\[ \chi^2_{N-S} = 23.2 - \nu = 15 - p = 0.08 \]

\[ \chi^2_{N-L} = 13.1 - \nu = 20 - p = 0.87 \]

Maria Grazia Pia, INFN Genova

on behalf of the T&A team

Geant4 Workshop, TRIUMF, September 2003
Physics Testing Project

Electromagnetic Physics
Process

- Iterative and incremental, RUP-based

Vision
- start with an initial set of basic electromagnetic tests
- use GoF component of HEPstatistics
- produce meaningful physics results
- role in physics and regression testing

First cycle
- geant4/tests/test50
- simple design (design iteration foreseen in near future)
- first set of meaningful results
Main User Requirements

- The test produces typical distributions of physical quantities of interest for testing a set of physical processes.
- The user shall be able to define electrons, positrons, antiprotons, pions, photons, ions.
- The experimental set-up (e.g. absorber size and material) can be changed by the user.
- The user shall be able to define position, direction, energy of primary particles.
- The user shall be able to define electromagnetic and hadronic processes.
- The user shall be able to choose different e.m. G4 Packages (Standard, LowE, Penelope)
- The user shall be able to switch on/off the individual physics processes.

URD in http://www.ge.infn.it/geant4/analysis/test

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Physics Tests

**Electromagnetic physics**
- Standard, LowE, Penelope
  - Particle CSDA range
  - Particle Stopping Power
  - Transmission coefficient
  - Backscattering coefficient
  - Photon Attenuation coefficient
  - Cross sections
  - Particle range
  - Bremsstrahlung energy spectrum
  - Multiple scattering distributions
  - Energy deposit in absorber
  - Bragg peak (including hadronic interactions)
  - etc.

**Hadronic physics**
- ?

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Test results

Photon attenuation coefficient

$$-\ln \left( \frac{\text{gammaTransmittedFraction}}{(\text{targetThickness} \times \text{absorberDensity})} \right)$$

Absorber Materials:

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

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X-ray Attenuation Coefficient - Al

\( \chi^2_{N-L} = 13.1 - \nu=20 - p=0.87 \)

\( \chi^2_{N-S} = 23.2 - \nu=15 - p=0.08 \)

- NIST-XCOM
- G4 Standard
- G4 LowE

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X-ray Attenuation Coefficient - Al

\[ \chi^2_{N-P} = 15.9 \quad v=19 \quad p=0.66 \]

- NIST-XCOM
- G4 LowE Penelope
X-ray Attenuation Coefficient - Ge

\[ \chi^2_{N-L} = 26.3 - v=23 - p=0.29 \]

\[ \chi^2_{N-S} = 27.9 - v=23 - p=0.22 \]

- **NIST-XCOM**
- **G4 Standard**
- **G4 LowE**
X-ray Attenuation Coefficient - Ge

\[ \chi^2_{N-P} = 10.1 \quad \nu = 21 \quad p = 0.98 \]

- NIST-XCOM
- G4 LowE Penelope
X-ray Attenuation Coefficient - U

\[ \chi^2_{N-L} = 6.6 - \nu = 20 - p = 0.99 \]

\[ \chi^2_{N-S} = 14.7 - \nu = 20 - p = 0.80 \]

- **NIST-XCOM**
- **G4 Standard**
- **G4 LowE**
X-ray Attenuation Coefficient - U

$\chi^2_{N-P} = 19.3 - \nu = 22 - p = 0.63$

- NIST-XCOM
- G4 LowE Penelope
Test results

Photon cross sections

attenuation coefficients with only one process activated

Absorber Materials:

Be, Al, Si, Ge, Fe, Cs, Au, Pb, U
Compton Scattering - Al

\[ \chi^2_{N-L} = 12.9 - \nu=8 - p=0.12 \]
\[ \chi^2_{N-S} = 8.7 - \nu=6 - p=0.19 \]

- **NIST-XCOM**
- **G4 Standard**
- **G4 LowE**
Compton Scattering - Al

\[ \chi^2_{N-P} = 2.5 - \nu = 6 - p = 0.87 \]
Compton Scattering - Cs

\[ \chi^2_{N-L} = 4.6 \quad \nu = 8 \quad p = 0.80 \]

\[ \chi^2_{N-S} = 1.8 \quad \nu = 8 \quad p = 0.99 \]

- \( \blacklozenge \) NIST-XCOM
- \( \blacktriangleleft \) G4 Standard
- \( \blackcircle \) G4 LowE
Compton Scattering - Cs

\[ \chi^2_{N-P} = 4.6 - \nu = 8 - p = 0.80 \]
Rayleigh Scattering - Al

$$\chi^2_{N-L} = 13.6 - \nu = 11 - p = 0.26$$

NIST-XCOM

G4 LowE
Rayleigh Scattering - Al

Photons - Coherent Scattering - Aluminium

(Geant4-05-02)

$\chi^2_{N-P}=7.2 - \nu=8 - p=0.52$

- NIST-XCOM
- G4 LowE Penelope
Rayleigh Scattering - Cs

Photons - Coherent Scattering - Cesium

(Geant4-05-02)

Coherent Scattering (cm²/g)

Energy (MeV)

NIST-XCOM

G4 LowE
Raleygh Scattering - Cs

Photons - Coherent Scattering - Cesium
(Geant4-05-02)

Coherent Scattering (cm²/g)

Energy (MeV)

NIST-XCOM
G4 LowE Penelope
Photoelectric Effect - Fe

Photons - Photoelectric Absorption - Iron

(Geant4-05-02)

NIST-XCOM
G4 Standard
G4 LowE
Photoelectric effect - Fe

Photons - Photoelectric Absorption - Iron
(Geant4-05-02)

- NIST-XCOM
- G4 LowE Penelope
Photoelectric Absorption - Ge

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2 compatible Monte Carlo are not necessarily the Truth!
Pair Production - Si

Photons - Pair Production - Silicon
(Geant4-05-02)

- NIST-XCOM
- G4 Standard
- G4 LowE
Pair Production - Si

Photons - Pair Production - Silicon
(Geant4-05-02)

- NIST-XCOM
- G4 LowE Penelope
Test results

**CSDA range and Stopping Power for electrons**
- no multiple scattering
- no energy fluctuations

**Absorber Materials:**
Be, Al, Si, Ge, Fe, Cs, Au, Pb, U
Electrons - CSDA Range - Aluminium

(Geant4-05-02)

- NIST-ESTAR
- G4 Standard
- G4 LowE
CSDA Range - Pb

Electrons - CSDA Range - Lead
(Geant4-05-02)

- NIST-ESTAR
- G4 Standard
- G4 LowE
Stopping Power - Al

Electrons - Stopping Power - Aluminium

(Geant4-05-02)

- NIST-ESTAR
- G4 Standard
- G4 LowE
Stopping Power - Pb

Electrons - Stopping Power - Lead

(Geant4-05-02)

NIST-ESTAR

G4 Standard

G4 LowE
CSDA Range - Al - G4LowE

Electrons - CSDA Range - Aluminium
Regression Testing - G4LowE

Regression testing

- NIST-ESTAR
- Geant4-05-00
- Geant4-05-02
CSDA Range - Pb - G4Standard

Electrons - CSDA Range - Lead
Regression Testing - G4Standard

Regression testing

NIST-ESTAR

Geant4-05-00

Geant4-05-02
Test results

CSDA range and Stopping Power for protons
- no multiple scattering
- no energy fluctuations

Absorber Materials:
Be, Al, Si, Ge, Fe, Cs, Au, Pb, U
CSDA Range Al

Protons - CSDA Range - Aluminium
(Geant4-05-02)

- NIST-PSTAR
- G4 Standard
- G4 LowE
CSDA Range Pb

Protons - CSDA Range - Lead
(Geant4-05-02)

- NIST-PSTAR
- G4 Standard
- G4 LowE
Protons - Stopping Power - Aluminium
(Geant4-05-02)

Stopping Power (MeV.cm²/g)

Energy (MeV)

- **NIST-PSTAR**
- **G4 Standard**
- **G4 LowE Ziegler**
Stopping Power Pb

Protons - Stopping Power - Lead
(Geant4-05-02)

- NIST-PSTAR
- G4 Standard
- G4 LowE
CSDA Range - Al - G4LowE

Protons - CSDA Range - Aluminium
Regression Testing - G4LowE

Regression testing

NIST-PSTAR

Geant4-05-00

Geant4-05-02
CSDA Range - Al - G4Standard

Regression testing

- NIST-PSTAR
- Geant4-05-00
- Geant4-05-02

Protons - CSDA Range - Aluminium
Regression Testing - G4Standard

Range (g/cm²) vs. Energy (MeV)
CSDA Range - Pb - G4LowE

Protons - CSDA Range - Lead
Regression Testing - G4LowE

Regression testing

- NIST-PSTAR
- Geant4-05-00
- Geant4-05-02
CSDA Range - Pb - G4LowE Ziegler

Protons - CSDA Range - Lead
Regression Testing - G4LowE Ziegler

Regression testing

- NIST-PSTAR
- Geant4-05-00
- Geant4-05-02
CSDA Range - Pb - G4Standard

Regression testing

- NIST-PSTAR
- Geant4-05-00
- Geant4-05-02
Test results

Transmission

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Energy distributions of transmitted e- on Al

Title: Energy of primary outgoing electron
Name: 20
Entries: 808377
Mean: 15.738
Rms: 2.8577
Extra Entries: 0
Overflow: 0
Underflow: 0

- Geant4 5.2/standard
- Geant4 5.2/standard

Energy of outgoing e- (keV)

20 keV e-, 320 nm
20 keV e-, 1040 nm

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Angular distribution of transmitted electrons

multiple scattering test
Thin Layer 1 (gallery Geant4)

- Geant4 5.2/ standard
- Geant4 5.2/ lowEnergy
- A.O. Hanson et al. Phys. Rev. 84 (1951) 634

15.7 MeV e-, 18.66 mg/cm² gold
Angular distribution of transmitted protons

multiple scattering test

Thin Layer 1 (geant4)


6.56 MeV proton, 92.6 mum silicon

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Test results

Backscattering for electrons and positrons

Absorber Materials:
Be, Al, Si, Ge, Fe, Mg, Ag, Au
Backscattering coefficient - E=100keV

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

- Lockwood et al. (1981)
- G4 LowE

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Backscattering coefficient - $E=1\text{MeV}$

Angle of incidence (with respect to the normal to the sample surface) = $0^\circ$

- Lockwood et al. (1981)
- G4 LowE
Backscattering low energies - Au

backscattering for e-

- energy range: 0.1 keV > 102. keV

Note:

experimental data often exhibit large differences!
Backscattering low energies - Al

backscattering for e-
energy range : 0.1 keV -> 102 keV

reference data: a database of electron-solid interactions compiled by David C. Joy (University of Tennessee)
Backscattering low energies - Si

$e^-$ backscattering on Si

$e^-$ energy range: 0.1 keV $\rightarrow$ 102 keV

reference data:
a database of electron-solid interactions
compiled by David C Joy (University of Tennessee)
Backscattering coefficient – 30keV

Positrons - Backscattering - 30 keV

(Geant4-05-02)

Total Backscattering Coefficients

Atomic number (Z)

Coleman (1992)

G4 LowE

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Test results: Bragg peak, protons

Absorber Material: water

Comparison with experimental data from INFN, LNS Catania

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Status and plans

Present situation

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

- Regression tests
  - already done twice

- Evaluation of the computing resources needed
  - see Sandra’s talk in parallel session

Plans

- Integration in the Geant4 general system testing
- Design iteration
- Complete test automation
- Extend test coverage
  - e.m processes for ions, muons, atomic relaxation, add other e.m. physics distributions...
  - hadronic physics
- Use more sophisticated algorithms of the GoF component

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Conclusions

- A lot of progress since last year’s workshop...
  - a lot of work, but also a lot of fun!

- A group of bright, enthusiastic, hard-working young collaborators...

- Ground for Geant4 Physics Book
More at IEEE-NSS,
Portland, 19-25 October 2003

B. Mascialino et al.,
A Toolkit for statistical data analysis

L. Pandola et al.,
Precision validation of Geant4 electromagnetic physics