

PHITS

Particle and Heavy Ion Transport code System

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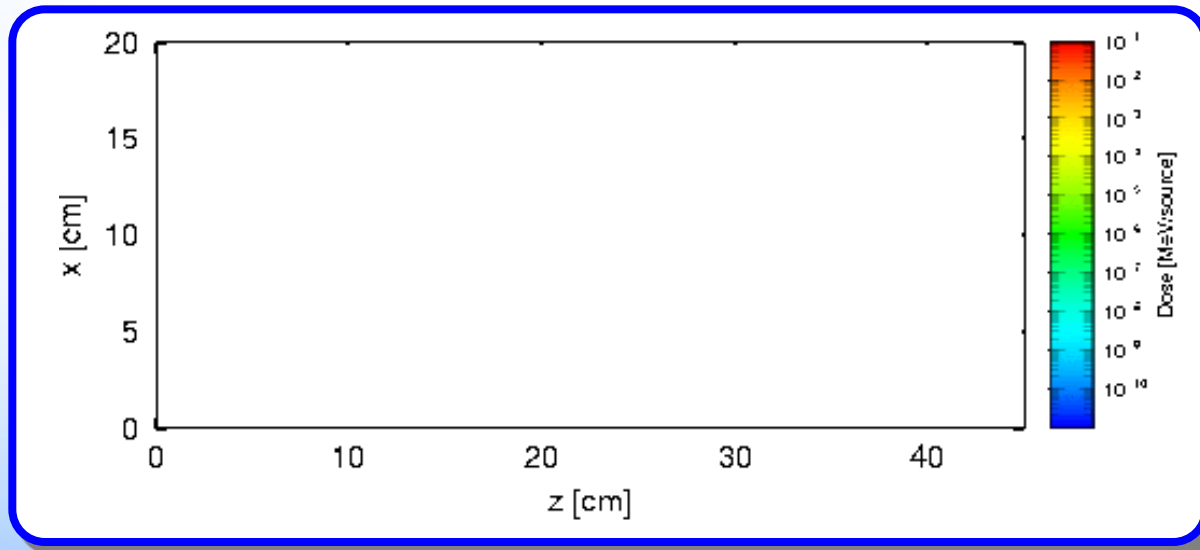


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1. **General Features of PHITS**
2. Nuclear Data in PHITS
3. Summary

What is PHITS?

Particle and Heavy Ion Transport code System

Capability

Transport and collision of all particles over wide energy range

in 3D phase space
with magnetic field & gravity

neutron, proton, meson, baryon
electron, photon, heavy ions

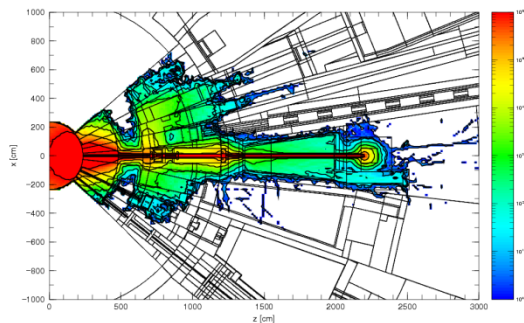
10^{-4} eV to 100 GeV/u

All-in-one-Package

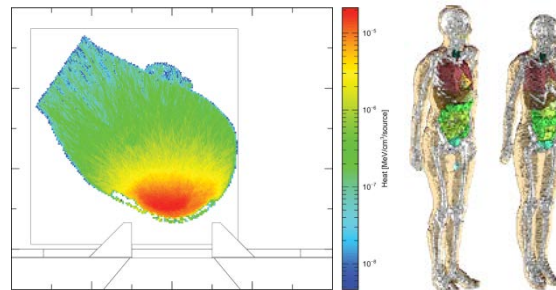
All contents of PHITS (source files, binary, data libraries, graphic utility etc.) are fully integrated in one package

OECD/NEA Databank, RSICC (USA, Canada) and RIST (Japan)

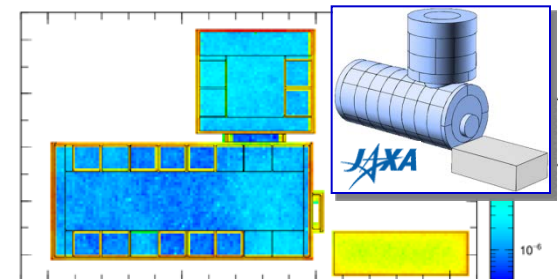
Applications



Accelerator Design

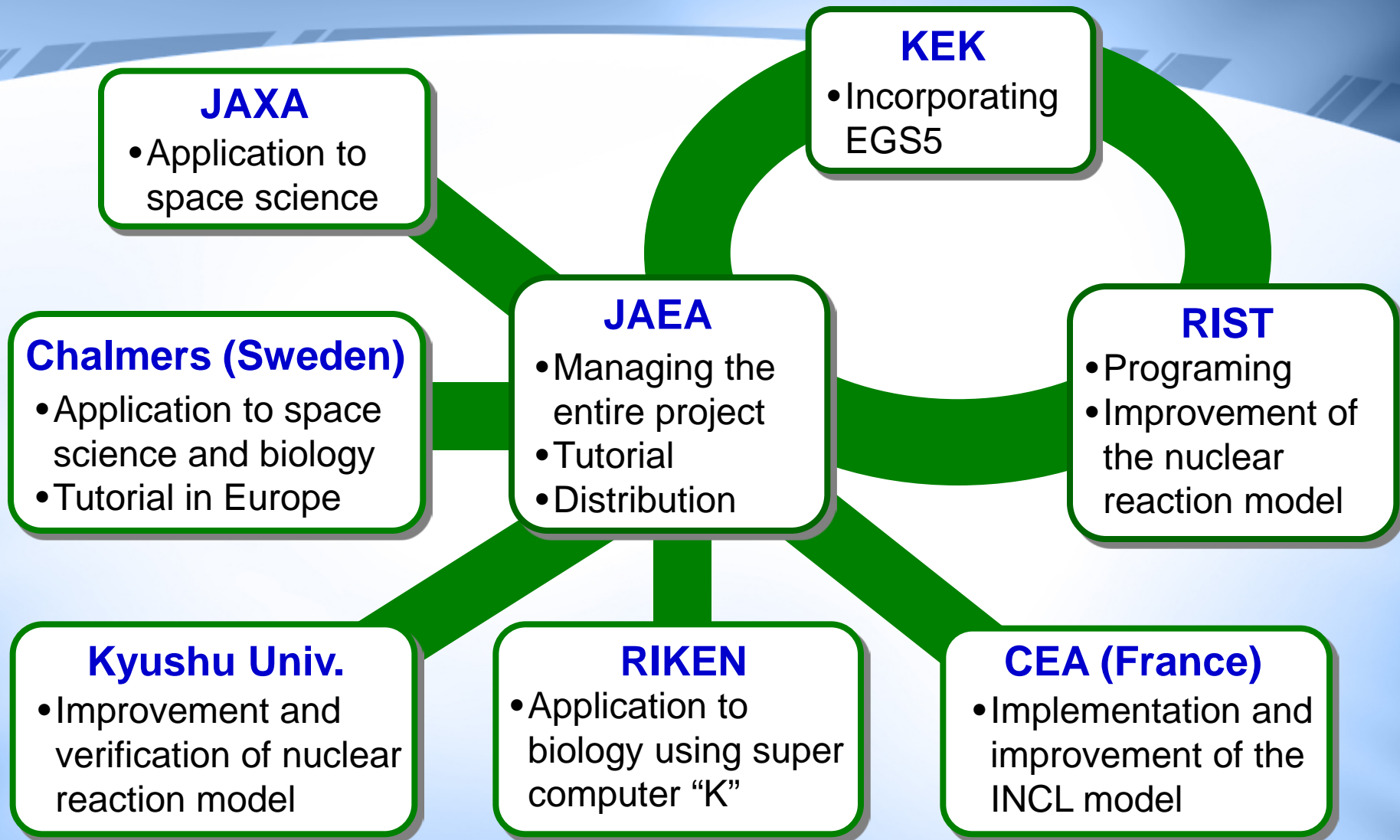


Radiation Therapy & Protection



Cosmic-ray Research

PHITS Developing Team



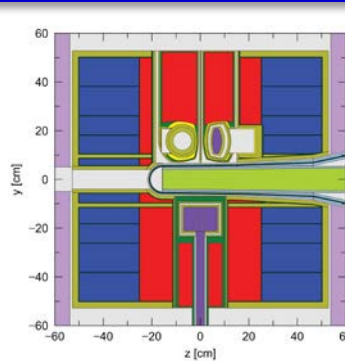
More than 1,200 researchers in various countries are registered as PHITS user

User Interfaces of PHITS

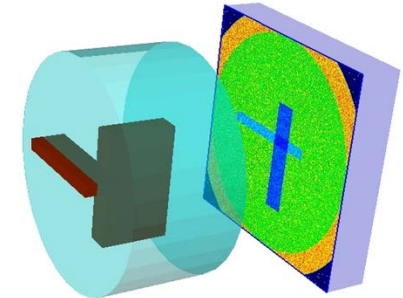
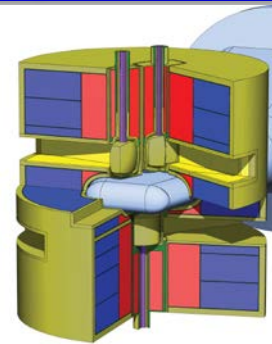
- Source code: Fortran (Intel Fortran 11.1, Gfortran 4.71 or later)
- Input file: Free-format text

You do not have to write Fortran program nor compile PHITS

- Geometry
 - GG format
 - Graphic Utility: (ANGEL)
 - SimpleGEO*



Geometry drawn by ANGEL



SimpleGEO

- Tally functions

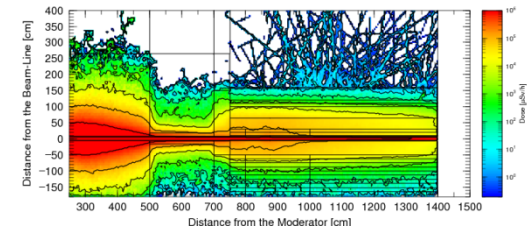
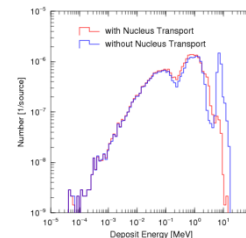
Track length, Flux, Heat, Yield, DPA, Production, LET distribution etc.

- Output Data

Text data, histograms, contour maps

- Platforms

Windows, Mac and Linux (MPI & OpenMP parallelization available)



* GUI-based software originally for FLUKA, <http://theis.web.cern.ch/theis/simplegeo/>

Map of Models used in PHITS

	Neutron	Proton, Pion (other hadrons)	Nucleus	Muon	Electron /Positron	Photon
High ↑ Energy ↓ Low	200 GeV Intra-nuclear cascade (JAM) + Evaporation 3.0 GeV (GEM)		100 GeV/n Quantum Molecular Dynamics (JQMD) + Evaporation (GEM)			100 GeV Atomic Data Library JENDL-4.0 / EPDL97
	20 MeV Intra-nuclear cascade (INCL4.6) + Evaporation (GEM)		d t ³ He α 10 MeV/n		100 MeV Atomic Data Library (EEDL / ITS3.0 / EPDL97)	140 MeV Photo- Nuclear
	Nuclear Data Library (JENDL-4.0) 10 ⁻⁵ eV	1 MeV 1 keV		Ionization SPAR or ATIMA	1 keV	1 keV

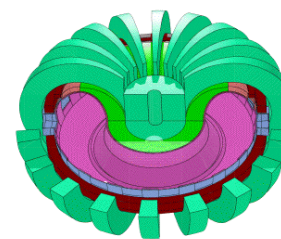
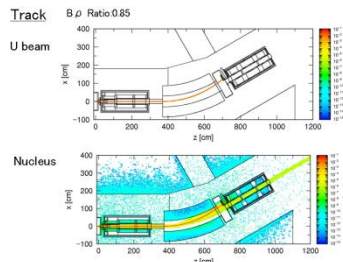
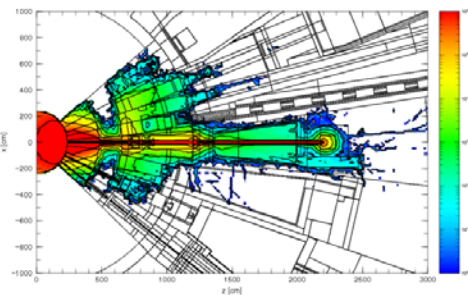
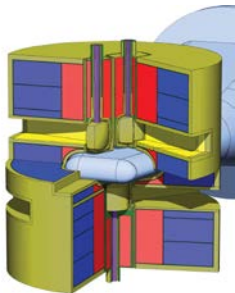
→ Event generator mode:

Specify all secondary charged particles produced from low-energy neutron interaction

Switching energies can be changed in input file of PHITS

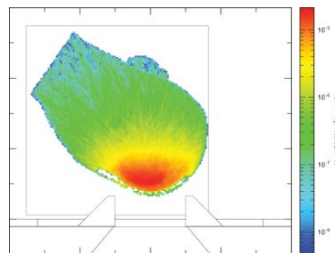
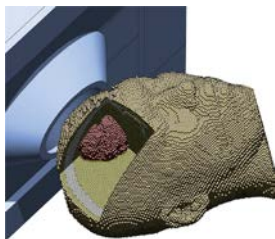
Applications of PHITS

Accelerator & Fusion Reactor Design



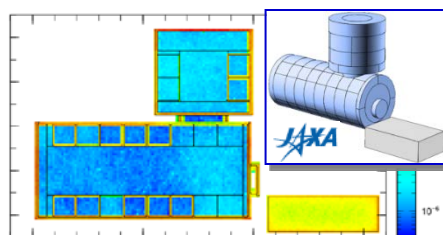
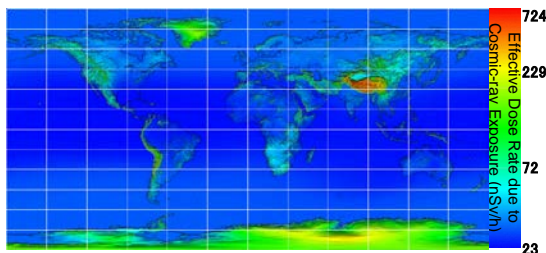
- J-PARC
- RIBF, FRIB
- New-HIMAC
- JT-60 etc.

Radiation Protection & Medical Physics



- Calculation of Dose Conversion Coefficients → ICRP116&123
- Dose estimation for radiation therapy & diagnostics

Cosmic-ray Research



- Aircrew & astronaut dose estimation
- Space & geoscience
- Cosmoclimate

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Nuclear Data Library

- **Nuclear data libraries** are necessary for simulating low-energy neutrons
- Cross sections of low-energy neutron significantly depend on shell structure

- PHITS Readable Format of nuclear data: **ACE format** (same as MCNP)
- Default Library included in PHITS: JENDL-4.0
- Optional Libraries: ENDF, LA150, JENDL-HE file

Generated by NJOY

Default procedure for simulating nuclear reaction using nuclear data library

1. Determine collision point based on total reaction cross section
2. Determine reaction channel, e.g. elastic, (n,n'), (n,2n), based on channel cross section
3. Determine energy and angle of the 1st outgoing particle from inclusive DDX
4. Iterate step 3 until all secondary particles are emitted

- Energy & Momentum are conserved **ONLY** in **AVERAGE!!**
- Information of residual nucleus cannot be determined!!

Not Event Generator Simulation

Event Generator Mode in PHITS

Nuclear Data Library

- Channel cross section
- Inclusive DDX of neutron

+

Special Evaporation Model

- Binary decay of recoiled nucleus
- Neutron decay width Γ_n is adjusted

Neutron
reaction
channel

(n,n')
(n,Nn')
capture
elastic

Energy and
angle of one
neutron

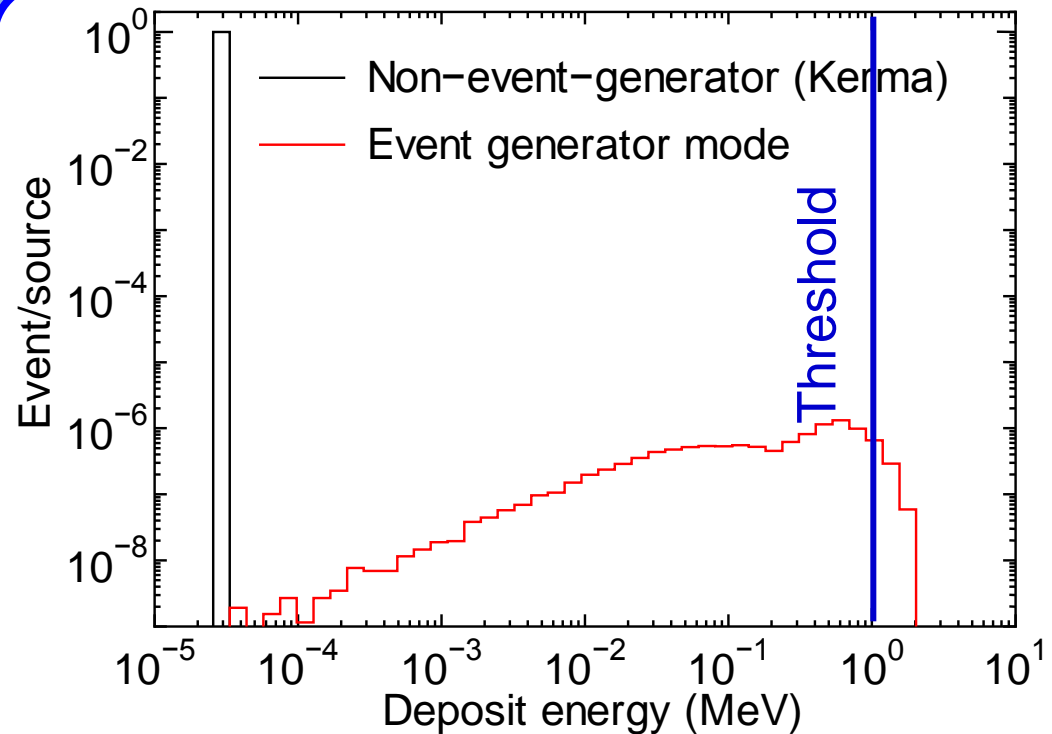
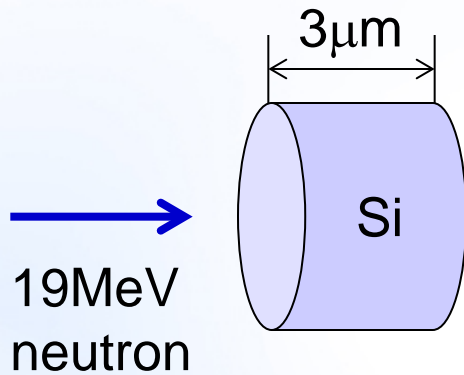
Final state of the
reaction,
including
emitted charged
particles and
photons

$\Gamma_n = 0$
 $\Gamma_n \neq 0$
 $\rightarrow \Gamma_n = 0$
 $\Gamma_n = 0$
Kinematics

Using this mode, we can determine ...

- all ejectiles (neutrons, charged particles, recoil nucleus and photons) with keeping energy and momentum conservation in an event
- deposit energy without using local approximation (Kerma factor)

Example of Event Generator Mode



Deposition energy distribution in 3μm Si

Single Event Upset (SEU) of Semi-conductor Devices

- SEU occurs when deposition energy exceeds a certain threshold
- SEU probability = 0 from non-event generator simulation → **Critical mistake!**
- SEU probability = 10^{-6} /source from event generator simulation

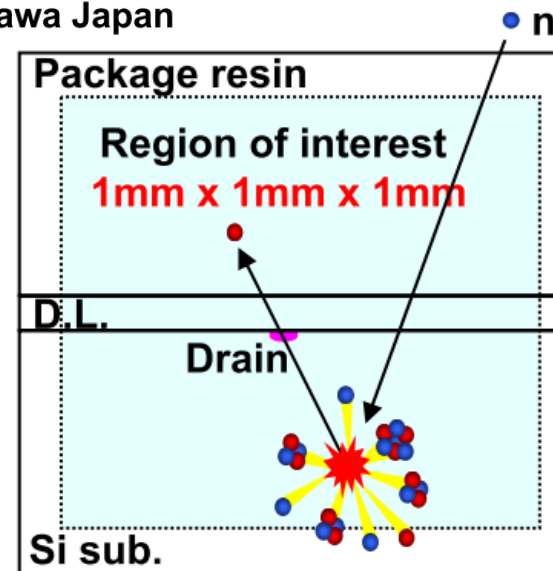
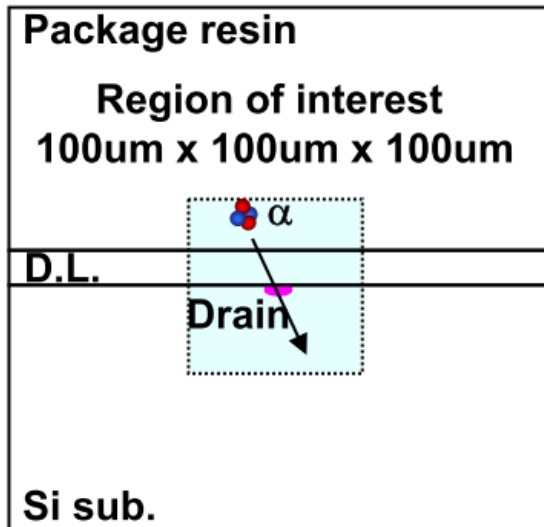
Practical Use of Event Generator Mode

2009 IRPS **SONY**

Alpha Particle and Neutron-induced Soft Error Rates and Scaling Trends in SRAM

Hajime Kobayashi, Nobutaka Kawamoto,
Jun Kase and Ken Shiraishi

Sony Corporation
Atsugi, Kanagawa Japan



D.L. : Dielectric (metallization) Layer

PHITS was used for the simulation of nuclear reactions.

New Event Generator Mode

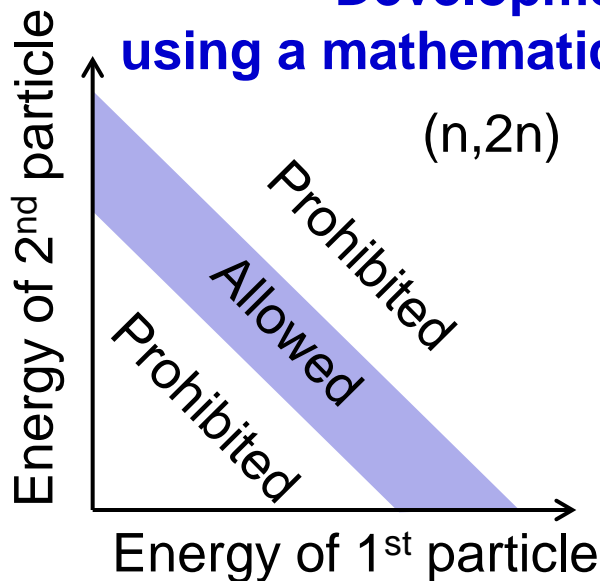
Problems in current event generator mode

- It cannot be used in combination with high-energy nuclear data library
- Energy spectra of secondary particles are not exactly the same as those in nuclear data library, due to the limitation of evaporation model



Development of a new event generator mode

using a mathematical model instead of the evaporation model



1. Determine energy spaces allowed by the energy conservation rule
2. Calculate the reaction probability for each energy space based on channel DDX
3. Based on the probability, determine the energies of 2 outgoing particles at once, using Monte Carlo method

DDX data for each channel are indispensable in this calculation!

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Summary

- ✓ PHITS is a general-purpose Monte Carlo particle transport simulation code used for various applications by **more than 1,200** researchers in many countries
- ✓ PHITS can transport nearly all particles over wide energy range
- ✓ Low energy neutrons are transported using **JENDL-4.0 in ACE format**
 - Change of ENDF format is not directly related to PHITS
- ✓ DDX data for each reaction channel are required in the new event generator mode
 - Important specially for **high-energy nuclear data library**

For more information on PHITS, please visit our website

<http://phits.jaea.go.jp>