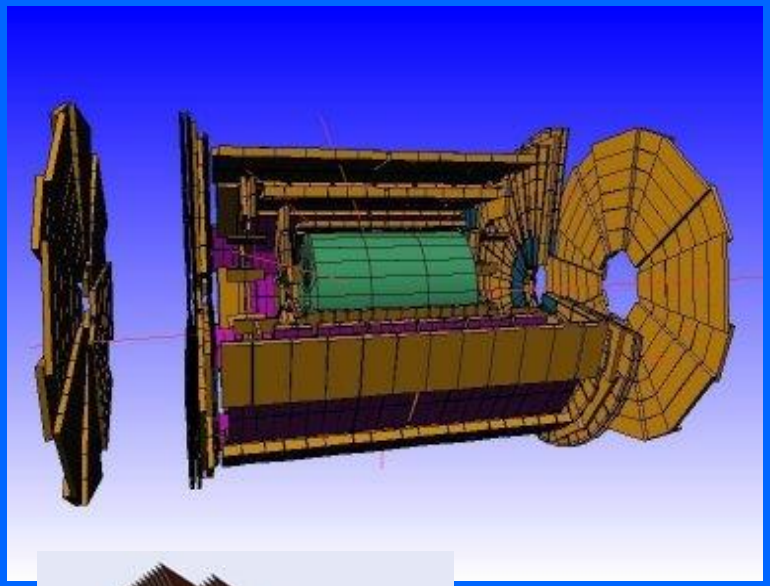
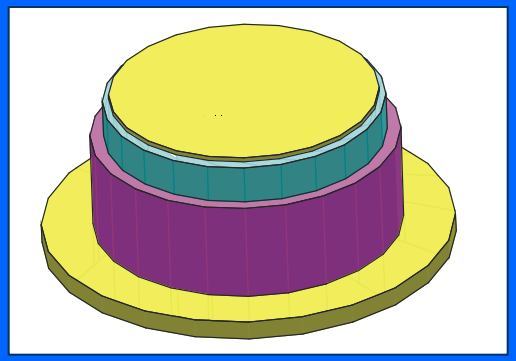
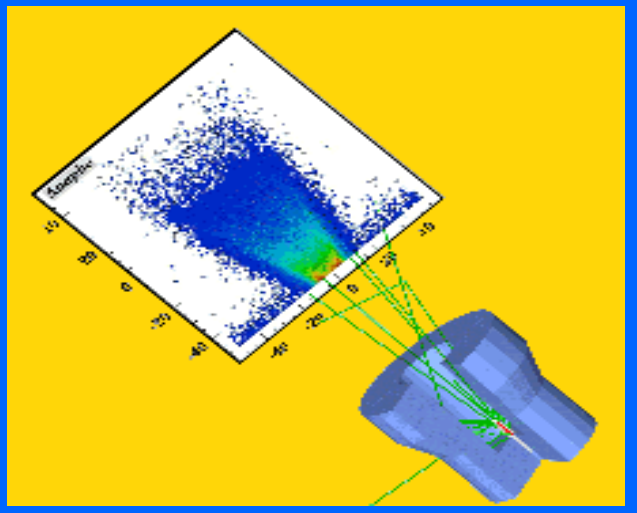
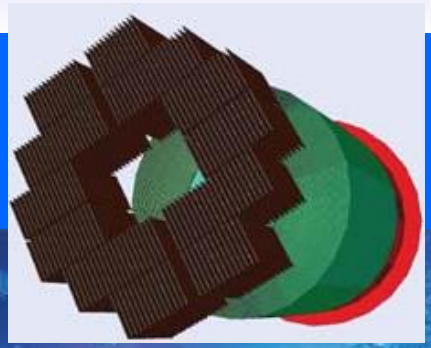
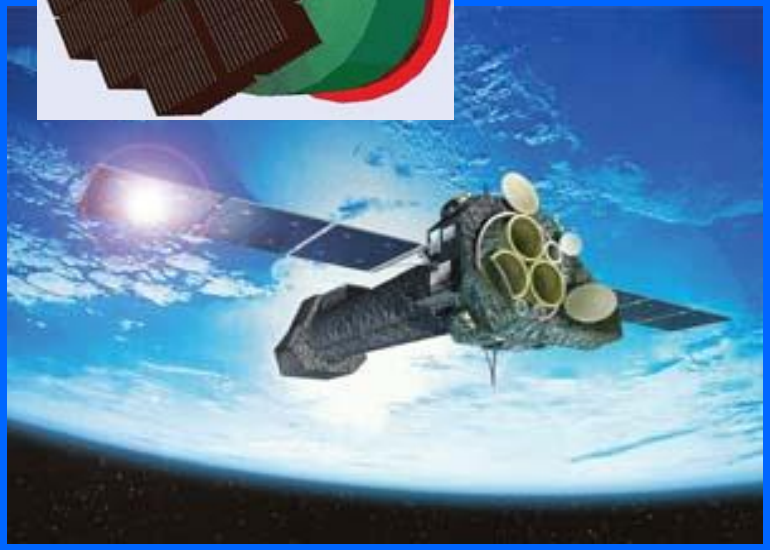






http://geant4.web.cern.ch/geant4/





Geant 4 and its validation

Luciano Pandola

INFN Gran Sasso and University of L'Aquila

for the Geant4 Collaboration

Siena, May 24th, 2004

What is Geant 4 ?

- OO Toolkit for the simulation of the interaction of particles with matter
  - physics processes (EM, hadronic, optical) cover a comprehensive set of particles, materials and over a wide energy range
  - it offers a complete set of functionalities (tracking, geometry, hits)
  - born for the HEP community, but extensively used also in medical physics, astroparticle physics and space applications
- It is also an experiment of distributed software production and management, as a large international Collaboration with the participation of various experiments, labs and institutes
- Has been creating exploiting a rigorous software engineering and Object Oriented technologies, implemented in the flexible C++ language

Where does it come from?

- Very high statistics to be simulated
  - robustness and reliability for large scale production
- Exchange of CAD detector descriptions
  - very complex geometries and experimental setups
- Transparent physics for experimental validation
  - possibility to use alternative/personalized physics models
- Physics extensions to high energies
  - LHC, cosmic ray experiments
- Physics extensions to low energies
  - space science, astrophysics, medical physics, astroparticle physics

  different users and communities than the traditional "MC-customers" from HEP

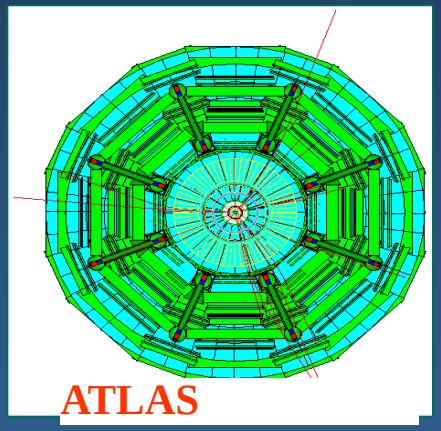
The Geant 4 kit

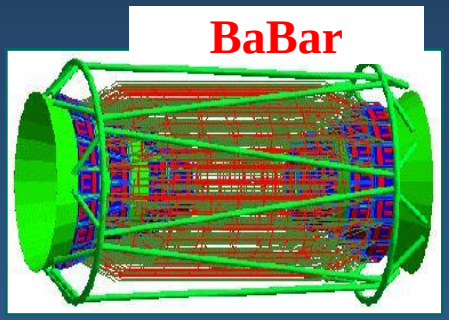
- Code
  - ~1M lines of code
  - continuously growing and updated
  - publicly downloadable from the web
- Documentation
  - 6 manuals
  - publicly available from the web
- Examples
  - distributed with the code
  - navigation between documentation and examples code
  - various complete applications of (simplified) real-life experimental set-ups
- Platforms
  - Linux, SUN *(DEC, HP)*
  - Windows-NT: Visual C++
- Commercial software
  - None required
  - Can be interfaced (eg: Objectivity for persistency)
- Free software
  - CVS
  - gmake, g++
  - CLHEP
- Graphics & (G)UI
  - OpenGL, X11, OpenInventor, DAWN, VRML...
  - OPACS, GAG, MOMO...

Who are the users of Geant4?

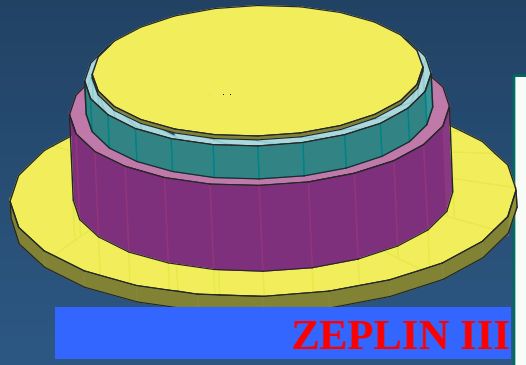
- The flexibility of Geant4 and the availability of dedicated physics models (i.e. low energy physics) make it widely used from different physics communities

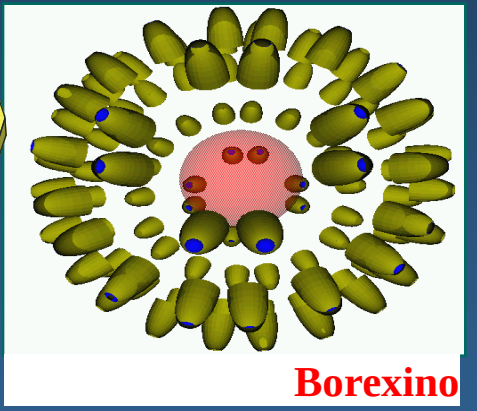
HEP and accelerator physics



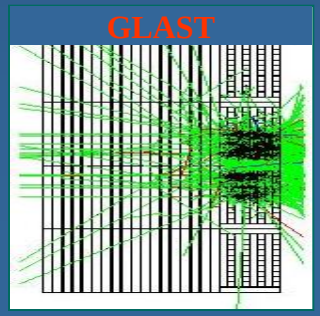


Astroparticle and underground physics

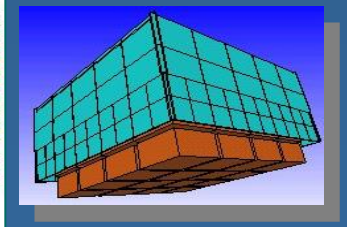




Astrophysics and γ ray astronomy



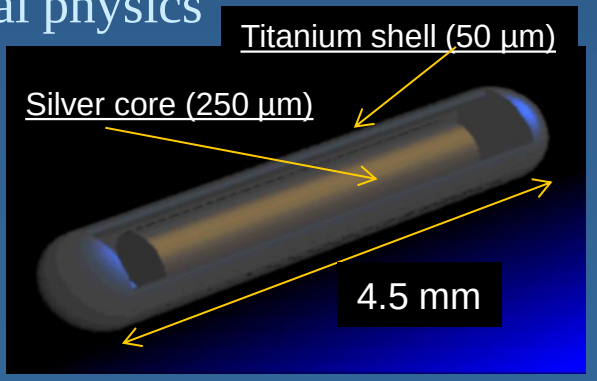
→ F.Longo talk



User requirements are continuously collected, tracked and updated

http://geant4.web.cern.ch/geant4/urd

Medical physics



Physics

- Uniform treatment of electromagnetic and hadronic processes
- Abstract interface to physics processes
  - Tracking independent from physics
- **Distinction between processes and models**
  - Often multiple models for the same physics process (complementary/alternative)

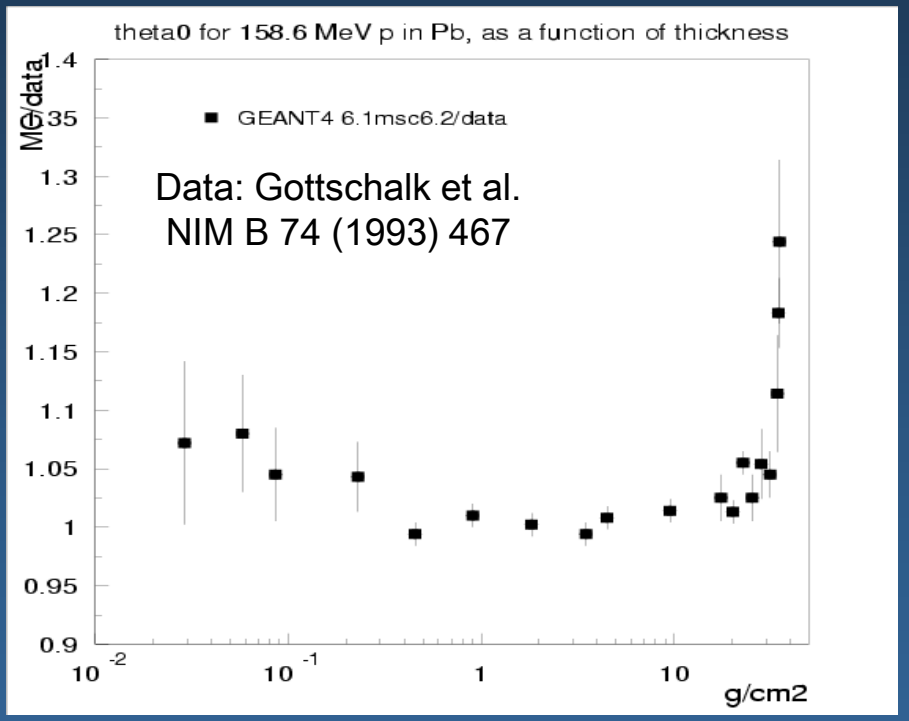
    Users can choose those that best match their needs (energy range, precision vs. CPU time)
- Open system
  - Users can easily create and use their own models
- Transparency
  - Calculation of cross-sections independent from the way they are accessed (data files, analytical formulae etc.)
  - Distinction between the calculation of cross sections and their use
  - Calculation of the final state independent from tracking

The activities in progress..

Electromagnetic Physics

Recent developments of physics processes:

- Improved multiple scattering models ➡
- Extensions to ultra-relativistic energies
- Scintillation and transition radiation
- Muon physics improved
  - ionisation
  - pair production
- Migration to cut-per-region



Re-desing → multi-model approach for processes from version 6.0

few bugs have been introduced → fixed in version 6.1

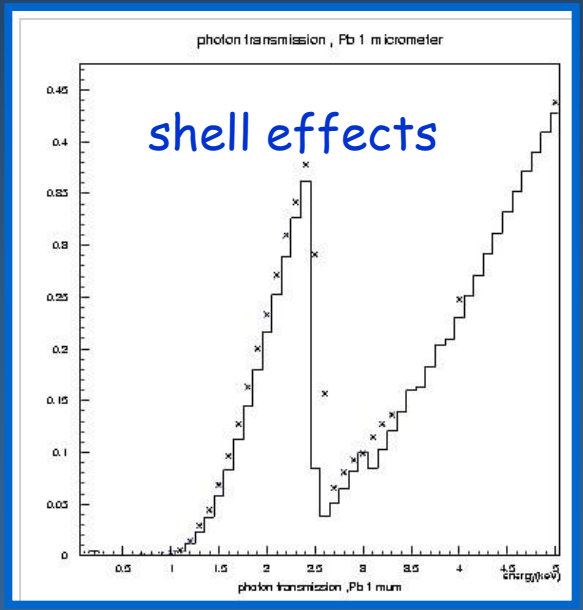
Low energy EM extensions

Geant4 provides dedicated Low Energy EM models

electrons, positrons and gammas down to 250 eV

Based on EPDL97, EEDL and EADL evaluated data libraries

neutrino/dark matter experiments, space and medical applications



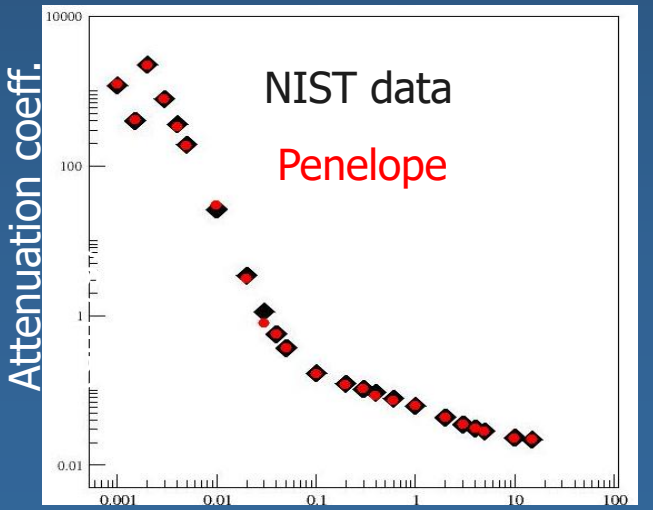
Hadron, anti-proton and ion models

The whole physics content of the Penelope Monte Carlo code has been re-engineered into Geant4

processes for photons: release 5.2, for electrons: release 6.0

New complete set of alternative and dedicated low energy EM physics models (atomic effects included)

Possible thanks to the OO-oriented technology used in Geant4



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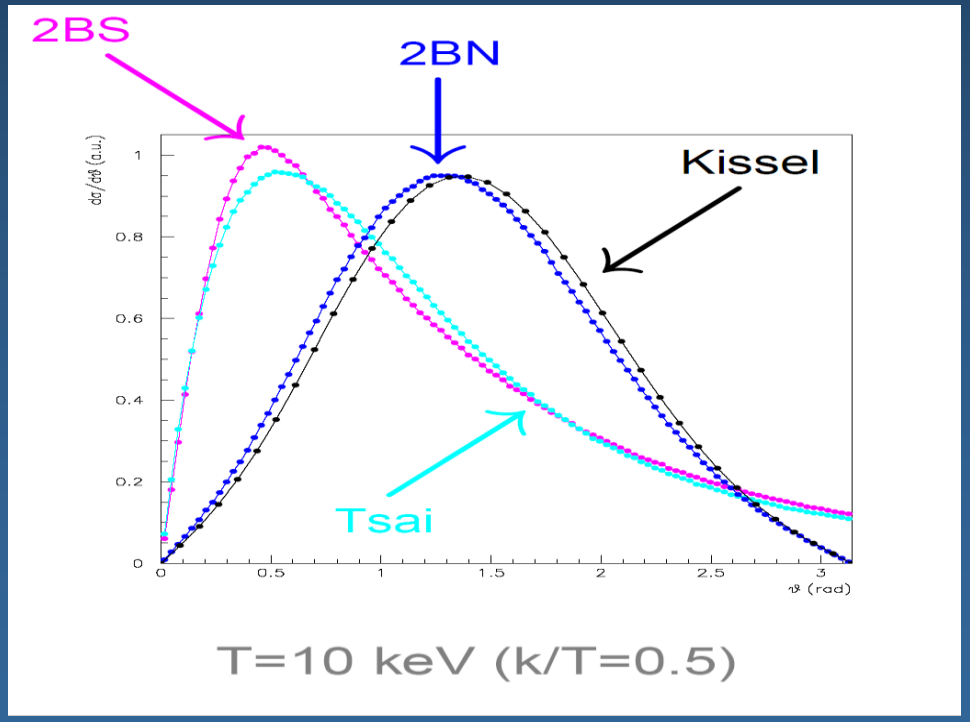
Low Energy Electromagnetic Physics

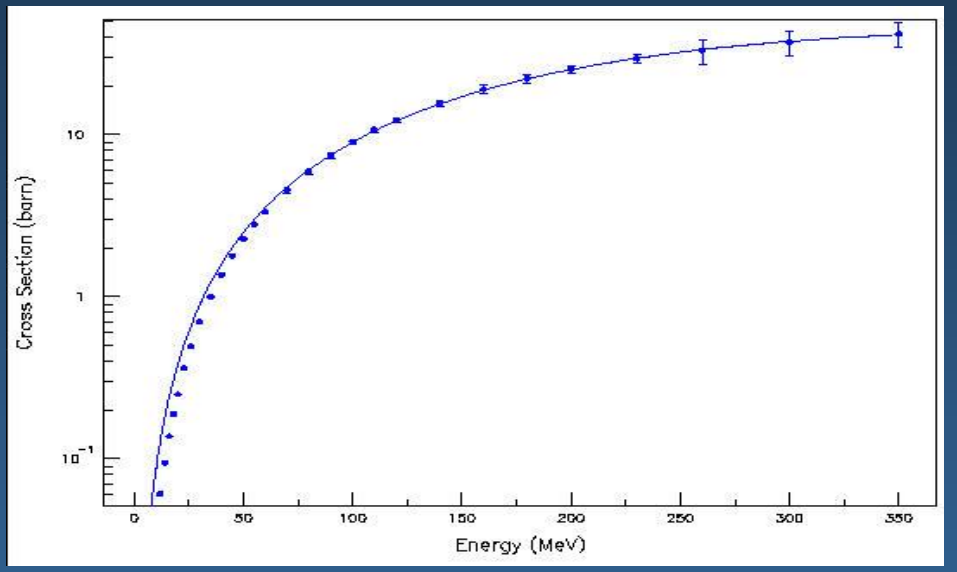
Bremsstrahlung angular distributions

3 LowE generators available in G4 6.0

correct treatment at energies < 500 keV



New PIXE model



New approach: parameterised model based on compilations of data

E: 5 keV → 500 MeV Z: 6 → 92

First implementation for protons, K-shell to be released with Geant4 6.2

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Hadronic physics

New models
- Theoretical: Binary & Bertini cascades, Internal conversion, Chiral invariant phase space decay (CHIPS) ...
- Parametrised: Low energy for antiparticles and strange particles, elastic scattering recoils...

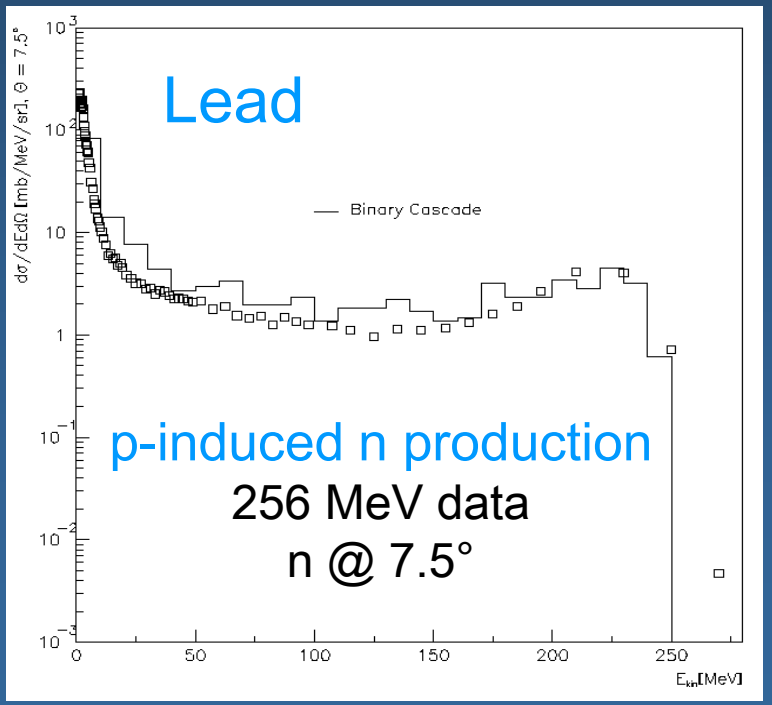
Databases

Photon evaporation and ratioactive decay, improved π cross sections

Physics lists

14 educated guess physics lists for hadronic physics available for different applications (calorimetry, dosimetry, etc.)

Other small improvements and bug-fixes



Kernel & geometry

Redesign of RunManager
- Modularization
- Additional entries
- Accomodated regions & cuts

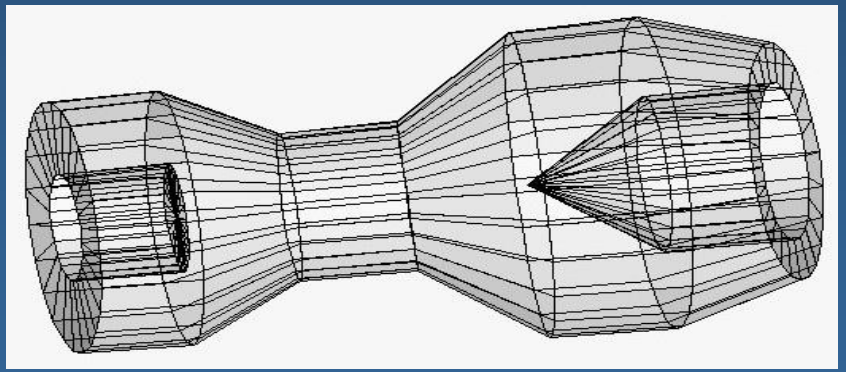
Geometry
- Abstraction of G4Navigator
- Addition of Divisions
  (extend capability of Replicas)
- Fixes in Solids
- Plans: Revision of 'tolerances'

Propagation in EM fields
- Performance enhanced

Biasing
- Geometrical / Importance biasing
- Addition of new techniques

→ Geant4 User Manual

Visualization
- New commands with better control
- Visualisation of boolean solids



Key issues: Performance and robustness improvements

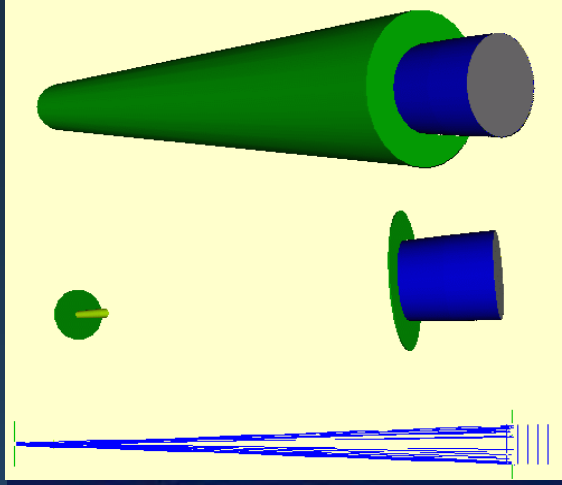
Great benefit from User feedback

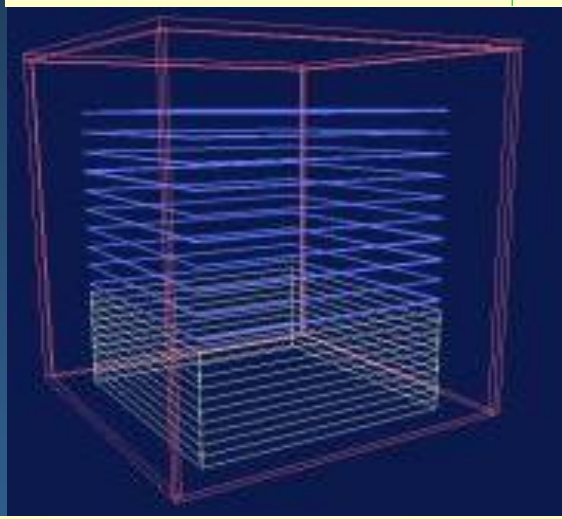
Geant4 advanced examples

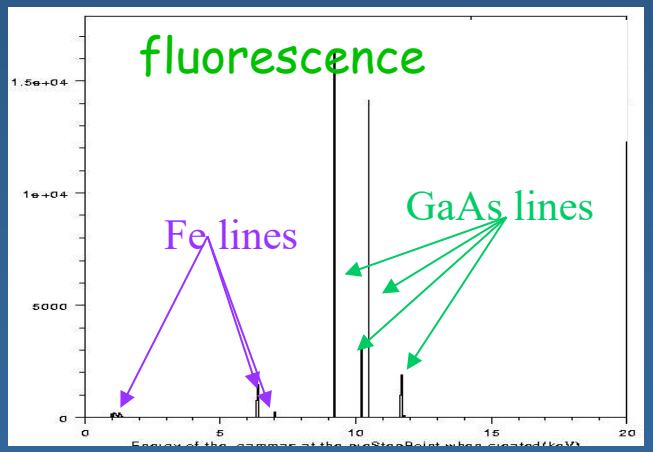
The Geant4 team supports the users with tutorial material (http://geant4.web.cern.ch/geant4/) and with public advanced examples, released with the code (http://www.ge.infn.it/geant4/examples/index.html)

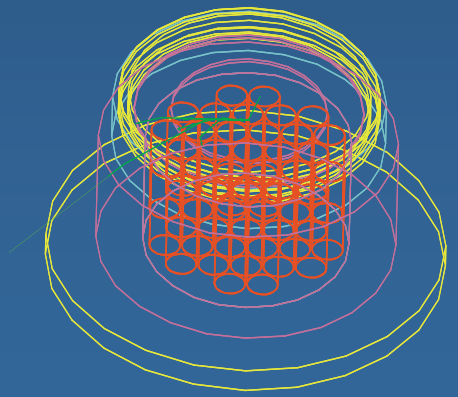
Full scale applications showing physics guidelines, advanced interactive facilities and usage of OO Analysis Tools in real-life set-ups

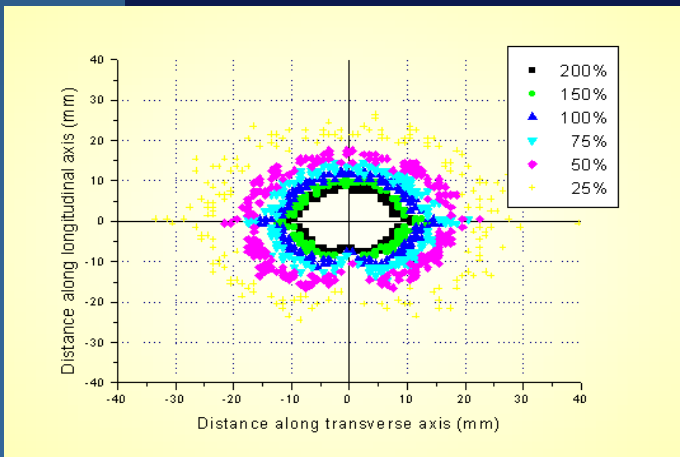
continuously upgraded and extended, in order to cover different experimental domains











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Geant4 Physics Book

- A project has been recently launched for a Geant4 Physics Book (→ LEP Yellow Reports BaBar Physics Book)
- Goal: to have a solid and comprehensive reference on Geant4 physics
- Main focus of the project is Geant4 physics models validation through the comparison with experimental data

  Collaborative effort involving Geant4 physics groups, experiments

Collaboration with detector experts: valuable and welcome!

The validation of Geant4

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Physics Validation

- Systematic and extensive validation of the whole physics content is fundamental in Geant4

  necessary stage to guarantee reliable simulations

- Specific validations at different levels
  - Microscopic physics validation of each model
    → cross section, angular/energy distributions
  - Macroscopic validation with experimental use cases
    → full simulation of experimental set-ups

The results of simulations must be **quantitatively** compared with established and authoritative reference data

experimental measurements on refereed journals and/or open standard dabatases (ICRU, NIST, Livermore)

Microscopic validation

A complete and reliable validation of each single model (or group) requires specific tests of several microscopic quantities

- Cross sections
- Angular/energy distributions or multiplicity of the final state
- Attenuation coefficients
- CSDA ranges
- Stopping powers

The analysis must be performed in a systematic way and for a wide range of materials and energies!

A flexible automatic system is required

job submission and statistical analysis

→ S. Donadio's talk

Where do we stand?

Systematic validation presently focused on EM physics

Standard, Low Energy and Penelope EM models tested

- Photons
- Electrons
- Positrons
- Protons

Reference data from the public NIST database

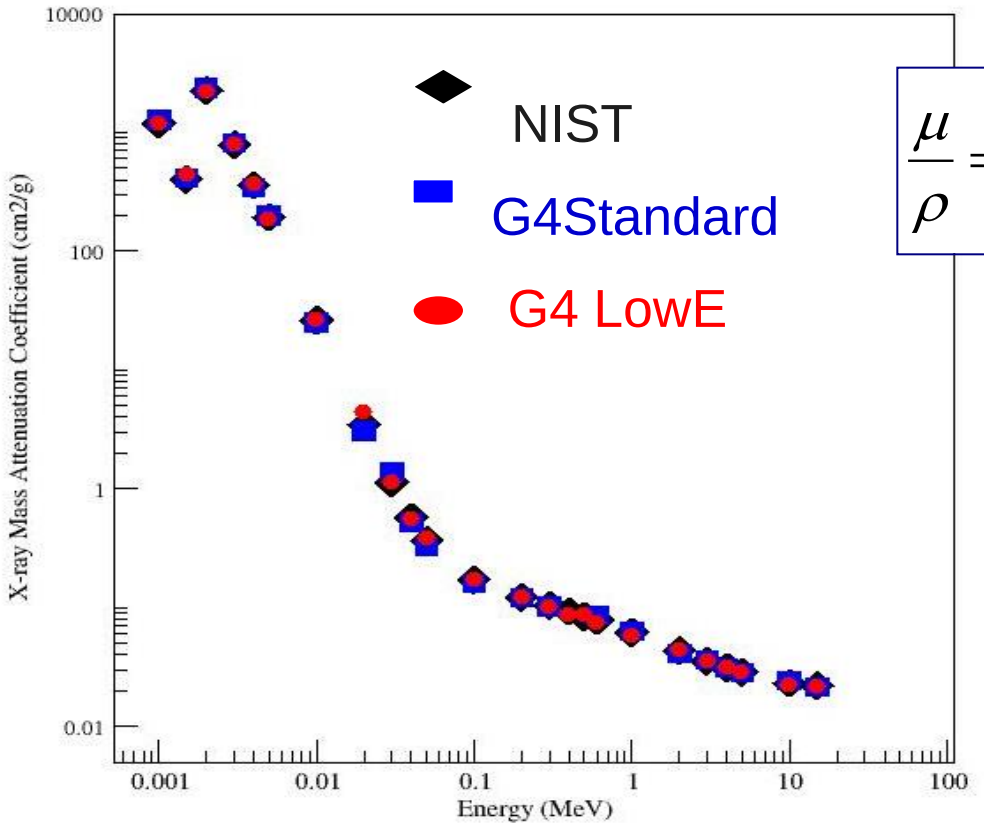
Similar work in progress for EM interactions of protons, α's and ions

reference data more difficult to collect

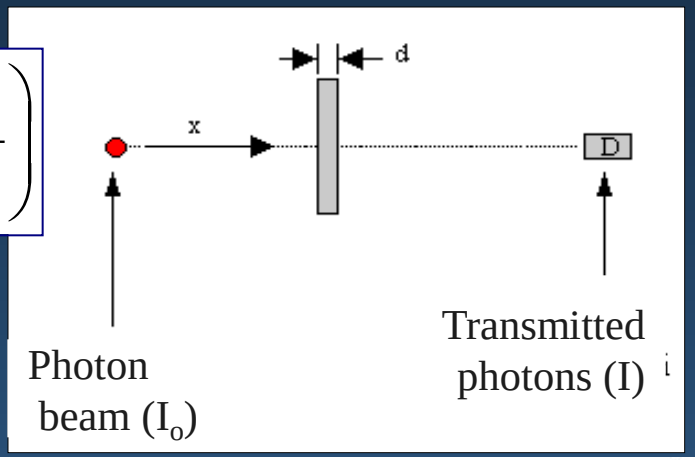
Next steps: quantitative and systematic validation of hadronic physics at microscopic level

A short selection of results ...

Photon mass attenuation coefficient

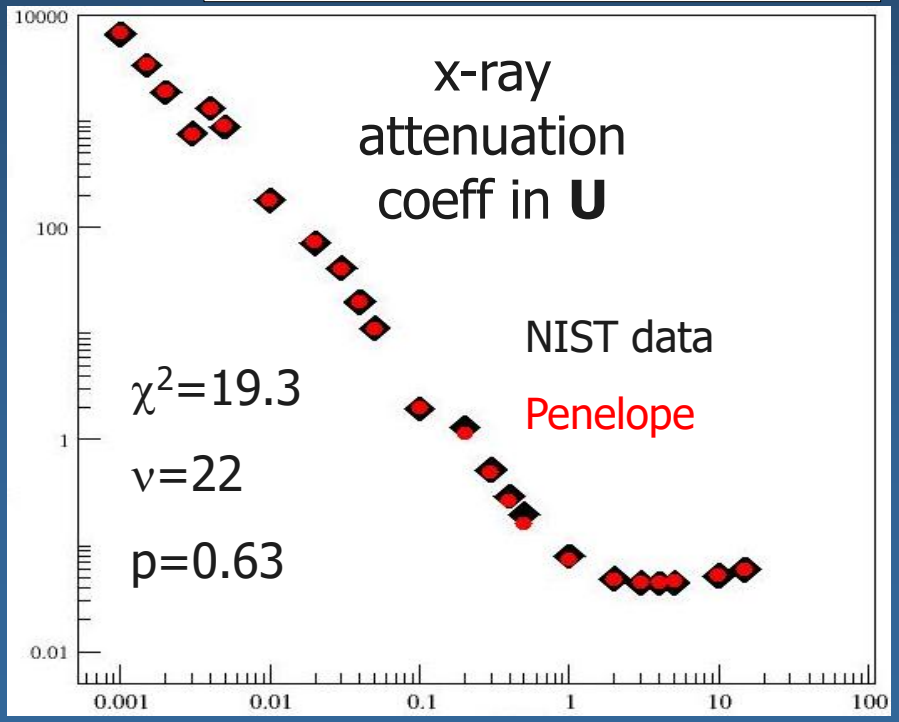


$$\frac{\mu}{\rho} = -\frac{1}{d\rho}\ln\left(\frac{I}{I_0}\right)$$



$\chi^2_{N\text{-}L}$=13.1 – ν=20 - p=0.87

$\chi^2_{N\text{-}S}$=23.2 – ν=15 - p=0.08



Absorber Materials:

Be, Al, Si, Ge, Fe, Cs, Au, Pb, U

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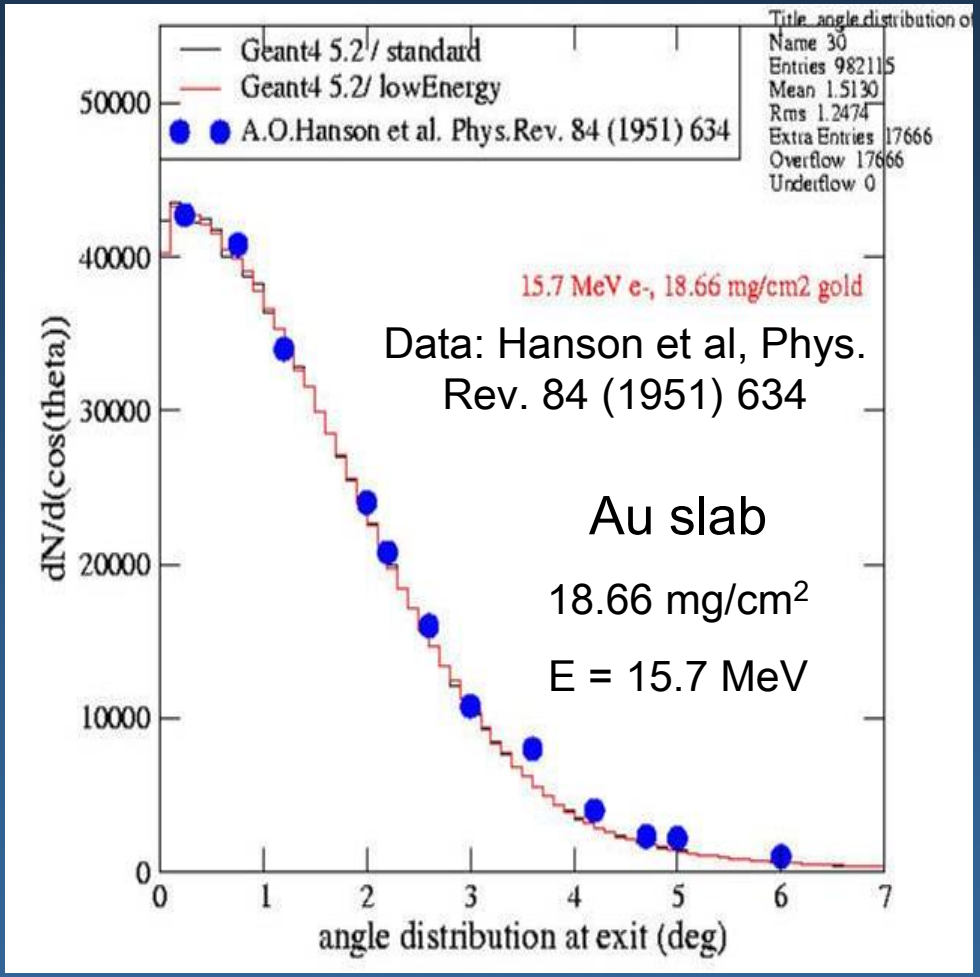
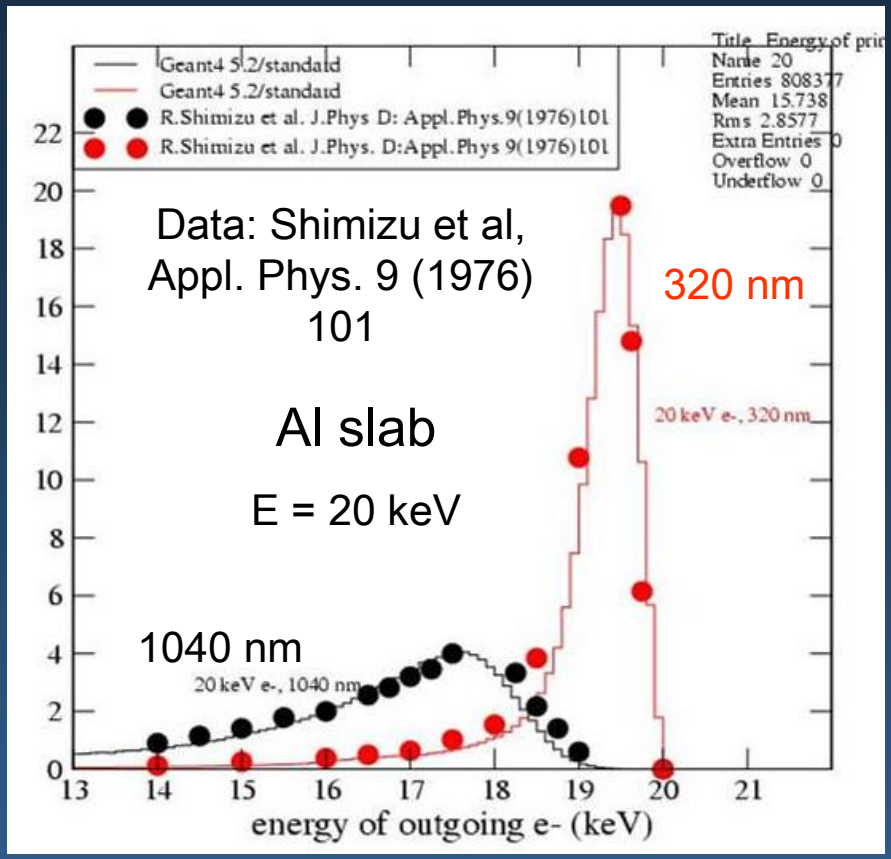
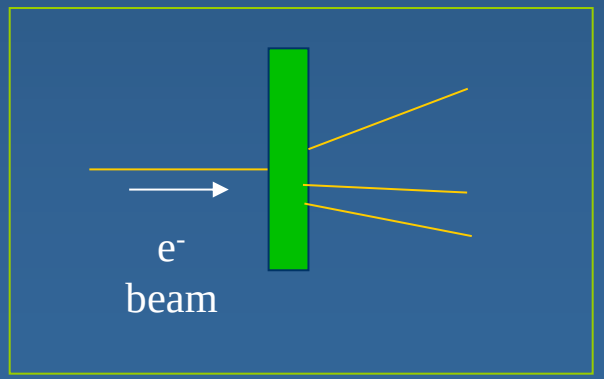
Transmission tests e⁻

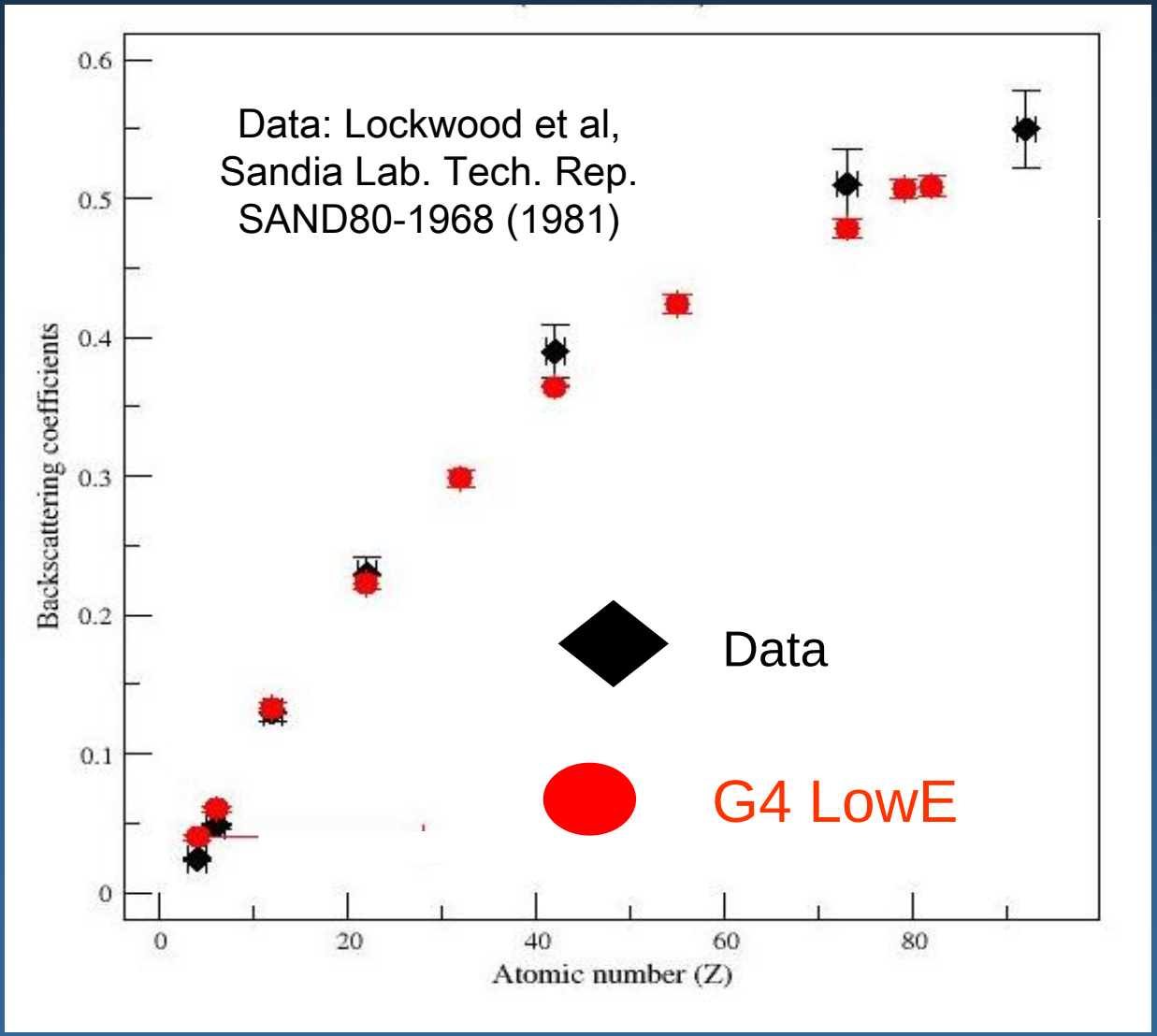


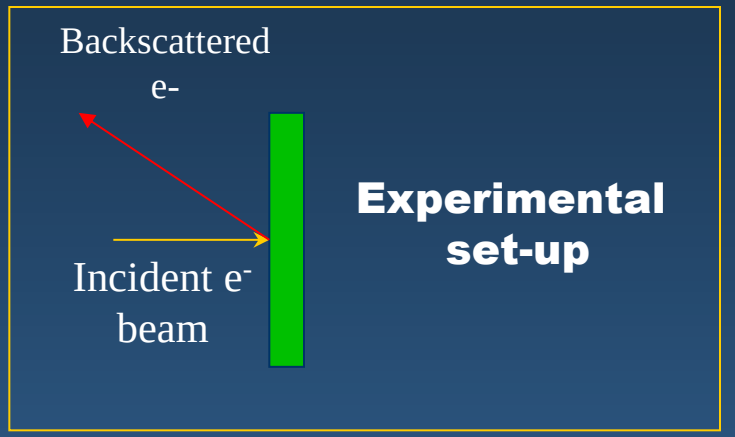




Experimental set-up

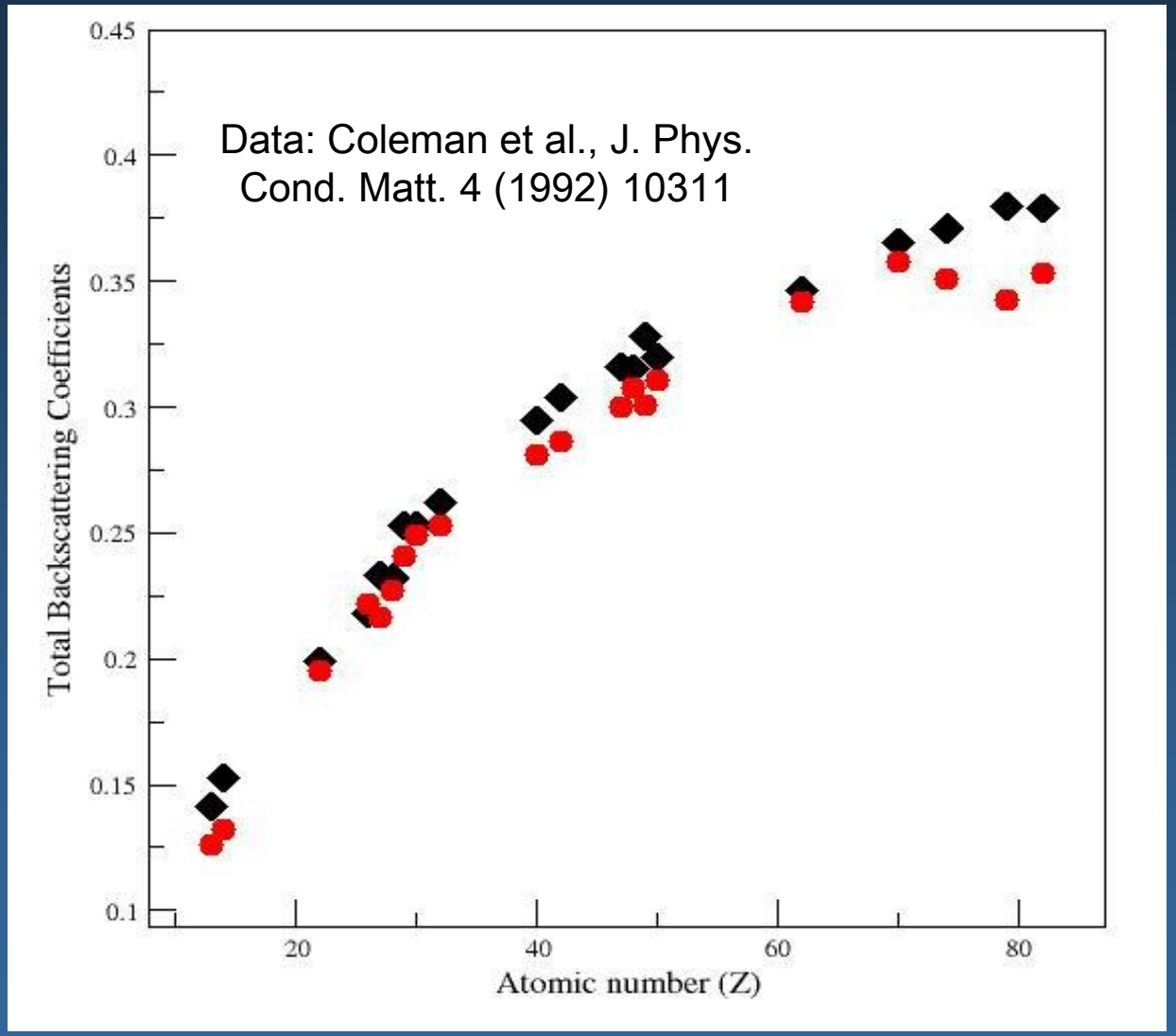
e^- backscattering vs. Z @ 100keV





Angle of incidence (with respect to the normal to the sample surface)= 0°

e^+ backscattering vs. Z @ 30 keV



Data

G4 Standard

Macroscopic validation

Experimental set-up validation

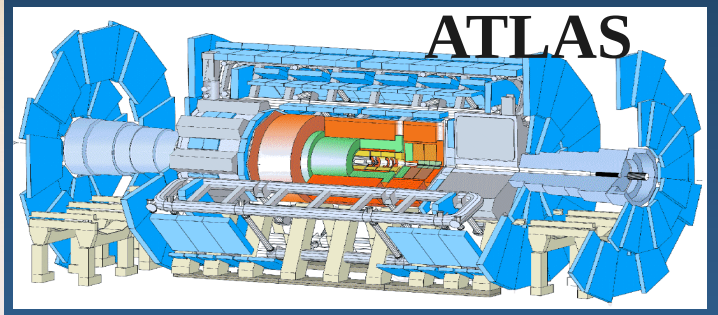
- All physics processes work together
- Test of geometry and tracking

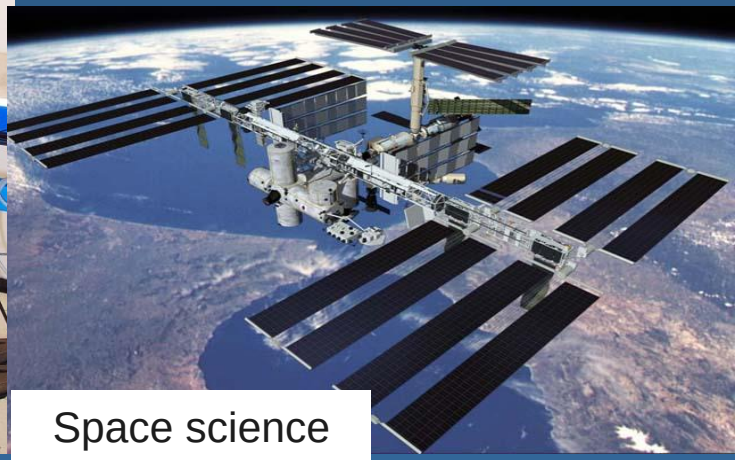
Needs care: understand systematic errors, distentagle physics from geometry...

Realistic and accurate simulation of complex experimental set-ups

⬇

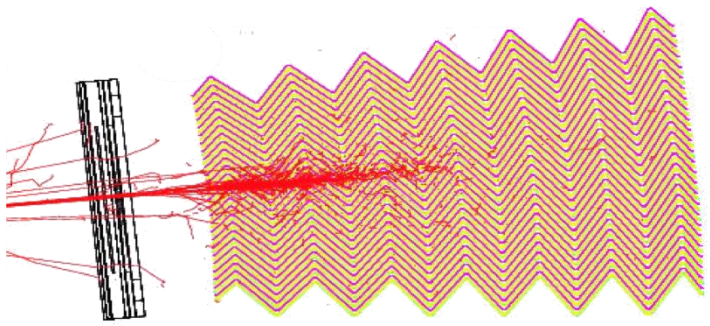
Collaboration of Geant4 developers and research groups of different experiments





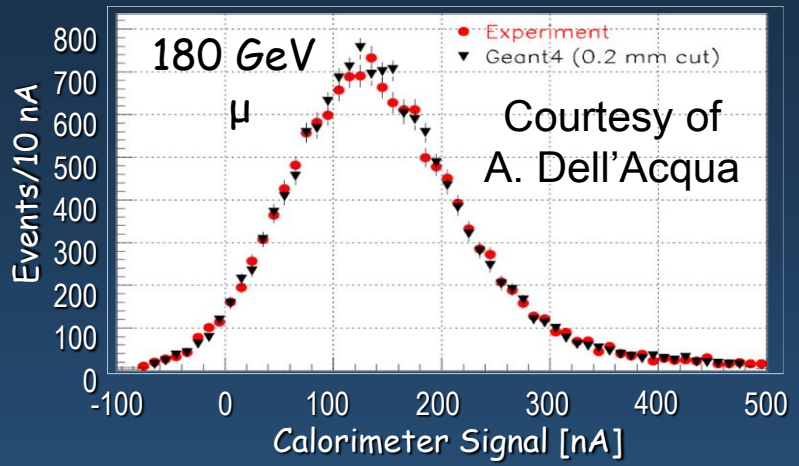
Geant4 electron response in ATLAS calorimetry

Electromagnetic Barrel Accordion Calorimeter

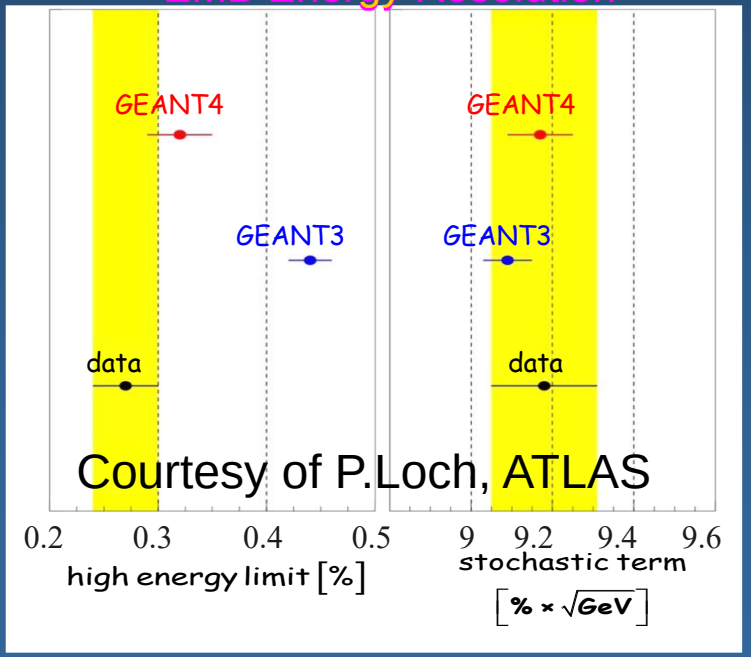


10 GeV Electron Shower

Hadronic EndCap Calorimeter (HEC)
(Liquid Argon/Copper Parallel Plate)



EMB Energy Resolution



Geant4 reproduces the average electron signal as a function of incident energy in all ATLAS calorimeters very well

Signal fluctuations in EMB are very well simulated

Much more tests from LHC experiments...

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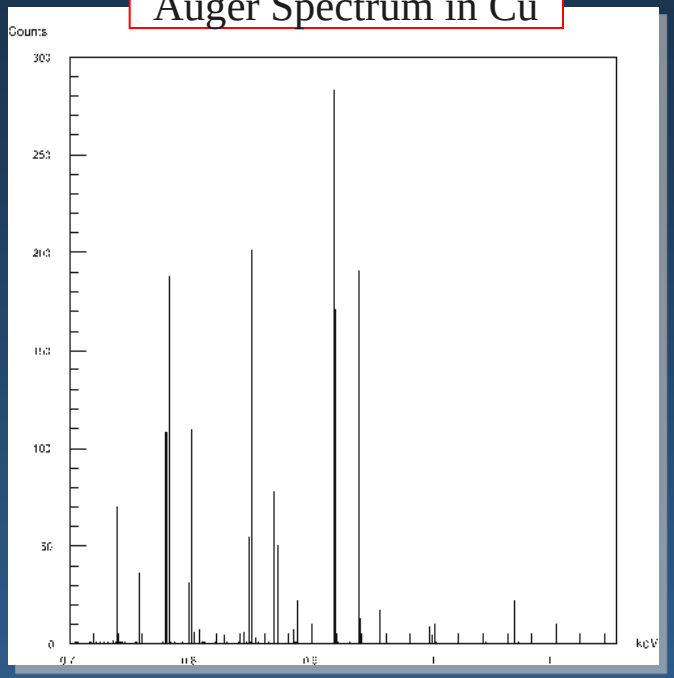
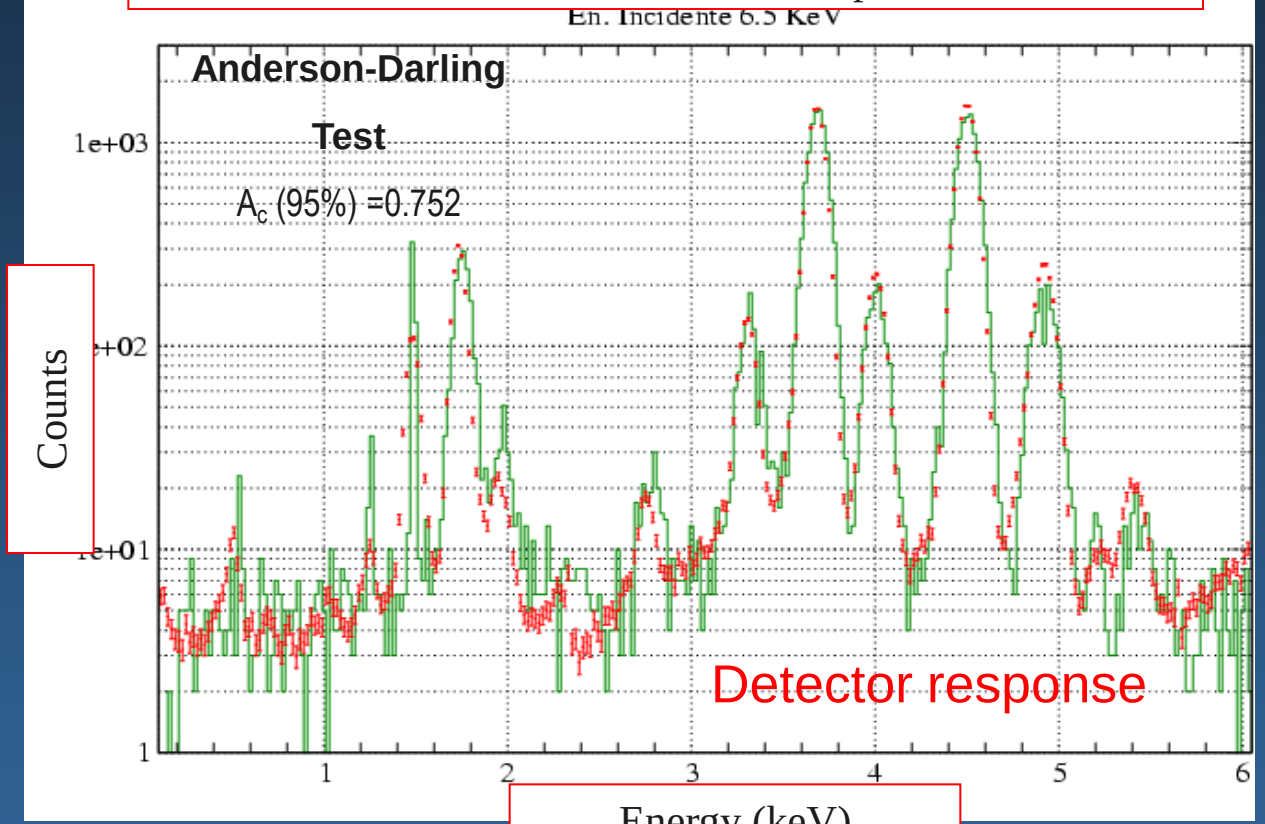
Auger effect, X-Ray fluorescence

Auger Spectrum in Cu



Simulation of Auger emission from pure materials irradiated by an electron beam with continuous spectrum

Iceland Basalt Fluorescence Spectrum



A.Mantero, M.Bavdaz, A.Owens, A.Peacock, M.G.Pia

Simulation of X-ray Fluorescence and Application to Planetary Astrophysics

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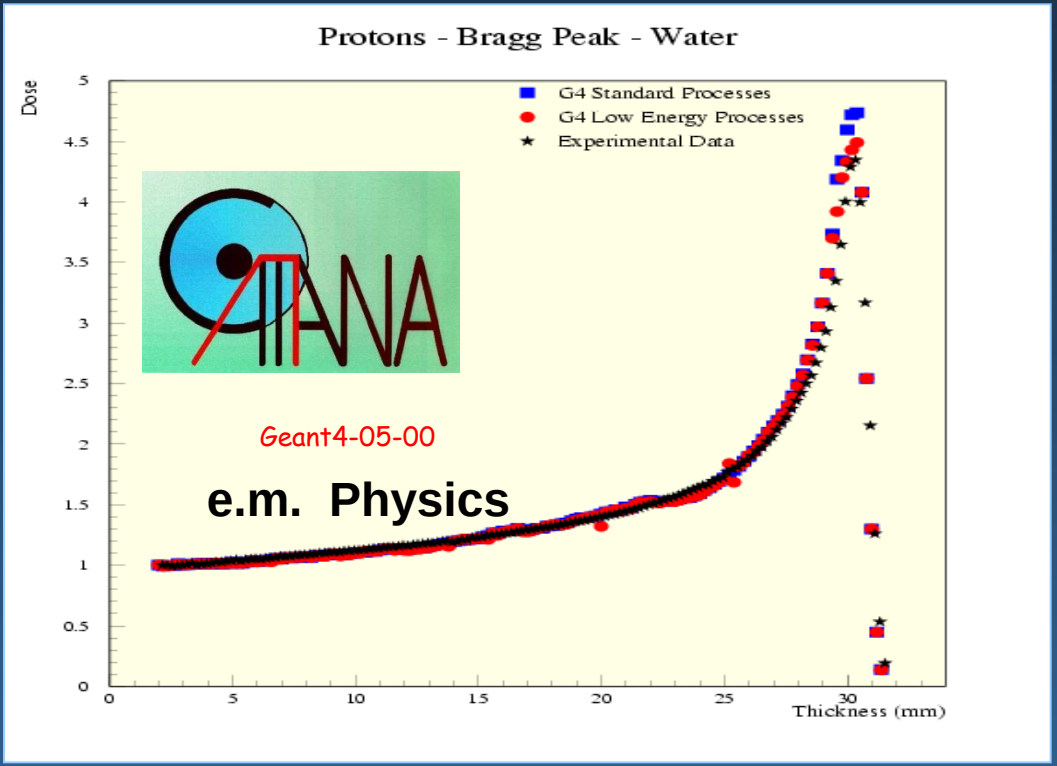
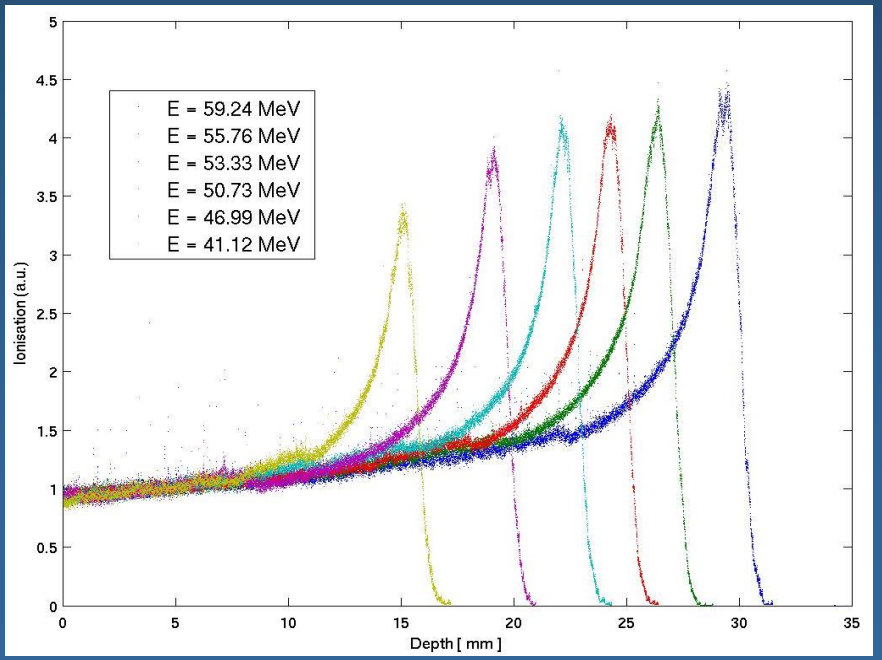
Bragg peak & protons



Absorber Material: water

Comparison with (dedicated) experimental data from INFN, LNS Catania

→ talk G.A.P. Cirrone



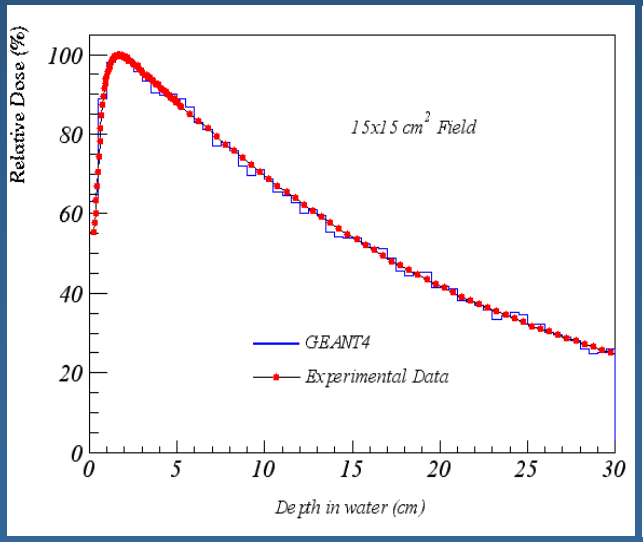
G.A.P.Cirrone, G.Cuttone, S.Donadio, S.Guatelli, S.Lo Nigro, B.Mascialino, M.G.Pia, L.Raffaele, G.M.Sabini

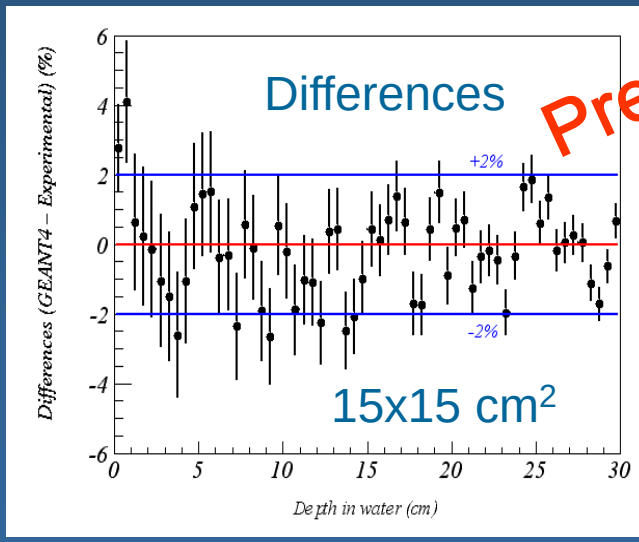
Implementation of a new Monte Carlo Simulation Tool for the Development of a proton Therapy Beam Line and Verification of the Related Dose Distributions

Medical physics applications

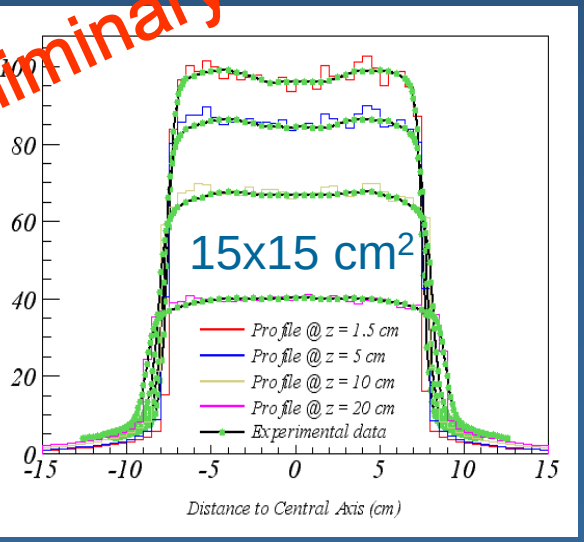
P. Rodrigues, A. Trindade, L.Peralta, J. Varela, LIP

- Simulation of photon beams produced by a Siemens Mevatron KD2 clinical linear accelerator
- Validation against experimental data: depth dose and profile curves

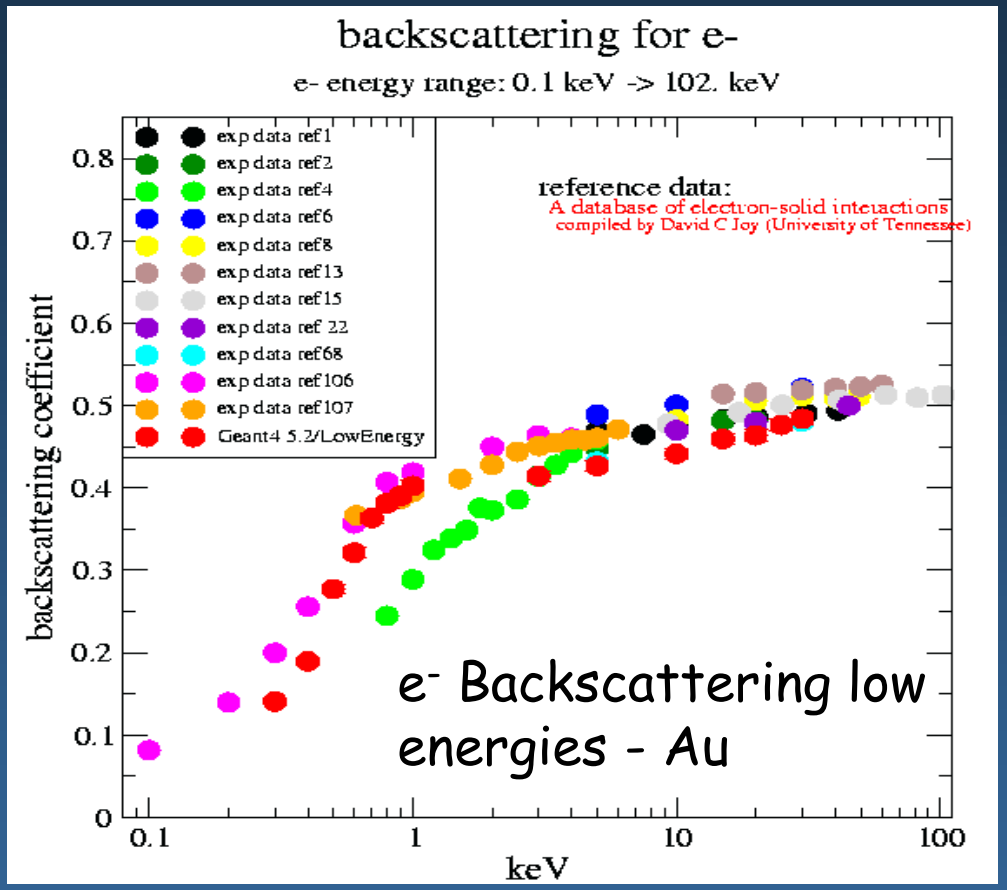


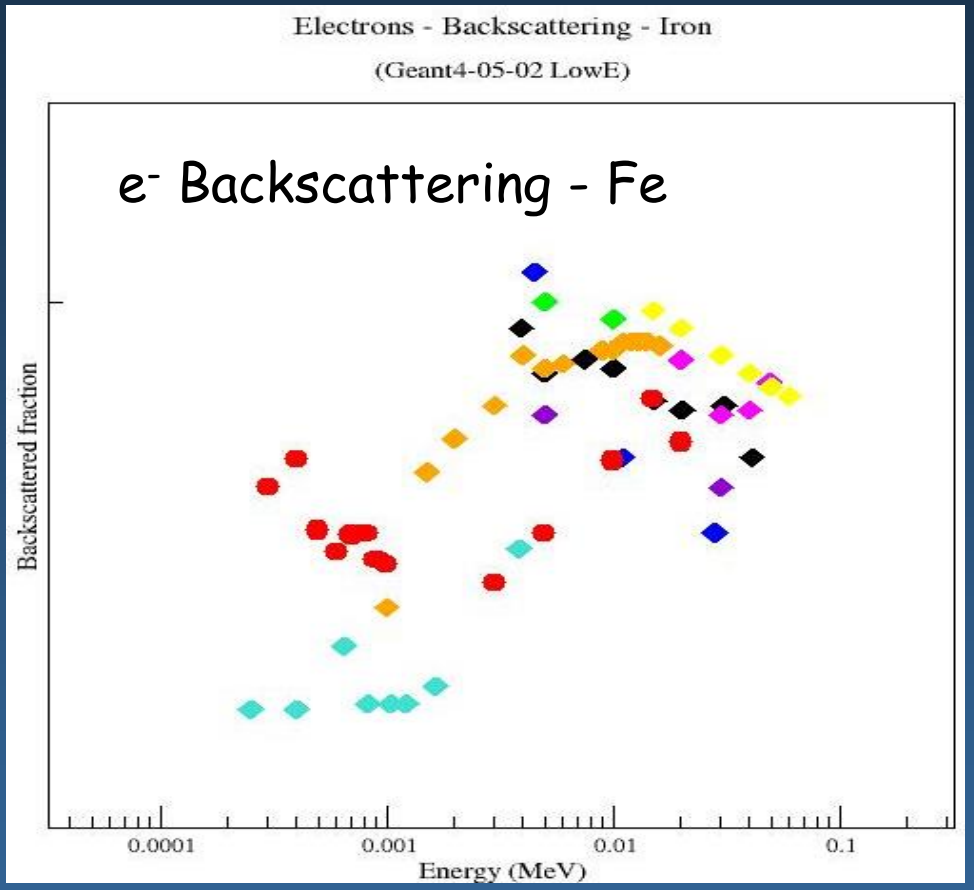


Preliminary !



A problem of validation: finding reliable data





Note:validation is not always easy, expecially at low energies

experimental data often exhibit large differences!

Status and plans

Present situation

- A large set of basic EM tests and results is available
  - CSDA range, stopping power, transmission, backscattering, Bragg Peak, angular distributions etc.
- Regression tests

Plans

- Complete test automation and use more sophisticated algorithms of the GoF component
  - see S. Donadio's talk
- Extend in a systematic way the test coverage
  - EM processes for ions, muons, atomic relaxation
  - hadronic physics (big challenge!)
  - new macroscopic validation tests in **different experimental domains** (e.g. underground physics, HEP, space science)