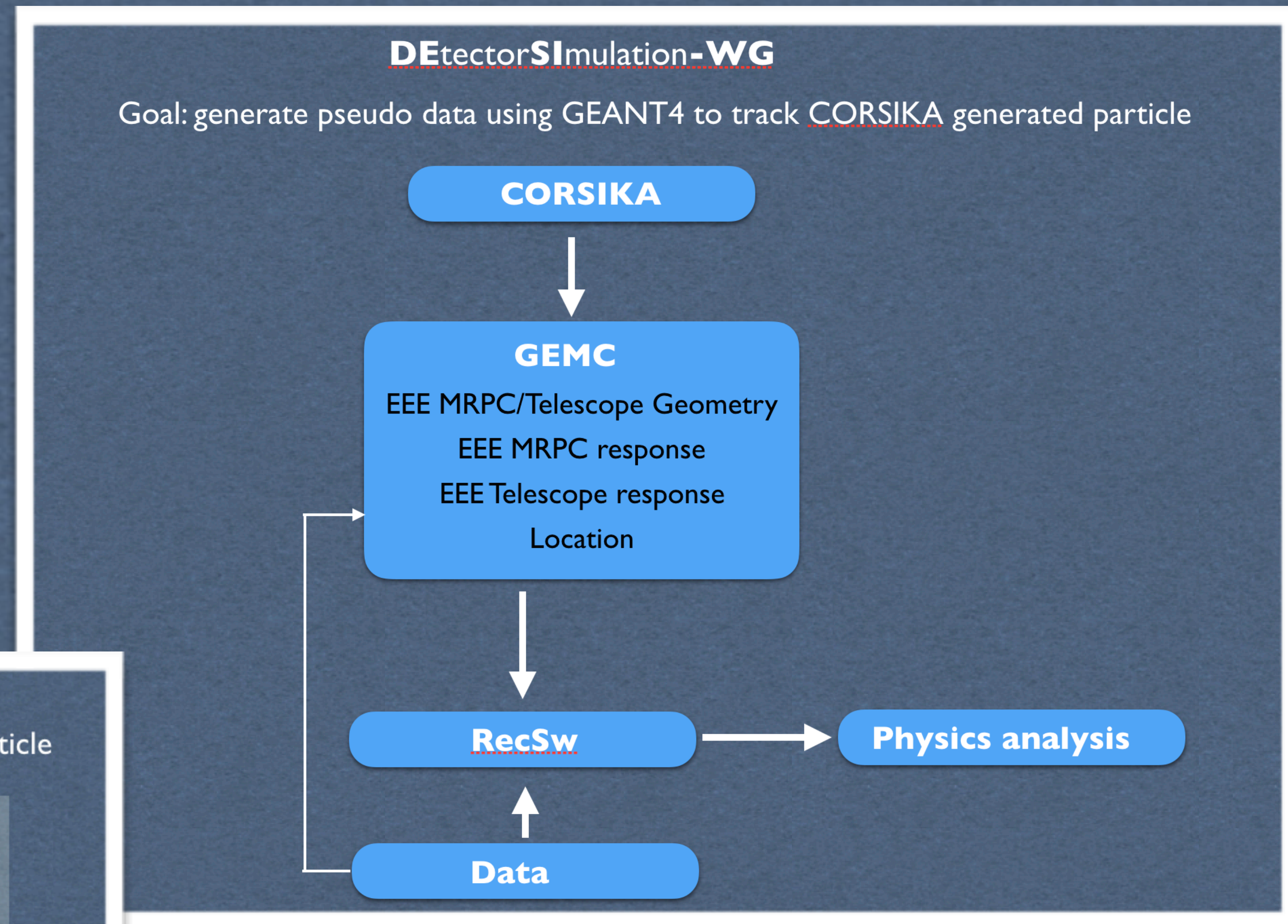
May 14 2020
EEE Meeting

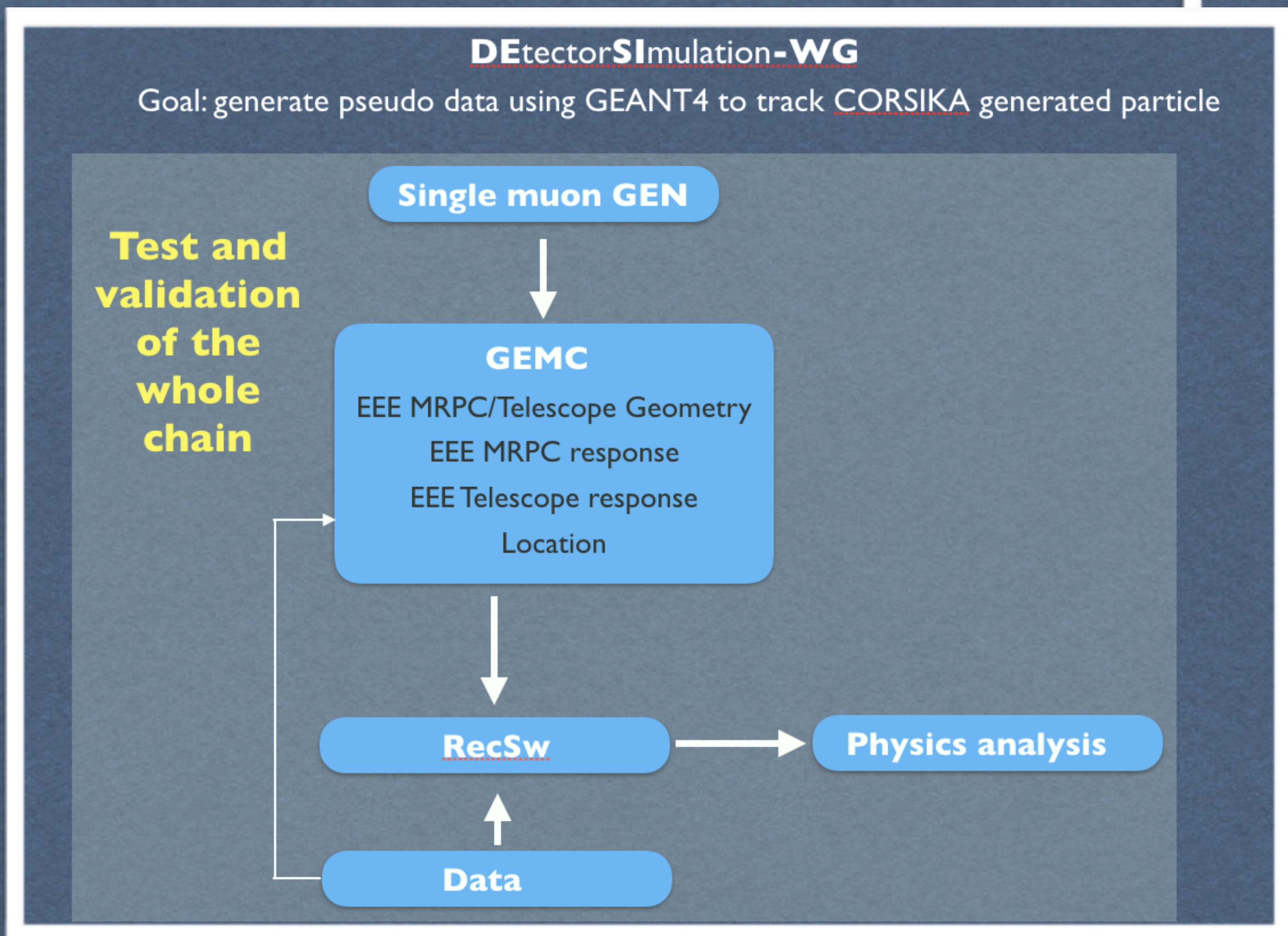
Detector Simulation Working Group (DeSi-WG)

EEE telescope simulation publication update

M.Battaglieri, S.Grazzi G.Mandaglio, S.Boi, M.P. Panetta, C.Pellegrino, S.Pisano
F.Coccetti, F.Noferini, M.Ungaro

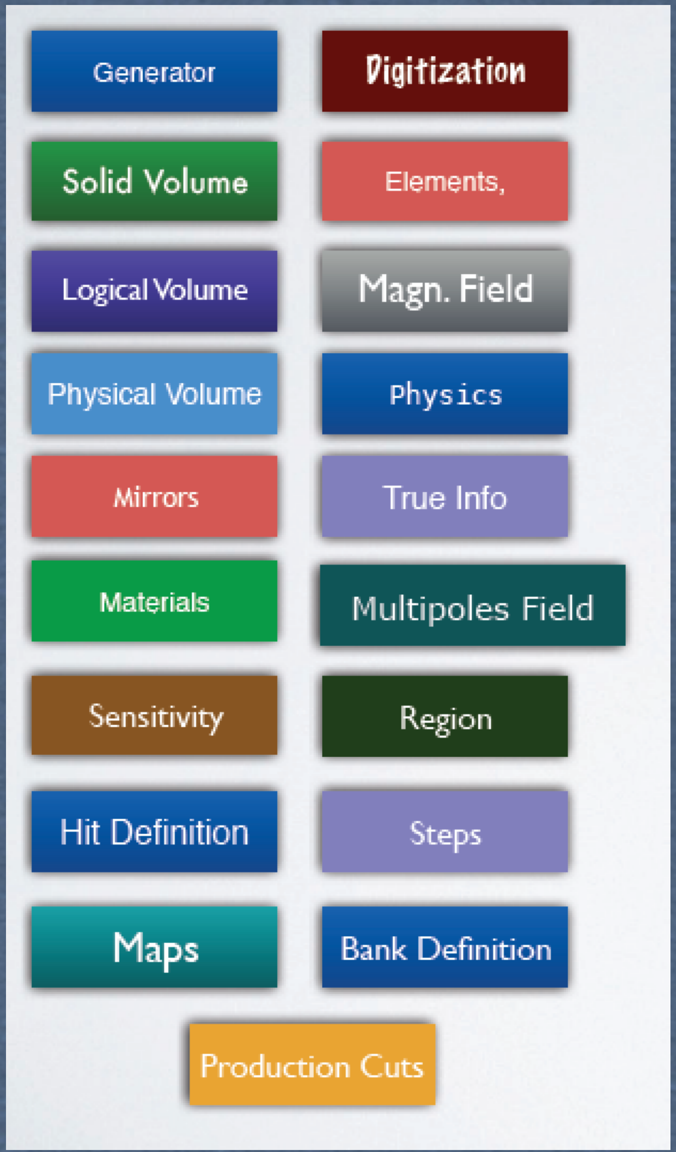
Final goal of simulation framework





Limited goal (relevant for NIM paper)

GEant4 Monte Carlo: GEMC



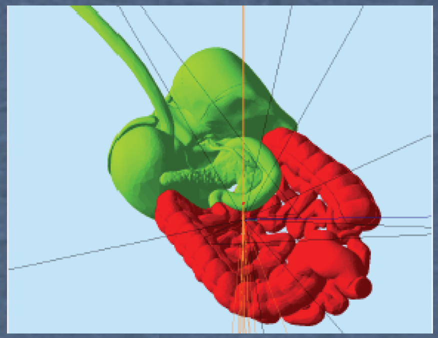
Realistic detector simulation

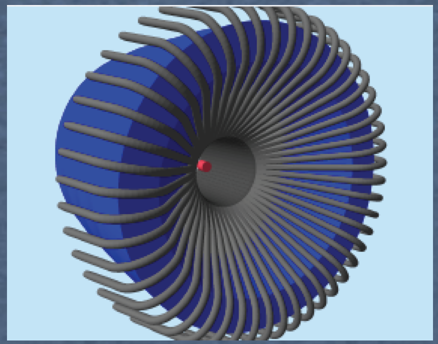
M.Ungaro

GEMC

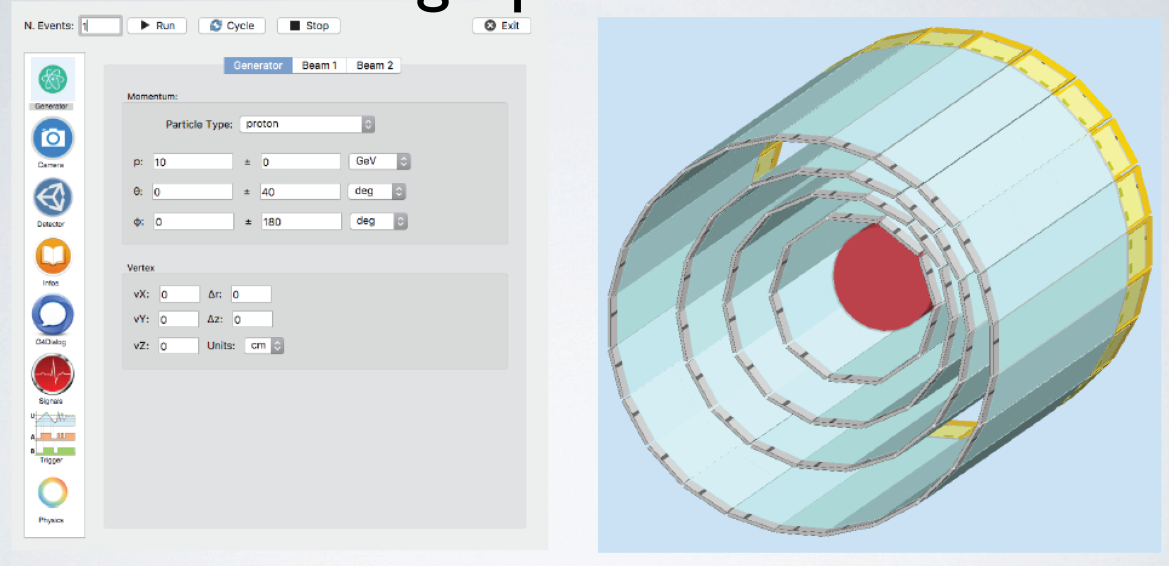
A GEANT4 libraries based simulation tools

- 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



- Working installation at CNAF
- Docker distribution for local applications

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

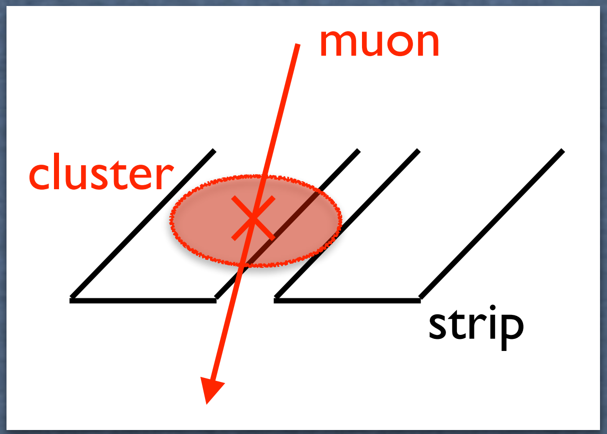
- Multi-telescopes: coincidence rates
- Single/multiple telescope(s) studies: bottom-up muons, …

✳ 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

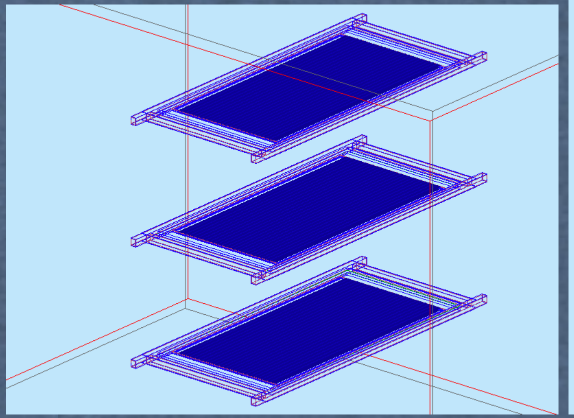
- 90x160 active area
- Active: 2.5cm x 24 strips + 0.7cm x (24-1) gaps
- Time spread: σ = 238ps
- Cluster size: $\sigma_X = 9.2$ mm
- Cluster size: $\sigma_Y = 15$ mm
- Light speed: 15.8 ns/cm
- HIT_{XY} is gaussian-spread and projected on the sensitive area to derive strip multiplicity

Ref: JINST13(2018)P08026

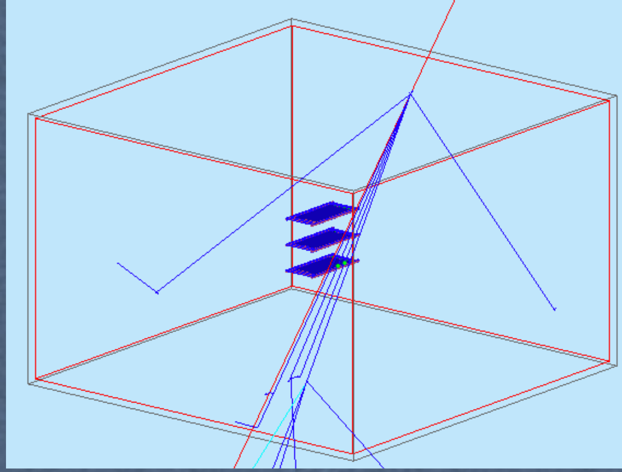
✳Telescope parameters

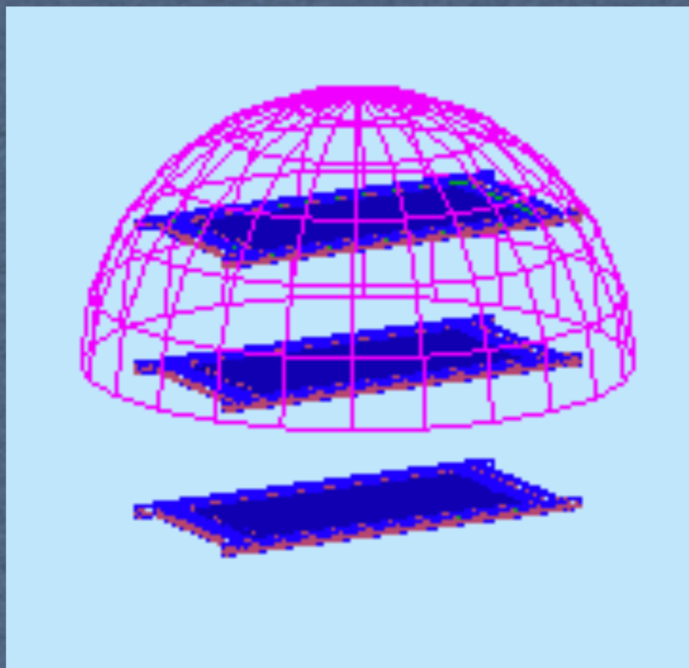
- 3 chambers
- -50/0/+50 cm apart
- placed in a concrete box wall on all sides (140cm concrete)

Ref: GENO-01



Concrete vault





Muon generation

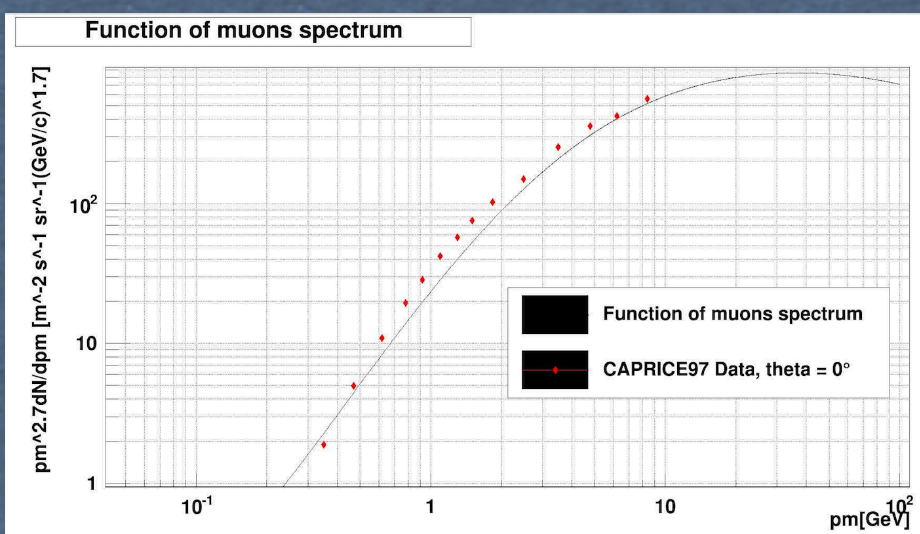
- Single-muon generation
- Semi-sphere generation such as to obtain a flat distribution on a plane surface
- Improved Gaisser parametrization for Flux(E_μ,Θ) to include Earth curvature (all latitudes) and low energy muons (<100GeV)

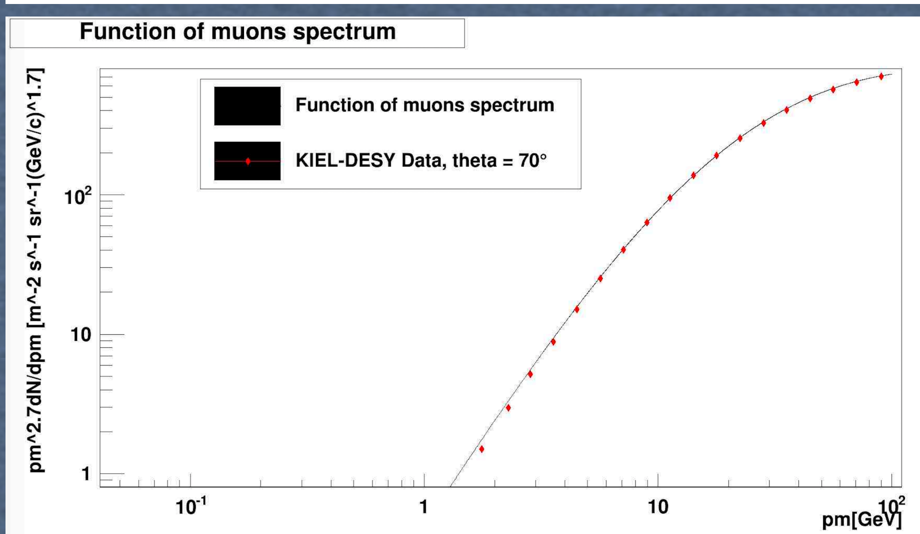
$$\frac{dI_\mu}{dE_\mu} = 0.14\left[\frac{E_\mu}{GeV}\left(1+\frac{3.64GeV}{E_\mu(\cos\theta^*)^{1.29}}\right)\right]^{-2.7}\left[\frac{1}{1+\frac{1.1E_\mu\cos\theta^*}{115GeV}}+\frac{0.054}{1+\frac{1.1E_\mu\cos\theta^*}{850GeV}}\right]$$

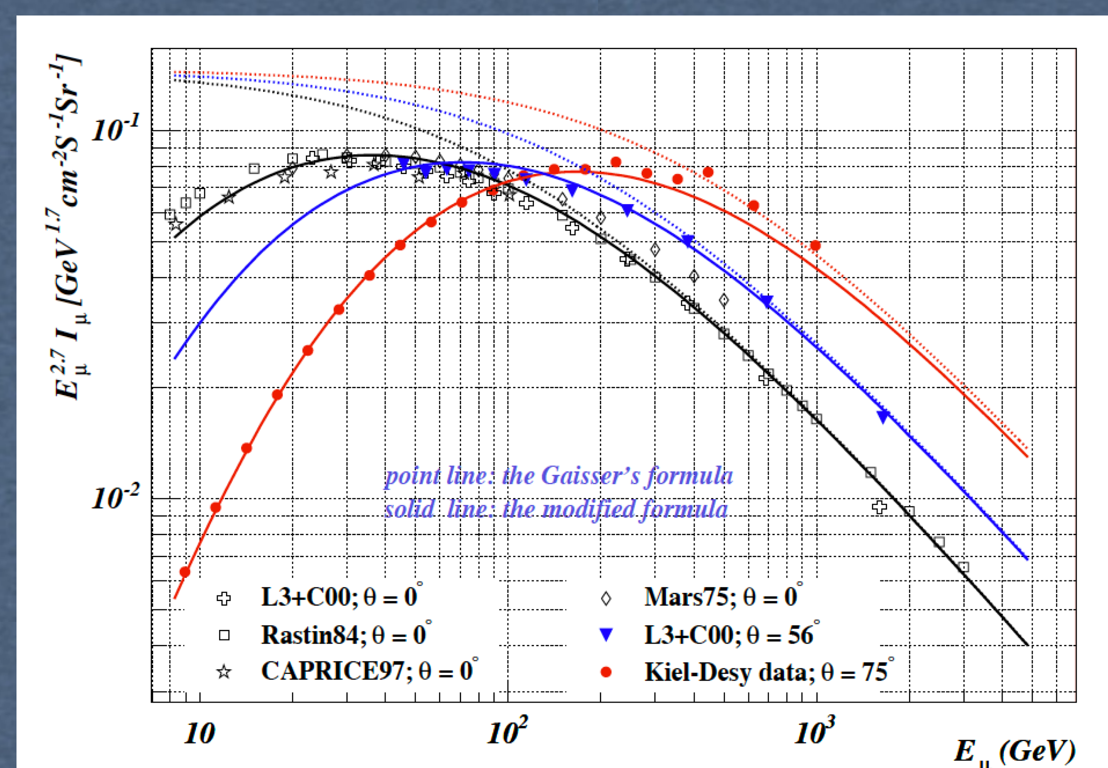
$$\cos\theta^* = \sqrt{\frac{(\cos\theta)^2+P_1^2+P_2(\cos\theta)^{P_3}+P_4(\cos\theta)^{P_5}}{1+P_1^2+P_2+P_4}}$$

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}

Simulations should provide:

- Absolute and angular efficiency
- ABSOLUTE single-mu rates (to be compared to the telescope response)
- effective comparison to world data parametrisation
- description (and compensation) of surrounding materials
- easy way to compare telescopes with different parameters (e.g. distance between the chambers)
- cross check of data quality and working conditions of different telescopes

Simulation needs to be validated comparing data

- Find a set of variables/parameters to compare to
- Find some telescopes with smooth and stable response
- Reasonably easy location to avoid unknown from the environment

- GENO-01, BOLO-01: smooth operations but complicated locations (second batch)
- **TORI-03: smooth and simple location (just a room at the last floor)**
- CERN-01: smooth and simple location with a different chamber separation (44cm/44cm)
- SAVO-01: smooth and simple location with a different chamber separation (46cm/46cm)

★ Experts are supporting the data performance assessment (D. De Gruttola, C. Ripoli)

★ Next stage: involve schools and do a systematic analysis on all telescopes

GENO-01

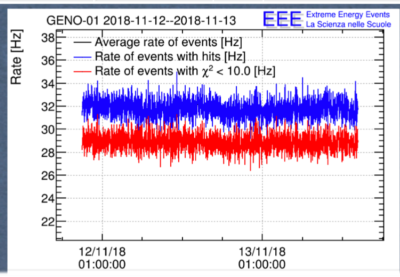
✳ First test: comparison to GENO-01
✳ The complicated location prevented a straightforward comparison
✳ Data shows an anisotropy in PHI difficult to correctly implement in simulation

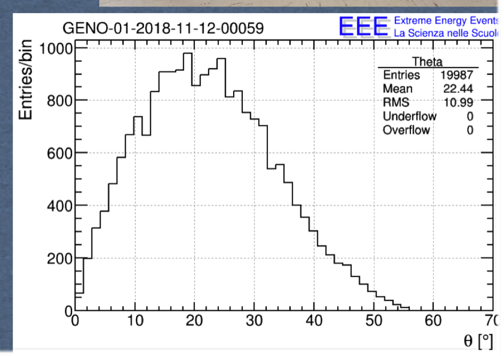
Comparison with GENO-01

✳ 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

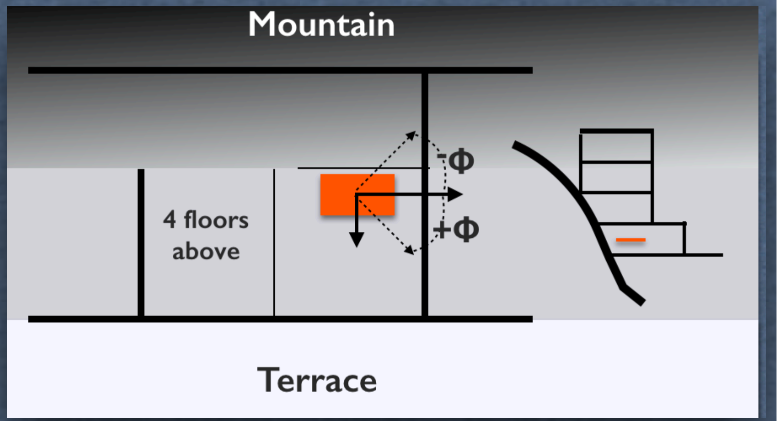
PLOT	ALARM	STATUS	OUTPUT
RateHitEvents	y_values	Clean	30.54 +- 0.71
DeltaTime	exp_fit_lambda	Clean	31.81 +- 0.22
HitMultTop	x_average	Clean	1.2898 +- 0.0044
HitMultMid	x_average	Clean	1.2569 +- 0.0044
HitMultBot	x_average	Clean	1.1956 +- 0.0039
HitMultTotal	x_average	Clean	3.7390 +- 0.0093
ClusterMultTop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

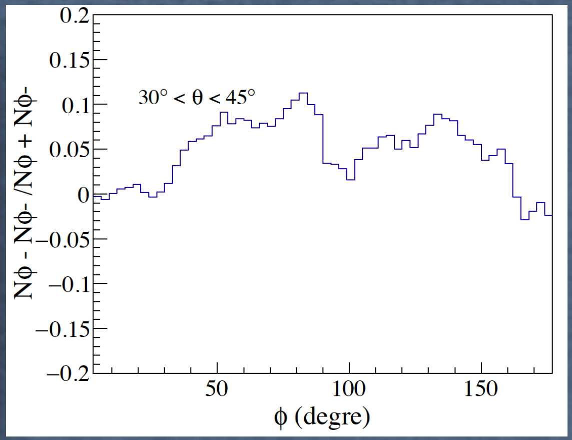
✳ Data are stable

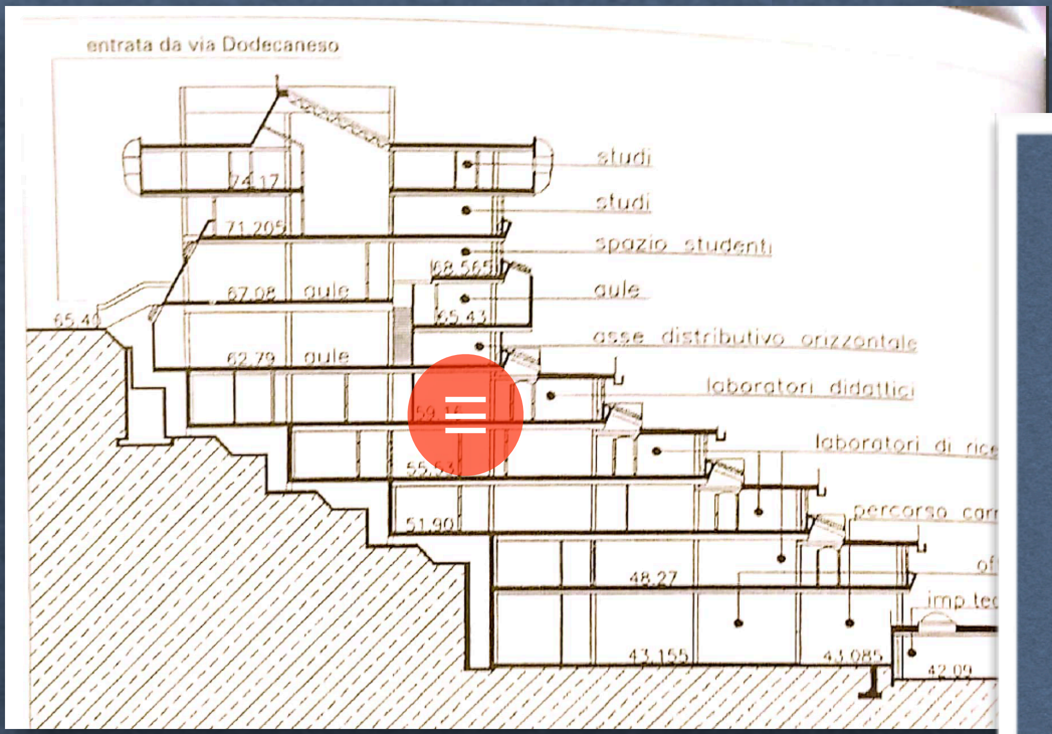




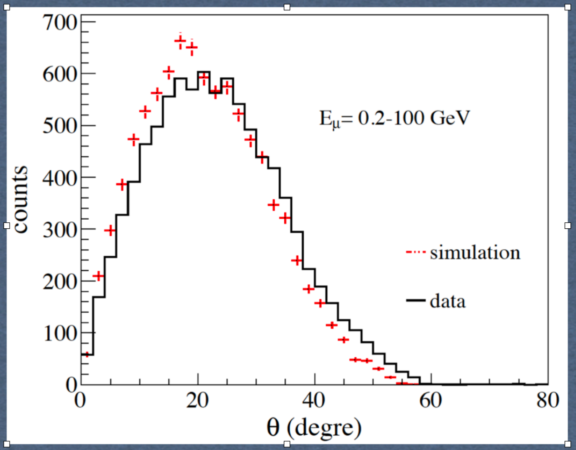
S.Grazzi

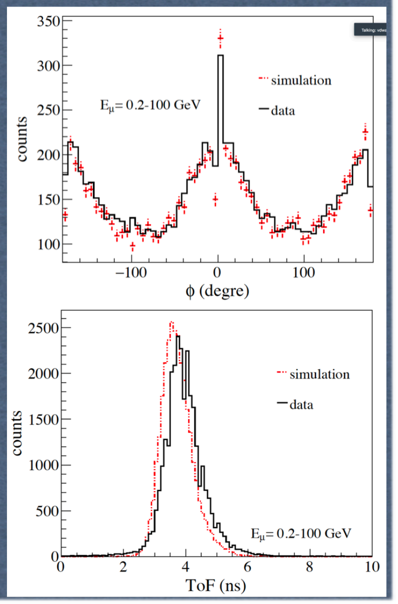






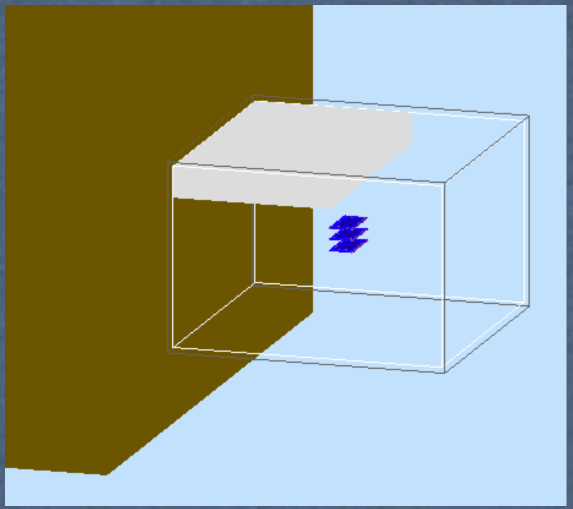
GENO-01/SIM comparison





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

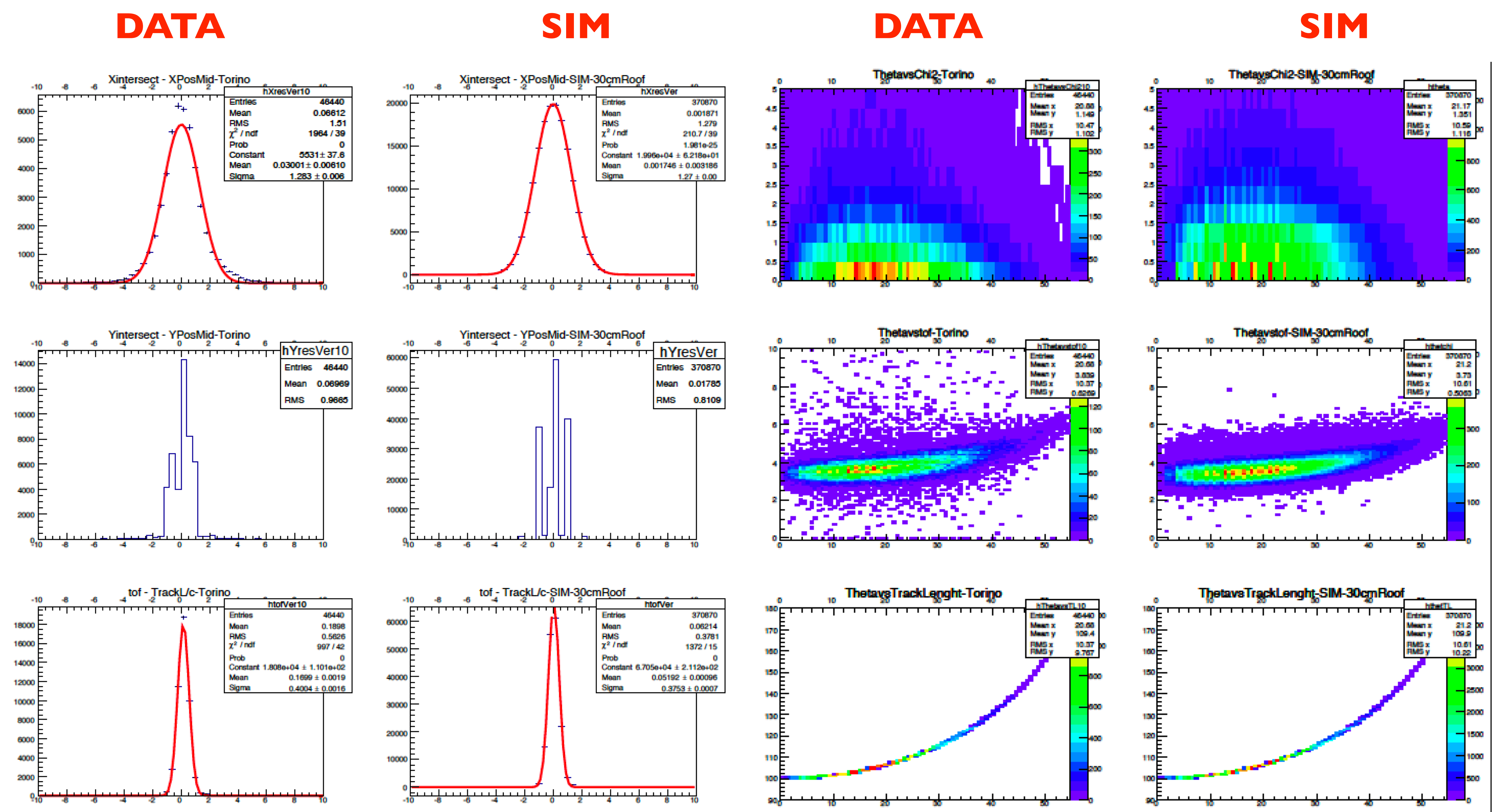
✳ Reasonable agreement but not optimal



✳ Still working to implement a more realistic geometry of surrounding materials

✳ Comparison of microsopic quantities

TORI-03



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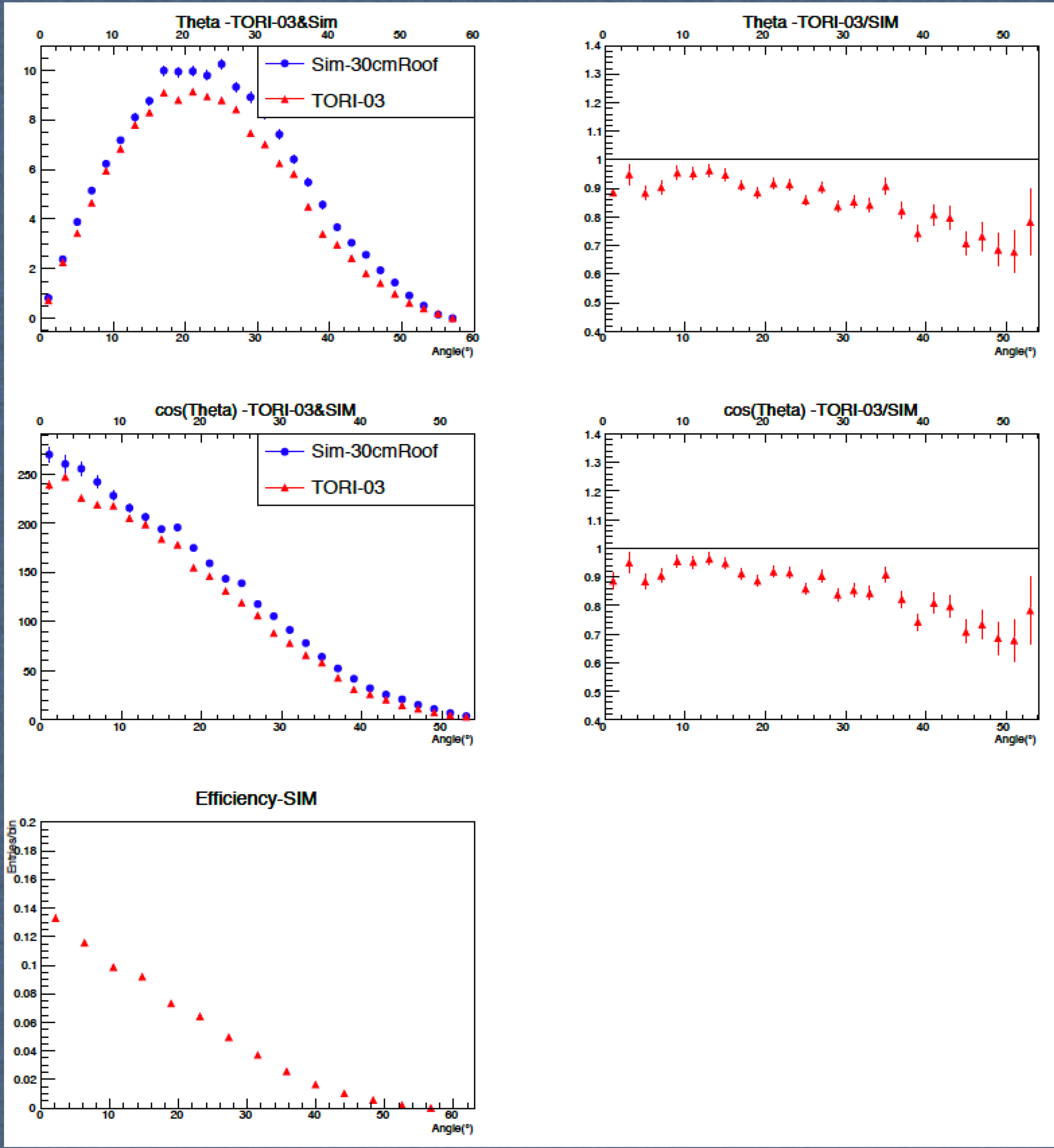
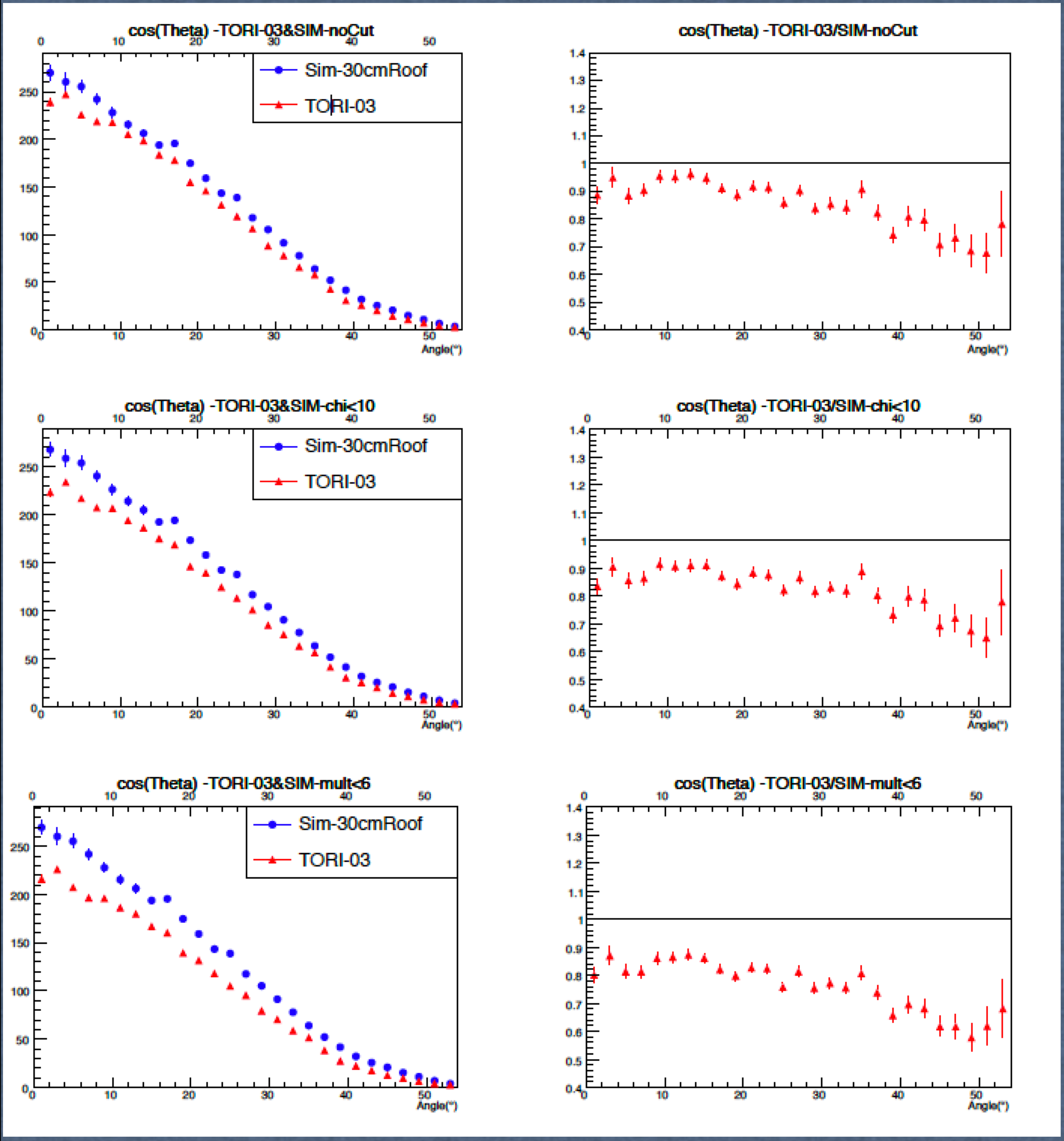


TORI-03

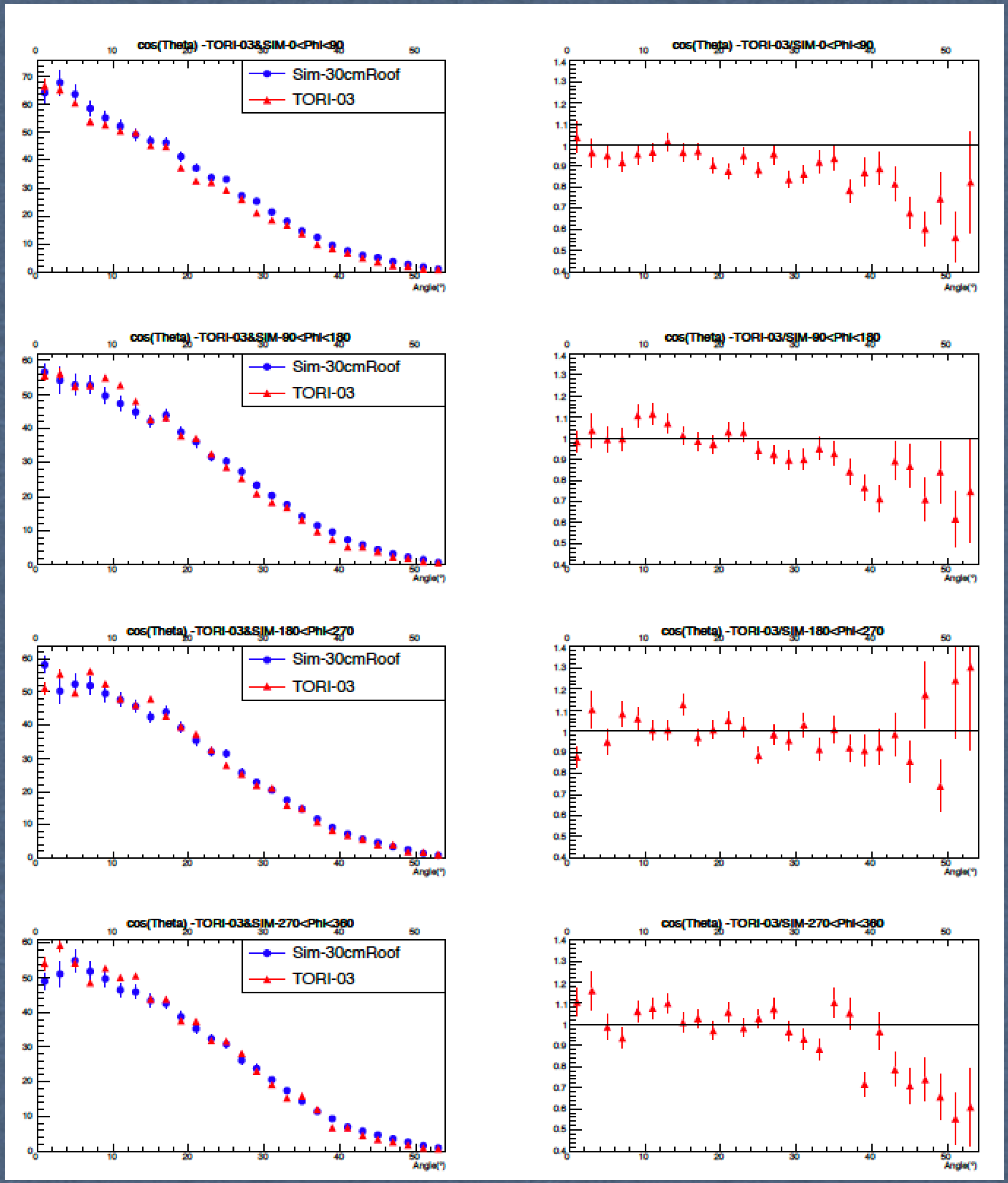
- Good agreement between data and simulation (world-data parametrization) both for absolute and angular behaviour
- Data are 10% lower with a reasonably smooth and constant ratio
- The region where the agreement is less good corresponds to large angles where the efficiency drops by a factor of ten
- Can have a better agreement in selected kinematics regions?



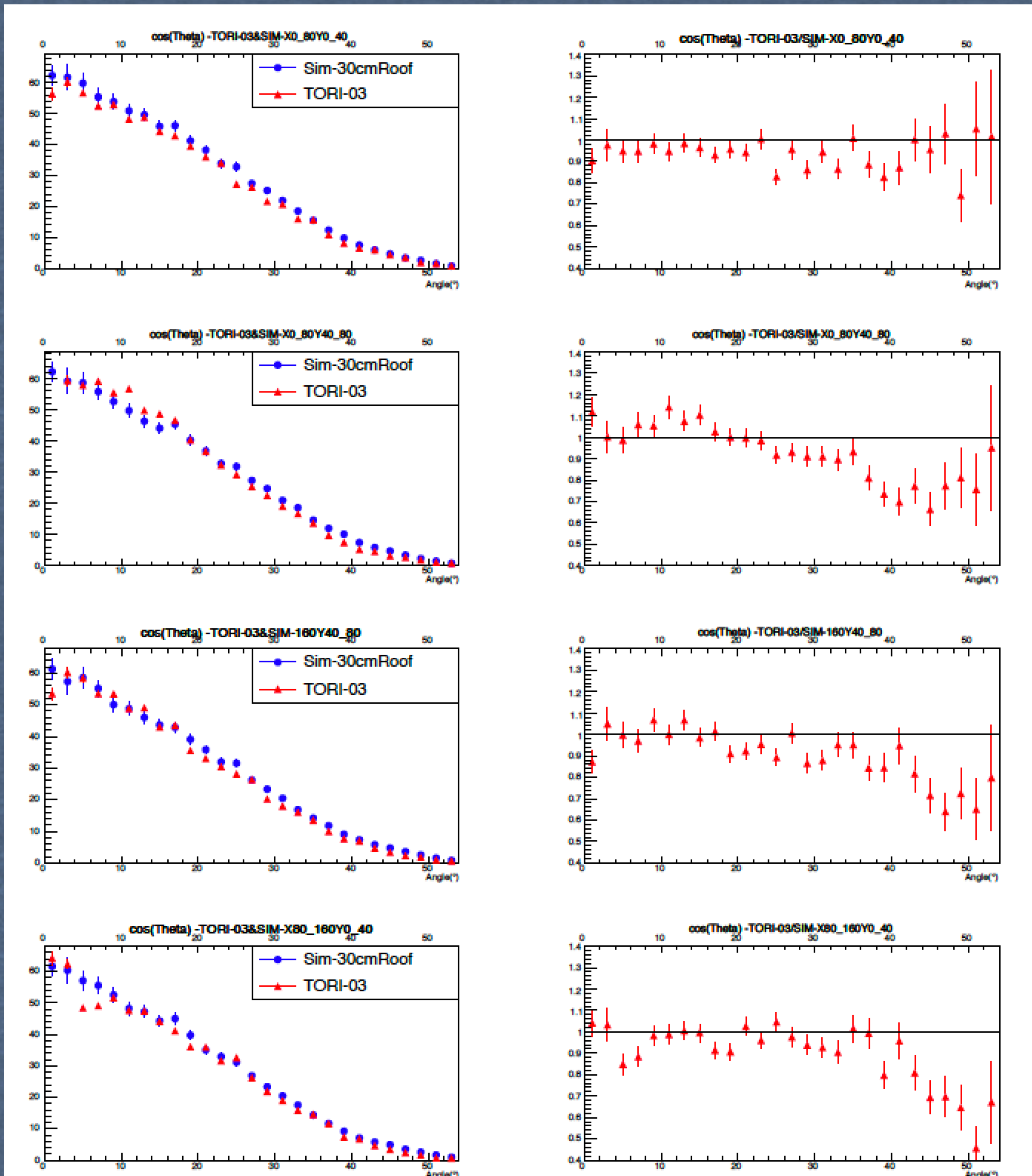
TORI-03

- Cuts on Chi2<19=0 does not help
- Either a cut on track multiplicity does not help

TORI-03



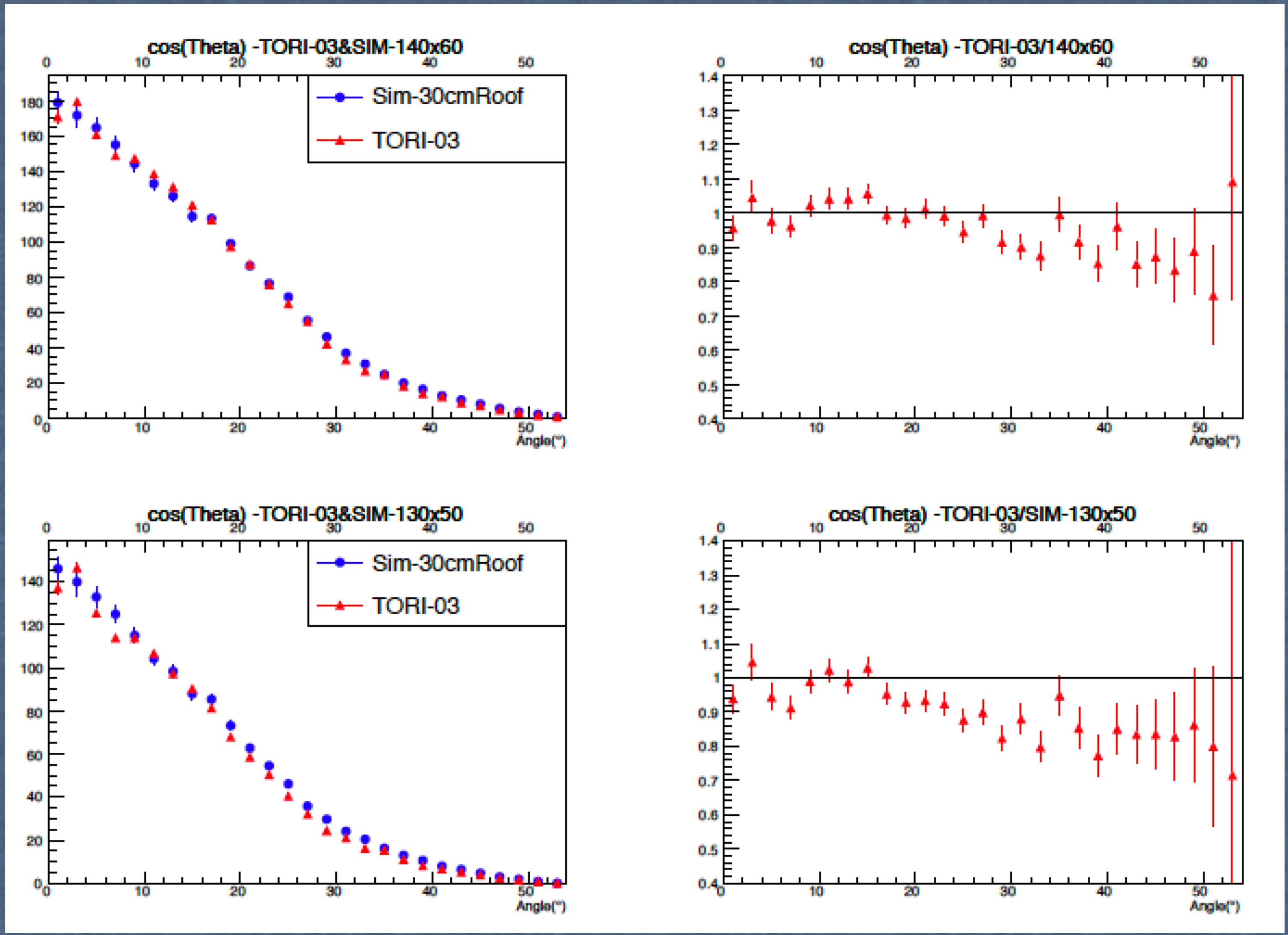
- Systematics checks on 4 directions (90deg each) confirms the same trend



TORI-03

- Systematics checks on 4 quadrants (XY) may indicate some misbehaviour at large angles in certain area of the detector.

TORI-03

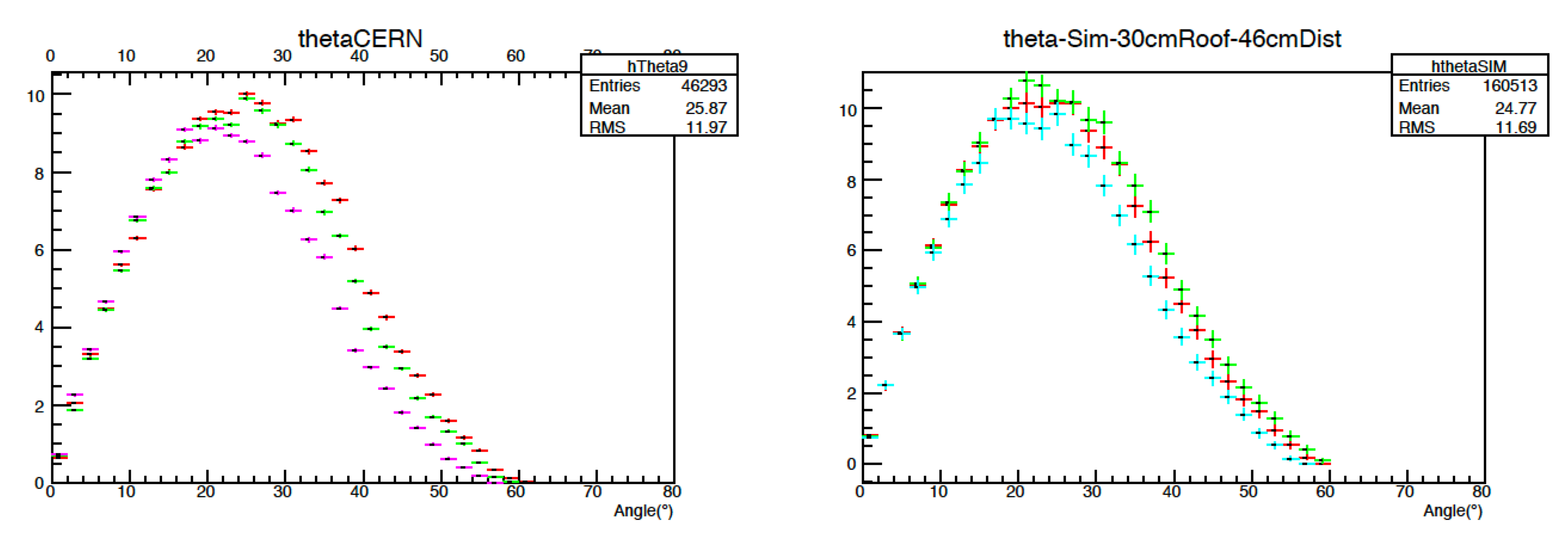


- Same conclusions when only a fiducial volume is considered

Check with some other telescopes

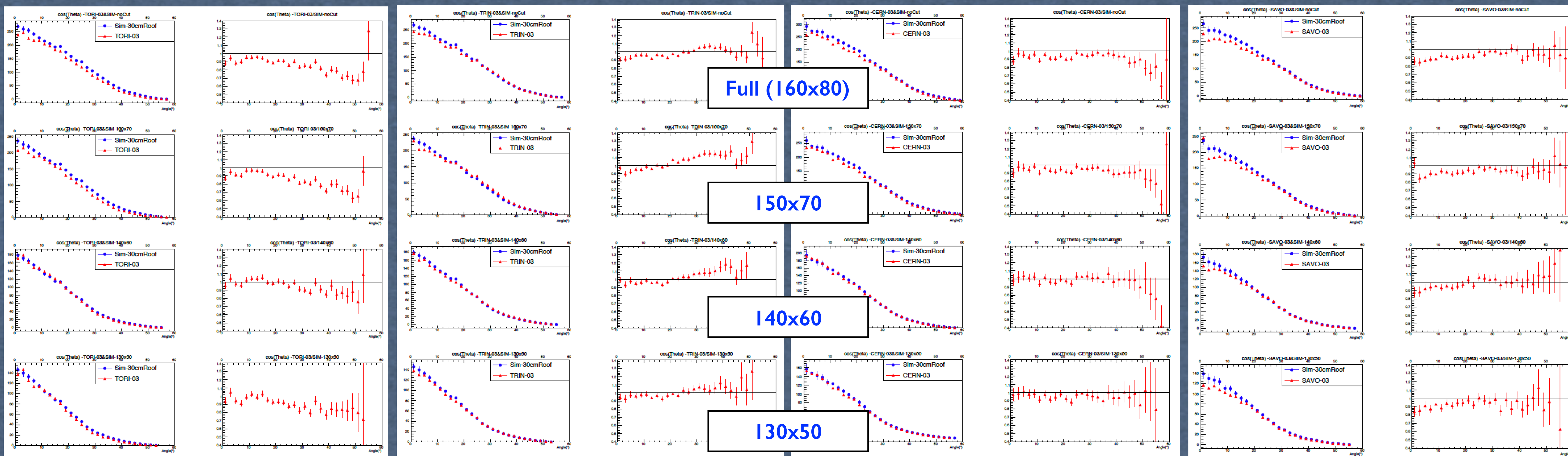
CERN-01: distance between chambers 44cm

SAVO-01: distance between chambers 46cm



Fiducial volumes

TORI-03 | **TRIN-01** | **CERN-01** | **SAVO-01**



- ✳ No significant difference with fiducialization
- ✳ TORI-03 shows the smoother agreement
- ✳ What's wrong?

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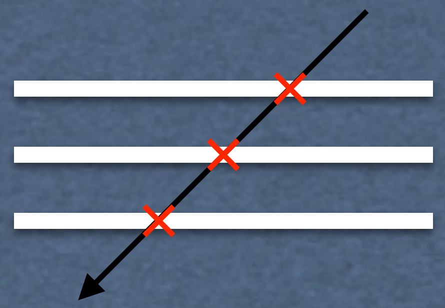
G.Mandaglio - UniMe

Local efficiency

What missing?

- The simulation framework does not describe the microscopic details of the avalanche
- gas flow dis-homogeneity not accounted for
- Different telescopes (same angular acceptance 50cm/50cm) have different rates

Before comparison to simulations data needs to be corrected for *local efficiency*



- Use the same data set
  - corrections are consistent with the data set used for analysis
  - monitor variation along time
- Use 2/3 hits to determine the efficiency of the 3rd
  - Method I: 2-hits trigger
  - Method II: 3-hits trigger using only 2/3 and guessing the 3rd
- Result: XY 2-dim map to correct data

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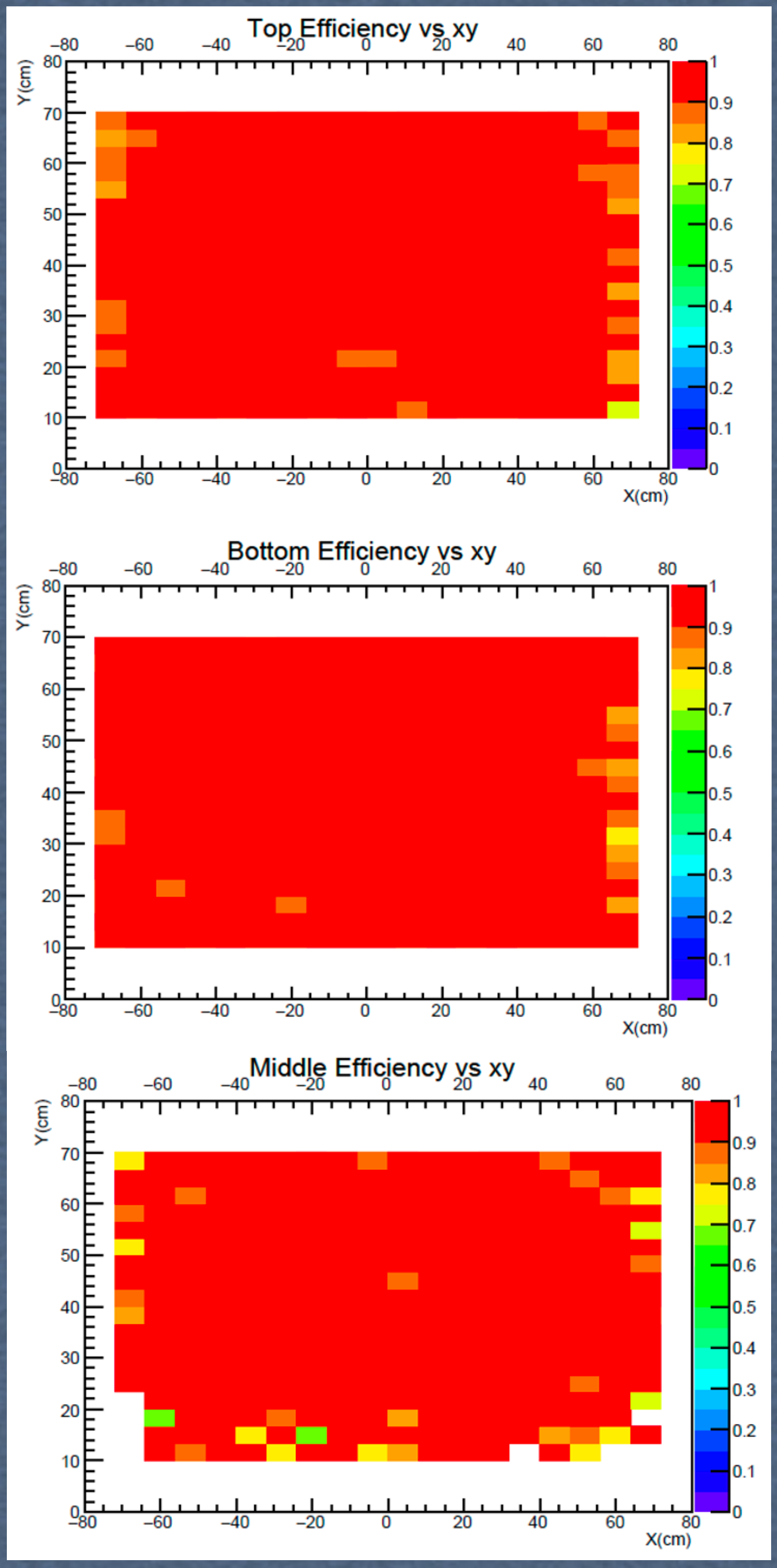
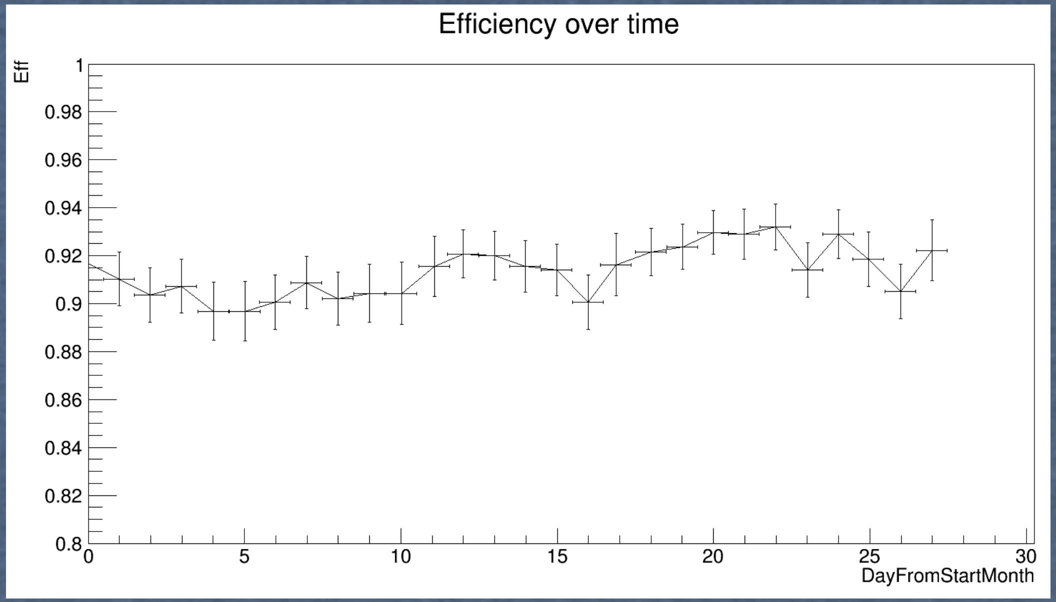
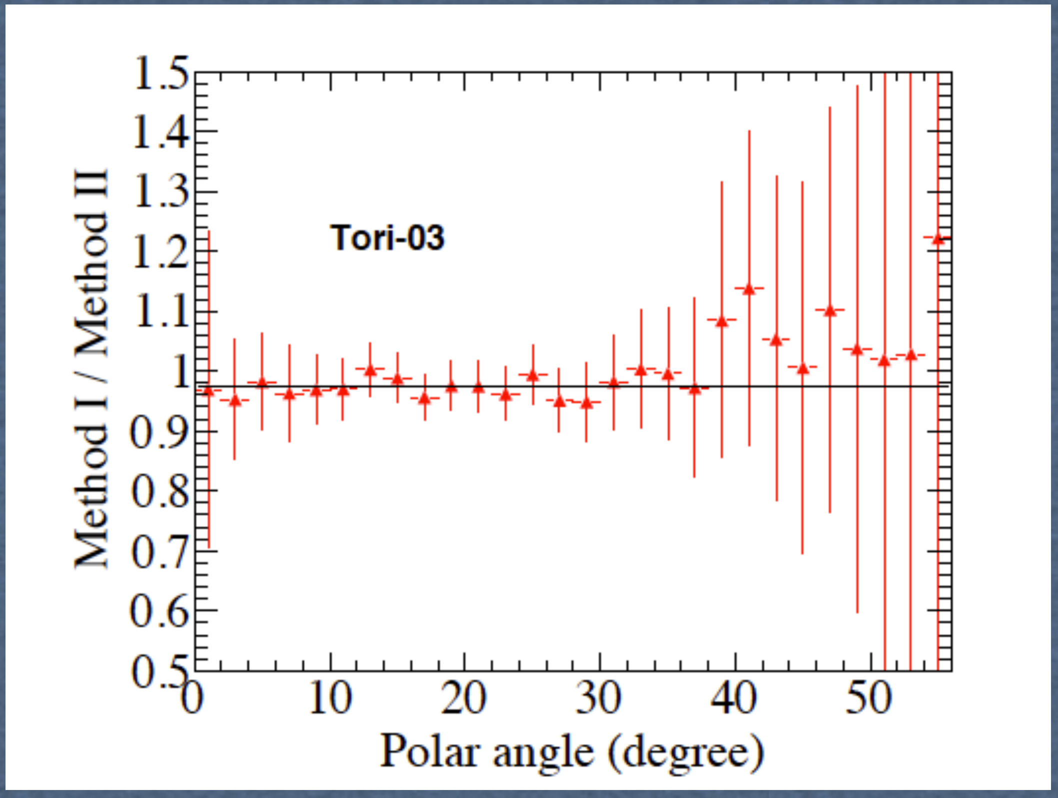
Local efficiency

data-to-data

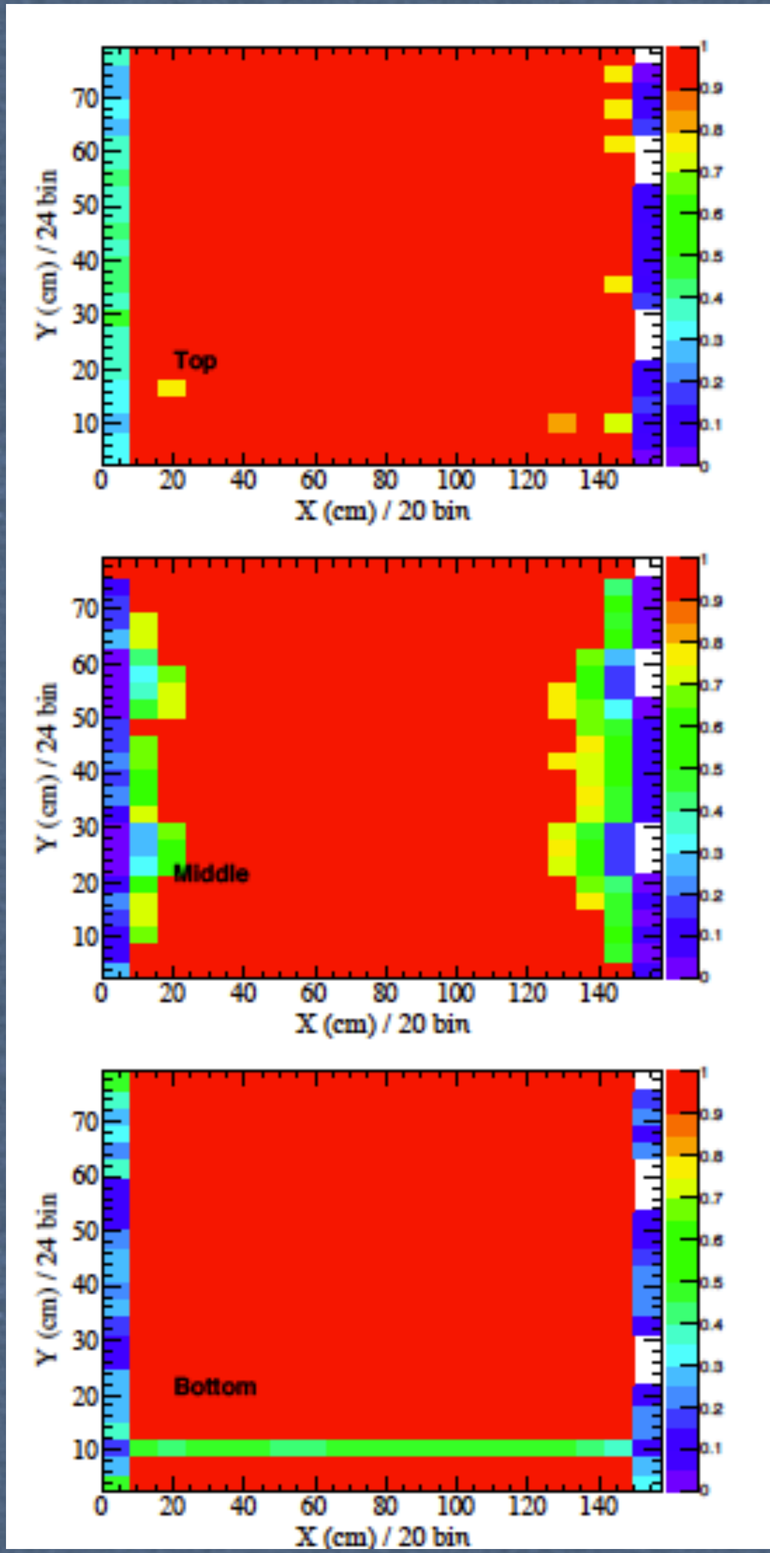
Method I







Method II



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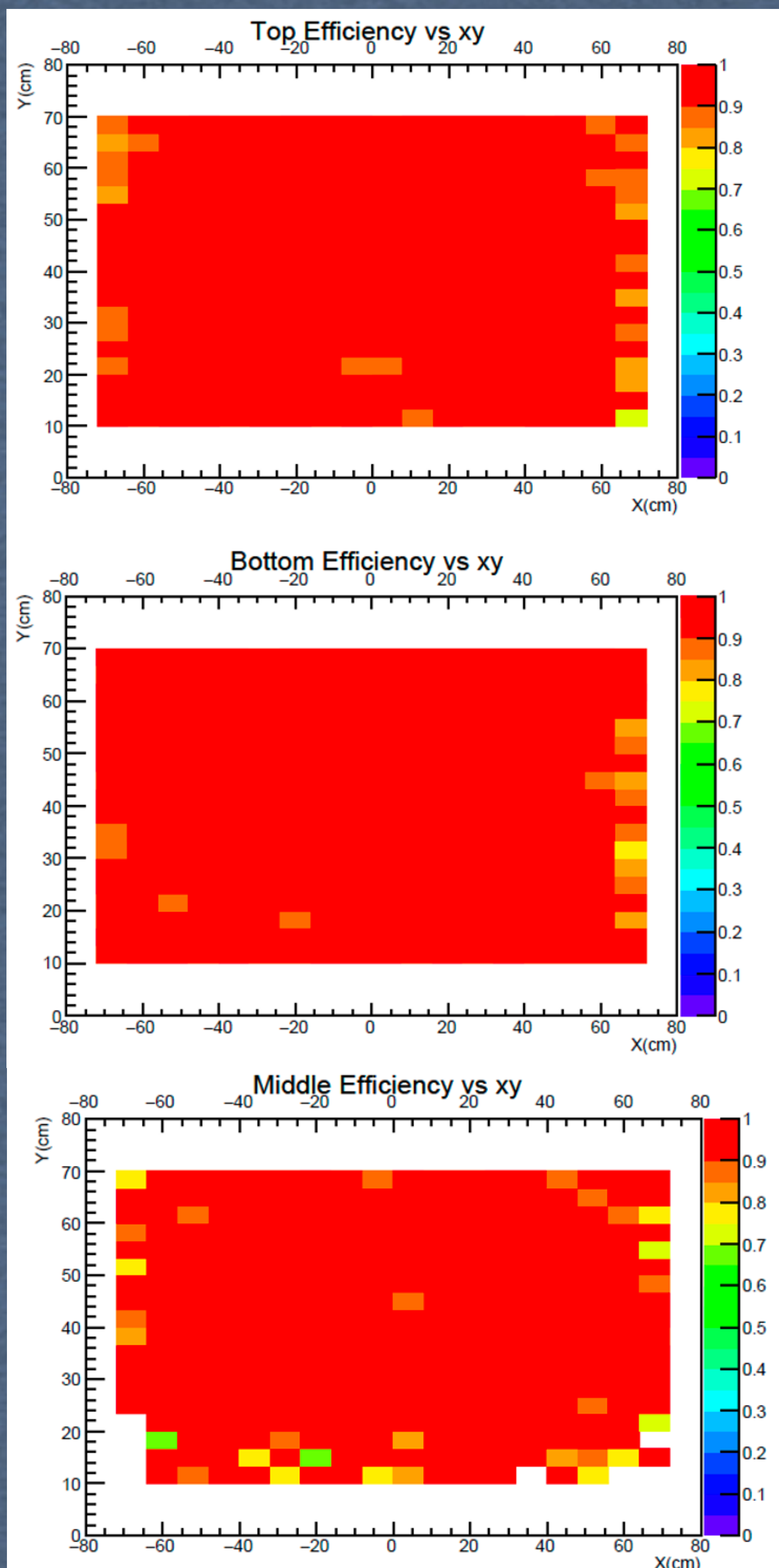
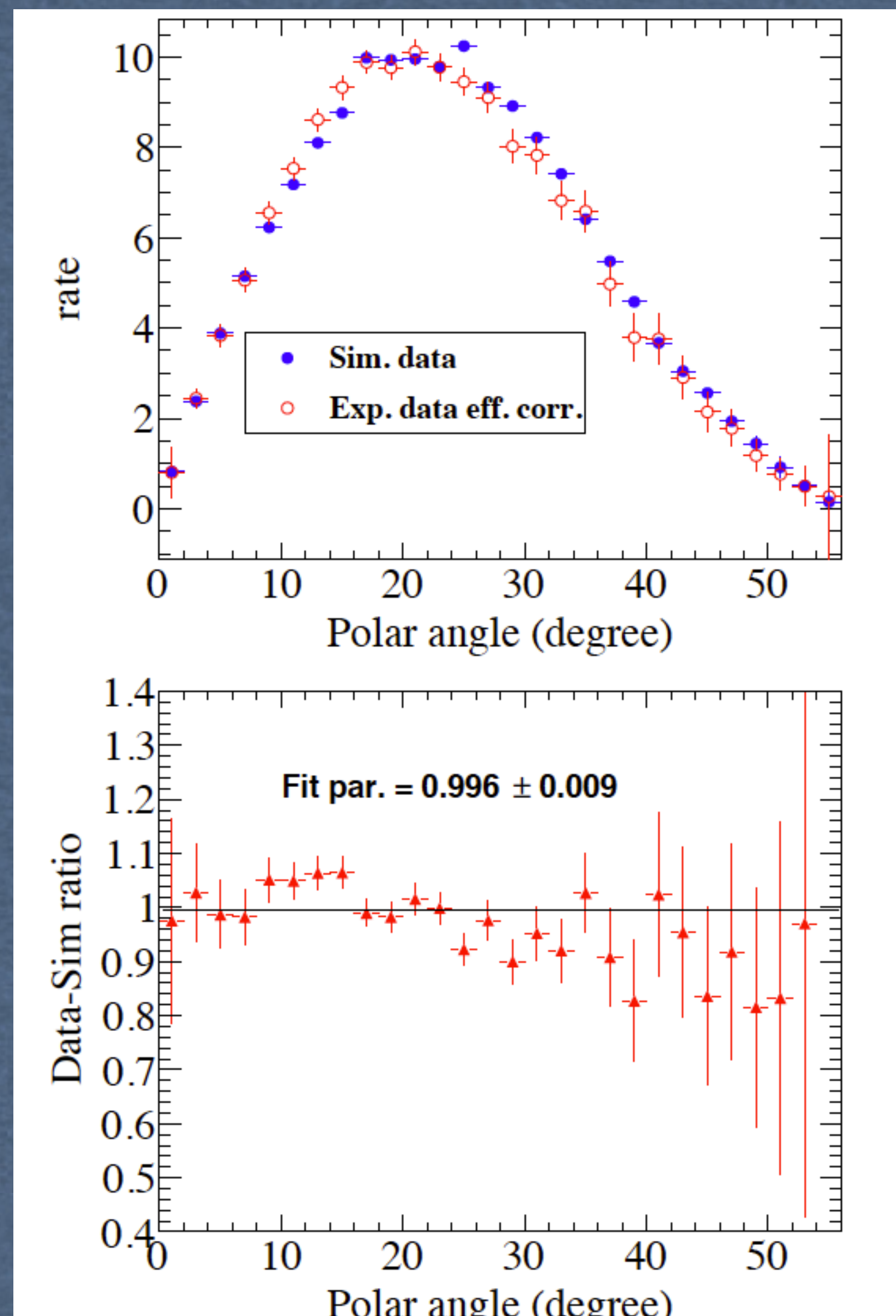
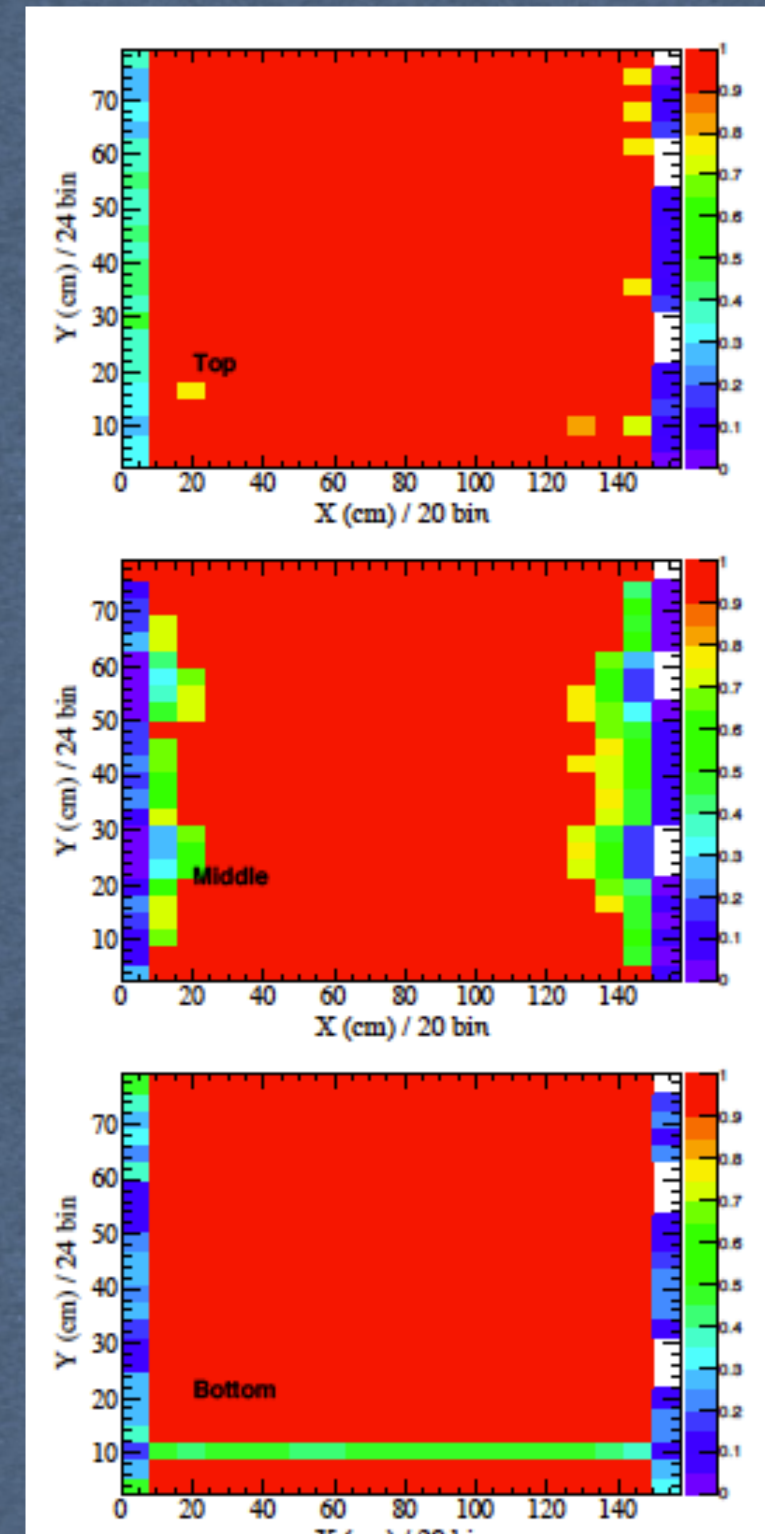
Local efficiency
data-to-sim

Method I





Method II



Local efficiency

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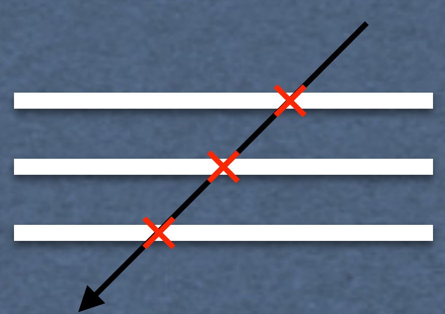
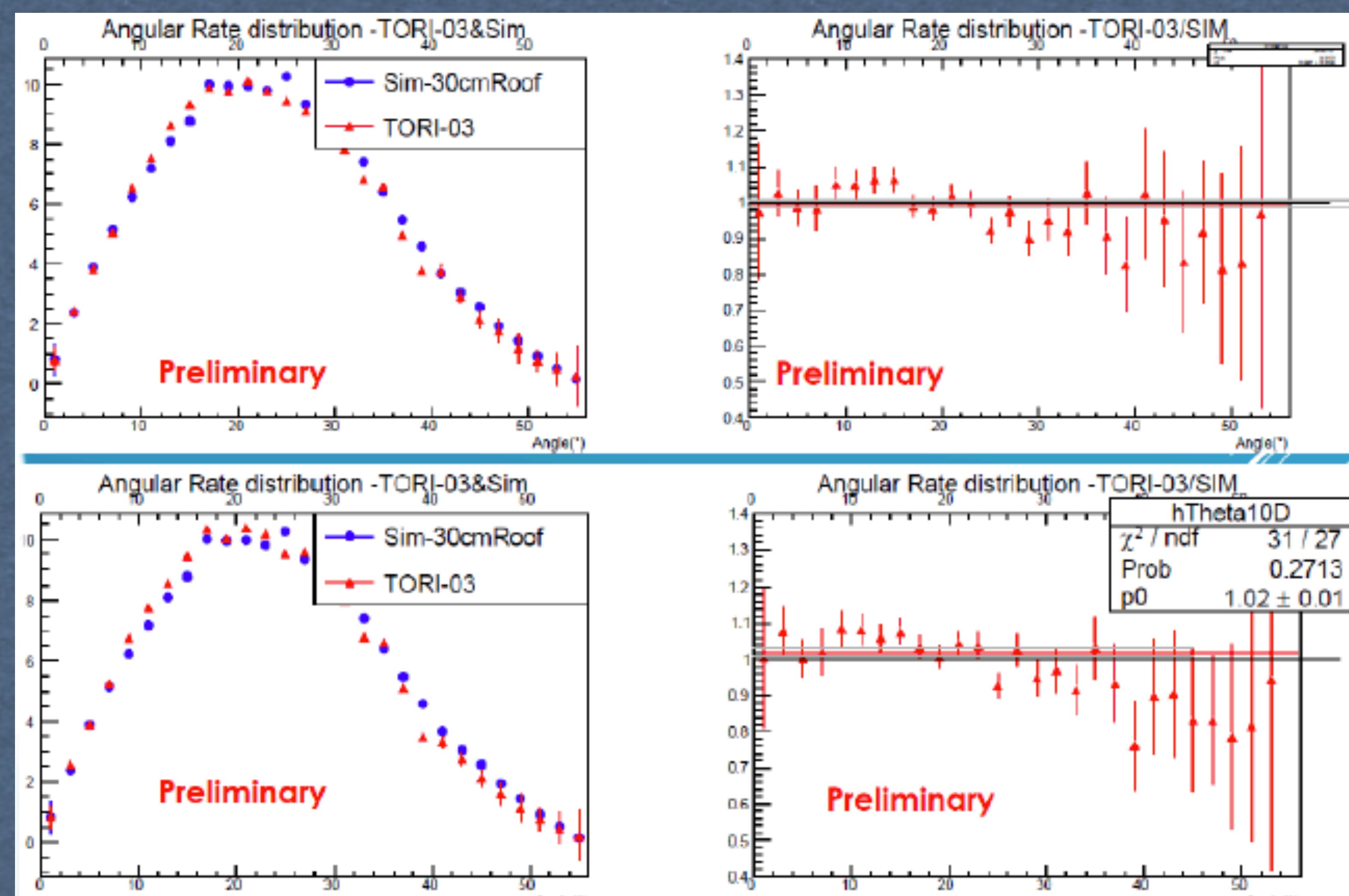
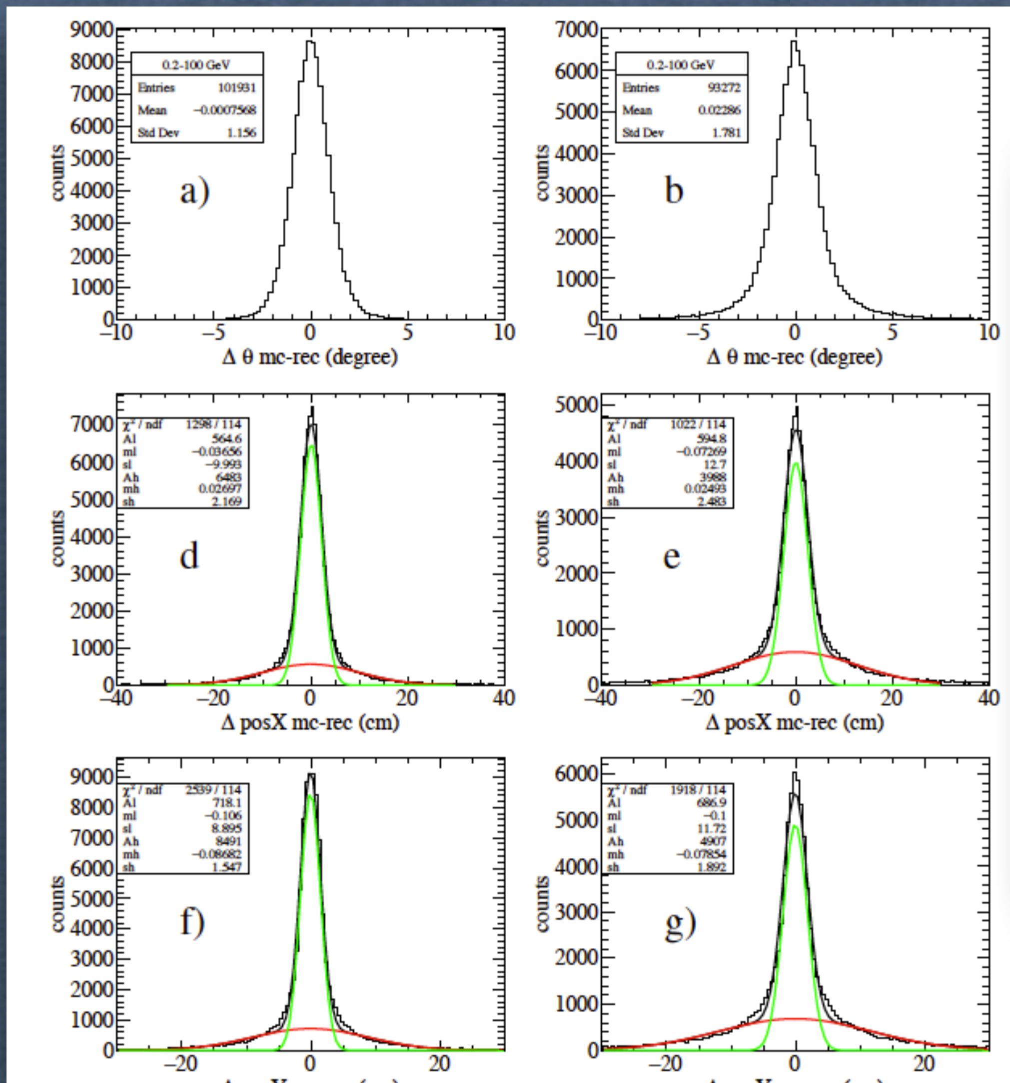


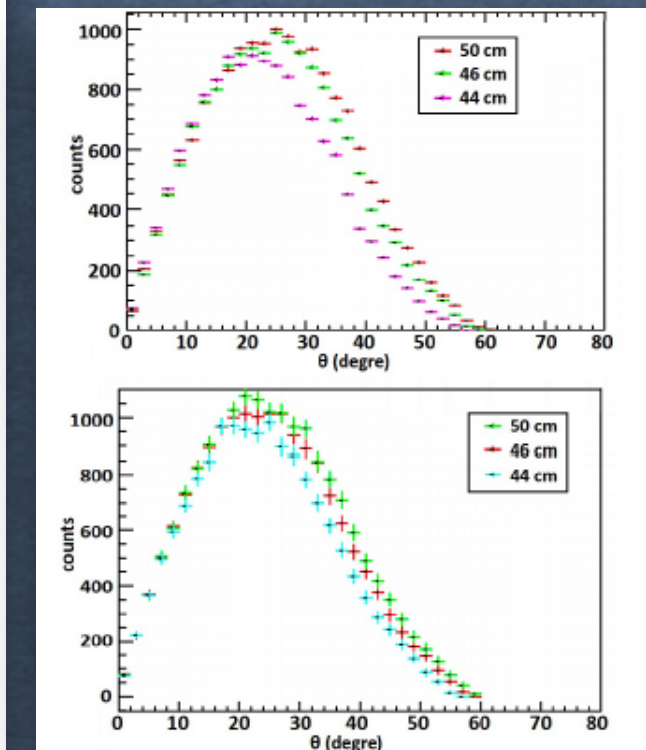


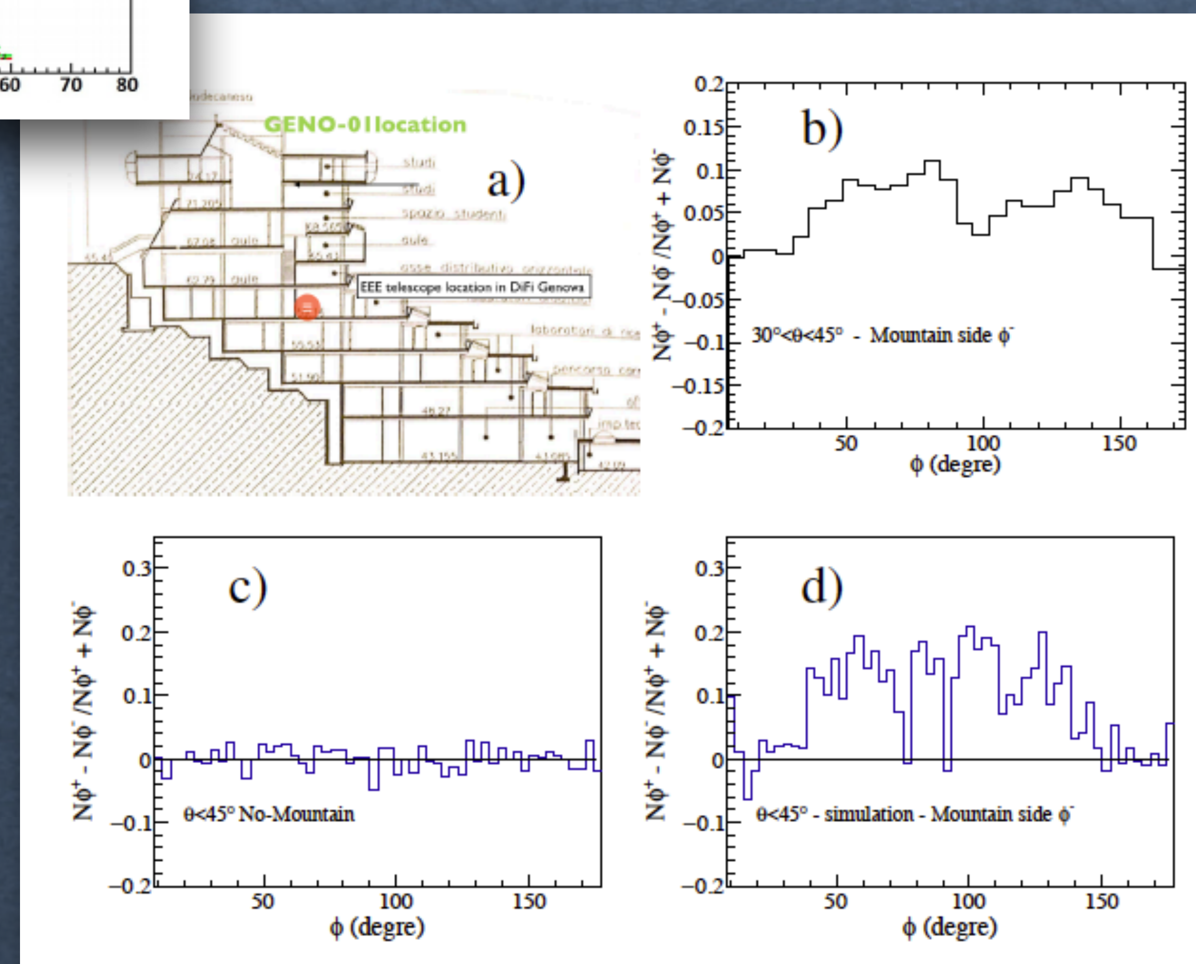
After correction, data and simulation match at level of 5-10%

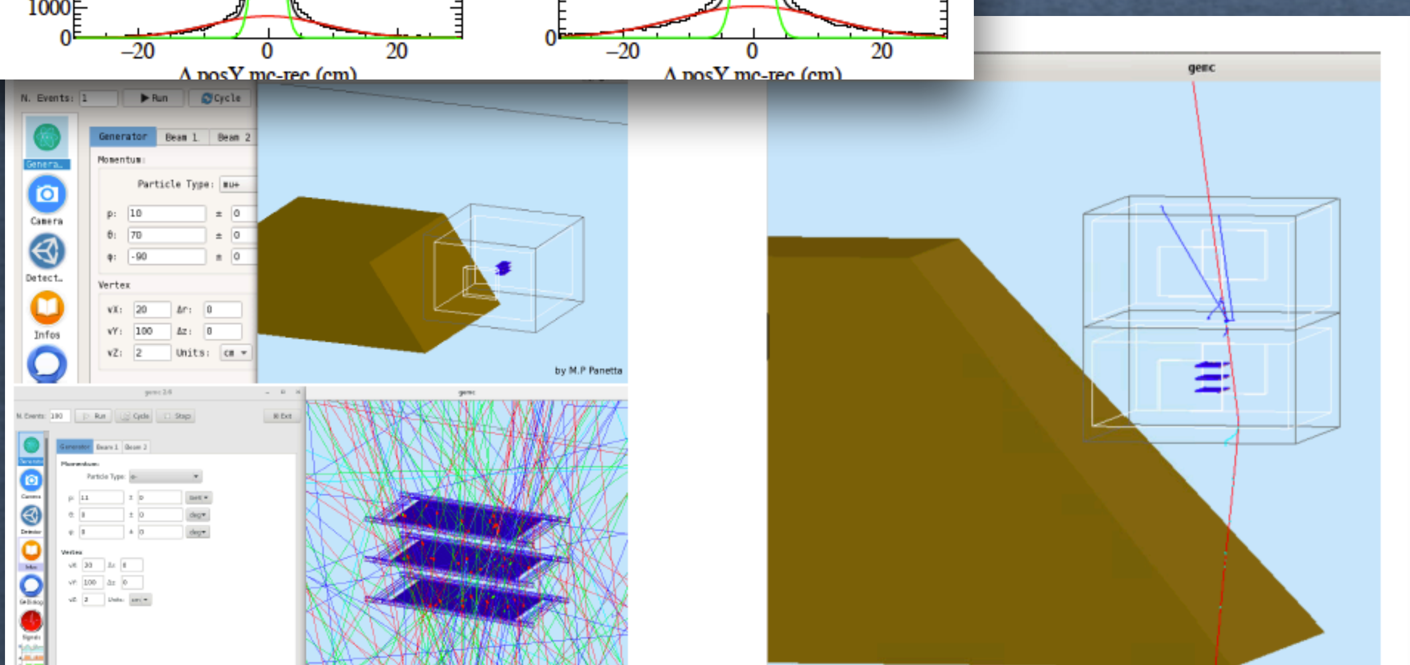
Simulation results

- Angular resolution
- Angular acceptance as a function of detector parameters
- Efficiency as a function of muon energy
- Effect of surrounding material
- Telescope rates equalisation









Figures thanks to M.P. Panetta

NIM paper

The Extreme Energy Events (EEE) telescope simulation framework

The EEE Colllaboration[1]

[a] *Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi, Roma*

Abstract

In this paper we describe the simulation framework of the Extreme Energy Events (EEE) experiment. Each EEE telescope is made by three Multi-gap Resistive Plate Chambers. By recording the triple coincidence of the three detectors, the cosmic muon track is fully measured providing a precise determination of the absolute time of the event and integrated/angular muon flux at Earth level. The response of the single MRPC and the combination of the three chambers have been implemented in a GEANT4-based framework to study the telescope response. The detector geometry, as well as details about the surrounding materials and the location of the telescope have been included in the simulations in order to realistically reproduce the experimental set-up of each telescope. A model based on the latest parametrization of cosmic muon flux has been used to generate single-event muons. The framework has been validated by comparing EEE data to simulation results.

Keywords: cosmic rays, cosmic muons, MRPC, GEANT4

1. Introduction

The EEE experiment[1] deployed a network of about 60 cosmic muons detectors in a area of 3×10^5 Km^2. Each telescope is made by three Multi-gap Resistive Plate Chambers (MRPC) [2] located in high schools and operated by students and teachers under supervision of EEE Collaboration researchers. MRPC are based on the same technology used by the ALICE experiment at CERN [3]. Telescopes work continuously from September to June following the school calendar. The experiment run for four years collecting a total of more than 100 billion of candidate muon tracks. Data are transferred daily from the telescope location to the INFN-CNAF in Bologna for data recording. Raw information are processed to reconstruct charged tracks hitting the three chambers (mainly cosmic muons) providing a precise determination of track direction, position and absolute arrival time [4]. Reconstructed muon tracks are used by researchers and students to determine time-correlated tracks in far telescopes from showers produced in the high atmosphere by high energy cosmic particle interactions. Other interesting studies include: monitoring of cosmic particles activity in relationship with the solar activity and the measurement of cosmic muon rate variation over time. During these years telescopes were assembled in different shapes (e.g. the distance between the three chambers varied from 40 cm/40 cm and 100 cm/100 cm, to the actual 50cm/50cm) resulting in a different solid angle coverage and subsequent difference in measured rates. Since telescopes are host in rooms located in non-dedicated buildings (high schools or University labs) it is mandatory to have a good description of surrounding materials that affect, in different ways, the cosmic muon flux detected by each telescope. To master the different experimental set ups and compare the telescope responses we develop a simulation framework based on GEANT4 libreries [5] that include single cosmic muon generation, propagation trough the surrounding materials and a parametric description of the MRPC response to charged particles. The same framework, interfaced to the CORSIKA cosmic shower generator [6] has also been used to study long range correlation between cosmic muons produced by extreme energy events and distributed over distances up to 1200 Km. A detailed report with results of this study is the subject of a separate publication currently in preparation.

2. The EEE telescope

The EEE network is composed by clusters of telescopes and stand-alone stations. Each station, that defines a "telescope" for Cosmic Rays (CR), is made of three Multigap Resistive Plate Chambers (MRPC), a CR dedicated version of the detector successfully used for

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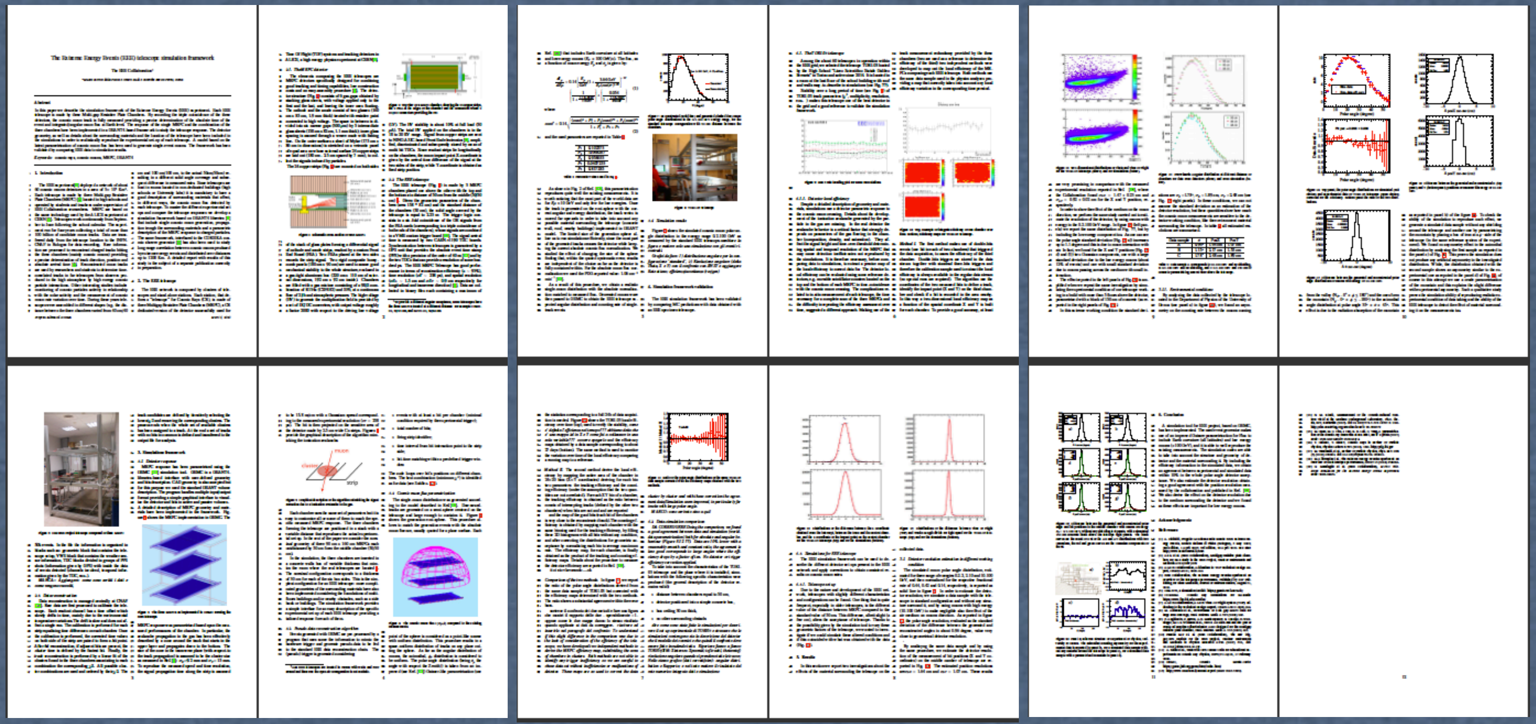

Status

- NIM as target journal
- 12 pgs written so far
- Still working on ‘Results’ section: few figures missing
- No CORSIKA results (another paper)
- Expected to circulate draft by end of June