



ATLAS NOTE

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Visualization of hits/tracks in the ATLAS forward region and forward detectors

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Abstract

Particle trajectories in the ATLAS forward region are simulated with GEANT4, but mainly hits in sensitive volumes (namely the detectors) are stored in the outputted ROOT files. To visualize hits/tracks in the whole ATLAS forward region a new `G4UserAction StoreSimulationHit` for GEANT4 was implemented, which stores information about every particle in every simulated step in a collection named *SimulationHitCollection*. This collection can be visualized either directly with ROOT or with VP1. The latter supports now various cuts and the visualization of the hits/tracks together with the forward region GeoModel and the forward region detector GeoModels.

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1 Simulation and Storing of hits/tracks in the forward region

GEANT4 is used to simulate the propagation of particles in the forward region of ATLAS. In the past mainly hits in sensitive volumes were stored in the outputted ROOT files. Besides some simulated hits were also stored in the truth collection. Now it's possible to store information about every particle in every simulated step in a new collection named *SimulationHitCollection*.

1.1 SimulationHitCollection

The packages *ForwardDetectors/ForwardSimulation/ForwardRegion_SimEv*, *ForwardDetectors/ForwardSimulation/ForwardRegion_EventCnv/ForwardRegion_EventTPCnv*, *ForwardDetectors/ForwardSimulation/ForwardRegion_EventCnv/ForwardRegion_EventAthenaPool* [2] implement the new *SimulationHitCollection* and the converter between the transient and persistent version used by StoreGate. The collection stores the information gathered by the G4UserAction *StoreSimulationHit*.

1.2 Forward Region GeoModel

The packages *ForwardDetectors/ForwardSimulation/ForwardRegionGeoModel*, *ForwardDetectors/ForwardSimulation/ForwardRegionMgField* and *ForwardDetectors/ForwardSimulation/ForwardRegionProperties* [2] implement the GeoModel of the whole forward region and the related magnetic fields. These packages are used to

- describe the forward region in the GEANT4 simulation,
- visualize the forward region in VP1.

To enable the forward region the jobOption has to include the following lines:

```
jobOption.py
```

```
from AthenaCommon.DetFlags import DetFlags
DetFlags.FwdRegion_setOn()
```

1.3 GEANT4

Two packages of GEANT4 were modified to implement the storing of all simulated hits of every particle during the simulation.

1.3.1 Simulation/G4Utilities/G4UserActions

A new G4UserAction *StoreSimulationHit* was implemented in this package. The UserAction is called on every simulated step and stores

- *Global Time* – past time since the creation of the event before¹ and after² the step,
- *Position* – position (x,y,z) in mm of the particle before and after the step,
- *Kinetic Energy* – kinetic energy in MeV of the particle before and after the step,
- *Momentum direction* – direction of momentum (px,py,pz) in MeV of the particle before and after the step,
- *Momentum* – momentum in MeV of the particle before and after the step,
- *Total deposit energy* – total deposit energy in MeV in this step,
- *PDG Code* – pdg code of the particle,
- *Track ID* – identifies the track belonging to the current step,
- *Parent ID* – identifies the track which created the current track.

If more information is needed in the future, one can modify the G4UserAction and the collection accordingly. There is a lot more information available in every step [1]. However the amount of data can easily exceed several gigabytes, therefore the stored information should be restricted to the minimum needed information. Furthermore the stored data should be restricted using the available cuts on

- *Energy* – *MinimumTotalEnergy*, *MaximumTotalEnergy*, *MinimumKineticEnergy* and *MaximumKineticEnergy* in MeV,
- *Momentum* – *MinimumMomentum*, *MaximumMomentum*, *MinimumTransverseMomentum*, *MaximumTransverseMomentum* in MeV,
- *Position* – cartesian coordinates *X,Y,Z* in mm and cylindrical coordinates *Phi* in rad and *Eta*. Possible cuts are *MinimumX*, *MaximumX*, *MinimumAbsX* and *MaximumAbsX*, analogously for the other coordinates,

¹before means, just before the physical interaction takes place

²after means, after the particle was propagated taking the physical interaction into account

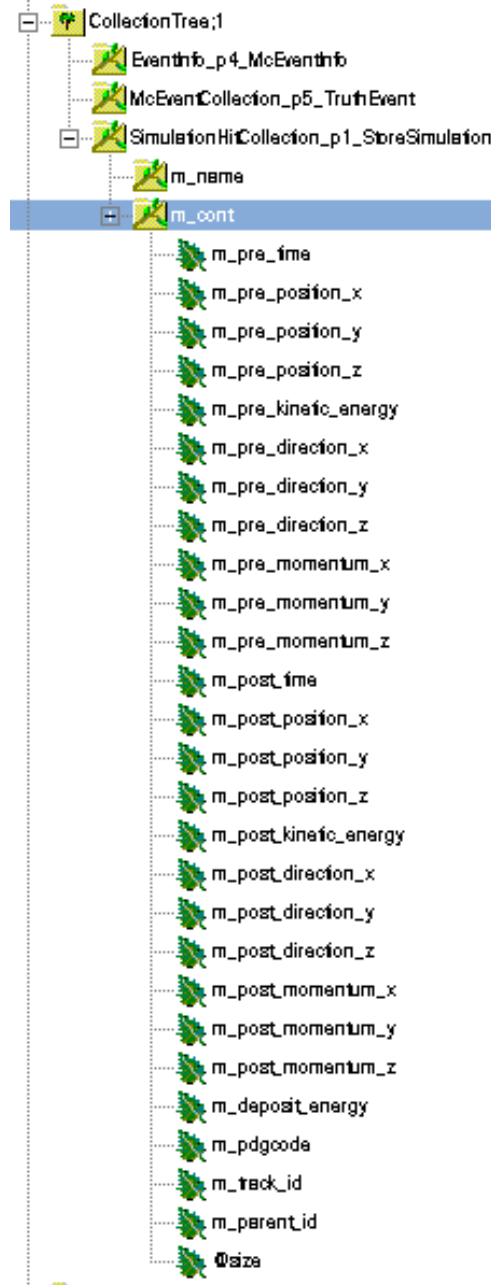


Figure 1: Available data members of *SimulationHitCollection* as shown in TBrowser

- *Orphan Tracks* – if a the parent track of a track wasn't stored, the track is called orphan track. Setting the cut *DiscardOrphans* to 1, discards all orphan tracks.

Notice the different effects when applying either a cut on total energy or on kinetic energy. Cutting on total energy includes slow heavy particles like deuterons, which are produced in nuclear reactions in the detector, these nuclear reactions can produce orphan tracks. Cutting on kinetic energy discards these heavy particles, however a slow moving heavy particle below the kinetic threshold can decay into lighter particles above the threshold, again this produces orphan tracks.

In the jobOption file one can use the *StoreSimulationHit* UserAction by adding

jobOption.py

```
def add_action():
    from G4AtlasApps import PyG4Atlas, AtlasG4Eng
    action = PyG4Atlas.UserAction('G4UserActions', 'StoreSimulationHit',
        ['BeginOfRun', 'EndOfRun', 'BeginOfEvent', 'EndOfEvent', 'Step'])
    action.set_Properties({"MinimumKineticEnergy" : "10.0", "MaximumAbsZ": "10.0"})
    AtlasG4Eng.G4Eng.menu_UserActions.add_UserAction(action)

from G4AtlasApps.SimFlags import SimFlags
SimFlags.InitFunctions.add_function("postInitG4", add_action)
```

where cuts on the minimum kinetic energy 10MeV and the Z co-ordinate $z \in \{-10\text{mm} \dots 10\text{mm}\}$ are applied in this example.

1.3.2 Simulation/G4Atlas/G4AtlasApps

This package was modified to add the *SimulationHitCollection* to the output stream as soon as the forward region is enabled in the jobOption file. If one wants to use the implemented G4UserAction without the forward region, this package has to be modified by changing the line

python/PyG4Atlas.py

```
# ForwardRegion
if DetFlags.ForwardRegion_on():
    stream1.ItemList += ["SimulationHitCollection#"]
```

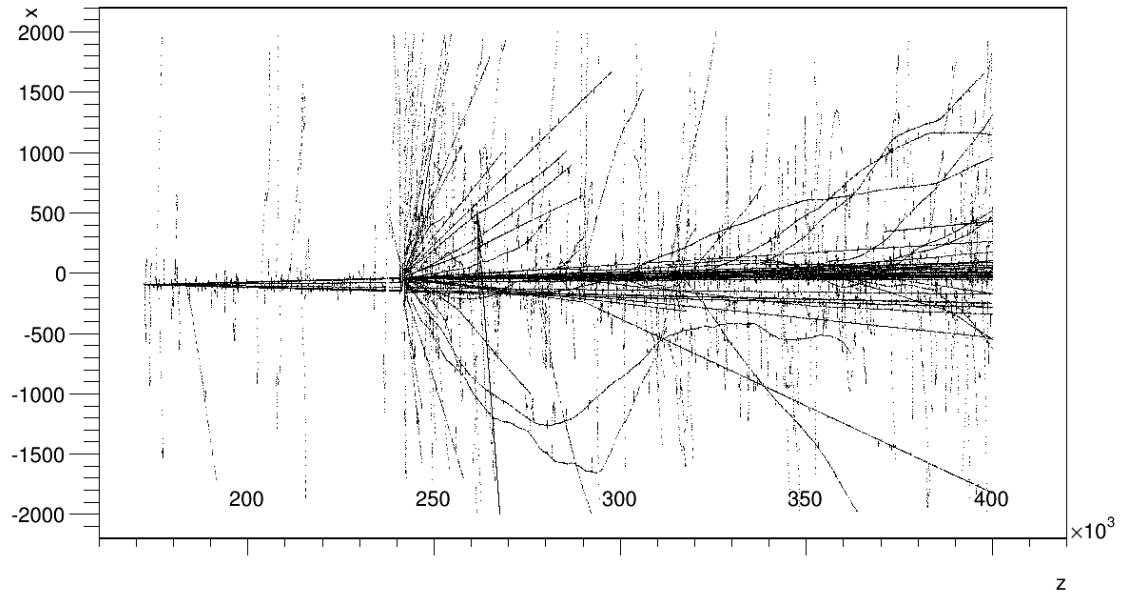
so the *SimulationHitCollection* is also included in the stream when the forward region isn't enabled.

2 Visualization of hits/tracks in the forward region

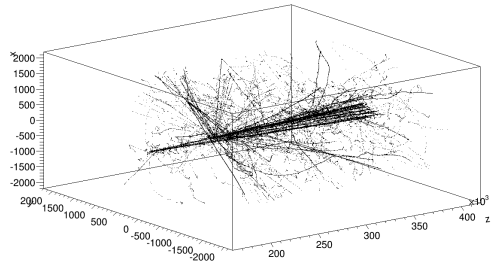
Once the ROOT file with the *SimulationHitCollection* is generated, the stored information can be visualized either directly with ROOT, or together with the GeoModel of the whole forward region and the detectors inside in VP1.

2.1 ROOT

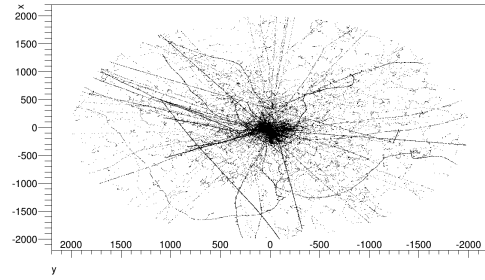
One can access the data in the collection directly inside ROOT. To access the stored data, one has to open the ROOT file with the *SimulationHitCollection* inside ROOT. The data in the collection can now be used to fill histograms and create plots. The easiest way to see a listing of the available data members is to open the collection in TBrowser, see Figure 1. For example, a simple visualization of the profile in the x-y plane of all simulated hits like in Figure 2c can be created as follows:



(a) x-z plane



(b) 3D View



(c) x-y plane

Figure 2: Direct visualization of a *SimHitCollection* with 10 events in ROOT.

```

TFile *_file0 = TFile::Open("AFP_hits_platesTest_cutted_1000MeV.pool.root")
_file0->Draw("SimulationHitCollection_p1_StoreSimulationHit_Collection_EventID_1.
           m_pre_position_x:SimulationHitCollection_p1_StoreSimulationHit_Collection_
           EventID_1.m_pre_position_y")

```

2.2 VP1

Different packages of VP1 were modified to implement the visualization of

- the Forward Region GeoModel,
- the simulated hits,
- the tracks reconstructed from the simulated hits.

2.2.1 graphics/VP1/VP1Algs

Package was modified to add support in VP1 for the Forward Region GeoModel. If the flag „-forwardregion” is passed as argument to VP1 it’s possible to visualize the Forward Region GeoModel. In total there are now four VP1 flags related to the forward region.

- -lucid – Init geometry and converters for the LUCID forward detector.
- -alfa – Init geometry and converters for the ALFA forward detector.
- -forwardregion – Init geometry and converters for the ForwardRegion.
- -zdc – Init geometry and converters for the ZDC forward detector.

To start vp1 with support for the forward region and the ALFA detector with a root file including a SimulationHitCollection one would use:

VP1

```
|| vp1 -forwardregion -alfa file.pool.root
```

The future AFP detector will be implemented in the same way.

2.2.2 graphics/VP1/VP1Base

There are now two new buttons in the main window of VP1, which move the camera perspective to the ALFA detector in the Forward Region. The buttons are labelled „FA” and „FC” adopting the convention of the other already available buttons in VP1 which move the camera perspective. In Figure 3 the buttons are yellow inked.

2.2.3 graphics/VP1/VP1Systems/VP1GeometrySystems

The geometry system of VP1 includes now support for the GeoModel of the whole Forward Region, see Figure 3. The different GeoModels of the Forward Region can be enabled with the Buttons in the yellow inked area of the menu.

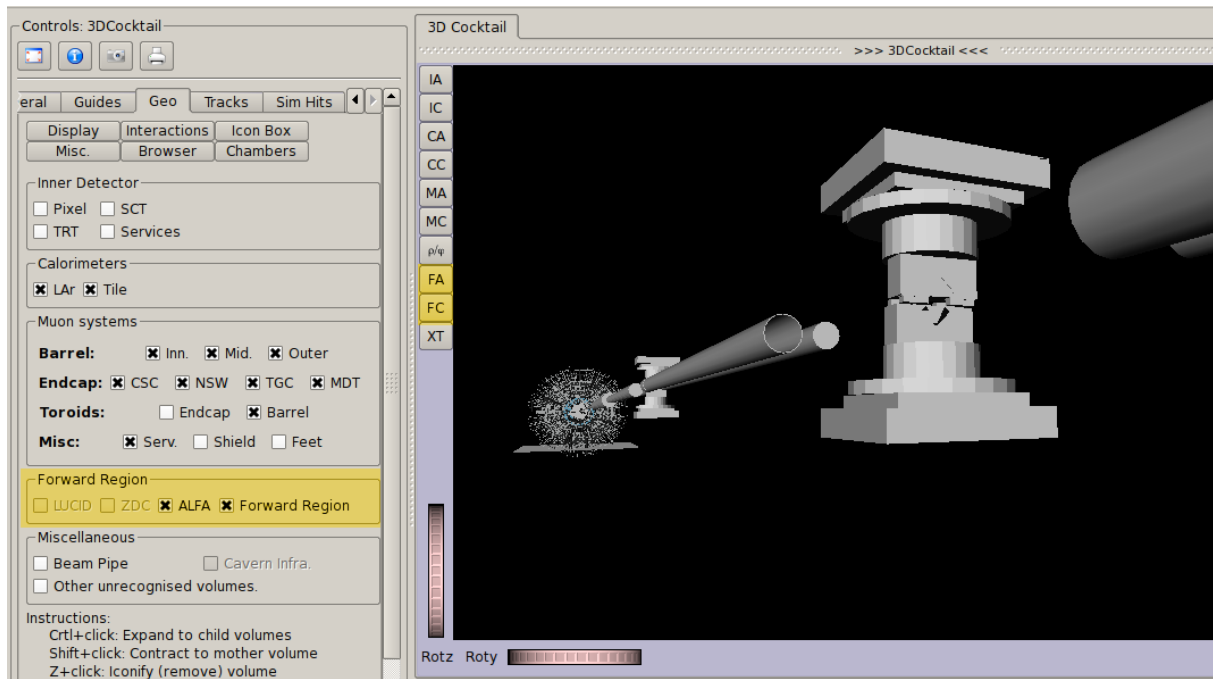


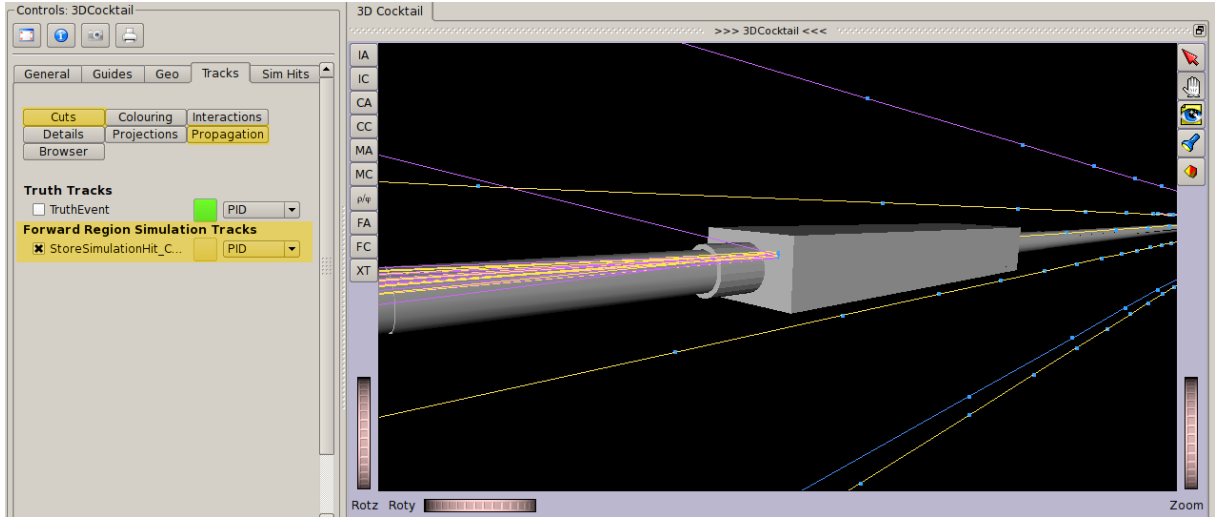
Figure 3: Forward Region GeoModel in VP1. New buttons are inked in yellow

2.2.4 graphics/VP1/VP1Systems/VP1SimHitSystems

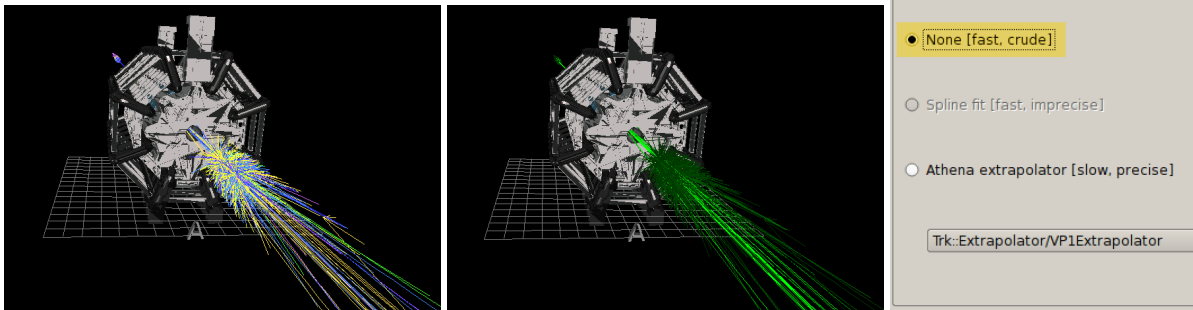
Due to changes in this package it's now possible to visualize the stored *SimulationHits* from a *SimulationHitCollection*. Every hit marks the position of a physical process simulated by GEANT4. The simulated hits are shown in Figure 4a as blue dots.

2.2.5 graphics/VP1/VP1Systems/VP1TrackSystems

The above mentioned *SimulationHits* are connected to tracks. This package was modified to implement support for the visualization of tracks generated from *SimulationHits*. Different cuts can be applied via the VP1 built-in cut dialog (see Figure 4a). In addition the tracks can be coloured according to their particle ID 4b, or to their momentum 4c. Before visualizing tracks, it's highly recommended to turn off the propagation extrapolator in the propagation dialog to improve the performance of visualization (see Figure 4d), because the propagation extrapolator doesn't work correctly at the moment and as a result needs a lot of time.



(a) Simulated hits are shown as blue dots. Reconstructed tracks are coloured according to their pdg code. The tracks can be visualized by clicking on the checkbox in the yellow inked area. The yellow inked buttons at the left top open the cut and propagation dialogs.



(b) Atlas detector with some tracks (c) Atlas detector with some tracks (d) Turn off the propagation extrapolation before visualizing the tracks. coloured according to their particle ID. coloured according to their momentum.

Figure 4: Visualizations in VP1

3 Analysis of hits/tracks in the forward region

The possibility to store all particle tracks in the *SimulationHitCollection* allows a detailed analysis of the development of showers in the forward region. An easy to extend ROOT-Macro was created, which reads in all simulated tracks from a given *SimulationHitCollection*. Different histograms can be filled with data from the stored hits and tracks. Some example studies were performed.

3.1 SoftQCD – Collision remnants induced showers in ALFA

We tested the hypothesis that particles produced in proton-proton collisions can cause showers which evolve in the whole forward region. And therefore generating background events in ALFA. To test this hypothesis 100 SoftQCD events @ 4 TeV with $\beta^* = 0.55$ m (which corresponds to the standard collision optics) and a cut on *Total Minimum Energy* 100 MeV were generated. The composition of the primary particles in these events is shown in Figure 5.

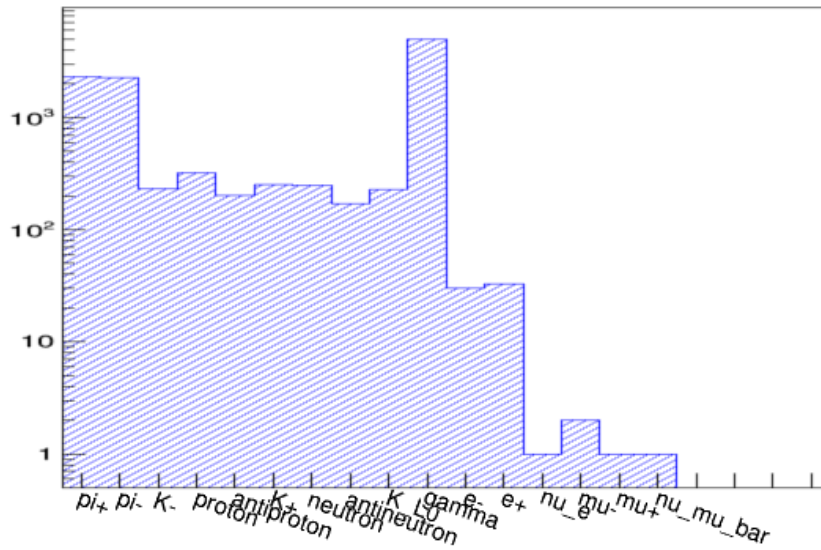


Figure 5: Composition of primary particles produced in the SoftQCD Events. Only 67 of the protons in the histogram are high energetic (with energy above 3.84 TeV) protons which survived the collision. These 67 protons are the signal ALFA wants to measure. All the other particles can cause background events due to the hypothesis.

With the *SimulationHitCollection* it's possible to distinguish between showers produced by protons which survived the collision and showers created by collision remnants. The deposited energy by these two components is visualized in Figure 6. From the plot it's clearly visible that the protons and their secondaries didn't deposit energy in the ALFA detector. Because of the used collision optics this is the expected result. Therefore all the deposited energy originates from the particles produced during collisions. The ALFA stations are visible in the right image of Figure 6 as high peaks. The gaps before and after every station are due to an imperfection in the simulation. The GeoModel of the Forward Region is missing a part of the beam pipe at these positions (something what has to be corrected).

With the *SimulationHitCollection* it's also possible to reconstruct specific hits which were caused by the mechanism described above. The reconstruction efficiency with the cut on *Total Minimum Energy* 100 MeV is shown in Figure 7. This simple analysis proofs the hypothesis, because the reconstructed hits in ALFA are caused by non primary proton particles via a *cascade of showers*.

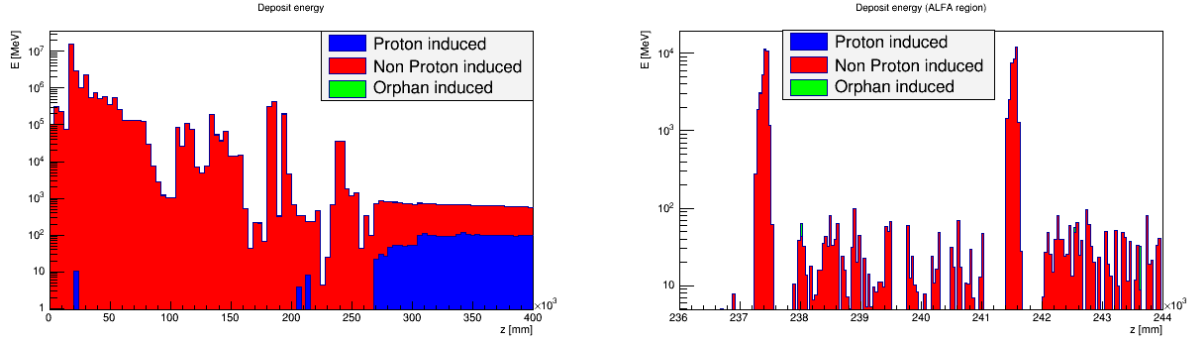


Figure 6: Deposited energy by the 67 surviving (out of 200) high energy protons (above 3.84 TeV) in blue and all other in the collision produced particles in red. On the left image the whole simulated forward region from 0 to 400 m is visible. A detailed view on the region of the ALFA detector between 236 m and 244 m is shown in the right plot.

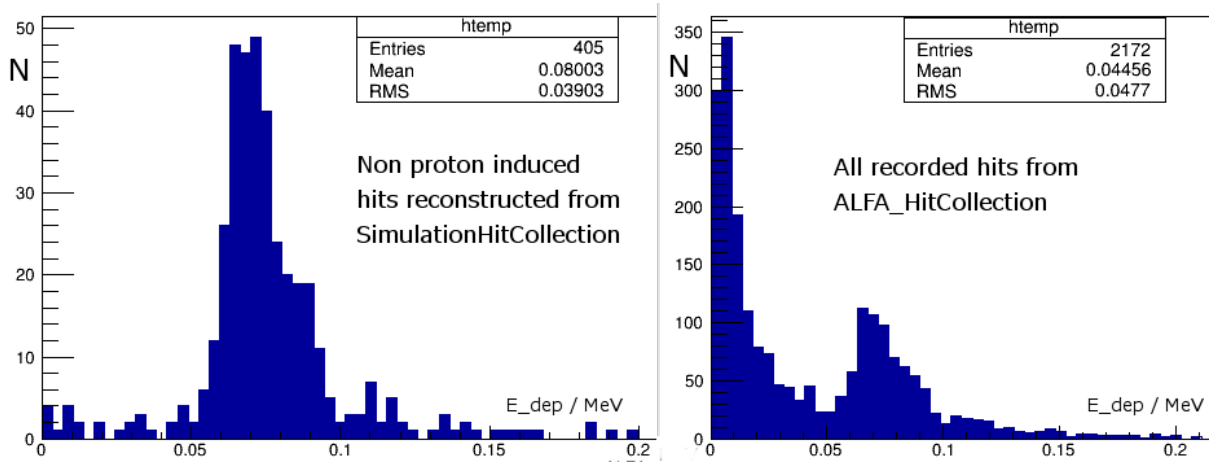


Figure 7: The number of hits against energy deposited by them is shown in this figure. (right) All the hits recorded in the ALFA_HitCollection are shown. (left) Only hits which were identified by the SimulationHitCollection as hits coming from non primary protons showers are shown. The difference between the pictures is only due to the cut on *Total Minimum Energy* 100 MeV

3.2 Simulated Rate in front of the first ALFA station

With the same sample as in the previous example, the simulated rate in front of the first ALFA station was investigated. The number of particles passing through a half-plane in front of ALFA in 100 SoftQCD events were integrated from y to ∞ . The curve of this simulated rate is shown in Figure 8.

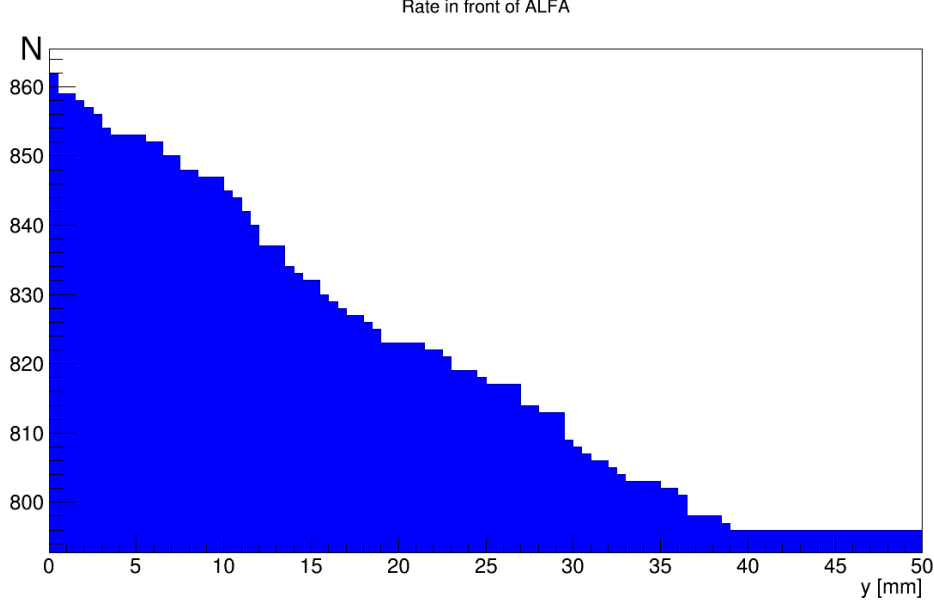


Figure 8: Rate as measured from a detector which measures all passing particles going from $y = 0$ to ∞

To get a more realistic result different aspects in this study have to be improved

- not all particles deposit energy in a real detector. So the plane should be casted into a volume, and instead of the number of passing trajectories, the number of detected hits which lead to a measurable signal should be counted,
- the finite size and form of the detector has to be taken into account,
- the rate is a function of time and hits from showers of background events probably arrive at a different time than the protons.

3.3 Multiple scattering of protons in ALFA

Protons are deflected by multiple scattering in the first ALFA station and propagated 4 m to the second station. Also due to the angle introduced at the first station, there is a loss in resolution in the second ALFA station. The multiple scattering angle was simulated by generating 500 protons @ 7 TeV parallel to z-axis directly in front of ALFA. Again there was a cut on *Total Minimum Energy* 100 MeV. The initial distribution in x is visible in Figure 9. It consists of two superimposed narrow and broad gaussian peaks.

The angle of the protons going trough a plane after the first and second ALFA station is plotted in Figure 10. From this figure one can make a rough estimate of the loss in resolution due to the multiple scattering angle. For example for a typical angle of $\Theta = 1 \cdot 10^{-6}$ rad after the first station, and a propagation length of $\Delta z = 4$ m, the resolution due to the multiple scattering becomes $\sigma_x \approx 2 \cdot \Theta \cdot \Delta z = 8 \mu\text{m}$.

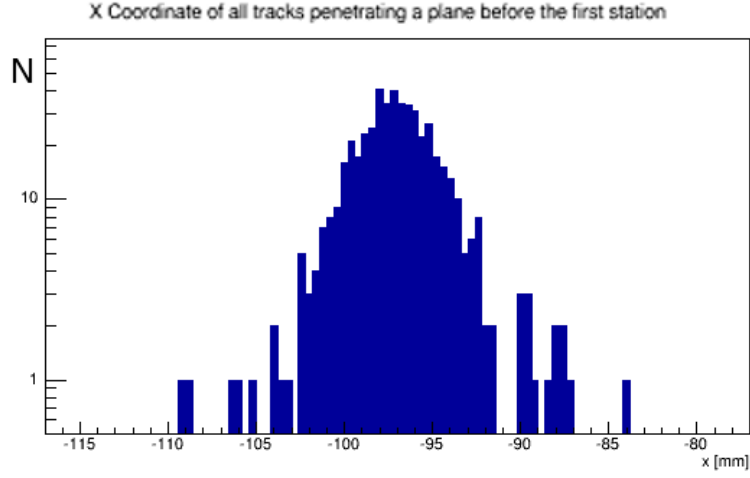


Figure 9: Initial distribution of the simulated protons in x . The distribution consists of two gaussian peaks. A narrow and a broader one.

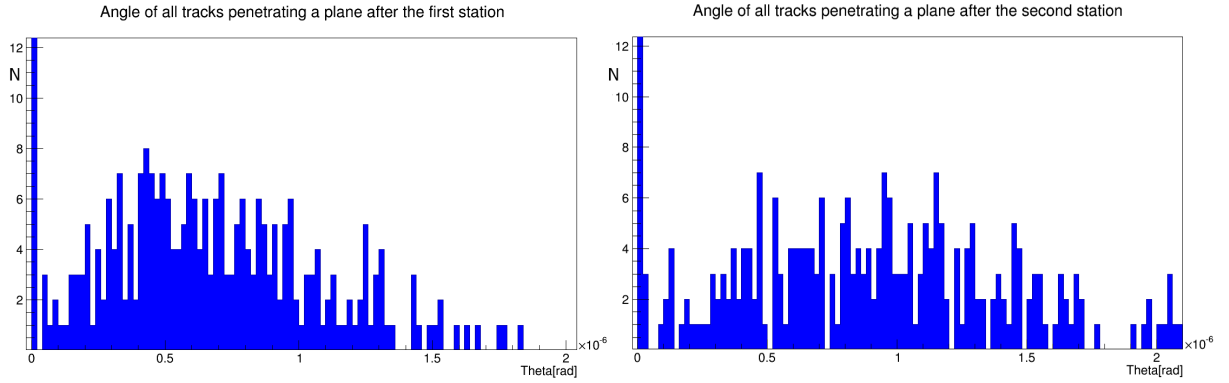


Figure 10: Angle between proton trajectory direction and z -axis at a plane after the first (on the left) and second (on the right) ALFA station. The high peak, which is not shown in full, at $\Theta = 0$ is caused by the protons which didn't interact in the detector. This is a result of the initial distribution of the protons as most of them are generated very close to the beam where ALFA is unable to detect them.

Acknowledgements

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References

- [1] <http://geant4.web.cern.ch/geant4/UserDocumentation/UsersGuides/ForApplicationDeveloper/html/ch05.html>
- [2] <https://svnweb.cern.ch/trac/atlasoff/browser/ForwardDetectors/ForwardSimulation>