Atmospheric showers simulation for background estimation for muons tomography

Samuel Béné ◊ Tomuvol Collaboration

- Problematic
- Atmospheric shower physics
- Simulation software
- Estimation of background contamination
- Conclusions

Problematic

- Objective : measuring variations in the flux of atmospheric muons
  - Knowledge of the open sky muons flux : essential to evaluate its attenuation
    - ➢ Simulation needed, to estimate the incoming flux on the target.
  - The number of muons expected to cross a structure such as the Puy-de-Dôme is small
    - ➢ Must put strong constraints on background contamination

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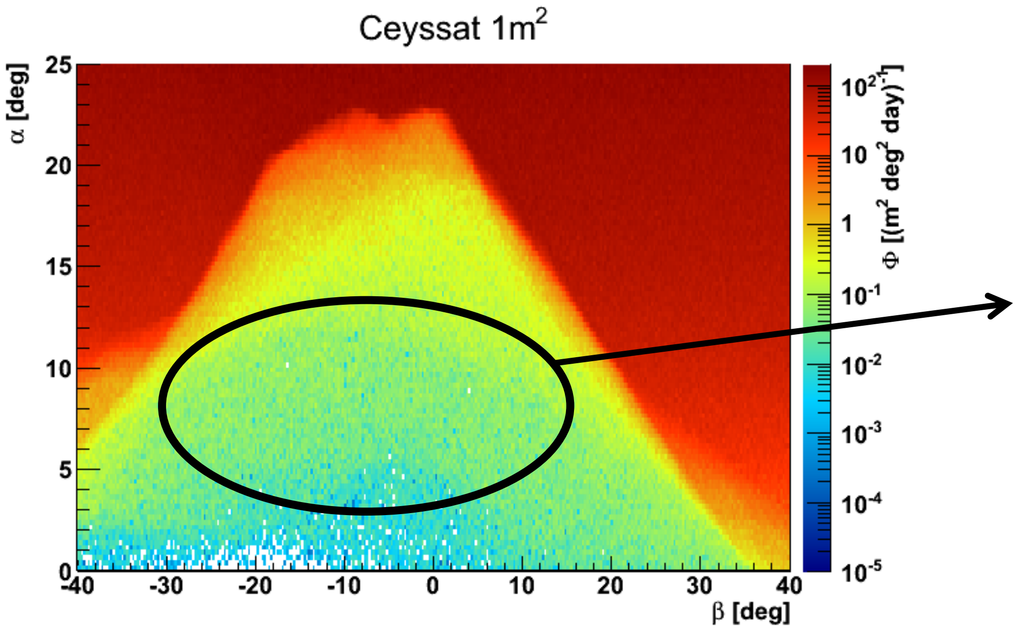
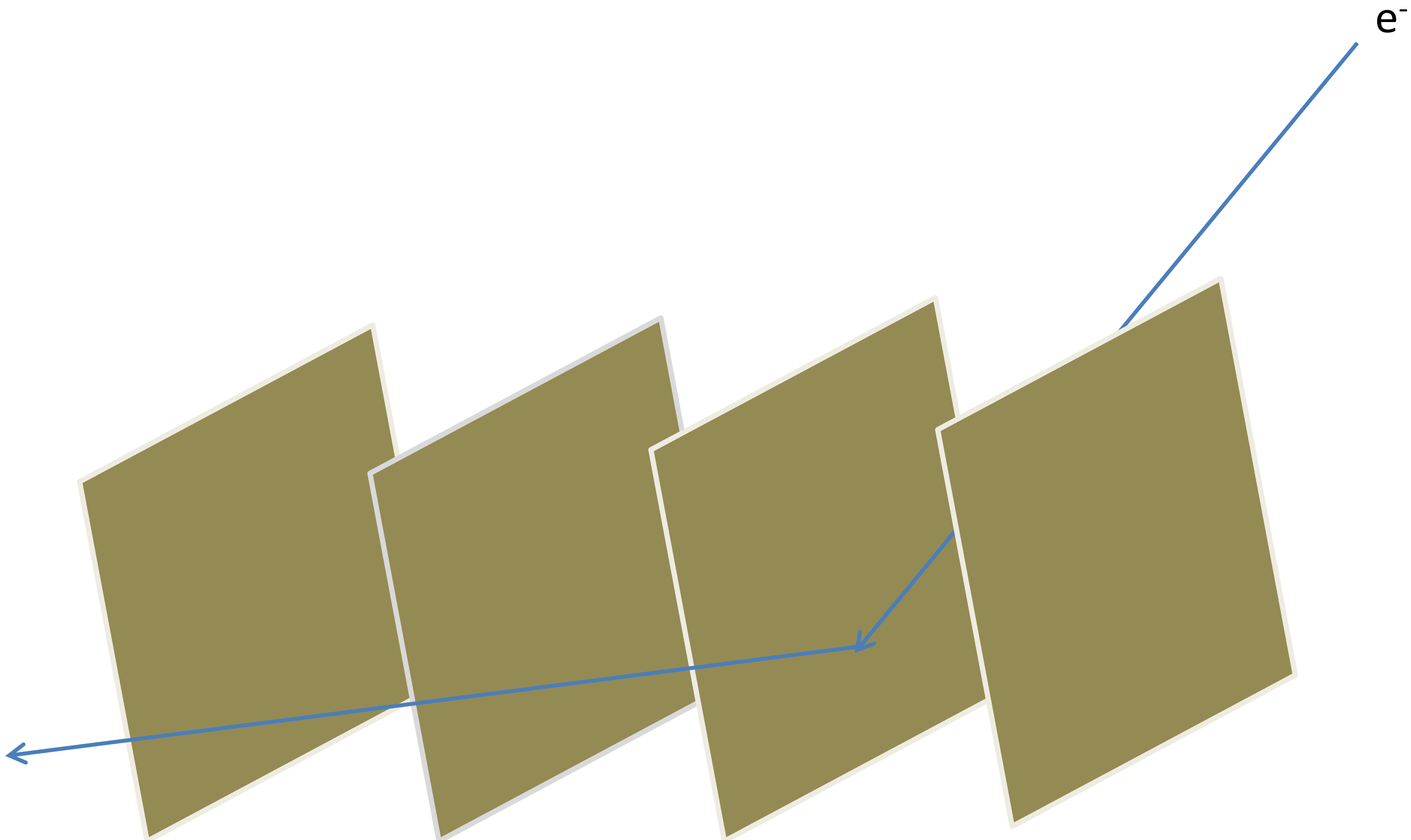


In this area : ~10^{-2} muons/(deg^2.day) are expected to hit a $1m^2$ detector

Background sources

Possible sources of background :

1. Low energy particles, other than muons, crossing the detector (negligible behind a shield, but not in the open sky) or backward muons



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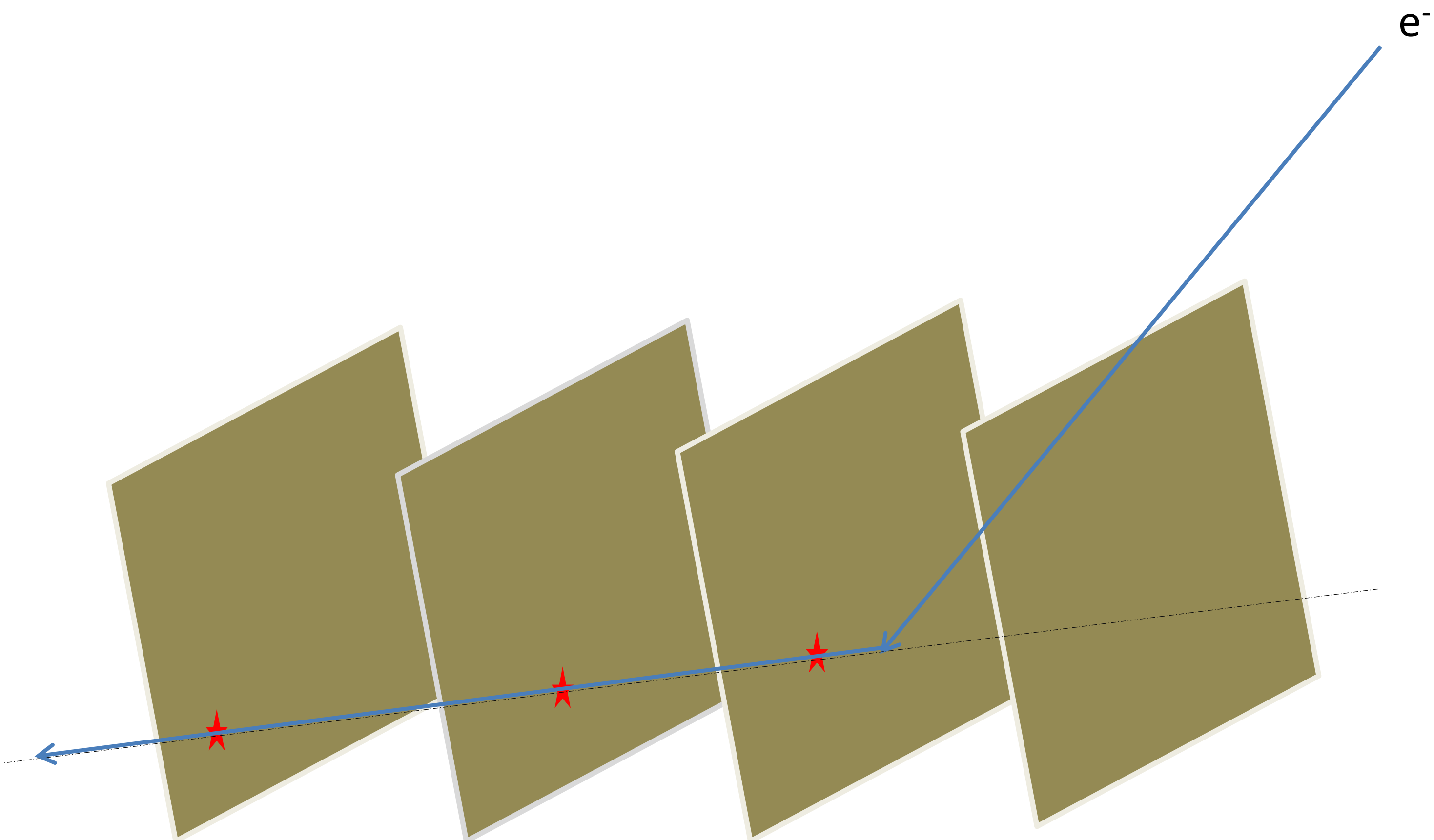

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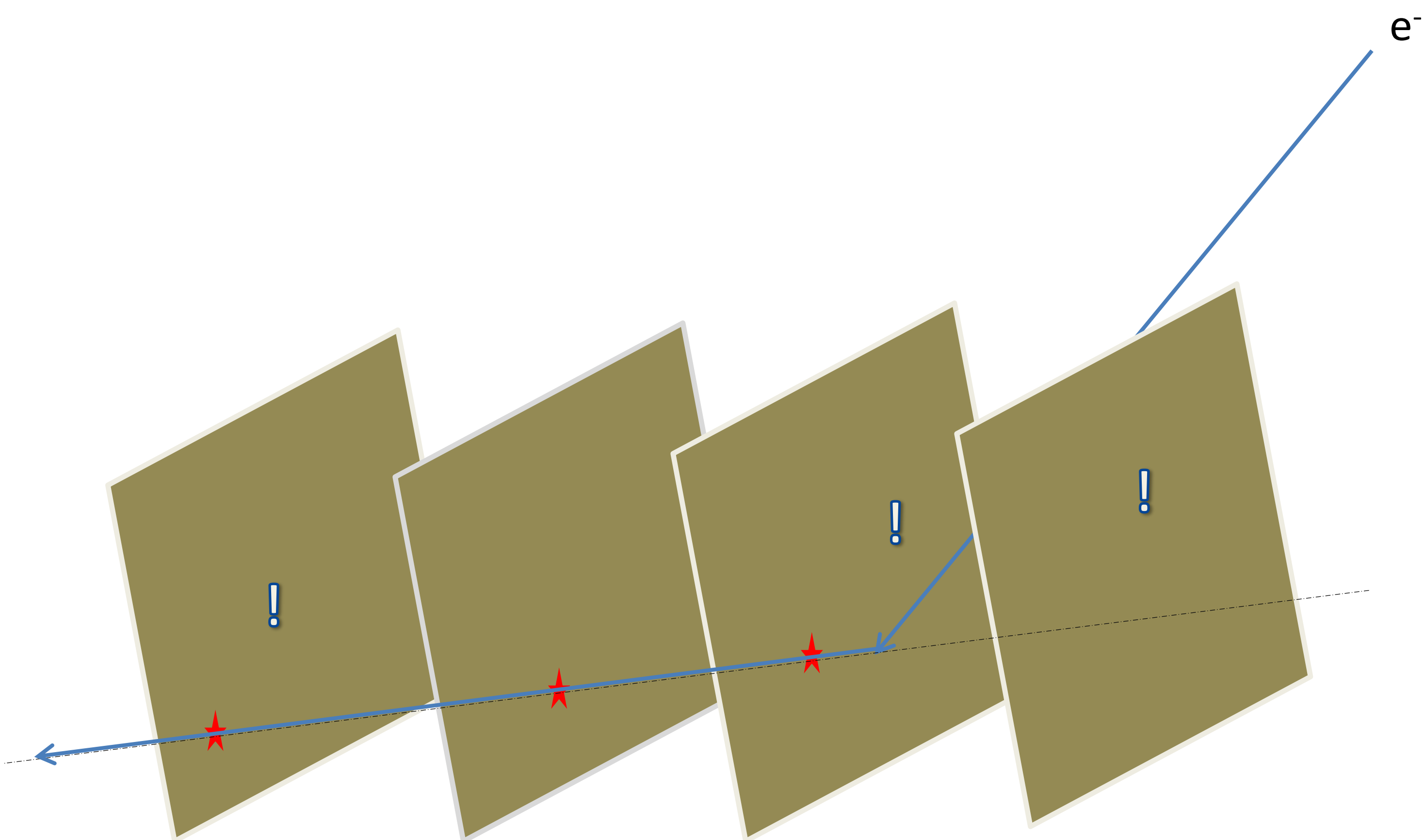

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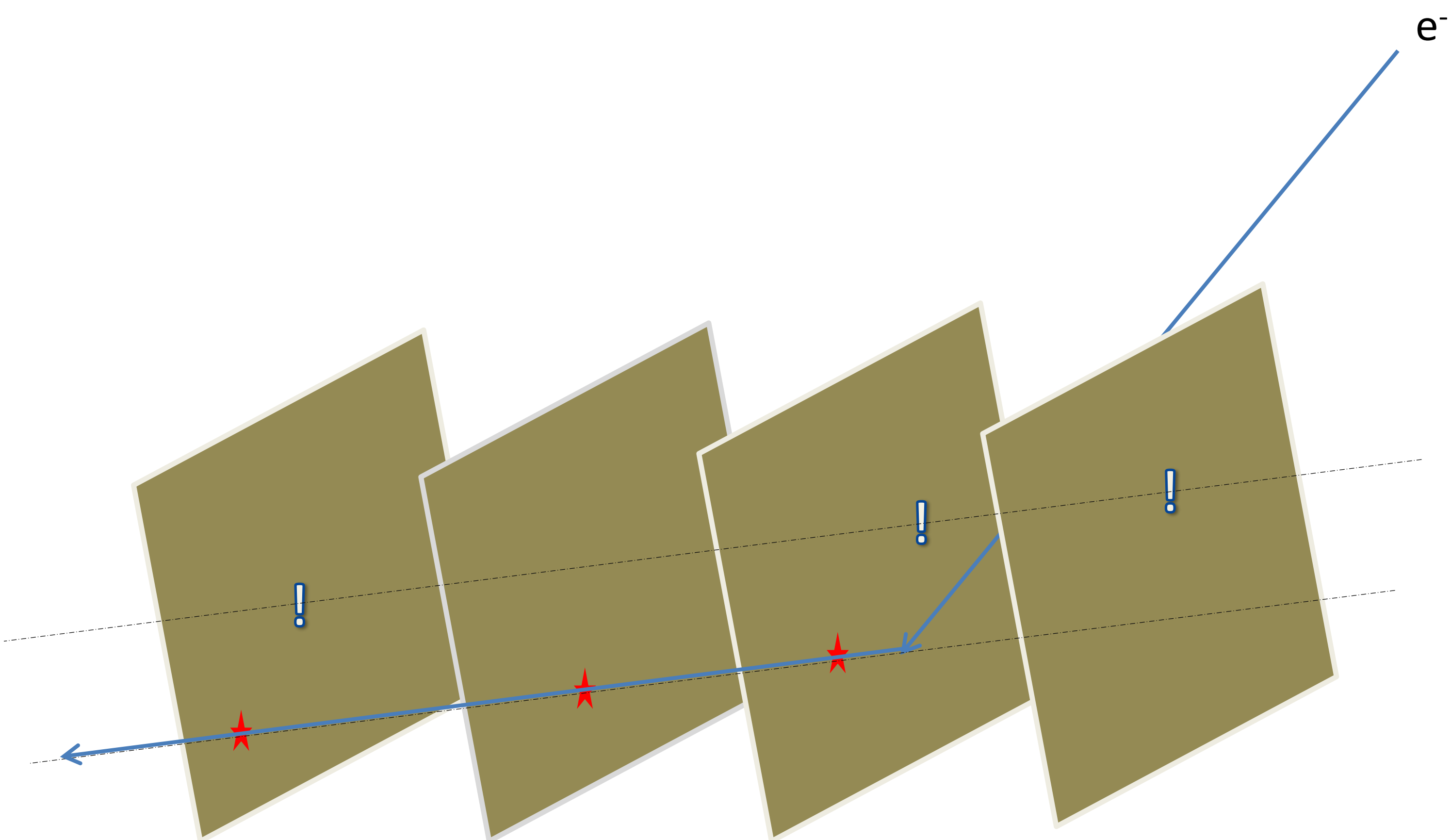

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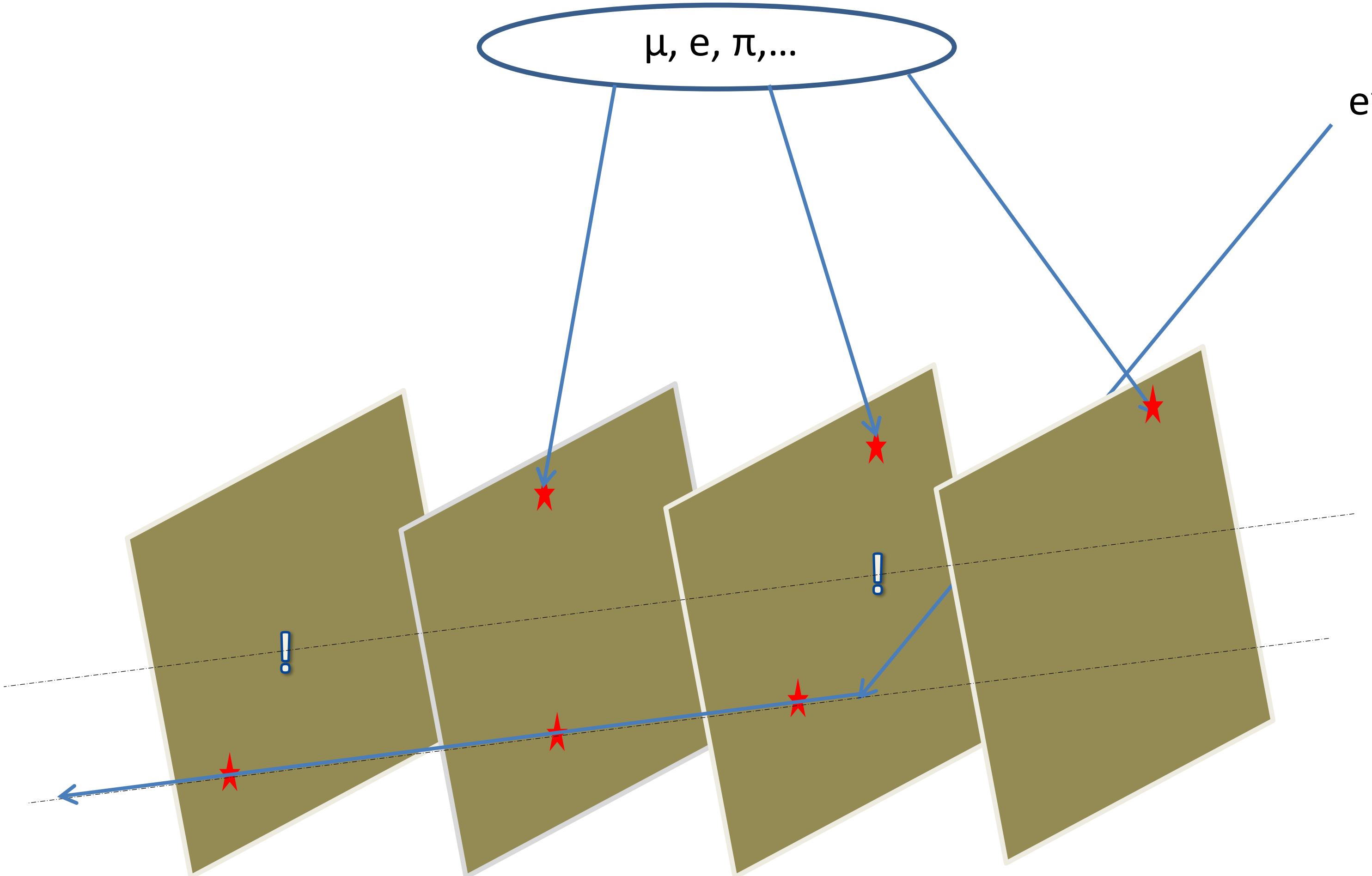

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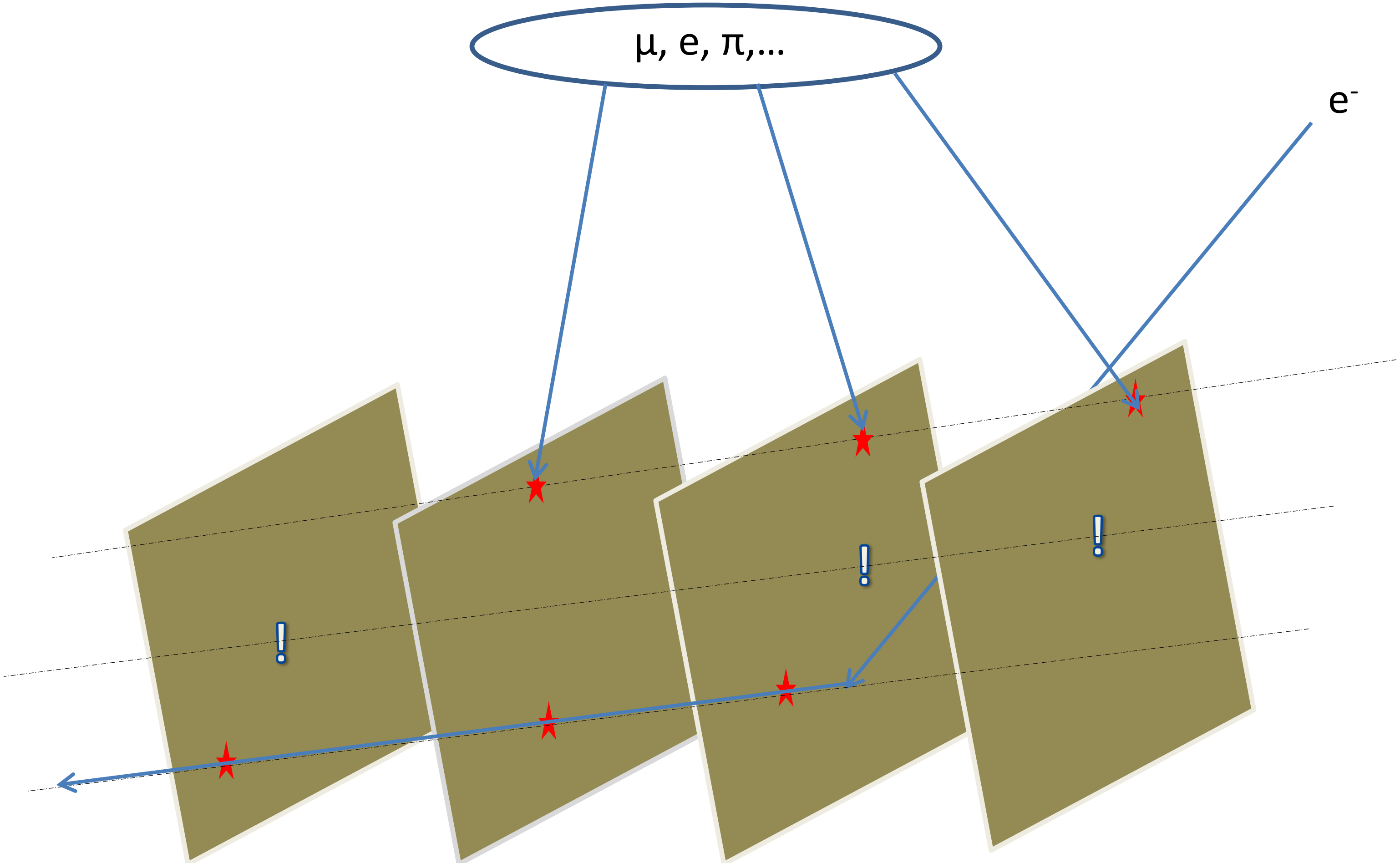

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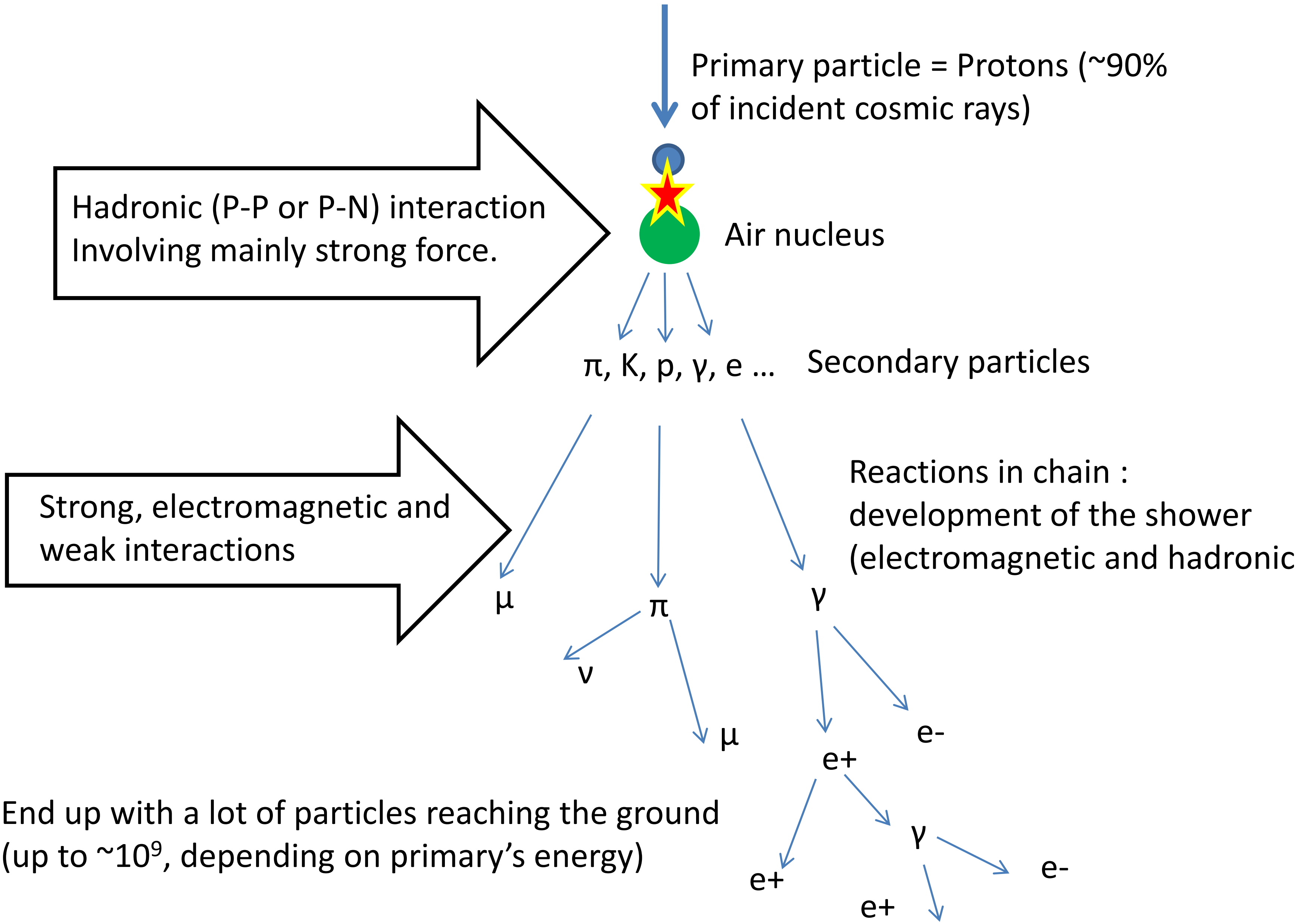
Fortuite coincidences induced by downgoing showers :

a priori no way to evaluate their contribution to background without modifying experimental setup

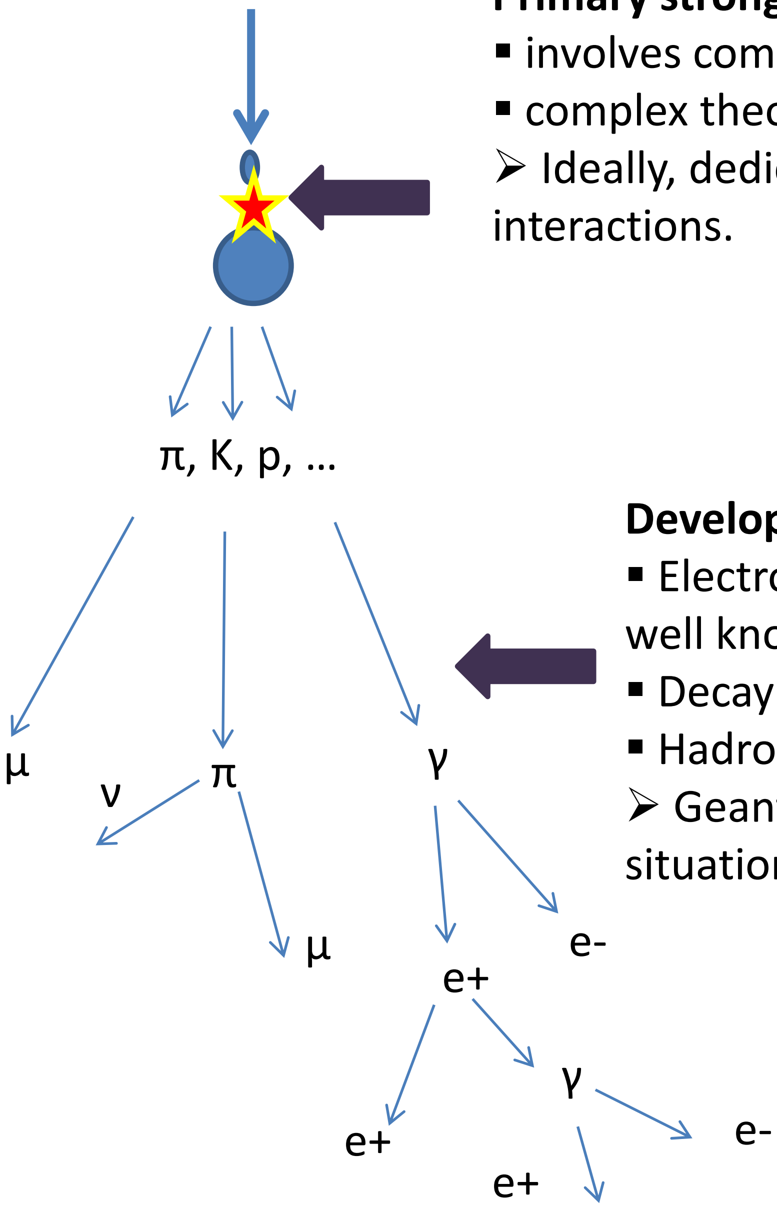
➢ 2nd need for a simulation

Atmospheric showers physics



End up with a lot of particles reaching the ground (up to ~10^9, depending on primary's energy)

The tools to simulate these events



Primary strong interaction :

- involves composite structure of hadrons (Parton model).
- complex theory, lots of different mechanisms involved.

➢ Ideally, dedicated software (e.g. Pythia) used to simulate these interactions.

Developpement of the shower :

- Electromagnetic processes become important and are very well known
- Decay of unstable particles also well known
- Hadronic interactions : stochastic processes

➢ Geant4 (Monte-Carlo) is well suited to describe such situations

<u>In most cases : all-in-one toolkit, embedding pieces of software for each part of the physics.</u>

➢ <u>CORSIKA commonly used for air showers</u>

Development of a Geant4 simulation for muon tomography

Motivation :

- Customization of the simulation
  - Geant4 : Can simulate the interactions of the particles with volcano or the detector
  - Corsika : Only the Earth's atmosphere is included
- Corsika is not originally intended to simulate the most horizontal showers (the one we are interested in for tomography)

Geant4 set-up (in development) :

- For the moment the Earth's magnetic field is not included
- Physics processes included : built-in list "QGSP_BERT" + one process added : $\gamma \rightarrow \mu^+\mu^-$
- Atmosphere : 1960 layers of air with variable density (same model as in Corsika)
- Primary particles : 1, 10 or 100 TeV protons entering the atmosphere at normal incidence

Comparison with Corsika results

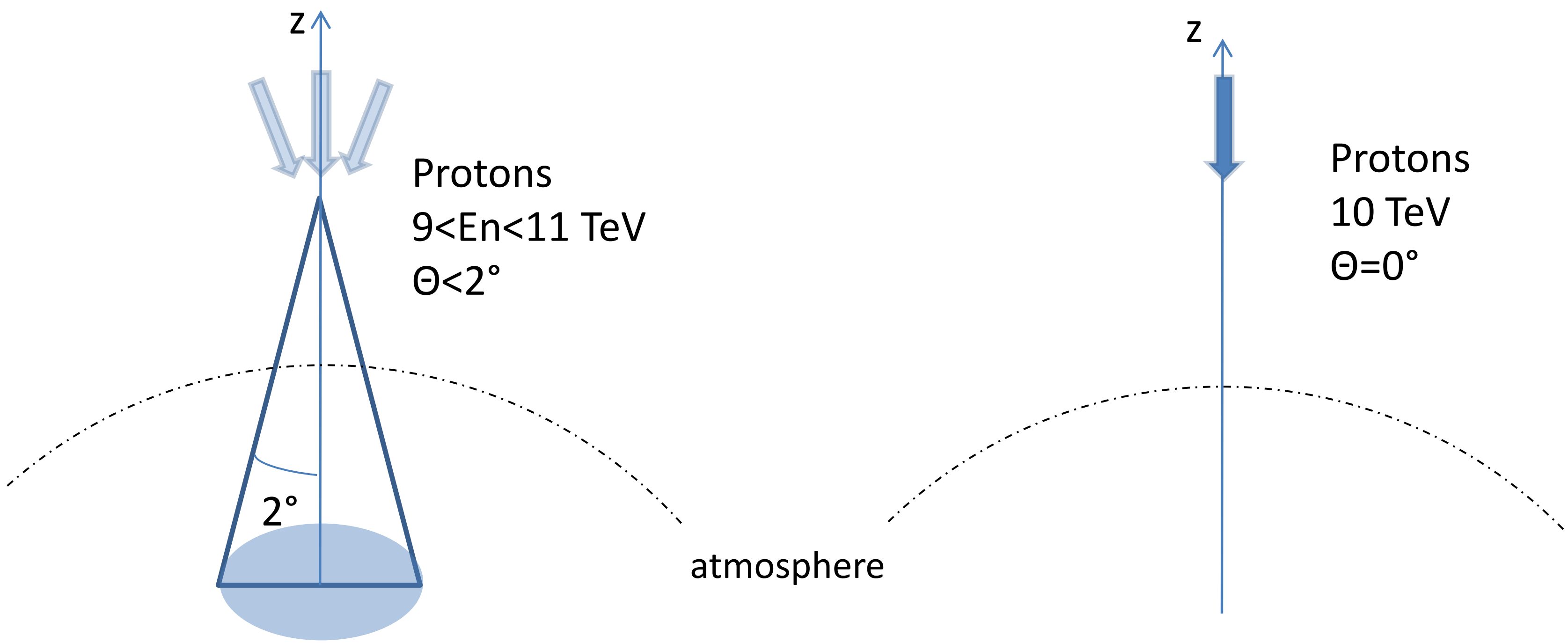
- Spatio-temporal and energy profiles of muons from both simulations are compared (at z=870m)

- Origin of the frame : in each shower → mean position in (X,Y) and arrival time of the muons.

- Only muons with E>10GeV are selected, so we can neglect the effects of Earth magnetic field, not included in the Geant4 simulation.

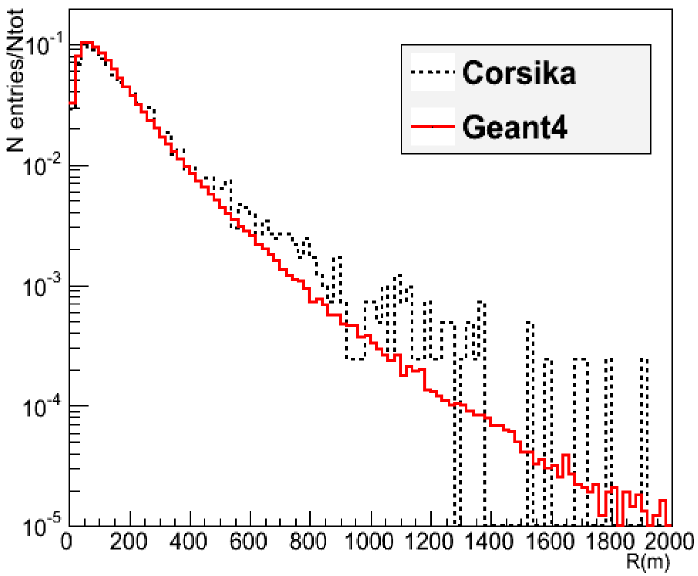
- Primary particles used for the comparison of the two softwares :

Corsika **Geant4**



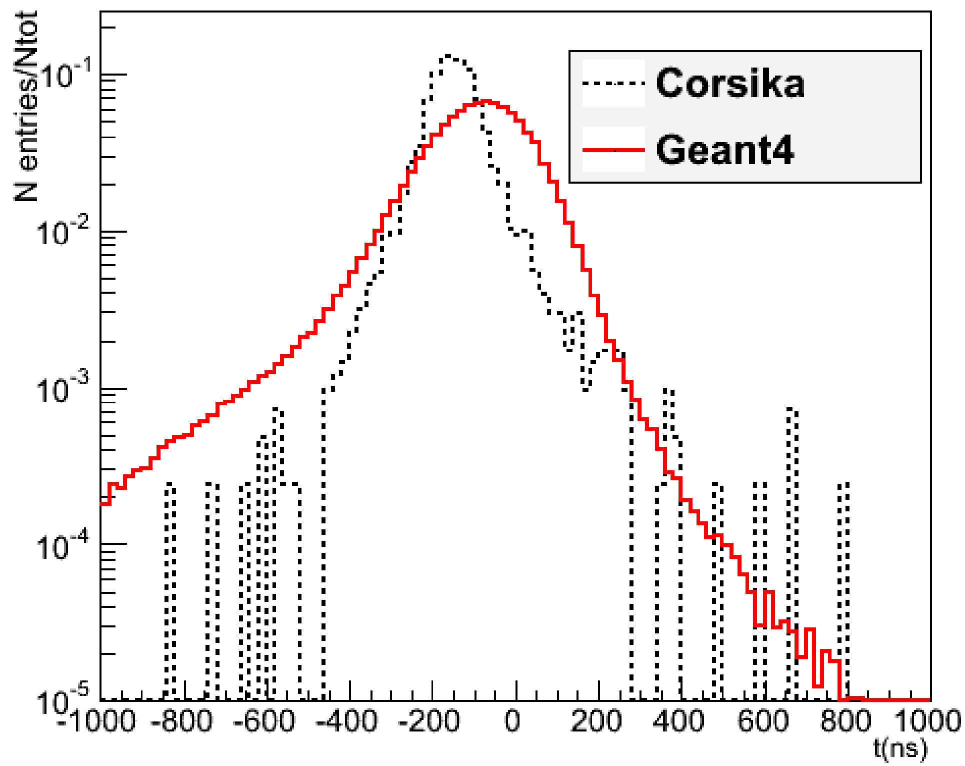
Comparison of Geant4 and Corsika results

Radial profiles

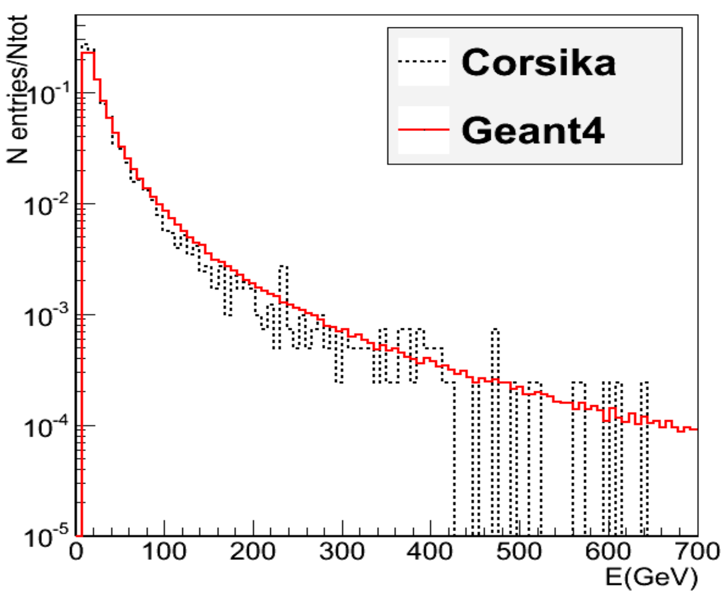


! Low statistics for Corsika results

Time profiles



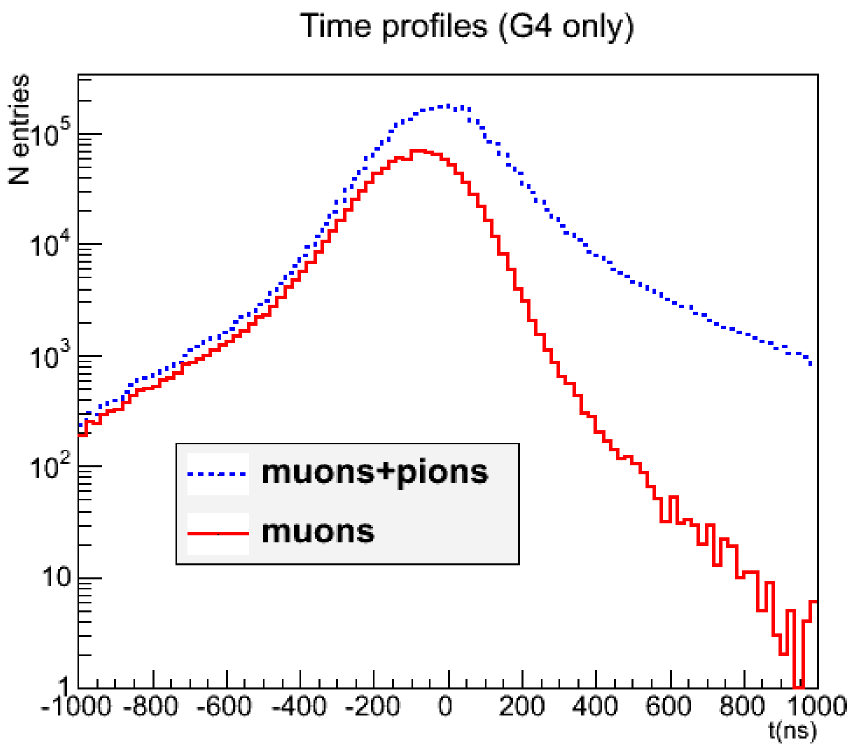
Energy Profiles

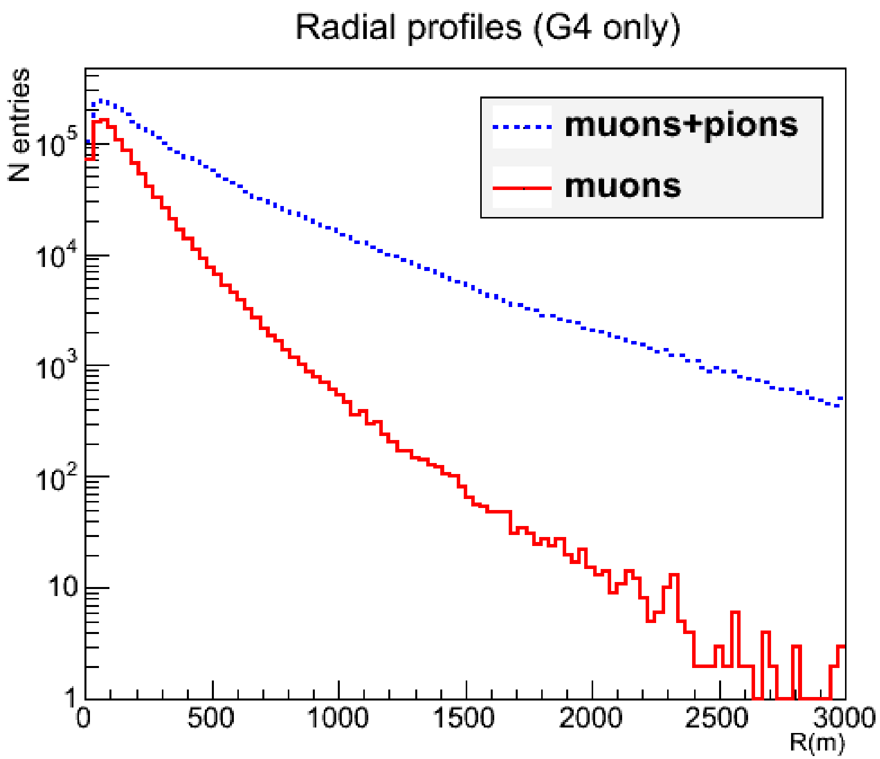


Agreement is good for R and E profiles, but there is a notable difference for arrival time profiles

Spatio-temporal distributions of muons+pions

- A surface detector is also sensitive to charged pions
  - We compared the muon distributions to the muons+pions ones, for Geant4
  - The difference in spread for the showers is significant, both for R and T

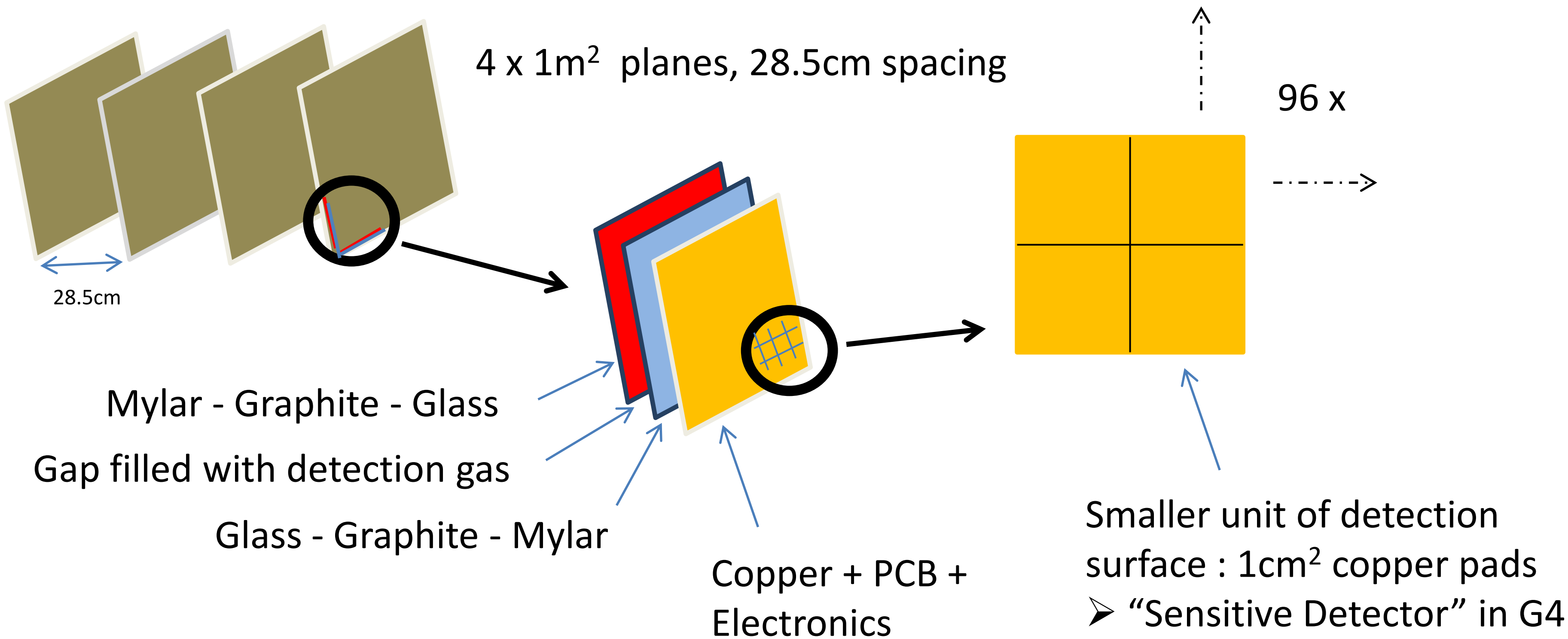




The shower reference frame is given only by muons

Construction of the detector in Geant4

- ToMuVol Detector (Glass Resistive Plate Chambers) as simulated in G4 :



Estimation of fortuite coincidences induced by downgoing showers

- We look for particles hitting the detector planes coherently, within a time window of 400ns (corresponding to our detector clock)

Retrieve data from Corsika ($\vec{r}$ and $\vec{p}$ of the muons)

⇩

Generate the muons in Geant4 with same $\vec{r}$ and $\vec{p}$

⇩

Analyze Geant4 hits on the detector and look for coincidences

→ Work in progress

Conclusions and prospects

Problematic :

- The atmospheric muon flux needs to be simulated to evaluate its attenuation through matter
- This is also required , along with the full simulation of the detector, to evaluate the amount of accidental coincidences
- Using Geant4 is a convenient way to go

✓ The radial and energy distributions of the muons (Emu>10GeV) from 10 TeV vertical showers simulated with Corsika and Geant4 are in agreement

✓ The time distributions of the muons (Emu>10GeV) from 10 TeV vertical showers simulated with Corsika and Geant4 are significantly different

✓ Pions significantly affect the observed topology of the showers if taken into account

✓ A first estimate for accidental coincidences should be obtained soon

Work to be done :

- Investigate the differences observed between Corsika and Geant4 muon distributions
- Improve the shower simulation in Geant 4 by:
  - a better treatment of the primary pp interaction using Pythia
  - taking into account the Earth magnetic field in the simulation
- Simulating an inclusive flux of muons with Geant4, covering full sky aperture and all energies