Korea Institute of Science and Technology Information

A Study on Heavy Ion Beam Simulation using Geant4

11th International Geant4 Tutorial in Korea

August 19 (Mon), 2024

Kyungho KIM

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Contents

Introductions

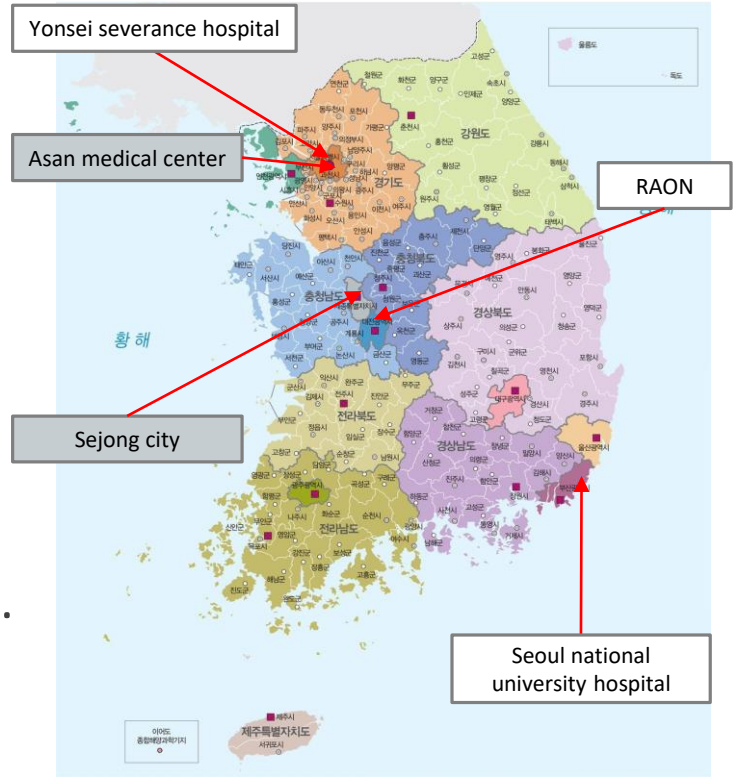
Motivation

The last few years have seen a rise in the number of particle accelerators built in Korea.

- Confirmed
  - RAON, 2023 (Scientific)
  - Yonsei Severance hospital, 2023 (Medical)
  - Seoul national university hospital, 2025 (Medical)
- Consideration
  - Asan medical center (Medical)
  - Sejong city (Medical)
- .. And so on.

But there has been relatively little focus on accelerator-based study of secondary particles.

=> Planning heavy ion beam simulation

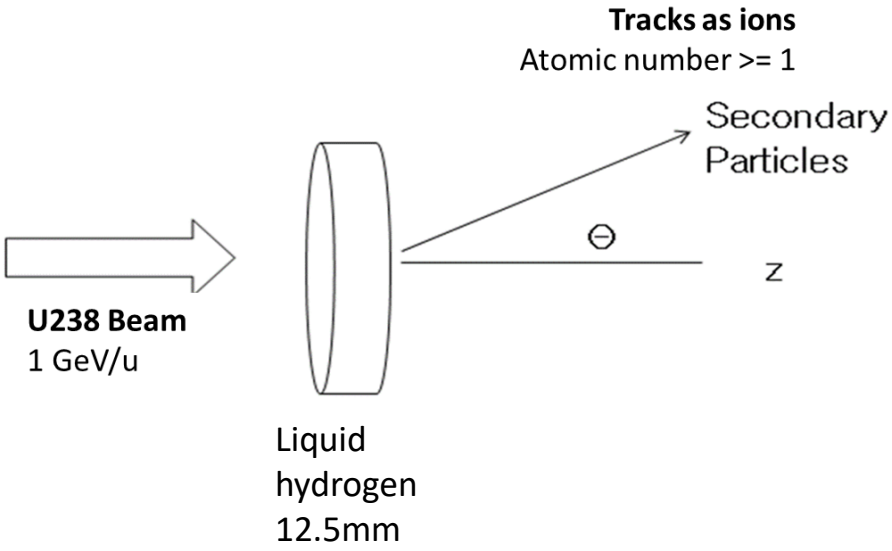


Validation of physics lists

Conditions

Conditions of experiments

- Geant4 version: 11.0.2
- 1 million events per each condition
- On KISTI-5 supercomputer (Nurion)



Schematic of simulation

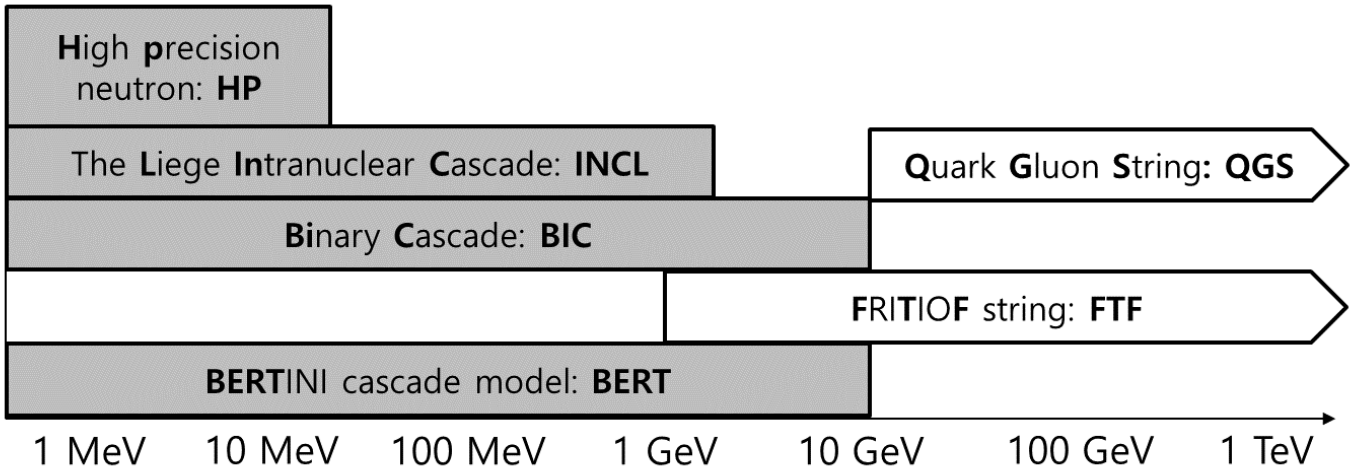
Simulation	Geant4 Beam		Target	
	Particle	Energy (MeV/u)	Materials	Thickness (mm)
U → Liquid Hydrogen	U	1000	Liquid Hydrogen	12.5

Beam & target conditions for validation

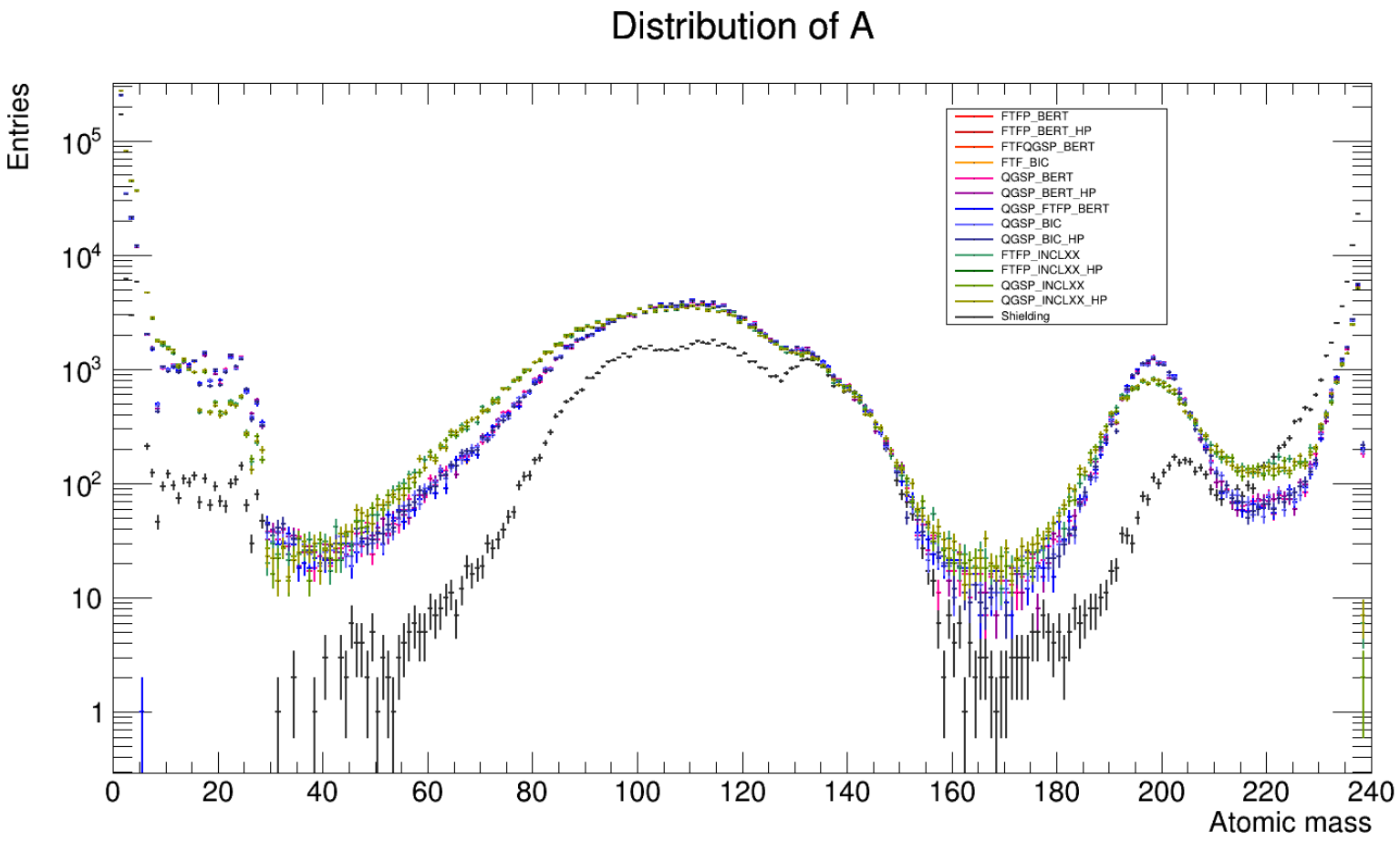
Physics List

Considered physics list in Geant4

- FTFP_BERT, FTFP_BERT_HP, FTFQGSP_BERT, QGSP_FTFP_BERT
- FTF_BIC, QGSP_BERT, QGSP_BERT_HP, QGSP_BIC
- FTFP_INCLXX, FTFP_INCLXX_HP, QGSP_INCLXX, QGSP_INCLXX_HP
- Shielding



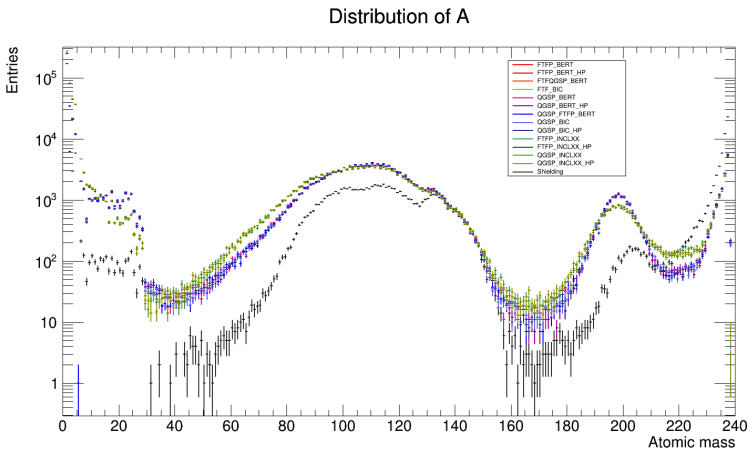
Distribution: Atomic Mass

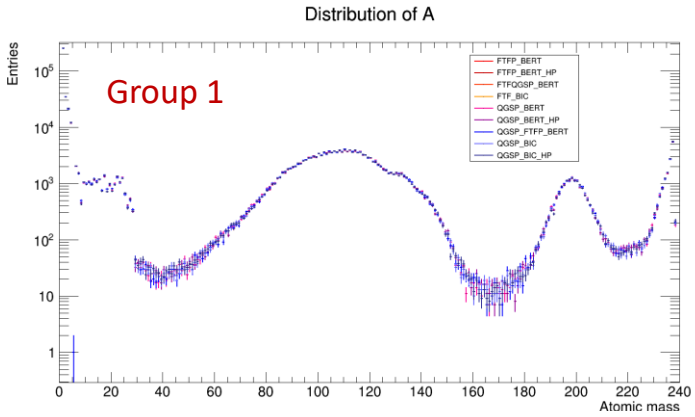


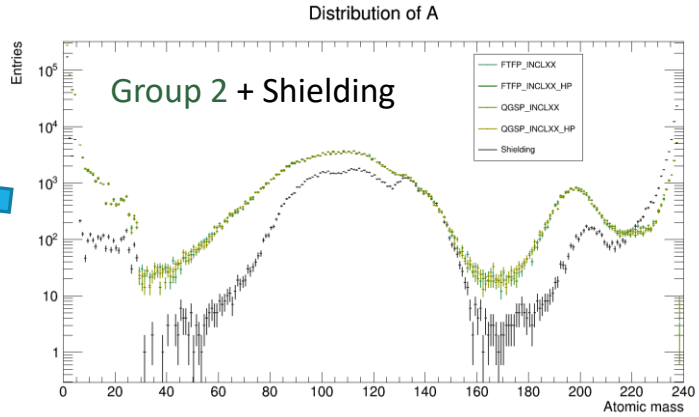
Distribution: Atomic Mass

PhysicsLists are separated to 3 groups

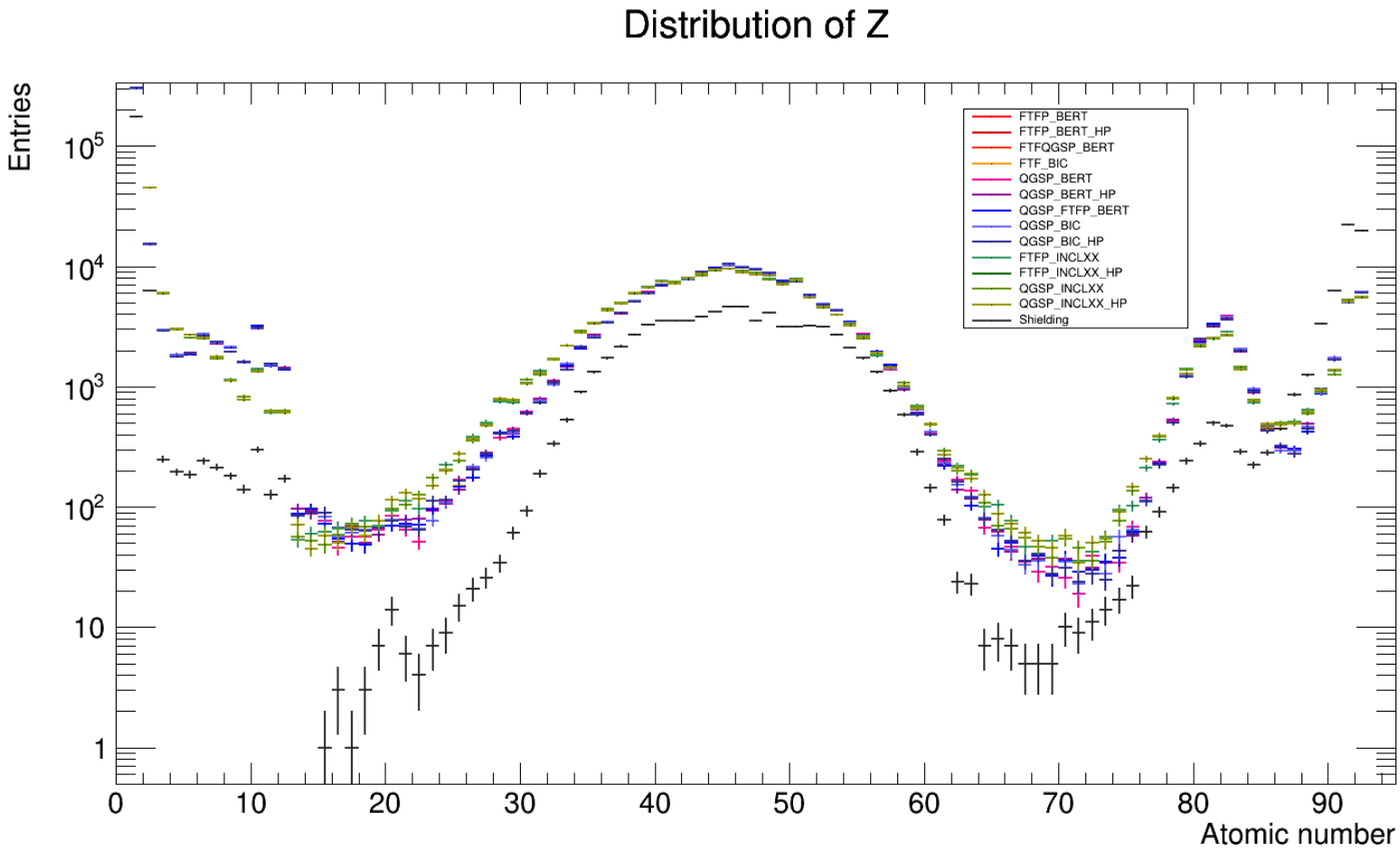
- Group 1: FTFP_BERT, FTFP_BERT_HP, FTFQGSP_BERT, FTF_BIC, QGSP_FTFP_BERT, QGSP_BERT, QGSP_BERT_HP, QGSP_BIC, QGSP_BIC_HP
- Group 2: FTFP_**INCLXX**, FTFP_**INCLXX**_HP, QGSP_**INCLXX**, QGSP_**INCLXX**_HP
- **Shielding**







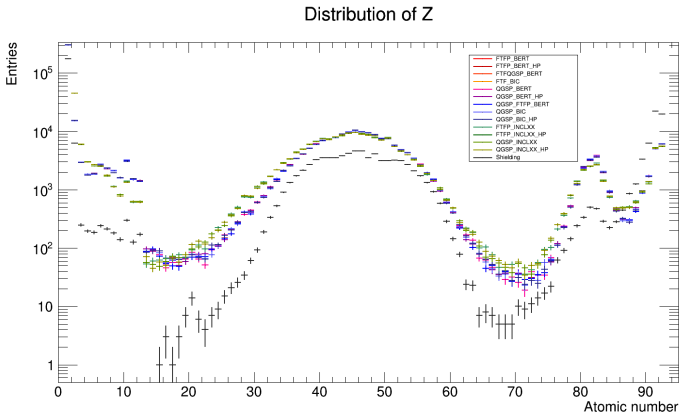
Distribution: Atomic Number

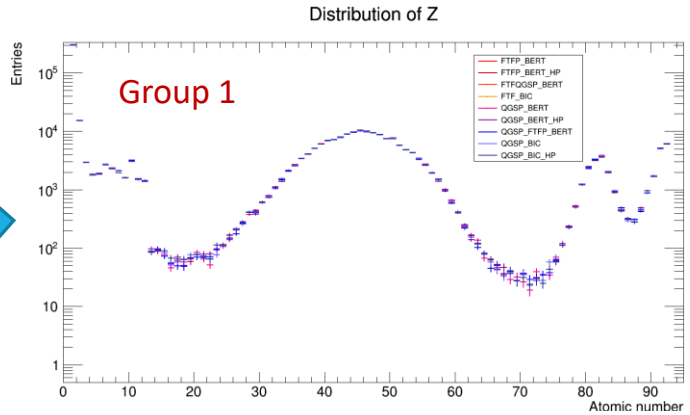


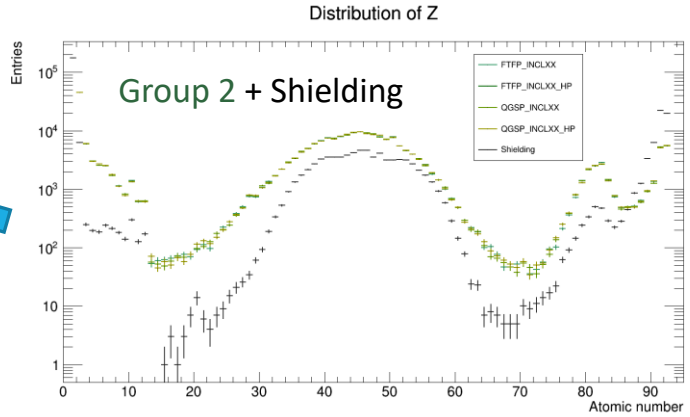
Distribution: Atomic Number

PhysicsLists are separated to 3 groups

- Group 1: FTFP_BERT, FTFP_BERT_HP, FTFQGSP_BERT, FTF_BIC, QGSP_FTFP_BERT, QGSP_BERT, QGSP_BERT_HP, QGSP_BIC, QGSP_BIC_HP
- Group 2: FTFP_**INCLXX**, FTFP_**INCLXX**_HP, QGSP_**INCLXX**, QGSP_**INCLXX**_HP
- **Shielding**







Finding the Best Physics List

The best physics list for studying heavy-ion beam simulation

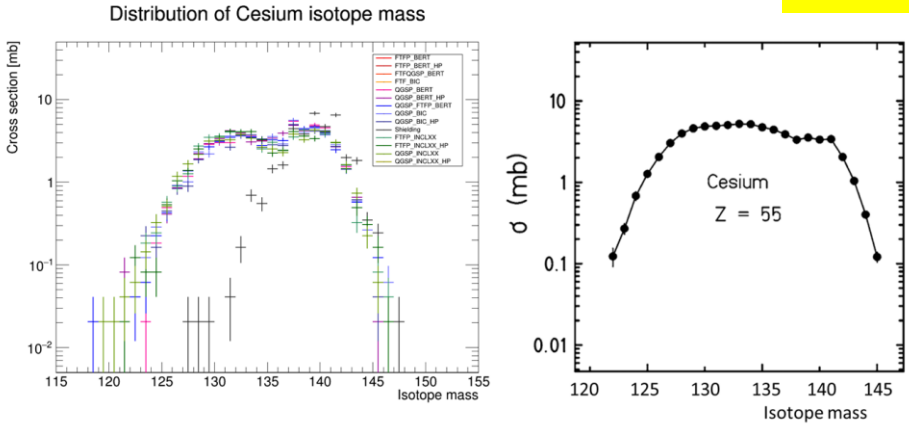
- The amount of the secondary particles

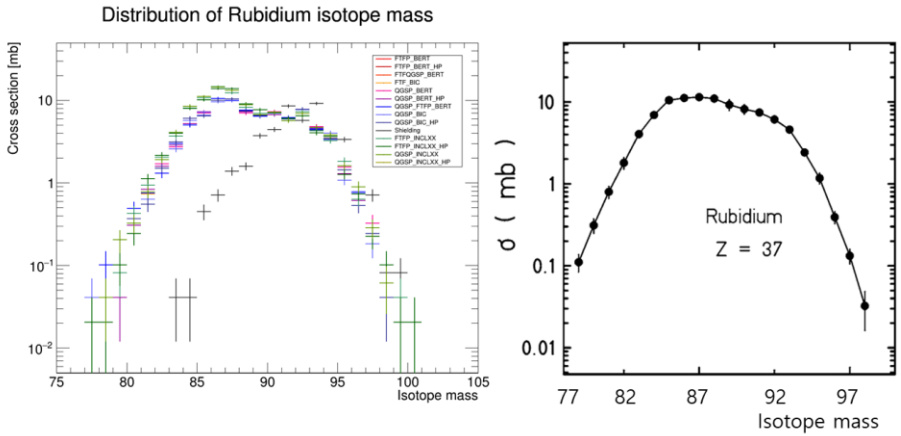
- The validity compared with experiment

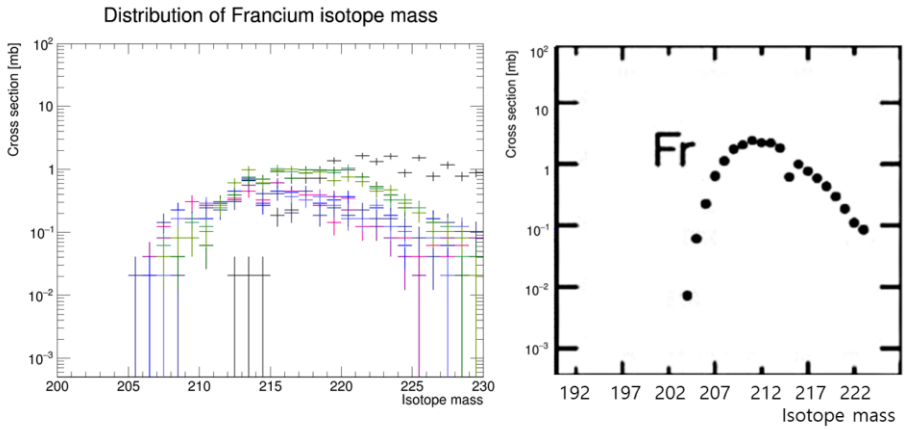
- Cost-effective CPU time

Isotope Distribution

M. Bernas, et al., Nucl. Phys. A 725, 213 (2003).







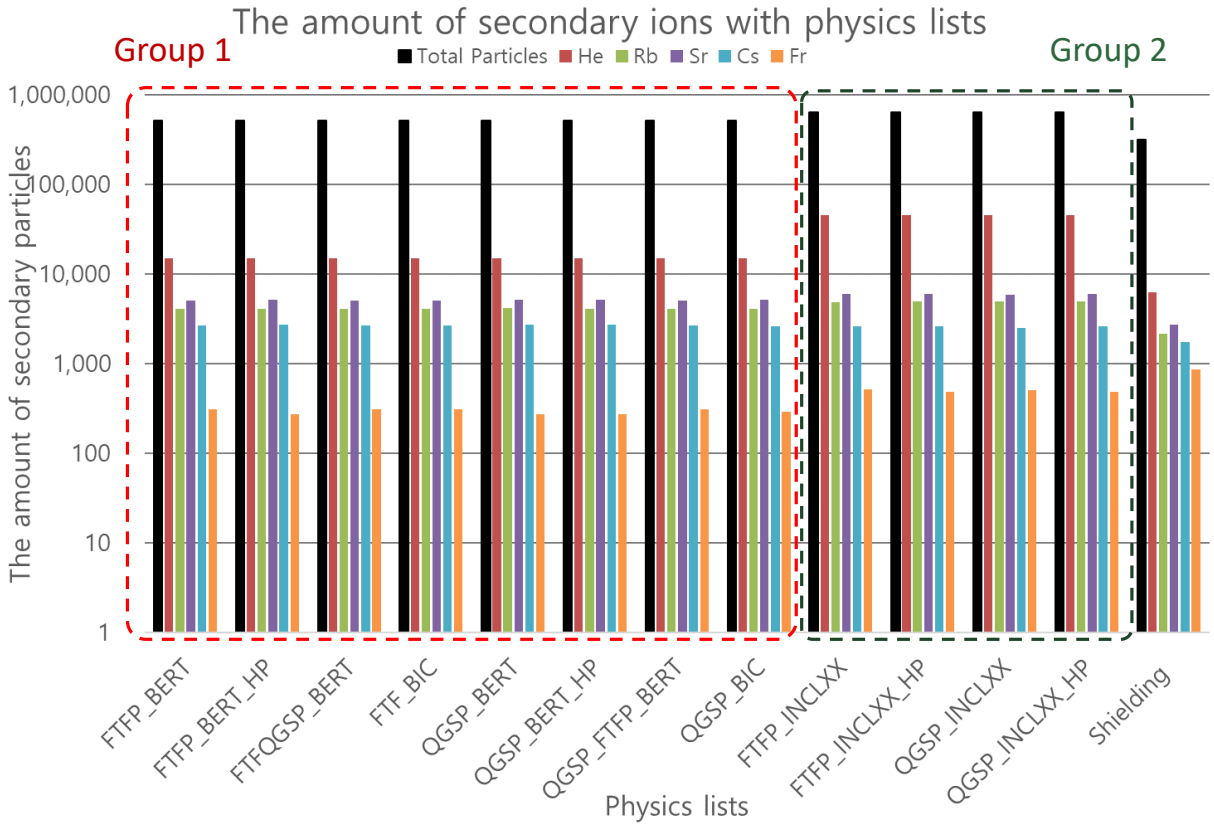
M. Bernas, et al., Nucl. Phys. A 725, 213 (2003).

J. Taieb, et al. Nucl. Phys. A 724, 413 (2003).

Created Secondary Ions

Group 2 physics list take more secondary ions.

- More detailed description than physics lists in group 1



Computing Time

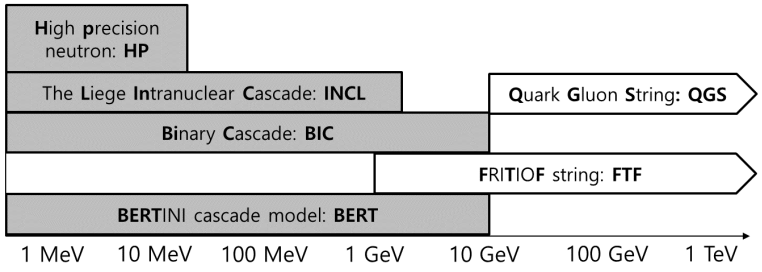
Excluding ‘Shielding’ for our suitable list (due to long runtime)

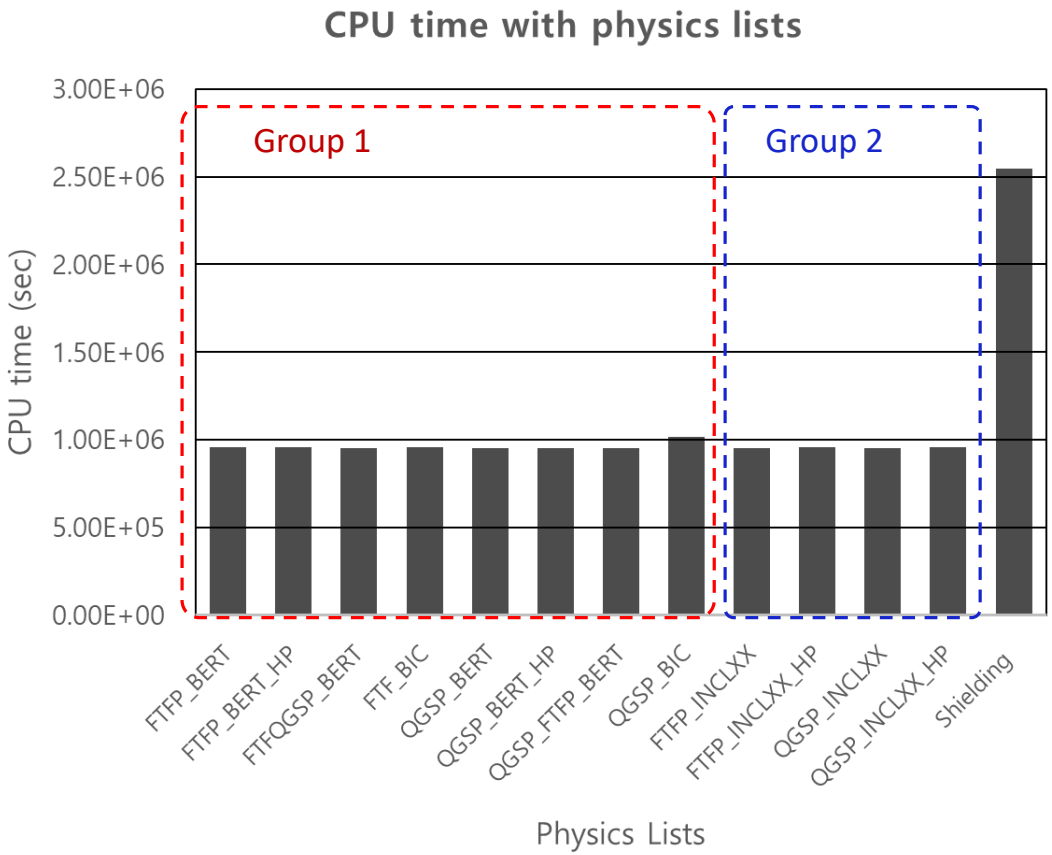
Others looks same.

- Any physics list (except Shielding) would be OK.

What would be the best?

- **FTFP_INCLXX**



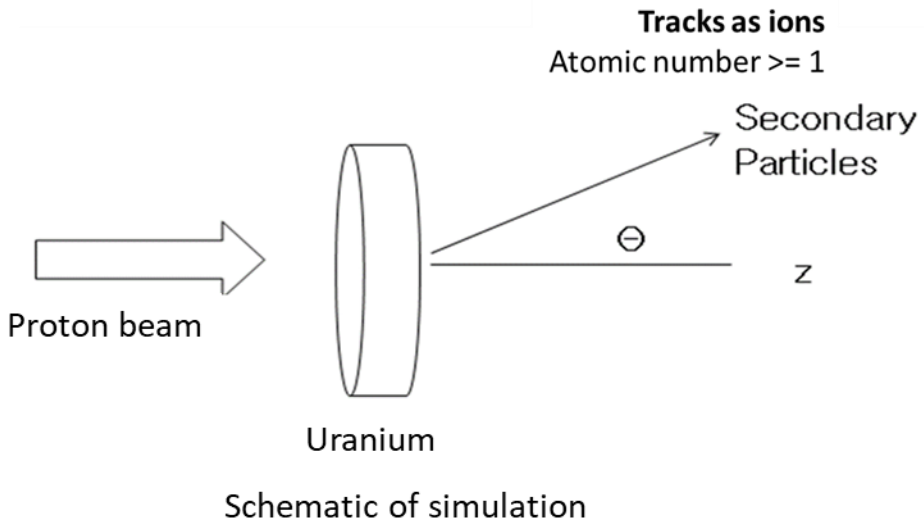


Prodution of secondary particles

Conditions

Conditions of experiments

- Geant4 version: 11.0.2
- 1 million events per each condition

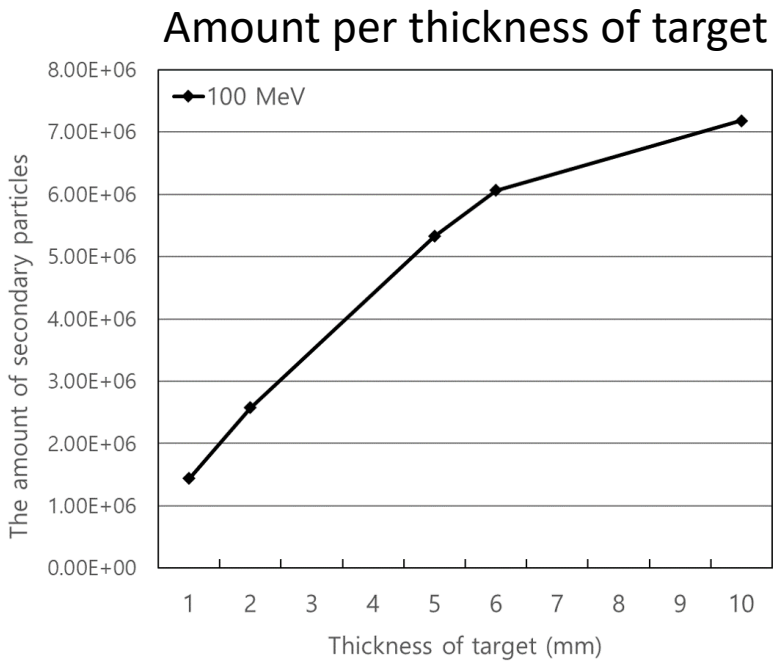


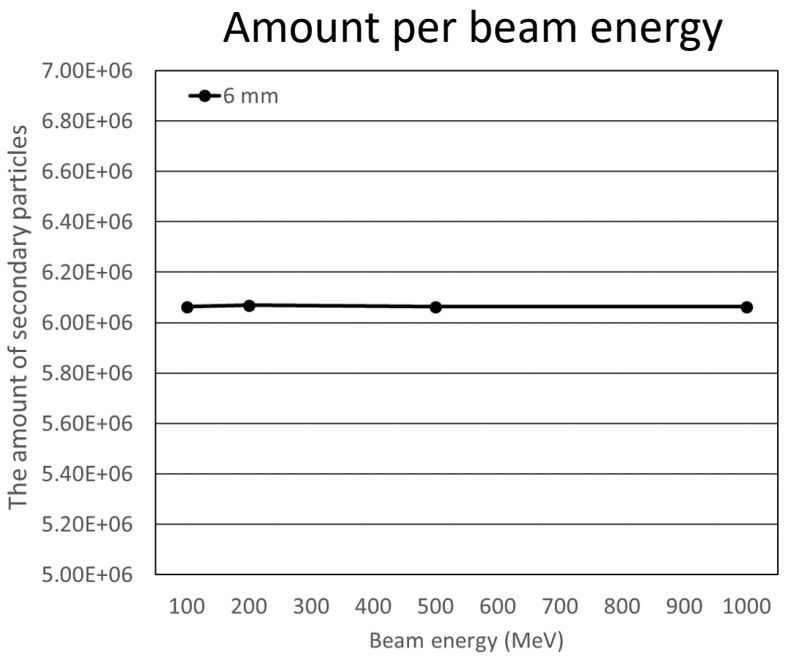
Schematic of simulation

Simulation	Geant4 Beam		Target	
	Particle	Energy (MeV/u)	Materials	Thickness (mm)
Proton → U	Proton	100, 200, 500, 1000	Uranium	6
Proton → U	Proton	100	Uranium	1, 2, 5, 6, 10

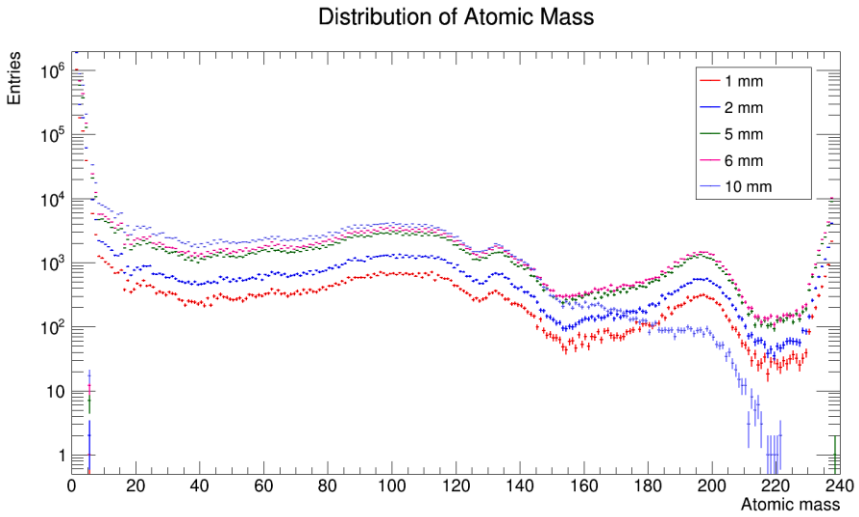
Beam & target conditions for validation

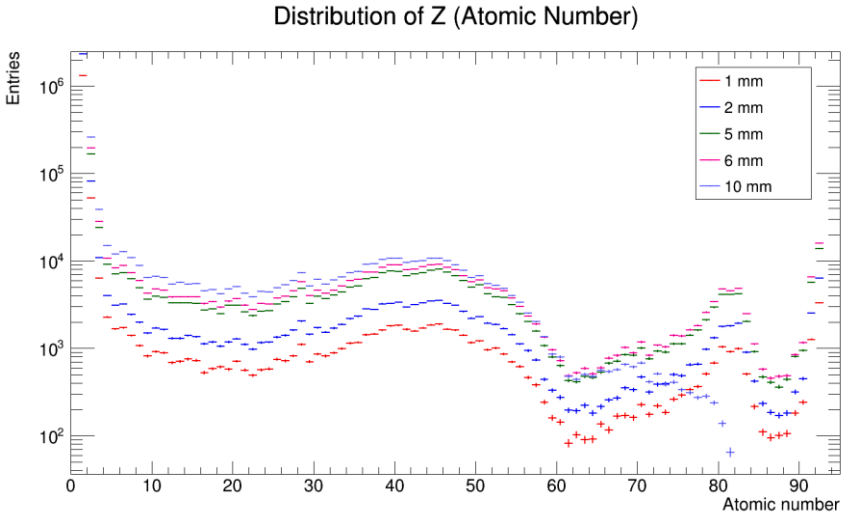
Amount of Secondary Particles

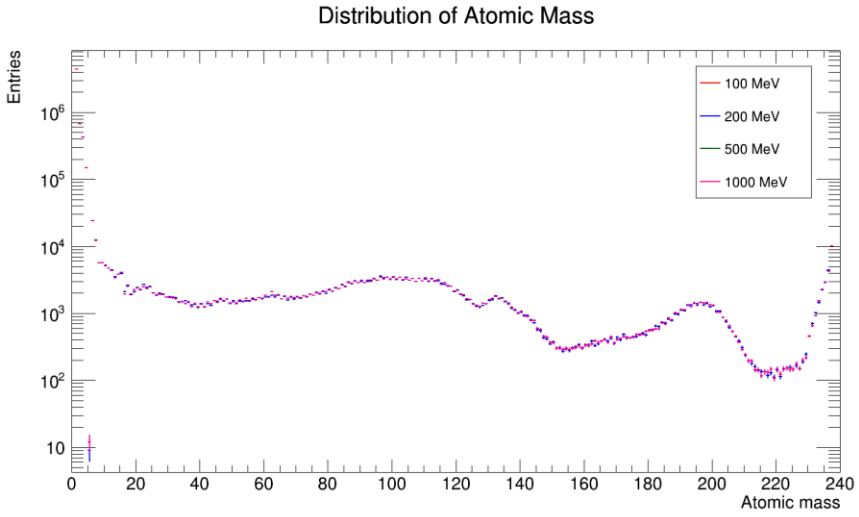


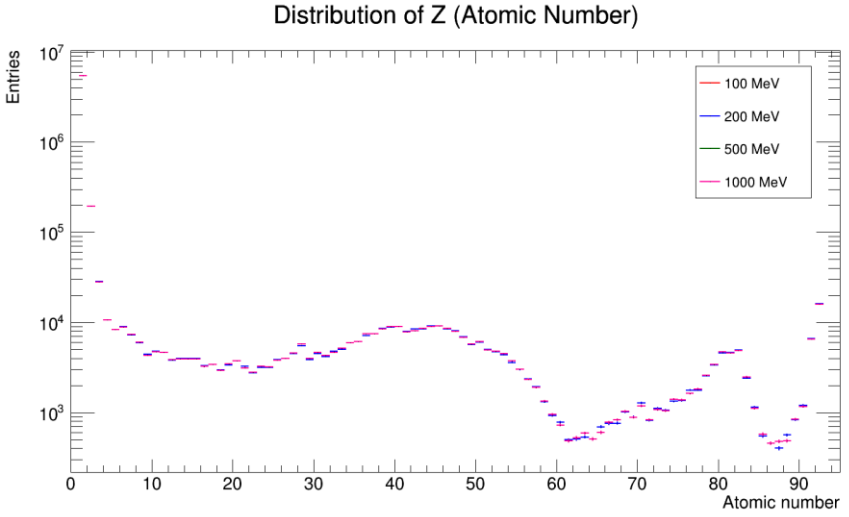


Amount of Secondary Particles

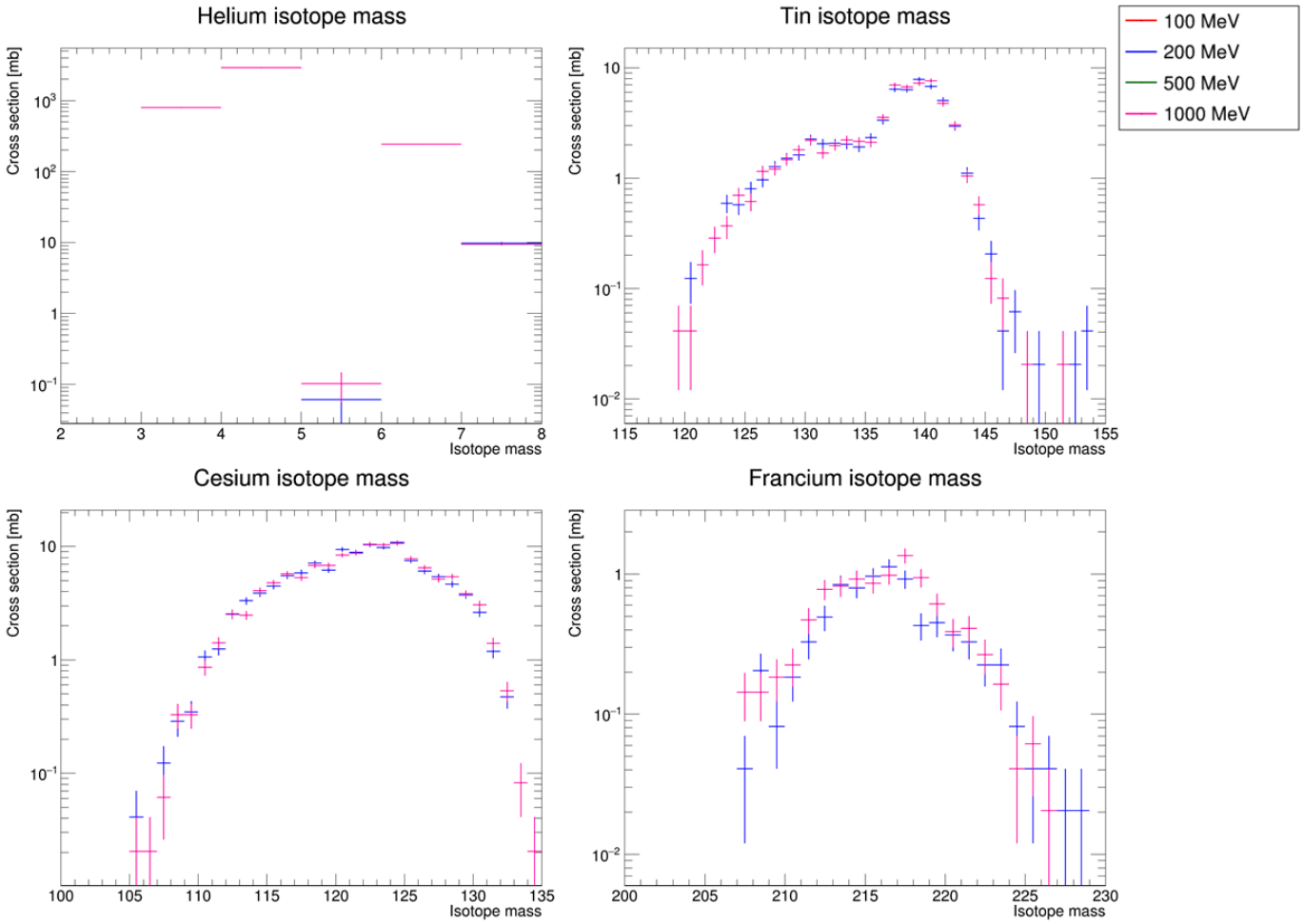




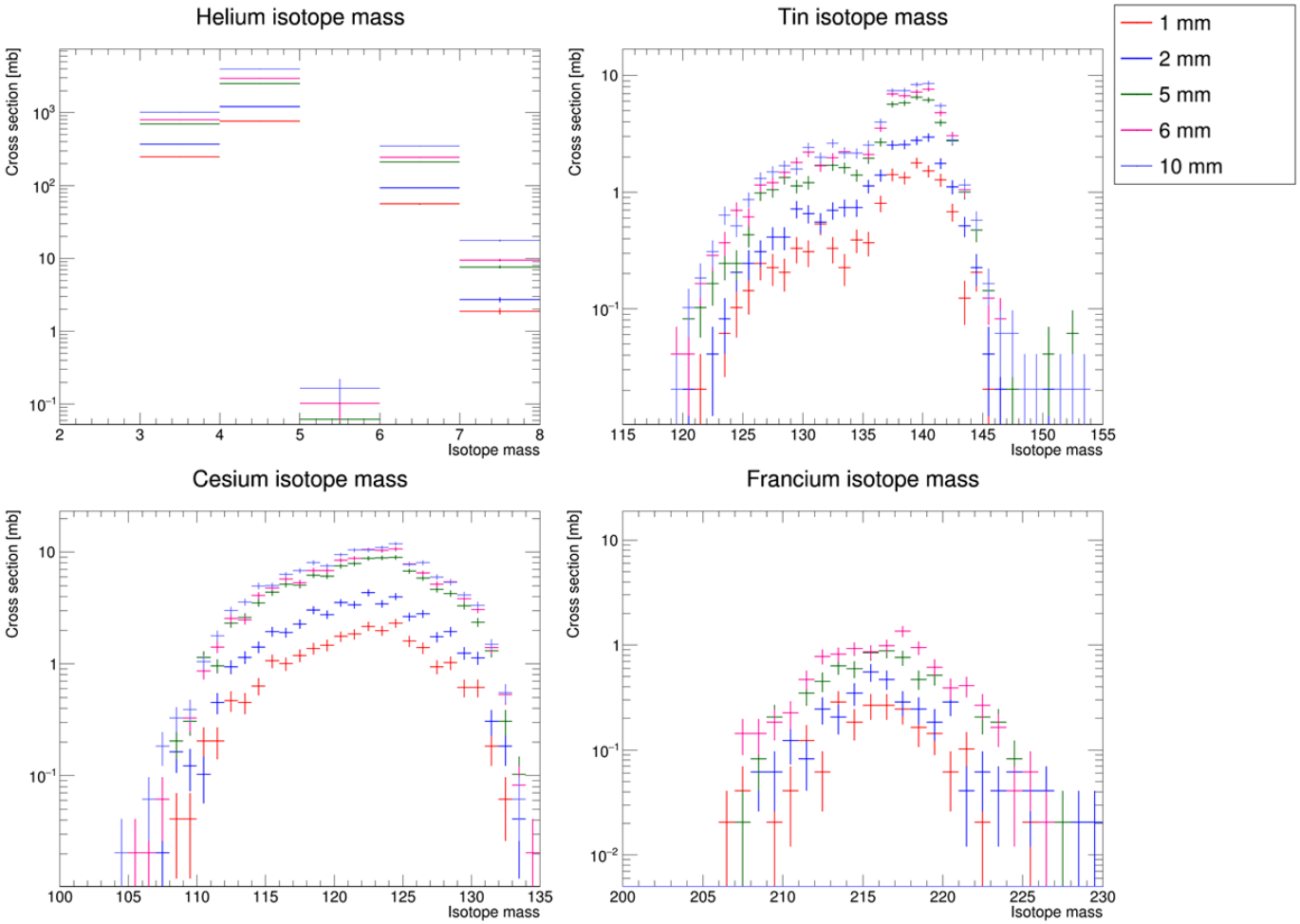




Amount of Specific Isotopes



Amount of Specific Isotopes

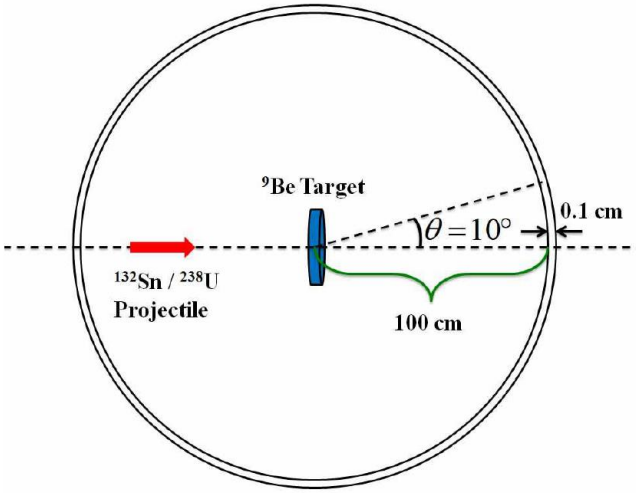


Additional: Collaboration with IBS CENS for RAON

Conditions

Conditions of experiments

- Geant4 version: 11.0.2
- 100,000 events per each condition
- PhysicsList: FTFP_INCLXX
- Ion counting condition
  - Escaped from Be target
  - Travel 100cm from target
  - Forward direction with θ < 10°



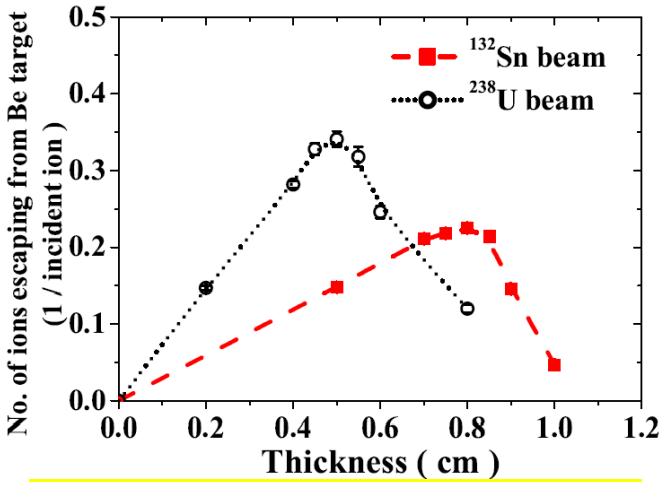
Simulation	Geant4 Beam		Target	
	Particle	Energy (MeV/u)	Materials	Thickness (mm)
Sn → Be	Sn132	200	Beryllium	1 ~ 10 mm (1mm step)
U → Be	U238	200		

Beam & target conditions for KoBRA simulation

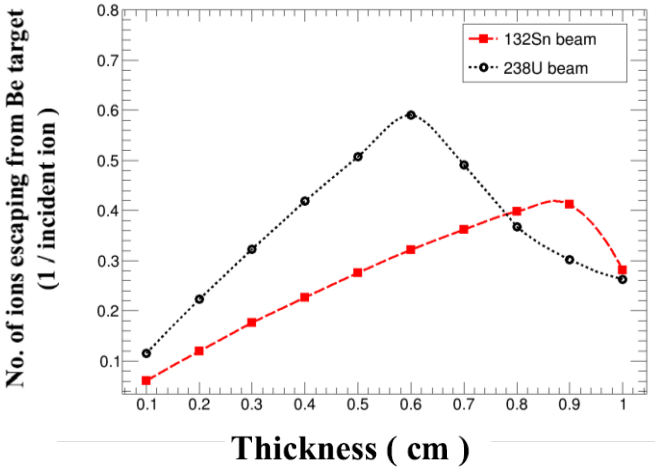
Amounts of Events

Tendency on distribution

- Thin target: penetrate the target
- Thick target: ions cannot escape from target
- What is the best target thickness for given condition?
- Comparison with previous study (by J. W. Shin)
  - Different physics list (FTF_BIC vs. FTFP_INCLXX)
  - Similar shape but different ‘maximum number of ions’

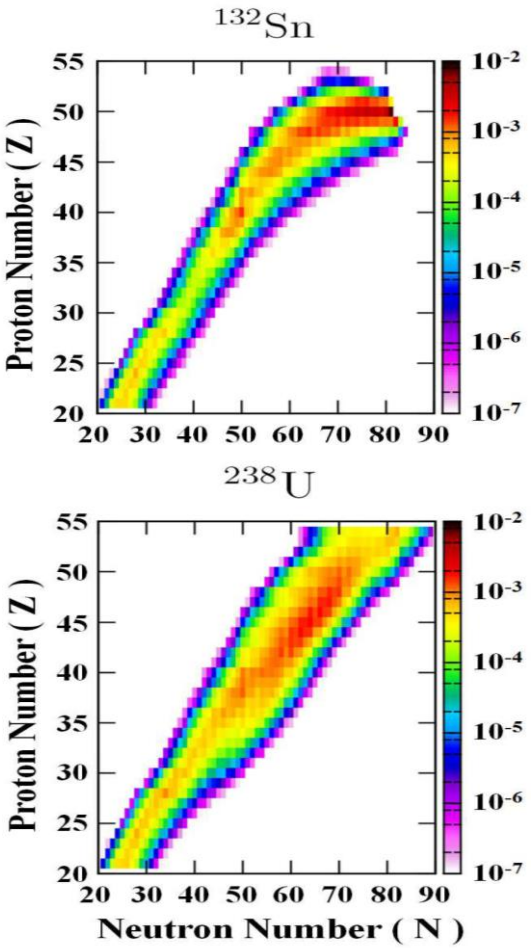


J. W. Shin *et al.*, NIM B 349, 221 (2015)



My work

Isotopic Production Yields



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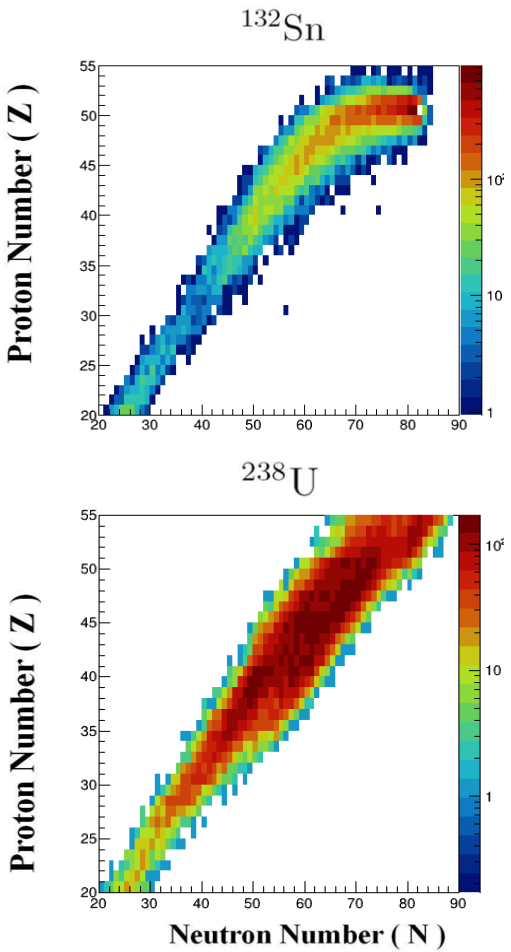


My work

Summary & Plan

We studied heavy ion beam simulation on Geant4.

- We found the optimized PhysicsList among Geant4 reference PhysicsLists with uranium beam emission to liquid hydrogen target.
- The atomic mass & number distributions are separated to 3 groups.
  - INCLXX group
  - Non-INCLXX group
  - Shielding
- Mass distribution of specific atoms (Cs, Rb, Fr) and comparison with real experiment are shown.
- CPU time and the amount of secondary ions are shown.
- The most optimized PhysicsList is FTFP_INCLXX.

We tested the proton beam emission to uranium target with various target thickness and beam energy.

We are collaborating IBS CENS to apply our Geant4 simulation to simulate RAON.

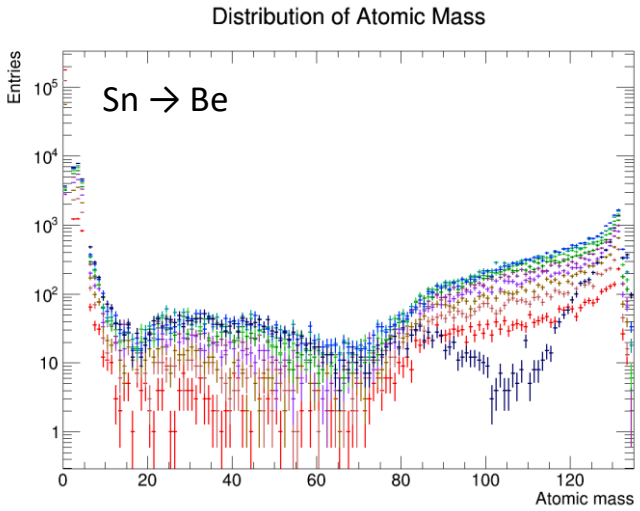
Thank you!

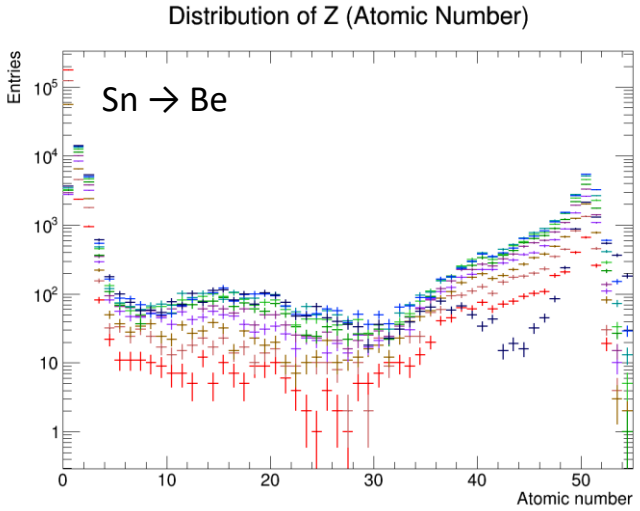
Acknowledgment

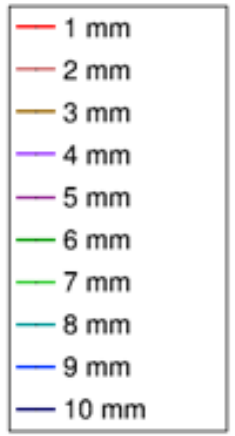
- National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (No. 2021R1F1A1064008)
- The major institutional R&D program, KISTI (No. K24L2M1C4) and National Supercomputing Center with supercomputing resources including technical support (KSC-2024-CHA-0001)

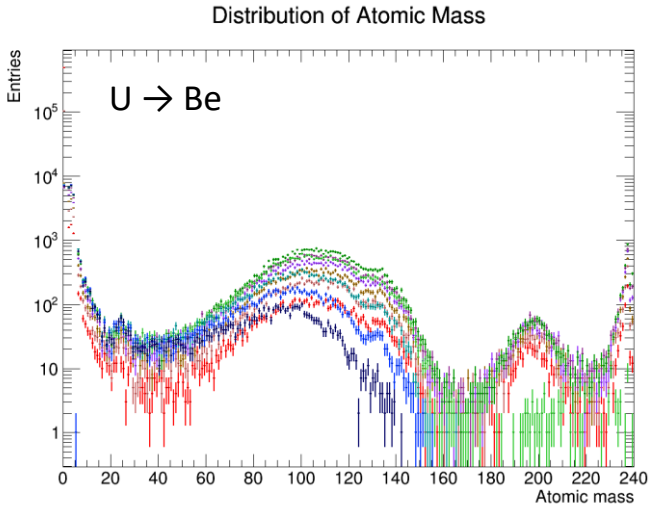
Backup

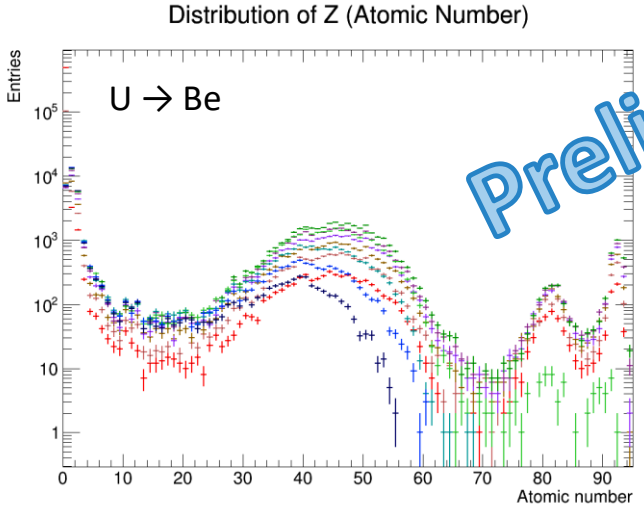
Distributions: Atomic Mass, Number











Preliminary

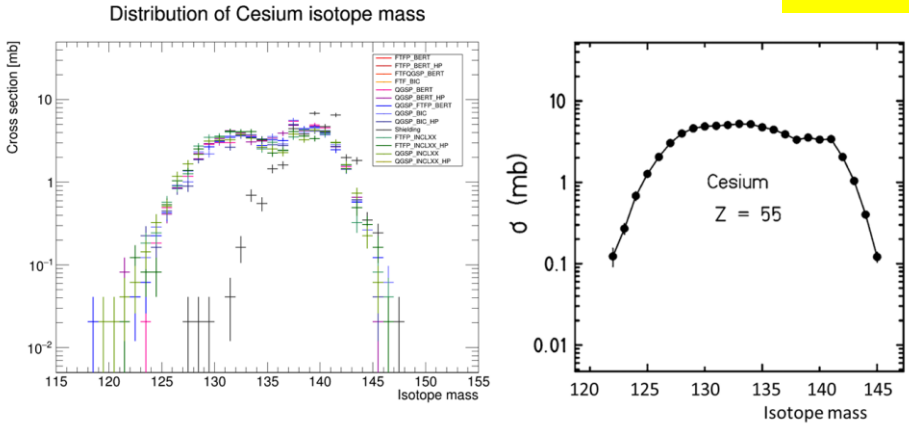
Calculation of Cross-section

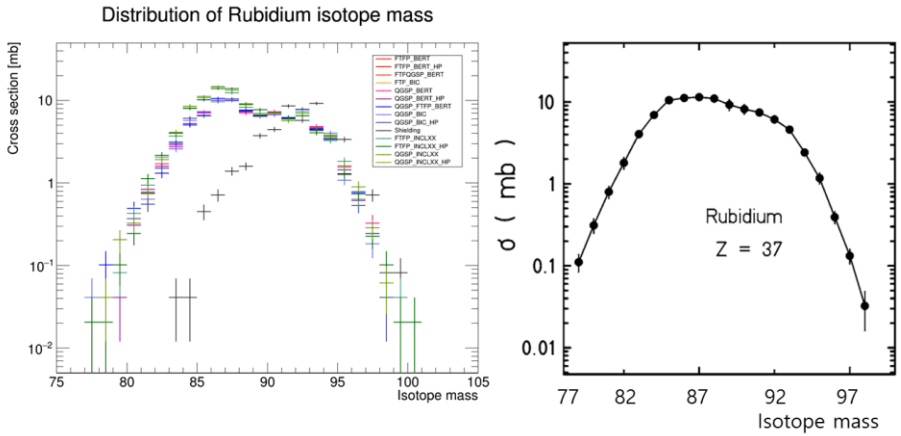
Calculation of cross-section

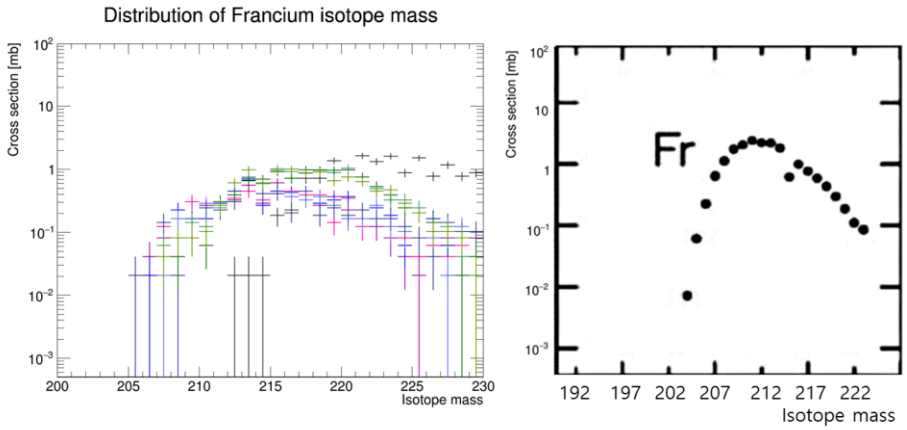
- $\sigma = \frac{N}{AB\delta_t \ell}$
  - N: the number of observed events
  - A: acceptance (set to 0.75)
  - ℓ: target length = 1.25cm
  - δ_t: the number density of target particles
    - $\delta_t = \rho / m_H = 4.23 \times 10^{22} (cm^{-3})$
  - B: effective number of beam particles = 1.24×10^6
    - $B = N_b \int_0^{\ell} e^{-\frac{x}{\lambda_1}} dx = N_b \times 1.24 = 1{,}240{,}000$
      - N_b: the number of beam particles incident to fixed target = 1,000,000
      - λ_1: interaction length = 734.5 cm

Isotope Distribution

M. Bernas, et al., Nucl. Phys. A 725, 213 (2003).





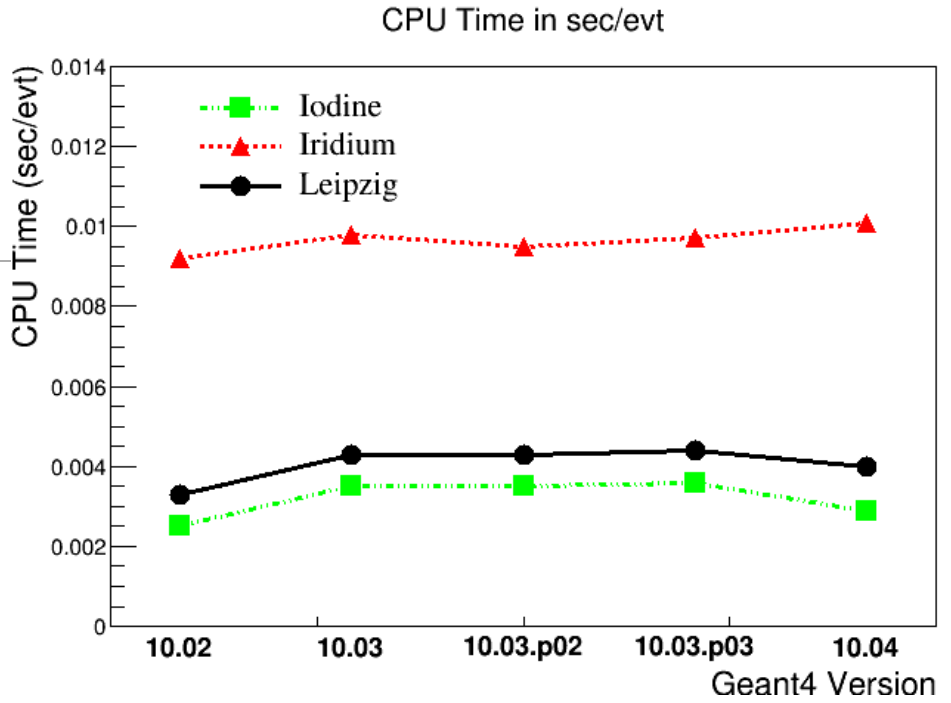


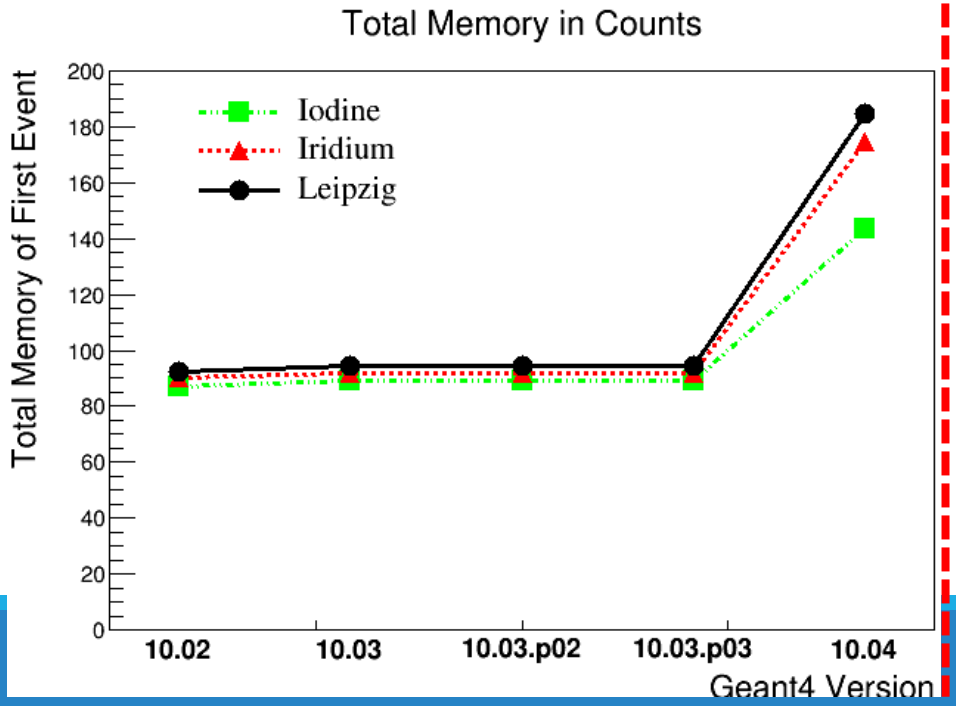
M. Bernas, et al., Nucl. Phys. A 725, 213 (2003).

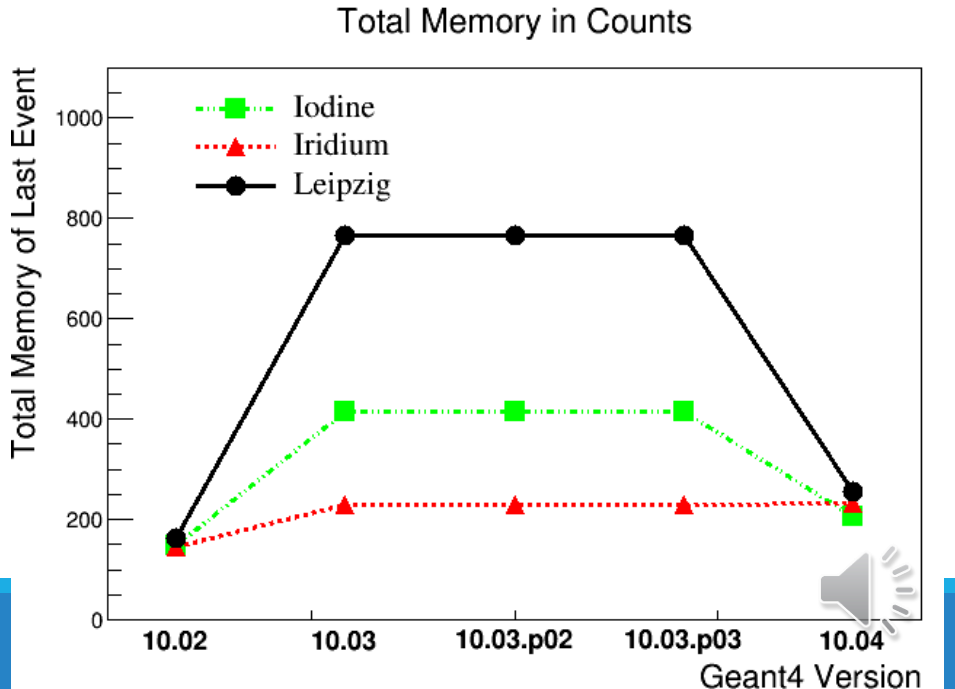
J. Taieb, et al. Nucl. Phys. A 724, 413 (2003).

1. KISTI-4 (Tachyon2)

QGSP BIC EMZ

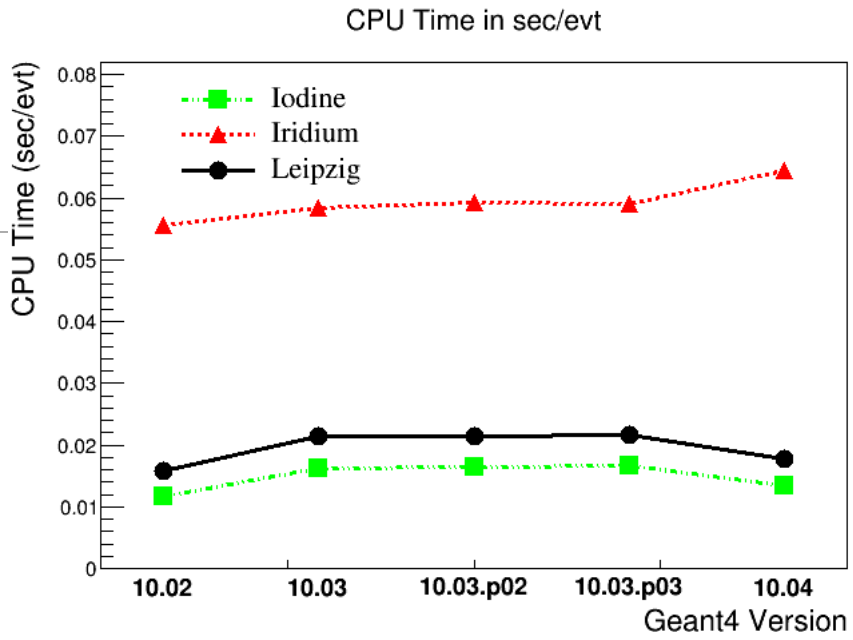


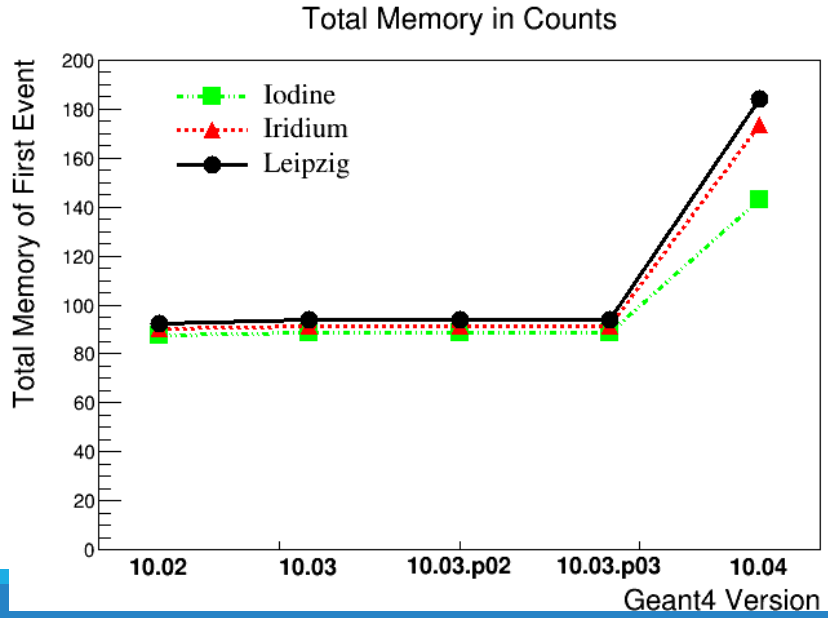


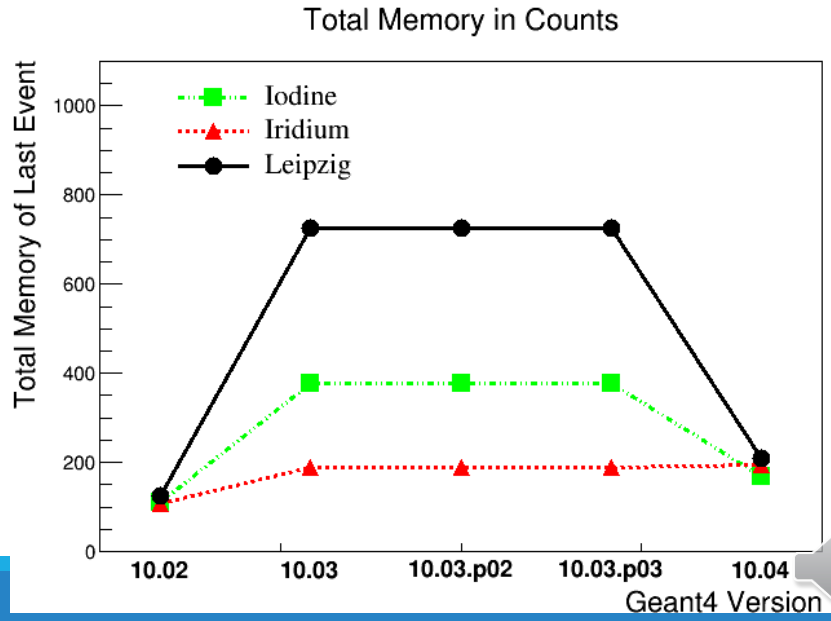


2. KISTI-5 (Nurion KNL)

QGSP BIC EMZ







Summary of profiling

As computing architectures evolve, the Geant4 simulation tool kit requires optimization for CPU time and memory size.

⇒ The role of profiling system is important.

The results will provide Geant4 users of HEP and medical physics with experiences of many-core processors of HPC.