Introduction to Geant4

Geant = « GEomety And Tracking »

Geant4 PHENIICS & IN2P3 Tutorial,

16 – 20 May 2022,

Orsay

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Credits

- Material in this presentation is from many sources
- And in particular from Makoto Asai presentations

Layout

- **Geant4 Overview**
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- **Geant4 Application Domains**
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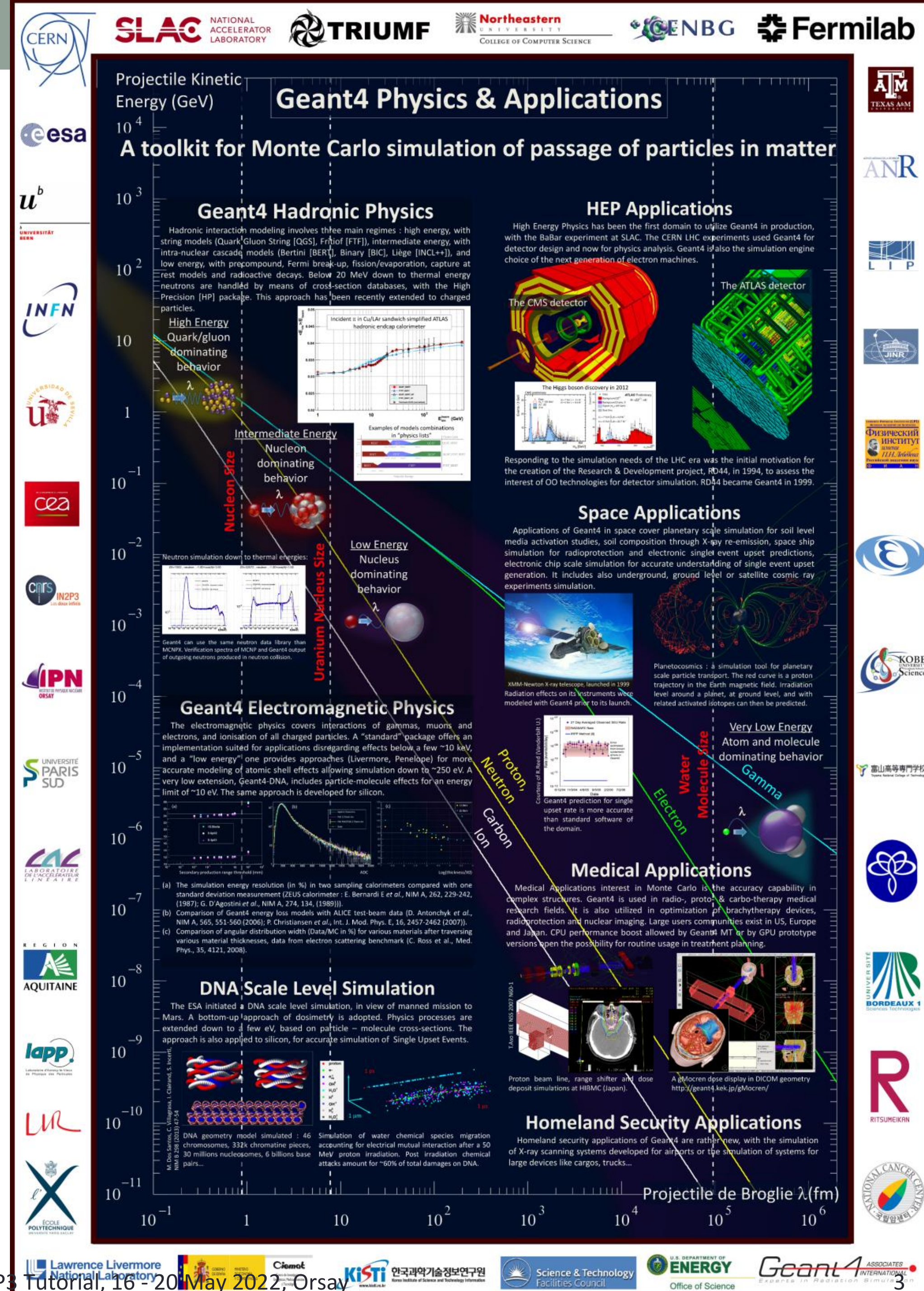
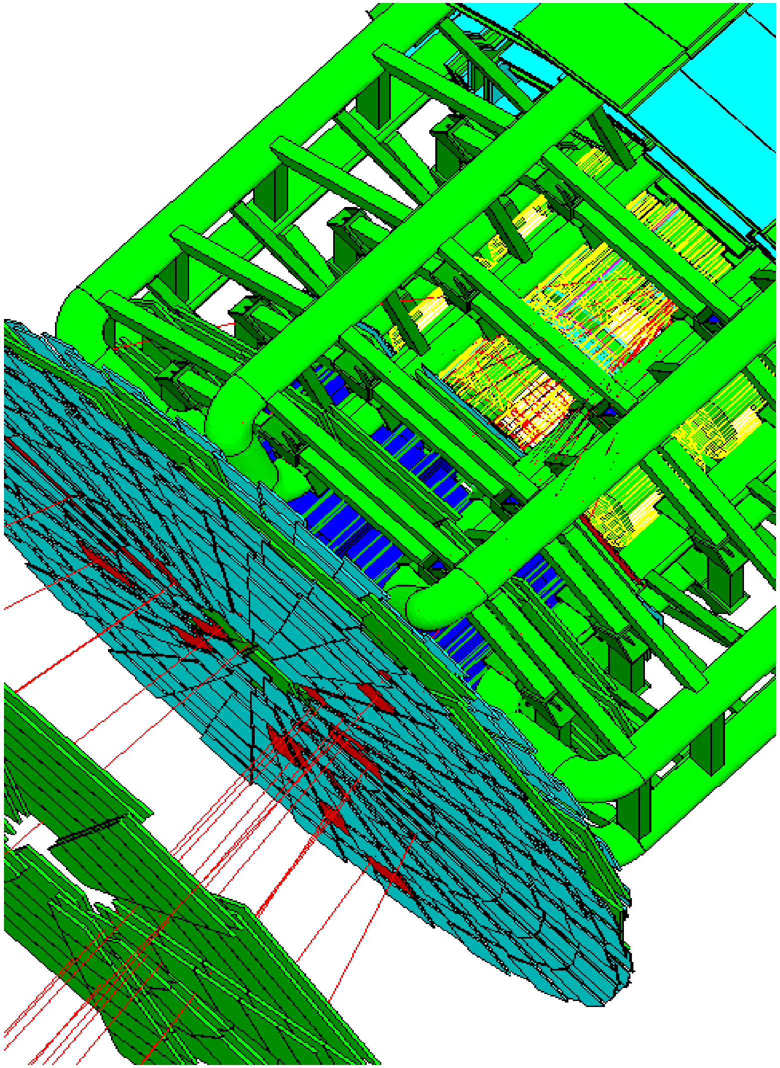
  - Geant4 in Space
  - Geant4 in Medical Science
  - Geant4 in Homeland Security
  - Geant4 in Other fields
- **Geant4 Toolkit Philosophy**



Geant4 Overview

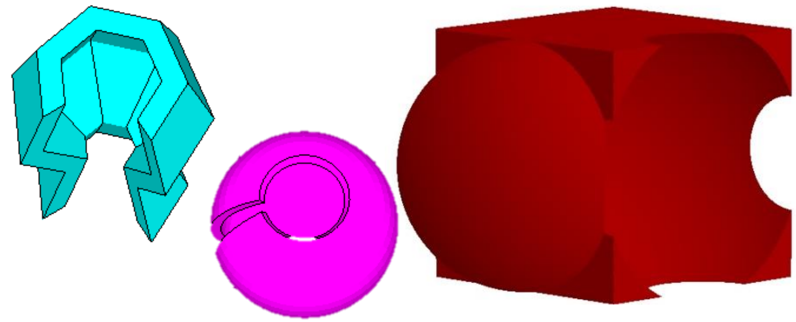
Geant4 & its key functionalities

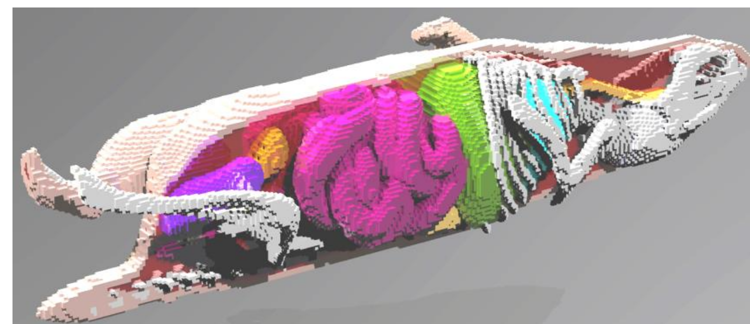
- General purpose Monte Carlo toolkit for simulating the passage of elementary particles through and interacting with matter.
- Wide variety of user domains
  - high energy and nuclear physics,
  - space engineering
  - medical applications
  - material science
  - radiation protection and security.
- Geant4 offers lots of the functionalities required for the simulation of elementary particle and nucleus passing through and interacting with matter.
  - Kernel
  - Geometry and navigation
  - Physics processes
  - Scoring
  - GUI and Visualization drivers
- Users can easily plug-in their extensions without interfering with the other parts of Geant4.
- Extensive user guide documents and examples are provided.

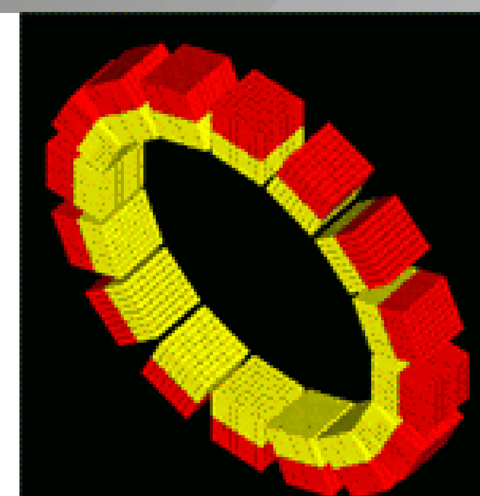


Key geometry capabilities

- Richest collection of shapes
  - CSG (Constructed Solid Geometry), Boolean operation, Tessellated solid, etc.
  - The user can easily extend
- Geometry structure described as hierarchy of volumes (or as 'flat' in some cases)
  - Describing setups up to billions of volumes
  - Tools for creating & checking complex structures
  - Some interface to CAD
- Navigating fast in complex geometry
  - Automatic optimization performed
  - Based on a virtual 3D grid with limited #volumes per grid cell & fast logic for finding adjacent cells
- Geometry models can be 'dynamic'
  - Changing the setup at run-time
    - e.g. "moving objects"

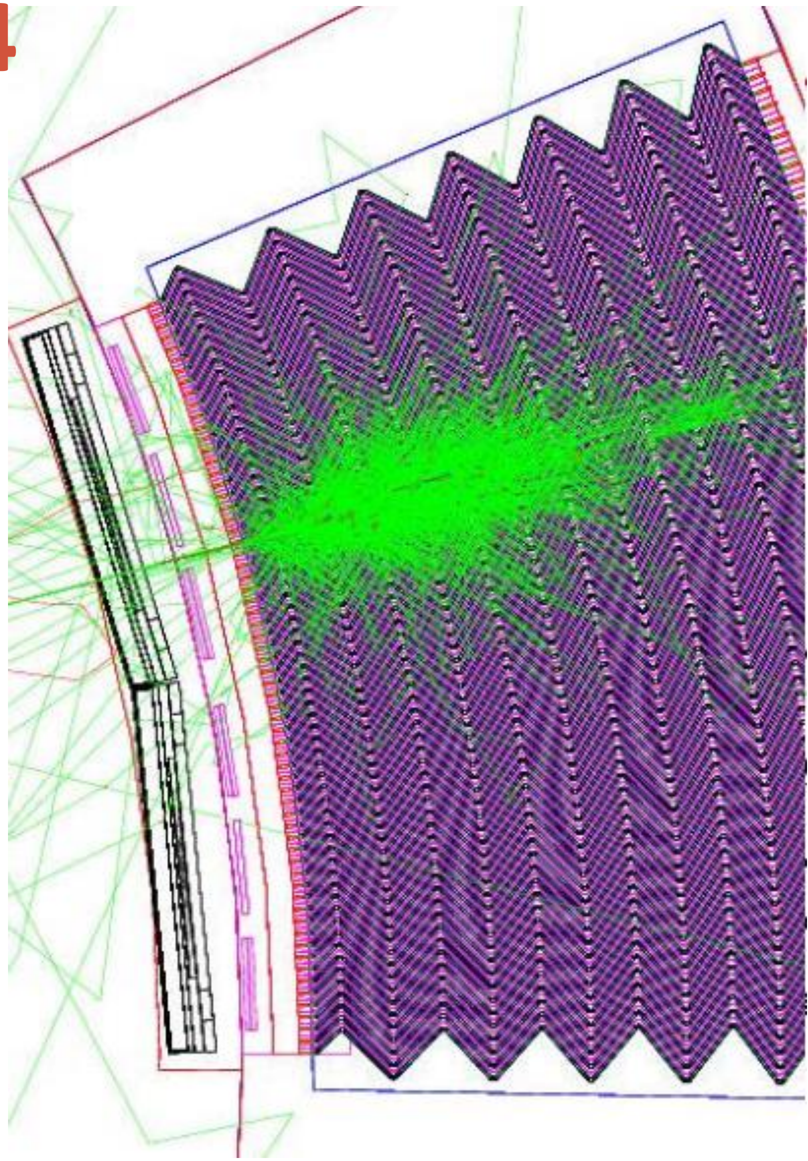


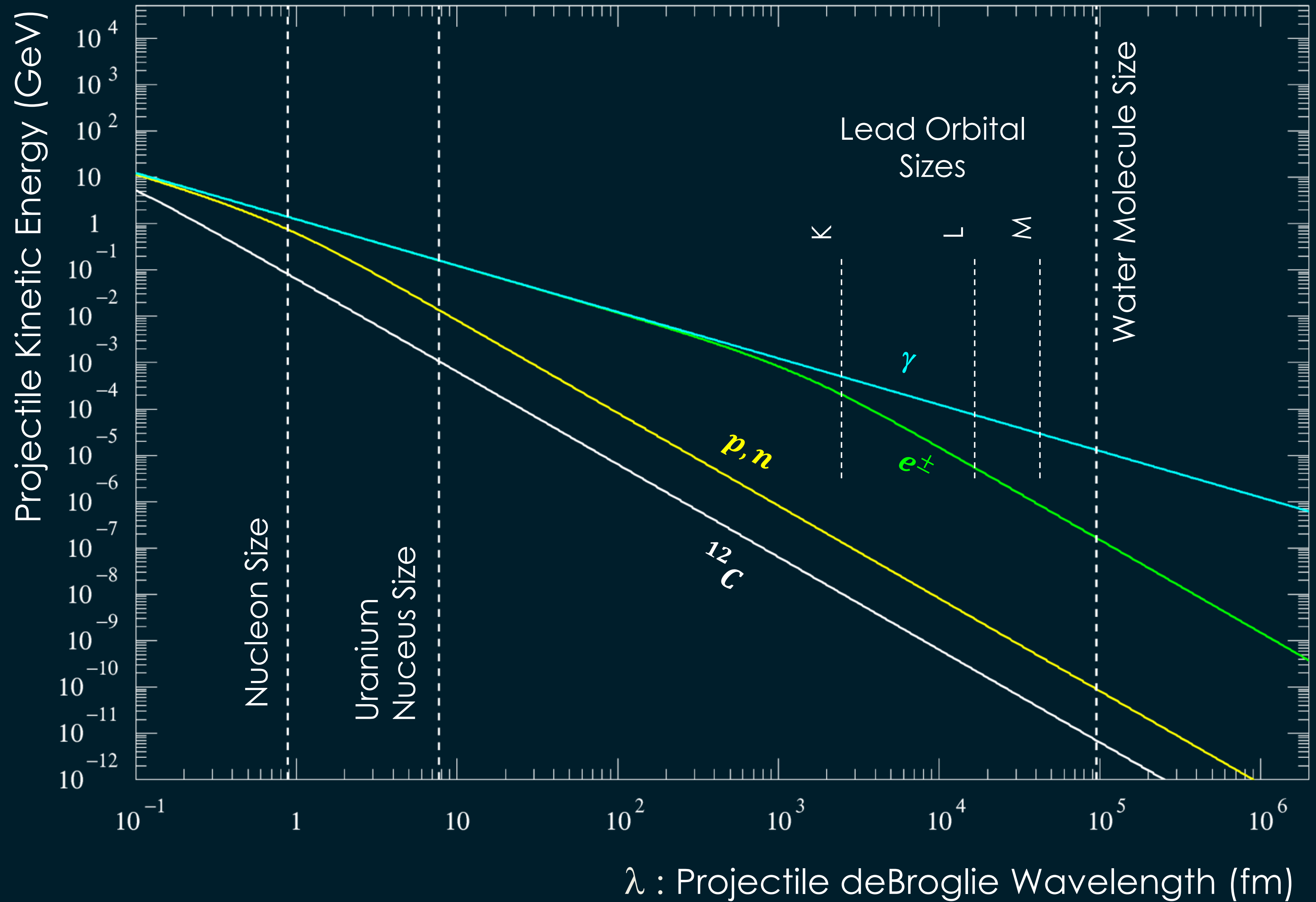


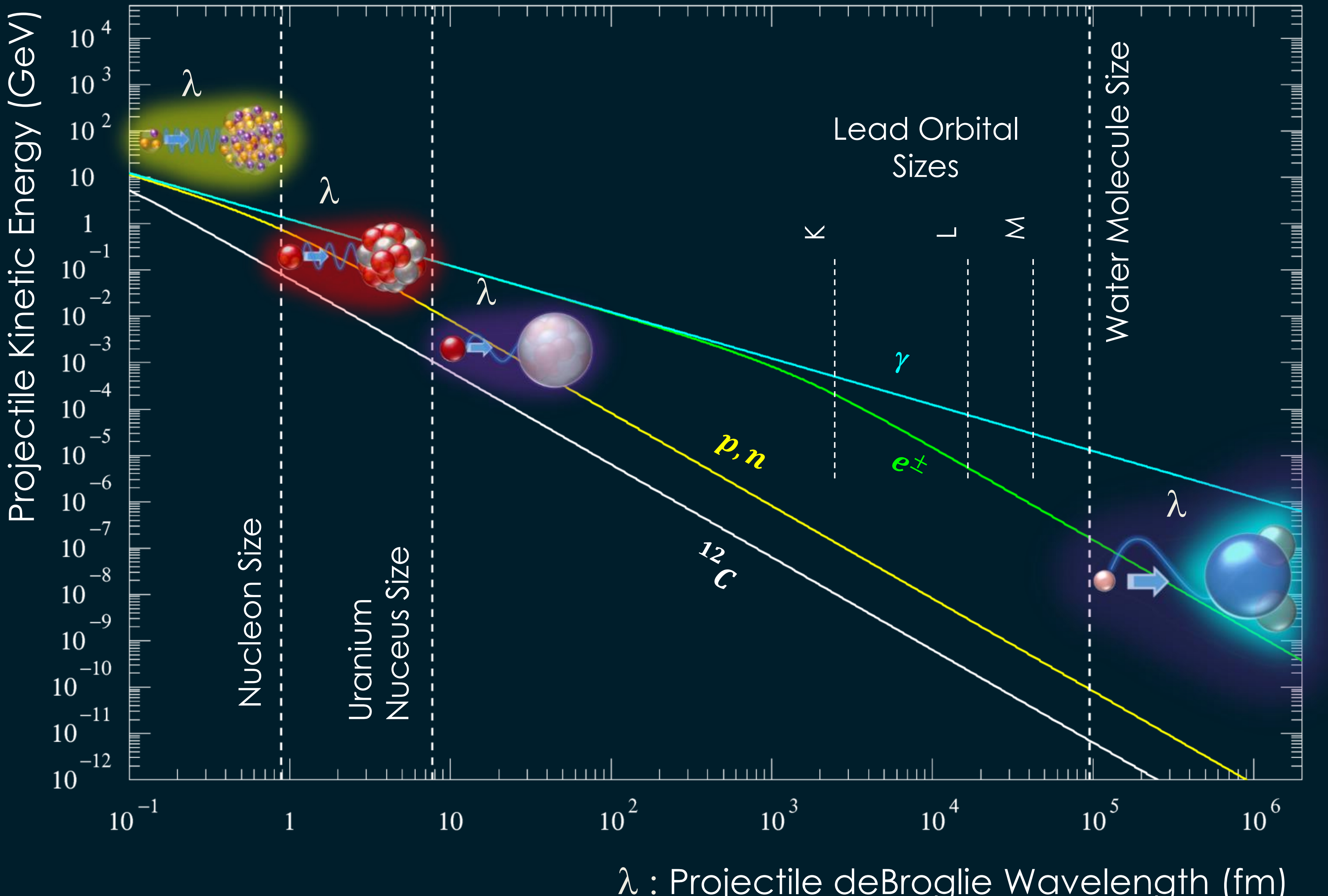


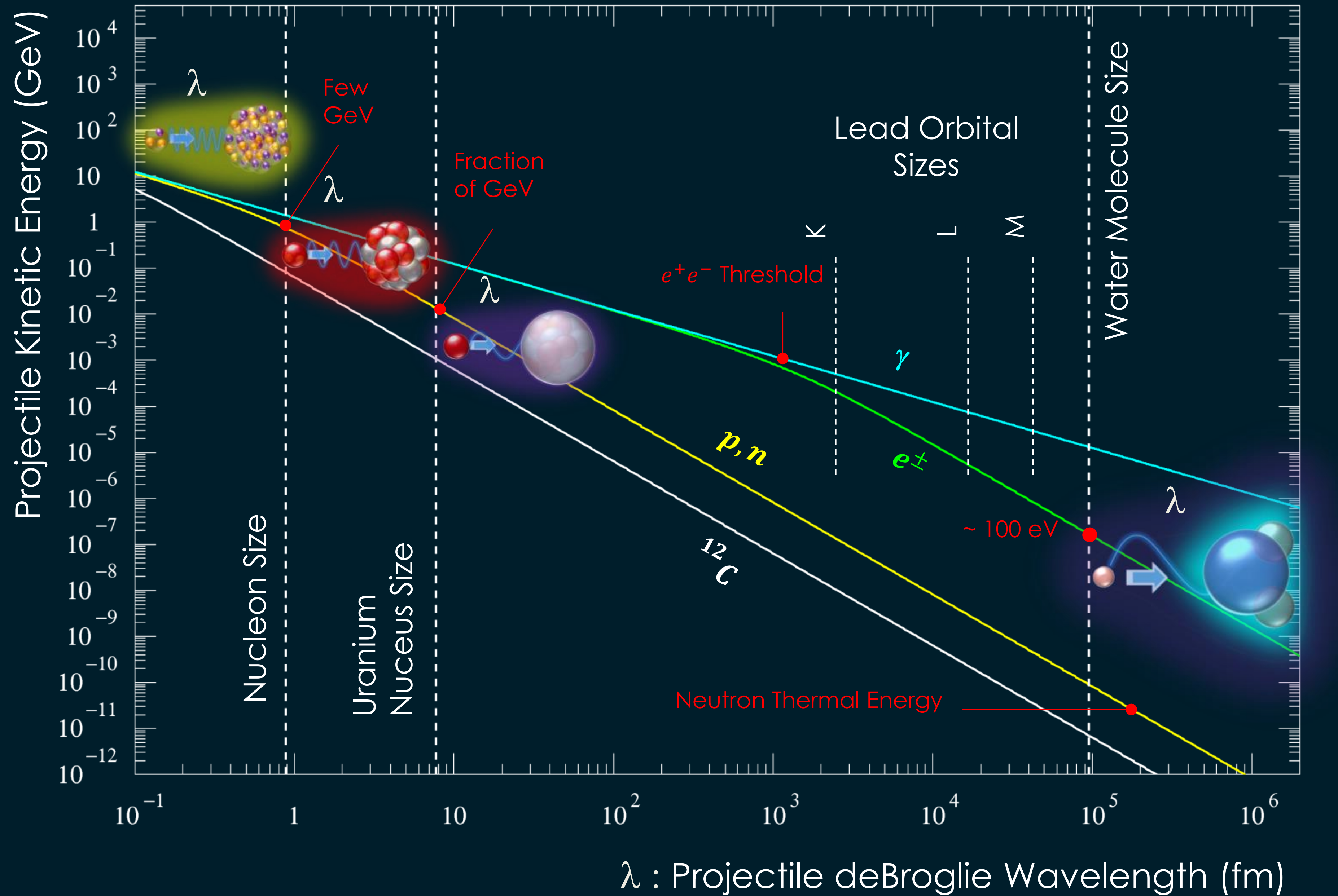
Physics models in Geant4

- Geant4 offers
  - Electromagnetic processes
  - Hadronic and nuclear processes
  - Photon/lepton-hadron processes
  - Optical photon processes
  - Decay processes
  - Shower parameterization
  - Event biasing techniques
  - And you can plug-in more
- Wide set of physics models provided
  - Complementary models with different energy range applicability
    - That can be combined to cover a wide range
  - Competing models with same energy range applicability
    - That can be selected by the user




Projectile Kinetic Energy (GeV)
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
Nucleon Size
Uranium
Nuceus Size
Lead Orbital
Sizes
K
L
M
Water Molecule Size
γ
e±
p, n
12C
10^-1
1
10
10^2
10^3
10^4
10^5
10^6
λ : Projectile deBroglie Wavelength (fm)


Projectile Kinetic Energy (GeV)
λ : Projectile deBroglie Wavelength (fm)
Nucleon Size
Uranium
Nuceus Size
Lead Orbital
Sizes
K
L
M
Water Molecule Size
γ
e±
p, n
12C
λ
λ
λ
λ


Projectile Kinetic Energy (GeV)
λ : Projectile deBroglie Wavelength (fm)
Few GeV
Fraction of GeV
Lead Orbital Sizes
K
L
M
Water Molecule Size
e+e− Threshold
γ
p, n
e±
12C
~ 100 eV
Neutron Thermal Energy
Nucleon Size
Uranium Nuceus Size
λ

Geant4 – Brief history

- **Dec 1994 - Project start**
  - RD44 project : assess OO benefit for detector simulation, to respond to complex needs of LHC and other fields.
- Apr 1997 - First alpha release
- Jul 1998 - First beta release
- **Dec 1998 - First Geant4 public release - version 1.0**
- …
- Several major evolutions: migration STL, "cuts per region", parallel worlds…
- …
- **Dec 6th 2013 : Geant4 version 10.0**
  - **First version with multi-threading -ie parallelism- support in production**
- …
- Dec 4th, 2020 - Geant4 version 10.7 release
  - …
  - 19th Nov 2021 – Geant4 10.6-patch03 release
- **Dec 10th 2021 : Geant4 version 11.0**
  - **Evolve from multi-threading to tasking**
  - **Mar 8th, 2022 - Geant4 11.0-patch01 release** ← Current version

- We currently provide one public release per year.
  - Announced on Collaboration Web pages and mailing list
    - **please subscribe** ! (☞ geant4 → user support → mailing list subscription)

GEANT4 collaboration

A SIMULATION TOOLKIT

https://geant4.web.cern.ch/

Geant4: a simulation toolkit
S. Agostinelli *et al.*
NIM A, vol. 506, no. 3, pp. 250-303, 2003

Geant4 Developments and Applications
J. Allison *et al.*
IEEE Trans. Nucl. Sci., vol. 53, no. 1, pp. 270-278, 2006

Recent Developments in Geant4
J. Allison *et al.*
NIM A, vol. 835, pp. 186-225, 2016

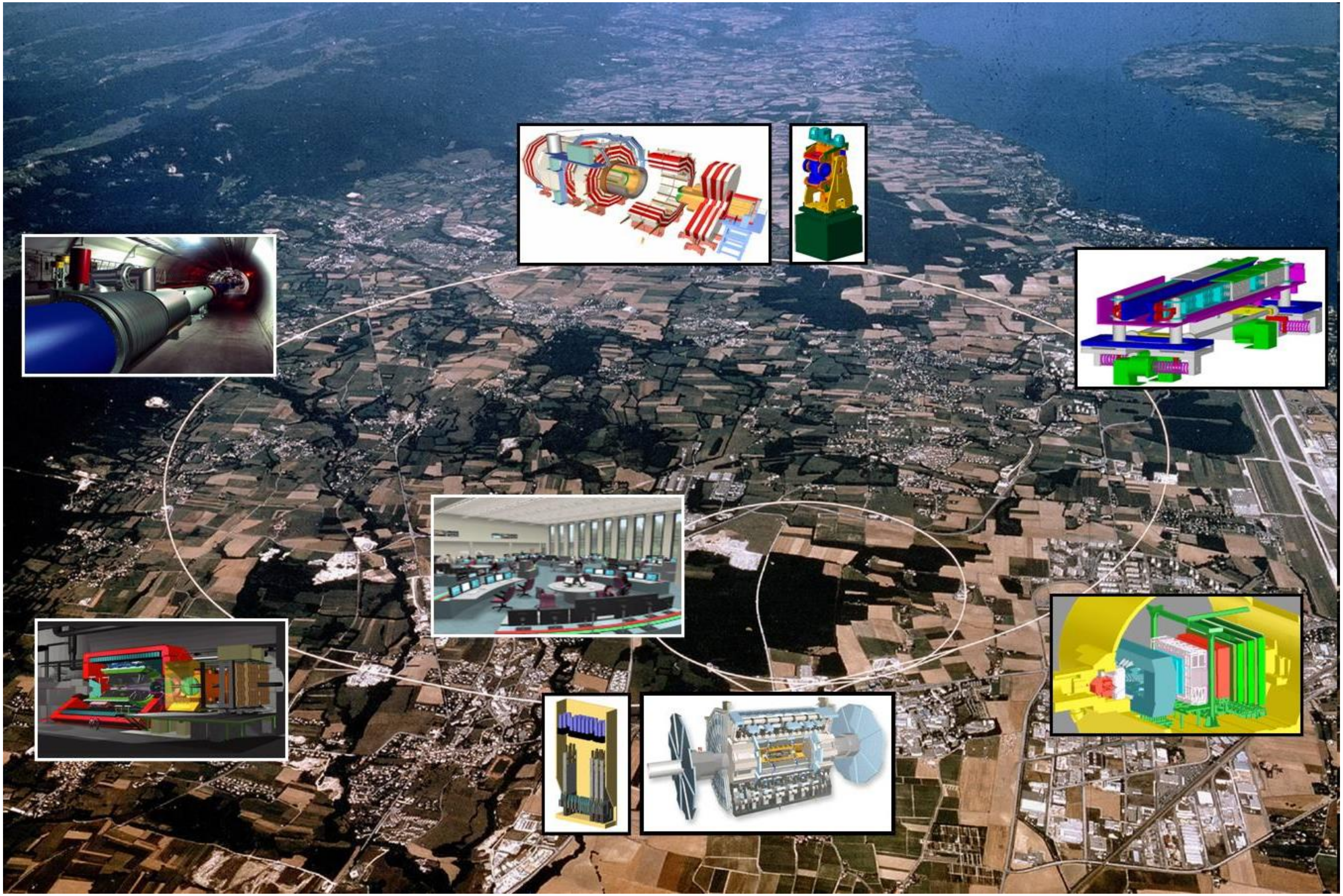
~130 members, ~30 FTE

- An international collaboration
  - >100 active members
  - 19 countries

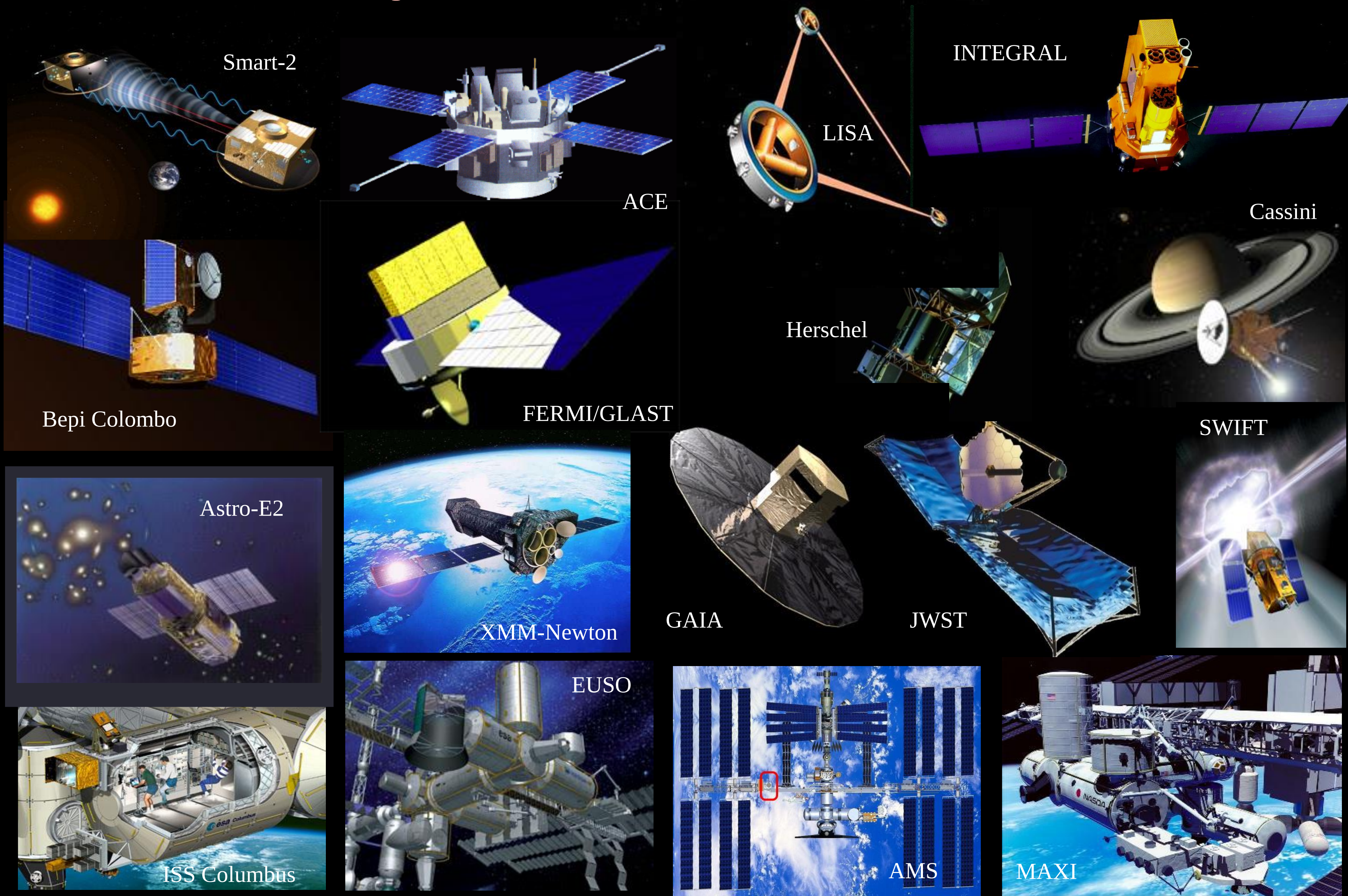
Geant4 application domains

not exhaustive

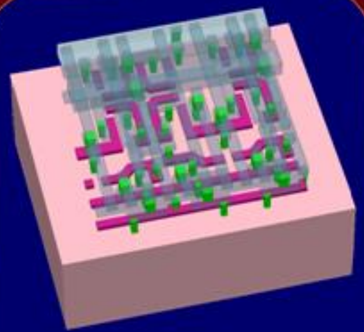
Large Hadron Collider (LHC) @ CERN



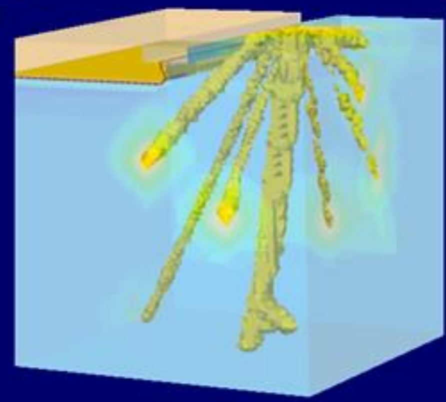
Geant4 in Space



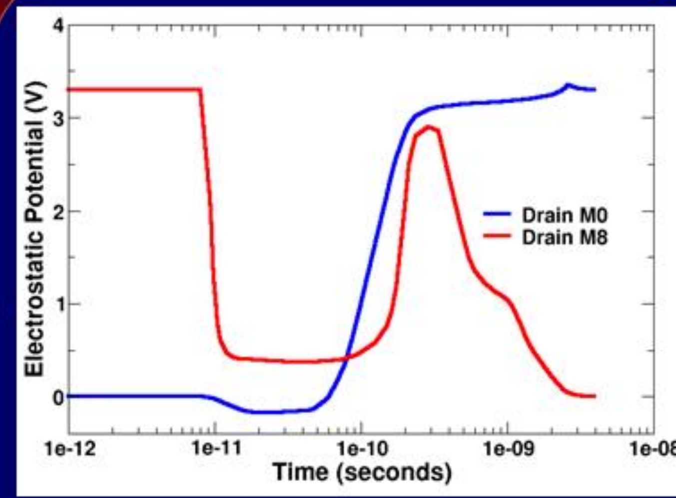
RADSAFE on SEE in SRAMs



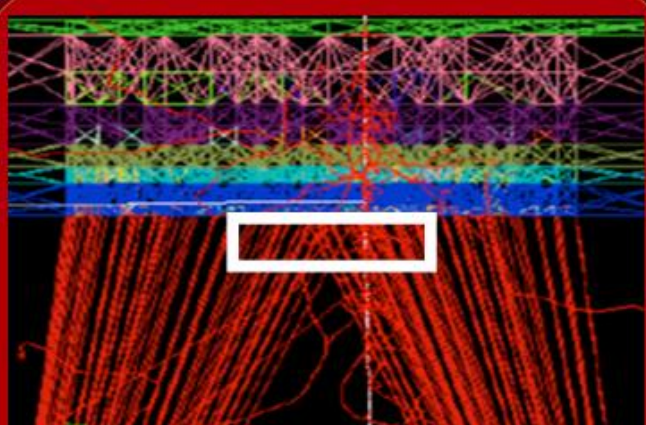
TCAD Cell Structure: SRAM Cell



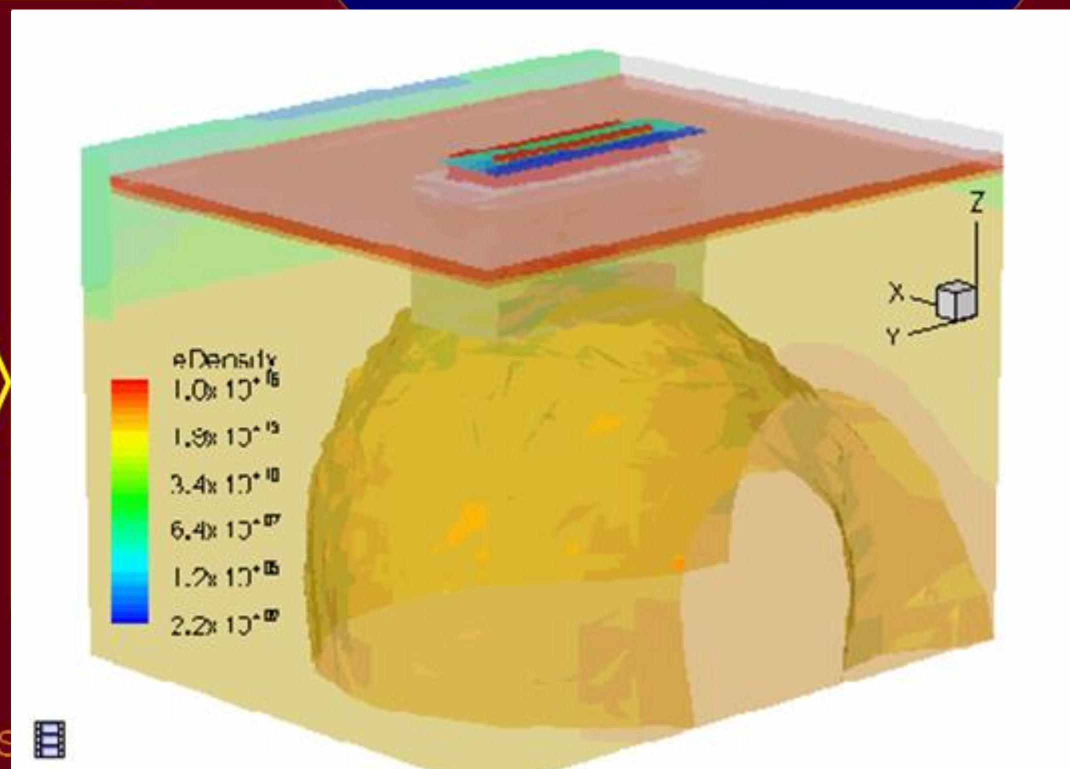
Single Charge Deposition in TCAD: Ne+W Event



SRAM Cell Upset

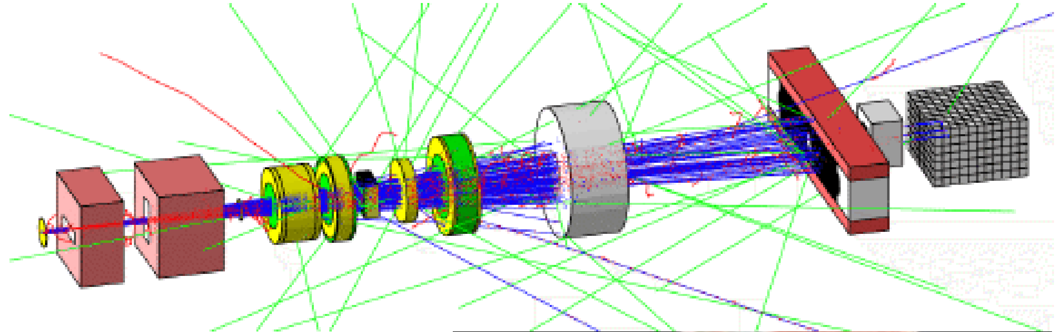


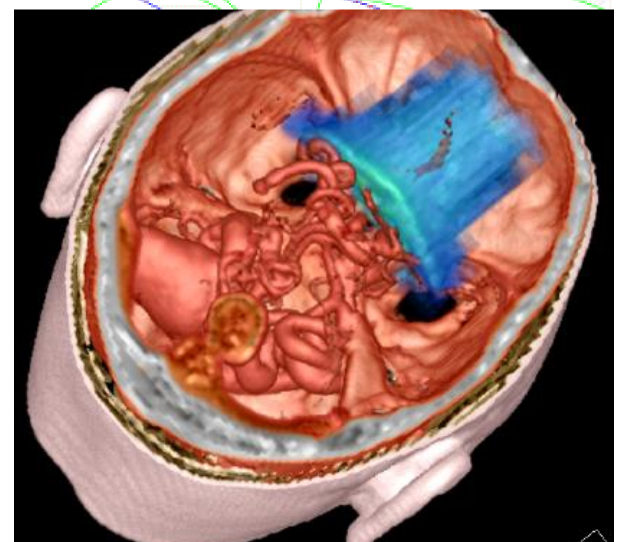
Geant4 Geometry and 523 MeV Neon Event

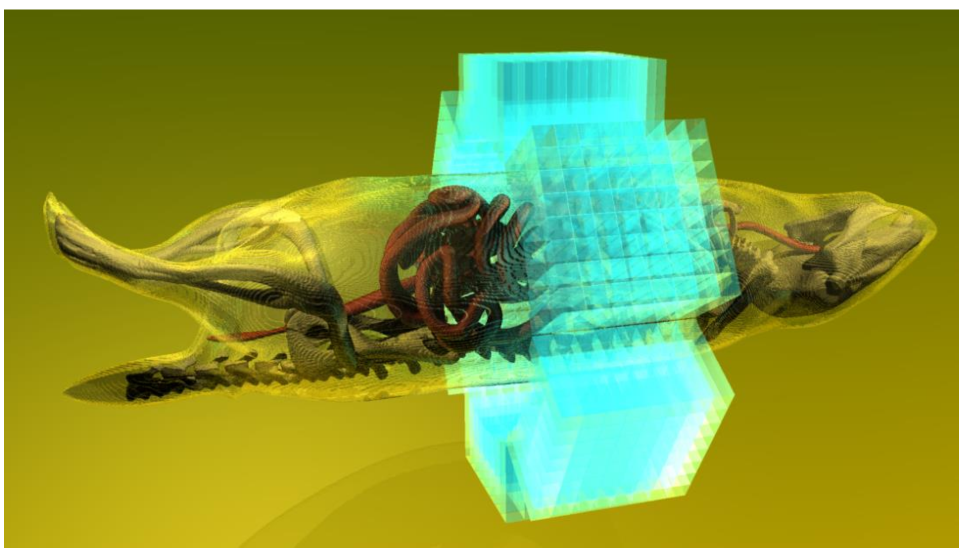


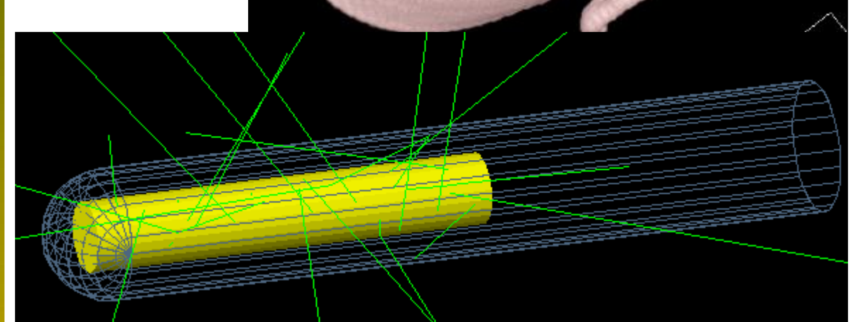
Geant4 in Medical Science

- Four major use cases
  - Beam therapy
  - Brachytherapy
  - Imaging
  - Irradiation study







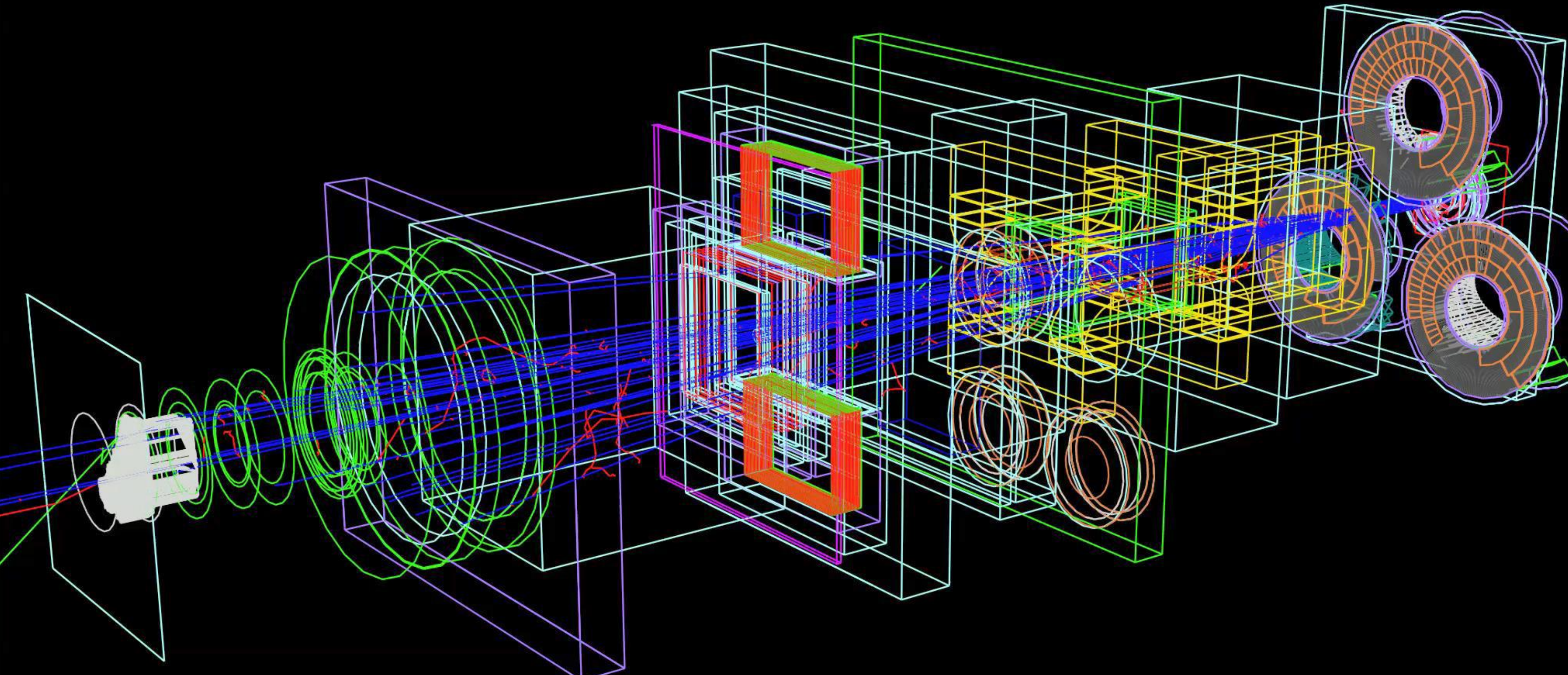


TOPAS

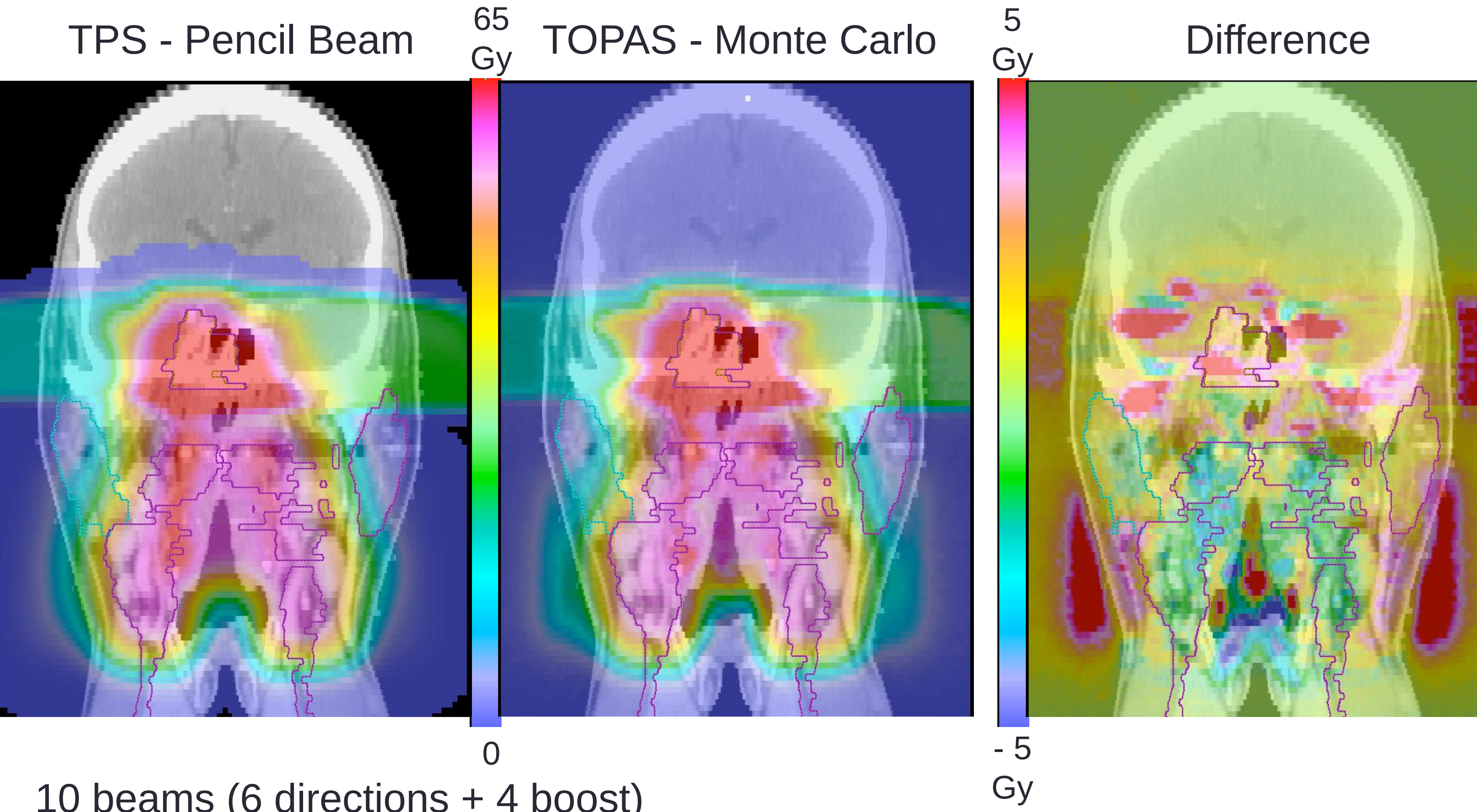
Tool for Particle Simulation

Joseph Perl - SLAC National Accelerator Laboratory
Bruce Faddegon, José Ramos - University of California San Francisco
Jungwook Shin – St Jude Children's Research Hospital
Harald Paganetti, Jan Schümann - Massachusetts General Hospital

Work supported by the U.S National Institutes of Health under contract numbers 1R01CA140735-01 & 2R01CA140735-05



Head and Neck Study - Dose

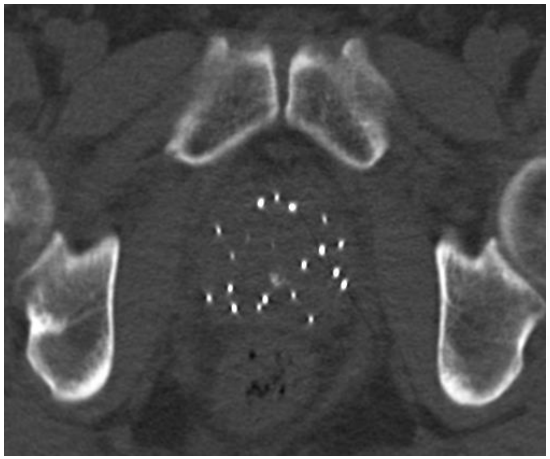


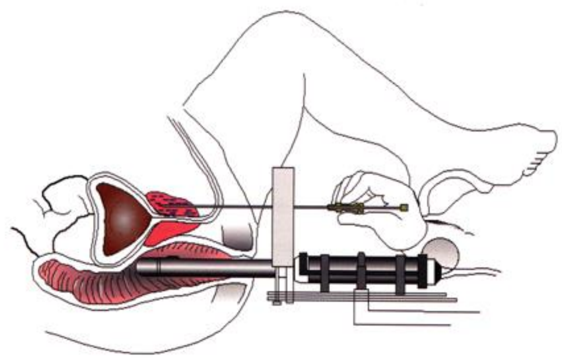
10 beams (6 directions + 4 boost)

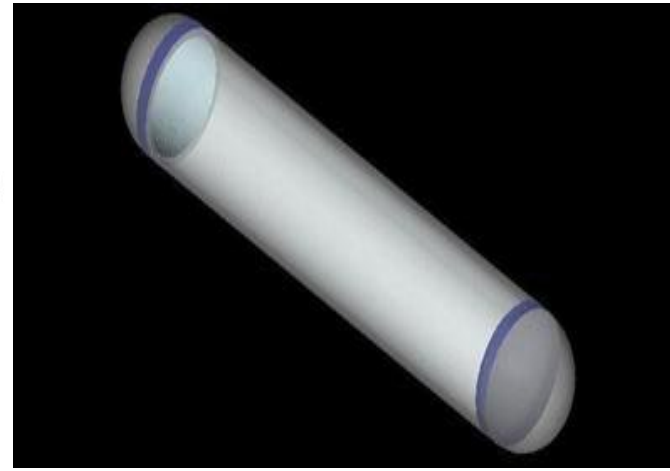
Prostate brachytherapy

Jean-François Carrier, CHUM

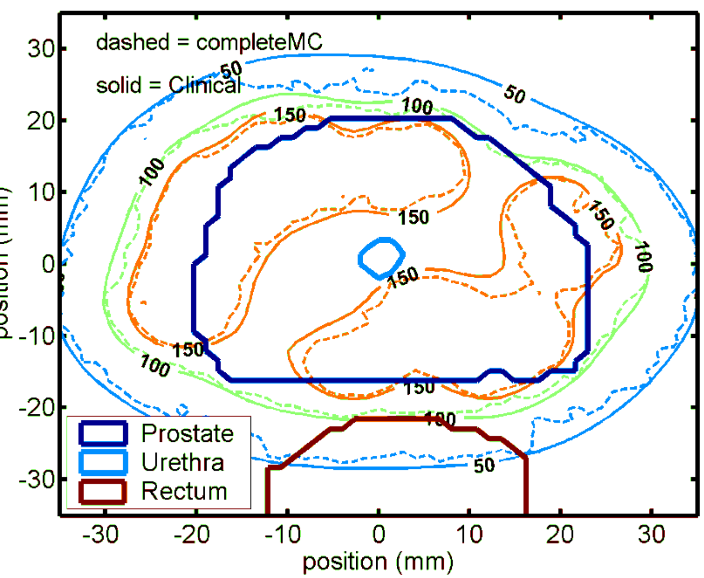
UNIVERSITÉ LAVAL

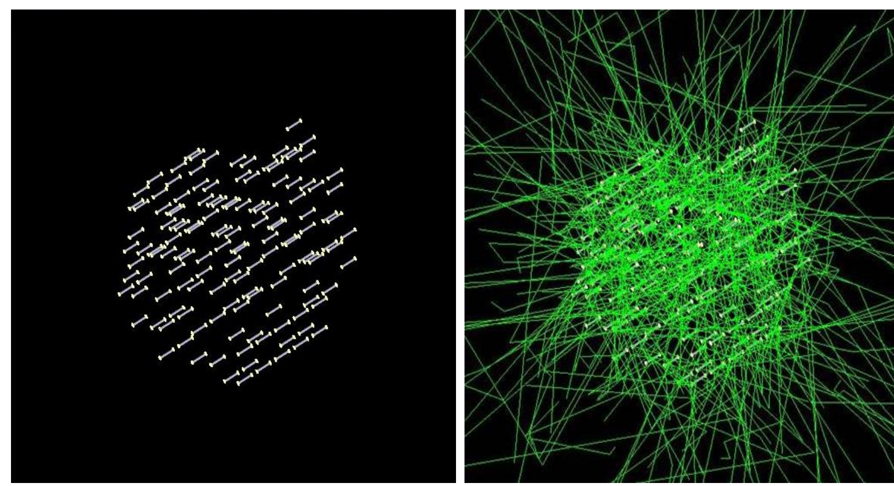




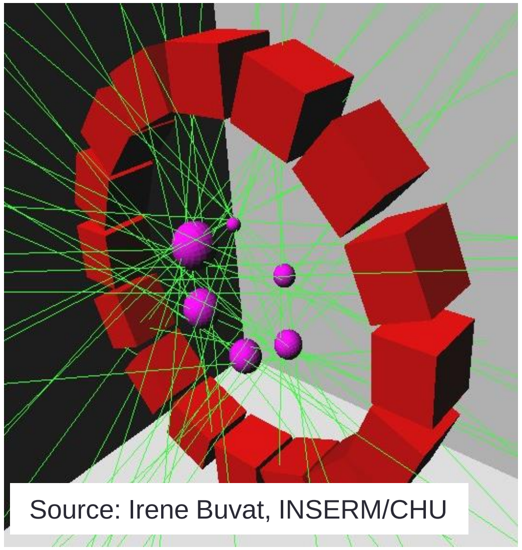


Carrier et al, IJROBP (68), 2007 pp.1190-1198

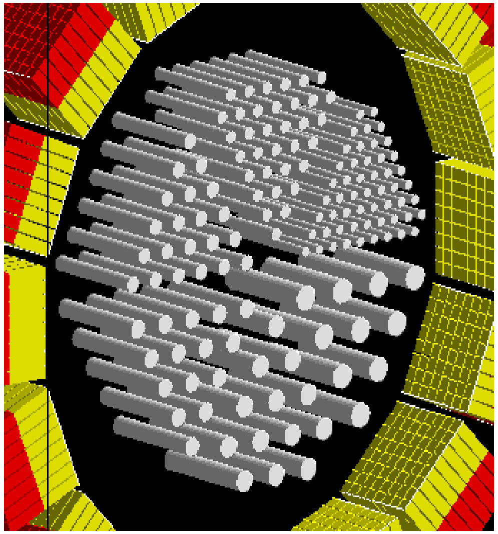


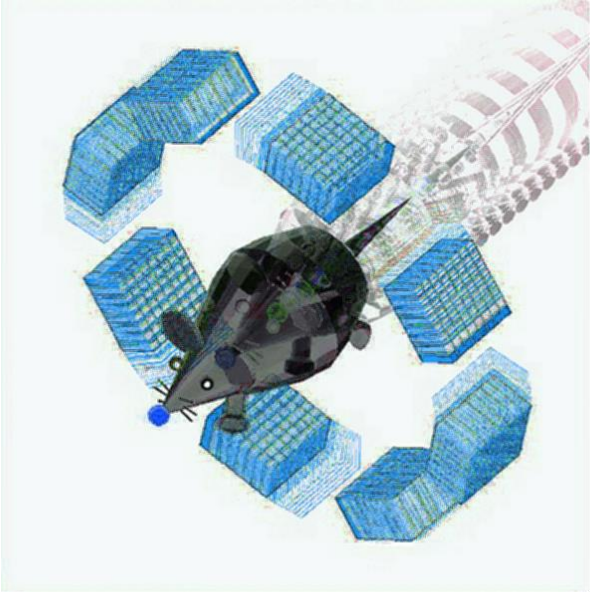


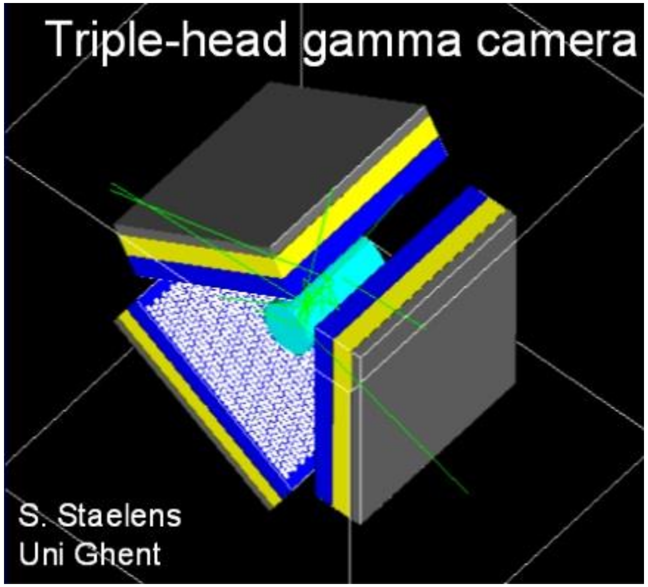
GATE: Geant4 Application for Tomography Emission

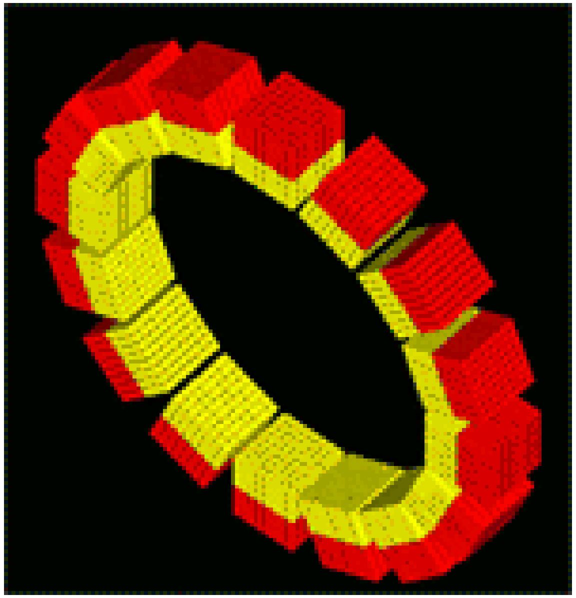


- Toolkit for Imaging applications
- based on the Geant4 toolkit
- easier to use for Imaging applications
- http://www.opengatecollaboration.org

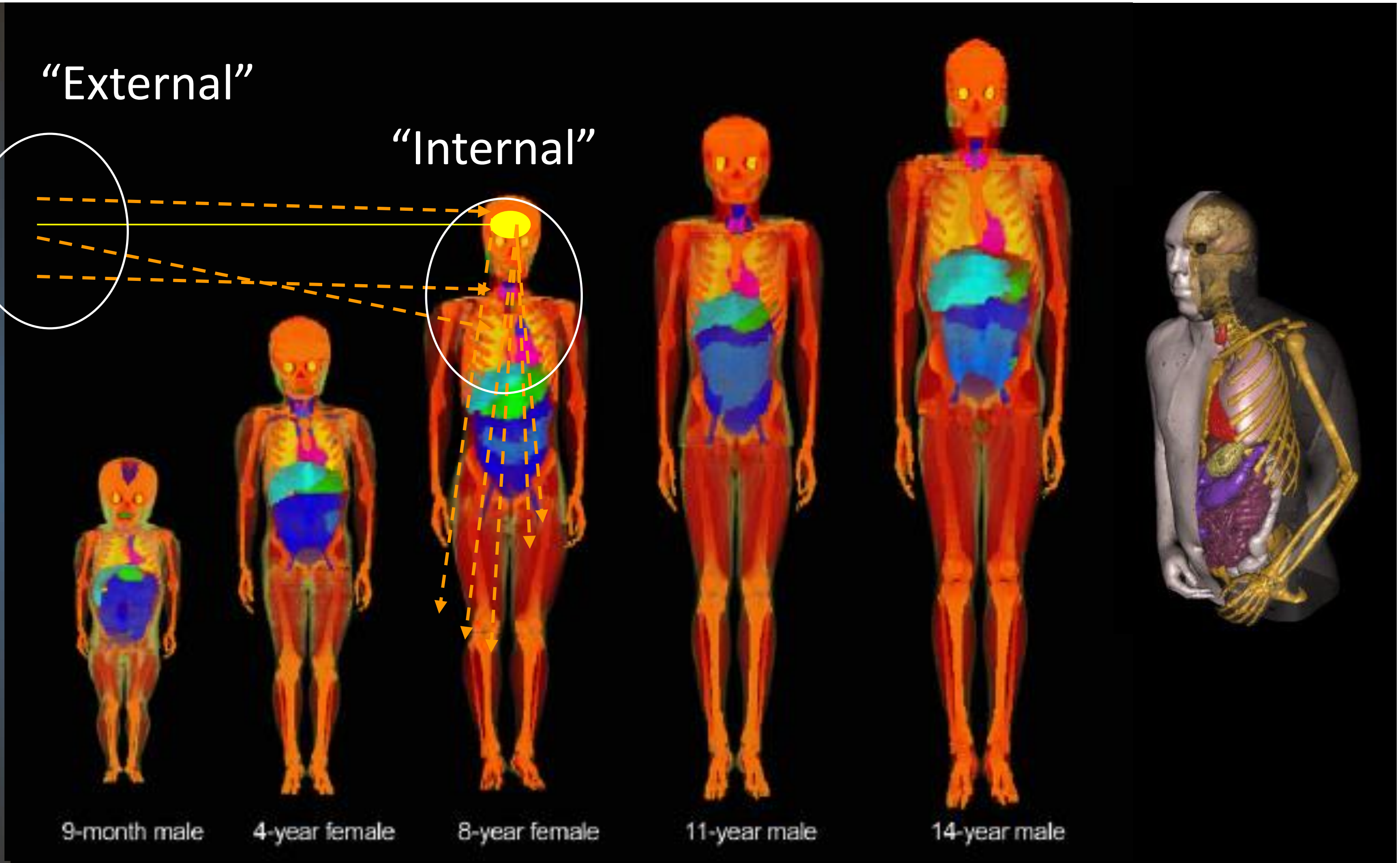








Neutron radiation issue in proton therapy



Phantoms implemented in Geant4 with dose calculation environment at MGH

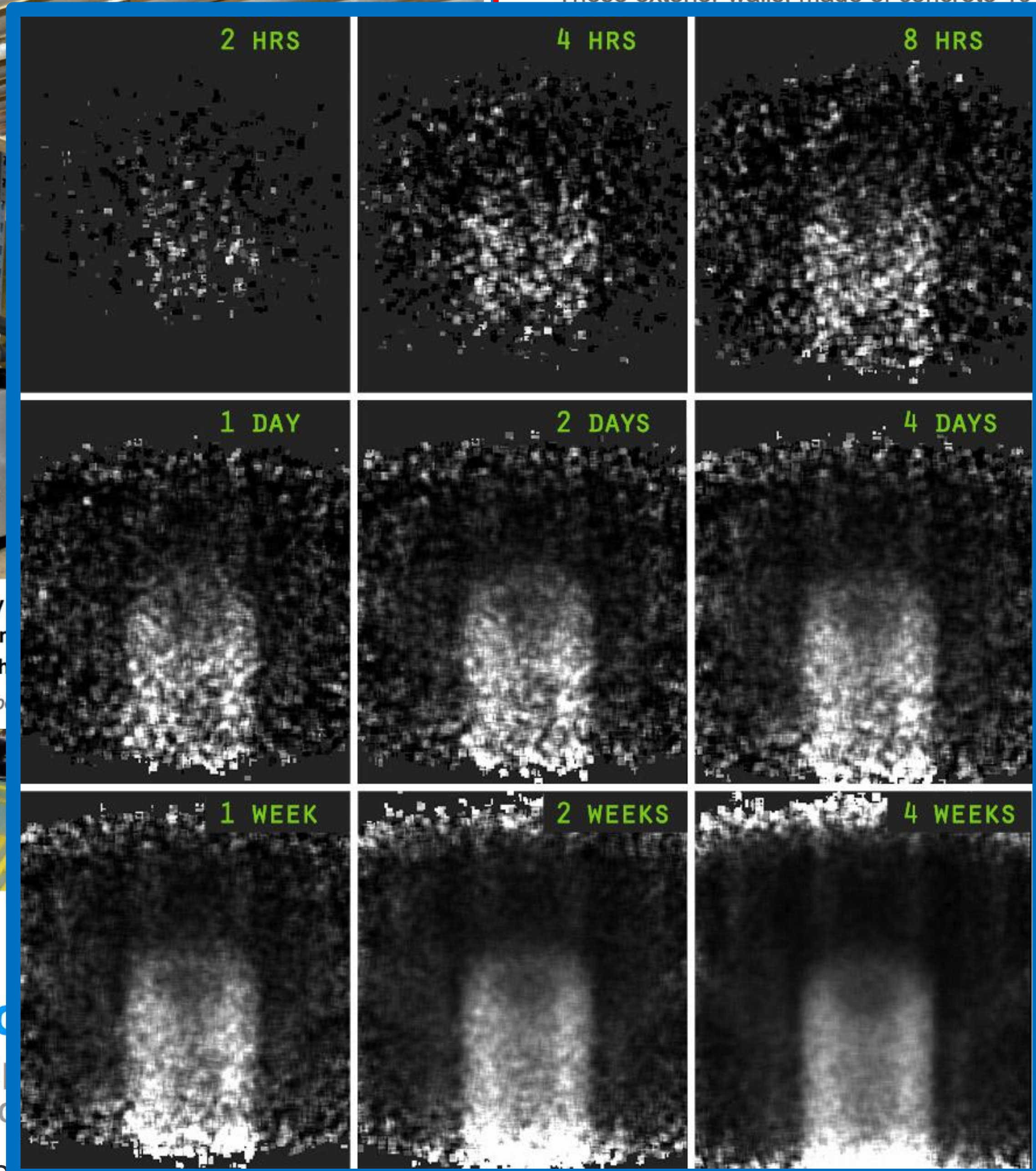
Geant4 in Homeland Security : simulating x-ray cargo radiography

Los Alamos National Laboratory
undergraduate research assistar
inside a muon tomography mach
Courtesy of: Los Alamos National Lab

feature
August 28, 2014

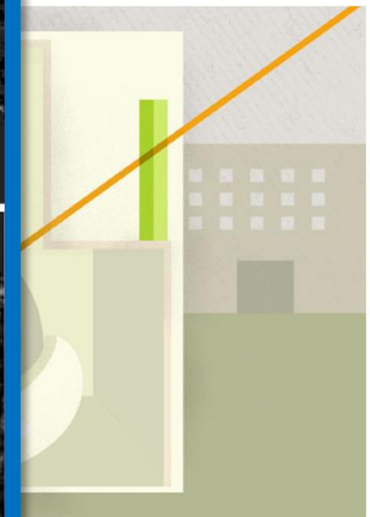
Particle physic

Cosmic rays can hel
the interior of the nuc



Those exterior walls, made of concrete 10 feet thick, offer their own
with the particle physics
educe the resolution to

the high radiation levels



green) on either side of
nuons (represented by the
By determining how the
ill compile the first picture of

me ticks down to the restart of
Large Hadron Collider,
ntists are making sure their
ctors run like clockwork.

https://www.symme ... nuclear-cleanup

Archeology

- Same “muongraphy” technique used in the recent discovery of a big void in the Great Pyramid
- Geant4 used in the simulation of the muon detection system

- Images : courtesy of D. Attié & S. Procureur

Geant4 on GPU ?

Can Geant4 run on GPU ?

- We have often the question “can Geant4 run on GPU ?”
  - Underlying hope : GPUs are fast, so running Geant4 on GPU would be fast !
  - Not that simple...

- GPU are fantastic to treat **« many very similar things » « behaving almost the same »**
  - Typical example and original motivation : optical photons
  - The treatment can be done in parallel, applying the same calculation to a set of data.
    - And this can be repeated calculation after calculation if the set of data is not destroyed by these calculations.
    - In other words, **no divergences** appear in the data set : the data set remains of « the same nature ».
  - GPUs are designed to make these parallel calculations efficiently, and they are performing nicely !

- But with a Monte Carlo like Geant4:
  - **« many very similar things » → « many very different things » !**
    - Many type of particles !
  - **« behaving almost the same » → « behaving not at all the same » !**
    - Interactions of particles are very different from on type to an other
    - Even particles of same type can undergo very different interactions !

    } → **Source of plenty of divergences !**
- Usage of GPU limited *a priori* to some « sectors », strongly linked to their divergences:

- Net gain of that ?
  - Great for medical applications (demonstrated) : low E elec. in simple geometries.
  - But for HEP and complicated geometries: **ongoing R&D**, first responses expected in a time scale of one year.

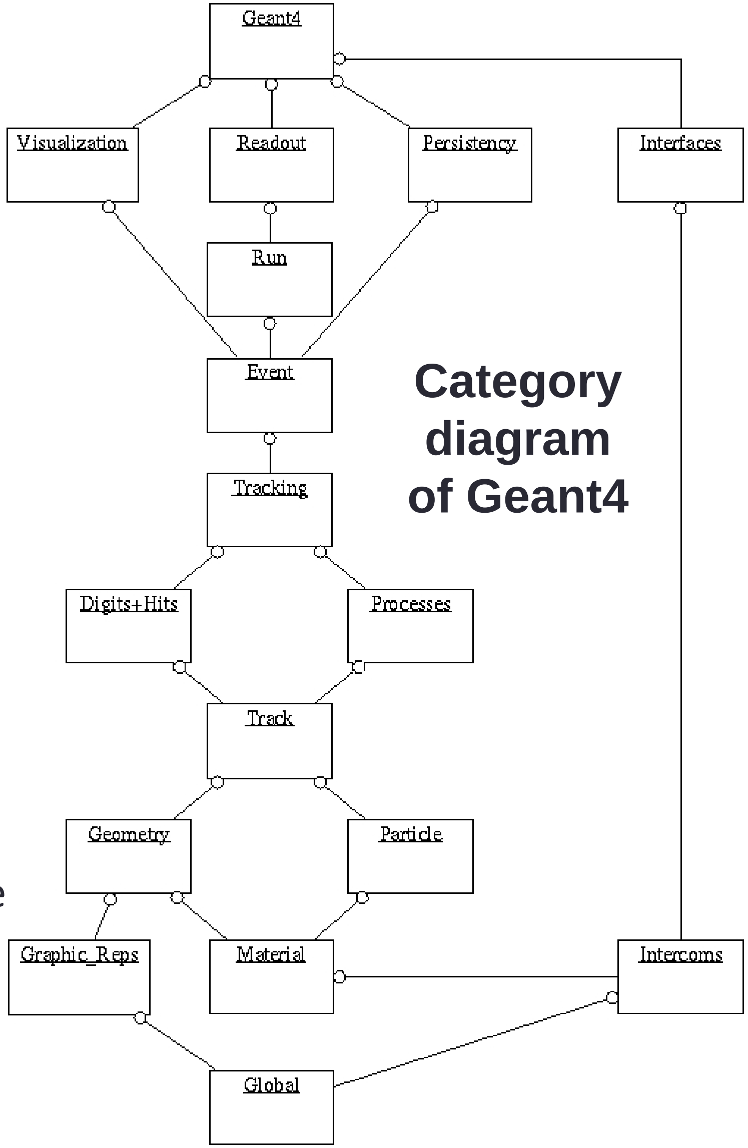
Geant4 toolkit philosophy

The Toolkit philosophy

- <u>**Geant4 is not an application**</u>
  - applications : eg powerpoint, root, etc.

Geant4 is a toolkit

- Which means:
  - **Geant4 provides tools / components**
    - Many of them are defined from abstract classes
    - All are open to the users (☞ you)
  - **You build your own application selecting the Geant4 components you need**
    - Either selecting ready to use tools
    - Or building your own, if needed, from the base abstract classes
  - **You instantiate the components in your own main program**
    - That you then compile and link
- You need a minimal knowledge of the Geant4 structure
  - And of the Geant4 base classes and existing tools
- Which is all what this tutorial is about !



Category diagram of Geant4