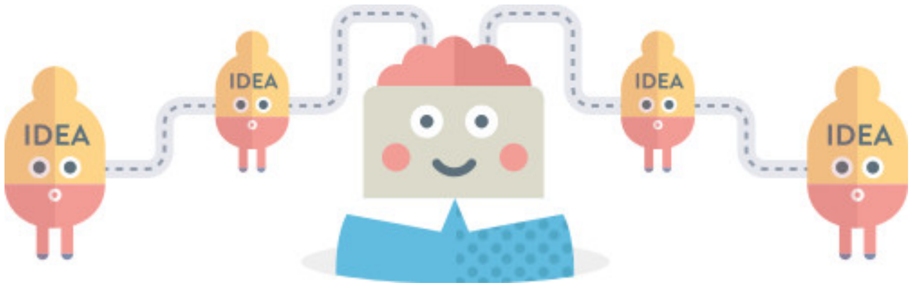
New software technologies
brains and hands



Maria Grazia Pia

INFN Genova, Italy

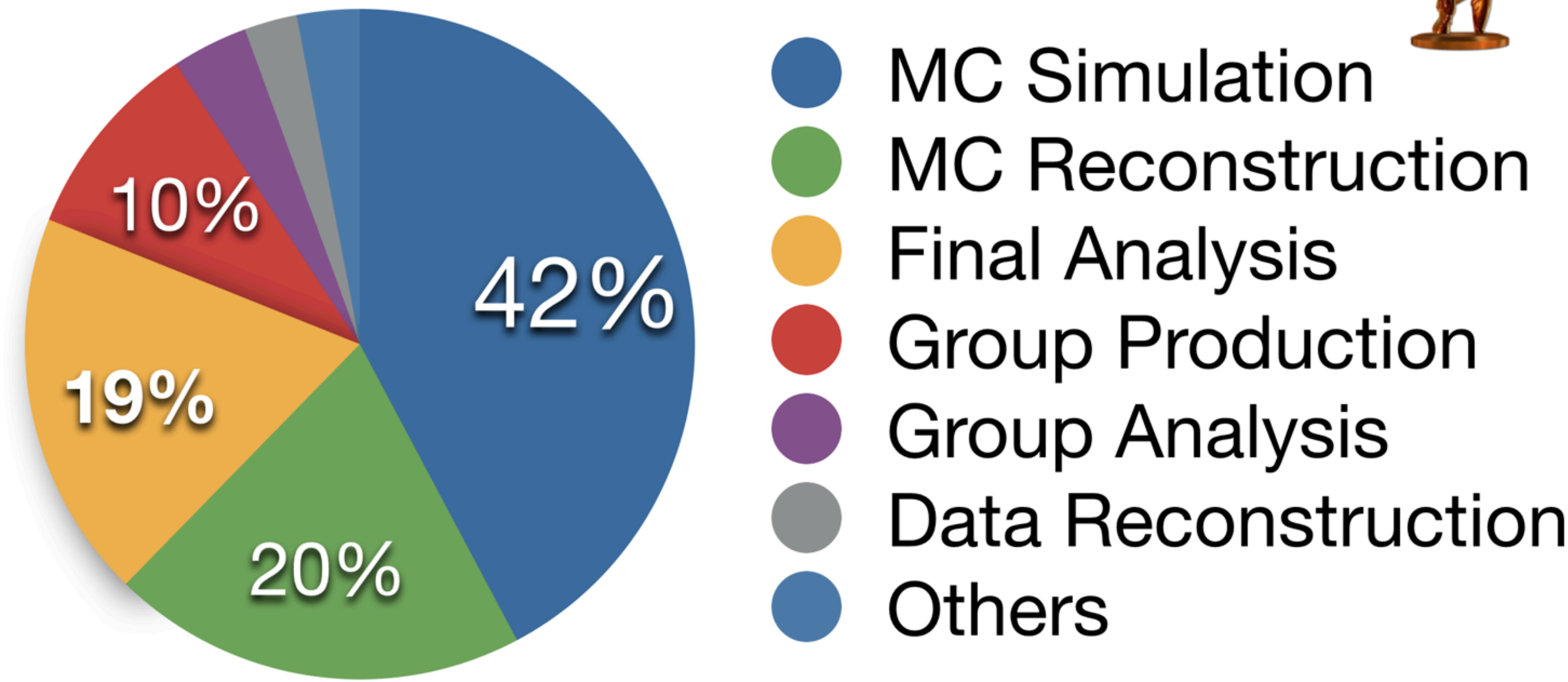
Workshop CCR INFN

Frascati, 28 maggio 2015

Collaborators: C. Choi, F. Giacomini, M. C. Han, G. Hoff, C. H. Kim, H. S. Kim, S. H. Kim, E. Ronchieri, P. Saracco, G. Weidenspointner

INFN CNAF, Bologna - Hanyang University, Seoul, Korea - CAPES, Brasilia, Brazil - MPE, Garching, Germany

GRID CPU Consumption



ATLAS, Run1

Courtesy of Graeme Stewart for the ATLAS Collaboration

Geant 4

S. Agostinelli et al.

Geant4: a simulation toolkit

NIM A, vol. 506, no. 3, pp. 250-303, 2003

5743 citations

Most cited publication in

- **Nuclear Science and Technology** } *(656886 papers)*
- **Instruments and Instrumentation** }
- Particle and Fields Physics *(282766 papers)*

Most cited **INFN** publication

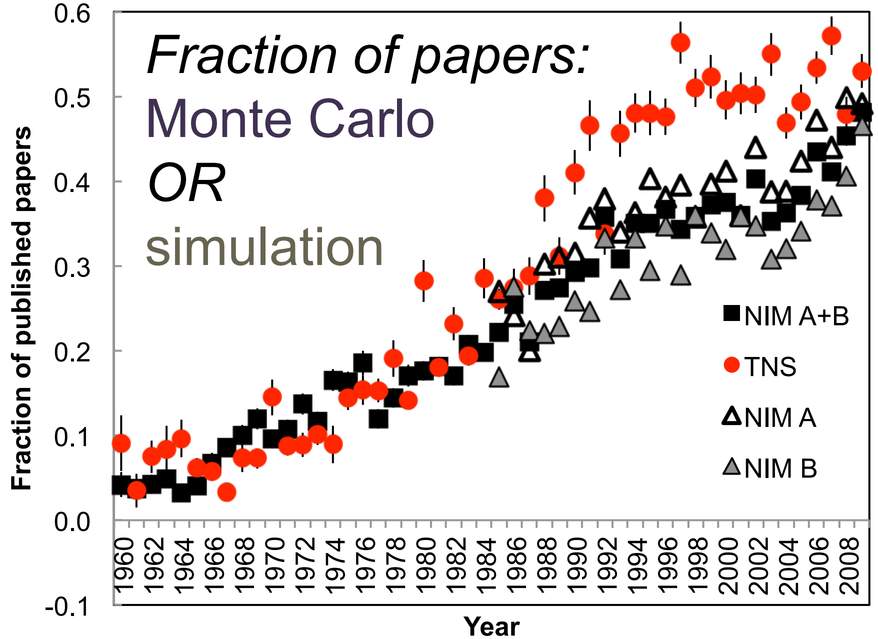
Most cited **CERN** publication

Citation analysis: Thomson-Reuters' WoS, 22 May 2015
Database since 1970

M. G. Pia, T. Basaglia, Z.W. Bell, P.V. Dressendorfer, The butterfly effect: correlations between modeling in nuclear-particle physics and socioeconomic factors, *IEEE NSS 2010 Conf. Rec.*

Instruments and Instrumentation

Nuclear Science and Technology



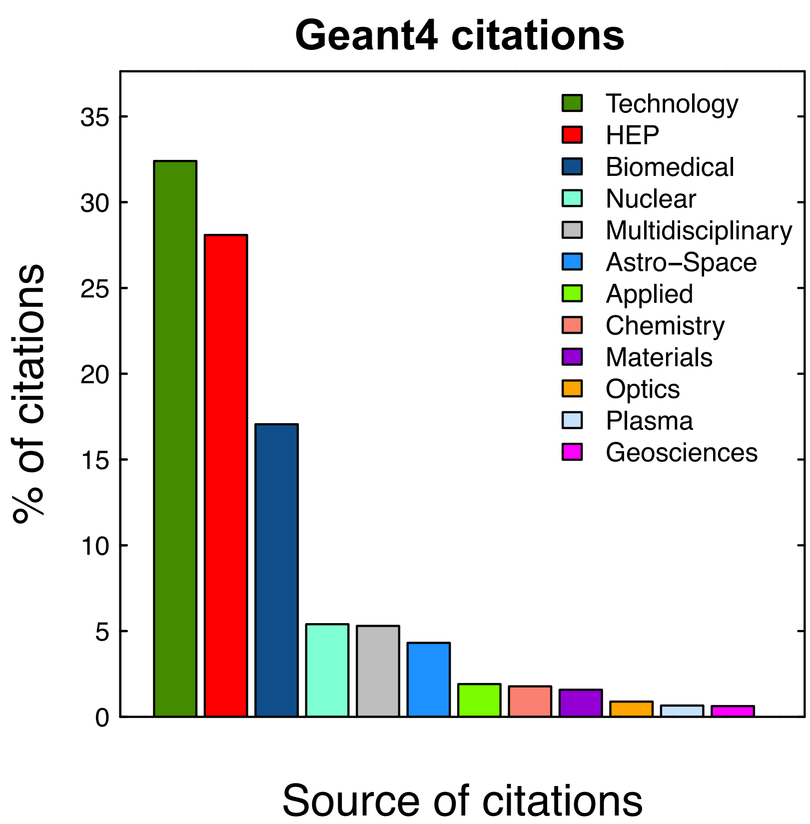
Top cited papers

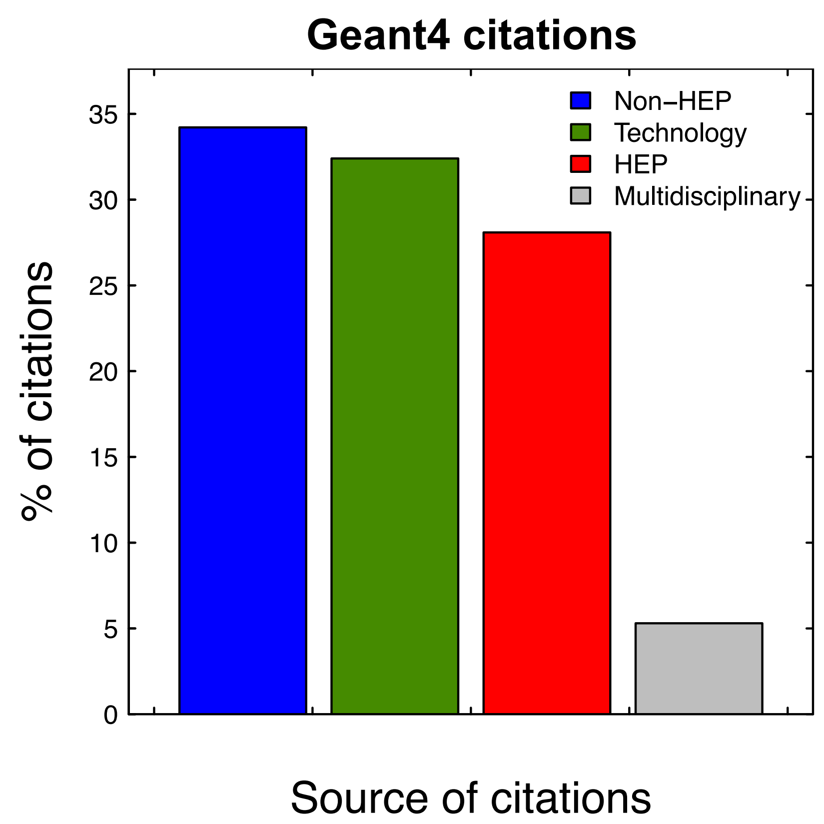
dominated by software!

1. **GEANT4-a simulation toolkit** — 5743
   EN By: Agostinelli, S; Allison, J; Amako, K; et al.
   NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT Volume: 506 Issue: 3 Pages: 250-303 Published: JUL 1 2003
2. **A MONTE-CARLO COMPUTER-PROGRAM FOR THE TRANSPORT OF ENERGETIC IONS IN AMORPHOUS TARGETS** — 3771
   By: BIERSACK, JP; HAGGMARK, LG
   NUCLEAR INSTRUMENTS & METHODS Volume: 174 Issue: 1-2 Pages: 257-269 Published: 1980
3. **ATHENA, ARTEMIS, HEPHAESTUS: data analysis for X-ray absorption spectroscopy using IFEFFIT** — 3033
   By: Ravel, B; Newville, M
   JOURNAL OF SYNCHROTRON RADIATION Volume: 12 Pages: 537-541 Part: 4 Published: JUL 2005
4. **WSXM: A software for scanning probe microscopy and a tool for nanotechnology** — 2660
   By: Horcas, I.; Fernandez, R.; Gomez-Rodriguez, J. M.; et al.
   REVIEW OF SCIENTIFIC INSTRUMENTS Volume: 78 Issue: 1 Article Number: 013705 Published: JAN 2007

Geant 4

Born from LHC experimental requirements
Multidisciplinary sources of citations

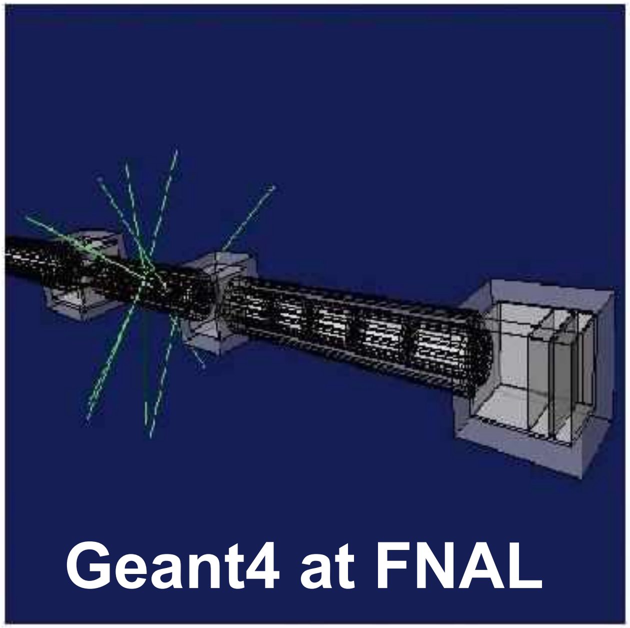




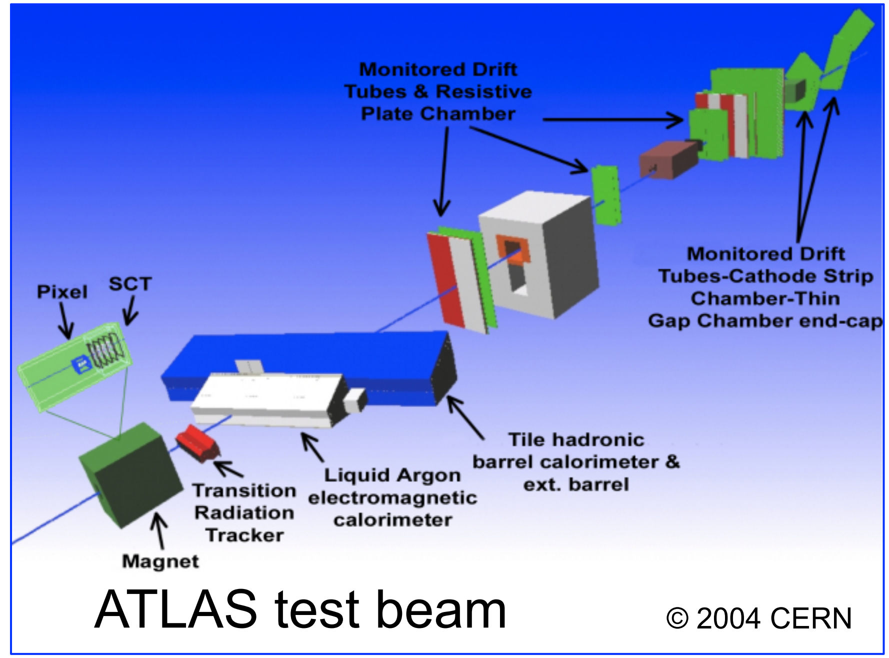
Based on Thomson-Reuters' Web of Science data

Maria Grazia Pia, *INFN Genova*

Beam lines

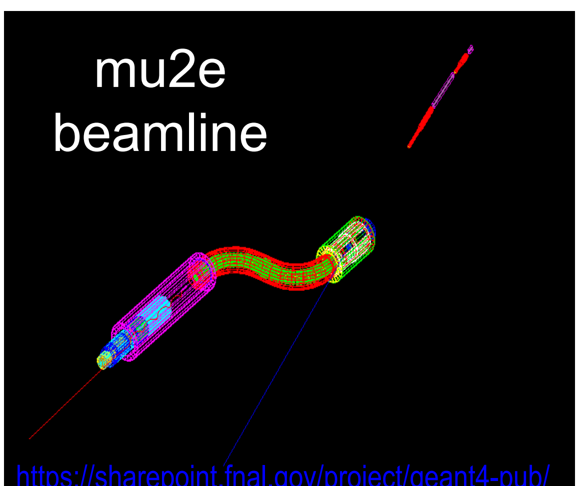


Picture of the MiniBooNE beamline (image:Panagiotis Spentzouris)



BDSIM - Accelerator Beamline simulation tool

BDSIM is a Geant4 extension toolkit for simulation of particle transport in accelerator beamlines.



https://sharepoint.fnal.gov/project/geant4-pub/SitePages/Home.aspx

G4beamline

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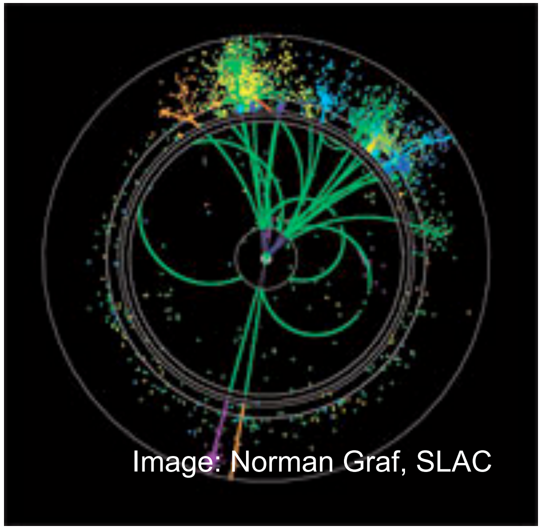
› Projects

G4beamline

Simulation tools based on Geant4

Future accelerator facilities



ILC International Linear Collider
simulated response to
$e^+e^- \rightarrow Z(\rightarrow \mu^+\mu^-) + \text{higgs} (\rightarrow bb)$

Proceedings of IPAC'10, Kyoto, Japan

POSITRON SOURCE SIMULATIONS USING GEANT4

A. Ushakov*, S. Riemann, A. Schälicke
DESY, Zeuthen, Germany

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Physics Procedia 37 (2012) 2114 – 2122

Physics
Procedia

TIPP 2011 – Technology and Instrumentation in Particle Physics 2011

Accelerator Backgrounds in a Muon Collider

Mary Anne Cummings a*, Stephen Kahn

Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA MOP019

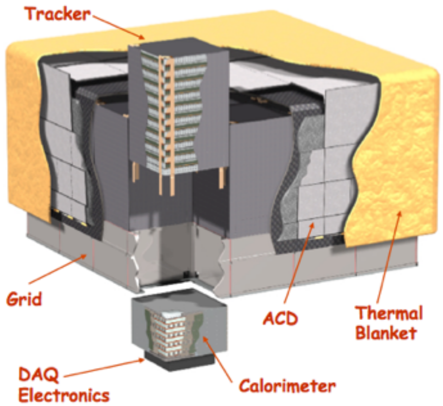
PERFORMANCE OF THE BUCKED COILS MUON-COOLING LATTICE FOR THE NEUTRINO FACTORY*

A. Alekou#, Imperial College London, London, U.K
J. Pasternak, Imperial College London, London/STFC-RAL ISIS, Chilton, Didcot, UK
C.Rogers, RAL ASTeC, Chilton, Didcot, UK

…and more

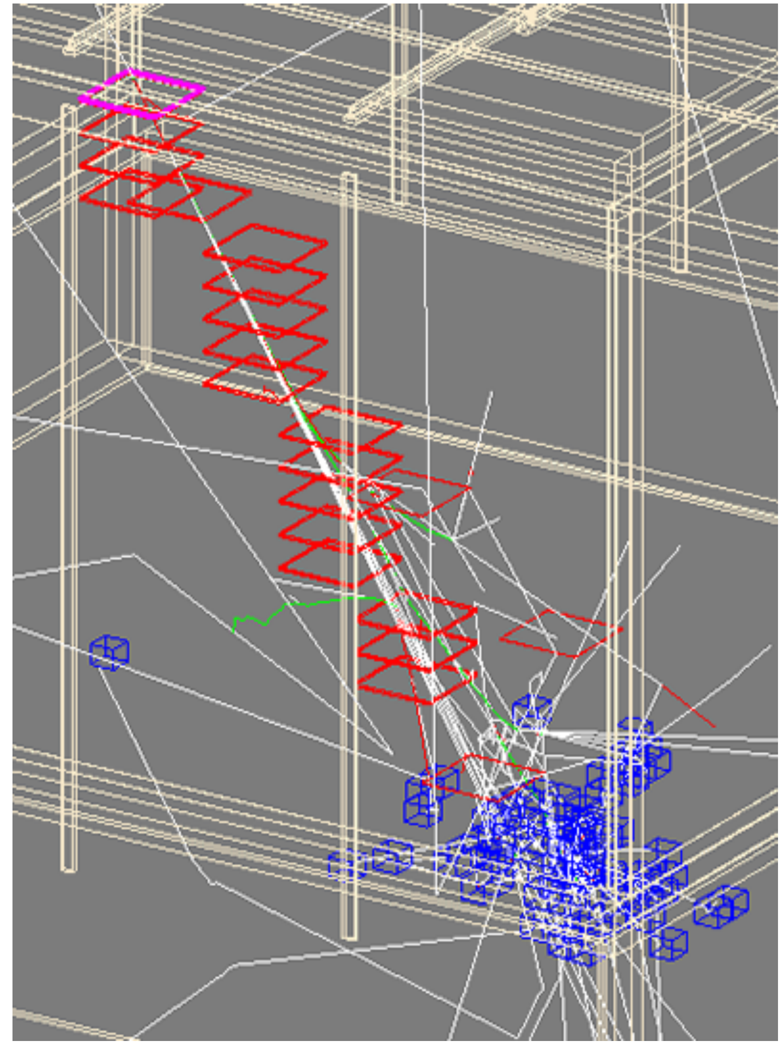
G4 Simulation for Fermi Large Area Telescope

Courtesy of Francesco Longo for the Fermi Collaboration



Fermi Gamma-ray Space Telescope

- Fermi Large Area Telescope: (http://www-glast.stanford.edu)
- Geant4 for MC particle interactions within the Fermi LAT simulation framework since 2004
  - Stored for further processing
    - McParticles – particles produced during trackinig
    - McPositionHits – positions and energy deposited in Silicon and ACD
    - McIntegratingHits – energy deposited in CsI crystals
- Still using Geant4 version 9.4.p01
- Generated at least 200e9 events
- So far stored MC triggered events
  - Gamma-rays (4.12e9 evts)
  - Protons (1.32e9)
  - HE electrons (5.14e8)
  - AllBackground (5.43e9)



Example of gamma-ray event

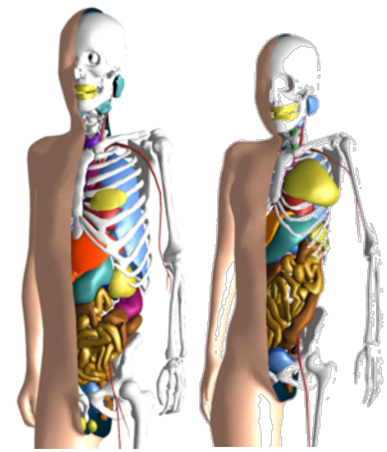
Computational Human Phantom

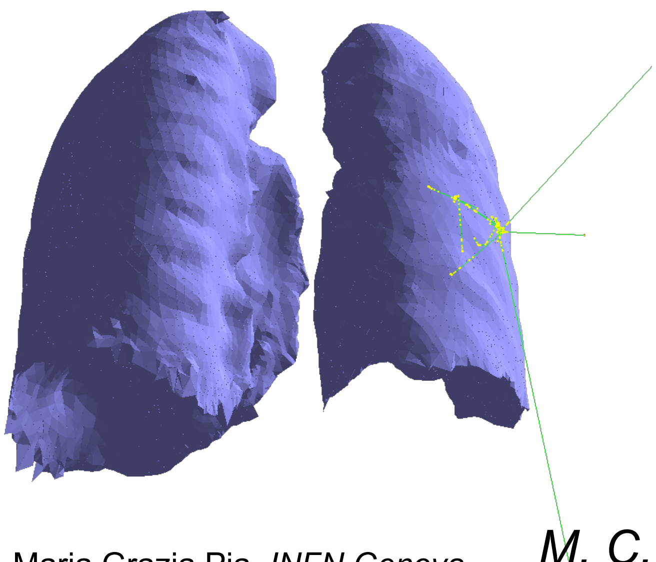
Voxel Phantom

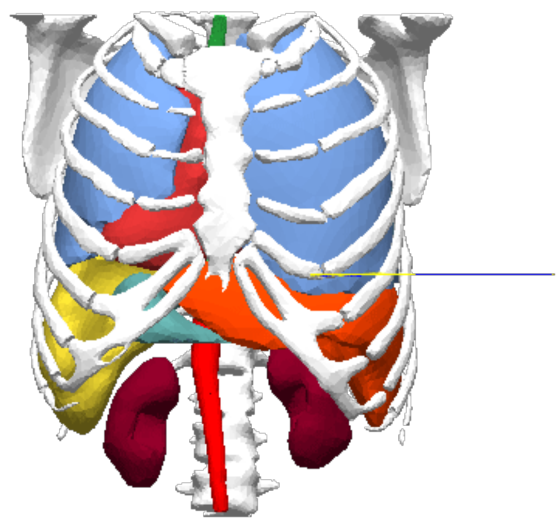
It can be implemented in Geant4, MCNP6, EGS, FLUKA…

Polygonal Phantom

It can be implemented in Geant4 and MCNP6, but in MCNP6 electrons cannot be transported in an *unstructured mesh geometry*







4D Phantom

It can be implemented only in Geant4 at the present time

Maria Grazia Pia, *INFN Genova*

M. C. Han, C. H. Kim et al., Hanyang Univ., Seoul

HUREL Hanyang University Radiation Engineering Laboratory

Nuclear power

Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA

GEANT4 STUDIES OF THE THORIUM FUEL CYCLE

Cristian Bungau, Roger Barlow, University of Manchester, UK
Adriana Bungau, Robert Cywinski, University of Huddersfield, UK

Annals of Nuclear Energy 71 (2014) 451–461

ELSEVIER

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

G4-STORK: A Geant4-based Monte Carlo reactor kinetics simulation code

CrossMark

Liam Russell [a,1], Adriaan Buijs [a,*], Guy Jonkmans [b]

[a] *Department of Engineering Physics, McMaster University, Hamilton, Ontario, Canada*
[b] *Chalk River Laboratories, AECL, Chalk River, Ontario, Canada*

PRL **109,** 152501 (2012) PHYSICAL REVIEW LETTERS week ending 12 OCTOBER 2012

Cosmic Ray Radiography of the Damaged Cores of the Fukushima Reactors

Konstantin Borozdin,[1] Steven Greene,[1] Zarija Lukić,[2] Edward Milner,[1] Haruo Miyadera,[1] Christopher Morris,[1,*] and John Perry[1]

[1]*Los Alamos National Laboratory, Los Alamos, New Mexico 87544, USA*
[2]*Computational Cosmology Center, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*

(Received 9 August 2012; published 11 October 2012)

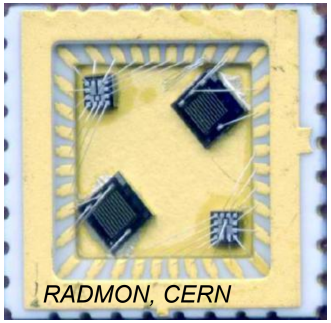
18th World Conference on Nondestructive Testing, 16-20 April 2012, Durban, South Africa

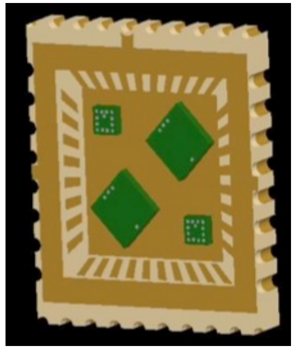
Design of New Neutron Imaging Facility at Triga Reactor in Morocco

Afaf OUARDI[1], Rachad ALAMI[1], Abdeslam BENSITEL[1]

…and more

Radiation effects





Just a small sample of applications!

840 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 58, NO. 3, JUNE 2011

Impact of the Radial Ionization Profile on SEE Prediction for SOI Transistors and SRAMs Beyond the 32-nm Technological Node

Mélanie Raine, *Student Member, IEEE*, Guillaume Hubert, Marc Gaillardin, *Member, IEEE*, Laurent Artola, Philippe Paillet, *Senior Member, IEEE*, Sylvain Girard, *Member, IEEE*, Jean-Etienne Sauvestre, *Member, IEEE*, and Arnaud Bournel

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 56, NO. 4, AUGUST 2009 2061

Packaging Effects on RadFET Sensors for High Energy Physics Experiments

Julien Mekki, Laurent Dusseau, *Senior Member, IEEE*, Maurice Glaser, Susanna Guatelli, *Member, IEEE*, Michael Moll, Maria Grazia Pia, and Federico Ravotti, *Member, IEEE*

3032 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 56, NO. 6, DECEMBER 2009

Operational SER Calculations on the SAC-C Orbit Using the Multi-Scales Single Event Phenomena Predictive Platform (MUSCA SEP^3)

Guillaume Hubert, Sophie Duzellier, Christophe Inguimbert, César Boatella-Polo, Françoise Bezerra, and Robert Ecoffet

Progress in NUCLEAR SCIENCE and TECHNOLOGY, Vol. 2, pp.509-515 (2011)

ARTICLE

GEANT4 Microdosimetry Study of Ionising Radiation Effects in Digital ASIC's

Miguel A. CORTÉS-GIRALDO[1,*], Francisco R. PALOMO[2], Esther GARCÍA-SÁNCHEZ[2] and José M. QUESADA[1]

[1] *Departamento de Física Atómica, Molecular y Nuclear, Universidad de Sevilla, 41080-Sevilla, Spain*
[2] *Departamento de Ingeniería Electrónica, Escuela Superior de Ingenieros, Universidad de Sevilla, 41092-Sevilla, Spain*

第46卷增刊 原 子 能 科 学 技 术 Vol. 46, Suppl.
2012年9月 Atomic Energy Science and Technology Sep. 2012

Geant4 在中子辐射效应中的应用

金晓明，王园明，杨善潮，马　强，刘　岩，林东生，陈　伟
（西北核技术研究所，陕西 西安　710024）

摘要：中子辐射效应是半导体器件在辐射环境中损伤的重要因素。本文建立了中子在半导体材料中的电离和非电离能量沉积、原子空位密度的 Geant4 模拟方法。电离能量沉积可用于分析电离总剂量效应，非电离能量沉积可用于分析位移损伤效应。电离 kerma 因子的模拟结果定量解释了中子辐照在 CMOS 工艺单片机中引起的电离增强效应。通过原子空位密度计算了中子引入的附加陷阱密度，分析了位移损伤对电离效应的增强作用。实验和模拟结果表明，中子的电离能量沉积加剧了 CMOS 工艺单片机的退化。

关键词：中子辐射效应；电离能量沉积；非电离能量沉积；原子空位
中图分类号：TN431；TN792 **文献标志码：**A **文章编号：**1000-6931(2012)S0-0607-04

Geant4 Application in Neutron Radiation Effects

JIN Xiao-ming, WANG Yuan-ming, YANG Shan-chao, MA Qiang, LIU Yan, LIN Dong-sheng, CHEN Wei
(*Northwest Institute of Nuclear Technology, Xi'an 710024, China*)

ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research B 261 (2007) 1133–1136
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Physical mechanisms of single-event effects in advanced microelectronics

Ronald D. Schrimpf [a,*], Robert A. Weller [a], Marcus H. Mendenhall [b], Robert A. Reed [a], Lloyd W. Massengill [a]

[a] *Electrical Engineering and Computer Science, Vanderbilt University, 5635 Stevenson Center, Nashville, TN 37235, United States*
[b] *Free Electron Laser Center, Vanderbilt University, Station B 351816, Nashville, TN 37235, United States*

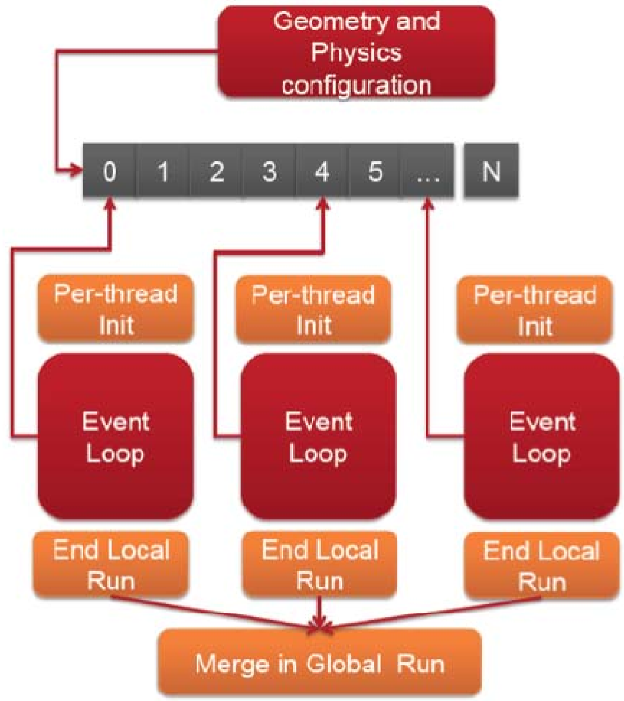
Speed

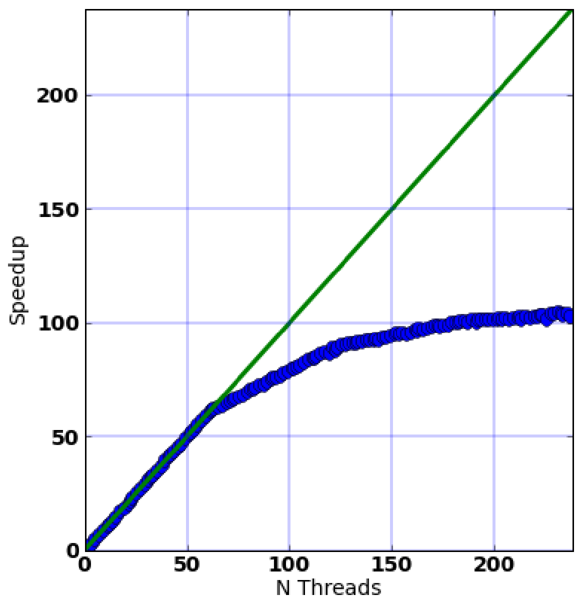
Today's hype

Geant4-MultiThreaded

- Adopt the same event-level parallelism as the prior distributed memory parallelization has done
- Replace *k* independent copies of the Geant4 process with an equivalent single process with *k* threads
- Uses the many-core machine in a memory-efficient scalable manner

Released in Geant4 10.0





Speedup obtained by running a HEP simulation (50 GeV pions with B-field) on the Intel® Xeon PhiTM (7110P, 1.238 GHz, 61 cores) co-processor, up to the maximum number of threads geant.cern.ch

geantv

CERN Accelerating science

Sign in

Directory

Geant

The best Geant ever

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Detector simulation is one of the most CPU intensive tasks in modern High Energy Physics.

While its importance for the design of the detector and the estimation of the efficiency is ever increasing, the amount of events that can be simulated is often constrained by the available computing resources.

Various kind of "fast simulations" have been developed to alleviate this problem, however, while successful, these are mostly "ad hoc" solutions which do not replace completely the need for detailed simulations.

One of the common features of both detailed and fast simulation is the inability of the codes to exploit fully the parallelism which is increasingly offered by the new generations of CPUs.

In the next years it is reasonable to expect an increase on one side of the needs for detector simulation, and on the other in the parallelism of the hardware, widening the gap between the needs and the available means. In the past years, and indeed since the beginning of simulation programs, several unsuccessful efforts have been made to exploit the "embarrassing parallelism" of simulation programmes.

GeantV News

Discussion on April 24, 2013

Here is the file summarising our discussions.

And what there is to conquer
By strength and submission, has already been discovered
Once or twice, or several times…

T. S. Eliot
Four Quartets - East Coker

CERN 90-06
29 May 1990

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

EXPERIENCE WITH VECTOR PROCESSORS IN HEP

Federico Carminati

CERN, Geneva, Switzerland

"In studying the vectorization opportunities offered by the GEANT code, it has been realized that the fundamental strategy should be to handle more than one particle at a time in the tracking process. This means that the program should now answer questions like *is a given particle in a given volume?* or *which is the next interaction point for the given particle?* and so on, not any more for a single particle at a lime, but for the maximum number of eligible particles in any given moment."

1989 CERN SCHOOL OF COMPUTING

Bad Herrenalb, Federal Republic of Germany
20 August-2 September 1989

Algorithms

Popular belief

Physics model X is intrinsically slow

Baroque methods to combine it with “faster” lower precision models and limit its use to cases where one is willing to pay for higher precision

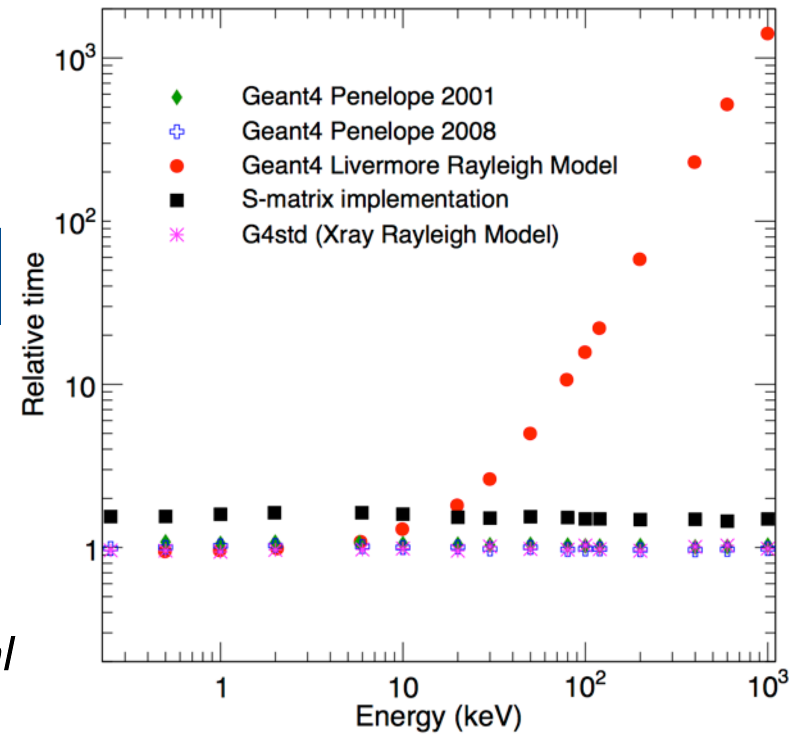
This design introduces an additional computational burden due to the effects of inheritance and the combination algorithms themselves

Truth

Physics model X is intrinsically fast

But its computationally fast physics functionality is spoiled by an inefficient sampling algorithm

Change the sampling algorithm!



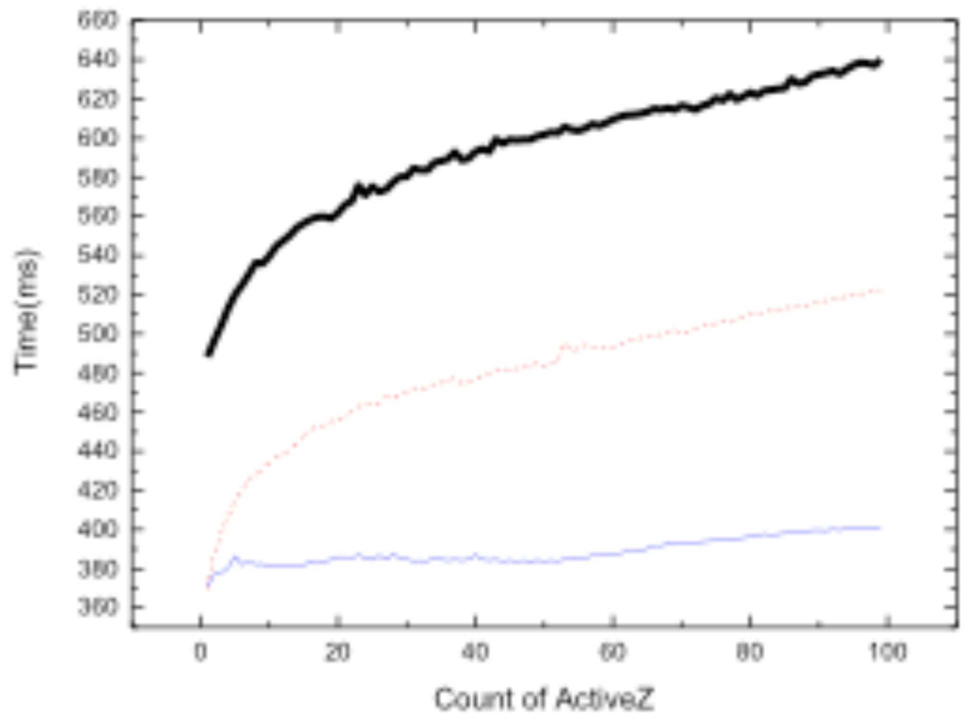
- **No code smell**
- Spotted through in-depth **code review** in the course of **software validation**

Refactoring data management

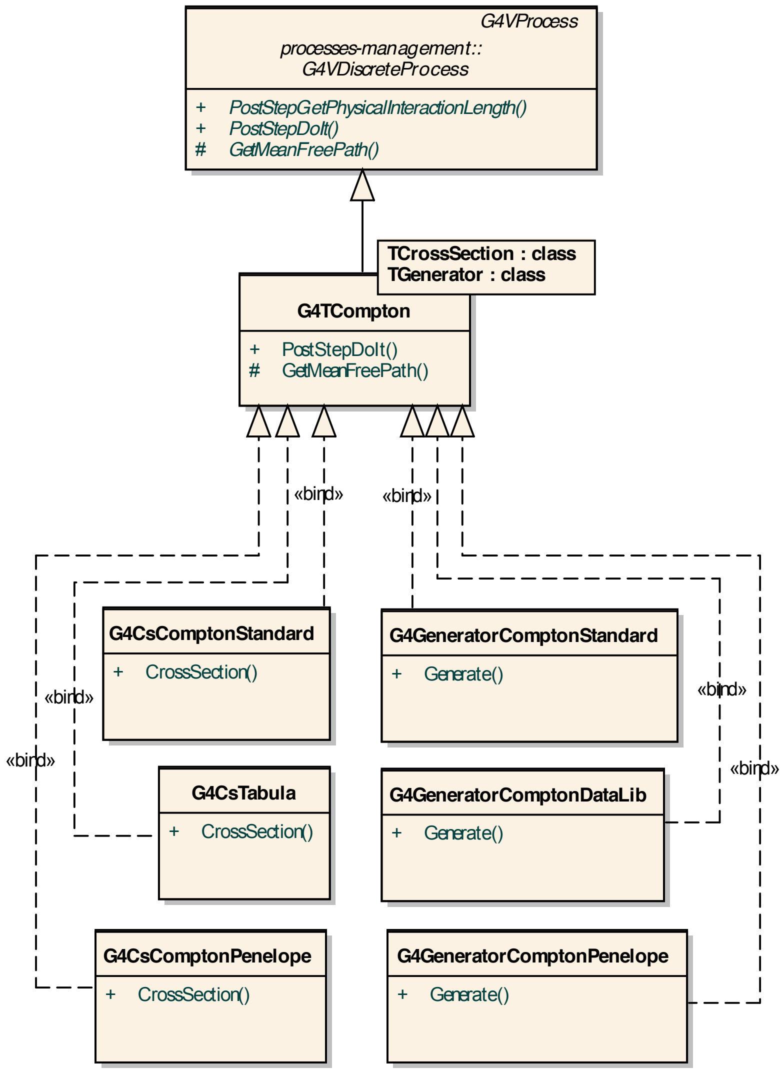
- Today's technology
  - …keeping an eye on the new C++ Standard

- Optimal container
- Pruning data
- Splitting files
- Software design

Min Cheol Han
Hanyang Univ., Seoul



Policy-based class design



Same functionality refactored into new design

No attempt to do any performance optimisation

~30% speed gain in electromagnetic physics processes *(preliminary)*

The fastest algorithm

no algorithm at all

Shift modeling from algorithms to data

Merging models

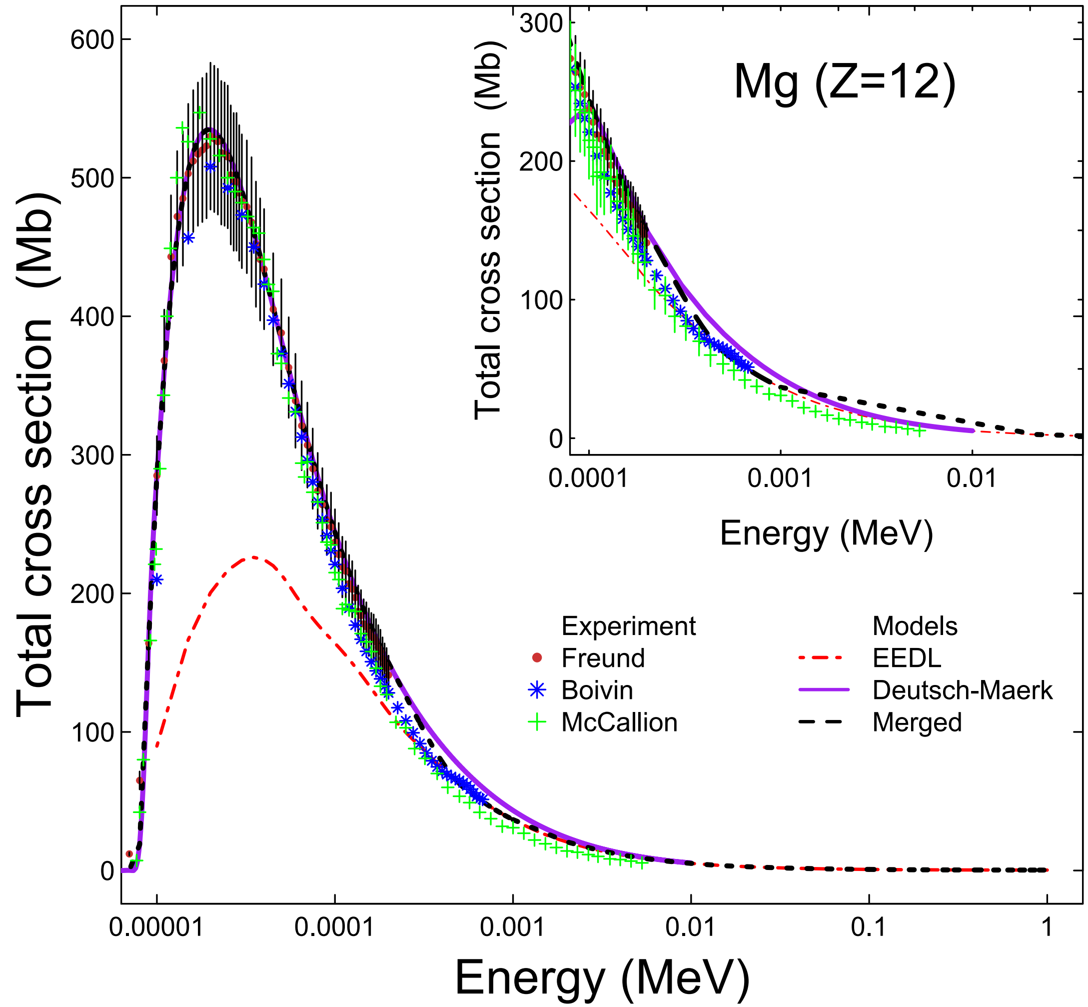
Smoothing data

Guidance from experimental data *(when available)*

Data libraries

Need mathematical expertise (smoothing algorithms)

Electron impact ionisation cross sections



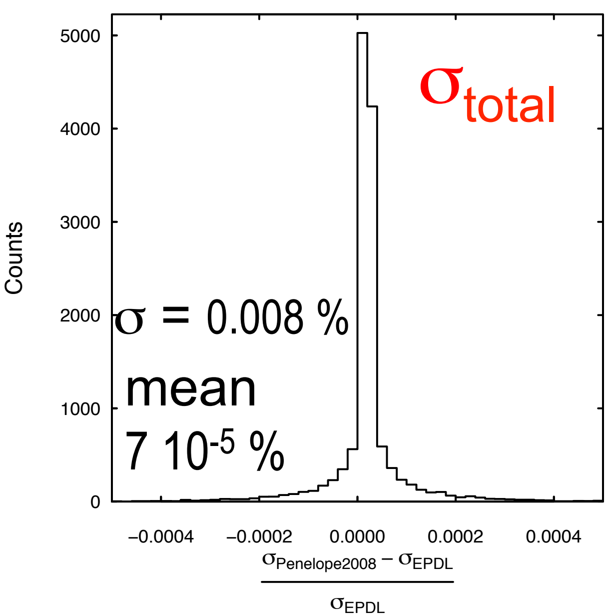
Example: LOESS local polynomial regression fitting
Beware: not optimized!

Prune

Number one in the stink parade is duplicated ~~code~~ physics

M. Fowler, *Refactoring*

Two Geant4 models, identical underlying physics content *(it used to be different)*



Efficiency w.r.t. experiment

"Livermore"	Penelope
EPDL97	EPDL97
0.38±0.06	0.38±0.06

Code bloat

Burden on

- Software design
- Maintenance
- User support

Unnecessary complexity

Maria Grazia Pia, *INFN Genova*

Content

- Physics
- Reliability
  - Validation
  - Testability
- Maintainability
- Predictivity

Physics

The physics of Monte Carlo codes is still intended for the detectors of the '80s

IA assumption

IPA

Is this physics validated?
Does it reflect the state of the art?

New frontiers in detector R&D

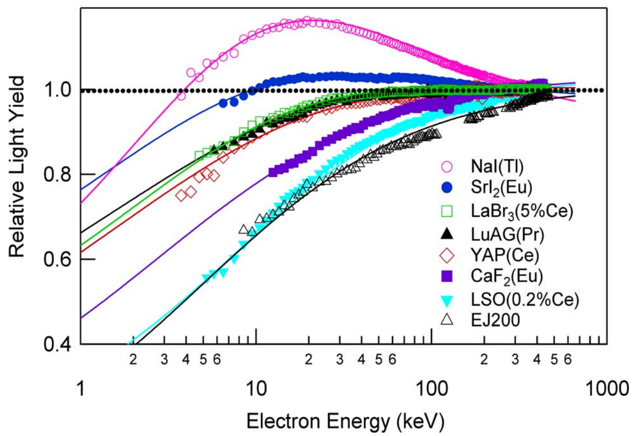
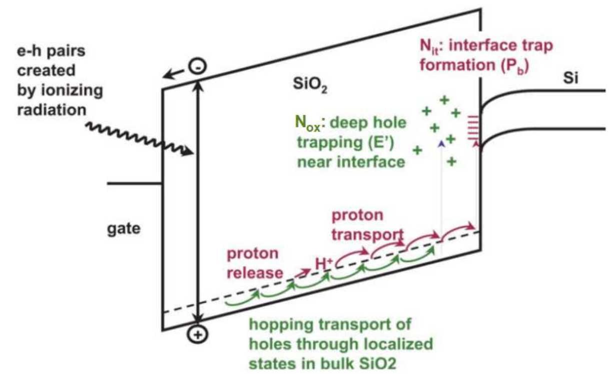


Fig. 1. Electron response (relative scintillation efficiency versus electron energy) of eight scintillators. Reprinted with permission from [17].



Incorporating materials science knowledge

Understanding underlying phenomena that contribute to making the signal in detectors

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 58, NO. 6, DECEMBER 2011 3219

Ionization Cross Sections for Low Energy Electron Transport

Hee Seo, Maria Grazia Pia, Paolo Saracco, and Chan Hyeong Kim

Reliability

need

documented, objective, quantitative

validation

Testable physics

Validation

- Limited documentation of **simulation validation**
  - Mostly in the form of specific use cases compared to measurements in the same experimental scenario
    - Do they apply to similar/different use cases?
    - How to extrapolate the results to different scenarios?
- Hardly any (quantitative) **validation of the basic physics models** implemented in Monte Carlo codes
  - Why?
- Oenology and Mozart opera
  - Widely applied in experimental practice

Establishing validity

Agreement
Good agreement
Excellent agreement
Satisfactory agreement
…

Comparison of simulation results and experimental data in the literature mainly rests on

- qualitative visual appraisal of figures
- indicators (%) deprived of any statistical meaning

Statistical methods and tools

R&D needed

Epistemological mistakes

- Comparison of different Monte Carlo codes
- Comparison of different physics models
- Comparison of simulation with theory

You need an experiment to test a cross section

Testing total cross sections calculated by *G4PEEffectFluoModel*

You can find the photoelectric cross section *G4PEEffectFluoModel* class in $G4INSTALL/source/processes/electromagnetic/standard/include (*G4PEEffectFluoModel.hh* header file) and $G4INSTALL/source/processes/electromagnetic/standard/src/ (*G4PEEffectFluoModel.cc* implementation). *G4PEEffectFluoModel* has a *ComputeCrossSsectionPerAtom* public member function, which returns the total photoelectric cross section for a given element corresponding to a given photon energy:

```
G4double ComputeCrossSectionPerAtom(const G4ParticleDefinition*,
                                    G4double kinEnergy,
                                    G4double Z,
                                    G4double A,
                                    G4double, G4double)
```

Geant4 photoelectric cross section

This is what we need indeed!

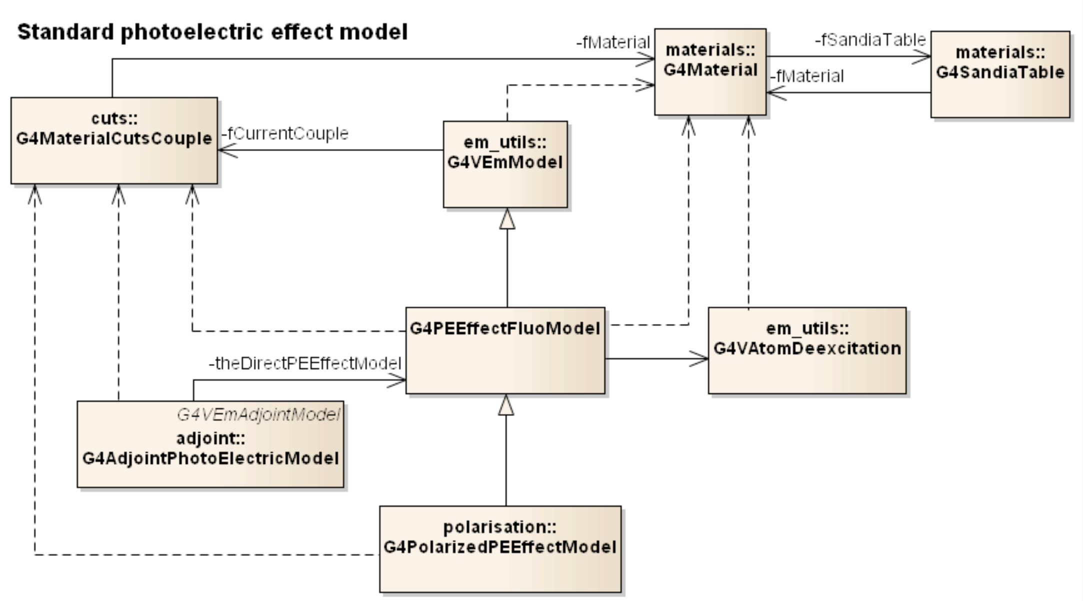
We create a simple unit test *G4PEEffectFluoModelTest.cc*, which instantiates a *G4PEEffectFluoModel* object and invokes *ComputeCrossSectionPerAtom* in pre-defined configurations of photon energy and target element. We place the unit test in $APCDIR/test.

We **build the test**:

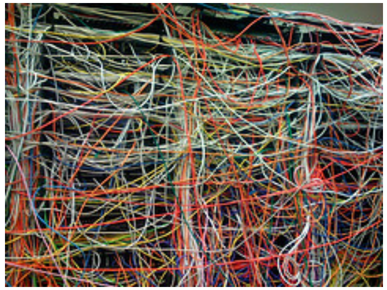
```
cd $APCDIR/test
setenv TESTTARGET G4PEEffectFluoModelTest
gmake
```

Then we **run the test**:

```
$G4WORKDIR/bin/Linux-g++/G4PEEffectFluoModelTest
```



Post-RD44 Geant4 electromagnetic software design



Hidden dependencies

on other parts of the software

One needs a geometry
(and a full scale application)
to test any photon cross section

Difficult to test ➔ no testing
often

Reverse engineered

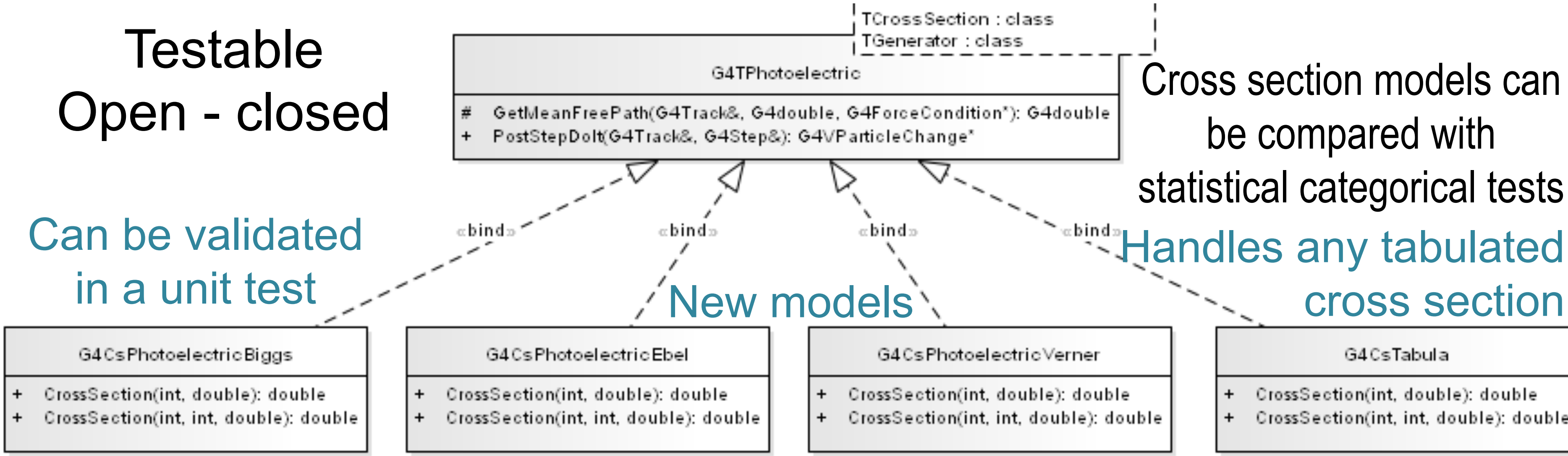
Maria Grazia Pia, *INFN Genova*

Detangling

Photoionisation

Testable
Open - closed

Can be validated in a unit test



New models

Cross section models can be compared with statistical categorical tests

Handles any tabulated cross section

Sweeping under the carpet?

Refactoring Geant4 physics into "clean code"

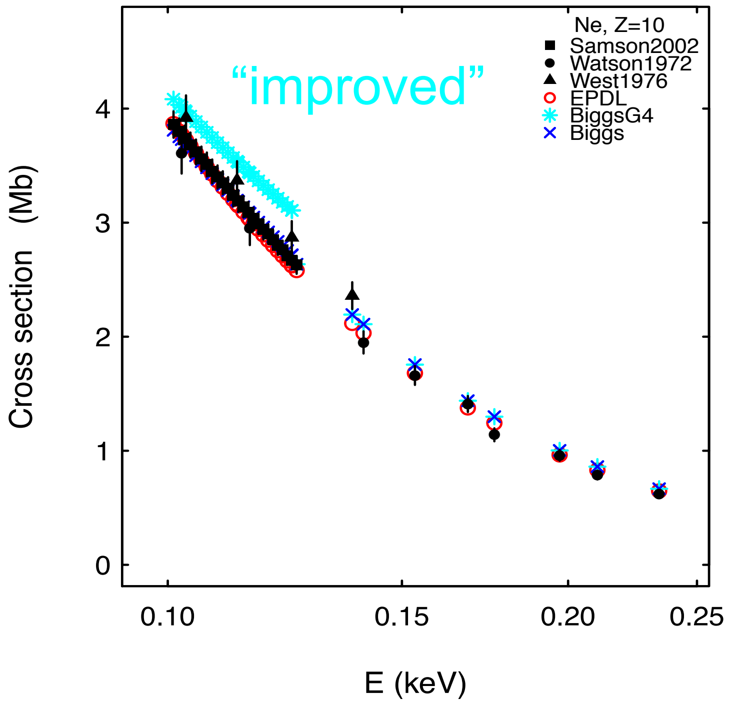
Refactoring ➔ preserve functionality

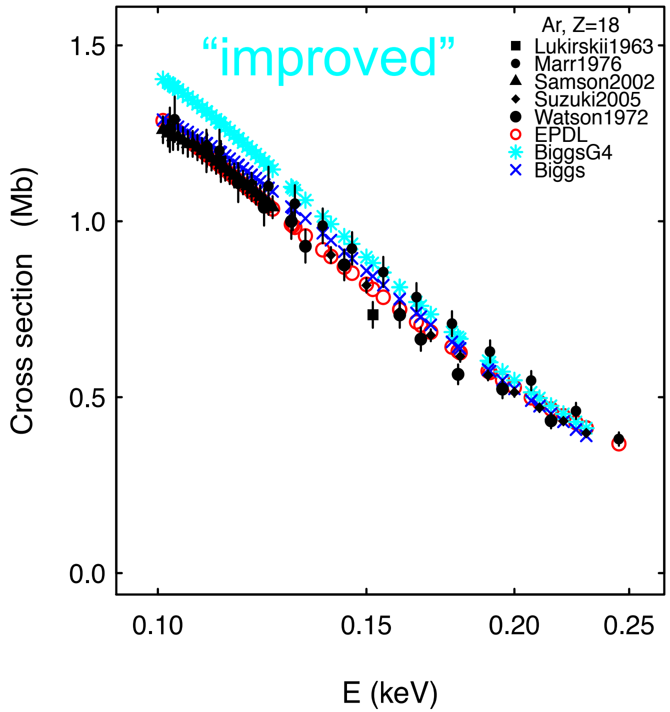
Was the original code verified?
Was the original code **validated**?
What was the test coverage?
Were the test process and the test results documented?

Photoionisation cross section

Cross sections in Geant4 "standard" photoelectric model are based on "**improved**" Biggs-Lighthill parameterisation

F. Biggs and R. Lighthill, Analytical Approximation for X-ray Cross Sections III, Sandia Lab. Report SAND-0070, 1988





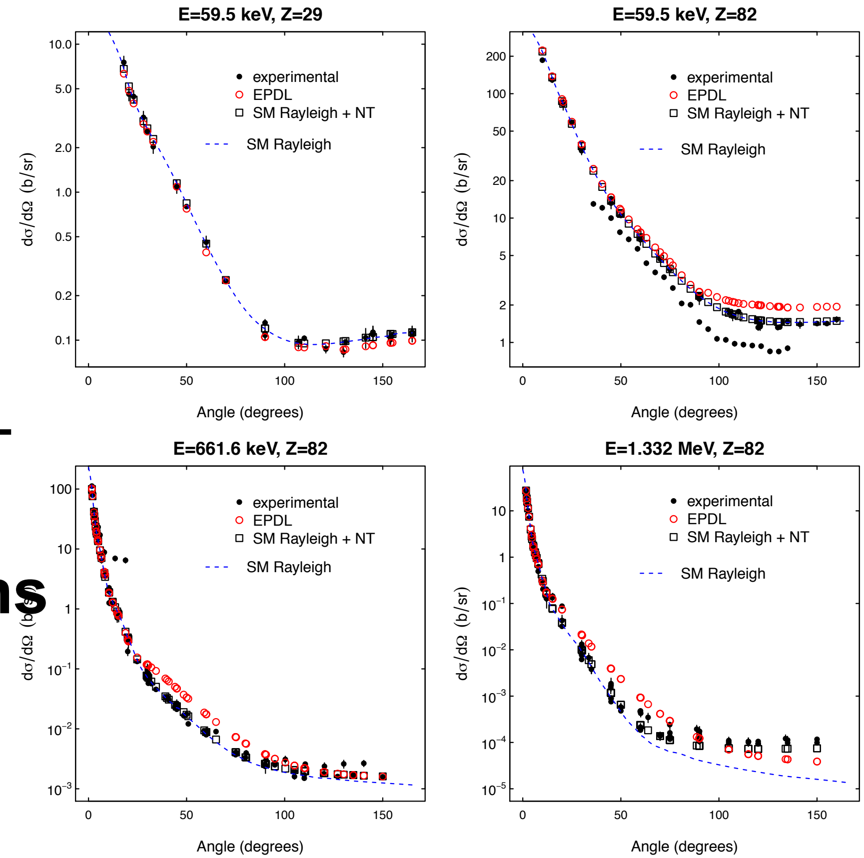
Photon elastic scattering

Differential cross section

- relativistic form factors *(EGS)*
- non-relativistic form factors *(Geant4, MCNP, Penelope, FLUKA…)*: Hubbell et al., EPDL

New

- numerical **S-matrix calculations**
- modified relativistic form factors,
- modified relativistic form factors with anomalous scattering factors



	Penelope 2001	Penelope 2008	EPDL	Relativ. FF	Non-Rel. FF	Modified FF	MFF ASF	RFF ASF	SM NT
ε	0.27	0.38	**0.38**	0.25	0.35	0.49	0.52	0.48	**0.77**
error	±0.05	±0.06	±0.06	±0.05	±0.06	±0.06	±0.06	±0.06	±0.05

ε = fraction of test cases compatible with experiment, 0.01 significance

Maintainability

The time scale of HEP, astroparticle and astrophysics experiments extends over decades

Maintainability is a major concern

See Elisabetta Ronchieri's talk

(maintainability implies testability: verify that functionality is preserved)

Lehman laws

M. M. Lehman,
Programs, Life Cycles, and Laws of Software Evolution,
Proc. IEEE, vol. 68, no. 9, Sep. 1980

1. Continuing Change

- A program that is used and that as an implementation of its specification reflects some other reality, **undergoes continual change** or **becomes progressively less useful**. The change or decay process continues until it is judged more cost effective to replace the system with a recreated version.

2. Increasing Complexity

- As an evolving program is continually changed, **its complexity**, *reflecting deteriorating structure*, **increases** unless work is done to maintain or reduce it.

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Answer to the Ultimate Question of Life, the Universe, and Everything

Douglas Adams, The Hitchhiker's Guide to the Galaxy

```
// G4HadronElastic
// 29 June 2009 (redesign old elastic model)
G4double dd = 10.;
G4Pow* g4pow = G4Pow::GetInstance();
if (A <= 62) {
bb = 14.5*g4pow->Z23(A);
aa = g4pow->powZ(A, 1.63)/bb;
cc = 1.4*g4pow->Z13(A)/dd;
} else {
bb = 60.*g4pow->Z13(A);
aa = g4pow->powZ(A, 1.33)/bb;
cc = 0.4*g4pow->powZ(A, 0.4)/dd;
}
```

Testable?

Calibrated?

Epistemic uncertainties?

G4ChipsAntiBaryonElasticXS

```
lastPAR[43]=920.+03*a8*a3;
lastPAR[44]=93.+.0023*a12;
```

G4GoudsmitSaundersonMscModel

```
if(i>=19)ws=cos(sqrtA);
```

G4EmCorrections

```
if(15 >= iz) {
if(3 > j) { tet = 0.25*Z2*(1.0 + 5*Z2*alpha2/16.); }
else      { tet = 0.25*Z2*(1.0 + Z2*alpha2/16.); }
}
```

Epistemology!

G4UrbanMscModel

```
coeffc1  = 2.3785 - Z13*(4.1981e-1 - Z13*6.3100e-2);
```

A new paradigm

simulation **result ± error**

Today's hype in many research domains

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 61, NO. 2, APRIL 2014 877

Theoretical Grounds for the Propagation of Uncertainties in Monte Carlo Particle Transport

Paolo Saracco, Maria Grazia Pia, and Matej Batic

Uncertainty Quantification

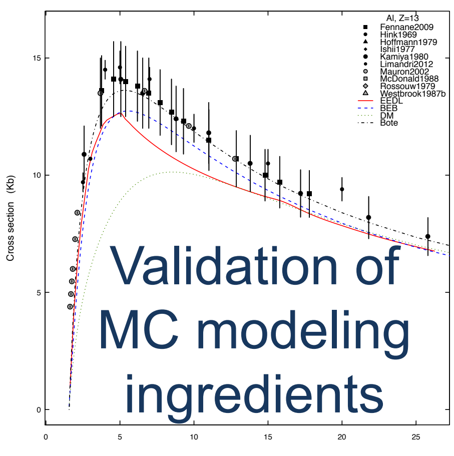
input

with uncertainties

Monte Carlo method

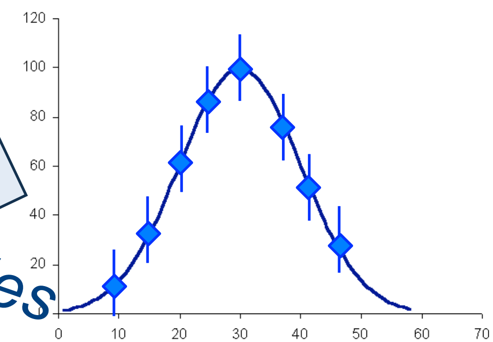
observable

with uncertainties



Validation of MC modeling ingredients

Beware: input uncertainties can be hidden in models and algorithms in the code



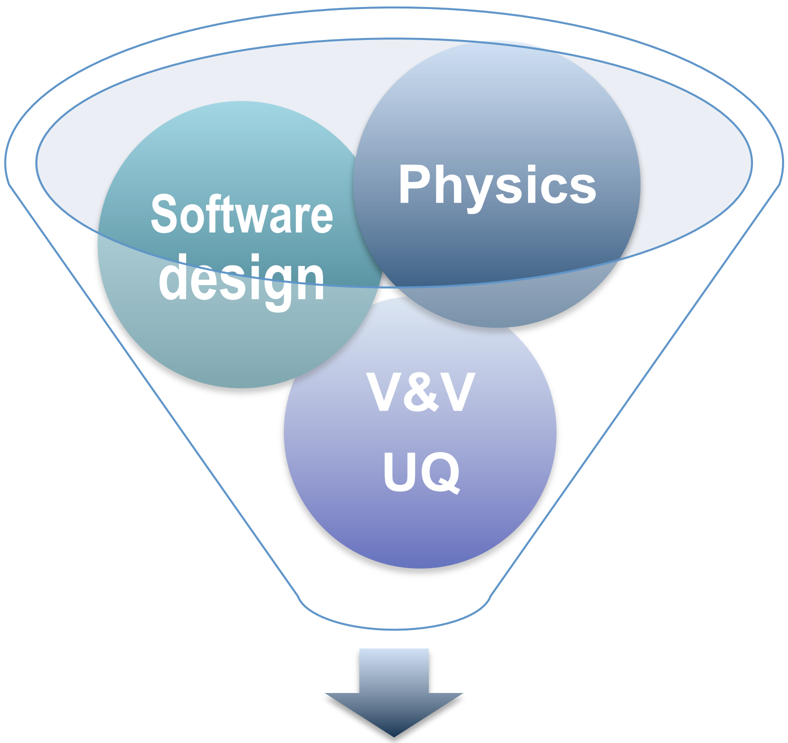
Uncertainties deriving from

- input uncertainties
- Monte Carlo algorithm
- simulation model

Uncertainty quantification is the ground for **predictive Monte Carlo simulation**

Conclusions

Vision supporting our research



State-of-the-art, quantified simulation

- **State-of-the-art physics**
- Quantitative **validation** applying statistical methods
- Exploration of modern **software design** methods
- Computational performance measurements
- R&D for simulation as a **predictive instrument**

Journal Publications

- S. H. Kim et al.,
Validation Test of Geant4 Simulation of Electron Backscattering
IEEE TNS, Apr. 2015

- P. Saracco, M. G. Pia, M. Batic
Theoretical Grounds for the Propagation of Uncertainties in Monte Carlo Particle Transport
IEEE Trans. Nucl. Sci., vol. 61, no. 2, pp. 877-887, Aug. 2014 Preprint Paper

- M. Batic, G. Hoff, M. G. Pia, P. Saracco, G. Weidenspointner
Validation of Geant4 simulation of electron energy deposition
IEEE Trans. Nucl. Sci., vol. 60, no. 4, pp. 2934-2957, Aug. 2013 Preprint Paper

- S. Hauf, M. Kuster, M. Batic, Z. W. Bell, D. H. H. Hoffmann, P. M. Lang, S. Neff, M. G. Pia, G. Weidenspointner, A.
Radioactive Decays in Geant4
IEEE Trans. Nucl. Sci., vol. 60, no. 4, pp. 2966-2983, Aug. 2013 Preprint Paper

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Validation of Geant4-based Radioactive Decay Simulation
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- M. Batic, M. G. Pia, S. J. Cipolla
Corrected ISICSoo class version
Comp. Phys. Comm. vol. 184, no. 9, pp. 2232-2233, Sep. 2013 Paper

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- H. Seo, M. G. Pia, P. Saracco, C. H. Kim
Ionization cross sections for low energy electron transport
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Anal. Chem., vol. 80, no. 22, pp. 8398-8405, Nov. 2008 Paper

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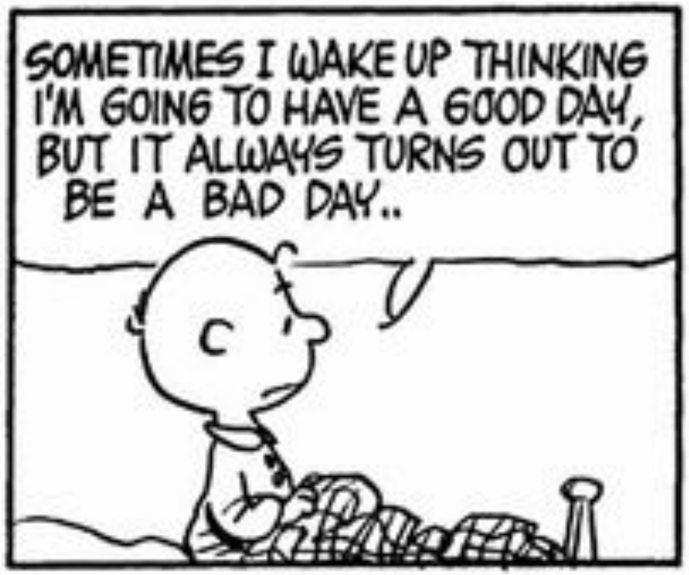
http://www.ge.infn.it/geant4/papers



Ein unnütz Leben ist ein früher Tod.

(Johann Wolfgang von Goethe)