Detector Simulation

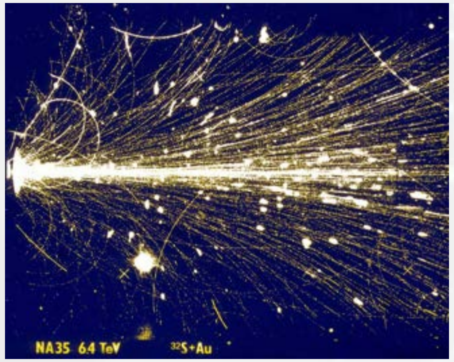
Why we need simulation?

- To model physics processes
- To design a set of analysis “cuts” that optimally find what we are looking for
- To understand how often we should see a certain type of event in our collision
- To train neural networks and other advancedanalysis techniques on specific signatures
- To simulate a new physics model invented by a theorist to see whether we can detect it

because .. it takes a lot of “stuff” to detect particles!

HEP experiment simulation
building blocks

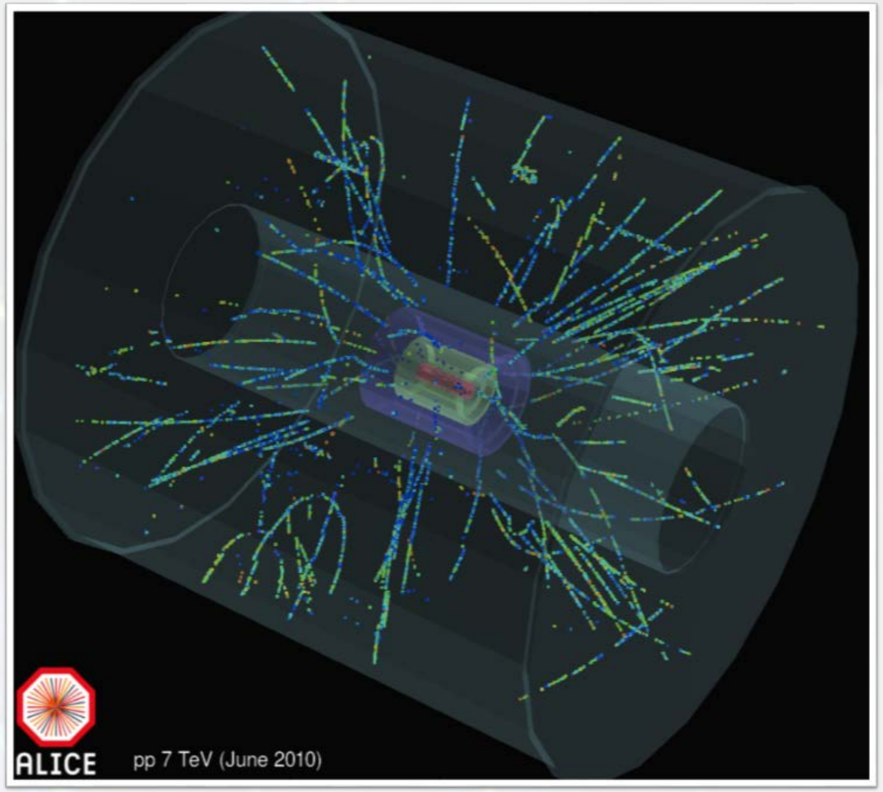
Event generation



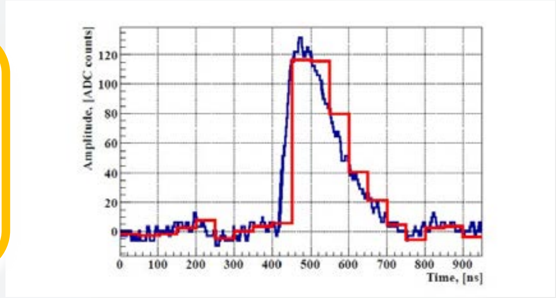
Particle interactions inside detector

Particle tracking

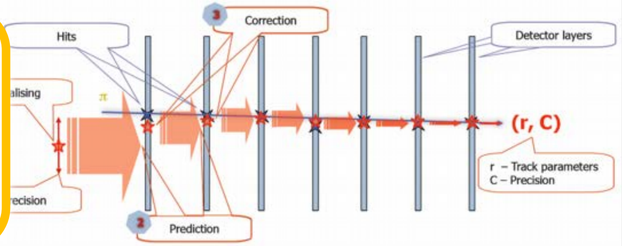
Register interactions in sensitive detectors

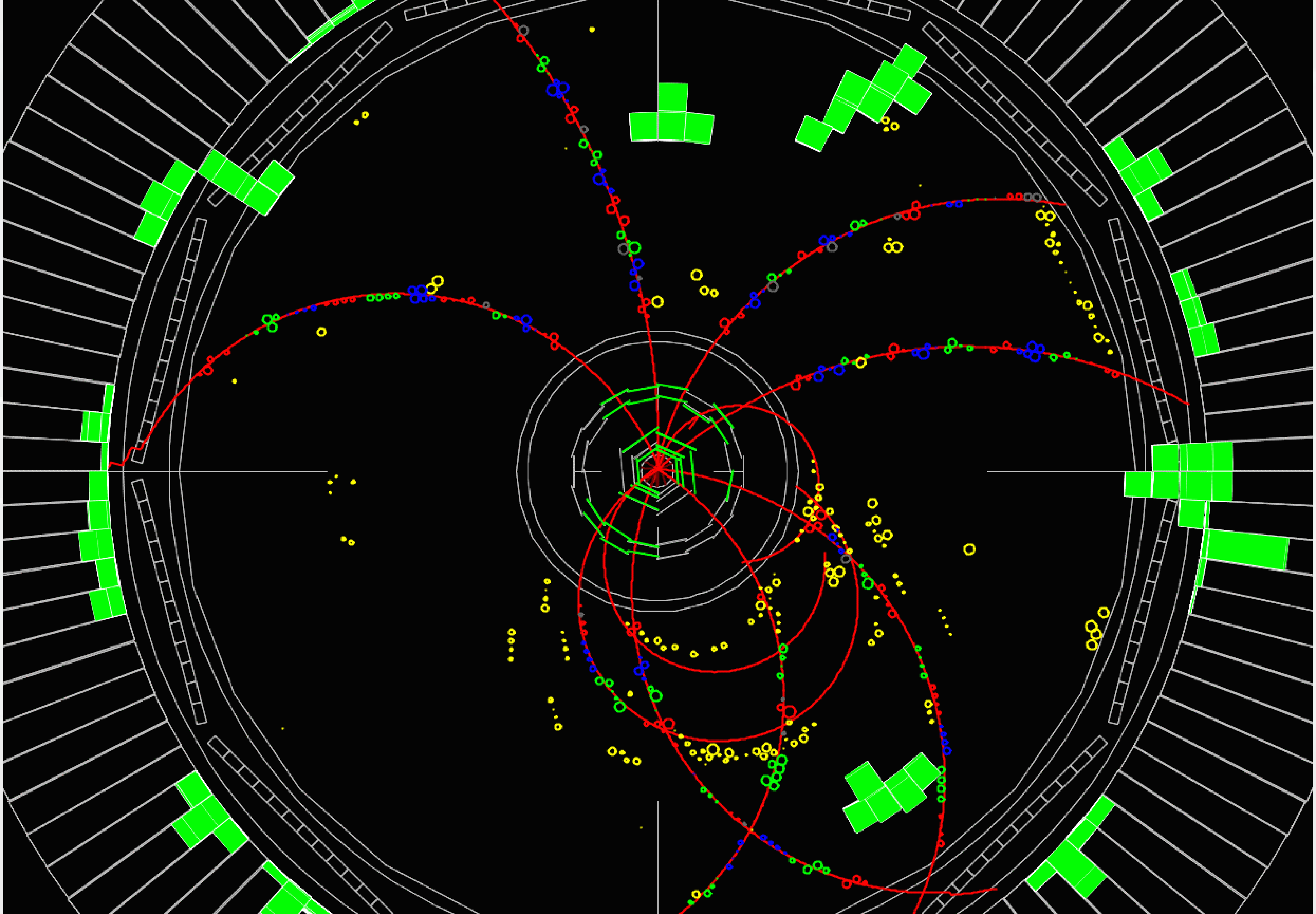


Detector signal digitization



Detector signal reconstruction





Detector simulation: the process

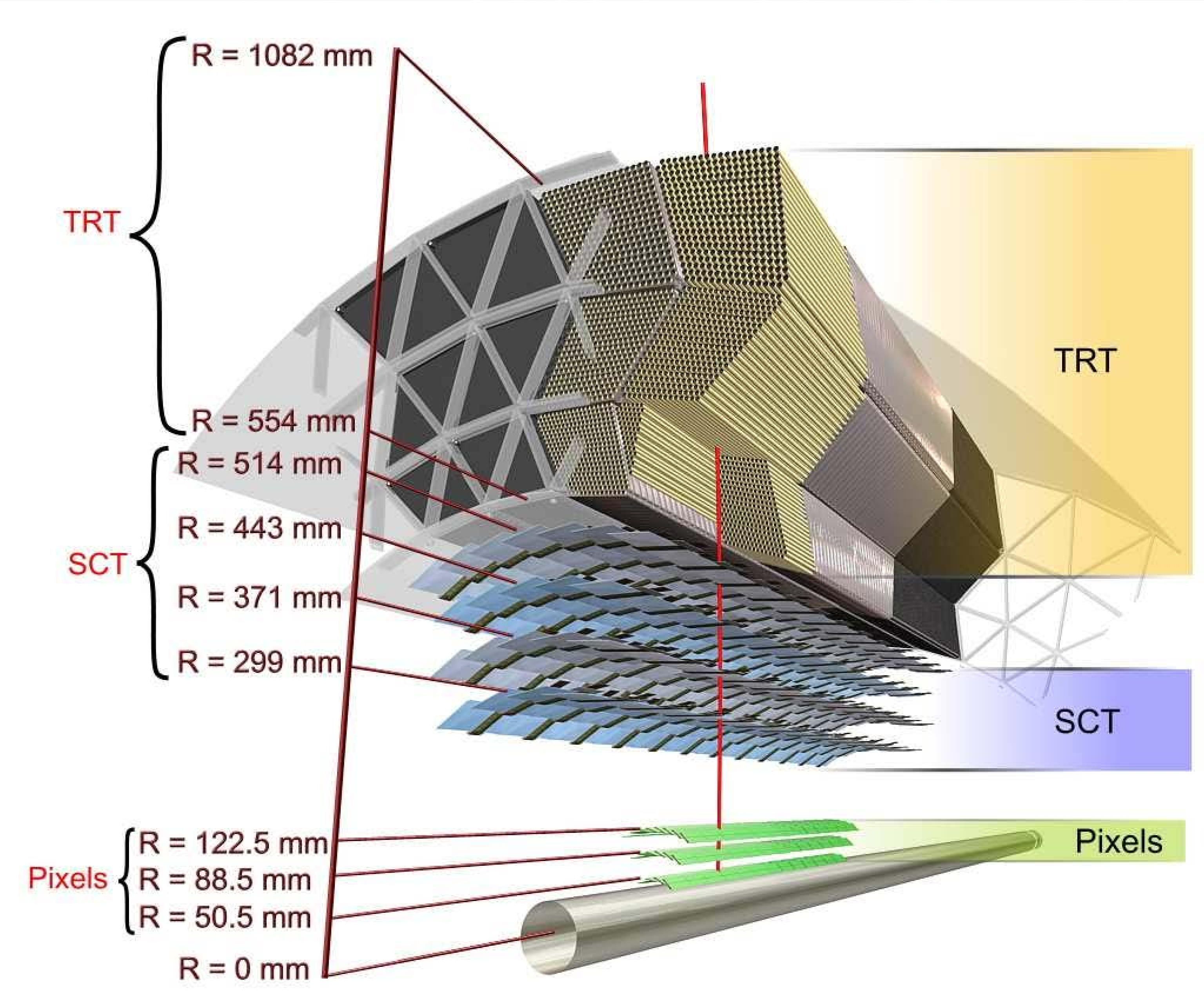
The **detector simulation** takes a set of particles, propagates them through the instrumented volume of the detector, calculating :

- particle energy loss
- particle trajectories
- secondary particles
- response of each of the detector elements to the passage of the particles

Detector Geometry and Materials

For the detector simulation an accurate (enough) detector description is needed.
The detector definition requires the representation of its geometrical elements, their materials and electronics properties.

The geometrical representation of detector elements focuses on the definition of solid models and their spatial position.


R = 1082 mm
TRT
R = 554 mm
R = 514 mm
R = 443 mm
SCT
R = 371 mm
R = 299 mm
R = 122.5 mm
Pixels
R = 88.5 mm
R = 50.5 mm
R = 0 mm
TRT
SCT
Pixels

Detector response simulation: digitization

The physical signal in the sensitive detector element, the detector response, is transformed with the help of electronics into a digital signal, which can be stored on tape or hard drive

The simulation of this step is called **digitization**, and the digitized data, the raw data (”digits”). Typical usages of the digitizer are

- Simulation of ADC and/or TDC
- Simulation of readout scheme
- Generation of raw data
- Simulation of trigger logics
- Simulation of pile-up

Geant4

http://geant4.cern.ch/

Geant4 is a C++ tool kit that tracks particles through matter, breaking the particle motion into small segments, applying appropriate physical processes and probabilities at each segment. It provides a complete set of tools for all domains of radiation transport:

- Geometry and Tracking
- Physics processes and models
- Biasing and Scoring
- Graphics and User Interfaces
- Propagation in fields.

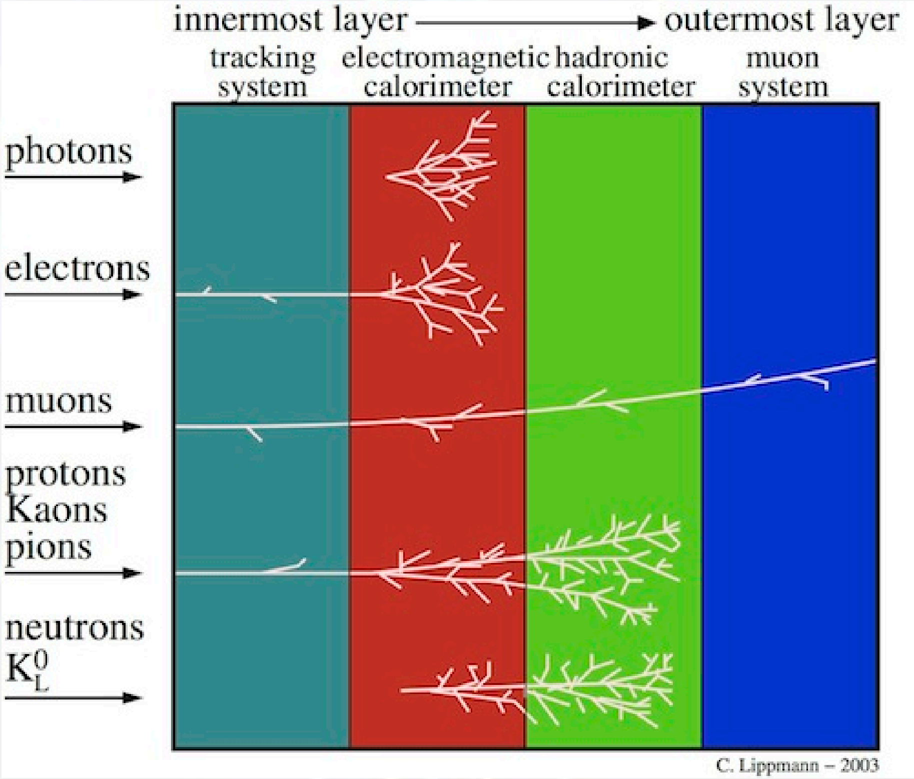
Geant4 physics processes describe electromagnetic and nuclear interactions of particles with matter, at energies from eV to TeV.

A choice of physics models exists for many processes providing options for applications with different accuracy and time requirements.

Simulation of Physics Processes

Physics processes describe how particles interact with the material.
Seven major categories are provided by Geant4:

- electromagnetic
- hadronic
- decay
- photolepton-hadron
- optical
- parametrization
- transportation



Simulation of Physics Processes

Electromagnetic physics processes

- Photon processes: Compton scattering, gamma conversion, photo-electric effect, e+e and muon pair production

- Charged particle Processsed (Electron/posítron, muons, ions …):
  - ionization and delta ray emission
  - Bremsstrahlung
  - positron annihilation
  - Multiple scattering

Hadronic interactions

- lepton-hadron interactions
- photonuclear and electronuclear reactions
- nucleus-nucleus reactions
- elastic scattering
- nuclear cascades
- fission, evaporation, break-up models
- low energy neutron interactions
- radioactive decay

Optical Photons:

- Cerenkov radiation
- Scintillation
- wavelenght shifting
- Absorption
- Rayleigh and Mie Scattering..

Geant 4 work flow

Pre-Initialization

Detector construction:
Geometry
Materials
EM Fields
Sensitivity

Physics List choice:
electromagnetic,
Hadronic high precison
neutrons…
+
Particle production cuts

Run-time

N events x

Primary vertex generation (from Event Generator):
Position
Direction
Energy
Particle type

→

Interaction with detector materials:
Production of secondaries,
Energy deposits
Energy loss
Multiple scattering etc

→

Register signals in sensitive detectors:
Deposited energy
Track momentum
Time
Position
Detector ID
Particle type
Etc

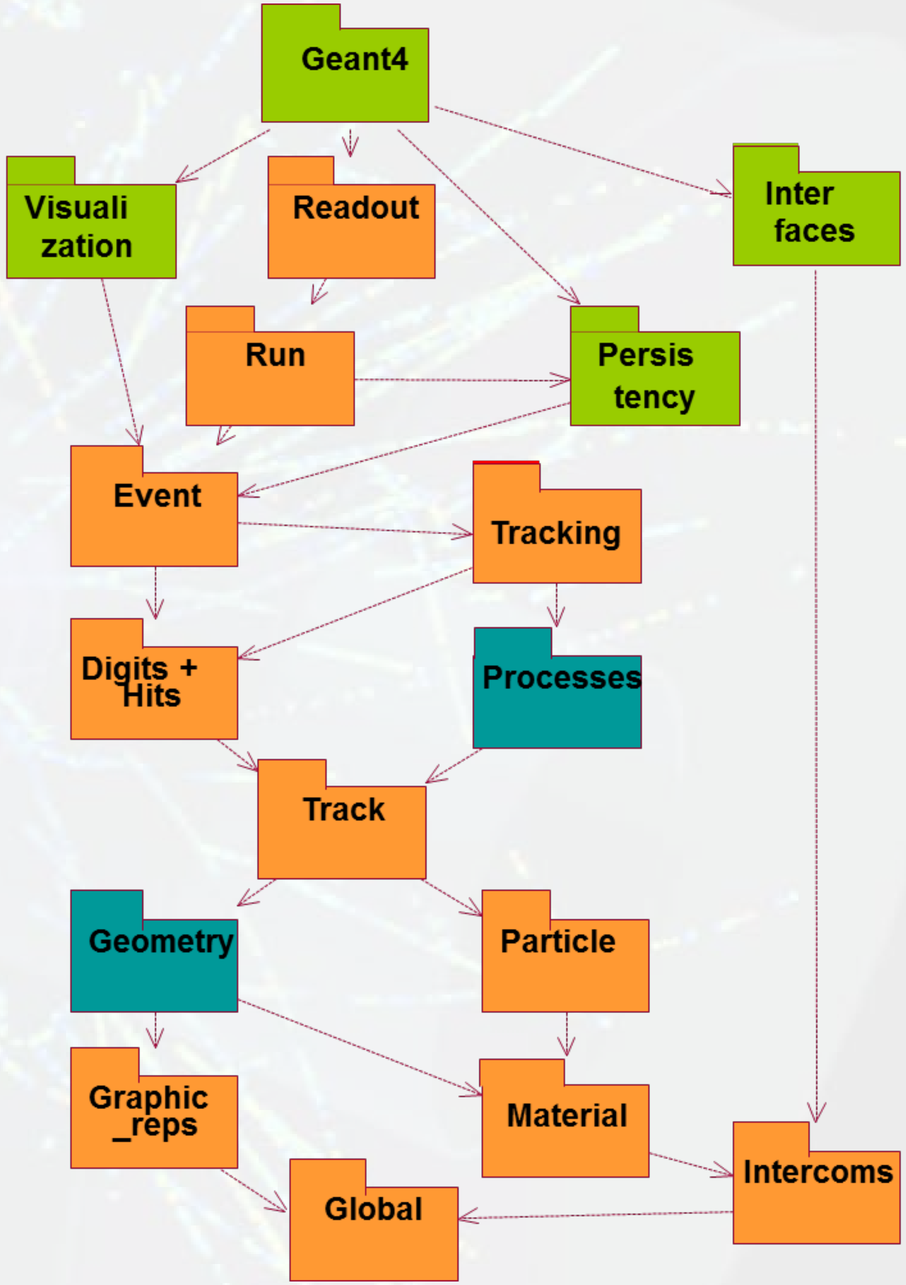
Geant4 kernel

Geant4 consists of 17 categories.

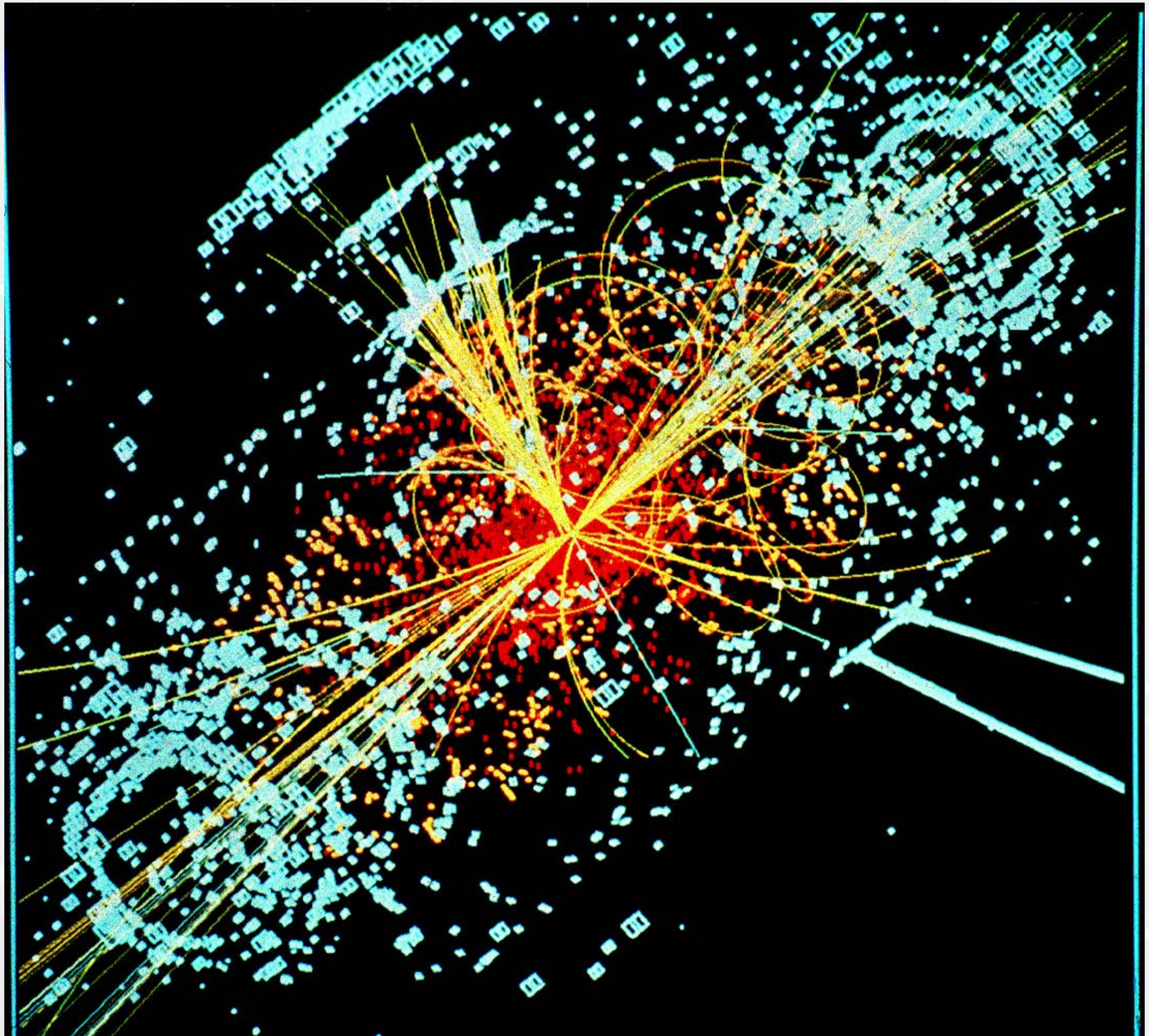
- Independently developed and maintained by WG(s) responsible to each category.
- Interfaces between categories (e.g. top level design) are maintained by the global architecture WG.

Geant4 Kernel

- Handles run, event, track, step, hit, trajectory.
- Provides frameworks of geometrical representation and physics processes.

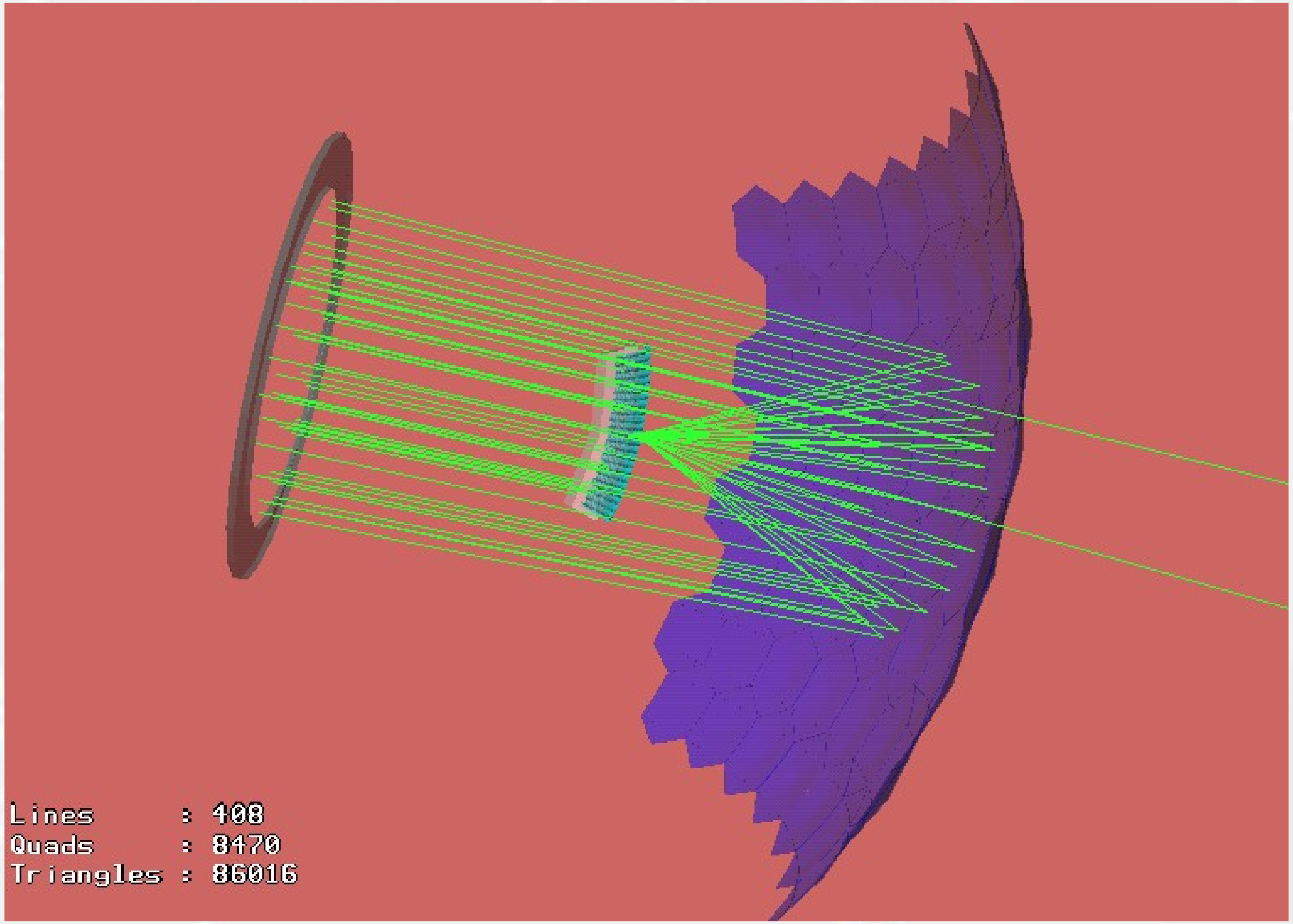


CMS simulated event

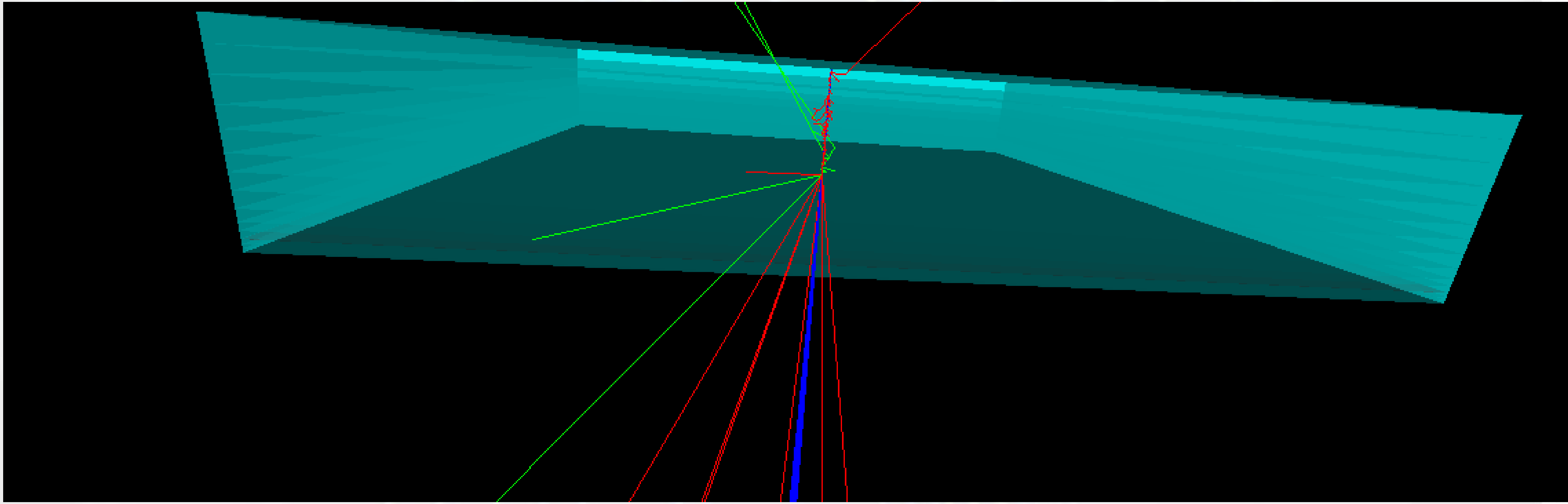


Geant4 @LIP

Simulation of a Fluorescence Detector of the Pierre Auger Cosmic Ray Observatory

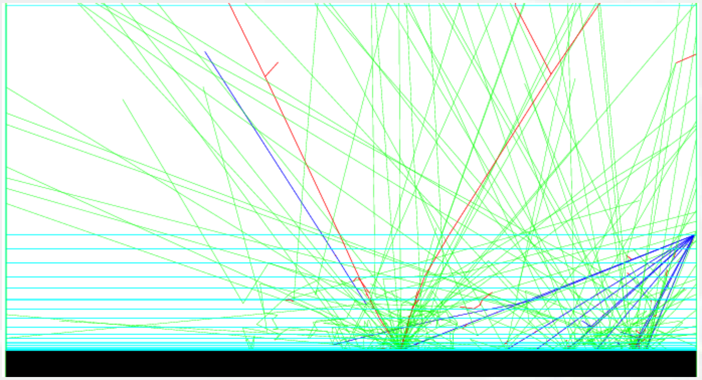


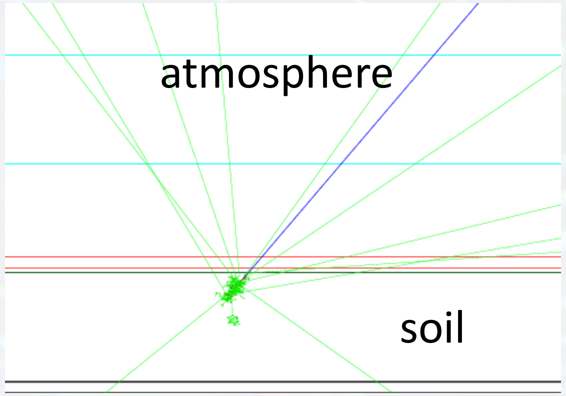
Geant4 @LIP

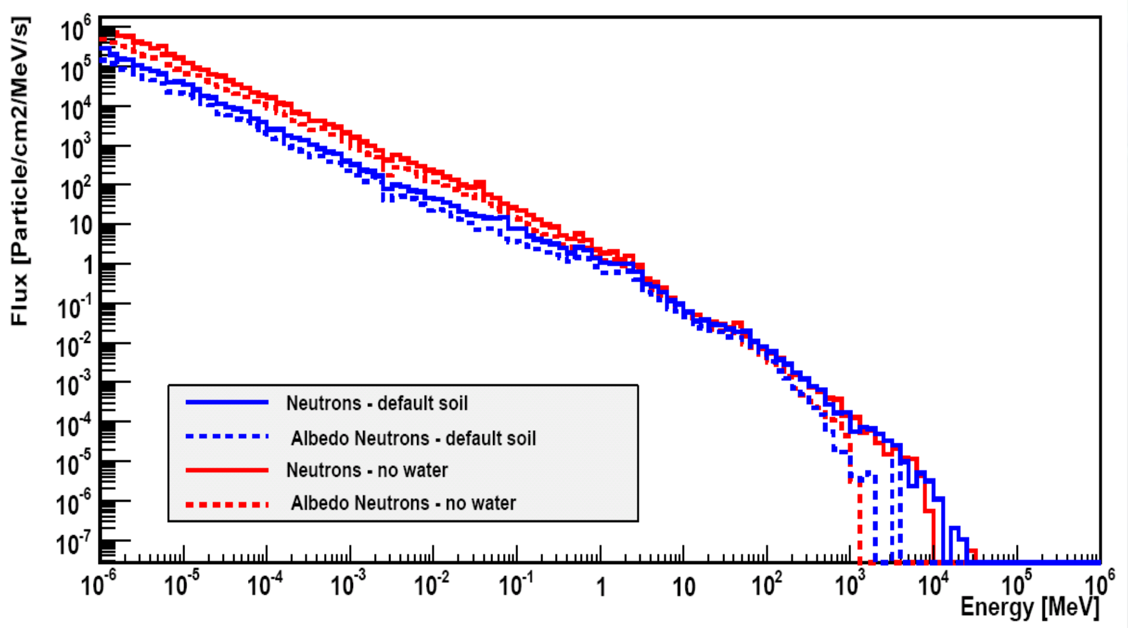


Simulation of particles interacting in the Martian atmosphere

detailed Martian Energetic Radiation Environment Model



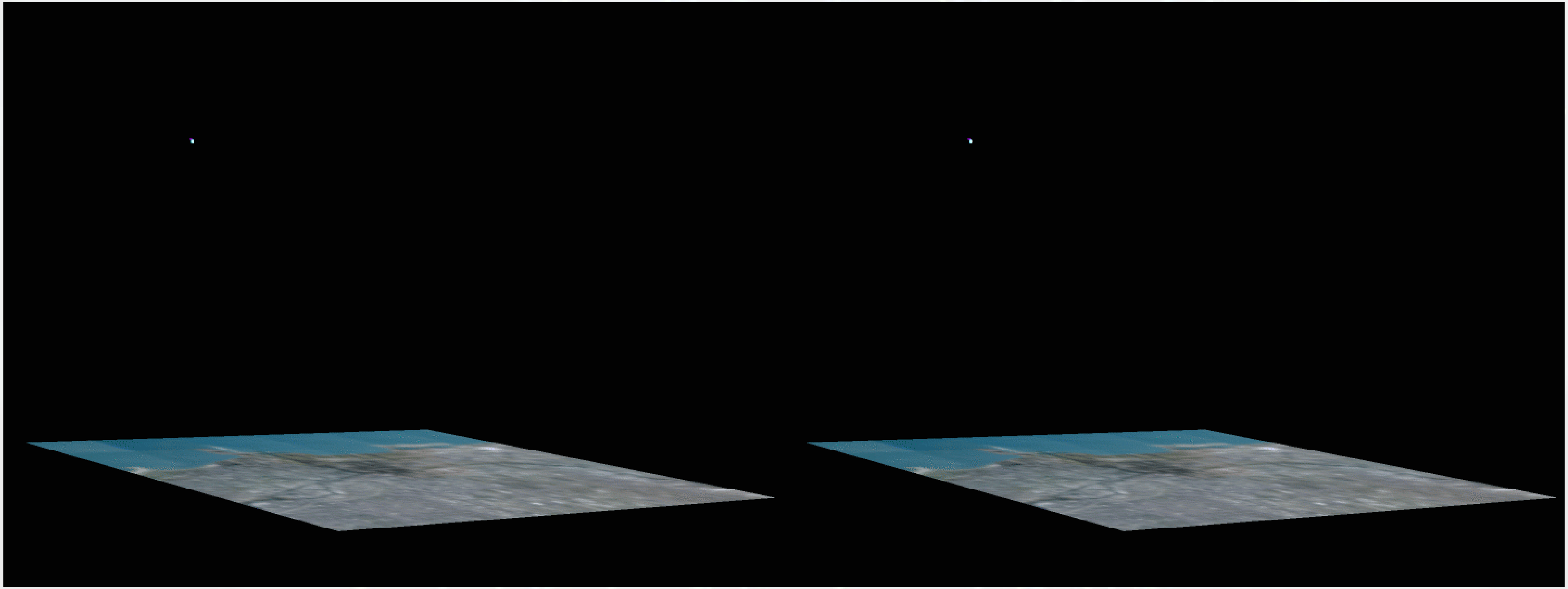




Neutron spectra for a **default soil composition** (blue line) and corresponding albedo (dashed blue line) and neutron spectrum (red line) and corresponding albedo (dashed red line) for the same soil composition but from which the **water contribution was withdrawn.**

Detector simulation enables the understanding of complex systems and interactions. It is a fundamental tool in High energy Physics and also in fields such as radiation interaction studies with Space and Biomedical and radiological applications.

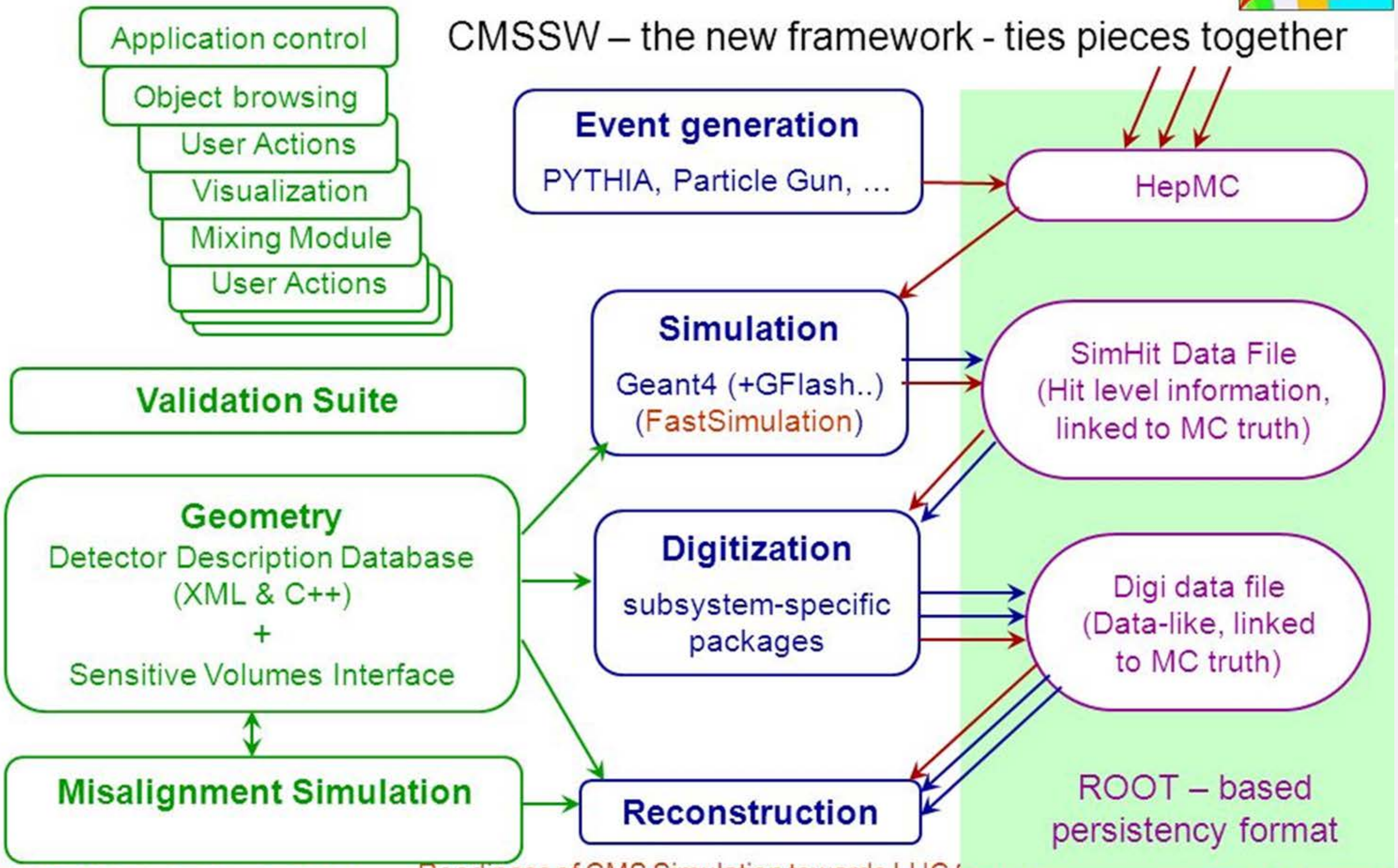
It is also a valuable tool for to visualize the complex interactions and is can be used to build virtual experiments!



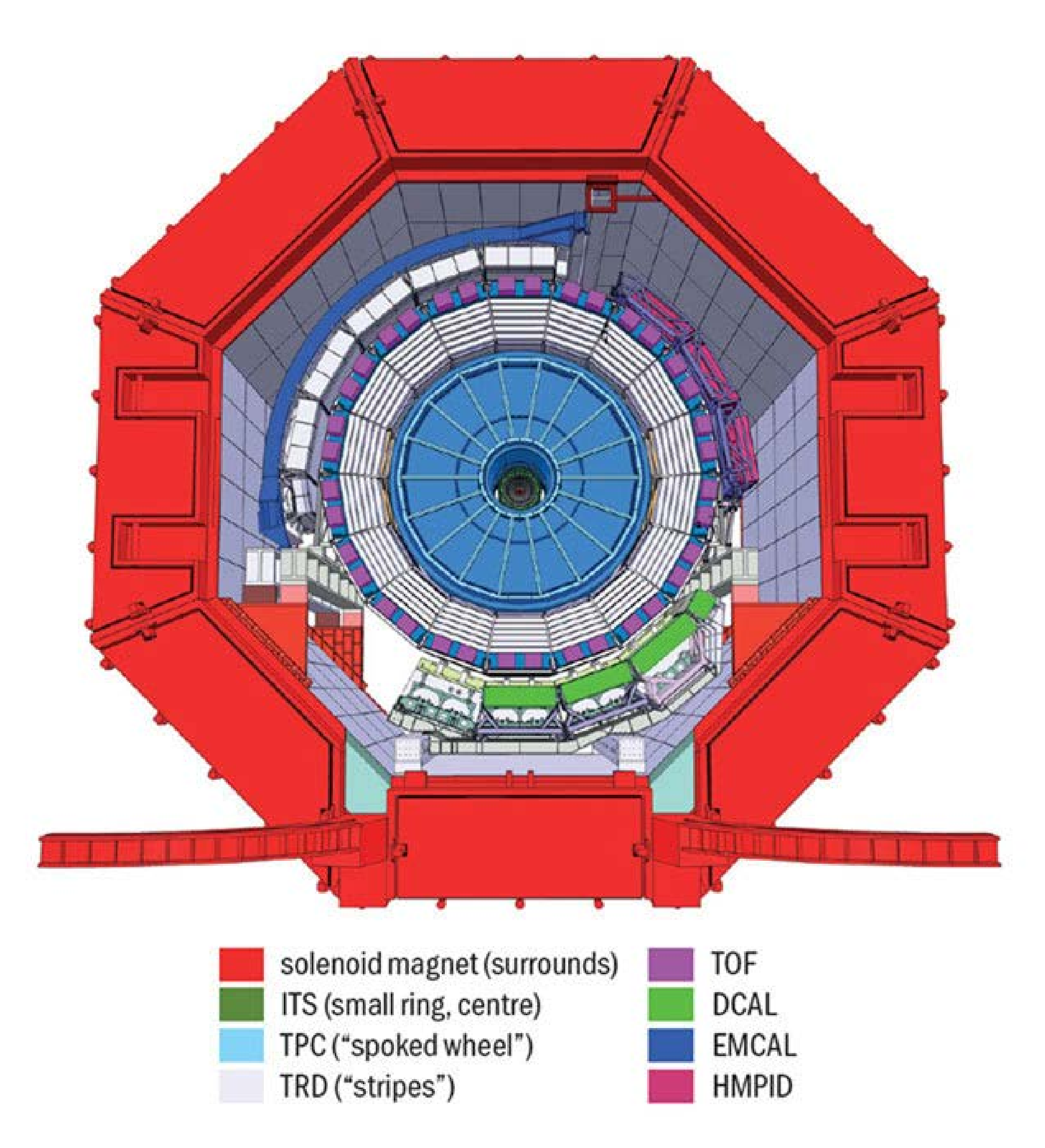
200GeV gamma ray shower, starting 5km high.

backup

Simulation Software – CMS Solution



ALICE as an example



Solenoid:
magnetic field enabling charged particle momentum measurement

ITS and TPC : trackers
register the passage ofd charged particles

TOF: Time of light detector
register the passage of charged particles with high time resolution

DCAL and EMCAL: calorimeters
Record the energy deposited by charges and neutral particles

TRD: Transition radiation detector
Fro electron identification

HMPID: cherenkov imaging detector
For high momentum charged particle ID