LATERAL DISTRIBUTION OF COSMIC RAY MUONS UNDERGROUND: Results from the CosmoALEPH Experiment

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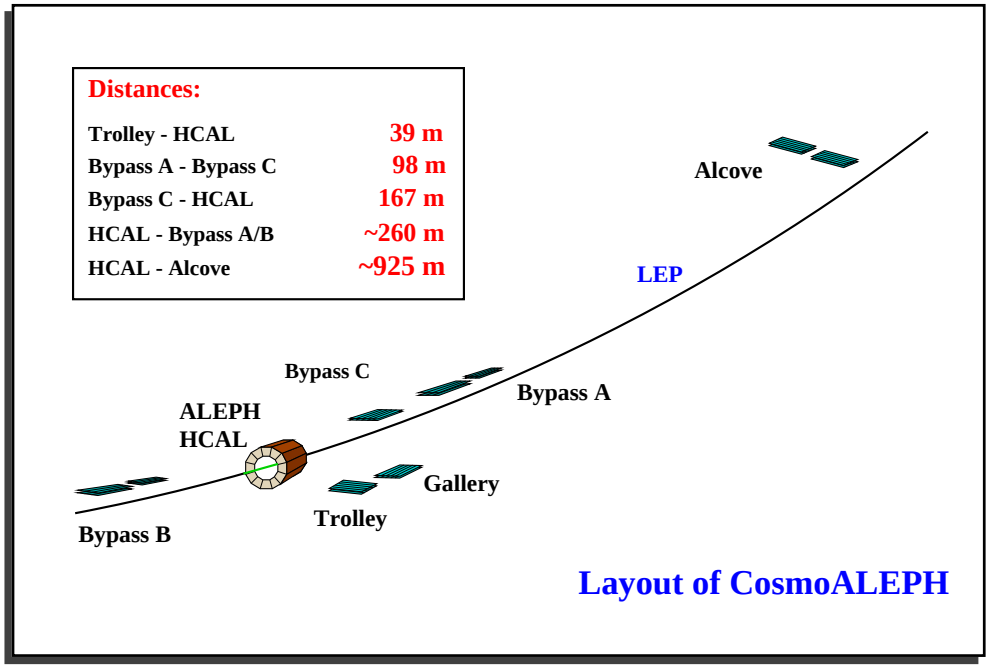
The Goal

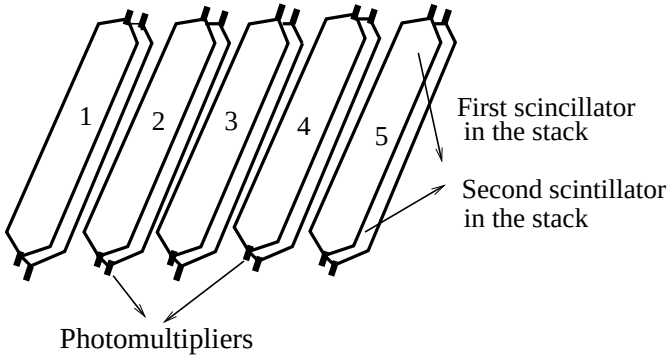
- To determine the chemical composition of primary cosmic rays from a comparison of the measured decoherence distribution with the distributions predicted by various MC models

- To analyse the muon multiplicity and transverse momentum distributions in order to study the primary chemical composition and specific characteristics of the extensive air shower development

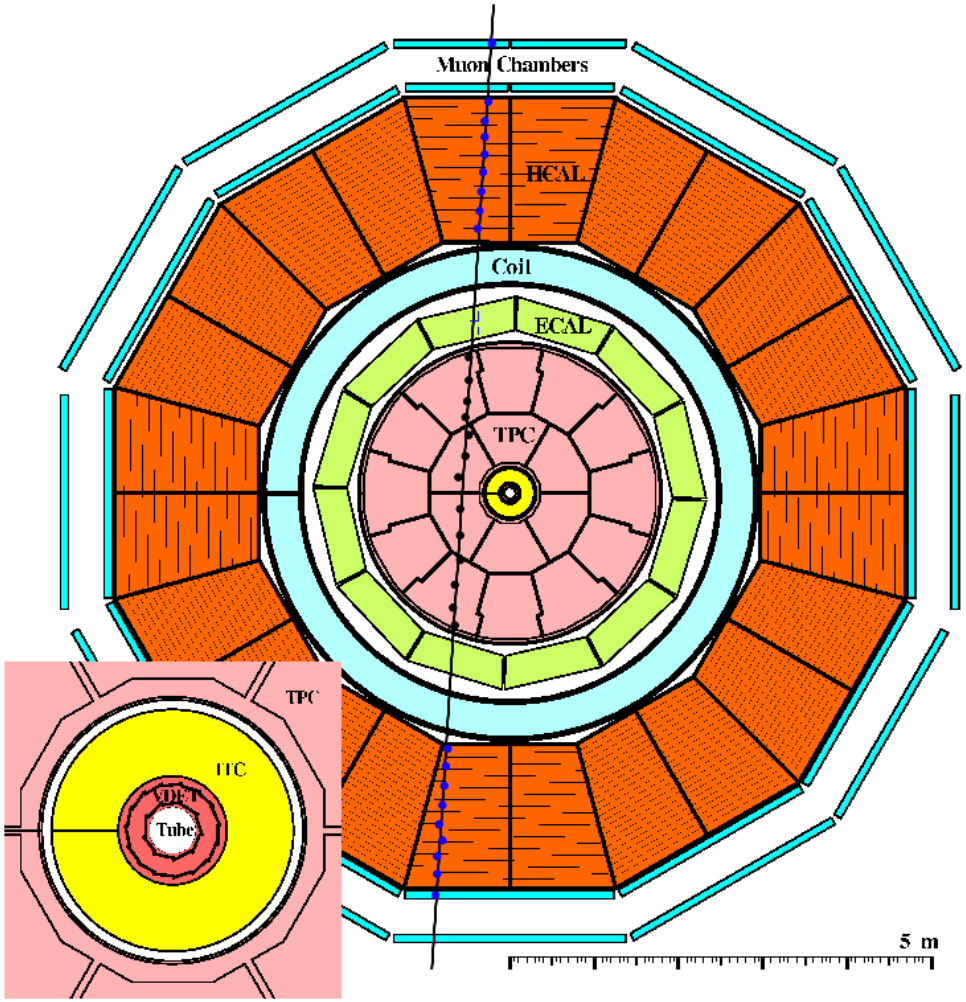
CosmoALEPH Location: underground at 125 m (75 GeV cutoff for vertical incidence)



TROLLEY: 5 Stacks



The ALEPH Detector



- **Superconducting Magnet (1.5 T)**
- **TPC (Time Projection Chamber)**
  Spatial resolution $\sim$ **160** μm
  Momentum resolution
  $\Delta p/p \approx 2.5\%$ **at 50 GeV/c**
  $\approx 60\%$ **at 1.5 TeV/c**
  Detectable momenta $\leq$ **3 TeV/c**
  Angular resolution $<$ **2 mrad**
- **HCAL (Hadron Calorimeter)**

Trigger: At least 8 double planes in one HCAL supermodule and 8 double planes in any of the three oposite supermodules fired simultaneously

Definition of the Decoherence Distribution

$$Rate\ (m^{-4}\ day^{-1}) = \frac{N_{coin}}{\epsilon_i \epsilon_j\ a_i a_j\ S_i S_j\ \rho_{i,j}\ \epsilon_{ov_i} \epsilon_{ov_j}\ T}$$

N_{coin} **is the background-subtracted coincidence rate**

$\epsilon_{i,j}$ **are the efficiencies of stations**

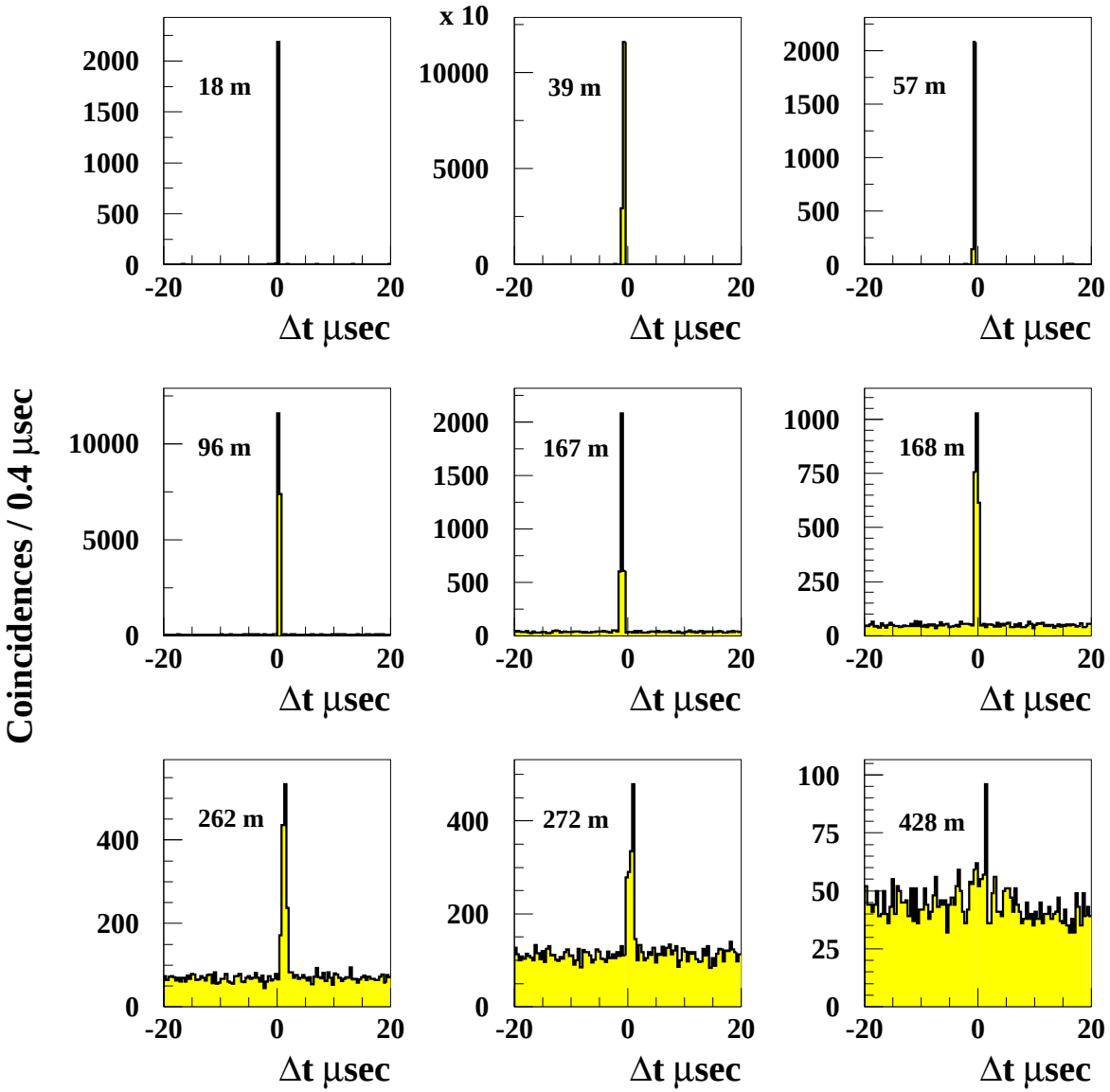
$a_{i,j}$ **correction factors for geometrical acceptances**

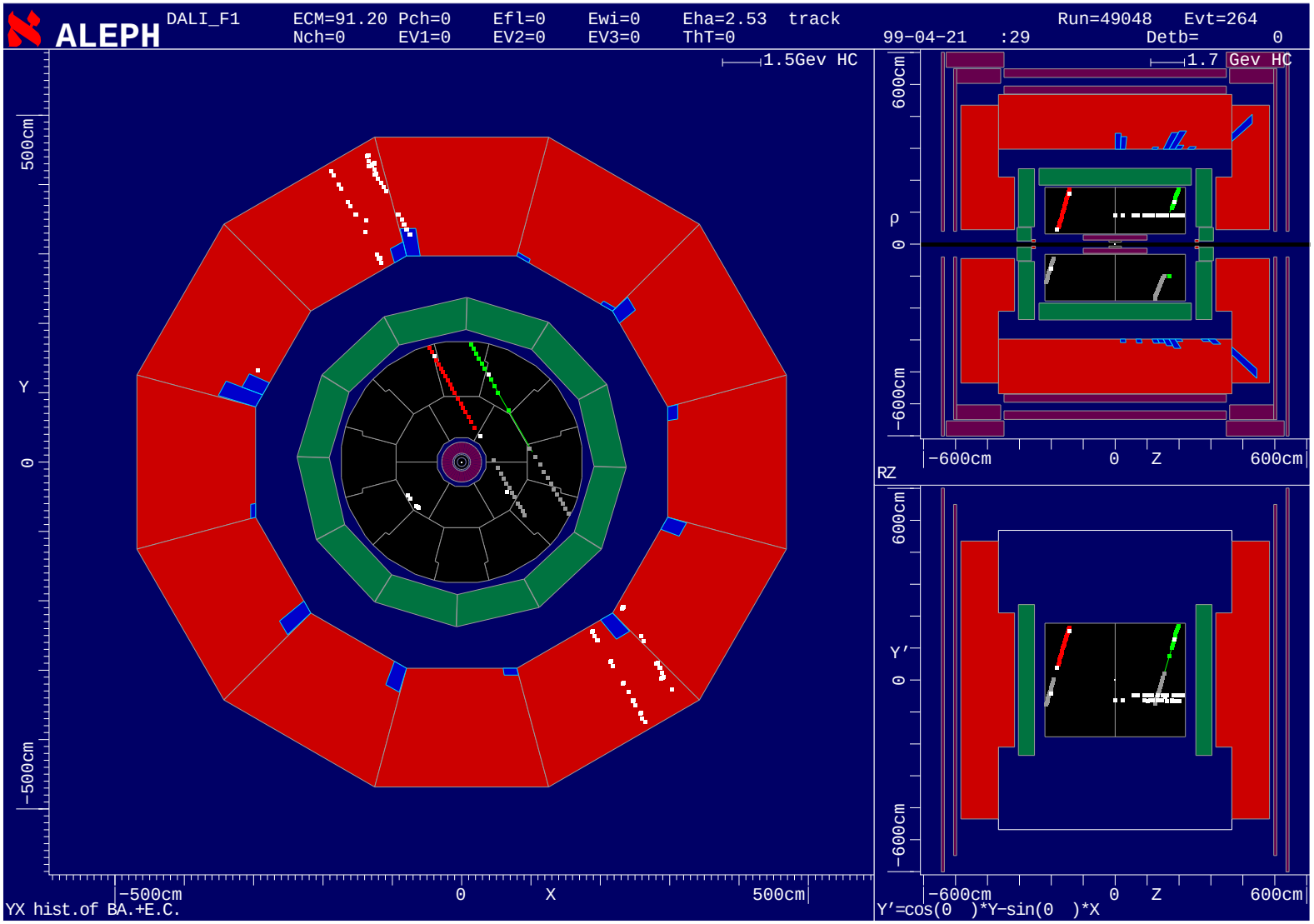
$\rho_{i,j}$ **parameter responsible for the stack orientation**

$\epsilon_{ov_{i,j}}$ **correction factors for the difference in the thickness of the overburden on top of each detector**

$S_{i,j}$ **the areas of detectors in m^2**

T **is the total effective up-time of stations in days**


CosmoALEPH (years 1995-2000)
Coincidences / 0.4 μsec
x 10
18 m
39 m
57 m
96 m
167 m
168 m
262 m
272 m
428 m
Δt μsec

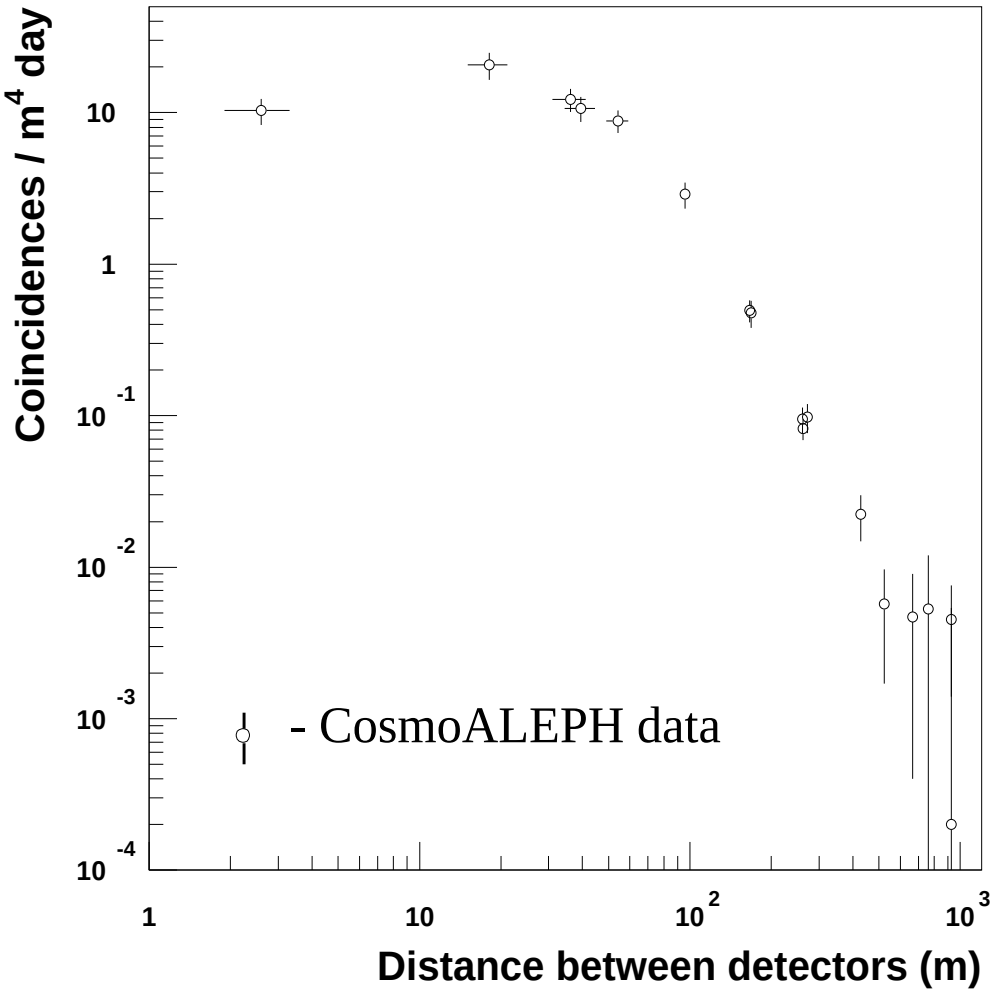


Display of an event with two muon tracks fully contained in each half of the fiducial volume of the TPC along the z-direction

CosmoALEPH data for years 1995 - 2000

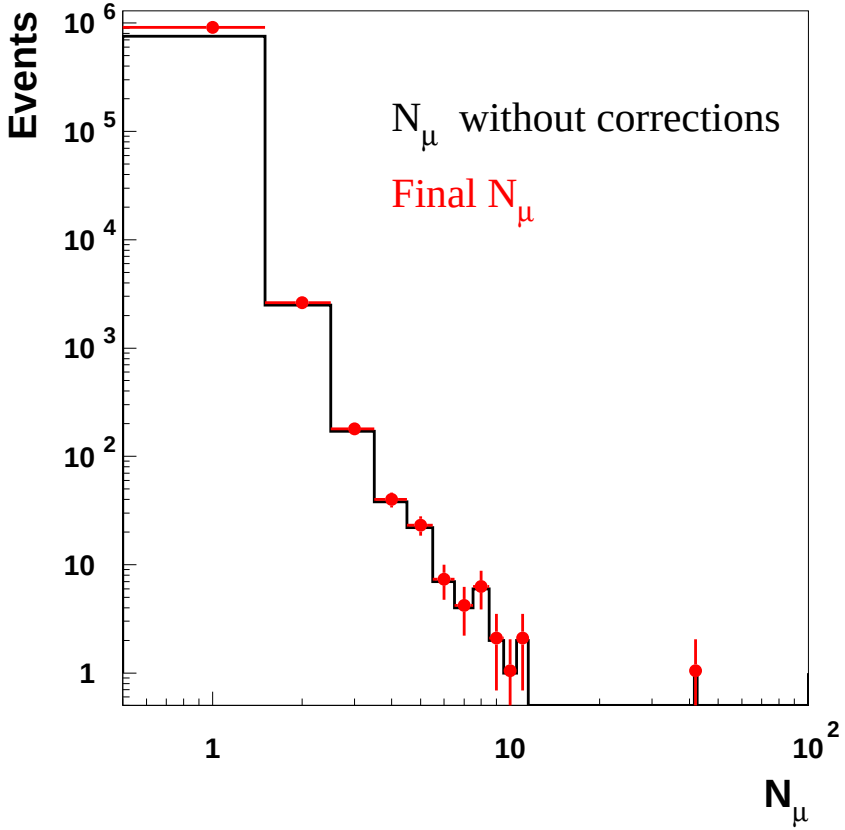
- about 10^9 events collected with all detector stations (1995 - 2000)
- about 10^6 recorded events in the TPC from dedicated runs (1999)

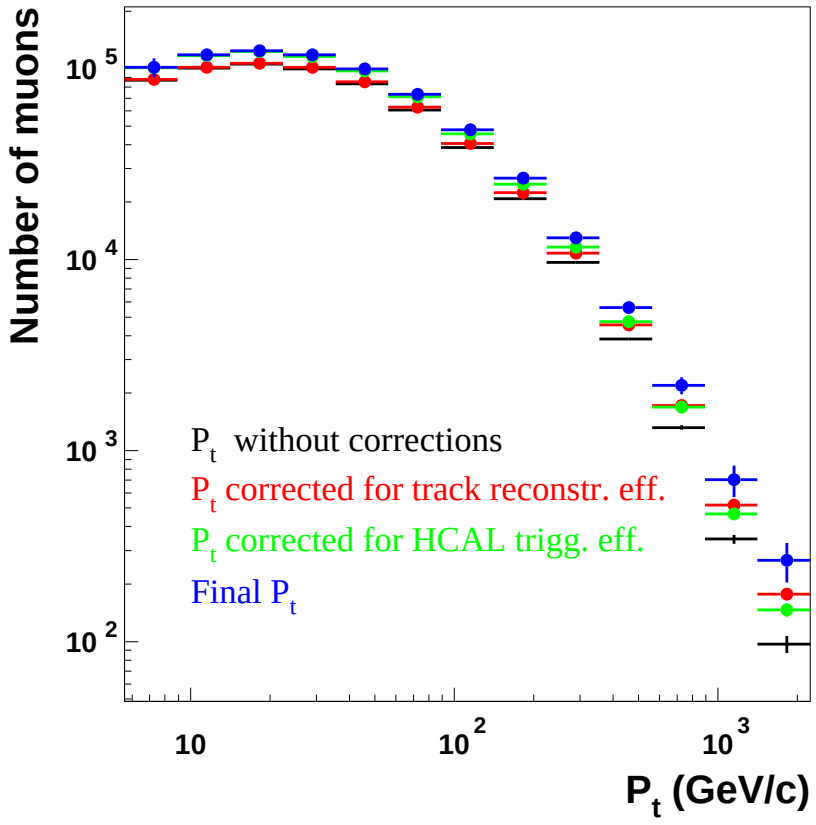
distance [m]	Rate [$m^{-4}\ day^{-1}$]
2.60 ± 0.700	10.2800 ± 3.8429
18.1 ± 3.000	20.6066 ± 4.2373
36.1 ± 5.100	12.2049 ± 2.0907
39.5 ± 5.100	10.6678 ± 2.0235
54.1 ± 5.100	8.8212 ± 1.5169
96.0 ± 3.200	2.8855 ± 0.5668
166.5 ± 5.20	0.4948 ± 0.0808
168.2 ± 3.10	0.4755 ± 0.0965
260.6 ± 3.10	0.0948 ± 0.0185
262.2 ± 5.20	0.0819 ± 0.0128
272.4 ± 3.30	0.0980 ± 0.0215
428.0 ± 3.40	0.0223 ± 0.0075
524.0 ± 3.50	0.0057 ± 0.0040
665.6 ± 3.50	0.0047 ± 0.0043
760.2 ± 3.50	0.0053 ± 0.0067
926.1 ± 3.40	0.0002 ± 0.0052
926.5 ± 5.30	0.0045 ± 0.0031



Multiplicity and Transverse Momentum: dedicated runs 1999

- Momentum P $>$ 5.0 GeV/c and momentum resolution $\frac{dP}{P} < 1.0$
- The muon track crosses the xz plane of the TPC
- The length of the full muon track is larger than 1.6 m





CORSIKA SIMULATIONS

- Models: QGSJET, VENUS, SIBYLL and NEXUS
- About 10^8 air showers of H, He and Fe primaries were generated
- Primary zenith angle θ range from 0° to 89°
- Primary energy in the range from 170 GeV to 10 PeV
- Two mass compositon models: Constant mass composition (CMC) with the same spectral slope $\gamma = 2.7$ for all primary elements and the Maryland composition model (MCM) with varying spectral index and energy cutoff $E_c \ \ (GeV)$

Composition model	Elements	γ	E_c (GeV)	γ $(E > E_c)$
MCM	proton	2.75	$3.0 \cdot 10^5$	3.35
	helium	2.77	$6.0 \cdot 10^5$	3.37
	iron	2.50	$8.4 \cdot 10^6$	3.10

- Energy cut-off: $E_\mu = 0.55 \cdot (e^{\frac{0.4 \cdot 0.32}{\cos\theta}} - 1)$ [TeV]

MC Coincidence Rates

- For each shower with ≥ 2 muons underground at the CosmoALEPH experiment level the distance and time difference between all possible pairs of two muons (for all showers) were computed

- The obtained coincidence rates of muons for each simulated primary element for different hadronic models and composition approaches were best fit with the Nishimura-Kamata-Greisen (NKG) formula

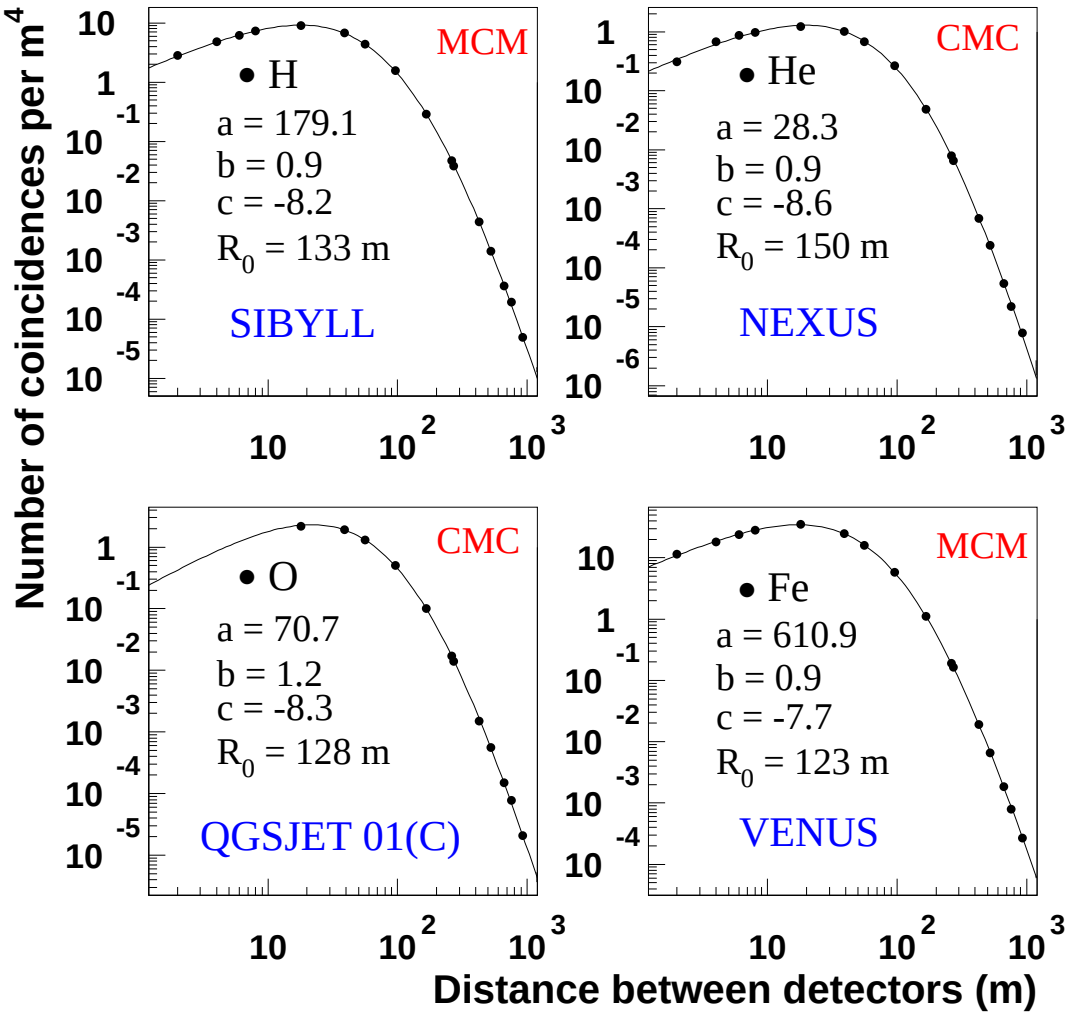
$$f_{p,He,Fe} = a \cdot \left(\frac{R}{R_0}\right)^b \left(1 + \frac{R}{R_0}\right)^c$$

- A constrained fit of the CosmoALEPH data was performed with the sum of the obtained functions for p, He and Fe

$$f = par(1) \cdot f_p + par(2) \cdot f_{He} + par(3) \cdot f_{Fe}$$

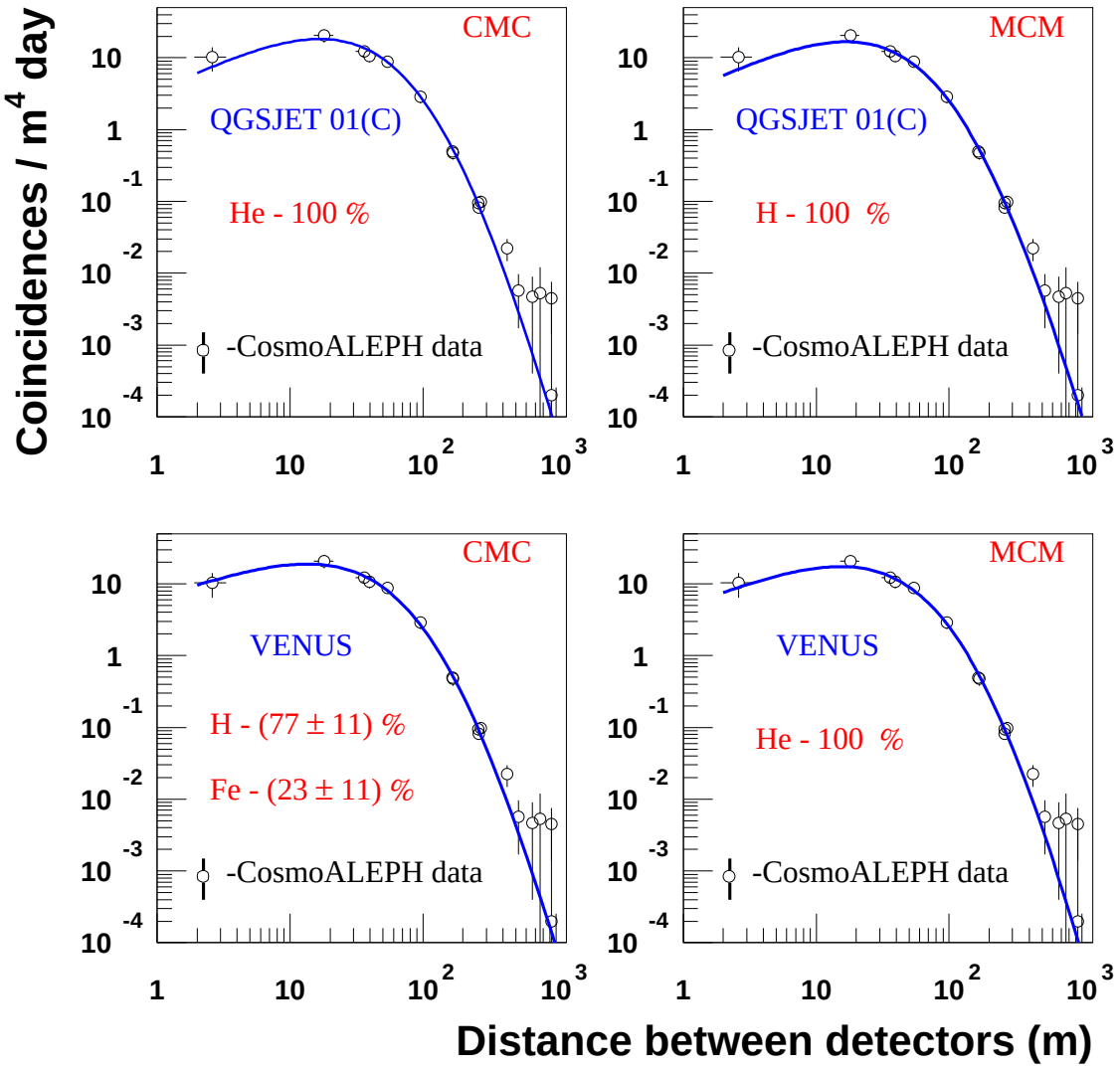
- The contributions par(1), par(2), par(3) of each element were determined

MC Decoherence Distributions for H, He, O and Fe fitted with NKG



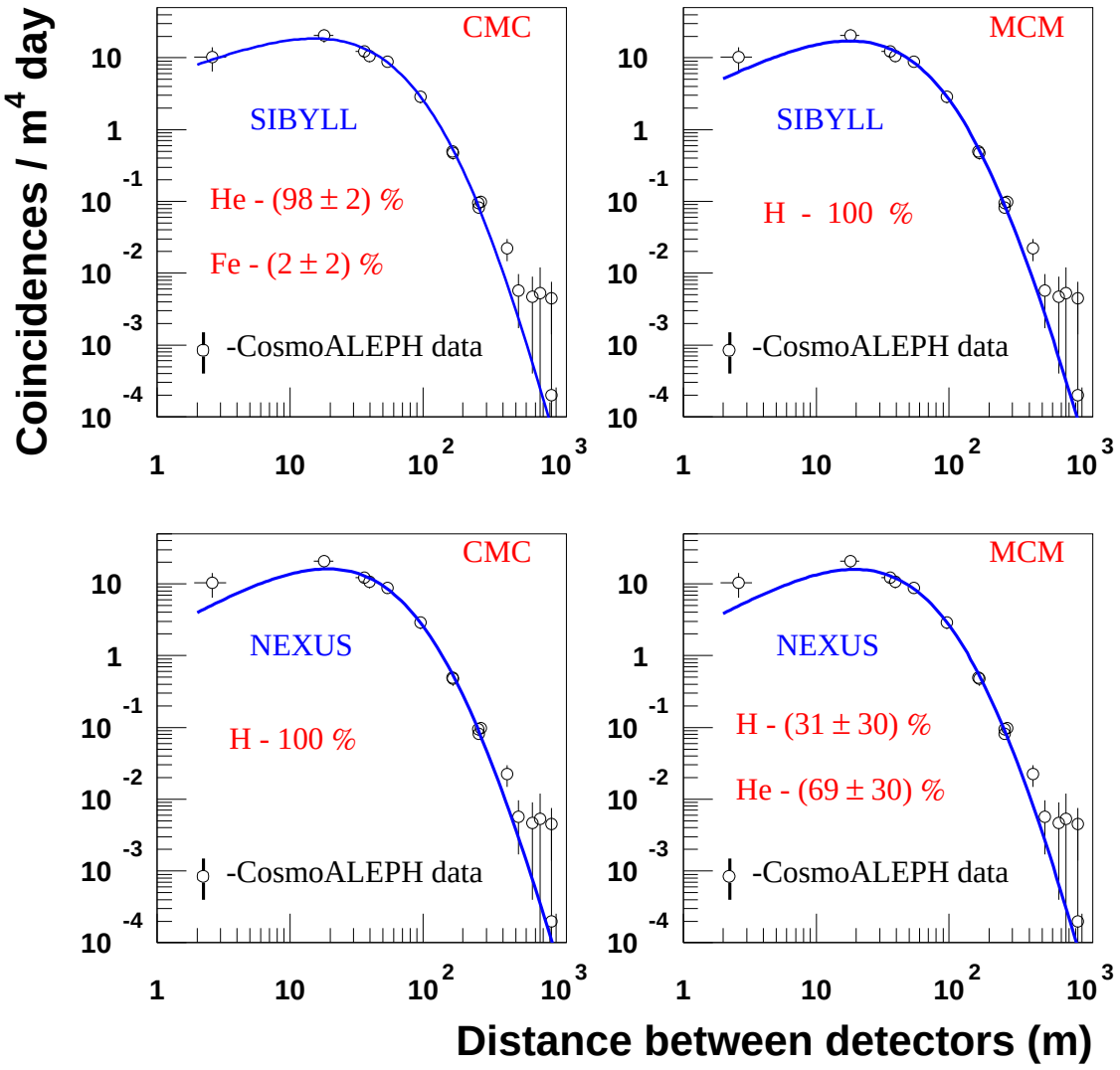
The obtained NKG parameterizations are in good agreement with simulations.

Comparison of the CosmoALEPH Decoherence with MC Predictions



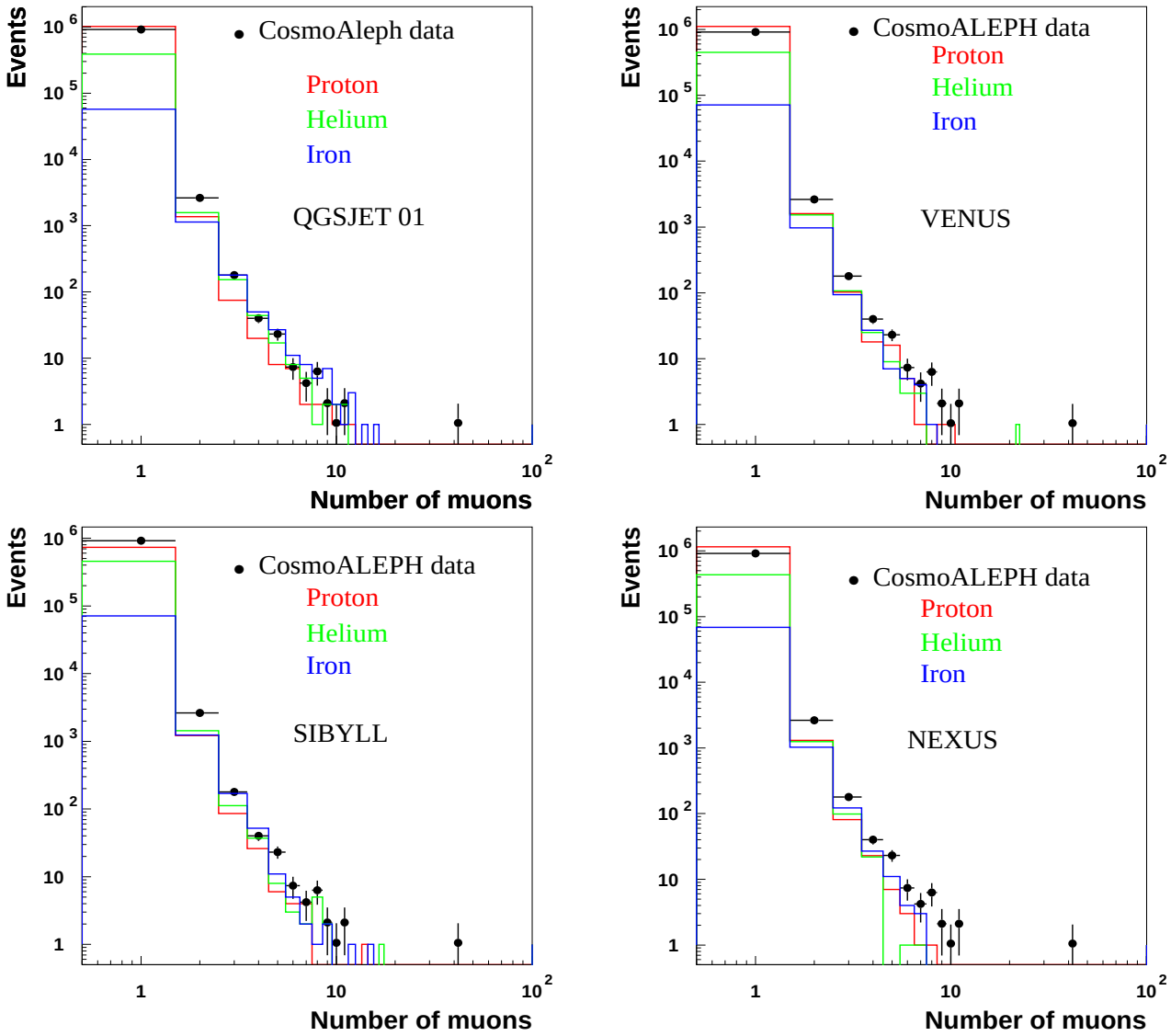
Blue line is the fit to the CosmoALEPH data with the sum of H, He and Fe parameterizations.

Comparison of the CosmoALEPH Decoherence with MC Predictions



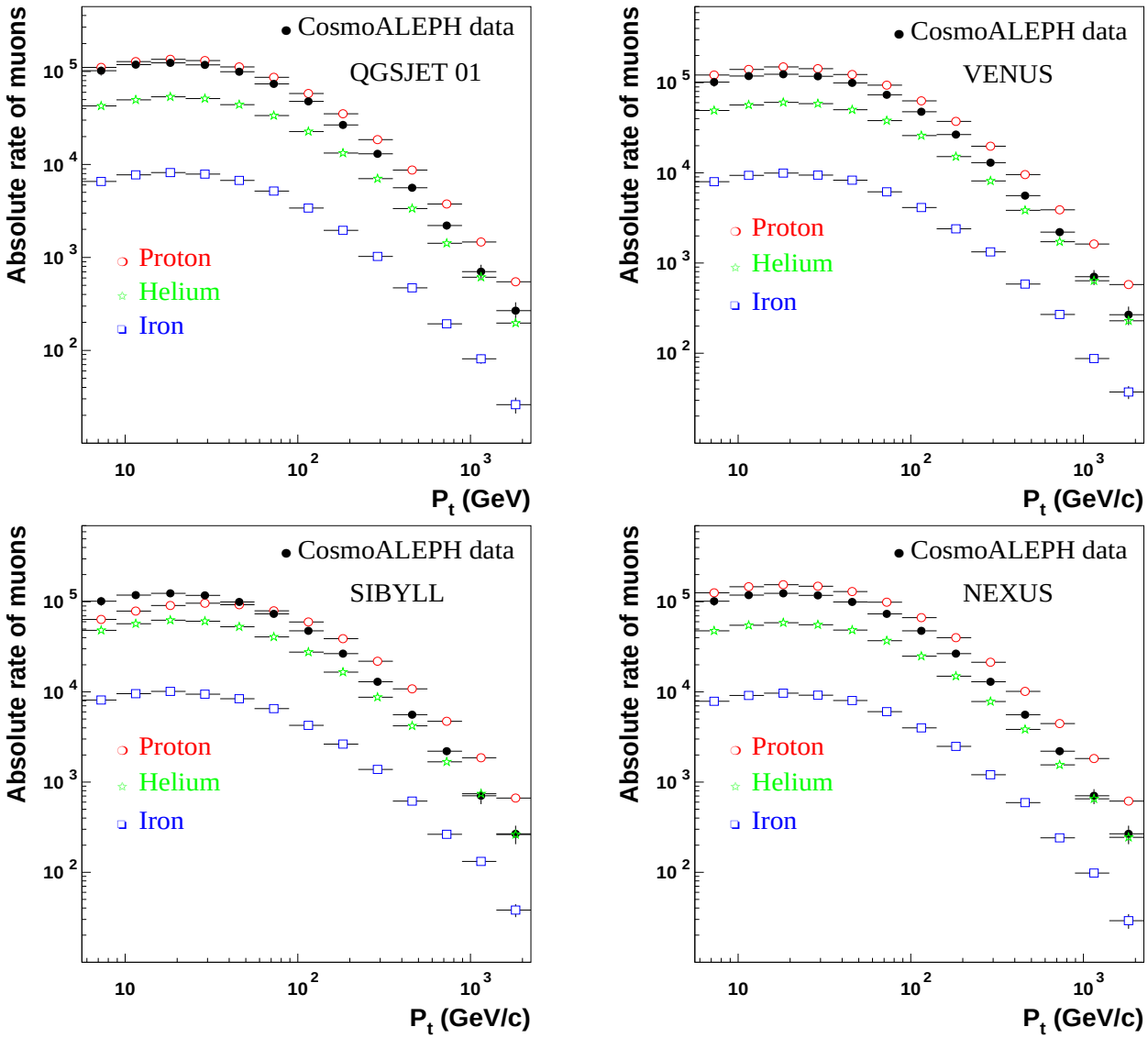
Blue line is the fit to the CosmoALEPH data with the sum of H, He and Fe parameterizations.

Comparison of the CosmoALEPH Multiplicity with MC Predictions



p, He and Fe primaries simulated with QGSJET, VENUS, SIBYLL and NEXUS

Comparison of the CosmoALEPH Transverse Momentum with MC



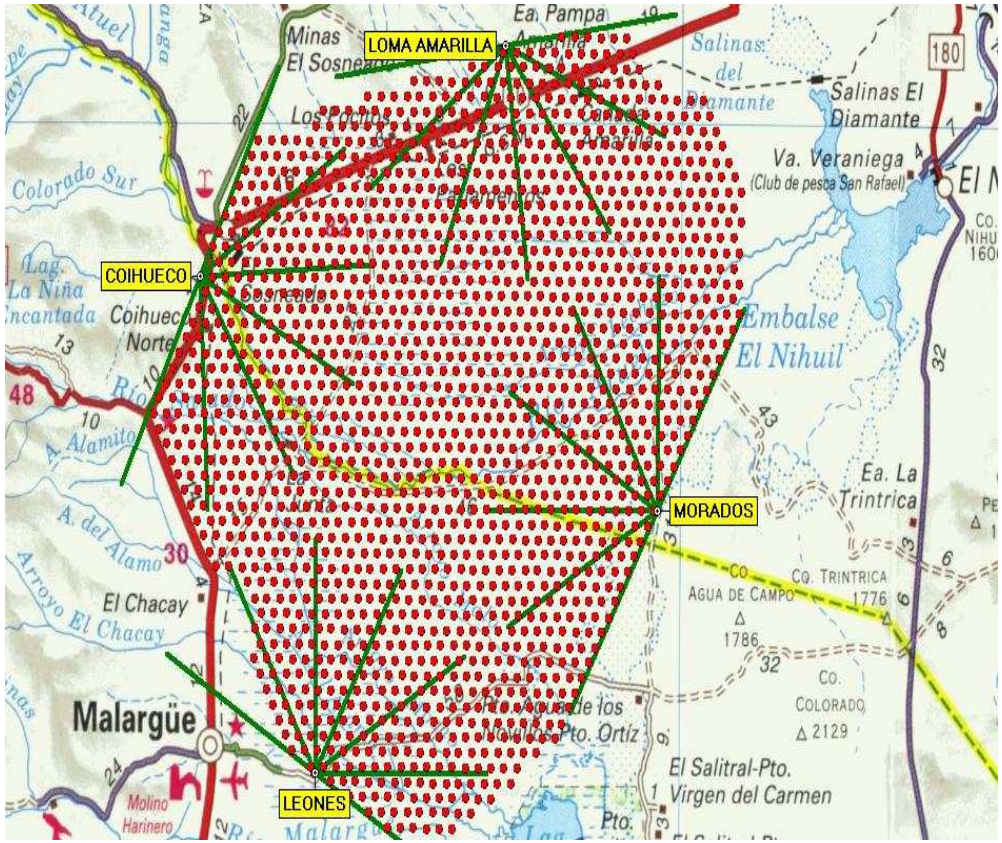
p, He and Fe primaries simulated with QGSJET, VENUS, SIBYLL and NEXUS

Conclusions

- The comparison of the measured CosmoALEPH decoherence distribution with the predictions from the CORSIKA models in the energy region $10^2 - 10^7$ GeV indicates a light dominated primary composition.
- Based on the predictions of the VENUS model and constant mass composition approach a primary composition of (77 ± 11) % protons and (23 ± 11) % iron nuclei for cosmic rays with a χ^2 - probability of about 84 % was determined.
- The absolute comparison between the measured multiplicity and transverse momentum distributions in the TPC and those predicted by different Monte Carlo models indicates also a dominant light composition.
- MC models are unable to reproduce events with high multiplicities.

The Southern Pierre Auger Observatory in Mendoza, Argentina

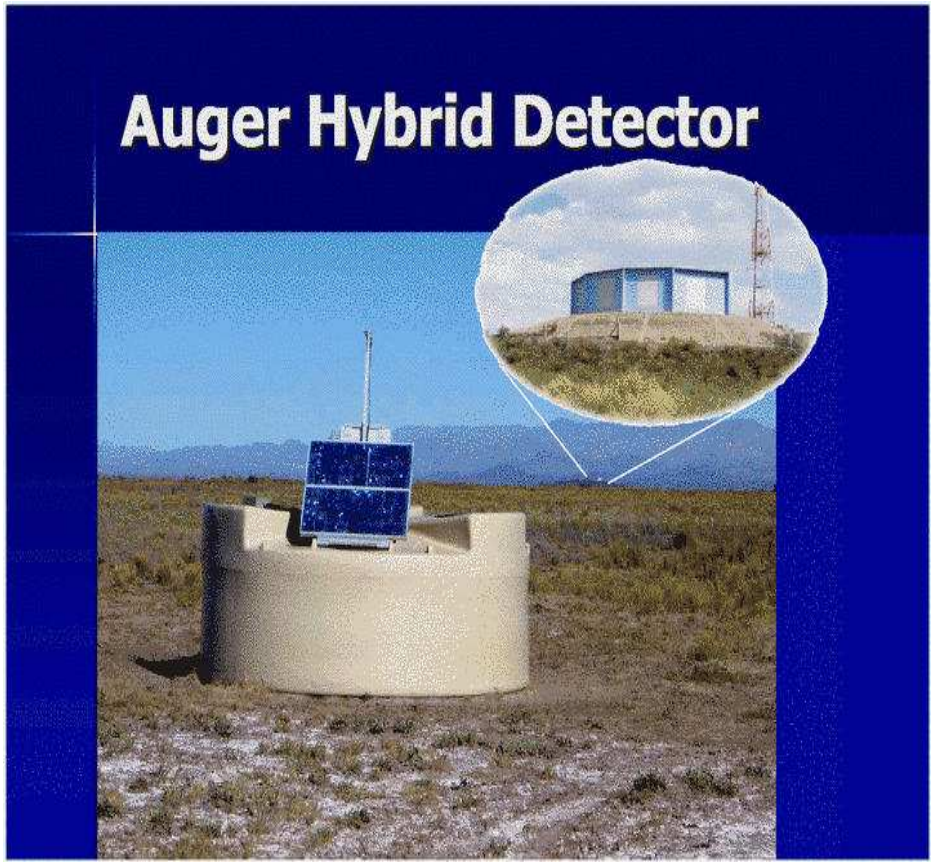
designed to study cosmic rays with energies greater than 10^{19} eV

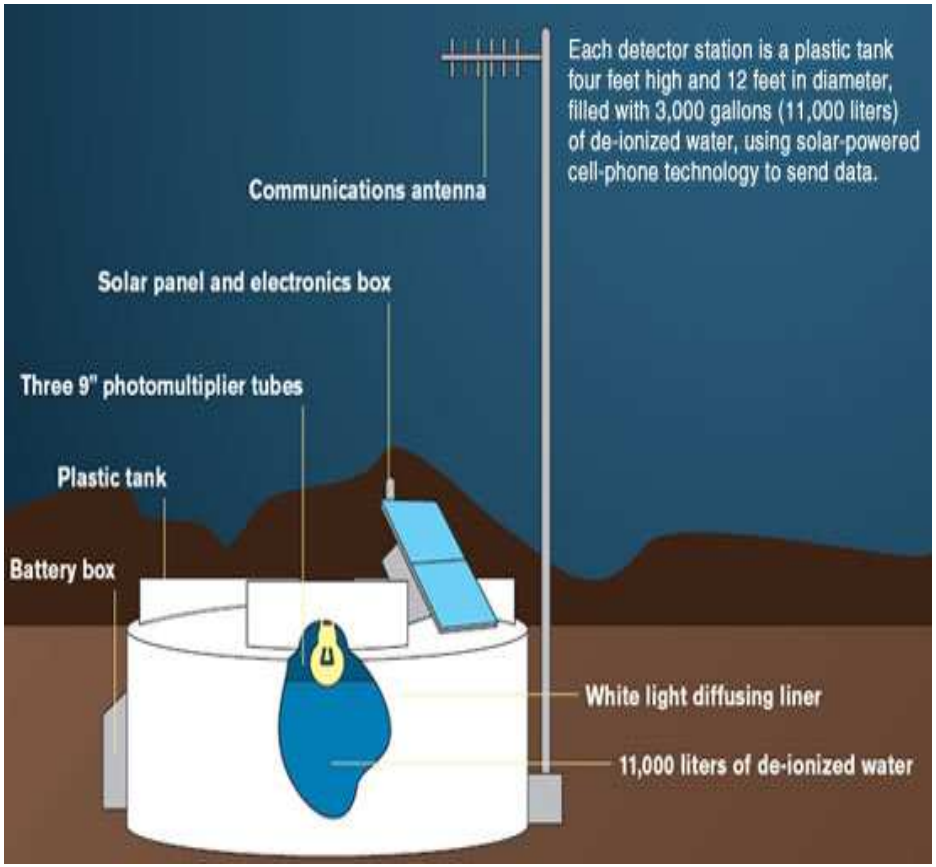


- **The Surface Detector Array**
  1600 water-cherenkov tanks with 1.5 km spacing covering area of 3000 km^2
- **Fluorescence Detectors**
  4 Stations each 6 telescopes

Water Cherenkov Detector

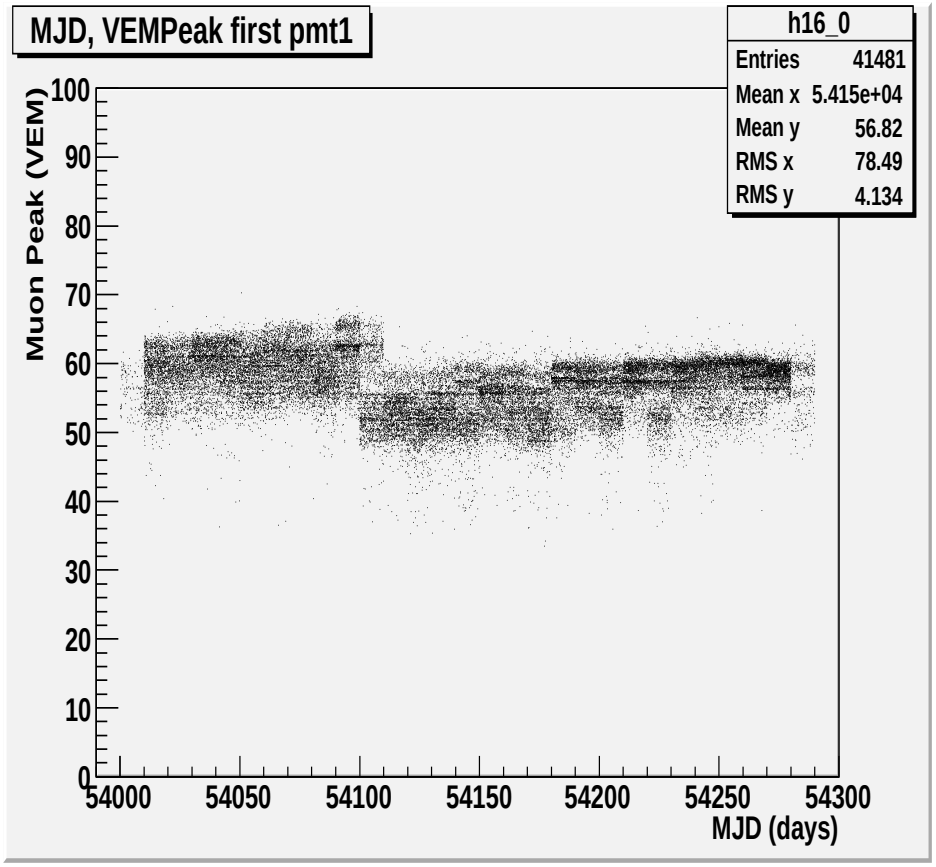
- cylindrical polyethylene tank with 3.6 m diameter, 1.6 m height
- Tyvek liner filled with 12 m^3 purified water
- 3 PMTs in the tank

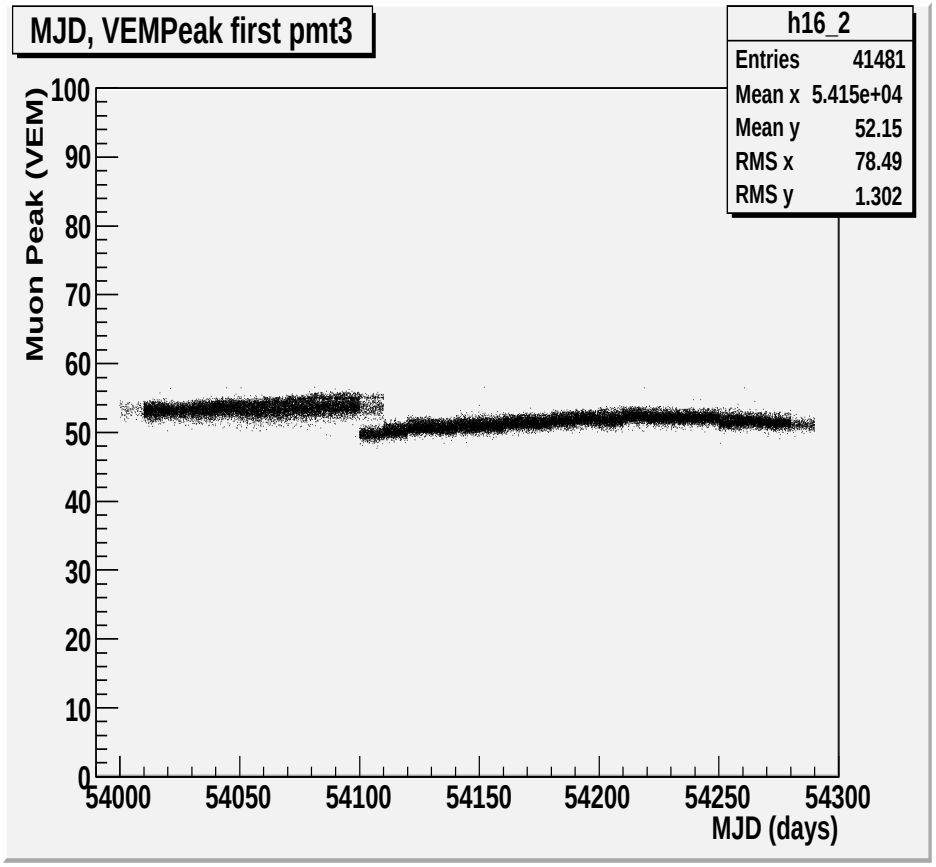




Analysis of the twin tanks data

- 10 m spacing between twin tanks
- twin tanks are used to study the signal fluctuations
- twin tank pair: 139 Dia - 186 Noche





Analysis of the twin tanks data

- twin tank pair: 139 Dia - 186 Noche
- good PMT: D/A = 32, RMS $<$ 0.5 channels