Heavy ion simulation in Geant4 with JQMD code

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Outline

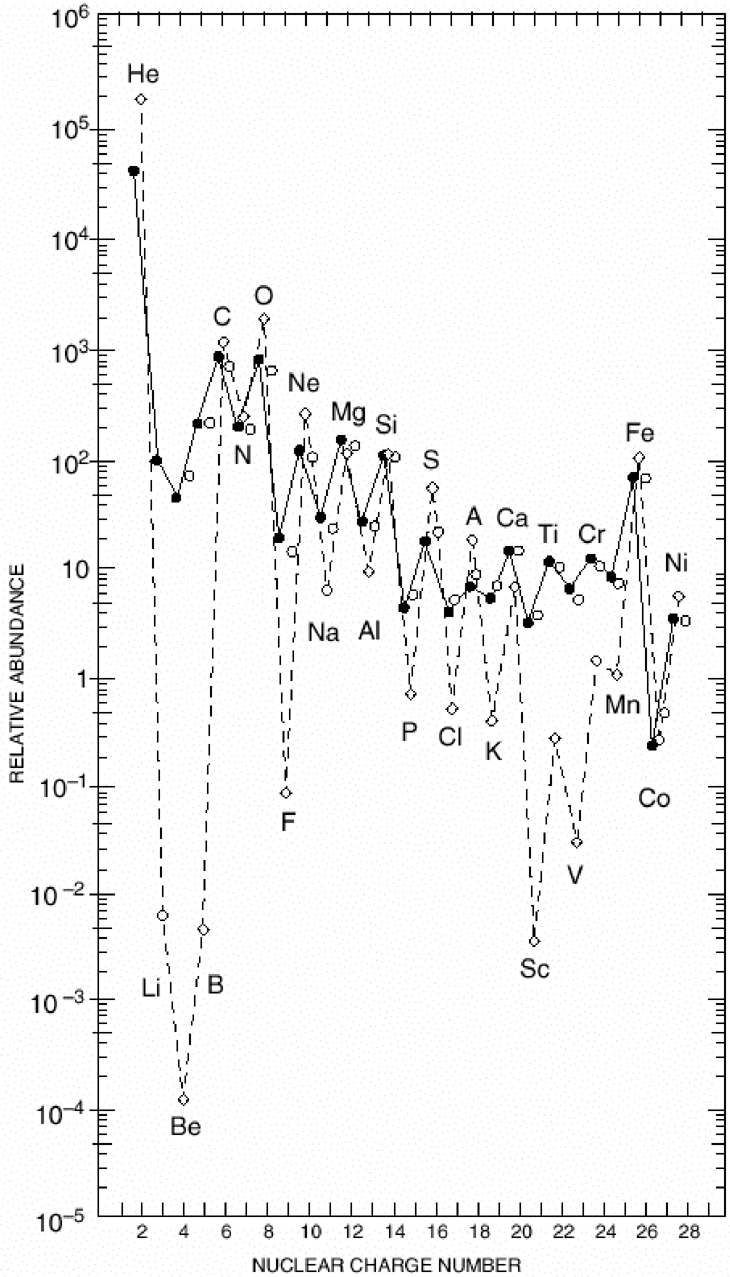
- Introducing joint activity of SLAC and JAERI for interfacing Fortran code of JQMD to Geant4
  - To satisfy the urgent need for beam test simulation of a SLAC experiment.
- Contents
  - Importance of heavy ions for simulations in space applications
  - What is JQMD
  - Interfacing JQMD to Geant4
  - Demonstration
  - Summary

We tried to connect Fortran code of JQMD to Geant4 which is written in C++.

Advantages of this method are

- It is more convenient interfacing to Fortran code directly than re-writing the code in C++.
- In the process of re-writing, new bugs may enter into the code. We can avoid this situation.
- Once the interface is established, the Fortran code and Geant4 can be updated independently.
- No copyright problems associated with re-writes.

Now, we discuss the importance of heavy ions in simulations of space applications



Relative abundances of elements in cosmic rays and solar system

Simpson (1983)

solid line: cosmic rays

open circle: high energy

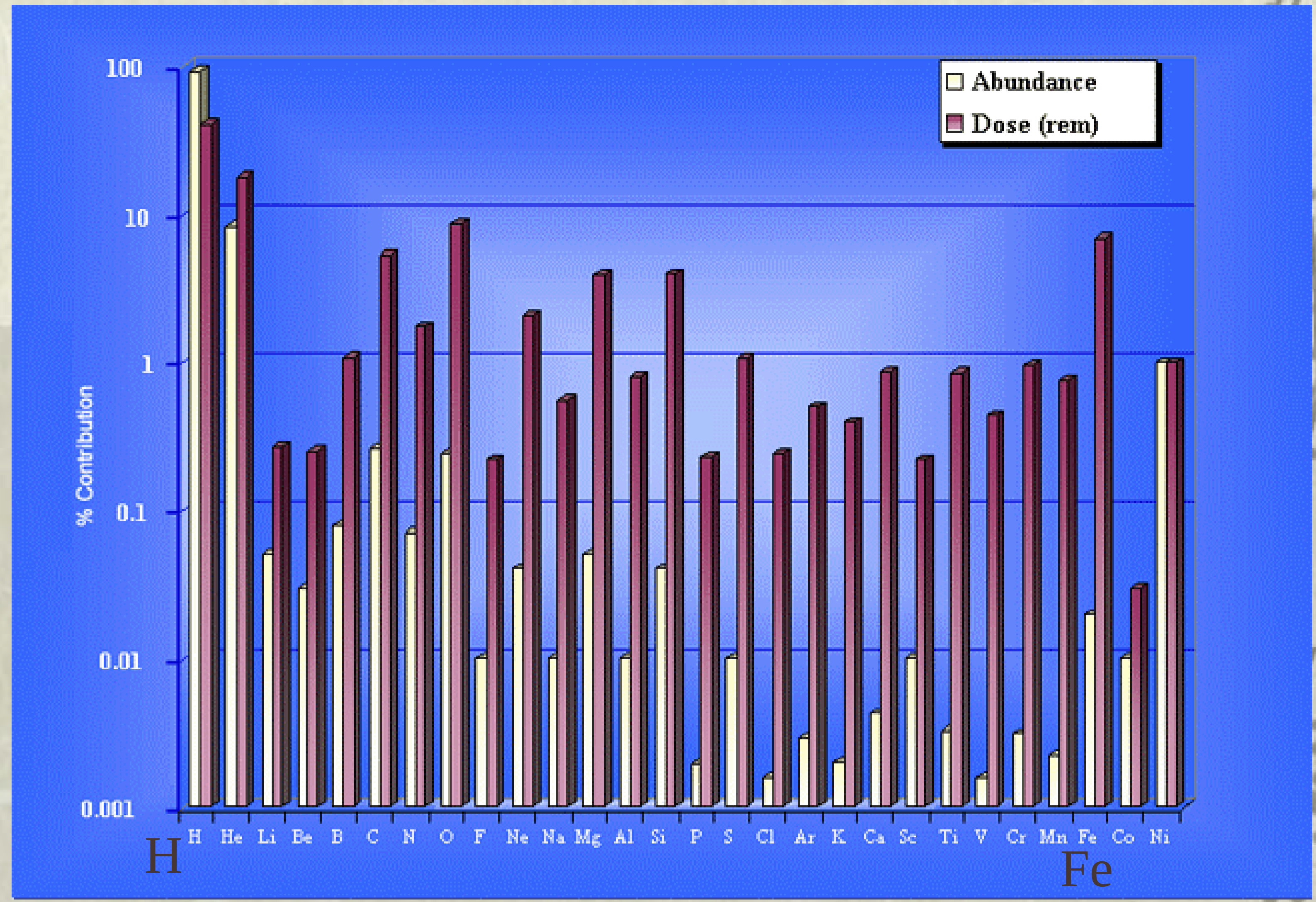
close circle: low energy

dashed line: the solar system

Many kinds of heavy ion are contained in cosmic rays.

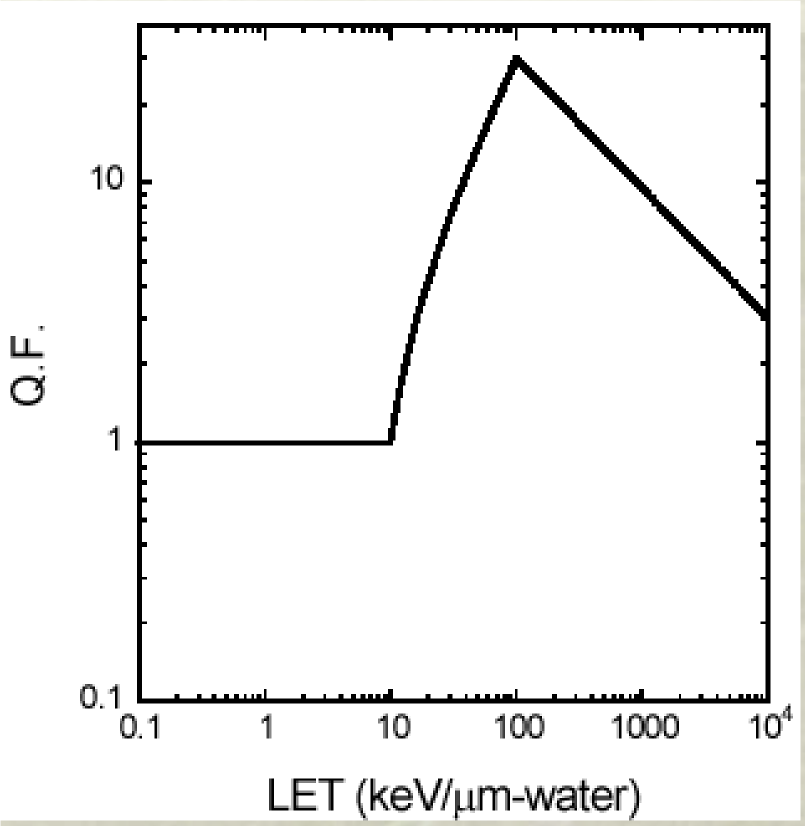
90% of cosmic rays are protons, up to 10% are heavier nuclei.

Comparison between Abundance and Dose(rem)



- From Web page of Space Radiation Health Project / JSC / NASA

QL relation in ICRP pub. 60



- Biological radiation damage is not a linear function of LET (dE/dx).
- Minimum ionization level of Iron ion is located around

the top of QL function.

HZE particles

- HZE (high energy and high charge) particles are less abundant, however they possess significantly higher ionizing power with a greater potential for radiation-induced damage not only for astronauts but also electronic instruments onboard spacecraft.

Secondary Particles

- Many neutrons, protons, gamma rays, mesons and fragmented heavy ions are produced by interaction between primary cosmic rays and shielding material of spacecraft.
- Some secondary particles have larger penetration power than the primary particle.
- Radiation weighting factor of neutrons is high.

These secondary particles are also important for the radiation environment in spacecraft.

Heavy ions in Geant4

- Definition of heavy ions
- Processes available in Geant4
  - Transportation
  - Several physical processes for heavy ions, for example, ionization process can be applied to heavy ions.

To calculate nucleus-nucleus interactions, we made new process which uses JQMD

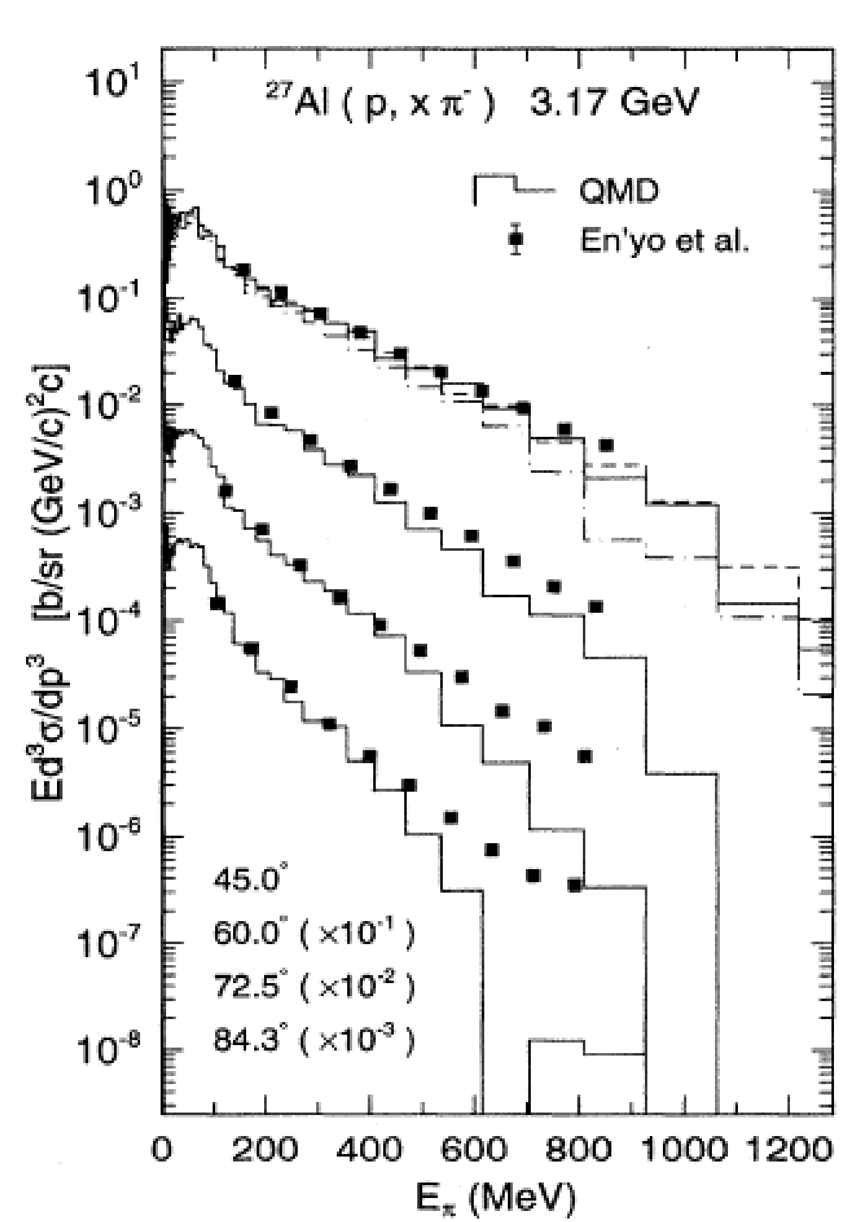
JQMD

- QMD (Quantum Molecular Dynamics) is quantum extension of classical molecular-dynamics model.
- QMD model is widely used to analyze various aspects of heavy ion reactions
- JQMD (Jaeri QMD) is a QMD code developed by JAERI (Japan Atomic Energy Research Institute).
- Written in Fortran

JQMD (cont.)

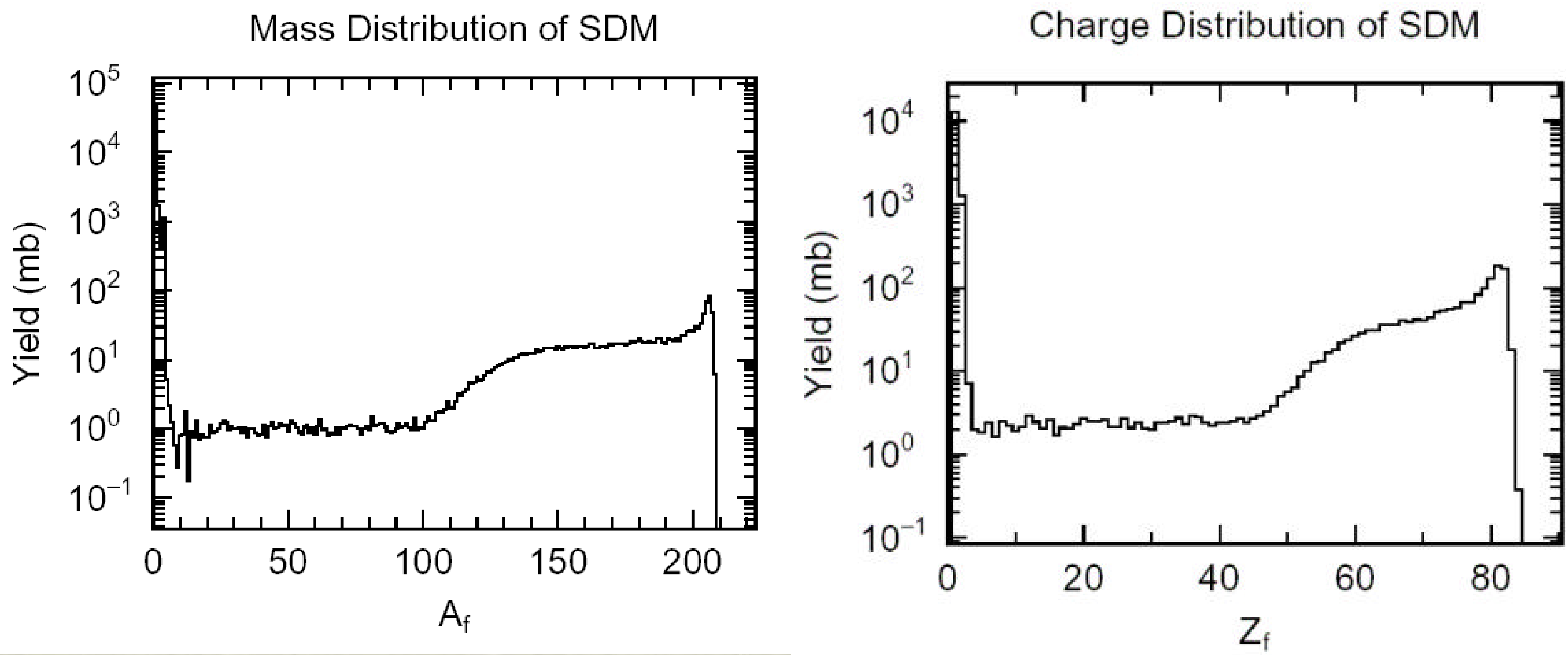
- Energy Range of JQMD
  several 10 MeV/N ~ about 3 GeV/N
- Projectile particle species
  nucleon (including proton) and pion
- SDM (Statistical Decay Model)
  JQMD includes SDM, i.e., evaporation and fission decays occur for excited nucleus
- Detailed description of JQMD is given in Niita et al, Physical Review C 52 (1995) 2620
- PHITS code niita@hadron03.tokai.jaeri.go.jp

Pi-minus from 3.17 GeV on Al

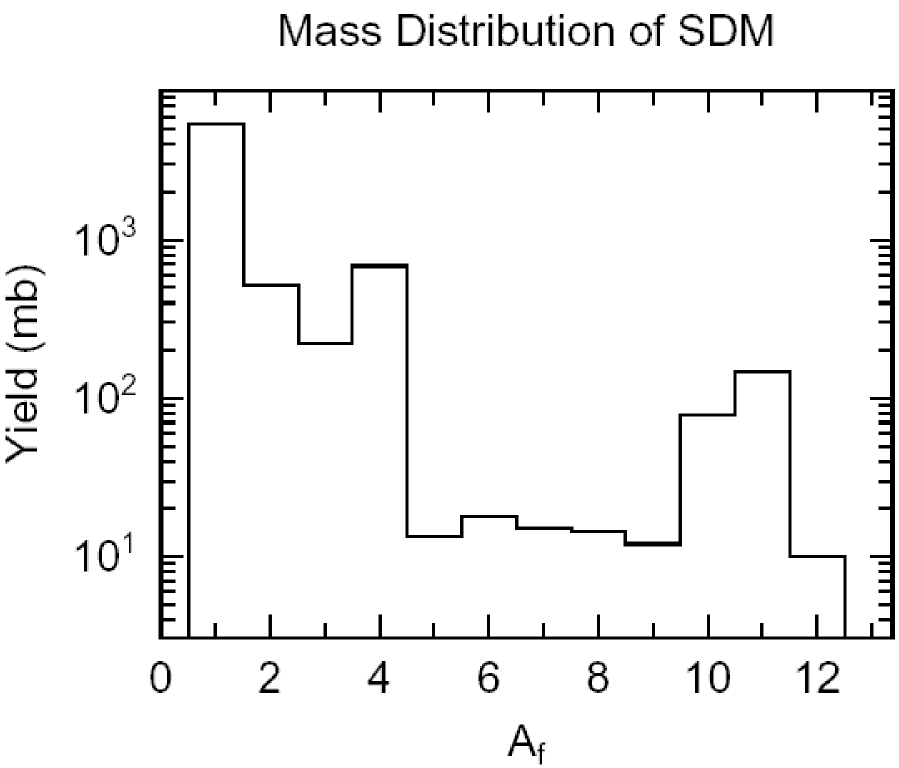


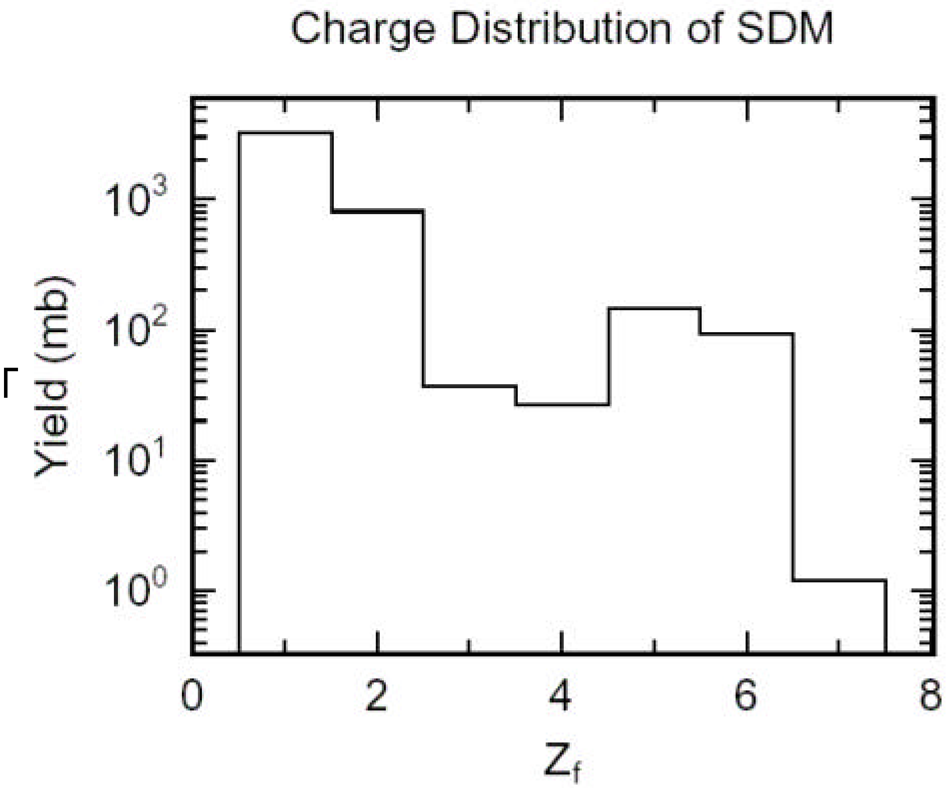
Niita et al,
Physical Review
C 52 (1995) 2620

Fragment Ions Production 3.17 GeV p on Pb



Fragment Ions Production
1 GeV/N C on C





In order to simulate heavy ions with Geant4, we made an interface between JQMD and Geant4.

So that, we made new process to deal with nucleus-nucleus interactions.

What Does a Process Do in Geant4

- Decides when and where an interaction will occur (GetPhysicalInteractionLength)
  - Cross section
- Generates the final state (DoIt)
  - Reaction model

Cross Section for heavy ions GetCrossSection()

- Triphathi Formula
  - NASA Technical Paper 3621 (1997)
  - G4TriphathiCrossSection
- Shen Formula
  - Nuclear Physics. A 491 (1989) 130
  - JQMD2G4ShenCrossSection

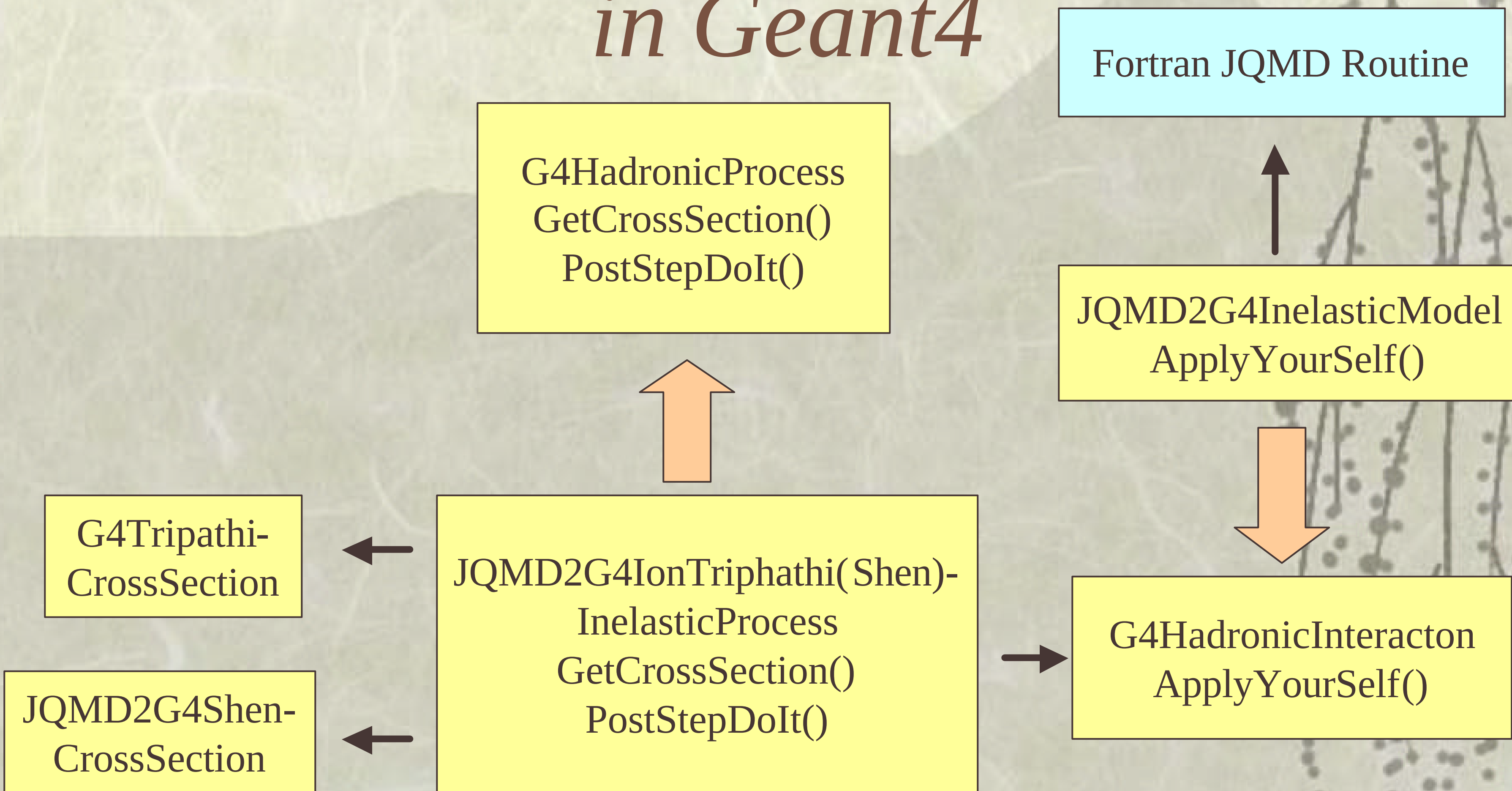
Reaction for heavy ions ApplyYourself()

JQMD2G4IonInelasticModel

In this class,

Fortan JQMD Routine is called.

Framework of Ion Interactions in Geant4



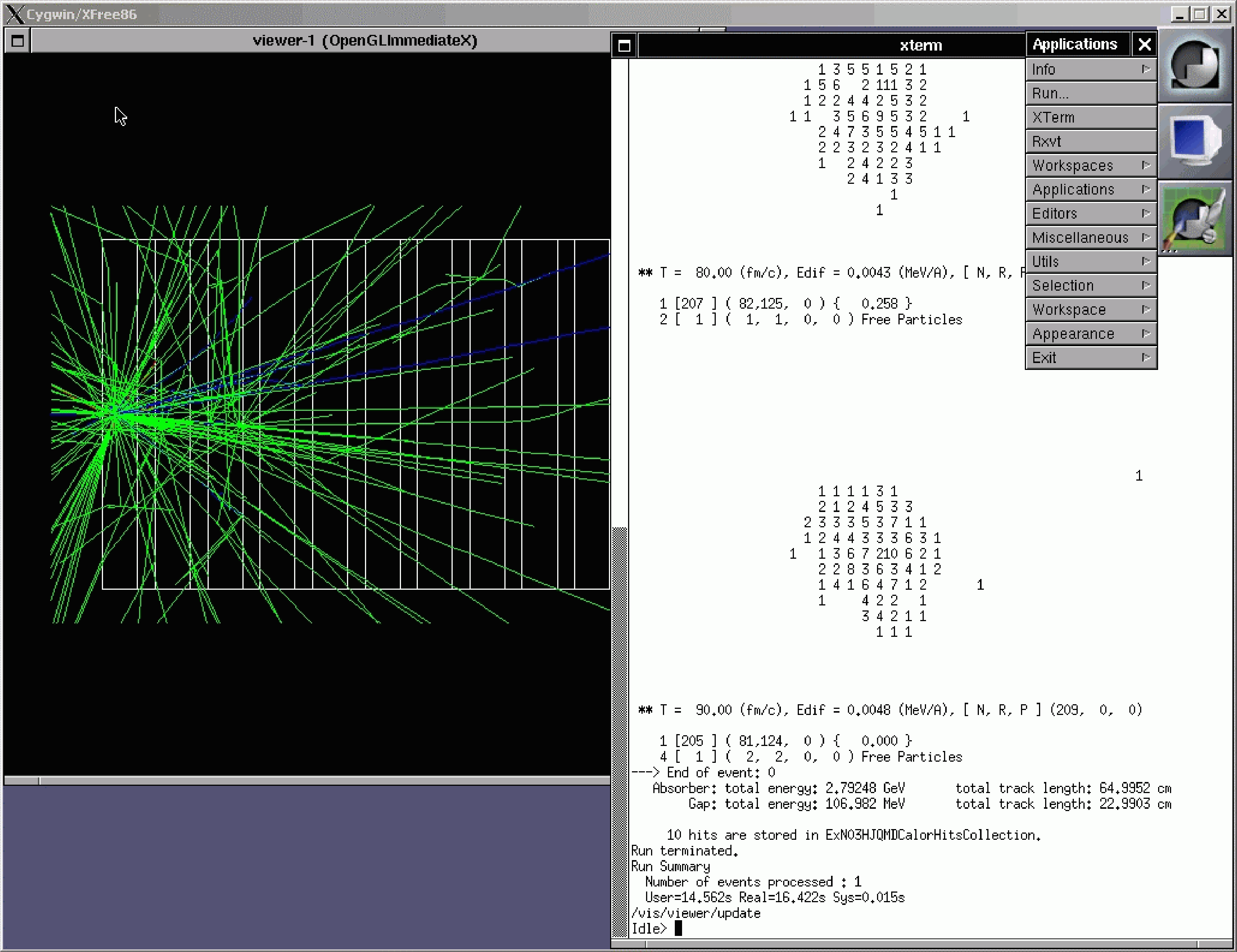
Using Fortran routines from C++

- Tested system
  - OS: Red Hat Linux 7.2 (6.2)
  - Compiler: gcc-2.95.3 (2.91.66 with egcs-1.1.2)
- We did not test this interface in other OS and compilers. Perhaps small modifications will be required.

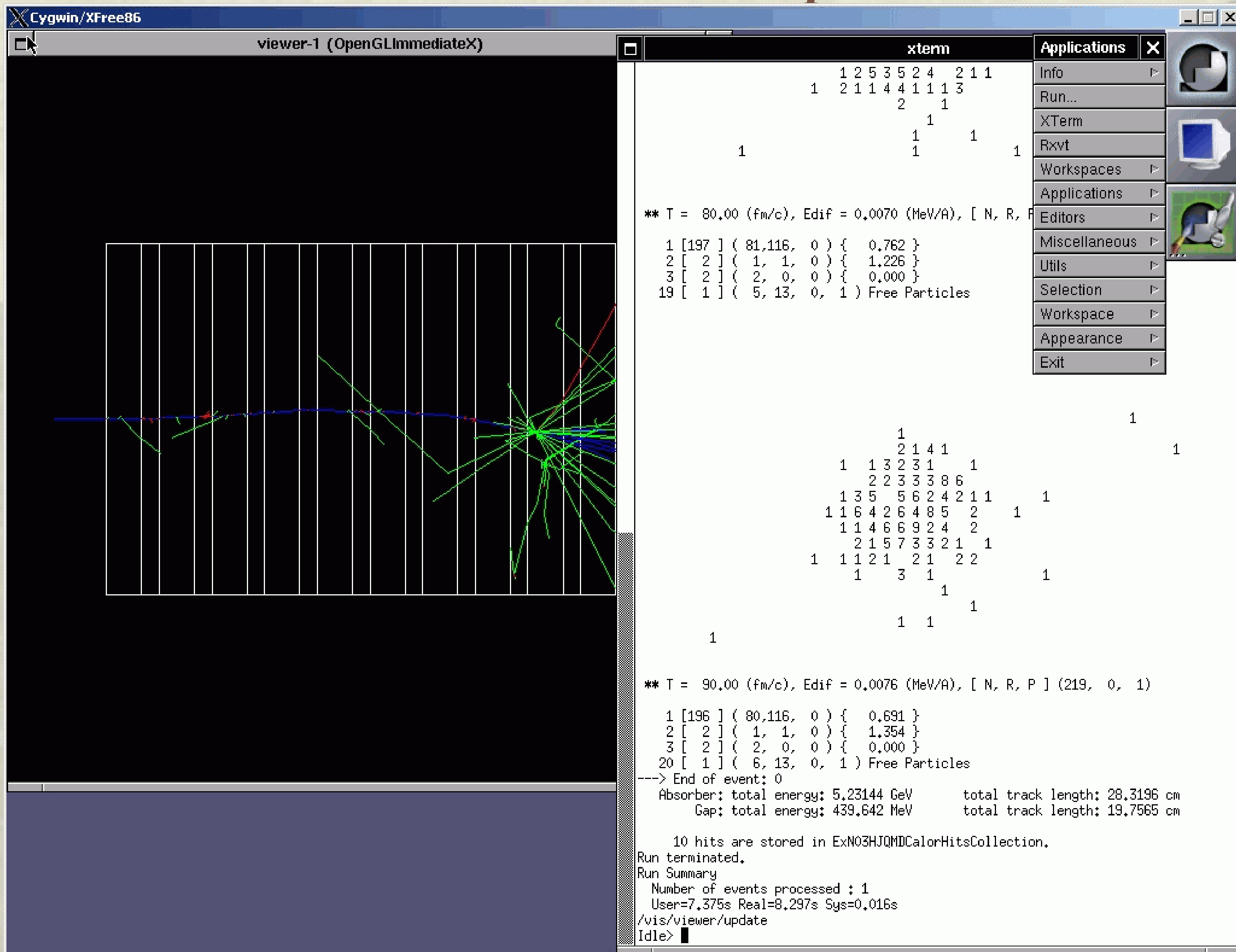
Demonstrations

- N03HJQMD
- ICRU Sphere

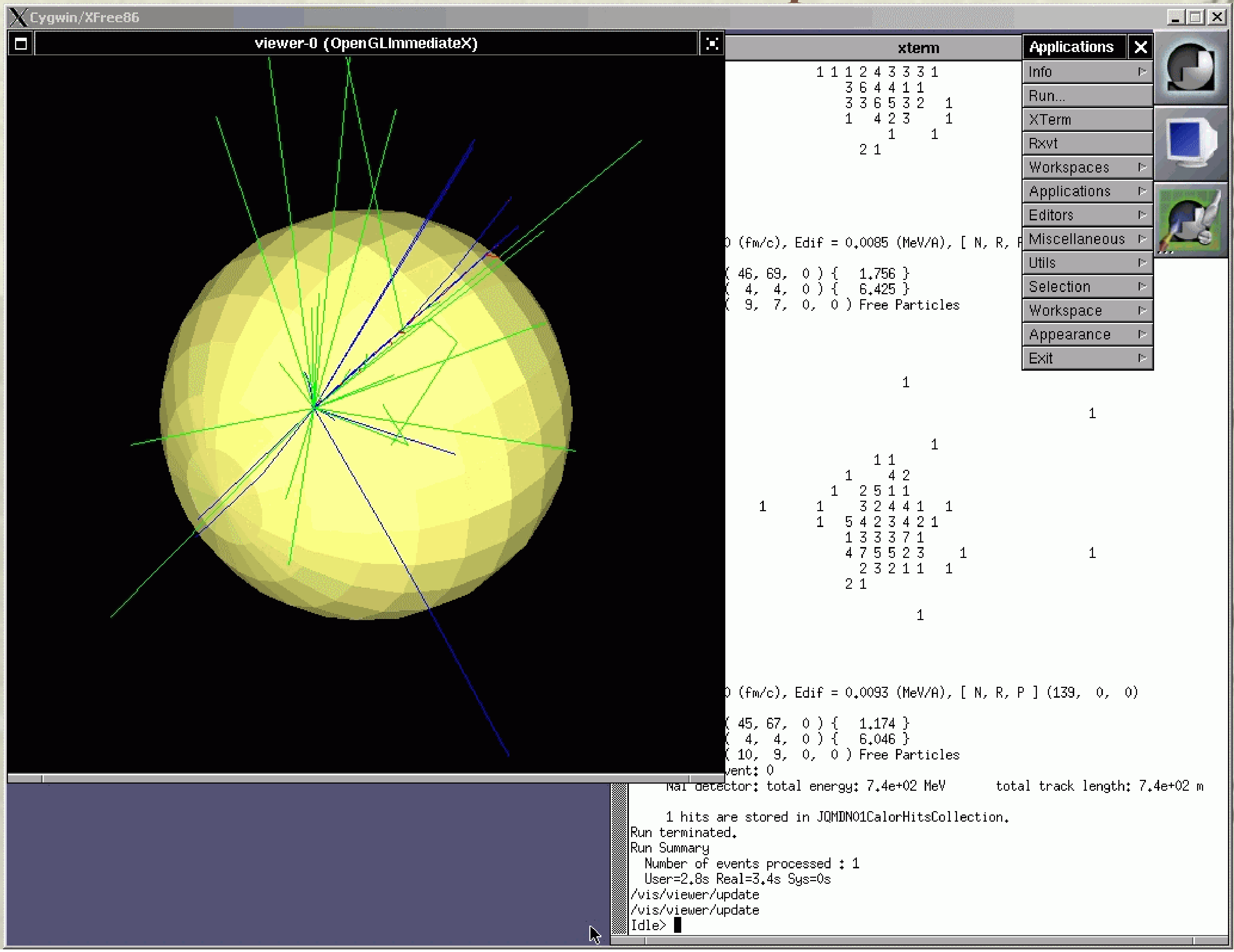
Simulation snapshot 1



Simulation snapshot 2



Simulation snapshot 3



Conclusions

- We successfully developed the interface between JQMD and Geant4.
- With this interface, we can simulate heavy ions in complex Geant4 geometries.
- Preliminary test results agree well with data. Much more validation to be done.

Further Studies planned in

- Ionization loss and multiple scattering processes dedicated to heavy ions
- Additional Cross Section tables
- Performance tuning