

Software for Detectors Detectors for Software

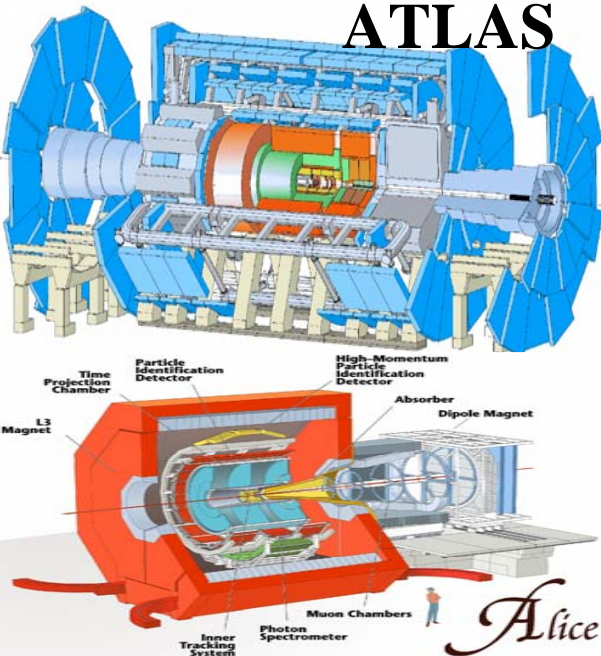
Maria Grazia Pia
INFN Genova, Italy

<http://www.ge.infn.it/geant4/talks>

Topical Seminar on Innovative Particle and Radiation Detectors

Siena, 1- 5 October 2006

ATLAS



LHC

Storage

raw recording rate 0.1–1 GByte/s
 accumulating at 12-14 PBytes/year

Processing

70,000 of today's fastest PCs
 (~6 hours' Intel CPU production today)

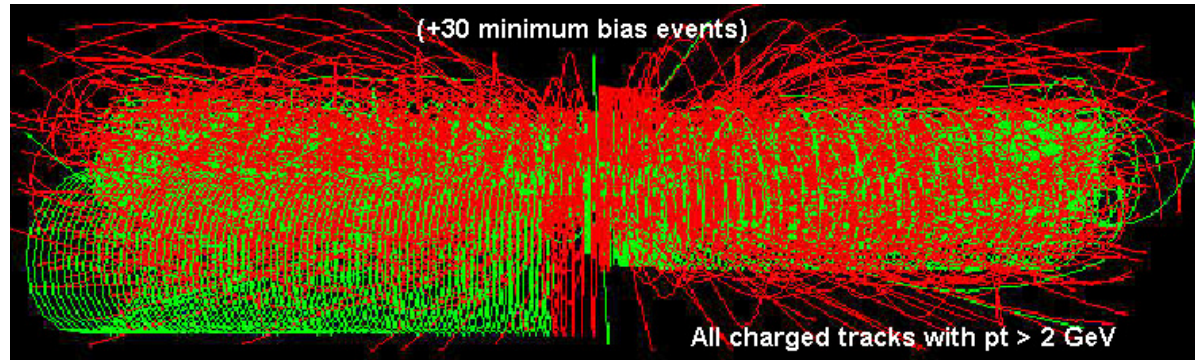
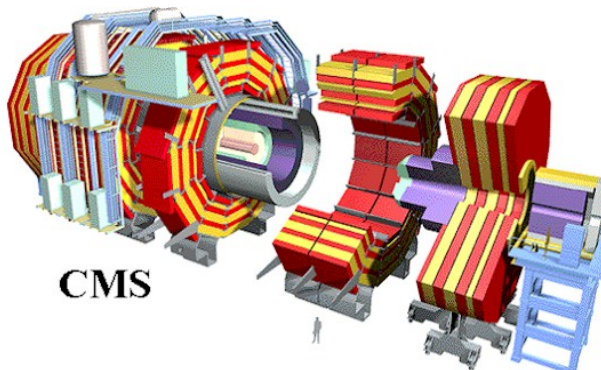
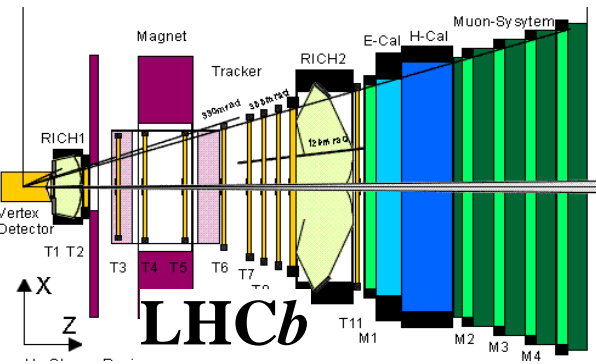
1000 person-years

"Offline" software effort per experiment

~5000 Physicists

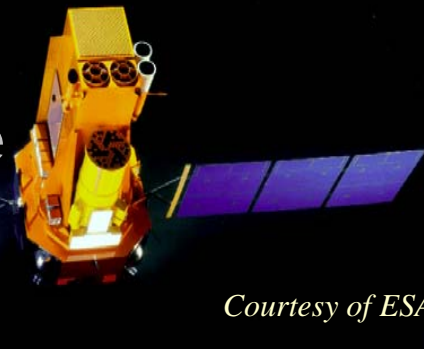
around the world, around the clock

20 years software life-span



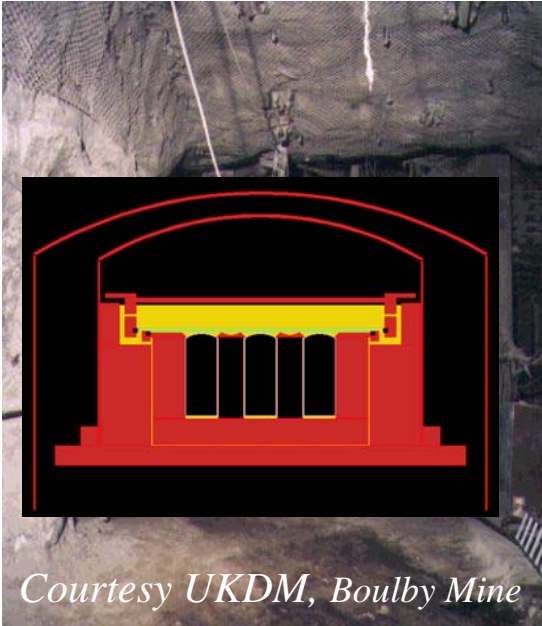
From deep underground...

...to space



Courtesy of ESA

Dark matter and ν experiments



Courtesy UKDM, Boulby Mine



Courtesy of Auger

X and γ astronomy,
gravitational waves etc.

Cosmic ray experiments

Variety of requirements from diverse applications

Physics
from the eV to the PeV scale

Detectors,
spacecrafts and environment

For such experiments software is often **mission critical**

Require reliability, rigorous software engineering standards



Radiotherapy Simulator

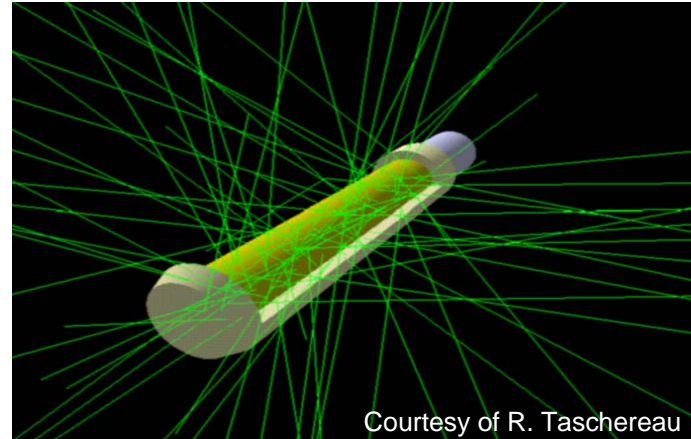
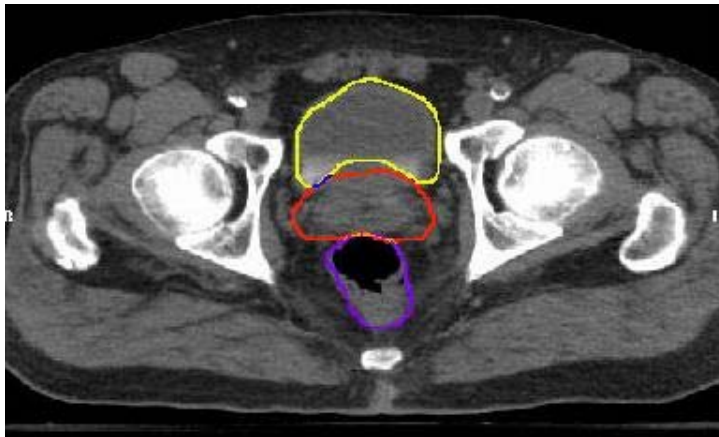
From
hospitals...

...to Mars



Courtesy of ESA

Medical Physics, Radiation Protection



Courtesy of R. Taschereau

- Accurate modelling of radiation sources, devices and human body
- Precision of physics
- Reliability
- Easy configuration and friendly interface
- Speed

Software for detectors



Software permeates HEP experimental life

- Detector design and optimisation
 - Trigger
 - Data acquisition
 - Reconstruction
 - Physics analysis
 - Radiation protection
 - Accelerator design and operation...
-
- Spacecrafts, mission trajectory calculation, patients' treatment planning, medical imaging etc.
 - Software is as essential as hardware in our experiments
and requires a large investment of resources
 - ➔ **LHC offline software and computing investments**
exceed the cost of a LHC experiment like ATLAS or CMS!

Challenges



Performance challenge

Increased needs of computing resources
New paradigms emerging: the grid

Programming challenge

Large scale software systems
Long timescale
Complexity of physics and detectors

Prediction challenge

Complexity of software systems
Large and geographically distributed development teams



Do we trust
software?

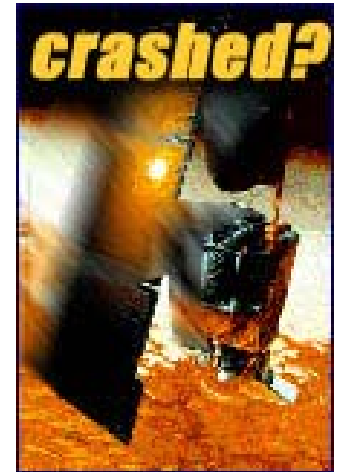
Ariane 5 crash



4 June 1996
36" after launch
\$500 million spacecraft

The primary cause was found to be a piece of software which had been retained from the previous launchers systems and which was not required during the flight of Ariane 5.

As well, the software contained implicit assumptions about the parameters, in particular the horizontal velocity that were safe for Ariane 4 but not Ariane 5.



10 November 1999

Failure to convert English measures to metric values caused the loss of the **Mars Climate Orbiter**, a spacecraft that smashed into the planet instead of reaching a safe orbit

Therac-25 accidents

6 known massive overdose cases
(June 1985 – January 1987)
Software coding error found
Poor software engineering practices
Safety analysis excluded software

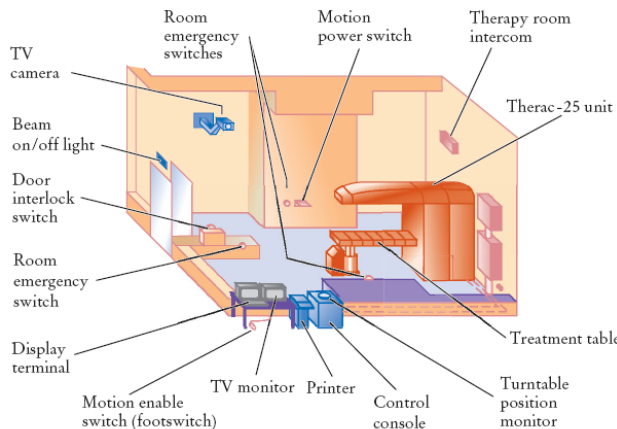
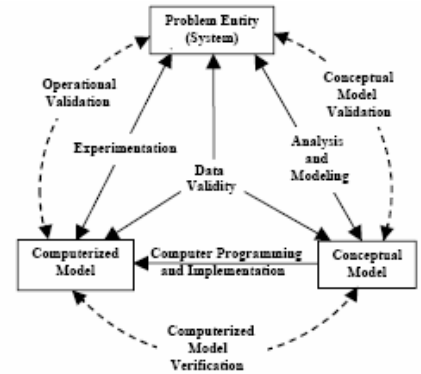


Figure 9 Typical Therac-25 Facility

Verification & Validation

Codes are not reality, only a model of reality



Software verification

Confirmation that the software correctly implements the specifications

- ➡ The software does what is supposed to do
- ➡ Software Quality Assurance

This is a computing issue

Software validation

Confirmation that the physical models implemented are correct representations of the physical phenomena of interest

- ➡ Ensure models reflect nature
- ➡ Check against experimental data

This is a physics issue



Started in 1996

ASCI experience

Accelerated Strategic Computing Initiative to certify US nuclear stockpile without testing

Lessons learned from 6 software projects

- 2 succeeded
- 4 missed initial milestone
- 2 cancelled

Major lesson is that one needs to improve:

- Verification
- Validation
- Software Project Management and Software Quality



V&V emphasized since the beginning in ASCI
Difficulties encountered by software project teams

- ➡ Need better V&V methods

Test coverage



- More complex issue for scientific software than for most business software
 - Huge number of variants and controls
- Are conventional test-coverage tools adequate for scientific software?
 - *Probably not...*
 - Show which lines of code we are not testing, but this does not say much about physical validity

The issue of test coverage is an **unsolved problem**



Validation is holistic

One has to validate the entire calculation system

- Including:
- User
 - Computer system
 - Problem setup
 - Running
 - Results analysis

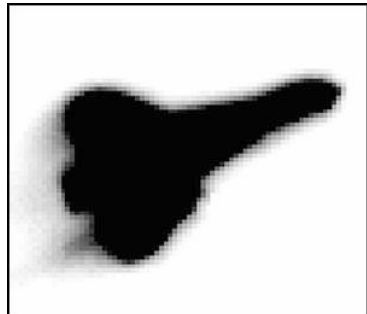
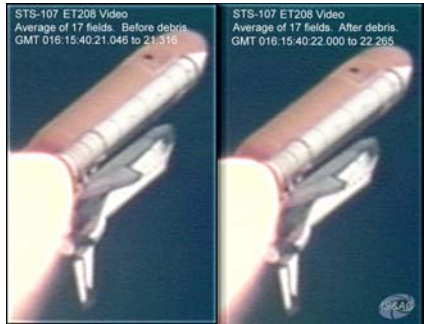


An inexperienced user can easily get wrong answers out of a good code in a valid régime



Experimental evidence in Geant4 Problem Report System
...but also in my personal editorial experience in a major scientific journal

Columbia Space Shuttle damage



- The Columbia Space Shuttle wing failed during re-entry due to hot gases entering a portion of the wing damaged by a piece of foam that broke off during launch
- Shortly after launch, Boeing did an analysis using the code CRATER to evaluate the likelihood that the wing was seriously damaged
- Problems with analysis:
 - The analysis was carried out by an inexperienced user
 - CRATER was designed to study the effects of micrometeorite impacts, and had been validated only for projectiles less than 1/400 the size and mass of the piece of foam that struck the wing
 - Didn't use a code like LS-DYNA that was the industry standard for assessing impact damage
- The prior CRATER validation results indicated that the code gave conservative predictions
- Analysis indicated that there might be some damage, but probably not at a level to warrant concern
- *(Maybe there was no way to fix the problem and avoid the accident)*

— NASA Columbia Shuttle Accident Report

Data for software validation



Passive observations of physical events
(e.g. supernovae explosions or the weather)

Experiments designed to elucidate a
general physics principle or law
(e.g. typical HEP experiments)

Experiments designed to certify a detector
(e.g. test beams)

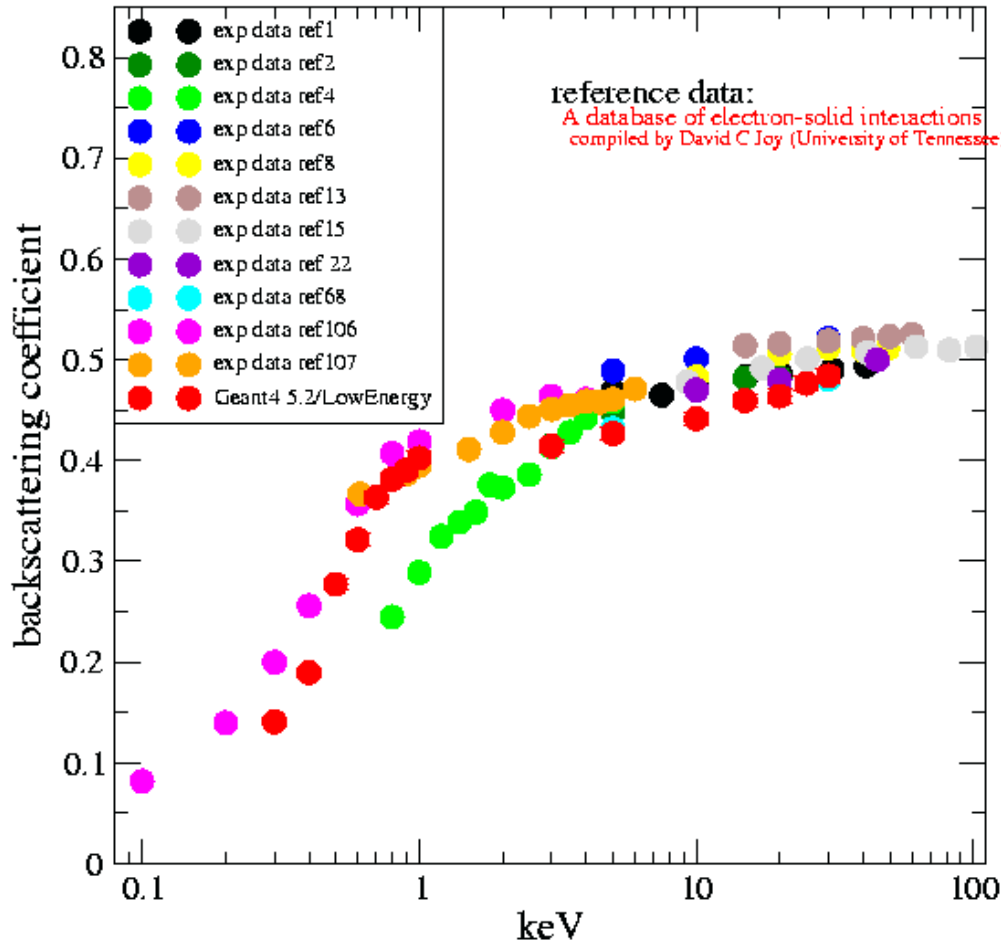


Experiments **specifically designed** to
validate a software system/component



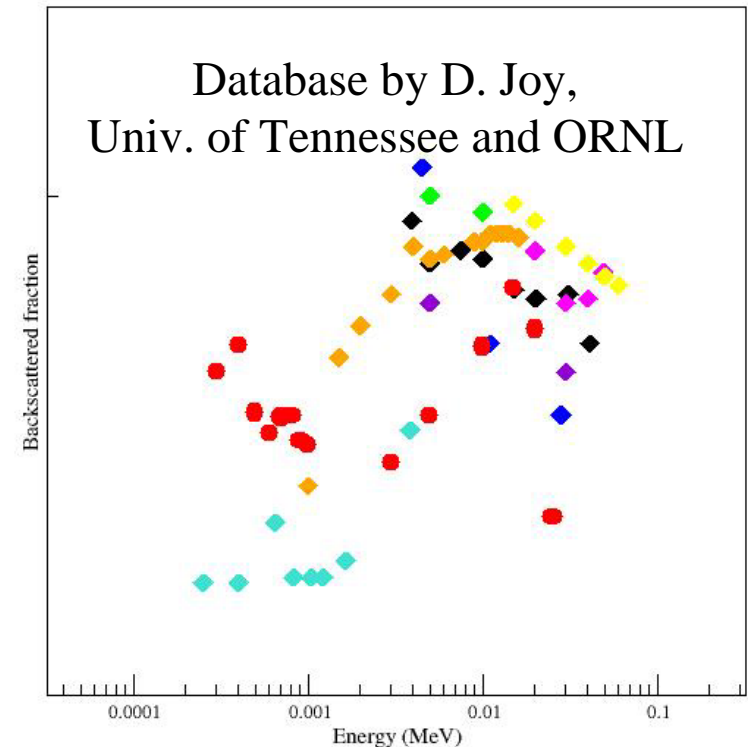
Validation: finding reliable data

backscattering for e-
e- energy range: 0.1 keV -> 102. keV



Electrons - Backscattering - Iron

(Geant4-05-02 LowE)



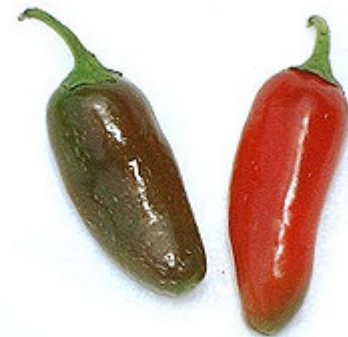
Geant 4 validation is not easy

experimental data often exhibit
large differences!

... or there are no data, or the details of the experimental setup are not documented, or the systematic is not analyzed, or experimenters are not keen to share their data, or...

We need a paradigm shift...

- Experimenters and funding agencies understand the value of experiments designed
 - to **explore new scientific phenomena**
 - to **test theories**
 - to **examine the performance of design components**
- Few appreciate the value of experiments explicitly conducted for **software validation**
- Gain of consciousness in some fields
 - NASA: experiments at accelerators
 - Military projects: e.g. weapon simulations
- What about particle physics?



One may say that few appreciate the need for funding software...

Maintaining correctness



Scientific codes are **frequently changed** throughout their lifetimes, not just when they are young



The more frequently a code is changed,
the more difficult it is to maintain its correctness

Techniques that help

- Protocol for change control
- Design methods
- Unit testing
- Integration testing
- Regression testing
- Automated testing
- Release management
- Bug tracking

Are they established in
the scientific software
development process?

...not just a problem with scientific software
(e.g. recent incident with a famous DB software)



Key elements for software quality

- Highly competent and motivated people in a good team
- Software project management
- Support from management and stakeholders
- Schedule and resources determined by requirements
- Software engineering: established best practices
- Project leader must control resources (otherwise “leader” is just a “cheerleader”)

D. Post, The Coming Crisis in Computational Science, LA-UR-04-0388

T. DeMarco, 2000; DeMarco and Lister, 1999; Cockburn and Highsmith, 2001; Thomsett, 2002; McBreen, 2001

Brooks, 1987; Remer, 2000; Rifkin, 2002; Thomsett, 2002; Highsmith, 2001

What happens in scientific journals?

Computational results without documented validation, but also:

M. Zaider et al., Rad. Res. 95, 231-247 (1983)

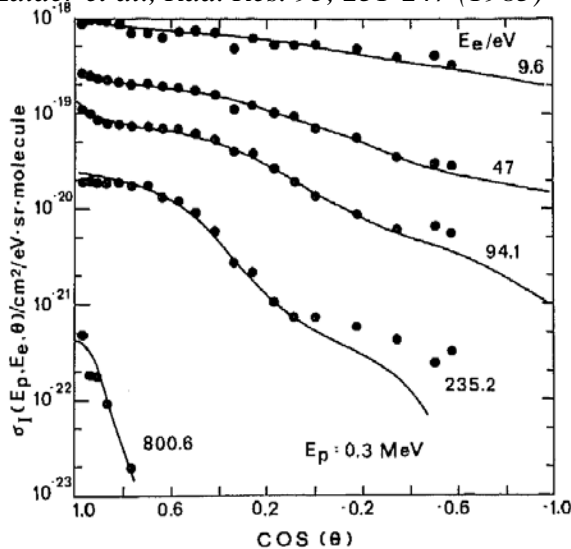
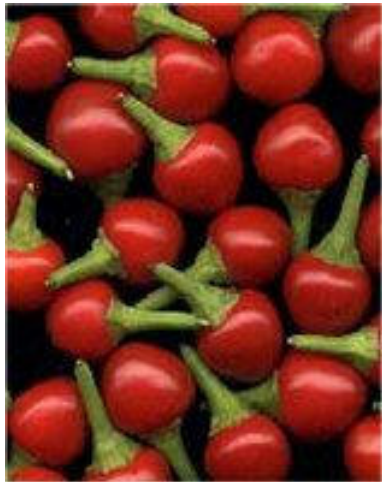


FIG. 5. Double differential electron production cross sections for 0.3 MeV protons incident on water vapor. The curves are as used in the code for production of (from the top) 9.6, 47, 94.1, 235.2, and 800.6 eV electrons. The experimental data (points) are from Toburen and Wilson (34).

J.-F. Carrier et al., Med. Phys. 31-3, 484-492 (2004)

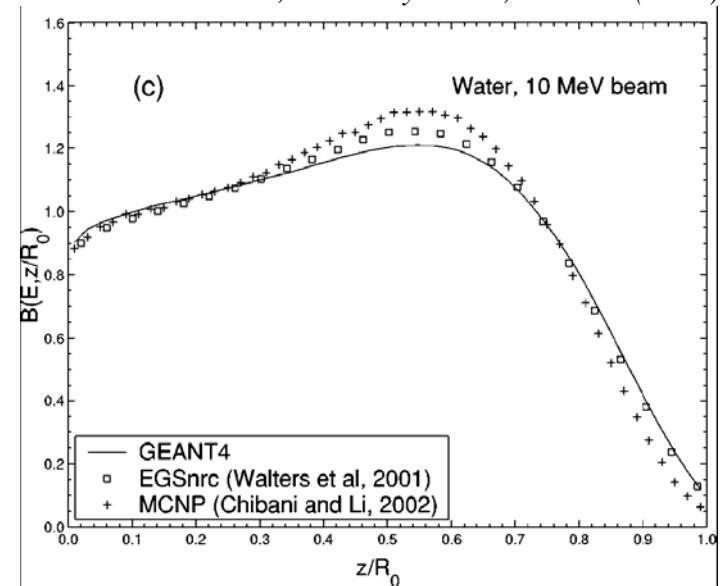


FIG. 4. Depth-dose curves for a water phantom irradiated by a parallel electron beam. The GEANT4 predictions are compared with the MCNP (Ref. 18) and EGSnrc (Ref. 16) predictions.

How well does the peer-review system work with software-oriented papers?

Many things that a referee cannot detect could be wrong with a computational paper ...



Methods

A **strong intellectual basis** for V&V
We need research in methodology
to test scientific code

Experiments



We need **specific, adequate, reliable** data
taken in **controlled** conditions
to test scientific code

To make progress on both fronts simultaneously will
require **collaboration** among the **hardware-oriented**
and **software-oriented** physics communities

We must be still and still moving
Into another intensity
For a further union, a deeper communion
...
In my end is my beginning.

Four Quartets – East Coker
Thomas S. Eliot, 1940

Does software have predictive capabilities?

Prediction: use of a computational model to foretell the state of a physical system under conditions for which the computational model has not been validated

Siena 2008...