25th ANNIVERSARY

25 years enabling scientific production and applications in the society

Geant4 software
from HEP to applications in the society

Tullio Basaglia[1], Zane W. Bell[2], Daniele D'Agostino[3,4], Paul V. Dressendorfer[2], Maria Grazia Pia[4]

[1]*CERN (retired), Geneva, Switzerland*
[2]*IEEE, Piscataway, NJ, USA*
[3]*Univ. of Genova, Italy*
[4]*INFN Genova, Italy*

Collaboration: Berkar Kaynak and Onur Potok *(Istanbul Univ., Turkey),* Elisabetta Ronchieri *(INFN CNAF, Bologna, Italy)*

27th IPPOG meeting, Madrid, 24 April 2024

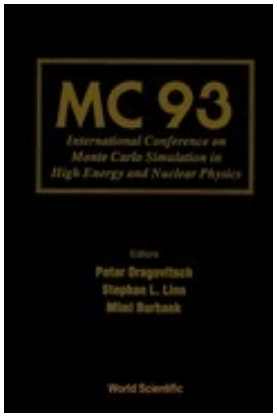
25 years in 15 minutes…

Due to limited time allocation, there is room only to highlight a few results

Geant4 is a software **toolkit**

for the simulation of the passage of particles in matter

~900000 lines of code



TOWARDS OBJECT-ORIENTED GEANT
-- ProdiG PROJECT --

Yoshinobu TAKAIWA,
Katsuya AMAKO, Jun-ichi KANZAKI, and Takashi SASAKI
KEK (National Laboratory for High Energy Physics)
1-1 Oho, Tsukuba, Ibaraki 305, Japan

1993

Itsuko Wasukoski
27.08.1993

S. Giani, Investigation of a class hierarchy for GEANT

MINI-WORKSHOP ON OBJECT ORIENTED GEANT

Held 24-27 August 1993 at CERN/CN/AS

MC 93, Int. Conf. on Monte Carlo Simulation in High Energy and Nuclear Physics

1994

DRDC/94-28

Letter of intent to the DRDC

May 26, 1994

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

P58 Proposal to CERN Detector R&D Committee

CERN/DRDC/94-29
DRDC / P58
11 August 1994

GEANT 4 : an Object-Oriented toolkit for simulation in HEP

RD44 (GEANT4)

GEANT 4: an Object-Oriented toolkit for simulation in HEP

ABSTRACT & FIGURES | HOME PAGE | NOTES & PUBLICATIONS

SPOKESPERSON: Simone GIANI
Experiment secretariat e-mail: Grey.Book@cern.ch

Beam:	
Approved:	24-11-1994
	07-12-1995
	01-07-1997
	21-10-1997
Completed	14-12-1998
Finished	14-12-2008
Status:	Finished

April 1997: First alpha release

July 1998: First beta release

15 December **1998**

Geant4 0.0 is born

25th ANNIVERSARY

A broad view: from HEP, beyond HEP

1994 **RD44 mandate**:
creating a detector simulation toolkit necessary for the next generation of HEP experiments

"A variety of requirements also come from heavy ions physics, CP violation physics, cosmic rays physics, medical applications and space science applications. In order to meet such requirements, a large degree of functionality and flexibility has to be provided."

RD44 Status Report, 1995

1998 "Geant4 has a **multi-disciplinary** nature,
providing functionality in a set of different scientific fields.
The Geant4 Object-Oriented design allows the user to
understand, **extend**, or **customise** the toolkit in all the domains."

RD44 Status Report, 1998

Enabling scientific production
and applications in many domains

Available online at www.sciencedirect.com
SCIENCE DIRECT®
Nuclear Instruments and Methods in Physics Research A 506 (2003) 250–303
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

GEANT4—a simulation toolkit

S. Agostinelli[ae], J. Allison[as,*], K. Amako[e], J. Apostolakis[a], H. Araujo[aj], P. Arce[l,m,x,a], M. Asai[g,ai], D. Axen[i,t], S. Banerjee[bi,l], G. Barrand[an], F. Behner[l], L. Bellagamba[c], J. Boudreau[bd], L. Broglia[ar], A. Brunengo[c], H. Burkhardt[a], S. Chauvie[bj,bl], J. Chuma[h], R. Chytracek[a], G. Cooperman[az], G. Cosmo[a], P. Degtyarenko[d], A. Dell'Acqua[a,i], G. Depaola[y], D. Dietrich[af], R. Enami[ab], A. Feliciello[bj], C. Ferguson[bh], H. Fesefeldt[l,o], G. Folger[a], F. Foppiano[ac], A. Forti[as], S. Garelli[ac], S. Giani[a], R. Giannitrapani[bo], D. Gibin[m,bc], J.J. Gómez Cadenas[m,bp], I. González[q], G. Gracia Abril[n], G. Greeniaus[p,h,ag], W. Greiner[af], V. Grichine[f], A. Grossheim[m,z], S. Guatelli[ad], P. Gumplinger[h], R. Hamatsu[bk], K. Hashimoto[ab], H. Hasui[ab], A. Heikkinen[ah], A. Howard[aj], V. Ivanchenko[a,ba], A. Johnson[g], F.W. Jones[h], J. Kallenbach[aa], N. Kanaya[i,h], M. Kawabata[ab], Y. Kawabata[ab], M. Kawaguti[ab], S. Kelner[at], P. Kent[r], A. Kimura[ay,bb], T. Kodama[aw], R. Kokoulin[at], M. Kossov[d], H. Kurashige[am], E. Lamanna[w], T. Lampén[ah], V. Lara[a,l,bq], V. Lefebure[l], F. Lei[bh,be], M. Liendl[l,a,br], W. Lockman[j,bn], F. Longo[bm], S. Magni[k,au], M. Maire[ao], E. Medernach[a], K. Minamimoto[aw,al], P. Mora de Freitas[ap], Y. Morita[e], K. Murakami[e], M. Nagamatu[aw], R. Nartallo[b], P. Nieminen[b], T. Nishimura[ab], K. Ohtsubo[ab], M. Okamura[ab], S. O'Neale[s], Y. Oohata[bk], K. Paech[af], J. Perl[g], A. Pfeiffer[a], M.G. Pia[ad], F. Ranjard[n], A. Rybin[ak], S. Sadilov[a,ak], E. Di Salvo[c], G. Santin[bm], T. Sasaki[e], N. Savvas[as], Y. Sawada[ab], S. Scherer[af], S. Sei[aw], V. Sirotenko[i,al], D. Smith[g], N. Starkov[f], H. Stoecker[af], J. Sulkimo[ah], M. Takahata[ay], S. Tanaka[bg], E. Tcherniaev[a], E. Safai Tehrani[g], M. Tropeano[ae], P. Truscott[be], H. Uno[aw], L. Urban[v], P. Urban[aq], M. Verderi[ap], A. Walkden[as], W. Wander[av], H. Weber[af], J.P. Wellisch[a,l], T. Wenaus[u], D.C. Williams[j,bf], D. Wright[g,h], T. Yamada[aw], H. Yoshida[aw], D. Zschiesche[af]

[a] European Organization for Nuclear Research (CERN) Switzerland
[b] European Space Agency (ESA), ESTEC, The Netherlands
[c] Istituto Nazionale di Fisica Nucleare (INFN), Italy
[d] Jefferson Lab, USA
[e] KEK, Japan

*Corresponding author. Tel.: +44-161-275-4179; fax: +44-161-273-5867.
E-mail address: john.allison@man.ac.uk (J. Allison).

doi:10.1016/S0168-9002(03)01368-8

16865 citations

Most cited paper in

- **Particles & Fields Physics**
  448762 papers
- **Nuclear Physics**
  339688 papers
- **Nuclear Science & Technology**
  386641 papers
- **Instruments & Instrumentation**
  721030 papers

Most cited articles in
Astronomy & Astrophysics:
14667 citations
Radiology, Nuclear Medicine & Medical Imaging:
12390 citations

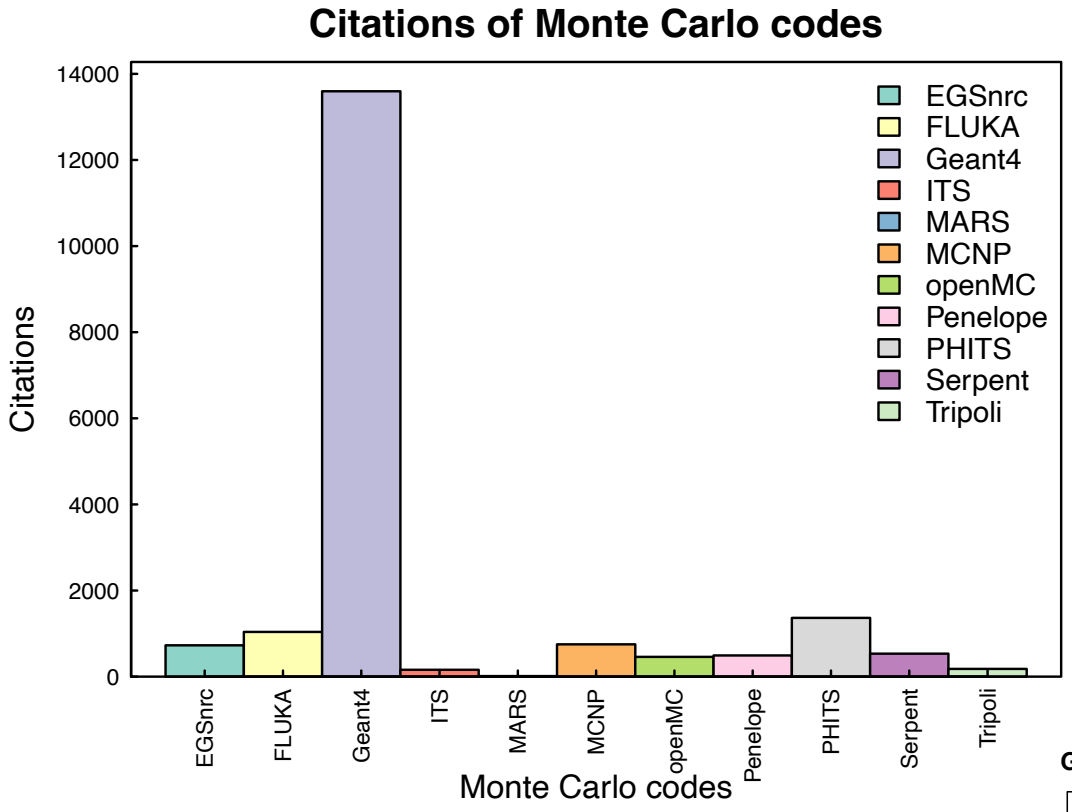
Food for Thought

The 5 most cited papers in
Instruments & Instrumentation are **software** papers

Web of Science, *Clarivate Analytics, 22/4/2024 - INFN subscription coverage: 1990* ➟

Monte Carlo transport codes

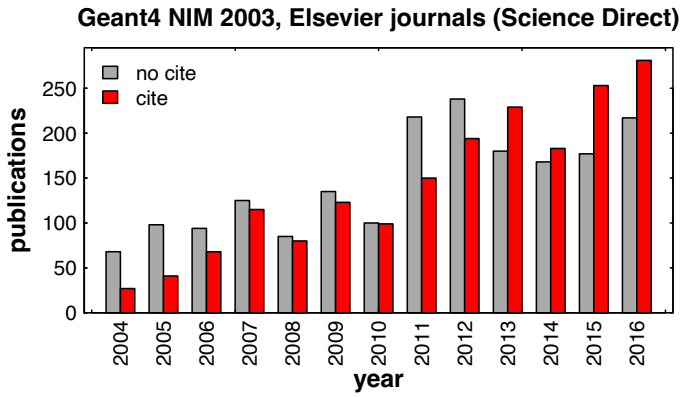
Usage characteristics



Variable publication dates of the respective reference papers
For some codes, large fraction of citations from the code's authors

Missing citations

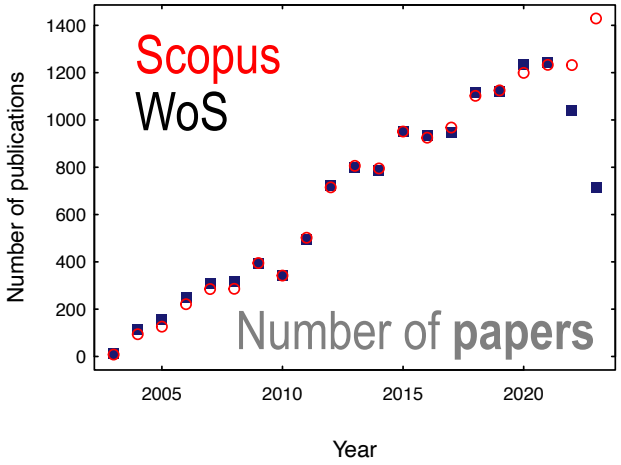
Many publications **do not cite scientific software** systems mentioned in the text and used to **produce the results**



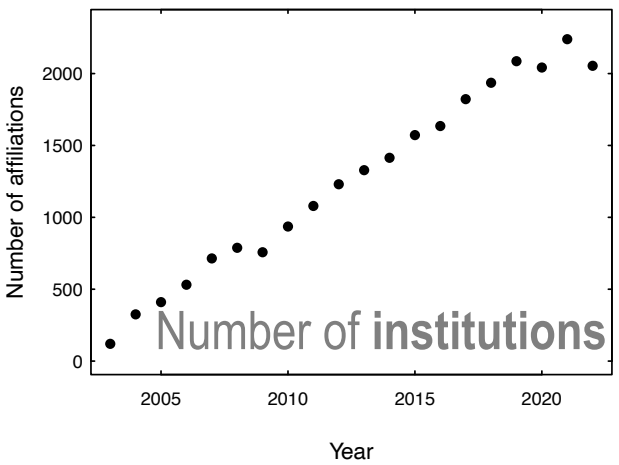
Time profile of the citations

Growing trend
Mann-Kendall **trend** test
H_0: no trend H_1: ↗ trend
Geant4: $p < 0.01$

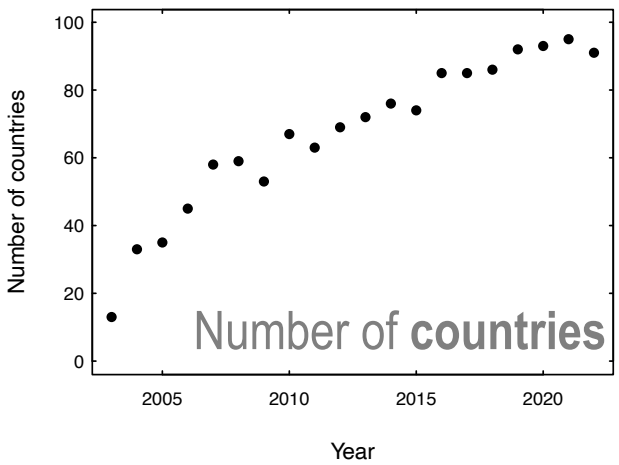
Geant4



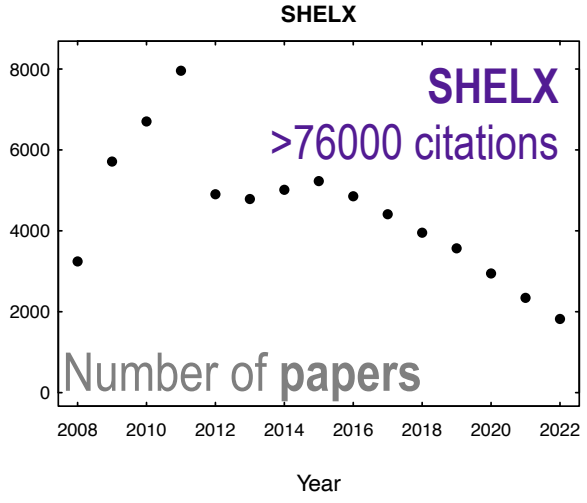
Geant4



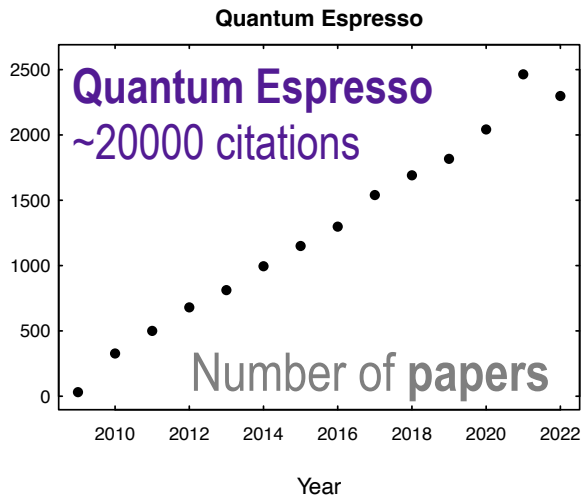
Geant4



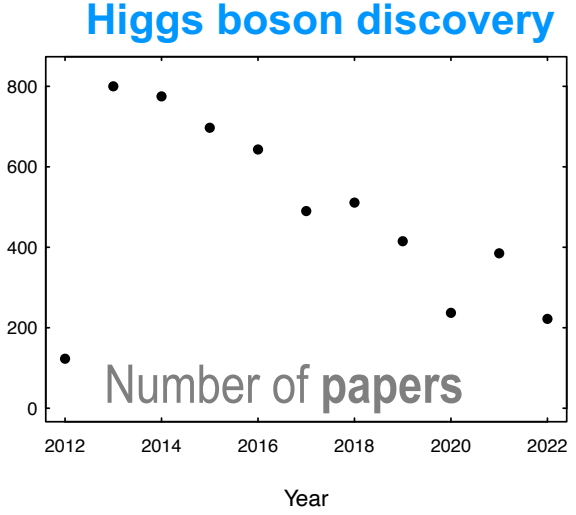
SHELX



Quantum Espresso



Higgs boson discovery



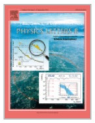
Rapidly **decreasing trend** common to HEP landmark discoveries

Cited by relevant papers

ELSEVIER

Physics Letters B

Volume 716, Issue 1, 17 September 2012, Pages 1-29



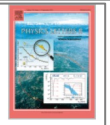
6121 citations

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

ELSEVIER

Physics Letters B

Volume 716, Issue 1, 17 September 2012, Pages 30-61



Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC ☆

Eur. Phys. J. C (2011) 71: 1534
DOI 10.1140/epjc/s10052-010-1534-9

THE EUROPEAN PHYSICAL JOURNAL C

Review

1244 citations

Heavy quarkonium: progress, puzzles, and opportunities

Search for Majorana Neutrinos Near the Inverted Mass Hierarchy Region with KamLAND-Zen

714 citations

A. Gando *et al.* (KamLAND-Zen Collaboration)
Phys. Rev. Lett. **117**, 082503 – Published 16 August 2016; Erratum Phys. Rev. Lett. **117**, 109903 (2016)

Indication of Reactor $\bar{\nu}_e$ Disappearance in the Double Chooz Experiment

967 citations

Y. Abe *et al.* (Double Chooz Collaboration)
Phys. Rev. Lett. **108**, 131801 – Published 28 March 2012

Dark Matter Results from 54-Ton-Day Exposure of PandaX-II Experiment

726 citations

Xiangyi Cui *et al.* (PandaX-II Collaboration)
Phys. Rev. Lett. **119**, 181302 – Published 30 October 2017

INSTITUTE OF PHYSICS PUBLISHING — PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. **49** (2004) 4543–4561 — PII: S0031-9155(04)80763-2

1617 citations

GATE: a simulation toolkit for PET and SPECT

and more...

First Result from the Alpha Magnetic Spectrometer on the International Space Station: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV

797 citations

M. Aguilar *et al.* (AMS Collaboration)
Phys. Rev. Lett. **110**, 141102 – Published 3 April 2013

Measurement of the Cosmic Ray $e^+ + e^-$ Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope

797 citations

A. A. Abdo *et al.* (Fermi LAT Collaboration)
Phys. Rev. Lett. **102**, 181101 – Published 4 May 2009

REVIEW ARTICLE | AUGUST 11 2008

Gas-assisted focused electron beam and ion beam processing and fabrication

Ivo Utke; Patrik Hoffmann; John Melngailis

816 citations

J. Vac. Sci. Technol. B 26, 1197–1276 (2008)
https://doi.org/10.1116/1.2955728

in particle physics

JHEP

PUBLISHED FOR SISSA BY SPRINGER

RECEIVED: *November 29, 2016*
REVISED: *March 24, 2017*
ACCEPTED: *April 6, 2017*
PUBLISHED: *April 28, 2017*

594 citations

Evidence for the two-body charmless baryonic decay $B^+ \to p\bar{\Lambda}$

Dark Matter Search Results from a One Ton-Year Exposure of XENON1T

1319 citations

E. Aprile *et al.* (XENON Collaboration)
Phys. Rev. Lett. **121**, 111302 – Published 12 September 2018

IOP PUBLISHING — PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. **57** (2012) R99–R117 — doi:10.1088/0031-9155/57/11/R99

TOPICAL REVIEW

838 citations

Range uncertainties in proton therapy and the role of Monte Carlo simulations

ELSEVIER

Journal of Archaeological Science

Volume 56, April 2015, Pages 41-60

Optical dating in archaeology: thirty years in retrospect and grand challenges for the future

LETTER

doi:10.1038/nature24647

Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

minerals

MDPI

https://www.mdpi.com/journal/minerals

Review

A Review of Sensor-Based Sorting in Mineral Processing: The Potential Benefits of Sensor Fusion

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER

10.1029/2018GL077784

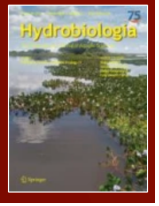
Termination of Electron Acceleration in Thundercloud by Intracloud/Intercloud Discharge

Geant4 is used in many different fields…

Home > Hydrobiologia > Article

Adineta vaga under fire: simulating the impact of radiation

ROTIFERA XVI | Open Access | Published: 16 August 2023 | (2023)



Nonlin. Processes Geophys., 27, 75–119, 2020

https://doi.org/10.5194/npg-27-75-2020

Nonlinear Processes in Geophysics

Open Access

EGU

The physics of space weather/solar-terrestrial physics (STP): what we know now and what the current and future challenges are

ELSEVIER

Journal of Food Engineering

Volume 149, March 2015, Pages 137-143

Improving phytosanitary irradiation treatment of mangoes using Monte Carlo simulation

Geosci. Instrum. Method. Data Syst., 2, 55–60, 2013

www.geosci-instrum-method-data-syst.net/2/55/2013/

doi:10.5194/gi-2-55-2013

Geoscientific Instrumentation Methods and Data Systems

Open Access

Towards a muon radiography of the Puy de Dôme

ELSEVIER

Mitochondrion

Volume 13, Issue 6, November 2013, Pages 736-742

Short communication

Predicted ionisation in mitochondria and observed acute changes in the mitochondrial transcriptome after gamma irradiation: A Monte Carlo simulation and quantitative PCR study

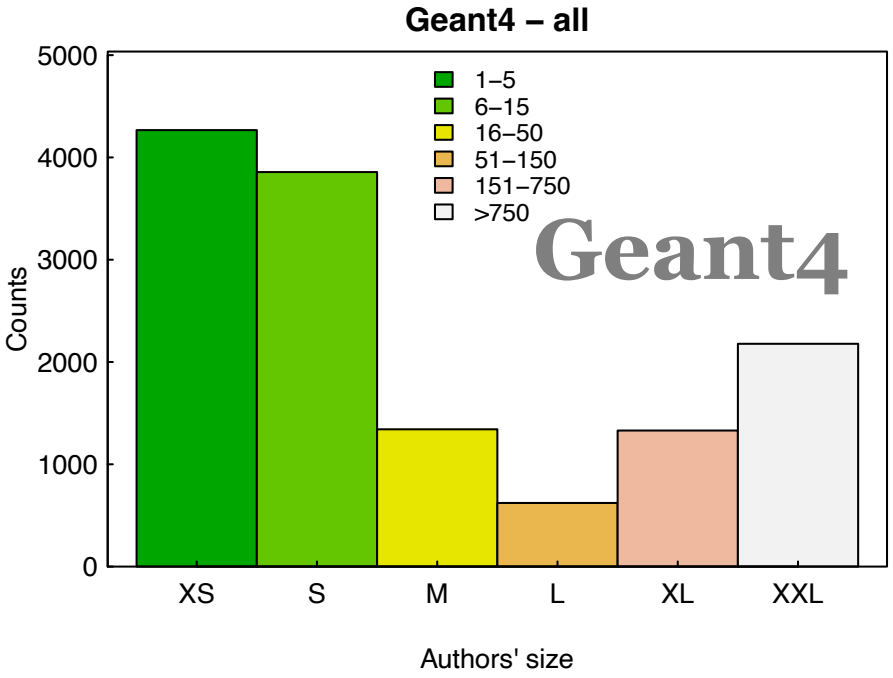
Advances in Computational Mathematics (2023) 49:62

https://doi.org/10.1007/s10444-023-10065-9

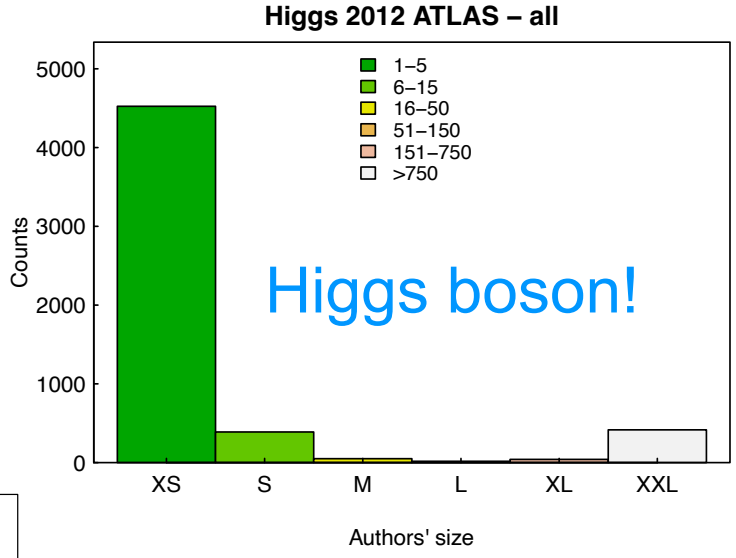
Check for updates

Finite basis physics-informed neural networks (FBPINNs): a scalable domain decomposition approach for solving differential equations

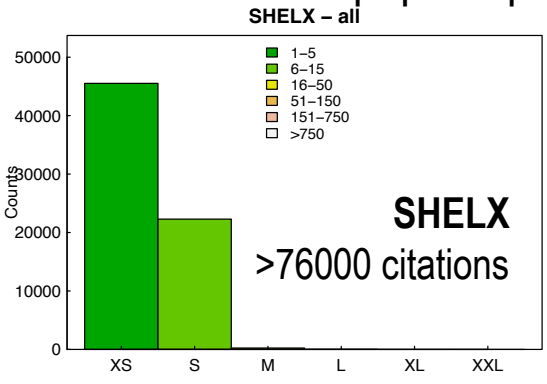
Used by small and large teams

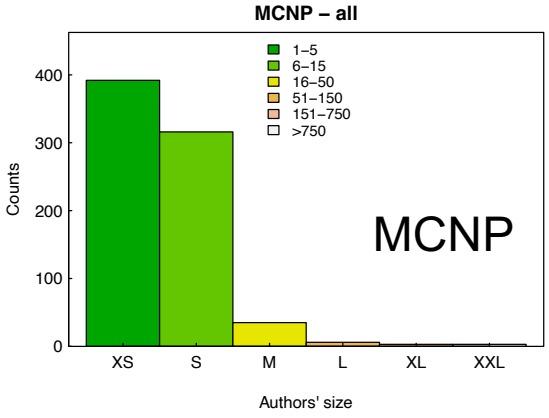


Research groups of widely varied sizes use Geant4: from XS to XXL



Other popular physics software systems





HEP

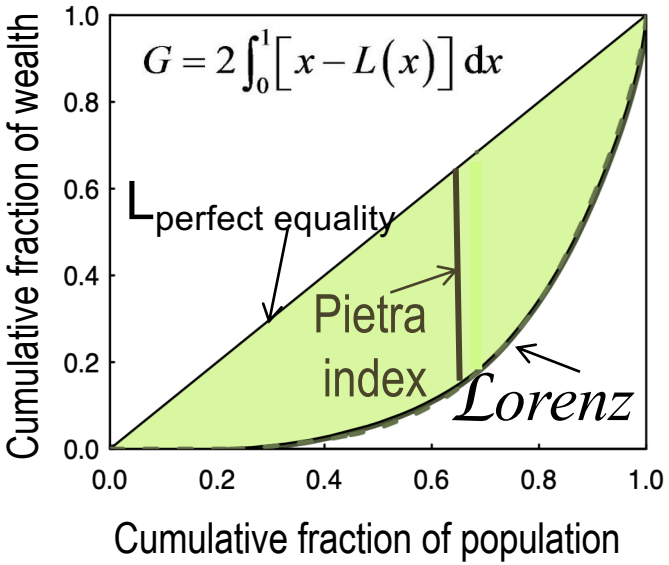
Geo-distribution: how fair?

In econometrics, **fairness of distribution** is measured by **inequality** indices

"The N richest people in the world are worth more than the poorest X%"

Gini index

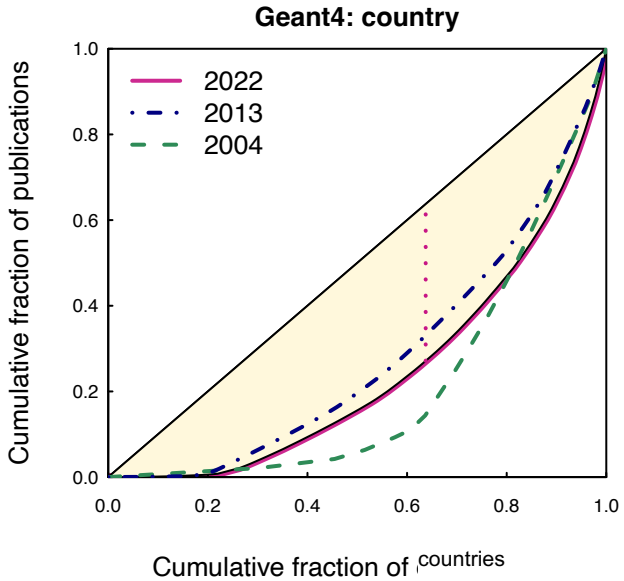
Most common measure of inequality

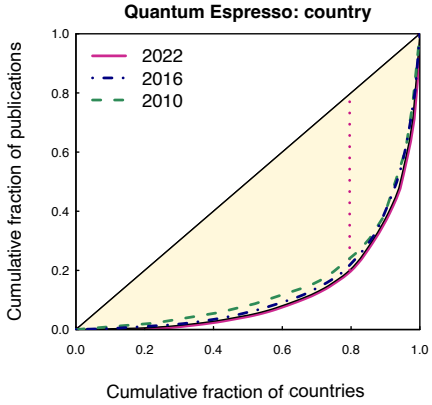


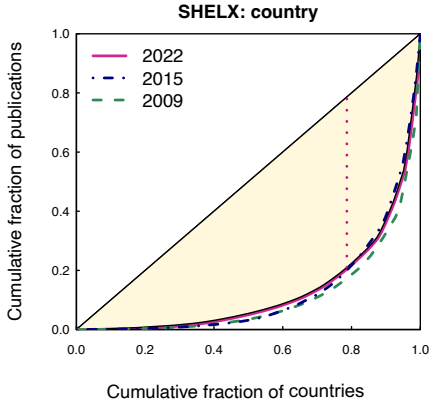
$0 \le \mathbf{G} \le 1$

0 → **1**

more unequal society







Diversity

Concept drawn from ecology:
number of species and their **abundance**

- **Diversity** measures the **richness** and the **complexity** of a community
- Related to the concept of **entropy** in information theory
- Measured by several indices, with different **sensitivity to rare species**

Recent consensus on **Hill indices** to measure diversity:
mathematical functions that combine **richness** and **evenness**

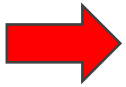
Hill indices

$$ {}^{q}D = \left(\sum_{i=1}^{S} p_i^q \right)^{1/(1-q)} $$

S = # of different species
p = proportion of species
q = *order of Hill index*

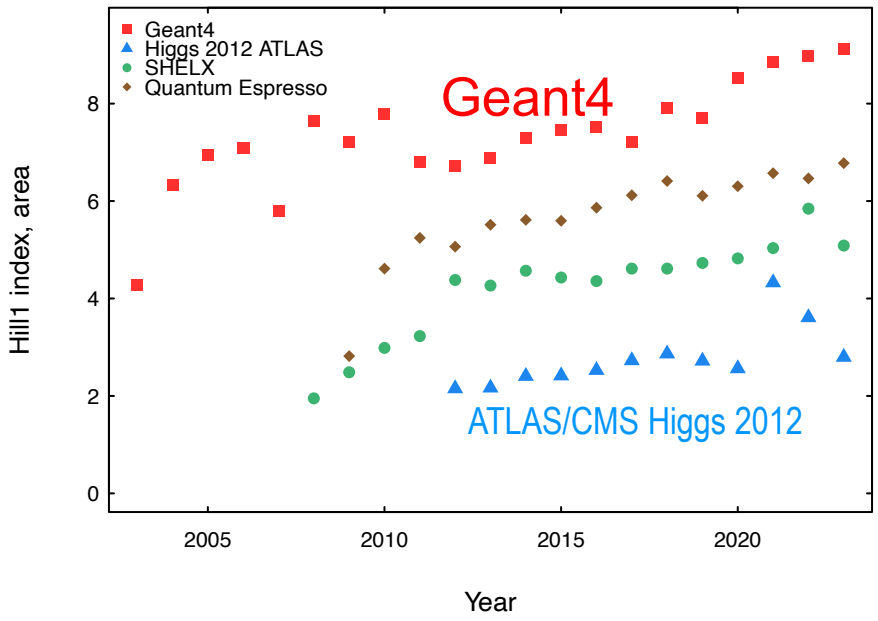
q	
0	number of species
1	$\lim_{q \to 1} {}^{q}D \equiv {}^{1}D = \exp\left(-\sum_{i=1}^{S} p_i \log p_i \right)$
2	${}^{2}D = 1/\sum_{i=1}^{S} p_i^2$

Hill indices can be interpreted as
effective number of species



compare the diversity
of communities

Diversity of research areas



Mann-Kendall **trend** test

H_0: no trend

H_1: ↗ trend

Geant4: $p < 0.01$

Cox-Stuart **trend** test

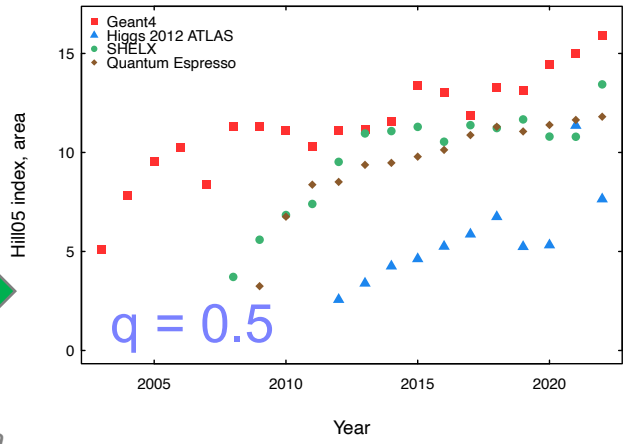
H_0: no trend

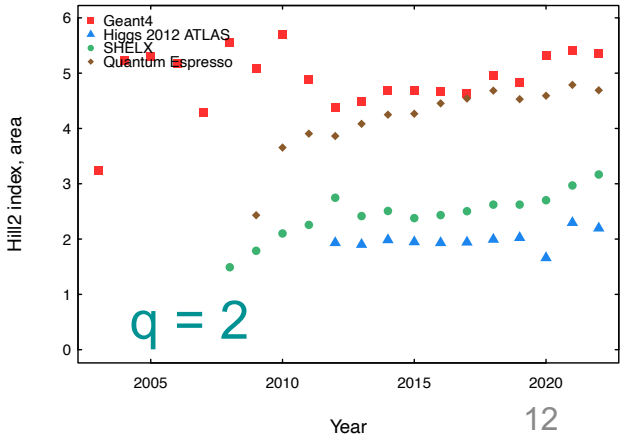
H_1: ↗ trend

Geant4: $p < 0.01$

Geant4 citations: growing diversity

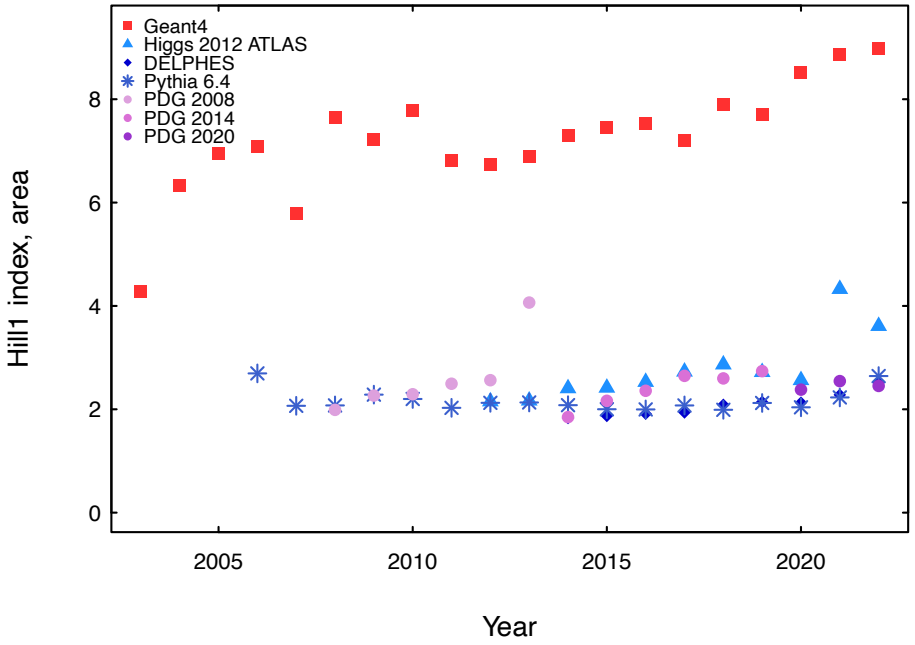
Largest diversity also when the emphasis is on **rare species** or on **more common** ones



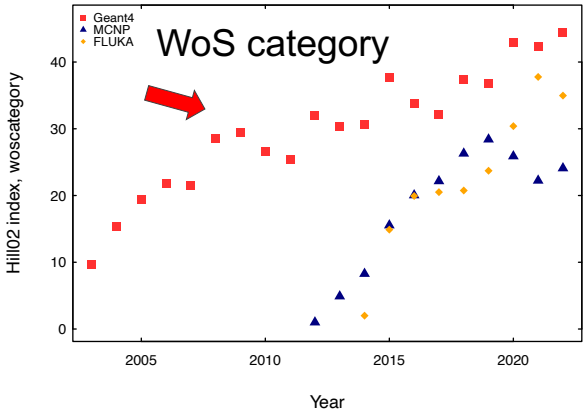


Diversity w.r.t. HEP

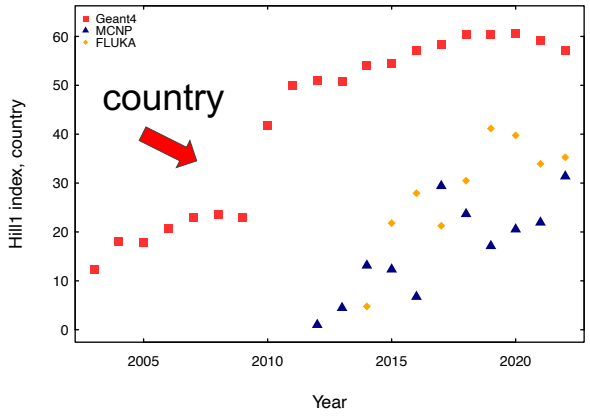
Geant4 citations exhibit much greater **diversity** of **research areas** than the citation of landmark HEP papers



Greater diversity is also observed w.r.t. the origin of the citations of other Monte Carlo transport codes



Geant4 MCNP FLUKA

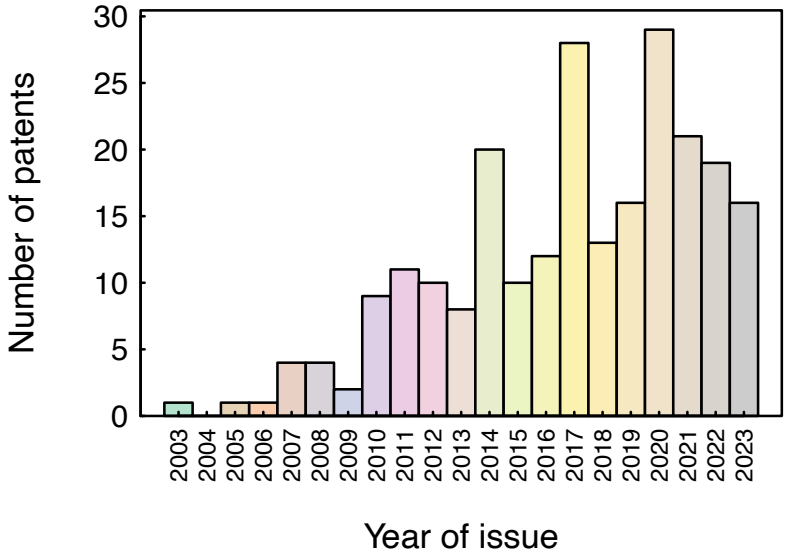


Warning: the small number of citations of some Monte Carlo codes is liable to generate apparent artifacts in the calculation of Hill indices

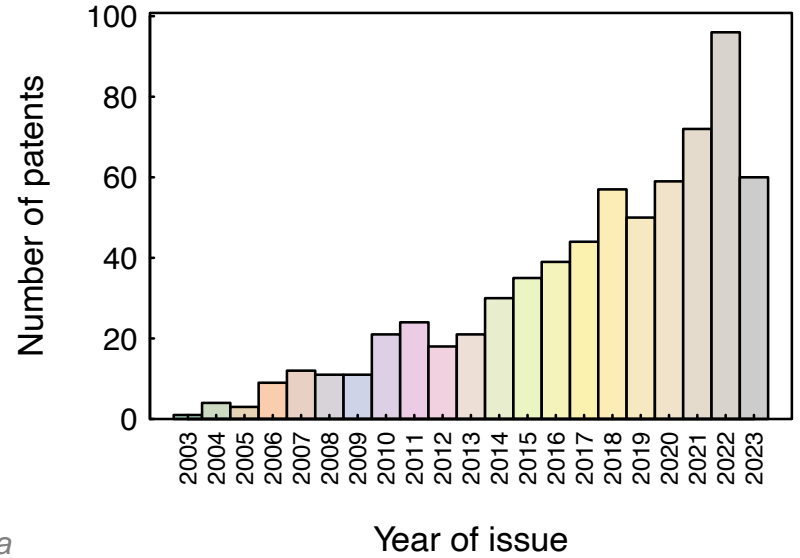
Patents based on Geant4

2003-2023

>200 patents
United States Patent and Trademark Office (USPTO)



>600 patents
European Patent Office



with growing trend

Mann-Kendall
and
Cox-Stuart
trend tests

H_0: no trend
H_1: ↗ trend

$p < 0.01$

Conclusions

Geant4 metrics >16000 citations

Most cited paper in Particle and Fields Physics, Nuclear Physics, Nuclear Science and Technology, Instruments and Instrumentation

Most cited paper authored by **CERN**, **ESA, INFN**...

Enables small and large groups to produce scientific results

Diverse research areas and fair geographical spread

RD44

Many new and original ideas

Depth of thought | **Paradigm shift** | **Courage**

Pease restore CERN subscription to the Web of Science!

Objective quantification of Geant4 scientific and social impact through rigorous **statistical data analysis**

More in progress, paper under review…