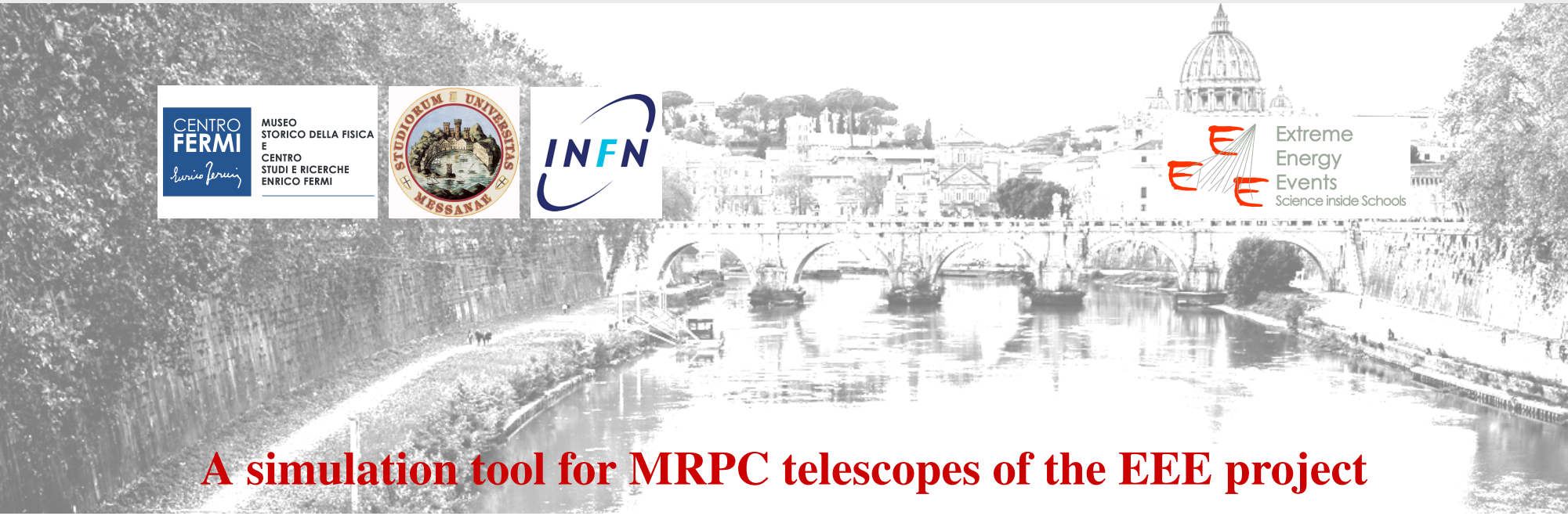



# A simulation tool for MRPC telescopes of the EEE project

Giuseppe Mandaglio for EEE Collaboration

*Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi*
*Dipartimento MIFT - University of Messina and INFN-Sezione di Catania*

The XV workshop on
**Resistive Plate Chambers and Related Detectors (RPC2020)**

University of Rome "Tor Vergata", February 14, 2020

# Outline

EEE Project (Extreme Energy Events)

EEE telescope

Simulation tool

Detector resolution evaluation

Efficiency and Rate

Conclusions

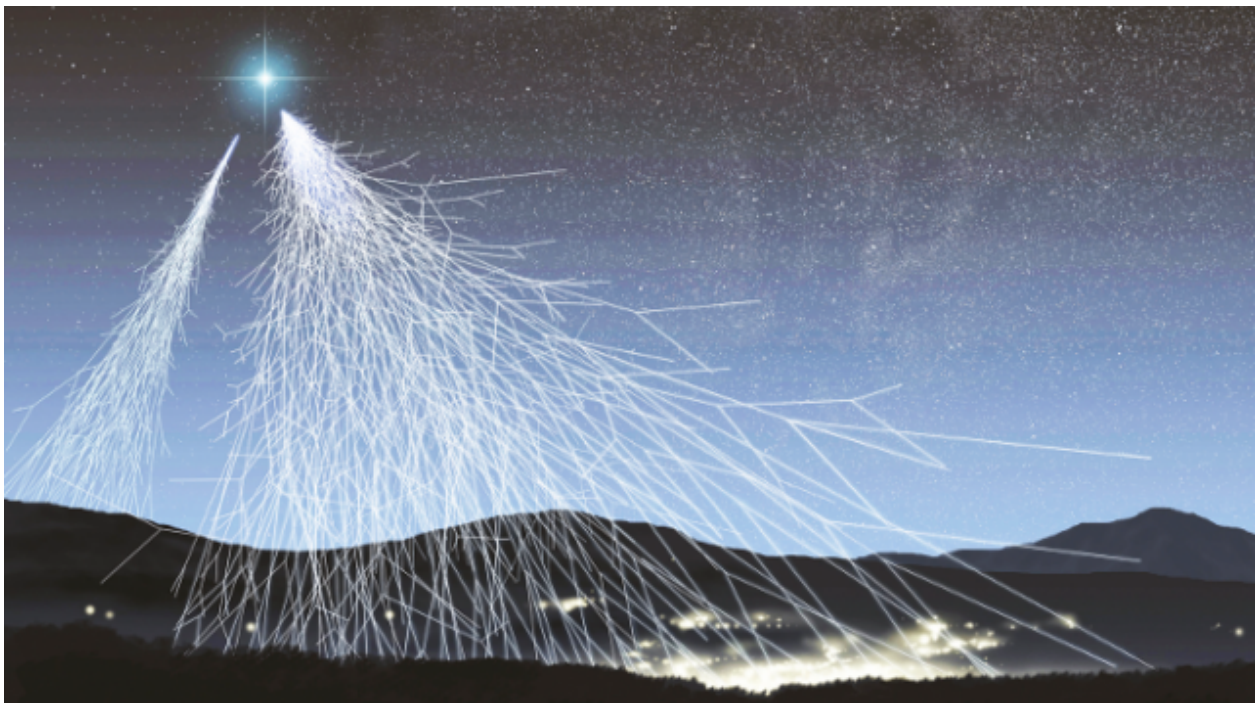
Extreme Energy Events
Science inside Schools

CENTRO FERMI
MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE ENRICO FERMI

INFN

CERN

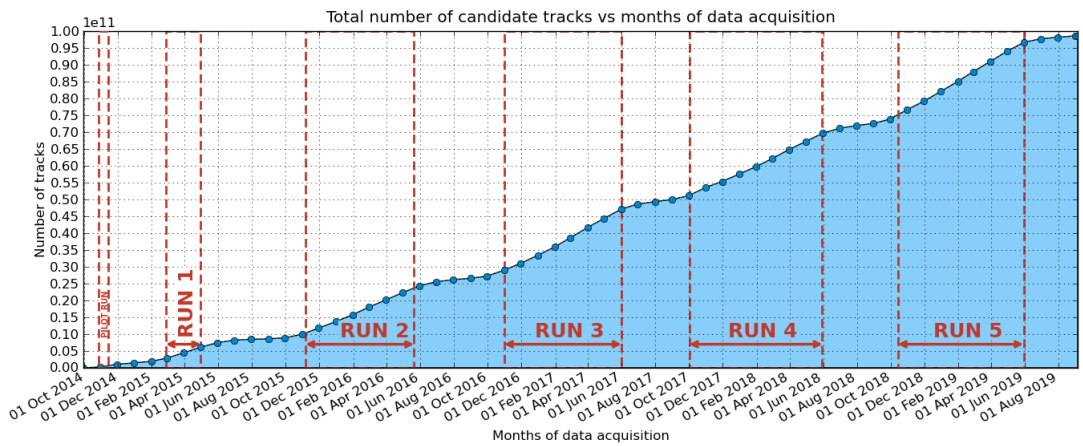
MINISTERO DELL' ISTRUZIONE, DELL'UNIVERSITÀ E DELLA RICERCA



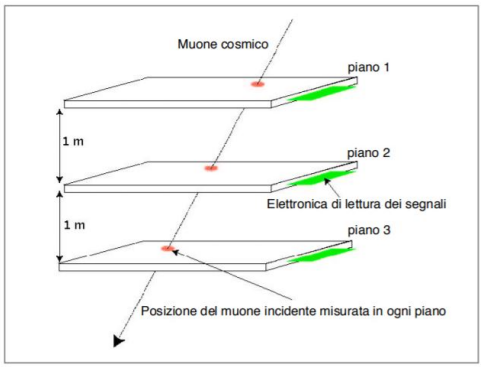
Extreme
Energy
Events
$E \approx 10^{15} - 10^{19}\ eV$

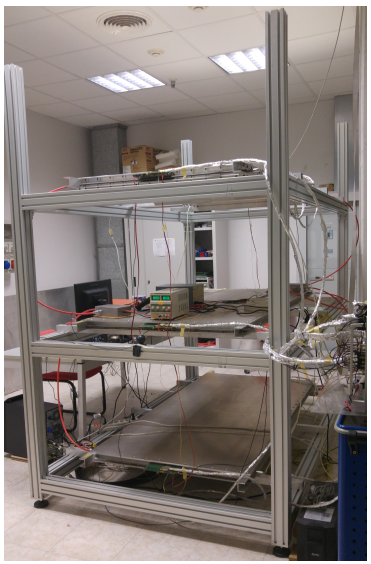

- The EEE network is the largest and long-living MRPC-based system
- 62 telescopes
- Educational and research purposes (see Fabrizio Coccetti Talk)

- More than 100 billion of candidate tracks ($\chi^2 < 10$) on tape



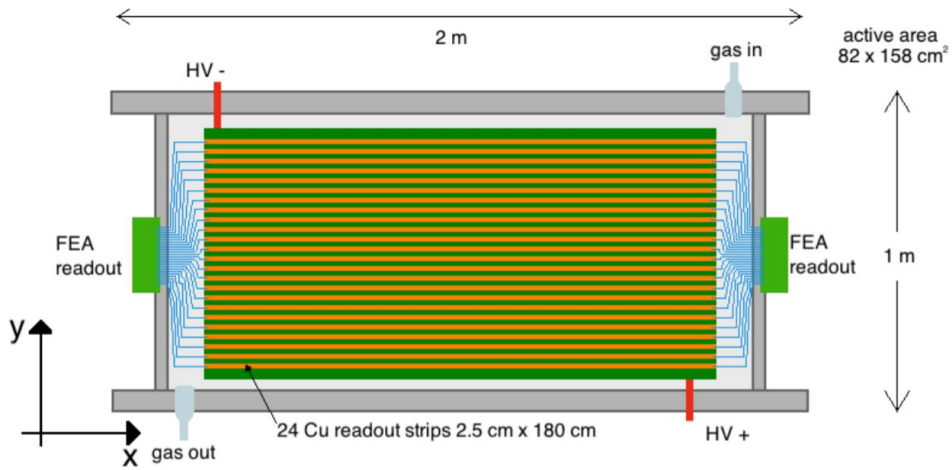
# MRPC (Multigap Resistive Plate Chamber) telescope



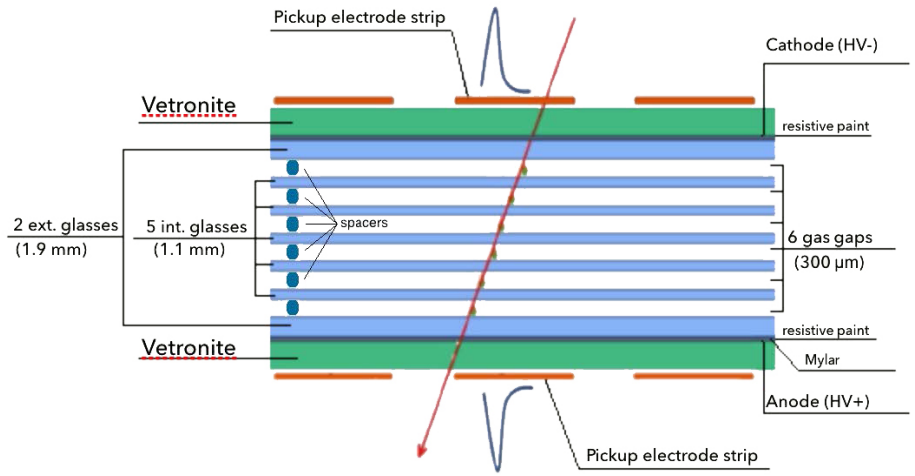



Picture of CATA-01 telescope hosted in UNICT

## Top view of a chamber




## Inner structure of the chamber



# Simulation tool purposes

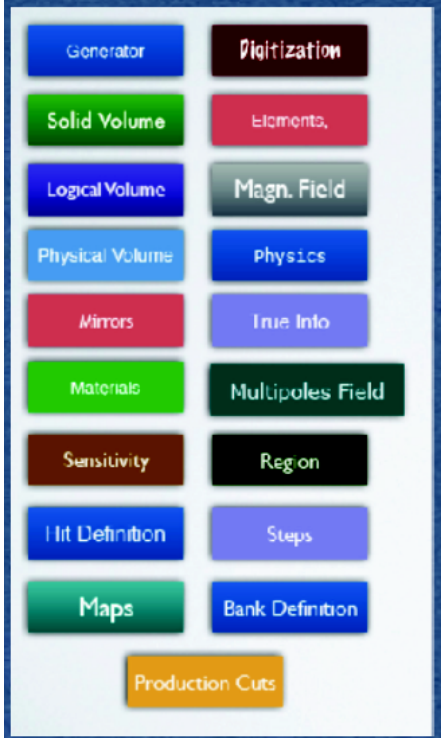
- Absolute and angular efficiency
- Absolute single-$\mu$ rates (to be compared to the telescope response)
- Effective comparison to world data parametrization
- Description (and compensation) of surrounding materials
- Easy way to compare telescopes with different parameters (e.g. distance between the chambers)
- Cross check of data quality and working conditions of different telescopes
- Machine independent tool for simulation

# GEMC

## GEant4 Monte Carlo: GEMC

https://gemc.jlab.org/gemc/html/index.html

M.Ungaro

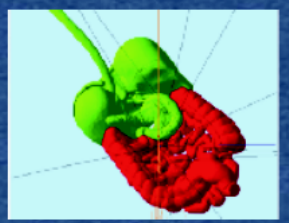


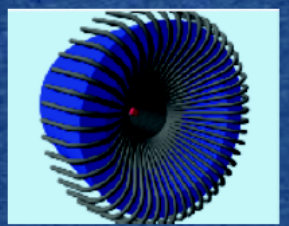

Realistic detector simulation

### GEMC

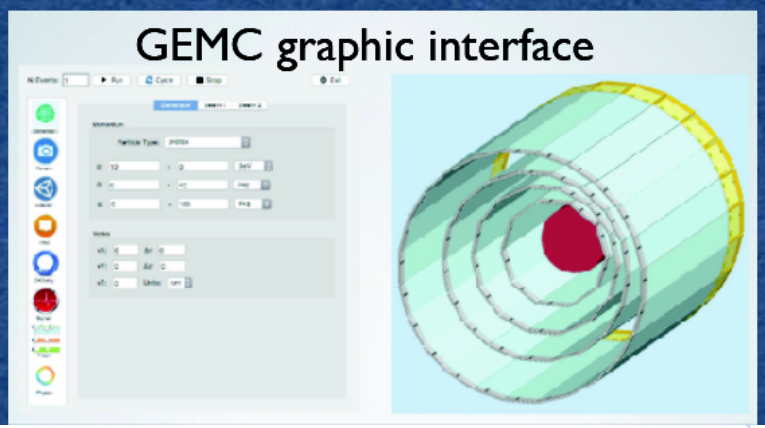
A GEANT4 libraries based simulation tools

- 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



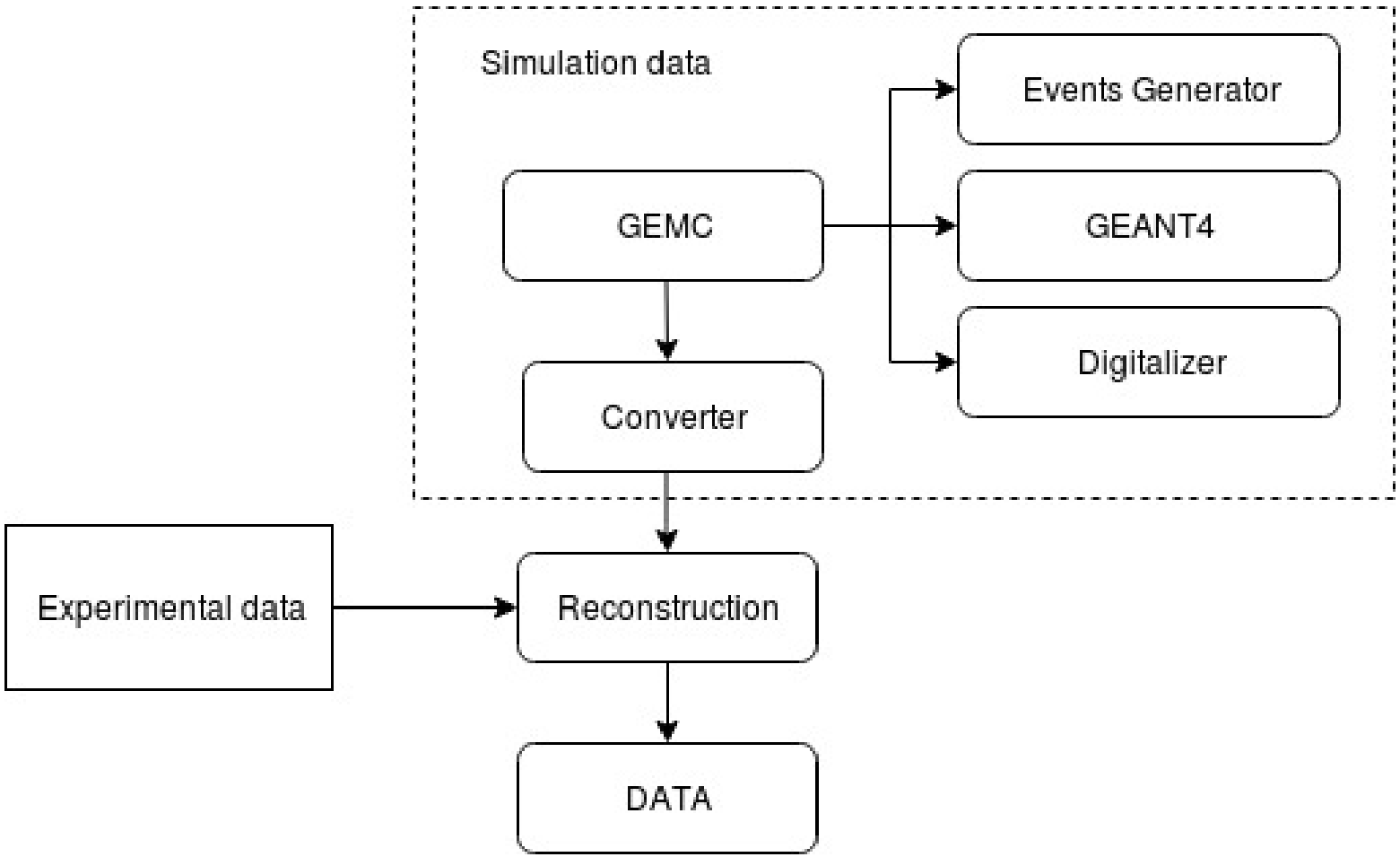


GEMC graphic interface



Slide by M. Battaglieri

# Simulation flow chart



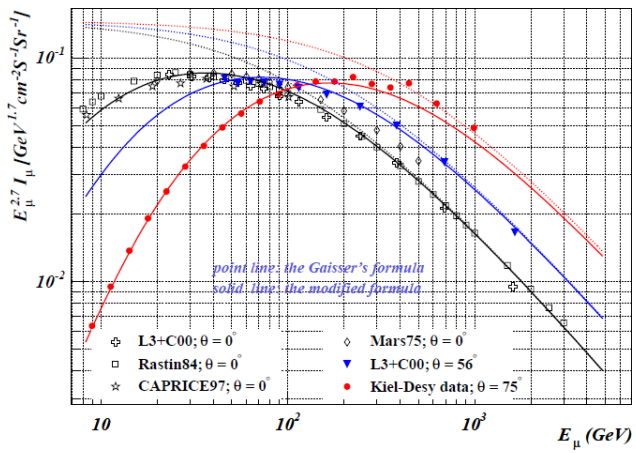
# Events Generator

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

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

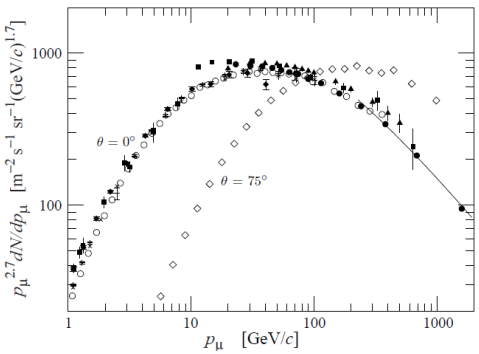
| $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ |
|---|---|---|---|---|
| 0.102573 | -0.068287 | 0.958633 | 0.0407253 | 0.817285 |

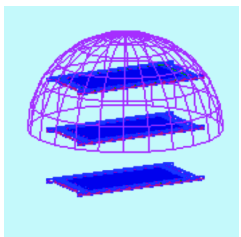
arXiv:1509.06176v1




Improved Gaisser parametrization for Flux($E_\mu$, $\theta$) to include Earth curvature (all latitudes) and low energy muons (<100 GeV)

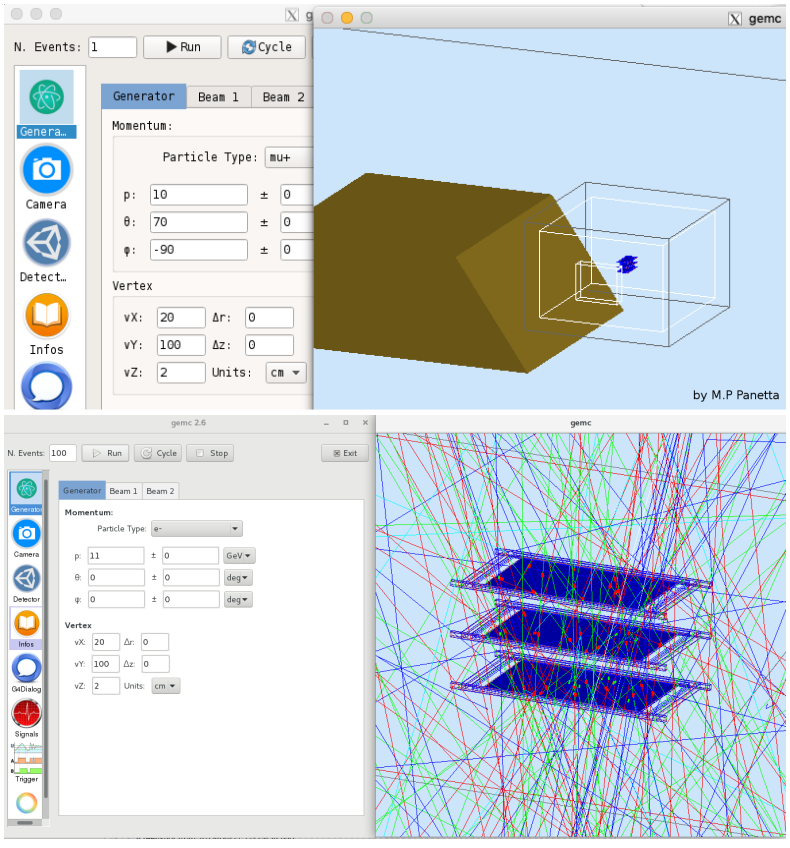
Semi-sphere generation such as to obtain a flat distribution on a plane surface

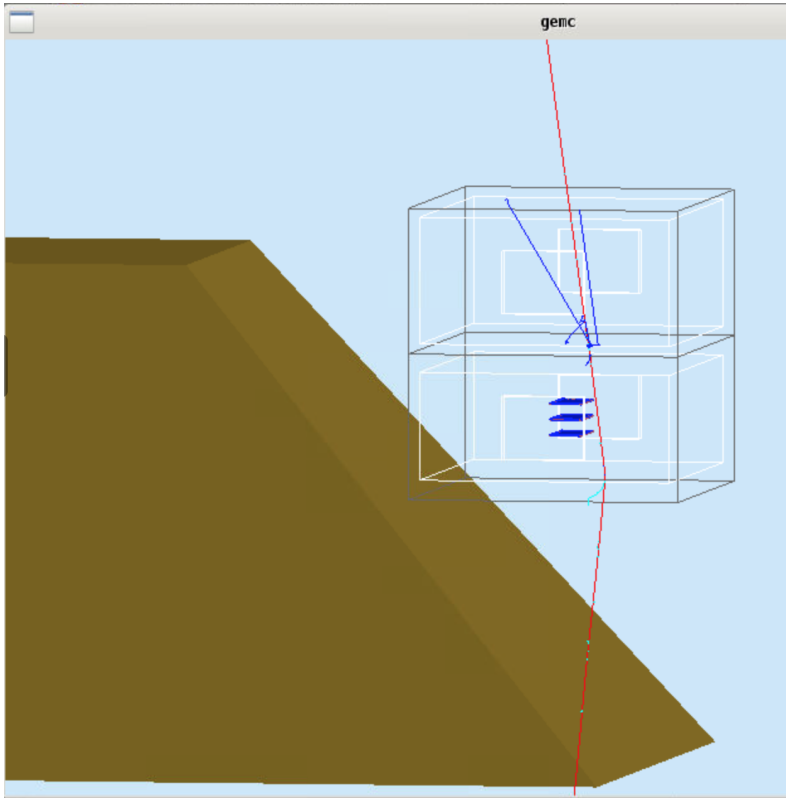


- good agreement with previous data, low-high energies, small-large angles our implementation checked on data
- Generation split in 3 $E_\mu$ intervals: [0.2 - 2 GeV]; [2-10 GeV] and [10 -100 GeV]
- Normalization factor for absolute flux: 1.06 $\mu$ cm$^{-2}$ min$^{-1}$.
- * Simulation ready to be interfaced with other events generator like CORSIKA.

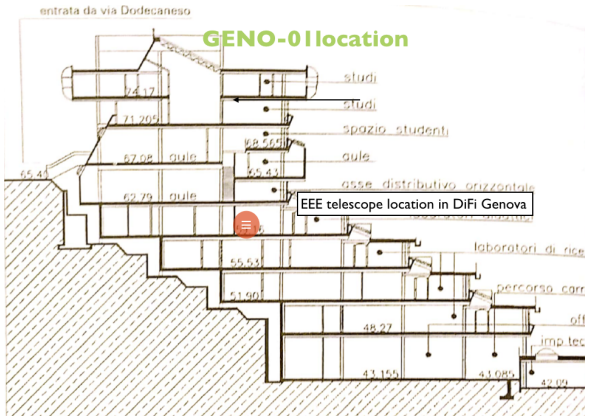
# Geometry and GUI



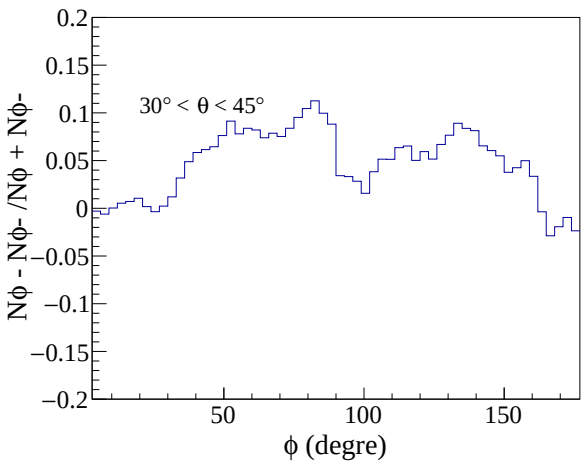




Figures thanks to M.P. Panetta

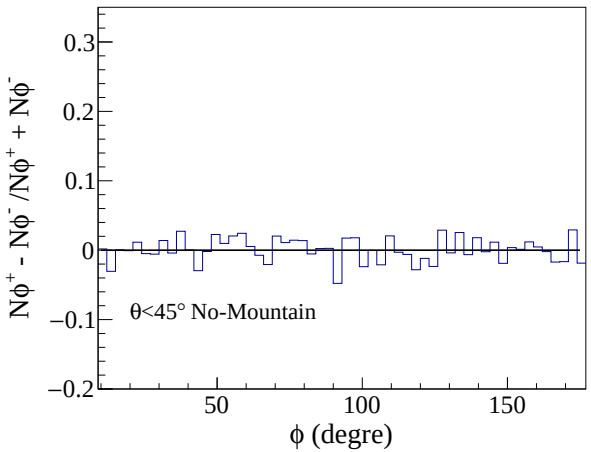
# Qualitative exp.-sim. data comparison

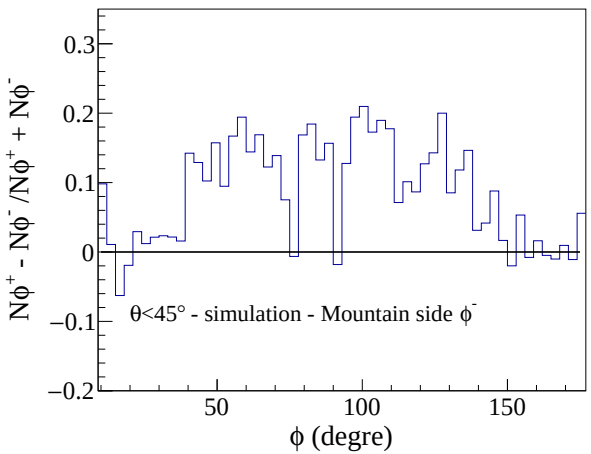



Experimental data



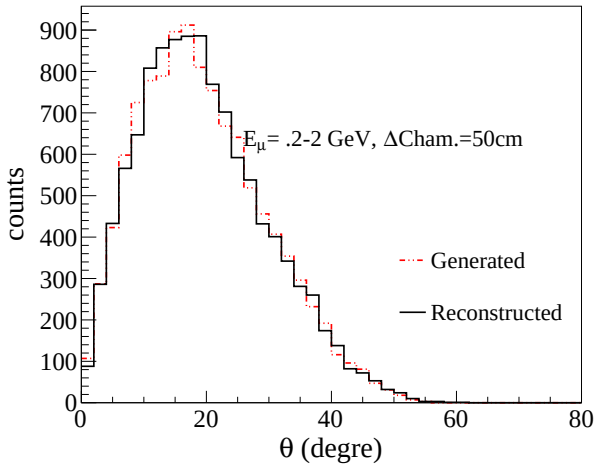

Simulated data

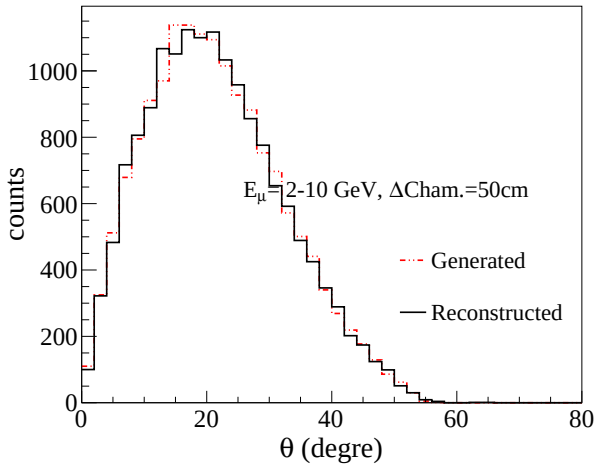


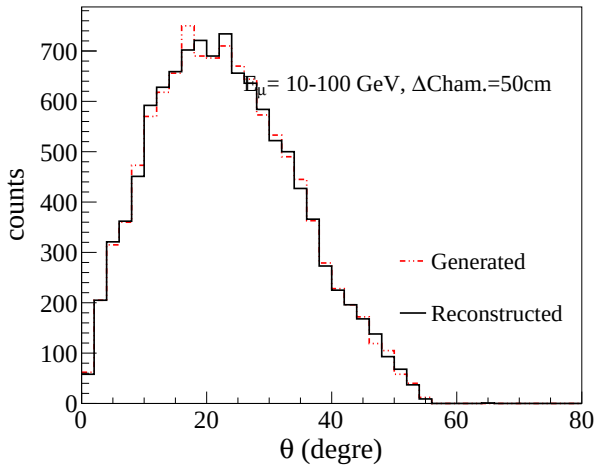



# Generated vs. reconstructed events

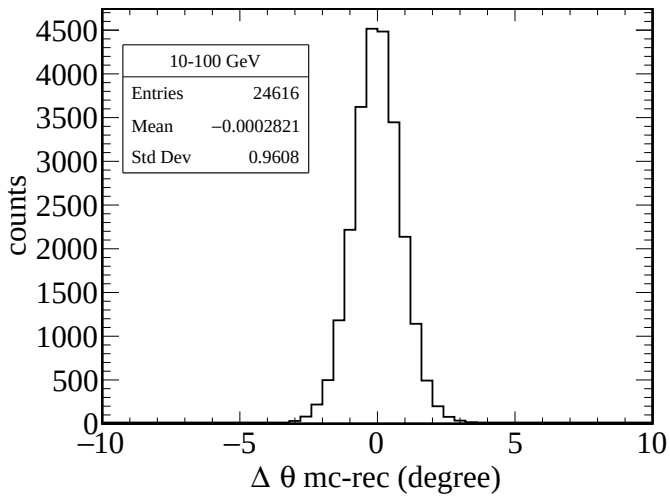
The reconstruction code used for exp. data efficiently identifies the muons direction of the simulated data in all investigated energy ranges.

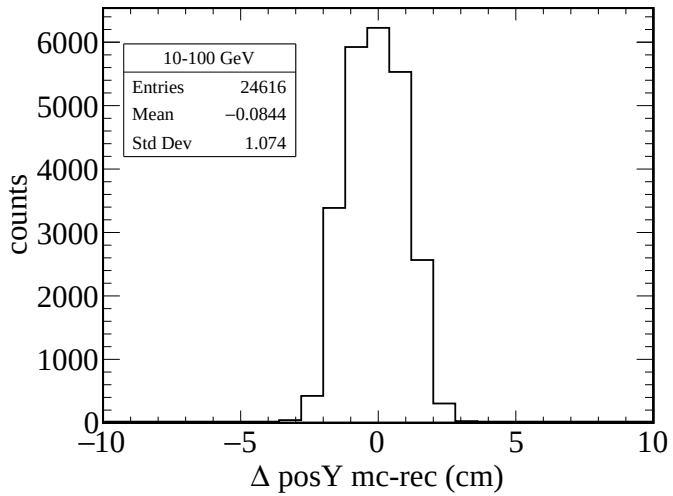


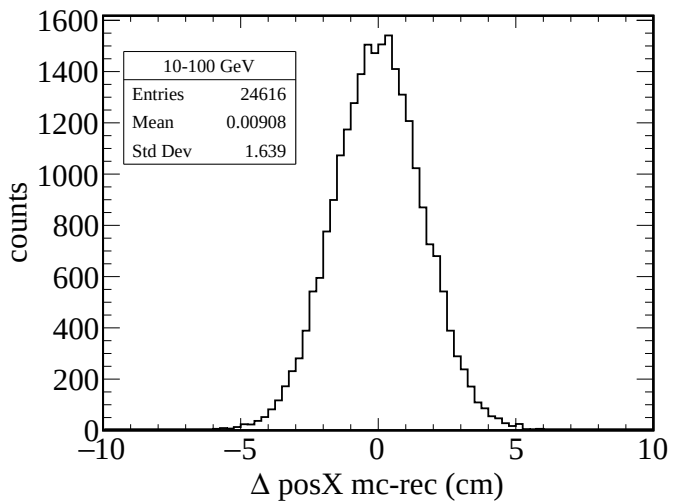



# Angular and Spatial Resolution Estimation - $E_\mu$=10-100 GeV



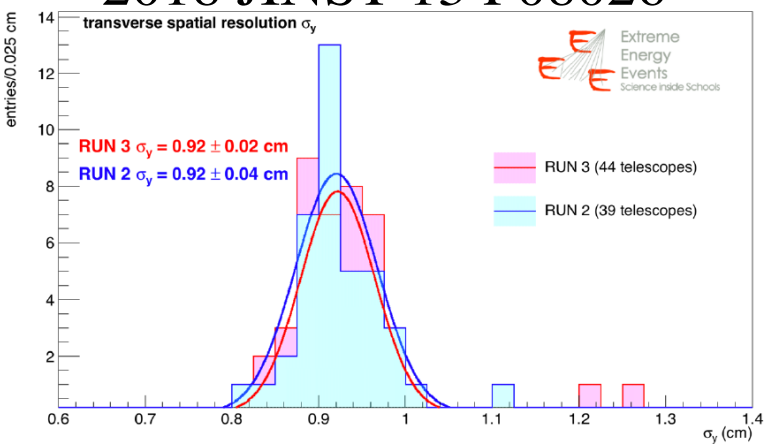



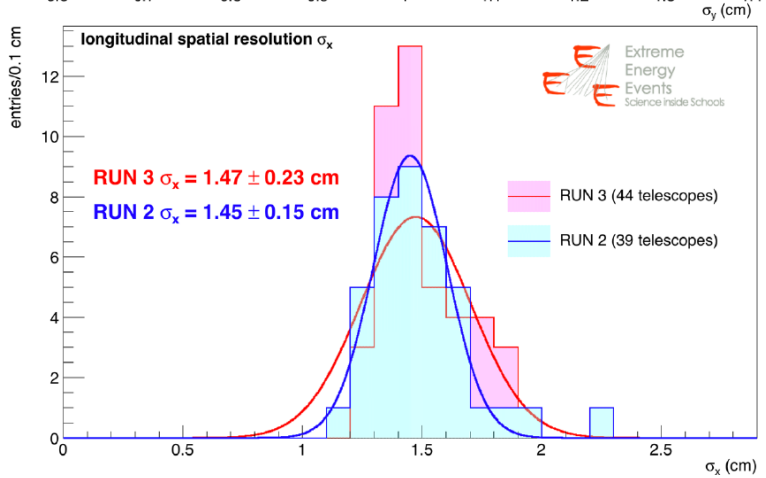



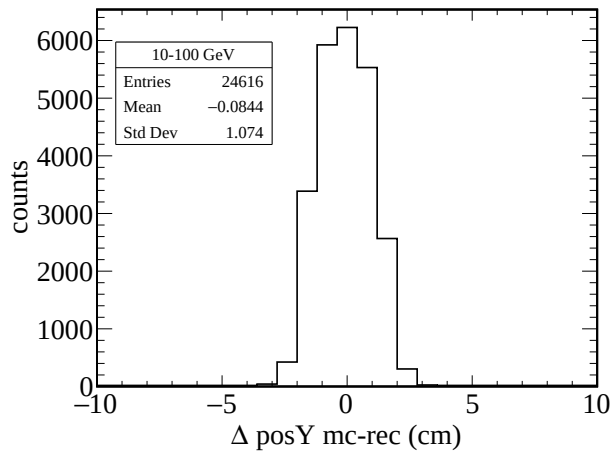

Differences between the generated and reconstructed polar angle, X and Y positions in middle chamber. High energy muons make the effects due to air medium negligible, then we use them to estimate the detector resolution.

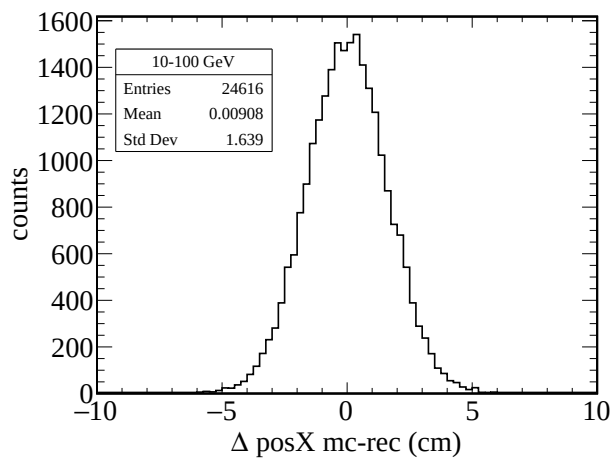
# Experimental and simulated spatial resolution estimation - $E_\mu$=10-100 GeV

2018 JINST 13 P08026



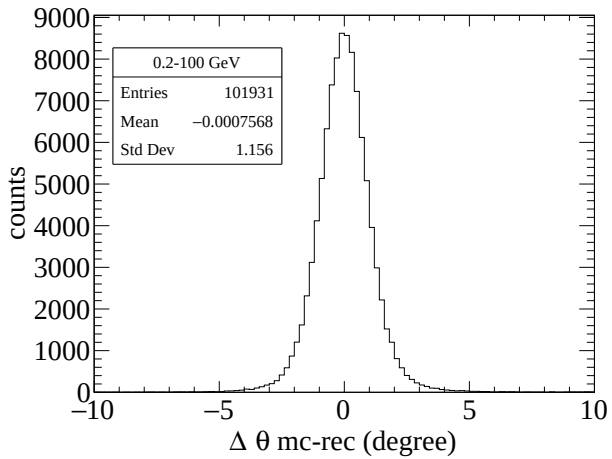



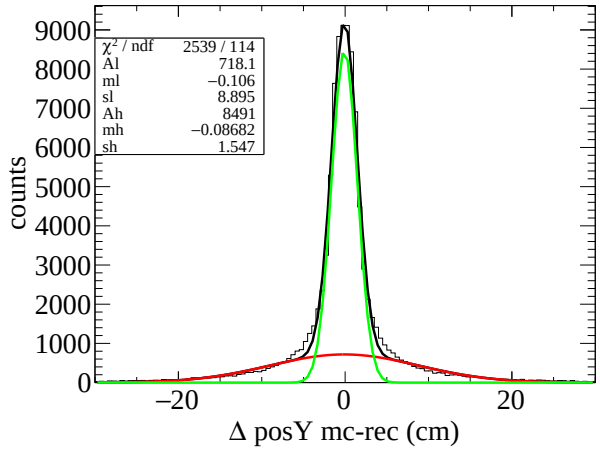



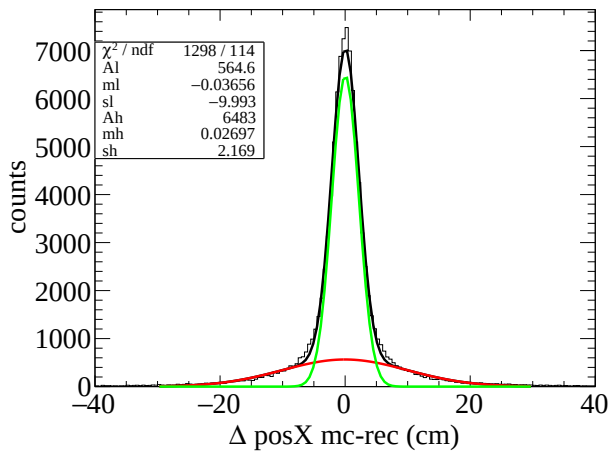

Experimental and simulated resolution estimations are in good agreement.

$\sigma_y = 0.92 \pm 0.02$ cm vs $\sigma_y = 1.074$ cm and $\sigma_x = 1.47 \pm 0.23$ cm vs $\sigma_x = 1.639$ cm

# Resolution leak for low energy muons - $E_\mu$=0.2-100 GeV



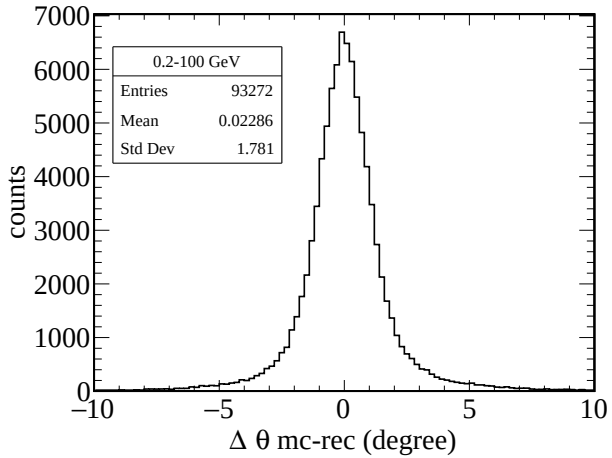




The resolution leak in cosmic rays detection is due to low energy muons interaction with medium. This effect does not depend on intrinsic detector resolution (see **2018 JINST 13 P08026**).

About 12% of events contributing to "bad" position resolution (fit component in red - contributed by low energy muons) are superimposed to events with good resolution (fit component in green).

# Resolution in shielding conditions - $E_\mu$=0.2-100 GeV

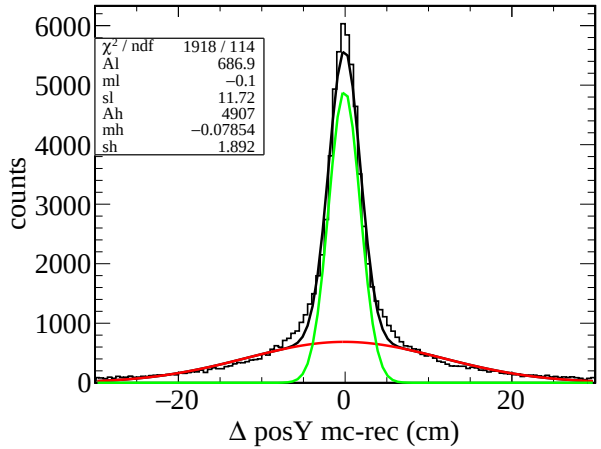


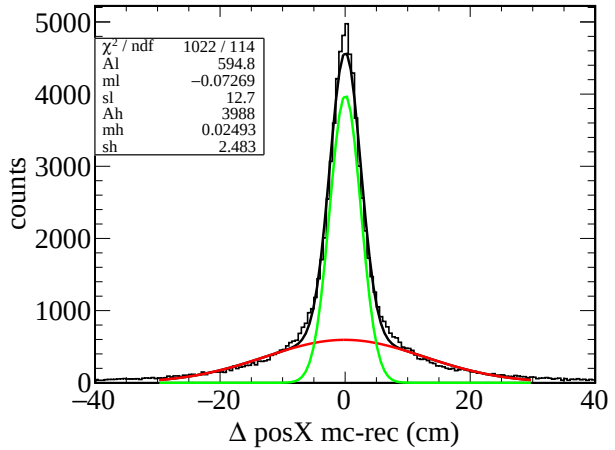

Detector working shielded by 5 floor, parametrized with 150 cm of concrete.

$\sigma_\theta$ =1.78° (1.1° NS)

$\sigma_X$ =1.89 cm (1.55 cm NS)

$\sigma_Y$ =2.48 cm (2.17 cm NS)

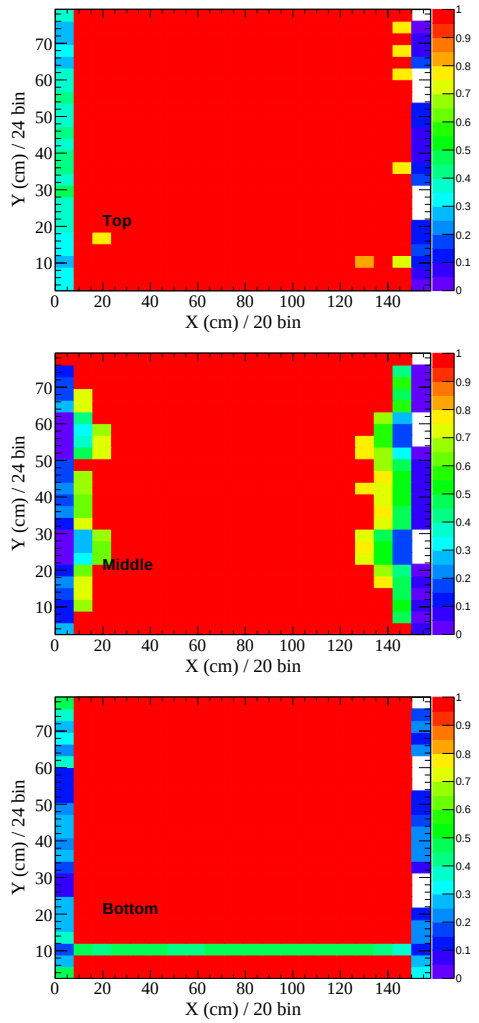


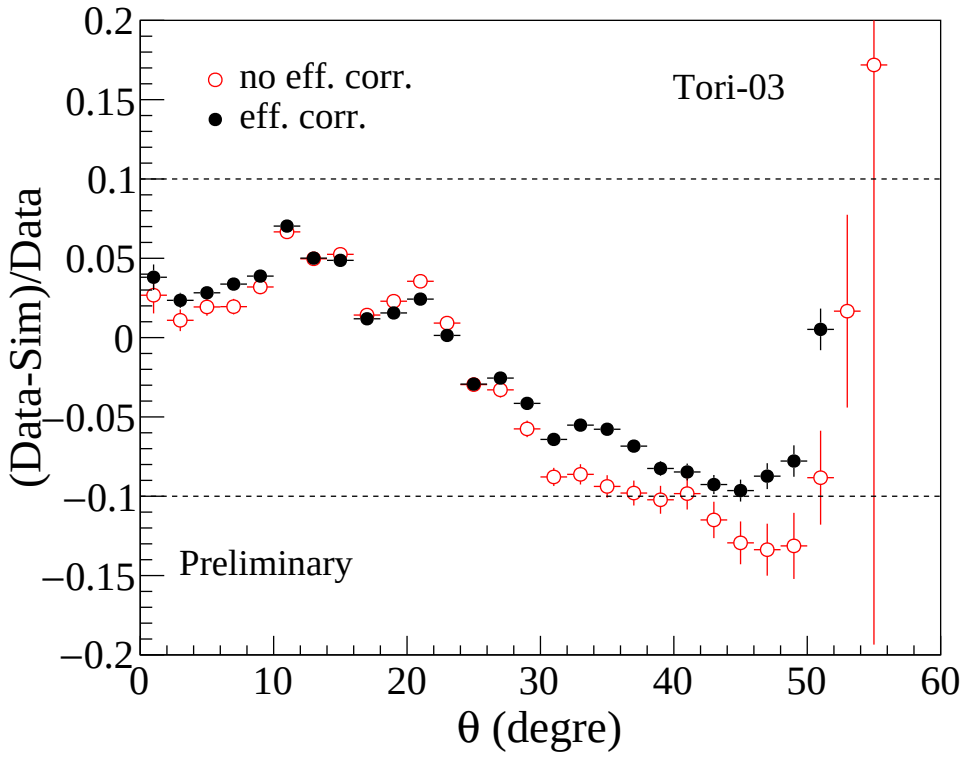

This prove once more that the cosmic rays resolution leak only depend by the effect of material surrounding the detector.

# Map efficiency correction - TORI-03

We estimate the tracking efficiency map (20X×24Y bins) of chambers by looking for the missing hit (bin map) in the reconstructed tracks normalized to the good tracks (no missing hit), and the counting efficiency map by correcting the bin rates with detector acceptance and then by normalising the rate of each bin to the average rate.
Total efficiency maps are obtained as the product of the tracking and counting efficiency.
Figures show the total efficiency map for top, middle and bottom chambers for TORI-03 telescope. The procedure is able to find the efficiency reductions due to gas leak in the middle chamber and the malfunction of a strip in bottom chamber.



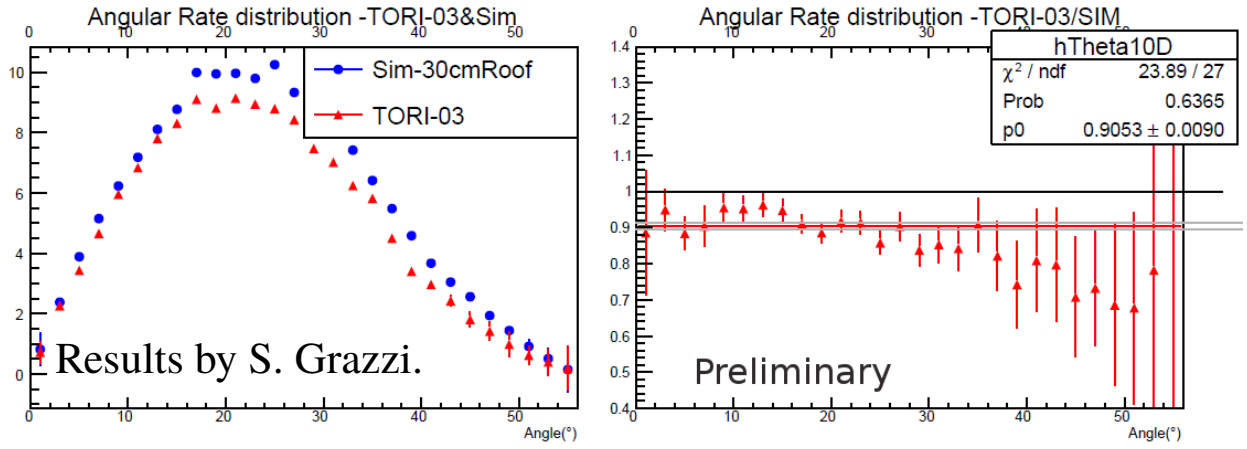
# Exp-Sim agreement I




The experimental and simulated polar angle data, without correction (open circles) and with the efficiency correction (full circles) are in agreement within 5-6% in both cases for polar angle below 35 degrees, with efficiency correction the agreement remains within 10% above 35 degrees.

# Exp-Sim agreement II

Simulated sample without detector efficiency corrections.




Red triangles represent the polar angle distribution of data collected by TORI-3, while the blue circles are the same distribution obtained by simulating a sample with the same statistic but without detector efficiency information

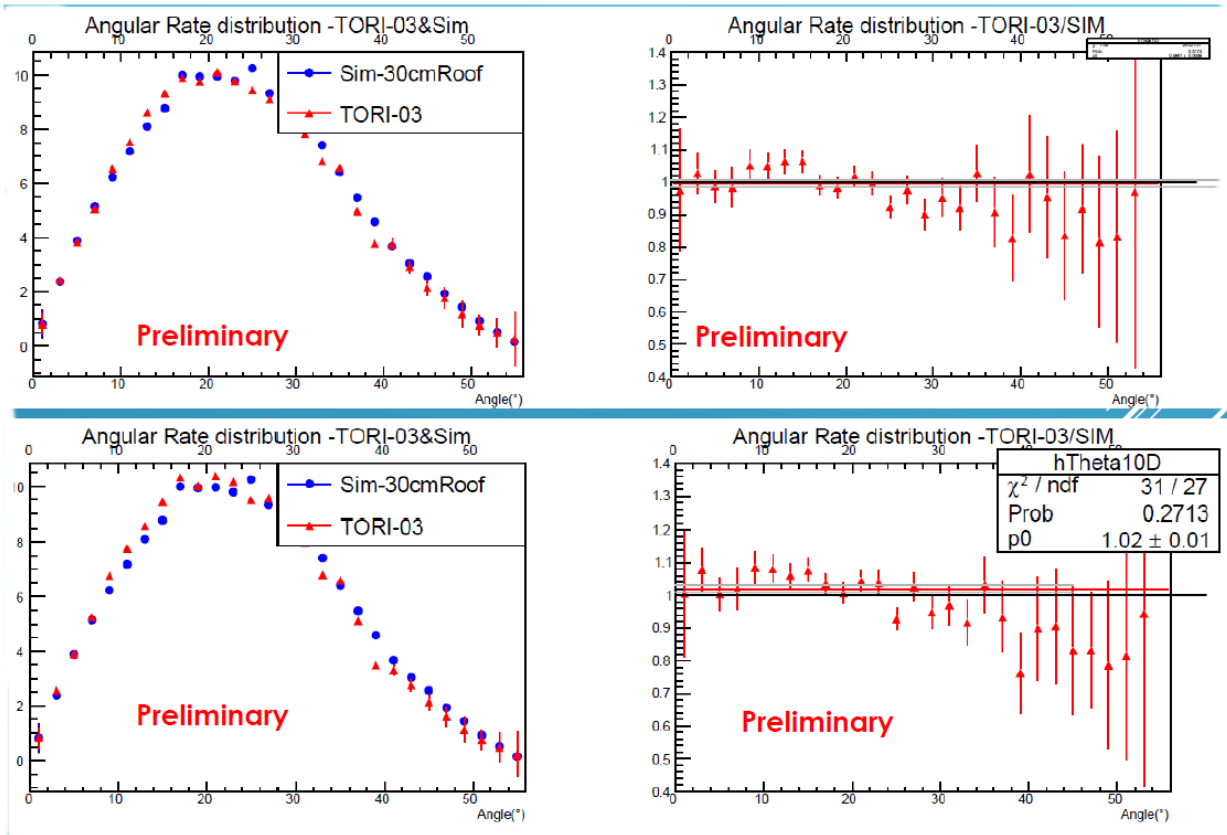
# Exp-Sim agreement III

Two independent methods (same strategy different algorithms) were developed to obtain the efficiency maps. The efficiency corrections improve the agreement data-sim also at larger polar angles in both procedures.

**No normalization in the comparison, just the detector efficiency corrections have been applied.**

.

Simulated data corrected for detector efficiency




Results by S. Grazzi

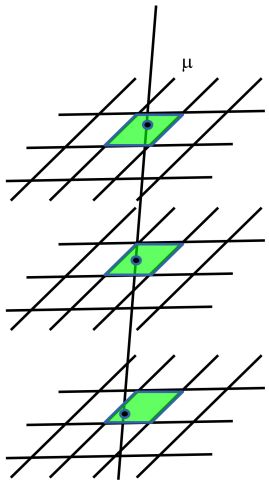
# Conclusions

- A simulation tool based on GEMC implemented for the EEE project has been presented.
- Estimations of detector resolutions and studies on the effect of the structures surrounding the telescopes have been discussed.
- Agreement Data-MC within **10%** up to the limit of the detector acceptance are already achieved and further investigations to improve the detector description are in progress.
- We plan to interface the present tool of simulation with Corsika event generator for the investigation of extensive showers of cosmic rays.

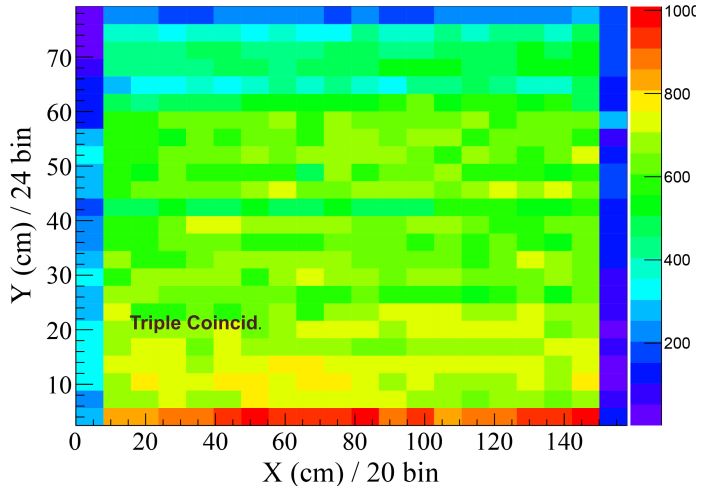
# Spares

# Tracking efficiency

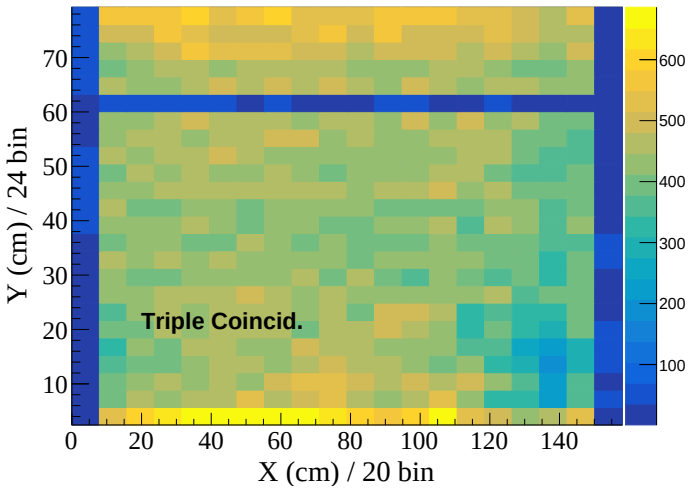
triple vertical coincidence



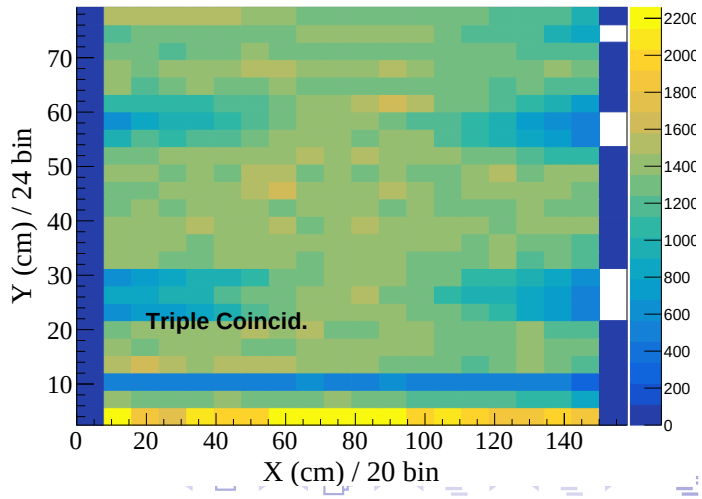

GENO-01




LECC-01

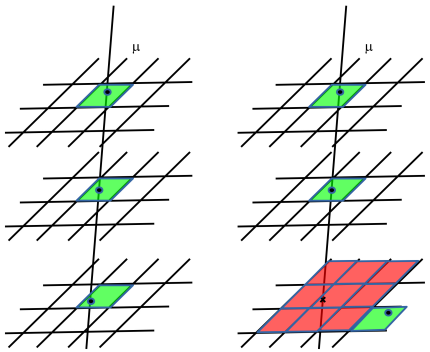



TORI-03

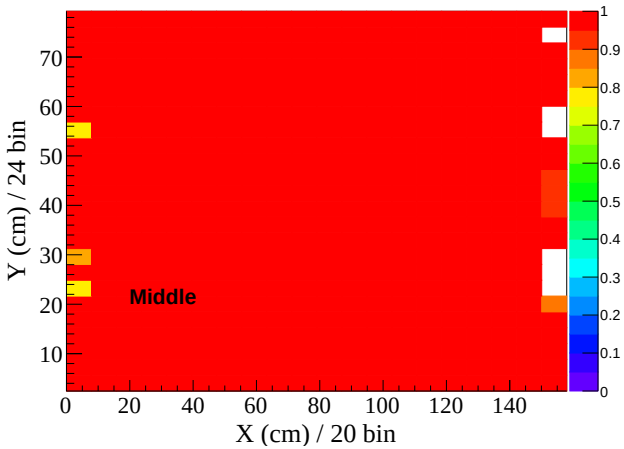


# Tracking efficiency

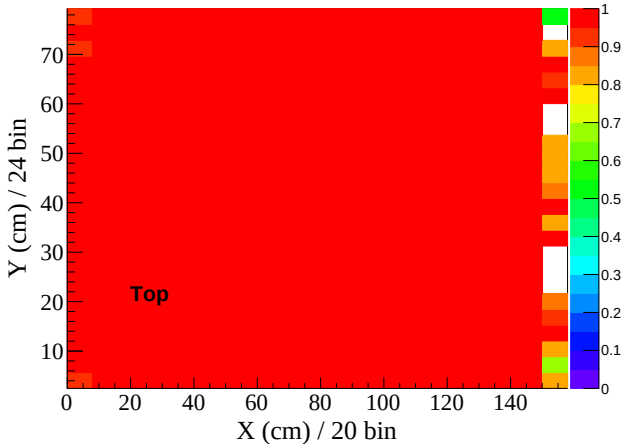
## Spurious inefficiency estimation

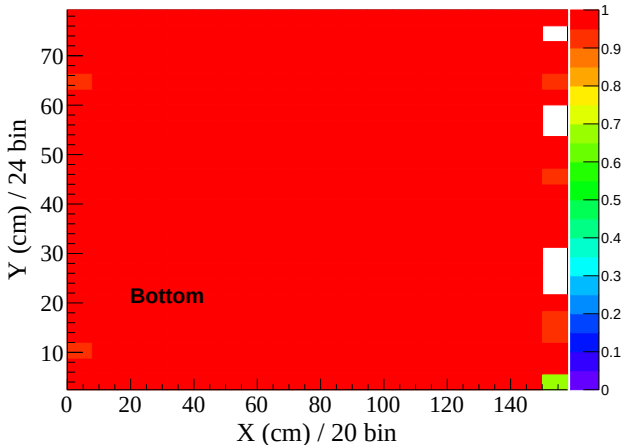



$$\epsilon = \frac{N_{tripl.}}{N_{tripl.}+N_{doubl+proj}}$$

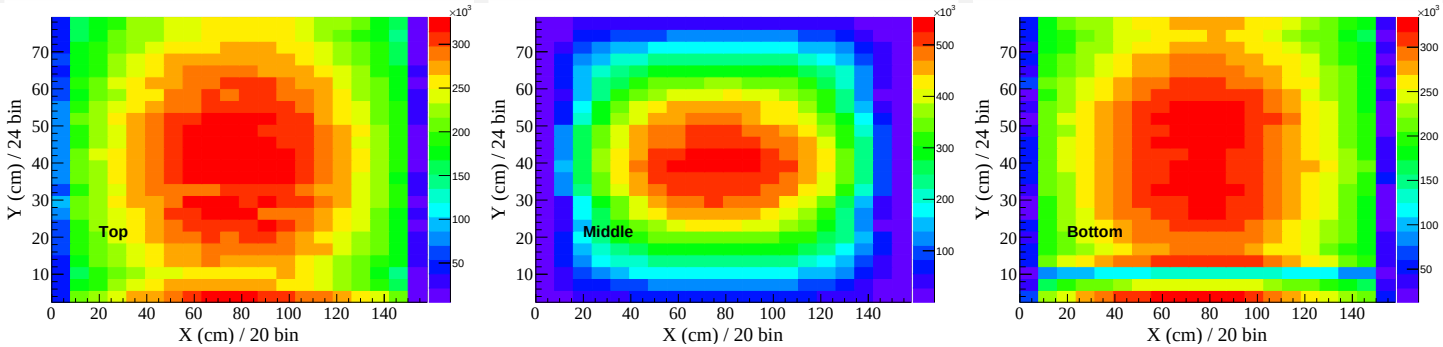



## TORI-03

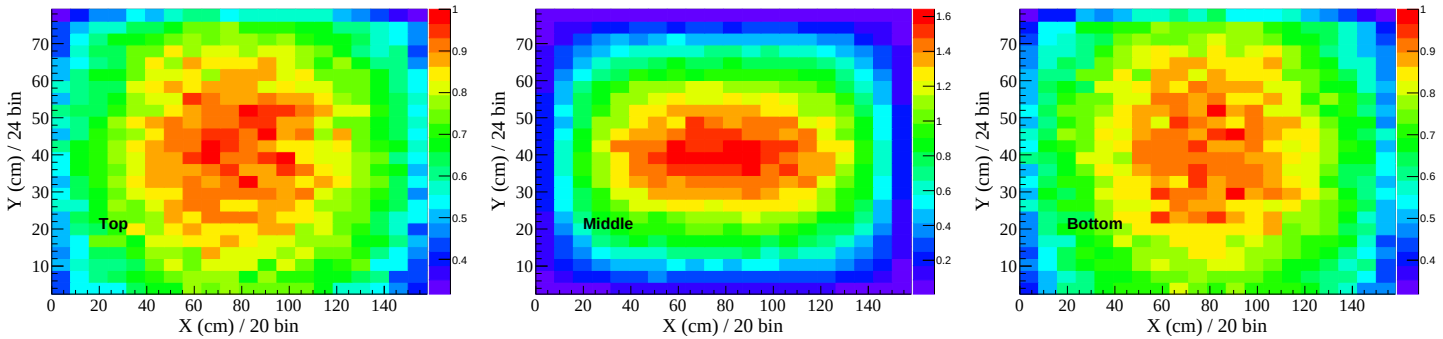


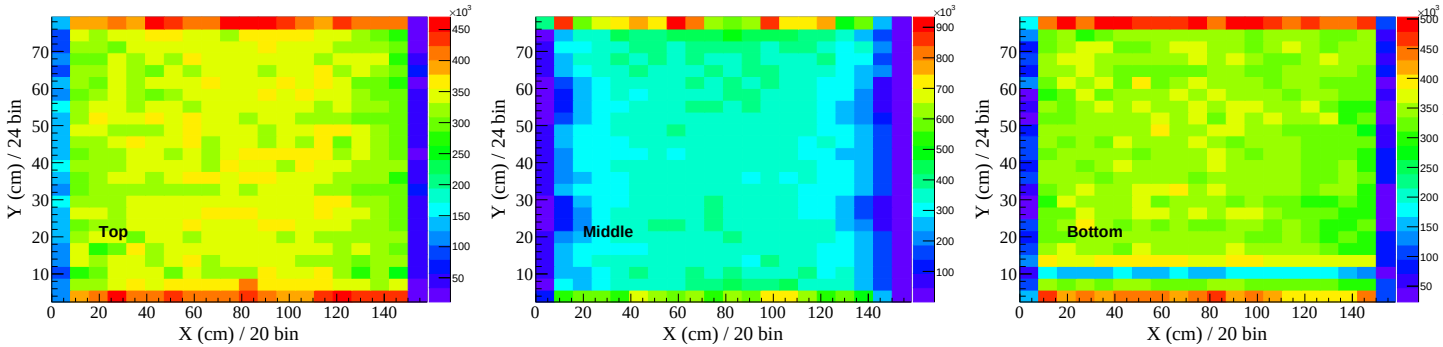
# Counting efficiency map - TORI-03




Hit distribution for each chamber of TORI-03 telescope.

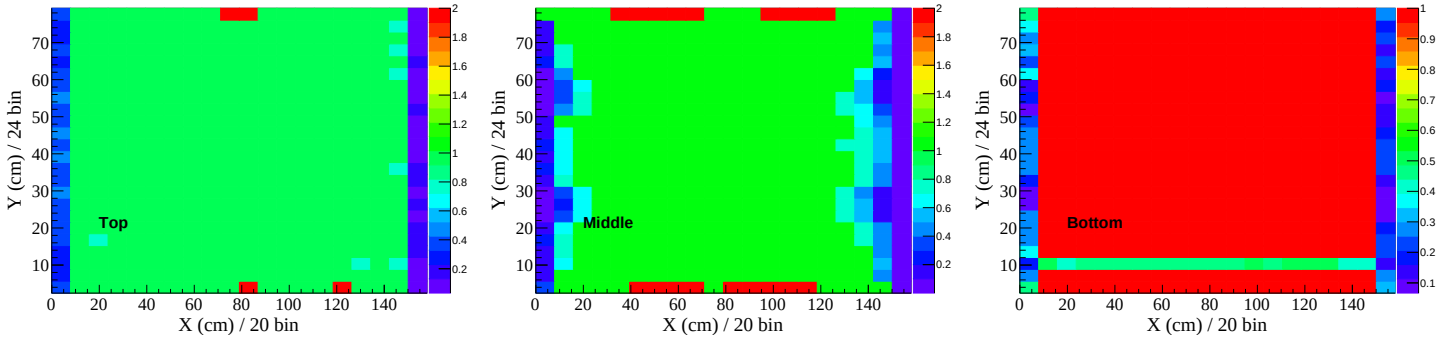



Hit distribution for simulation data (no inefficiency).

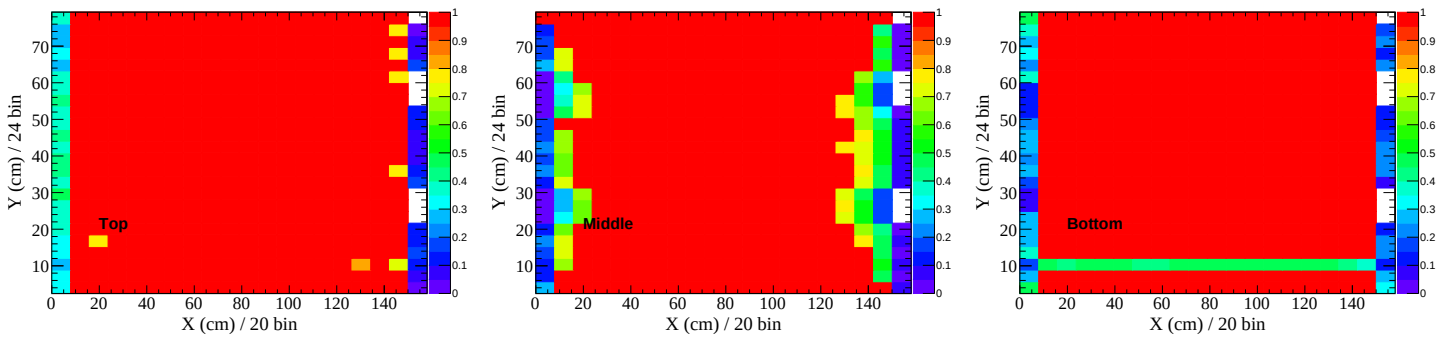



Maps obtained as the ratio of the hit distribution of data and simulation.

# Hit map acceptance correction - TORI-03




The maps corrected for the acceptance are normalized to the average rate.




Total efficiency maps are obtained as the product of the counting and tracking efficiency.