GEANT4: Release 6.2 Update

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v055

Outline

- Relevant developments until December 2003 (G4 release 6.0)
- Highlights of developments, improvements and fixes in
  - Kernel
  - Physics Processes
  - Physics Lists

  in releases 6.1 (Mar 2003) and 6.2 (June 2004)
- Geant4's use in production
  - Improvements to help identify problems
  - Performance

Notes:

- For more information see *http://cern.ch/geant4/*
  - for full details the release notes at *http://cern.ch/geant4/source/*
  - only some individual attributions mentioned

Geant4 6.0 - general picture

1. New capabilities in Geant4 6.0 for HEP
   - ⌘ EM ('standard') : new 'model' implementation
   - ⌘ Hadronic physics lists ported & included
2. Numerous improvements
   - ⌘ to existing physics modeling & models;
   - ⌘ in physics process implementations;
   - ⌘ extending functionality that existed
3. Fixes, improvements, refinements
   - ⌘ Resulting from the high level of user feedback
     - ⌘ which is reflected in many developments, fixes & improvements

Focus of 6.x releases

- Release 6.0 included
  - New physics models
  - Integrated solutions
    - Physics list for hadronic use cases
  - Redesigned / revised implementations
    - EM (std)
  - Refined functionality
  - Interface changes
- Release 6.1 (Mar 04)
  - Stability improvements
    - For production
  - New tools to identify production issues
  - Fixes / improvements
- Release 6.2 (Mar 04)
  - Additional models
  - Performance focus

The high level of user feedback is reflected in developments, fixes & improvements

Part I: The ‘Kernel’

New developments & improvements
in Geometry, Tracking,
Run & Event handling

Kernel: summary 6.0/6.2

Development

- Modular Run Manager
- Better HEPMC input
- Abstract Navigator
- New Biasing
  - Biasing:“weight-window” technique

Refinements

- General Particle Source
  - Design iteration
- Integration of motion in field
  - Enabled tuning of accuracy parameters for particle type, Energy, …

Improvements

Navigator:

- New ‘*check mode*’
- better verbosity

Fixes

- Corrected ‘safety’ in solids
  - Addressed propagation & photon problems
    - Reported by LHCb
- Fixes for case of missed intersections in field
  - purging magnet example
- Fixes for a 'point outside' problem seen in solids
  - problem in displacement in field

Kernel: Geometry

- Protections & actions for stuck tracks
  - New check in G4Navigator counts zero steps
  - Actions taken:
    - After 10 does corrective action
    - After 25 abandons event

G. Cosmo

- Improved verbosity for checking when navigating
  - 'Check' mode, combined with verbose level=1, prints more information
    - To help identify issues in user geometry or in navigation

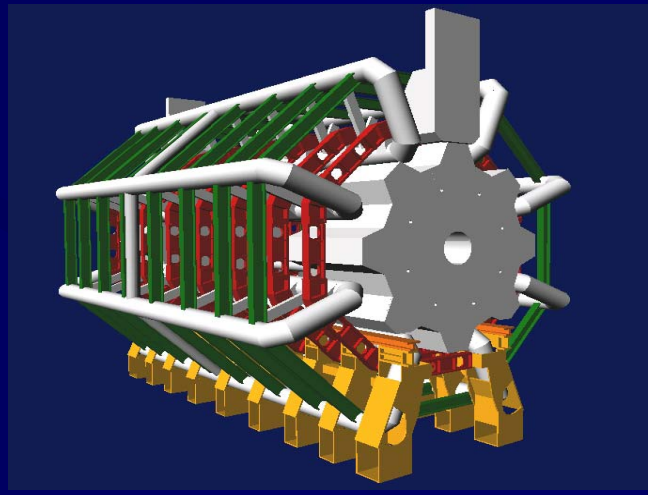
View of Atlas toroid
Courtesy of Atlas

- Reflection of division volumes
  - Experiment request

I. Hrivnacova

- Solids:
  - Framework for twisted solids (derived/refined)
  - New `G4TwistedTubs` shape

O. Link

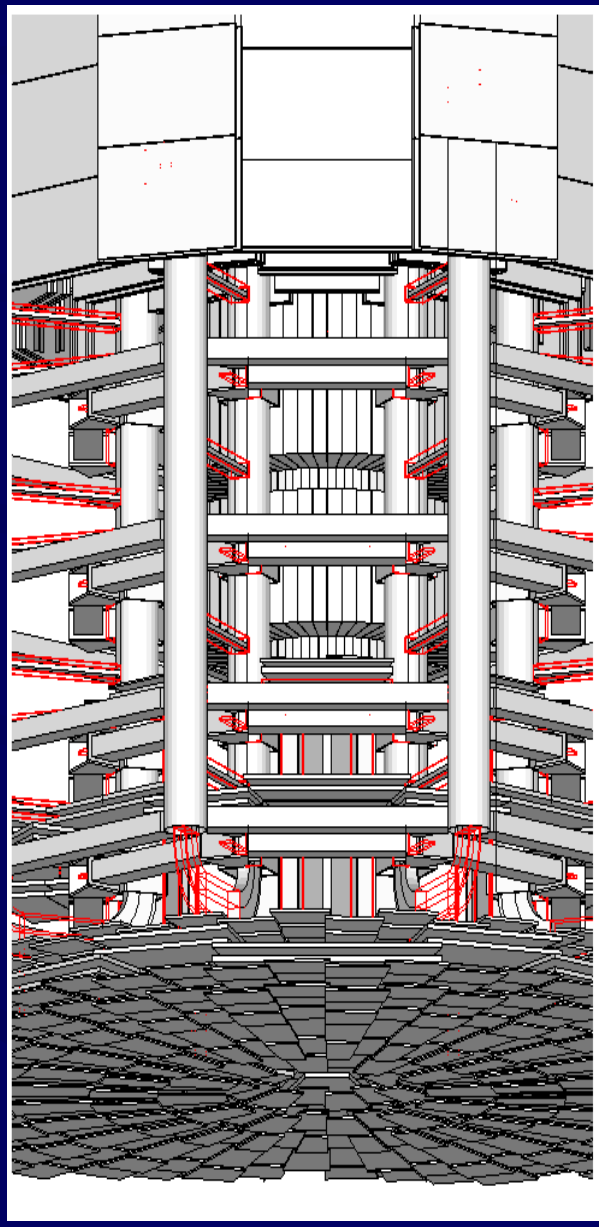


Kernel: Identifying geometry issues

- It is easy to create *overlapping* volumes
  - During tracking Geant4 has not performed check for malformed geometries
- Added new ability to perform checks of the navigation & model geometry (J.Apostolakis & G.Cosmo)
  - New 'check mode'
    - Available unless G4_NO_VERBOSE environment variable is set when compiling the Geant4 installation
  - More message to aid users/developers in identifying issue

Note: The full problem of detecting 'significant' *overlaps* is now addressed by the specialised tools:

- Commands for verification (DC Williams; G Cosmo)
- DAVID intersects graphics volumes (S. Tanaka)
- Example with full navigation (M Liendl)



Thanks to S. Tanaka

Kernel 6.2: Hits & Events

- ***Digitization & Hits***
  - G4SDManager, G4SDStructure: added optional argument *warning* to FindSensitiveDetector(pathName, warning), defaulted to true, to eventually exclude warning issued by G4SDManager when sensitive detector is not found.
- ***Event***
  - Design iteration of the G4GeneralParticleSource class:
    - New classes have been added.
      See http://reat.space.qinetiq.com/gps for more details of the changes.
    - New formula for converting integral spectrum to differential one.
  - G4EventManager:
    - Added access methods to G4TrackingManager and G4StackManager.
    - Fixed incorrect behaviour of event abortion requested by BeginOfEventAction().

Part II: Physics

Using the Physics

&

Physics modelling

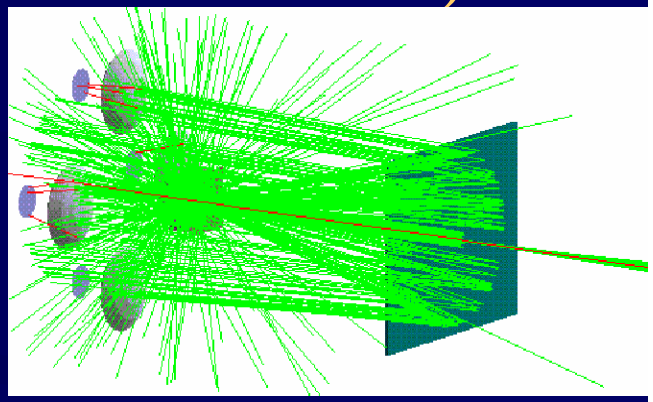
Tailored Physics 'lists'

- "Educated guess" physics lists are for direct use, or as a starting point to modify.
- Revised with experience of comparisons with data
  - Provide 'tested' options, with known performance;
  - The same package is tested for different detector technologies.
- Physics lists for hadronic use-cases updated with
  - New physics models of Geant4 6.0
  - Experience from comparisons (eg Jan-Mar 2004)
  - Latest updates in March 2004 for Geant4 6.0; June for 6.1 / 6.2
- New module for use cases of 'standard' electromagnetic physics
  - Module includes sample physics lists for these standard EM use cases.
- Distribution
  - Included in Geant4 releases
    - Hadronic since Geant4 6.0 (Dec 2003) – ported version for major release
    - Current physics lists version is included in minor releases, patches.
  - Most up-to-date from the G4 hadronic physics web pages
    http://cmsdoc.cern.ch/~hpw/GHAD/HomePage

EM Physics Processes (6.0)

- New "model-based" EM standard physics processes are now the default (since 6.0)
  - for maintaining and refining
  - keeping user code unchanged
    - Old (frozen) implementation is still available
  - Issues encountered in transition
    - Fixed in 6.0 patch 1 and 6.1
- Fix for reproducibility issue
  - Multiple scattering does not use tables (due to ions)
- Refinements
  - Tail of multiple scat. angular distribution
- New in Low Energy EM
  - New models (2BN, 2BS) for Bremstrahlung (Lisbon & INFN)
  - New processes for electrons & positrons (a-la Penelope)

EM Physics Processes (6.1 & more)



- Multiple scattering
  - Tuning for tail of angular distribution
  - Improvement for muons of `E>1 PeV`
- Ionization
  - Updated energy intervals, fluctuation models …
  - Multiple scattering does not use table
    - Needed to ensure repeatability
  - Added PAI (Photon-Absorption-Ionisation) model
- Optical processes
  - New process for wavelength shifting
  - Adoption of `G4SurfaceProperty` class for materials
- Fixed problem reports
  - ionisation in air with low pressure less than 10-4 Atm;
  - in simulation of fluctuation of energy losses in very small steps (performance issue, from ALICE).

EM Physics: 'Standard' / 6.2

- Improvements in Multiple Scattering (MS) model
  - Changed true to geometrical length conversion (& reverse)
    - Meant to reduce step size dependence due to low energy MS
  - Expected to affect the resolution of sampling calorimeters
- Use 'integral method' for μ, ion & hadron ionisation (as e^-)
  - New default still limits step to 20% current range (as in G4 5.2)
- Improved Sampling in Integral methods
  - For processes whose cross-sections have peaks
- Energy loss fluctuations
  - For very small steps, modified to reduce step-dependence in results
  - Smoothed sampling of Gaussian fluctuations, when $\sigma_E > E_{loss}$

EM 'Standard' 6.2 (cont)

- New, second, Photo Absoption Ionisation (PAI) model
  - Splits the cross section between electrons and photons
- Updated
  - calculation of radiative corrections
    - for Bethe-Bloch model for muon energy above 1 GeV.
  - parameterization for $\mu \rightarrow e^+ e^-$ model in region E > 100 GeV

Electromagnetic Processes (Low-energy)

- New models for PIXE
- Photoelectric angular distribution: redesign, with reimplementation of Sauter-Gavrila distr.
- Fix in positron energy loss process ('Penelope' variant)

Hadronic Physics:
Extensions & Improvements / 6.0

- Added biasing in framework
  - leading particle biasing for any reaction
  - cross-section biasing for e-/N and γ/N reactions
- *Binary cascade:*
  - included *pion projectiles*
  - added light ion reactions
  - improved transition to pre-equilibrium model
- *Bertini Cascade*
  - improved in the range `5-10 GeV`
  - verified its suitability for isotope production estimation
- QGSM string model: improved meson splitting
- Improved selection of element for creating final state

Hadronics: improvements in 6.1

- **Identifying initial conditions in crashes & other problems**
  - White-board and Signal-handler prints the reaction conditions.
    - Also run-time checking the energies of all secondaries for NaN values.
- **Improvement of CHIPS (Chiral invariant Phase Space) model**
  - Big upgrade of the CHIPS nuclear fragmentation model: more hyperons are added to fragmentation algorithm
  - New conservation, step by step, of energy/momentum and charge/baryon number
    - Fixed issues identified.
- Fixes
  - 'Logic' fixes, eg for suspended particles
  - Fixed a few memory leaks and for occasional non-conservation scenarios
- **Refinements**
  - Introduced minimal transverse mass for diffractive scattering of gammas.
  - Updated implementation of μ-nuclear absorption at rest.

Hadronic processes
Technical issues (6.1 and 6.2)

- Identifying problem conditions (6.1)
  - Added white-board, signal handler and C++ exceptions
    - That record initial reaction conditions and print them out in case of 'soft' error or program crash
  - As a result problems can be fixed faster
    - Instead of needing 2-5 days to reproduce, can be found in an hour.
      - Turnaround time for a fix is much faster, even for rare problems.
- Particle ID after interaction
  - Optionally kill primaries (LHCb request)
    - can be steered from user code
- Fixes for reported problems

Hadronic Models: new & improved in 6.2

- Evaporation models
  - *Ablation*: new model for use with abrasion code
  - GEM model implementation
  - HETC emission probabilities for Weisskopf-Ewing evaporation model
- Ion Reactions
  - *Wilson's Abrasion* for induced ion reactions.
  - *EM dissociation* for ion-ion collisions
- High energy elastic scattering: new *coherent elastic* model
  - requires a tabulation, which is kept as a 'data set' (provided)
- Diverse
  - new μ^- nuclear absorption code
  - Improved fast radioactive decay code
  - GNASH2 transition probabilities now available
    - in exciton precompound model

Hadronics: Cross Sections & Scattering

- Cross sections:
  - Newest pion scattering data of 'Barashenkov'
    - remove discontinuities
  - Fix in high energy p-H cross-sections (G3 legacy bug)
  - Ion-ion cross-sections
    - Tripathi's systematics for ion-ion cross-sections for light ions
    - Parameterizations from Shiver, Kox and Shen
- *Scattering term*
  - extended for nucleon induced reactions to `8 GeV`
  - included s-wave absorption
  - pion induced reactions (up to `1.5 GeV`)

Hadronics: Improvements & fixes

- Element selection in creating final state
  - fix for materials with many elements
  - now choosing isotope before calling model
    - using $A^{2/3}$ cross-section approximation

Hadronic Processes
Summary of changes in 6.2

- New packages and models:
  - *Ablation*: model for evaporation (for use with abrasion code).
  - *Abrasion*: package for ion reactions.
  - *EM dissociation*.
  - *Coherent elastic*: new model for high energy elastic scattering, requiring a new provided data set for elastic scattering data.
- Cross sections:
  - Removed discontinuities in pion scattering data.
  - Fix in high energy p-H cross-sections (G3 legacy bug).
- Particle ID after interaction
  - Optional kill primaries – can be steered from user code (LHCb request)
- Fixes for reported problems

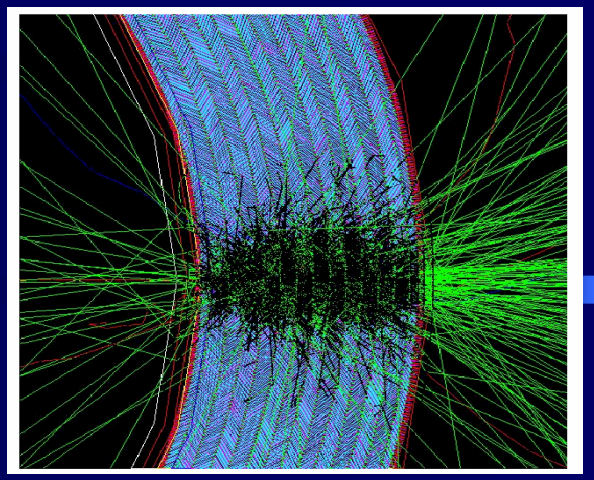
Part III: Auxiliary

User Interaction

Performance

‘Platforms’

User Interactivity



- Visualization
  - Ported OpenInventor driver to Windows
    - And revised, so as not to depend on HEPVis
  - Renamed ‘zlib’ prefix to ‘heprep_z’
    - To resolve conflict with other programs/libraries with zlib
- Environments
  - New version of MOMO Java tools
    - MOMO included in distribution (since 6.0) includes
      - GGE (Geometry editor)
      - GPE (Physics editor)
    - New version of GPE includes change/fix.

‘Platform’ changes

- Enabled loading of dynamic libraries
  - Shared library mechanism
  - Targeted for Windows
    - Request of LHCb
  - Also usable on
    - MacOS 10.3
- Newly supported (June 2004)
  - gcc 3.2.3 on Linux
    - Red Hat 7.3 and SLC 3
  - Visual C++ .net 7.1
    - on Windows XP
- ‘Higher’ Optimization level
  - -O2 is new default (for gcc)
    - in place of -O (ie –O1)
- OS / compilers verified
  - Emerging platforms
    - MacOs 10.3 with gcc 3.3
    - icc 8.0 (IA-32 & IA-64)
  - Check for porting
    - Latest gcc: now 3.4
- Dropped / Dropping
  - egcs already
    - end-2003
  - gcc 2.95.2 & Vis C++ 6
    - end-2004

Allocator and Dependencies

G4Allocator

- Added utility methods
  - to de-allocate storage
  - to print total pages
- Under user control & responsibility

AIDA

- Examples moved to AIDA 3.2.1
  - Many use PI implementation

CLHEP

- G4 6.2 requires CLHEP 1.8.1.0
- Moved development to 1.9.1.1 (beta)
  - Works since September (ref-03)
    - Thanks to CLHEP team
    - Await public release!!
  - For now, still works with 1.8.1.0
- Geant4 7.0
  - See next slide

Geant4 7.0 and ‘dependencies’

- For Geant4 7.0 evaluated/ing impact of potential moves to:
  - <cmath> (agreed)
  - CLHEP 2.0 (under discussion)
  - <sstring> (postponed full move)
- Concern for use of CLHEP 2.0, focused on
  - Usability of long units names
    - Clhep::units::GeV
    - Compromise of clhep::GeV is still seen as ‘bulky’
  - Impact of move on user communities is unclear

CPU Performance (condensed)

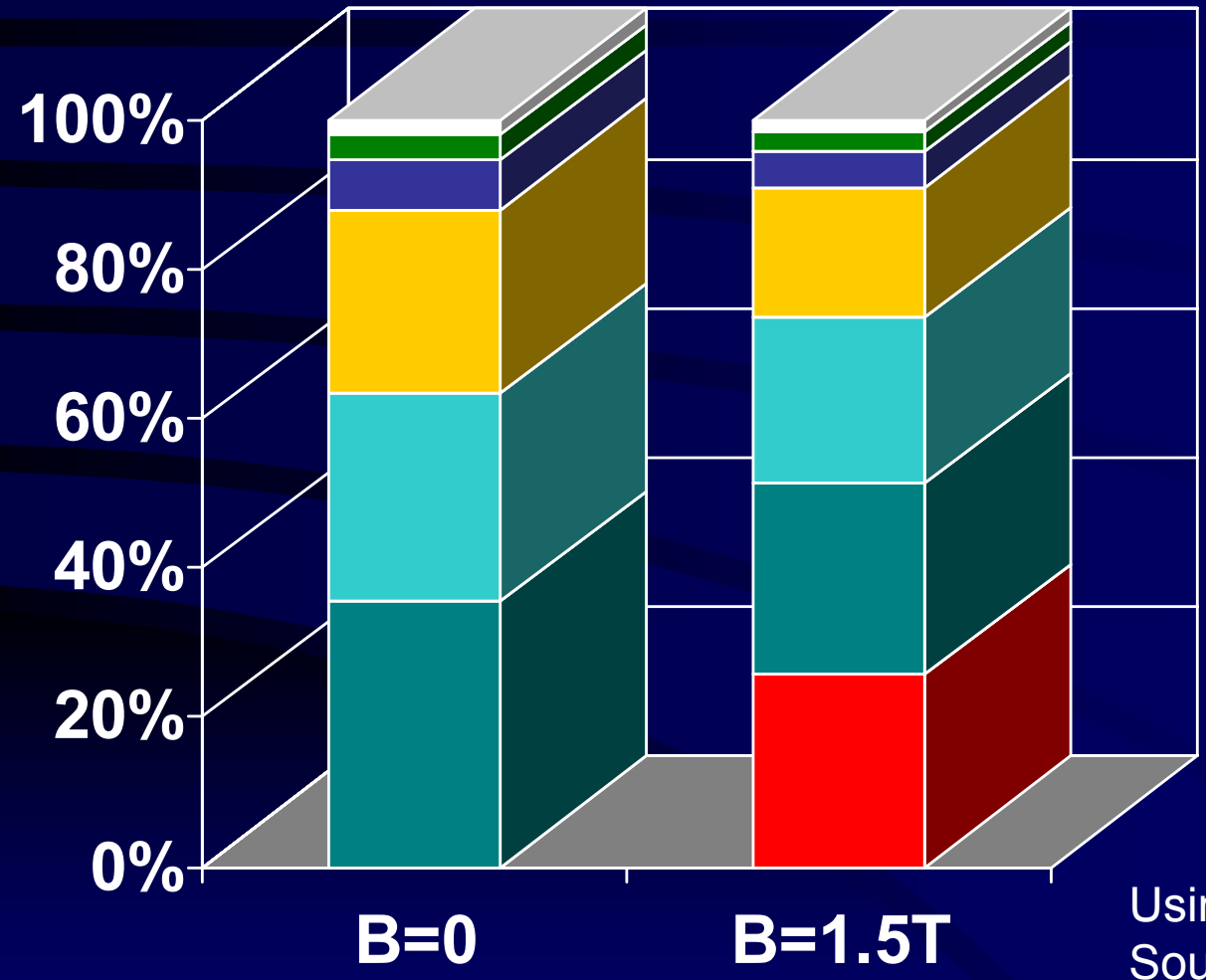
- Our geometry benchmarks
  - demonstrate that the geometry is as good or faster (simple or complex cases)
- Performance in several experimental setups (with Geant4 releases 2 and 3) was comparable to Geant3
  - A few counterexamples, including BTeV ECAL.
  - New issues arose in Geant4 4.0
    - and nearly all were addressed (in patches & release 4.1)
- Difficult cases remain, including
  - Some setups of EM showers (particularly large blocks)
  - Field propagation in complex setups (eg CMS), factor ~ 2x

  which are under active investigation.
- Collecting a set of benchmarks
  - To follow computing performance regularly
- Goal is that Geant4 is at least as fast as Geant3 in almost all cases
  - When comparisons are made for configurations that obtain the same physics performance.
    - And, of course, when its power is used adequately

CPU Performance

- Performance in several experimental setups
  - Issues raised in 2002: BTeV ECAL, Atlas EMB,
    - Slowdown typically 2.0x - 3.0x compared to Geant 3.21
    - Degradation from Geant4 3.2
      - Issues in Geant4 4.0 were resolved (in patches & release 4.1)
    - Improvements lead to typical factor ~1.8x vs G3 (eg EMB, Sep 02)
- In 2003/4 the most difficult cases included
  - Some setups of EM showers (eg large blocks – "no geometry")
  - Field propagation in complex setups (eg CMS), factor ~ 2x
- Performance improvements obtained
  - About 20% better (CMS) with 5.2
    - Key areas identified: EM & propagation in fields

Time fractions with 6.2 patch 1

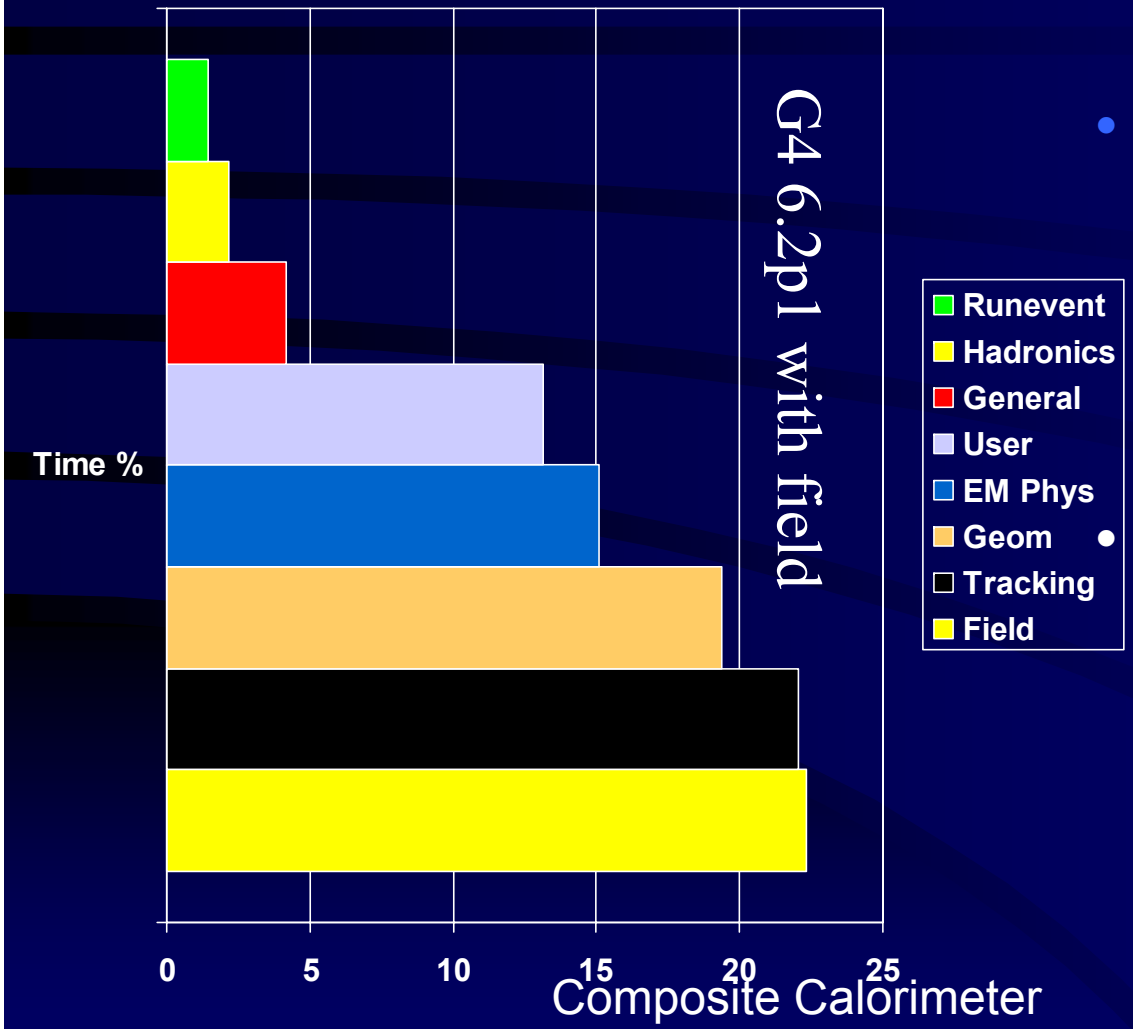


G4 Code only

- Run/Event
- Hadronics
- General
- EM Phys
- Geometry
- Tracking
- Field

Using Composite Calorimeter.
Source R Yaari

Performance: status & actions



- Improvements since Geant4 5.2 (June 2003)
  - Refinements in field propagation, EM (std), Ionisation for last step
    - Simple benchmarks: 8-15% improvement
  - Status of CPU time used:
    - ~1.5x G3 (CMS, end-2003)

Infrequent project meeting jointly with experiments

- to identify major areas of time and memory usage
- to identify tools: external and 'internal' to G4
- to test potential improvements from Geant4 developers

Source: R Yaari

CPU ‘Benchmark’ suite

- Benchmark suite created
  - Simple setup(s)
    - Started from Extended TestEm2
  - Test beam(s)
    - LHC experiment calorimeter(s)
  - Magnetic field
    - derived from simplified BaBar setup
- Benchmarks in regular use
  - used to check dev-tag performance

New example applications

Contributed by partners

- *Cosmic ray charging* from LISA (ESA)
- *Hadron therapy*
- *Medical linac*
- *Purging magnet* (S Larson, Karolinska)
- *Radio protection*
- *LXe: Optical* (TRIUMF)
- *Parallel: ExDiane* (CERN & INFN)

Revised 3 EM(std) *'extended'* examples

  – Added check for automating regression tests

Part IV: Past 6.2 / Future

Regression testing

‘Migrations’ in 7.0

Upcoming features

Patches for release 6.2

- Patch 1 (July 2004)
  - Fix for multiple scattering
    - Particles above 80 GeV suffered large deflections in thin media
- Patch 2 (upcoming)
  - Fix for problem with switching materials in parameterized volumes
  - Fix for problem report in Bertini cascade (HARP)

Statistical testing 2003/4

- Establishment of ‘statistical testing’ suite
  - Automated comparison of physics quantities
    - Against ‘standard’ data (eg NIST)
      - INFN and SLAC efforts
    - Reusing donated ‘test-beam’ comparisons
      - Full applications from ATLAS, CMS.
    - Simple setups for ‘regression testing’
      - Simplified, typical HEP detectors without digitisation
    - For details see A Ribon’s talk in G4 Workshop 2004 (soon)
- Note also the established benchmark suite for computing performance
  - Simple and test-beam setups

Kernel Changes for 7.0

Several changes in kernel are planned for the 7.0 release. A number will impact users

In order of the effects:

- New scheme of storing/retrieving physics tables
  - Enables user to read a portion & generate the rest
- New "unknown" particle and "unknown decay" process
  - For particles whose physics is not simulated, we now create
  - Enables full decay chains to be treated uniformly
- New dedicated class/process for user step limitation
  - Separating step length limitation from track killing
- Possibility to alter detector sensitivity with the parameterized volume
- **For process writers, new methods in Particle Change**
    - **Eg SetEnergyChange becomes ProposeEnergy**
  - New UI commands for G4GeneralParticleSource

Established new releases & new features

- Established releases
  - End of June (minor release)
  - End of December (major release)
- The activities planned in 2004
  - taking into consideration requirements of all users including those from LHC experiments / LCG

Requirements and Releases

- Geant4 Users' Technical Forum http://cern.ch/geant4/technical_forum
  - Requirements collection and first-level prioritization
  - Quarterly meetings, next ones: 4th Oct (Catania), 16th Nov (CERN).
- Upcoming developments and releases
  - 2004 work items & planned release contents
    - At URL http://cern.ch/geant4/source/planned_features.html
    - Started from requirements and requests of users/experiments
  - Next major release Geant4 7.0 in mid-December
    - New developments
    - Improvements and other refinements
    - Changes that require interface changes
    - Any fixes, further performance improvements.
- Developments available
  - In monthly development tags
  - In open β releases each quarter
    - If there are relevant developments, not included a minor or major release.

Feedback and improvements

Much feedback received from users, partners:

- On physics validation
  - LCG, ATLAS, CMS, BaBar, GLAST, HARP.
- Extensive pre-production tests
  - CMS, ATLAS and LHCb (2003-04)
- Large scale and emerging production

Enabled and assists in identifying open issues.

Challenges / Ongoing

- Identifying ‘unwanted’ changes
  - Towards an ‘acceptance’ suite
    - Regression tests for automated testing
    - In addition to user/experiment acceptance tests
- Performance improvement
  - Large productions / always a goal
- Expanding use of ‘best-practice’
  - Eg new methods to identify ‘hard’ problems

Summary

- Geant4 latest minor releases 6.1 and 6.2 included
  - Refinements and new features in the kernel
    - Allocator features; navigator
  - New models, improvements & refinements in EM
    - Improving the new 'model-based' implementation
    - Reducing memory footprint
  - Extensions, improvements & new models in hadronics
    - Also leading particle & cross section biasing
  - Revisions for hadronic physics lists & new EM (std) lists
- Geant4 is evolving
  - With experience in experiment production and use in medical, space and other application domains.
  - Much, excellent, feedback from LHC experiments, BaBar in 2003/4
  - Users' Technical Forum meetings for discussing requirements and priorities