Geant4 Toolkit – and Collaboration: : an introduction

John Apostolakis (CERN)

for the Geant4 collaboration

Outline

1. The Geant4 Toolkit and Organisation
2. Geant4 use in HEP and other fields
3. Improvements in Geant4 capabilities
   - A few
4. Strengths seen in use, production
   - Users extend toolkit, create applications
5. The new Geant4 Sofware License

1. The Geant4 Toolkit: a precis

- Radiation transport - physics models for wide energy range
  - EM: few eV – TeV
  - Hadronic/neutrons : threshold/thermal to > 300 GeV
  - Decay, optical
- Capable, fast geometry modeler
  - Complex geometries
- Access to each part of the kernel, physics
  - General tracking engine
- Multi-faceted visualization, choice of user interface
  - User can choose existing, extend, customise
- Configurable in almost every aspect
  - physics choices (lists), how to create geometry, ...
- Open, readable, 'transparent' implementation
  - Clear design enables us to revise, maintain- by developers and users

Organization

- "New" Geant4 Collaboration
  - Collaboration Agreement (CA) finalized, approved in 2005
  - 'Launched' end-January 2006
  - Most and largest parties of G4/MoU signed
    - SLAC, CERN, Lebedev, IN2P3, KEK/Japan, ESA, HIP, LIP, PPARC ... soon INFN.
  - New Steering Board
  - New Oversight Board
    - chair Petteri Nieminen (ESA), deputy KEK
- Agreed and adopted Geant4 Software License (June 2006)
  - Based on EGEE model ... more later

Organization

- Around 80 active contributors, making ~25 FTE
  - Physicists, computer scientists, engineers
  - Most contributing part time, in area of expertise
    - With about 20% full or almost full time
- Members from labs, institutes, universities
  - Labs play big part in infrastructure tasks, as meeting points.
- Working groups plan, undertake most tasks
- Steering Board (WG coordinators)
  - Decides scientific, technical goals
  - Creates the plans for development, support
- SB chair/deputy coordinate general, multi-WG issues

2. Geant4's in HEP, production

- HEP Experiments in large scale production
  - BaBar (2001)
  - CMS (2003)
  - ATLAS (2004)
  - LHCb (2004)
- Used in many existing experiments
  - KamLAND, Borexino, HARP, ...
- Used to study future experiments
  - ILC, NA48/3 (PA326), ...

Geant4's use outside HEP

A first sample

- Imaging, radiotherapy, dosimetry
  - PET and SPECT imaging (GATE),
  - brachytherapy, hadrontherapy,
- Space: satelites and planetary missions
  - XMM, INTEGRAL, Bepe Colombo, LISA, ...
- Radiation assessment, dosimetry
  - Effects on electronics (TCAD), ...

2. Geant4 improvements

- Improved stability of EM energy deposition, resolution
  - From revision of electron transport (Multiple scattering)
  - Enables better accuracy at higher cuts - with less CPU
- Extensions to geometry modeler
- Ability to revise many particle properties
- Refinements, improvements in hadronics
- Physics Lists

First results

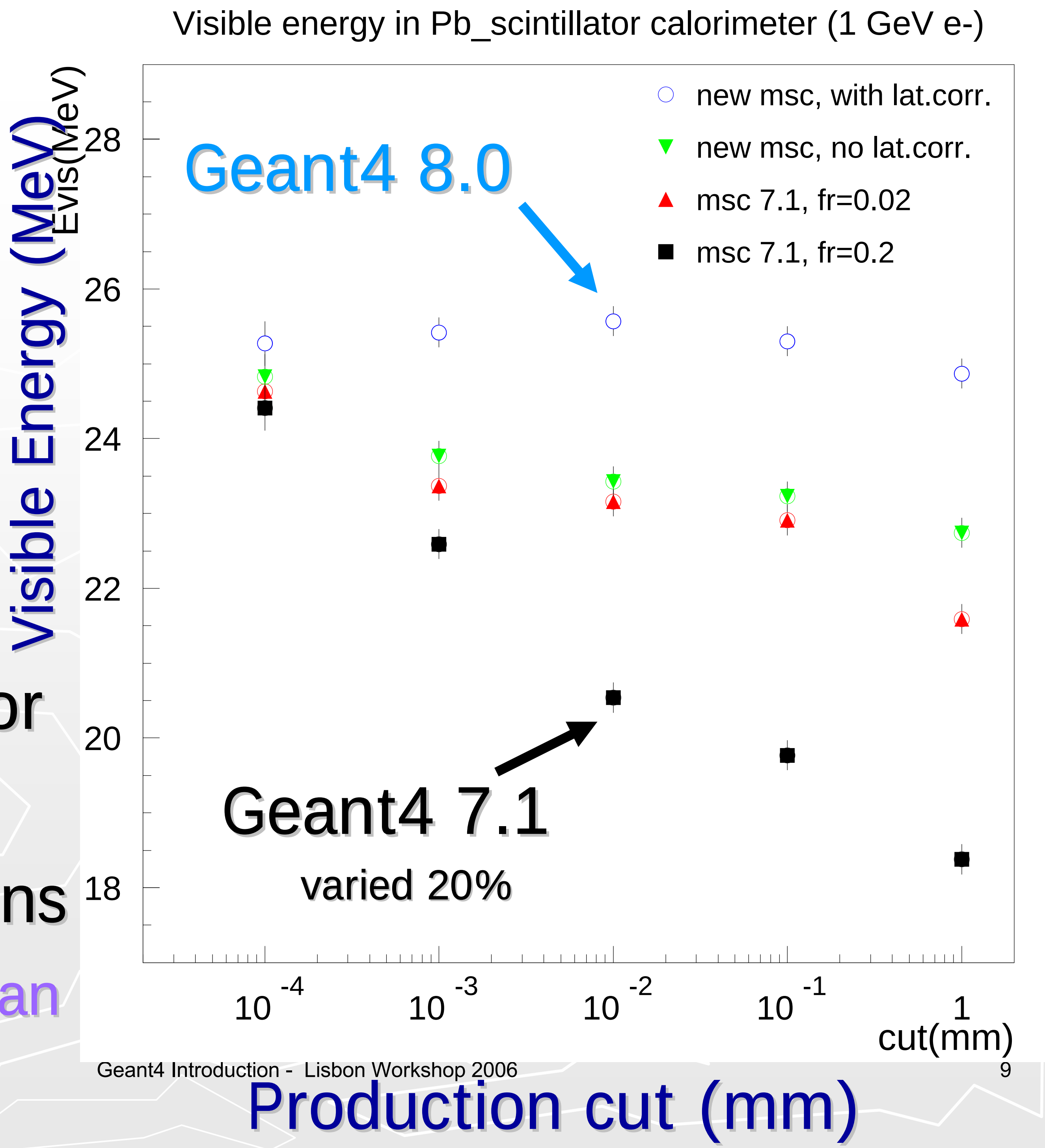
Visible Energy

In Pb scintilator

Calorimeter

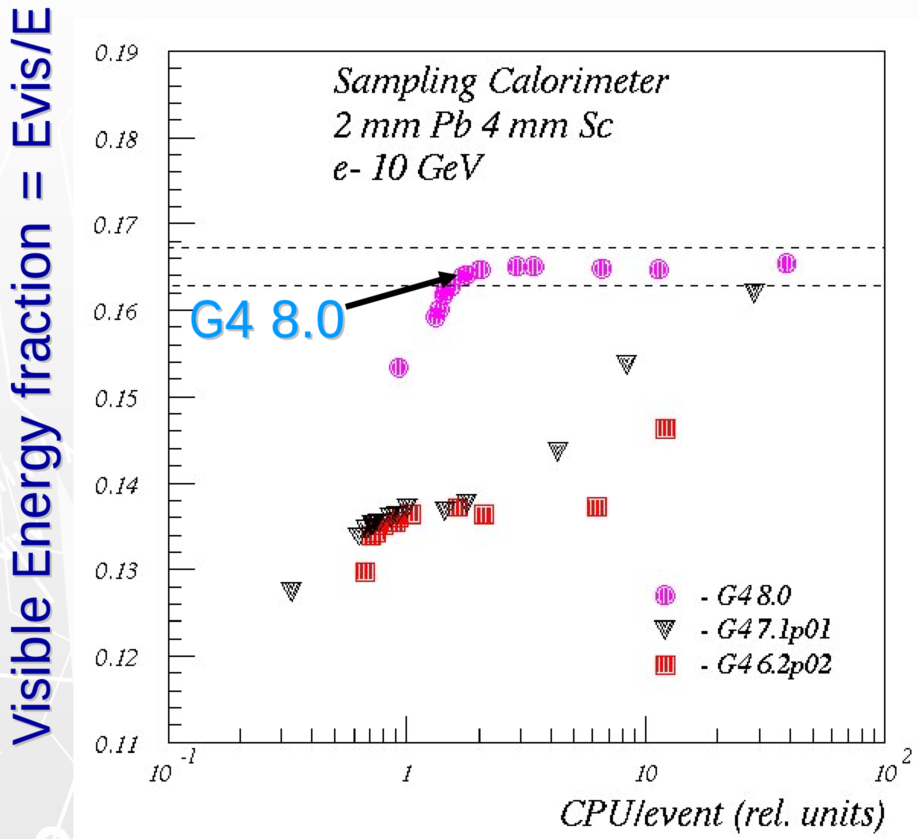
1 GeV electrons

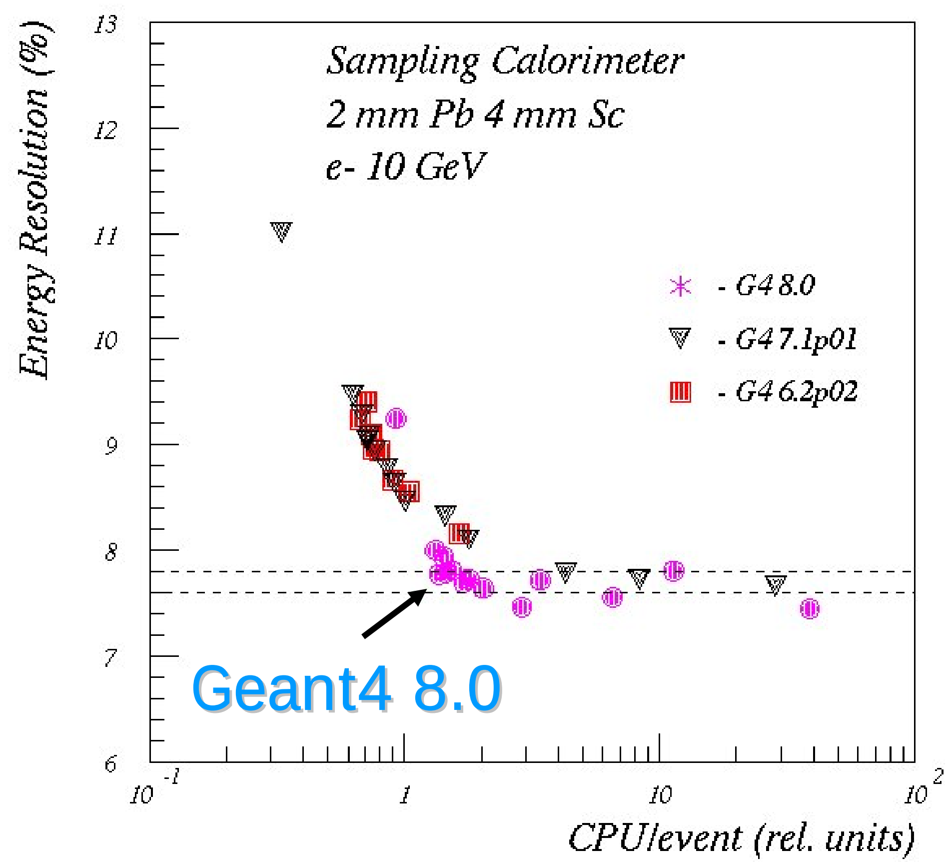
M. Maire, L. Urban



CPU versus physics performance

Simple calorimeter similar to LHCb setup





More stable $E_{visible}$, resolution and less CPU

Some recent developments

- Speedups for initialisation/navigation
  - Option to only re-optimise parts that change with run
  - New voxelisation options being studied for regular geometries
- Overlap checks at geometry construction
- Revised implementation of particles
  - Impacting advanced users, customizing
- Refinements in hadronic physics

Geometry improvements

- New solids for unusual shapes
  - Twisted trapezoid, ellipsoid, tetrahedron
- Ability to measure volume (mm^3)
  - Use it to measure also the mass of a setup
- Refinement for dynamic geometries
  - Option: re-optimise only parts that changed with run
- New ability to detect overlap problems
  - when user creates his/her geometry setup
- Tool for large regular (‘voxel’) geometries
  - When only material varies in regular structure

Verification / validation

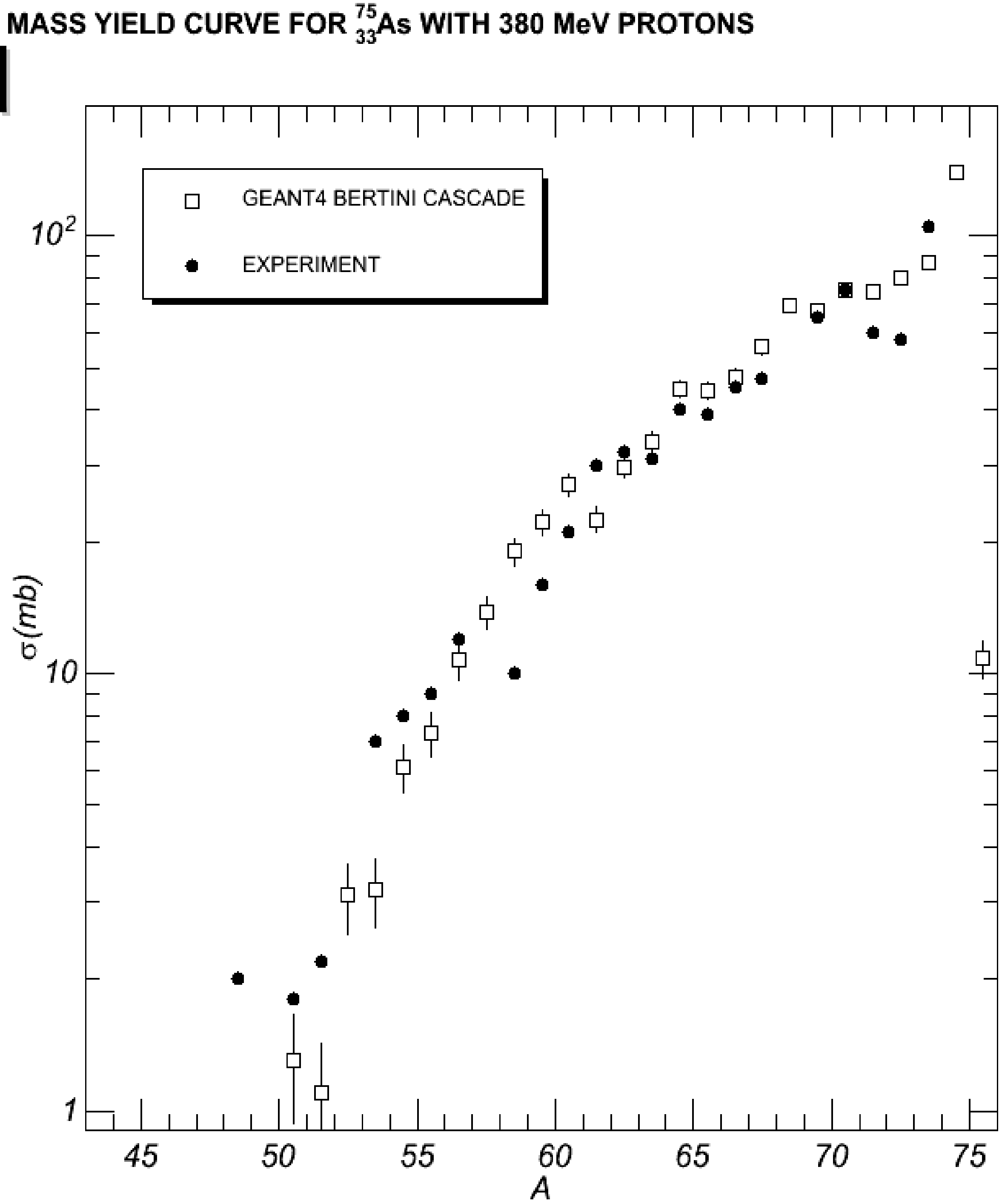
- Additional thin-target comparisons
  - For verifying models
- Validation
  - New comparisons (eg CMS TB2004, ATLAS CTB)
  - Revisiting test-beam comparisons
    - Eg Atlas HEC
  - EM calibration below per-cent level
  - Open challenges for hadronic calorimetry
    - Shower shape, energy density (at low values)

Mass yield curve

Geant4 Bertini

vs

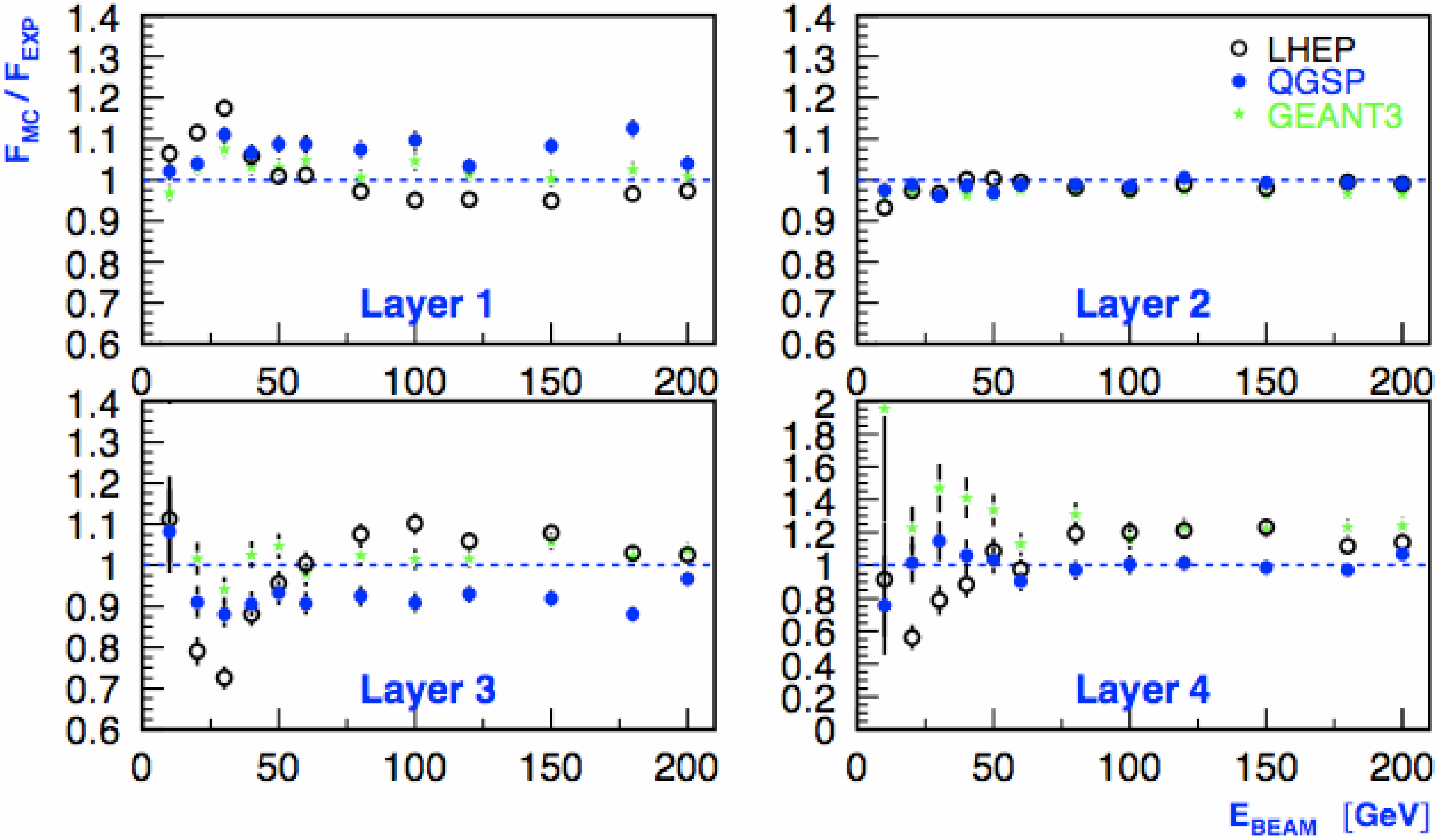
Experiment



ATLAS HEC:

G4 7.0p01 PRELIMINARY, Oct 2005

Updated comparisons from 5.2



Thanks to A. Kiryunin, ATLAS-HEC

Additional capabilities

- Fast simulation (shower parameterisation)
  - Originally a framework for users' parameterisations
  - New GFLASH concrete implementation
    - See presentation in EPA-3 (Tues)
  - Extending use of 'Regions' to fast simulation
- Handle 'unknown' particles (with no G4 physics)
  - Accept from Event Generator, transport, decay
- Now allow change in particles' properties
  - In initialisation phase the user can change unstable particles' mass, width, ..

3. Users apply and extend G4

- Tools using Geant4 for class of related applications
  - GATE tool
    - “Geant4 Application for Tomographic Emission”
  - BDSIM for beam-line simulations
- Users extend Geant4
  - Special solids for own geometry (many -> G4)
    - Atlas endcap solid (fan), twisted tube (KEK), Tet (vanderbilt)
  - GFLASH shower parameterization (from Atlas, CMS -> G4)
  - ‘Regular’ navigation (10-100 mil volumes at one level)
  - Use of 2,500 materials

Key strengths exploited: open architecture & source

Users extend Geant4

- For regular voxel phantom geometries
  - Tens of millions of volumes at one level!
  - Revising one/two navigation class(es)
    - K. Sutherland, H. Jiang
- To simulate thousands of materials
  - Varying in density
  - storing physics tables for tens/hundreds
    - H. Jiang / H. Paganetti
- Utilize toolkit and open source
  - And customise for own application requirements / constraints

Robustness, testing

- Low rate of problems in production
  - CMS reports 10^{-5} per event (G4-related) with G4 6.2
  - Other experiments have low incidence too.
- New, large-scale, regressions testing
  - Finds rare problems
  - Used LCG/EGEE Grid
    - Need and got > 150 CPU-weeks in 10 days
      - G4 VO: thanks to LCG team, CERN, Imperial C., Nikhef, CIEMAT
  - Identifies physics revisions, finds new software issues
      - See A. Ribon's talk at CHEP 2006

Geant4 Software License

Release 8.1

- Text available from:
  - http://cern.ch/geant4/license/
  - Based on EGEE model
- Key issues considered
  - Need and wish to enable users to use freely, modify and redistribute original or revised versions (with conditions)
  - Need to protect the contributor's reputation from those who might revise the code, but not make clear that they changed it when they published results or when they redistributed revised versions
  - Need to have users give credit to the collaboration for work undertaken utilising Geant4 as a tool (or toolkit)
  - Need to ensure the presence of a strong disclaimer of warranty and liability
  - Wish to enable user in academia, research institutes and commercial contexts to use and/or revise the code in the different manners of use: as users of an application written using Geant4, as developers of applications or toolkits based on Geant4, and as developers of tools that utilise Geant4 as part of another product
  - Need and wish to impose a minimal burden and no significant impediment to commercial use that includes Geant4 software but also includes proprietary revisions that a company developed as significant investment

Platforms / configurations

- Support for CLHEP 2.0.X series (since 8.0)
    - With Geant4 release 8.1 it is version 2.0.2.3
  - Option to use 1.9.x available
    - Now version 1.9.2.3
    - Expected to retain it for Dec 2006 release
- OS / compilers verified
  - SLC3 with gcc 3.2.3 (IA32)
  - SLC4 with gcc 3.4.5 (IA32 & AMD64) and gcc 4.1.1
  - Win/XP with VC++ 7.1/8.0
  - MacOS 10.4 with gcc 4.0.1
  - SunOS 5.8 with CC 5.5

http://www.in-cites.com/hotpapers/2004/november04-eng.html

http://www.in-cites.com/hotpapers/2005/july05-eng.html

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Physics and Astronomy

1. Nanoscience and engineering in mechanics and materials • **Article**
   Journal of Physics and Chemistry of Solids, Volume 65, Issue 8-9, 1 August 2004, Pages 1501-1506
   Chong, K.P.
2. Geant4-a simulation toolkit • **Article**
   Nuclear Instruments and Methods in Physics Research Section A:

Toolkit Summary

- EM physics model/algorithm improvements
  - Revised Multiple Scattering improves stability of E_{vis}, σ_E
- Hadronic shower shape issues under study
  - extending thin target verification
  - thick target studies to weight importance of channels
- Improved physics models deployed in PL (8.1)
  - Improved Stopping, n-H, p-H elastic
  - key physics lists revised: QGSP, LHEP
- New capabilities
  - geometry, materials, particle properties, ...

Summary ... for the rest

- Geant4 Collaboration ‘renewed’ Feb 2006
- Users are utilizing toolkit capabilities
  - Tailoring Geant4
  - Building applications for new fields on top of it
- Geant4 Software license adopted for 8.1
  - Blend of copyleft and BSD

Backup Slides

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"Super Hot" Papers in Science Published Since 2003

Engineering

(Sorted by citations. 3 of 128)

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;

Tutorials in 2005-2006

- Geant4 Users' Tutorial
  CERN, **25-27 May 2005**.
- 2nd Finnish Geant4 Workshop and Tutorial
  HIP, Helsinki (Finland), **6-7 June 2005**.
- Geant4 short course
  INFN Pisa, Pisa (Italy), **12 January 2006**.
- Geant4 training course
  Austrian Academy of Sciences, Vienna (Austria), **18-20 May 2006**.
- 4-day Geant4 tutorial
  SLAC, Stanford (USA), **7-10 March 2006**.
- 4-day Geant4 tutorial
  Jefferson Lab, Newport News, Virginia (USA), **22-25 May 2006**.
- Geant4 tutorial course, McGill University, Montreal (Canada), **25-28 September 2006**.
- Geant4 Course at the 10th Topical Seminar on Innovative Particle and Radiation Detectors, Siena (Italy), **5-6 October 2006**

Workshops and Symposium

- Workshops
  - 4th Geant4 Developers Workshop on bio-medical applications and physics validation
    INFN Genova, Genova (Italy), **13-20 July 2005**.
  - 10th Geant4 Users Conference and Collaboration Workshop
    Bordeaux (France), **3-10 November 2005**.
    Presentations for the Users Workshop
  - 11th Geant4 Collaboration Workshop, LIP, Lisbon (Portugal), **9-14 Oct 2006**.
- Space Users Workshops
  - Workshop for SPENVIS and Geant4 Space applications
    Catholic University, Leuven (Belgium), **3-7 October 2005**.
  - Geant4-Spenvis Space Users' Workshop, NASA Jet Propulsion Laboratory - Pasadena, CA (USA), **6-10 November 2006**.
- Symposium on the Applications of the Geant4 Simulation Software at the 9th ICATPP Conference, Villa Olmo, Como (Italy), **17-21 October 2005**

User meetings and Topical meetings

- User Meetings
  - Geant4 Users Conference, Bordeaux (France),
    3-10 November 2005, with 10th Collaboration Workshop.
  - Regular Geant4 Technical Forum meetings 4-6/year planned
    - Meetings: 5 in 2005 including 2 at workshops, 3 in 2006 to date
    - Last meeting: 14th G4 TF meeting, CERN, **25 April 2006**
- Geant4 Physics Verification & Validation Meeting
  - CERN, 17-19 July 2006
- **Topical Meetings & Workshops**
  - Monte Carlo MC 2005 Topical Meeting, Chatanooga, TN, 17-21 April 2005
  - Hadronic Shower Simulation Workshop, Fermilab, Batavia, IL, 6-8 Sept 2006.

More slides on EM revisions, performance

Energy deposition and cuts: issues

- Electron transport is key to accurate energy deposition, resolution
  - in setups with materials with very different Z
- Users reported results strongly dependent on cut value (or step limits)
  - Sampling calorimeters: Atlas (Cu–lAr), ILC (W-Si), LHCb (Pb-Sci)
  - In water phantoms with perturbing layer (Poon & Verhaegen)
- Cut dependence verified in HEP sampling calorimeters (eg Cu-lAr, Pb-Sci)
  - Energy deposited varied 10%-30% when production cuts are changed from 1 µm to 1 mm
    - Effect existed in previous Geant4 releases (5.x, 6.x and 7.x)
- An extensive investigation concluded that the Multiple Scattering process could be improved
  - Revisions provided in Geant4 8.0 address these issue

M. Maire, L. Urban

Energy deposition and cuts: resolution

Revisions of Multiple Scattering (available in release 8.0)

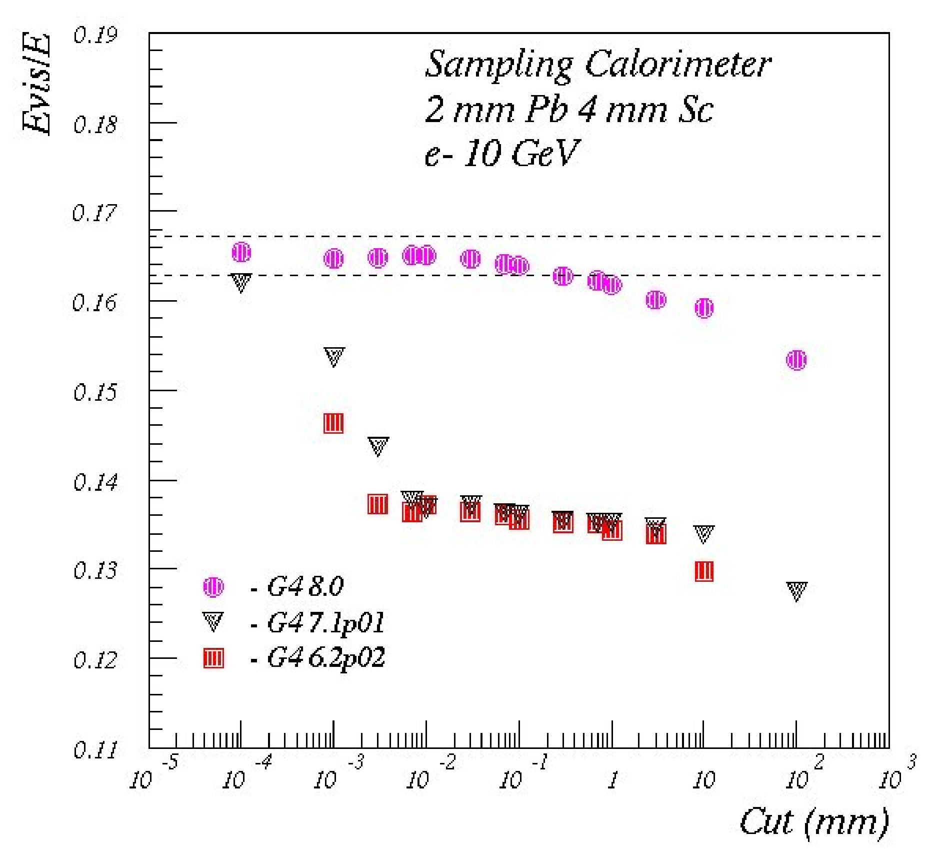
- Improvements to physical model – calculating displacement and applying it
  - Introduced correlation between scattering angle and lateral displacement
  - Ensure recalculation of geometry 'safety' before sampling the displacement
    - Since the safety value limits the displacement allowed
- Improvements in restricting step:
  - Stricter step restriction
    - using smaller fraction (0.02 vs old 0.02) of particle's range
    - in all volumes, including the starting volume of track
  - Restrict step size using geometrical information
    - Ensures more than one step in each volume

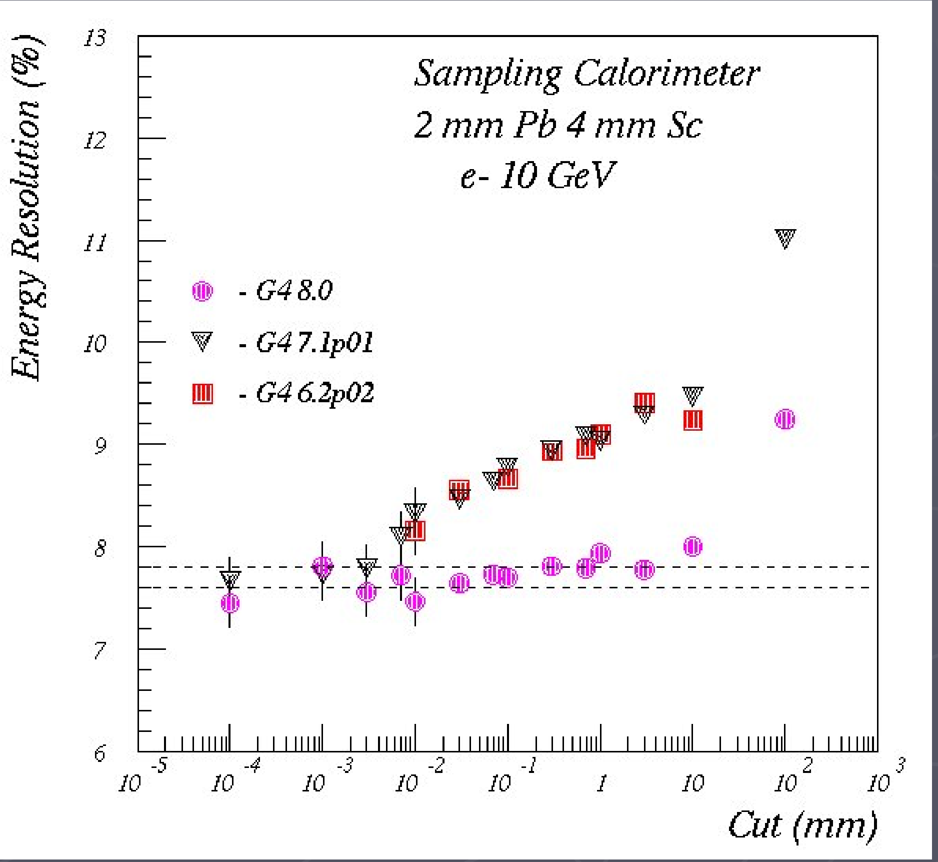
Note: User can switch off the extra new step limitation (for comparisons)

For more information please see upcoming talk "The recent Upgrades in the Geant4 Standard Electromagnetic Physics Package"

M. Maire, L. Urban

Multiple Scattering model upgrade LHCb type calorimeter

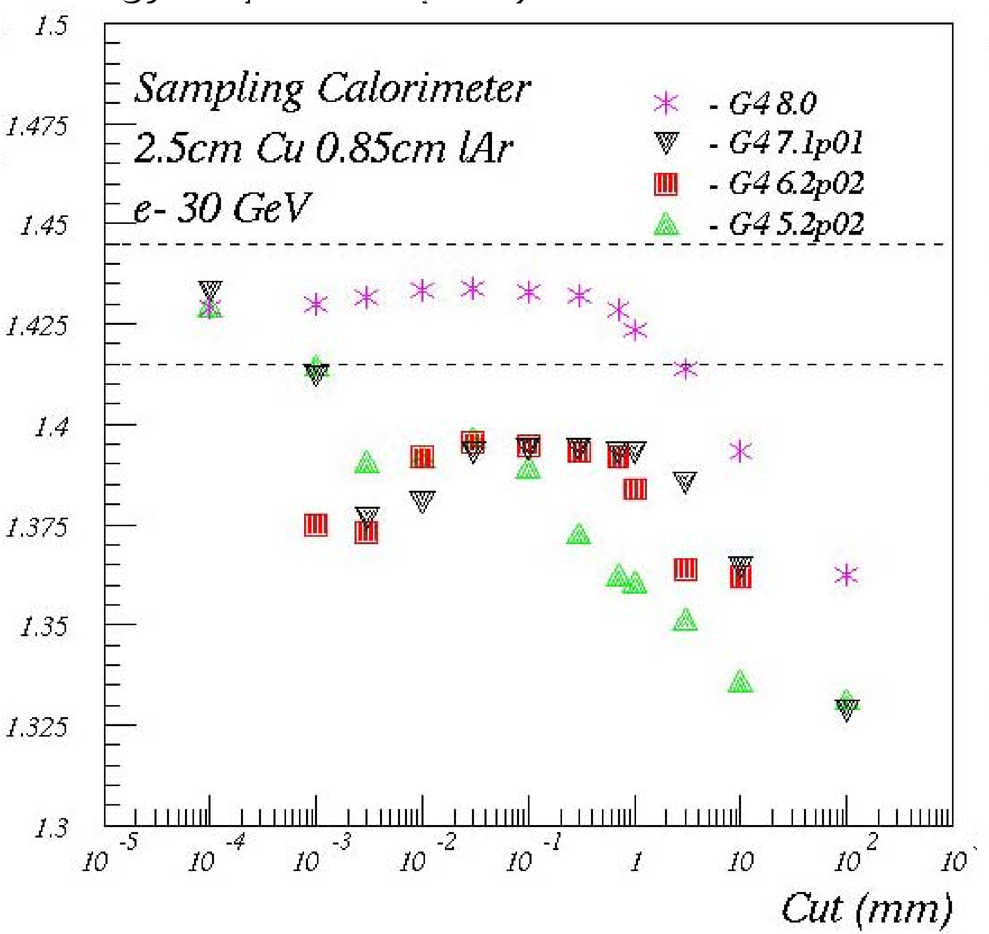




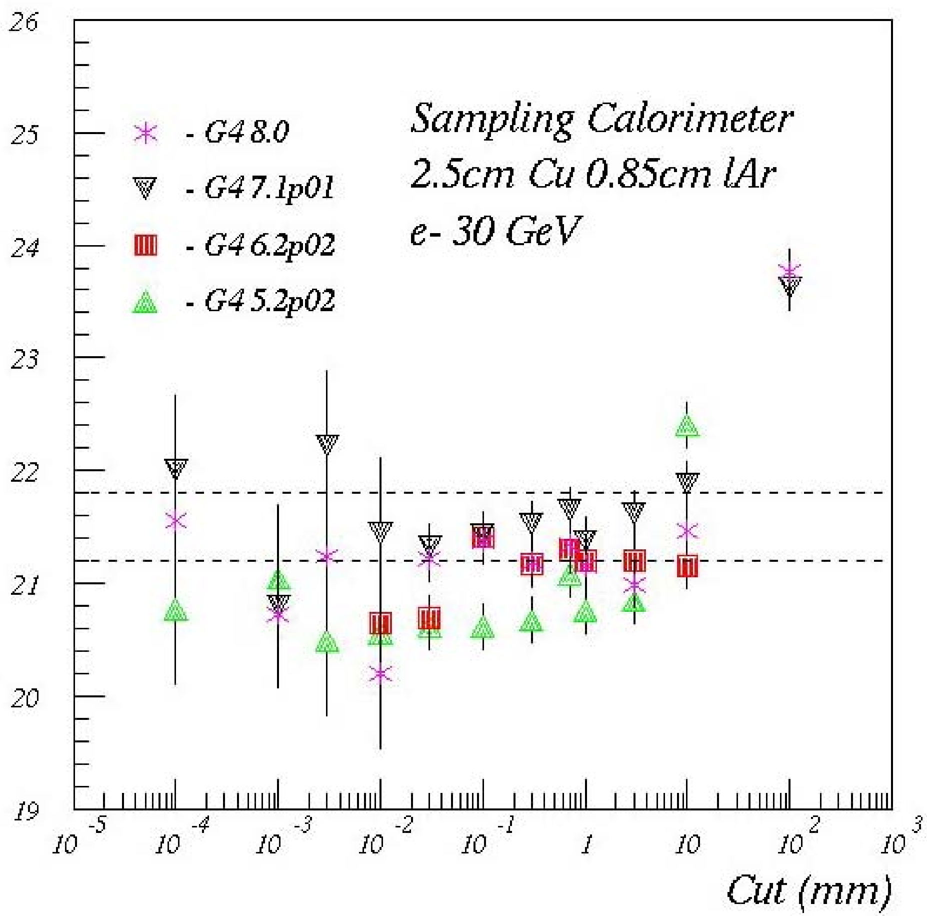
V. Ivantchenko

Atlas HEC : Cu(25mm)-lAr(8.5mm)

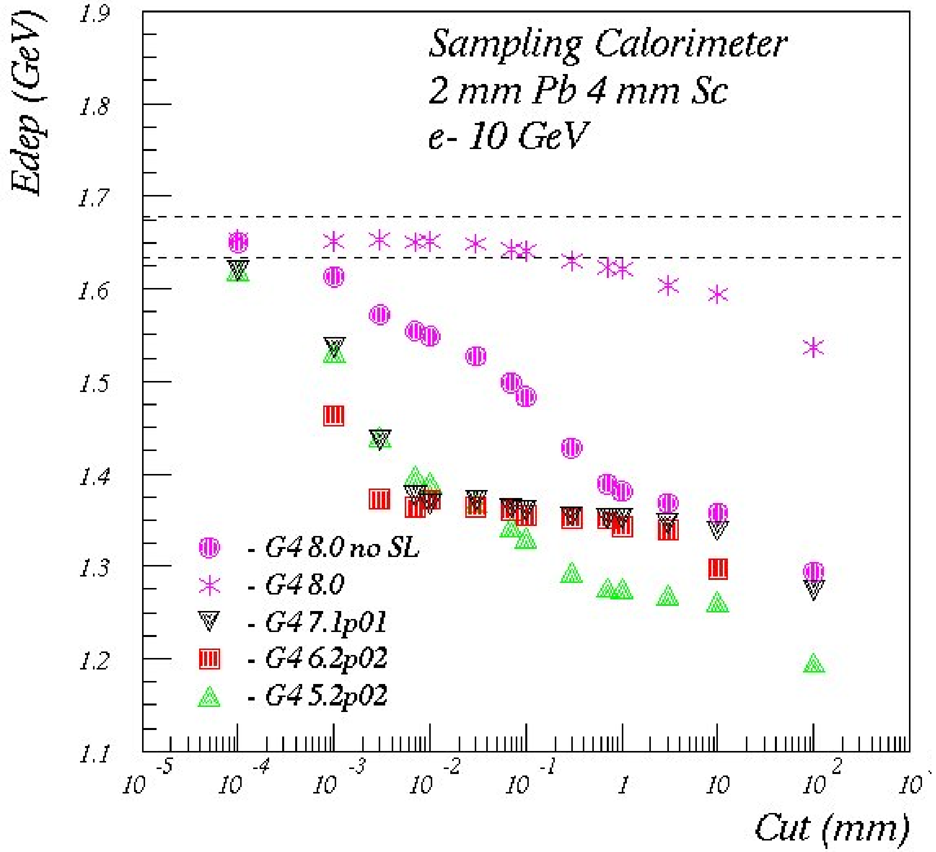
Energy Deposited (GeV)

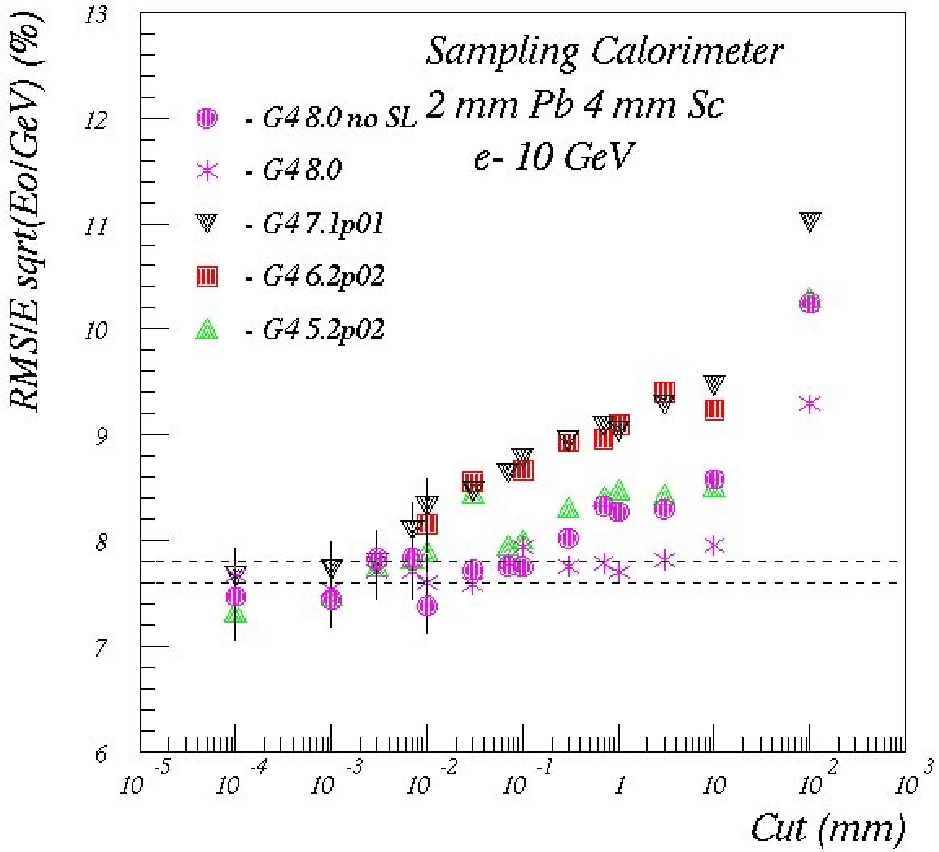


RMS/ (E * sqrt(E_0/GeV) (%)



LHCb : Pb(2mm)-Sc(4mm)





Energy deposition and cuts (more)

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M. Maire, L. Urban

Revisions of Multiple Scattering (8.0)

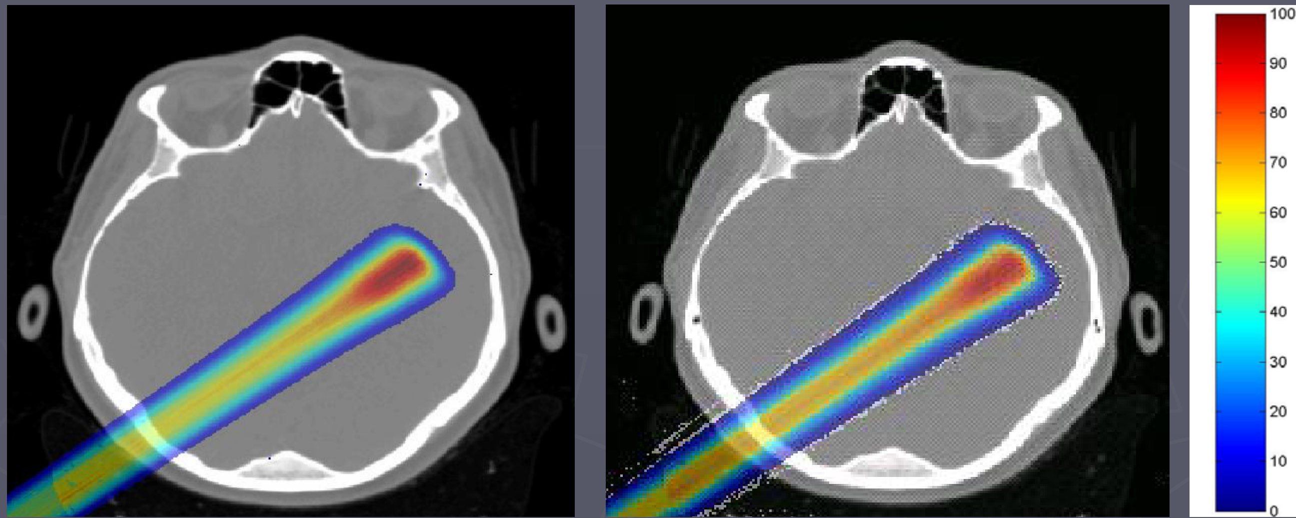
- Improvements to physical model – calculating displacement and applying it
  - Introduced correlation between scattering angle and lateral displacement
  - Ensure recalculation of geometry 'safety' before sampling the displacement
    - Since the safety value limits the displacement allowed
  - step restriction not only after boundary with parameter facrange but also from the start of the track and from geometry (facgeom)
- Improvements in restricting step:
  - Stricter step restriction in all volumes using fraction (0.02) of particle range
    - Including the starting volume of track (new)
      - Previously only applied after first boundary
  - Step restriction using geometrical information to guarantee at least
    - 2 steps in the start volume
    - 4 steps in other volumes a track crosses
- User can switch off this step limitation (for comparisons)

For further information please see upcoming talk "The recent Upgrades in the Geant4 Standard Electromagnetic Physics Package"

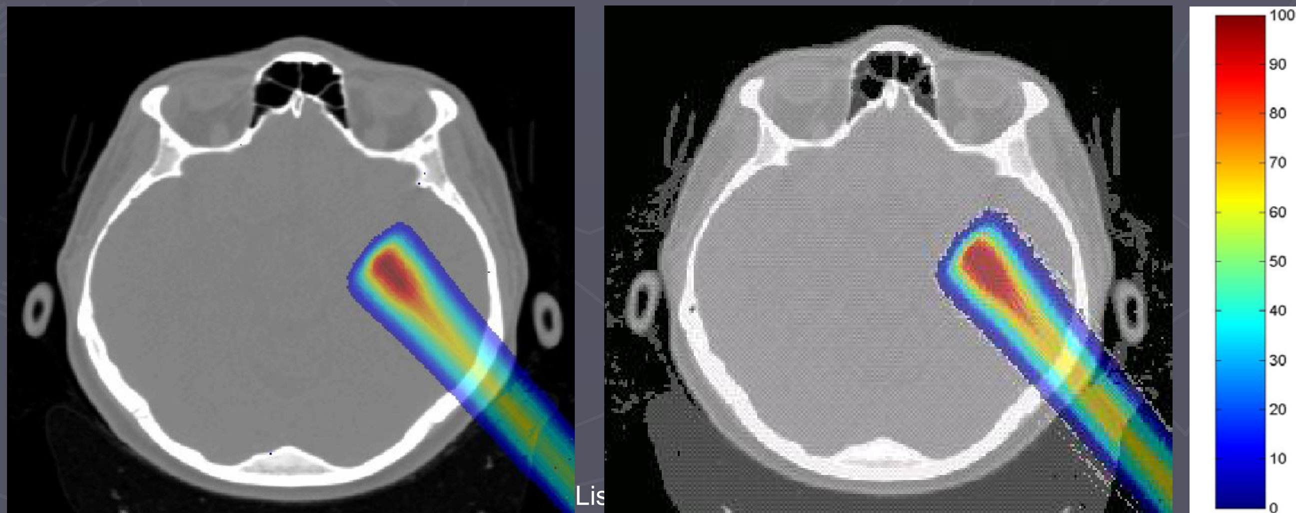
M. Maire, L. Urban

More on applications

Example 2



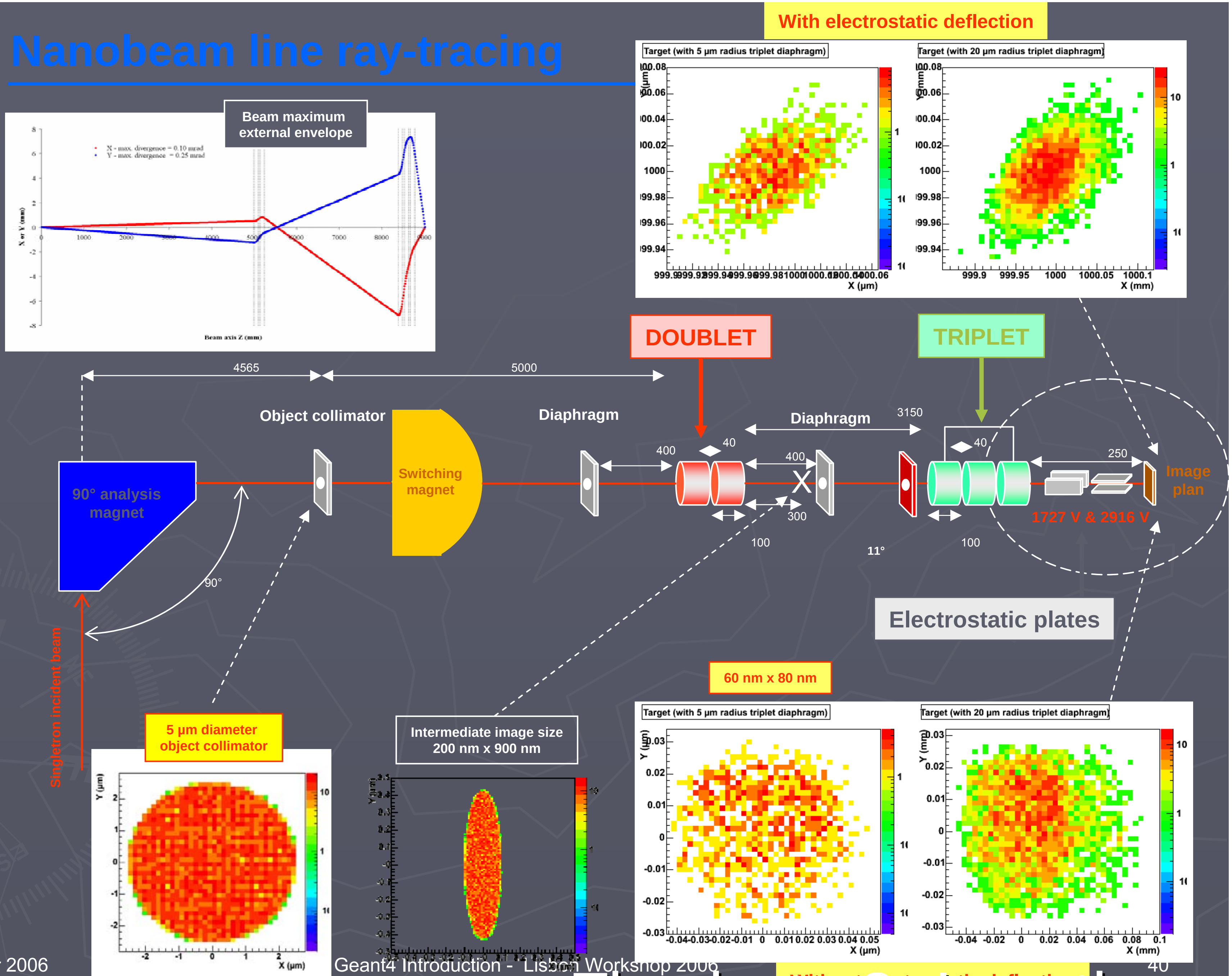
FOCUS Monte Carlo



FOCUS Monte Carlo

Thanks to H. Paganetti, MGH

Nanobeam line ray-tracing



Thanks to S. Incerti

Geant4 8.0 developments

Additional information

Geometry:
solids and dynamical geometries

- Additional solids
  - Generic twisted trapezoid shape with different endcaps - (O. Link)
  - New ellipsoid (G.Guerrieri, INFN/Genova) and elliptical cone (D. Anninos, CERN/Cornell)
  - Tetrahedron (M. Mendelhall, Vanderbilt Univ.)
- Testing and Improvements (O. Link, CERN)
  - Solid accuracy tests identified problems in torus, sphere (theta)
  - Fix in sphere and improvement of torus (new polynomial solver)
- Localized re-optimization for dynamic geometries
  - Change and re-optimize only part of a large geometry (G. Cosmo)
    - Enables lightweight initialisation for changes in dynamic geometries

Other new features in geometry

- Overlap detection at construction time
  - When a volume is placed it is checked optionally for 'overlaps'
    - If it overlaps sister volumes or protrudes from its mother
    - Points on its surface are sampled
    - An exception is generated if a point is outside the mother or inside a sister volume
  - Applicable for placement and parameterised volumes
- Extended use of G4Region:
  - Was used for G4ProductionCuts and G4VUserRegionInformation,
  - Can now create User Limits for Regions (7.1)
  - Now enabled its use with parameterisation / Fast Simulation
    - All these data members are optional

Nested parameterization

- In the past G4VPVParameterization::ComputeMaterial() method used to take only the copy number of the immediate physical volume
  - There was no way to get a copy number of its (grand)mother volume
- To implement boxes in 3-Dimensional alignment with varying material (e.g. DICOM), one parameterization has to take care of three dimensions.
  - One big mother volume filled by one tiny cell with 3-dimensional parameterization
- With newly introducing nested parameterization, a touchable instead of naïve copy number is provided to ComputeMaterial() method.
  - Material of a box can be indexed not only with the copy number of the immediate volume but also with copy numbers of its (grand)mother volumes
  - The big mother box can be replicated twice in first and second axes, and then parameterized only along the third axis.
  - Performance improvement in both voxelization and navigation/tracking

Non-static particle definition

- In Geant4 8.0, all particle definition class objects are instantiated when GenerateParticle() method of physics list is invoked
  - Until now, most particle definition objects were static and the GenerateParticle() method ensured they were linked in the executable
- A side effect is foreseen if your physics list has physics processes/models as data members of your physics lists.
  - such processes or models may not been instantiated properly.
- Released revised physics lists to address this
- What to do
  - In case processes/models are defined as data members, they are actually instantiated at the moment your physics list itself is instantiated, i.e. before GenerateParticle() method is invoked.
  - If you use your own copy/customized physics list you will need to migrate
    - For example if you derived from one of the "educated guess" physics list,
    - How to do this
      - define pointers for such processes/models as the data members, and make sure all processes/models are actually instantiated in your GenerateProcess() method.

Concrete sensitivity classes

- Until 7.1 Geant4 provided only an abstract class (G4VSensitiveDetector) for the user to define his/her detector sensitivity.
  - Various example detector classes are provided.
    - Good to store hits in their detectors (HEP experiments).
  - But is not convenient for radiation applications (Space/medical/HEP)
    - Where the main interest is scoring dose/flux.
- G4 8.0 introduces G4MultiFunctionalDetector
  - In it you can register concrete 'scorers' to build a custom scoring detector.
  - Now provide scorers for EnergyDeposition, Surface Flux, Dose, Track Length
    - additional concrete classes are under development.
  - Note: G4MultiFunctionalDetector is a G4VSensitiveDetector.

Concrete sensitivity classes

- Each G4VPrimitiveSensitivity class generates one hits collection per event. By registering more than one classes of G4VPrimitiveSensitivity, G4MultiFunctionalDetector generates more than one collections.
- G4THitsMap template class (an alternative to G4THitsCollection) introduced. It is also a derived class of G4VHitsCollection.
  - It is more convenient for scoring purposes, and simpler
- New class G4VSDFilter introduced. Can be attached to G4VSensitiveDetector and/or G4VPrimitiveSensitivity to define which kinds of tracks are to be scored.
  - E.g., surface flux of protons of more than 1 GeV/c can be scored by G4PSSurfaceFluxScorer with a filter.
- Current G4Scorer and its related classes are kept, for the time being
  - Expect these to be declared obsolete.

Bertini Cascade

- Isotope production
  - Proton and neutron induced
- Elastic scattering interface (release 7.1)
  - G4CascadeElasticInterface (for < 1 GeV)
- Kaon extensions
- Validation
- Optimization for speed, model tuning

A. Heikkinen, D. Wright

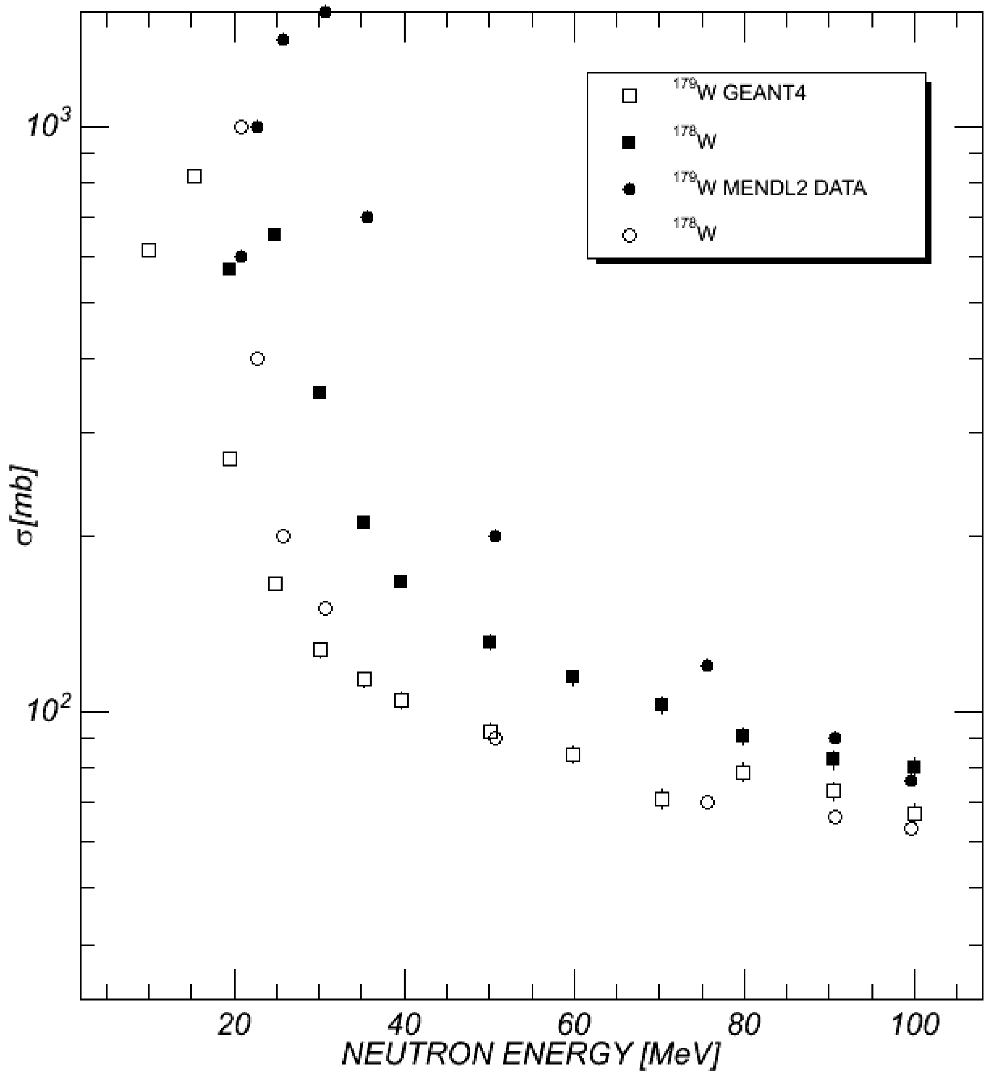
Bertini Cascade

- Isotope production
  - Proton and neutron induced
- Elastic scattering interface for release 7.2
  - G4CascadeElasticInterface (for < 1 GeV)
- Kaon extensions
- Validation
- Optimization for speed, model tuning
- Ion-ion interactions (future)

Bertini hadronic models in Geant4 7.1

- Submodels implemented for proton, neutron, pion bullets:
  - `G4ElementaryParticleCollider`
  - `G4IntraNucleiCascader`
  - `G4NonEquilibriumEvaporator (pre-equilibrium)`
  - `G4EquilibriumEvaporator`
  - `G4Fissioner`
  - `G4BigBanger`
- Latest Bertini extension (June, 2005)
  - First partial release providing elastic part of intra-cascade treatment for kaon, lambda, sigma, and xi by Dennis Wright (SLAC)
    - Now stable and available at CVS (use `KAON`-flag)
    - This SLAC-tag is to be released fully in Geant4 7.2 release

ISOTOPES PRODUCED BY NEUTRONS ON $^{180}_{74}W$



Low-energy neutron induced isotope production is usually treated with Geant4 isotope production model using of evaluated data libraries

Yet in some cases Bertini model performs quite well and might be useful

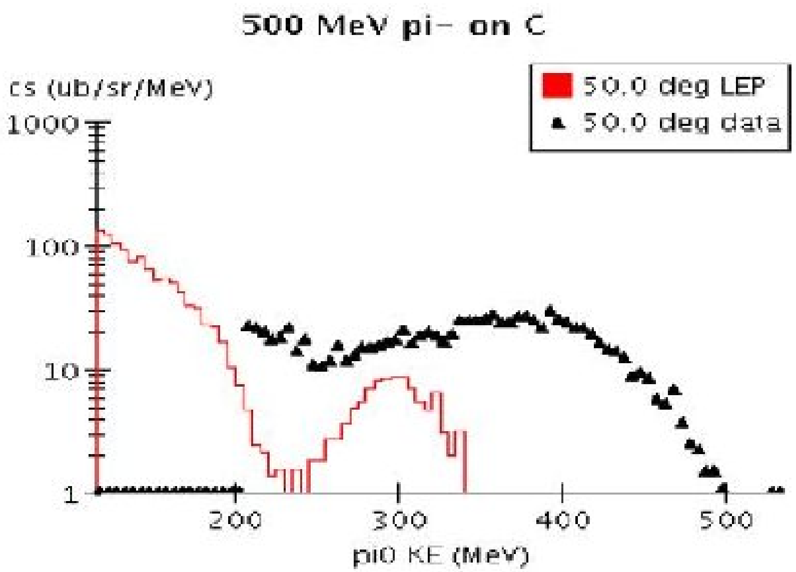


Figure 1: Current GEANT4 LEP physics list setting against data (Ouyang, Peterson 1992)

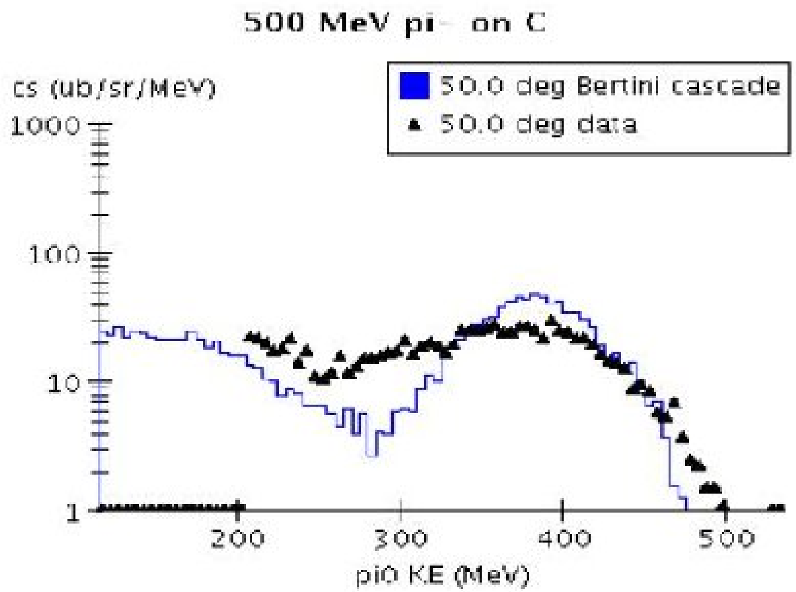
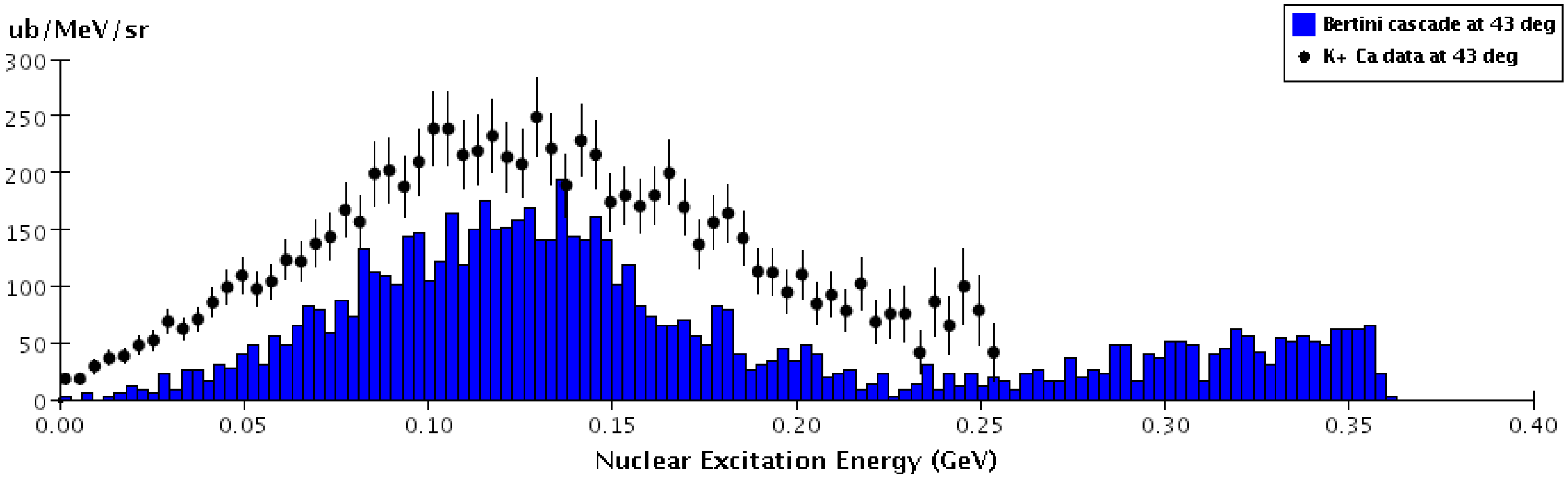
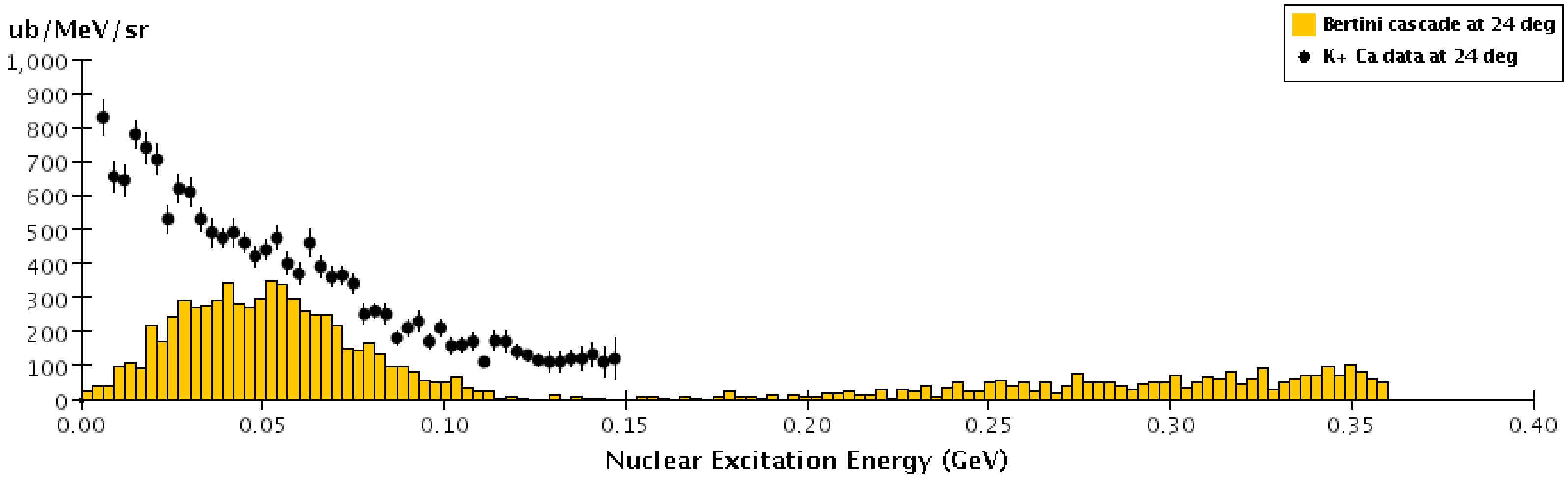


Figure 2: Bertini cascade model

705 MeV/c K+ quasi-elastic scattering from Ca



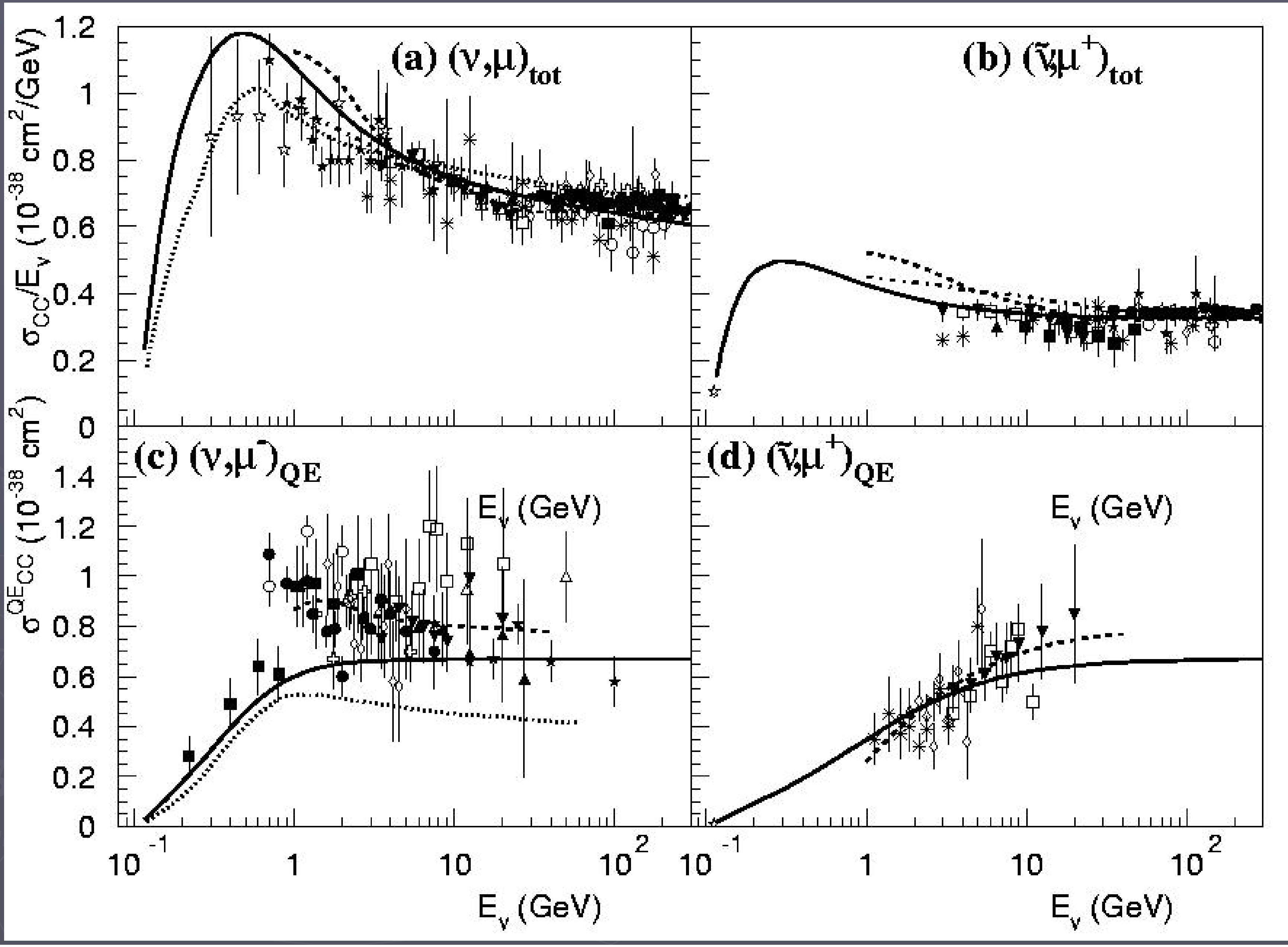


New Developments in CHIPS

- G4QCaptureAtRest for nuclear capture of negative hadrons, muons, and low energy neutrons/antineutrons.
- Process level tests for comparison of simulated parameters with experimental data
  - Validation tests for at rest and in-flight (test19/test29).
- G4QCollision for photo- and lepto-nuclear reactions
  - with DIS simulation of neutrino-nuclear reactions.
- New fixed version of CHIPS for QGSC and FTFC.

M. Kosov

Neutrino-nuclear interactions for CNGS



Physics Lists

- Revised to work with Geant4 8.0
  - Co-work with particles revision
- Utilise EM(std) physics builders
  - Tested by EM(std) WG on HEP calorimeter setups
- Now γ-A interactions is default in all PLs
  - QGSP_GN is now QGSP, includes γ–nuclear
  - A few 'engines' suppressed
    - LHEP_GN, ..
- New variant with 'old' EM physics
  - QGSP_EMV uses multiple scattering with 7.1 parameters

Migrations

- Migrations:
  - Use of <sstream> instead of <strstream>
  - Support for CLHEP-2.0.X (compatible with 1.9.X series)
- Changes required in User Code
  - Fast parameterisation
    - Region replaces ‘envelope’.
  - Creating and instantiating physics lists : impact of the revised, "non-static", particle definitions
  - G4VProcess base class
    - StartTracking() now has argument const G4Track*

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   Chong, K.P.
2. Geant4-a simulation toolkit • **Article**
   Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 506, Issue 3, 1 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.; Burk
3. Radiation pneumonitis and pulmonary fibrosis in non-small-cell lung cancer: Pulmonary function,

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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;