Improving Light Anti-Ion & Ion Inelastic Cross Sections

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Ion Inelastic Cross Sections in Geant4

- 3 cross sections are available for ions
  - ***G4ParticleHPInelasticData***
    - Based mostly on TENDL-2014, with some isotopes taken from ENDF/B-VII.1 ; applicable only below 200 MeV ; used only in QGSP_BIC_AllHP
  - ***G4ComponentGGNuclNuclXsc***
    - Based on Glauber-Gribov ; covers all energies ; used in nearly all physics lists (except QBBC)
  - ***G4ParticleInelasticXS***
    - Based on *G4ParticleHPInelasticData* below 20 MeV, and *G4ComponentGGNuclNuclXsc* at higher energies ; covers all energies ; used only in QBBC
- 1 cross section for light anti-ions
  - ***G4ComponentAntiNuclNuclearXS***
    - Based on Glauber-Gribov ; covers all energies ; used in all physics lists

Three Recent Suggestions to Improve

- We got, in the last couple of months, 3 independent suggestions to improve our light ion and anti-ion inelastic cross sections:
  - From ALICE measurements, to **increase** the low-energy inelastic cross sections of light anti-ions
    - Presented at the LPCC Detector Simulation workshop on 2/3 November 2020
  - From AMS-02 data (and Fluka predictions), to **increase** the inelastic cross sections of light ions for all energies
    - Email communication by a DAMPE experimentalist
  - From TALYS and EXFOR, to **decrease** the very low-energy inelastic cross sections of light ions
    - Email communication by a DAYA BAY and JUNO experimentalist

Summary and outlook

ALICE Experiment at CERN LHC as a tool to study antinuclei absorption in detector material

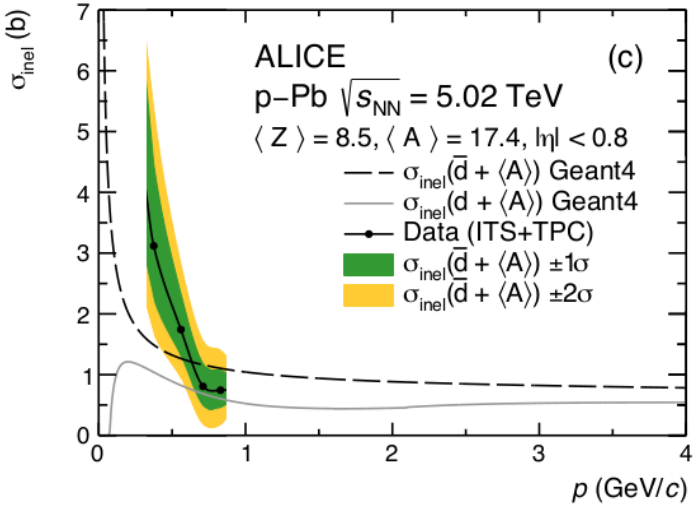
- Analysis of raw reconstructed antinuclei/nuclei ratios
- Constrain $\sigma_{inel}(\overline{d})$ via comparison with Geant4-based simulations
  - Benchmark on $\sigma_{inel}(\overline{p})$ - in good agreement with existing data
  - First experimental information on $\sigma_{inel}(\overline{d})$ (and $\sigma_{inel}(\overline{^3He})$) at low *p*!

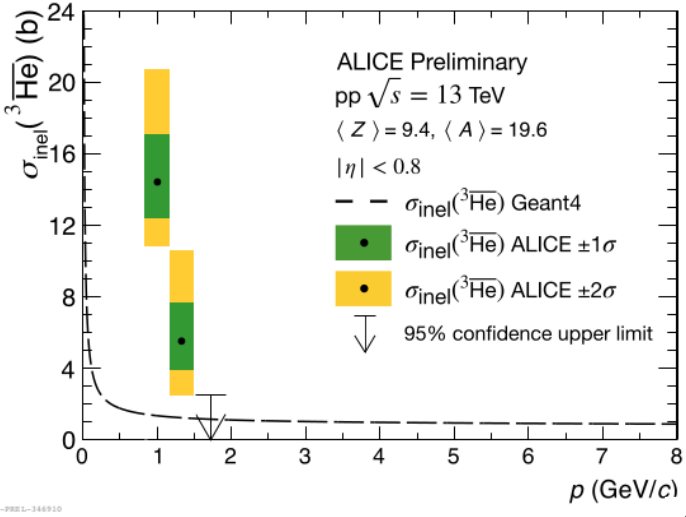
Stronger rise at very low momentum than predicted by Geant4!

- Adjust the antinuclei inelastic c.s. in Geant4 at very low *p*?

Work in progress towards further results

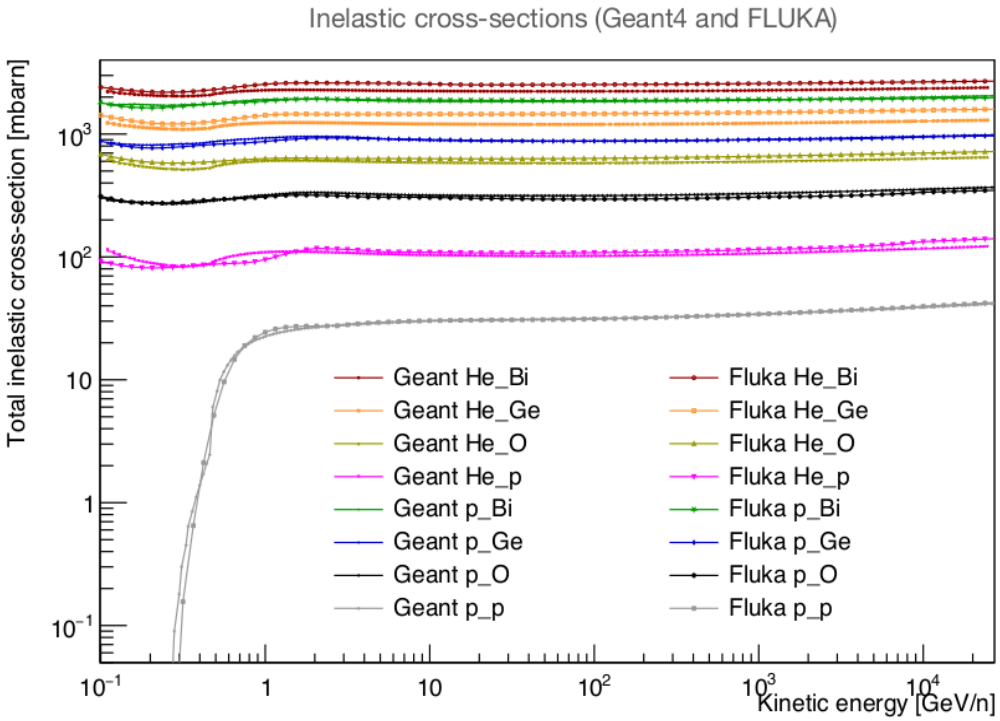
- Understand the origin of steep rise at low momentum
- Analyse more data with higher statistics for (anti)^{3}He
- Try to extend the analysis to (anti)^{4}He

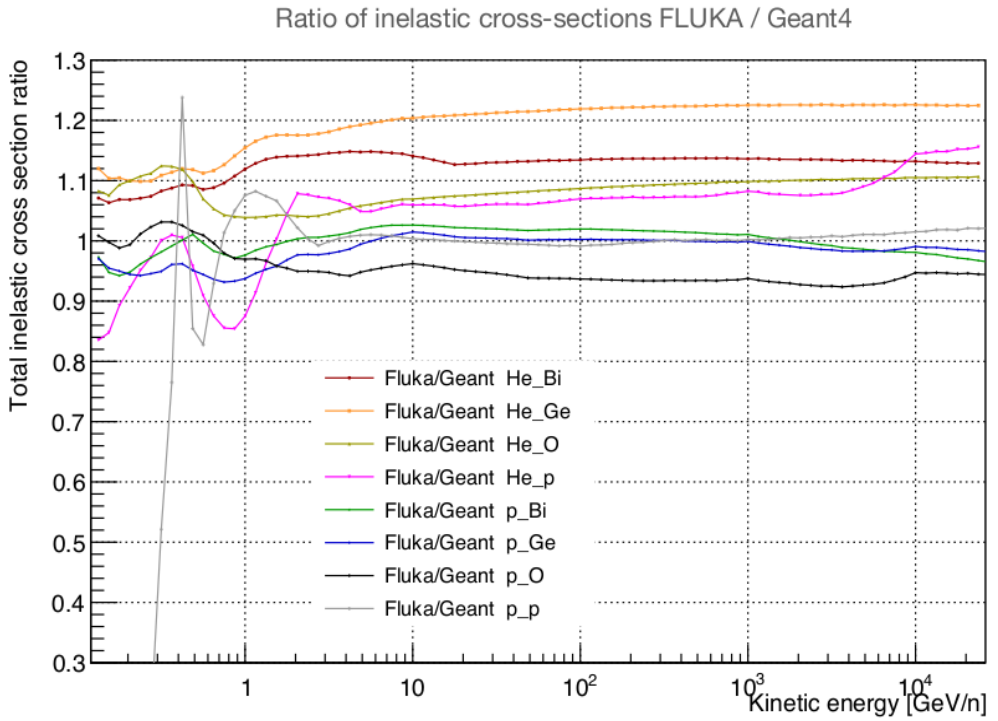




Email by Andrii Tykhonov (Geneve University, working on DAMPE and HERD)
(likely using FTFP_BERT physics list with Geant4 version 10.4 or 10.5)

Inelastic cross sections: projectile - ***H / He*** target - ***Bi / Ge / O / H***





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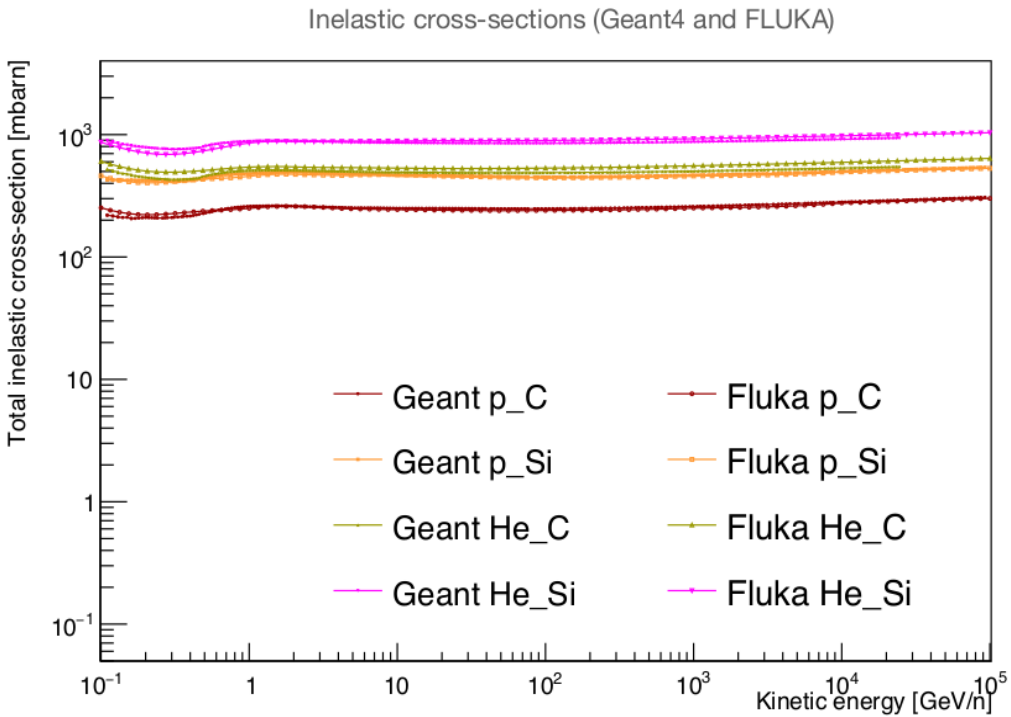
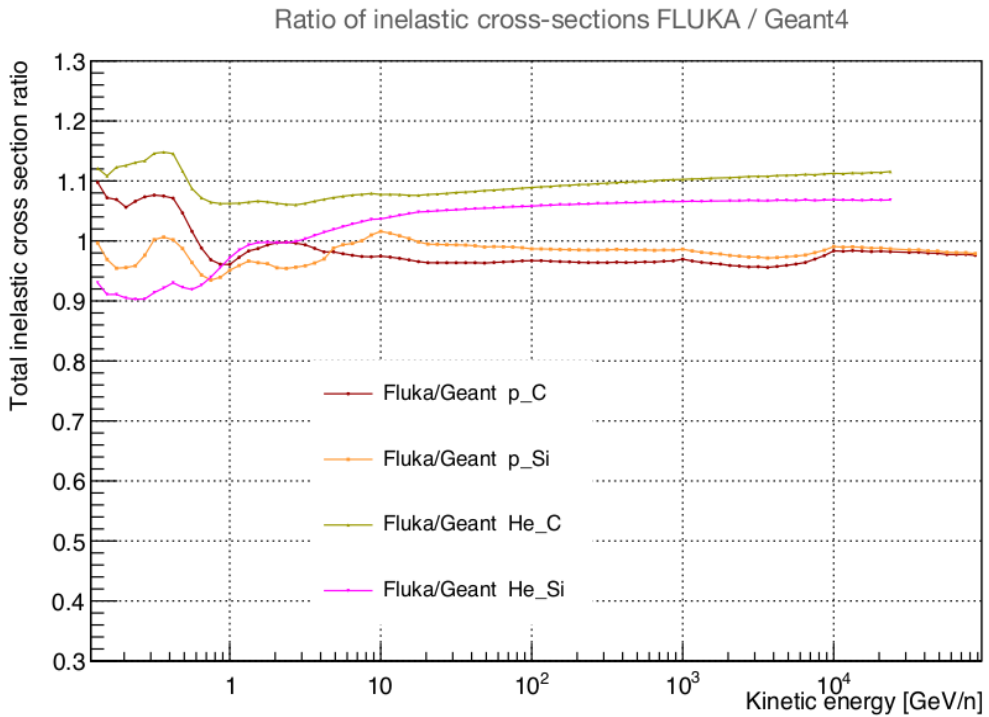
Inelastic cross sections: projectile - ***H / He*** target - ***C / Si***





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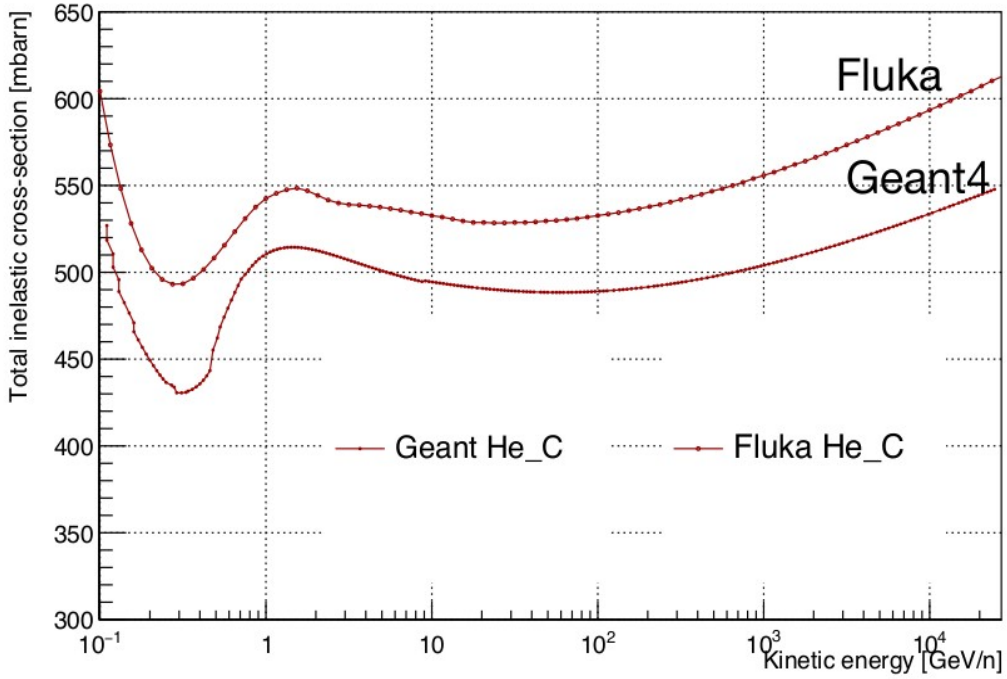
Inelastic cross sections: projectile - ***H / He*** target - ***C***

Inelastic cross-sections (Geant4 and FLUKA)



Inelastic cross-sections: comparison with data (AMS-02)

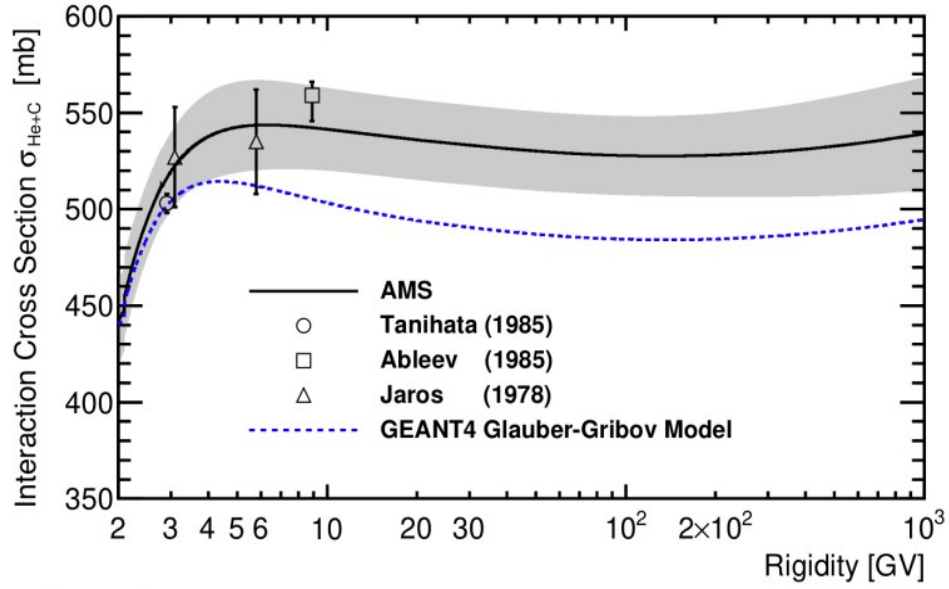


Figure credit:
https://ams02.space/advances-data-analysis/measurements-nuclei-cross-sections-cosmic-rays

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(likely using FTFP_BERT physics list with Geant4 version 10.4 or 10.5)

Conclusions

- **He — Bi / Ge / O / C / H inelastic** cross-sections are all higher in Fluka compared to Geant4
  - Notably, the biggest difference is for **He—Bismuth (~ 10 –15%)** and **He—Germanium (~ 20%).**
  - **He — Carbon** cross-sections are **~10%** higher in Fluka and **match well with AMS-02 data.**
  - ==> the data suggests FLUKA He-Carbon inelastic cross-sections are more accurate in FLUKA. **Does the same conclusion hold for He-Bi / He-Ge?**

My check with G4 10.7 (and 10.6.p03)

G4 **10.7** (in parentheses **10.6.p03**) :

=== **α** (projectile) - **12C** (target) ===

ekin	G4ComponentGGNuclNuclXsc	G4ParticleInelasticXS
1 GeV	437.24 mb (same)	331.76 mb (988.74)
10 GeV	510.15 mb (same)	331.76 mb (988.74)
100 GeV	489.91 mb (same)	489.47 mb (same)
1000 GeV	492.74 mb (same)	492.30 mb (same)

=== **α** (projectile) - **74Ge** (target) ===

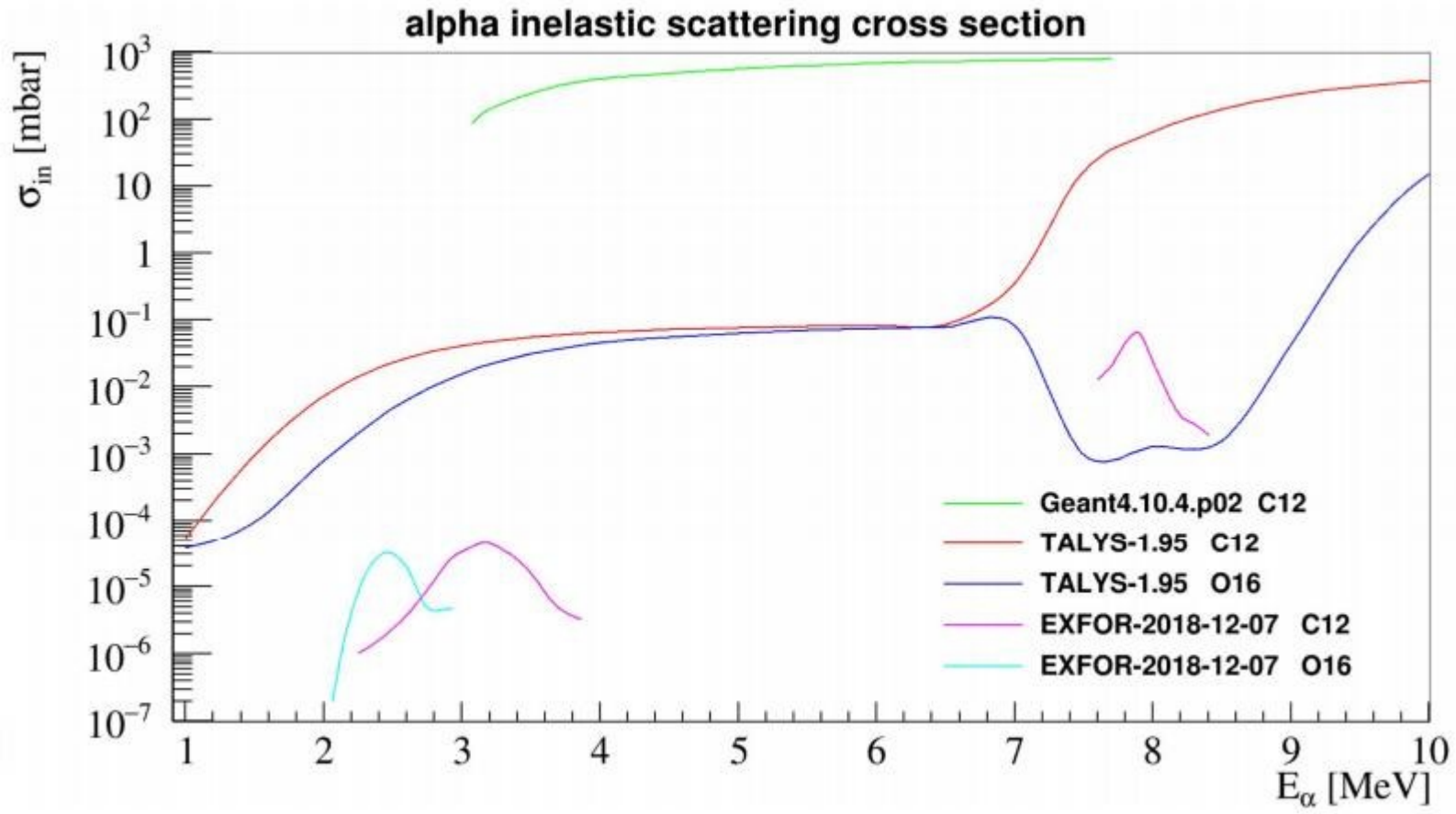
ekin	G4ComponentGGNuclNuclXsc	G4ParticleInelasticXS
1 GeV	1110.44 mb (same)	1100.26 mb (1014.00)
10 GeV	1243.91 mb (same)	1100.26 mb (1014.00)
100 GeV	1210.34 mb (same)	1223.76 mb (same)
1000 GeV	1215.28 mb (same)	1228.76 mb (same)

=== **α** (projectile) - **209Bi** (target) ===

ekin	G4ComponentGGNuclNuclXsc	G4ParticleInelasticXS
1 GeV	2042.52 mb (same)	2042.73 mb (2043.23)
10 GeV	2279.83 mb (same)	2280.05 mb (2280.06)
100 GeV	2228.28 mb (same)	2228.49 mb (same)
1000 GeV	2236.46 mb (same)	2236.67 mb (same)

Stable results for G4ComponentGGNuclNuclXsc and consistent with G4ParticleInelasticXS except for 12C target, where G4ParticleInelasticXS seems too high in G4 10.6 and now too low in 10.7

Email by Zeyuan Yu (IHEP China, working on Daya Bay and JUNO neutrino experiments)
(used G4ComponentGGNuclNuclXsc cross section with Geant4 10.4.p02)



My check with G4 10.7 (and 10.6.p03)

G4 **10.7** (in parentheses **10.6.p03**) :

=== **α** (projectile) - **12C** (target) ===

ekin	G4ComponentGGNuclNuclXsc	G4ParticleInelasticXS	G4ParticleHPInelasticData
1 MeV	0.000 mb (same)	0.0000 mb (same)	0.001 mb (same)
2 MeV	0.000 mb (same)	0.0000 mb (same)	0.252 mb (same)
3 MeV	58.701 mb (same)	0.0000 mb (73.607)	1.017 mb (same)
4 MeV	378.899 mb (same)	0.0000 mb (379.007)	1.467 mb (same)
5 MeV	565.375 mb (same)	0.0000 mb (566.344)	1.641 mb (same)
6 MeV	684.455 mb (same)	0.0000 mb (683.436)	2.870 mb (same)
7 MeV	765.356 mb (same)	0.0000 mb (765.611)	4.557 mb (same)
8 MeV	822.747 mb (same)	0.0000 mb (823.378)	69.167 mb (same)
9 MeV	864.748 mb (same)	0.0000 mb (865.284)	234.415 mb (same)
10 MeV	896.193 mb (same)	0.0000 mb (896.259)	376.764 mb (same)

- === **α** (projectile) - **16O** (target) ===

ekin	G4ComponentGGNuclNuclXsc	G4ParticleInelasticXS	G4ParticleHPInelasticData
1 MeV	0.000 mb (same)	3.9e-05 mb (4.7e-05)	4.0e-05 mb (same)
2 MeV	0.000 mb (same)	0.0009 mb (0.0016)	0.0076 mb (same)
3 MeV	0.000 mb (same)	0.0162 mb (0.0171)	0.1272 mb (same)
4 MeV	221.172 mb (same)	0.0455 mb (0.0450)	0.3509 mb (same)
5 MeV	479.238 mb (same)	0.0637 mb (0.0635)	0.5971 mb (same)
6 MeV	645.547 mb (same)	0.0750 mb (0.0746)	0.8368 mb (same)
7 MeV	759.686 mb (same)	0.0764 mb (0.0692)	1.2073 mb (same)
8 MeV	841.581 mb (same)	0.0076 mb (0.0711)	1.2596 mb (same)
9 MeV	902.289 mb (same)	1.0958 mb (3.0983)	1.4851 mb (same)
10 MeV	948.409 mb (same)	23.8804 mb (45.7778)	17.0809 mb (same)

Stable results for G4ComponentGGNuclNuclXsc and too high ; G4ParticleHPInelasticData is close to TALYS and EXFOR ; G4ParticleInelasticXS is consistent with PHP for 16O, whereas for 12C, is consistent with GG in G4 10.6, and likely buggy in G4 10.7

Extra:
Extension of Cross Sections

Unrelated Request of Extension : Light Hyper-nuclei and Anti-Hyper-nuclei

- ALICE has required the transport of hyper-triton in Geant4
  - Request made during the Geant4 Technical Forum on 23 March 2020
  - Hyper-triton : bound state of proton – neutron – lambda
- This requires at least hadronic elastic and inelastic cross sections of hyper-triton – and other light hyper-nuclei and anti-hyper-nuclei
  - So we need to extend our cross sections
- What is already available in Geant4 for hyper-nuclei ?
  - INCL + ABLA should be already able to produce and handle hyper-nuclei, (not yet anti-hyper-nuclei !) although it needs to be tested and validated
  - For ALICE it is enough to cover energies below ~15 GeV ...