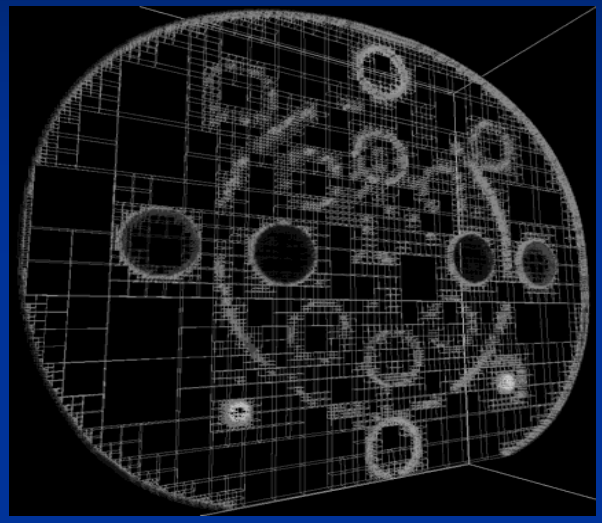
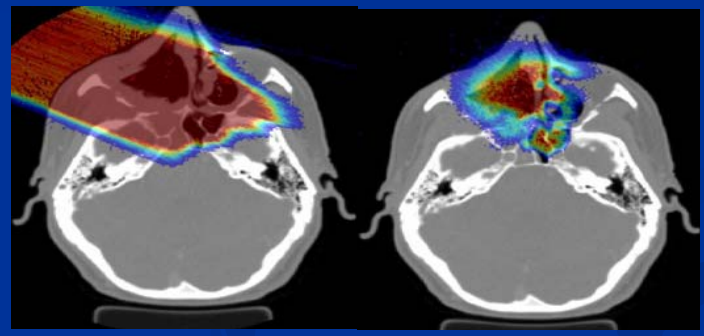
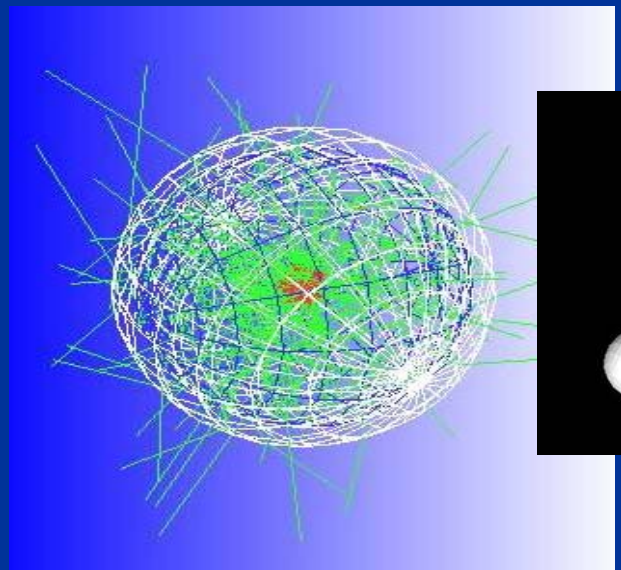
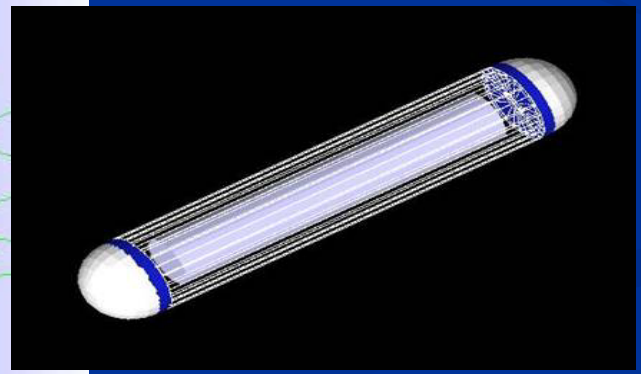
Geant4 Medical Application Activity in North America

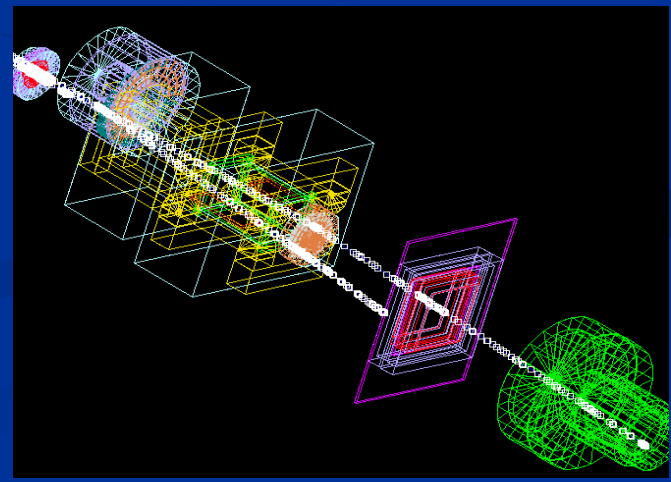


J. Perl, D. Wright, M. Asai
SLAC/SCCS









What is G4NAMU?

G4NAMU – the Geant4 North America Medical Users Organization

Launched in May of 2005 to provide a meeting place for the rapidly growing Geant4 medical user community of North America.

The purpose of G4NAMU is to bring this community together to share issues and advice, to develop regional collaboration and to communicate as a group to the Geant4 developers.

Who is G4NAMU?

G4NAMU's current membership includes 52 members from 27 institutions throughout Canada and the United States.

Current subscribers to the mailing list (page 1 of 3):

- SLAC: Joseph Perl, Makoto Asai, Dennis Wright
- Harvard & Mass General: Harald Paganetti, Xing-Qi Lu , Roelf L. Slopsema
- UCSF: Bruce Faddegon, Inder Daftari
- Jefferson Lab: Paul Gueye, Stan Majewski, Mark Smith, David Hamlette, Michael Epps, Marion MacCormic
- ULaval: Jean-François Carrier, Luc Beaulieu, Louis Archambault, Vincent Hubert Tremblay
- CHUQ: Luc Gingras
- UPenn: Steven Avery , Dickson Goulart, Jim McDonough
- Stanford: Todd Pawlicki, Gary Luxton, Lei Xing
- Louisiana State University: Blair Smith
- (continued on next slide…)

Who is G4NAMU? (continued)

Current subscribers to the mailing list (continued):

- McGill: Emily Poon, Frank Verhaegen, Jan Seuntjens
- Triumf: Peter Gumplinger, Frederick Jones
- Memorial Sloan-Kettering: C. Ross Schmidtlein, Assen Kirov, Sadek Nehmeh, Christopher Danford
- Johns Hopkins: Jingyan Xu
- University of Arkansas: Hongyu Jiang
- Fox Chase: Charlie Ma, Jiajin Fan, Jinsheng Li
- Advanced Laser Light Source: Jean-Claude Kieffer, Jean-Philippe Moreau
- University of Wisconsin – Madison: Hazim A Jaradat
- INRS: Francois Vidal, Sylvain Fourmaux, Ludovic Lecherbourg, Rémy Toth
- Université de Sherbrooke: Daniel Houde
- (continued on next slide…)

Who is G4NAMU? (continued)

Current subscribers to the mailing list (continued):

- University of Alberta: Robert Fedosejev, Craig Unick
- Walter Reed Army Medical Center: Dan Fry
- Texas A&M: Yong Chen
- University of Washington: Ruth Schmitz
- Hopital Maisonneuve-Rosemont: Brigitte Reniers
- University of Minnesota: Lihong Qin
- Xoft Inc.: Steve Axelrod

G4NAMU within the World Geant4 Collaboration

- Of course all Geant4 users are part of a world wide community.
  - Medical Applications forum and other user forums are available for discussion and exchange, as well as other Geant4 workshops and meetings.
- But regional efforts also have a role.
  - In Europe, some efforts are being organized through Maria Grazia Pia of INFN, and through others
  - In Japan, some efforts are being organized through Takashi Sasaki of KEK (including carbon beams, parallel computing)
  - In North America, there has been no similar effort at regional organization

G4NAMU as Regional Voice

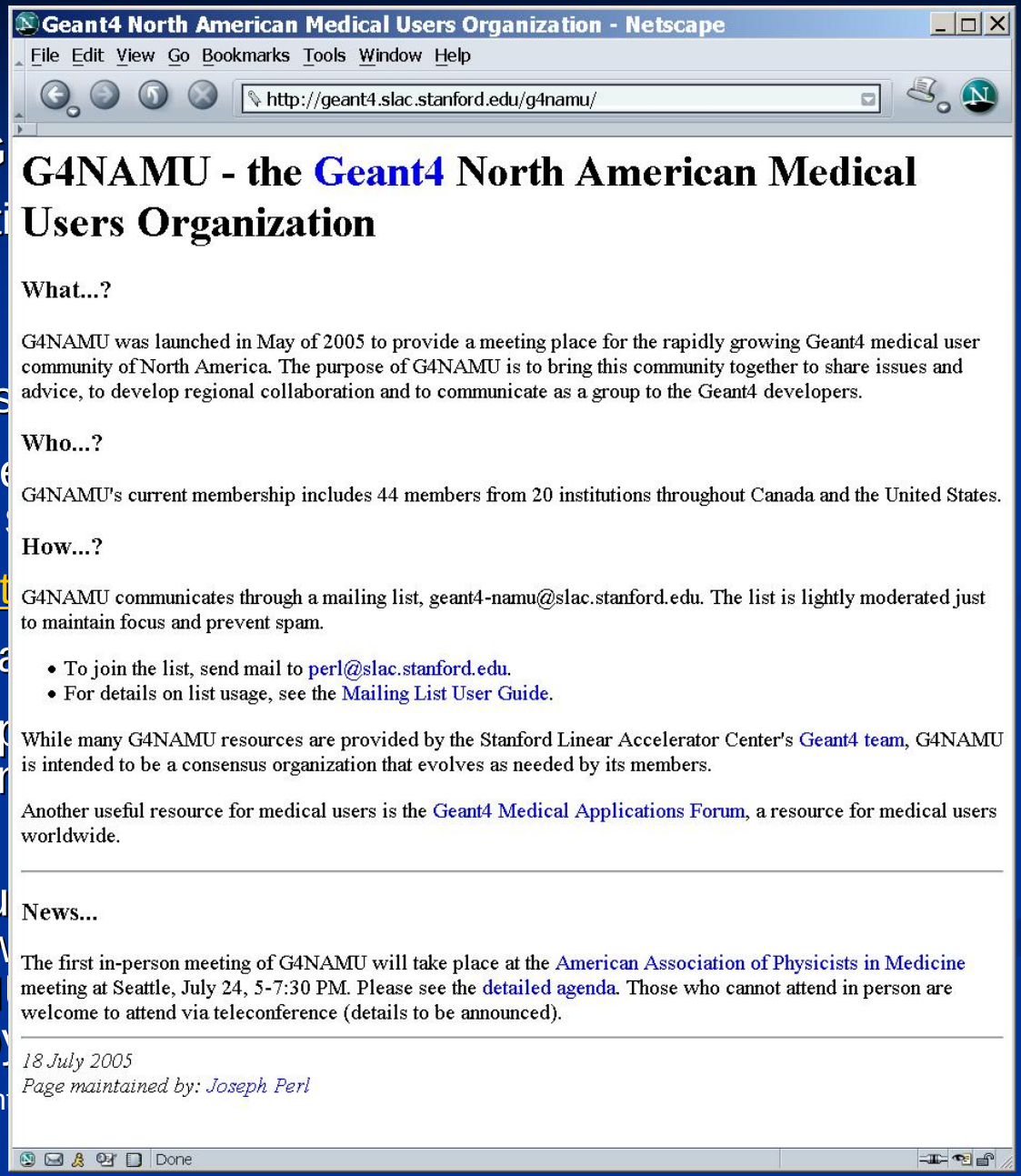
- G4NAMU can serve as voice of the North American Geant4 Medical User community
  - Organize regional workshops or tutorials
  - Foster nearby collaborations
  - Speak with a collective voice to regional funding agencies
  - Meet regional certification needs
    - At its meeting last October in San Diego, the American Nuclear Society (ANS) recognized the formation of a Computational Medical Physics Working Group (CMPWG). CMPWG will be hosted by three divisions of ANS - Mathematics and Computations (M&C), Biology and Medicine (BMD), Radiation Protection and Shielding (RPSD).
    - CMPWG may become involved in benchmarking codes for Medical Physics applications.

How Should G4NAMU Work?

- We've agreed to use a mailing list.
  - geant4-namu@slac.stanford.edu
  - The list is lightly moderated just to maintain focus and prevent spam.
  - To join the list, send mail to perl@slac.stanford.edu.
- We will have periodic meetings and will try, as we have today, to take advantage of existing meetings.
  - Next meeting: March 6th, 2006 at SLAC
- We can go beyond this:
  - Provide workshops or tutorials
  - Develop additional Geant4 examples
  - Certify certain parts of the code for use in our communities
  - Collect requirements for Geant4 developers

Where Does SLAC Fit into G4NAMU

- Three of us are from
  - Largest center of G
  - Expertise in essenti
  - Three seats on the
  - Our laboratory and the medical physics
- From SLAC, we've se initial G4NAMU web
  - http://geant4.slac.st
  - Extremely boring pa
- J. Perl would be happ G4NAMU requiremer developers
- While the SLAC grou we understand that w community. G4NAM evolves as needed b



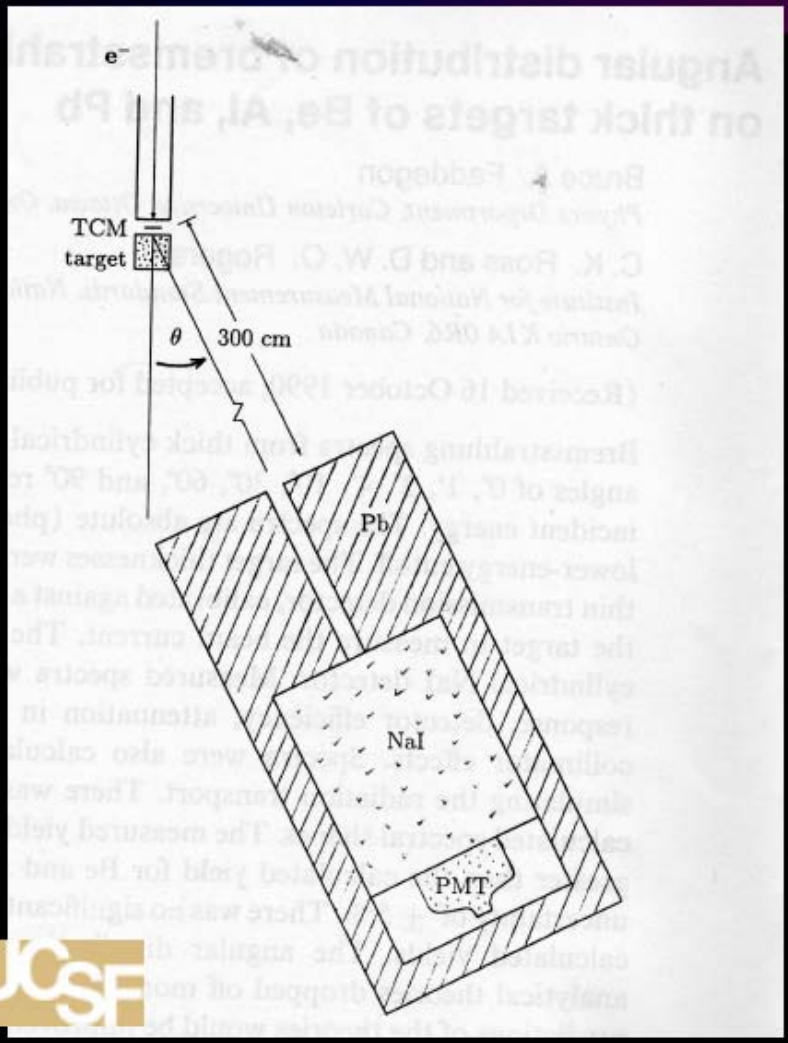
Some Next Steps

- Improve communication between Geant4 developers and the medical physics community.
- Collect requirements for Geant4 developers.
- Validation:
  - Clarify what studies have been done, what results have been found, what studies still need to be done.
  - Perform additional beam tests as needed.
  - Compare results made by Geant4 with experiments and/or other MC codes in Medicine.

An accurate experimental benchmark of bremsstrahlung for radiotherapy quality beams

Bruce Faddegon, UCSF
Joseph Perl, SLAC
Tsukasa Aso, SLAC
Makoto Asai, SLAC

Thick-target bremsstrahlung measurement at 10-30 MV

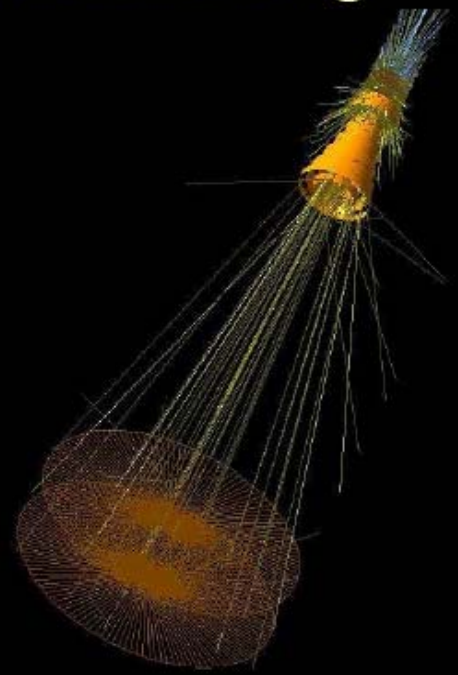


- Bremsstrahlung yield: photons per unit solid angle per unit energy interval
- Targets: Be, Al, Pb, thickness is CSDA range
- Yield on beam axis, Al and Pb, 10, 15, 20, 25 and 30 MV
- Yield at 15 MV, Be, Al and Pb at 0, 1, 2, 4, 10, 30, 60, 90°
- Back angle in progress

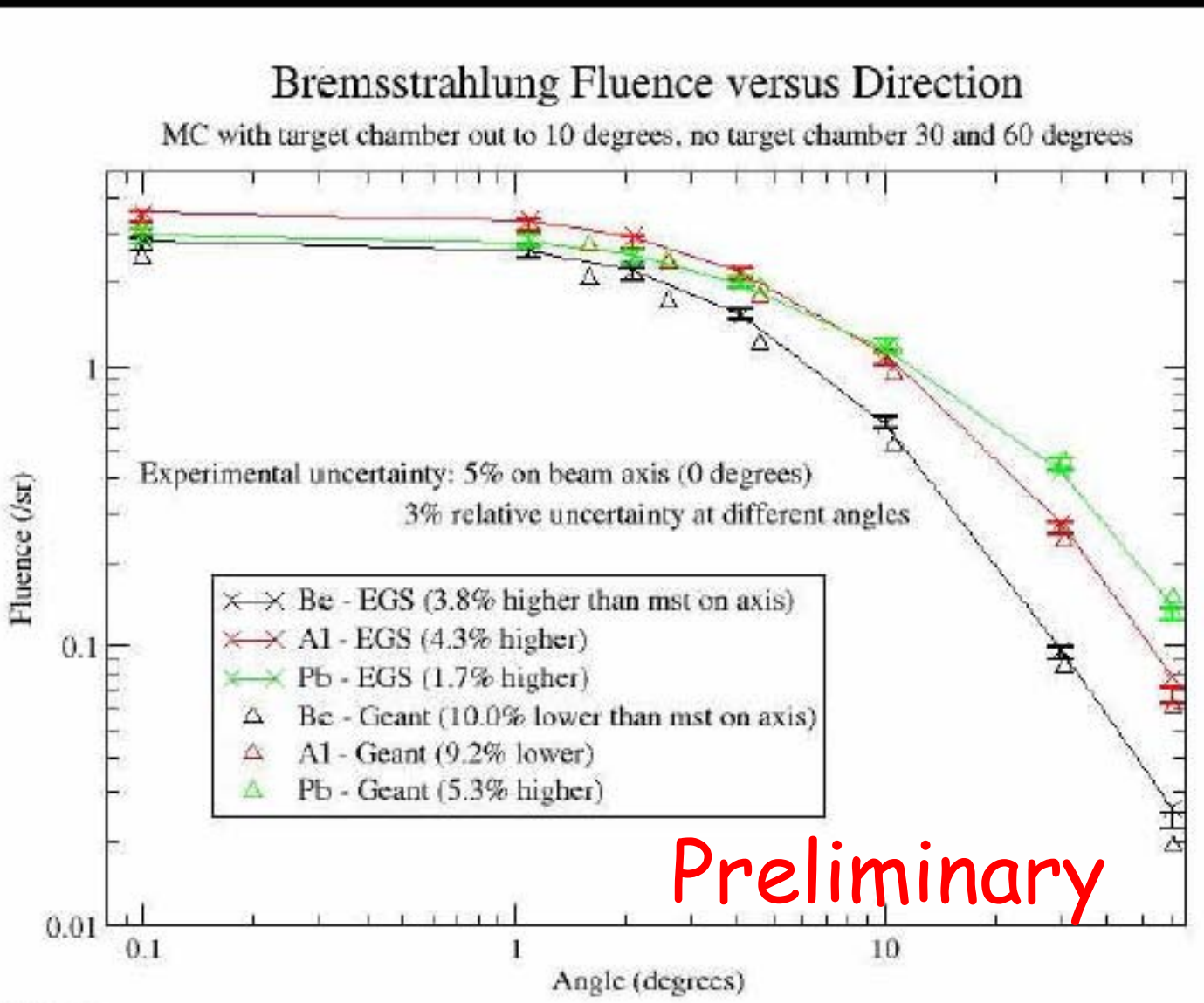
Monte Carlo simulation: 15 MeV electrons on Be/Al/Pb target

- Geant4
- New geometry: scoring sphere around beamline and target developed by M. Asai
- New scoring developed by T. Aso
- Installation and support by J. Perl

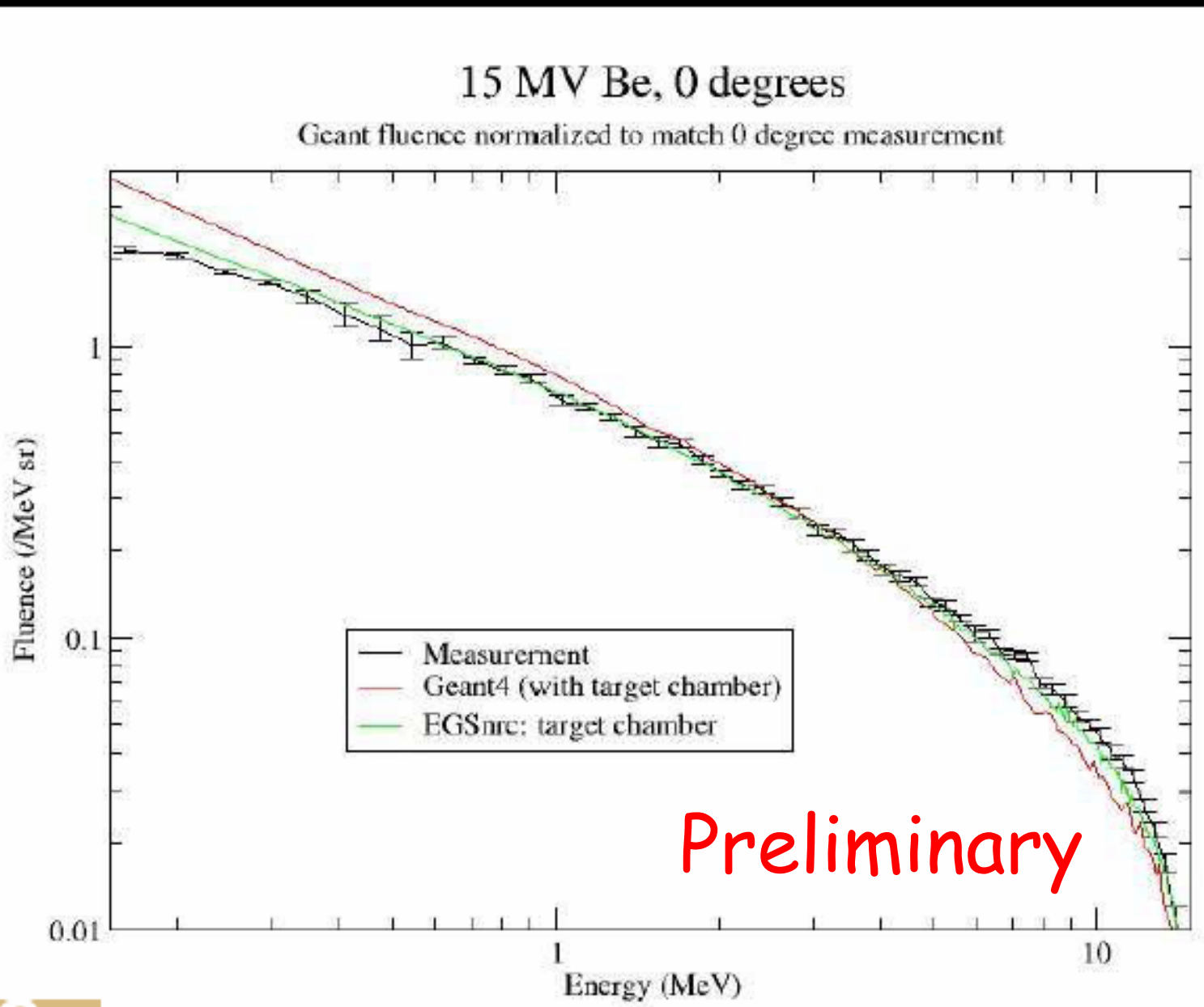
- EGSnrc with BEAM user code from NRCC
- Revised scoring



UCSF


Bremsstrahlung Fluence versus Direction
MC with target chamber out to 10 degrees, no target chamber 30 and 60 degrees
Experimental uncertainty: 5% on beam axis (0 degrees)
3% relative uncertainty at different angles
Be - EGS (3.8% higher than mst on axis)
Al - EGS (4.3% higher)
Pb - EGS (1.7% higher)
Be - Geant (10.0% lower than mst on axis)
Al - Geant (9.2% lower)
Pb - Geant (5.3% higher)
Preliminary
Fluence (/sr)
Angle (degrees)
1
0.1
0.01
0.1
1
10

fluence


15 MV Be, 0 degrees
Geant fluence normalized to match 0 degree measurement
Fluence (/MeV sr)
1
0.1
0.01
1
10
Energy (MeV)
Measurement
Geant4 (with target chamber)
EGSnrc: target chamber
Preliminary

Some Next Steps

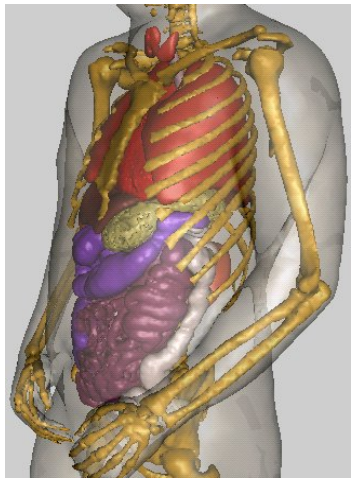
- Improve communication between Geant4 developers and the medical physics community.
- Collect requirements for Geant4 developers.
- Validation:
  - Clarify what studies have been done, what results have been found, what studies still need to be done.
  - Perform additional beam tests as needed.
  - Compare results made by Geant4 with experiments and/or other MC codes in Medicine.
- Calculation speed:
  - Understand issues.
  - Suggest and validate variance reduction methods.
- Create additional medical examples.
- Continue discussion on the mailing list. Invite additional colleagues to the list.
- Maintain Relationships with Relevant North American Professional Organizations:
  - ANS Computational Medical Physics Working Group (CMPWG). They have asked Harald Paganetti to represent Geant4.
  - AAPM Task Group No. 105: "Guidance report on clinical implementation of the Monte Carlo method in external beam radiation therapy treatment planning."
- Work on ways to improve funding for Geant4 medical work in North America.

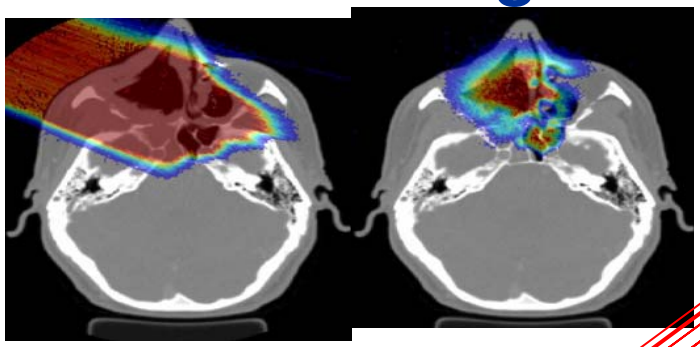
Some Next Steps

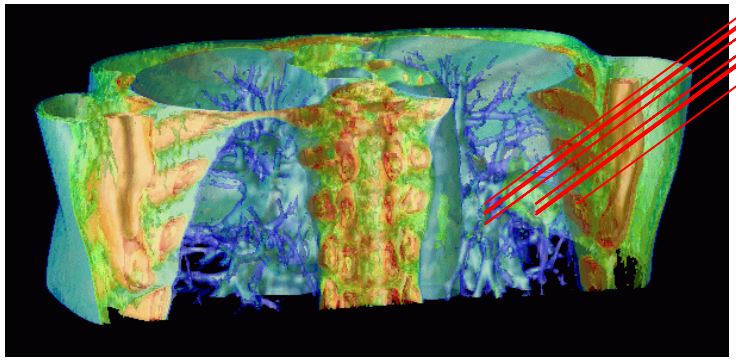
- Develop the G4NAMU web site:
  - Should answer question: Why would I use Geant4 for medical physics?
  - Clarify which physics lists are recommended for which medical problems.
  - Provide a medical physicist's overview of each Geant4 release's release notes. I.e., what should a medical physicist know about this new release.
  - Collect references to papers.
    - For those papers that are publicly available, include actual copies of the papers.
    - For those papers that are restricted by subscriber permissions, include abstract and then link to actual publication (which not all viewers will be able to actually read).
  - Show Geant4 results in three sections:
    1. Where is Geant4 known to give good results? Link to appropriate publications.
    2. Where is Geant4 known to give poor results? Link to appropriate publications. Include discussion known problems and of what is planned to improve these issues.
    3. Where are Geant4 results unknown? I.e., what additional tests do we know we need to perform?
  - Show member names by work area.
- Hold tutorials aimed at medical users.
  - SLAC, early March 2006, details to be announced
  - Jefferson Lab, later in 2006, details to be announced
  - Smaller tutorials annually as part of AAPM annual meeting

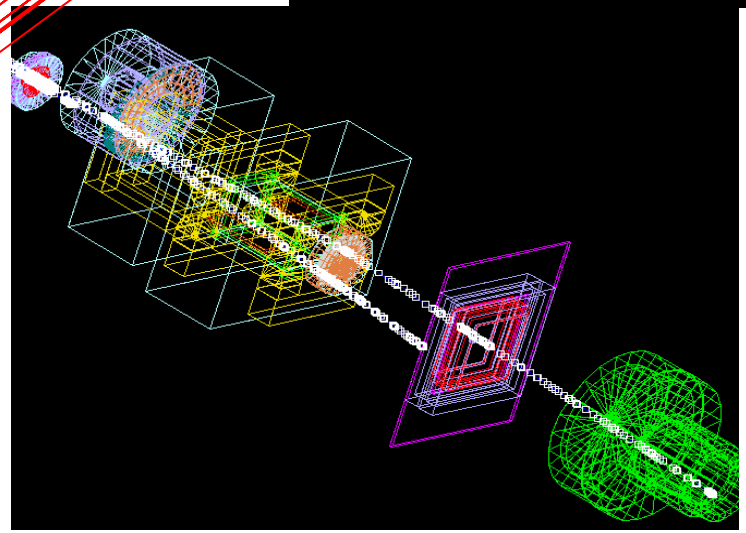
G4NAMU in External Beam Therapy

(Ad-Hoc Working Group Coordinator: Harald Paganetti)

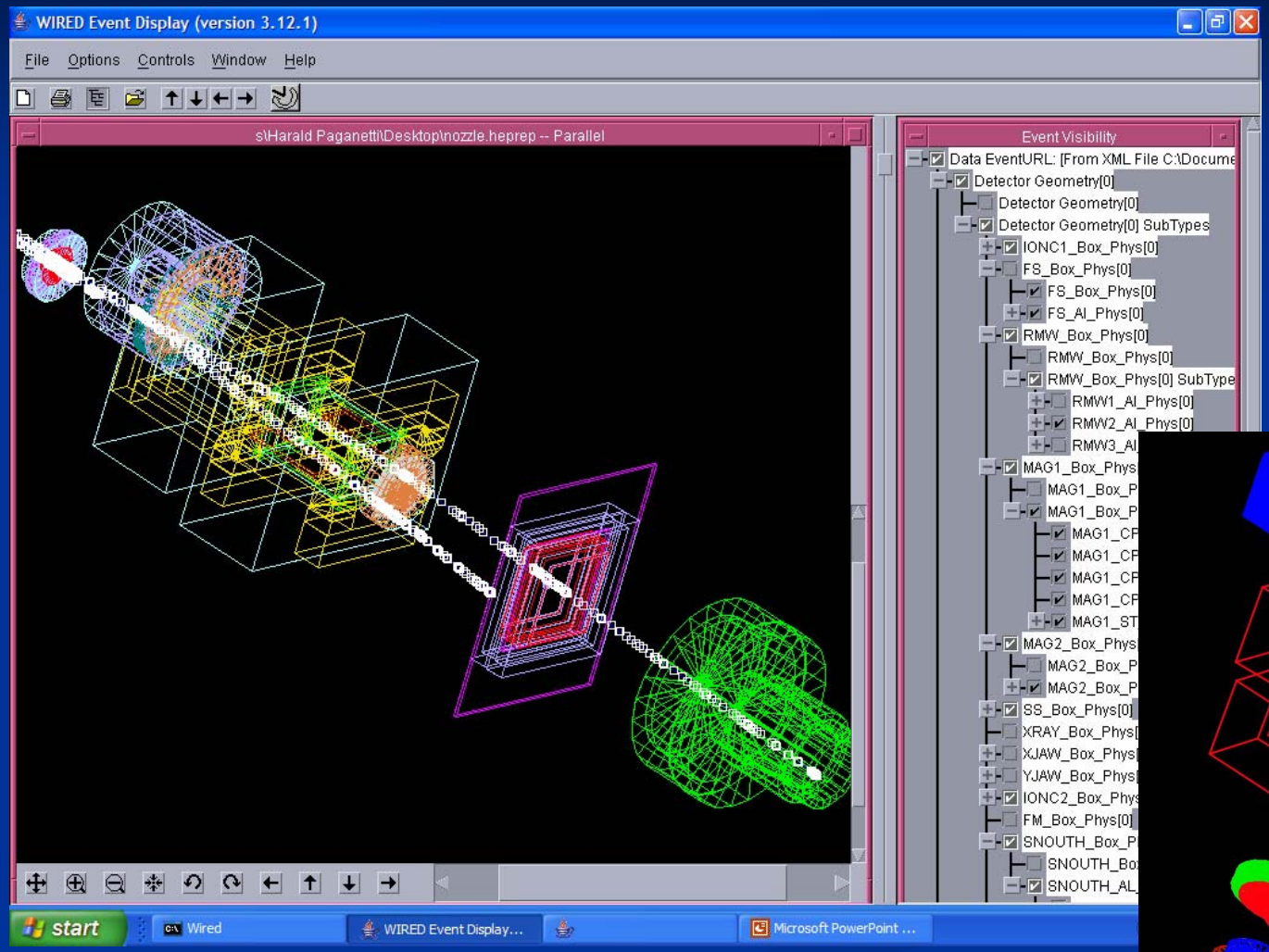


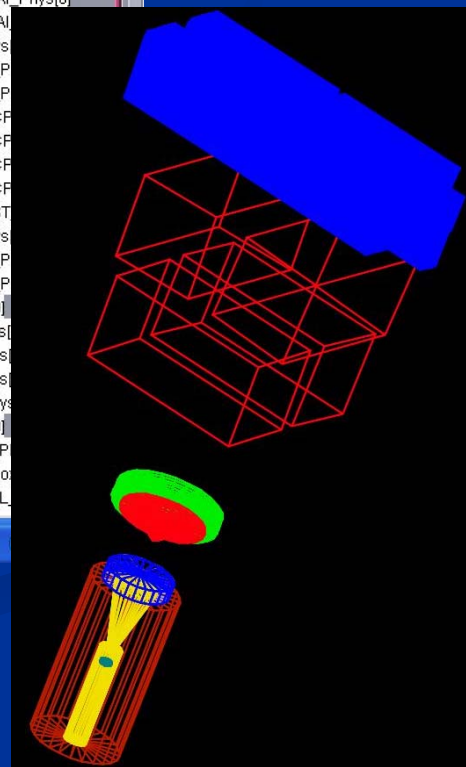




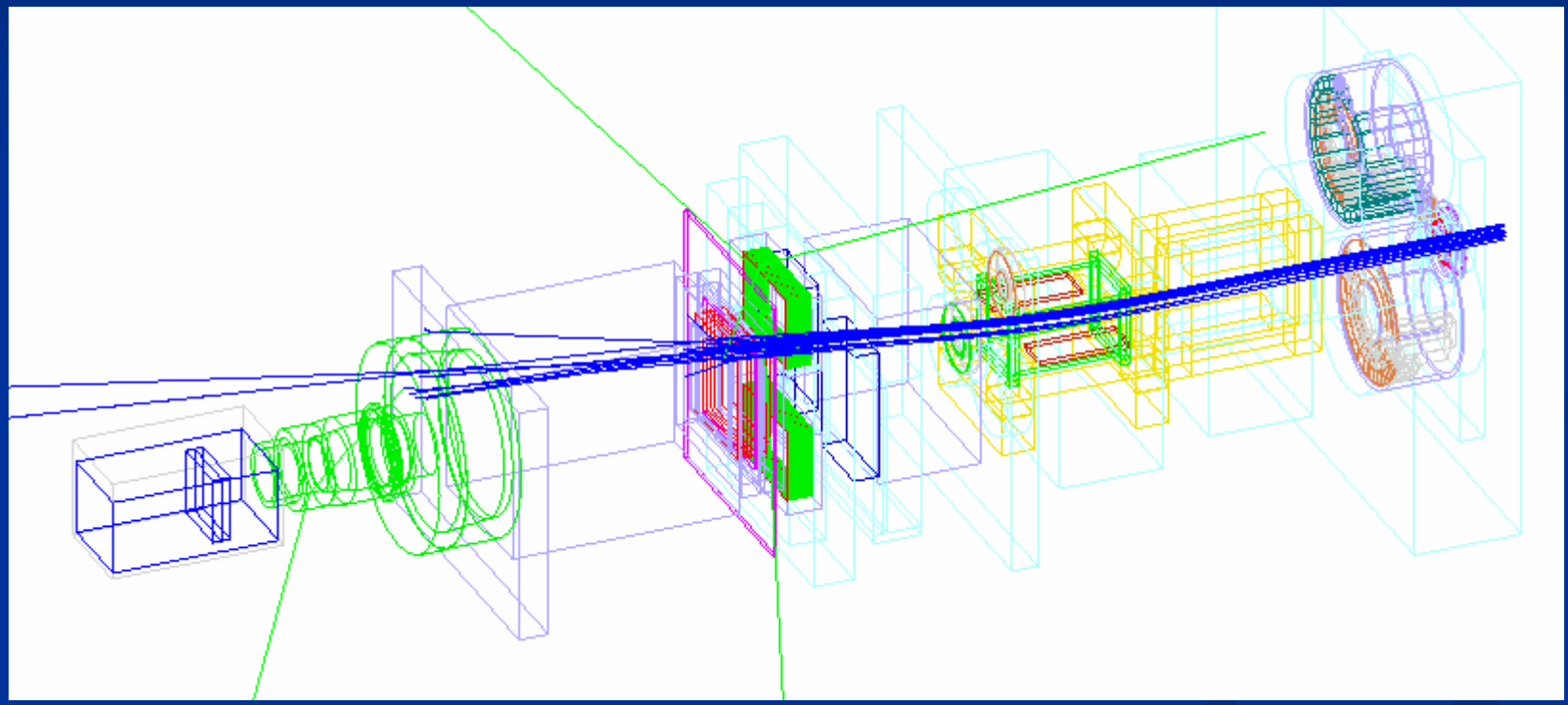


Beamline design and quality assurance

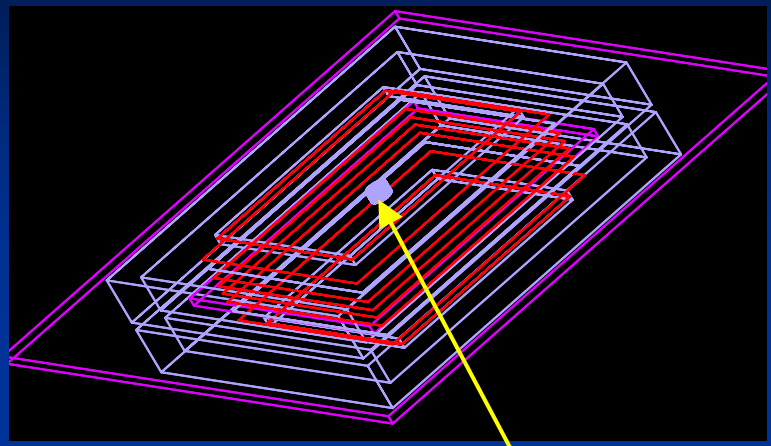




Magnetic fields



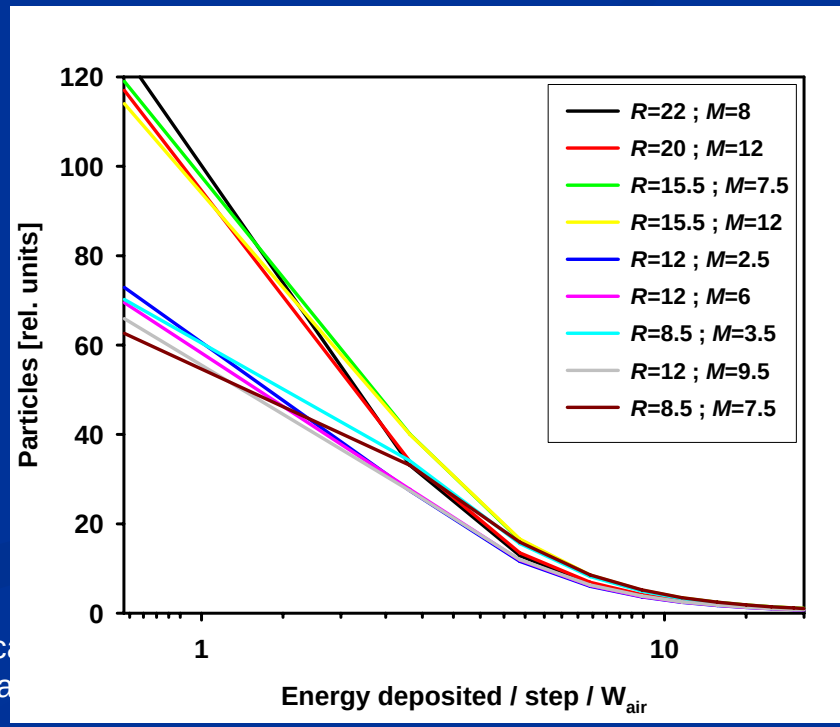
Absolute dosimetry



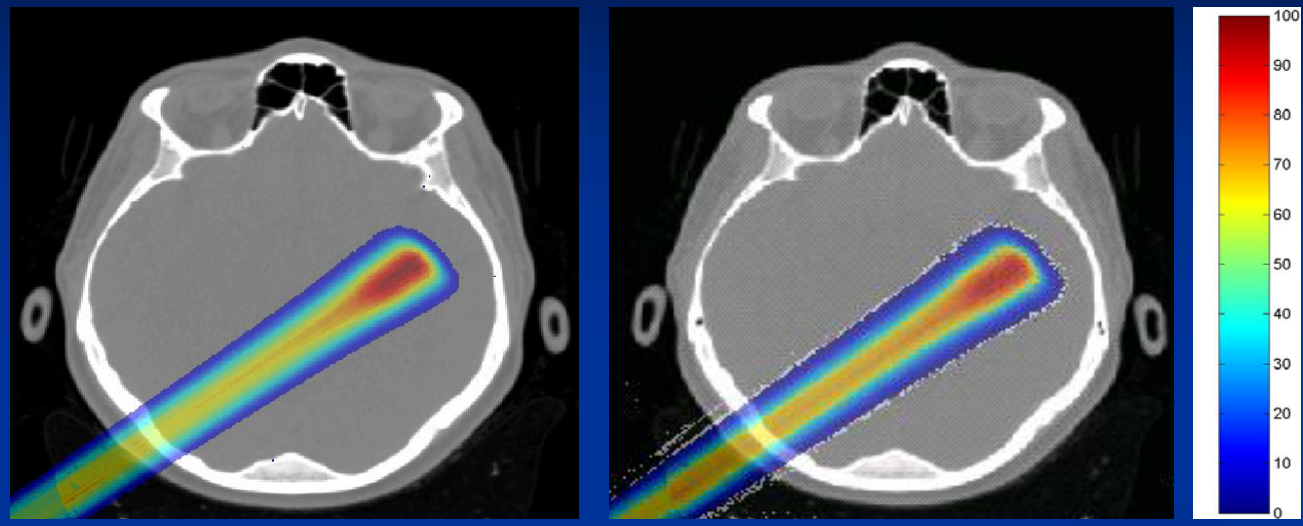
Volume for absolute dosimetry

$$Output - Factor \cong \frac{D_{cal}}{i_{ic}} \left[cGy / MU \right]$$

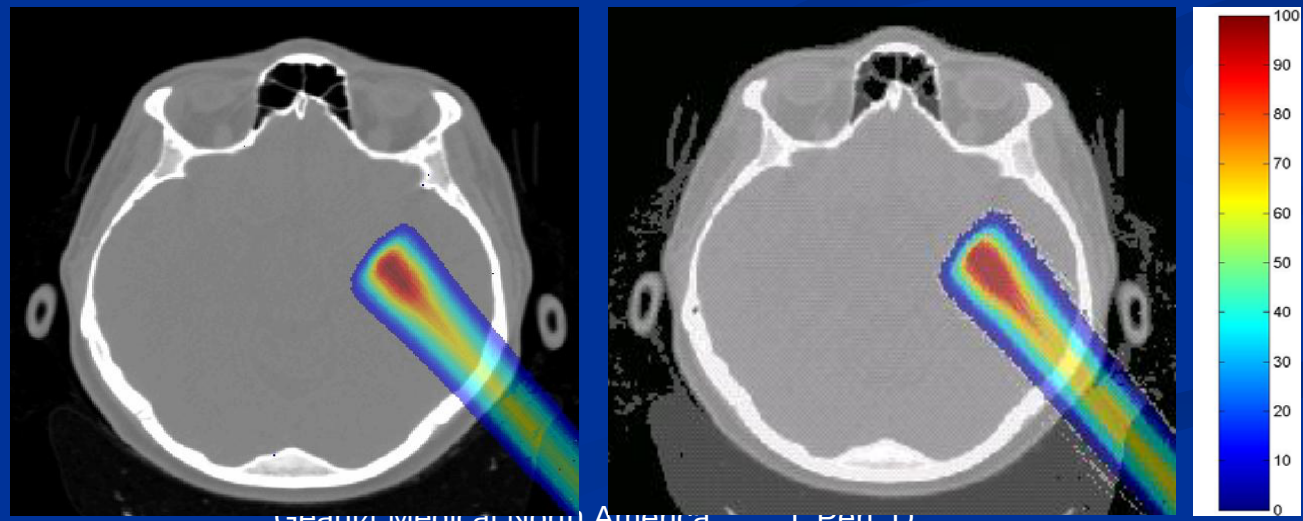
$$i_{ic} = \frac{e \cdot \varepsilon_{ic}}{W_{air}} \times \int\int \left(\frac{dE}{dx} \right)_{air} p \cdot d\xi dF$$



Patient dose calculation

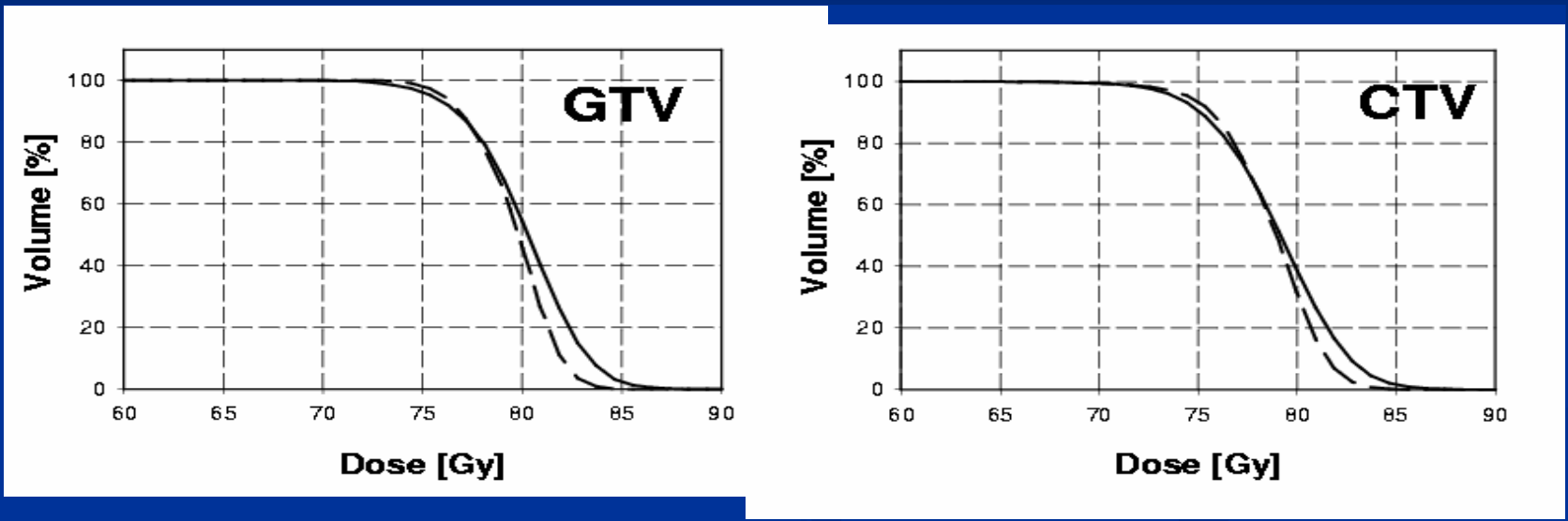


FOCUS Monte Carlo



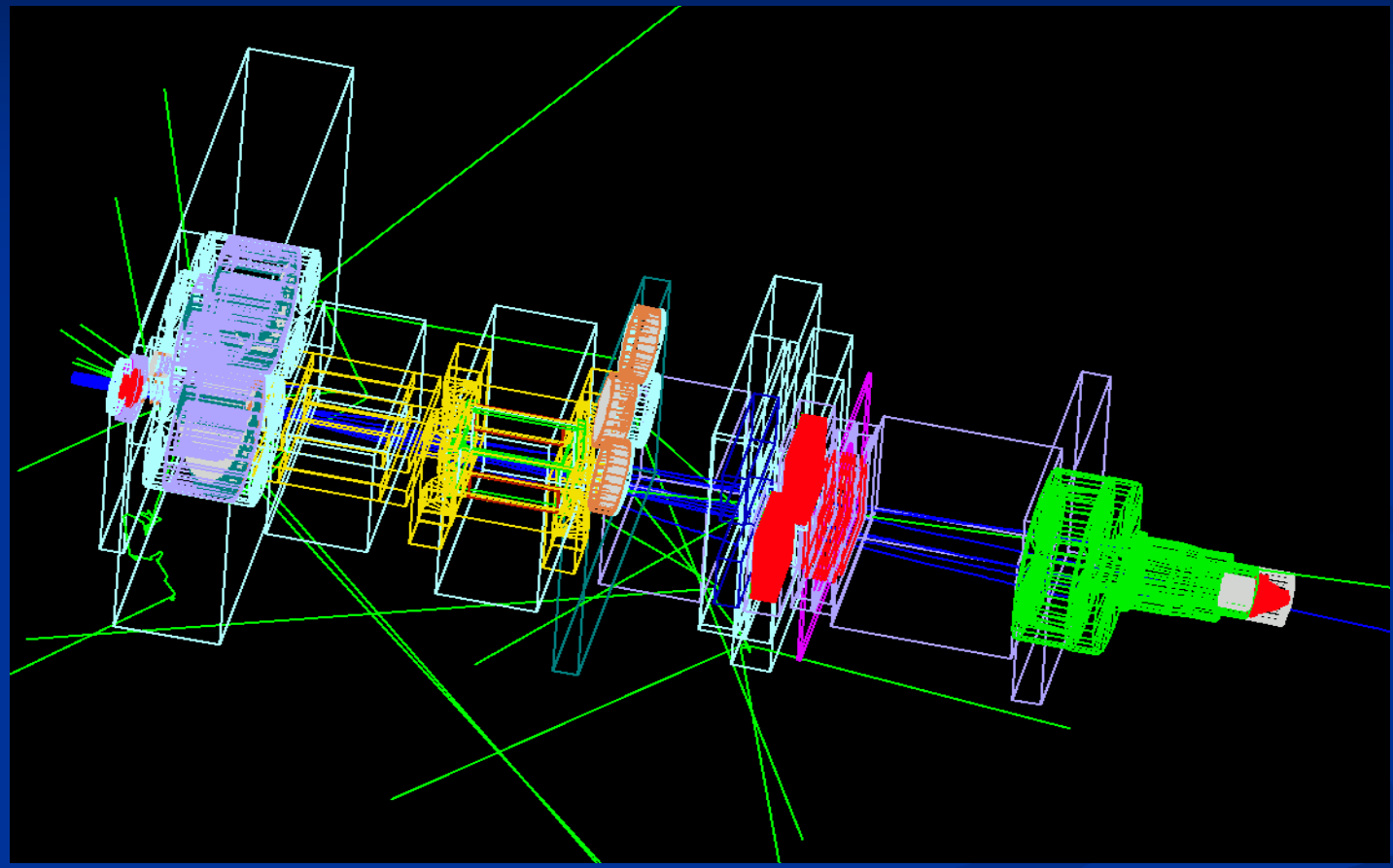
FOCUS Monte Carlo

Time dependent simulations

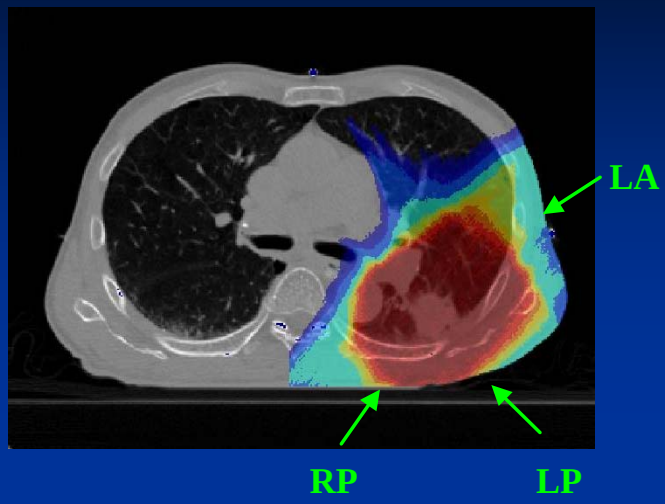


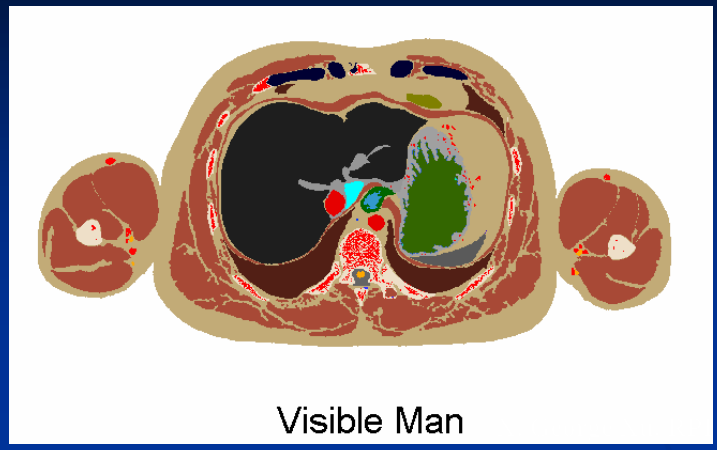
Solid lines: **Patient in inhale**
Dashed lines: **Considering the entire breathing phase**

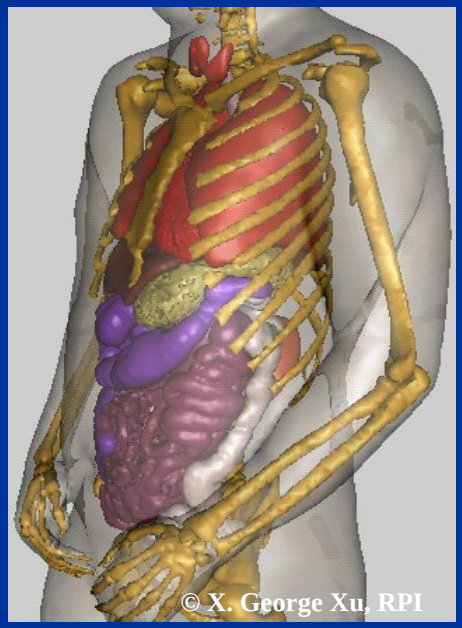
Radiation Protection

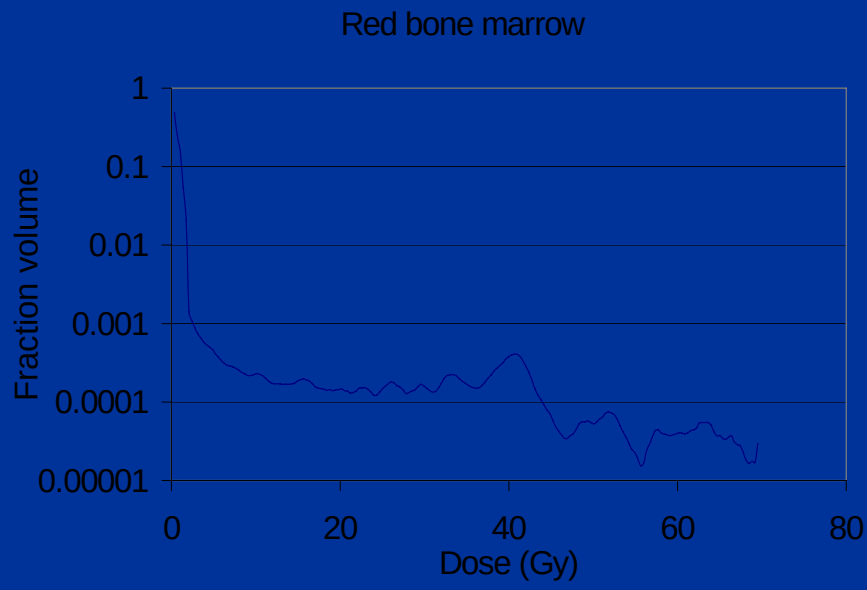


Radiation Risk

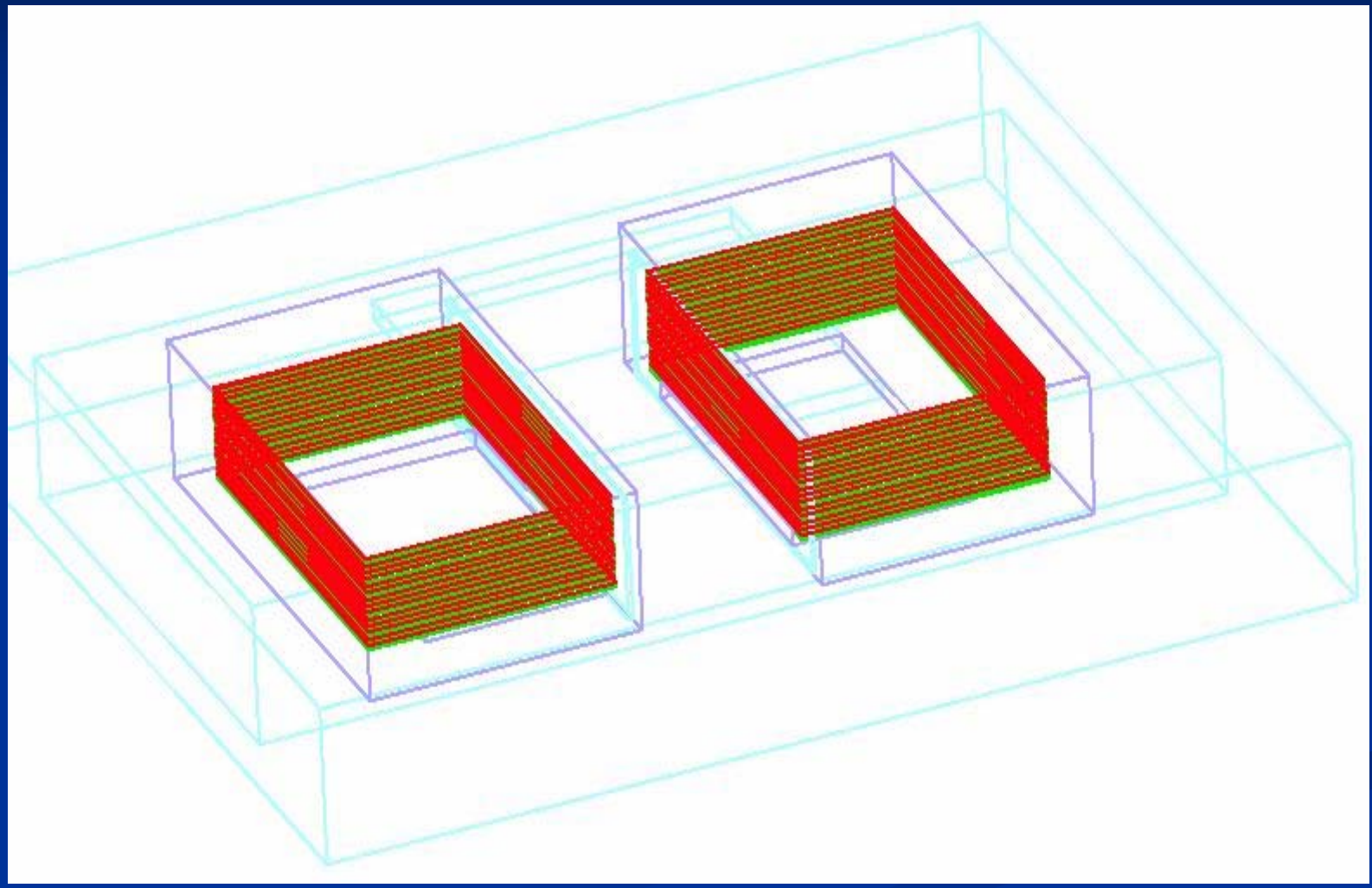








Detector Simulation

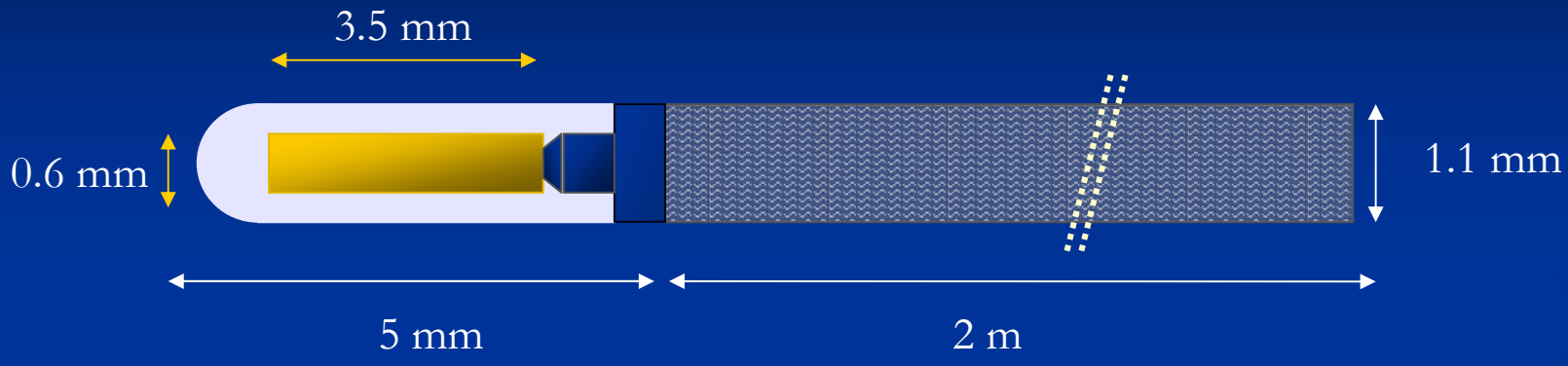


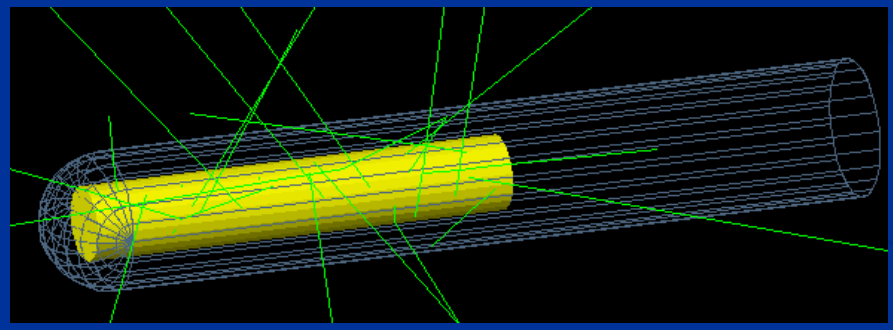
G4NAMU in Brachytherapy

(Ad Hoc Working Group Coordinator: Paul Gueye)

Modeling of encapsulated ^{192}Ir source

(Courtesy of McGill University)

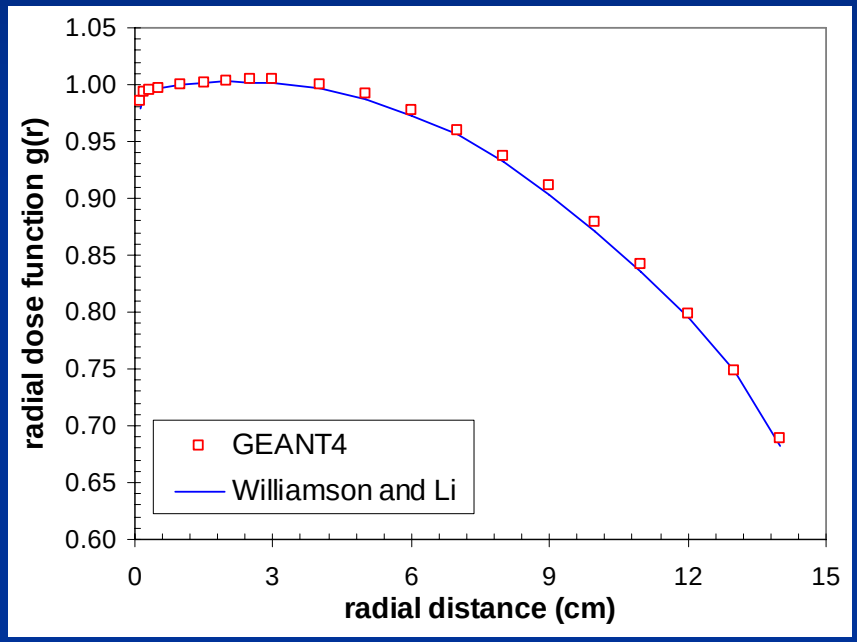


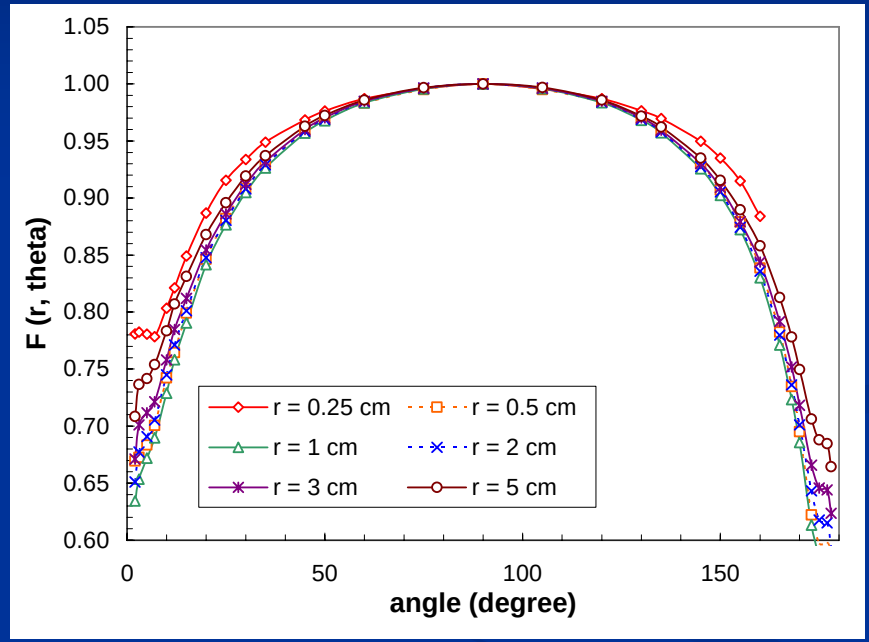


MicroSelectron Classic HDR source (part no. 080950)

Radial dose and anisotropy functions of encapsulated source

(Courtesy of McGill University)





Radial dose function

GEANT4:

~0.4% higher than Williamson and Li

(Med. Phys. **22**, 809-819, 1995)

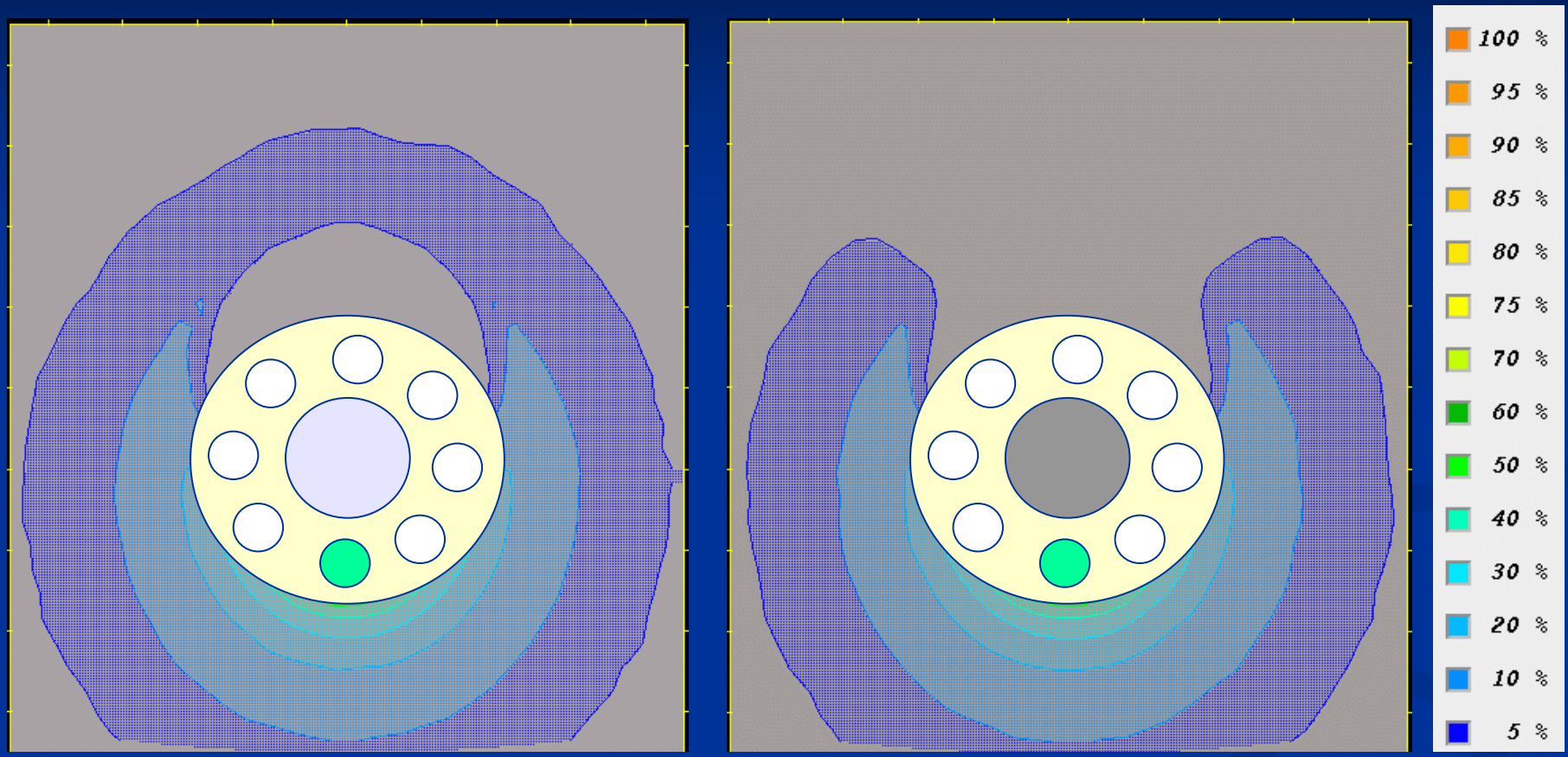
Anisotropy function

GEANT4:

±1% agreement with Williamson and Li

Isodose distributions

(Courtesy of McGill University)

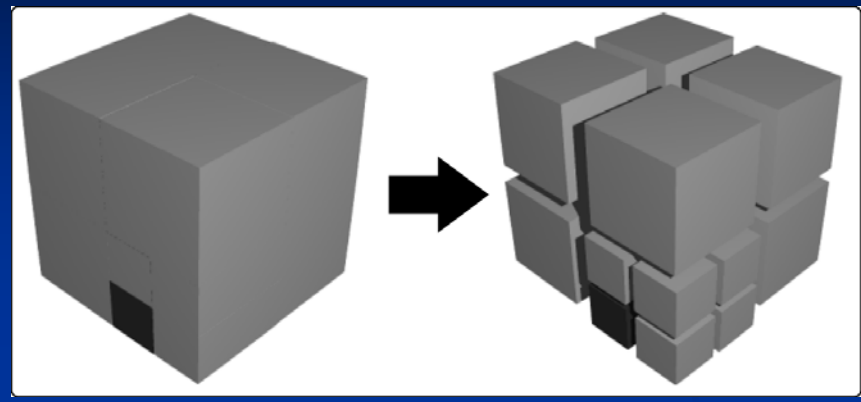


Presence of lead shielding reduces the dose distribution in a lucite phantom by up to 20%, and it is confirmed by ion chamber measurements.

Octree geometry compression – DICOM images

UNIVERSITÉ LAVAL

Voxel-based geometry



Objectives:

- **Reduce the number of voxels**
- **Keep the critical information**

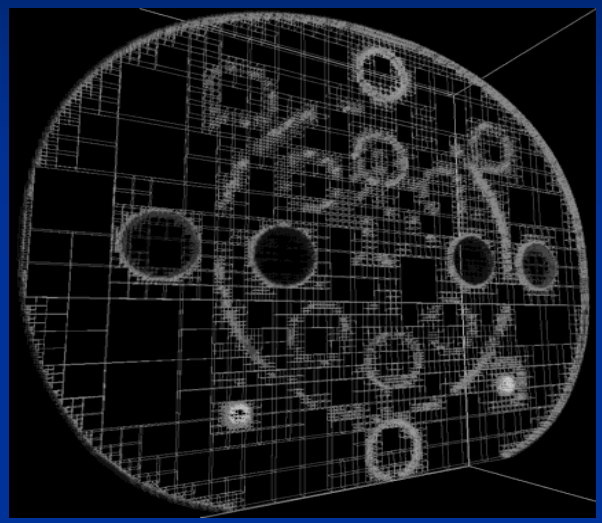
- **Indexing of the density distributions using a density gradient threshold:**
  - **High resolution kept only in heterogeneous area**
  - **Can easily reduce the number of voxels by 75%**
- **Does not affect dose distribution**

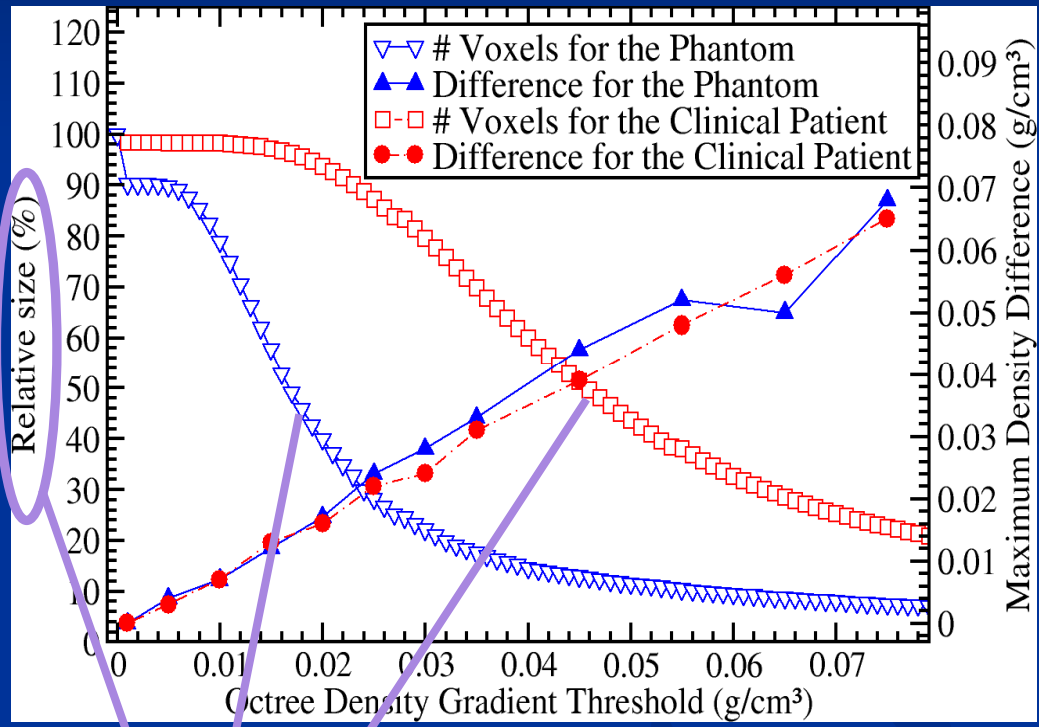
V. Hubert-Tremblay, MSc project

Octree geometry compression – DICOM images

UNIVERSITÉ LAVAL

Examples: CT phantom + thorax patient

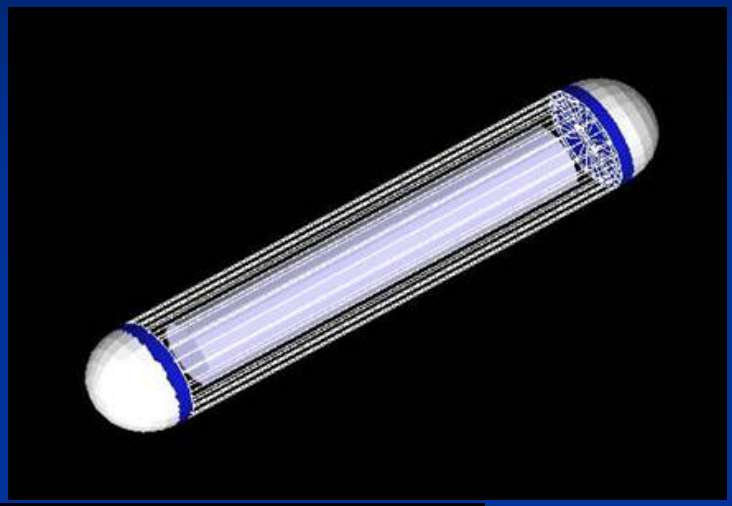


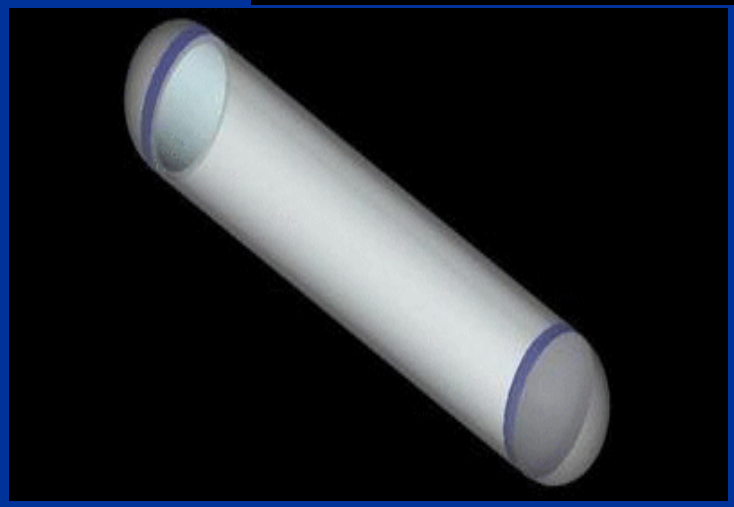


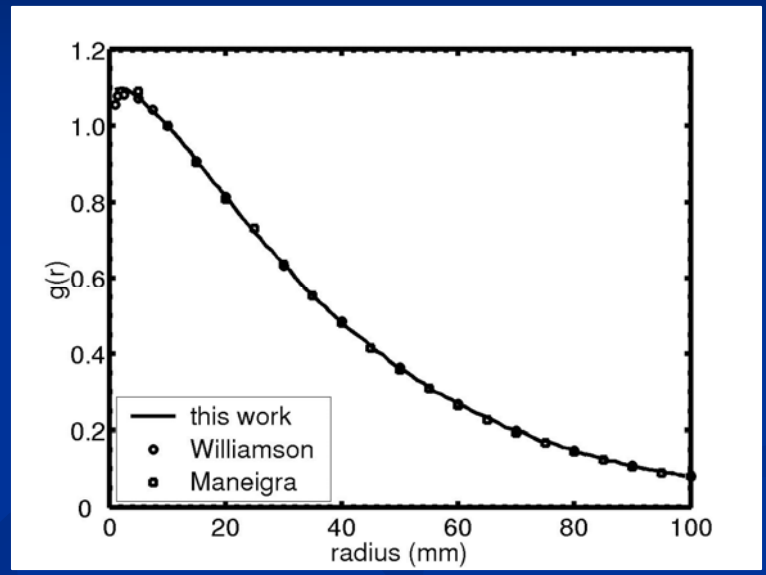
Voxel number v/s DGT

Prostate brachytherapy - LDR

LDR ^{125}I source, Amersham 6711







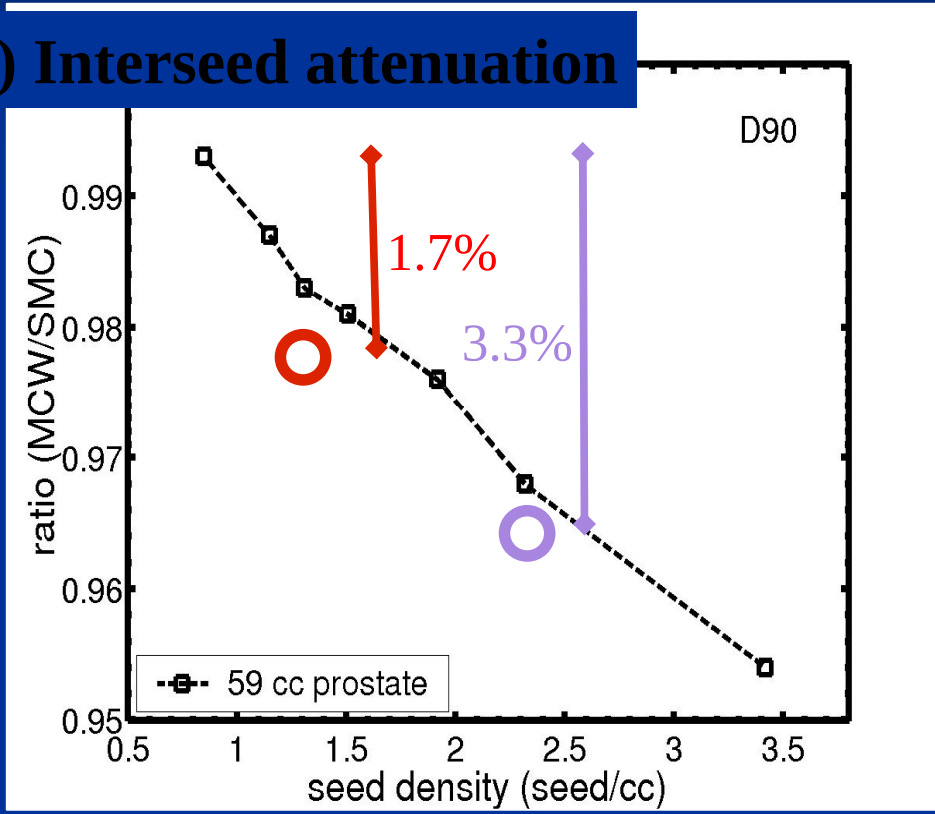
Validation of the model: radial dose function

J.-F. Carrier, Ph.D. project

Prostate brachytherapy - LDR

MC simulations on clinical treatment plans

1) Interseed attenuation



RED PLAN

- **77 seeds**
- **0.6 mCi activity**
- **1.7% of the D90 value is lost due to interseed attenuation**

BLUE PLAN

- **137 seeds**
- **0.3 mCi activity**
- **3.3% of the D90 value is lost due to interseed attenuation**

This interseed attenuation is not considered in TG43 (clinical) dose calculations

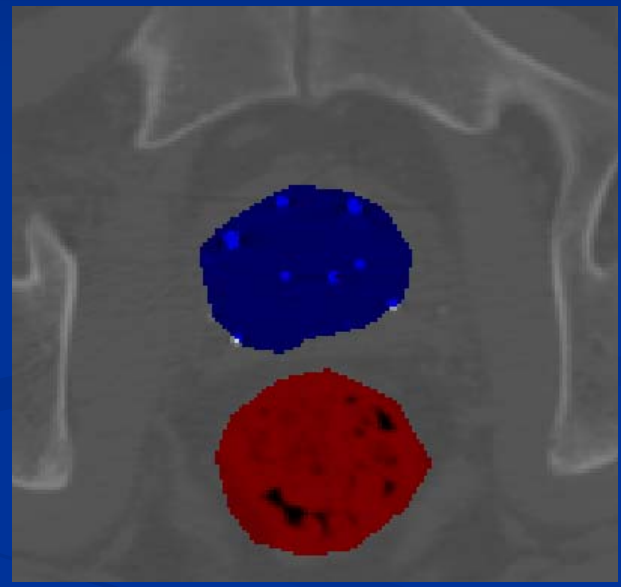
Prostate brachytherapy - LDR

MC simulations on clinical treatment plans

2) Medium composition: CT-based MC

CT image

G4 DICOM reader[1]
Organ contours
Seed positions

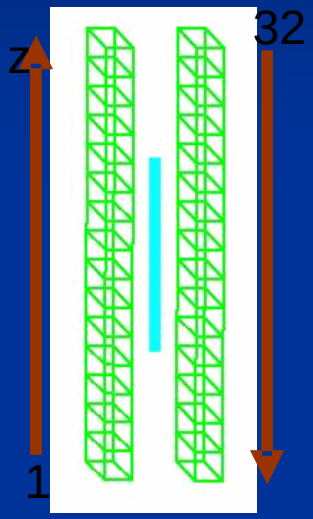


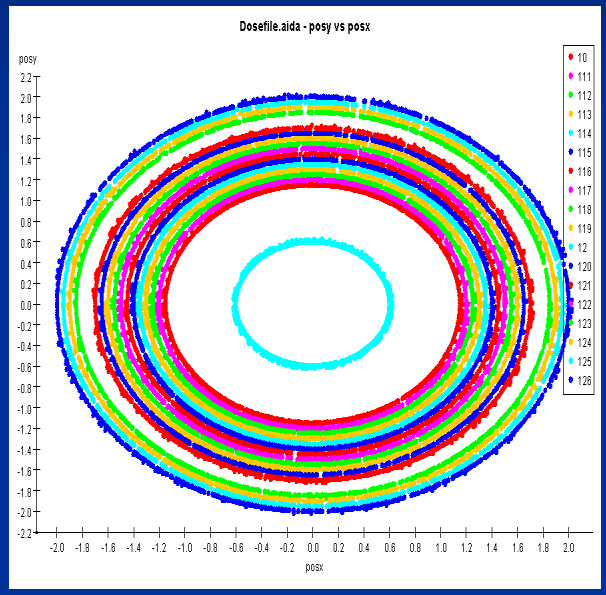
G4 geometry

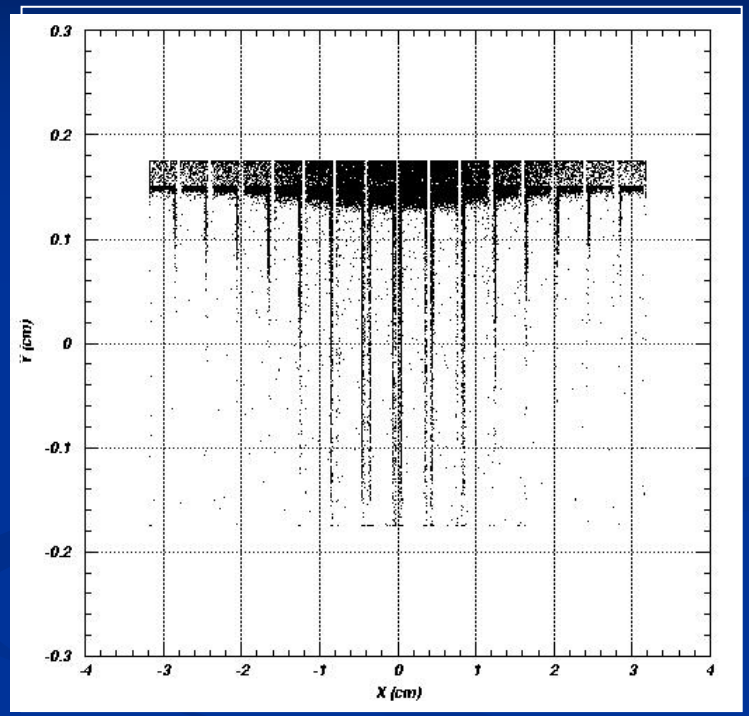
D90: 5-7% differences between water MC and CT-based MC

[1] http://www.physmed.phy.ulaval.ca/phys_med/DICOM

Hampton University
(Collaboration: NIST, EVMS)





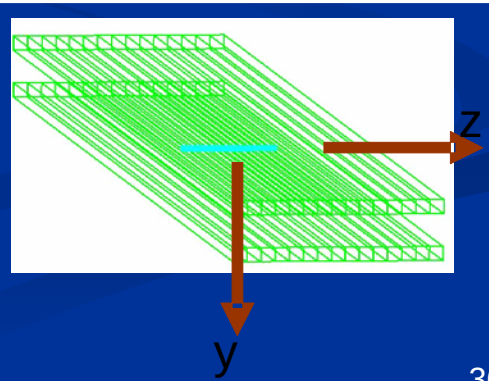


Scintillating Fiber based Beta Detector

→ Absolute calibration of sources

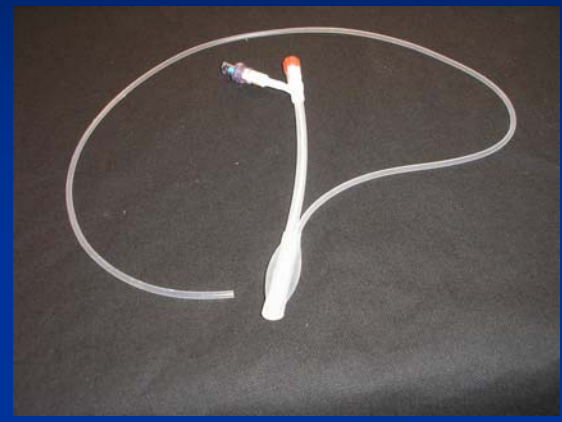
Lawrence Tynes, Ph.D.: Detector

Nnenna Onumah, Ph.D.: Geant4



Hampton University

(Collaboration: Proxima Therapeutics, dePaul)

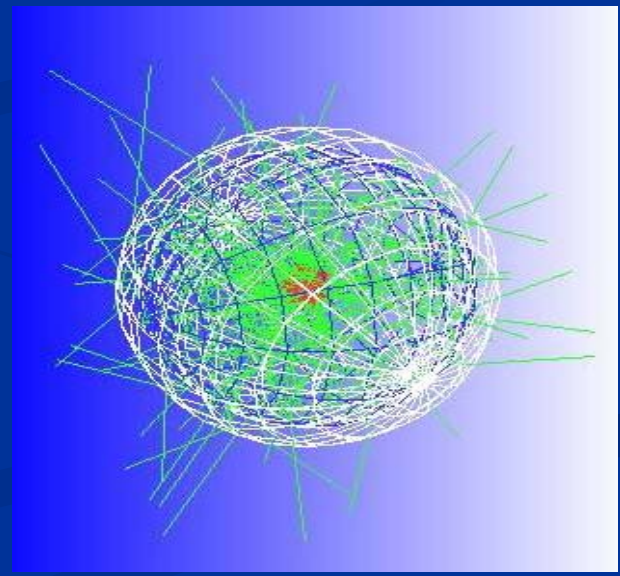


Active Mammosite

→ Absolute real-time position measurement (within ±1 mm)

→ Absolute real-time dose measurement

→ Modelization of the dose distribution using CT scan data & 4D phantom



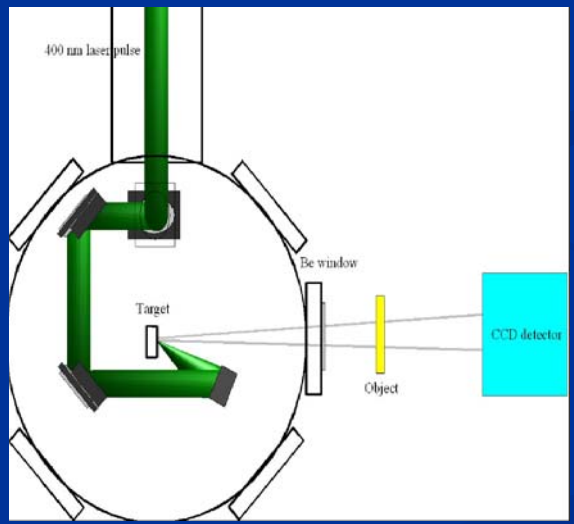
Jacquelyn Winston, M.Sc.: Detector

Rachel Black, Ph.D. : Detector, Geant4 & VTK

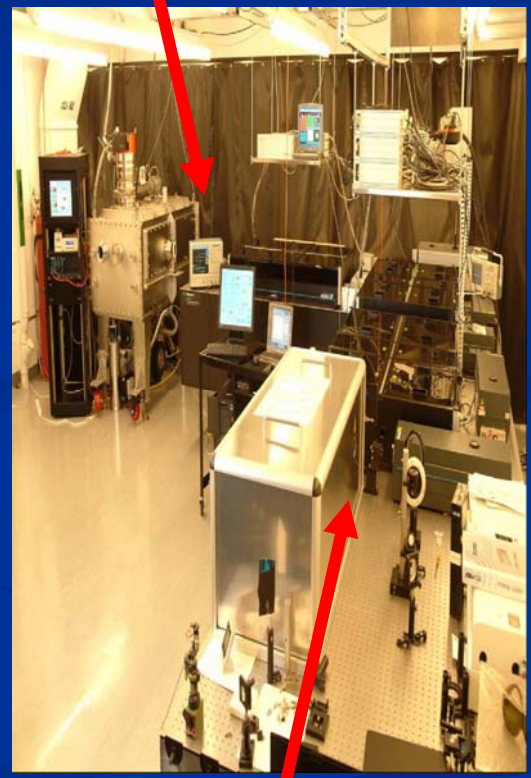
ALLS Facility
Ultrafast Laser & Biomedical Research

Advanced Laser Light Source

- Varennes, Canada
- Dynamics of biological processes



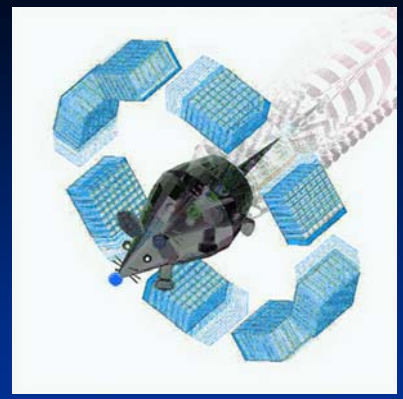
10 Hz, 300 mJ, 25 fs



100 Hz, 100 mJ, 25 fs

G4NAMU in Imaging

(Ad-Hoc Working Group Coordinator: Assen S. Kirov)



Membership in the

OpenGATE collaboration

(www.opengatecollaboration.org)

Whose goal is

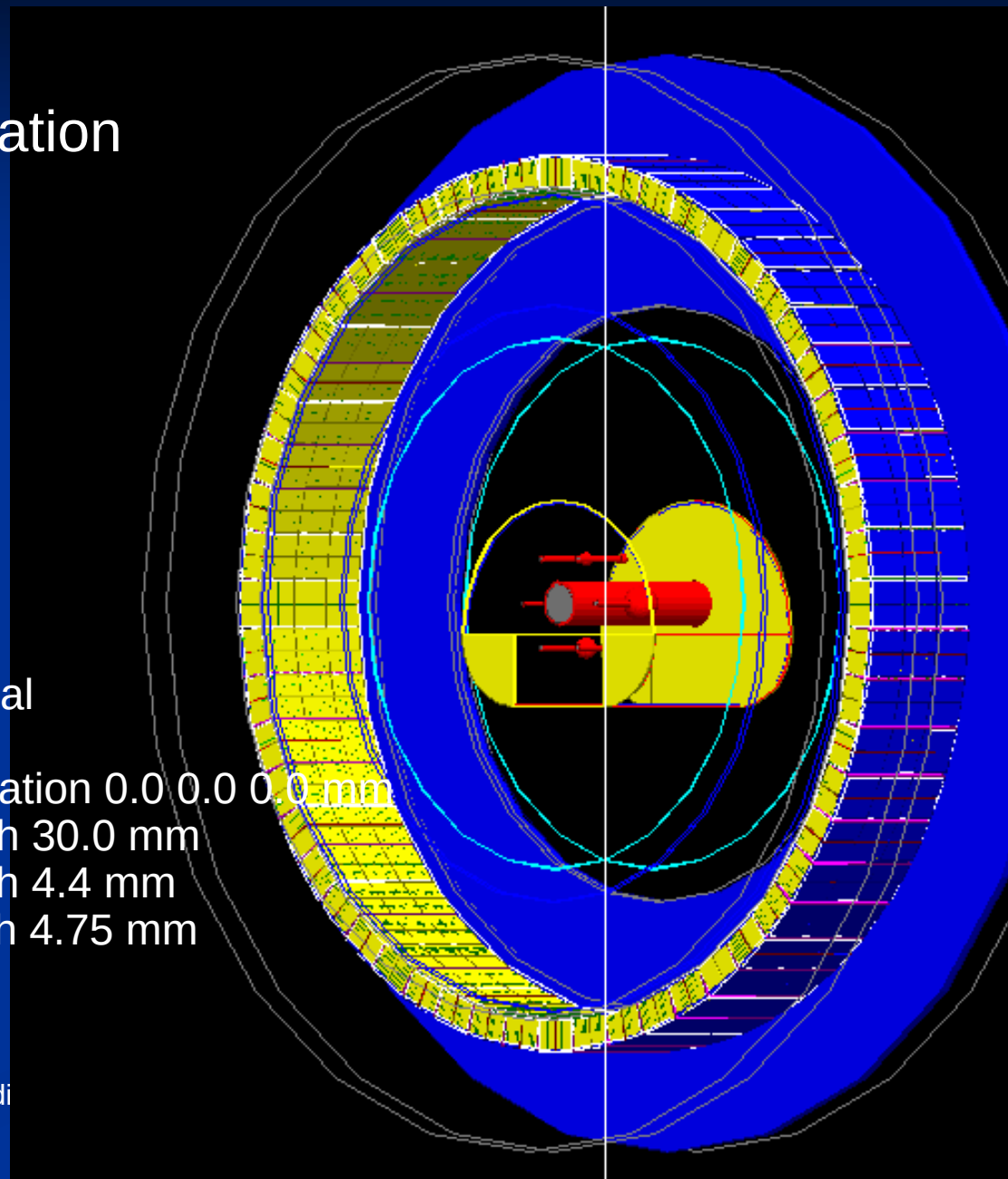
- the creation of an elaborate and flexible Monte Carlo program that allows realistic simulation of the physical processes, detector geometry and all factors affecting emission tomography applications

- realistic modeling of patient and small animal anatomy

- based on GEANT4

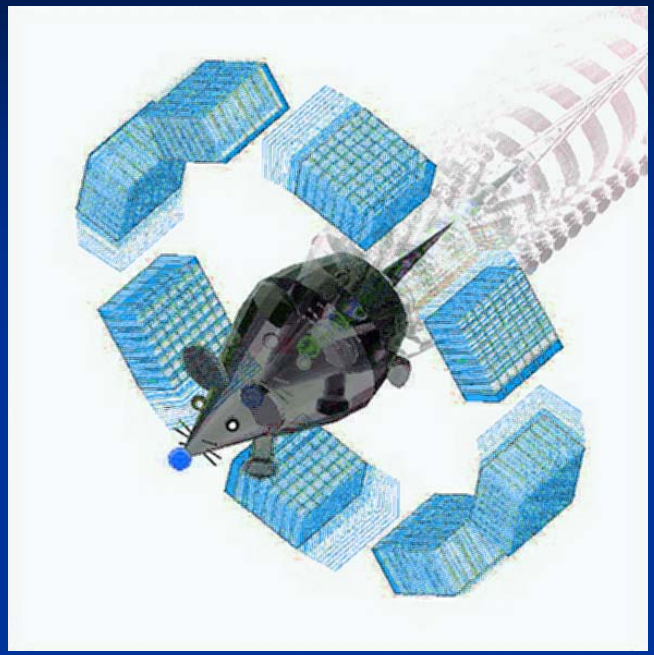
User Layer

-Verbosity and visualization
-Geometry
-Digitizer
-Physics
-Sources
-Outputs
-Experiment



…
/gate/block/daughters/name crystal
/gate/block/daughters/insert box
/gate/crystal/placement/setTranslation 0.0 0.0 0.0 mm
/gate/crystal/geometry/setXLength 30.0 mm
/gate/crystal/geometry/setYLength 4.4 mm
/gate/crystal/geometry/setZLength 4.75 mm
/gate/crystal/setMaterial BGO
…

GATE time and movements



Needed for:

- Patient and organ motion
- Scanner rotation
- Activity distribution changes

GEANT4 limitations:

- geometry: static during simulation
- no source movements

Solutions in GATE:

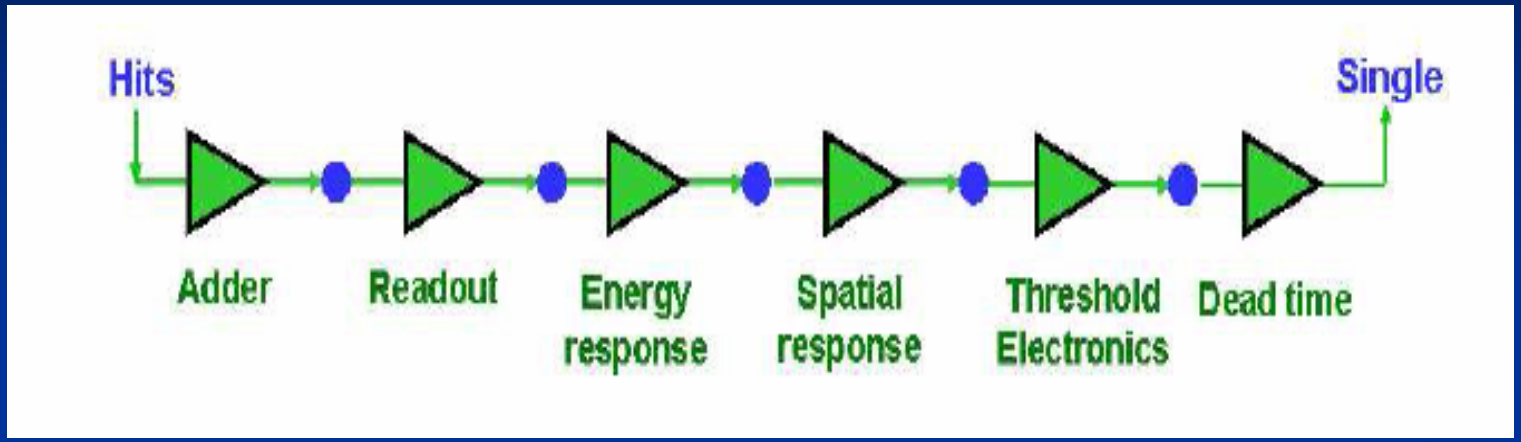
- Geometry updated between simulation time steps
- The source is confined to a smaller volume moving inside a larger emission volume

Santin et al, 2003

Strul et al, 2003

Jan *et al*, PMB 49 (2004) 4543

GATE digitization



- Resolution blurring, spatial blurring, crosstalk

- Parallelizable and non-parallelizable dead times

- Coincidence processing

- Post simulation processing of output files stored before digitization

GATE validation

- **PET** at least 5 patient and microPET scanners
  energy spectra, sensitivity, resolution, scatter faction, count rates, image quality, contrast recovery
- **SPECT** at least 5 systems
  energy spectra, sensitivity, resolution,…
- **Prototype** at least 4 systems
  energy spectra, sensitivity, resolution…

More than 15 references in Jan *et al*, PMB 49 (2004) 4543 and at www.opengatecollaboration.org