

Geant 4

Geant4 - Current and Future

Makoto Asai (SLAC)
May 9th, 2014 @ U. Ferrara



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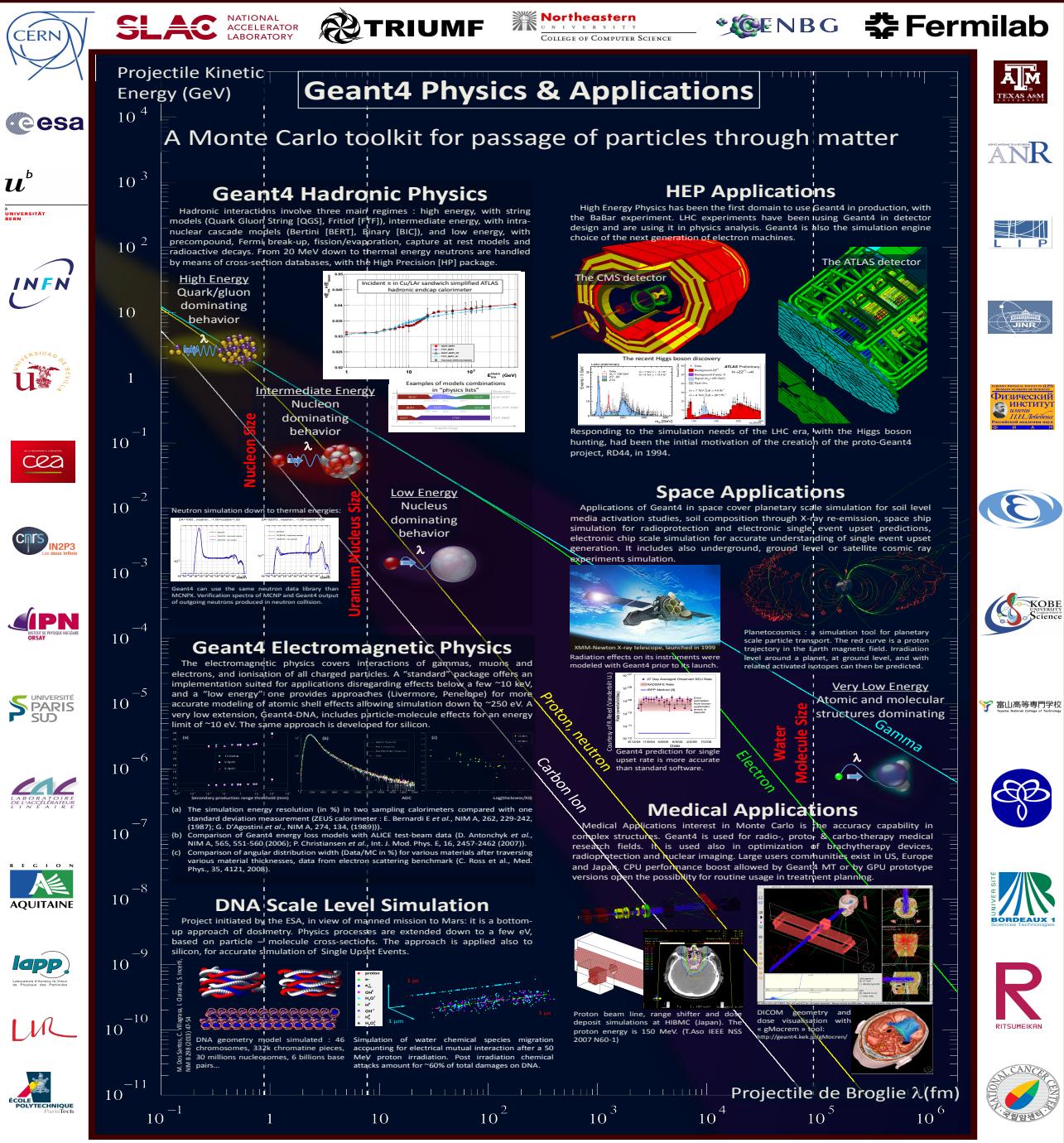


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Contents

- General introduction and brief history
 - Highlights of user applications
 - Geant4 license
 - Geant4 – the future
 - Acknowledging Prof. Vincenzo Guidi for this wonderful opportunity !



Geant 4

General introduction
and brief history



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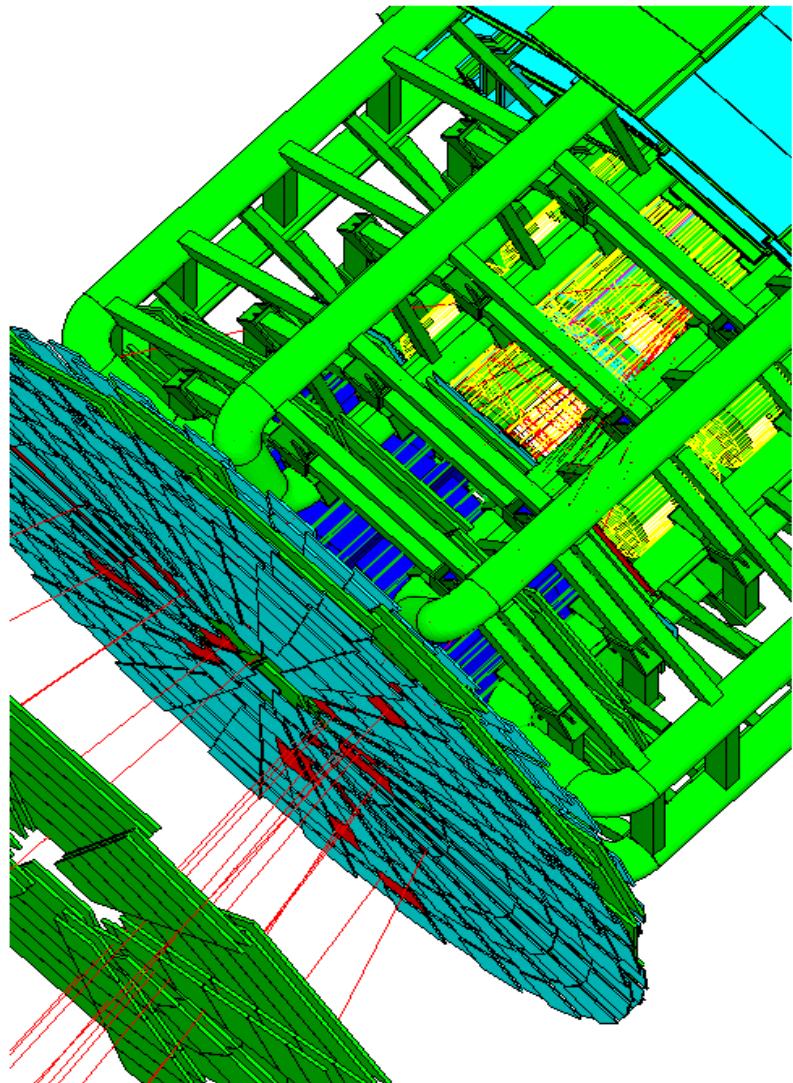
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- Geant4 is a general purpose Monte Carlo simulation tool for elementary particles passing through and interacting with matter. It finds quite a wide variety of user domains including high energy and nuclear physics, space engineering, medical applications, material science, radiation protection and security.
- In order to meet wide variety of requirements from various application fields, a large degree of functionality and flexibility are provided.
- Geant4 has many types of geometrical descriptions to describe most complicated and realistic geometries
 - CSG, Tessellated and Boolean solids
 - Placement, replica, divided, parameterized, reflected and grouped
 - XML/GDML/CAD interfaces
- Everything is open to the user
 - Choice of physics processes/models
 - Choice of GUI/Visualization/persistency/histogramming options

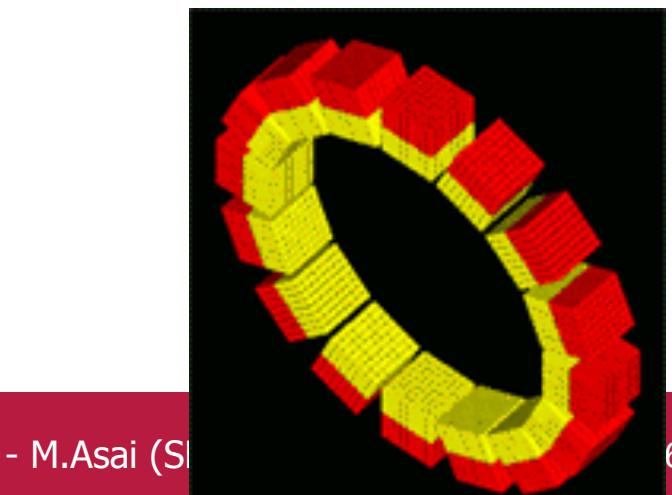
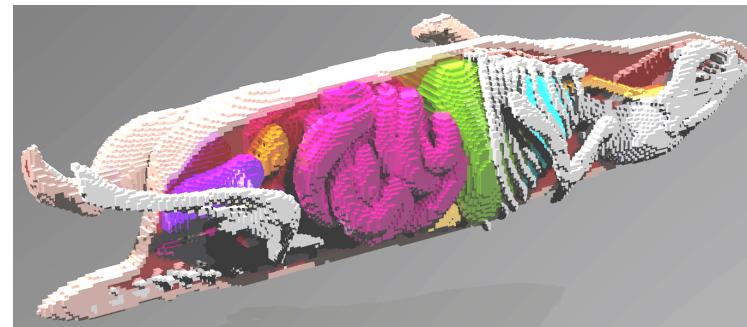
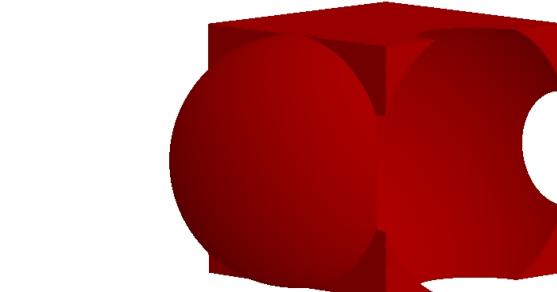
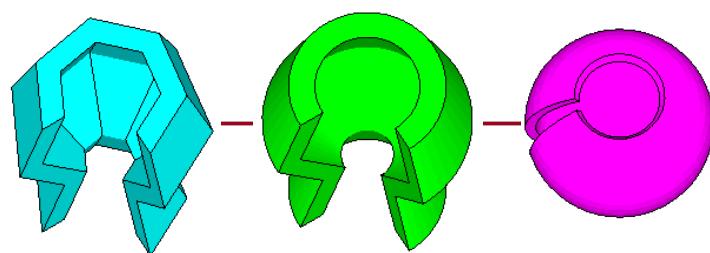
Key Geant4 functionalities

- 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.



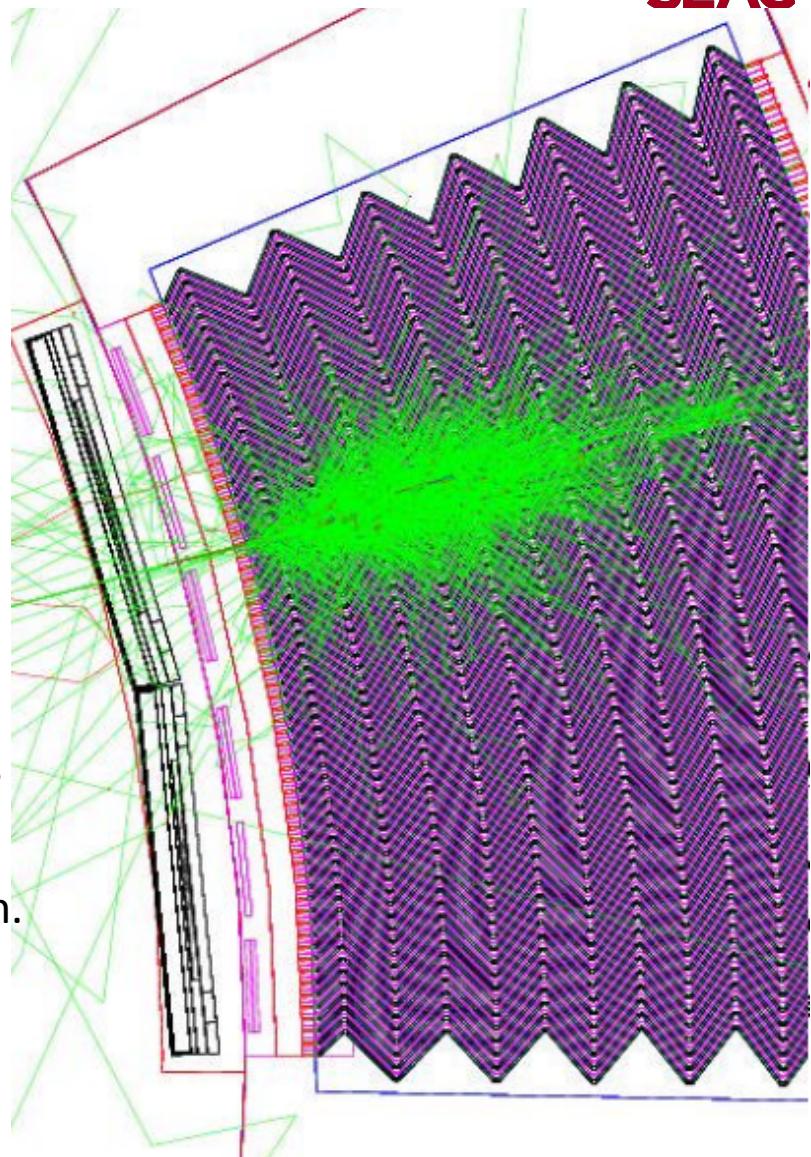
Key geometry capabilities

- 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”



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.

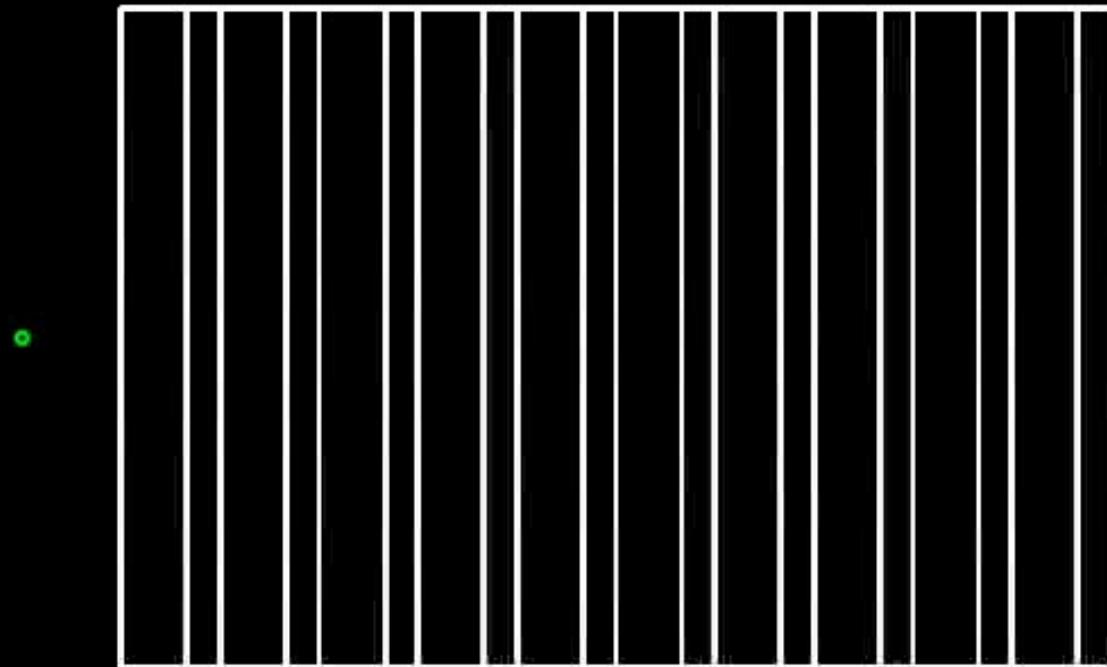


10 Gev π^-

Produces neutron
chain reaction

e- red
e⁺ blue
 π^+ magenta
 π^- cyan
n yellow
 ν green
Others grey

Duration 2 ns



Geant4 – Its history

- Dec '94 - Project start
 - Apr '97 - First alpha release
 - Jul '98 - First beta release
 - Dec '98 - First Geant4 public release - version 1.0
 - ...
 - Dec 2nd, '11 – Geant4 version 9.5 release
 - Oct 22nd, '12 - Geant4 9.5-patch02 release
 - Nov 30th, '12 – Geant4 version 9.6 release
 - Mar 20th, '14 - Geant4 9.6-patch03 release
 - Dec 6th, '13 – Geant4 version 10.0 release
 - Feb 28th, '14 - Geant4 10.0-patch01 release
 - We currently provide one public release every year.
 - Beta releases are also available.
 - Release announcements on Collaboration Web pages and through the announcement mailing list
-  **Retroactive patch release**
-  **Current version**

Geant4 – A Simulation Toolkit

Geant4



SLAC NATIONAL ACCELERATOR LABORATORY



IN2P3
Les deux infinis



<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

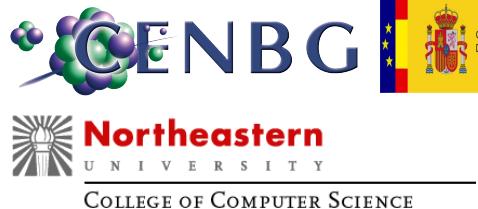
IEEE Trans. Nucl. Sci., vol. 53, no. 1, pp. 270-278, 2006



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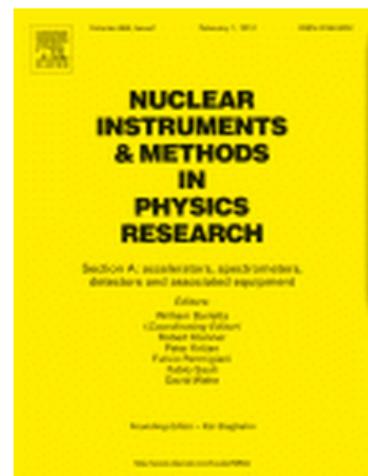
- An international collaboration
 - >100 active members
 - 19 countries

Top 25 Hottest Articles

Nuclear Instruments and Methods in Physics Research Section A: Accelerators,
Spectrometers, Detectors and Associated Equipment

October to December 2013

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1. Geant4-a simulation toolkit

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 506, Issue 3, July 2003, Pages 250-303

Agostinelli, S.; Allison, J.; Amako, K.; Apostolakis, J.; Araujo, H.; Arce, P.; Asai, M.; Axen, D.; Banerjee, S.; Barrand, G.; Behner, F.; Bellagamba, L.; Boudreau, J.; Broglia, L.; Brunengo, A.; Burkhardt, H.; Chauvie, S.; Chuma, J.; Chytracek, R.; (...)

Cited by Scopus (5171)



2. 3D printing in X-ray and gamma-ray imaging: A novel method for fabricating high-density imaging apertures

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 659, Issue 1, December 2011, Pages 262-268

Miller, B.W.; Moore, J.W.; Barrett, H.H.; Frye, T.; Adler, S.; Sery, J.; Furenlid, L.R.

Cited by Scopus (7)



3. Two-dimensional visualization of cluster beams by microchannel plates

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 735, January 2014, Pages 12-18

Khoukaz, A.; Bonaventura, D.; Grieser, S.; Hergemoller, A.-K.; Kohler, E.; Taschner, A.



4. Experimental study and FLUKA simulations of a prototype micromegas chamber in a mixed neutron and photon radiation field

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 677, June 2012, Pages 52-60

Alexopoulos, T.; Cerutti, F.; Charitonidis, N.; Gazis, E.; Kokkoris, M.; Skordis, E.; Tsinganis, A.; Tsipolitis, G.; Vlastou, R.



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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Rahman, Z., Ahmad, S.B.,
Mirza, S.M., (...), Mirza, N.M.,
Ahmed, W.

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Hecht, A.A., Blakeley, R.E.,
Martin, W.J., Leonard, E.

Liao, C., Yang, H.

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Author Name

- Banerjee, S. (561)
- Stugu, B. (556)
- Lankford, A.J. (554)
- Eigen, G. (547)
- Seiden, A. (542)

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Subject Area

- Physics and Astronomy (4,183)
- Engineering (914)
- Medicine (770)
- Energy (405)
- Mathematics (338)

Holm, P., Peräjärvi, K.,
Ristkari, S., Siiskonen, T.,
Toivonen, H.

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S Agostinelli, J Allison, K Amako, J Apostolakis... - Nuclear instruments and ..., 2003 - Elsevier

Geant4 is a toolkit for simulating the passage of particles through matter. It includes a complete range of functionality including tracking, geometry, physics models and hits. The physics processes offered cover a comprehensive range, including electromagnetic, ...

[Cited by 9728](#) [Related articles](#) [All 20 versions](#) [Cite](#) [Save](#) [More](#)[Geant4 developments and applications](#)

J Allison, K Amako, J Apostolakis... - Nuclear Science, ..., 2006 - ieeexplore.ieee.org

Abstract—**Geant4** is a software toolkit for the simulation of the passage of particles through matter. It is used by a large number of experiments and projects in a variety of application domains, including high energy physics, astrophysics and space science, medical physics ...

[Cited by 2234](#) [Related articles](#) [All 23 versions](#) [Cite](#) [Save](#) [More](#)[GATE \(**Geant4** Application for Tomographic Emission\): a PET/SPECT general-purpose simulation platform](#)

D Strulab, G Santin, D Lazaro, V Breton... - Nuclear Physics B- ..., 2003 - Elsevier

We present the development of GATE, the **Geant4** Application for Tomographic Emission, as a new general purpose simulation platform for PET and SPECT applications. Built on top of the **Geant4** simulation toolkit, it provides multiple new features with the objective to ease ...

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G Santin, D Strul, D Lazaro, L Simon... - ... Record, 2002 IEEE, 2002 - ieeexplore.ieee.org

Emission, is a simulation platform developed for PET and SPECT. It combines a powerful simulation core (the **Geant4** toolkit) and a large range of developments dedicated to nuclear medicine. In particular, it models the passing of time during real acquisitions, allowing to ...

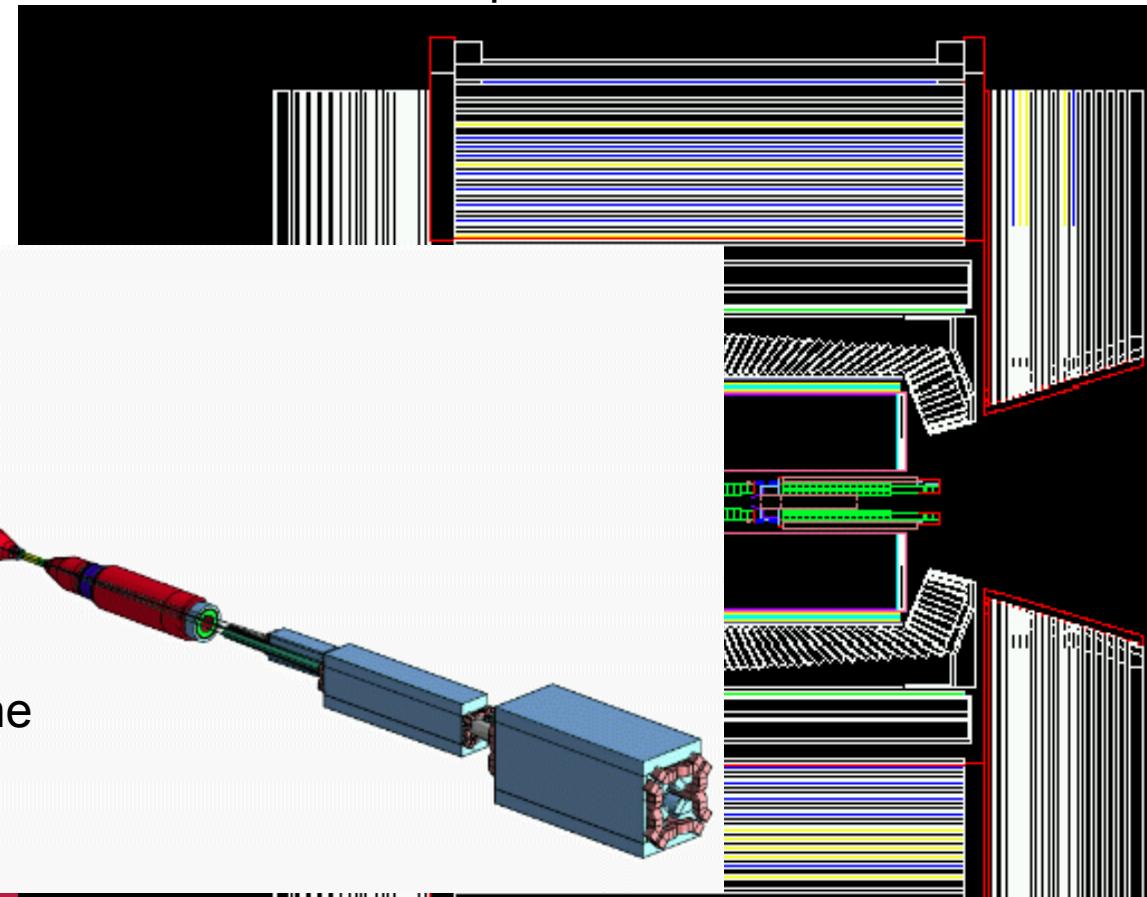
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Geant 4

Highlights of Users Applications

To provide you some ideas
how Geant4 would be utilized...

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

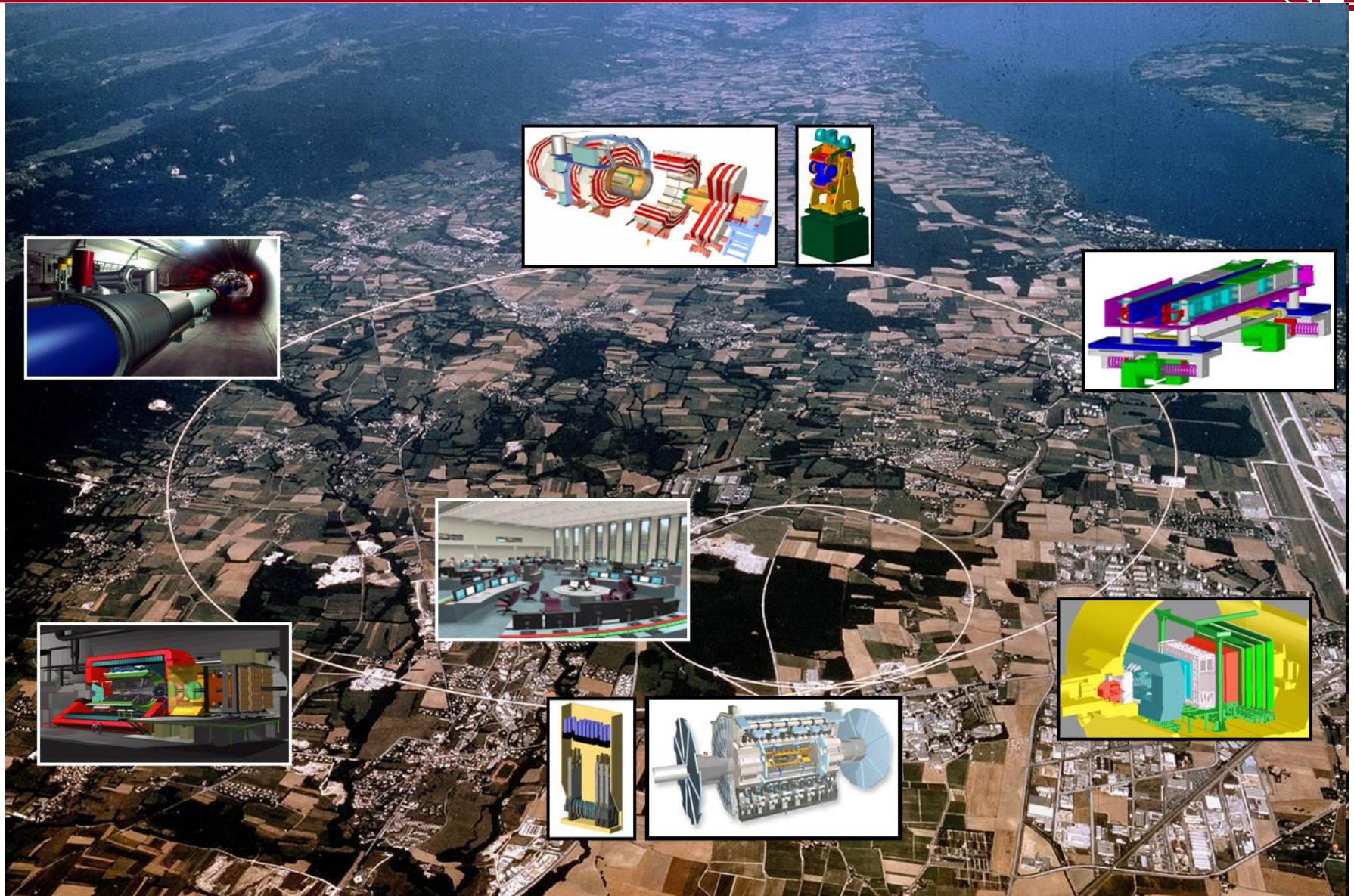


Now simulating PEP beam line
as well ($-9\text{m} < z_{\text{IP}} < 9\text{m}$)

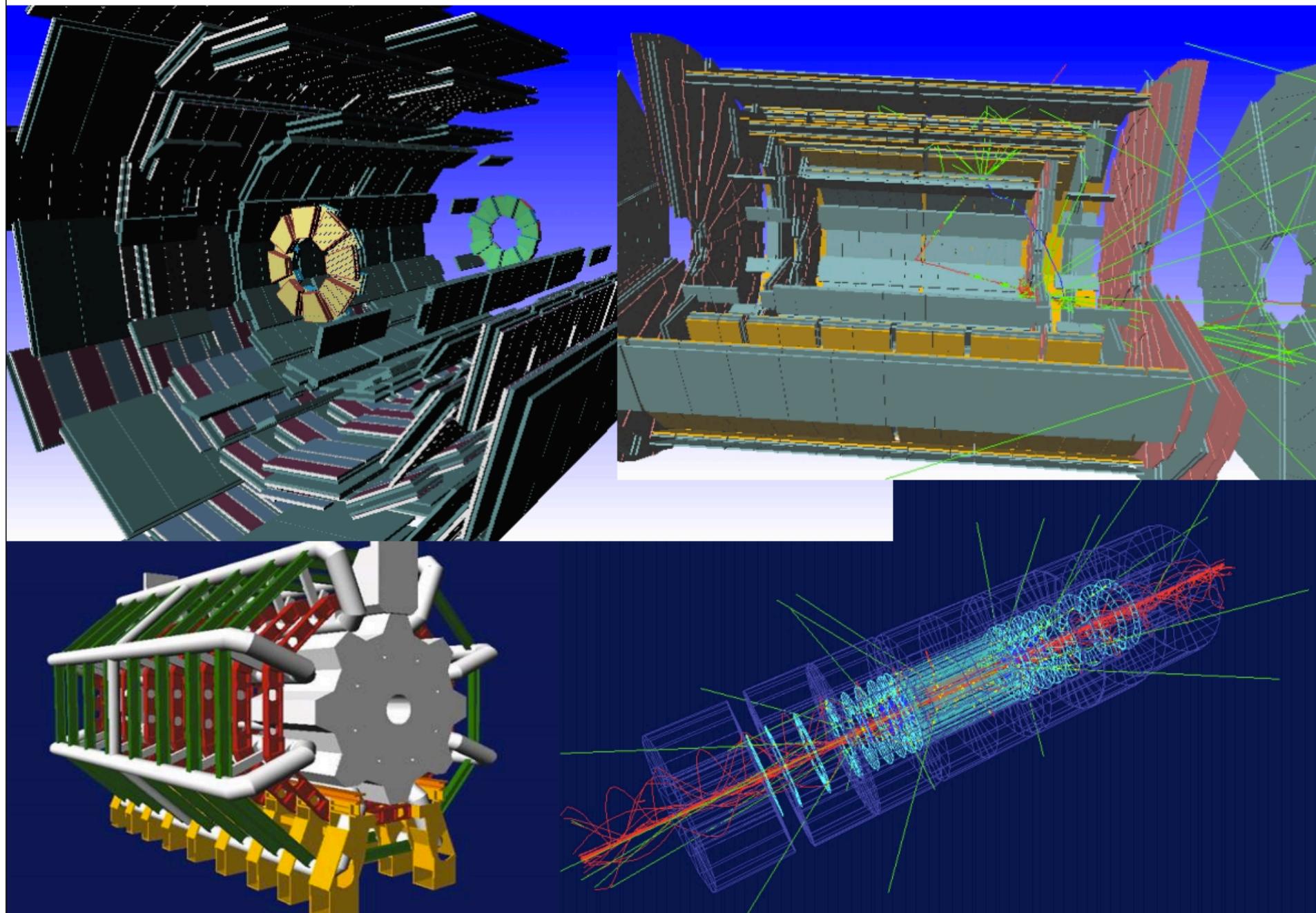
Courtesy of D.Wright (SLAC)

Large Hadron Collider (LHC) @ CERN

SLAC



Geant4 in High Energy Physics (ATLAS at LHC)



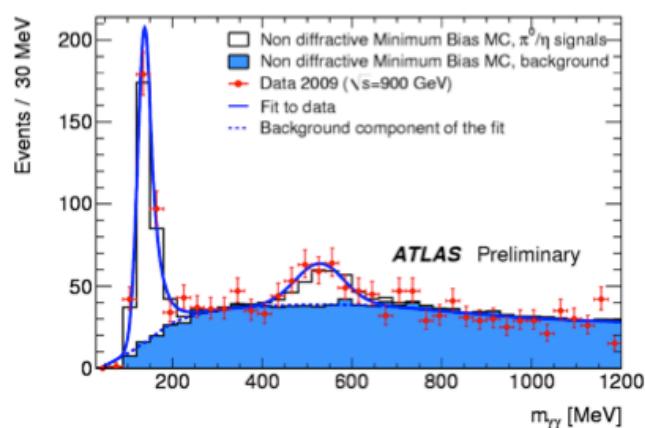
Geant4 has been successfully employed for



- Detector design
- Calibration / alignment
- First analyses

T. LeCompte (ANL)

GEANT4 Comparisons with the Calorimeters



Invariant mass of pairs of well-isolated electromagnetic clusters.

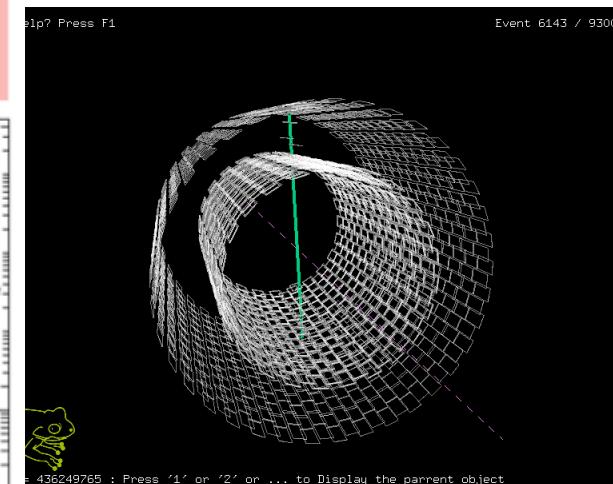
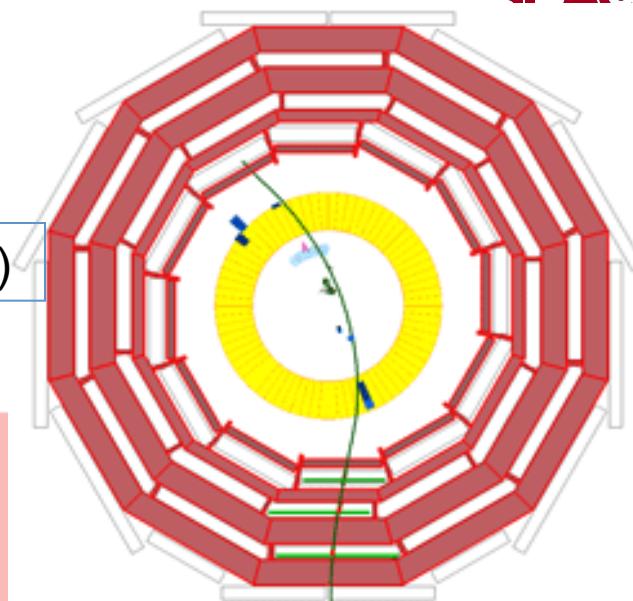
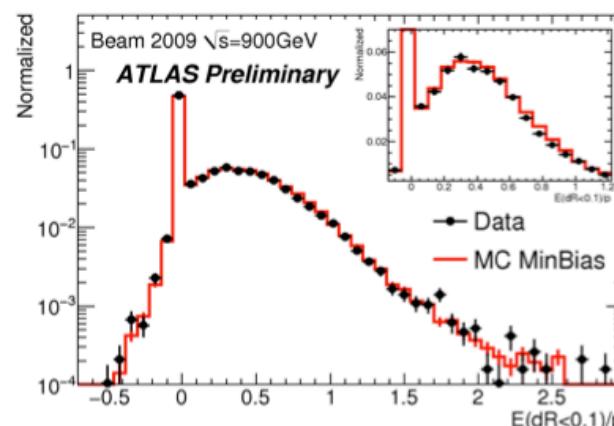
The π^0 mass is within $0.8 \pm 0.6\%$ of expectations.

The η^0 mass is within $3 \pm 2\%$ 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.

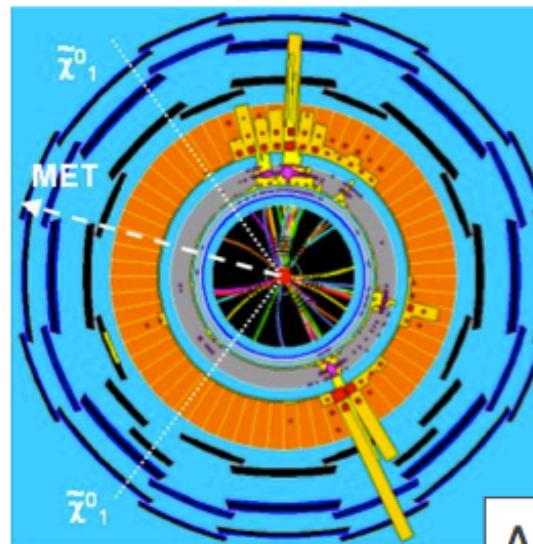
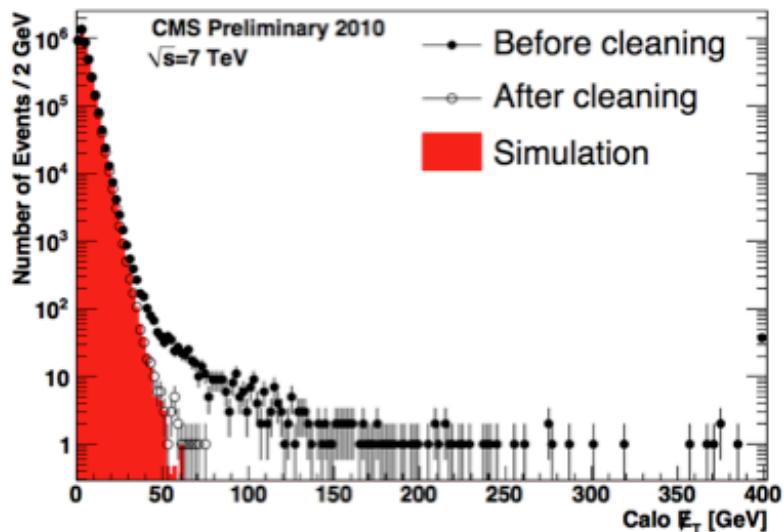
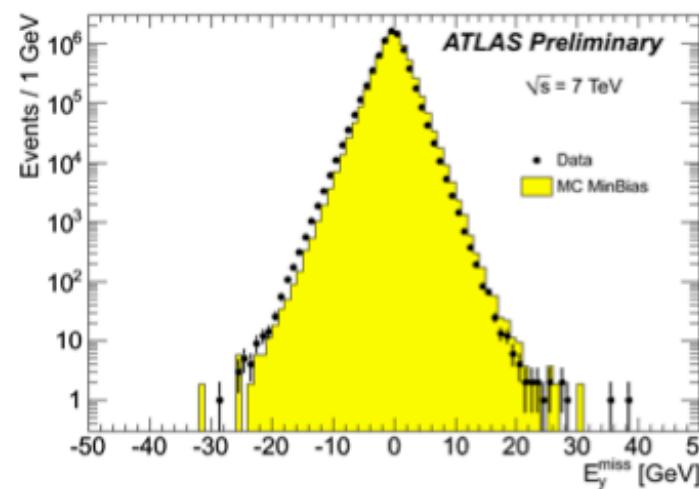
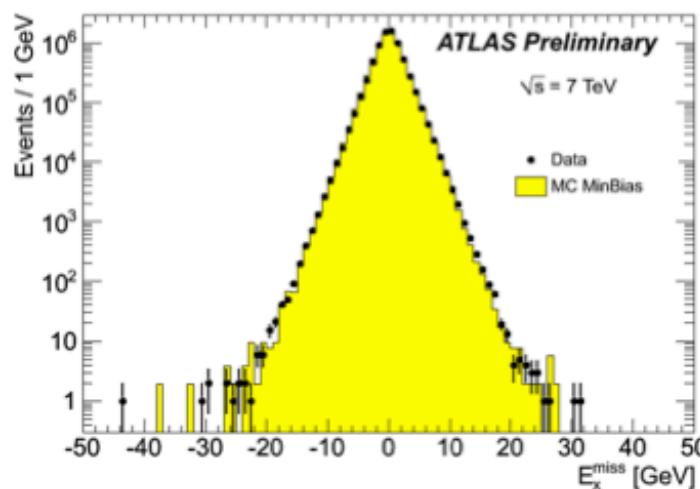
This plot agreed better than we ever expected. (I sent the student who made it back to make sure that they didn't accidentally compare G4 with G4.)



Figures from CMS

Missing E_T

SI AC



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.

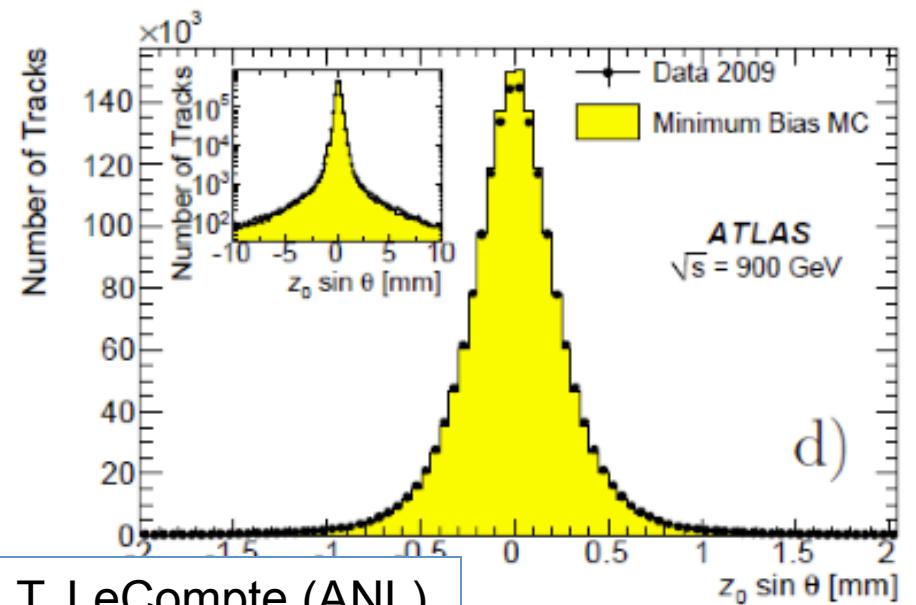
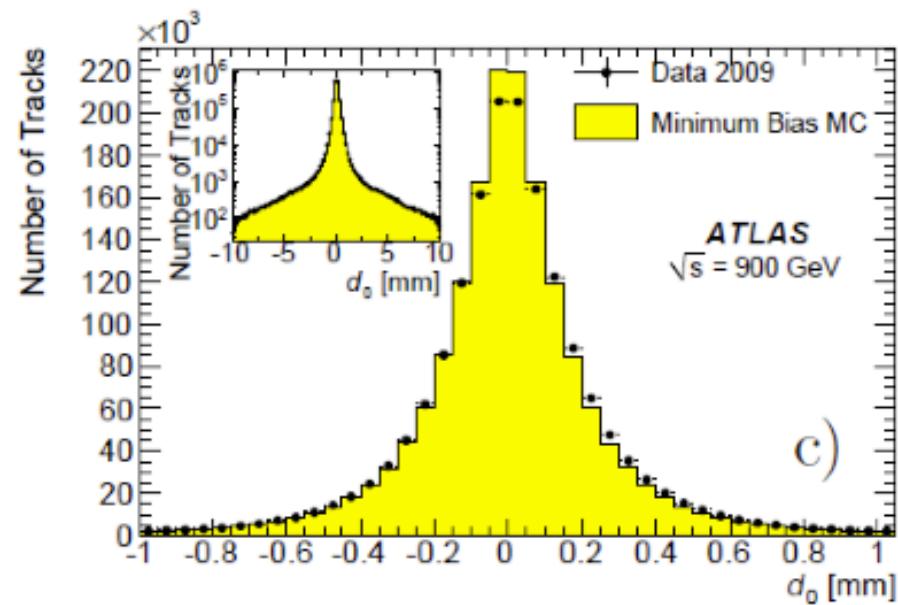
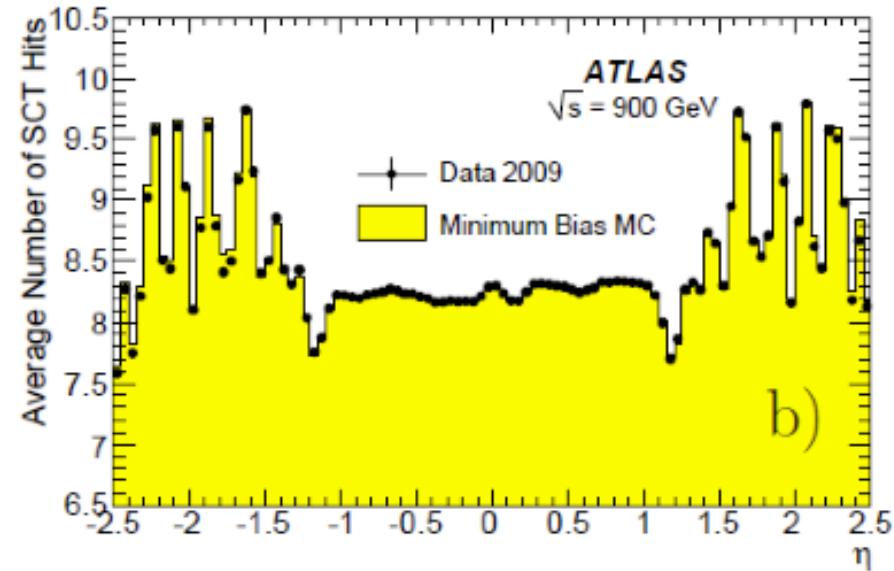
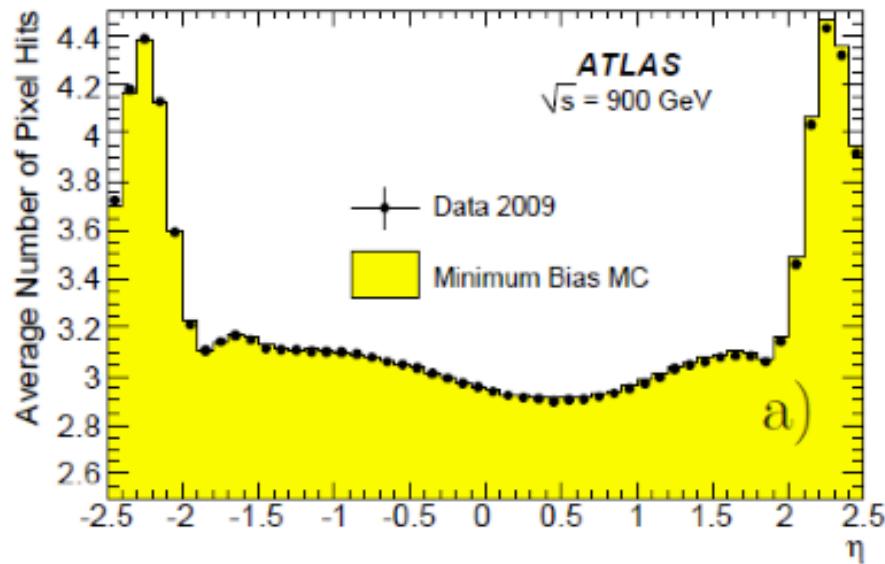
You can even see that the ATLAS detector is not quite centered – in both data and MC.

A GEANT4 event.

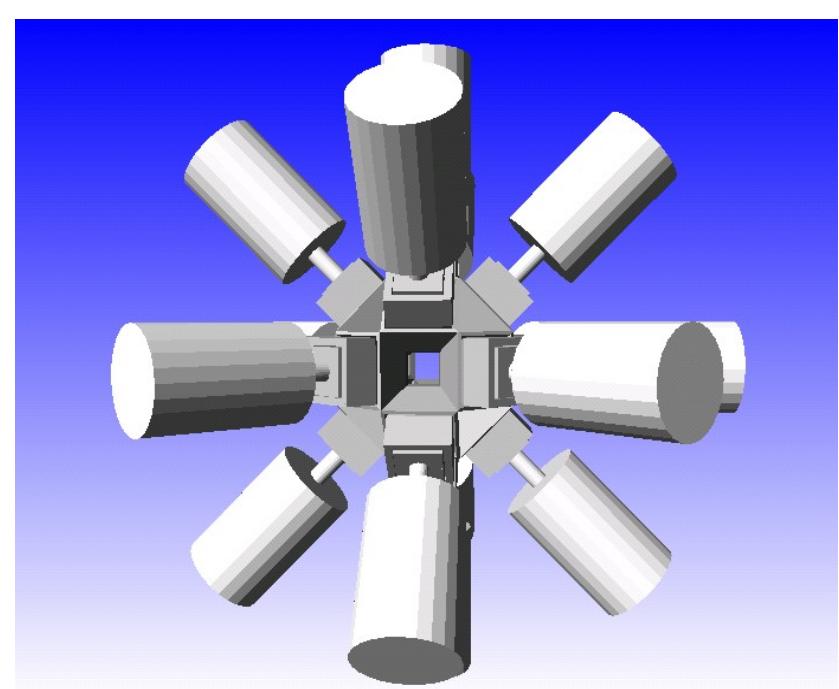
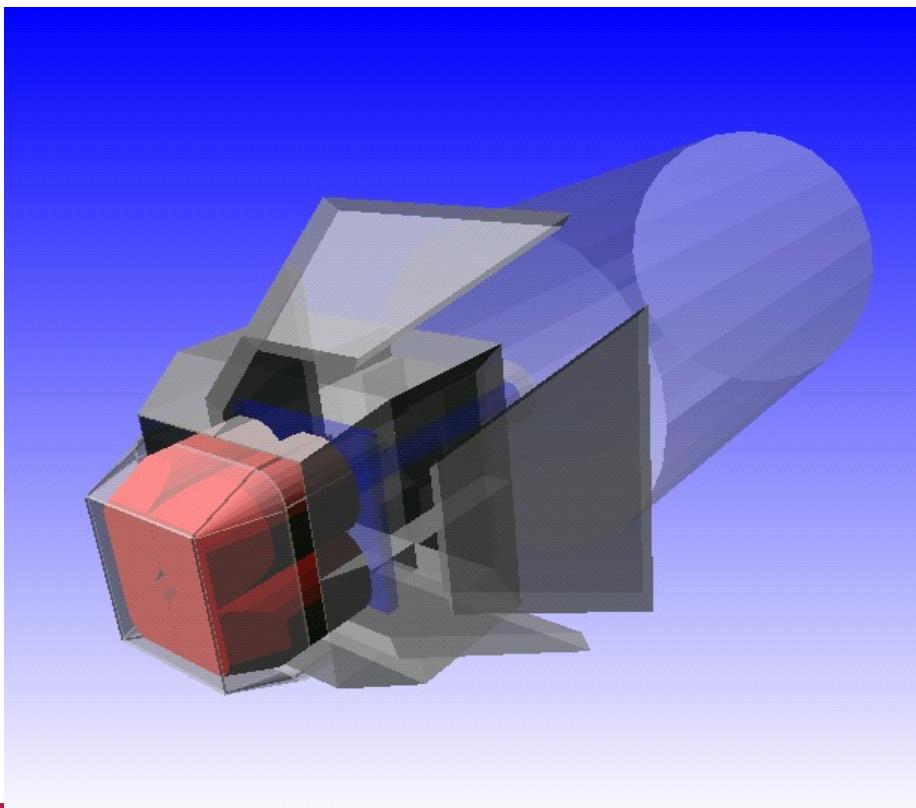
Both ATLAS and CMS plots are made from a tiny piece of the very earliest data.

T. LeCompte (ANL)

Data and simulation agreements



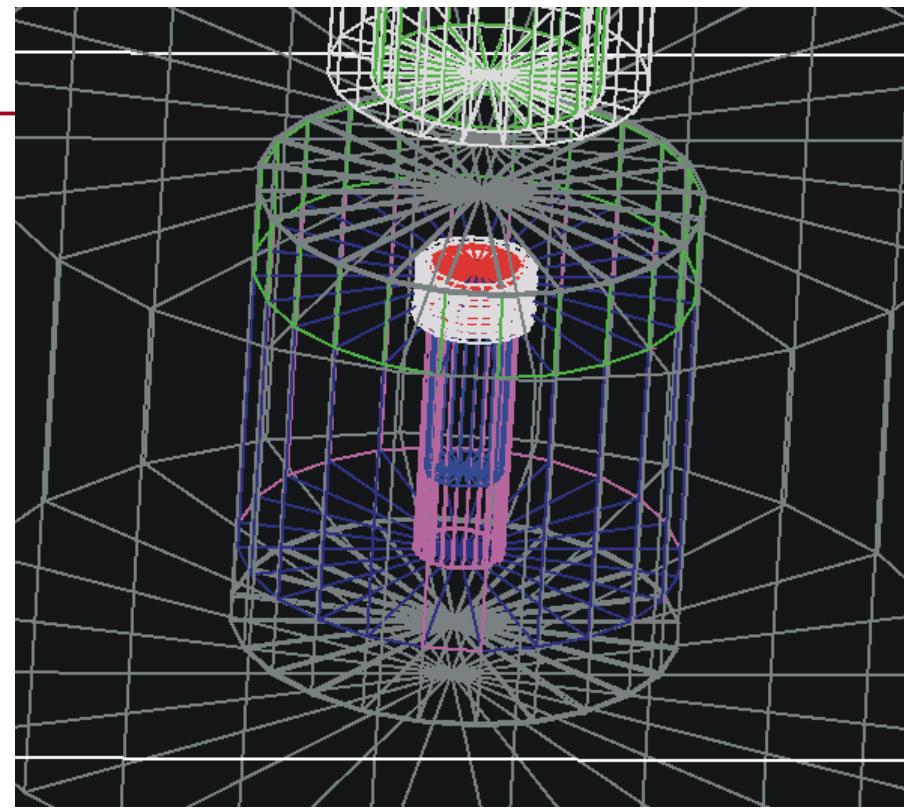
- TIGRESS is an experimental facility for the ISAC-II radioactive ion beam accelerator at TRIUMF.
- TIGRESS is a Gamma-Ray Spectrometer
 - Assembled over 6 years, ending in 2008
 - TIGRESS uses High-Purity Germanium Crystals for gamma detection, which will be one of the most advanced, most efficient gamma-ray spectrometer in the world.



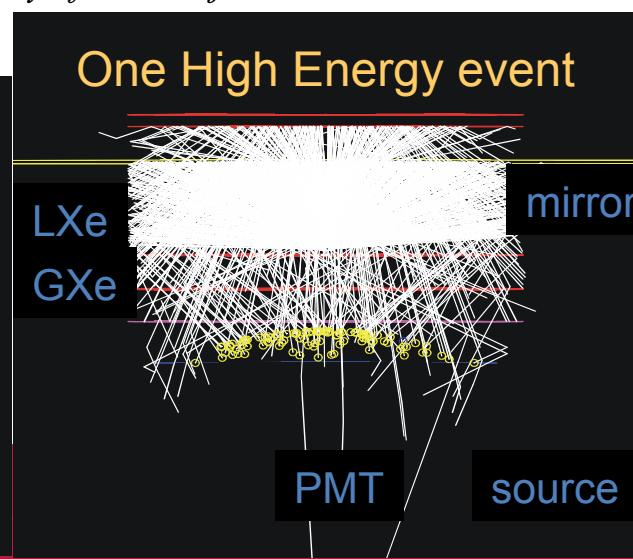
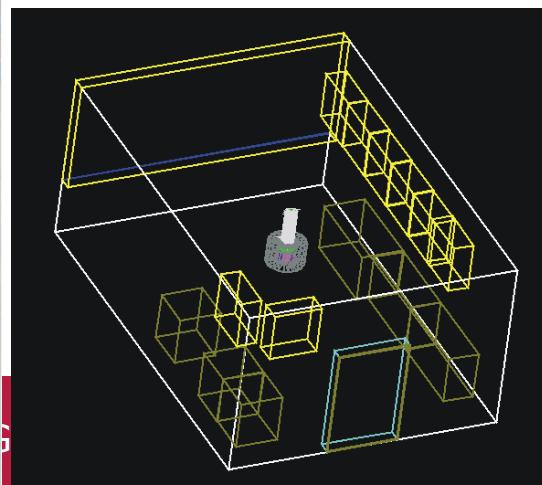
Courtesy of M.A.Schumaker (Guelph)

Boulby Mine dark matter search

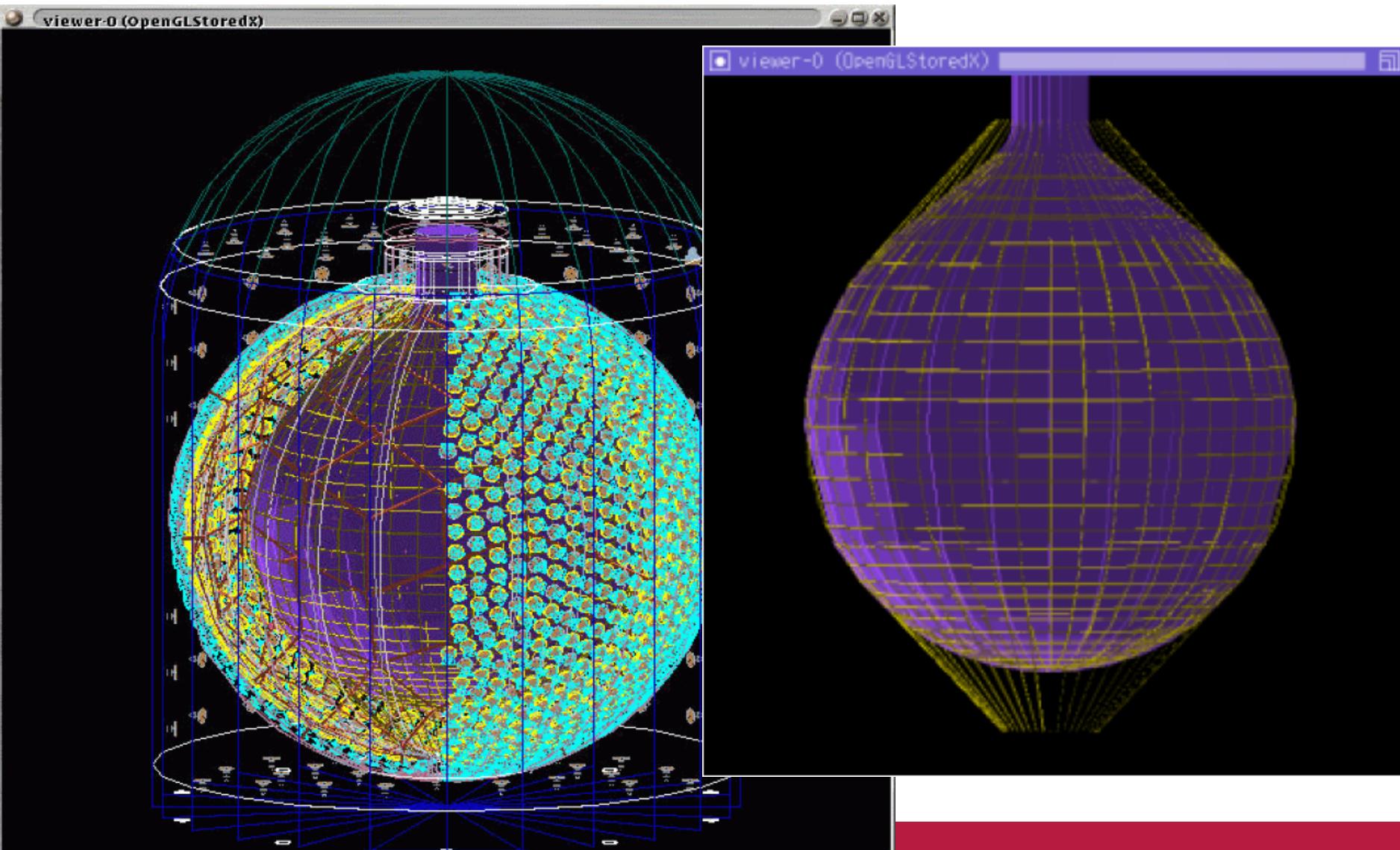
Prototype Simulation



Courtesy of H. Araujo, A. Howard, IC London

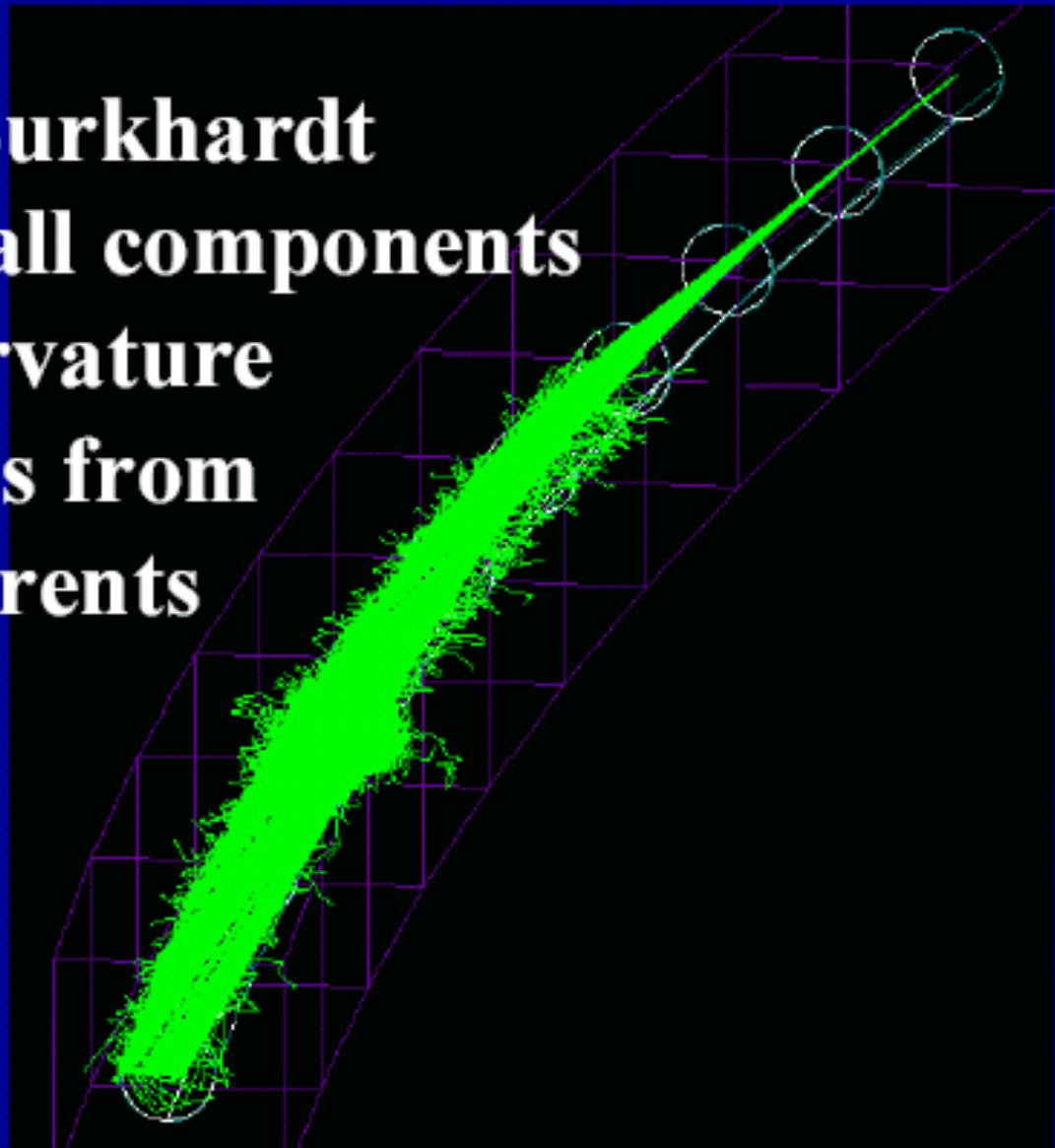


- Kamioka Liquid-scintillator Anti-Neutrino Detector

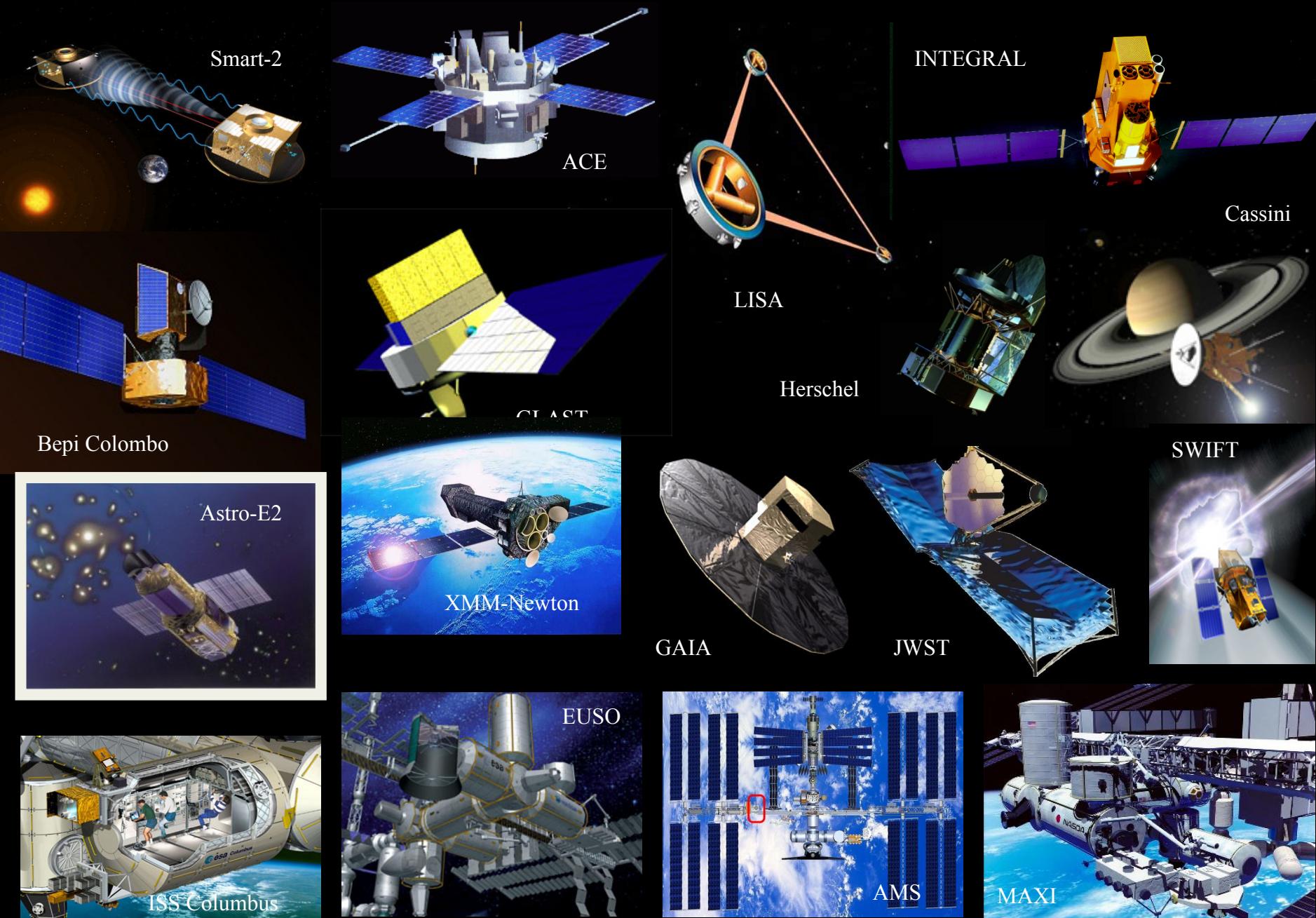


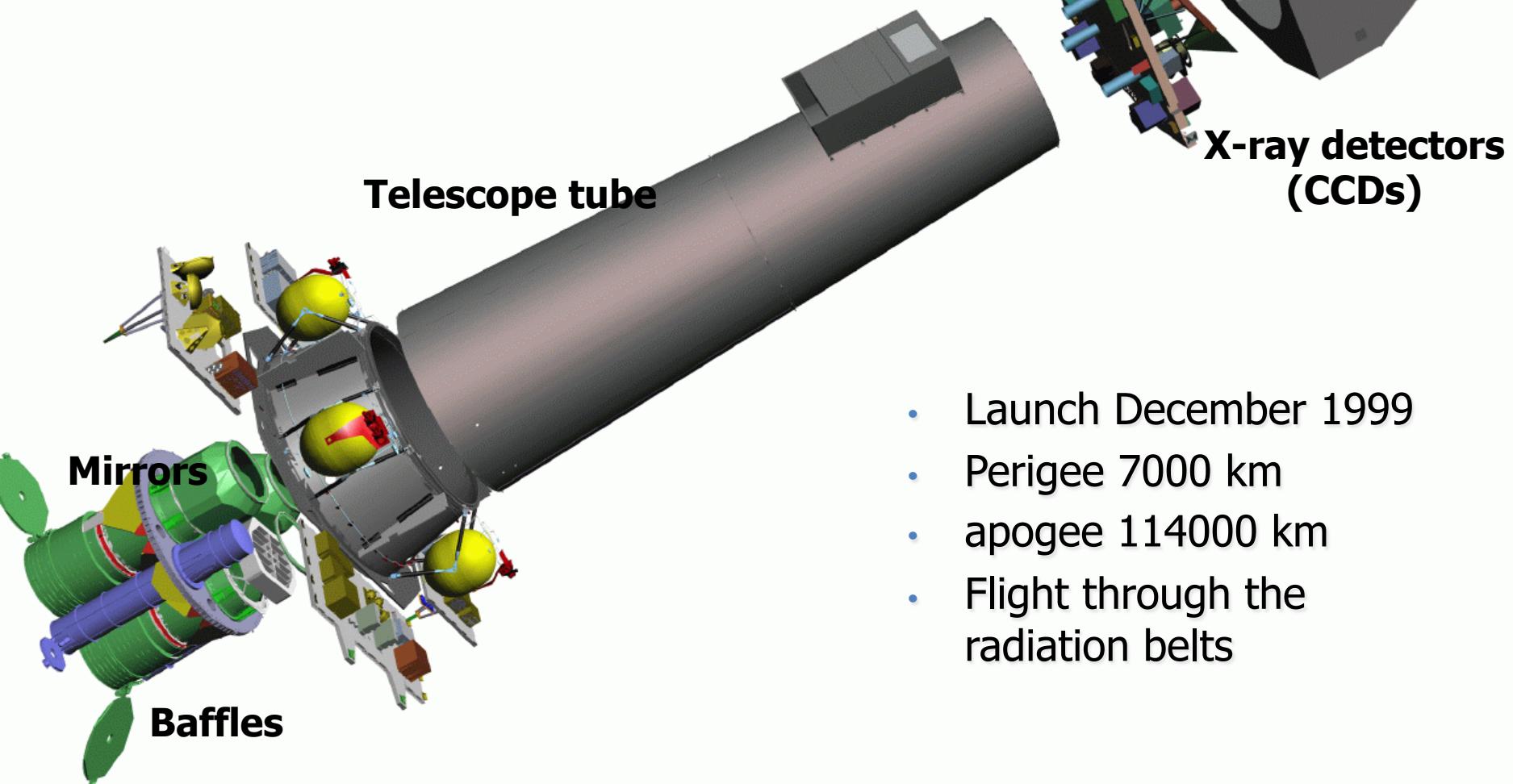
Synchrotron Radiation

**Generator of H. Burkhardt
Implemented for all components
Based on local curvature
Individual photons from
individual parents**

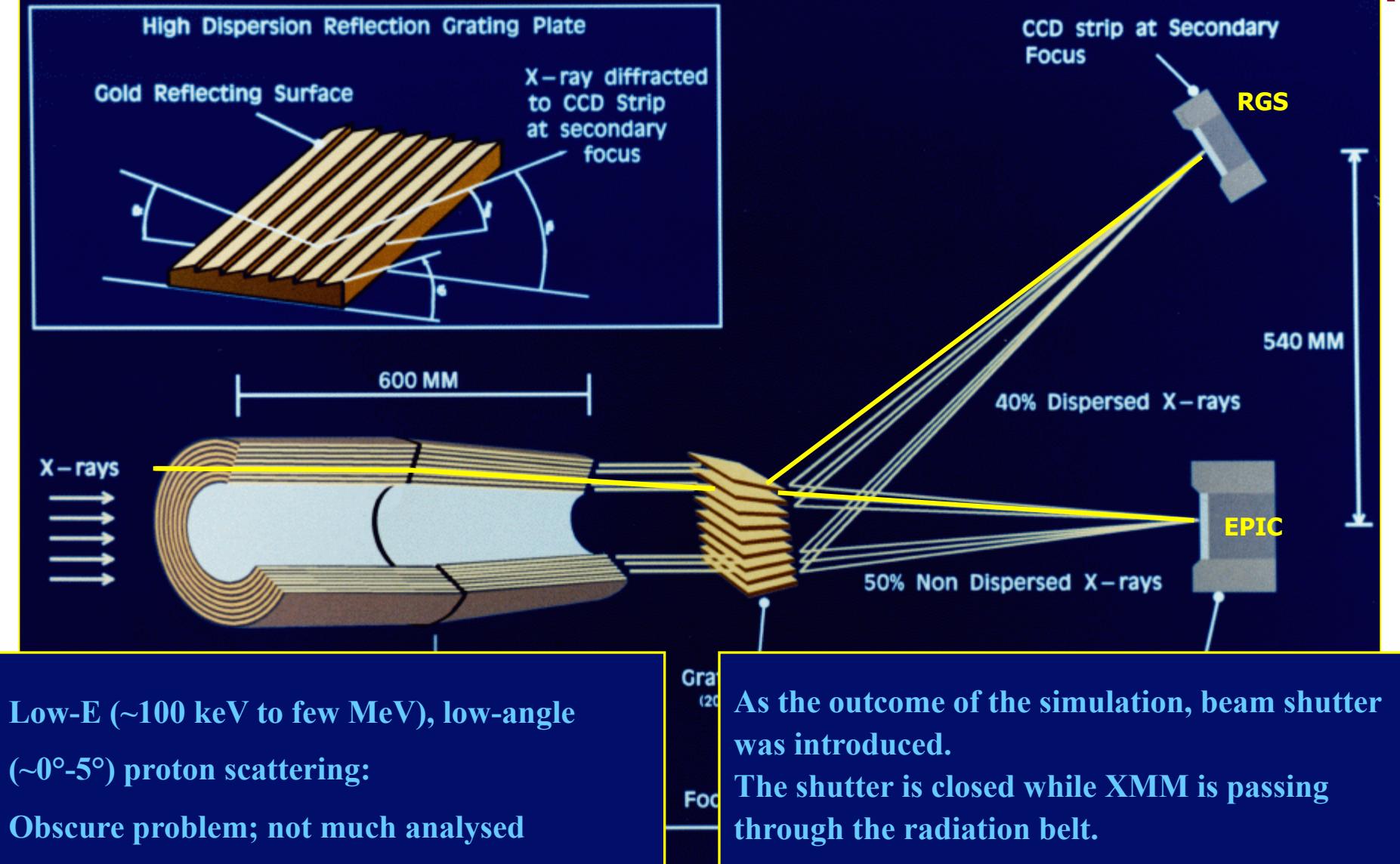


Geant4 in space



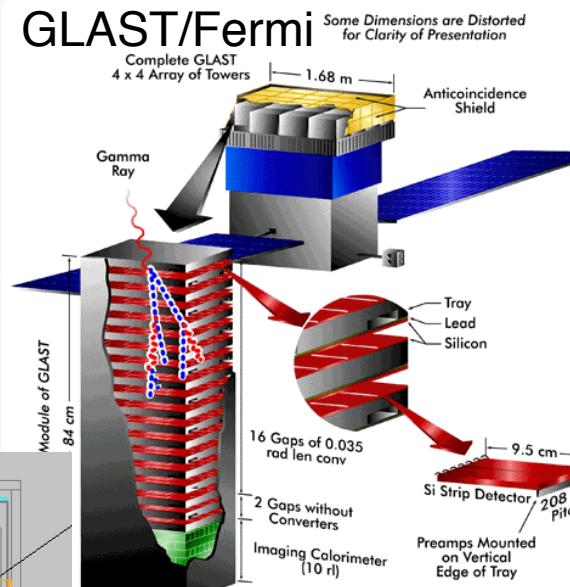
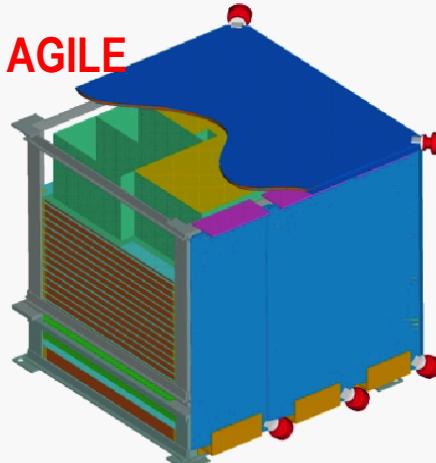
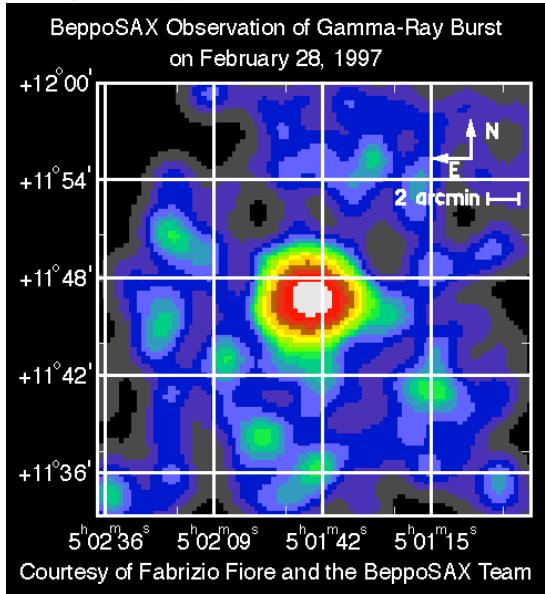


- Launch December 1999
- Perigee 7000 km
- apogee 114000 km
- Flight through the radiation belts

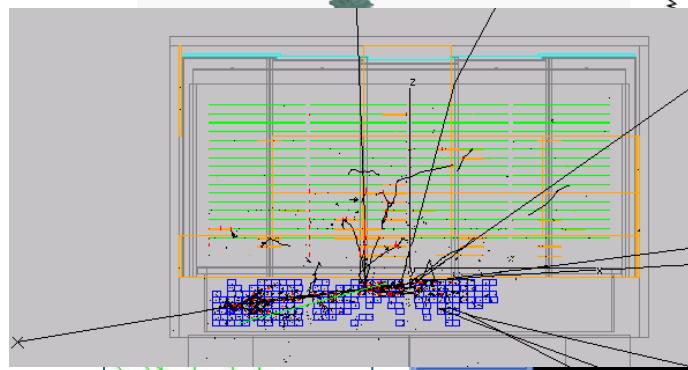


γ astrophysics

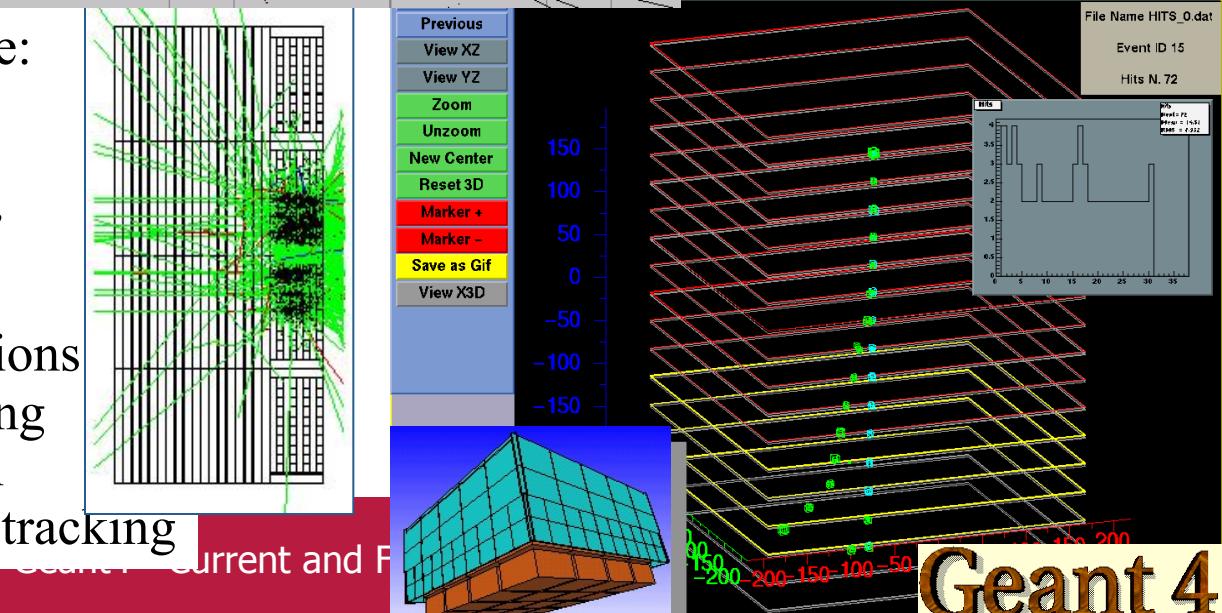
γ -ray bursts



GLAST / Fermi

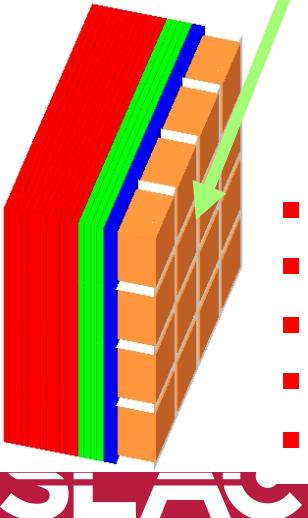


GLAST Hits Display



Typical telescope:
Tracker
Calorimeter
Anticoincidence

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

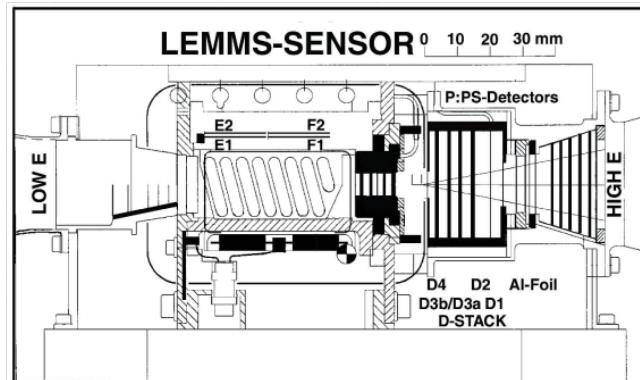


Current and Future

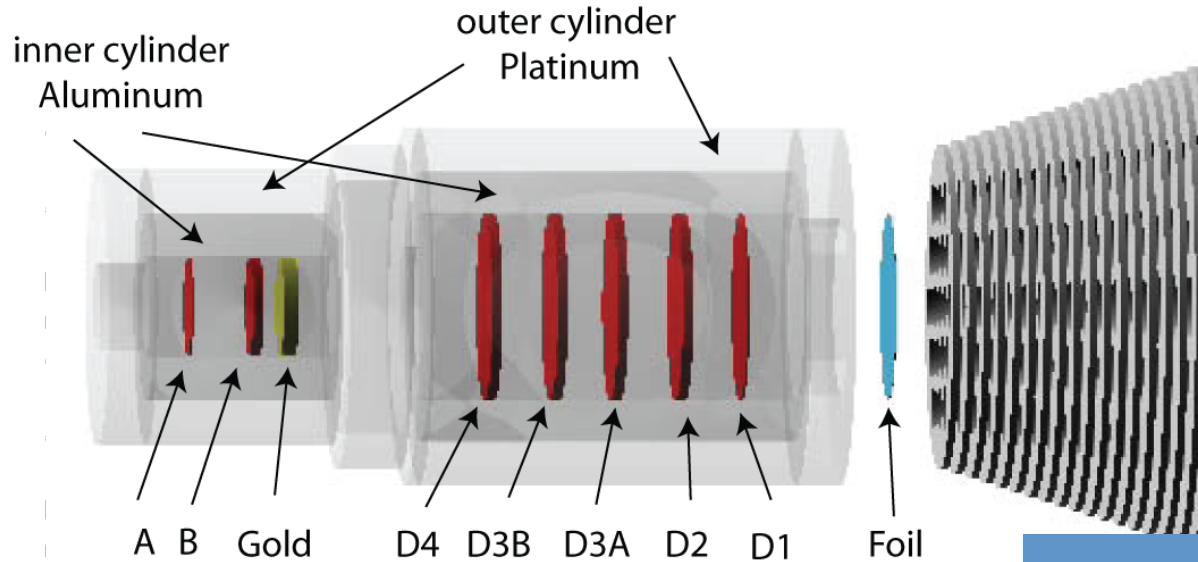
SLAC



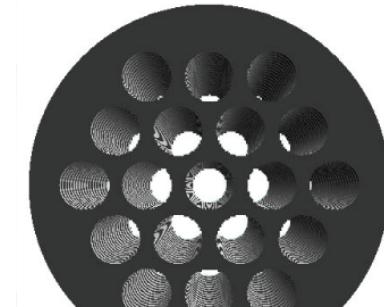
GEANT4 simulation of the Cassini-Huygens Low Energy Magnetospheric Measurement System (LEMMS)



LEMMS opaque side view High Energy side



collimator (front end view)



Courtesy of D.Haggerty (JHUAPL)

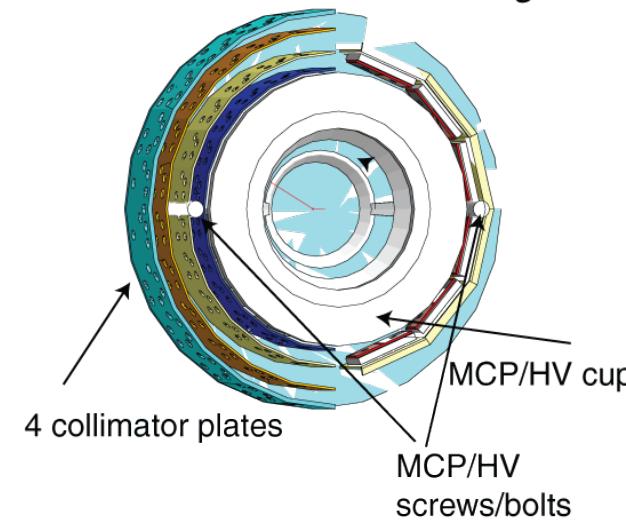
GEANT4 simulations of The Messenger Energetic Particle Spectrometer (EPS)



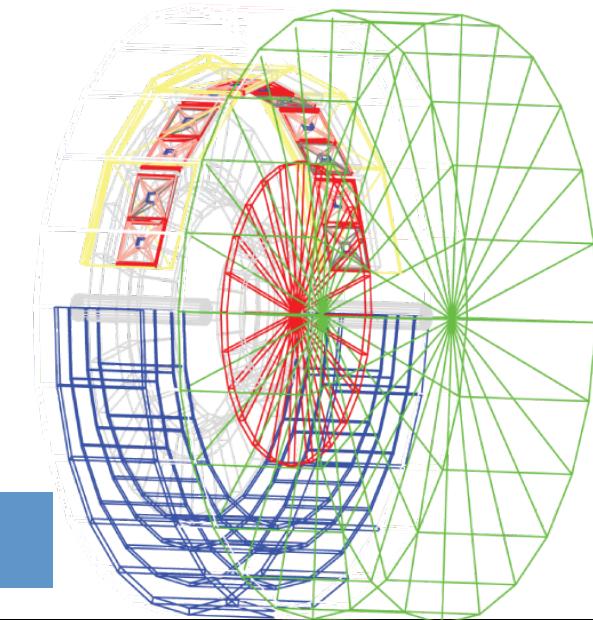
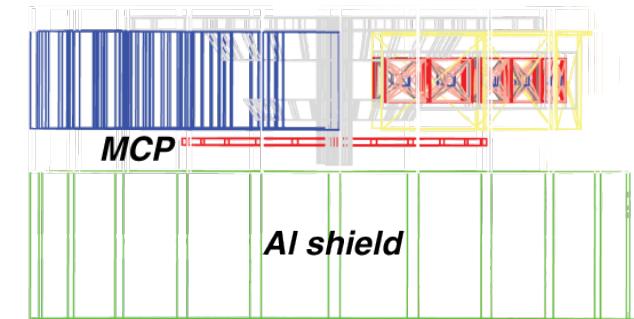
View looking into the Collimator



Bottom view of EPS simulation geometry

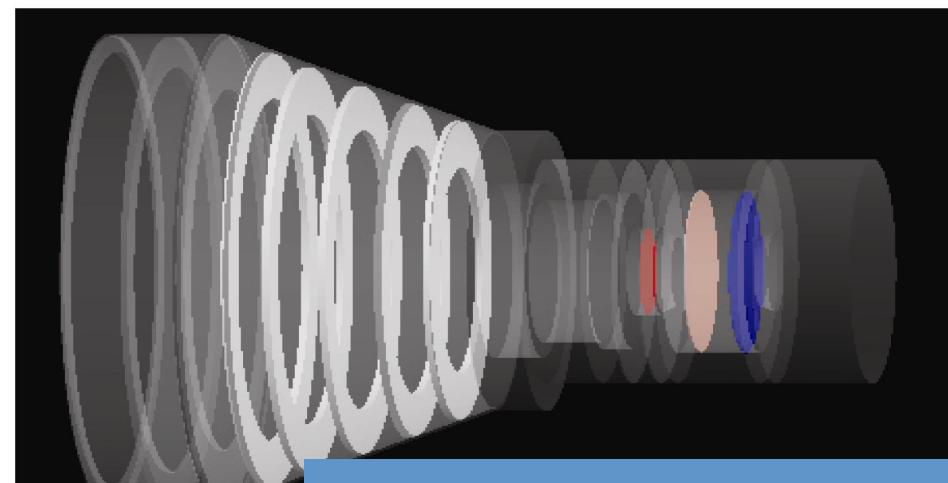
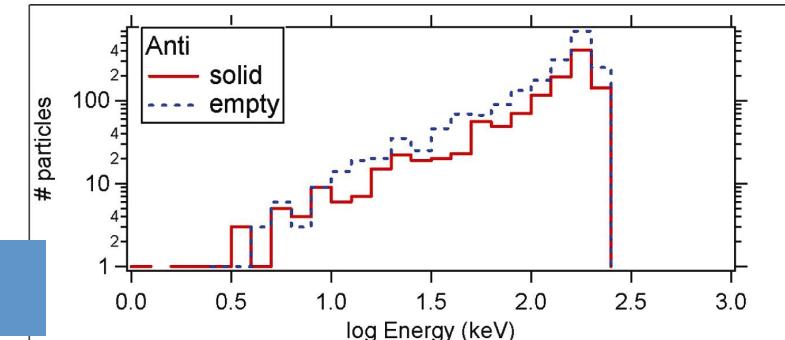
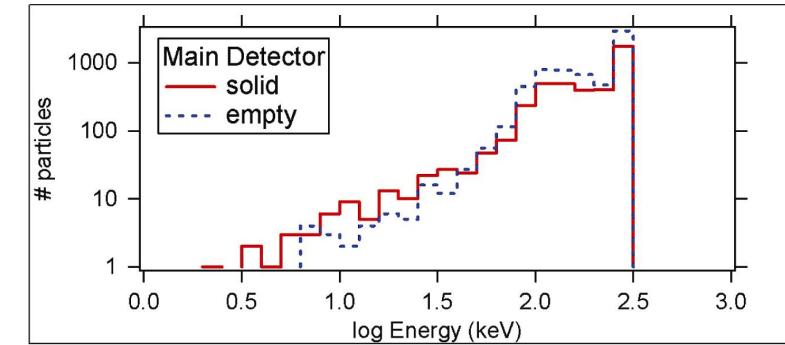
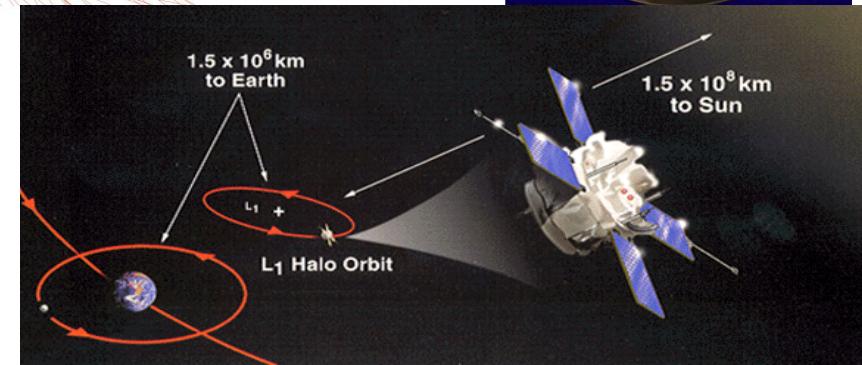
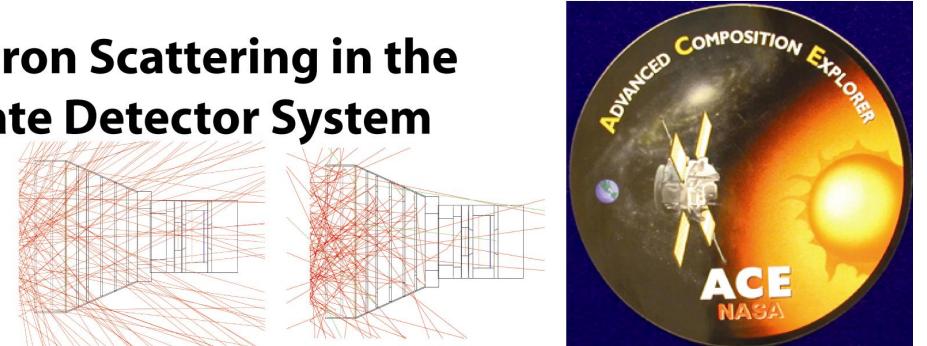
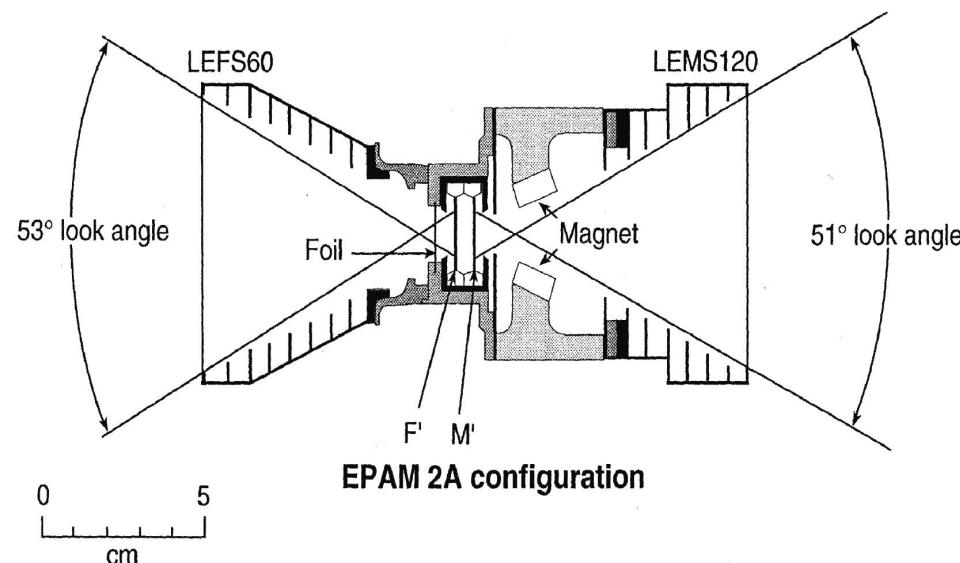


Wireframe view with some shielding



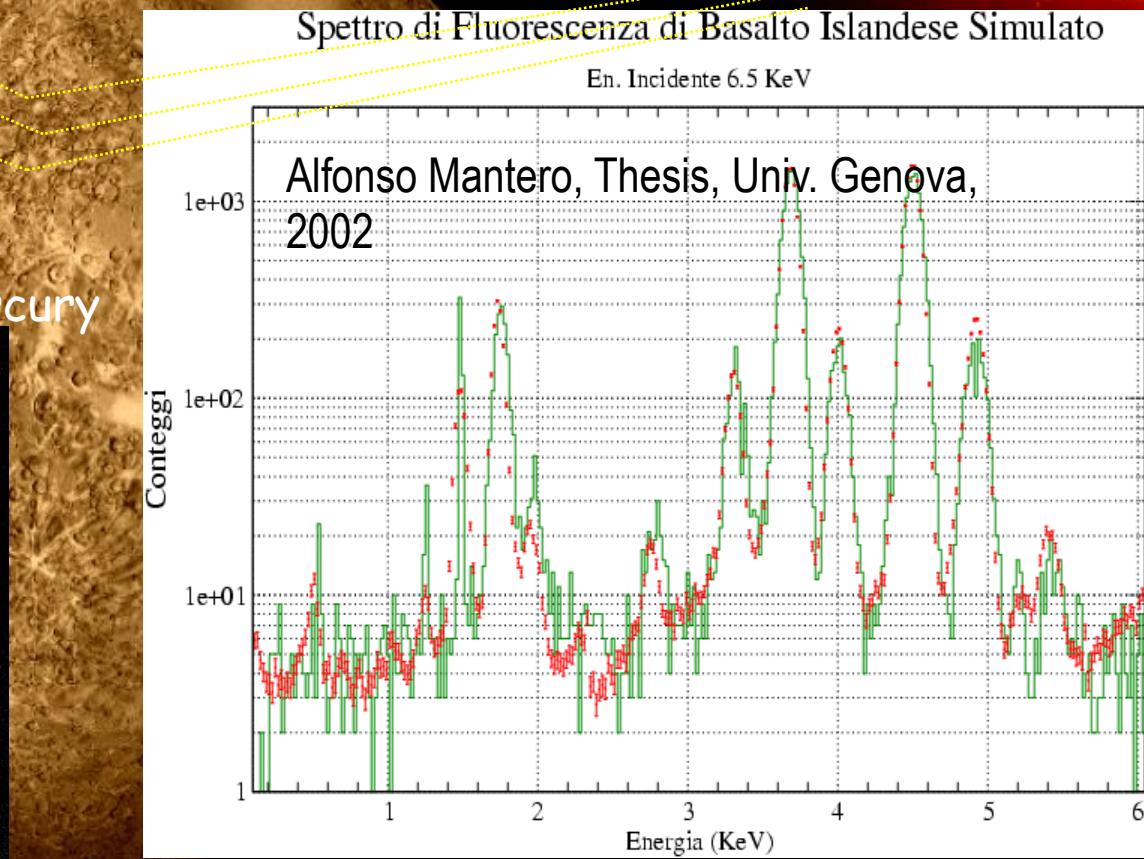
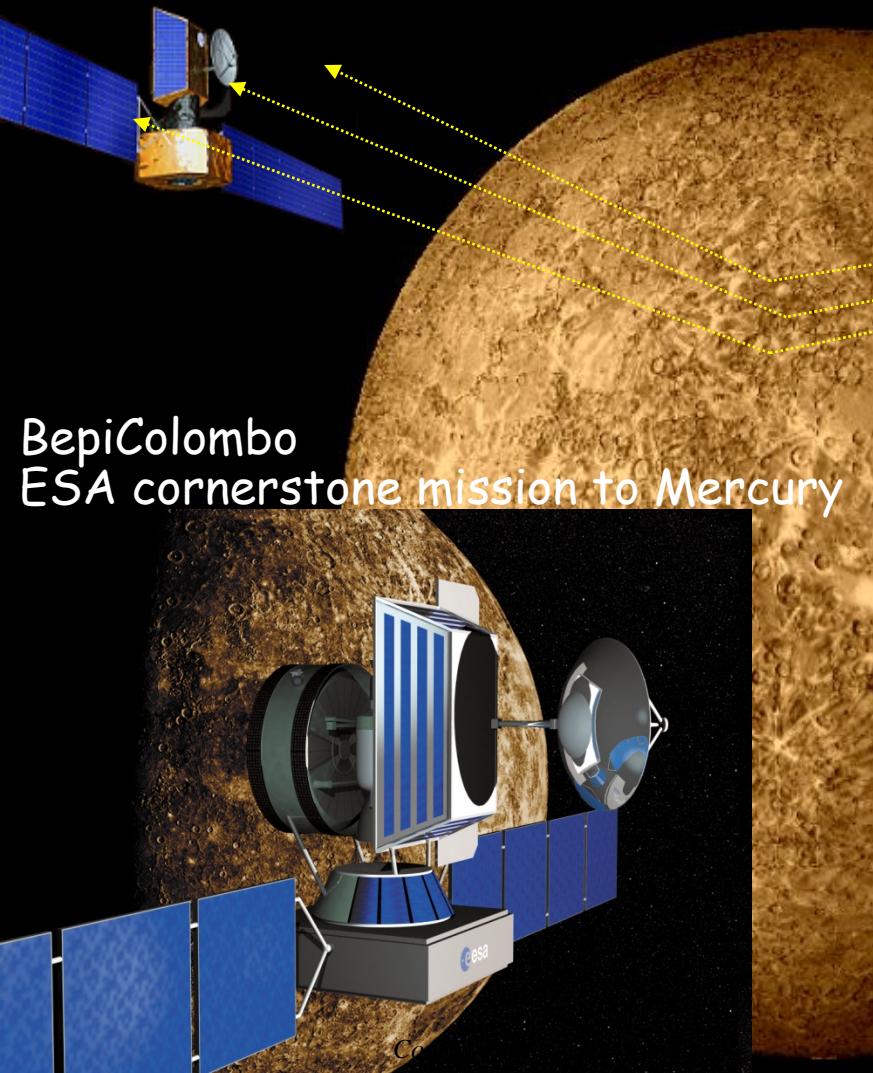
Courtesy of D.Haggerty (JHUAPL)

Solar Energetic Electron Scattering in the ACE/EPAM Solid State Detector System



Courtesy of K.Haggerty (JHUAPL)

Bepi Colombo: X-Ray Mineralogical Survey of Mercury





PlanetoCosmics

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

SLAC

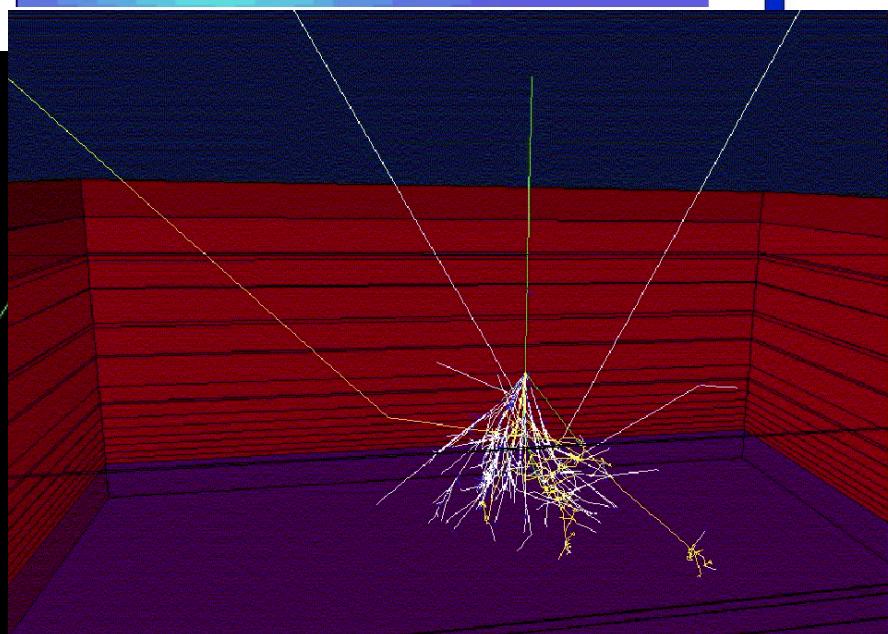
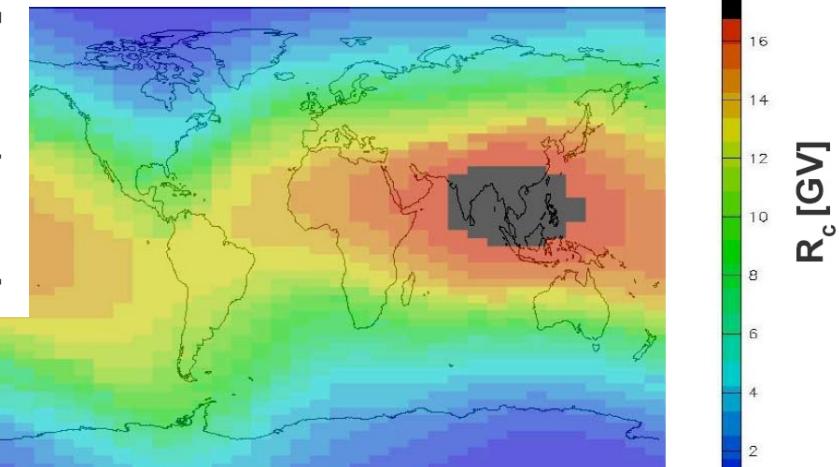
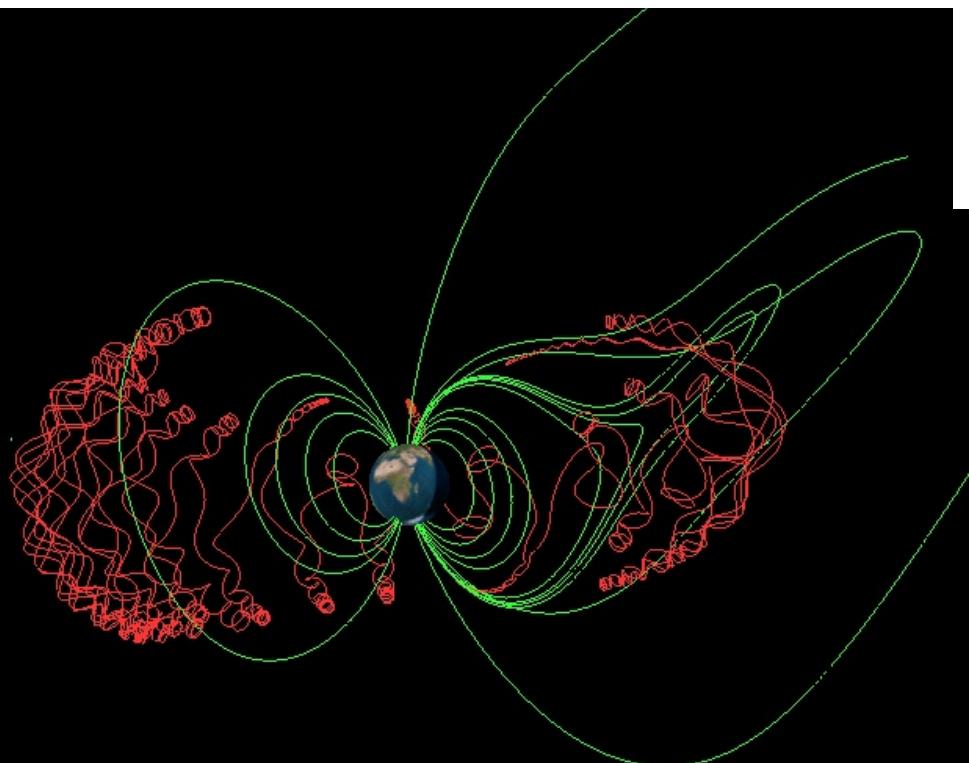
28th International Cosmic Ray Conference

— 4277

Cutoff Rigidities vs position

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

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

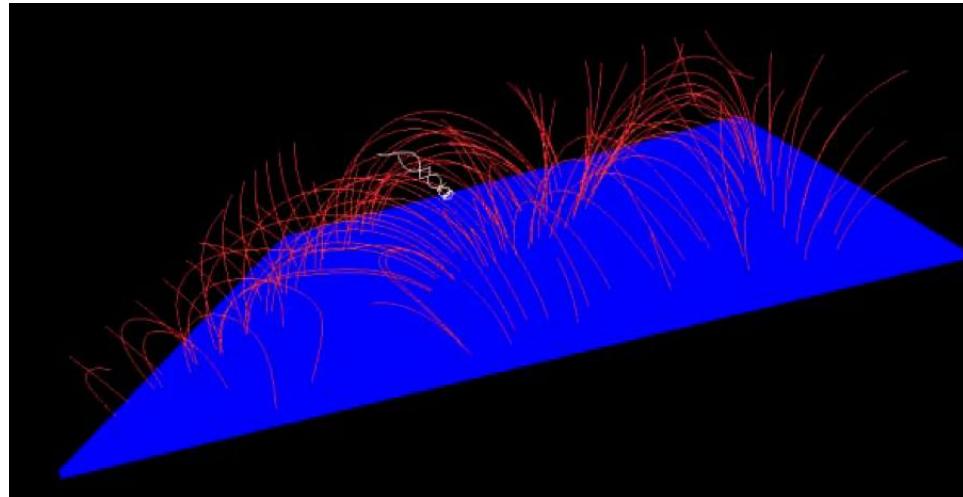
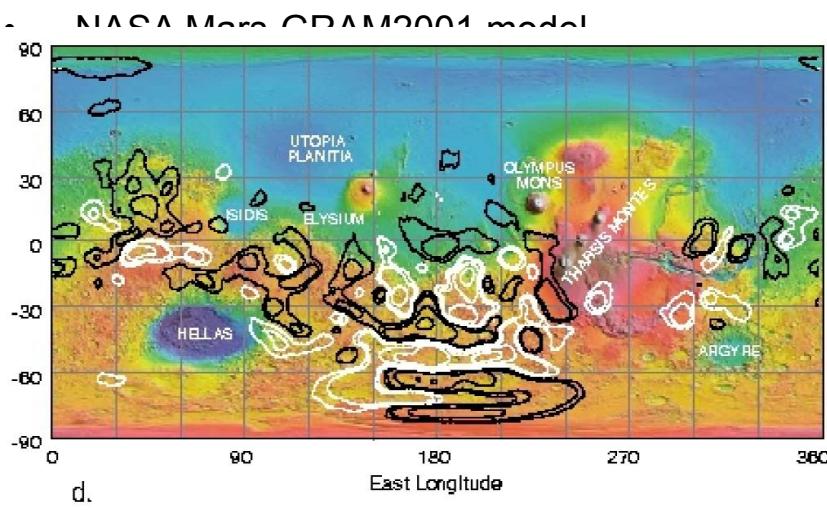
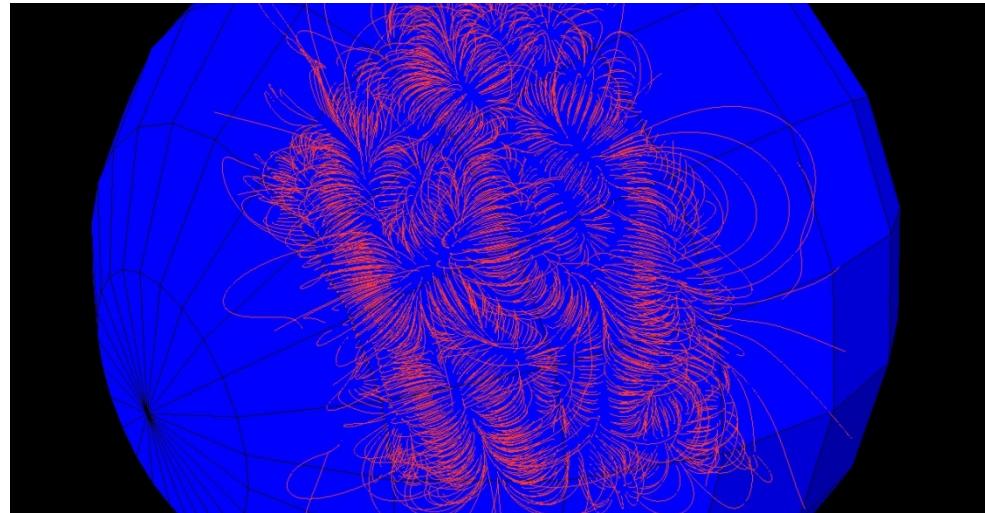
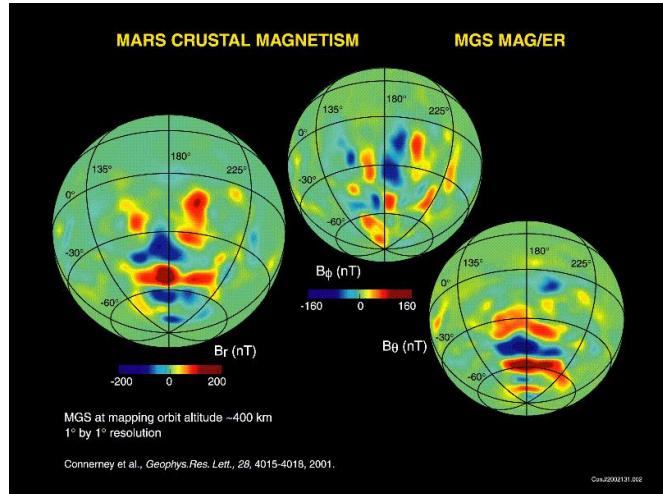




PlanetoCosmics

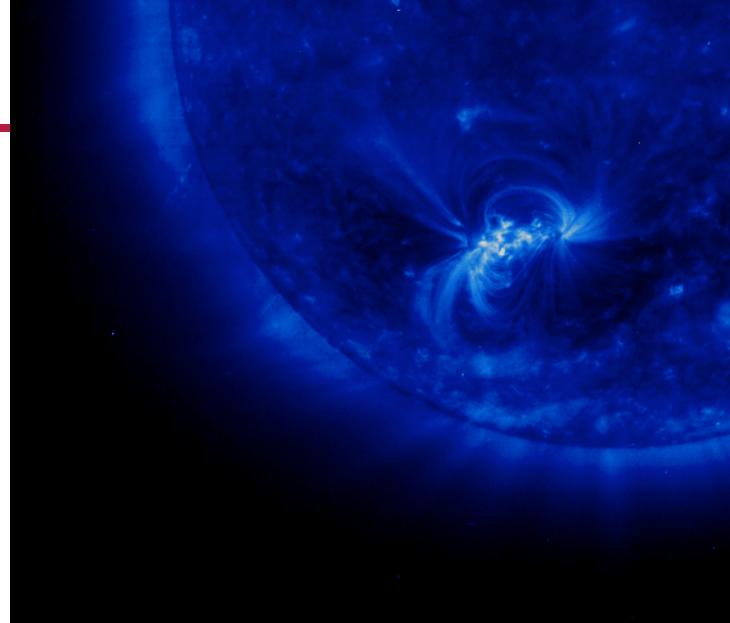
Mars field and atmosphere

SLAC

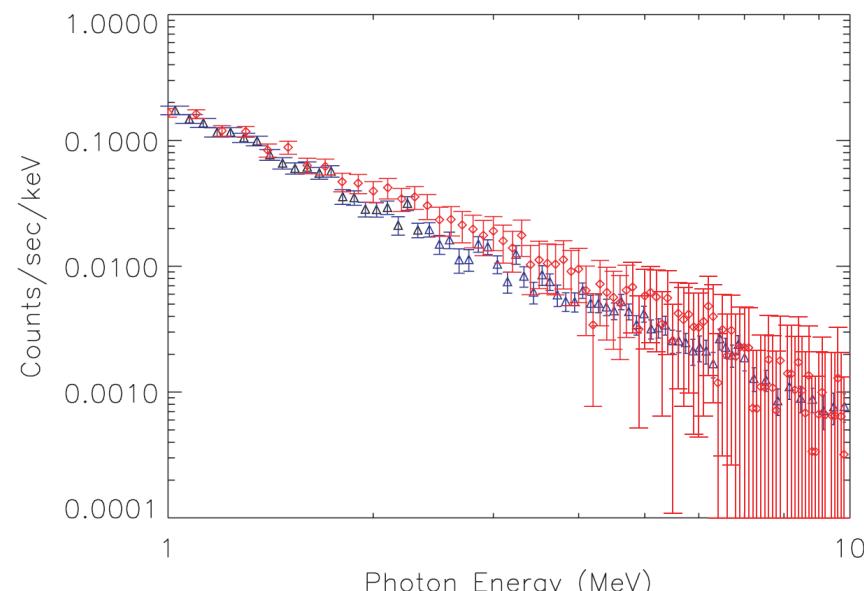


Solar event gamma-rays

- 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 MAKISHIMA¹ and Yukari MATSUMOTO²

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

Mitsuhiko KOHAMA, Yukikatsu TERADA and Toru TAMAGAWA
RIKEN (Institute of Physical and Chemical research), Wako-shi, Saitama

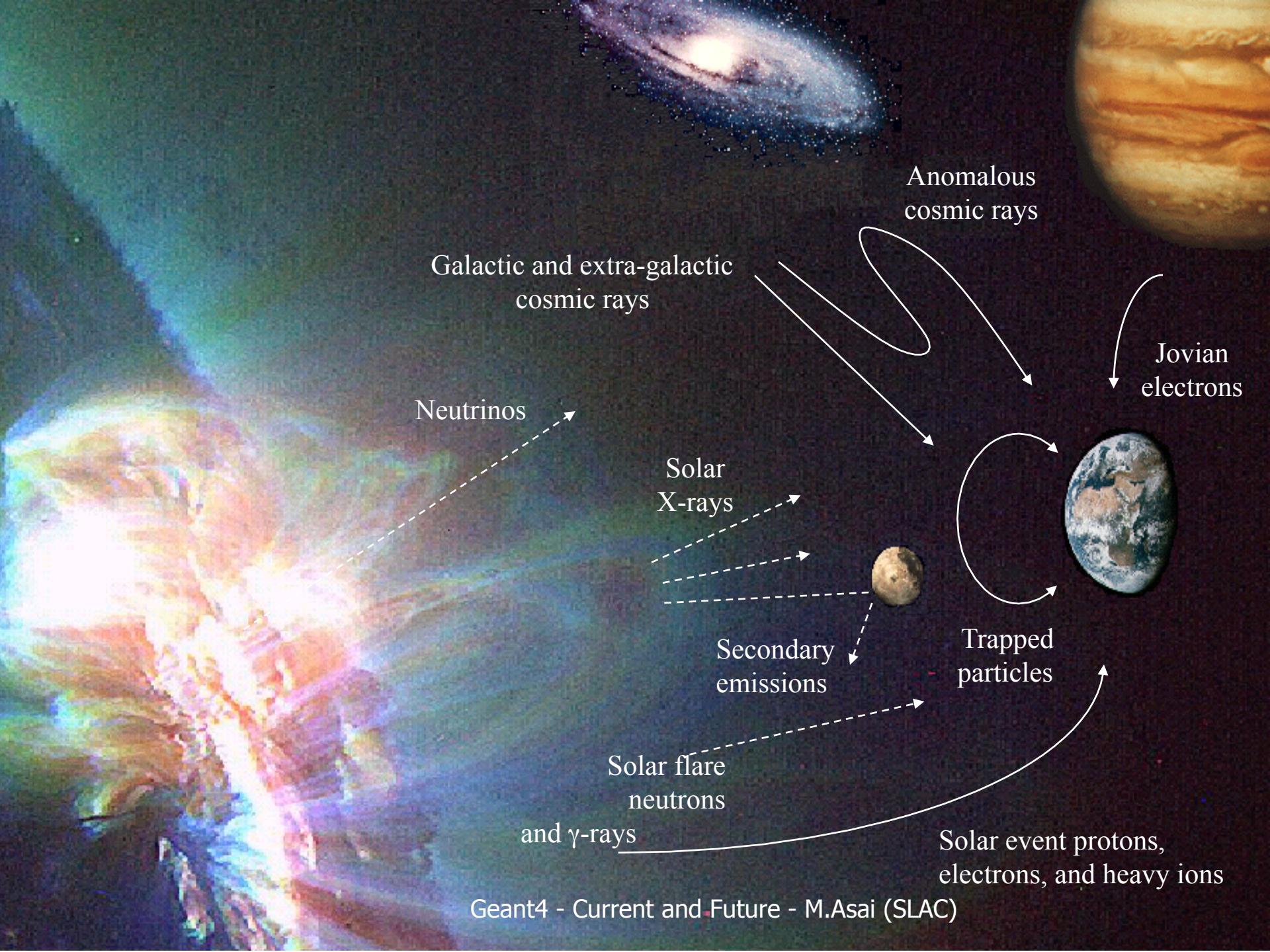
¹Also at RIKEN

²Present address: Mitsubishi Electric Co., Ltd.

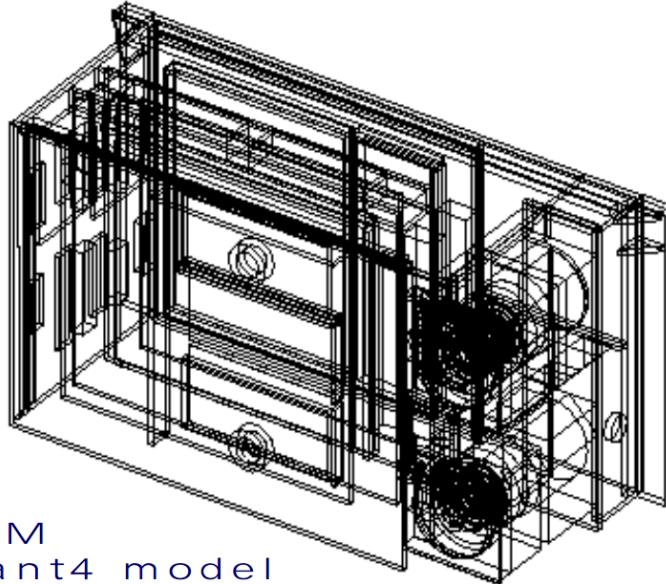
(Received ; accepted)

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-



ESA Standard Radiation Environment Monitor (SREM)



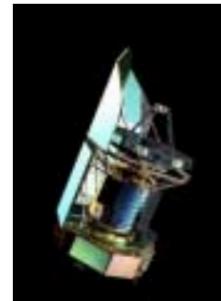
INTEGRAL



ROSETTA



PROBA-1



HERSCHEL



GSTB V2

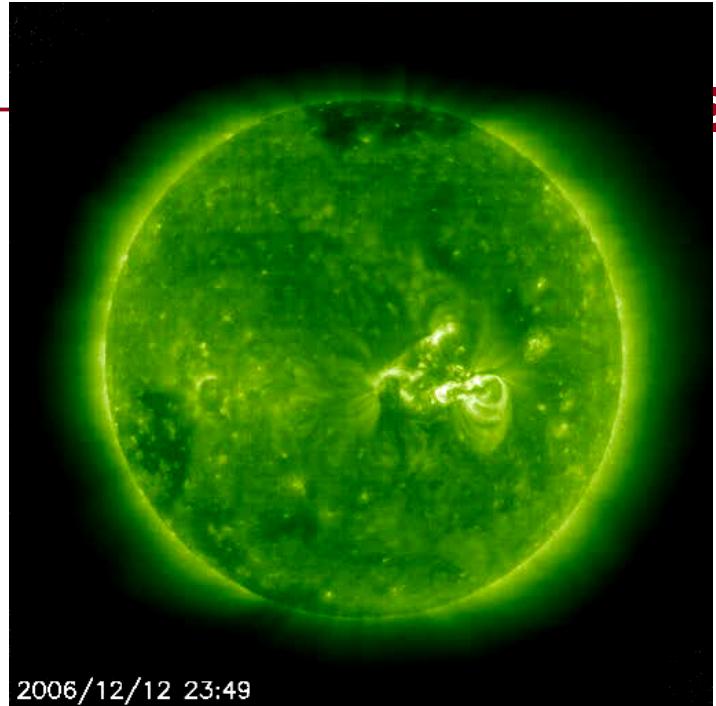
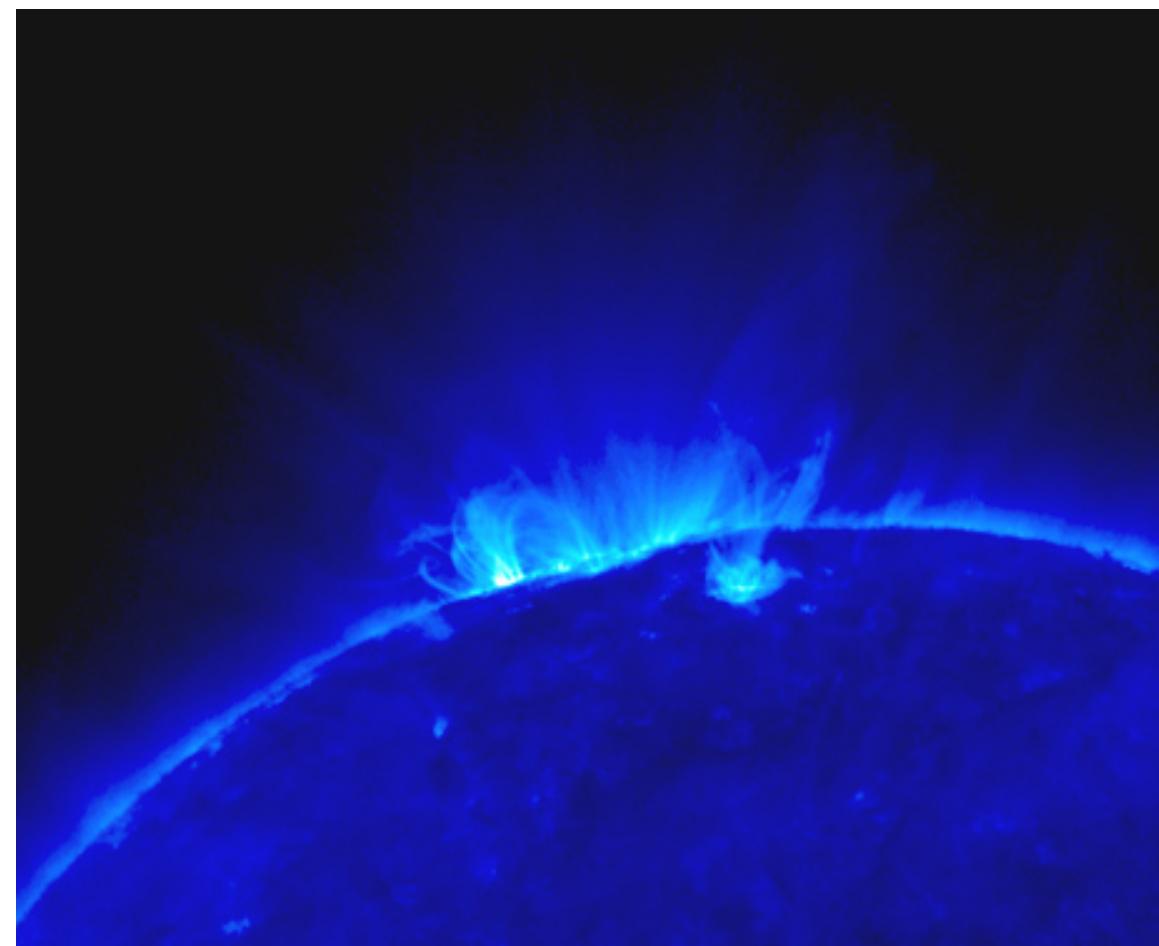


PLANCK

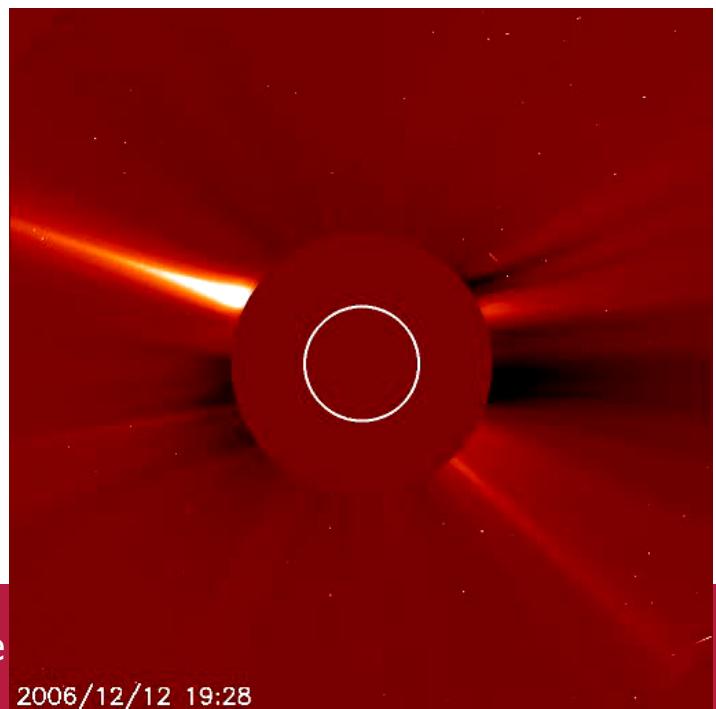


GAIA

Solar event of 13 December 2006



2006/12/12 23:49



2006/12/12 19:28



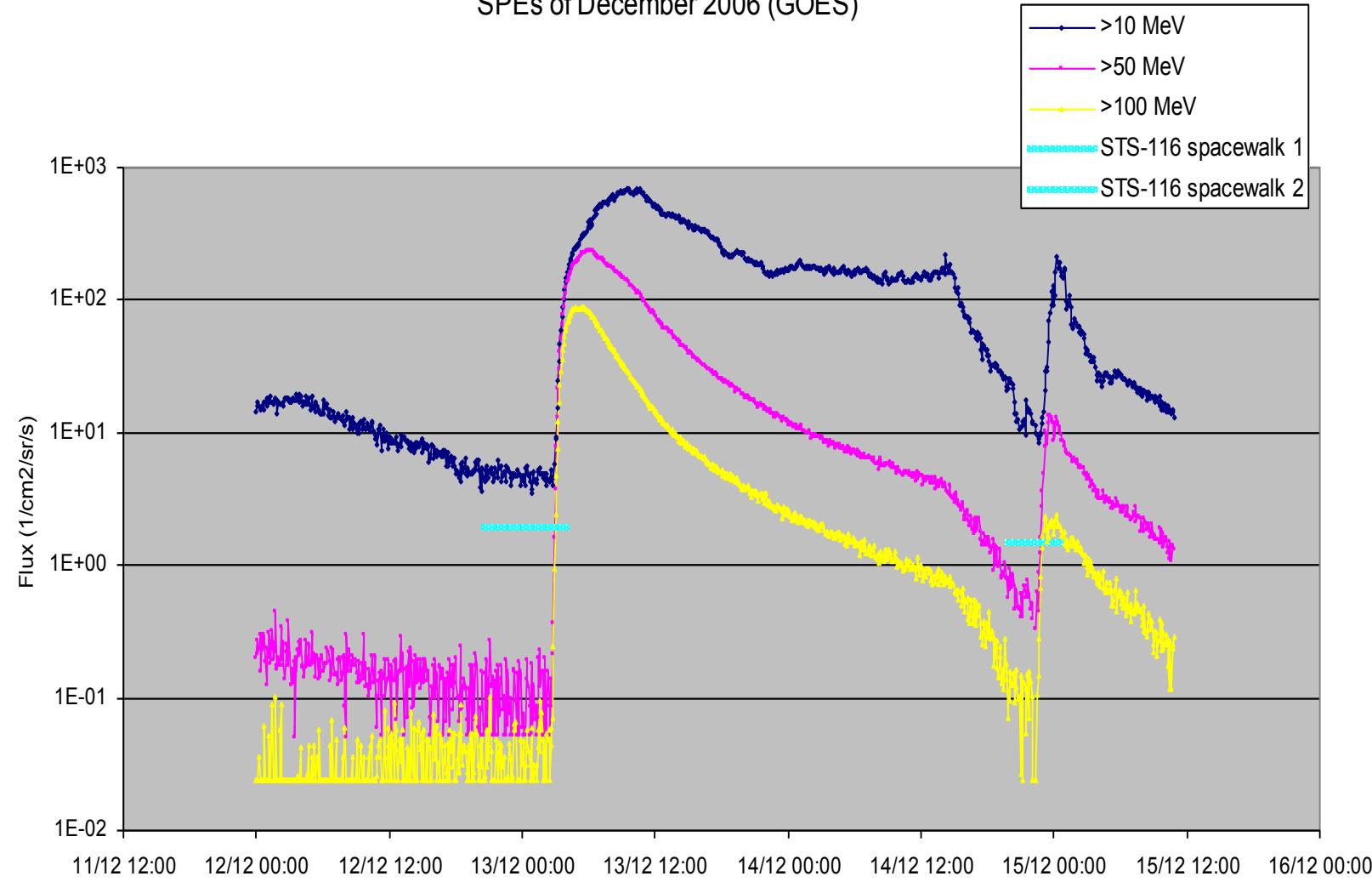
International Space Station (ISS)

STS-116 mission to ISS

SLAC



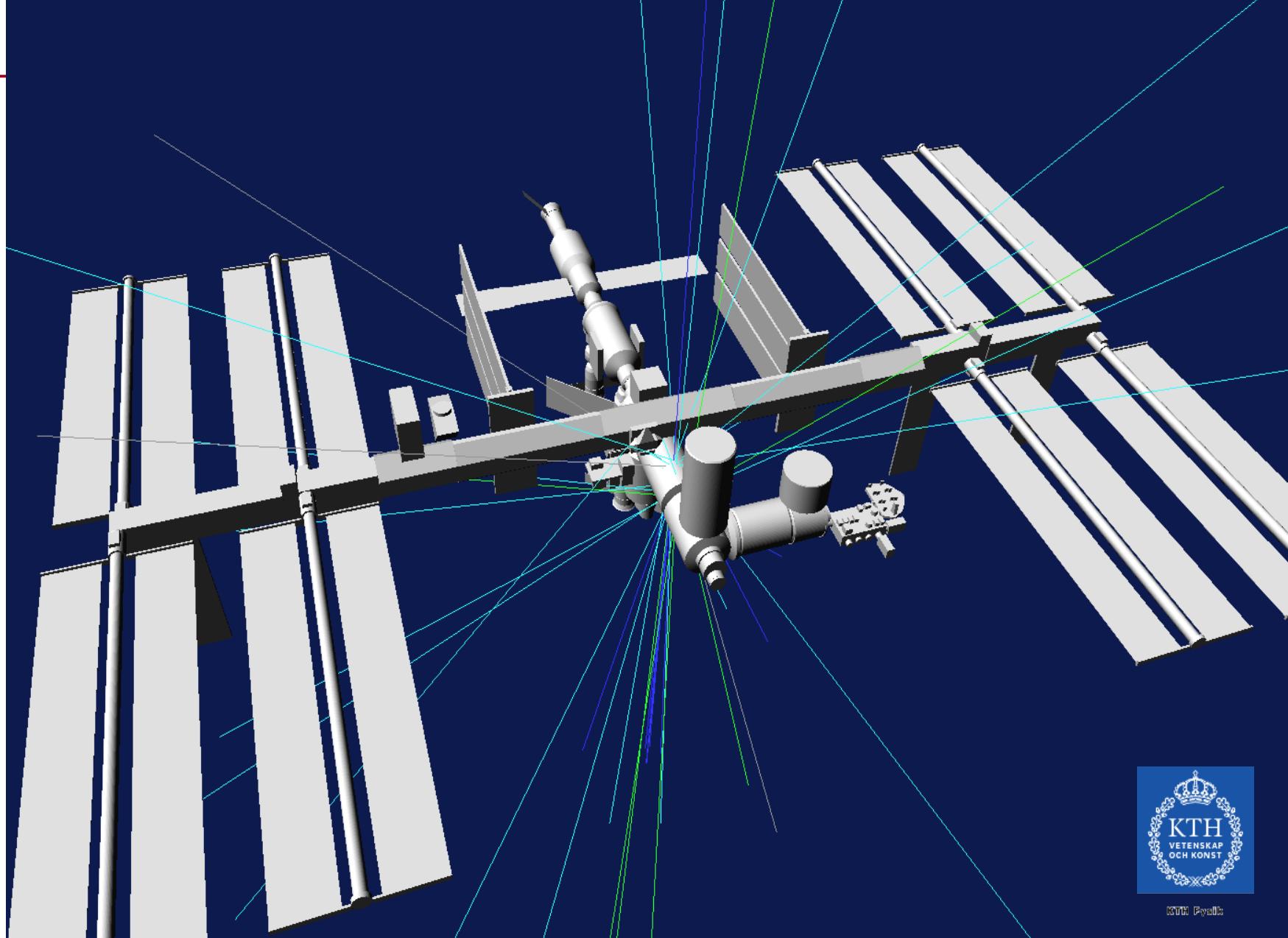
SPEs of December 2006 (GOES)



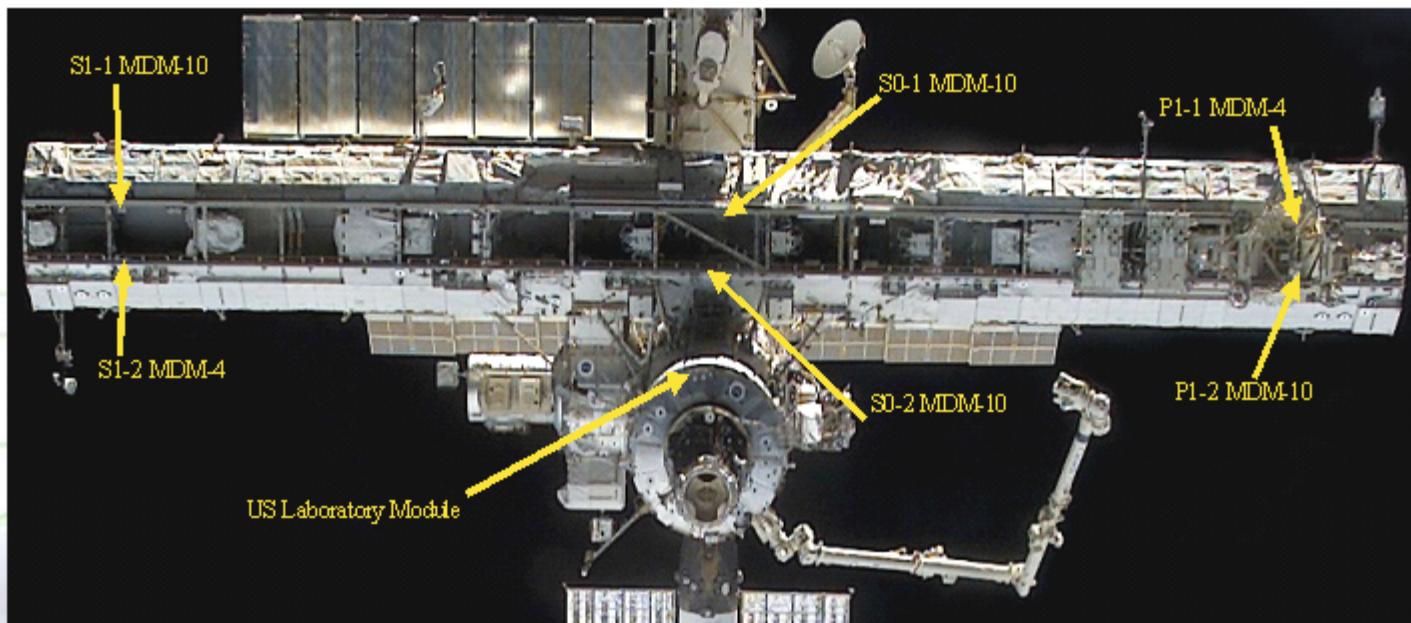
Courtesy T. Ersmark, KTH Stockholm



KTH Fysik



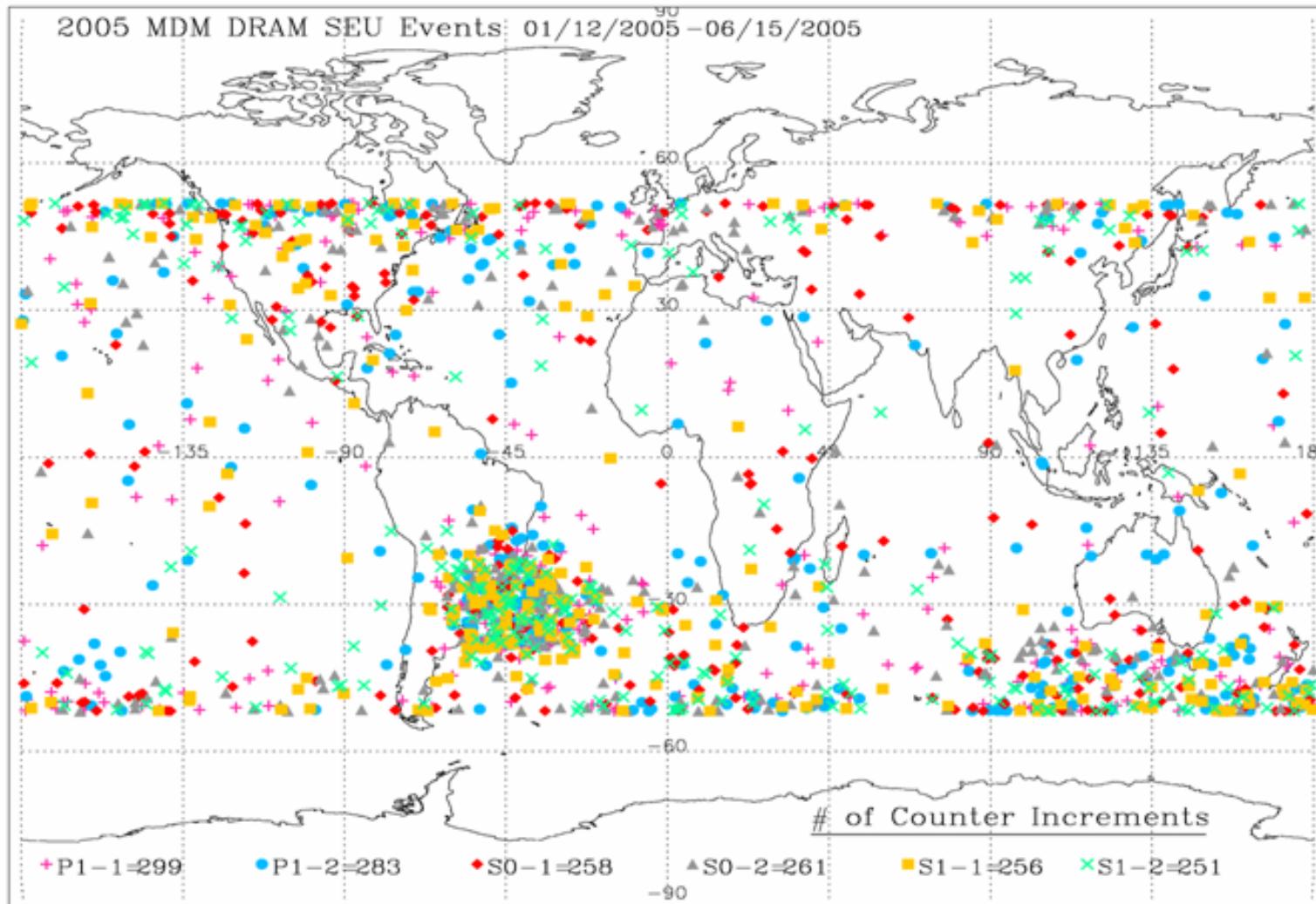
ISS Single Event Upset Observations



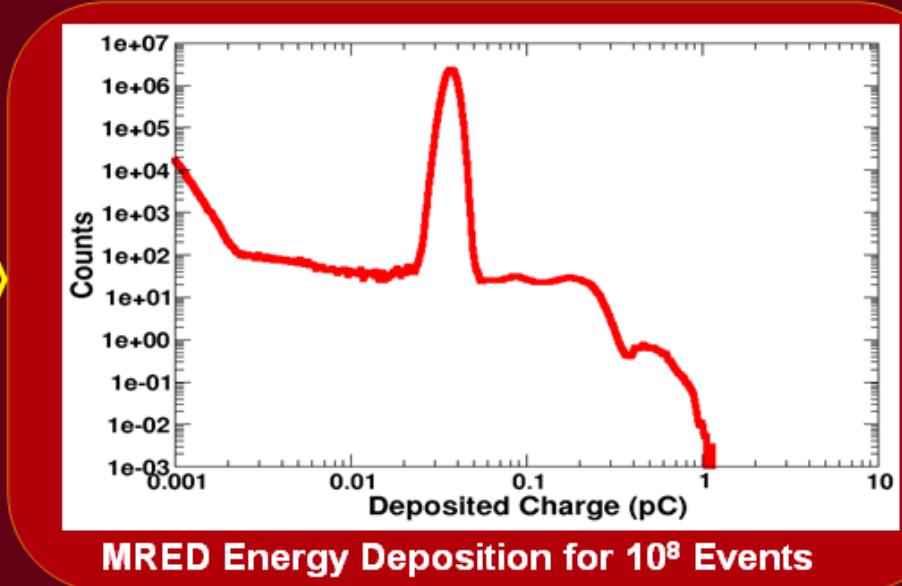
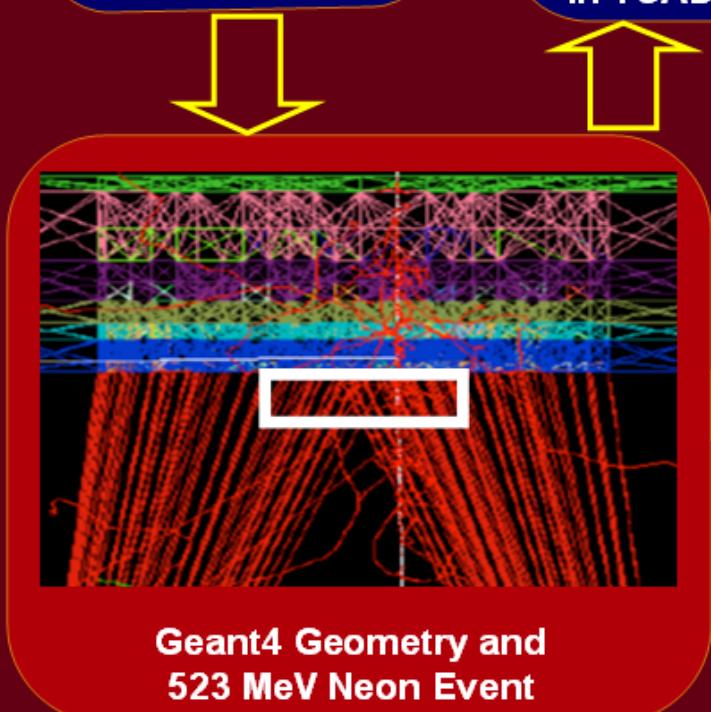
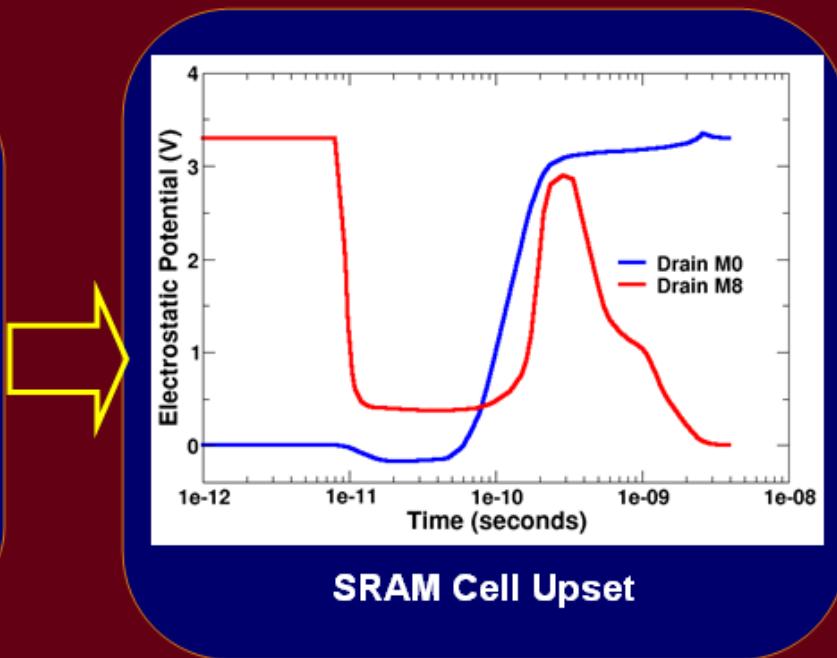
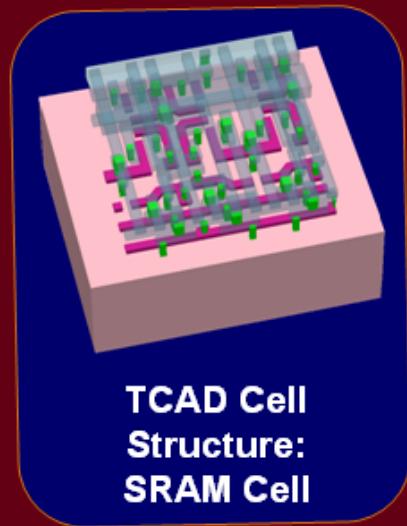
MDM-DRAM	Measured SEU Count/238 days	SEFA SEU Count/238 days	FOM SEU Count/238 Days
Lab-1 40 g/cm ²	488	287	83
Lab-3 40 g/cm ²	490	287	83
P1-2: 10 g/cm ²	536	6202	1647
S1-1: 10 g/cm ²	488	6202	1647

19

ISS Single Event Upset Observations

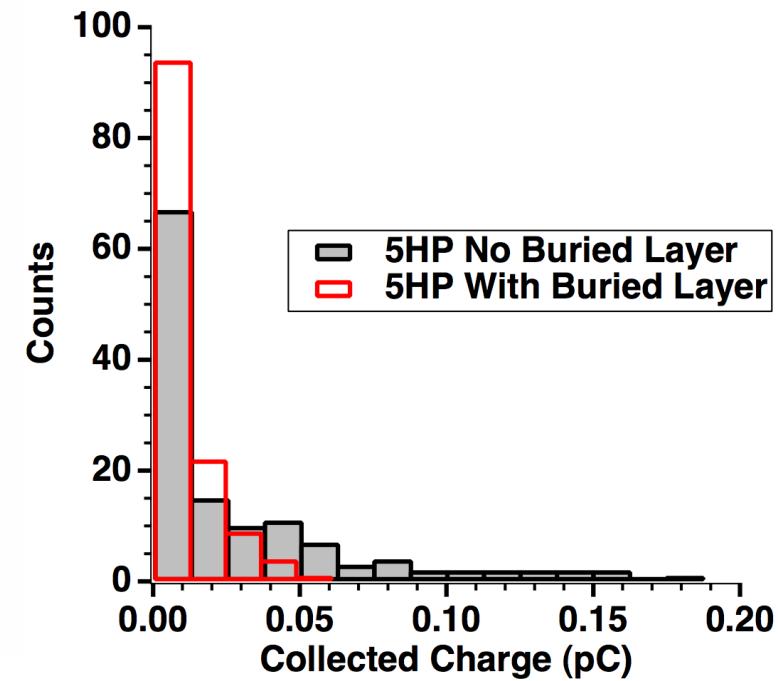
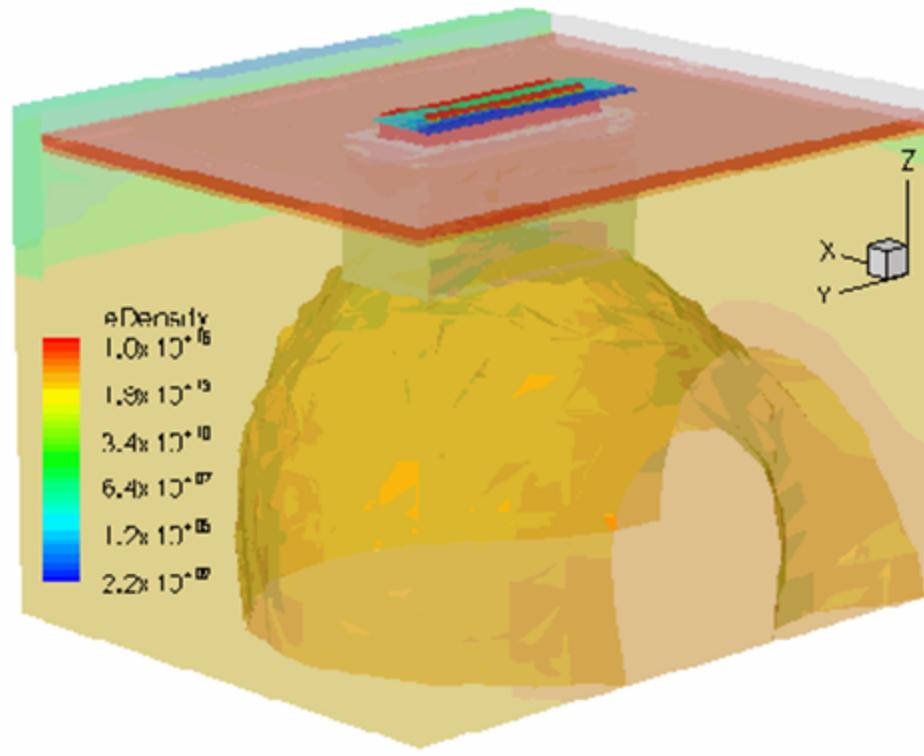


RADSAFE on SEE in SRAMs



Simulation of Radiation Events

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



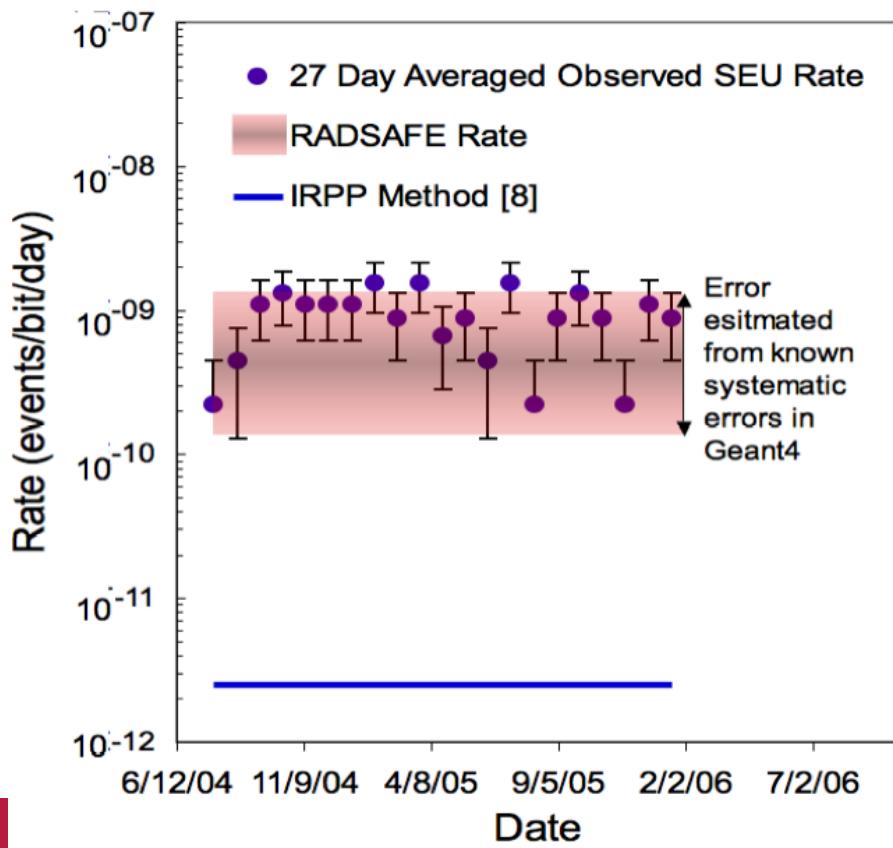
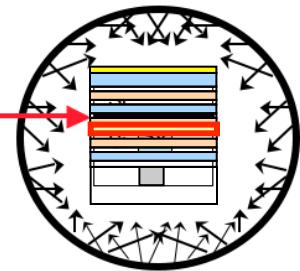
Courtesy of R.Reed (Vanderbilt U.)

Geant4 - Current and Future - M.Asai (SLAC)

Observed and Predicted SEU Rate for an SRAM

- SRAM used on NASA 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

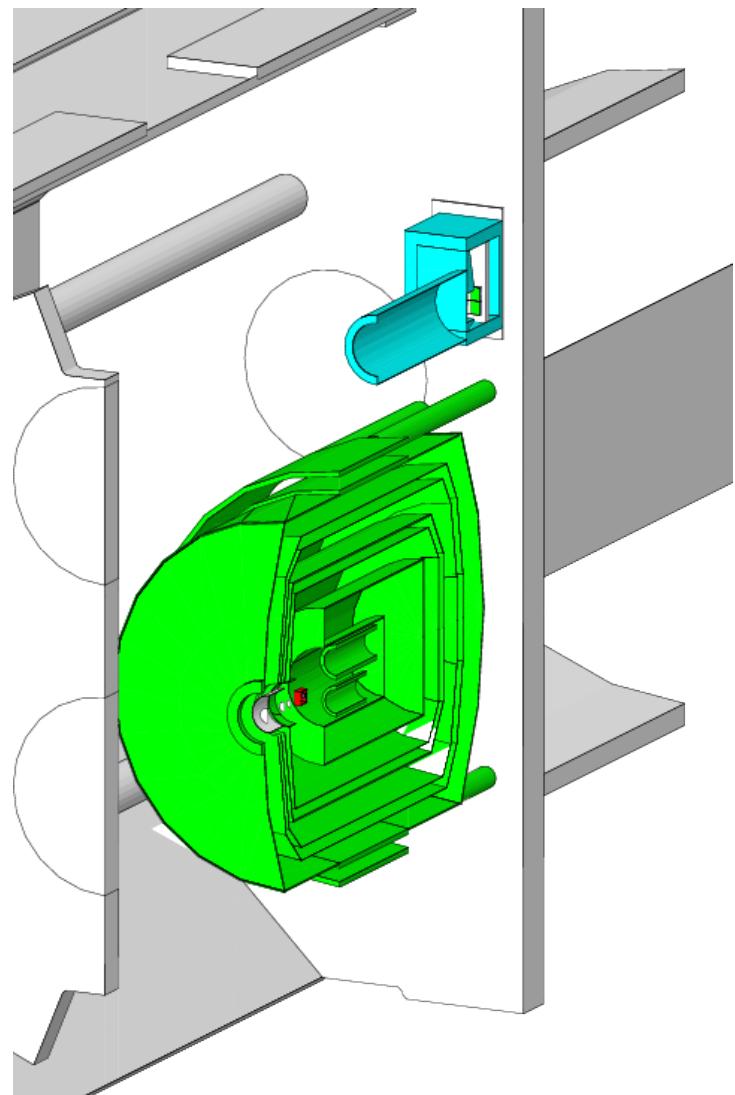
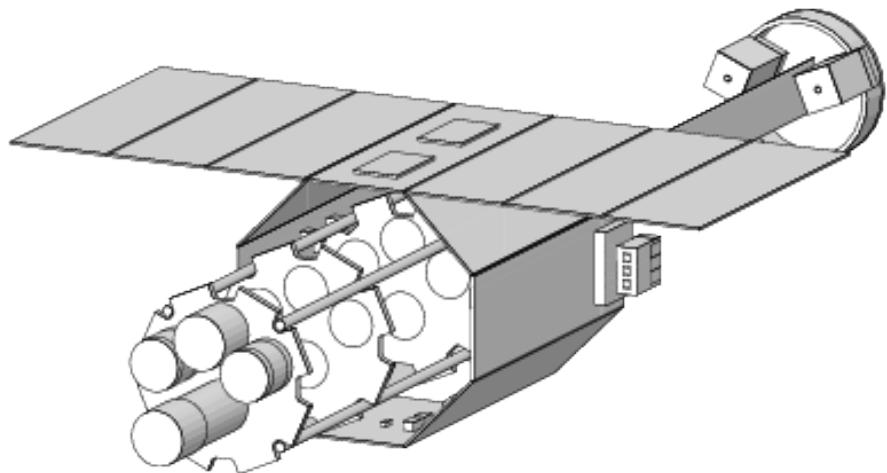
Multi-layered Stack



Courtesy of R.Reed (Vanderbilt U.)

ASTRO-H (1)

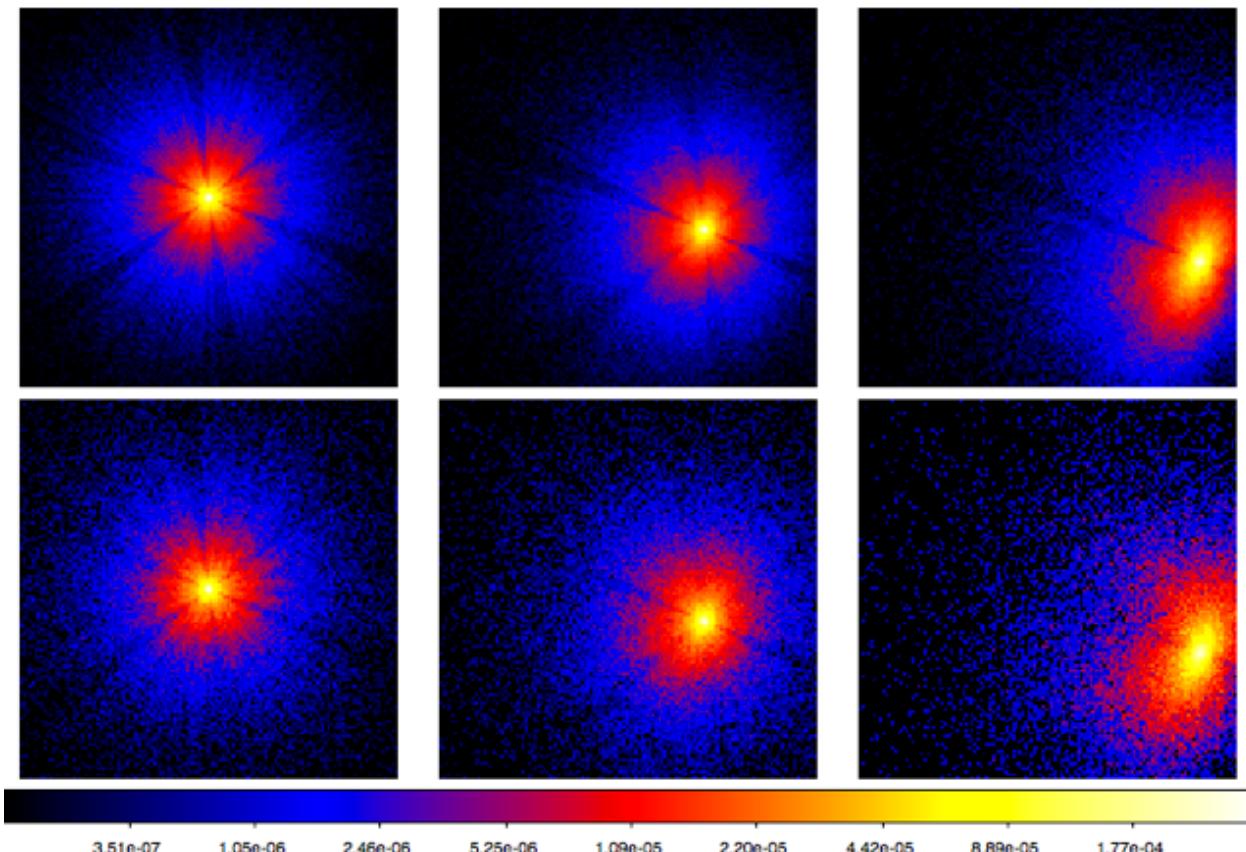
SLAC



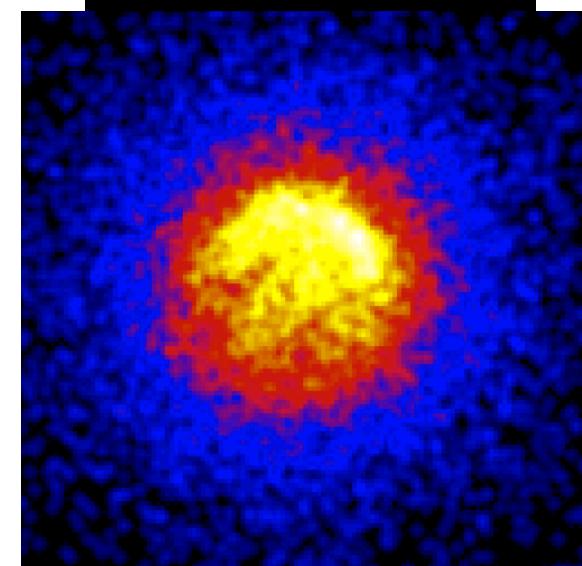
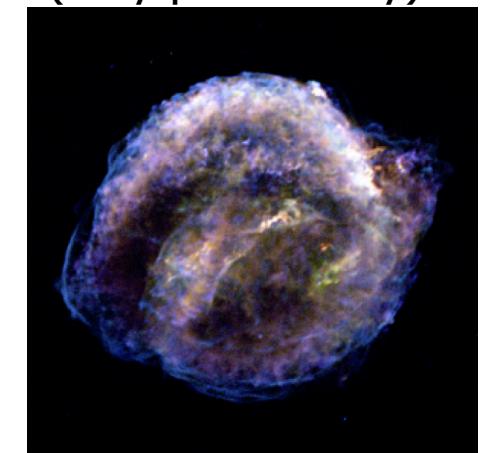
SXI and SXS

Point source on HXI

Left; center; right - 0arcmin; 2arcmin; 4arcmin
top; bottom - 10keV; 30keV



Kepler SNR on HXI
(very preliminary)

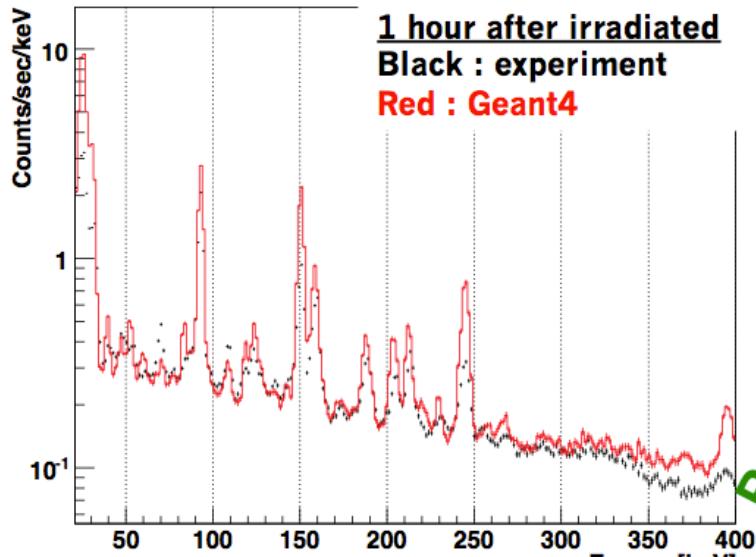




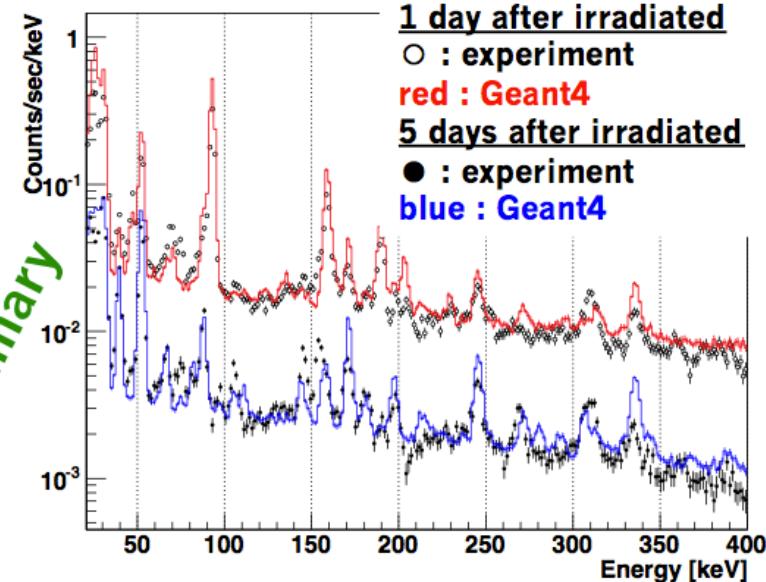
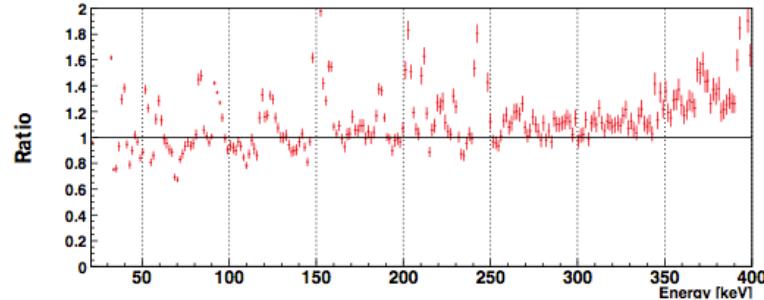
Time evolution of the activation background



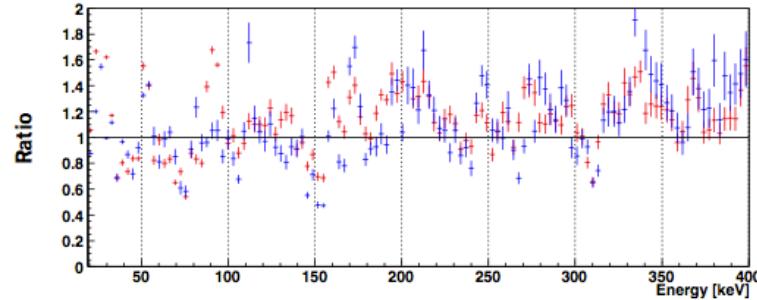
Comparison with Geant4



Ratio (simulation/experiment)



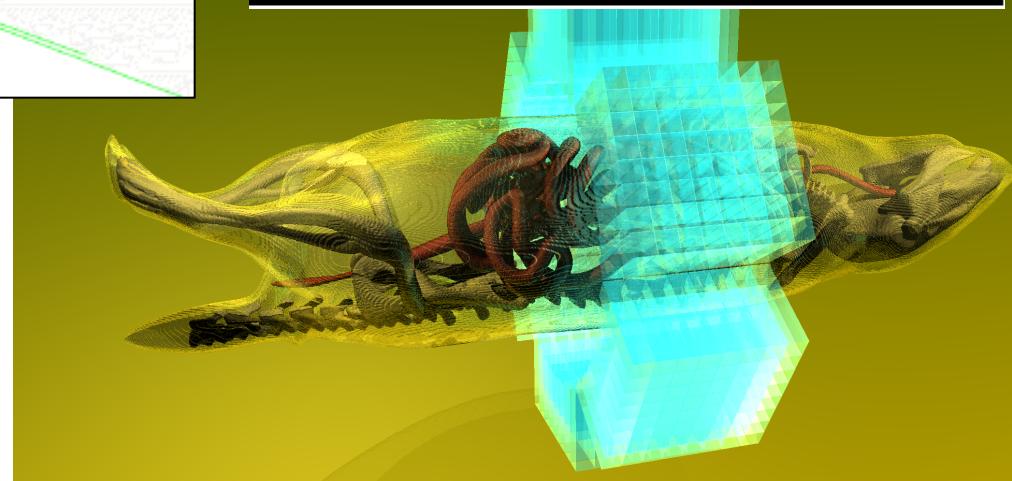
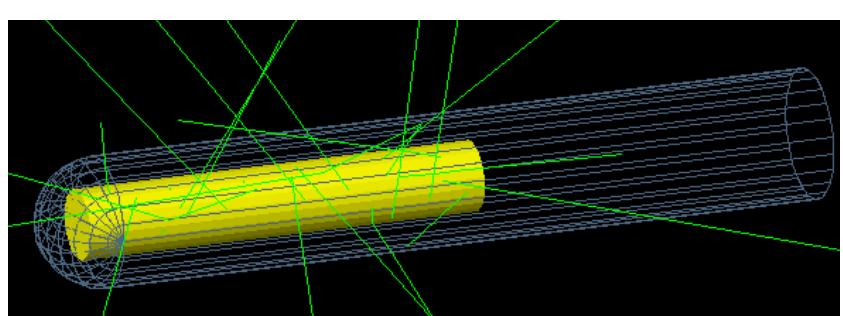
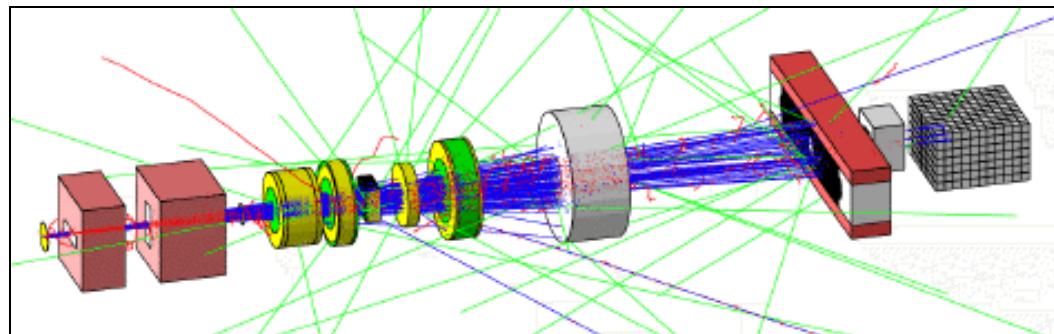
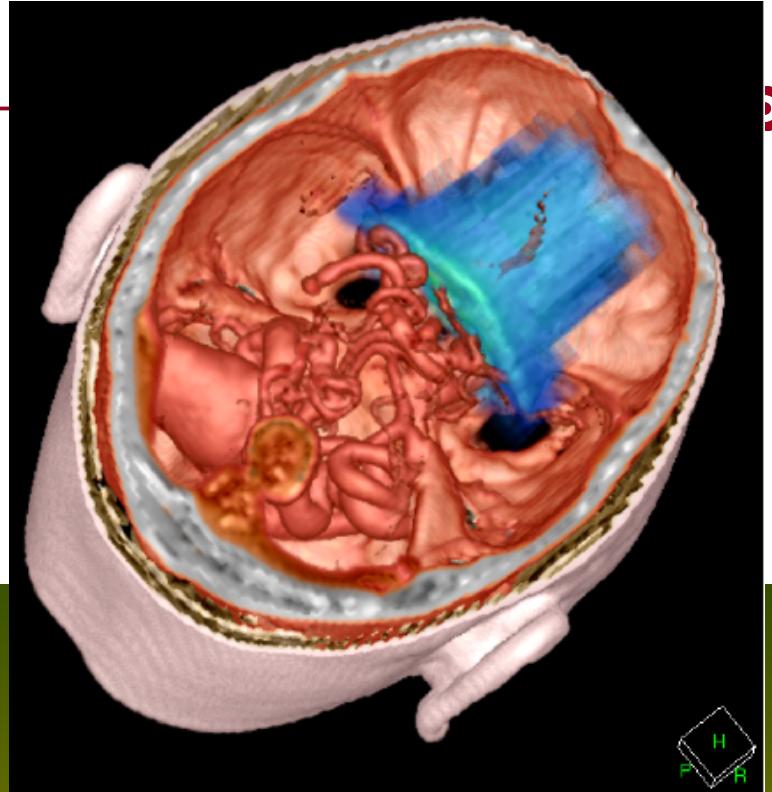
Ratio (simulation/experiment)



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

Geant4 @ Medical Science

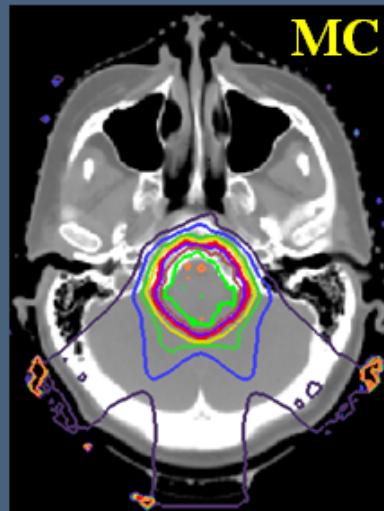
- Four major use cases
 - Beam therapy
 - Brachytherapy
 - Imaging
 - Irradiation study



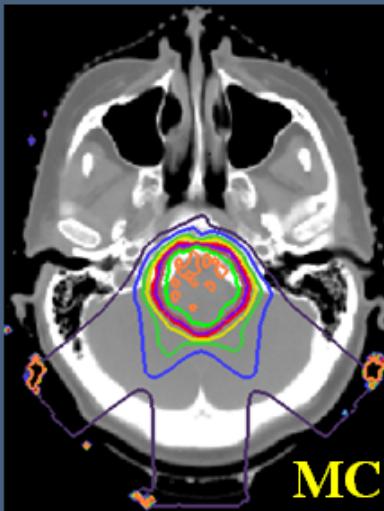
Patient simulation



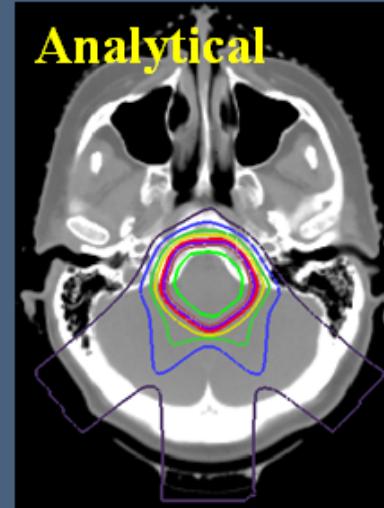
- [purple] 10 Gy
- [blue] 20 Gy
- [green] 30 Gy
- [yellow] 35 Gy
- [red] 40 Gy
- [purple] 42 Gy
- [brown] 44 Gy
- [green] 46 Gy
- [orange] 48 Gy



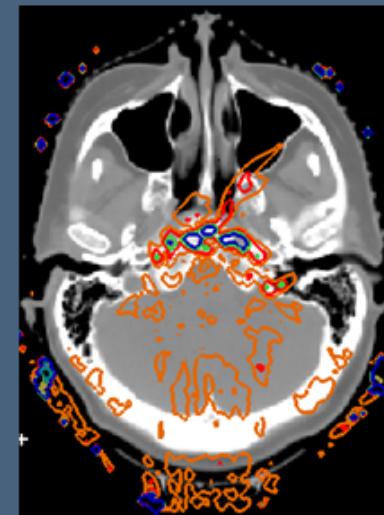
MC:Dose-to-tissue



MC:Dose-to-water

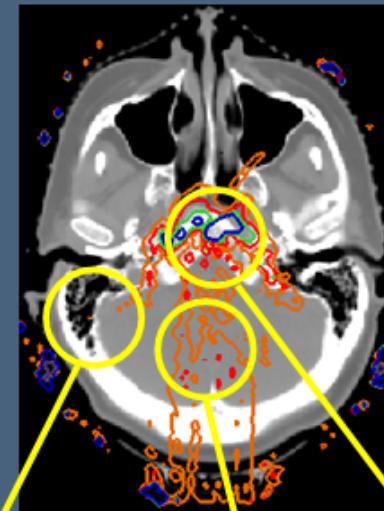


Analytical



Differences

- [yellow] 1 Gy
- [red] 2 Gy
- [green] 3 Gy
- [blue] 4 Gy



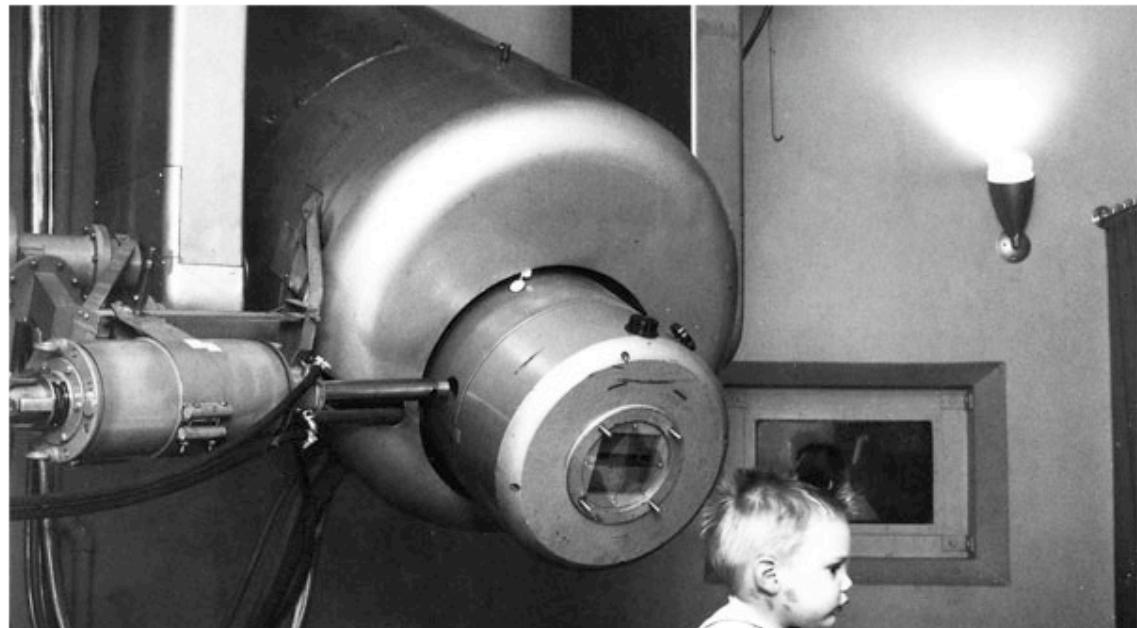
Penumbra

Range

Dose homogeneity

Connection between HEP and Medical Physics has long history, especially at Stanford.

- First medical linac outside of Europe
- 50th anniversary of first treatment
- <http://news-service.stanford.edu>
- ...



Modes of Beam Therapy

- X-Ray (from brems of electrons on high Z target) ~ 4 - 25 MeV
- Electrons (for skin or small depth, special cases of whole body irradiation, and also IORT) ~ 4 - 25 MeV
- Protons, Ions (from cyclotron) ~160 MeV



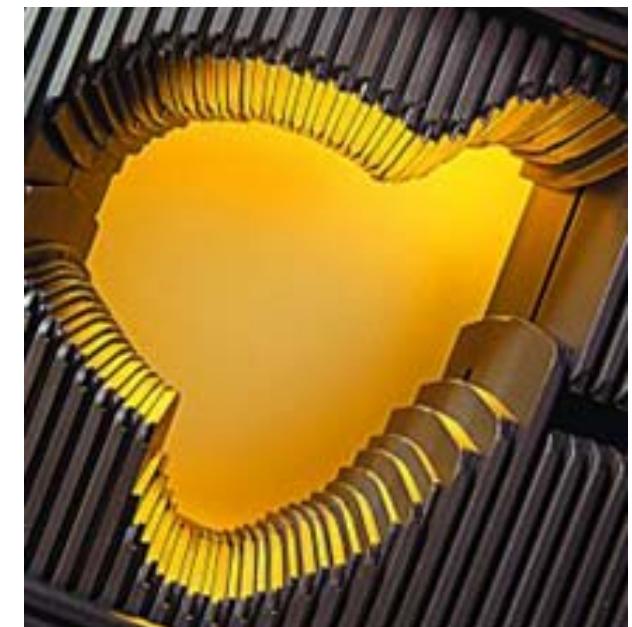
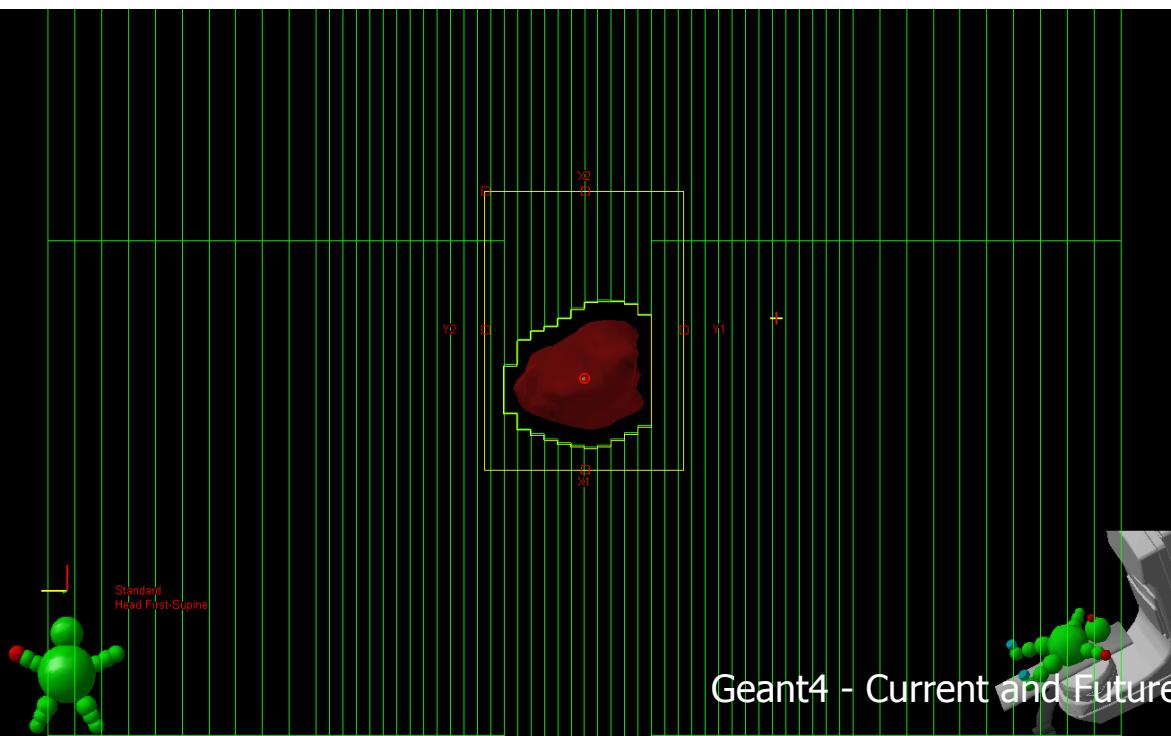
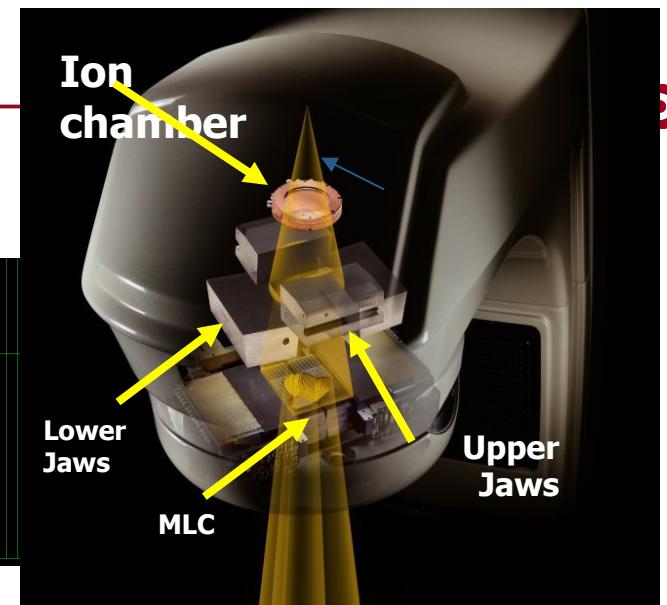
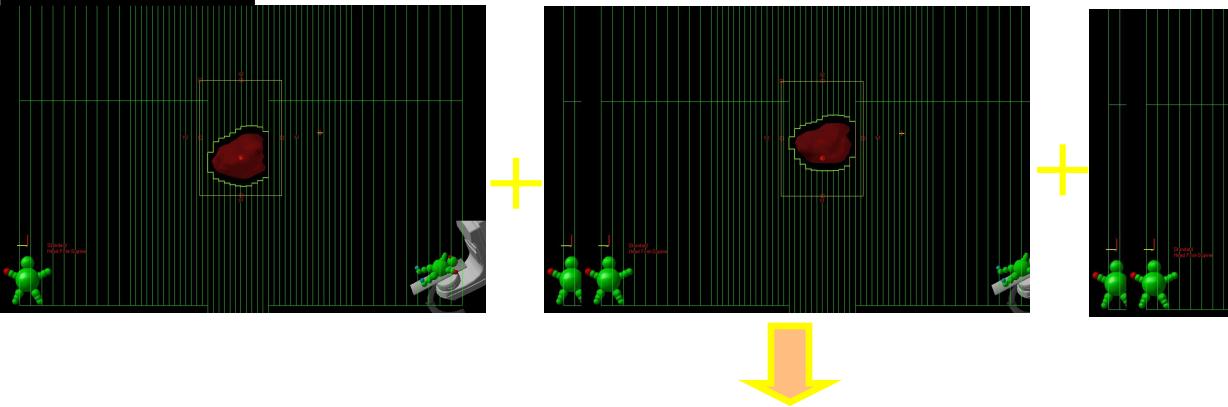
The first patient to receive radiation therapy from the medical linear accelerator at Stanford was a 2-year-old boy.

Stanford University Dept
of Radiation Oncology



4D RT Treatment Plan

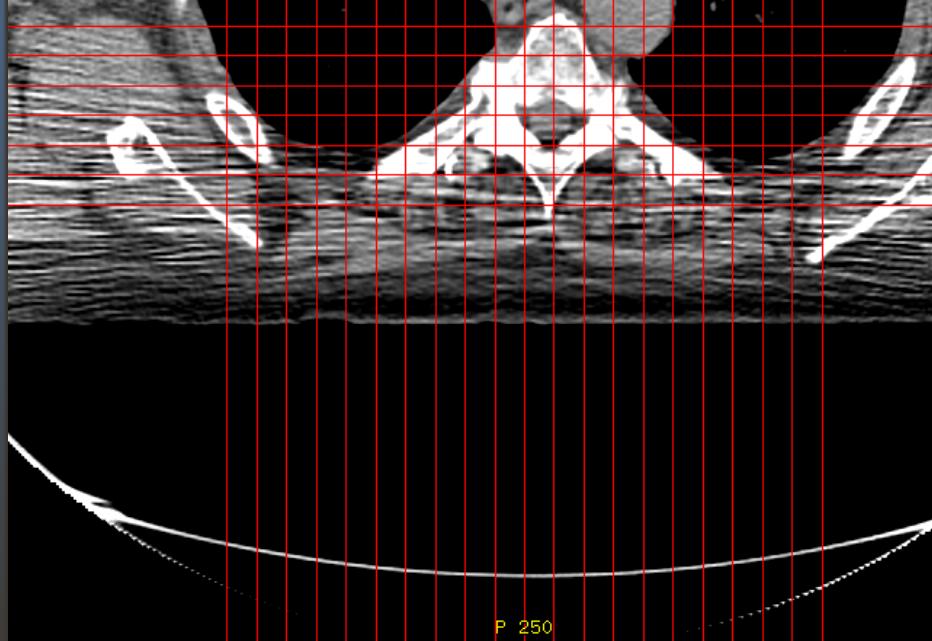
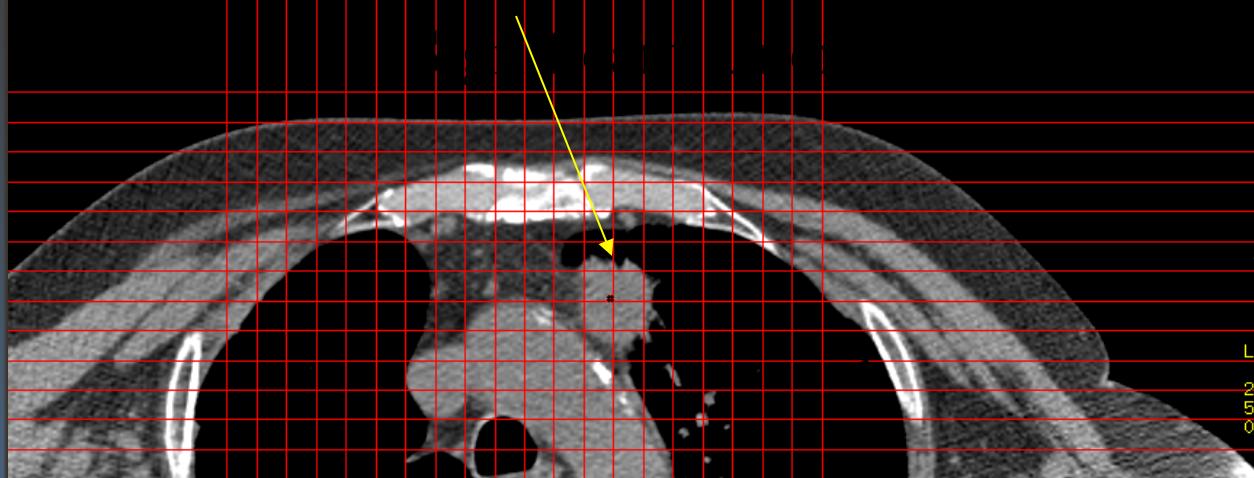
source: Lei Xing, Stanford University



Geant4 - Current and Future

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

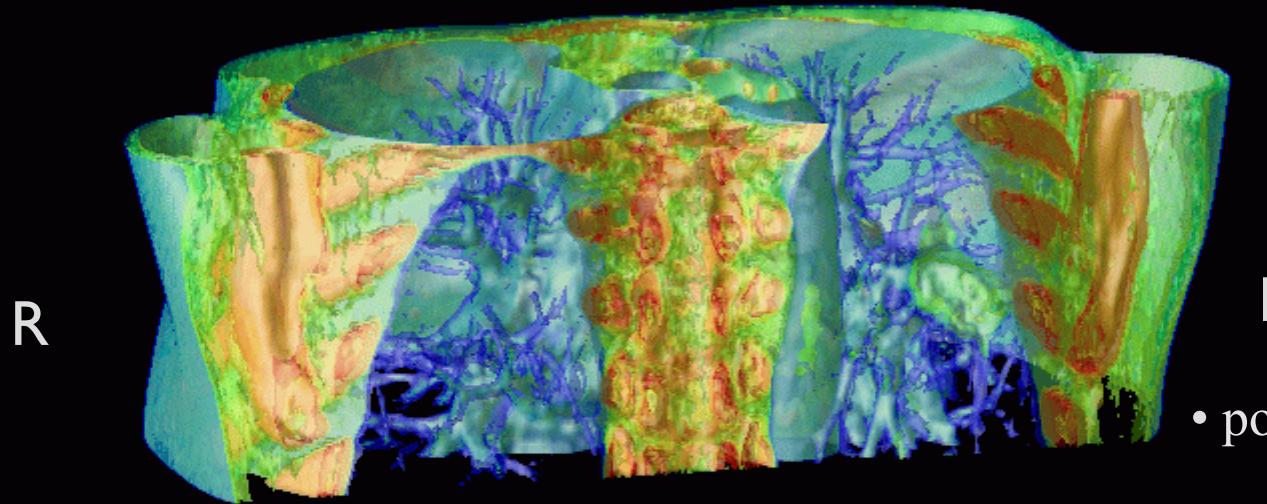
Lateral Motion of Lung Tumor



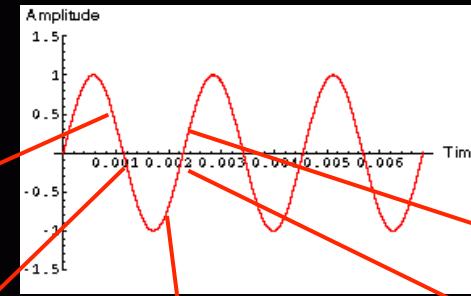


- Breathing Patient -

© Eike Rietzel



- posterior view
- posterior cut





Tool for Particle Simulation

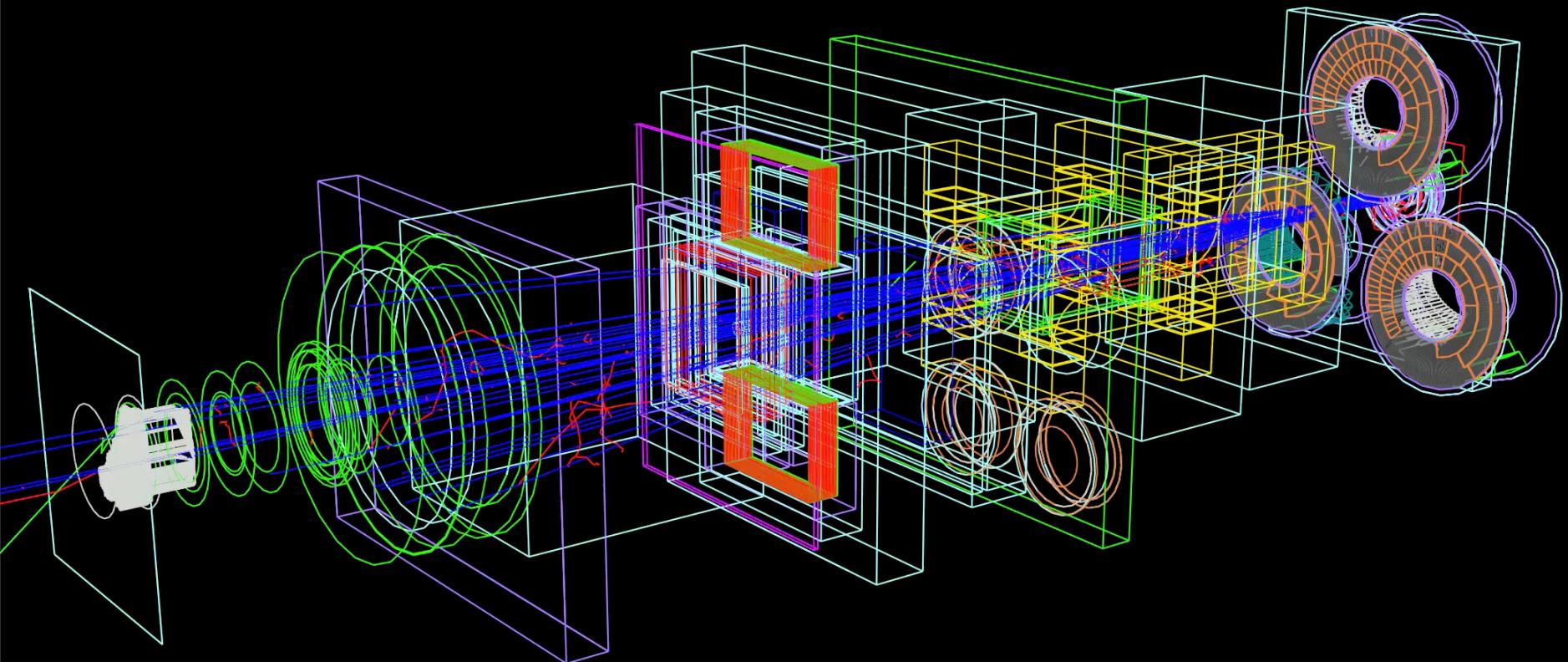
Joseph Perl - SLAC National Accelerator Laboratory

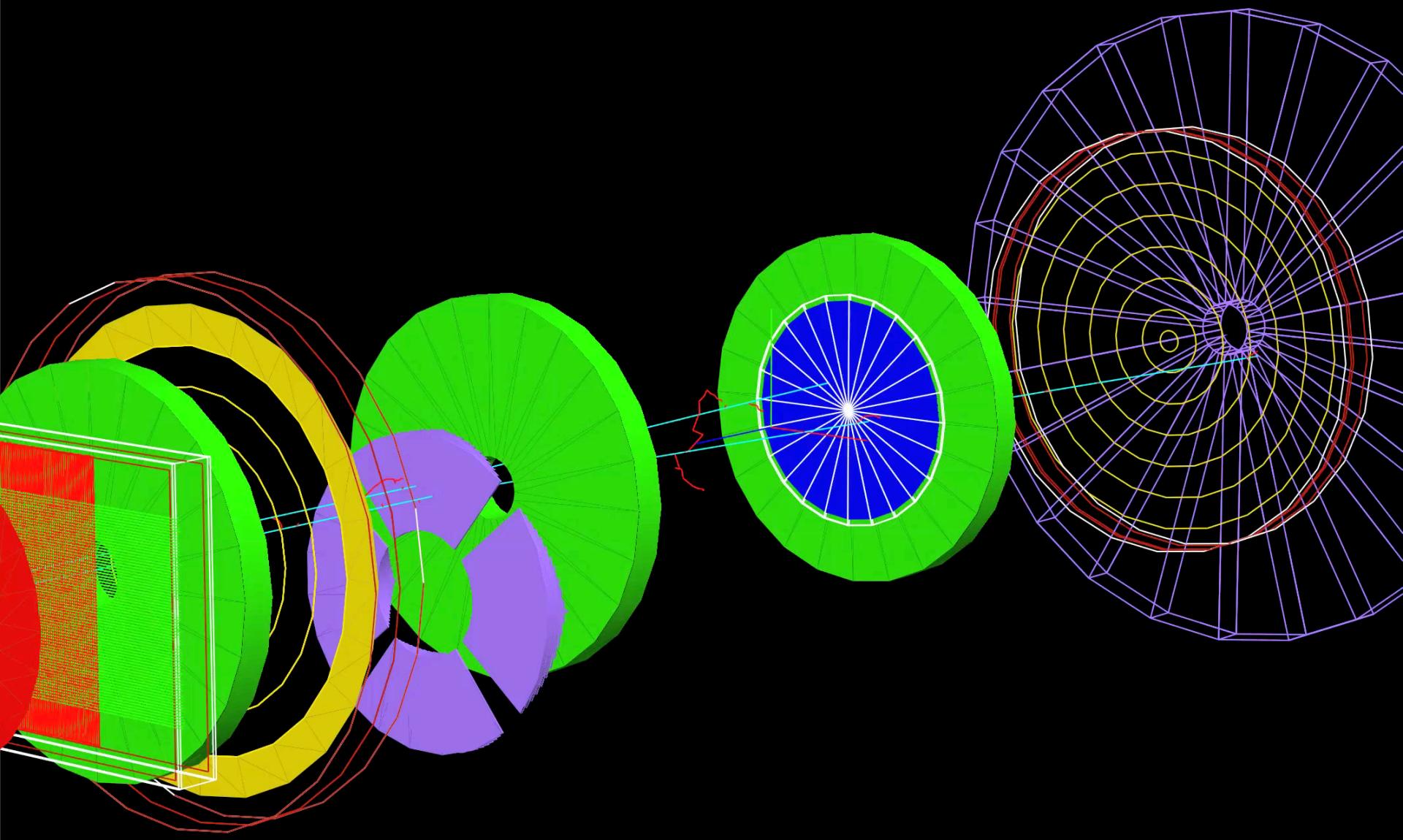
Bruce Faddegon, José Ramos - University of California San Francisco

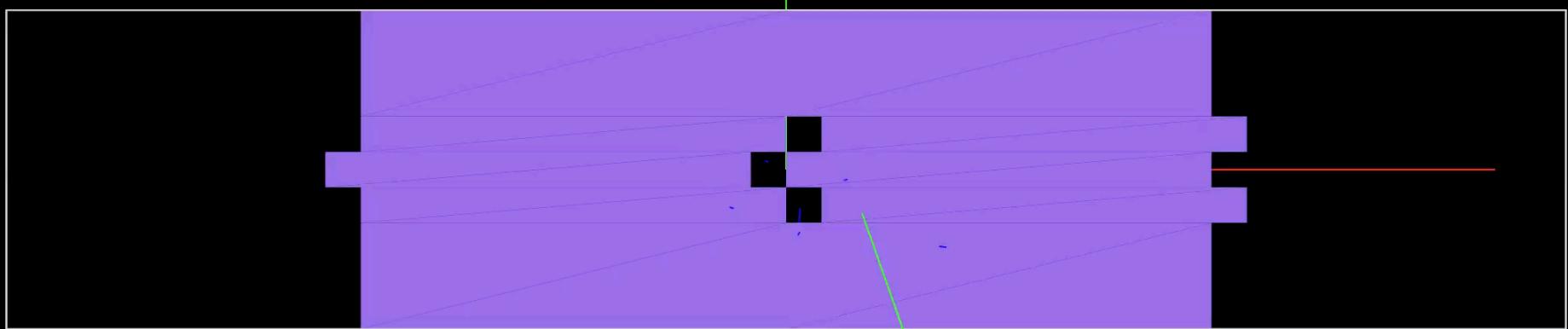
Jungwook Shin – St Jude Children's Research Hospital

Harald Paganetti, Jan Schümann - Massachusetts General Hospital

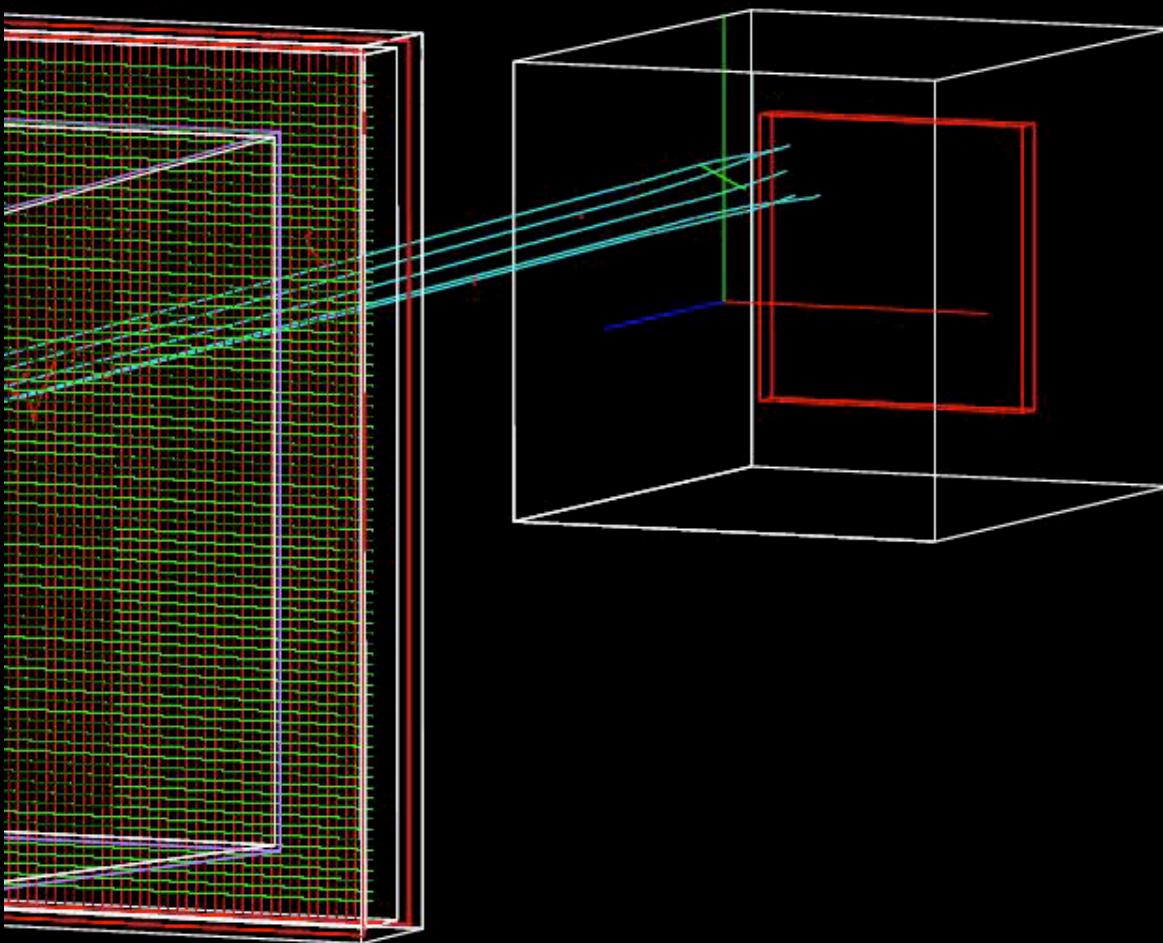




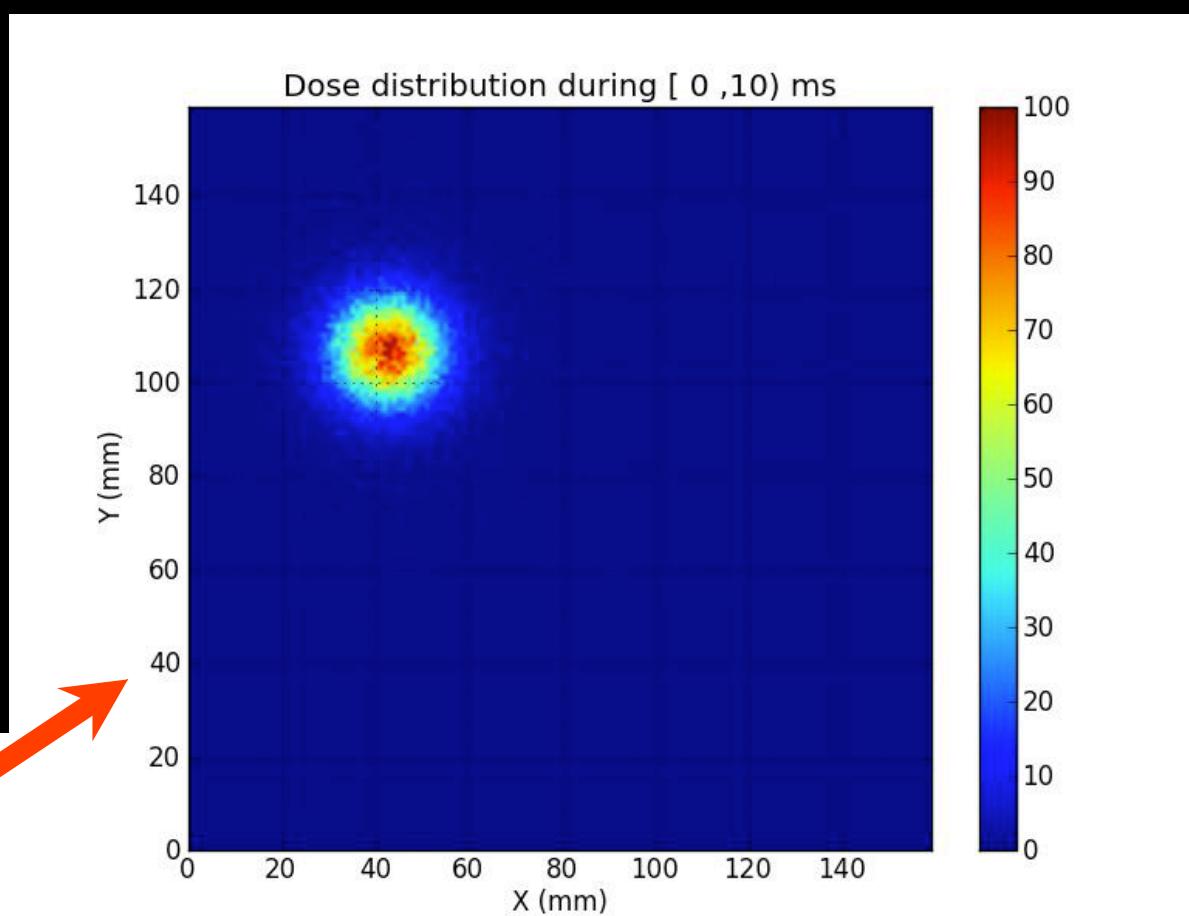
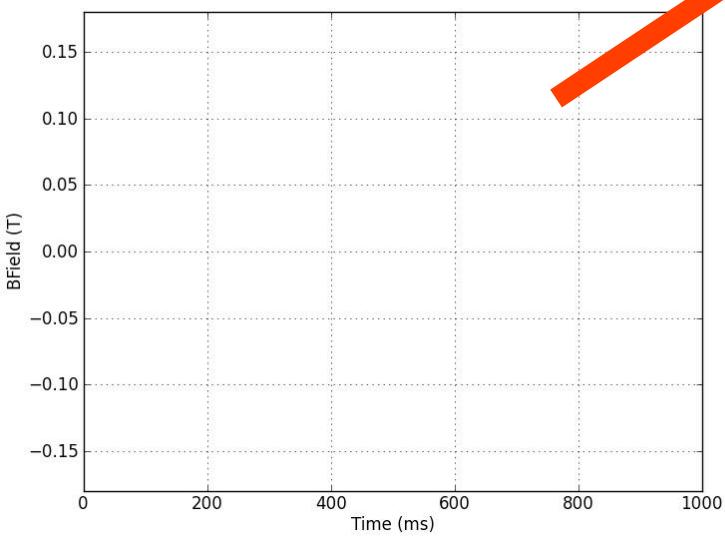




Raster Scanning

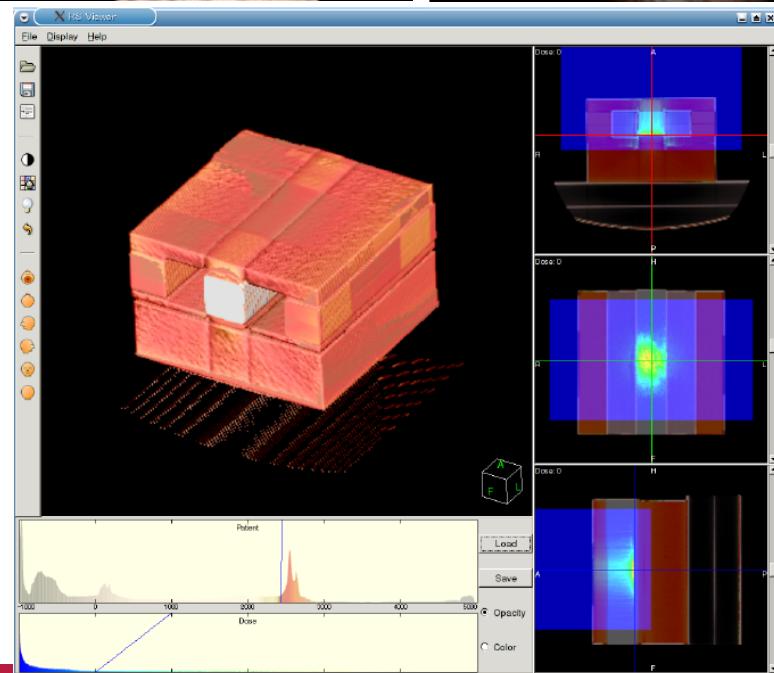
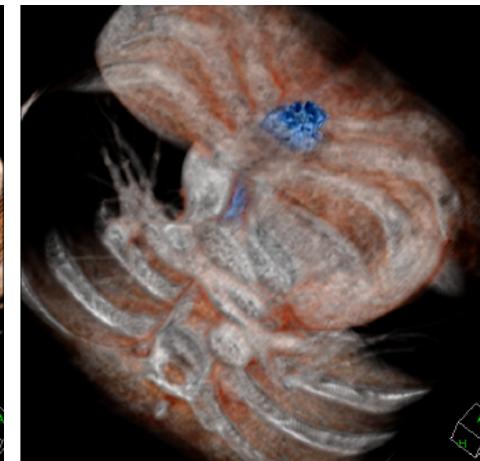
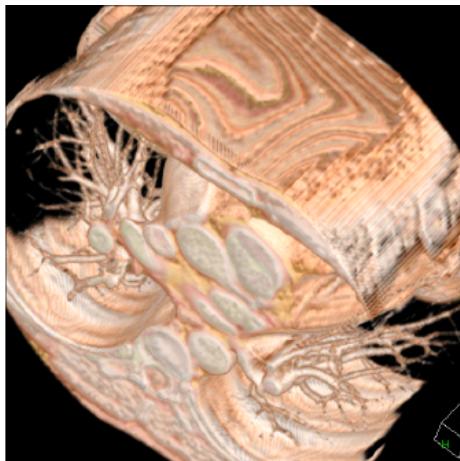
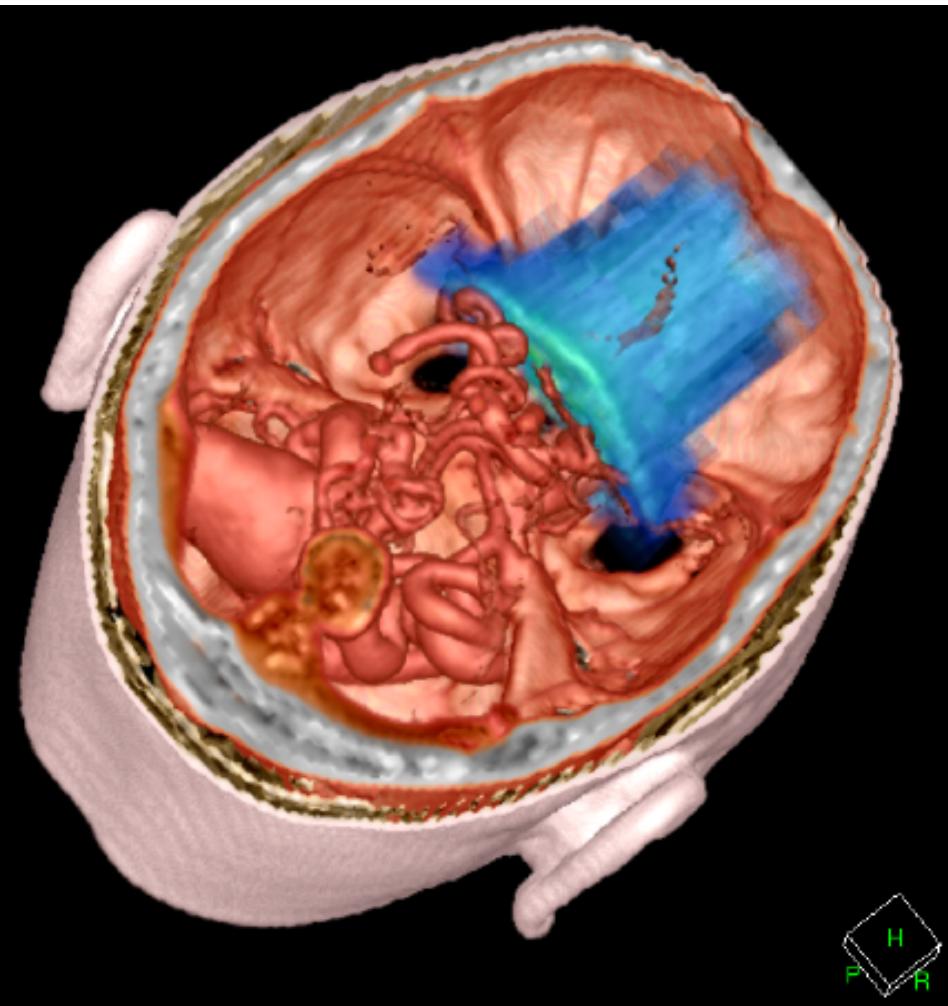


Raster Scanning



Screen shots of gMocren

SLAC



T. Sasaki, et. al. (KEK, JST/CREST)

SLAC

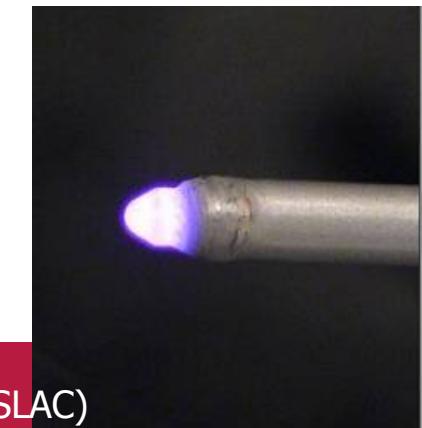
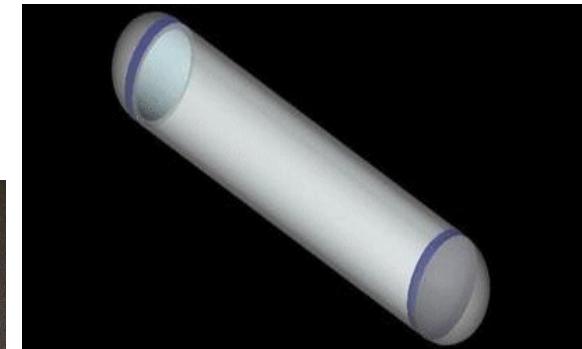
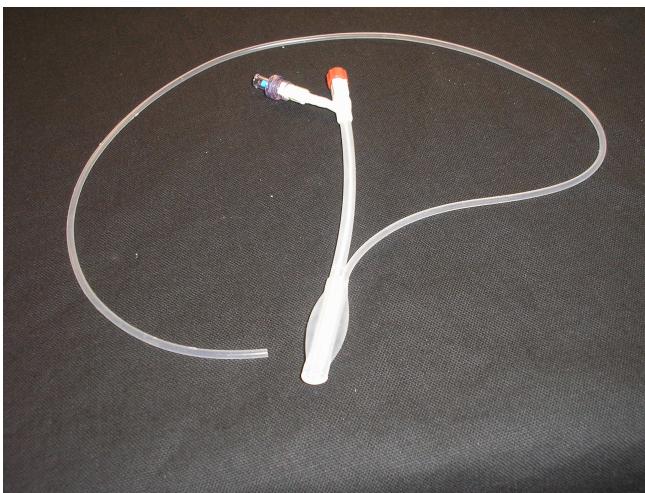
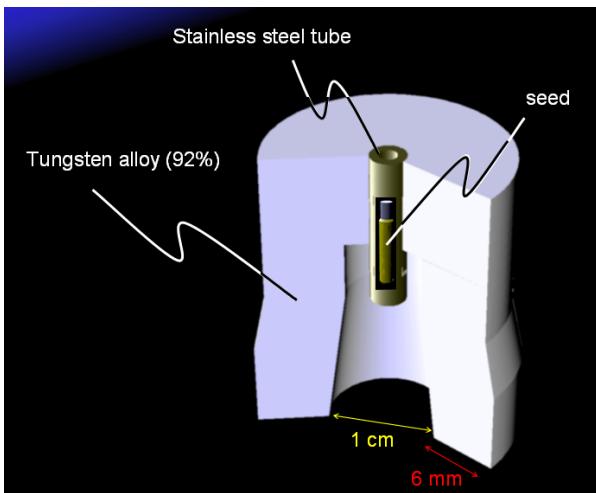
Geant4 - Current and Future - M.Asai (SLAC)

“Brachy” - from the Greek for “Short”, referring to short distance therapy

- Gamma and Beta emitters

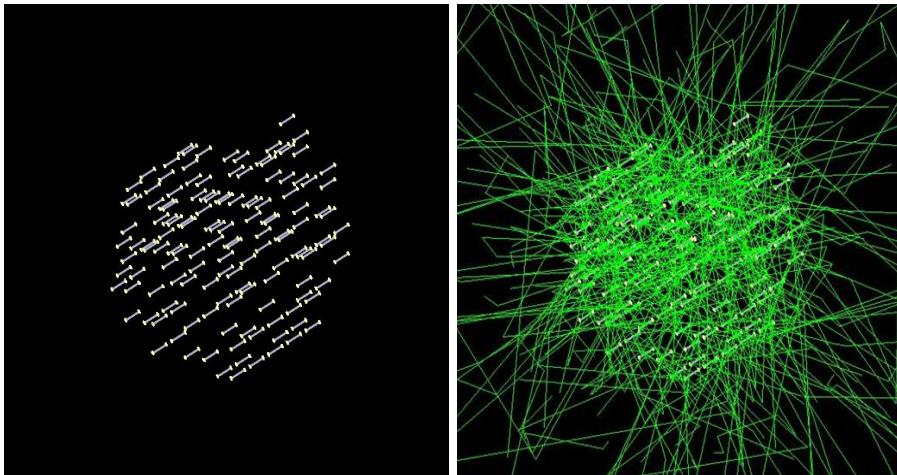
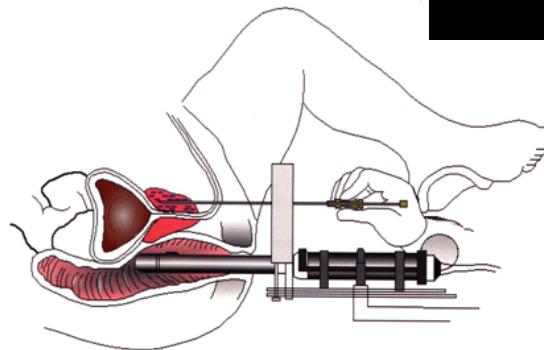
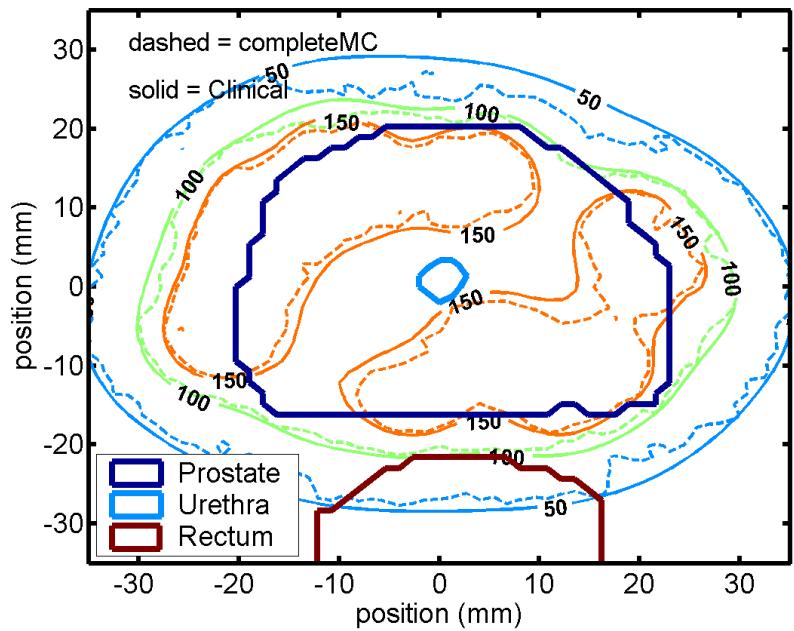
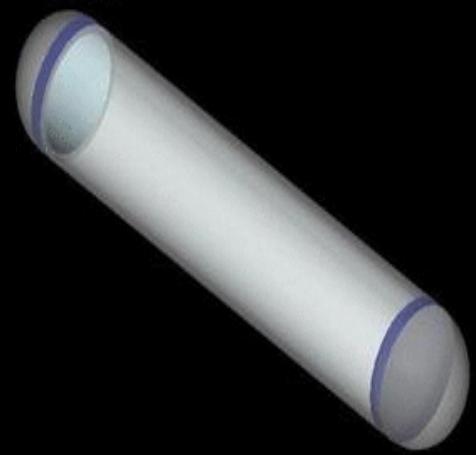
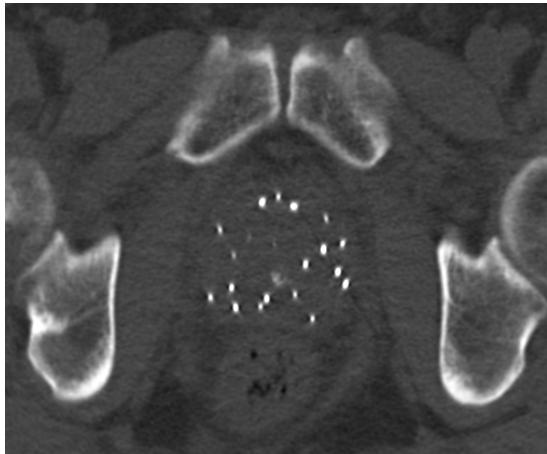
Modes of Brachytherapy:

- Outside of body, placed close to the skin (for superficial tumors)
- Temporarily inserted into the body (typically through catheters)
- Permanently implanted (“seeds”)
- Electronic Brachytherapy



Prostate brachytherapy

Jean-François Carrier, CHUM

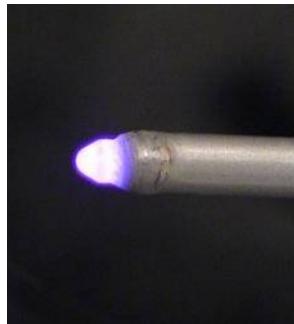


Axxent Miniature X-ray Tube

SLAC

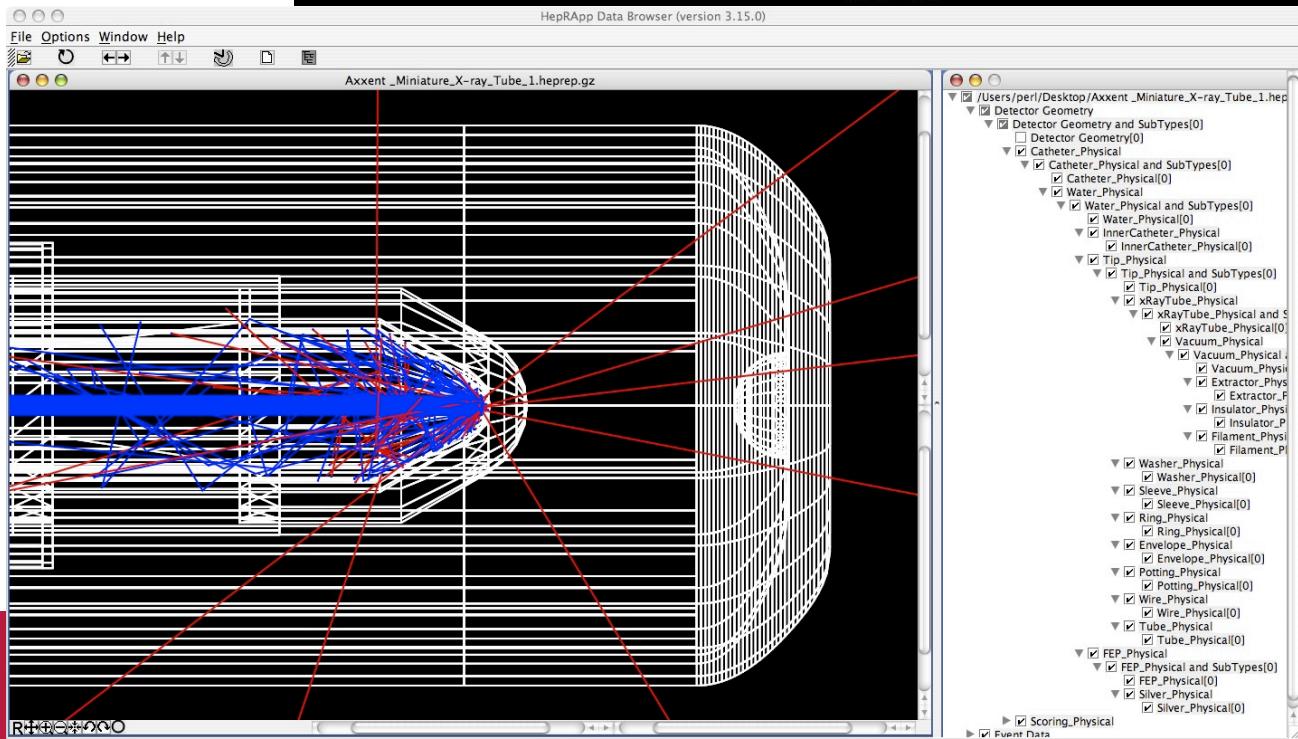
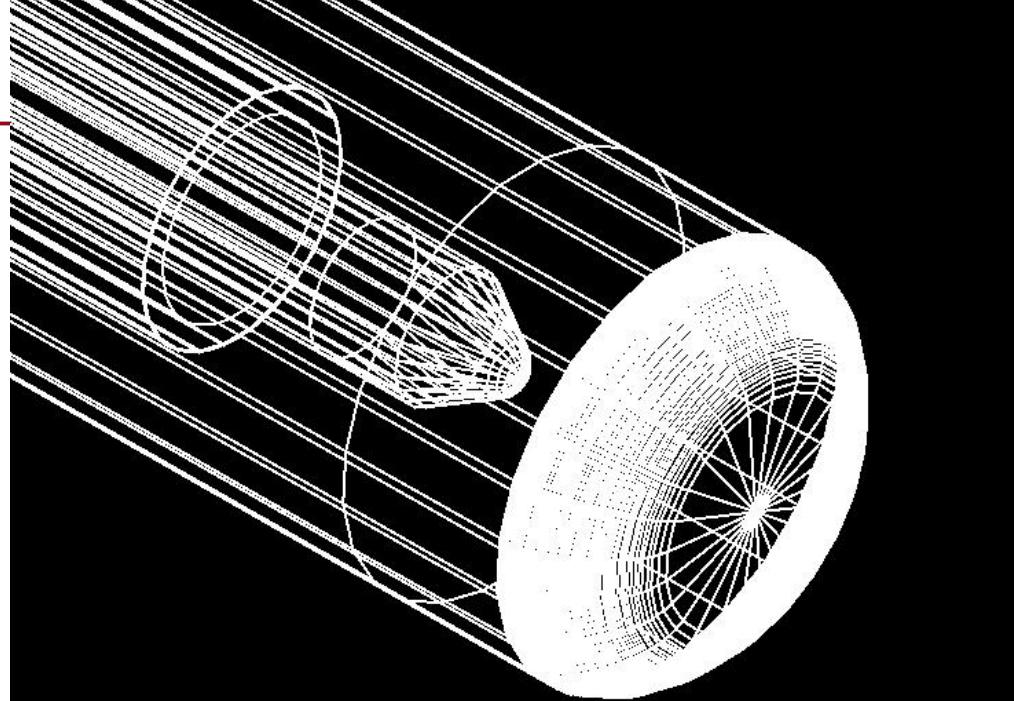


Derek Liu, et. al.
McGill University



Axxent Miniature X-ray Tube

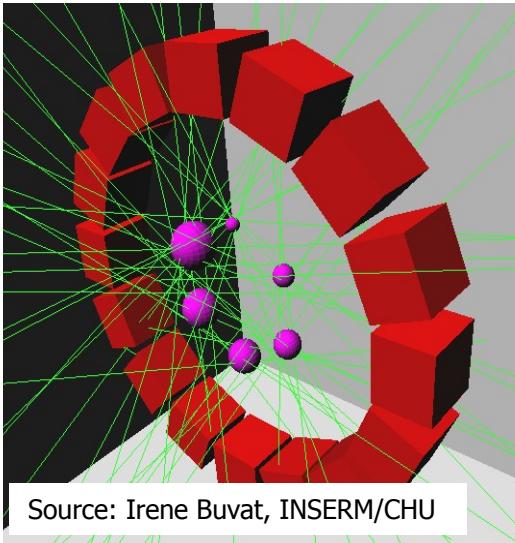
- Geometry
 - Tip thickness 0.2 mm
 - Transmission Tungsten target thickness 0.7 um
 - 2 mm water
 - Why use Geant?
 - Complex geometry
 - Low energy physics
 - C++
 - Coding flexibility



Derek Liu, et. al.
McGill University

GATE: Geant4 Application for Tomography Emission

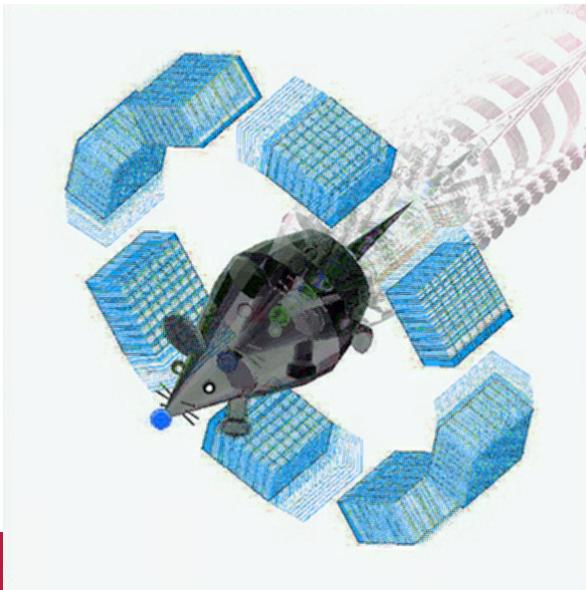
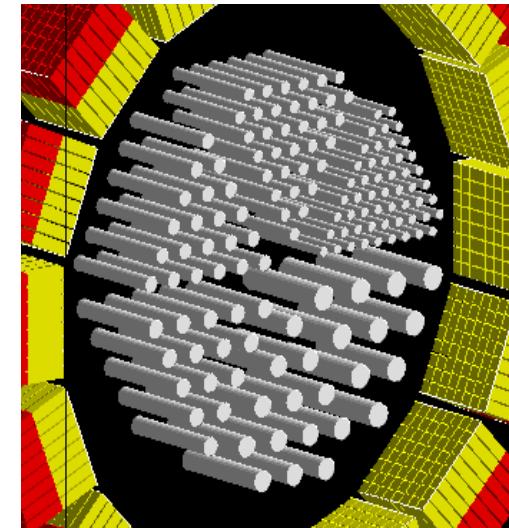
SLAC



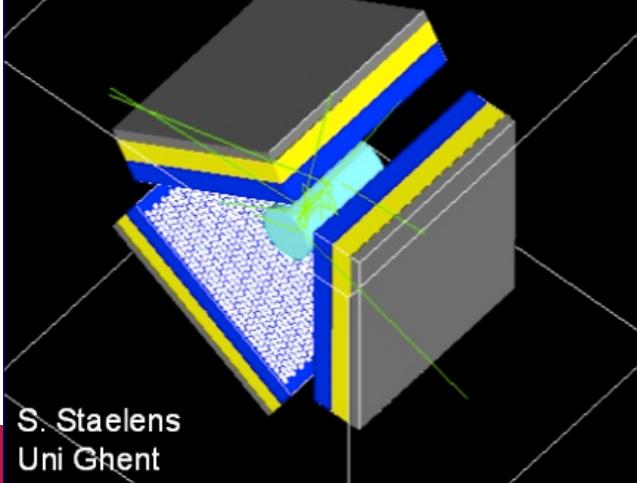
Toolkit for Imaging applications

- based on the Geant4 toolkit
- easier to use for Imaging applications
- More than 400 subscribers to gate user mailing list

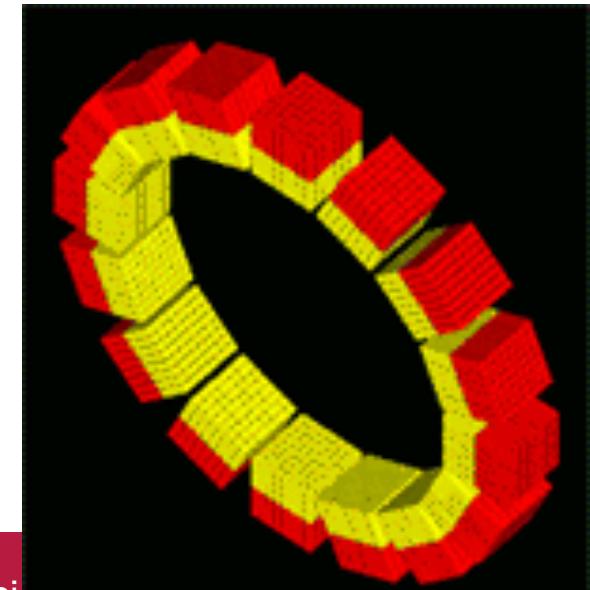
<http://www.opengatecollaboration.org>



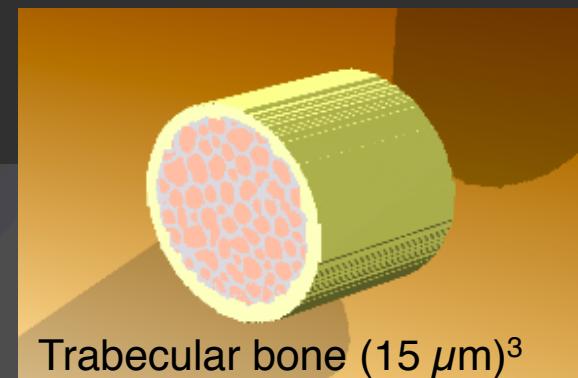
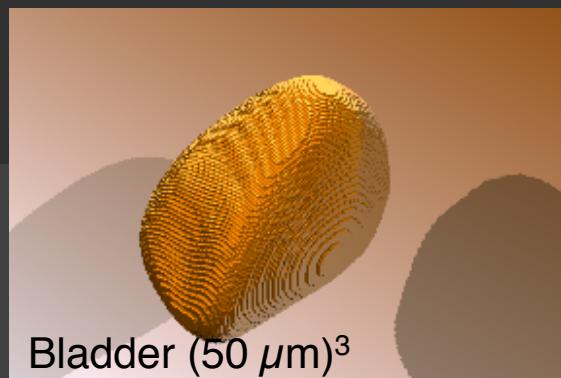
Triple-head gamma camera



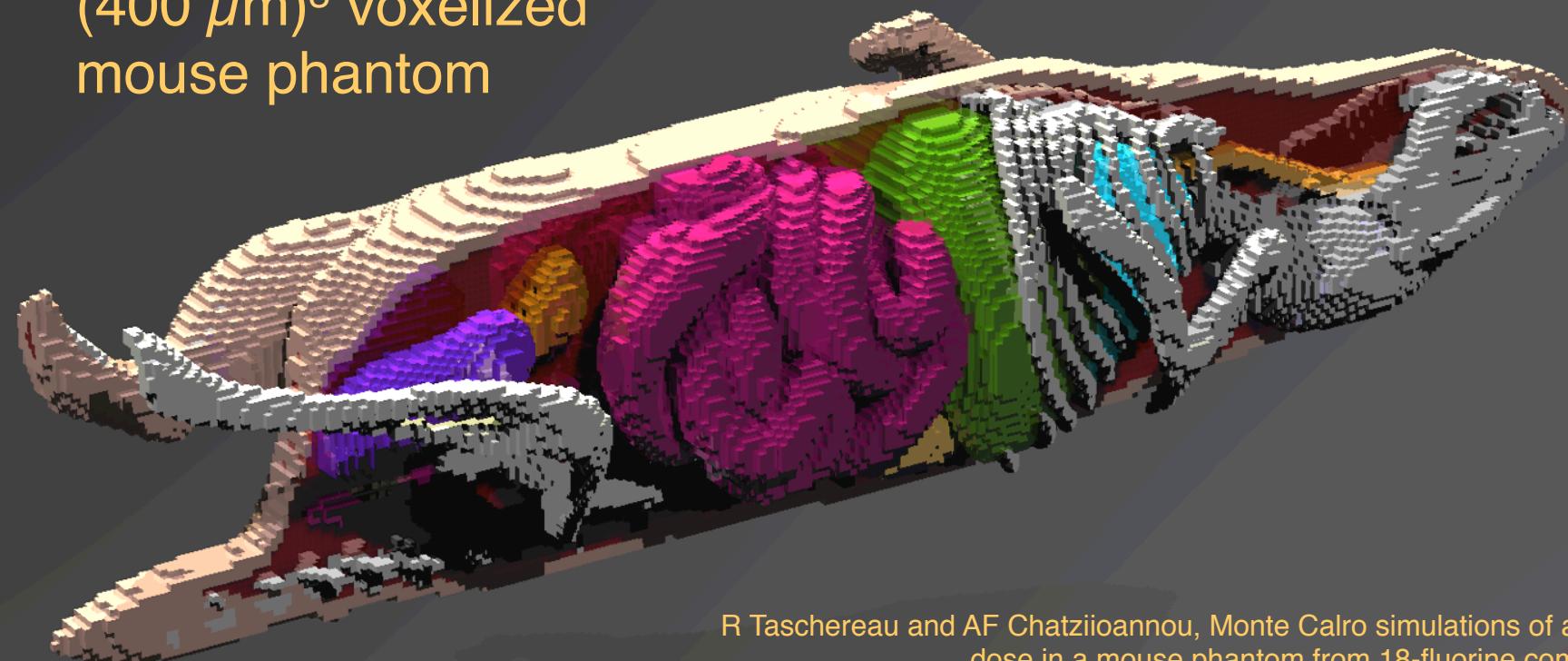
S. Staelens
Uni Ghent



High resolution phantoms



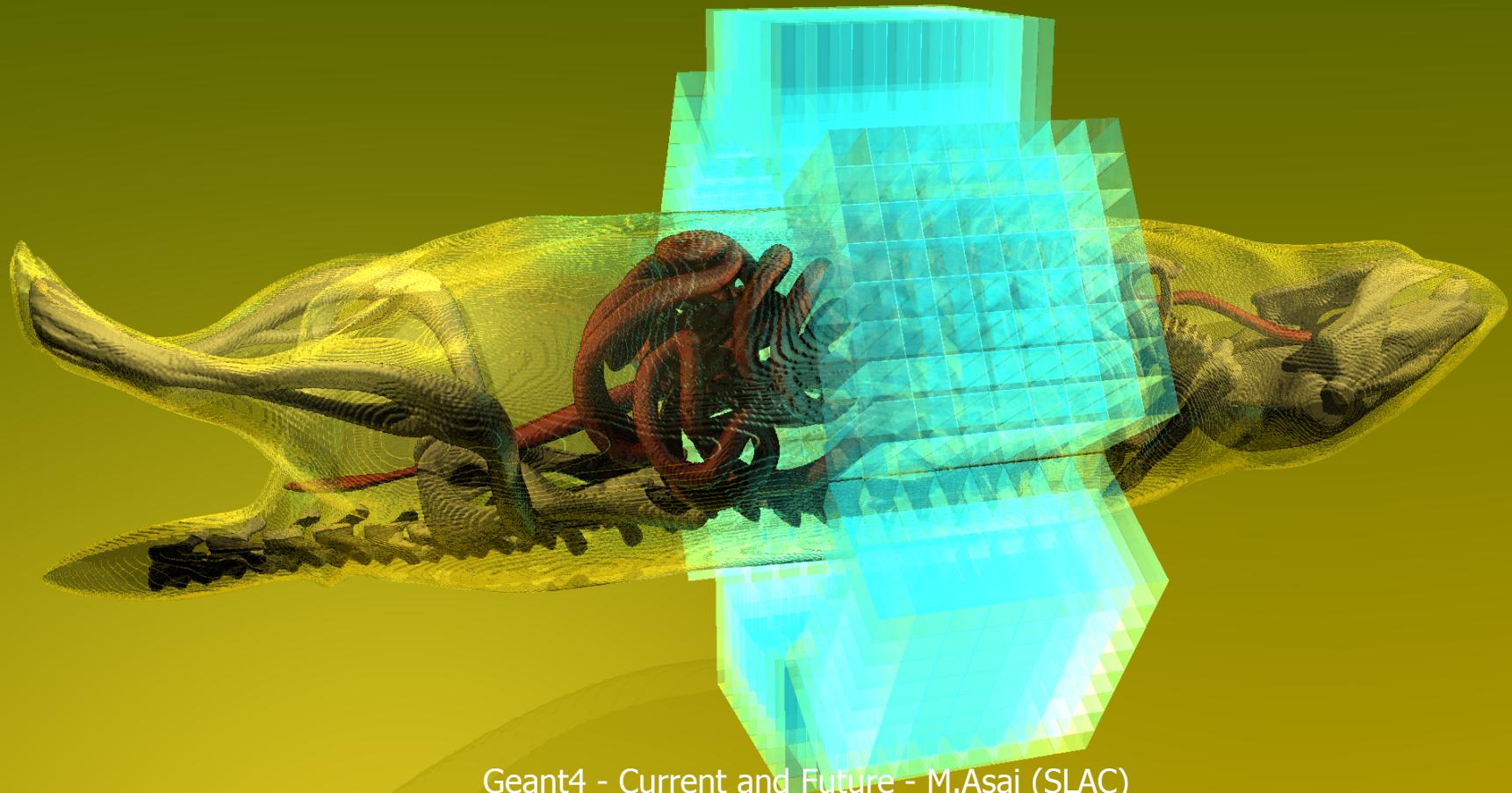
(400 μm)³ voxelized
mouse phantom



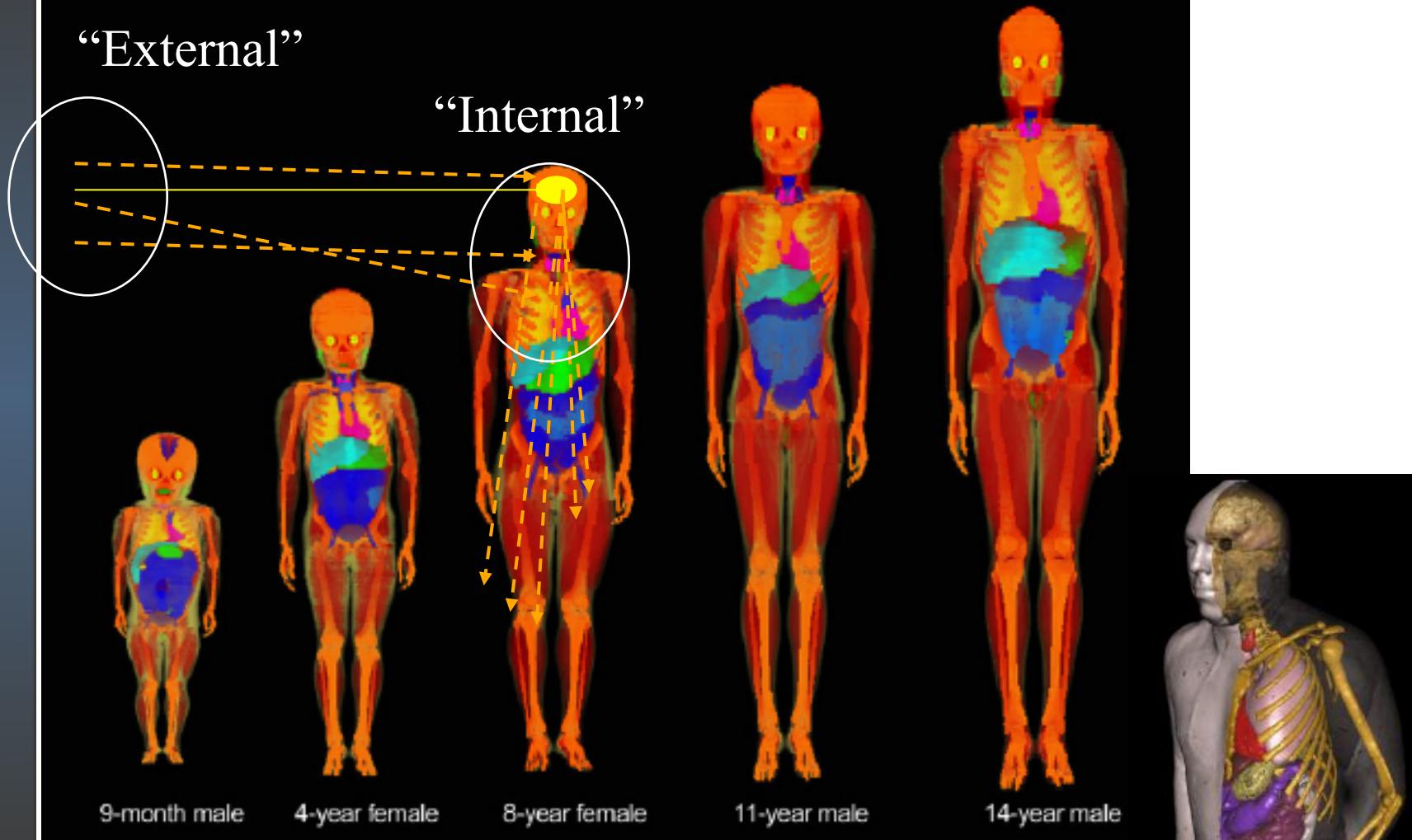
R Taschereau and AF Chatzioannou, Monte Carlo simulations of absorbed dose in a mouse phantom from 18-fluorine compounds, Medical Physics, 34(3), 1026-36 (2007)

Mouse phantom in OPET scintillator crystal array

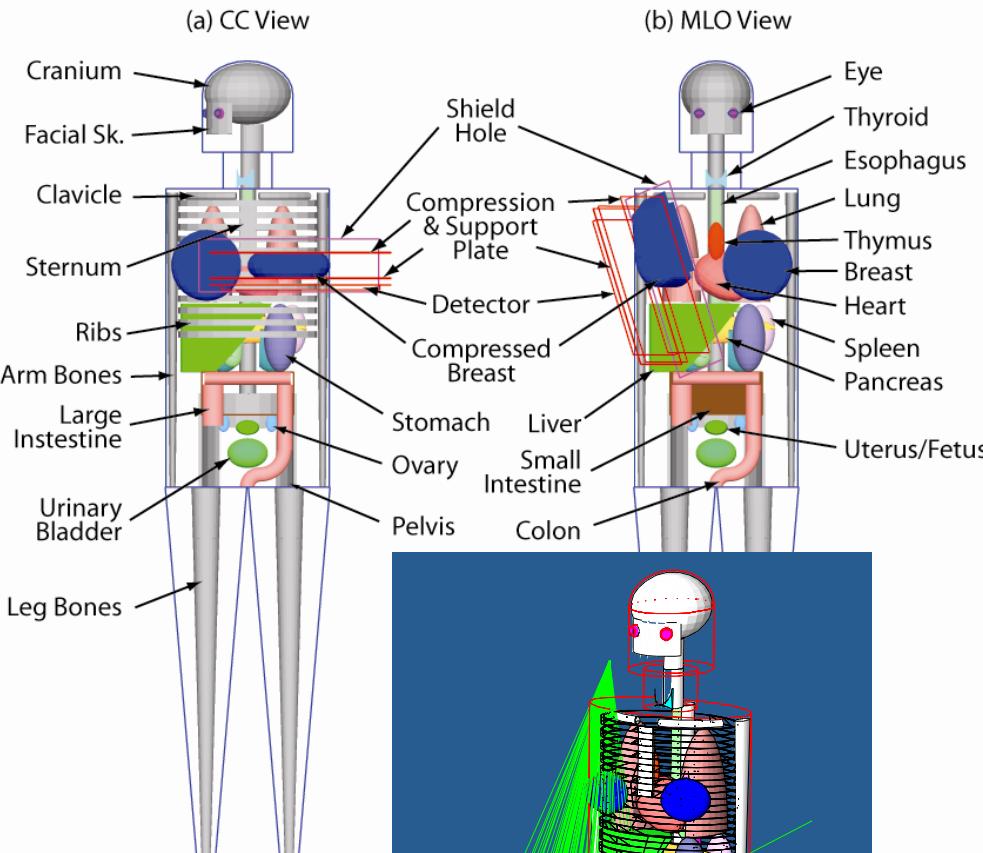
A Douraghy, F Rannou, G Alexandrakis, RW Silverman and AF Chatzioannou,
FPGA Electronics for OPET: A dual-modality optical & PET imaging
tomography, AMI-SMI conference, Providence RI, 2007



The risk associated with neutron radiation in proton therapy



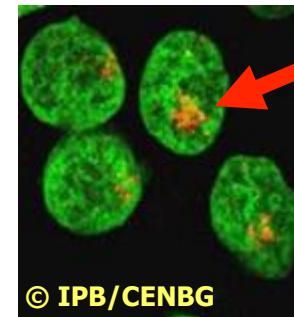
Phantoms implemented into the Geant4 Monte Carlo dose calculation environment at Mass. Gen. Hosp.



- First comprehensive scientific study of radiation dose to different organs from x-ray scatter during mammography and breast CT.
- Simulation includes a modified version of ORNL anthropomorphic phantom.
 - 66 different tissue volumes.
- ICRU and ICRP tissue chemical composition.
- Various mammographic and breast CT x-ray spectra analyzed.

AIFIRA irradiation facility in Bordeaux, France

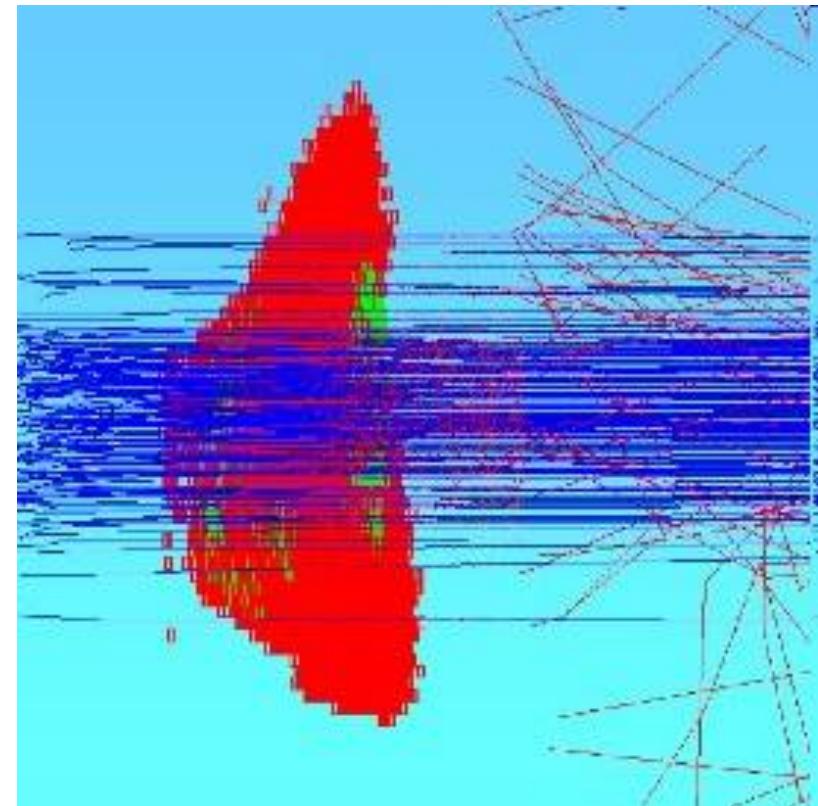
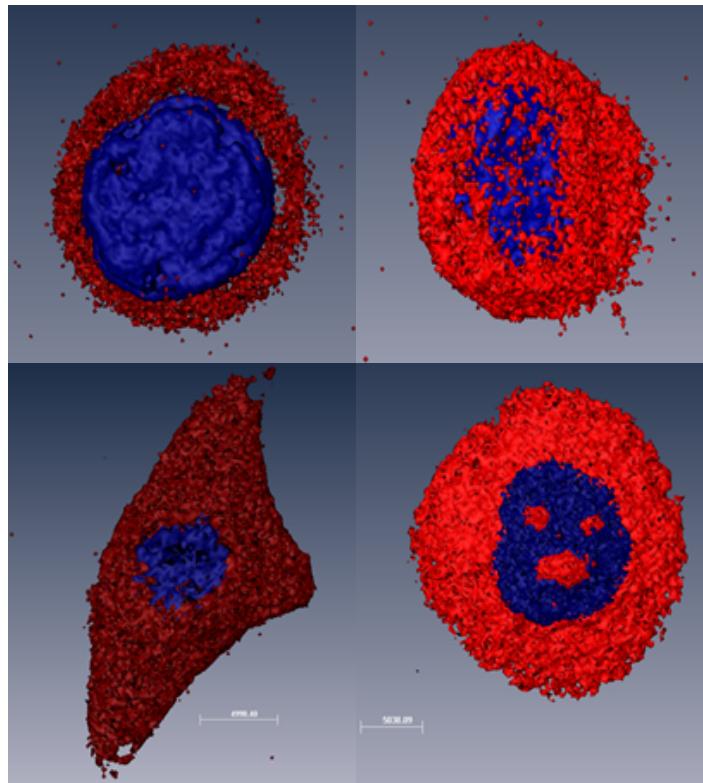
- AIFIRA equipped with a cellular irradiation microbeam line
- 3 MeV proton or alpha beam
- **single cell & single ion mode**
- Targeting accuracy on living cells **in air** : a few μm
- Able to quantify DNA damages like double strand breaks



Courtesy of Sébastien Incerti (IN2P3-CNRS / CENBG)

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
 - $0.36 \times 0.36 \times 0.16 \mu\text{m}^3$ voxel size
- Full CENBG microbeam irradiation setup simulated

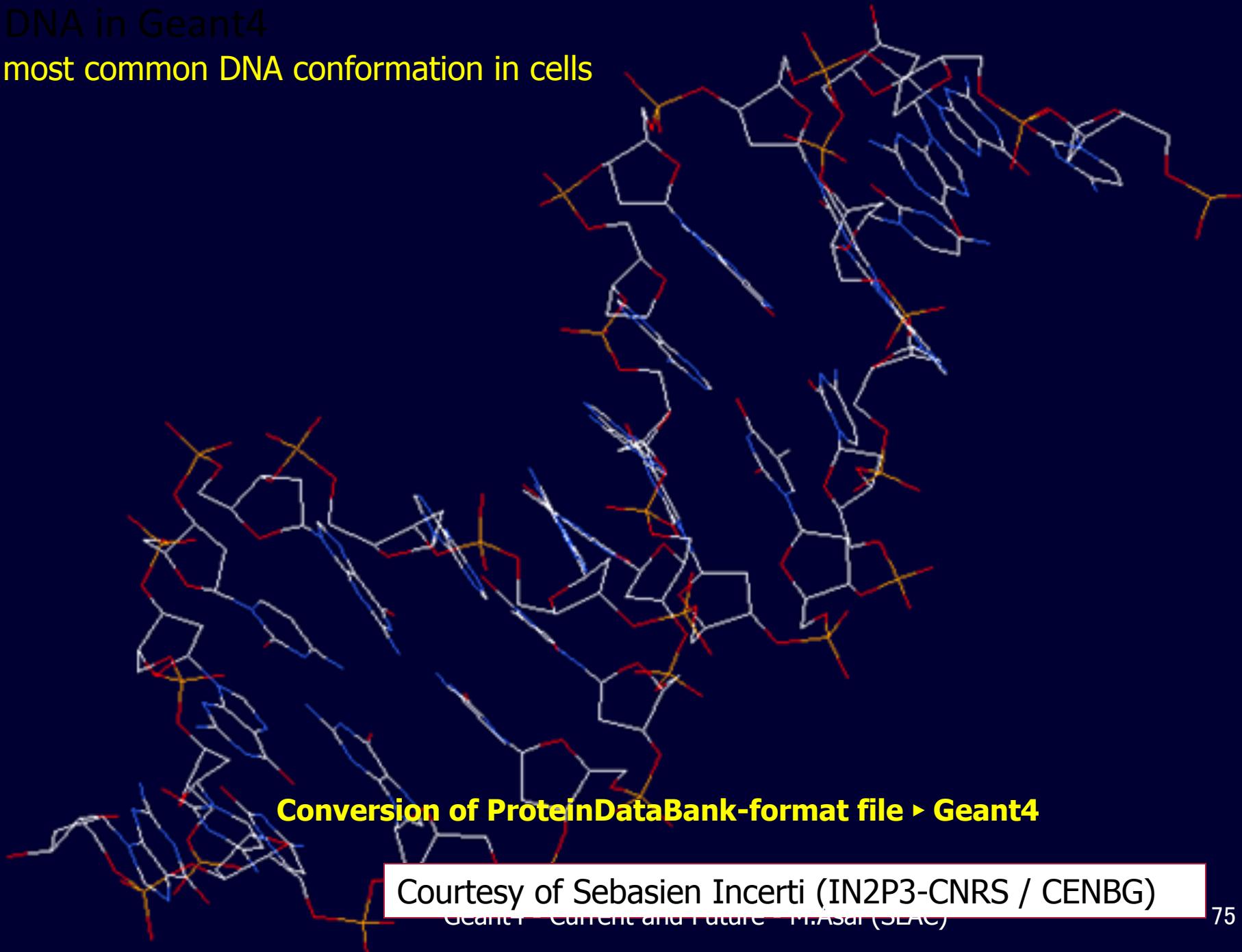


Courtesy of Sébastien Incerti (IN2P3-CNRS / CENBG)

Giant P - Current and Future - M. Asai (SLAC)

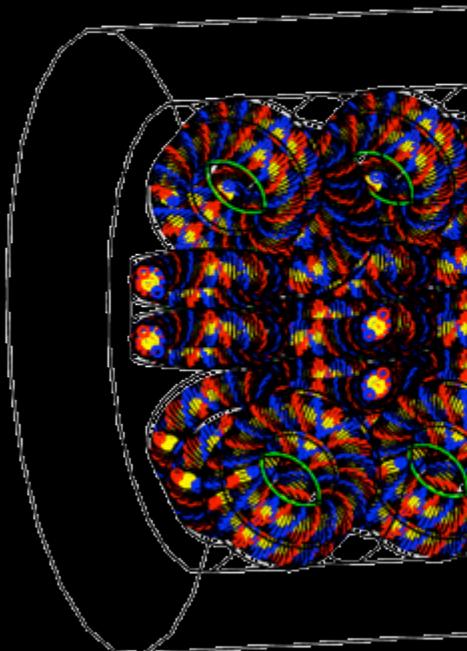
DNA in Geant4

most common DNA conformation in cells



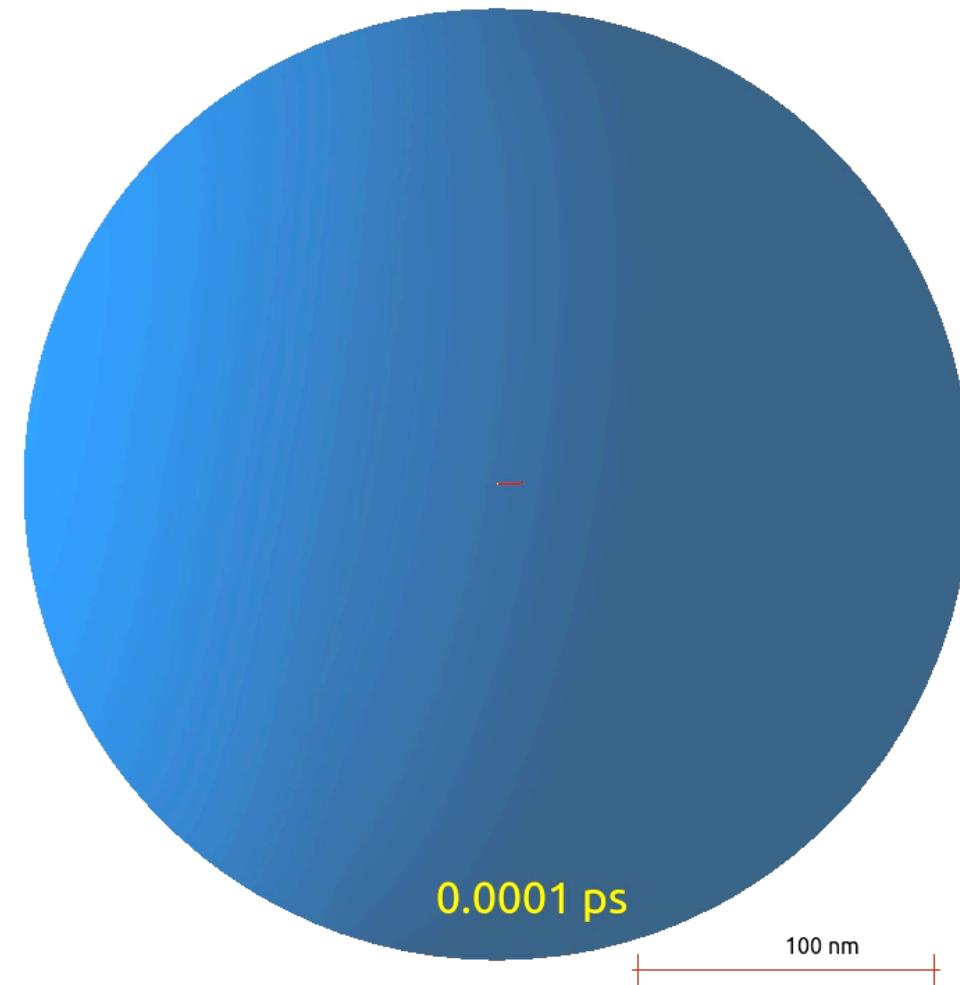
Physics phase: primary radiation interacting with matter (DNA) and producing radicals

Chemistry phase: Brownian motion of radicals (further cell level damage) and interactions between radicals



Chromatine fib
(constituent of chrom

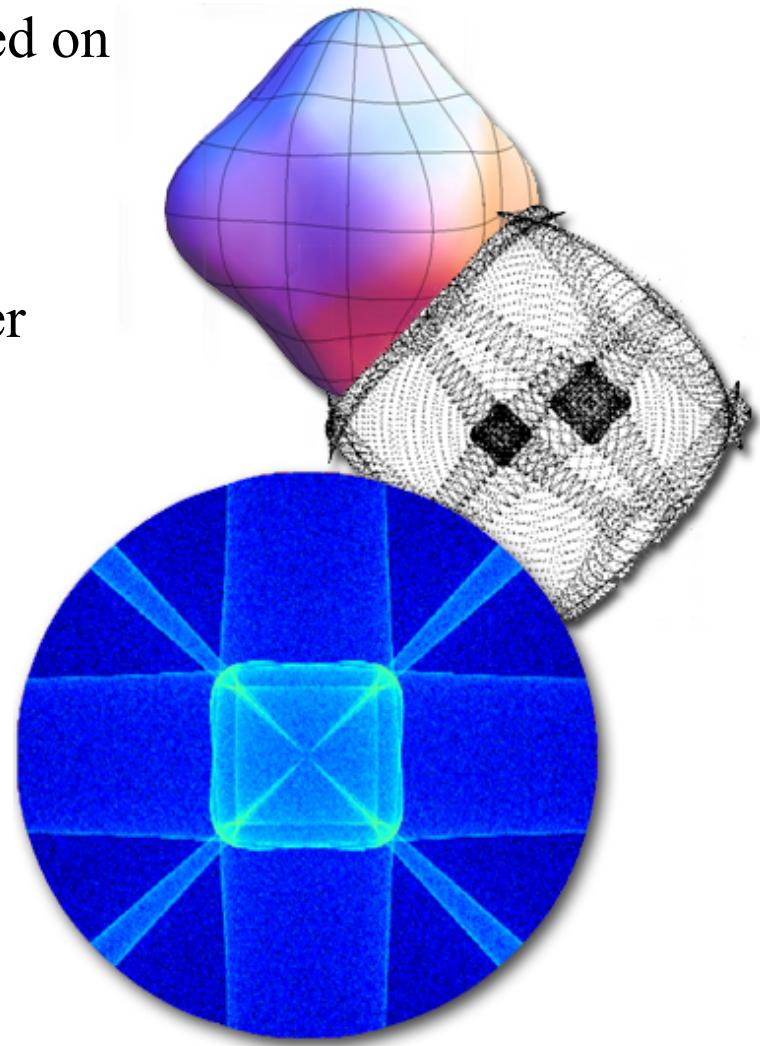
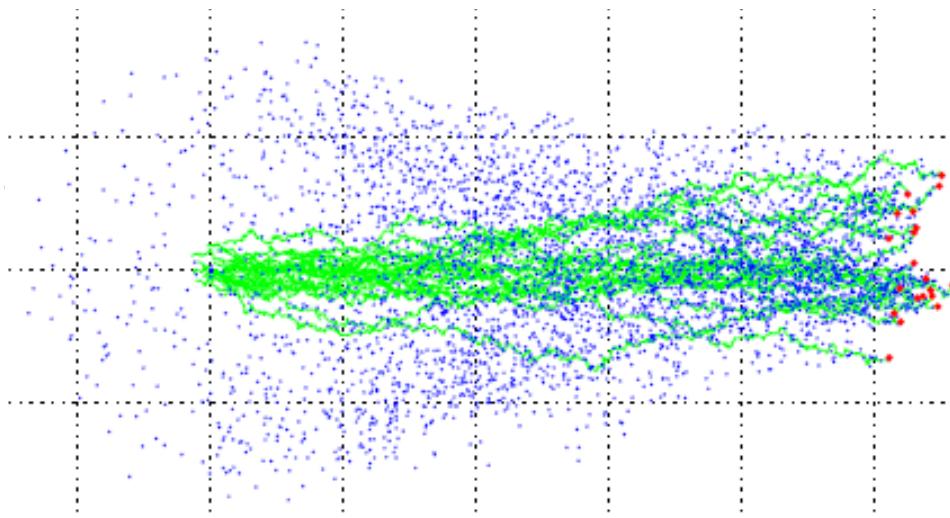
Courtesy of Sébastien



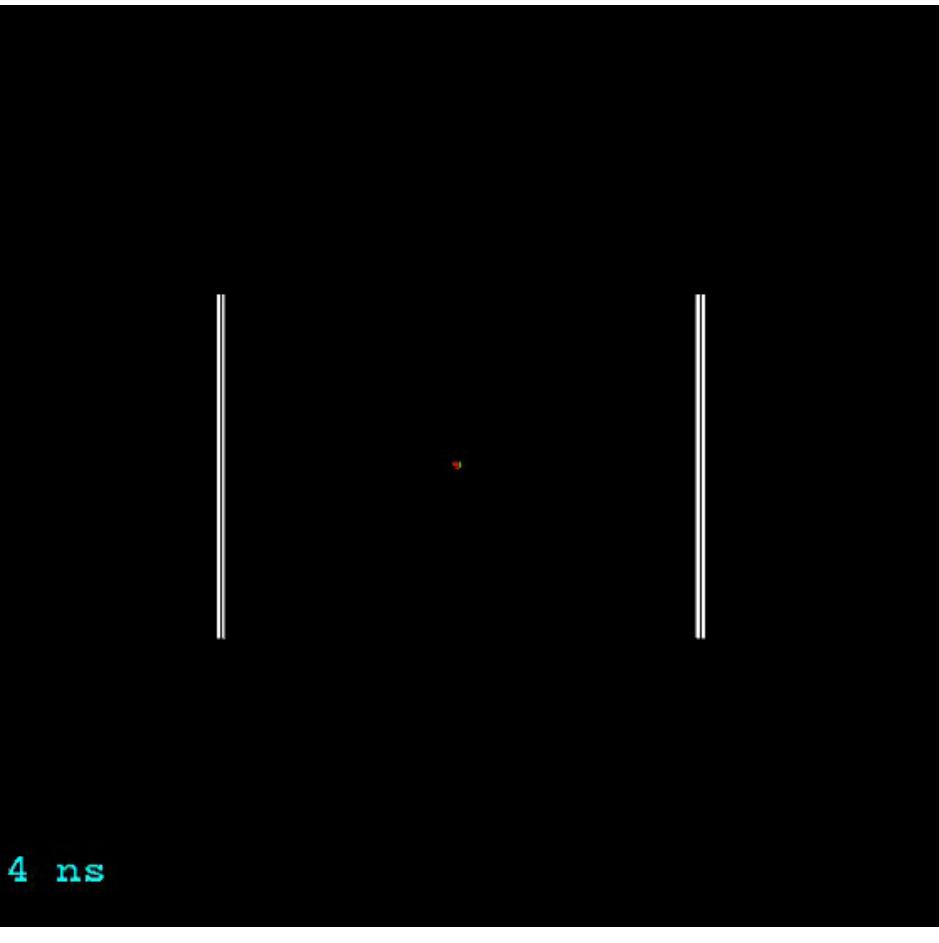
Condensed Matter Physics in Geant4

SLAC

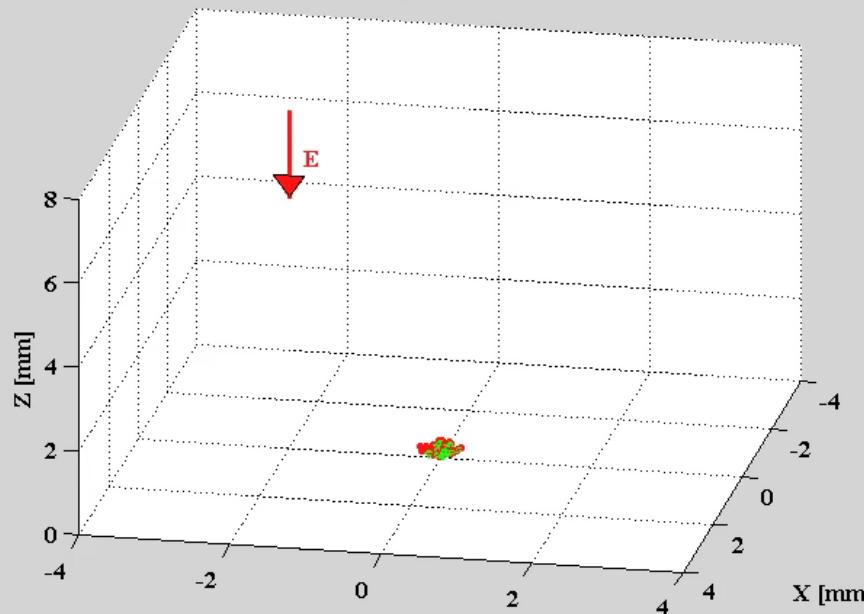
- Phonon propagation, including focusing based on elasticity tensor (right)
- e-/h+ transport, including conduction band anisotropy and Luke-Neganov emission, under development (below)



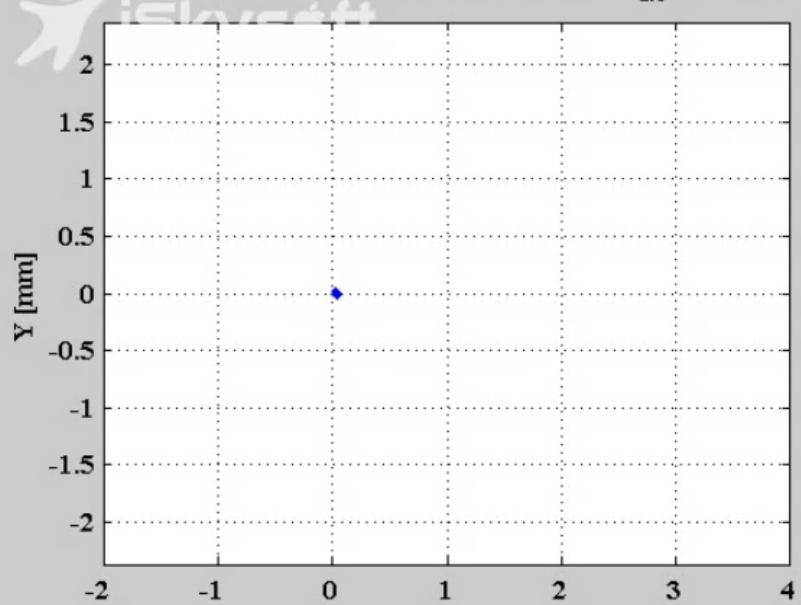
e-/h propagation with Luke phonon emission in Ge crystal



Electrons: $E = 1.0 \text{ V/cm}$; 20 scatters; $T_{\text{ave}} = 0.007 \mu \text{s}$; $v_d = -29.5 \text{ km/s}$

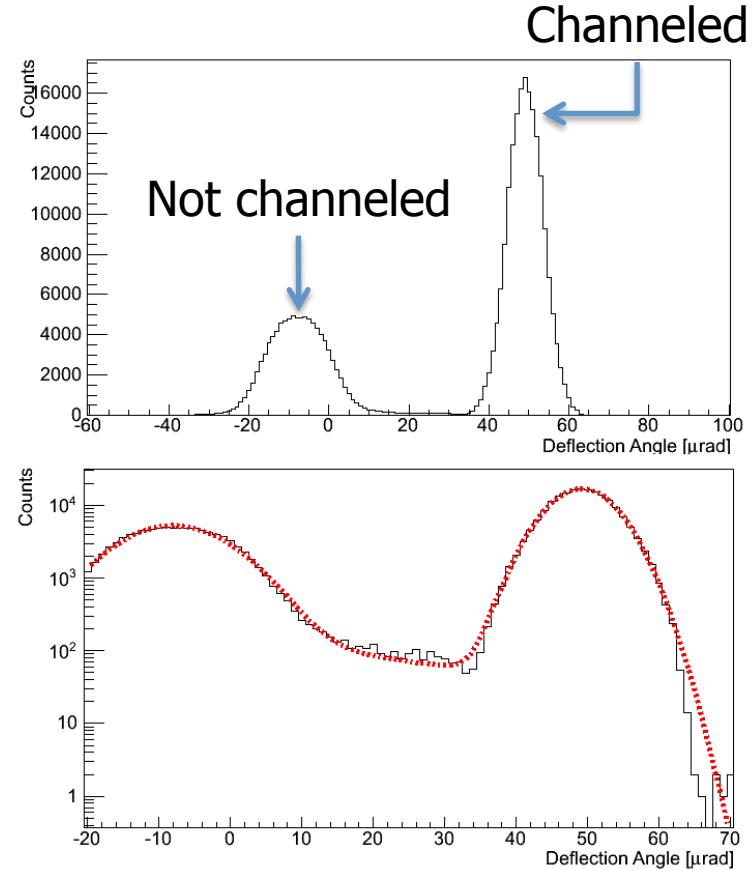
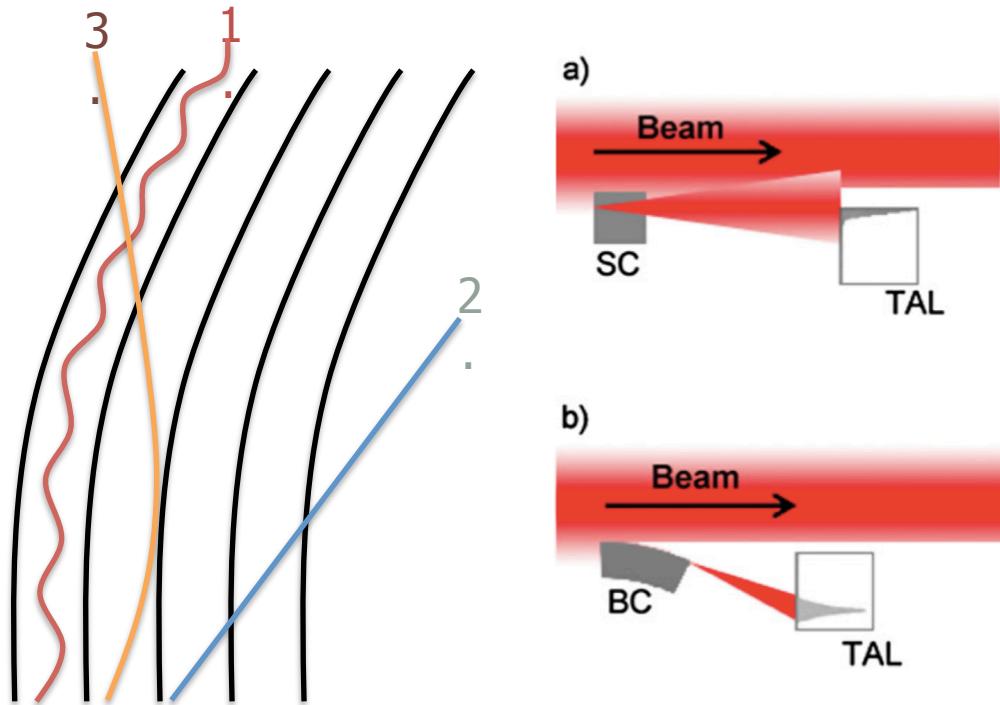


Hole Trajectories: $E = 1.0 \text{ V/cm}$; 10 scatters; Time $\text{ave} = 3.5 \text{ ns}$



Bent crystal as a collimator

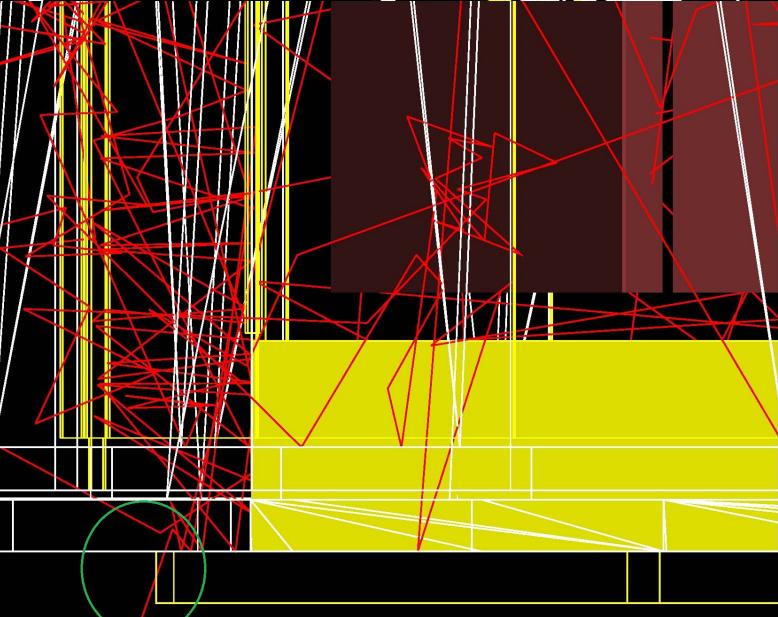
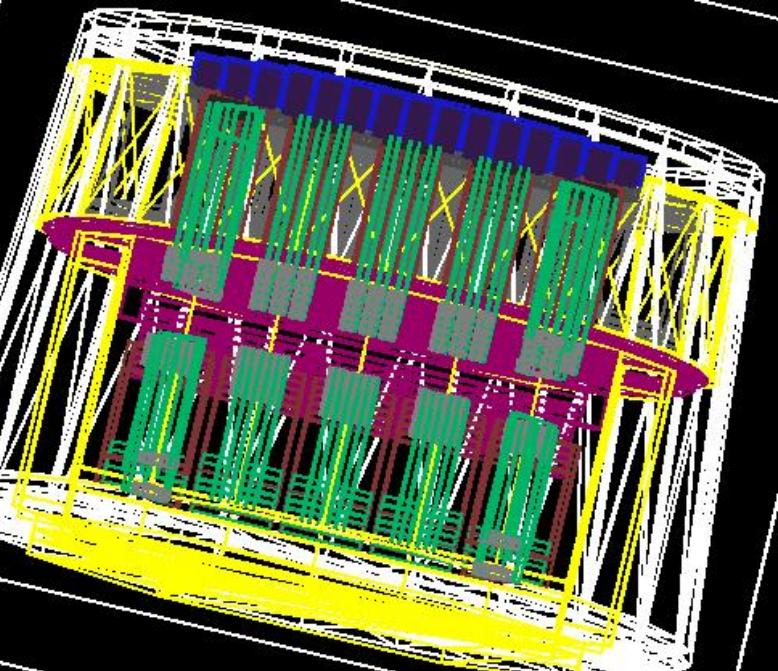
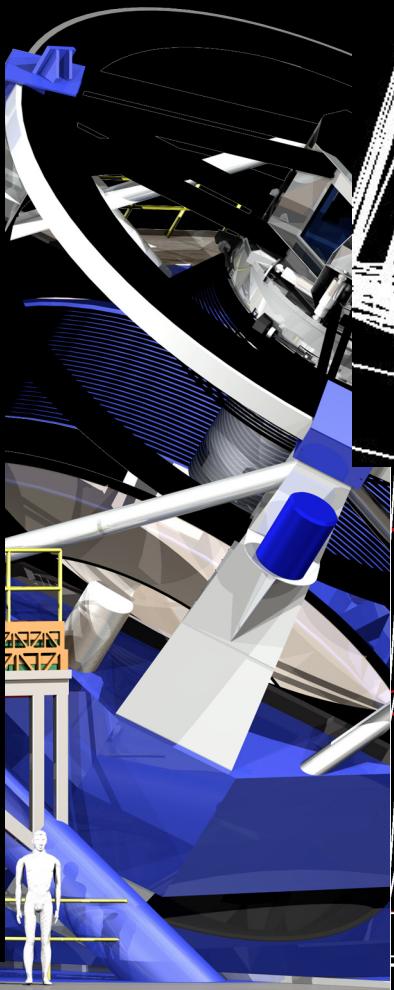
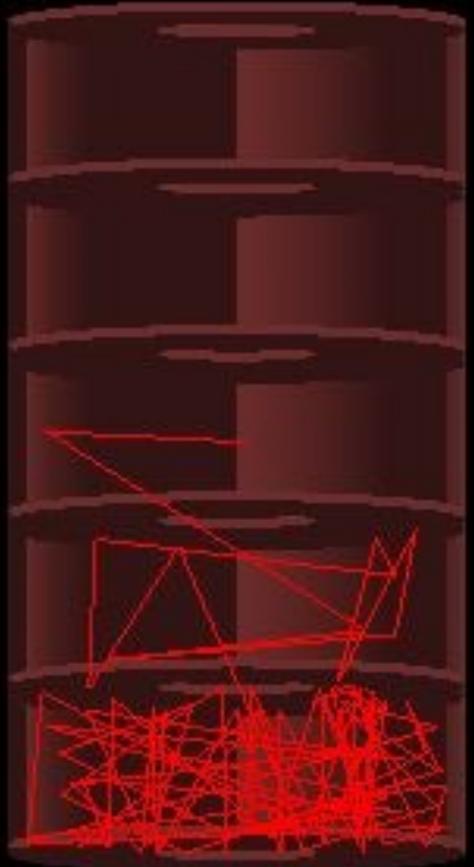
- Bent crystal can be used as a collimator to deflect particles of beam halo.
- This study will be extended for T-513 experiment at SLAC LCLS ESTB



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)

Geant 4

Geant4 license



NATIONAL
ACCELERATOR
LABORATORY



U.S. DEPARTMENT OF
ENERGY

Office of Science

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SLAC

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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.
- Simple enough that you can read and understand it.

<http://cern.ch/geant4/license/>

Also available in the downloaded release code.

The screenshot shows a web browser window displaying the Geant4 License page. The title bar says "Geant4: License". The address bar shows the URL "http://geant4.web.cern.ch/geant4/license/". The page header features the "Geant 4" logo. On the right side of the header, there are links for "Download", "User Forum", "Gallery", "Site Index", and "Contact Us". Below the header, there is a search bar with the placeholder "Search Geant4". A "Related Links" sidebar on the right contains two items: "Geant4 Software License" and "Source code download". The main content area includes sections for "The Geant4 Software License" (last established on June 30, 2006), "Copyright Holders of the Geant4 Collaboration" (listing institutions like Bath University, Budker Institute, etc.), and "Institutions" (listing specific institutions). The page has a light beige background with blue headings and links.

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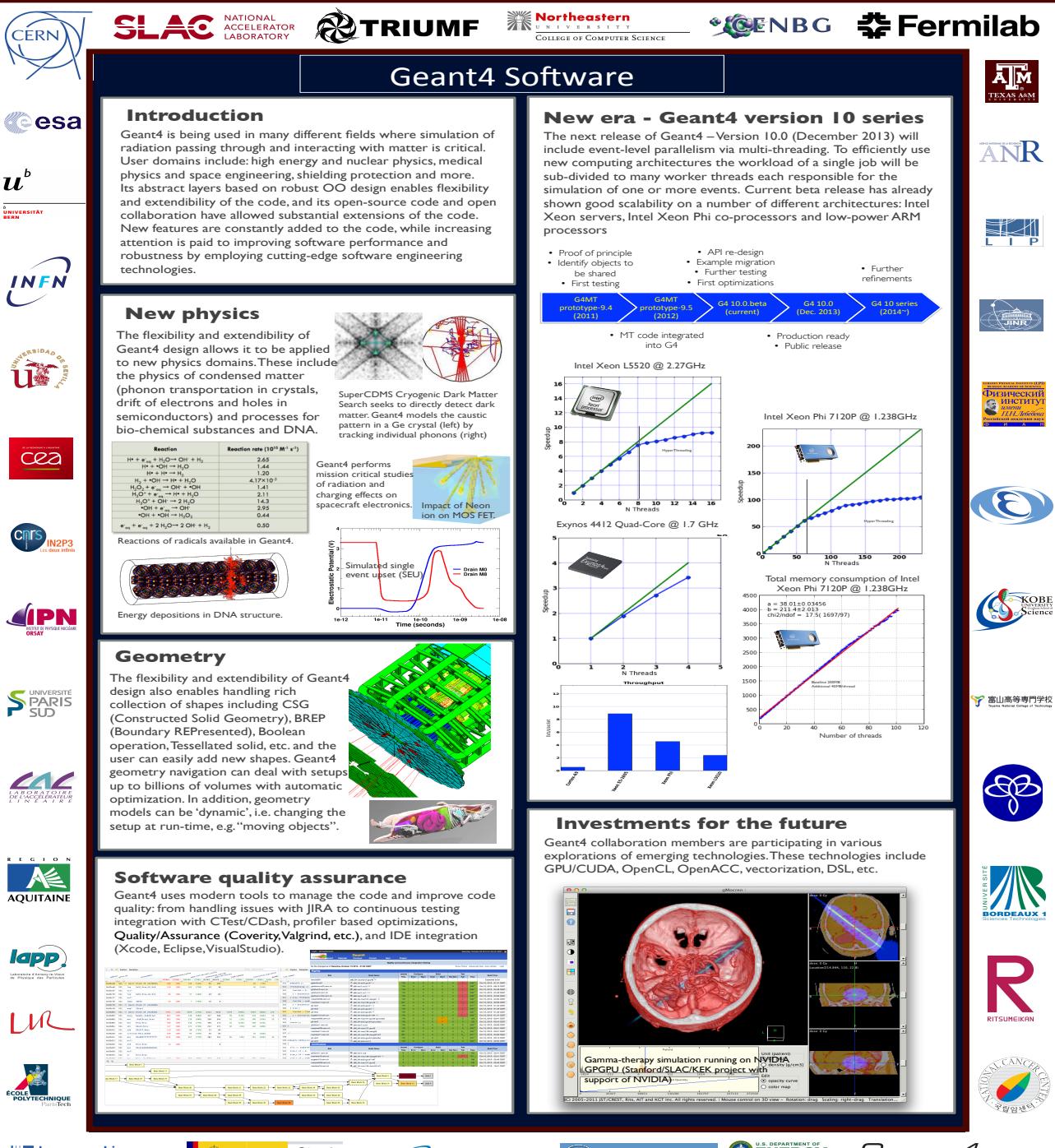
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Geant4 – the Future



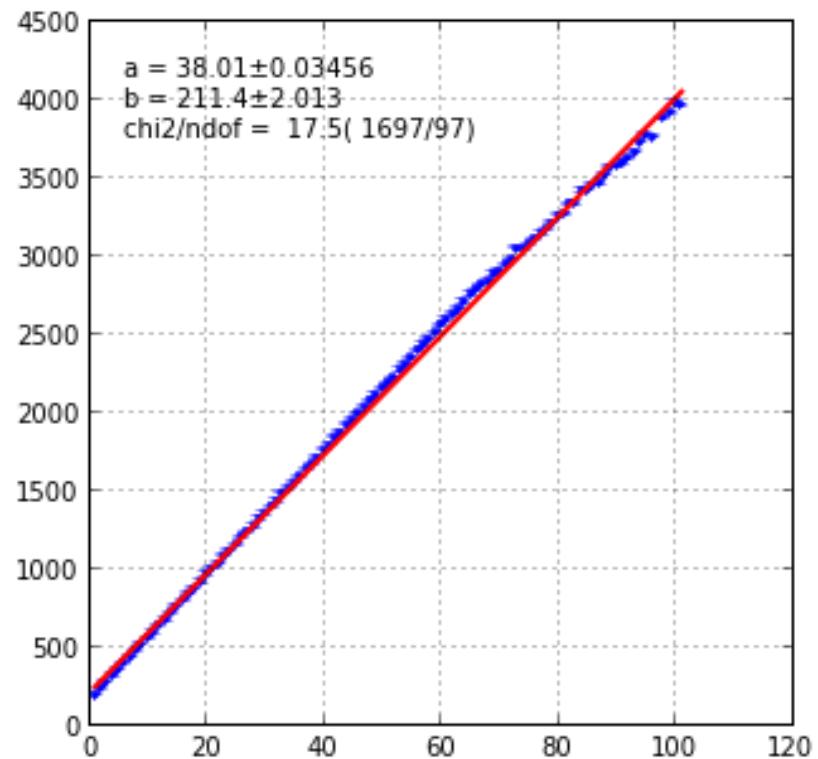
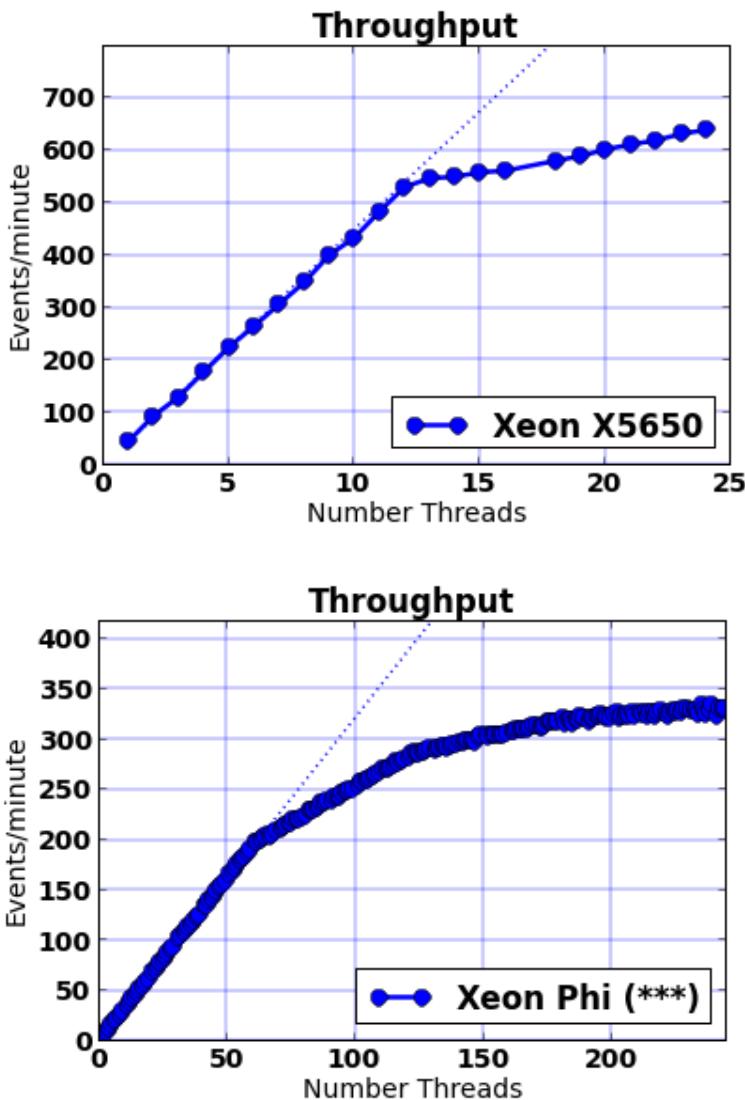
Geant4 version 10 series

- 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



- 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

CPU / Memory performances



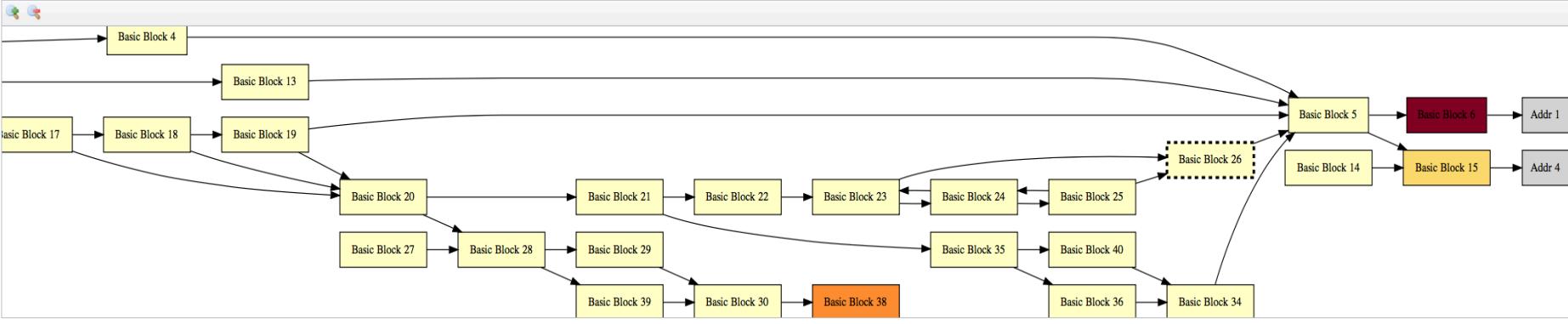
Software quality assurance (<http://code.google.com/p/gooda/>)

SLAC

- SLAC is working with Google on performance measurements of Geant4-based application using Gooda tool, a PMU-based event data analysis package.

		Cycles	Samples	Enter search term								
		address	princ_l#	disassembly		unhalted_core_cycles	ups_retried:stall_cycles	instruction_retried	ups_retried:any	load_latency	instruction_starvation	bandwidth
				249801	(100%)	183440 (73%)	81361 (95%)	96333 (105%)	157004 (62%)	102099 (40%)	3478 (3478)	(1%)
0x30ce8	521	Basic Block 26 <0x30b2b>		268 (0%)		146 (54%)	95 (32%)	105 (38%)		20 (20%)	7 (7%)	
0x30ce8	521	lea 0x0,%rax,8,%r8		139 (0%)		102 (73%)				20 (14%)		
0x30cef	521	null										
0x30cf0	521	lea 0x8,%rax,8,%r9		80 (0%)		37 (46%)		48 (60%)				
0x30cf7	521	null										
0x30cf8	521	jmpq 30b2b		50 (0%)		7 (14%)		16 (28%)		8 (8%)		
0x30cf9	521	Basic Block 27 <0x30d00>										
0x30cf9	521	nopl (%rax)										
0x30d00	521	Basic Block 28 <0x30ed9..>		7463 (2%)		5649 (75%)	3111 (3133)	3478 (46%)	4929 (66%)	129 (129)	65906 (59%)	41559 (37%)
0x30d00	521	movq %xmm0,-0x8(%rsp)		805 (0%)		548 (68%)	317 (286)	99 (12%)	378 (46%)	20 (20)	65906 (59%)	41559 (37%)
0x30d06	521	mov -0x8(%rsp),%rax		805 (0%)		716 (88%)	206 (264)	10 (1%)	566 (70%)	20 (20)	65906 (59%)	41559 (37%)
0x30d0b	521	mov %rax,%rcx		566 (0%)		438 (77%)	190 (173)	70 (12%)	298 (52%)			
0x30d0e	521	shr \$0x34,%rcx		517 (0%)		373 (72%)	222 (271)	30 (5%)	149 (28%)			
0x30d12	521	sub \$0x3ff,%ecx		119 (0%)		88 (73%)	32 (60)					
0x30d18	521	cvttsi2sd %ecx,%xmm4		199 (0%)		95 (47%)	40 (60)			20 (10%)		
0x30d1c	521	mov \$0x800fffffffffffff..		1232 (0%)		957 (77%)	484 (505)	60 (4%)	765 (62%)	30 (30)		
0x30d23	521	null										
0x30d26	521	and %rcx,%rax		10 (0%)				8 (8%)				
0x30d29	521	mov \$0x3fe00000000000..										
0x30d30	521	null										
0x30d33	521	or %rcx,%rax										
0x30d3c	521											

		Cycles	Samples	Enter search term							
		line number	source	unhalted_core_cycles	ups_retried:stall_cycles	instruction_retried	ups_retried:any	load_latency	instruction_starvation	bandwidth	instructions
		513	G4double y;	249801 (100%)	183440 (73%)	81361 (95%)	96333 (105%)	157004 (62%)	102099 (40%)	3478 (3478)	(1%)
		514	if(theEnergy <= edgeMin) {	43596 (17%)	35500 (81%)	5730 (7862)	24814 (56%)	19478 (44%)			
		515	lastIdx = 0;	636 (0%)	519 (81%)	63 (120)	308 (48%)	318 (50%)			
		516	y = dataVector[0];	1202 (0%)	1082 (90%)	111 (158)	4035 (335%)	924 (76%)			
		517	} else if(theEnergy >= edgeMax) {	3170 (1%)	2353 (74%)	651 (738)	1113 (35%)	1520 (47%)			
		518	lastIdx = numberOfNodes-1;								
		519	y = dataVector[lastIdx];								
		520	} else {								
		521	lastIdx = FindBin(theEnergy, lastIdx);	109860 (43%)	76853 (69%)	45196 (54010)	65906 (59%)	41559 (37%)			
		522	y = Interpolation(lastIdx, theEnergy);	84798 (33%)	61193 (72%)	29102 (32887)	59616 (70%)	35646 (42%)			
		523	}								
		524	return y;								
		525	}	6539 (2%)	5941 (90%)	508 (557)	1034 (15%)	2554 (39%)			
		526									
		527	-----								
		528									
		529	G4double G4PhysicsVector::FindLinearEnerg...								
		530	{								
		531	if(l >= numberOfNodes) { return 0.0; }								
		532	size_t n1 = 0;								
		533	size_t n2 = numberOfNodes/2;								
		534	n1 + n2 == numberOfNodes - 1;								



New physics – new opportunities

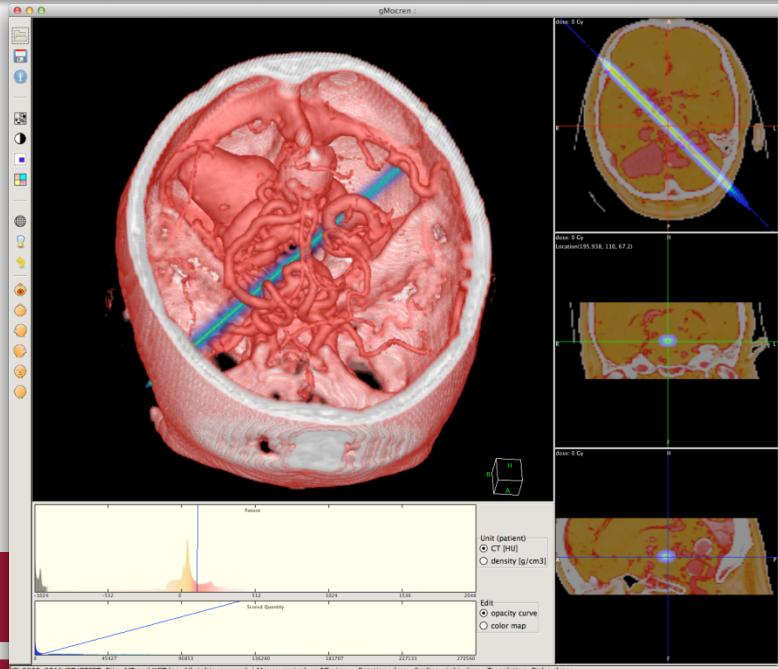
- Neutrino interactions
 - Should come with enriched event biasing options
- Electron/hole drift in semiconductor
- More phonon physics
- Channeling effects
- Physics with crystal structure in general
 - X-ray diffraction
- Target material polarization
- Single atom irradiation
- Chemical reactions of 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.

Investment for the future

– Low energy EM physics ported to GPU

Primary	Phantom	Time/History CPU (sec)	Time/History GPU (sec)	CPU/GPU
20 MeV electron	Water	1.06E-03	2.52E-05	42.1
20 MeV electron (e-spread)	Lung	1.20E-03	2.67E-05	44.9
20 MeV electron (e-spread)	Bone	9.76E-04	2.54E-05	38.4
6 MeV photon	Water	4.47E-04	1.12E-05	39.9
6 MV photon (e-spread)	Lung	3.52E-04	9.16E-06	38.4
6 MV photon (e-spread)	Bone	3.59E-04	9.00E-06	39.9
18 MV photon (e-spread)	Lung	4.05E-04	1.12E-05	36.2
18 MV photon (e-spread)	Bone	4.29E-04	1.17E-05	36.7



Observed GPU speed up over a single-thread CPU: ~40x

Left: Irradiation of 50 million 6 MeV monochromatic photons calculated by GPGPU (not for real treatment use, demonstration purposes only !)

Collaboration of SLAC, Stanford ICME and KEK with support of NVIDIA

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.
- This year is the 20th year anniversary of Geant4. After 20 years with several architectural evolutions, Geant4 is still steadily evolving.
 - Latest evolution was Geant4 version 10.0 released in December 2013 that is the first fully multithreaded large-scale physics software in the world.
- Given Geant4 is nowadays mission-critical for many users including all LHC experiments, space missions, medical applications, etc., Geant4 is to be kept maintained and still evolving for at least next decade.
- It is my honor to be here at Ferrara and I would like to thank Prof. Vincenzo Guidi once again for this wonderful opportunity !