Detection of cosmic rays by LEP experiments

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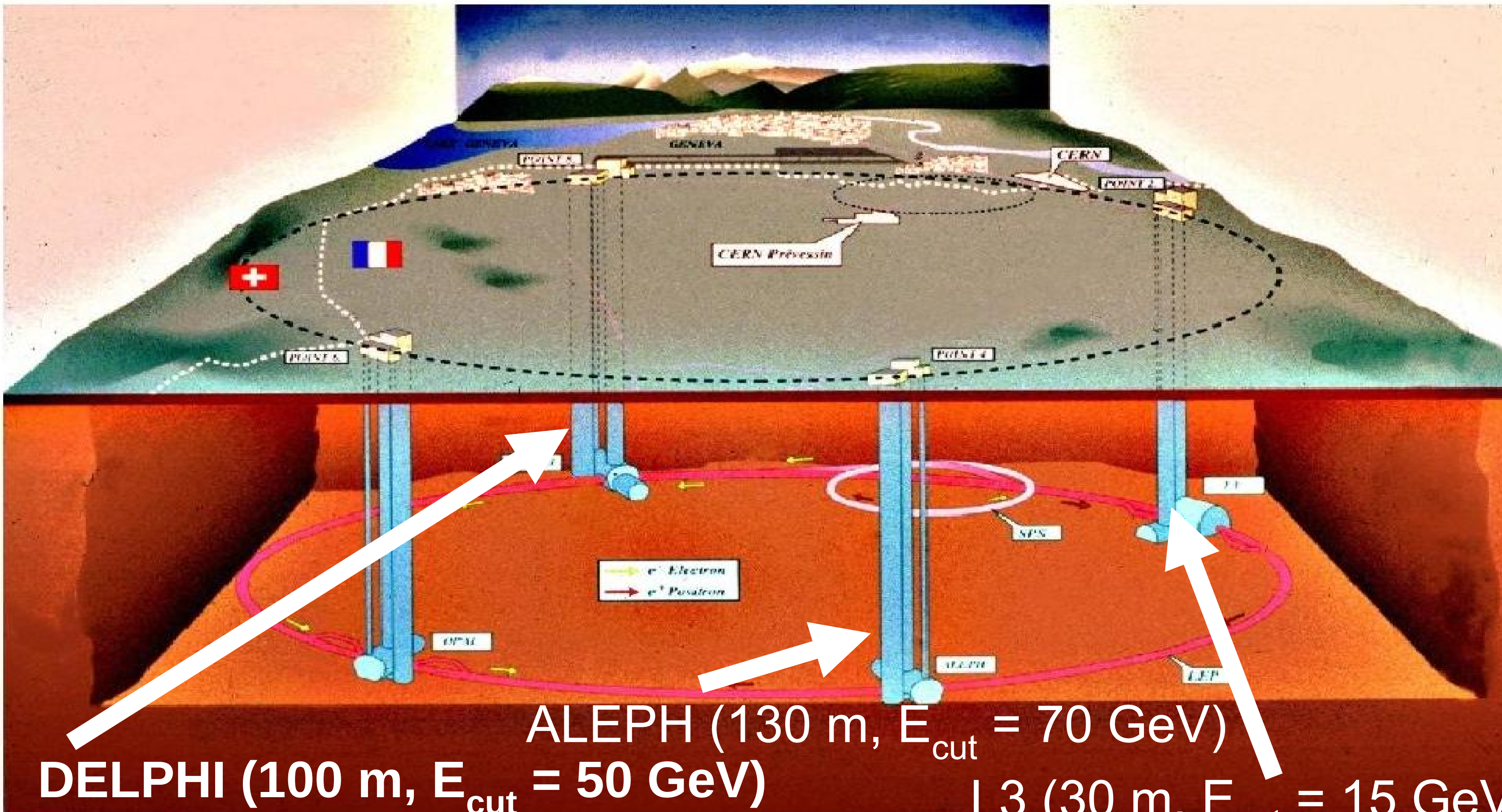
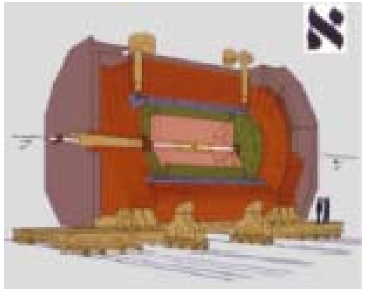
(many thanks to Pierre Le Coultre, Lawrence Jones, Claus Grupen)

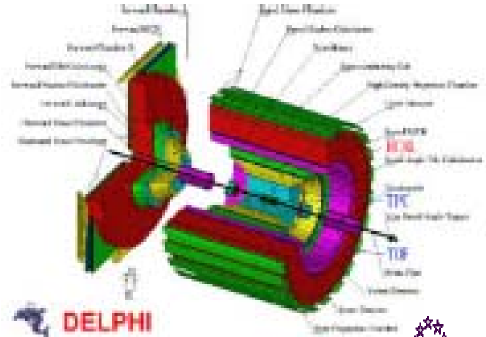
Experiments

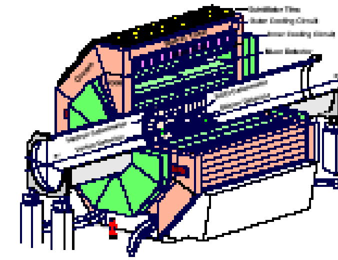
Accelerator experiments with possibility to detect also cosmic rays (H. Waschmuth – 1993), different underground location, different measurement techniques (TPC, HCAL, muon chambers, surface array)



Experiments II







Cosmo-ALEPH

130 m underground

Hadron calorimeter

TPC + 5 scintillator stations

Muon energy spectrum

Charge ratio

Multiplicity, lateral distributions, sources

DELPHI

100 m underground

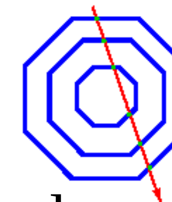
Hadron calorimeter

TPC, TOF, muon chambers

Multiplicity,

sources

L3+C



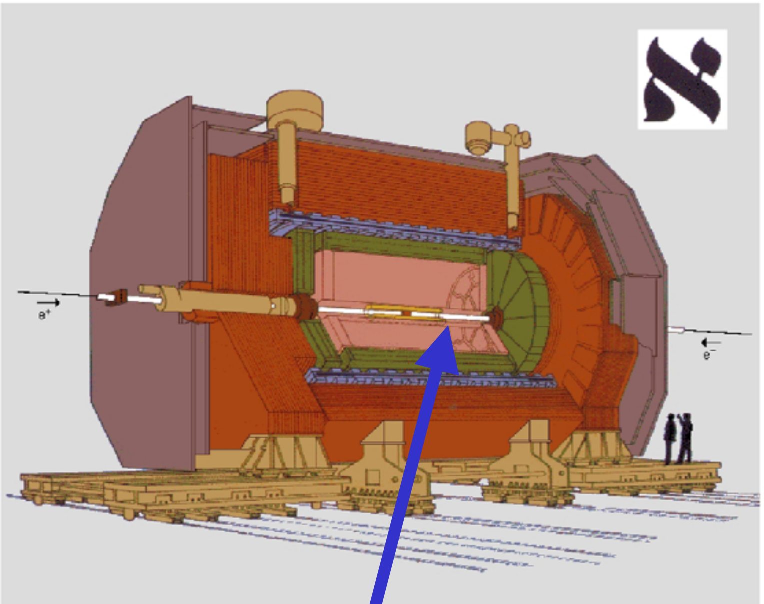
40 m underground

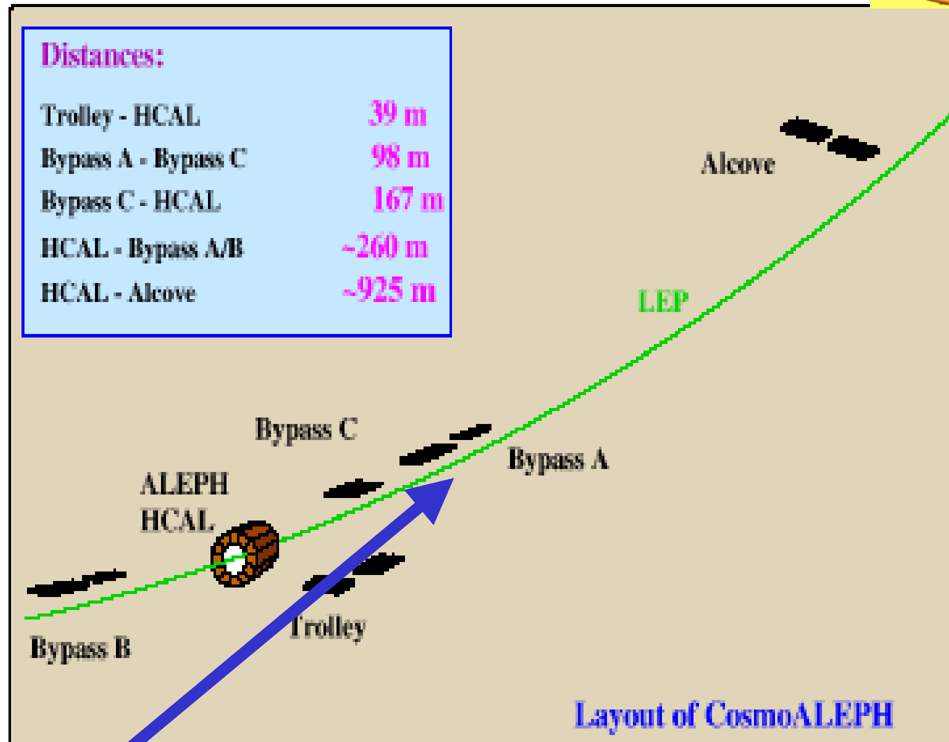
Drift chambers

Timing scintillators, surface array, dedicated trigger

Muon spectrum, charge ratio, antiproton limit, sources, flares …, multiplicity

Cosmo-ALEPH

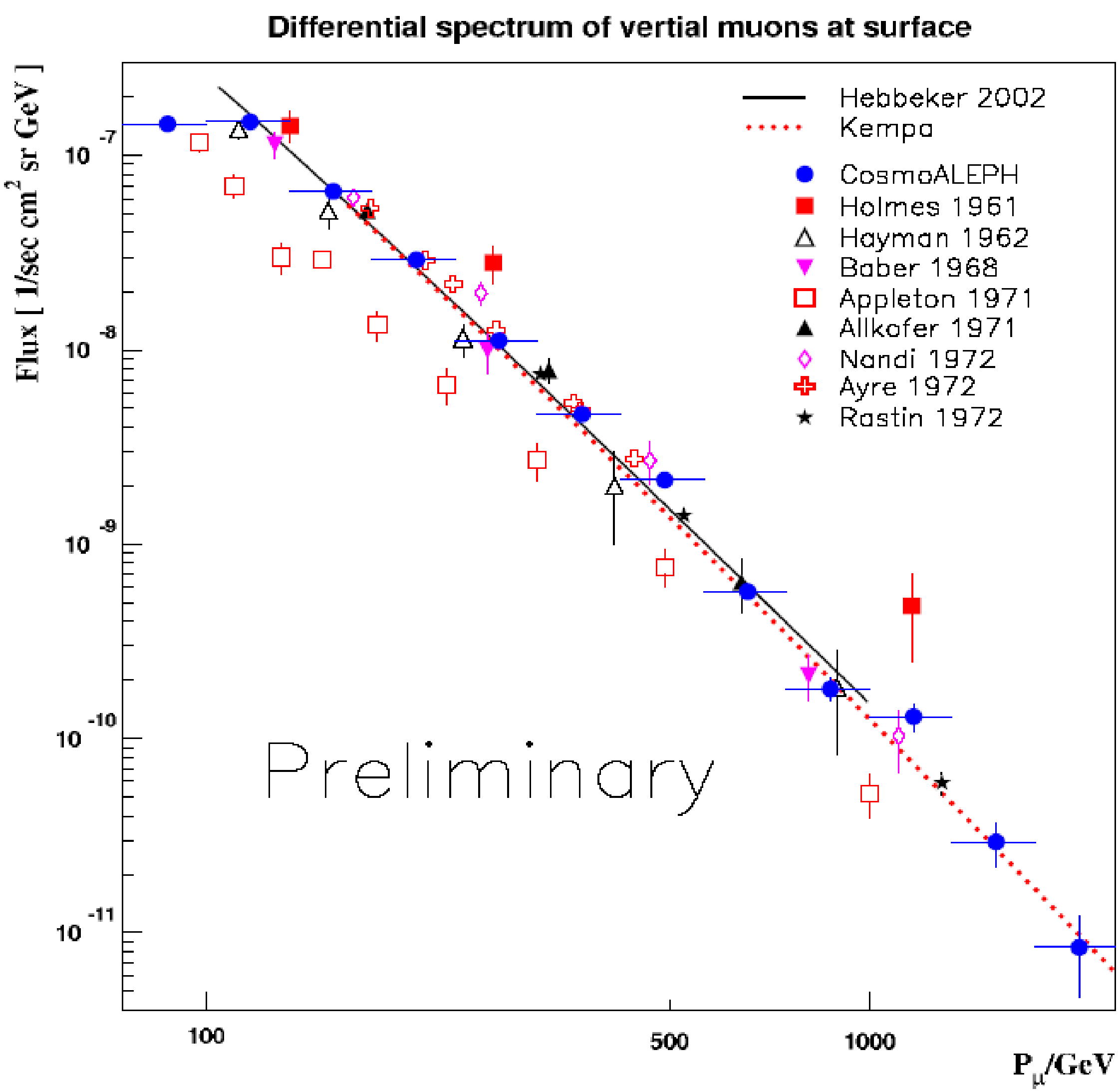




16 m^2 TPC, array of 5 scintillators, experiment running with respect to beam crossing frequency => 11 % duty cycle. Also dedicated runs without beams in accelerator (CosmoALEPH trigger from HCAL)

maximal detectable momentum 3 TeV

Cosmo-ALEPH
Momentum spectrum of vertical muons

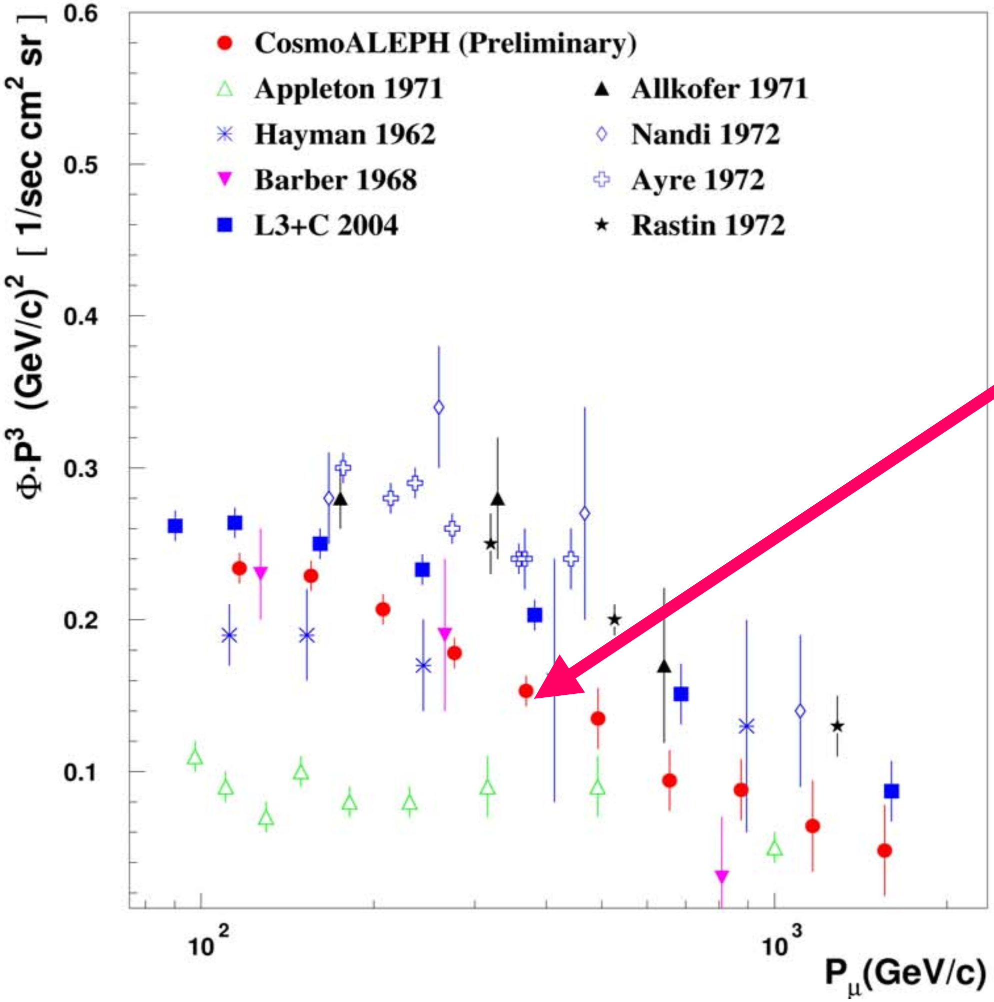


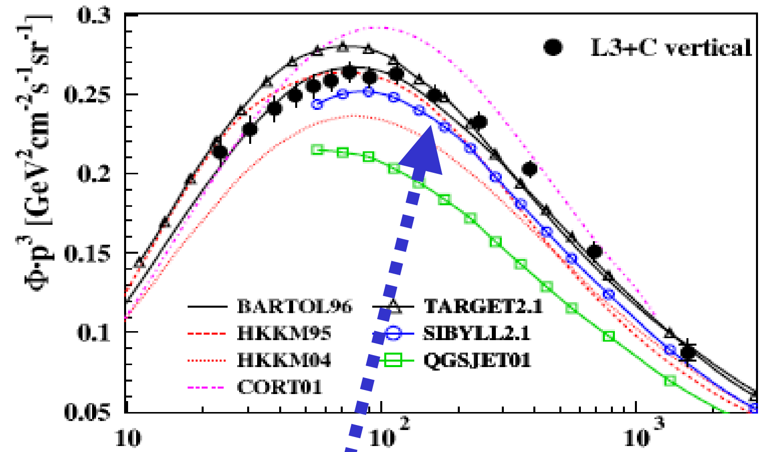
Normalized at 200 GeV to world average

Conversion from underground momentum to ground energy according to energy loss formula:

dE/dx=-a-bE (a=0.21 GeV/m.w.e, b = 4x10^{-4} m.w.e.$^{-1}$)

Cosmo-ALEPH
Momentum spectrum of vertical muons

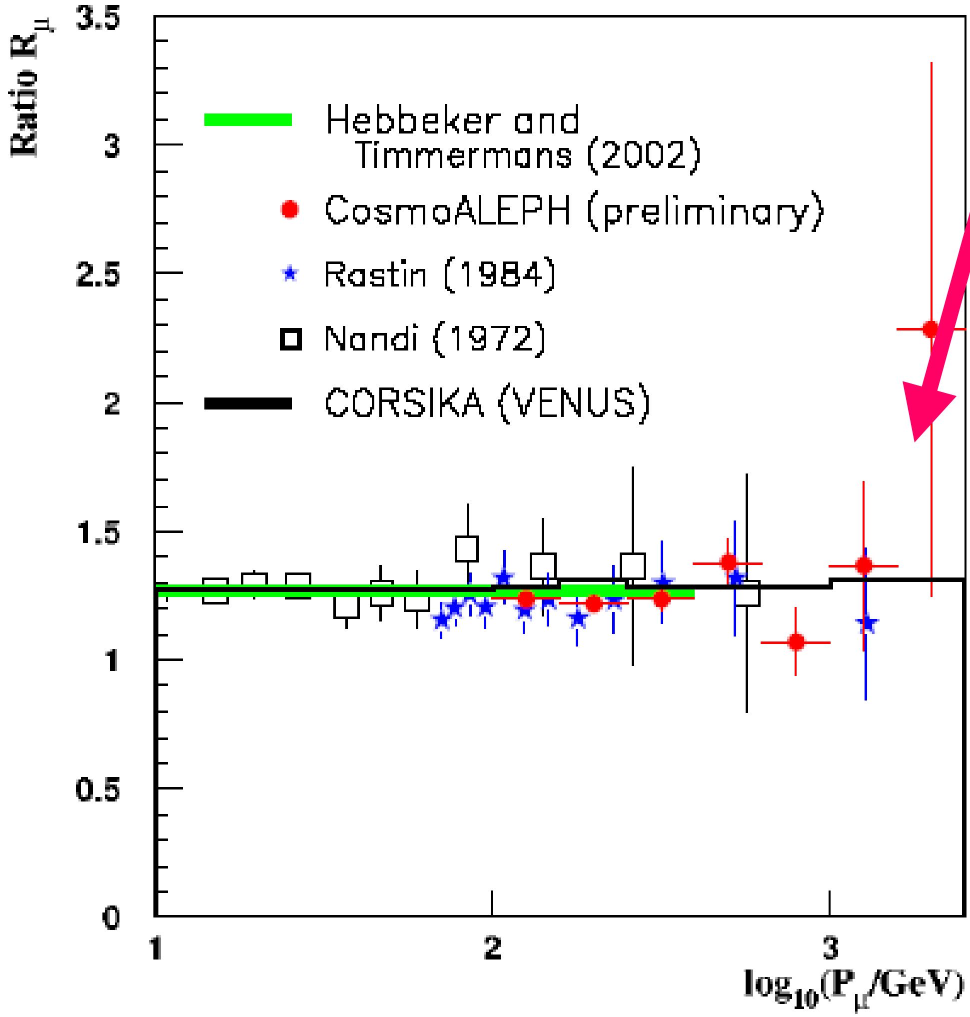




ALEPH (Preliminary data) as compared to other data.

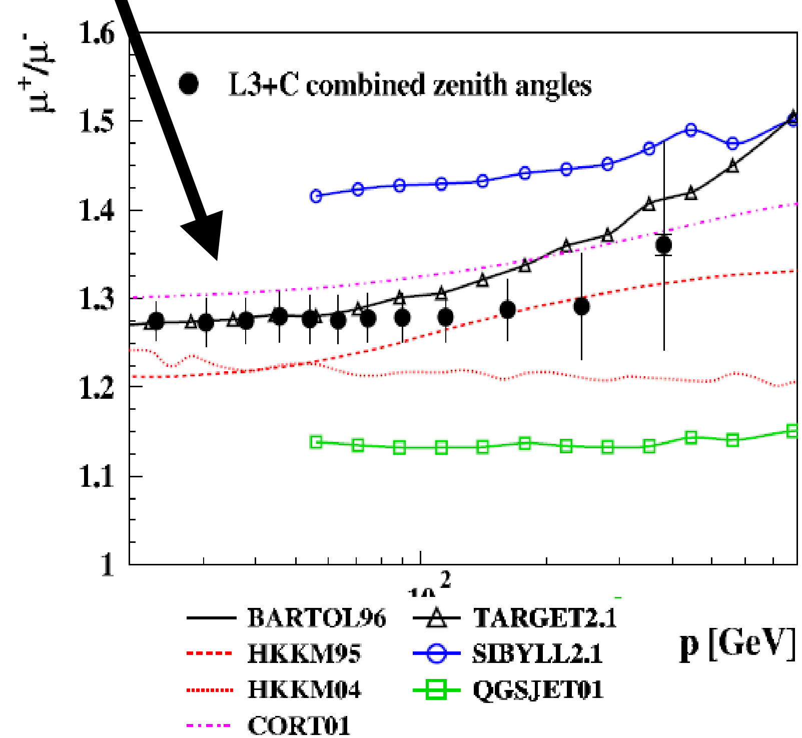
For a given primary flux and composition this result will test interaction models and help to constrain their parameters (like in L3+C case – Lawrence Jones talk). It also constrains calculations of atmospheric neutrino flux.

Cosmo-ALEPH
Charge ratio



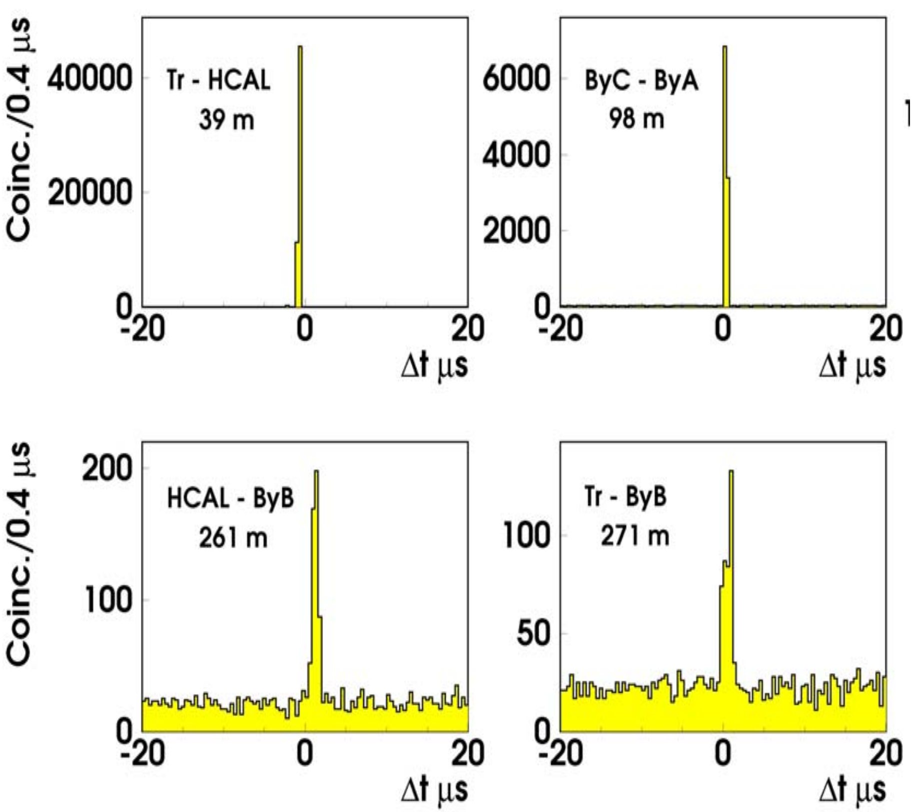
ALEPH (Preliminary data)

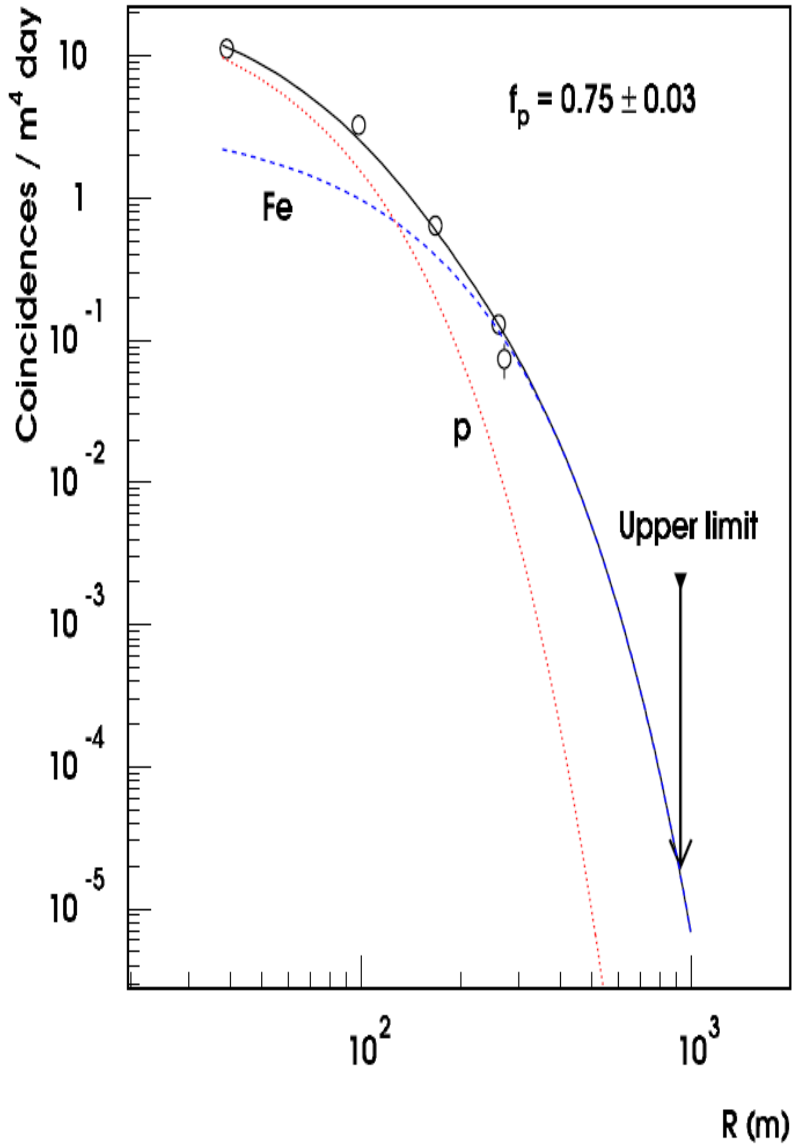
another test of interactions models (has been done with L3+C data, see Lawrence Jones talk)



Cosmo-ALEPH
High energy lateral muons

Number of coincidences as a function of distance between scintillators gives information about composition.





Cosmo-ALEPH
Multi-muon bundles

Sensitive to primary energies 10^{14} – 10^{16} eV

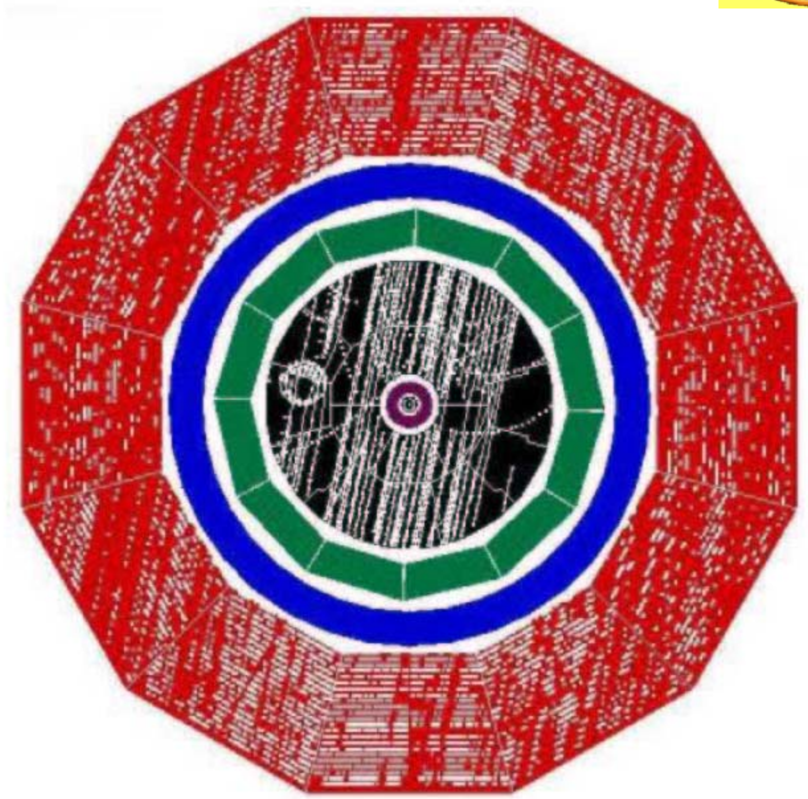
For E>10^{14} eV at given energy more muons for heavier nuclei

High energy muons (E >70 GeV) are sensitive to dynamics of the first interactions

Test of interaction models

Simulation: CORSIKA, QGSJET

Difficulty: unknown core position (small detectors) => scattering of shower centers over some area (200x200 m^2) in MC



Multiplicities up to 150 in 16 m^2 TPC

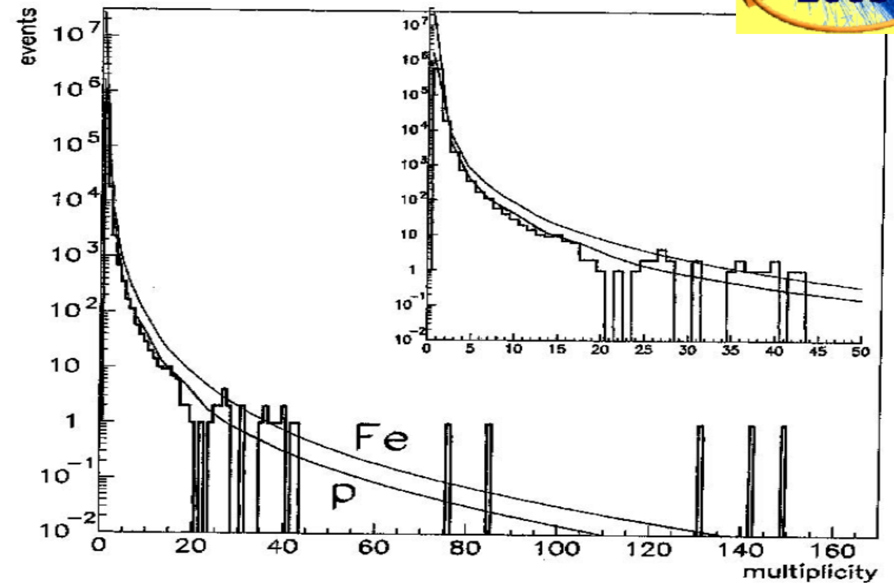
Cosmo-ALEPH
Multi-muon bundles

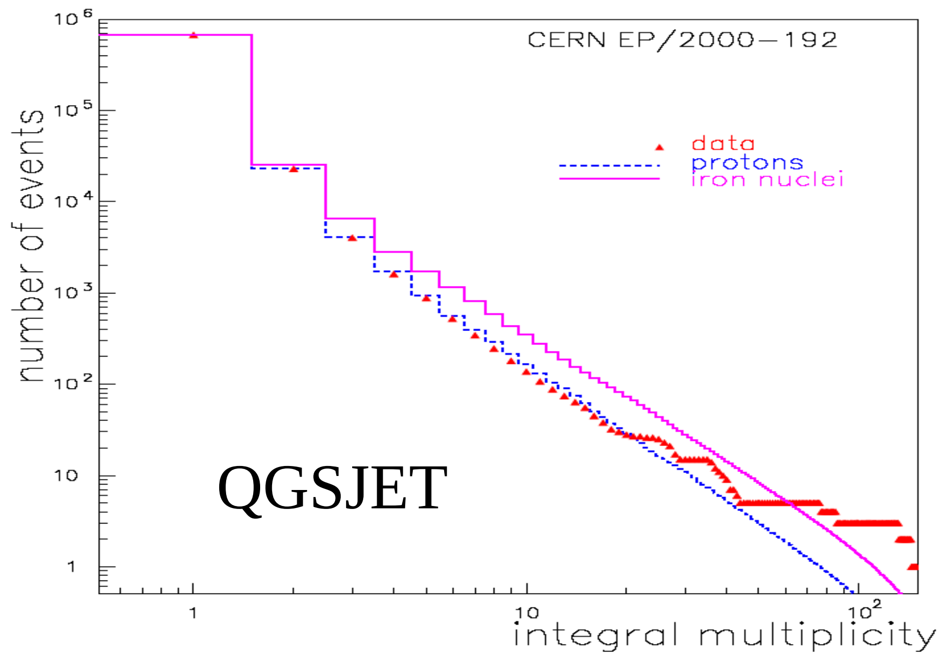
Composition unknown => two assumptions: all particles are p or Fe, data should be somewhere in the middle of the two predictions

Low multiplicities (low energies): proton like

Medium multiplicities: transition to heavier nuclei

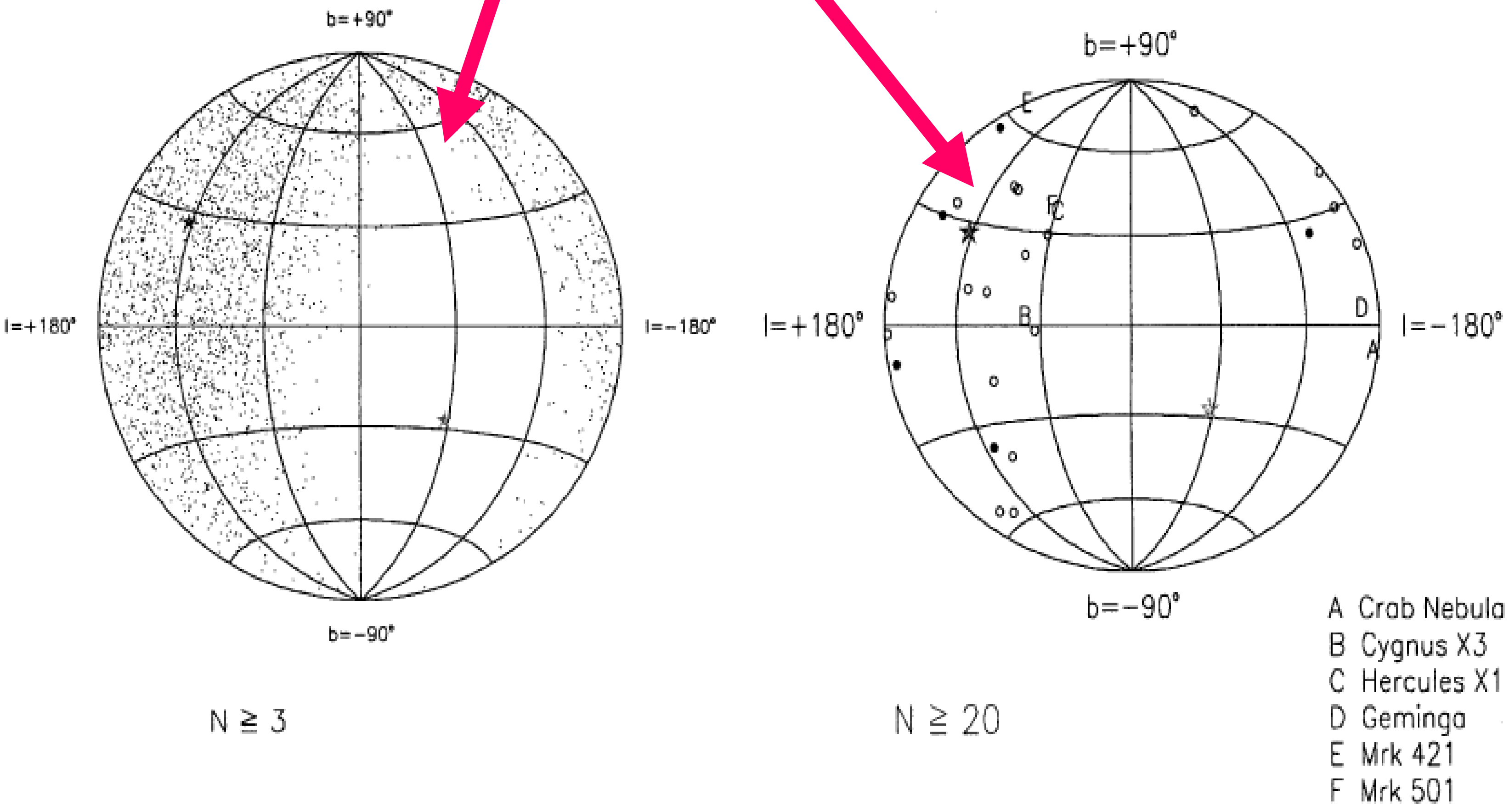
Some excess of events at the highest multiplicities compared to MC with iron





Cosmo-ALEPH
Multi-muon bundles, sources

Events with more than 3 and 20 muons, no apparent clustering around known sources:



DELPHI

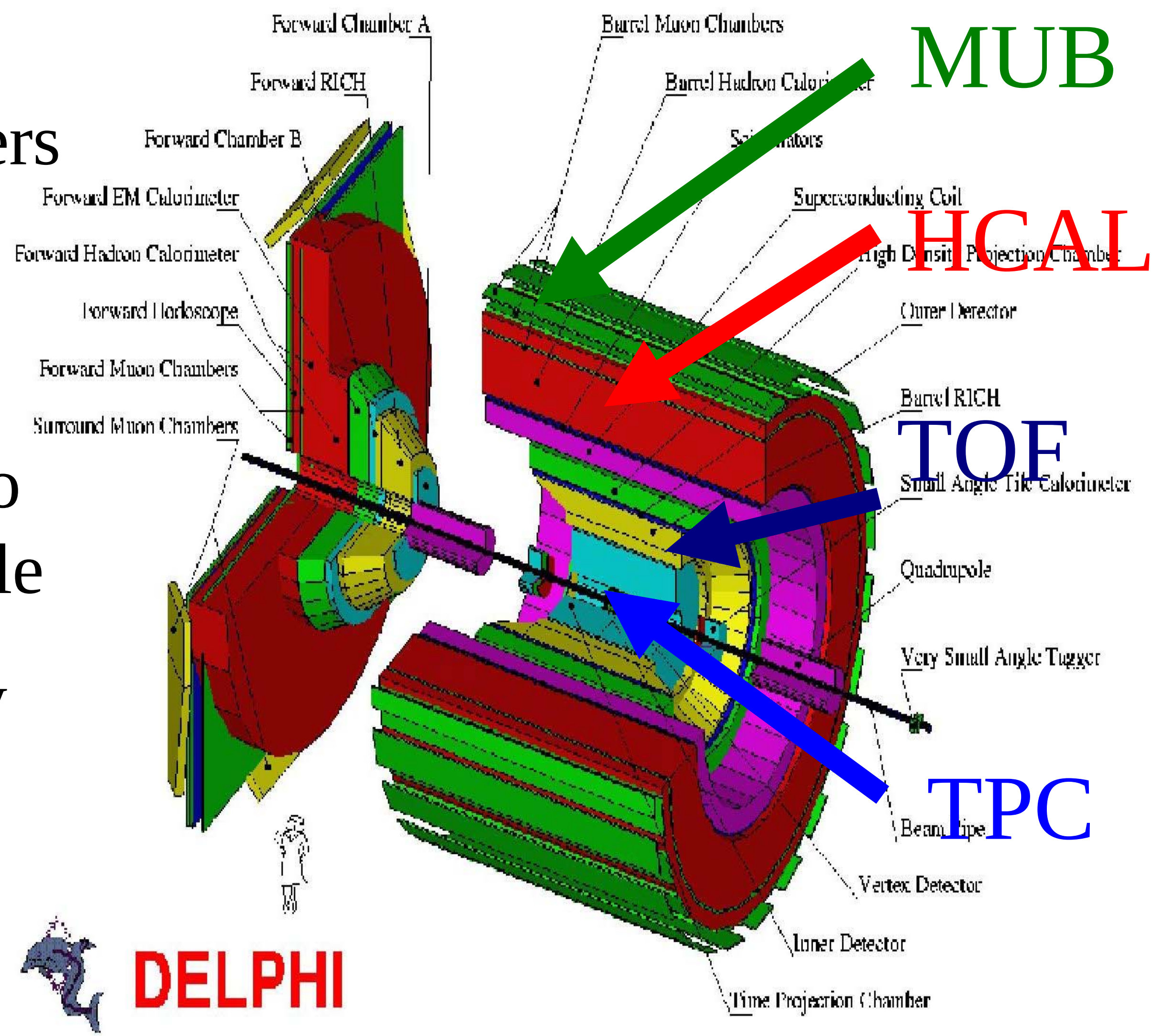
Main detector - 75 m^2
HCAL

TPC and muon chambers partly used

TOF served as trigger

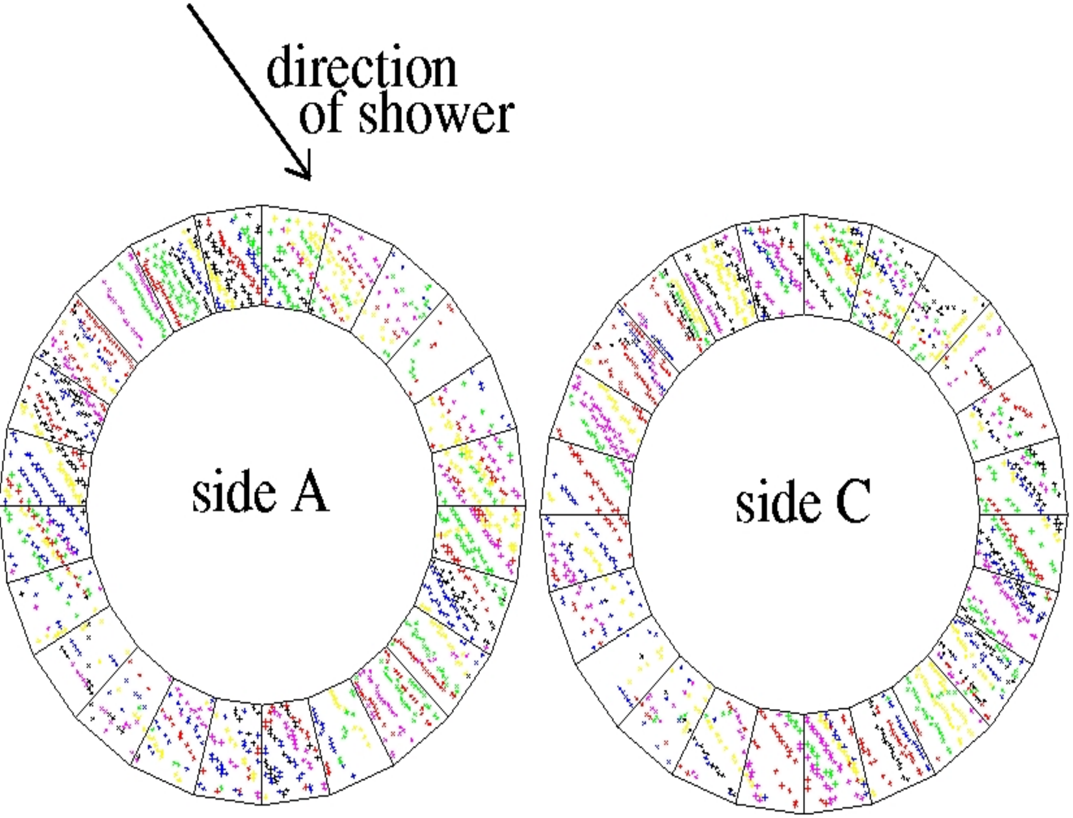
Running with respect to BCO => 18% duty cycle

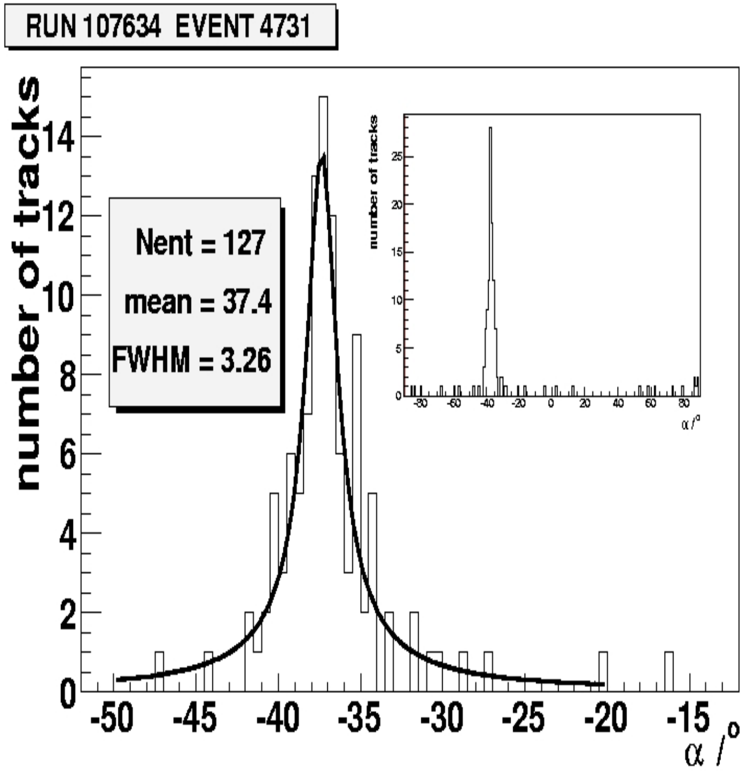
Fine HCAL granularity allowed analysis of multi-muon bundles



DELPHI
High multiplicity event

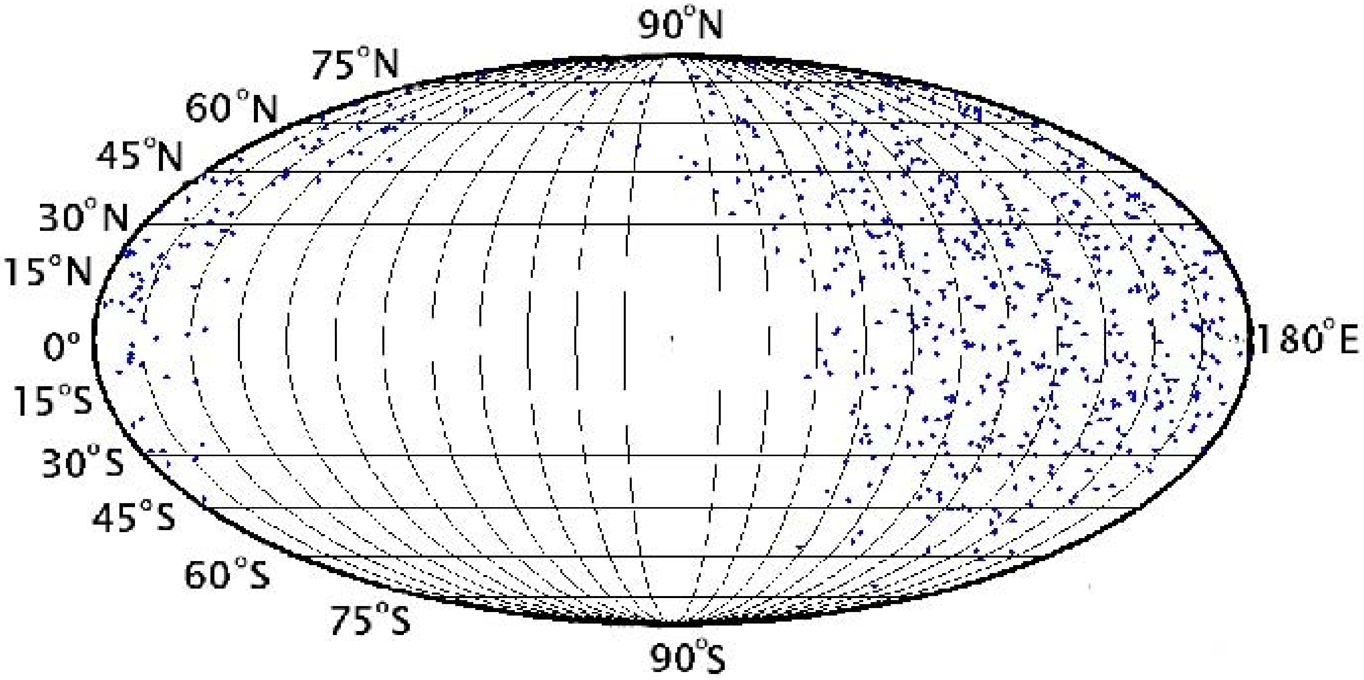
Reconstruction up to multiplicity 130





DELPHI
Point sources

No event clustering for high multiplicity events, N(HCAL)>15, N(TPC)>5

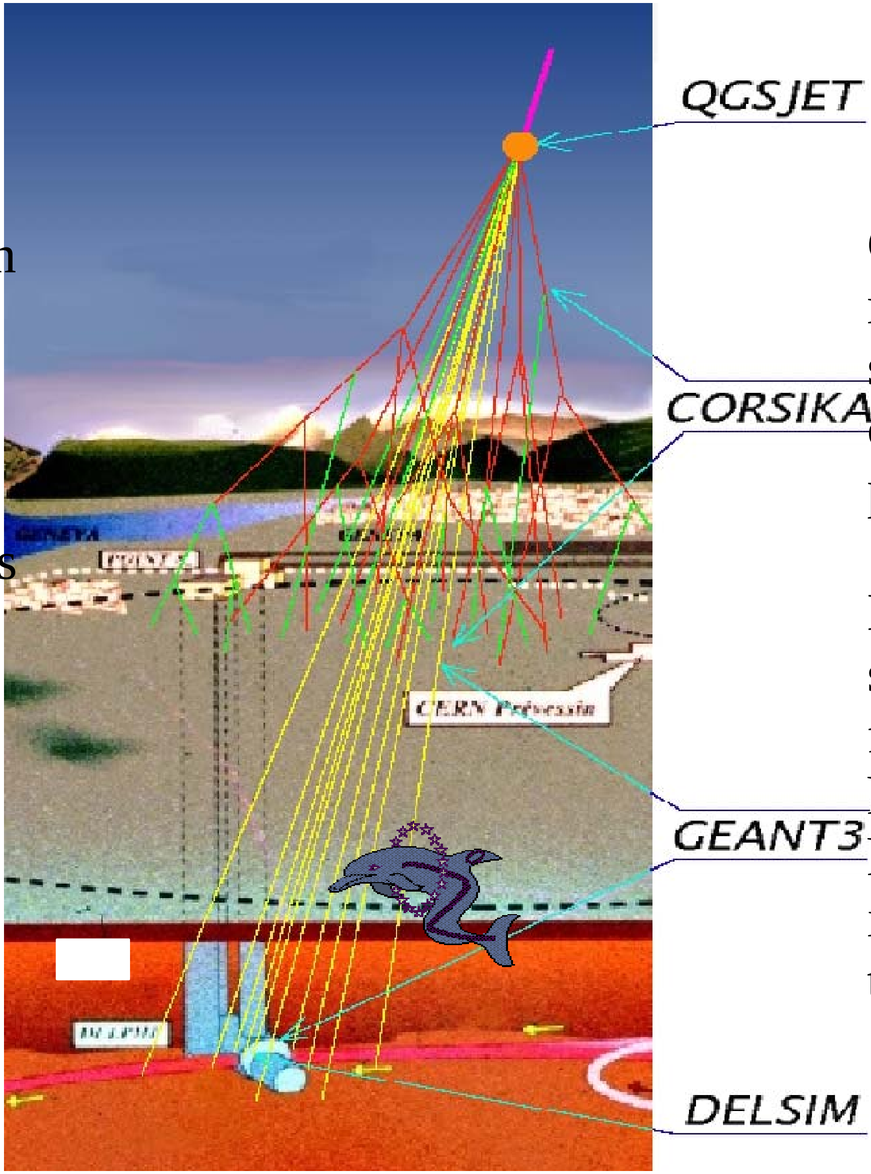


DELPHI Motivation

Measurement

Detection of multi-muon bundles originated from cosmic rays in the DELPHI detector.

Not many measurements from medium depth underground.

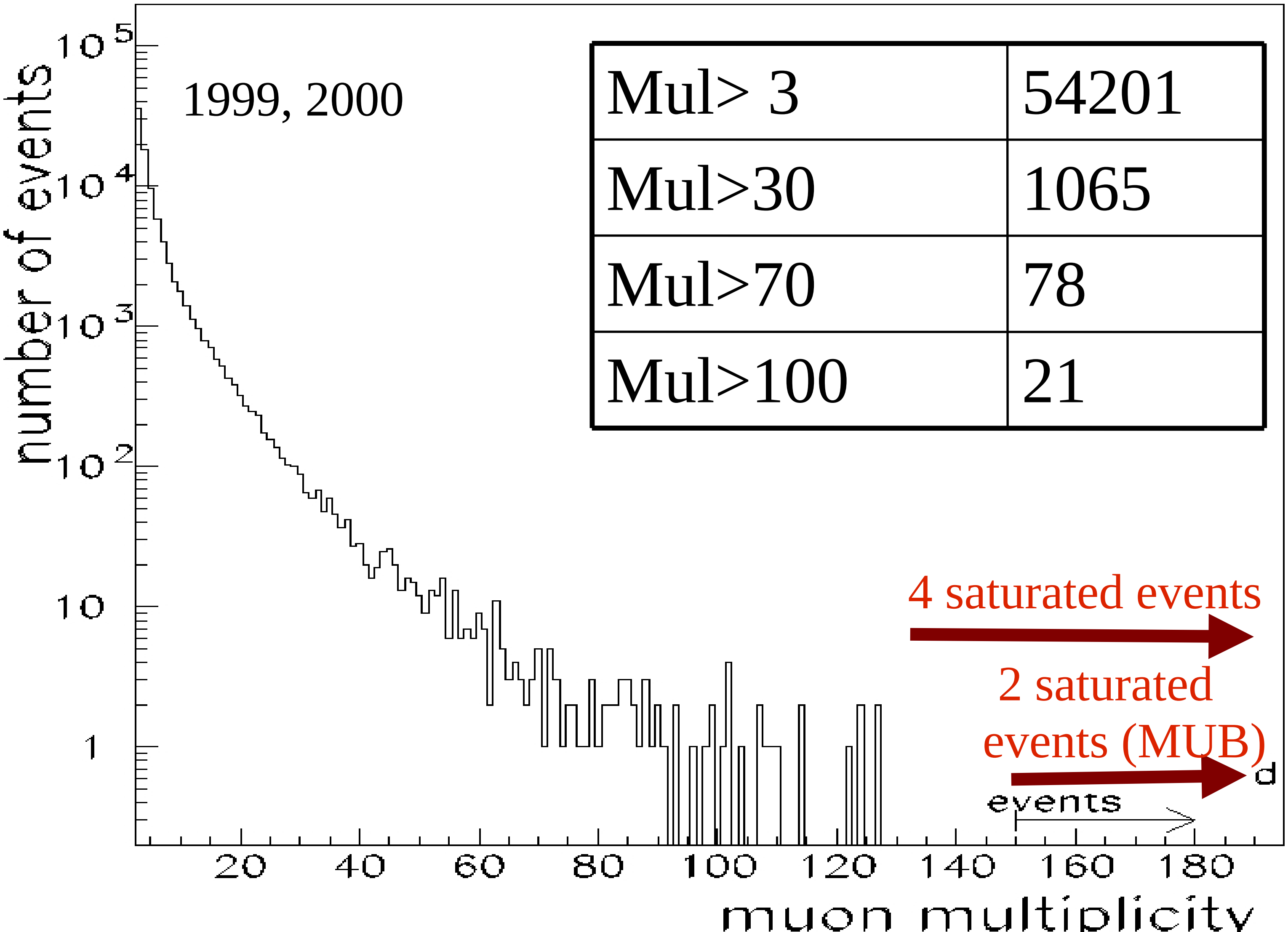


Simulation

Comparison of the measurement with MC simulations describing cosmic ray shower propagation.

High energy muons are sensitive to dynamics of first interactions. The high energy model of hadron-hadron interactions is in fact tested.

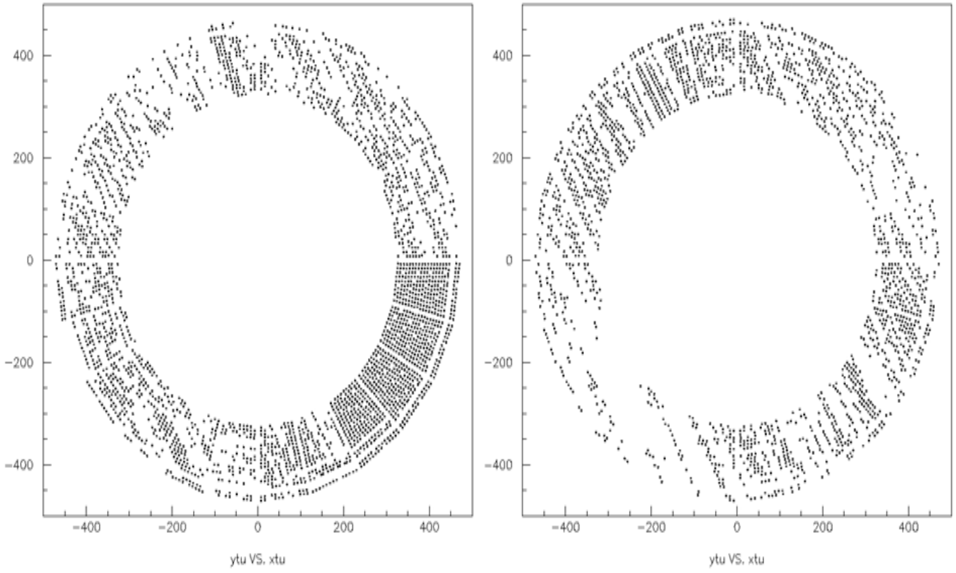
DELPHI
Muon multiplicity

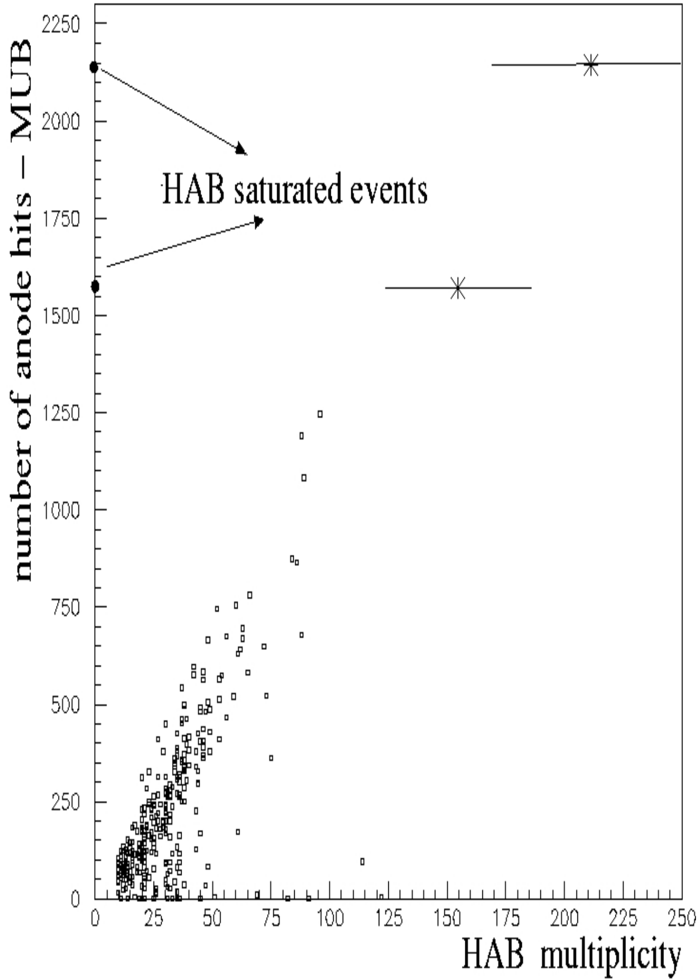


Mul> 3	54201
Mul>30	1065
Mul>70	78
Mul>100	21

DELPHI
Saturated events

- too many hits, reconstruction in HCAL fails
- 6 such events, parallel ‘tracks’ of un-hit tubes -> cosmic
- 2 events in MUB $\Rightarrow$ multiplicity >150





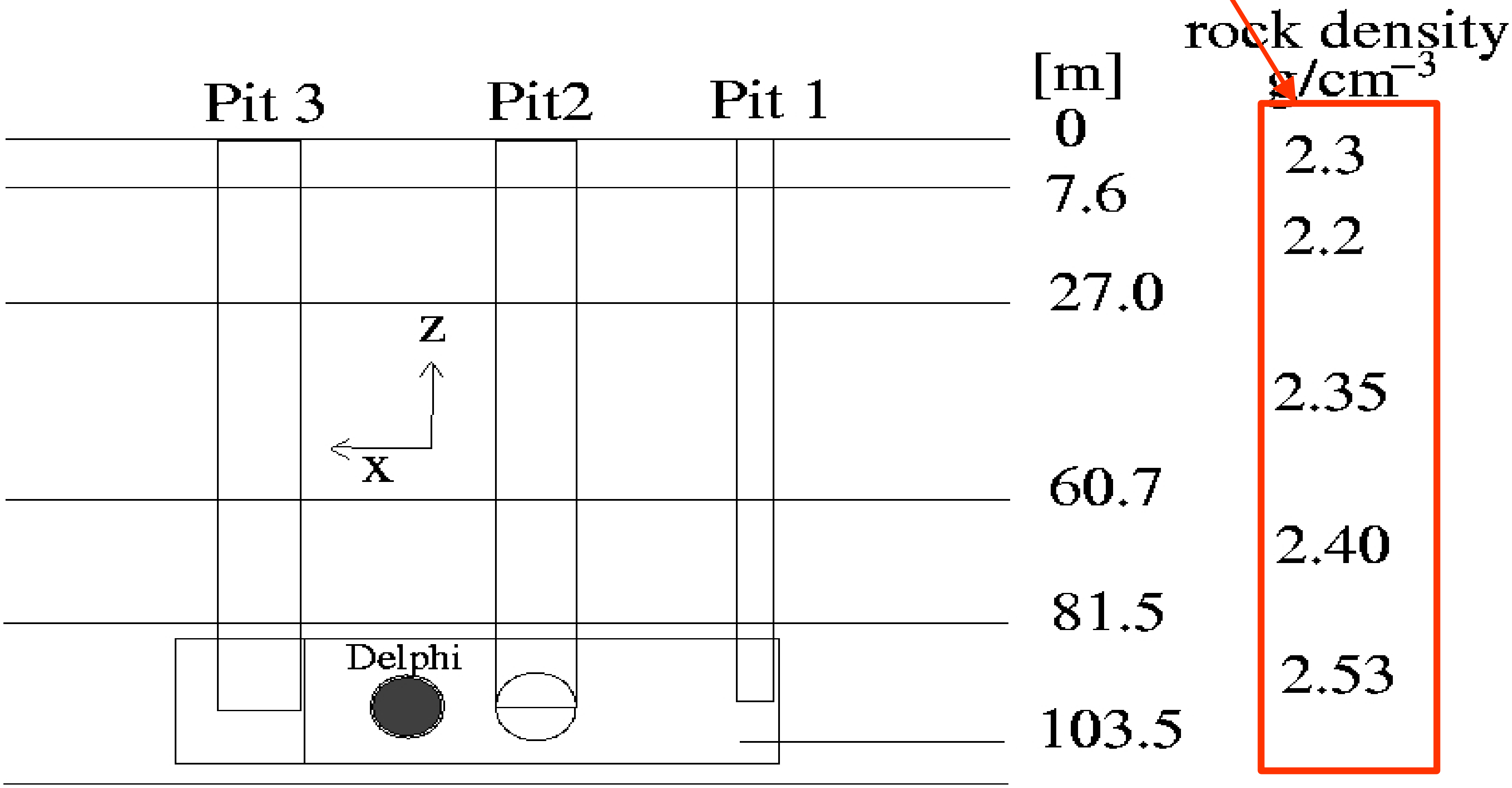
DELPHI
MC simulation

- QGSJET, CORSIKA, GEANT3, DELSIM
- Primary particles: p, Fe
- Primary energies $10^{12} – 10^{18}$ eV
- Events generated according to E^{-1} and weighted by $E^{-2.7(3.0)}$
- Shower smearing within radius R = 200 m at the detector level

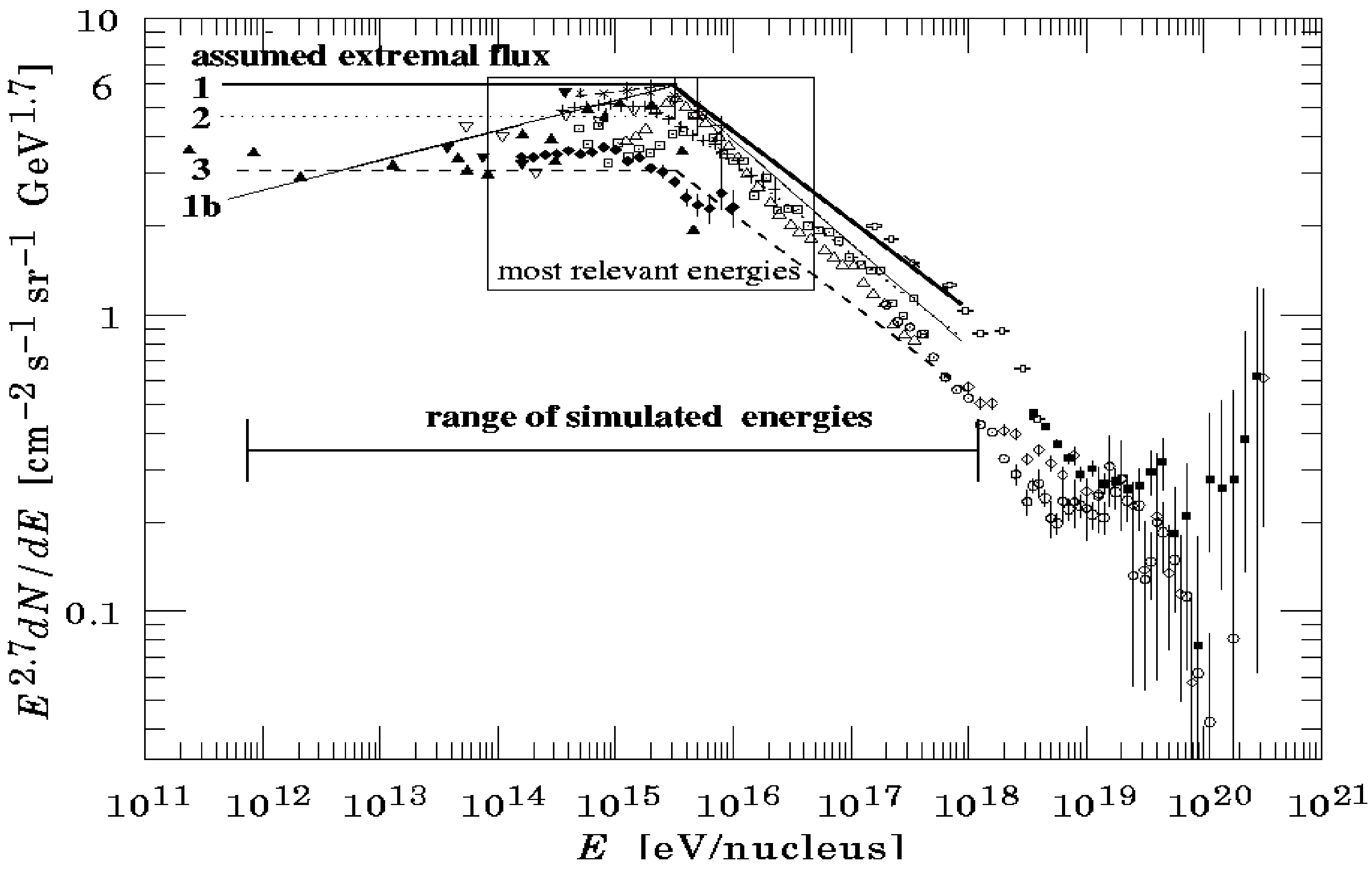
DELPHI
Geant rock parametrization

5 layers with proper rock density
& experimental cavern description

Rock parameterisation

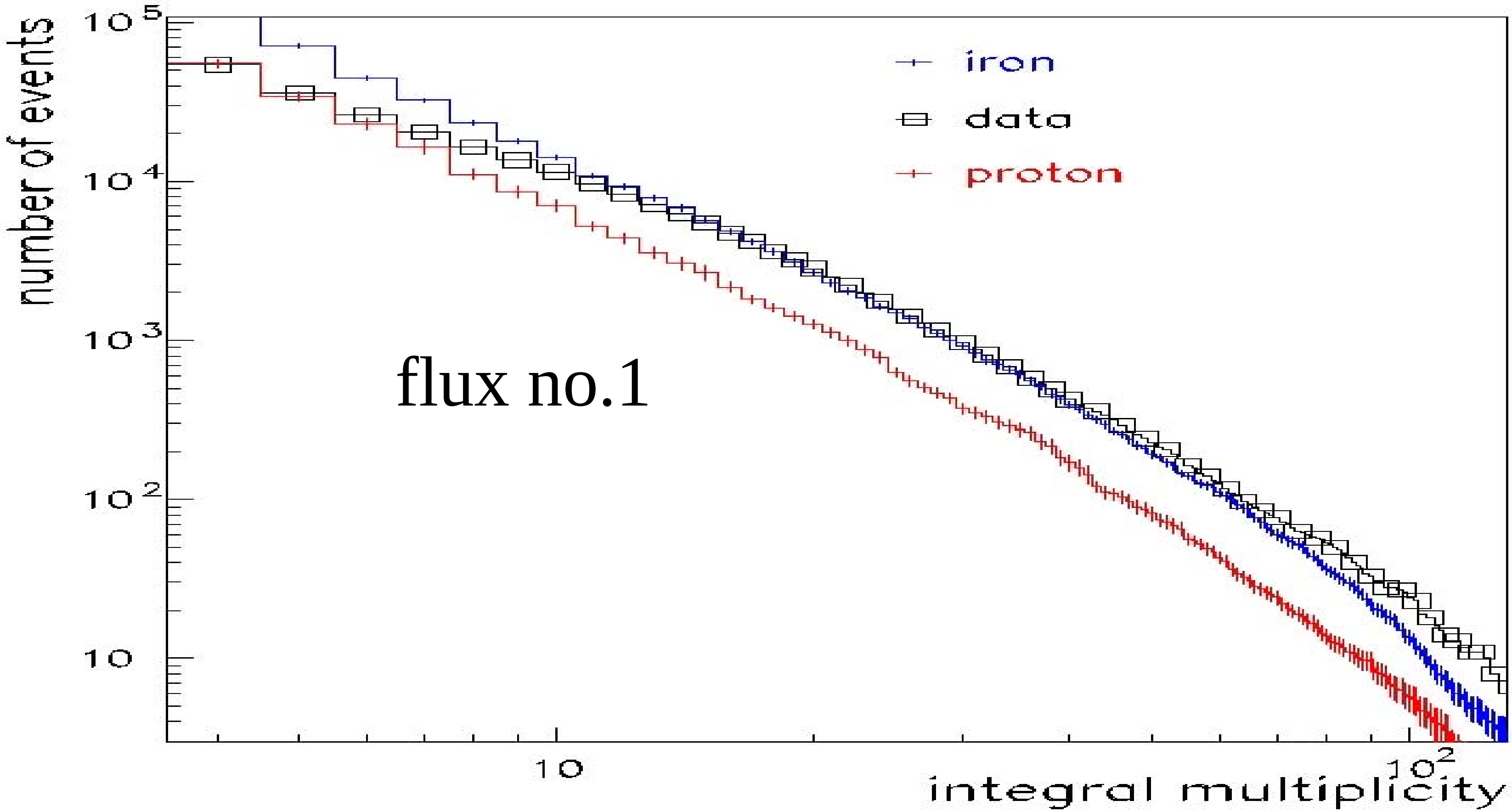


DELPHI
Choice of flux

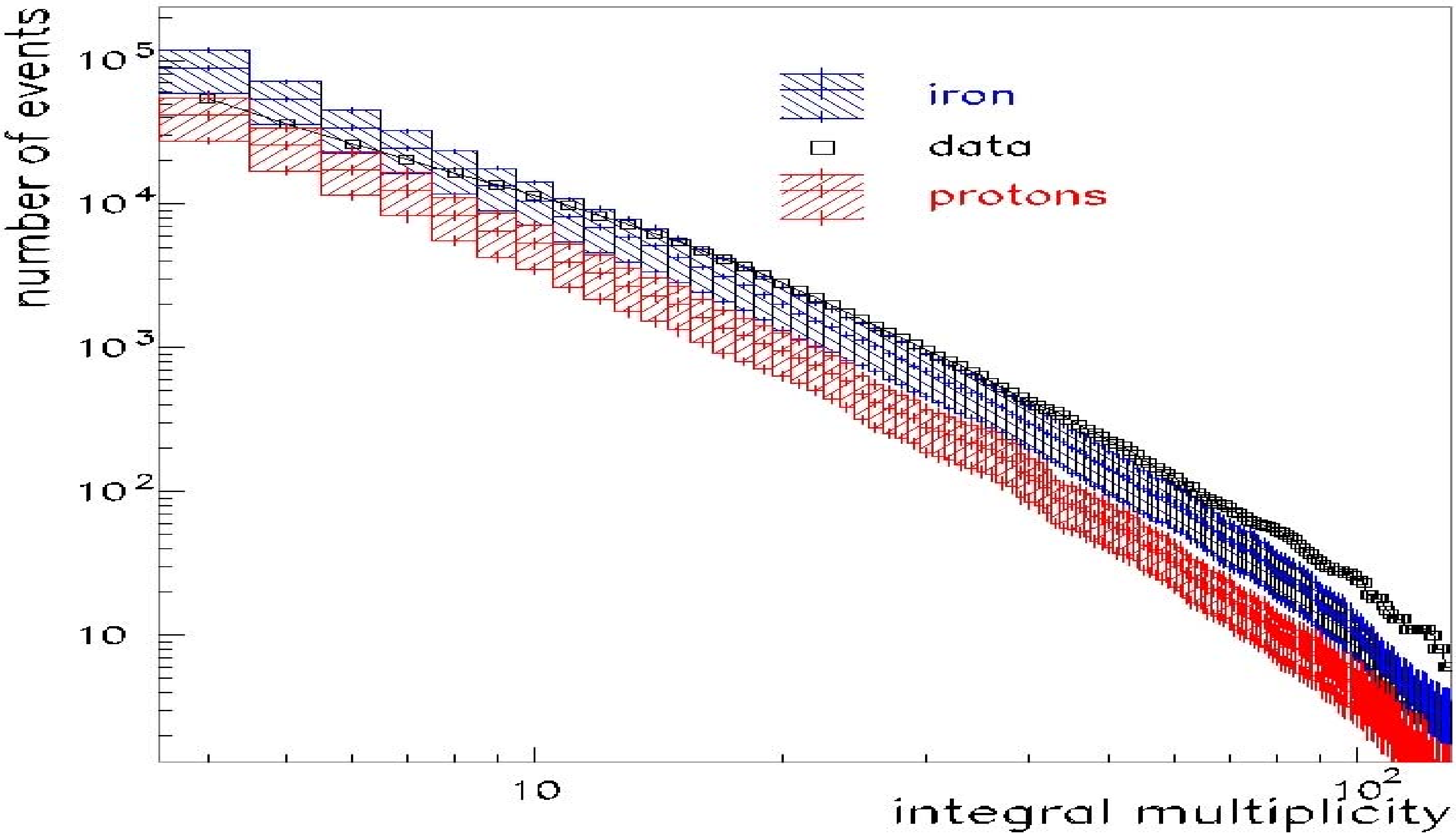


DELPHI Results

HCAL – MC (QGSJET) vs. DATA



DELPHI
Results II –different flux

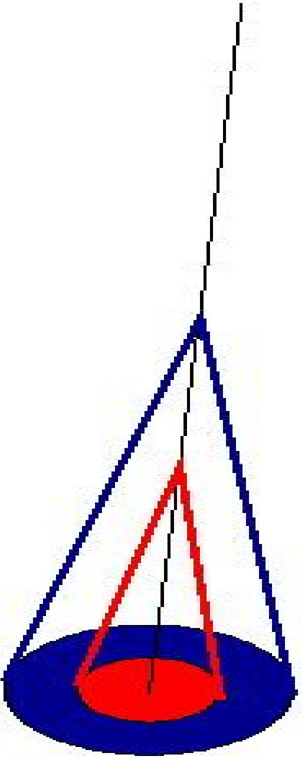


flux 1, 2, 3- influence of the flux of primary particles

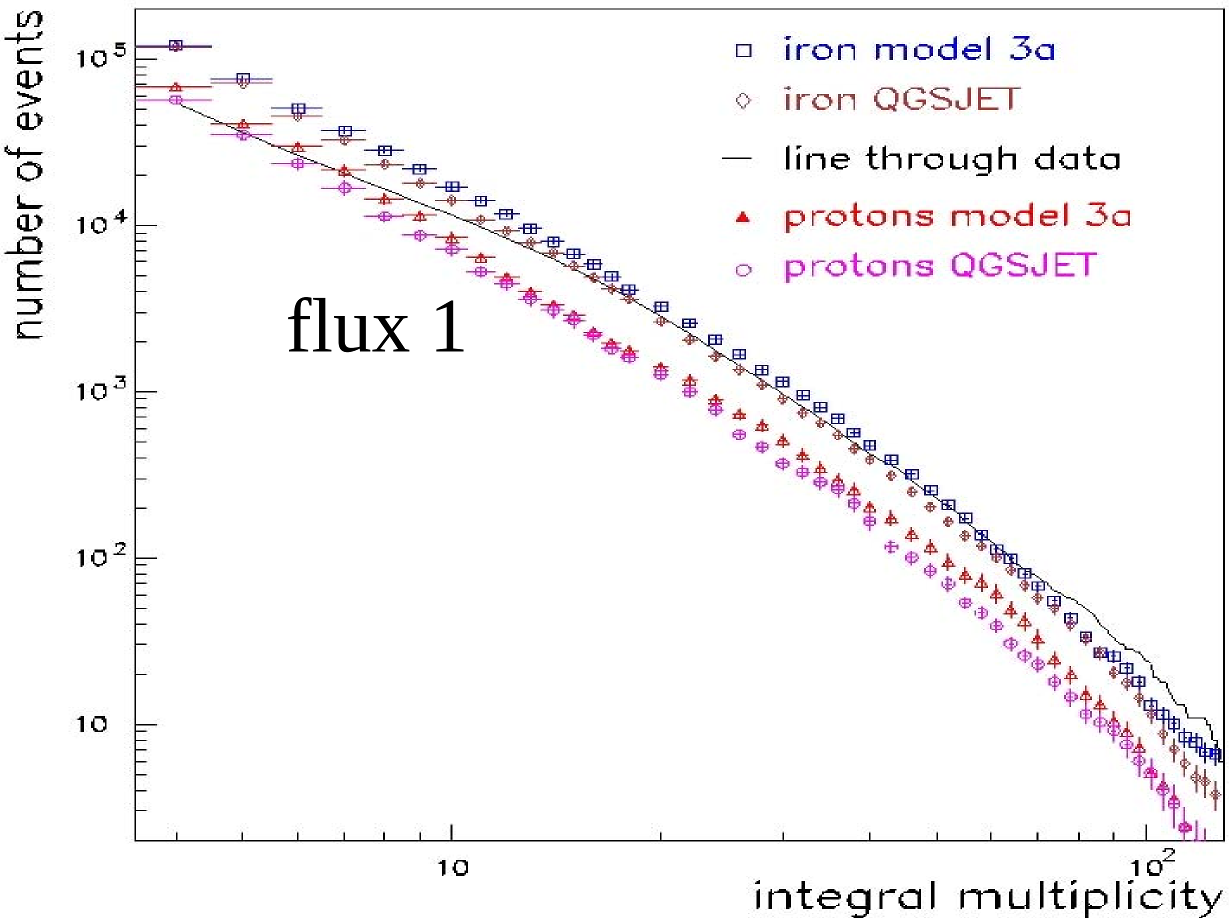
DELPHI

Results III –test (toy) model (J.Hoerandel J.Phys. G 29, 2439 (2003)

cross-section ↓, elasticity ↑



Decreasing σ the core gets more dense



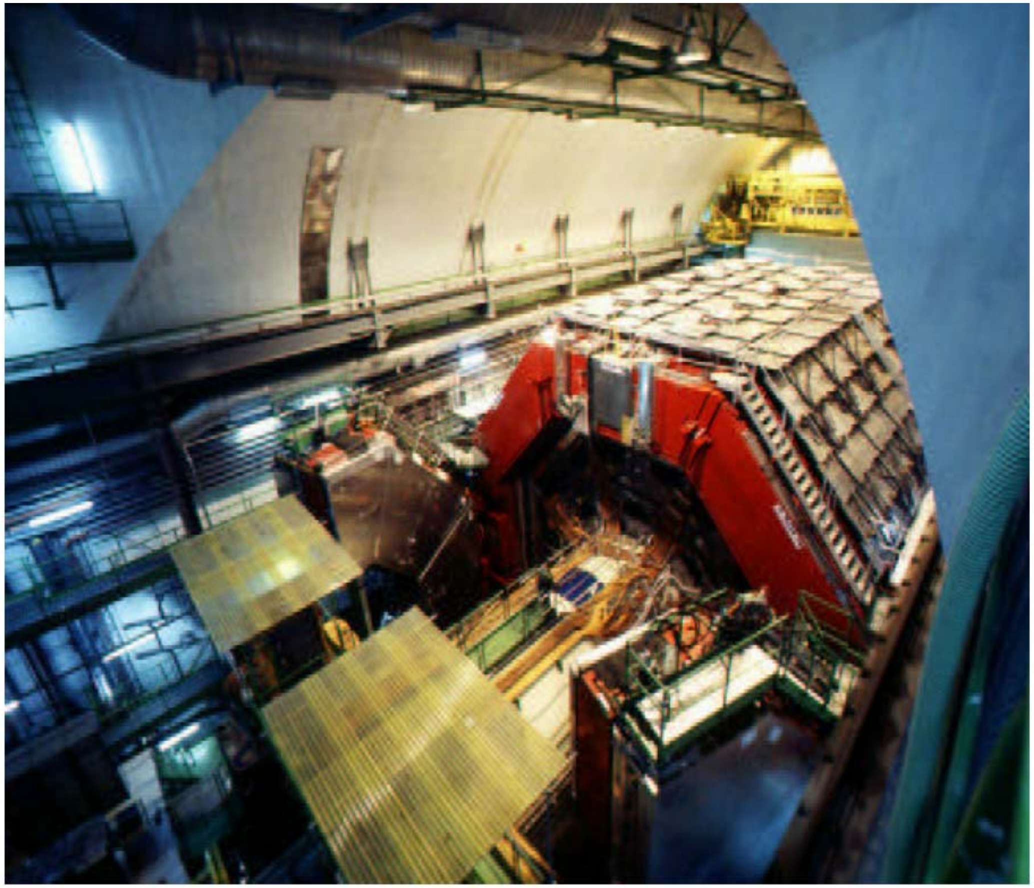
DELPHI
Results – DATA/MC comparison

- Proton MC prediction is in agreement with the data for small multiplicities (first 3 bins), high flux
- Trend from light to heavier component in cosmic ray composition
- Large region of multiplicities to be in agreement with prediction for iron nuclei; Excess of high multiplicity events with respect to MC prediction
- Modification with smaller cross-section (higher elasticity) goes in the right direction to describe data

L3+C

Air shower detector:

50 scintillators, S = 30 x 54 m^2



Muon detector

30 m underground,magnet (0.5 Tesla)

High precision drift chambers

202 m^2 of scintillators

Trigger and DAQ: independent of L3

Geom. acceptance: 200 m^2sr

Energy threshold:15 GeV

Mom. resol.: = 7.6 % at 100 GeV/c

Ang. resol.: 3.5 mrad above 100 GeV

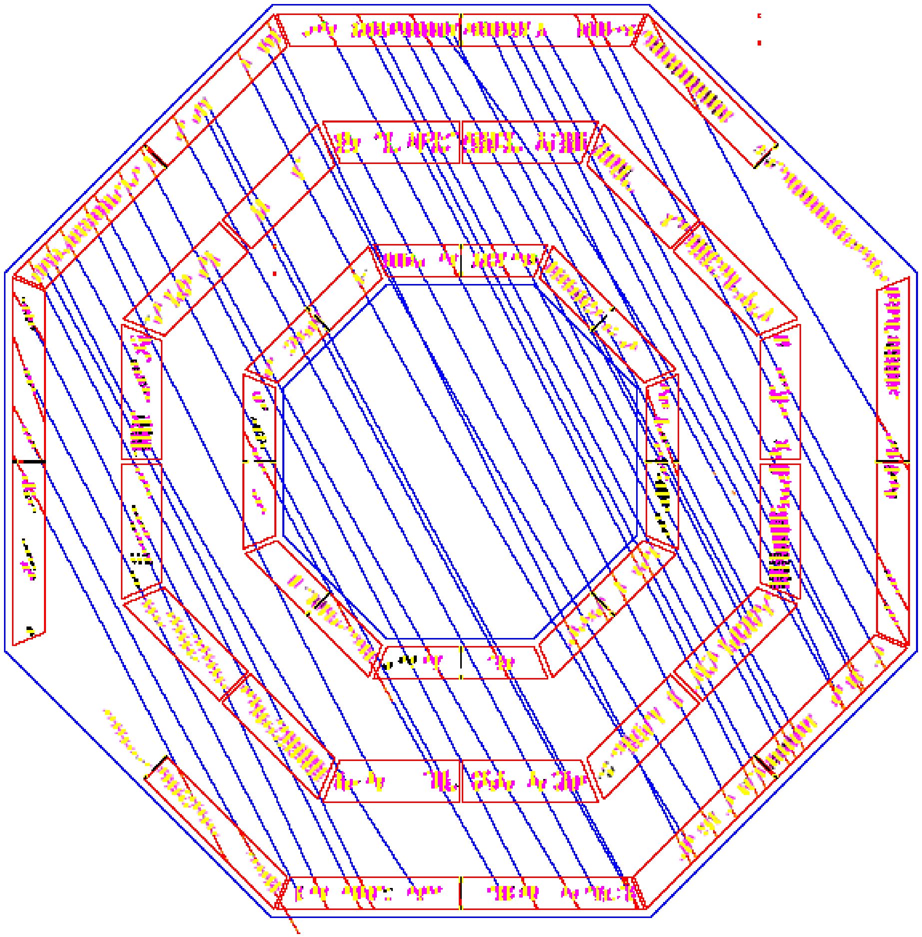
L3+C
Composition, Multi-muon bundles

L3+C can study multi-muon events also in coincidence with surface array.

Muon multiplicity can be studied as a function of shower size.

Muon momentum can be measured for individual muons in the bundle.

Analysis of the abovementioned items is still in progress …



L3+C
Composition, Multi-muon bundles

Some results:

Muon multiplicity in events with:

E>30TeV (surface array),

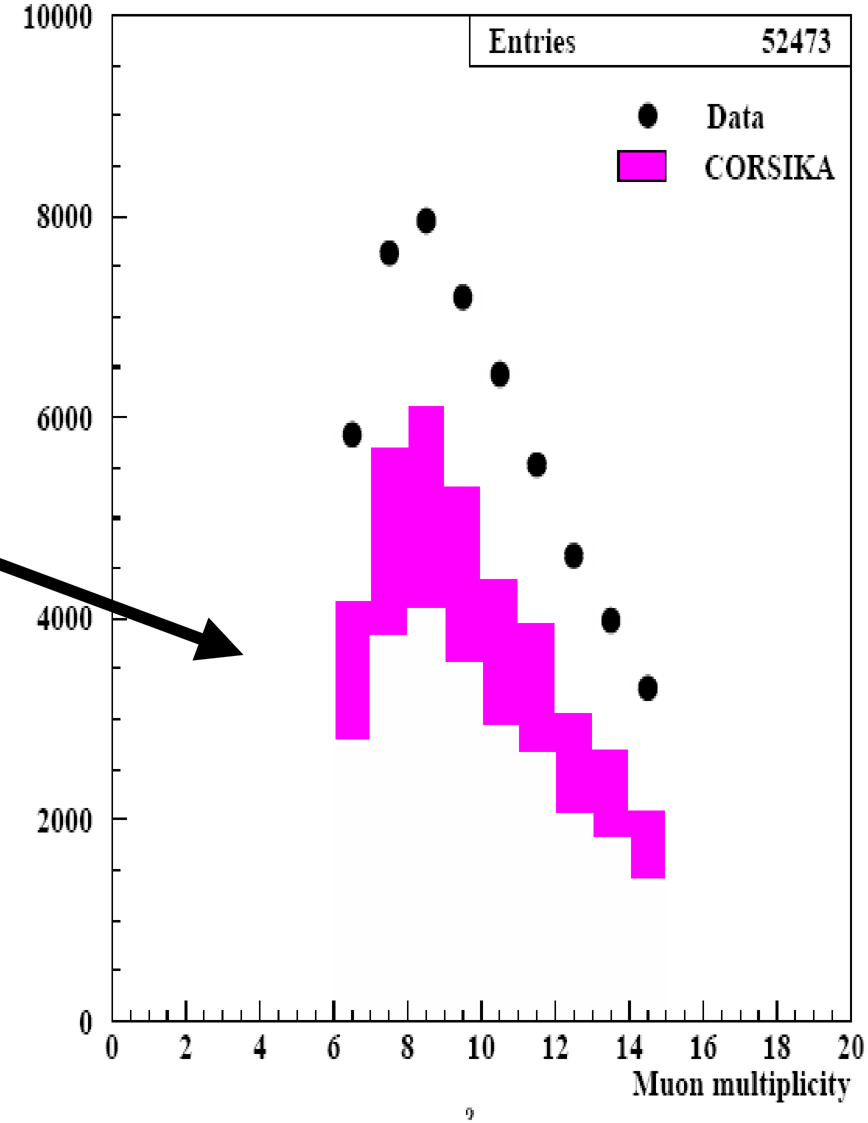
14>N(muons)>5,

N(muons, E>100GeV)>5

MC assuption:

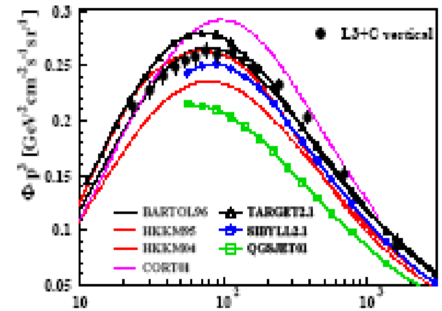
p:He:CNO:Fe=2:2:1:1

Analysis indicates deviation from prediction of MC models (surplus of multi-muon data with large muon energies compared to MC simulation)

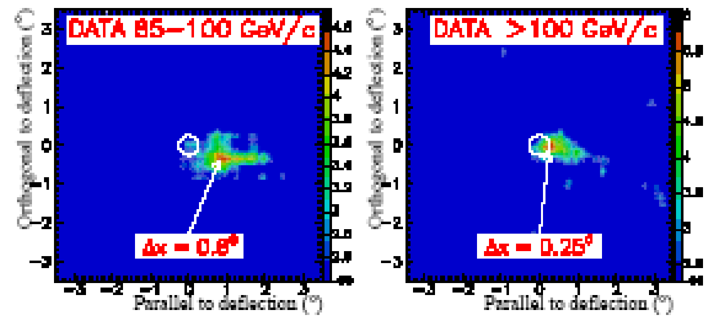


L3+C

Many more results concerning:



• Angular dependence of the muon spectrum and charge ratio (zenith angle between 0 and 58 deg.) - small total uncertainty

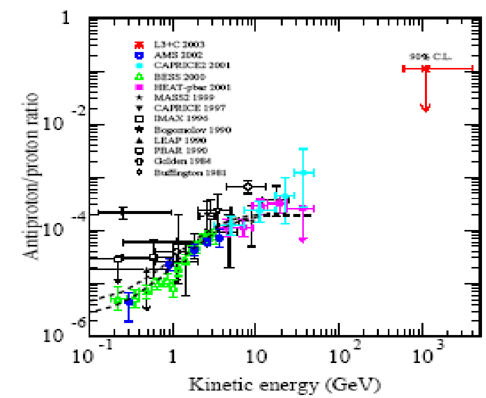


• source searches

• search for signals from GRB

• coincidences with solar flare

• limit on proton/anti-proton flux from moon shadow



• meteorological effects

etc.

…….. will be discussed in talk of Lawrence Jones ……..

LEP - Conclusions I

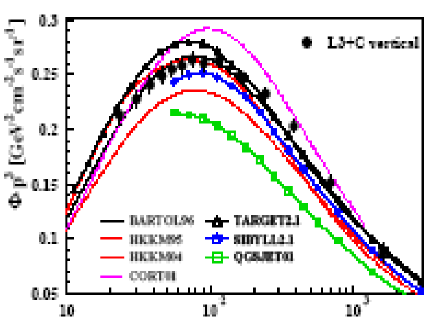
LEP experiments provided important results in the field of cosmic ray physics (HE interactions, source searches, composition …)

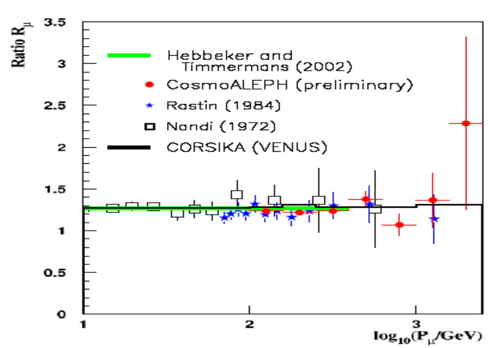
Atmospheric muon energy spectrum, charge ratio (and angular dependencies of both items)

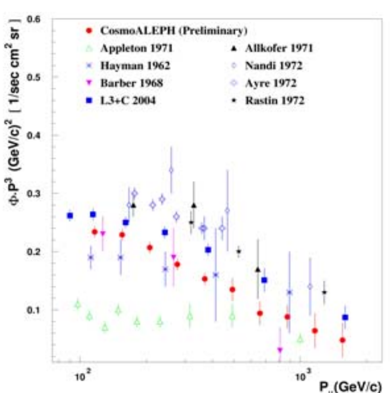
- Hadronic interaction models cannot describe observed muon spectrum and charge ratio (for given CR composition)

- Atmospheric neutrino spectra can be better constrained

- Impact also to the field of neutrino astronomy: neutrino induced muon background can be better defined

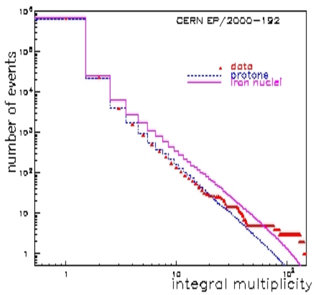






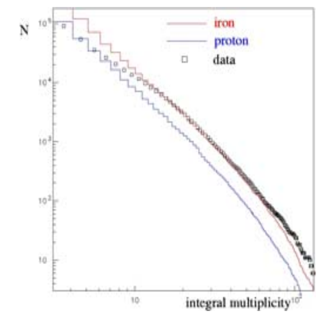
LEP - Conclusions II

Muon bundles



- Low multiplicities favor light nuclei as primaries, median multiplicities show trend to heavier primaries

- At high multiplicities the interaction models probably fail to describe hard muon bundles



Sources, solar flares, $\bar{p}$/p ratio, solar anisotropy

- No steady source, no excess of events pointing towards to 8 studied GRB, one possible flare may have been observed (see L.J. talk)

- Estimated upper flux limit for solar protons above 40 GeV (solar flare 14 July 200) (L.J. talk)

- Analysis of moon shadow allowed to estimate upper flux limit for antiprotons (L.J. talk)