Geant4 and its applications: an overview

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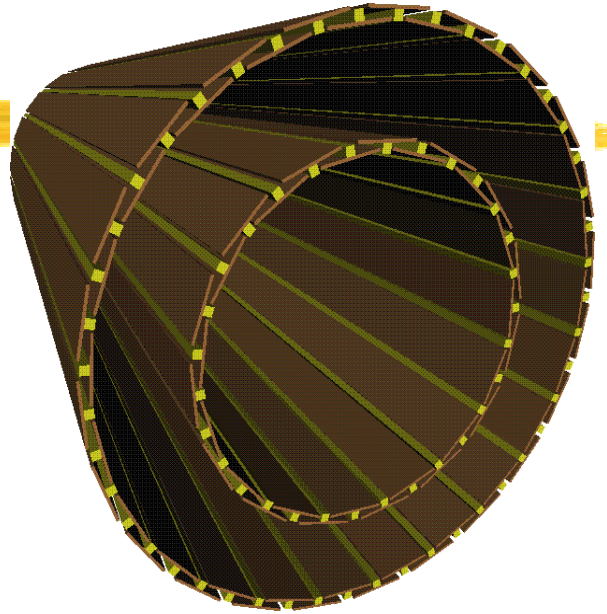
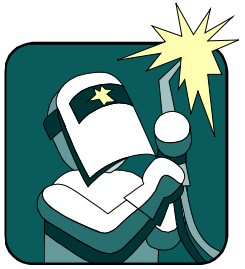


CMS silicon vertex detector: G4 model

What does GEANT do ?

Provides the means to use setup dependent code



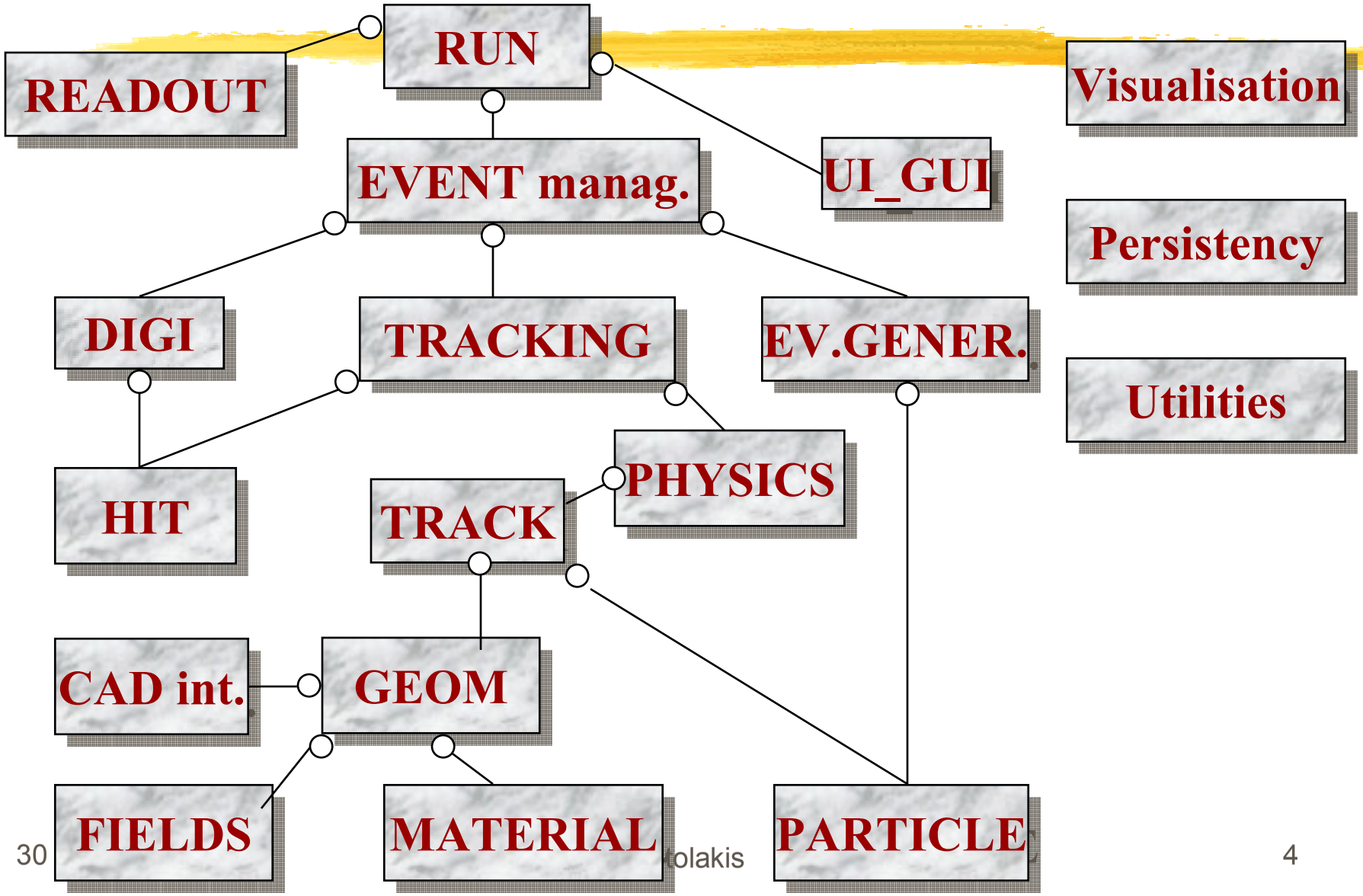
- geometry of the setup/experiment
- event generators (incoming particles)
- details of sensitive volumes for recording hits

in a setup-independent infrastructure

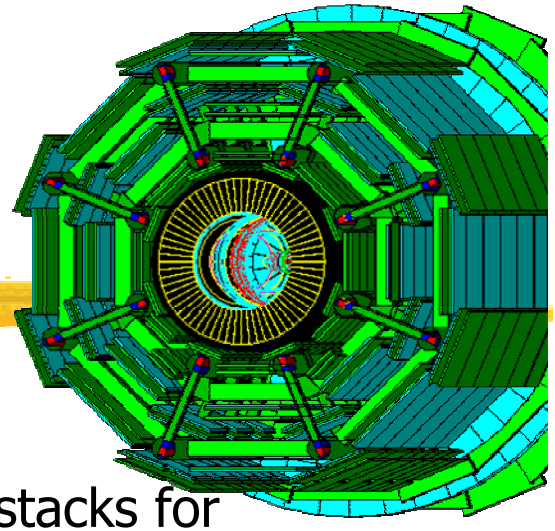
- tracking & geometrical primitives
- physics
- visualization, etc

to simulate the particle interactions in matter.

The Geant4 toolkit

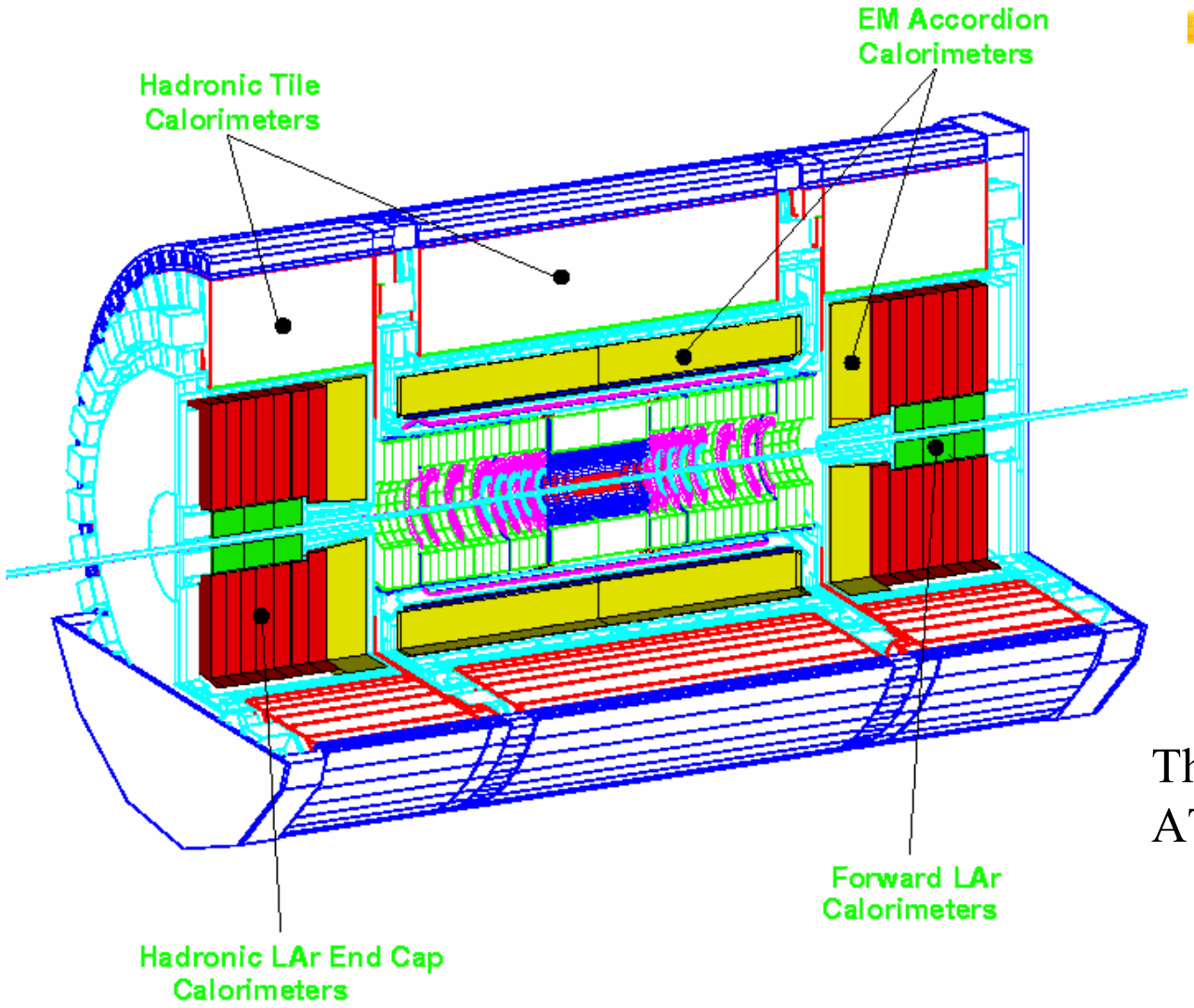


Geant4 kernel



- Tracking is general
  - Particles experience physical processes
  - sensitive detectors 'hit'
- Materials
  - From isotopes to mixtures
  - User creates as needed
- Particles
  - Properties
  - e^-, e^+, γ, proton, neutron, π, μ, ..
- Events
  - provides stacks for prioritising particles
- Run
  - a run has a fixed geometry & event-generator
- Geometry
  - Solids: CSGs, Boolean, ..
  - Voxelisation for speedy navigation
  - Motion in EM field

1. The ATLAS calorimeters



Thanks to ATLAS

Geant4 physics

- Electromagnetic physics
  - 'Standard', performant
  - Low-energy for below 1 KeV, atomic relax.
- Optical processes
- Hadronic physics
  - Neutrons, protons
  - Pions, ….
- Options
  - For different precision
  - Per use case
- Modeling approaches
  - Data-driven
  - Parameterised
  - Theoretical

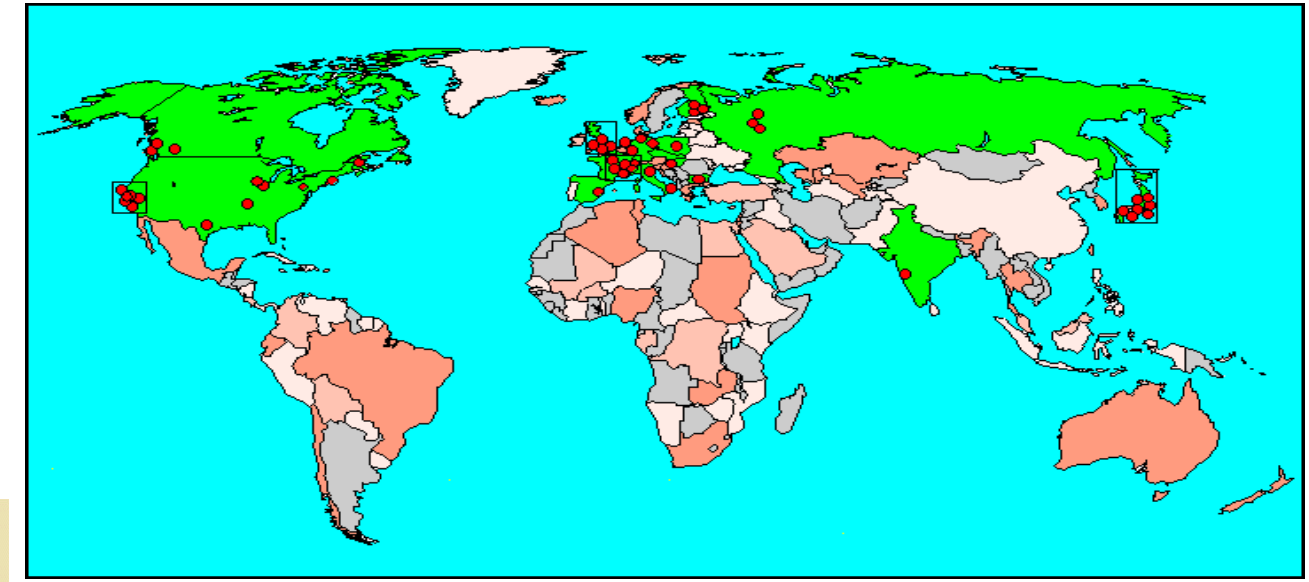
Electro-Magnetic physics

- Gammas:
  - Gamma-conversion, Compton scattering, Photo-electric effect
- Leptons(e, mu) + charged particles(hadrons, ions):
  - Ionisation, Bremstrahlung, Energy loss, Multiple scattering, transition radiation, Synchrotron radiation, PAI model energy loss
- Photons:
  - Cerenkov, Rayleigh, Reflection, Refraction, Absorption, Scintillation
- Implementation of further physics in low-energy
  - down to 250 eV
  - Including atomic relaxation
- High energy muons and lepton-hadron interactions

Hadronic physics processes

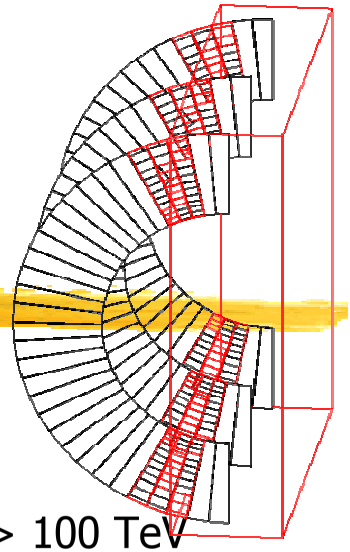
- Inelastic and coherent elastic scattering
- Capture of neutral, strongly interacting particles by nuclei, and neutron-induced fission
- Neutron transport
  - down to thermal energies
  - using customised choice from standard data libraries.
- Processes at rest for long-living, stopping particles
- New parameterisations:
  - *total cross-section p/n-N (0/14MeV to 20GeV),*
  - *differential cross-section p-p (0.1MeV to 3GeV)*
- High Energy extensions
  - using techniques from heavy ion generators, and
  - cascade & pre-equilibrium & evaporation

Geant4 Collaboration



Collaborators also from non-member institutions, including
Budker Inst. of Physics
IHEP Protvino
MEPHI Moscow
Pittsburg University

Some Geant4 strengths

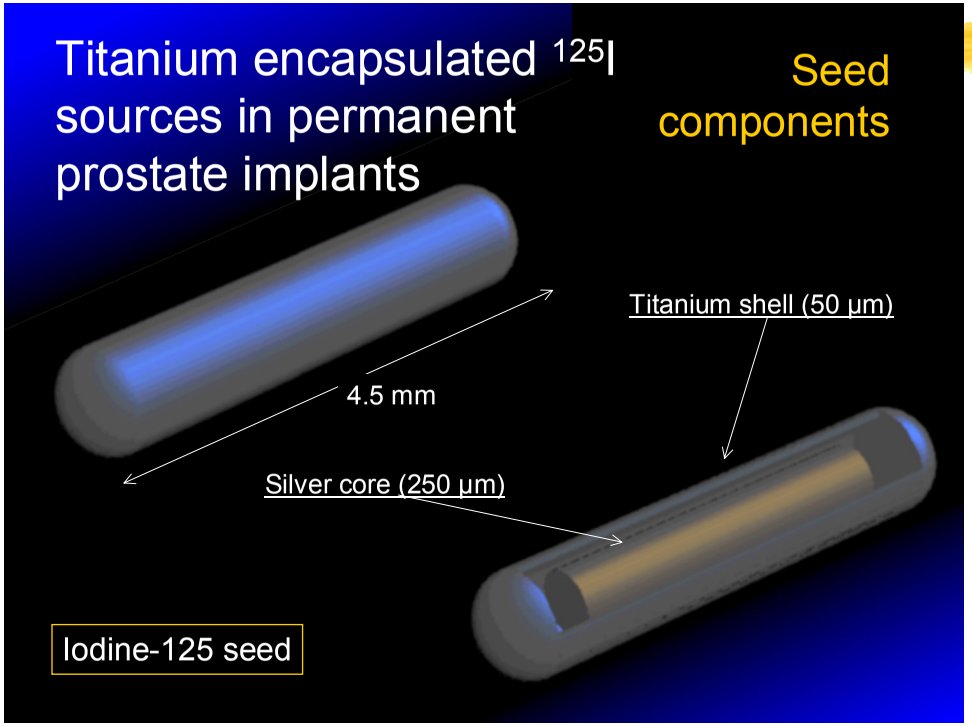


- Geometry
  - Able to handle complex setups
  - Performant
  - Can be used with changing geometry
- Engineering approach
  - Software Engineering and OO technology
  - OO Design
  - C++ Implementation
- Flexibility
  - Toolkit: use what is needed
  - Precision as required
- Physics
  - Extensive Range
    - Eg EM: 250eV to > 100 TeV
  - Diverse approaches can be utilised
    - Eg theor., data, param mod
- Adaptability
  - Choice of physics for use case
  - Trade off precision for CPU performance
  - Open to user refinements, new processes, ..

Application areas

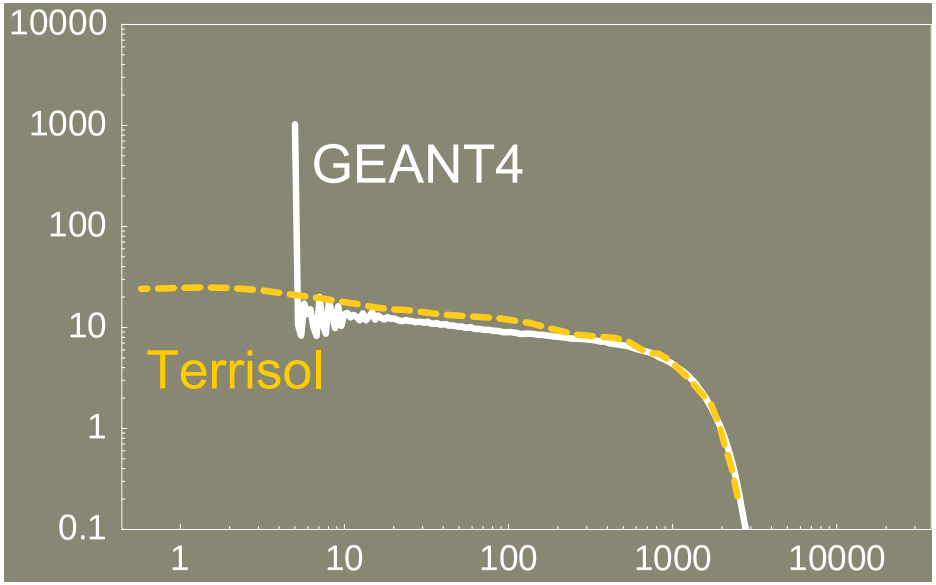
- HEP
  - Detector simulation
    - BaBaR, CMS, Atlas, LHCb ..
  - Low-background experiments
    - Underground radiation env.
- Space
  - Satellite shielding studies
  - Detector risk assessment (XMM)
  - Gamma ray 'telescope' GLAST
  - Single event upsets, ..
- Medical
  - Brachytherapy
  - Medical accelerators
    - Treatment head optimisation
  - Comparison with treatment planning systems
- Other / future
  - Aircraft radiation env.

First brachytherapy application



Exploiting X-ray fluorescence to lower the energy spectrum of photons (and electrons) and enhance the RBE

10 keV electron in water



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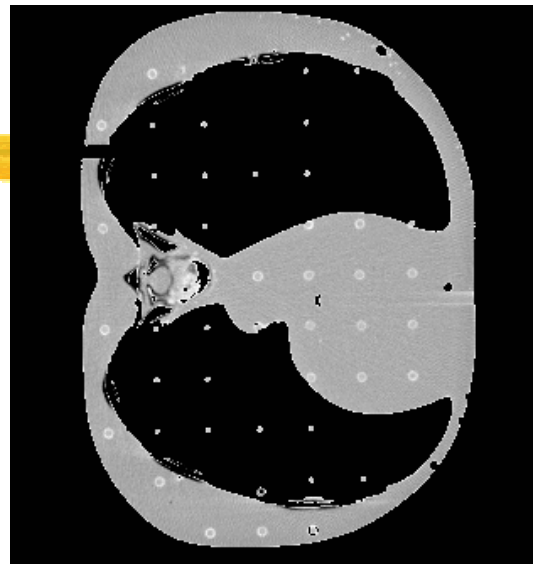
Comparison with commercial treatment planning systems

M. C. Lopes [1], L. Peralta [2], P. Rodrigues [2], A. Trindade [2]
[1] IPOFG-CROC Coimbra Oncological Regional Center - [2] LIP - Lisbon

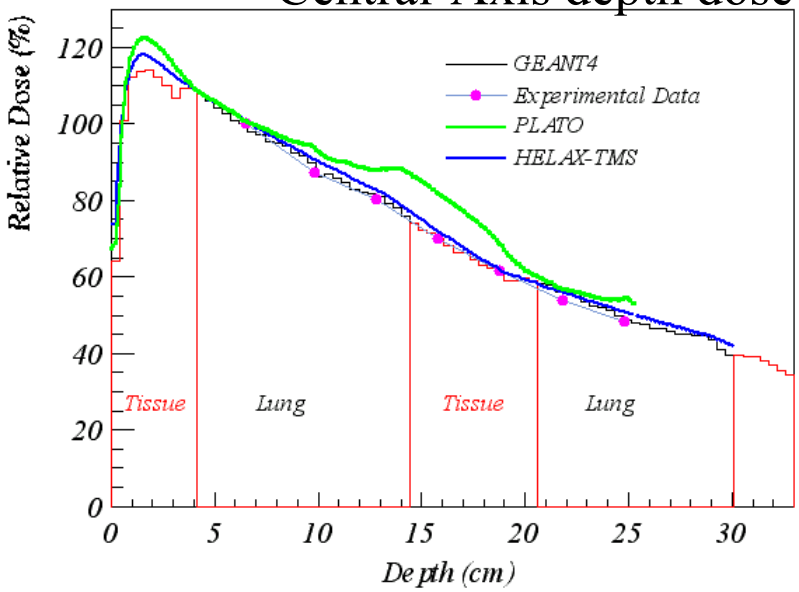


CT-simulation with a Rando phantom
Experimental data obtained with TLD LiF dosimeter

CT images used to define the geometry:

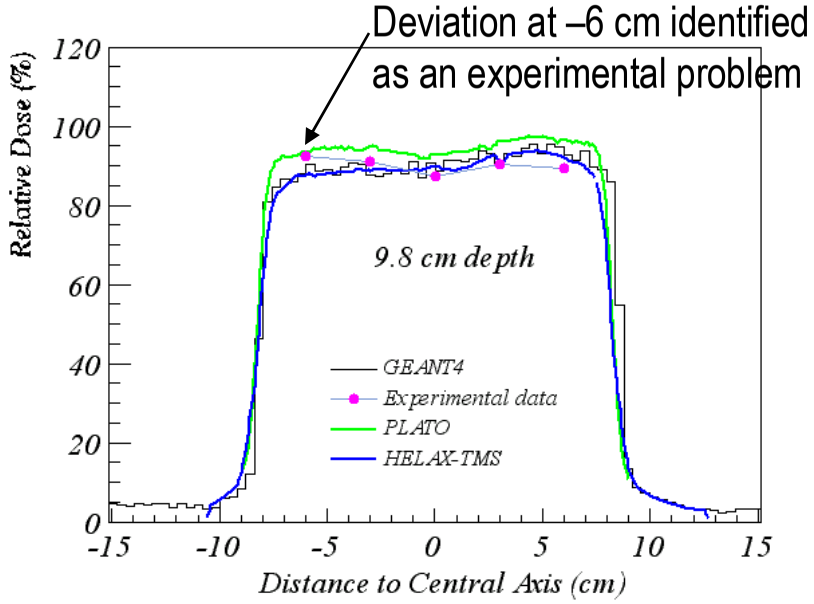
a thorax slice from a Rando anthropomorphic phantom

Central-Axis depth dose

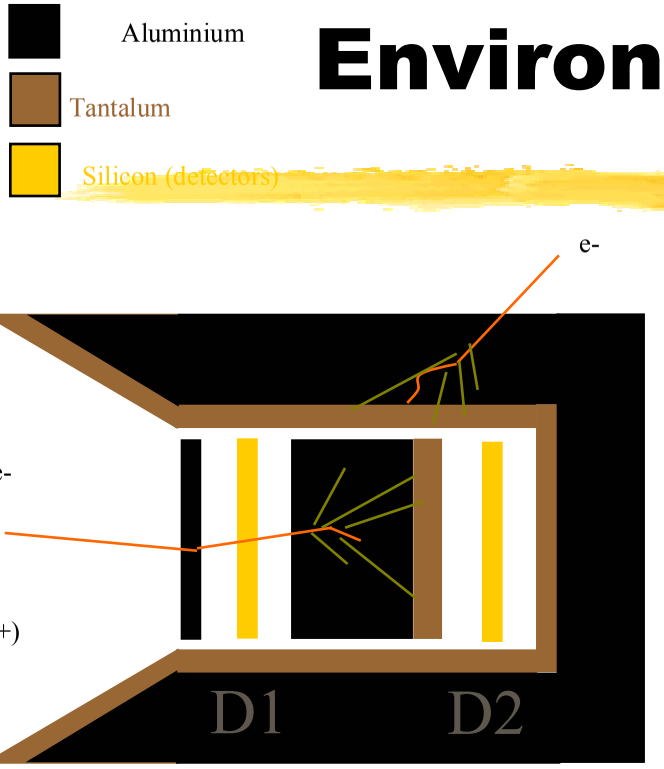


Profile curves at 9.8 cm depth

PLATO overestimate the dose at ~ 5% level



Standard Radiation Environment Monitor (SREM)



Trade-off:

- Performance
- Cost
- Mass
- Volume

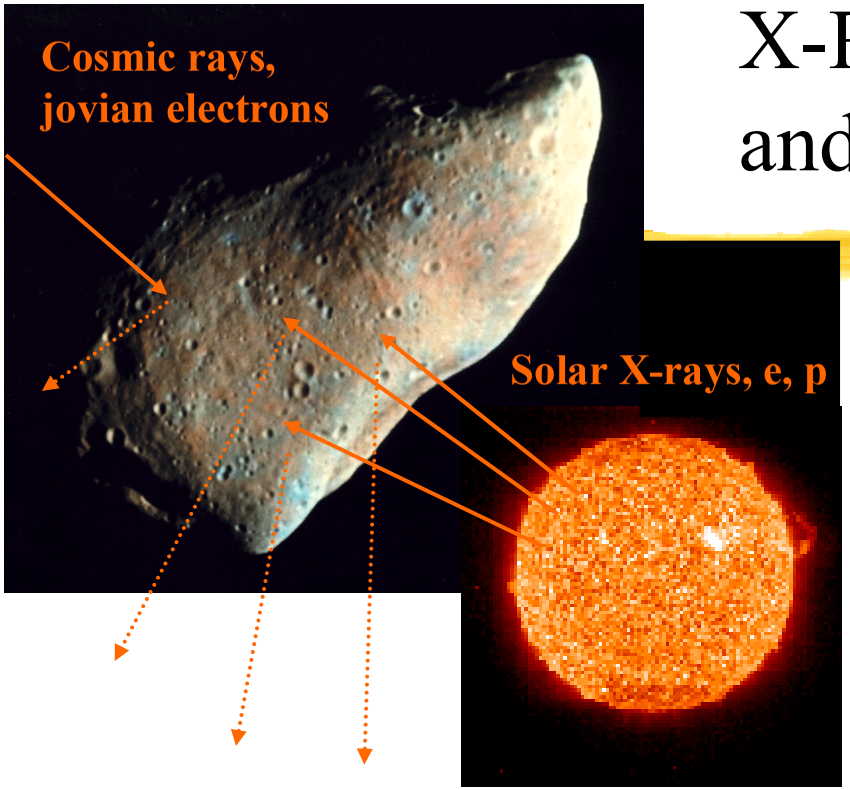
Optimised Al-Ta "Sandwich structure".

Simulation outcome: modularity (D3)

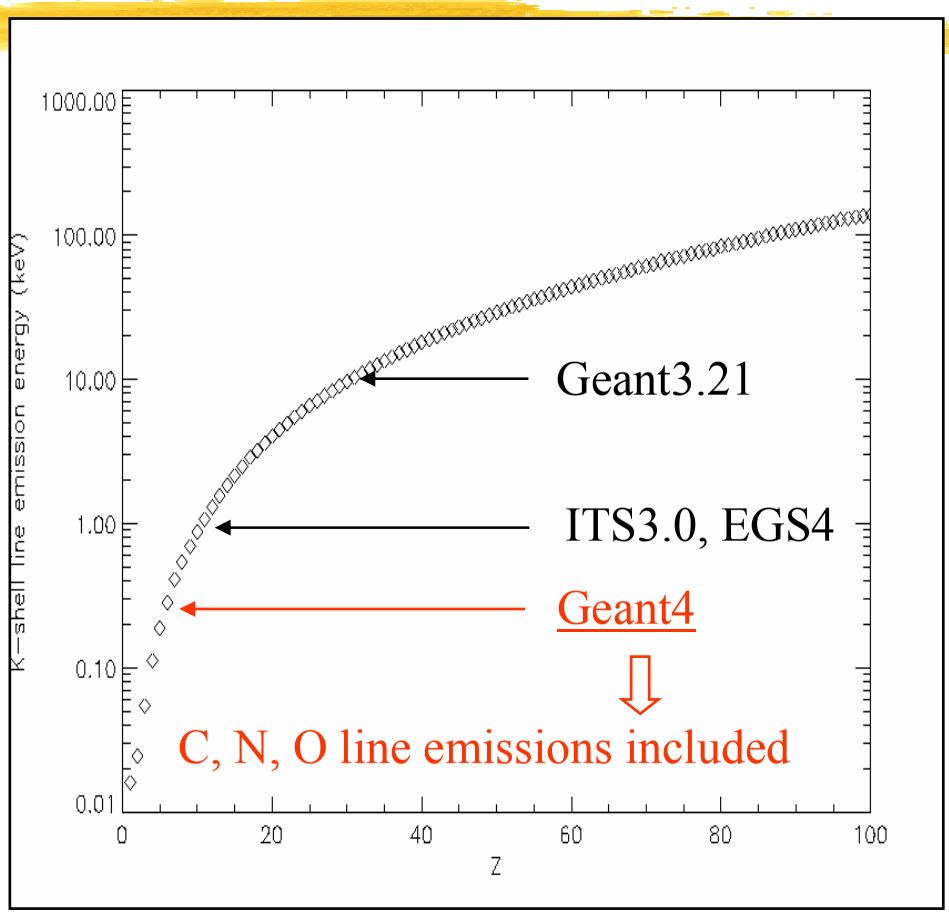
Geant4: CAD-tool interface

- Electrons > 0.5 MeV
- Protons > 10 MeV
- Heavy ions qualitatively

X-Ray Surveys of Asteroids and Moons



Courtesy SOHO EIT



Induced X-ray line emission: indicator of target composition (~100 μm surface layer)

The CERN 'Geant4 team'

- Geometry
  - Setup description
  - Navigation
  - EM field 'propagation'
- Physics
  - Hadronics
    - Neutrons, protons, ..
  - EM ('standard')
    - Down to 1 KeV
    - Processes for precision (tracking) detectors
- Integration testing
- Software management
  - QA work, porting, PRS, ..
- Interaction with Root, PI, SEAL, SPI, …
- Visitors
  - EM (std & low E), hadronics
  - Kernel, …

Geant4 Capabilities

- Powerful Geant4 kernel
  - tracking, stacks, geometry, hits, ..
- Extensive & transparent physics models
  - electromagnetic, hadronic, ...
- Visualization, GUI, ...
- Extensive and growing set of application areas