One-evening-attempt to see how flat surface and mountain affect the angular distribution of muons

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- What is needed
  - Angular and energy dependent estimate for flux of muons at surface
  - Energy dependent muon range in rock
  - Simple definition for different geometries

Energy and angular dependent muon flux at sea level

- Gaisser's formula
- http://pdg.lbl.gov/2011/reviews/rpp2011-rev-cosmic-rays.pdf

$$\frac{dN_\mu}{dE_\mu d\Omega} \approx \frac{0.14\, E_\mu^{-2.7}}{\text{cm}^2 \text{ s sr GeV}} \times \left\{ \frac{1}{1 + \frac{1.1 E_\mu \cos\theta}{115\,\text{GeV}}} + \frac{0.054}{1 + \frac{1.1 E_\mu \cos\theta}{850\,\text{GeV}}} \right\},$$

low energy muons decay before reaching the surface and high energy pions decay before they interact, thus the average muon energy increases. An approximate extrapolation formula valid when muon decay is negligible ($E_\mu > 100/\cos\theta$ GeV) and the curvature of the Earth can be neglected ($\theta < 70°$) is

Simple Parametrisation for muon range in standard rock

Calculation of the Underground Muon Intensity Crouch Curve from a Parameterization of the Flux at Surface

ICRC '07
arXiv:0706.1110v1

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$$X[mwe] = p_0 \cdot \log_e\{(p_1 \cdot E_\mu[GeV]) + p_2\}, \quad (5)$$

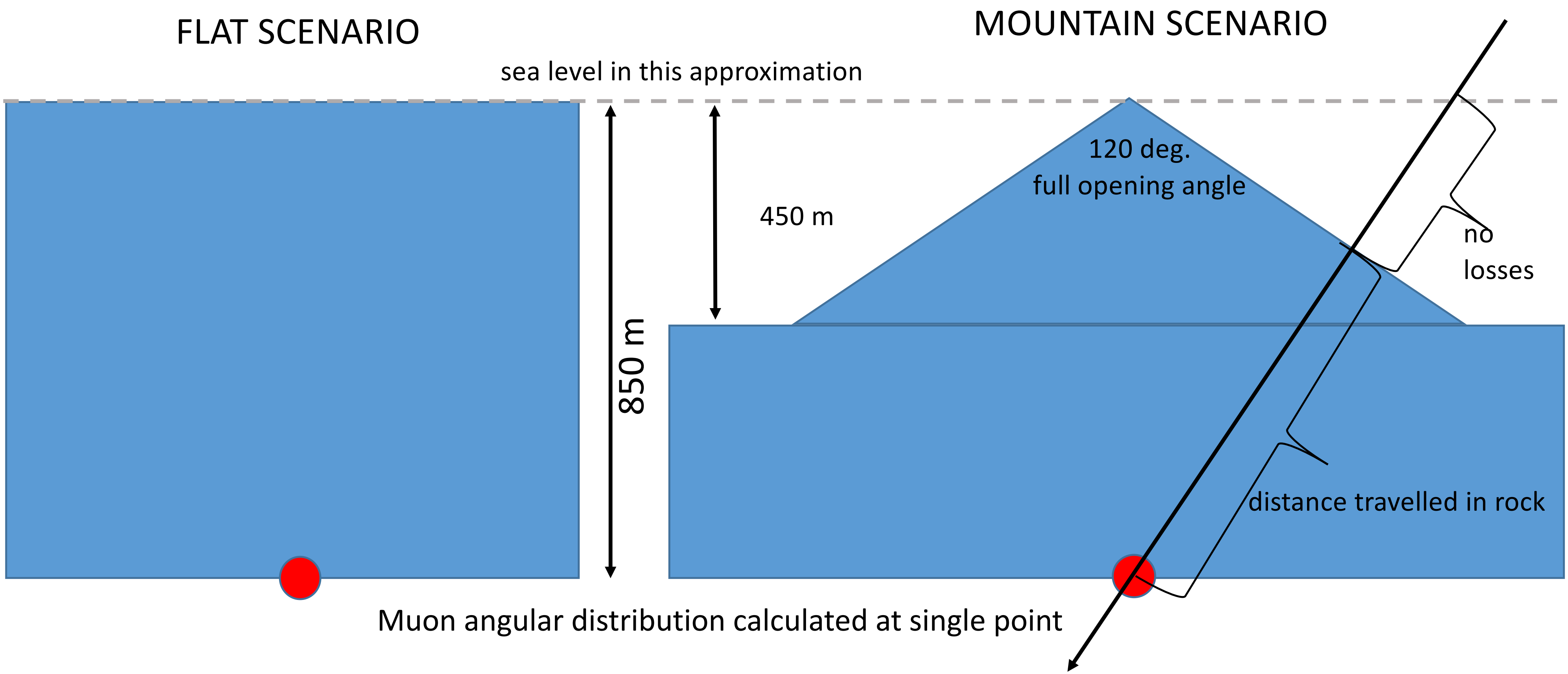
	p_0 $[mwe]$	p_1 $[GeV^{-1}]$	p_2 [ ]
standard rock	2298.2	0.001920	0.99809
Soudan rock	2098.9	0.002119	0.99789

Table 3: Fitted coefficients for the parameterization (Eq. 5) of the average muon range in standard and Soudan rock.

Scaling that with the standard rock:

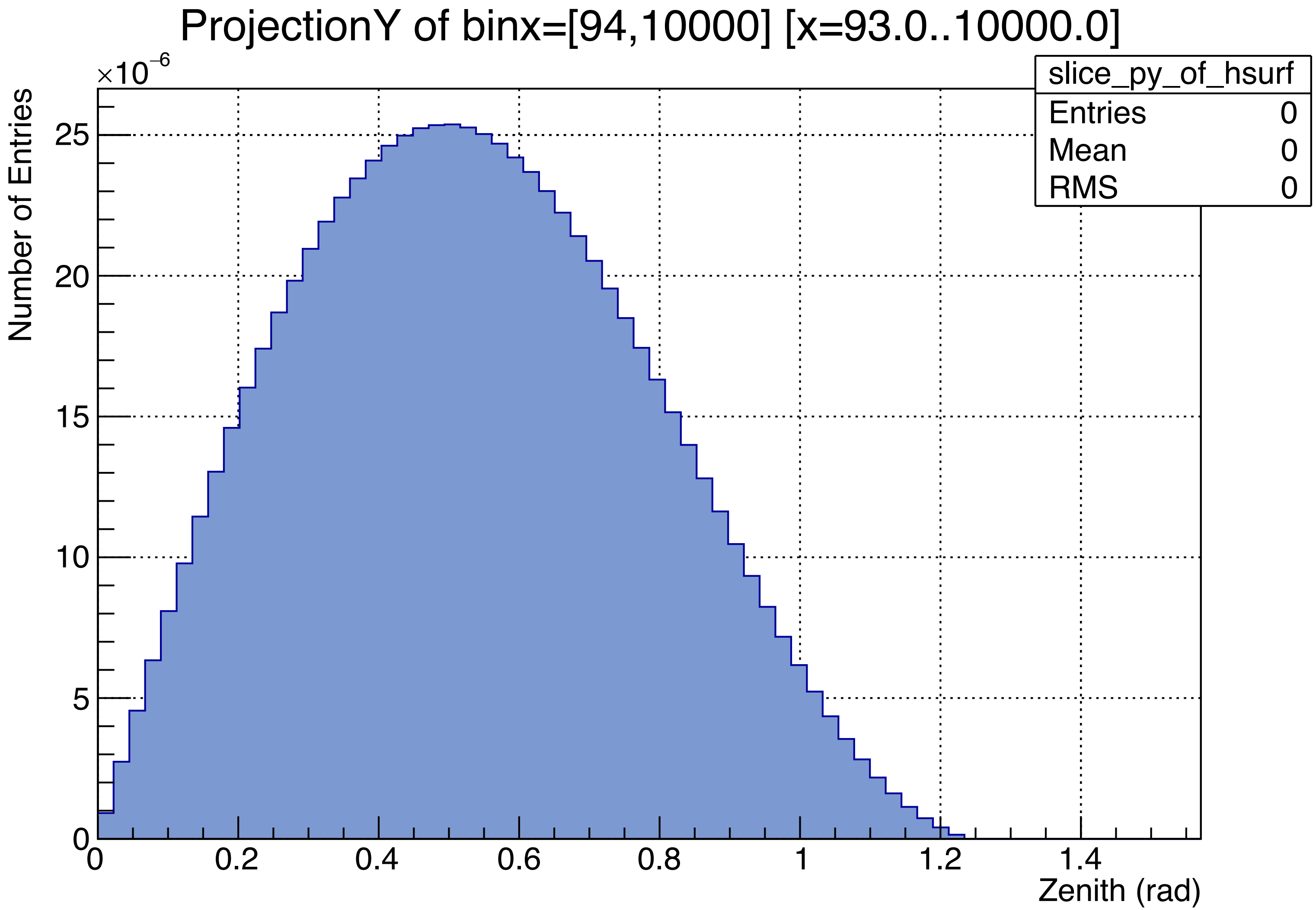
density 2.65 g/cm3; 1 m.w.e. = 100 g/cm^2

Two geometries

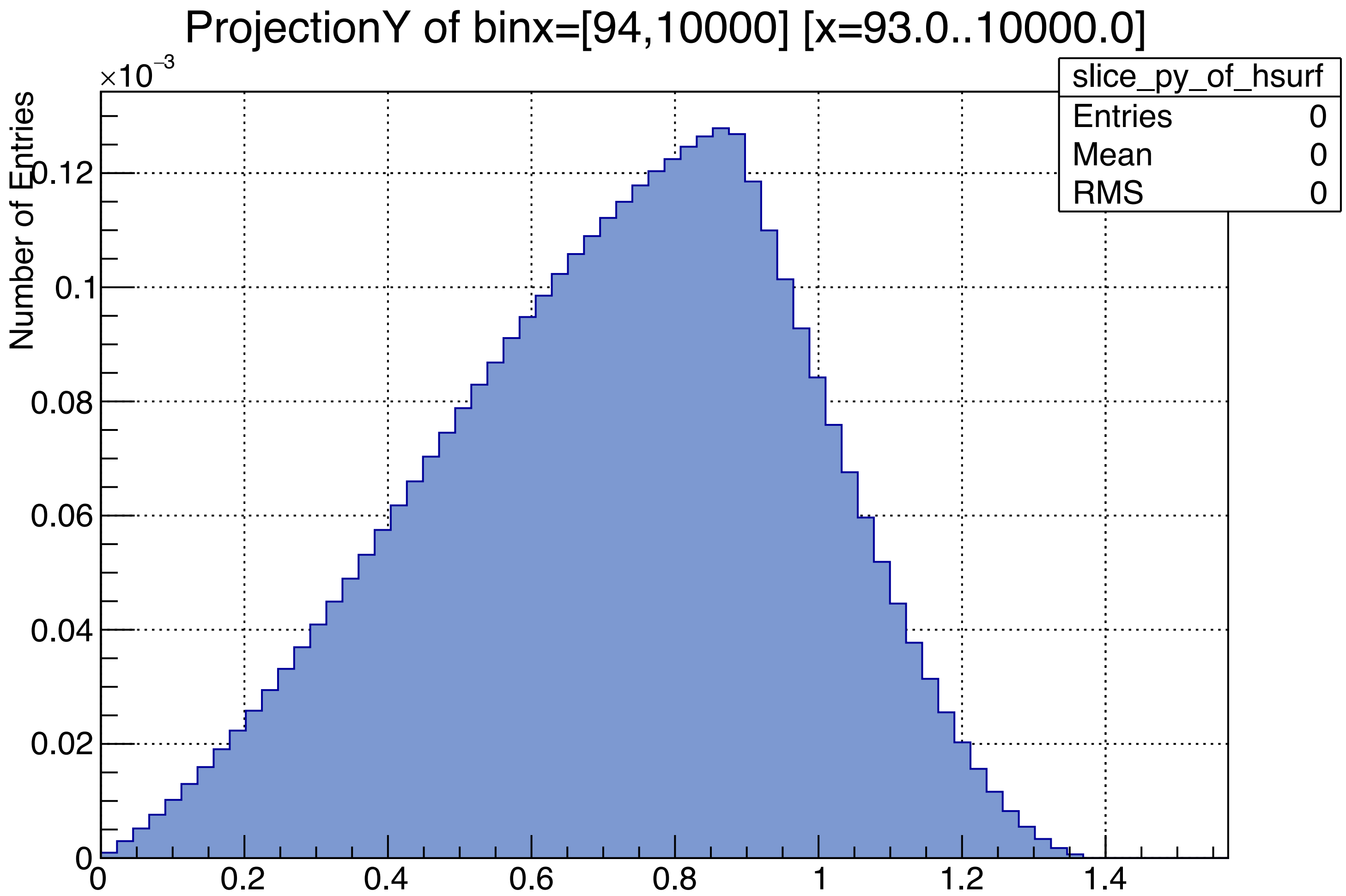


if distance in rock > energy dependent range
=> no muons with that energy from that direction

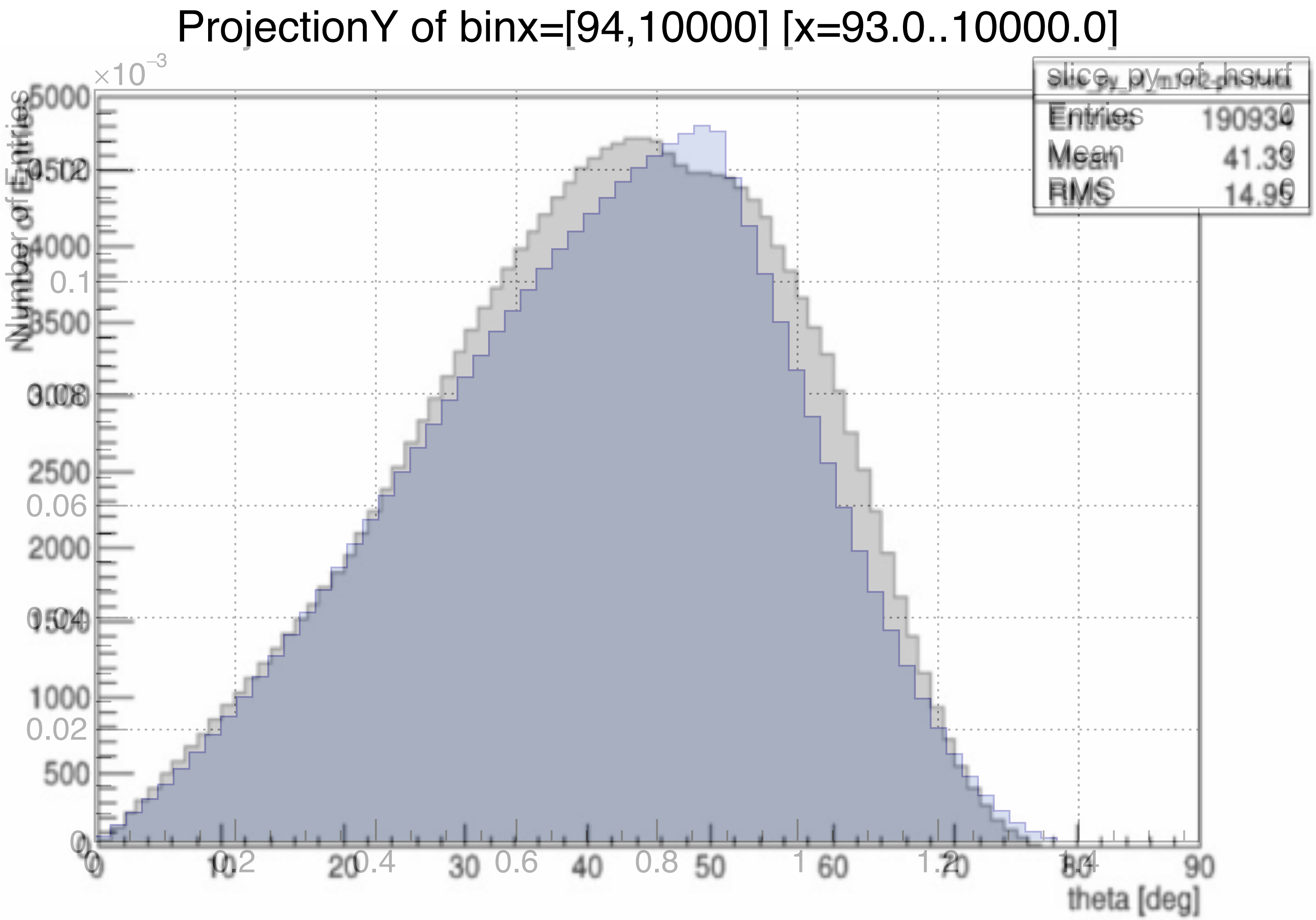
Zenith angle distribution: Flat surface scenario

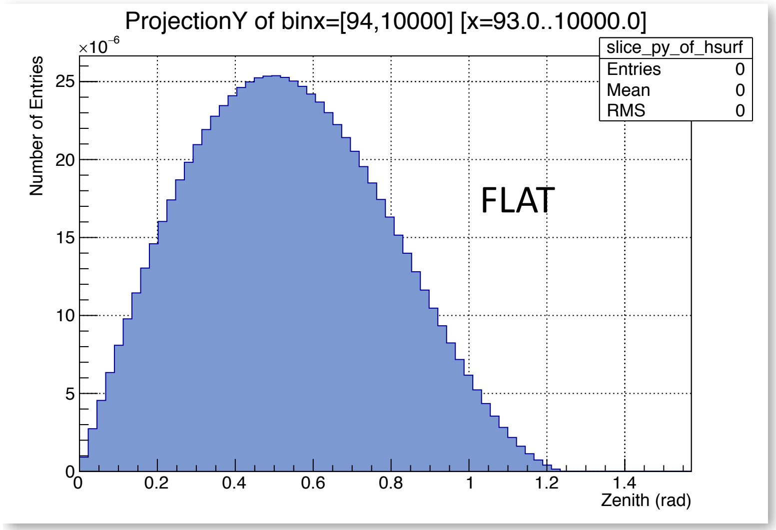


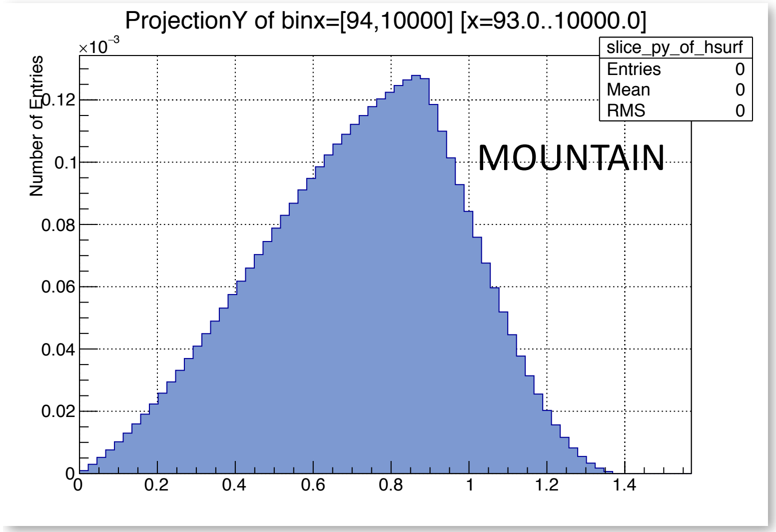
Zenith angle distribution: Mountain scenario

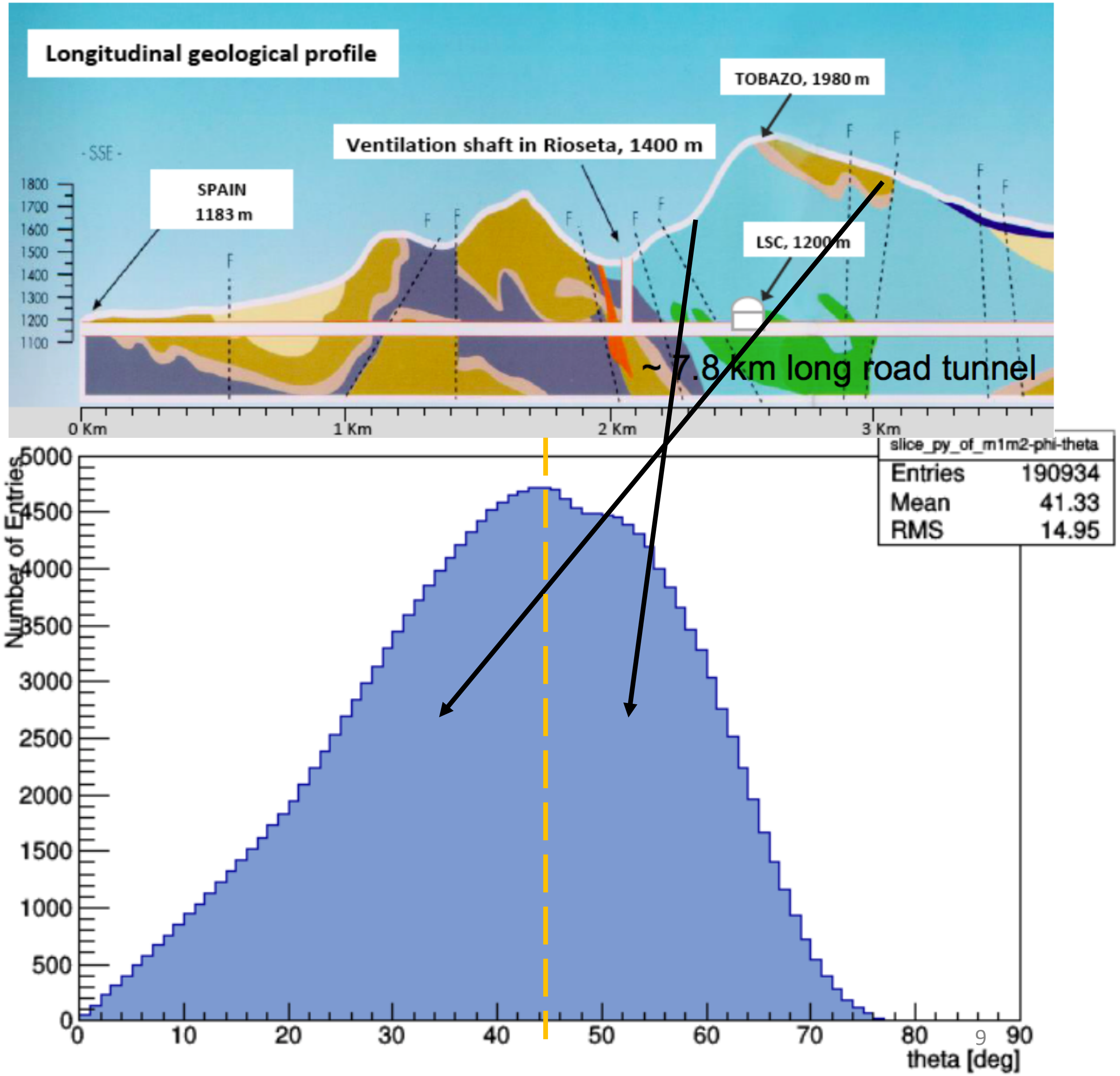


Zenith angle distribution: Mountain scenario




ProjectionY of binx=[94,10000] [x=93.0..10000.0]
slice_py_of_hsurf
Entries 0
Mean 0
RMS 0
FLAT
Number of Entries
Zenith (rad)


ProjectionY of binx=[94,10000] [x=93.0..10000.0]
slice_py_of_hsurf
Entries 0
Mean 0
RMS 0
MOUNTAIN
Number of Entries


Longitudinal geological profile
TOBAZO, 1980 m
Ventilation shaft in Rioseta, 1400 m
- SSE -
SPAIN
1183 m
LSC, 1200 m
~ 7.8 km long road tunnel
0 Km
1 Km
2 Km
3 Km
slice_py_of_m1m2-phi-theta
Entries 190934
Mean 41.33
RMS 14.95
Number of Entries
theta [deg]

Summary & Conclusions & Outlook

- Calculation of the zenith angle distribution of muon flux performed using simplified assumptions of muon flux at surface level, simplified muon range in standard rock and two simple geometry.

- The mountain profile shifts the “peak” of the distribution to larger values of zenith angle.

- I hope this simple illustration triggers fruitful discussion about the future implementation of the more detailed description of mountain geometry.