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EMMA

A New Underground Cosmic-Ray Experiment

NANP05 – Dubna, June 2005

Contents

EMMA – Experiment with MultiMuon Array

Introduction of the Experiment

The purpose of the underground multimuon experiment is to study the composition of cosmic rays at the knee region (10^{15} – 10^{16} eV)

- **The aim is to detect high-energy muons formed among the firsts interactions in an air shower, by filtering out low-energy muons with the rock overburden**

- **The setup and the depth are nearly optimised for the primary composition on the knee region**
  ☞ **first dedicated and optimised underground cosmic-ray experiment**

- **Existing caverns and existing detectors are used**
  ☞ **low-cost experiment**

To be carried out in the depth of 85 metres (∼200 m.w.e) in the Pyhäsalmi mine, Pyhäjärvi, Finland.

Status of the Experiment
and Preliminary time table

(1) The prototype is under construction

- **First at the ground for testing, then set-up underground**
- **Small area, about 10m^2**

(2) Full-size detector

- **Simulations have been done from the design of the experiment, and will be performed more**
- **Preparation for underground cavern**
- **Waiting for more detectors**

Time table

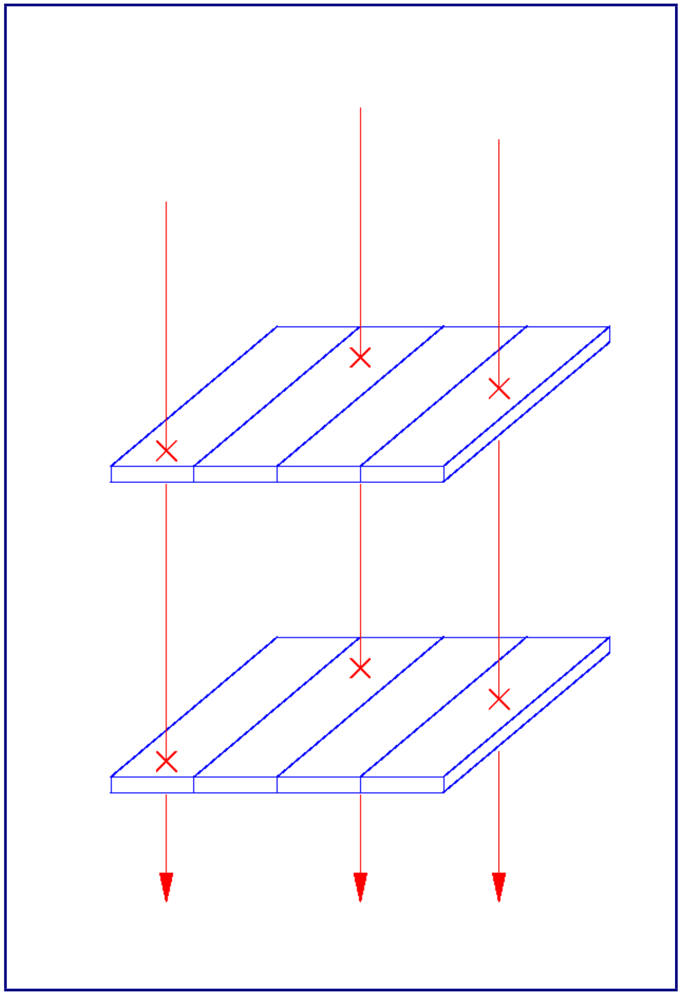
- **Prototype takes data by the end of the year (2005)**
- **Finish the cavern preparations by the end of the year**
- **Testing of the new detectors, and starting up the building of the full-scale detector beginning of 2006**
- **Taking data with the full set-up by the end of 2007**

Experimental Setup

Underground array

DELPHI Muon Barrel Chambers (MUB)

- **Position sensitive detectors. Area of one planck about 3 m^2**
- **We have 10 planks. They have been thoroughly tested.**
- **Prototype: 6 plancks**
- **Full set-up: Area of about 200 m^2 (three units of 50–60 m^2)**
- **Rest of the MUB's (around 80) should arrive during this summer/autumn**



Surface array

- **Small surface EAS-array will probably be used: 16 1-m^2 plastic scintillators (INR-Moscow)**

The Depth

The most interesting energy range of muons is roughly between 50 GeV and 100 GeV

- **at higher energies the statistics gets smaller**
- **at lower energies muons could not be confidently detected (too many muons)**

✓ **The vertical depth of about 70 metres of rock (∼200 m.w.e) filters out muons with energy lower than $E_\mu \approx$ 50 GeV**

✓ **About 150 metres of rock (∼400 m.w.e) cuts-off muons with energy lower than $E_\mu \approx$ 100 GeV**

☞ **The range in vertical depth (of rock): 50 – 150 metres (shallow depths)**

> **In the mine, there are free and empty caverns at the depth of 85 metres (210 m.w.e) and 210 metres (480 m.w.e)**

Energy Threshold
and Selection of the Depth

Passing of muons in the rock was simulated using Geant4

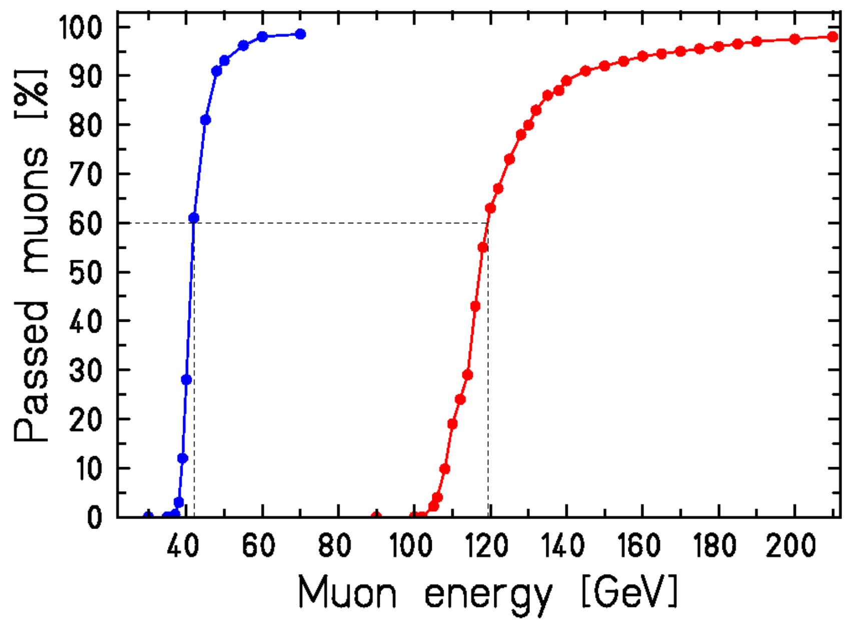
- **rock properties known (ρ_{ave} = 2.85 g/cm^3)**
- **rock modelled in 3D with holes and caverns included**

☞ **Cut-off energies (60%):**
42 GeV (85 m) and 120 GeV (210 m)

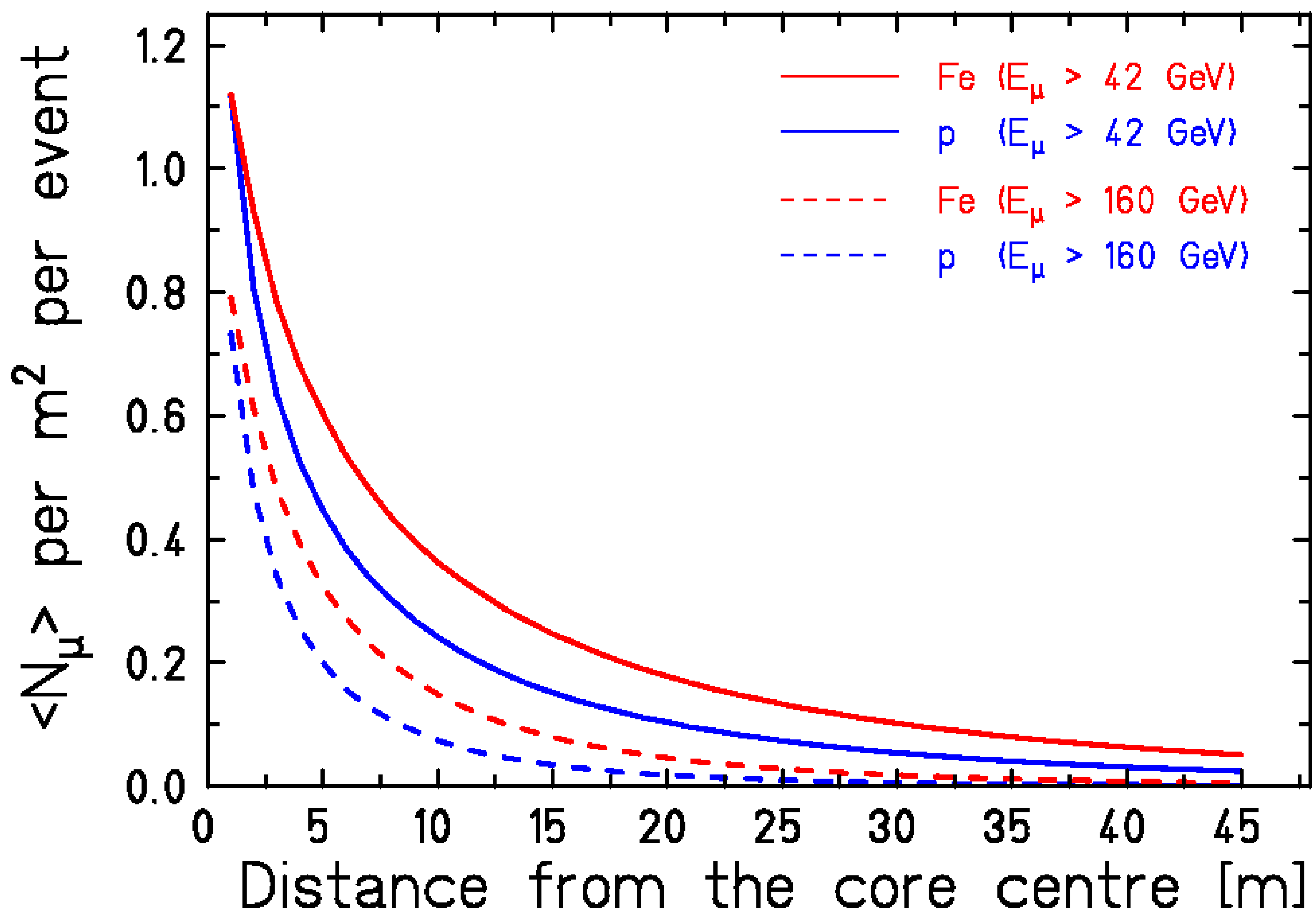
In the depth of 210 m (versus 85 m):

- **the separation of muon densities would be better**
- **the statistics would be much worse**
- **the energy threshold also quite high**

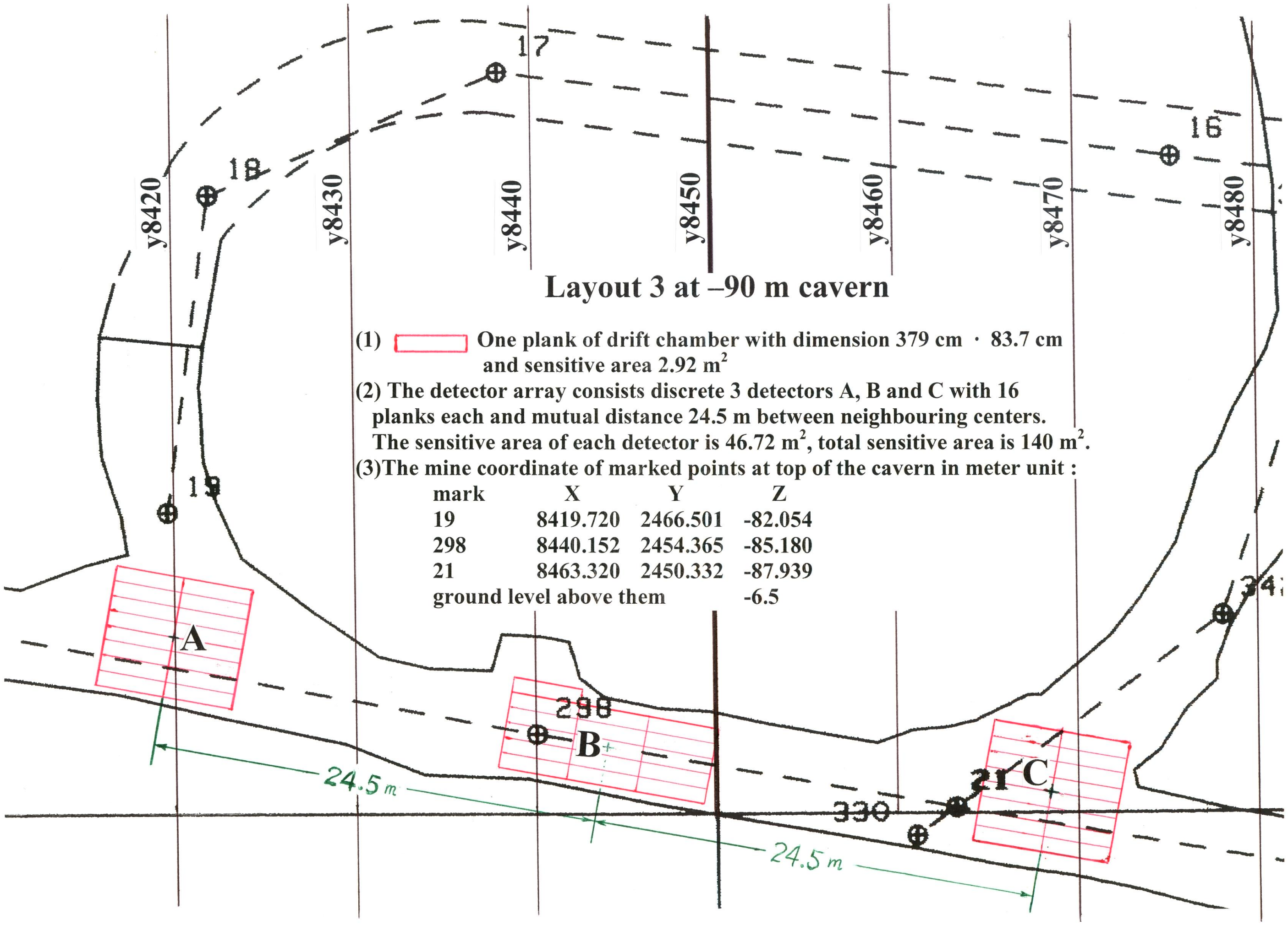
☞ **The detector is set-up at the depth of 85 metres.**



Muon LDF


Fe (E$_\mu$ > 42 GeV)
p (E$_\mu$ > 42 GeV)
Fe (E$_\mu$ > 160 GeV)
p (E$_\mu$ > 160 GeV)
<N$_\mu$> per m^2 per event
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
5
10
15
20
25
30
35
40
45
Distance from the core centre [m]

Detector Layout
at the depth of 85 metres



Selection Criteria for the Knee Region

Preliminary simulations

- **Air-shower simulations with Corsica**
- **Selected:**
  - ✓ **Depths 85 m and 210 m (Thresholds: $E_\mu > 50$ GeV and $E_\mu > 160$ GeV).**
  - ✓ **Detector area 50 m^2 (of one unit).**
- **Two detector stations**
  - ✓ **the central detector: more muon hits (N_c)**
  - ✓ **the outer detector: the other detector (N_o)**

(1) Determination of energy

- **the total number of hits, $N = N_c + N_o$**
- **using surface array (optional)**

(2) Determination of primary particle

- **using the gradient of the lateral distribution function:**

$$p = \frac{N_c - N_o}{N_c + N_o} \qquad \text{or} \qquad W = \frac{N_c}{N_o}$$

Selection Criteria for the Knee Region
(1) Energy Determination

- **Underground Array (50 m^2, depth 85 m):**

Core dist. [m]	Primary Cosmic-Ray Energy: **0.5 GeV** Dens. [m^{-2}]	N_μ	**1 GeV** Dens. [m^{-2}]	N_μ	**Knee** Dens. [m^{-2}]	N_μ	**10 GeV** Dens. [m^{-2}]	N_μ	**20 GeV** Dens. [m^{-2}]	N_μ	
5	0.117	5.9	0.224	11.2	0.410	20.5	1.84	92	3.47	173	p
	0.141	7.1	0.292	14.6	0.566	28.3	2.57	128	4.87	243	Fe
22	0.023	1.2	0.043	2.2	0.075	2.5	0.309	15	0.571	29	p
	0.043	2.2	0.079	4.0	0.138	6.9	0.551	28	0.990	50	Fe

The energy selection in the knee region:
Number of muons in the central detector: 10 $<$ N$_\mu$ $<$ 60
☞ **Accuracy: the knee region (a decade with 1 to 3 bins)**

- **Surface Array:**

☞ **Accuracy: about 20%**

Shower-core distribution

Simulated 10000 proton- and iron-initiated air showers at the knee energy

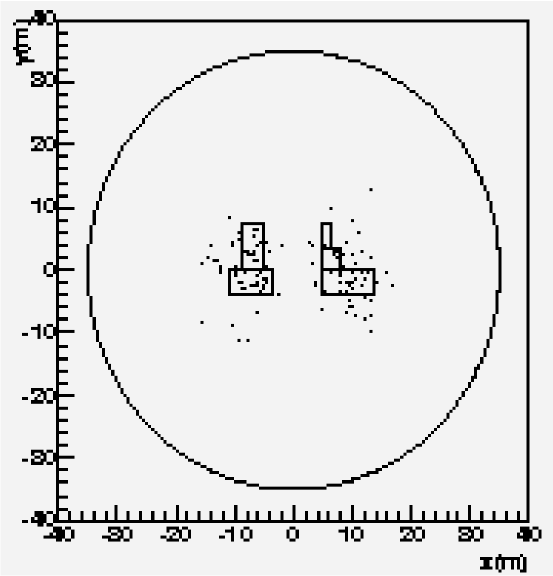
Depth 210 metres

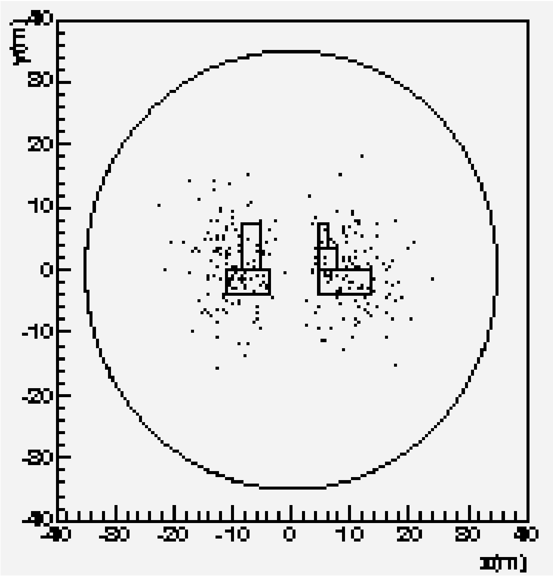
Selection criteria:

- **Number of muons in the central detector: $10 < N_\mu < 80$**
- **Density ratio: $p > 2/3$**

Selected:

- **216 proton-initiated showers (top)**
- **432 iron-initiated showers (bottom)**





Selection Criteria for the Knee Region

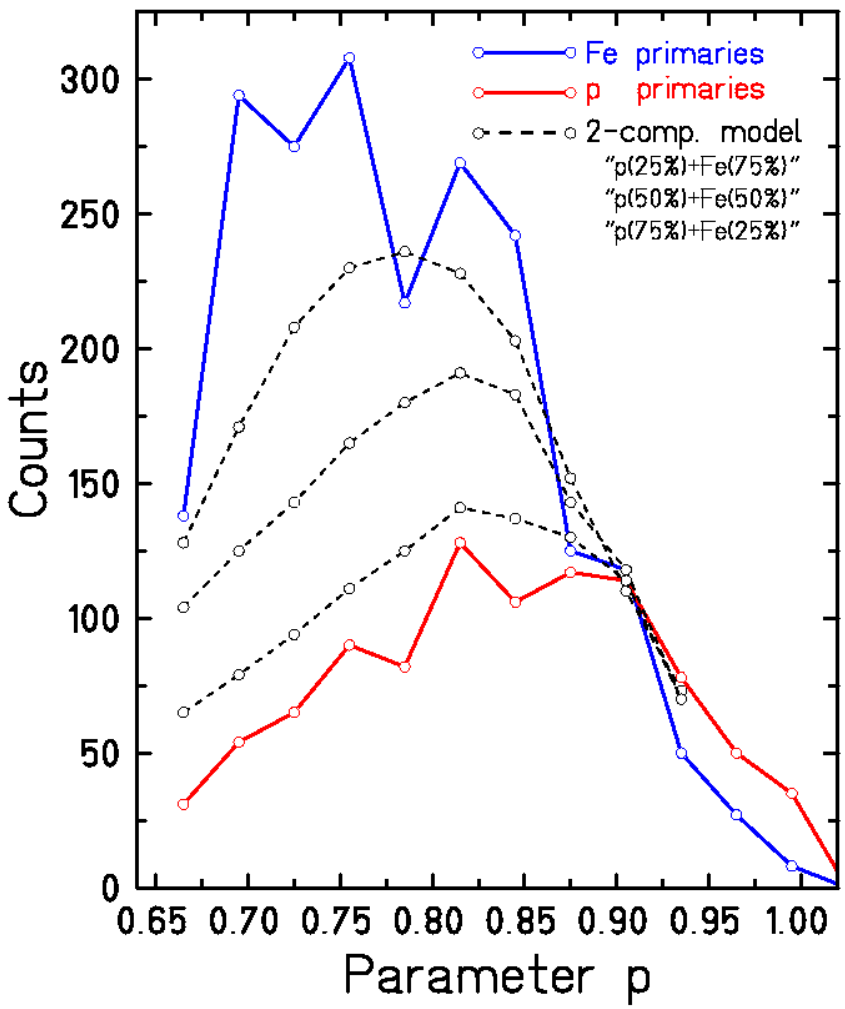
(2) Primary-particle Determination, Two-component Model

Simulation at 210 metres, above the knee

A measured curve (composition) should be located in between the proton and iron curves

One year running (1σ stat. uncertainty):
$<$ln A$>$ = 2.01 $\pm$ 0.10 (1 – 3 PeV)
$<$ln A$>$ = 2.01 $\pm$ 0.17 (3 – 10 PeV)

$<$ln A$>$ = $\sum$ r$_i$ lnA$_i$
p (0.75) + Fe (0.25) $\longrightarrow$ $<$ln A$>$ = 1.01
p (0.50) + Fe (0.50) $\longrightarrow$ $<$ln A$>$ = 2.01
p (0.25) + Fe (0.75) $\longrightarrow$ $<$ln A$>$ = 3.02



Conclusions

- **The prototype detector of the underground multimuon experiment is under construction**
- **Prototype detector starts running underground around January 2006**
- **The full-size detector (∼200 m^2) could start running by the end of 2007**
- **From the simulations we believe that, from statictical view, about two-year running at the depth of 85 metres could give some new information on the composition of cosmic rays in the knee region**

Personnel and Collaborators

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