Summary of the User Session

3-5 November, 2005

S. Incerti
CENBG

Warning !

Please, refer to the author abstract and slides

The following slides are just a quick summary of conclusions and may contain errors

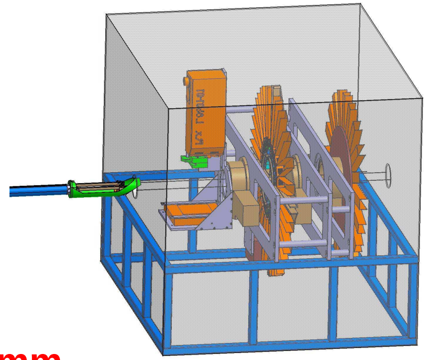
Not much free time to prepare the slides…

Thank you for your understanding

Detector Design for Imaging

I. Piqueras : Study for the design of a multi modality imaging system dedicated to small animal

SPECT : Single Photon Emission Computed Tomography
PET : Positron Emission Tomography
CT : Computed Tomography



Simulation of micro-SPECT with G4 & comparison with references : dx < 1 mm

- Scintillation Process

- Definition of the scintillator material and optical properties of the medium:

- Boundary Process (between YAP and Air): “Al coating” simulation

- Surface YAP- PMT window: two dielectric materials

Simulation of CT with G4 : working

Starting PET with GATE

G4 useful for the design f the platform
MicroCT working
MicroSpect : one camera working
Micro PET : R&D

A. Trindade : Simulation of the Clear-PEM scanner for breast cancer imaging with Geant4

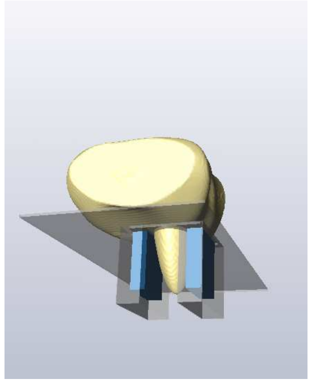
Geant4 toolkit is used for the simulation of the Clear-PEM scanner (dx < 5 mm & high sensitivity)

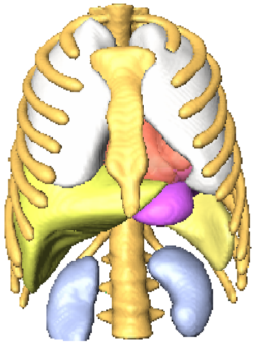
The developed simulation framework includes:

- a **patient model**

- a detailed description of the **detector geometry**

- a C++ high-level simulator of the **signal formation and data processing** in the on-detector front-end and off-detector digital electronic systems was developed





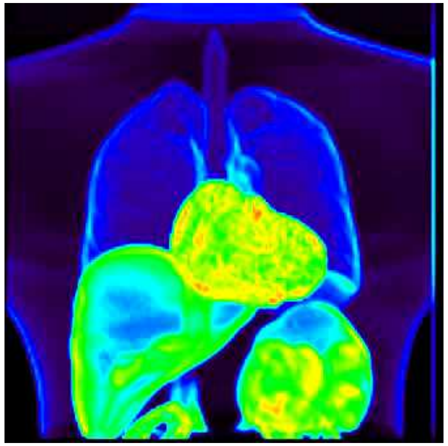
- The NURBS CArdiac Torso (NCAT) phantom was implemented in Geant4, as a voxelized geometry (G4VPVParameterisation)
- A detailed description of the scanner geometry and material properties were implemented (~35000 solids)
- Several 5 min. acquisition exams were simulated with Geant4 to assess lesion visibility.
- Computational resources: 70 d CPU (140 jobs), 236 GB, data production at CERN (LXBATCH), CASTOR storage

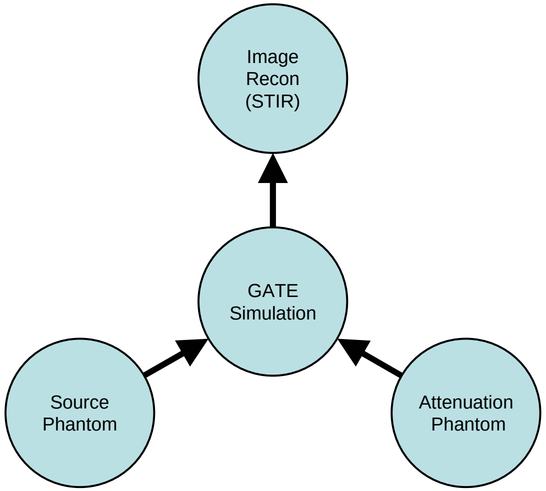
A simulation framework based on Geant4 able to reproduce the realistic conditions of a breast exam with the Clear-PEM scanner was developed and has been used, since late 2002, to evaluate the system design concept.

Simulation data is currently being used to test the data acquisition electronics system, optimize the image reconstruction algorithms and, in the future, provide useful guidelines for the pre-clinical deployment phase of the scanner.

N. Lang : Simulated PET acquisition of a respiratory and cardiac moved NCAT-human torso phantom using the GATE toolkit

- Realistic experiment PET/CT scanner
- GATE simulated PET scan
- Voxelized 3D-anatomy of human body
- Respiratory and cardiac motion implemented
- Emission and attenuation configuration
- Simulation of lesion or infarction



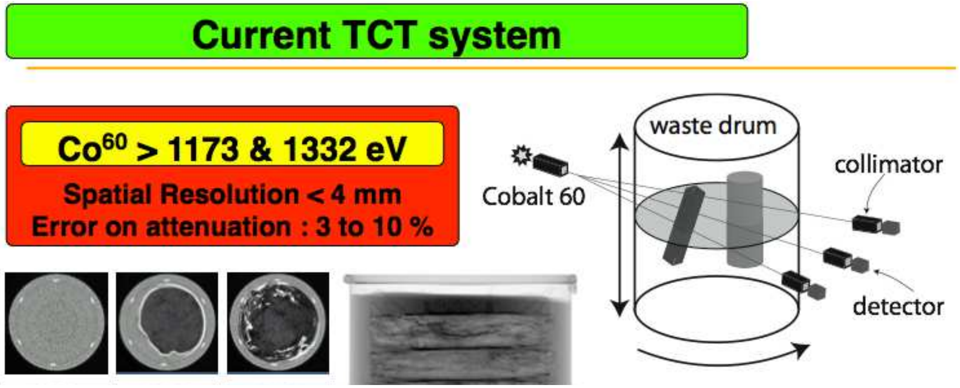


- **Problem:**
  - Image blurring during long scan times
  - Attenuation correction with static CT data produces artifacts in images

- **Solution:**
  - Gated listmode PET freezes motion
  - Use of software morphing (optical flow) to produce motion free images inheriting the full statistics

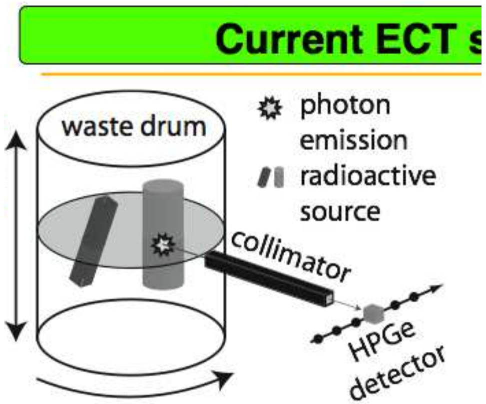
- Weeks of CPU-Time (2,4 GHz Xeon) needed for single image
- Attenuation increases CPU time by factor of 10 !
- Parallel cluster computing needed (not yet implemented in GATE)

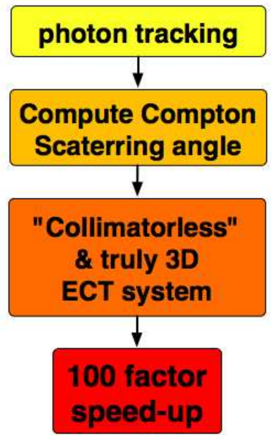
P. Leroy : Geant4 simulations for Emission Tomography on low-activity radioactive waste drums with Compton detectors

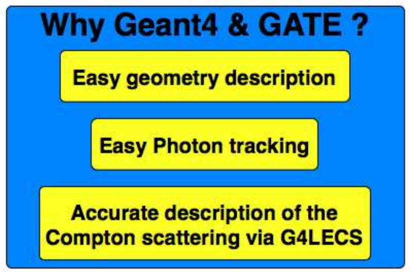


Spect on low activity radioactive waste oil barrel: radiologic contents form 100 keV to 2 Mev - 100 kBq to 100 GBq, long spectrometric measurements with cobalt 60 (>1173 and 1332 ev) in front of the waste drum, collimator and HPGe detector

Poor stat. because large collimator, acquisition time > one day : too much for industrial application.
Use G4 and Gate to study Compton detectors: no more collimator, truly 3D acquisition-> gain of factor 100

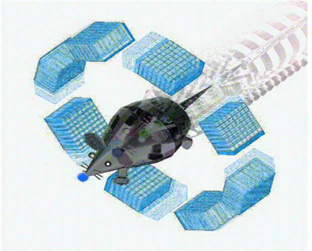






Gate +Galecs Doppler effect important for the first scattering angle computation.
G4lecs package very important for them

I. Buvat : GATE : a simulation toolkit for emission tomography in nuclear medicine and molecular imaging



Optimize **detector design** , assessing acquisitions…

Home made code available, from 1995 to 1999
After 1999, 8 home made codes and 7 publicly released

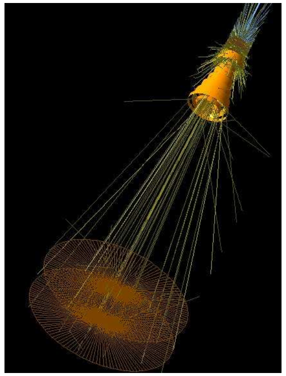
More than **400 users** to the gate user mailing list
T
Time dependence important for spect / pet imaging
Gate slow : emitting object large, voxelised maps, tracking slow through any border, low detection efficiency-> need high stat

Use **accelerating** methods :
variance reduction technique, combine MC and non MC, parallel simu

- Simulations will be more and more present in (nuclear) medical imaging in the future:
  - as a invaluable guide for designing imaging protocols and interpreting SPECT and PET scans,
  - in the very imaging process of a patient

External Therapy

B. Faddegon : An accurate experimental benchmark of bremsstrahlung for radiotherapy quality beams



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

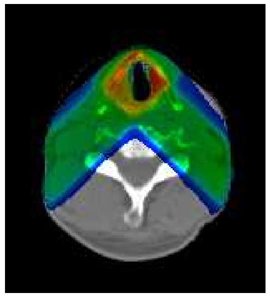
Geant4 & ITS & EGSnrc with BEAM user code from NRCC

- **Need to improve bremsstrahlung cross-sections**
  - **Total yield for low-Z targets (10-20%)**
  - **Energy spectra for low-Z targets, eg, ratio fluence at 1 MeV to 10 MeV is 50% high for Be and Al**
  - **Angular distribution, eg, ratio fluence on beam axis to 1 degree off axis high by 7-10%, all targets**
- **Timing should be pretty good with bremsstrahlung splitting employed (under investigation)**
  - **Slow for low-Z targets by factor of 3**

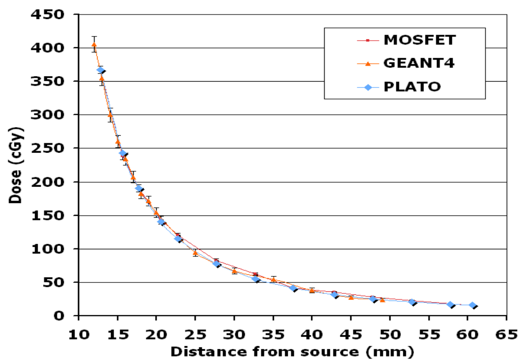
A. Raaijmakers : Simulations for the virtual prototyping of a radiotherapy MRI-linear accelerator system: Linear accelerator output, CT-data implementation, dose deposition in the presence of a 1.5 T magnetic field

- Simulation of a radiotherapy accelerator has been achieved
- CT-data implementation is working fine and is showing agreement with TPS PLATO
- Already, physicians come up with clinical cases of inhomogeneous target volumes in patients, where they want to know the dose distribution more accurately
- Need to validate our simulated dose distributions in a magnetic field (better dose control)
- Ionization chamber response in a magnetic field is still a problem

GEANT4 is a very practical tool for our purposes, though there is room for some improvement
(navigation, boundary crossing)



- **Space**: microdosimetry simulations
- **Hadrontherapy**: verification of light ion fragmentation models
- **Terrestrial Radiation Protection**: silicon microdosimetry of Pu-Be neutron source
- **Brachytherapy**: development of real-time rectal dosimetry system for prostate HighDoseRate
- **Microbeam Radiation Therapy**: MOSFET dosimetry system
- **Medical Imaging**: development of a small animal PET scanner
- Refer to poster



Hadrontherapy

I. Gudowska : Simulation of light ion transport in a water phantom using Geant4

- **Problems with accurate comparison with experiments:**
  - **beam energy in front of the phantom, beam energy spread**
  - **use in MC calculations of the recommended stopping power data ICRU49 (p,α), ICRU73 (heavier ions)**

- **Position of the Bragg peak obtained by different MC codes within ± 2 mm**

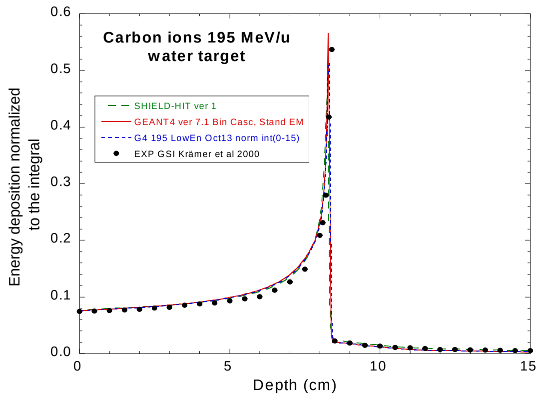
- **Geant4 results agree reasonably well with the experimental data regarding position/height of the Bragg peak**

- **Contribution to the energy deposition from the fragmentation processes is quite good for ions up to ^{12}C and energies up to 200 MeV/u,**

  Geant4 reproduces well the Bragg peak curve in this energy region

- **For higher ion energies above about 200 MeV/u verification of the**
  nuclear inelastic interactions required

- **Validation of the partial cross-sections for production of secondary particles necessary**



I. A. Pshenichnov : Fragmentation of light nuclei in water phantoms studied with Geant4

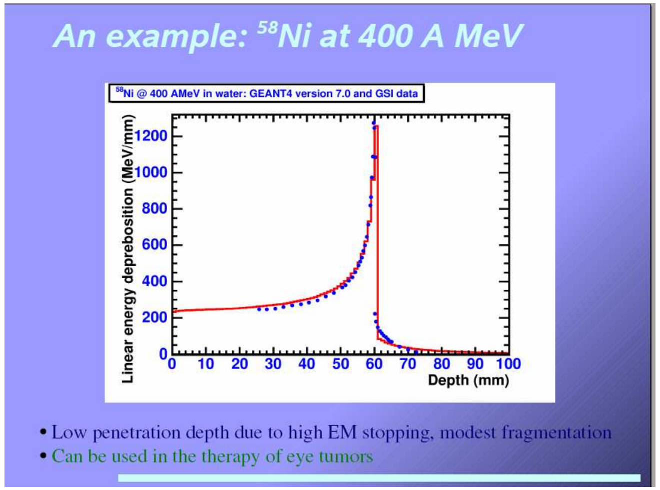
GEANT4 validation for heavy-ion therapy

● Both Bragg peak position and shape are well described by GEANT4 v7.0 with its "standard" electromagnetic model and binary cascade/Fermibreakup models.

● The peak position is predicted with accuracy of ~12 mm for carbon and oxygen ions in the energy range from 135A to 330A MeV.

● The calculations with the mean ionization potential for water *I*=70.89 eV (default value) are in reasonable agreement with proton and heavyion data.

● The energy deposition beyond the Bragg peak due to projectile fragmentation can be described with an accuracy of ~10%.



Secondary neutrons from proton and ion beams: harmful ? No !

● Fast neutrons go through the phantom easily: may concern the shielding of the treatment room.

● Low energy (~ MeV) neutrons have a large probability to interact, but can deposit only low energy on average (~ 0.01 MeV/mm)

● The dose from neutrons is below 1.5% of the total dose for typical irradiation conditions.

●Depthdose distributions were calculated.

● Physics of secondary neutrons was studied.

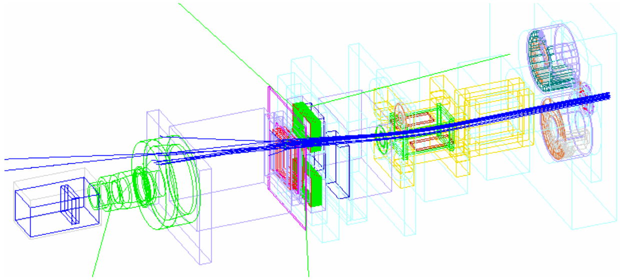
● The distributions of positron emitting fragments were calculated.

●GEANT4 v7.0 seems to be well suited for heavyion therapy simulations !

H. Paganetti : Significance of time-dependent (four-dimensional) geometries for Monte Carlo simulations in radiation therapy

Key to 4D Monte Carlo

Geometry changes during the simulation via C++ class architecture based on GEANT4



Modification of the GEANT4 source code

Instead of re-doing the optimization for the entire geometry, only re-optimize parts of geometry

Four-dimensional Monte Carlo (based on GEANT4) is a technique capable of simulating geometry variations (beam delivery or patient) during dose calculation.

The technique allows the investigation of interplay effects for any given dose rate.

H. Paganetti : Geant4 based proton dose calculation in a clinical environment: Technical aspects, strategies and challenges

Physics Setup

Beam entering the simulated area	Hounsfield U to Materials
Generic Treatment Head Geometry	Generic Patient Geometry
Treatment Head Geometry	Patient Geometry
Beam Setup	Patient setup

Absolute dosimetry

Routine use of (proton) Monte Carlo dose calculation (using GEANT4) requires work in many different areas of treatment head and patient modeling

- requires establishing a link between treatment planning and Monte Carlo
- is being done at MGH

T. Sasaki : Status and plan for the hadron therapy simulation project in Japan

HIBMC new beam line, 12 C at 290 MeV/u and 400 MeV/U
Agreement software / measurement on water phantom.

2nd prototype
Will include simulation driver based on PYTHON,
geometry model frame work,
interface to DICOM/DICOM-RT,
Visualization tools,
GRID
JQMD vs binary ?

SLIDES ?

T. Aso : A Geant4-based simulation of irradiation system for hadron therapy

Tools to setup their own irradiation system with minimum coding effort

3 levels
Geometry + particle therapy system+ beam module

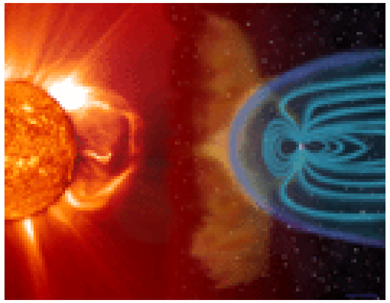
They are collecting geometry information of irradiation system

SLIDES ?

Space & Biology

P. Gonçalves : Simulation of radiation monitors for future space missions

Simulation of particle transport from the source to the detector



- description of the radiation environment
- modelling injection and propagation of particles from the Sun
- scaling of SPE fluxes to other planets

Detailed detector simulation

- Interaction of incident particles with detector materials.
- Generation & propagation of secondary signals (Fluorescence photons, ionization charges, ...).
- Detection of secondaries by readout devices (photodetectors, ...).
- Integration of readout electronics, signal digitization, trigger, ...
- Generation of simulated raw data (real data like) for further data processing (pedestal subtraction, calibration, event reconstruction,...) & Data analysis.

Geant 4

DIGITsim

A new generation of compact, lightweight, general purpose radiation monitors are needed for future Space Missions (e.g. BepiColombo).

A simple concept based on a scintillating crystal is under study.

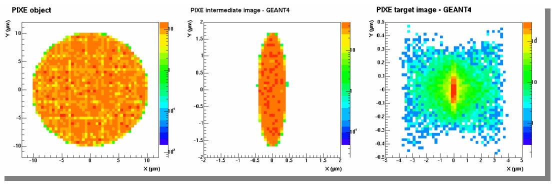
LIP will be responsible for implementing the required Geant4 based detector simulations (contract with EFACEC/Portugal).

G. Santin : Recent developments in Geant4-Related Activities at ESA

Sorry, no abstract, no slides, and missed talk

S. Incerti : Geant4 simulations for microdosimetry at the cellular level and nanoprobe design

Ray tracing for the new CENBG nanobeal line with G4
Under improvement using a high granularity field map for focusing quadrupoles
Combination E & M fields works fine



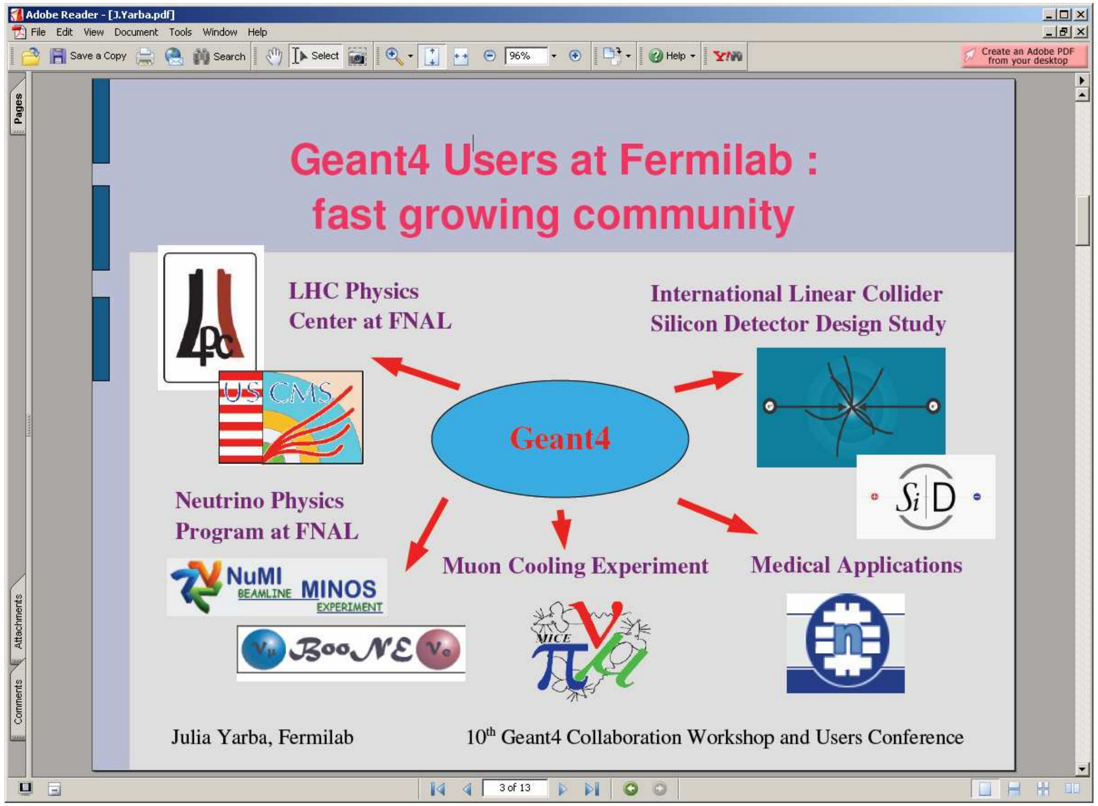
Comparison of cellular irradiation setups with G4
New voxellized cell geometries
Realistic nucleus, cytoplasm and chemical composition expected for microdosimetry
Geant4 DNA, Aurora,…

Z. Francis : Geant4 DNA Physics processes

- **Electrons correction terms should be reviewed**
- **Electrons & protons Calculated cross sections should be validated and compared to experimental data.**
- **Implemented processes should be tested on different machines.**
- **With these processes we should be able to estimate the energy deposed in the cell or even in the DNA molecule (nanometer scale).**
- **These processes are very time consuming which makes them useless at the macroscopic scale.**

HEP

J. Yarba : Status of Use and Support of G4 at Fermilab



The Geant4 use in FNAL experiments and projects has picked up several years ago and is rapidly growing

- The community of the Geant4 users at and around FNAL includes may young physicists and students, with little or no experience in the area of detector simulation

- Help to users requires "personalized" approach

- Creating webbased, stepbystep instructions for Geant4 users allows efficient education/support

- Manpower available at FNAL for Geant4 support is limited but there are hopes for more resources

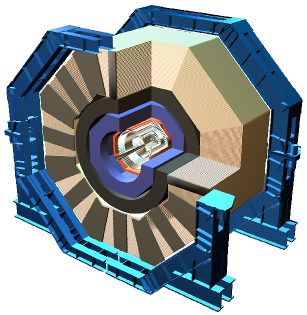
J McCormick : Full Detector Simulation for the International Linear Collider

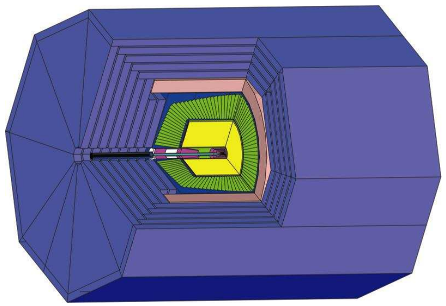
3 different detector concepts for ILC, study same event into the 3 setups
ILC: e+ e- collision at sqrt(s) ~1TeV

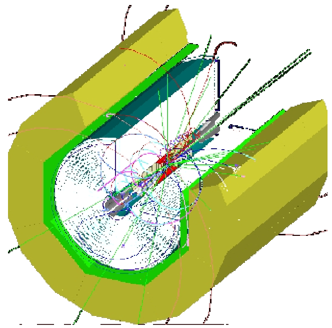
Detector description should not be hard coded,
need parameterization in order to be used for different detectors

Trackers: pixel, Silicon microstrip, TPC
Calorimeters EM = Si, scintillation, hybrid
Hadronic calorimeter : scintillator, GEM, RPC
Absorbers: Steel Tungsten

gdml construction of the G4 simulation with xml format …
benchmarks for detector concepts

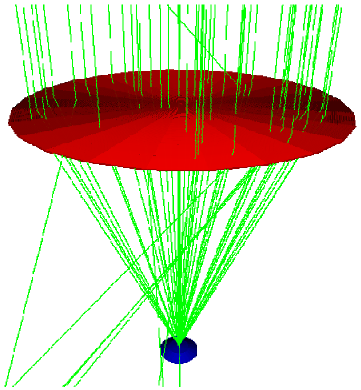






B. Tomé : A Geant4 based simulation for Fresnel lenses

- Fresnel lenses in Air Shower Telescopes
- Fresnel lens description with Geant4
- Lens performance and optimization studies
- Air Shower Telescope simulation



• Geant4 potential explored in detailed studies of Fresnel lens performance.

• Complete simulation of a IACT using Fresnel optics is being set.

• Geant4 advanced example using a Fresnel lens is available.

• Geant4 geometry description capabilities and availability of optics physics processes provide the necessary tools to set a simulation of Fresnel lenses.

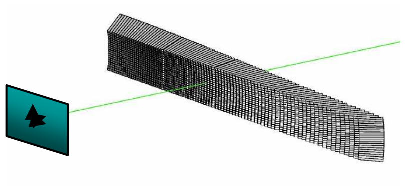
• Description of Fresnel lenses geometry allows for detailed performance & optimization studies of IACT´s.

• An end to end simulation, covering air shower, lens and readout simulation can be implemented.

Ph. Miné : H4SIM, a Geant4 simulation program for the CMS ECAL supermodule

CMS has a Geant4 simulation program, OSCAR, for the complete detector, interfaced with the reconstruction

H4sim is a **standalone simulation of one supermodule** in H4



Geometry description by Geant4 data cards with a text file
DDD (Detector Description Database) in XML format

Geant4 based H4sim is widely used by the ECAL CMS community
Interpretation of test beam data
Test of algorithms and cosmic precalibration

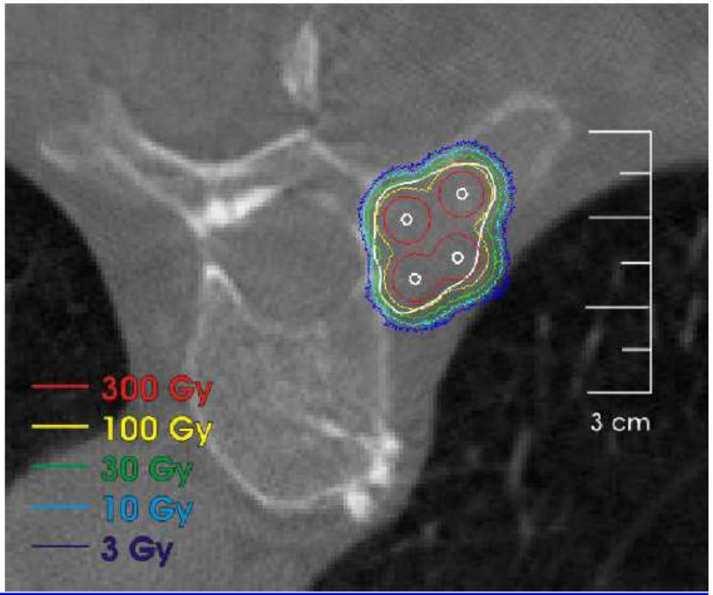
H. Yoshida : Geant4 for Education in HEP and Radiation Therapy

Report on workshop “Geant4 for education” : teachers + developers
Toolkit for teachers to create course materials
Python interface for interactivity and easy construction
Common physics list
Geant4 server

SLIDES ?

Dosimetry & computing

- Simulation on a 50 CPU Linux-Cluster using MPI
- Parallelisation by event/seed distribution
- Histogramming: ROOT-Toolkit
- Geant4 is used for:
  - Dose calculations
  - Helping to develop or calibrate detector systems
  - Future use
- Dose planning using CT-data
  - Dicom-library DCMTK
  - Clinical study
  - ^{32}P implants
  - Tumor therapy



P. Guèye : Fundamental Physics and Basic Research in Brachytherapy with Geant4

SLIDES ?

development of scintillating based detectors to determine absolute 3D dose distribution measurements with accuracy better than ±100 µm [

measuring 2D and 3D in-vivo dose maps to provide real time feedback to physicians for (possible) adjustment of patient treatment planning

studies on the energy dependence of cancer cells to address, among others, mono-energetic Brachytherapy source treatment, reaction mechanisms associated with cancer cell destruction, and cancer genome identification

The G4 toolkit is primarily used to optimize the detector development.

At the fundamental level, a combined Geant4 and molecular biology code is being developed to provide understanding of energy deposition and associated physics processes at the molecular level.

Recent publication works indicate possible problems in the tracking and/or physics within the electron algorithms of Geant4. A research program focusing on the measurements of absolute cross sections in the energy regime of interest is underway to obtain key information on the corresponding physical processes.

C. Thiam : Gate for brachytherapy applications

- GATE is already in use for dosimetry applications in both animal and human models.
- Certain challenges still remain in for GATE to become a MC code for dosimetry applications.
- Concerning a bracytherapy application using Iodine 125 sources: a study for kerma/dose calculation with « track length estimator » method is under validation

➢ Optimization of the execution speed, improved flexibility in the dose calculation module

➢ Validation studies in the use of GATE for internal and external dosimetry applications

➢ GEANT4 validation for dosimetry related to the electrons (tests of the multiple scattering in the next versions)

➢ Dosimetry on images patient voxelized (modeling with real patients data)

C. Thiam : Gate simulations in a grid environment

- The computation time was reduced although not sufficiently for clinical practice: further optimisations are going on

Remark : Submission and retrieval times are very important using sequential submission (need to use multithreaded submission)

- A portal has been created to ease the access to this applications for the medical physicists

- A large community of users is interested in GATE

- Real production is done on grid infrastructure

- Inter-connection between web and grid services needs to be validated on production infrastructure

J. De Beenhouwer : Importance Sampling in Gate

- Goal: to reduce computing time
- Idea: augmented sampling of interesting events : source biasing, leading particle biasing, geometry splitting, weight windows, forced detection
- Introduces bias, which is corrected for by introducing statistical weights
- Result : Equal mean value; reduced variance of mean value

- The efficiency of these techniques is inversely related to the sensitivity of the detector
- The acceleration compared to an analogue simulation is between 5 and 15 for Geometrical Importance Sampling and between 105 and 159 for Forced Detection
- The FD code currently only covers the effects of nuclear decay and Compton scattering. An extension to include Rayleigh scattering and / or the photoelectric effect is considered. Especially lead fluorescence is not yet dealt with correctly
- FD is being integrated into GATE without modifications to GEANT4

R. Reuillon : Possible issues to optimize stochastic simulation time with parallel sequences

In this work we first discuss how to optimize the whole computing time of Geant4 simulation relying on parallel independent experiments which suppose a sound distribution of pseudo-randdom numbers.

Second we present how to optimize the access speed to random numbers independently from the generation algorithm.

For parallell and distributed simulations, random numbers should be generated in parallel, i.e. each logical process (LP) should autonomously get its own sub-sequence of a global random sequence. If such an autonomy is not guaranteed, the parallelism is affected (Hellekaleck 1998), and each LP process must then refer repetitively to a central RNG which creates a bottleneck. Designers of parallel stochastic simulations always have to reply to this fundamental question: how can we make a safe RNG repartition in order to keep efficiency and a sound statistical quality of the simulation. Indeed the validation of such parallel simulation is a critical issue. Paul Coddington precisely states: "Random number generators, particularly for parallel computers, should not be trusted. It is strongly recommended that all simulations be done with two or more different generators, and the result compared to check whether the random number generator is introducing a bias" (Coddington, 1997). The basic concept to parallelize an RNG is to take the elements of the sequence generated by the RNG and to distribute them among LPs in some way. Three major partitioning methods can be found in the literature [2-7]: the Leap Frog (LF) technique, the Sequence Splitting (SS) and the Independent Sequences (IS). We examine how they can be implemented and an exemple using GATE (Geant 4 derived software) is given (Maigne et al. 2004). Hybridization of the techniques previously listed is currently a research direction.

In addition to the possibility offered by parallel streams of random numbers, we recently showed that massive unrolling optimizations could now be efficiently applied to pseudo-random number generation on regular desktop computers (Hill 2003). This approach does not depend on the generation algorithm but it only stems from the classical unrolling optimization. A memory mapping approach is also introduced to overcome the limits we had with regular unrolling. Both approaches will be presented and are portable on Unix derived platforms. The implementation of such techniques on clusters and on a computing grid is discussed. Every research field using quasi-Monte Carlo simulation can be concerned by this kind of software optimization techniques.

SLIDES ?