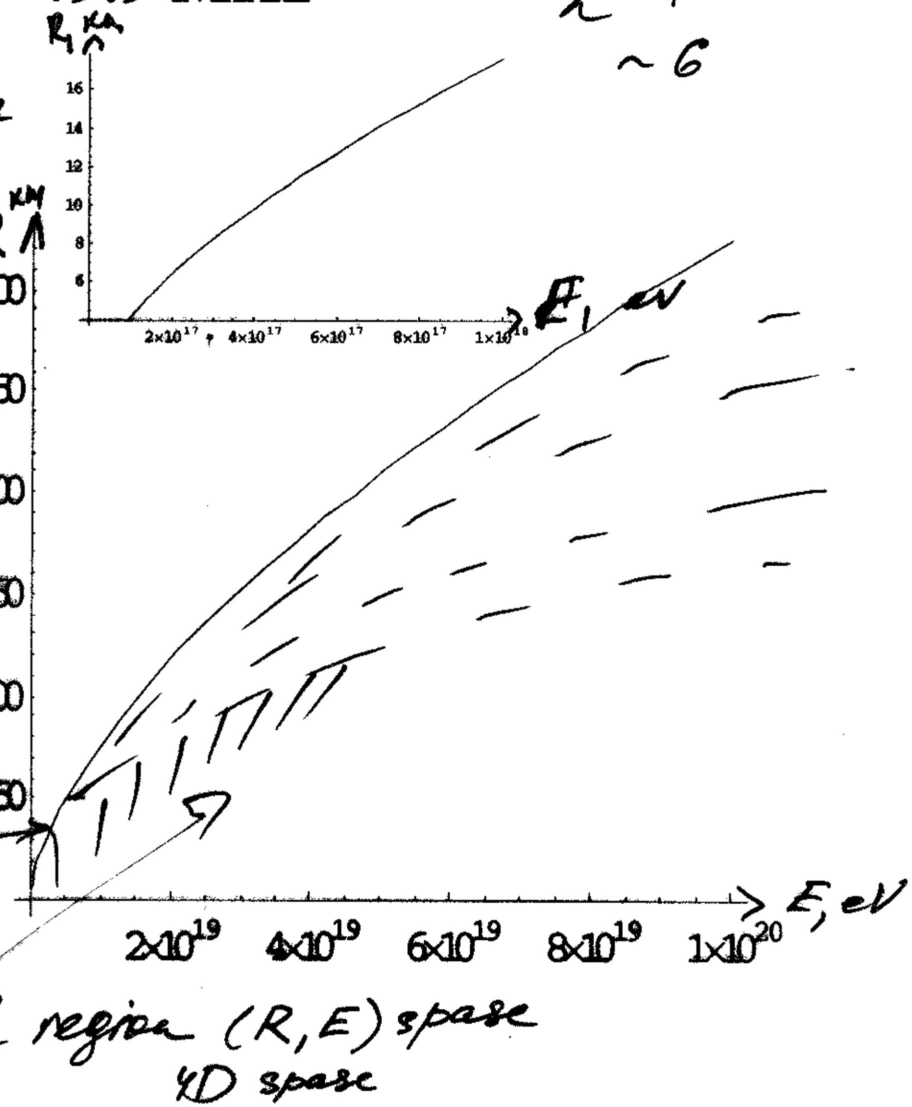
$$\sigma_b^{ud} = 33 * (f / 30\,MHz)^{-1.84} (E / 10^{20})^{1.9} (R / 10\,km)\,m^2$$

air density
atmospheric condition → simulation? measure-?

Figure 1. RCS [m^2] for UD case as a function of

R[km],E[eV] f=49.9 MHz





Jicamarca radar – 4 days running

- Observation time – 4 days (345600 sec)
- E > 10^17 eV ~ 15 events
- E > 10^18 eV ~ 7 events
- E > 10^19 eV ~ 0.7 events
- E > 10^20 eV ~ 0.2 events

$\eta \sim 10\%$

σ parametrization affects $E > 10^{19}$ eV – can be off by factor of multiple choice 10, 5, 2, ...

Conclusions

- There are many uncertainty in the proposed method - lifetime of ionization column is one example(in the present estimation is hidden in the efficiency ~ 10%) requires tuning of the optimum timing scenario of the experiment and a good simulation..
- Radar detection – ground clutter and related scattering effects; can be more realistically understood in the real experimental conditions
- .. Testing the technique