

Geant 4



Distributed Processing, Monte Carlo and CT interface for Medical Treatment Plans

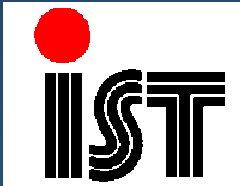
<http://www.ge.infn.it/geant4/talks>

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CERN¹

INFN Genova²

National Institute for Cancer Research, IST Genova³



ICATPP Conference

Como, 6 -10 October 2003

Including contributions from:

S. Agostinelli, S. Garelli (IST Genova)

L. Archambault, L. Beaulieu, J.-F. Carrier, V.-H. Tremblay (Univ. Laval)

M.C. Lopes, L. Peralta, P. Rodrigues, A. Trindade (LIP Lisbon)

G. Ghiso (S. Paolo Hospital, Savona)



Maria Grazia Pia, INFN Genova

The goal of radiotherapy

Delivering the required therapeutic dose to the tumor area with high precision,
while preserving the surrounding healthy tissue

Accurate dosimetry is at the basis of radiotherapy treatment planning

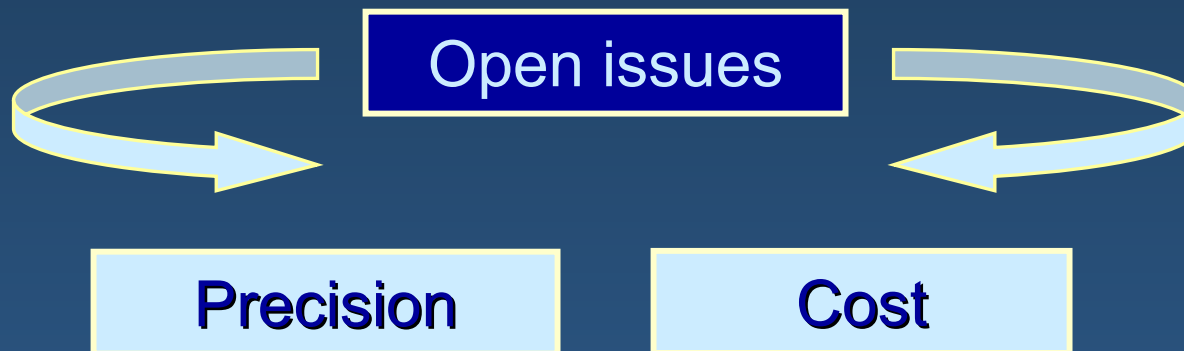
Dosimetry system

Calculate the dose released to the patient by the radiotherapy system

- precision
- accurate model of the real configuration (from CT)
- speed adequate for clinical use
- user-friendly interface for hospital usage

The reality

- Treatment planning is performed by means of commercial software
- The software calculates the dose distribution delivered to the patient in a given source configuration



Commercial systems are based on approximated analytical methods, because of *speed constraints*

Approximation in geometry modeling

Approximation in material modeling

Each treatment planning software is specific to one technique and one type of source

Treatment planning software is expensive

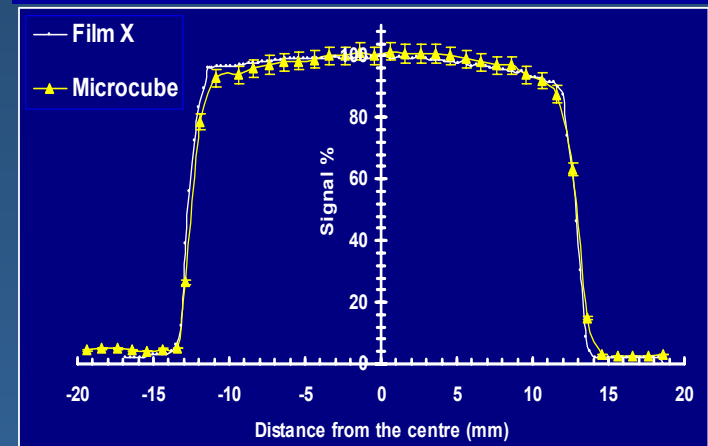
Commercial factors

- Commercial treatment planning systems are governed by commercial rules (*as any other commercial product...*)
- i.e., they are produced and marketed by a company only if the investment for development is profitable



- No commercial treatment planning systems are available for non-conventional radiotherapy techniques
 - *such as hadrontherapy*
- or for niche applications
 - *such as superficial brachytherapy*

Treatment planning systems for hadrontherapy are quite primitive
not commercially convenient so far



Monte Carlo methods in radiotherapy

Monte Carlo methods have been explored for years as a tool for precise dosimetry, in alternative to analytical methods

de facto,

Monte Carlo simulation is not used in clinical practice

(only side studies)

- The limiting factor is the **speed**
- *Other limitations:*
 - reliable?
 - for “software specialists only”, not user-friendly for general practice
 - requires ad hoc modeling

The challenge

Develop a

precise

general purpose

**dosimetric
system**

with the capability of

realistic geometry
and material modeling

interface to CT images

with a

user-friendly interface

at

low cost

performing at

adequate **speed** for clinical usage

A real life case

A dosimetric system for brachytherapy

(but all the developments and applications presented in this talk are general)

The prototype

- Activity initiated at IST Genova, Natl. Inst. for Cancer Research (F. Foppiano et al.)
 - hosted at San Martino Hospital in Genova (the largest hospital in Europe)
- Collaboration with San Paolo Hospital, Savona (G. Ghiso et al.)
 - a small hospital in a small town

Major work by **Susanna Guatelli** (Univ. and INFN Genova)

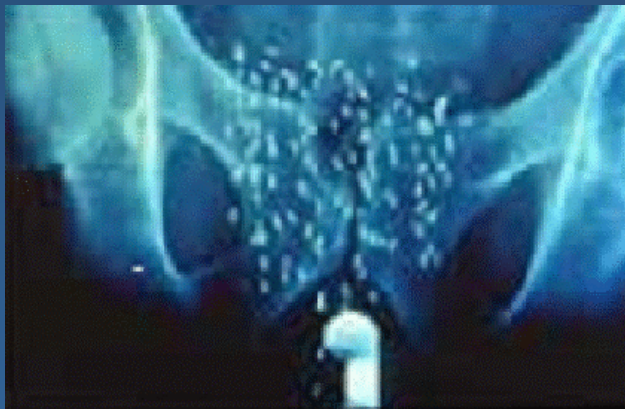
MSc. Thesis, Physics Dept., University of Genova, 2002

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

Brachytherapy

Brachytherapy is a medical therapy used for cancer treatment

Radioactive sources are used to deposit therapeutic doses near tumors, while preserving surrounding healthy tissues



Techniques:

- endocavitary
 - lung, vagina, uterus
- interstitial
 - prostate
- superficial
 - skin

Commercial software for brachytherapy

- Various commercial software products for treatment planning
 - eg. *Variseed V 7, Plato BPS, Prowes*
- No commercial software available for superficial brachytherapy with Leipzig applicators

Precision

- Based on approximated analytical methods, because of *speed constraints*
- Approximation in source anisotropy
- Uniform material: water

Cost

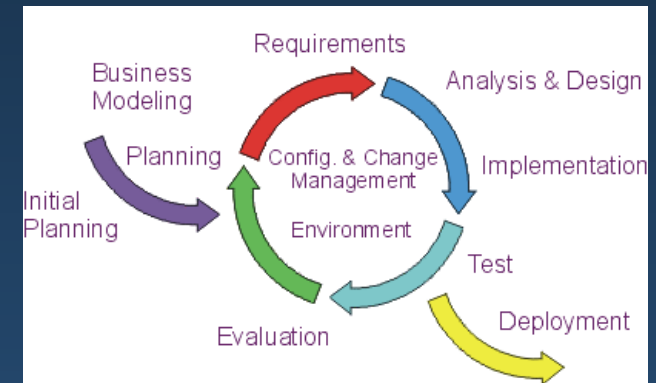
- Each software is specific to one technique and one type of source
- Treatment planning software is expensive (~ hundreds K \$/euro)

An open-source dosimetry application

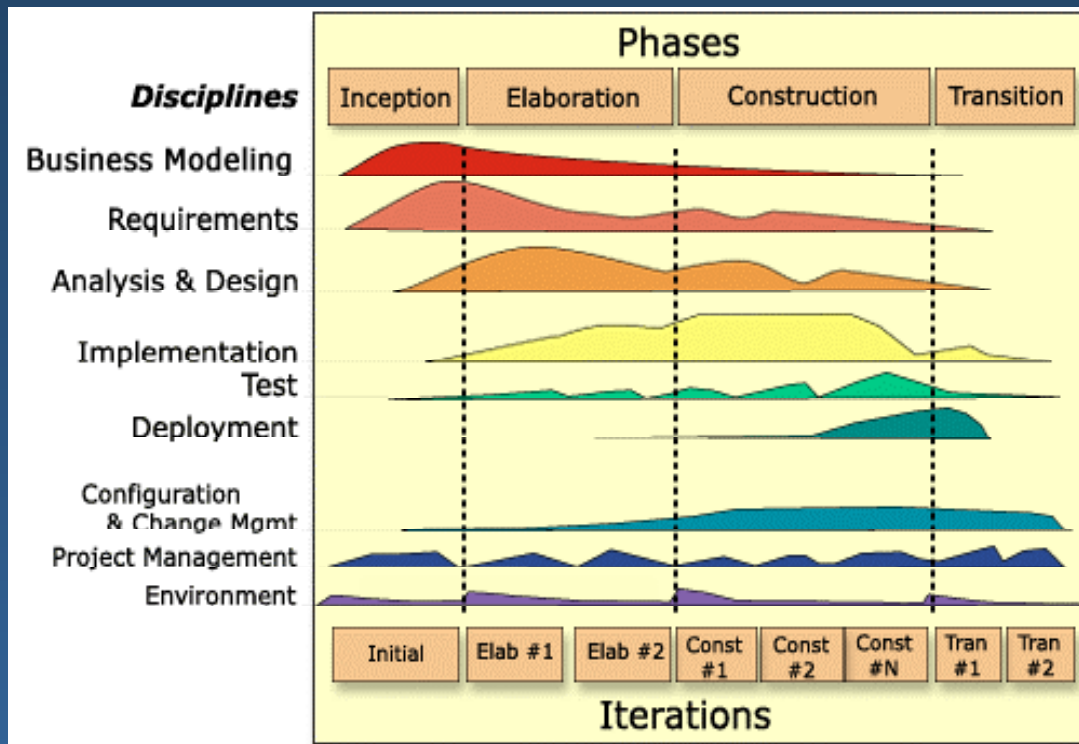
OO Design
Geometry Modeling & CT interface
Dosimetric analysis
User Interface
Distributed processing
Outlook

The software process

The project is characterized by a **rigorous software process**



The process follows an **iterative and incremental** model



Process based on the Unified Process, especially tailored to the specific context of the project

RUP used as a practical guidance to the process

Requirements

Calculation of 3-D dose distribution in tissue
Determination of isodose curves

Precision



Based on Monte Carlo methods
Accurate description of physics interactions
Experimental validation of physics involved

Accurate model of the real experimental set-up



Realistic description of geometry and tissue
Possibility to interface to CT images

Easy configuration for hospital usage



Simple user interface + Graphic visualisation
Elaboration of dose distributions and isodoses

Speed



Parallelisation
Access to distributed computing resources

Other requirements



Transparent
Open to extension and new functionality
Publicly accessible

Precision

Based on Monte Carlo methods

Geant 4

Accurate description of physics interactions

**Extension of electromagnetic interactions
down to low energies (< 1 keV)**

Experimental validation of physics involved

**Microscopic validation of the physics models
Comparison with experimental data
specific to the brachytherapeutic practice**

Geant 4

The foundation

What characterizes Geant4

The fundamental concepts,
upon which all the rest is built

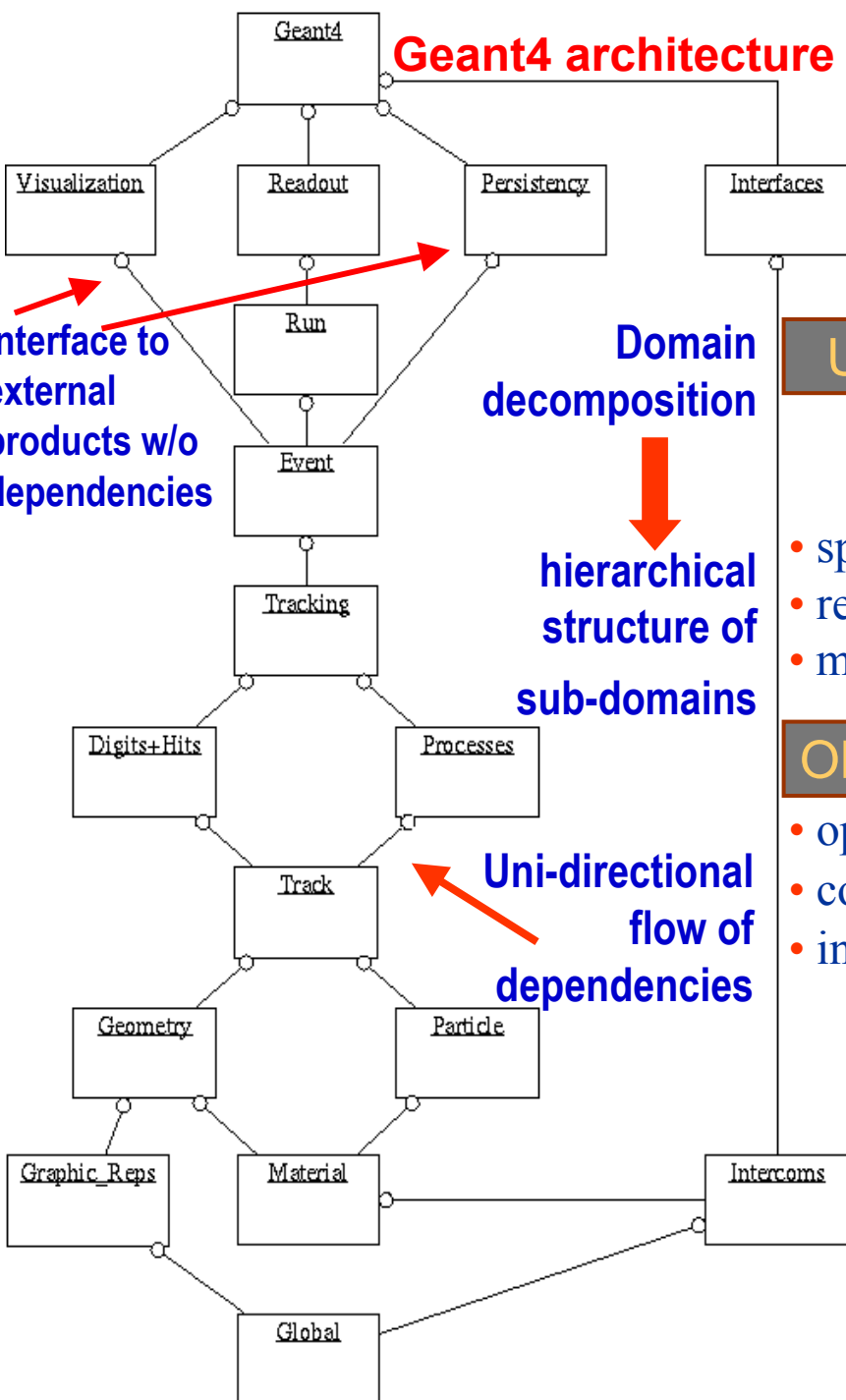
Physics

From the Minutes of LCB (LHCC Computing Board) meeting on 21 October, 1997:

"It was noted that experiments have requirements for **independent, alternative physics models**. In Geant4 these models, differently from the concept of packages, allow the user to **understand** how the results are produced, and hence improve the **physics validation**. Geant4 is developed with a modular architecture and is the ideal framework where existing components are integrated and new models continue to be developed."

Software Engineering

plays a fundamental role in *Geant4*



User Requirements

- formally collected
- systematically updated
- PSS-05 standard

Software Process

- spiral iterative approach
- regular assessments and improvements (SPI process)
- monitored following the ISO 15504 model

Object Oriented methods

- OOAD
- use of CASE tools

- openness to extension and evolution
- contribute to the transparency of physics
- interface to external software without dependencies

Quality Assurance

- commercial tools
- code inspections
- automatic checks of coding guidelines
- testing procedures at unit and integration level
- dedicated testing team

Use of Standards

- de jure and de facto

Geant 4

The functionality

What Geant4 can do

Geant 4

- Run, Event and Track management
- PDG-compliant Particle management
- Geometry and Materials
- Tracking
- Detector response
- User Interface
- Visualisation
- Persistency
- **Physics Processes**

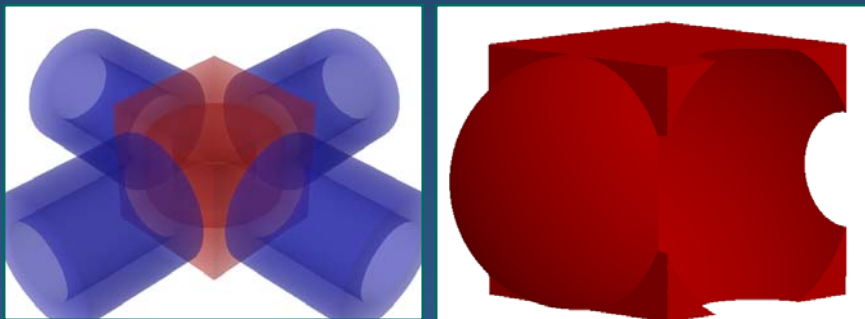
- Code and documentation publicly distributed from web
- 1st production release: end 1998
 - *2 new releases/year since then*
- Developed and maintained by an international collaboration of physicists and computer scientists

Geometry

Detailed detector description and efficient navigation

Multiple
representations
Same
abstract interface

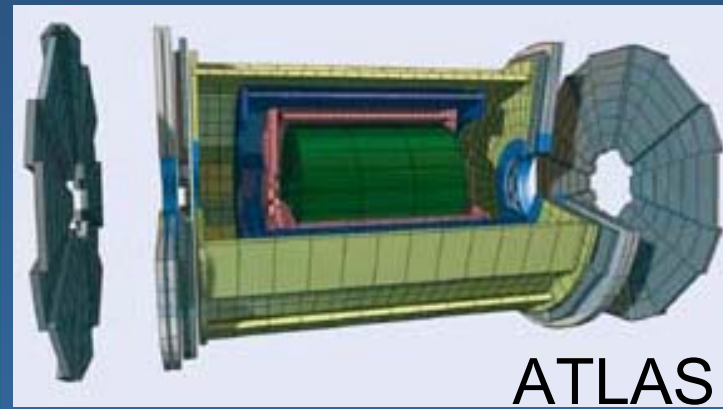
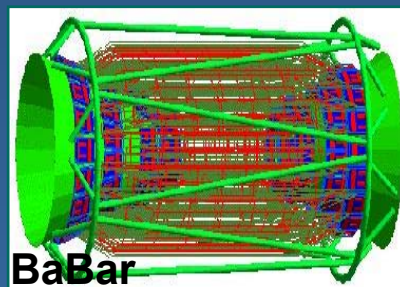
- **CSG** (*Constructed Solid Geometries*)
 - simple solids
- **BREPS** (*Boundary REPresented Solids*)
 - volumes defined by boundary surfaces
 - polyhedra, cylinders, cones, toroids etc.
- **Boolean solids**
 - union, subtraction...



CAD exchange: ISO STEP interface

Fields: variable non-uniformity and differentiability

Maria Grazia Pia, *INFN Genova*



Physics processes

Transparency

- Tracking independent from physics
- Final state independent from cross sections
- Use of public evaluated databases

● Object Oriented technology

- implement or modify any physics process without changing other parts of the software
- open to extension and evolution

● Electromagnetic and Hadronic Physics

- Complementary/alternative physics models

Electromagnetic Physics

- Multiple scattering
- Bremsstrahlung
- Ionisation
- Annihilation
- Photoelectric effect
- Compton scattering
- Rayleigh effect
- γ conversion
- e^+e^- pair production
- Synchrotron radiation
- Transition radiation
- Cherenkov
- Refraction
- Reflection
- Absorption
- Scintillation
- Fluorescence
- Auger

electrons and positrons
 γ , X-ray and optical photons
muons
charged hadrons
ions

- High energy extensions
 - needed for LHC experiments, cosmic ray experiments...
- Low energy extensions
 - fundamental for space and medical applications, dark matter and ν experiments, antimatter spectroscopy etc.
- Alternative models for the same process

Hadronic physics

- Data-driven, Parameterised and Theoretical models
 - the most complete hadronic simulation kit on the market
 - alternative and complementary models
- Cross section data sets: transparent and interchangeable
- Final state calculation: models by particle, energy, material

Interface to external tools

Through abstract interfaces

no dependence
minimize coupling of components



Similar approach

- Visualisation
- (G)UI
- Persistency
- Analysis

The user is free to choose the concrete system he/she prefers for each component

AIDA (analysis)

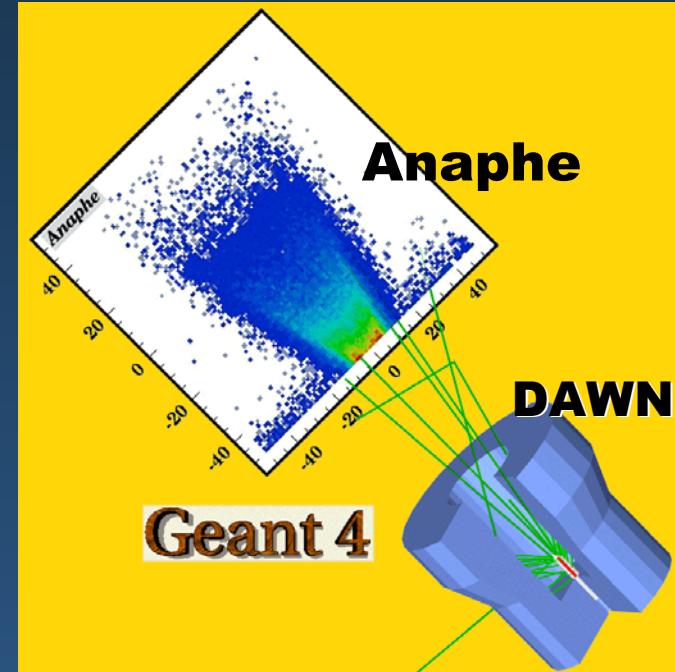
- Anaphe
- JAS
- Open Scientist

UI

- command-line
- X11/Motif
- GAG
- MOMO
- OPACS...

Visualisation drivers

- OpenGL
- OpenInventor
- X11
- Postscript
- DAWN
- OPACS
- HepRep
- VRML...



Monte Carlo methods in radiotherapy

Studies of Geant4 and
commercial treatment planning systems

GEANT4 Dose Calculation



Parameter selection

Geant 4

Beam A

Beam B

Beam X

CPU #1

CPU #2

CPU #16

16-CPU FARM

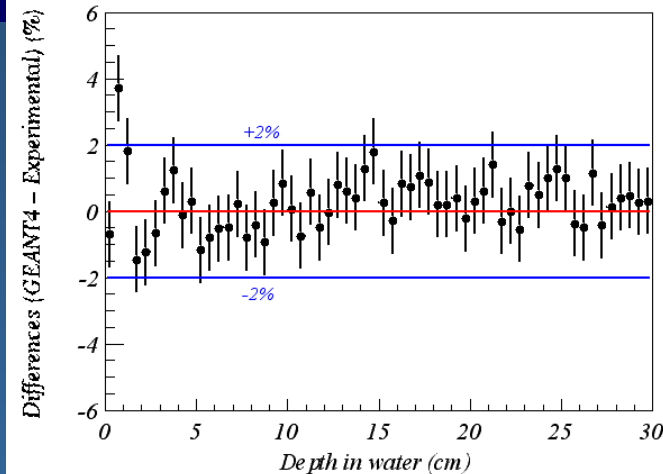
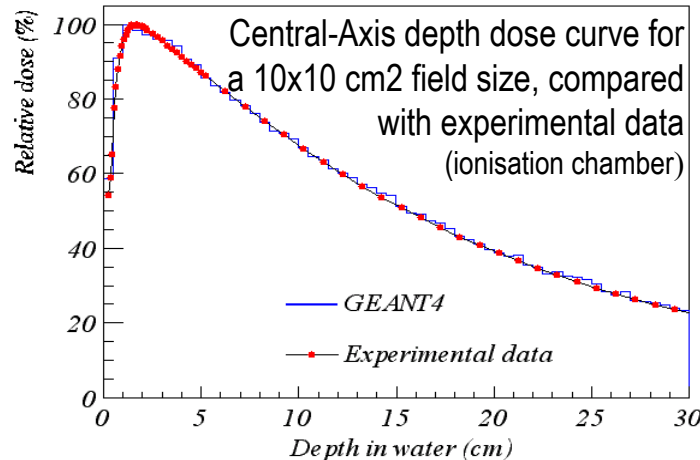
Central disk
Phase Space Data
CT Images

M.C. Lopes ¹,
L. Peralta ²,
P. Rodrigues ²,
A. Trindade ²

¹ IPOFG-CROC Coimbra
Oncological Regional Center

² LIP - Lisbon

Validation of phase-space
distributions from a
Siemens KD2
linear accelerator at
6 MV photon mode



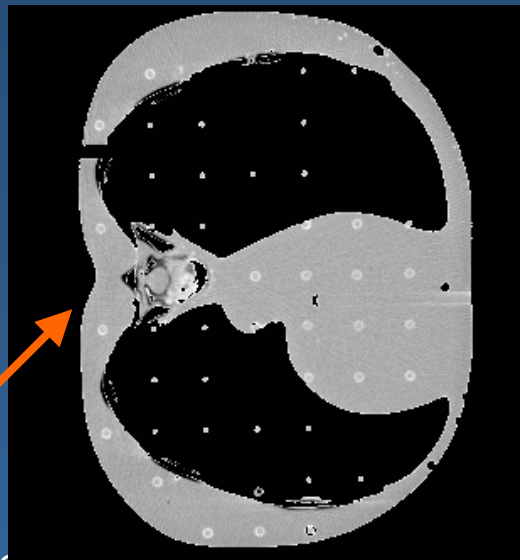
Comparison with commercial treatment planning systems

M. C. Lopes

IPOFG-CROC Coimbra Oncological Regional Center
L. Peralta, P. Rodrigues, A. Trindade
LIP - Lisbon

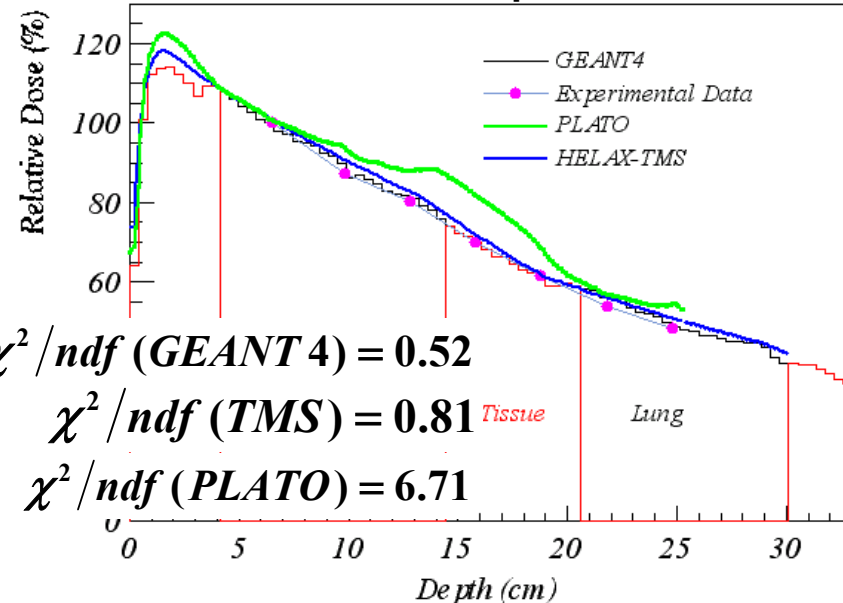
CT-simulation with a Rando phantom
Experimental data with TLD LiF dosimeter

CT images used to define the geometry:
a thorax slice from a Rando anthropomorphic phantom

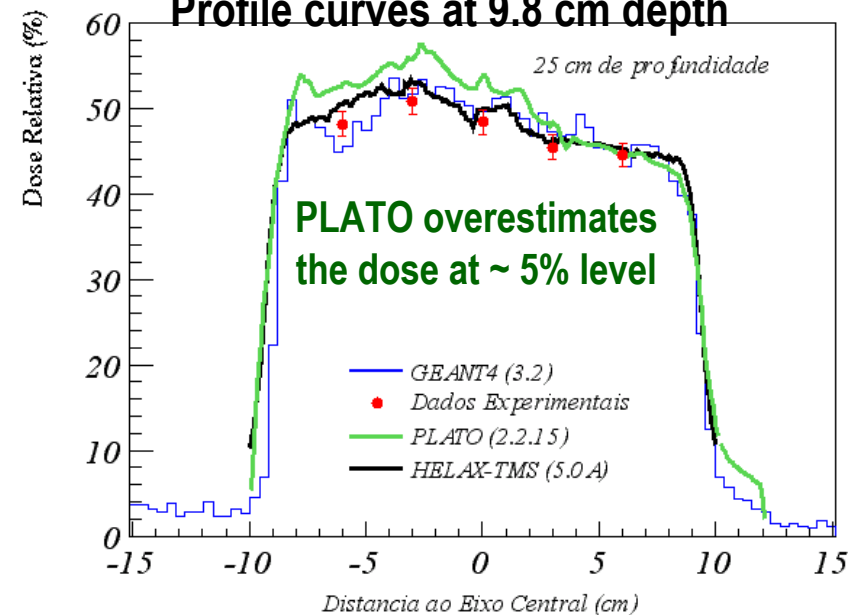


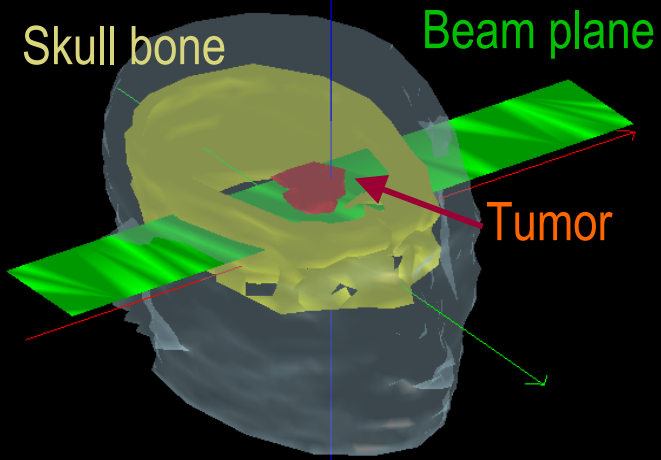
Maria Grazia Pia, INFN Genova

Central-Axis depth dose



Profile curves at 9.8 cm depth





Head and neck with two opposed beams for a 5x5 and 10x10 field size

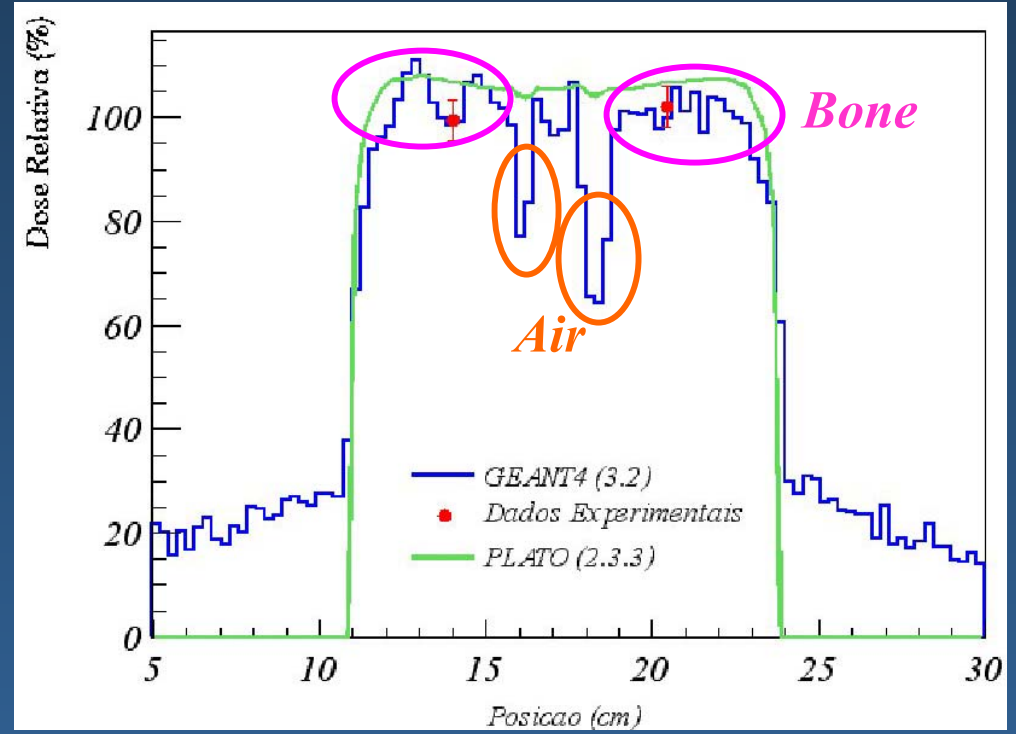
A more complex set-up

M. C. Lopes¹, L. Peralta², P. Rodrigues², A. Trindade²
¹ IPOFG-CROC Coimbra Oncological Regional Center - ² LIP - Lisbon

An off-axis depth dose taken at one of the slices near the isocenter

PLATO fails on the air cavities and bone structures and cannot predict accurately the dose to tissue that is surrounded by air

Deviations are up to 25-30%



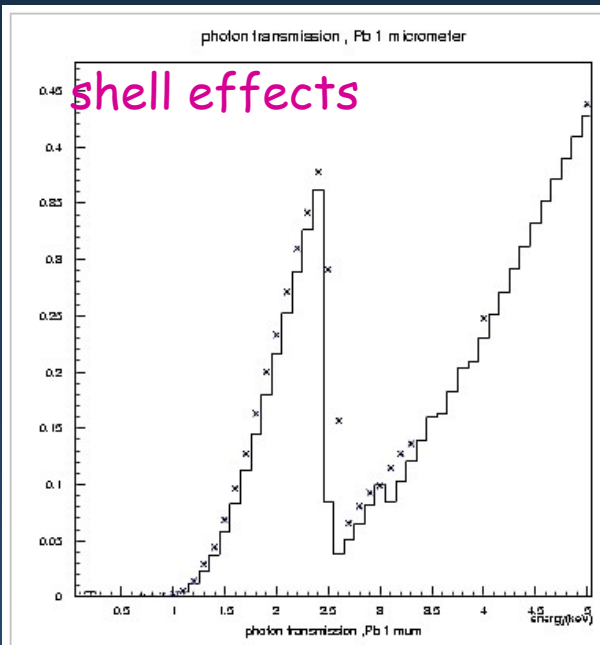
In some tumours sites (ex: larynx T2/T3-stage) a 5% underdosage will decrease local tumour control probability from ~75% to ~50%

Physics

Physics models in Geant4 relevant to
medical applications

Low Energy Electromagnetic Physics

- A set of processes extending the coverage of electromagnetic interactions in Geant4 down to “low” energy
 - 250 eV (*in principle even below this limit*) for electrons and photons
 - down to approximately the ionisation potential of the interacting material for hadrons and ions
- Processes based on detailed models
 - shell structure of the atom
 - precise angular distributions
- Specialised models depending on particle type
 - data-driven models based on the Livermore Libraries for e^- and photons
 - analytical models for e^+ , e^- and photons (reengineering of Penelope into Geant4)
 - parameterised models for hadrons and ions (Ziegler 1977/1985/2000, ICRU49)
 - original model for negative hadrons



Geant 4

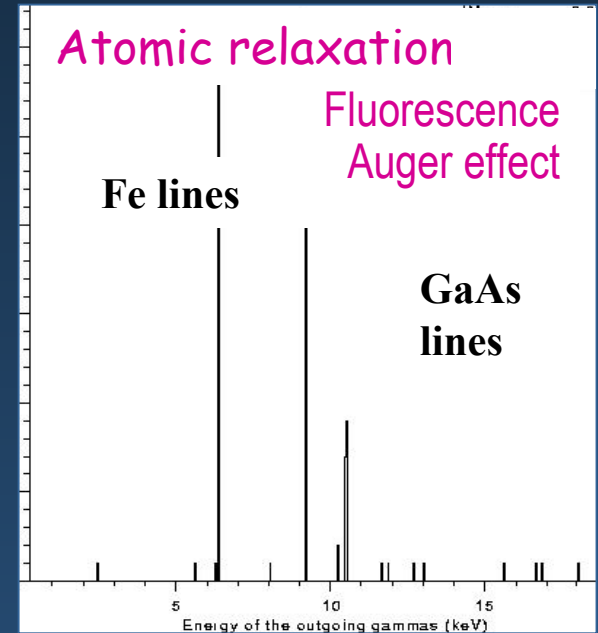
e, γ down to 250 eV

EGS4, ITS to 1 keV

Geant3 to 10 keV

Based on EPDL97, EEDL and EADL evaluated data libraries

Based on Penelope analytical models



Hadron and ion models based on Ziegler and ICRU data and parameterisations

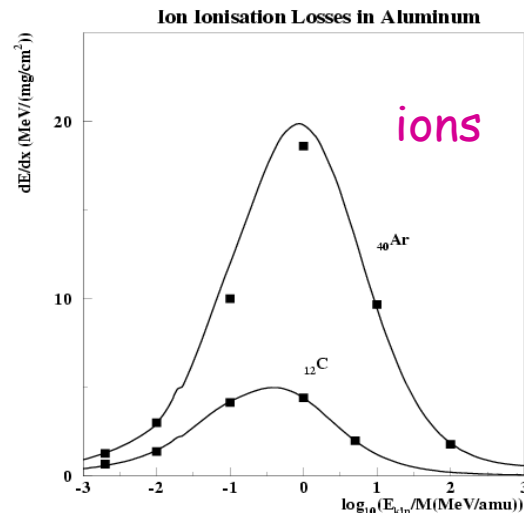
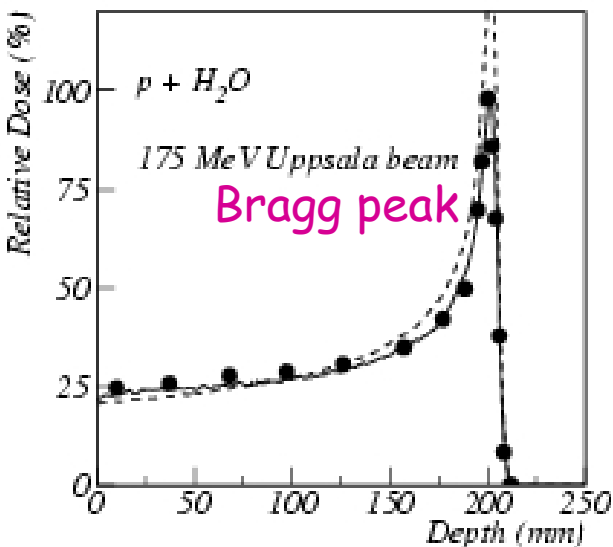
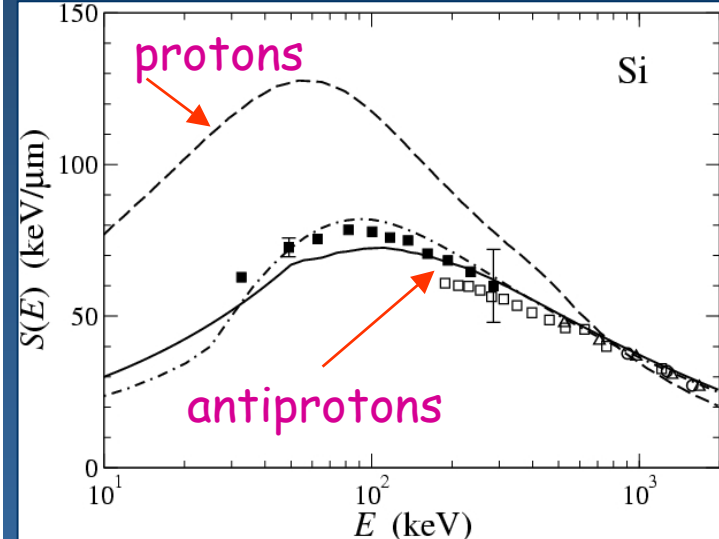


Figure 9: Ion electronic stopping power in aluminum. Points - the best fit on the data from Ref.[12], solid line - GEANT4 parameterisation. The accuracy of the data is about 5%.

Barkas effect (charge dependence) models for **negative hadrons**

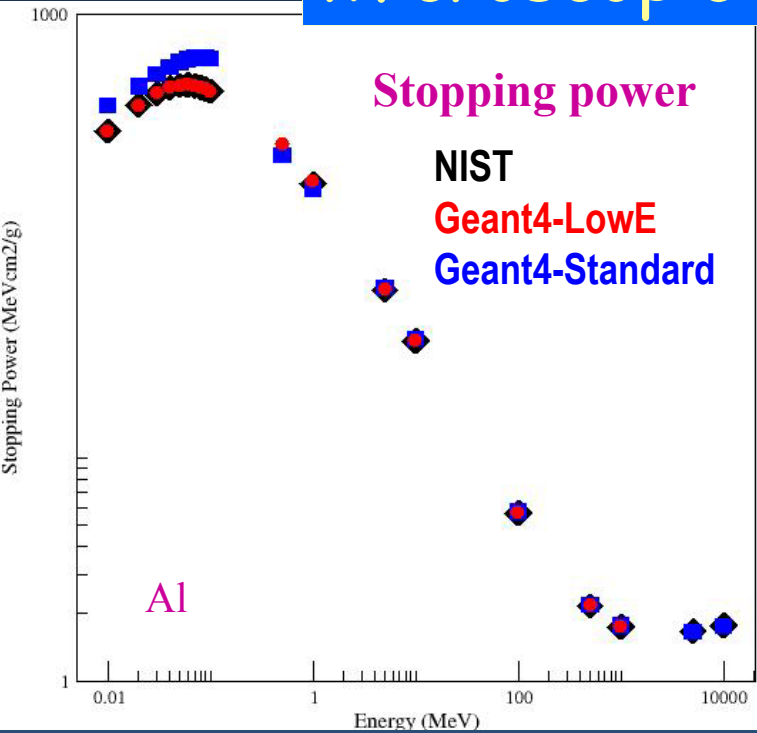


Validation

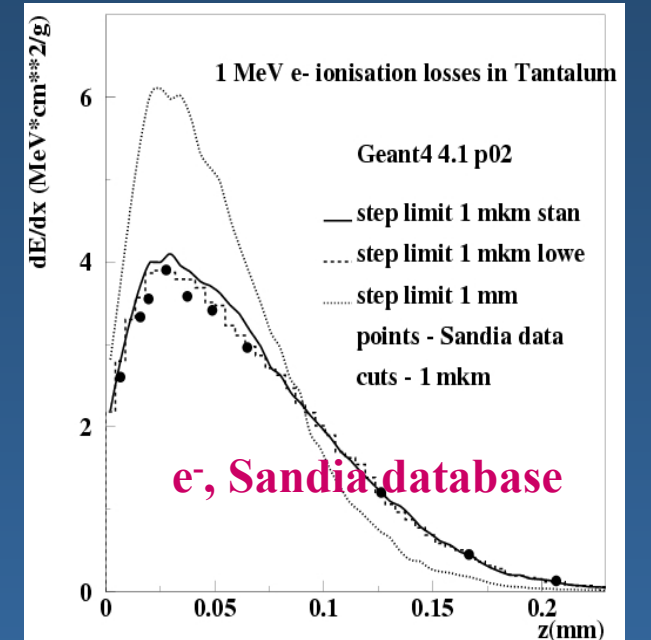
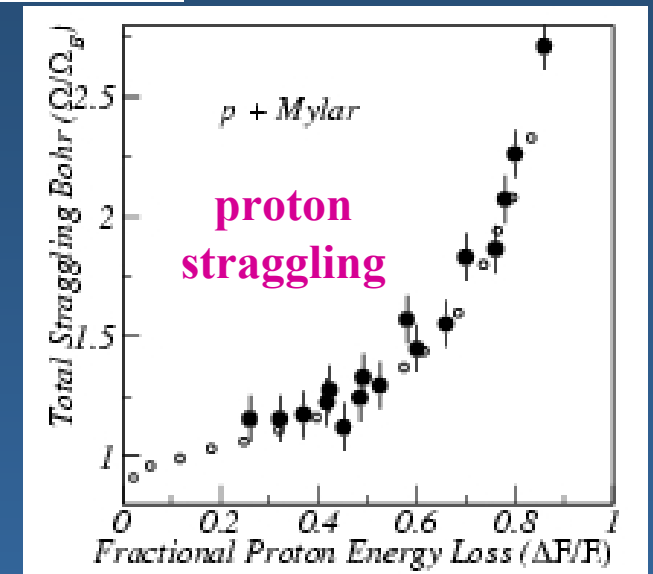
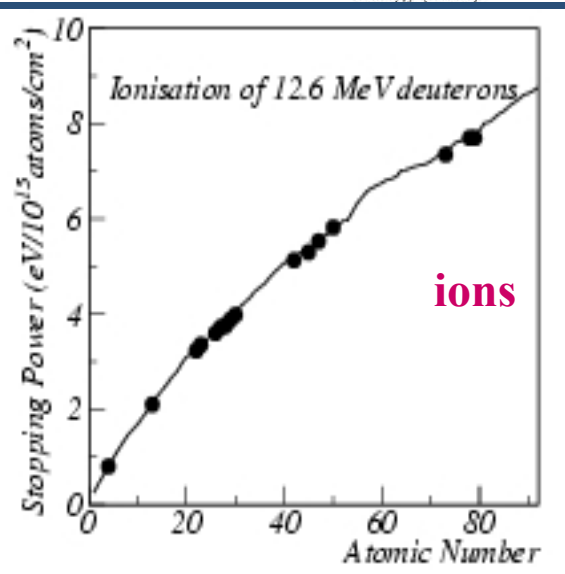
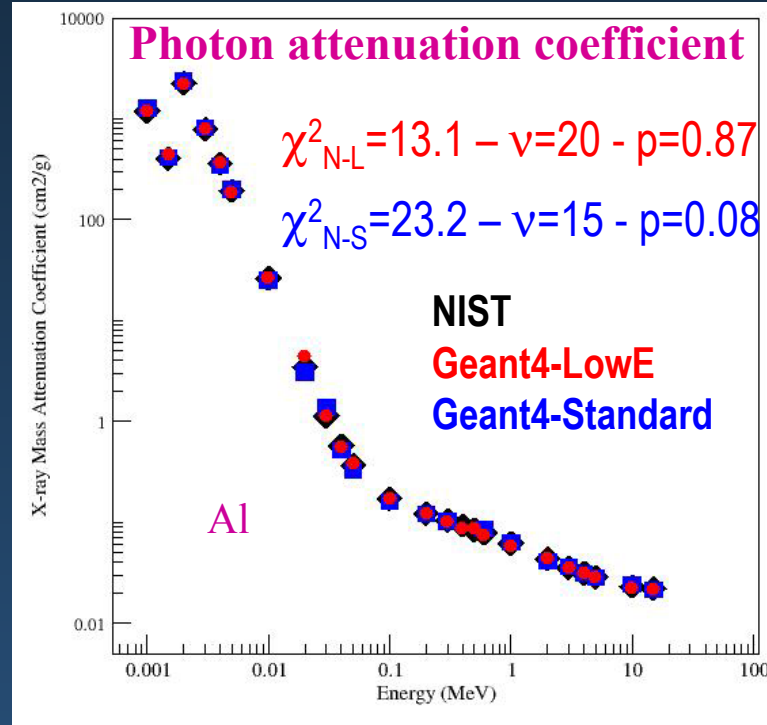
Microscopic validation:
verification of Geant4 physics

Dosimetric validation:
in the experimental context

Microscopic validation

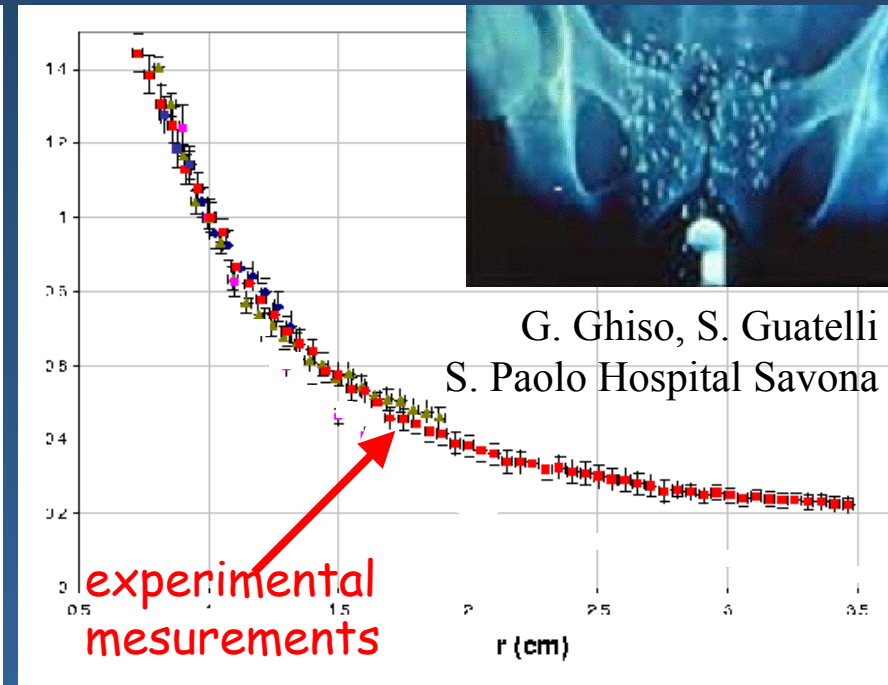
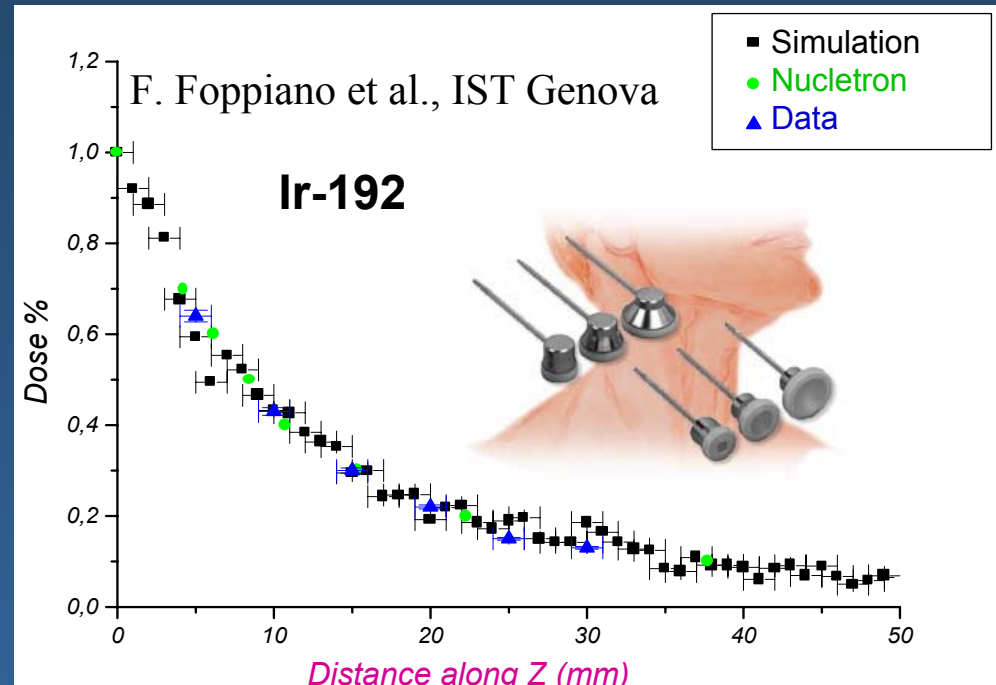


many more validation results available!



Dosimetric validation

Comparison to
manufacturer data,
protocol data,
original experimental data



General purpose system

→ For any brachytherapy technique

Object Oriented technology
Software system designed in terms of Abstract Interfaces

→ For any source type

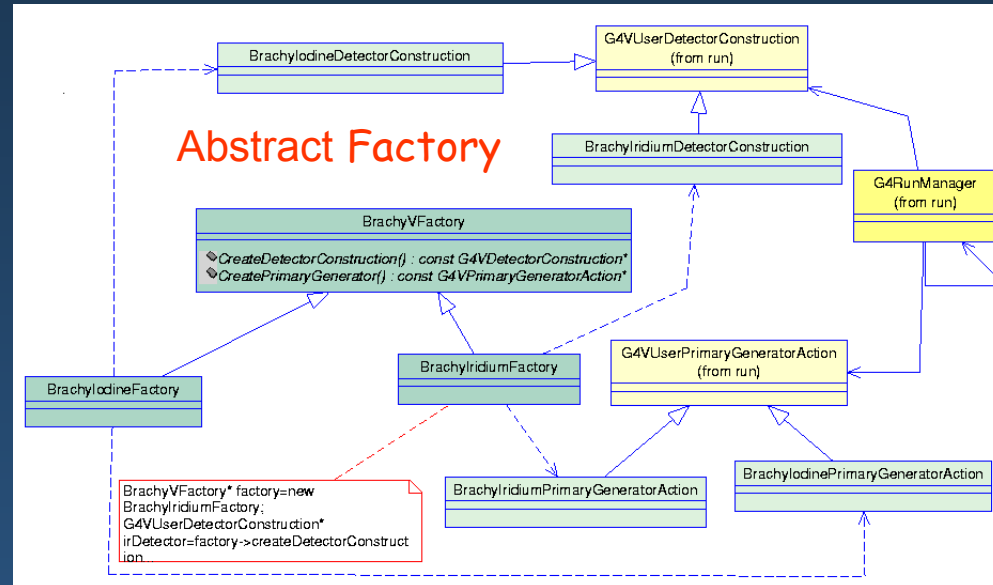
Abstract Factory design pattern
Source spectrum and geometry transparently interchangeable

Flexibility of modeling

Configuration of

- any brachytherapy technique
- any source type

through an **Abstract Factory**
to define geometry, primary spectrum



CT DICOM interface

- through Geant4 parameterised volumes
- parameterisation function: material

Phantom

- various materials
water, soft tissue, bone, muscle etc.

General purpose software system for brachytherapy

Realistic model of the experimental set-up

→ Radioactive source

**Spectrum (^{192}Ir , ^{125}I)
Geometry**

→ Patient

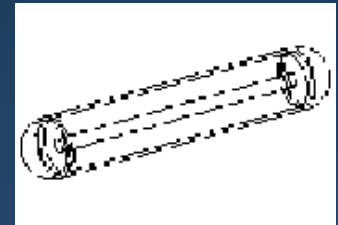
**Phantom with realistic material model
Possibility to interface the system to CT images**

Modeling the source geometry

Precise geometry and material model of any type of source



- Iodine core
- Air
- Titanium capsule tip
- Titanium tube



I-125 source for interstitial brachytherapy

Iodine core:

Inner radius :0
Outer radius: 0.30mm
Half length:1.75mm

Titanium tube:

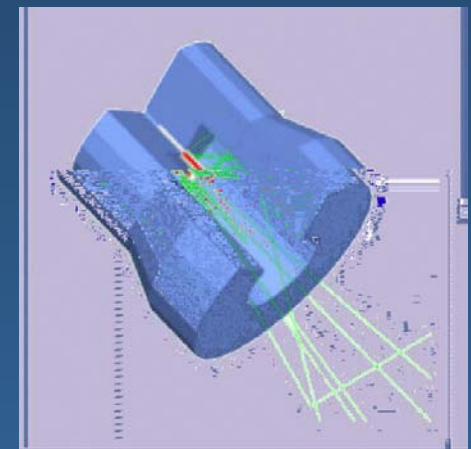
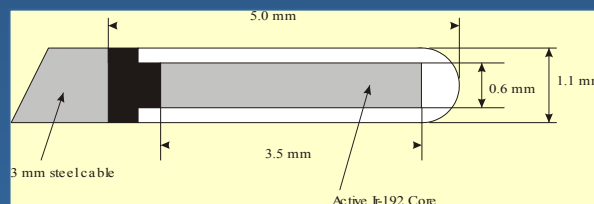
Outer radius:0.40mm
Half length:1.84mm

Air:

Outer radius:0.35mm
half length:1.84mm

Titanium capsule tip:

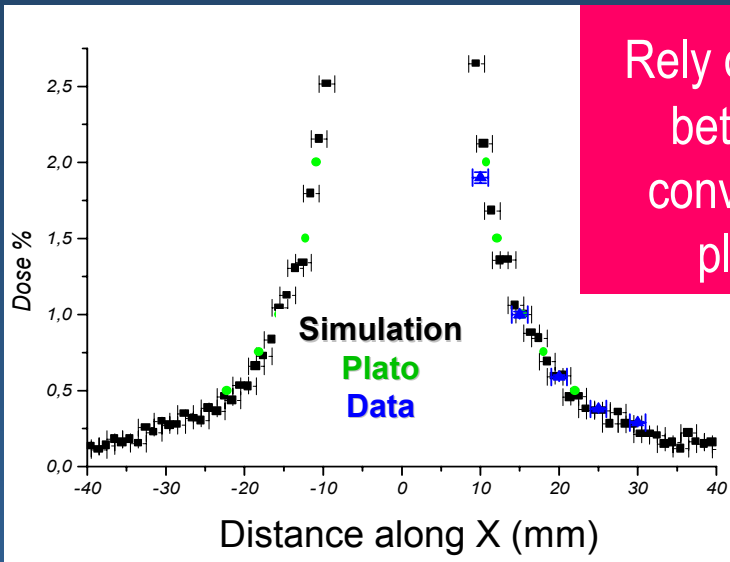
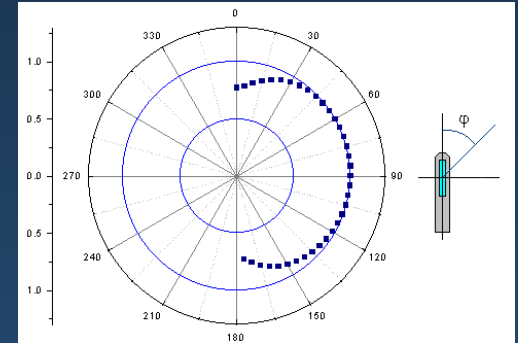
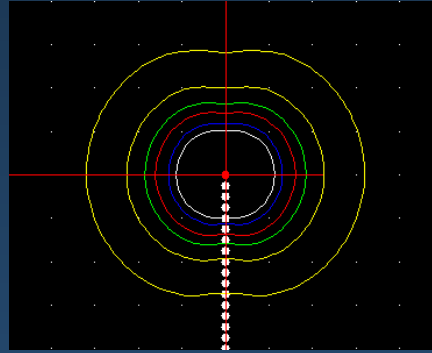
Box
Side :0.80mm



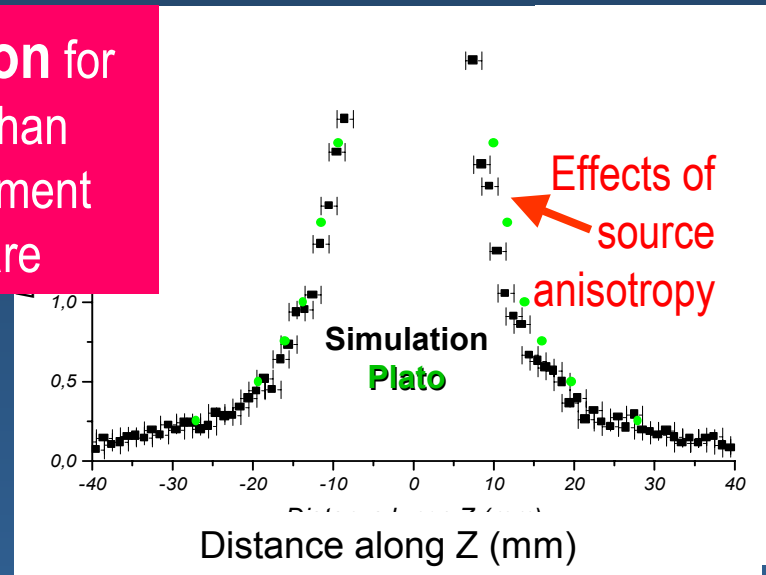
Ir-192 source + applicator
for superficial brachytherapy

Effects of source anisotropy

Plato-BPS treatment planning algorithm makes some crude approximation (φ dependence, no radial dependence)



Rely on **simulation** for better accuracy than conventional treatment planning software



Transverse axis of the source

Comparison with experimental data

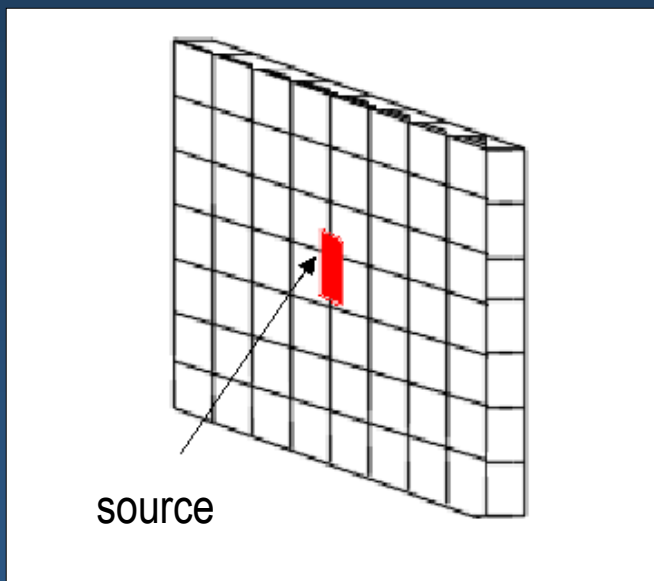
Maria Grazia Pia, *INFN Genova*

Longitudinal axis of the source

Difficult to make direct measurements

Modeling the patient

Modeling a phantom



of any material

(water, tissue, bone, muscle etc.)

thanks to the flexibility of Geant4 *materials* package

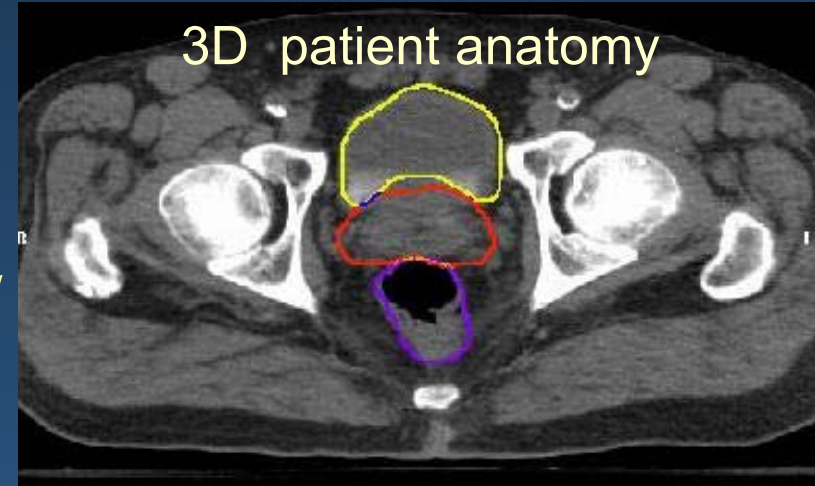
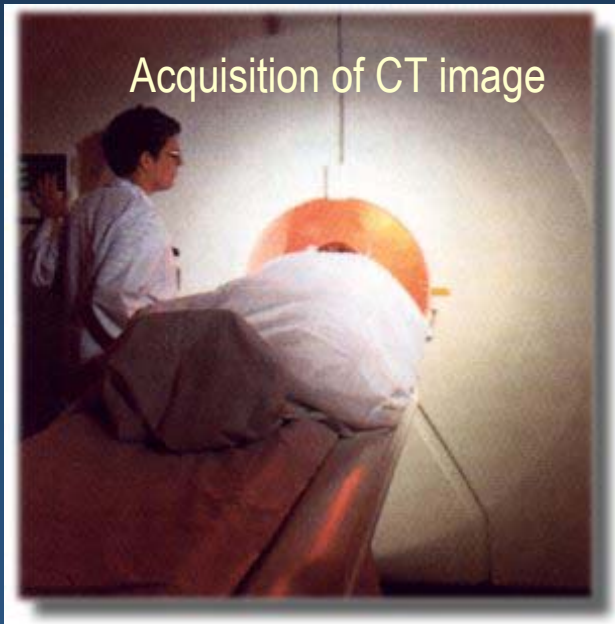
Modeling geometry and materials from CT data



DICOM

Digital Imaging and COmunication in Medicine

Computerized Tomography allows to reproduce the real 3D geometry of the patient



file

DICOM is the universal standard for sharing resources between heterogeneous and multi-vendor equipment

Maria Grazia Pia, *INFN Genova*

```
..... DICM..... UL.....  
..... OB..... UI..1.2.840.10008.  
5.1.4.1.1.2..... UI..1.3.12.2.1107.5.  
1.4.40238.5.0.14178572411846..... UI..  
1.2.840.10008.1.2.1..... UI..1.3.12.2  
.1107.5.1.4..... SH..SIEMENS_S5VA30A  
..... CS..ISO_IR 100..... CS" ORIGINAL\P  
RIMARY\AXIAL\CT_SOM5 SPI..... UI..1.2.  
840.10008.5.1.4.1.1.2..... UI..1.3.12  
.2.1107.5.1.4.40238.5.0.141785724118  
46... DA..20020109...! DA..20020109..  
" DA..20020109...# DA..20020109...0 TM  
..093934.657000 ..1 TM..094310.18600  
0 ..2 TM..094324.432987 ..3 TM..0943  
24.432987 ..P.SH.....' .CS..CT..p.LO..  
SIEMENS .....LO..HOTEL-DIEU DE QUEBEC  
.....ST$.COTE DU PALAIS.QUEBEC.QUEBEC  
.CANADA .....PN.....SH..HNCT40238...
```

Pixels

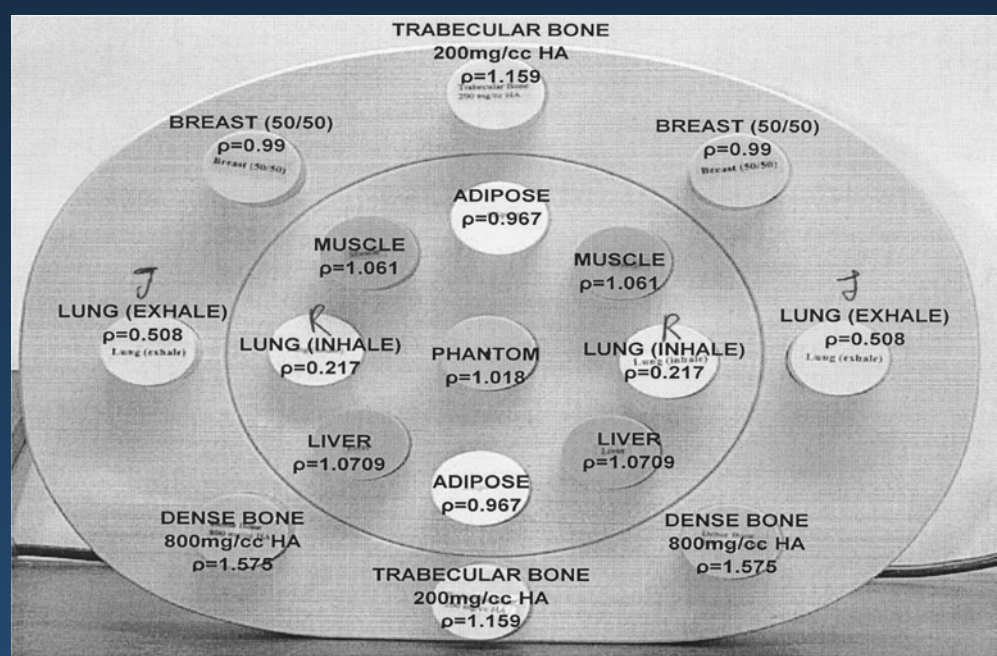
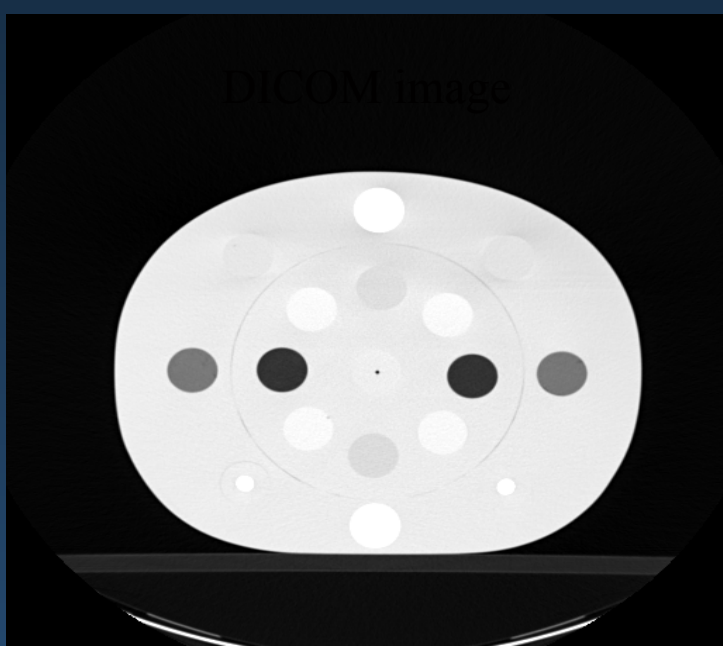
grey tone
proportional to
material density



Geant4-DICOM interface

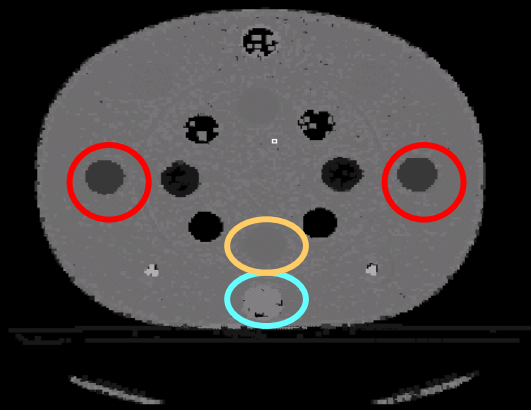


- Developed by L. Archambault, L. Beaulieu, V.-H. Tremblay (*Univ. Laval and l'Hôtel-Dieu, Québec*)
- Donated to Geant4 for the common profit of the scientific community
 - under the condition that further improvements and developments are made publicly available to the community
- Released with Geant4 5.2, June 2003 in an extended example
 - with some software improvement by S. Guatelli and M.G. Pia
- First implementation, further improvements foreseen



viewer 0 (OpenGLStoredX)

Geant 4

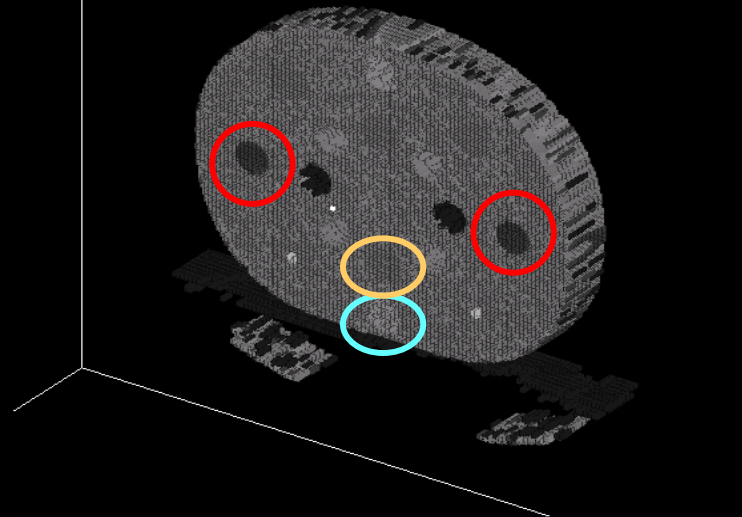


Geant 4
side view



viewer 0 (OpenGLStoredX)

Geant 4 3-D view



User-friendly interface to facilitate the usage in hospitals

→ Dosimetric analysis

**Graphic visualisation of dose distributions
Elaboration of isodose curves**

→ Web interface

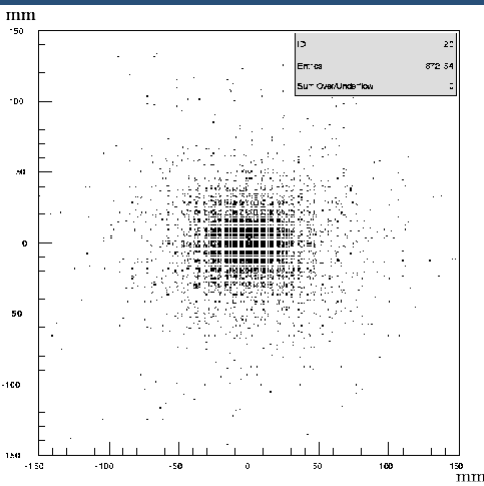
**Application configuration
Job submission**

Dosimetry

Simulation of energy deposit through
Geant4 Low Energy Electromagnetic package
to obtain accurate dose distribution

Production threshold: 100 μm

2-D histogram
with energy deposit
in the plane containing
the source



Analysis of the energy
deposit in the phantom
resulting from the simulation

Dose distribution

Isodose curves

AIDA + Anaphe

for analysis

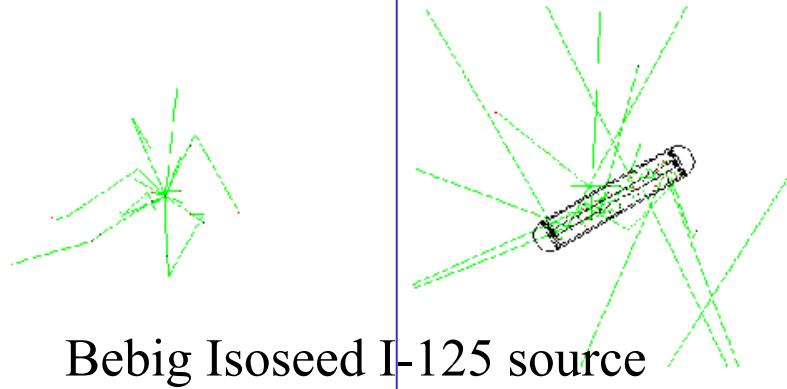
Python

for interactivity

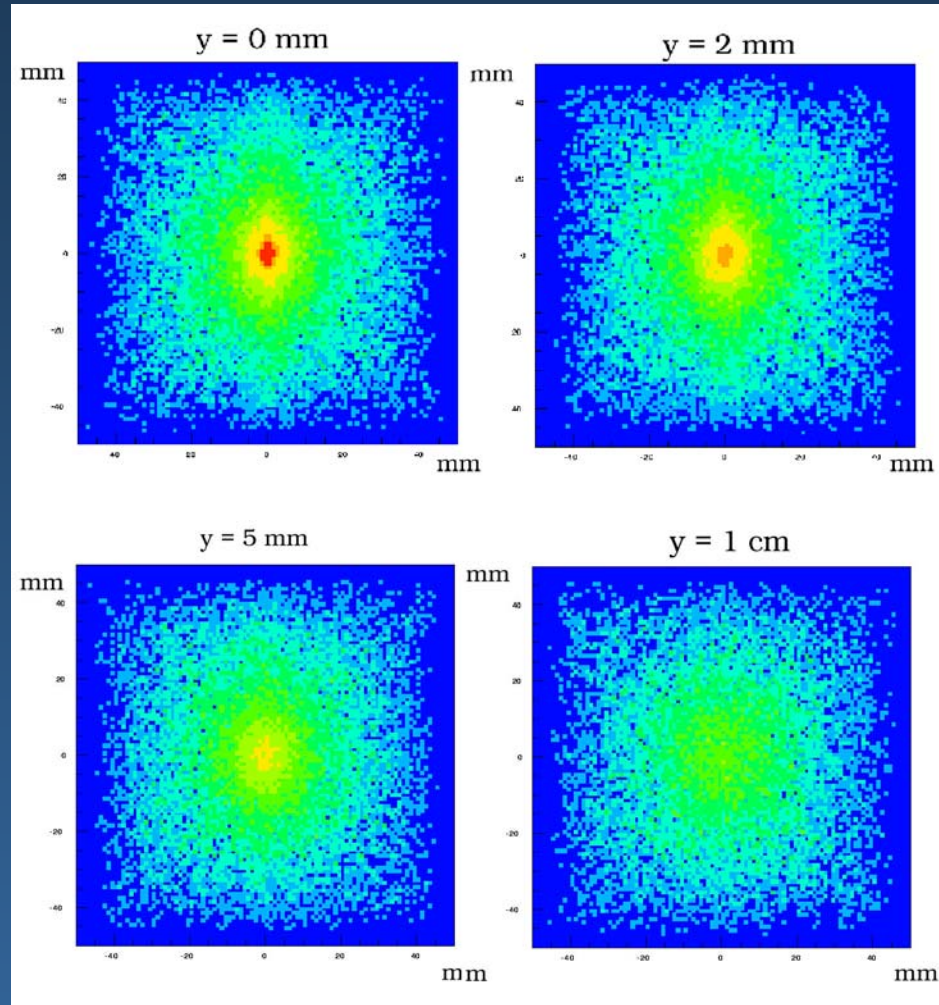
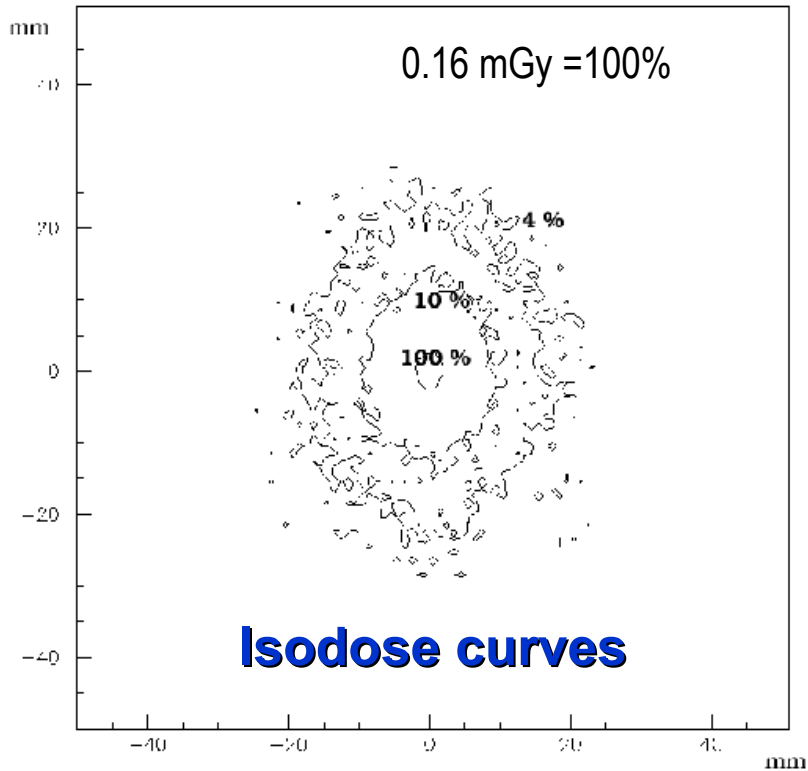
may be any other AIDA-compliant analysis system

Dosimetry

Interstitial brachytherapy



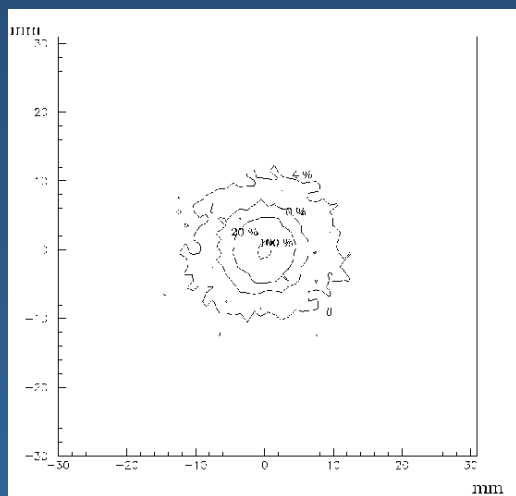
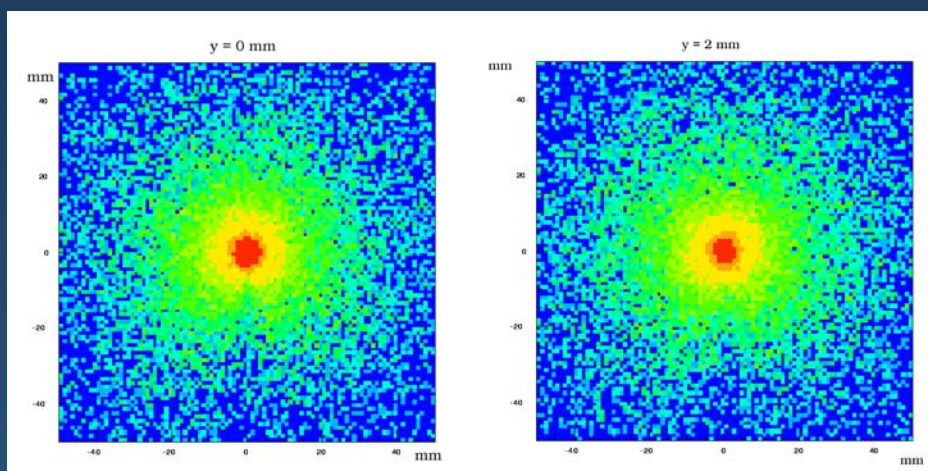
Bebig Isoseed I-125 source



Dosimetry

Endocavitary brachytherapy

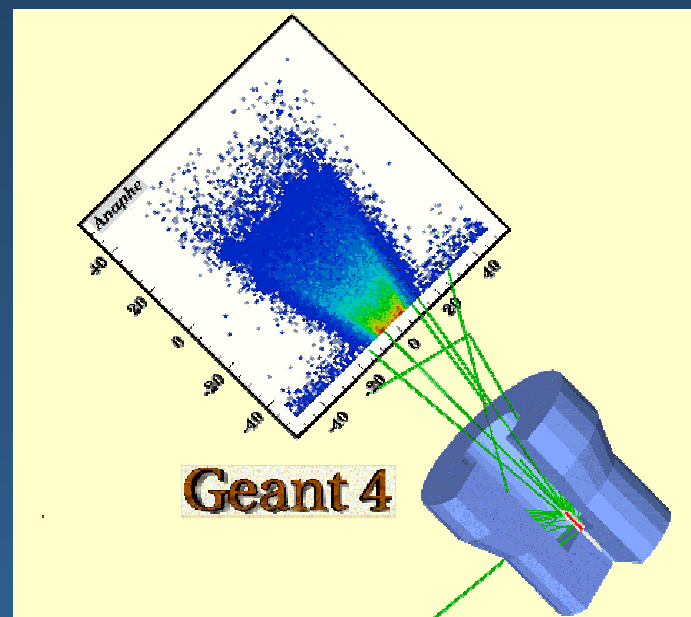
MicroSelectron-HDR source



Dosimetry

Superficial brachytherapy

Leipzig applicator



Application configuration

File Edit View Go Communicator Help

Back Forward Reload Home Search Netscape Print Security Shop Stop

Bookmarks Location: <http://guatelli.home.cern.ch/guatelli/brachy-diane/simulation.html> What's Related

Red Hat Network Support Shop Products Training

2. Running the simulation

In order to run your simulation:
fix the simulation parameters,
the number of events of the run.

Then press **BeamOn**.

The **result** of the simulation is the dose distribution in the plane containing the source.

2.1 Choose the simulation parameters

2.2.1 Choose the radioactive source

Available radioactive sources: I-125, Ir-192, Leipzig

I-125

2.2.2 Choose the phantom absorber material

Available materials: water, soft_tissue, air

water

2.2.3 Choose the number of gamma delivered by the source

1000

2.2.4 Press beamOn to run the simulation

BeamOn

2.2.5 Back again to the simulation default parameters if you like !

Reset

100%

Fully configurable
from the web

Run modes:

- demo
- parallel on a cluster
(*under test*)
- on the GRID
(*under development*)

Speed adequate for clinic use

→ Parallelisation

Transparent configuration in sequential or parallel mode

→ Access to distributed computing resources

Transparent access to the GRID through an intermediate software layer

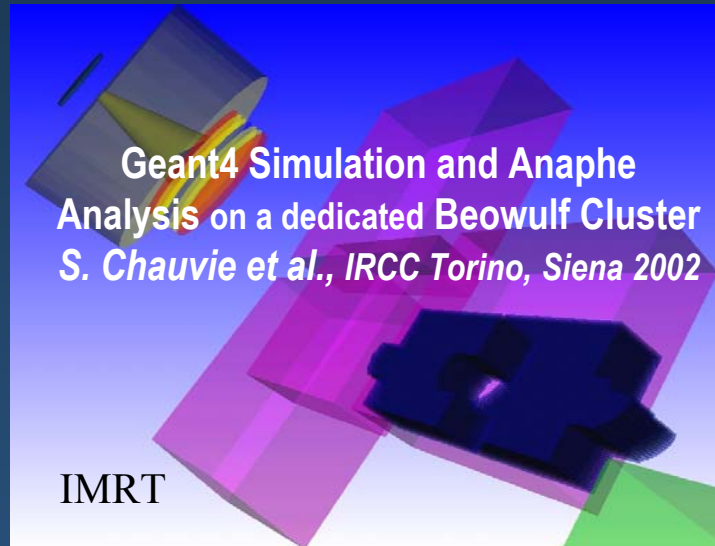
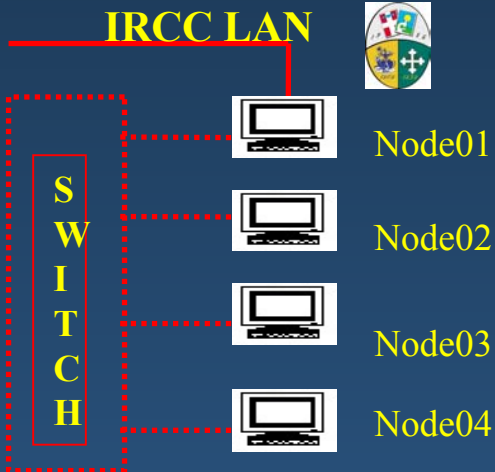
Performance

Endocavitary brachytherapy	↔	1M events 61 minutes
Superficial brachytherapy	↔	1M events 65 minutes
Interstitial brachytherapy	↔	1M events 67 minutes

on an “average” PIII machine, as an “average” hospital may own

Monte Carlo simulation is not practically conceivable for clinical application, even if more precise

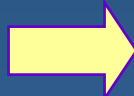
Access to distributed computing



Previous studies for parallelisation of a Geant4 based medical application

- speed OK
- but expensive hardware investment + maintenance

Alternative strategy



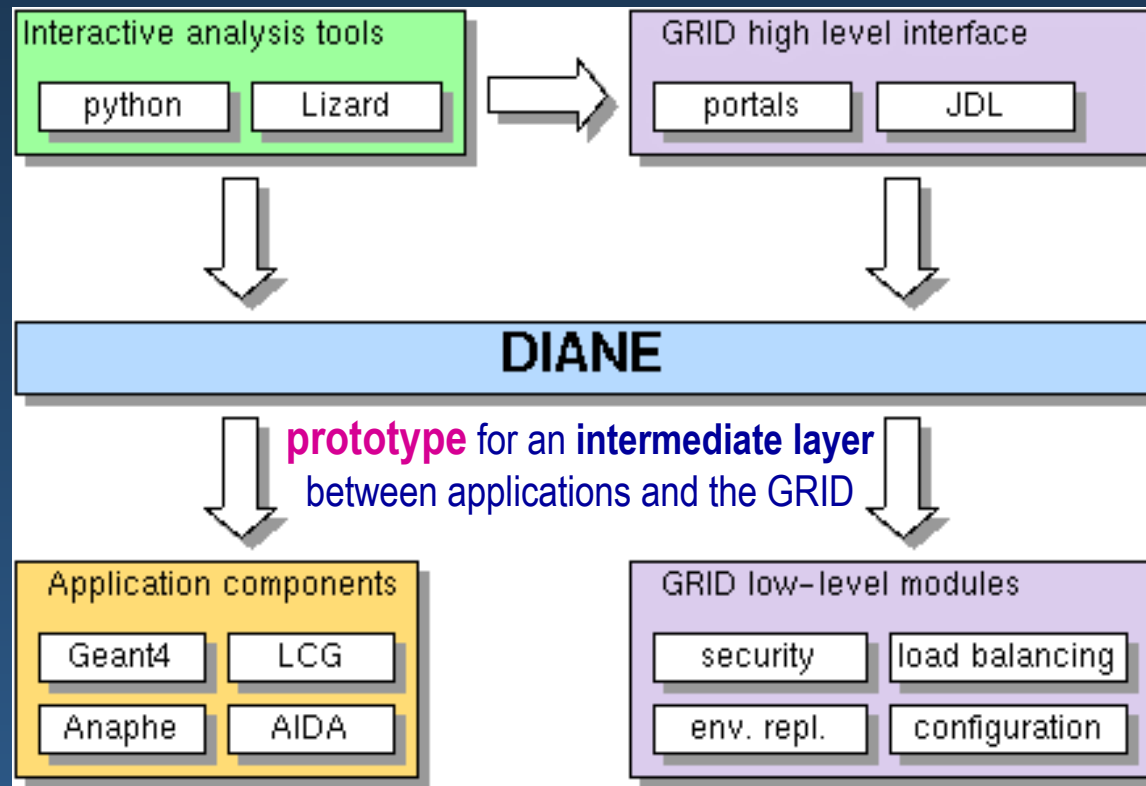
DIANE

Transparent access
to a distributed computing environment

Parallelisation

Access to the GRID

DIANE Distributed ANalysis Environment



Hide complex details of underlying technology

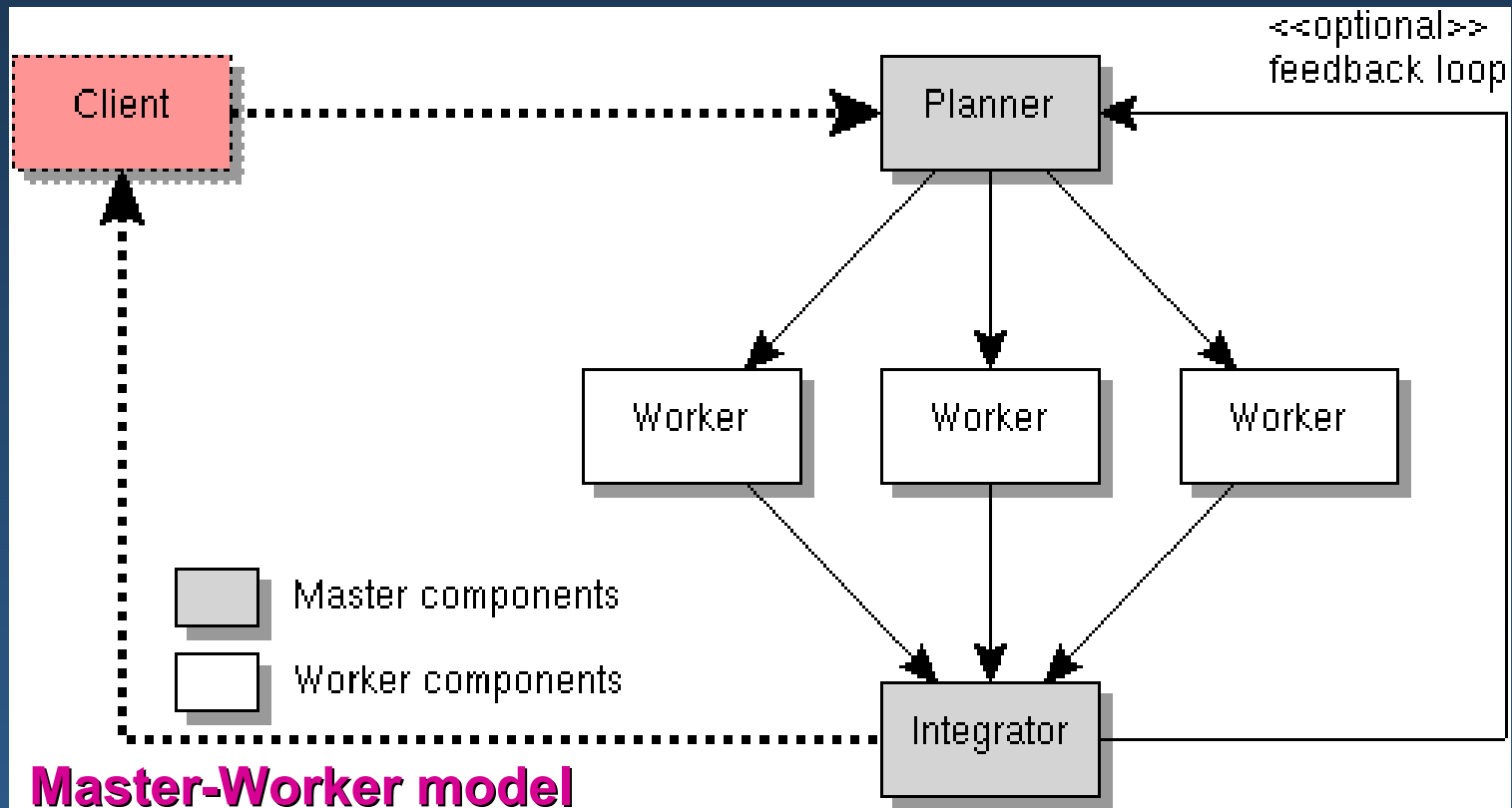
Developed by J. Moscicki, CERN

<http://cern.ch/DIANE>

Parallel cluster processing

- make fine tuning and customisation easy
- transparently using GRID technology
- application independent

DIANE architecture



Master-Worker model

Parallel execution of independent tasks

Very typical in many scientific applications

Usually applied in local clusters

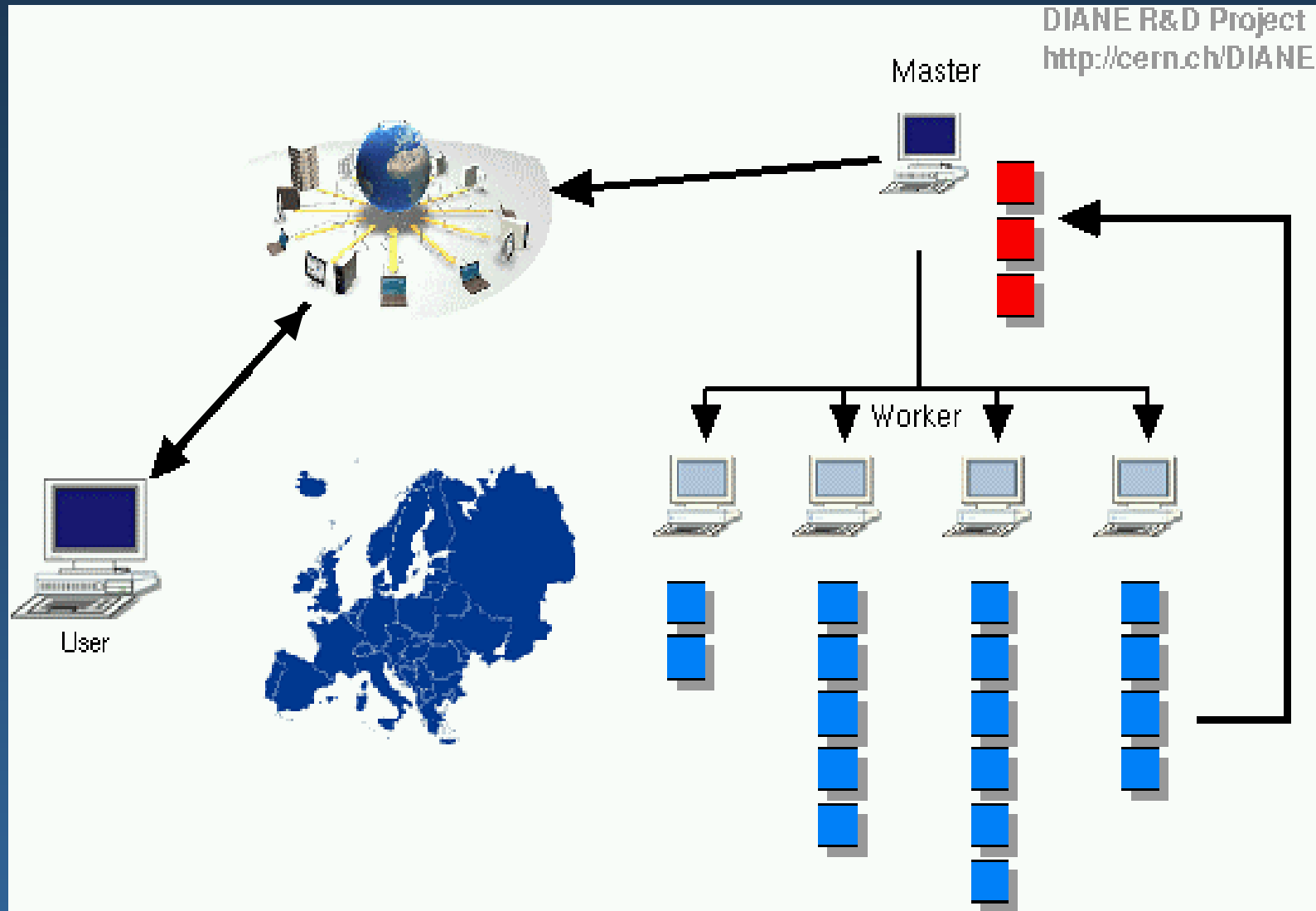
R&D in progress for
Large Scale Master-
Worker Computing

Running in a distributed environment

The application developer is shielded from the complexity of underlying technology via DIANE

- Not affecting the original code of application
 - standalone and distributed case is the **same code**
- Good separation of the subsystems
 - the application does not need to know that it runs in distributed environment
 - the distributed framework (DIANE) does not need to care about what actions an application performs internally

Parallel mode: local cluster



preliminary: further optimisation in progress

Performance: parallel mode

Endocavitary
brachytherapy

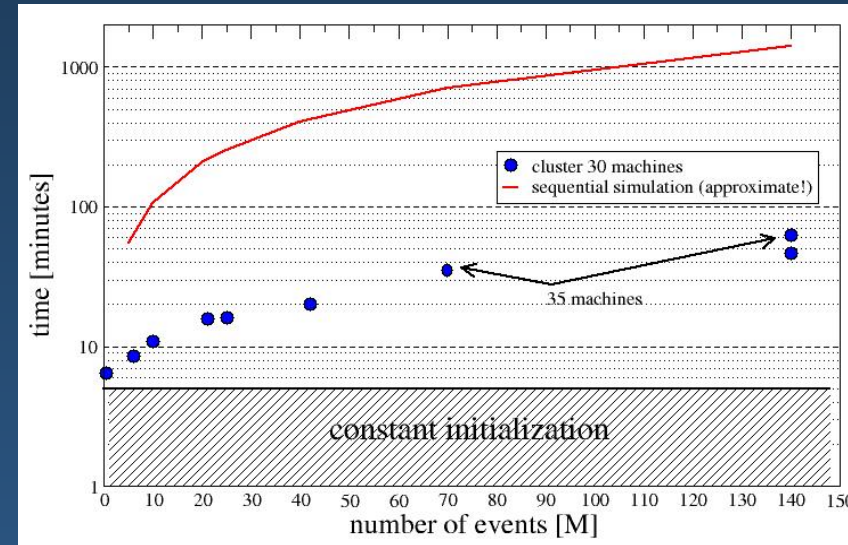
1M events
4 minutes 34''

Superficial
brachytherapy

1M events
4 minutes 25''

Interstitial
brachytherapy

5M events
4 minutes 36''



on up to 50 workers, LSF at CERN, PIII machine, 500-1000 MHz

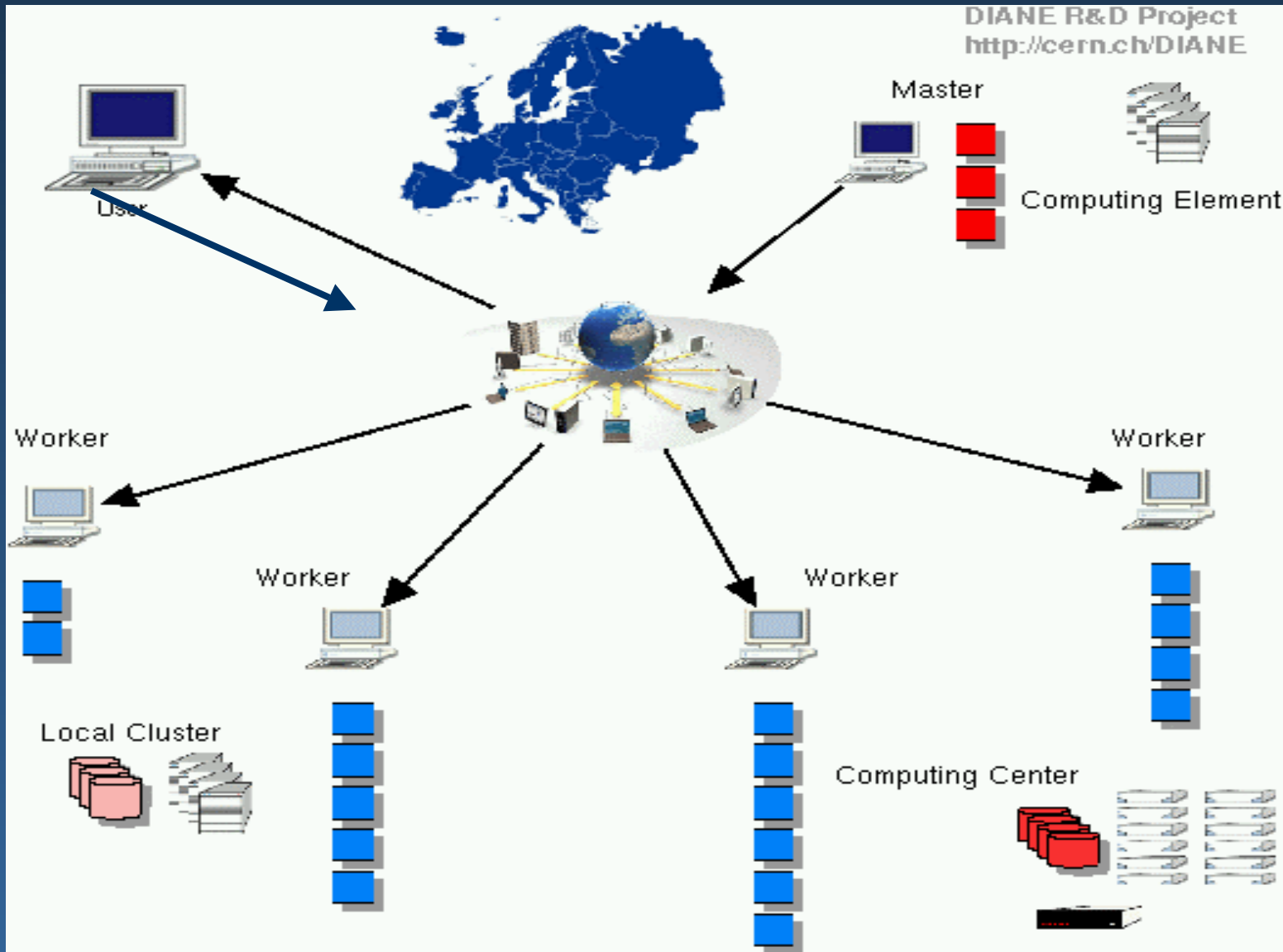
Performance adequate for clinical application, but...

it is not realistic to expect any hospital to own and maintain a PC farm

Parallel mode: distributed resources

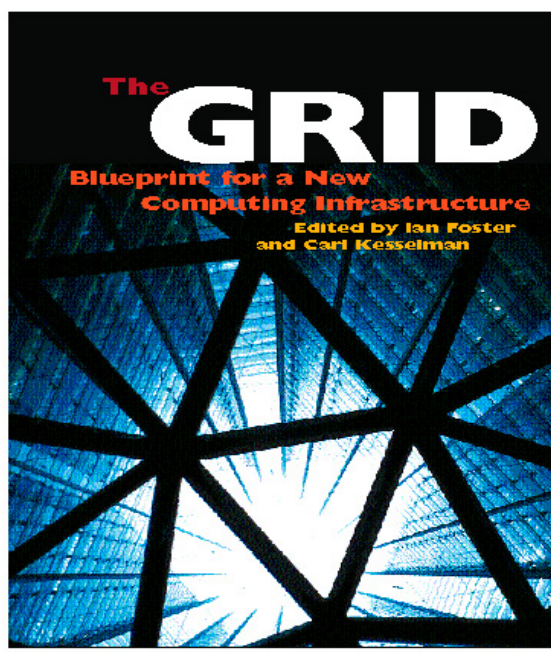
Distributed
Geant 4
Simulation:

DIANE
framework and
generic GRID
middleware



Grid

Wave of interest in grid technology as a basis for “revolution” in e-Science and e-Commerce



Ian Foster and Carl Kesselman's book:

“A computational Grid is a hardware and software infrastructure that provides dependable, consistent, pervasive and inexpensive access to high-end computational capabilities”

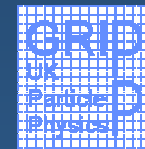
An infrastructure and standard interfaces capable of providing transparent access to geographically distributed computing power and storage space in a uniform way

Many GRID R&D projects, many related to HEP



US projects

Maria Grazia Pia, INFN Genova



European projects

Running on the GRID

- Via DIANE
- Same application code as running on a sequential machine or on a dedicated cluster
 - completely transparent to the user



A hospital is not required to own and maintain extensive computing resources to exploit the scientific advantages of Monte Carlo simulation for radiotherapy

Any hospital

- even small ones, or in less wealthy countries, that cannot afford expensive commercial software systems –
may have access to
advanced software technologies and tools for radiotherapy

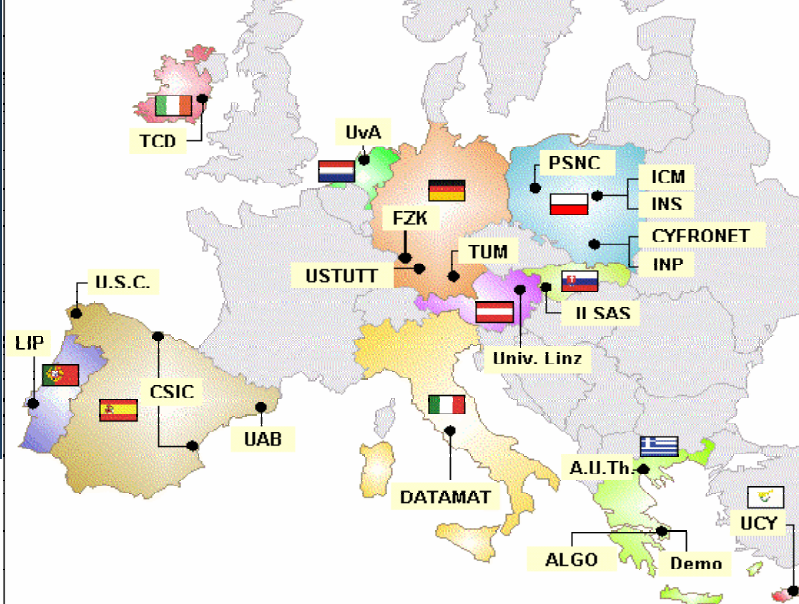
Traceback from a run on CrossGrid testbed

Resource broker running in Portugal

Current #Grid setup (computing elements):
5000 events, 2 workers, 10 tasks (500 events each)

matchmaking CrossGrid computing elements

- aocegrid.uab.es:2119/jobmanager-pbs-workq
- bee001.ific.uv.es:2119/jobmanager-pbs-qgrid
- cgnode00.di.uoa.gr:2119/jobmanager-pbs-workq
- cms.fuw.edu.pl:2119/jobmanager-pbs-workq
- grid01.physics.auth.gr:2119/jobmanager-pbs-workq
- xg001.inp.demokritos.gr:2119/jobmanager-pbs-workq
- xgrid.icm.edu.pl:2119/jobmanager-pbs-workq
- zeus24.cyf-kr.edu.pl:2119/jobmanager-pbs-infinite
- zeus24.cyf-kr.edu.pl:2119/jobmanager-pbs-long
- zeus24.cyf-kr.edu.pl:2119/jobmanager-pbs-medium
- zeus24.cyf-kr.edu.pl:2119/jobmanager-pbs-short
- ce01.lip.pt:2119/jobmanager-pbs-qgrid



Spain

Greece

Poland

Portugal

Other requirements

Transparency

Design and code publicly distributed
Physics and models exposed through OO design

Openness to extension and new functionality

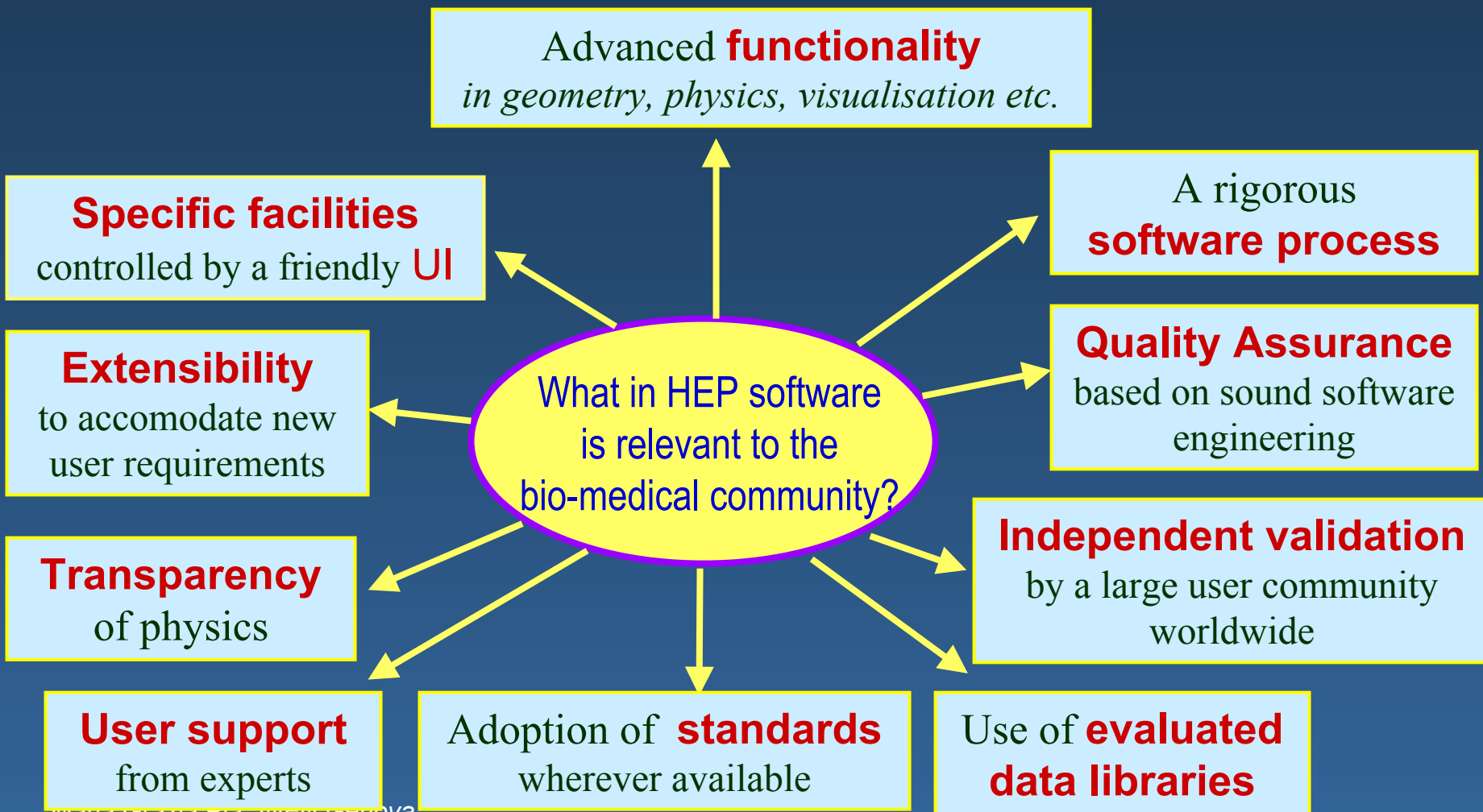
OO technology: plug-ins for other techniques
Treatment head
Beam line for hadrontherapy
...

Publicly accessible

Application code released with Geant4
Based on open source code (Geant4, AIDA etc.)

Transparency

Medical physics does not only require fast simulation and fancy analysis...



Extension and evolution

Configuration of

- any brachytherapy technique
- any source type

System extensible
to any source configuration
without changing
the existing code

General dosimetry system for radiotherapy

- extensible to other techniques
- plug-ins for external beams
(factories for beam, geometry, physics...)

Plug-ins in progress

- treatment head
- hadrontherapy
- ...

Conclusions

Summary

- A precise dosimetric system, based on Geant4
 - Accurate physics, geometry and material modeling, CT interface
- Full dosimetric analysis
 - AIDA + Anaphe
- Simple interface
 - configuration from WWW
- Fast performance
 - parallel processing
- Access to distributed computing resources
 - GRID

The dream of medical physics for the past 40 years...

Beware: R&D prototype!

Technology transfer

Particle physics software aids space and medicine

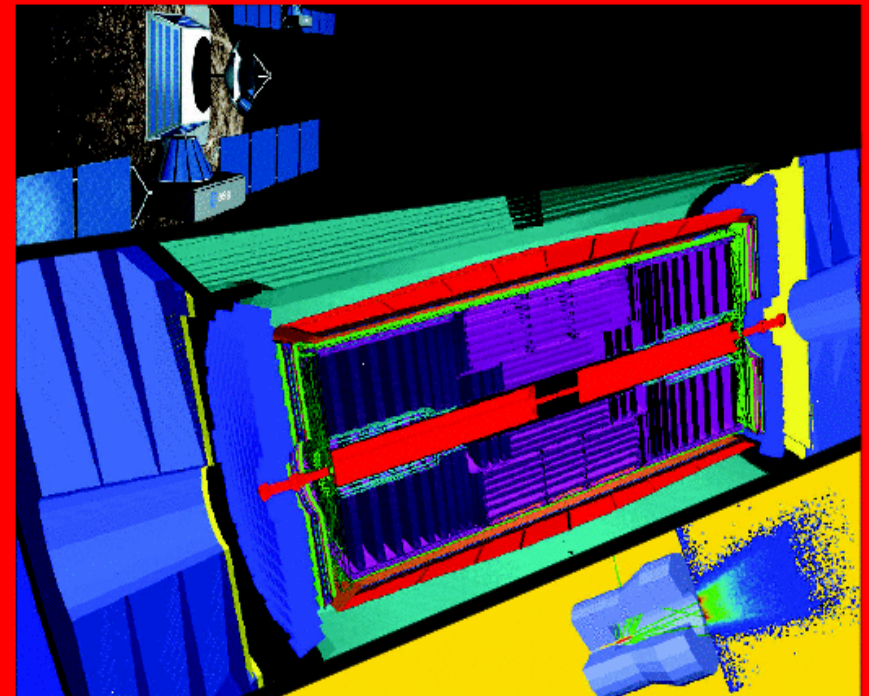
“Geant4 is a showcase example of technology transfer from particle physics to other fields such as space and medical science”

Maria Grazia Pia, *INFN Genova*

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

VOLUME 42 NUMBER 5 June 2002



Simulation for physics, space and medicine

<http://www.cerncourier.com>

NEUTRINOS

Sudbury Neutrino Observatory confirms neutrino oscillation p5

TESLA

Electropolishing steers superconducting cavity to new record p10

COSMOPHYSICS

Joint symposium brings CERN, ESA and ESO together p15

Thanks!

Geant4 has fostered a collaborative aggregation of contributions from many groups all over the world

- G. Cosmo (*CERN, Geant4*)
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M.G. Pia (*INFN Genova*) – particle physicist