January 14 2019
EEE Meeting
Centro Fermi - Rome

Detector Simulation Working Group (DeSi-WG)

EEE telescope simulation
Model validation

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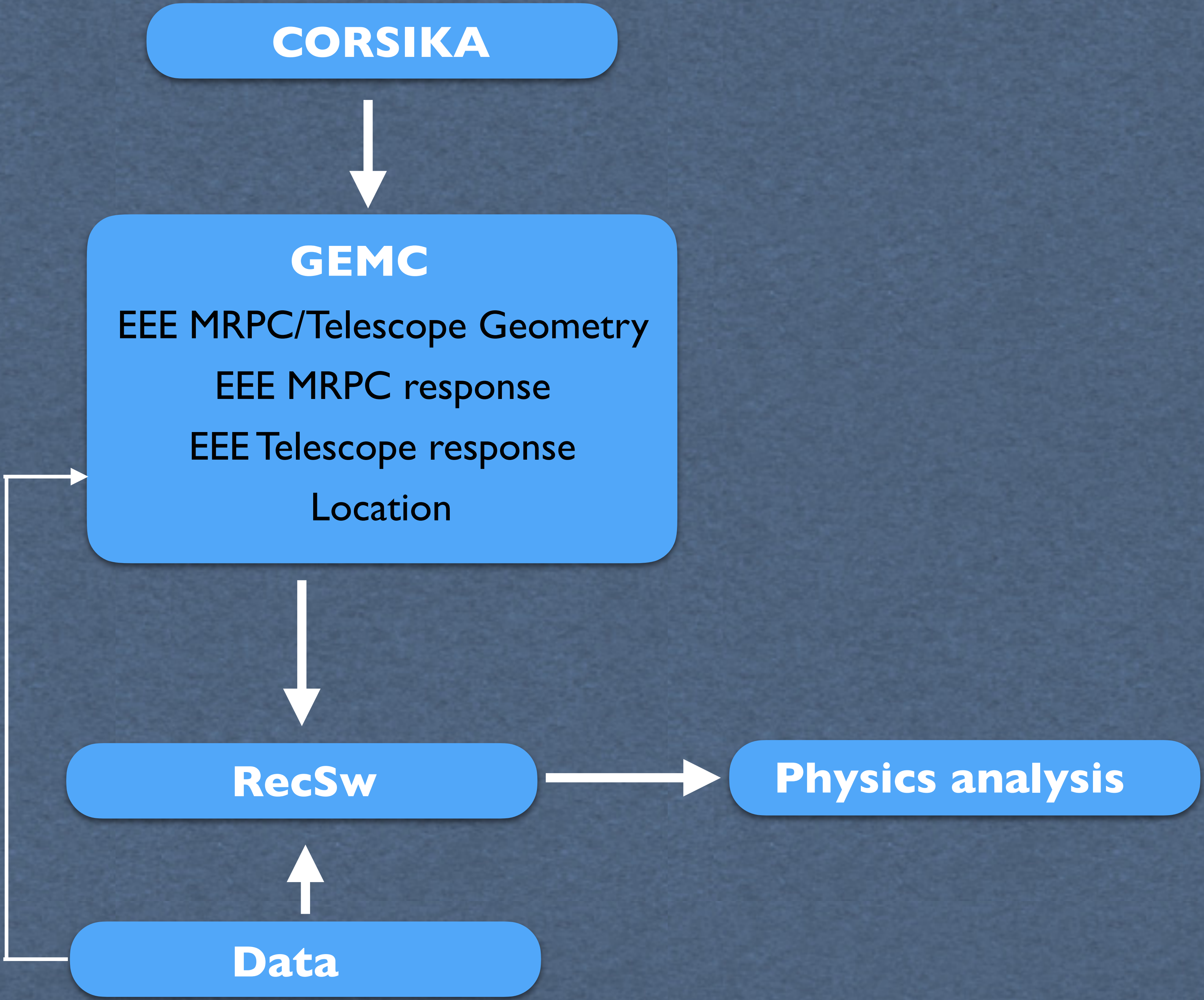
F.Coccetti, F.Noferini, M.Ungaro

DEtectorSImulation-WG

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



CORSIKA

GEMC

EEE MRPC/Telescope Geometry

EEE MRPC response

EEE Telescope response

Location

RecSw

Physics analysis

Data

EEE-Telescope simulation: response

- ✓ Already done
- ✓ Done from last update
- To be done

Work plan

- ✓ Define critical parameters in MRPC response: timing, efficiency, strip multiplicity, …
- ✓ Define a measurement procedure to asses parameters (eg. scintillator hodo for efficiency, top/bottom chambers for precise track determination, …)
- ✓ Test the characterization procedure on a telescope (as a template)
- ✓ Implement the response in GEMC
- ✓ Check results sensitivity to details of the new response
- ✓ Define a subset of few (important) parameters
- ✓ Define a simplified characterization procedure that could be extended to the other telescopes
- Identify tasks for schools (Alternaza Scuola Lavoro) and tasks requiring EEE-experts
- Document the procedure writing a note
- Distribute to other schools

EEE-Telescope simulation: response to cosmic validation

Work plan

- ✓ Single hit: GEMC produces already reasonable distributions and absolute rates
- ✓ For detailed comparison we need to implement the same analysis chain used to process data
- ✓ Implement in GEMC output necessary information to feed to the RecSW
- ✓ Establish at which level of details pseudo-data have to be similar to data
- ✓ Identify variables (multeplicity, angular distribution, timing, …) to be used to validate simulations
- ✓ Validate simulations comparing variables and rates
- ✓ No interaction with school for this task (Too difficult!)
- Write a note for internal use

✓ Already done
✓ Done from last update
• To be done

EEE-Telescope simulation: location

Work plan

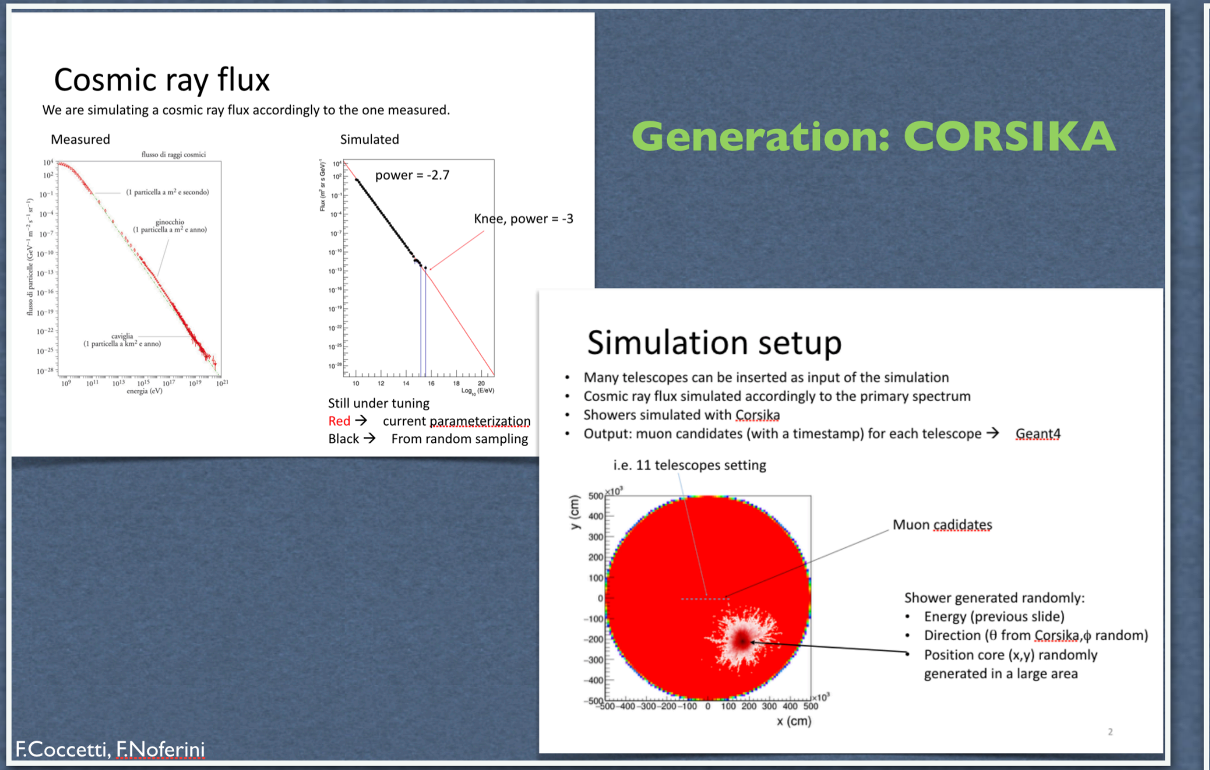
- ✓ GEMC infrastructure is ready for precise surrounding geometry/material description
- ✓ Use SV-Chiabrera as a template (simple geometry, single layer roof + walls and windows)
- ✓ Coordinate with teacher how to obtain construction details (drawings, wall/roof size, composition,…)
- Implement information in GSIM
- Test results looking at absolute rate variation
- Teach/show students the effect of surrounding materials running GEMC with different parameters
- Define the full characterisation procedure and write a note
- Distribute to other schools

EEE-Telescope simulation: CORSIKA

Work plan

- ✓ Feed CORSIKA output to GEMC replacing the internal muon generator
- ✓ Generate a shower form a high energy primary with CORSIKA and sample the particle flux at sea level
- ✓ Convert info (4-momentum, particleId, vertex, time,…) from CORSIKA to LUND
- ✓ Feed LUND to GEMC to replace the internal cosmic generator
- Repeat validation comparing sim to data
- Start physics analysis: multiple coincidence, long-range coincidence, …
- No interaction with school for this task (Too difficult!)
- Write a note for internal use

What has been done so far



Generation: CORSIKA

Cosmic ray flux

We are simulating a cosmic ray flux accordingly to the one measured.

Still under tuning

Red → current parameterization

Black → From random sampling

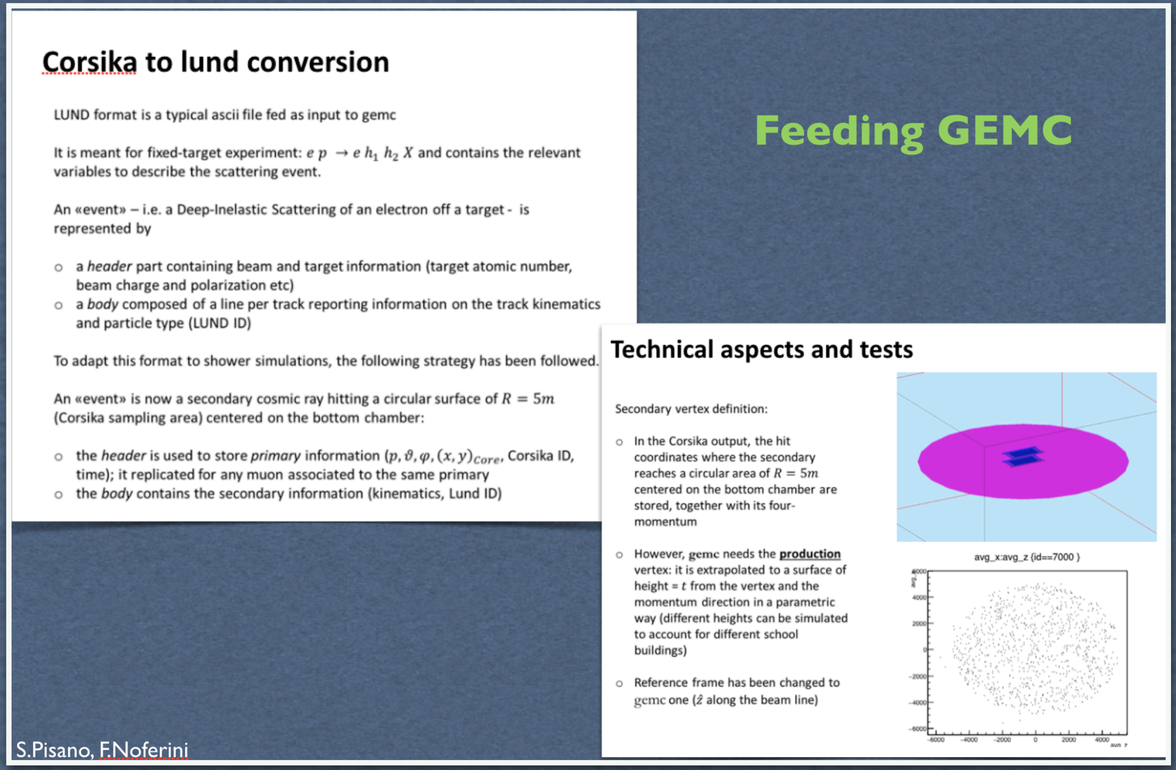
Simulation setup

- Many telescopes can be inserted as input of the simulation
- Cosmic ray flux simulated accordingly to the primary spectrum
- Showers simulated with Corsika
- Output: muon candidates (with a timestamp) for each telescope → Geant4

Shower generated randomly:

- Energy (previous slide)
- Direction (θ from Corsika,ϕ random)
- Position core (x,y) randomly generated in a large area

F.Coccetti, F.Noferini



Feeding GEMC

Corsika to lund conversion

LUND format is a typical ascii file fed as input to gemc

It is meant for fixed-target experiment: $e\ p \rightarrow e\ h_1\ h_2\ X$ and contains the relevant variables to describe the scattering event.

An «event» – i.e. a Deep-Inelastic Scattering of an electron off a target - is represented by

- a *header* part containing beam and target information (target atomic number, beam charge and polarization etc)
- a *body* composed of a line per track reporting information on the track kinematics and particle type (LUND ID)

To adapt this format to shower simulations, the following strategy has been followed.

An «event» is now a secondary cosmic ray hitting a circular surface of $R = 5m$ (Corsika sampling area) centered on the bottom chamber:

- the *header* is used to store *primary* information $(p, \vartheta, \varphi, (x, y)_{Core}$, Corsika ID, time); it replicated for any muon associated to the same primary
- the *body* contains the secondary information (kinematics, Lund ID)

Technical aspects and tests

Secondary vertex definition:

- In the Corsika output, the hit coordinates where the secondary reaches a circular area of $R = 5m$ centered on the bottom chamber are stored, together with its four-momentum
- However, gemc needs the **production** vertex: it is extrapolated to a surface of height = t from the vertex and the momentum direction in a parametric way (different heights can be simulated to account for different school buildings)
- Reference frame has been changed to gemc one ($\hat{z}$ along the beam line)

S.Pisano, F.Noferini

Side-activity

- Installed a VM (eeevm01.ge.infn.it) with ROOT, GEMC and EEE data
- Granted access to teachers (SV, Recco, Voghera, Cinisello)
- WIKI page (https://wiki.ge.infn.it/eee)with detailed instruction on how to open an X-session
- Easy connection and display exported via MobaXterm (Windows) or ssh (Mac/Linux)
- ROOT tutorial in preparation (D.Menasce)
- ROOT via WEB under investigation (D.Menasce)

GEMC
EEE configuration available and running

- Simple simulations
- Surrounding material effect
- EEE full simulations

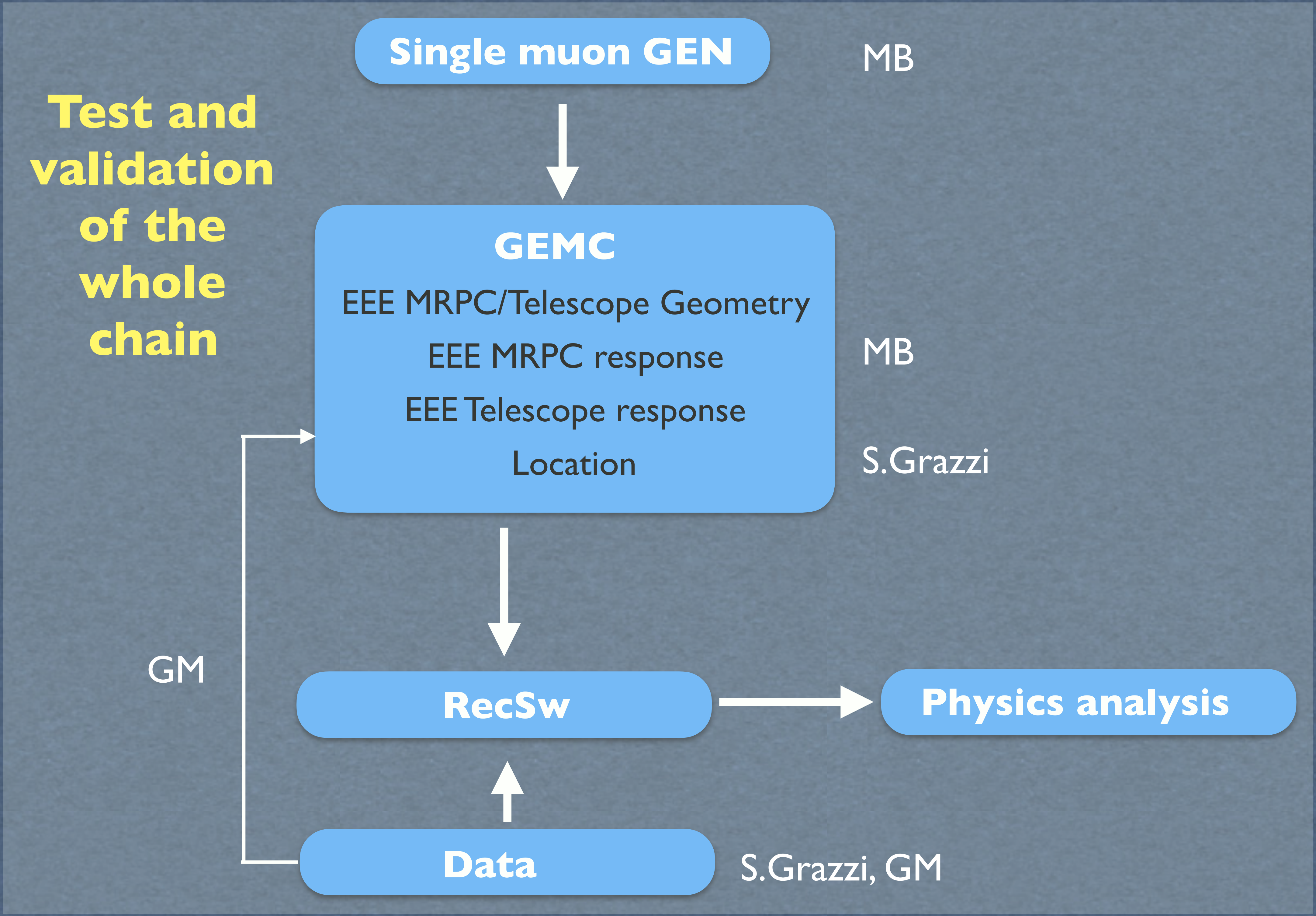
ROOT
v6.0

- EEE data analysis
- GEMC pseudo-data analysis

In stand-by waiting for high stat CORSIKA simulation

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 MB

EEE Telescope response

Location S.Grazzi

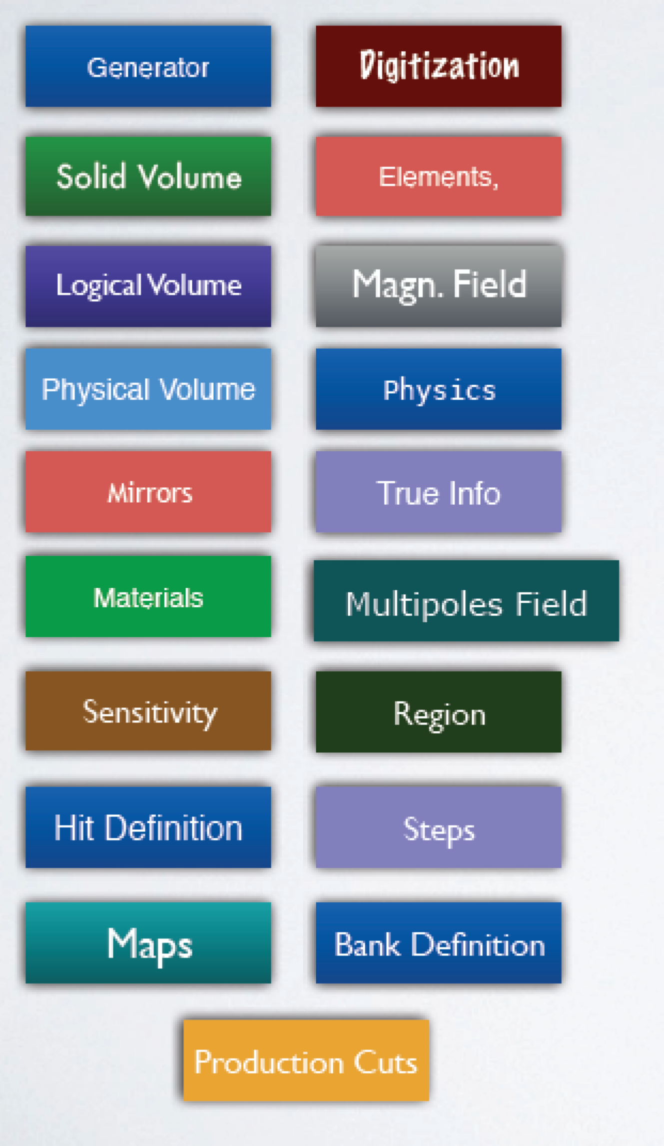
GM

RecSw → **Physics analysis**

Data S.Grazzi, GM

GEant4 Monte Carlo: GEMC

M.Ungaro

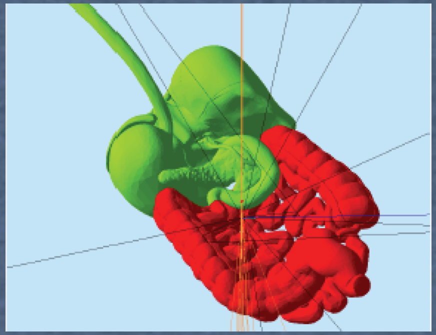


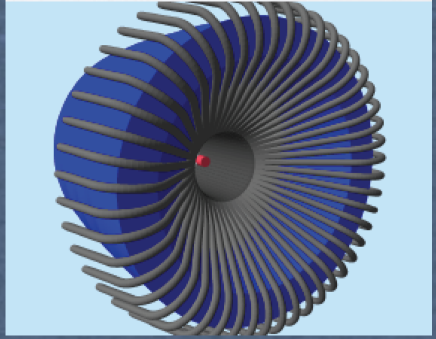
Realistic detector simulation

GEMC

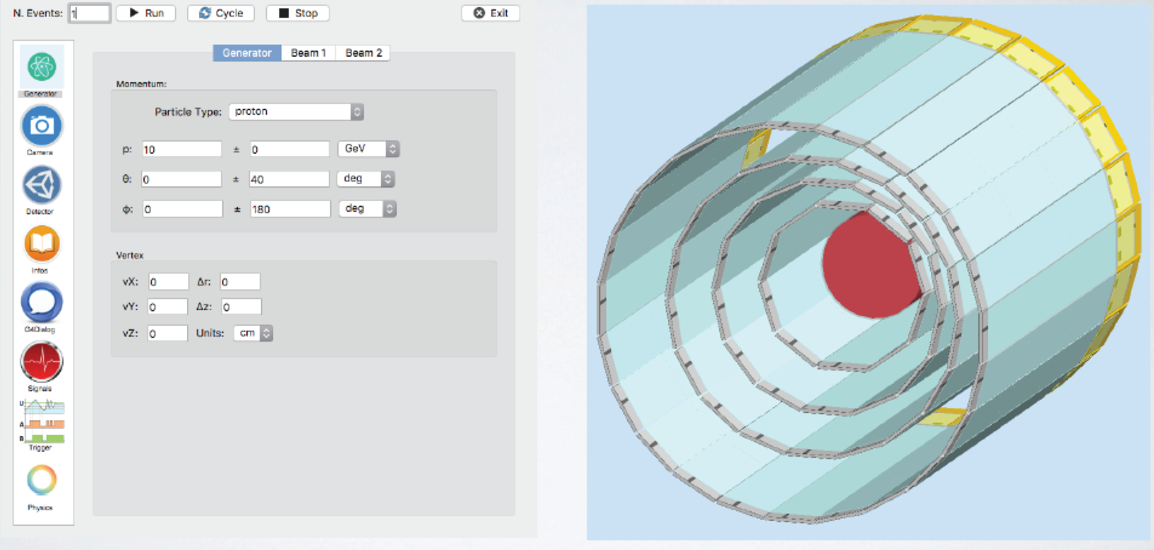
A GEANT4 libraries based simulation tools

- components description
- components interaction
- user-defined geometry and hit
- internal generator (included cosmic rays)
- multiple input/output format
- CAD geometry accepted
- interactive/batch mode
- source on GitHub





GEMC graphic interface



N. Events: 1

Momentum:

Particle Type: proton

p: 10 ± 0 GeV

θ: 0 ± 40 deg

ϕ: 0 ± 180 deg

Vertex

vX: 0 Δr: 0

vY: 0 Δz: 0

vZ: 0 Units: cm

Installed (and now working!) in EEE cluster at CNAF!

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

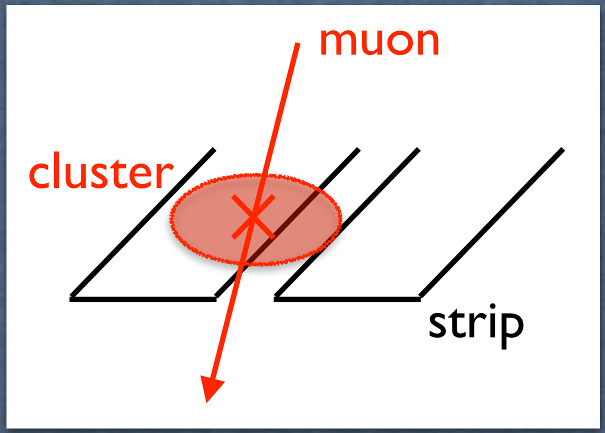
- Multi-telescopes: coincidence rates
- Single/multiple telescope(s) studies: bottom-up muons, …

✳ 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 Ynand T



✳MRPC parameters

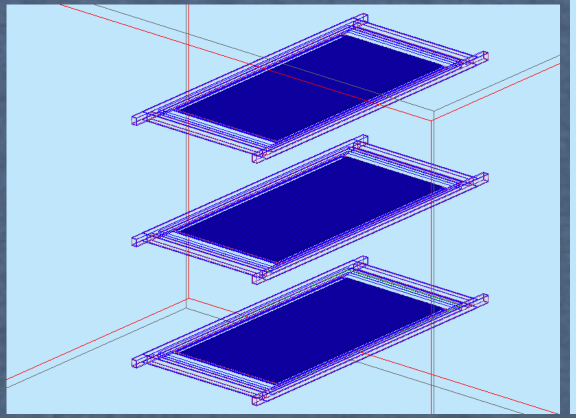
- 90x160 active area
- Active: 2.5cm x 24 strips + 0.7cm x (24-1) gaps
- Time spread: σ = 238ps
- Cluster size: σ_X = 9.2 mm
- Cluster size: σ_Y = 15 mm
- Light speed: 15.8 ns/cm
- HIT_{XY} is gaussian-spread and projected on the sensitive area to derive strip multiplicity

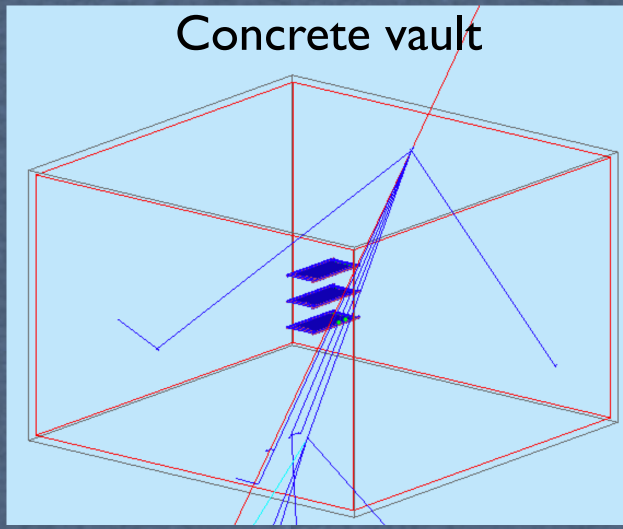
Ref: JINST13(2018)P08026

✳Telescope parameters

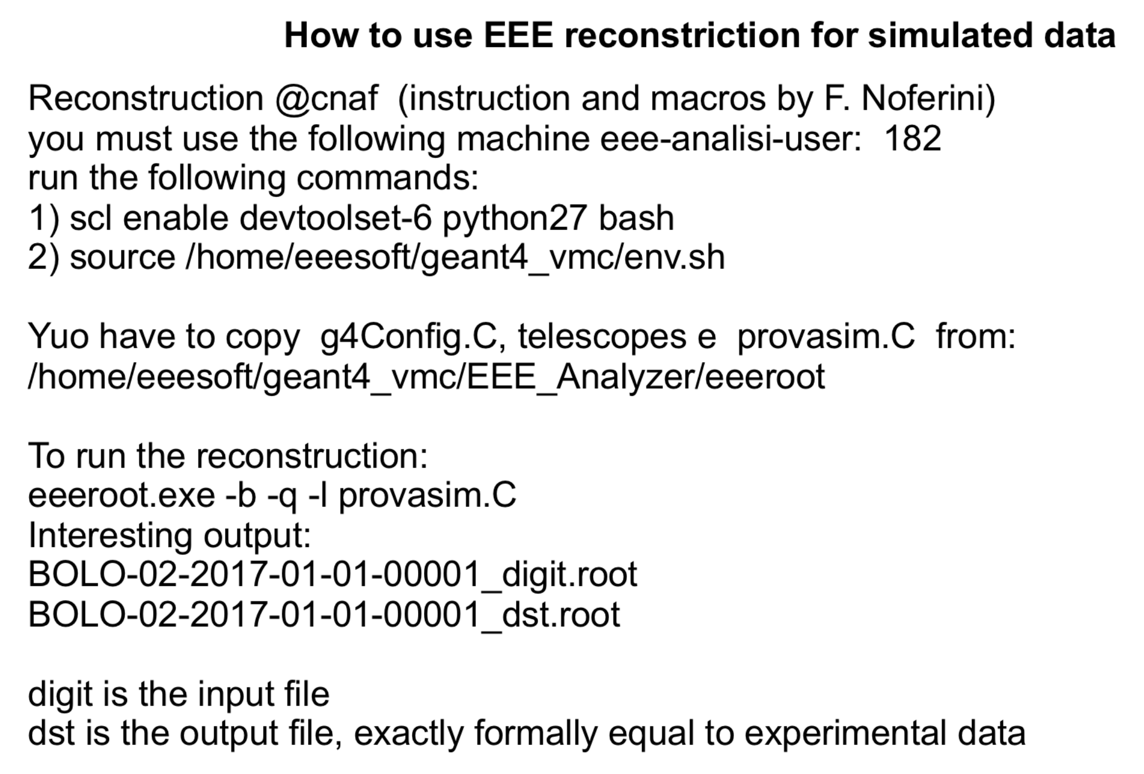
- 3 chambers
- -50/0/+50 cm apart
- placed in a concrete box wall on all sides (140cm concrete)

Ref: GENO-01





EEE-Sim reconstruction



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

`gemc_to_eee()`

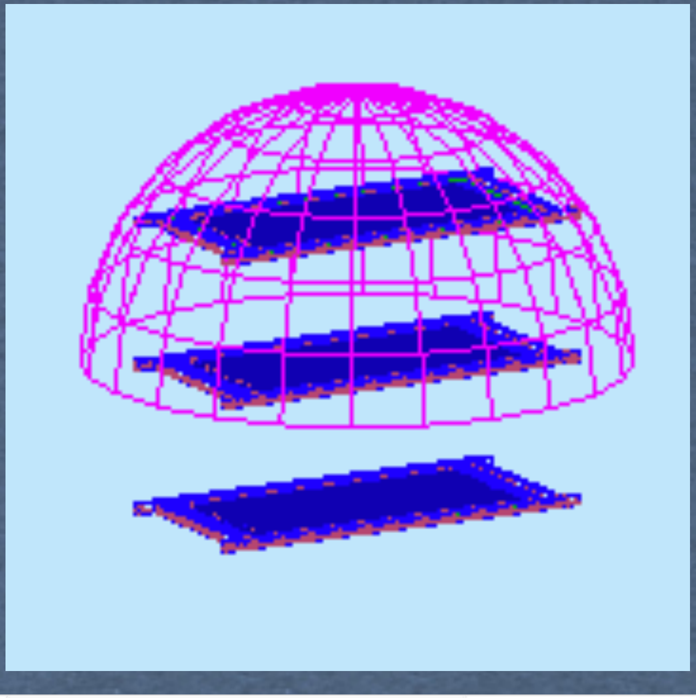
the routine reads the gemc root-file output and convert it in a root-file readable by EEE-reconstruction code (F. Noferini)

`…_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



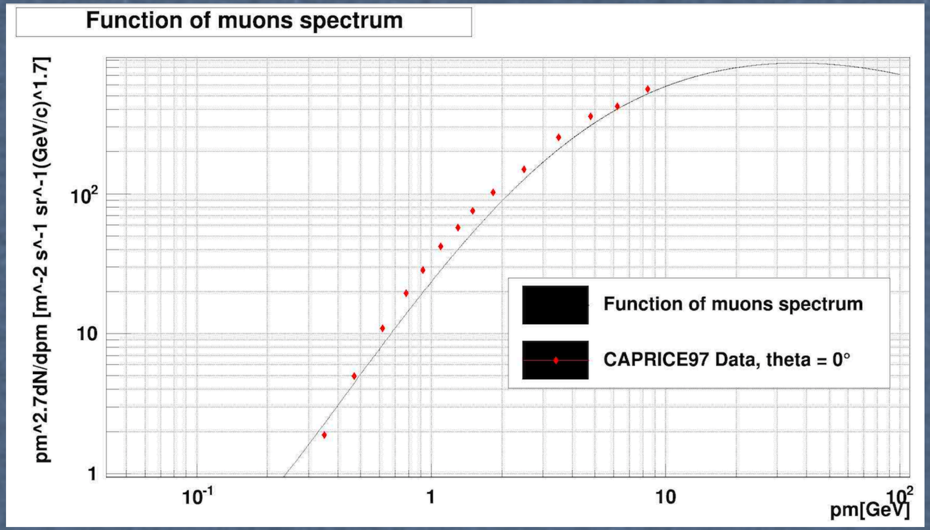
- ✳ Single-muon generation
- ✳ Semi-sphere generation such as to obtain a flat distribution on a plane surface
- ✳ Improved Gaisser parametrization for Flux(E_μ,Θ) to include Earth curvature (all latitudes) and low energy muons (<100GeV)

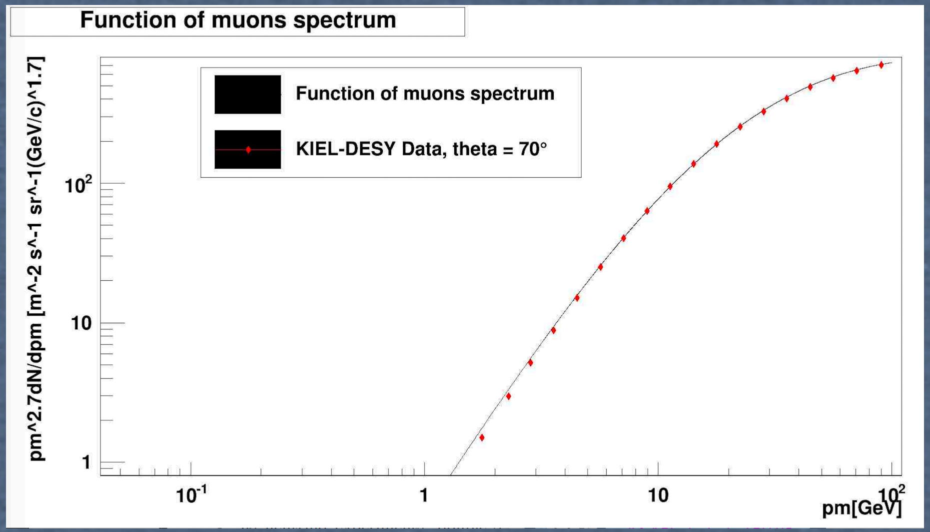
$$\frac{dI_\mu}{dE_\mu} = 0.14\left[\frac{E_\mu}{GeV}\left(1+\frac{3.64GeV}{E_\mu(\cos\theta^*)^{1.29}}\right)\right]^{-2.7}\left[\frac{1}{1+\frac{1.1E_\mu\cos\theta^*}{115GeV}}+\frac{0.054}{1+\frac{1.1E_\mu\cos\theta^*}{850GeV}}\right]$$

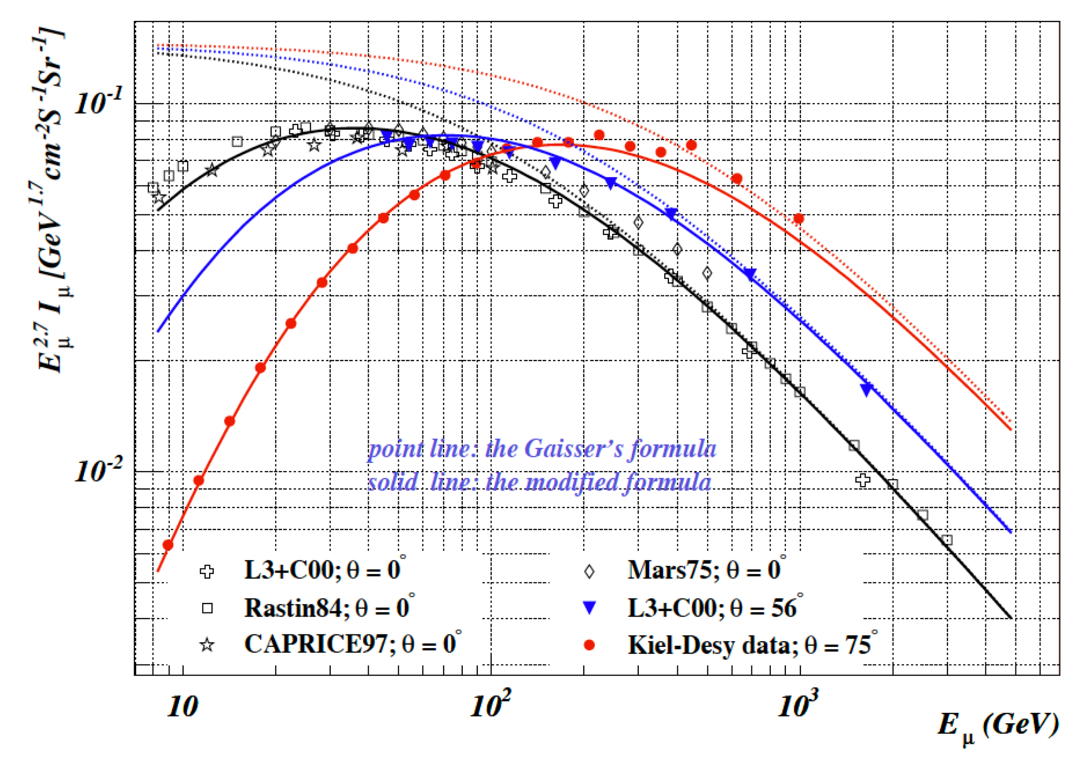
$$\cos\theta^* = \sqrt{\frac{(\cos\theta)^2+P_1^2+P_2(\cos\theta)^{P_3}+P_4(\cos\theta)^{P_5}}{1+P_1^2+P_2+P_4}}$$

P1	P2	P3	P4	P5
0.102573	-0.068287	0.958633	0.0407253	0.817285

arXiv:1509.06176

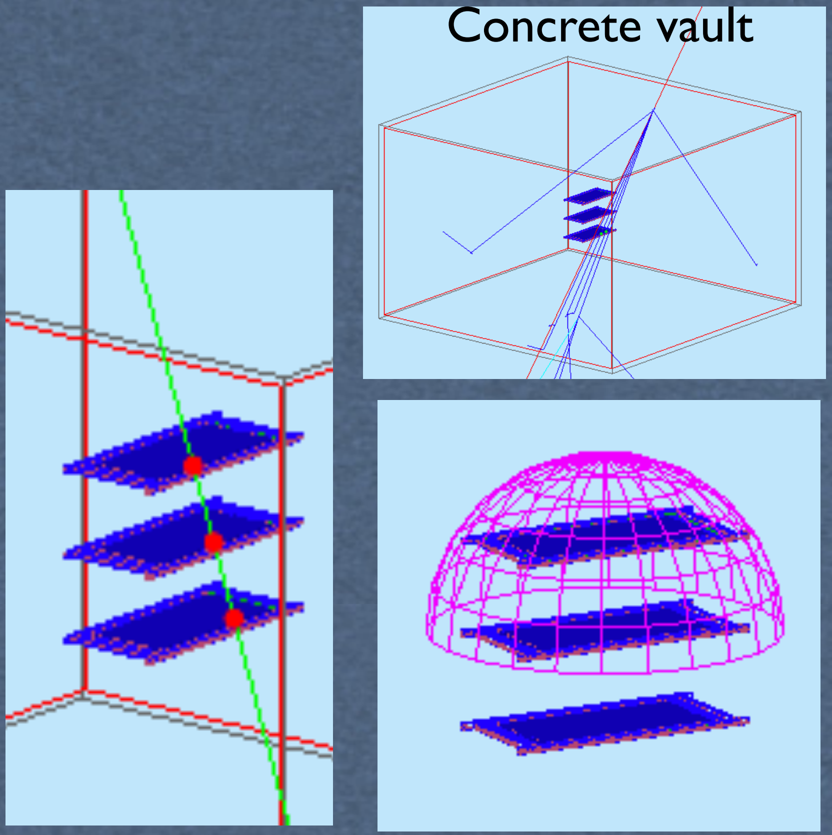


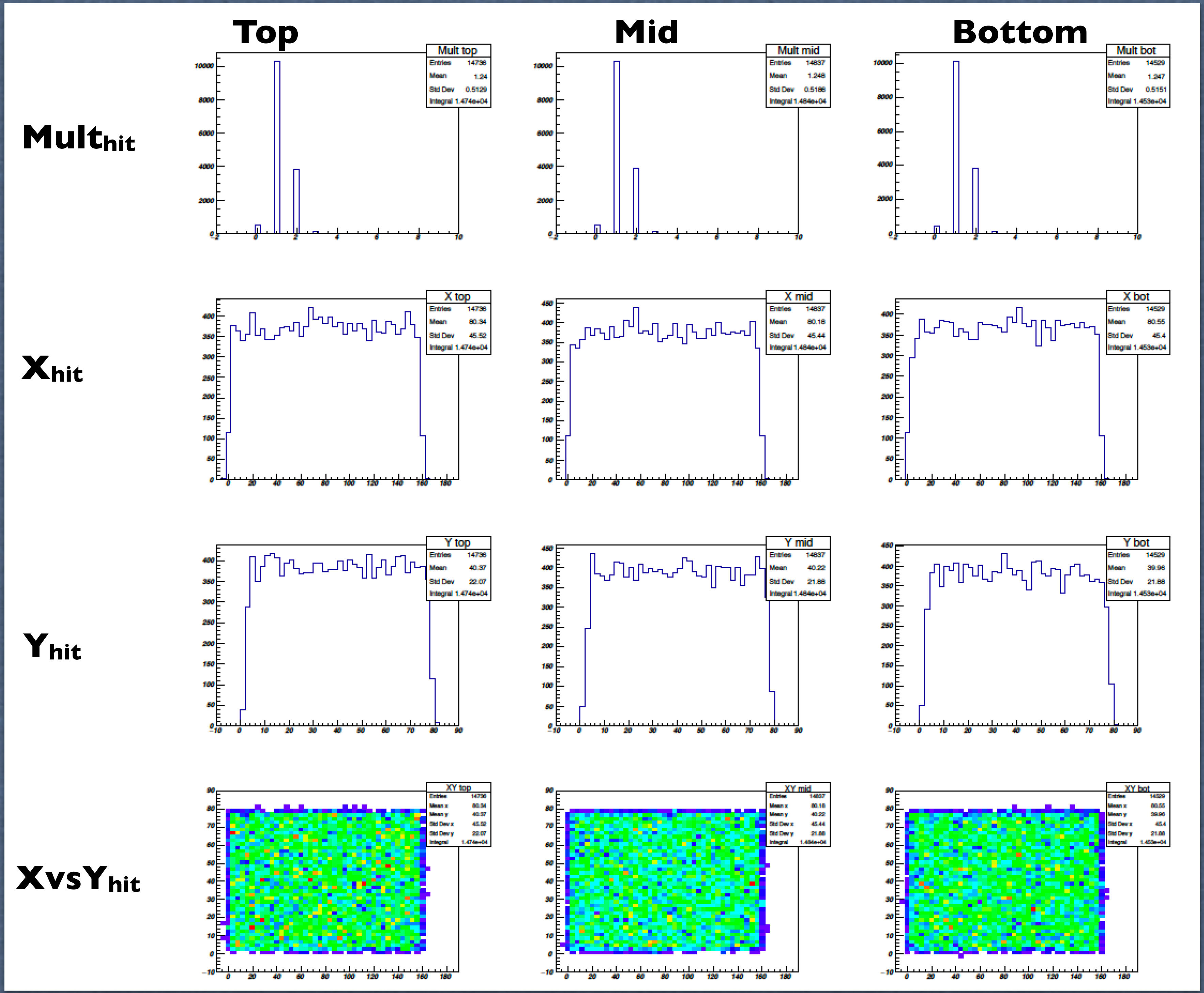




- ✳ good agreement with previous data
- ✳ low/high energies, small/large angles
- ✳ our implementation checked on data
- ✳ Generation split in 3 E_μ intervals:
  - [0.2 GeV - 2 GeV]
  - [2GeV-10 GeV]
  - [10GeV-100 GeV]
- ✳ Normalization factor for absolute flux:
  - 1.06 μ cm^{-2} min^{-1}

EEE-Telescope simulation: geometry

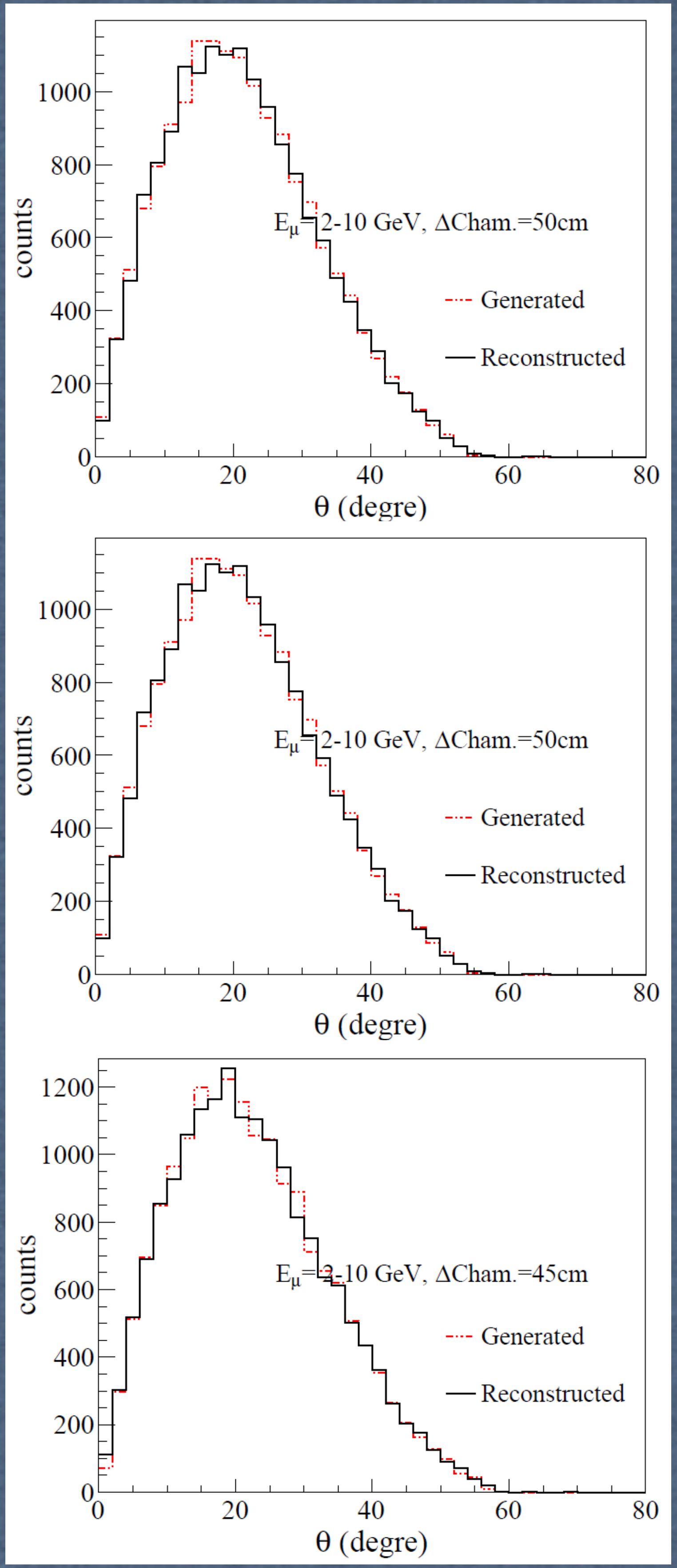




✴Telescope Parameters

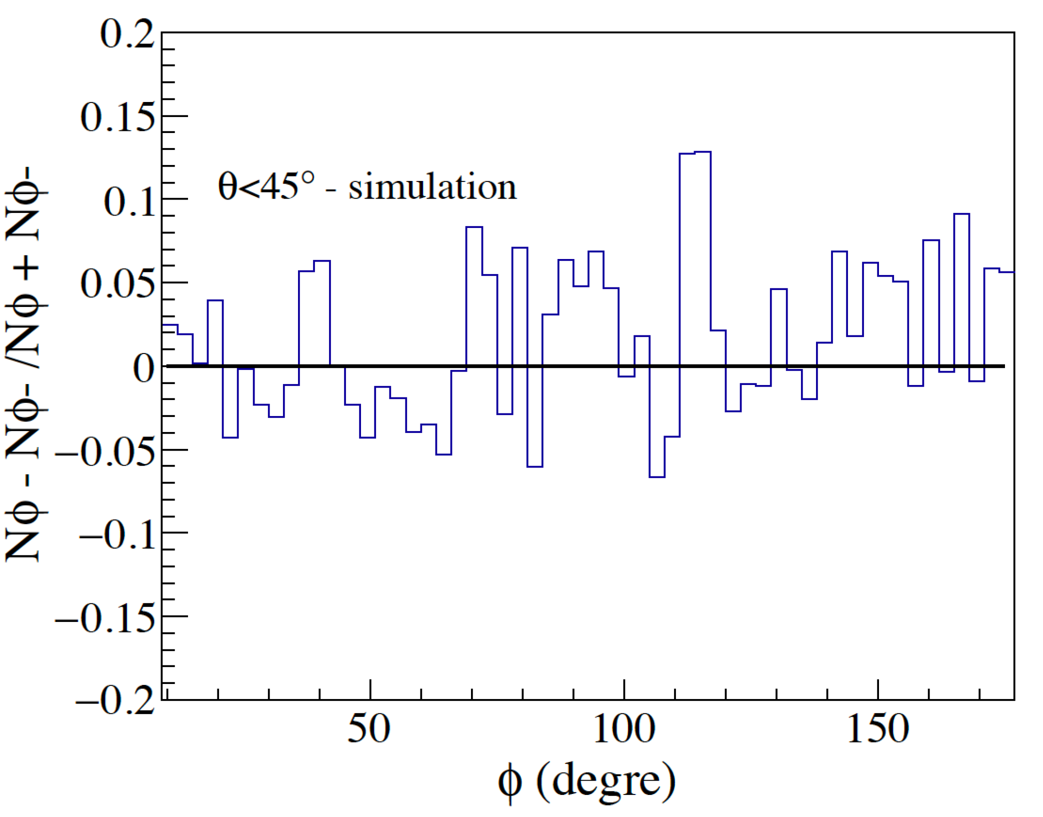
- 3 chambers
- -50/0/+50 cm apart
- placed in a concrete box wall on all sides (140cm concrete)

✴Individual response to cosmic muons (2-10 GeV) of the three chambers

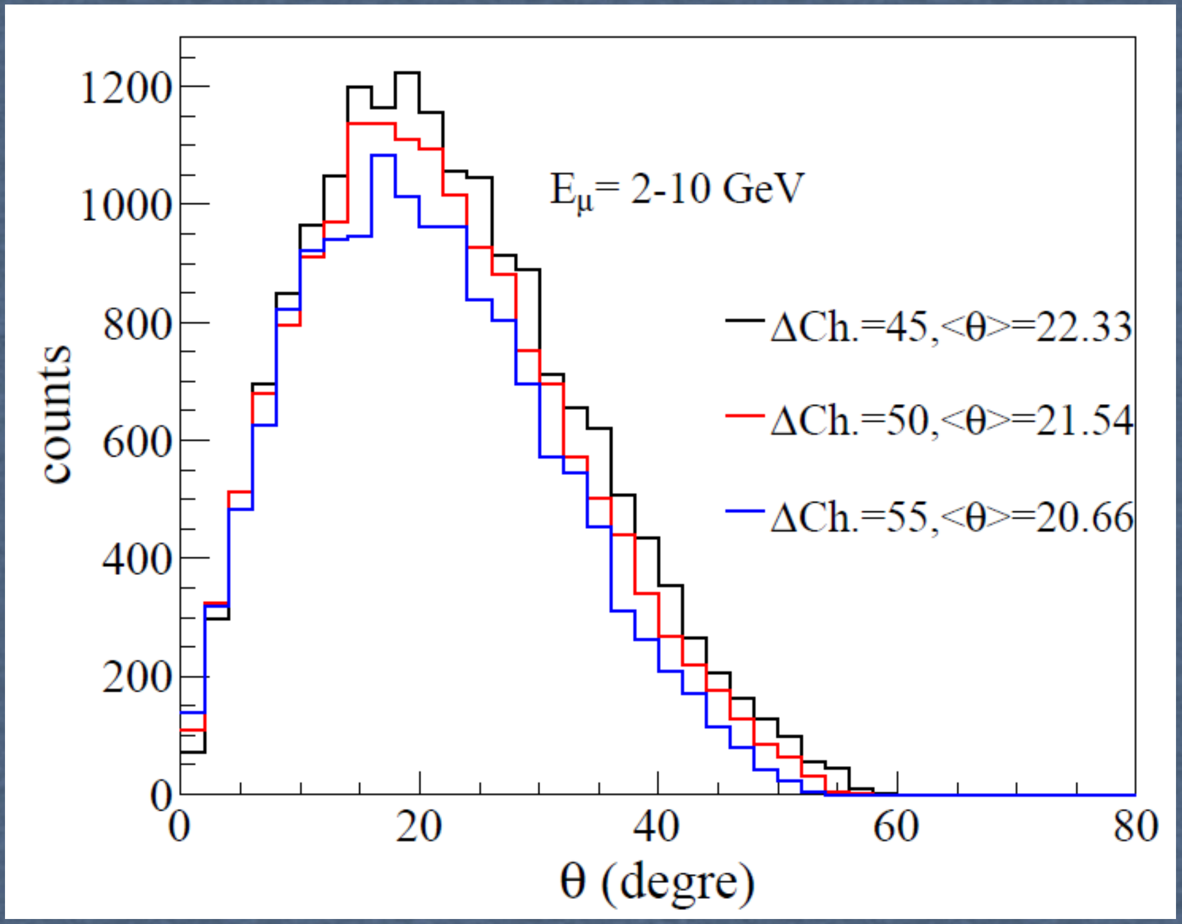


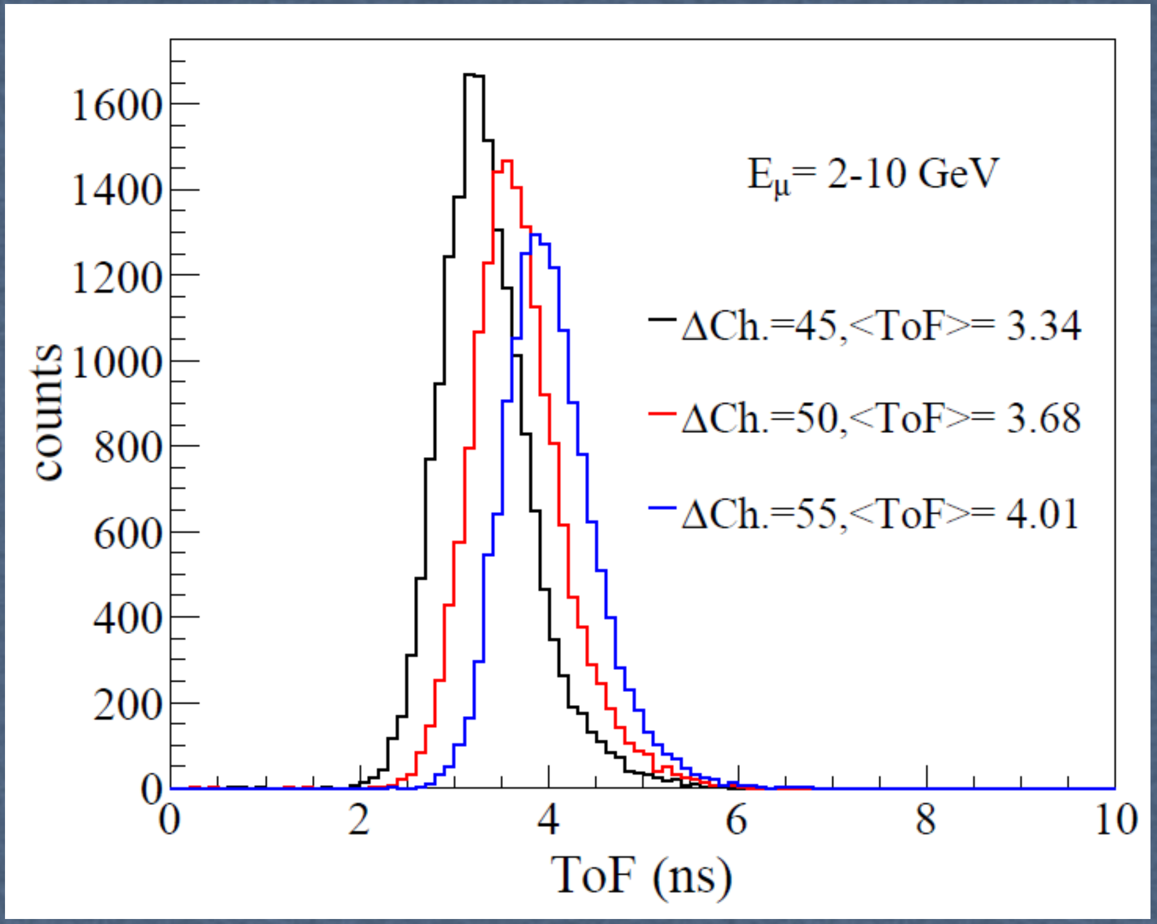
EEE-Sim validation

✳ Sanity checks (REC vs. GEN):
- Energy spectrum
- Theta
- Phi
- Phi asymmetry
- $\Delta Z_{chambers}$ changes (45cm, 50cm and 55cm)



Dependence on $\Delta Z_{chambers}$



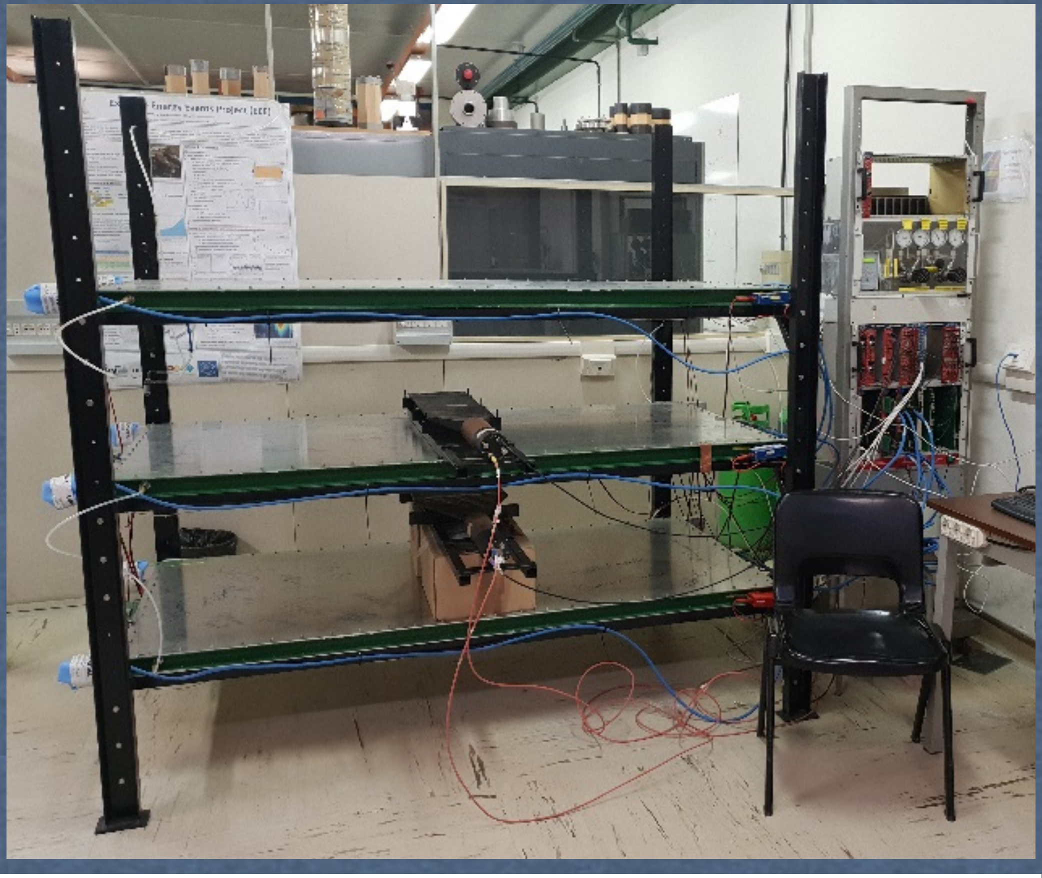


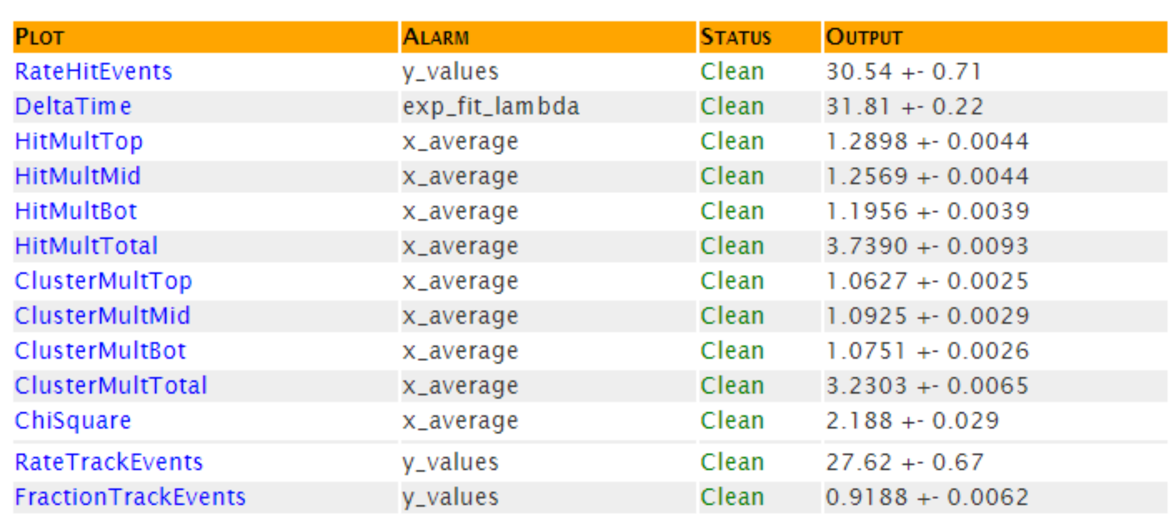
- Tool to check the dependence of observables on telescope parameters

Comparison with GENO-01

✳ Comparison to GENO-01 telescope

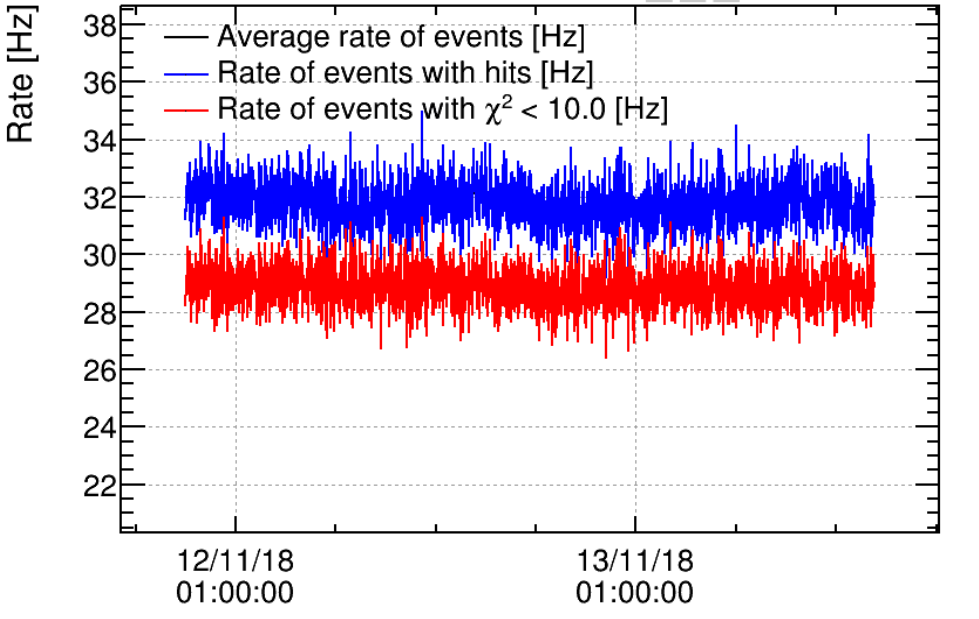
- built in March 2017 at CERN and delivered in Oct 2017
- installed at the 4th floor (4 floors above) of Dpt.Physics/INFN-GE
- Commissioned in Aug '18, data taking since Sept '18
- full control of geometry and environmental parameters
- The location and surrounding materials can be an issue

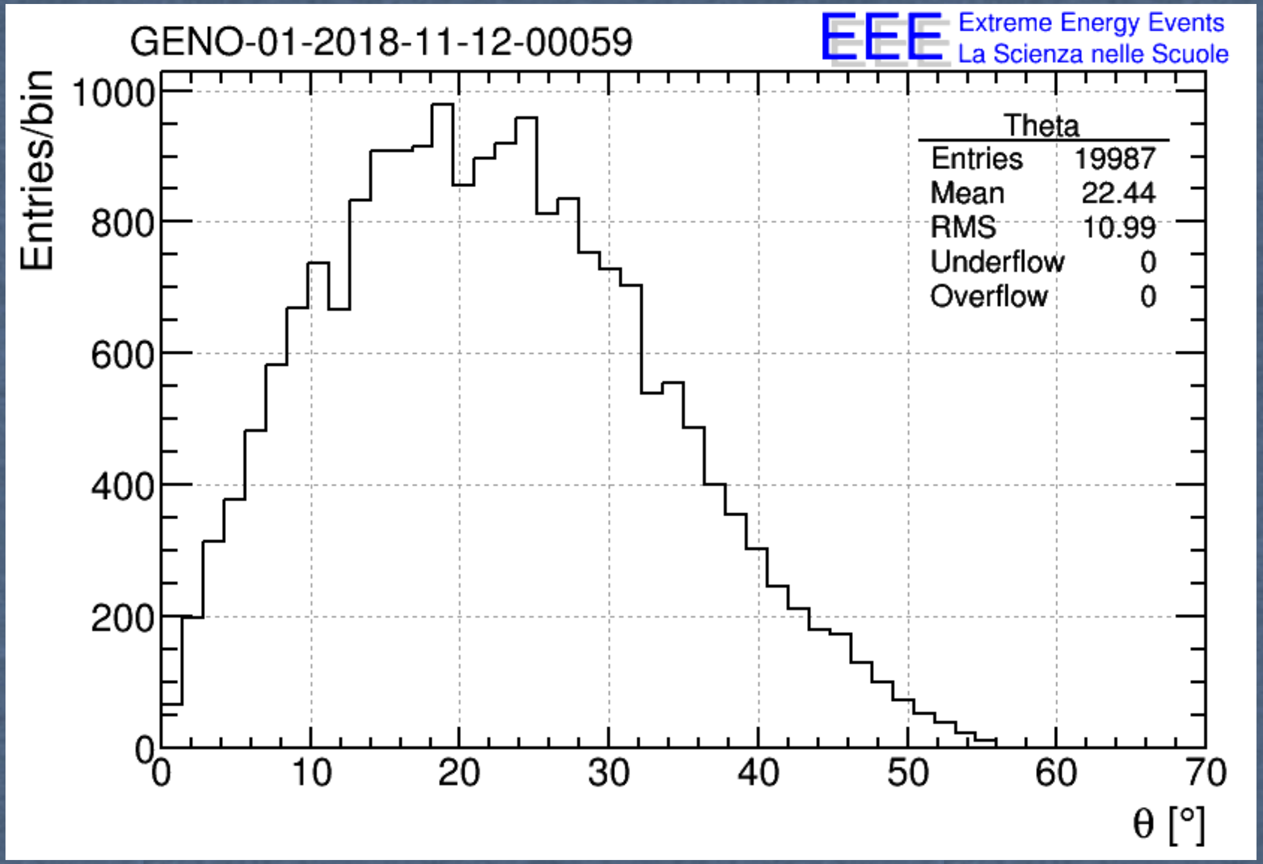




PLOT	ALARM	STATUS	OUTPUT
RateHitEvents	y_values	Clean	30.54 +- 0.71
DeltaTime	exp_fit_lambda	Clean	31.81 +- 0.22
HitMultTop	x_average	Clean	1.2898 +- 0.0044
HitMultMid	x_average	Clean	1.2569 +- 0.0044
HitMultBot	x_average	Clean	1.1956 +- 0.0039
HitMultTotal	x_average	Clean	3.7390 +- 0.0093
ClusterMultTop	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

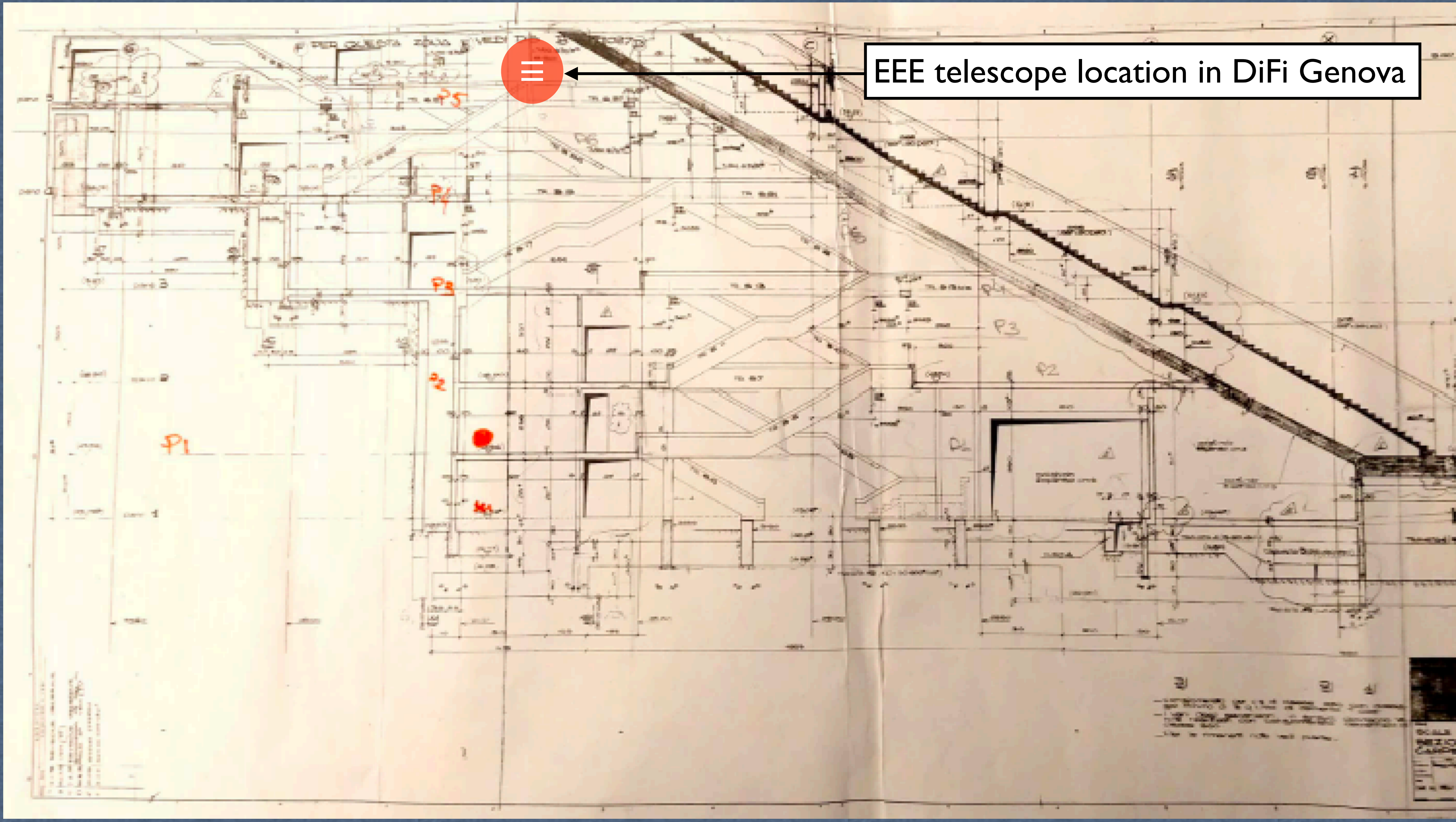
✳ Data are stable





S.Grazzi

GENO-01location

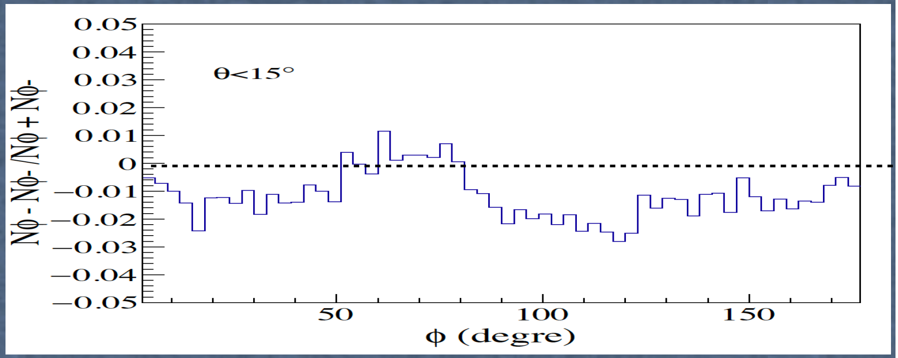


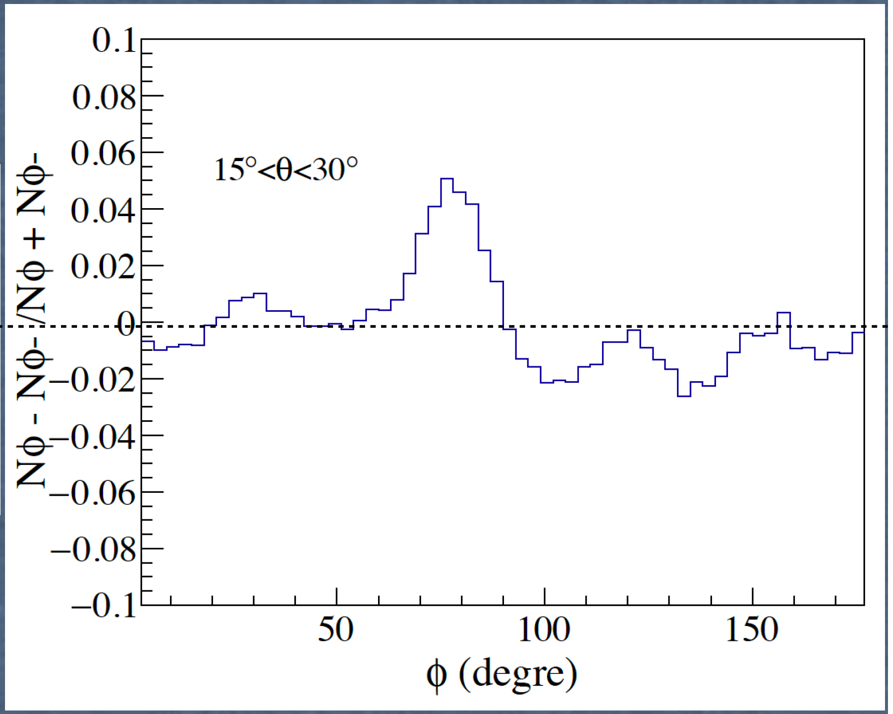
EEE telescope location in DiFi Genova

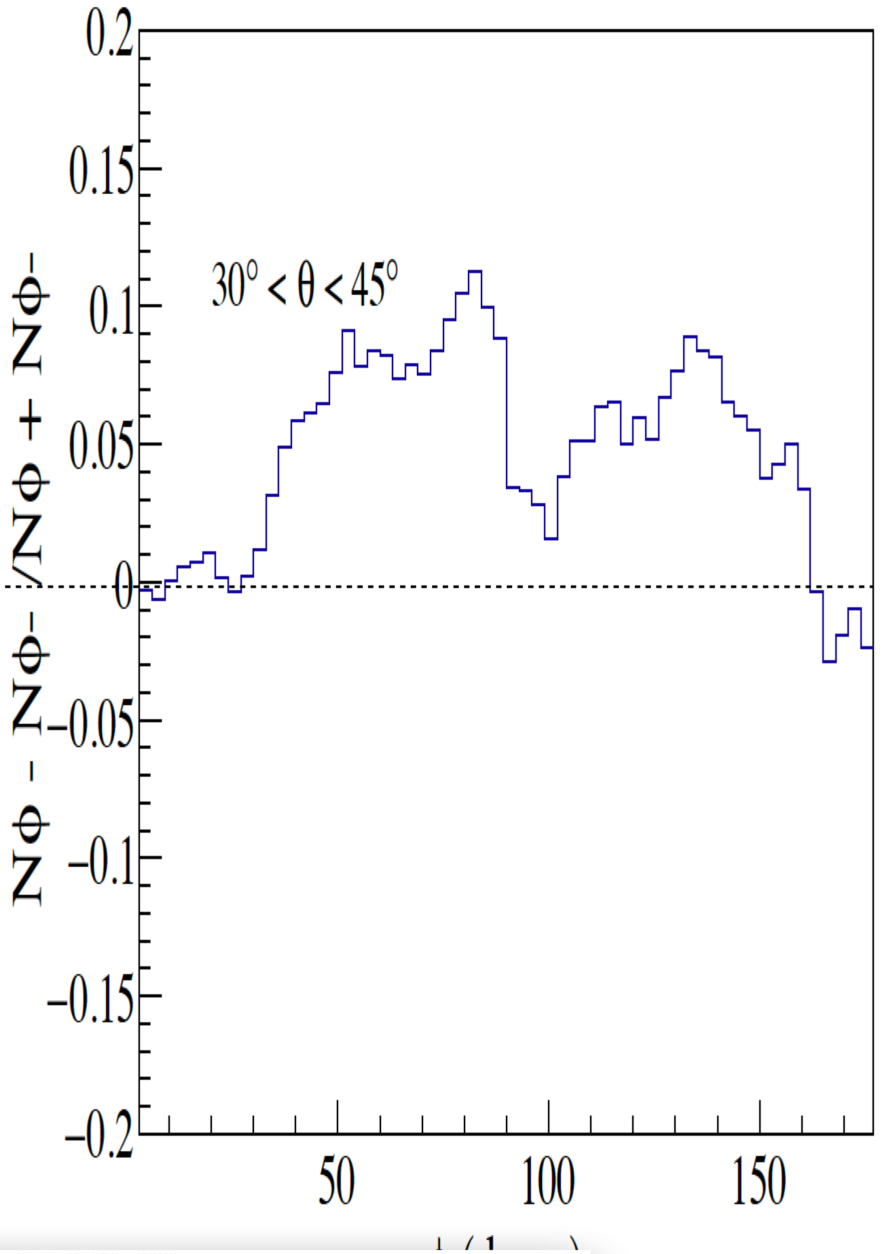
EEE-Sim results

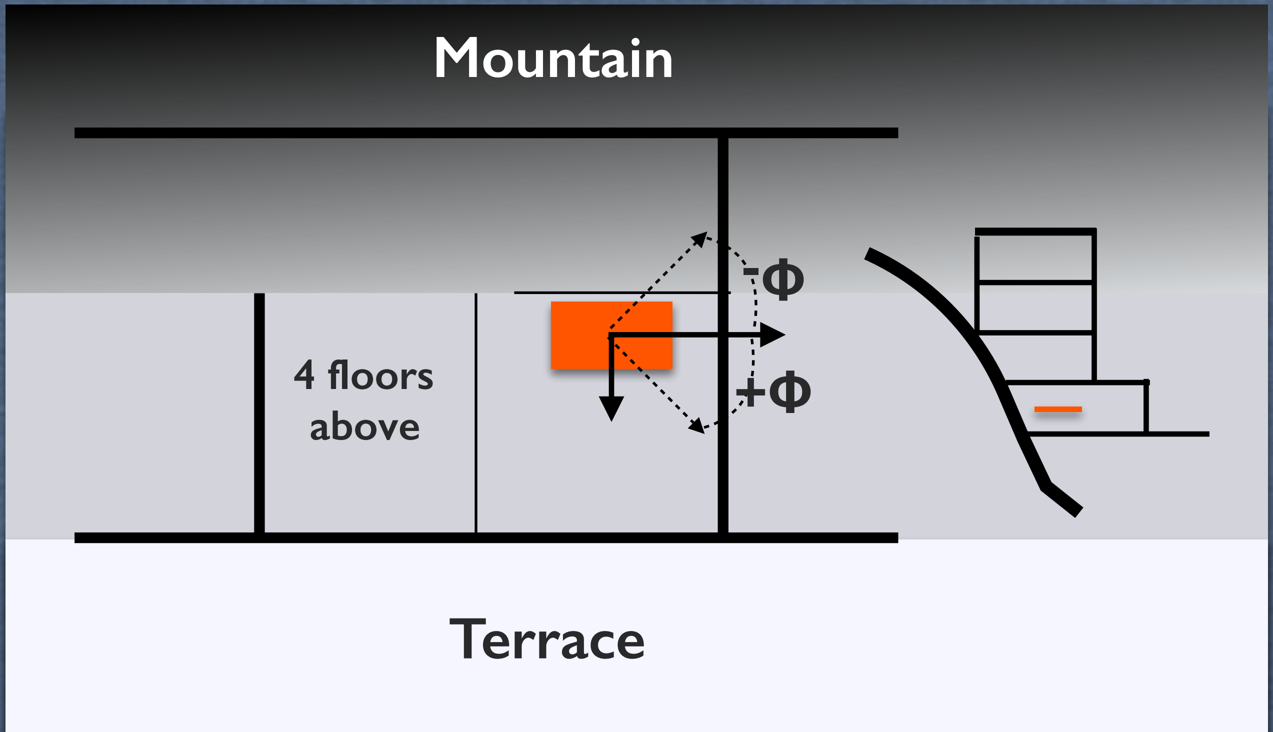
Systematic checks for data/sim agreement

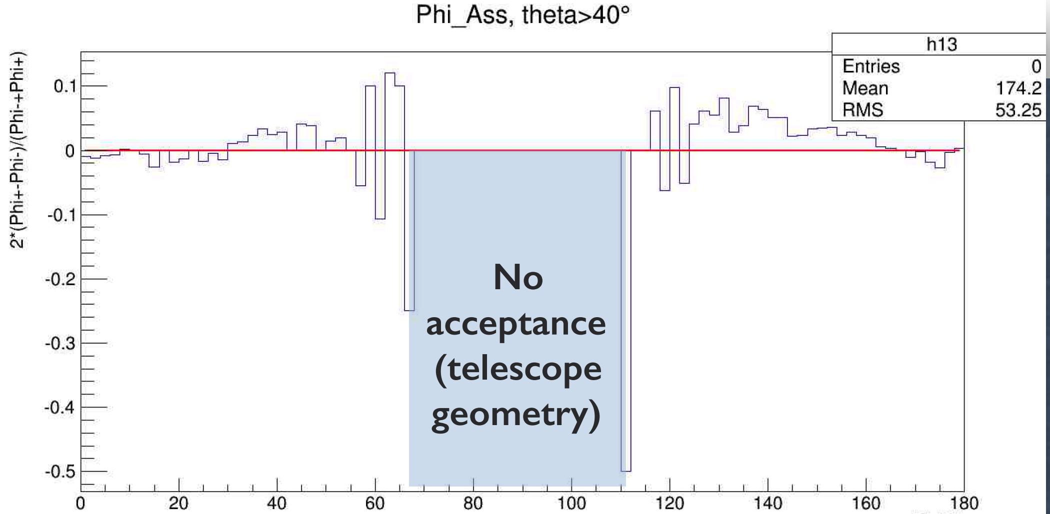
- Phi asymmetry due to different materials crossed







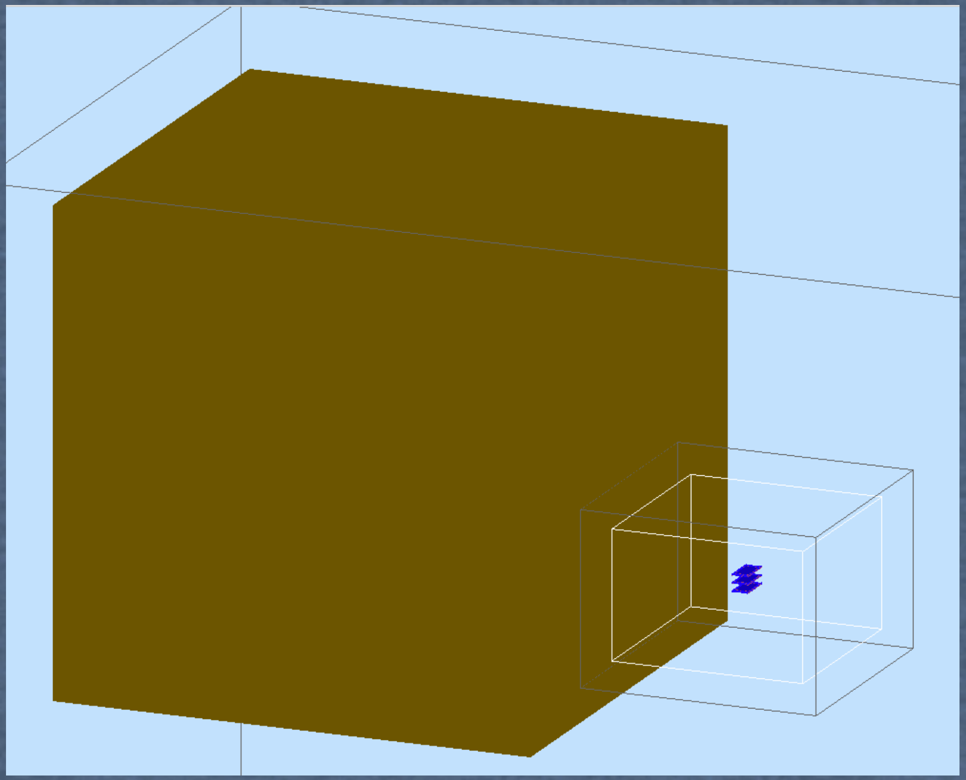




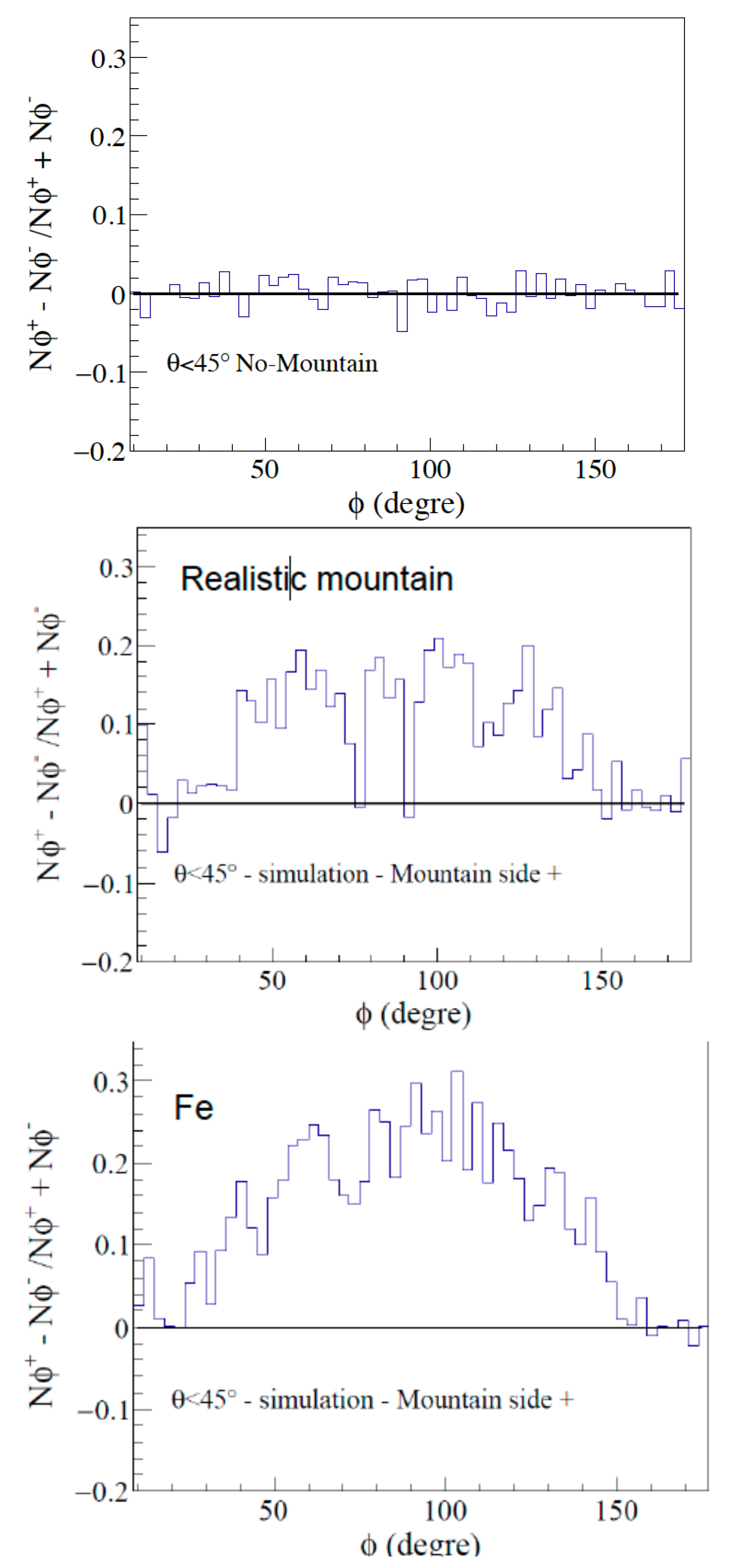
No acceptance (telescope geometry)

Simulating the environment

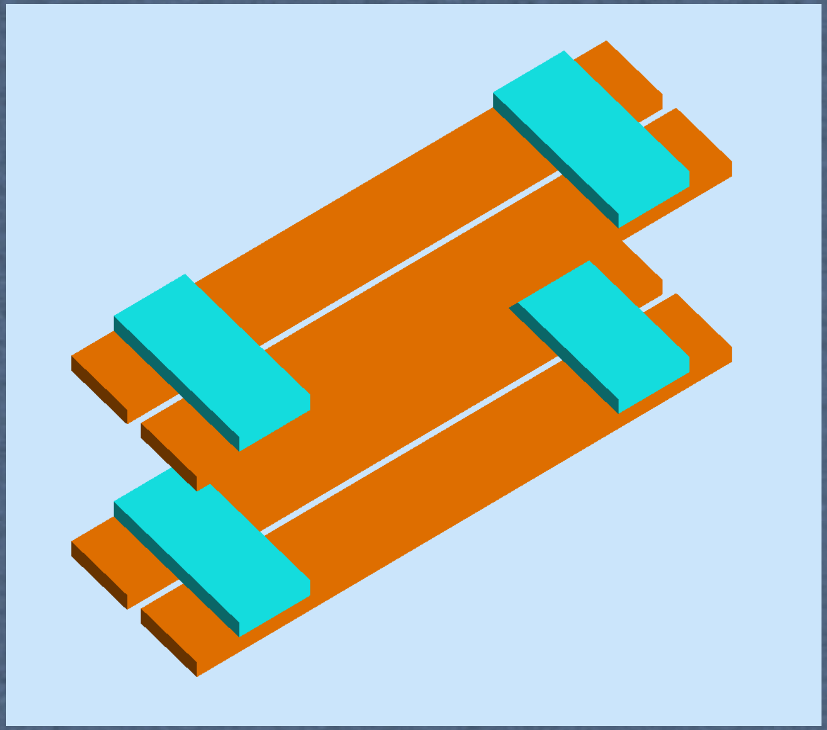
- the ‘mountain’ on one side is simulated as a block of iron/concrete with clearance and $\Delta\Theta \pm 15$



- The phi asymmetry shows, as expected positive values (as in the data set)
- Muon tomography is an efficient way to check for anisotropy related to the surrounding materials



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

EEE-Sim absolute rates

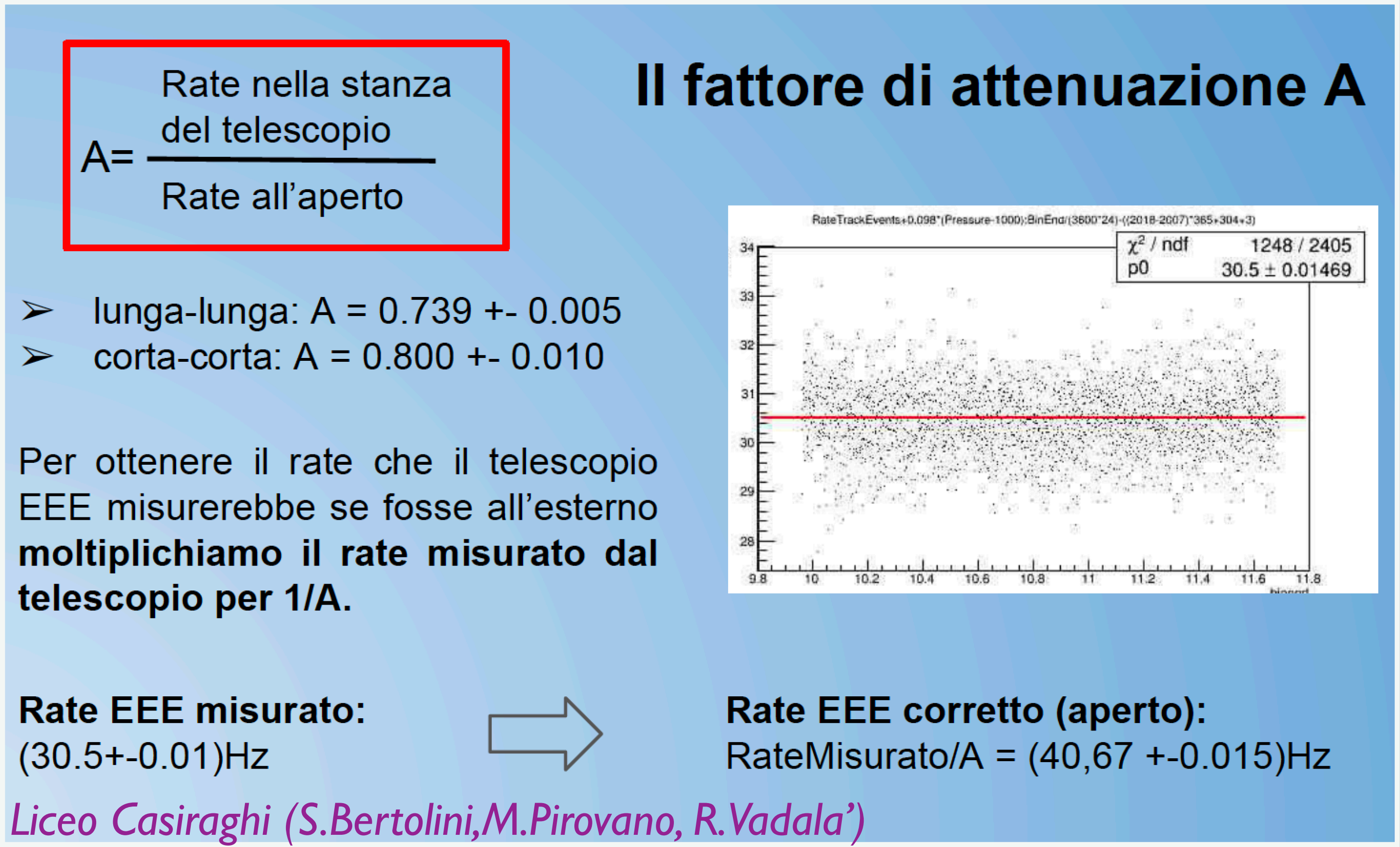
R_{Data} = (30.5 ± 0.1) Hz

R_{Sim} = (35 ± 4) Hz

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

$A_{ASTRO} = R_{dentro}/R_{fuori}$ = (0.77 ± 0.05)

R_{Corr} = (40.7 ± 0.1) Hz



$$A = \frac{\text{Rate nella stanza del telescopio}}{\text{Rate all'aperto}}$$

Il fattore di attenuazione A

- ➢ lunga-lunga: A = 0.739 +- 0.005
- ➢ corta-corta: A = 0.800 +- 0.010

Per ottenere il rate che il telescopio EEE misurerebbe se fosse all'esterno **moltiplichiamo il rate misurato dal telescopio per 1/A.**

Rate EEE misurato:
(30.5+-0.01)Hz

Rate EEE corretto (aperto):
RateMisurato/A = (40,67 +-0.015)Hz

Liceo Casiraghi (S.Bertolini,M.Pirovano, R.Vadala')

Systematic checks

R_{Sim}= (42 ± 4) Hz

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

R_{Sim}= (35 ± 4) Hz

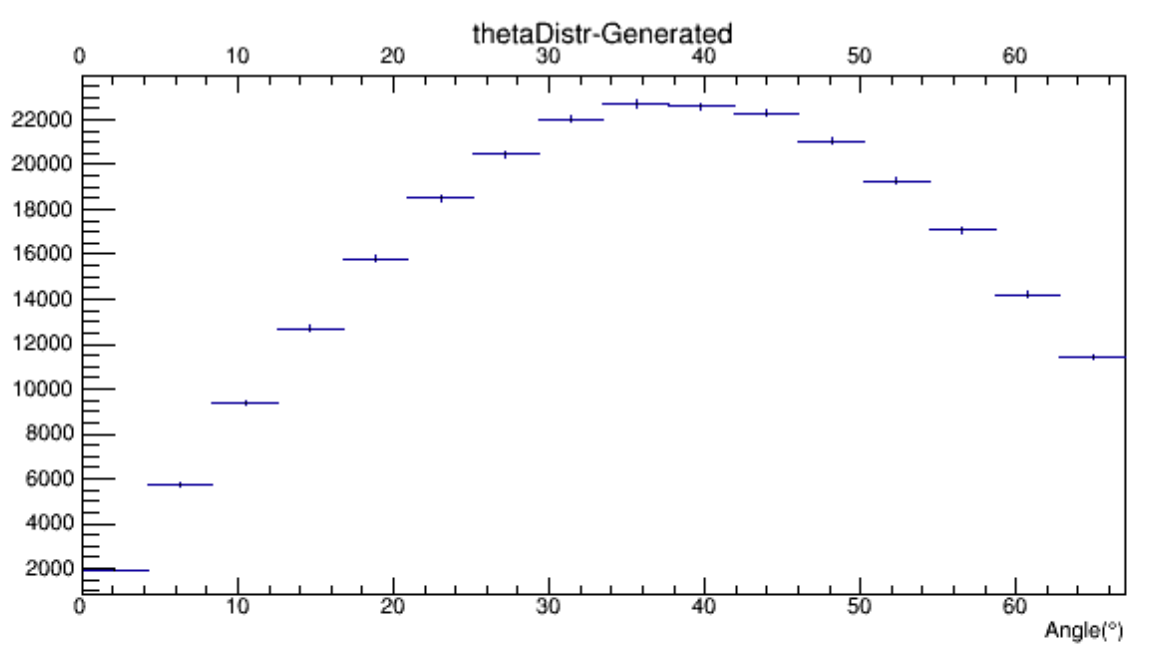
- Concrete vault thknss = 140cm
- Gen Sphere R=150cm
- Gen Sphere ΔZ=-50cm

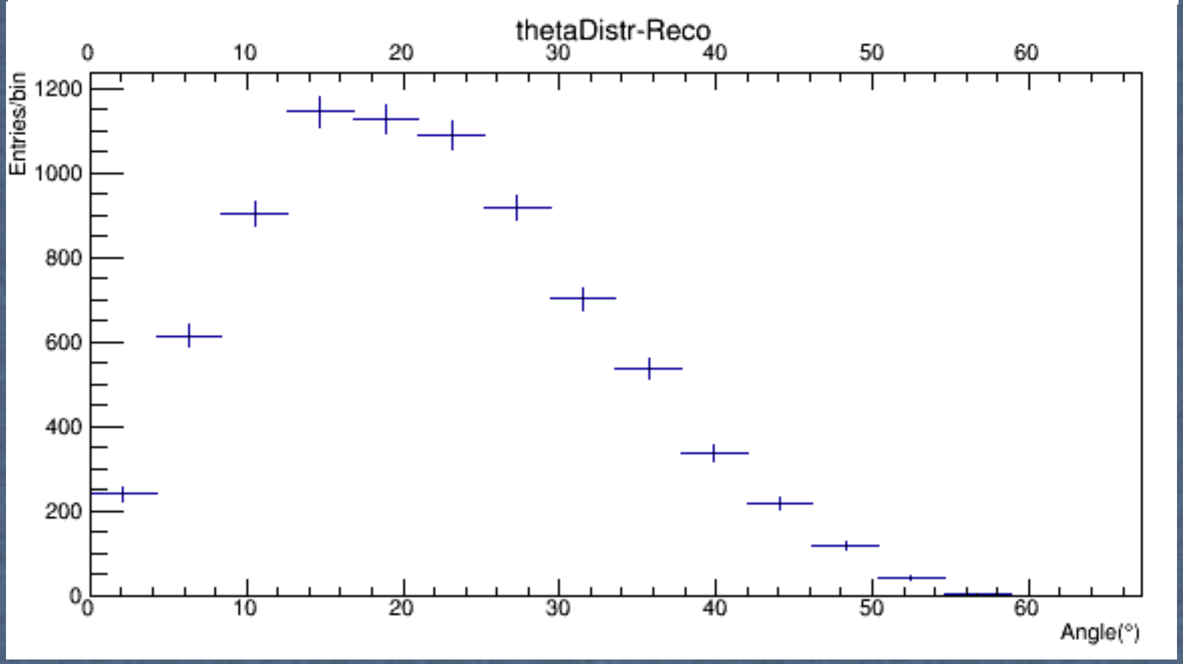
R_{Sim}= (35 ± 4) Hz

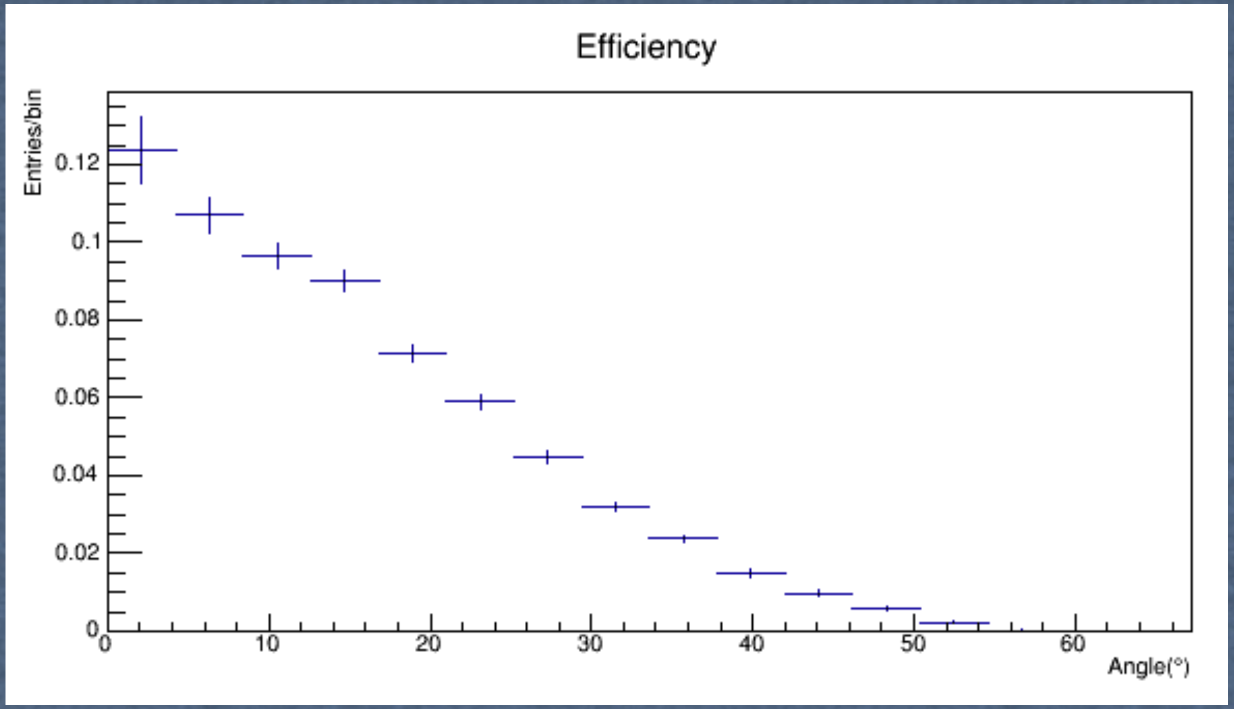
- Concrete vault thknss = 140cm
- Gen Sphere R=250cm
- Gen Sphere ΔZ=-50cm

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**

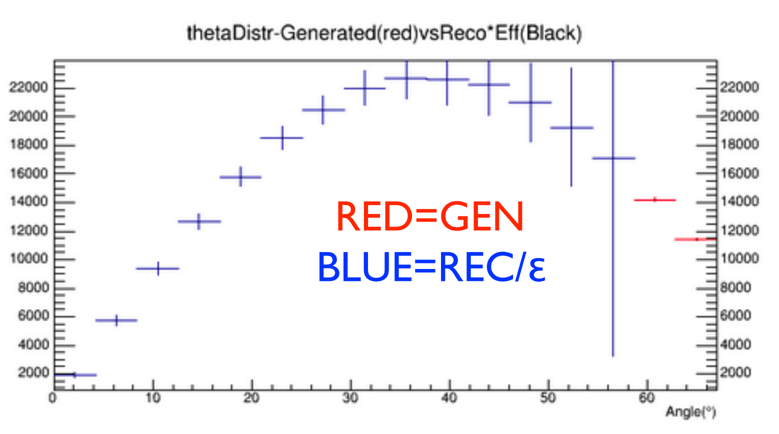
GENO-01 angular efficiency







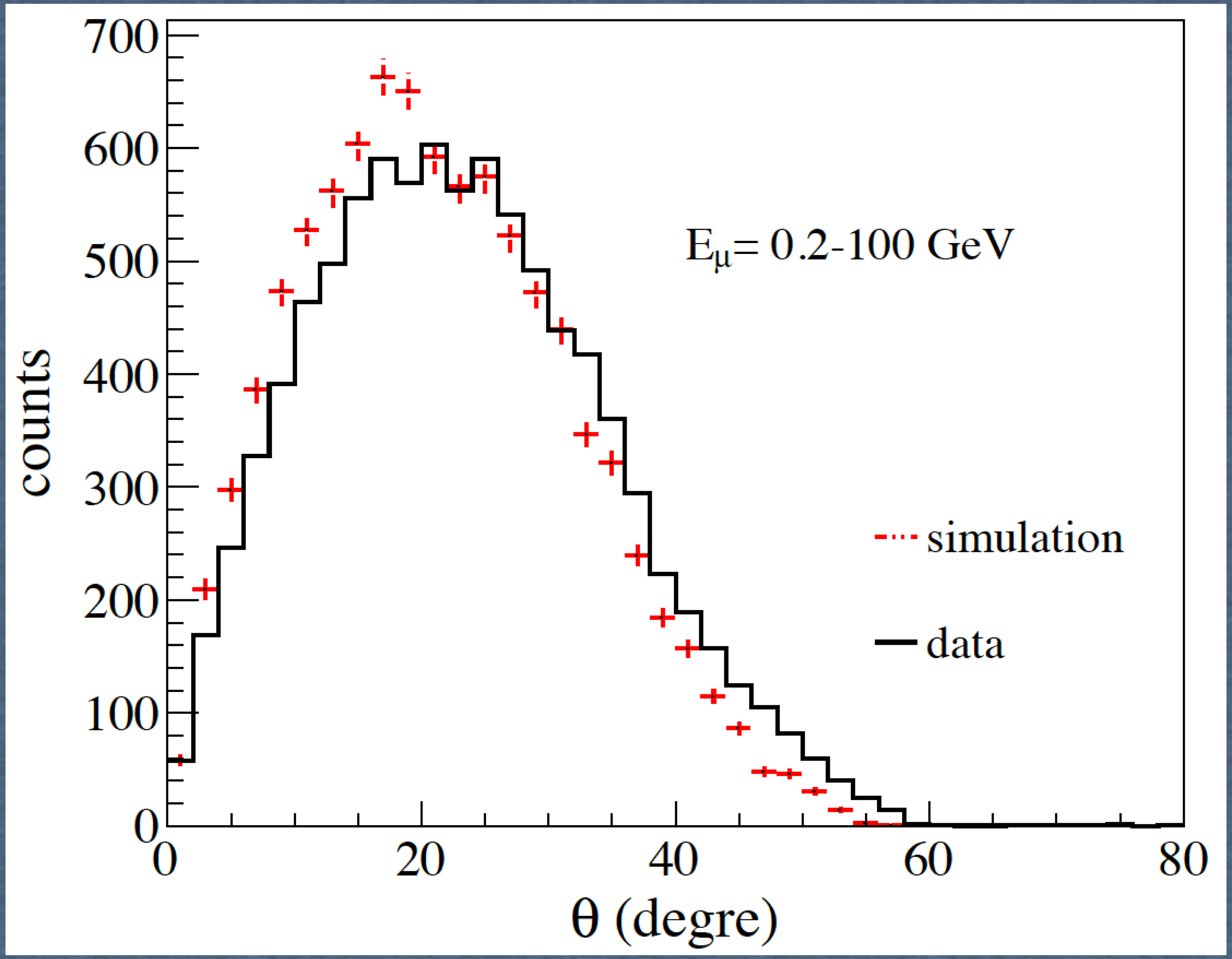
- ✳ As a check: GEN = REC/ε (where ε≠0)

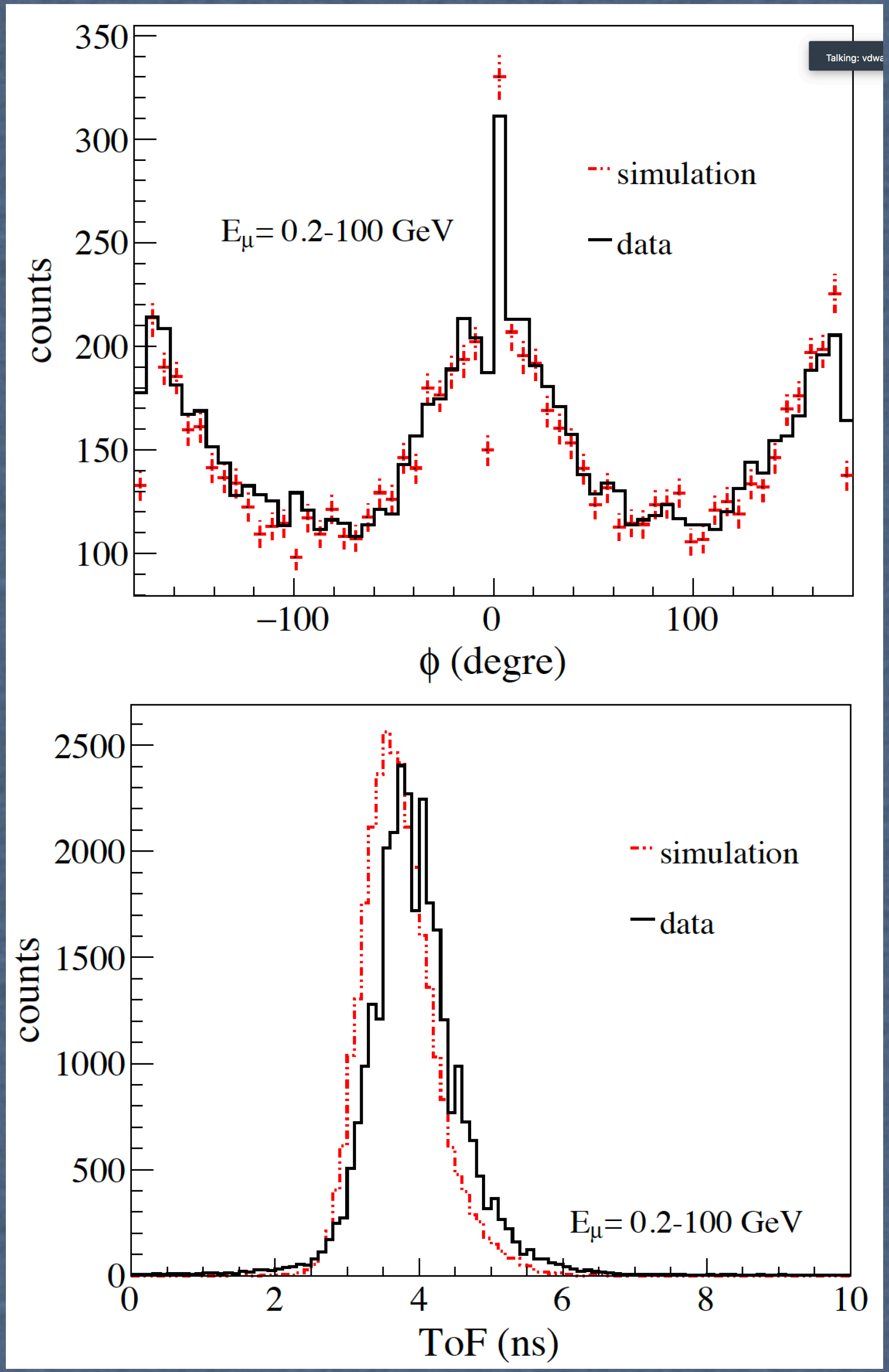


- ✳Sim angular distribution represents a projection of world data on EEE GENO-01 telescope

S.Grazzi

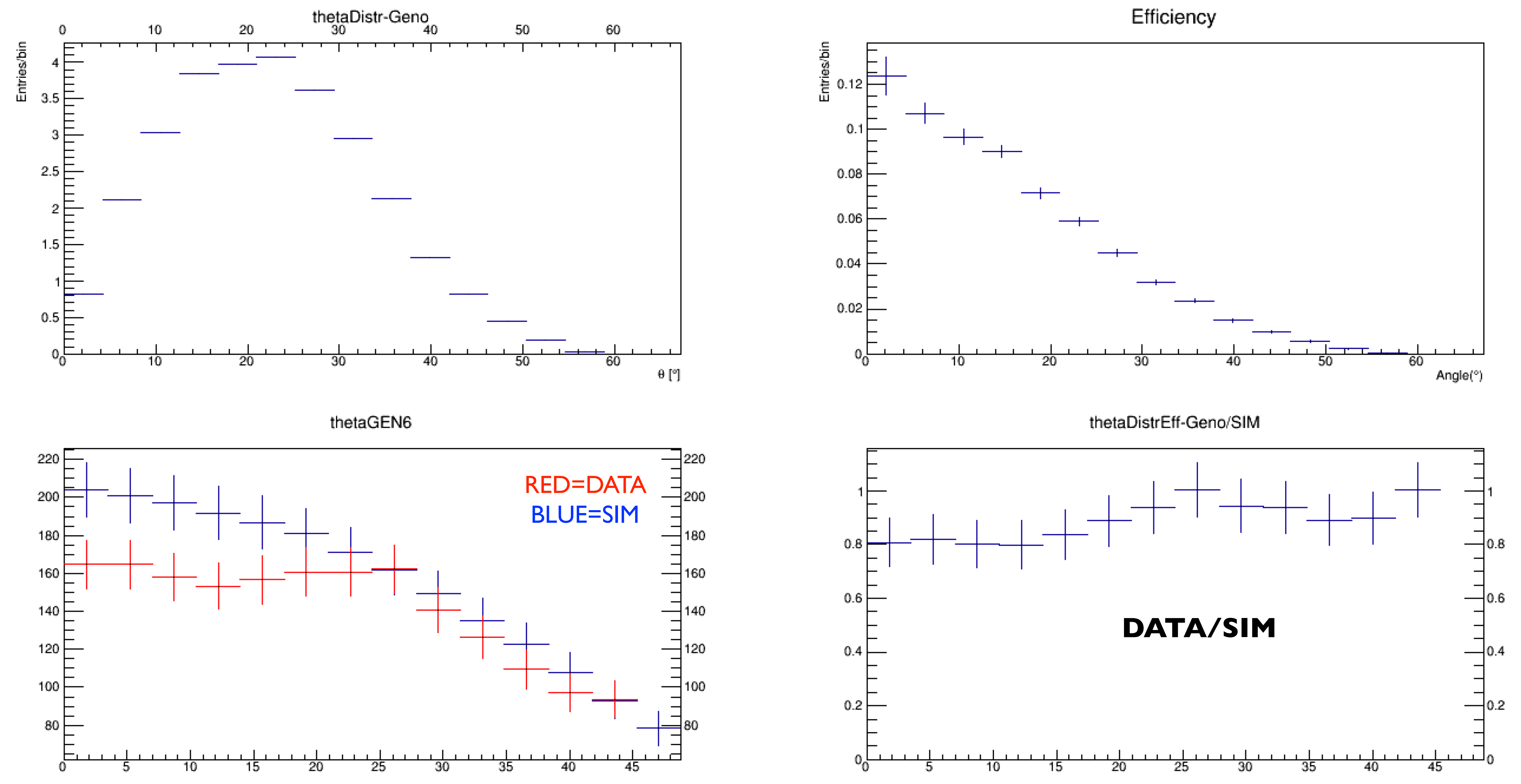
GENO-01/SIM comparison





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

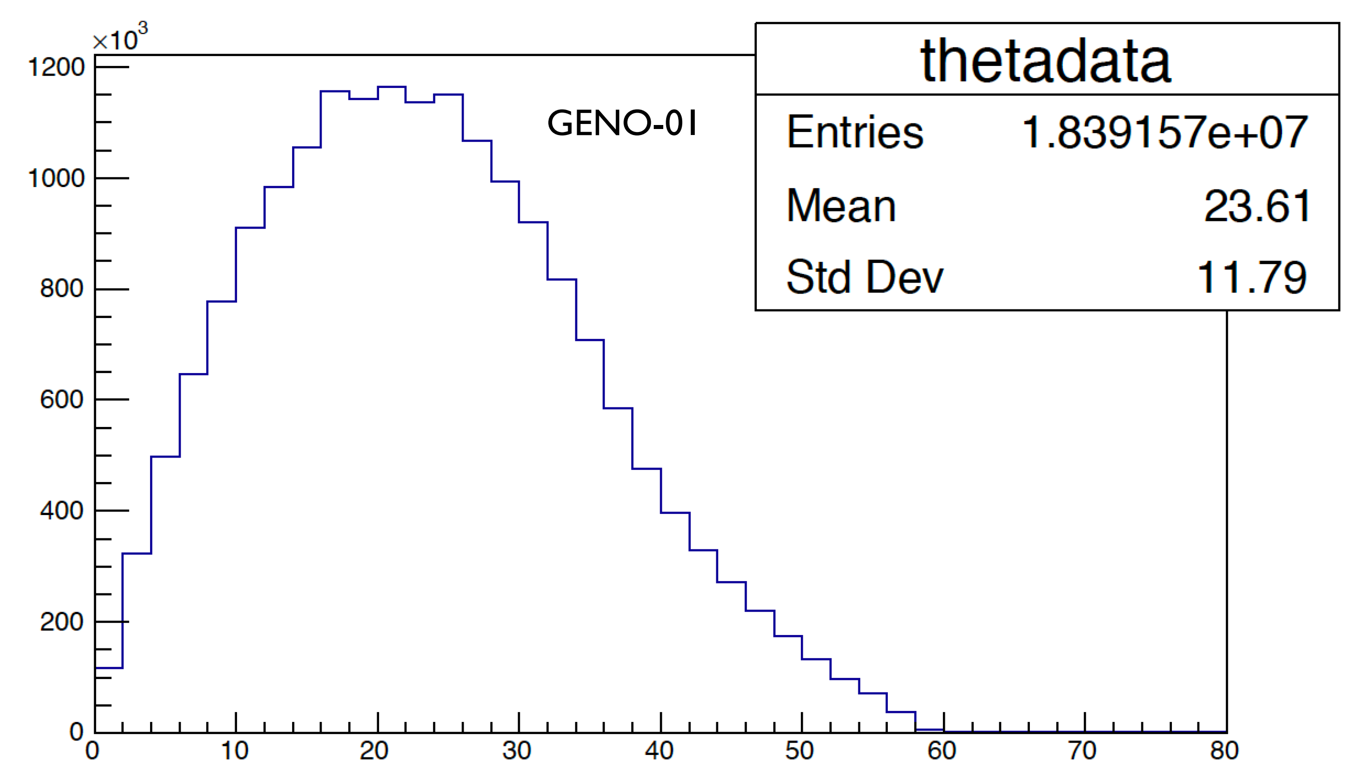
GENO-01 angular distribution

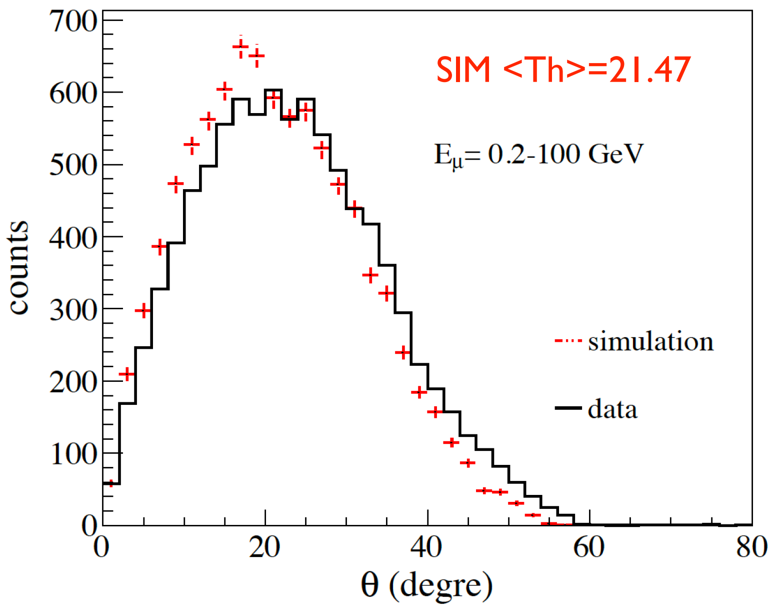


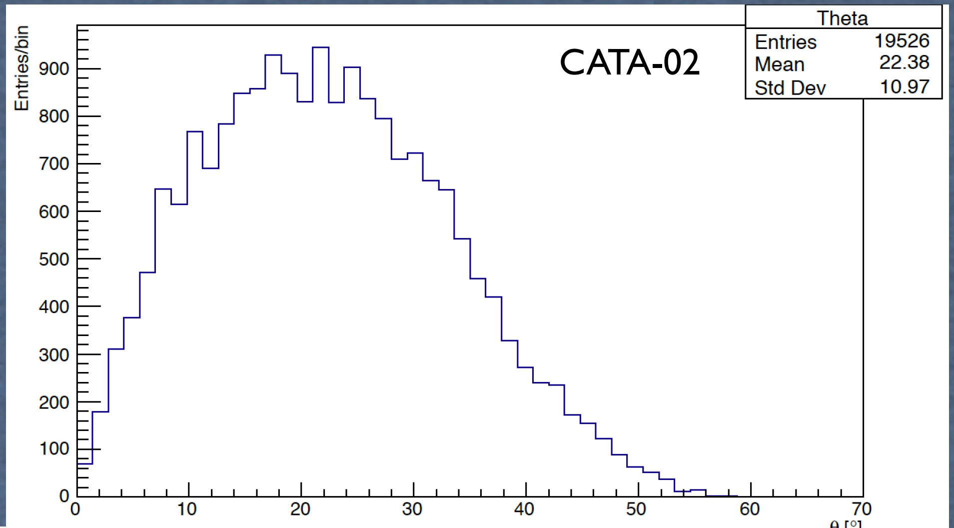
- GENO-01 angular distribution underestimate θ<20°
- Is it related to GENO-01 environment parametrisation?

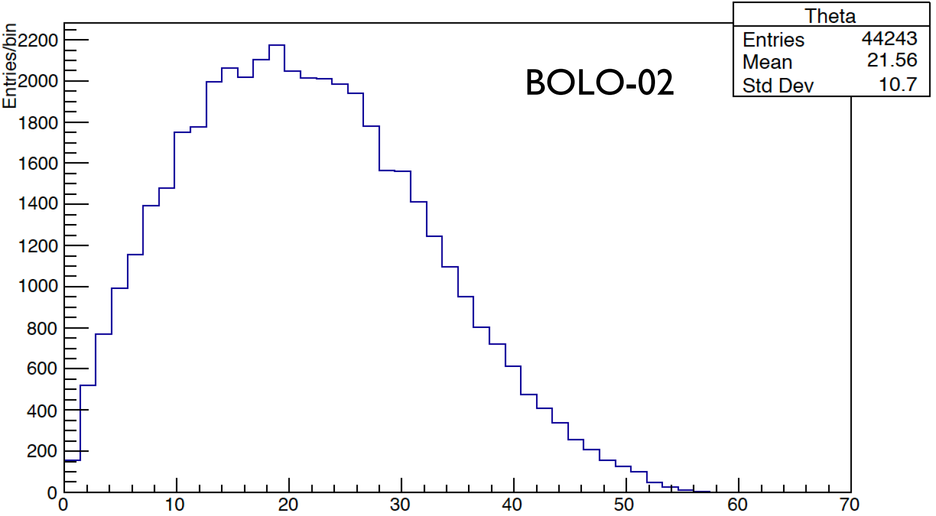
Comparison with other telescopes

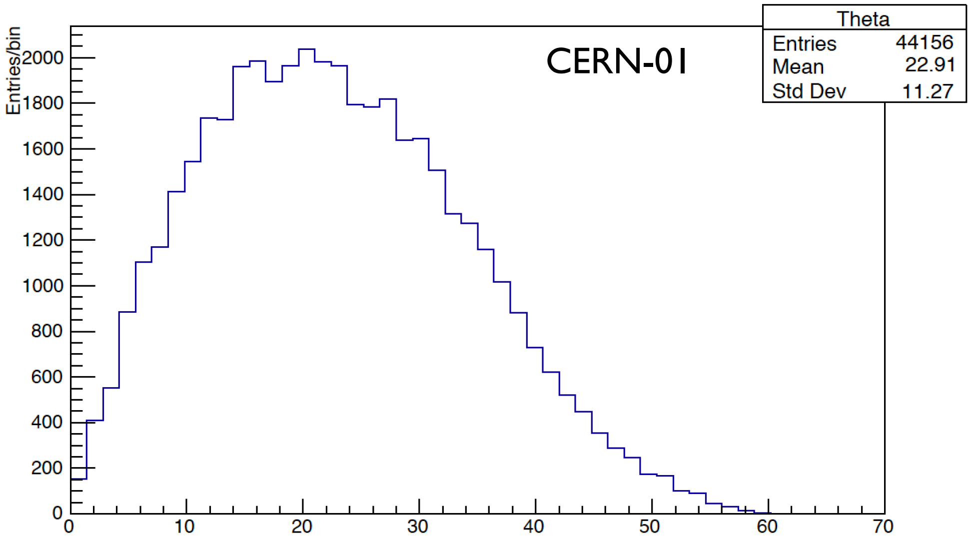
- It seems that DATA distribution is peaked at larger angles (wrt SIM)



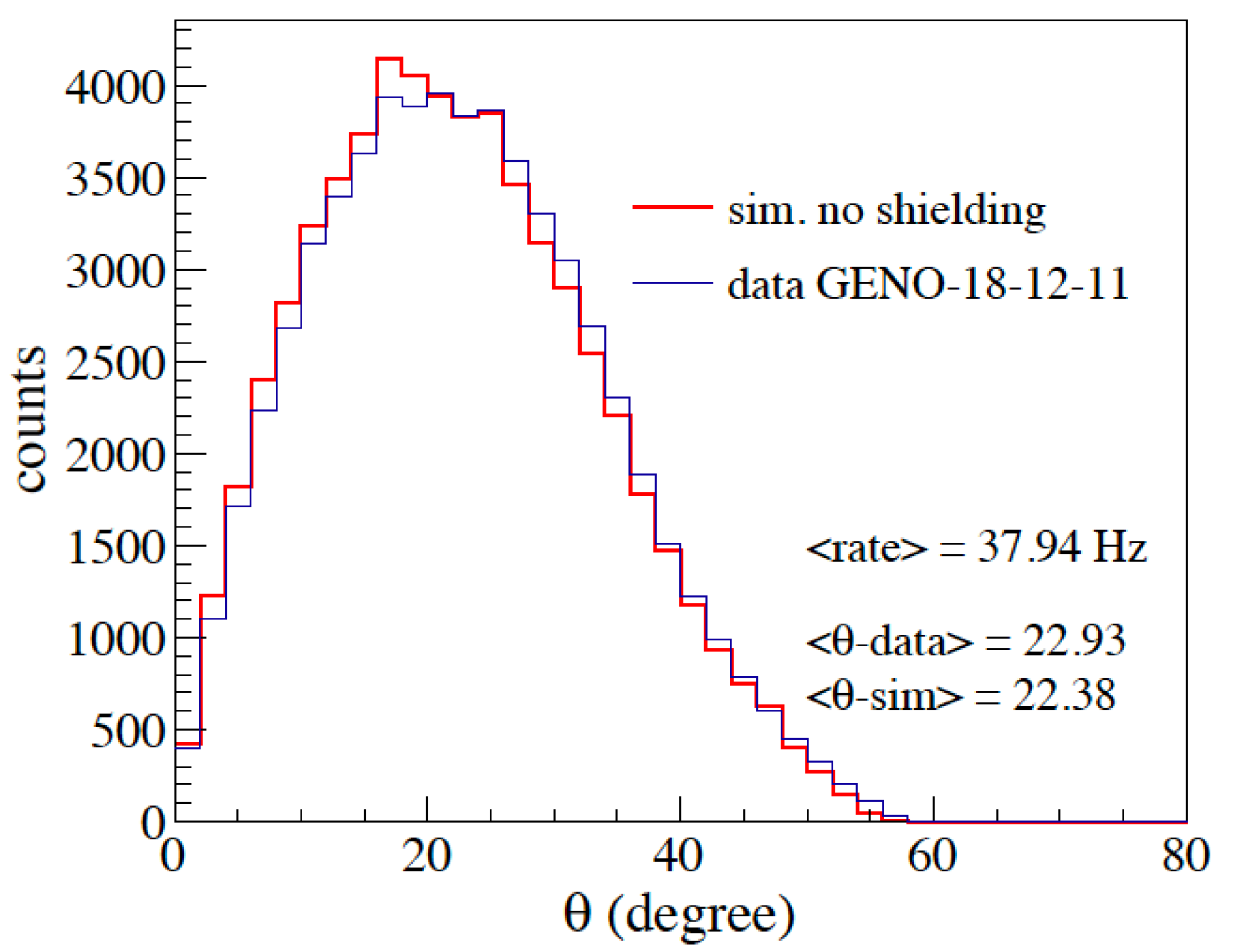


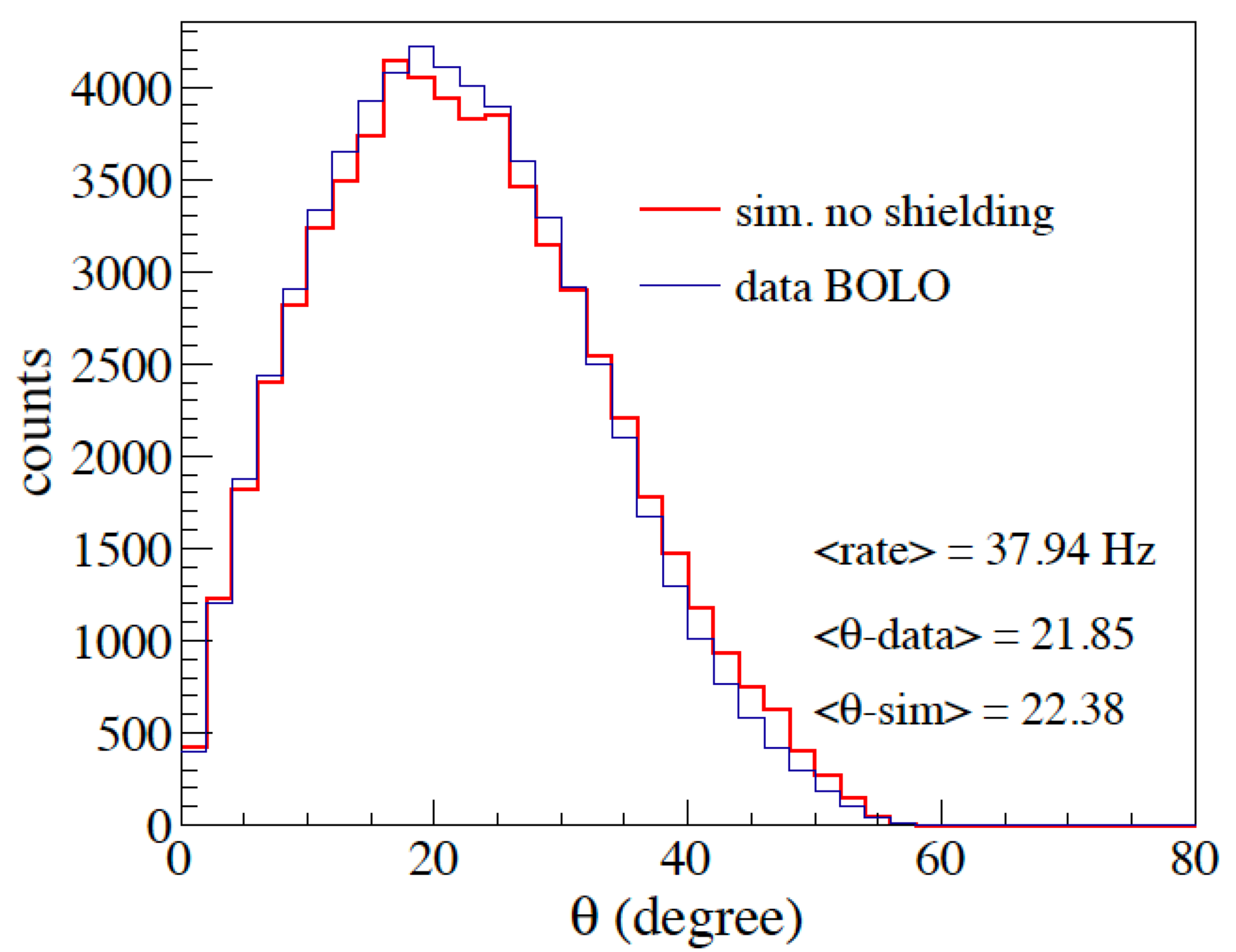




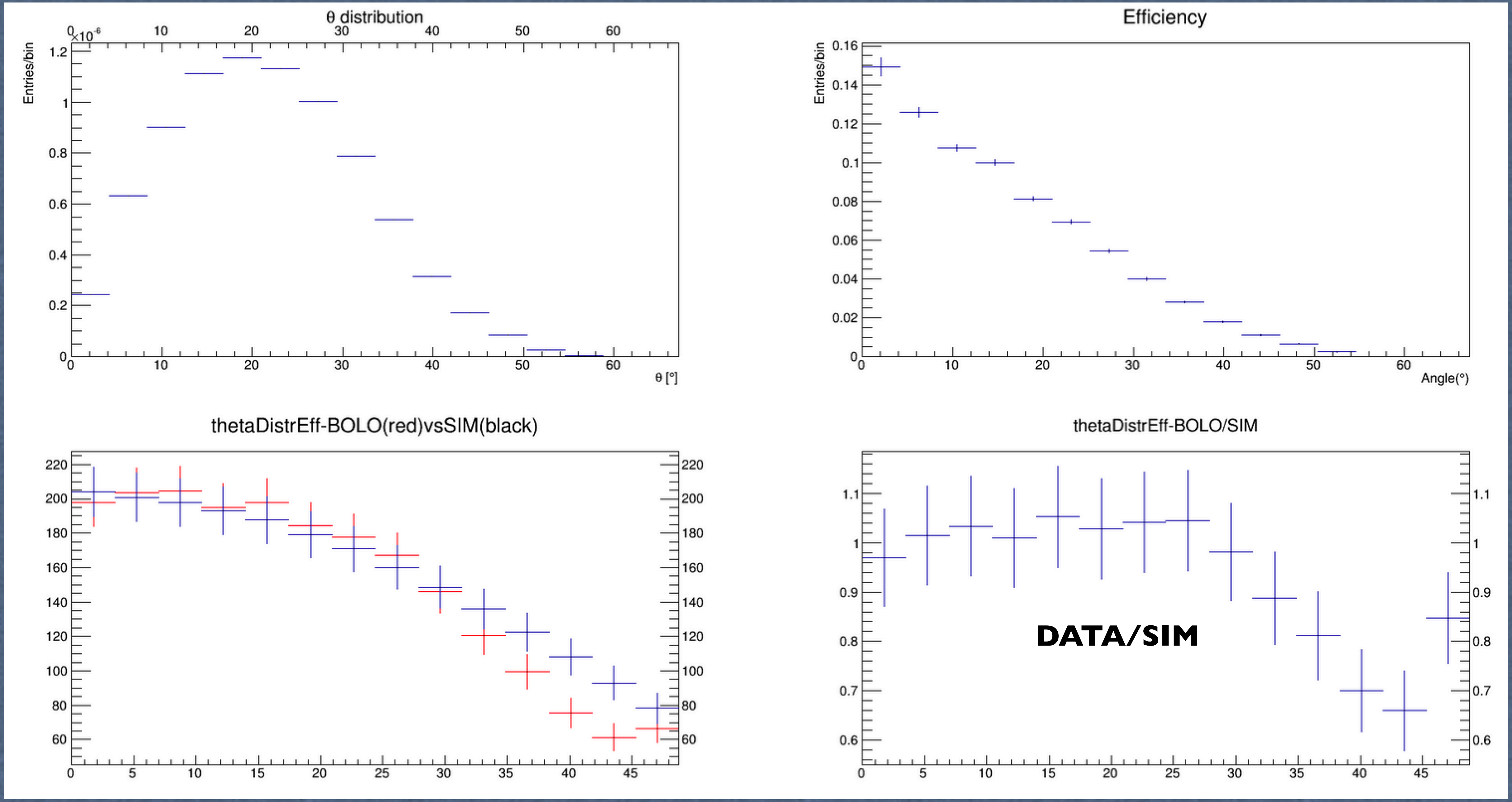


Comparison with other telescopes

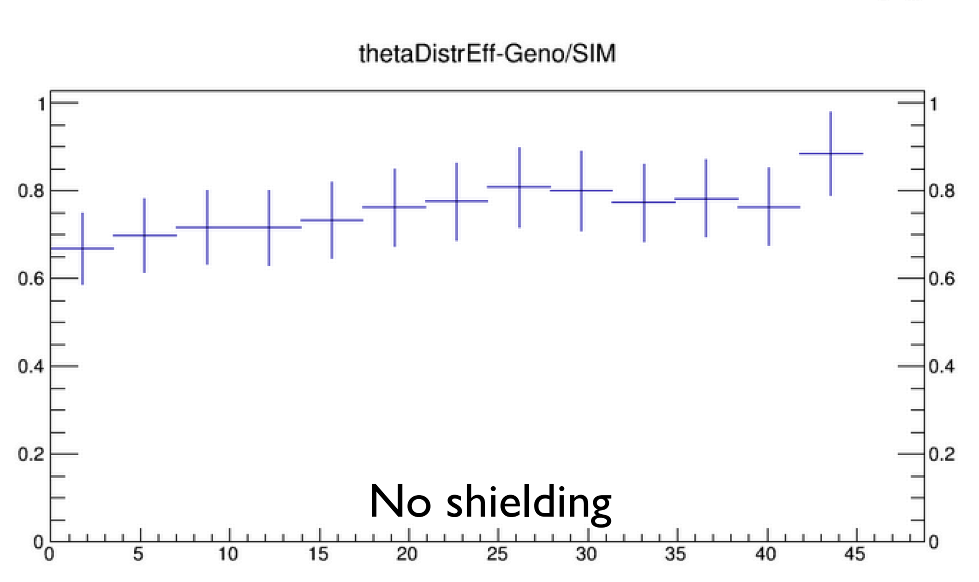


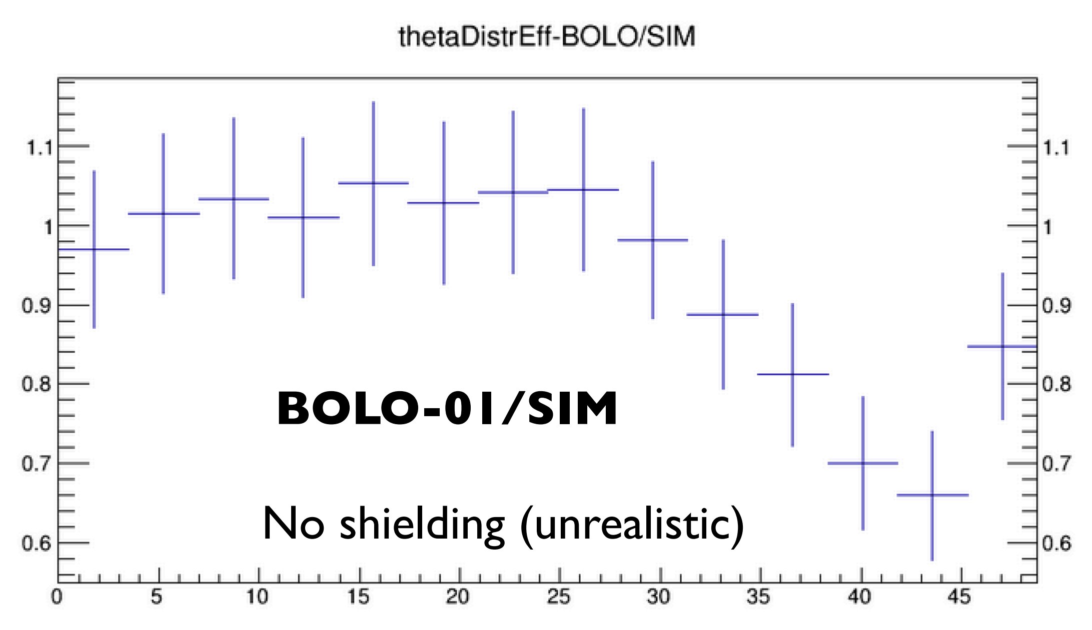


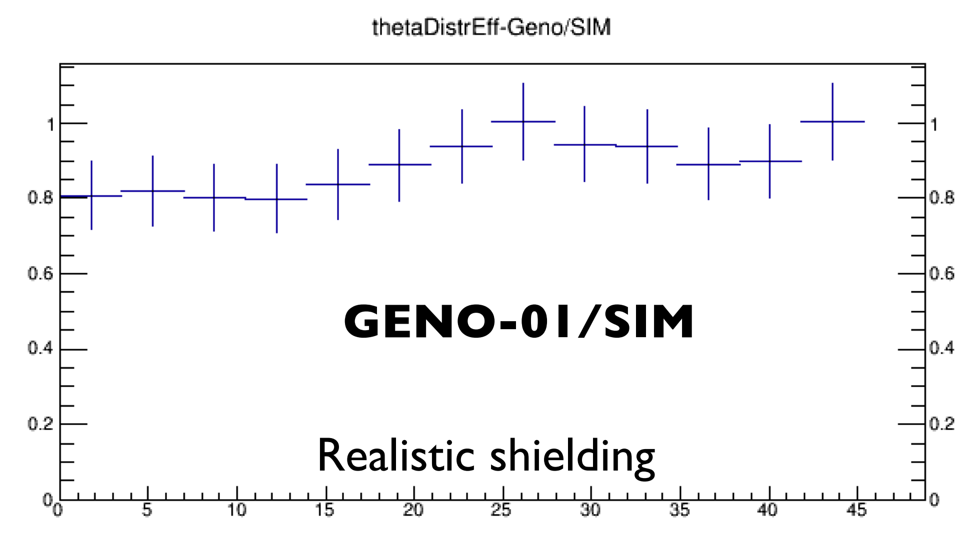
Comparison to BOLO-01(no shielding)

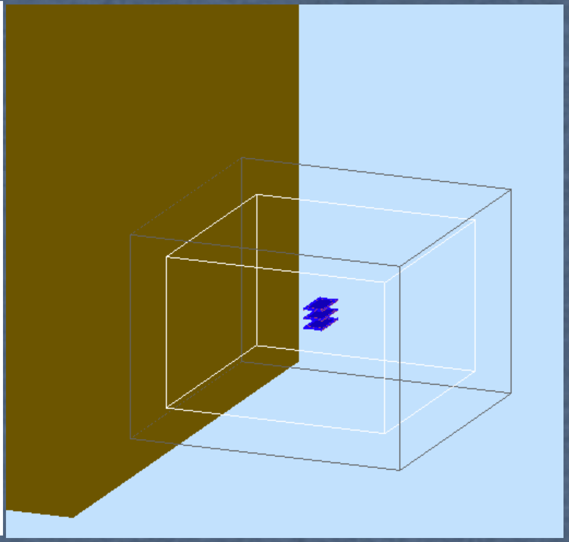


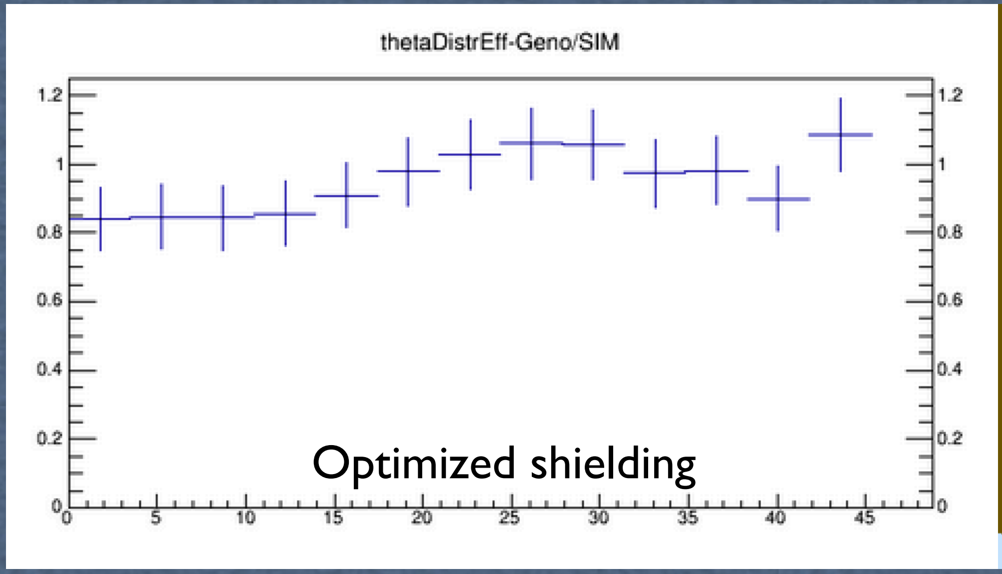
Data/sim comparison

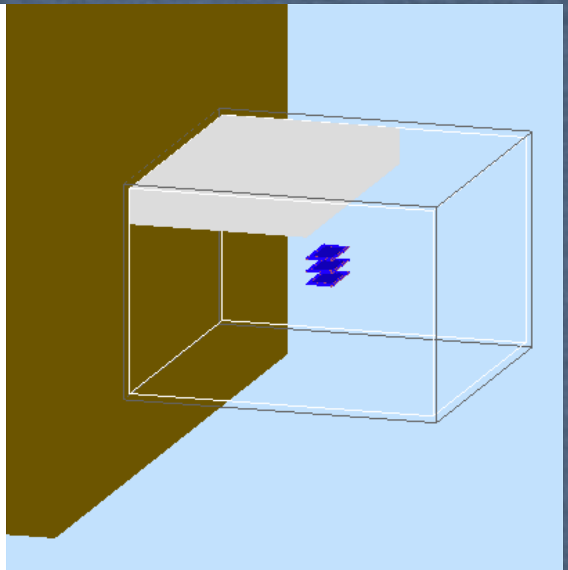






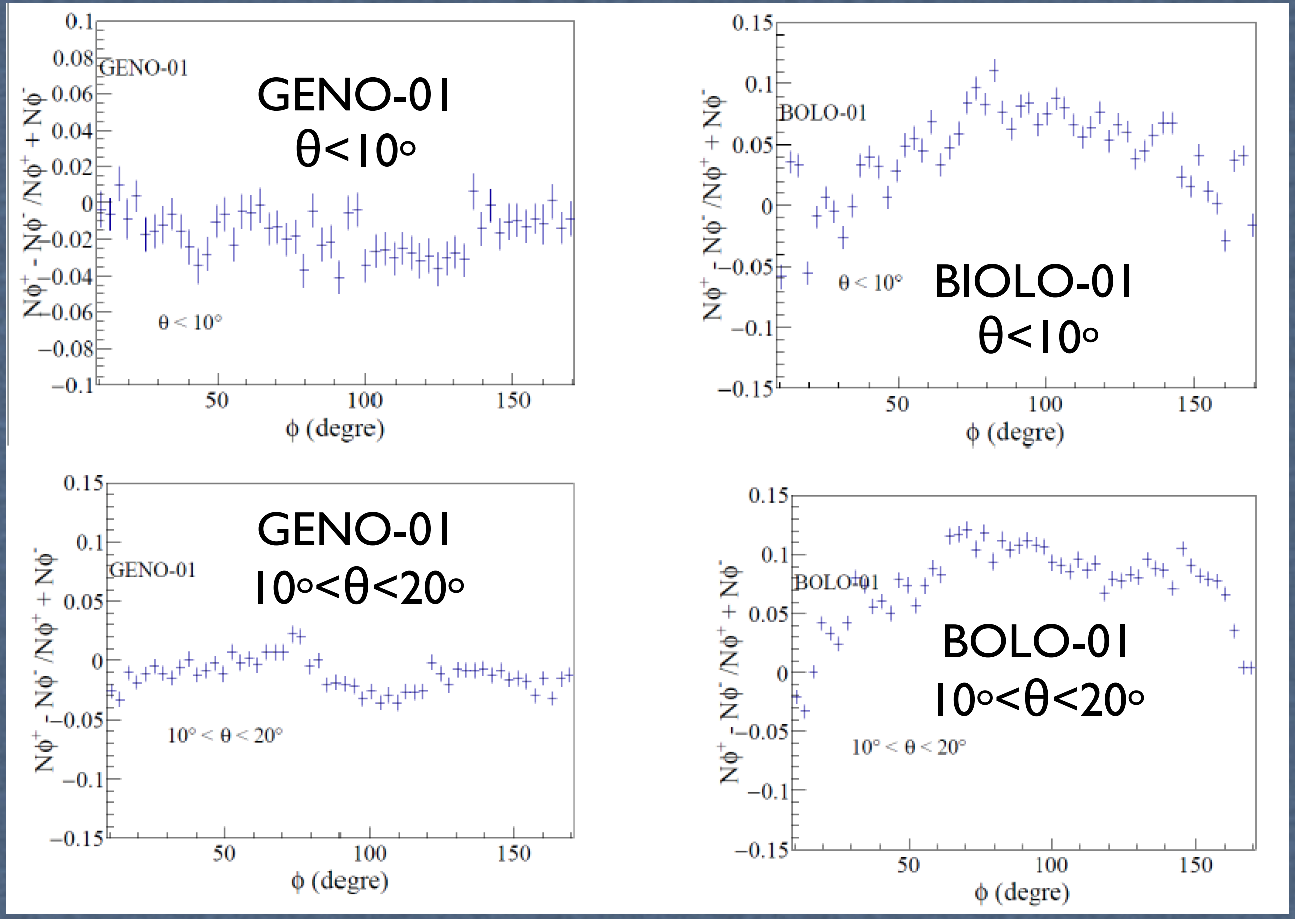






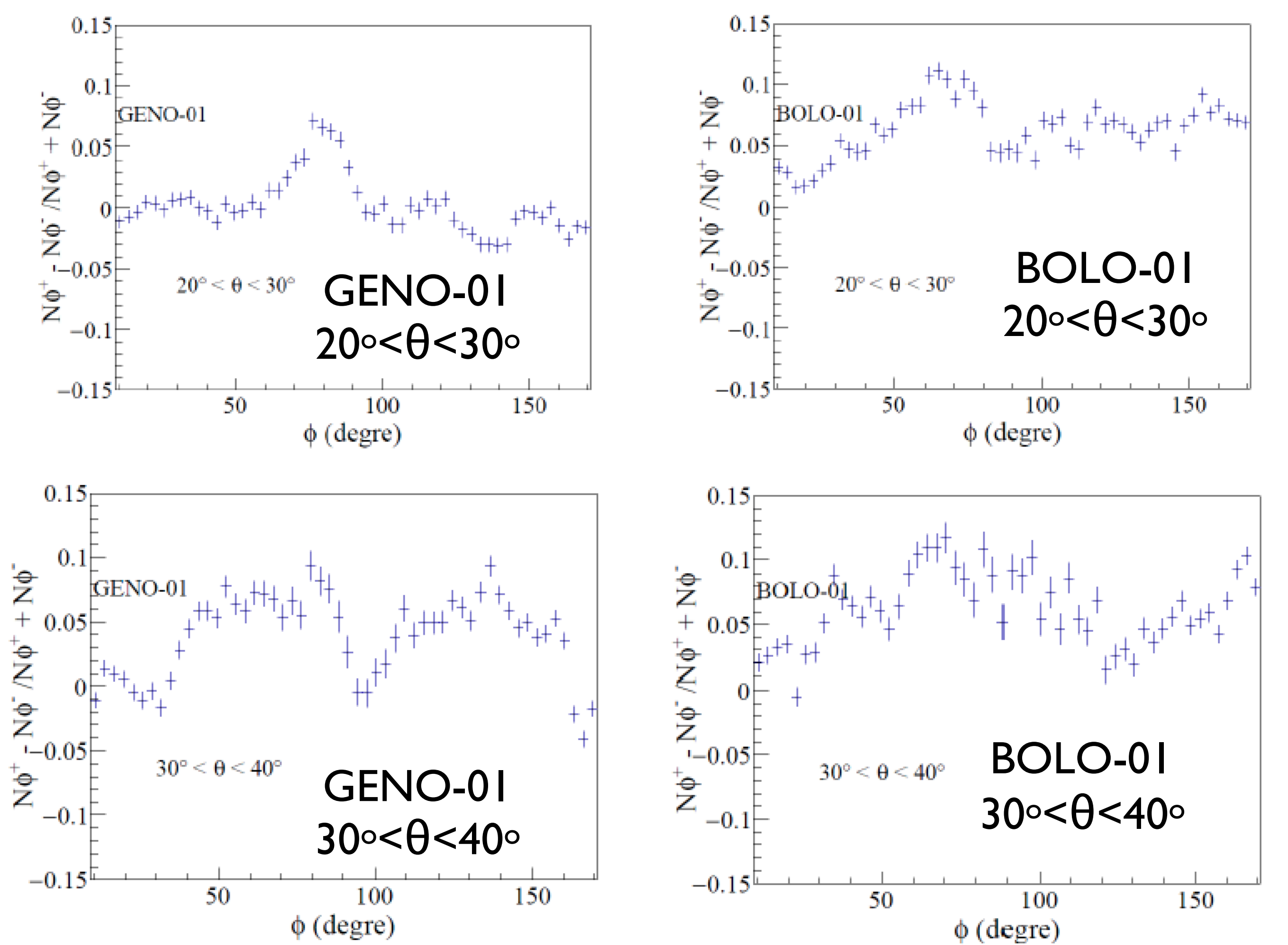
- Significant effect of environment simulation on angular distribution

Data/sim comparison



GENO-01

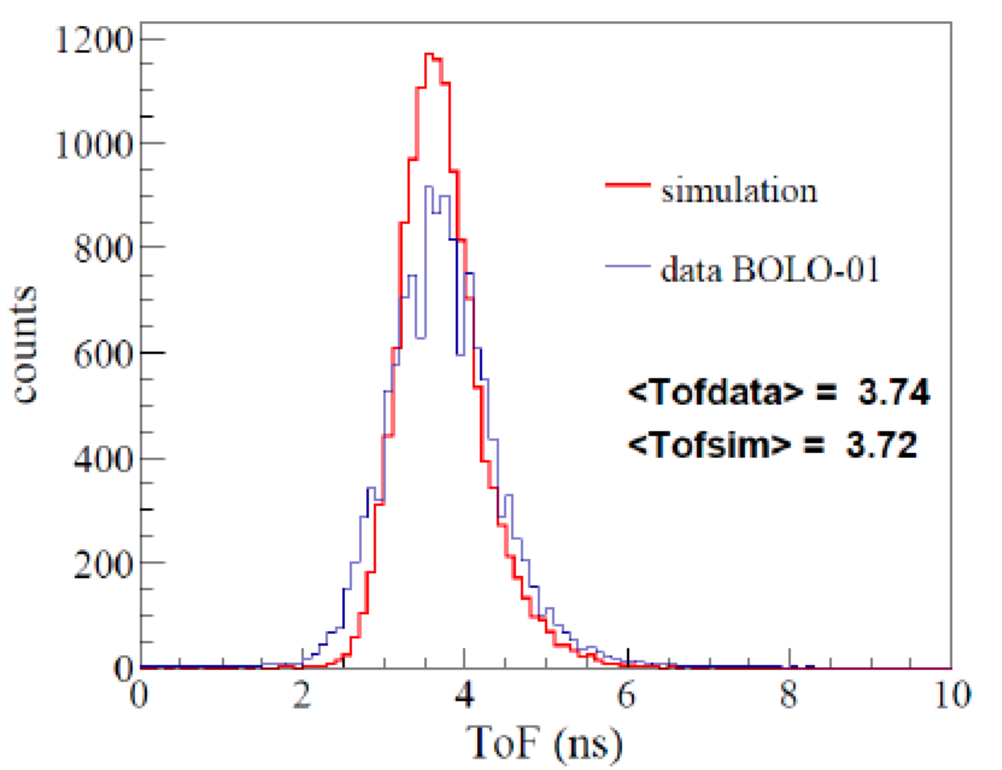
- small angles show no asymmetry
- A ~10% asymmetry rises for θ>20°
- Consistent with the GENO-01 location (mountain on one side)

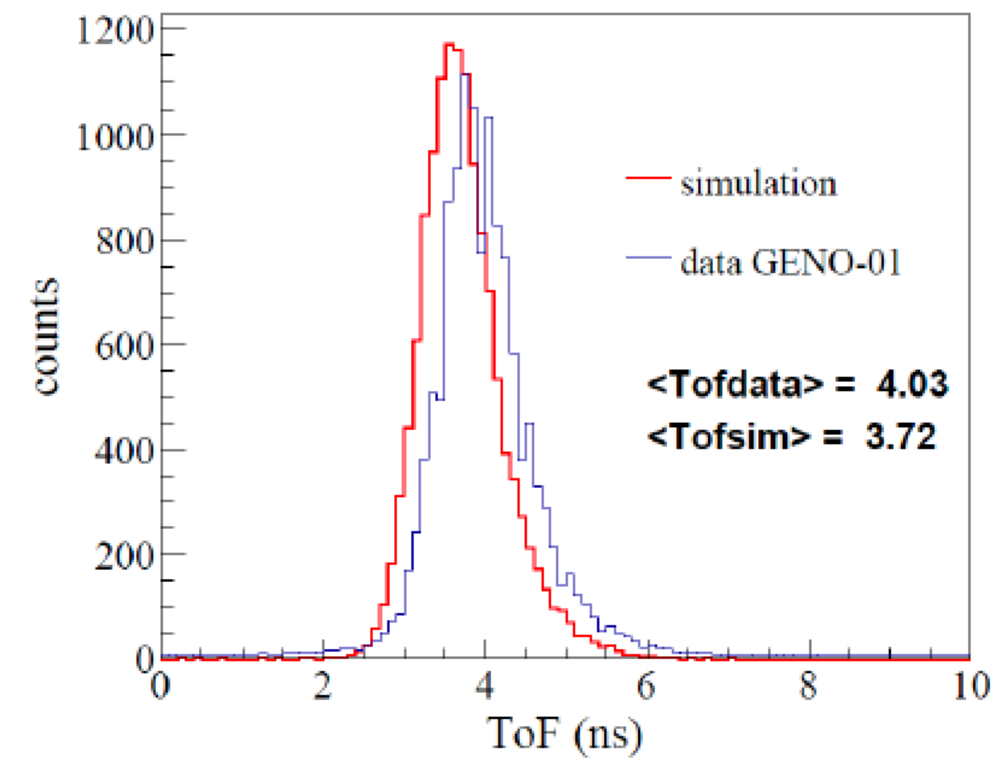


BOLO-01

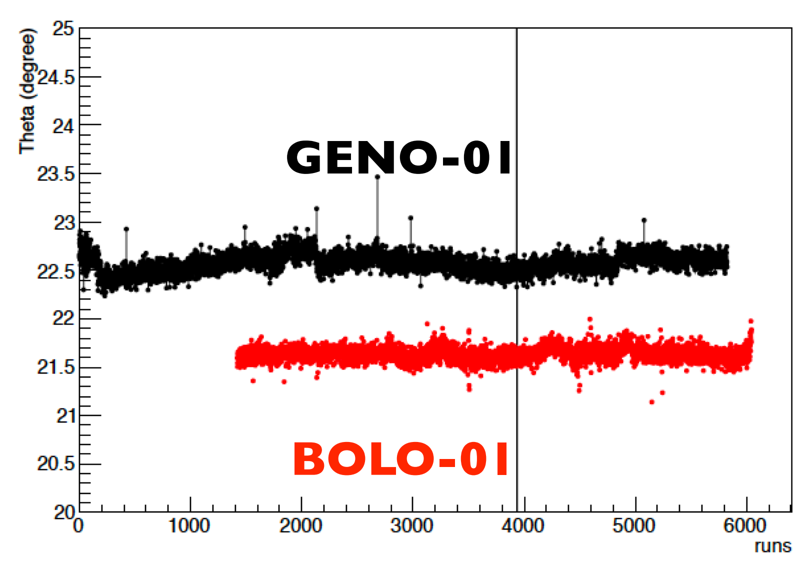
- all angles show a similar (10%) asymmetry
- It can be explained by a reduced acceptance at large angles with a significant L/R asymmetry

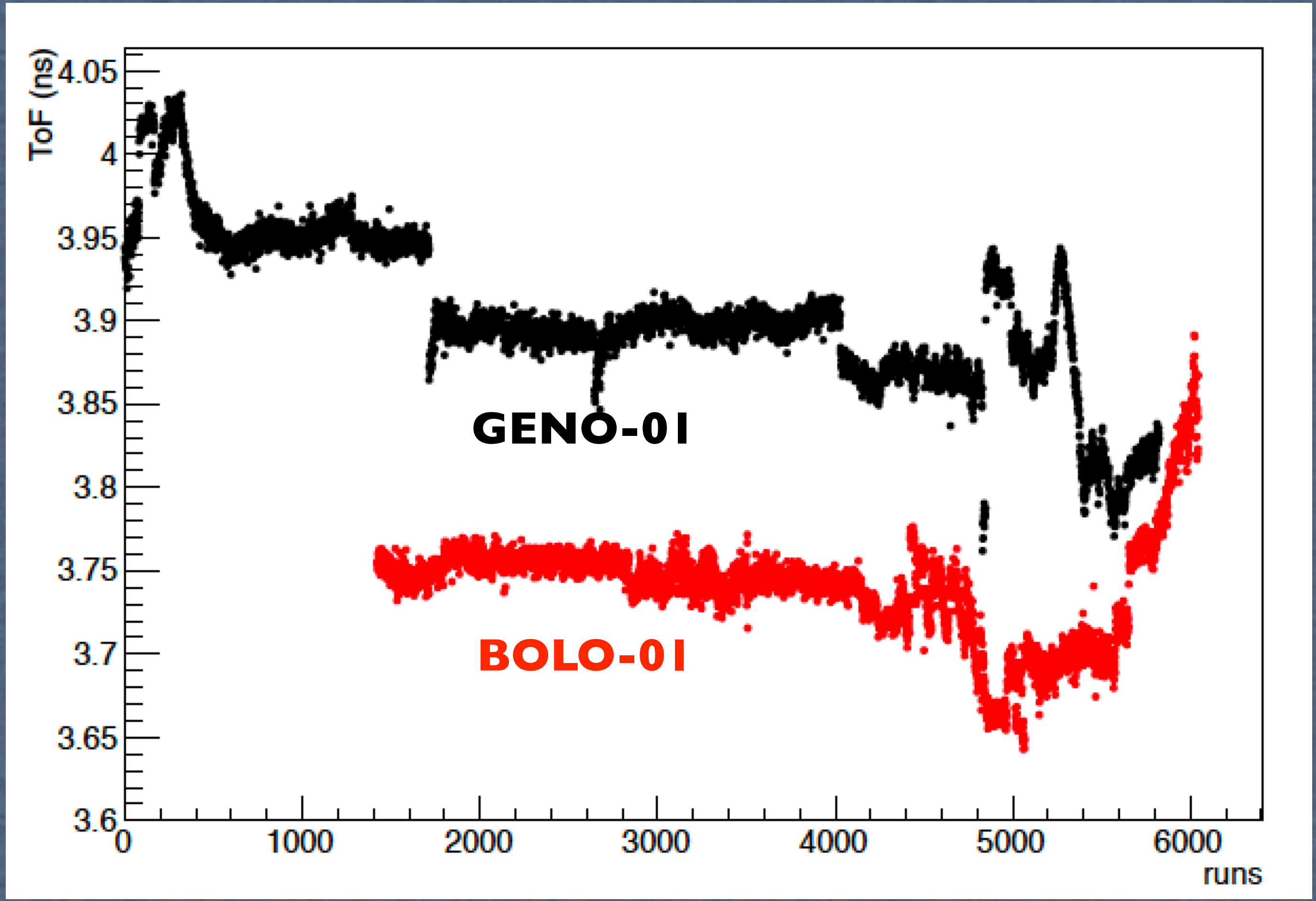
Other comparisons





- ✳ Theta ave is stable in time





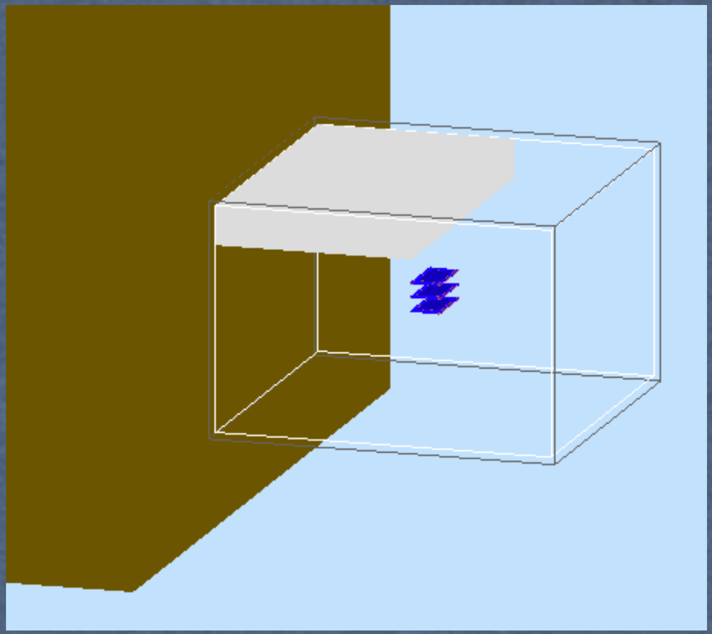
- ✳ Different TOF between GENO-01 and BOLO-01 (?)
- ✳ TOF value is unstable (~5%): why?

Systematics checks

- ✳ Effect of changing data selection: fiducial volume excluding side hits
- ✳ Effect of changing parameters in the microscopic parametrisation of the MRPC response
- ✳ Effect of changing the generation procedure
- ✳ Effect of changing concrete vault
- ✳ Effect of changing generation parameters

No significant effect found

Strategy



- ✳ Changing roof size checking absolute rates and asymmetry for a detailed and realistic description of the environment for GENO-01
- ✳ Implement a realistic environment description for BOLO-01
- ✳ Search for a reference telescope (last generation, stable in time, well controlled) with a simplified location
- ✳ Use ASTRO for out-door/in-door comparisons

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
- Simulation can be used to understand variation of telescope parameters
- Disagreement for theta could be due to materials around the telescope
- Next steps:
  - investigation of the theta discrepancy
  - high statistic GEANT4 simulation at CNAF
  - 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

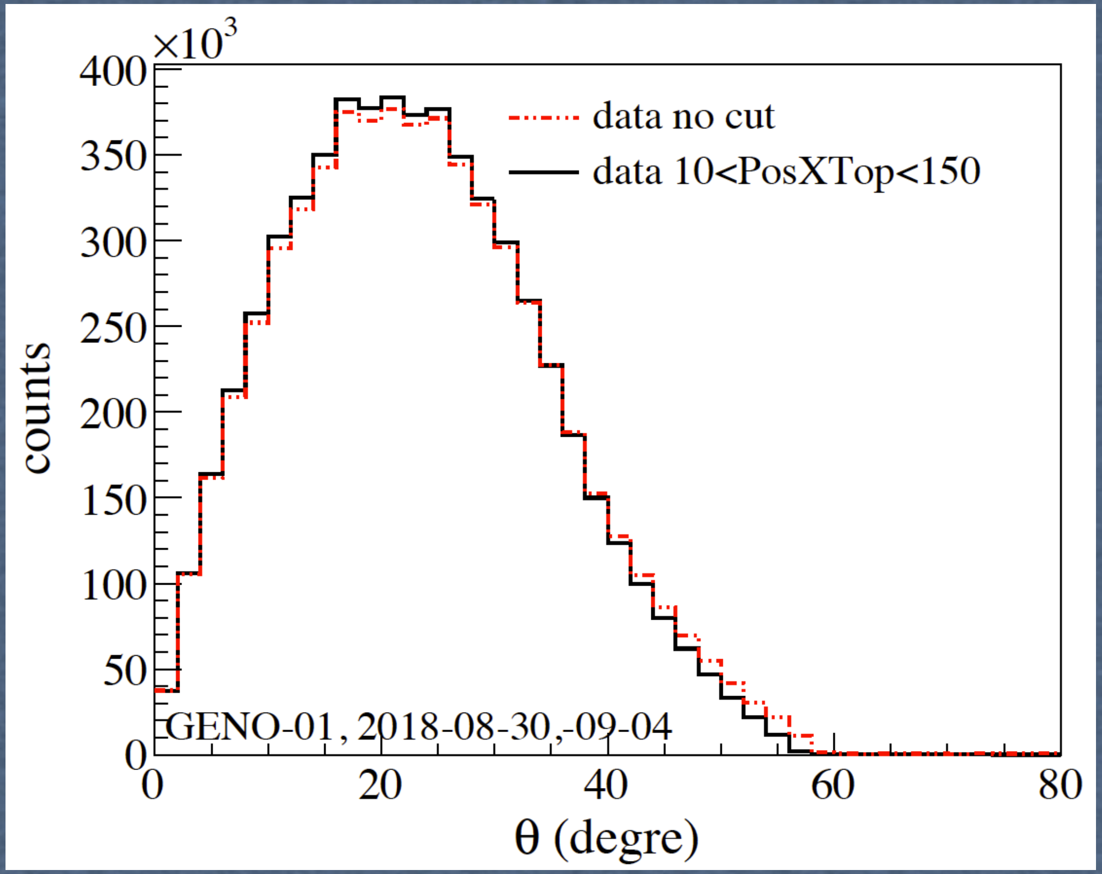
Back up

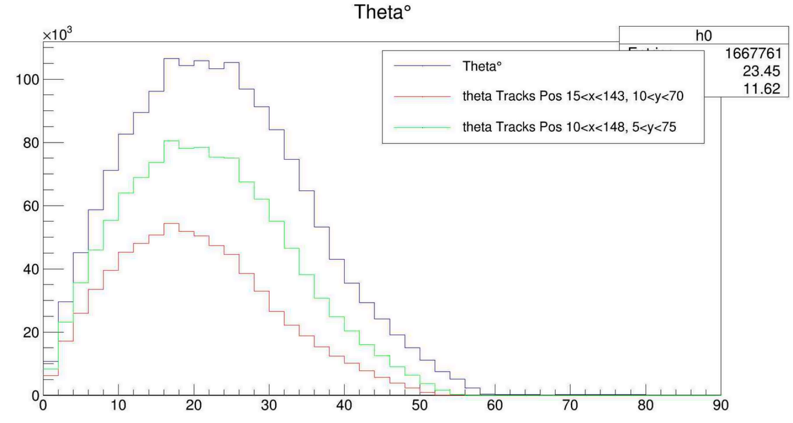
EEE-Sim results

Systematic checks for data/sim agreement

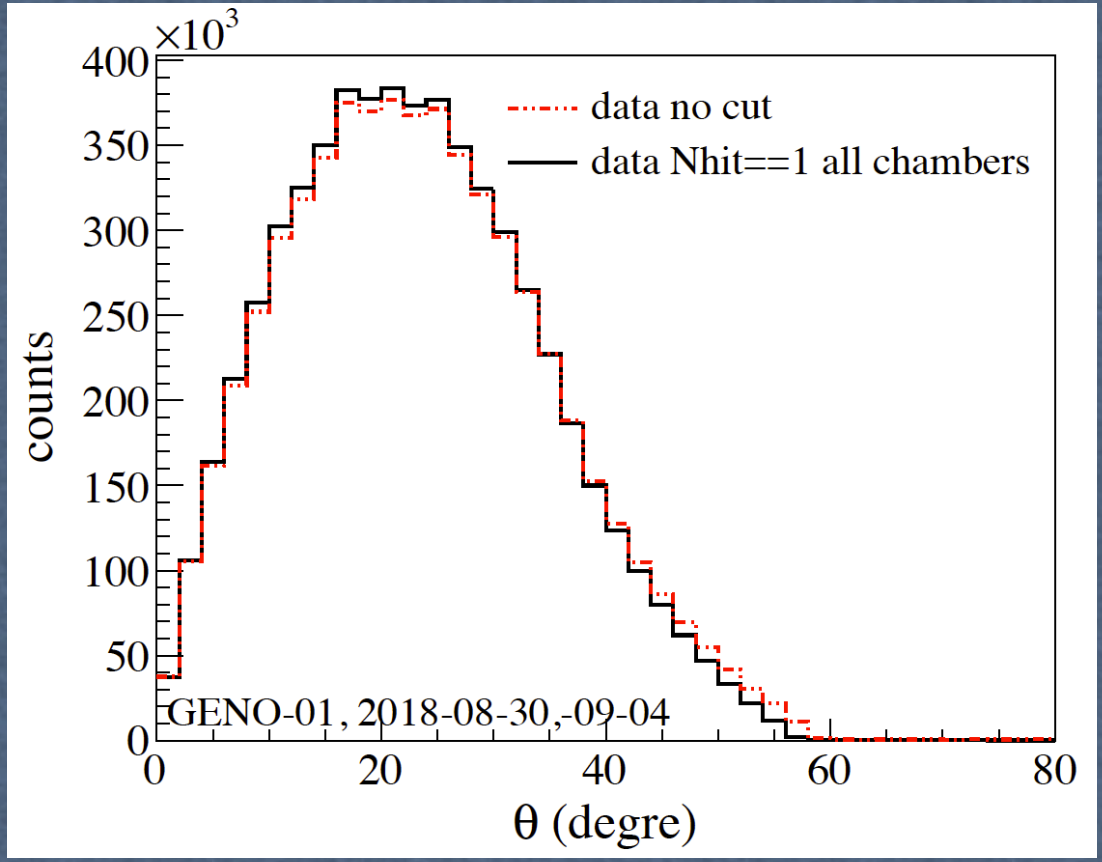
✳Effect of changing data selection

- **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 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

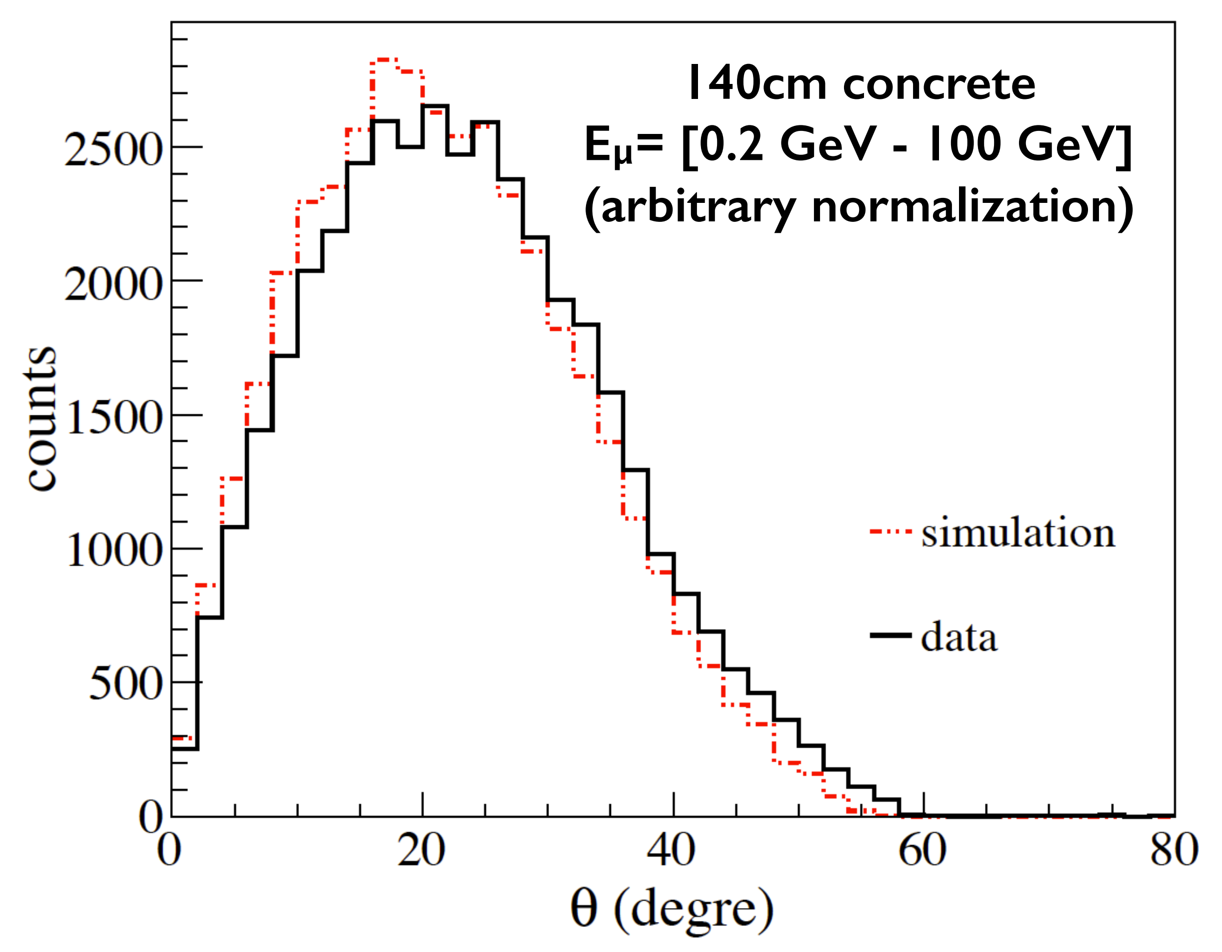
- Effect of changing the generation procedure
    - **Generation semi-sphere**: R = [150cm-250cm]; position in Z = [centered, offset to -50cm]

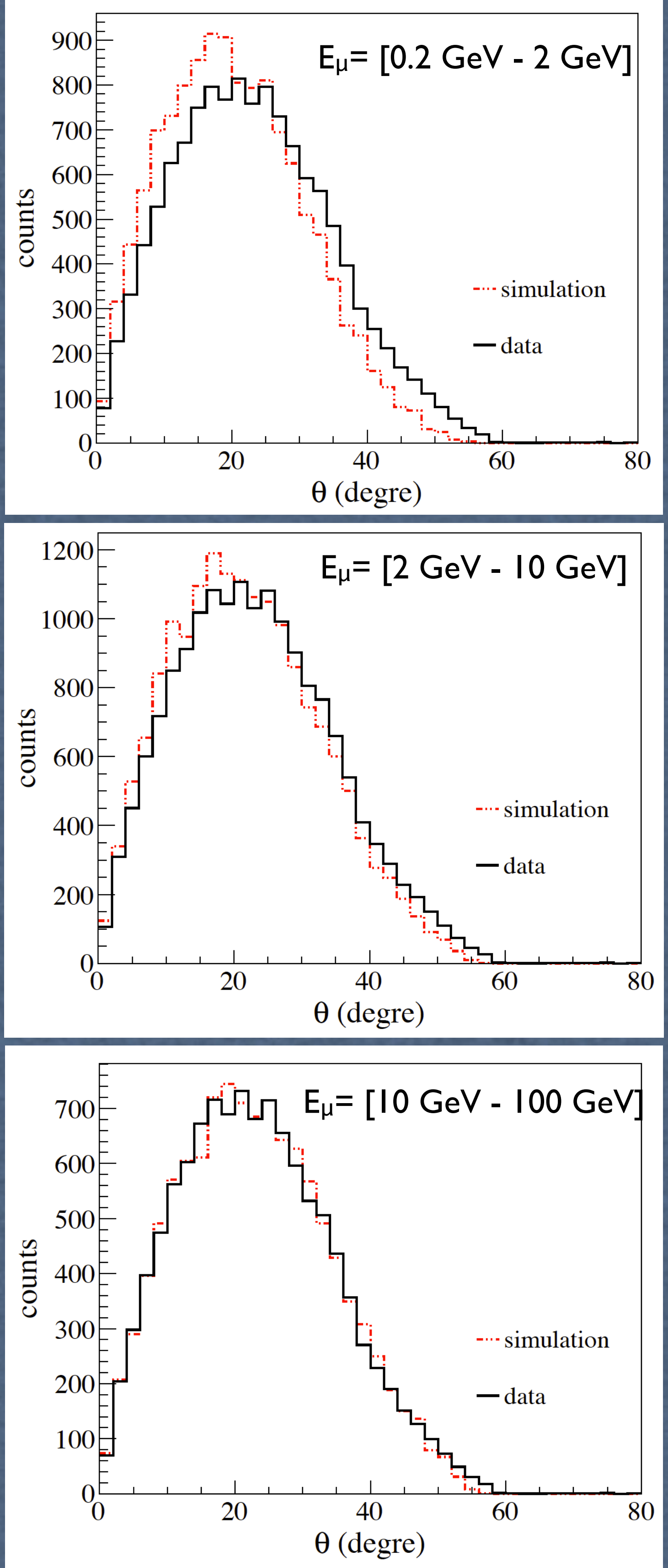
No significant effect found since the SIM algorithm uses only the first hit as the REC does for data

- 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



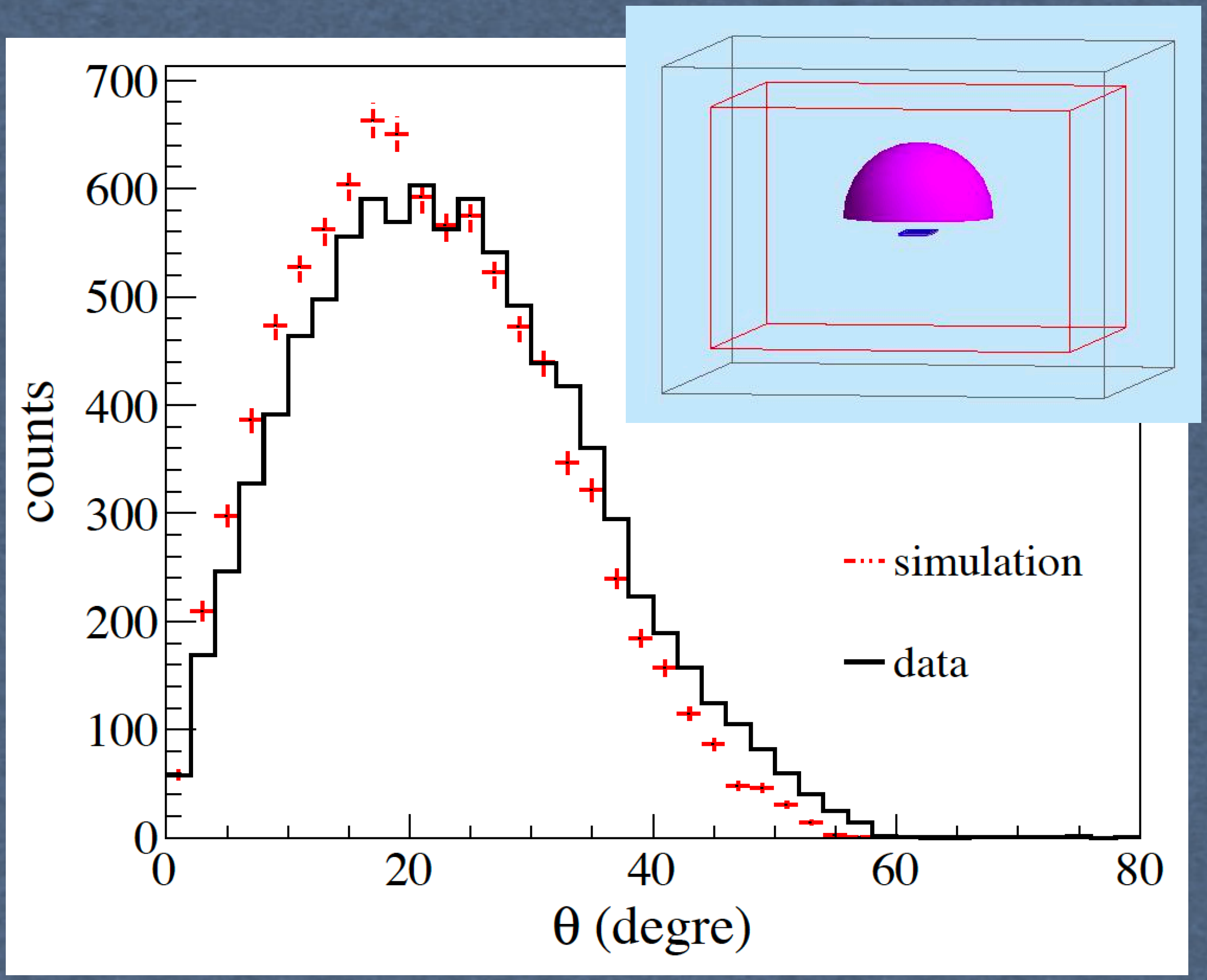


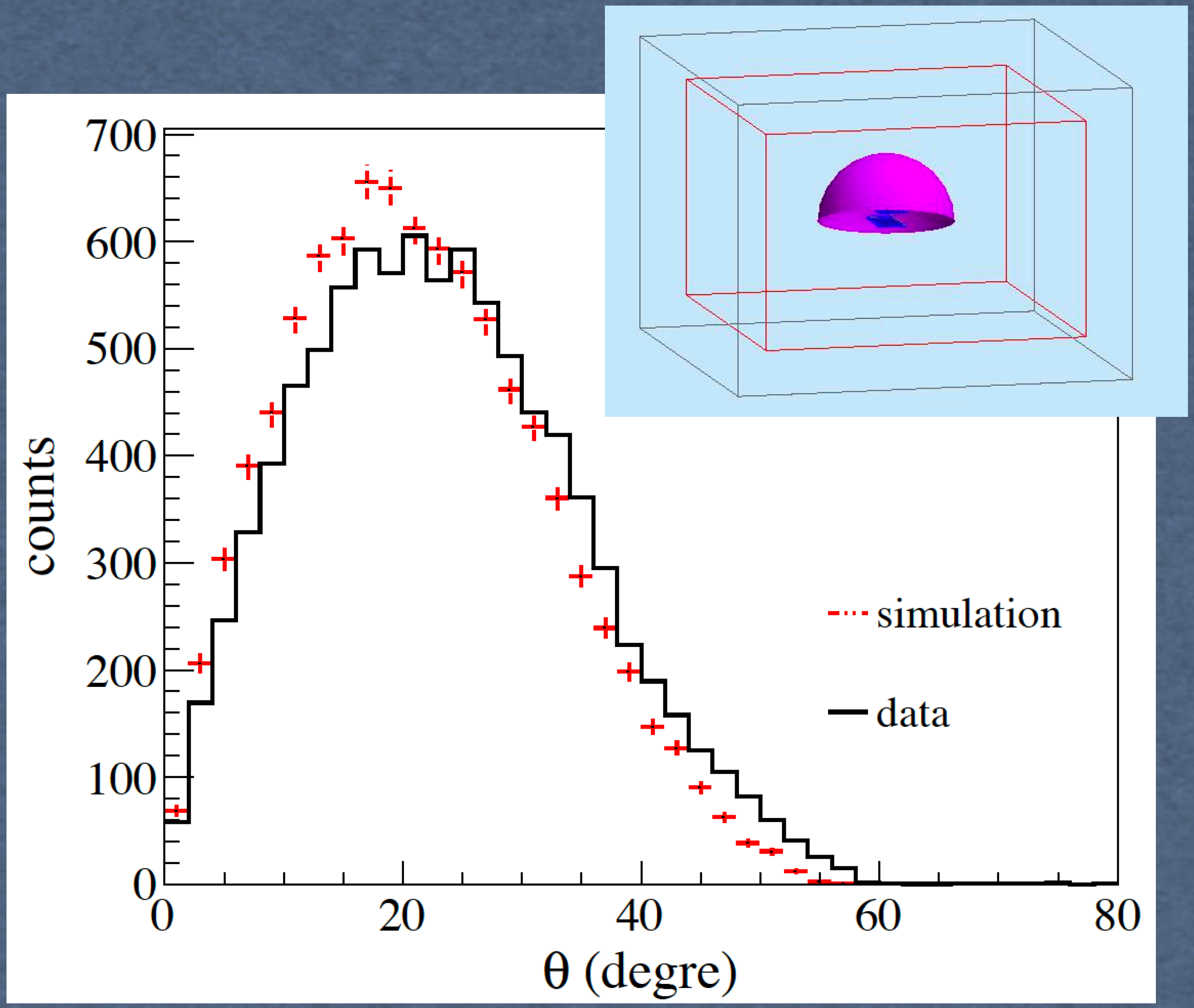
✳Better agreement if we only consider high energy muons

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