Physics Snacks @ STP 2023

Measurement of the charge asymmetry of atmospheric muons with the CMS detector

The Charge Ratio Analysis Team

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Cosmic rays

Cosmic rays from outer space routinely bombard the earth and its atmosphere with energies up to 10^{20} eV.

Atmospheric Muons

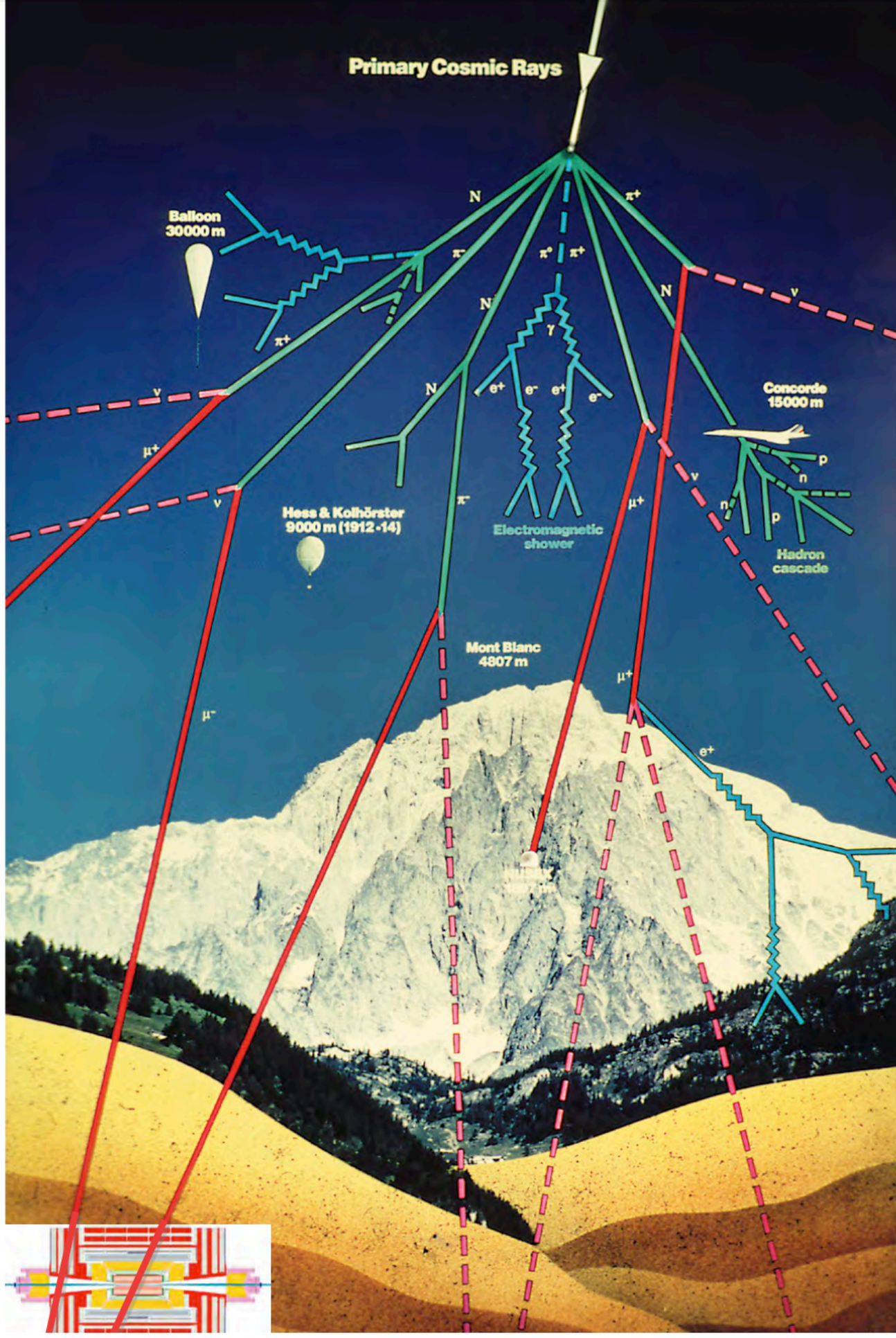
Stem from cosmic ray showers, produced via interactions of high-energy cosmic-ray particles (nuclei), entering the upper layers of the atmosphere, with air nuclei:

(p, He, ..., Fe) → hadrons, $e^{\pm}\gamma$

$(\pi^{\pm}, K^{\pm})$ → $\mu^{\pm}$ ν_μ ($\bar{\nu}_\mu$) and

$\mu^{\pm}$ → $e^{\pm}$ ν_e $\bar{\nu}_\mu$ ($\bar{\nu}_e$ ν_μ)

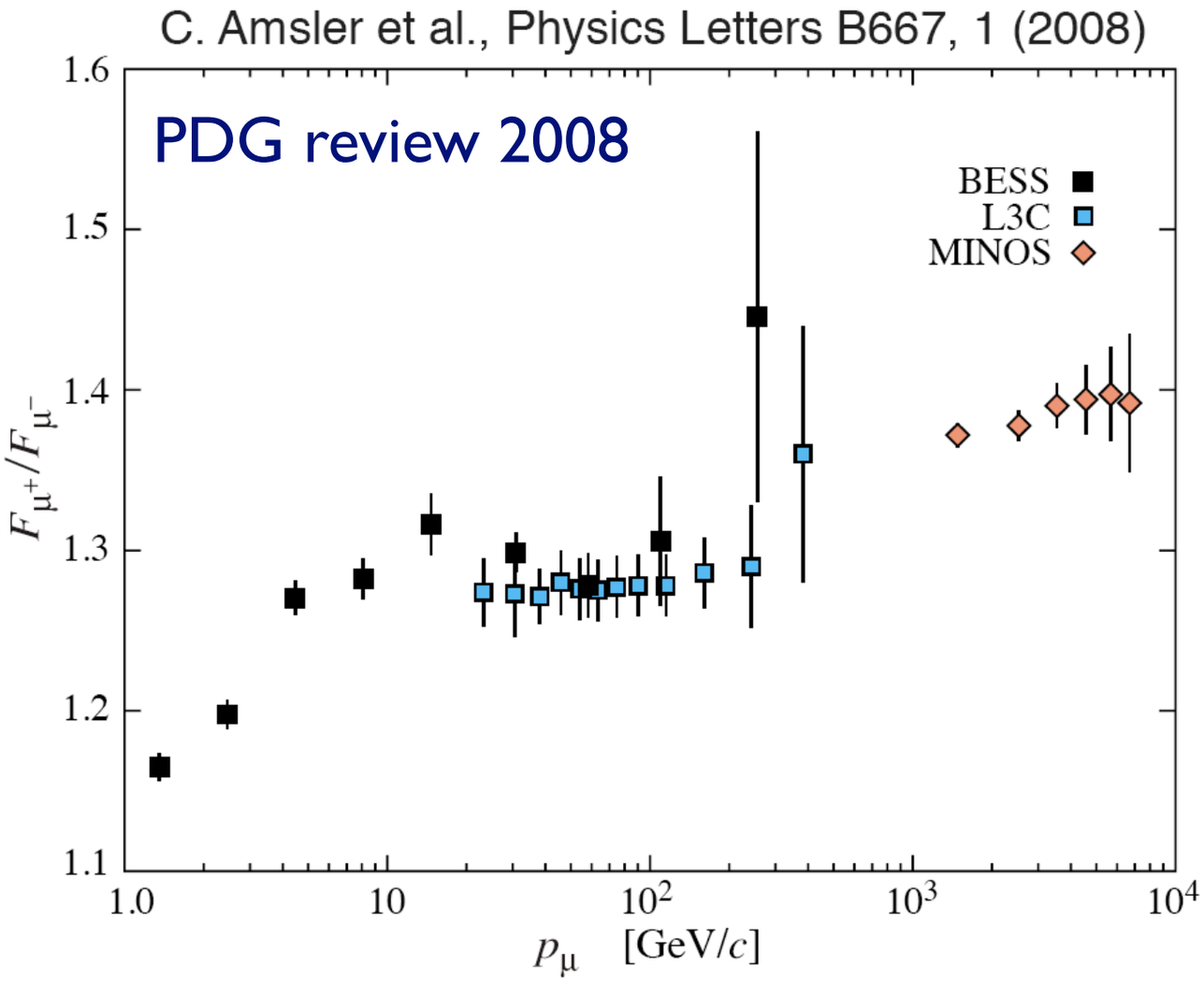
Long-lived muons cross the overburden and reach CMS.



Charge ratio of atmospheric muons

- Ratio of μ^+ over μ^- reflects excess of π^+ vs π^- and K^+ vs K^-.
- Above critical momentum of 115 GeV/c pions start to interact before they decay (850 GeV/c for Kaons) → predicts a change in charge ratio between 0.1 and 1 TeV.
- The momentum range 0.2 to 1 TeV/c is sparsely covered by measurements.

Previous measurements

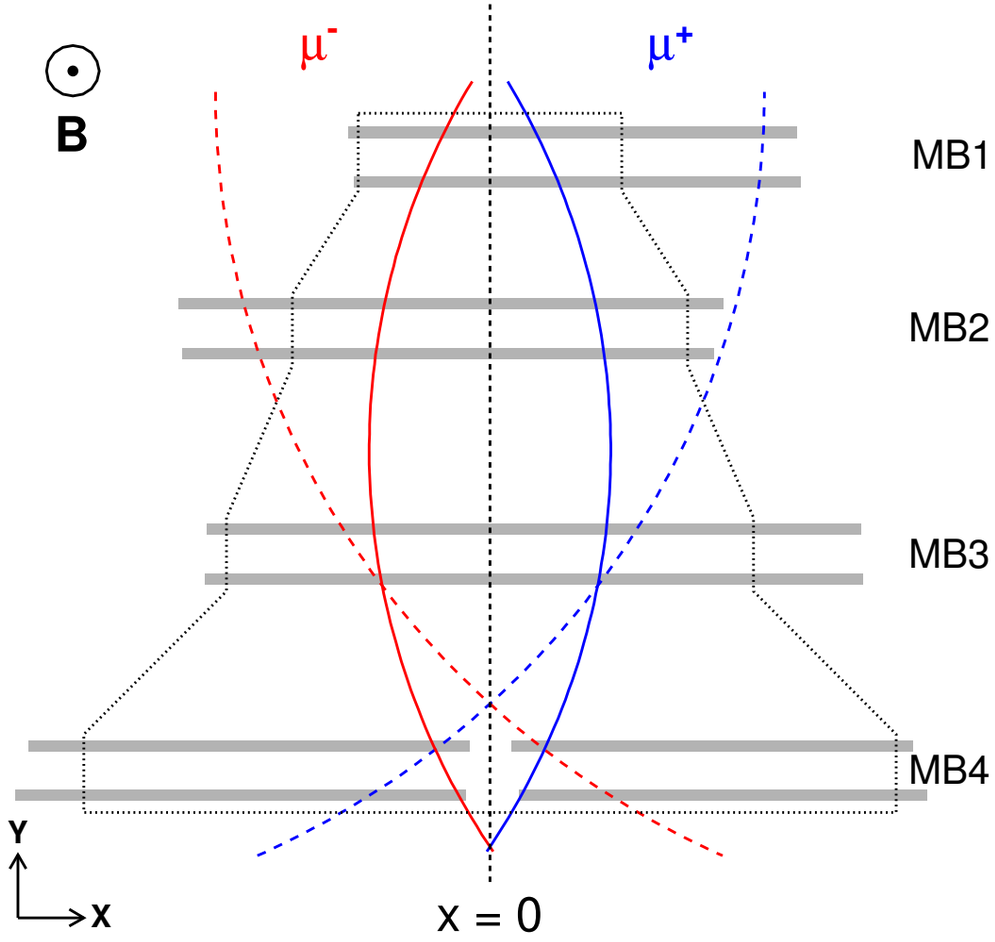


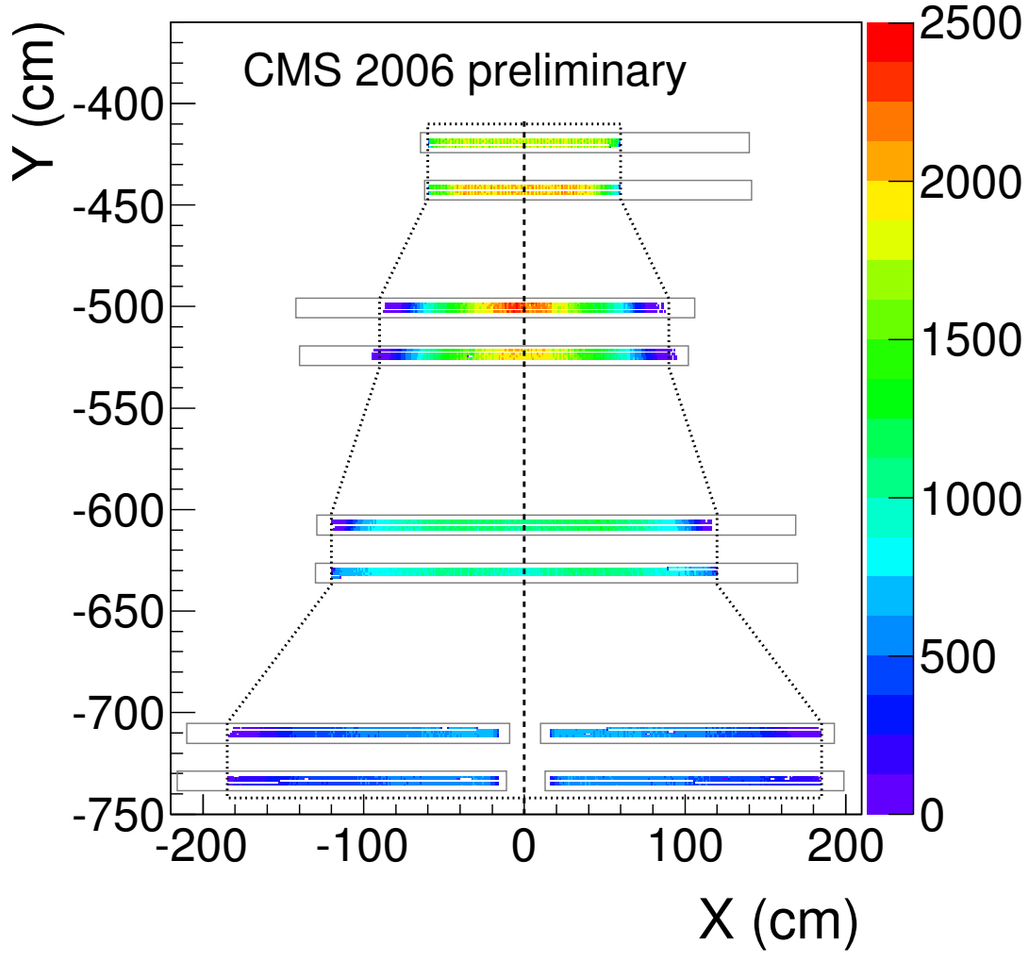
Constrains models of cosmic showers. Important for understanding atmospheric neutrinos.

MTCC analysis

Uses a perfectly left-right symmetric fiducial volume: equal acceptance for μ^+ and μ^- (trigger and reconstruction). Only hits inside the fiducial volume are accepted (symmetric illumination plot).

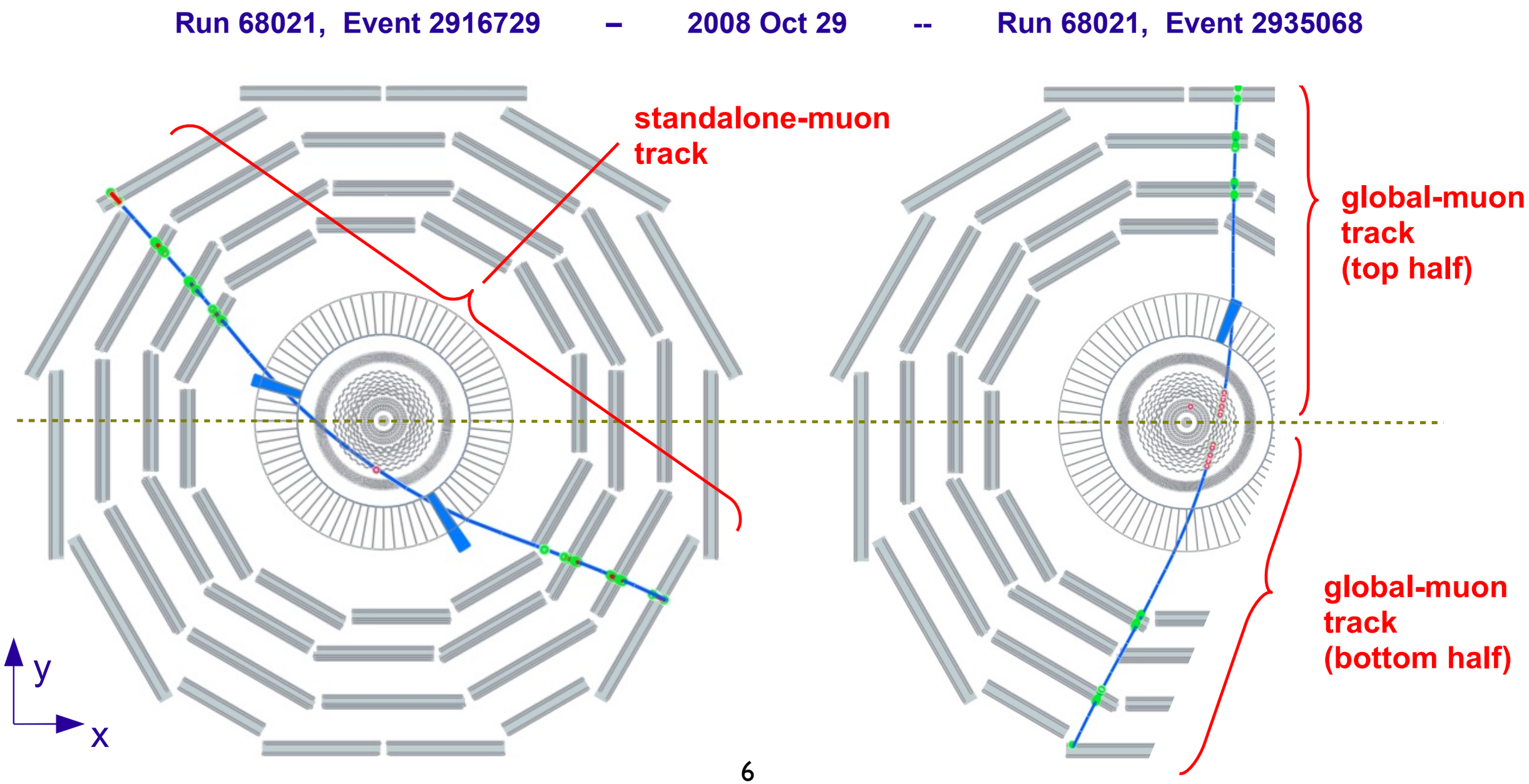
Same selection as in CMS Note 2008/016: fiducial volume and track quality cuts.





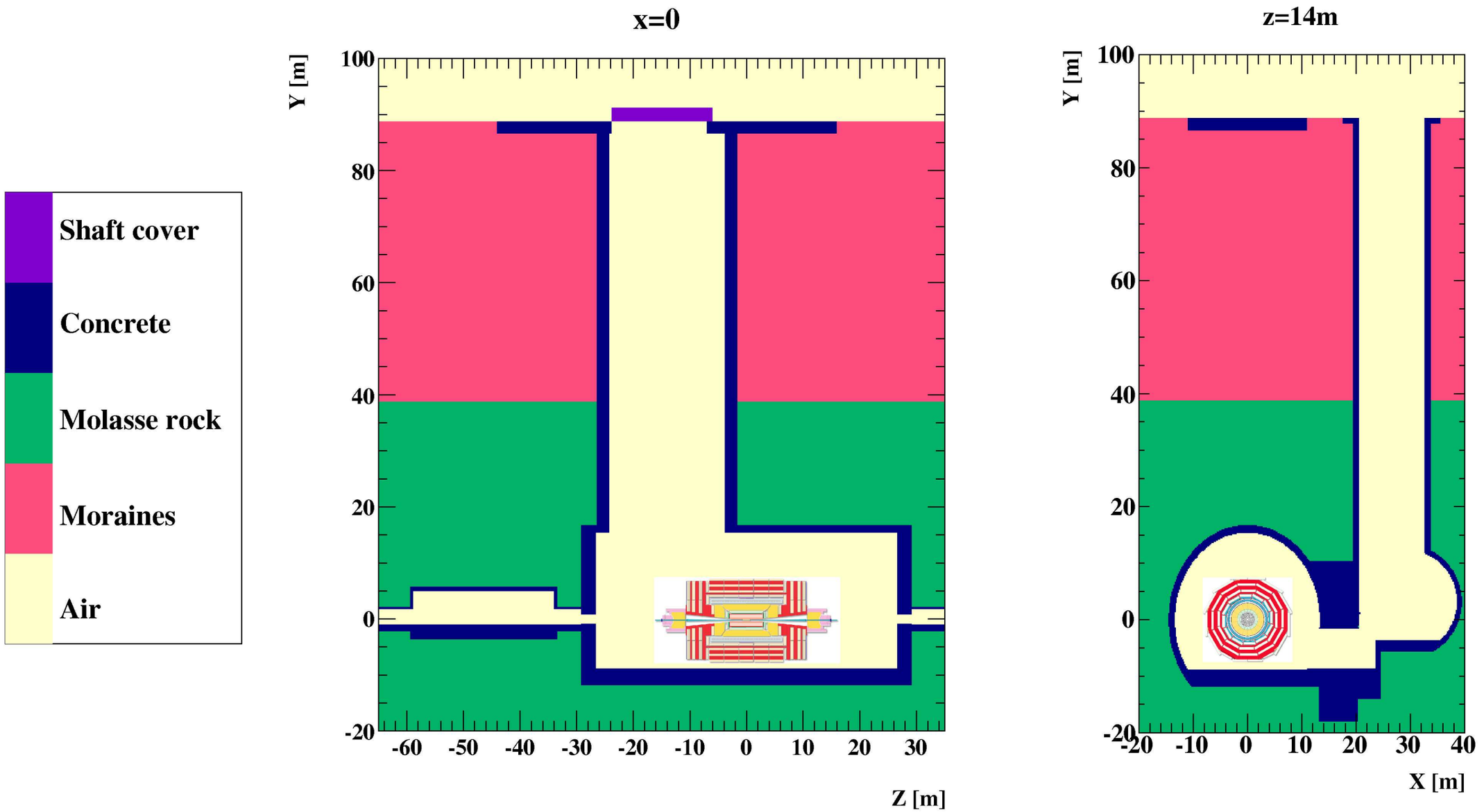
Cosmic-muon events

Cosmic muons crossing the CMS detector from top to bottom, recorded in CRAFT08, leave signals in the muon system, tracking detectors and calorimeters.



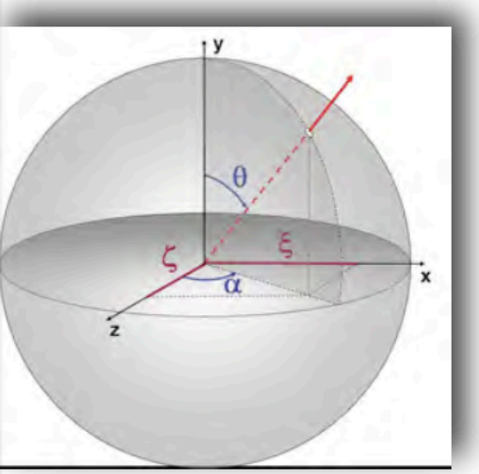
Propagation to the Earth's surface

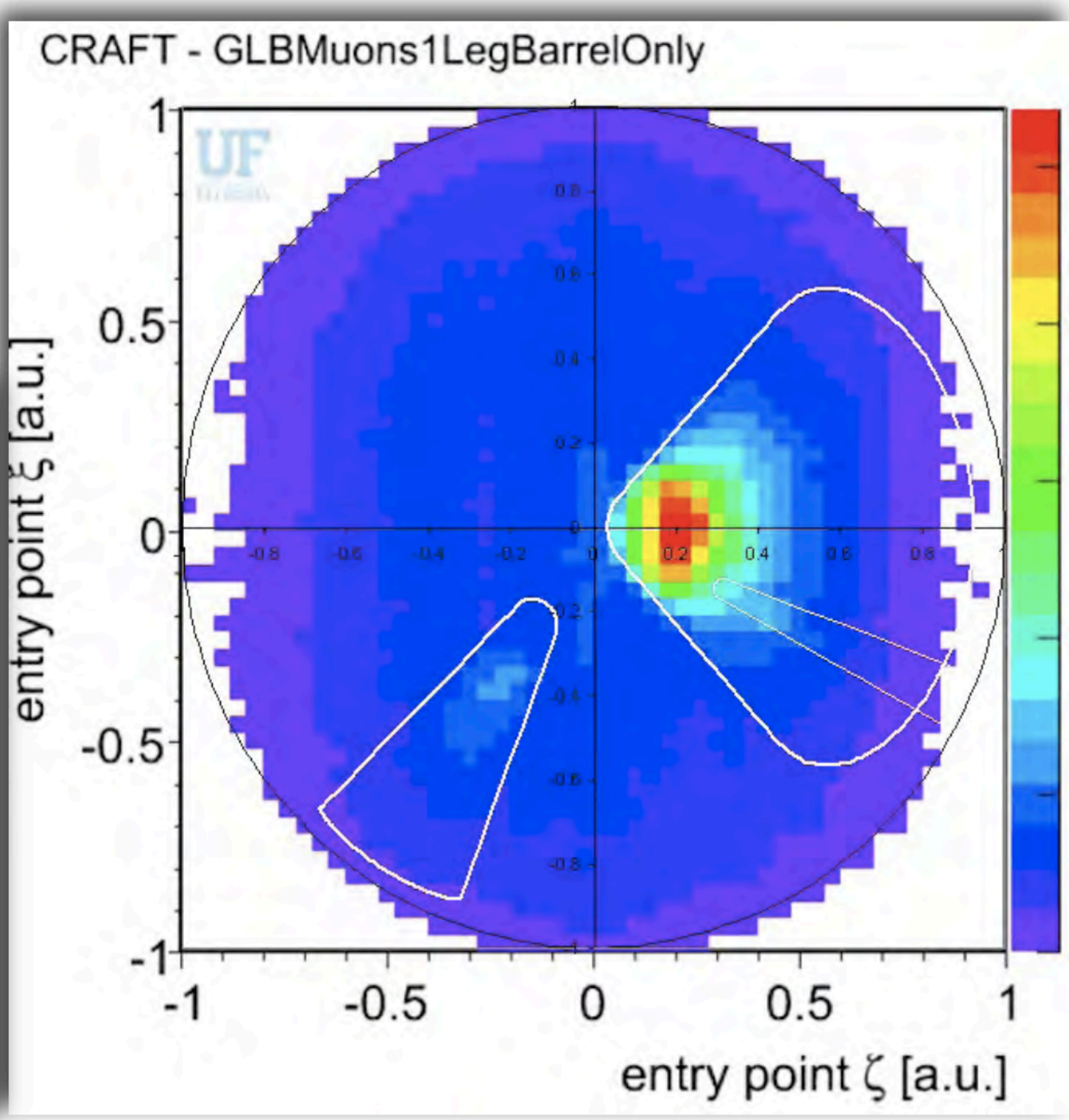
Material map used in CMS cosmic muon generator to calculate the expected energy loss of muons, along straight line extrapolation from Earth surface to surface of CMS.

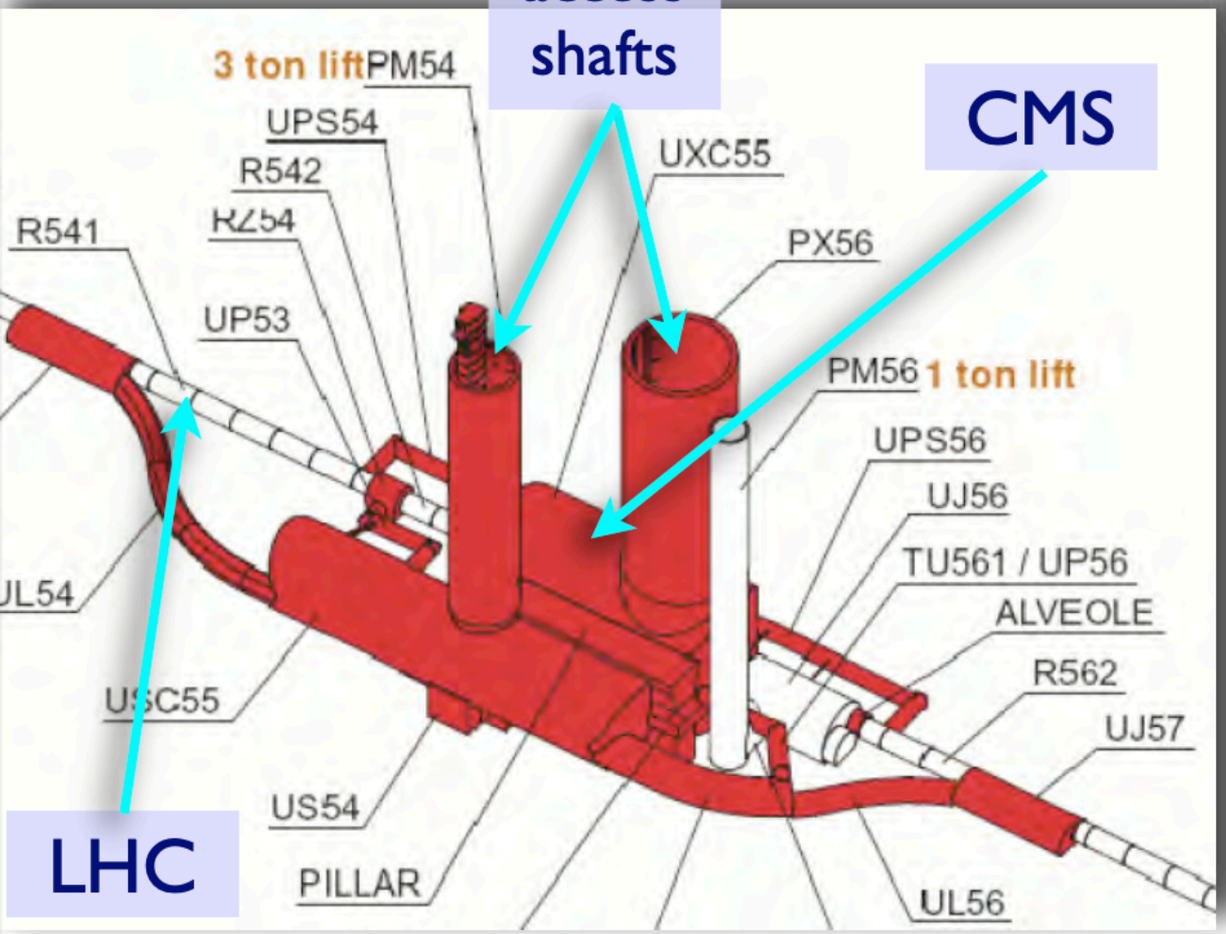


Exposure of CMS

Incidence of cosmic muons as seen from IP. Relevant for astrophysics studies.







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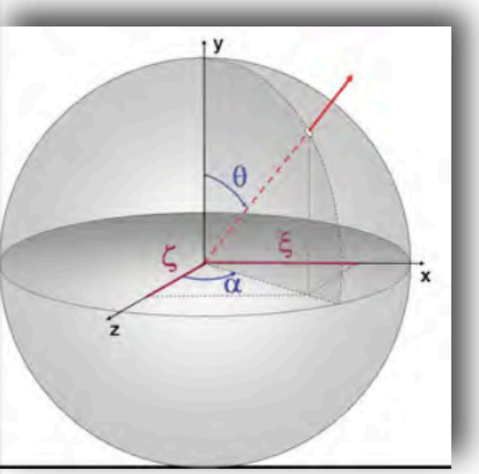
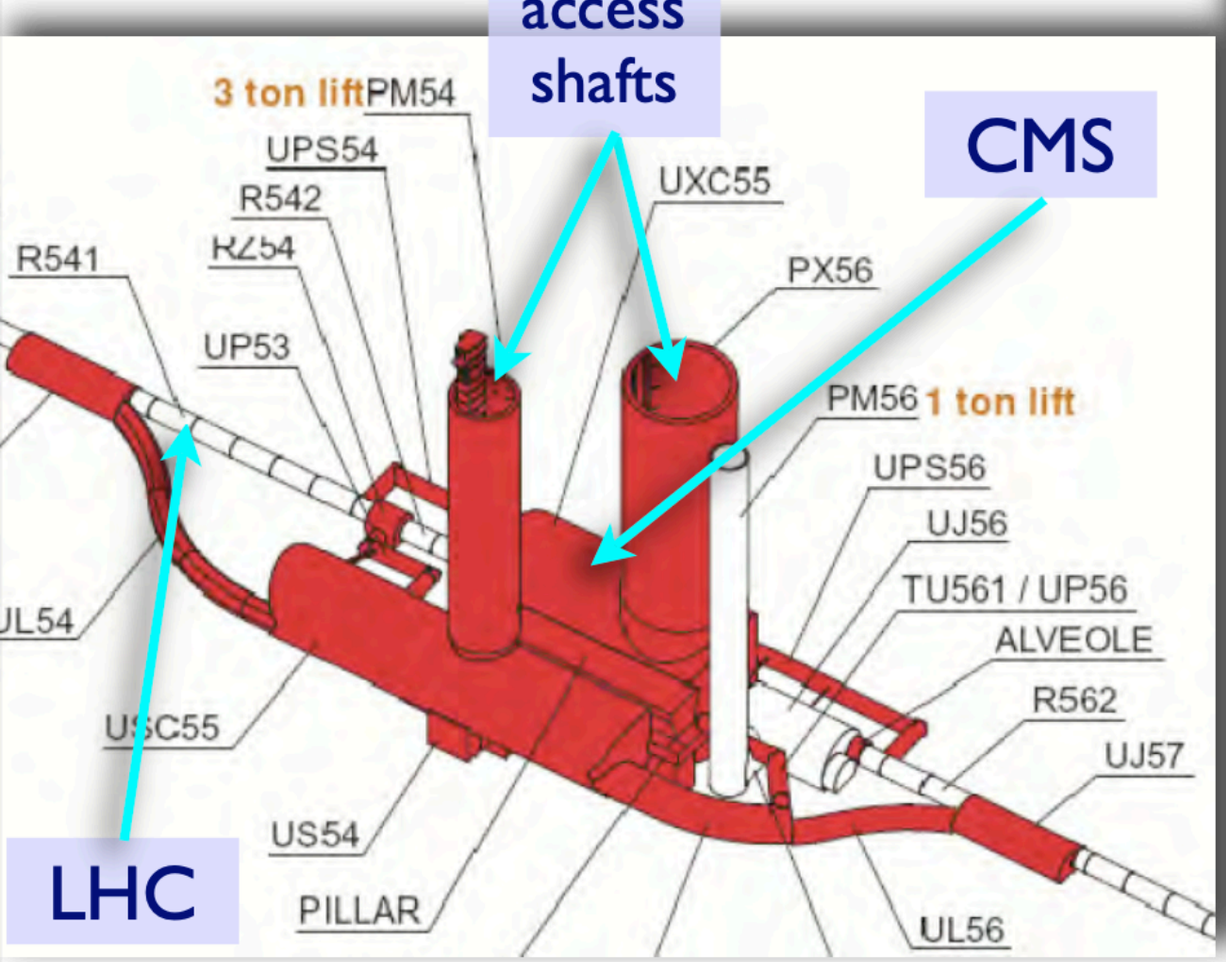




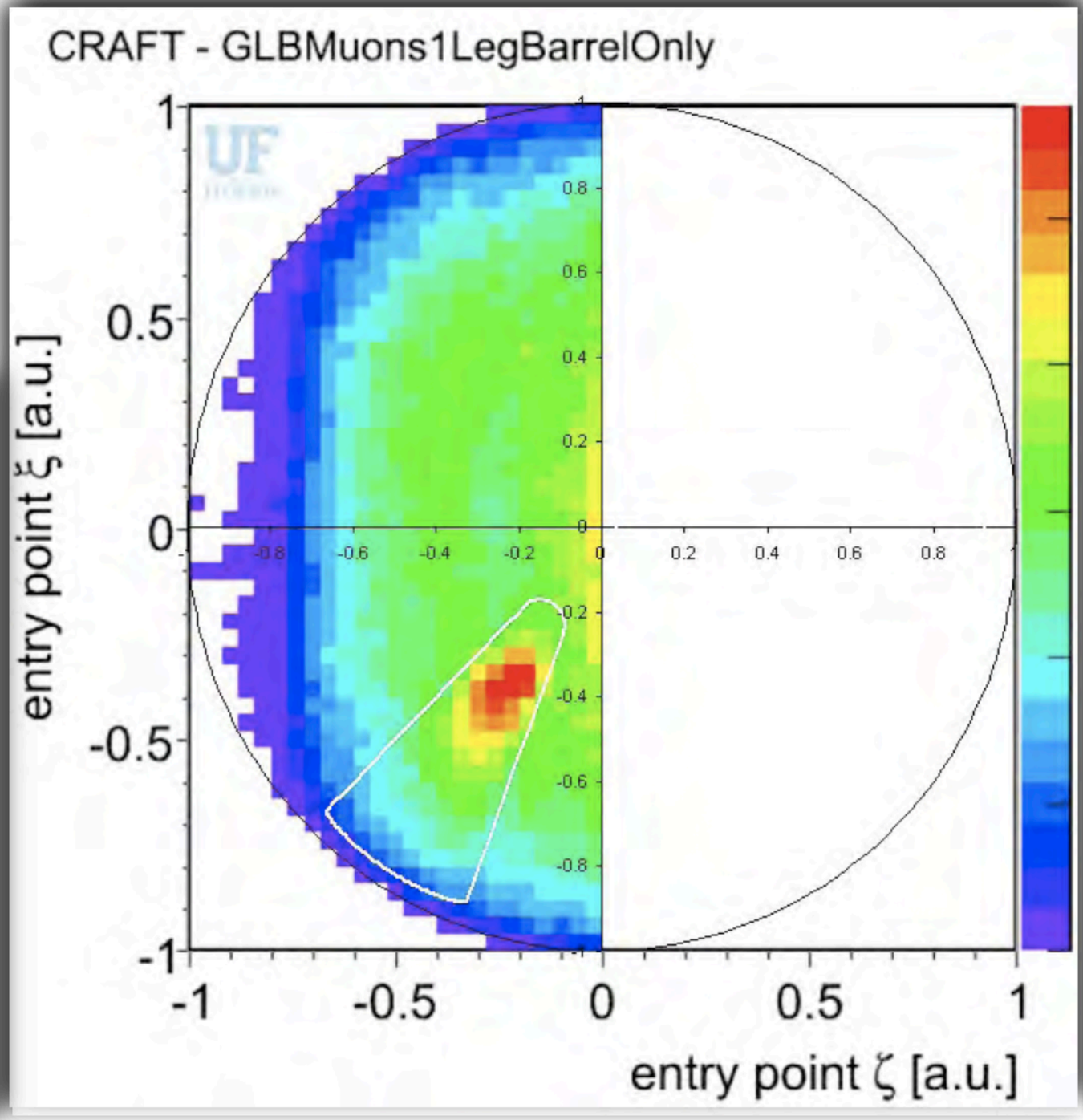


Table 3: systematic uncertainties

Table 3: Charge ratio and relative statistical and systematic uncertainties as a function of p and $p \cdot \cos\theta_z$ for the global- and standalone-muon fits. The $\pm$ and $\mp$ signs indicate the bin-to-bin correlation and anti-correlation, respectively, within a given source of systematic uncertainty.

global

				global-muon σ/R (%)						
p range (GeV/c)	R	stat.	syst.	selection	alignment	B field	trigger	rates	rock	scale
30 - 50	1.268	1.15	2.13	$\pm$1.59	$\mp$0.10	$\pm$0.20	$\mp$0.47	$\pm$1.30	$\mp$0.26	$\mp$0.04
50 - 70	1.302	1.22	0.63	$\pm$0.45	$\pm$0.01	$\mp$0.01	$\mp$0.25	$\pm$0.10	$\mp$0.35	$\mp$0.07
70 - 100	1.274	0.87	0.74	$\pm$0.14	$\pm$0.10	$\pm$0.01	$\mp$0.10	$\pm$0.10	$\pm$0.70	$\mp$0.03
100 - 200	1.280	0.83	0.33	$\pm$0.25	$\mp$0.08	$\mp$0.16	$\mp$0.01	$\pm$0.10	$\mp$0.04	$\mp$0.08
200 - 400	1.295	1.60	1.25	$\pm$0.59	$\mp$0.22	$\pm$0.44	$\pm$0.14	$\pm$0.10	$\pm$0.84	$\pm$0.48
400 - ∞	1.349	3.53	3.48	$\pm$1.01	$\mp$0.99	$\mp$2.55	$\pm$0.59	$\pm$0.10	$\pm$1.21	$\pm$1.33
				global-muon σ/R (%)						
$p \cdot \cos\theta_z$ range (GeV/c)	R	stat.	syst.	selection	alignment	B field	trigger	rates	rock	scale
30 - 50	1.265	1.11	1.96	$\pm$1.25	$\mp$0.00	$\pm$0.10	$\pm$0.46	$\pm$1.39	$\mp$0.36	$\mp$0.05
50 - 70	1.280	0.85	1.00	$\pm$0.85	$\pm$0.10	$\mp$0.07	$\pm$0.09	$\pm$0.03	$\pm$0.51	$\mp$0.07
70 - 100	1.281	0.89	0.73	$\pm$0.48	$\mp$0.43	$\mp$0.13	$\pm$0.12	$\pm$0.03	$\mp$0.27	$\mp$0.10
100 - 200	1.291	1.04	0.60	$\pm$0.19	$\pm$0.18	$\pm$0.18	$\pm$0.02	$\pm$0.03	$\pm$0.49	$\pm$0.13
200 - 400	1.336	2.52	1.90	$\pm$1.16	$\pm$0.93	$\mp$0.67	$\pm$0.09	$\pm$0.03	$\pm$0.47	$\pm$0.86
400 - ∞	1.440	6.39	4.68	$\pm$1.76	$\pm$0.58	$\mp$2.39	$\mp$0.44	$\pm$0.03	$\pm$0.44	$\pm$3.52

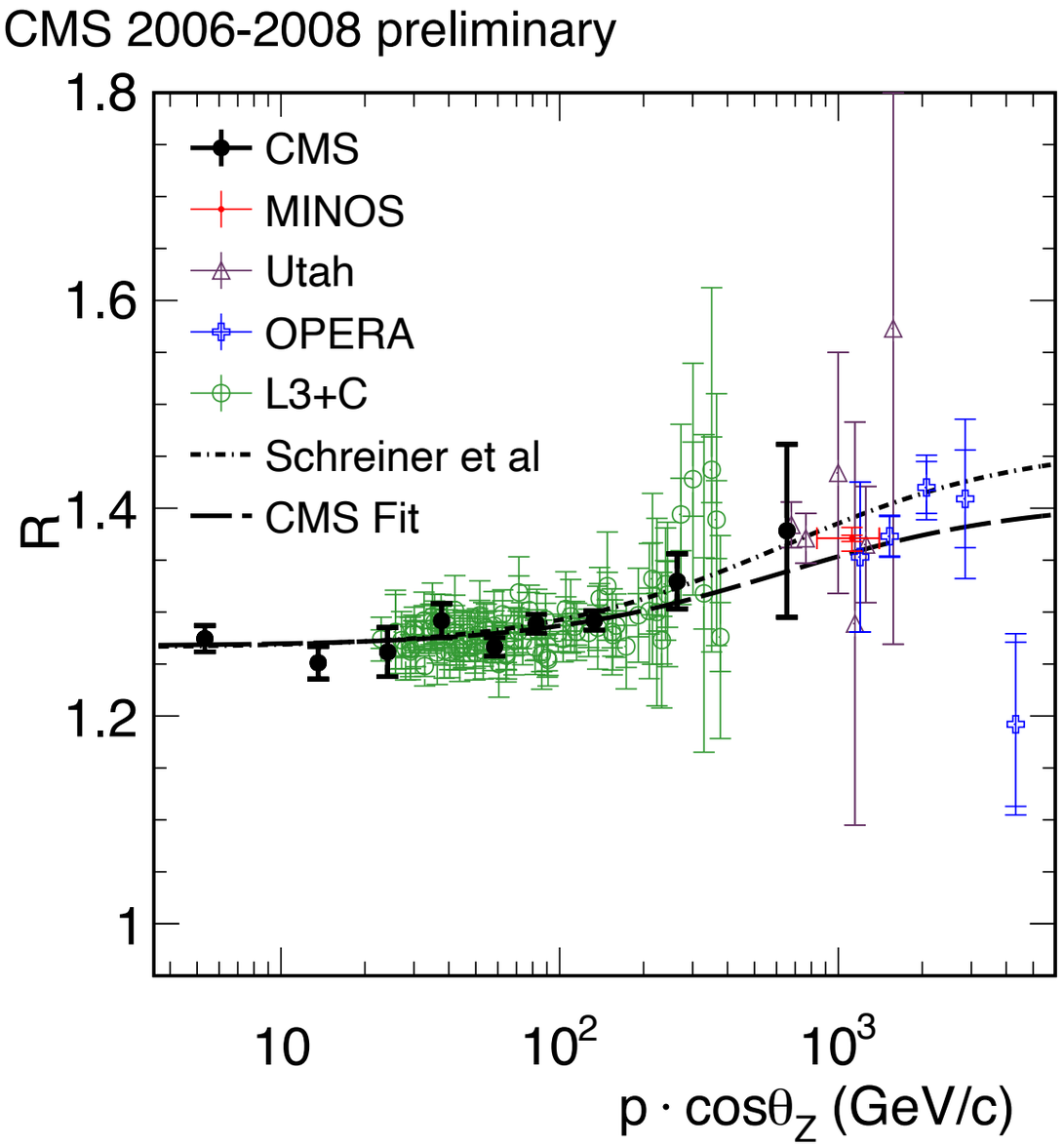
standalone

				standalone-muon σ/R (%)							
p range (GeV/c)	R	stat.	syst.	selection	alignment	B field	trigger	rates	rock	scale	ch. mis.
30 - 50	1.287	0.5	1.5	$\pm$0.26	$\pm$0.24	$\pm$0.22	$\mp$0.43	$\pm$1.30	$\mp$0.26	$\mp$0.05	$\pm$0.02
50 - 70	1.274	0.5	0.8	$\pm$0.07	$\pm$0.29	$\pm$0.07	$\mp$0.34	$\pm$0.10	$\mp$0.35	$\mp$0.06	$\pm$0.02
70 - 100	1.272	0.4	0.9	$\pm$0.09	$\pm$0.20	$\pm$0.14	$\mp$0.15	$\pm$0.10	$\pm$0.70	$\mp$0.06	$\pm$0.02
100 - 200	1.298	0.3	0.6	$\pm$0.08	$\pm$0.54	$\pm$0.03	$\mp$0.07	$\pm$0.10	$\mp$0.04	$\mp$0.01	$\pm$0.02
200 - 400	1.305	0.8	1.4	$\pm$0.28	$\pm$0.12	$\mp$0.70	$\pm$0.07	$\pm$0.10	$\pm$0.84	$\pm$0.60	$\pm$0.21
400 - ∞	1.350	2.2	6.0	$\pm$0.28	$\mp$3.44	$\mp$1.21	$\mp$0.18	$\pm$0.10	$\pm$0.76	$\pm$3.01	$\pm$1.94
				standalone-muon σ/R (%)							
$p \cdot \cos\theta_z$ range (GeV/c)	R	stat.	syst.	selection	alignment	B field	trigger	rates	rock	scale	ch. mis.
30 - 50	1.285	0.4	1.7	$\pm$0.24	$\mp$0.66	$\pm$0.15	$\mp$0.44	$\pm$1.39	$\mp$0.36	$\mp$0.06	$\pm$0.02
50 - 70	1.263	0.4	0.9	$\pm$0.11	$\pm$0.41	$\pm$0.15	$\mp$0.27	$\pm$0.03	$\pm$0.51	$\mp$0.08	$\pm$0.02
70 - 100	1.299	0.4	0.9	$\pm$0.07	$\pm$0.72	$\pm$0.15	$\mp$0.10	$\pm$0.03	$\mp$0.27	$\mp$0.08	$\pm$0.03
100 - 200	1.295	0.4	0.7	$\pm$0.03	$\pm$0.32	$\mp$0.31	$\mp$0.01	$\pm$0.03	$\pm$0.49	$\pm$0.14	$\pm$0.02
200 - 400	1.328	1.1	2.2	$\pm$0.24	$\mp$0.88	$\mp$1.18	$\pm$0.03	$\pm$0.03	$\pm$0.47	$\pm$1.17	$\pm$0.47
400 - ∞	1.326	3.3	8.2	$\pm$1.39	$\mp$4.48	$\pm$0.59	$\mp$0.53	$\pm$0.03	$\pm$0.44	$\pm$3.95	$\pm$2.82

Fit results

The CMS result, together with previous measurements, along with a fit of the pion-kaon model to the CMS data. Result from the fit in the region p < 100 GeV/c:

$R = 1.2766 \pm 0.0032(\text{stat}) \pm 0.0032(\text{syst})$, with $\chi^2/\text{d.o.f.} = 7.3/11$



Conclusions

- We have measured the flux ratio of positive- to negative-charge cosmic muons, as a function of the muon momentum, using CMS data.

- We have obtained the most precise measurement to date of the charge ratio in the regions $p \cdot \cos\theta_z < 650$ GeV/c and $p < 850$ GeV/c.

- This measurement implies a good understanding of:
  - muon reconstruction in full p range
  - muon (L1) trigger efficiencies
  - muon tracking alignment, especially at high p remarkable at this early stage of the experiment.

- This is the first muon physics measurement with the complete CMS detector. Also, the first in the TeV region !

We ask for APPROVAL of PAS MUO-10-001

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ABSTRACT

We present a measurement of the ratio of positive to negative muon fluxes from cosmic ray interactions in the atmosphere, using data collected by the CMS detector both at ground level and in the underground experimental cavern at the CERN LHC. Muons were detected in the momentum range from 5 GeV/c to 1 TeV/c. The surface flux ratio is measured to be $1.2766 \pm 0.0032\,(\text{stat.}) \pm 0.0032\,(\text{syst.})$, independent of the muon momentum, below 100 GeV/c. This is the most precise measurement to date. At higher momenta the data are consistent with an increase of the charge ratio, in agreement with cosmic ray shower models and compatible with previous measurements by deep-underground experiments.

Physics Letters B 692 (2010) 83–104