CosmoLEP

An underground cosmic ray muon experiment in the LEP ring

K. Eggert
CERN

- Targets
- Physics motivation
- Why muons?
- History
- Cosmics in ALEPH detector
- The proposed muon array
- Performance simulations
- Schedule and Milestones
- Budget

CosmoLEP

an underground cosmic ray muon experiment in the LEP ring

Study of high-multiplicity muon bundles using the ALEPH detector complemented by a large area muon chamber array

High precision, large acceptance detectors (new in cosmic ray physics) are ideal for the study of

multi-muon bundles

Aleph:

- high precision, large area (16 m^2) TPC with excellent particle resolution and pattern recognition
- angular resolution: $\sim$ 1 mrad
- momentum resolution: $\sim$ 5-10% at 100 GeV
- hadron barrel calorimeter (50 m^2) with particle tracking
- outside muon chambers

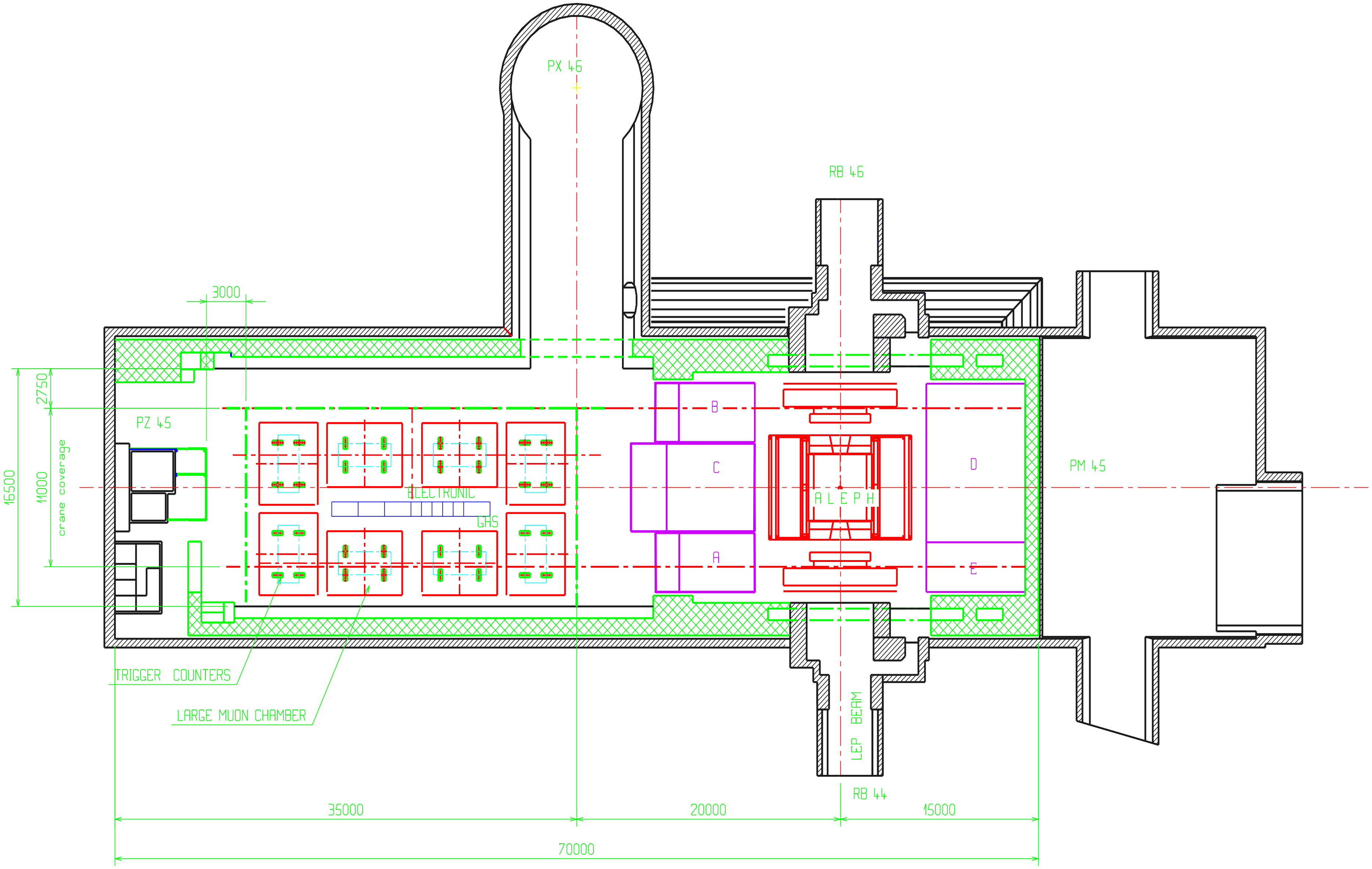
Ideal location for muon measurements (140 m underground)

- complete absorption of the electromagnetic and hadronic components of the cosmic ray air shower
- $p_\mu > 70$ GeV (other underground exp. $\sim$ 1 TeV)
- small multiple scattering (few mrad)

Underground areas along the circumference ($\sim$ 30 Km) of the LEP tunnel

- Time coincidences over large distances between LEP experiments (6 Km) and further stations

The proposed muon array close to the ALEPH experiment



Physics motivation

Origin of cosmic rays: galactic and extra-galactic acceleration

The primary particle spectrum and the particle composition of cosmic rays, in particular around and above the "knee" ($\sim 3{\cdot}10^{15}$ eV), give hints to the acceleration mechanism of cosmic rays.

Composition at 10^{14} eV (directly measured e.g. by JACEE balloon exp.) favours light elements.

Above the "knee" a trend to heavier elements, like Fe, is expected.

Particle composition data above 10^{14} are not consistent.

Forward particle production is almost unknown and extrapolations are difficult (model dependent).
The "knee" region corresponds to TEVATRON energies complicated via nucleon-nucleus, nucleus-nucleus and pion-nucleus interactions.

Anomalies have been frequently reported:

Centauro and Anti-Centauro, Disoriented Chiral Condensates (DCC) see e.g. direct observation by JACEE experiment.

Search for point-like sources

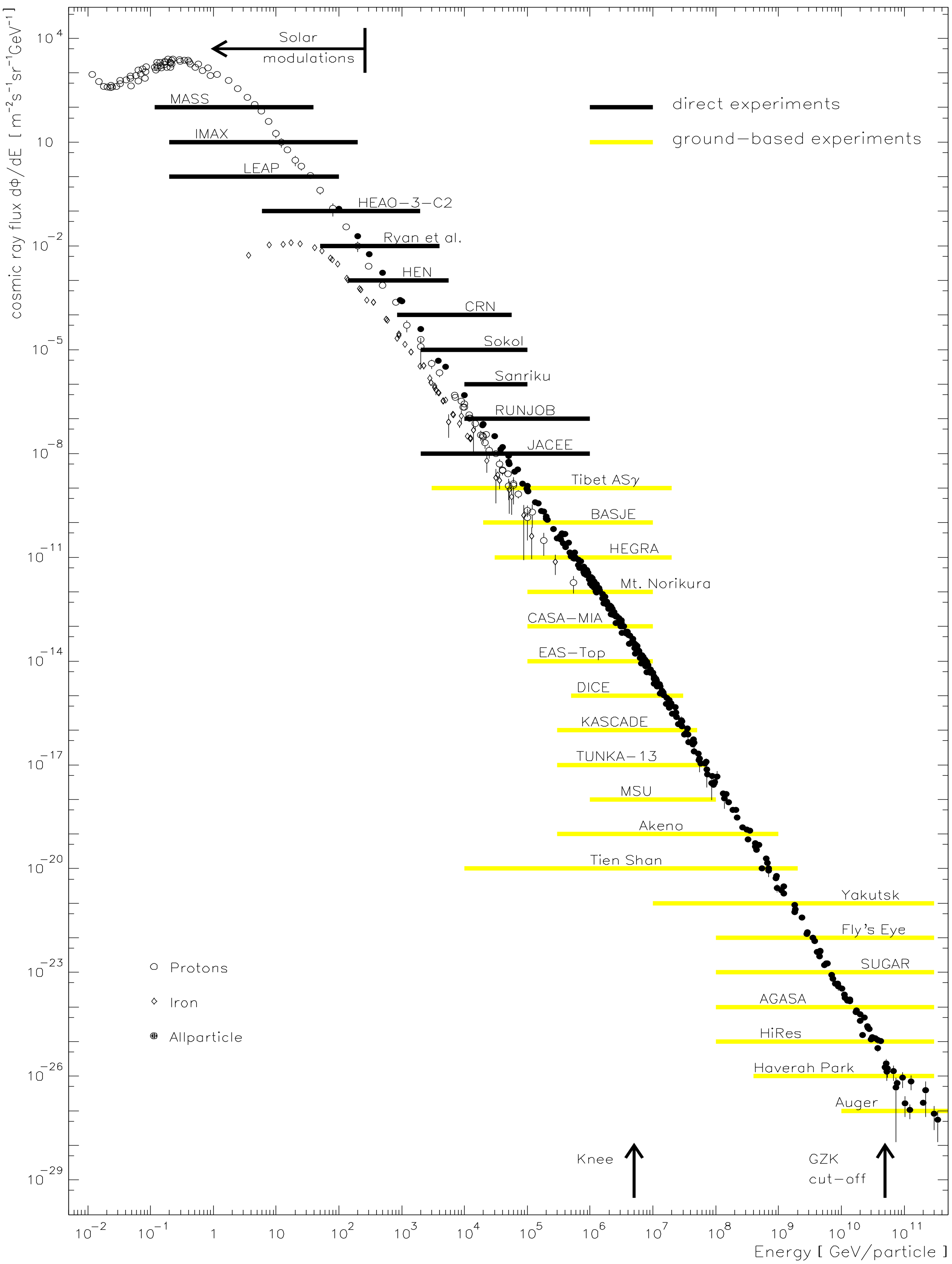
Angular resolution for muon bundles is around a few mrad

Large distance muon showers

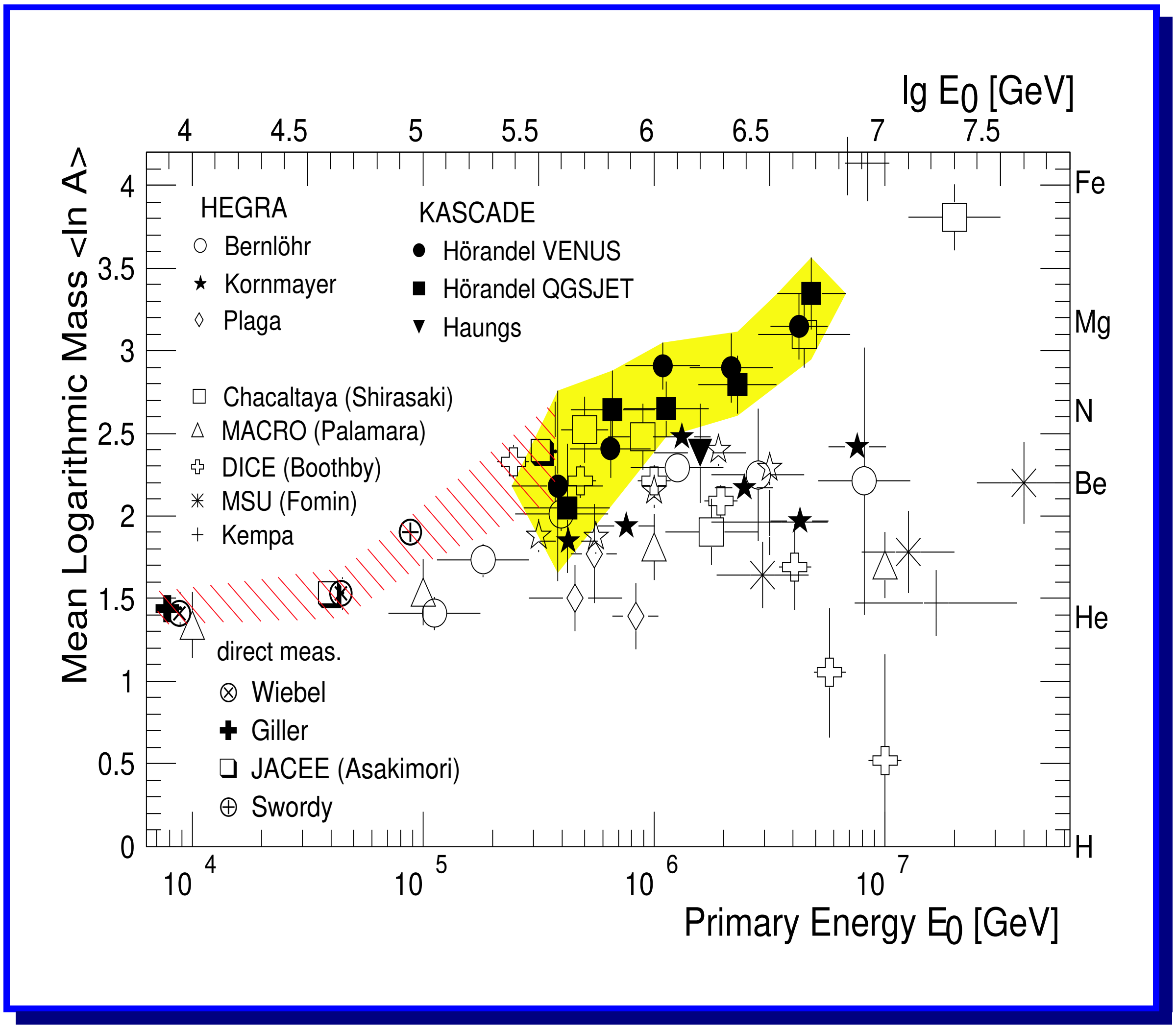
extra-atmospheric radiation and cosmic beam dumps

energetic cosmic dust grains, partially disintegrated at large distances

Energy spectrum of primary cosmic rays



Particle composition of cosmic rays



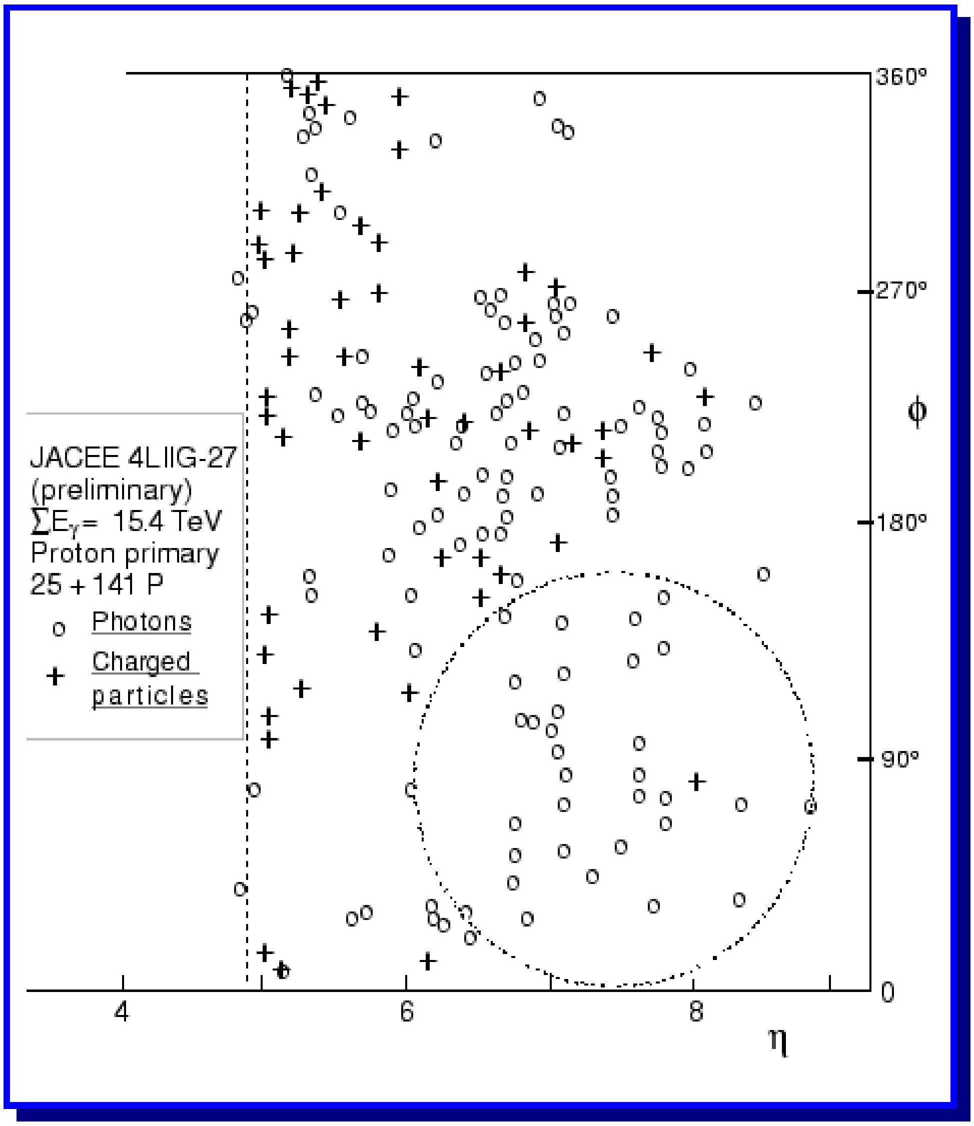
at $E = 10^{14}$ eV (JACEE balloon exp.)

p(1)	He(4)	C-N-O(14)	Ne-Si(24)	Fe(56)
24%	31%	21%	12%	12%

at energies above the “knee” ($> 3 \cdot 10^6$ GeV)
the data are not consistent

$\Rightarrow$ **Further measurements are needed**

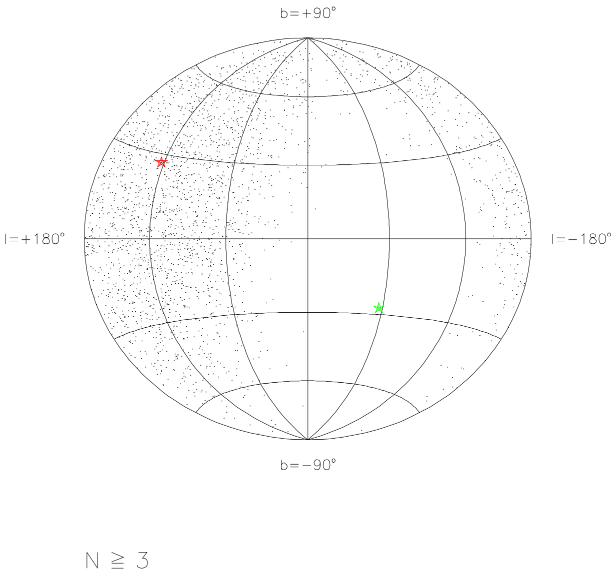
A high multiplicity event observed by the JACEE balloon-borne emulsion experiment

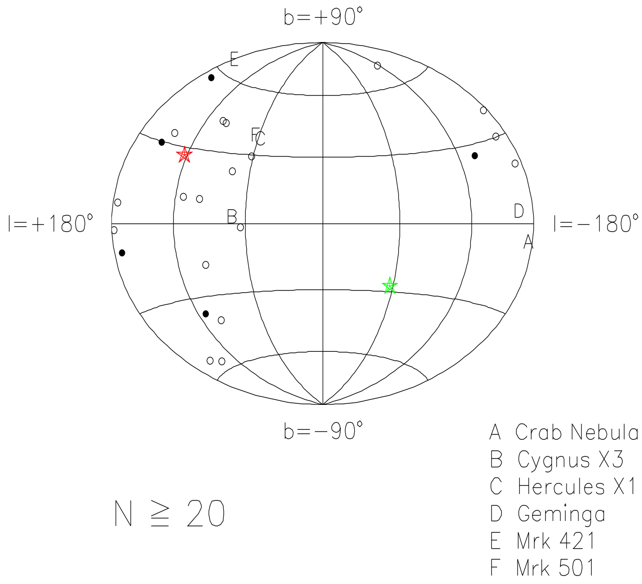


$$\eta = -\ln\tan\theta/2 \ \ (\theta : \mathrm{product.angle})$$

An anomalous concentration of photons has been observed in a limited range of phase space (Anticentauro).

Point-like sources





Apparent origins of the events on the sky in galactic coordinates for multiplicities N≥3 and N≥20.

Filled circles:	five highest multiplicity events
Asterisks:	Celestial North and South pole
A-F:	Some important gamma ray sources (A-D: galactic, E-F: extragalactic)

Muons probe the primary interaction

Muons transport the information of the first interaction through the atmosphere.

Electromagnetic cascade is more calorimetric in nature and less sensitive to model uncertainties, important for establishing the energy spectrum.

Muons of different momenta trace details of the cosmic ray cascades at different heights depending on the muon momenta.

E(pion)$\sim$ 100 GeV:
interaction and decay probabilities are equal at the start of the cascade (height 20-30 Km), most sensitive to the primary interaction.

E(pion)$\sim$ 2000 GeV:
very small part of the phase space, decay probability is low

E(pion)$\sim$ few GeV:
probing the end of the cascade, more calorimetric

Other muon experiments

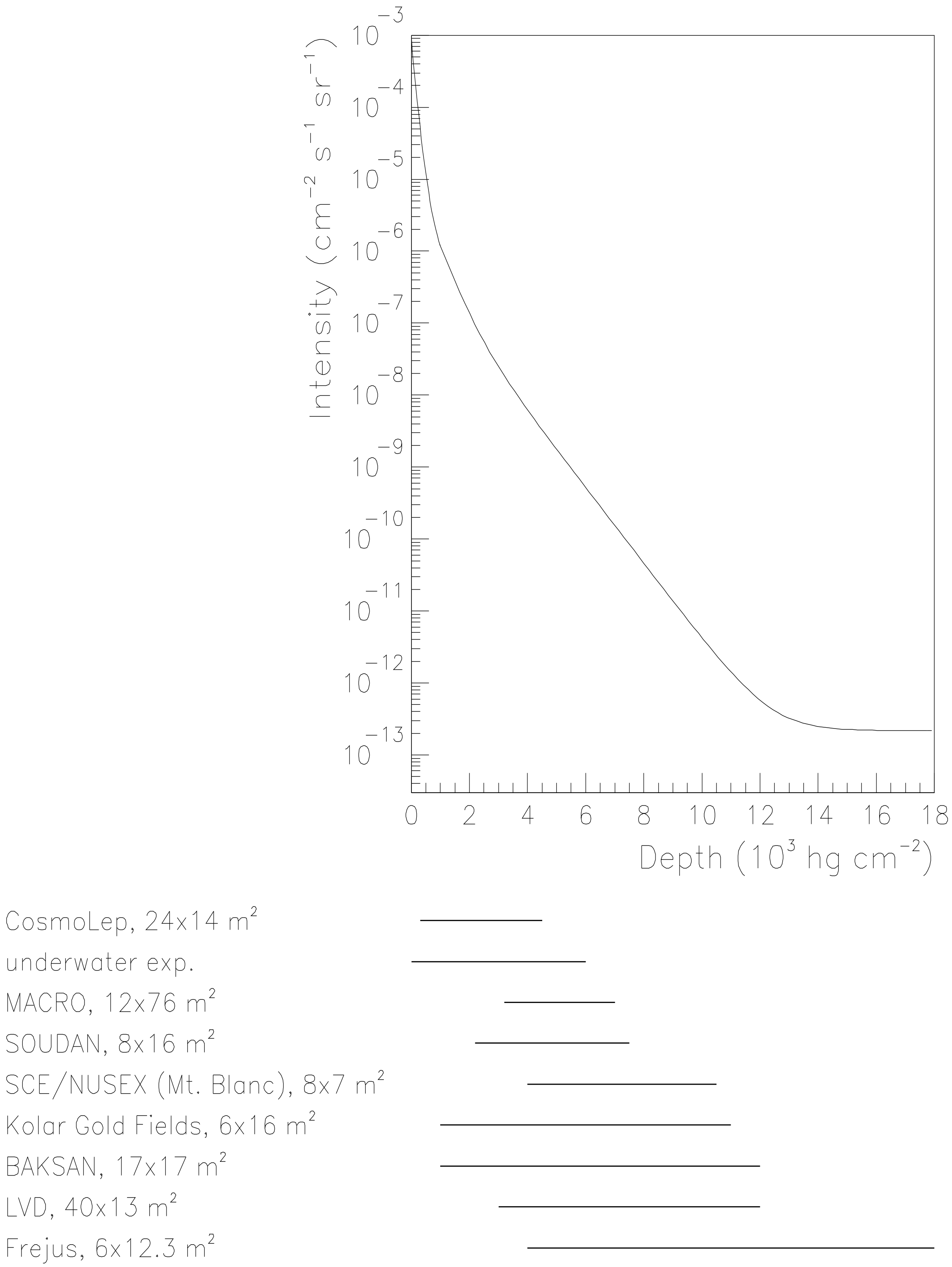
Surface experiments with GeV cut-offs: KASCADE, HEGRA, CASA-MIA, MSU,....

Deep underground experiments with TeV cut-offs: MACRO, LVD, FREJUS, SOUDAN, BAKSAN and UNDERWATER EXP.

CosmoLEP (p$_\mu > 70$ GeV) is in the right range

To better understand the interplay between particle composition and interaction models, the information of all experiments has to be combined and confronted with the various models

The muon flux measured by underground experiments



History of CosmoLEP

The use of large underground detectors at CERN has been proposed by several groups in the past:

O.C. Allkofer, K. Eggert, P. Erhard et al. *"The UA1 detector as a possible cosmic ray device"*,
Proc. 17th Int. Cosmic Ray Conf., Paris, **10** (1981) 401
H. Wachsmuth, *"Proposal to search for Cosmic Ray coincidences in the LEP detectors "* draft, 16.Dec.1993 (CosmoLEP-note 94.000)
A. Ball, G. Bonvicini,C. Grupen, et al. CERN/LEPC 94-10, LEPC/M 109 (1994)
P. Le Coultre, L3C collaboration, Proceedings of the 25th Int. Cosmic Ray Conf., Durban, South Africa, Vol. 7, p. 305.

"L3+Cosmics Experiment" in "Experiments at CERN in 1998"

1993: CosmoALEPH has been proposed by H. Wachsmuth
Feasibility study for CosmoLEP with additional stations around ALEPH (agreed by LEPC and the Research Board) to search for time coincidences over large distances

1998: L3C, a cosmic ray experiment taking data in parallel with L3 (recognized experiment at CERN)
Active data taking with an L3 independent read-out, using a dedicated counter array on the top of the L3 experiment for triggering. Participation on large distance coincidences via GPS time marks

1998/99: the CosmoLEP group analyzes the multi-muon cosmic data of ALEPH, taken during the LEP runs and in dedicated cosmic runs

The results of the ALEPH cosmic data have led to this proposal

Interest of the other LEP experiments in cosmic data (DELPHI) and in large distances coincidences (OPAL).

European wide coincidences measurements via GPS time marks, involving the HERA experiments (H1,ZEUS) and KASCADE in Karlsruhe and perhaps others.

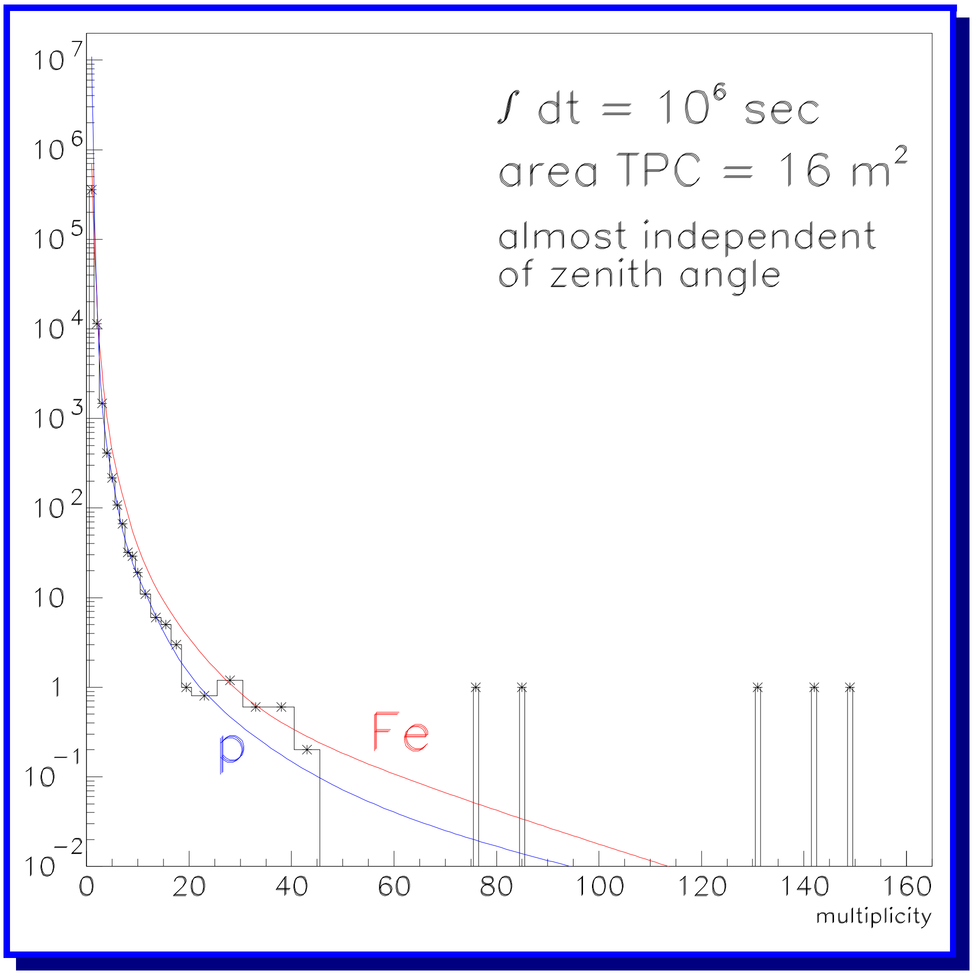
Input for the CosmoLEP proposal

- Measurements with the ALEPH detector
  - during LEP runs $\int dt = 10^6$ sec
  - dedicated cosmic runs $\int dt = 0.5 \cdot 10^6$ sec

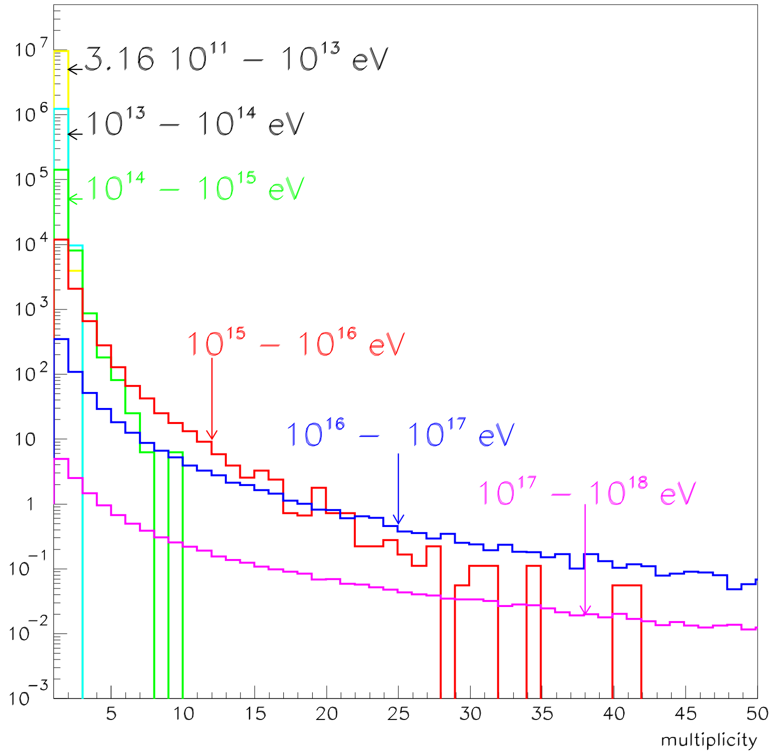
- Measurements of time coincidences over large distances by the CosmoALEPH group

- CORSIKA air shower simulations
  - interaction model QGSJET
  - comparison with other models
    * VENUS
    * DPMJET
    * SIBYLL
  - For simplicity compare p and Fe induced showers

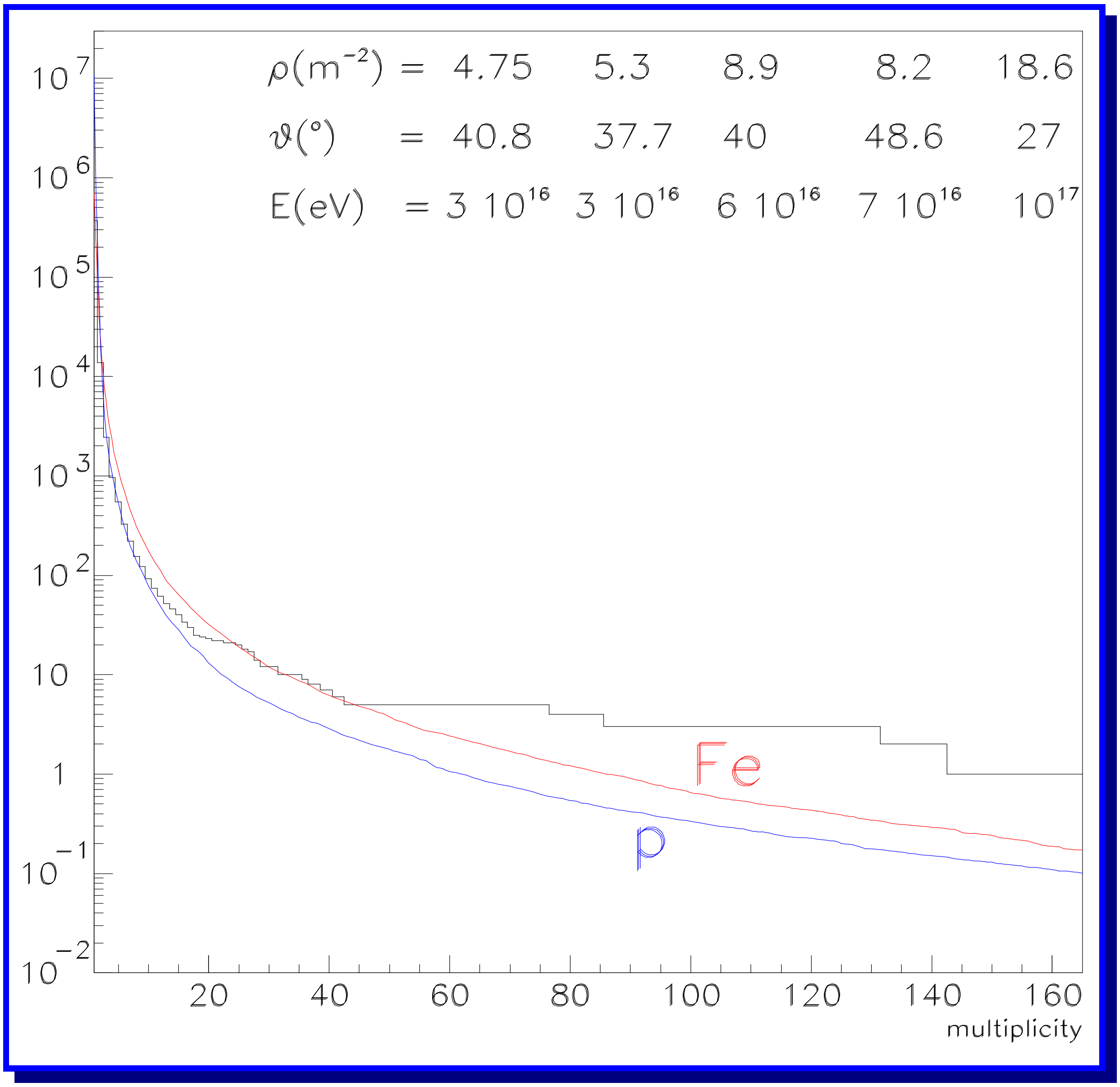
Differential muon multiplicity distribution (TPC)



Contribution of primary energy intervals (protons)



Integral muon multiplicity distribution (TPC)



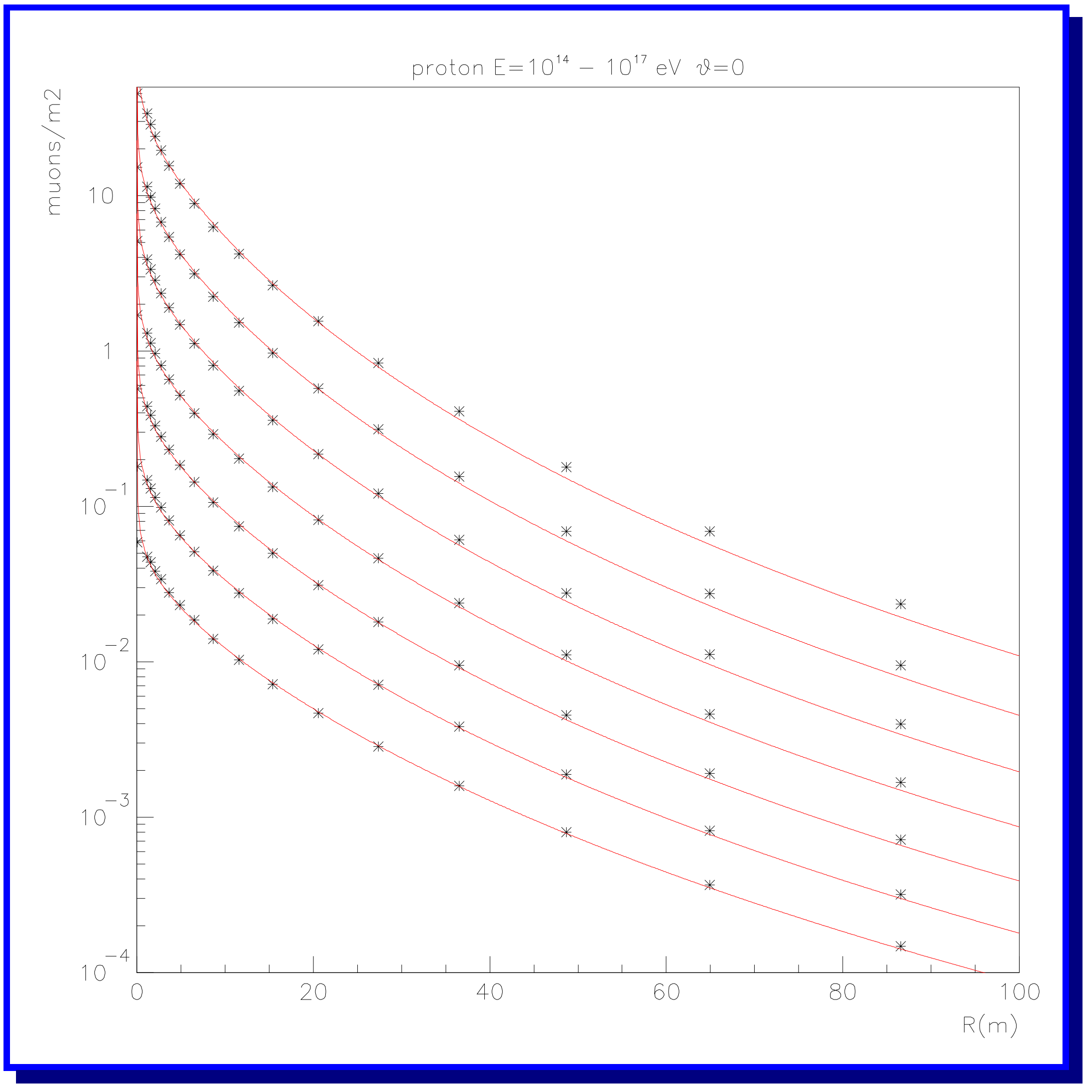
Data from the 1997/98 LEP runs

$\int dt = 10^6 sec$

p,Fe curves form CORSIKA Monte Carlo.

The energy of the highest multiplicity events has been calculated assuming the shower center close to the TPC

Muon lateral distribution



E= $10^{14}, 3 \cdot 10^{14}, 10^{15}, \ldots\ldots, 10^{17}$ eV

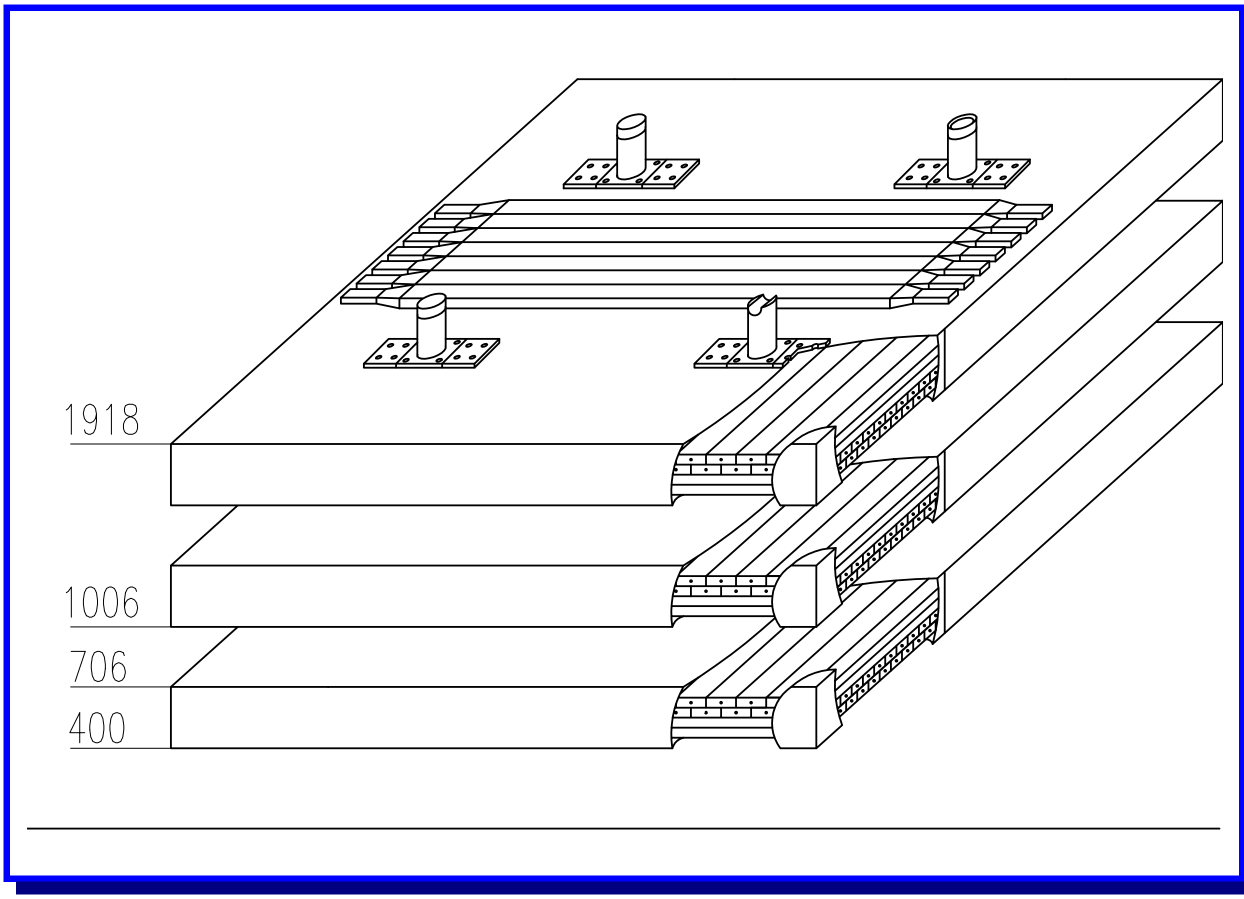
Fit function (à la Greisen):

$$\rho(r, E, \theta = 0) = P_1 \left(\frac{r}{P_2}\right)^{-0.3} \left(1 + \frac{r}{P_2}\right)^{-5.1}$$

central density :

$$\rho(r = 1m, E, \theta = 0) \approx 7 \cdot 10^{-7}\, E^{0.96} (GeV)$$

Muon chamber module



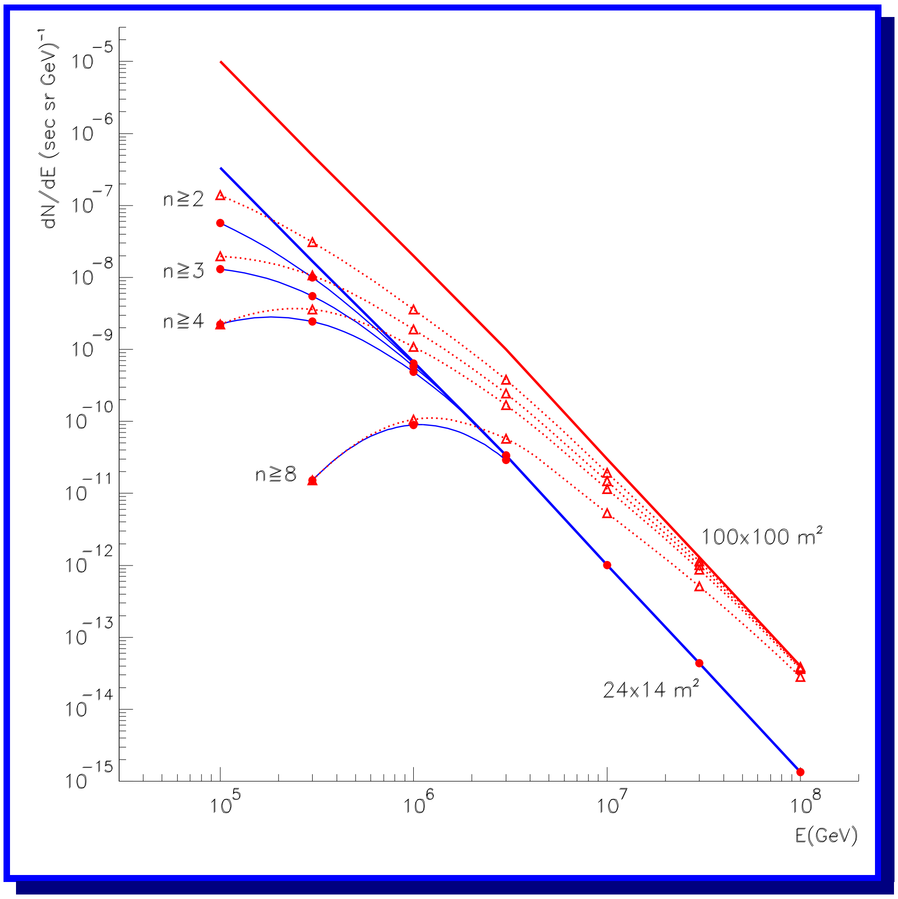
Large area (20 m^2) drift tube chambers (UA1)

non-flammable gas mixture :	90% Ar / 10% CO_2
resolution :	$\leq$ 1 mm
two particle separation :	$\sim$ 5 mm
read-out capacity:	16 hits/wire

Trigger counters (from Padova) cover $\sim$ 20% of the chamber area

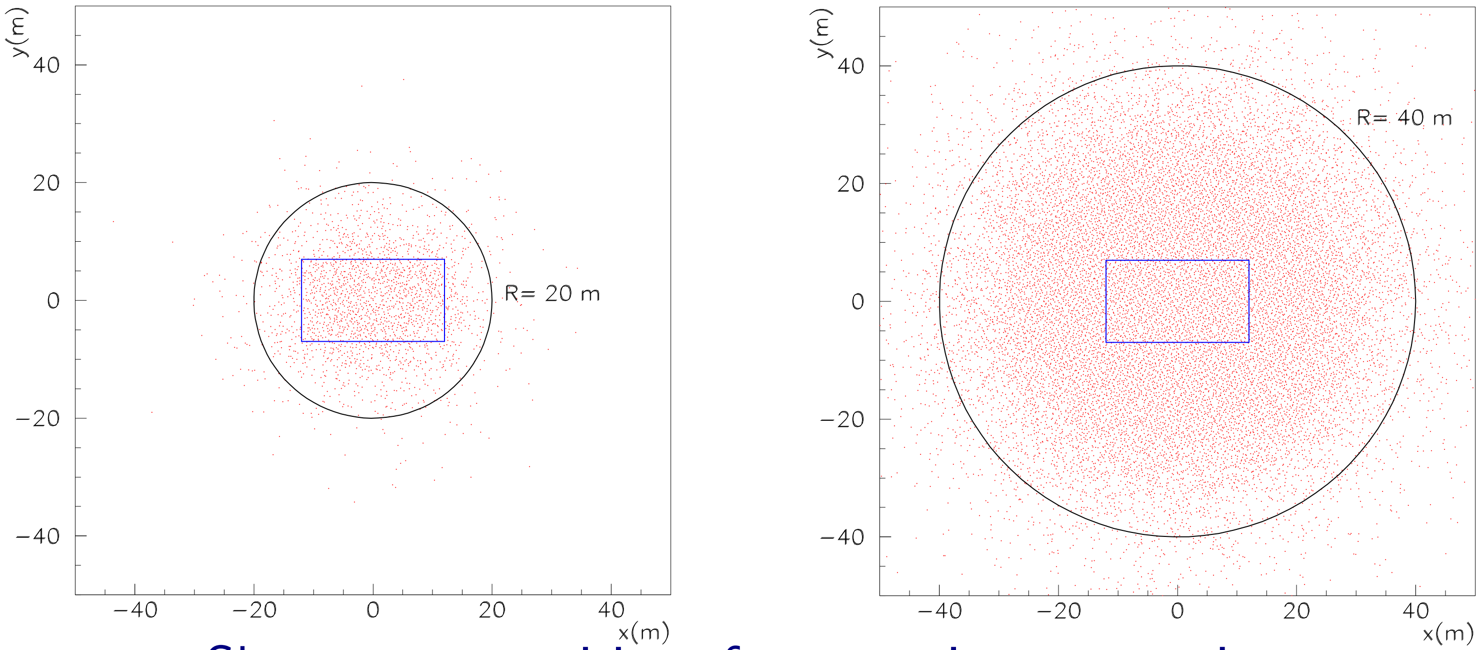
Trigger: n-fold coincidence between all counters

Effect of the n-fold coincidence trigger on the primary spectrum (protons) for two areas



E= 10^6 GeV

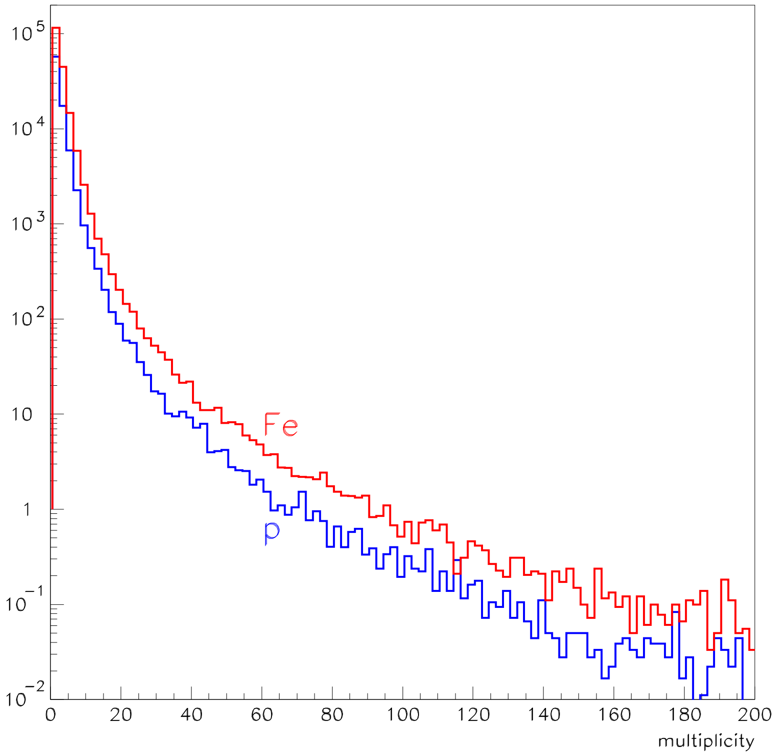
E= 10^7 GeV



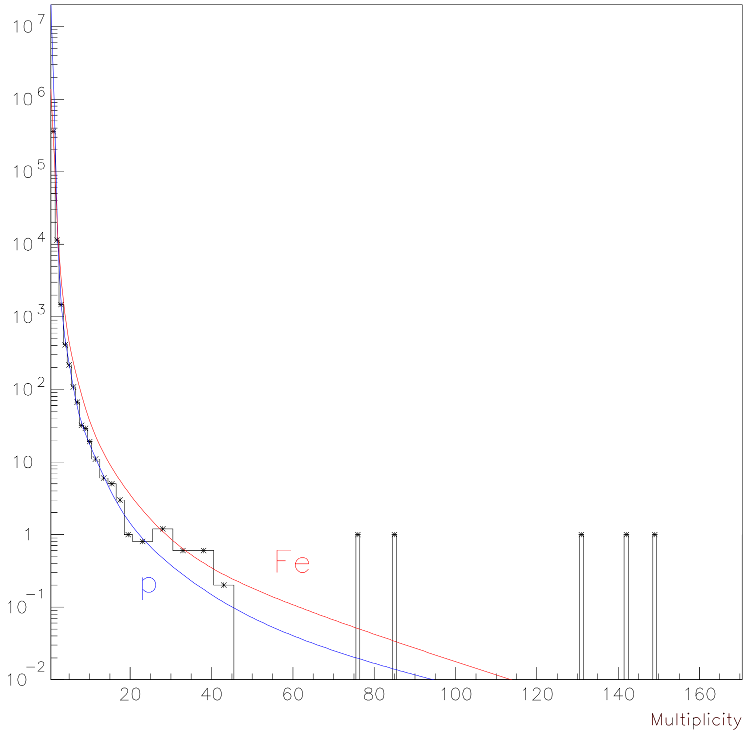
Shower core positions for two primary energies

A 4-fold coincidence was required as a trigger

Multiplicity distribution



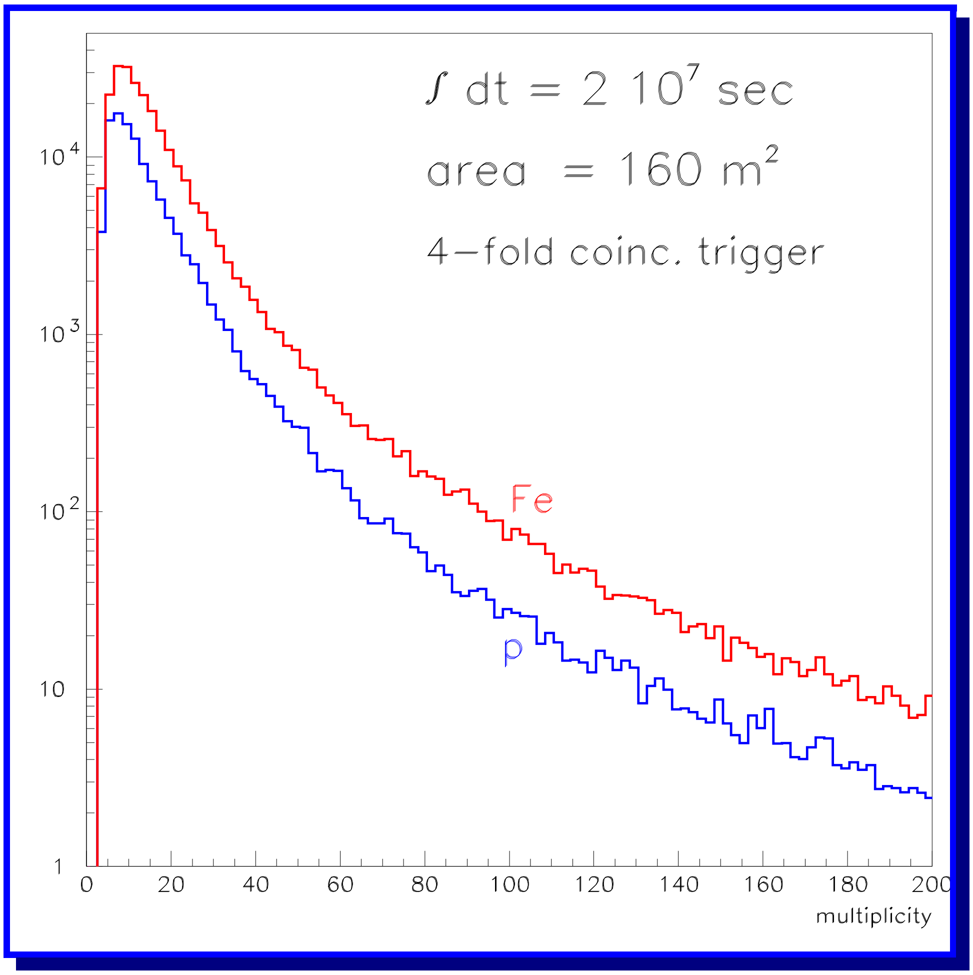
In one module (20 m^2) for a running time of $2 \cdot 10^7$ sec and 4-fold coincidence trigger



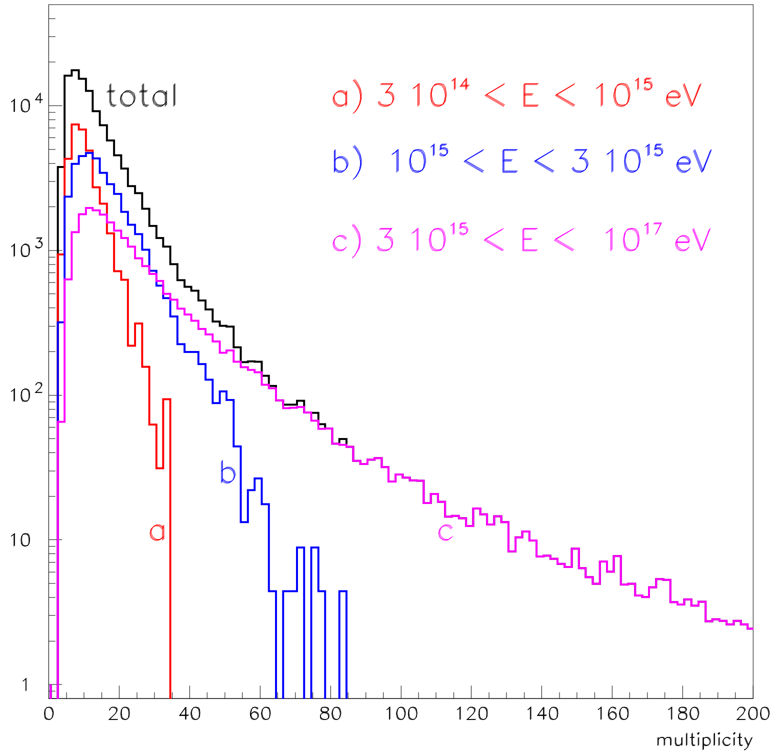
compared to the TPC (16 m^2) and a running time of 10^6 sec

Increase in statistic $\sim$ 200 (10 from area, 20 from 1 year running time)

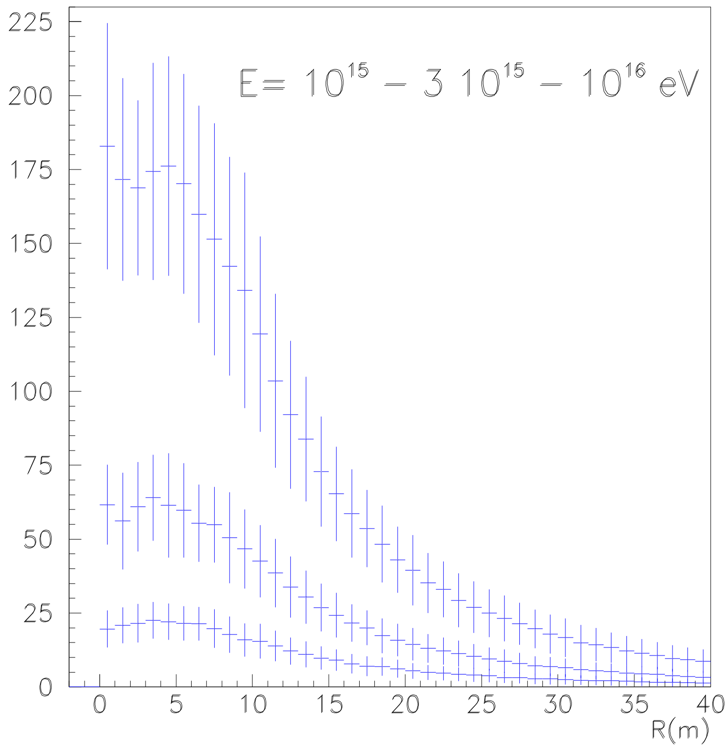
Differential muon multiplicity distribution (array)



Contribution of primary energy intervals (protons)

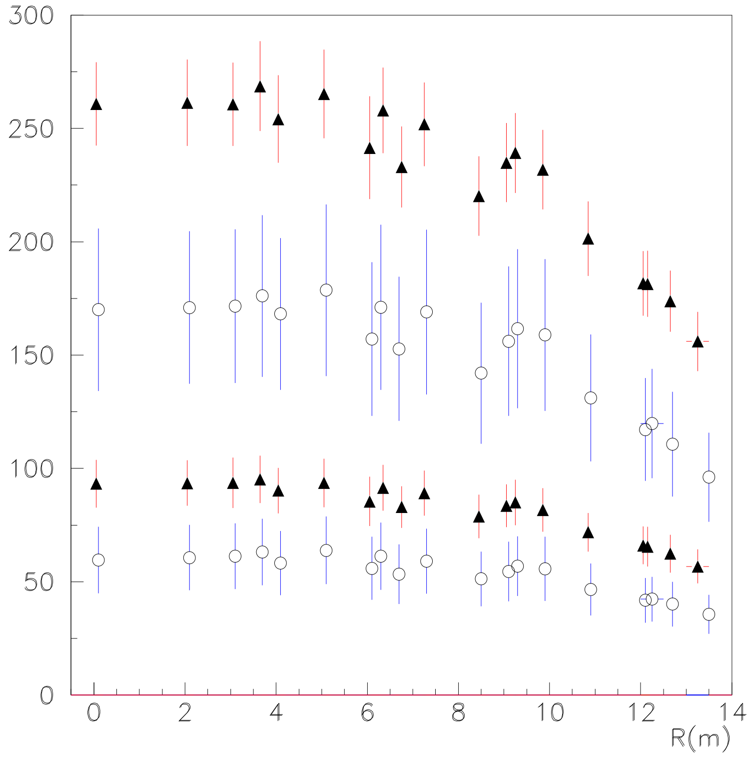


Total multiplicity (array)



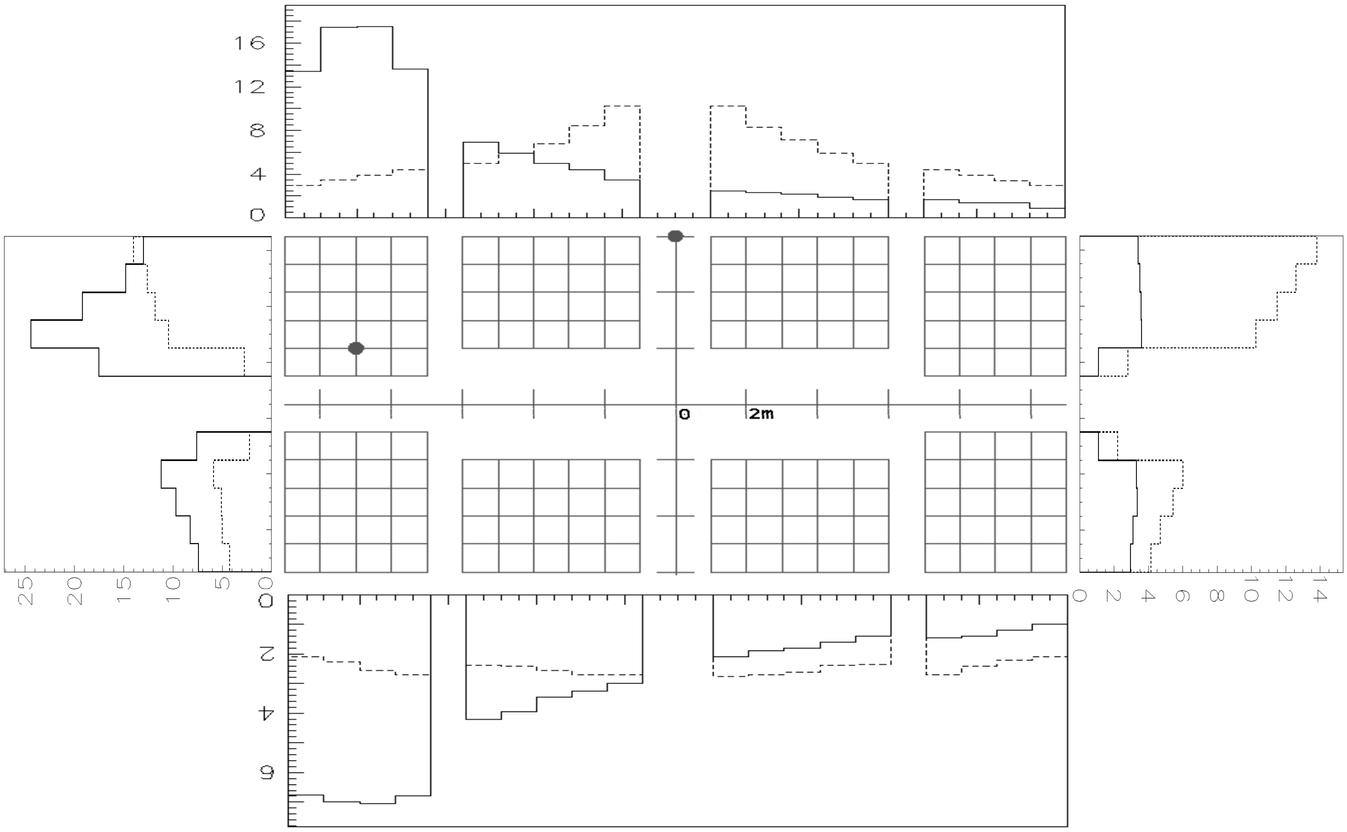
Total number of muons is almost constant for distances R< 6 m from the array center and decreases with larger R. (for protons)

Comparison of proton (open circle) and iron (triangles) induced showers
E= $3{\cdot}10^{15}$ and 10^{16} eV



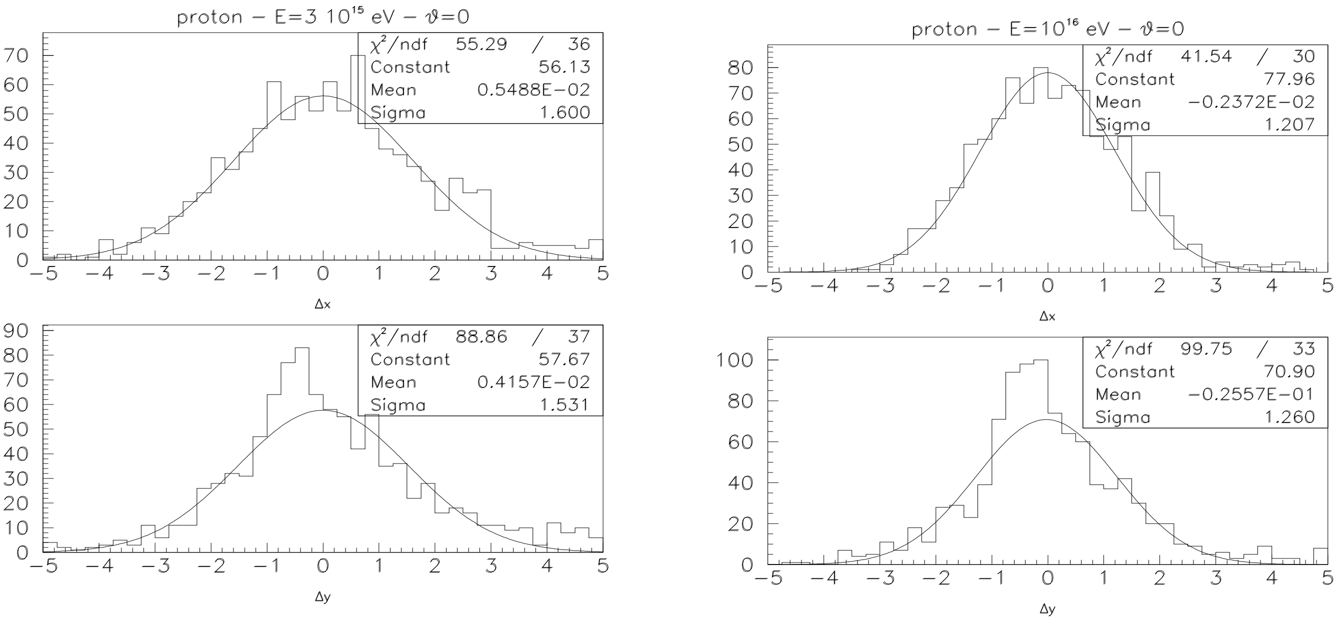
Reconstruction of muon bundle core

Muon shower profile for two core positions (protons, E$=10^{16}$ eV)

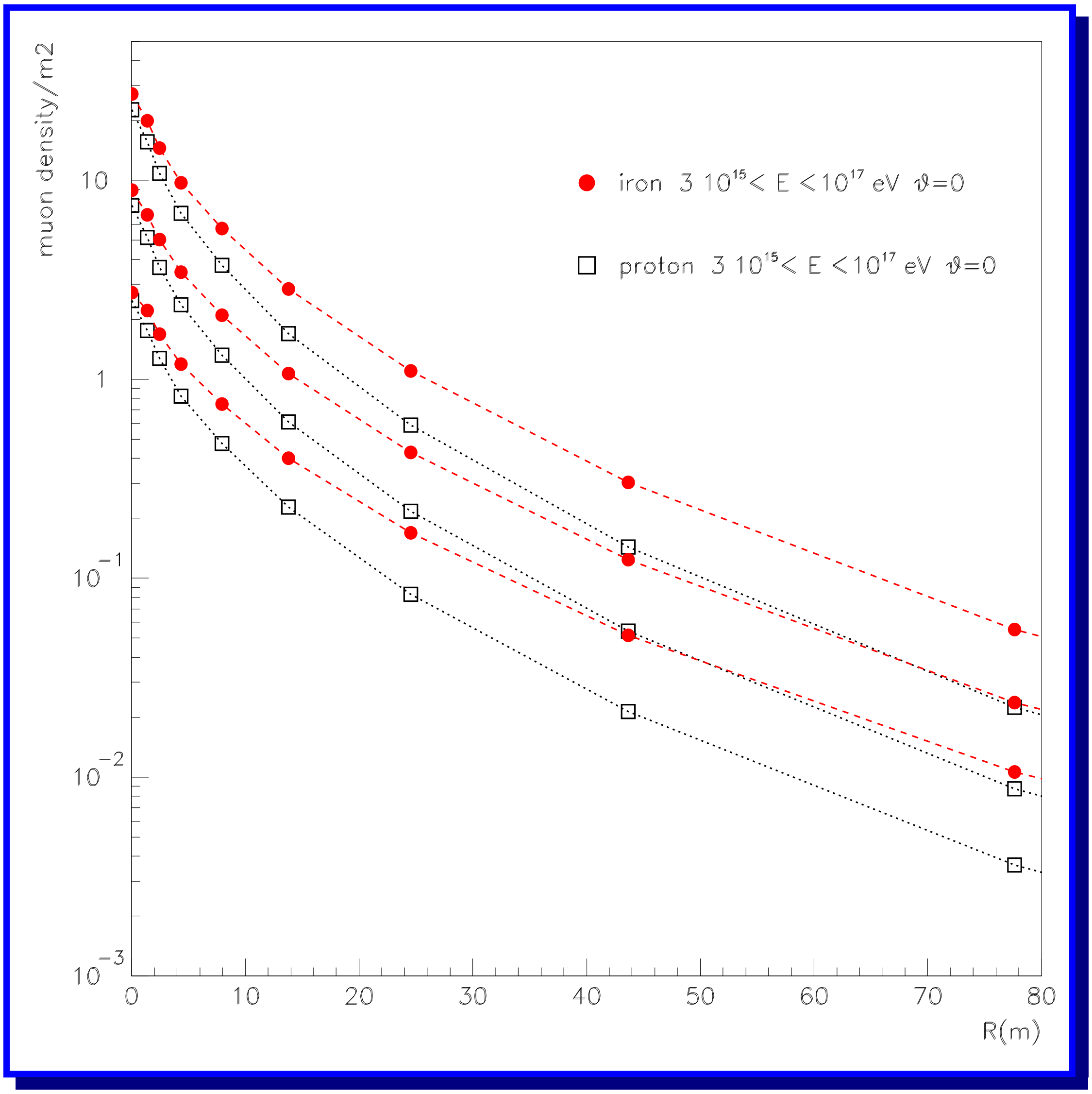


Accuracy of core determination

$\sigma \sim 1.5(1.2)$ m for E$_p$ $= 3 \cdot 10^{15}(10^{16})$ eV



Lateral muon-density distribution
for p and Fe induced showers



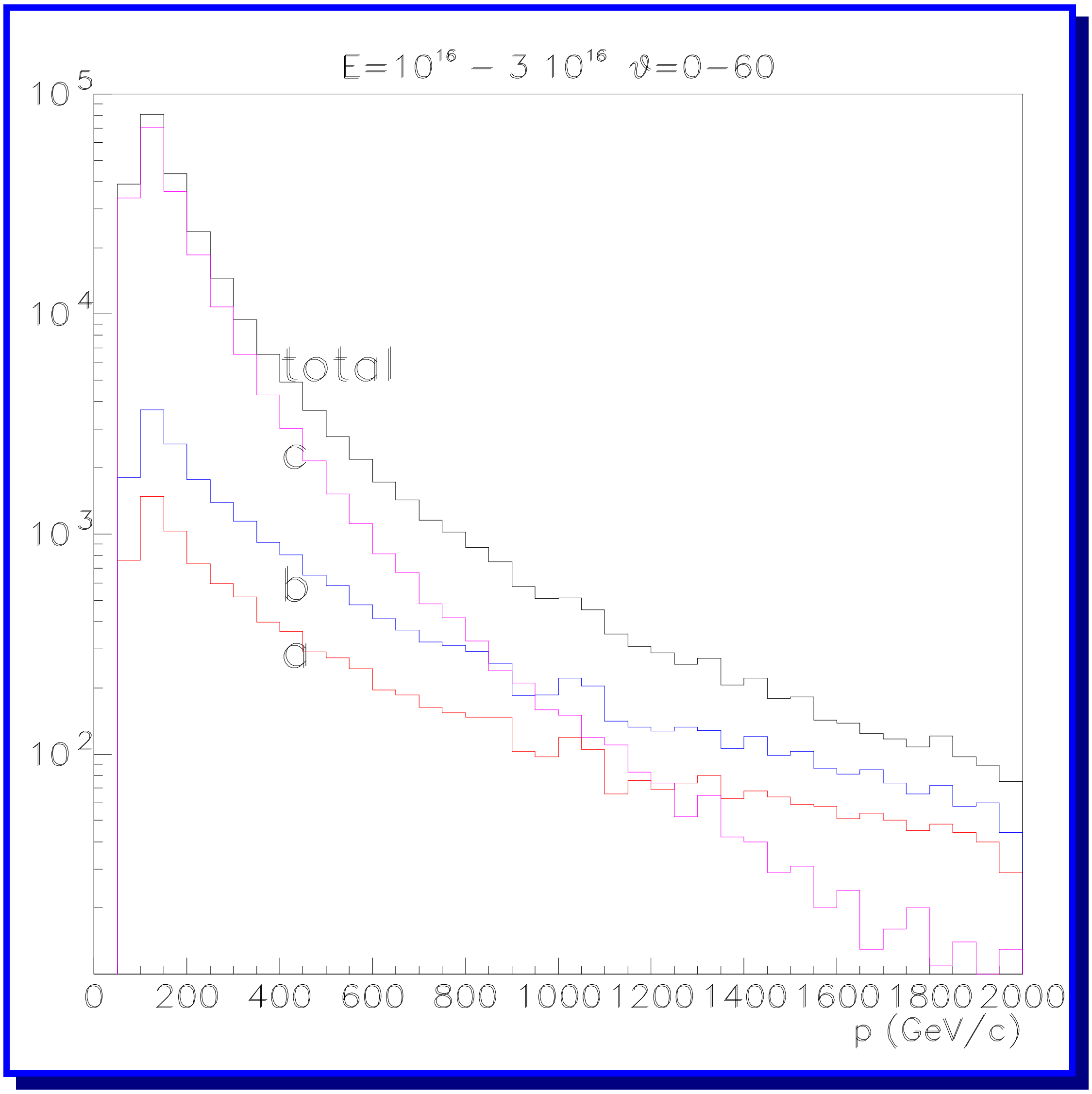
Energy intervals:

$$3 \cdot 10^{15} - 10^{16}, 10^{16} - 3 \cdot 10^{16}, 3 \cdot 10^{16} - 10^{17} eV$$

The distribution is flatter for Fe-induced muon bundles with almost the same density in the center.

key: to separate p from Fe

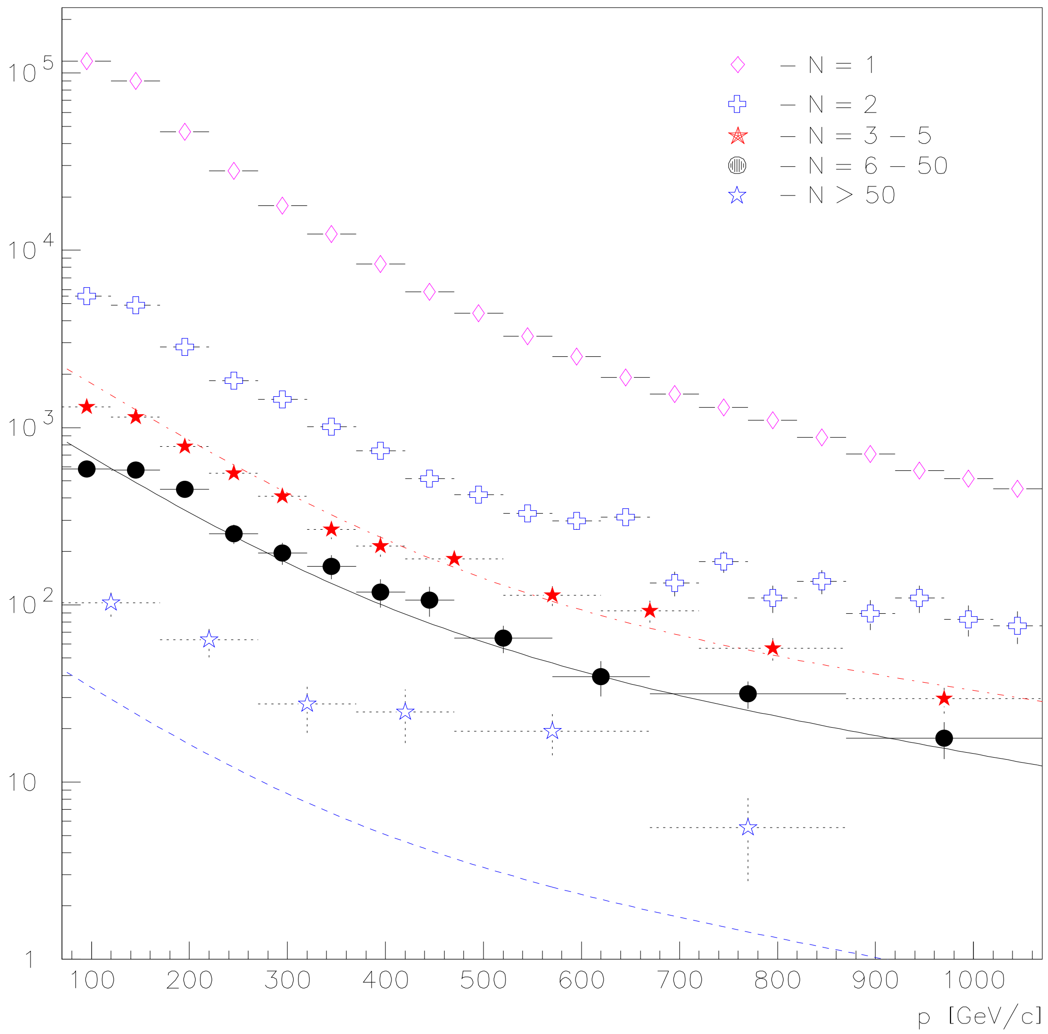
Momentum distribution from CORSIKA for muons close to the core (R$< 3, < 5$m) and outside (R>10 m)



a) R$<$ 3m b) R$<$ 5m c) R>10 m

High momentum muons are more frequent in the shower center.

Muon momentum distribution (TPC)

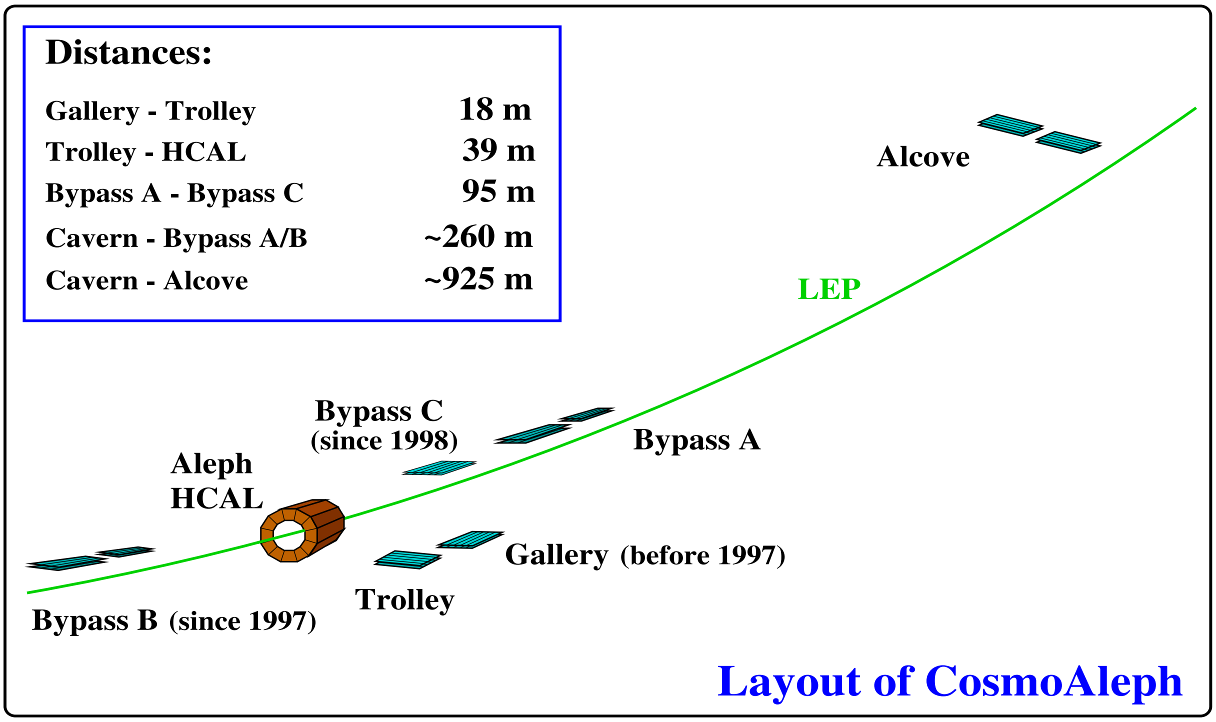


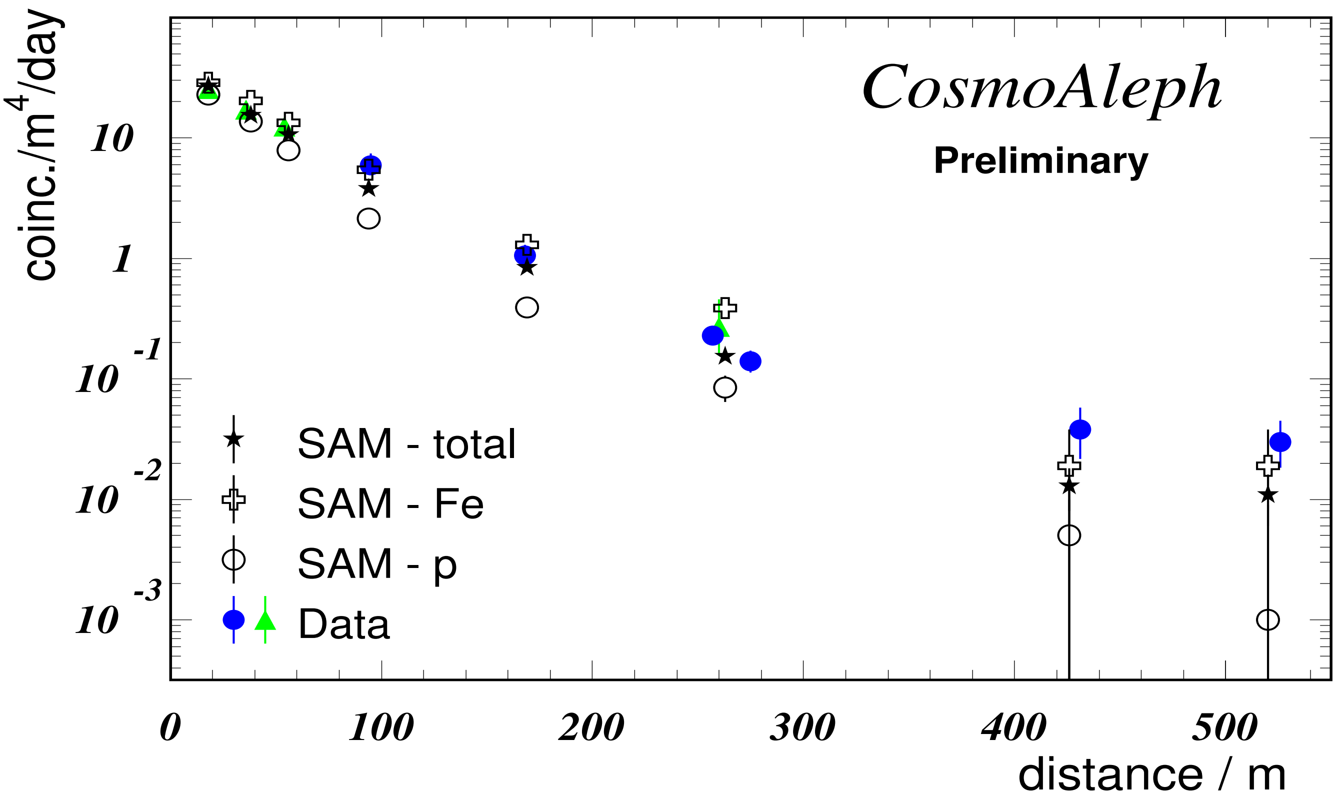
Only tracks ($\sim$ 30%) with $\Delta p/p^2 < 10^{-3}$ GeV^{-1} were considered.

The momentum distribution for multi-muon events is flatter than for single muons.

CosmoALEPH

Time coincidences over large distances





Schedule and Milestones

- ALEPH steering committee nominated a subgroup to study the implication of the proposal.
- The subgroup did not see major complications with the CosmoLEP installation but recommended that the safety division TIS assess the safety compliance.
- A first meeting with TIS has not revealed any insoluble safety problems.
- Extensive tests of the UA1 muon chambers with a non-flammable gas (Ar 90%,CO_2 10%).

  Test of a complete module with counters and electronics prior to installation.
- First installation of two modules in the ALEPH pit (Nov. '99).
- Final installation before the end of the year '99.
- Installation of the further counters stations (200 counters from HEGRA) at different positions along the LEP ring (e.g. between ALEPH and L3).
- Eventually installation of a chamber station in pit 3.
- Data taking during the year 2000.

Budget

Material budget:

Mechanics, installation and gas system for the muon chambers	38. kFS
Detectors and installations for safety requirements, assuming that some material is available from TIS, fences	15. kFS
Cables, connectors etc	18. kFS
Repairs of the muon chambers and associated electronics, gas consumption in the test set-up	8. kFS
GPS systems with read-out and specialized electronics	22. kFS
Installation of the trigger counters: mechanics, repairs, cables	12. kFS
DAQ and data storage	18. kFS
Electronics pool rental	
1999	50. kFS
2000	80. kFS
Gas consumption	
1999	6. kFS
2000	14. kFS
Transport and installation of 200 HEGRA counters (year 2000) The estimation depends on the cost of transport, status of the counters and availability of cables usable at CERN	30. kFS
Total	311. kFS

Contribution from participating institutes (1999-2000)	100. kFS
Contribution from CERN (1999-2000)	211. kFS

Subsistence allowances for students and physicists (50% for eastern countries) and one project associate	
1999	32. kFS
2000	75. kFS

Summary:

Total CERN contribution 1999	133. kFS
2000	185. kFS