PHITS

Multi-Purpose Particle and Heavy Ion Transport code System

Contents

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Overview of PHITS (Particle and Heavy Ion Transport code System) :

1951		1983		1997		2001		2003
NMTC	→	NMTC/JAERI	→	NMTC/JAERI97	→	NMTC/JAM	→	PHITS
(ORNL)		High Energy Fission		CG geometry		JAM, GG Magnetic Field		JQMD, MCNP Gravity

PHITS = MCNP+JAM+JQMD

MCNP	Neutron, Photon, Electron Transport by Nuclear Data
JAM	Hadron-Nucleus Collisions up to 200 GeV
JQMD	Nucleus-Nucleus Collisions by Molecular Dynamics

External Field: Magnetic Field, Gravity
Optical and Mechanical devices

Language and Parallelism

- FORTRAN 77
- MPI

Transport Particle and Energy

Proton	0 ~ 200 GeV
Neutron	10^{-5} eV ~ 200 GeV
Meson	0 ~ 200 GeV
Barion	0 ~ 200 GeV
Nucleus	0 ~ 100 GeV/u
Photon	1 keV ~ 1 GeV
Electron	1 keV ~ 1 GeV

Geometry: CG and GG

Tally, Mesh and Graphic

- Tally: Track, Cross, Heat, Star, Time, DPA, Product, LET
- Mesh: cell, r-z, xyz
- Counter:
- Graphic: ANGEL (PS generator)

New Features of PHITS (Recent Developments, released by ver.2.00)

(1) Duct Source option
for Neutron Long Beam Line calculations

(2) Super Mirror function
for Neutron Optics: reflection on the wall

(3) Time Dependent Materials
for moving material, T0 chopper, …

(4) Time Dependent Magnetic Fields
Pulse Magnet for neutron optics,
Wobbler Magnet (AC magnet)

(5) Dumpall option
for re-calculation of whole process (history tape)

(6) Event Generator Mode
a full correlated transport for all particles and energies

(7) LET and LETDOSE tallies
dose and track length as a function of LET (dE/dx)

Event Generator Mode

We have developed a model which can describe all ejectiles of collisions with energy and momentum conservation for all energy region and for all particles and nuclei.
(for collisions of neutron based on nuclear data)

What can we do by this mode ?

(1) Deposit energy (heat) without local approximation (Kerma factor).

(2) Deposit energy distribution.

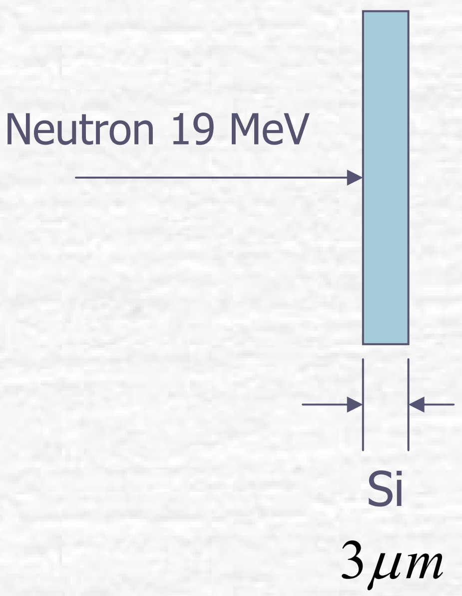
(3) DPA without evaluated Displacement cross section data.

(4) Any correlation, coincident experiments.

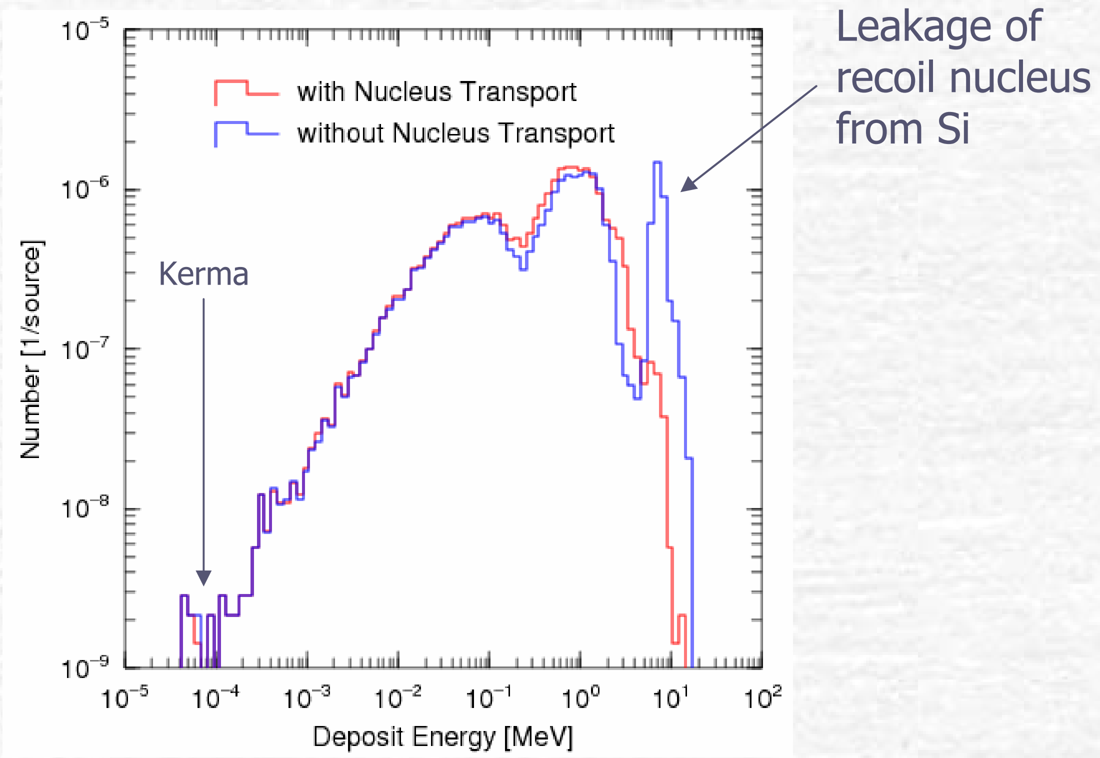
(5) Bridge to micro-dosimetry code.

*An example of **Event Generator Mode***

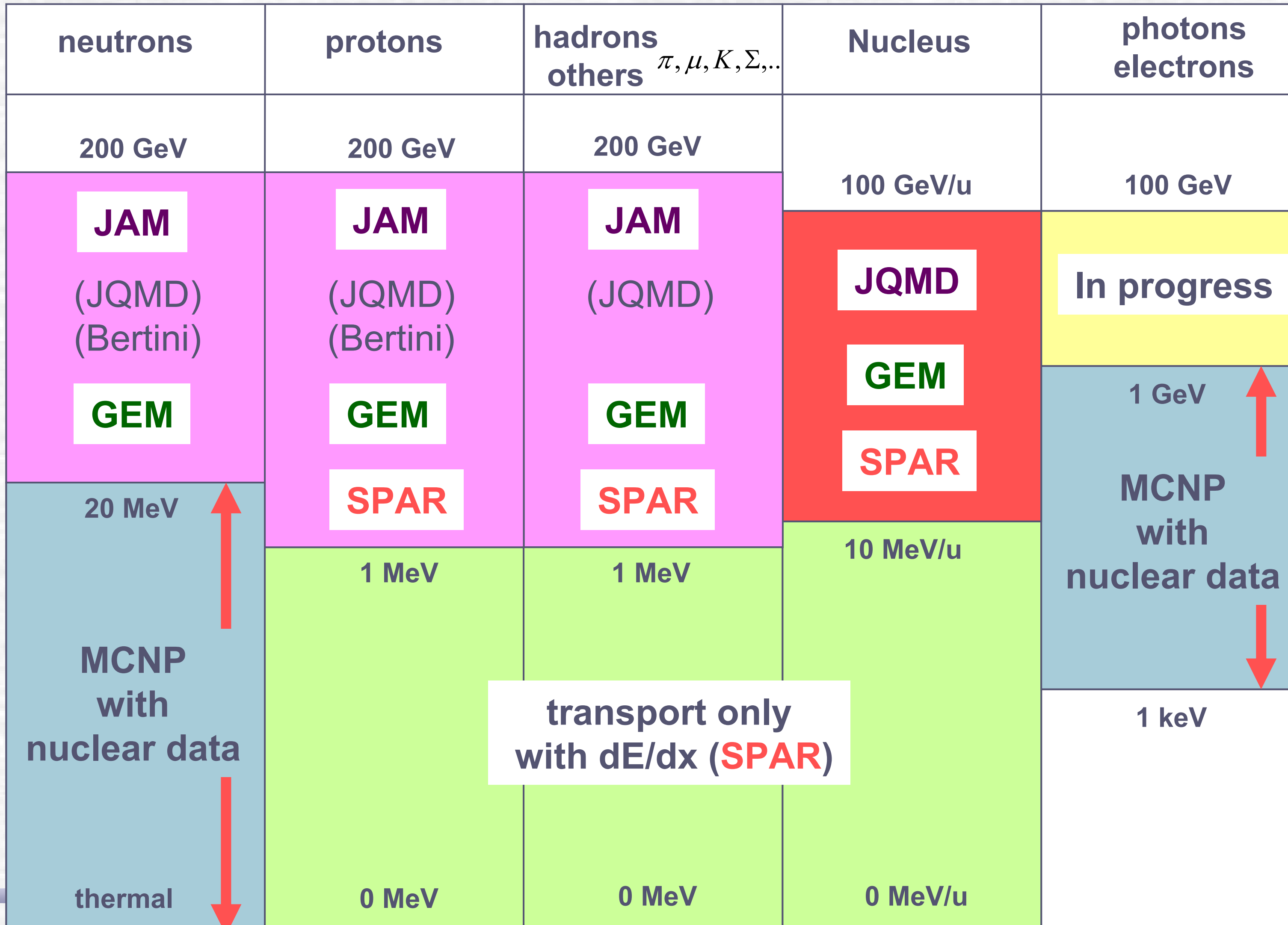
Neutron-induced semiconductor soft error



Deposit Energy Distribution by PHITS



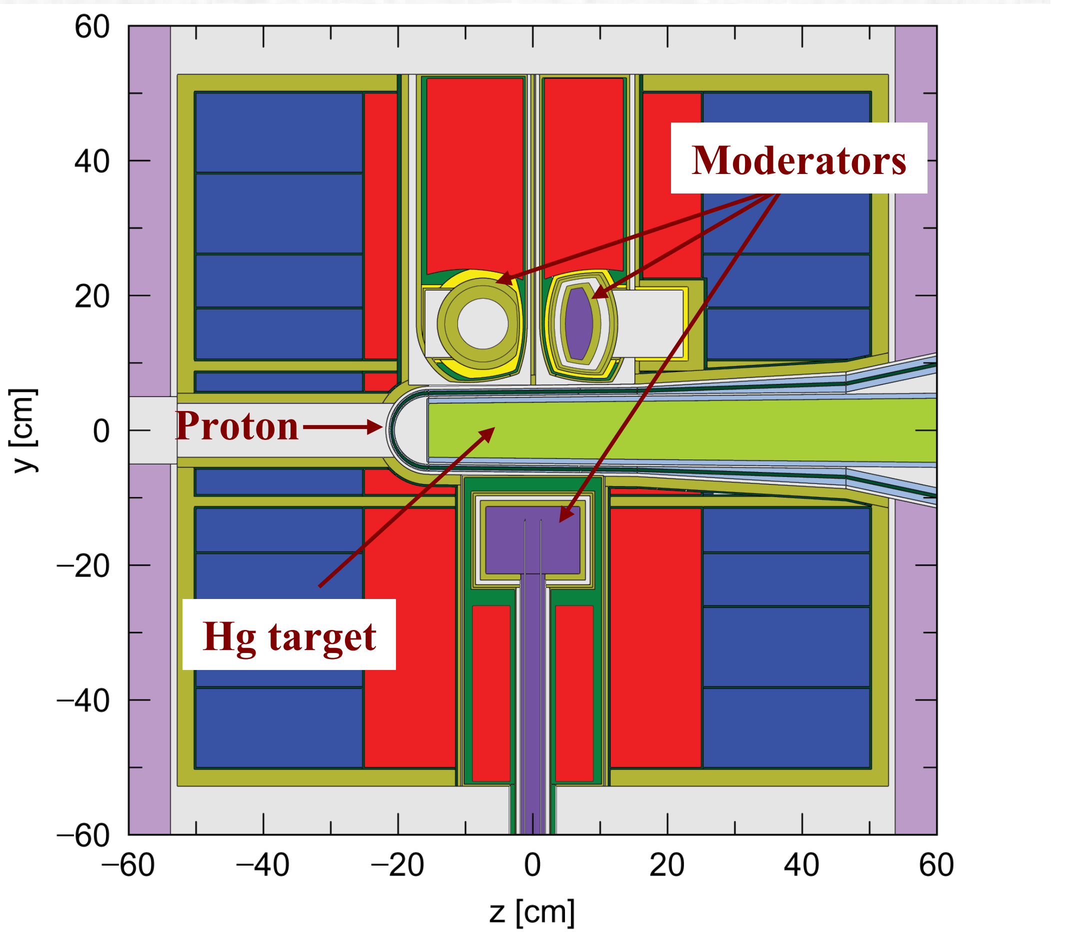
PHITS code Acceptance and Models

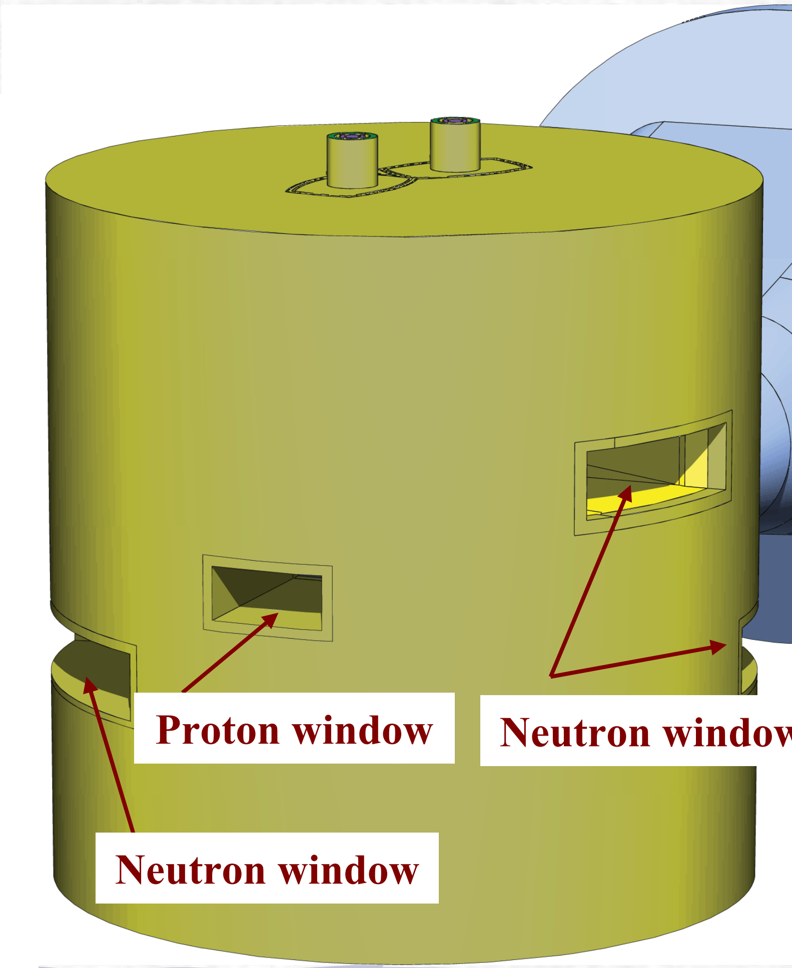


Map of PHITS

Heat estimation in PHITS

PHITS has been extensively used for
Optimization and Shielding design around Hg target of J-PARC





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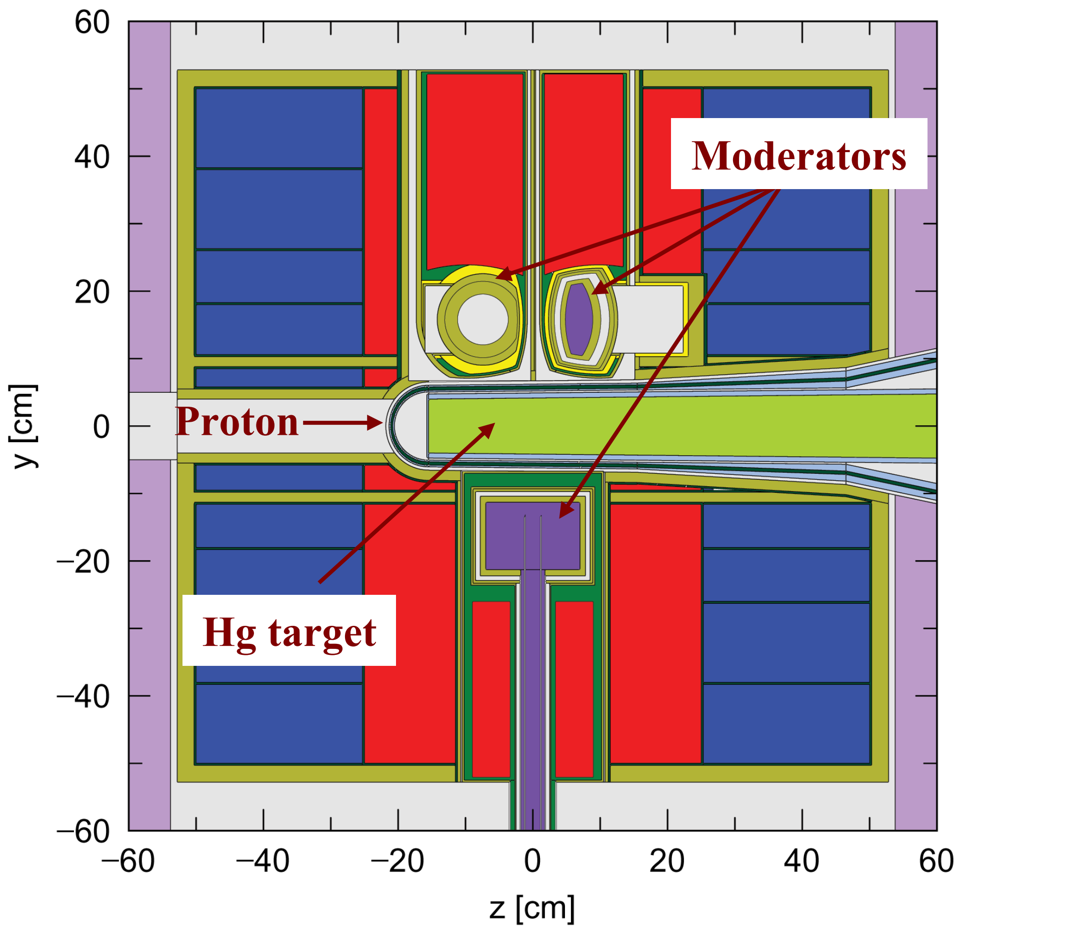

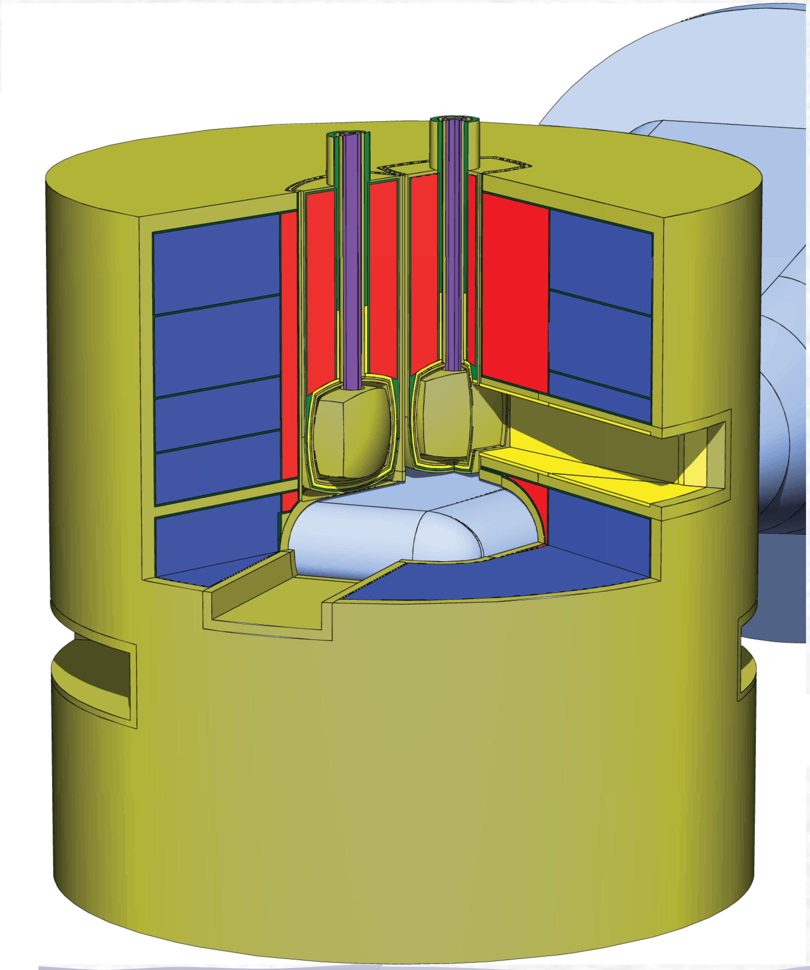

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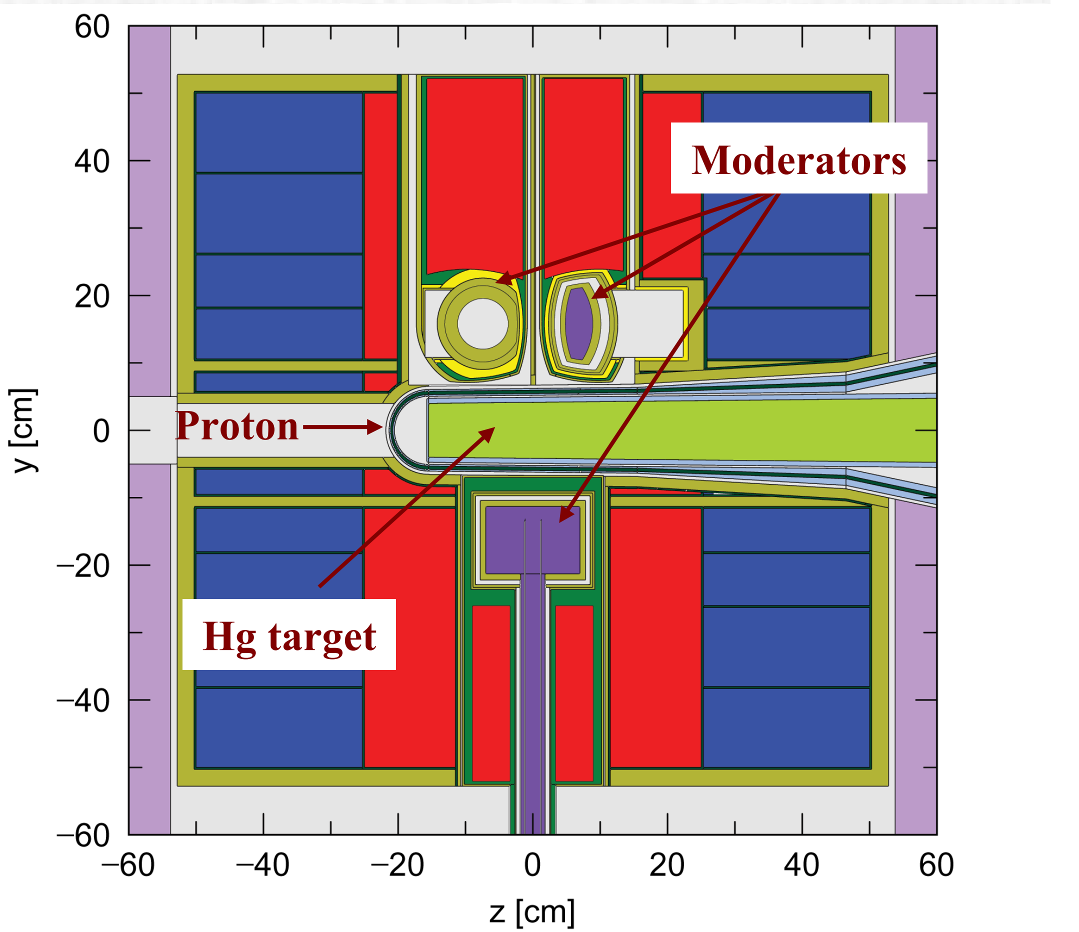

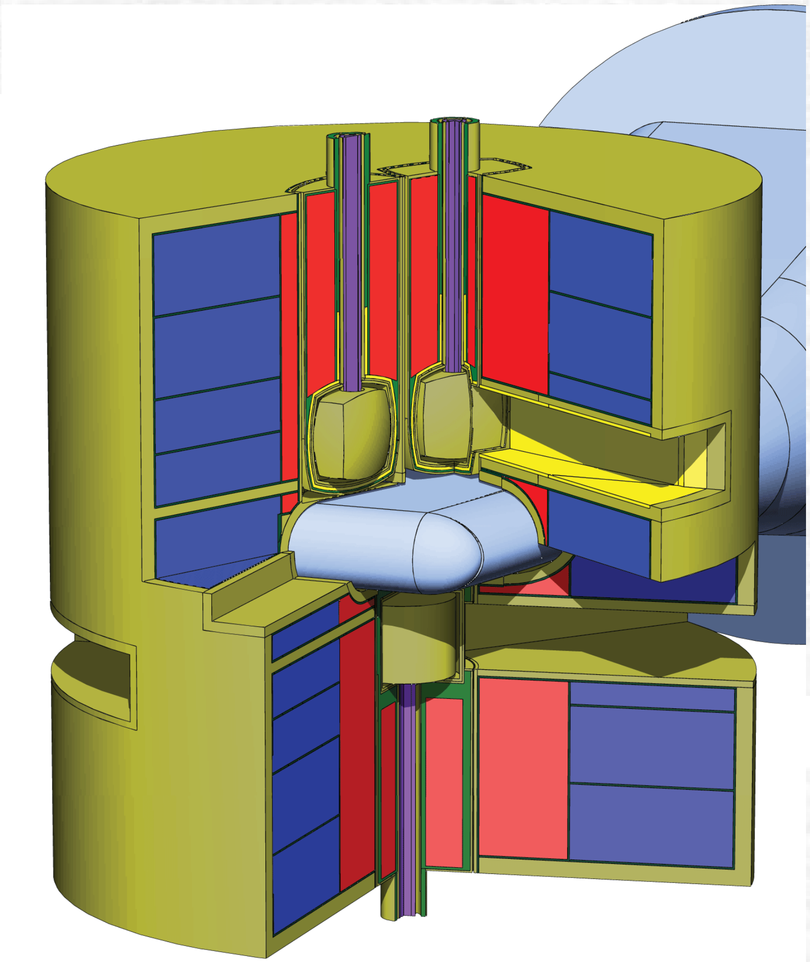

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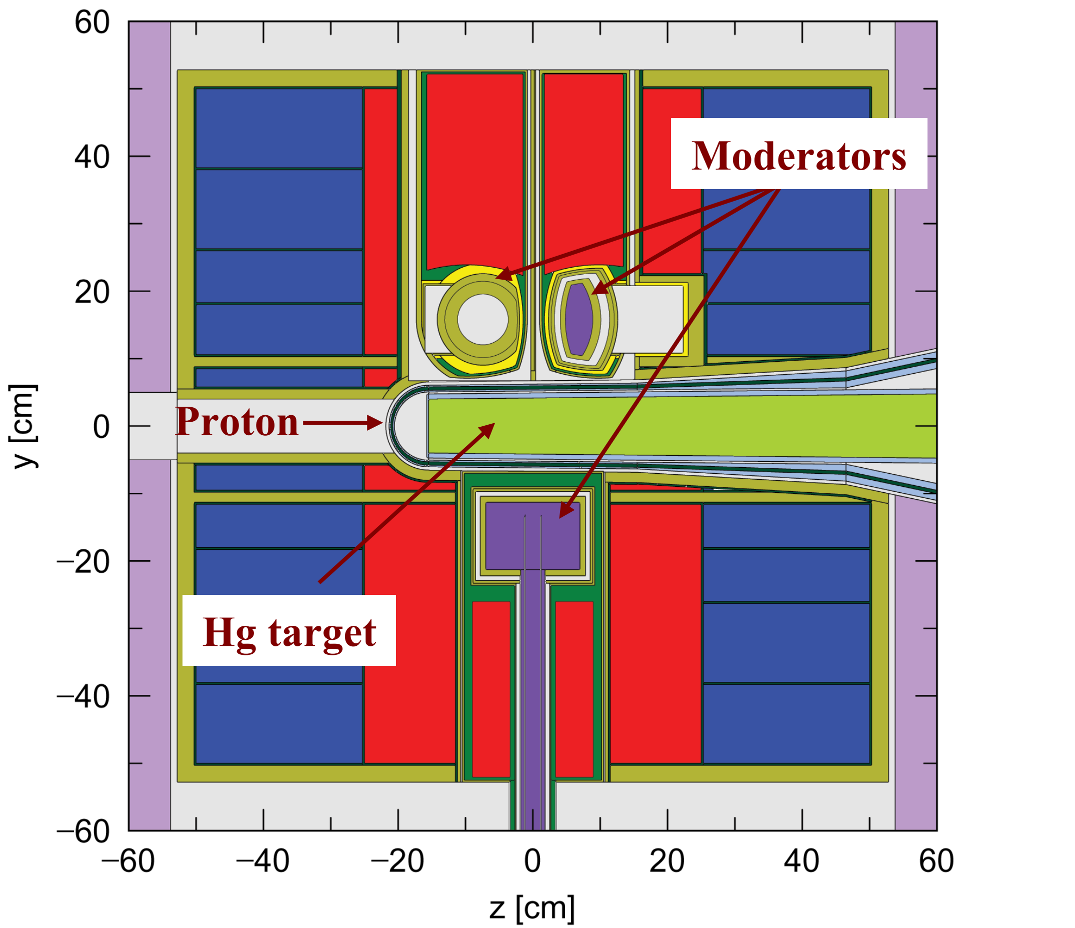

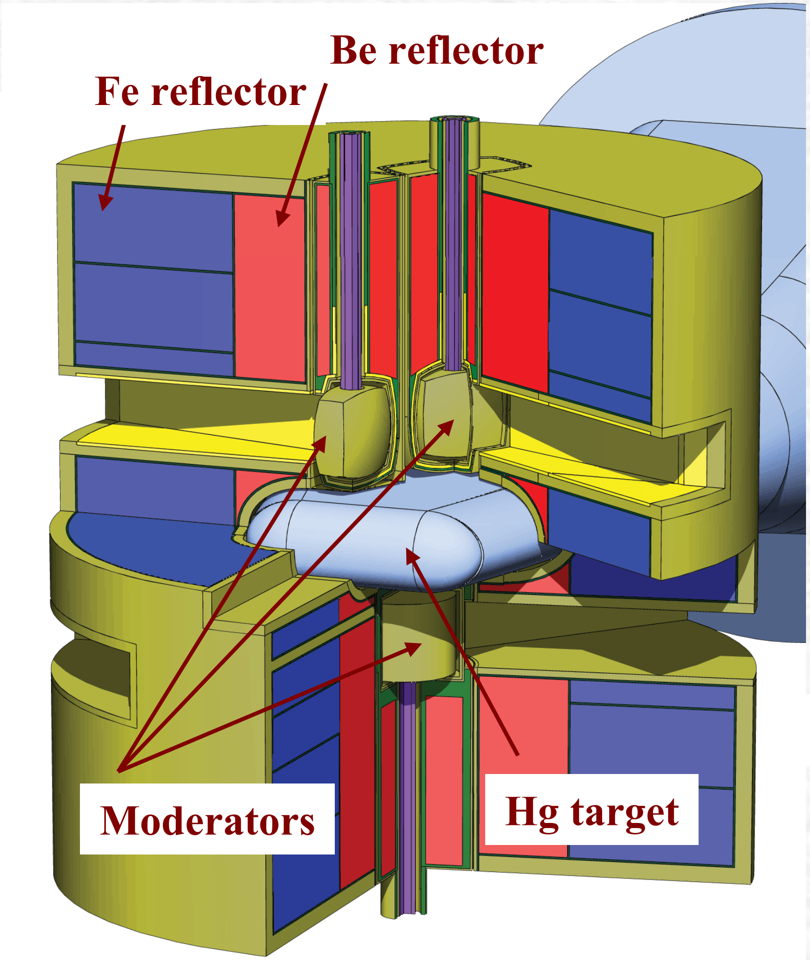

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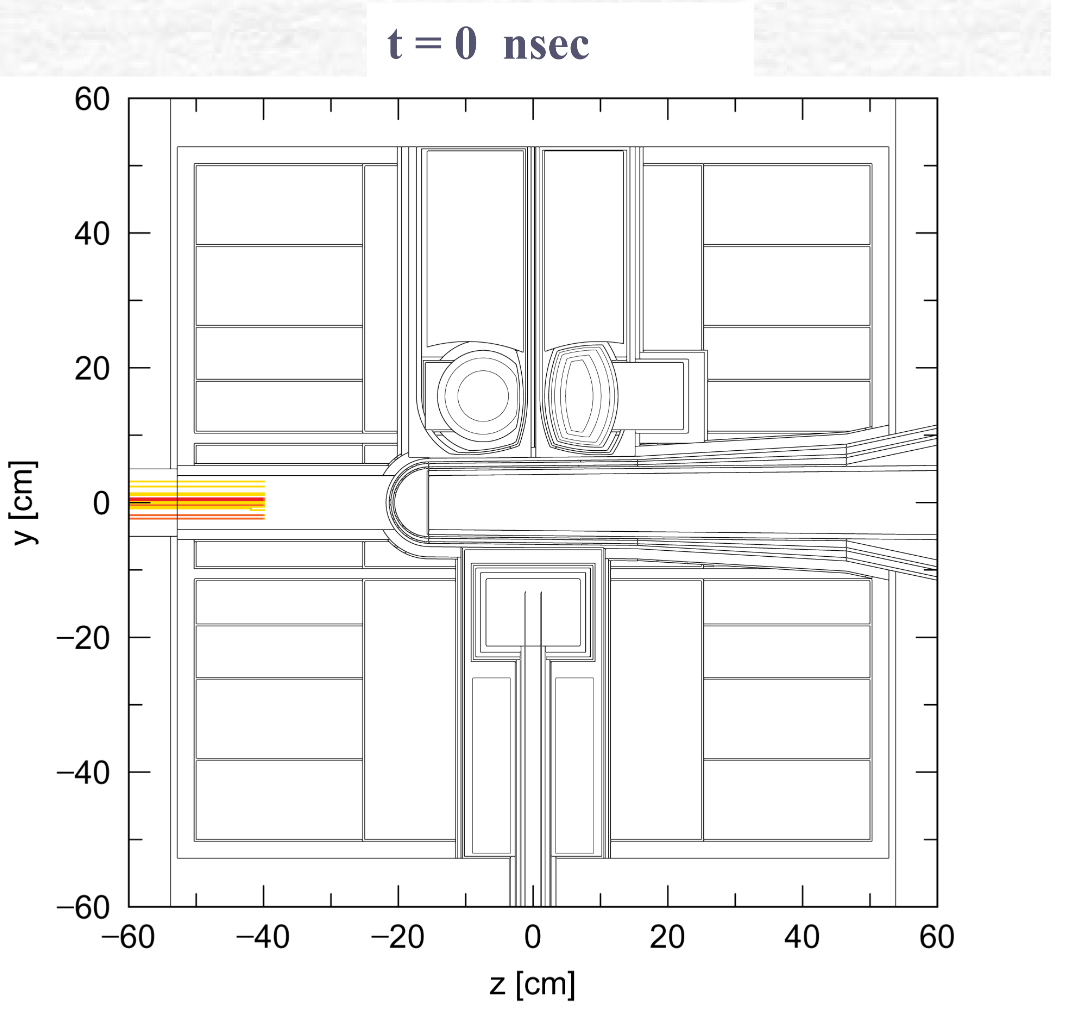

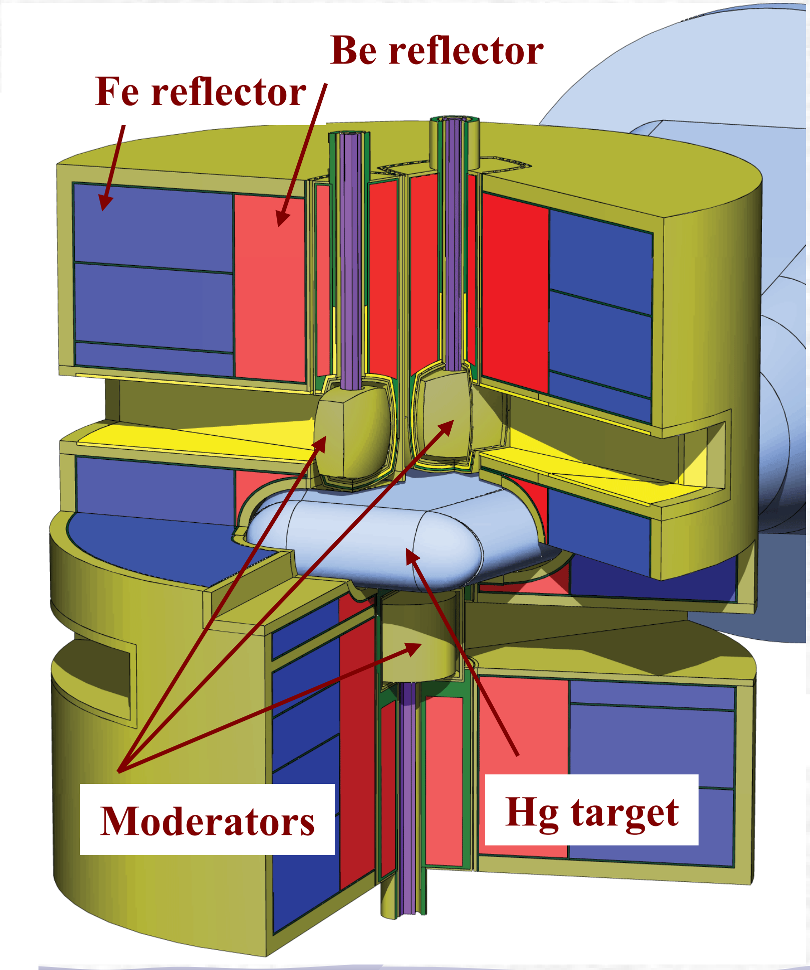

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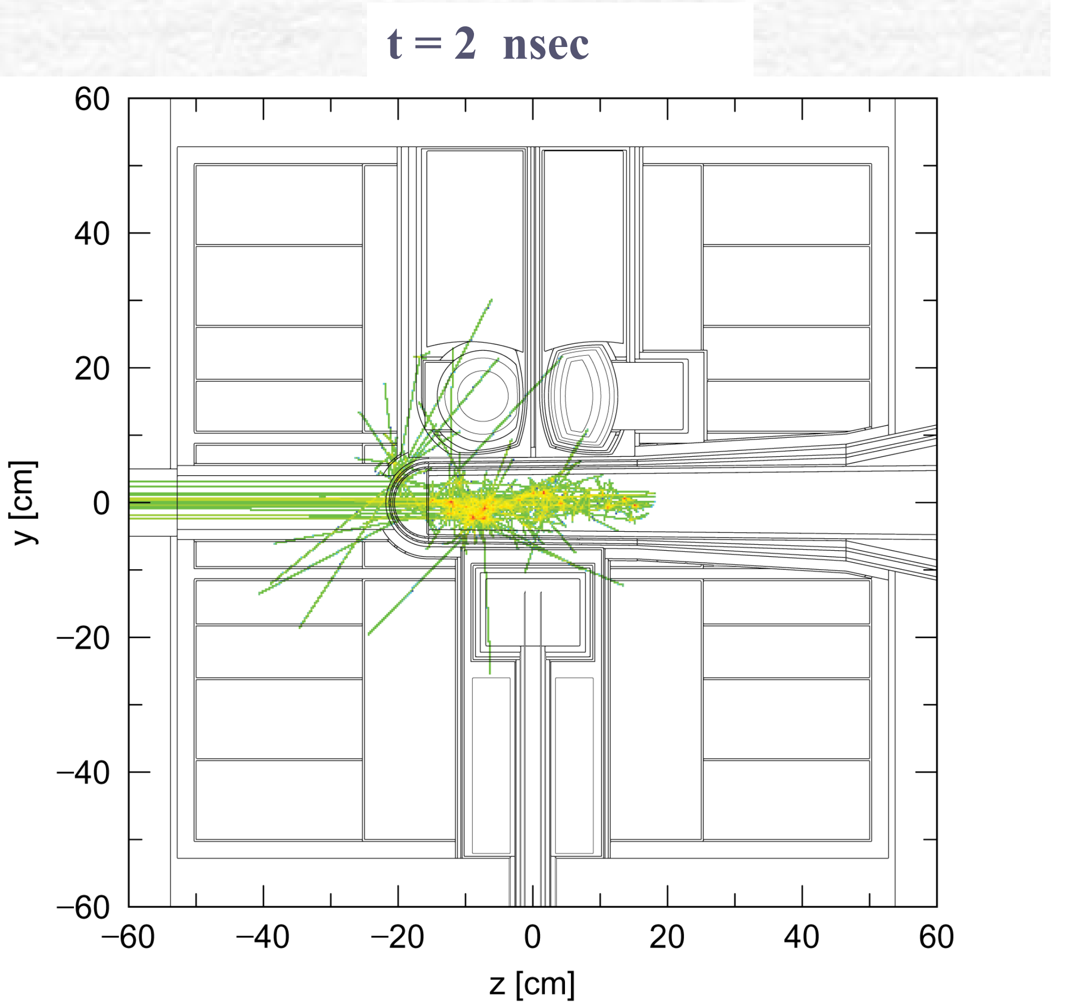

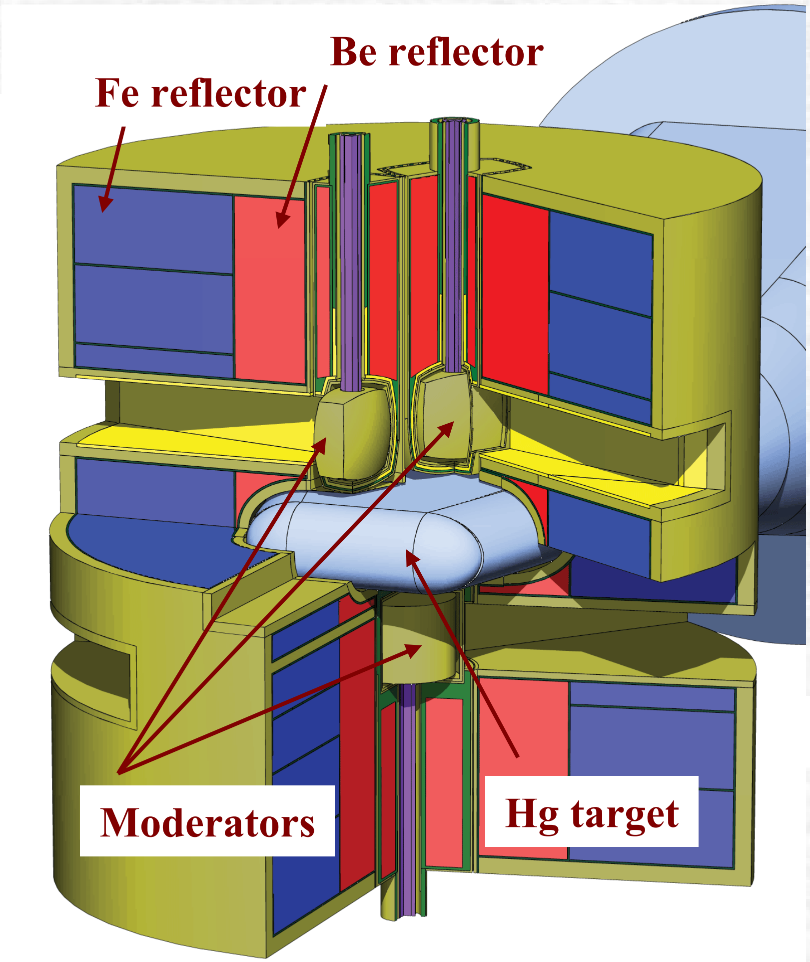

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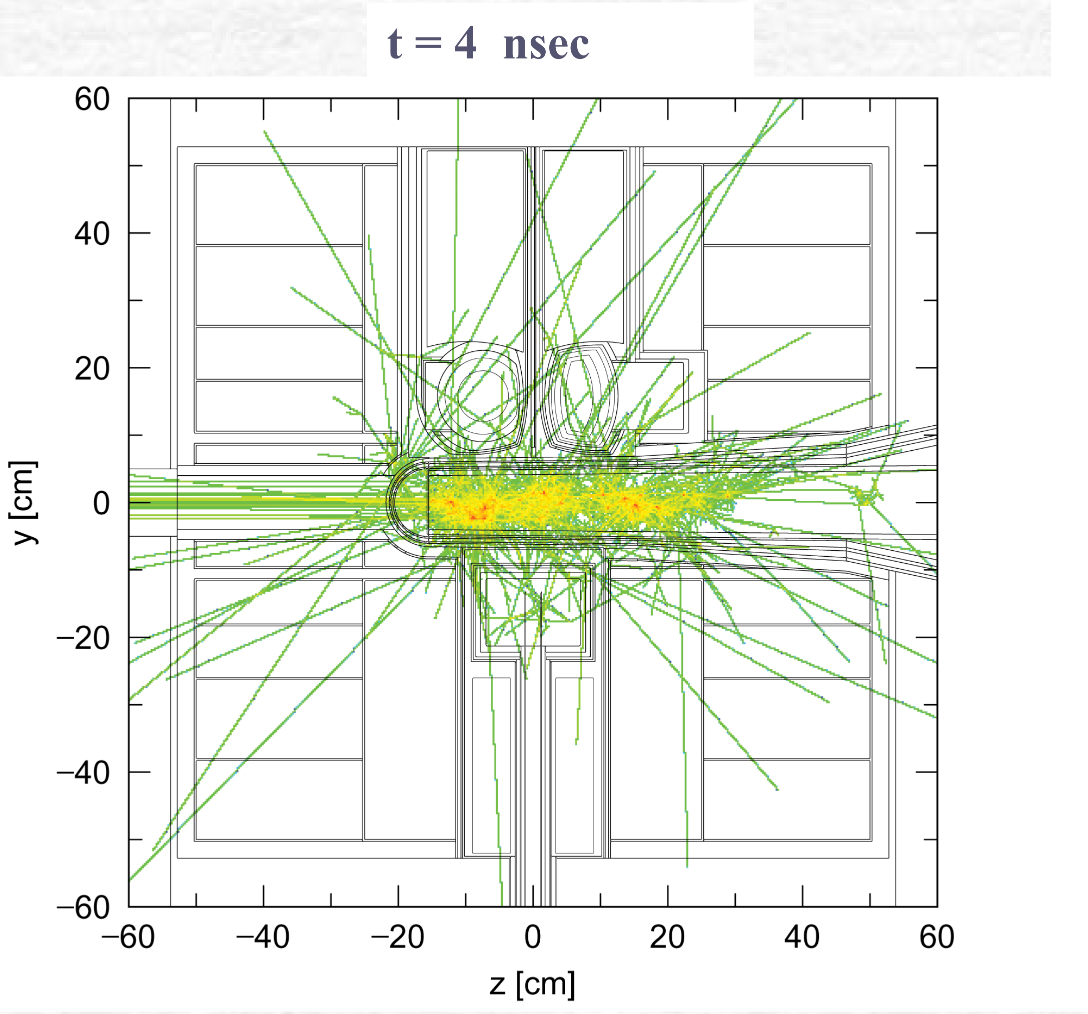

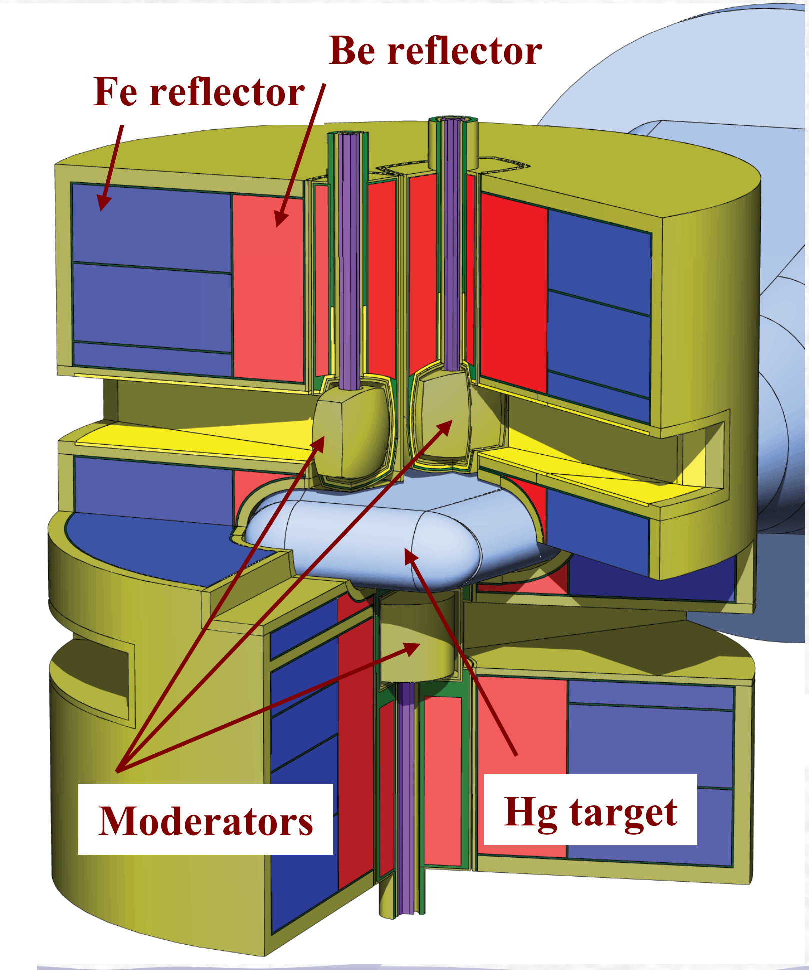

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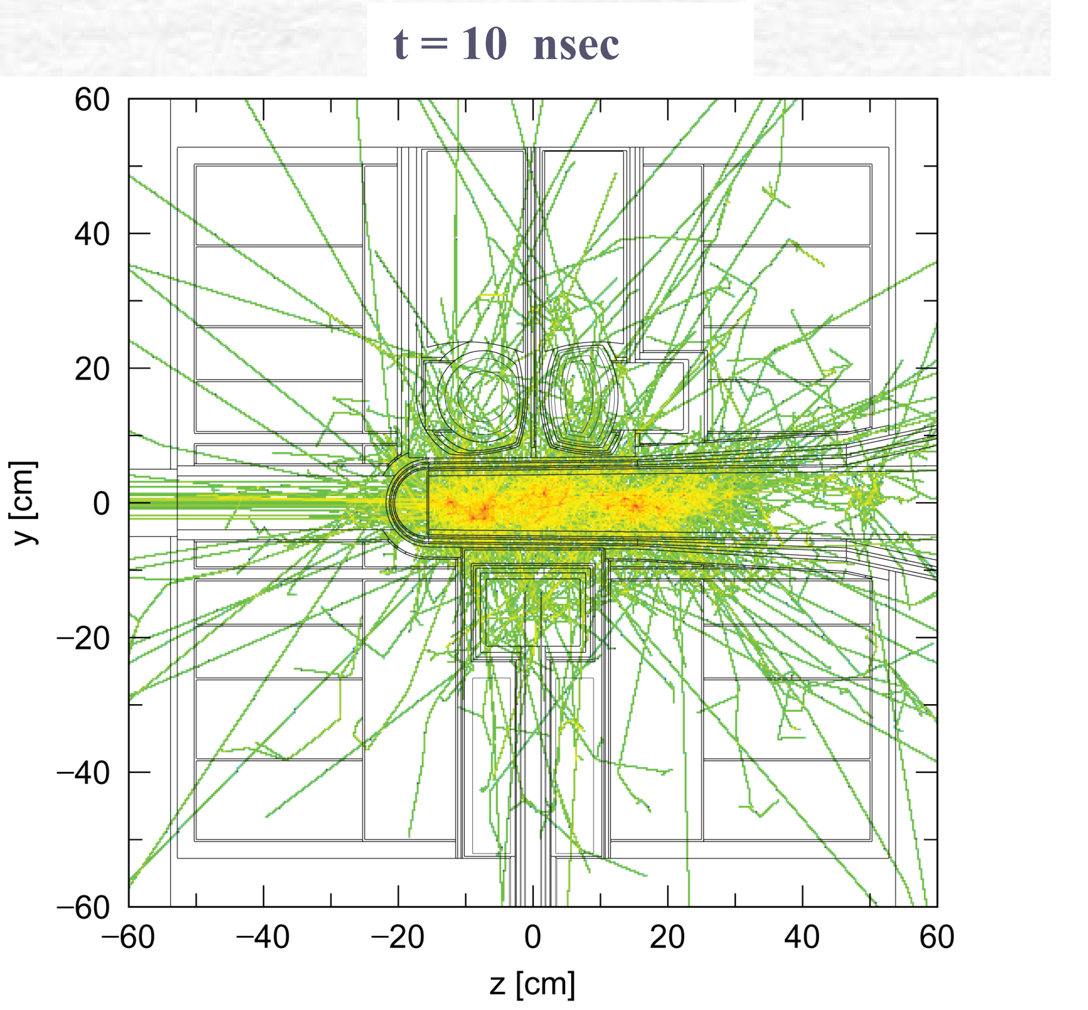

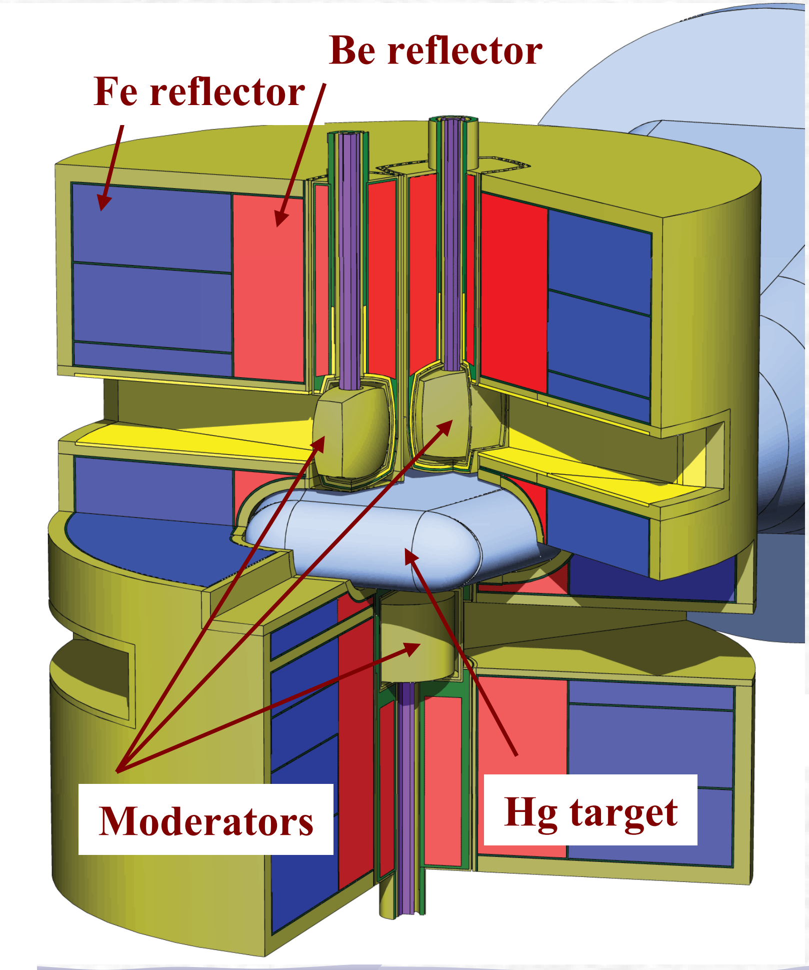

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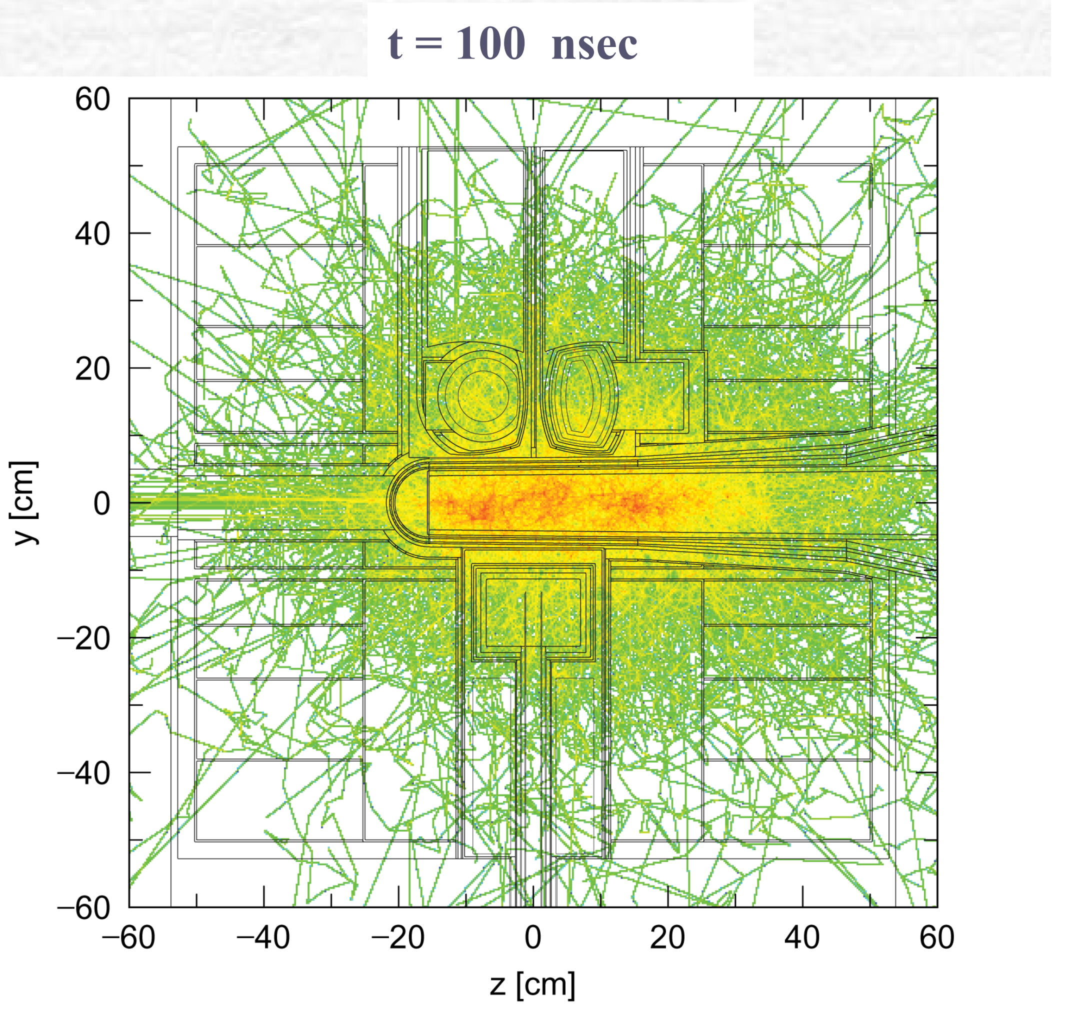

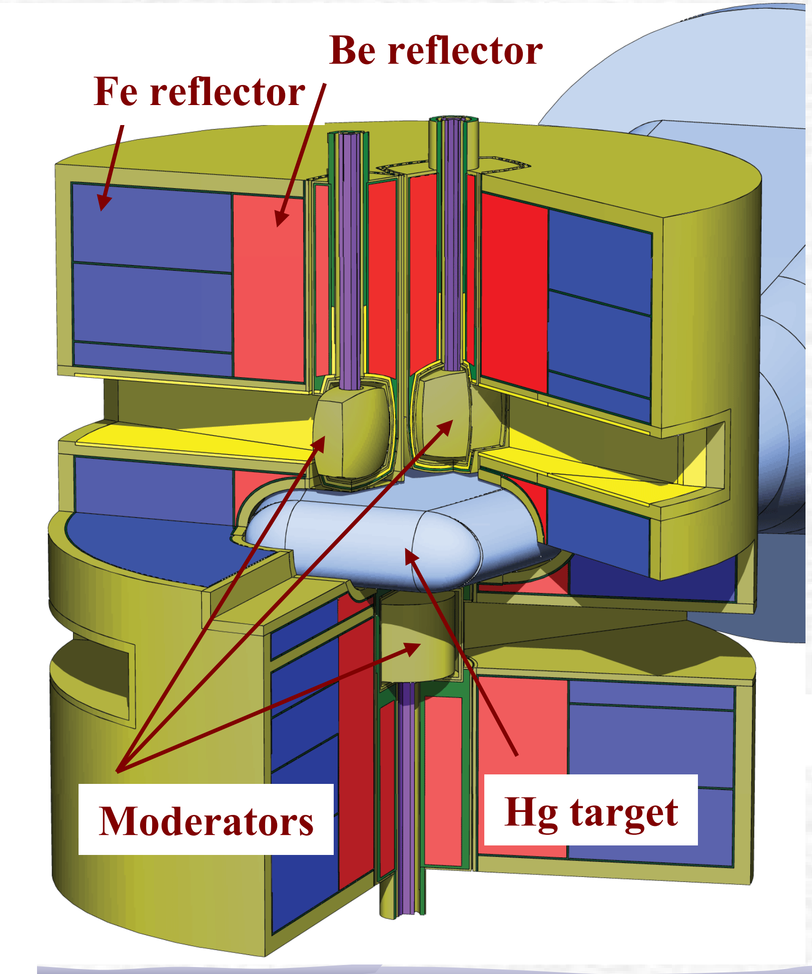

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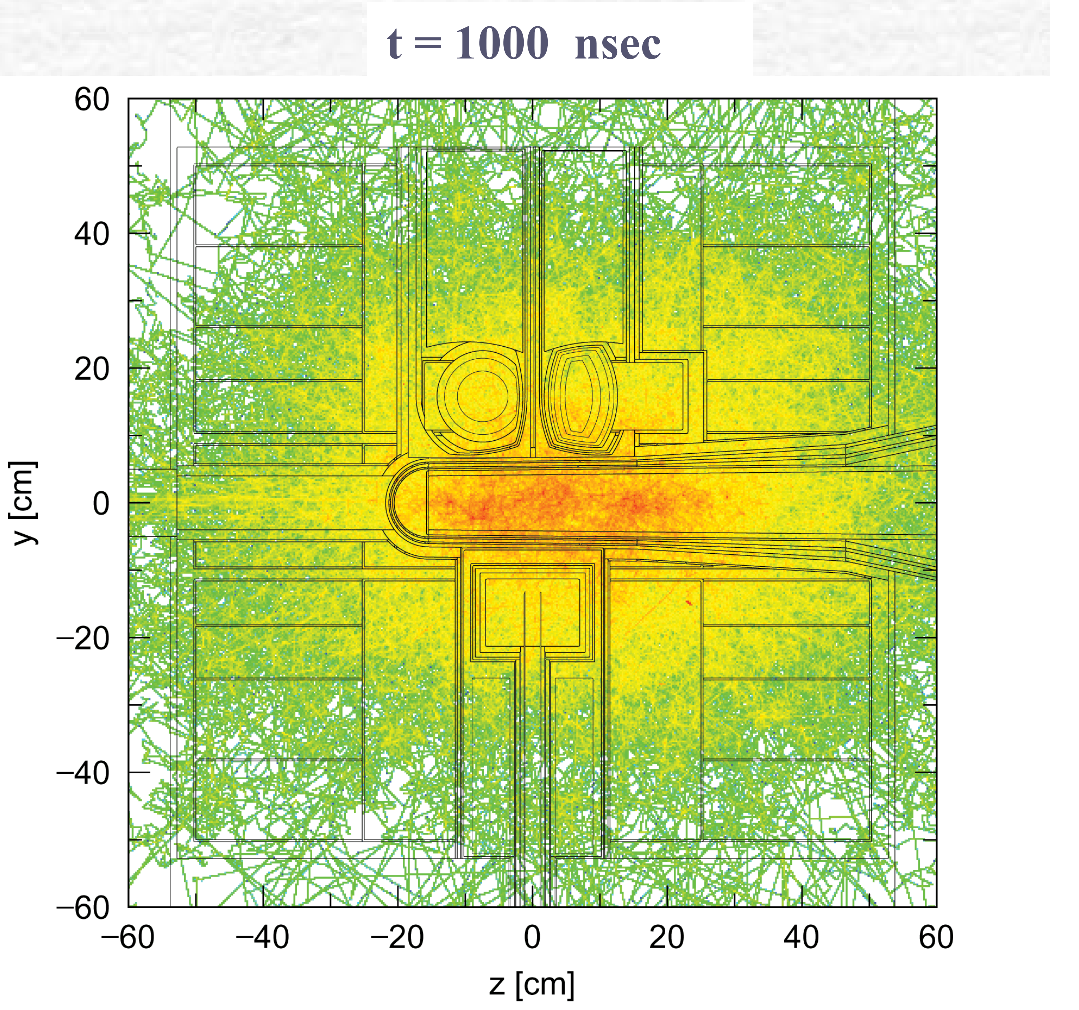

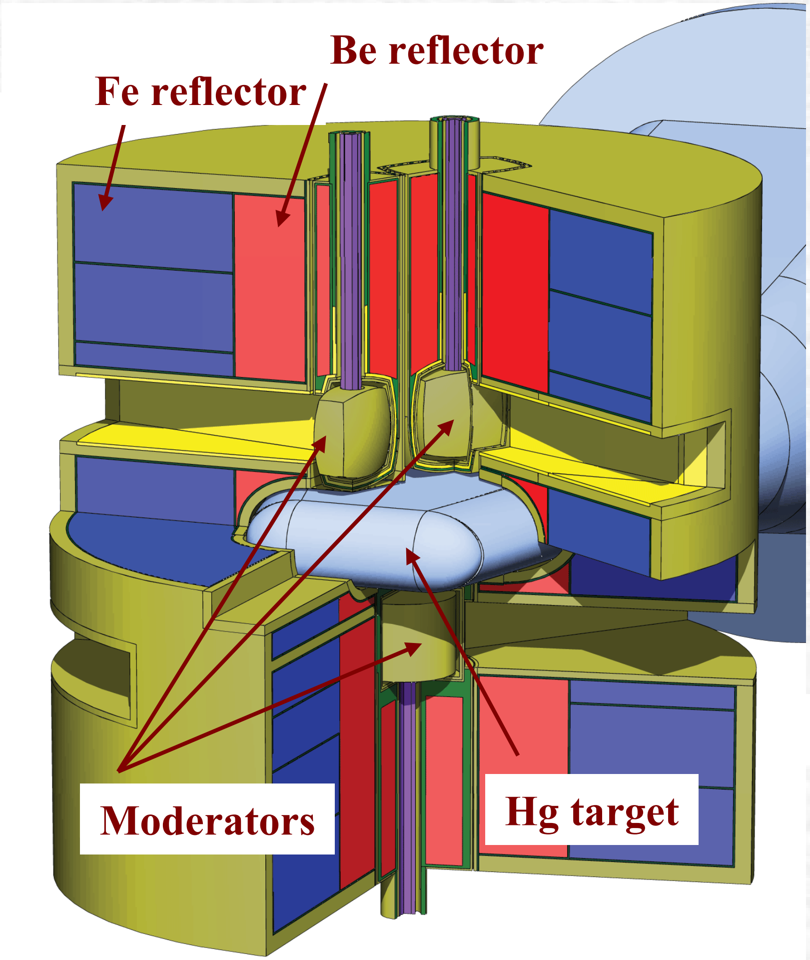

Heat estimation in PHITS

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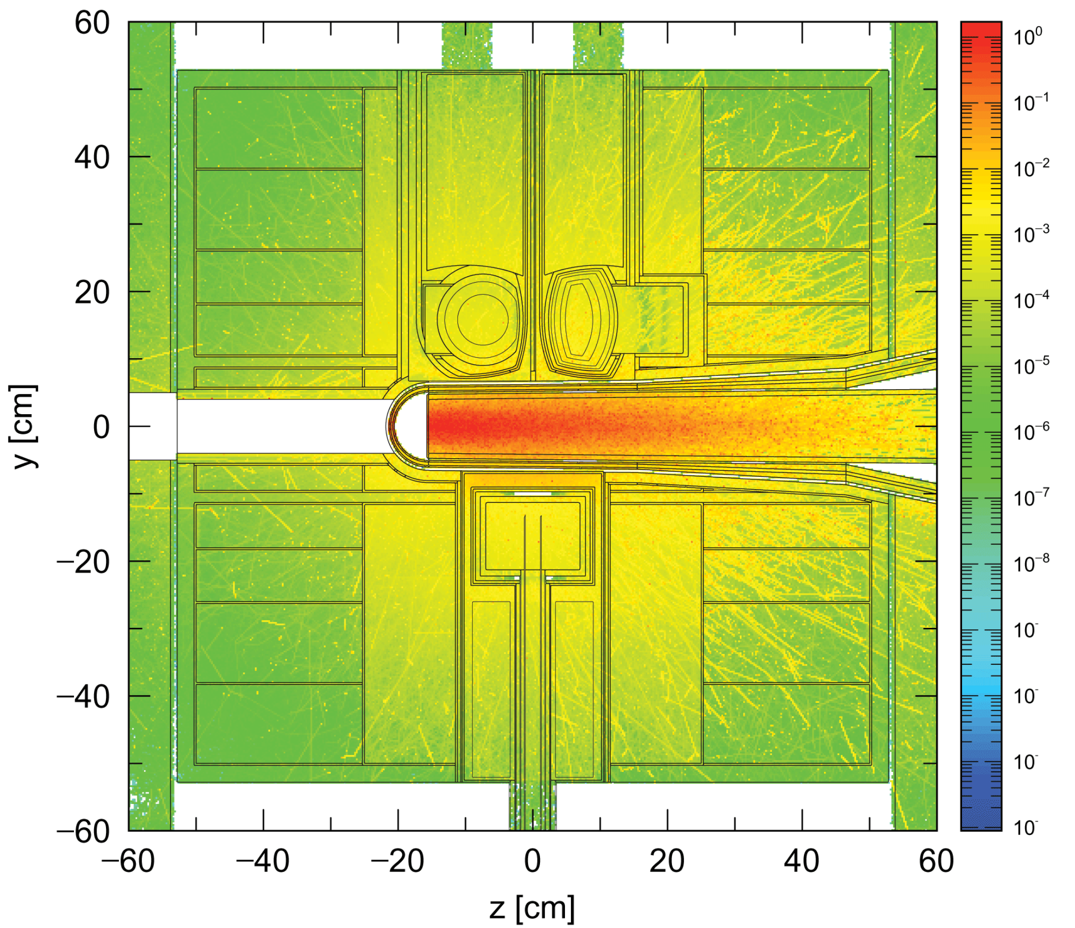
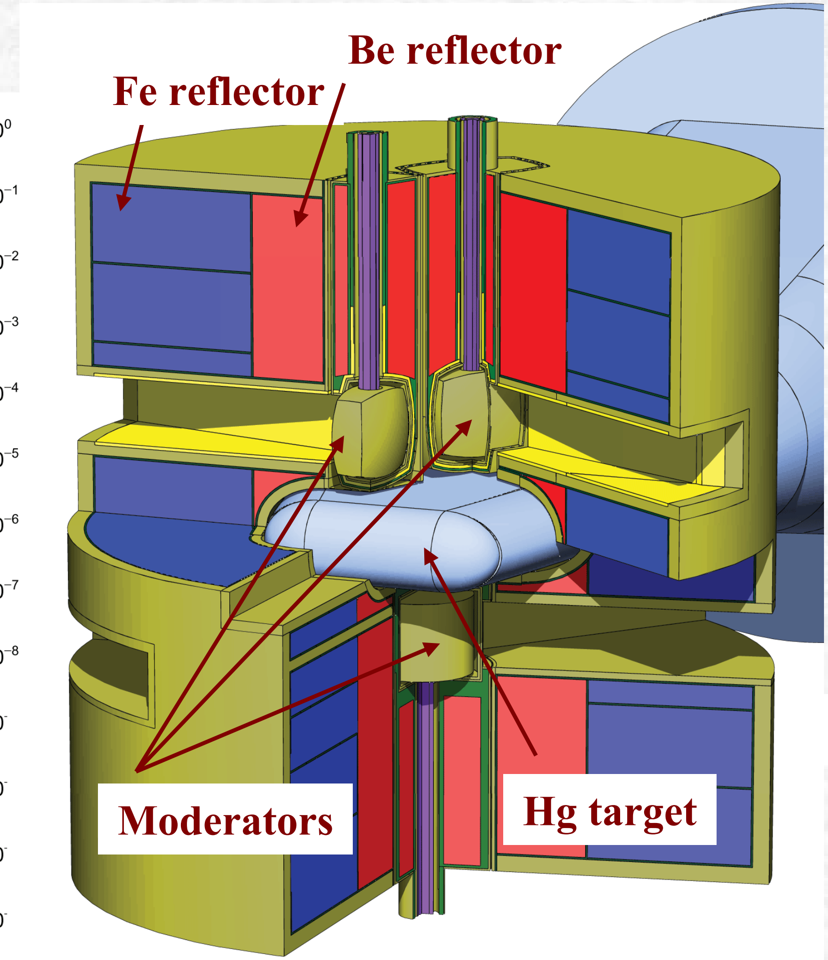
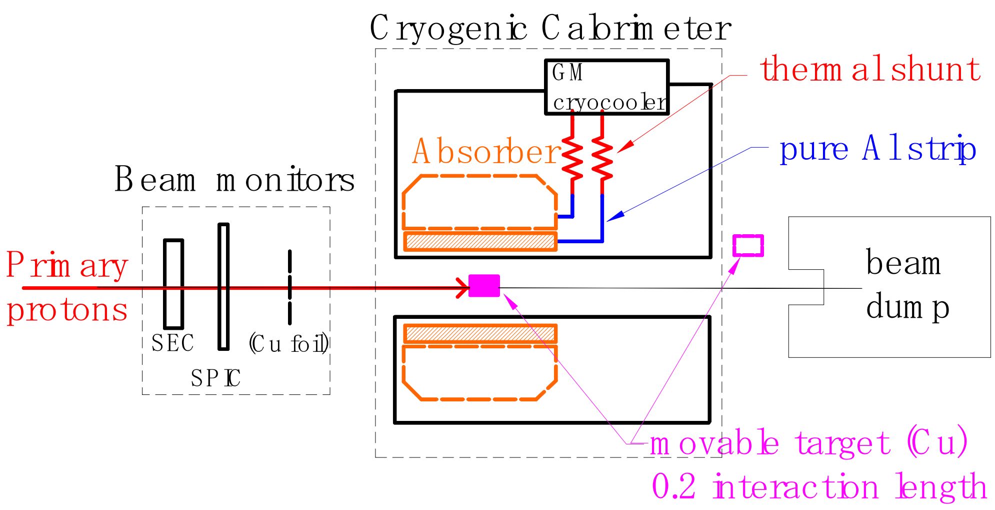
Energy Deposition

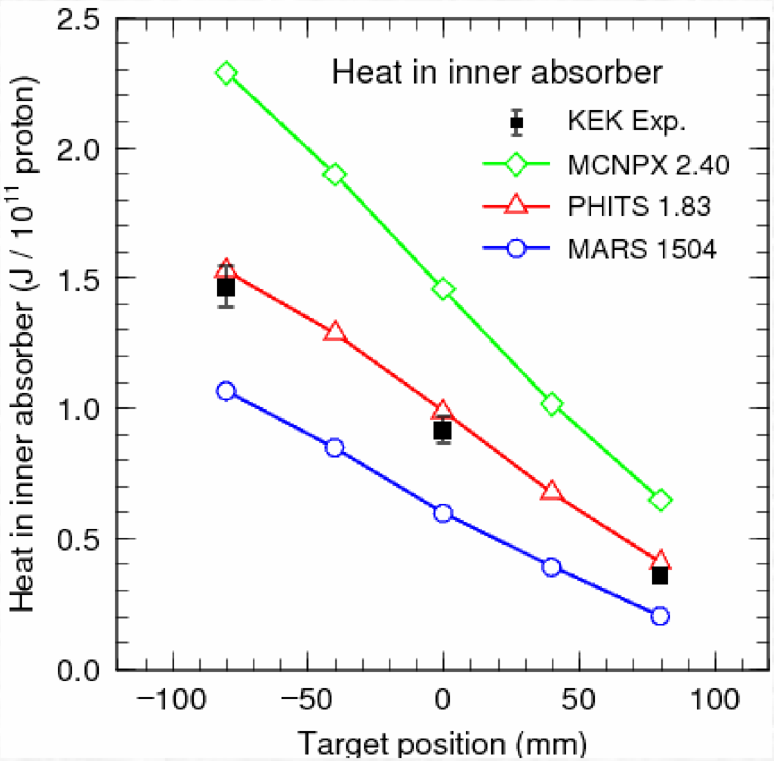




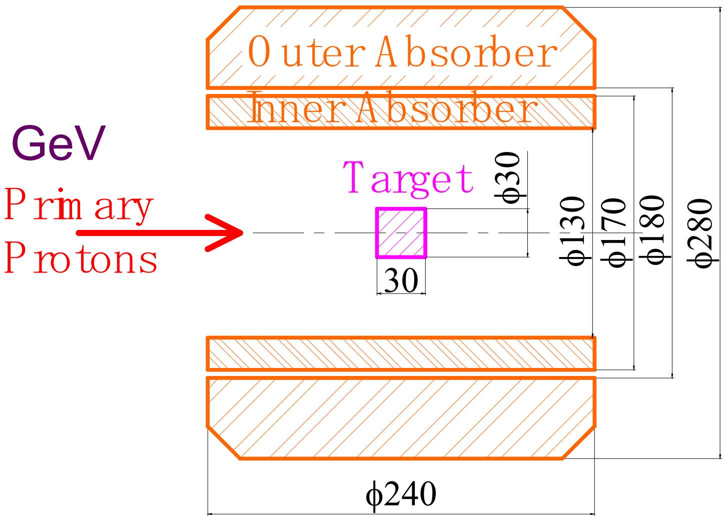
Benchmark test of ***HEAT*** *: compared with KEK experiment*



Exp. and Cal. by H. Ohnishi et.al.
Nucl. Instr. and Meth. A545 (2005) 88



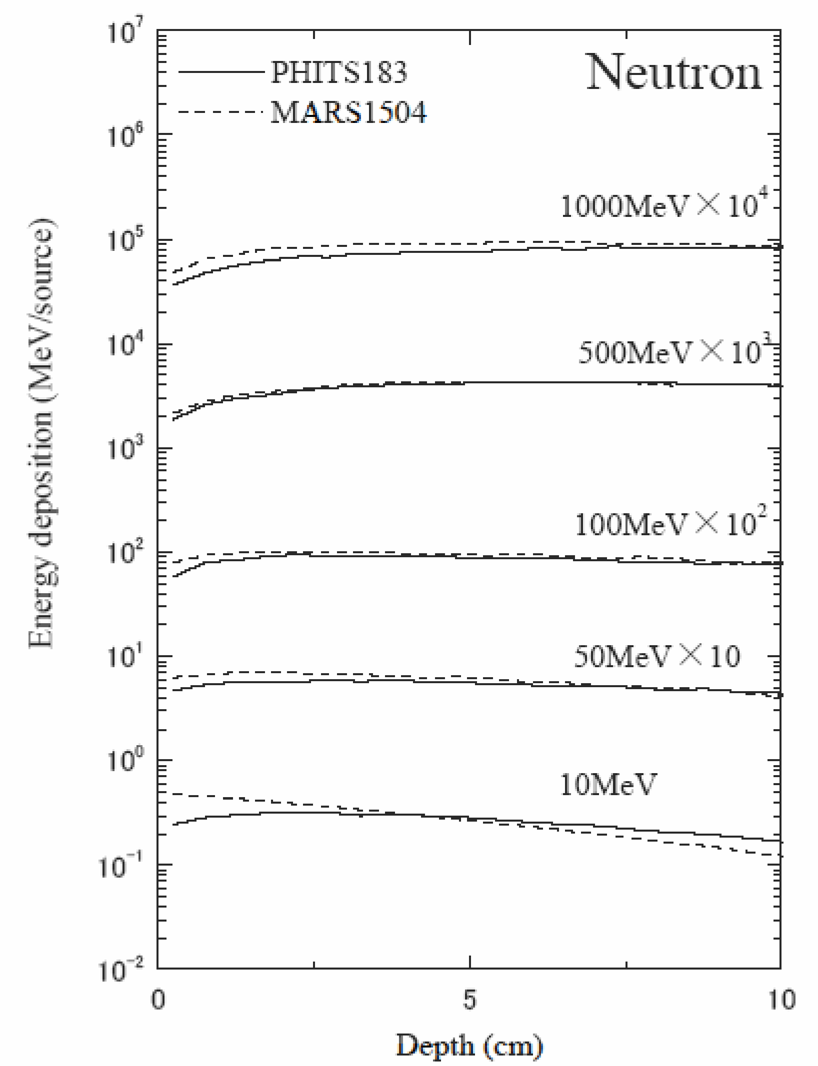
12 GeV

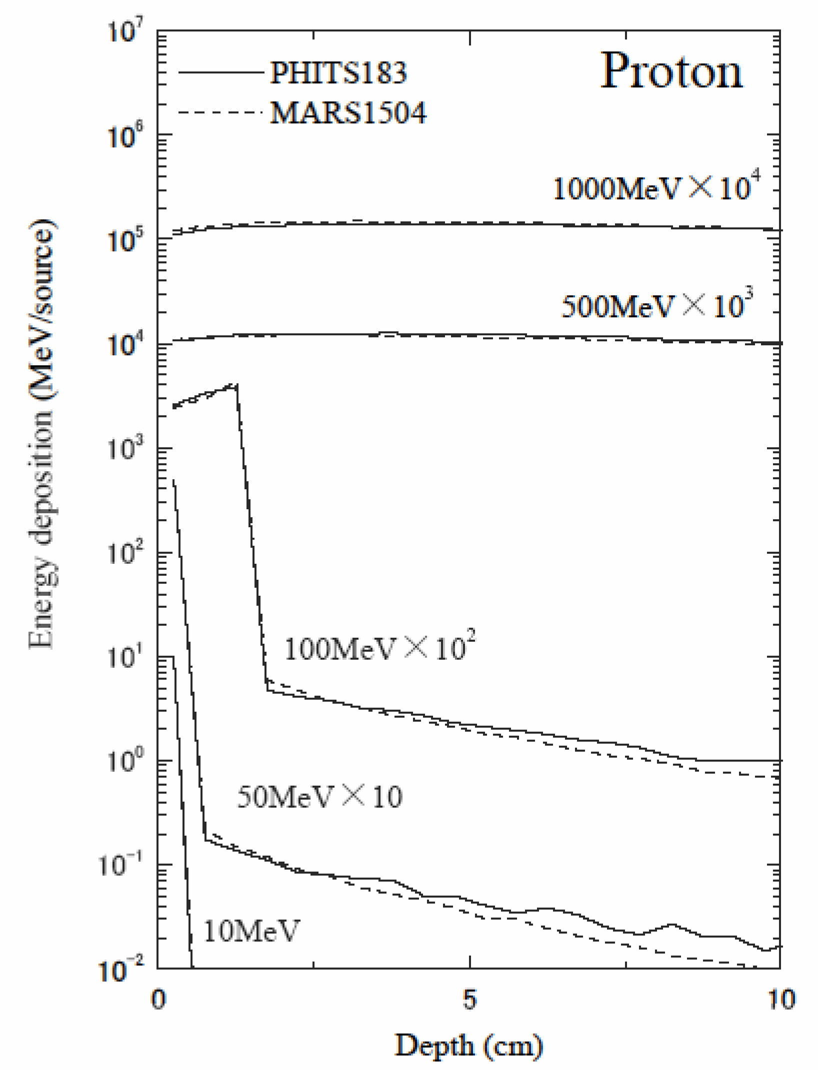


MCNPX: calculated by N. Matsuda

Depth Dose Distribution in Cu 10cm radius

calculated by H. Ohnishi. in Dr. thesis





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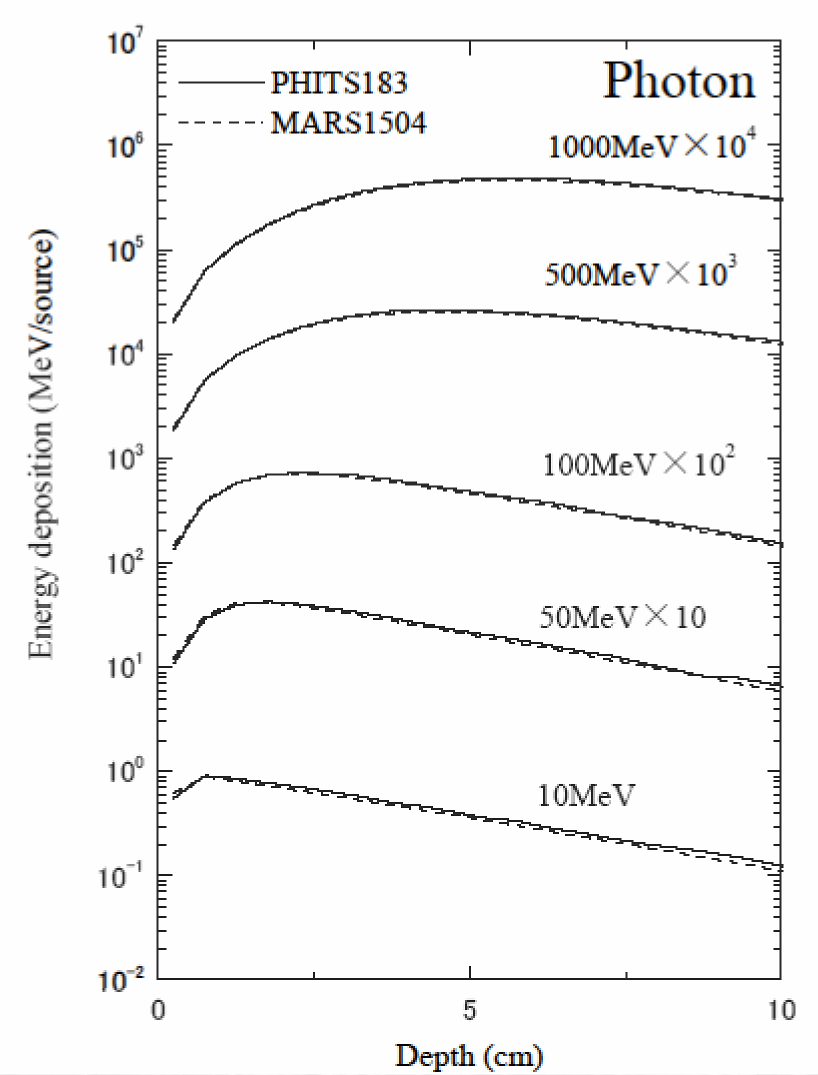
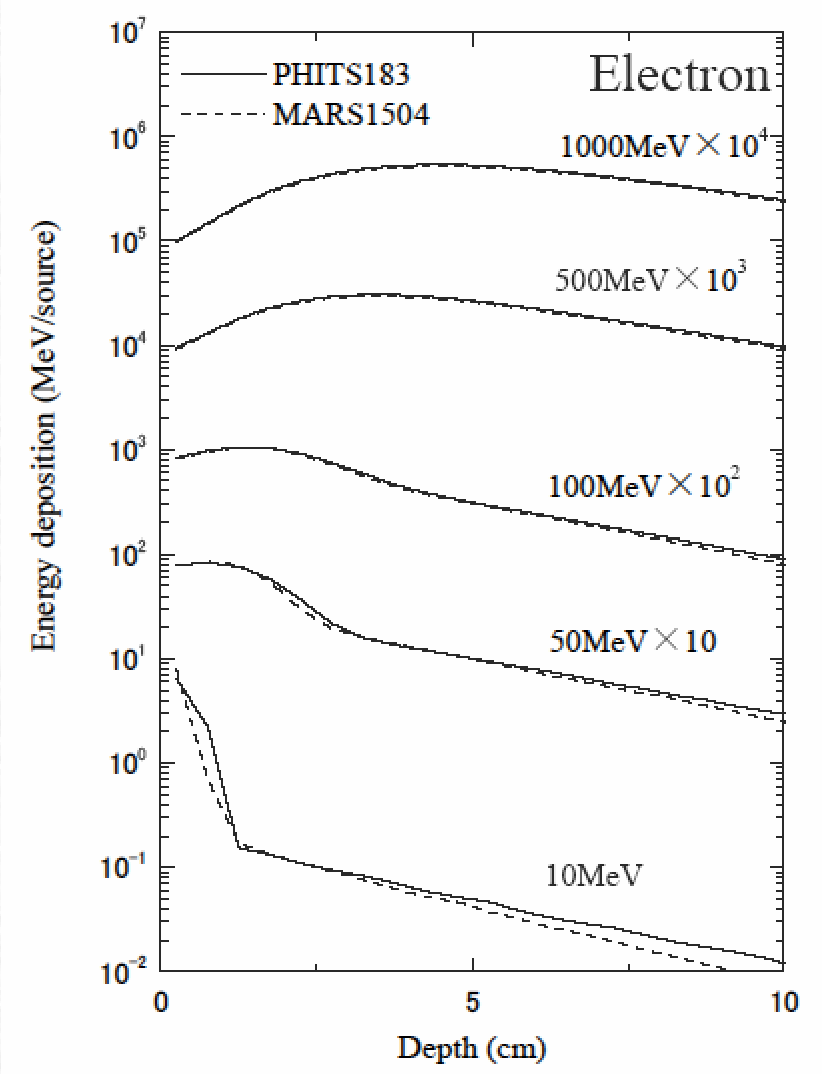
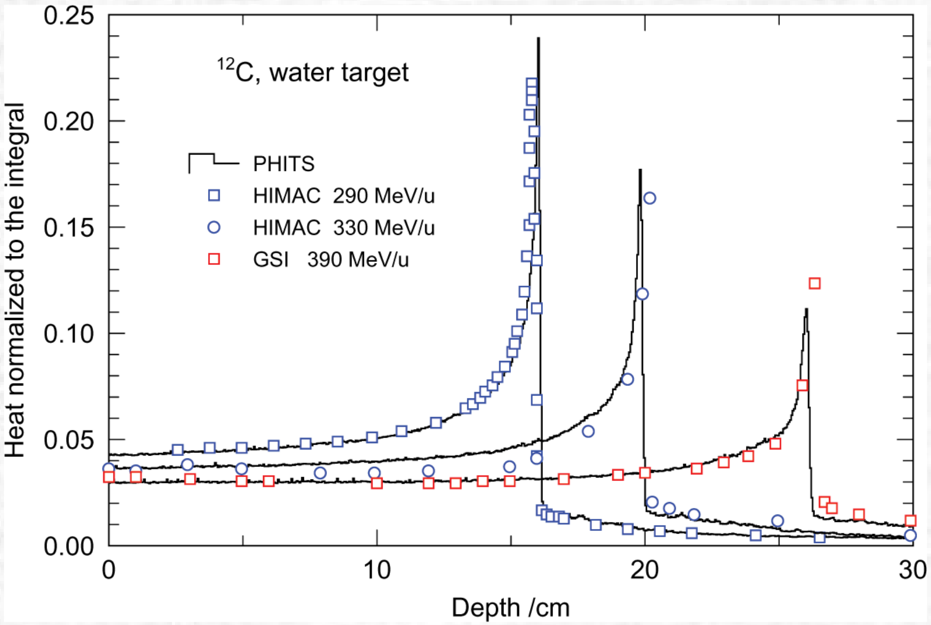
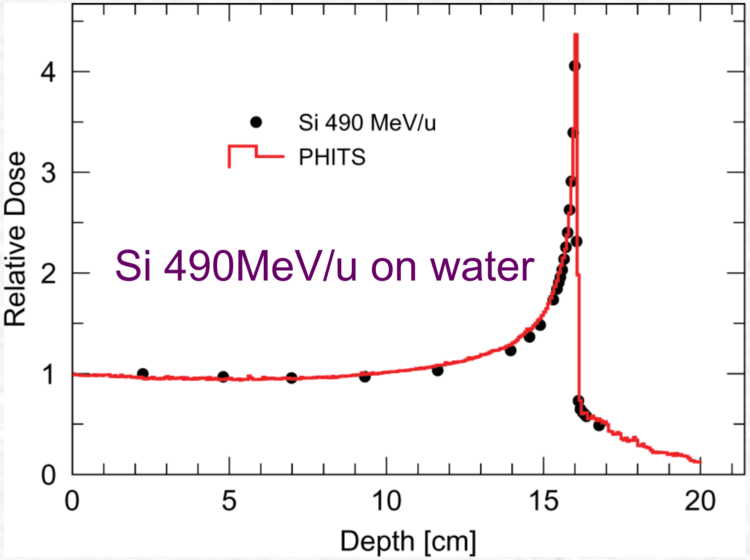


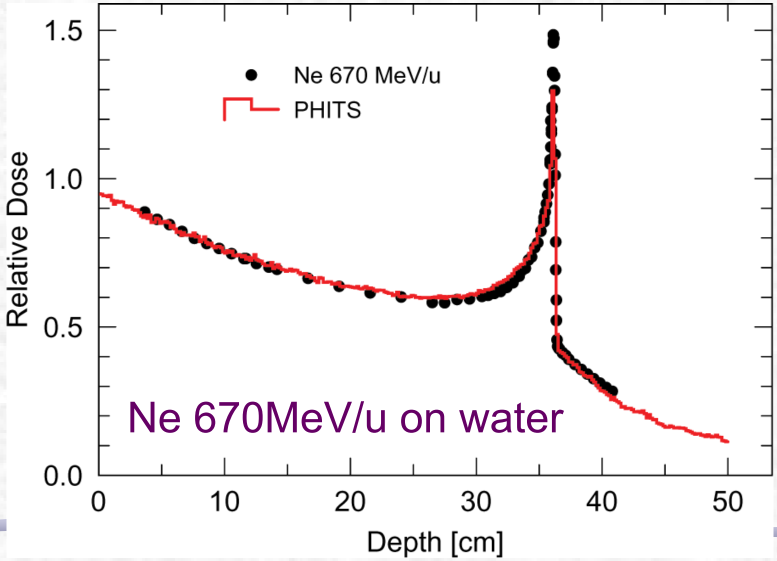


Depth Dose Distribution in Water Phantom

C 290, 330, 390 MeV/u on water

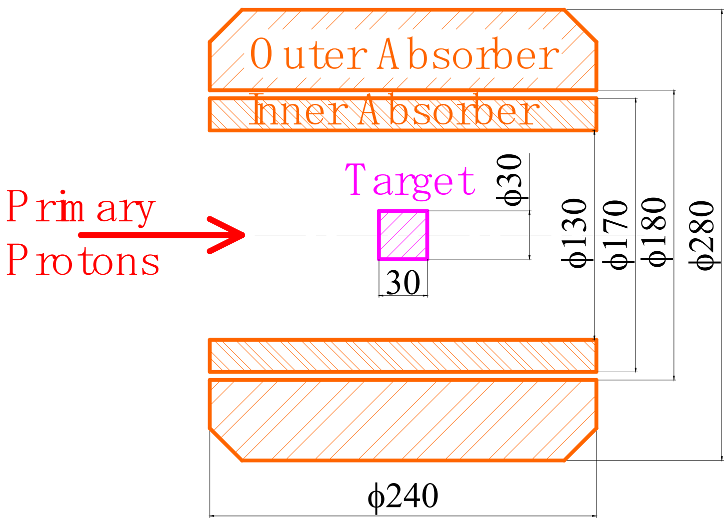


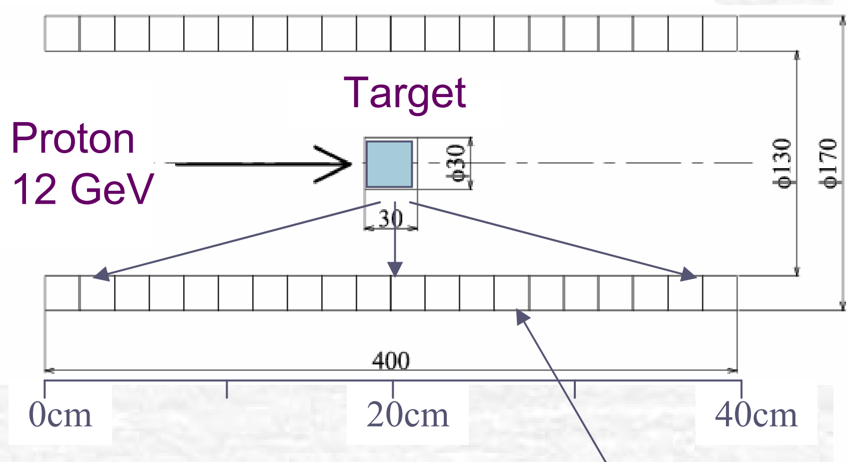


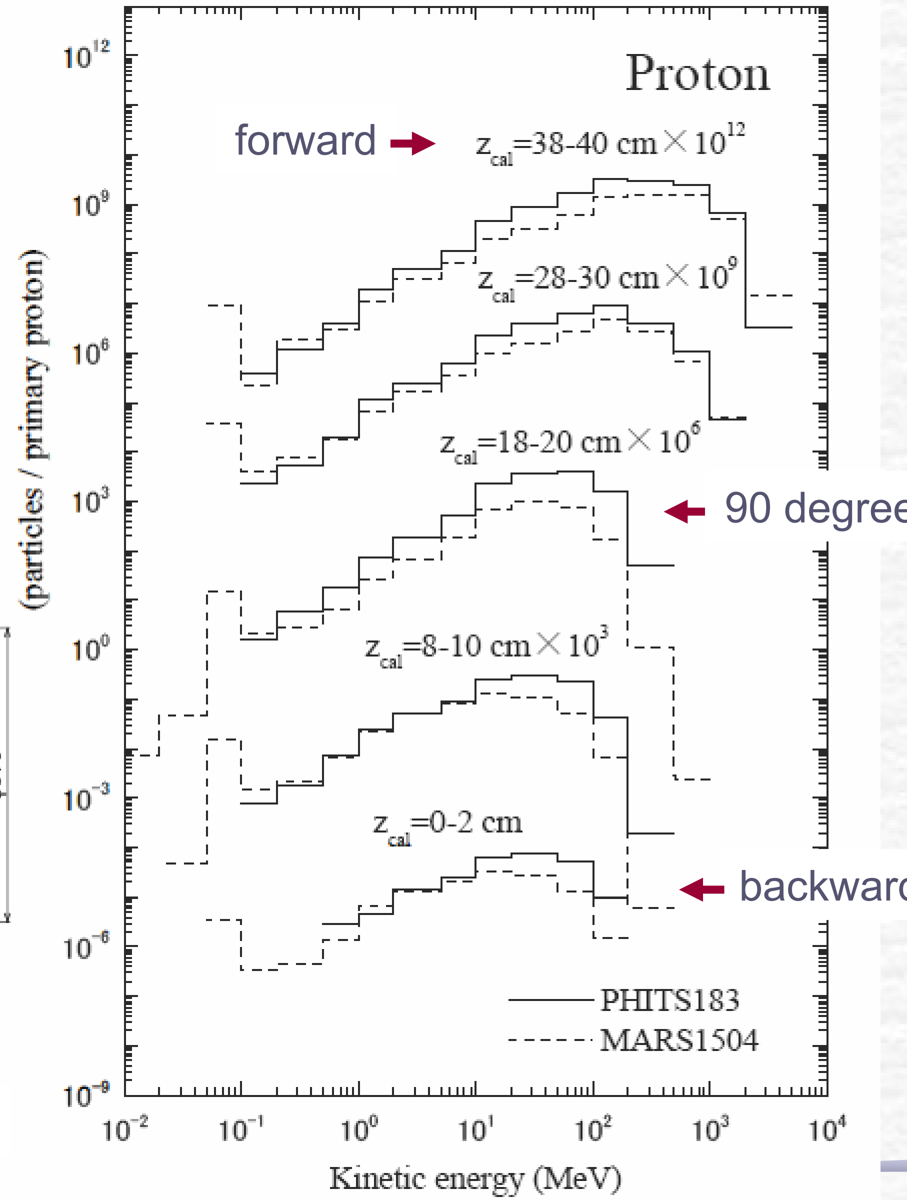


DDX of Secondary Particles

calculated by H. Ohnishi. in Dr. thesis







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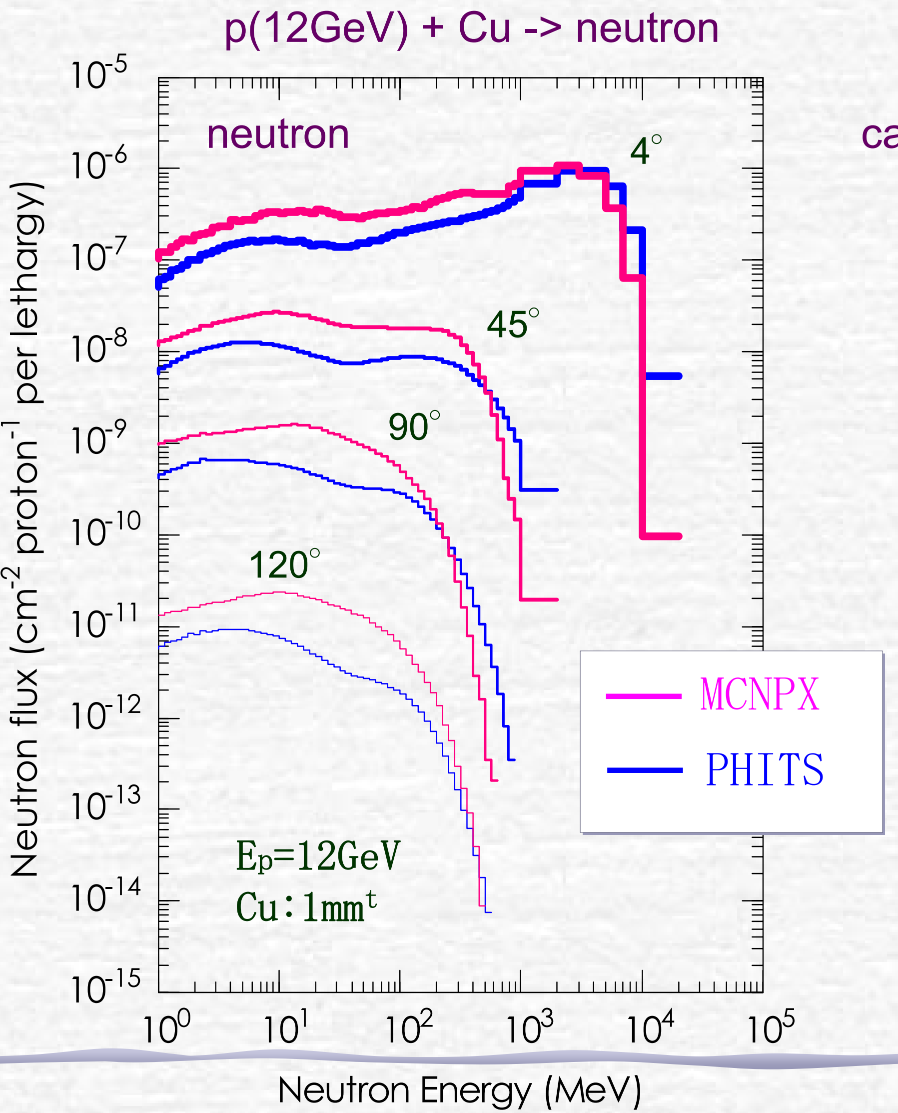
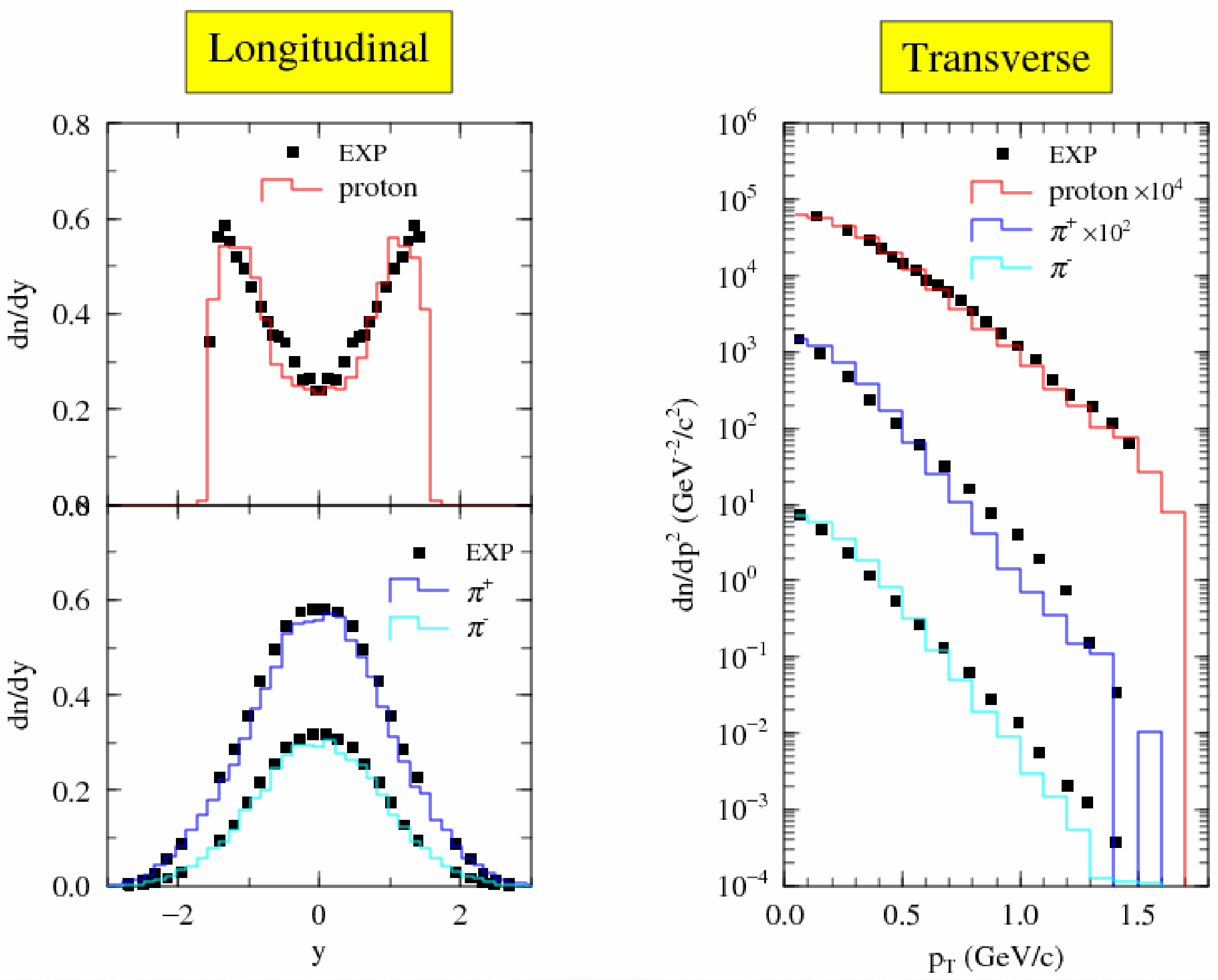


calculated by N. Matsuda

DDX of elementary process, p(12GeV/c) + p , by JAM

JAM: Y. Nara et.al. Phys. Rev. **C61** (2000) 024901

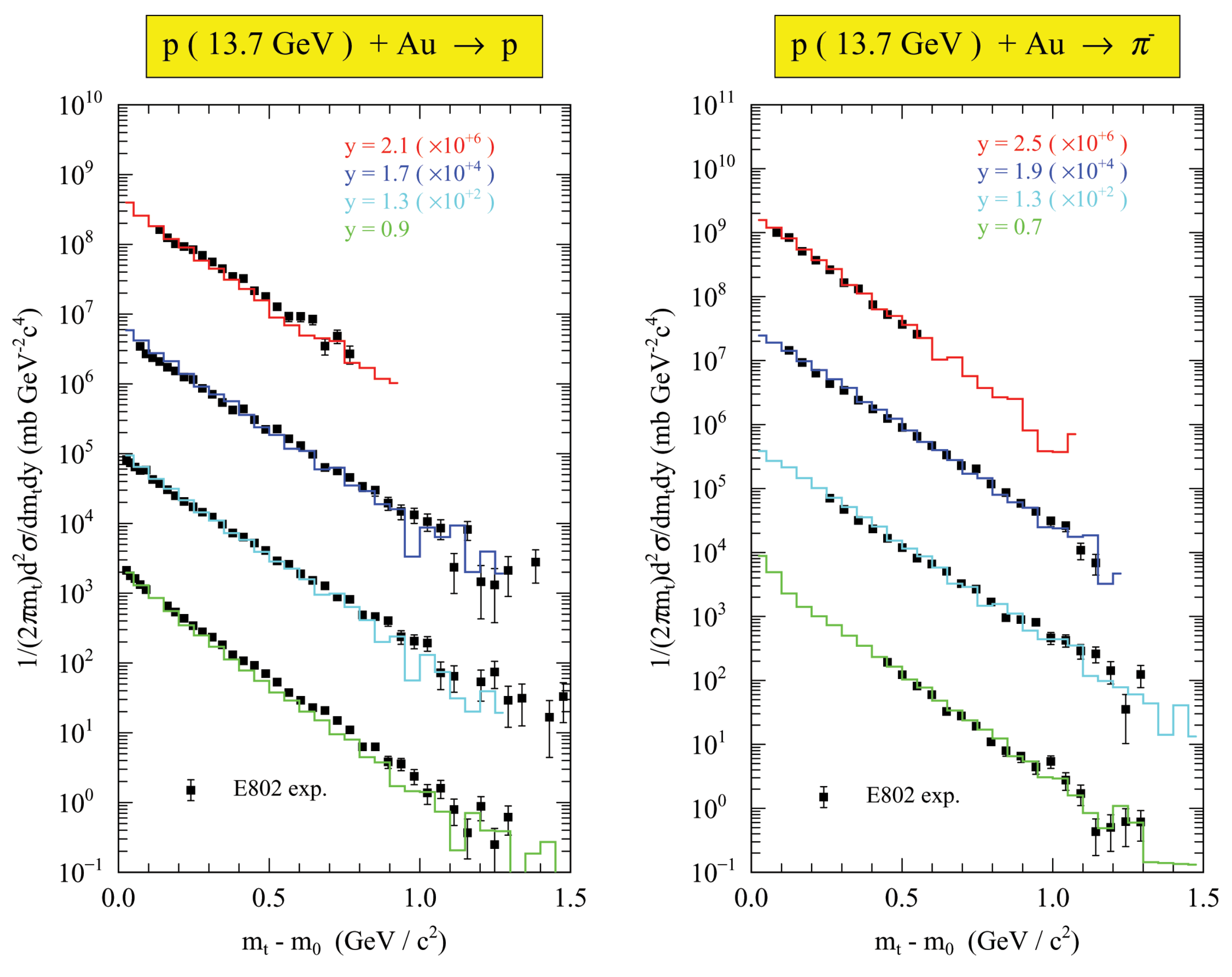
rapidity distribution transverse momentum distribution



Data : Nucl. Phys. **B69** (1974) 454

DDX of p(13.7GeV) + Au by JAM

JAM: Y. Nara et.al. Phys. Rev. **C61** (2000) 024901



Data : E802, Phys. Rev. **D45** (1992) 3906

DPA estimation in PHITS

PKA cross section

DPA value :

$$DPA = \left(\int \sigma_{DX}(E) \cdot \phi(E) \cdot dE \right) \cdot t$$

Displacement cross section :

$$\sigma_{DX}(E) = \sum_i \int \nu_d(T) \cdot \frac{d\sigma_d^i(T,E)}{dT} \cdot dT$$

Number of displacement Atom :

$$\nu_d(T) = \left(\frac{\beta}{2T_d} \right) \cdot T_{dam}(T)$$

threshold energy

Damage energy :
by Lindhard-Robinson model

$$T_{dam}(T) = \frac{T}{1 + \kappa g(\varepsilon_T)}$$

$$g(\varepsilon) = 3.4008 \cdot \varepsilon^{1/6} + 0.40244 \cdot \varepsilon^{3/4} + \varepsilon$$

$$\kappa = \frac{(0.0793 Z_1^{2/3} Z_2^{1/2} (A_1 + A_2)^{3/2})}{(Z_{1c}^{2/3} + Z_2^{2/3})^{3/4} A_1^{3/2} A_2^{1/2}}$$

$$\varepsilon = \frac{0.8853 A_2}{(27.2) Z_1 Z_2 (Z_{1c}^{2/3} + Z_2^{2/3})^{1/2} (A_1 + A_2)} \cdot T$$

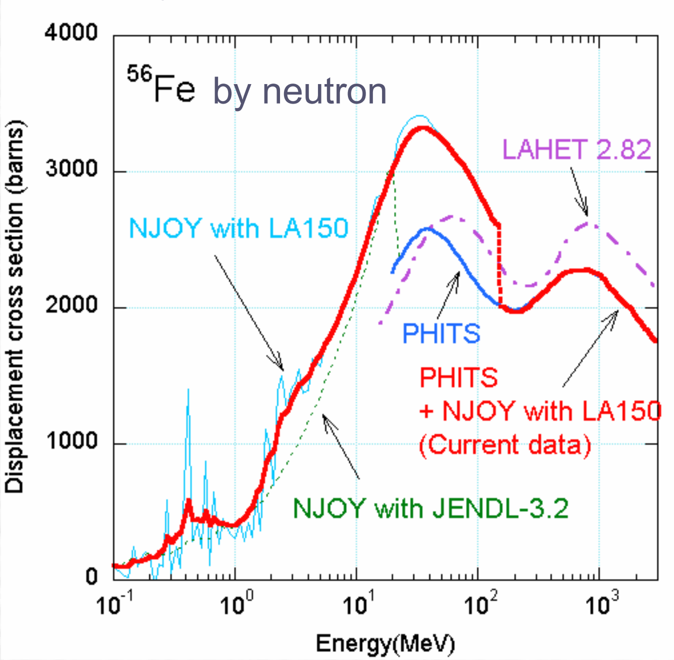
Material	Td (eV)
Be	40
C	40
Al	25
Cr	40
Fe	40
Ni	40
Cu	30
Pb	25

There are two ways to get the displacement cross sections

(1) using evaluated displacement cross sections.
local approximation, limited materials (Be,C,Cr,Fe,Ni,Cu,Pb)

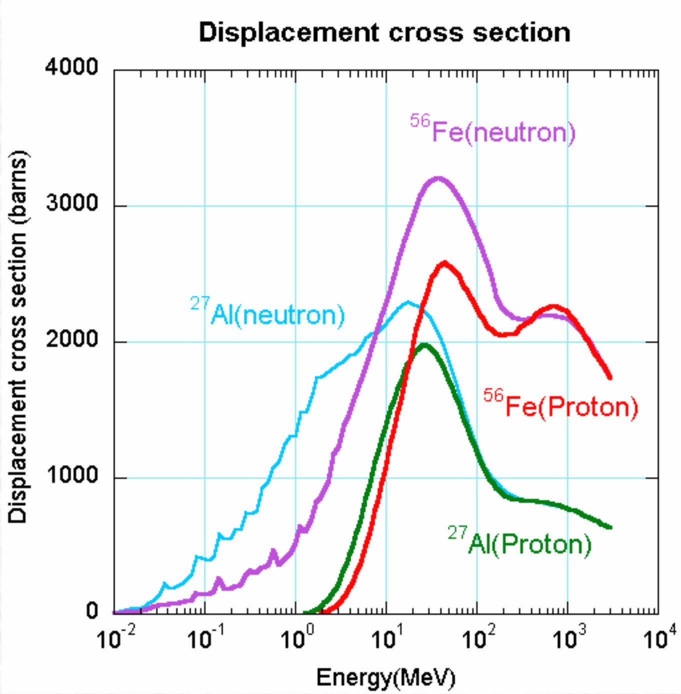
(2) calculating PKA cross sections in an event by event.
it is possible in PHITS by the event generator mode.

Displacement cross sections
by NJOY with nuclear data
by Cascade model, JAM, Bertini



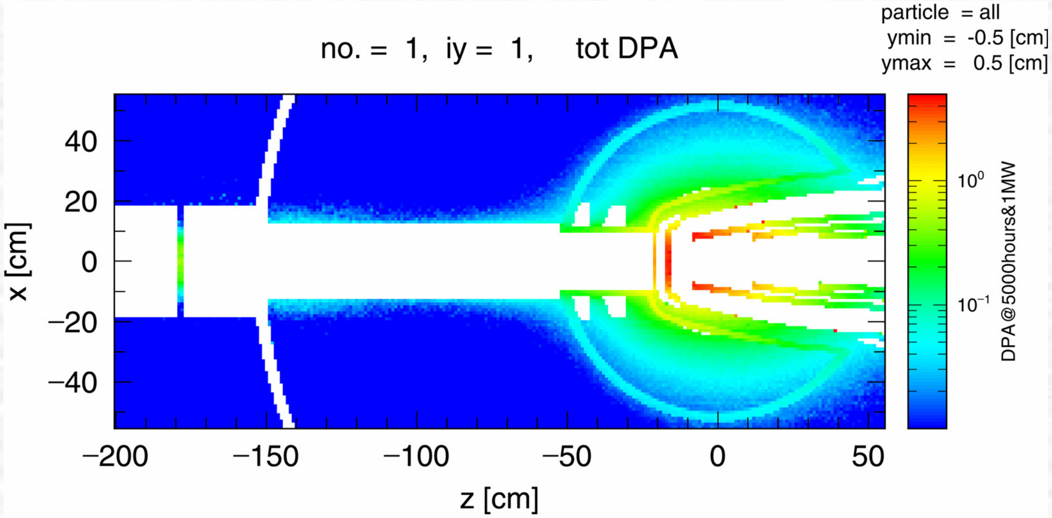
smoothing

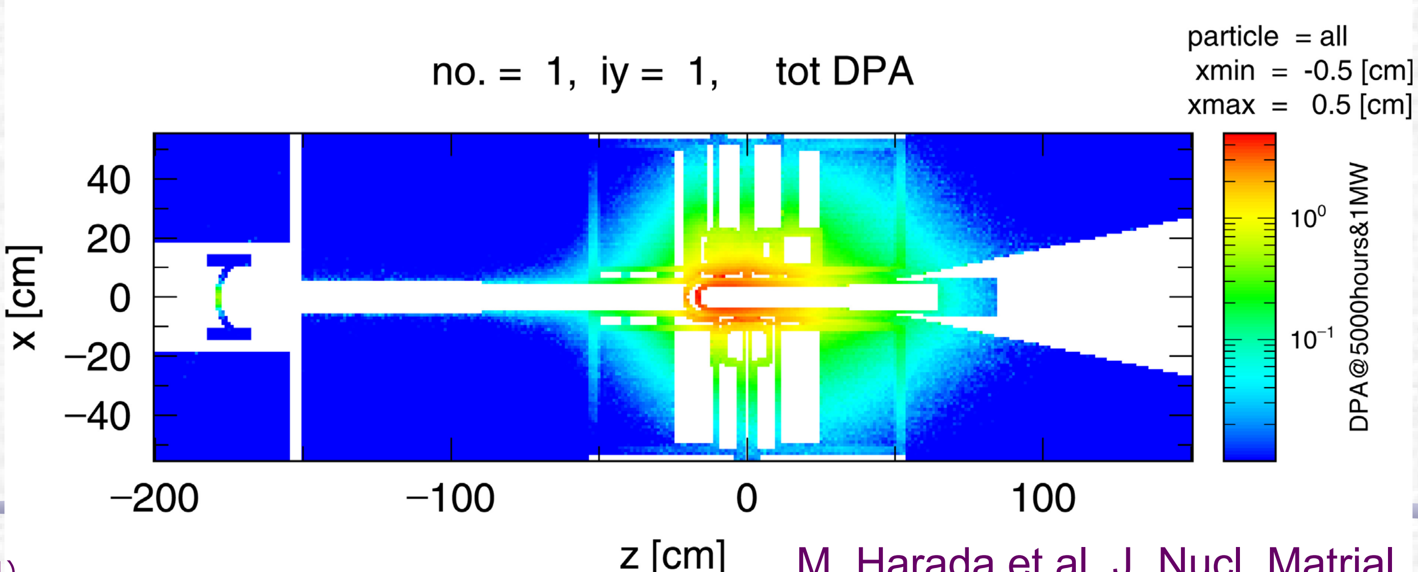
Evaluated data table of



M. Harada et.al, J. Nucl. Matrial. **343** (2005) 197

DPA map of target-moderator-reflector assembly of J-PARC





M. Harada et.al, J. Nucl. Matrial. **343** (2005) 197

Maximum calculated DPA, Allowable DPA and Life

Component 1	Component 2	Material	Maximum DPA	Allowable DPA	Assumed life time
			(DPA/5000MWhr)		(Year*)
Target	Target Vessel	SS316L	**3.9**	**5**	**>1**
Reflector	Reflector Vessel	A6061-T6	**2.8**	**20**	**>6**
Moderator	Coupled moderator Vessel	A6061-T6	**2.8**	**20**	**>6**
Proton Beam window	Downstream window	A5083	**0.44**	**10**	**>10**
Water-cooled shield	Vessel	SUS304L	**0.16**	**5**	**>30**
Middle section	Vessel	SUS304L	**0.04**	**5**	**>30**
* 5000 hour opration is assuemd in 1 year.					

M. Harada et.al, J. Nucl. Matrial. **343** (2005) 197

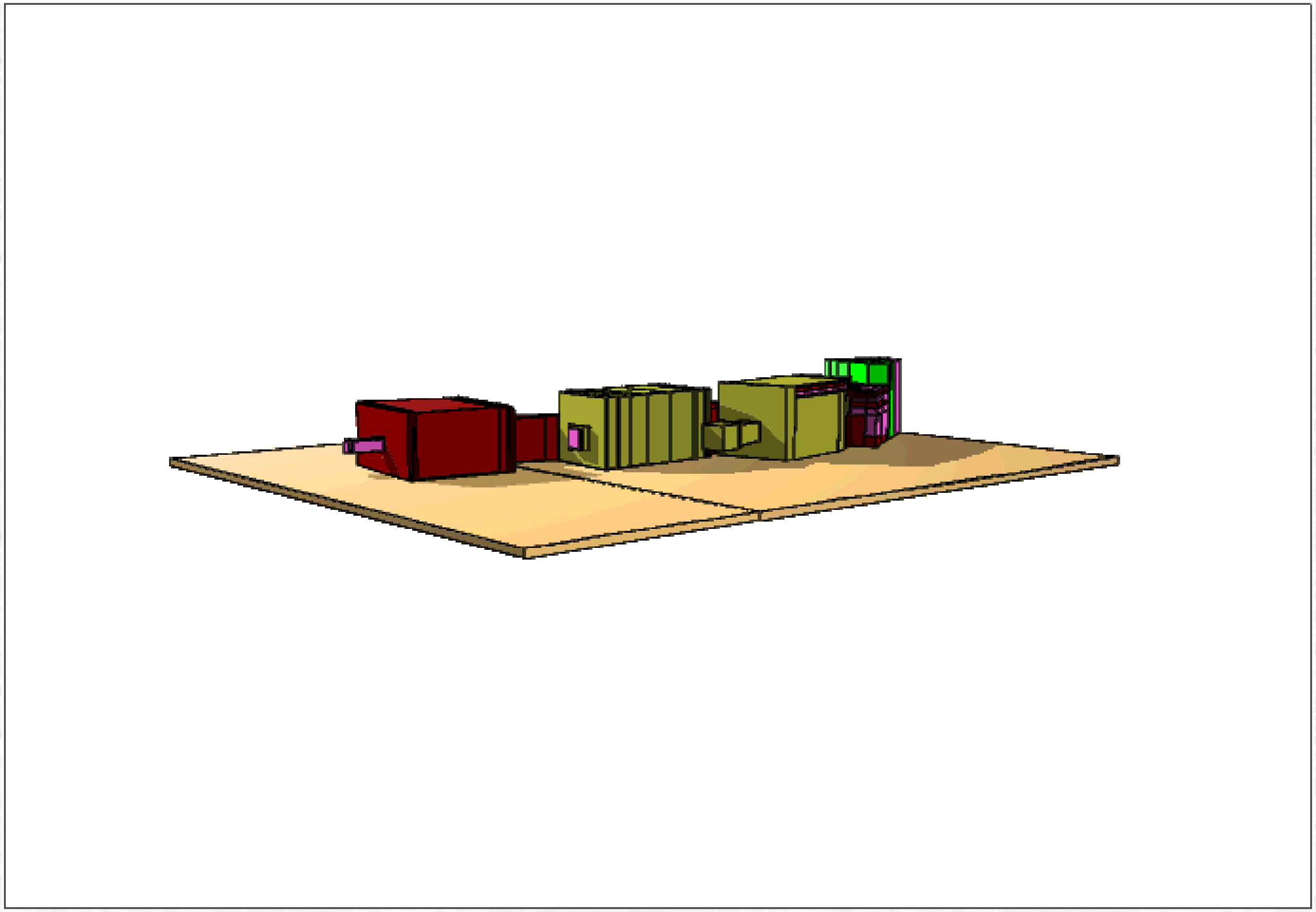
Conclusions

PHITS has a great ability of carrying out the HEAT and DPA analysis of High Power Target system for almost all particles and heavy ions with wide energy range.

- The depth dose distribution in a bulk material agrees well between MARS and PHITS.
  dE/dx and total integrated collisional processes are OK.
- The DDX of secondary particles sometime affects very much on the HEAT and DPA values at a local position.
- The transport of recoil nuclei is very important for HEAT and DPA estimation in a small region.
  Non-local approximation is necessary for very thin material.
- Displacement cross sections (PKA cross sections) should be improved for above 10 MeV.
  more comparisons with the data of energy spectrum of residual nuclei are necessary.

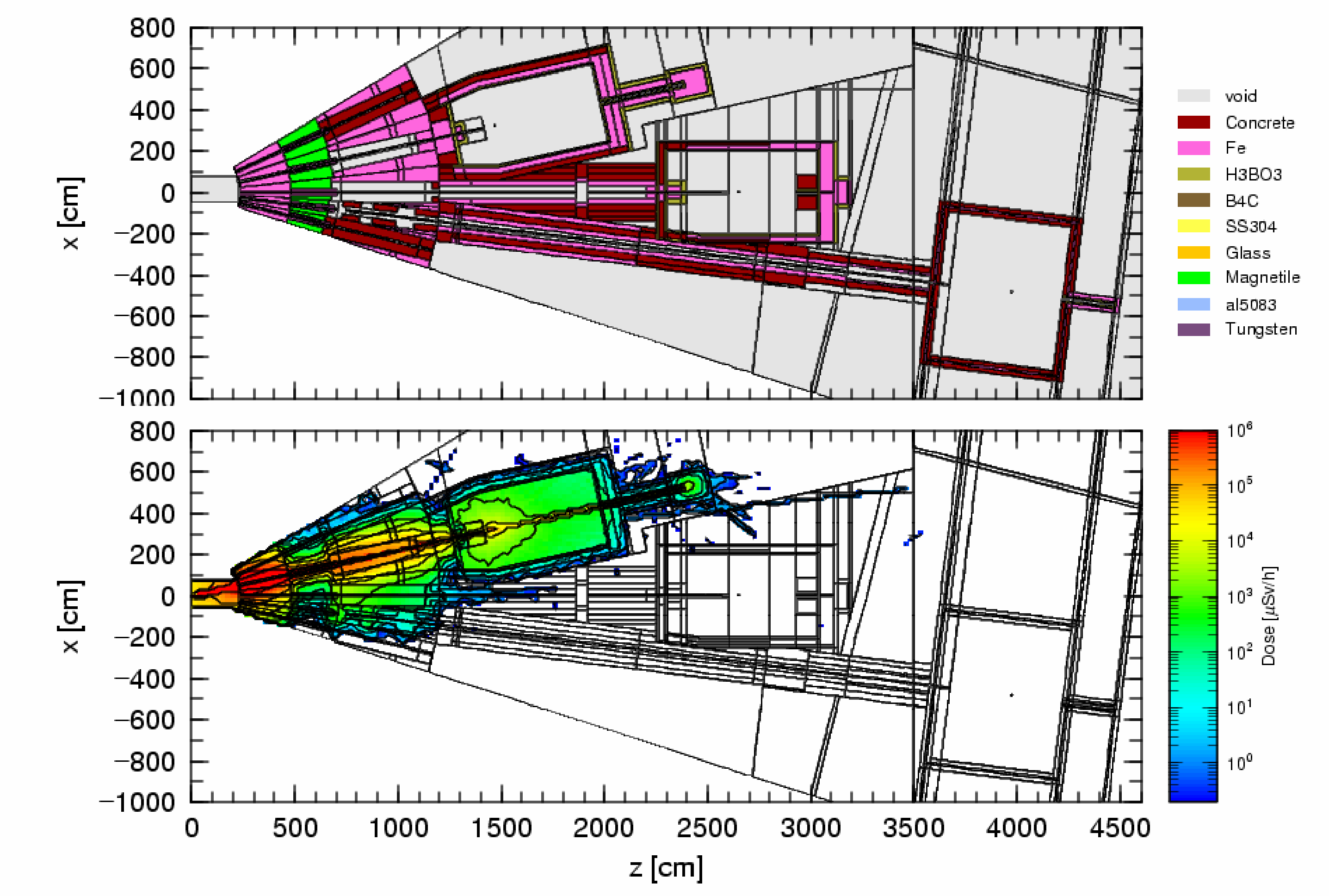
User Interfaces of PHITS

3D view of the calculation model



User Interfaces of ***PHITS***

2D view and 2D output of the final results by color clusters and contour plots with geometry



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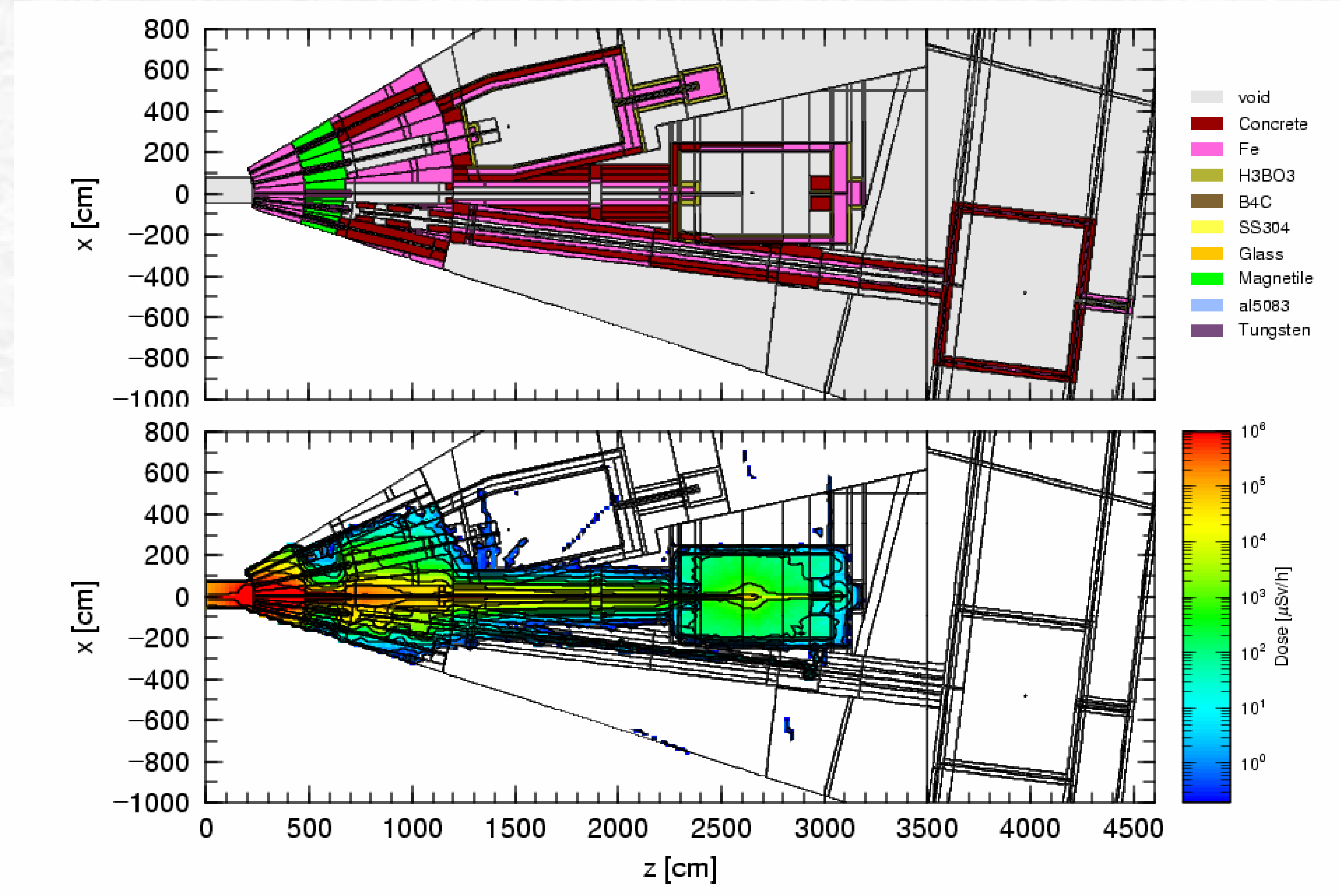

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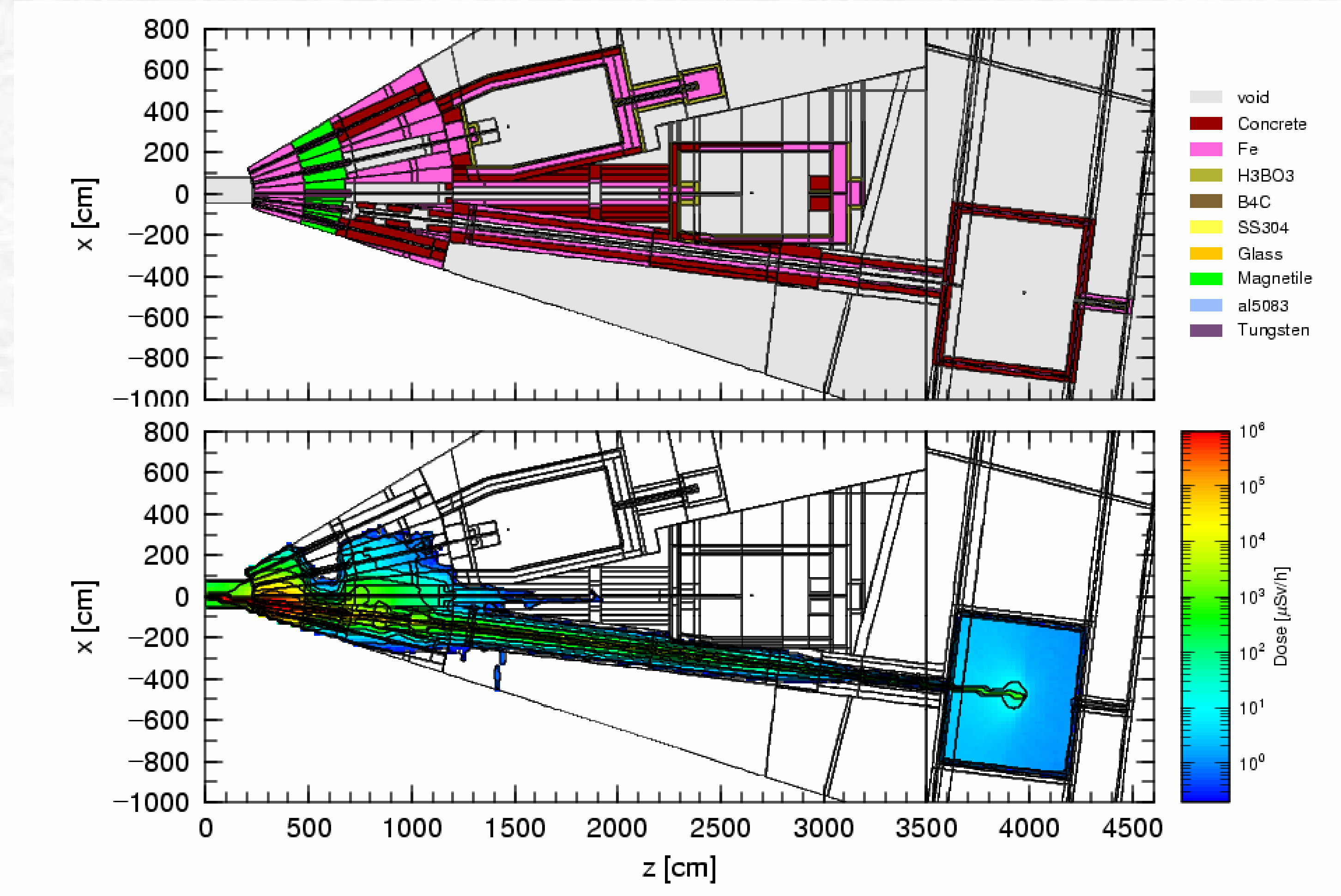


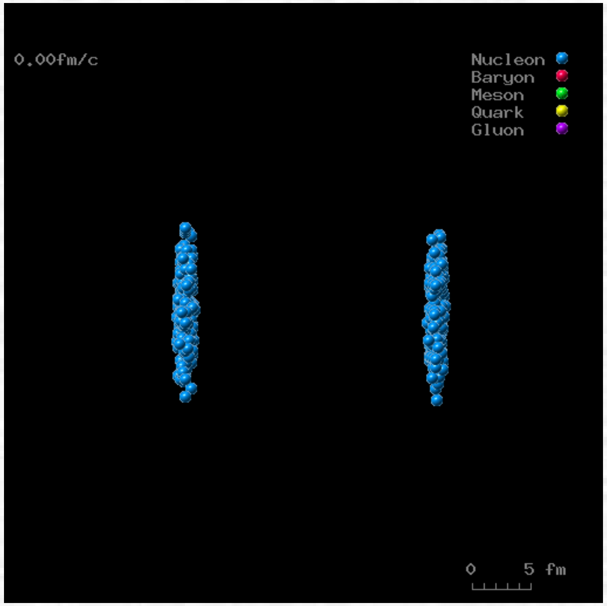
JAM code *for Hadron Nucleus Collisions up to 200 GeV*

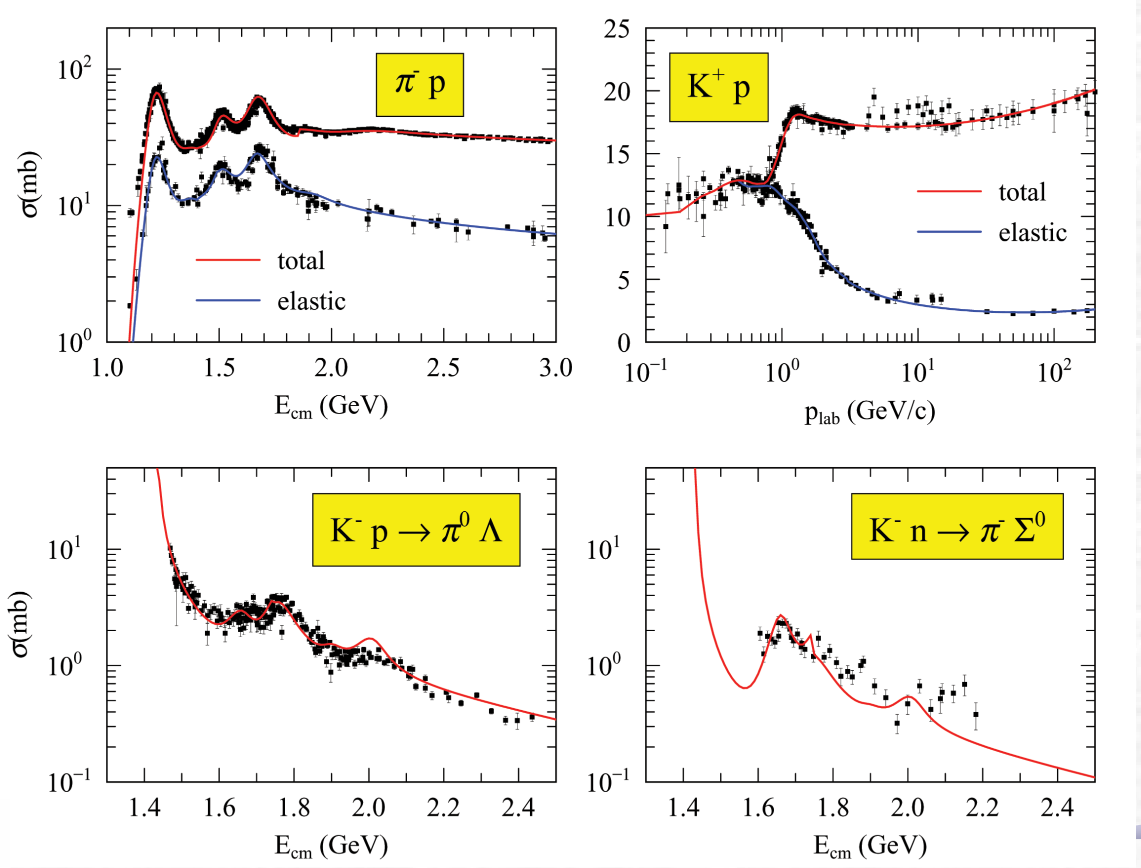
Introducing JAM *(Jet AA Microscopic Transport Model)*   Y. Nara et.al. *Phys. Rev.* **C61** (2000) 024901

JAM is a ***Hadronic Cascade Model***, which explicitly treats all established hadronic states including resonances with explicit spin and isospin as well as their anti-particles.

We have parameterized all ***Hadron-Hadron Cross Sections***, based on ***Resonance Model*** and ***String Model*** by fitting the available experimental data.

Au + Au 200AGeV





119 kinds of Mesons

170 kinds of Baryons

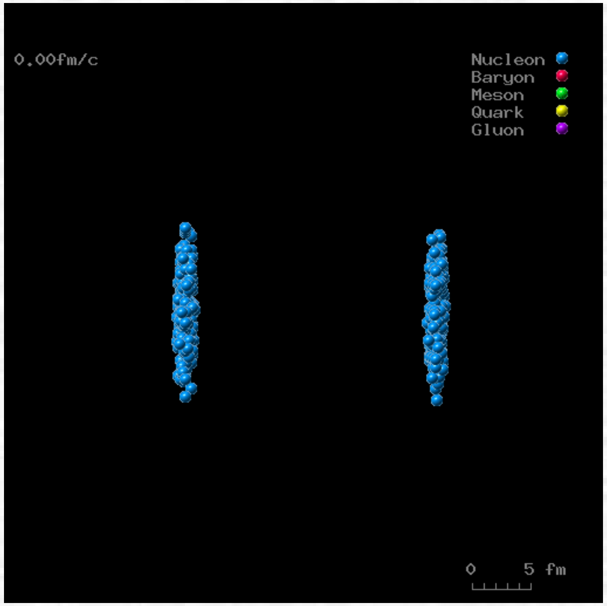
JAM code *for Hadron Nucleus Collisions up to 200 GeV*

Introducing JAM *(Jet AA Microscopic Transport Model)* Y. Nara et.al. *Phys. Rev.* **C61** (2000) 024901

JAM is a ***Hadronic Cascade Model***, which explicitly treats all established hadronic states including resonances with explicit spin and isospin as well as their anti-particles.

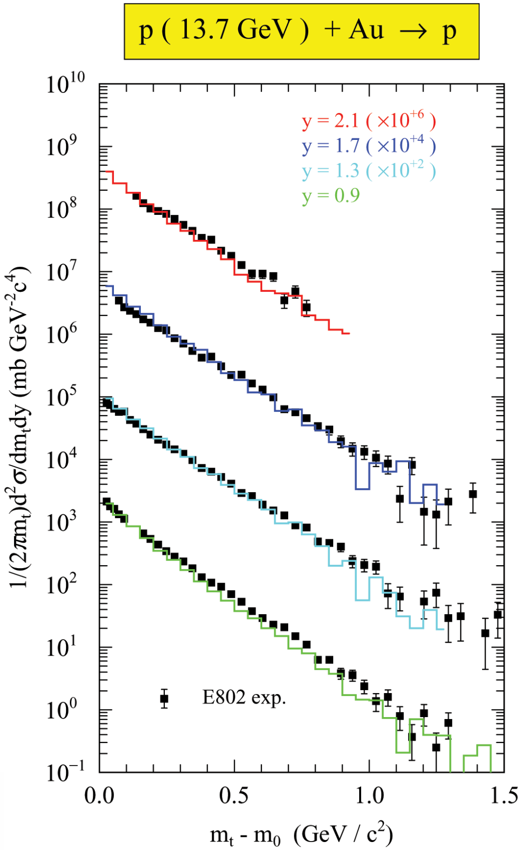
We have parameterized all ***Hadron-Hadron Cross Sections***, based on ***Resonance Model*** and ***String Model*** by fitting the available experimental data.

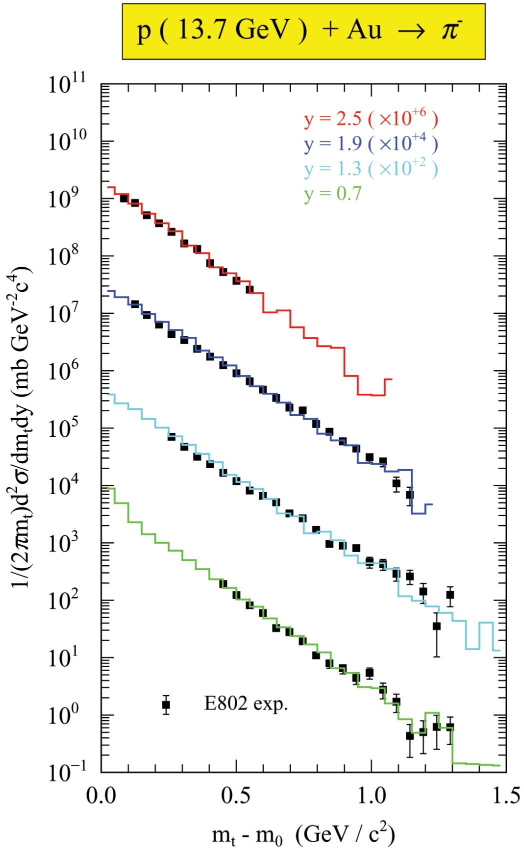
Au + Au 200AGeV



119 kinds of Mesons

170 kinds of Baryons



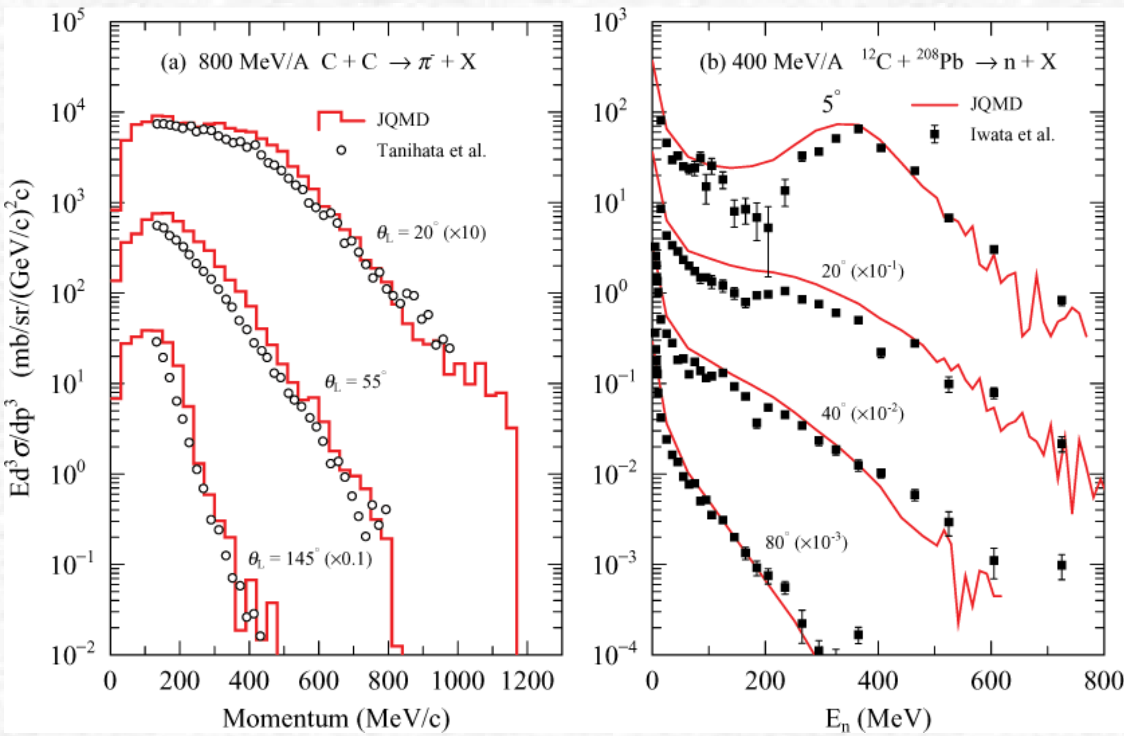


JQMD code *for Nucleus-Nucleus Collisions up to 100 GeV/u*

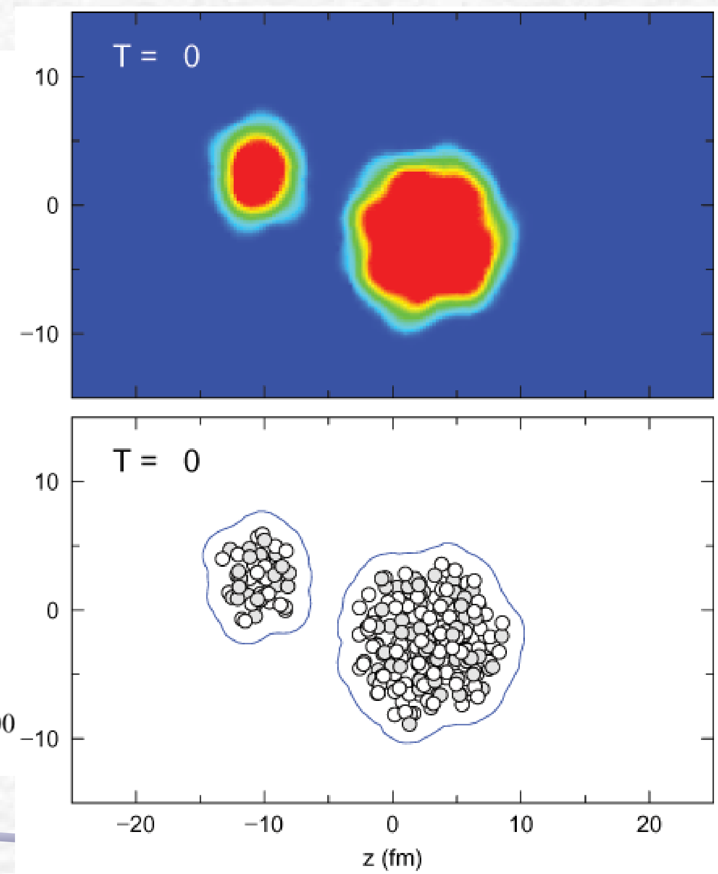
JQMD *(Jaeri Quantum Molecular Dynamics)* *for Simulation of Nucleus-Nucleus Collisions*

K. Niiita et.al. *Phys. Rev.* **C52** (1995) 2620 *http://hadron31.tokai.jaeri.go.jp/jqmd/*

Analysis of Nucleus-Nucleus Collisions by ***JQMD***



^{56}Fe 800 MeV/u on ^{208}Pb



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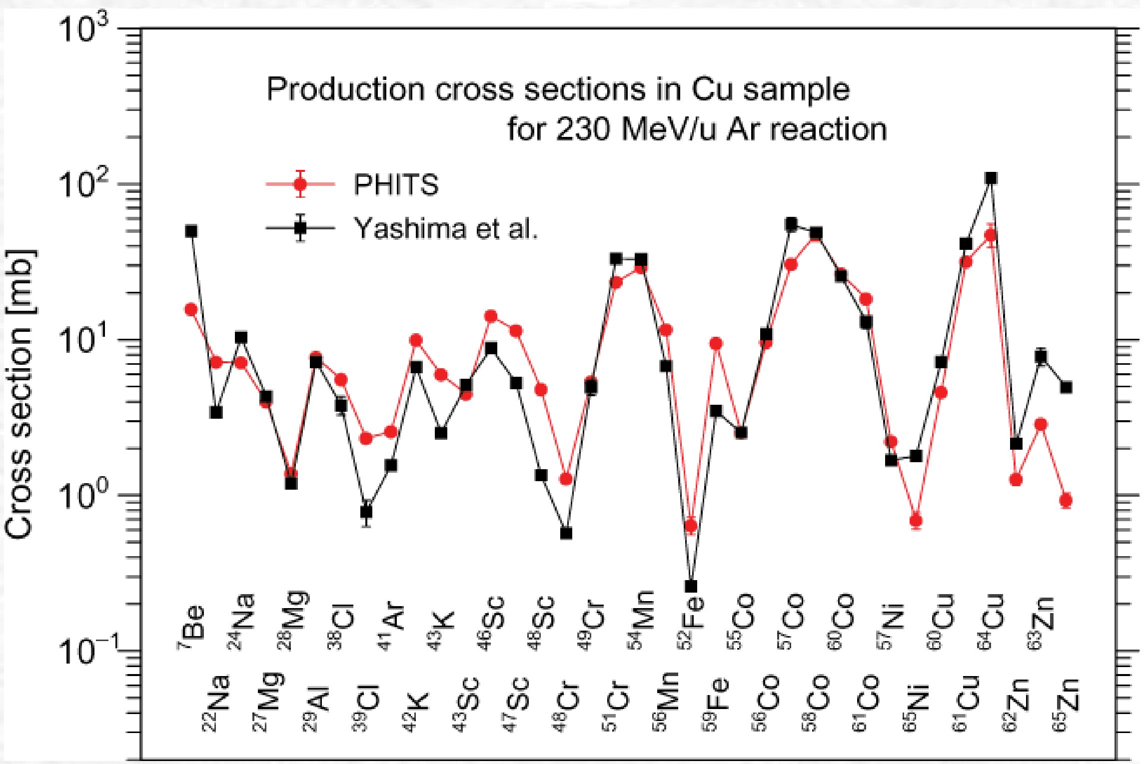

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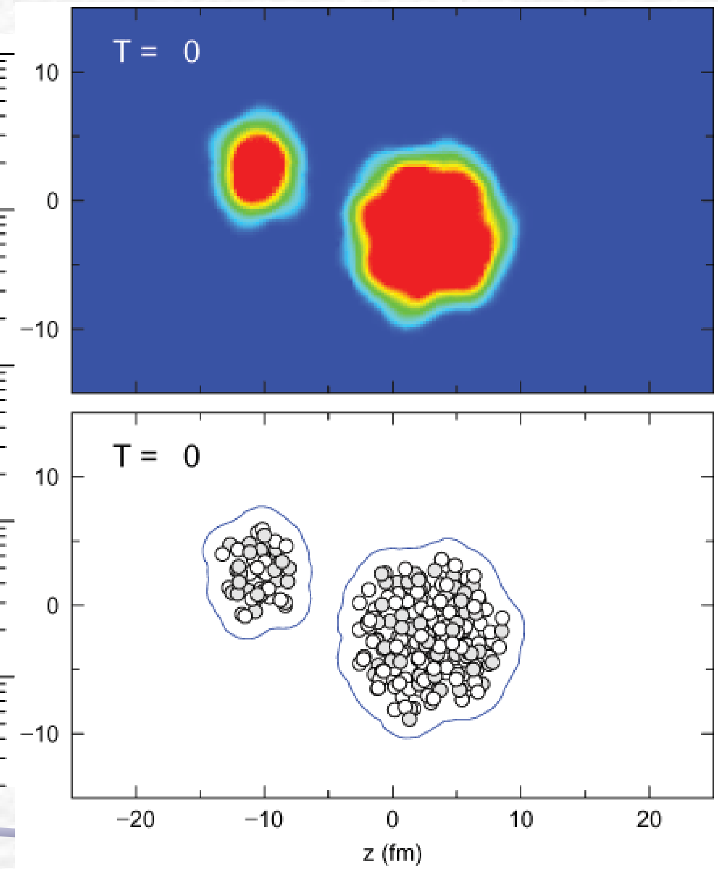
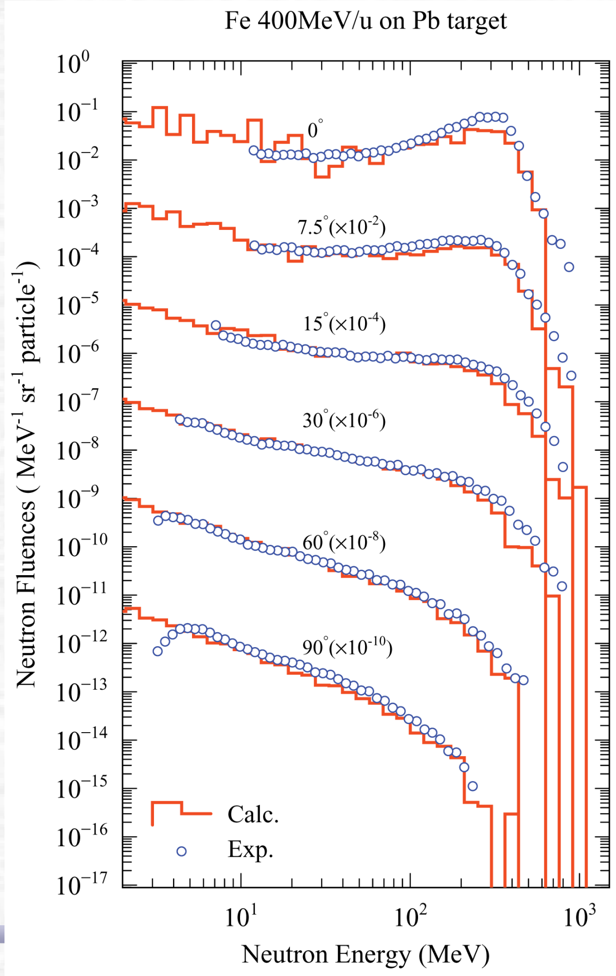


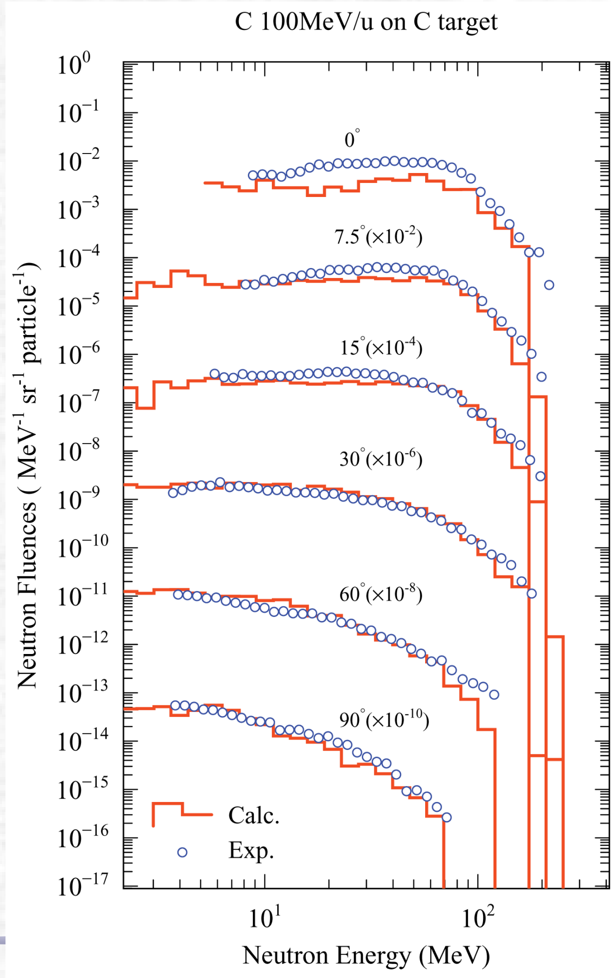
JQMD code in PHITS

Introducing JQMD in PHITS : H. Iwase et.al. *J. Nucl. Sci.Technol.* **39** (2002) 1142

Results of PHITS

Neutron Spectra from Thick Target





Heat by photon transport

by Kerma (local approximation)
or by Ionization of Electrons

Photon induced in Cu
800, 100, 10 MeV