Recent Developments in Geant4 for Medical Physics

Joseph Perl (SLAC National Accelerator Laboratory)
for the Geant4 Collaboration

International Workshop on Recent Advances in Monte Carlo Techniques for Radiation Therapy,

Montreal, 8 June 2011

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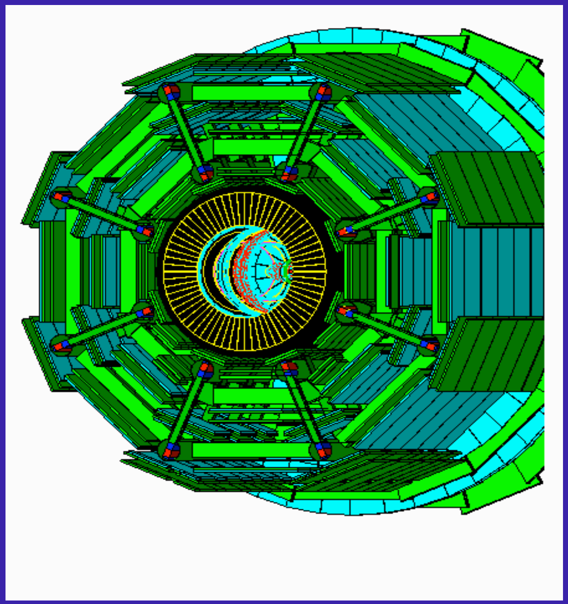
Recent

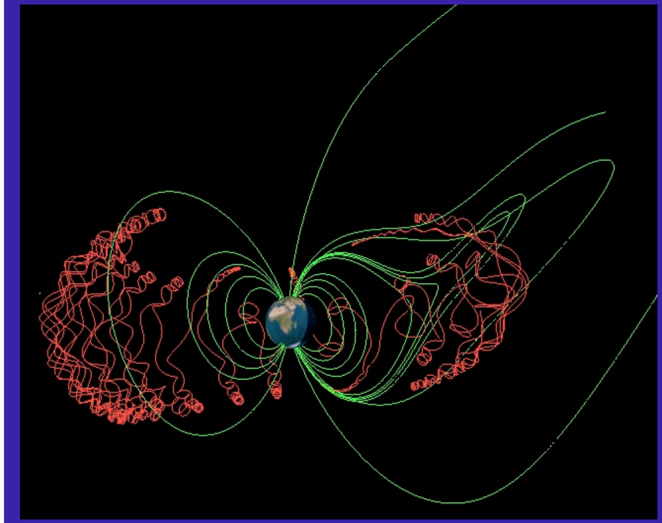
Since last workshop in this series was 2007, recent means since 2007

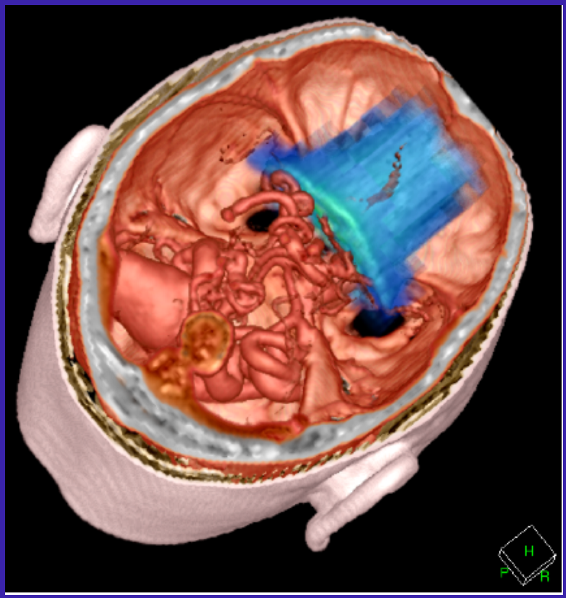
No Longer New

Geant4 can no longer be referred to as a “new” tool for medical physics. At MGH, use goes back about ten years. Here in Quebec, nearly as far. Results from these and other early adopter communities in Europe and Japan have profoundly influenced the development of the toolkit.

Medicine is one of three co-equal branches of Geant4







Geant4 Timeline

- Dec ’94 - Project start
- Apr ’97 - First alpha release
- Jul ’98 - First beta release
- Dec ’98 - First Geant4 public release - version 1.0
- one to three public releases every year.
  - Bimonthly pre- releases to registered testers.
- June 29th, ’07 - Geant4 version 9.0 release
- Dec 14th, ’07 - Geant4 version 9.1 release
- Dec 19th, ’08 - Geant4 version 9.2 release
- Dec 18th, ’09 - Geant4 version 9.3 release
- Dec 17th, ’10 - Geant4 version 9.4 release
  - Feb 18th, ’11 - Geant4 9.4-patch01 release ← Current version

Release rate has settled down to just one per year, plus mid-year Betas.

Four years since last Major release, e.g, since last time we made users significantly adapt their code

Physics: Overall

Many improvements, much validation work done.

Extensive list of Publications, updated regularly:
https://twiki.cern.ch/twiki/bin/view/Geant4/EMJournalPublications

Major new publication in press from MC2010 conference in Tokyo:
Recent Improvements in Geant4 Electromagnetic Physics Models and Interfaces, Ivanchenko et al.

Many detailed talks on physics validation are available from the agenda page of the latest Geant4 Collaboration Workshop:
http://indico.cern.ch/conferenceTimeTable.py?confId=102427#20101004

See in particular parallel session 2A

14:10	Validation of electron, proton and alpha ranges
14:30	Electron Energy Backscatter: Systematic comparison of Geant4 9.3 simulation against experimental data
14:50	Multiple scattering model validation at low energy in water for Dose point kernels and pencil beam kernels (comparisons with EGSnrc and MCNP4C)
15:10	Validations of the standard EM physics for Radiotherapy applications (comparisons with measurements and EGSnrc)
15:30	Fano cavity results

Physics: How Low is Low

Significant integration of “Standard” and “Low-Energy” EM.
Now permits mixing and matching within a single job
https://twiki.cern.ch/twiki/bin/view/Geant4/LoweMigratedProcesses

Reach of “Standard” has moved progressively lower.
In general, unless you are concerned specifically at the DNA level, you will probably find the Standard EM to be appropriate for your work

Physics: Scattering

Geant4‘s most commonly used multiple scattering model, the Urban model, was improved by separating tuning for e, Mu and Hadron

We still tune from the same data as before, from the 50s (Hanson), but new separated tunings give better match to recent NRCC benchmarks (EPAPS)

Standard recommendation for clinical linacs: “EM Option 3”

Many MSC Models

Model	Particle type	Energy limit	Specifics and applicability
Urban (Urban 2006)	Any	-	Default model, (Lewis 1950) approach, tuned to data, used for LHC production.
Screened Nuclear Recoil (Mendenhall and Weller 2005)	p, ions	< 100 MeV/A	Theory based process, providing simulation of nuclear recoil for sampling of radiation damage, focused on precise simulation of effects for space app.
Goudsmit-Saunderson (Kadri 2009)	e^+, e^-	< 1 GeV	Theory based cross sections (Goudsmit and Saunderson 1950). EPSEPA code developed by Penelope group, final state using EGSnrc method (Kawrakov et al. 1998), precise electron transport
Coulomb scattering (2008)	any	-	Theory based (Wentzel 1927) single scattering model, uses nuclear form-factors (Butkevich et al. 2002), focused on muons and hadrons
WentzelVI (2009)	any	-	MSC for small angles, Coulomb Scattering (Wentzel 1927) for large angles, focused on simulation for muons and hadrons.
Ion Coulomb scattering (2010)	ions	-	Model based on Wentzel formula + relativistic effects + screening effects for projectile & target. From the work of P. G. Rancoita, C. Consolandi and V. Ivantchenko.

Physics: Brems

Previous publication showed we were ok but not as accurate as EGSnrc or PENELOPE:
Benchmarking of Monte Carlo Simulation of Bremsstrahlung from Thick Targets at Radiotherapy Energies, Faddegon et al
Med. Phys. 35, 4308 (2008); doi:10.1118/1.2975150

Because of integration of Low Energy with Standard EM,
now have option to use Livermore or Penelope Brems models

Ability to configure angular generator separately

Work is ongoing to see whether these changes will improve our match to benchmarks

Physics: Proton

Spline approximation of dedx and cross section tables provides a Bragg peak position which is stable within 0.1 mm versus variation of production cut or step limit (release 9.2)

NIST PSTAR database

Physics: Ion

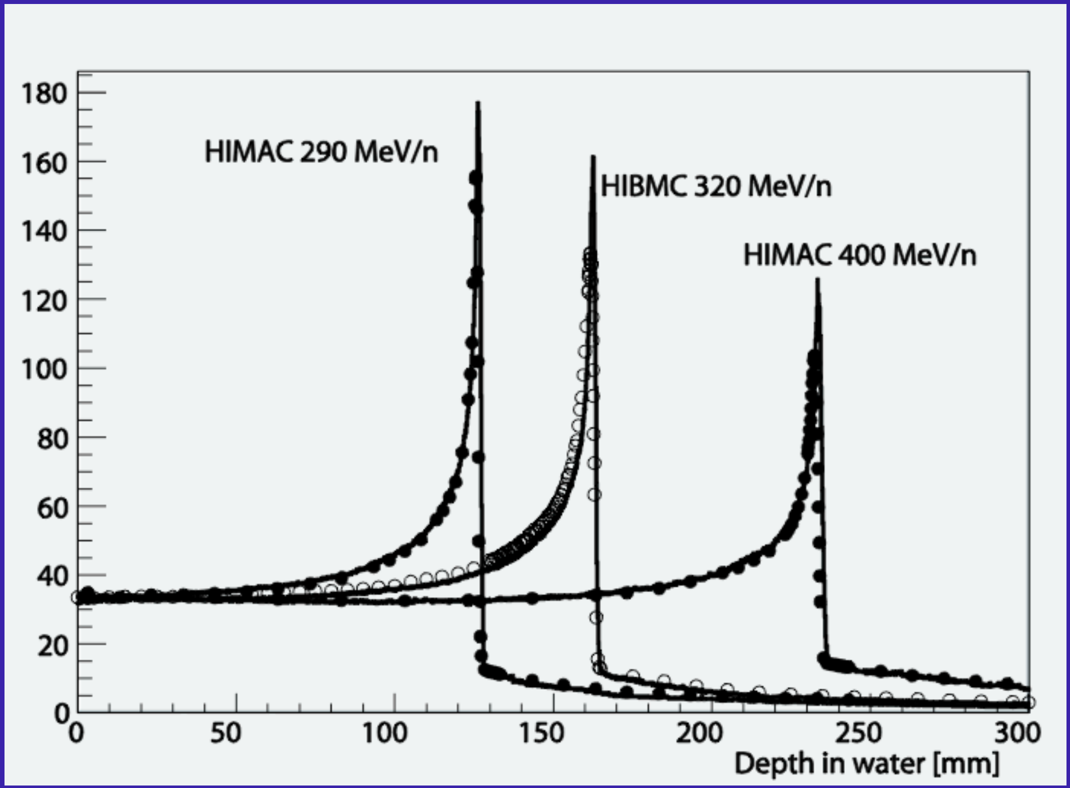
Numerical tables of stopping powers as a function of energy for all ion-material combinations available in ICRU 73 report are built into Geant4. (so use material name “G4_WATER” if you want this data).

Spline algorithm for interpolation was introduced to handle EM data (stopping powers, ranges, cross sections) essential for ion Bragg peak

New energy loss fluctuation model was introduced for ions and nuclear stopping model was implemented as a separate Geant4 process (before it was coupled with the ionisation energy loss process).

Stable against simulation step length and delta-ray production threshold

Physics: Ion



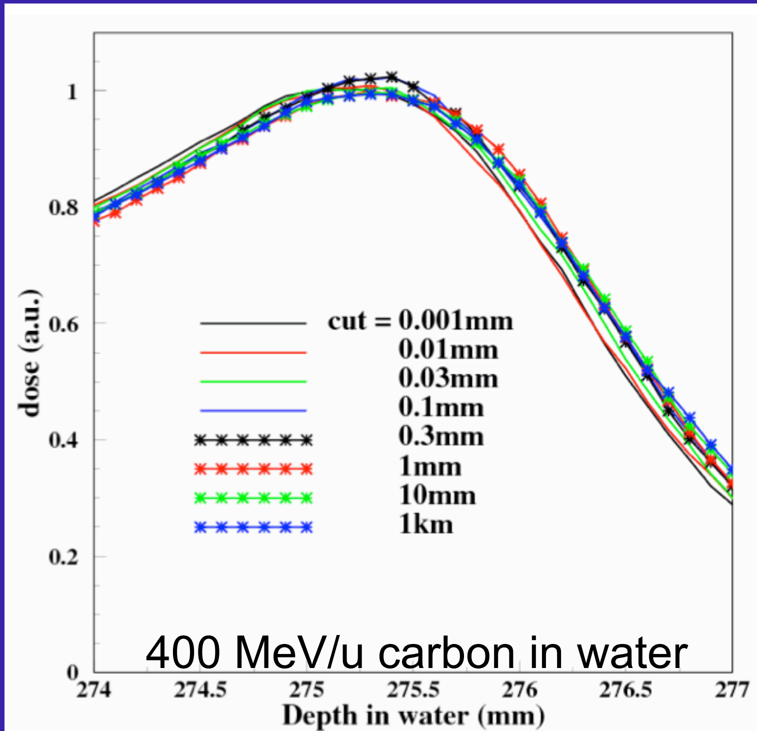


Fig. 1 Zoomed simulated depth-dose curves for various range cuts.

In press from MC2010 conference in Tokyo:
New Geant4 Electromagnetic Physics Developments for Ion Therapy Applications
Toshito, Bagulya, Lechner, Ivanchenko, Maire, Akagi and Yamashita

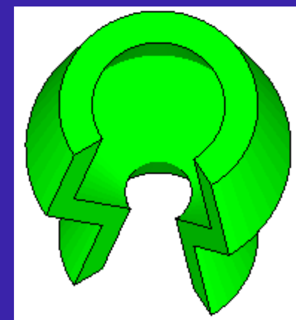
Physics: DNA Scale

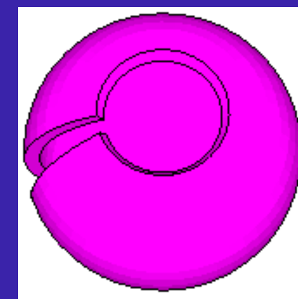
Significant effort is under way to bring Geant4 to size and energy scales of DNA (and, by happy coincidence, the scale of latest-generation computer chips).

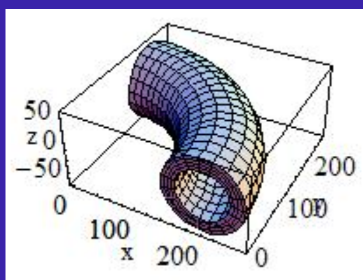
Please see separate talk by Sebastien Incerti for details on this work

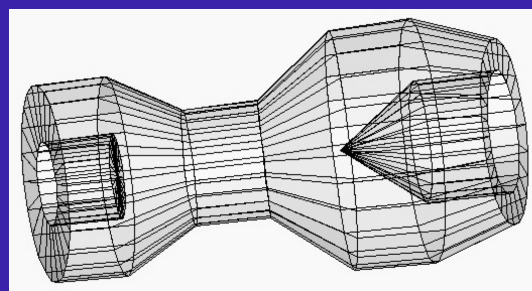
Geometry: Solids

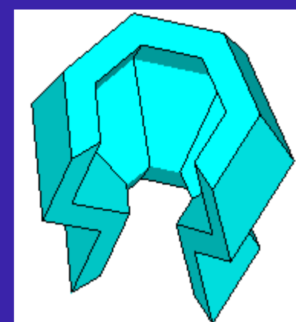
Already large library of solids
continues to expand

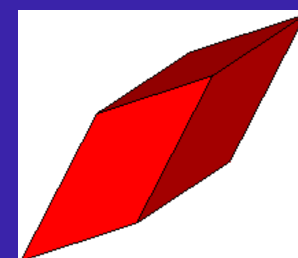


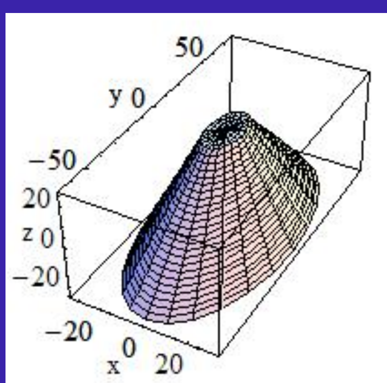


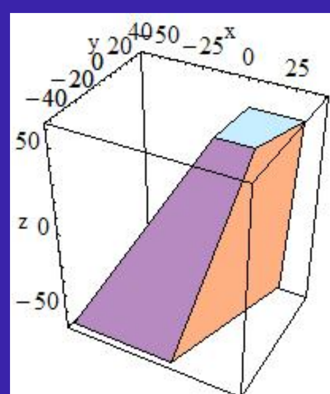


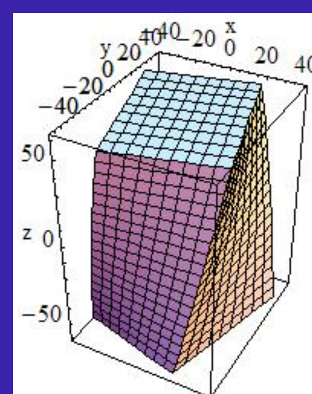


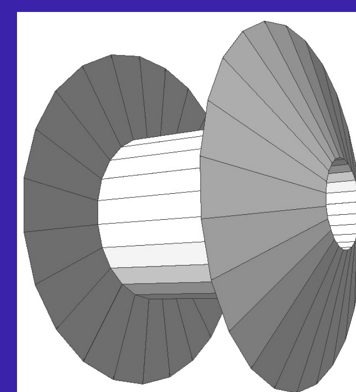












Geometry: CAD

CAD to GDML

Magdalena Constantin's technical note and upcoming paper on modeling of TrueBeam

Tools: FASTRAD, STViewer
Or, hot off the press, cadmesh
(new entry I just heard about from Geant4 user Chris Poole in Australia)

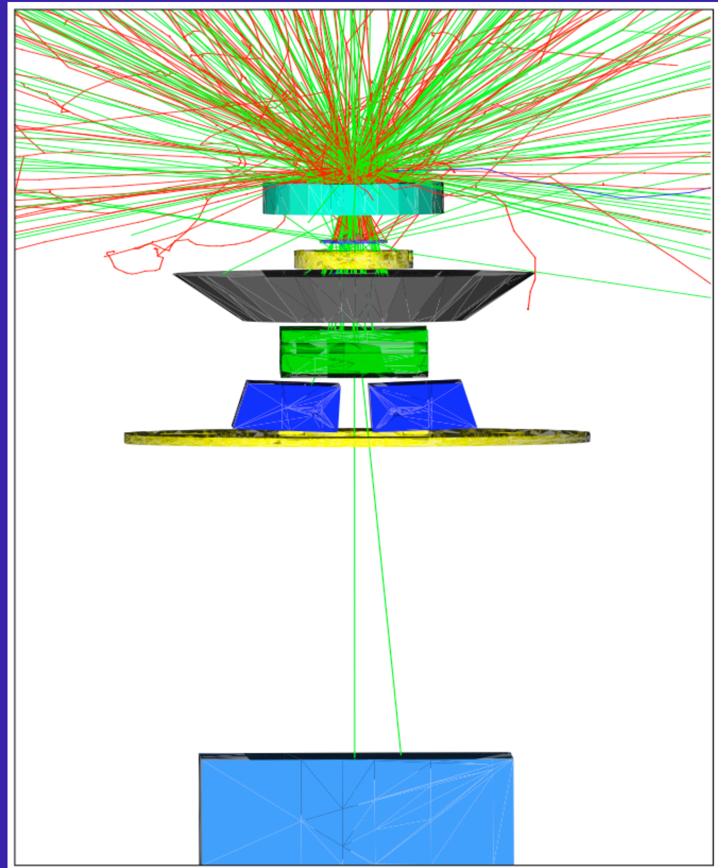


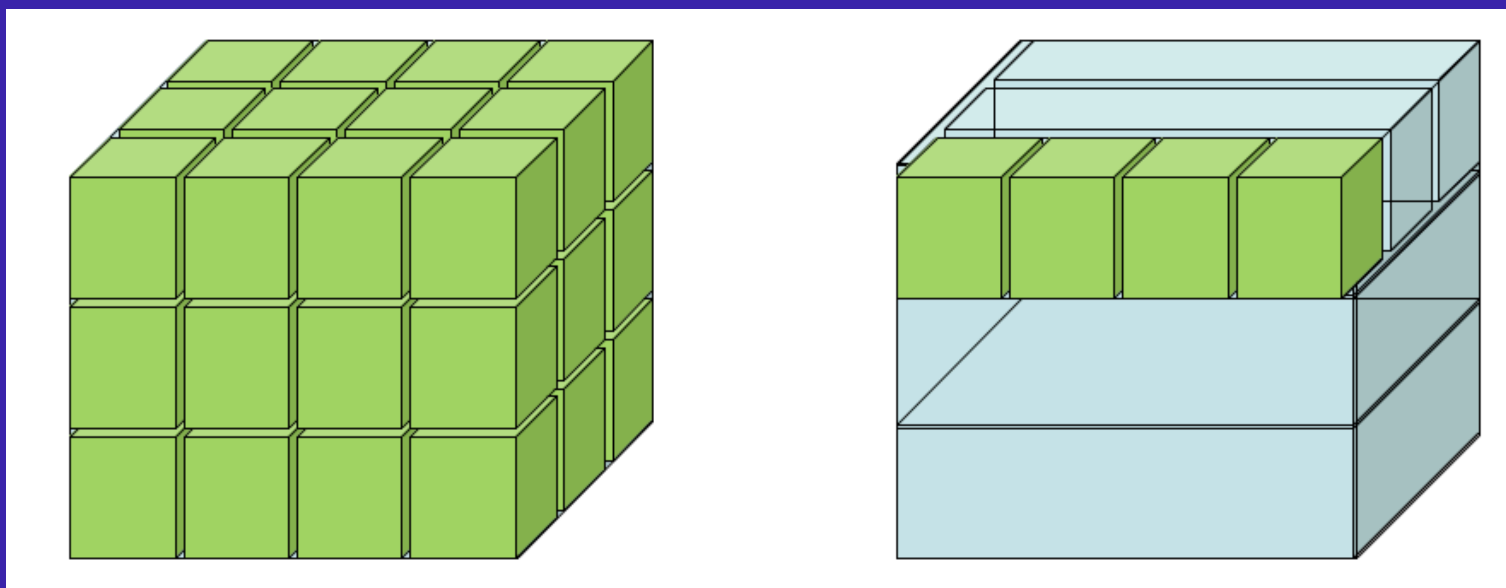
FIG. 4: Visualization of Geant4 particle trajectories along the treatment head components using OpenInventor. Electrons are photons shown in red and green, respectively. Field size was set to $10 \times 10\text{cm}^2$ and SSD to 100 cm. Note that for proprietary reasons, the appearance of some of the components in this figure has been modified.

Linking Computer-Aided Design (CAD) to Geant4-based Monte Carlo Simulations for Precise Implementation of Complex Treatment Head Geometries
Magdalena Constantin, Dragos E. Constantin, Paul J. Keall - Stanford
Anisha Narula, Michelle Svatos - Varian Medical Systems
Joseph Perl - SLAC
Phys. Med. Biol. 55 N211   doi: 10.1088/0031-9155/55/8/N03

Geometry: Voxels

Parameterizations for Voxel Geometries

“Nested Parameterization” allows space-savings and fast navigation of replicas with flexibility of material parameterization

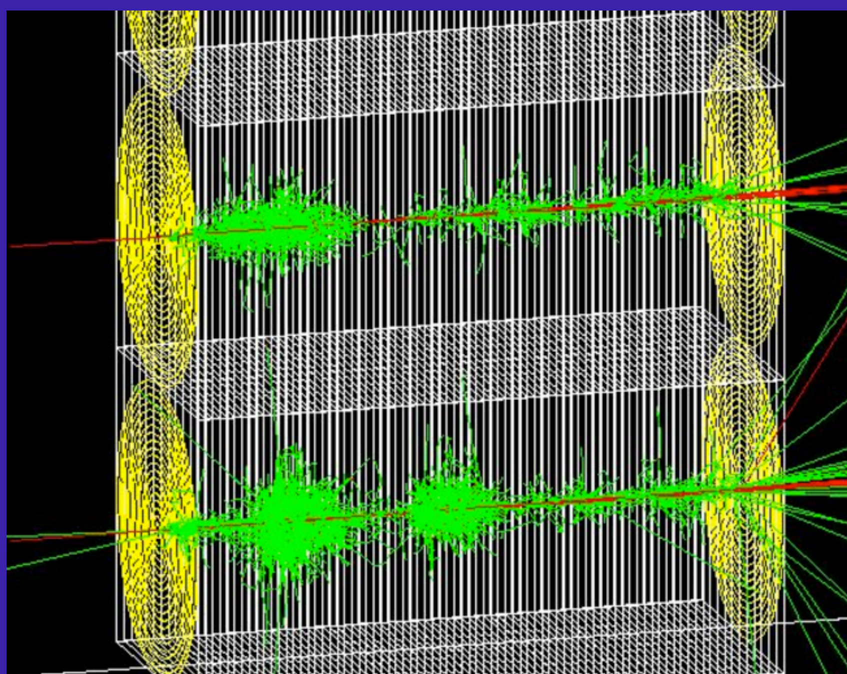


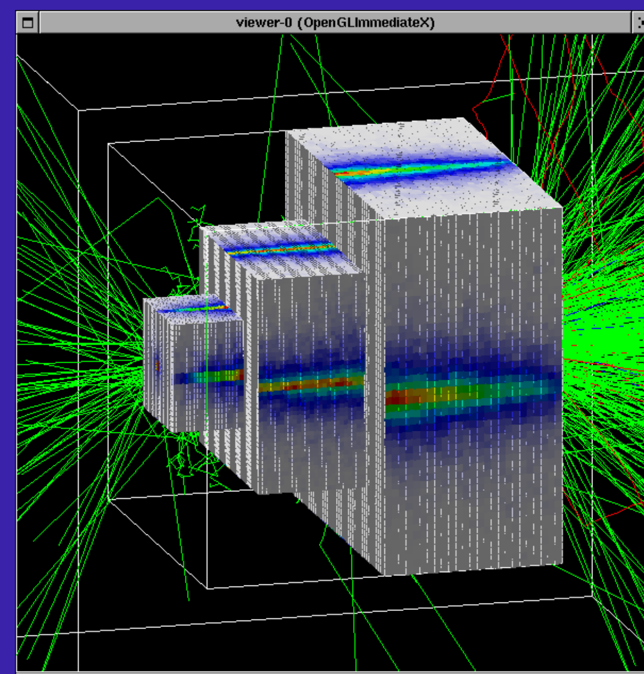
See Jan Schuemann’s poster for comparison of various navigators

Geometry: Scoring

Parallel Worlds give you freedom to score without concern of overlaps or real-world segmentation.

“Multi-functional Detector” provides key architectural support for “sensitive volumes”.
Can then write your own scoring or use pre-built scorers.





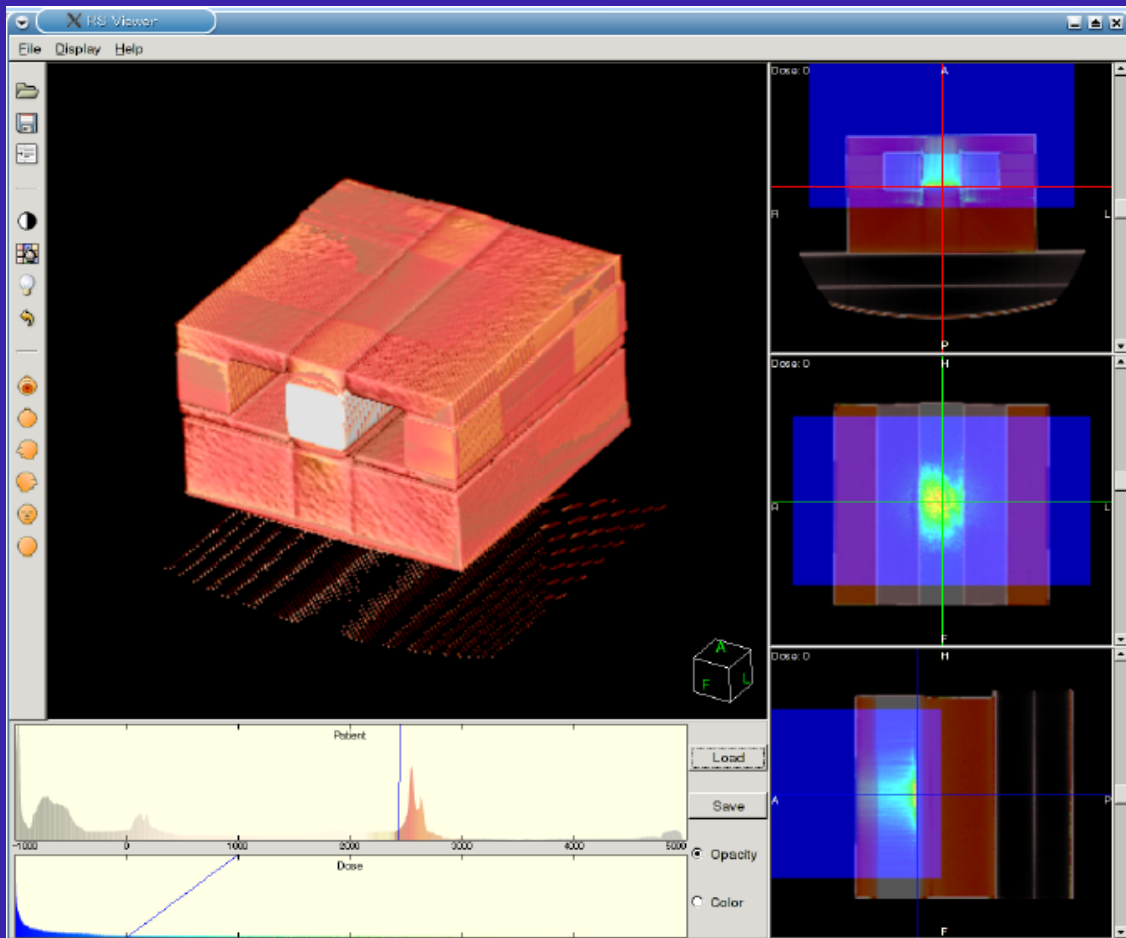
Layered Mass Geometry

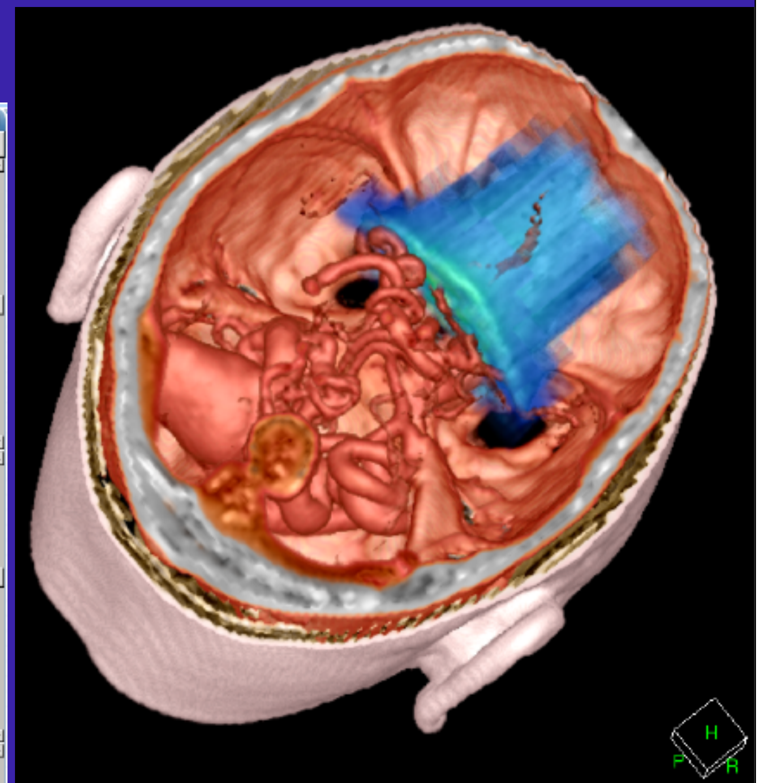
Until right now, the speed and memory value of Nested Parameterization has been unavailable for certain classes of problems, most critically, Brachytherapy.

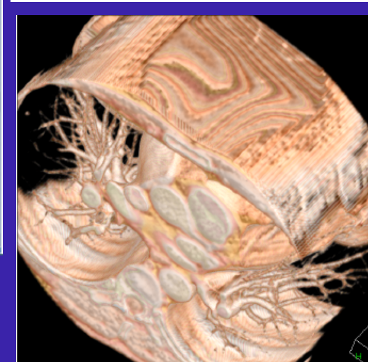
Please see separate talk by Shirin Enger for the solution to this problem

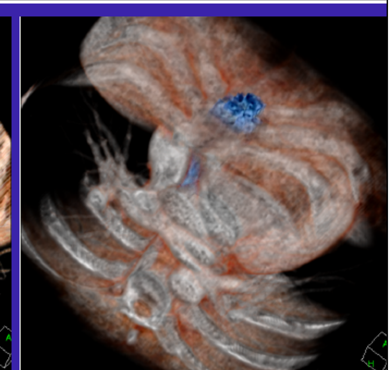
Volume Visualization

gMocren from JST/CREST, Japan









Contact: Takashi Sasaki, here this week
http://geant4.kek.jp/gMocren

Applications

It was always intended that communities should come together to build specific applications based on Geant4.
Analogous to how BEAMnrc and DOSxyz wrap EGSnrc.

All large HEP collaborations do this: LHC, Fermi Space Telescope, etc.

The Aerospace community has done this: RADSAFE and SPENVIS.

Medical Applications (alphabetically):
GAMOS, GATE, PTSim

Included examples that are nearly applications:
geant4/examples/advanced/hadrontherapy

Additional applications in development: G4DBR, TOPAS

Discussion of these applications is outside the scope of this talk
(Geant4 distinguishes Core Geant4 Activities versus User Applications)

Upcoming: Usability

CLHEP external library no longer required

Built-in ability to produce Root or AIDA files

Entirely new make system

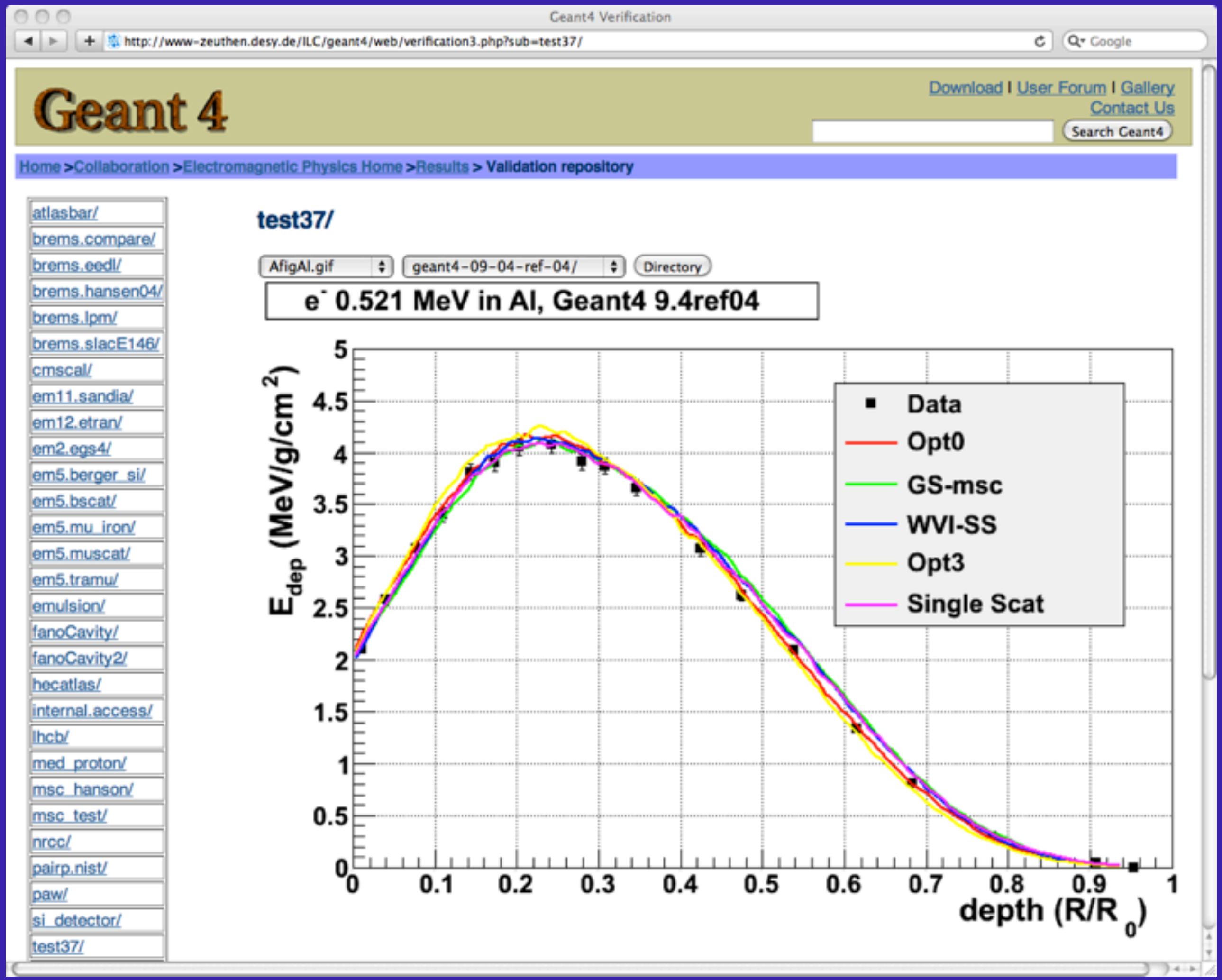
Automating confusing process-ordering parts of the physics list

Reorganizing examples

Unifying warning/error messages

Upcoming: Accuracy

Validation Framework: increasingly automating this process



http://www-zeuthen.desy.de/ILC/geant4/web/verification3.php

Upcoming: Memory

Nested Parameterization has solved key memory issues for most applications in external beam.

Layered Mass Geometry will extend these advantages to Brachytherapy.

Variable density material

Upcoming: Speed

Multi-threaded prototype

Variable density material may help the extent that cache speed is issue

Geant4 Wants You

The Geant4 collaboration needs more medical physicists to move from being just users to being collaborators.

Take a role in the service work of the collaboration, responsibility for improving core functionality of use to the entire Geant4 community.

No specific minimum amount of your time required, but an ongoing ownership role in the work of the collaboration.

In exchange, you get more direct influence in direction of the toolkit.

Geant4 is Good for You

- As a Geant4 developer, you contribute to a shared code that remains free to everyone, including you.

- You retain full rights to continue to develop your code, modify it, contribute back those mods or keep them for yourself

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Technical Forum

The Geant4 Technical Forum is a formal venue for Geant4 users to communicate with Geant4 developers and to put their requirements onto the record.

We invite you to attend the forum here tonight, 5:30-6:30,
led by technical forum deputy chair, Bruce Faddegon