CMS: Cosmic muons in simulation and measured data

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on behalf of the CMS collaboration
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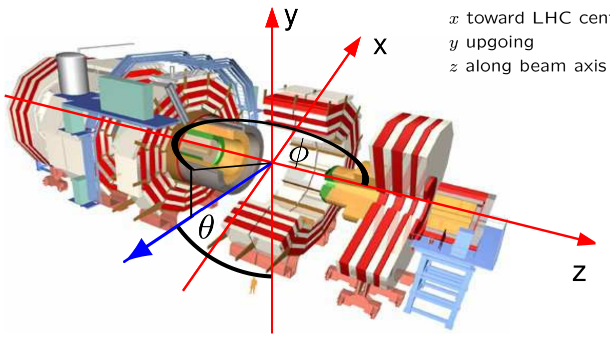
A dedicated cosmic muon Monte-Carlo event generator CMSCGEN has been developed for the CMS experiment. The simulation makes use of parameterisations of the muon energy and the angle of incidence, based on measured and simulated data of the cosmic muon flux, taking the energy dependence of the angle of incidence into account. The geometry and material density of the CMS cavern and access shafts are taken into account, too. The event generator is integrated in the complete CMS detector simulation chain. Cosmic muons can be generated on earth's surface as well as for the detector located underground. Many million cosmic muon events have been generated and compared to measured data, taken with the CMS detector at its nominal magnetic field of 3.8 T during commissioning.

The CMS detector and cosmic muons

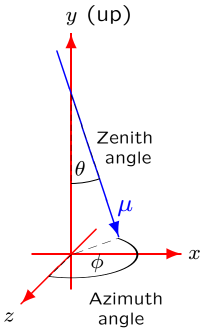


x toward LHC centre
y upgoing
z along beam axis

θ polar angle with respect to vertical y axis ($\theta = 0 \Leftrightarrow$ downward)
ϕ azimuthal angle in horizontal $z - x$ plane

The cosmic single muon generator CMSCGEN

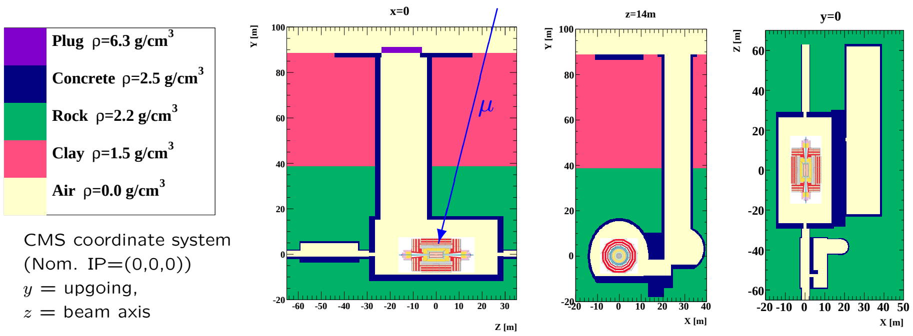
- Air shower program CORSIKA
  - EPOS interaction model for high energy interactions
  - GHEISHA interaction model for low energy hadronic interactions
- CORSIKA[1] simulation results fitted with polynomials
  - $\Rightarrow$ Differential flux $\frac{d\Phi}{dp\, d\cos\theta\, d\phi}$ parameterisation[2]
  - Flux normalisation to data (vertical μ's@100 GeV): $C_{\rm norm} = (2.59 \pm 0.18) \cdot 10^{-3} {\rm m}^{-2}{\rm s}^{-1}{\rm GeV}^{-1}{\rm sr}^{-1}$
- Maximally allowed phase space:
  - $\phi \in [0, 2\pi)$ (azimuthal isotropy)
  - $0° < \theta < 84°$ (extrapolated parameterisation for $\theta > 75°$)
  - $3 < p_\mu < 3000$ GeV (new physical processes at low energy, extrapolation invalid)



[1] D. Heck *et al.* CORSIKA, Forschungszentrum Karlsruhe Report FZKA 6019 (1998)
[2] Ph. Biallass, Th. Hebbeker, arXiv:0907.5514v1 [astro-ph.IM]

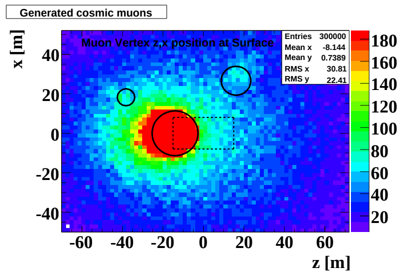
Propagation of muons from the surface to the CMS detector

Energy loss simulated in propagating muons through different material densities (Air, Wall, Plug, Clay, Rock)



CMS coordinate system (Nom. IP=(0,0,0))
y = upgoing,
z = beam axis

- Muons after propagation (parameterised integrated energy loss)
  - entering cylinder volume surrounding the CMS detector
  - Vertices on cylinder passed to CMS full GEANT[2] simulation



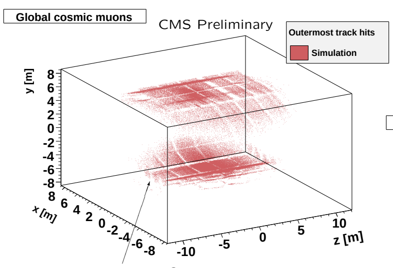
- Vertices at surface of generated muons reaching CMS
- Higher intensity of low energy muons passing (partly) through shafts

[2] Nuclear Instruments and Methods in Physics Research A 506 (2003) 250-303 and IEEE Transactions on Nuclear Science 53 No. 1 (2006) 270-278

Measured CMS data versus simulation distributions

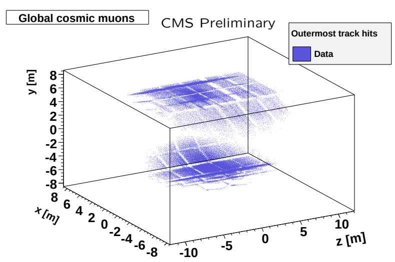
- Cosmic data taking period 2008
- 300 Million events have been recorded with $B = 3.8$ T
- 200 Million events have been recorded with $B =$ off
- Cosmic muon flux at CMS: 800 Hz
- Event selection:
  - CMS magnetic field on (B=3.8 T)
  - Global Cosmic Muons (Muon chambers + Central Tracker)
  - Mixture of 4 different cosmic muon triggers
  - $p_\mu > 10$ GeV
  - $0 < \theta < 60°$

Simulated global muons

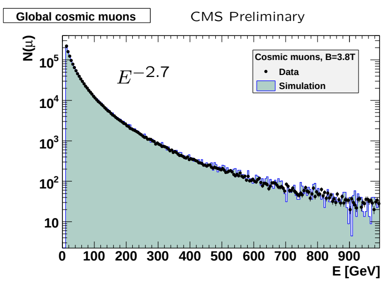


Full GEANT[2] simulation

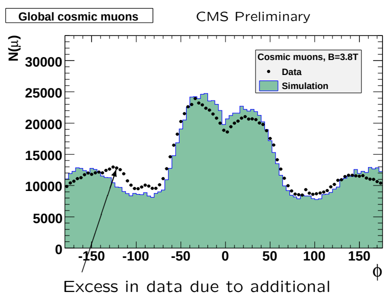
CMS data global muons



Energy of muons

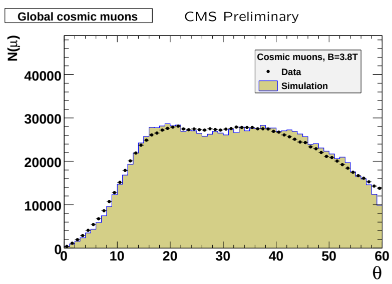


Azimuthal angle ϕ of muons



Excess in data due to additional auxiliary shaft not included in available simulated event samples yet

Polar angle θ of muons



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