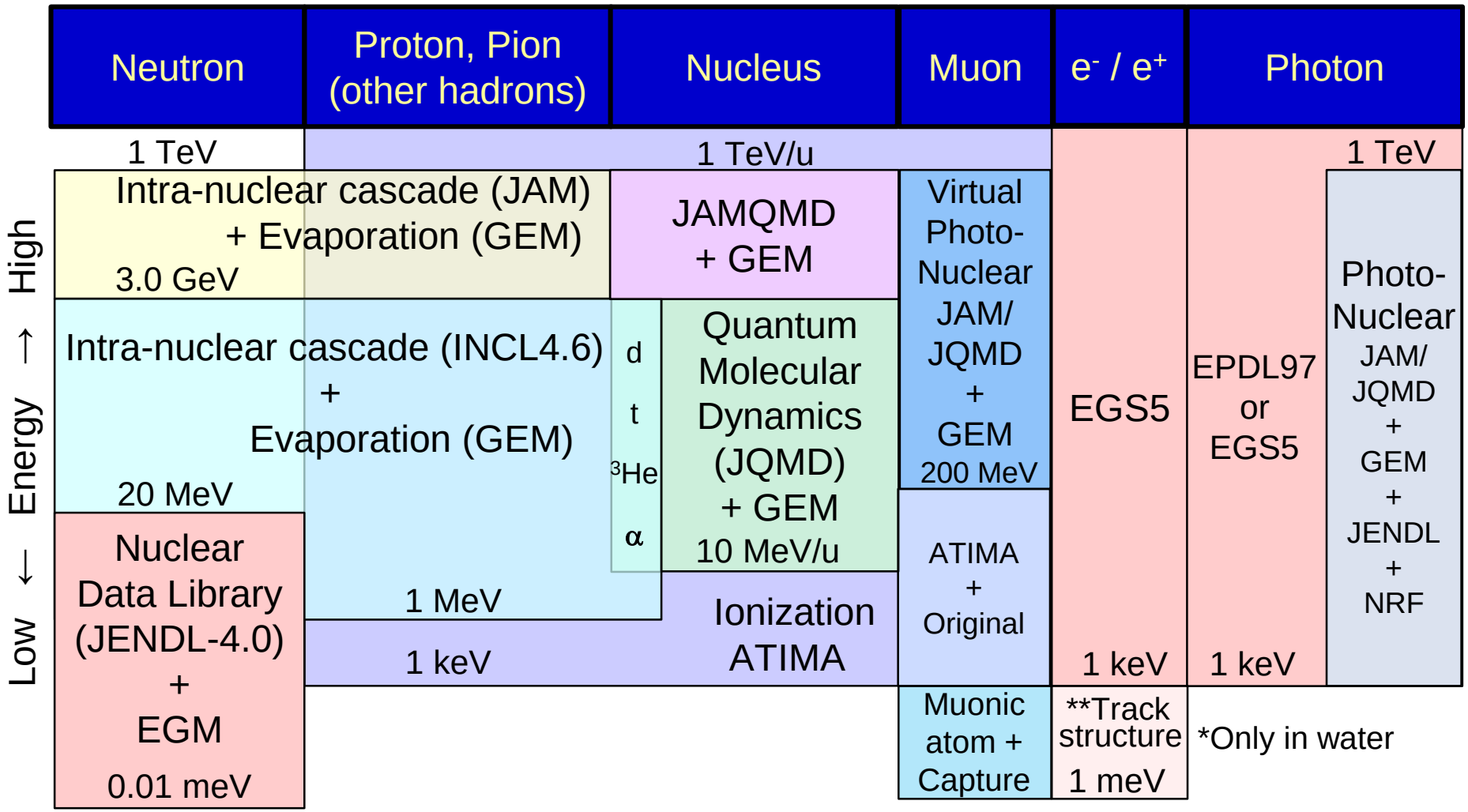
Features of PHITS3.10

PHITS development team, Mar. 2019

Map of Models Recommended to Use in PHITS



Neutrino with energy below 20 MeV can cause interaction with ^{1}H, ^{2}H, and electron, though it is not written in this map

Major Upgraded Features in v3.08

PHITS 3.08 was distributed only through PHITS tutorial

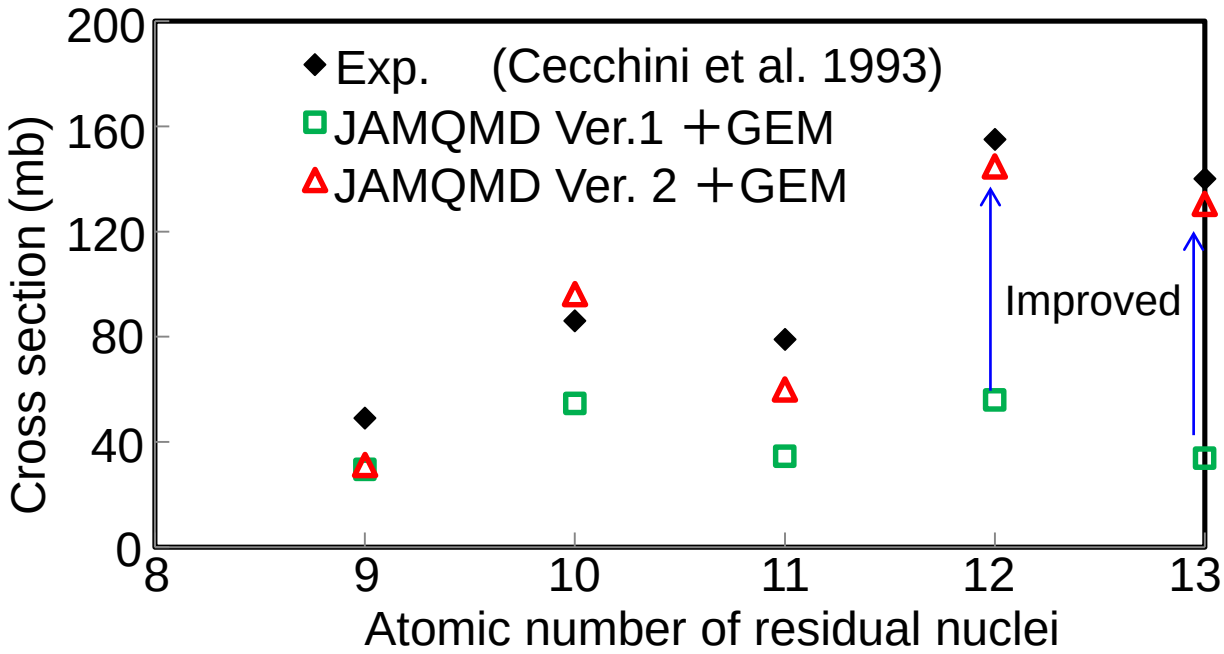
Upgraded Points from v3.02

- ✓ JAMQMD2 is developed for high-energy nucleus-nucleus interaction
- ✓ Neutrino interaction model is developed & implemented
- ✓ [weight window] & [t-wwg] become applicable to xyz-mesh
- ✓ Emission of Auger electrons, internal conversion electrons, & characteristic X-rays can be considered in the RI source function
- ✓ Several types of dose conversion coefficients are implemented
- ✓ Source generation function in tetrahedral mesh is developed
- ✓ Tetrahedral geometry created by CAD become readable in PHITS
- ✓ Neutron and γ-ray emissions are considered at once in GEM
- ✓ Detector response can be calculated even when [forced collisions] is used
- ✓ Probability density of the number of interactions per history can be calculated using [t-interact] (former [t-star])
- ✓ Several activation cross section data libraries used for [t-yield] and [t-dchain] are implemented
- ✓ [t-heat] is merged into [t-deposit]
- ✓ PHITS executable file in MPI version for Windows is implemented

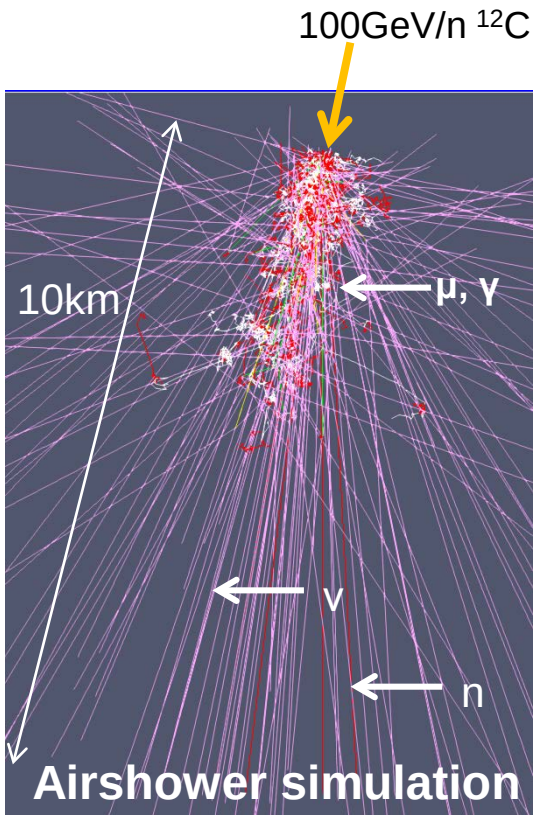
Development of JAMQMD version 2

Nucleus-nucleus interaction model for 3 GeV/n ~ 1 TeV/n

Useful for cosmic-ray and high-energy physics simulations



Cross section of 14.6AGeV ^{28}Si(^{27}Al,x)

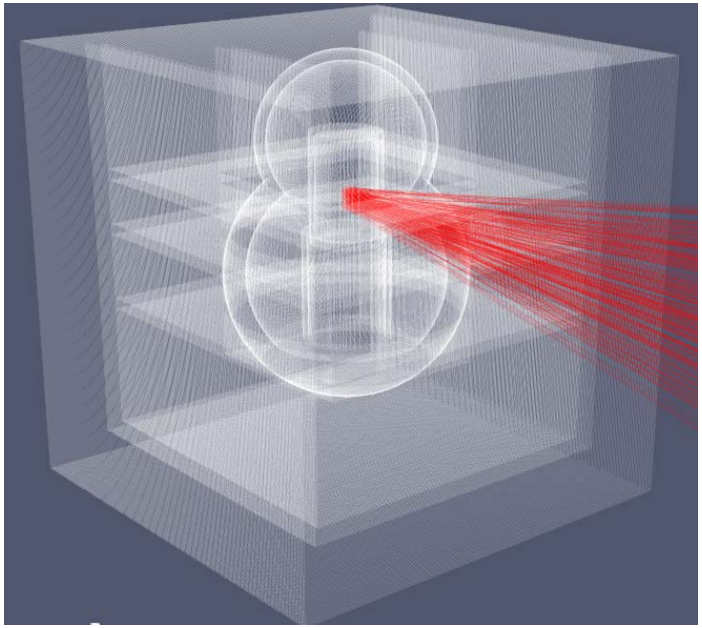


- ✓ Improve the accuracy of fragment yields
- ✓ Automatically used for nucleus-nucleus interaction above 3GeV/n

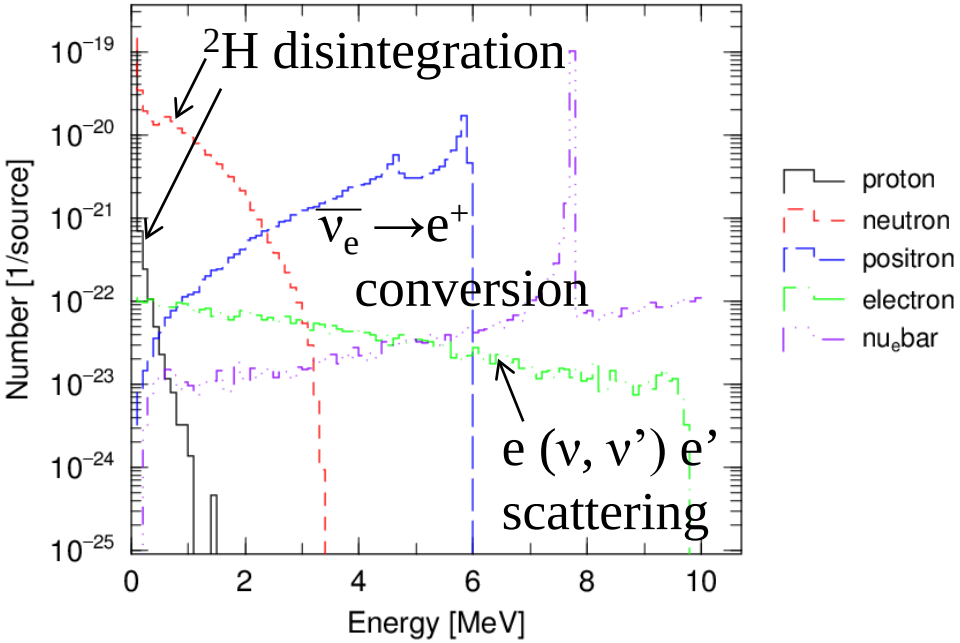
*T.Ogawa *et al.*, *Phys. Rev. C.*, **98,** 024611 (2018)

Development of Neutrino Interaction Model

***Applicable to neutrino interaction with ^{1}H, ^{2}H or e^{-}**



Neutrino can penetrate nuclear reactor



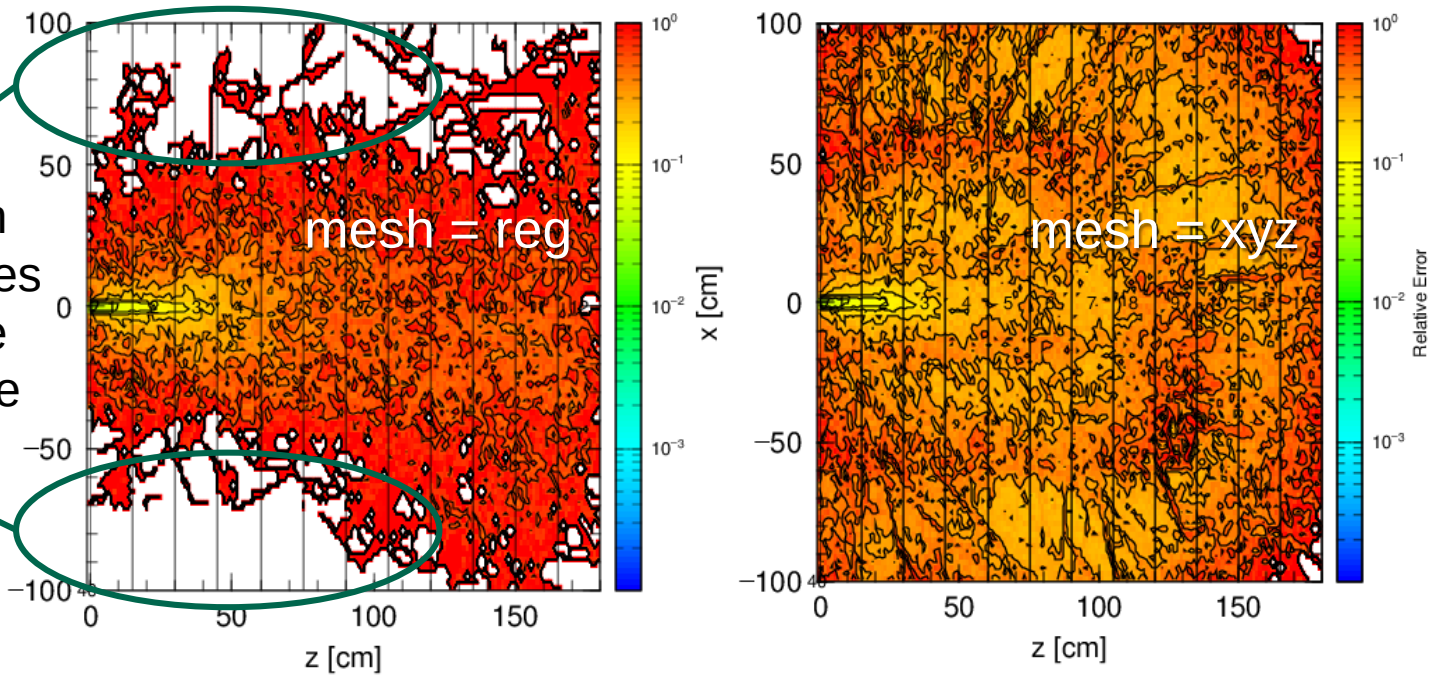
Energy distribution of secondary particles produced by $^{2}H(\bar{\nu}_e,X)$

- ✓ Consider only when ntrnore is set to 1 (D=0) in [parameter]
- ✓ Recommend to use this option in combination with [Forced Collisions]
- ✓ Interaction with heavier target & neutrino oscillation are under consideration

*Some functions are available only after version 3.10

xyz-mesh for [weight window] & [t-wwg]

Few particles can reach lateral edges because cells are divided only to the vertical direction



Statistical uncertainties of [t-track] obtained using [t-wwg] with reg (left) and xyz (right) meshes. Cells are divided only to the vertical direction.

(see lecture/advanced/weight in more detail)

You do not have to divide a cell into many pieces for defining different weight windows

Major Upgraded Features in v3.10

PHITS 3.10 is distributed since April 2019

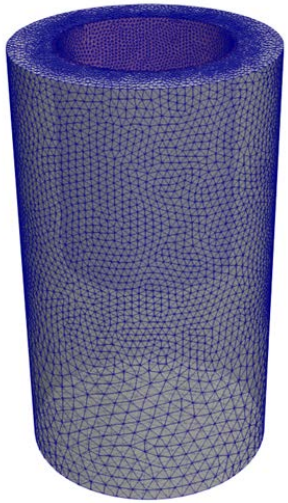
Upgraded Points from v3.08

- ✓ Procedure for coupling PHITS with thermal analysis software such as ANSYS Fluent is established
- ✓ Sample files for using JENDL-4.0/HE are provided
- ✓ Function to read magnetic field maps written in xyz or r-z grid is developed
- ✓ [t-dchain] has become applicable to xyz-mesh
- ✓ Error and warning ID numbers are introduced for some messages
- ✓ Accuracy of electron track-structure mode is improved
- ✓ Detector resolution in any form given by user-defined function can be considered
- ✓ INC-ELF, an intra-nuclear cascade model developed in Kyushu Univ., is improved
- ✓ A new gshow option is introduced to visualize tetrahedral and voxel geometries
- ✓ Time for reading lattice structure is reduced by introducing compressed format
- ✓ Function to calculate water-equivalent dose is implemented in [t-deposit]
- ✓ Remaining batch number has become adjustable using batch.out

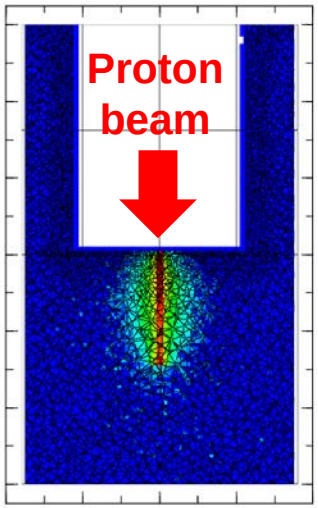
Coupling with thermal analysis

- ✓ Create geometry in thermal analysis code such as ANSYS Fluent
- ✓ Meshing to tetrahedral mesh => Output in NASTRAN bulk data format
- ✓ Import => PHITS radiation transport => Output in OpenFOAM field data
- ✓ Import => Thermal analysis by ANSYS Fluent

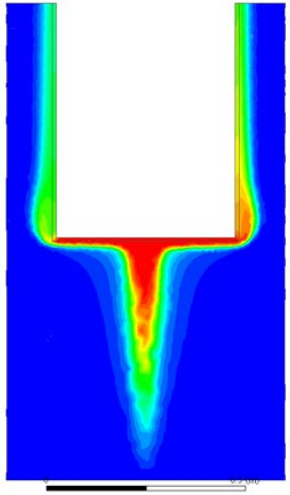
Fluent → PHITS → Fluent



NASTRAN bulk data format



OpenFOAM Field data format



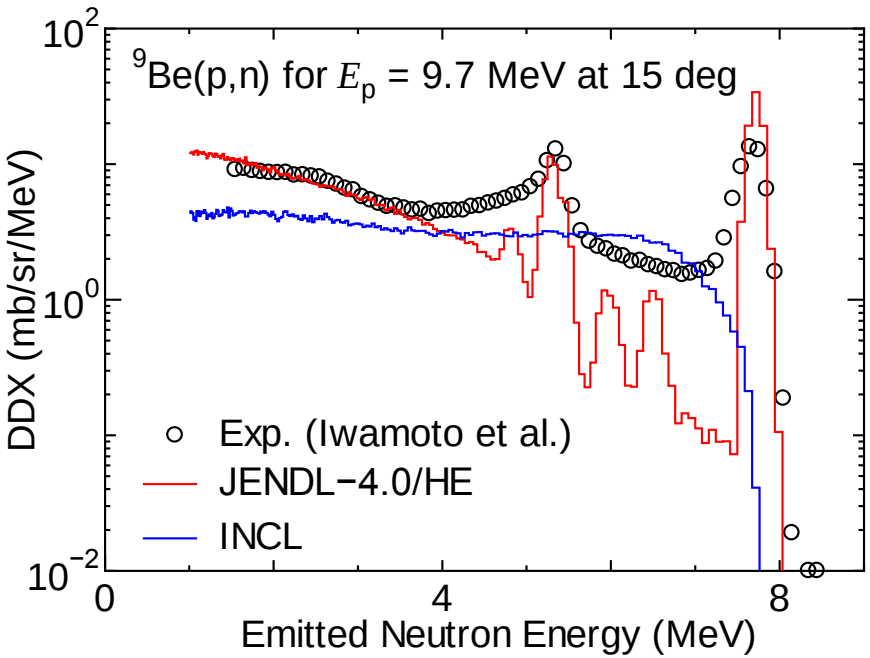
Tetra-mesh geom. | Deposition energy | Temperature

Read & write in general tetrahedral mesh geometry are possible and thus seamless coupling to other physics becomes possible

Sample files for using JENDL-4.0/HE

What is JENDL-4.0/HE?

- ✓ High-energy nuclear data library for neutrons and protons up to 200 MeV
- ✓ Precisely reproduce the DDX of nuclear reactions particularly for lighter targets
- ✓ Data for neutrons below 20 MeV are the same as JENDL-4.0



DDX of ^{9}Be(p,n) reaction calculated by PHITS using JENDL-4.0/HE or INCL

Important notice!

- ✓ Data for only several elements are included in the PHITS package. Data for other elements will be released via JAEA website in future
- ✓ Event generator mode cannot be used in combination with JENDL-4.0/HE
- ✓ Calculation of deposition energies is not feasible using either [t-deposit] nor [t-heat]

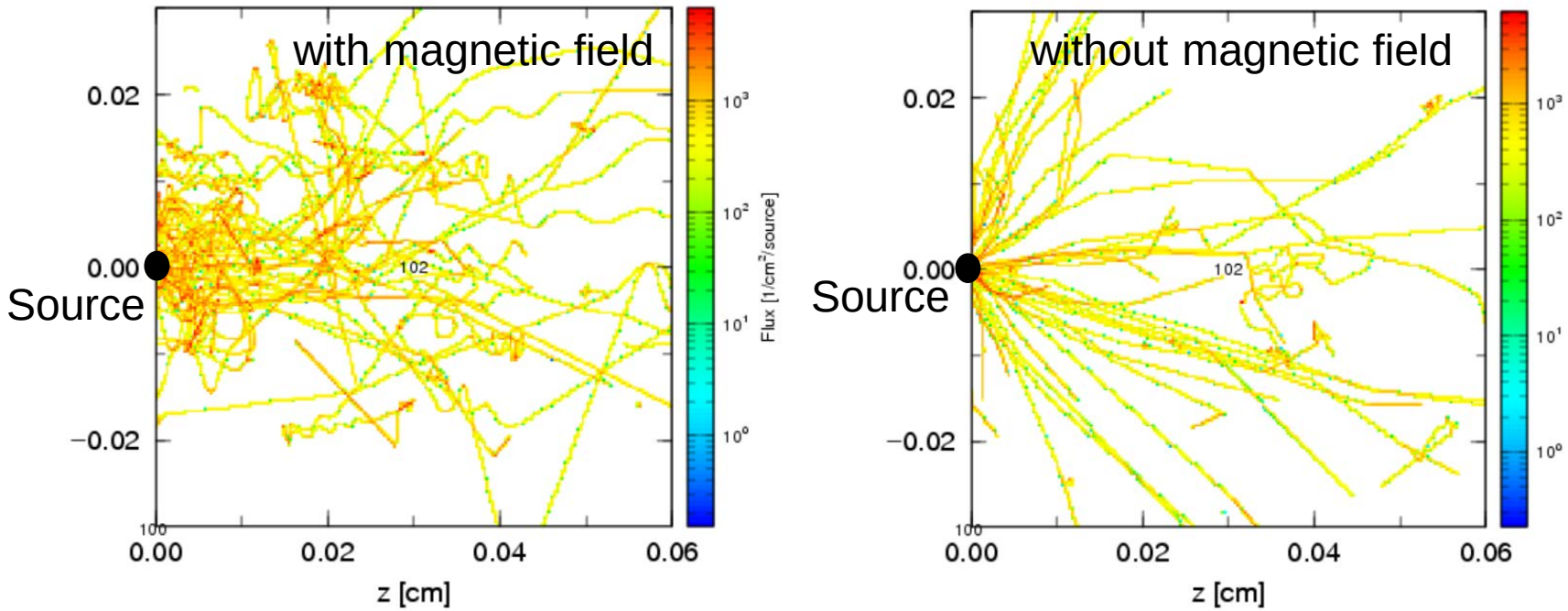
Applications are limited to e.g. shielding calculation and neutron source design

Please see phits/recommendation/jendlHE

S. Kunieda et al., JAEA-Conf 2016-004 (2016), https://wwwndc.jaea.go.jp/ftpnd/jendl/jendl40he.html

Function to Read Magnetic Field Map

- ✓ Both xyz and r-z grid fields can be read
- ✓ Both map- and list-type data can be read
- ✓ Applicable to symmetry and asymmetry fields to certain axes
- ✓ Particle motions are analyzed by Runge-Kutta method



Electron trajectories in metal target with (left) and without (right) magnetic field

Please see phits/utility/magmap in more detail

Magnetic field data are provided by Dr. Sakata @ Osaka Univ.