The Geant4 Toolkit: Evolution and Status

John Apostolakis & Makoto Asai for
the Geant4 Collaboration

Outline

- Geant4 introduction and Application Areas
- New kernel capabilities
- Physics model improvement, tuning
  - EM Physics – new models
  - Hadronic Physics model improvement
- Computing Performance and Multi-core
- In each case, only highlights are shown
  - These slides can be found at http://bit.ly/g4mc2010

Geant4 Introduction

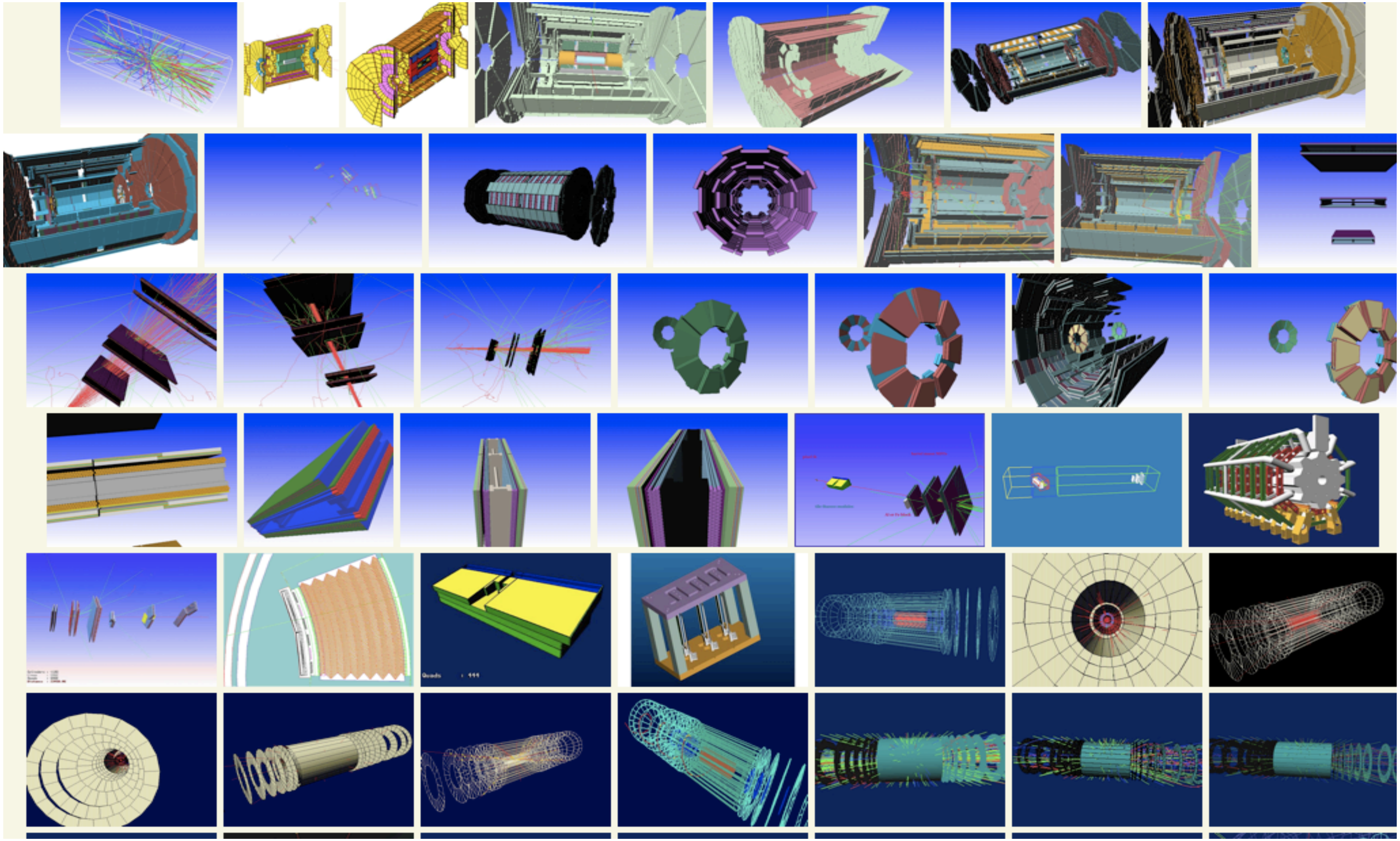
Application Domains

A tour of tools based on Geant4

Geant4 toolkit on one slide

- Mature, extensible kernel
  - Powerful geometry modeler, E/B fields, track stacking
- Diverse set Physics models (mostly 2 alternatives)
  - e-/e+/gamma 10s eV to TeV
  - Hadron-nucleus interactions up to 1 TeV
  - Neutron interactions from thermal to 1 TeV
  - Ion-ion interaction from 100s MeV/n to 10 GeV/n
  - Optical, weak (decay of unstable and radioactivity)
- Tools for input, output, visualization, scripting
- Every increasing use
  - Over 2000 citations for G4 NIMA paper (2003)
- Product of collaboration of 90 contributors
  - Effort: HEP (75%), Biology/medical (15-20%), space (5-10%).
- Open Source: Distributed via web. G4 license since 2006.

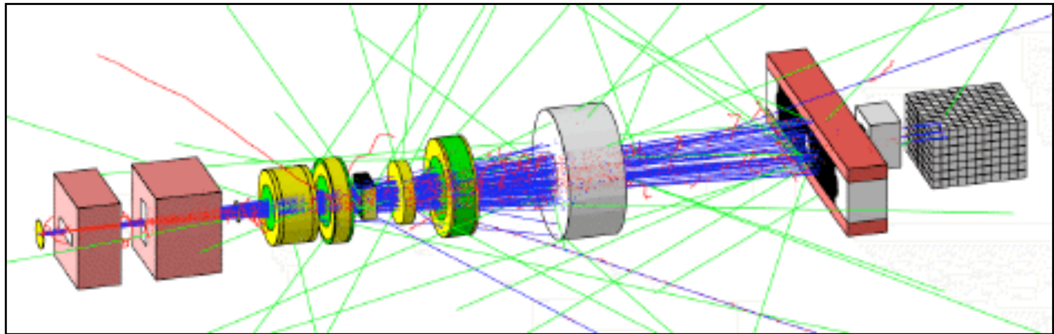
High Energy Physics Experiments

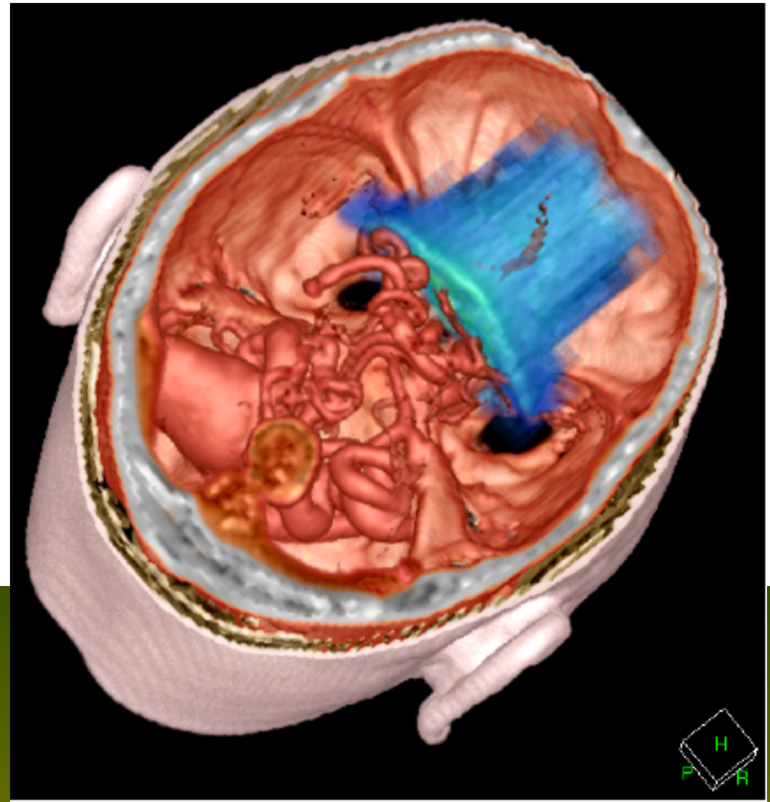


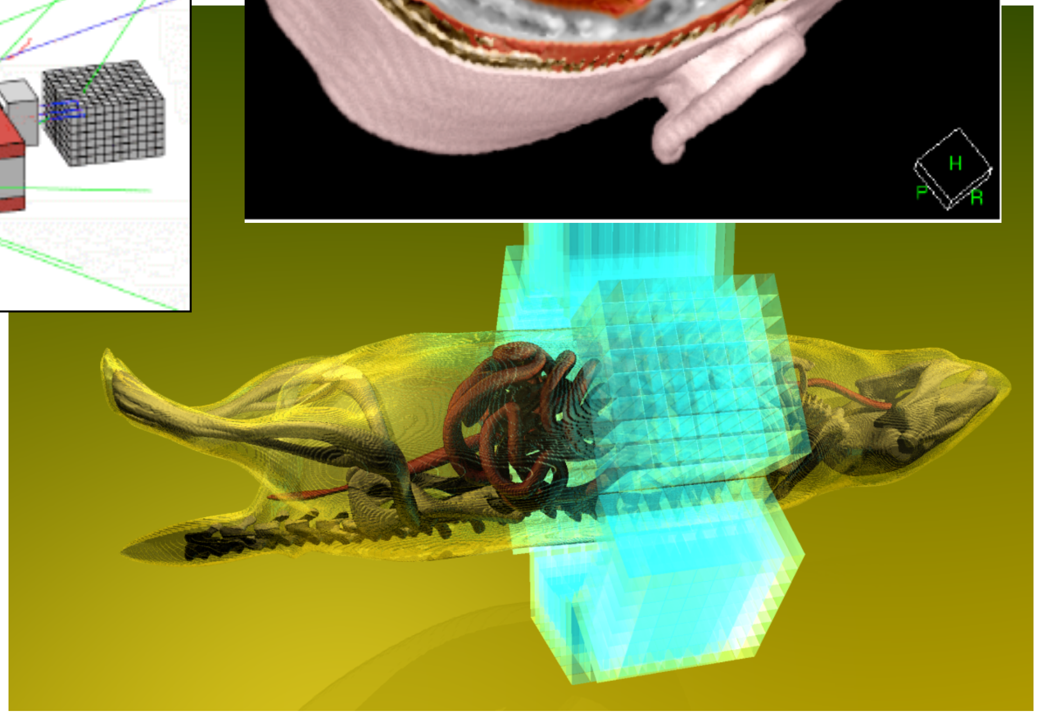
Space: radiation effects, science

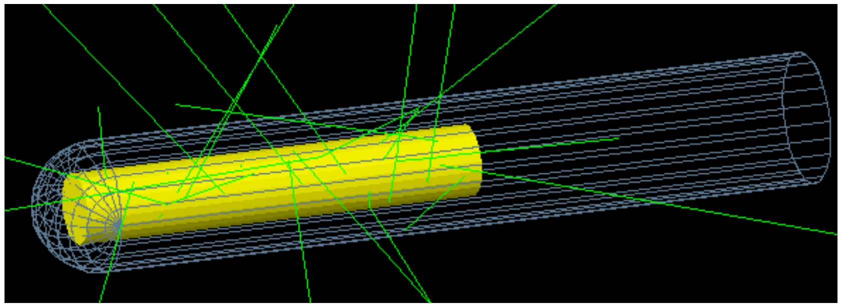
Geant4 @ Medical Science

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









Application Areas

- Established as the leading tool for the simulation of detector response for High Energy Physics (HEP) experiments
  - Used at ATLAS, CMS and LHCb as the production simulation (the fourth large LHC experiment is preparing to use it in production)
  - Used in a large number of smaller experiments, in nuclear physics, dark matter searches, ..
- Widely used in medical applications
  - Radiotherapy (external and brachytherapy)
  - Medical imaging
- Space
  - Satellite electronics radiation assessment
  - Planetary science applications.

Tools based on Geant4 (sample)

Medical physics

- GATE
  - Tomography/dosimetry*
  - Widely used, cited.
- Tools for radiotherapy
  - PTSim
  - Hadrontherapy
  - GAMOS

  Each is presented in E5 (Wed)

Accelerator beamline:

- G4BEAMLINE
- BDS-SIM

Medical phys., accelerators

- HEP: "Version1" of Detectors
  - SLIC
- Space radiation and environment tools
  - GRAS (radiation analysis)
  - Planetocosmics (planet environment),
  - SPENVIS
  - CRÈME-MC
  - MULASSIS (shielding)

HEP, Space

Geant4 Physics

A lightning update

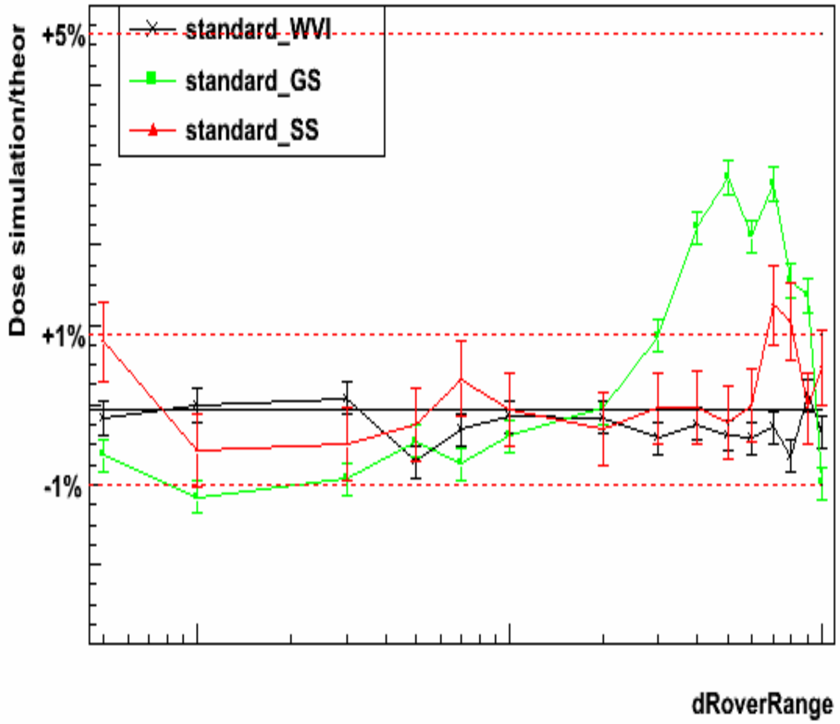
EM Physics

- Many model refinements
  - See EM talk*
- Converged on unified design for EM models
  - Anyone can combine models for a process
  - Choosing ‘best’ of lowE and Standard packages.
- Validation extended
  - Suite of 15 tests and over 200 thin-target cases
  - Regular regression cross-checks for EM calorimeter performance

*Talk by V. Ivantchenko (Session I2, Wednesday 16:00-18:30)

Multiple Scattering

- Improvement of MS
  - New step limitation
  - Greater stability
- Benchmarking PBM paper
- Models tuned for e-, p, μ



Hadronic Physics

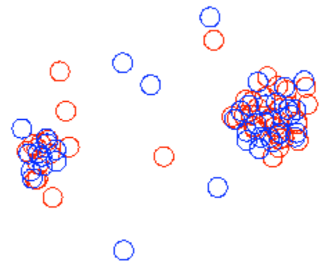
- FTF, CHIPS models improved, extended
  - FTF now works down to 3 GeV (overlap with cascade), improved and retuned
    - Details in talk of V. Uzhinskiy (moved to J2 - Thursday)
  - CHIPS: new model for hadron-nucleus interactions.
- Bertini cascade: improved pion cross-sections
  - Poster PB #16
- Improvement in elastic, quasi-elastic interactions
  - New quasi-elastic at high energy (CHIPS for QGS, FTF)
  - Improved cross sections for elastic scattering
- Improved Pre-compound / de-excitation
  - Precompound: revised cross-sections, transition
  - SMM corrections (from original authors)
  - Mix simple and GEM evaporation
    - Details is talk of J.M. Quesada (previous talk- was J2 session)

Overview of G4 Hadronic Improvements: D. Wright, J2 Thur.

Ion-ion interactions

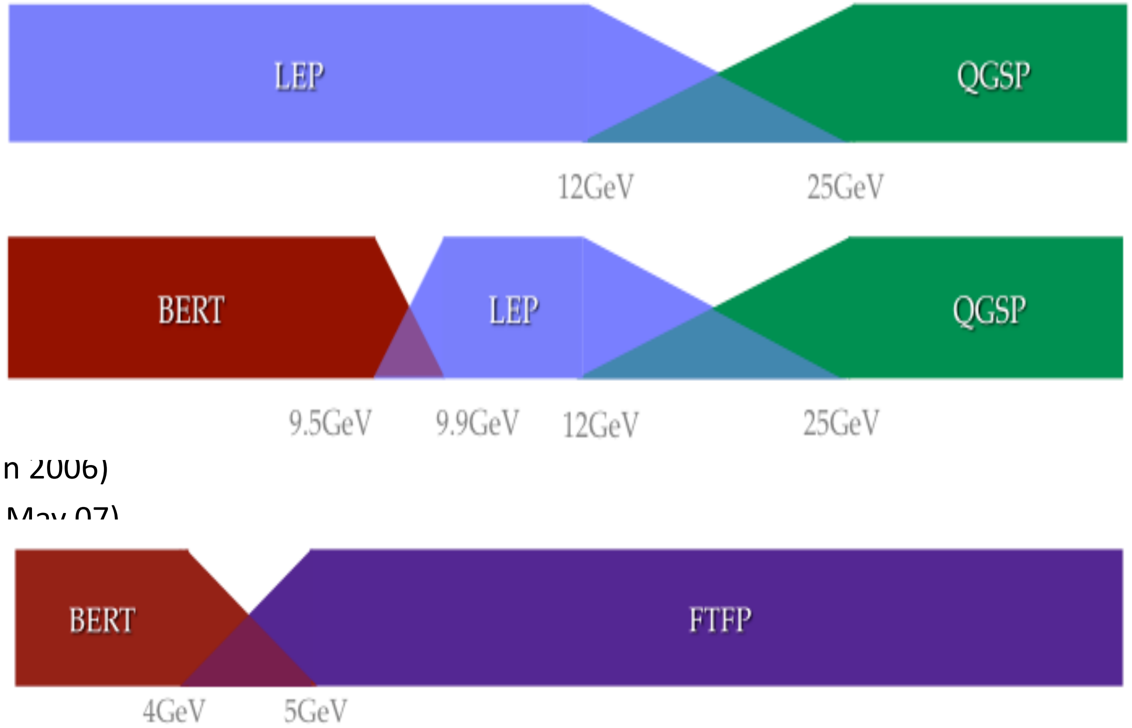
- 'Previous', older models
  - Binary light-ion cascade (BLIC)
    - E<10 GeV/A; projectiles: C or lighter
  - Abrasion / ablation
- New Interface to DPMJET 2.5
  - Created for space applications (funded by ESA)
- New native QMD model (G4QMD)
  - Borrows from JQMD
    - nucleus creation method and potential
  - Uses scatterer of Binary cascade
    - See talk by T. Koi (J1 - earlier)

G4 QMD reaction



Fe 290MeV/n on Al

Example of evolution of <u>production</u> physics lists



- LHEP
- QGSP (2003)
- QGSP_BERT (2007)
  - Adds Bertini cascade
  - Ongoing improvements
    - Revised Mult. Scatt. (G4 8.1, Jun 2006)
    - Improved quasi-elastic(G4 8.3, May 07)
    - Revised elastic ('08)
- FTFP_BERT
  - FTF extension down to 3 GeV (2009)
  - Is not the leading *alternative* to QGSP_BERT

Production physics lists for HEP Applications

Kernel developments

Improved ‘parallel’ geometries

New scoring, via UI commands

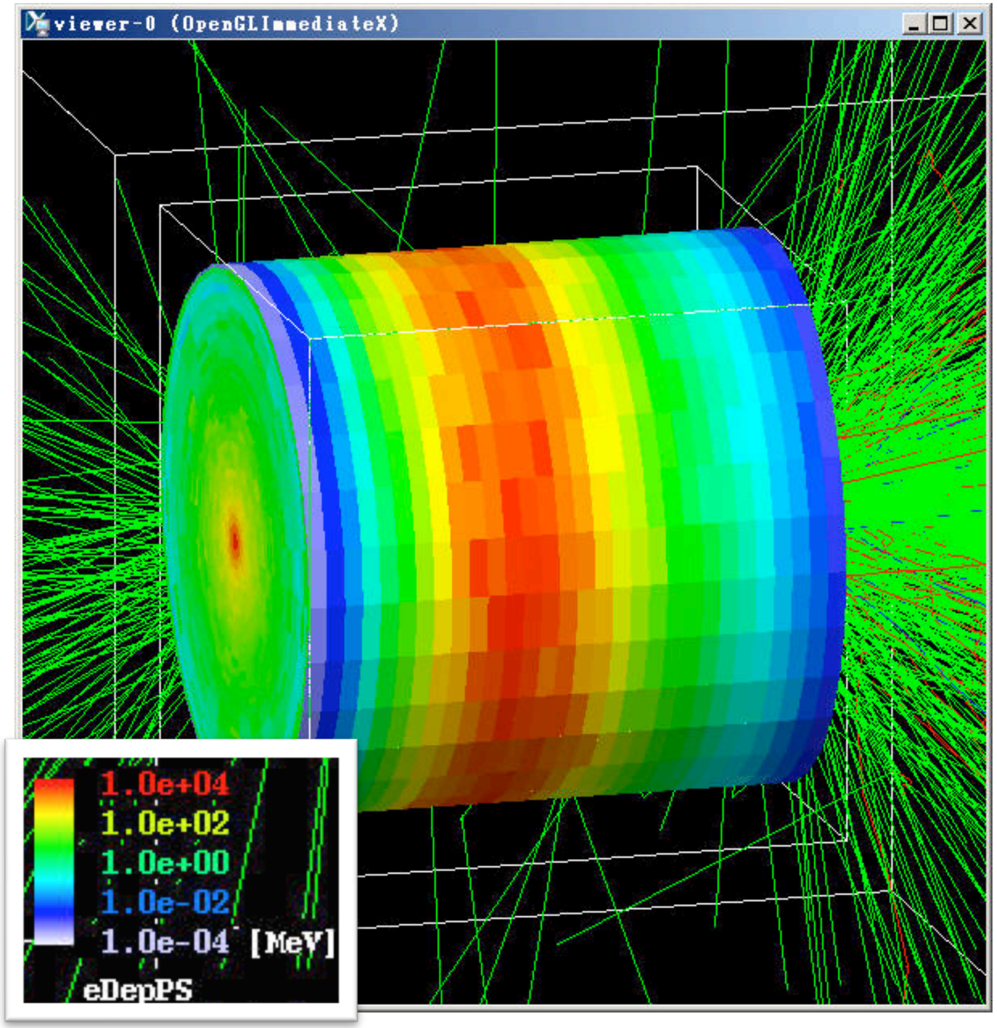
Propagating tracks back in time

Parallel geometries

- Joint navigation in two or more geometries
  - Step is limited by first boundary found
  - Replaces & extends earlier case-by-case abilities (1998, 2003)
- Many uses in toolkit already
  - Materials (‘mass’ geometry) – used for physics
  - Scoring / tallying
  - Importance biasing and weight window
  - Shower parameterization (and other fast simulation)
- Engineered flexible framework – open to additional uses
  - By developers of tools, advanced applications

New Scoring via scripting

- Scoring redesigned,
  - Tallies for does, energy deposition, fluence, ...
- Driven by interactive commands or scripts:
  - Start/stop of scoring
  - Choice of quantities
  - Location, orientation of meshes
- Uses parallel geometry capability
- Scoring via user-defined hits is still possible

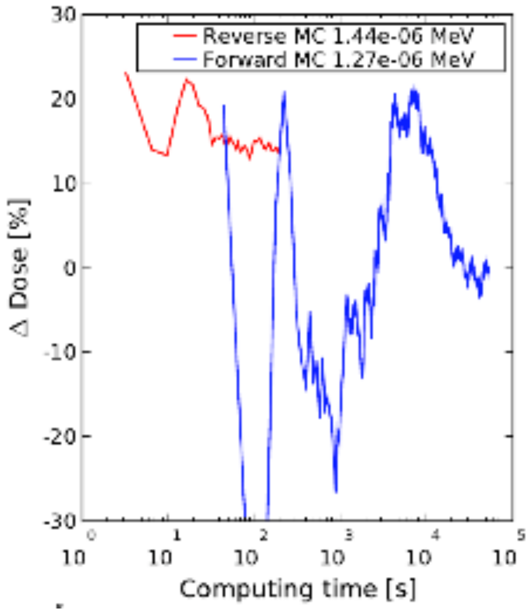


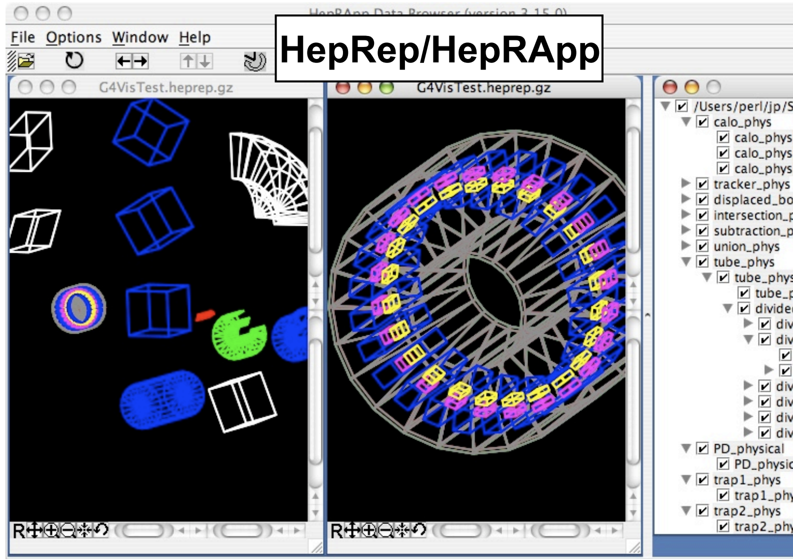
Reverse Monte Carlo

- Tracks e-/gamma/proton back in time
  - from sensitive target volume
  - to an extended source(s).
- Adjoint MC*
  - Continuous gain of energy
  - Multiple scattering
  - Discrete ionisation, bremsstrahlung, Comp photo-electric
- Test cases show 5-15% accuracy
  - 100-500 faster for small target.
- Alternative, 'simple' reversal
  - With propagation of error matrices
  - For track reconstruction (HEP).

*Thanks to Tom Jordan

Results for electron exp(-E/2MeV) spectrum

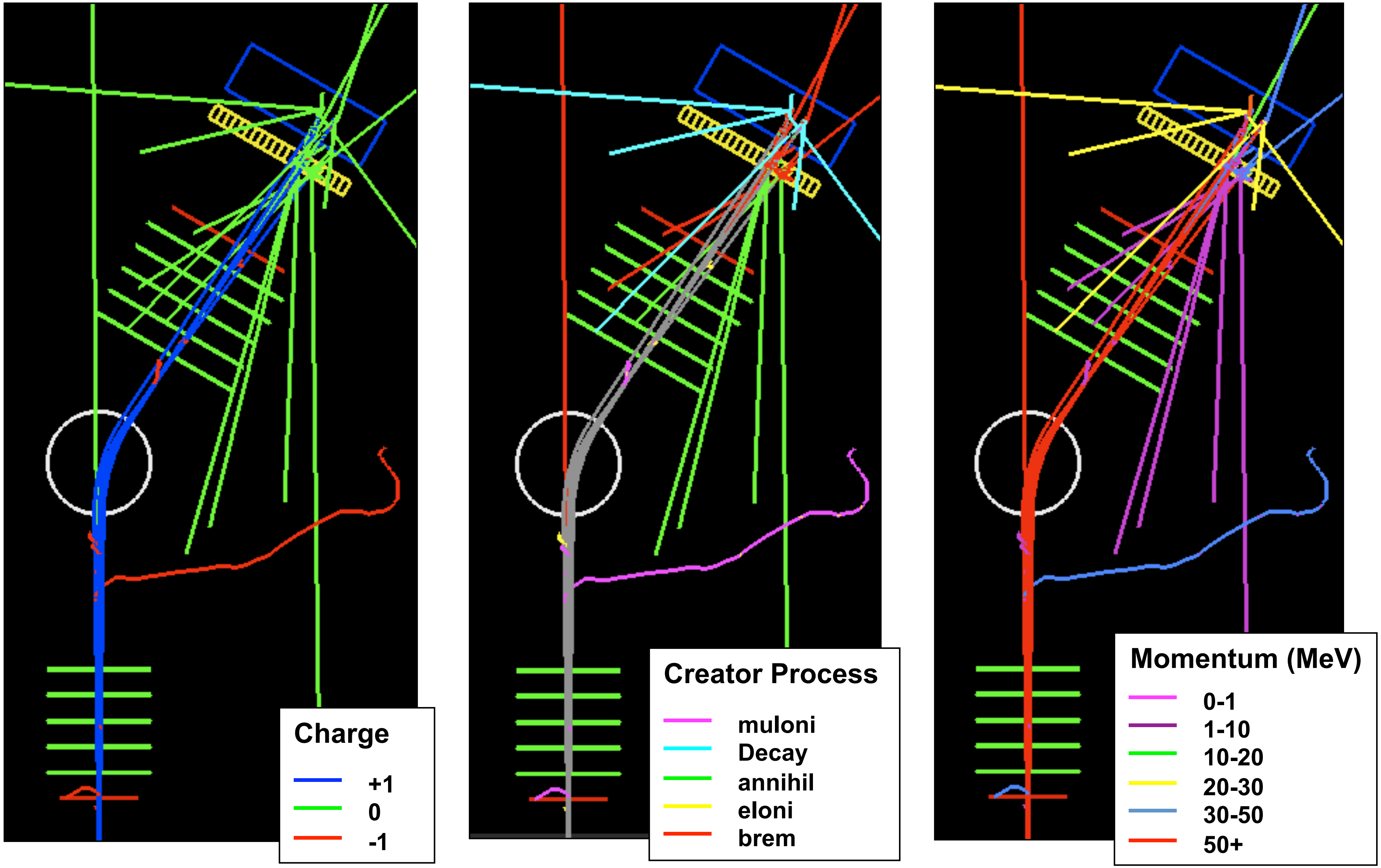




Other toolkit elements

- Expanded visualisation
  - Trajectories “a-la-carte”
  - Hooks to track attributes
- Interactive/GUI-driven environment
  - to explore detector, hits
  - Choice of simple (OpenGL) or full featured interface
    - Joint Qt driver for viz/UI
- Input of geometry description from CAD
  - Tools to translate to GDML, tesselated solids
    - Commercial FASTrad tool (from TRAD)

Trajectories 'a-la-carte'



Computing Performance

"Driving" Applications

Improvements

Multi-core

Computing Performance - *Context*

Computing performance is a significant issue for many communities of users

- Big HEP experiments make large productions
  - Running on 10k CPUs many months each year
- Medical dose estimation need turnaround time
  - accuracy needs => significant statistics
  - use complicated geometries (CT)
- Few sacrifices in physics modeling accepted
  - Need the ‘best’ physics modeling
  - In addition to “as-fast-as-possible” computation
- Backdrop: hardware is now many-core computers

Performance *Improvement*

- Measured measure CPU time & number of memory allocation
  - Tools: standard (valgrind, perfmon2) and custom (igprof, FAST)
  - Undertaken in close collaboration with key user communities
- Eliminated hotspots and frequent causes memory allocation. :
  - Improvements in Bertini cascade (30%), EM Low Energy (25%), step integration in magnetic field (15%), geometry (5-10%).
  - Several improvements (not all) relevant for typical use cases.
- Eased the cost of improved physics modeling in large scale productions (e.g. use of Bertini cascade in HEP.)
  - Afterwards the CPU-time cost has returned to the cost with older versions of the simpler, less precise modeling
    - e.g. parameterised models for E<~18 GeV, as in QGSP physics list

Improvements for voxel geometries

- Navigation in a regular grid of voxels is greatly improved
  - No longer is there a penalty of large memory use.
- New option to ignore boundaries between voxels with the same material and density
  - Real speedups for new "Regular" navigation
    - e.g. of 4 in CT-scan test case with 57 "materials" by skipping boundaries (vs previous 'Nested' method).
    - *P. Arce IEEE/NSS 2008*
- Alternative methods of gluing volume in GATE

CPU TIME SPENT ON TRACKING 1000 GEANTINOS

Vx 1-D	Vx 3-D	Nest	Reg(4)	Reg(57)	Reg(500)	Reg(no)
2030	1.98	1.62	0.30	0.40	0.74	1.45

Parallelism and multi-core

Older efforts / New era

- Distributed-memory Parallel Geant4 (v1=2000)
  - ParGeant4 developed and released (2002) - joint output
- New issue: reduce memory use
  - Multi-process/copy-on-write
    - 70 MB extra/worker (vs. baseline 250MB)
  - Multi-threading
    - Big task – not in original design

Multi-thread prototype

- Developed *prototype* multi-threaded Geant4
    - shares the physics tables and geometry
    - 20MB added per thread
    - 95% efficiency on 32 cores,
      - Bottlenecks fixed in memory allocation, creation of new ion.
- Today's Challenge:
  - Whether/how to incorporate into code repository.

Summary

- Several Physics model improvements
  - EM physics from 10s eV to TeV
  - Hadron-nucleus models up to TeVs.
- Improved Computing Performance
  - Multi-core alternatives investigated
- IMPACT - Very wide use in diverse fields
  - Many tools based on G4 for diverse fields
  - Over 2000 citations for G4 NIMA paper (2003)
- Flexibility, Open Source enable many uses