OMA School on Monte Carlo Simulations: general introduction

UNIVERSITAT DE BARCELONA

Alfredo Ferrari,
CERN, Geneva
On behalf of all lecturers

Garching, November 6th 2017

Optimization of Medical Accelerators

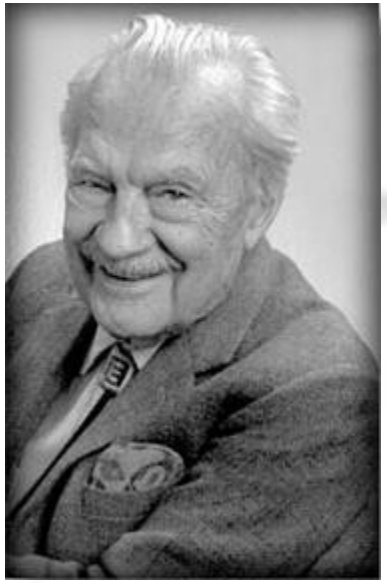
- European Training Network funded by the European Union
- To support Early Stage Researchers' training and mobility
- International consortium of more than 30 partner organisations: universities, research centres, treatment centres and private companies.
- R&D at interface between physics and life sciences:

- beam imaging and diagnostics
- treatment optimization
- facility design and optimization.

www.oma-project.eu

The Monte Carlo method:

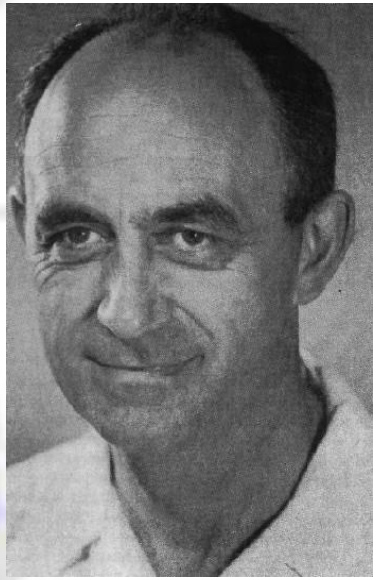
Invented in the late 40's by **John von Neumann**, **Stanislaw Ulam** and **Nicholas Metropolis** (who gave it its name), and independently by **Enrico Fermi**



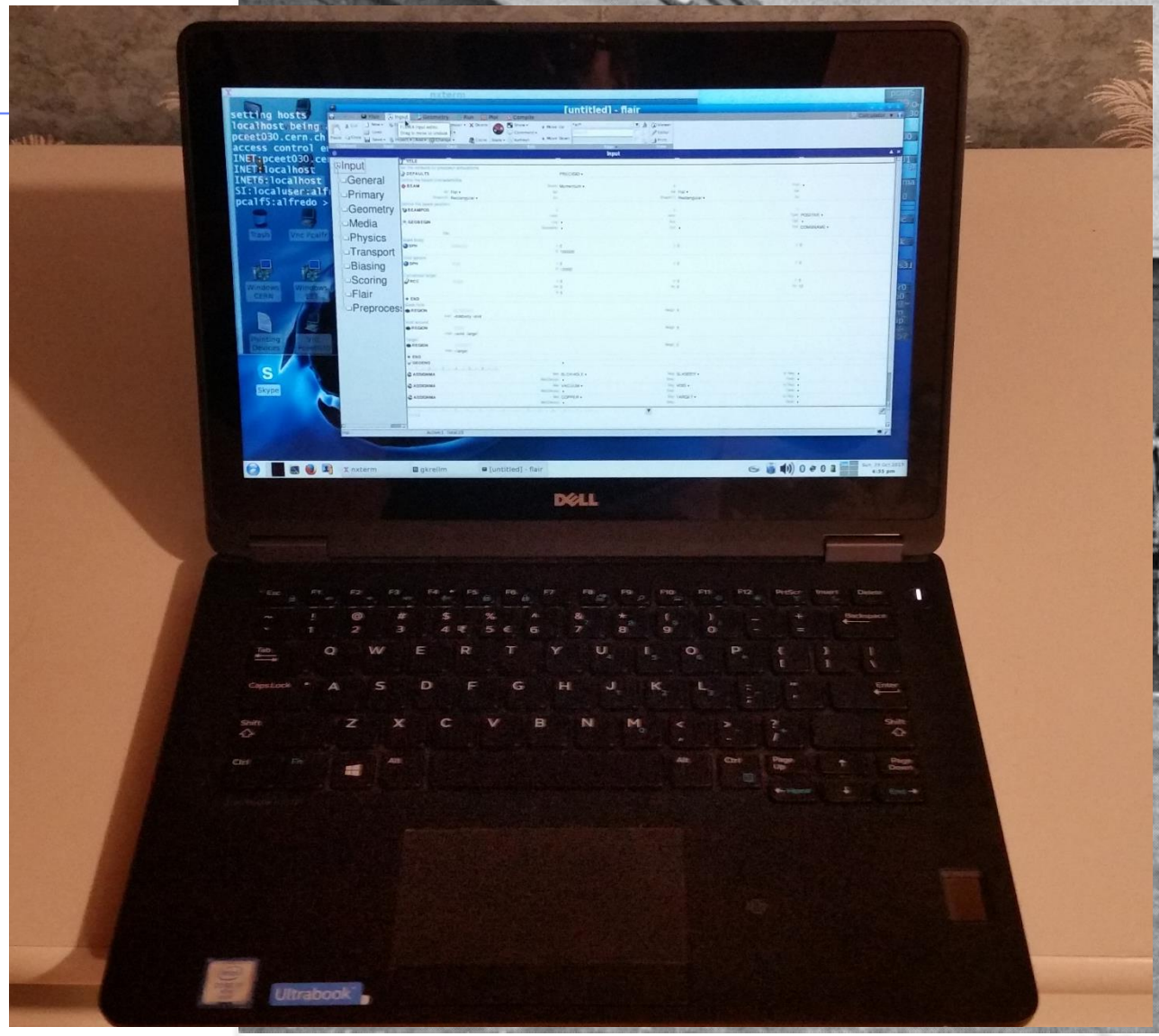
N. Metropolis

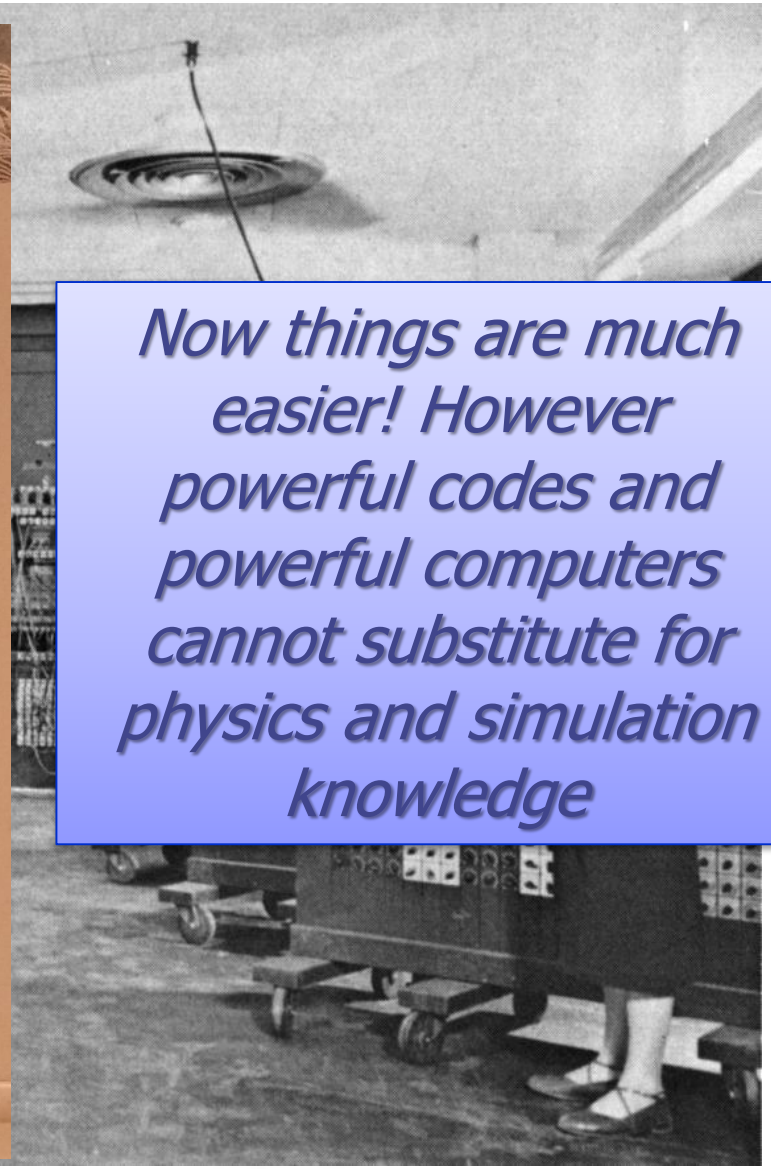
S. Ulam

J. von Neumann



E. Fermi





Now things are much easier! However powerful codes and powerful computers cannot substitute for physics and simulation knowledge

The ENIAC

Electronic Numerical Integrator And Computer

Disclaimer:

What this school is about:

- Give the students some general introduction to the Monte Carlo method
- Introduce them to 3 well known and widely used MC codes (next slide for the names!) for accelerator and medical applications
- Present some of their features and explore some simple examples with guided exercises
- Possibly stimulate the interested students to explore further one or more of these codes

… and what it is not:

- The school is in no way intended to give you a starting expertise in ***ANY*** of the 3 codes
- There is no claim that the material presented is complete and exhaustive about any of the codes
- There is no claim that the 3 MC codes are the best or the only ones to be suitable for accelerator and/or medical applications, indeed others like EGSnrc, MCNP, PHITS could have been perfectly legitimate choices. It just happened that I had the availability of experts for those 3, experts who I heartily thank for their participation

General purpose EM/HAD MC codes:

- PENELOPE: https://www.oecd-nea.org/tools/abstract/detail/nea-1525
  - EM 100 eV – 1 GeV EM
  - Language: Fortran. Systems: Linux/Unix/Windows
- FLUKA: http://www.fluka.org
  - coupled HAD+EM+A. 1 keV – 100000 TeV EM, 0-10000 TeV HAD
  - Language: Fortran. Systems: Linux/Unix/Windows (virtual machine)
- GEANT4: http://geant4.web.cern.ch/geant4 (→ GeantV: http://geant.cern.ch/)
  - coupled HAD+EM+A.
  - Language: C++. Systems: Linux/Unix/Windows/MAC
- MARS: http://www-ap.fnal.gov/MARS
  - coupled HAD+EM+A. 1 keV – 100 TeV EM, 0-100 TeV HAD
  - Language: Fortran.
- MCNP(6/x): http://mcnp(x).lanl.gov/
  - "nearly all particles, nearly all energies"
  - Language: Fortran90. Systems: Linux/Unix/Windows
- PHITS: http://phits.jaea.go.jp/
  - coupled hadronic+EM+A. 1 keV – 1 GeV EM, 0-200 GeV HAD
  - Language: Fortran
- EGSnrc: https://nrc-cnrc.github.io/EGSnrc/
  - EM 1 keV – 10 GeV EM
  - Language: Fortran/C/C++. Systems: Linux/Windows/MAC
- …

The chosen ones!

School Agenda:

	6 Nov	7 Nov	8 Nov	9 Nov	10 Nov
8:30 - 9:00	General introduction (A. Ferrari)	Penelope models (low-energy elctromagnetic) (J.M. Fernández-Varea)	Geometry in FLUKA (E. Skordis)	Heavy ion beams and radioactivity in FLUKA (A. Mairani)	Geant4 for space and medicine (G. Dedes and M. Pinto)
9:00 - 9:30	Principles of Monte Carlo calculations and codes (F. Salvat)				
9:30 - 10:00		Electron accelerator modeling with Penelope + Tutor (L. Brualla)	FLUKA models (A. Ferrari)	Scoring in FLUKA (A. Mairani)	
10:00 - 10:30					
10:30 - 11:00	coffee break		coffee break	coffee break	coffee break
11:00 - 11:30	Introduction to Geant4 (G. Dedes and M. Pinto)	Transfer to Munich + lunch	Ionization and transport in FLUKA (F. Salvat-Pujol)	Medical applications with FLUKA (A. Mairani)	Outlook in Penelope (F. Salvat-Pujol)
11:30 - 12:00					
12:00 - 12:30				Transfer to Munich + lunch	lunch
12:30 - 13:00	lunch		lunch		
13:00 - 13:30		Exercises with Penelope			
13:30 - 14:00					Outlook in GeantV (A. Gheata)
14:00 - 14:30	Structure and operation of PENELOPE (F. Salvat)		Accelerators in FLUKA (E. Skordis)	Exercises with FLUKA	
14:30 - 15:00					GeantV: machine learning techniques (S. Vallecorsa)
15:00 - 15:30	Introduction to FLUKA (A. Ferrari)	coffee break	Social activity		
15:30 - 16:00		Exercises with Geant4			coffee break
16:00 - 16:30	coffee break			coffee break	Outlook in FLUKA (A. Ferrari)
16:30 - 17:00	Introduction to Flair (E. Skordis)	Poster session		Exercises: medical applications with FLUKA	
17:00 - 17:30					Closing remarks
17:30 - 18:00	Geometry in Penelope (F. Salvat)				
18:00 - 18:30					

Francesc Salvat Gavalda (MC principles & Penelope)

Professor in the Department of Physics of the Universitat de Barcelona.

Leader of the development team of PENELOPE, a state-of-the-art Monte-Carlo simulation code system for the coupled transport of electrons, positrons, and photons in the sub-GeV energy domain.

Expertise in:

- Numerical solution of the Schroedinger and Dirac radial equations.
- First-principles calculations of atomic structure (self-consistent
- calculations a la Hartree-Fock).
- Distorted-wave calculations of elastic scattering of electrons and positrons on atoms and molecules.
- Distorted-wave calculation of cross sections for inner-shell ionization of atoms by electron and positron impact.
- Modelling of dielectric response of solids for electronic-stopping calculations of charged particles down to a few 100 eV

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Georgios (George) Dedes (Geant4):

George Dedes is a staff scientist of the Department of Medical Physics (LS Parodi), in the Ludwig-Maximilians University of Munich. He graduated in 2004 from the Physics Faculty of the Aristotle University of Thessaloniki in Greece, with a specialization in Particle and Nuclear Physics. From 2004 to 2008 he performed his doctoral studies at the Max-Planck Institute for Physics in Munich and at the Technical University of Munich. The topic of his dissertation was the study of the potential for the discovery of a supersymmetric Higgs particle, using the ATLAS experiment of the LHC accelerator at CERN.

From 2010 to 2013, he worked for the Nuclear Physics Institute of Lyon (IPNL) and the CREATIS Medical Imaging Research Center of the University of Lyon, on the topics of prompt gamma modelling in Geant4, prompt gamma range monitoring for particle therapy and proton computed tomography. Since 2013, he works on several computational aspects of particle therapy, such as prompt gamma particle range monitoring, proton imaging, Monte Carlo treatment planning for proton therapy and laser ion acceleration.

Marco Pinto (Geant4 Applications):

Marco Pinto was awarded his PhD in Medical Physics in 2014 by the Claude Bernard University in Lyon, France, for his research on prompt-gamma monitoring for ion therapy. He had previously worked on a project related to photon therapy monitoring. He is currently a postdoctoral researcher at the Chair of Medical Physics (LS Parodi) of the Ludwig Maximilians University in Munich, Germany, where he is investigating analytical methods for fast prediction of PET and PG distributions in ion therapy and GPU-based Monte Carlo tools for dose calculation in carbon ion therapy.

Alfredo Ferrari (myself) (Fluka)

Main author of the FLUKA code

INFN Milan, 1984-1998:

- Milan Superconducting Cyclotron project
- Dosimetry and Radioprotection
- MC simulations (MORSE, EGS, FLUKA)
- ATLAS (responsible for all background issues)
- ICARUS (neutrino physics)
- Nuclear Physics
- Cosmic ray physics

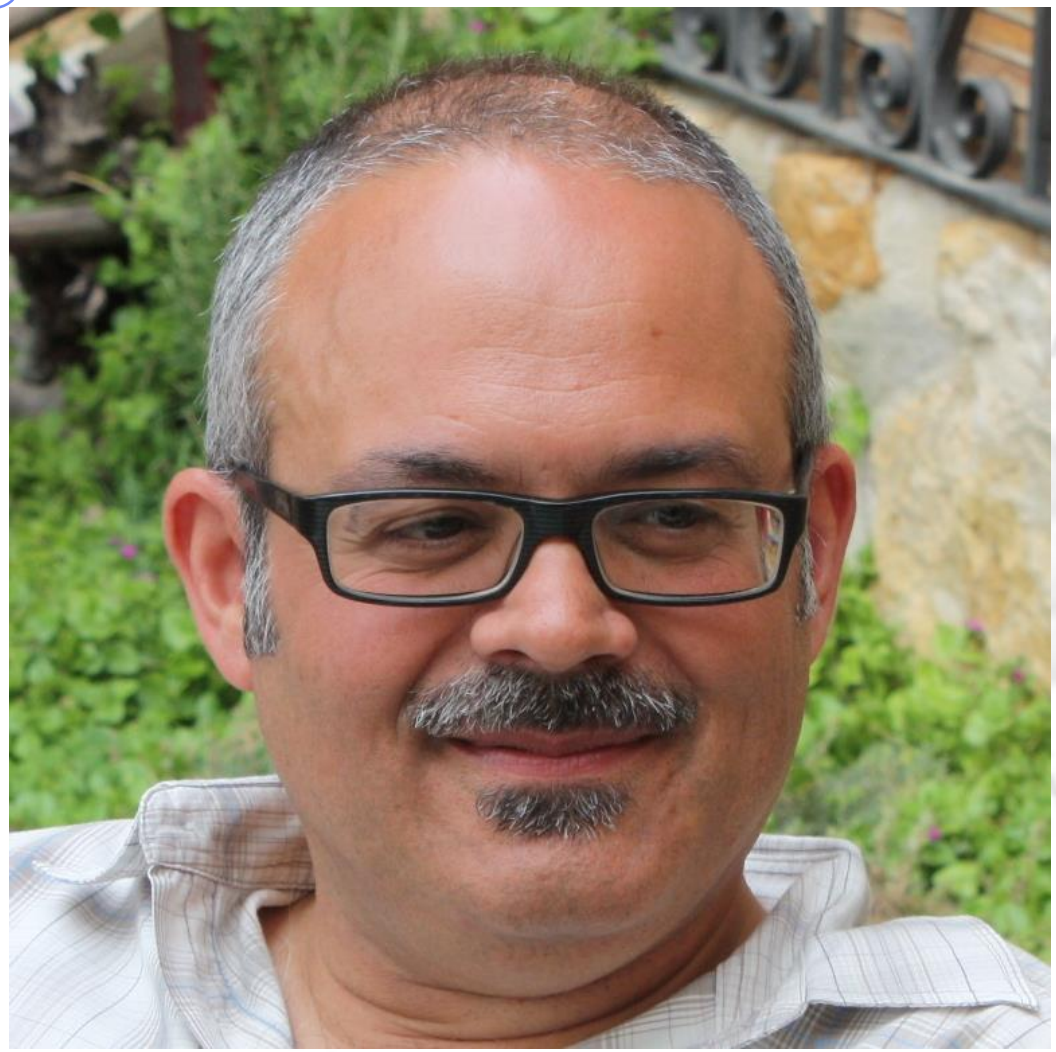
CERN, 1998-now:

- FLUKA (Collaboration coordinator and Project leader)
- CNGS and ICARUS (neutrino beams and physics)
- n_ToF (facility design and neutron cross sections experiments)
- CERN accelerator problems
- (FLUKA) Medical Applications (ENVISION, ENTERVISION, OMA…)

Eleftherios (Lefteris) Skordis (Fluka & Flair)

Eleftherios (Lefteris) has studied Applied physics in the N.T.U. Athens specialising in Nuclear and High Energy Physics. He has been a member of the FLUKA section at CERN since 2012 performing a substantial number of studies of different elements of the LHC accelerator complex. He is currently at the last year of his PhD studies (with the University of Liverpool) on the short and long term effects of radiation in and around the collimation system of the LHC.

Jose Maria Fernandez-Varea (Penelope)



Professor in the department of physics of the Universitat de Barcelona.

Coauthor of PENELOPE.

Active research in various topics in radiation physics, with expertise in:

- Theoretical modelling of the interaction of photons and charged particles with atoms and condensed matter
- Development of Monte Carlo algorithms.
- Application of Monte Carlo techniques to medical physics (radiotherapy and nuclear medicine).

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Lorenzo Brualla (Penelope applications)

UNIVERSITÄT DUISBURG ESSEN

Lorenzo Brualla is Privatdozent at the Faculty of Medicine of the University of Duisburg-Essen in Germany. He obtained his PhD in Physics at the Polytechnic University of Catalonia (Spain) in 2002. After his PhD he worked as post-doctoral researcher at the International School for Advanced Studies (SISSA) in Italy and the University of Barcelona in Spain. In 2012 he obtained his Habilitation as Privatdozent at the University of Duisburg-Essen in the area of experimental radiation oncology. His main lines of research are Monte Carlo simulation of radiation transport applied to radiotherapy and dosimetry problems, with emphasis on the small fields used for the treatment of ocular malignancies. He has also worked in the field of quantum Monte Carlo for the simulation of condensed matter. He is one of the authors of the Monte Carlo system PRIMO for the simulation of external beam radiotherapy treatments. He is the author of the penEasyLinac code for automatic generation of geometrical descriptions of medical linear accelerators. He is also author of several variance-reduction techniques

Francesc Salvat Pujol (Fluka & Penelope):

Joined the FLUKA development team in late 2016.

Previous experience:

- Time-of-flight coincidence measurements of correlated secondary electron emission from solids under keV electron bombardment.
- Modelling of sub-keV electron inelastic scattering in solids within the semi-classical dielectric formalism, with detailed account of bulk and surface energy losses, implemented in own MC code for quantitative analysis and interpretation of in-house coincidence measurements.
- Density functional theory calculations of electronic bandstructure of solids during postdoc at Goethe Universitaet Frankfurt, Germany.
- Application of low-energy electron transport models for applications in nanoscale metrology problems for the semiconductor industry during postdoc at NIST.

Currently at CERN in the FLUKA Development and Applications team:

- Modelling of direct nuclear reactions and nuclear elastic scattering on the basis of the DWBA.

Andrea Mairani (Fluka & Medical Applications)

Researcher at the Heidelberg Ion Beam Therapy Center (HIT), Staff at the Italian National Center for Oncological Hadron Therapy (CNAO). Responsible of the MC simulation at CNAO.

Clinical Activity

Monte Carlo (MC) simulations for the support of the clinical activity at CNAO, HIT and at the Marburg Ion Beam Therapy Center (MIT): database generation, plan verification in water and treatment plan comparisons. Dosimetric benchmark of the performed MC simulations. CNAO only: Quality assurance and daily experimental medical physicist activity. Commissioning of TPS. Establishment of a novel MC-based tool for eye treatment with proton pencil beam scanning technique

Research and Developments

Development and benchmarks against dosimetric and in vitro biological data of a novel MC-based treatment planning system (TPS) for all the beam modalities available at CNAO and HIT: proton, He-, C- and O- ion beams. Experimental activity and the biological modeling in collaboration with the Translational Radiation Oncology (E210) unit at the German Cancer Research Center. Collaboration with Siemens for the support and the development of TPS.

Supervision of Master students and PhD students

Research and developments in external projects

Development of MC-based tool and biological models for internal dosimetry and improvements of nuclear reaction models.

Andrei Gheata (GeantV):

Andrei holds a degree in nuclear physics from the University of Bucharest, and a PhD in particle physics. Early 2000s, he started working in HEP simulation, developing interfaces to several particle transport packages (including FLUKA) within the Virtual Monte Carlo project. Andrei has made several contributions to the ROOT project, mainly related to the geometry package, and he is the author of many software components used in production by the ALICE experiment, notably the data analysis framework. Since April 2015, he has been working as software developer in the SFT group from CERN. Andrei contributed to the conceptual design and is one of the main developers within the GeantV project, which is aiming to modernize detector simulation software

Sofia Vallecorsa (GeantV):

PhD in High Energy Physics. Extensive experience as software developer in the field of High Energy Physics with significant expertise through the full chain of data analysis and simulation workloads. Scientific Associate at CERN, she works on the application of Machine Learning techniques to particle physics simulation and code optimisation in terms of scalability on modern architectures (many-cores, GPUs). Since 2016, she joined the Gangneung-Wonju University group in the CALICE experiment and she is a member of the AIDA-2020 Governing Board. In December 2013, she was granted the Marie-Heim Vogtlin fellowship from the Swiss National Fund to work on data analysis at the IceCube neutrino experiment at the South Pole. From 2007 to 2012, worked as a Research fellow at the Israel Institute of Technology, on software development for the ATLAS experiment at CERN. Invited speaker to several conferences and workshops.

Enjoy the school !