Applications of Geant4 for Education

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Contents

- Motivation
  - Geant4's aspects for education;
    - Not to learn Geant4 but to use Geant4 to learn
    - Workshop in 2005
- Educational examples in other fields
- Geant4's tool kits for educational applications
  - Geant4Py; Python wrapper of Geant4
  - WxPython; Python wrapper of wxWidgets
  - Visualization and analysis tools on the Python s/w bus
  - Web service
- Examples
- TODO : Courseware

Questions

- This topic isn't the main stream of simulation applications but will contribute for better understanding of the microscopic phenomena and improvement of interdisciplinary understanding of macroscopic measurements
- Which level?
  - – University, and if possible Professionals
- Which Learning style?
    - Lab works, Hands-on, projects in one CD
    - Distant learning
- How can we create materials?
- Who can participate for creation? What knowledge is required?

Educational uses of Partial Differential Equation-based simulations

- Create application oriented models to fill the gap between the PDEs and phenomena and to understand them more deeply
- Reports from Comsol MultiPhysics Conference 2005
  - To investigate the basic laws of physics: Tuebingen: Theoretische Physik
  - To teach Biomechanics and Biomedical Physics: Uppsala, Molecular Biotechnology
  - To Teach and Discover Transport Phenomena: Rensselaer Polytechnic, Chemical and Biological engineering
  - To Teach Chemical Engineering: Worcester Polytechnic
  - For Bioengineering Education: Penn State Univ. Bioengineering

Teach Biomechanics and Biomedical physics through models

- J. Gantelius, Uppsala Univ.
  - Blood flow and Gas exchange in an Alveolus
  - Model the treatment of a liver cancer tumour through resistive heating of an inserted electric probe
  - Structural-Fluid interaction in a Network of Blood Vessels
    - Convey a more practical feeling of the meaning of the equations
    - Real examples, solve real problems
    - Apply theoretical knowledge to numerical methods
- P. J. Butler and M. C. Ferko of Penn SU
  - 3-D vascular graft simulation: structural fluid interaction
    - Poiseulle flow of blood and its interaction with the elastic wall
    - Students gained new insight that was otherwise unobtainable either by experiments or by conventional analytical models.

Geant4's educational aspects

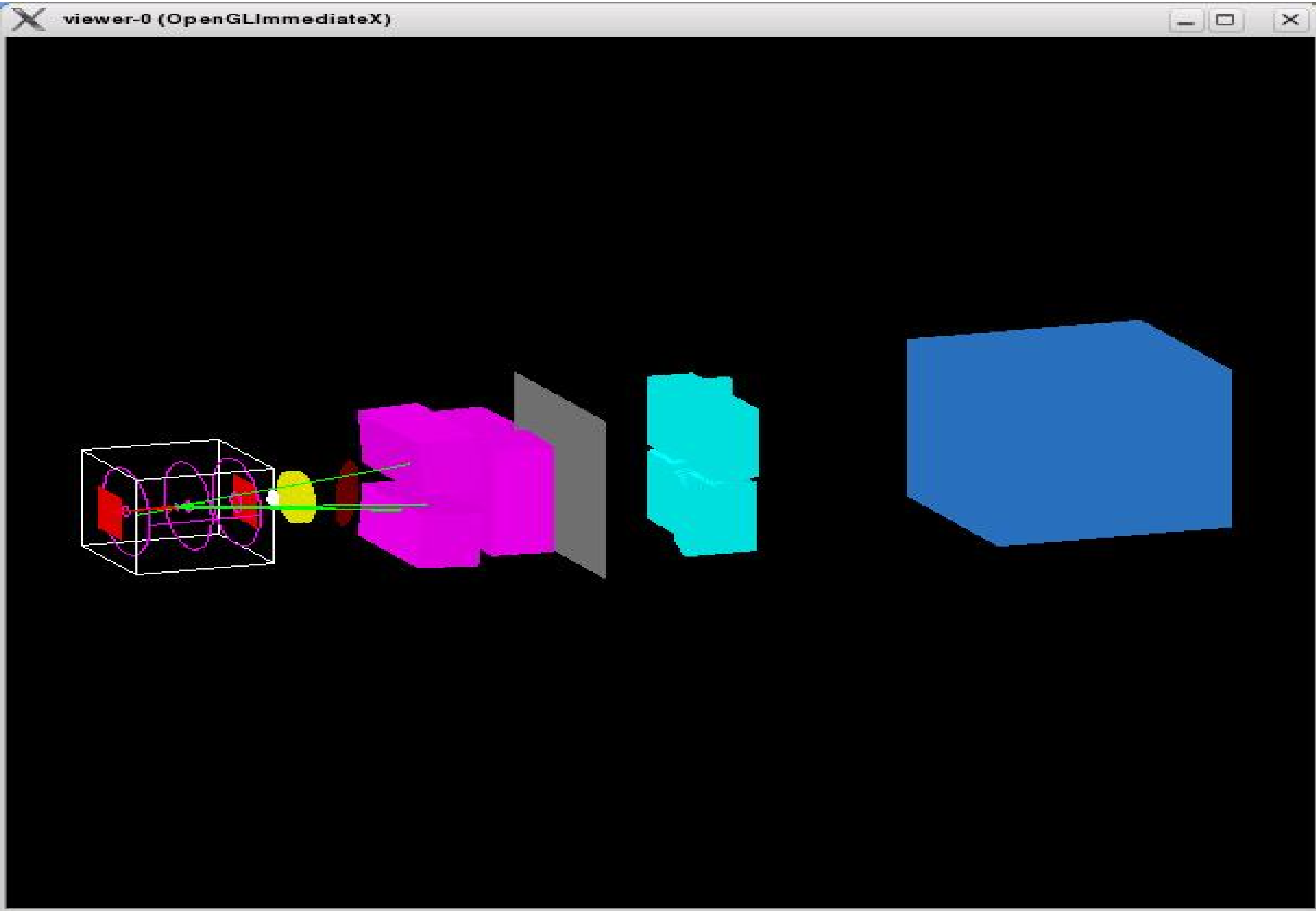
- Geant4 is based on a set of phenomenological knowledge, each of them having its own limitation of applicability, and can be used to learn the real life of various fields; physics, space, medical etc..
- Geant4 is capable of handling complex geometries encountered in the real life of various fields
- We expect that the educational materials will fill the gap between microscopic phenomena and the macroscopic quantities or observables.
- Geant4 public distribution contains many realistic examples and test suites
    - Course materials for standard electromagnetic physics by M. Maire
    - Advanced examples coordinated by M. g. Pia
    - And others
- Geant4 provides full set of toolkits i.e. GUI, visualization, interfaces to analysis tools etc. which are the key elements for creation of good educational contents.

Geant4 medical examples

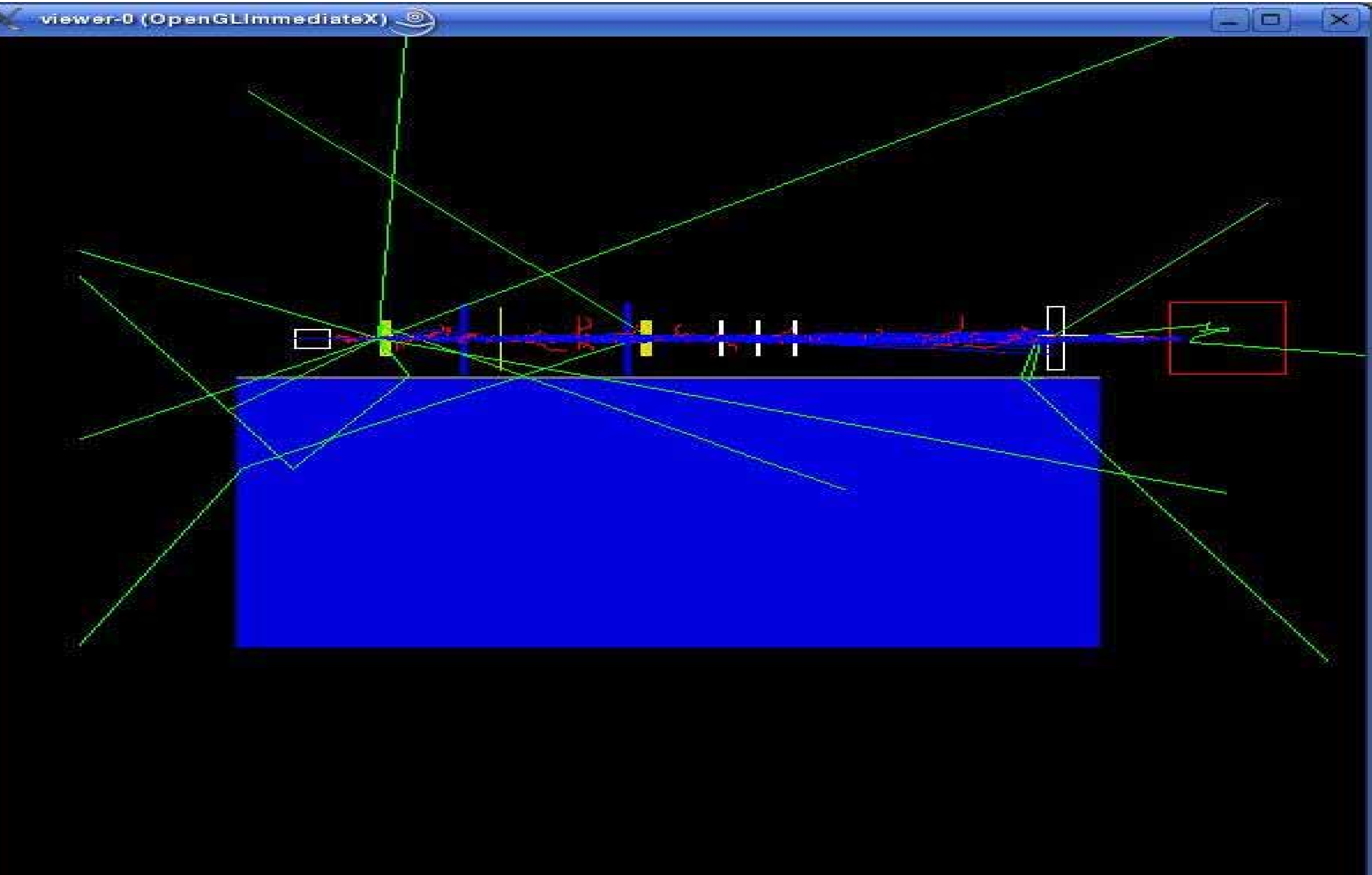
- Medical_linac by M. Piergentile
  - IMRT
  - voxelized water phantom
- Brachytherapy by S. Guatelli

- Hadronterapy by G.A.P. Cirrone et al.
  - Beam line geometry of LNS-INFN Catania
- DICOM by L. Archambault et al.
  - Voxelized DICOM geometry
- Gammatherapy by
  - 50 MeV electron beam line
- And others
- These are the raw stuffs for educational purposes.

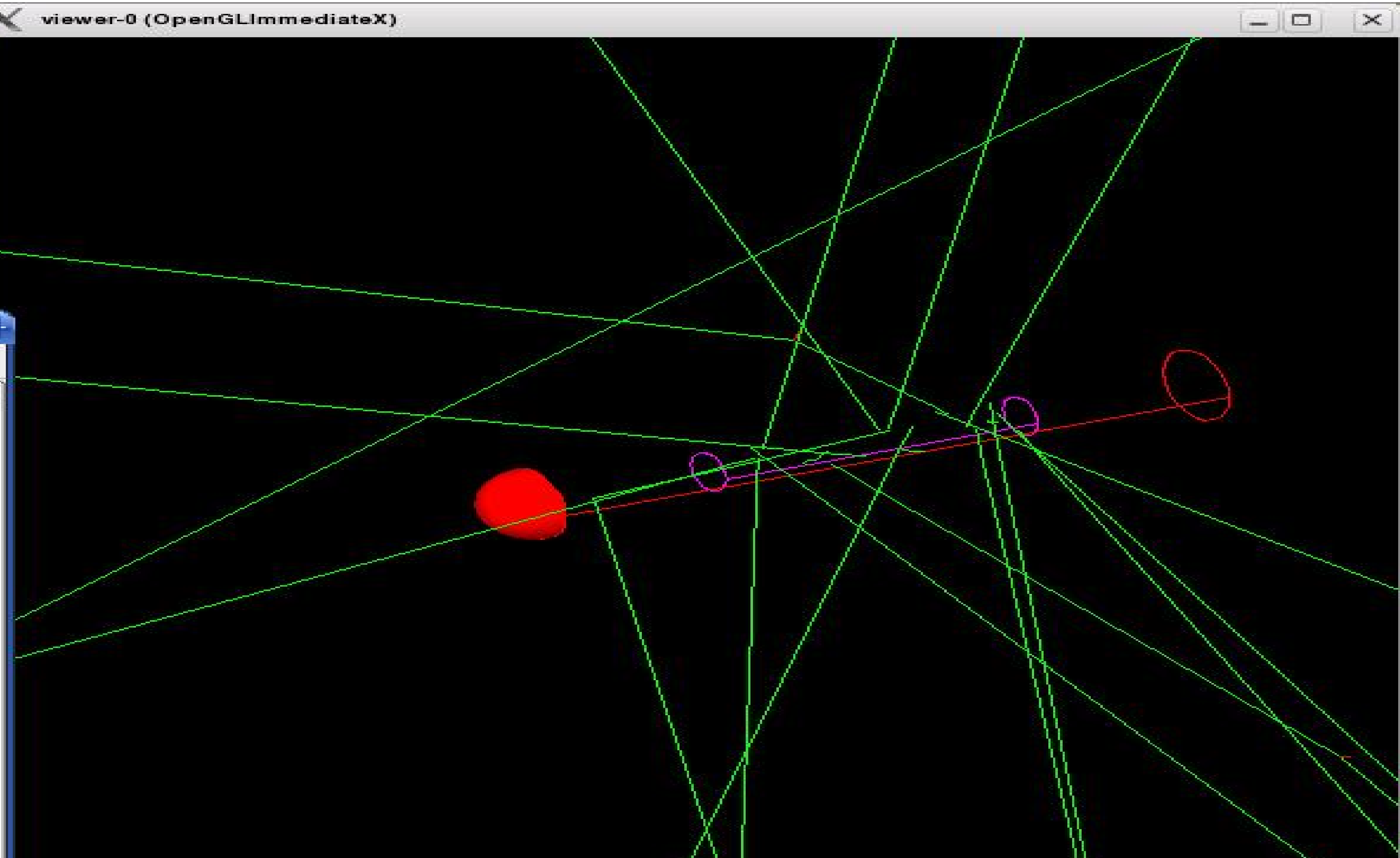
Medical Linac



Hadrontherapy



Brachytherapy



Geant4Py Tool kits for Educational Applications

- We anticipate two user categories;
  - Contents Creators (*teachers, or professionals*)
  - End Users (*students and eventually professionals under distant learning*)
- Geant4Py Tool kits For Contents Creators
  - Developed by K. Murakami, now available in geant4-8.1/environments/g4py
  - Python's powerful scripting capabilities are exploitable
  - Python interface can work as component bus.
  - Modules are available
    - Material / Geometry (predefined geometry / easy geometry set-up)
    - Physics list (EM, Hadrons, Ion)
    - Detector response (Calorimeter / Tracker)
    - Analysis packages (ROOT, HBOOK, AIDA, ...)
    - Visualization
    - GUI (Qt, Tkinter, wxPython...) / Web applications (mod-python, CherryPy)
- Course ware For End Users
  - Scripting with Python is NOT required!
    - They are not necessarily required to learn Python language.
    - Of course, they can modify the course materials with the knowledge of Python and can contribute for their improvements.
  - GUI / Web applications should be provided for e-learning
    - They can be built on the Python interface.

Steering Geant4 Applications with Python

- Characteristics of Geant4 Simulation
  - Big software, many developers, complex structure
  - Long life, evolving developments
  - Unexpected use cases
- Power of Boost.python wrapper
  - Existing C++ libraries are wrappable by end users who only have access to header files and binaries.
- Steering with Python
  - Use of the interpreting language to interface the compiled libraries
  - No “main” program. Control of simulation by Python

Use of Geant4Py
case 1 : wrapping C++ codes

- Create an application in C++ and wrap its classes as necessary
  - Examples are found in g4py/site-modules/
    - examples/education/lesson2
  - Performance isn't deteriorated,
  - Much more interactive than the terminal interfaces
  - Python based GUI tool kits can be employed for better user friendliness
  - Connection with analysis tools is easy
  - Integration into the Web server

Predefined Packages

- Site-module package contains pre-defined components.
  - Material
    - sets of pre-defined materials
      - NIST materials via G4NistManager
  - Geometry
    - “exN03” geometry as an example of pre-defined geometries
    - *“EZgeometry”*
      - provides functionalities for easy geometry set-up (applicable to target experiments)
  - Physics List
    - pre-defined physics lists, exN03 etc.
    - easy access to cross sections, stopping powers, ... via *G4EmCalculator*
  - Primary Generator Action
    - particle gun
  - Sensitive Detector
    - calorimeter type
    - tracker type
- They can be used just by importing modules.
- They can be combined and connected to higher application layers (Analysis / GUI components).

Use of Geant4Py

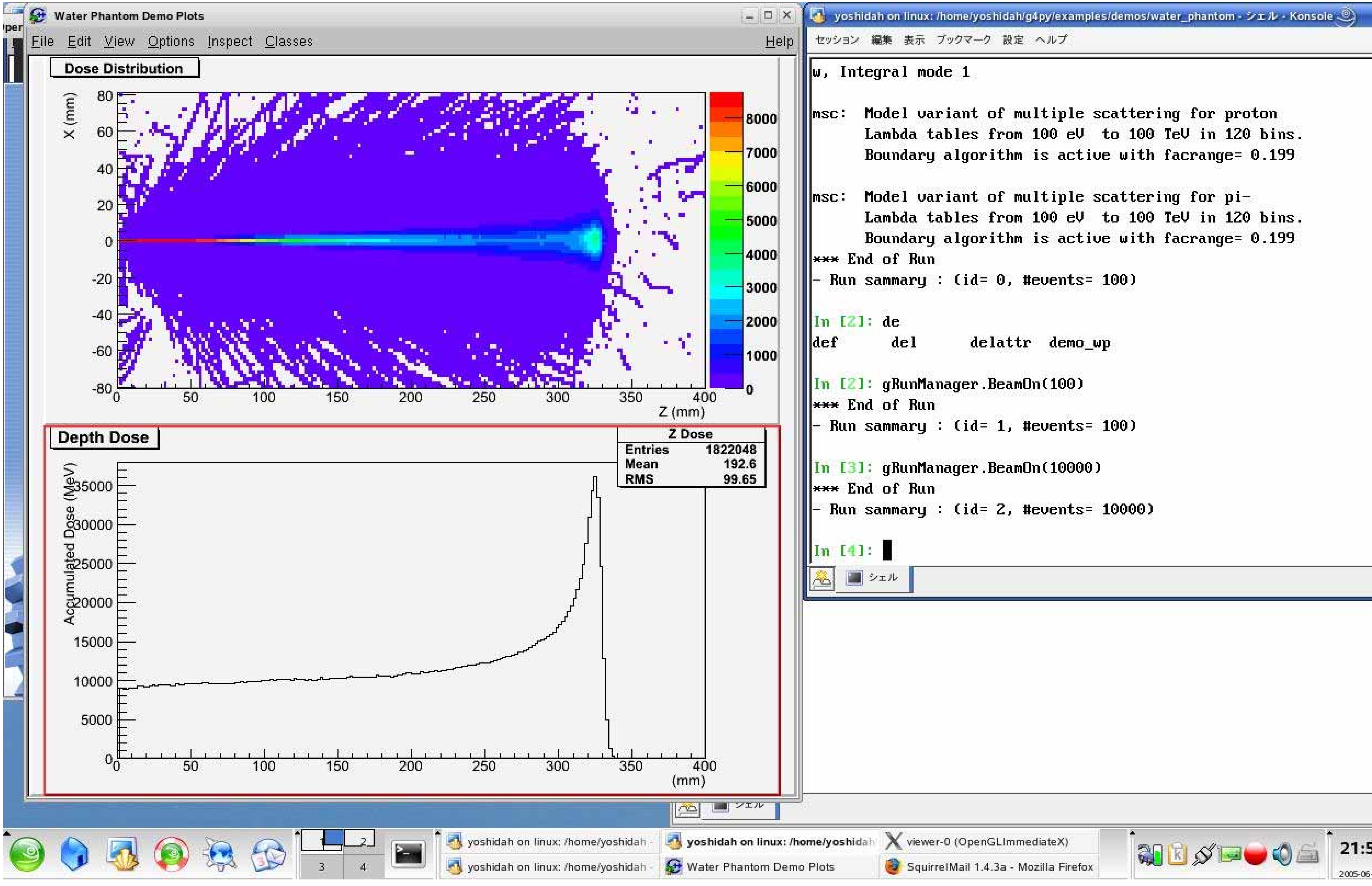
case 2 : purely Pythonic scripting

- Pre-defined “site-modules” provide easy construction of “simple” geometries
  - No C++ coding is necessary to create your own detector, beam line etc.. Python script can do all.
  - Typical e.m. Physics list is provided. Importing them is sufficient to use them in your Python script
  - Performance isn't so bad
- Integration with analysis tools and use of fancy GUI tools are just same as the case 1
- examples/education/lesson1

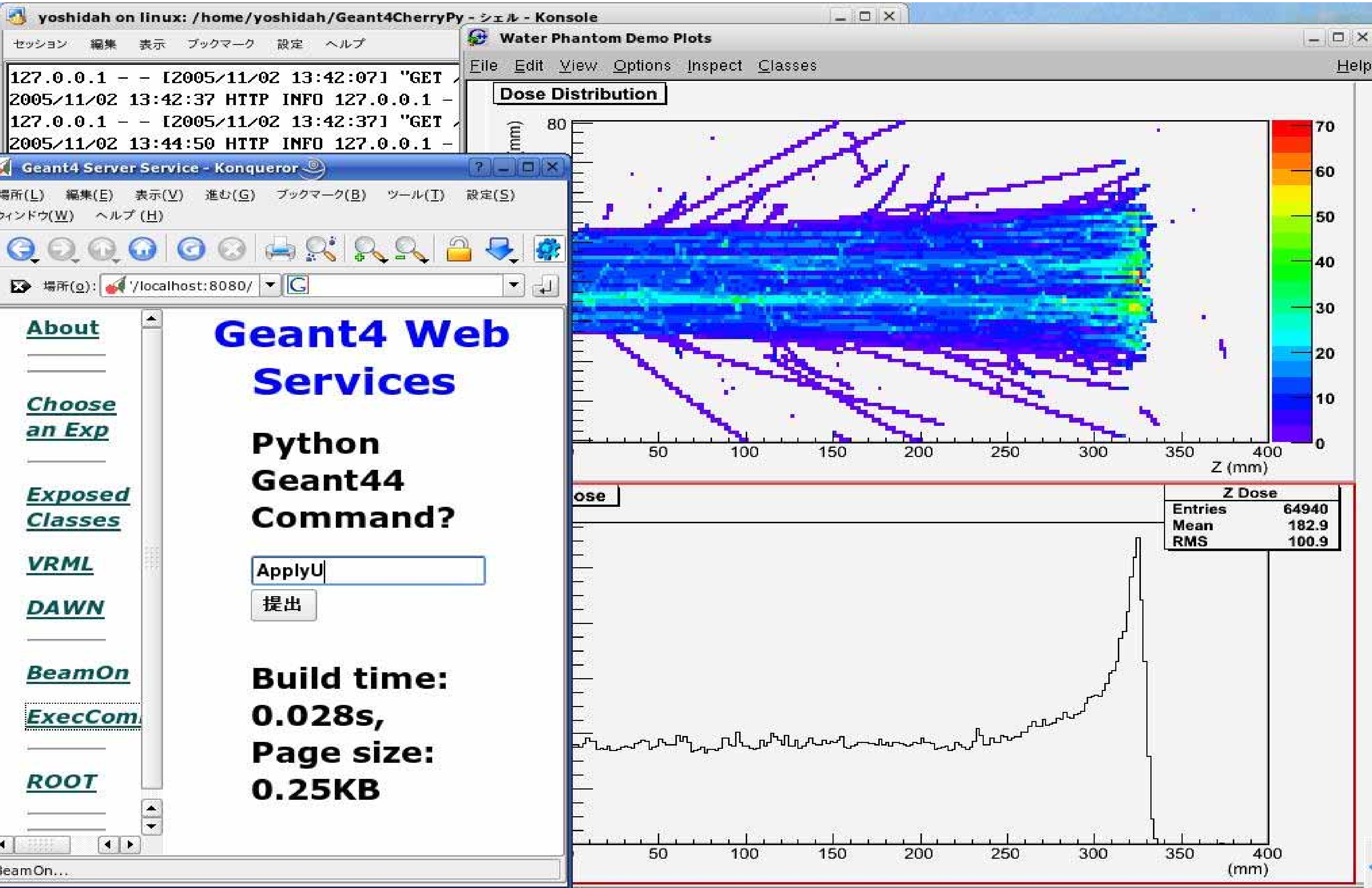
Extending its connectivity

- Plot tools : matplotlib, GNUPLOT
- Analysis tools : ROOT, PAIDA
- Web server : CherryPy
  - Purely Pythonic Web server
  - Powerful template language supported
  - Session and cookie management etc.
- GUI tool kit : Tkinter, **wxPython**
  - **Dedicated for each example**
  - **Replacing the old GUI tools of Geant4**
- **Geant4 for Education project is the typical case which requires all these functionalities**

Connect to ROOT
histogramming on the fly



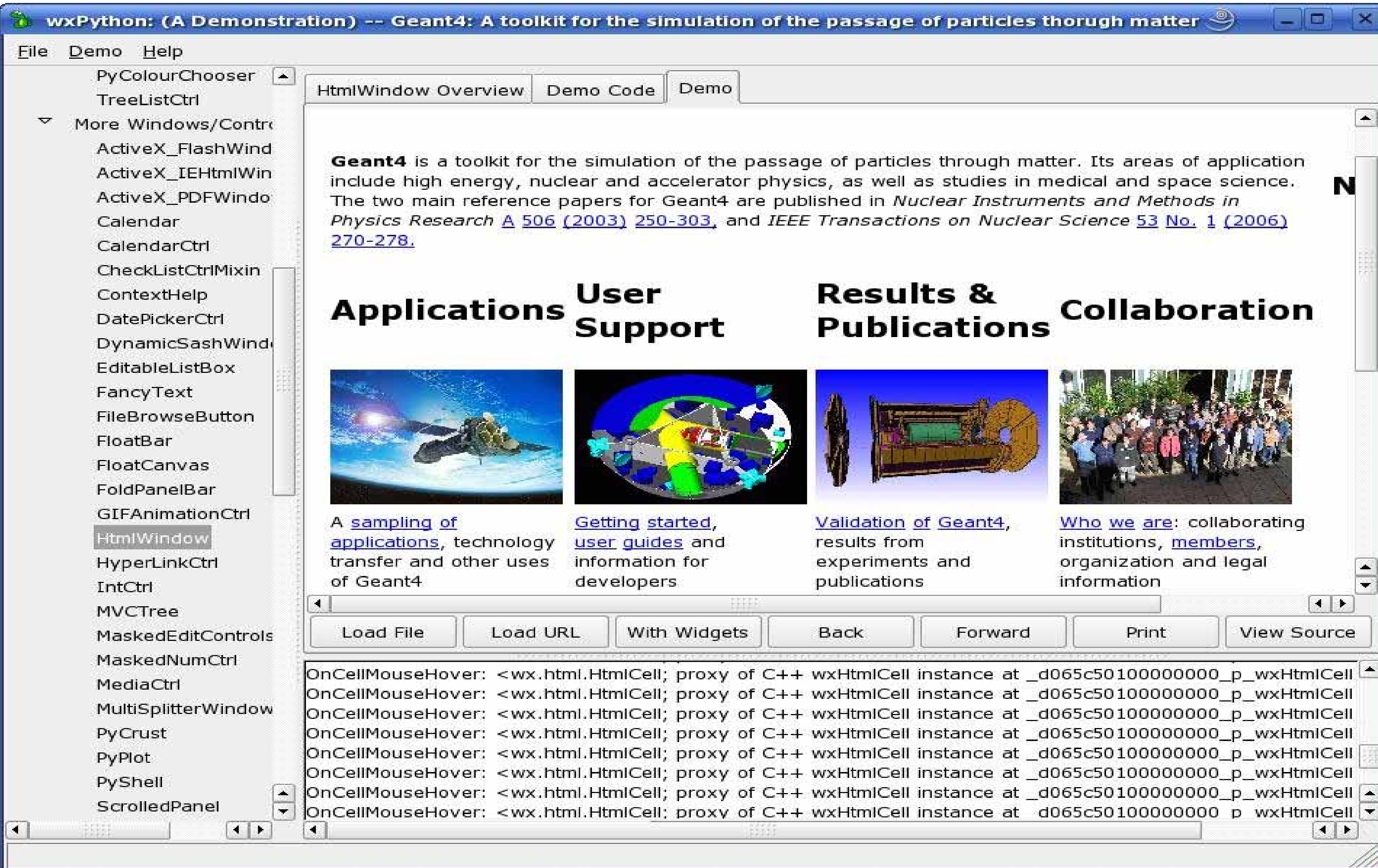
Geant4 Web Server
steering, visualization and analysis



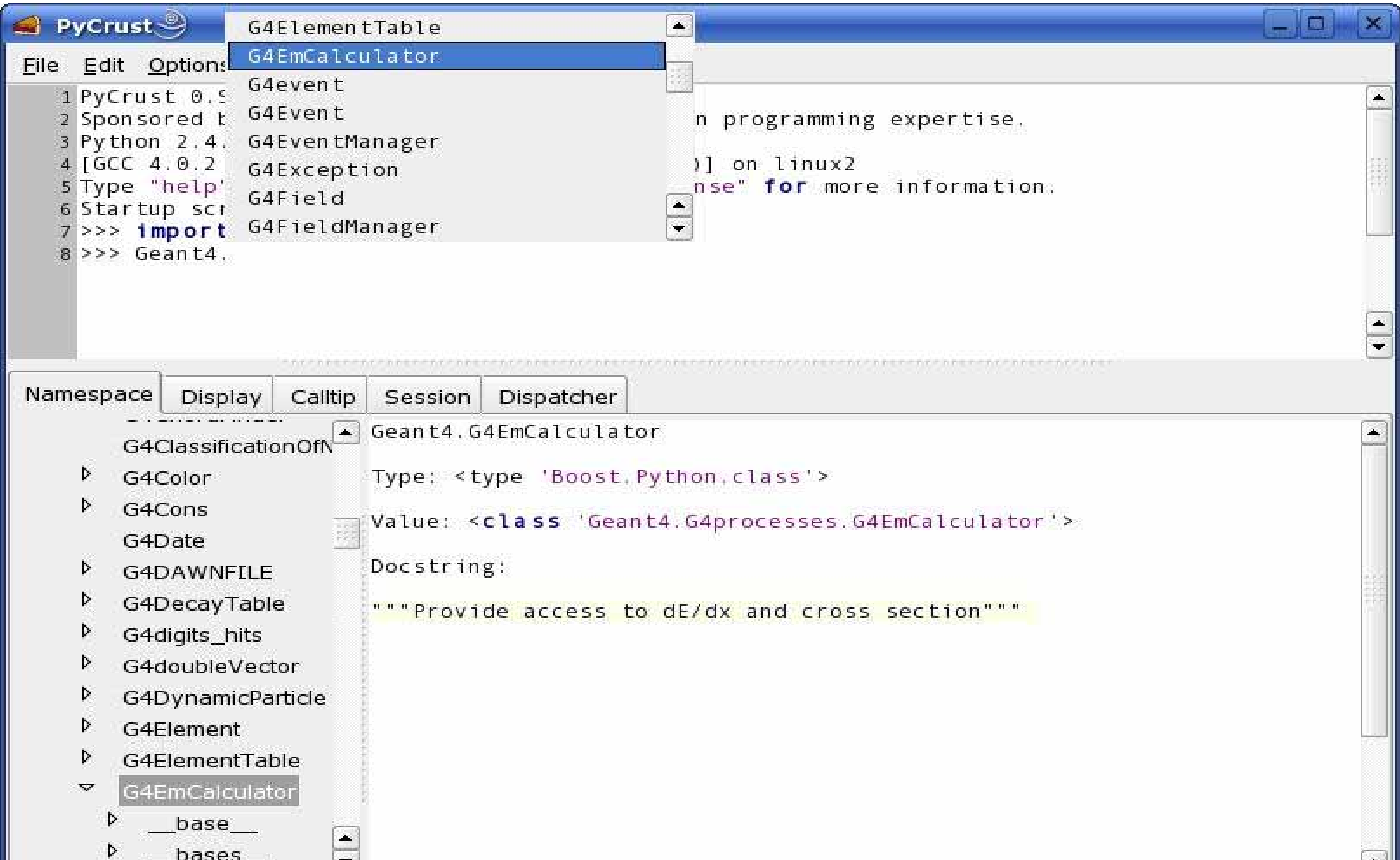
GUI builder is mandatory

- WxPython is our choice
  - Wxwidgets (C++ library) is wrapped with Python
    - Open and free
  - Many advanced features and widgets
  - A little lengthy scripting (than Tkinter) to profit its power
  - Multi platform, keeping platforms look and feel
  - Book has come

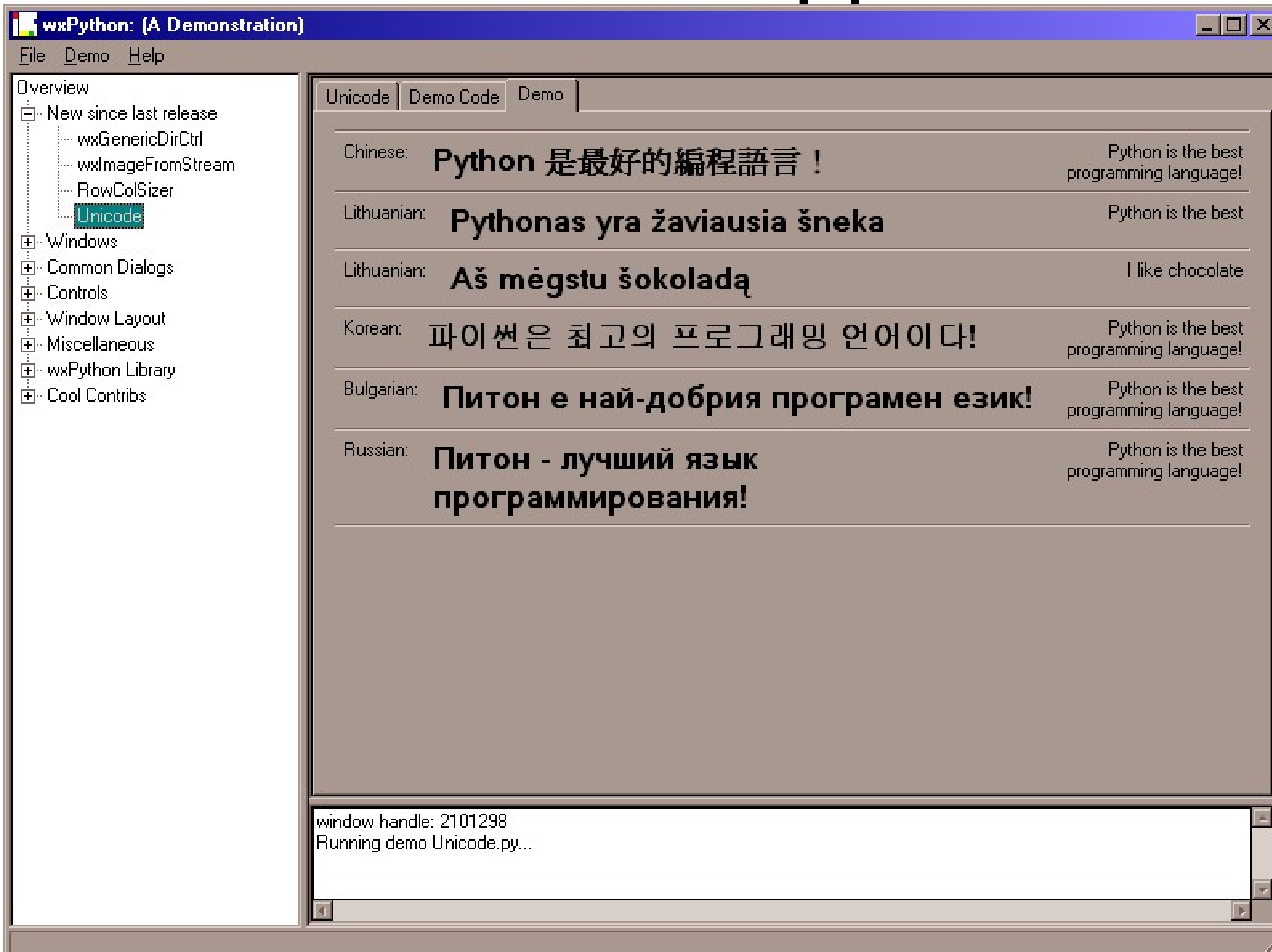
Off the shelf widgets



IDEs are available



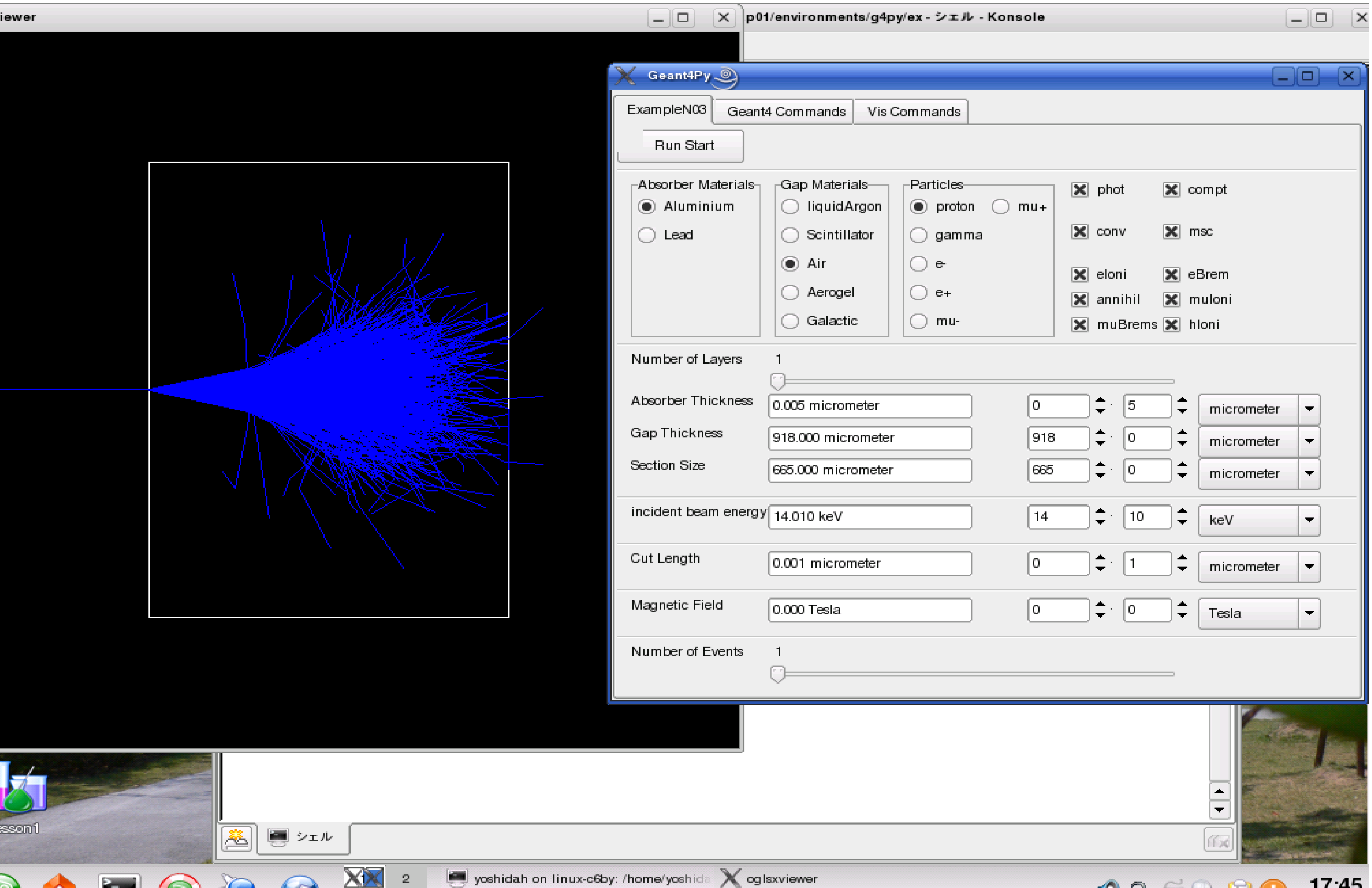
Unicode is supported



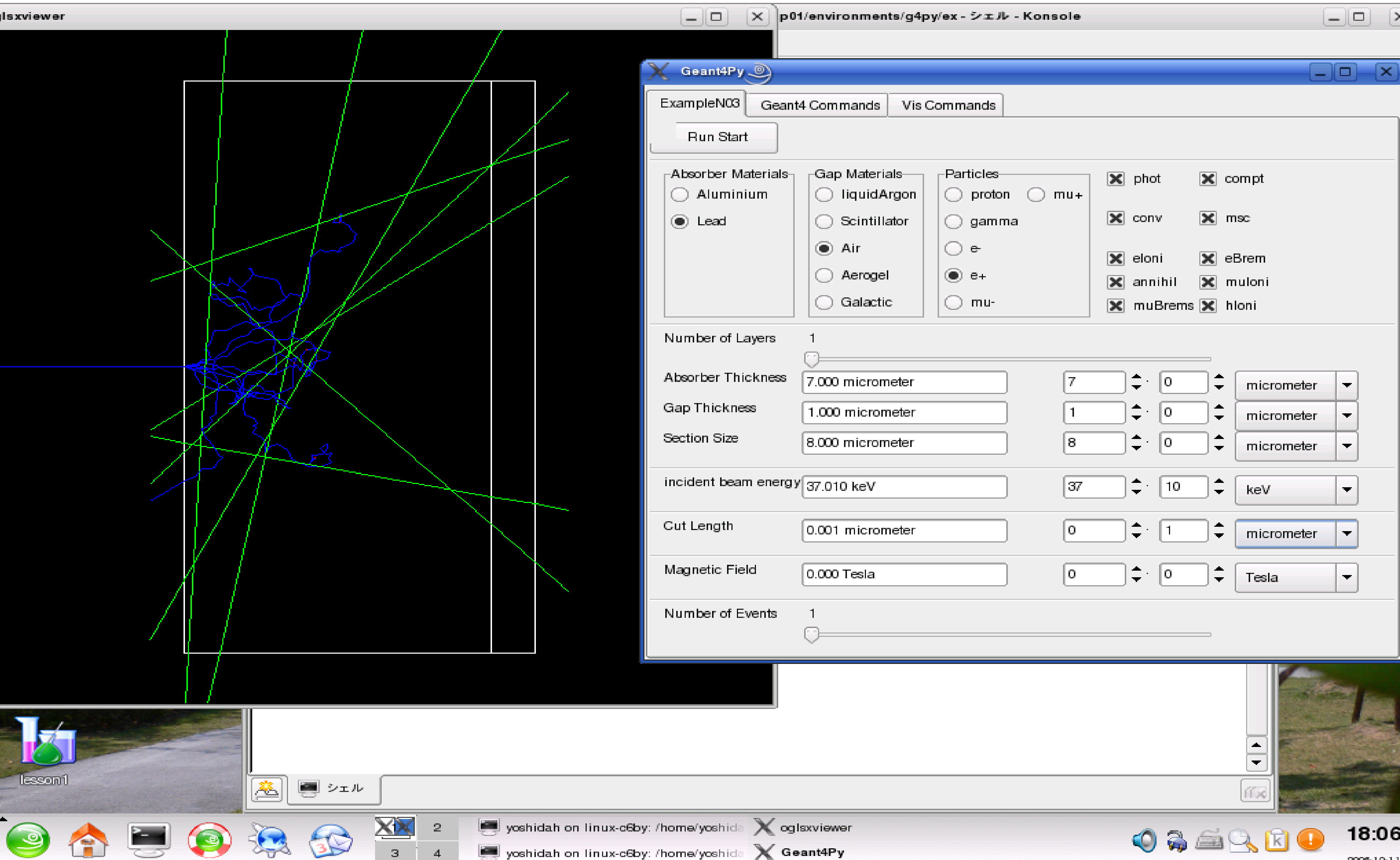
Educational examples

- Virtual experiments to understand the microscopic phenomena, included since geant4-version 8.1
  - lesson1
    - measurement of mass attenuation coefficients in various materials with variable dimensions
    - And other observations
  - lesson2
    - taken from Michel Maire's exampleN03
    - sandwich calorimeter
    - electromagnetic processes on/off
- Platforms
  - Linux and Mac OS X are tested

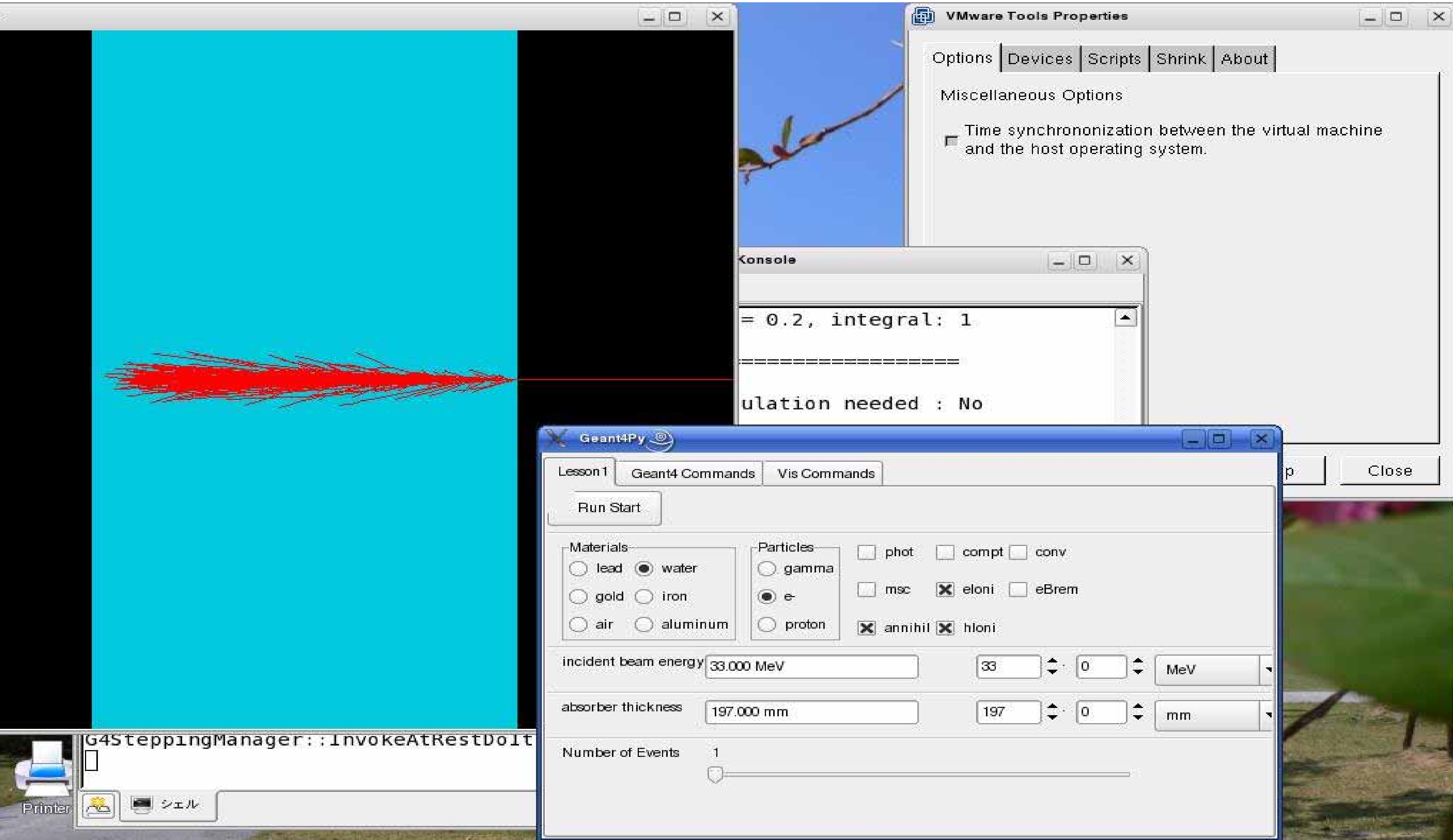
14keV proton into air



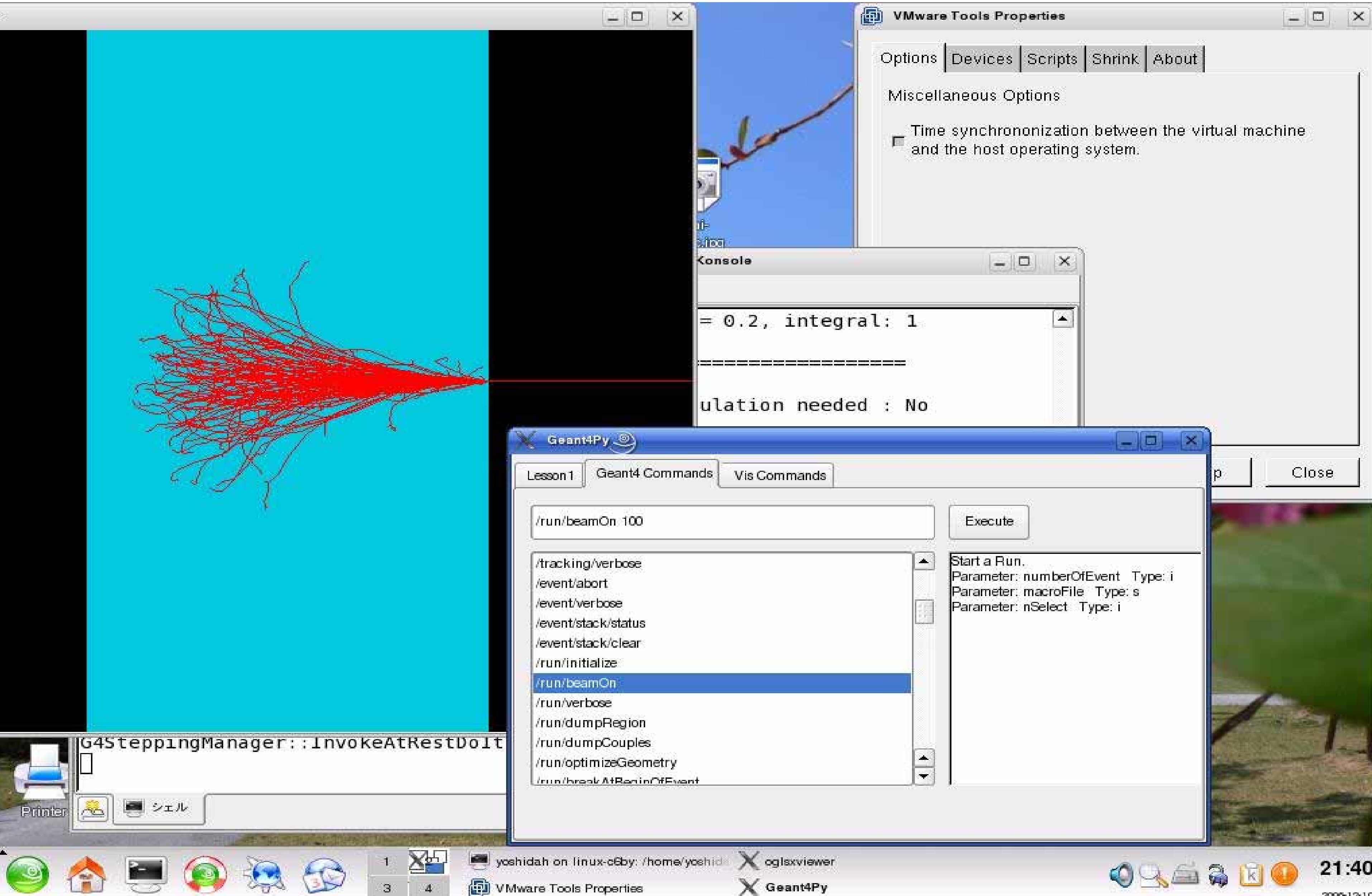
37keV positron into 7um lead



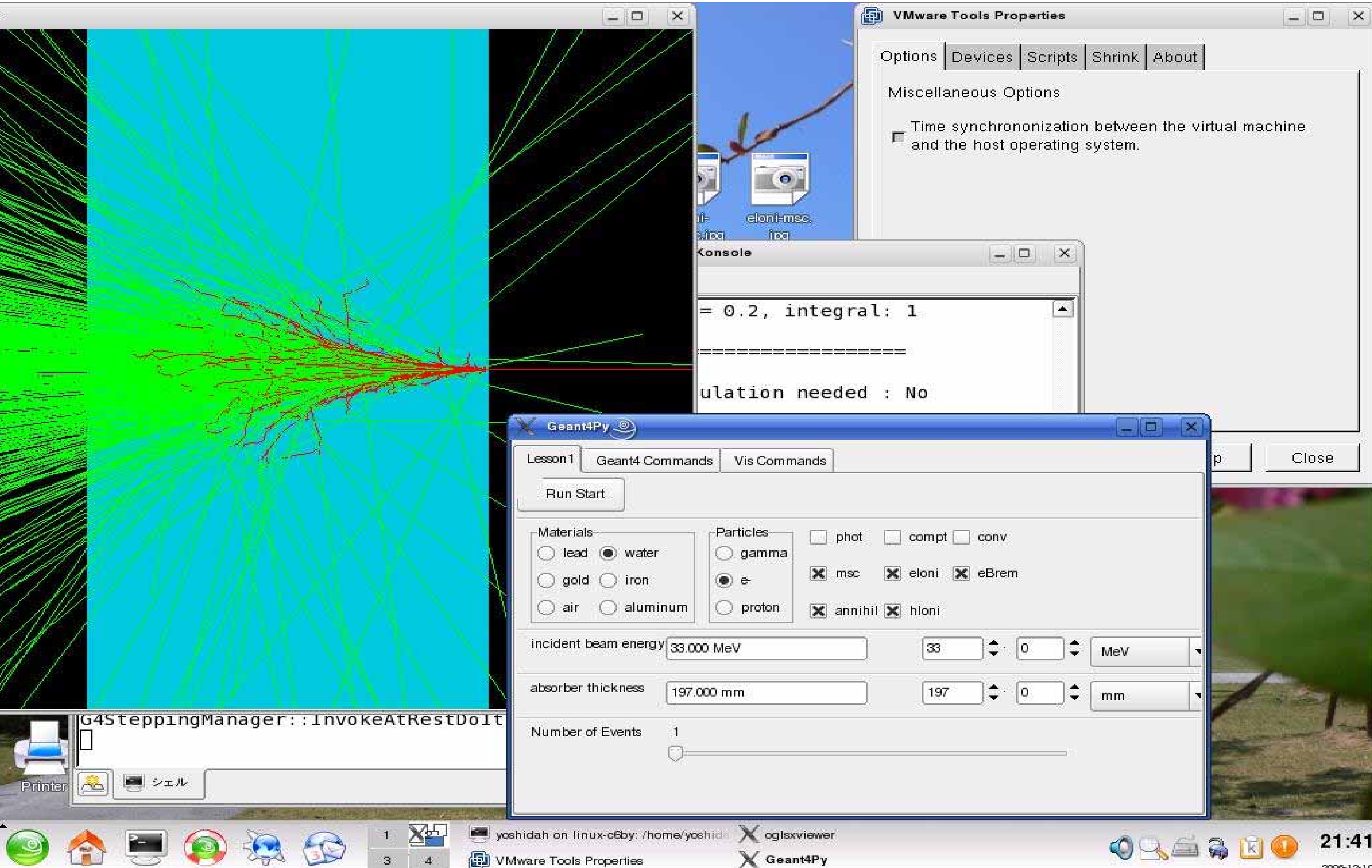
33MeV electron into water, Ionization is on



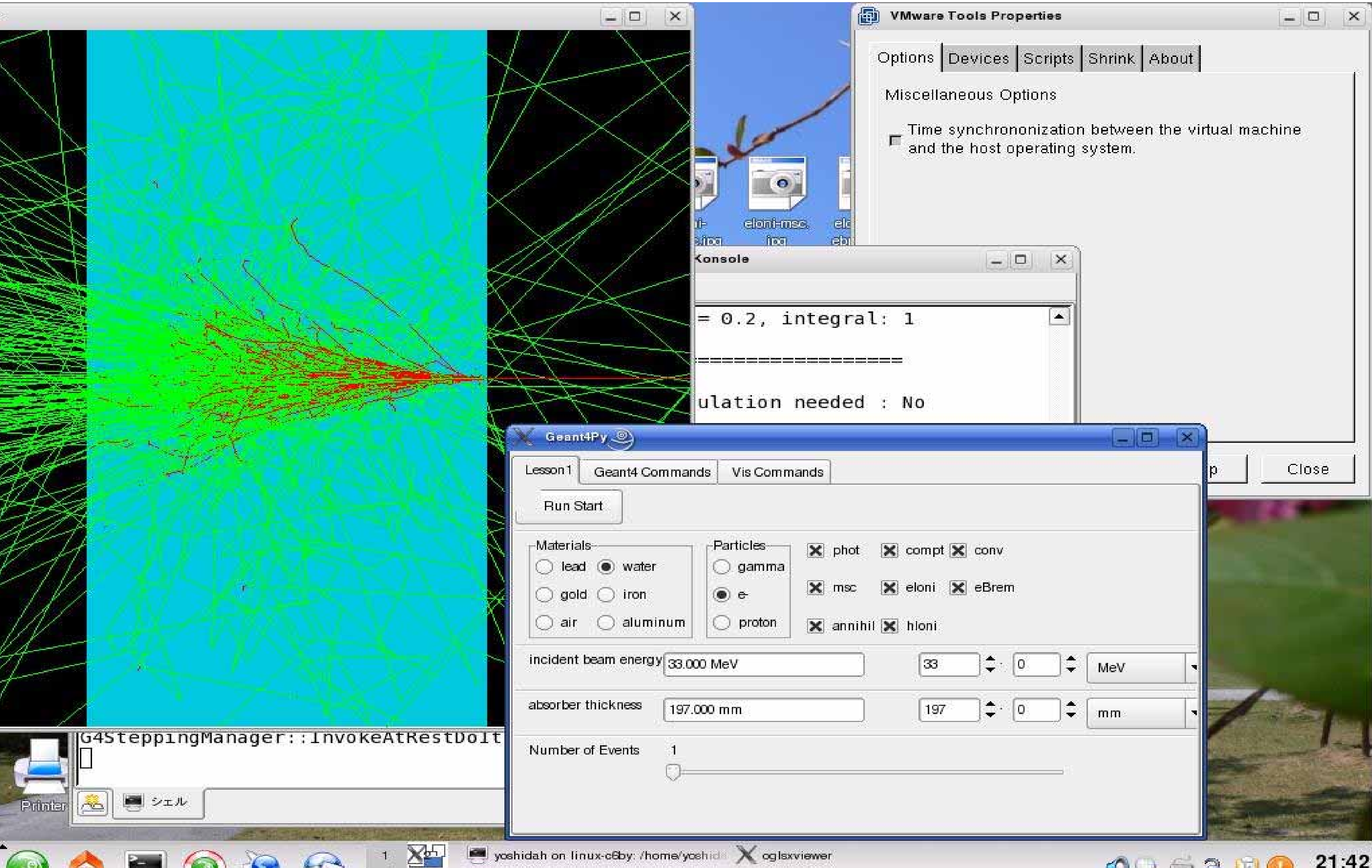
Multiple scattering is on



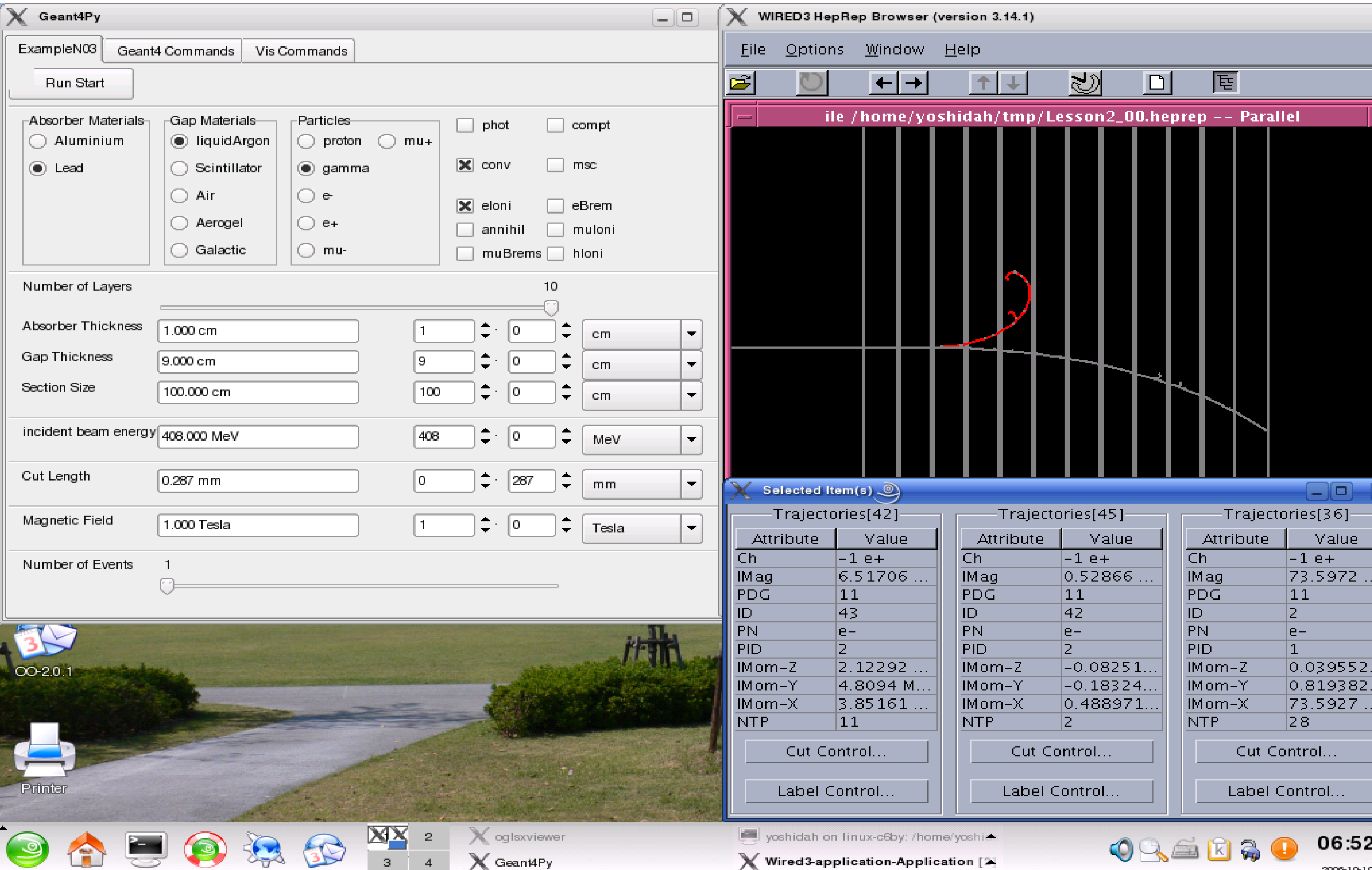
Bremsstrahlung is on



Compton, photoelectric ans pair creation are on



Measurement with Wired



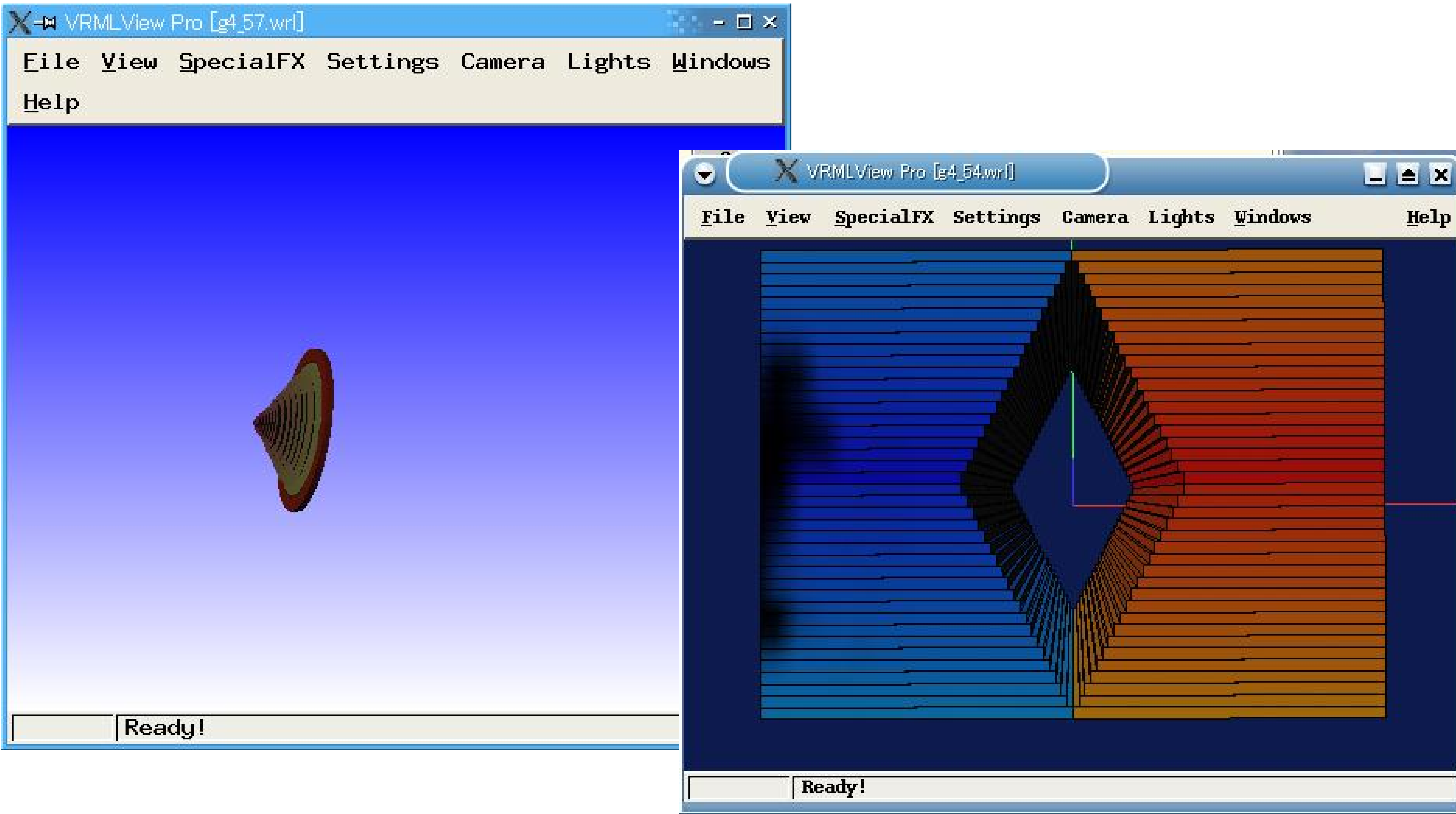
Courseware creation TODO

- Realistic and Standard geometries
  - Concrete and realistic “standard” geometries must be provided whose geometrical data must be available publicly.
- Generic and Customizable geometries
  - Some generic geometries which can be customized by teachers will be useful to create their own course ware
- Interactive customization
  - We need much more interactivities for creators of course ware to customize for their own applications

To-do List of Realistic and Standard Geometries for

- Standard ionization chambers
  - Track visualization in and around
  - Build up cap
  - Total number of created ions
- Curie well chamber
- Gamma camera
  - Number of photons
  - Energy spectrum
- PET
- GM counter
  - Track visualization
- etc.

MOMO: Tool prototype for Geometry creation a la BEAMnrc:
giving the BEAMnrc parameters, you get the geometry



“Standard” Physics Lists are available

- A common physics list must be provided -> done by Denis Wright
- Medical max < 1 GeV
- Start with N03 by Michel
  - Switching on/off any processes
  - Hadronic processes
    - P elastic, inelastic
    - N elastic, inelastic
    - **π**
    - Ion
    - Radioactive decays, generic decays
  - Choice of models
    - LEP, Bertine, Binary cascade
  - Process can be turned on one by one. Range cut and step size must be easily modifiable
  - Only the hadronic processes can be visualized – Michel’s cut magic

To conclude

- Geant4Py provides highly functional and in depth steering of Geant4 kernel
- It serves as the software bus to extrenal GUI toolkits, analysis tools and others
- Preliminary educational examples are successfully created
- Existing Geant4 examples can be developed for educational applications
- Collaboration between medical specialists are mandatory for successful creation of educational materials