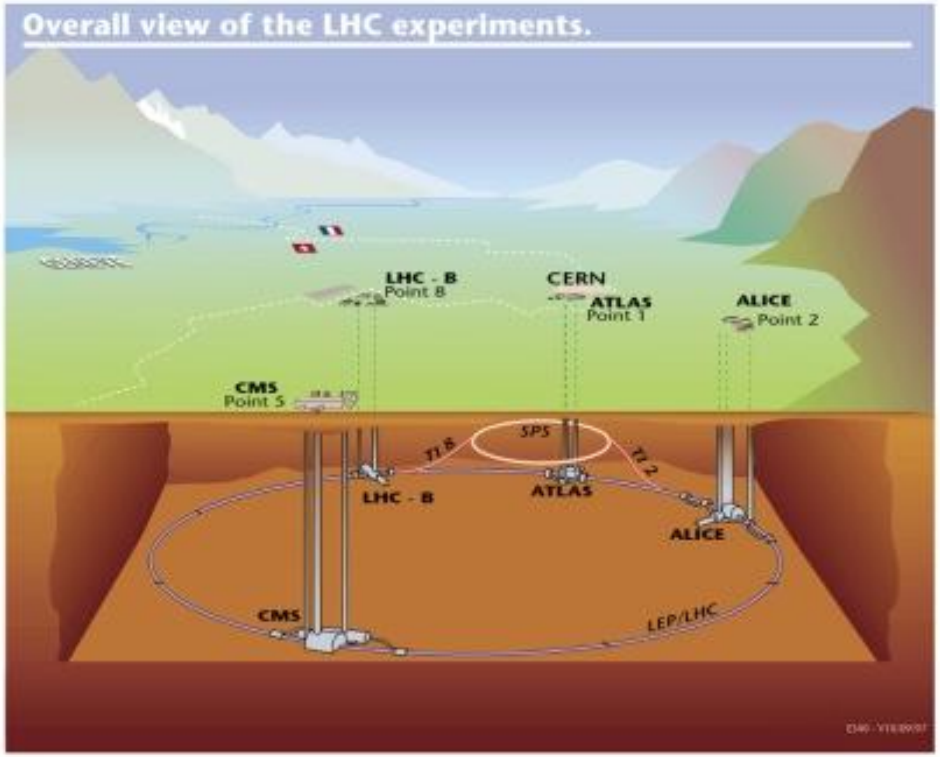
# Performance and Results of the ALICE Experiment for Cosmic ray Physics

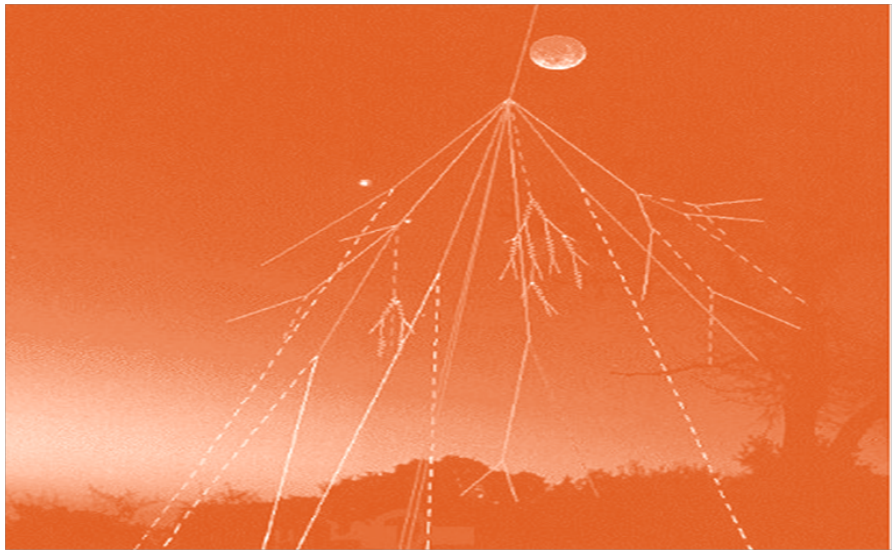
Martin Subieta
for the ALICE Collaboration
INFN Sezione di Torino
Universita' Degli Studi di Torino

**Epiphany Conference, Cracow, Poland**

January 12th, 2011

# Alice experiment at LHC

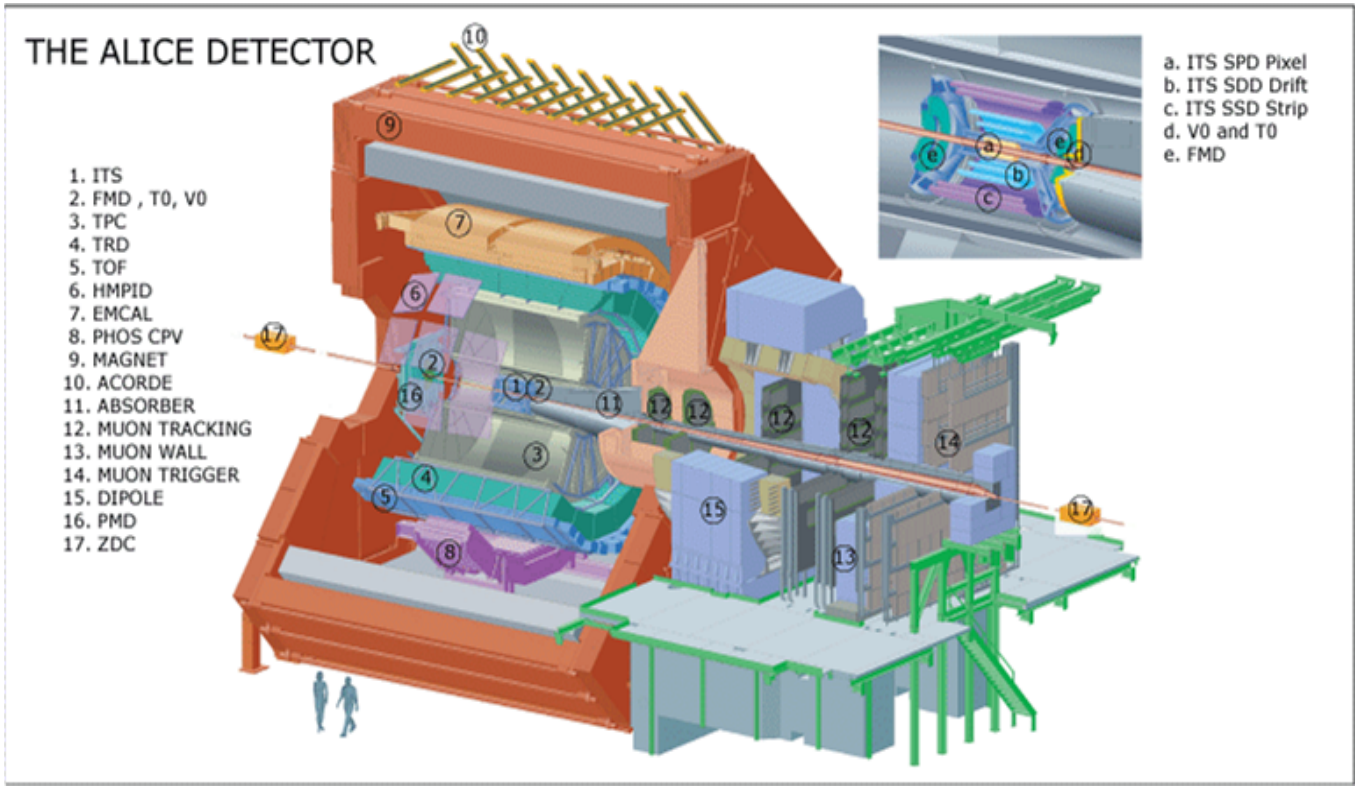


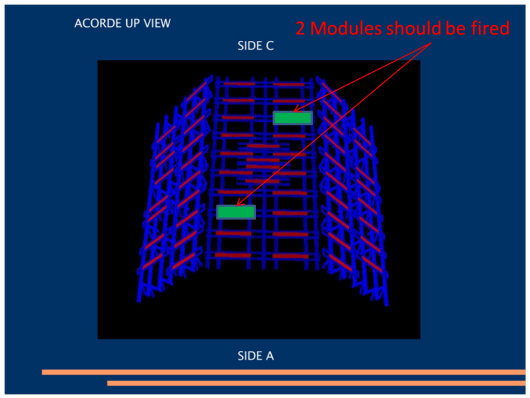
- ALICE located at 40 m underground
- 30 m of rock (molasse)
- Energy threshold $\sim 15$ GeV (near-vertical muons)

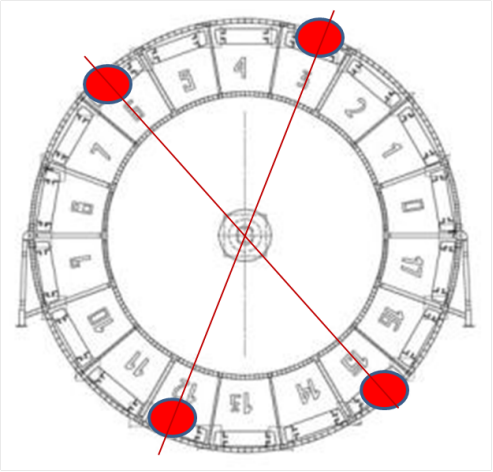
# Detectors used

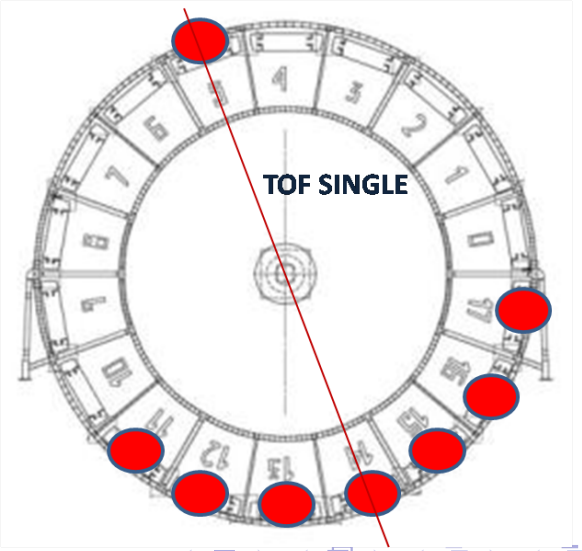
1. Central detectors are used for detecting athmospheric muons
   - Trigger: ACORDE,TOF and SPD
   - Tracking: TPC
2. Forward muon spectrometer is used to detect quasi-horizontal muons
   - Trigger: Muon trigger chambers
   - Tracking: Muon tracking chambers



# Description of the trigger





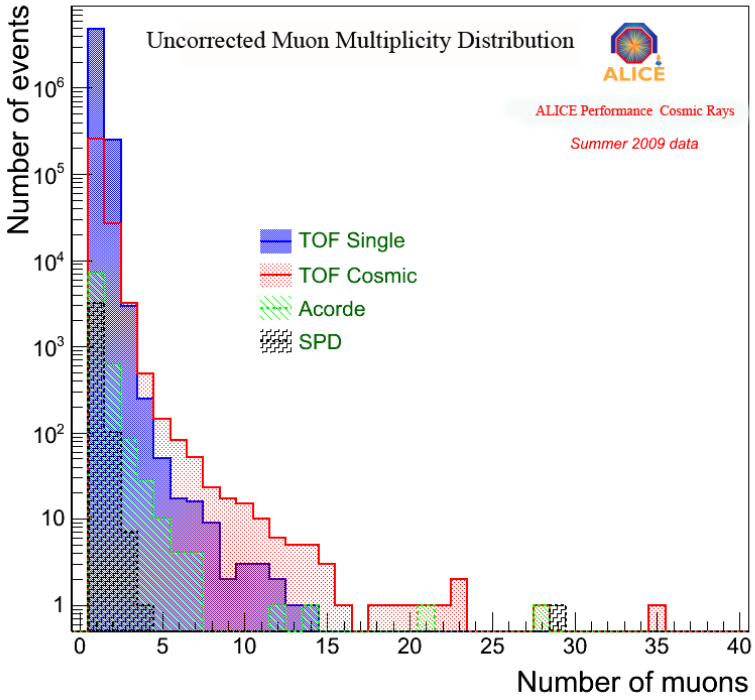

- ACORDE-60 scintillators, trigger coincidence: two scintillators (AMU)
- TOF cylinder of MRPC surrounding the TPC has two trigger types:
  - 1 pad up hit and 1 pad down and $\pm$ 3 pads hits: TOF Single (OB3)
  - 4 pads everywhere: TOF Cosmic (OCP)
- SPD the two innermost layers of ITS, trigger when muon cross the two layers: (SCO)

# Data sample summer 2009

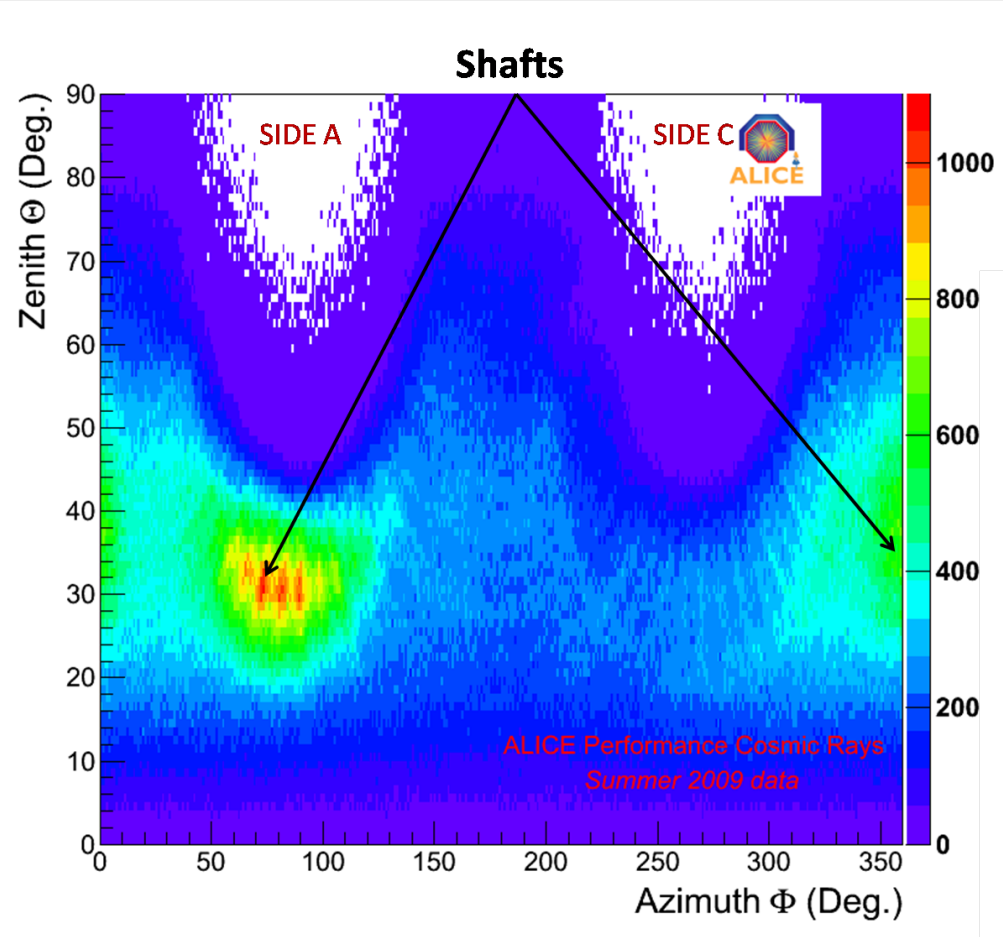
| # Run | Time [h] | Rec. Pass2 [%] | # Events OB3 OCP AMU | # Events Mu > 0 OB3 OCP AMU | Rate Mu > 0 OB3 [Hz] | Rate Mu >0 OCP [Hz] | Rate Mu > 0 AMU [Hz] | # Interaction Events | # Multi - Mu Events mu > 3 |
|---|---|---|---|---|---|---|---|---|---|
| 83811 | 9.48 | 100 | 3422599 | 719832 | 20 | 1 | 0.03 | 152 | 152 |
| 83775 | 1.27 | 100 | 580925 | 148666 | 30.1 | 1.8 | 0.05 | 29 | 19 |
| 83802 | 1.05 | 90.6 | 382985 | 81830 | 20.5 | 1.1 | 0.03 | 18 | 15 |
| 84148 | 6.4 | 100 | 2720090 | 682773 | 28 | 1.6 | 0.04 | 103 | 98 |
| 84205 | 4.5 | 98.6 | 1681171 | 424331 | 24.7 | 1.4 | 0.04 | 84 | 76 |
| 84254 | 7 | 86.2 | 2330994 | 587554 | 22 | 1.3 | 0.03 | 99 | 81 |
| 84389 | 2.23 | 82.1 | 599723 | 151642 | 17.8 | 1 | 0.03 | 33 | 34 |
| 84420 | 5.12 | 97.6 | 1958776 | 495292 | 25.4 | 1.4 | 0.04 | 80 | 92 |
| 84455 | 4.43 | 98.1 | 1883982 | 478493 | 28.3 | 1.6 | 0.04 | 98 | 82 |
| 84479 | 1 | 96.1 | 377985 | 96761 | 25.4 | 1.5 | 0.04 | 19 | 18 |
| 84993 | 1.52 | 86.4 | 460389 | 120291 | 20.7 | 1.2 | 0.03 | 17 | 24 |
| 85024 | 1.35 | 89.7 | 493870 | 128554 | 24.9 | 1.4 | 0.04 | 18 | 18 |
| 85031 | 0.51 | 92.5 | 304872 | 79945 | 41 | 2.4 | 0.06 | 9 | 10 |
| 85032 | 0.43 | 94.1 | 14388 | 3759 | 2.3 | 0.13 | 0.004 | 1 | 0 |
| 85034 | 11 | 96.9 | 3906585 | 1023590 | 24.4 | 1.4 | 0.04 | 197 | 161 |
| TOTAL | 57.29 | | 21119334 | 5223313 | | | | 957 | 880 |

- The whole sample of "good quality" data collected in 2009 was analyzed
- 15 runs $\rightarrow$ total time $\sim$ 2.4 days live time

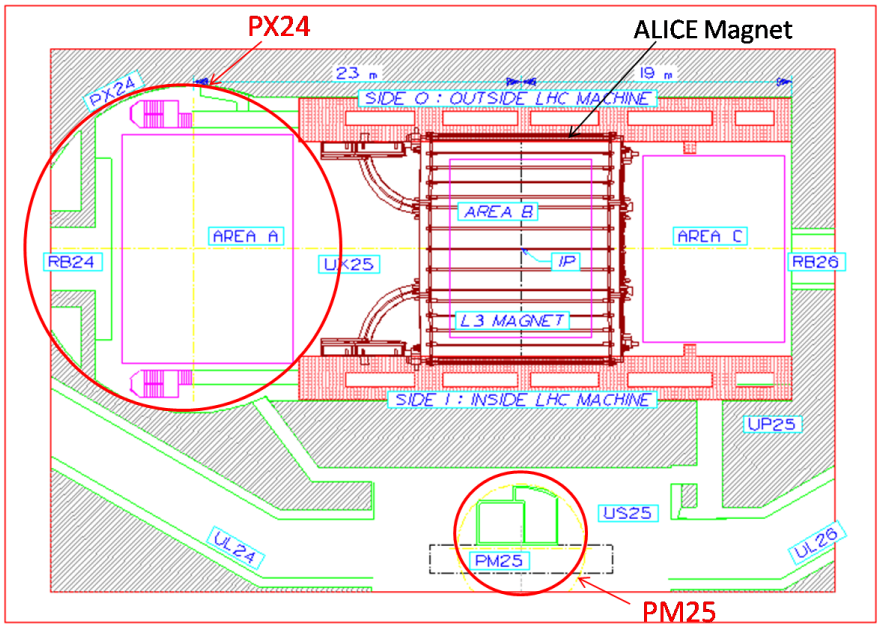
- Tigger type $\rightarrow$ TOF: OB3-OCP
- ACORDE: AMU, SPD: SCO
- Maximum high-multiplicity observed $\rightarrow$ 35$\mu$



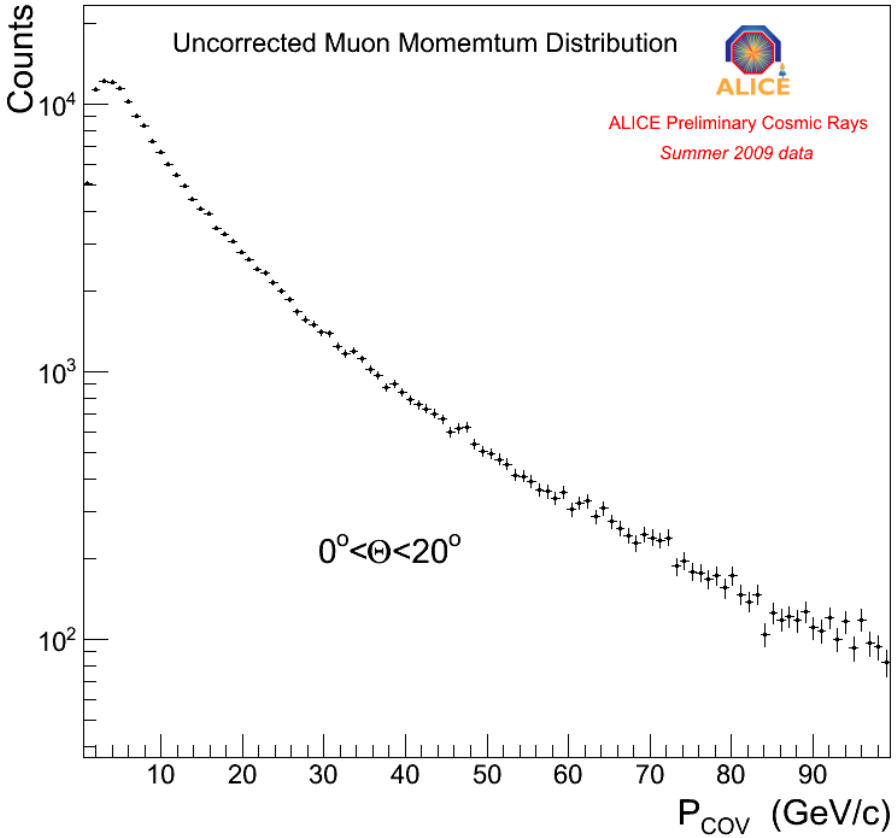
# Zenithal and azimuthal angular distributions




- Muons with zenith angle $0^o - 20^o$ were selected in order to avoid those muons which crossing the ALICE shafts
- Mean loss energy $\sim$ 15 GeV (till ALICE level $\sim$ 40 m underground)



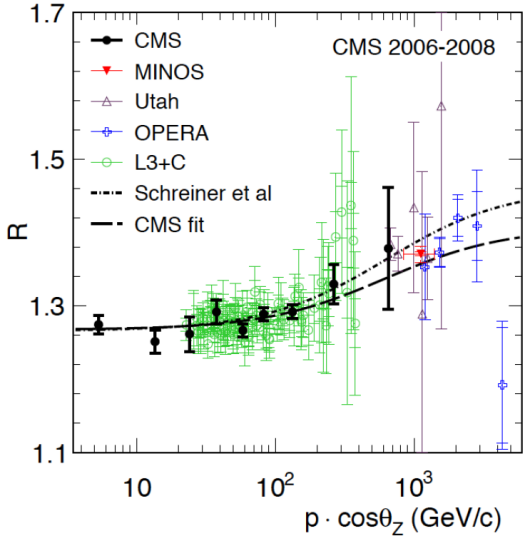
# Uncorrected muon momentum distribution



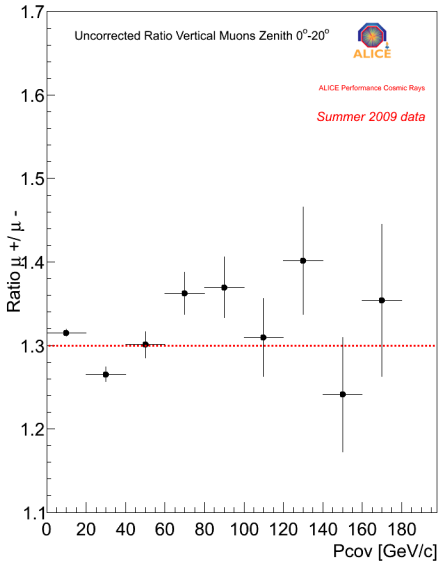

- Pcov = P measurement of near-vertical muons
- Pcov $\longrightarrow$ best way to measure the momentum
- It's calculated as an update of the covariance matrix parameters (Kalman filter algorithm)
- We estimated an error around 25-30% at P = 100 GeV/c

# Muon charge ratio $\mu^+/\mu^-$

CMS experiment




ALICE experiment




- 270 million of events recorded (October-November 2008) with B = 3.8 T
- P region $< 100$ GeV/c $\rightarrow$ charge ratio value of 1.2769$\pm$0.0025(stat)$\pm$0.0025(syst)
- In agreement with L3+C measurement $\rightarrow$ 1.285$\pm$0.003(stat)$\pm$0.019(syst)

- 15 runs with Pass 2 $\sim$ 5 million of events ($\sim$ 570888 vertical muon events)
- In P region $< 100$ GeV/c $\rightarrow$ uncorrected charge value of 1.314
- Detailed corrections studies are ongoing

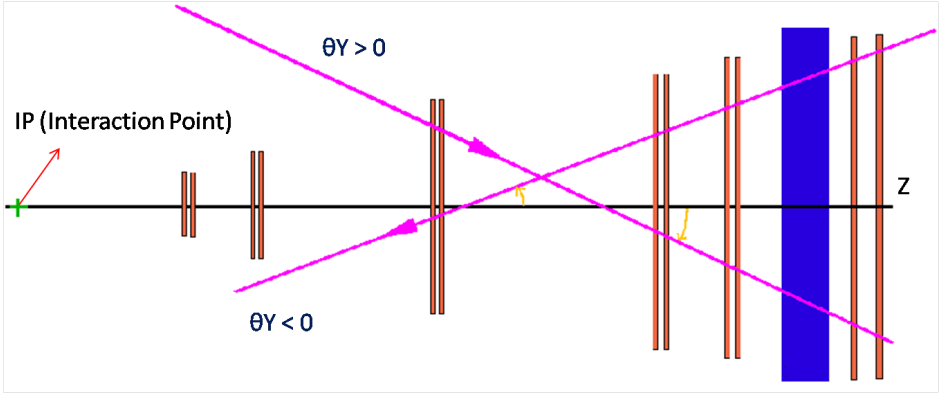
# Data sample Aug.- Sep. 2009 (Muon Spectrometer)

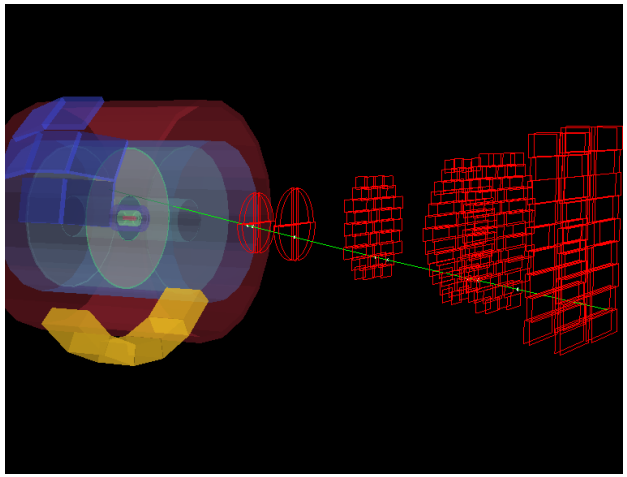
| Date | Run | Time[h] | Rate[Hz] | Events |
|---|---|---|---|---|
| 24/08/09 | 81185 | 3 | 0.24 | 2560 |
| ” | 81249 | 4 | 0.28 | 3604 |
| ” | 81278 | 1 | 0.27 | 1036 |
| 25/08/09 | 81282 | 2 | 0.27 | 2108 |
| ” | 81286 | 2 | 0.26 | 1882 |
| ” | 81292 | 3 | 0.27 | 2544 |
| ” | 81298 | 1 | 0.27 | 1310 |
| ” | 81315 | 3 | 0.27 | 2625 |
| ” | 81391 | 6 | 0.27 | 5761 |
| ” | 81516 | 4 | 0.26 | 4157 |
| 26/08/09 | 81540 | 4 | 0.27 | 3807 |
| ” | 81544 | 1 | 0.23 | 877 |
| ” | 81545 | 4 | 0.25 | 339008 |
| ” | 81683 | 5 | 0.25 | 4032 |
| ” | 81771 | 3 | 0.25 | 2829 |
| ” | 81812 | 3 | 0.24 | 2612 |
| ” | 81818 | 5 | 0.28 | 5104 |
| ” | 81827 | 4 | 0.28 | 4368 |
| ” | 81937 | 4 | 0.27 | 4088 |
| ” | 82118 | 2 | 0.27 | 1734 |
| ” | 82164 | 1 | 0.28 | 1339 |
| 28/08/09 | 82172 | 8 | 0.27 | 8023 |
| ” | 82281 | 3 | 0.25 | 2454 |
| ” | 8233900 | 2 | 0.26 | 2255 |
| ” | 82439 | 4 | 0.26 | 3622 |
| 29/08/09 | 82461 | 6 | 0.26 | 5476 |
| ” | 82439 | 4 | 0.26 | 3622 |

| Date | Run | Time[h] | Rate[Hz] | Events |
|---|---|---|---|---|
| 02/09/09 | 83745 | 6 | 0.22 | 5055 |
| ” | 83814 | 2 | 0.22 | 1469 |
| ” | 83822 | 6 | 0.26 | 6044 |
| 03/09/09 | 83845 | 4 | 0.26 | 3621 |
| ” | 83909 | 3 | 0.26 | 2420 |
| ” | 83997 | 5 | 0.28 | 4676 |
| 04/09/09 | 84039 | 5 | 0.28 | 4637 |
| ” | 84046 | 5 | 0.28 | 4630 |
| ” | 84141 | 3 | 0.29 | 6922 |
| 05/09/09 | 84201 | 5 | 0.29 | 390088 |
| ” | 84209 | 3 | 0.30 | 3316 |
| ” | 84228 | 6 | 0.28 | 6625 |
| ” | 84392 | 6 | 0.29 | 5762 |
| 06/09/09 | 84447 | 8 | 0.27 | 8275 |
| ” | 84464 | 6 | 0.26 | 5857 |
| ” | 84585 | 8 | 0.27 | 7622 |
| 07/09/09 | 84643 | 8 | 0.27 | 7692 |
| ” | 84660 | 1 | 0.27 | 915 |
| ” | 84815 | 3 | 0.27 | 3237 |
| ” | 84854 | 4 | 0.26 | 3384 |
| 08/09/09 | 84888 | 7 | 0.27 | 7157 |
| ” | 85014 | 1 | 0.25 | 1153 |
| ” | 85021 | 6 | 0.24 | 5541 |
| 09/09/09 | 8503900 | 8 | 0.25 | 6778 |

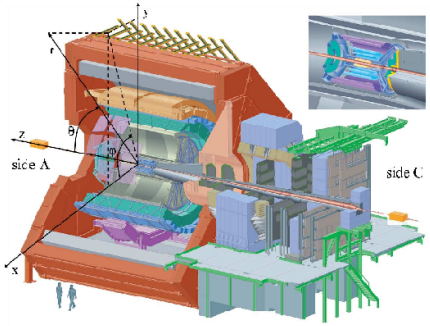
- 51 Runs $\rightarrow$ 104 chunks analyzed
- Total Time $\sim$ 9 days (B=0.7T)
- 8192 events reconstructed

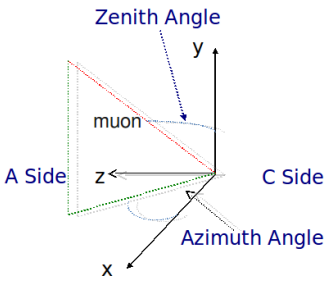
# Data sample selected

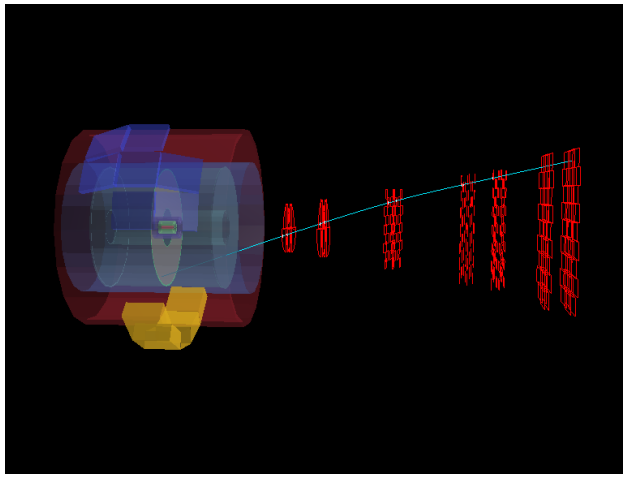


Number of events selected with $\Theta Y > 0 \rightarrow$ 5876

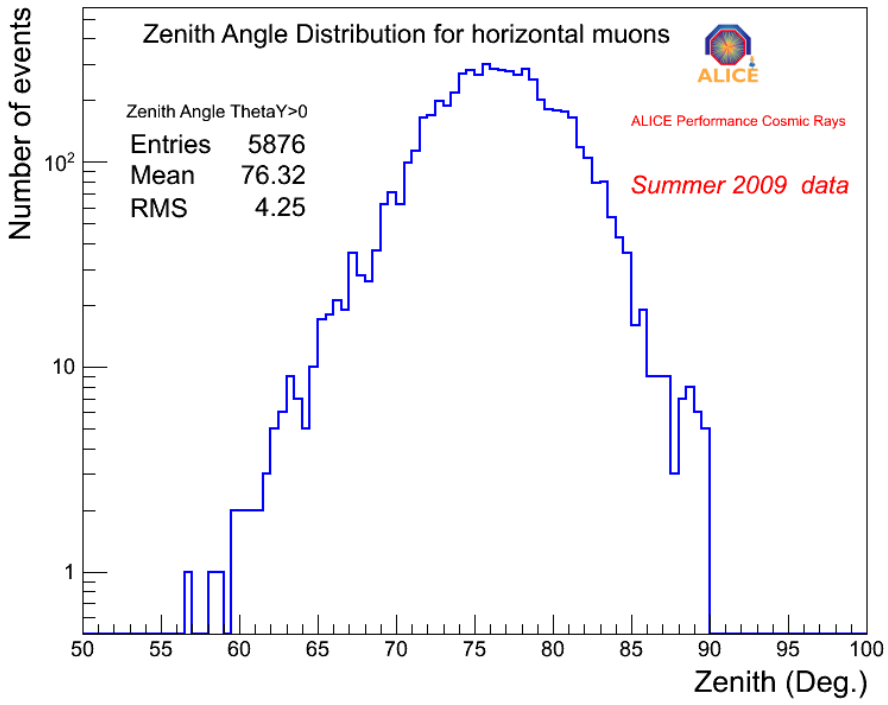


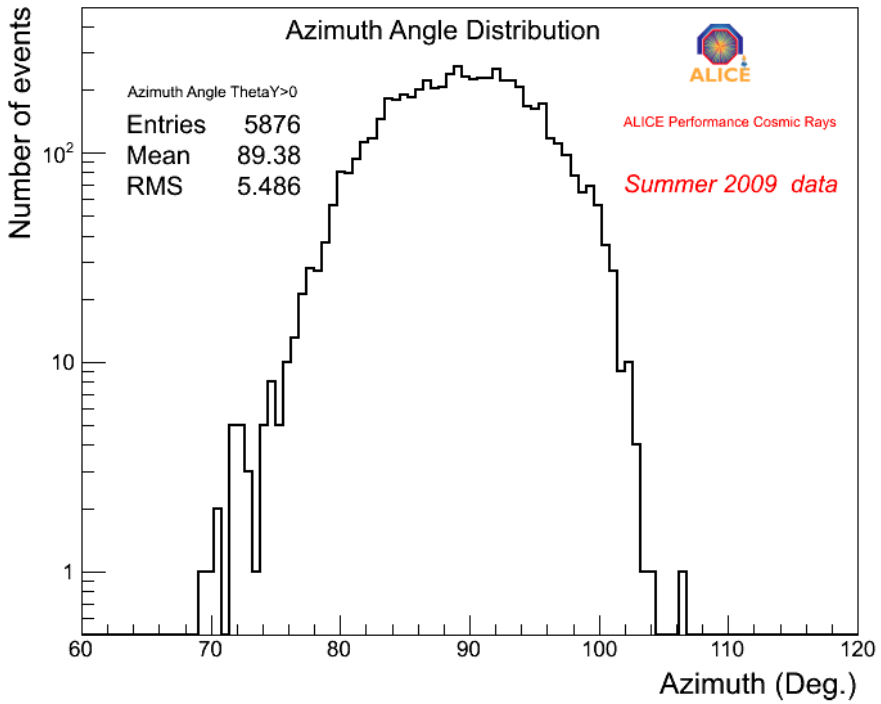



# Selecting events according zenith & azimuth angular efficiencies

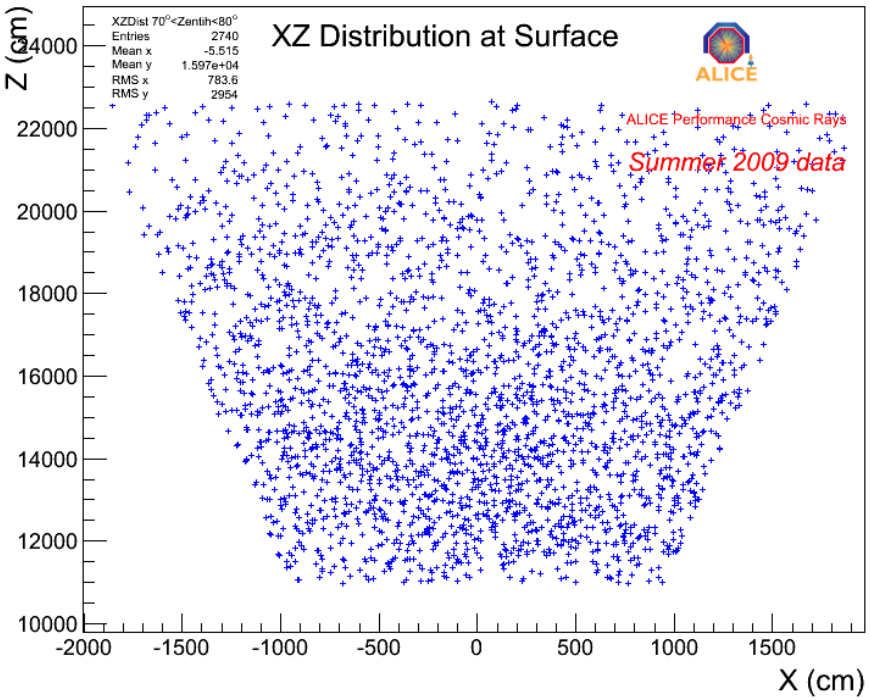
High zenithal efficiency within range $[70^o - 80^o]$




High azimuthal efficiency within range $[85^o - 95^o]$



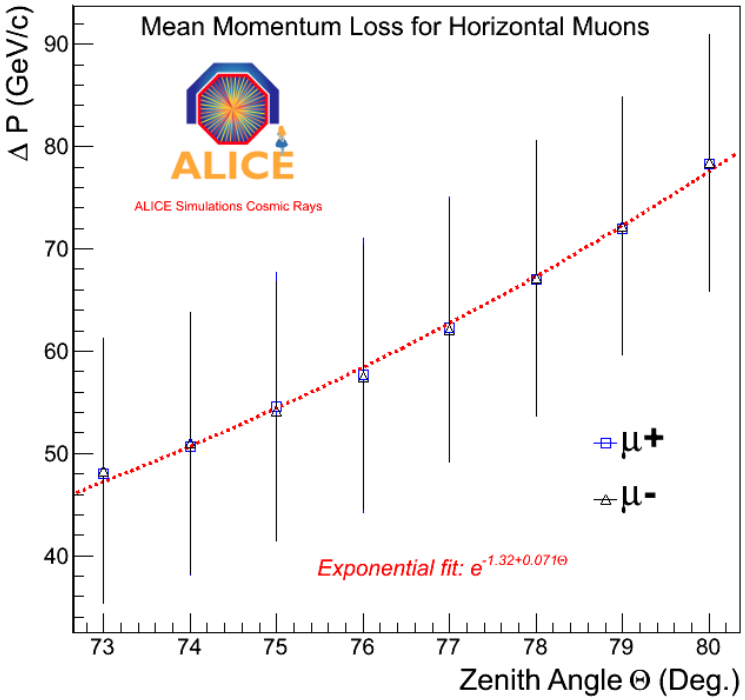
# Spatial distribution at surface



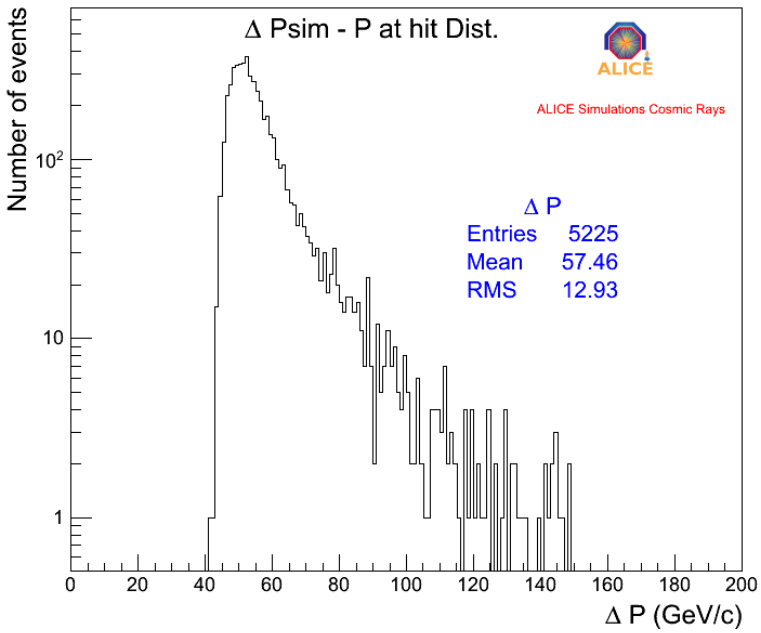

Taking into account high zenith and azumithal efficiencies we loss $\sim$47% of the selected events

- Muon tracks were extrapolated up to the surface at 40 m
- We got a selected area $\rightarrow$ 3900 $m^2$ at surface
- Slant depth $\rightarrow$ from $\sim$ 118 m to $\sim$ 230 m (from surface till ALICE level)

# Energy loss (MC simulations)

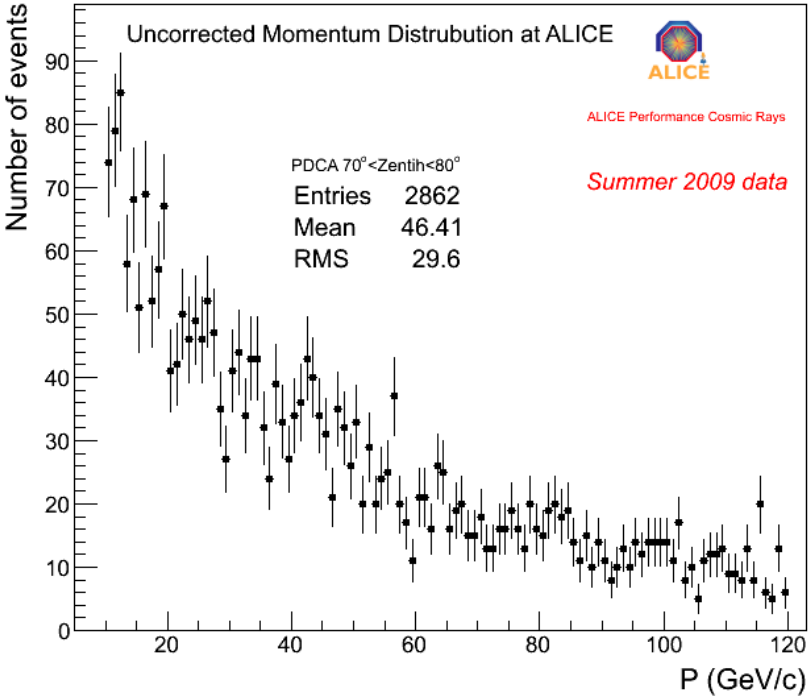



- In Total 80000 $\mu$ were simulated from surface (P = 150 GeV/c & P = 100 GeV/c)
- below, the P loss distribution for zenith angle $76^o$

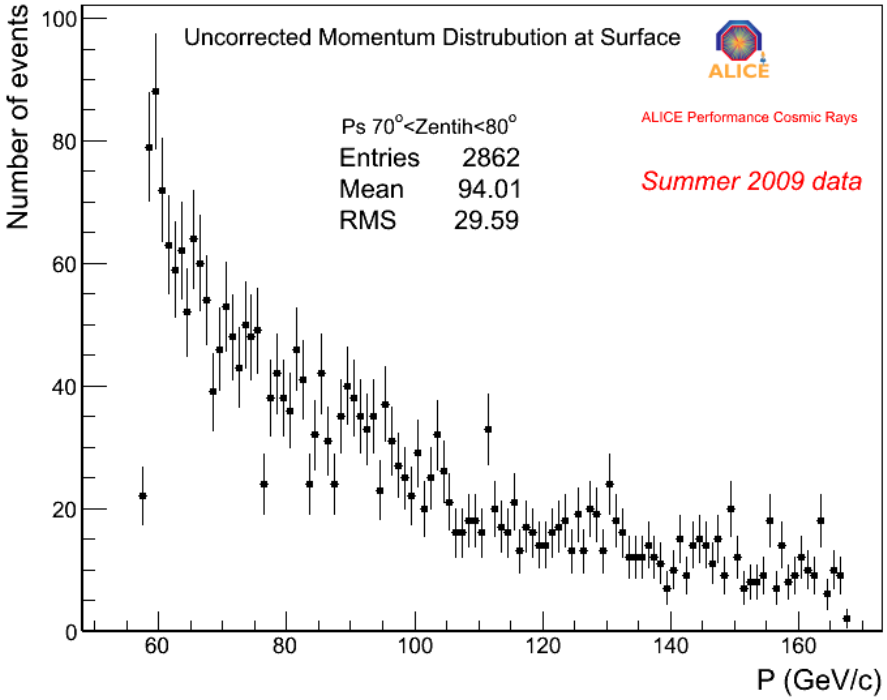



- $< \Delta Ploss >$ of P Simulated at surface - P at muon chambers distribution
- Energy loss from $\sim$ 50 to 80 GeV

# Uncorrected muon momentum distribution ($70^o - 80^o$)



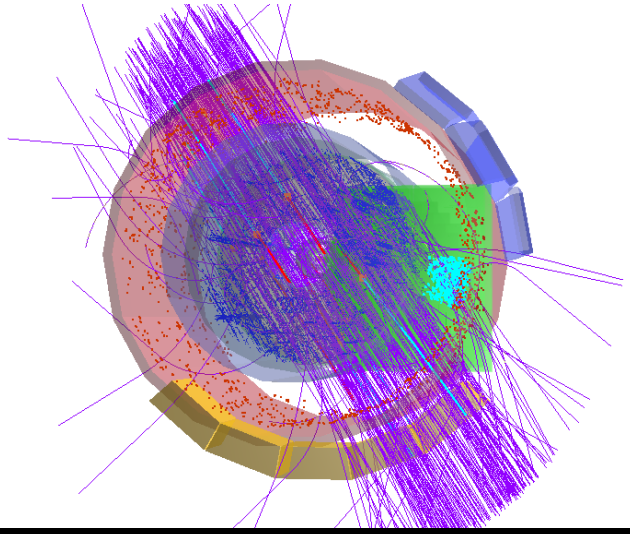

ALICE LEVEL



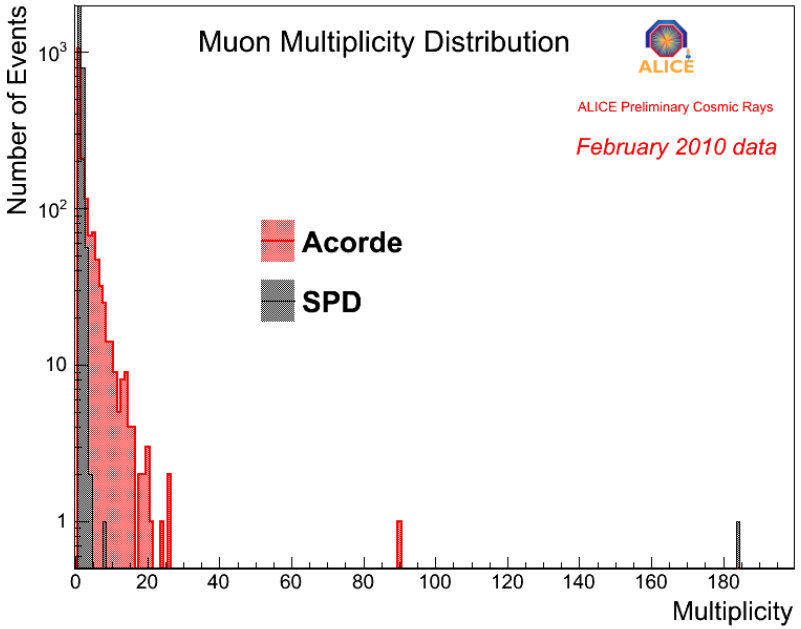

SURFACE LEVEL

# Data sample february 2010

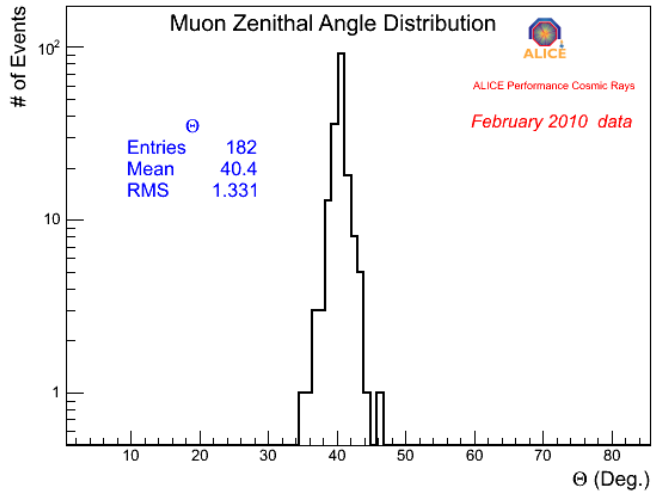
| # Run | Time [h] | Rec. Pass2 [%] | # Events SCO AMU | # Events Mu > 0 SCO AMU | Rate Mu >0 SCO [Hz] | Rate Mu > 0 AMU [Hz] |
|---|---|---|---|---|---|---|
| 109432 | 12.9 | 100 | 11070 | 6043 | 0.12 | 0.01 |
| 109477 | 3.4 | 100 | 3010 | 1653 | 0.12 | 0.01 |
| 109547 | 5.2 | 100 | 4601 | 2476 | 0.12 | 0.01 |
| 109576 | 2.3 | 100 | 2032 | 1075 | 0.12 | 0.01 |
| 109580 | 4.6 | 100 | 3732 | 1985 | 0.11 | 0.01 |
| 110499 | 4.8 | 100 | 2604 | 1869 | 0.10 | 0.003 |
| 110519 | 1.4 | 100 | 643 | 460 | 0.10 | 0.002 |
| 110520 | 7.3 | 100 | 4679 | 3305 | 0.12 | 0.004 |
| 110651 | 4.2 | 100 | 2610 | 1846 | 0.12 | 0.004 |
| 110865 | 6.3 | 100 | 13595 | 4353 | 0.19 | 0.004 |
| TOTAL | 52.4 | | 48576 | 25065 | | |

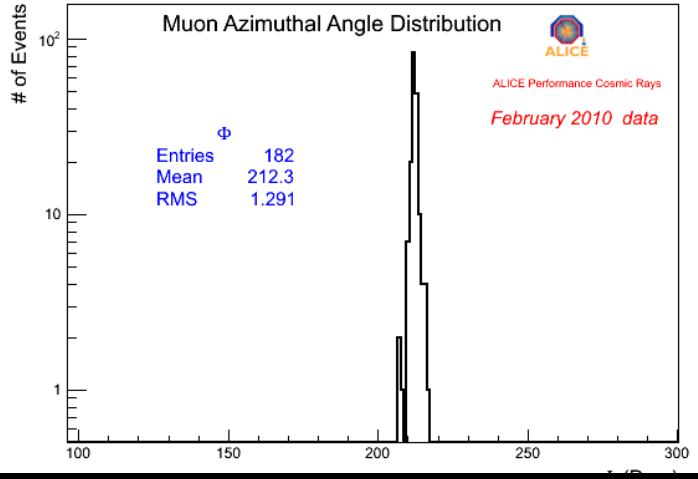


- Trigger type $\rightarrow$ SPD SCO
- ACORDE AMU
- Time: $\sim$ 2.2 effective days
- Very high multiplicity was observed 182 muons



# Very high muon multiplicity found (event: 6353)

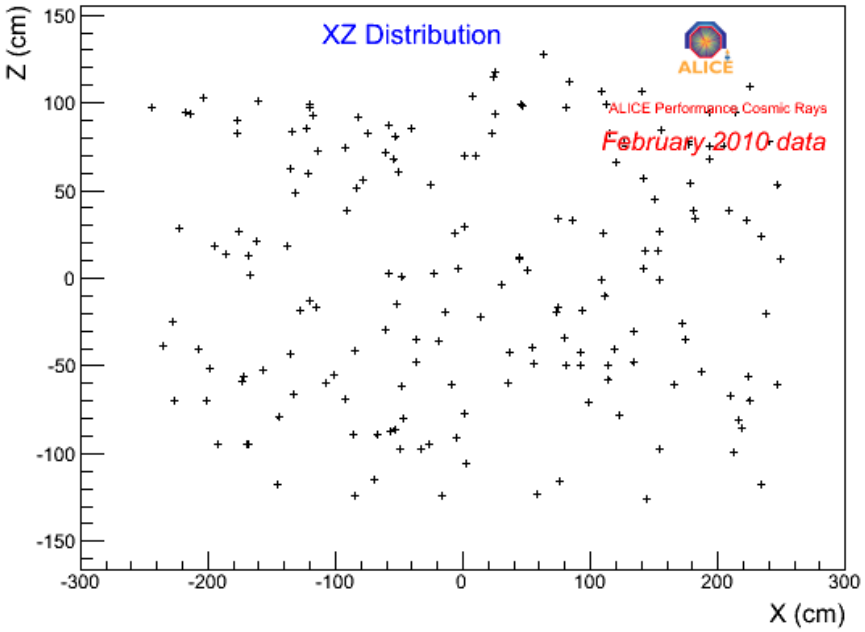


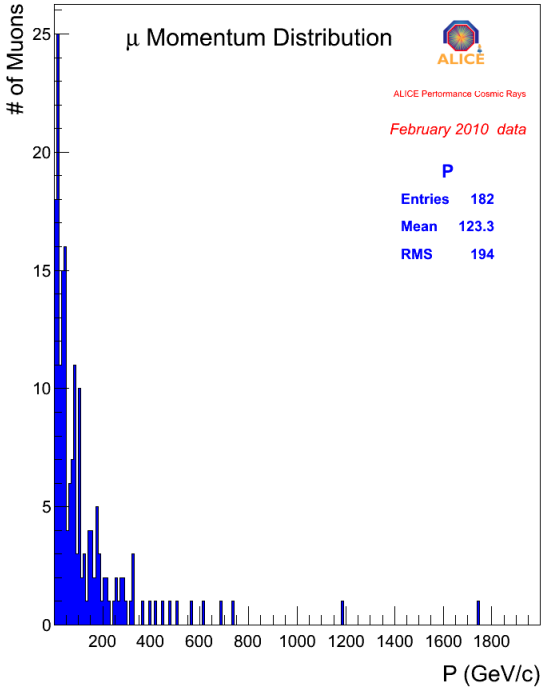




## Main characteristics

- Time Run: 11519 $\sim$ 1.04 h
- Chunk id $\rightarrow$ 110519022.20
- # Tracks $\rightarrow$ 459
- Multiplicity (Pass 2) $\rightarrow$ 182 $\mu$
- # Muons with matched tracks (Up&Down) $\rightarrow$ 121 $\mu$
- Mean Zenith direction $\sim 40^o$
- Mean Azimuth direction $\sim 212^o$

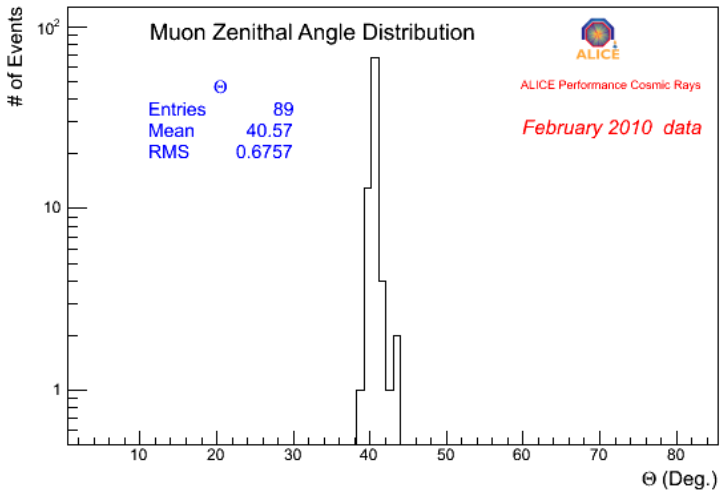
# Spatial and momentum distribution



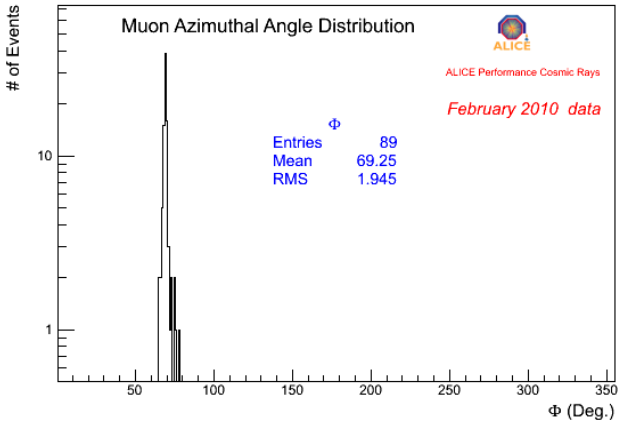

- Area $\sim$ 15 $m^2$
- Local Density of Muons (LDM) $\sim$ 12 $\mu/m^2$
- Mean momentum $\sim$ 123 GeV/c

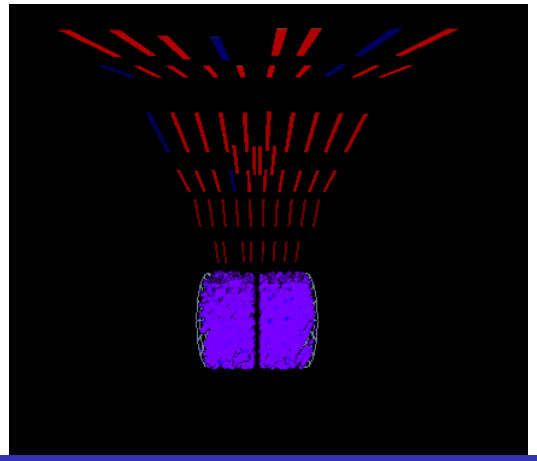
# Very high muon multiplicity found (event: 3723)



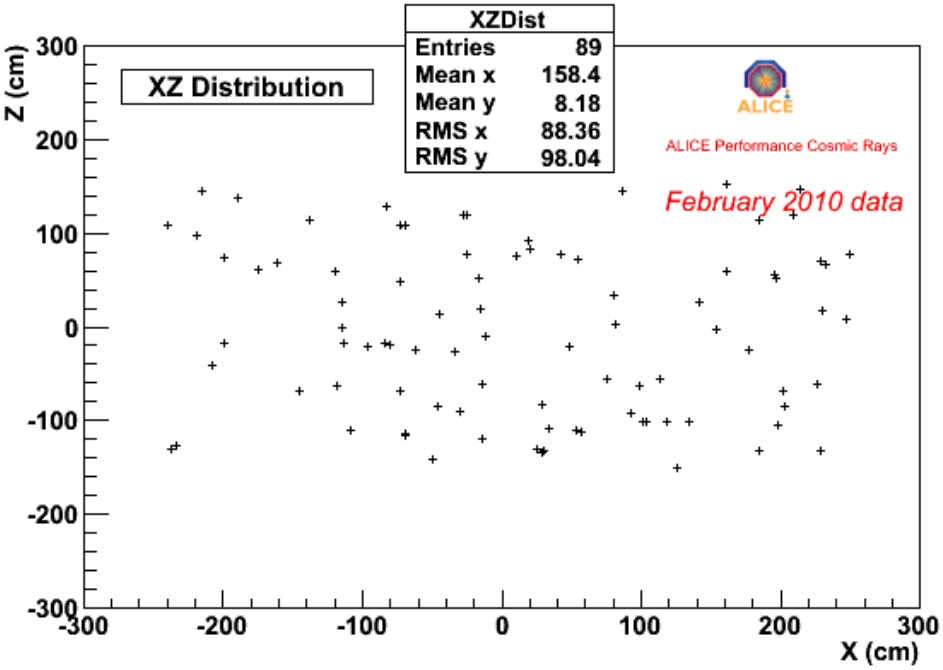

## Main characteristics

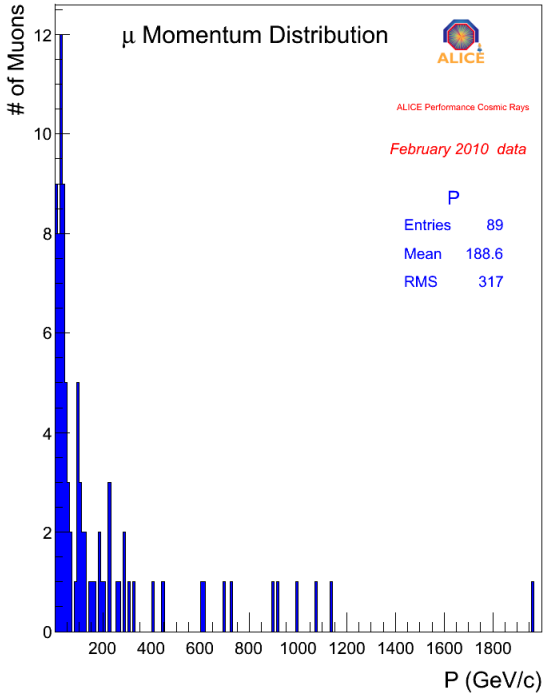
- Time Run: 109547 $\sim$ 5.2 h
- Chunk id $\rightarrow$
- # Tracks $\rightarrow$ 182
- Multiplicity (Pass 2) $\rightarrow$ 89 $\mu$
- # Muons with matched tracks (Up&Down) $\rightarrow$ 42 $\mu$
- Mean Zenith direction $\sim 41^o$
- Mean Azimuth direction $\sim 69^o$



# Spatial and momentum distribution




- Area $\sim$ 15 $m^2$
- Local Density of Muons (LDM) $\sim$ 6 $\mu/m^2$
- Mean momentum $\sim$ 189 GeV/c

# Muon multiplicity & density related with primary energy

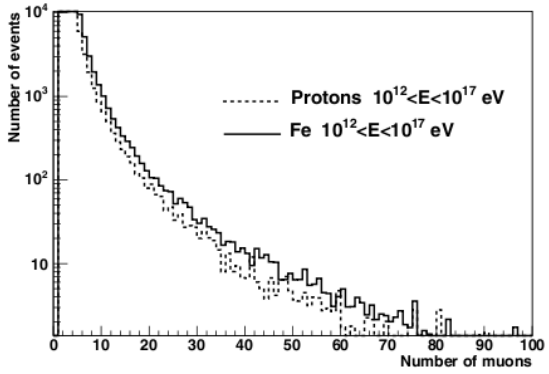
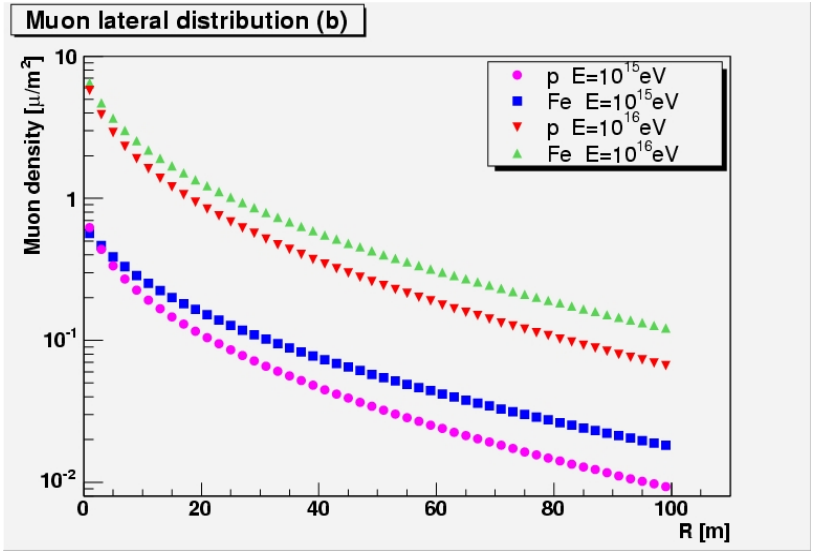



**Figure 6.462.** Comparison of the muon multiplicity distribution in ALICE in 30 days of data taking for pure proton and pure iron composition.




- Simulation muon multiplicity studies was done with primaries (p,Fe) within energy range $10^{12} < E < 10^{17}$ eV
- Maximum multiplicities observed $\sim$ 100 $\mu$ for 30 live days of data taking
- Real data: local Density of Muons (LDM) $\sim$ 12 $\mu/m^2$ Ev: 6353 182 muons Eprimary $> 10^{16}$
- Real data: local Density of Muons (LDM) $\sim$ 6 $\mu/m^2$ Ev: 3723 89 muons $>= 10^{16}$
- This kind of events are rare, with a frequency less than $\sim$ 1 each 3 years

# Conclusions

- We have analyzed all the cosmic data available, with the B = 0.5 T (Summer 2009-Feb. 2010).
- We can Study atmospheric muons with central detectors (vertical muons) as well as with the forward muon spectrometer detector (horizontal muons).
- It's possible measure: number of muons, momentum, charge, direction.
- Corrections in the measurement of the ratio $\mu^+/\mu^-$ for vertical muons $(0^o - 20^o)$ as well as for horizontal muons $(70^o - 80^o)$ is in progress.
- Study and search events with very high muon multiplicity can be a test for hadron interaction models.