V. Avati
K. Eggert

CORAL

A Cosmic Ray experiment in and above the LHC tunnel

Armenia:	Yerevan Physics Institute
Austria:	Institute for High Energy Physics
Bulgaria:	Institute for Nuclear Research and Nuclear Institute
	Central Laboratory of Mechatronics and Instrumentation, Bulgarian Academy of Sciences
Czech Republic:	FzU, Institute of Physics of the AS CR
	Institute of Particle and Nuclear Physics, Charles University
Finland:	Helsinki Institute of Physics
	Rovaniemi Polytechnic
	University of Oulu and Sodankylä Geophysical Observatory
Germany:	University of Siegen
India:	Tata Institute of Fundamental Research
Italy:	Laboratori Nazionali del Gran Sasso and INFN
Japan:	Osaka City University
Mexico:	Cinvestsav-IPN
	Universidad Autonoma de Puebla
Poland:	Warsaw University of Technology
Russia:	IHEP, Institute for High Energy Physics
Switzerland:	CERN
USA:	Case Western Reserve University
	University of Michigan

CORAL principal set-up

Astroparticle Physics

- particle spectrum + composition
- point like sources ???

Particle Interaction Physics

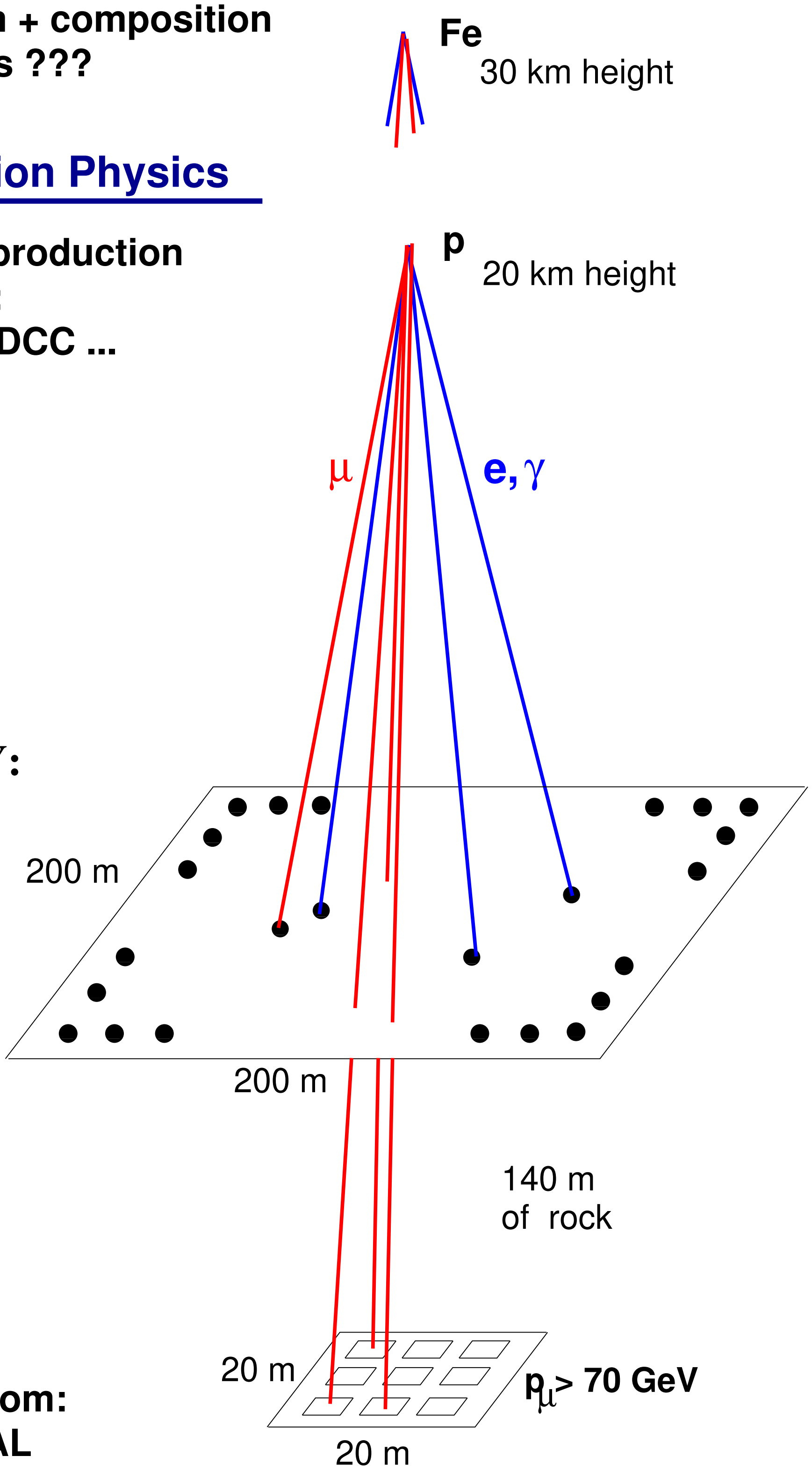
- forward particle production
- new phenomena:
  Centauro, QGP, DCC ...

SURFACE ARRAY:

HEGRA counters
Indian counters

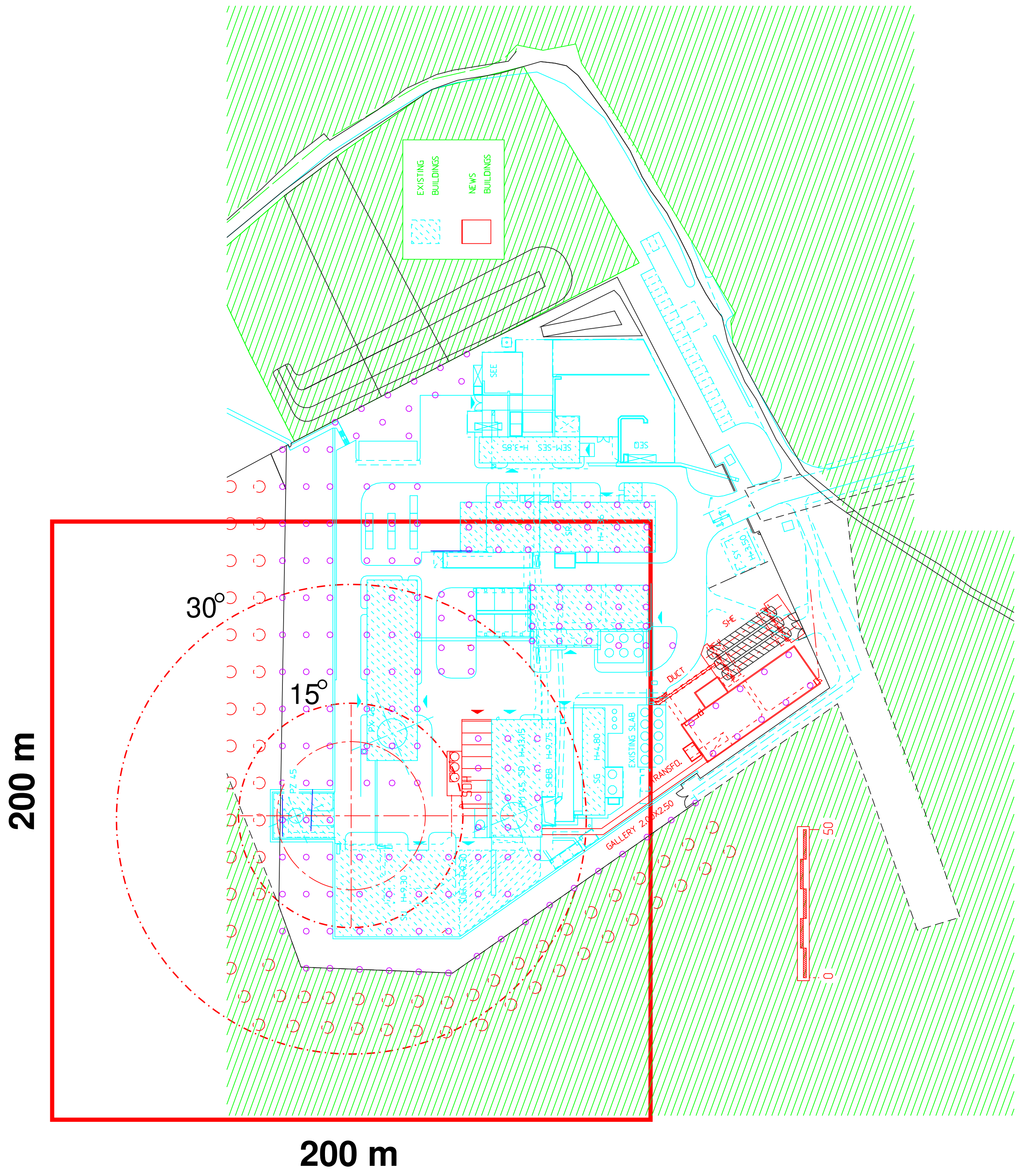
UNDERGROUND ARRAY:

muon chambers +
trigger counters from:
UA1, DELPHI, OPAL



not in scale

Surface Array at PA4

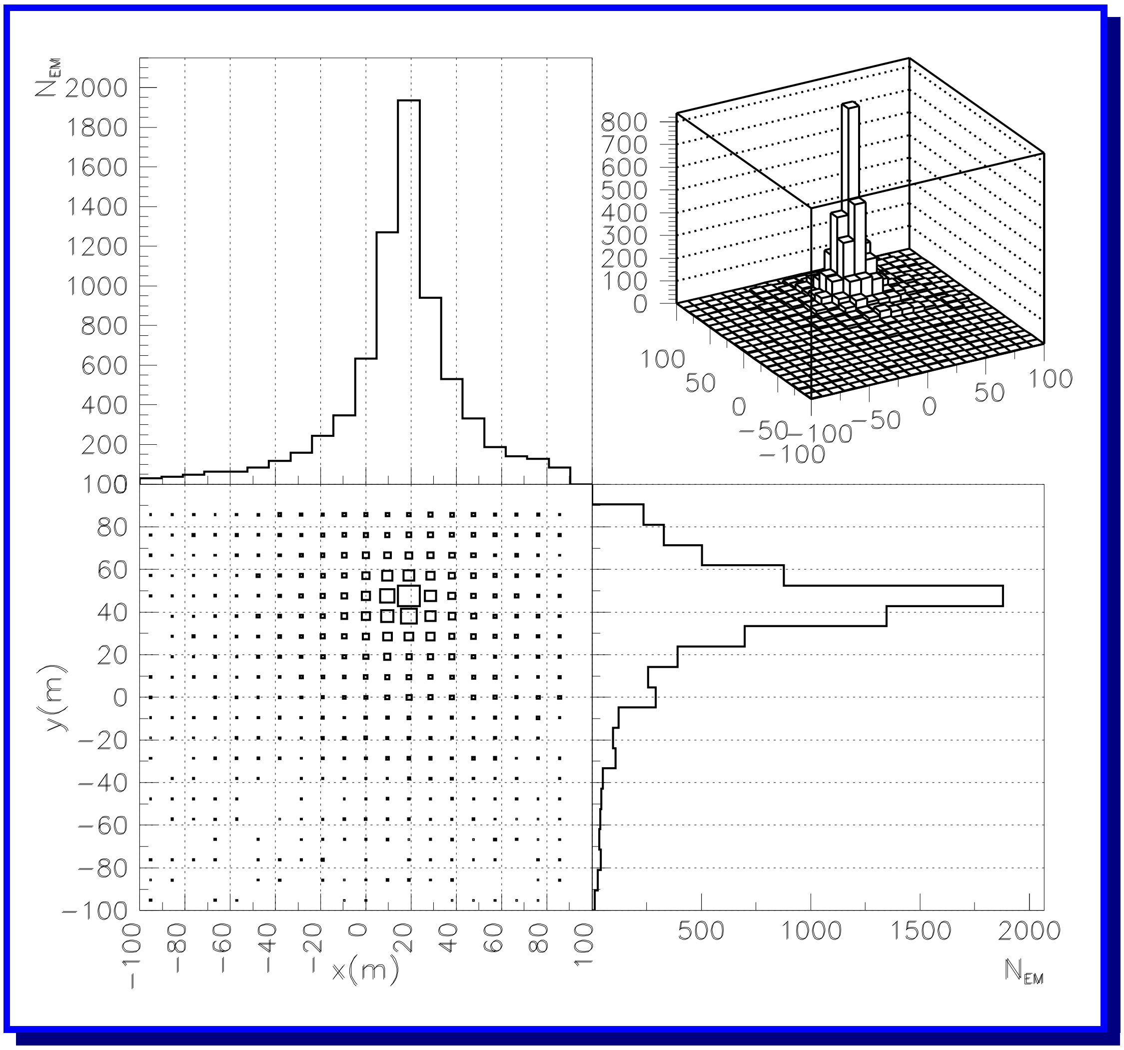


CERN AREA: 186 counters

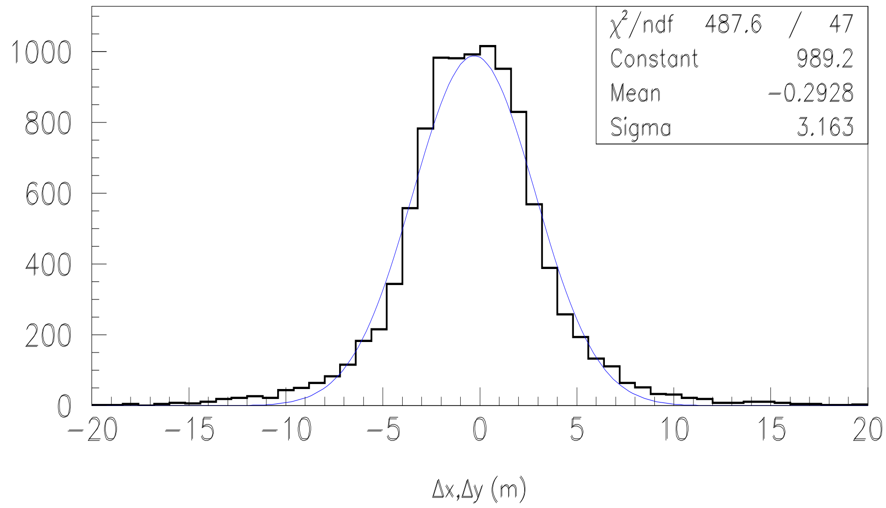
EXTENDED ARRAY: 251 counters

Negotiations with farmers are positive
(ref.: Buhler - Broglin, Troendle)

Location of the shower core in the top array



$$\sigma \sim 3m; \quad \sigma(\theta) \sim 2 - 5mrad$$



Probe with muons

Muons transport the information about the first interactions through the atmosphere

Muons of different momenta trace details of the cosmic ray cascades at different heights

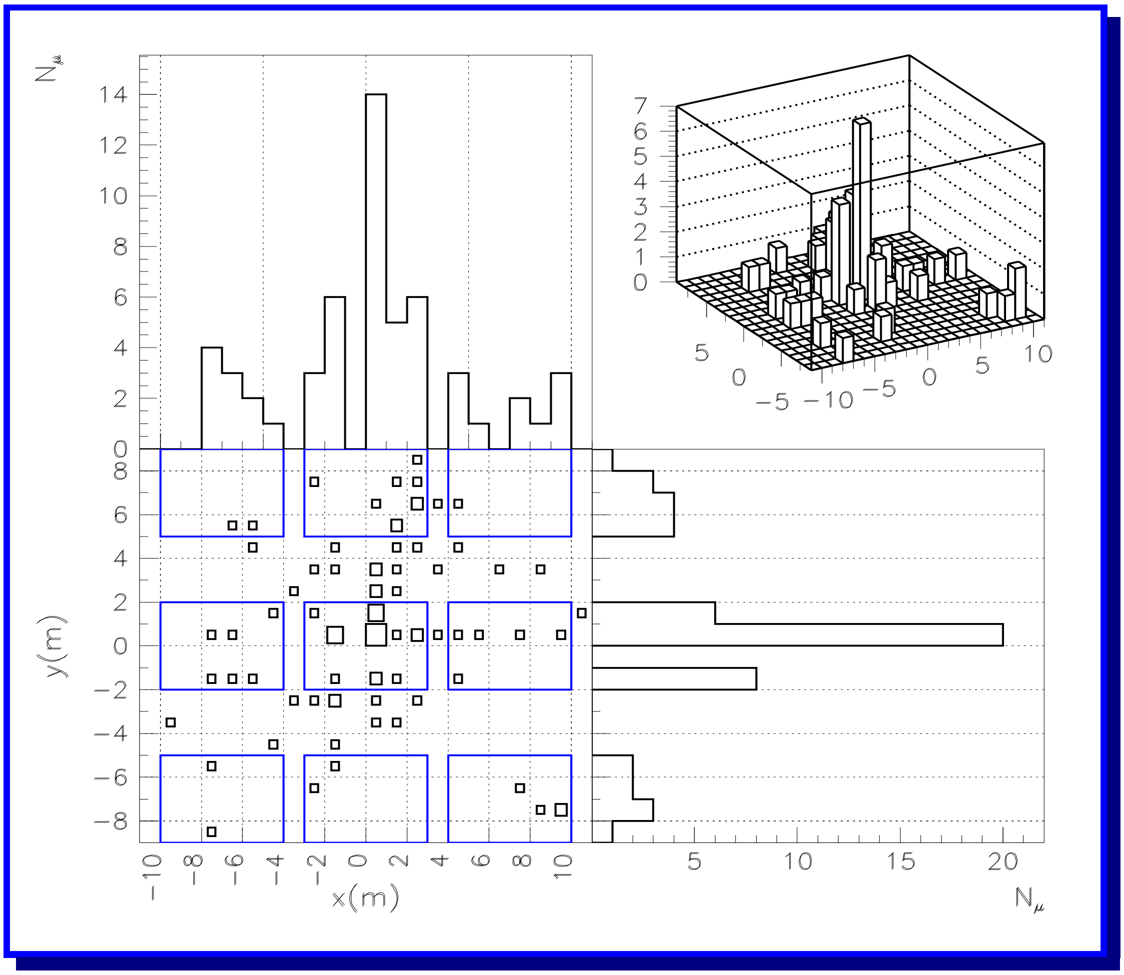
Surface:	$E_\mu \sim$ few GeV probes the end of the air shower cascade
Underground:	$E_\mu \sim 70$ GeV interaction and decay probabilities of pions are similar at a height of ~ 15 Km probes the early interactions
Deep: underground:	$E_\mu \sim 1$ TeV probes early interactions, but with very low statistics

$$N_\mu(p_\mu > 1 TeV)/N_\mu(p_\mu > 70 GeV) \sim 1.5\%$$

CORAL ($p_\mu > 70$ GeV) is at the right depth

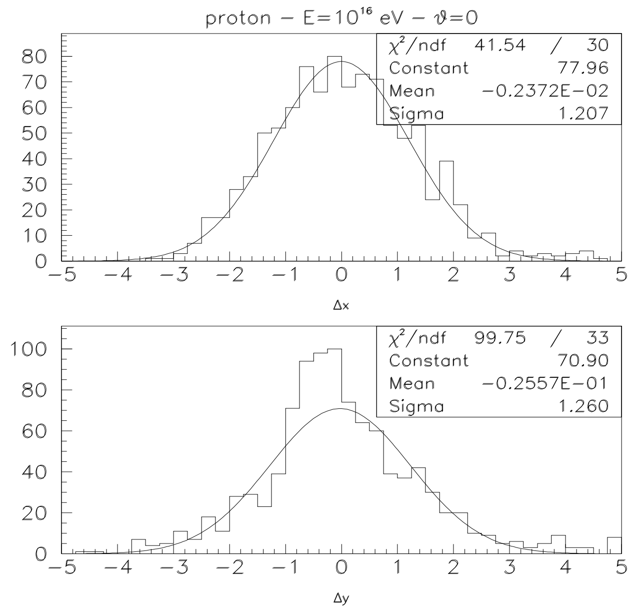
Reconstruction of muon bundle core

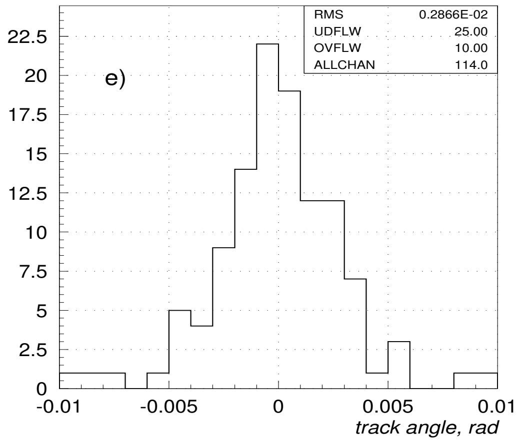
Muon shower profile (protons, E=10^{16} eV)



$\sigma_{core} \sim 1.2$ m

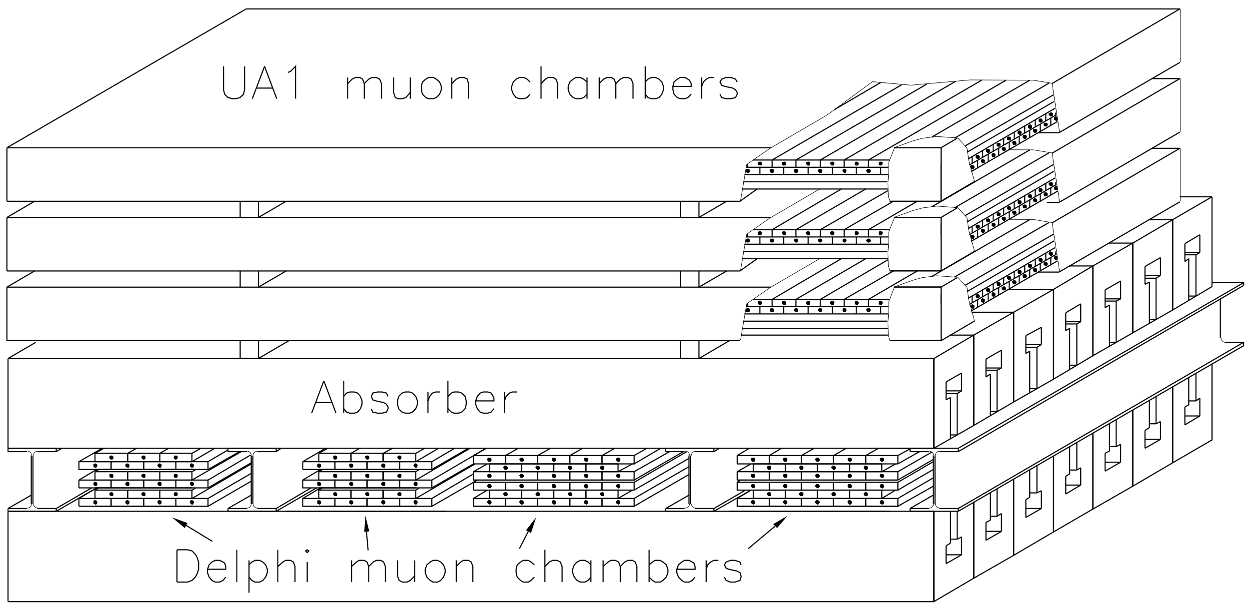
$\sigma_{axis} = 3mrad/\sqrt{N} \sim$ 0.1-0.2 mrad





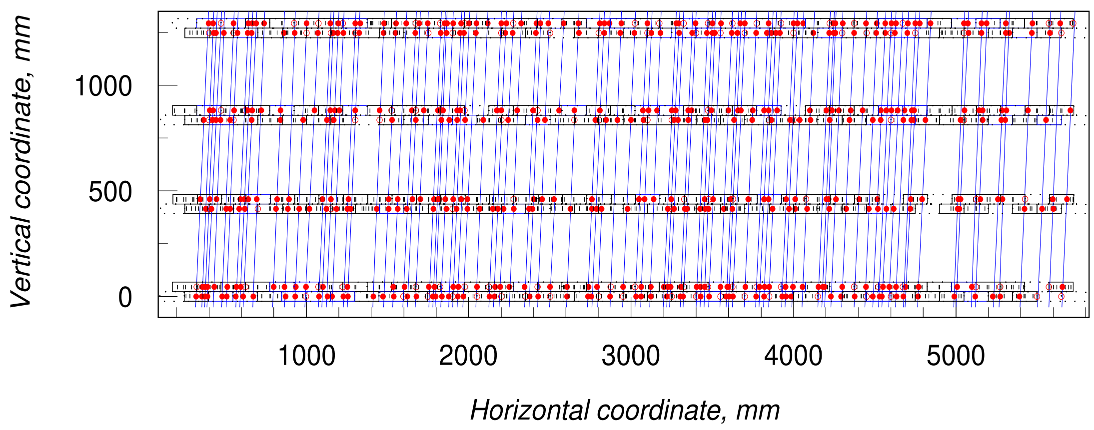
$\sigma_\mu(\theta) \sim 3$ mrad

Muon chamber module



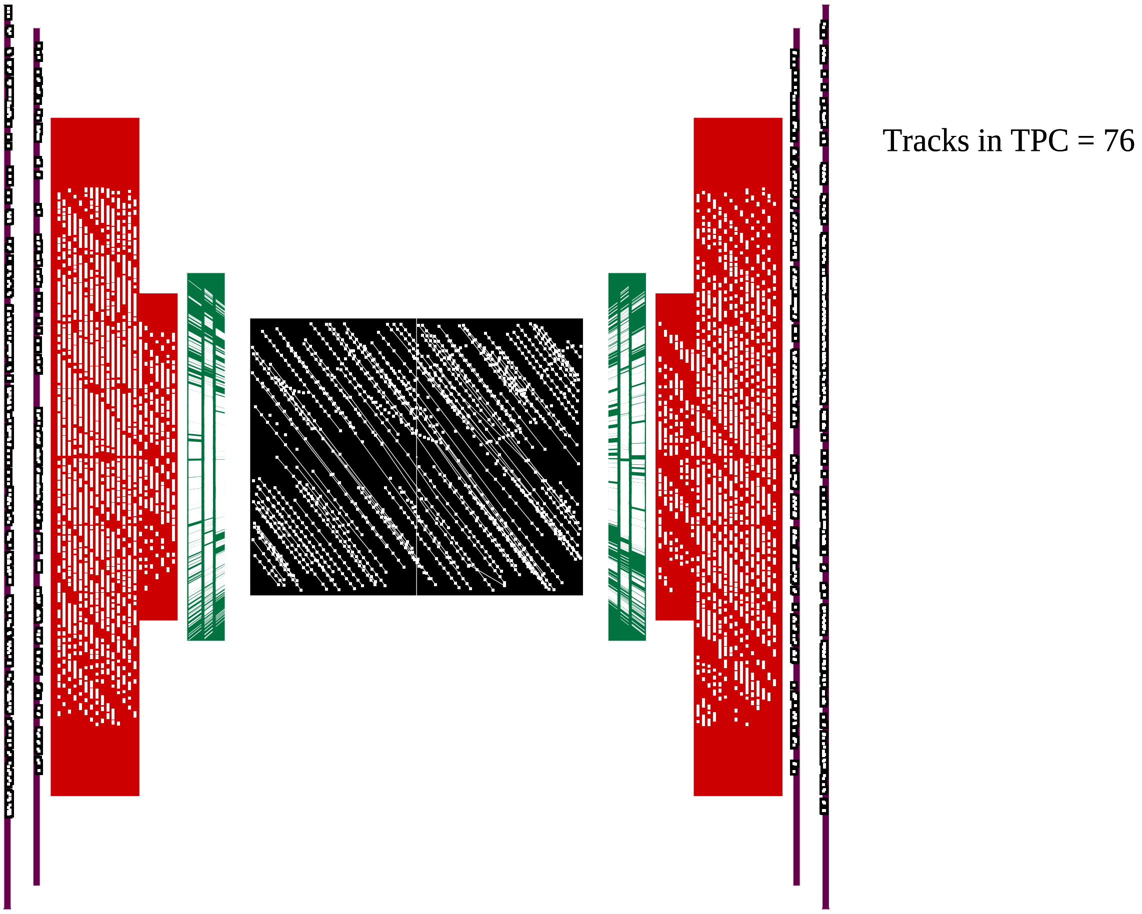
12 planes per projection1 + 6 planes per projection2

Test set-up in underground area UA2:

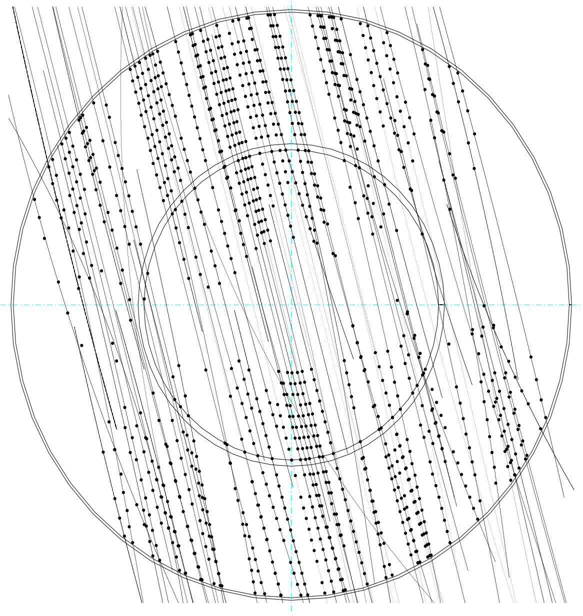


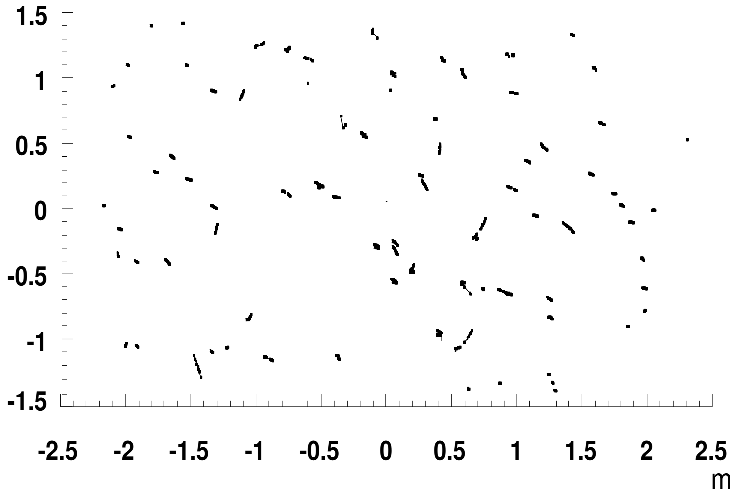
> 100 reconstructed muon tracks

A high multiplicity event in the ALEPH detector



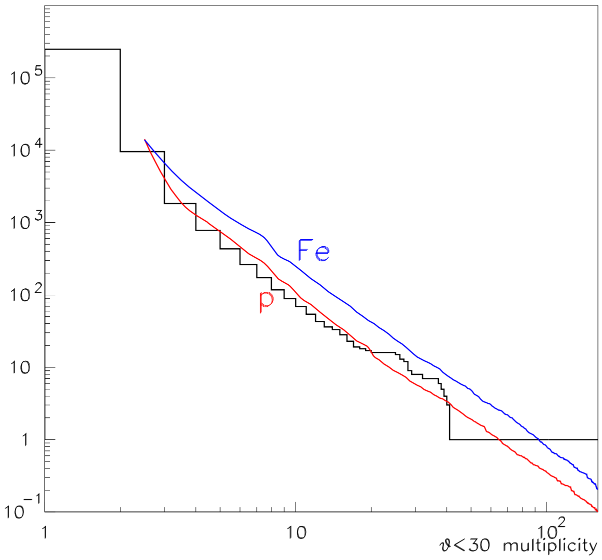
View perpendicular (top) and along the LEP ring (bottom left), along the muon shower direction (bottom right)



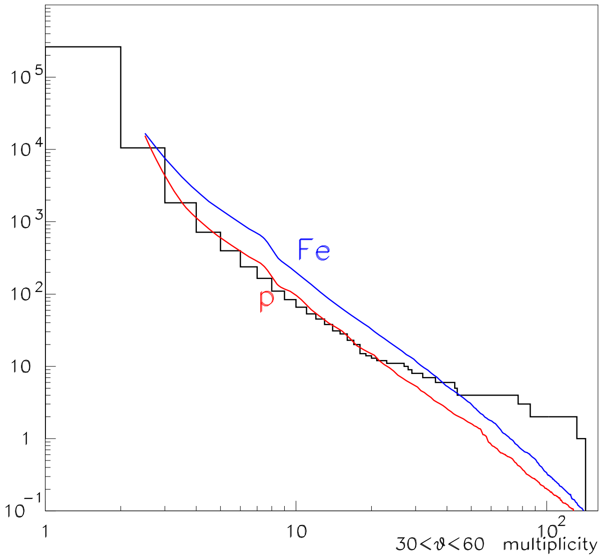


Are the Aleph high-multiplicity events outstanding?

Integral multiplicity distribution:

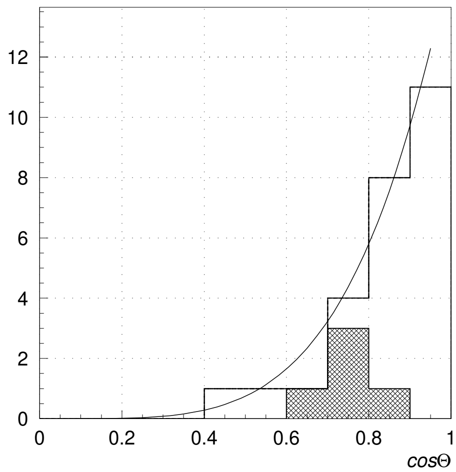


$\theta < 30^o$



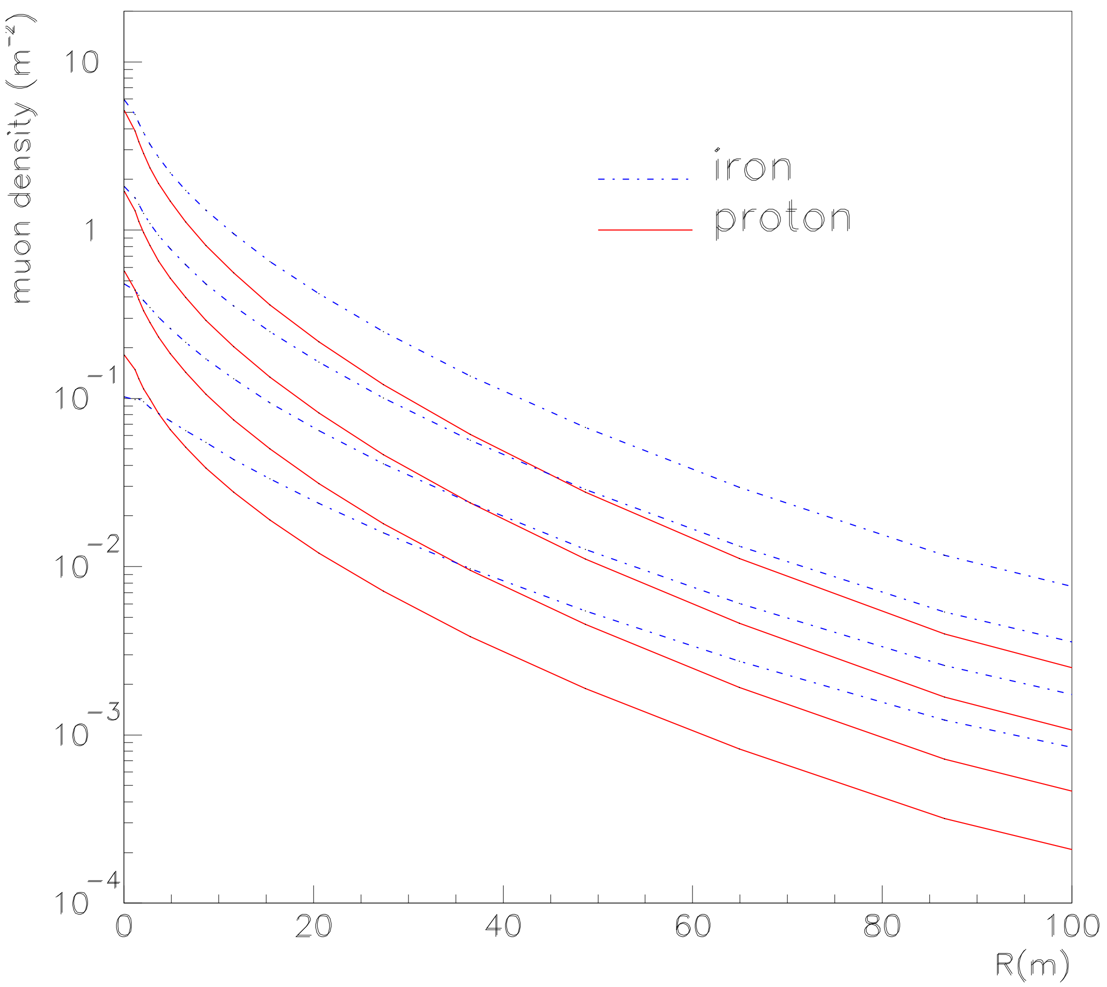
$\theta > 30^o$

cosθ distribution



Experiment					M.C.	
N tracks	ρ_μ m^{-2}	Zenith angle, ^{o}	Primary energy, eV	Interaction height, km	>E	Expect. events
76	4.8	40.6	$3.0 \cdot 10^{16}$	$7.8^{+\infty}_{-5.3}$	$1.0 \cdot 10^{16}$	1.6
85	5.3	38.4	$3.0 \cdot 10^{16}$	$39.3^{+\infty}_{-36.3}$		
142	8.9	40.5	$5.7 \cdot 10^{16}$	$3.7^{+152.6}_{-1.8}$	$3.0 \cdot 10^{16}$	0.2
149	18.6	27.3	$7.4 \cdot 10^{16}$	$2.7^{+\infty}_{-1.4}$	$6.0 \cdot 10^{16}$	0.04
131	8.2	48.0	$8.2 \cdot 10^{16}$	$3.5^{+\infty}_{-1.8}$		

Muon lateral distribution

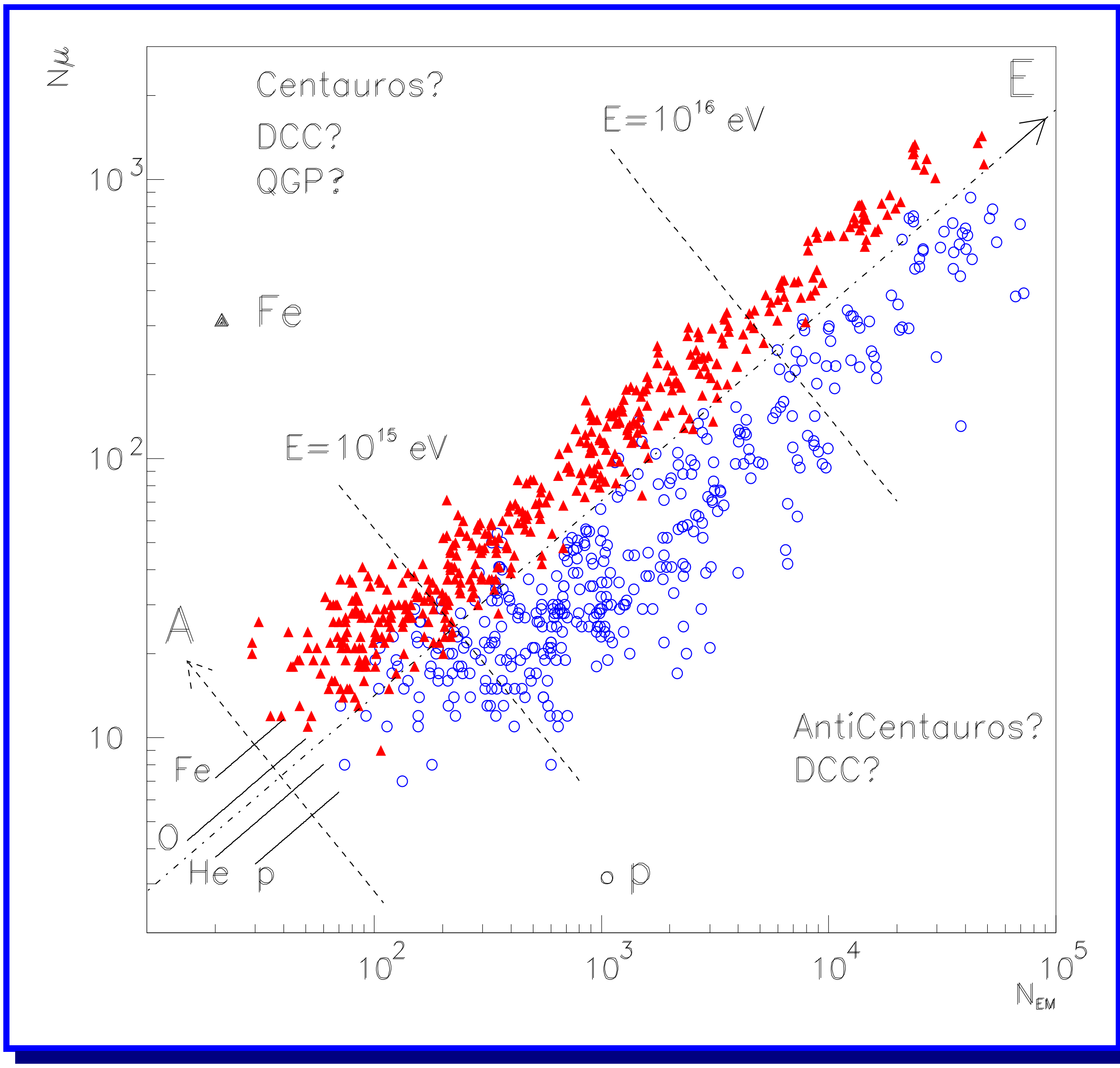


E$=3 \cdot 10^{14}, 10^{15}, 3 \cdot 10^{15}, 10^{16}$ eV

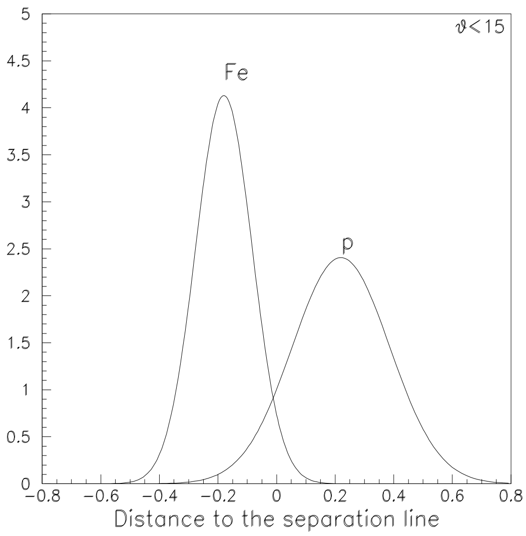
- Identification of p and Fe induced showers

- Search for anomalies in the forward particle production

Electron - muon correlation



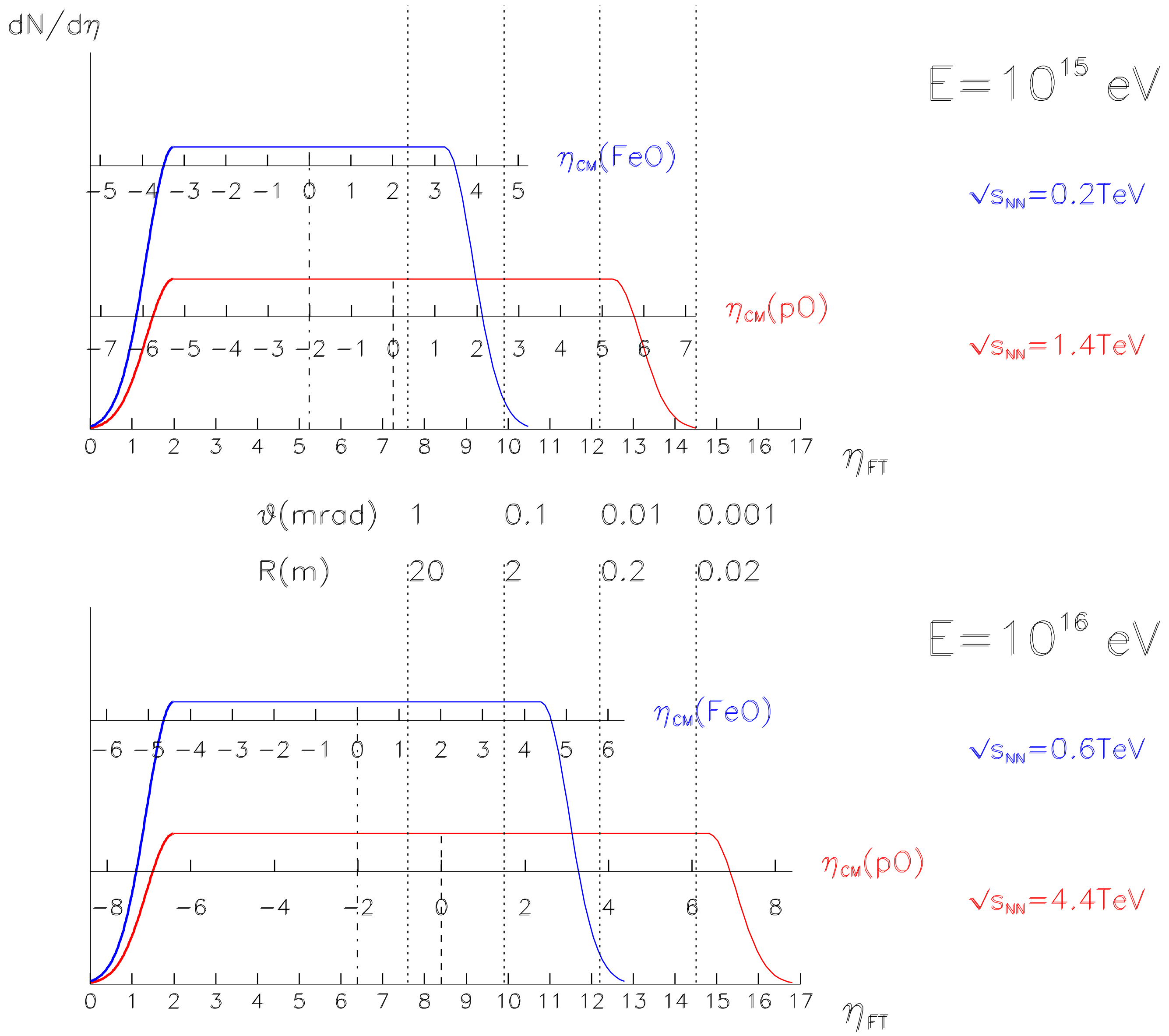
$\theta < 15^o$
N_e in R$<$ 50 m
N_μ in array (20x20 m^2),
$p_\mu > 70$ GeV
Shower core in the
muon array
$5 \cdot 10^{14} <$ E $< 5 \cdot 10^{16}$ eV



Particle composition
Search for exotic events

Comparison CR ⇔ LHC for pO and FeO interactions

Schematic pseudorapidity distributions:

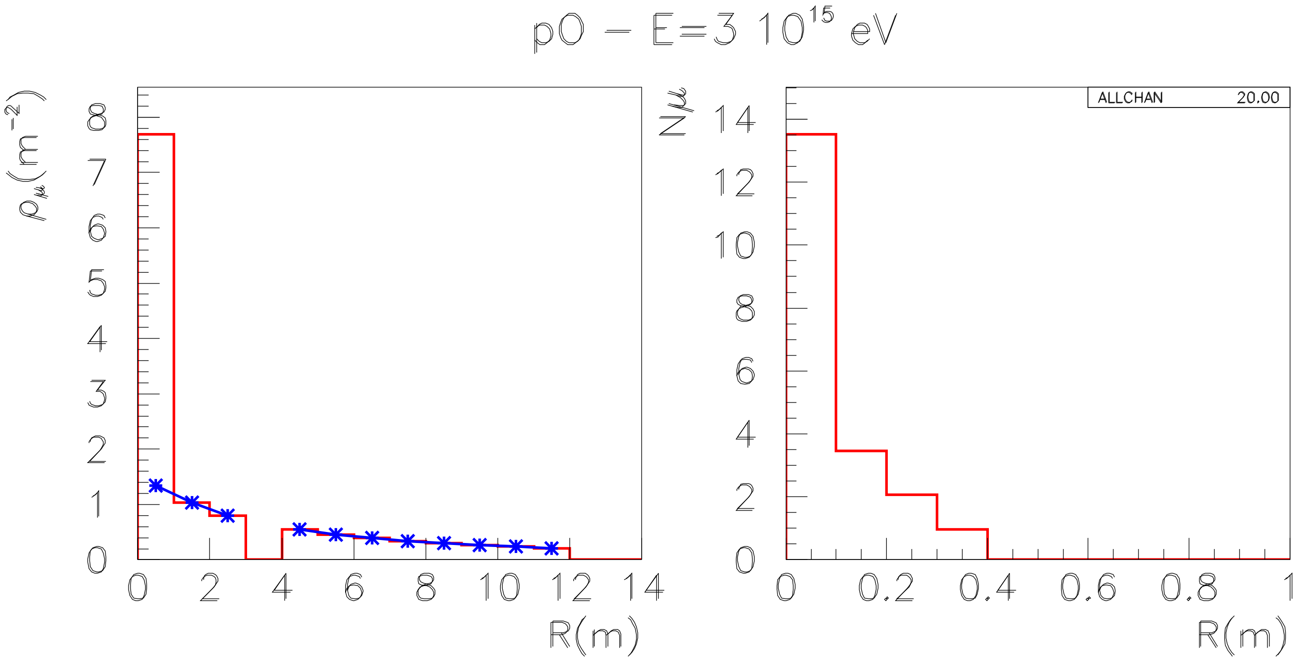


- CR at a few 10^{16} eV are close to LHC energies for pO
  LHC: $\sqrt{s}_{NN}$=6.7 TeV (FeO) and 9.9 TeV (pO)

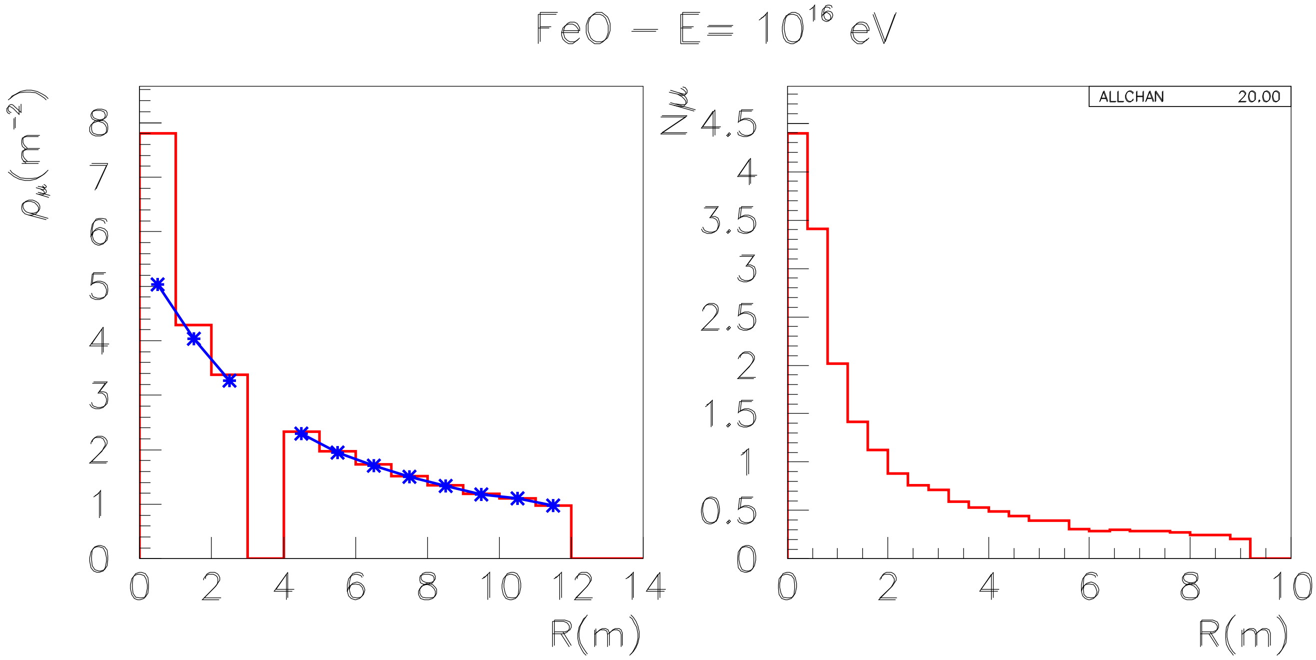
- Sensitivity from 90^o in the cms-system up to the very forward cones

- 100 GeV at 1 mrad $\Rightarrow$ p_t=100 MeV

Muons from additional forward charm production



20 muons in 11.5< η <15.5



20 muons in 9< η <13

CORAL acceptance and rates

Geometrical Acceptance:

A_μ: underground array alone

$A_{e,\mu}$: coincidence of surface and underground arrays

array:		extended	CERN
Θ	$A_\mu / sr\, m^2$	$A_{e,\mu} / sr\, m^2$	$A_{e,\mu} / sr\, m^2$
$0^o - 15^o$	413.2	391.7	301.2
$15^o - 30^o$	1129.0	710.5	472.3
$30^o - 45^o$	1542.2	452.5	384.8

Expected statistics:

in $6 \cdot 10^7\, sec$ ($\sim$ 3 years of running)

coincidence of surface and underground arrays

$E[eV] \downarrow / \Theta \rightarrow$	$0^o - 15^o$	$15^o - 30^o$	$30^o - 45^o$
$> 1 \cdot 10^{15}$	34100	61800	39400
$> 3 \cdot 10^{15}$	4580	8310	5290
$> 1 \cdot 10^{16}$	410	750	480
$> 3 \cdot 10^{16}$	46	84	53
$> 1 \cdot 10^{17}$	4	8	5

Conclusions

With the existing detectors from

HEGRA (scintillation counters)

UA1, DELPHI and OPAL (muon chambers)

and the existing infrastructure at the LHC underground area in point 4

a simultaneous and complementary measurement of the muonic ($p_\mu > 70$ GeV) and electromagnetic components of the cosmic ray air showers (E$>10^{14}$ eV) can be economically done.

Study of high-multiplicity muon events with precise muon chambers over 20x20 m^2

Sensitivity to:

- fluctuations in the charged-to-neutral ratio (DCC)
- forward heavy flavour production
- events with highest muon density

$p_\mu > 70$ GeV favours muons from the early interactions