High1 workshop on Particle, String and Cosmology

January 21 ~ 27, 2024

The status of Geant4 simulation tool kit

2024. 1. 23

Kihyeon CHO (KISTI)

Working with

- Dr. Kyungho Kim
- Dr. Alexei Sytov
- Kihong Park

Contents

- Geant4?
- Geant4 @ KISTI
    1. Profiling
    2. Beam simulation
    3. Channeling in Crystal
    4. Plan and Outreach
- Summary

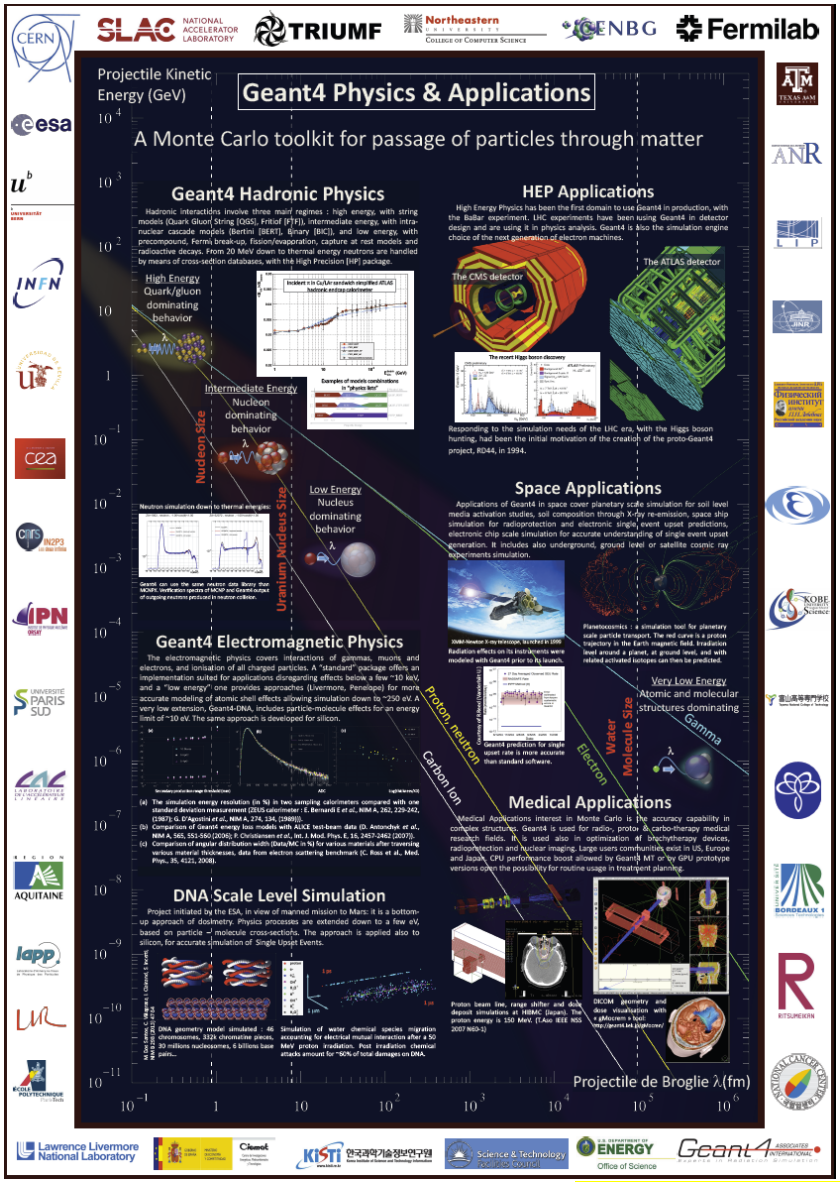
Geant4?

Geant4

- Toolkit for the simulation of the passage of particles through matter
- History
  - Dec 1994 – Project start
  - Dec 1998 – First Geant4 public release
  - Latest version – Geant4 version 11.2 (December 2023)
- Features
  - Object-oriented technology based on C++
  - Particle: ɣ, e-/e+, n, p, muon, ion, neutrino, etc.
  - Energy range
    - From thermal energy up to 1 PeV (hadronic)
    - From 250 eV to 1 PeV (EM interaction)
- Homepage:
  http://geant4.web.cern.ch

Geant4 Collaboration

- Geant4 is not upgrade version of GEANT3, but totally different simulation tool kit.
- Korean institutes: KISTI, NCC, IBS
- KISTI is the leading institute of Geant4 in Korea since 2012.

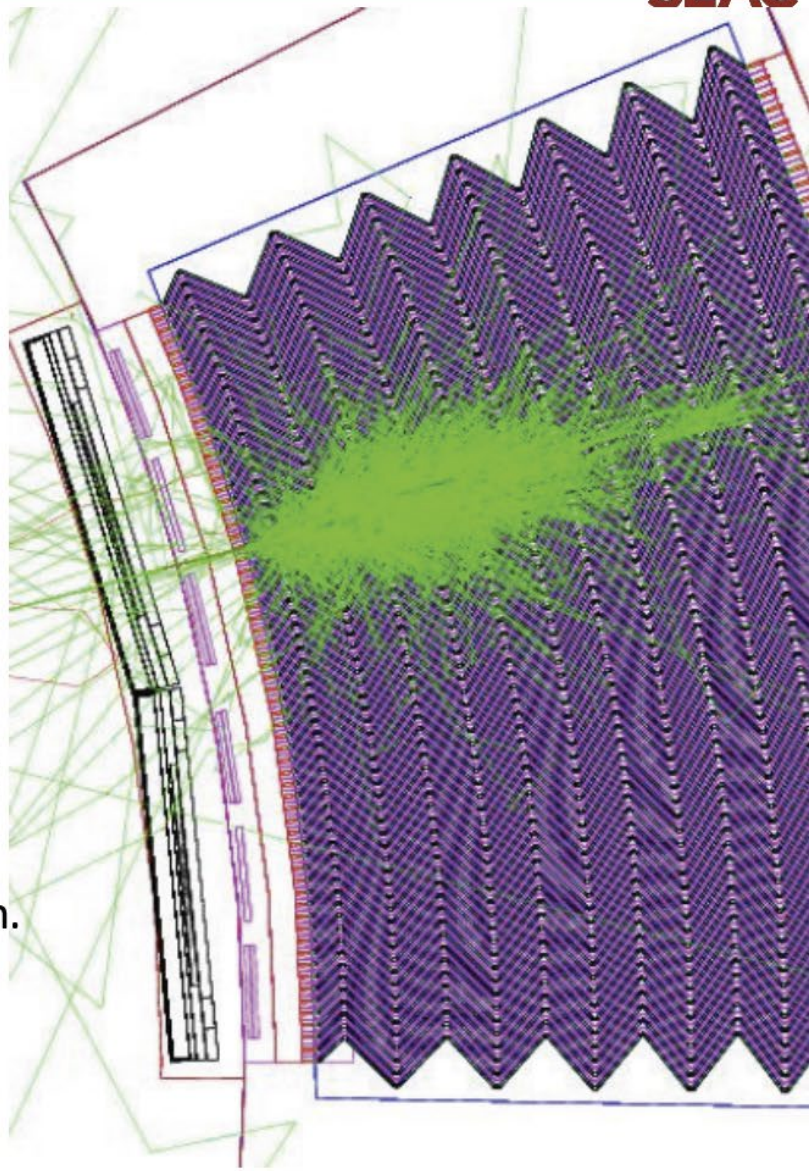


Ref. Makoto Asai

Physics models in Geant4

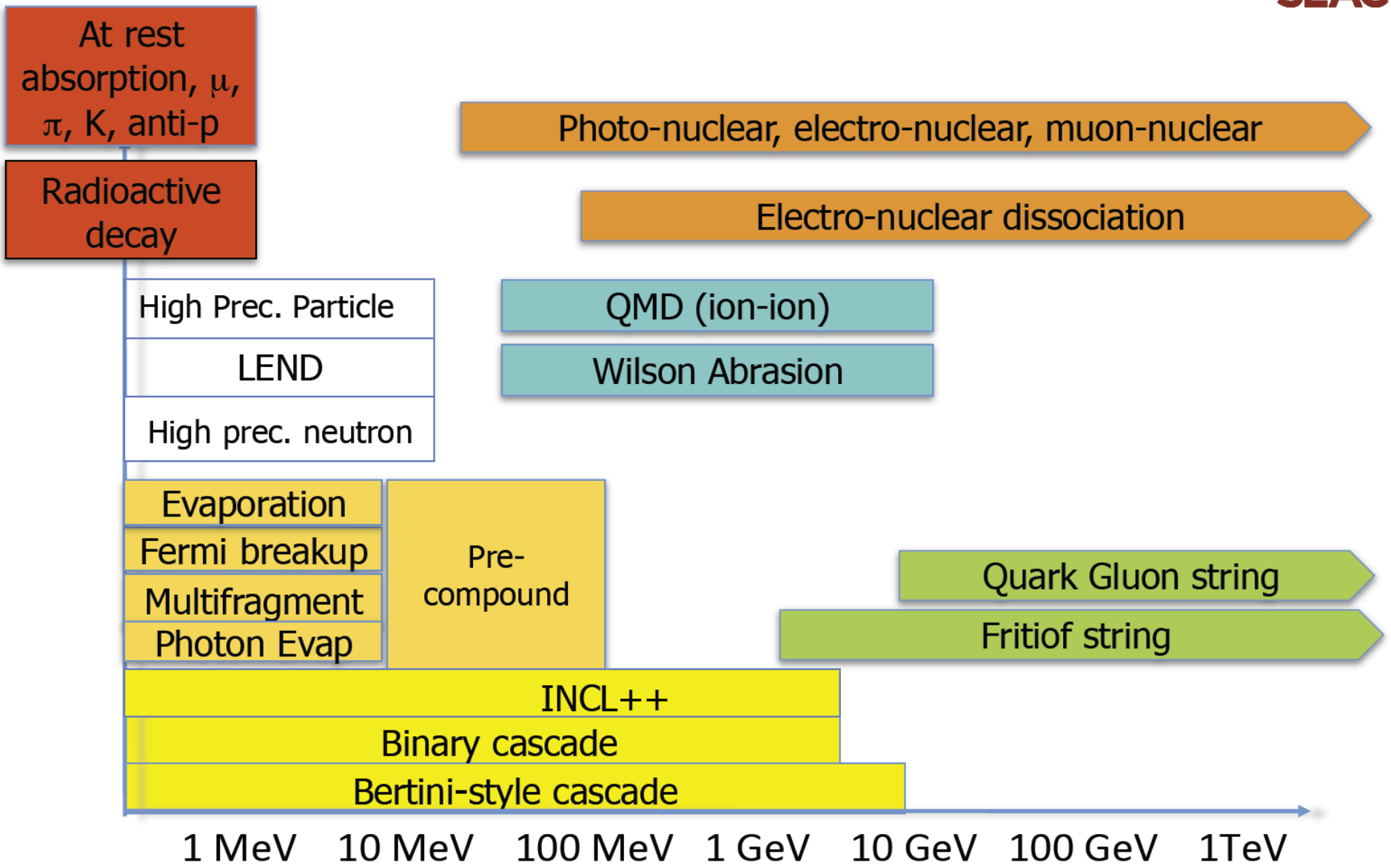
SLAC

- Geant4 offers
  - Electromagnetic processes
  - Hadronic and nuclear processes
  - Photon/lepton-hadron processes
  - Optical photon processes
  - Decay processes
  - Shower parameterization
  - Event biasing techniques
  - And you can plug-in more
- Geant4 provides sets of alternative physics models so that the user can freely choose appropriate models according to the type of his/her application.
  - For example, some models are more accurate than others at a sacrifice of speed.



Ref. Makoto Asai

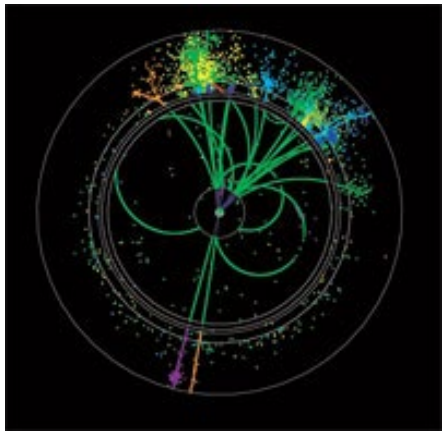
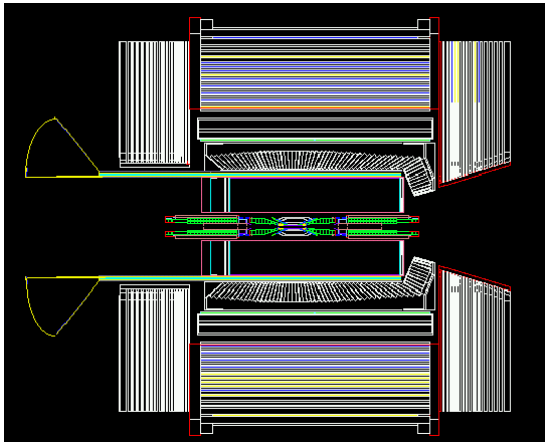
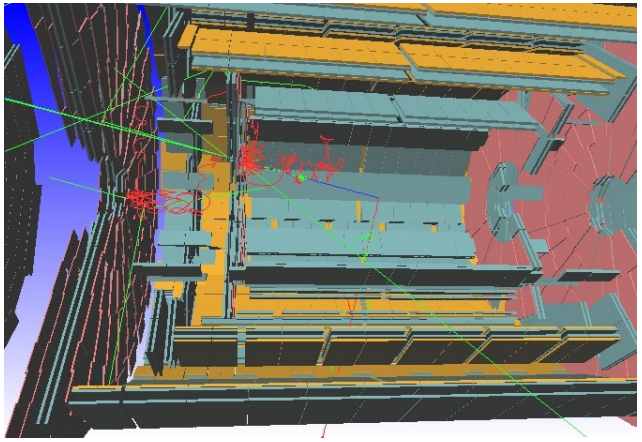
Hadronic Model Inventory



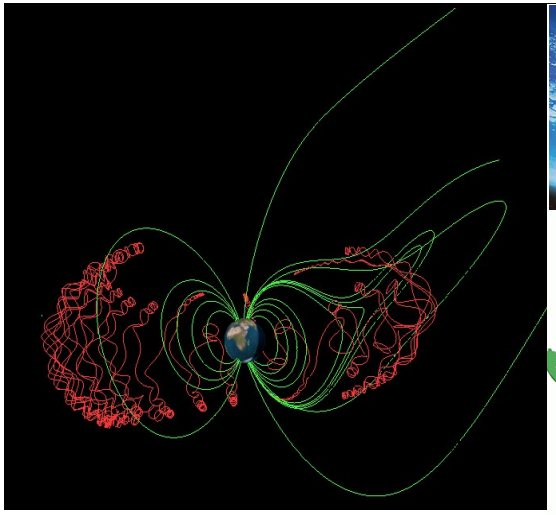
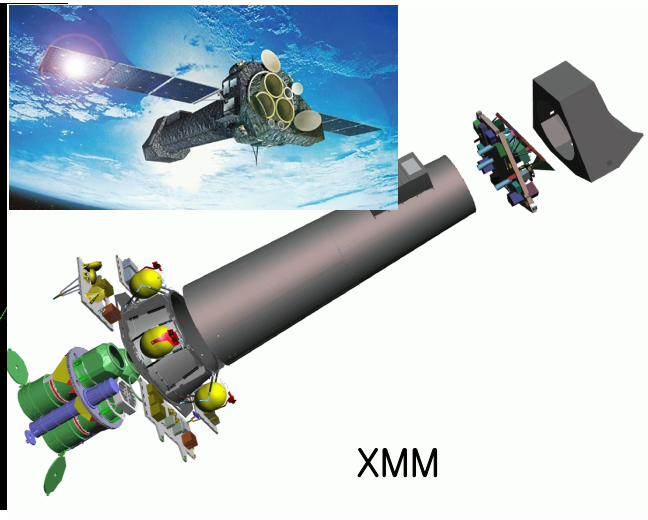
Ref. Makoto Asai

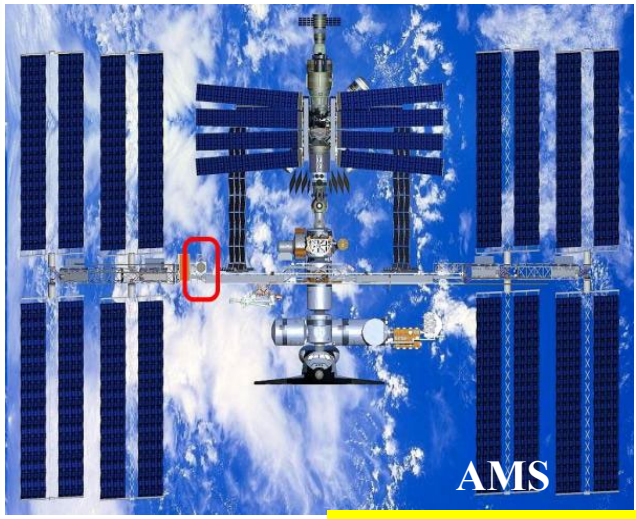
Application Examples

- Detector simulation in high energy physics

- Space Science

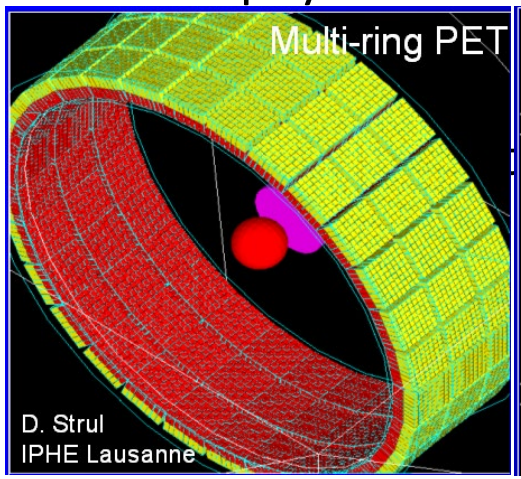



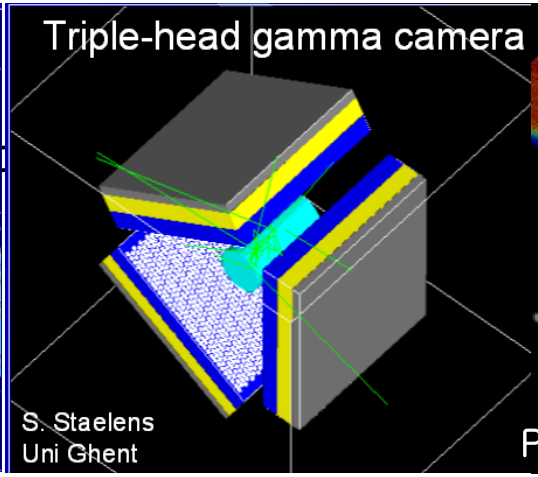


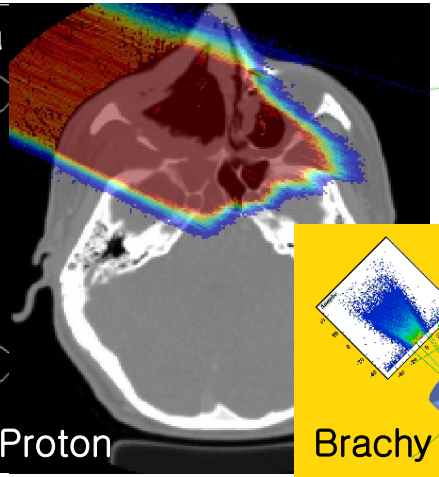
Ref. Makoto Asai

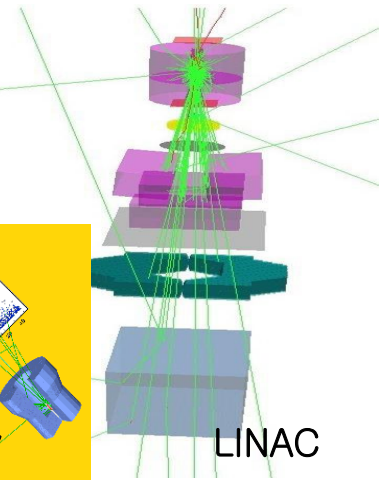
Application Examples

- Medical physics

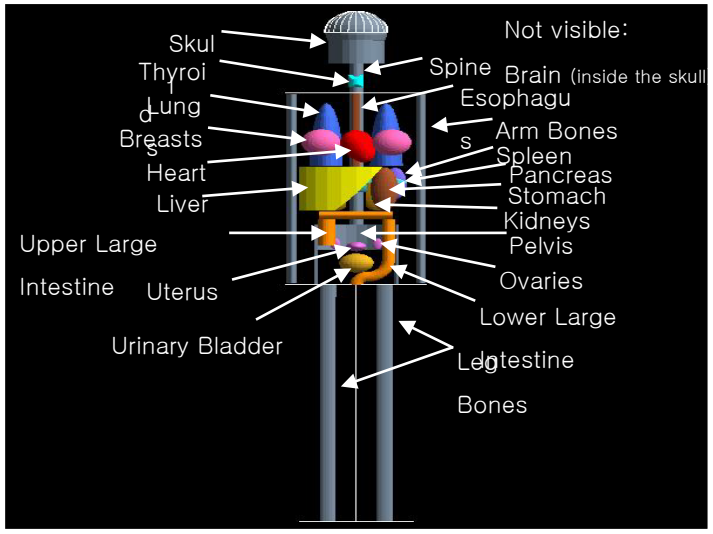


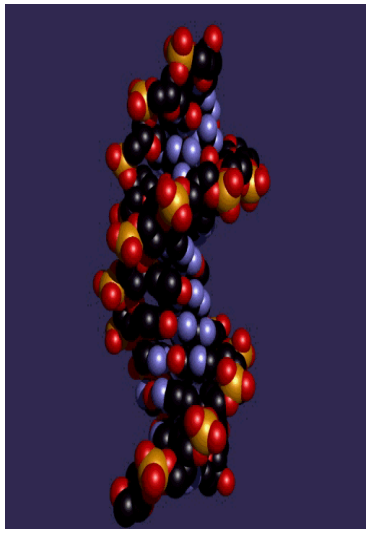






- Etc.





Ref. Makoto Asai

KiSTi 한국과학기술정보연구원
www.kisti.re.kr Korea Institute of Science and Technology Information

Geant4 @ KISTI

Geant4 @ KISTI (2012~2018)

1. Geant4 Collaboration
   - 1-1. Physics List and Validation Tool Kit Group (Chair: Gunter)
     - 1-1-1. Porting @Tachyon2 & Test
     - 1-1-2. Validation @ Tachyon2 (CPU 제공: 200,000 CPU*h) – Andrea
     - 1-1-3. Physics List using Beam (FKPPL) – Chanyoung Lee
   - 1-2. Quality and Assurance Group (Group: Soon Jun) – Insung Yeo
     - 1-2-1. Profiling and Benchmark for Medical Physics (cf. SimpliCarlo)
2. Fermilab (Parallel/Vector) W/ Soon
   - 2-1. Performance Test using GPU (cf. 1-2-1) – Jangho Kim
   - 2-2. Hadron Physics Parallelization (cf. EM Physics)

Geant4 @ KISTI (2020~)

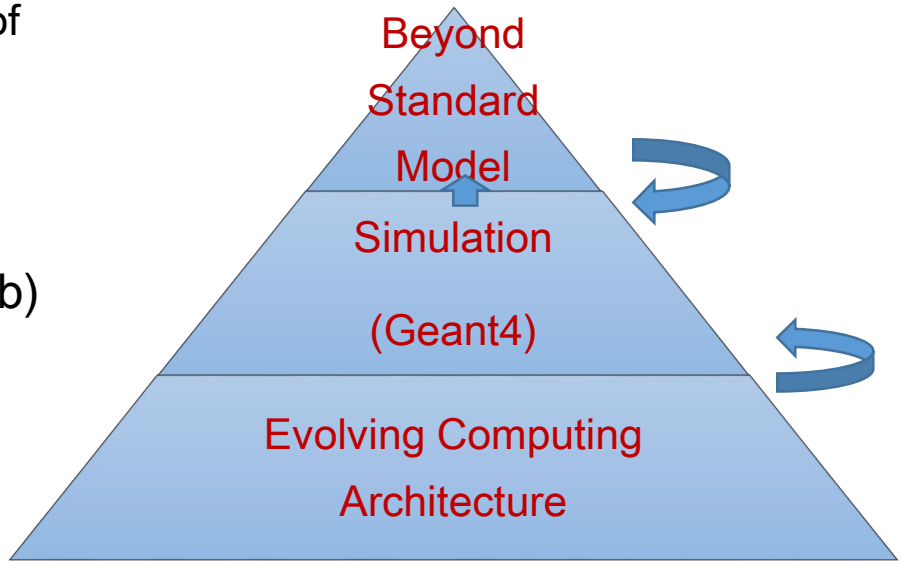
1. Geant4 Collaboration
   - 1-1. Physics List and Validation Tool Kit Group (Chair: Gunter) – Kyungho Kim
     - 1-1-1. Porting @ nurion & Test
     - 1-1-2. Validation @ nurion => CPU 제공: 10*3200시간*노드 (1노드=68core)
     - 1-1-3. Physics List using Beam (FKPPL)
   - 1-2. Quality and Assurance Group (Group: Soon Jun)
     - 1-2-1. Profiling and Benchmark for Medical Physics (cf. CMSExp)
   - 1-3. Electro Magnetic Physics (Group: Vladimir) => 1.0 FTE (Alexei)
     - 1-3-1. Steering and radiation effects in oriented crystals and their applications
2. Fermilab (Parallel/Vector) W/ Soon
   - 2-1. Performance Test using GPU (cf. 1-2-1)
   - 2-2. Hadron Physics Parallelization (cf. EM Physics)

1. Profiling

- Why profiling?
  - HL-LHC(BSM) needs upgrade of simulation tool
  - Evolving computing also needs upgrade of simulation tool

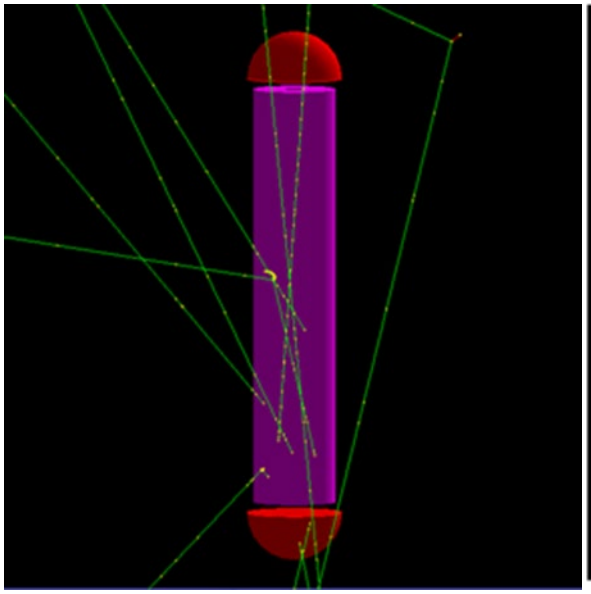
  ⇒ Needs profiling system to check upgrade of simulation tool

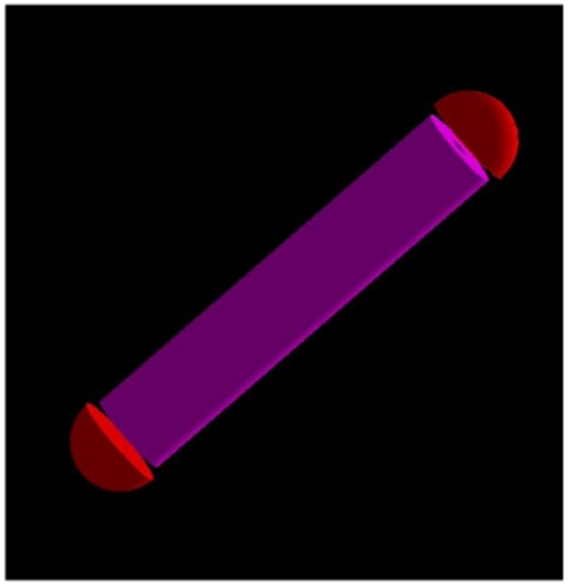
- Current status
  - High energy physics profiling (Fermilab)
    - SimpliCarlo (Sequential)
    - CMSExp (Multi-Thread)
  - Low energy physics profiling (KISTI)
    - Brachytherapy code (Sequential)
    - KISTI-4 vs. KISTI-5 (KNL and SKL)
    - CPU time and Memory

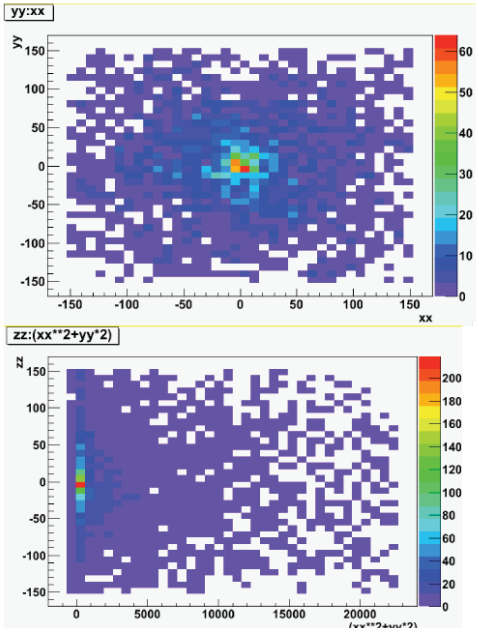


Profiling for low energy physics

- Profiling system using brachytheray simulation (Low energy physics)
- cf. Brachytherapy(MeV) vs. SimplifiedCarlo(TeV)







- Results (Brachytherapy v.10.02 & Geant4 v.10.04)

  1) CPU

  2) Memory size

  3) Version dependency

  4) Event number dependency

  5) KISTI-4 machine dependency

KISTI-4 vs. KISTI-5

Specification	KISTI-4	KISTI-5	
Name	Tachyon2	Nurion KNL	Nurion Skylake
Model	SUN Blade 6275	Cray C5500	
Process	Intel Xeon X5570 (Nehalem) 2.93GHz	Intel Xeon Phi 7250 (KNL) 3.0464 TFlops/CPU	Intel Xeon 6148 (Skylake) 1.536 TFLops/CPU
Architecture	multicore	many-core	multicore
Node	8core/node 3,200 node	68core/CPU 1CPU/node 8,305 node	20core/CPU 2CPU/node 132 node
Core	25,408	564,740	5,280
Rpeak	0.3 Pflops	25.3 Pflops	0.4 Pflops
Memory	DDR3/1333MHz 76.8TB	16GBx6, 6Ch/CPU 96GB/node 778.6 TB	16GBx12, 6Ch/CPU 192GB/node 24.8 TB
Storage	234 TB disk 2.3 PB disk 2.1 PB Tape	21 PB disk 0.8 PB SSD 10 PB Tape	
Interconnect	Infiniband 40G 4XQDR	OPA@12.3GB/s Fat-Tree, 50% Blocking	
Service date	2010.8~2018.11	2018.10~	

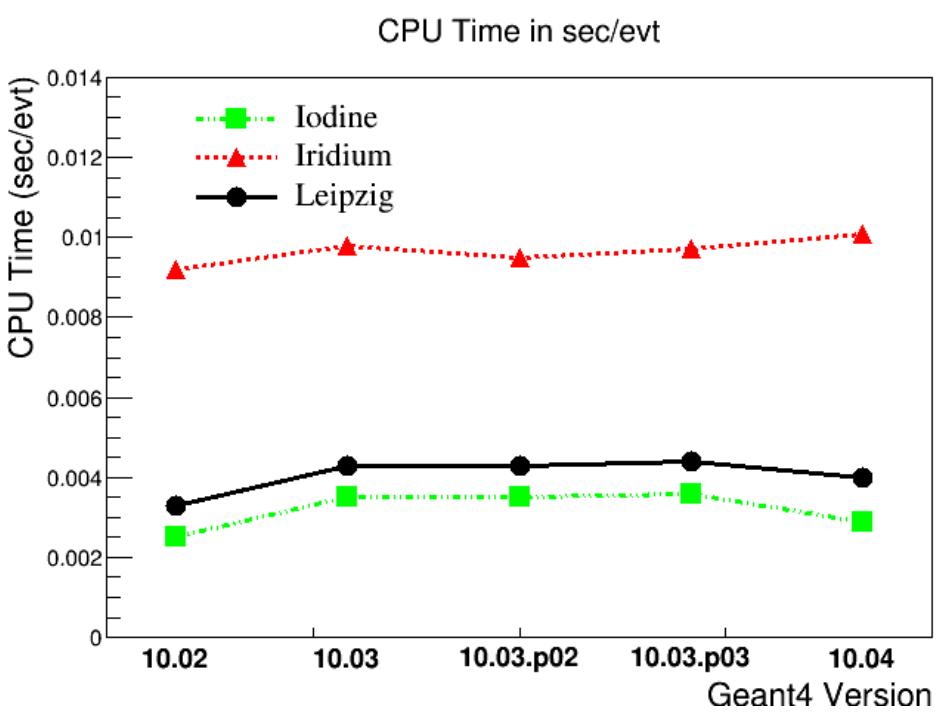
Profiling system

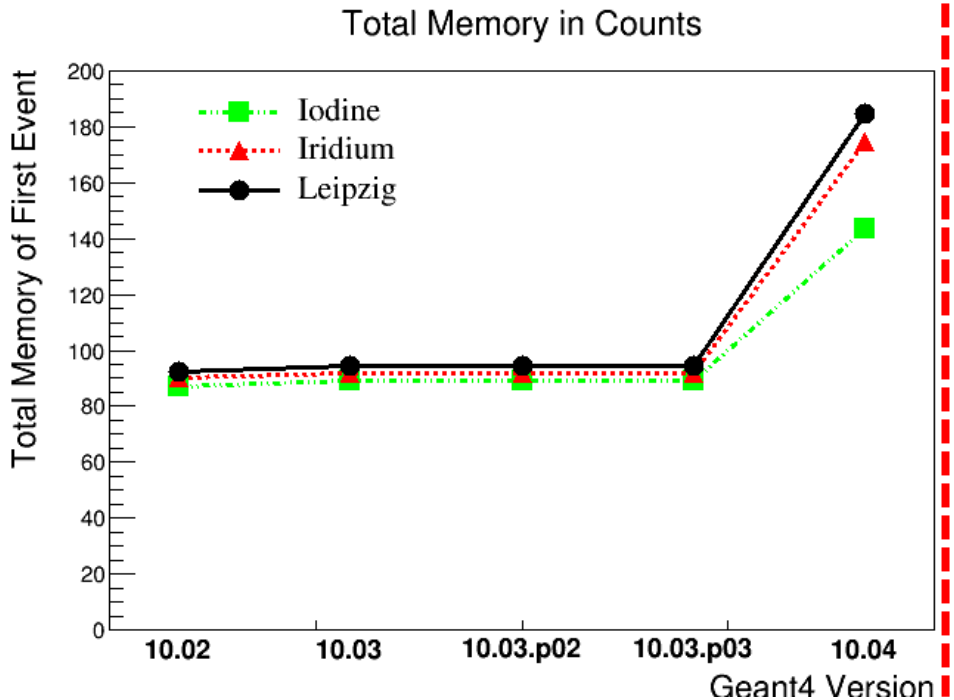
Content	Brachytherapy				
Geant4 Version	10.02	10.03	10.03p02	10.03p03	10.04
Brachy version	10.02				

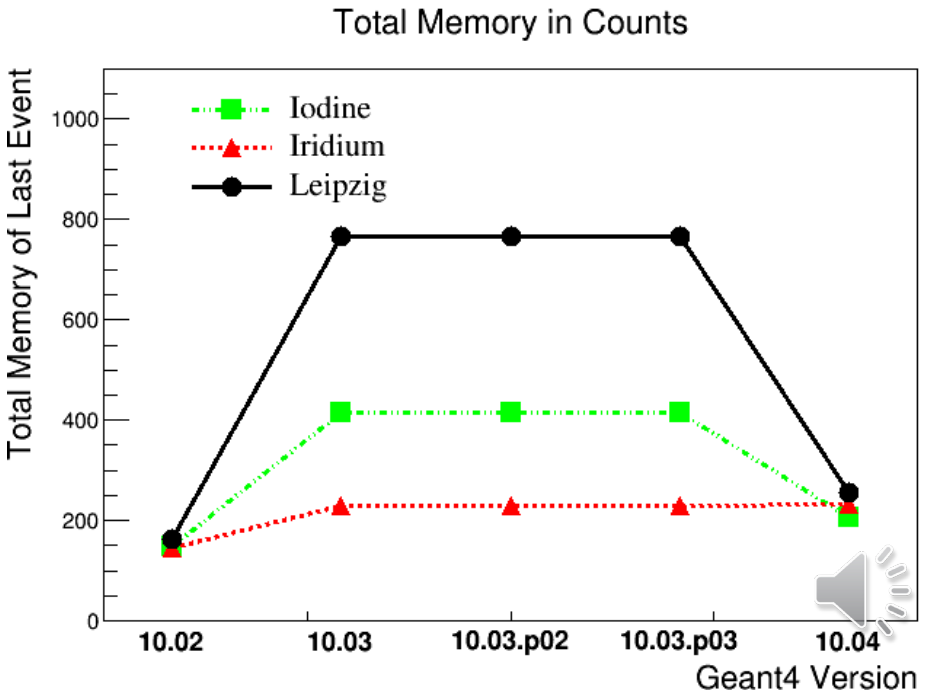
- Macro file
  - IodiumSourceMacro.mac (endocavitary brachytherapy)
  - IridiumSourceMacro.mac (interstitial brachytherapy)
  - LeipzigSourceMacro.mac (superficial brachytherapy)
- Physics list
  - QGSP_BIC_LIV
  - QGSP_BIC_EMZ
  - QGSP_BIC_EMY
- Supercomputer
  - KISTI-4 (Tachyon2)
  - KISTI-5 (Nurion KNL)
  - KISTI-5 (Nurion Skylake)
- 1 sequential core to compare with KISTI-4

1) KISTI-4 (Tachyon2)

QGSP BIC EMZ

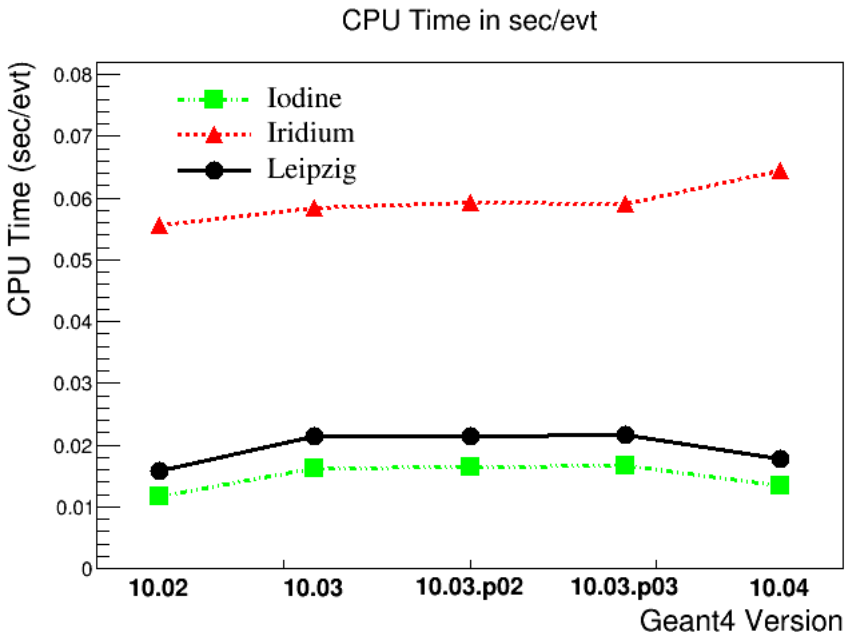


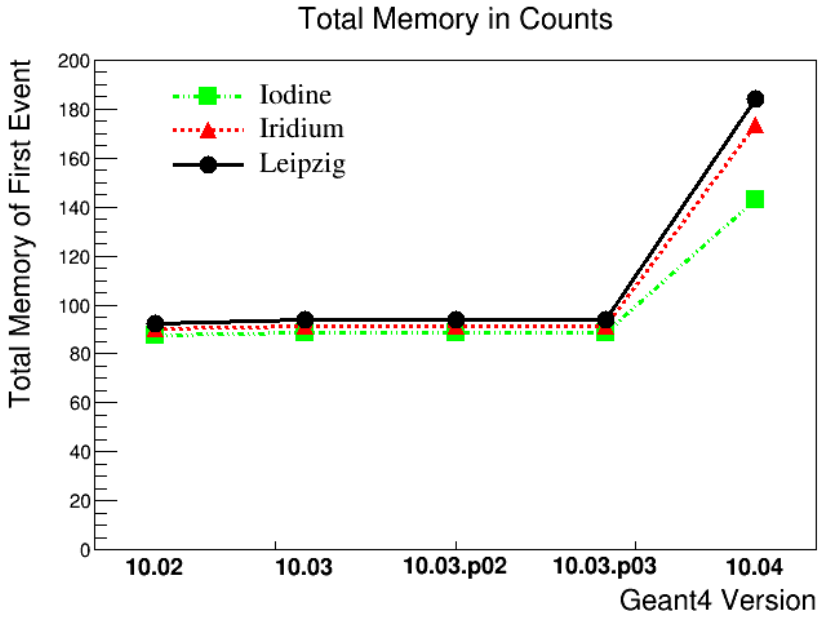


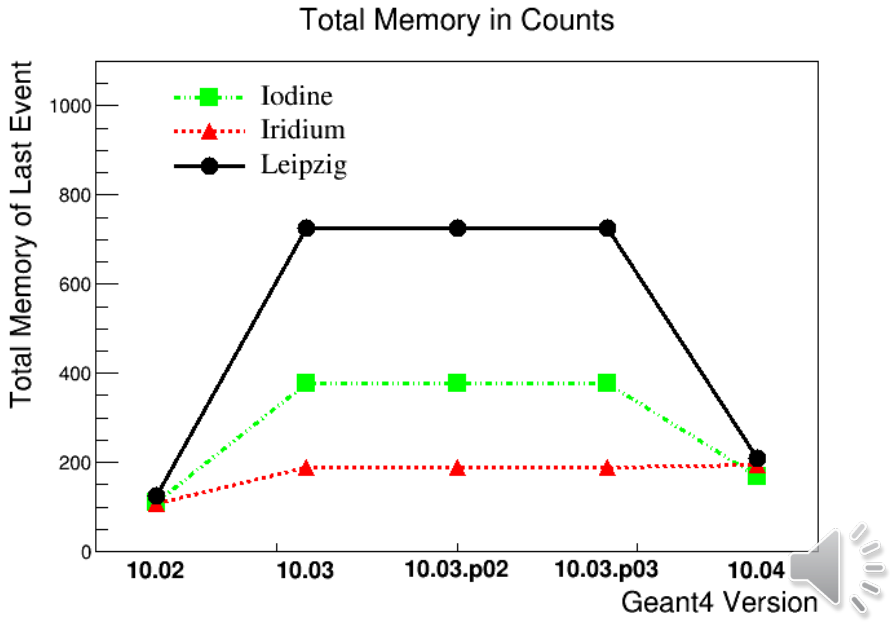


2) KISTI-5 (Nurion KNL)

QGSP BIC EMZ







Summary of profiling

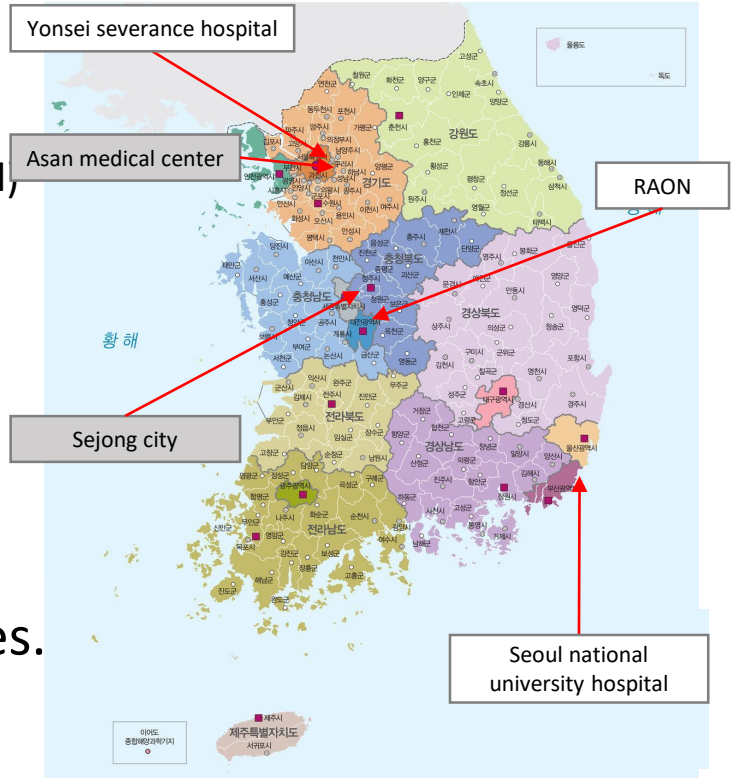
- As computing architectures evolve, the Geant4 simulation tool kit requires optimization for CPU time and memory size.

$\Rightarrow$ 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.

2. Beam simulation

- 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.

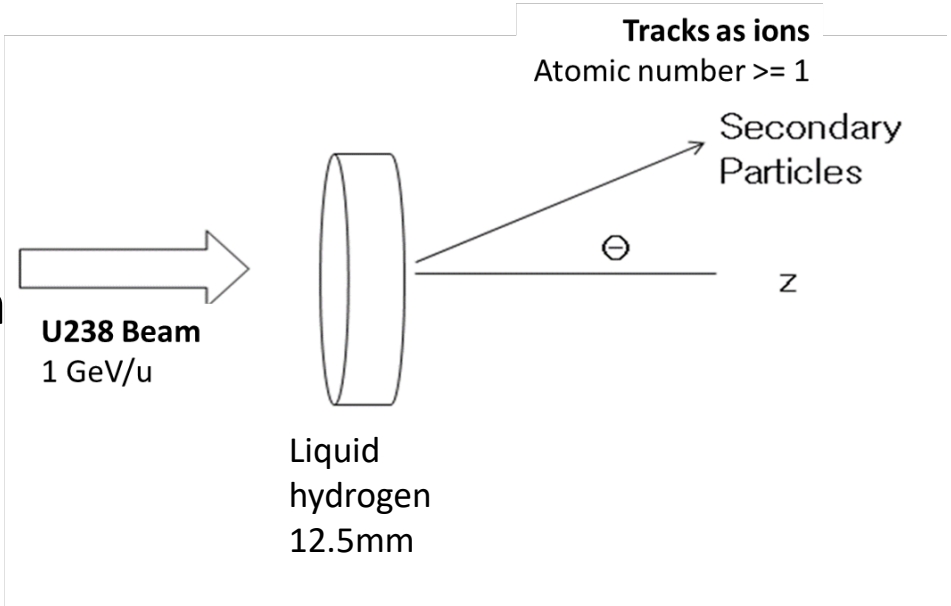


But there has been relatively little focus on accelerator-based study of secondary particles.

⇒ Planning heavy ion beam simulation

1) Validation of physics list

- Conditions of experimen
  - Geant4 version: 11.0.2
  - 1 million events per each



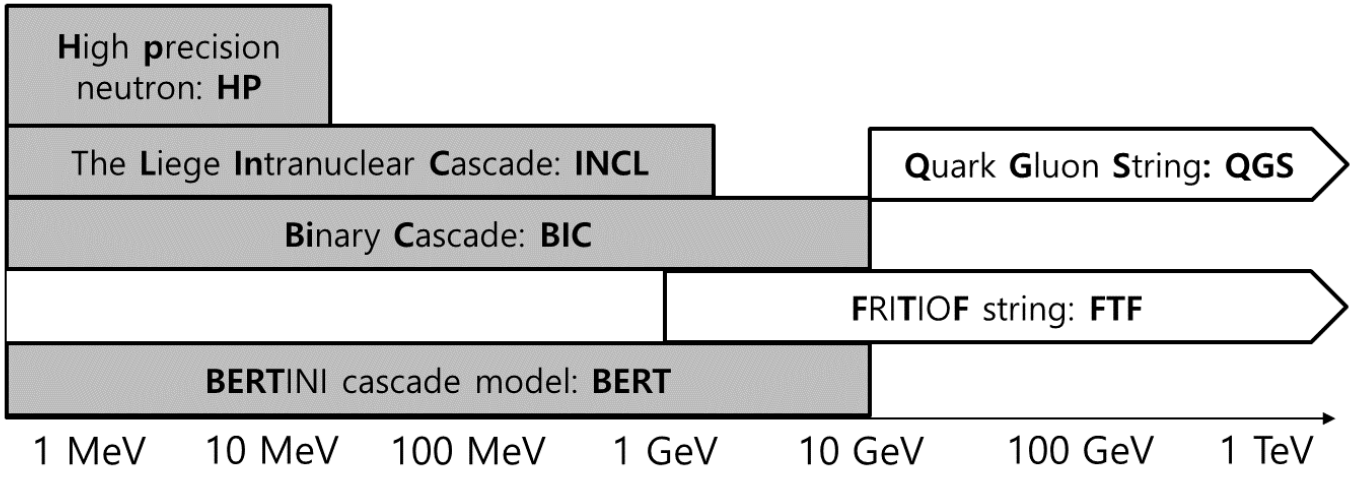
Schematic of simulation

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

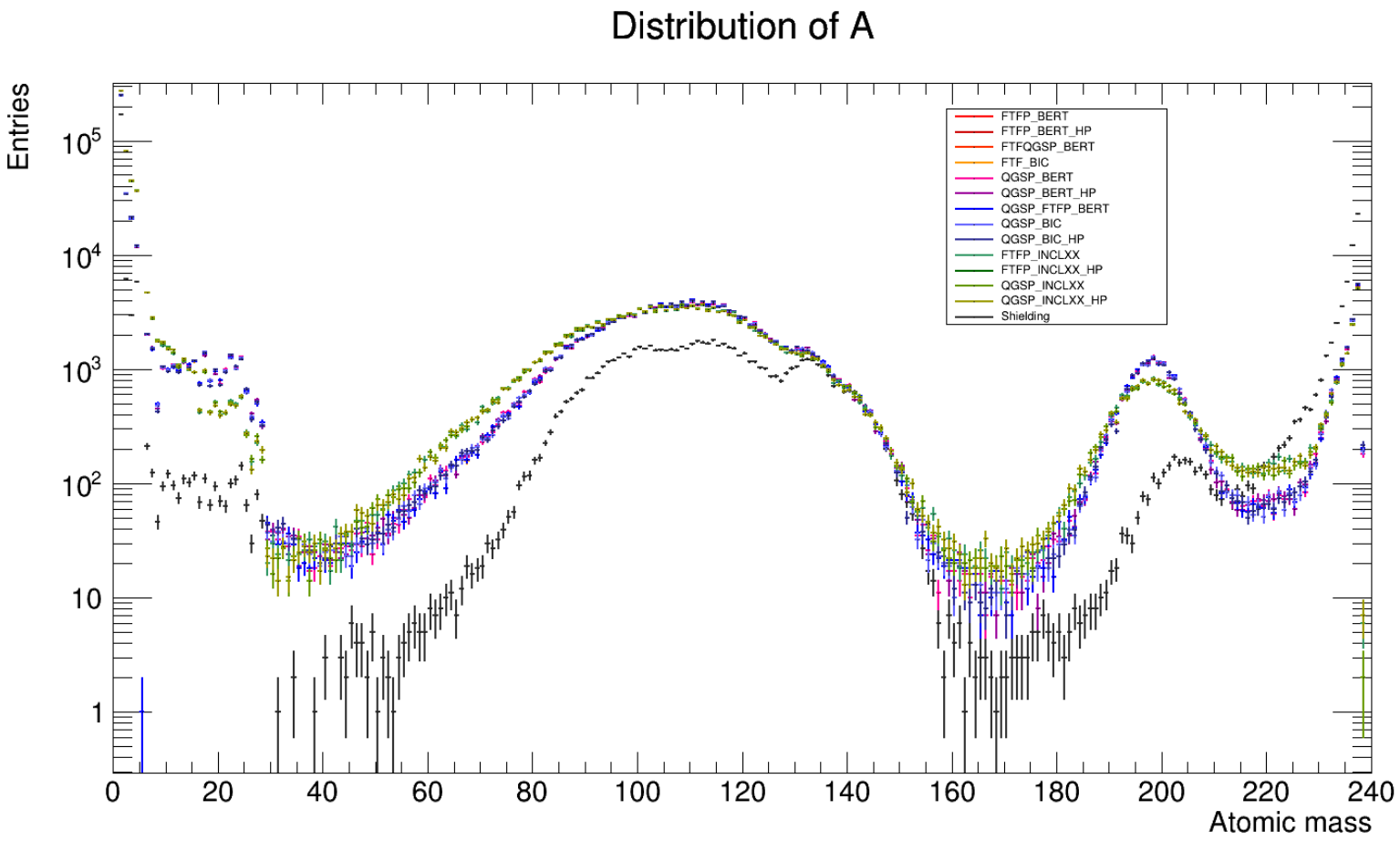
Beam & target conditions for validation

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

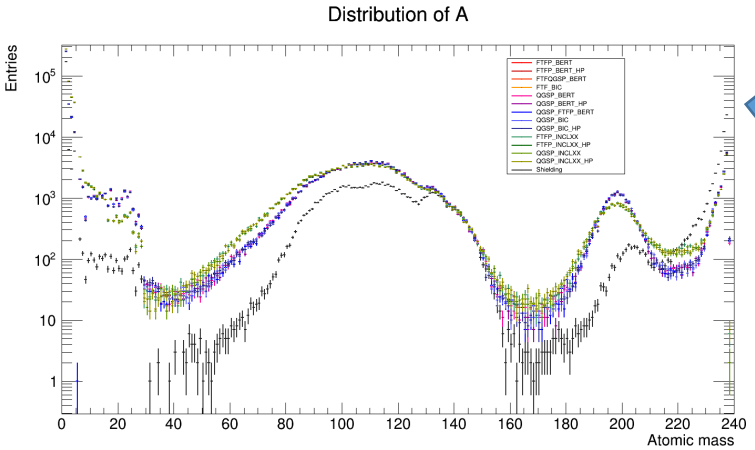


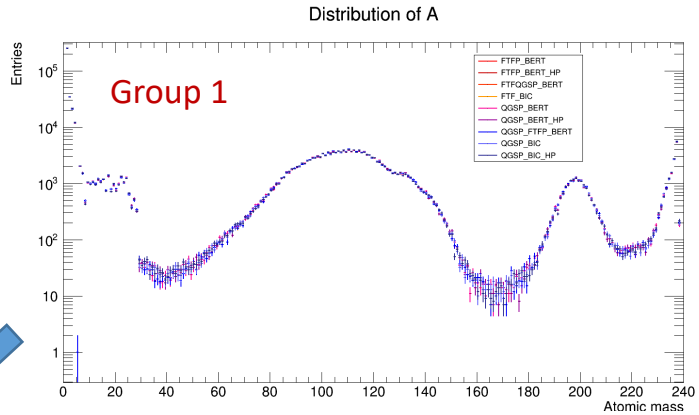
Distribution: Atomic Mass

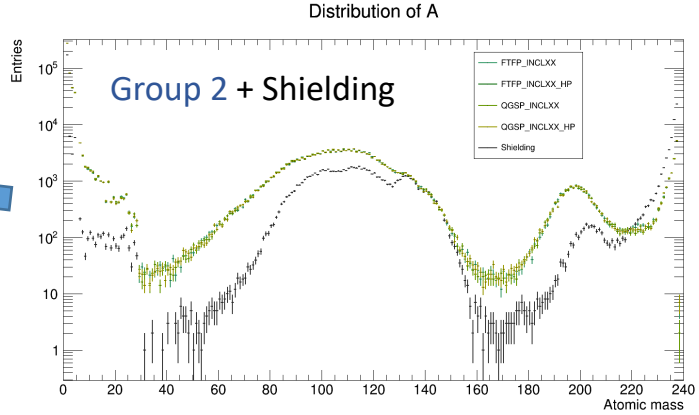


Distribution: Atomic Mass

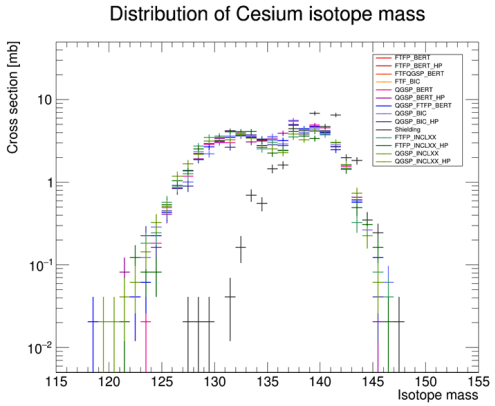
- PhysicsLists are separated to 3
  - Group 1: FTFP_BERT, FTFP_BERT_HP, FTFQGSP_BERT, FTF_BIC, QGSP_FTFP_BERT, QGSP_BERT, QGSP_BERT_HP, QGSP_BIC, QGSP_BIC_HP
  - Group 2: FTFP_**INCLXX**, FTFP_**INCLXX**_HP, QGSP_**INCLXX**, QGSP_**INCLXX**_HP
  - **Shielding**



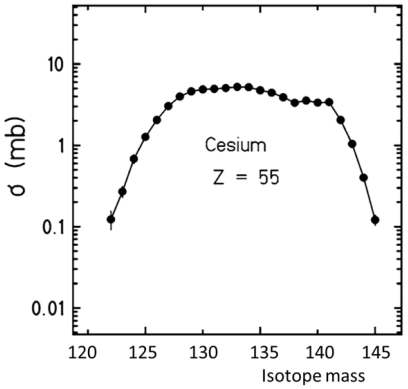


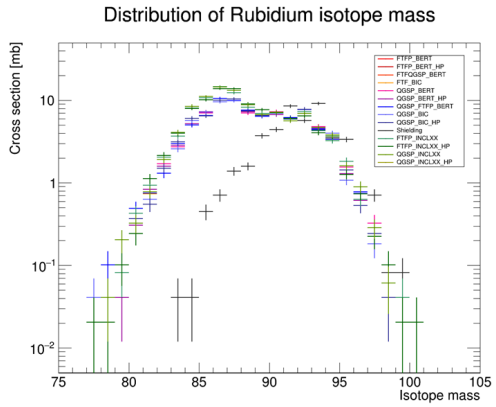


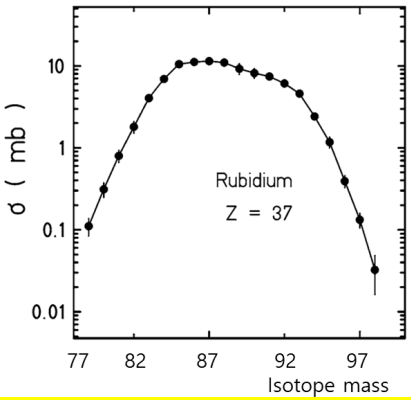
Validation compared with experiments

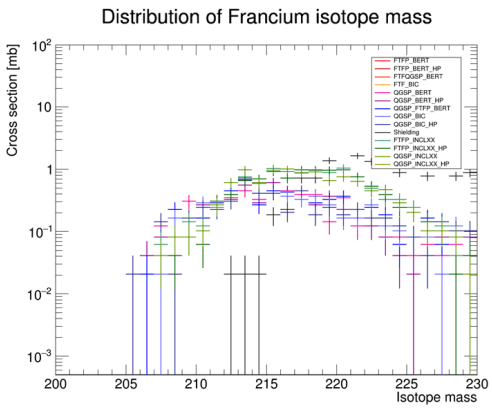


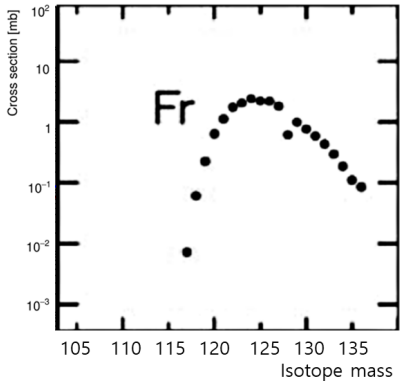
M. Bernas et al., Nucl. Phys. A 725, 213 (2003)











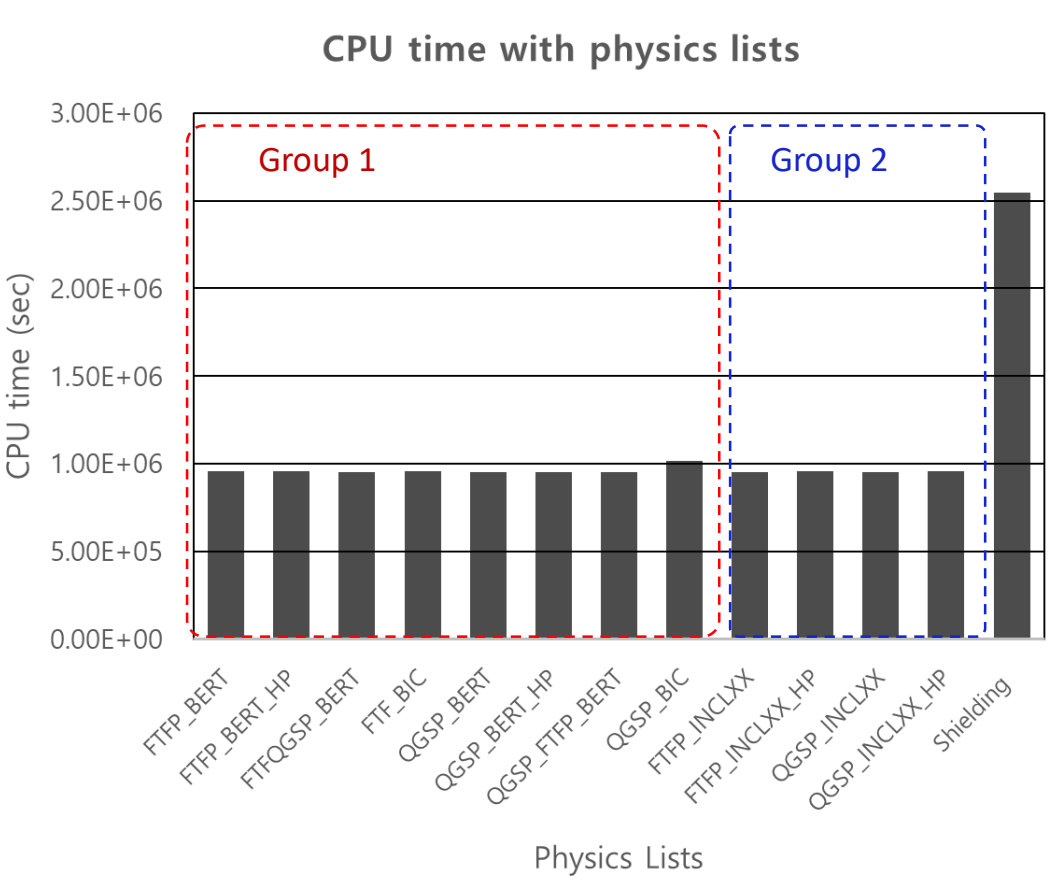
M. Bernas et al., Nucl. Phys. A 725, 213 (2003)

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

Cost effective CPU time

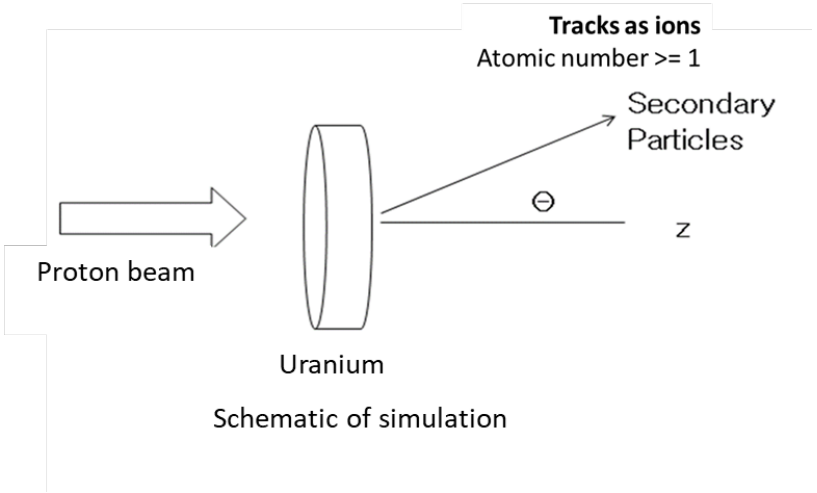
- Excluding ‘Shielding’ for our suitable list (due to long runtime)
- Others look same.
  - Any physics list (except Shielding) would be OK.
- The best

  => FTFP_INCLXX(_HP)



2) Production of secondary particles

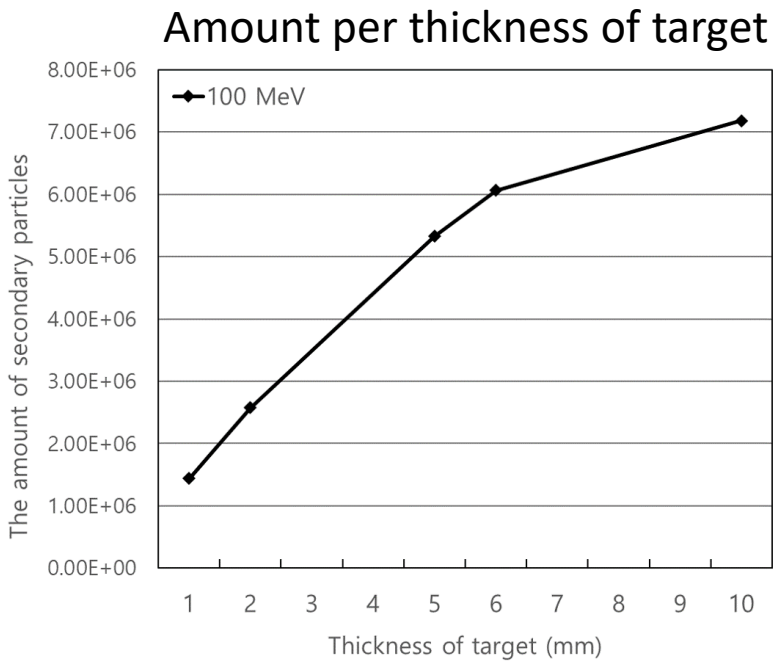
- Conditions of experiments
  - **FTFP_INCLXX**
  - Geant4 version: 11.0.2
  - 1 million events per each condition

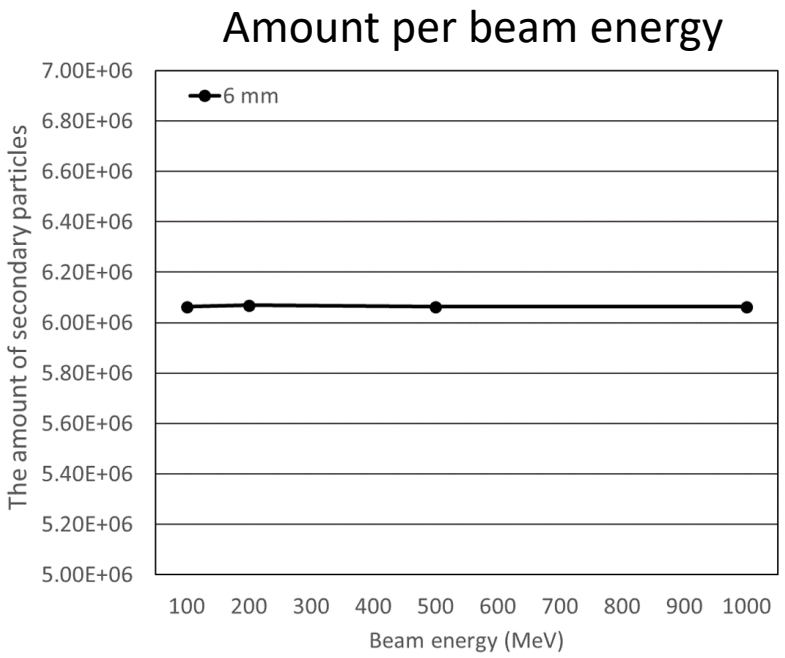


Schematic of simulation

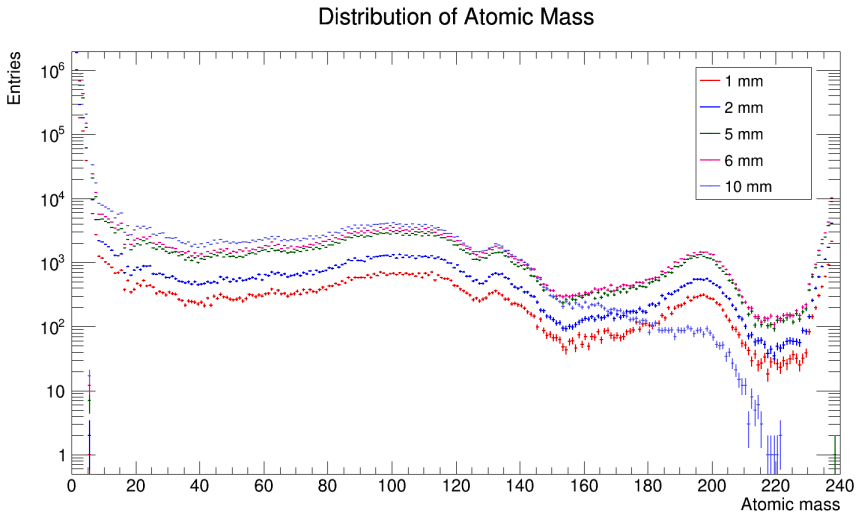
Simulation	Geant4 Beam		Target	
	Particle	Energy (MeV/u)	Materials	Thickness (mm)
Proton → U	Proton	100, 200, 500, 1000	Uranium	6
Proton → U	Proton	100	Uranium	1, 2, 5, 6, 10

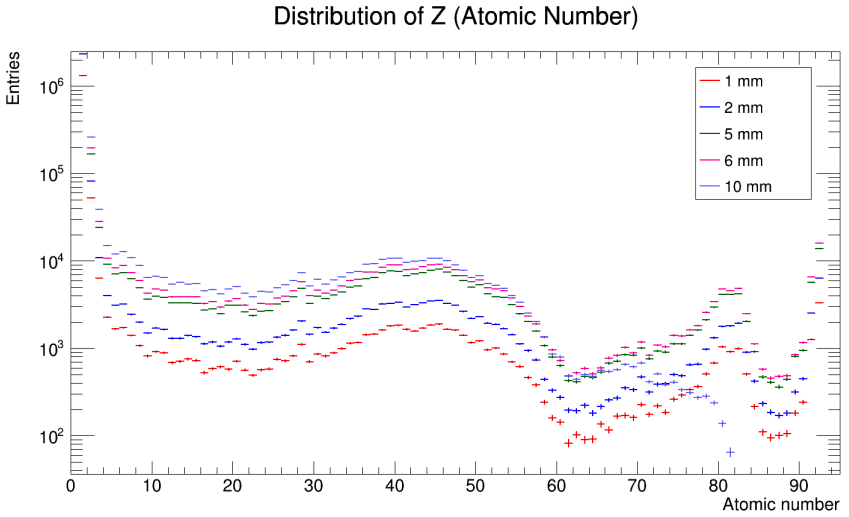
Amount of Secondary Particles

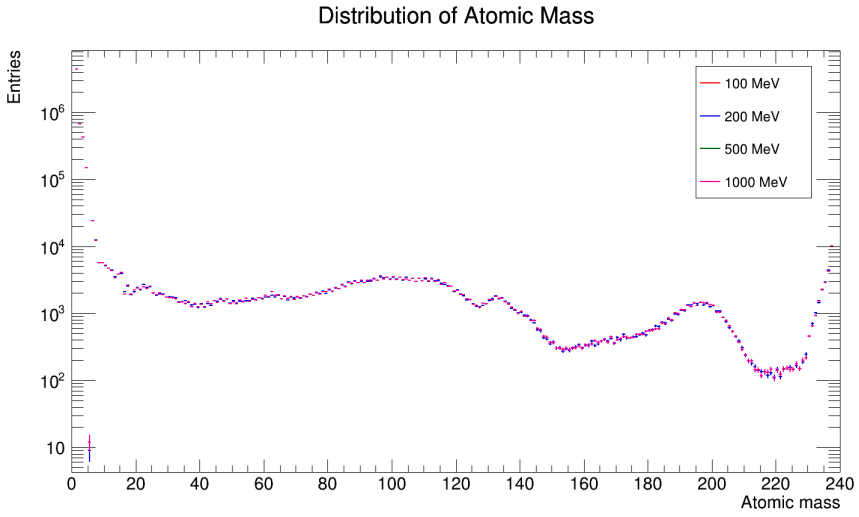


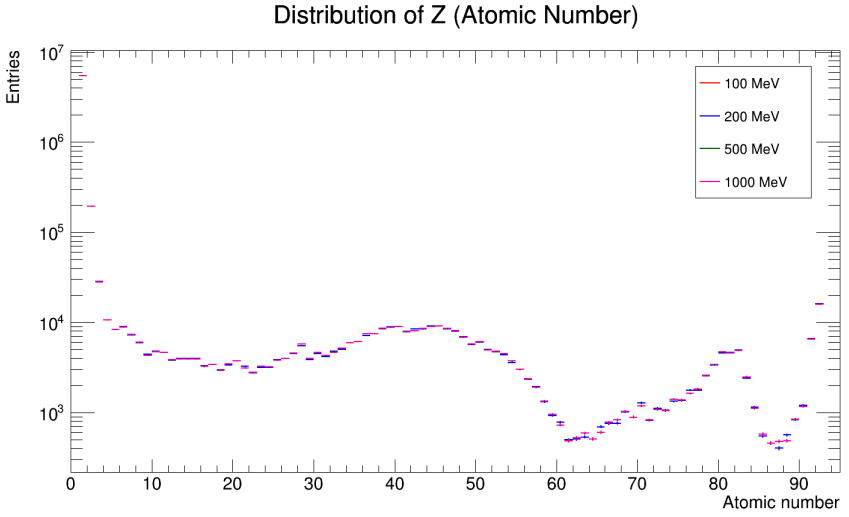


Amount of Secondary Particles



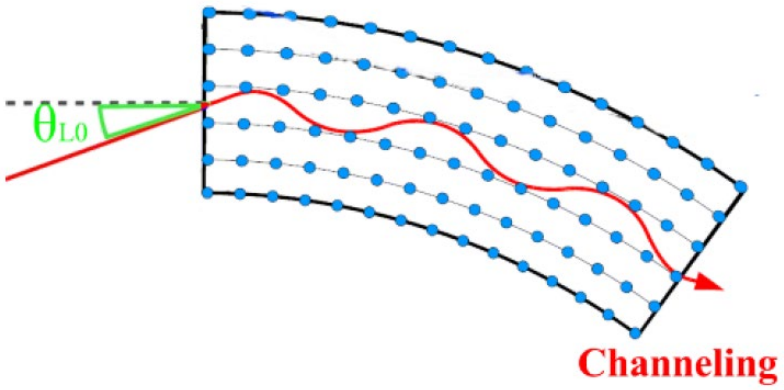






3. Channeling in Crystal

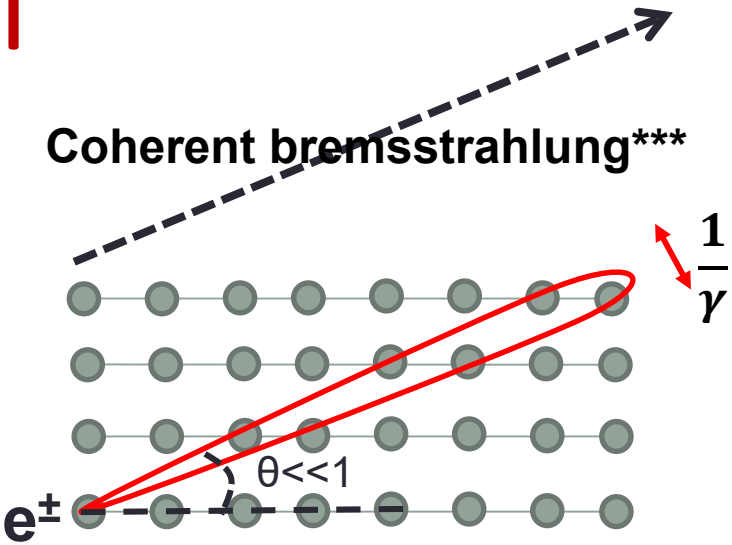
Channeling*



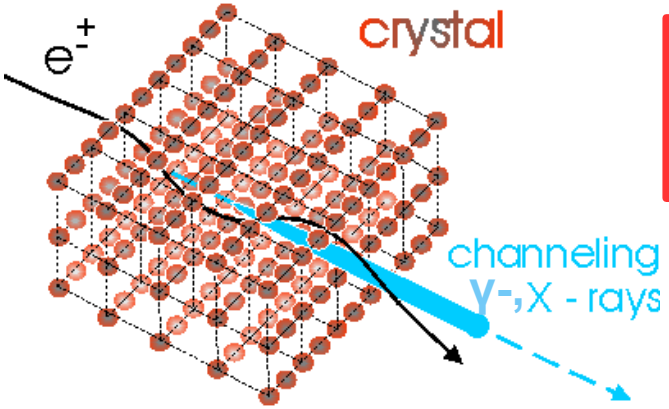
Enegies: MeV - TeV

Equivalent magnetic field: more than 100 T

Coherent bremsstrahlung***

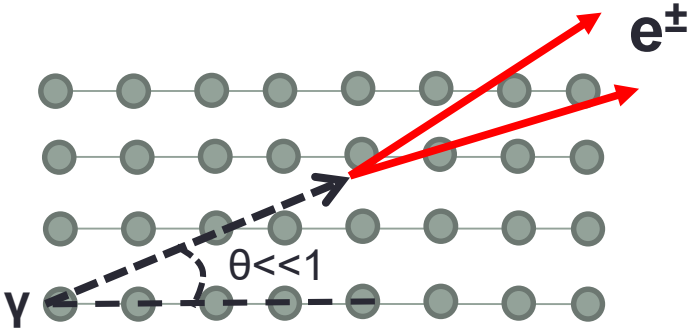


Channeling radiation**



Planar/ Axial field $10^{9}/10^{11}$ V/cm

Coherent pair production****



*J. Stark, Zs. Phys. 13, 973–977 (1912); J. A. Davies, J. Friesen, J. D. McIntyre, Can J. Chem. 38, 1526–1534 (1960)
**M.A. Kumakhov, Phys. Lett. A 57(1), 17–18 (1976)
***B. Ferretti, Nuovo Cimento 7, 118 (1950); M. Ter-Mikaelian, Sov. Phys. JETP 25, 296 (1953).

Marie Sklodowska-Curie Action Global Individual Fellowships by A. Sytov in 2021-2024, Project TRILLION GA n. 101032975

Main goal: The **implementation** of both physics of **electromagnetic processes i n oriented crystals** and the design of specific applications of crystalline effects int o **Geant4** simulation toolkit as Extended Examples **to bring** them **to a large scient ific and industrial community** and under a free Geant4 license.

Group:

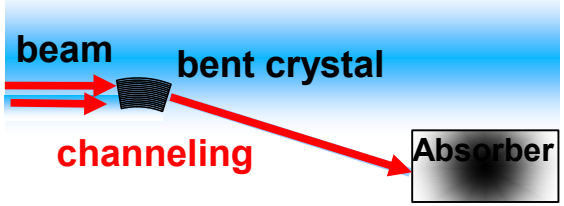
- **A. Sytov** – project coordinator
- **L. Bandiera** – INFN supervisor
- **K. Cho** – KISTI supervisor
- **G. Kube** – DESY supervisor
- **I. Chaikovska** – IJCLab Orsay supervisor

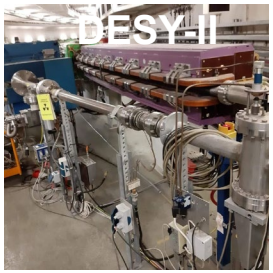
Location:

- 2 years at **KISTI** (partner organization)
- 1 year at **INFN Section of Ferrara** (host organization)
- 1 month of secondment at **DESY** (partner organization)
- 1 month of secondment at **IJCLab Orsay** (partner organization)

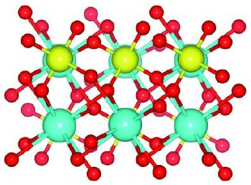
Applications

Crystal-based collimation or beam extraction from an accelerator



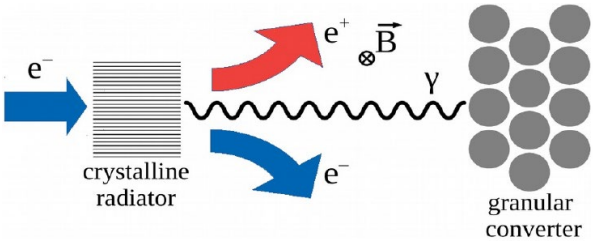


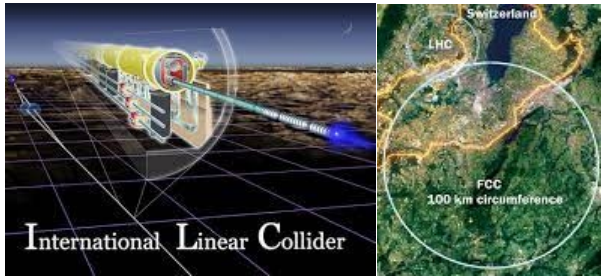
Ultrashort crys talline calorime ter



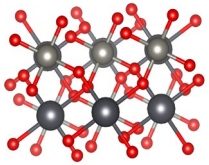
Gamma-ray Space Telescope

Positron source for future e +/e- and muon colliders

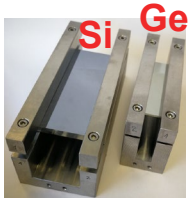




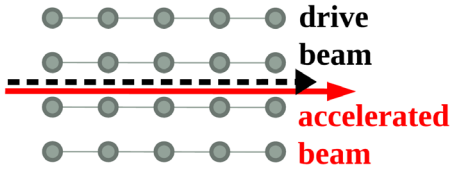
Oriented crystals



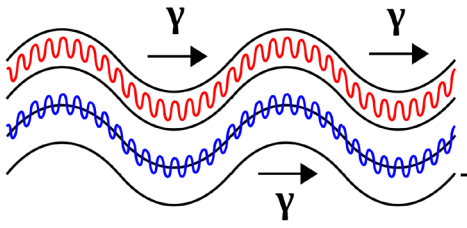
Measurement of dipole magneti c and electric moments of exoti c particles

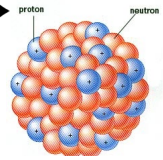


Plasma acceleration



X and γ-ray source for nuclear and medical physics





4. Plan and Outreach

- We studied heavy ion beam simulation on Geant4.
  - We found the optimized physics lists among Geant4 reference physics lists.
  - The most optimized physics list is FTFP_INCL++(_HP).
- Next, we will test $^{132}Sn/^{238}U$ beam emission to ^{9}Be target with various target thickness => RAON experiment

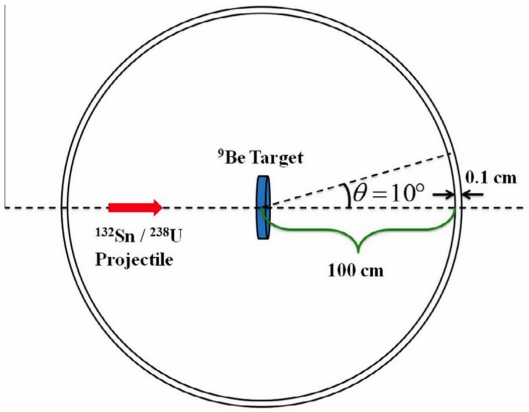
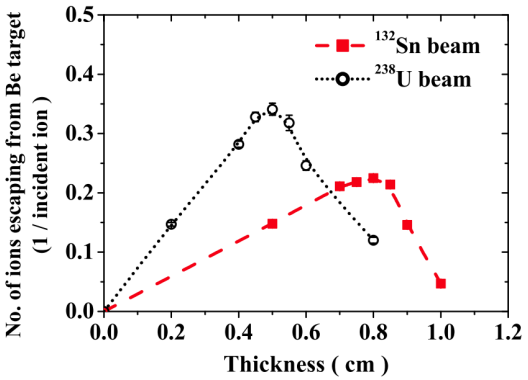


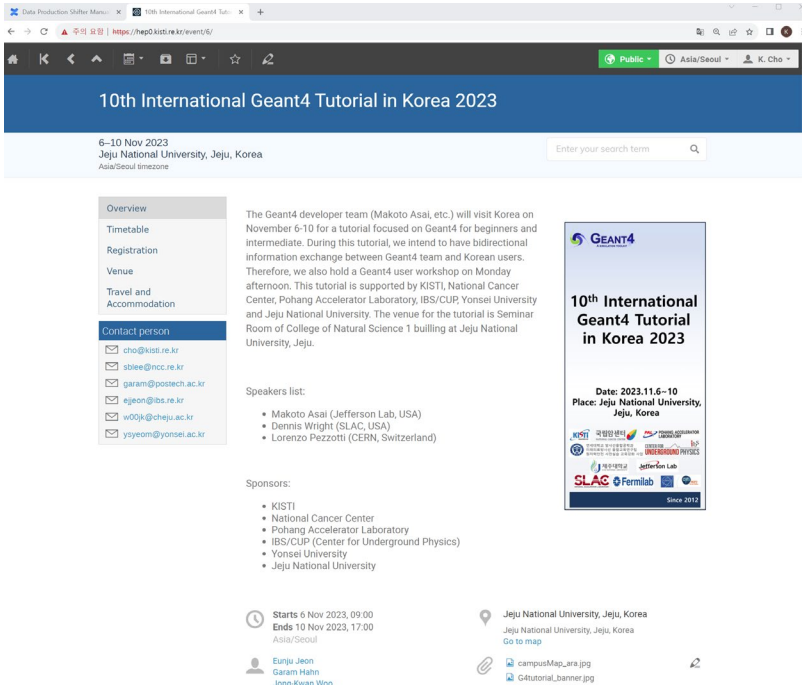
Fig. 9. Schematic diagram of the simulation setup.



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

10th International Geant4 Tutorial in Korea 2023

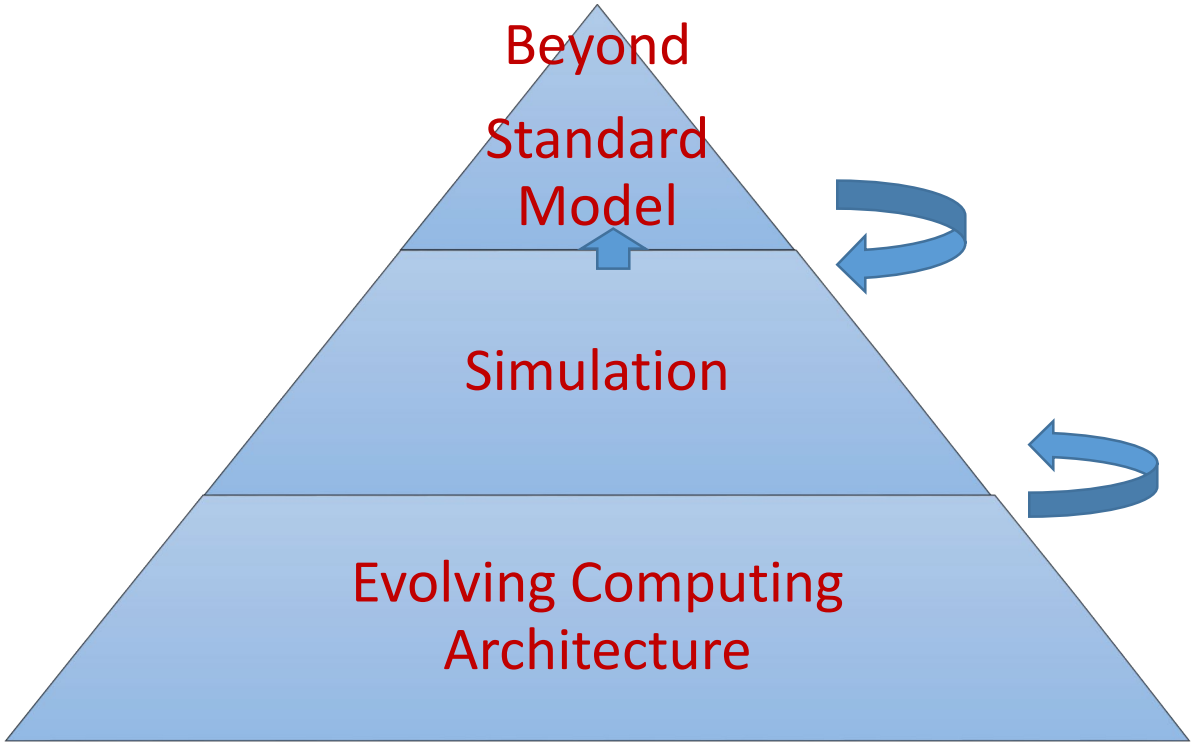
- Date: 2023. 11.06~10
- Place: Jeju National University
- https://hep0.kisti.re.kr/event/6/



Summary

Particle physics leads IT.

- Beyond Standard Model
- Simulation
- Evolving computing architecture



Summary

- Computing needs solutions for the evolving architecture (KISTI-5 and KISTI-6).
- To fulfill the gap between physics and computing, we also need to focus on simulation R&D.
- Geant4 is the most accurate simulation tool kit. Therefore we focus on it.

$\Rightarrow$ Physics goes beyond standard model.

Acknowledgement

- National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (No. 2021R1F1A1064008)
- The major institutional R&D program, KISTI (No. K-24-L02-C04-S01) and National Supercomputing Center with supercomputing resources including technical support (KSC-2023-CHA-0005)
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Thank
you!