

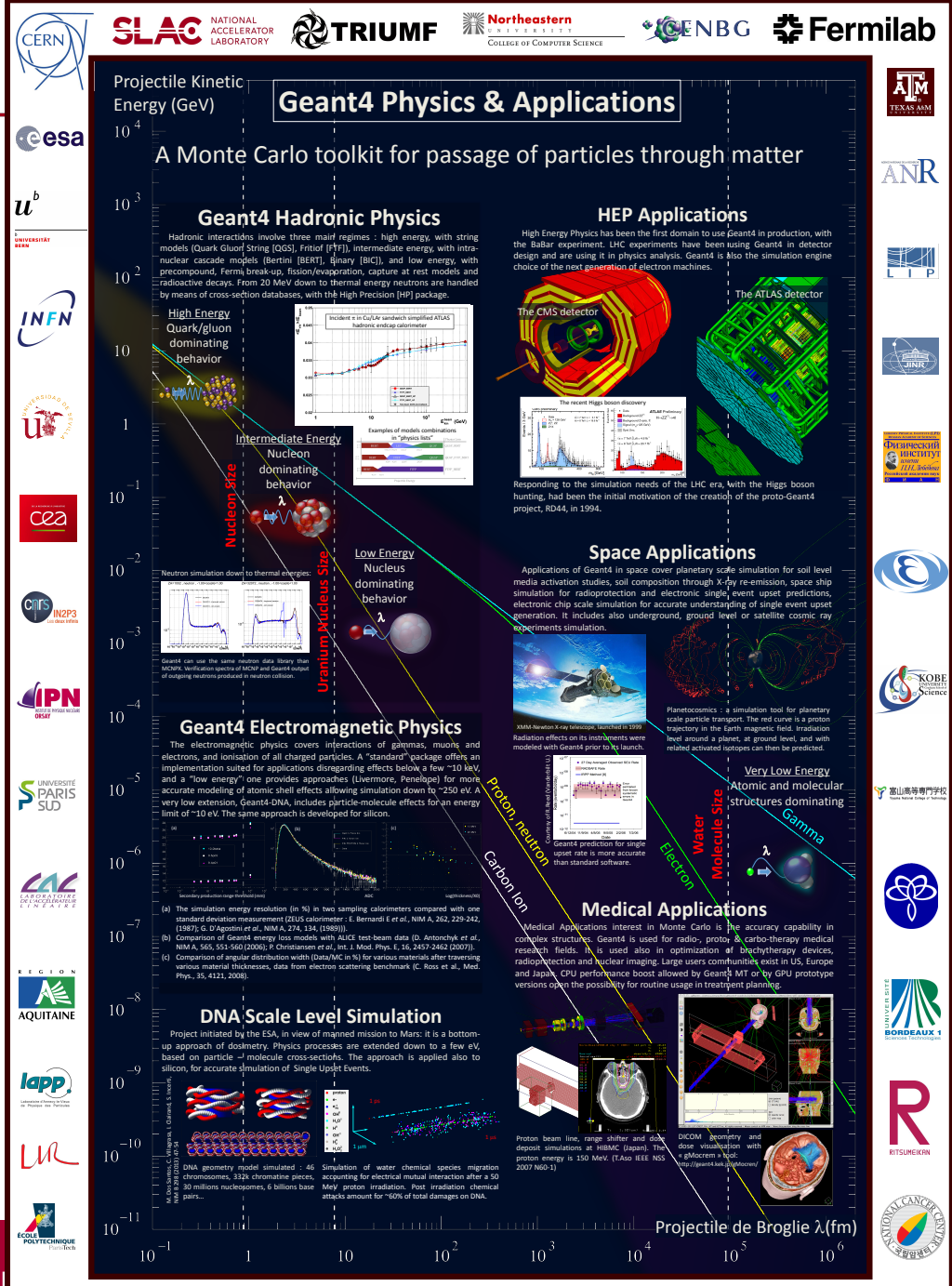
GEANT4
A SIMULATION TOOLKIT

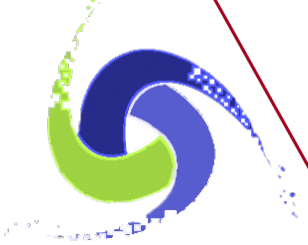
Geant4
General Introduction

Makoto Asai
SLAC National Accelerator Laboratory
June 10, 2021

Contents

- General introduction and brief history of Geant4
- Geant4 license
- Highlights of user applications
- Geant4 – the future



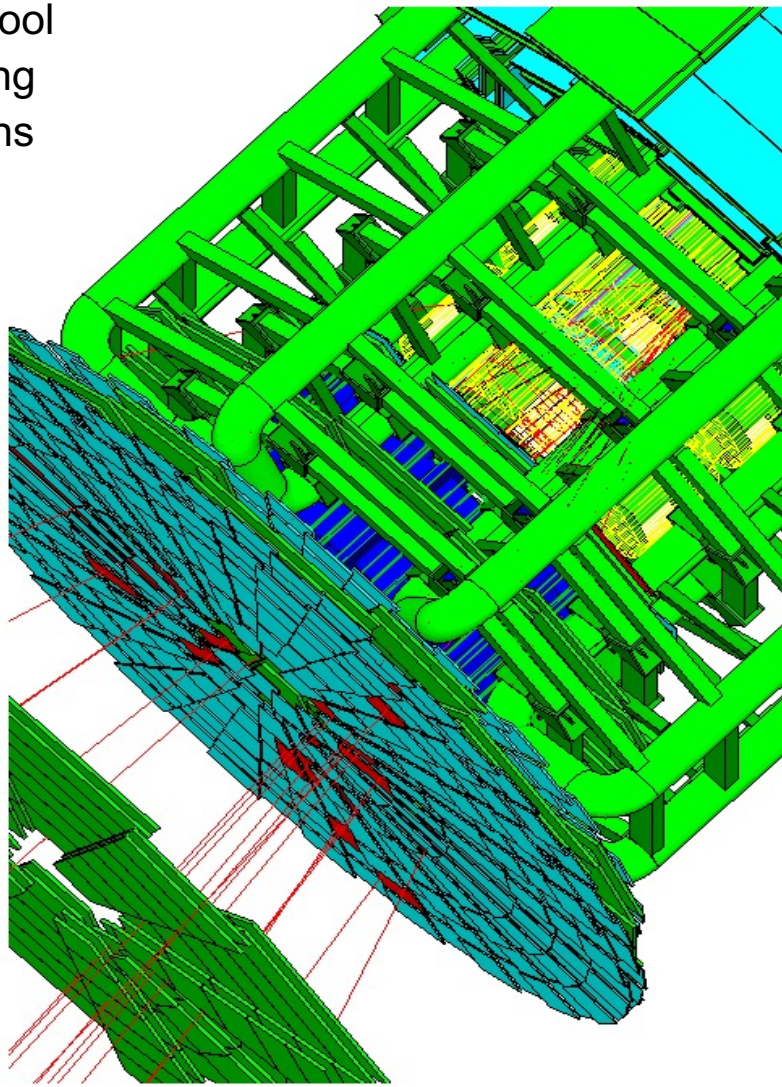


GEANT4
A SIMULATION TOOLKIT

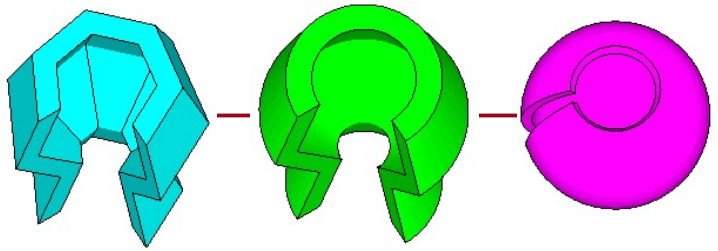
General introduction and brief history

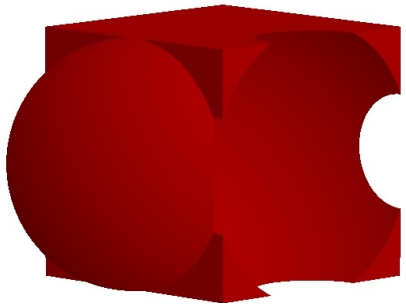
Key Geant4 functionalities

- Geant4 is a general-purpose Monte Carlo simulation tool for elementary particles passing through and interacting with matter. It finds quite a wide variety of user domains including high energy and nuclear physics, space engineering, medical applications, material science, radiation protection and security.
- Geant4 offers most, if not all, 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
- Thanks to the polymorphism mechanism of C++, the users can easily plug-in their extensions without interfering with the other part of Geant4.
- Extensive user guide documents and examples are provided.

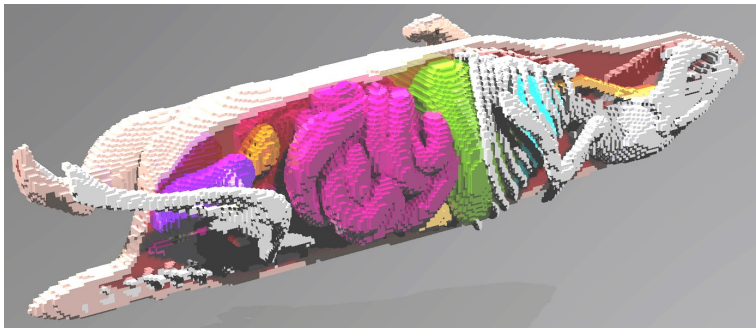


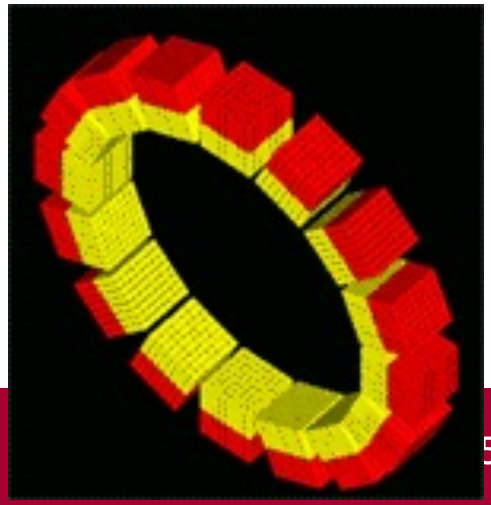
Key geometry capabilities



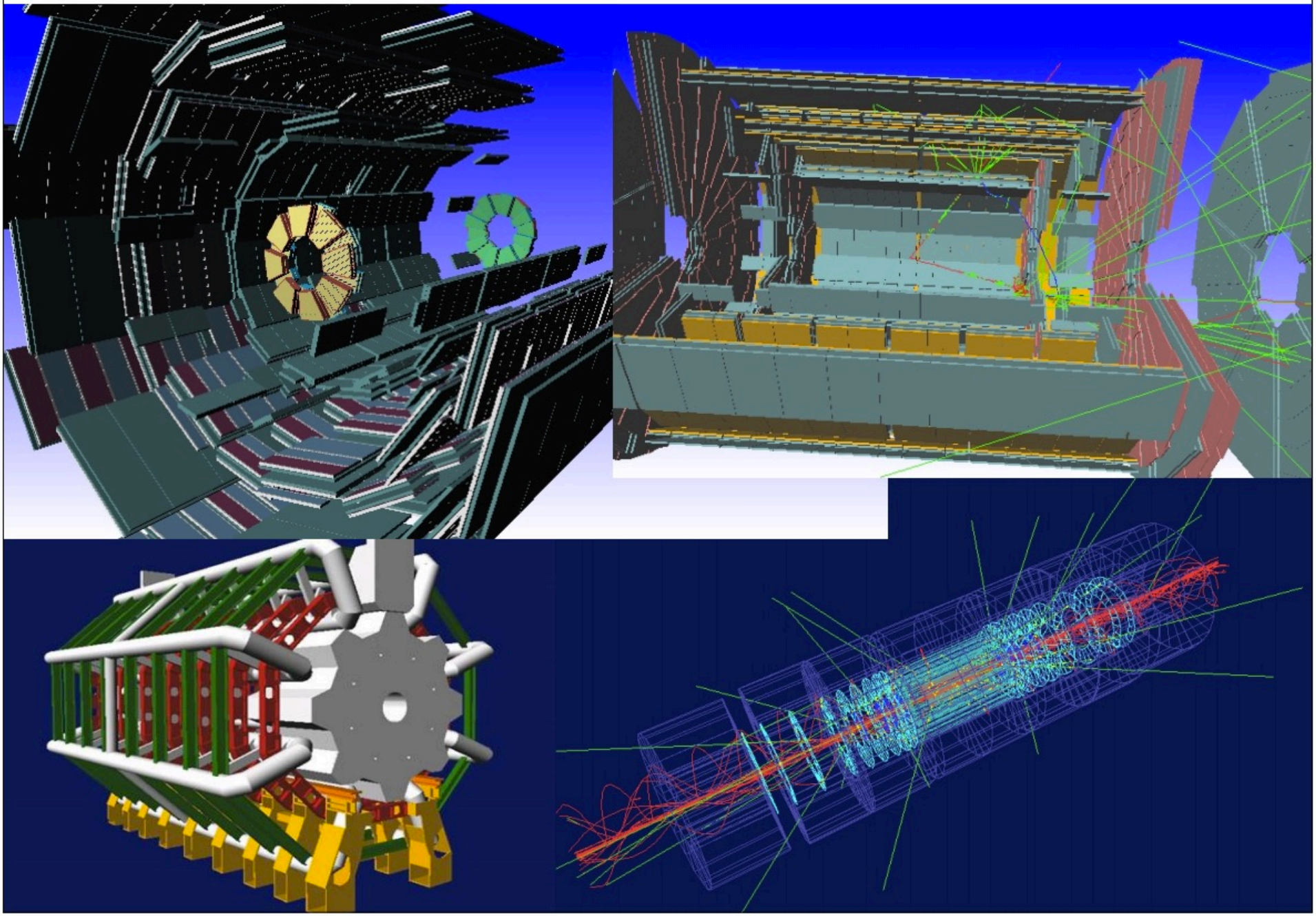


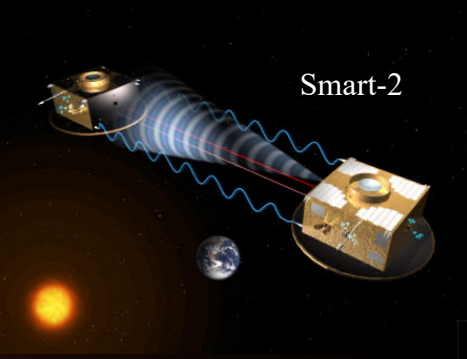
- Richest collection of shapes
  - CSG (Constructed Solid Geometry), Boolean operation, Tessellated solid, etc.
  - The user can easily extend
- Describing a setup as hierarchy or ‘flat’ structure
  - Describing setups up to billions of volumes
  - Tools for creating & checking complex structures
  - Interface to CAD
- Navigating fast in complex geometry model
  - Automatic optimization
- Geometry models can be ‘dynamic’
  - Changing the setup at run-time, e.g. “moving objects”



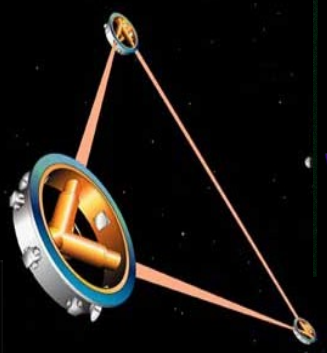


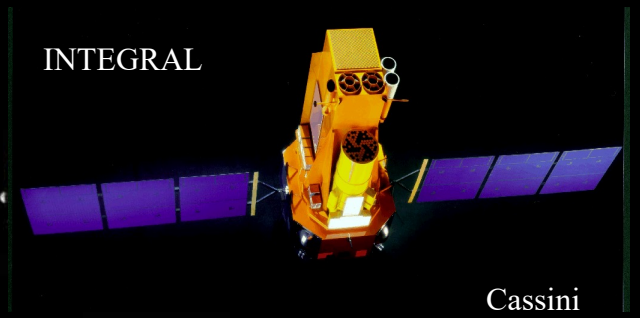
Geant4 in High Energy Physics (ATLAS at LHC)



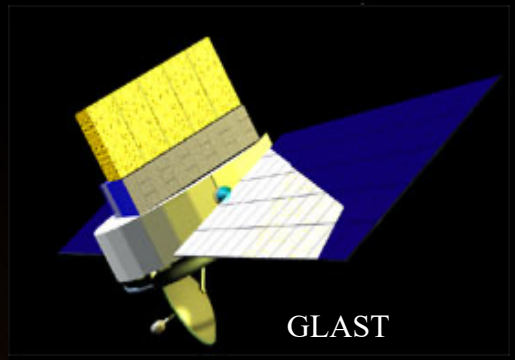

Smart-2

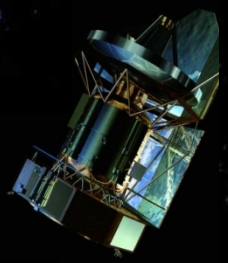

ACE

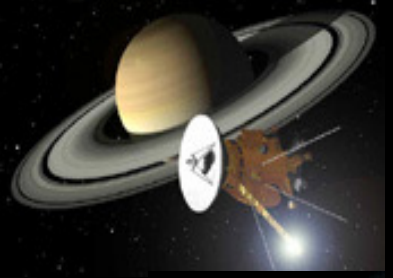

LISA


INTEGRAL
Cassini


Bepi Colombo


GLAST


Herschel

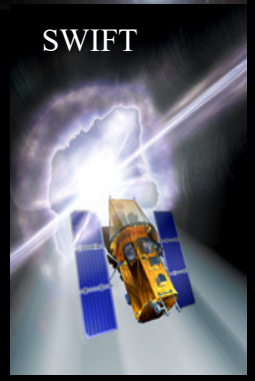



Astro-E2

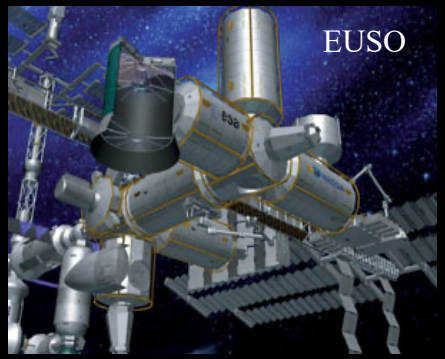

XMM-Newton

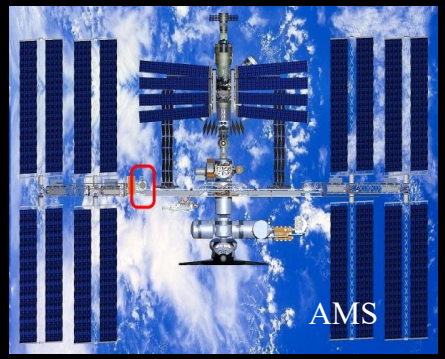

GAIA

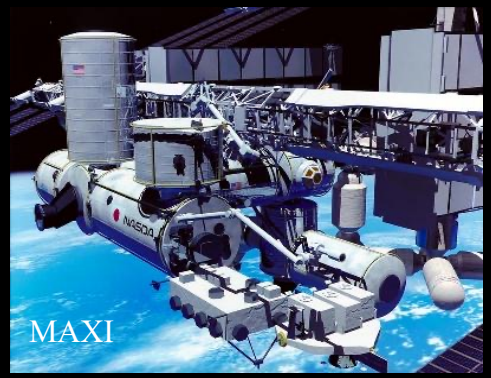

JWST


SWIFT


ISS Columbus

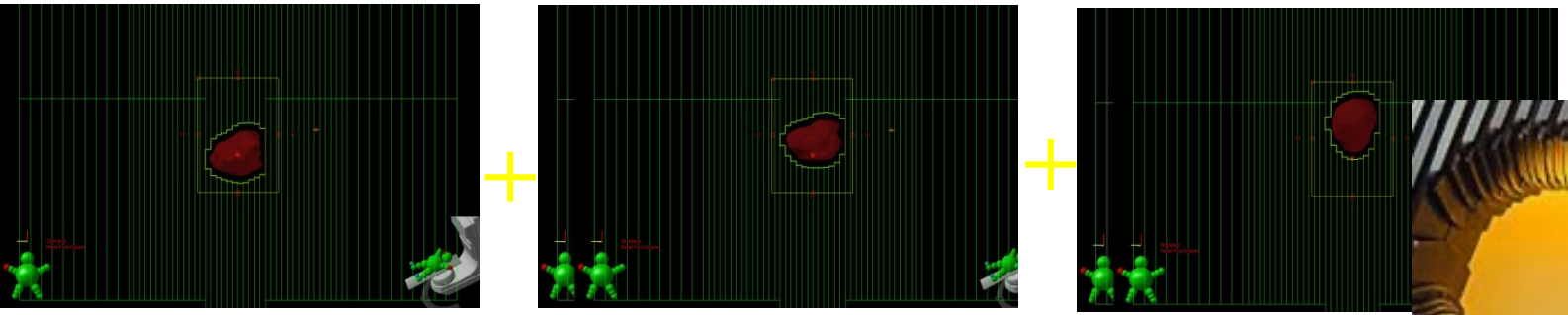

EUSO


AMS

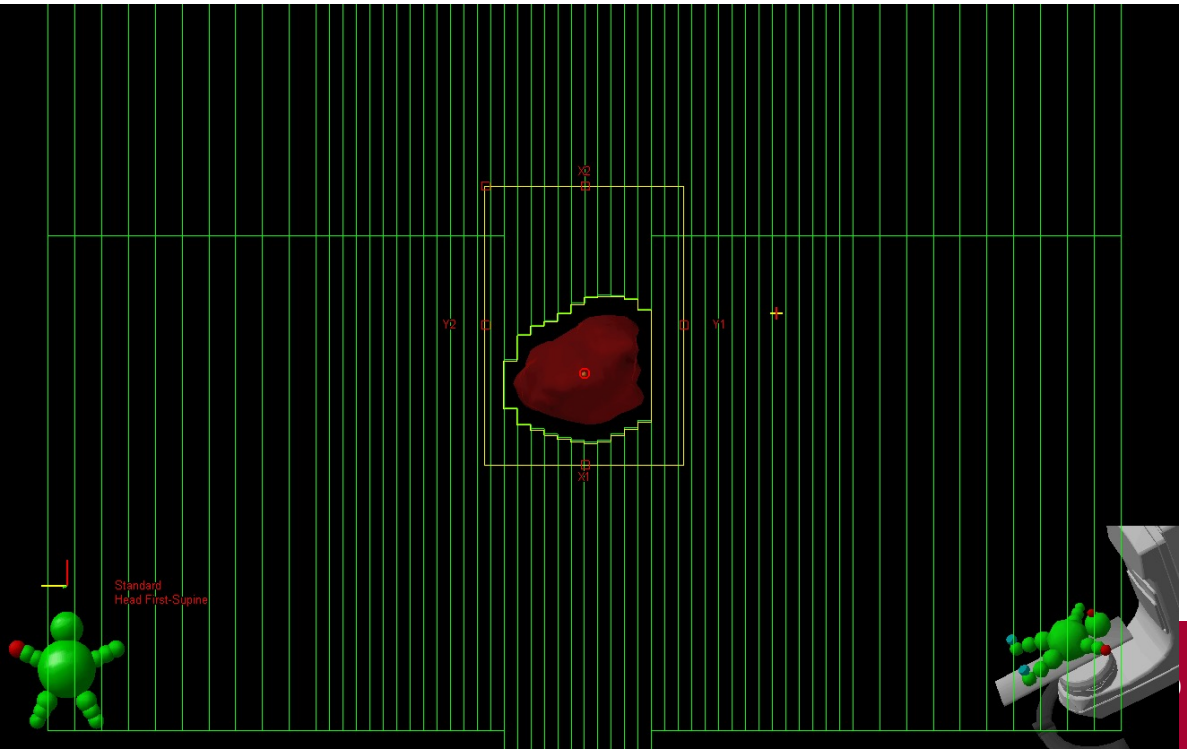

MAXI

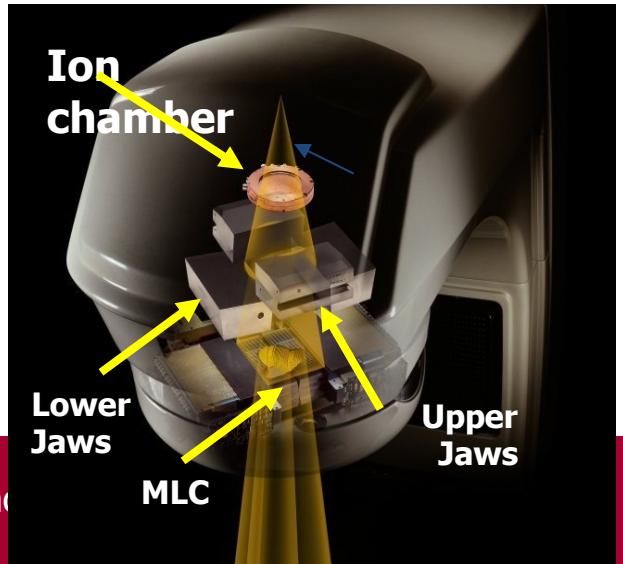
4D RT Treatment Plan

Source: Lei Xing, Stanford University



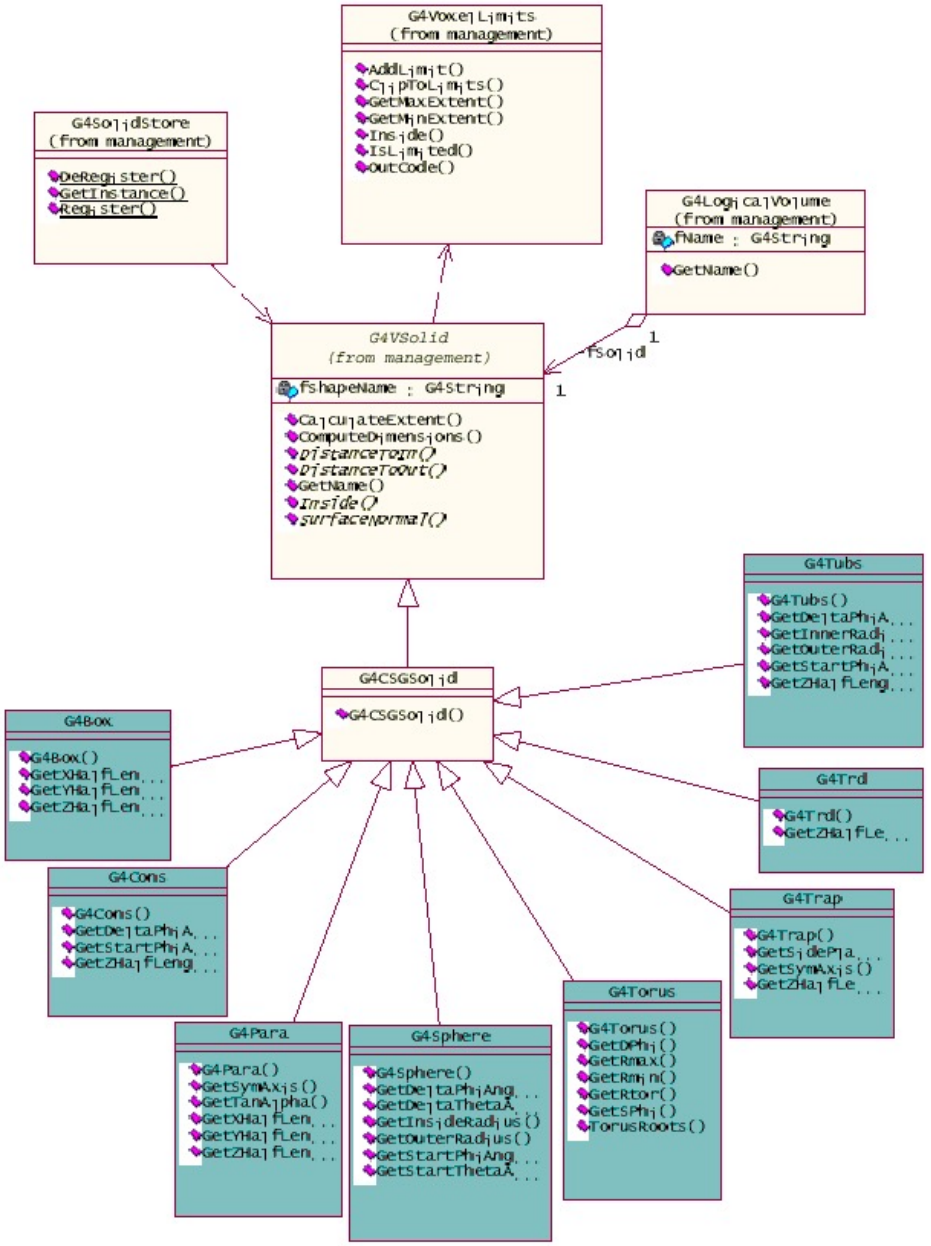




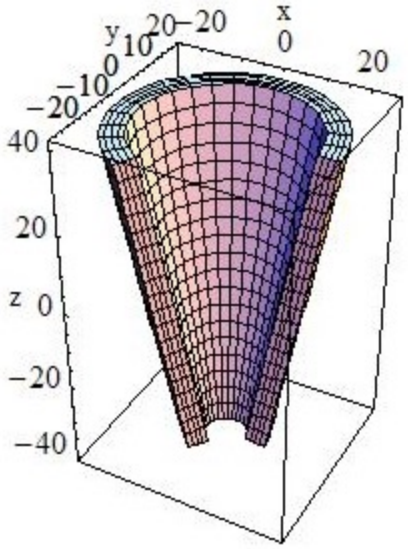


G4VSolid

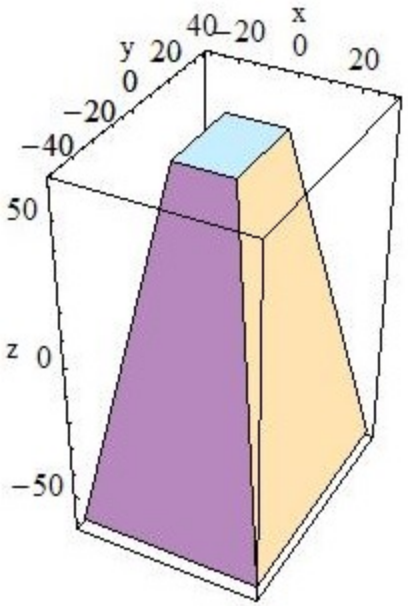
- Abstract class. All solids in Geant4 are derived from it.
- It defines but does not implement all functions required to:
  - compute distances between the shape and a given point
  - check whether a point is inside the shape
  - compute the extent of the shape
  - compute the surface normal to the shape at a given point
- User can create his/her own solid class.



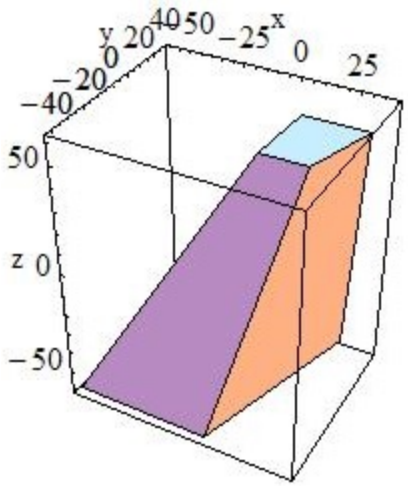
Some CSG solids



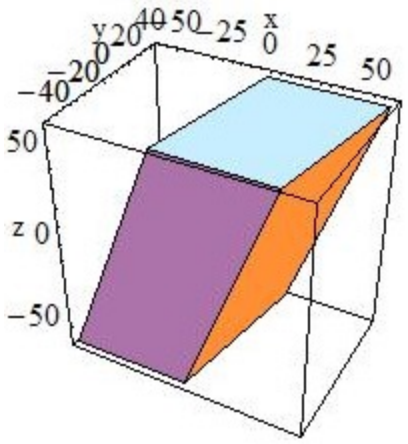
G4Cons



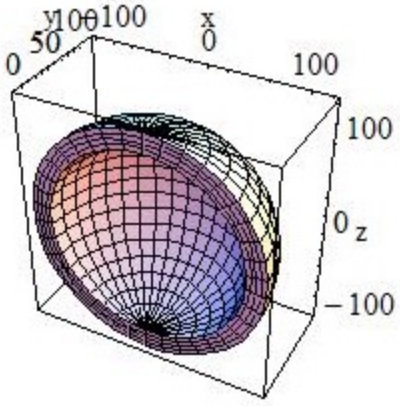
G4Trd



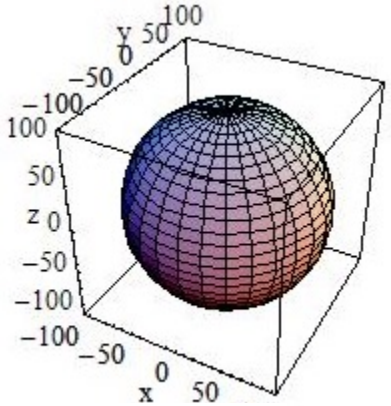
G4Trap



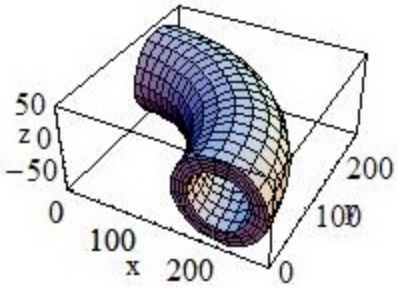
G4Para
(parallelepiped)



G4Sphere



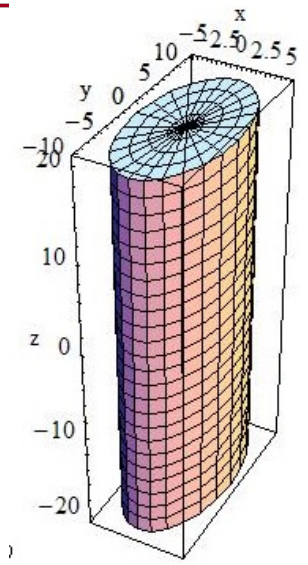
G4Orb
(full solid sphere)



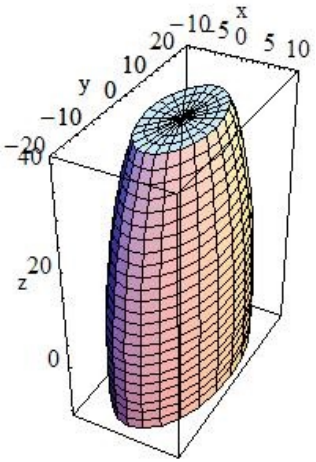
G4Torus

Consult to Section 4.1.2 of Geant4 Application Developers Guide for all available shapes.

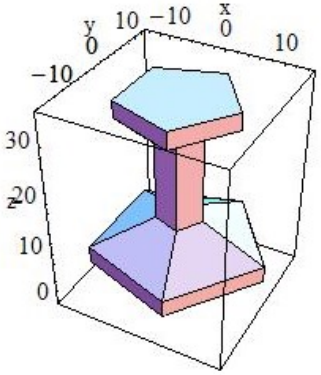
Some Specific CSG solids



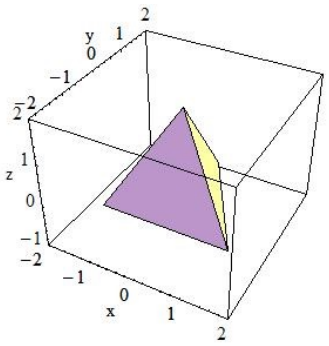
G4EllipticalTube



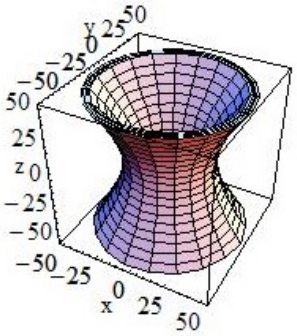
G4Ellipsoid



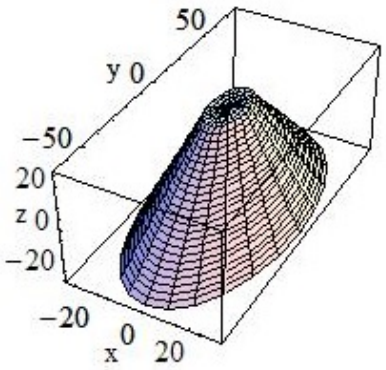
G4Polyhedra



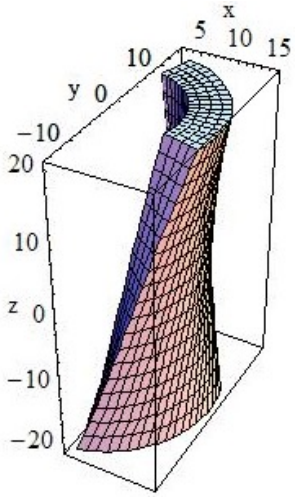
G4Tet
(tetrahedra)



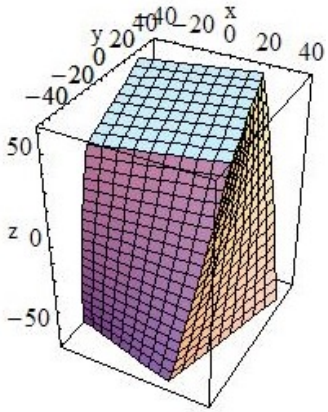
G4Hype



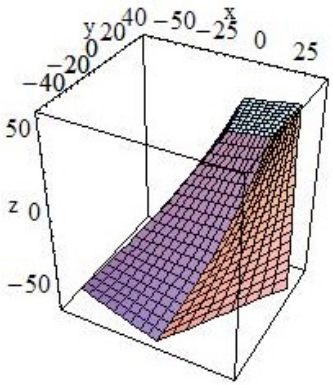
G4EllipticalCone



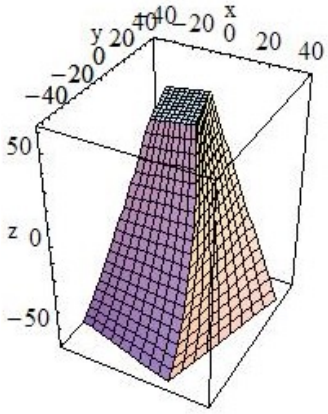
G4TwistedTubs



G4TwistedBox



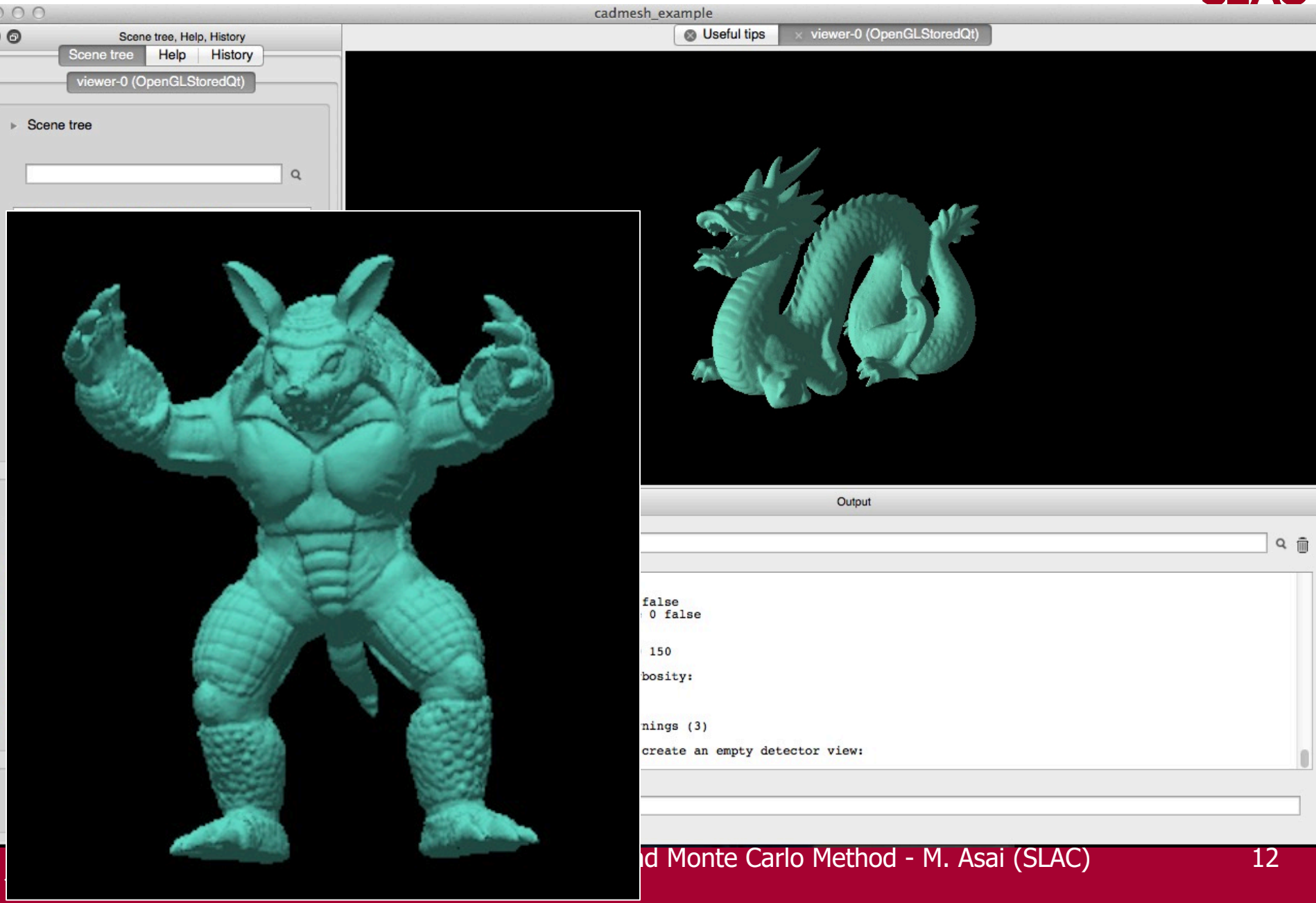
G4TwistedTrap



G4TwistedTrd

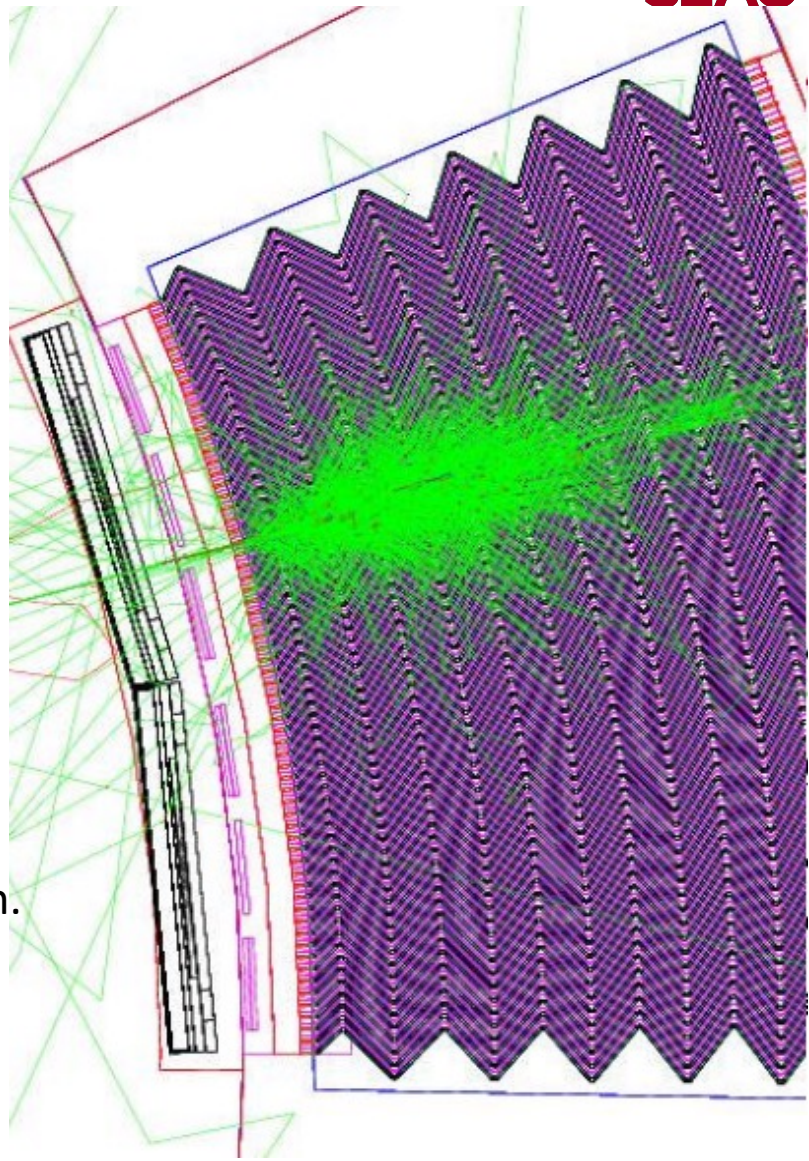
Consult to Section 4.1.2 of Geant4 Application Developers Guide for all available shapes.

Tessellated solid

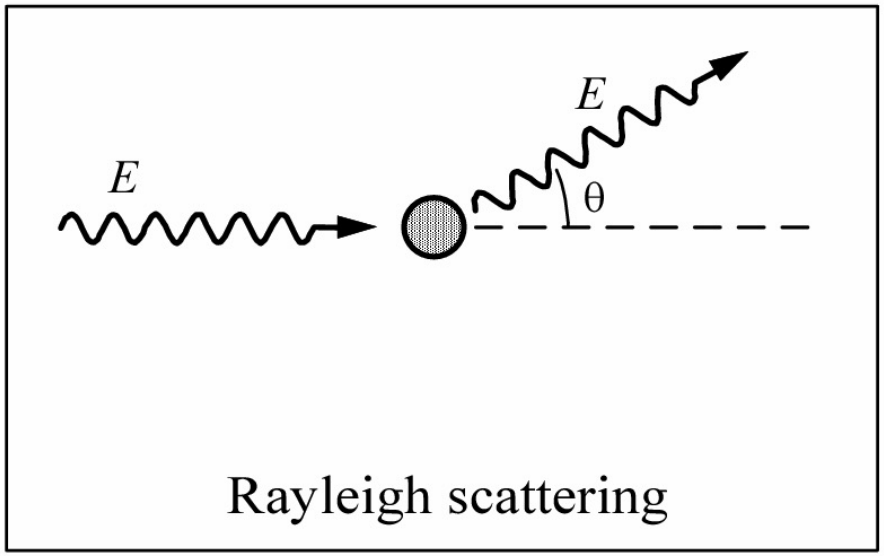


Physics models in Geant4

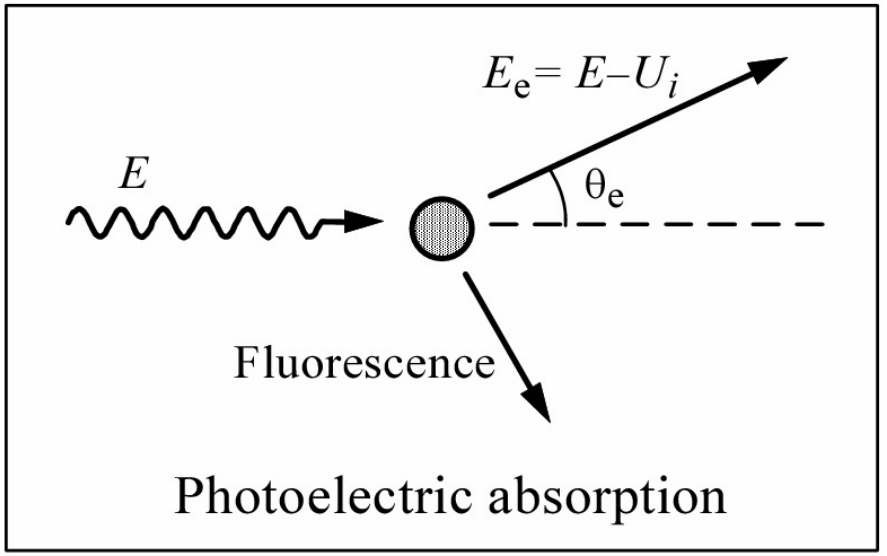
- Geant4 offers
  - Electromagnetic processes
  - Hadronic and nuclear processes
  - Photon/lepton-hadron processes
  - Optical photon processes
  - Decay processes
  - Shower parameterization
  - Event biasing techniques
  - And you can plug-in more
- Geant4 provides sets of alternative physics models so that the user can freely choose appropriate models according to the type of his/her application.
  - For example, some models are more accurate than others at a sacrifice of speed.



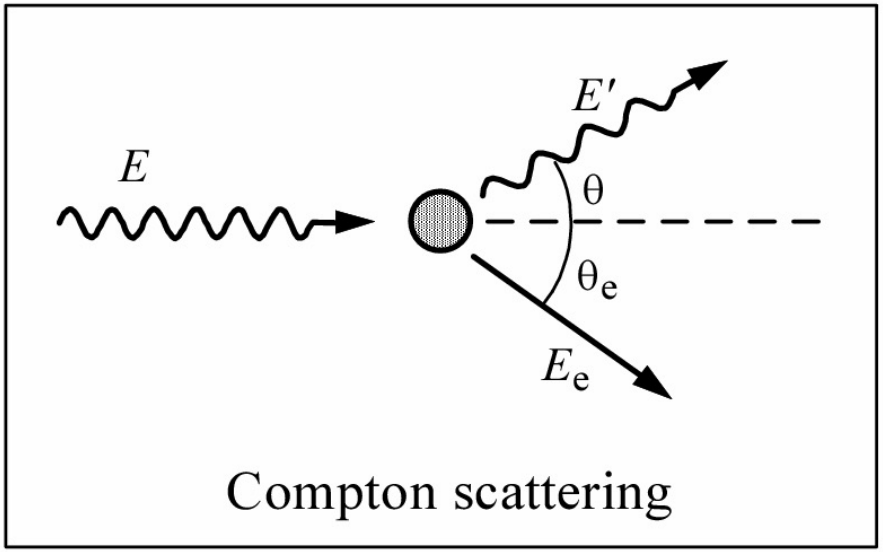
Photon interactions



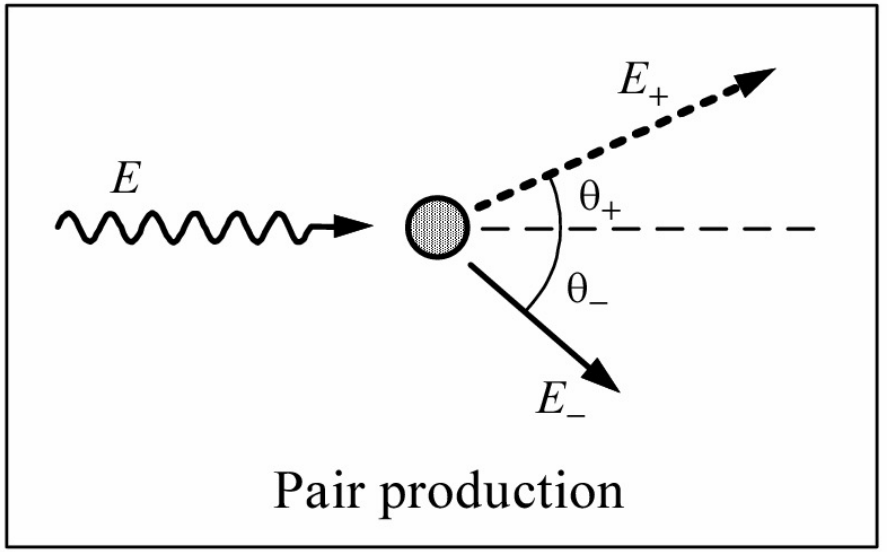
Rayleigh scattering



Photoelectric absorption

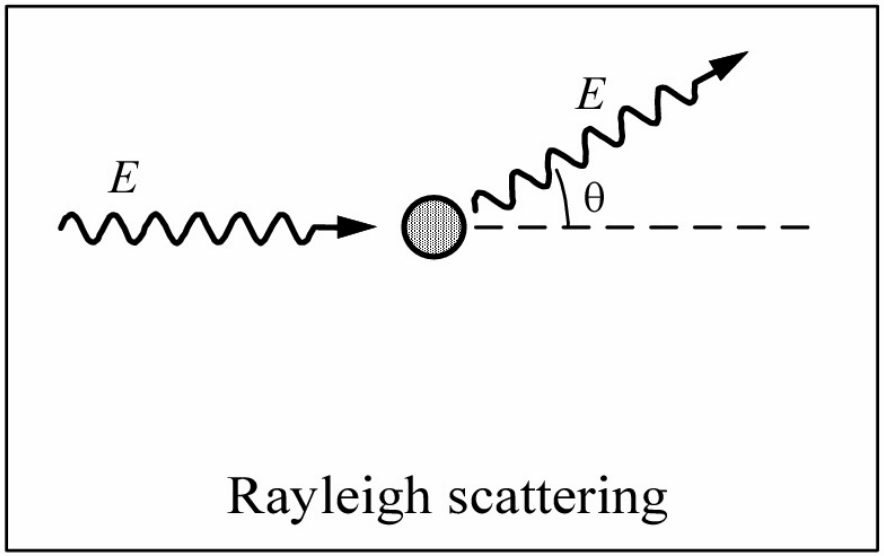


Compton scattering

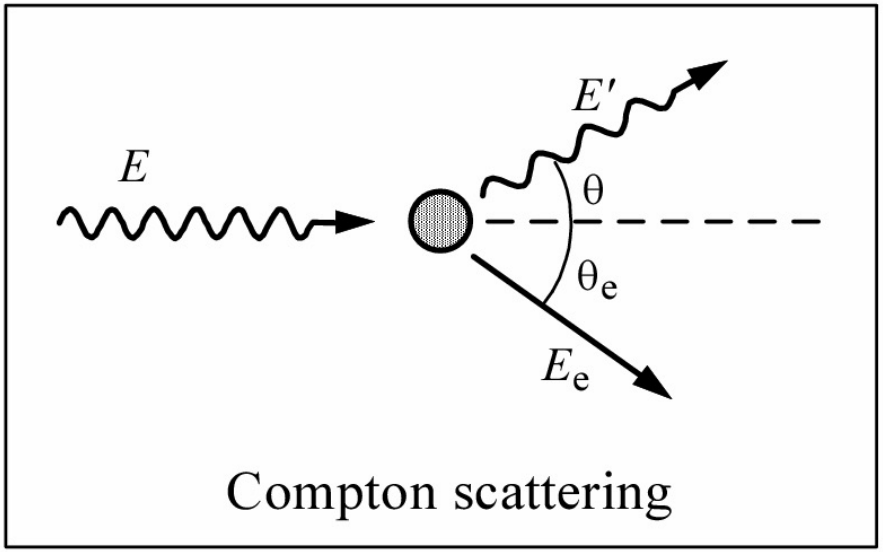


Pair production

Photon interactions



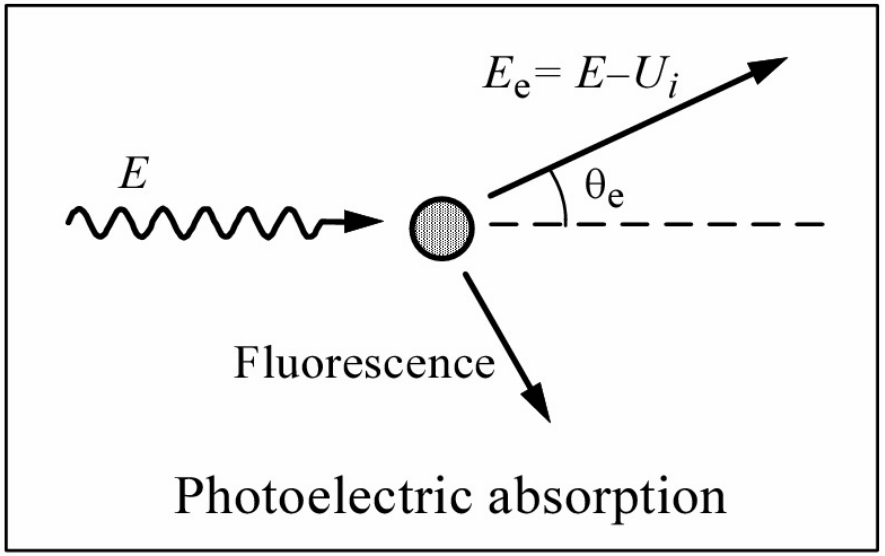
- Coherent (Rayleigh) scattering : negligible for >MeV, relatively small contribution for keV



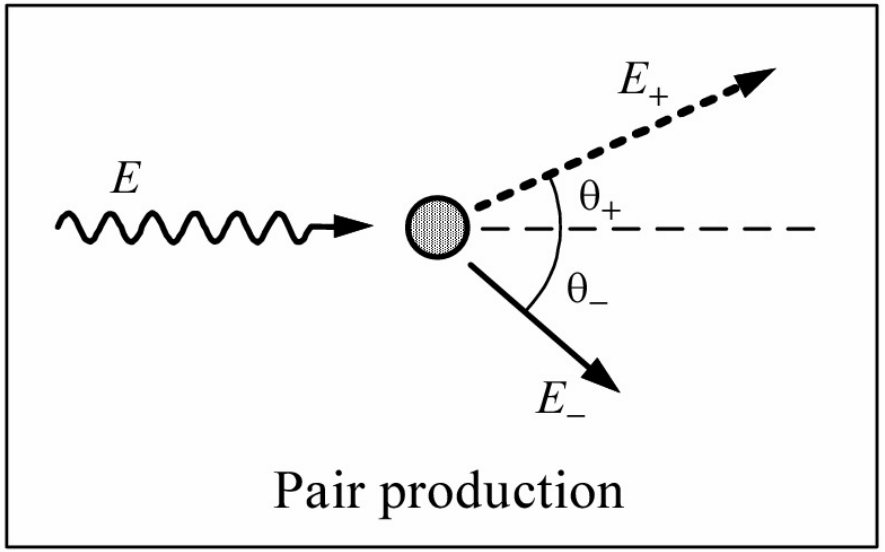
- Incoherent (Compton) scattering : dominant process for >MeV, modeling the interaction with Klein-Nishina equation is good enough for most cases

Photon interactions

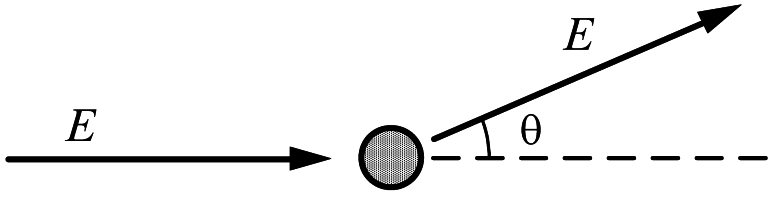
- Photo-electric absorption :
  almost negligible for >MeV,
  dominant process in keV energy
  range where cross-section
  uncertainties are 5-10%



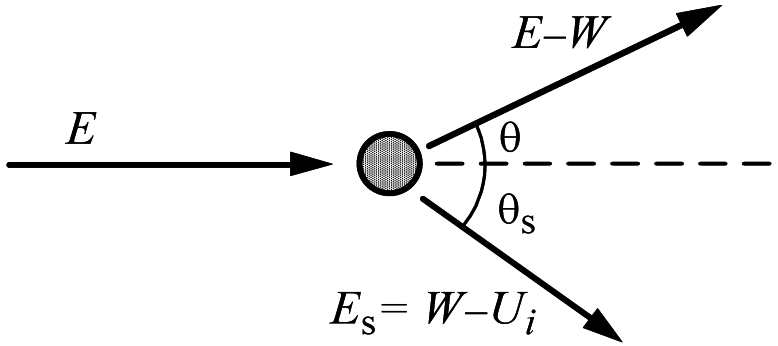
- Pair production :
  total cross-sections are based on
  highly sophisticated partial-wave
  analysis calculations which are
  known to be accurate to much
  better than 1%



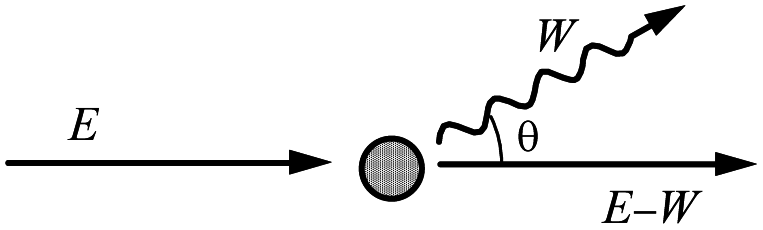
Electron/positron interactions



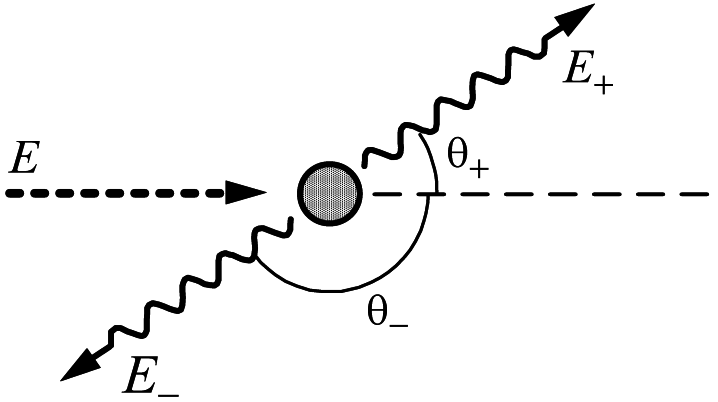
Elastic scattering



Inelastic scattering

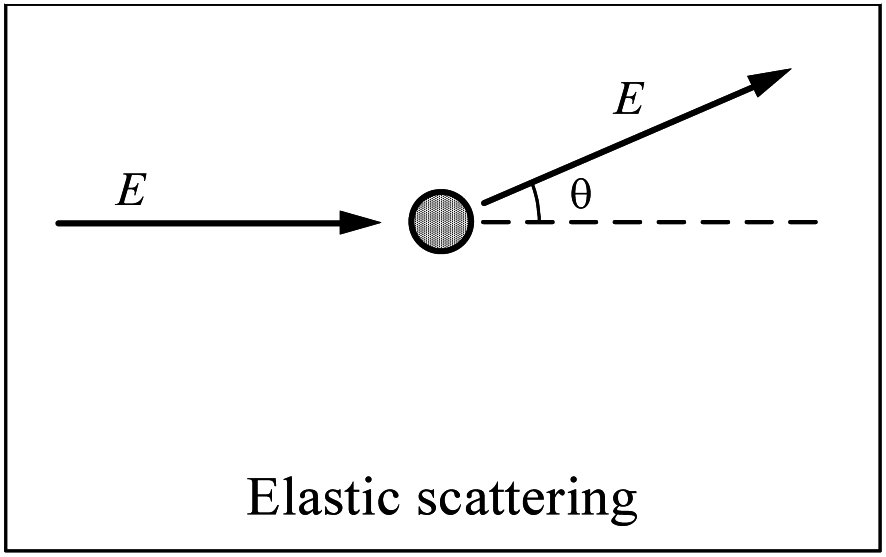


Bremsstrahlung emission



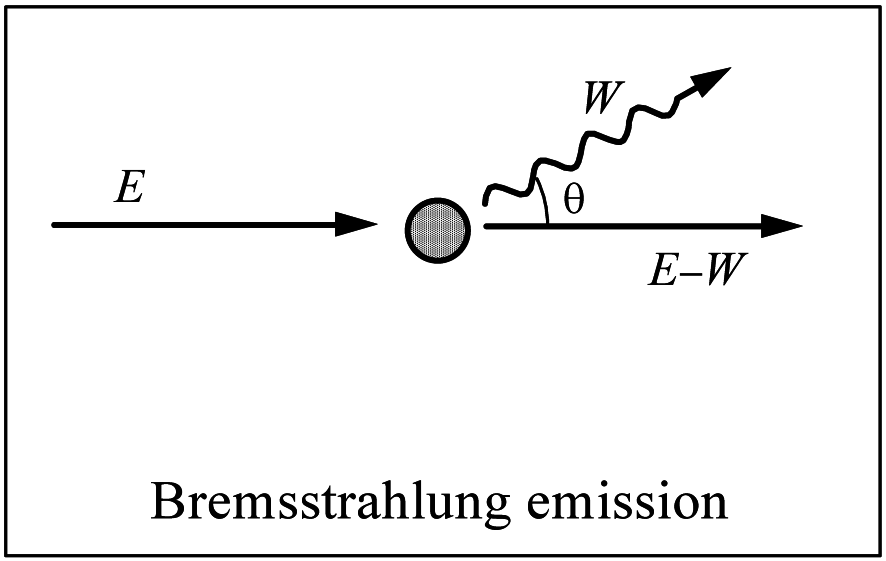
Positron annihilation

Electron/positron interactions



Elastic scattering

- Elastic collisions with nuclei and atomic electrons :
  very well understood in terms of partial-wave analysis calculations



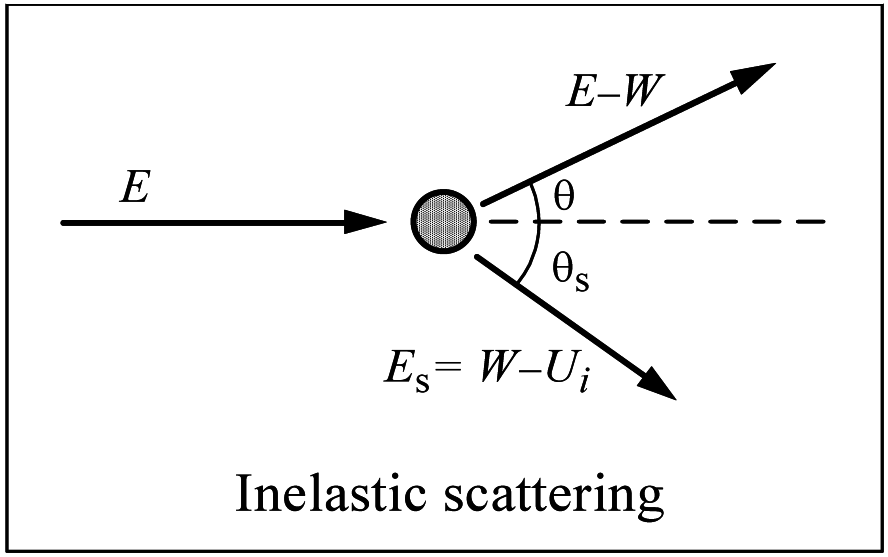
Bremsstrahlung emission

- Bremsstrahlung in the nuclear and election fields :
  Very well understood at >100MeV, well understood at < 2MeV in terms of partial-wave analysis calculations, interpolation in the intermediate energy range with reasonable agreements

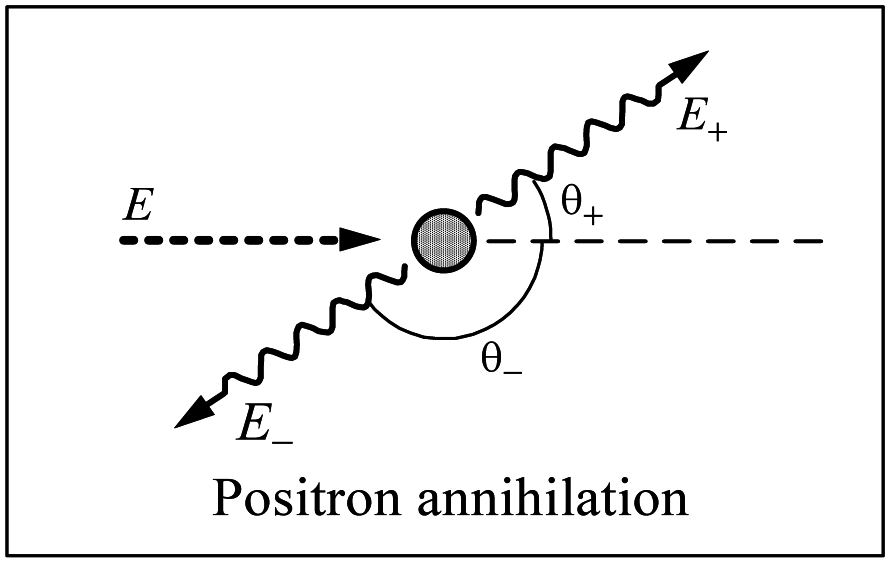
Electron/positron interactions

- Inelastic collisions with atomic electrons that lead to ionizations and excitations :
  hard collision with energy transfer larger than binding energies : Møller (e-) and Bhabha (e+) cross-sections, Bethe-Bloch stopping power theory has excellent agreement with measurements

- Positrons : annihilation



Inelastic scattering

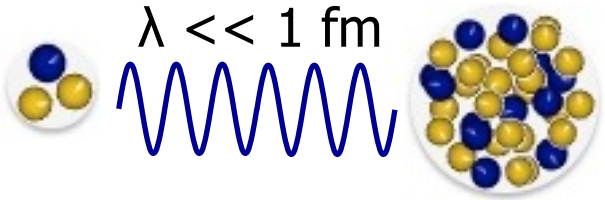


Positron annihilation

Hadron Physics Model

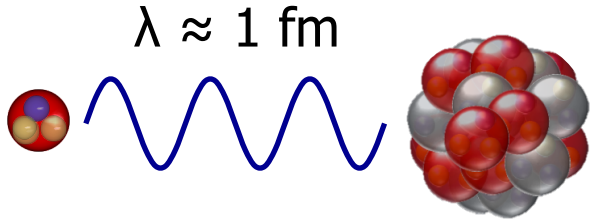
High Energy Region

- Quark-Gluon interaction is dominant
- Models: String model
  - Quark-Gluon string model (QGS)
  - Fritiof



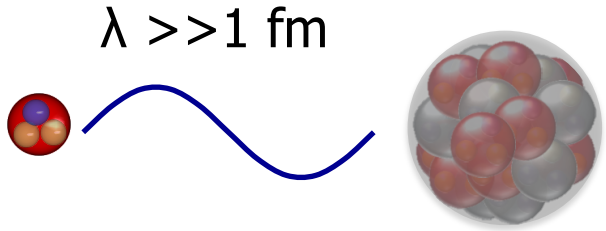
Intermediate Energy Region

- Nuclear-Nuclear interaction is dominant
- Models : Nuclear cascade model
  - Binary cascade model
  - Bertini model

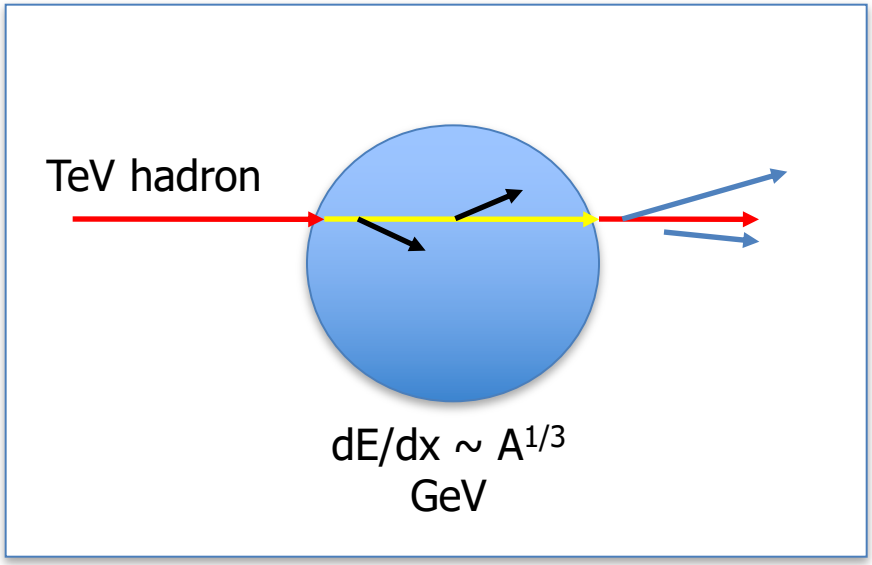


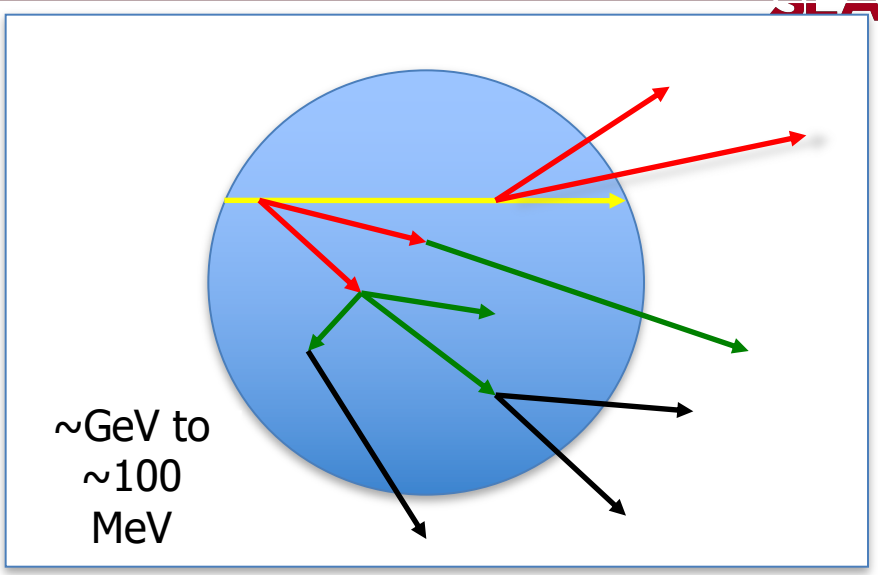
Low Energy Region

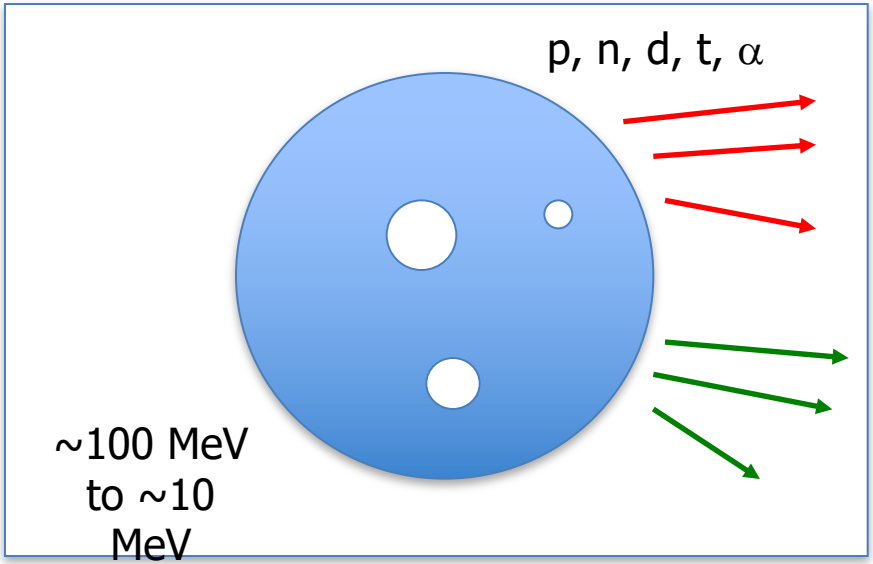
- Atomic interaction is dominant
- Models : Pre-compound model
  - Fission/Evaporation
  - Gamma Evaporation
  - Radioactive Decay
  - Capture at rest

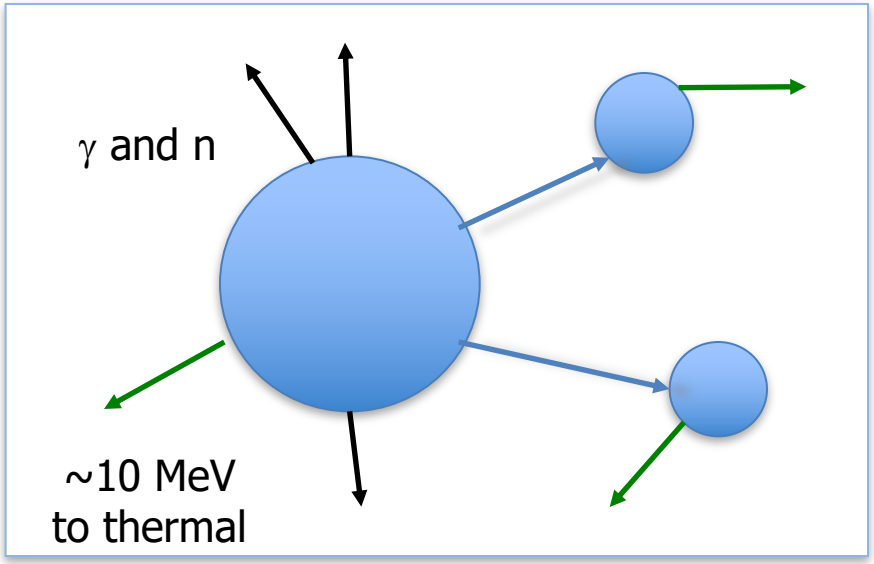


Schematic view of hadronic interaction

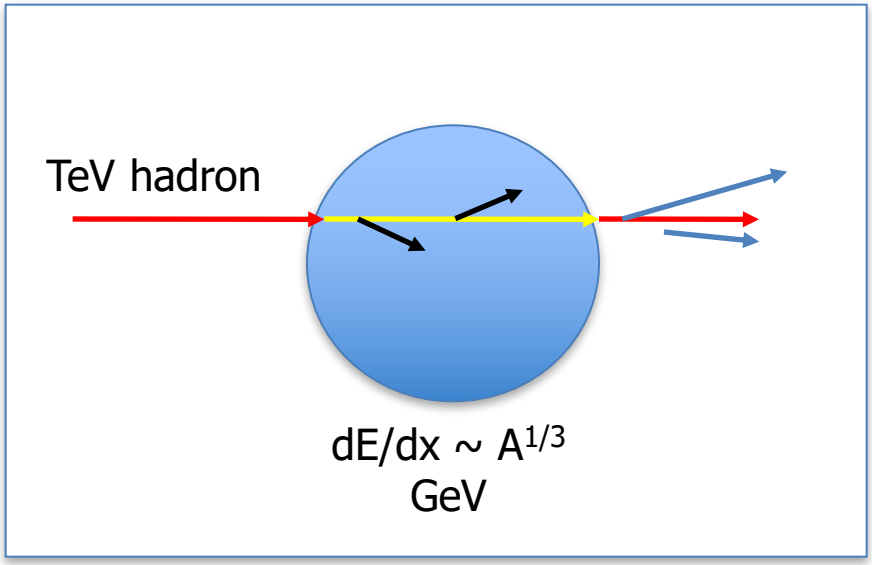








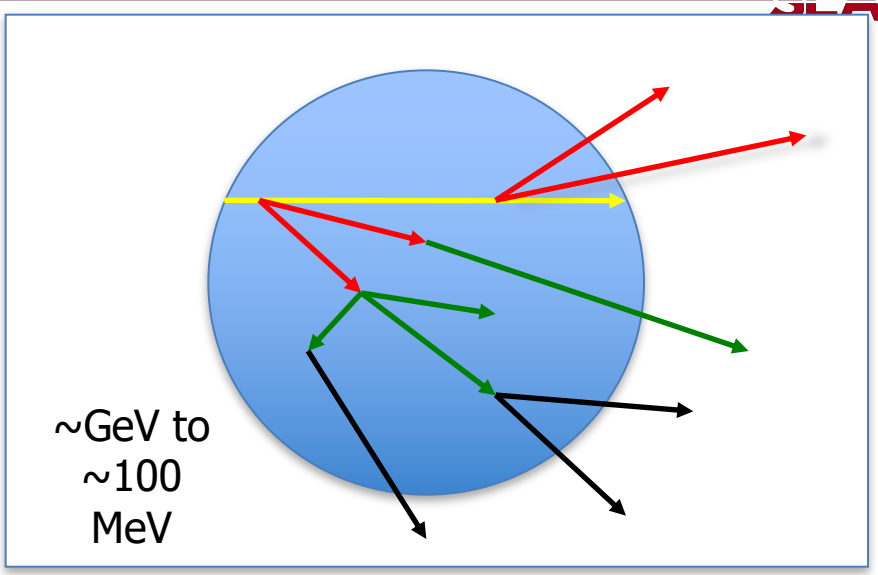
Schematic view of hadronic interaction



High energy :

- A ~TeV hadron, represented by a QCD string, impacts the nucleus, and as it passes by nucleons in the nucleus, excites them to form other strings.
- The strings de-excite by breaking and exchanging quarks with un-excited nucleons, thus starting a Reggeon, or quark-level, cascade. This affects only the nucleons within a small radius of the initial particle path.
- In Geant4, QGS and FTF models handle this energy region.

Schematic view of hadronic interaction



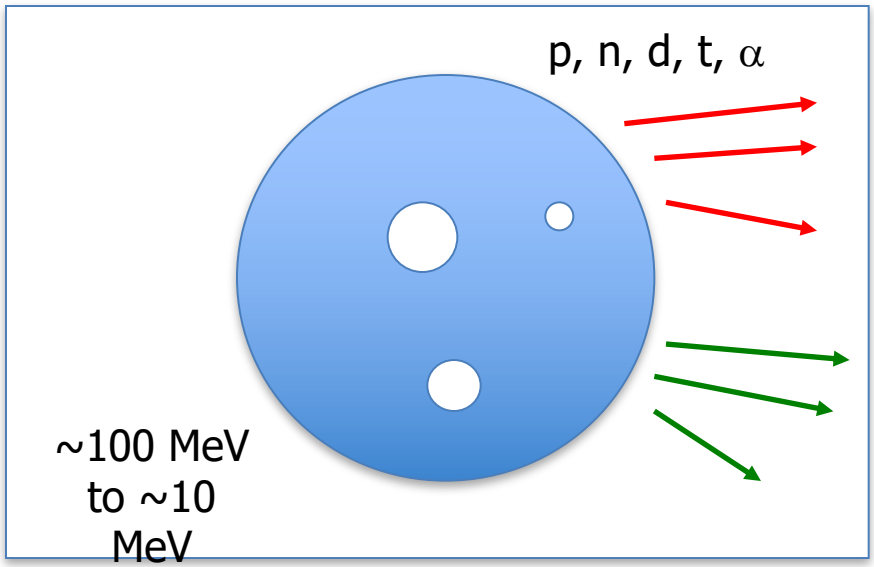
Intermediate energy :

- Once the high energy hadron has passed through the nucleus, it leaves behind ~GeV hadrons which interact with other nucleons, producing still more hadrons in an intra-nuclear cascade.
- Some of these escape the nucleus and others are absorbed, producing a highly excited residual nucleus.
- In Geant4, interactions at these energies are handled by the Bertini, Binary and INCL models.

Schematic view of hadronic interaction

Pre-compound nucleus :

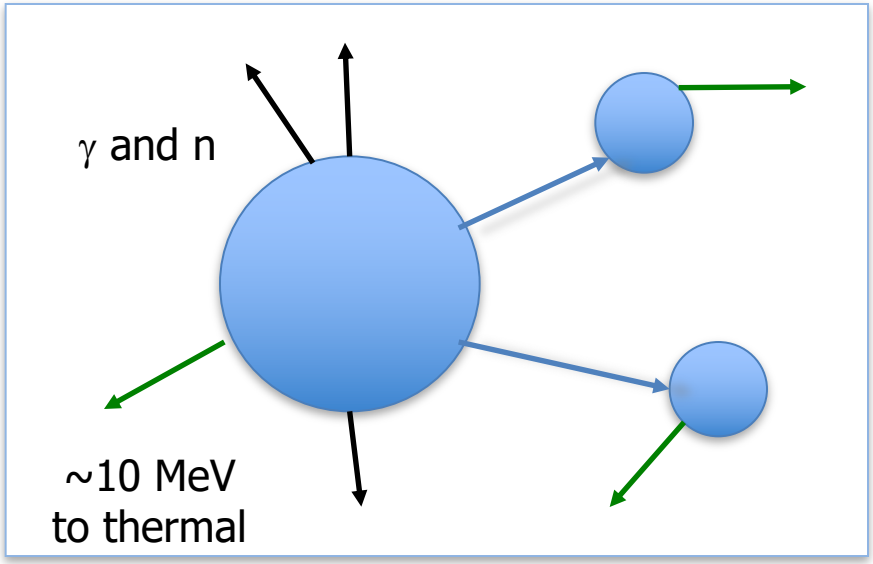
- During the cascade stage, the nuclear excitation is built up as a sum of hadronic particle-hole states.
- When these states collapse, medium to low energy nuclear fragments, such as n, p, d, t, 3He, alpha, Li, Be, etc. are emitted until the nucleus reaches equilibrium.
- In Geant4, this physics is handled by "exciton" decay, multi-fragmentation and fission models.



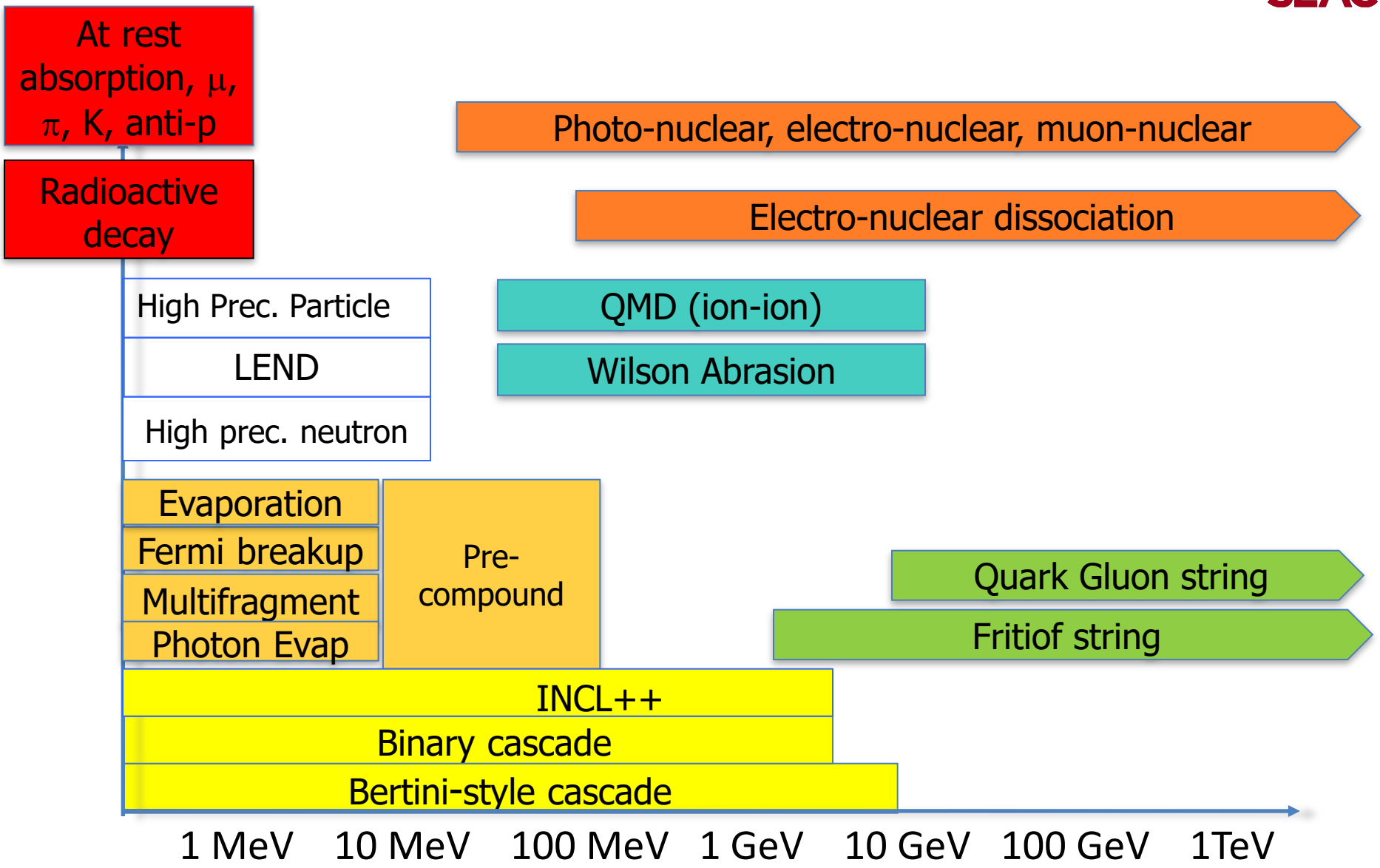
Schematic view of hadronic interaction

Equilibrium evaporation :

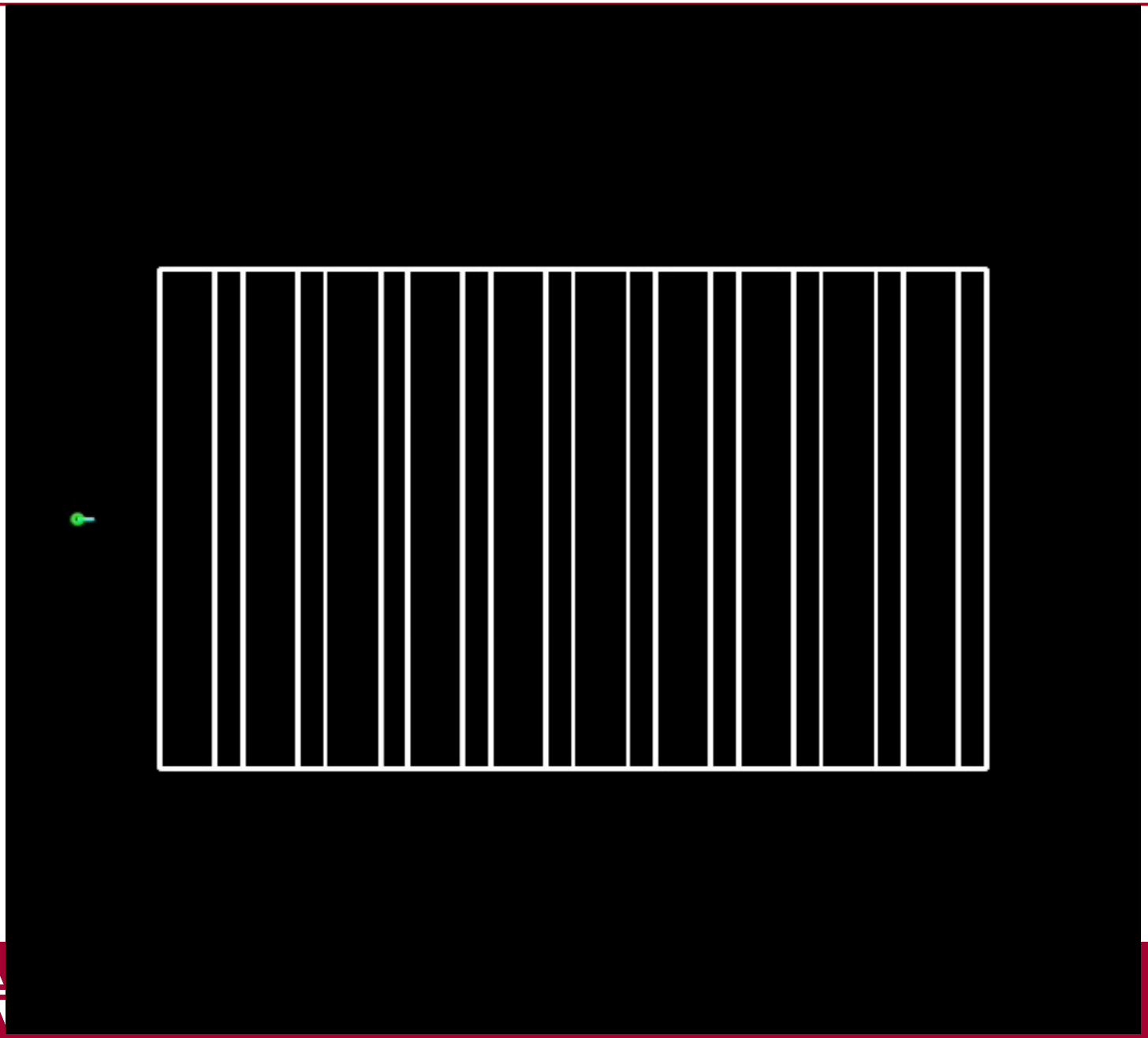
- After the pre-compound stage, mostly low energy neutrons and gammas are emitted in more or less exponential energy spectra, and at discrete energies.
- In Geant4, this physics is handled by the photon evaporation and low energy particle models.



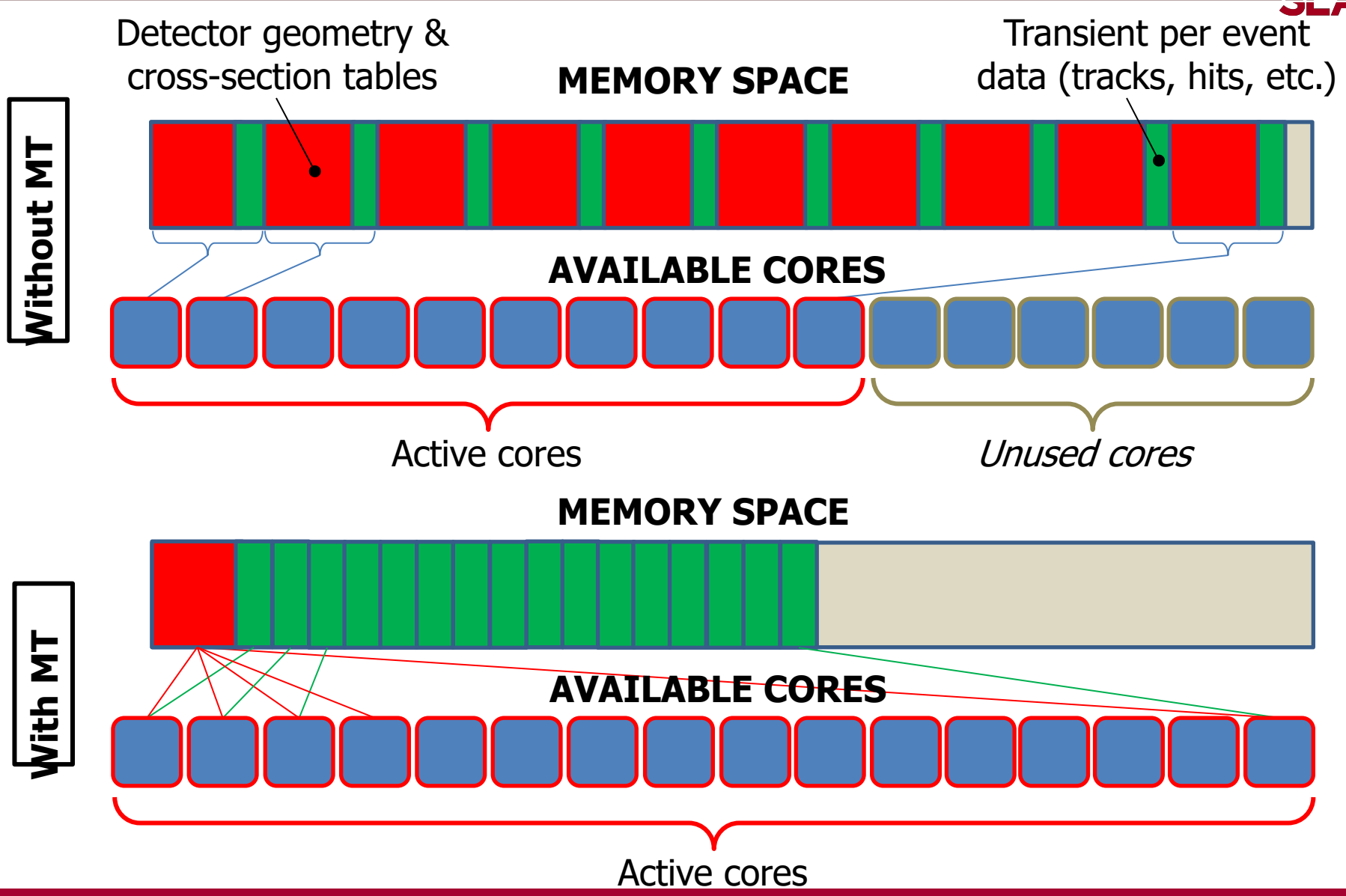
Hadronic model inventory of Geant4



10 GeV π- on Pb / liq.Ar



Geant4 runs in multithreaded mode



Geant4 History

R&D phase (RD44)

Production phase

- Early discussions, for example at CHEP 1994 @ San Francisco
- Dec ’94 – R&D project start
- Apr ’97 - First alpha release
- Jul ’98 - First beta release
- Dec ’98 - First Geant4 public release - version 1.0

- Several major architectural revisions
  - E.g. STL migration, “cuts per region”, parallel worlds, **multithreading**

- Dec 4th, ’20 – Geant4 version 10.7 release
  - Feb 5th, ’21 - Geant4 10.7-patch01 release ← Current version
  - Next week - Geant4 10.7-patch02 release
- We currently provide one public release every year.
  - Next version - Geant4 11.0 (planned in Dec 2021)

Geant4 – A Simulation Toolkit



















http://www.geant4.org/





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













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



























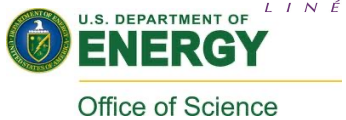














S. Agostinelli et al.

Geant4: a simulation toolkit

NIM A, vol. 506, no. 3, pp. 250-303, 2003

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GEANT4 - A simulation toolkit

Agostinelli S., Allison J., Amako K., Apostolakis J., Araujo H., Arce P., Asai M., (...), Zschiesche D.

(2003) *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 506 (3), pp. 250-303.

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J. Allison et al.

Recent developments in Geant4

NIM A, vol. 835, pp. 186-225, 2016

Outline

Abstract

Keywords

1. The evolution of GEANT4

2. Multithreading

3. Kernel functionalities

4. Recent developments in physics modeling

4.4. Results

5. Toolkit extensions

6. Validation

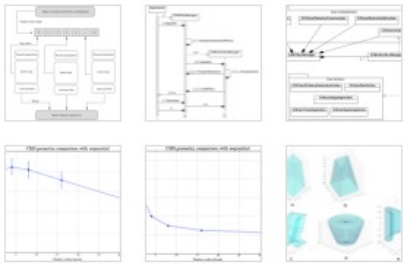
7. Outlook for the next decade

Acknowledgments

References

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Figures (23)



Show all figures

Tables (14)

Table 1

Table

ELSEVIER

Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 835, 1 November 2016, Pages 186-225



Recent developments in GEANT4

J. Allison [a, b], K. Amako [c, a], J. Apostolakis [d], P. Arce [e], M. Asai [f], T. Aso [g], E. Bagli [h], A. Bagulya [i], S. Banerjee [j], G. Barrand [k], B.R. Beck [l], A.G. Bogdanov [m], D. Brandt [n], J.M.C. Brown [o], H. Burkhardt [d], Ph. Canal [j], D. Cano-Ott [p], S. Chauvie [q] ... H. Yoshida [bs, a]

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https://doi.org/10.1016/j.nima.2016.06.125

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Highlights

- Multithreading resulted in a smaller memory footprint and nearly linear speed-up.
- Scoring options, faster geometry primitives, more versatile visualization were added.
- Improved electromagnetic and hadronic models and cross sections were developed.
- Reverse Monte Carlo and general biasing methods were added.
- Physics validation efforts were expanded and new validation tools were added.

Recommended articles

Review of Geant4-DNA appli

Physica Medica, Volume 32, Issue

Purchase PDF

Simulation of Auger electron

Nuclear Instruments and Metho

Purchase PDF

Geant4 Monte Carlo simulati

Nuclear Instruments and Metho

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1 2

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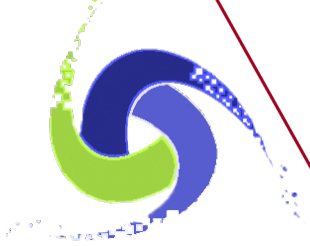
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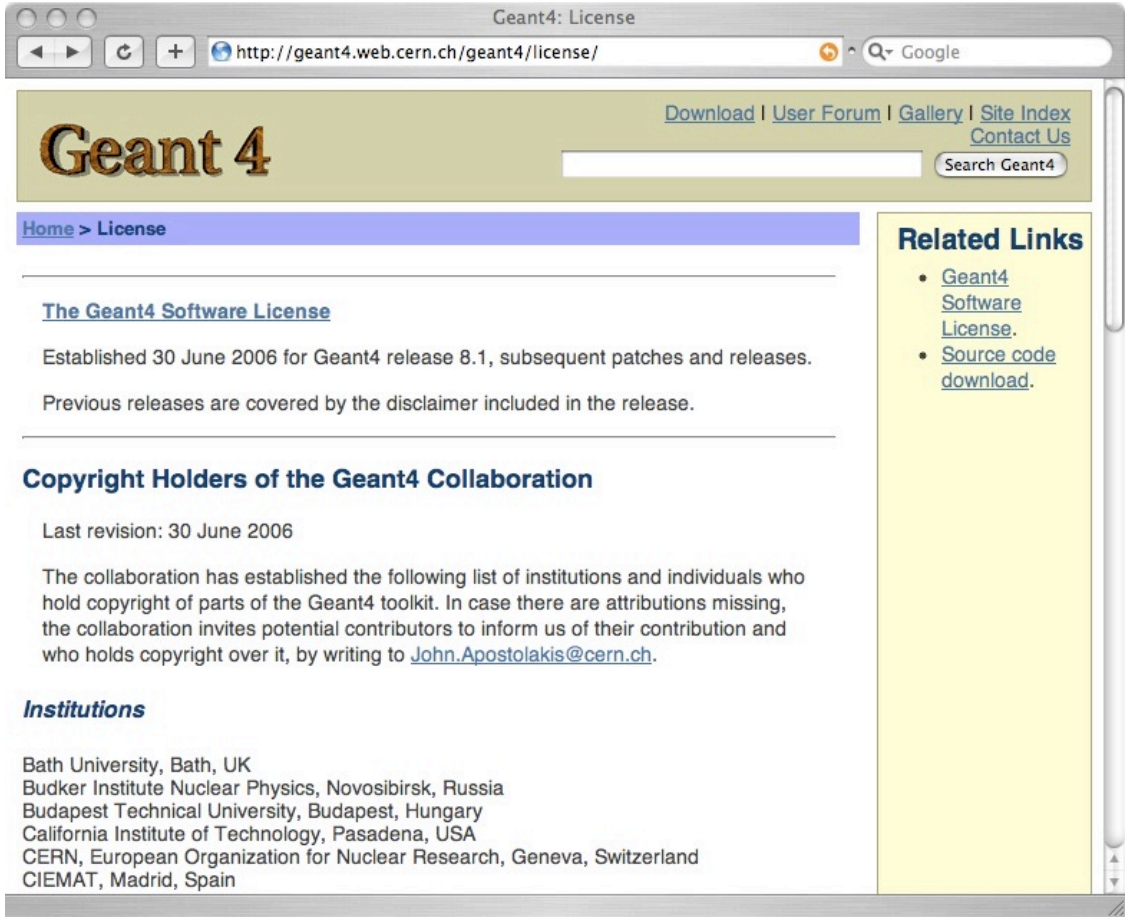
GEANT4
A SIMULATION TOOLKIT

Geant4 license

The New Geant4 License

In response to user requests for clarification of Geant4's distribution policy, the collaboration recently announced a new license.

- Makes clear the user's wide-ranging freedom to use, extend or redistribute Geant4, even as part of some for-profit venture.
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- Simple enough that you can read and understand it.
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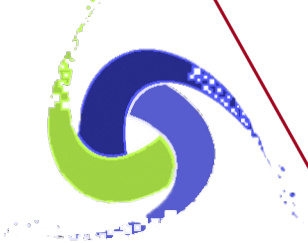
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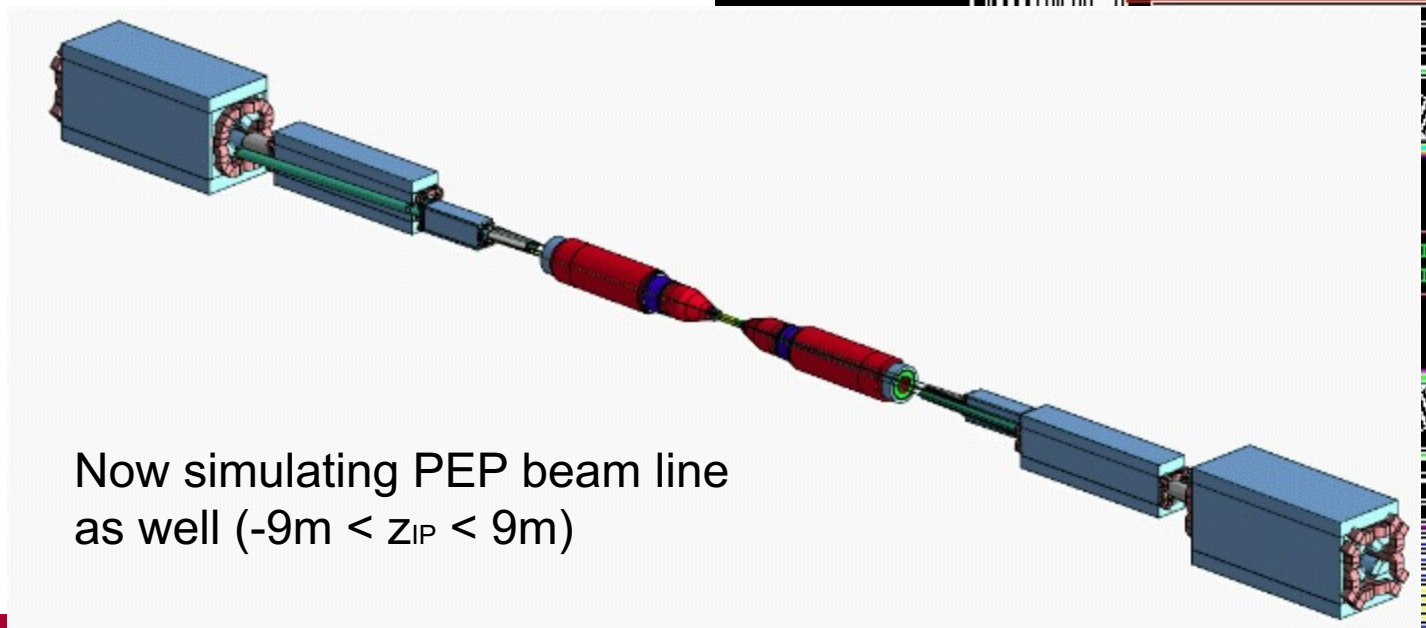
GEANT4
A SIMULATION TOOLKIT

Highlights of Users Applications

To provide you some ideas how Geant4 would be utilized…

BaBar

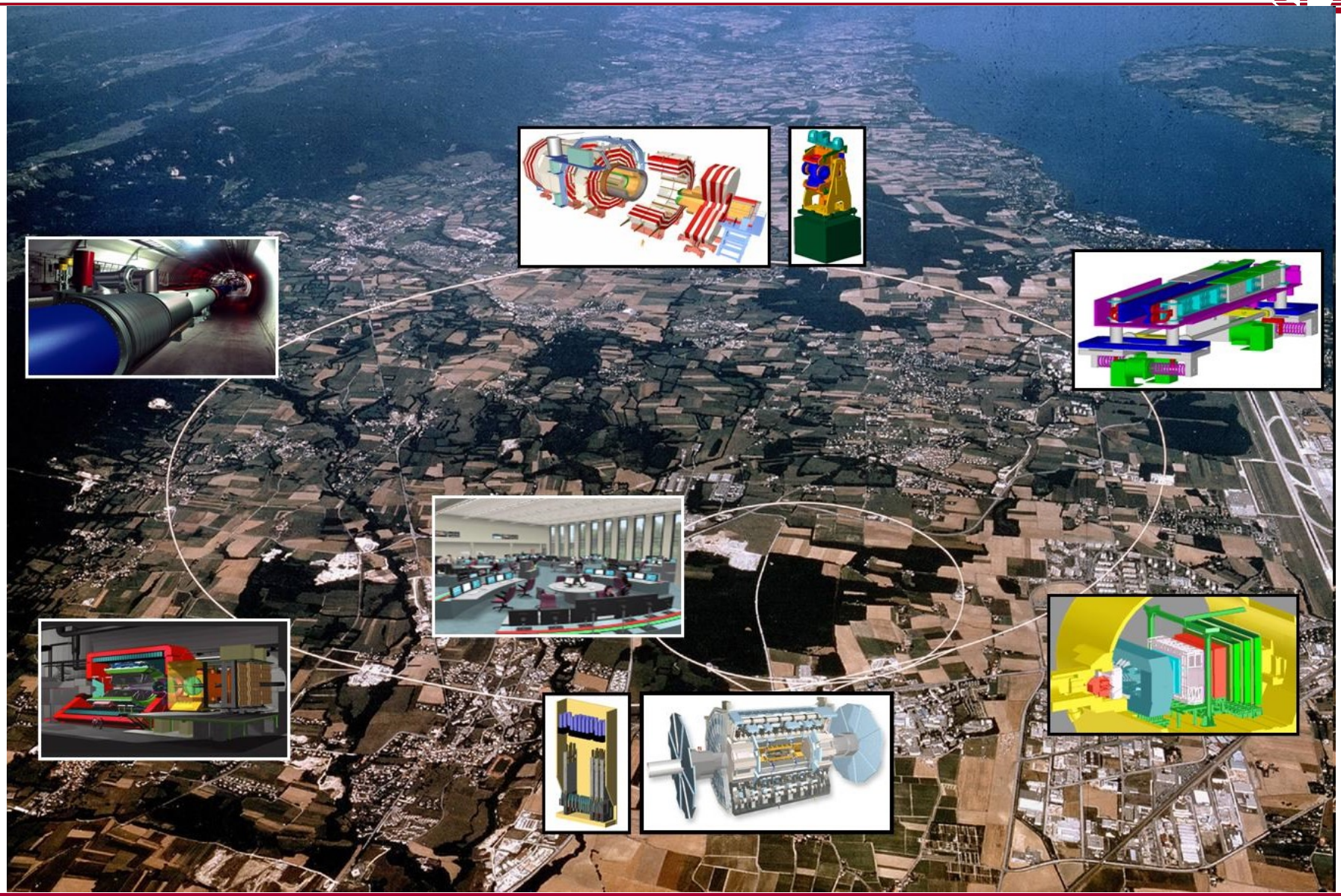
- BaBar at SLAC is the pioneer experiment in HEP in use of Geant4
  - Started in 2000
  - Simulated ~$2*10^{10}$ events so far
  - Produced at 20 sites in North America and Europe



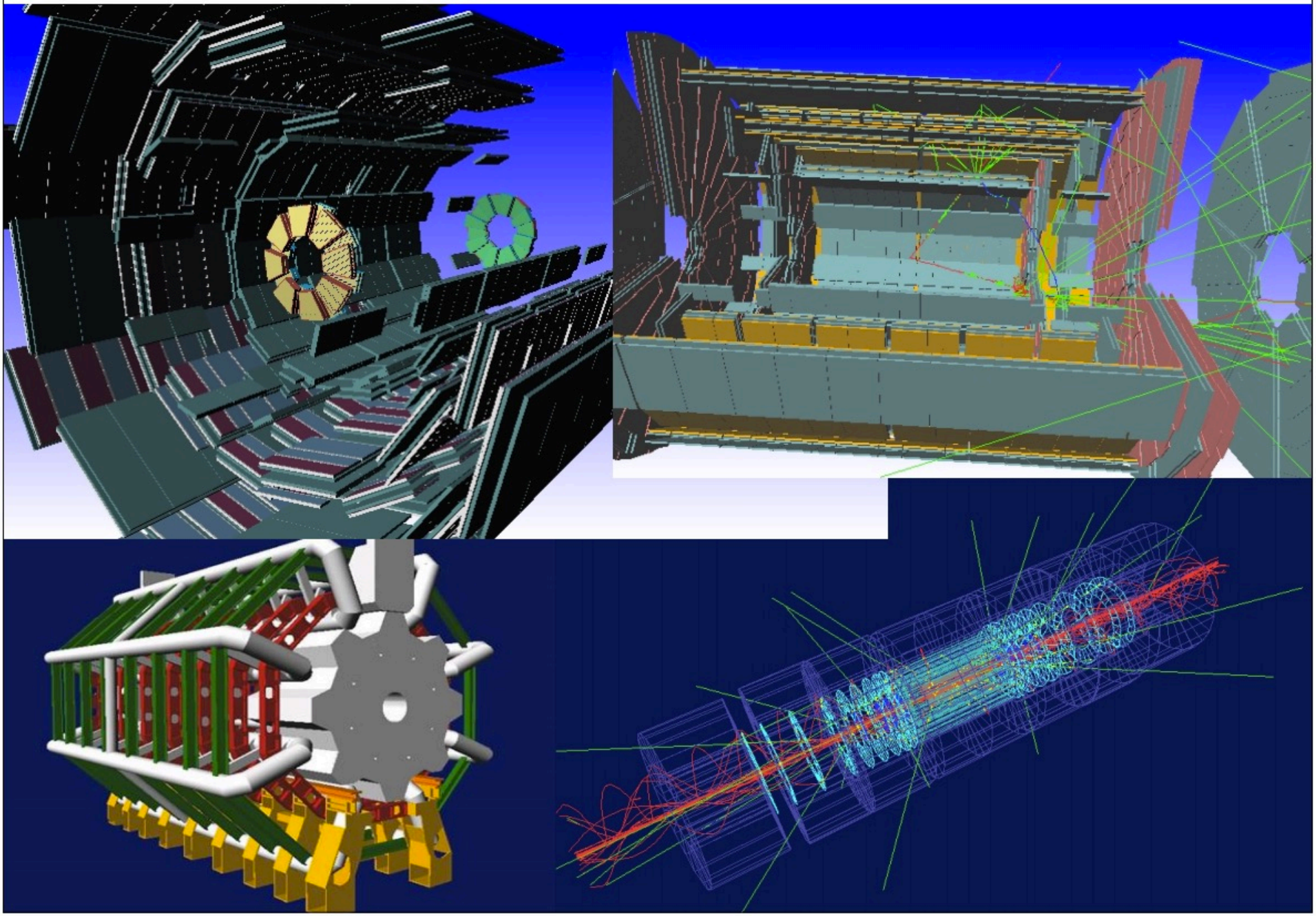
Now simulating PEP beam line as well (-9m < z_{IP} < 9m)

Courtesy of D.Wright (SLAC)

Large Hadron Collider (LHC) @ CERN



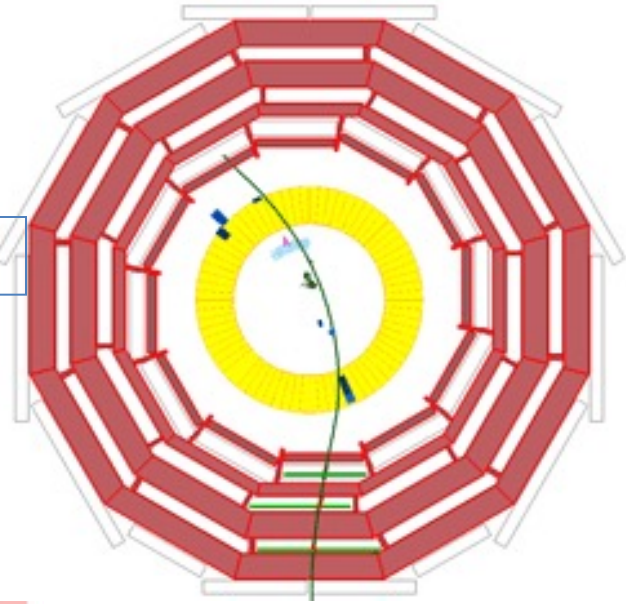
Geant4 in High Energy Physics (ATLAS at LHC)



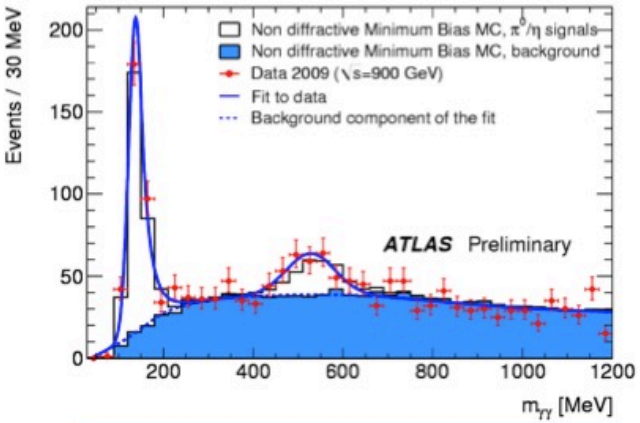
Geant4 has been successfully employed for

- Detector design
- Calibration / alignment
- First analyses

T. LeCompte (ANL)



GEANT4 Comparisons with the Calorimeters



Invariant mass of pairs of well-isolated electromagnetic clusters.

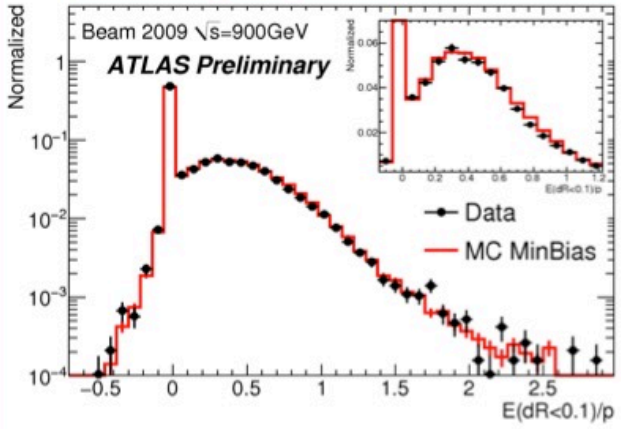
The π^0 mass is within 0.8 ± 0.6% of expectations.

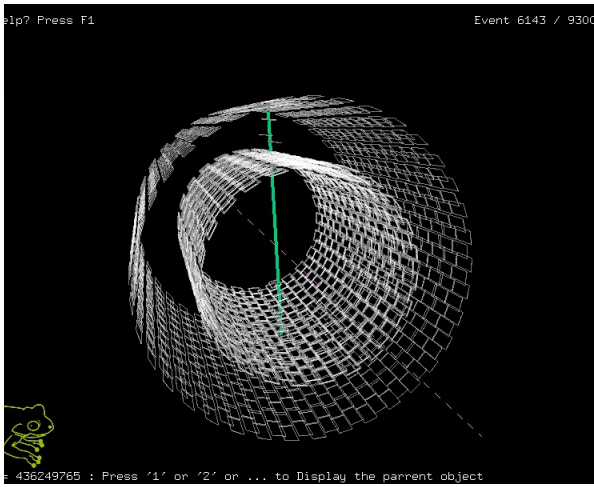
The η^0 mass is within 3 ± 2% of expectations.

The detector uniformity is better than 2%.

Response of the calorimeter to single isolated tracks. To reduce the effect of noise, topological clusters are used in summing the energy.

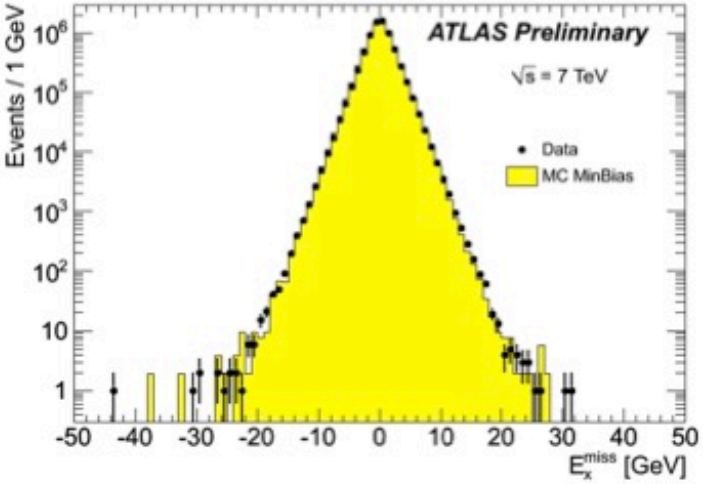
This plot agreed better than we ever expected. (I sent the student who made it back to make sure that they didn't accidentally compare G4 with G4.

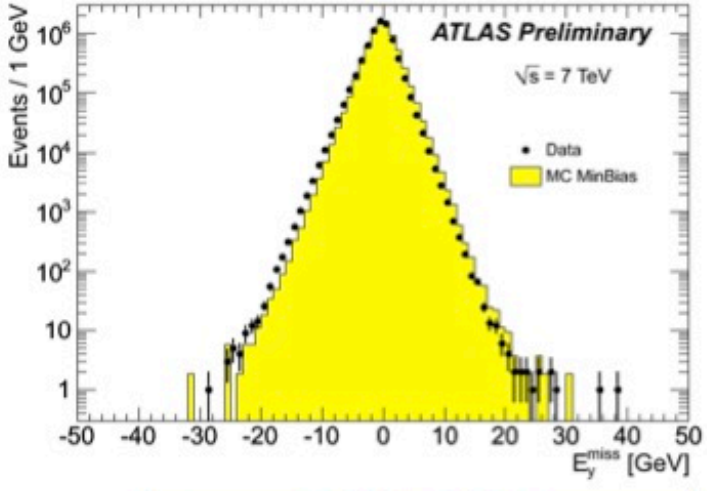


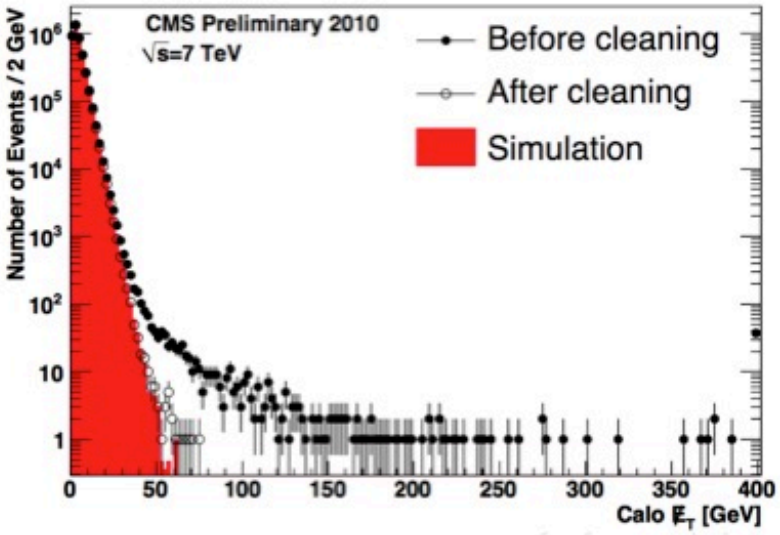


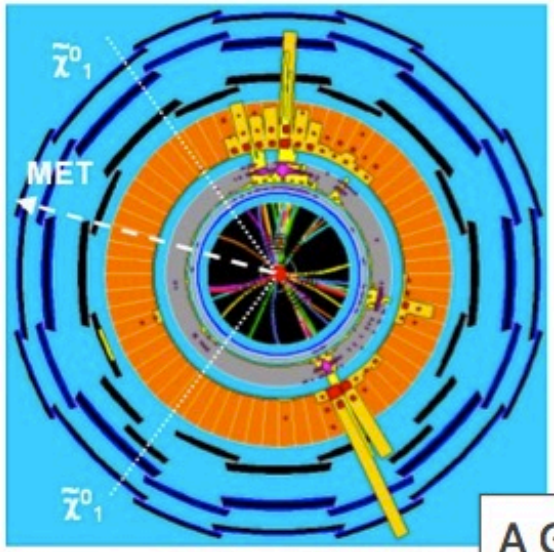
Figures from CMS

Missing E_T









A GEANT4 event.

This is one of the hardest things to get right. MET incorporates everything measured in the detector and attempts to identify non-interacting particles, such as neutrinos or dark matter.

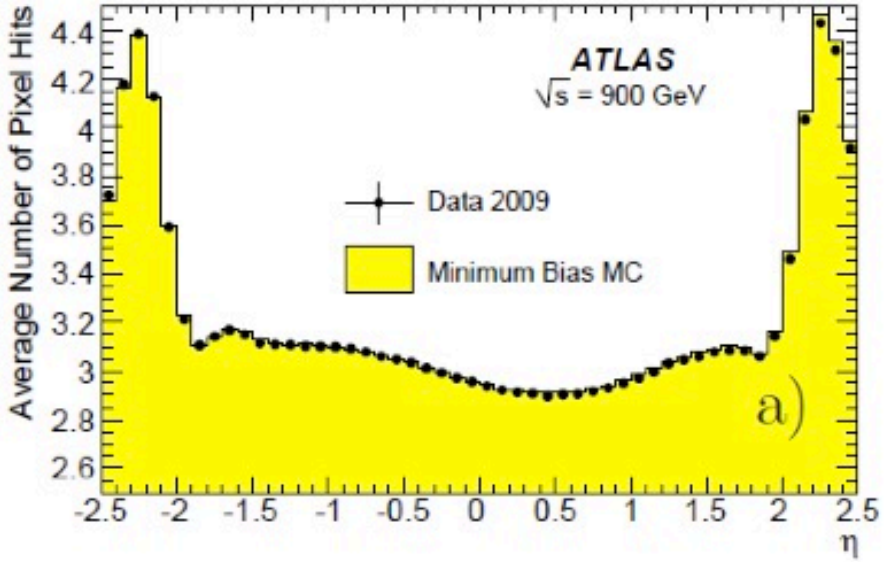
Agreement is astounding.

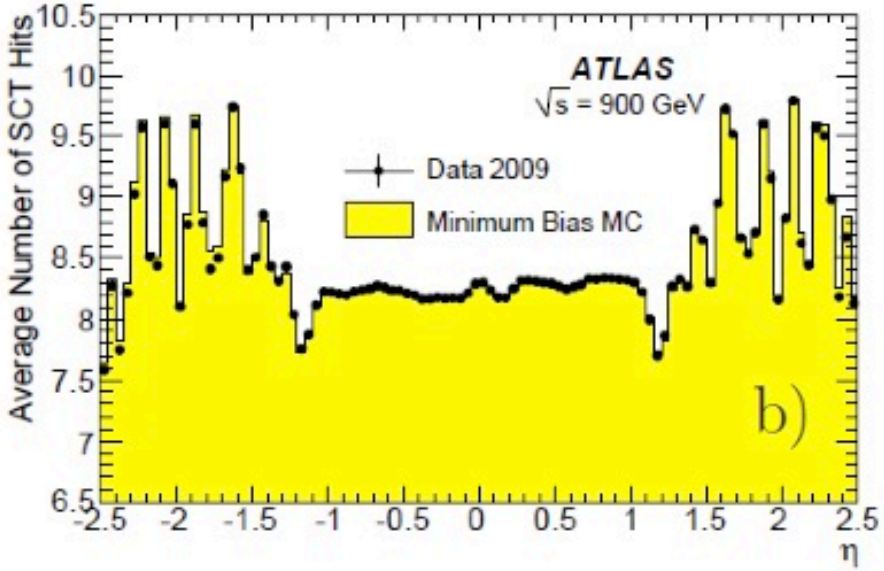
You can even see that the ATLAS detector is not quite centered – in both data and MC.

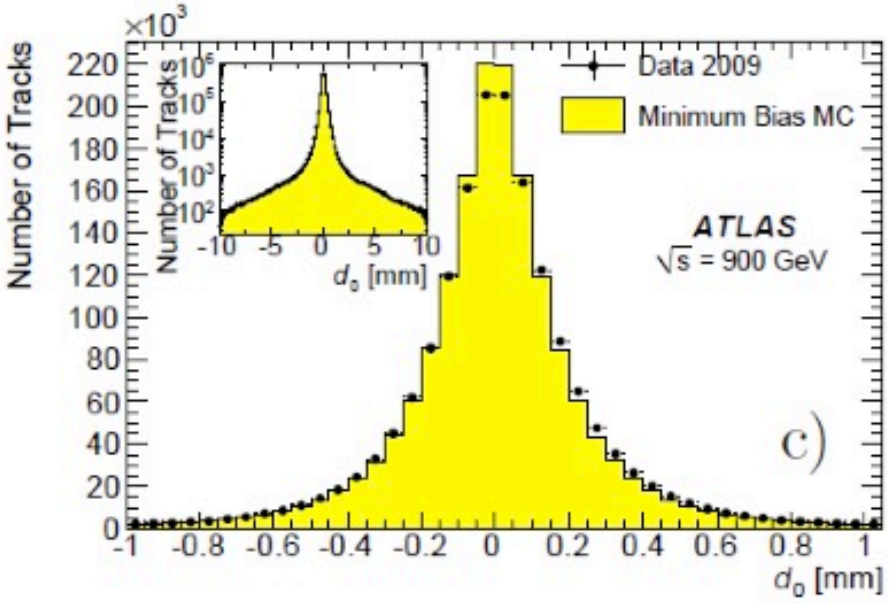
Both ATLAS and CMS plots are made from a tiny piece of the very earliest data.

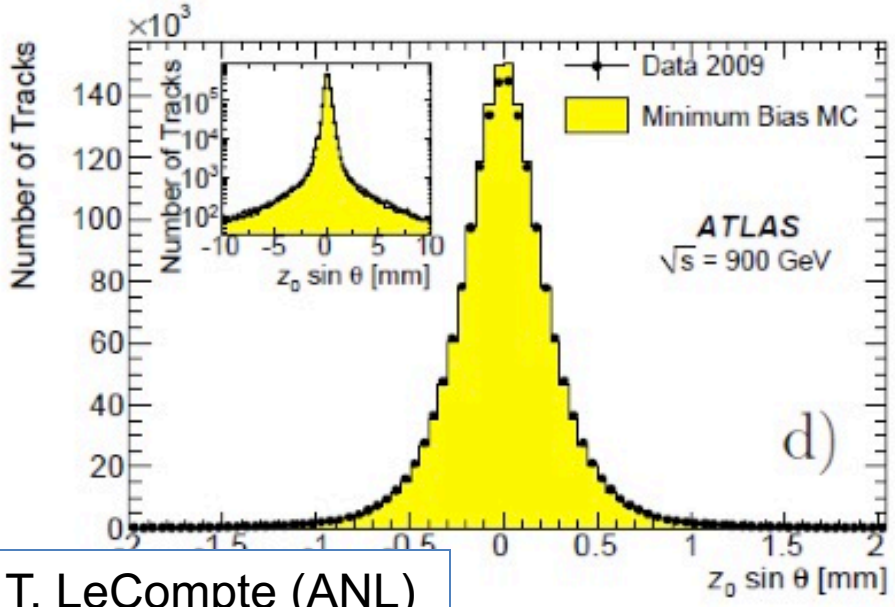
T. LeCompte (ANL)

Data and simulation agreements



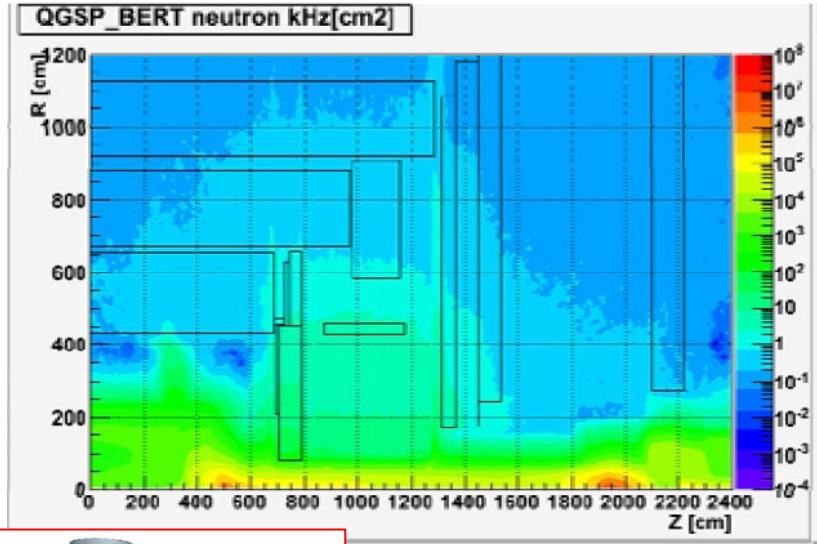


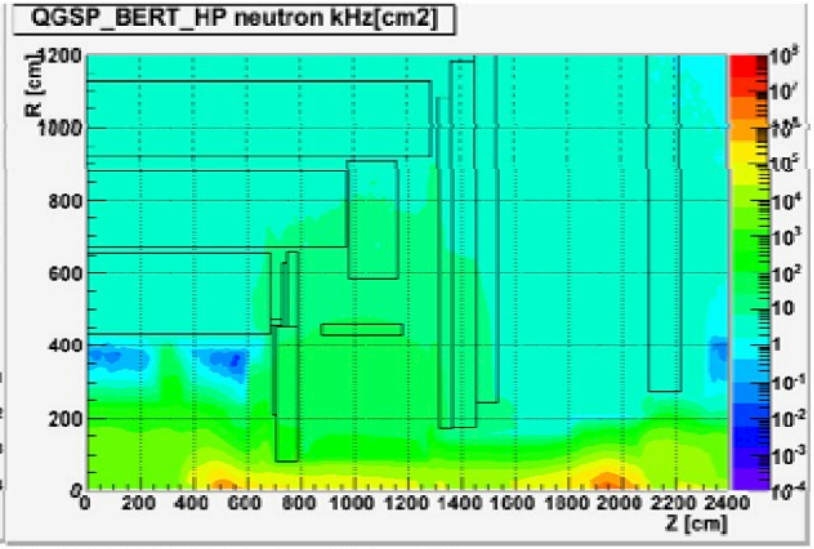


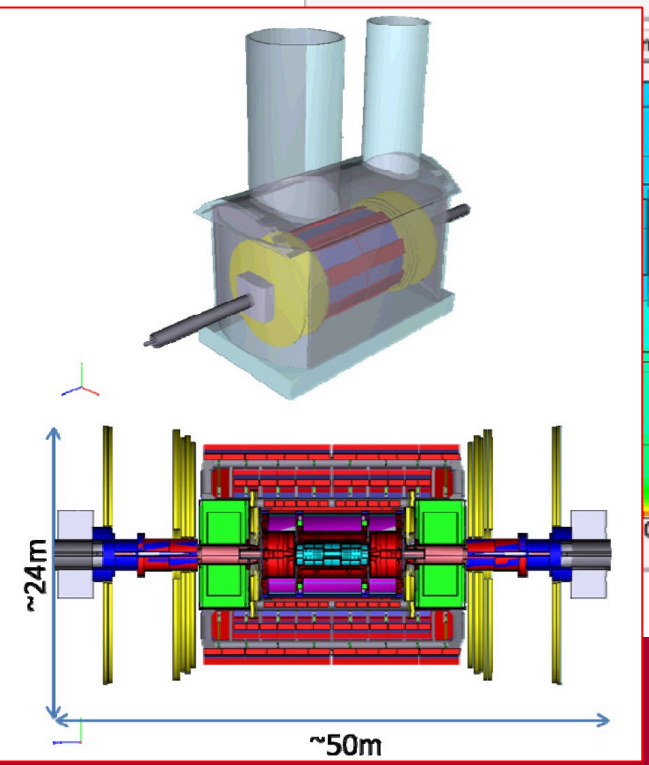


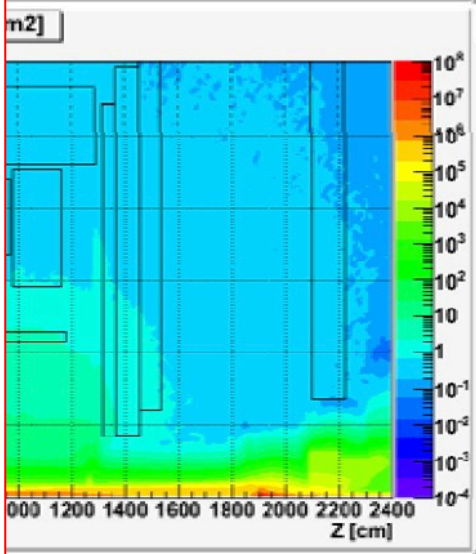
T. LeCompte (ANL)

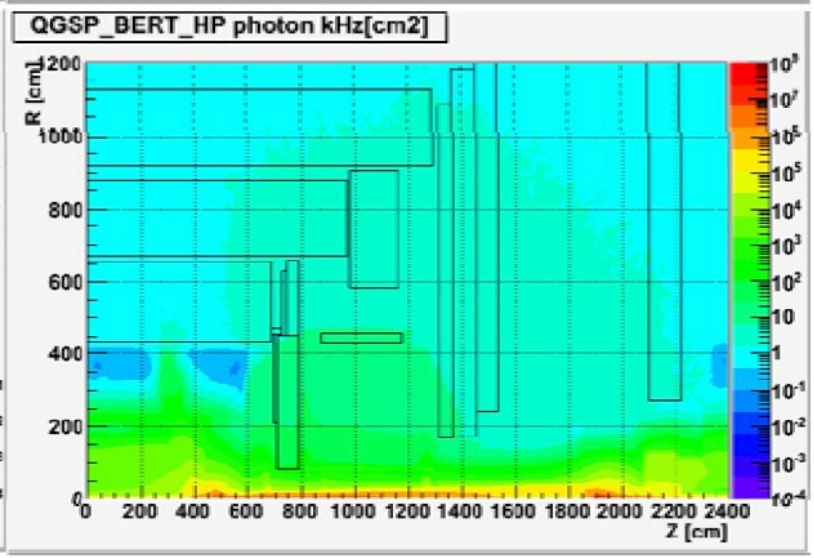
ATLAS cavern background study

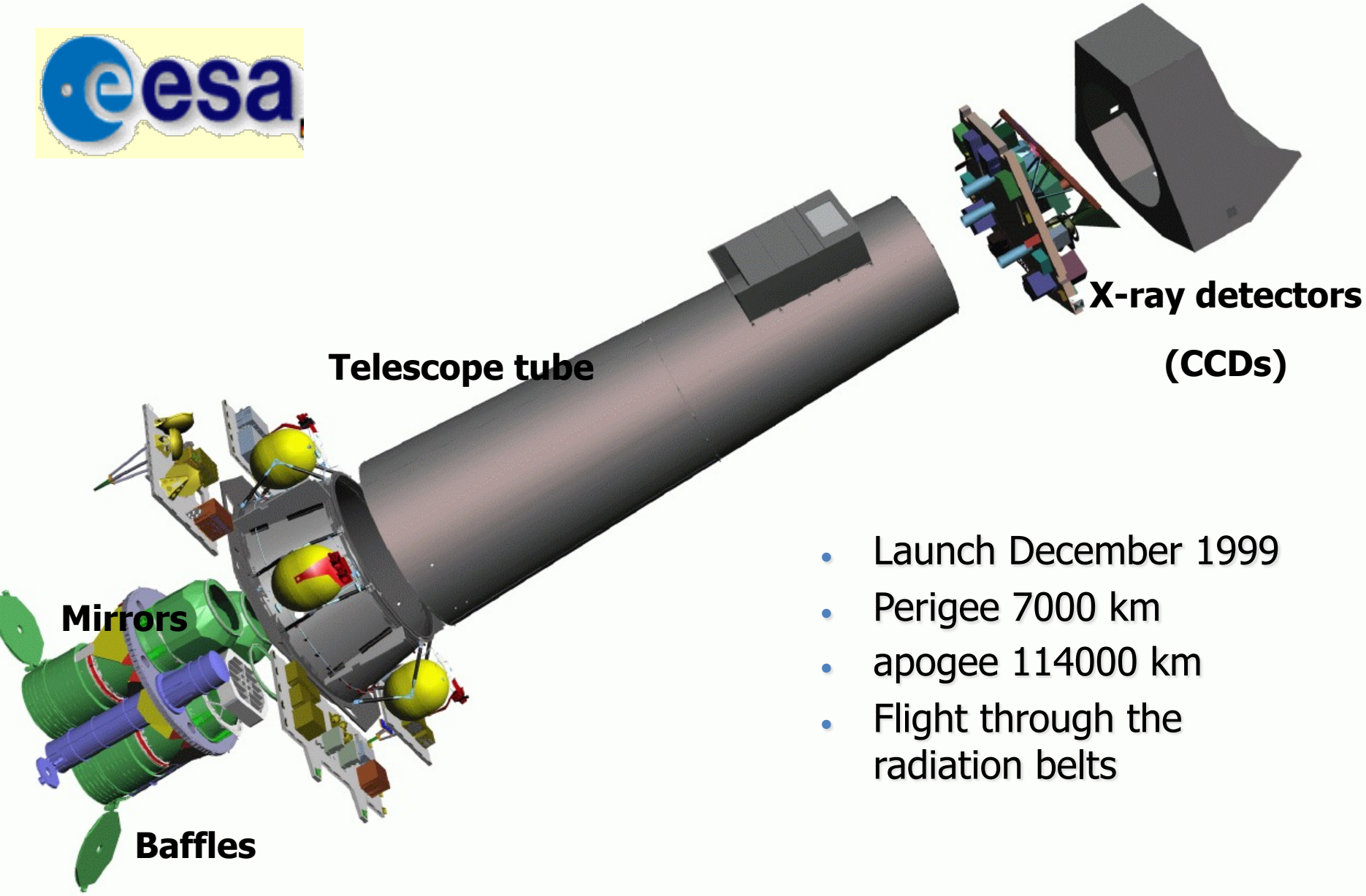




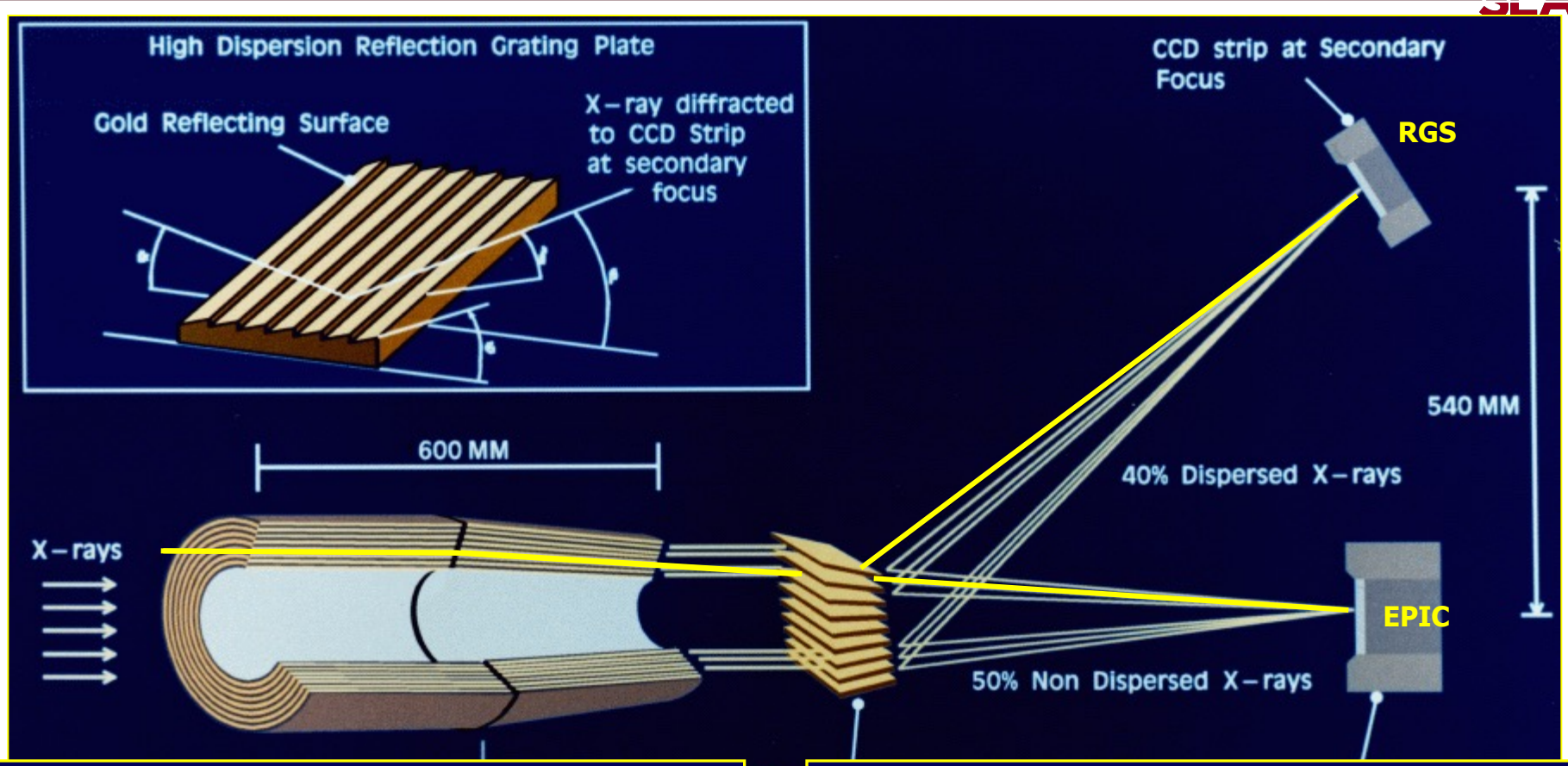








- Launch December 1999
- Perigee 7000 km
- apogee 114000 km
- Flight through the radiation belts



Low-E (~100 keV to few MeV), low-angle (~0° -5°) proton scattering:

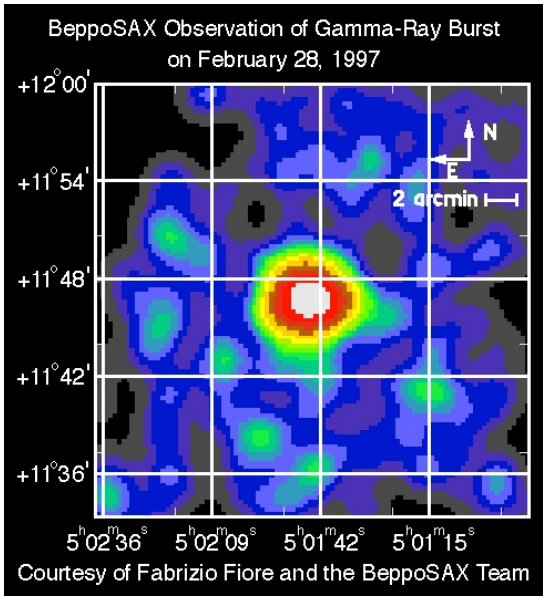
Obscure problem; not much analysed

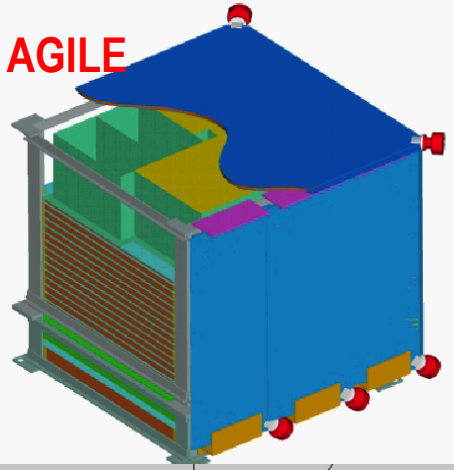
As the outcome of the simulation, beam shutter was introduced.

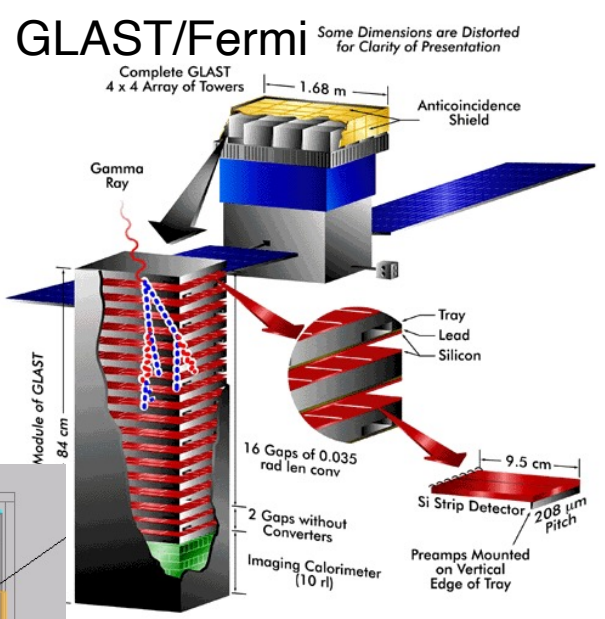
The shutter is closed while XMM is passing through the radiation belt.

γ astrophysics

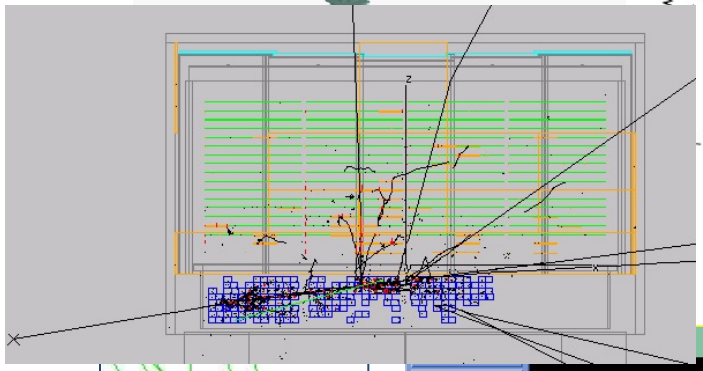
γ-ray bursts

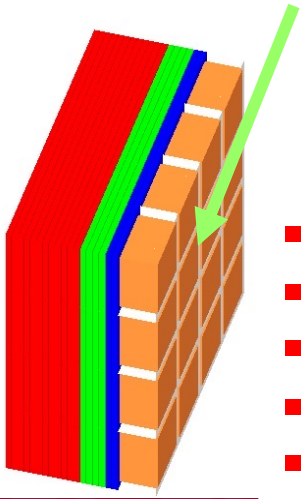






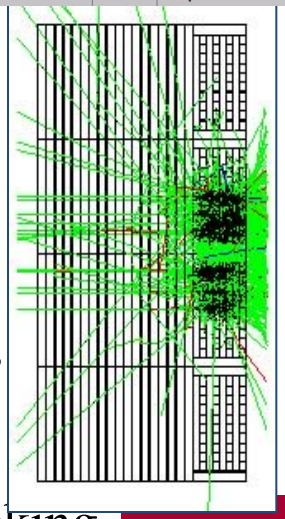
GLAST / Fermi

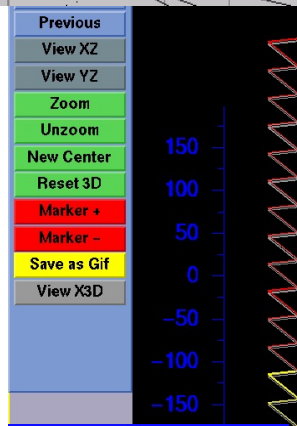


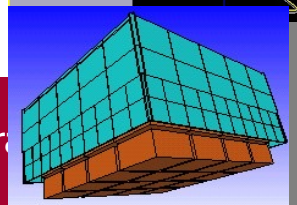


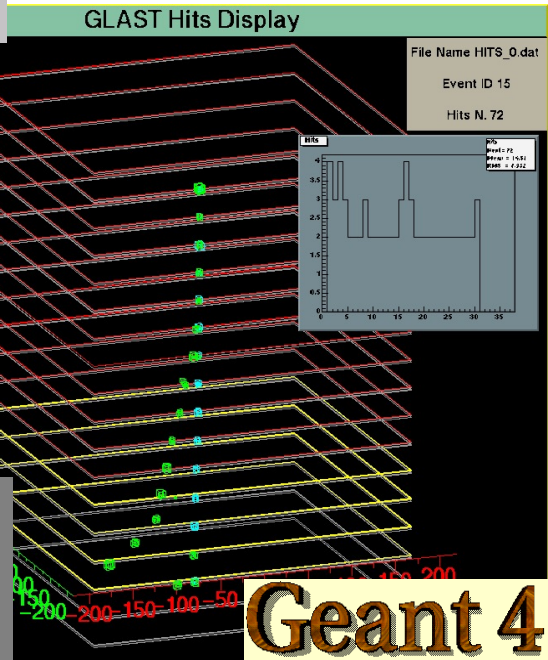
Typical telescope:
Tracker
Calorimeter
Anticoincidence

- γ conversion
- electron interactions
- multiple scattering
- δ-ray production
- charged particle tracking



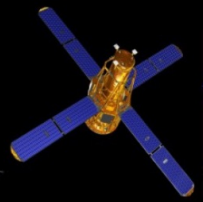




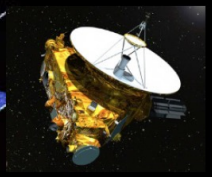


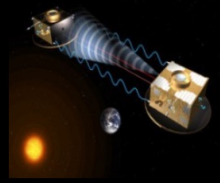
Geant4 in space

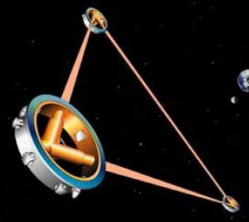

Akebono

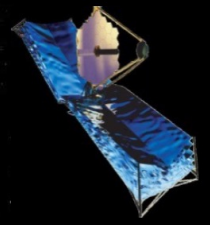

RHESSI


ACE

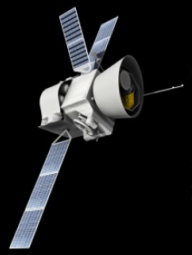

New Horizons


LISA Pathfinder


LISA

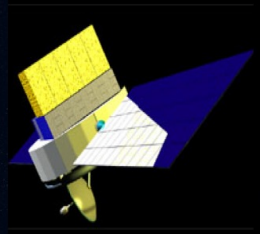

JWST


INTEGRAL


BepiColombo

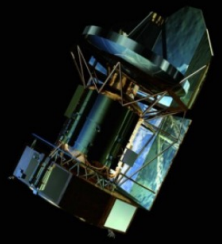

Messenger


Astro-H


Fermi


SOHO


GAIA


Herschel


Cassini

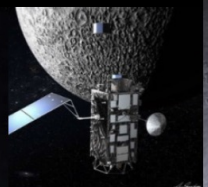

Suzaku

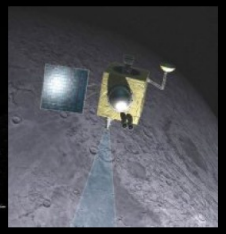

SWIFT


XMM-Newton


JUICE


JUNO


Kaguya


Chandrayaan-1

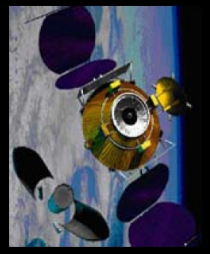

Chandrayaan-2


Columbus

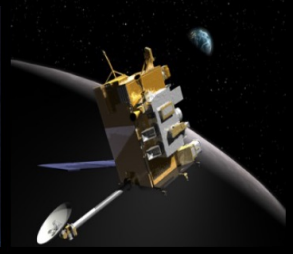

EUSO


AMS


MAXI

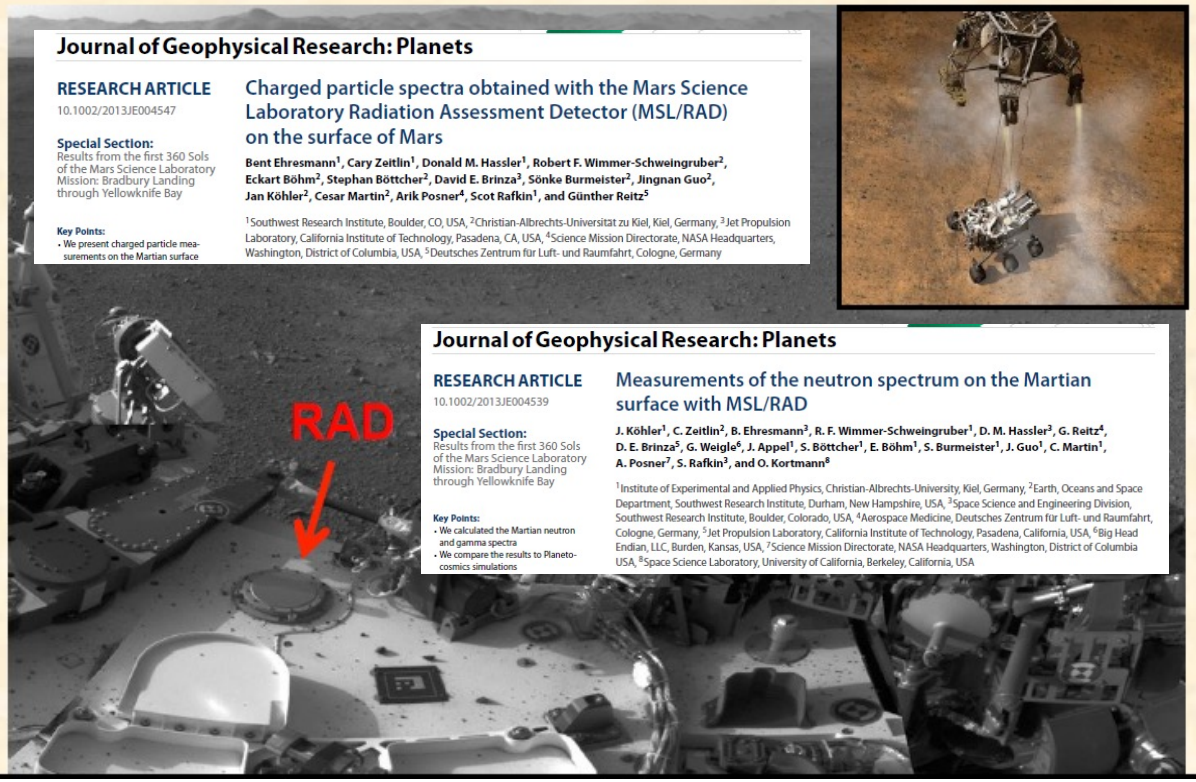

ConeXpress

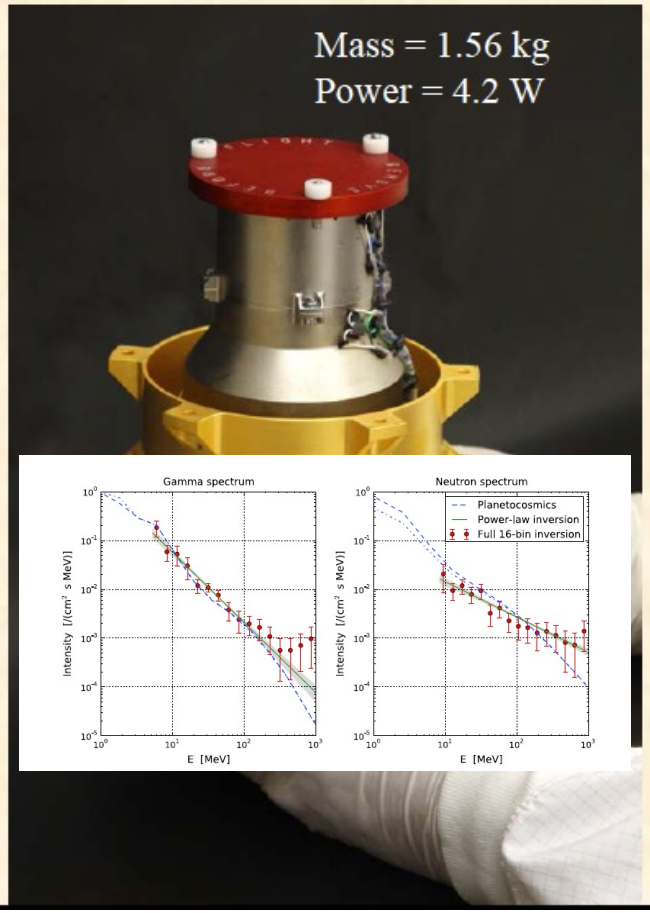

Chang'e-1


LRO

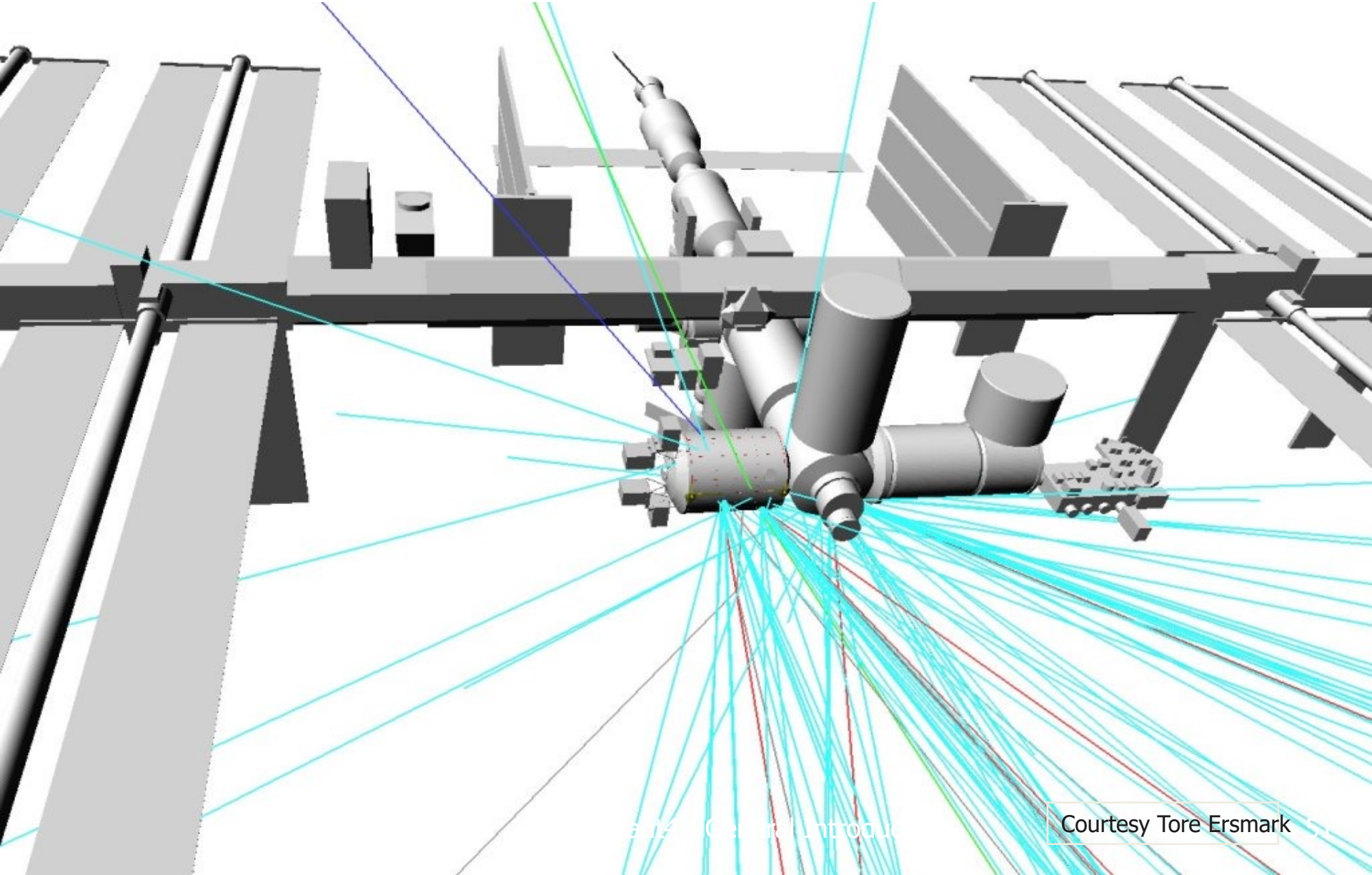
MSL Radiation Assessment Detector (RAD)

- RAD is a compact, highly capable radiation analyzer to characterize the full spectrum of space radiation (both charged & neutral particle).
- MSL RAD is currently characterizing the radiation environment on the surface of Mars.





International Space Station



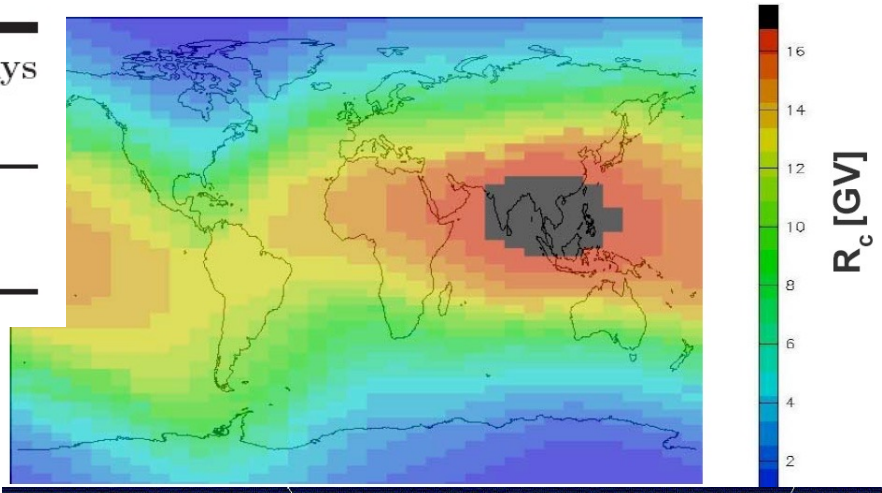
Courtesy Tore Ersmark

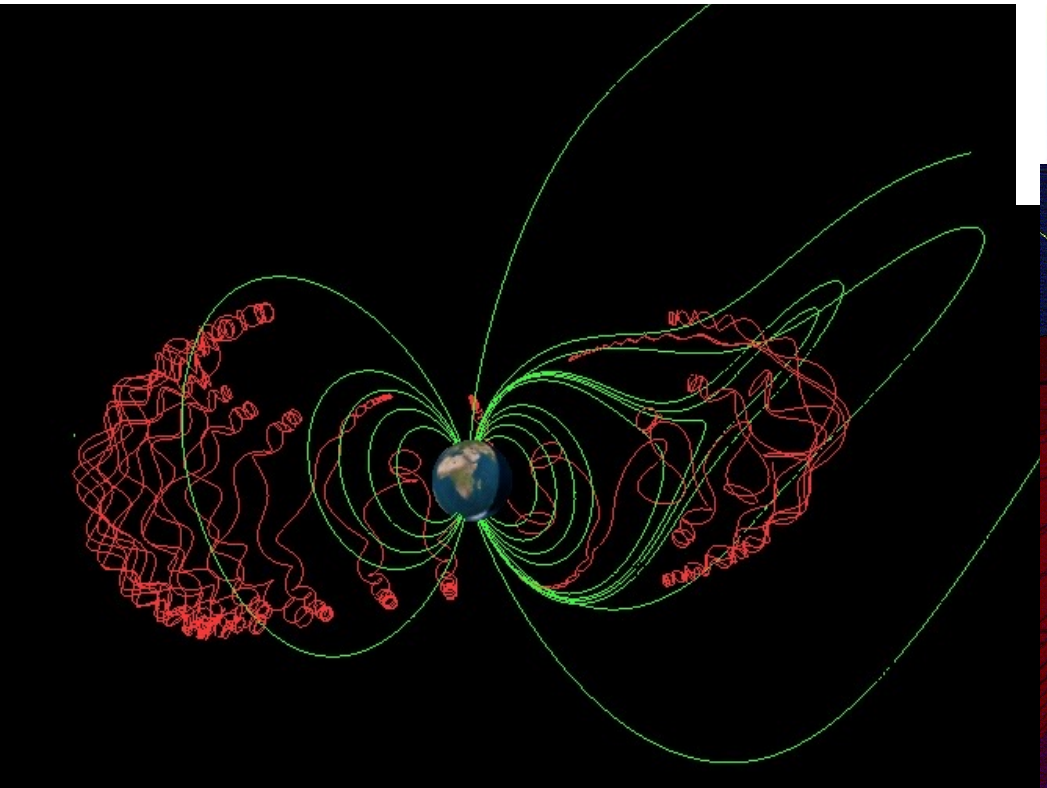
PlanetoCosmics
Geant4 simulation of Cosmic Rays in planetary Atmo-/Magneto- spheres

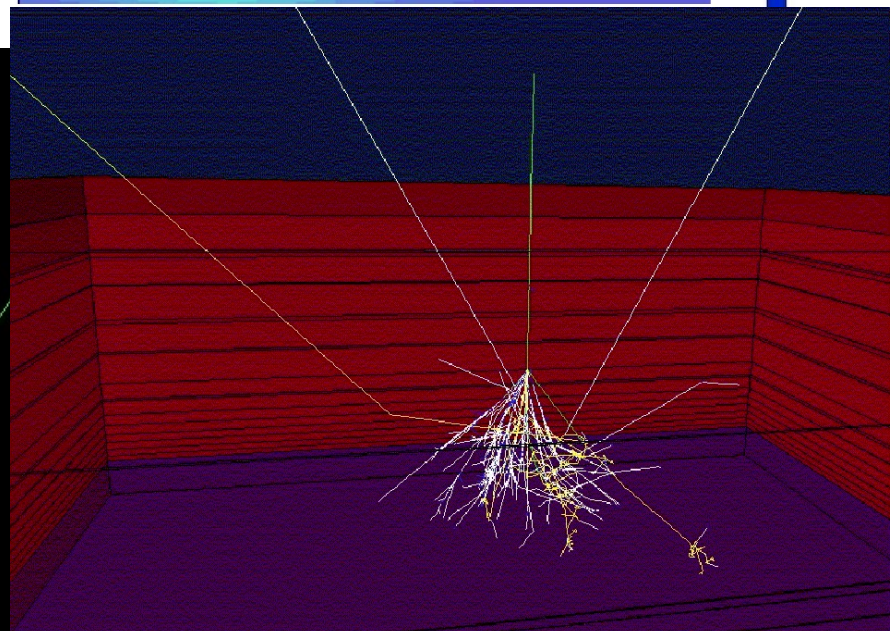
Geant4 Simulation of the Propagation of Cosmic Rays through the Earth's Atmosphere

L. Desorgher, E. O. Flückiger, M. R. Moser, and R. Bütikofer
Physikalisches Institut, University of Bern, CH-3012 Bern, Switzerland

Cutoff Rigidities vs position



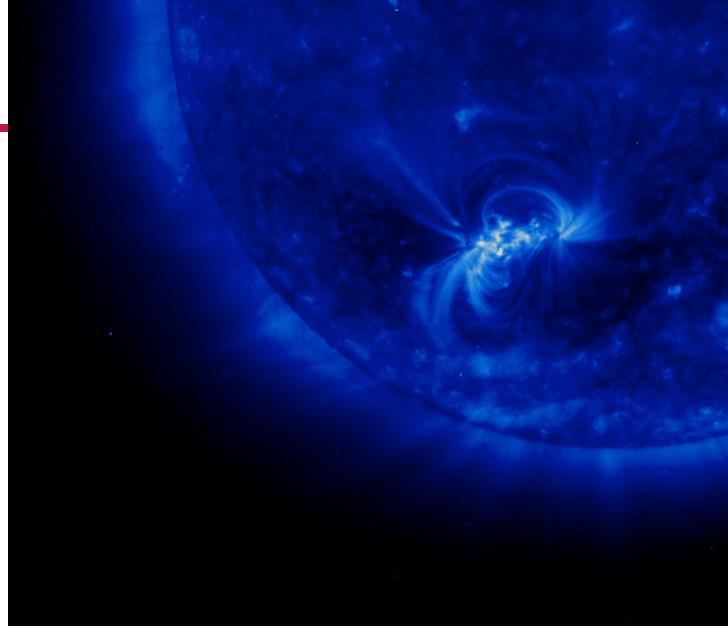


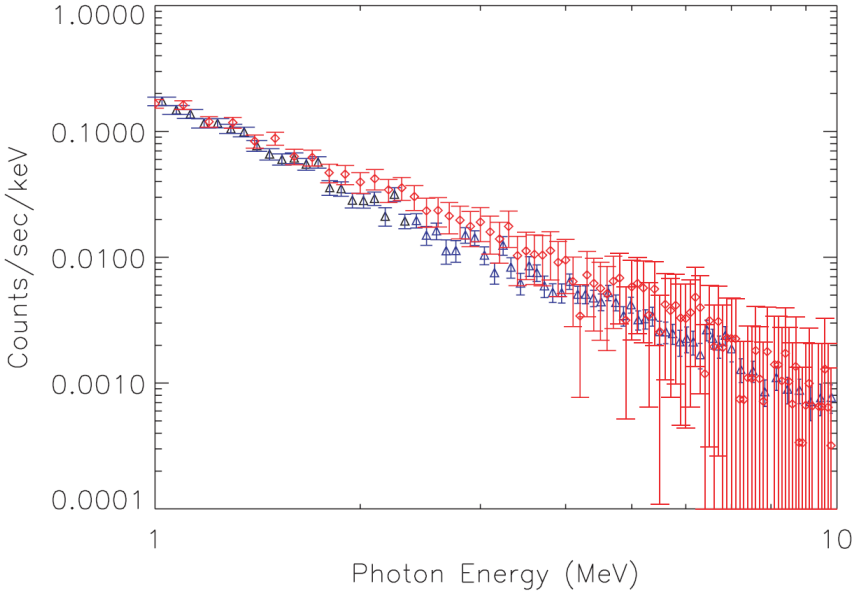


Solar event gamma-rays

- Electron Bremsstrahlung – induced gammas in solar flares
- Compton back-scattering

  → observable gamma-ray spectrum much softer than predicted by simple analytic calculations





Effects of Compton scattering on the Gamma Ray Spectra of Solar flares

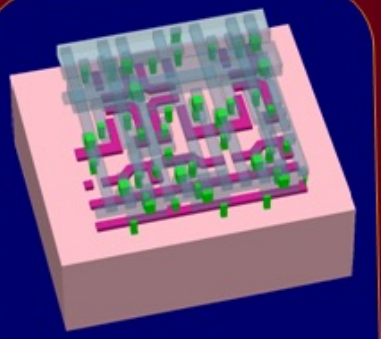
Jun'ichi KOTOKU
National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, JAPAN
junichi.kotoku@nao.ac.jp
Kazuo MAKISHIMA[1] and Yukari MATSUMOTO[2]
Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo, 113-0022
and
Mitsuhiro KOHAMA, Yukikatsu TERADA and Toru TAMAGAWA
RIKEN (Institute of Physical and Chemical research), Wako-shi, Saitama
[1]*Also at RIKEN*
[2]*Present address: Mitsubishi Electric Co., Ltd.*

(Received ; accepted)

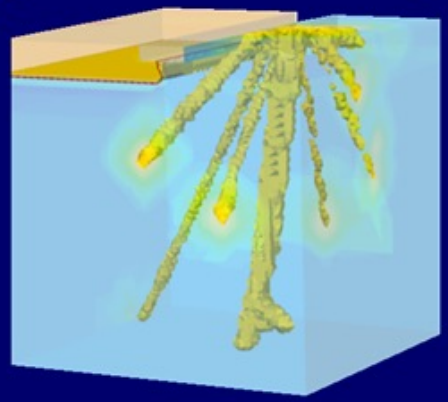
Abstract

Using fully relativistic GEANT4 simulation tool kit, the transport of energetic electrons generated in solar flares was Monte-Carlo simulated, and resultant bremsstrahlung gamma-ray spectra were calculated. The solar atmosphere was ap-

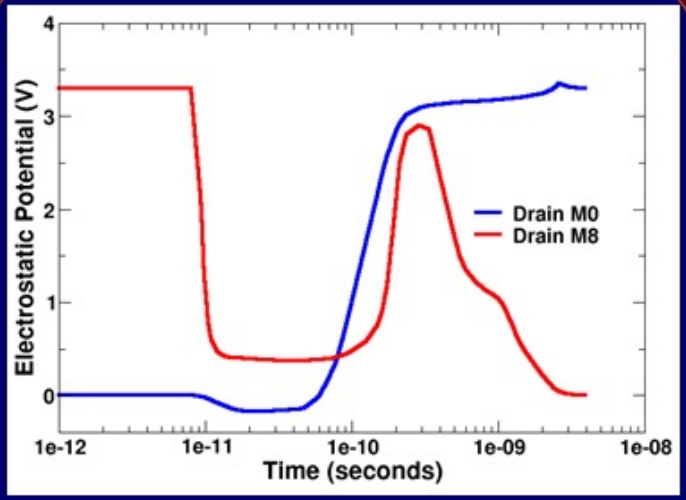
RADSAFE on SEE in SRAMs



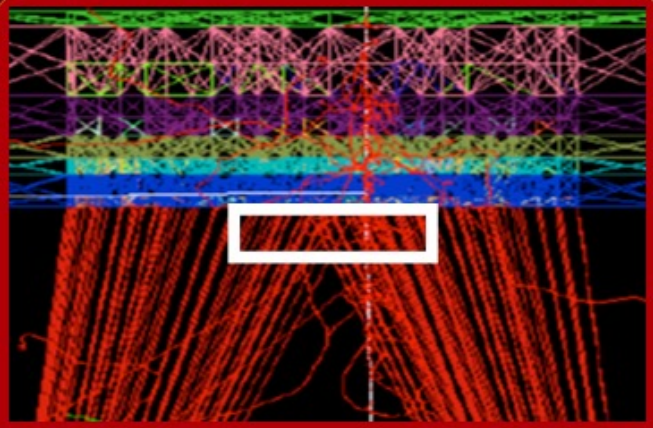
TCAD Cell Structure: SRAM Cell



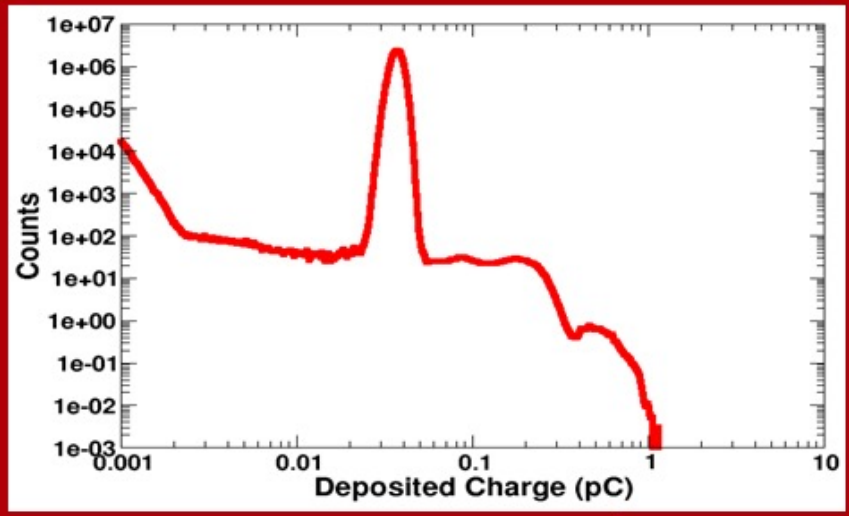
Single Charge Deposition in TCAD: Ne+W Event



SRAM Cell Upset



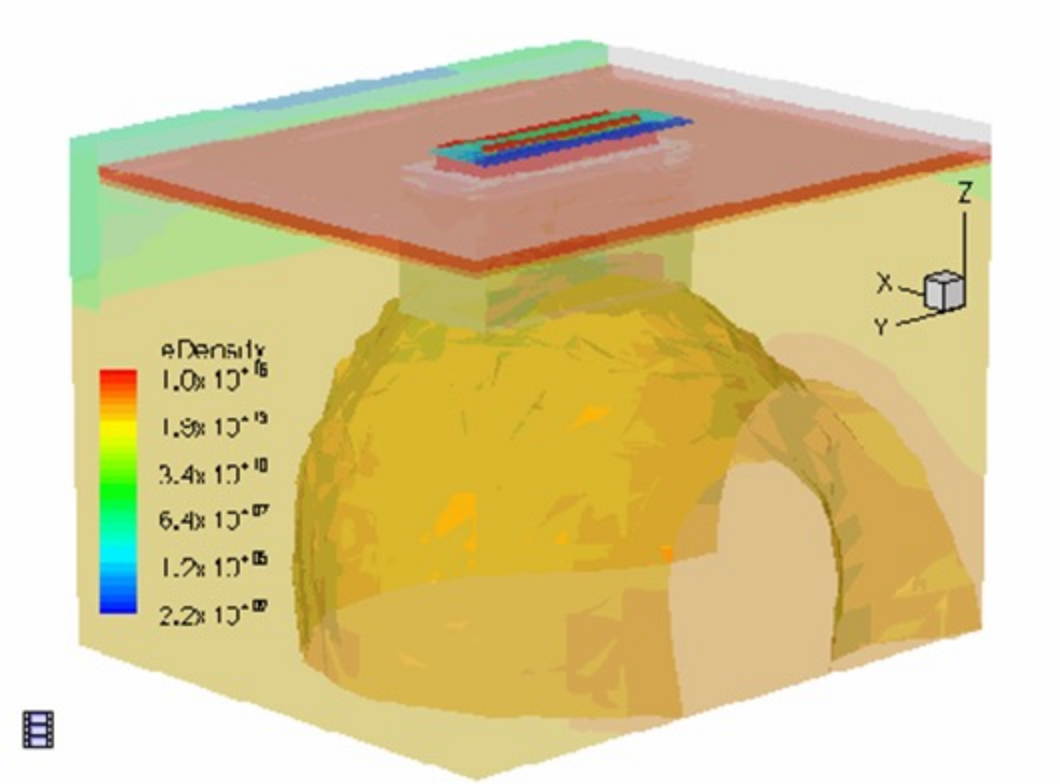
Geant4 Geometry and 523 MeV Neon Event

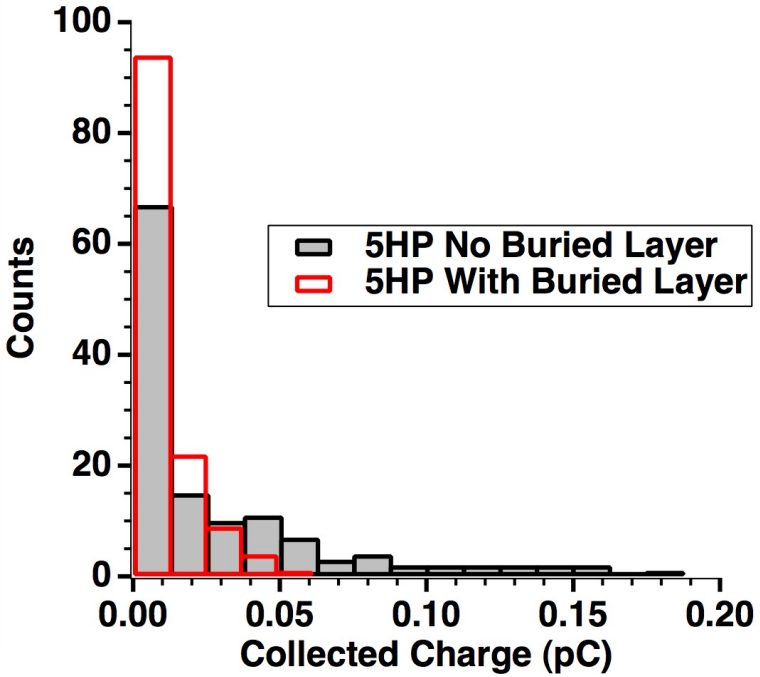


MRED Energy Deposition for 10^8 Events

Simulation of Radiation Events

- 63-MeV proton incident on a SiGe Heterojunction Bipolar Transistor (HBT)
- Iso-charge surfaces following a nuclear reaction



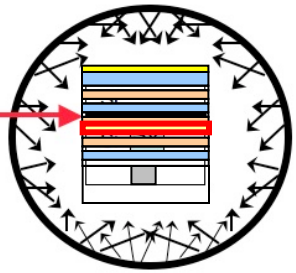


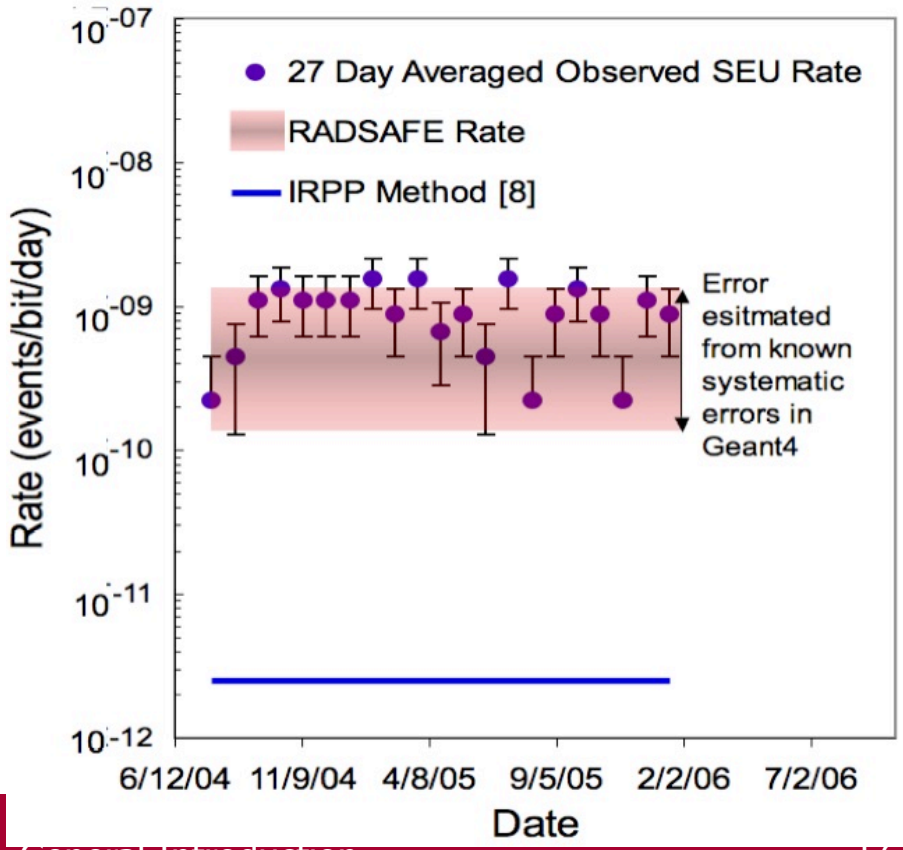
Courtesy of R.Reed (Vanderbilt U.)

Observed and Predicted SEU Rate for an SRAM

- SRAM used on NASA Messenger spacecraft
- Observed Average SEU Rate:
  - $1x10^{-9}$ Events/Bit/Day
- Vendor predicted rate using CREME96:
  - $2x10^{-12}$ Events/Bit/Day
  - Classical Method nearly a factor 500 lower than observed rate
- MRED rate (includes reaction products):
  - Between $1.3x10^{-10}$ and $1.3x10^{-9}$ Errors/Bit/Day

Multi-layered Stack



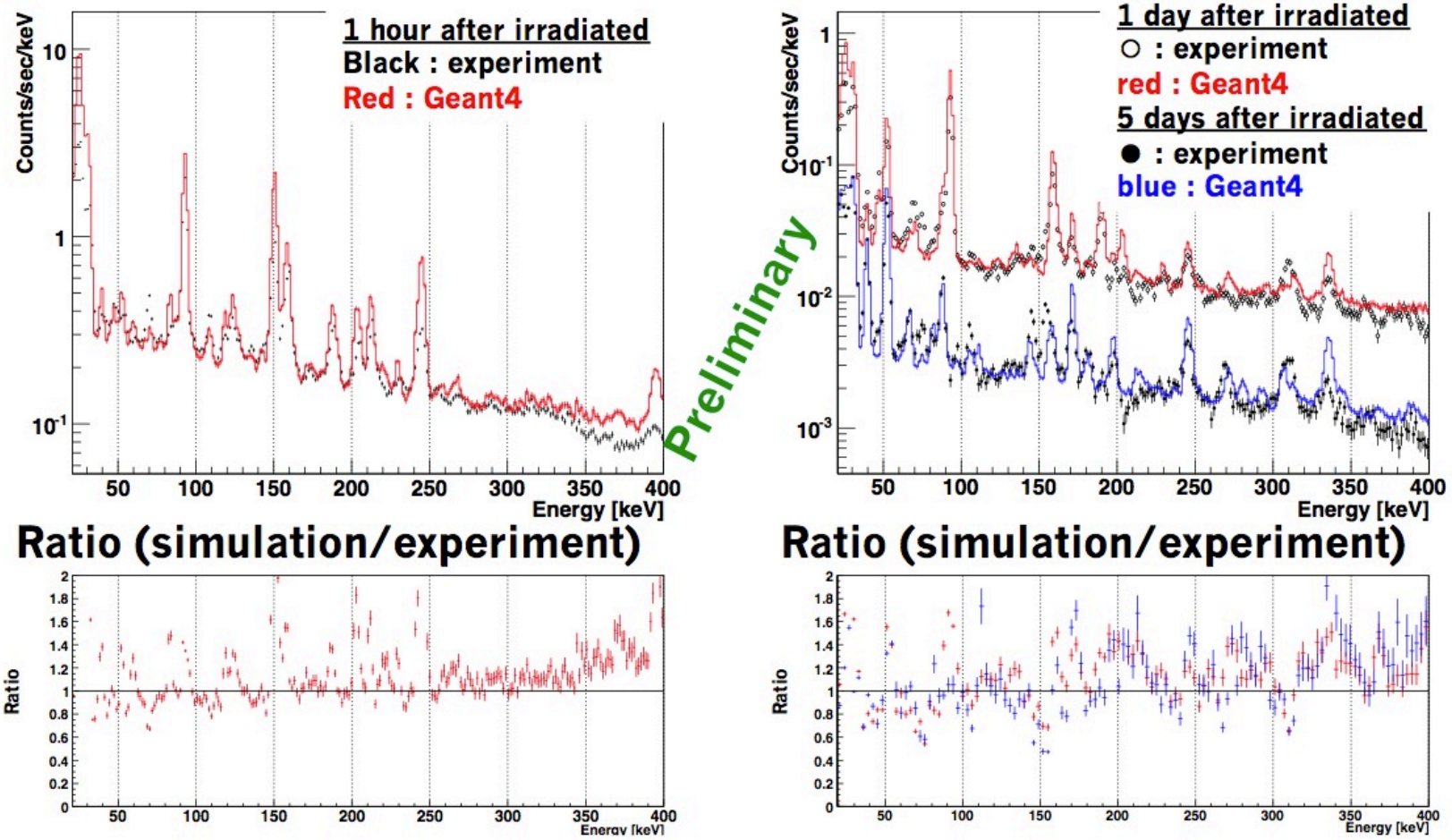


Courtesy of R.Reed (Vanderbilt U.)

Time evolution of the activation background



Comparison with Geant4

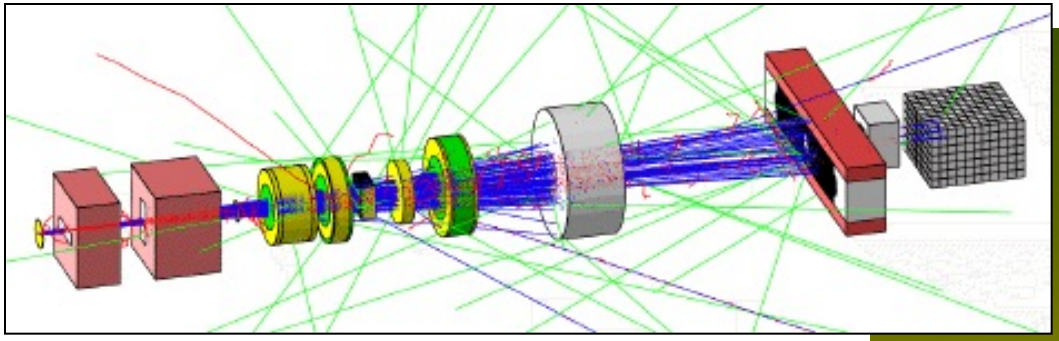


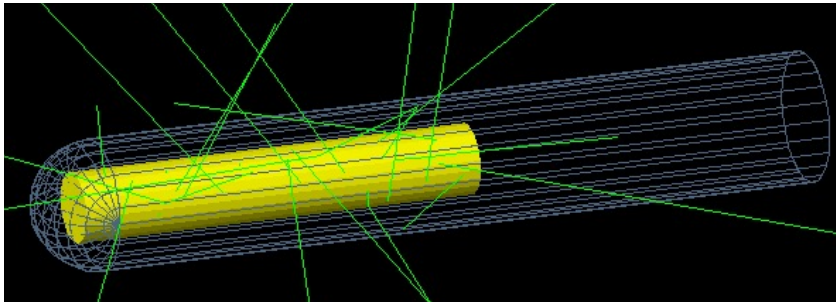
❖ Simulation results agrees with experimental data within a factor of two in terms of the line intensities

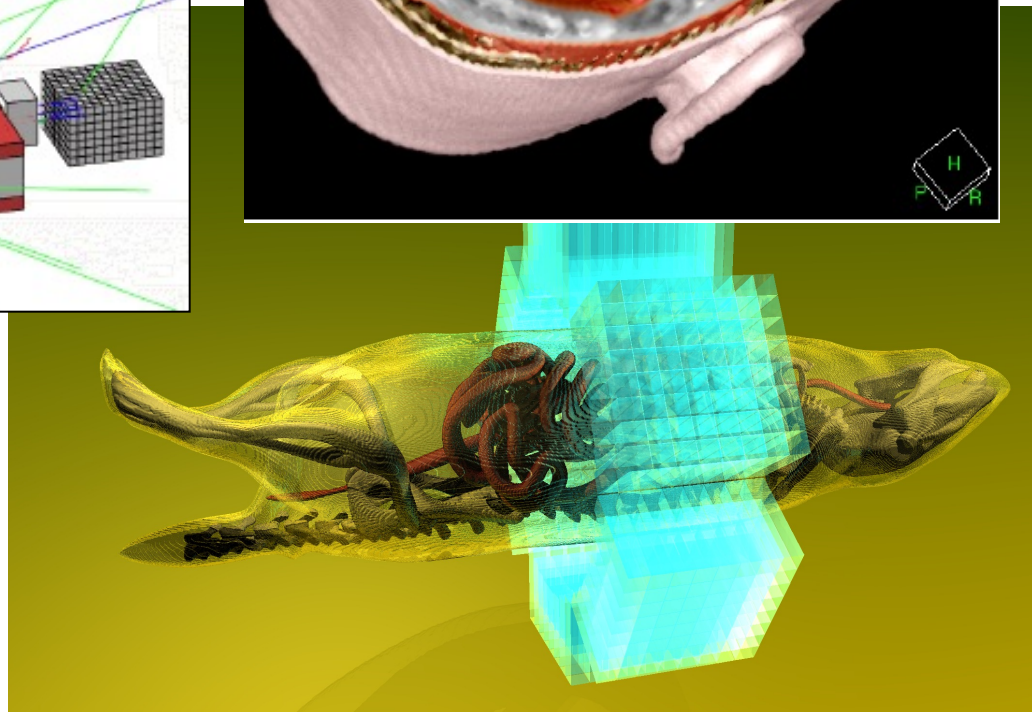
Geant4 @ Medical Science

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



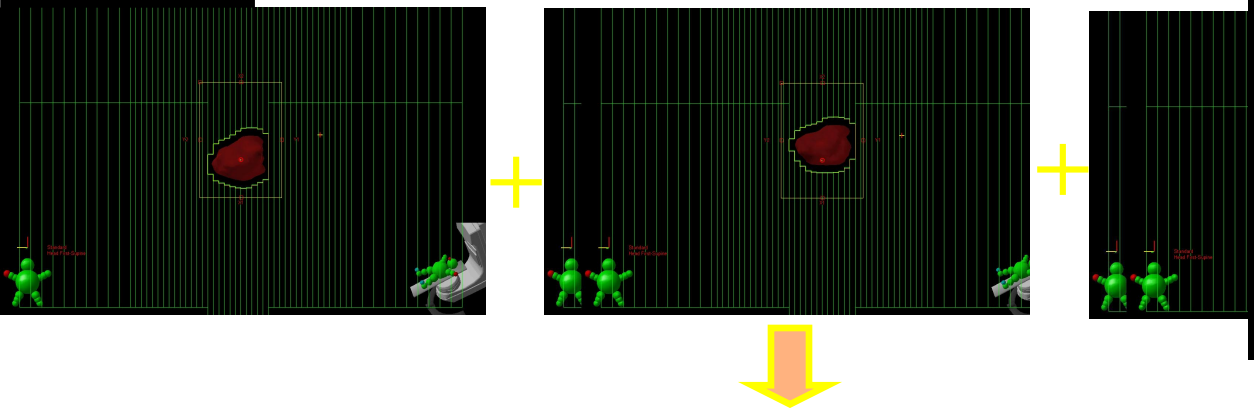


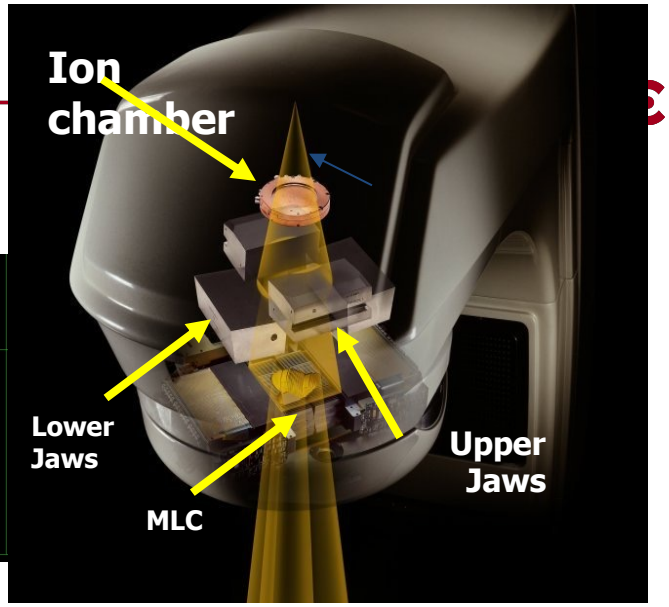


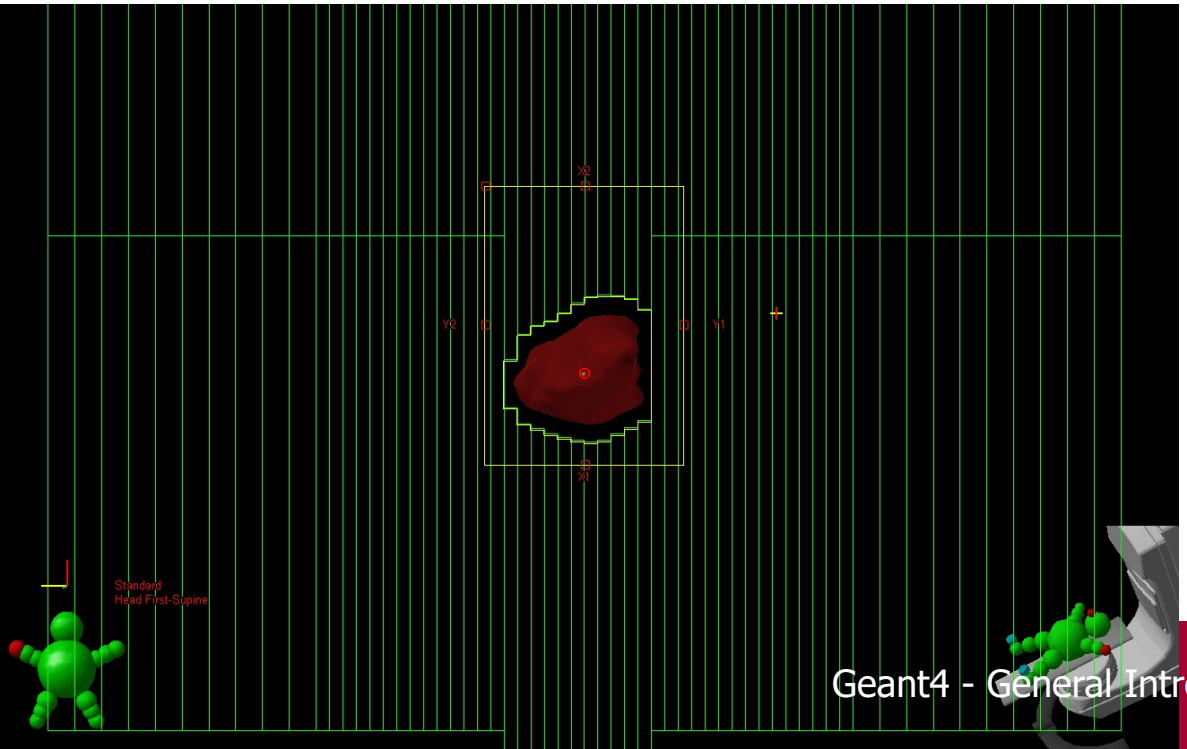


4D RT Treatment Plan

ource: Lei Xing, Stanford University



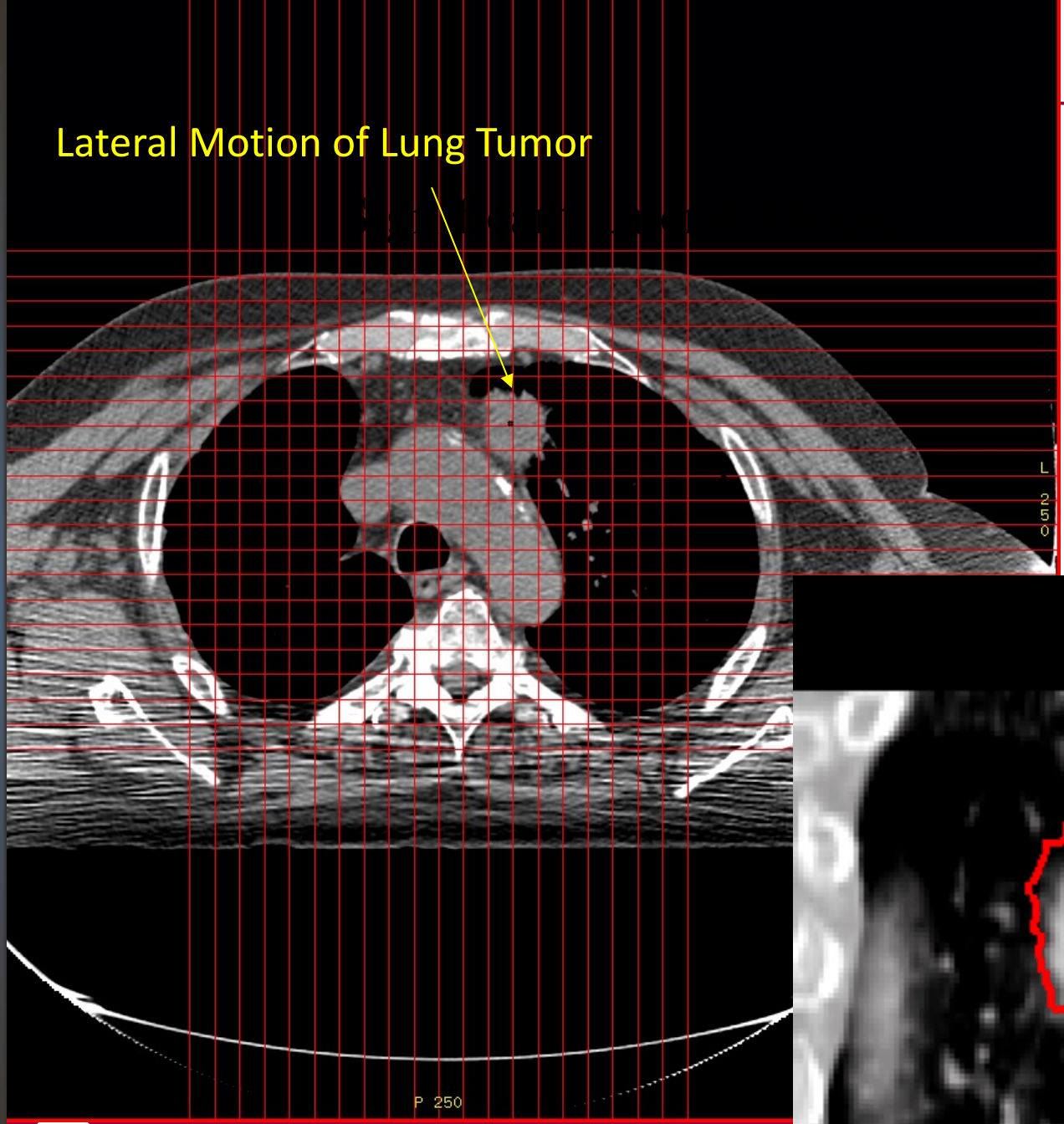


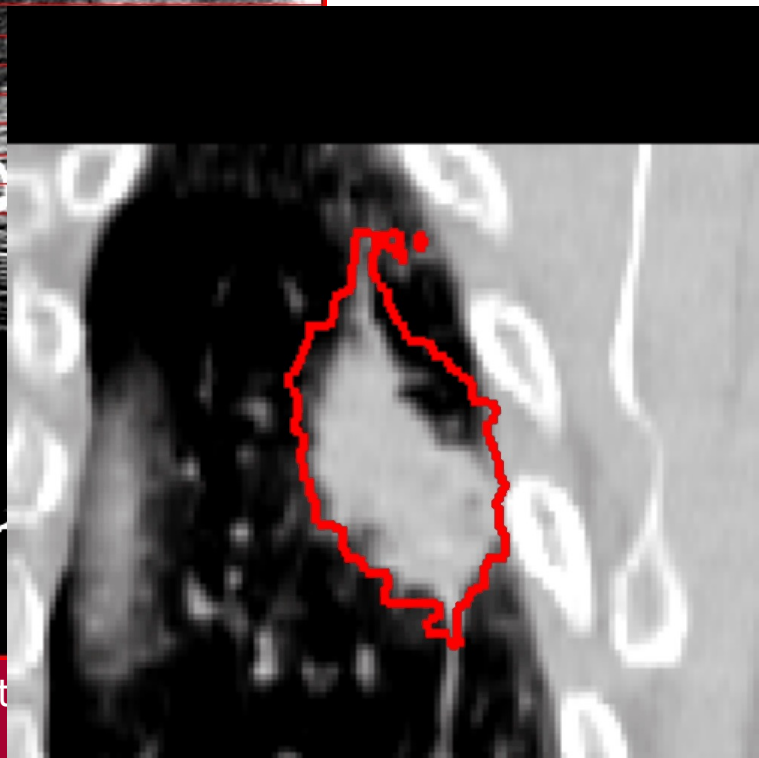




Y. Yang, S. Huq, L Xing, Med. Phys, 2006

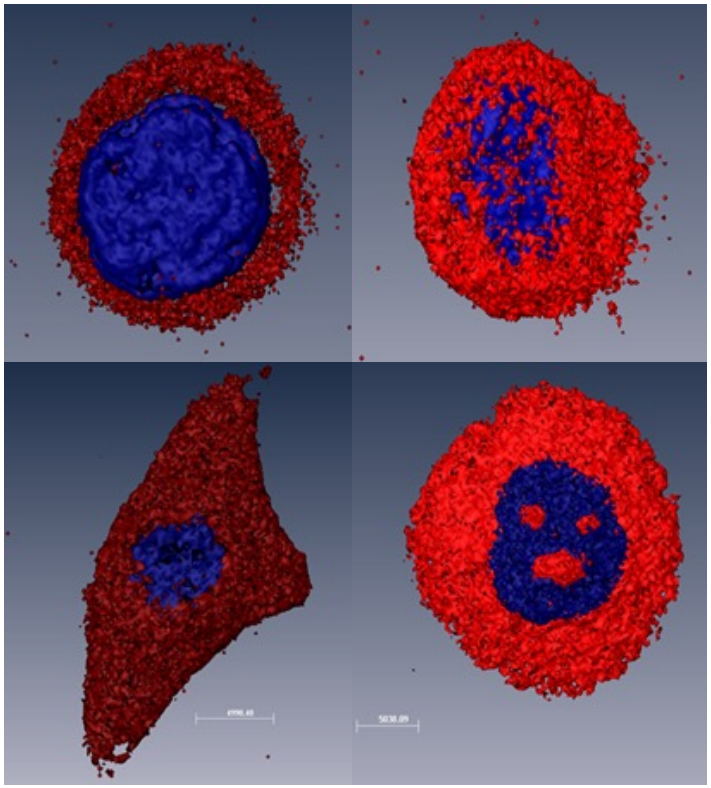
Lateral Motion of Lung Tumor

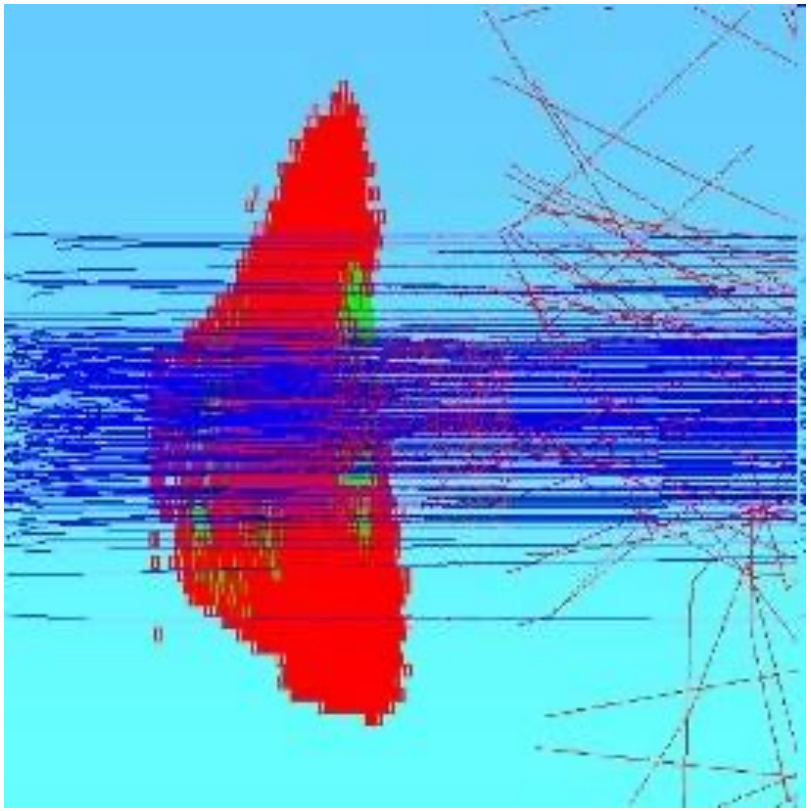




Single cell irradiation

- Example of single cell irradiation by 3 MeV alpha particles in a high-resolution cellular phantom
  - 4h or 24h incubated cell
  - 64 x 64 x 60 resolution
  - 0.36 x 0.36 x 0.16 μm^3 voxel size
- Full CENBG microbeam irradiation setup simulated

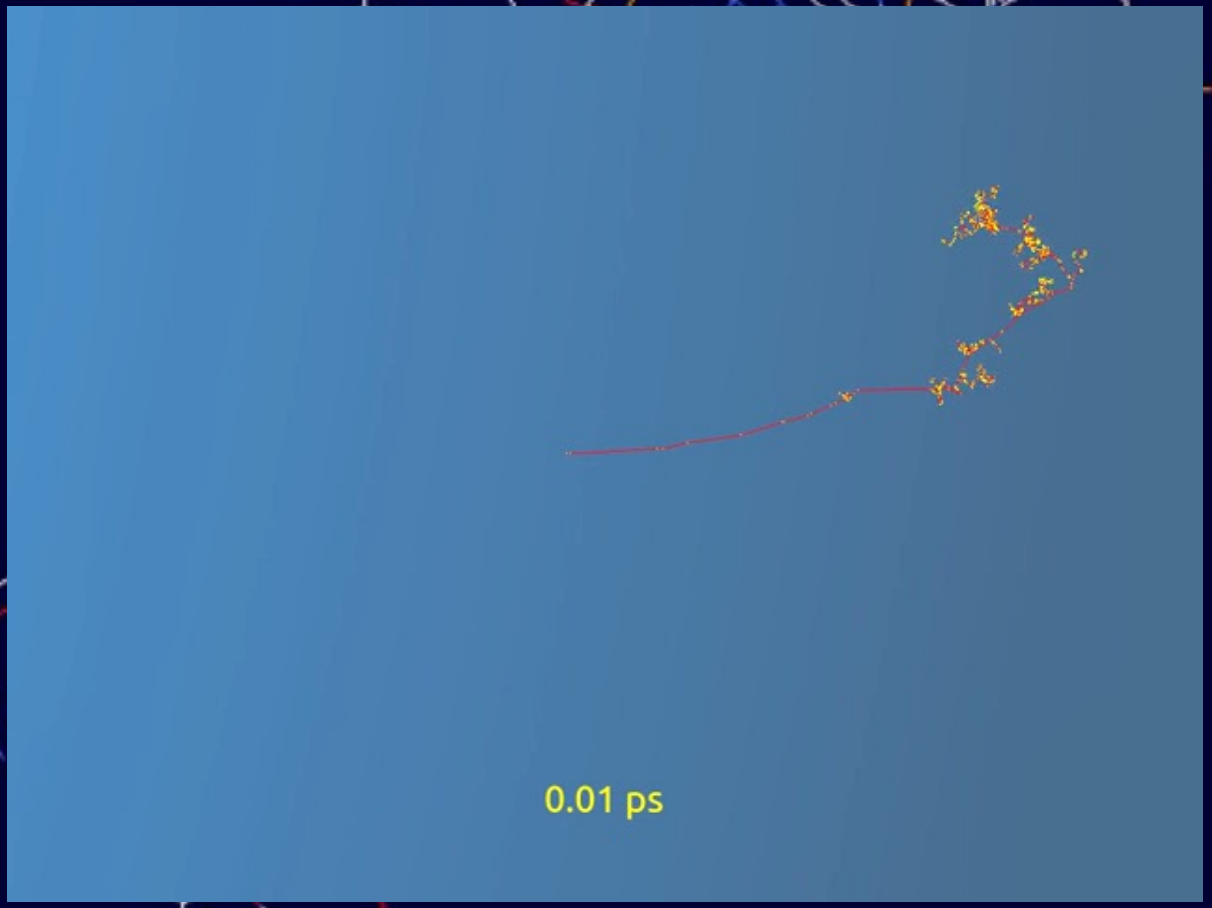




Courtesy of Sebasien Incerti (IN2P3-CNRS / CENBG)

DNA in Geant4

most common DNA conformation in cells



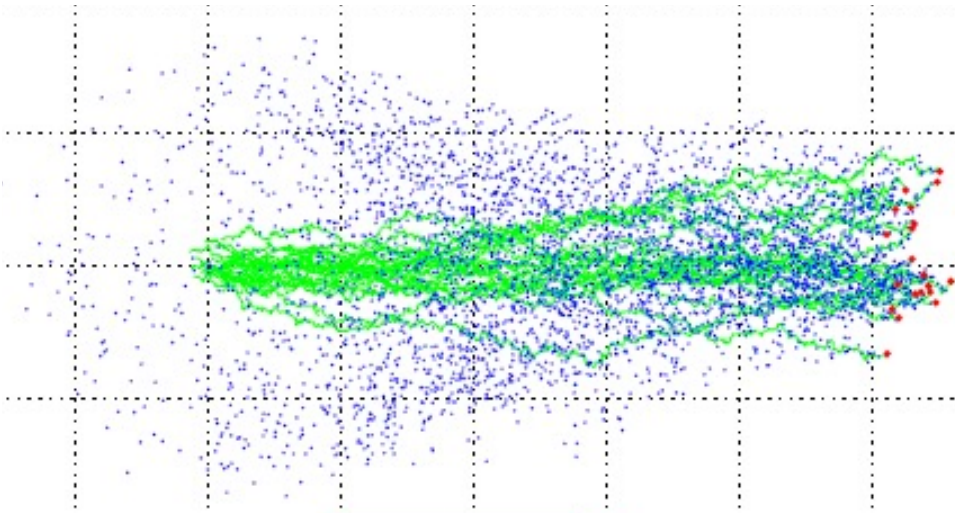
Conversion of ProteinDataBank-format file ▸ Geant4

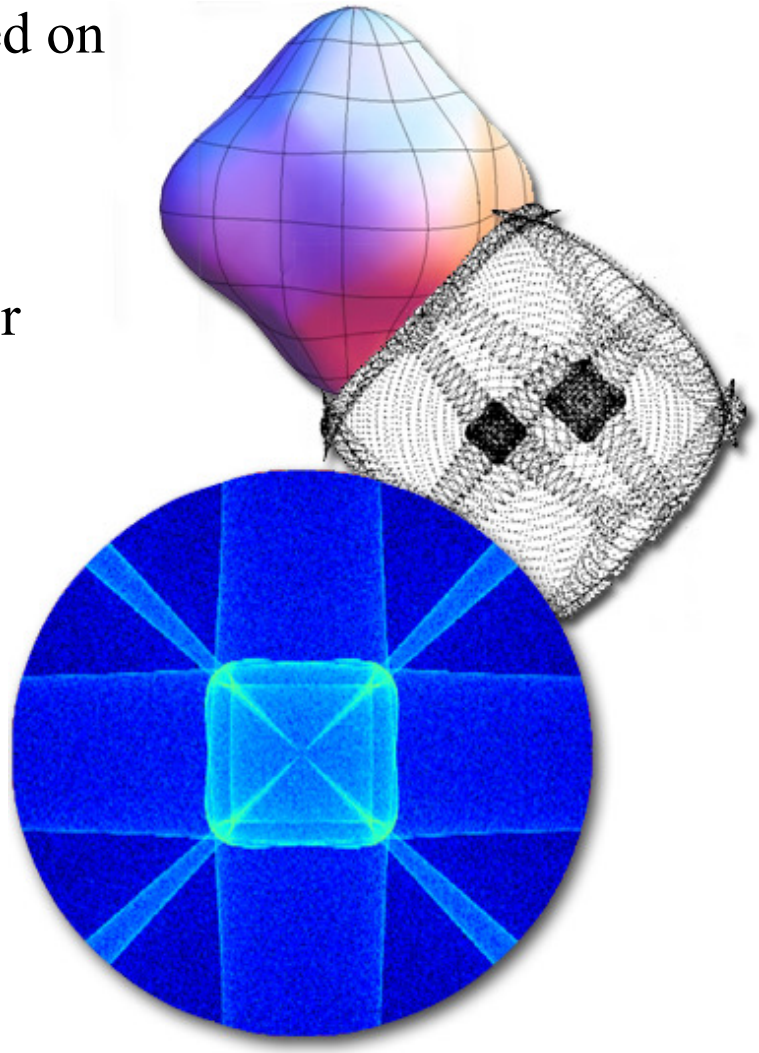
Courtesy of Sebasien Incerti (IN2P3-CNRS / CENBG)

Condensed Matter Physics in Geant4

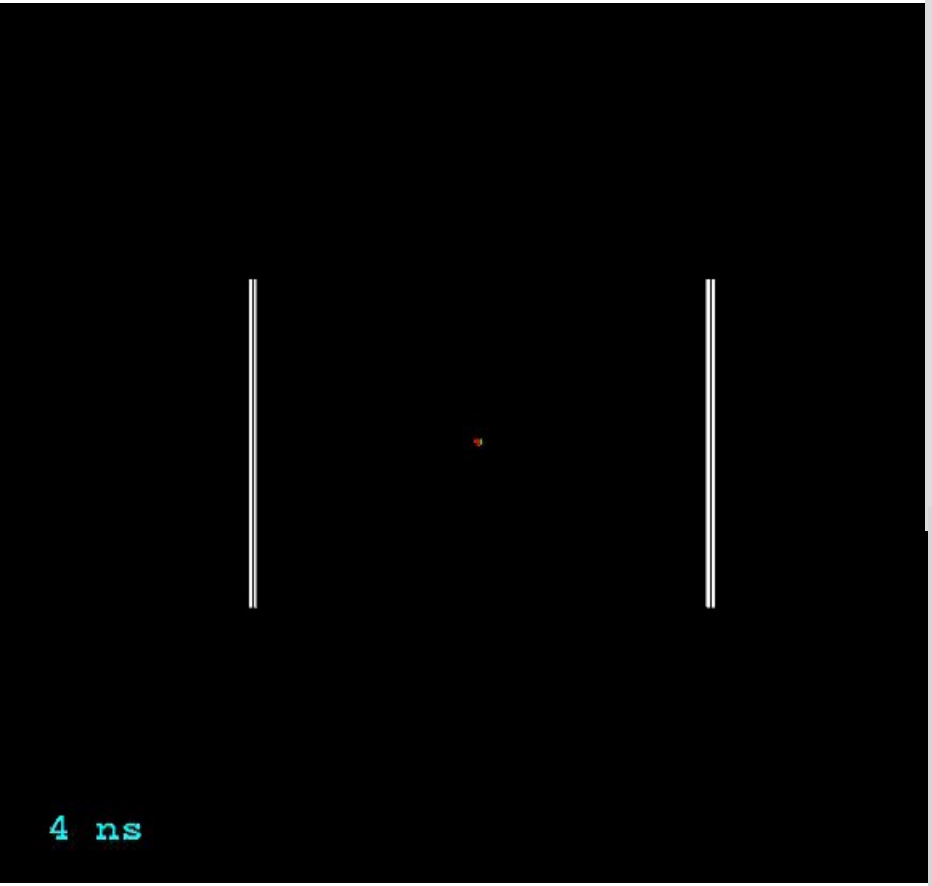
- Phonon propagation, including focusing based on elasticity tensor (right)

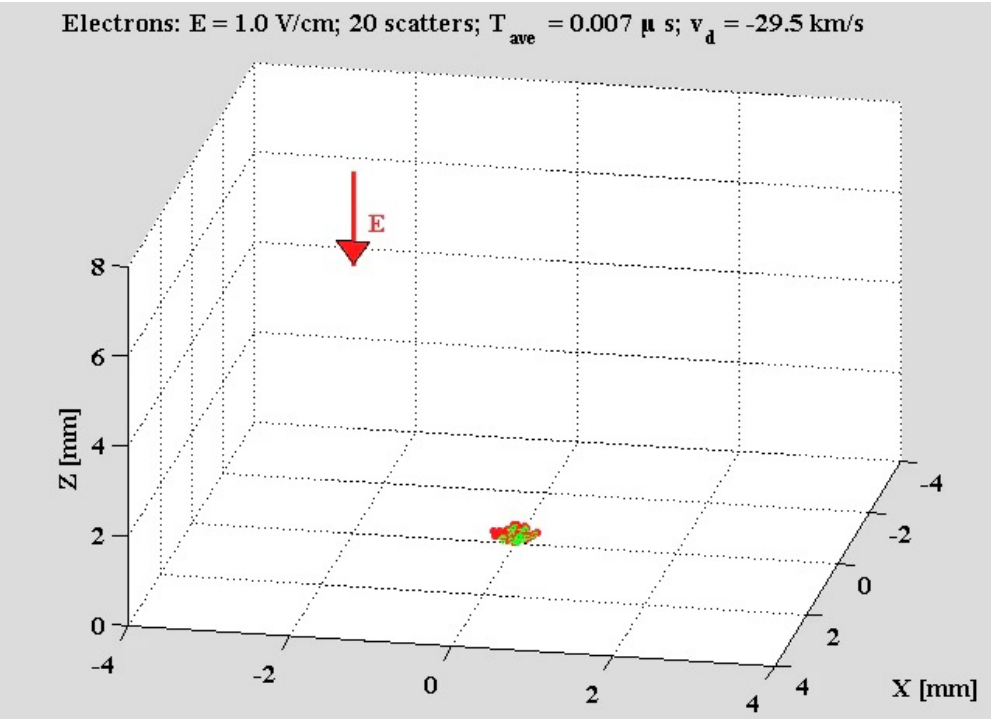
- e-/h+ transport, including conduction band anisotropy and Luke-Neganov emission, under development (below)

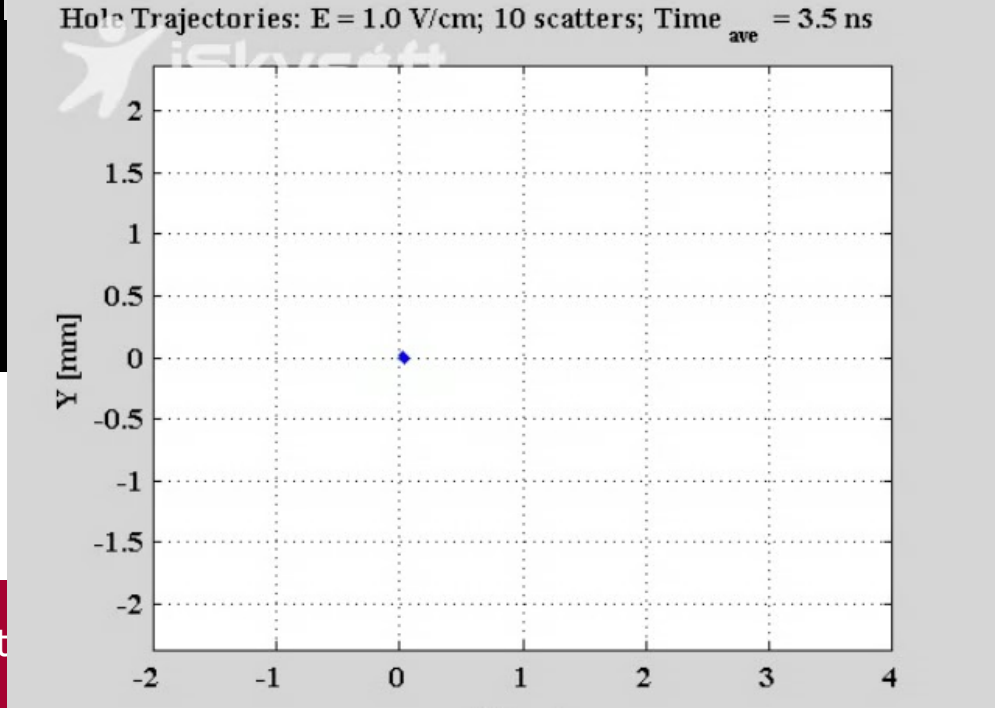




e-/h propagation with Luke phon emission in Ge crystal

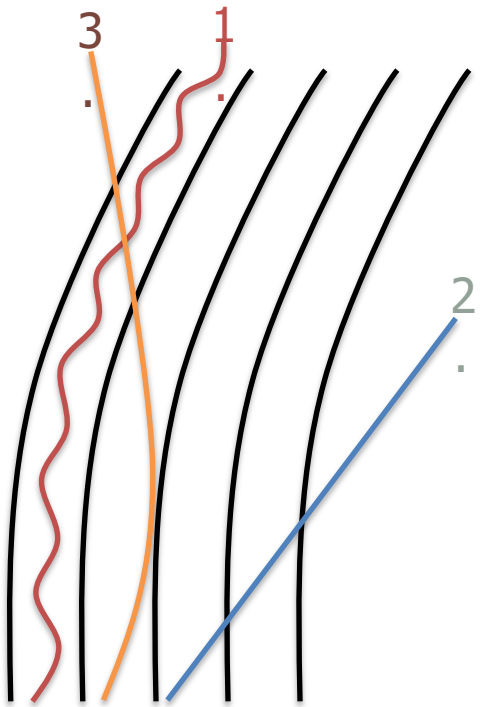


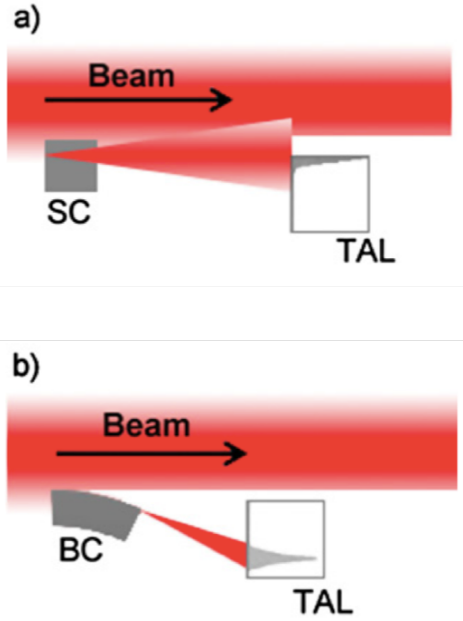


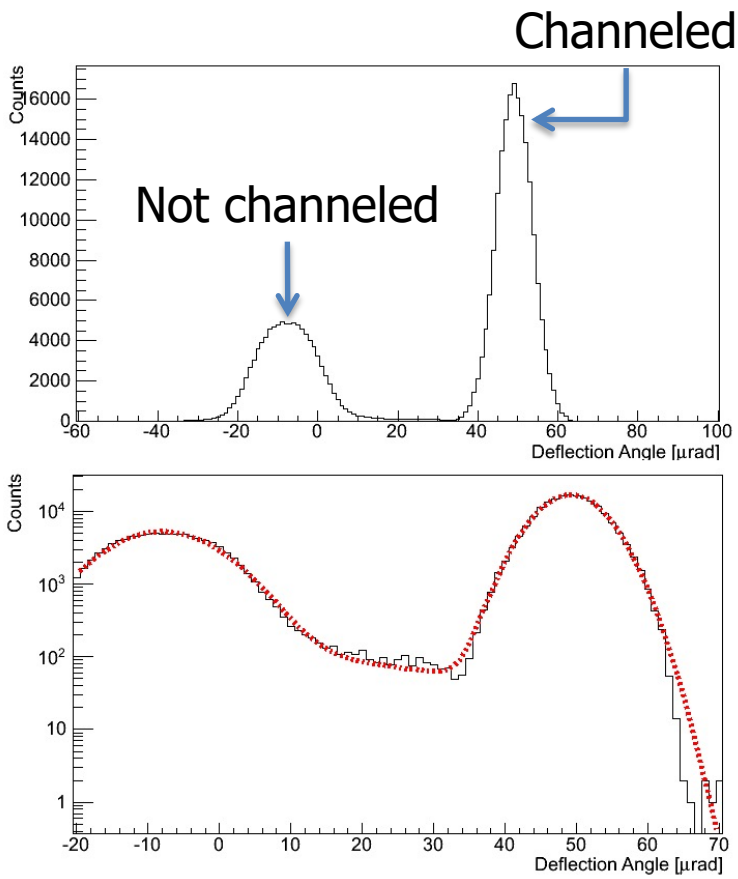


Bent crystal as a collimator

- Bent crystal can be used as a collimator to deflect particles of beam halo.
- This study will be extended for T-513 experiment at SLAC LCLS ESTB



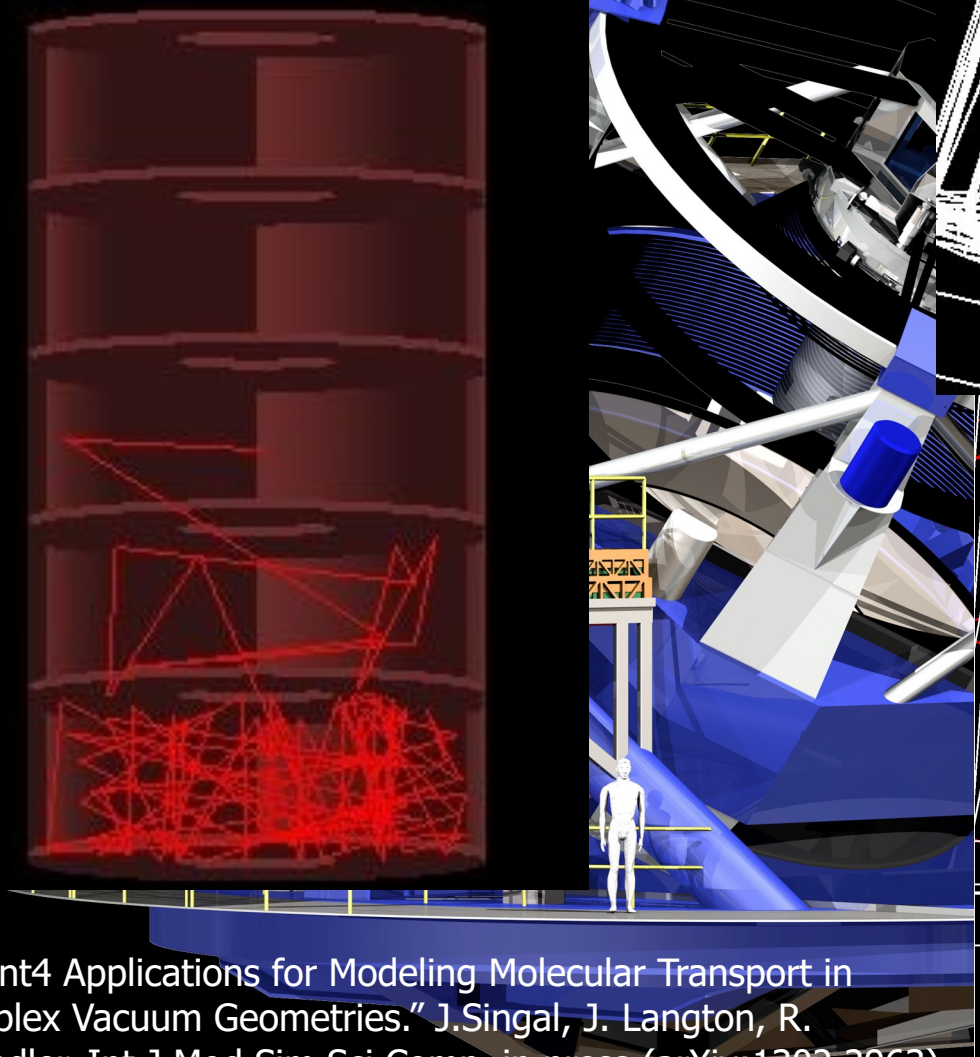


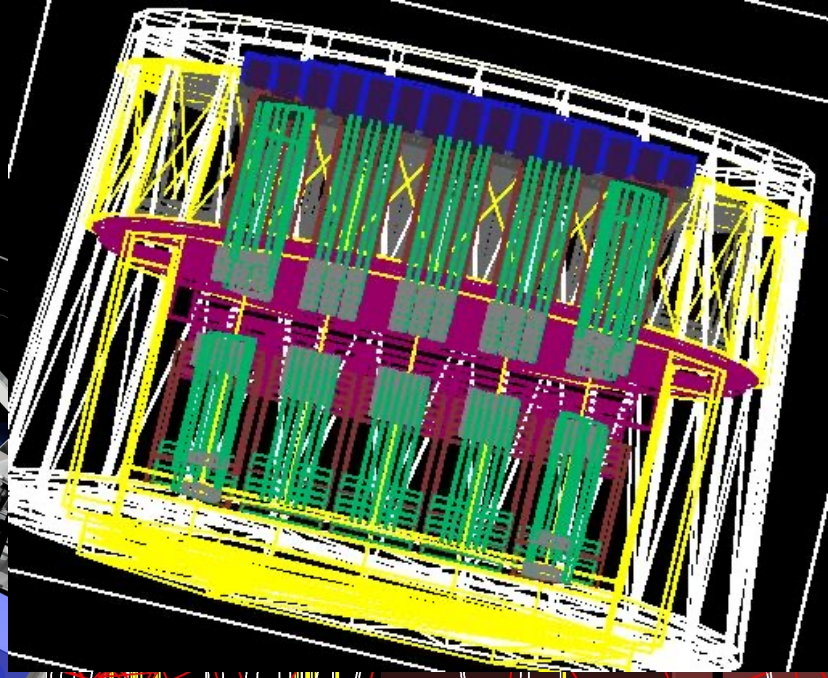


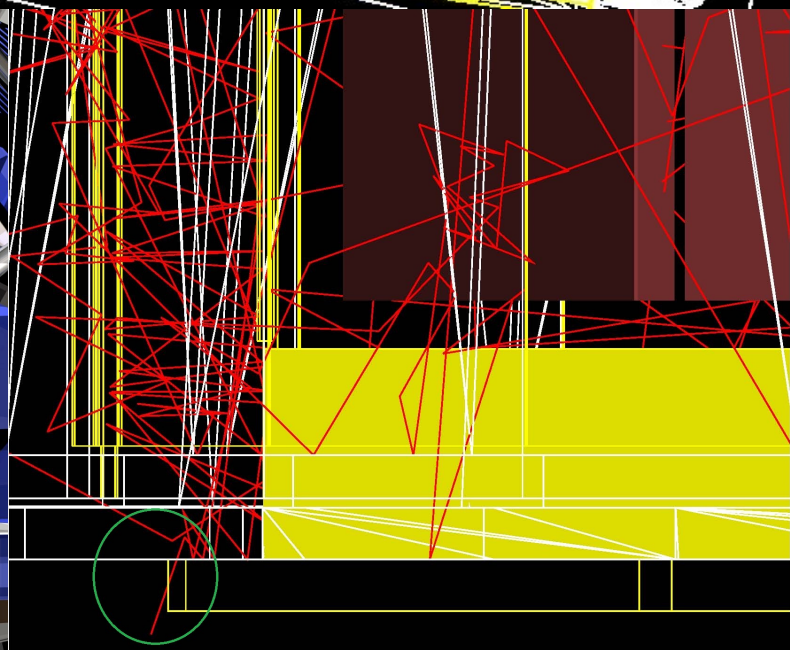
Enrico Bagli (INFN/Ferrara)

- W. Scandale et al., Phys. Lett. B 680 (2009) 129

LSST (Large Synoptic Survey Telescope)







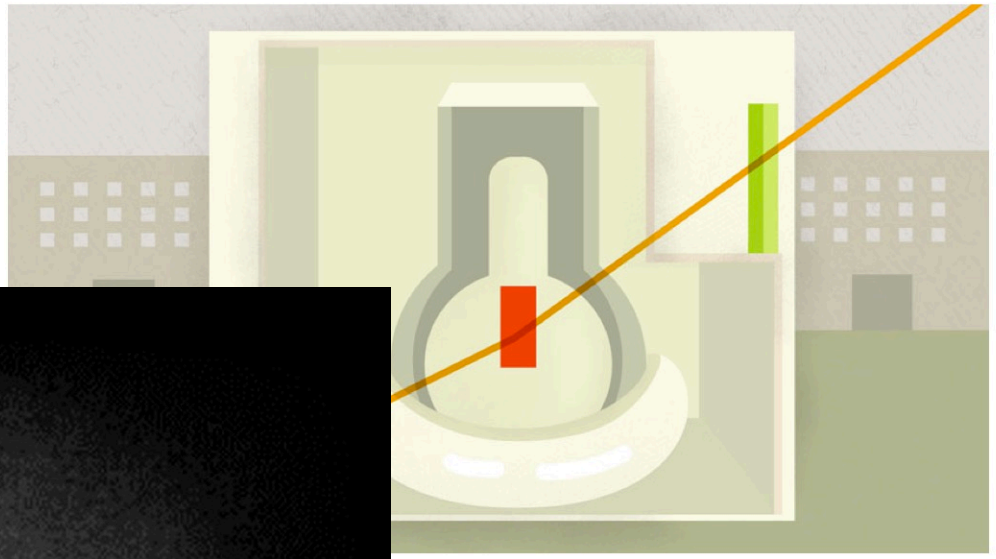
"Geant4 Applications for Modeling Molecular Transport in Complex Vacuum Geometries." J.Singal, J. Langton, R. Schindler, Int J Mod Sim Sci Comp, in press (arXiv:1302.2963)

symmetry of particle physics



Those exterior walls, made of concrete 10 feet thick, offer their own challenge. Based on computer simulations run with the particle physics software GEANT4, the walls are expected to reduce the resolution to about 30 centimeters.

In addition, the team must also prepare for the high radiation levels present just outside of the reactor units.



ors (shown here in green) on either side of
ecord the path of muons (represented by the
rough the reactor. By determining how the
ctors, scientists will compile the first picture of

with Shawna X.

As time ticks down to the restart of the Large Hadron Collider, scientists are making sure their detectors run like clockwork.

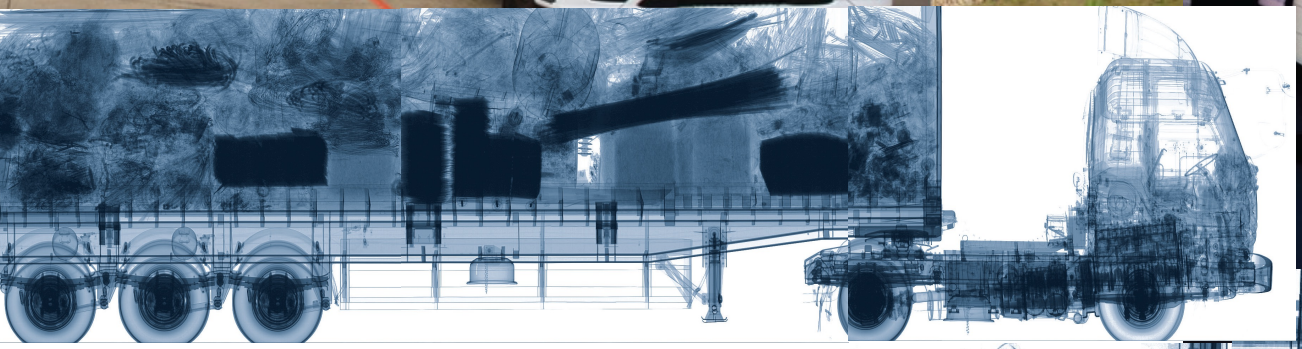
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Simulating x-ray cargo radiography

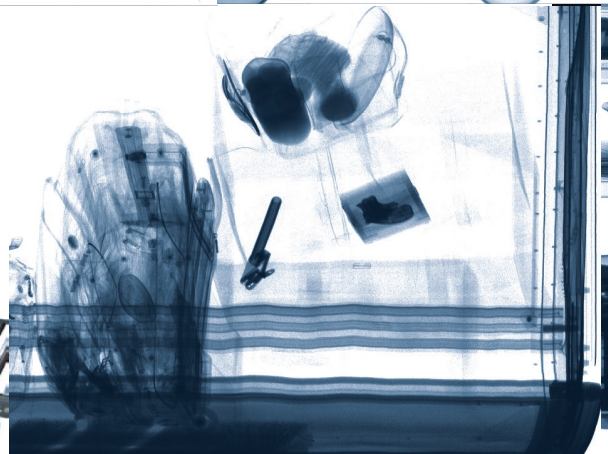














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SCIENTIFIC REPORTS

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Altmetric: 170 Views: 808 More detail »

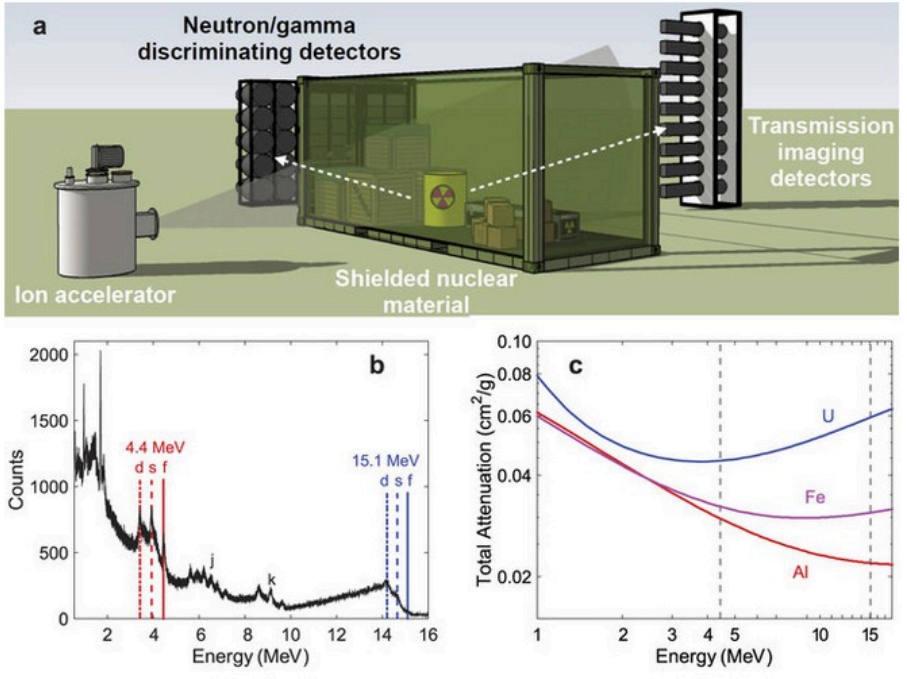
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Uncovering Special Nuclear Materials by Low-energy Nuclear Reac

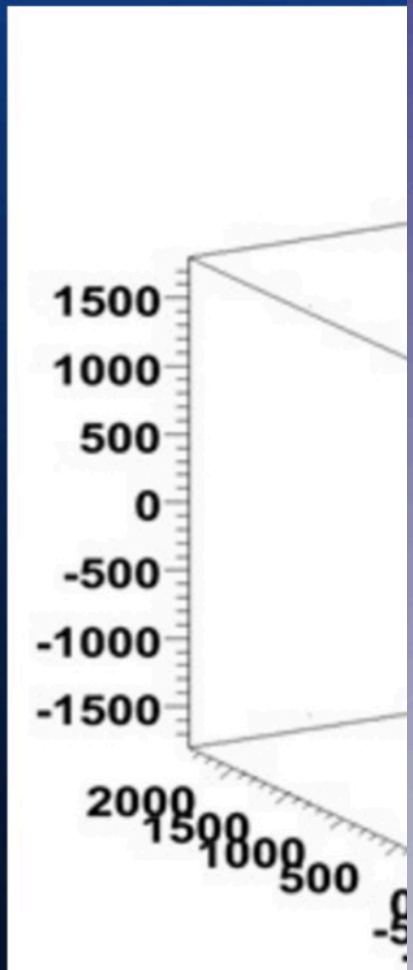
P. B. Rose, A. S. Erickson, M. Mayer, J. Nattress & I. Jovano

Scientific Reports **6**, Article number: 24388 (2016)
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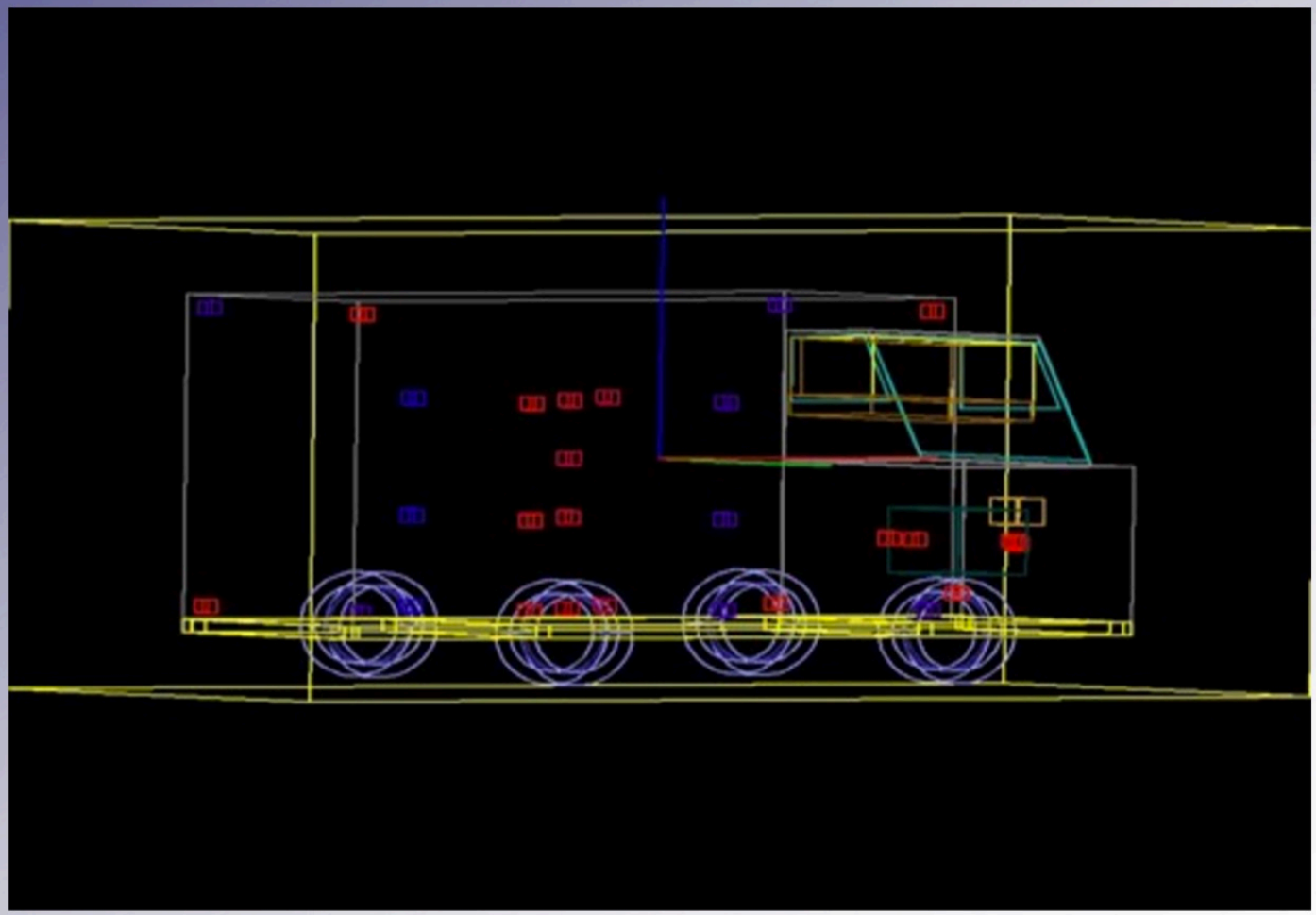
Figure 1: Illustration of the imaging method using a low-energy nuclear reaction radiation source.

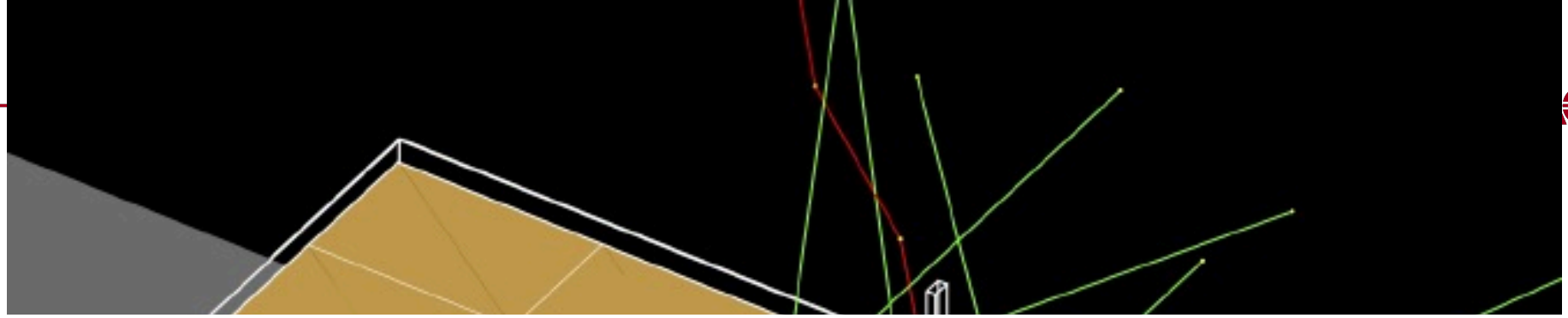


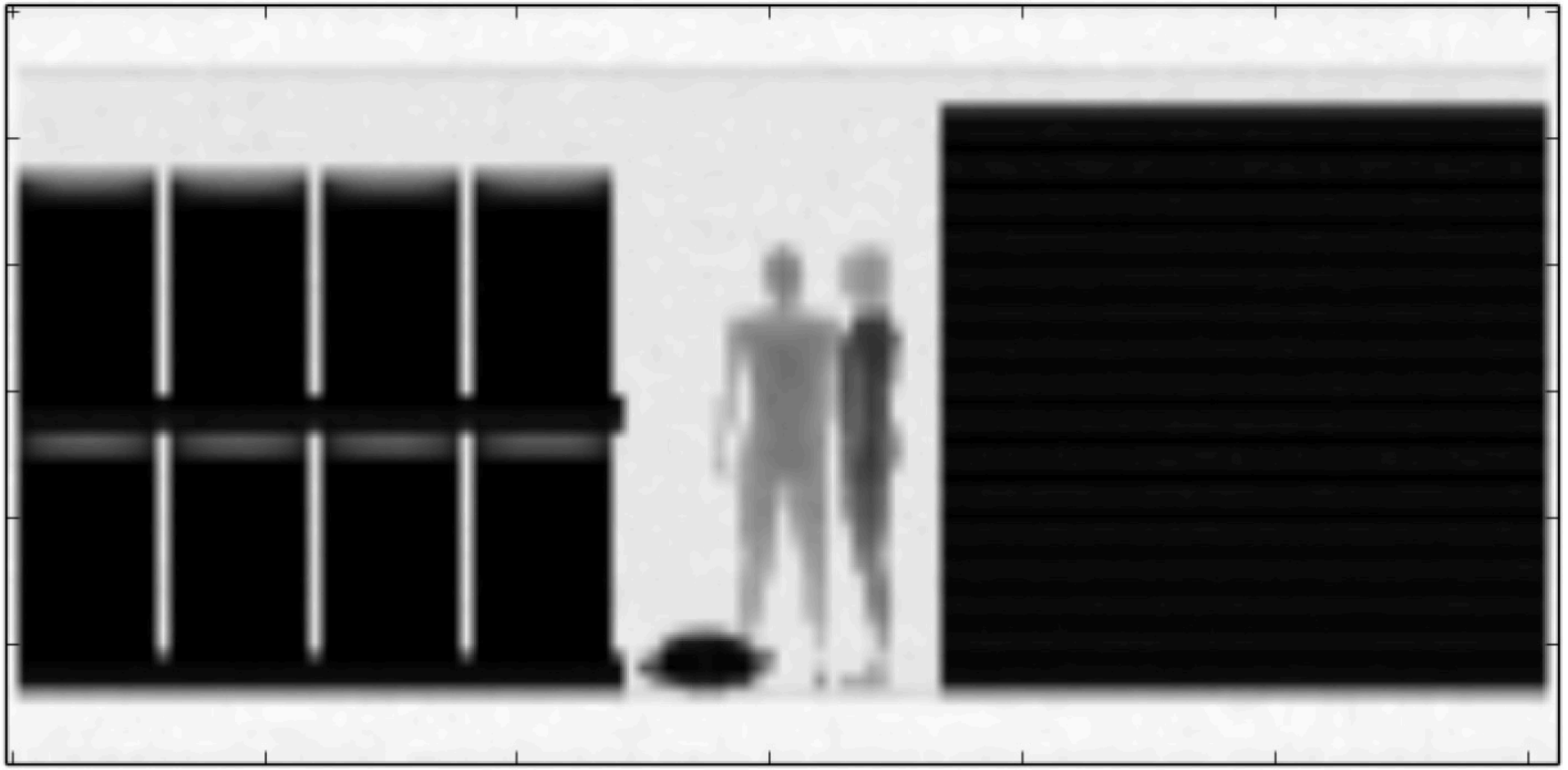
Muon tomography for nuclear threat detection



Simulated Truck
Red Boxes are Uranium
Blue are Lower Z Materials









Geant4 – the Future

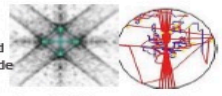
Geant4 Software

Introduction

Geant4 is being used in many different fields where simulation of radiation passing through and interacting with matter is critical. User domains include: high energy and nuclear physics, medical physics and space engineering, shielding protection and more. Its abstract layers based on robust OO design enables flexibility and extendibility of the code, and its open-source code and open collaboration have allowed substantial extensions of the code. New features are constantly added to the code, while increasing attention is paid to improving software performance and robustness by employing cutting-edge software engineering technologies.

New physics

The flexibility and extendibility of Geant4 design allows it to be applied to new physics domains. These include the physics of condensed matter (phonon transportation in crystals, drift of electrons and holes in semiconductors) and processes for bio-chemical substances and DNA.



SuperCDMS Cryogenic Dark Matter Search seeks to directly detect dark matter. Geant4 models the caustic pattern in a Ge crystal (left) by tracking individual phonons (right)

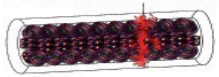
Reaction	Reaction rate (10^{17} m^{-3} s^{-1})
$H^+ + e_{aq}^- + H_2O \rightarrow OH^- + H_2$	2.65
$H^+ + {}^{\bullet}OH \rightarrow H_2O$	1.44
$H + H \rightarrow H_2$	1.20
$H_2 + {}^{\bullet}OH \rightarrow H^+ + H_2O$	4.17×10^{-5}
$H_2O_2 + e_{aq}^- \rightarrow OH^- + {}^{\bullet}OH$	1.41
$H_2O^+ + e_{aq}^- \rightarrow H^+ + H_2O$	2.11
$H_2O^+ + OH^- \rightarrow 2\,H_2O$	14.3
${}^{\bullet}OH + e_{aq}^- \rightarrow OH^-$	2.95
${}^{\bullet}OH + {}^{\bullet}OH \rightarrow H_2O_2$	0.44
$e_{aq}^- + e_{aq}^- + 2\,H_2O \rightarrow 2\,OH^- + H_2$	0.50

Reactions of radicals available in Geant4.

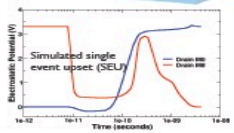
Geant4 performs mission critical studies of radiation and charging effects on spacecraft electronics.



Impact of Neon ion on MOS FET.

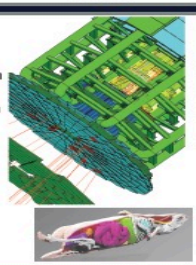


Energy depositions in DNA structure.



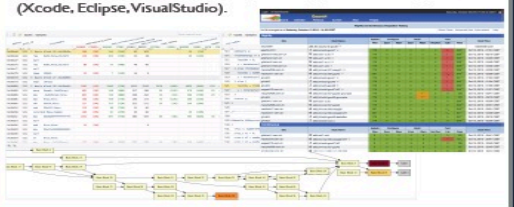
Geometry

The flexibility and extendibility of Geant4 design also enables handling rich collection of shapes including CSG (Constructed Solid Geometry), Boolean operation, Tessellated solid, etc. and the user can easily add new shapes. Geant4 geometry navigation can deal with setups up to billions of volumes with automatic optimization. In addition, geometry models can be 'dynamic', i.e. changing the setup at run-time, e.g. "moving objects".



Software quality assurance

Geant4 uses modern tools to manage the code and improve code quality: from handling issues with JIRA to continuous testing integration with CTest/CDash, profiler based optimizations, **Quality/Assurance (Coverity, Valgrind, etc.)**, and IDE integration (Xcode, Eclipse, VisualStudio).



New era - Geant4 version 10 series

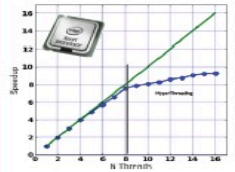
The new release of Geant4 – Version 10.0 (December 2013) include event-level parallelism via multi-threading. To efficiently use new computing architectures the workload of a single job is sub-divided to many worker threads each responsible for the simulation of one or more events. Version 10.0 has already shown good scalability on a number of different architectures: Intel Xeon servers, Intel Xeon Phi co-processors and low-power ARM processors

- Proof of principle
- Identify objects to be shared
- First testing
- API re-design
- Example migration
- Further testing
- First optimizations
- Further refinements

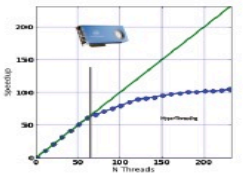


- MT code integrated into G4
- Production ready
- Public release

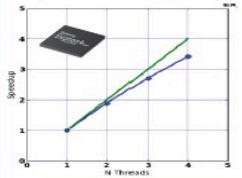
Intel Xeon L5520 @ 2.27GHz

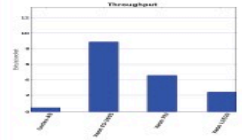


Intel Xeon Phi 7120P @ 1.238GHz

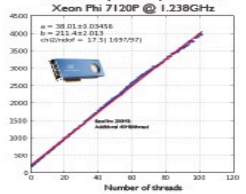


Exynos 4412 Quad-Core @ 1.7 GHz



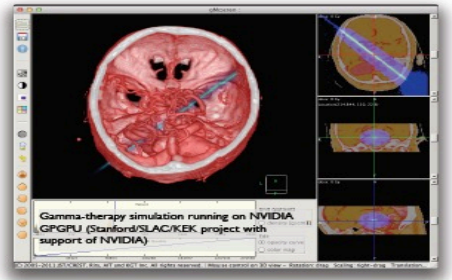


Total memory consumption of Intel Xeon Phi 7120P @ 1.238GHz



Investments for the future

Geant4 collaboration members are participating in various explorations of emerging technologies. These technologies include GPU/CUDA, OpenCL, OpenACC, vectorization, DSL, etc.



Gamma-therapy simulation running on NVIDIA GPGPU (Stanford/SLAC/KEK project with support of NVIDIA)

New physics – new opportunities

- Physics of O(100TeV)
- Neutrino interactions
  - Should come with enriched event biasing options
- Electron/hole drift in semiconductor
- More phonon physics
- Channeling effects and physics with crystal structure in general
  - X-ray diffraction
- Single atom irradiation
- Target material polarization
- Chemical reactions of radicals in DNA-scale
- New domains ?

- Note : Geant4 kernel is robust enough over 20 years of evolution. This stability enables risk-free extensions to new physics.

New computing trends

- HPC and cloud friendliness
  - Seamlessly combining MPI and MT
  - Smart data collection from millions of threads
- Code re-engineering
  - Solid library, EM physics
  - Splitting transportation process
- GPU as a co-processor
  - Off-loading some calculations to GPU, e.g. EM physics, thermal neutron physics, DNA physics and chemical processes, etc.

- Will be integrated into Geant4 with (hopefully) minimum API changes

To sum up

- Geant4 is a general-purpose Monte Carlo simulation tool for elementary particles passing through and interacting with matter. It finds quite a wide variety of user domains including high energy and nuclear physics, space engineering, medical applications, material science, radiation protection and security.
- After 20 years with several architectural evolutions, Geant4 is still steadily evolving.
  - Latest evolution was Geant4 version 10 that was the first fully multi-threaded general-purpose large-scale physics software in the world.
  - Next Geant4 version 11 will be fully task-based with envision to hybrid computing architecture.
  - New physics models for coming experiments, e.g. hadronic model for multi-TeV regime (for energy frontier), specialized EM model for noble liquid (e.g. liq.Xe) and neutrino physics model (for intensity frontier)
- Given Geant4 is nowadays mission-critical for many users including all HEP experiments, space missions, medical applications, etc., Geant4 is to be kept maintained and still evolving for at least next decade.