Version 10.5.p01

Current Status and Prospects

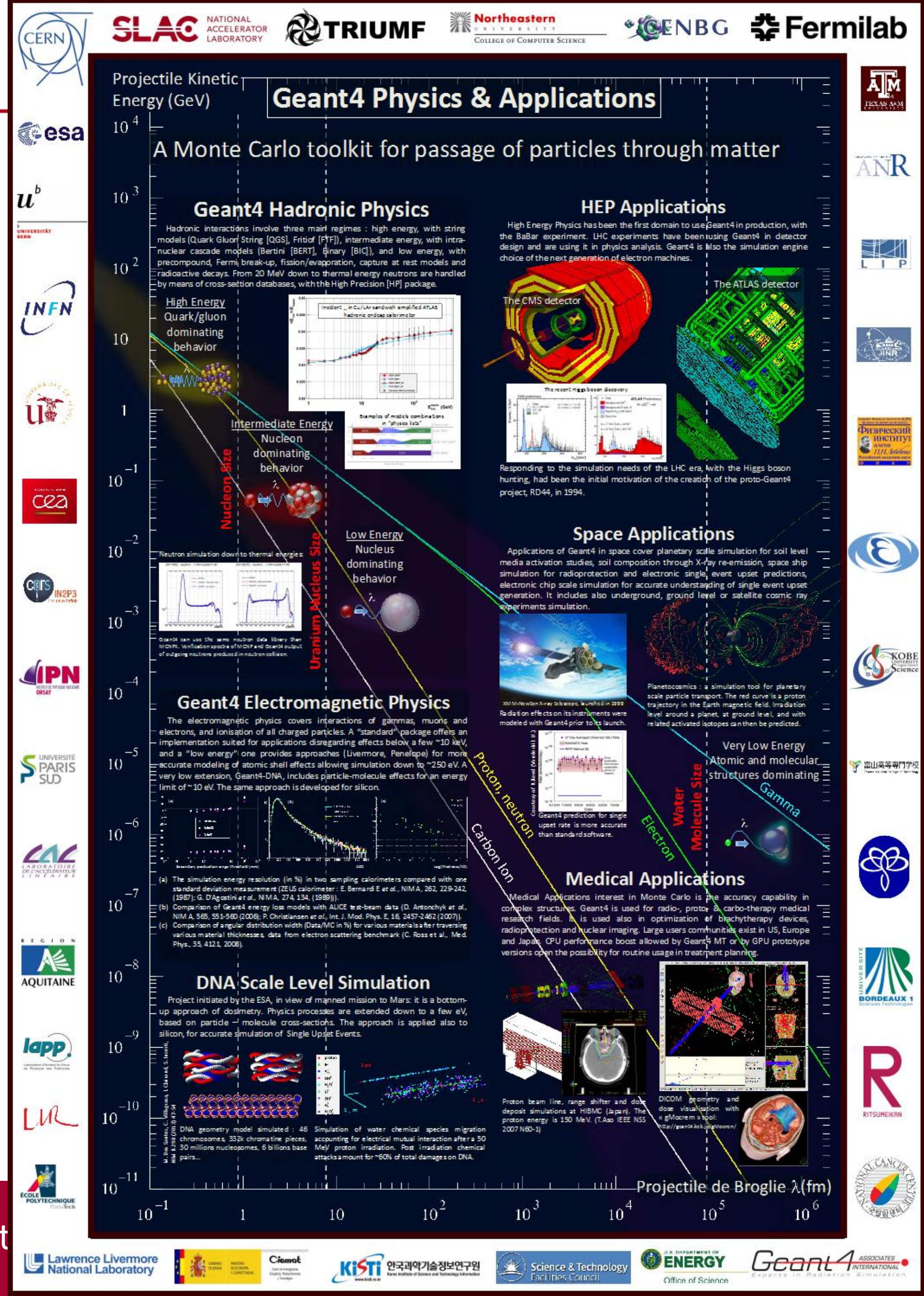
Makoto Asai (SLAC)

ENSAR2 workshop: GEANT4 in nuclear physics

April 26, 2019

Contents

- Recent developments
- Highlights of user applications
- Geant4 license
- Following up
- Geant4 – the future



Version 10.5.p01

Recent developments

Geant4 History

R&D phase (RD44)

Production phase

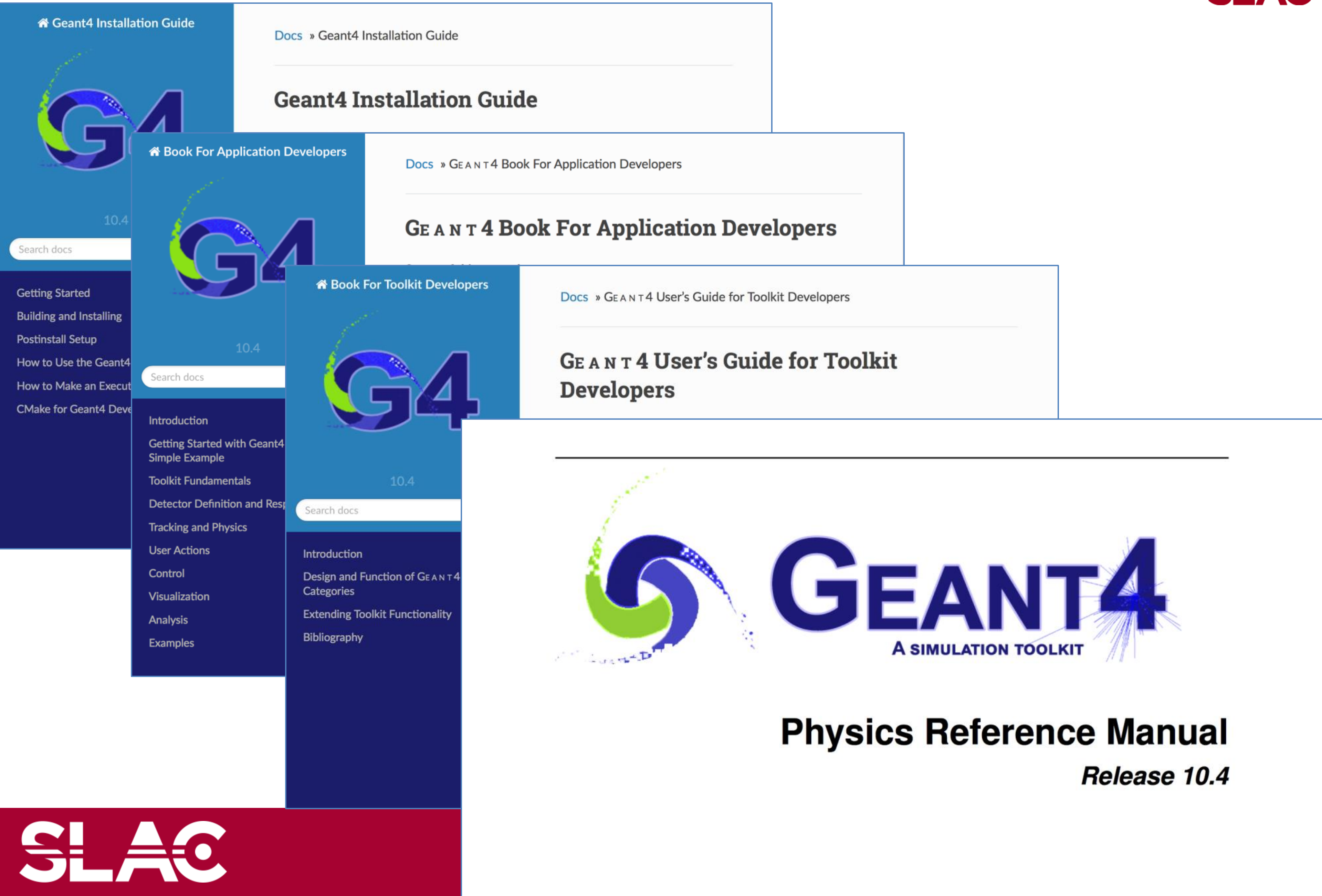
- Early discussions, for example at CHEP 1994 @ San Francisco
- Dec ’94 – R&D project start
- Apr ’97 - First alpha release
- Jul ’98 - First beta release
- Dec ’98 - First Geant4 public release - version 1.0

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

- Dec 8th, ’17 – Geant4 version 10.4 release
  - Feb 12th, ’19 - Geant4 10.4-patch03 release ← Retroactive patch release
- Dec 7th, ’18 – Geant4 version 10.5 release
  - Apr 17th, ’19 - Geant4 10.5-patch01 release ← Current version

- We currently provide one public release every year.
  - Next scheduled release – Geant4 10.6 on Dec 6th, ’19

10.4 came with new user's guides and new logo

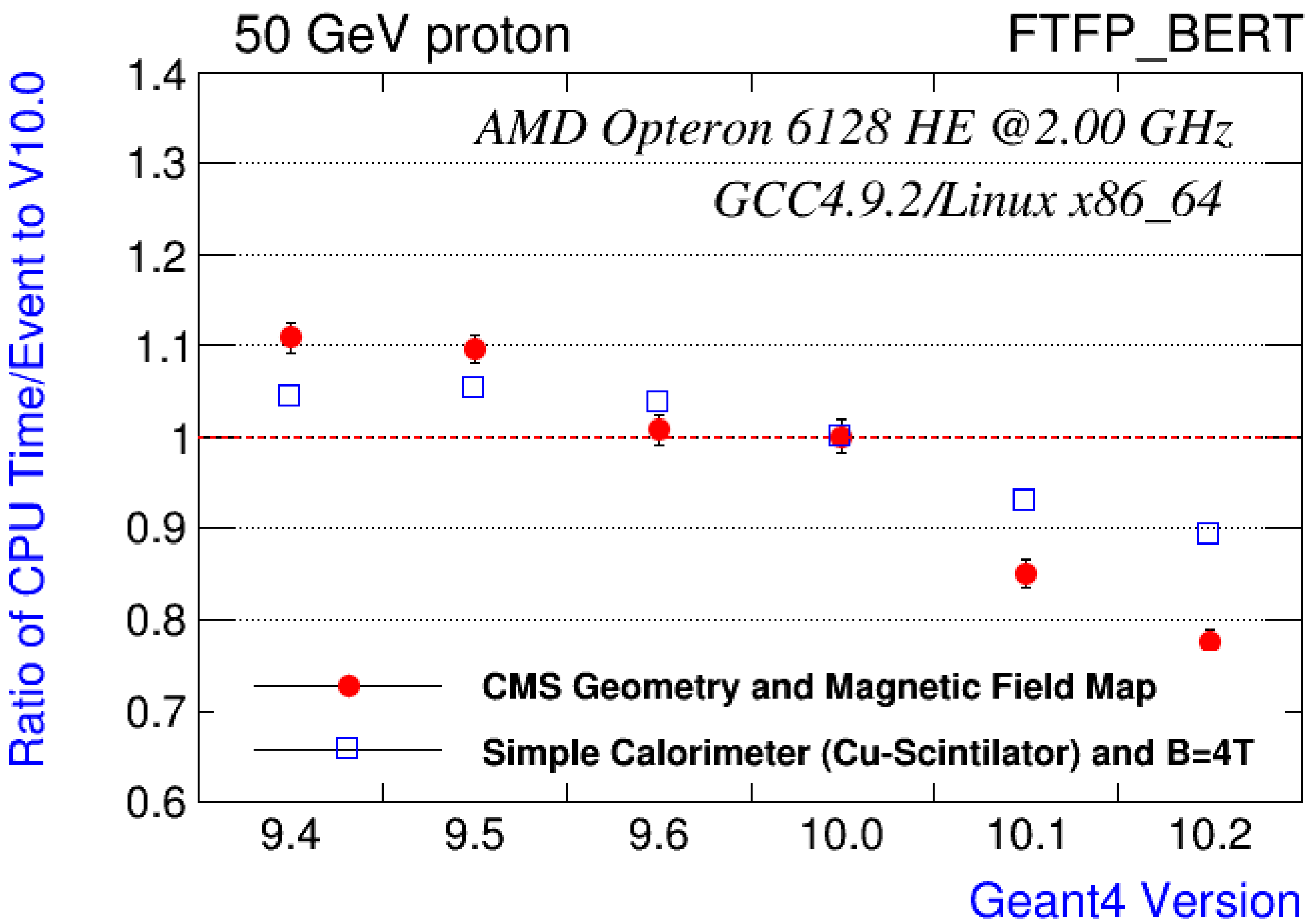


Geant4 version 10 series

- The release in 2013 was a major release.
  - Geant4 version 10 – release date : Dec. 6, 2013
- The highlight is its multi-threading capability.
  - The world first large-scale physics software fully multithreaded
- Geant4 version 10 series will be evolving.
  - Performance improvements (both in physics and computing)
  - Missing functionalities yet to be migrated to multithreading,
  - Additional APIs
  - Additional functionalities
  - New physics

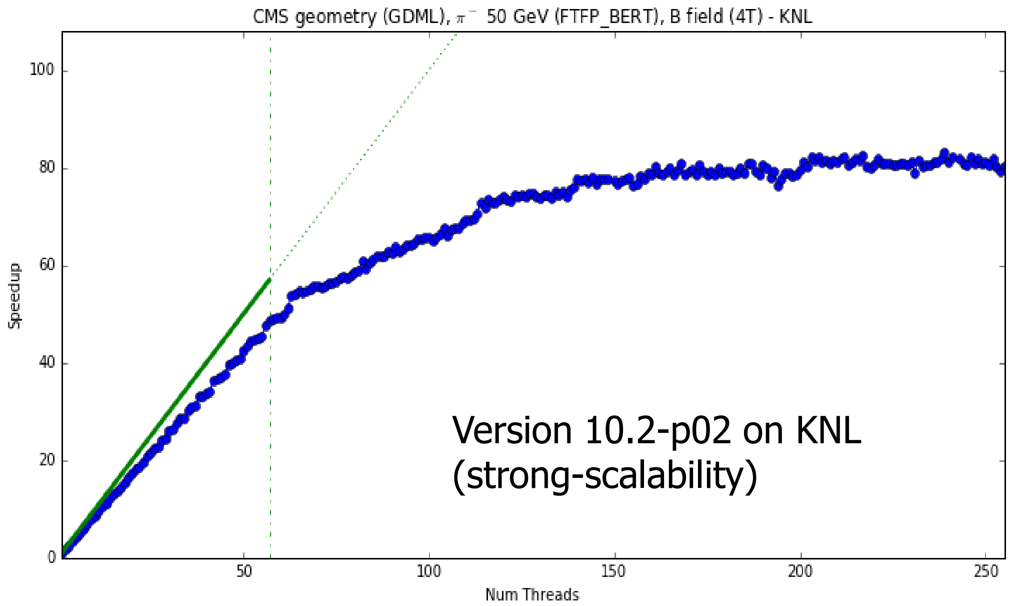
G4MT prototype-9.4 (2011)	G4MT prototype-9.5 (2012)	G4 10.0.beta (Jun.2013)	G4 10.0 (Dec. 2013)	G4 10 series (2014~)
• Proof of principle • Identify objects to be shared • First testing	• MT code integrated into G4	• API re-design • Example migration • Further testing • First optimizations	• Production ready • Public release	• Further refinements

We are making it faster!



ATLAS : "The 10% CPU improvement we gain from the move from G4 9.6 to 10.1 is invaluable to the collaboration."

Many core, many thread



- For three years we have provided support for running Geant4 on KNC.
  - ATLAS, CMS successfully multithreaded
- We will soon extend our support to KNL.
  - With KNL, thanks to x86 binary compatibility including the use of gcc, work-flow is tremendously simplified.

System	Time to completion (5k events)
Xeon E5-2620 @ 2.1 GHz (12 cores, 24 threads)	570 s
KNC (31s1P) @ 1.0 GHz (228 threads)	1000 s
KNL (7210, quadrant mode, MCDRAM only) @ 1.3 GHz (255 threads)	378 s (x3 improvement w.r.t. KNC)
KNL (shared library)	480 s (25% slower than static library)

More memory-efficient, more HPC friendly

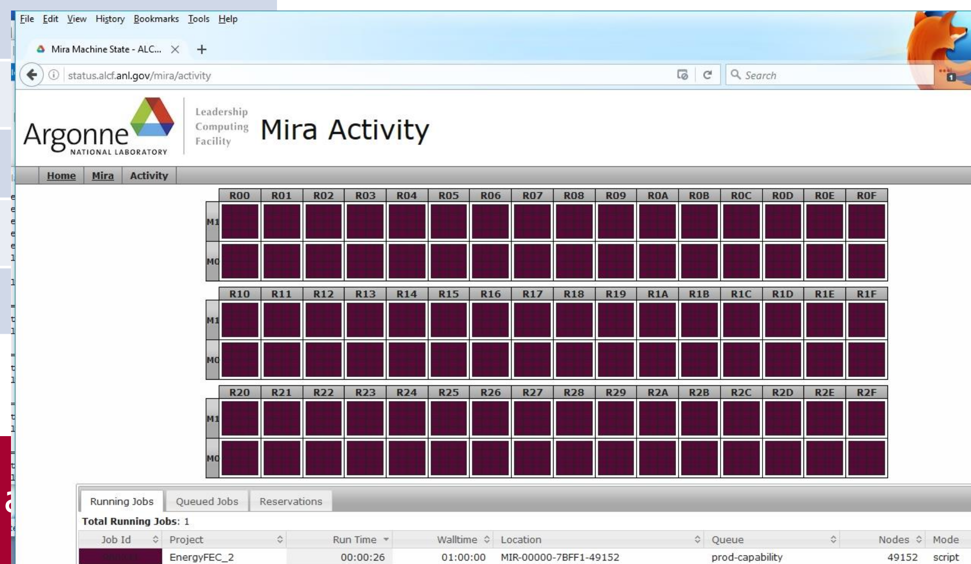
Version	Intercept	Memory/thread
9.6 (seq.)	113 MB	(113 MB)
10.0.p02-seq	170 MB	(170 MB)
10.0.p02-MT	151 MB	28 MB
10.3.beta-MT	148 MB	9 MB

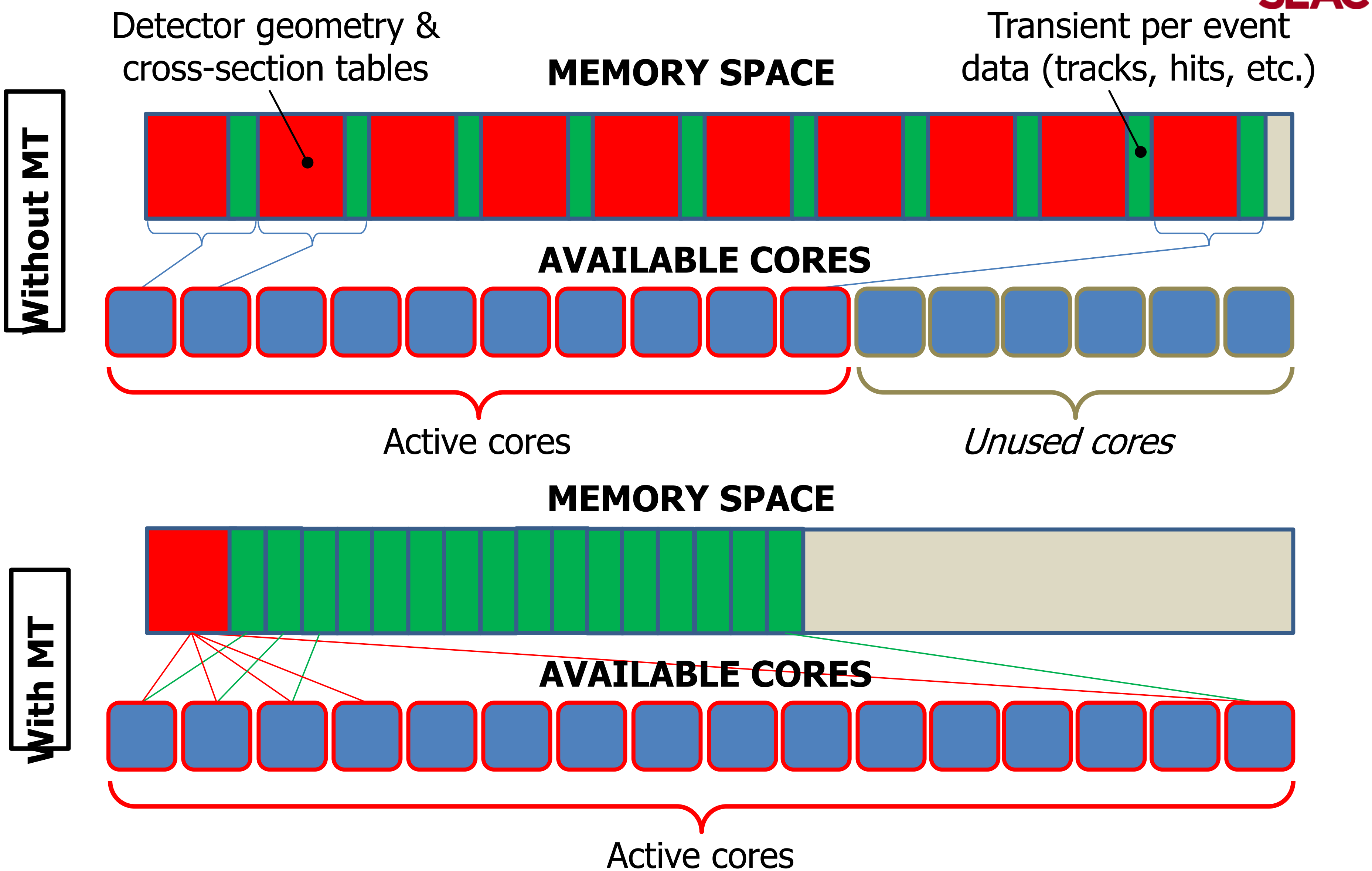
Memory space required for Intel Xeon Phi 3120A
Full-CMS geometry (GDML), 4 Tesla field, 50 GeV pi- (FTFP_BERT)

# of CPU	# of threads	Speed-up factor	efficiency
10	80	79	98. 8%
20	160	158	98. 8%
40	320	317	99. 0%
80	640	626	97. 8%
160	1280	1251	97. 7%
320	2560	2297	89. 7%
640	5120	3555	69. 4%

Tachyon-2 supercomputer @ KISTI (South Korea)
FTFP_BERT physics validation benchmark

- Geant4 has successfully run with a combination of MT and MPI on Mira Bluegene/Q Supercomputer (@ANL) with all of its 3 million threads
  - Full-CMS geometry & field
- I/O is the limiting factor to scale large concurrent threads:
  - Granular input data files, output data/histograms, etc.
  - 2017 work item
  - Targeting also Cori @ NERSC




Without MT
Detector geometry & cross-section tables
MEMORY SPACE
Transient per event data (tracks, hits, etc.)
AVAILABLE CORES
Active cores
Unused cores
With MT
MEMORY SPACE
AVAILABLE CORES
Active cores

User's code migration

- If you have a running code with version 9.6 and you want to stick to sequential mode, you do not need to migrate. It should run with version 10.0.
  - Except for a few obsolete interfaces that you had already seen warning messages in v9.6.
- Migration of user's code to multi-threading mode of Geant4 version 10.0 should be fairly easy and straightforward.
  - Migration guide is available.
  - Geant4 users guides are updated with multi-threading features.
  - Most examples have been migrated to multi-threading.
  - Geant4 tutorials based on version 10.0 has already started.
- G4MTRunManager collects run objects from worker threads and "reduces".
- Toughest part of the migration is making user's code thread-safe.
  - It is always a good idea to clearly identify which class objects are thread-local.
- Every file I/O for local thread is a challenge
  - Input : primary events : examples are offered in the migration guide.
  - Output : event-by-event hits, trajectories, histograms

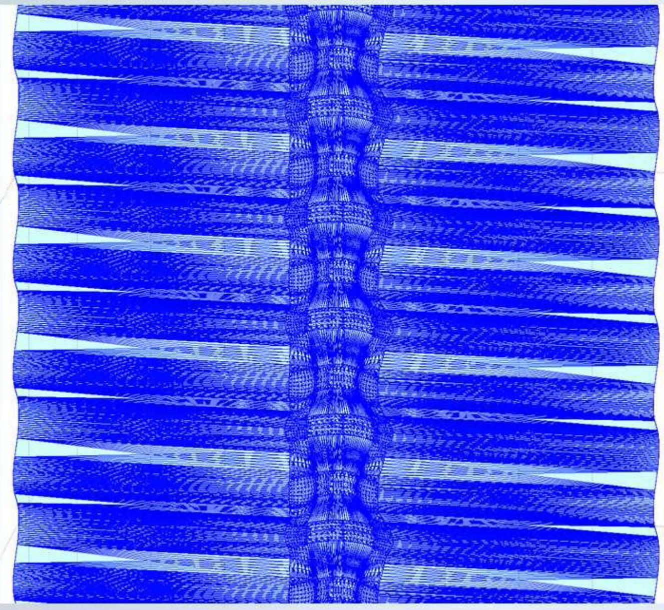
Tessellated solids

- **G4TessellatedSolid**
  - Generic solid defined by a number of facets (**G4VFacet**)
    - Facets can be triangular (**G4TriangularFacet**) or quadrangular (**G4QuadrangularFacet**)
  - Constructs especially important for conversion of complex geometrical shapes imported from CAD systems
  - But can also be explicitly defined:
    - By providing the vertices of the facets in *anti-clock wise* order, in *absolute* or *relative* reference frame
  - GDML binding

- **G4ExtrudedSolid** is re-implemented to internally use **G4TessellatedSolid.**

Geometry updates – New solid library

- An important effort was begun in the last few years to write a new solid library, reviewing at the algorithmic level most of the primitives and provides an enhanced, optimized and well-tested implementation to be shared among software packages.
- In most cases considerable performance improvement was achieved.
  - For example, the time required to compute intersections with the tessellated solid was dramatically reduced with the adoption of spatial partitioning for composing facets into a 3D grid of voxels.
- Such techniques allow speedup factors of a few thousand for relatively complex structures having of order 100k to millions of facets, which is typical for geometry descriptions imported from CAD drawings.
  - Consequently, it is now possible to use tessellated geometries for tuning the precision in simulation by increasing the mesh resolution, something that was not possible before.



Method	Speedup
Inside	2423x
DistanceToIn	1334x
DistanceToOut	1976x

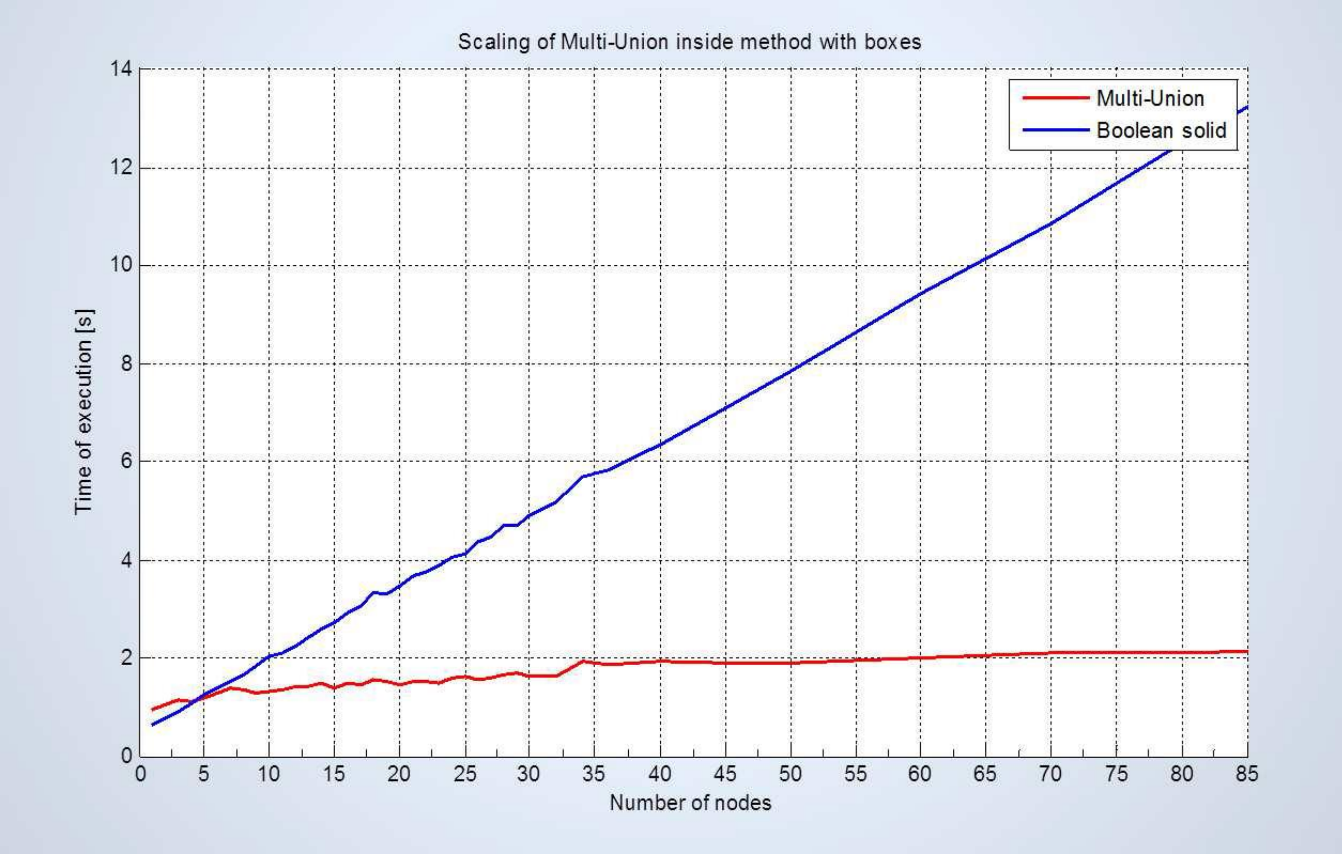
Information	Value
Number of facets	164.149
Number of voxels	100.000
Memory saved compared with original Geant4	22% (51MB)

New in v10.4

New “multi-union” solid

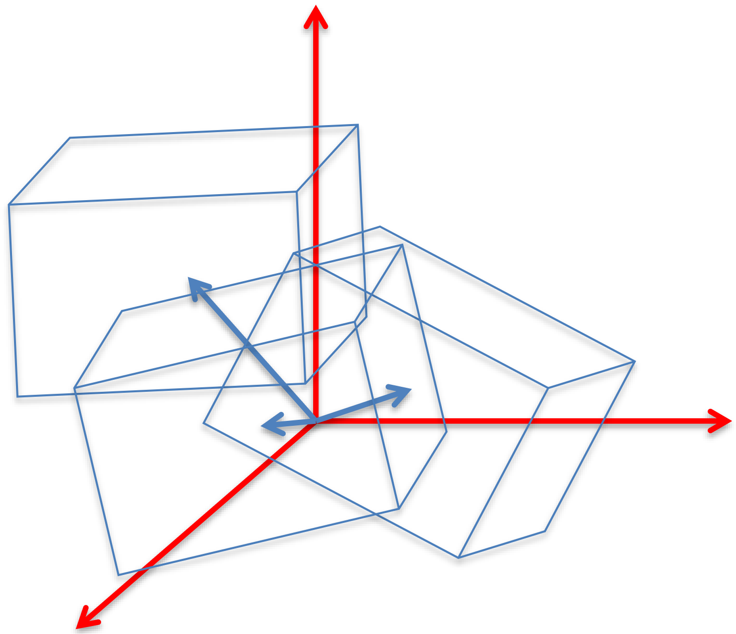
- In addition to a full set of highly optimized primitives and a tessellated solid, the library includes a new "multi-union” structure implementing a composite set of many solids to be placed in 3D space.
- This differs from the simple technique based on Boolean unions, with the aim of providing excellent scalability on the number of constituent solids.
- The multi-union adopts a similar voxelization technique to partition 3D space, allowing dramatically improved speed and scalability over the original implementation based on Boolean unions.

New in v10.4



G4MultiUnion

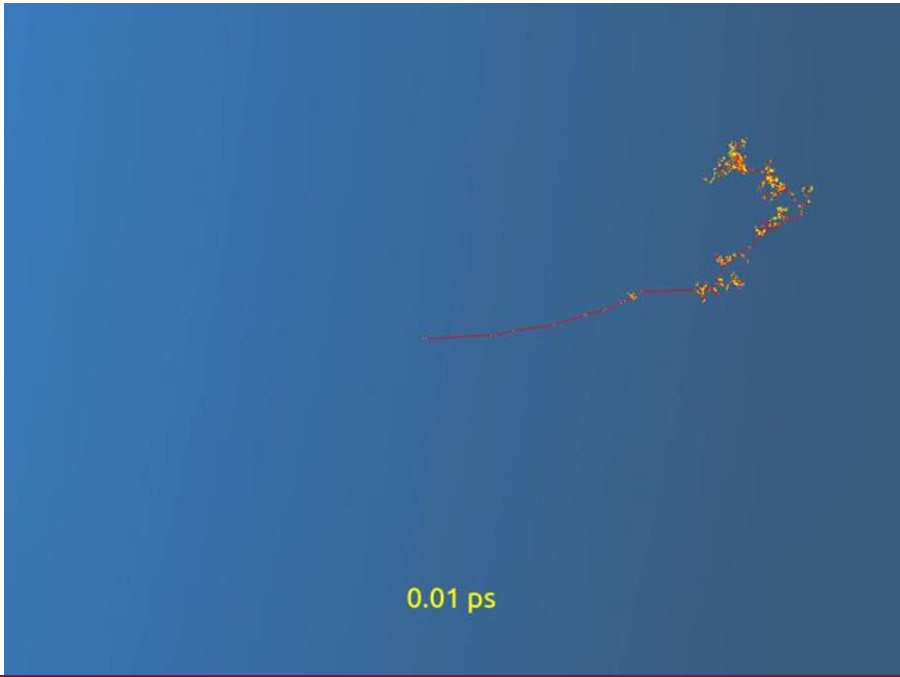
```
G4MultiUnion* munion_solid = new G4MultiUnion(“UnitedBoxes");

for( int i=0 ; I < nNode ; i++)
{
  G4Box* aBox = new G4Box(…);
  G4ThreeVector pos = G4ThreeVector(…);
  G4RotationMatrix rot = G4ThreeVector(…);
  G4Transform3D tr = G4Transform3D(rot, pos);
  munion_solid -> AddNode( *aBox, tr );
}

munion_solid -> Voxelize();
```



Note : G4MultiUnion is a solid. Use it to create a logical volume.

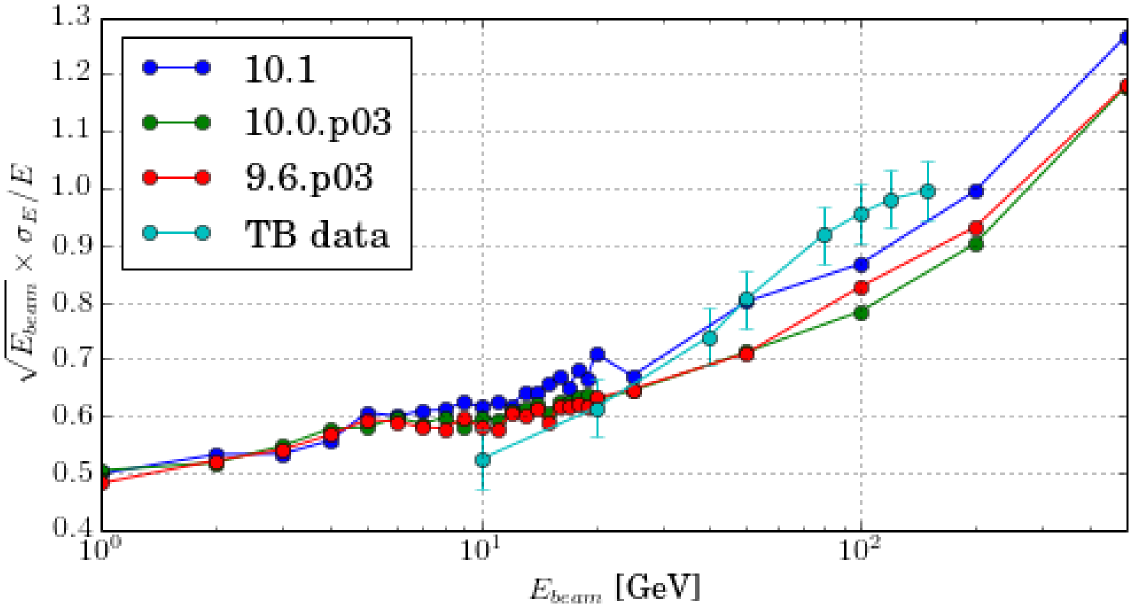
New features in EM physics

- Multiple/single scattering
  - Introduction of optional displacement on geometrical boundary
  - New G4LowEWenzalVIModel for low-energy applications
- Gamma processes
  - Photo-effect and Compton cross-sections at low-energy integrated
- High-energy models
  - Improvements in gamma->muons, positron->hadrons and positron->muons
  - Synchrotron radiation for all particle types
- Atomic de-excitation
  - New alternative fluorescence dataset (Bearden)
- New radiolysis process for water and silicon
  - Physics stage followed by physico-chemical and chemical stage
- Introduction of phonon transport with a new concept of crystal
- Channeling effect in straight and bent crystal
- Lots of code refinements along with MT

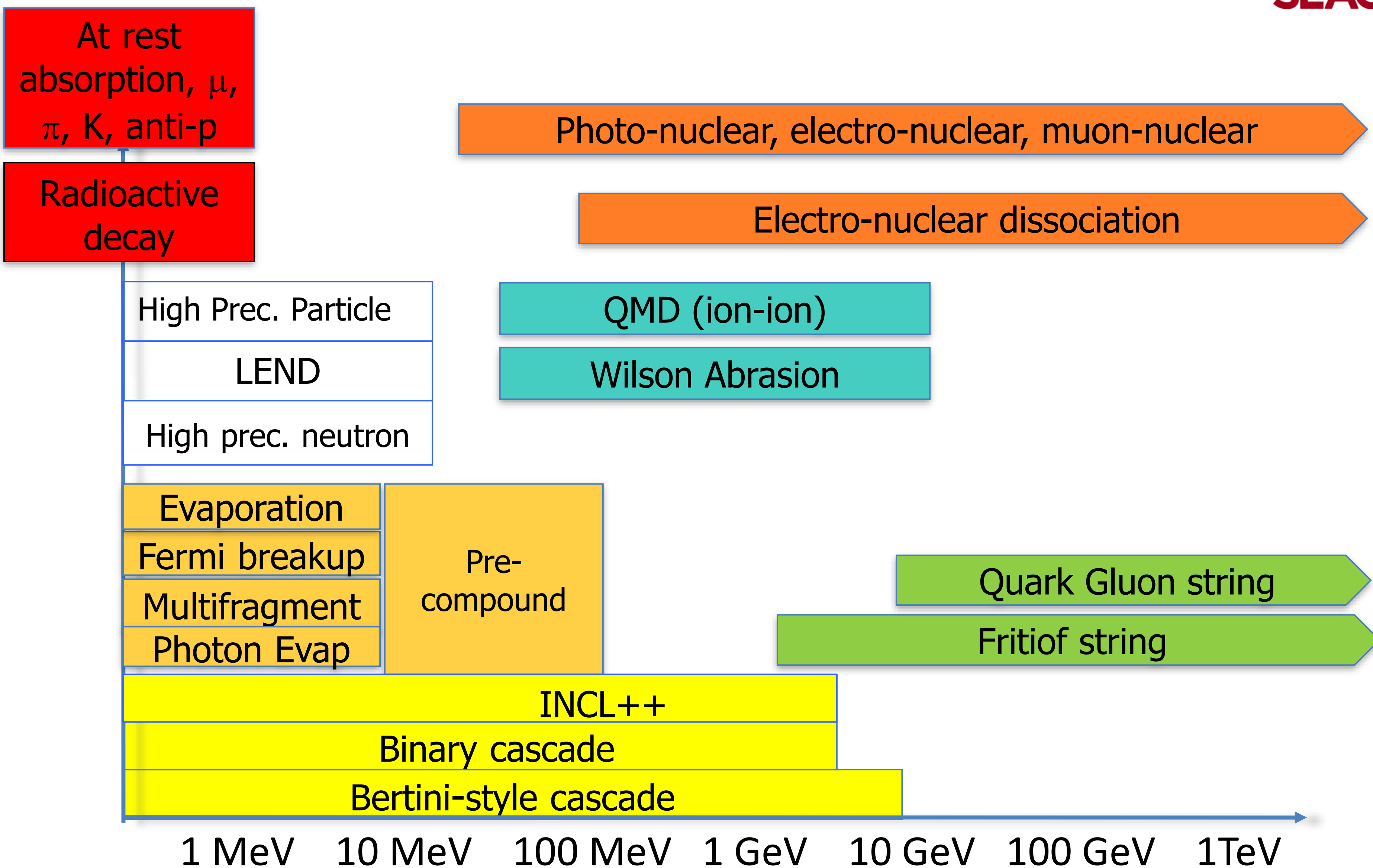


New features in hadronic physics

- FTFP_BERT is now the recommended physics list for most of high-energy use-cases
- Generation of Isomer (a.k.a. metastable nuclides)
  - by default lifetime > 1 nsec
- Neutron_HP is extended to Particle_HP to cover p, d, t, α
- Alternative low-energy neutron model with GND (Generalized Nuclear Data) format
- Liege intra-nuclear cascade model (INCLXX) extended up to 20 GeV
- FTF model extended to nucleus-nucleus and antinucleus-nucleus interactions
- Radioactive decay redesigned with rare decay channels
- New hadron stopping models based on Bertini
- Decommission of LHEP and CHIPS models

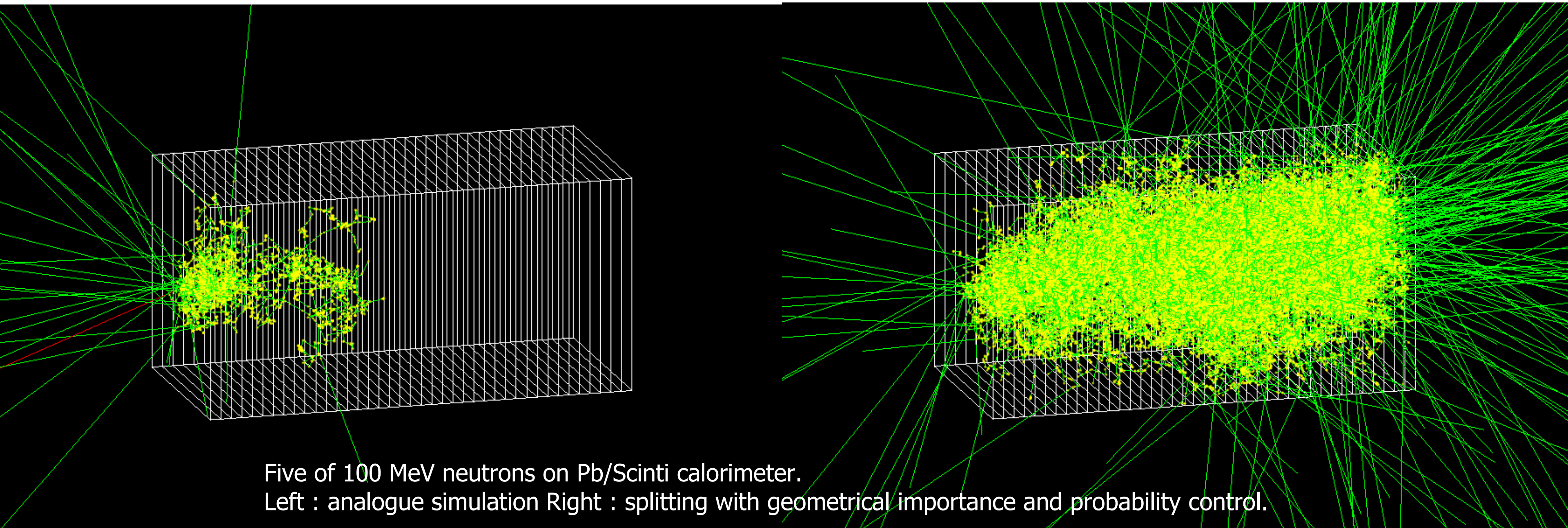


Hadronic Model Inventory



New biasing scheme

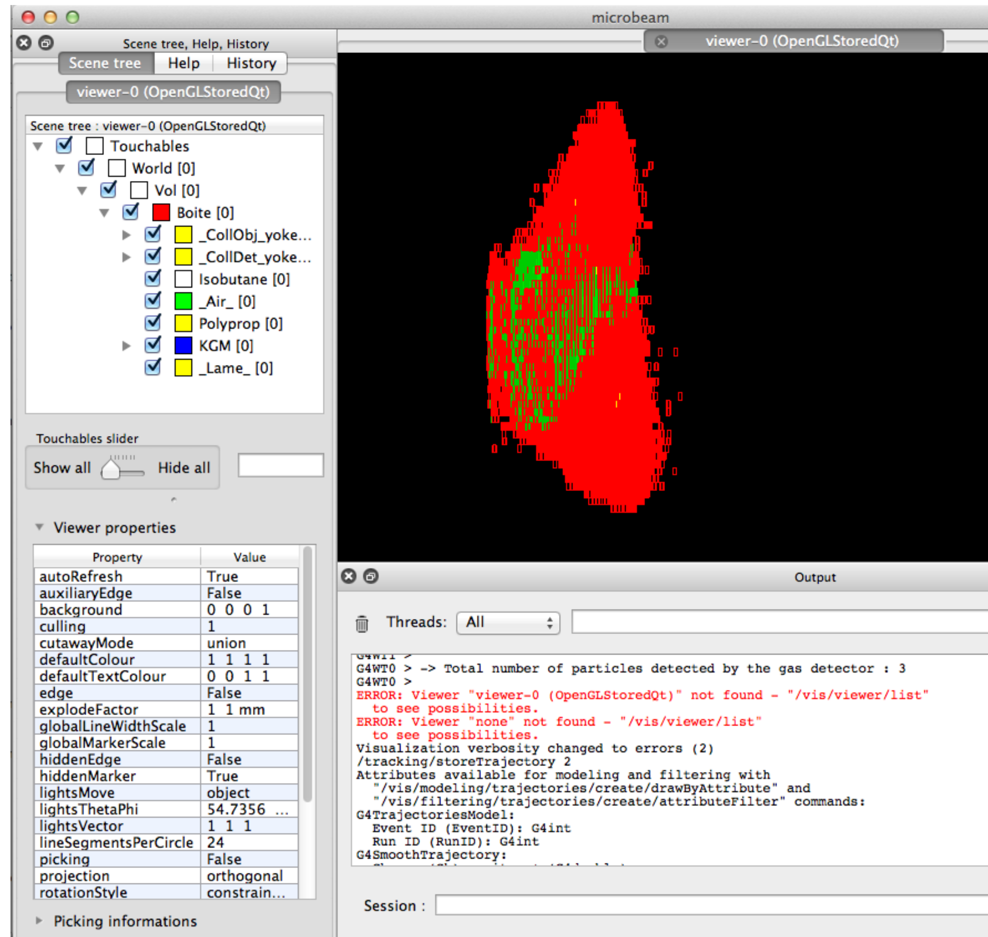
- Event biasing (a.k.a. variance reduction) scheme has been fully revised at version 10.
- It allows treating many biasing options in coherent manner.
- Such options include:
  - Physics process biasing : alters physics process
    - Cross-section biasing, forced interaction, forced passage, etc.
    - Biasing final products of an interaction, e.g. distribution
  - Non-physics biasing : alters the transportation of particle
    - Geometrical importance, splitting / Russian roulette, weight window, etc.
- Easily extensible to new (or user-defined) options
- Well-integrated with built-in scoring functionalities.
- New examples are available.

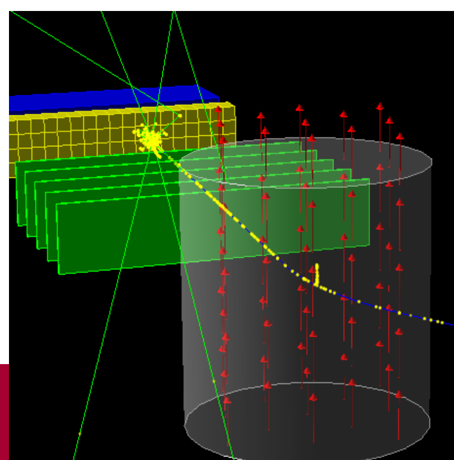


Five of 100 MeV neutrons on Pb/Scinti calorimeter.
Left : analogue simulation Right : splitting with geometrical importance and probability control.

New features in analysis, GUI and visualization

- New built-in fully-multithreaded histogramming tool
  - 1-D and 2-D histograms and scatter plots, n-tuples
  - Data format compatible with ROOT, XML, AIDA, CSV
    - Extensible to other format
- GUI and visualization
  - New Qt driver with OpenGL
    - Viewer properties and picking panel, dock-able widgets
    - Multithread output filtering
  - More than 30% faster drawing on OpenGL
  - Magnetic field lines





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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(2003) Nuclear Instruments a

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J. Allison et al.

Recent developments in Geant4

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

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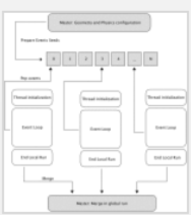

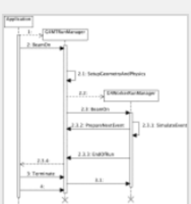

ELSEVIER

Nuclear Instruments and Methods in Physics 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],

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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.

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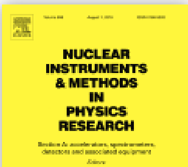
SEARCH MENU



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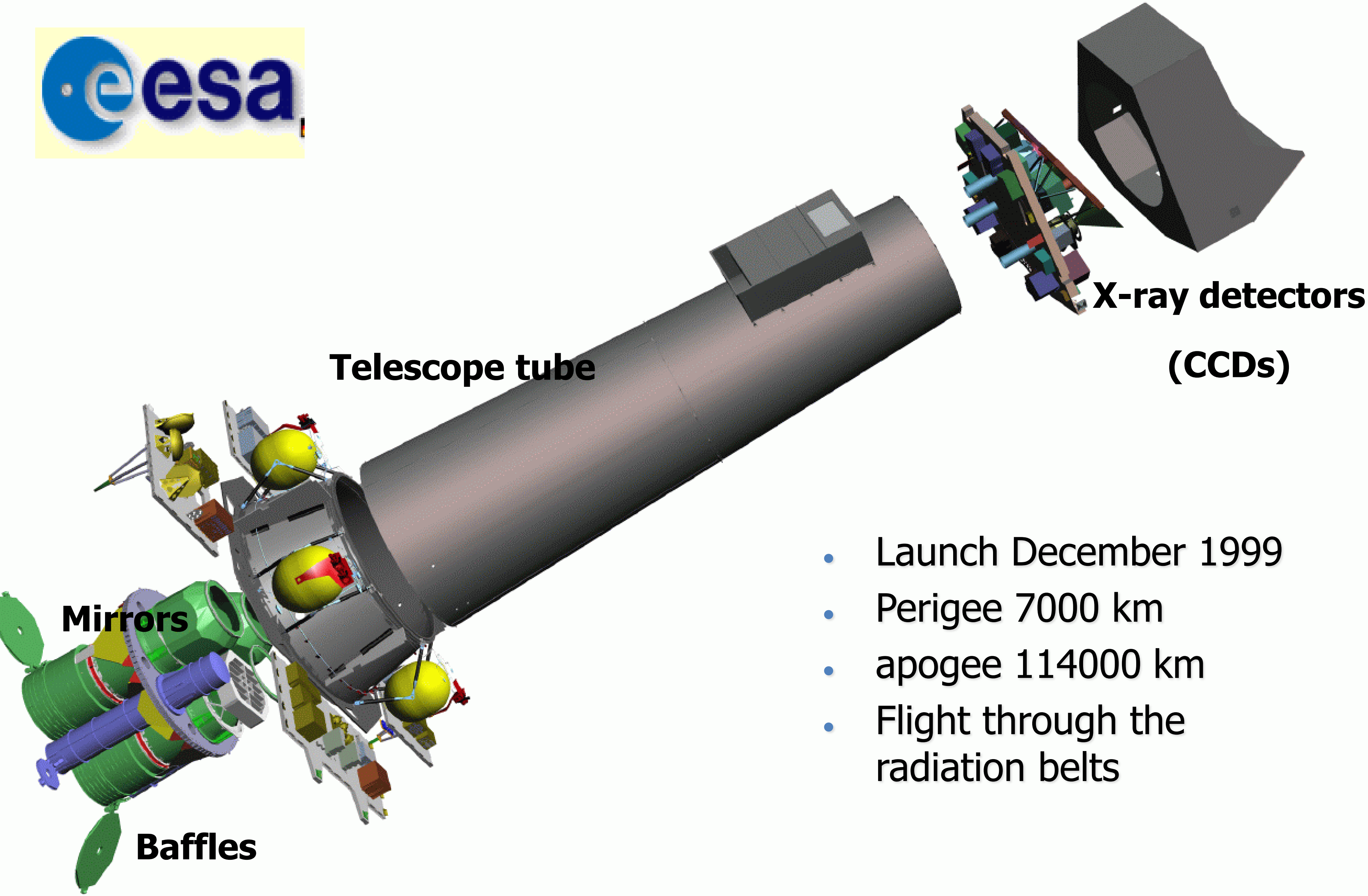
Feedback

GEANT4
A SIMULATION TOOLKIT

Version 10.5.p01

Highlights of Users Applications outside of HENP

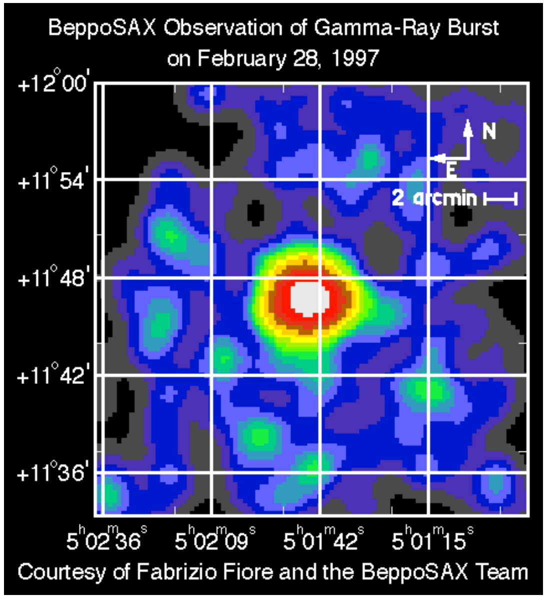
To provide you some ideas how Geant4 would be utilized…

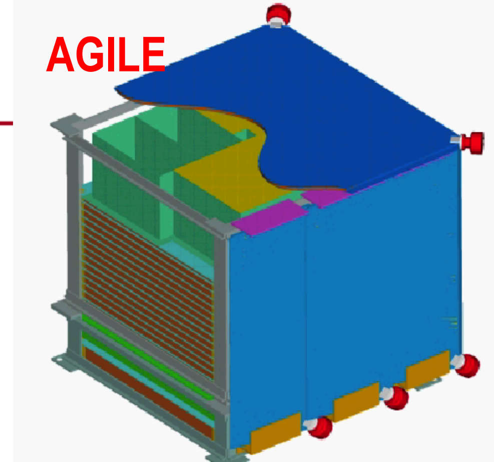


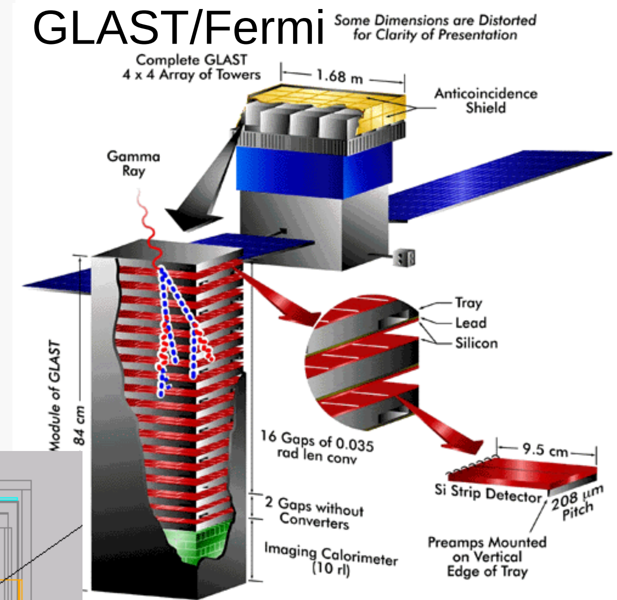
- Launch December 1999
- Perigee 7000 km
- apogee 114000 km
- Flight through the radiation belts

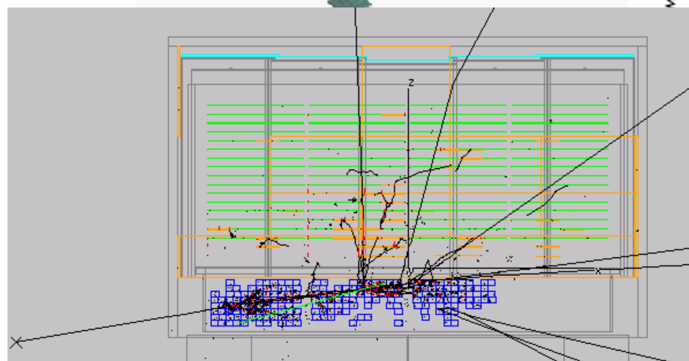
γ astrophysics

γ-ray bursts

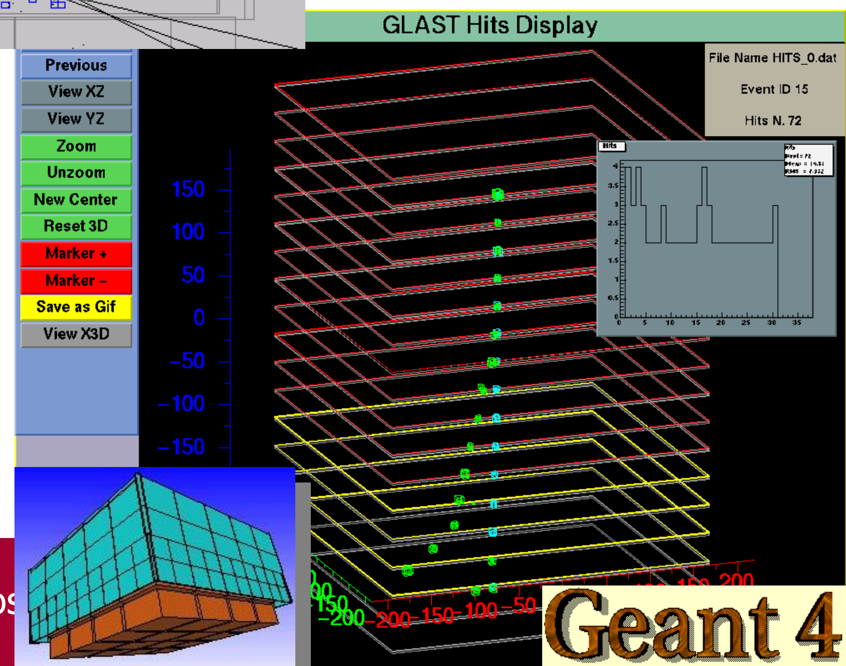


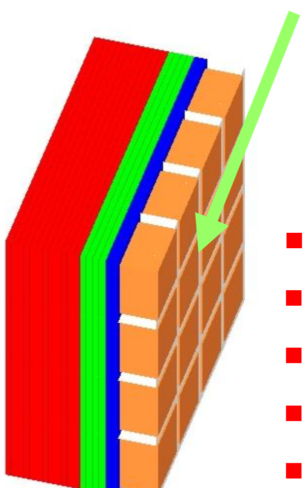




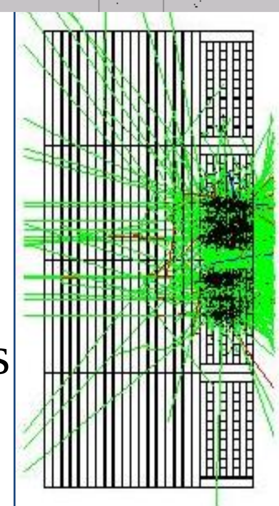


GLAST / Fermi





Typical telescope:
Tracker
Calorimeter
Anticoincidence



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

Geant4 in space

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.

Journal of Geophysical Research: Planets

RESEARCH ARTICLE
10.1002/2013JE004547

Special Section:
Results from the first 360 Sols of the Mars Science Laboratory Mission: Bradbury Landing through Yellowknife Bay

Key Points:
- We present charged particle measurements on the Martian surface

Charged particle spectra obtained with the Mars Science Laboratory Radiation Assessment Detector (MSL/RAD) on the surface of Mars

Bent Ehresmann[1], Cary Zeitlin[1], Donald M. Hassler[1], Robert F. Wimmer-Schweingruber[2], Eckart Böhm[2], Stephan Böttcher[2], David E. Brinza[3], Sönke Burmeister[2], Jingnan Guo[2], Jan Köhler[2], Cesar Martin[2], Arik Posner[4], Scot Rafkin[1], and Günther Reitz[5]

[1]Southwest Research Institute, Boulder, CO, USA, [2]Christian-Albrechts-Universität zu Kiel, Kiel, Germany, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [4]Science Mission Directorate, NASA Headquarters, Washington, District of Columbia, USA, [5]Deutsches Zentrum für Luft- und Raumfahrt, Cologne, Germany

Journal of Geophysical Research: Planets

RESEARCH ARTICLE
10.1002/2013JE004539

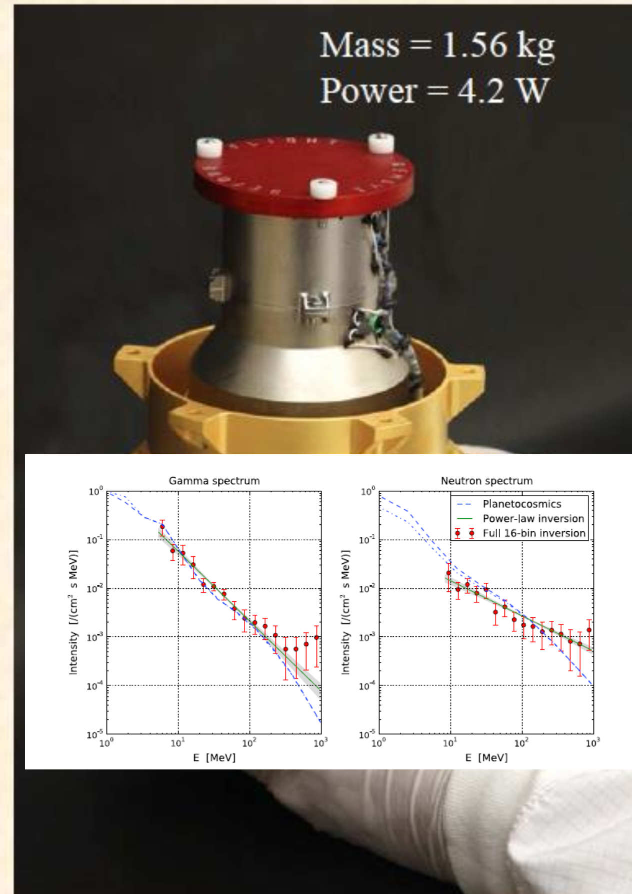
Special Section:
Results from the first 360 Sols of the Mars Science Laboratory Mission: Bradbury Landing through Yellowknife Bay

Key Points:
- We calculated the Martian neutron and gamma spectra
- We compare the results to Planetocosmics simulations

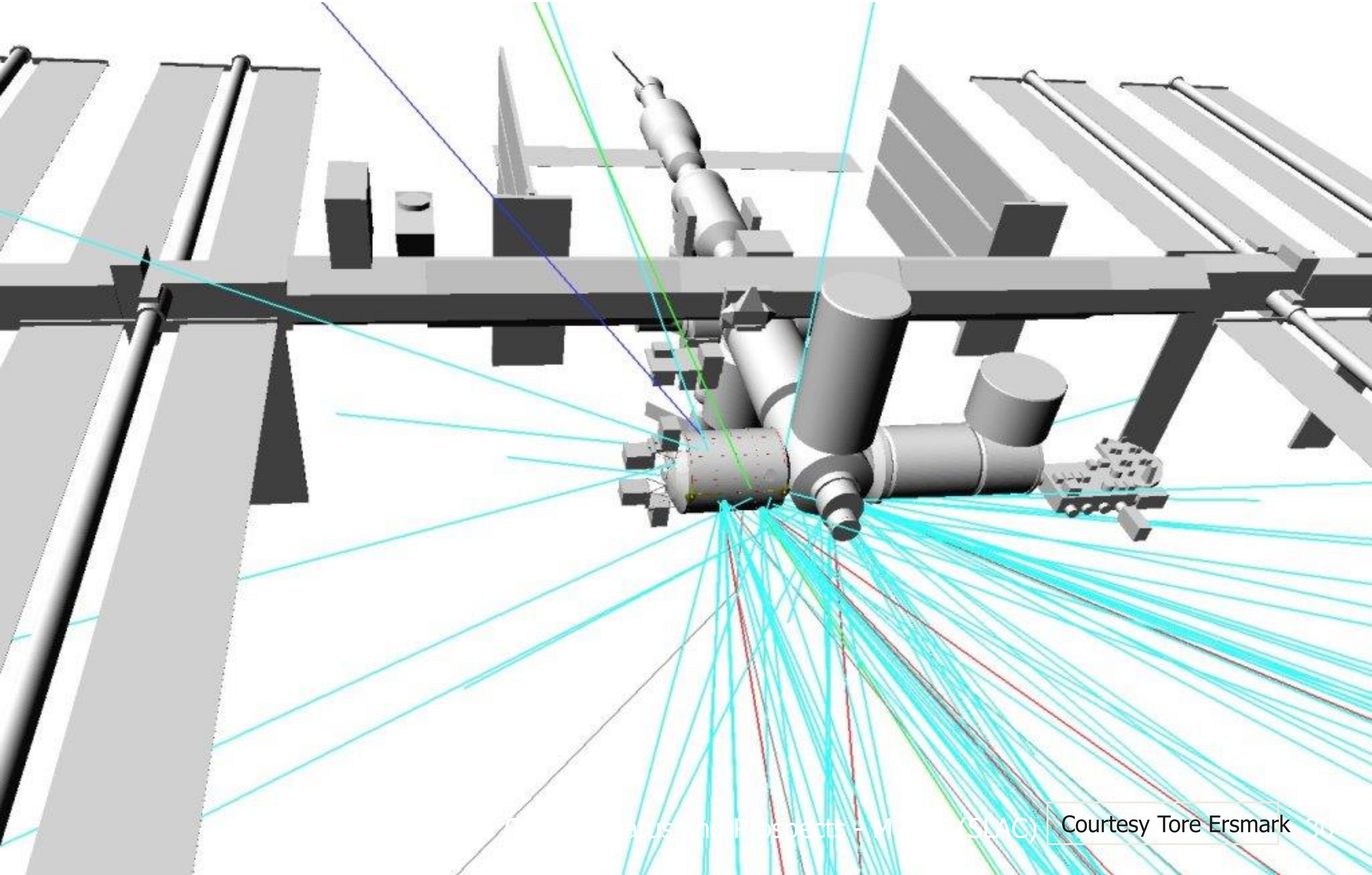
Measurements of the neutron spectrum on the Martian surface with MSL/RAD

J. Köhler[1], C. Zeitlin[2], B. Ehresmann[2], R. F. Wimmer-Schweingruber[1], D. M. Hassler[2], G. Reitz[4], D. E. Brinza[5], G. Weigle[6], J. Appel[1], S. Böttcher[1], E. Böhm[1], S. Burmeister[1], J. Guo[1], C. Martin[1], A. Posner[7], S. Rafkin[3], and O. Kortmann[8]

[1]Institute of Experimental and Applied Physics, Christian-Albrechts-University, Kiel, Germany, [2]Earth, Oceans and Space Department, Southwest Research Institute, Durham, New Hampshire, USA, [3]Space Science and Engineering Division, Southwest Research Institute, Boulder, Colorado, USA, [4]Aerospace Medicine, Deutsches Zentrum für Luft- und Raumfahrt, Cologne, Germany, [5]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, [6]Big Head Endian, LLC, Burden, Kansas, USA, [7]Science Mission Directorate, NASA Headquarters, Washington, District of Columbia USA, [8]Space Science Laboratory, University of California, Berkeley, California, USA



International Space Station



Courtesy Tore Ersmark

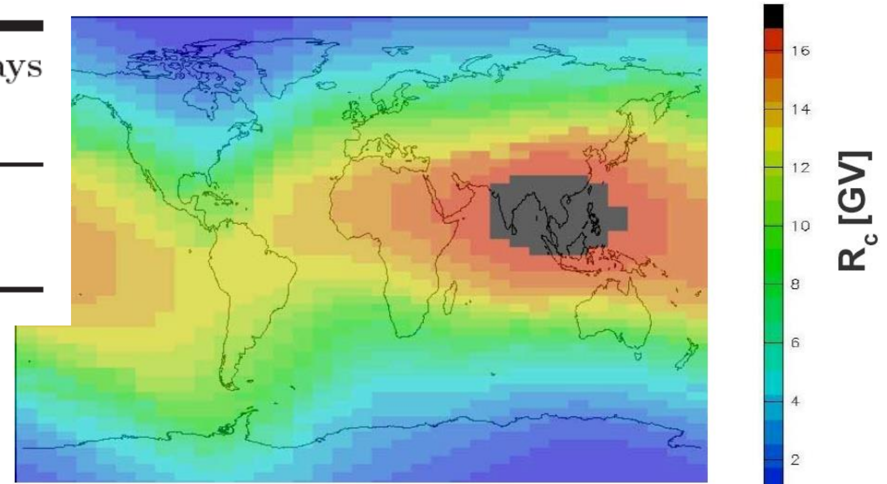
PlanetoCosmics
Geant4 simulation of Cosmic Rays in planetary Atmo-/Magneto- spheres

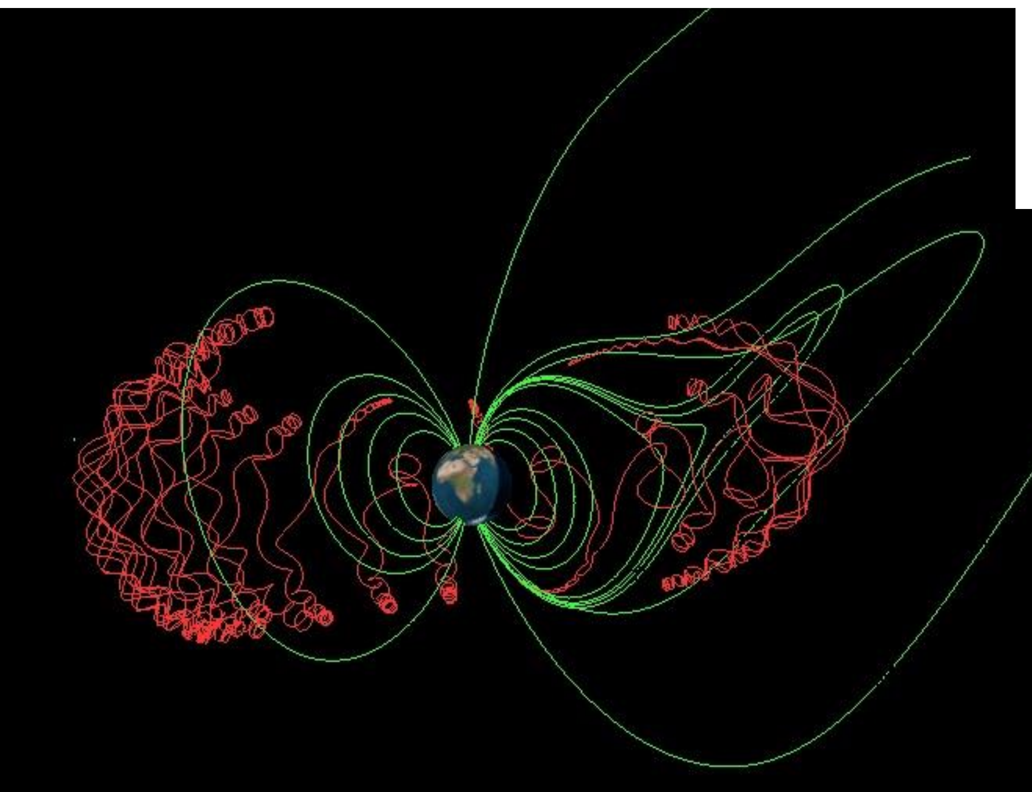
28th International Cosmic Ray Conference — 4277

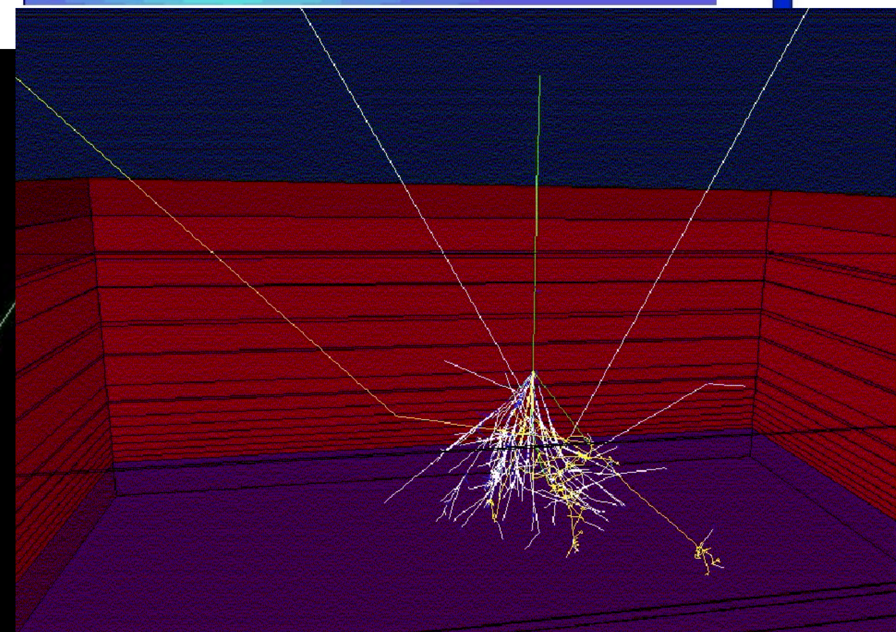
Geant4 Simulation of the Propagation of Cosmic Rays through the Earth's Atmosphere

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

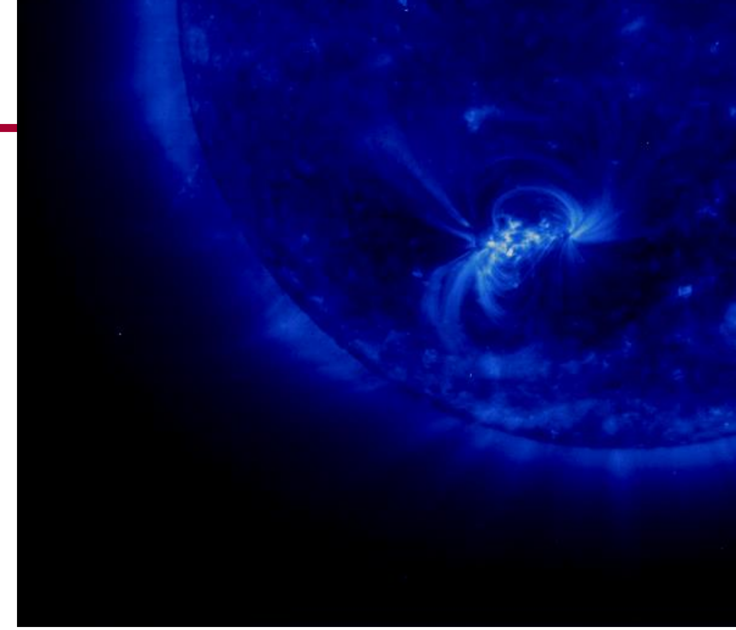
Cutoff Rigidities vs position





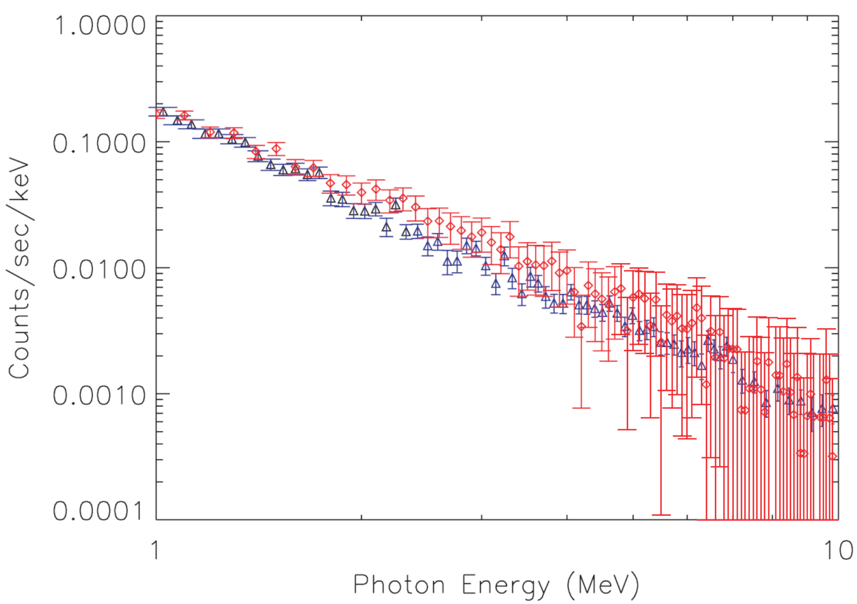


Solar event gamma-rays



- 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

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Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo, 113-0022

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RIKEN (Institute of Physical and Chemical research), Wako-shi, Saitama

[1] *Also at RIKEN*

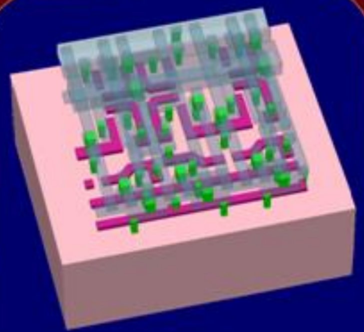
[2] *Present address: Mitsubishi Electric Co., Ltd.*

(Received ; accepted)

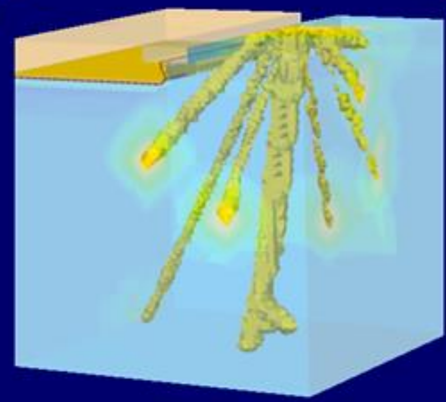
Abstract

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-

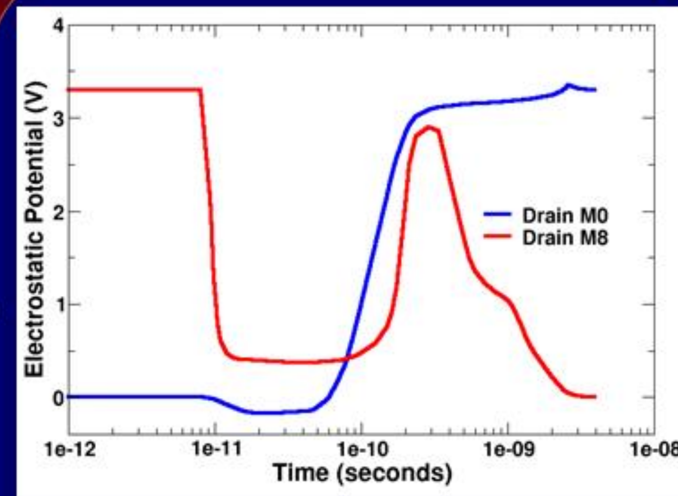
RADSAFE on SEE in SRAMs



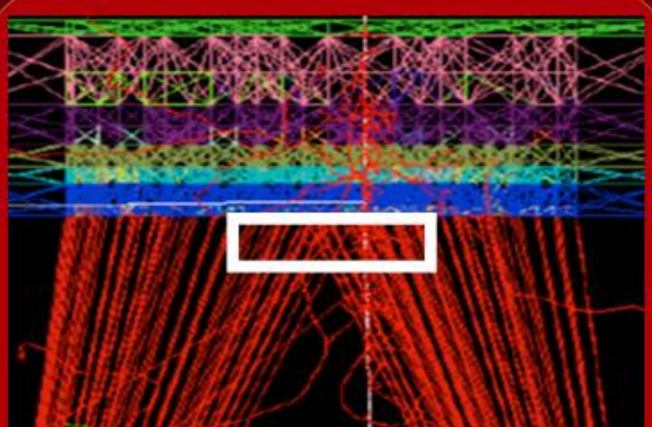
TCAD Cell Structure: SRAM Cell



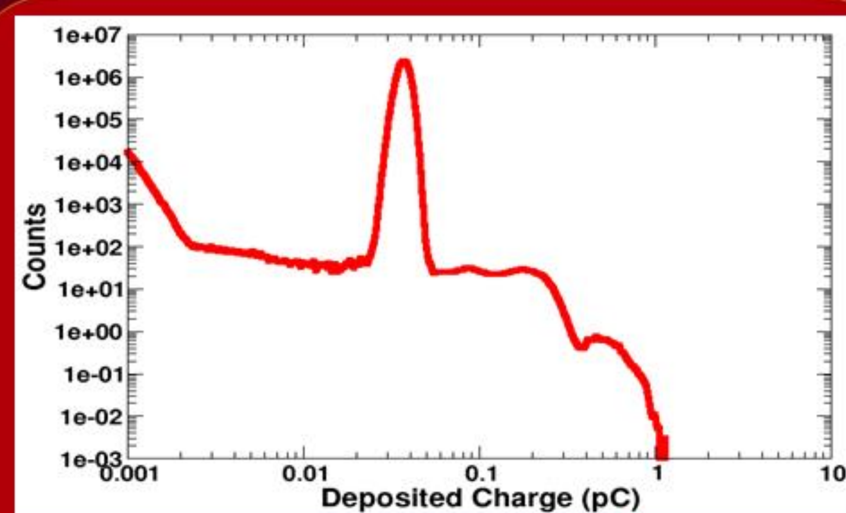
Single Charge Deposition in TCAD: Ne+W Event



SRAM Cell Upset



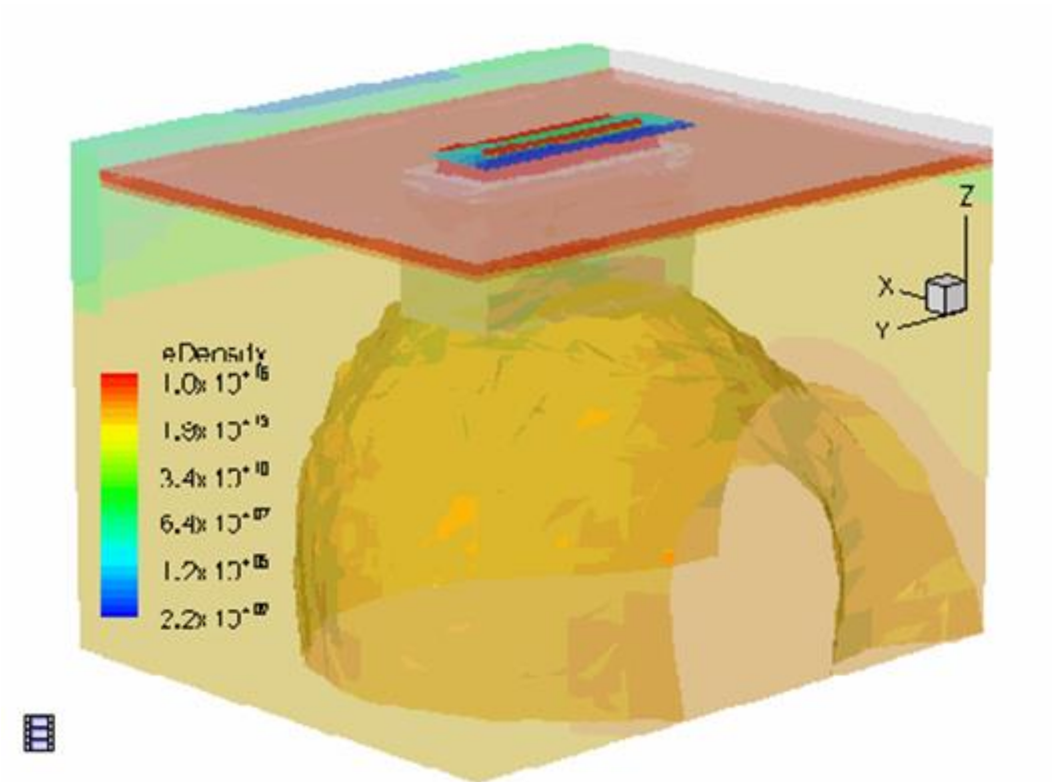
Geant4 Geometry and 523 MeV Neon Event

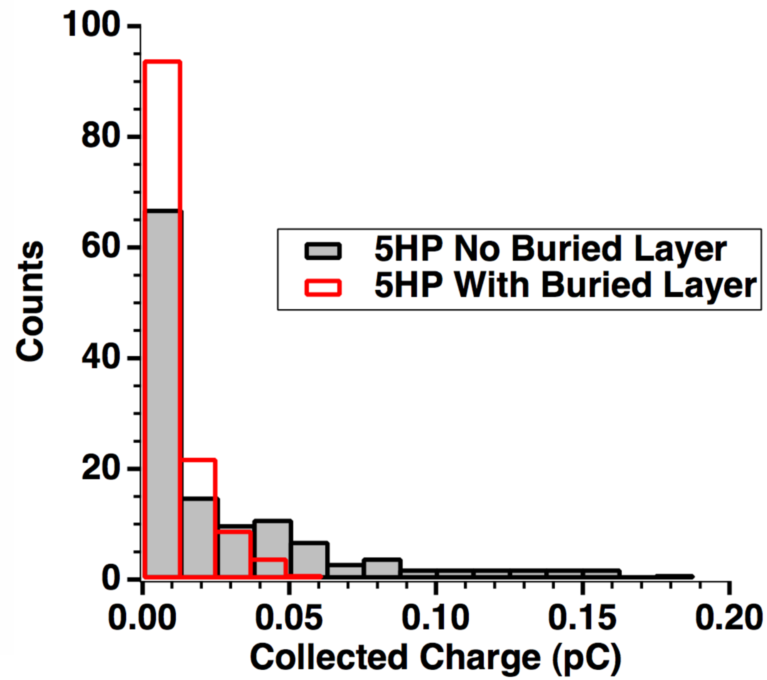


MRED Energy Deposition for 10^8 Events

Simulation of Radiation Events

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





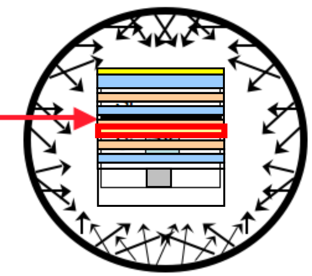
Courtesy of R.Reed (Vanderbilt U.)

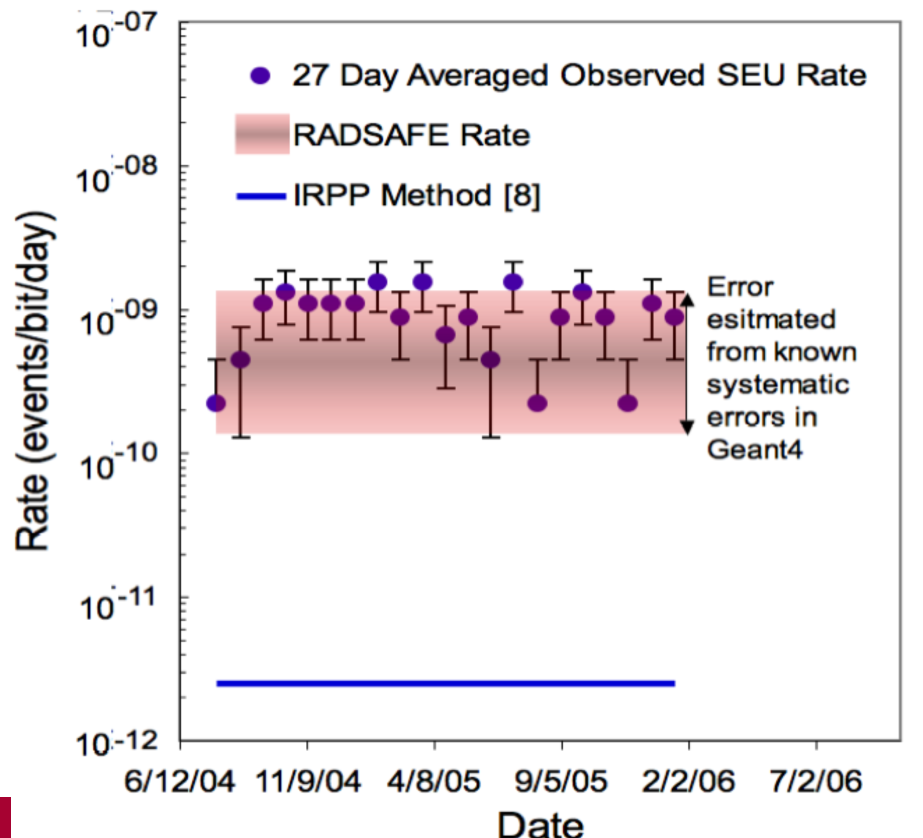
Observed and Predicted SEU Rate for an SRAM

SLAC

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

Multi-layered Stack

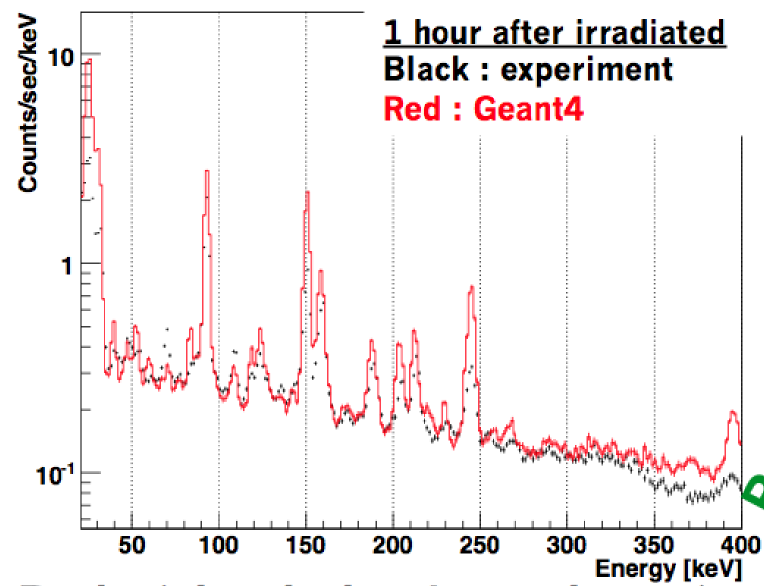


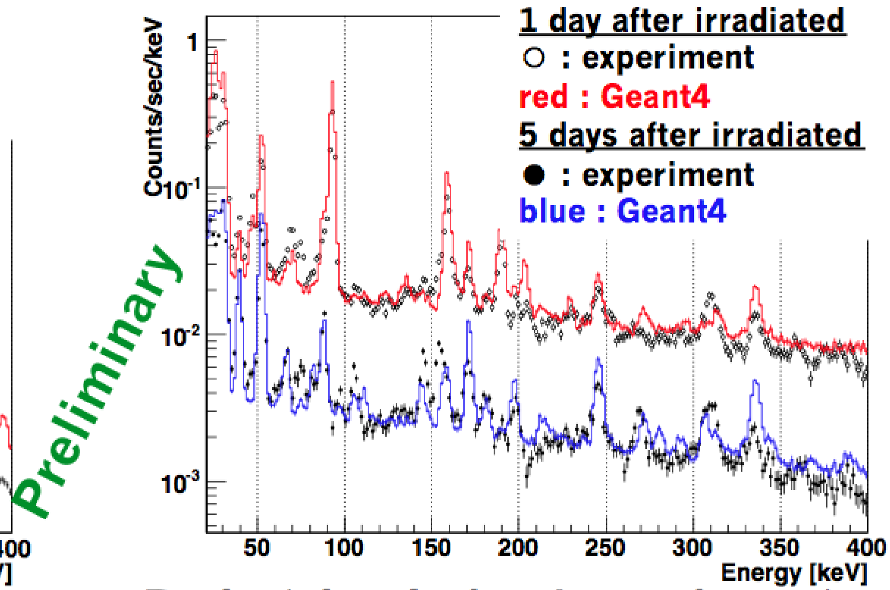


Courtesy of R.Reed (Vanderbilt U.)

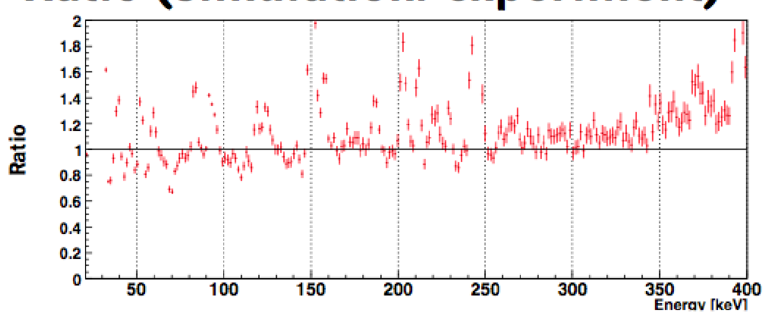
Time evolution of the activation background

Comparison with Geant4

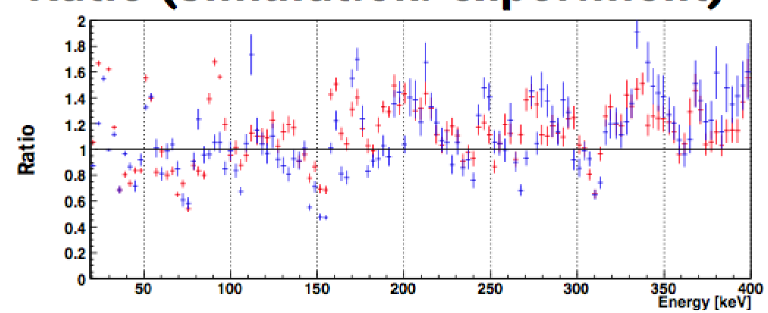




Ratio (simulation/experiment)



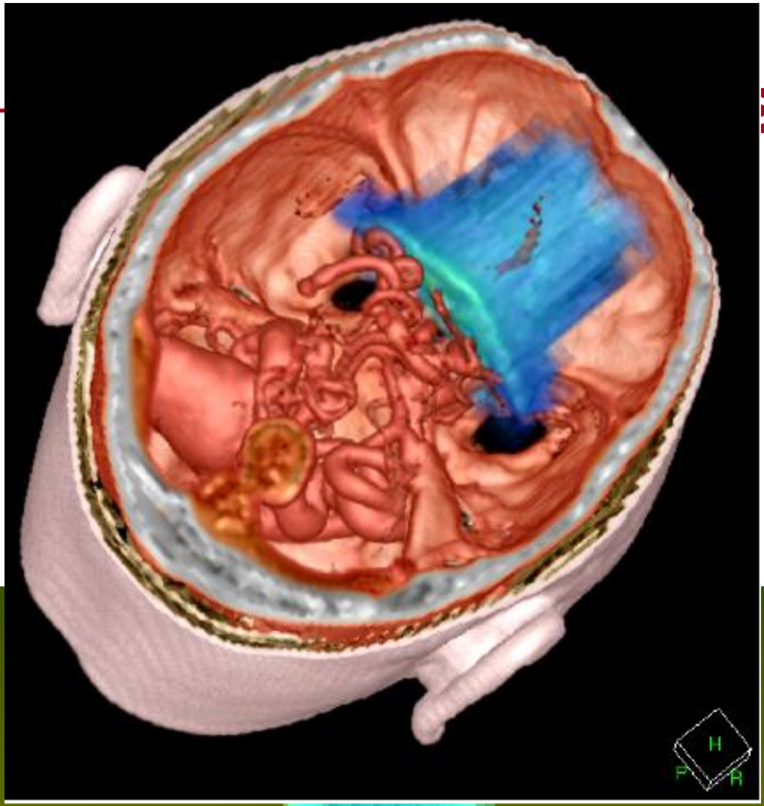
Ratio (simulation/experiment)

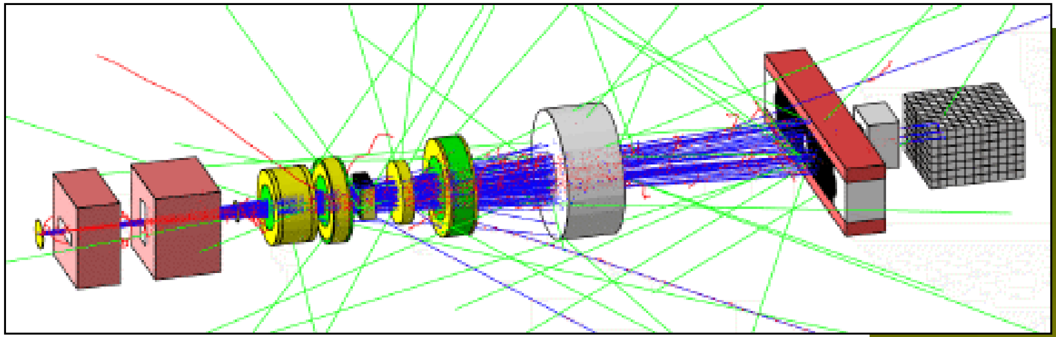


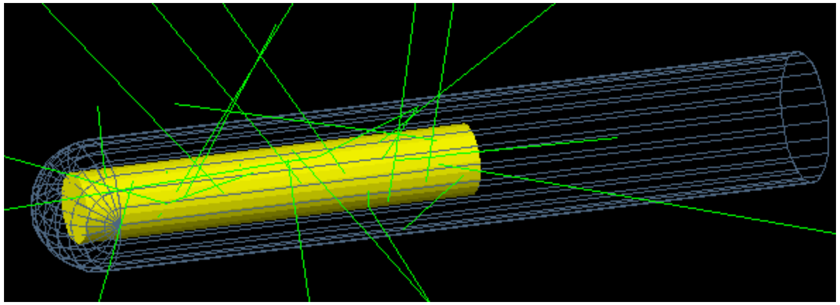
❖ Simulation results agrees with experimental data within a factor of two in terms of the line intensities

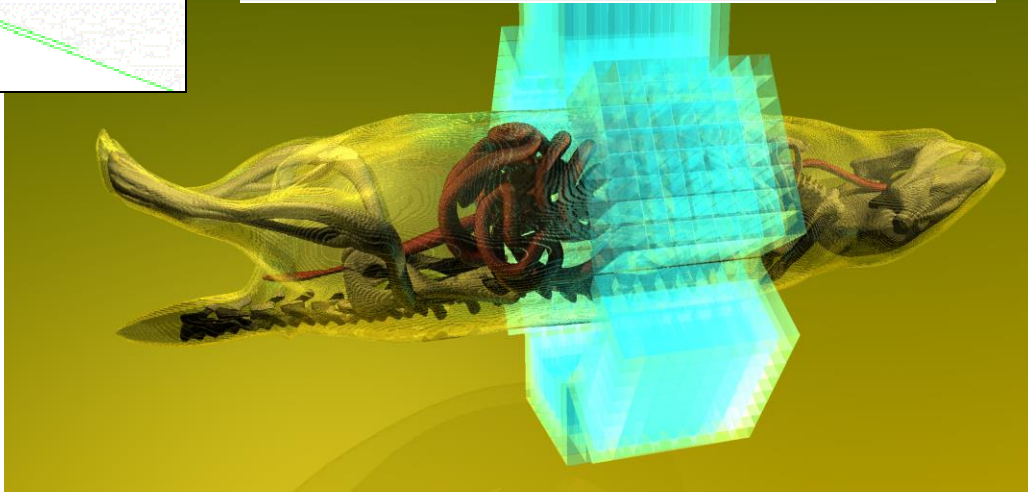
Geant4 @ Medical Science

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



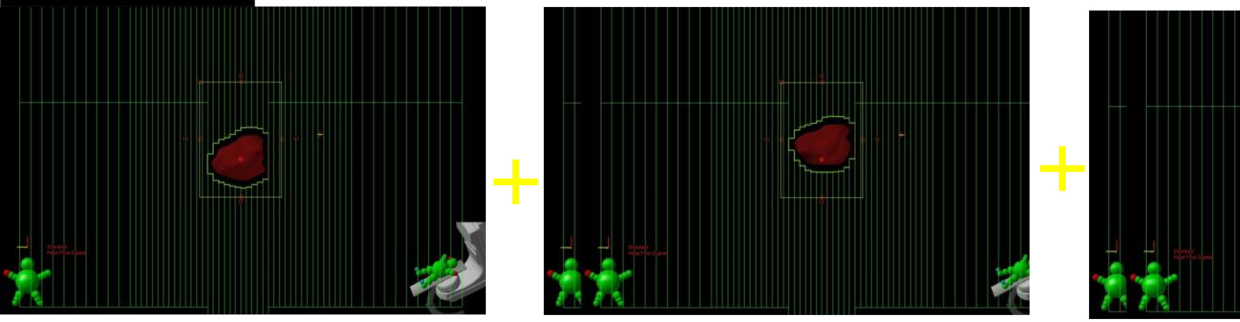


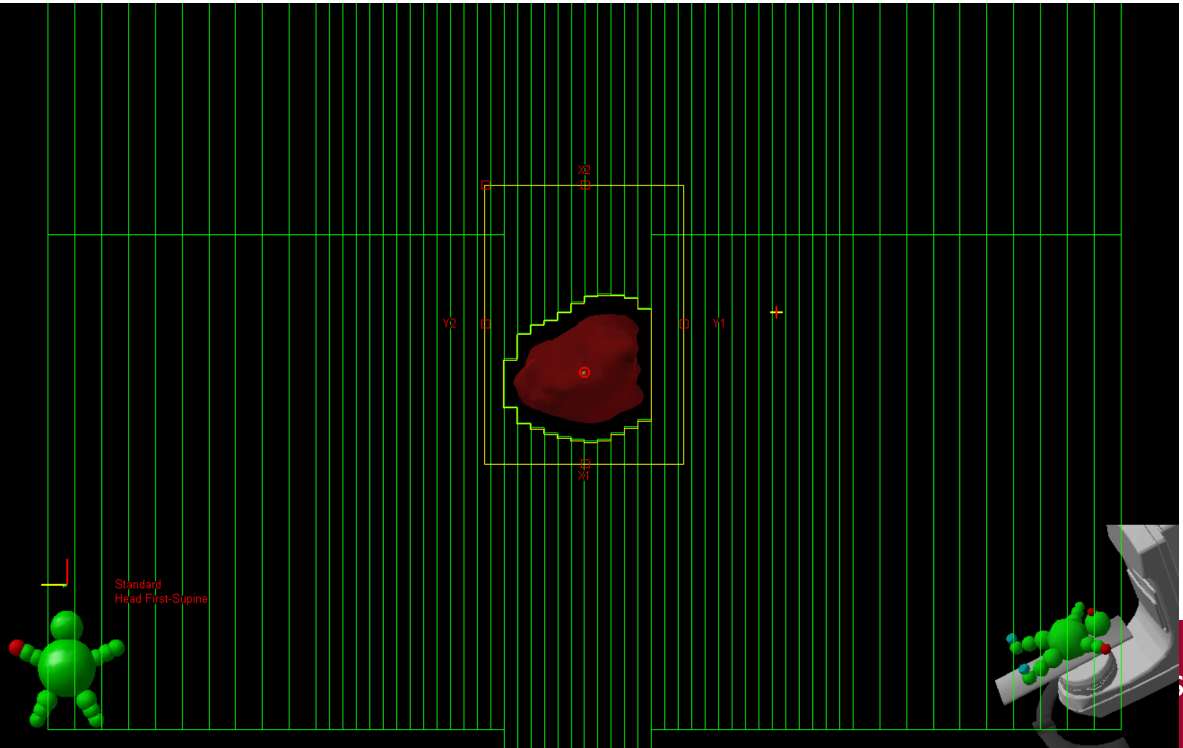


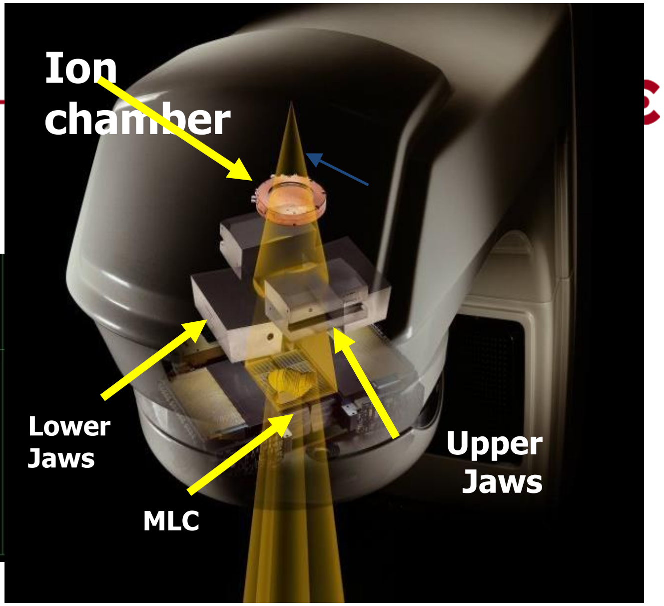


4D RT Treatment Plan

Source: Lei Xing, Stanford University

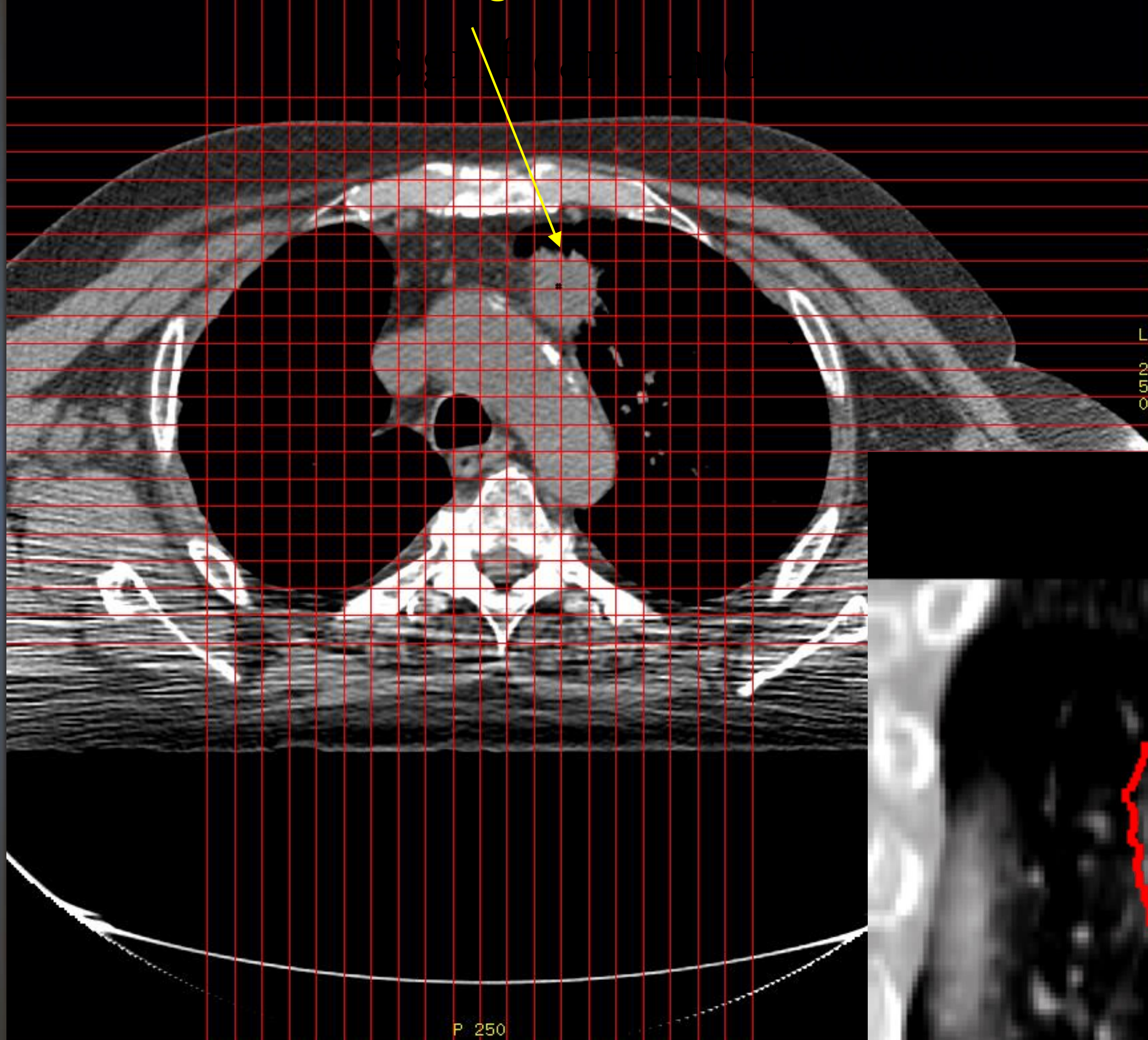


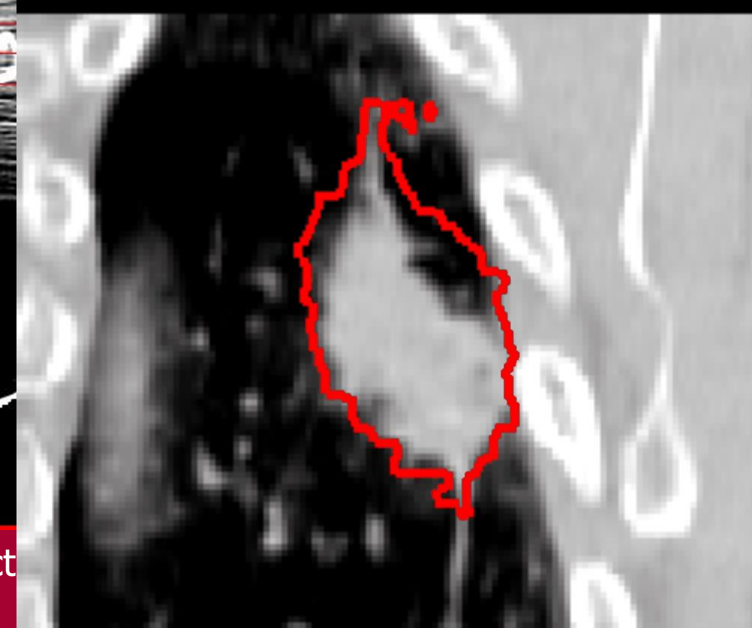




Y. Yang, S. Huq, L Xing, Med. Phys, 2006

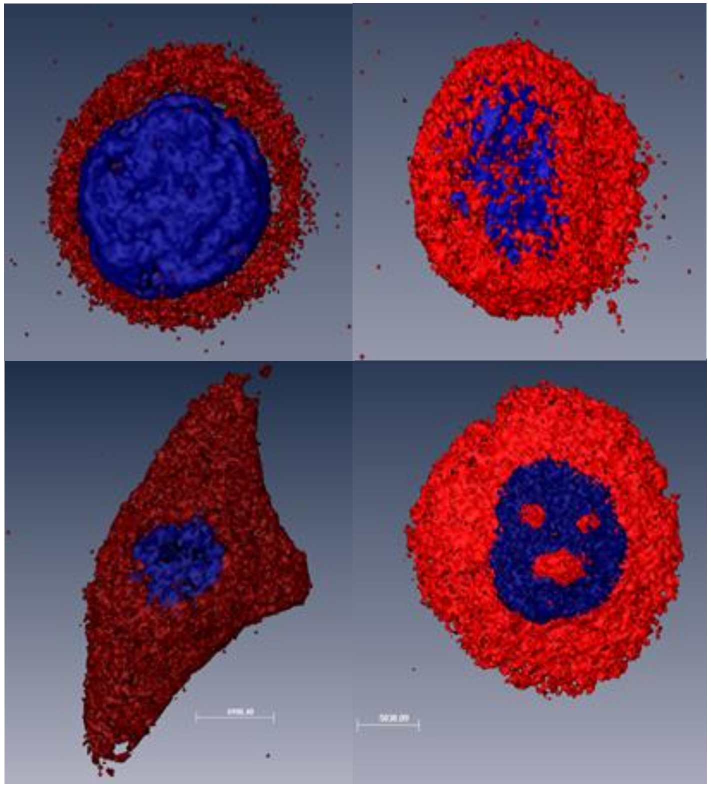
Lateral Motion of Lung Tumor

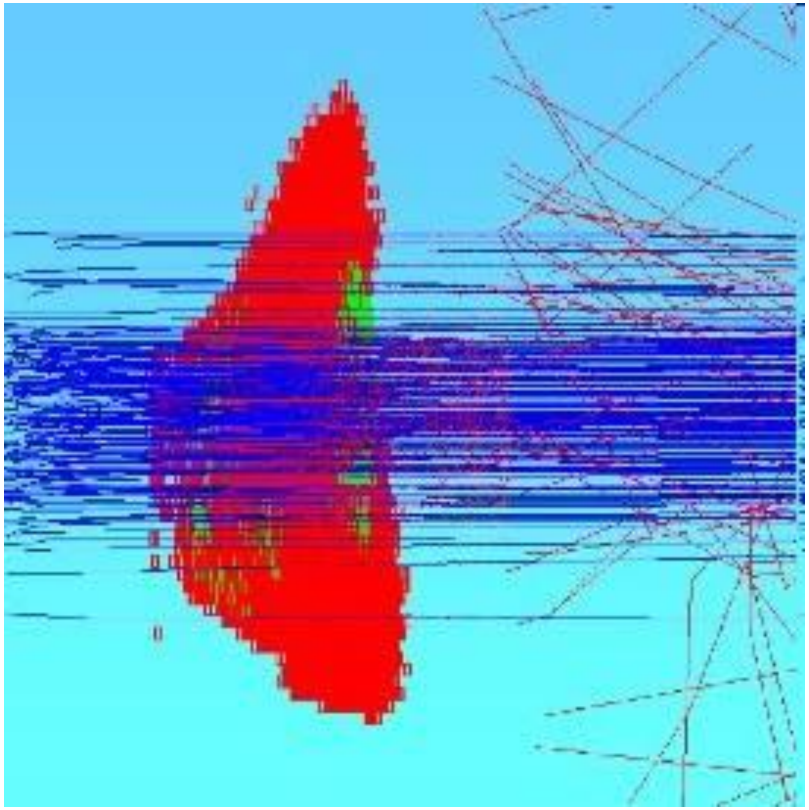




Single cell irradiation

- 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

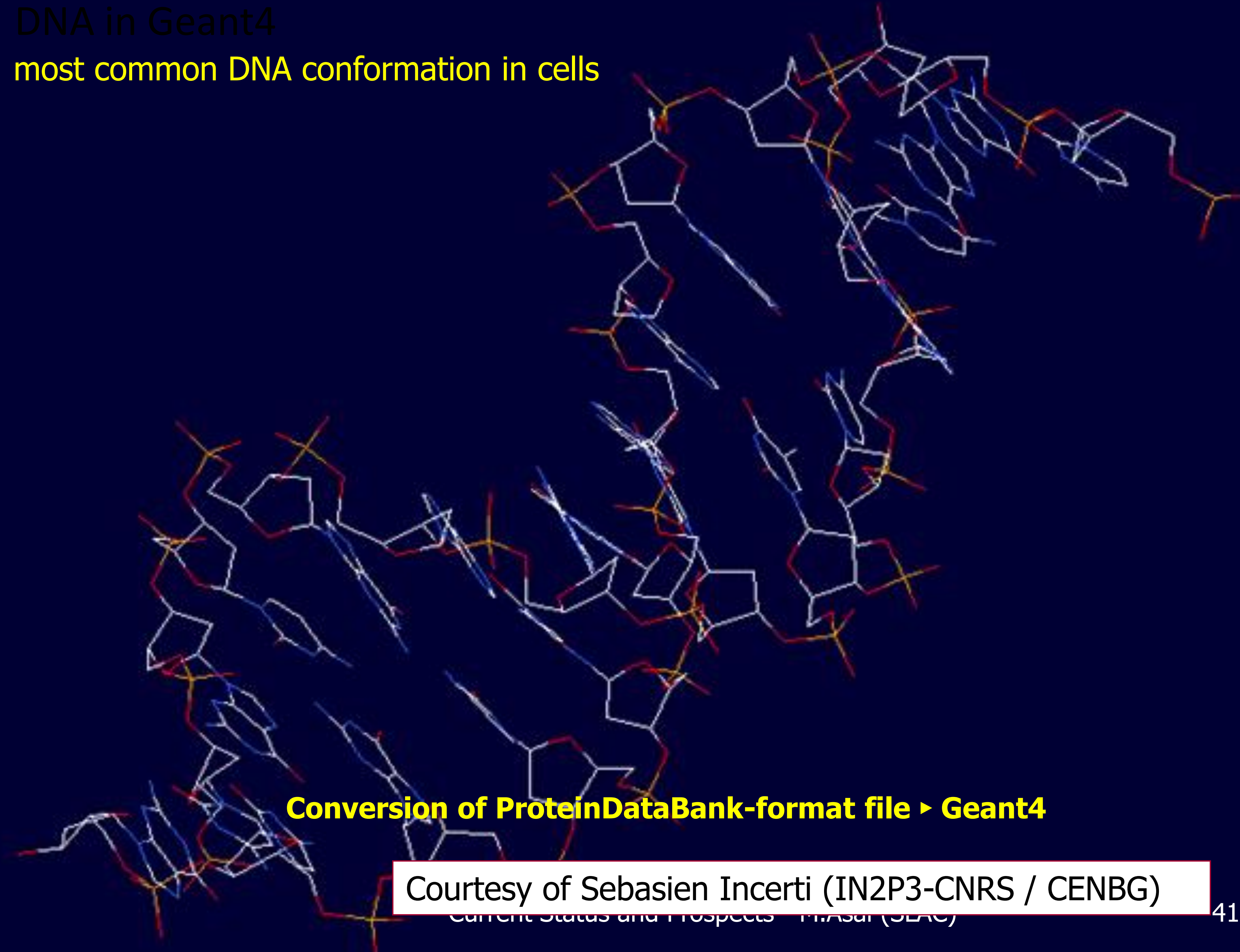




Courtesy of Sebasien Incerti (IN2P3-CNRS / CENBG)

DNA in Geant4

most common DNA conformation in cells



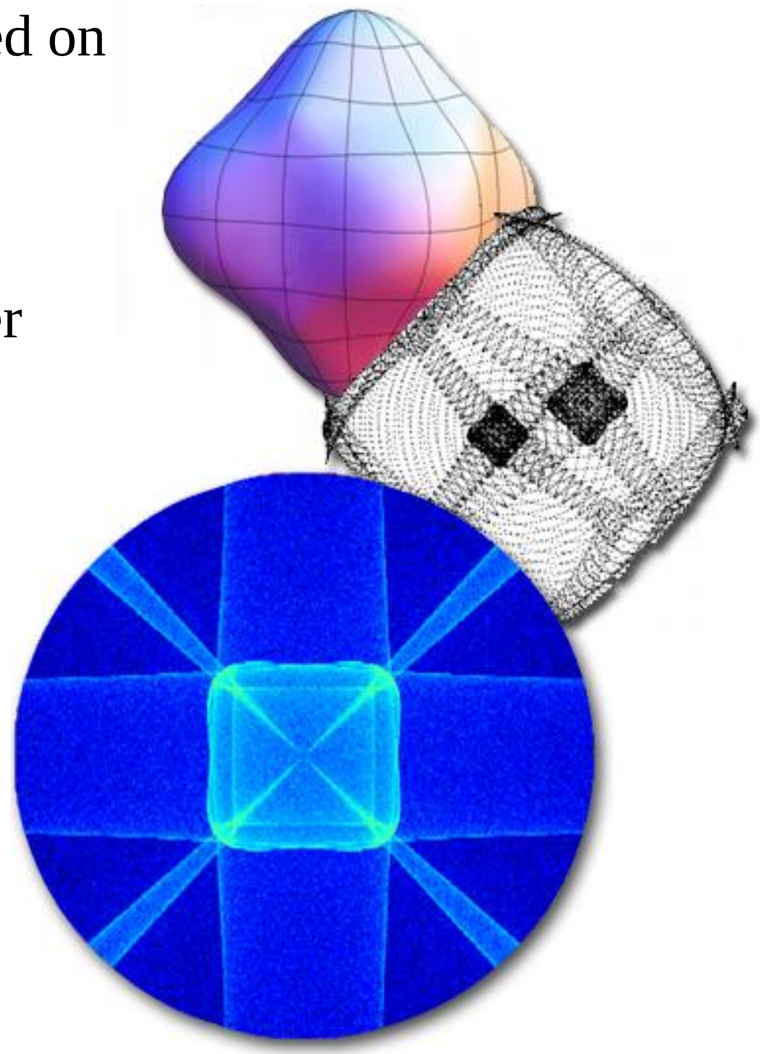
Conversion of ProteinDataBank-format file ▸ Geant4

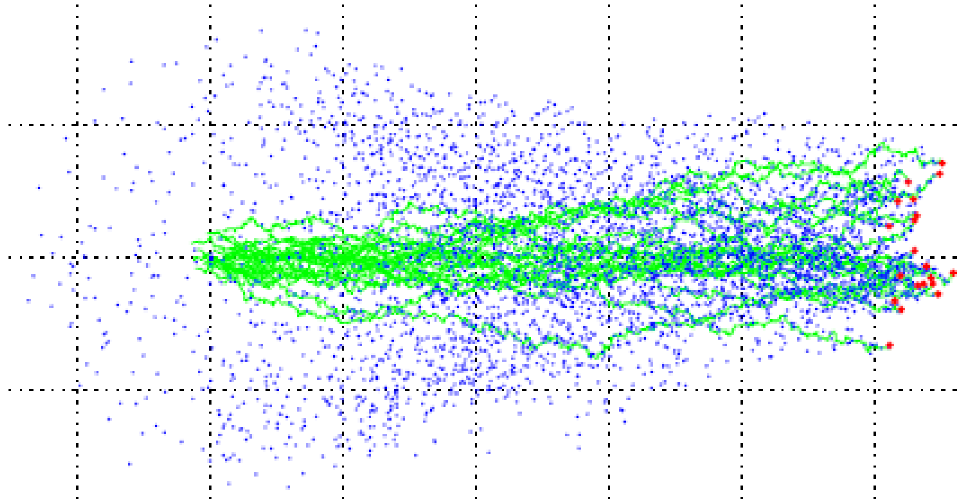
Courtesy of Sebasien Incerti (IN2P3-CNRS / CENBG)

Condensed Matter Physics in Geant4

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

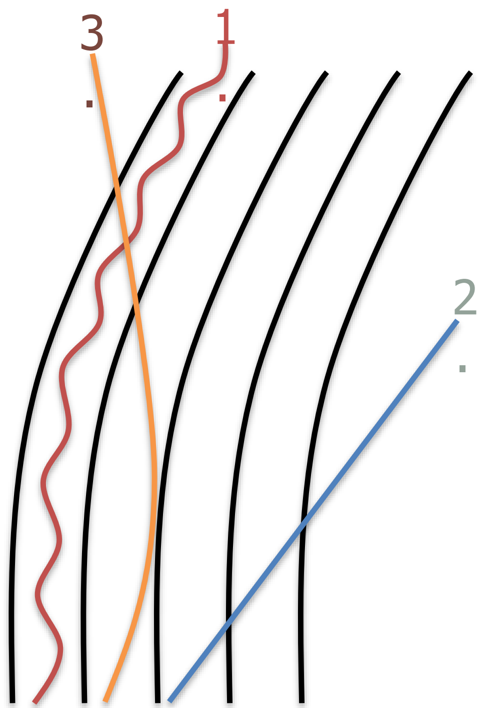
•e-/h+ transport, including conduction band anisotropy and Luke-Neganov emission, under development (below)

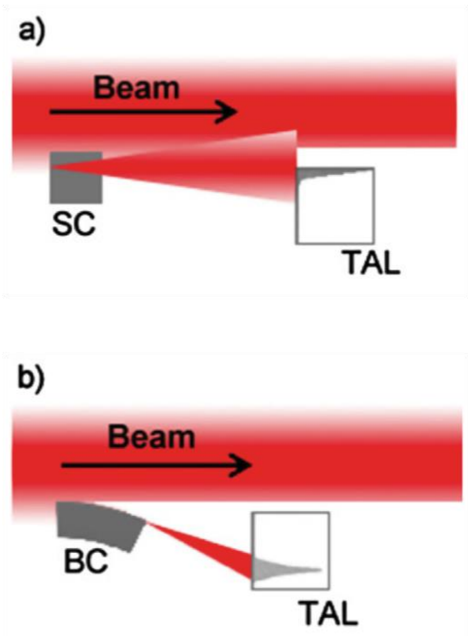


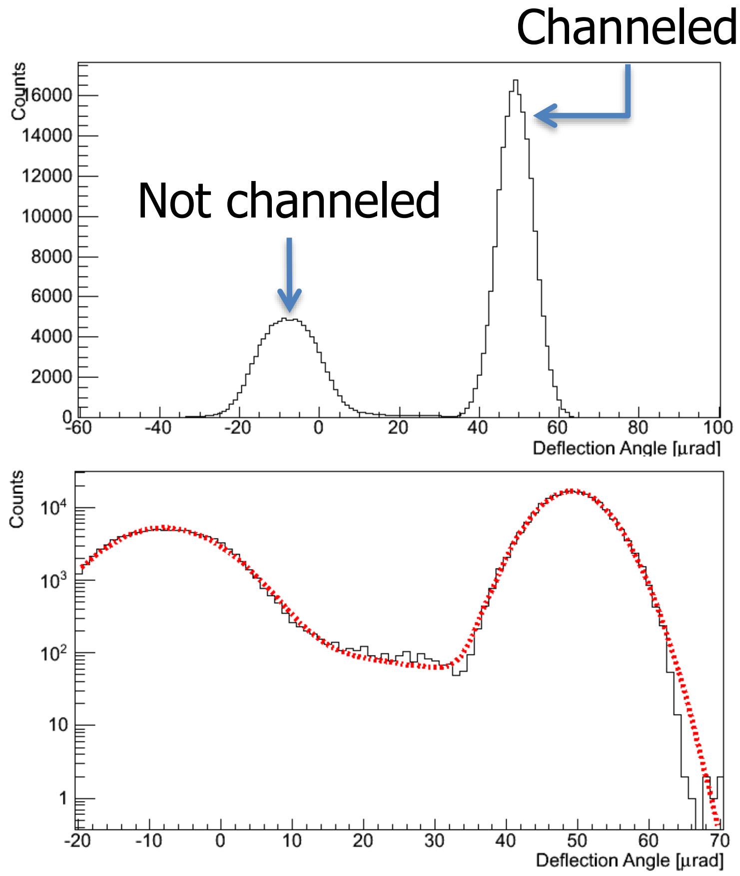


Bent crystal as a collimator

- 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

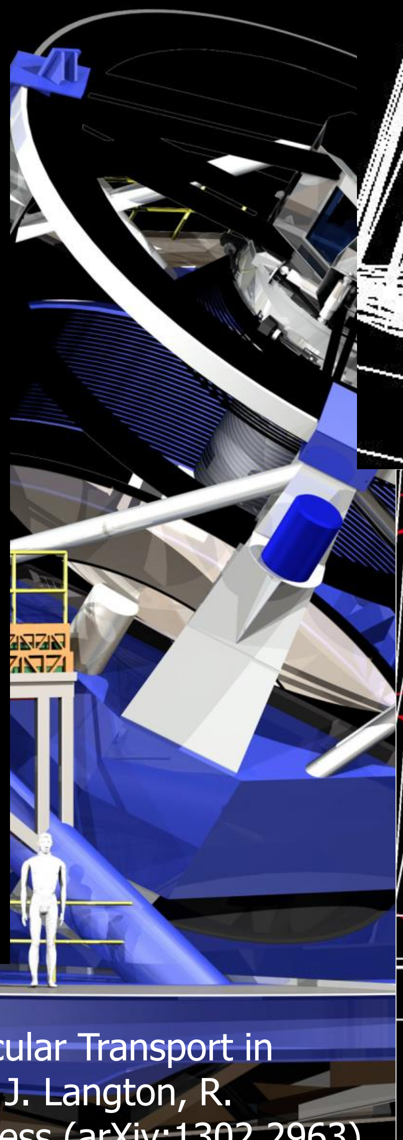
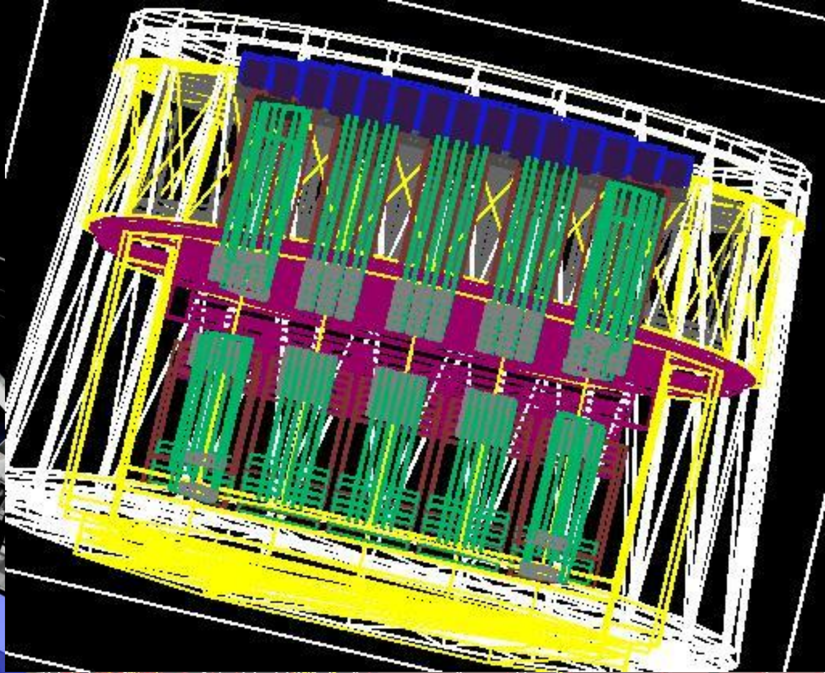
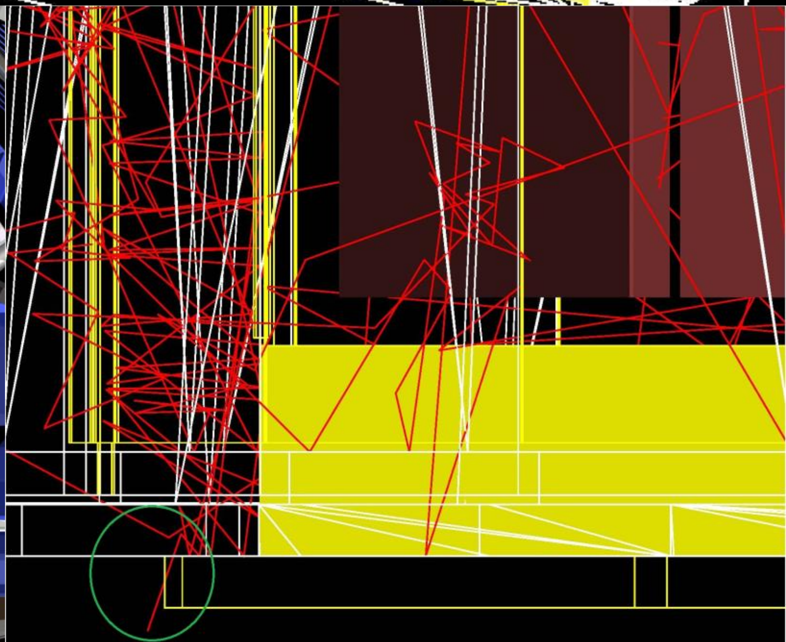






Enrico Bagli (INFN/Ferrara)

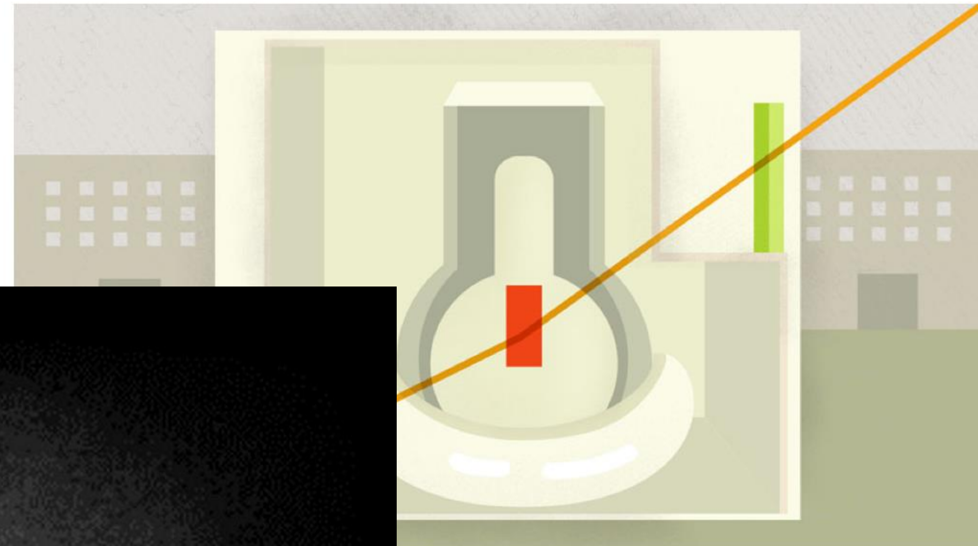
- W. Scandale et al., Phys. Lett. B 680 (2009) 129

“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 record the path of muons (represented by the hrough the reactor. By determining how the ectors, scientists will compile the first picture of

with Shawna X.

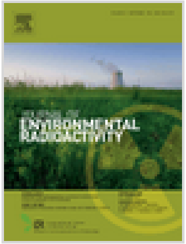
As time ticks down to the restart of the Large Hadron Collider, scientists are making sure their detectors run like clockwork.

age

ELSEVIER

Journal of Environmental Radioactivity

Volumes 162–163, October 2016, Pages 118–128



Evaluating remediation of radionuclide contaminated forest near Iwaki, Japan, using radiometric methods

D.C.W. Sanderson[a], A.J. Cresswell[a], K. Tamura[b], T. Iwasaka[c], K. Matsuzaki[d]

[a] Scottish Universities Environmental Research Centre, East Kilbride, Glasgow G75 0QF, United Kingdom

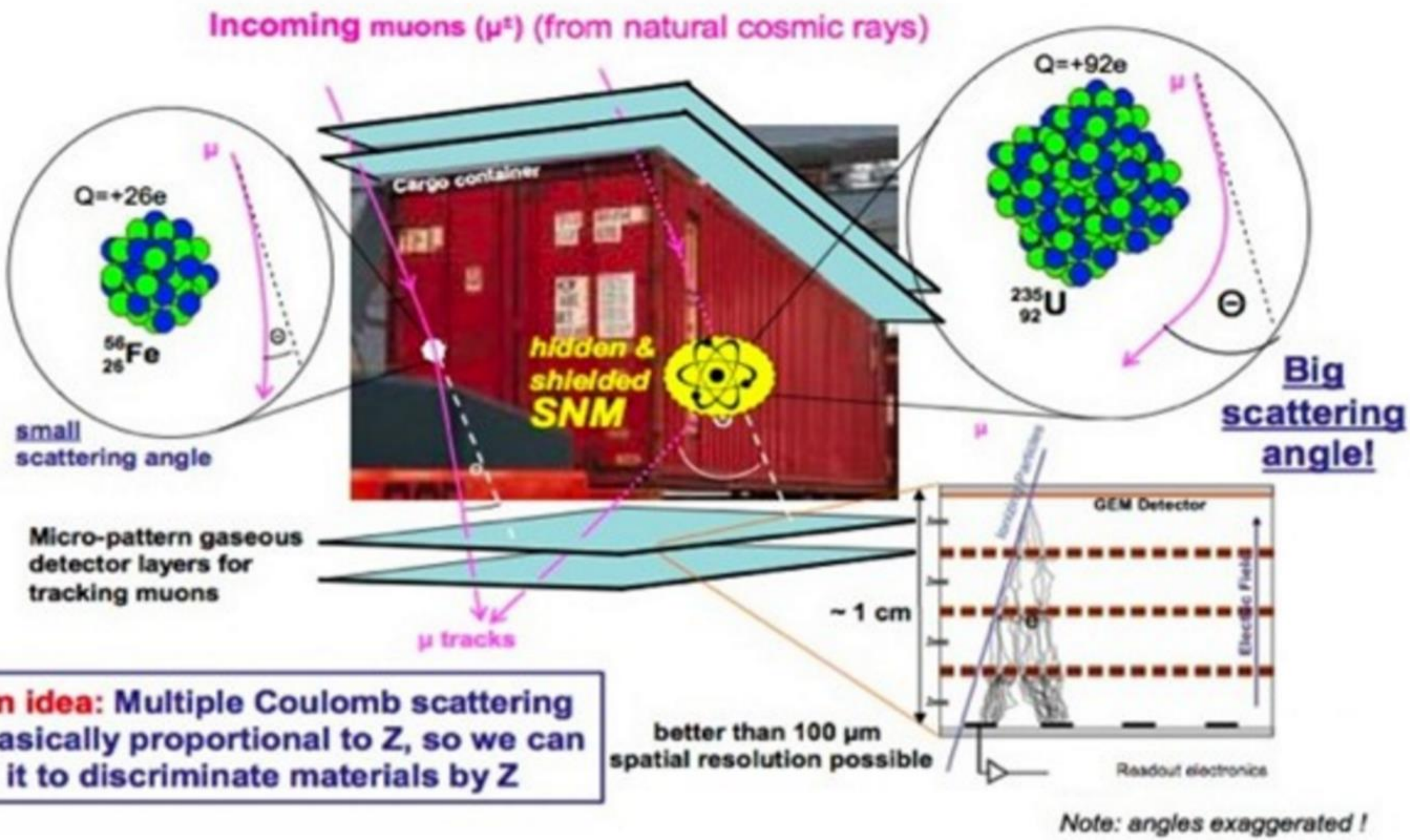
[b] Faculty of Life and Environmental Sciences, University of Tsukuba, Japan

[c] Miraishiko Inc., Kanegaya, Asahi-ku, Yokohama, Japan

[d] Yunodakesansonai, Iwaki, Japan

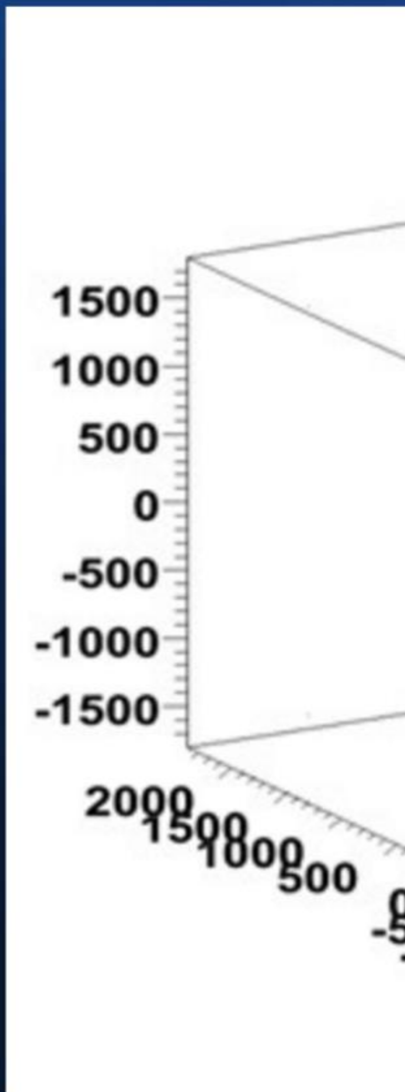
Received 24 December 2015, Revised 10 May 2016, Accepted 15 May 2016, Available online 24 May 2016

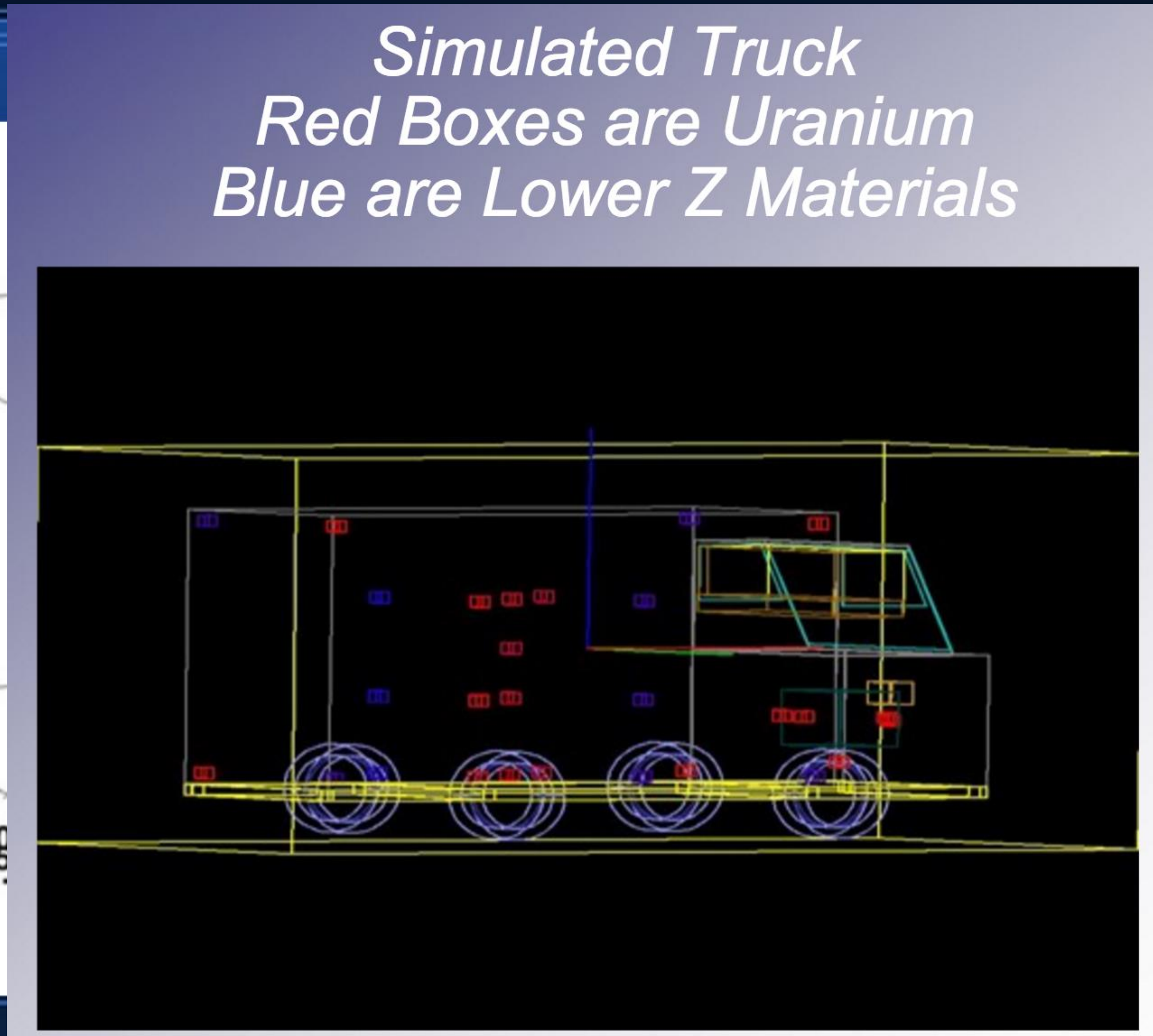
Muon tomography for nuclear threat detection



Main idea: Multiple Coulomb scattering is basically proportional to Z, so we can use it to discriminate materials by Z

Muon tomography for nuclear threat detection





Simulating x-ray cargo radiography

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SCIENTIFIC REPORTS

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Article | OPEN

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)
doi:10.1038/srep24388
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Applied physics Imaging techniques

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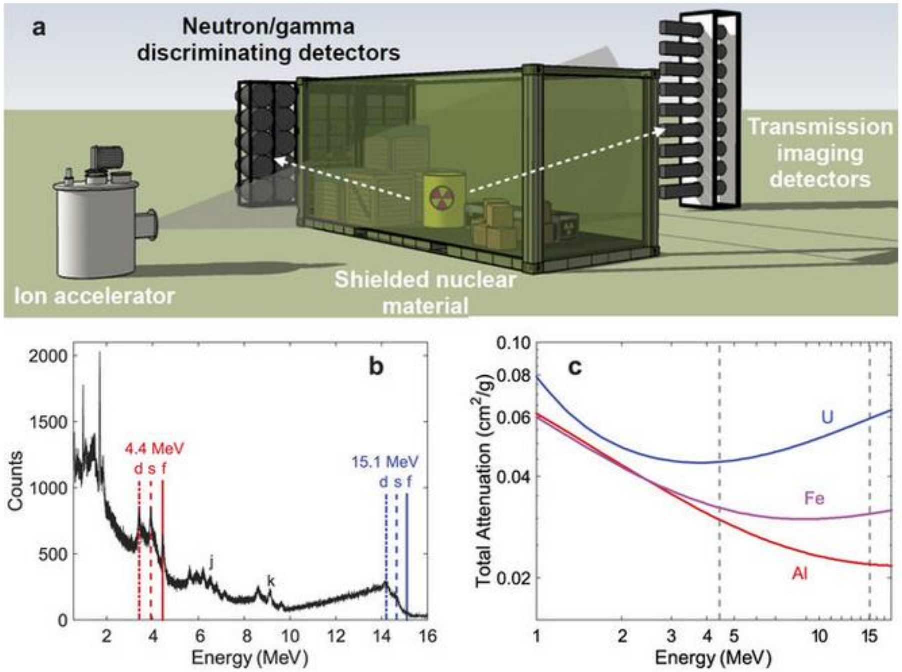
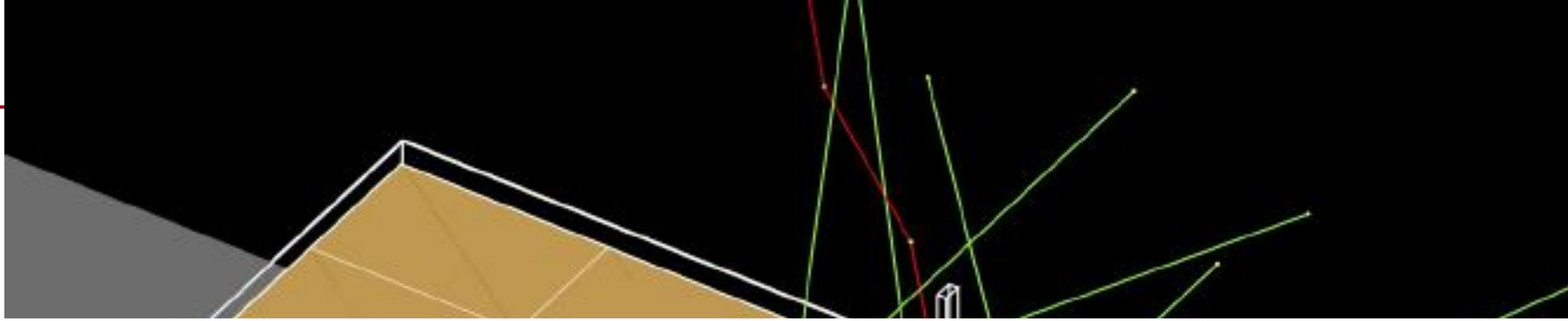
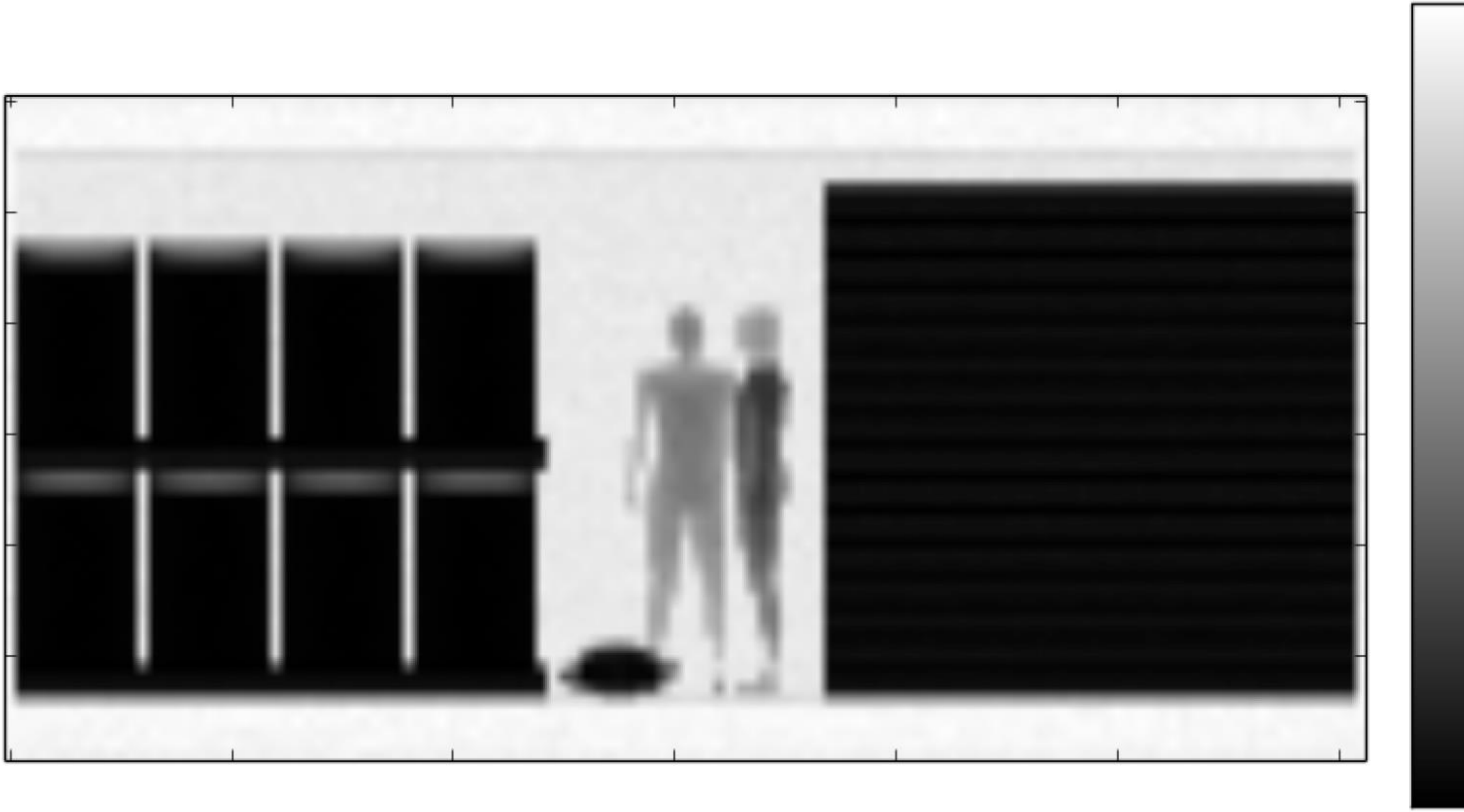
Figure 1: Illustration of the imaging method using a low-energy nuclear reaction radiation source.



SLAC

Current Status a





Version 10.5.p01

Geant4 license

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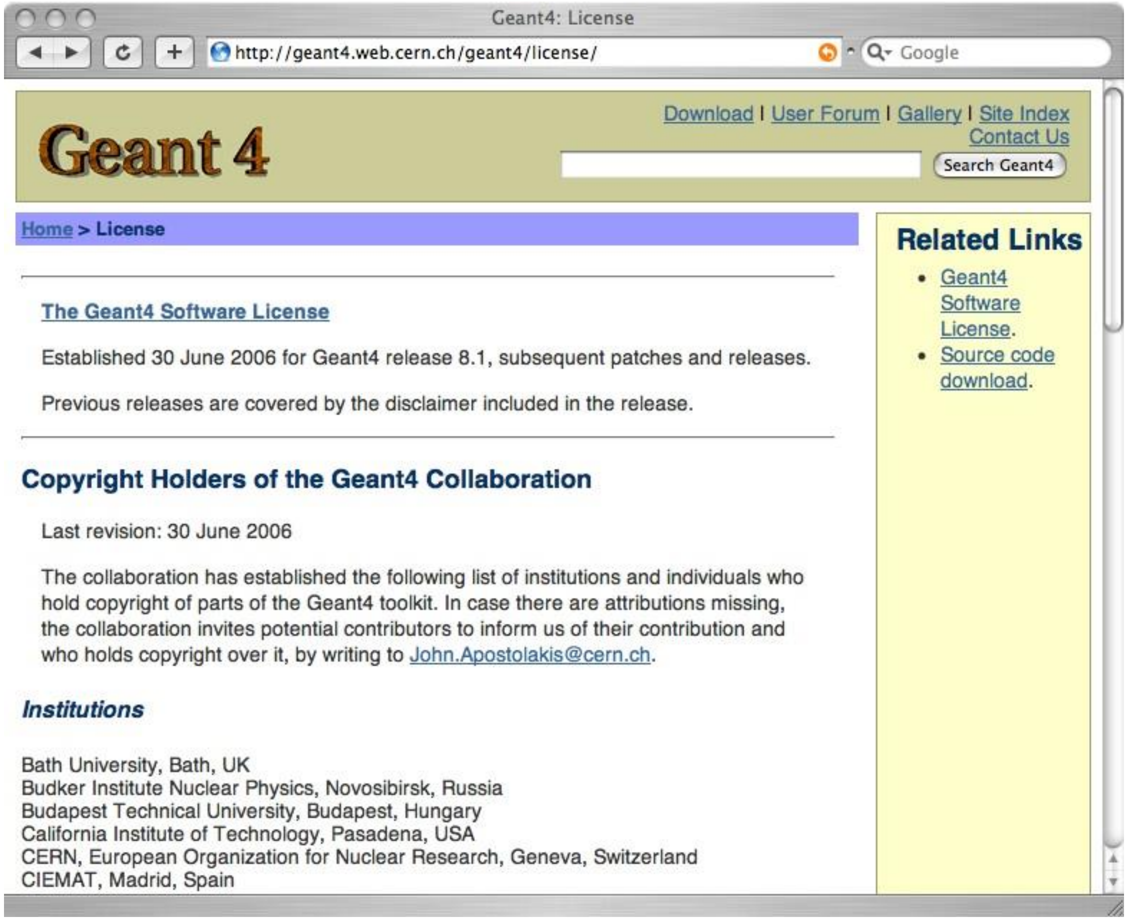
- Makes clear the user's wide-ranging freedom to use, extend or redistribute Geant4, even as part of some for-profit venture.
- The license was released along with the latest Geant4 release 8.1.
- Simple enough that you can read and understand it.

- http://cern.ch/geant4/license/



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Version 10.5.p01

Following up

Following up http://geant4.org/

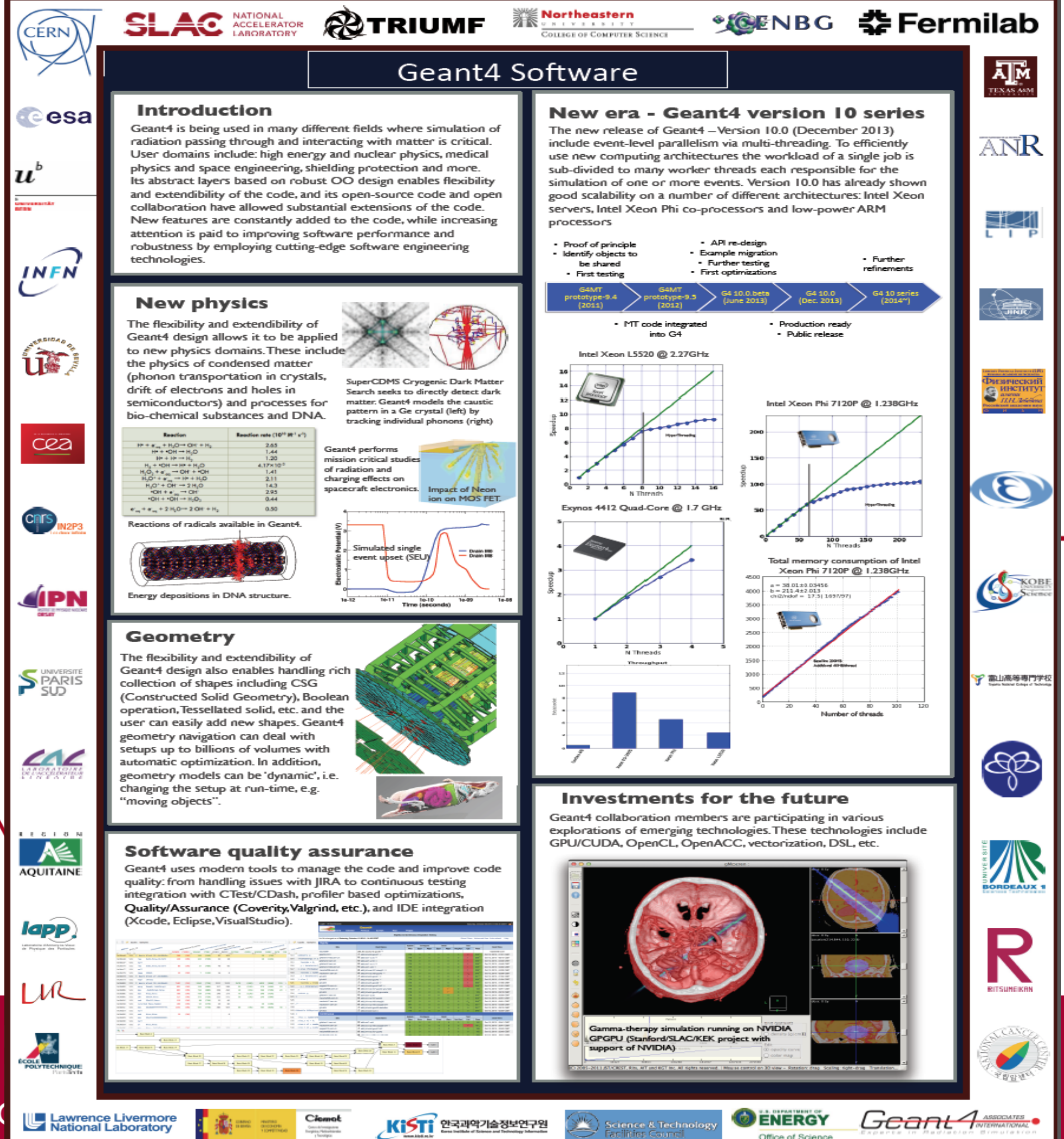
- Please keep maintaining your Geant4 installation updated.
  - **Geant4 10.5.p01 is the current version**
  - Irregular patch releases may be more important than regular releases.
  - Check our web page regularly to find release news, or register to Geant4 announcement mailing list https://geant4.web.cern.ch/support/mailing_list_subscription
- If you have a question
  1. Look for our documents.
     - Users guides, Twiki pages, tips pages, examples and their READMEs, past tutorial materials
  2. Post your question on Geant4 HyperNews

     http://hypernews.slac.stanford.edu/HyperNews/geant4/cindex
     - Please make sure to do a bit of survey that no one else has already asked the same question before you.
  3. As the final method, write us a mail.
     - Avoid anonymous mail account such as hotmail, gmail, etc.
  4. Or, catch us at meetings/conferences/tutorials.

Following up http://geant4.org/

- If you identify an issue.
  - Geant4 Bugzilla https://bugzilla-geant4.kek.jp
  - You may also use Geant4 HyperNews to start with
- If you have a requirement / concern.
  - Geant4 Technical Forum https://geant4.web.cern.ch/collaboration/technical_forum
  - A few times per year, publicly open to any user to discuss requests, requirements and priorities that may concern functionality, performance, user support or any other Geant4-user related aspects.
  - Next Technical Forum will be held at Jefferson Lab (VA. U.S.) in September where Nuclear Physics requirements/priorities will be highlighted.
    - Contact me, Alberto and/or Dennis if you want to make a presentation.
- If you want to make a contribution
  - For small fixes/enhancements : Geant4 GitHub https://github.com/Geant4/geant4/releases
  - Large scale contribution : present at Geant4 Technical Forum and/or contact Geant4 WG coordinators.

Geant4
– the Future



New physics – new opportunities

- Physics of O(100TeV)
- Specialized EM model for noble liquid (e.g. liq.Xe)
- 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, neutron scattering in crystal
- 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
  - Sub-event level parallelization
- 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.
- 2019 is the 20th year anniversary of Geant4 public releases. After 20 years with several architectural evolutions, Geant4 is still steadily evolving.
  - Latest major evolution was Geant4 version 10.0 released in December 2013 that is the first fully multithreaded general-purpose large-scale physics software in the world.
  - New physics models for coming experiments, e.g. hadronic model for multi-TeV regime, neutrino physics model, physics with crystal structure.
  - Given Geant4 is nowadays mission-critical for many users in all of above-mentioned domains, Geant4 is to be kept maintained and still evolving for at least next decade.