The L3 + Cosmics experiment.

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(On behalf of the L3 collaboration.)

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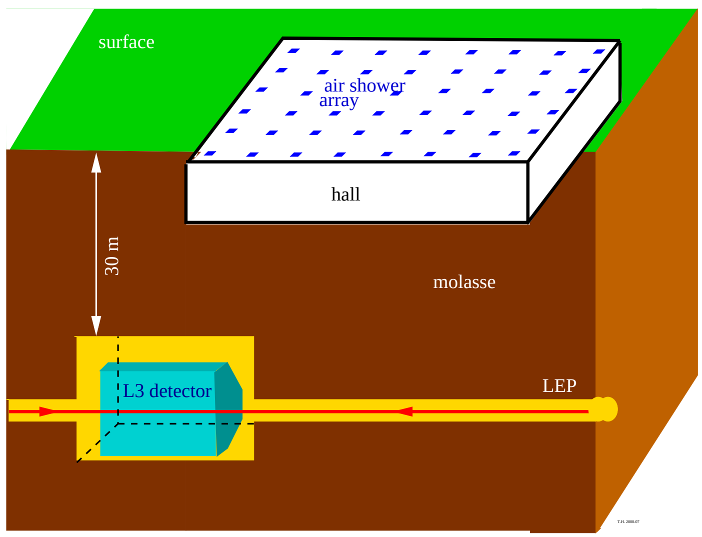
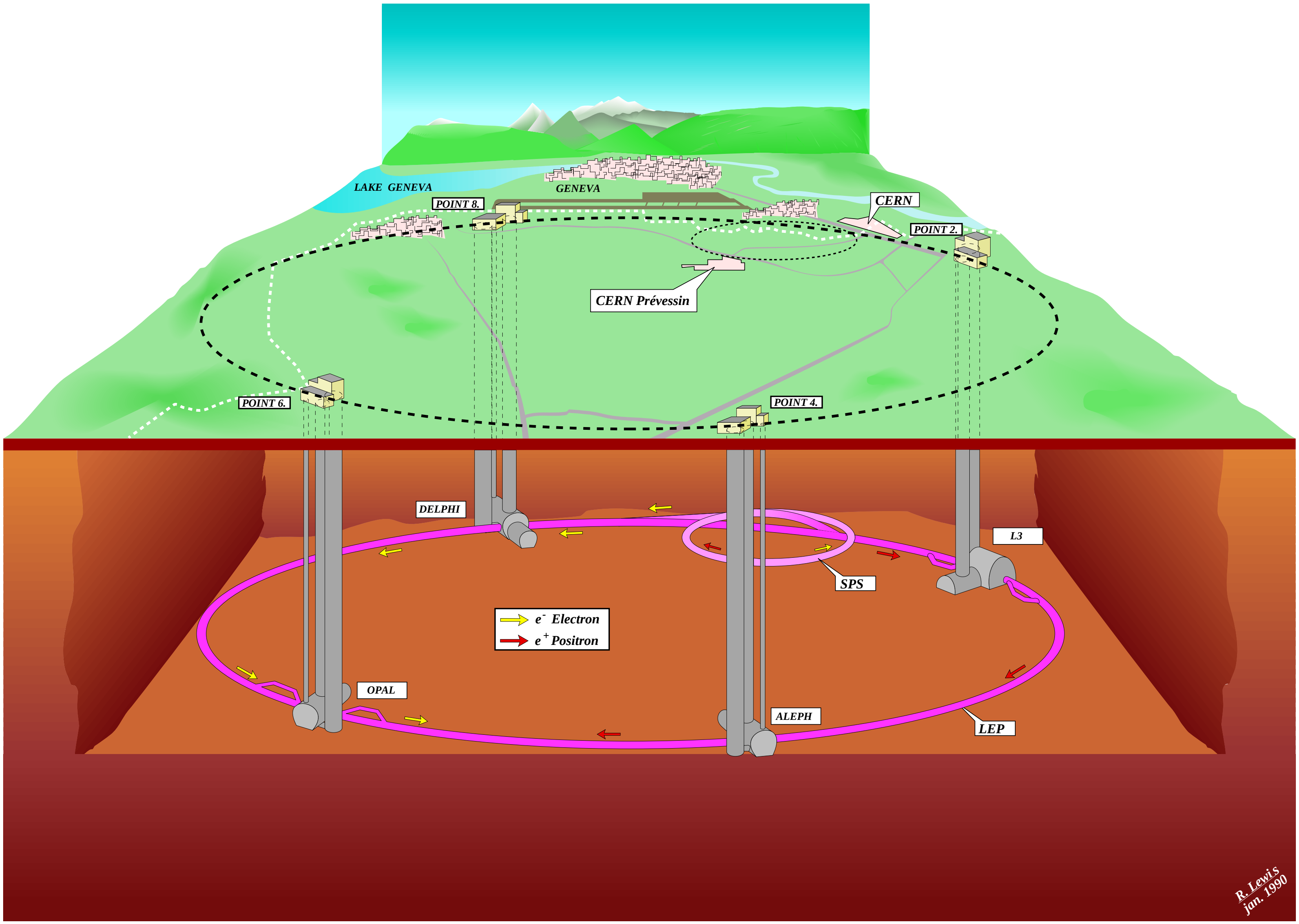


Contents

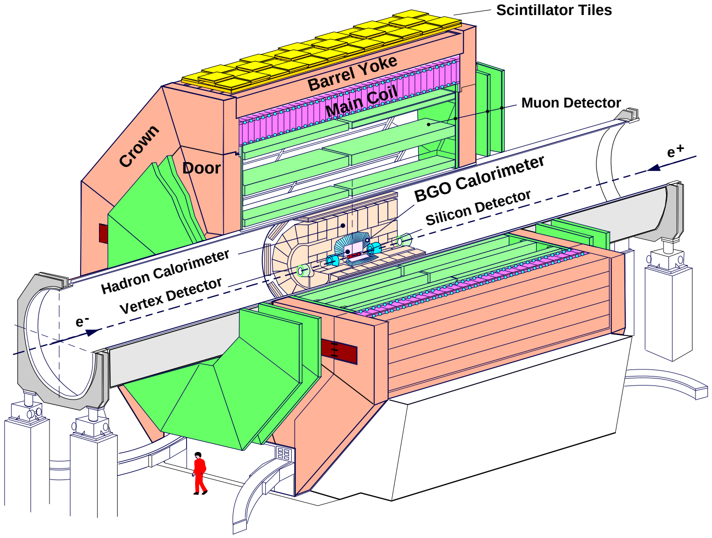
- The L3+C tool-set.
- Physics topics addressed by L3+C
- Brief description of three of the topics.
  - The μ-momentum spectrum.
  - Combined results from the Air shower array and μ detector. .
  - The moon shadow.
- Conclusions.

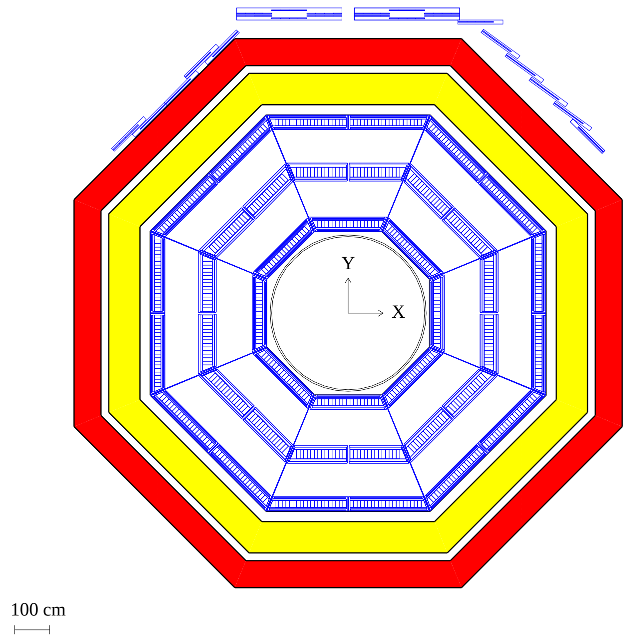
LEP at CERN (Geneva) Longitude: 6^o E; Latitude: 46^o N; Altitude: 450 m; L3: -45 m



The L3+C setup

The μ detector





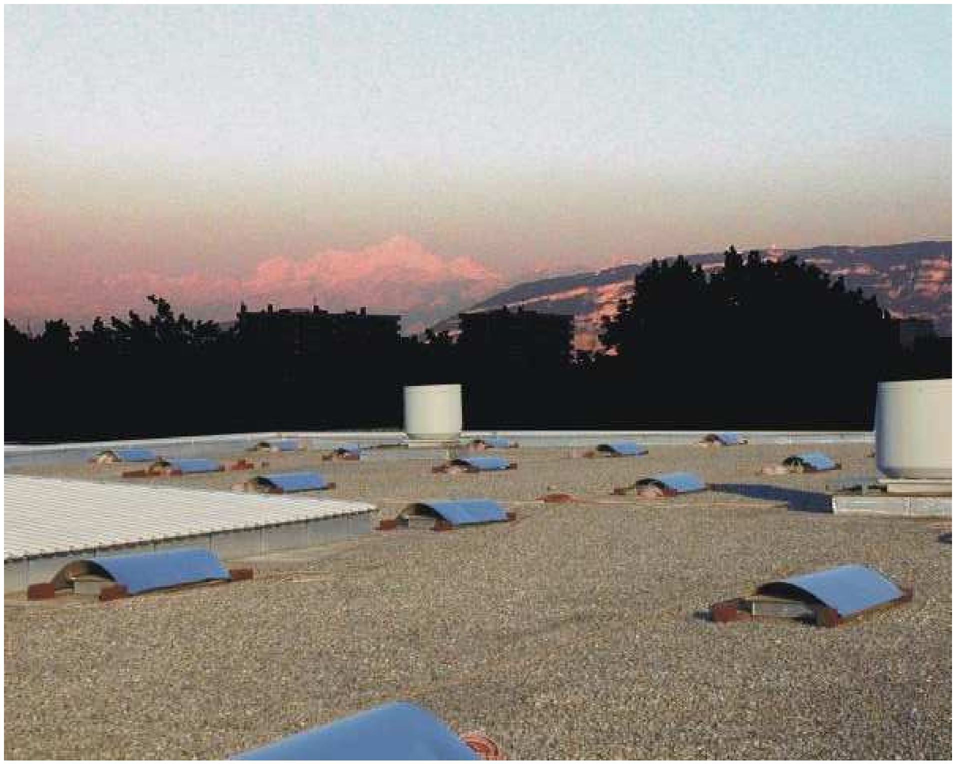
- Magnet (0.5 T, 1000 m^3)
- High precision P and Z drift chambers ($>$ 22000 channels)
- t_o-detector (202 m^2 of scintillator)
- Trigger and DAQ independent of L3

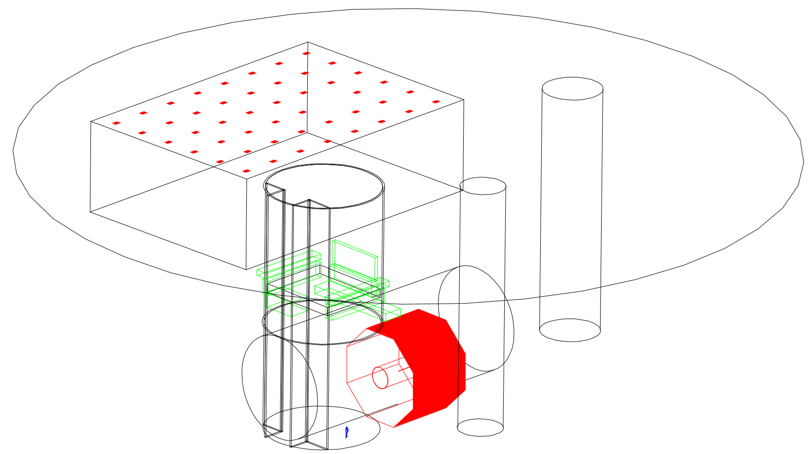
The L3+C setup

The μ detector. Properties.

- **Hadronic and EM components** **filtered by 30 m. of molasse**
- **μ threshold:** $E_\mu > 18GeV (> 7Gev)$
- **Geometrical acceptance :**$\Sigma \cdot \Omega \simeq$ **200** $m^2 sr$
- **Momentum resolution:** $\Delta p/p =$ **5.5**$\%$ **at 100 GeV/c**
- **Angular resolution:** $\delta\ \Theta <$ **5 mrad above 100 GeV/c**
- **GPS timing :event time to 1** μ**sec**
- **Trigger and DAQ independent of L3**
- **Online Monitoring and DataBase independent of L3**

The L3+C setup,Air Shower Scintillator Array





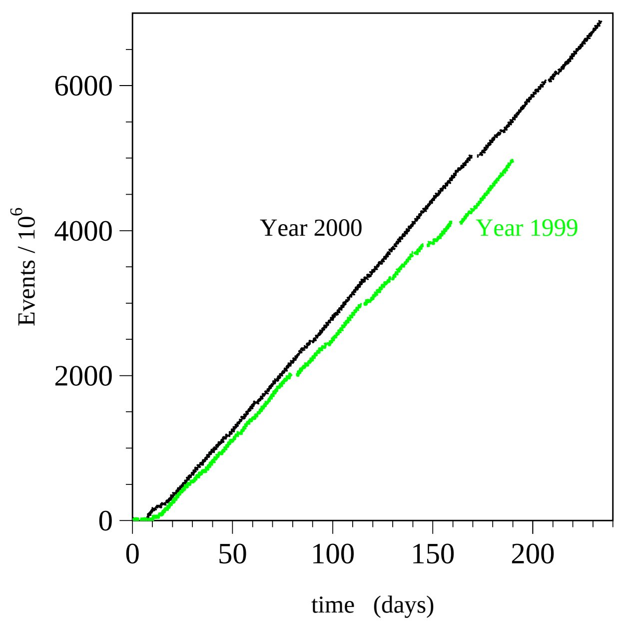
The L3+C setup

The air shower scintillator array.

- **47 modules of scintillation counters, 0.5 m^2 each.**
- **Layout: six rows on a 30 x 50 m^2 surface.**
- **GPS synchronised clock.**
- **Arrival times + Integrated signal intensity recorded for each module.**
- **Trigger: ≥ 1 detector "hit" per row of 8 detectors for 3 adjacent rows**
- **Shower rate =1.7 Hz (47% associated with a muon in L3)**
- **E-trigger threshold =10 TeV**
- **Δ Θ of shower axis= 4^o above 30 TeV**
- **25 events/ day with E 10^{15} eV**
- **Events flagged when L3+C gets a trigger and vice versa**

Number of collected events during the two years

11.85 $\cdot\ 10^9$ μ**-triggers, 312.1 d live-time**



+ 28 $\cdot\ 10^6$ **shower-triggers, 212 d live-time**

The reconstruction in the μ spectrometer

Two different methods used:

1st

- Momentum measured twice (upper and lower octant) Then,matched.
- Allows to measure directly the efficiency of the different octants.

2nd

- Octants aligned iteratively with muons.
- Muons fitted across whole spectrometer.
- Momentum resolution improves thanks to much larger lever arm.

Momentum resolution:

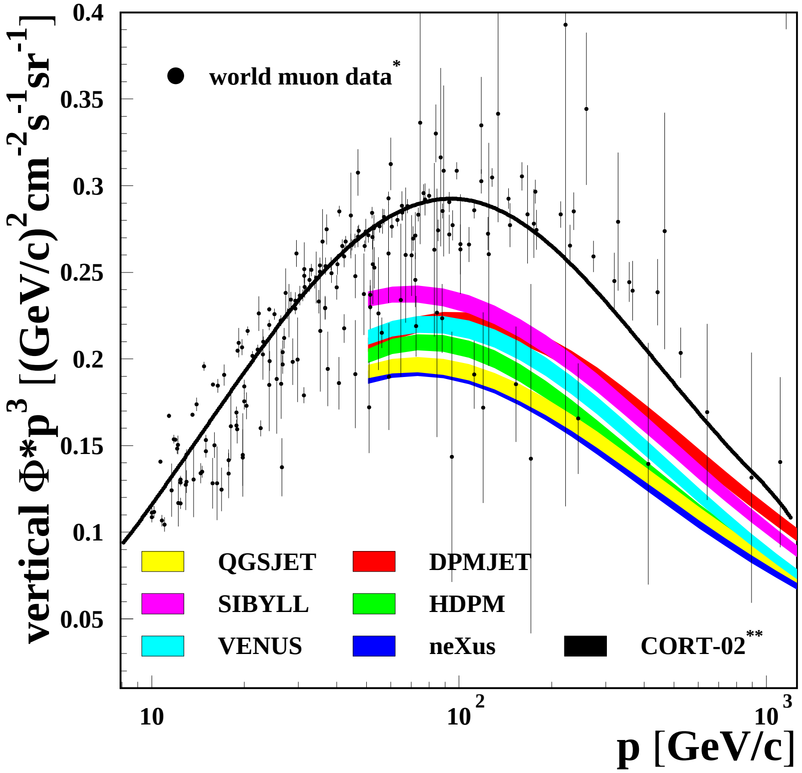
1st: $\Delta p/p = 8.\%$ (100 GeV), 100.% (1 Tev)
2nd: $\Delta p/p = 5.5\%$ (100 GeV), 22.% (1 Tev)

Physics topics addressed by L3+C

- The μ-momentum spectrum and charge ratio.
- The primary cosmic ray composition.
- The primary antiprotons around 1 TeV and the Moon shadow.
- Search for burst signals from point sources.
- Search for VHE Gamma Ray Bursts.
- Seach for HE protons from Sun (solar flares).
- Correlations over large distances.
- Search for exotic events.

We will concentrate next in the first 3 topics.

The vertical atmospheric muon momentum spectrum and the μ^+/μ^- charge ratio



*(from hep-ph/0102042)
**(from hep-ph/0201310)

The vertical atmospheric muon momentum spectrum (x p^3)

Dots :

L3+C 1999 data

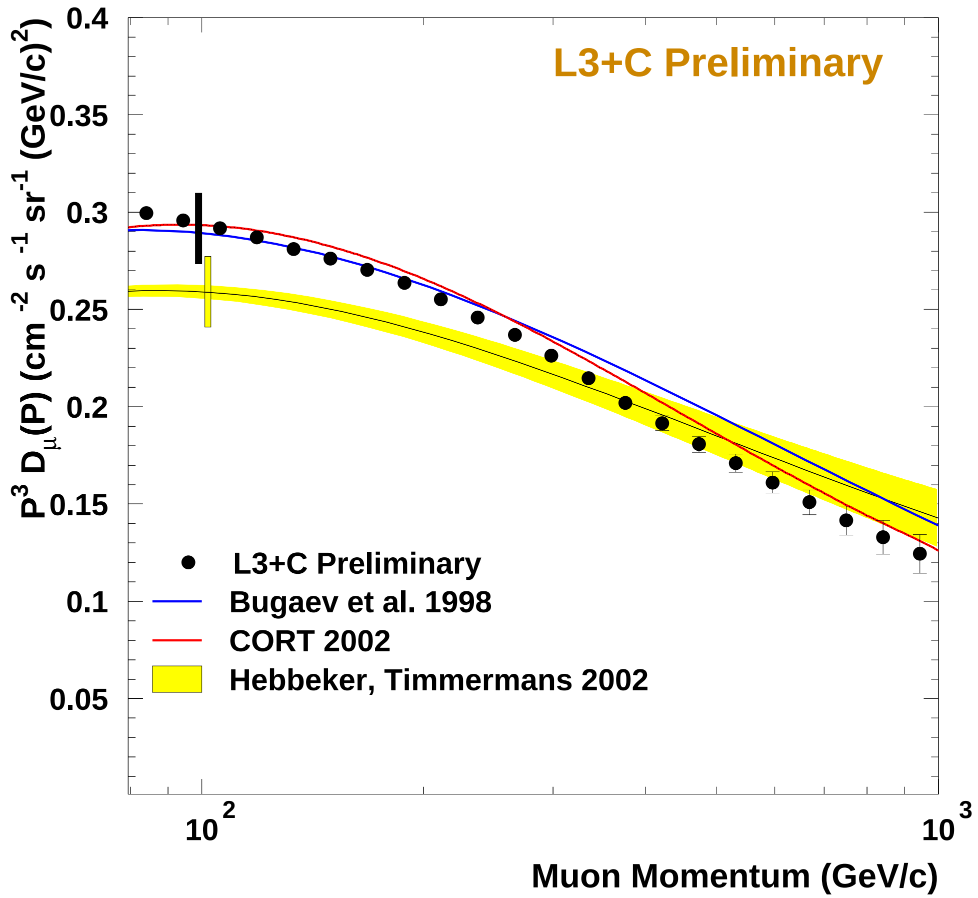
Black bar:

Normalization error (6.2%)

Yellow band :

Current world average

from selected data

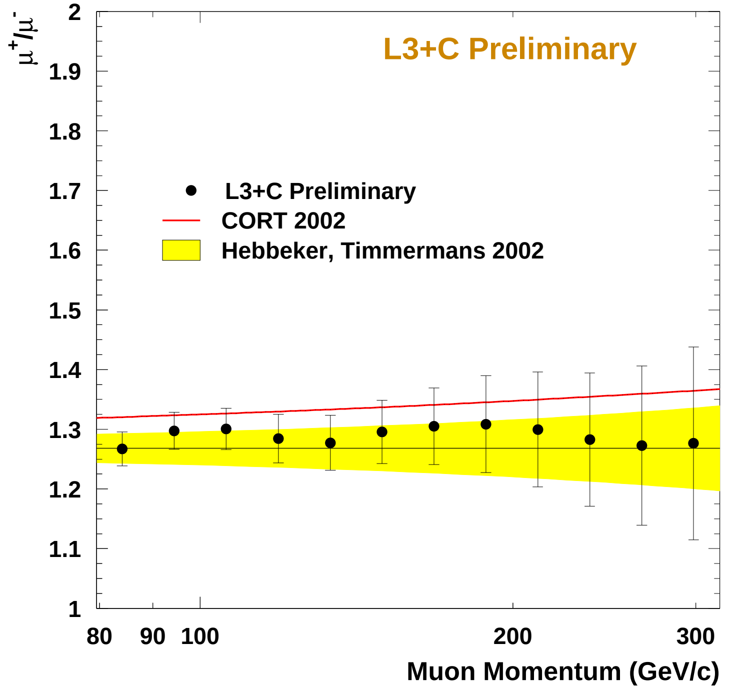


The charge ratio of vertical atmospheric muons

Errors increase a lot at large momenta due to uncertainty in the chamber and octant alignment.

Charge ratio $\mu^+\mu^-$:

- Sensitive to primary composition.
- Determinant for the $\bar{\nu}/\nu$ ratio



Next steps

- New reconstruction algorithm
- Analysis of full data sample
  (1999 and 2000)

Flux energy range: 80-1000 GeV $\longrightarrow$ 40-2000 GeV
Charge ratio: 80-300 GeV $\longrightarrow$ 40-600 GeV
Better understanding of normalization $\longrightarrow$ aim to total systematic error of 3%

Combined results from the air shower array and the μ spectrometer

Combined results from the air shower array and the μ spectrometer

From the air shower in "stand-alone"

Shower direction:

χ^2 fit to the timing information

Shower size and shape:

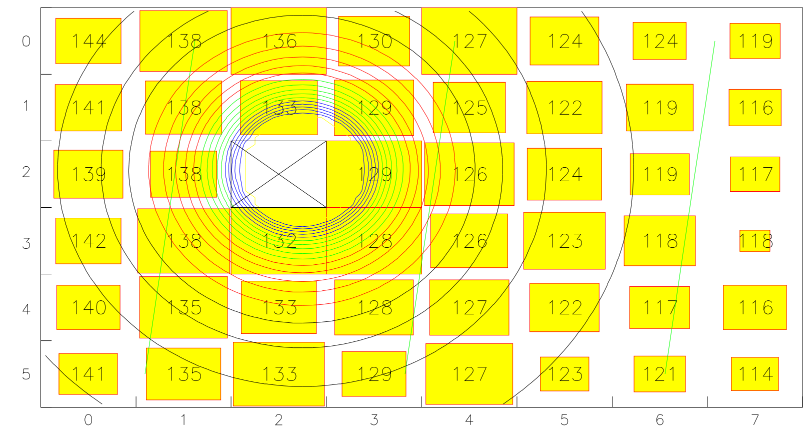
Maximize the probability

$\prod_{modules} \sum_n \mathbf{P(adc|\ n)P(n\ |\ \rho_{NKG})}$

ρ_{NKG} **=f(N_e,age,r,r$_M$)**

(N_e= Nb of ch. particles, r: distance to core,r$_M$=Moliere radius)

(Nishimura,Kamata,Greisen,1960)



we get:

- **Size:** Total amount of charged particles at sampling plane
- **Age:** Shape of the shower
- **Core position**

Shower sizes

Selection:

-Reconstructed shower core inside the array.

-Small age parameter(sharply peaked showers)

-Position resolution $\approx$ 5 m.

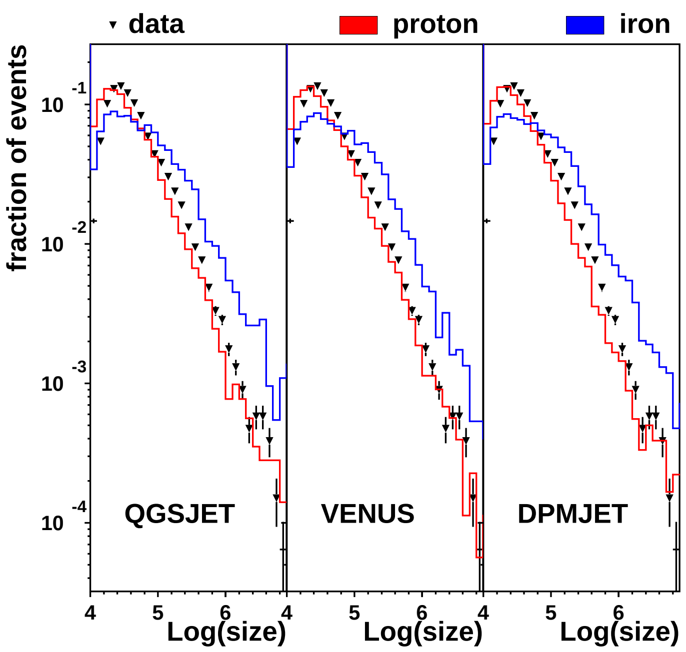
Features:

-Good agreement between data

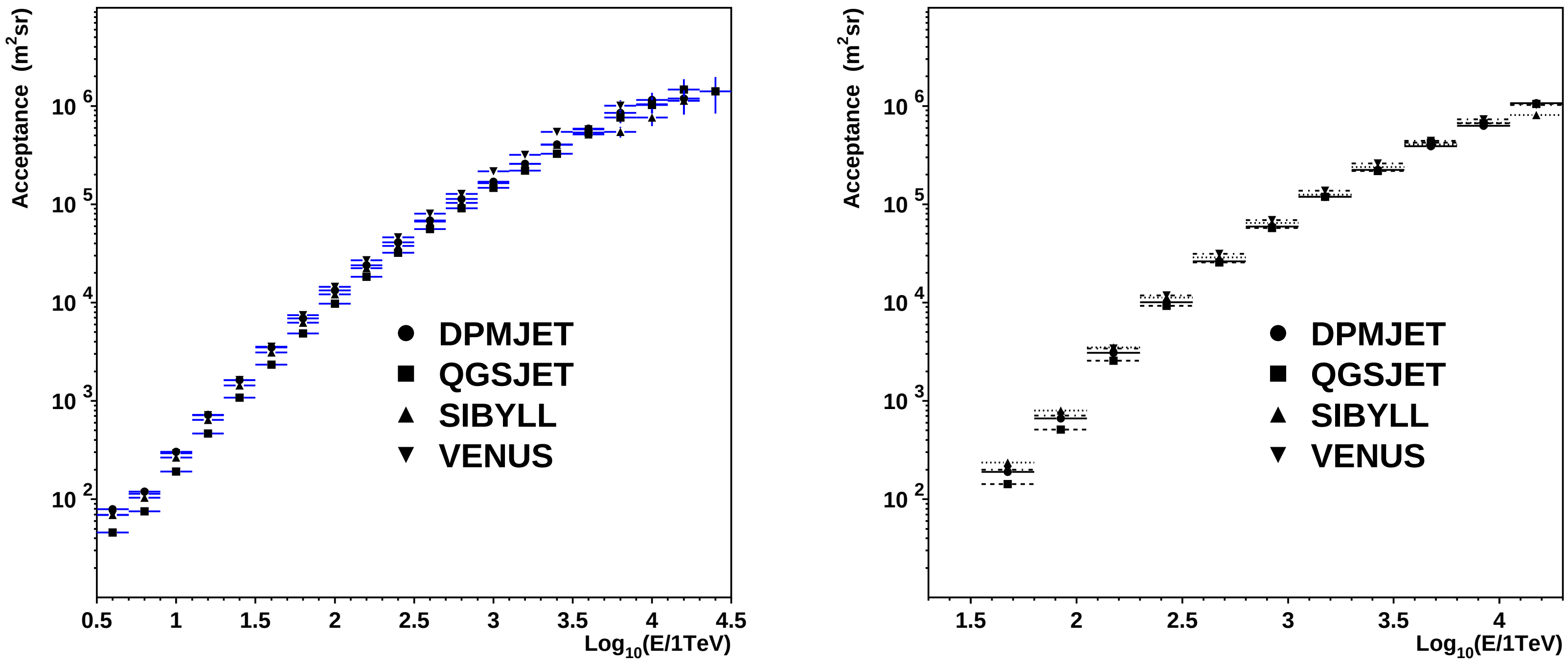
and proton showers,as expected

-Iron predicts harder spectrum, as expected

-But too many MC events at small sizes



Primary energy range



Geometric acceptance at the trigger level for

proton showers (left)

iron showers (right)

within a 60^o cone around zenith,as function of the primary energy.

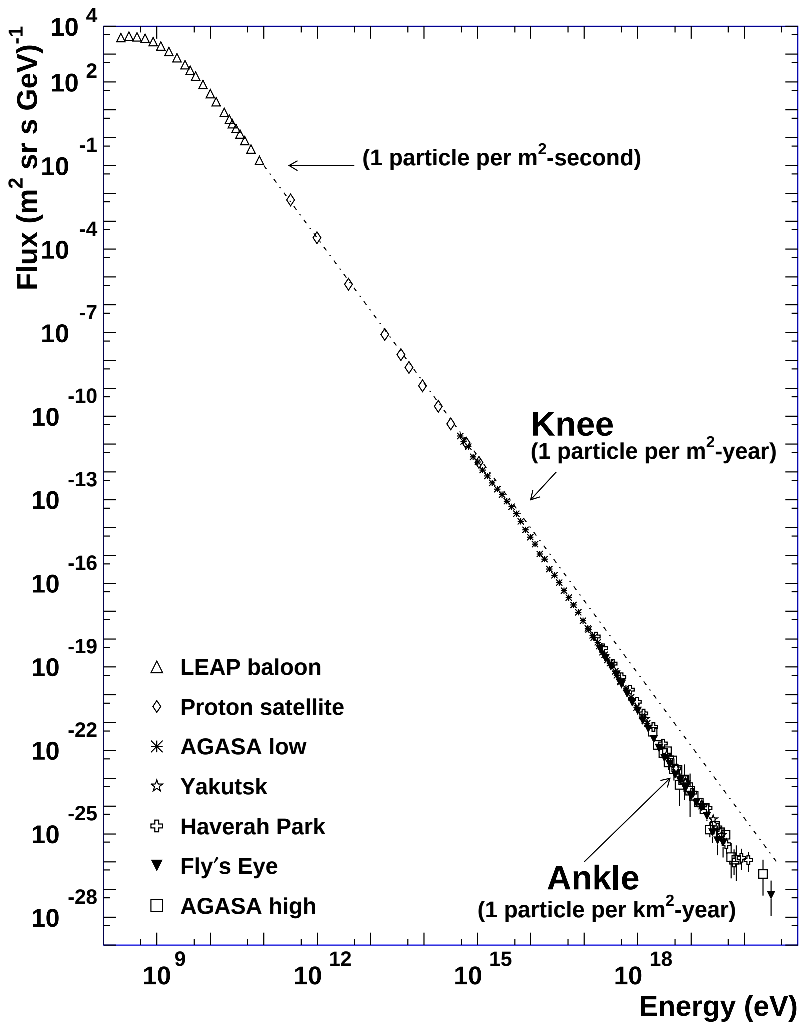
Primary energy range

After selections, the range is

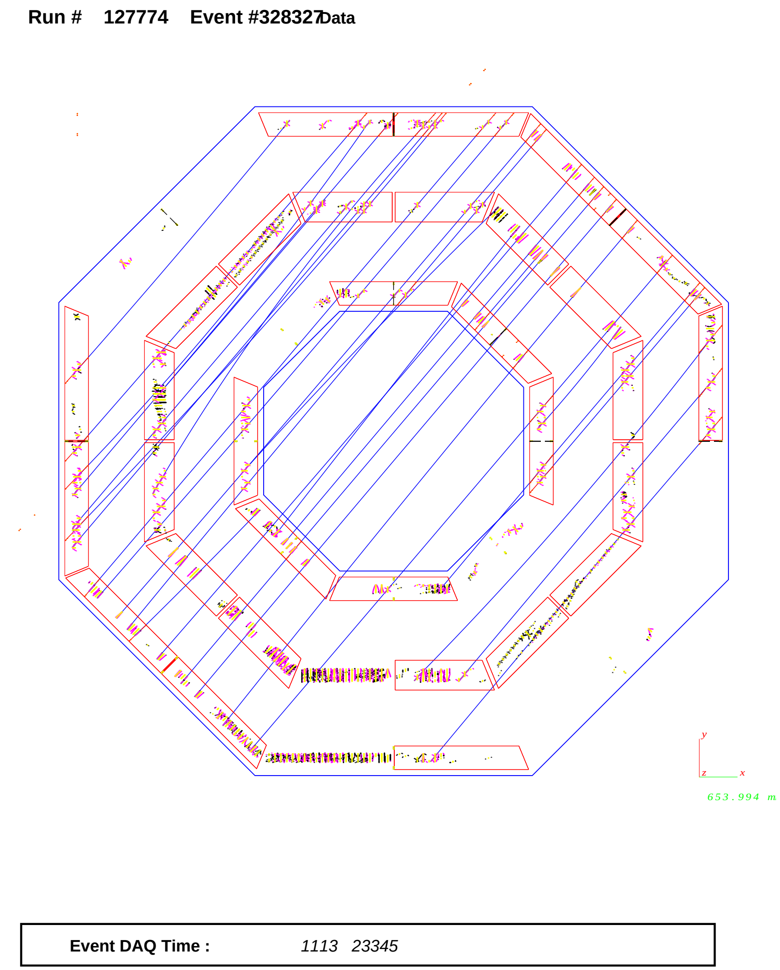
≈ 100 TeV-10 PeV

≈ 10^{14}-10^{18} eV

("Knee region")



Muon counting in the μ spectrometer



Normalisation:

-The number of μ in L3 data is compared to QGSJET predictions for p and Fe.

μ-counting:

-Counting from the raw data.
-Two dimensional cross octant reconstruction

Same two counting procedure applied to data and Monte-Carlo.

Muon densities

Muon densities

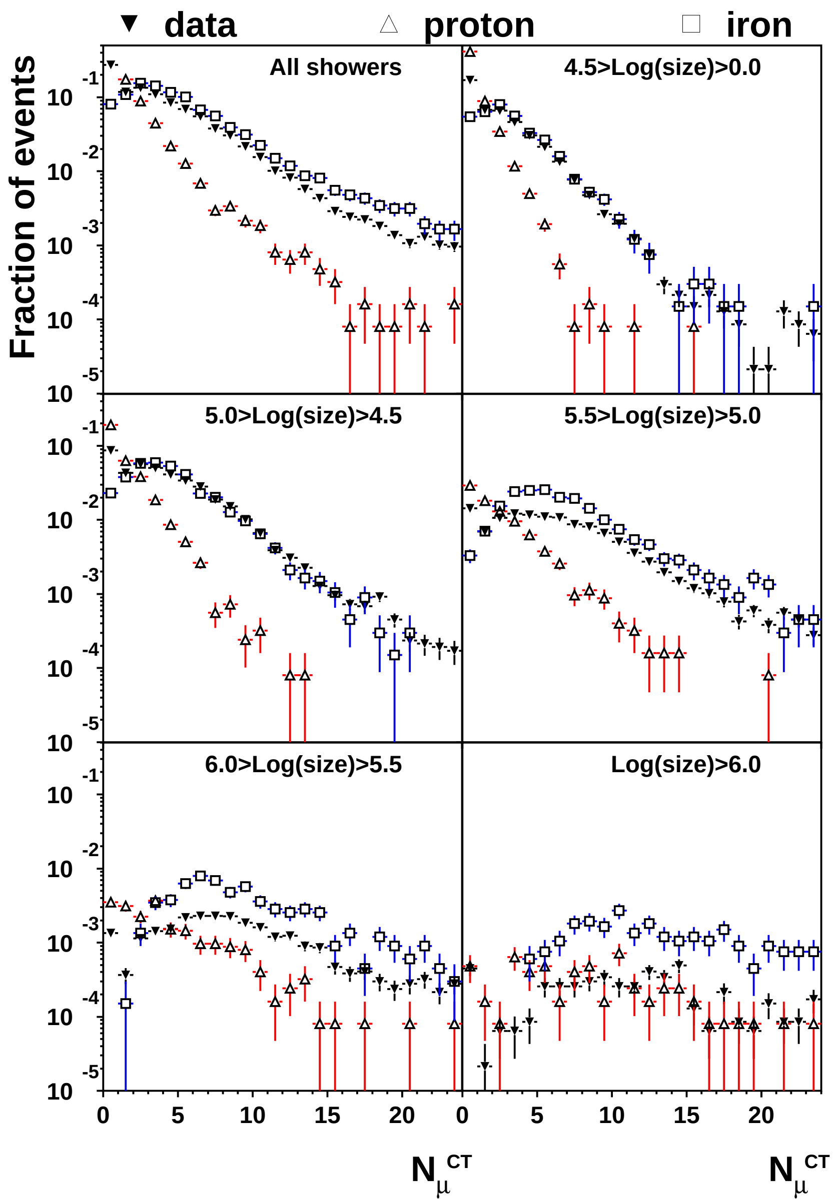
Results are similar for all models

-Either heavy composition.

Contradicts low energy experiments

Contadicts Size spectrum

-Or the models fail to reproduce muon data at this energies



Very forward physics

The μ Pseudorapidity:

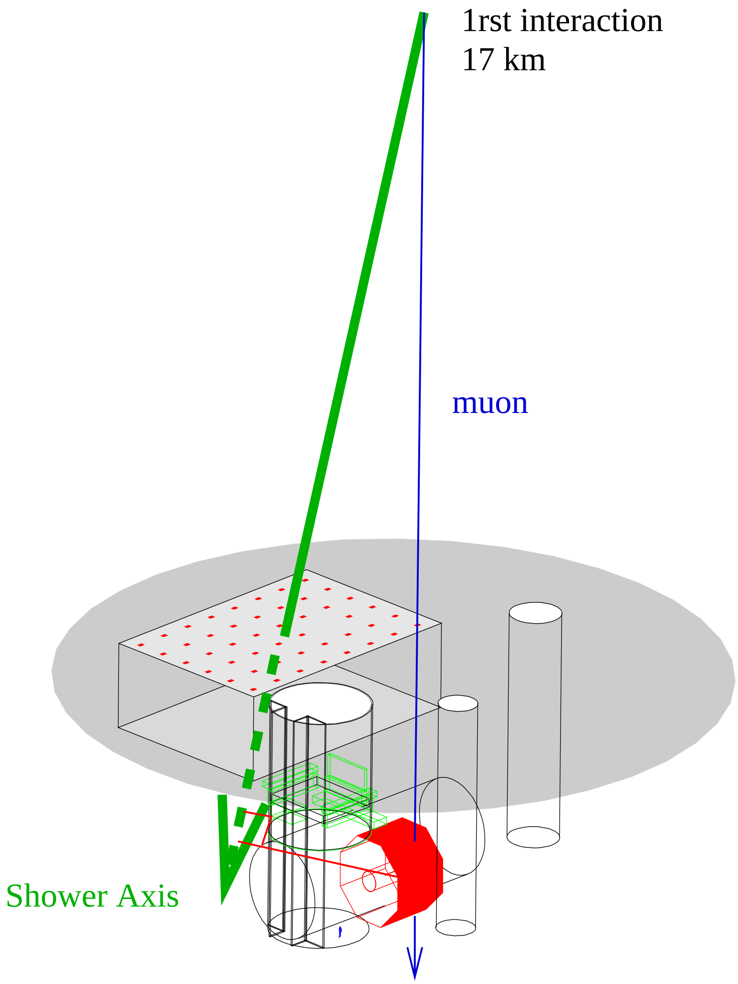
$$\eta = -ln(tg(\Theta/2)) = -ln(tg(d/2h))$$

h $=$ 17$\pm$8 Km.

-6.5 $> \eta >$ -8.5

$\Delta\eta = 0.4$ units

(due mainly to the uncertainty of the primary interaction height h)



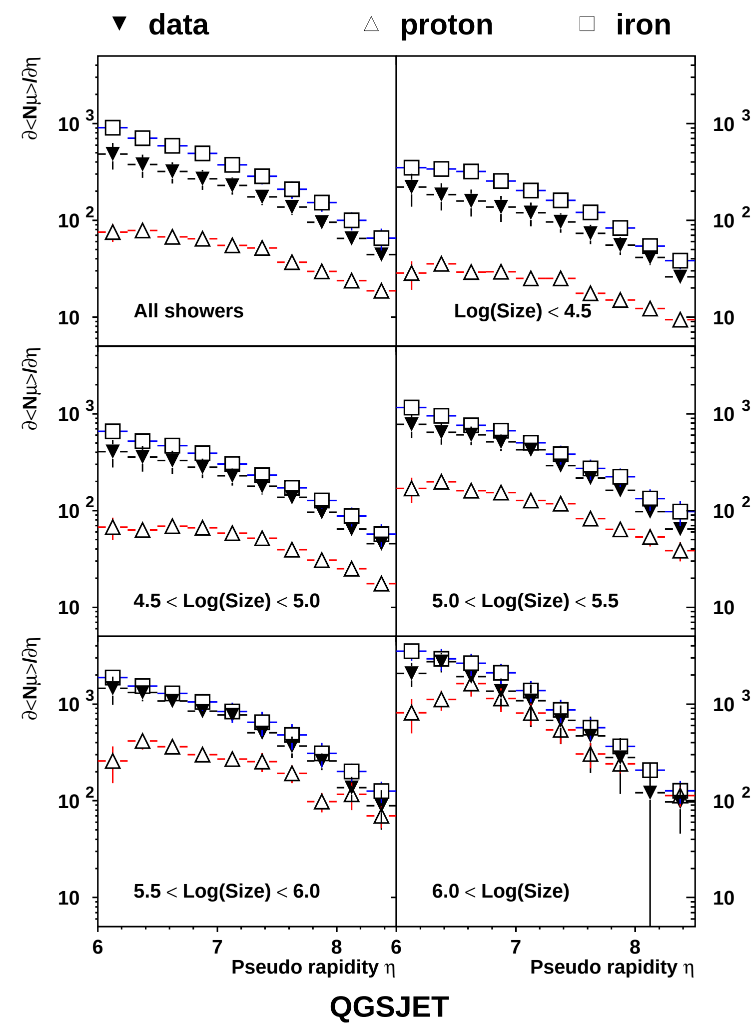
Average muon contents of air showers as function of the pseudorapidity

- Data compared to QGSJET
proton and Iron predictions

- All showers,
and 5 different shower size ranges

- Other models,similar

Discrepancies with the models in CORSIKA,
except for high shower sizes.

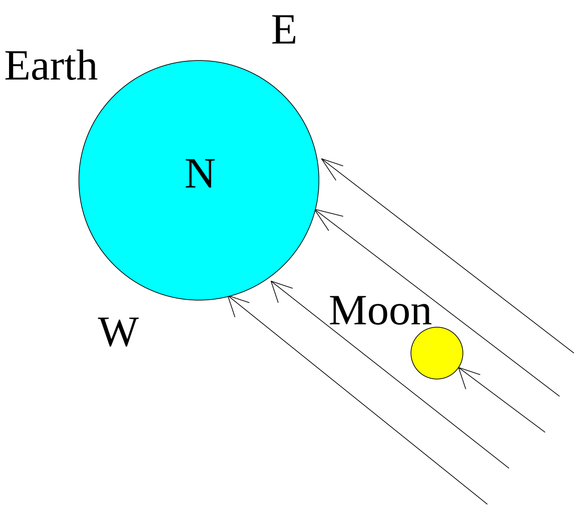


The moon shadow

The moon shadow

Cosmic rays are blocked by the Moon. (Clark 1957)

$\longrightarrow$ deficit of CR when looking the Moon.



- Size of the deficit $\longrightarrow$ angular resolution of the experiment
- Position of the deficit $\longrightarrow$ pointing error.

  Moon shadow has been observed. (SOUDAN. MACRO, CASA...)

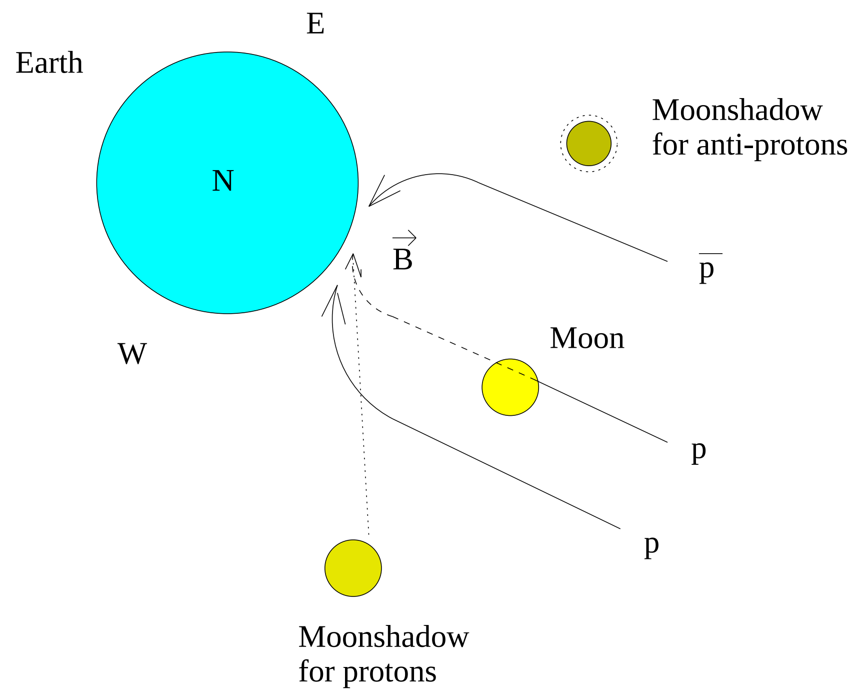
Effects of the geomagnetic field

positive charged particles deflected to the East

$\longrightarrow$ Deficit appears shifted to the West.

$\longrightarrow$If present,antimatter in CR will induce a deficit in the opposite side.

Deflection $\simeq 1^O$/ E(TeV/c)



Earth-Moon = ion spectrometer (Urban et al., ARTEMIS experiment)

Trajectory of the Moon as seen from L3+C

GENEVA:(6.02^{0}N, 46.25^{0}E)

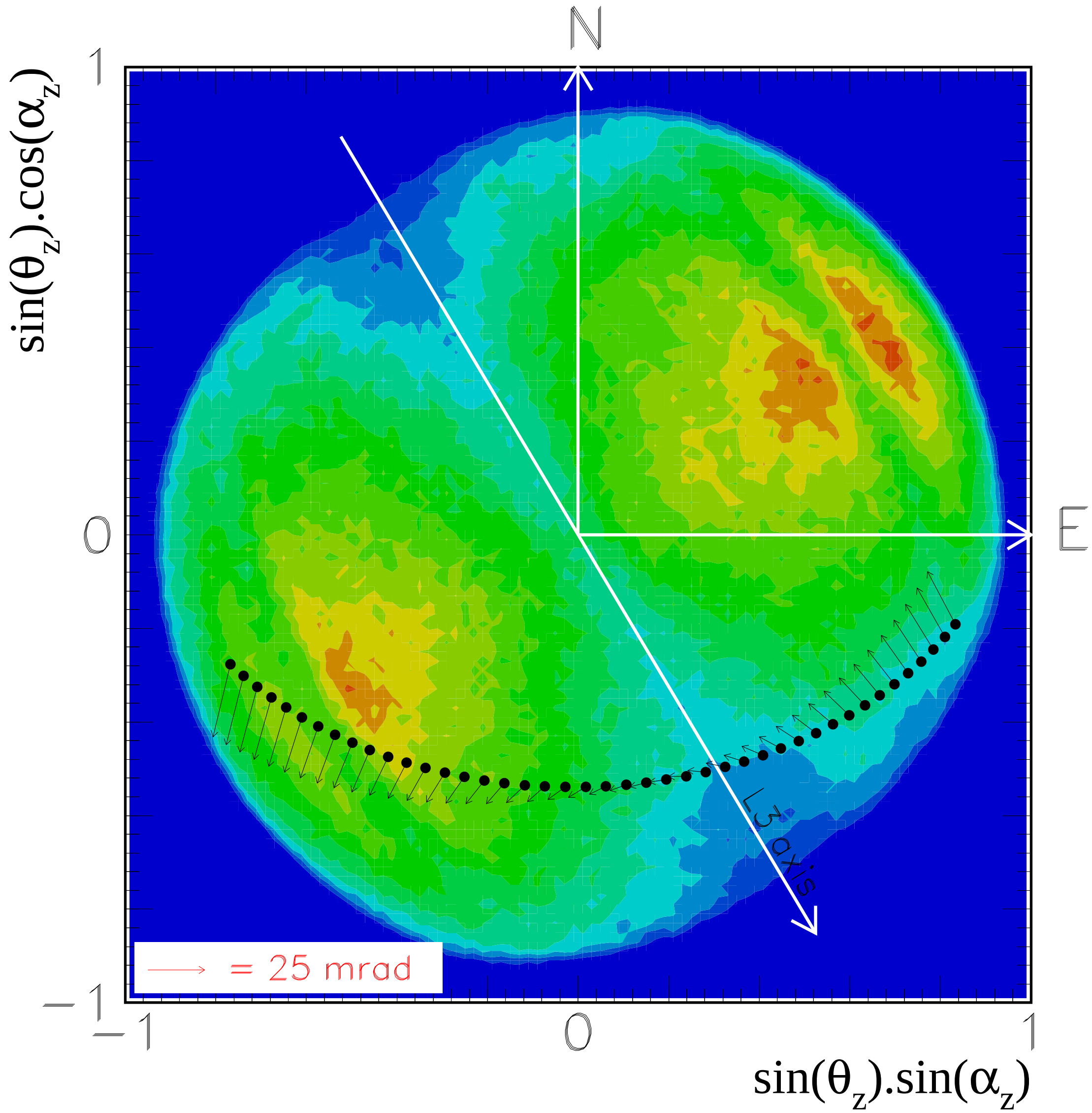
Sky seen by L3+C:

1 pixel = 1 direction

Moon trajectory:

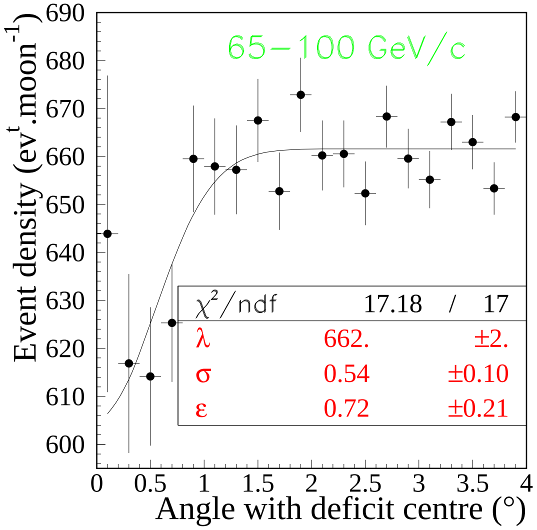
Deflection = f(Moon location)

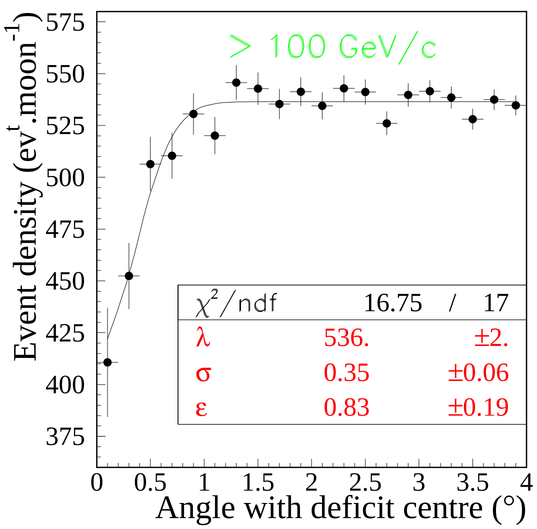
1 TeV protons



Observation of the Moon shadow in L3+C

$$f(\theta) = \lambda \cdot (1 - \epsilon \frac{R_{Moon}^2}{2\sigma^2} \cdot e^{-\frac{\theta^2}{2\sigma^2}}) \quad (1)$$





σ is the experimental angular resolution.Here includes:

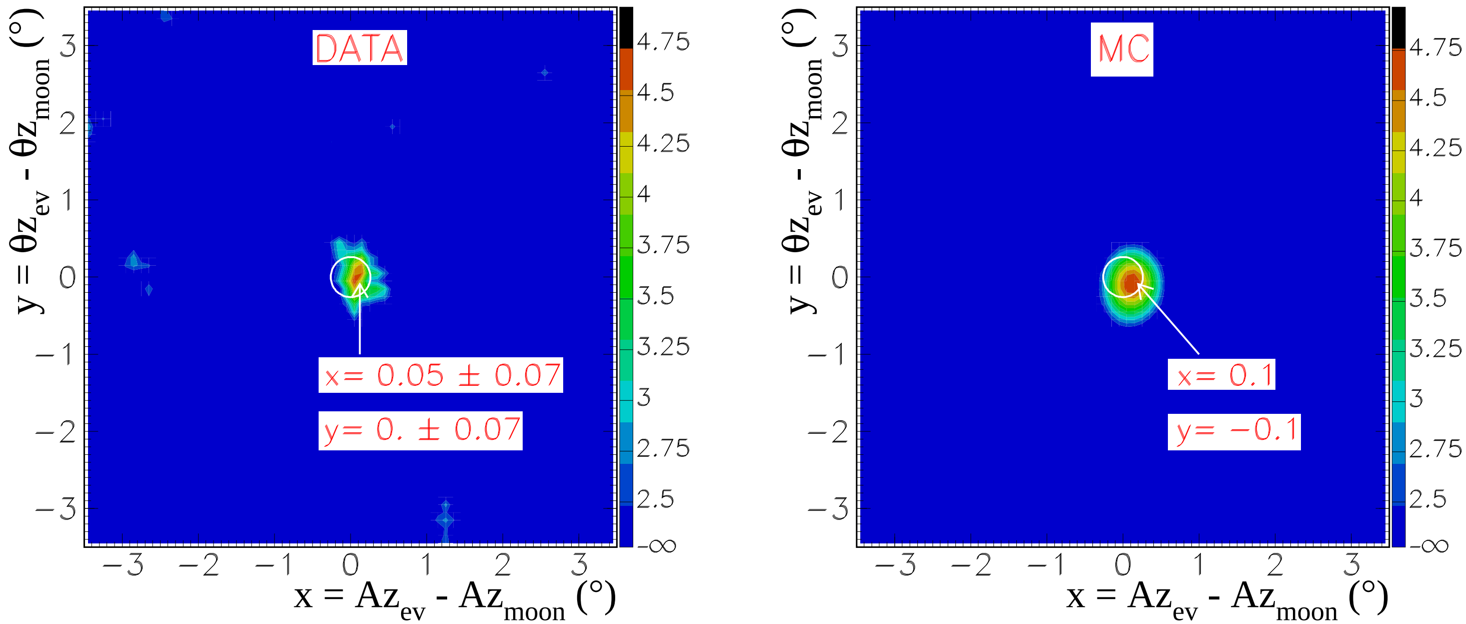
- The angle between μ and primary particle
- the multiple scattering (mainly in the molasse)
- the detector angular resolution

$+$ the Moon shadow elongation by geomagnetic field.

The last contribution can be strongly reduced by a good choice of reference system.

Determination of the pointing error

$\mid p_\mu \mid > 100$ GeV/c, use local coordinates system Zenith vs Azimuth
Background: Moon's path on sky delayed in time.
Substracted from source map $\longrightarrow$ Moon effect.
Smoothing: uniform distribution.
Result in standard deviations from normal distribution.

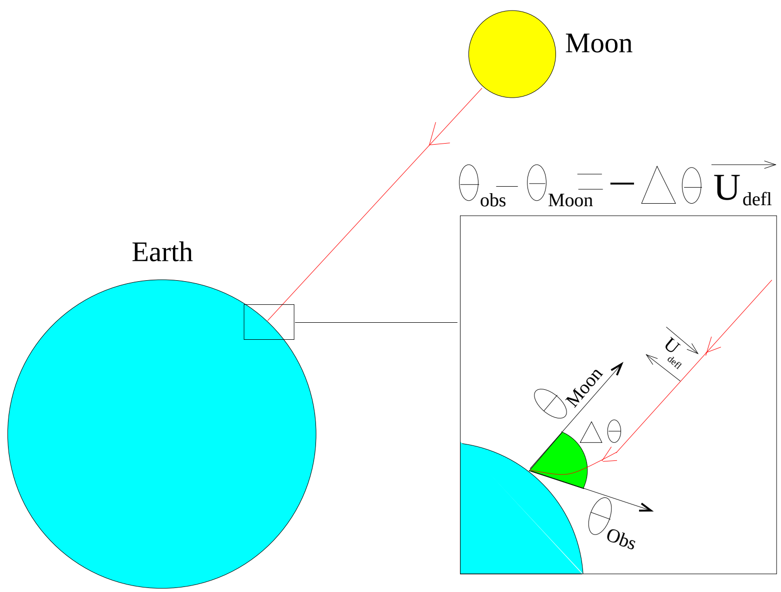


From comparison Data-Mc :pointing error $\simeq 0.1^o$

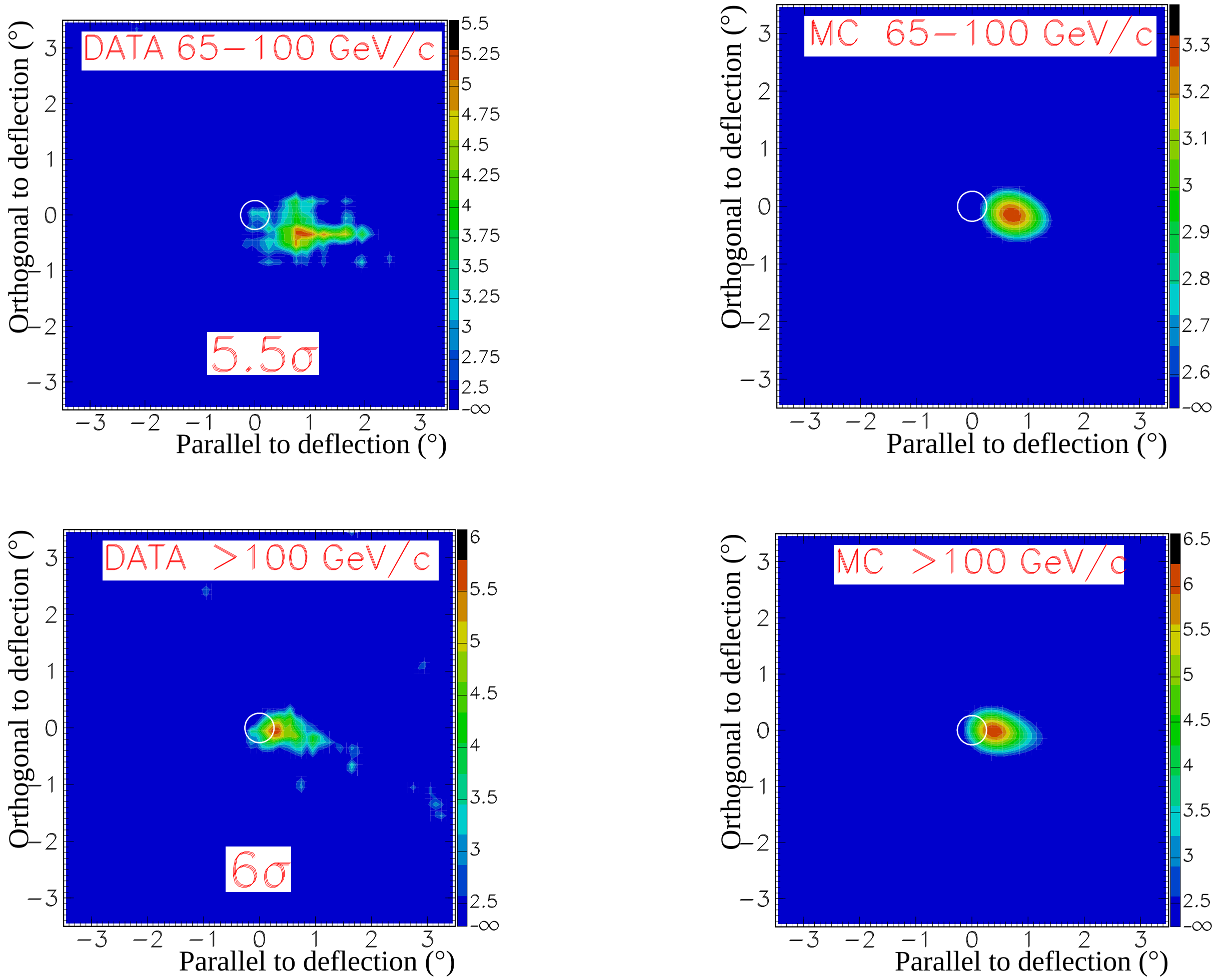
Deflection coordinate system

Choose a reference system with axes parallel to the deflection (Horizontal) and normal to the deflection Vertical)

- **Coordinates given by θ_H and θ_V**
- **Along V, dispersion due to angular resolution**
- **Along H, dispersion due to angular resolution + geomagnetic effect**
  $\longrightarrow$Signal density optimized along H



Observation of the geomagnetic field effect in the system H-V



65 - 100 GeV/c:Δx=0.80^o

>100 GeV/c:Δx=0.25^o

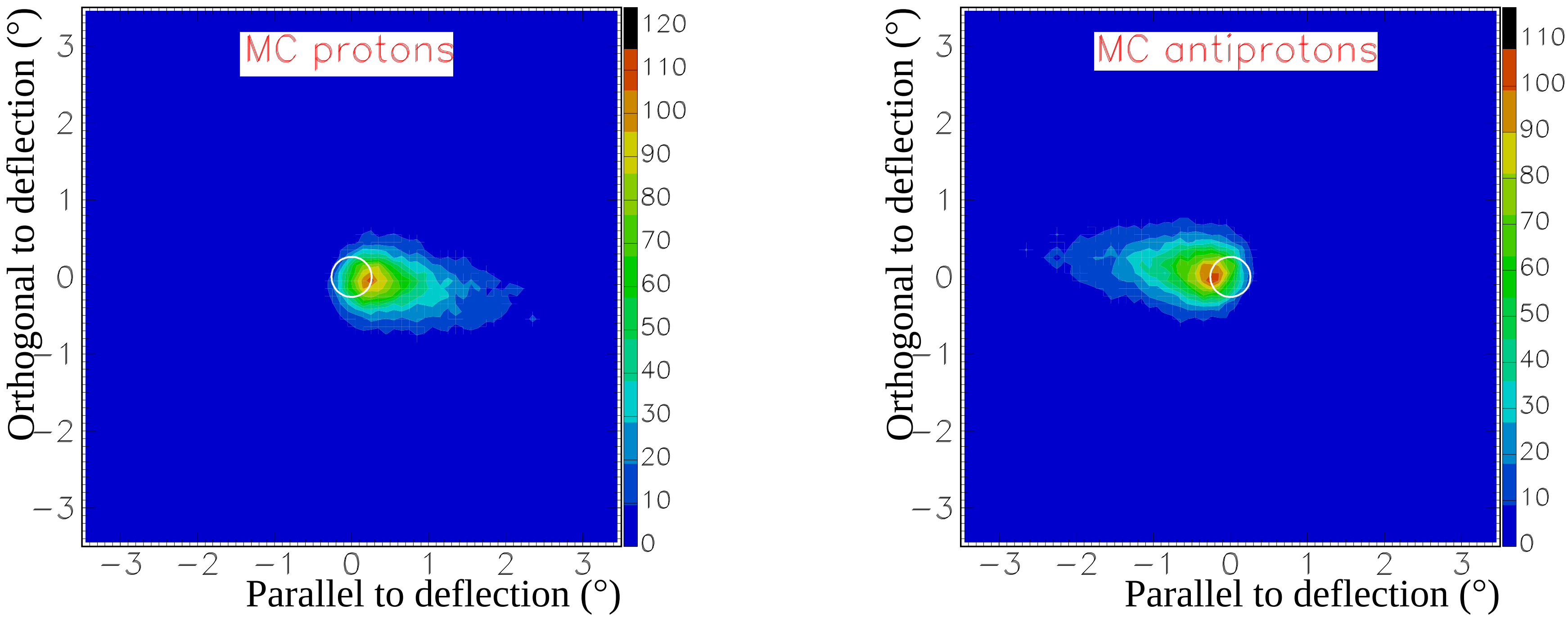
Determination of the effective angular resolution.

- Geomagnetic field $\longrightarrow$ horizontal axis.
- Projection on vertical axis: angular resolution only.

- Project Moon window contents on vertical axis.
- Fit to a gaussian.
- σ values obtained:
  - LE (Low Energy sample,65 - 100 GeV/c): $0.30^o \pm 0.07^o$
  (recall : 0.54 ± 0.10^o in local zenith-azimuth system)
  - HE (High Energy sample,>100 GeV/c:): $0.22^o \pm 0.05^o$
  (recall : $0.35^o \pm 0.06^o$ in local zenith-azimuth system)

Search for antimatter

Simulation: “anti-shadow” symmetric to Moon shadow.
$|\ p\ | > 100$ GeV/c



Measurement of the $\bar{p}/\bar{p}$ ratio.

$| p_\mu | >$ 65 GeV/c, deflection coordinates system.

Hypothesis: $\bar{p}$, p spectrums with same index.

Assumption: data can be described by
- A planar background
- 2 symmetric Gaussian deficits for matter and antimatter
- (25% He, CORSIKA)

Maximum likelihood fit:

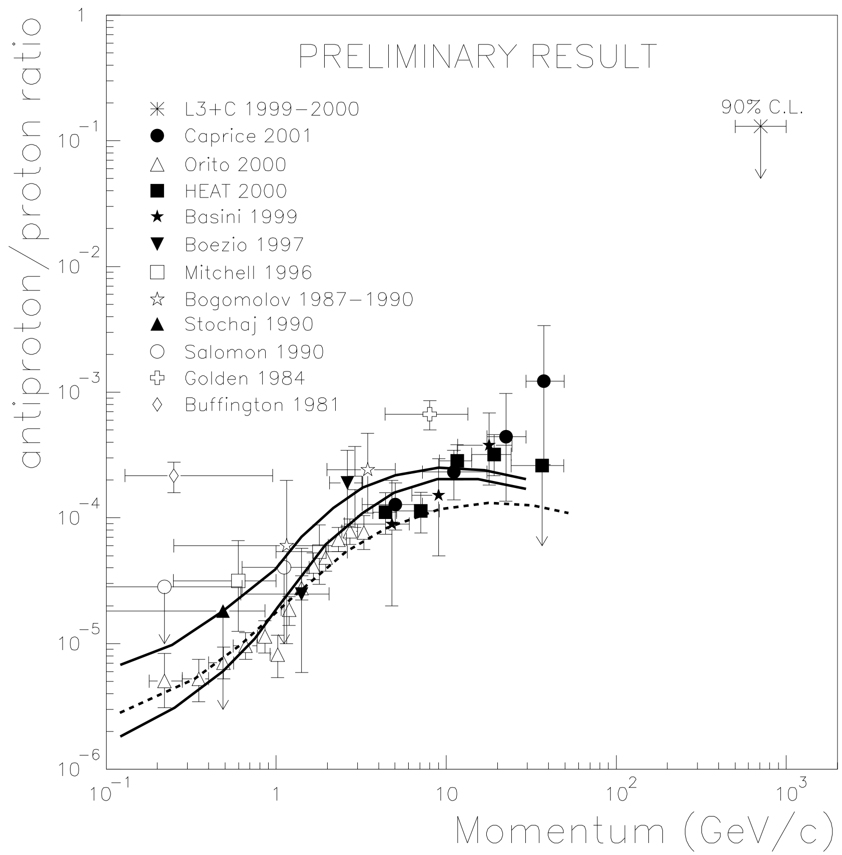
$$f(x,y) = ax + by + c - N[\ G(x_o, y_o, \sigma) + r\ G(-x_o, -y_o, \sigma)\ ]$$

x_o, y_o :offset due to the geomagnetic field.
r :$\bar{p}$/matter ratio.

$\longrightarrow$ Moon shadow observation with 8σ significance

Preliminary measurement: r= -0.14 $\pm$ 0.15 $\longrightarrow$ r< 0.13 with 90 % C.L.

Existing data in $\bar{p}/p$ ratio. L3+C preliminar limit.



L3+C: $\bar{p}/p \leq$ 0.17 (90 % CL)
Expected with full statistics: $<$ 0.1

Summary

- Preliminary results of the measurement of the vertical atmospheric muon spectrum together with the charge ratio and the zenith angle dependence have been obtained. Disagreement with CORSIKA simulation models is found. Introduction of some new features in the reconstruction program that has been totally rerun allowed to recalculate efficiencies and to reduce the systematic errors. Definitive results will be soon available.

- Joint analysis of data from the Air Shower Scintillator Array and μ espectrometer has allowed measurements of electron and muon densities in the energy range 100 TeV to 10 PeV. Comparison with all model predictions present in CORSIKA show large discrepancies in the number of muons, mainly in the forward region.These measurements may improve the understanding of the development of Air Showers in the Atmosphere and the Primary Cosmic Ray composition.The use of other models is planned.

- A significant moon shadow effect has been observed. The good angular resolution of the experiment has allowed to observe clearly the **offset** and the **elongation** of the Moon "muon shadow" expected for the geomagnetic field **for 2 different energy ranges.** A preliminary measurement of the $\bar{p}/p$ **ratio** yields un upper limit of **0.17 at 90% C.L.** for the muon sample with $E_\mu \geq 65$ GeV/c.

- Analysis on the subjets mentioned, but not discussed in this talk is underway.

Thank you for your attention !!