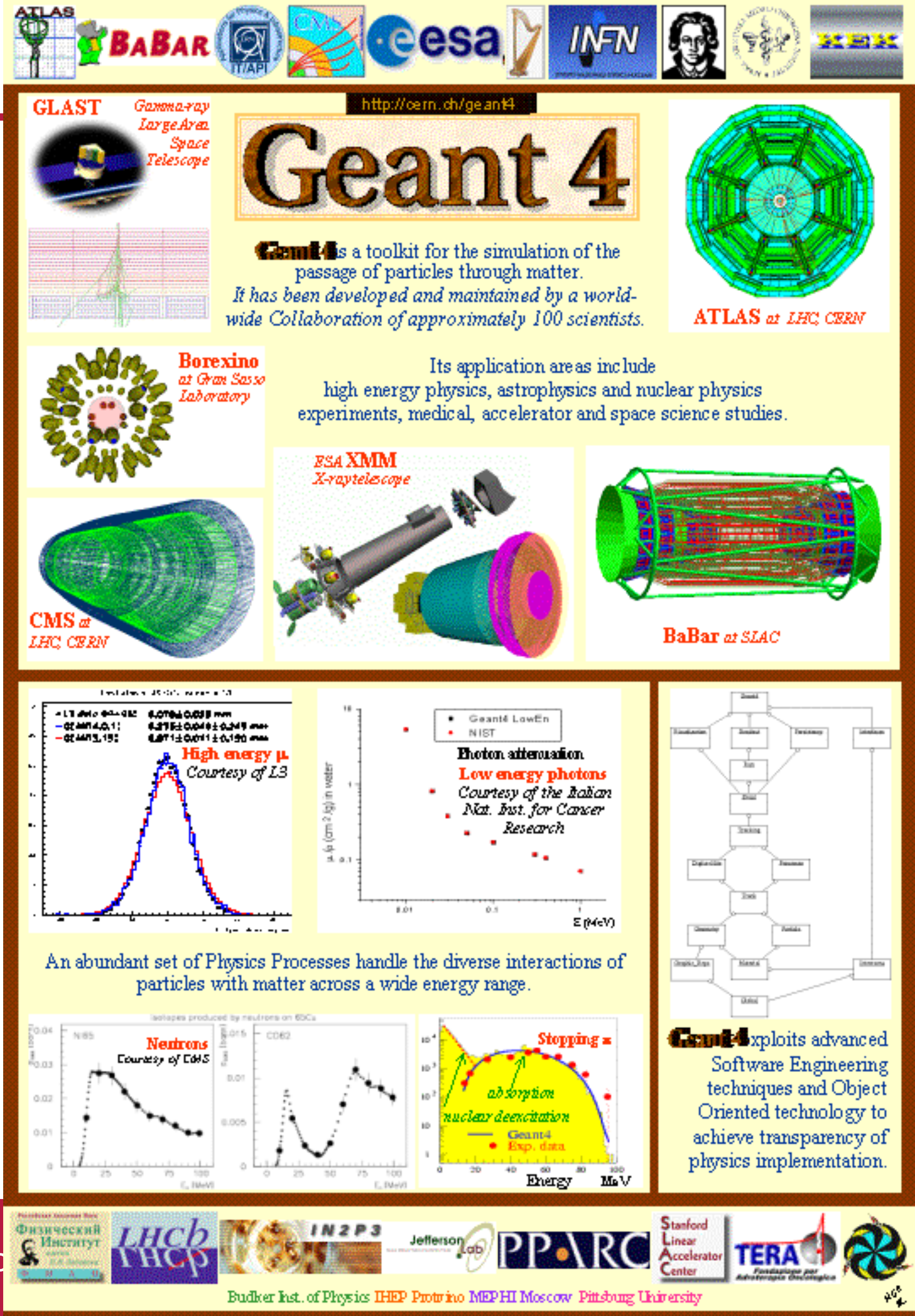
Roadmap for Geant4

Makoto Asai (SLAC)
For the Geant4 Collaboration
CHEP 2012

Contents

- Geant4 – past and present
- Recent and ongoing developments
- Future and opportunities



GEANT4 – PAST AND PRESENT

- Geant4 history
- BaBar and Geant4
- Large Hadron Collider
- Beam Transport
- Space Applications
- Medical Applications
- Impact of Geant4

Geant4 History

R&D phase (RD44)

Production phase

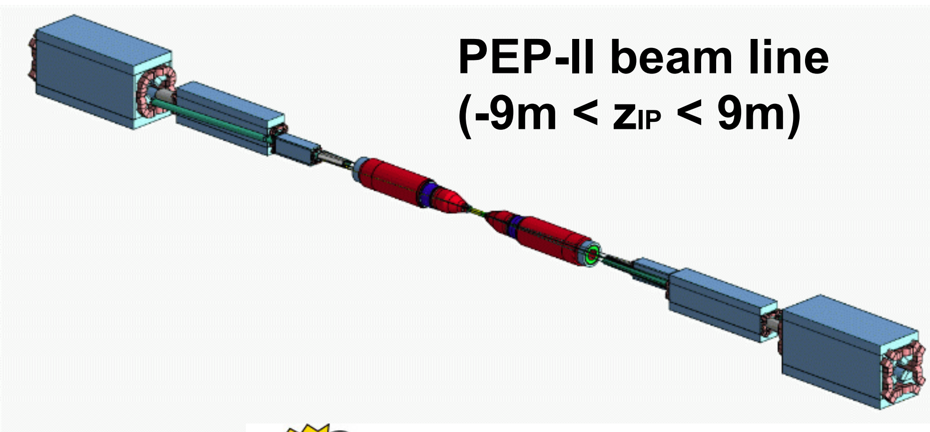
- Geant4 started at CHEP 1994 @ San Francisco
  - "Geant steps into the future" R. Brun et al.
  - "Object oriented analysis and design of a GEANT based detector simulator" K. Amako et al.
- Dec '94 - CERN RD44 project start
- Apr '97 - First alpha release
- Jul '98 - First beta release
- Dec '98 - First Geant4 public release - version 1.0

- Several major architectural revisions
  - E.g. STL migration, "cuts per region", parallel worlds

- Dec 17th, '10 - Geant4 version 9.4 release
  - Apr 20th, '12 - Geant4 9.4-patch04 release ← Retroactive patch release
- Dec 2nd, '11 - Geant4 version 9.5 release
  - Mar 27th, '12 - Geant4 9.5-patch01 release ← Current version
- We currently provide one public release every year.

BaBar and Geant4

- BaBar is the pioneer HEP experiment in use of OO technology, and the first customer of Geant4.
  - During the R&D phase of Geant4, we acknowledge lots of valuable feedbacks were provided by BaBar.
- BaBar started its simulation production in 2000 and had produced more than 10 billion events at more than 20 sites in Europe and North America.



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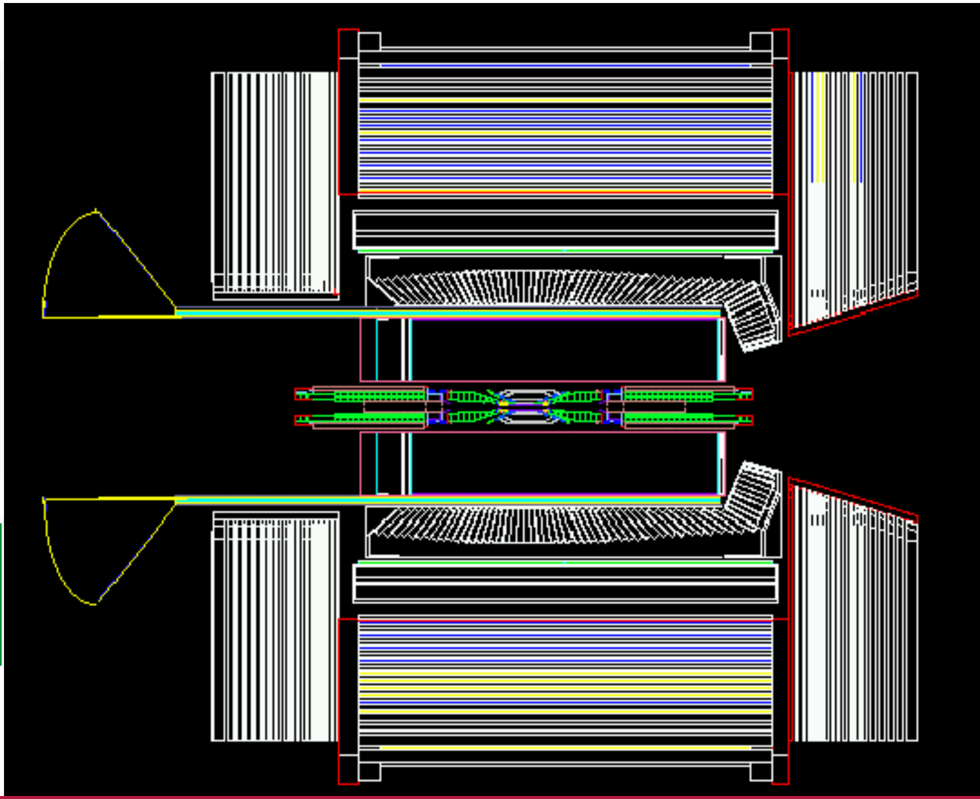
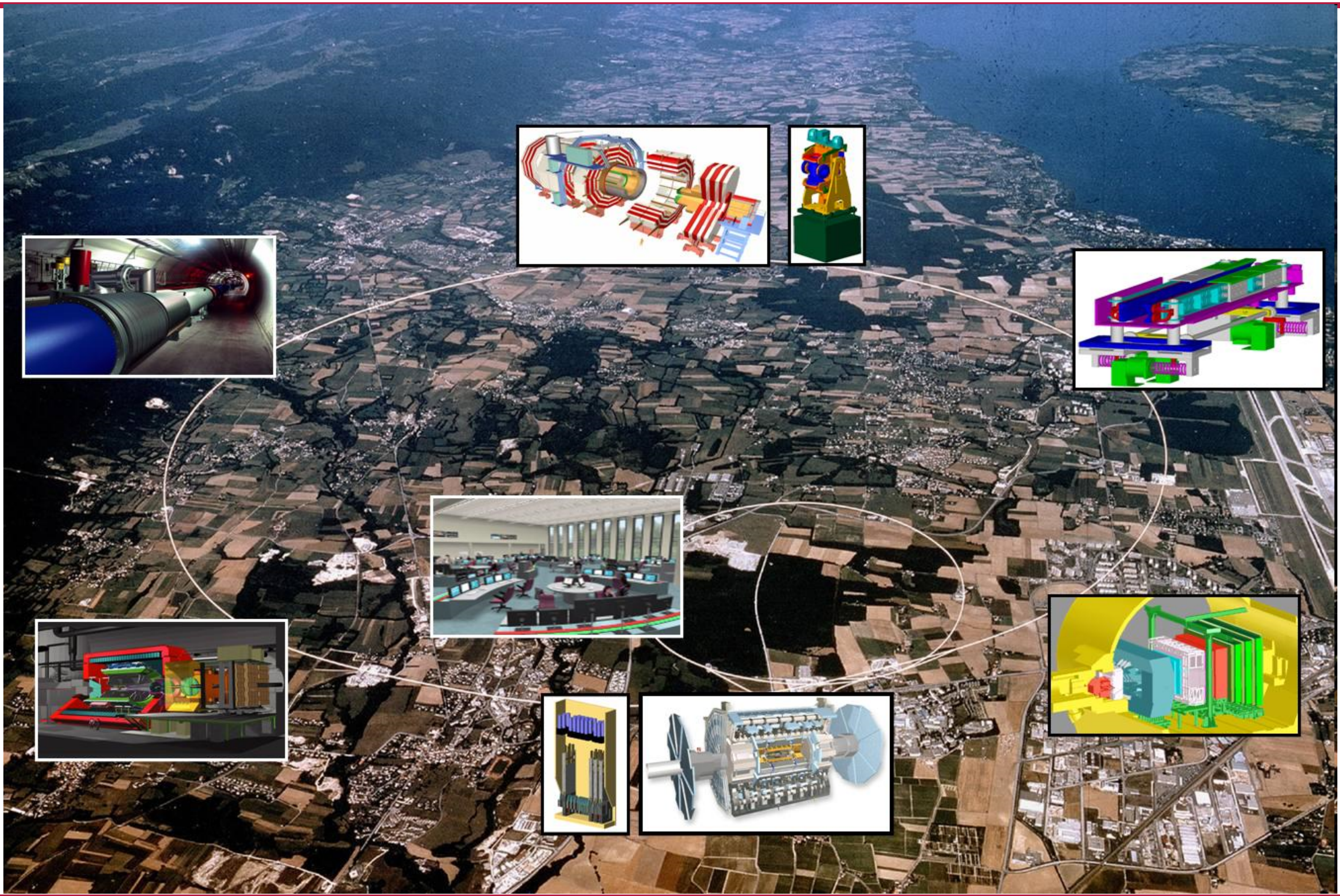
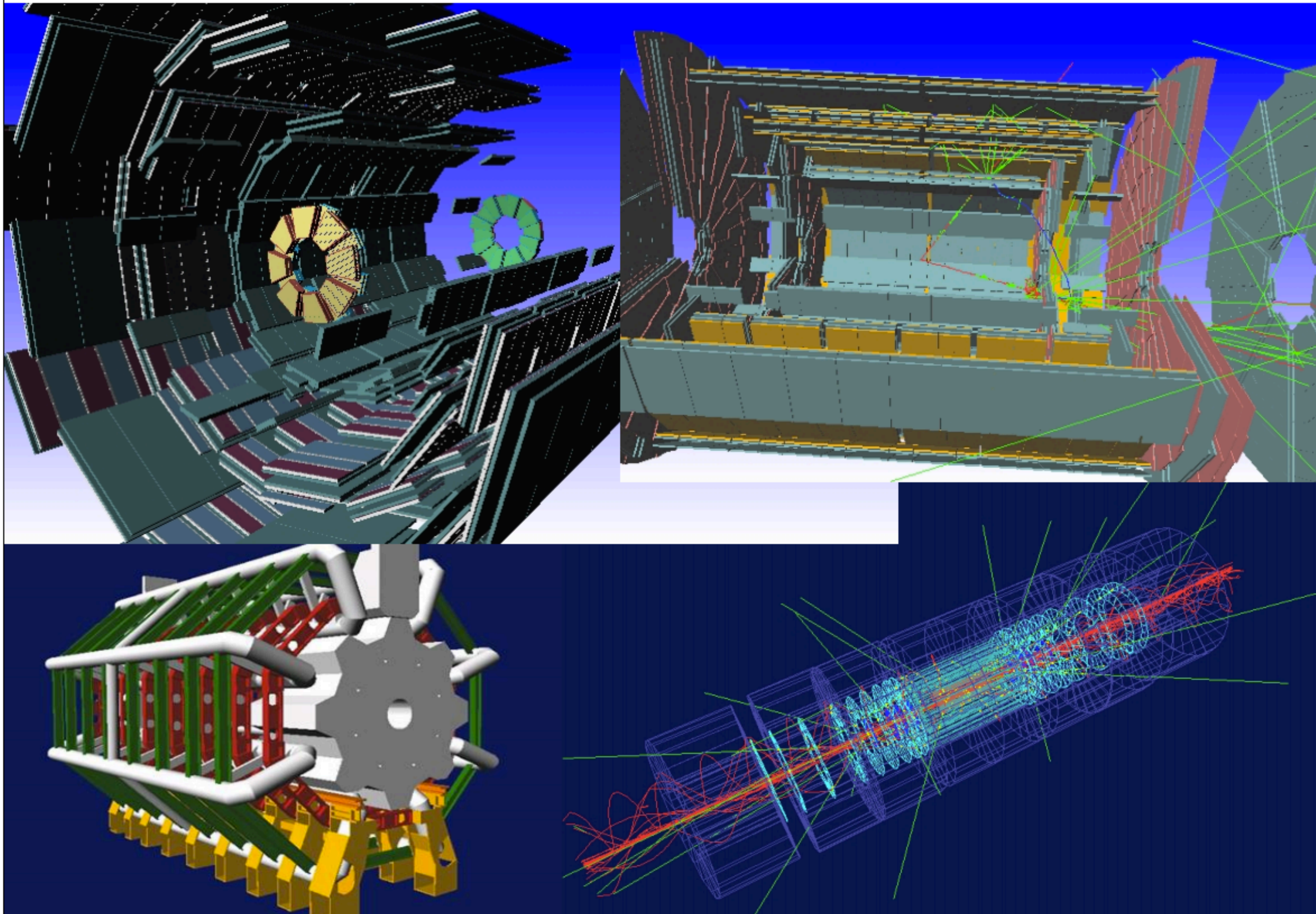


Large Hadron Collider (LHC) @ CERN

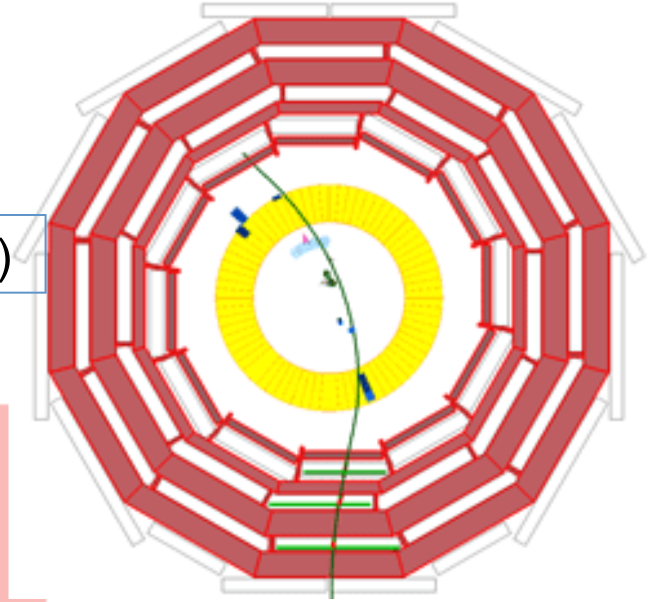


Geant4 in High Energy Physics (ATLAS at LHC)



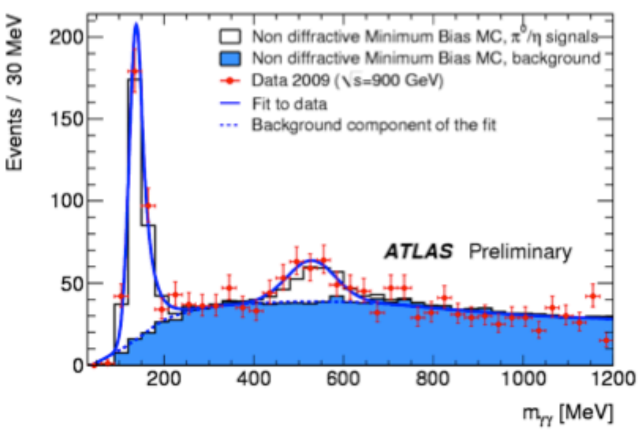
Geant4 has been successfully employed for

- Detector design
- Calibration / alignment
- First analyses



T. LeCompte (ANL)

GEANT4 Comparisons with the Calorimeters



Invariant mass of pairs of well-isolated electromagnetic clusters.

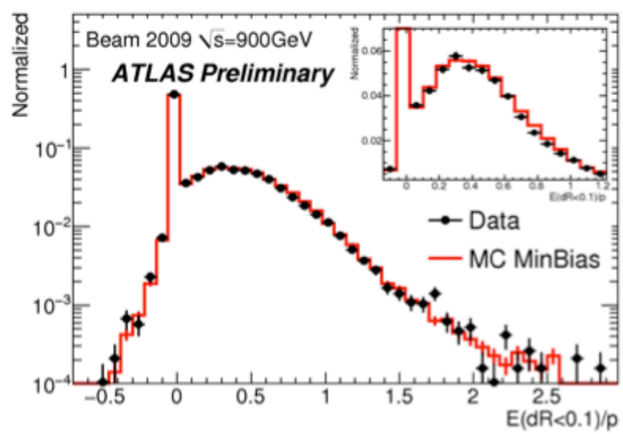
The π^0 mass is within 0.8 ± 0.6% of expectations.

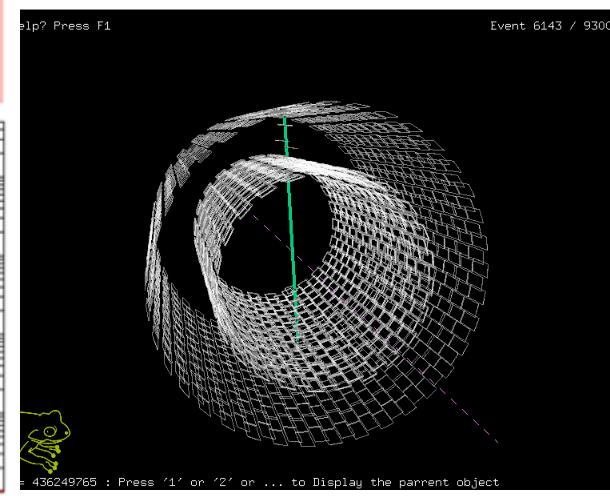
The η^0 mass is within 3 ± 2% of expectations.

The detector uniformity is better than 2%.

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

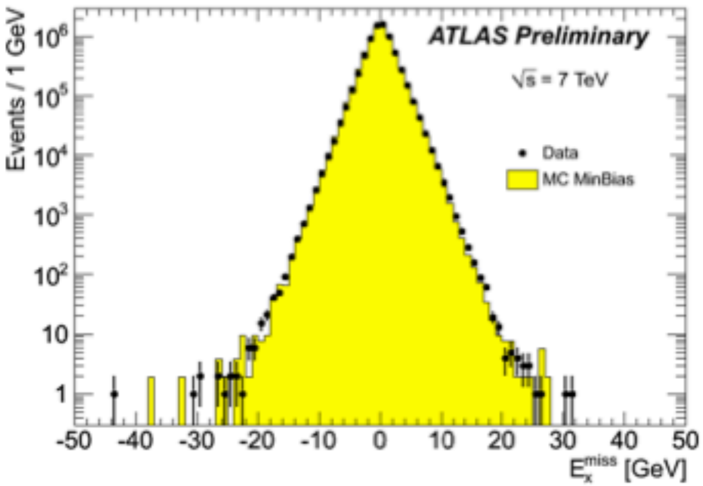
This plot agreed better than we ever expected. (I sent the student who made it back to make sure that they didn't accidentally compare G4 with G4.

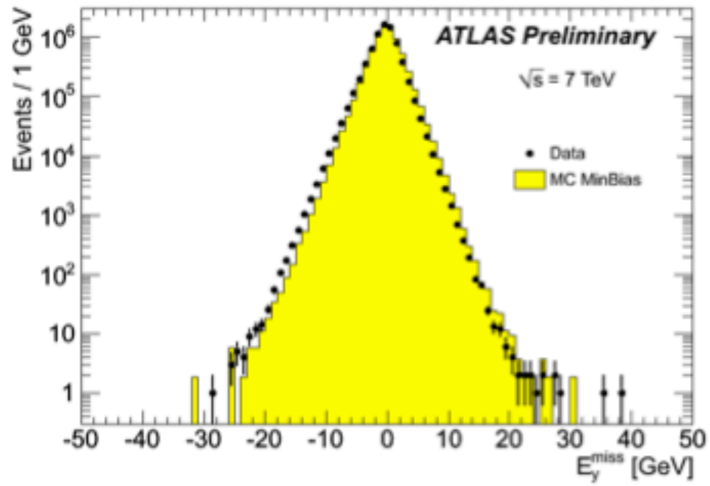




Figures from CMS

Missing E_T

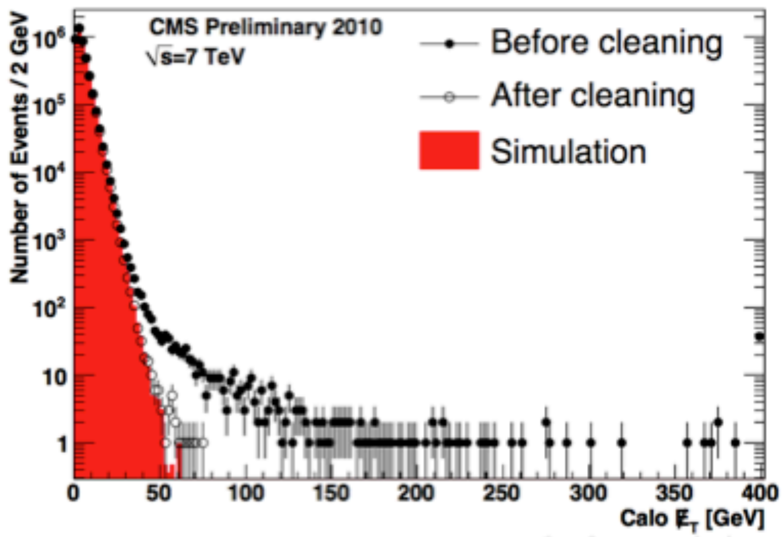


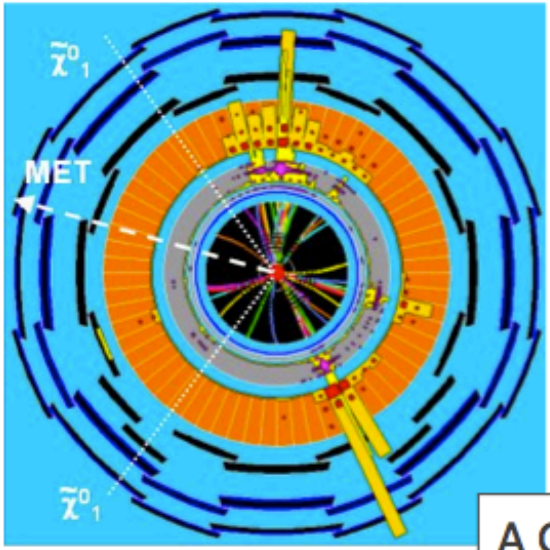


This is one of the hardest things to get right. MET incorporates everything measured in the detector and attempts to identify non-interacting particles, such as neutrinos or dark matter.

Agreement is astounding.

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



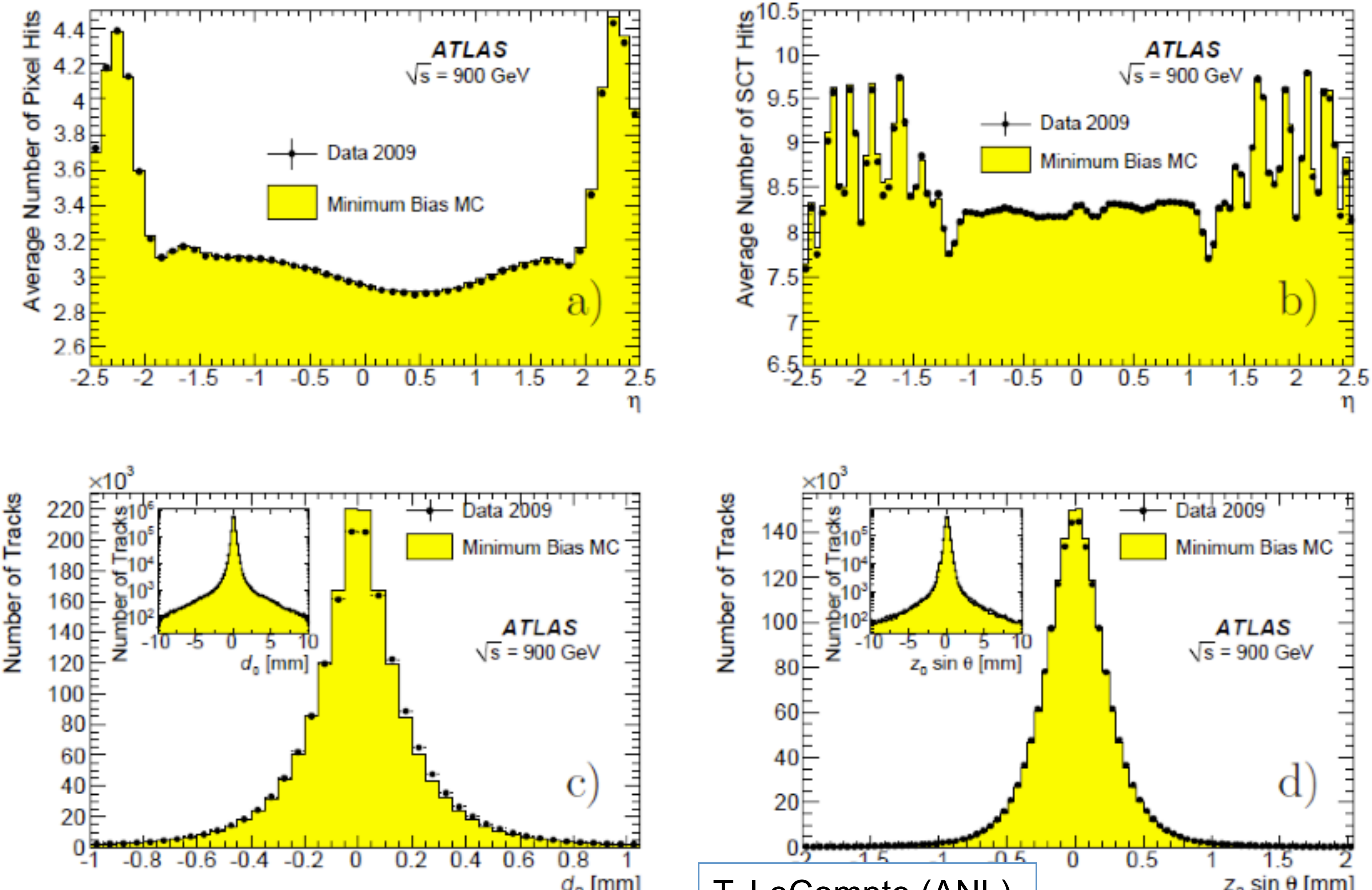


A GEANT4 event.

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

T. LeCompte (ANL)

Data and simulation agreements



T. LeCompte (ANL)

Beam transport for Project X

Muons, Inc.

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G4BEAMLINE

A "Swiss Army Knife" for Geant4, optimized for simulating beamlines.

Getting Started | Documentation | Download | Support | Example | Forum | Doxygen | New Feature Requests

HistoRoot has been separated from G4beamline, and is a separate application available here.

The advantage is that HistoRoot is now compiled, and runs ~100 times faster on large files.

The G4beamline validation document is now available here.

G4beamline 2.12 is now available here.

The G4beamline User's Guide is available here.

G4beamline now supports the making of movies

Here is a Flash movie of Example1: Movie. This example is just a gaussian beam expanding in free space (the 4 virtualdetectors are not visible). Muons are blue and a handful of decay electrons and neutrinos are red and gray. This 10 second movie took 12 seconds of CPU time to produce.

The G4beamline Tutorial given at LEMC 2008 was videotaped by Fermilab Visual Media Services. part 1 part 2

Click here for a Flash video giving a screencast of using G4beamline for a simple example.

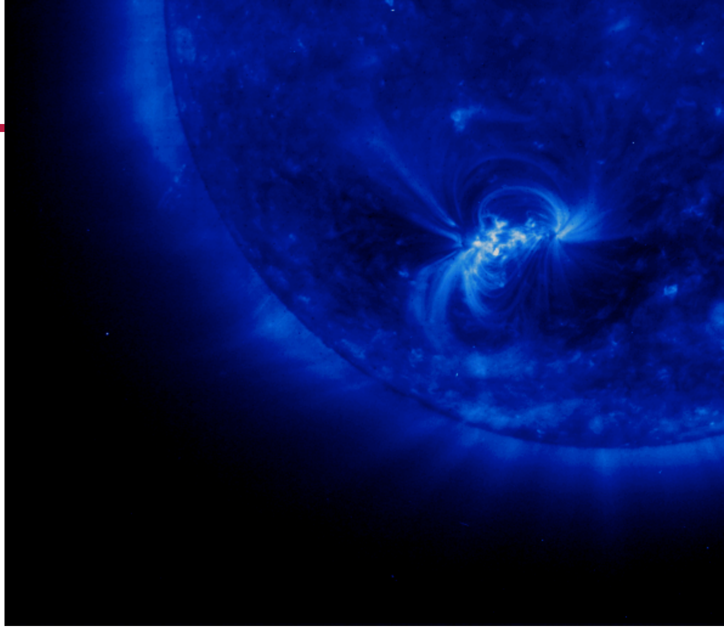
General

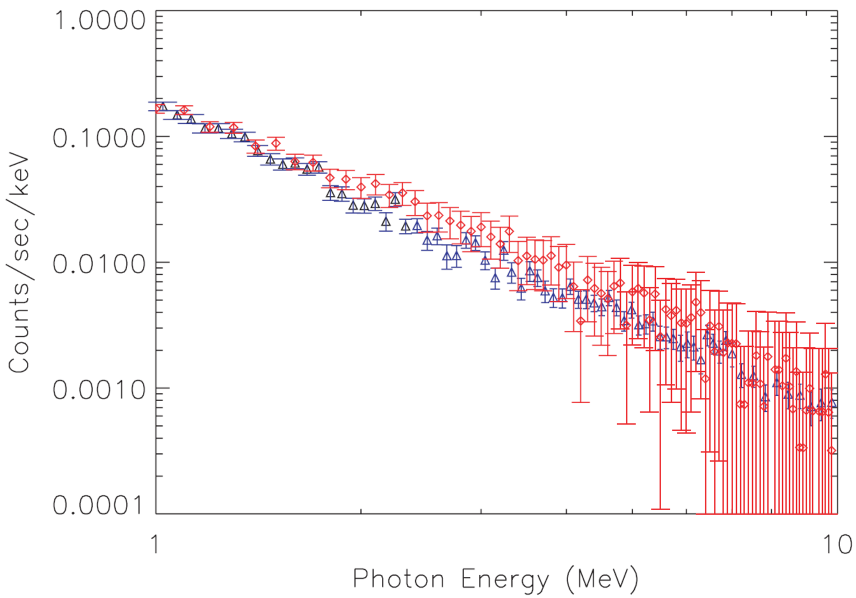
G4beamline is a single-particle tracking program based on the Geant4 simulation toolkit. It is specifically designed for the simulation of beamlines.

The key aspect of g4beamline is that the input file defining the simulation is not significantly more complicated than the problem being simulated (by contrast, any C++ simulation program will inherently be significantly more complicated than the problem) — G4beamline isolates the user from programming complexities. To make this possible, g4beamline does not give the user all of the power and flexibility of the underlying Geant4 toolkit; it does, however, provide enough flexibility to simulate many different systems that can be considered "beamlines" one way or another. For instance, there is a "cosmic-ray beam", and the notion of "beamline" is rather flexible. In use, one normally just lays out the beamline elements along the beam centerline, using "centerline coordinates" that rotate appropriately whenever needed (e.g. when a bending magnet is placed, or at a target to take a secondary beam off at an angle).

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

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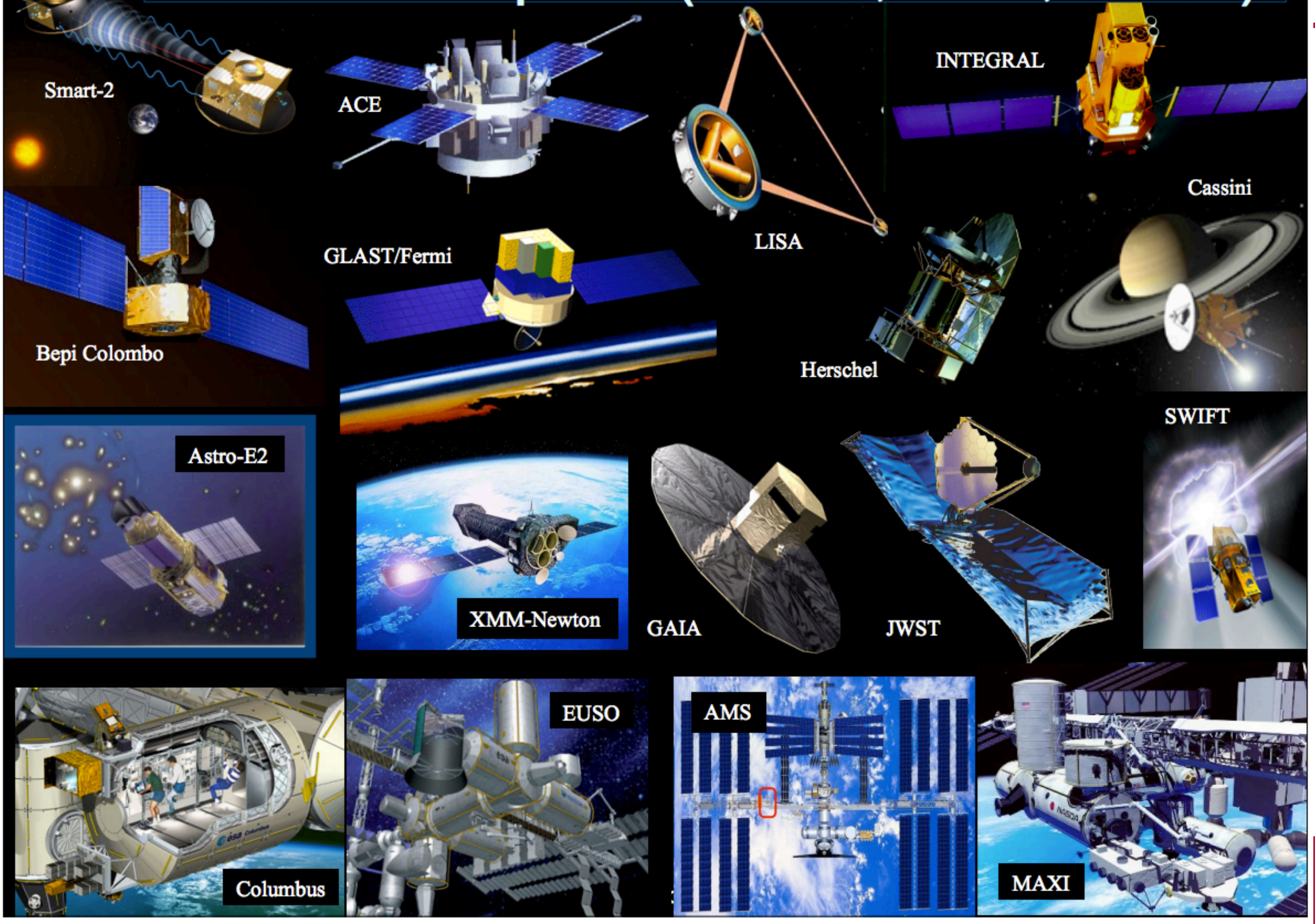
(Received ; accepted)

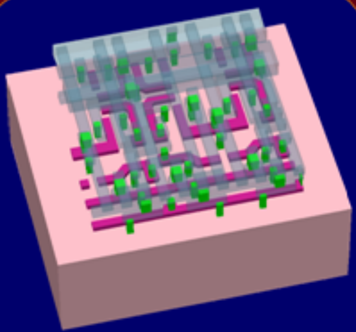
Abstract

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-

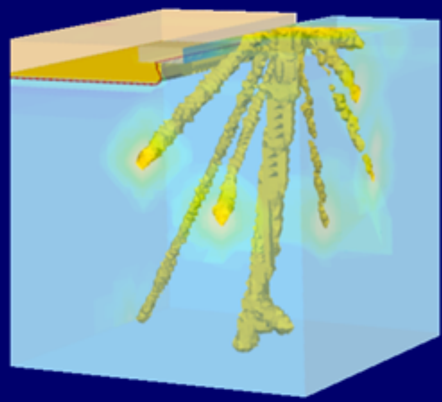
Geant4 in Space (NASA, ESA, JAXA)



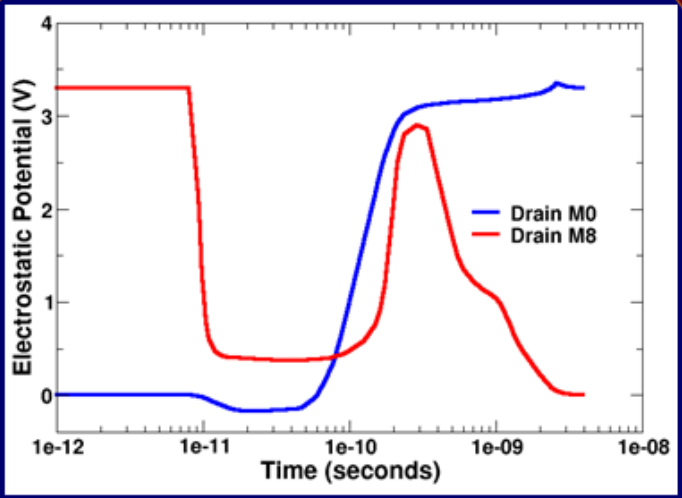
RADSAFE on SEE in SRAMs



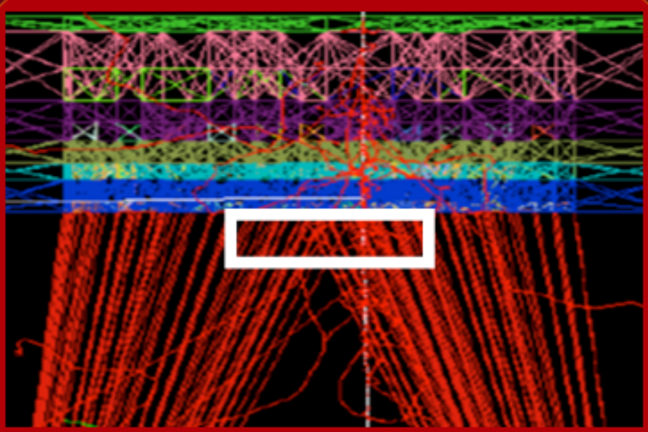
TCAD Cell Structure: SRAM Cell



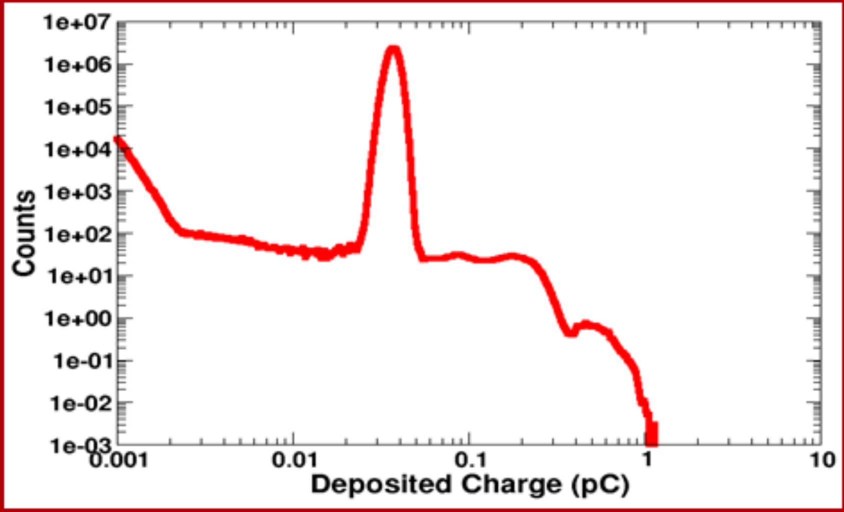
Single Charge Deposition in TCAD: Ne+W Event



SRAM Cell Upset



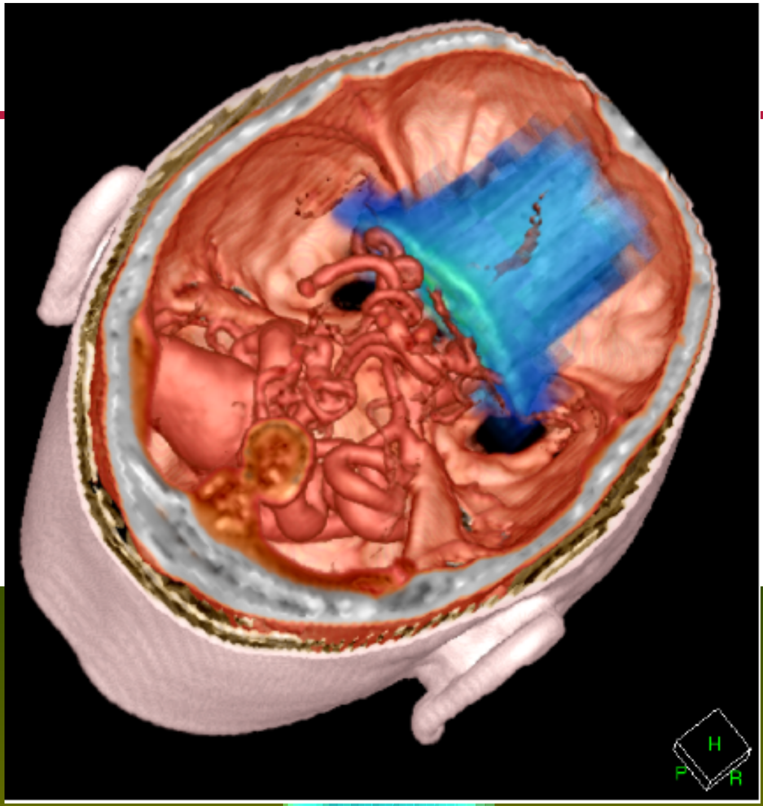
Geant4 Geometry and 523 MeV Neon Event

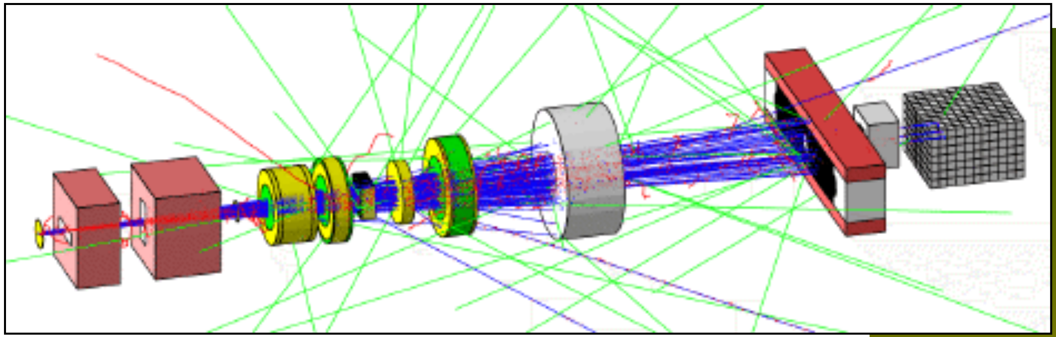


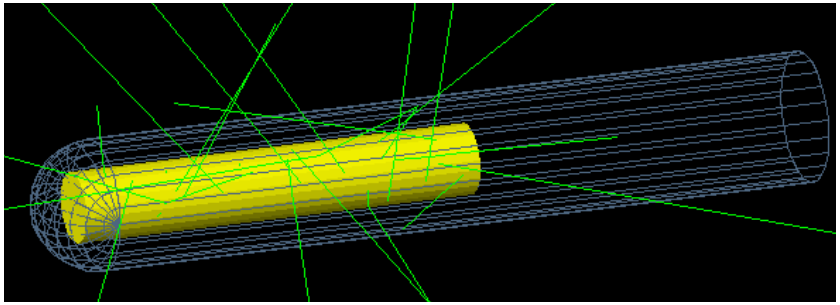
MRED Energy Deposition for 10^8 Events

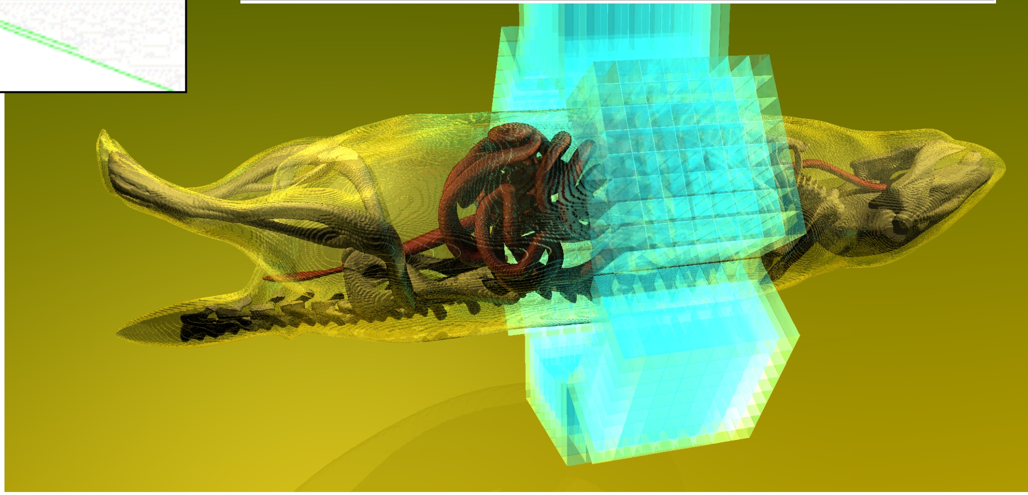
Geant4 @ Medical Science

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









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1 Citations: 133
Title: GEANT4-A SIMULATION TOOLKIT
Authors: 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; COOPERMAN G; COSMO G; DEGTYARENKO P; DELL'ACQUA A; DEPAOLA G; DIETRICH D; ENAMI R; FELICIELLO A; FERGUSON C; FESEFELDT H; FOLGER G; FOPPIANO F; FORTI A; GARELLI S; GIANI S; GIANNITRAPANI R; GIBIN D; CADENAS JJG; GONZALEZ I; ABRIL GG; GREENIAUS G; GREINER W; GRICHINE V; GROSSHEIM A; GUATELLI S; GUMPLINGER P; HAMATSU R; HASHIMOTO K; HASUI H; HEIKKINEN A; HOWARD A; IVANCHENKO V; JOHNSON A; JONES FW; KALLENBACH J; KANAYA N; KAWABATA M; KAWABATA Y; KAWAGUTI M; KELNER S; KENT P; KIMURA A; KODAMA T; KOKOULIN R; KOSSOV M; KURASHIGE H; LAMANNA E; LAMPEN T; LARA V; LEFEBURE V; LEI F; LIENDL M; LOCKMAN W; LONGO F; MAGNI S; MAIRE M; MEDERNACH E; MINAMIMOTO K; DE FREITAS PM; MORITA Y; MURAKAMI K; NAGAMATU M; NARTALLO R; NIEMINEN P; NISHIMURA T; OHTSUBO K; OKAMURA M; O'NEALE S; OOHATA Y; PAECH K; PERL J; PFEIFFER A; PIA MG; RANJARD F; RYBIN A; SADILOV S; DI SALVO E; SANTIN G; SASAKI T; SAVVAS N; SAWADA Y; SCHERER S; SEIL S; SIROTENKO V; SMITH D; STARKOV N; STOECKER H; SULKIMO J; TAKAHATA M; TANAKA S; TCHERNIAEV E; TEHRANI ES; TROPEANO M; TRUSCOTT P; UNO H; URBAN L; URBAN P; VERDERI M; WALKDEN A; WANDER W; WEBER H; WELLISCH JP;

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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.; Coope
   Cited by SciVerse Scopus (3266)
2. **Big-bang nucleosynthesis: A probe of the early Universe**
   Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 611, Issue 2-3, December 2009, Pages 224-230
   Coc, A.
   Cited by SciVerse Scopus (1)
3. **Neutron detection gamma ray sensitivity criteria**
   Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 654, Issue 1, October 2011, Pages 412-416
   Kouzes, R.T.; Ely, J.H.; Lintereur, A.T.; Mace, E.K.; Stephens, D.L.; Woodring, M.L.
4. **Application of PWO crystals for detection of low-activity gamma-radiation in the energy range above 3MeV**
   Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 537, Issue 1-2, January 2005, Pages 439-442
   Drobychev, G.Y.; Baryshevsky, V.G.; Fedorov, A.A.; Khruschinsky, A.A.; Korjik, M.V.; Lecoq, P.; Missevitch, O.V.

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[GEANT4—a simulation toolkit](#) — [PDF] from kobe-u.ac.jp
S Agostinelli, J Allison, K Amako… - 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 5000 - Related articles - All 29 versions

[Geant4 developments and applications](#) — [PDF] from neu.edu
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 929 - Related articles - BL Direct - All 16 versions

[CITATION] **Geant4**: a simulation toolkit
J **Geant4** Collaboration - Nucl. Instr. and Methods A, 2003
Cited by 70 - Related articles

[Geant4 low energy electromagnetic physics](#) — [PDF] from infn.it
S Chauvie, S Guatelli, V Ivanchenko… - … Record, 2004 IEEE, 2004 - ieeexplore.ieee.org
Abstract The **Geant4** simulation toolkit includes a specialised package, implementing a precise treatment of electromagnetic interactions of particles with matter below 1 keV. The **Geant4** low energy electromagnetic package provides a variety of models describing the …
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[GATE: A Geant4-based simulation platform for PET and SPECT integrating movement and time management](#) — [RTF] from ciemat.es
G Santin, D Strul, D Lazaro, L Simon… - Nuclear Science, …, 2003 - ieeexplore.ieee.org
Abstract GATE, the **Geant4** application for tomographic emission, is a simulation platform developed for PET and SPECT. It combines a powerful simulation core, the **Geant4** toolkit, with newly developed software components dedicated to nuclear medicine. In particular, it …
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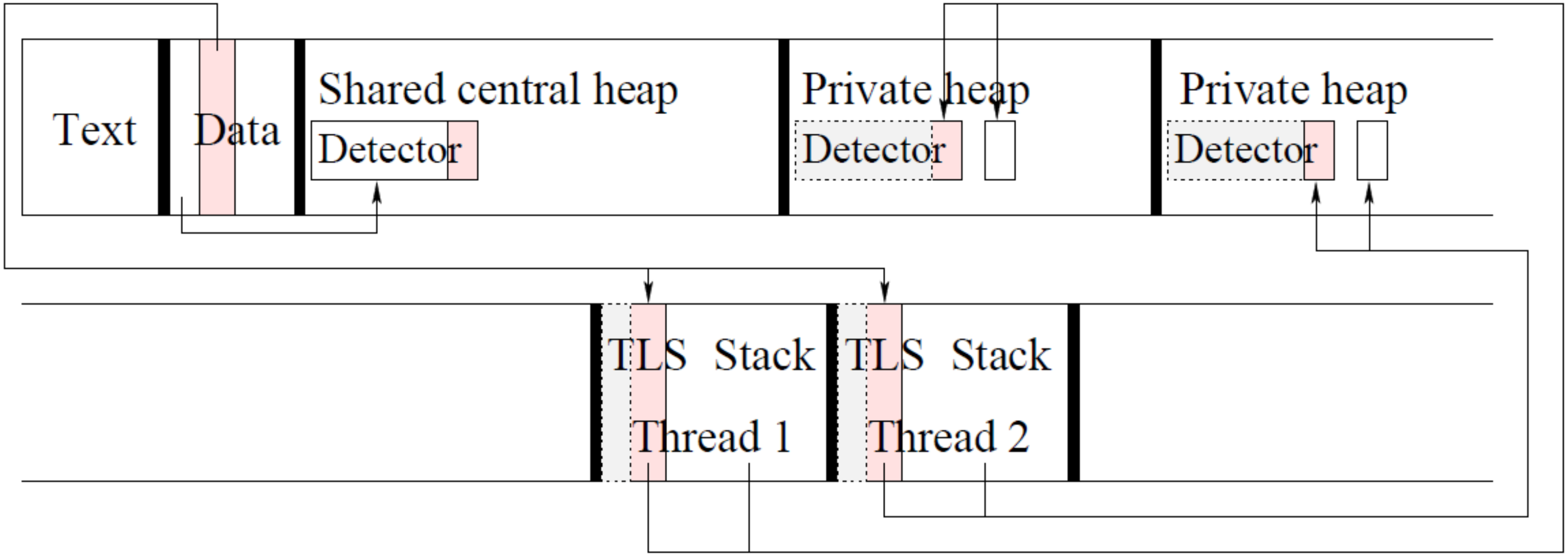
HIGHLIGHTS OF RECENT AND ONGOING DEVELOPMENTS

- Multi-thread Geant4
- Layered Mass Geometry in Parallel World
- Improving Current EM and Hadronic Physics
- Improving Usability
- Collaboration-wide Developments
- Extending Physics Coverage
    - Phonon, activation, chemistry for DNA damages

Multi-threaded Geant4

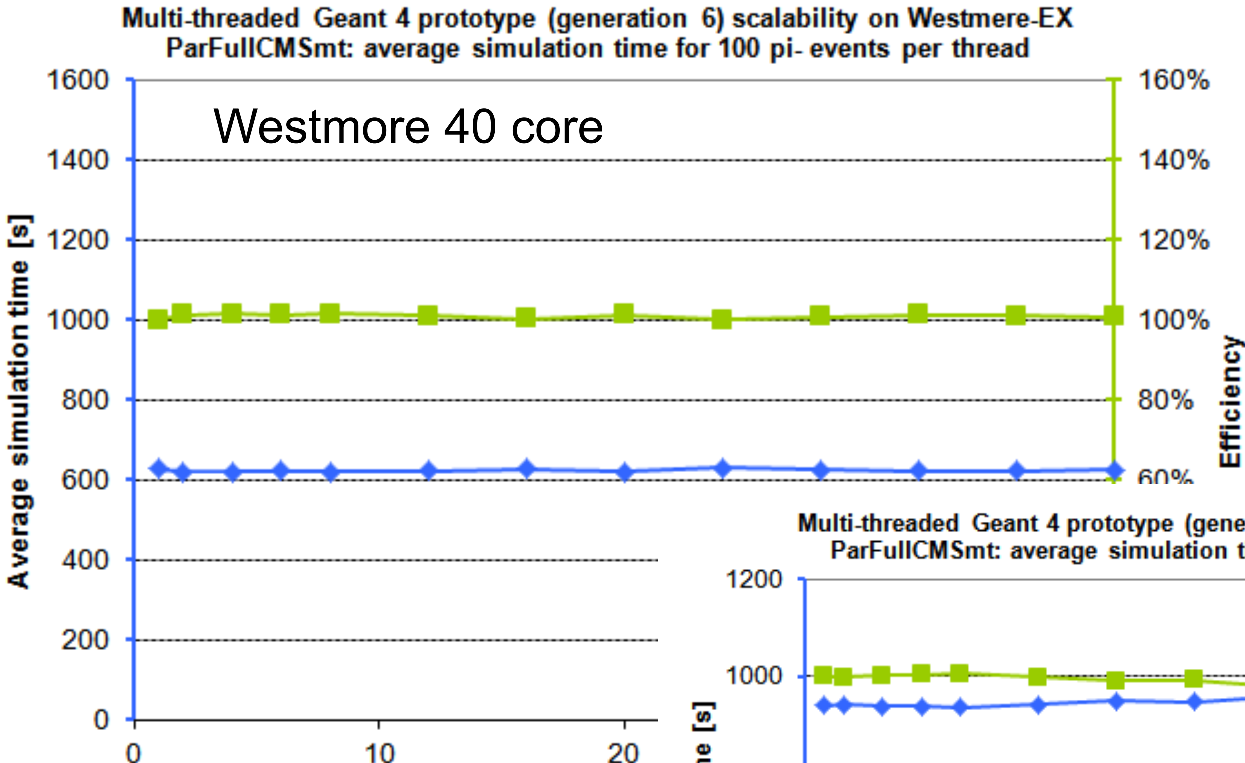
- Offers event-level parallelism within one job with many threads.
- Uses the many-core machine in a memory-efficient scalable manner.
- Shares "relatively read-only data" among threads for memory footprint reduction.
  - Relatively read-only data : data written at initialization phase but kept unchanged during the event loop
- Allocates thread-local heap for transient objects.
  - Full-CMS benchmark showed only 25MB of memory per thread.



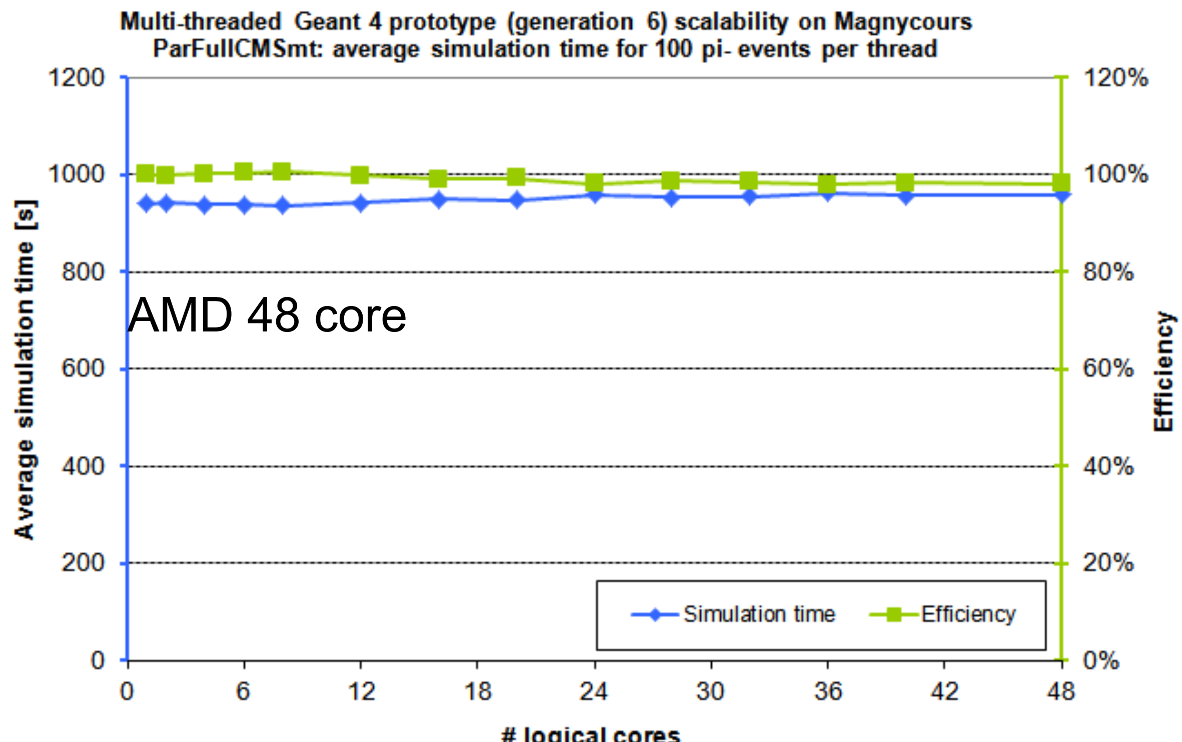
Multi-threaded prototype

- Current prototype release based on v9.4p01
  - Not for production yet
  - Supports all kind of geometries, detector/scoring
  - Current limitations
    - Currently supporting Linux platforms only
    - Batch job only – no interactive GUI / visualization yet adapted
    - Tested only for most common physics lists
  - Requires small user-code migration
- Thanks to pioneer testers, we have identified some issues and most of them have already been solved.
  - Instability for too many threads compared to number of cores
  - Overhead of dynamic loading libraries
- Dedicated HyperNews forum for multi-threading has started.
  - User support and user's feedback
  - We request user's feedback for further improving efficiency and usability.

G4MT prototype has shown excellent scalability



Courtesy of Andrzej Nowak (OpenLab)

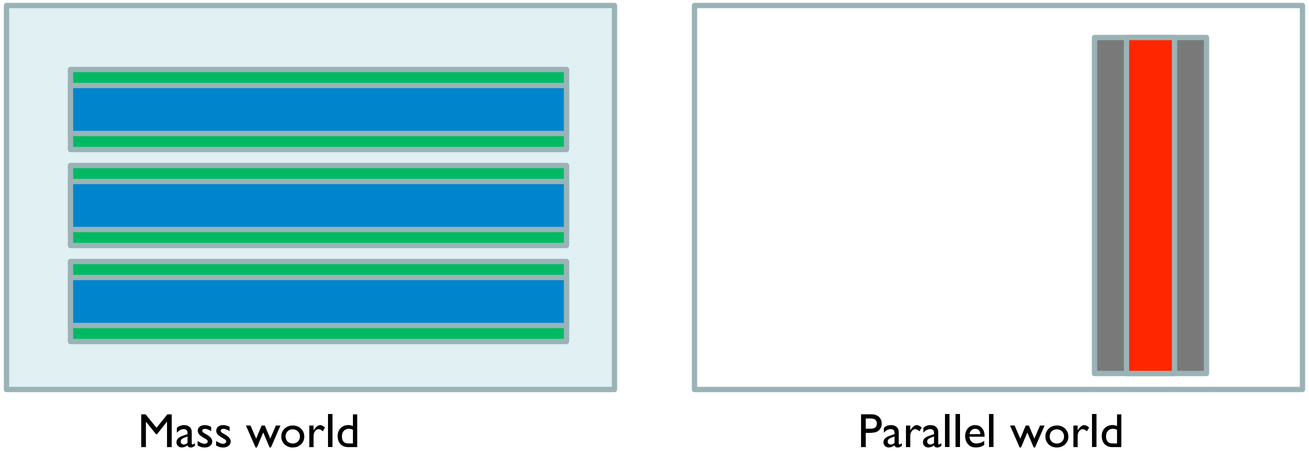


Andrzej Nowak, CERN openlab 2011

Note: scaling was still perfect with using 80 threads on Westmore (2 threads per core). Latest news – G4MT showed perfect scalability for Intel MIC prototype as well.

Layered mass geometries in parallel worlds

- Parallel geometry may be stacked on top of mass geometry or other parallel world geometry, allowing a user to define more than one worlds with materials (and region/cuts).
  - Track will see the material of top-layer, if it is null, then one layer beneath.
  - Alternative way of implementing a complicated geometry
    - Rapid prototyping
    - Safer, more flexible and powerful extension of the concept of “many” in Geant3



Layered mass geometries in parallel worlds

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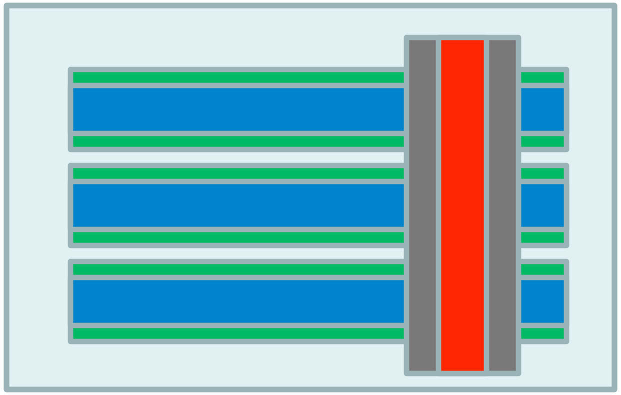
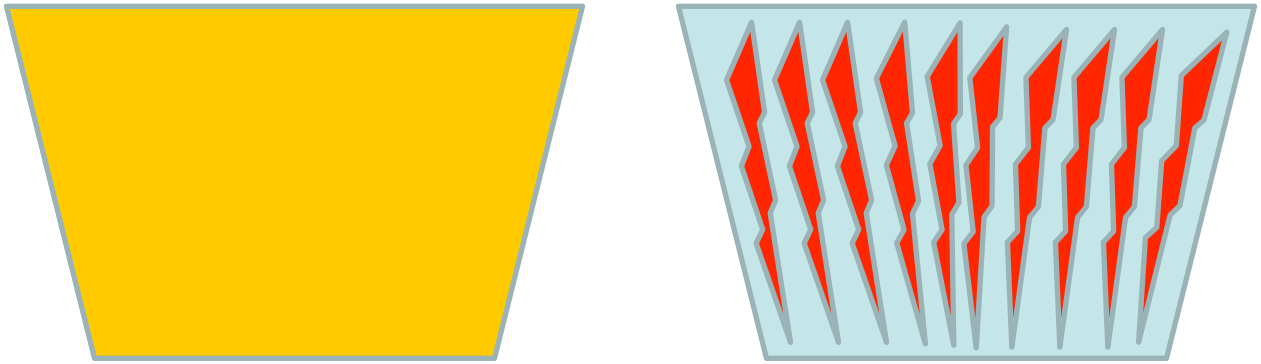


Mass world

Parallel world

Layered mass geometries in parallel worlds - continued

- A parallel world may be associated only to some limited types of particles.
  - May define geometries of different levels of detail for different particle types
  - Example for sampling calorimeter: the mass world defines only the crude geometry with averaged material, while a parallel world with all the detailed geometry. Real materials in detailed parallel world geometry are associated with all particle types except e+, e- and gamma.
    - e+, e- and gamma do not see volume boundaries defined in the parallel world, i.e. their steps won't be limited
  - Shower parameterization such as GFLASH may have its own geometry



Geometry seen by e+, e-, γ Geometry seen by other particles

EM Physics

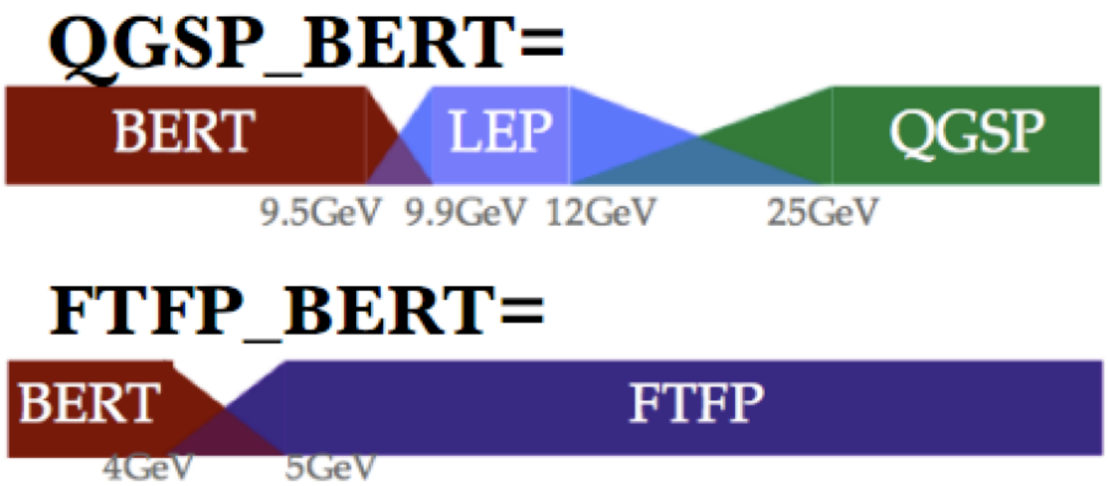
- Electromagnetic physics is of primary importance
  - since visible energy of hadrons is from ionization and bremsstrahlung.
  - electromagnetic component in a hadronic shower: $\pi^0 \rightarrow \gamma\ \gamma$

- For the main observables, Geant4 electromagnetic physics describes the experimental data with agreement within 1%.

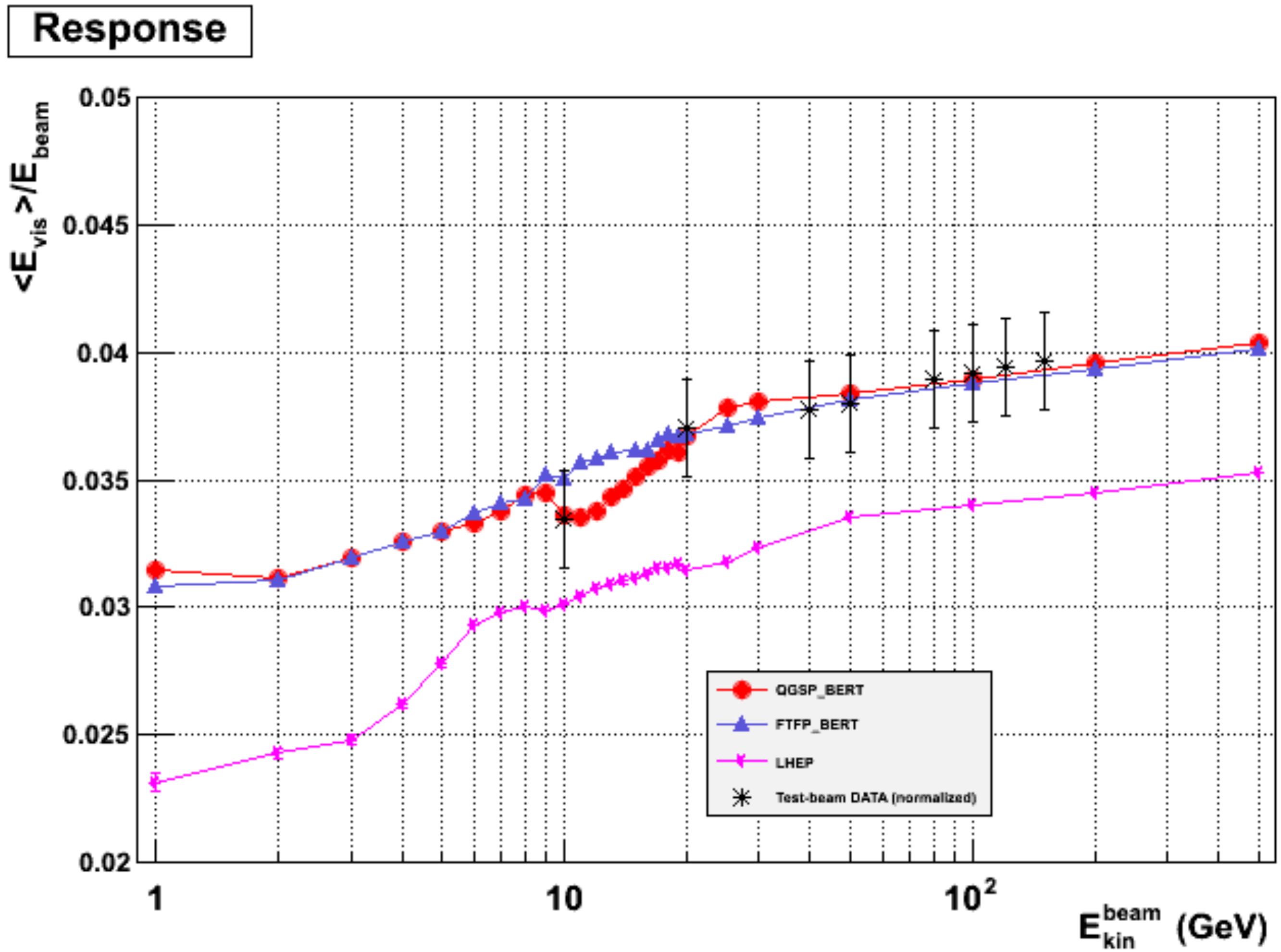
- We are now concentrating on the points of G4 electromagnetic physics, where the disagreement with data is above 1%, and work is on-going.
  - *ATLAS, CALICE, and CMS report that Geant4 electron shower lateral profiles agree on the core but are slightly (1 - 2%) narrower in the tails.*
  - These issues are due to a fast and approximate description of our models, or because of medium and atomic physics effects.

Hadronic physics for production

- Evolution of Geant4 physics lists used in production by LHC experiments:
  LHEP → QGSP → QGSP_BERT → FTFP_BERT
- We currently offer three production physics lists.
  - FTFP_BERT : recommended
  - QGSP_FTFP_BERT : transition / conservative
  - QGSP_BERT : legacy / stable
- Now the spine of Geant4 hadronic physics is made of FTF_BERT_Preco.



Energy response vs. beam energy



FTFP_BERT has a smoother energy response than QGSP_BERT

Improvement in usability

- Removal of ordering numbers in physics list
  - Automatic consistency check
  - Ease of combining physics builders, adding a process to “pre-packaged” physics list
- Unifying error/warning message format
  - At v9.5, all the warning/error messages have the same banner and footer.
  - “cout”/”cerr” destinations are user-configurable.
  - Enables automated detection of warning/error messages embedded in output files of massive production runs.
- Restructuring and polishing examples

CMake, CLHEP

- In version 9.5, the CMake system for installation replaced the old Configure-based installation script. CMake has been extended to cover all features including download of data files.
  - GNUMake build scripts are still available for user's applications for backward compatibility sake.

- Geant4 now comes with an embedded CLHEP module (based for this release on version 2.1.1.0 of CLHEP), which includes the subset of CLHEP library classes required by Geant4. With the CMake system, the embedded CLHEP is selected by default.
  - On installation there is a choice between using this embedded module or installing CLHEP as an external library.

- With these two changes, installation of Geant4 libraries is now much more straightforward.

Collaboration-wide developments in 2012-2013 (1)

- Performance improvements
  - Design iterations for some kernel classes
    - Cache-hit-rate improvement, reduction of virtual abstract layers, avoiding too deep recursive calls, etc.
  - Review implementations of physics and transportation
    - Much of this code was implemented without computing performance in mind.
    - We must not lose physics performance, though. Massive verifications are required.
  - Changes must be transparent to user's code (at least for average users).

Collaboration-wide developments in 2012-2013 (2)

- Event/track level full reproducibility
  - Recently ATLAS identified a bug, which occurs 20 times in 1 billion events (each event has millions of interactions).
    - But these 20 events were so significant that they all passed all the ATLAS event filters.
  - To pinpoint the problem, we do need event/track level full reproducibility.
    - As long as it starts with the same random number engine status, it should regenerate exactly the same result regardless of other conditions.
      - In particular, as we shift to multi-threading, we cannot reproduce the problem without track level reproducibility.
  - Many of the causes have already been identified and solved.
  - Thanks to our Northeastern colleagues, we now have a couple of tools to identify the “break point”.
    - These tools must be useful for user’s code as well.

Collaboration-wide developments in 2012-2013 (3)

- Event biasing options
  - Review, unify and enrich existing biasing options
  - Review interface between processes and tracking for forced-interaction and forced-flight biasing
    - Prototype of (multi-)differential cross-section for process-based biasing and reverse-MC
  - Coherent treatment of track weights
    - Tracks which are not interacting with biased process are also biased.

General Status

- Currently launching MC12 production campaign
  - ~3500M events will be produced (2000M G4 only, 1500M G4-hybrid)
  - G4 9.4 p3 in production, from G4 9.4 p1 in MC11
- Understood the desire to develop only FTFP_BERT
  - ATLAS is validating the move from QGSP_BERT in MC12
- Developing for MC13, expect freezing around ~Dec.
  - Anticipating using G4 9.5, possibly with G4 internal CLHEP version (if ATLAS doesn't move to 2.X in time)
- Major infrastructure revisions underway
  - Integrated Simulation Framework to combine Geant4 simulation with "fast" simulation flavors in the same event
  - Will feed back to G4 developers any interesting issues that arise during development and benchmarking (G4 developers on the review team)
  - Hoping to take advantage of the parallel geometry developments and some other parallelism developments that have come up in G4 – but memory is still not an issue for us, so large-scale parallelism is not yet necessary.
- Still, the finalization of MC12 took us quite a while…

Multithreading

Plan for new multithreaded application

Will process multiple events simultaneously
Will run multiple modules processing the same event simultaneously
This will all be controlled explicitly by the application

All parts need to work within one concurrency model

Present application is memory resource limited
- in future may not be able to afford 2GB / CPU core

Each additional thread requires its own stack
- default size on SL5 is 10MB/stack

One concurrency model will allow use of only one thread pool
- minimizes memory
- avoids oversubscribing available cores

Interested in Geant-MT if it can fit with this working model

Where concurrency is controlled by the experiment's application
- E.g. Application calls specific Geant methods at proper time from a thread controlled by application

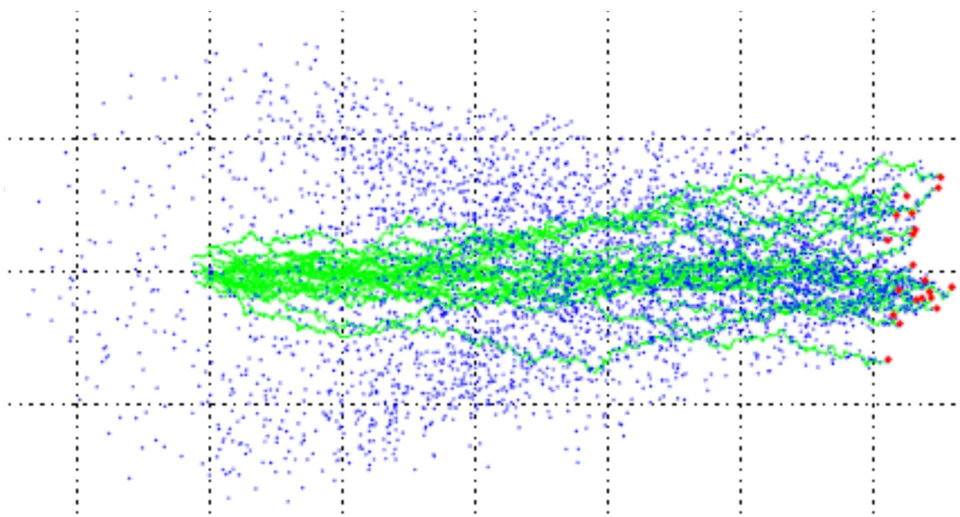
Collaboration-wide developments in 2012-2013 (4)

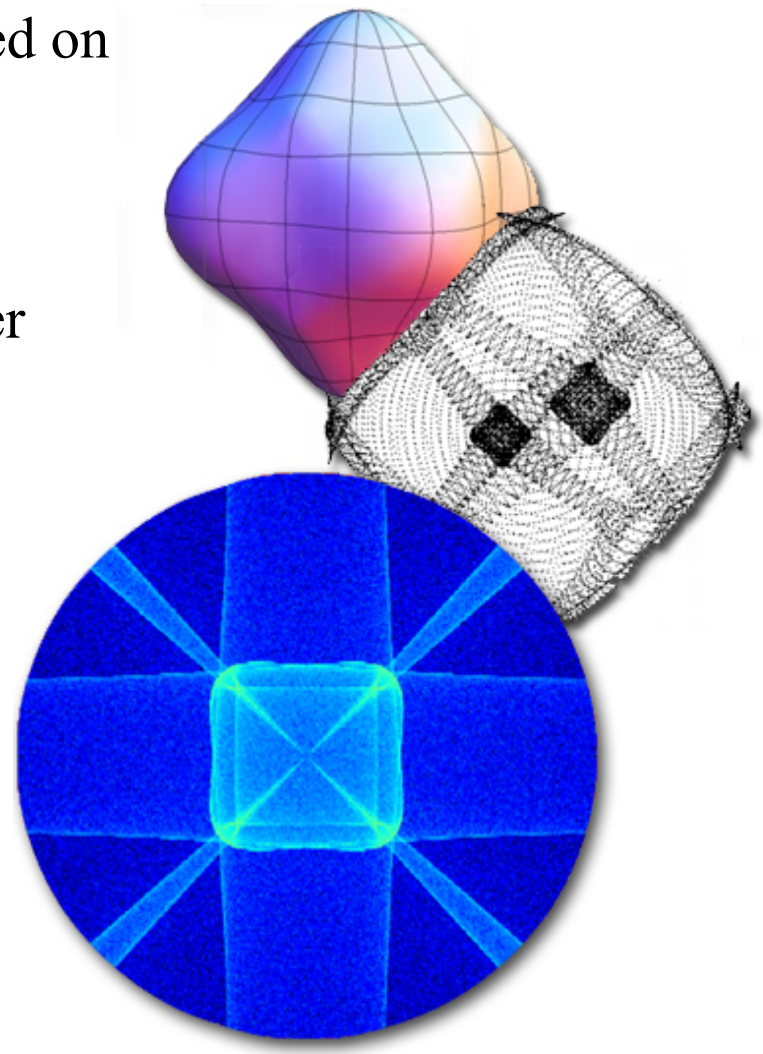
- Geant4-MT
  - A few more prototype releases for every Geant4 patch releases in 2012
    - G4MT v9.5-p01 will be released in a couple of weeks
  - Improving usability in particular for external “frameworks”
  - Catching up all performance improvements by design iterations
  - Confirming no performance penalty for single-thread execution
  - G4MT v9.6 at the end of 2012 or early 2013 will be the final prototype release
  - In 2013 we will merge G4MT into the main code base
- Year 2012-2013
  - We anticipate version 9.6 at the end of this year will be the final minor release of Geant4 version 9 series.
    - Release of 2013 (November 2013) will be a major release
  - Geant4 version X (name t.b.c.)
    - Multi-thread capable
    - Minimal migration cost
    - (First) beta release in June 2013

Condensed Matter Physics in Geant4

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

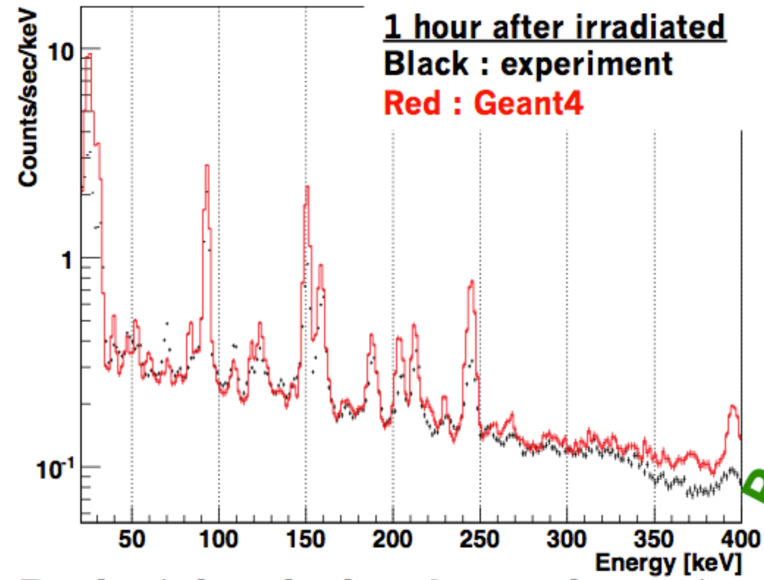
- e-/h+ transport, including conduction band anisotropy and Luke-Neganov emission, under development (below)

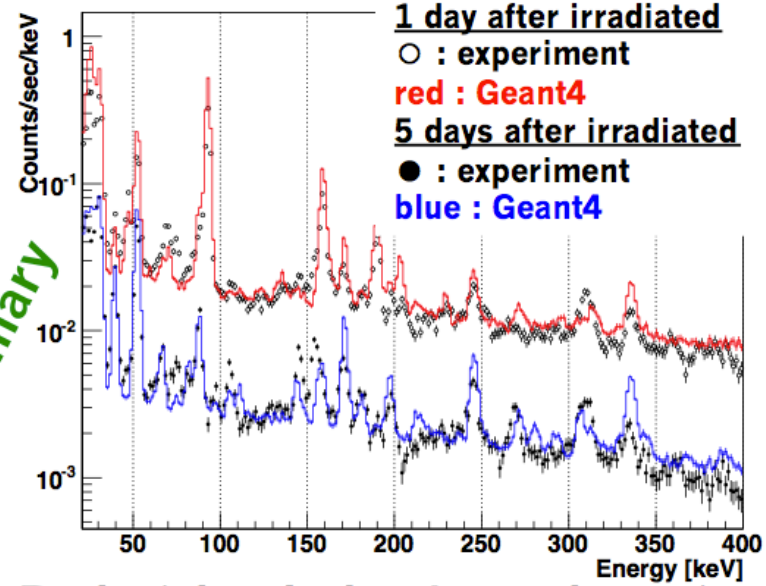




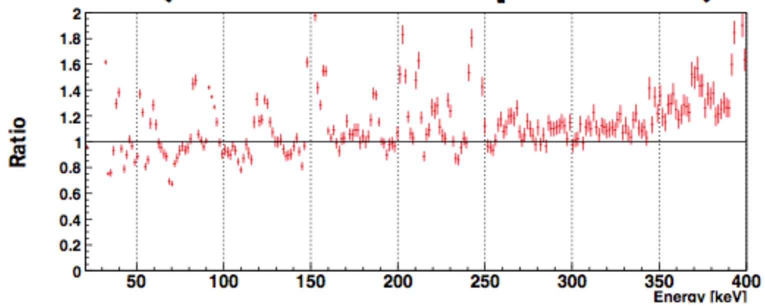
Time evolution of the activation background

Comparison with Geant4

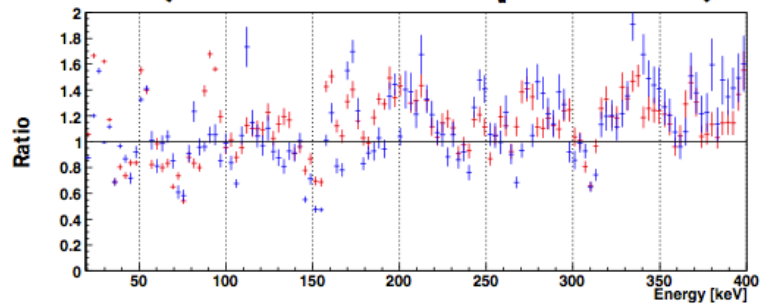




Ratio (simulation/experiment)



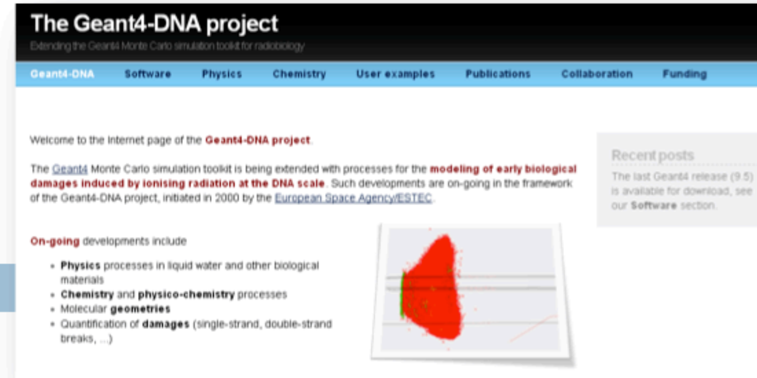
Ratio (simulation/experiment)



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

The Geant4-DNA project

http://geant4-dna.org



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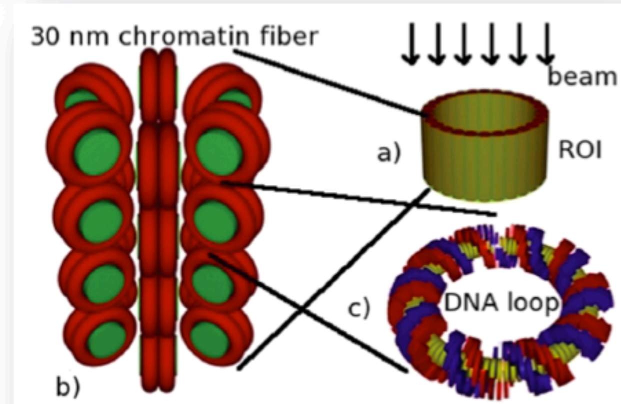
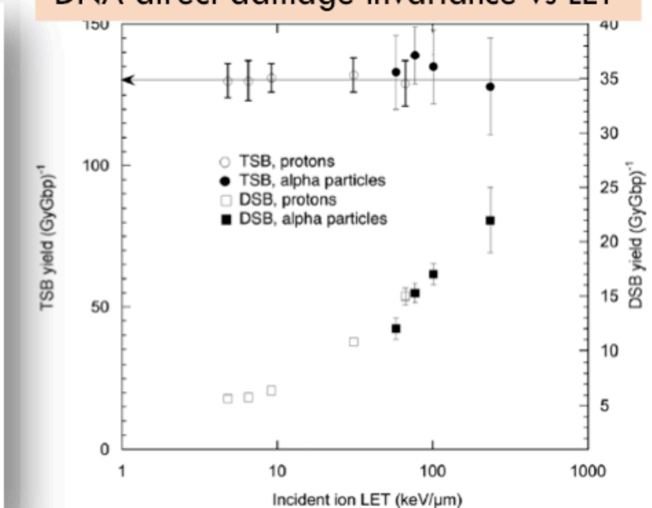
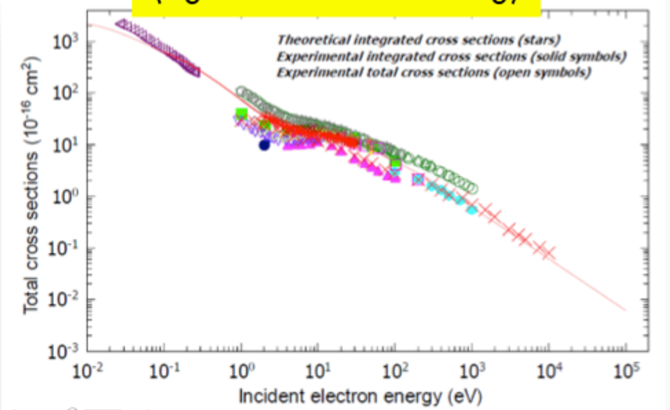
- Initiated in 2001 by the European Space Agency
- Purpose
  - extend Geant4 capabilities for the modelling of early DNA damages from ionising radiation in biological cells
  - including physical and physico-chemistry processes
    - water radiolysis
  - down to the eV and nanometer scales
- Status
  - A full component of the Geant4 toolkit



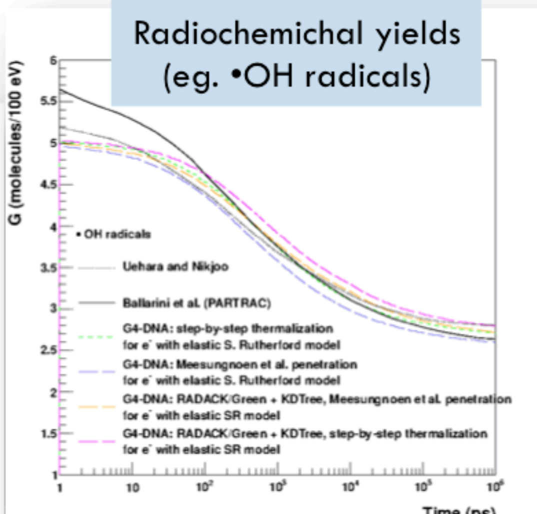
DNA direct damage invariance vs LET



Accurate physics models (eg. e- elastic scattering)



Radiochemichal yields (eg. •OH radicals)



FUTURE AND OPPORTUNITIES

New trends

- New trends
  - Hardware : GPGPU, Intel new generation chips, etc.
  - Programming language : CUDA, OpenCL, DSL, etc.
- The Geant4 Collaboration acknowledges several pilot / prototyping projects worldwide which pursue major architectural revision of Geant4.
  - Concurrency project at CERN and FNAL
  - “Transforming Geant4” initiative at DOE Office of Science
  - GPGPU projects at Stanford, in Europe, in Japan
  - Etc.

Futures

- We are eager to make Geant4 faster.
  - Without sacrificing functionality, physics performance, flexibility.
  - Evolutionary rather than revolutionary.
    - Won't cause user's rewrite-from-scratch.
  - We also want to be free from specific hardware / programming paradigm.
- We will keep eyes on new trends, keep in touch and/or participating with projects which explore them, and get whatever the useful bits into our design iterations. For example,
  - Through concurrency project at CERN/FNAL, we expect to learn the most efficient way of grouping tracks to improve cache-hit-rate.
  - Through "transforming Geant4" initiative at DOE Office of Science, we expect to improve algorithm and cache-hit-rate.
  - Through SLAC/Stanford/NVIDIA project, we expect to learn the most efficient way to deal a large data table (e.g. a large cross-section table) in terms of memory/cache.

To sum up

- Geant4 is now in its 14th year of production phase.
- Despite its age, it is yet evolving and being enriched with new functionalities.
  - This demonstrates the advantage of the use of OO technologies.
  - And shows the appropriateness of the early design adopted 18 years ago.
- Improvement of physics quality and speed remains a priority to Geant4.
  - Tackling the percent-level inaccuracies in EM physics is the current challenge.
  - Large invests in hadronics physics have lead to a “Darwinian” emergence of the FTF_BERT_Preco physics configuration, which looks to be on track for an “universal” response to hadronics physics needs.
- New technologies trigger in-depth rethinking of simulation paradigm.
  - Many options, many possibilities,
- Geant4 has accommodated part of these by providing a multi-threading prototype, based on event-parallelism.
  - That will become the Geant4 baseline by 2013.
- We keep eyes on all other opportunities, with the sake of keeping the plane flying.