Geant4 at release 5.2

Highlights of recent and ongoing developments

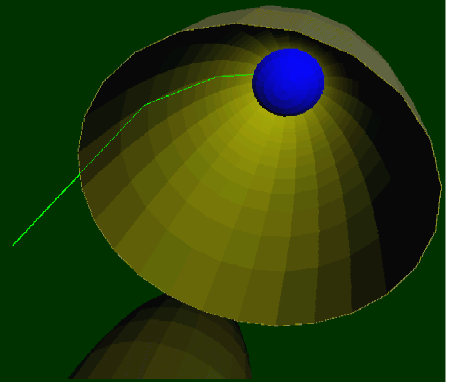
John Apostolakis, CERN

for the Geant4 collaboration

Outline

1. One slide overview of Geant4
2. Physics highlights
   – Modeling and verification
   – Validation
3. New capabilities
   - just released (in version 5.2)
4. Some ongoing developments
   – In progress
   – Planned for the 2nd half of 2003

Geant4 Overview



- Powerful structure and kernel
  - tracking, stacks, geometry, hits, …
- Extensive & transparent physics models
  - electromagnetic
  - hadronic
  - decay, optical, …
- Interfaces
  - visualization, GUI, persistency.
- Efficiency enhancing techniques
  - Framework for fast simulation (shower parameterization)
  - Variance reduction / event biasing

Part 2

Physics Highlights

Modeling,

Verification &

Validation

Highlight of developments in EM (std) in 2002

- Multiple scattering (L. Urban)
  - Angular distributions (see next slides)
- Ultra relativistic energies (H. Burkardt, S. Kelner, R. Kokoulin)

  γ to μ μ process
- Ionization for Generic Ions (V. Ivanchenko)

- New model of Transition radiation (V. Grichine)
  - for TR detectors
- Redesign of processes
  - prototype model approach for energy loss processes (V. Ivanchenko):
    - Ionization and Bremsstrahlung

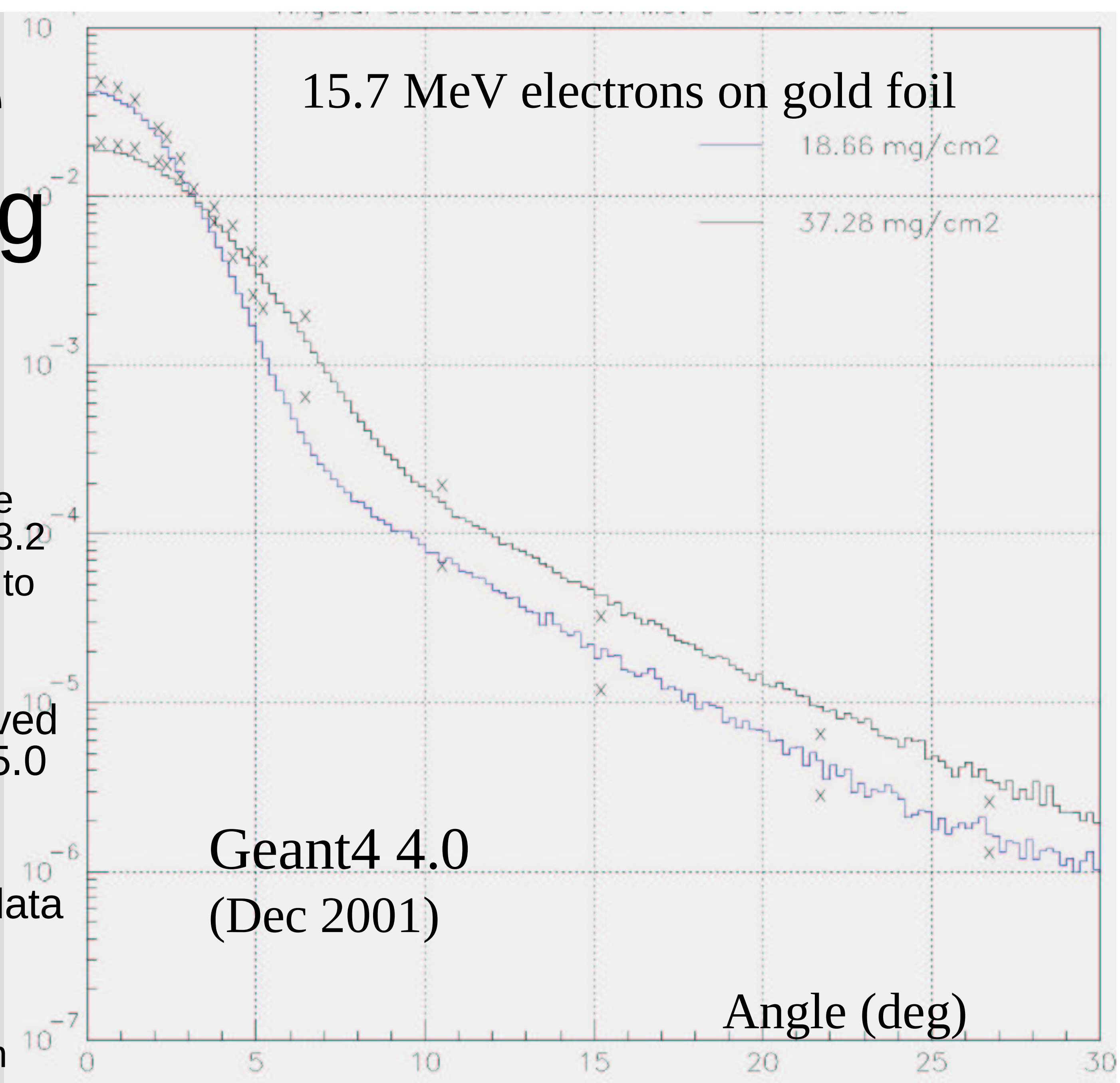
Multiple scattering

Small differences between G4 & G3 observed below 1 MeV
- Results competitive versus data in G4 3.2
- Differences traced to Multiple Scattering

MS modeling improved in Geant4 4.0 & 5.0

Examples of comparisons to data

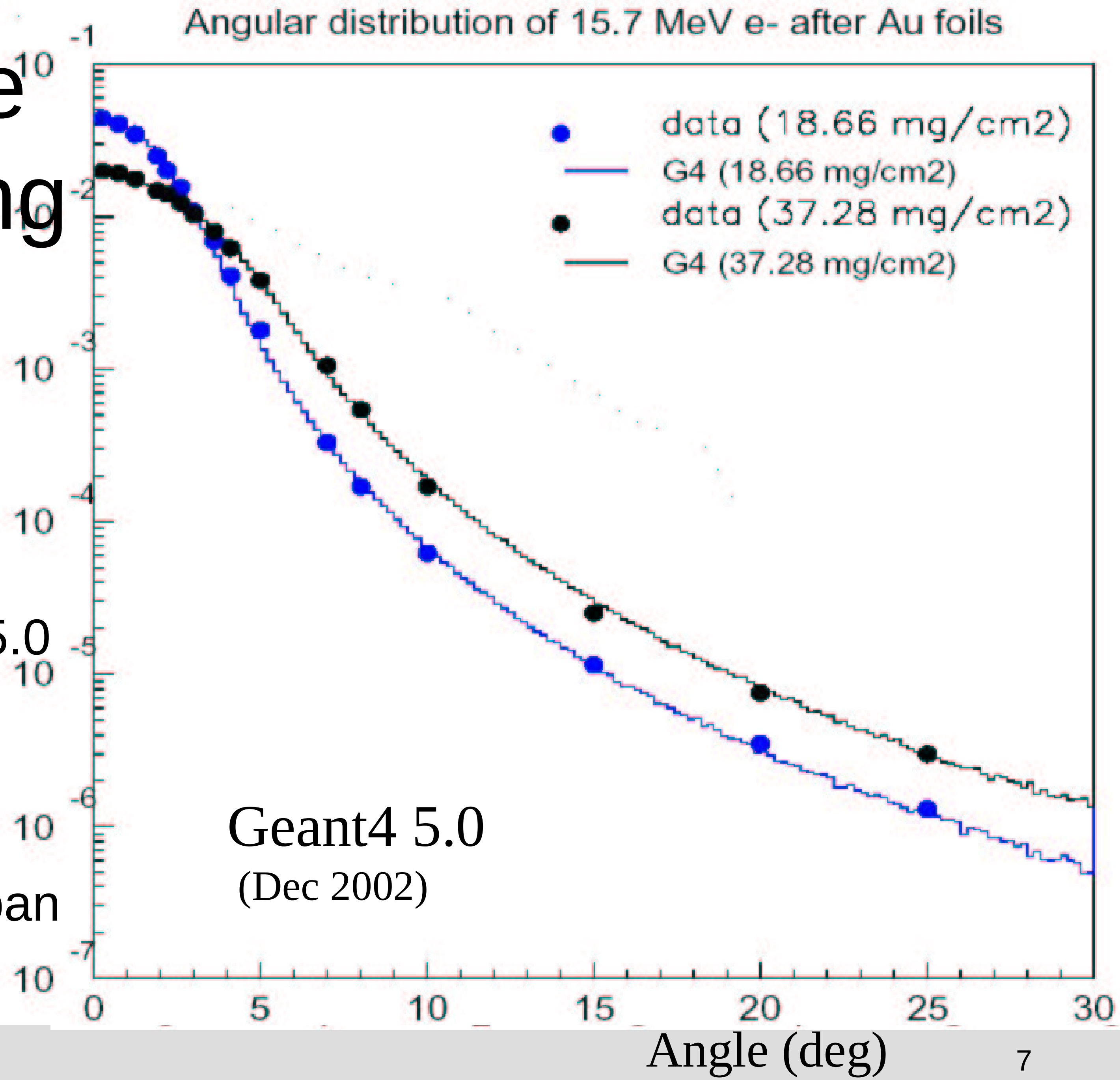
Thanks to L. Urban



Multiple scattering

- Refined modeling of angular distributions
  - in Geant4 5.0

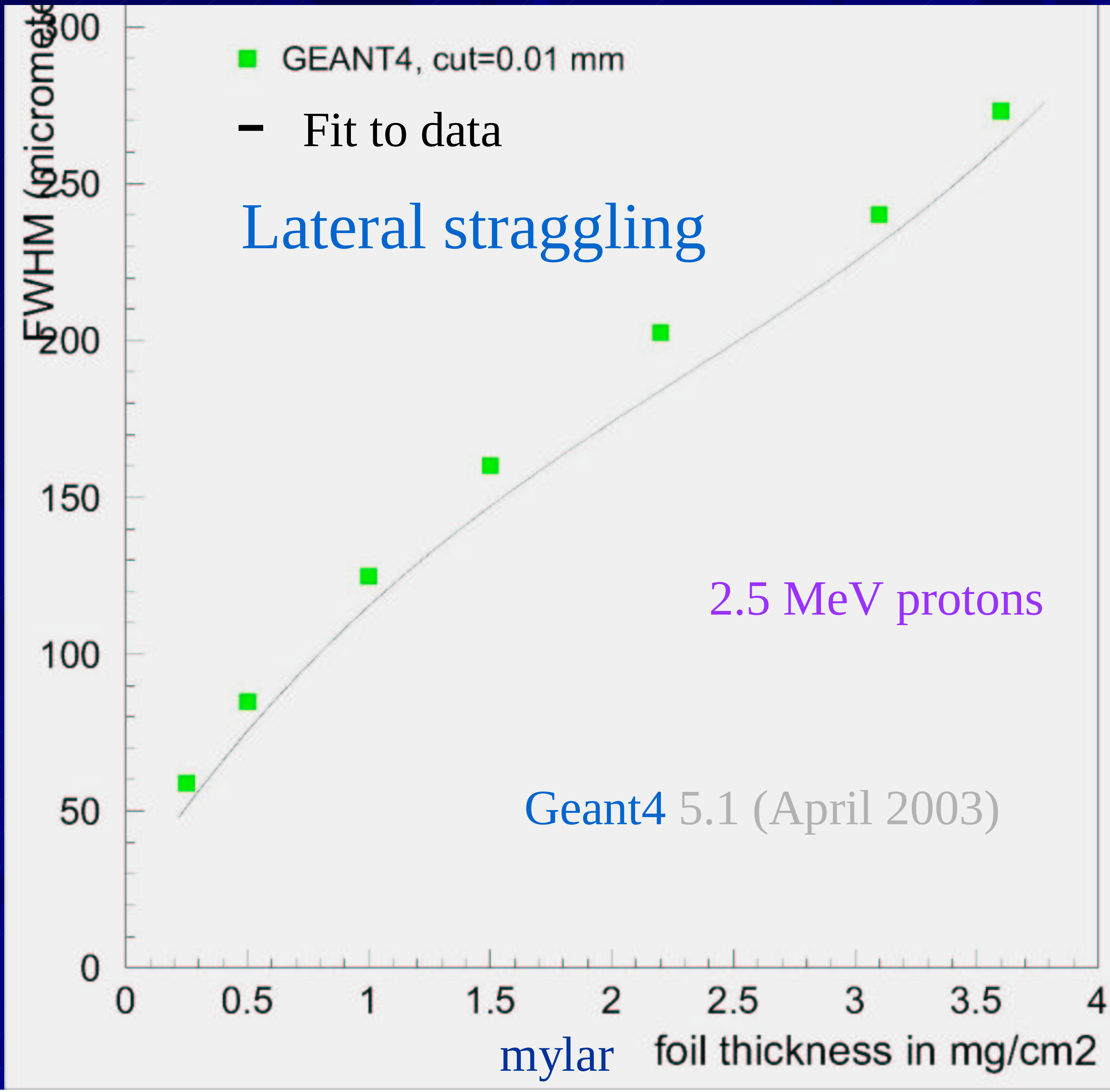
Modeling & comparisons: L. Urban



New in MS

Multiple scattering: refinements

- Backscattering
- Straggling
- Transmitted energy



Hadronic Physics Highlights

Geant4 releases Dec 2002- June 2003 included

- New theoretical hadronic models (G4 5.0)
  - for the cascade energy range (100s MeV- ~5 GeV)
    - Binary cascade
    - Bertini cascade
- Update of ‘tailored’ hadronics physics-lists
  - with new modeling options from Geant4 5.0
    - March/April 2003
- Improvements in models & cross-sections

  Including
  - Improved X-sections for pion X-sections

Models: Cascade energy range

- Parameterized process (1997)
- Chiral Invariant Phase Space decay, "CHIPS"
  - For γ-Nucleus, π capture, string-'backend'
    - First release Dec 2001 in Geant4 4.0
    - Refinements and extension in 2002

  M Kosov,
  P Degtyarenko,
  JP Wellisch
- Bertini cascade (Dec 2002, Geant4 5.0)
  - Re-engineered from HETC by HIP
    - See the presentation of A Heikinen

  A Heikinen
  N Stepanov
  JPW
- Binary cascade model (Frankfurt, CERN)
  - First release for nucleon induced interactions (in G4 5.0)

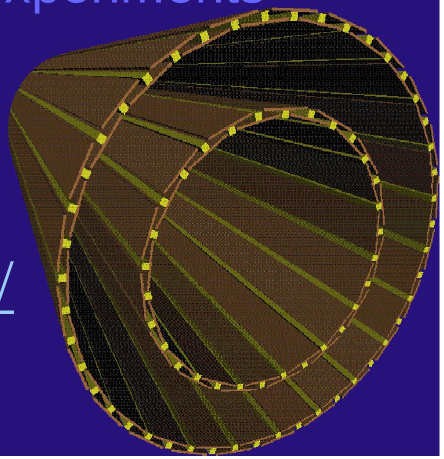
  G Folger
  JPW
- Extensive verification suite
  - See CHEP 03 presentation by D. Wright, V. Ivantchenko, ..
- For further details,
  - see the CHEP 03 presentation by J.P. Wellisch

Tailored Physics 'lists'

- Created and distribute "educated guess" physics lists
  - correspond to major use cases of Geant4 involving hadronic physics,
  - to use directly, and as a starting point for users to modify,
    - facilitate the specialization of those parts of hadronic physics lists that vary.
  - First released in September 2002
    - Using physics models of Geant4 4.1.
- Revised with experience of comparisons with data
  - This provide 'tested' options, with performance guarantees;
- Updated with physics models of Geant4 5.0: March/April 2003
- Distribution
  - today from in the G4 hadronic physics web pages http://cmsdoc.cern.ch/~hpw/GHAD/HomePage
  - Shortly in a binary release for CERN use in g4 AFS area (July 2003)

Use cases of Physics Lists

- HEP calorimetry.
- HEP trackers.
- 'Average' HEP collider detector
- Low energy dosimetric applications with neutrons
- low energy nucleon penetration shielding
- linear collider neutron fluxes
- high energy penetration shielding
- medical and life-saving neutron applications
- low energy dosimetric applications
- high energy production targets
  e.g. 400GeV protons on C or Be
- medium energy production targets
  e.g. 15-50 GeV p on light targets
- LHC neutron fluxes
- Air shower applications
- low background experiments



Contributors: http://cern.ch/geant4/organisation/working_groups.html#wg.Had

Physics lists for calorimetry

- LHEP is the fastest for CPU
  - uses the LEP and HEP parameterized models for inelastic scattering.
- QGSP,
  - uses theory-driven modeling for reactions of πs, Ks, and nucleons.

  It employs
  - Quark Gluon String Model
    - for the 'punch-through' interactions of the projectile
  - A Pre-equilibrium decay model
    - with an extensive evaporation phase to model the nucleus 'after the punch'.
- QGSC, is similar to QGSP but uses CHIPS for fragmentation
  - The CHiral Invariant Phase-Space decay (CHIPS)
- FTFP starts with QGSP and replaces instead the string
  - with a diffractive string excitation
    - similar to that in FRITJOF, and the Lund fragmentation functions.

Partial list of relevant comparisons

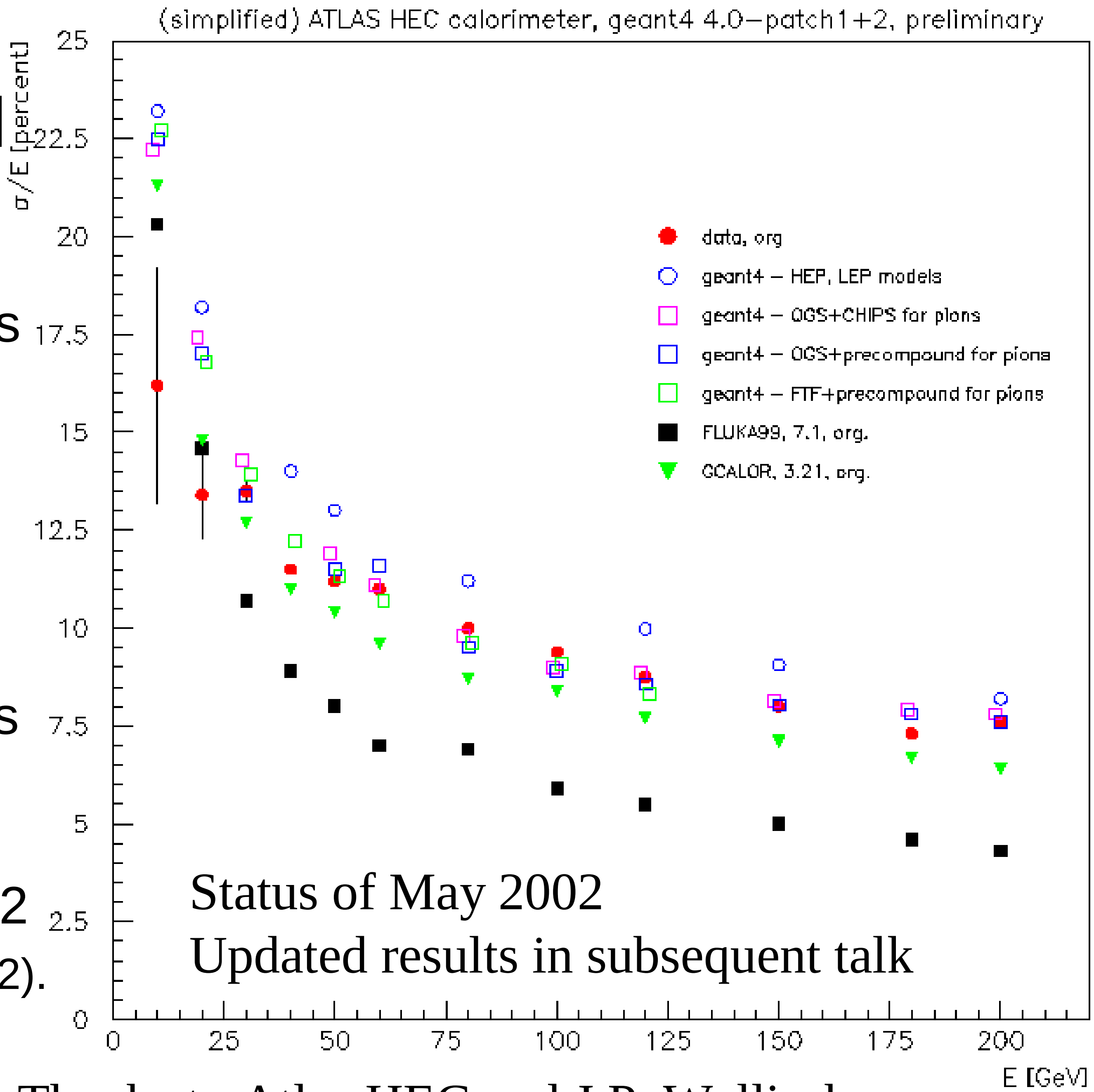
- ATLAS test beams
  - FCAL m, e
  - HEC m, e-
  - EM Barrel
  - TileCal
  - TRT
  - Muon chambers (extra hits)
  - …
- BaBar data
  - Drift Chamber
- ALICE
  - Few 100 MeV proton uscop
  - TIARA neutron benchm.
- CMS HCAL test beam
- BTeV ECAL test beam

I will try to give a few highlights, most through October 2002, leaving the latest results for the subsequent talk of S Solodkov

Resolution

Original (org) results from Calor 2002 presentation,
(March 2002).

Open symbols from additional physics lists JPW, May 2002, using geant4 4.0-patch2
(released: end Feb 2002).



Status of May 2002
Updated results in subsequent talk

Thanks to Atlas HEC and J.P. Wellisch

Validation: future perspective

- Validation is ongoing
  – the largest part of the current effort is on hadronic physics,
  – yet continued effort to understand some effects in EM
- Close collaboration with the LHC Experiments (and the Validation subproject), BaBar and numerous other users
  – Has, is and will be greatly appreciated !
  – Is vital for enabling the use in large experiments & other uses
  – Will be important during the lifetime of G4
- **How good does it need to get?**
  – Eg to ensure that HEP experiments are unaffected by its uncertainties (to the degree possible) ?
  – This big question is up to Geant4 'customers' to answer!
    - We need your help in this, in order to provide the best possible tool.

Part 3

New capabilities

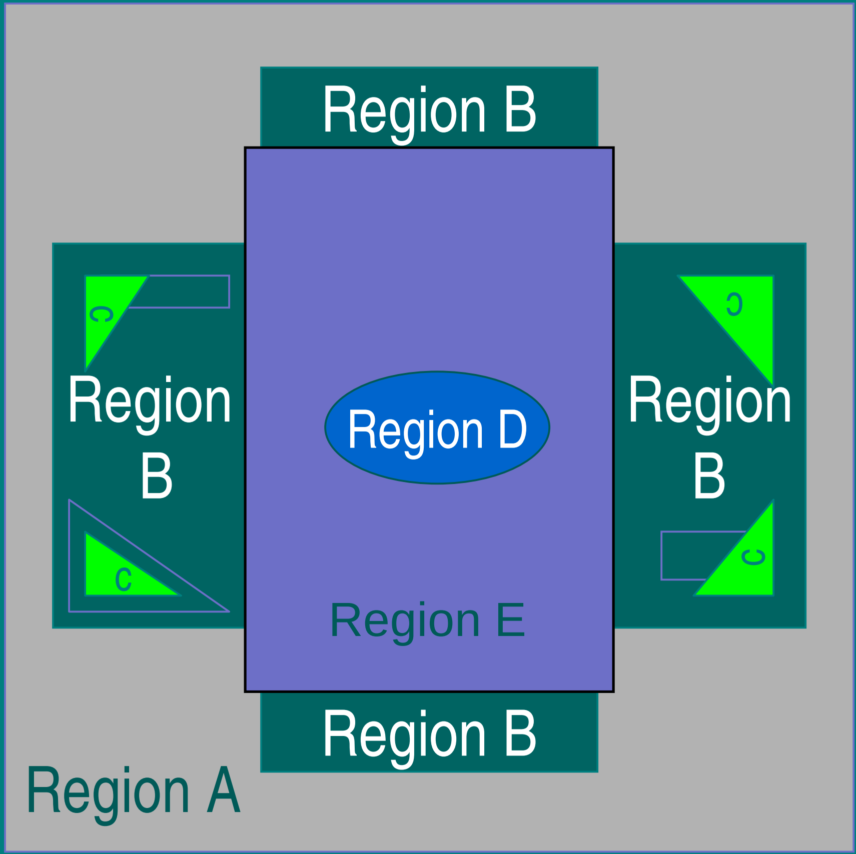
Cuts per region

Detector overlaps

Performance

Region & its properties

- A « region » is :
  - Set of geometry volumes in a sub-detector or sub-system;
  - any group of volumes;
- A cut in range is associated to a region;
  - a different range cut for each particle is allowed in a region .
- Typical Uses
  - barrel + end-caps of the calorimeter can be a region;
  - “Deep” areas of support structures can be a region.



Cuts per region status

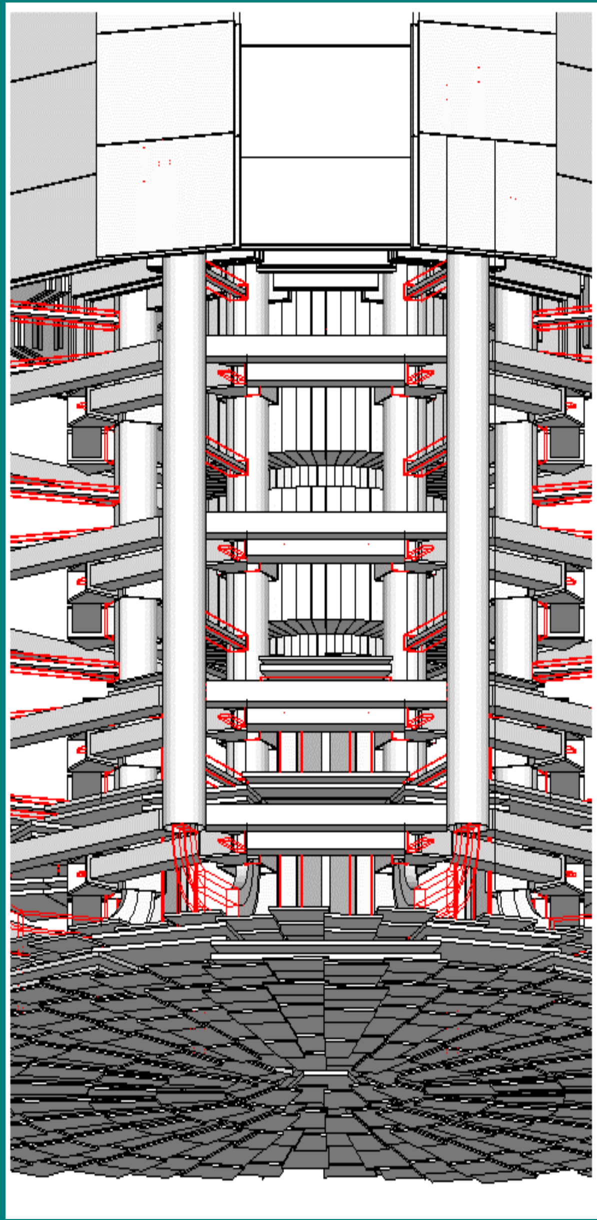
- Designed in 2002
  (M Asai, JA, G Cosmo, M Verderi, M Maire, H Kurashige ..)
  – without severe design revision of the existing GEANT4;
- Implementation
  – Geometry, Kernel (Particles, Run), EM processes, ..
    - (G. Cosmo, M Asai / H Kurashige, V Ivantchenko / M Maire)
  – First available in α, β releases (Jan/March)
  – Improved implementation in public release 5.1 (April)
    - Recovered functionality: storage of physics tables
    - Comparable run-time performance
- Further refinements, validation (May-June 2003)
    - Refinement of ‘final’ step

Other Development highlights

- Detector description
  - Improved tools to detect incorrect geometry definitions
    - see next slide
- Improved field per volume
  - New feature: user can choose accuracy depending on track parameters
  - Ability to set 'null' field
- Variance reduction / event biasing
  - Importance: biasing by geometry
  - Leading particle biasing

Debugging geometries

- It is easy to create *overlapping* volumes
  - During tracking Geant4 does not check for malformed geometries
- The problem of detecting 'significant' *overlaps* is now addressed by
  - DAVID intersects graphics volumes
    - Created by S. Tanaka, released ca 1997
  - Commands to run verification tests
    - Created by DC Williams; released in 4.0
    - New capabilities added in 5.2 (June 2003)
  - New example with full tracking / navigation
    - Created by M Liendl (CMS); released in 5.0



Thanks to S. Tanaka

Variance reduction

- Geant4 has been able to do event biasing
  - Before 2002 only in user code;
  - New general purpose built-in methods released in 2002
    - Further refinements & methods are under development.

M Dressel

- Importance biasing:
  - Splitting/Russian roulette (first released in G4 4.1, June 2002).
    - Revised design, implementation in G4 5.0, Dec 2002
  - Importance values can be associated to a volume
    - In the 'mass' geometry or in a dedicated 'parallel' geometry.
  - Enabling simulation of shielding applications with improved time efficiency by large factors
    - Varied options in driving MC 'history' and scoring tallies
    - No changes to the kernel were required.

N.Kanaya

- Other methods (eg forced interaction) in development

CPU Performance

- Our geometry benchmarks
  - demonstrate it is as good (simple cases) or much faster (complex cases).
- Simple EM setups
- Performance in several experimental setups
  - 2001 reports comparable to Geant3 (BaBar, Atlas EMB, FCAL)
  - In 2002 a number of counterexamples: BTeV ECAL, Atlas EMB,
    - Slowdown typically 2.0x - 3.0x compared to Geant 3.21
    - Some due to issues in Geant4 4.0
      - which were addressed (in patches & release 4.1)
  - Improvements lead to typical factor ~1.8x vs G3 (eg EMB, Sep 02)
- In 2003 the most difficult cases include
  - Some setups of EM showers (eg large blocks – "no geometry")
  - Field propagation in complex setups (eg CMS), factor ~ 2x

Performance (project, actions)

- Improvements in Geant4 5.2 (June 2003)
  - Refinements in EM (std), Ionisation for last step
  - Refinements in field propagation
  - Simple benchmarks: 8-15% improvement
  - Current (preliminary) report:
    - ~15-20% improvement, ~1.5x G3 (CMS, July 2003)
- Instituted project meeting (first 15th July 2003)
  - 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
- Collecting a set of benchmarks
  - To monitor computing performance regularly

Geant4 5.2: other issues

- Release 5.2 builds on the release 5.1 of end-April, which provided the "cuts/region" capabilities - a major development required by large experiments (on timescales agreed Sept 2002, which revised original ones of Feb 2002).
- Full release notes.
- ***Focus***:
  - priority to improvements to stability and performance
  - moved to full direct use of stl, taking out "g4stl" in code (was for non-std STL implement eg gcc/egcs)
- **Key fixes:**
  - Massless particles that caused NaNs & core dumps (found by CMS, using new physics lists)
  - Multiple scattering: fixes for muons, electrons at high energies (GLAST reports). To do: further revisions >100 MeV
  - Improved pion cross-sections
- **New in 5.2**
  - Alternative physics models for low-energy EM, implementing Penelope models
  - Example implementing TIARA-experiment setup for neutrons.

Part 4

Current development: the highlights

Imminent

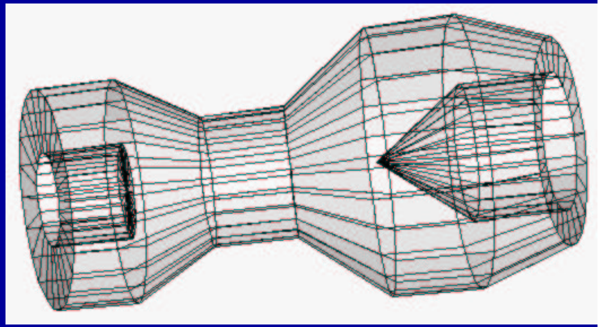
Scheduled

In Progress 2003 (highlights)

- Cuts per region
  - See next slide(s)
- Improvements of multiple scattering
  - For short dense materials, at high energies
- Additional refinements of physics lists
  - Regular updates
  - Binary release in CERN area, on AFS (July 2003)
- Design iteration of EM (std) processes
  - With benefits in tailoring, maintenance
- Further extension and automation of testing
  - Statistical testing: ‘benchmarks’ and test-beams

Further highlights of 2003 planned developments

- Additions to physics processes/models
  - Extension of binary cascade model to π induced reactions
  - EM-std implementation with "model" approach.
  - Refinements, including
    - Improvement to recoil in elastic scattering
    - Improved X-sections for pions.
- Redesign of RunManager
  - Modularisation
  - separation of 'mandatory behaviour'
- Visualisation
  - of importance, scoring geometries
- Several other planned developments, including RTAG / experiments' requirements.



See http://cern.ch/geant4/source/planned_features.html

Hadronics developments (for G4 6.0)

- Review of the pion and kaon reaction cross-sections
- Inclusion of light ion reactions into *binary cascade*
- Inclusion of pion projectiles into *binary cascade*, extensions to the scattering term, and inclusion of absorption
- Inclusion of light and heavy ion reactions into *quark-gluon string model*
- Inclusion of recoils into *elastic scattering*
- Design iteration for hadronic framework
  - to allow for direct implementation of biasing at the framework level
- Implementations for leading particle biasing and cross-section biasing
- Completion of combined re-engineering of HETC and INUCL
- Redesign the physical architecture of the hadronic code
  - to simplify the structure

In progress (also)

- The refinement of the design of EM physics processes through the use of ‘models’.
  - To enable the specialization of key features;
  - To enable the easy use of different models for a single process (e.g. Ionization) in one application.
- Additional variance reduction techniques
  - Filter for enhancing processes in hadronic interactions.
- New ‘division’ volumes
  - Enabling slicing with offset

Primary areas of CERN contribution

- Geometry
  - G Cosmo, M Dressel, J Apostolakis, O Link (from July), V Grichine (from August, part in geometry)
- Hadronics
  - JP Wellisch, G Folger, V Ivantchenko, A Ribon (part, other in validation), M Kosov (from July)
- Software management, System Testing, Release
  - G Folger, S Sadilov, G Cosmo, I McLaren (part-time)
- EM Physics & Error propagation
  - V Ivantchenko, P Mendez(G4e), V Grichine (part)

Upcoming Releases

- Developments available
  - In monthly development tags
  - In open β releases every two months
  - Latest β release (February)
    - Included cuts per region
- Upcoming releases
  - 'Scheduled' release Geant4 6.0 for end December
    - New developments, improvements, refinements.
    - Any fixes, further performance improvements.
  - 2003 work items & planned release contents on web
    - Started from User & Experiment Requirements and Requests

http://cern.ch/geant4/

Summary

- Results of comparing Geant4 versus data,
  – Have provided excellent 'yardsticks' of EM perf.
  – Are testing the hadronics, with increasing coverage
- Geant4 has demonstrated important strengths:
  – stability of results, flexibility, transparency.
  – it is in production use today in running HEP experiments (BaBar, HARP) and is expected to be soon in CMS
- Geant4 is evolving
  – With the feedback from LHC experiments, BaBar and numerous other experiments and application domains.
- Refinements & further development are ongoing.

THE END

Thanks to all

- Contributors
- Users

After the END …

Slides after this are backups,
not part of the presentation.

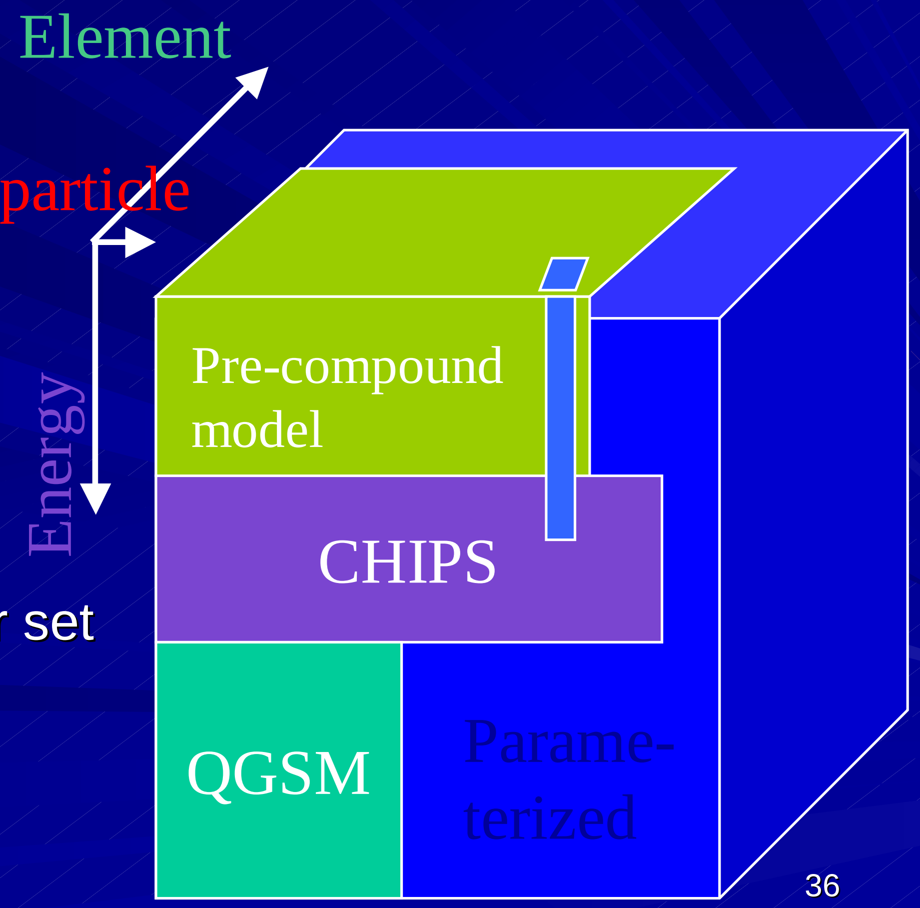
v0.8 24th March 2003, 18:40 GMT

Hadronic physics: models, processes and 'lists'

- Five level implementation framework
- Variety of models and cross-sections
  - for each energy regime, particle type, material
  - alternatives with different strengths and CPU requirements.

- Illustrative example of assembling models into an inelastic process for set of particles
  - Uses levels 1 & 2 of framework

Components can be assembled in an optimized way for each use case.



Improvements in Geometry

- Reflection of volume hierarchies
  - Eg to create endcap geometry

I Hrivnacova
G Cosmo
V Grichine

- Improved voxelisation for performant navigation
  - 3-D for parameterized volumes
    - Now equal performance to ‘placed’ volume
  - Option to avoid voxelizing some volumes

G Cosmo

- ‘Illegal’ geometries detected & rejected
  - E.g. incompatible daughters (placed & parameterized)

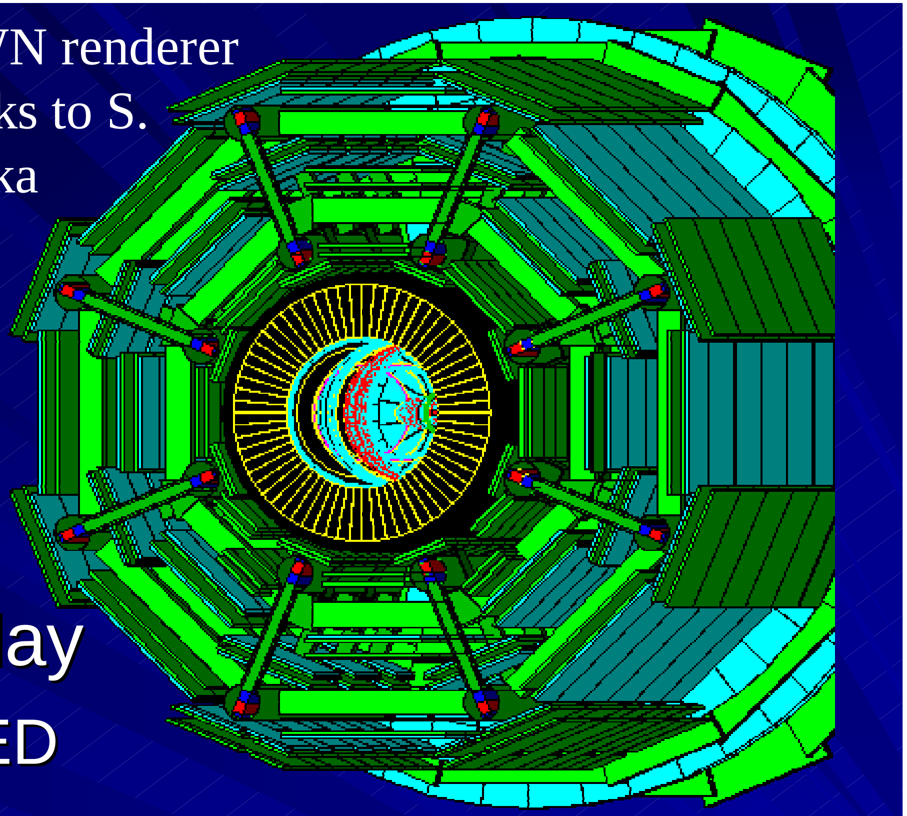
G Cosmo

- XML binding: GDML 1.0 released
    - Specification & Implementation
      - Refinements currently on ‘hold’.

R Chytracek

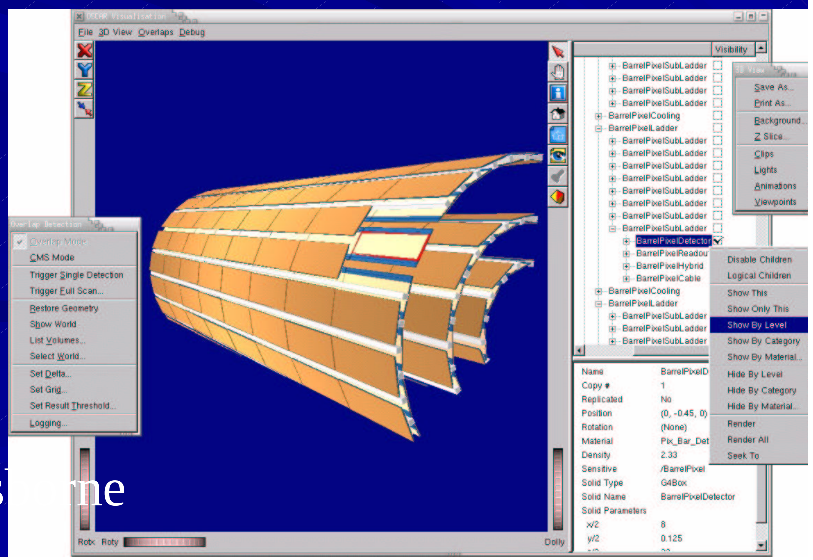
Visualization

DAWN renderer
Thanks to S. Tanaka



Geometry, hits

- New
  - "DTREE": hierarchy display
  - HEPREP driver for WIRED
- Other Current Drivers
  - ***OpenGL***
  - ***VRML***
  - ***DAWN*** *Renderer*
  - Also from others, eg
    - IGUANA (for CMS simulation)



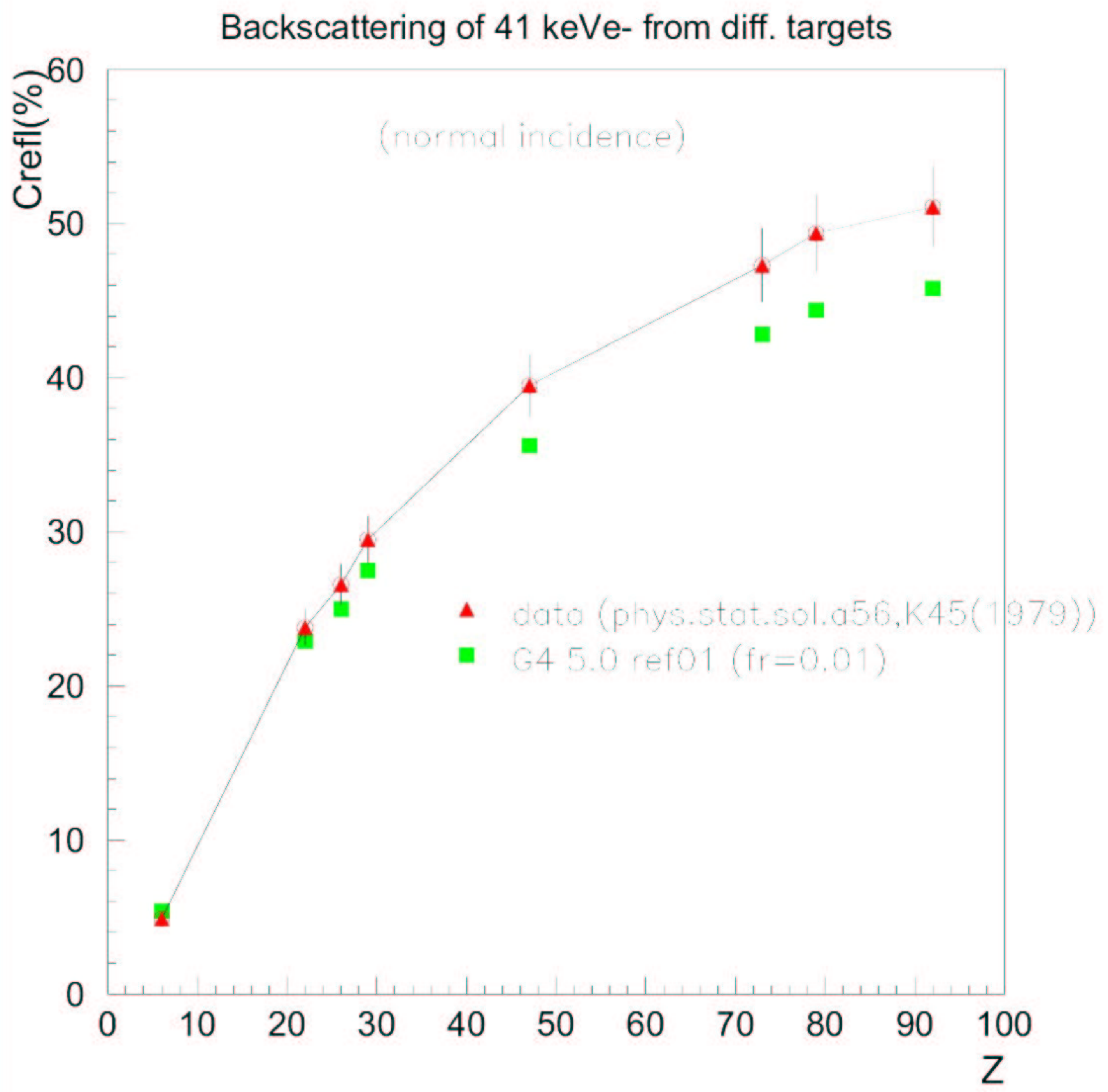
Iguana, thanks to L.Tuura, I. Os ne

MS in progress

Multiple scattering:

Refinements

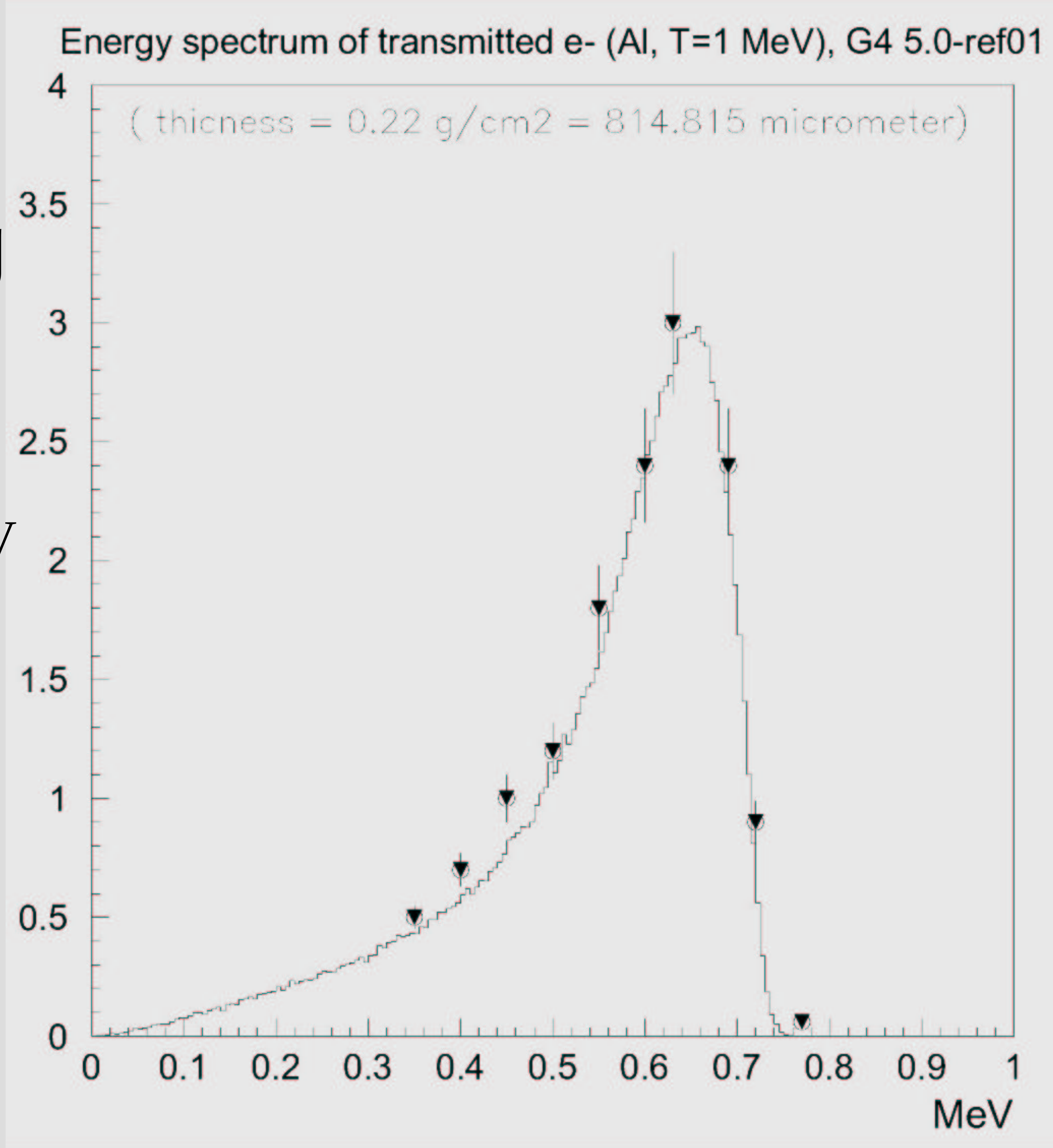
- Backscattering
- Straggling
- Transmitted energy



23rd July 2003

Multiple scattering latest

Electrons of 1MeV incident on Al



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Electromagnetic physics

- Gammas:
  - Gamma-conversion, Compton scattering, Photo-electric effect
- Leptons(e, μ), charged hadrons, ions
  - Energy loss (Ionisation, Bremstrahlung) or PAI model energy loss, Multiple scattering, Transition radiation, Synchrotron radiation,
- Photons:
  - Cerenkov, Rayleigh, Reflection, Refraction, Absorption, Scintillation
- High energy μ
- Alternative implementation
  - 'Standard' for applications that do not need to go below 1 KeV
  - 'Low Energy': down to 250eV (e+/γ), O(0.1) μm for hadrons
    - Including specialized HEP applications

Support: new & continued

- Documentation
  - Revisions of the user and reference guides
    - After assessments of overall structure & detailed
  - LXR for code reference
    - see http://geant4www.triumf.ca/lxr/
- New tool for collecting requirements
- Continued Support
  - of users' questions, problems
    - HyperNews, Problem reporting system, email.
  - of comparisons with data
    - By wide variety of users, in HEP, space, medical phys., ..

Testing and QA 2002/3

- Establishment of 'statistical testing' suite
  - Automated comparison of physics quantities
    - Against 'standard' data (eg NIST)
    - In 'test-beam' applications
    - Including 'regression testing'.
    - For details see
- Establishing a benchmark suite for computing performance.

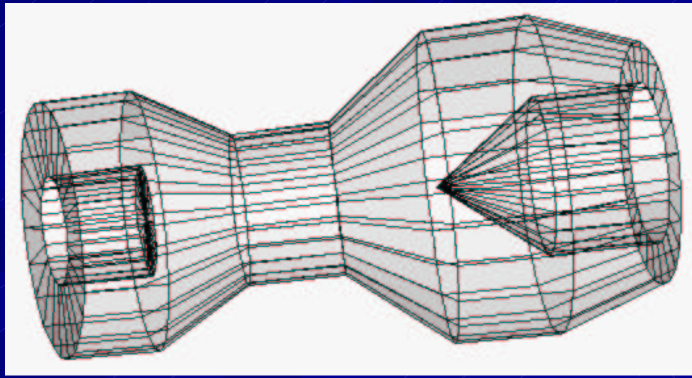
Examples of improvements

Fixes and improvements in Geant4 release 4.1 (June 2002)

- Geometry
  - Fix for voxelisation of reflected volumes
  - Fix for exit normal angle
  - Fix for problem in very small step in field
- EM
  - Improvements in Multiple Scattering, Ionisation, ..
- Hadronics
  - Fix for energy conservation in parametrised models.
  - Fix for small peak at $\phi=0$ in parametrised models.

New Viz functionality

- New commands, with better control
- DTREE
  - Output of geometry tree
    - To ascii
- Visualisation of Boolean solids



- Future:
  - DCUT: slice view in multiple drivers
  - Improved DrawTrajectory()
    - Curved trajectory handling