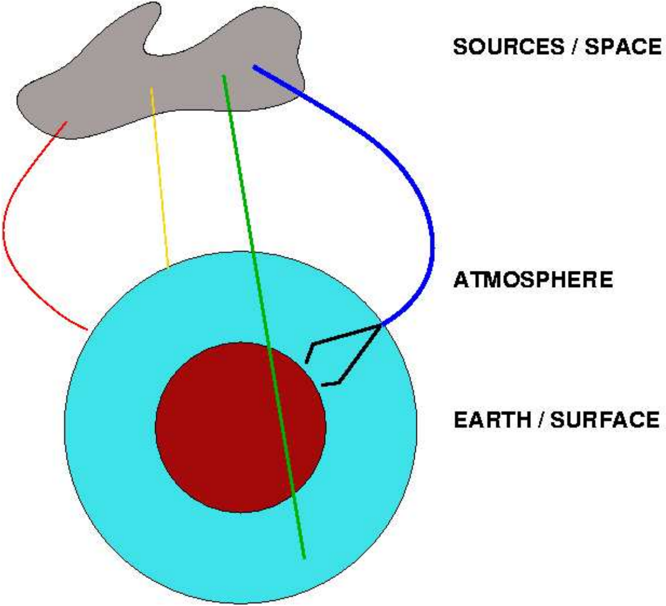
On top of the bottom of the Earth: UFO at South Pole ?!

Junior aka Wombat

University of Ghent

16-17 februari 2006 Group Meeting in Reverie

The talk follows the cosmic ray along his/her path...from source to detector.



Outline

Cosmic Rays

+ Classifi cation name of high energetic particles who travel through space, might interact with the ISM or magnetic fi elds and sometimes reach the Earth.
+ Name fi rst given by Milikan in 1925. Cosmic $\longrightarrow$ come from outher space. Rays $\longrightarrow$ radiation which ionizes the medium they pass.
+ They come in different kinds:

- γamma-rays
- νeutrinos
- electrons and positrons
- charged/ionized nuclei: p (87%), He (12%), ..., Fe (not-conclusive / energy-depandant / fully stripped)

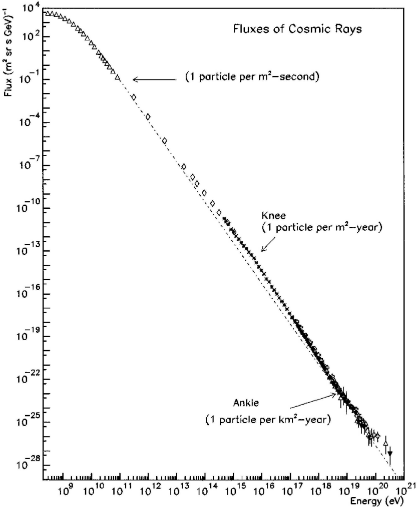
+ the nuclei are extra carriers of information (after well-known optical astronomy, gamma-ray astronomy and radio astronomy) of astrophysical processes:
their advantage = more “reactive” then neutrinos (bigger cross section)
their disadvantage = they are charged and therefore deflected by galactic and intergalactic magnetic fi elds; so they loose their direction information (exception for extreme high energies > TeV $\longrightarrow$ mapping of point sources)

Non-nucleonic Cosmic Rays

+ electrons and positrons:
    - galactic origin; short mean free path length
    - energy depletion through Compton scattering with CMBR
    - measured e^- to e^+ ratio $\longrightarrow$ acceleration at source
    - e^+ likely to be secondary ($\gamma + \gamma \longrightarrow e^+ + e^-$)
    - only 2% of all particle flux
+ νeutrinos:
    - come from all kinds of sources and directions (Brecht)
    - in a straight line from the source
    - very small cross section
+ γamma:
    - similar to neutrinos
    - absorption by ISM & interaction with CMBR

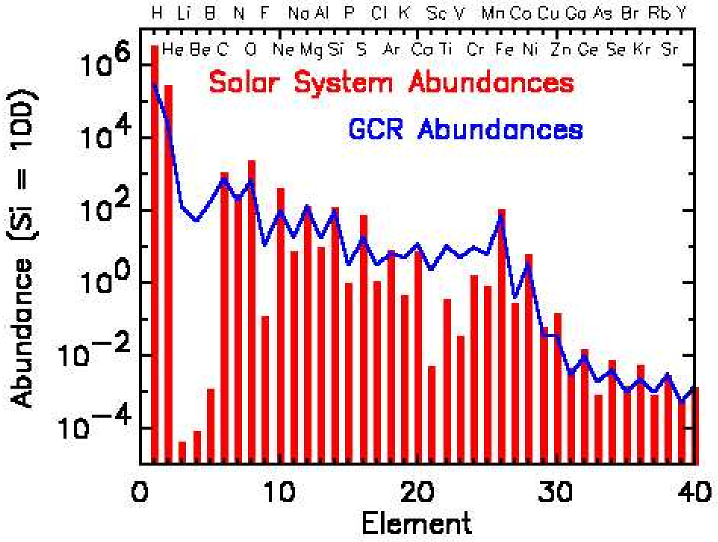
Cosmic Rays: Energy distribution on top of the atmosphere

+ power law ($\frac{dN}{dE} \propto E^{-\gamma}$) with different slopes $\rightarrow$ knee ($\gamma = 2.7$) & ankle ($\gamma = 3.0$)



Cosmic Rays: Composition (relative abundance)

+ indirect method to determine their sources and the way they have traveled



Unidentifi ed Flying Objects: Cosmic Rays

+ their kinetic energy spans a region of 14 orders of magnitude and therefore there exist a classifi cation by energy (comparison):

- anamalous cosmic rays: unexpected low energies ; created near edge of our solar system (heliosteath: border of heliosphere & ISM) ; neutral atoms which interact, get ionized and accelerated by solar winds termination shock or cosmic rays which loose energy (decelerate) while they hit the shock front of solar wind
- solar cosmic rays: relatively low energies (10-100 keV) ; coming from the sun and are accelarated via the solar magnetic fi elds ; their composition follows that of the sun ; fluxes follow the 11 year sunspot cycle ; dependant on solar activity / solar flares
- galactic cosmic rays: high energy particles from far away in our galaxy ; uniformly distributed in space by galactic magnetic fi eld ($\sim \mu$G); electrons, protons, nuclei (stripped during high speed travelling through the Galaxy) ; Forbush decrease because off solar winds; shielded by the heliosphere
- ultra high energy cosmic rays: near the GZK limit coming from extra galactic sources $\longrightarrow$ Freija

Outline

First steps in understanding them ...

+ ionizing particles bombarding the Earth atmosphere fi rst noticed by Victor Hess in 1912 during a balloon flight dedicated for radio-activity measurements: his research was rewarded with the Nobelprice in 1936 together with Carl Andersen. (solar eclipse/electroscope)

+ discovery of new particles: muons (late 30s), pions (1947 on a moutaintop), positrons, “strange” particles $\longrightarrow$ induced by / created during interaction with molecules/particles of the Earths atmosphere in the so-called shower

+ only means of studying energetic collision and decay processes in the early fi fties because lack of high energy accelerators

+ in 1938 Pierre Auger discovered air showers by placing detectors apart from each other and interpreting the arrival times.

+ in 1954 fi rst Extensive Air Shower project in Harvard.

Nowaday questions?

- Where do they come from (direction / source) and how do they get their high energies (cosmic accelerators) ?
- What is the composition of the charged nuclei ?

Outline

1. Cosmic Rays
   - What are they?
   - History
   - Origin - Theoretical Models
2. Experiments - how to detect?!
   - Different Experimental Detection Methods
   - Extensive Air Showers (EAS)
   - IceTop
3. Outlook

Powerfull sites

sources

+ large energy range !
+ supernova explosions and accompagnying remnant (Emax)
+ black holes, quasars, AGN, GRB,..
+ decay of massive objects
+ "exotic" physics: superstrings, Dark Matter, topological defects in the early universe
+ top-down or bottom-up
+ magnetic fields & size of acceleration region
+ nuclei $\longrightarrow$ other particles like γ-rays & νeutrinos via decay and interaction with surrounding matter or ISM on their way through the universe

Accelaration mechanisms

+ second order yields power law with $\gamma = 2$ (maybe 2,7 by energy dependant containment time in the galaxy disk)
+ first order (energy gain prop. to Z)
+ shocks: accretion shocks near supermassive black hole / termination shock of solar or galactic winds / intergalactic shock waves /...

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LOW ENERGY PARTCLES < 1 PeV

high in the sky measurements

Balloon & Satellite

+ small devices
+ low energy particles
+ low flux and small cross section for high energies
+ not suffcient statistics at higher energies
+ combination of different detector types for energy, charge and ID (TRD,SciFi,TCD,pixelated Silicon,hodoscopes) + balloon: CREAM / ANITA / ...
+ satellite: AMS / HEAO Heavy Nuclei Experiment ...

HIGH ENERGY PARTCLES > 1 PeV

air shower measurements on the ground

Air Cherenkov Method $\longrightarrow$ gamma-ray research

+ Particles moving with almost speed equal to c. Creation of Cherenkov light. Disk arriving at detector on the ground. Its caracteristics: 200 m wide and 1 m thick! Very faint light; telescopes on mountains!
+ disadvantage: small duty cycle (dark & moonless nights)
+ HESS / EAS-TOP / Whipple / MAGIC

Fluorescence Method

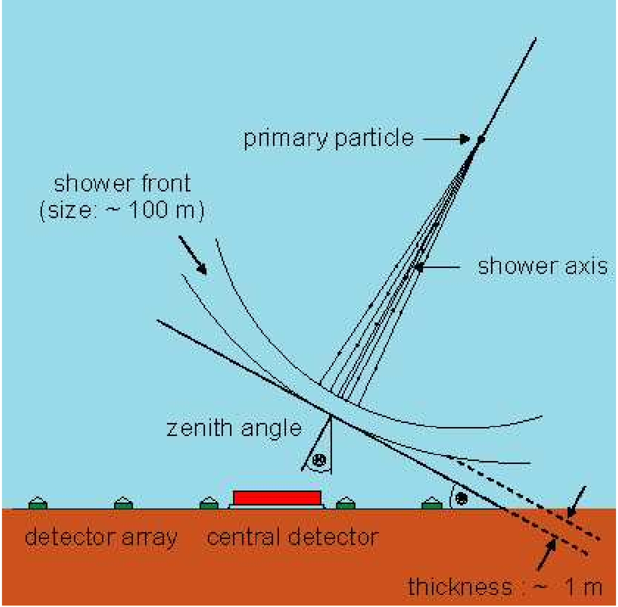
+ High energy particles excite the nitrogen atoms in the air. As a reaction this atom emits light within a certain wavelength region.
+ Auger / Fly's Eye / HiRes

Surface Array Method

- water Cherenkov tanks
- scintillator detectors

+ Uses particles which reach the observation level. They interact with the detector medium or detector and leave a signal. Direct in scintillator and indirect via Cherenkov light in Water(Ice) Tanks.
+ IceTop / Auger / AGASA / KASKADE / SPASE / HAVERAH PARK / MILAGRO

Outline


primary particle
shower front
(size: ~ 100 m)
shower axis
zenith angle
detector array
central detector
thickness : ~ 1 m

EAS Defi nitions:

- Shower axis = direction of primary / incoming shower core
- Shower front = leading particles over the hole geometry
- Shower plane = plane perpendicular to shower axis or tangent to shower front where shower core hits the ground / projection plane for inclined showers: TShowerPlane = Tarrival + dFront/c
- Downstream = signals at the low time side compared with arrival of shower core for inclined showers
- Upstream = not downstream or core
- Curvature of shower front = inverse of the radius of the sphere at the shower core position on the ground which you get when you plot TShowerPlane or time for certain % of total charge is achieved (t10,..)
- Risetime = time for the integrated signal to go from 10% to 50% of its total value / front thickness
- COG = Center Of Gravity: fi rst guess of core impact parameter
- Aging of a shower = spread out from shower core in function of time
- VEM = Vertical Equivalent Muon: typical signal in tank for vertical traveling muon which crosses the center of the detector

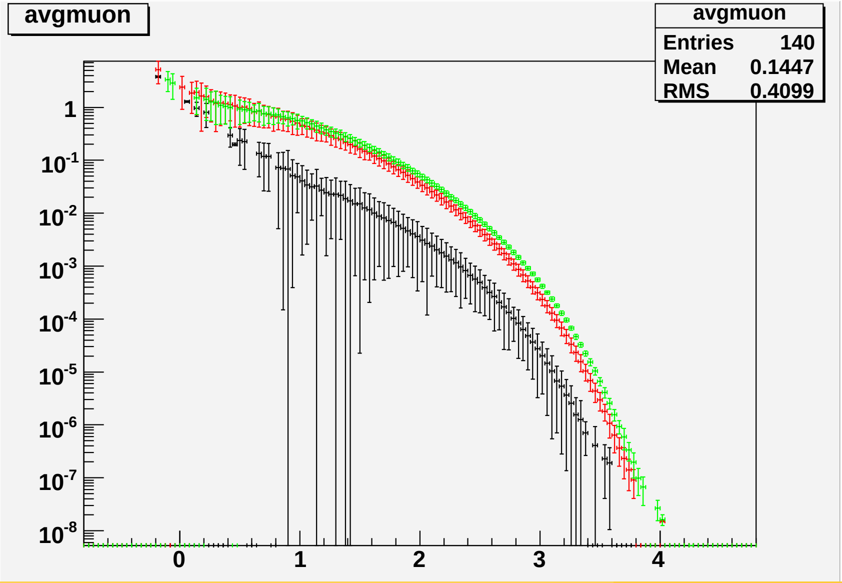
+ Different physics behavior in the atmosphere for different primary particles:

- Type of fi rst interactions (em / hadr.) ; description is big unknown, there are different kind of modelations
- Energy per nucleon
- Altitude of fi rst interaction

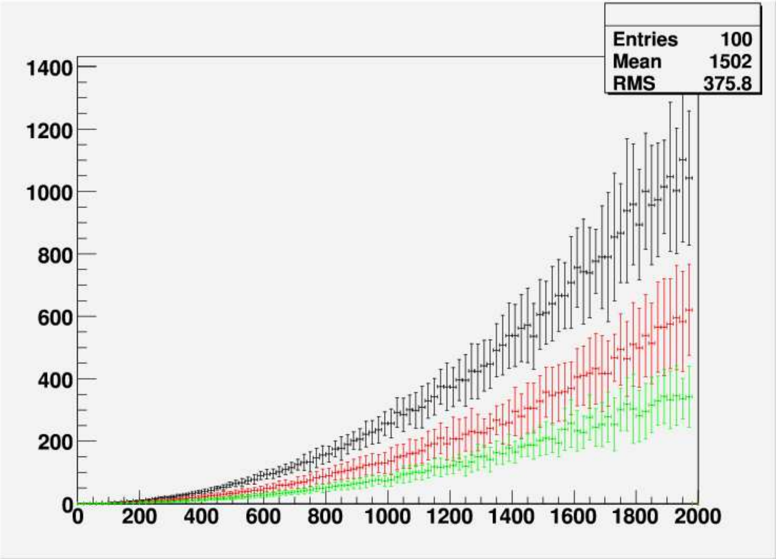
+ Lead to observables to distinguish:

- Muon density at observation level (ratio muon/em part.): superposition model & N_μ prop. to $E^{0.85}$ leads to $N_\mu(Fe)$ prop. to $A^{0.15} \times N_\mu(p)$; we see 30% instead of 80%
- Curvature of shower front
- Rise times
- Xmax = slant depth where the shower reaches a maximum number of particles ; longitudinal shower profi le

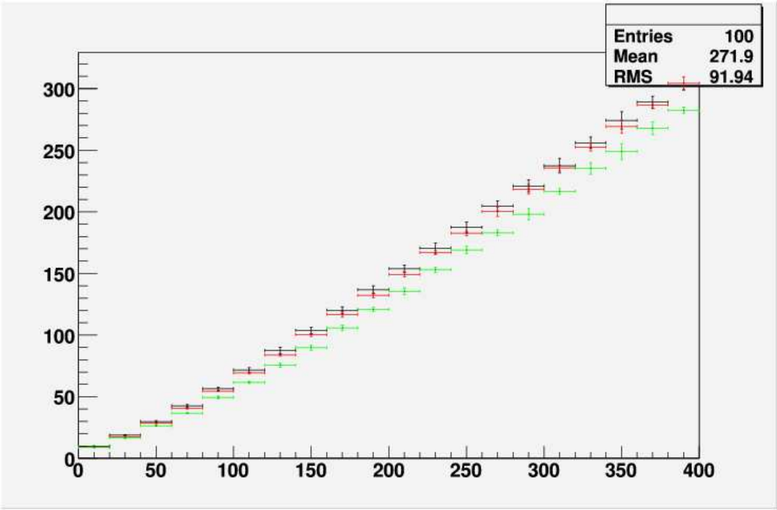
Muon Density at certain distance from the core for 800TeV showers: black = γamma / red = proton / green = iron



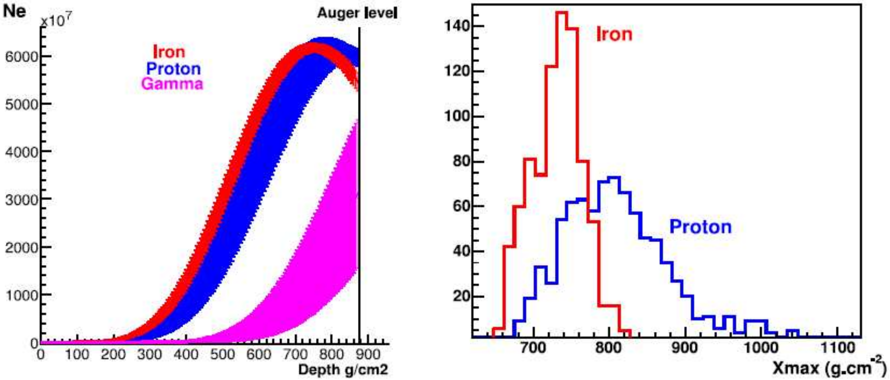
Curvature (T0) of 640TeV showers: black = γamma / red = proton / green = iron



RiseTime (T_{10-80}) of 640TeV showers: black = γ / red = proton / green = iron



longitudinal development (showerprofi le) of vertical 10^{20} eV showers:



Physics inside the shower (microscopic)

+ First interactions:

dependant on primary ID; EM or hadronic; at these energies there are for obvious reasons no manmade accelerators yet; modelling; Pomerons and Mini-jet models for hadronic interaction.

influence on total shower is big for hadronic and muonic part, not for EM-part because of high statistics and many well-known “low” energy interactions

formation of muons and hadrons (pions,kaons,neutrons,...) by fragmentation and decay ...

+ Muons: desintegration of low-energy particles; can reach the ground because few interactions and time dilatation; are goin in straight line (bundle)

+ Shower development:

hadronic interactions

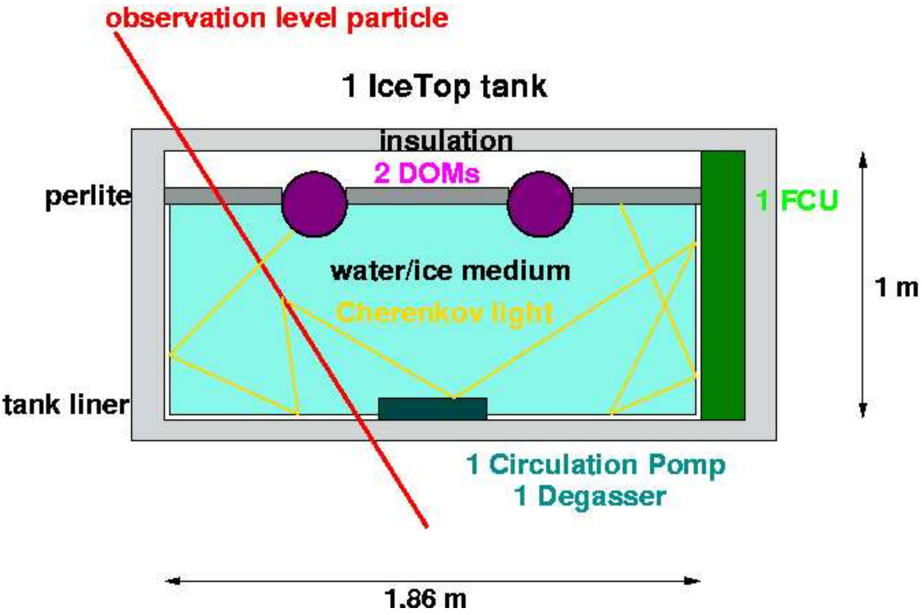
EM-part: pair-production, Brehmstralung, Compton-scattering

Cherenkov

Outline

What? Where? Why?

+ Surface Detector Array
+ near the South Pole
+ 80 stations placed in a triangular grid
+ separation of 125 m
+ instrumented area about $1km^m$ ($\approx$ same effective area)
+ each 2 tanks
+ 10m separation
+ with each 2 DOMs (1 High Gain ($1.\ 10^7$) & 1 Low Gain ($5.\ 10^4$))
+ surface area $\approx 3.6m^2$ (doubled for very high energies)
+ Composition measurements in Energy region between “knee” & “ankle”
+ Horizontal showers $\longrightarrow$ neutrino-induced


observation level particle
1 IceTop tank
insulation
2 DOMs
perlite
1 FCU
water/ice medium
Cherenkov light
1 m
tank liner
1 Circulation Pomp
1 Degasser
1.86 m

+ What do we want:

- direction (θ & ϕ)
- energy (E)
- particle type (ID)
- core location (x,y)

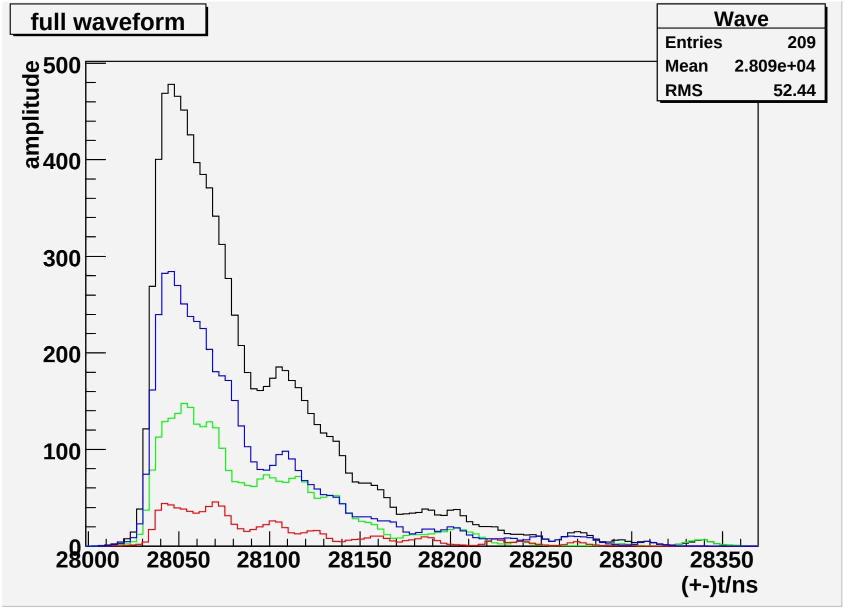
$\longrightarrow$ 6 variables

+ Only two types of information:

- arrival times
- amplitudes

$\longrightarrow$ digitized waveforms

airshower waveform: 245 TeV protonshower between 40 & 50 m from core:



Outlook

+ What to do in the near future:
  - continue research on single muon (particle) waveform
  - start looking for patterns in airshower data
  - for composition reasons
  - extend shower physics knowledge
+ What to do in the far future:
  - write algorithms for muon counting
  - write algorithms for curvatures after detector respons
+ Very far future:
  - composition measurements
  - horizontal showers
  - ...