Projectile Fragmentation: Physics Validation Of The GEANT4 Toolkit Against LISE^{++} For Rare Isotopes Studies

FRIB

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Facility for Rare Isotope Beams

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GEANT4 & LISE^{++} Description

❑**LISE^{++}, "LIgne Super Epluchée"**

- Software used worldwide and designed to simulate the fragment separators

✓ To produce a radioactive nuclear beam (RNB) via fragmentation;

✓ To predict the intensity and purity of rare isotope beams; and

✓ To simulate nuclear physics experiences;

- Friendly interface and **no need to master C^{++}**.

❑**GEANT4, GEometry ANd Tracking 4**

- Monte Carlo tool maintained by a world-wide collaboration;
- Especially dedicated for the simulation of interactions between particles and matter;
- Applications: high energy, nuclear physics, space and material science to medical physics;
- C^{++} background is required.

Motivation & Goal-Expectation

- FRIB (Facility for Rare Isotope Beams) uses intensively LISE^{++} and GEANT4 to model the experiences for rare isotopes studies
  - Comprehensive and systematic validation of these codes against each other is lacking.

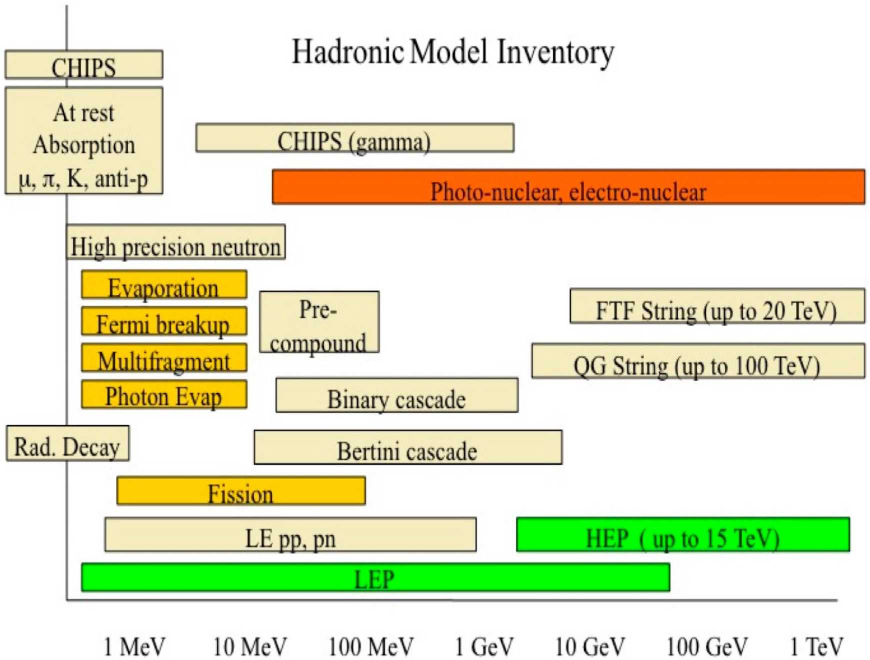
  Goal: Validating fragmentation physics in GEANT4 using LISE^{++} results

- Comparative study between tools through isotopic and isobaric distributions in terms of cross-section - probabilities of given processes to occur

- **Expectation**
  - Identify the discrepancies between codes;
  - Identify strengths and weaknesses of each of them;
  - Development of a benchmark code for a systematic validation.

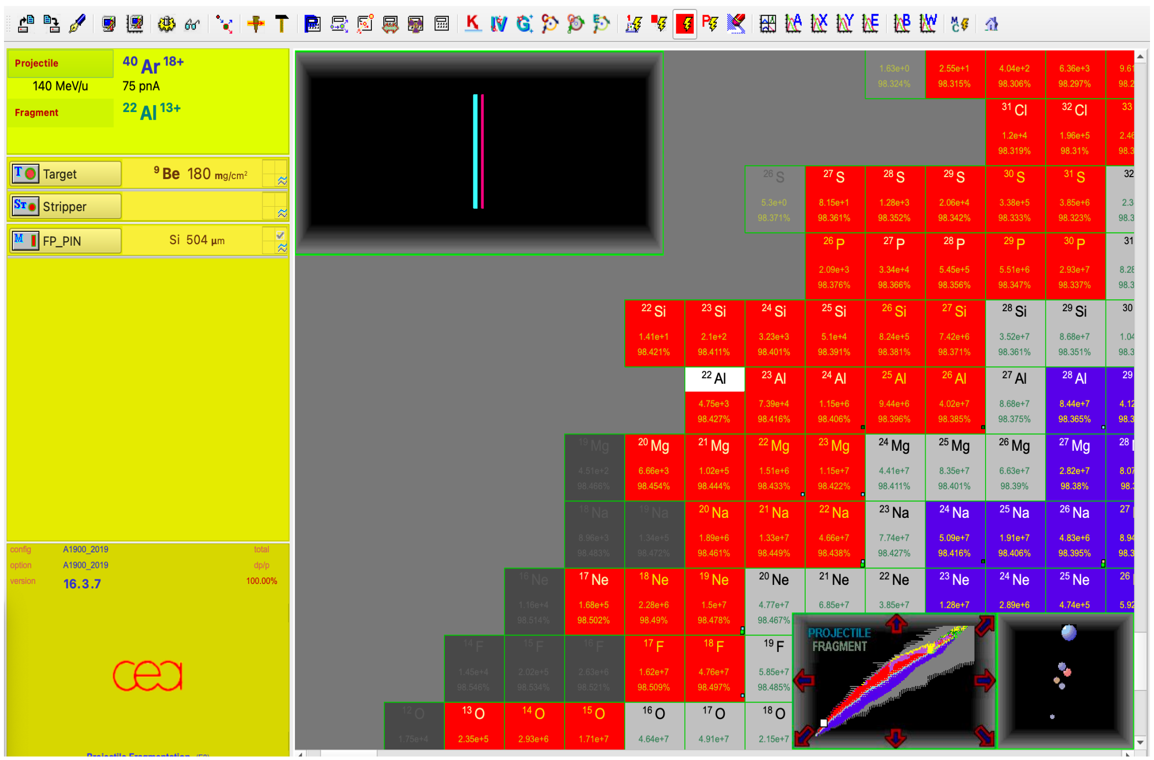
GEANT4 Models Study for Fragmentation reaction

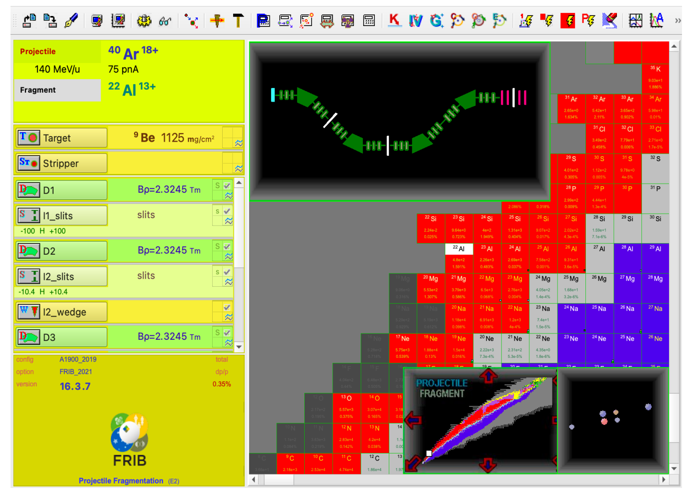
❑**Tens of categories of hadronic models**



Models	Characteristics
FTFP_BERT	- Recommended for HEP (>4 GeV) - Uses BERT for hadrons (< 5GeV)
QGSP_BERT	- Recommended for HEP - Uses BERT up to ~10 GeV
QGSP_BIC	- Recommended for medical applications
Shielding	- Recommended for shielding applications, space physics, HEP
QBBC	- Recommended for space applications, radiation protection; - Combination of BIC, BIC-Ion, BERT, CHIPS, QGSP and FTFP.

LISE^{++}: Spectrometer Design





Designing our own "Spectro-meter" → big challenge.

Projectile Fragmentation: Simulation

- **A 140 MeV/u beam of ^{40}Ar with an intensity of 75 pnA impinges on 180 mg/cm^2 of ^{9}Be target:**

$^{40}Ar + {}^{9}Be \rightarrow X$, X indicates all fragments produced

LISE^{++}:

Beam characteristics: ^{40}Ar

- Energy: 140 MeV/u;
- Intensity: 75 pnA = 4.68x10^{11} pps =1350 enA

Target characteristics: ^{9}Be

- Linear density: 180 mg/cm^2
- Density: 1.848 g/cm^3
- Thickness: 0.097297 cm

GEANT4:

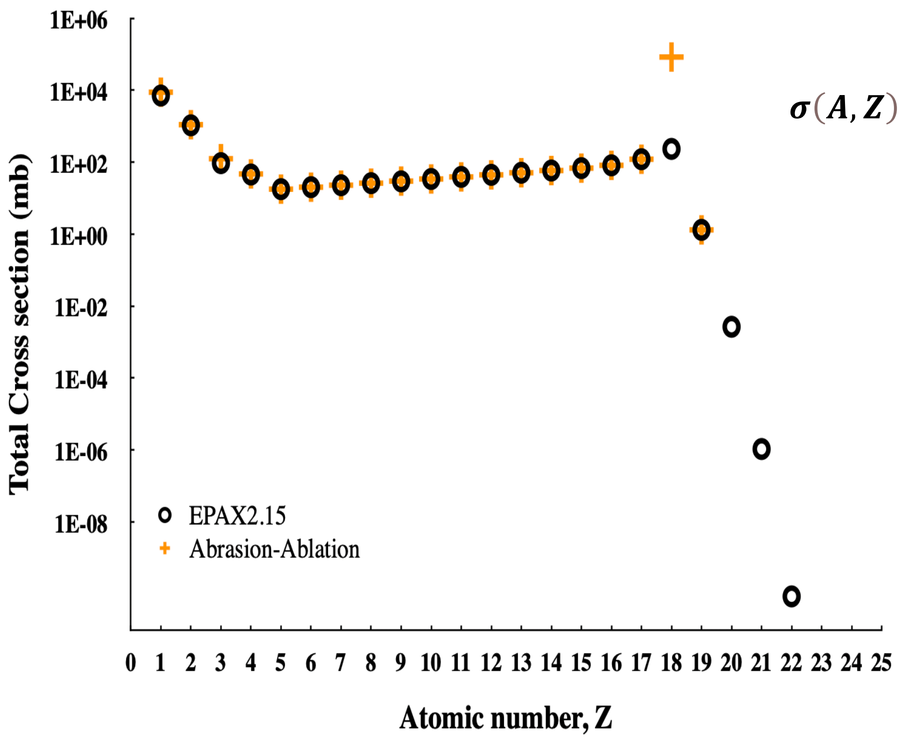
Beam characteristics: ^{40}Ar

- Energy: 140 MeV/u;
- Incident events number: 10 million

Target characteristics: ^{9}Be

- Density: 1.848 g/cm^3
- Thickness: 0.097297 cm
- Cut: 0.1 mm

LISE^{++}: Cross-section production



EPAX formula

$$\sigma(A,Z) = Y_A \sigma_Z (Z_{prob} - Z) = Y_A * n * exp\left(-R\left|Z_{prob} - Z\right|^U\right) \quad (1)$$

Y_A is the mass yield;

σ_Z is the Charge dispersion, representing the distribution of elemental cross sections with a given mass, A, around its maximum, Z_{prob};

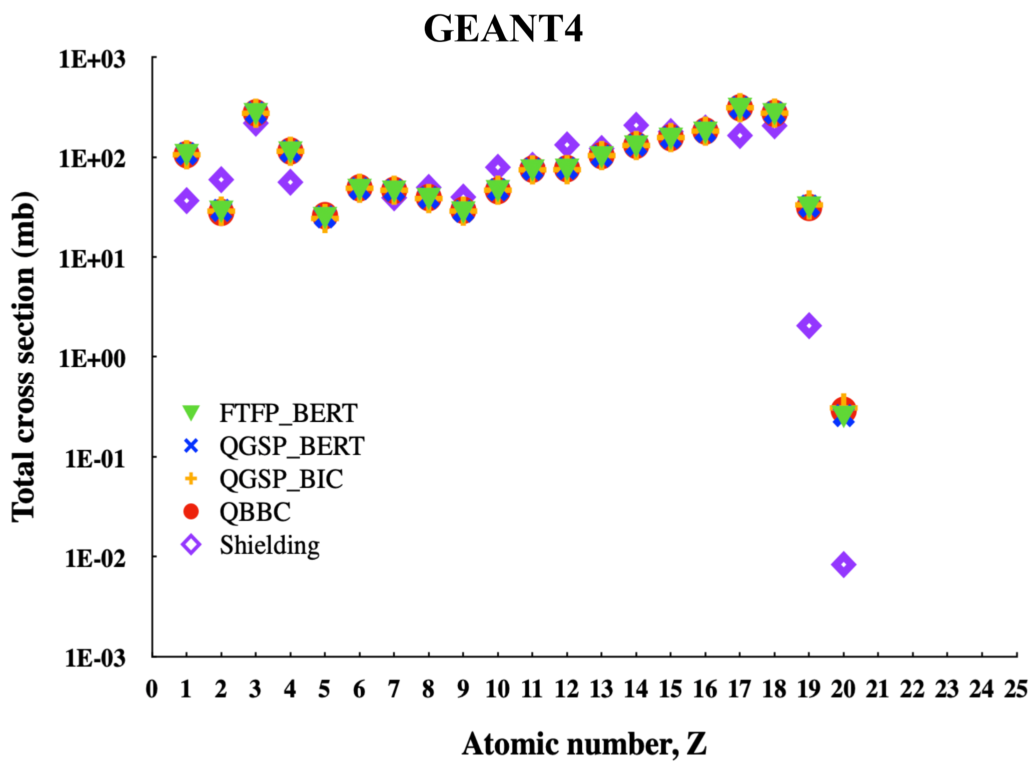
$n = \sqrt{R/\pi}$ is a normalization factor.

Abrasion-Ablation model

$$Y = I * t * N_t * \sigma * \varepsilon_t \quad (2)$$

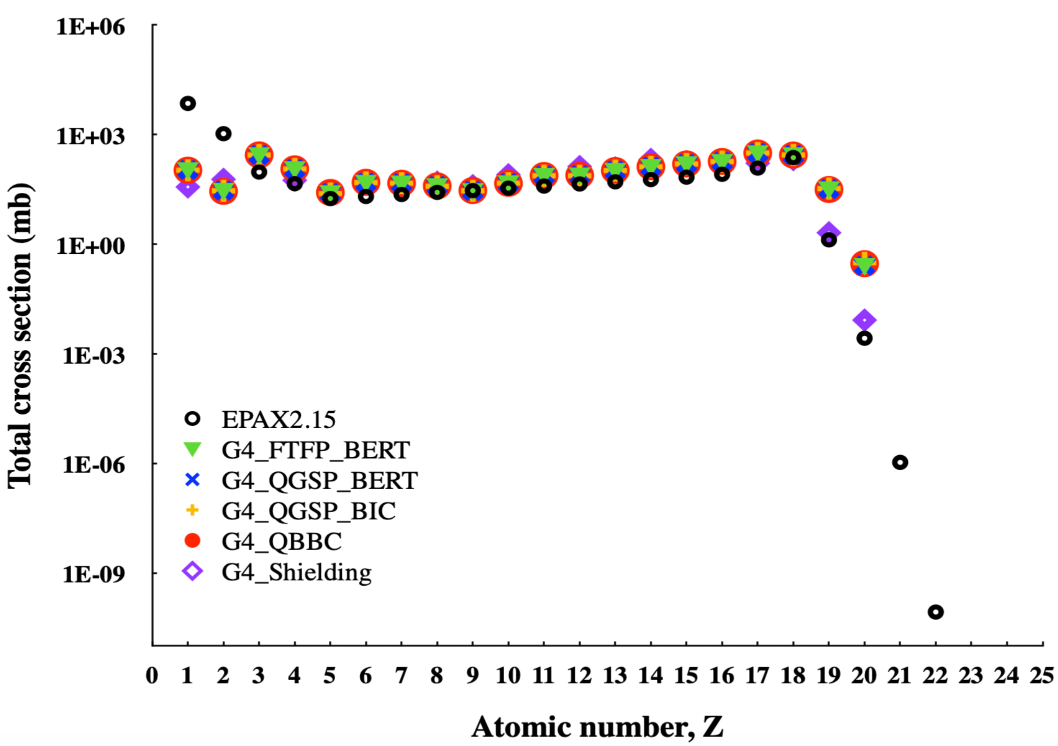
$$N_t = \frac{d_t * A}{N_A} \quad (3)$$

GEANT4: Cross-section production 2/2



- The look of the distributions are almost the same, except a slight differences with Shielding in the light fragments production and up to Z=18 region;
- QGSP_BERT and FTFP_BERT superimpose perfectly because they are interchangeable and can become competitive in some specific cases.

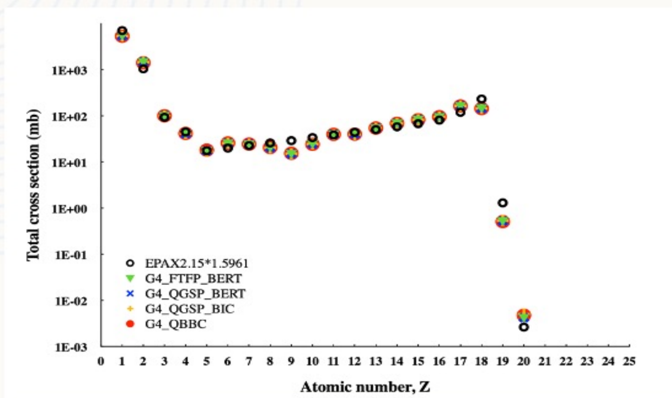
GEANT4 vs. LISE^{++}: Isotopic distributions

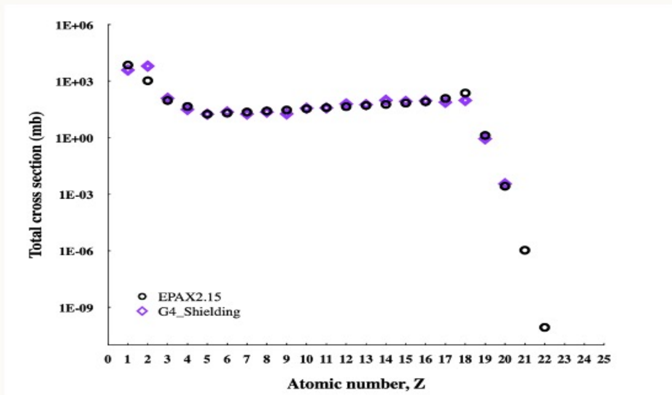


- All five GEANT4 models overlap with the EPAX distribution
- GEANT4 and LISE^{++} disagree in the lightest fragments production region
- Shielding model looks more suitable in the region up to Z=18

❖ Characterize the processes in the domain up to the beam: Pick-up, charge exchange.

GEANT4 vs. LISE^{++}: Agreement

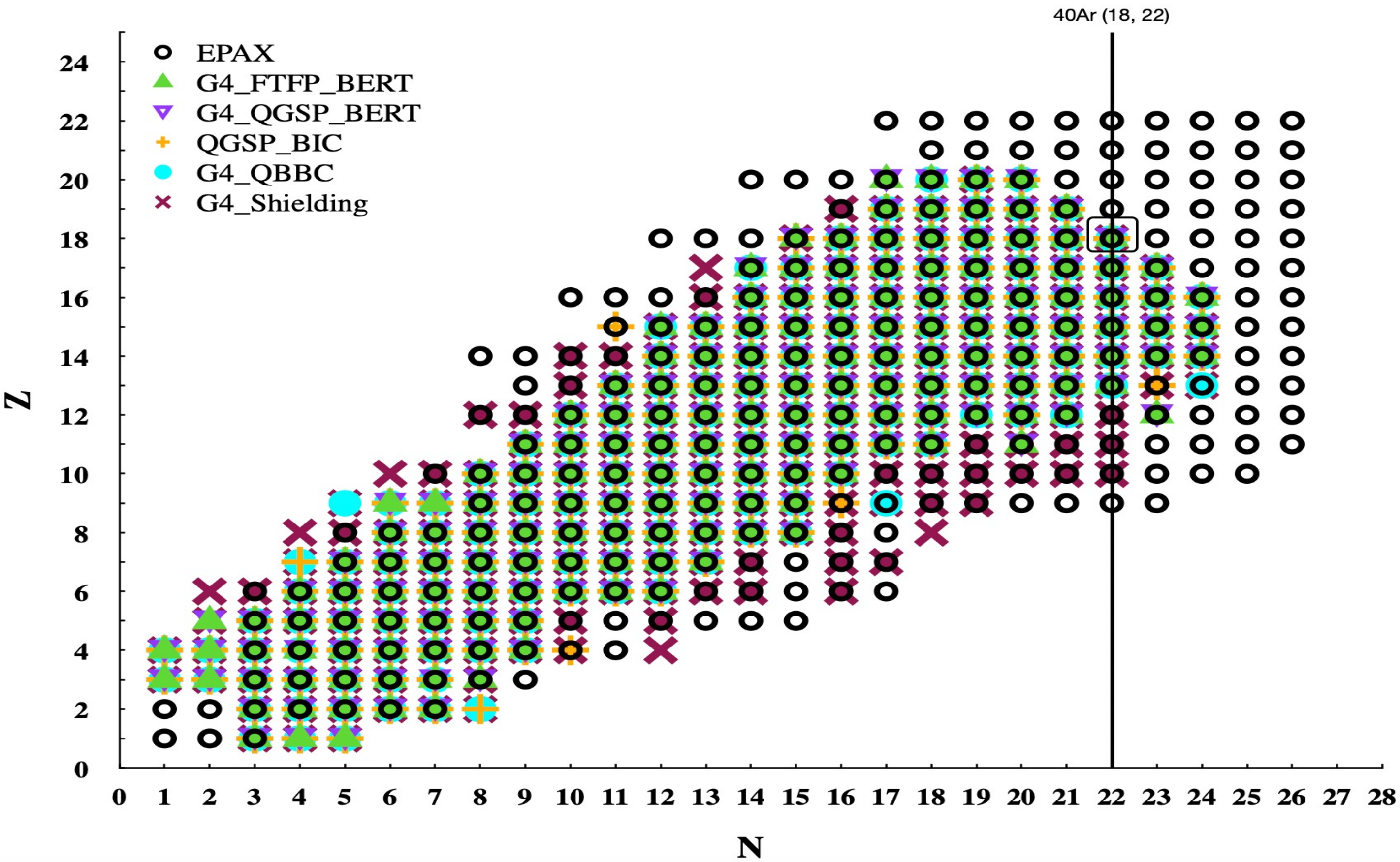




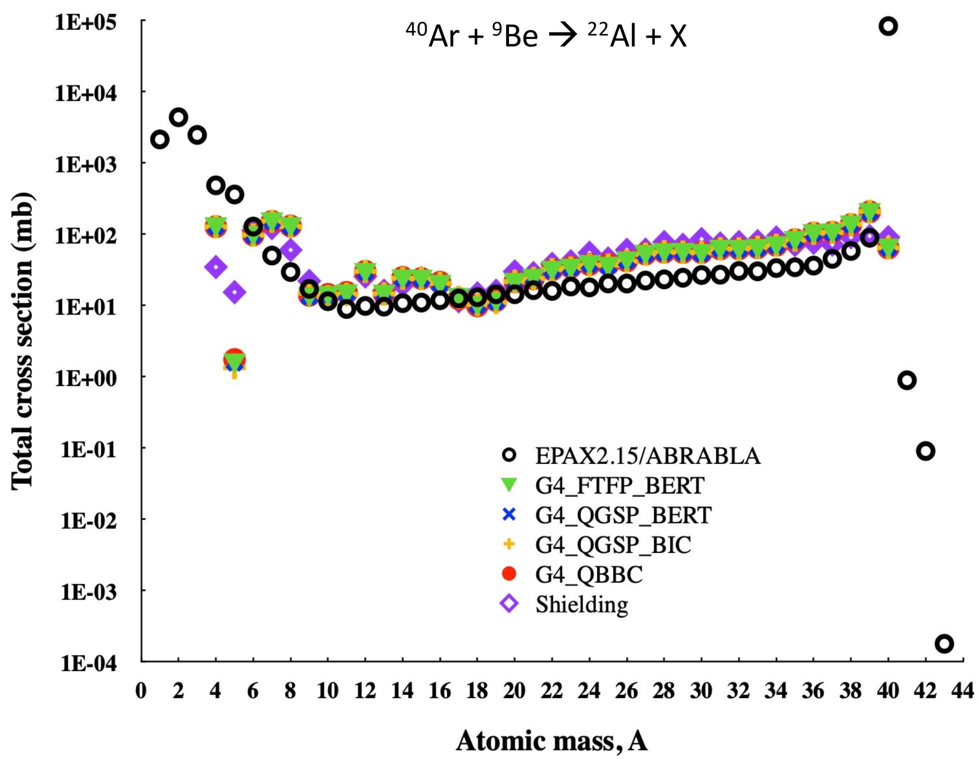
EPAX-GEANT4 (FTFP_BERT, QGSP_BERT, QGSP_BIC, QBBC)					
Atomic mass range	1-2	3-4	5	6-18	19-20
Order of magnitude	50.96	2.74	1.42	1.89	60.94
EPAX-Shielding					
Order of magnitude	105.78	1.78	1.37	2.16	2.35

- ❑ FTFP_BERT, QGSP_BERT, QGSP_BIC and QBBC
- ▪ good agreement with EPAX in the Z=2-18 region;
- ▪ Significant disagreement in the Z=1-2 and up to Z=18 regions.
- ❑ Shielding
- ▪ Good agreement except in the light fragments production region

Fragments production: GEANT4 vs. LISE^{++}



GEANT4 vs. LISE^{++}: Isobaric distributions



- LISE^{++} through EPAX and the ABRABLA model superimpose perfectly each other;
- The region of the light nuclei and beyond A=40 need further studies;
- Confirmation of the conclusions that arose from the isotopic distribution;
- The physics underlying the fragmentation processes well described by GEANT4.

Conclusion & Perspectives

Conclusion

- ❑Five GEANT4 models, Shielding, QGSP_BIC, QGSP_BERT, FTFP_BERT and QBBC were compared to the $LISE^{++}$ tool through the parameterized formula EPAX2.15 and the Abrasion-Ablation model
- ❑GEANT4 describes reasonably the physics underlying the fragmentation reaction using $LISE^{++}$ results
- ❑Shielding model turns out to be particularly interesting for the study of rare isotopes
- ❑A paper is in a review process and will be submitted in the coming days

Perspectives

- ❑Further studies needed to highlight the strengths and weaknesses of each tool
  - Provide explanation about the difference between GEANT4 and $LISE^{++}$ in the light and up to the beam fragments production region;
  - Provide clarification on the so-called pick-up or charge exchange process between the tools.

Thank you for your attention!

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