November 21st 2018

Detector Simulation Working Group (DeSi-WG)

EEE telescope simulation
Model validation

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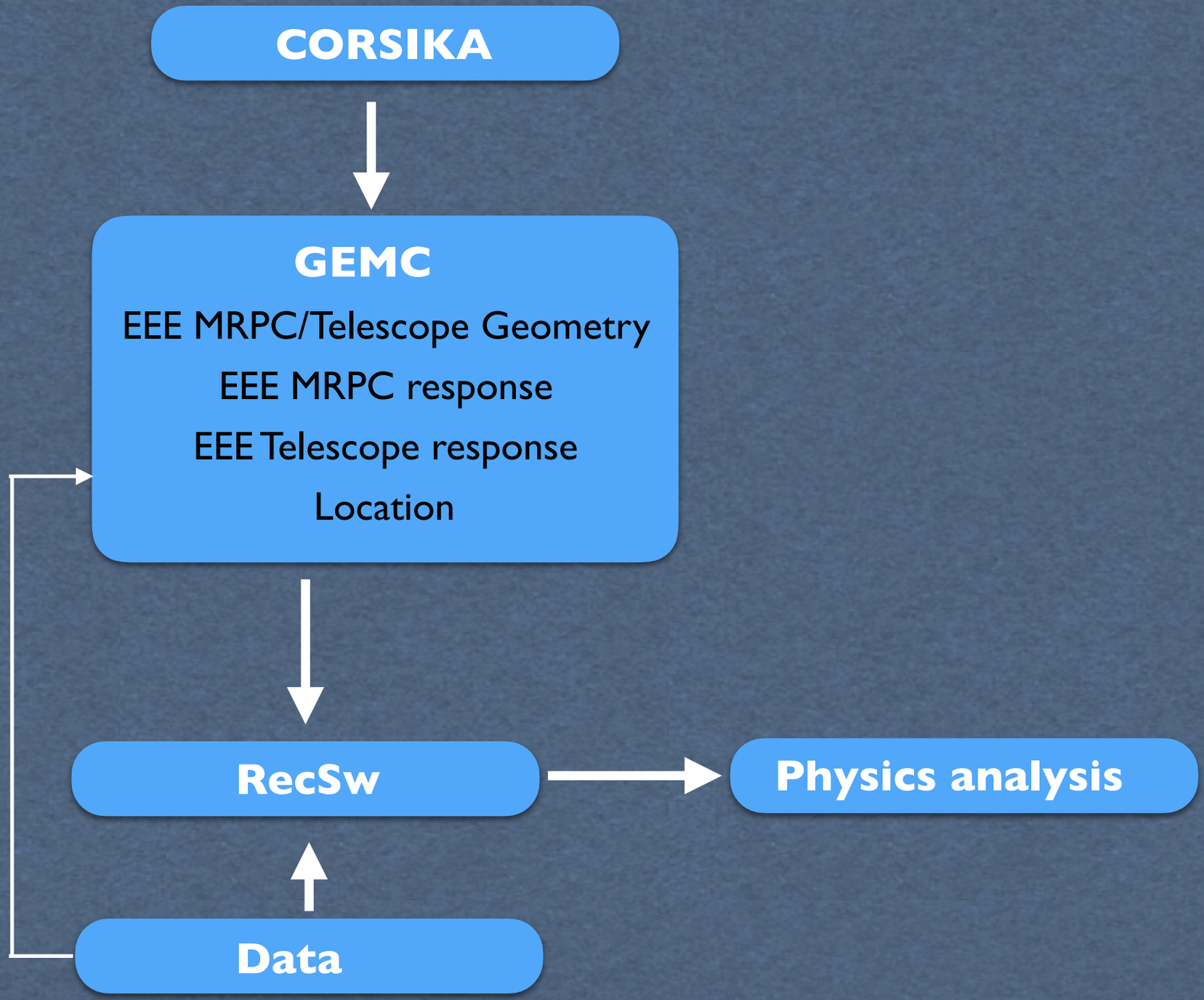
F.Coccetti, F.Noferini, M.Ungaro

DEtector**SI**mulation**-WG**

Goal: generate pseudo data using GEANT4 to track CORSIKA generated particle



DEtector**SI**mulation**-WG**

Goal: generate pseudo data using GEANT4 to track CORSIKA generated particle

Test and validation of the whole chain

Single muon GEN — MB

GEMC

EEE MRPC/Telescope Geometry

EEE MRPC response

EEE Telescope response

Location

MB

S.Grazzi

G.Mandaglio

RecSw → **Physics analysis**

Data — S.Grazzi, G.Mandaglio

EEE-MRPC response to cosmic rays in GEANT4

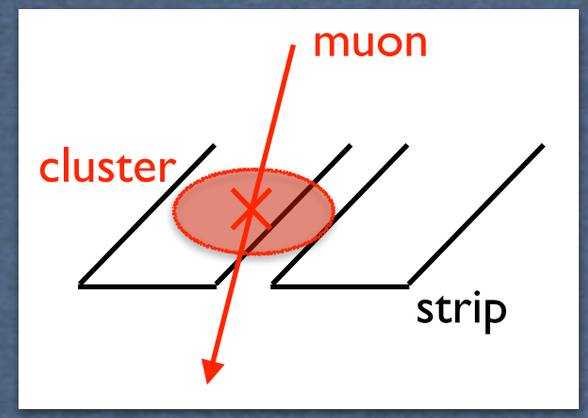
- MRPC geometry: material, size, …
- MRPC response (parametrized)
- Telescope response: geometry, trigger, …
- Telescope location: effect of roof, walls, surrounding materials, …
- Telescope: muon rates for different multiplicities
- Multi-telescopes: coincidence rates
- Single/multiple telescope(s) studies: bottom-up muons, …

✳ EEE MRPC response

✳ No avalanche simulated in details

✳ Effective hit process:

- Sample XY (and Z) muon hit on on bottom strip plane
- Assume both strips and gaps are active
- Apply a spread to account for multiple hits and spread position resolution X and Y and T



✳ MRPC parameters

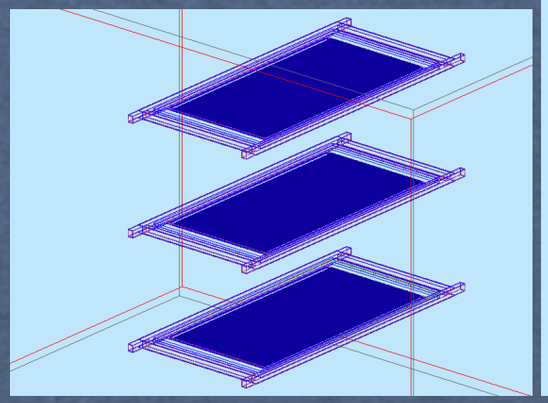
- 90x160 active area
- Active: 2.5cm x 24 strips + 0.7cm x (24-1) gaps
- Time spread: σ = 238ps
- Cluster size: σ_X = 9.2 mm
- Cluster size: σ_Y = 15 mm
- Light speed: 15.8 ns/cm
- HIT_{XY} is gaussian-spread and projected on the sensitive area to derive strip multiplicity

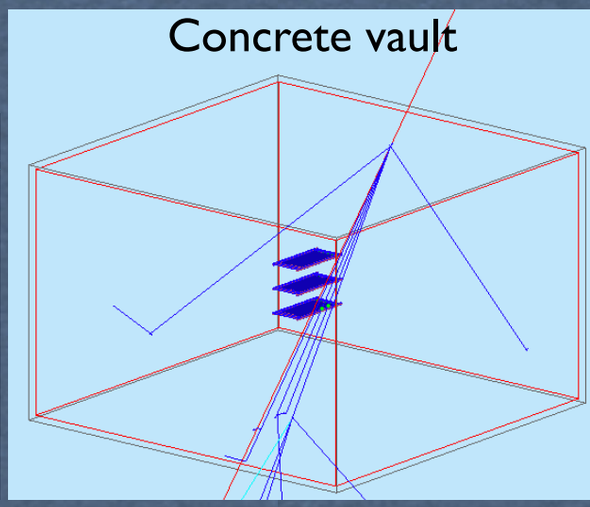
Ref: JINST13(2018)P08026

✳ Telescope parameters

- 3 chambers
- -50/0/+50 cm apart
- placed in a concrete box wall on all sides (140cm concrete)

Ref: GENO-01





EEE-Sim reconstruction

`gemc_to_eee()` the routine reads the gemc root-file output and convert it in a root-file readable by EEE-reconstruction code (F. Noferini)

How to use EEE reconstriction for simulated data

Reconstruction @cnaf (instruction and macros by F. Noferini)
you must use the following machine eee-analisi-user: 182
run the following commands:
1) scl enable devtoolset-6 python27 bash
2) source /home/eeesoft/geant4_vmc/env.sh

Yuo have to copy g4Config.C, telescopes e provasim.C from:
/home/eeesoft/geant4_vmc/EEE_Analyzer/eeeroot

To run the reconstruction:
eeeroot.exe -b -q -l provasim.C
Interesting output:
BOLO-02-2017-01-01-00001_digit.root
BOLO-02-2017-01-01-00001_dst.root

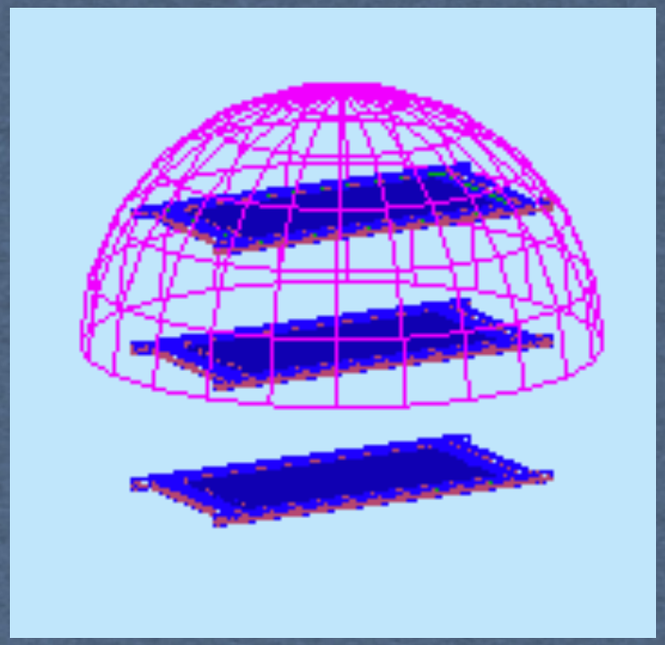
digit is the input file
dst is the output file, exactly formally equal to experimental data

`…_digit.root`

- TTree name -> **EventsDigits**
- **seconds/I** -> trigger time in seconds
- **nanoseconds/I** -> trigger time in nanoseconds
- **type/I** -> Event Type: 0=gps, 1=trigger
- **nhit** --> Numer of hit (At least 6)
- **chamb[nhit]/I** --> chamber number
- **strip[nhit]/I** --> strip number (0-23 left, 24-47 right)
- **timeHit[nhit]/F** --> hit time inside the trigger window (-10 ns +10 ns)
- **totHit[nhit]/F** --> time over threshold in ns (coud be equal to 0)

G.Mandaglio

Muon generation



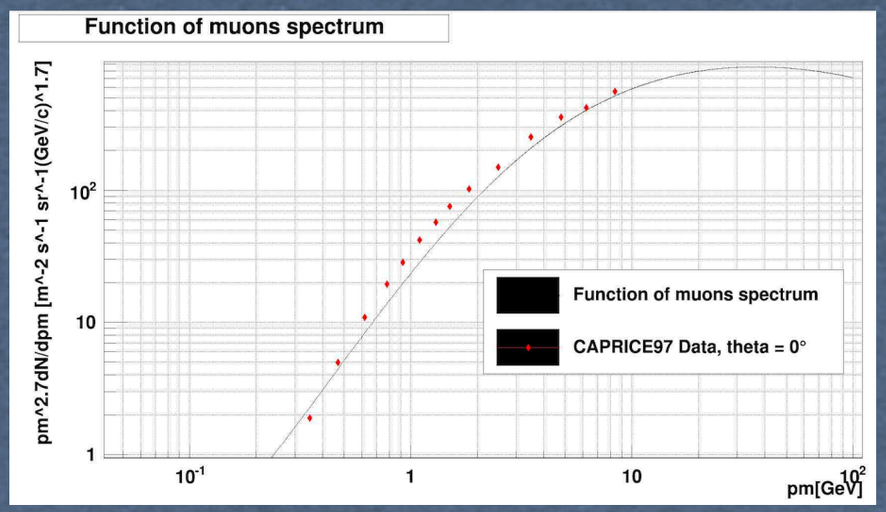
- Single-muon generation
- Semi-sphere generation such as to obtain a flat distribution on a plane surface
- Improved Gaisser parametrization for Flux(E_μ,Θ) to include Earth curvature (all latitudes) and low energy muons (<100GeV)

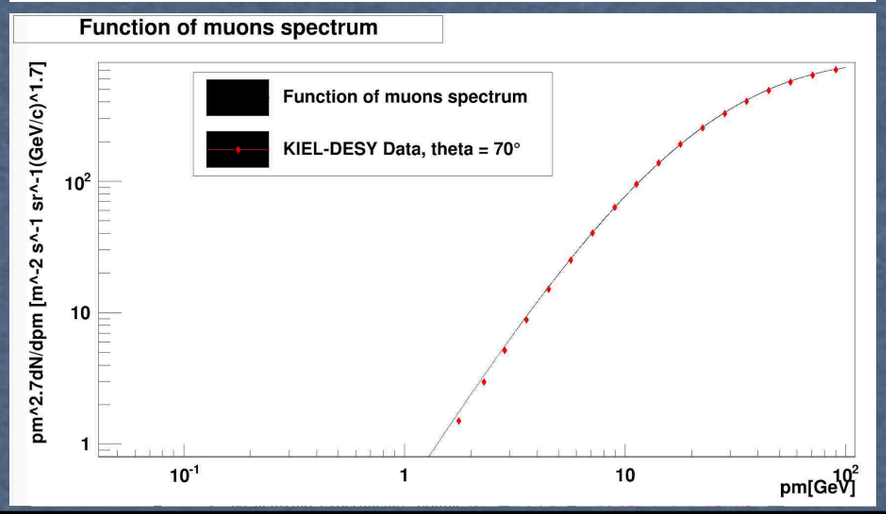
$$\frac{dI_\mu}{dE_\mu} = 0.14\left[\frac{E_\mu}{GeV}\left(1+\frac{3.64GeV}{E_\mu(\cos\theta^*)^{1.29}}\right)\right]^{-2.7}\left[\frac{1}{1+\frac{1.1E_\mu\cos\theta^*}{115GeV}}+\frac{0.054}{1+\frac{1.1E_\mu\cos\theta^*}{850GeV}}\right]$$

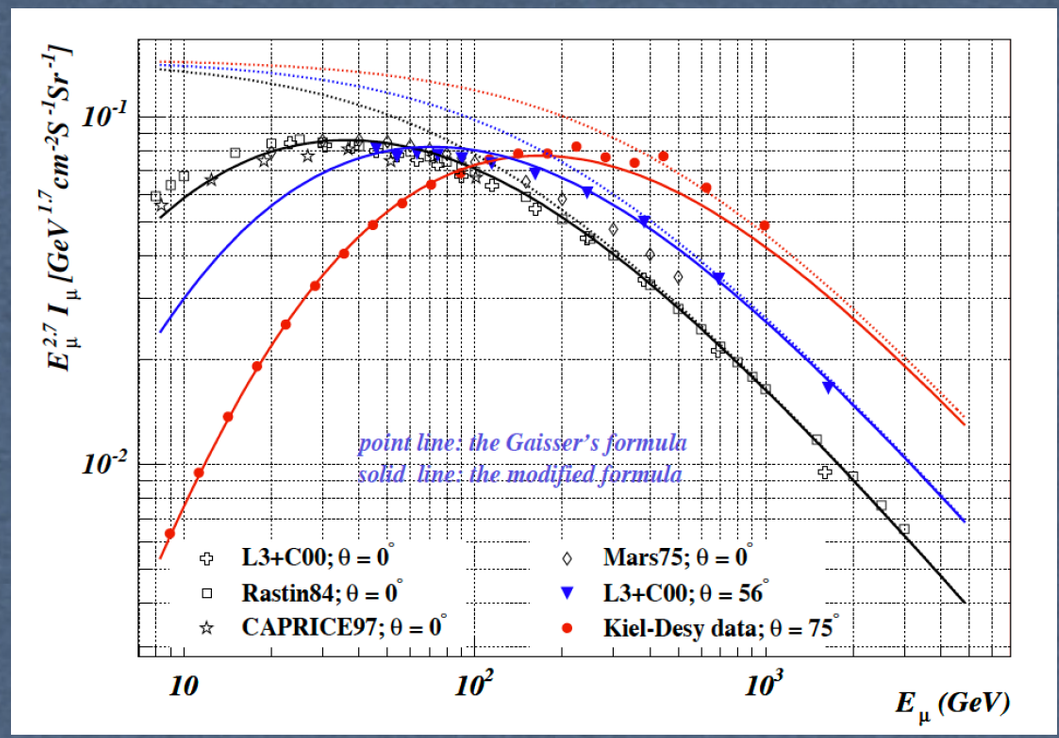
$$\cos\theta^* = \sqrt{\frac{(\cos\theta)^2+P_1^2+P_2(\cos\theta)^{P_3}+P_4(\cos\theta)^{P_5}}{1+P_1^2+P_2+P_4}}$$

P_1	P_2	P_3	P_4	P_5
0.102573	-0.068287	0.958633	0.0407253	0.817285

arXiv:1509.06176

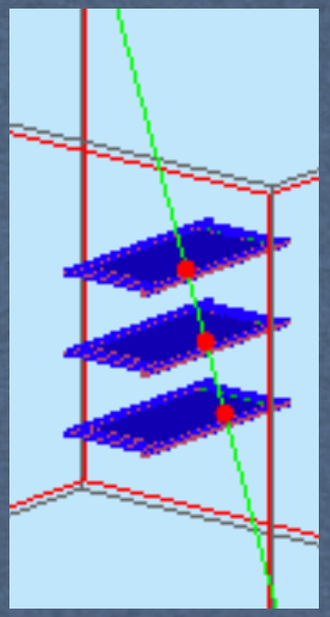


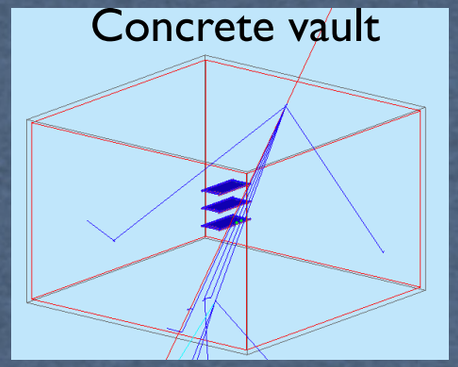


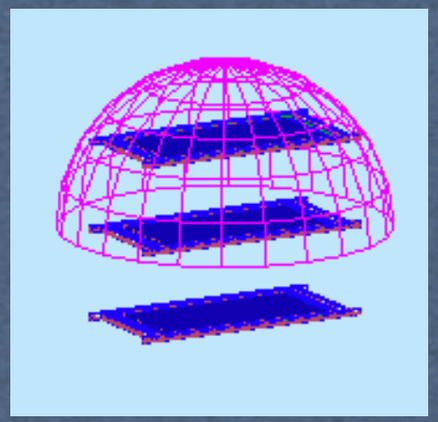


- good agreement with previous data
- low/high energies, small/large angles
- our implementation checked on data
- Generation split in 3 E_μ intervals:
  - [0.2 GeV - 2 GeV]
  - [2GeV-10 GeV]
  - [10GeV-100 GeV]
- Normalization factor for absolute flux:
  1.06 μ cm^{-2} min^{-1}

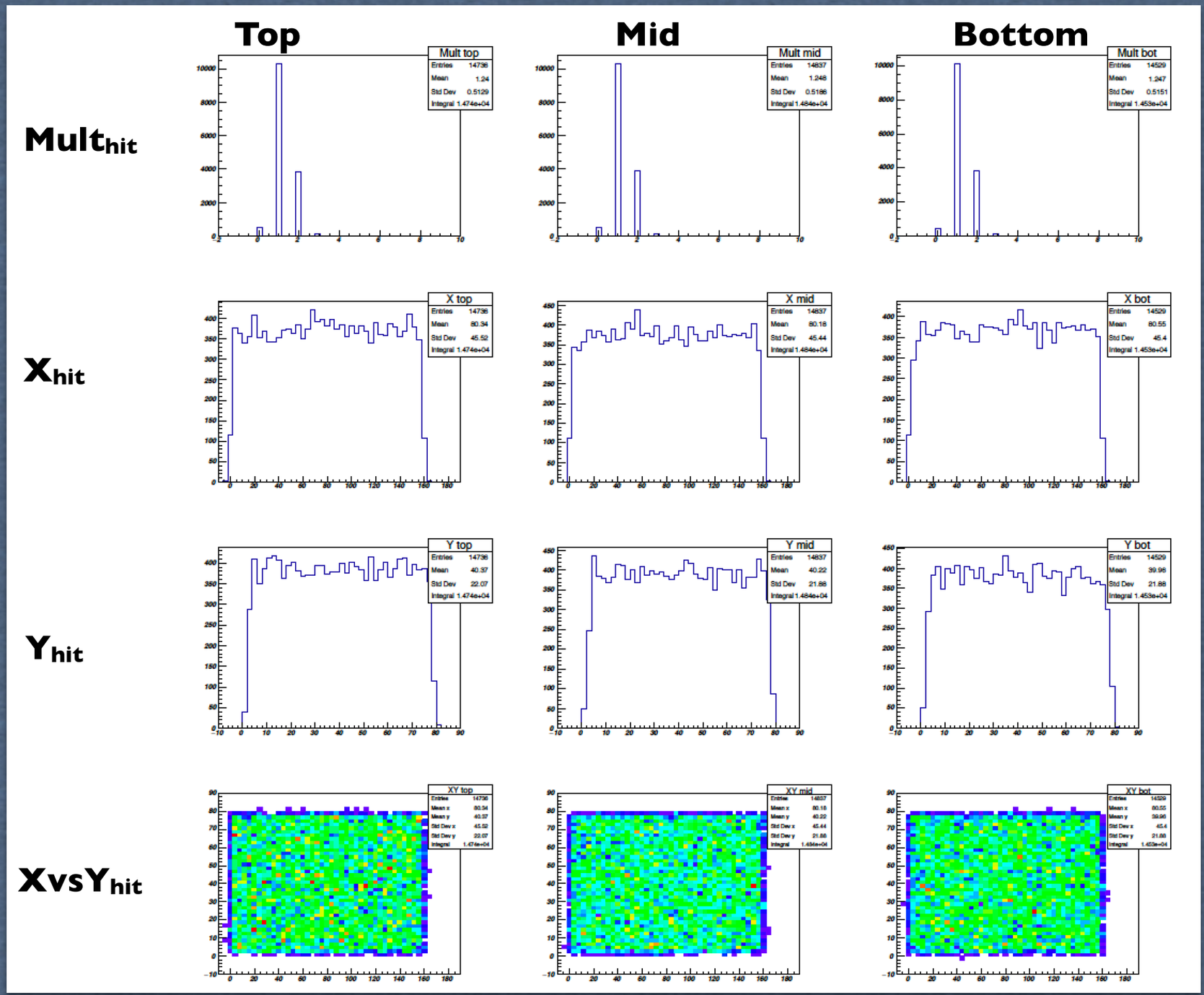
EEE-Telescope simulation: geometry





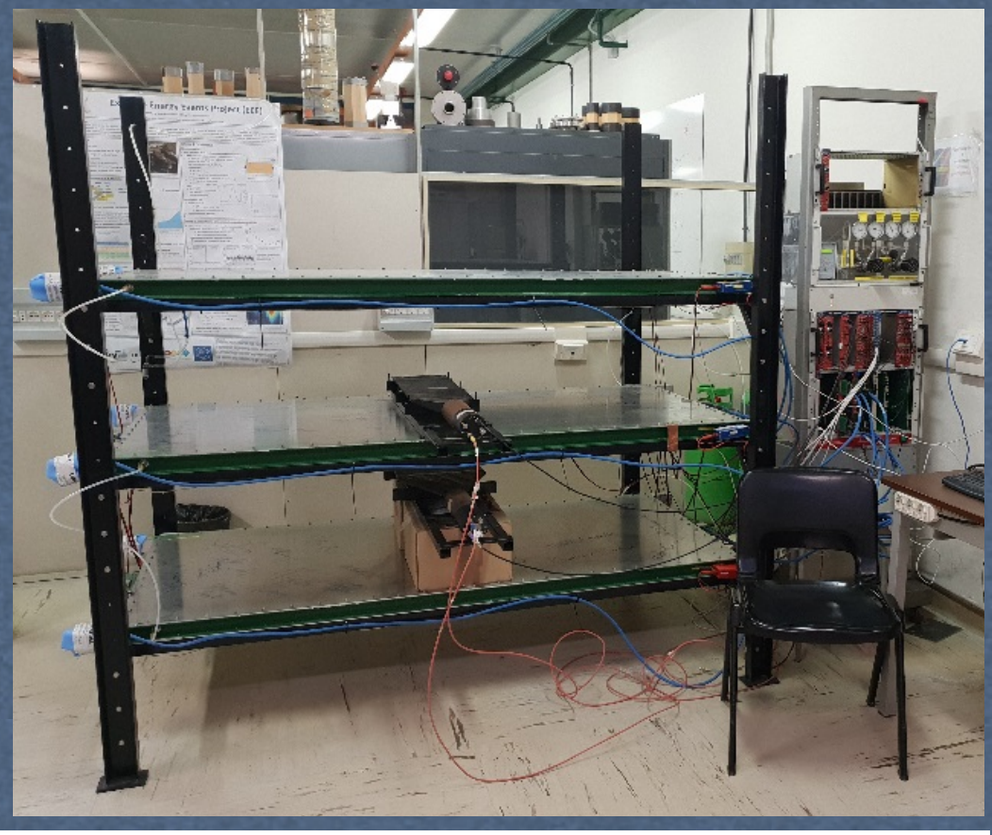


- Telescope Parameters
  - 3 chambers
  - -50/0/+50 cm apart
  - placed in a concrete box wall on all sides (140cm concrete)
- Individual response to cosmic muons (2-10 GeV) of the three chambers

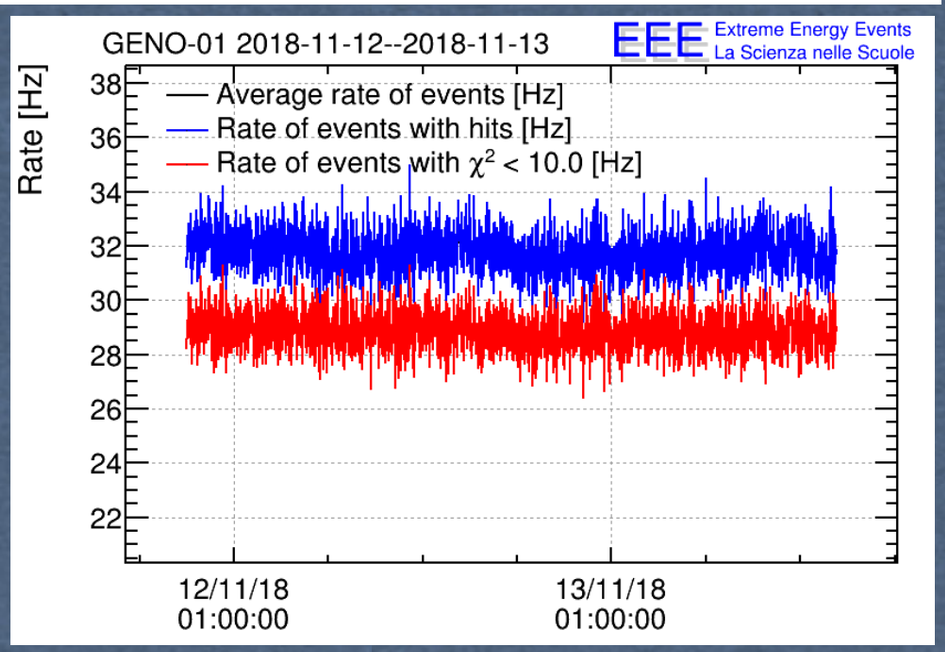


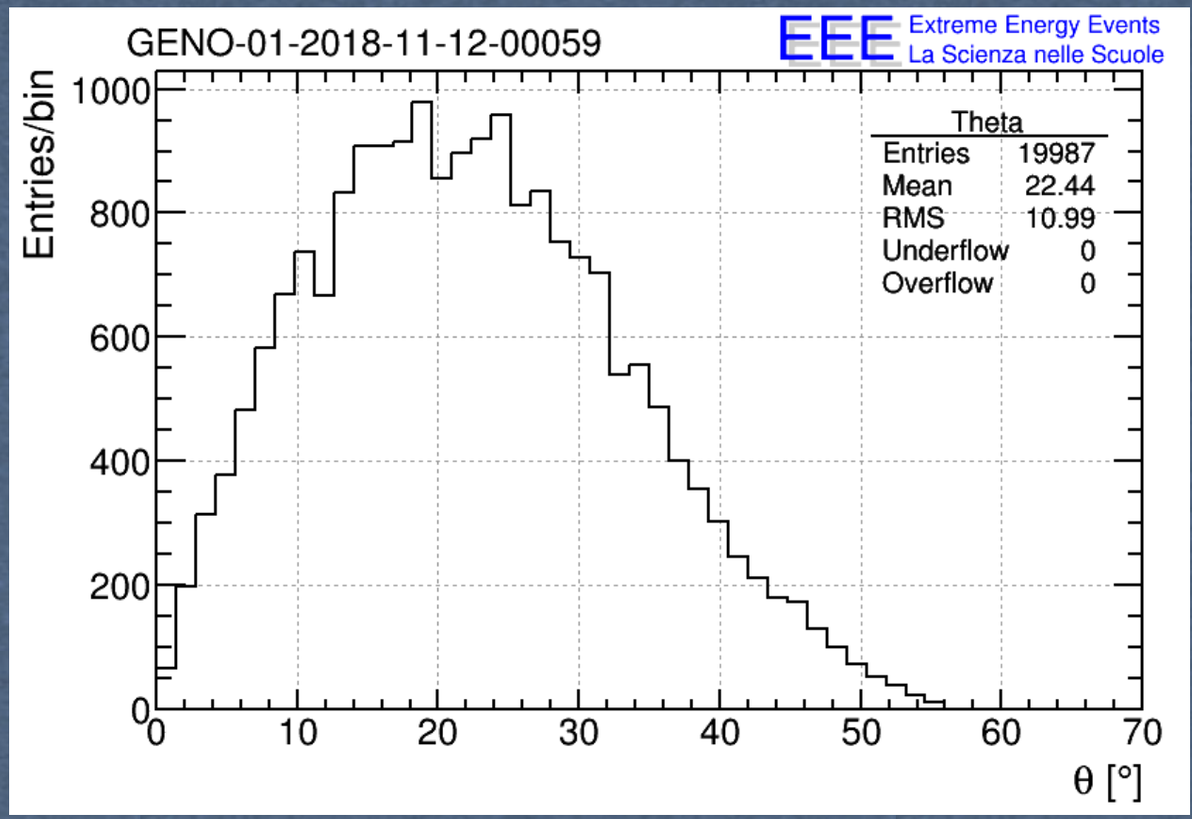
Comparison with GENO-01

- Comparison to GENO-01 telescope
  - built in March 2017 at CERN and delivered in Oct 2017
  - installed at the 4th floor (4 floors above) of Dpt.Physics/INFN-GE
  - Commissioned in Aug '18, data taking since Sept '18
  - full control of geometry and environmental parameters
  - The location and surrounding materials can be an issue



Plot	Alarm	Status	Output
RateHitEvents	y_values	Clean	30.54 +- 0.71
DeltaTime	exp_fit_lambda	Clean	31.81 +- 0.22
HitMultTop	x_average	Clean	1.2898 +- 0.0044
HitMultMid	x_average	Clean	1.2569 +- 0.0044
HitMultBot	x_average	Clean	1.1956 +- 0.0039
HitMultTotal	x_average	Clean	3.7390 +- 0.0093
ClusterMultTop	x_average	Clean	1.0627 +- 0.0025
ClusterMultMid	x_average	Clean	1.0925 +- 0.0029
ClusterMultBot	x_average	Clean	1.0751 +- 0.0026
ClusterMultTotal	x_average	Clean	3.2303 +- 0.0065
ChiSquare	x_average	Clean	2.188 +- 0.029
RateTrackEvents	y_values	Clean	27.62 +- 0.67
FractionTrackEvents	y_values	Clean	0.9188 +- 0.0062





- Data are stable and good!

S.Grazzi

EEE-Sim absolute rates

R_{Data}= (30.5 ± 0.7) Hz

Energy	fraction of the spectrum (%)
0.2 - 2 GeV	44.5
2- 10 GeV	41
10- 100 GeV	14.2
100 - 500 GeV	0.3
Tot	**100**

R_{Sim}= (42 ± 4) Hz

- Concrete vault thknss = 20cm
- Gen Sphere R=150cm
- Gen Sphere ΔZ=-50cm

R_{Sim}= (35 ± 4) Hz

- Concrete vault thknss = 140cm
- Gen Sphere R=150cm
- Gen Sphere ΔZ=-50cm

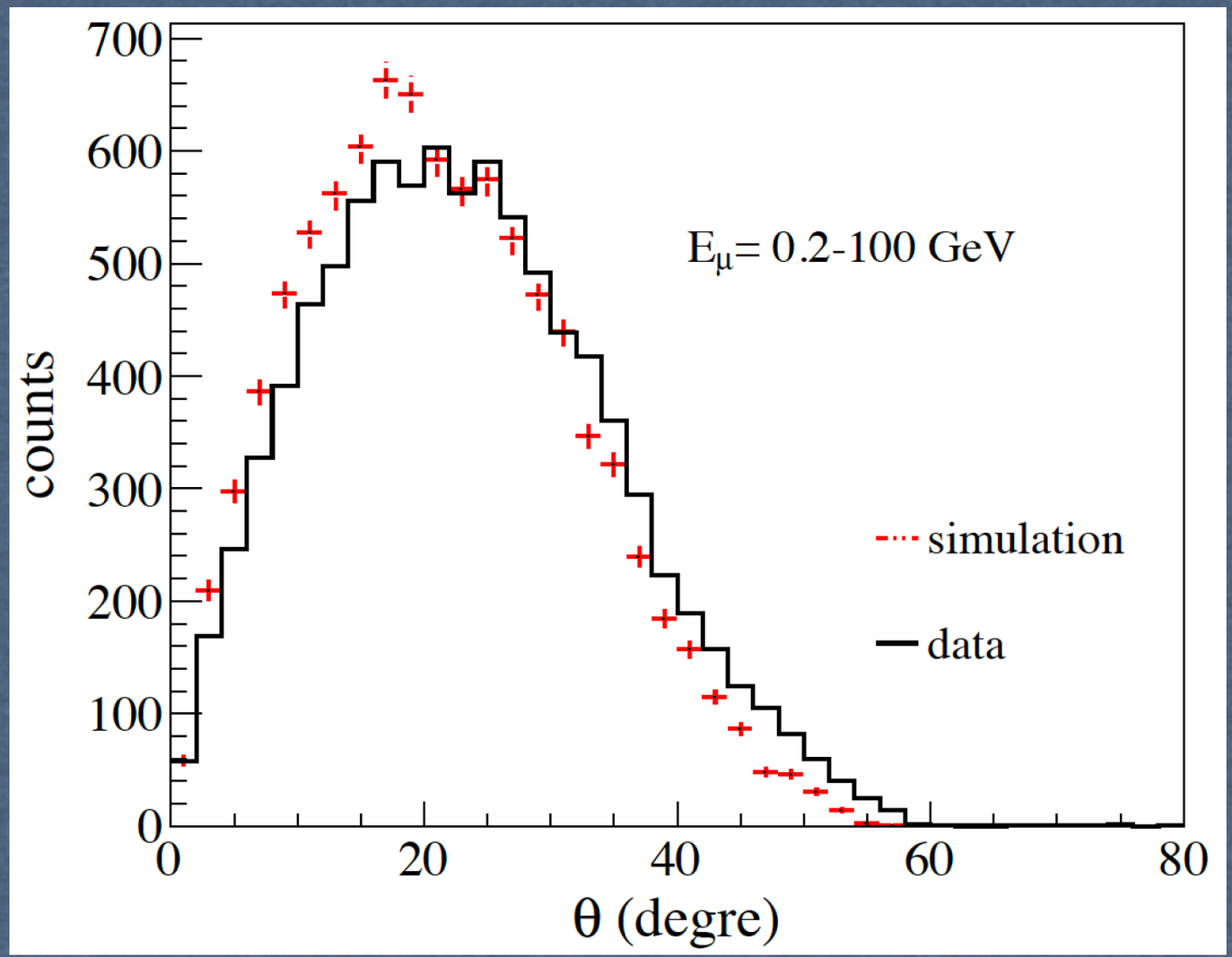
R_{Sim}= (35 ± 4) Hz

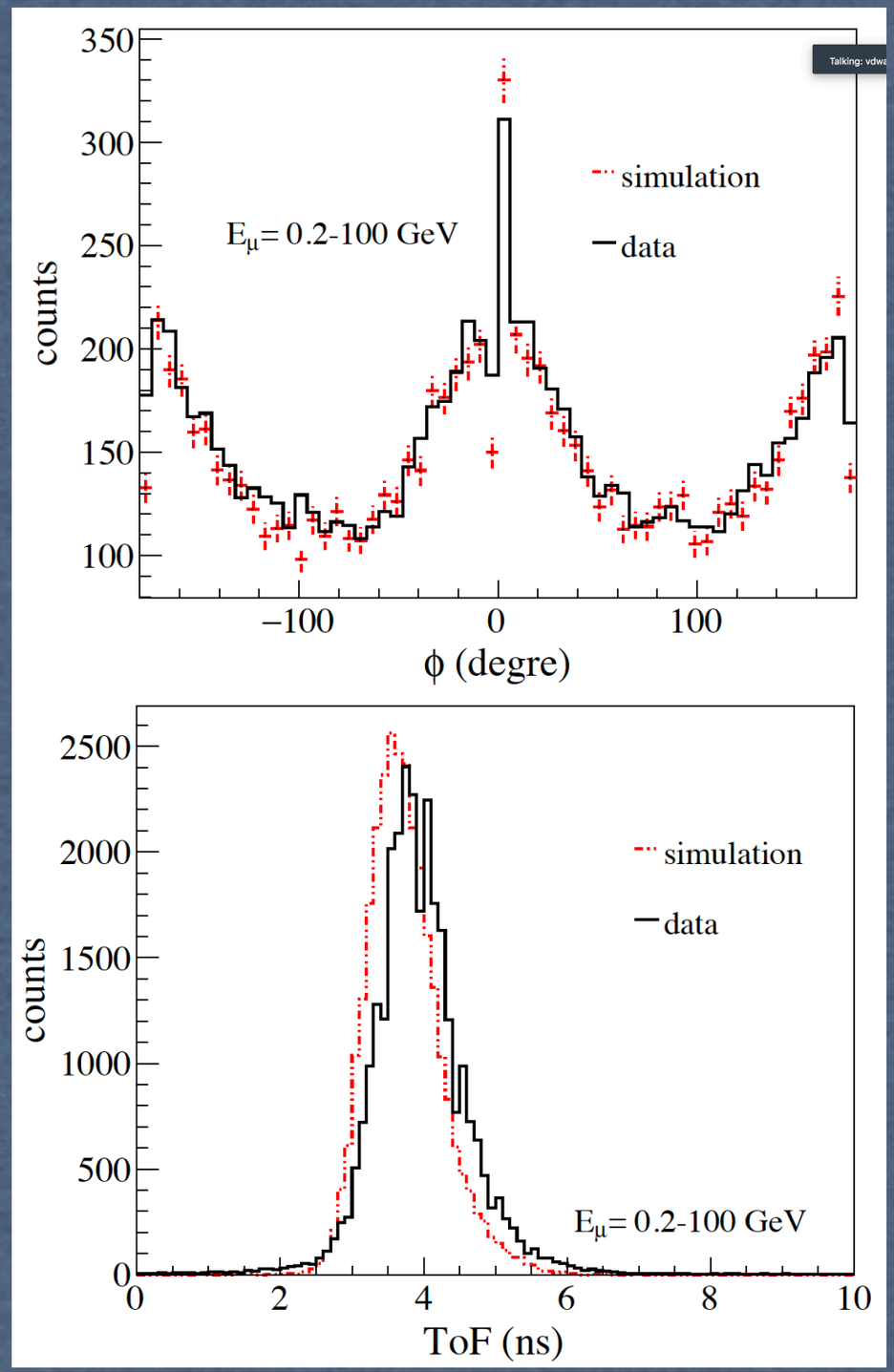
- Concrete vault thknss = 140cm
- Gen Sphere R=250cm
- Gen Sphere ΔZ=-50cm

R_{Sim}= (35 ± 4) Hz

- Concrete vault thknss = 140cm
- Gen Sphere R=250cm
- Gen Sphere ΔZ=0cm

Data/SIM comparison





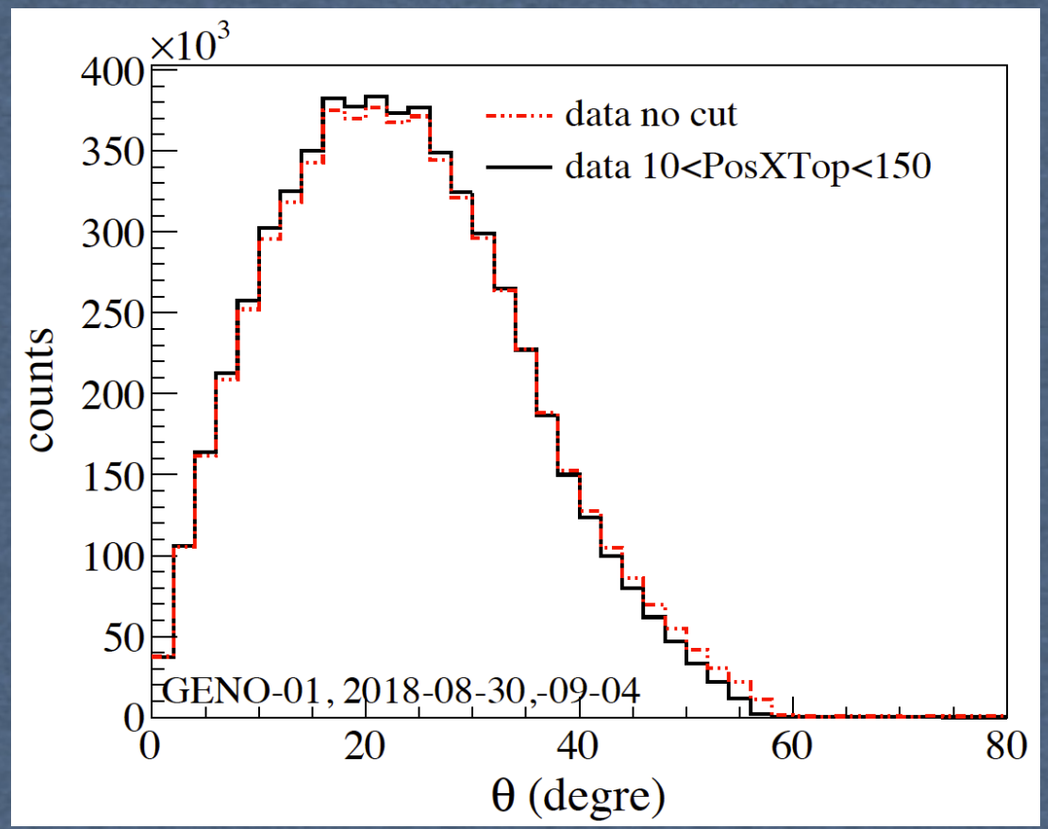
- Sim 10% higher than data rate (absolute)
- Sim theta distribution shifted down by ~1-2°
- Good consistency with high energy muons

EEE-Sim results

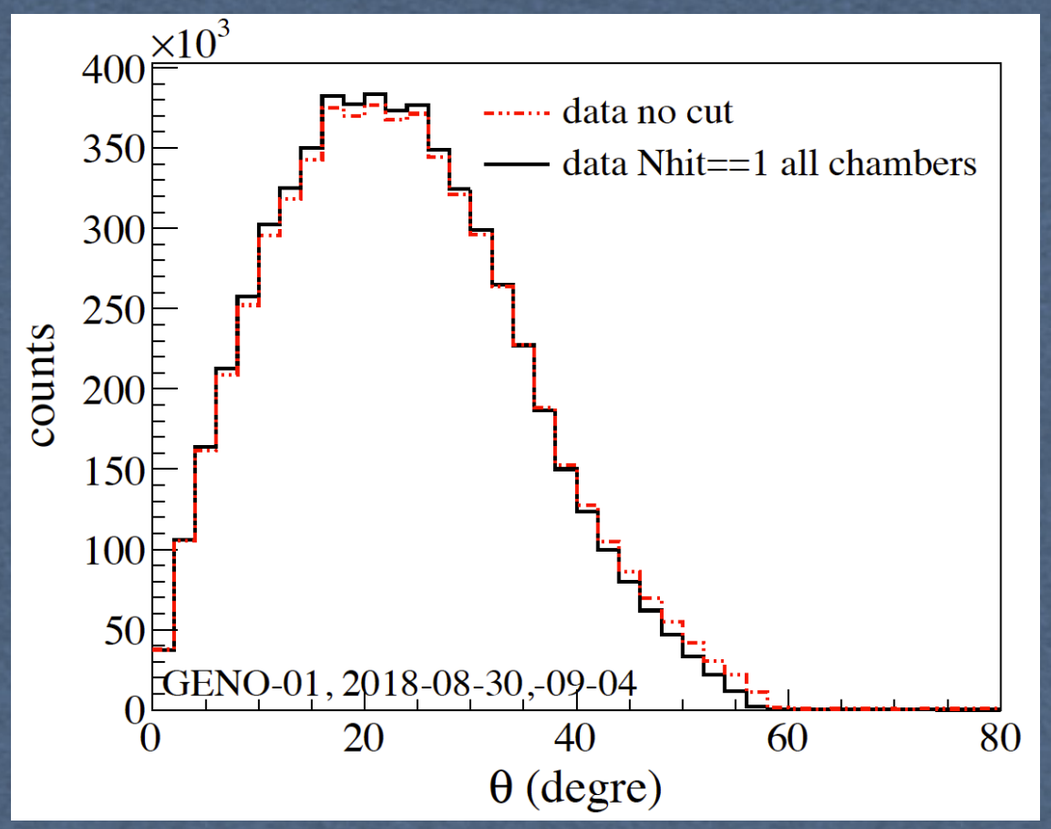
Systematic checks for data/sim agreement

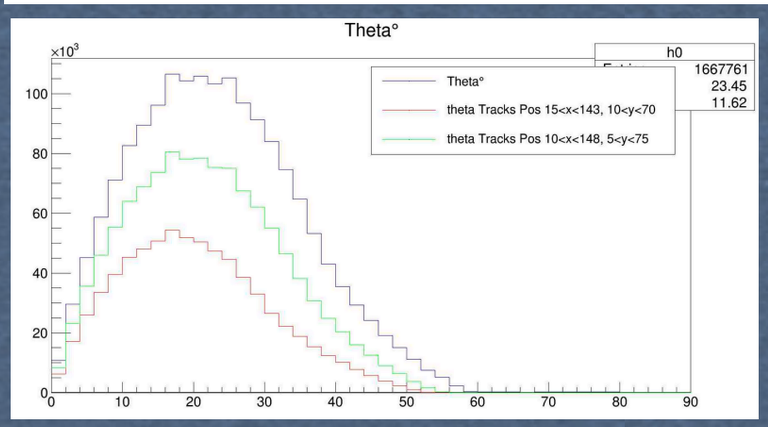
✳**Effect of changing data selection**

- **Fiducial cuts to the data**: 80x150 (over 90x160)



- **Hit selection**: only 1 hit

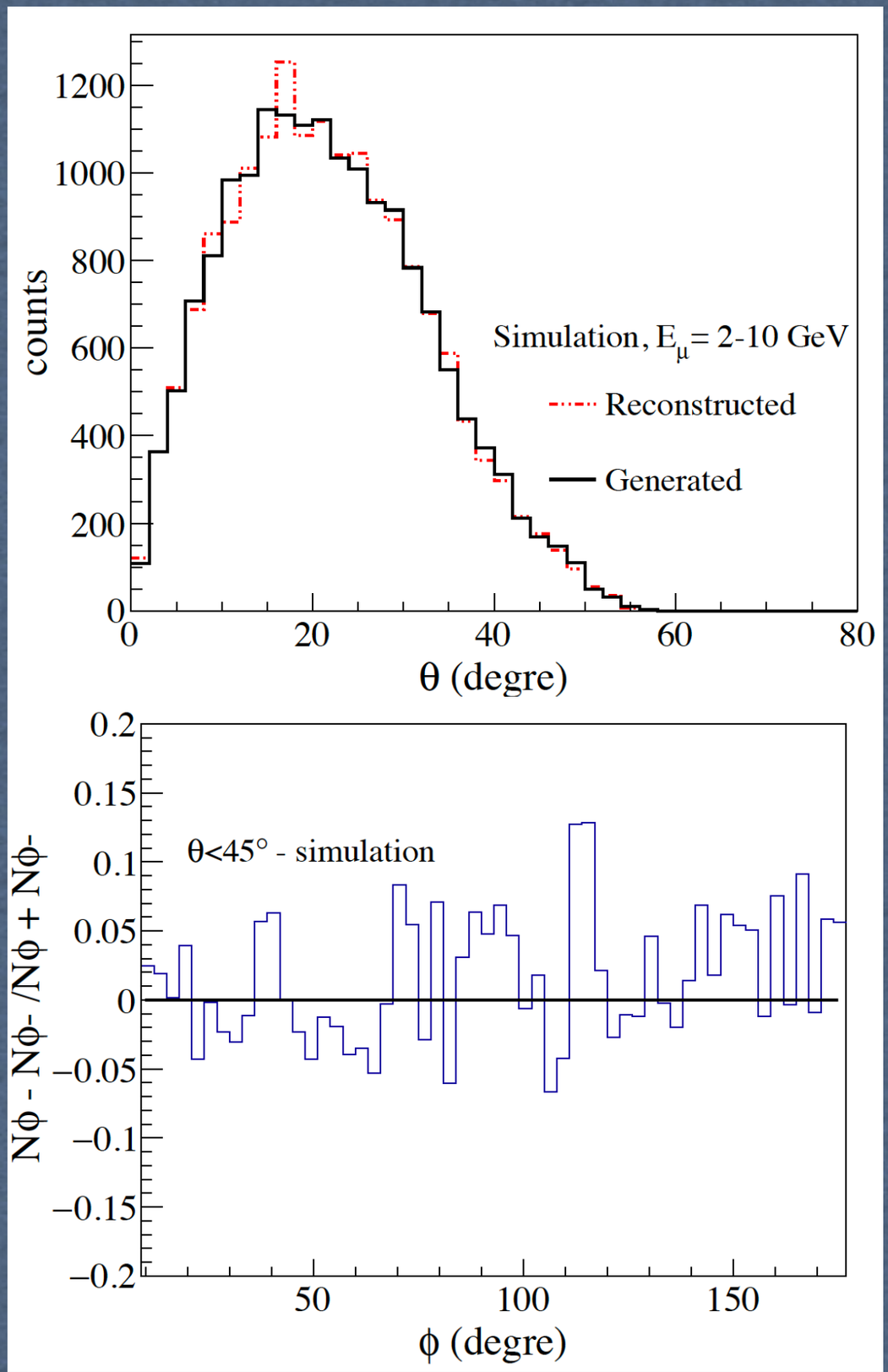




No significant effect found

✳Theta angular distribution compared to other telescopes (CERN) with similar results

EEE-Sim validation



- Sanity checks (rec.vs.gen):
  - Energy spectrum
  - Thetas
  - Phi
  - Phi asymmetry

EEE-Sim results

Systematic checks for data/sim agreement

✳Effect of changing parameters in the microscopic parametrisation of the MRPC response

- **Time spread**: σ = 94ps [NIM A539 (2008) 263] - 238ps [JINST13(2018)P08026]
- **Cluster size**: σ_X = 8.4mm [NIM A539 (2008) 263] - 9.2mm [JINST13(2018)P08026]
- **Cluster size**: σ_Y = 8.4mm [NIM A539 (2008) 263] - 15.mm [JINST13(2018)P08026]
- **Light speed**: 11.24ns/cm [NIM A539 (2008) 263] - 15.8ns/cm [ReconstructionCode]

No significant effect found since the SIM algorithm uses only the first hit as the REC does for data

✳Effect of changing the generation procedure

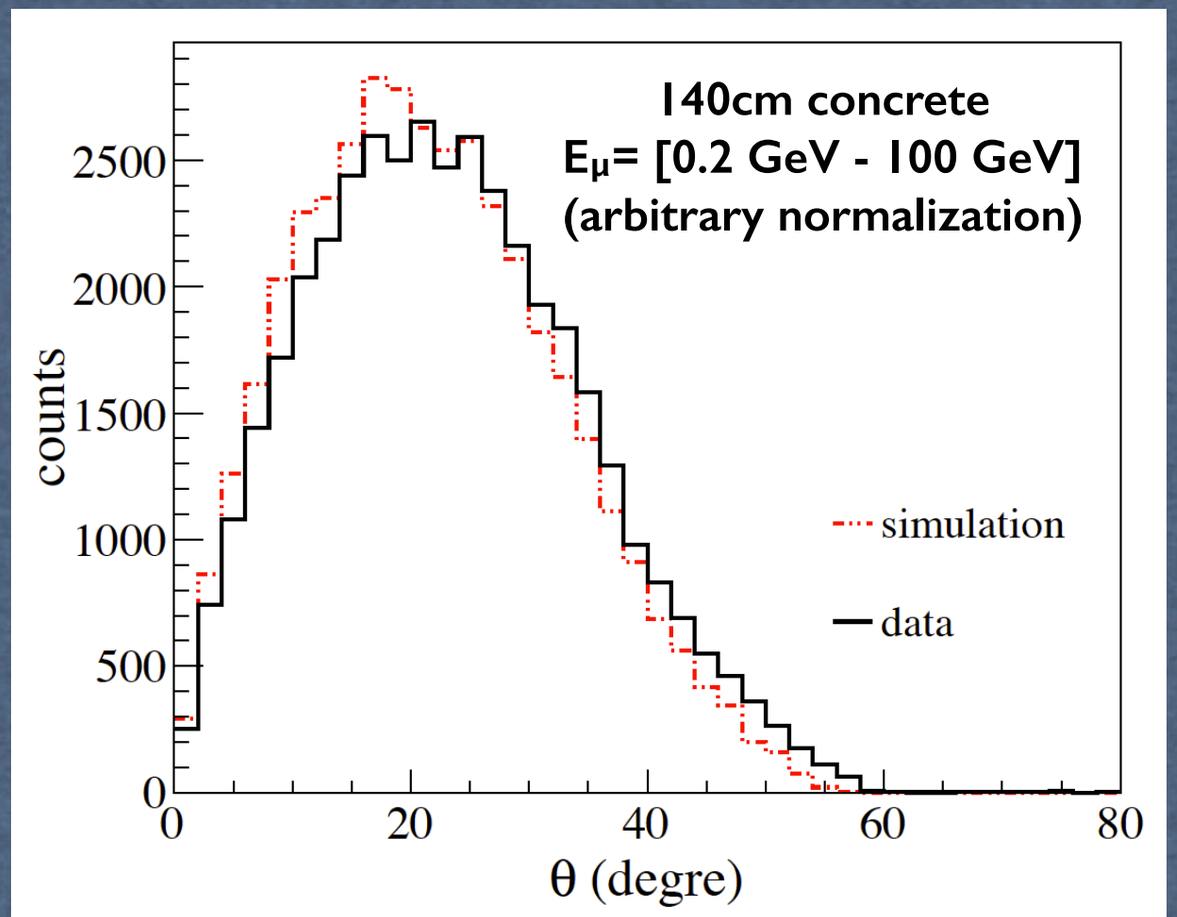
- **Generation semi-sphere**: R = [150cm-250cm]; position in Z = [centered, offset to -50cm]

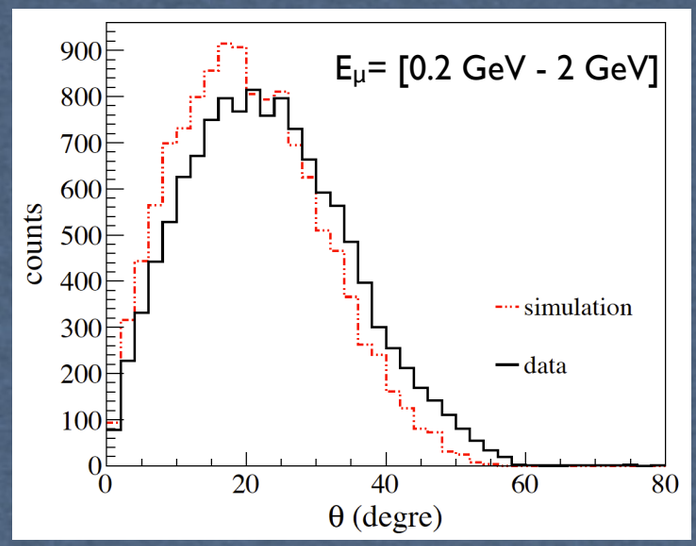
No significant effect found since the SIM algorithm uses only the first hit as the REC does for data

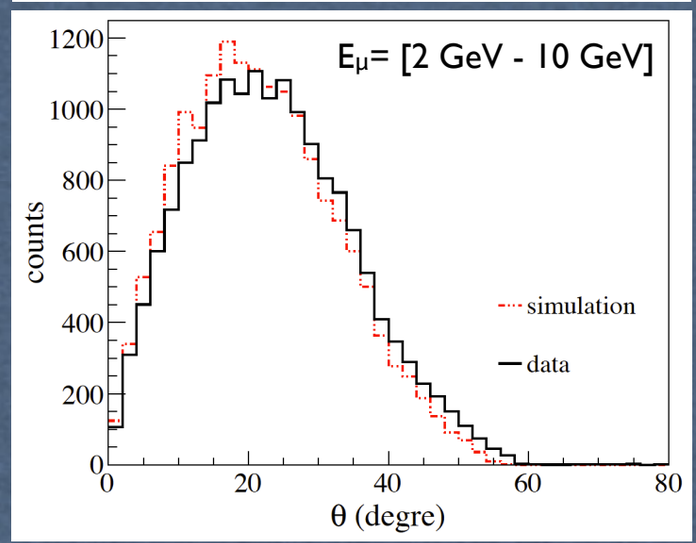
✳ Surrounding material have a significant impact on absolute rate. What about the angular distribution?

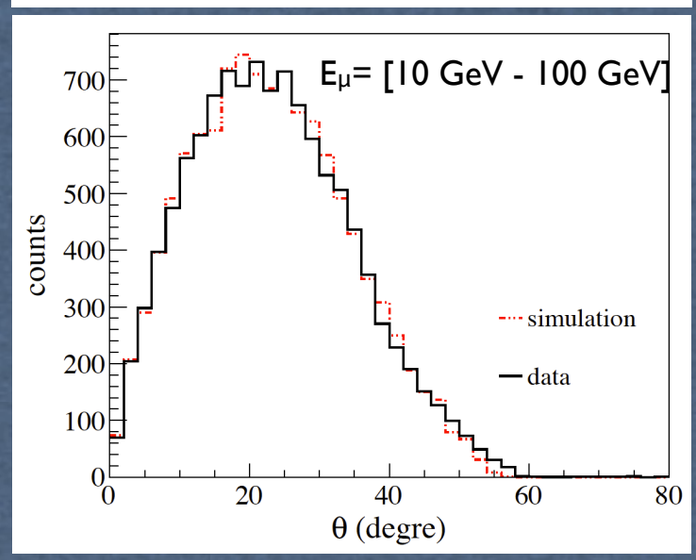
✳Effect of changing concrete vault

- ✳ Concrete vault [0cm - 140cm]
- ✳ Expected to be ~140cm
- ✳ Best rate matching obtained for 140cm







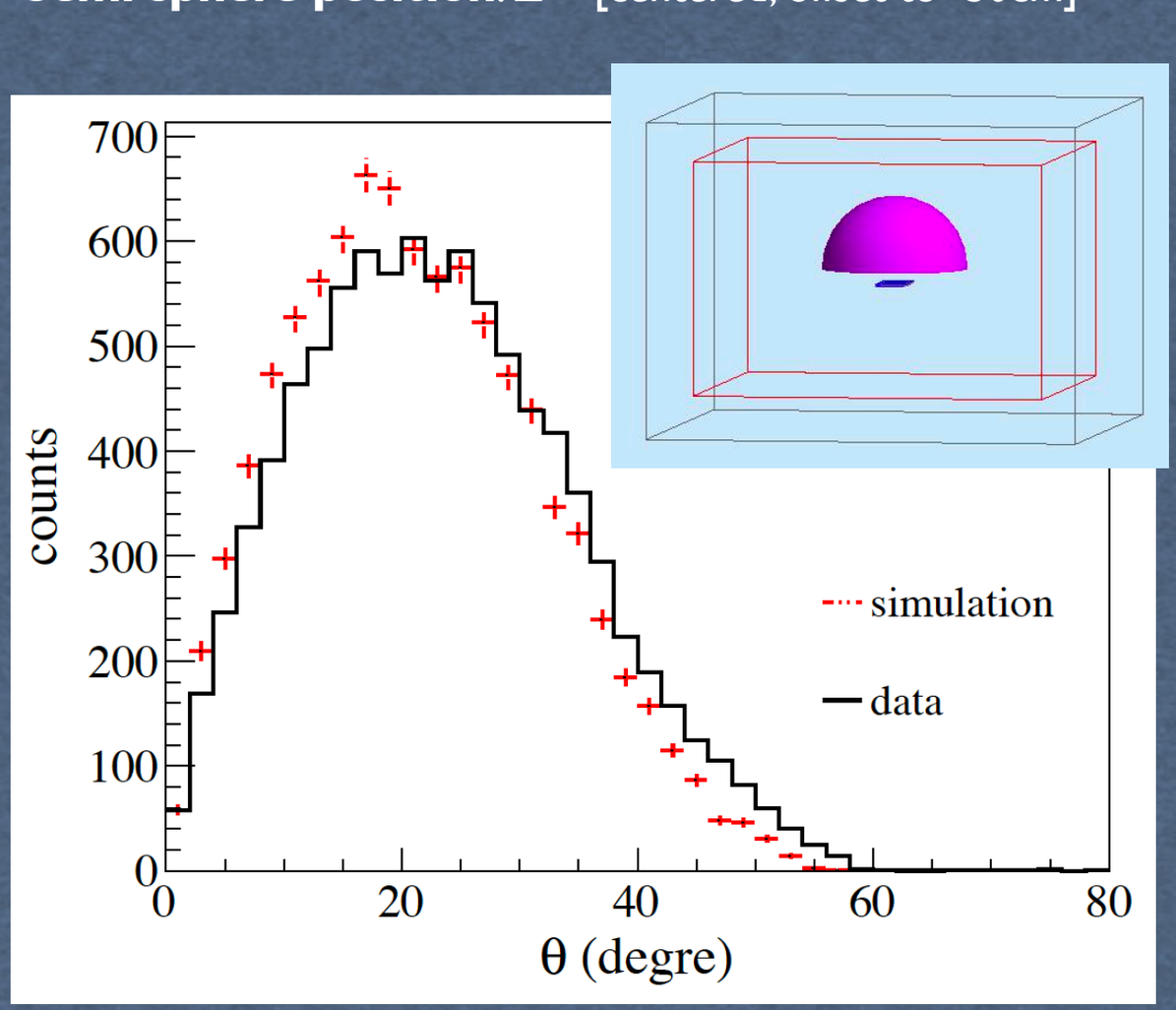


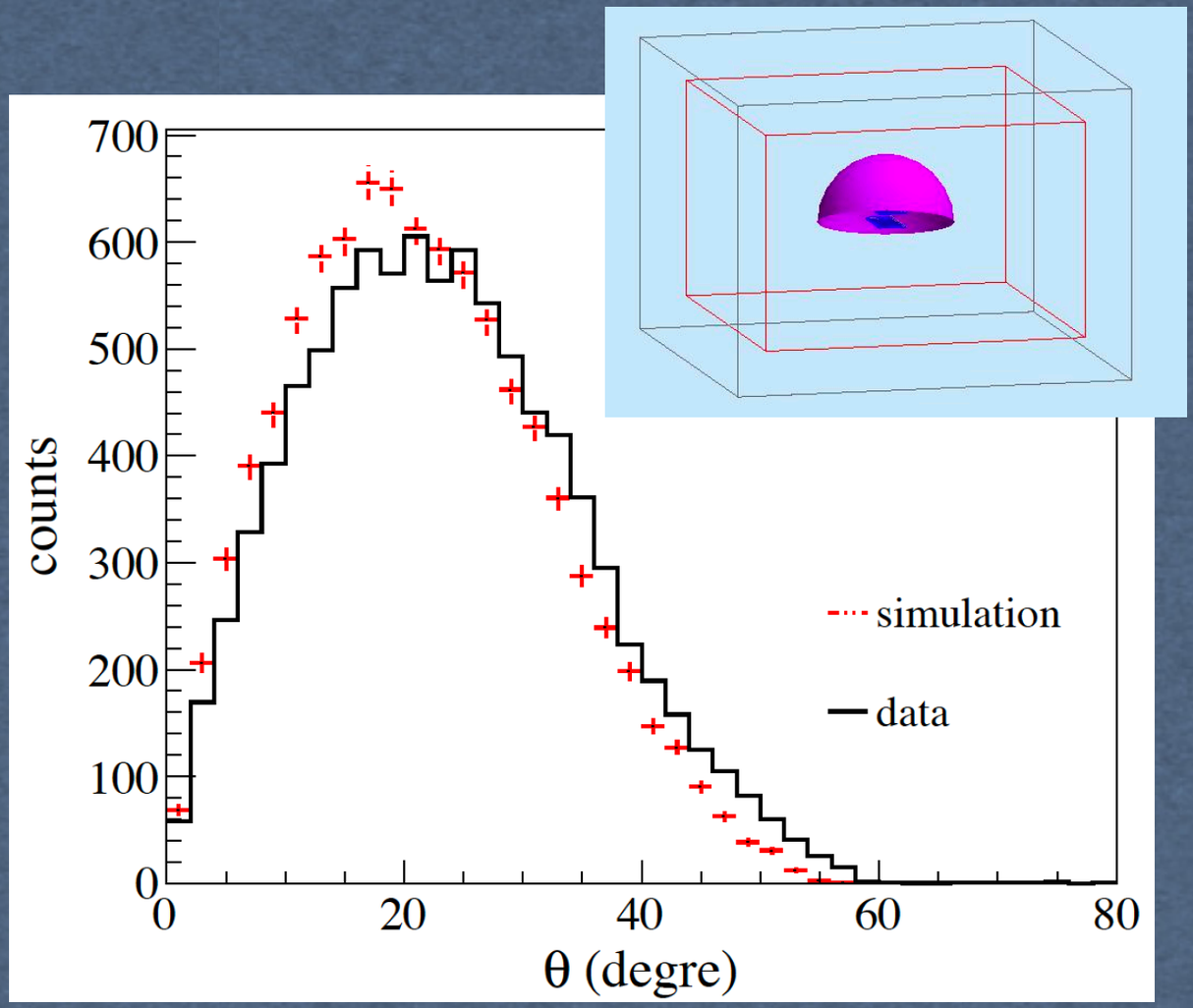
✳Better agreement if we only consider high energy muons

Systematic checks for data/sim agreement

✳Effect of changing generation parameters

- **Semi sphere size**: R = [150cm-250cm]
- **Semi sphere position**: Z = [centered, offset to -50cm]



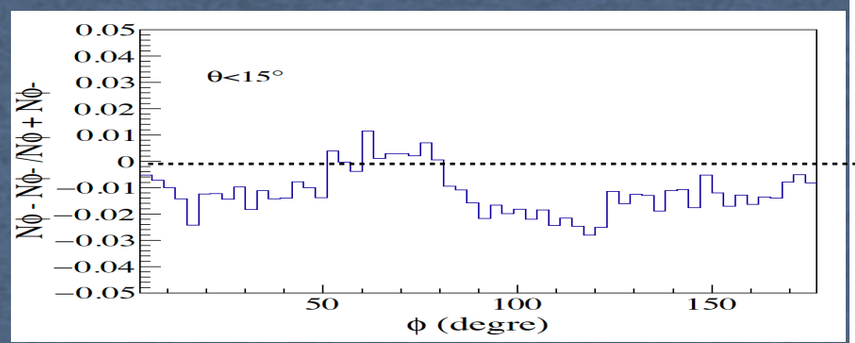


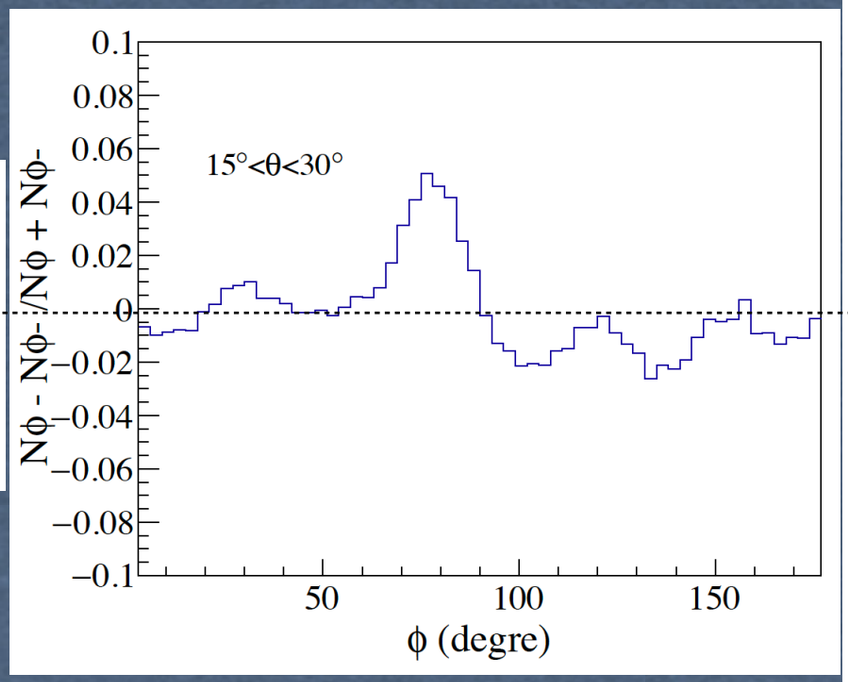
No significant effect found since the SIM algorithm uses only the first hit as the REC does for data

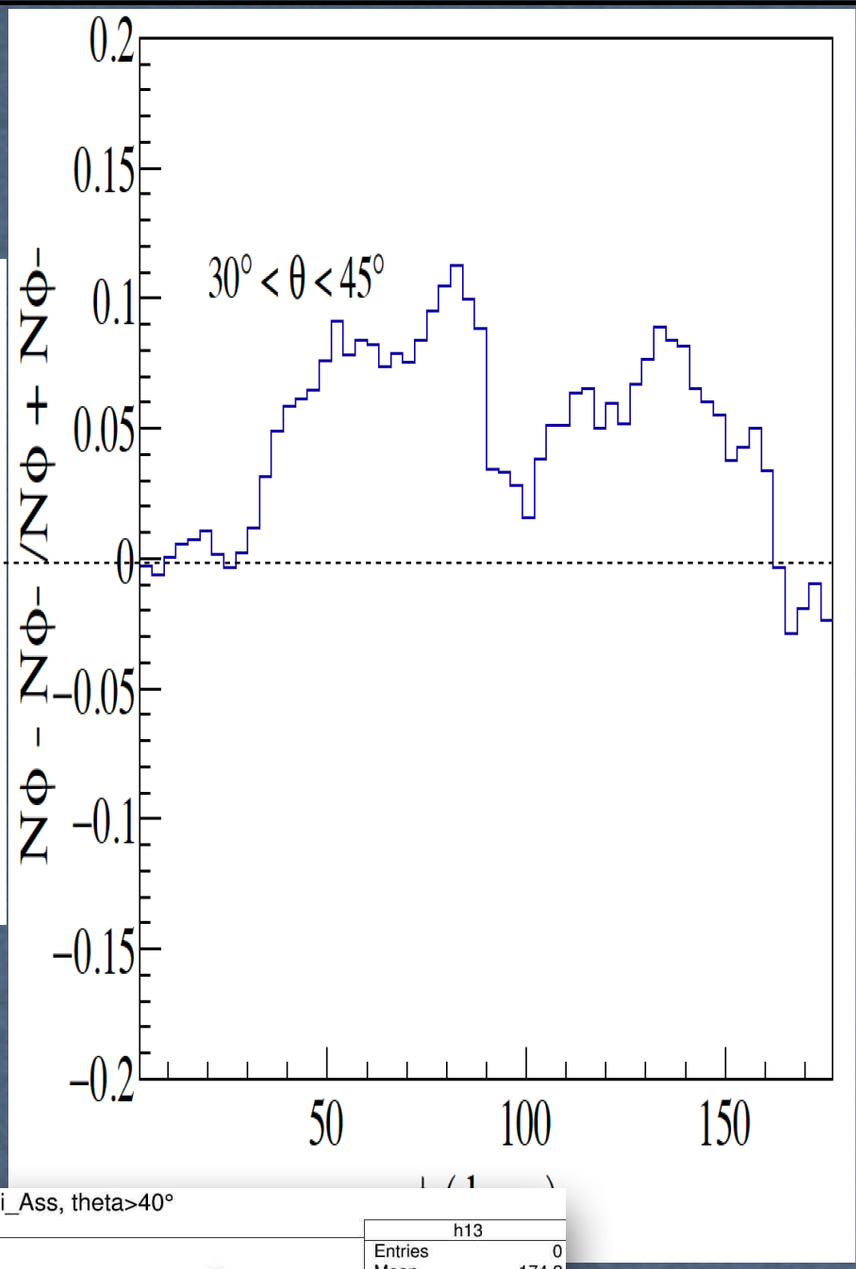
EEE-Sim results

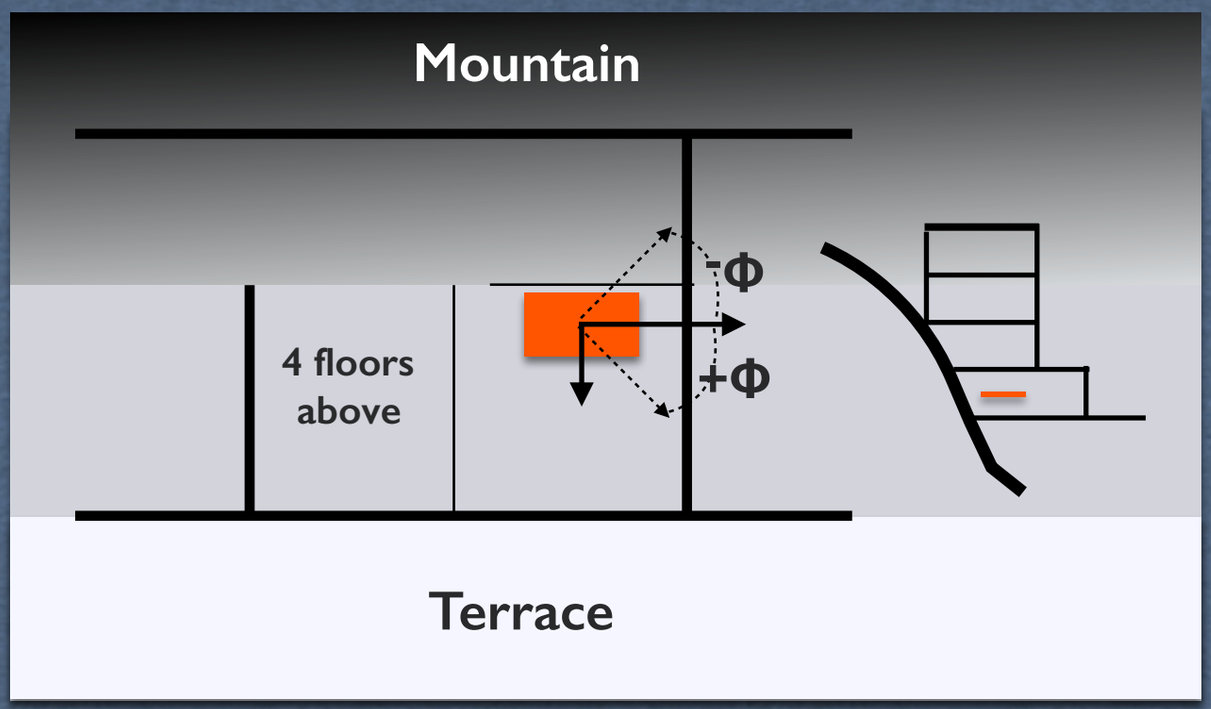
Systematic checks for data/sim agreement

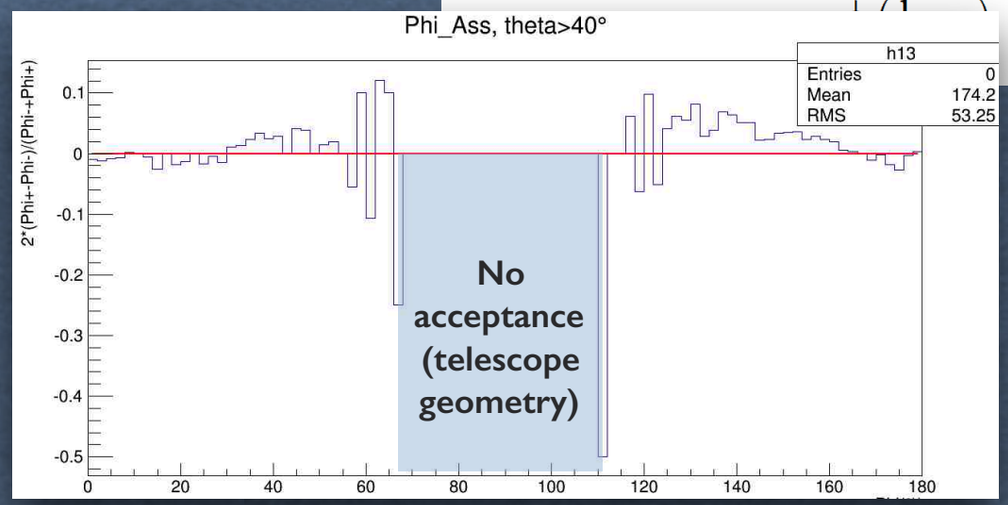
- Phi asymmetry due to different materials crossed





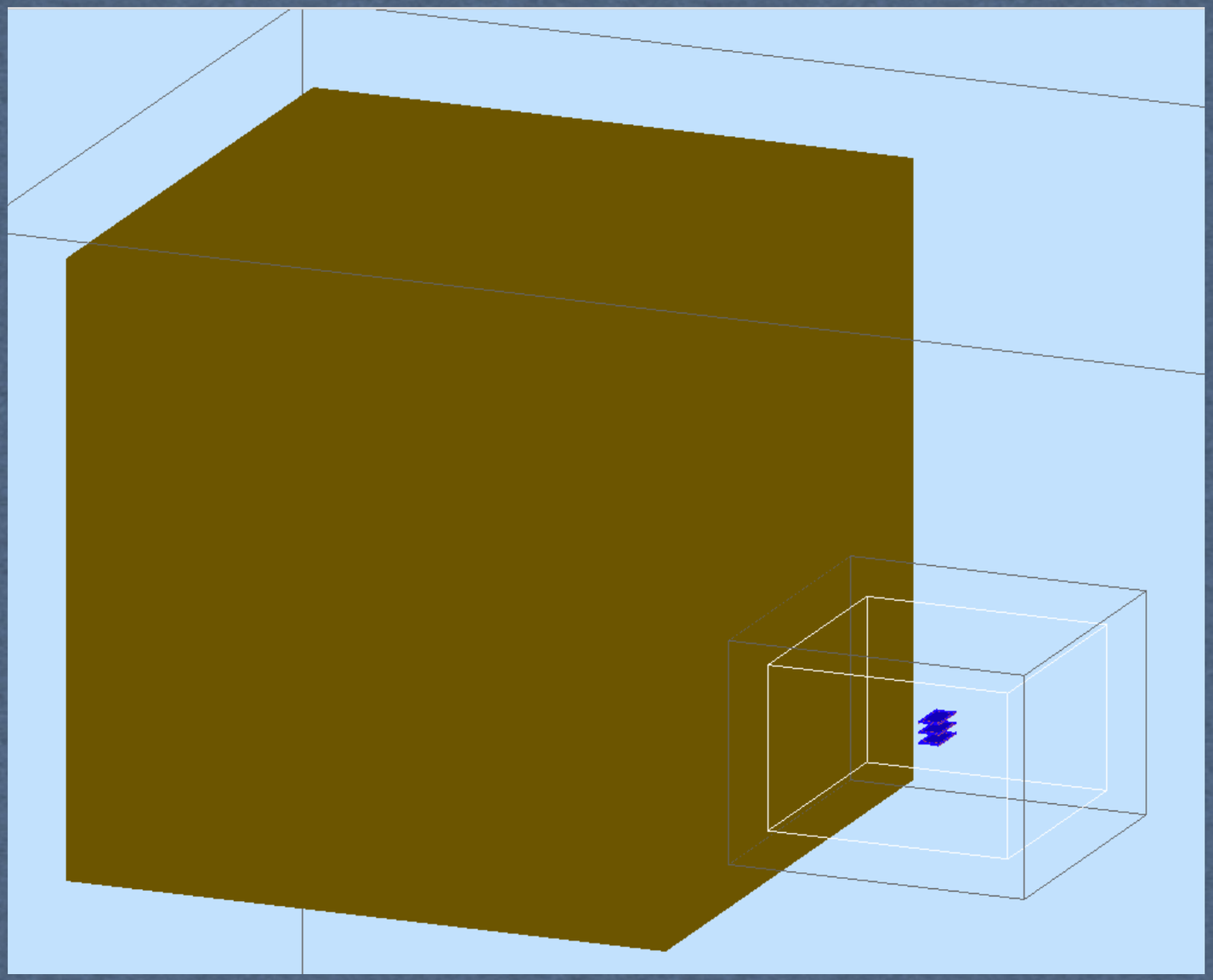






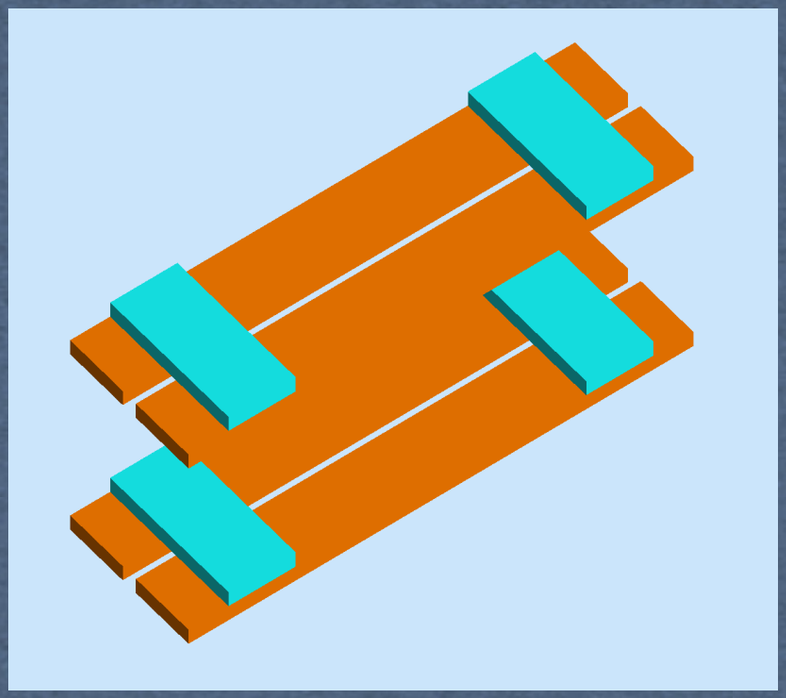
Simulating the environment

✳ the ‘mountain’ on one side is simulated as a block of iron with clearance and ΔΘ±15



✳ Work in progress

Confirming absolute rates using a cosmic box (ASTRO)



Liceo Casiraghi

- 8 scintillators bars (60x8x2 + 18x8x2)cm3
- Plastic wrapped in 200um-Gd-linen mylar
- Extruded plastic + WLS coupled to SiPMs (single side)
- FPGO readout, 3 sets of thresholds
- P,T,H + GPS signal
- All possible pairs of counters to select cosmic muons and cosmic neutrons
- Transportable
- Battery for stand-alone operations up to ~20h
- Planned test with EEE-CB ion Sardinia

- Excellent stability in time (~1%)
- Absolute rate compared to simulations shows a good matching (10%) for outside measurement
- Measure and correct for the attenuation factor (A) due to the material sourrounding EEE telescope

Pair	Data (Hz)	Sim (Hz)
LongLong	1.99 ± 0.01 Hz	2.1 ± 0.1
ShortShort	0.42 ± 0.01 Hz	0.46 ± 0.05
ShortLong	1.01 ± 0.01	0.93 ± 0.05

Summary and future plans

- EEE MRPC response implemented in GEANT4
- EEE data reconstruction program modified to process pseudo-data
- Simulations matches (@10%) data angular and time distribution
- Absolute rates of single muon hits on the telescope (3 chambers) are comparable to measured rates
- Disagreement for theta could be due to materials around the telescope
- Next steps:
  - investigation of the theta discrepancy
  - use of CORSIKA to generate and propagate multi-muon hits (primary hadron in high atmosphere + shower propagation to the sea-level)
  - Sim/data for multi-telescopes correlation comparison