

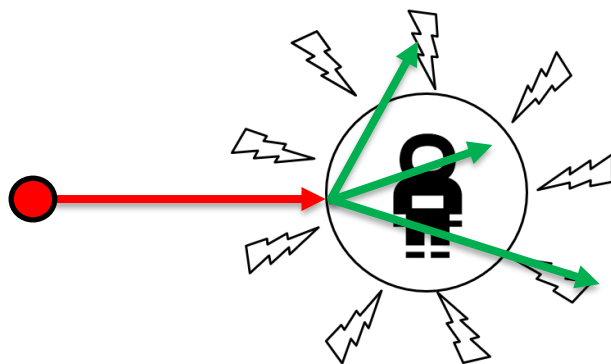
Experimental cross sections needed for space radiation protection

Francesca Luoni
WANDA 2021,
29/01/2021



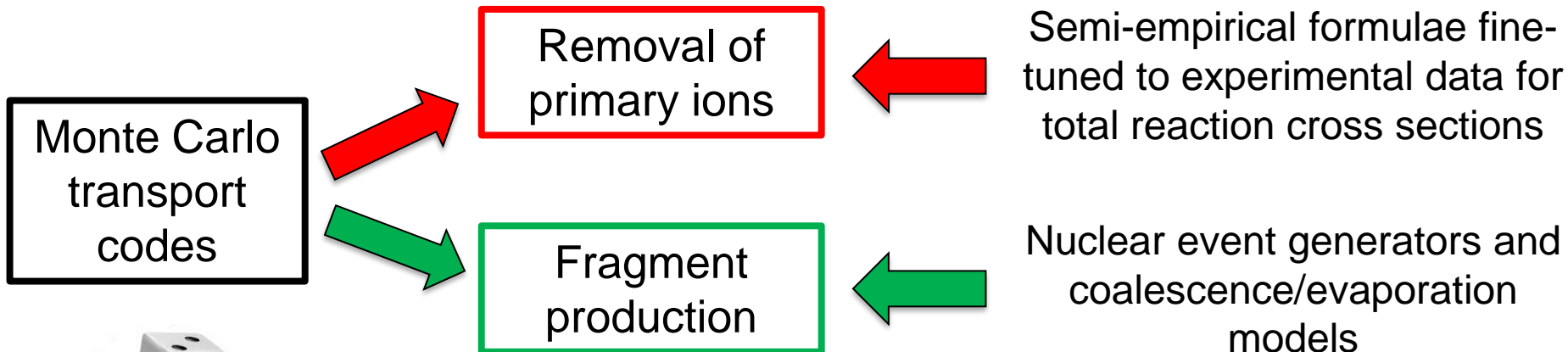
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Cross sections in transport codes



GCR = biggest hindrance for manned deep-space exploration missions

Total (non-differential) cross sections σ



Double differential cross sections $\frac{\partial^2 \sigma}{\partial E \partial \Omega}$

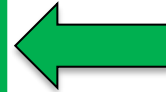
Double differential cross sections



Monte Carlo
transport
codes



Fragment
production



Nuclear event generators and
coalescence/evaporation
models

Double differential cross sections $\frac{\partial^2 \sigma}{\partial E \partial \Omega}$



REVIEW

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Are Further Cross Section Measurements Necessary for Space Radiation Protection or Ion Therapy Applications? Helium Projectiles

OPEN ACCESS

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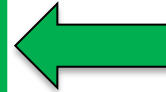
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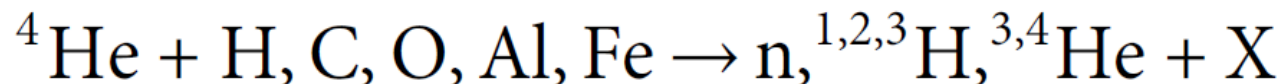


Nuclear event generators and
coalescence/evaporation
models

Double differential cross sections $\frac{\partial^2 \sigma}{\partial E \partial \Omega}$

What cross section data are needed?

Helium-projectile, isotopic double-differential, cross sections for the
production of neutrons and light ions

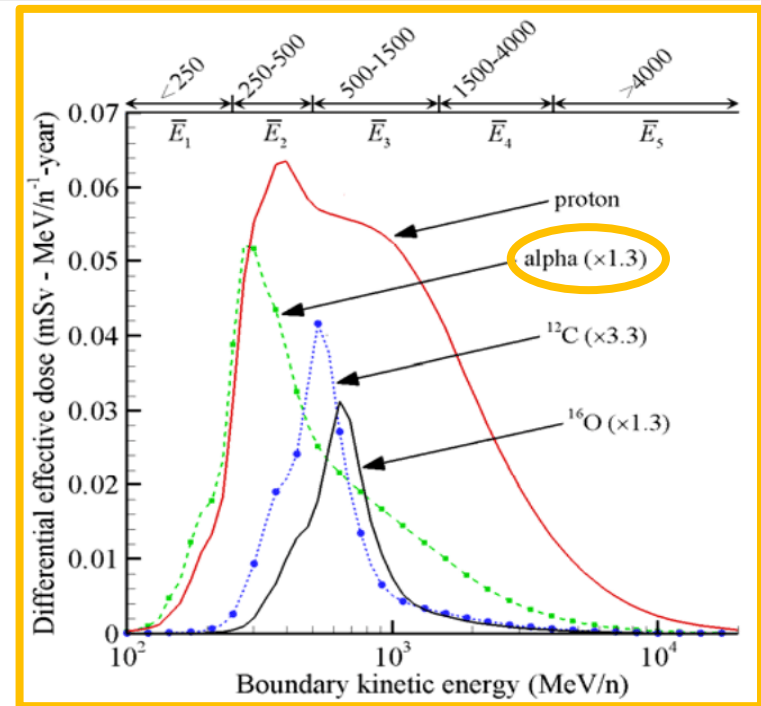
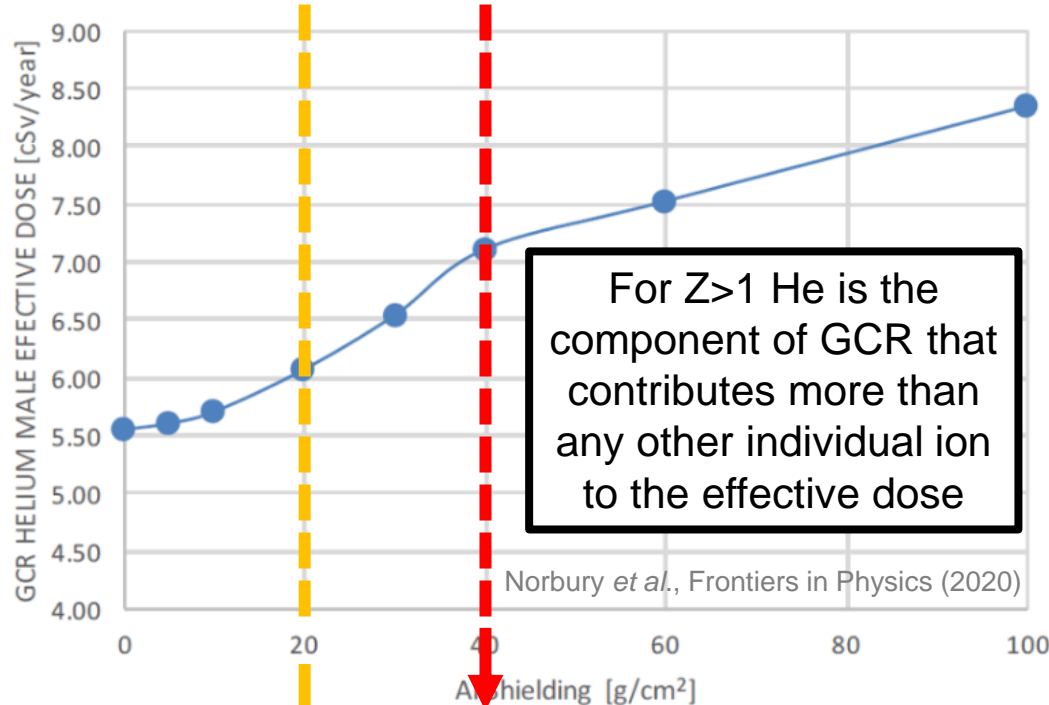


Currently, in literature there are no high-quality cross-section data of this type

Norbury *et al.*, *Frontiers in Physics* (2020)

Why helium projectile?

Helium-projectile, isotopic double-differential, cross sections for the production of neutrons and light ions



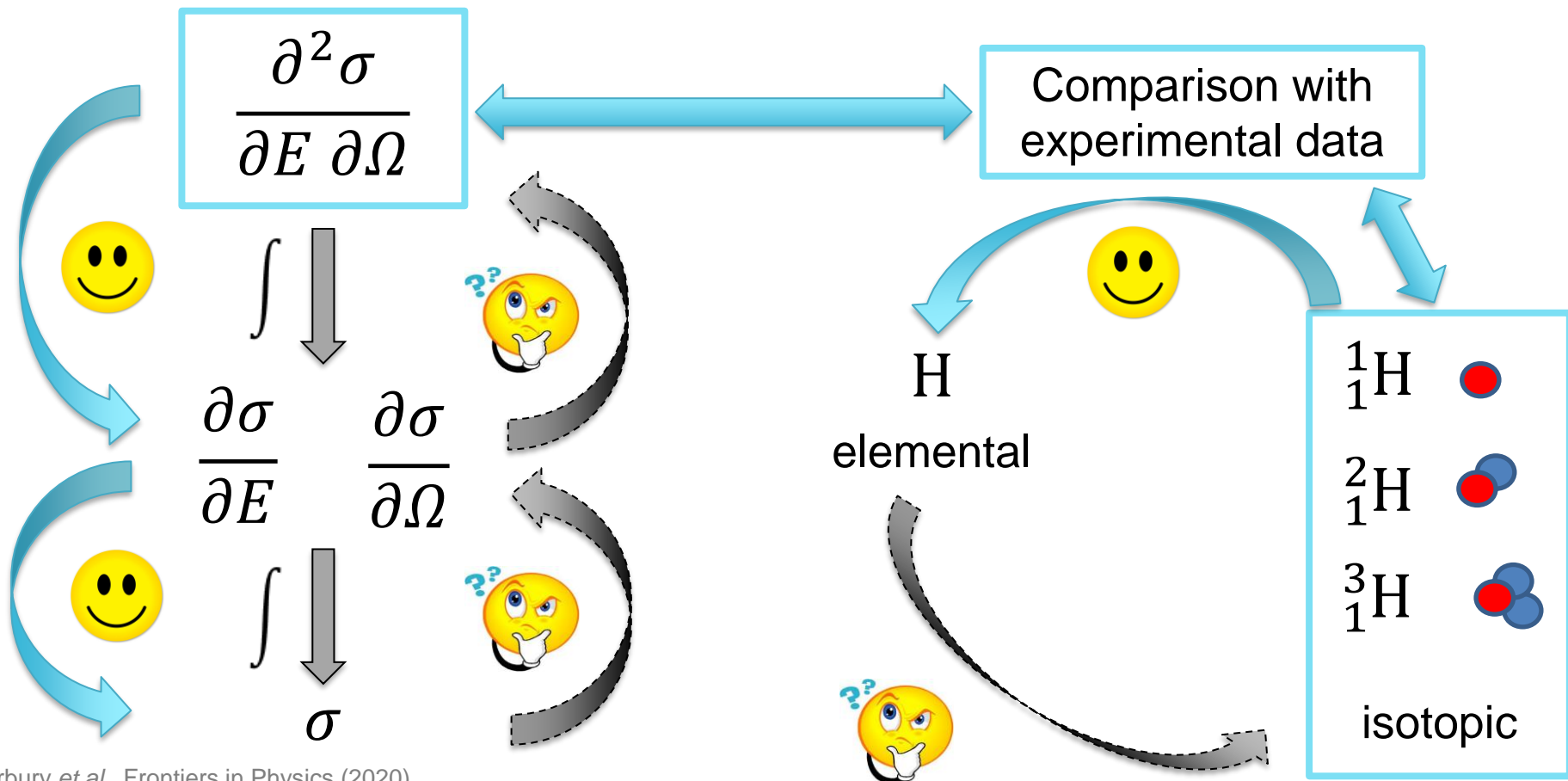
He contribution to the effective dose = **46%** of the total ion ($Z>1$) contribution
 He contribution to the effective dose = **14%** of the total contribution

He contribution to the effective dose = **30%** of the total ion ($Z>1$) contribution
 He contribution to the effective dose = **12%** of the total contribution

Slaba and Blattnig, Space Weather (2014)

Why isotopic double-differential?

Helium-projectile, **isotopic double-differential**, cross sections for the production of neutrons and light ions




Total reaction cross sections

Monte Carlo
transport
codes

Removal of
primary ions

Semi-empirical formulae fine-tuned to experimental data for total reaction cross sections

Total (non-differential) cross sections σ

$$\frac{\partial^2 \sigma}{\partial E \partial \Omega} \xrightarrow{\iint} \sigma$$


... but $\frac{\partial^2 \sigma}{\partial E \partial \Omega}$ are hard to be measured \rightarrow waiting for the ideal sets of data, we can start removing uncertainty to one part of the MC simulations

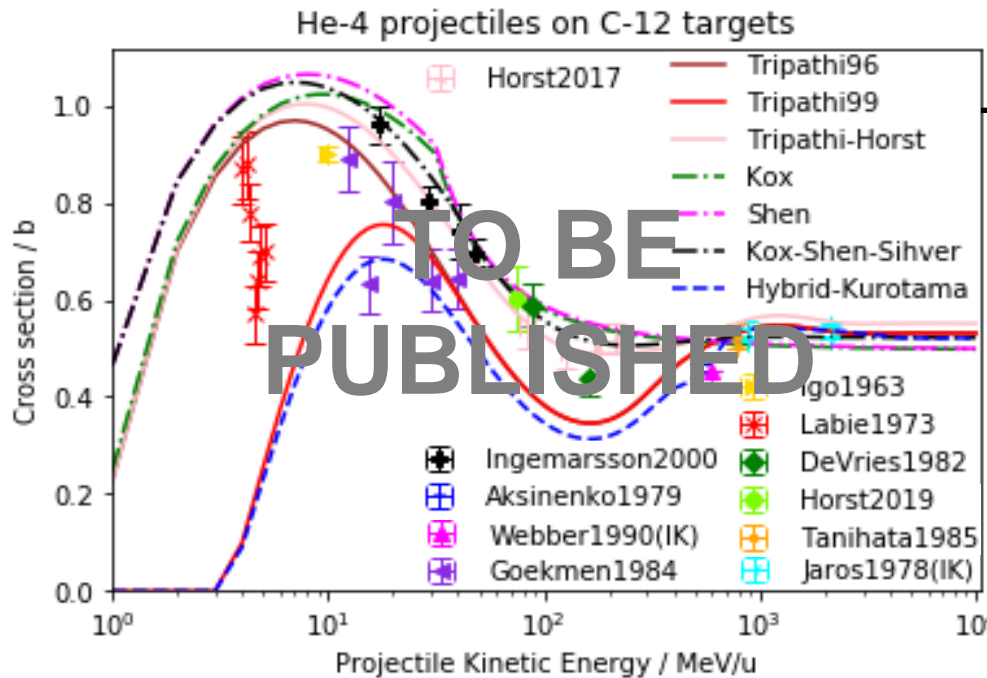
- Total reaction cross-section database created:
1680 data from ca. 100 peer-reviewed publications
- Implementation of a code that is comprehensive for the most used semi-empirical formulae in Monte Carlo codes



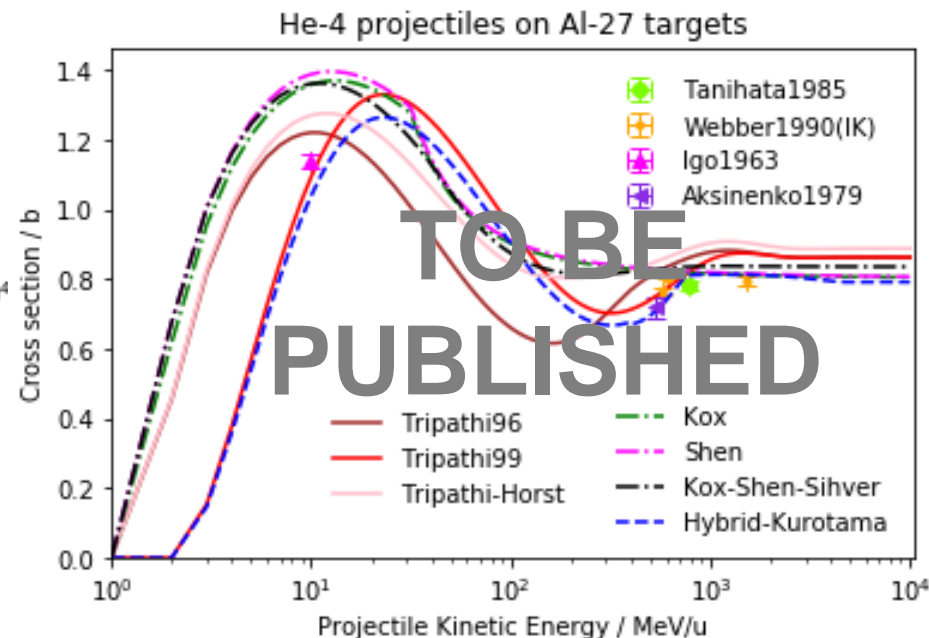
To be published

^4He -projectile σ : some systems

Currently, there is no semi-empirical formula that agrees well with the experimental data for all systems

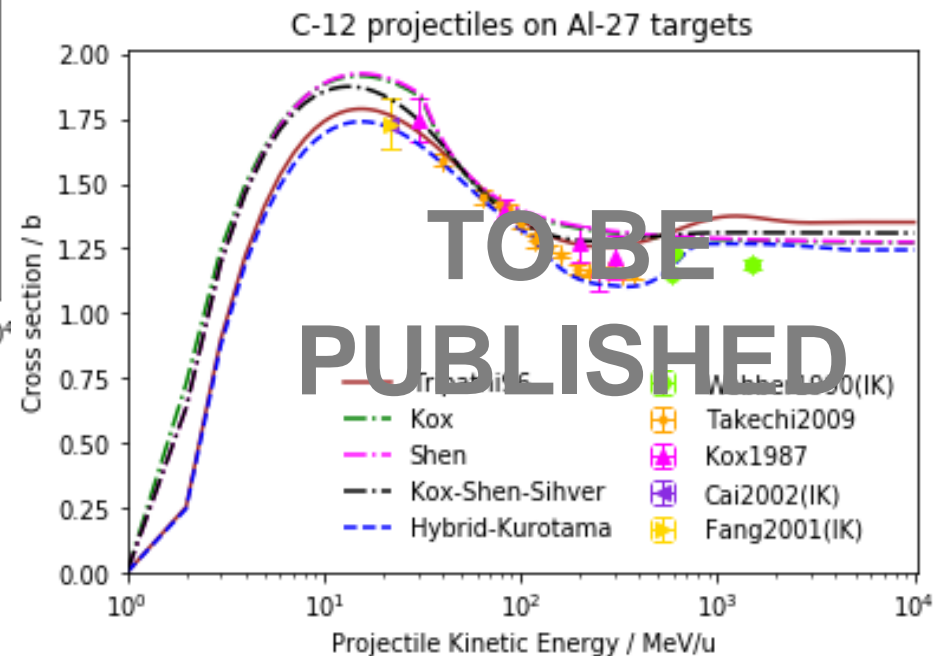
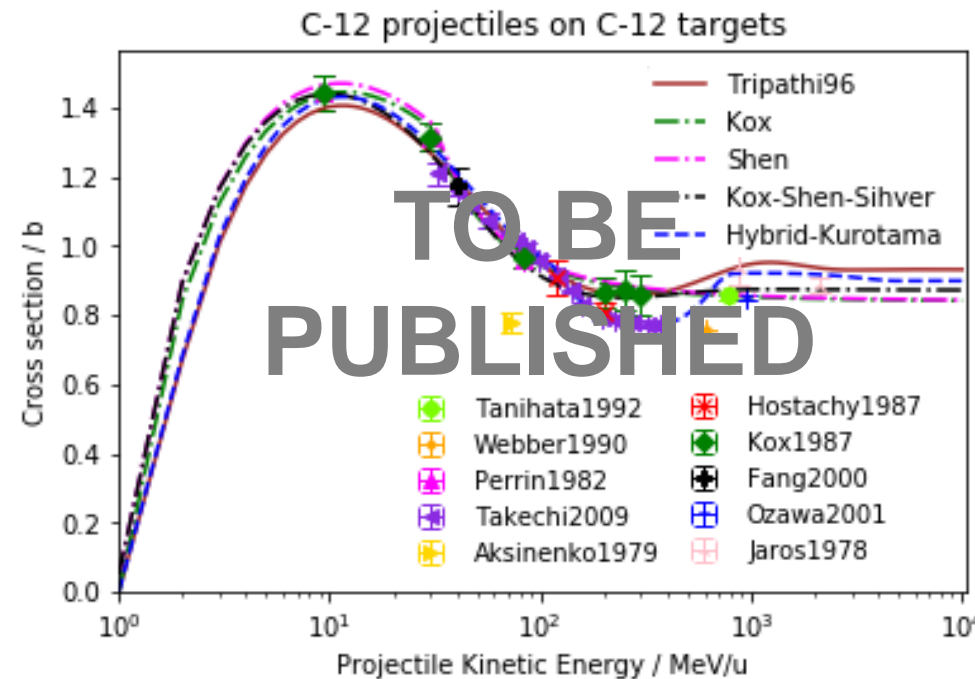


Better-quality data for low energies necessary



^{12}C -projectile σ : some systems

Currently, there is no semi-empirical formula that agrees well with the experimental data for all systems

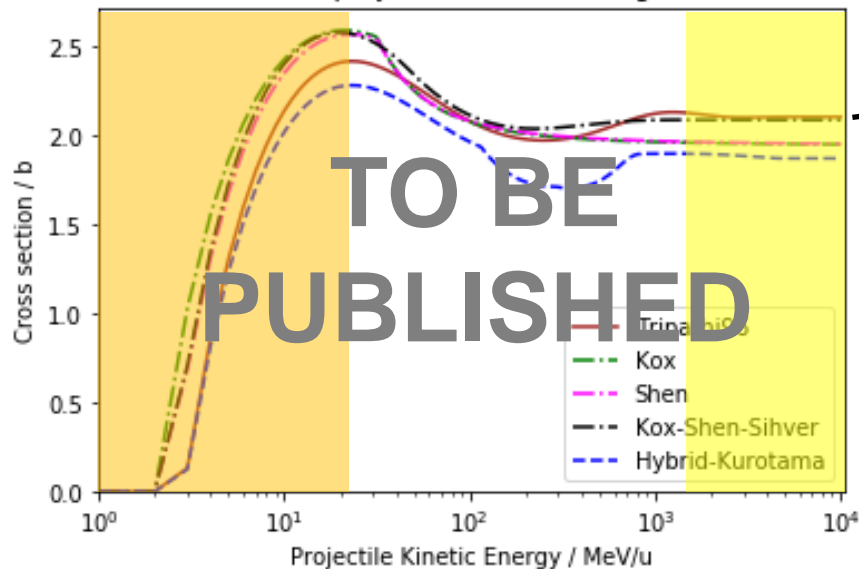


To be published

Missing σ data

Currently, there is no semi-empirical formula that agrees well with the experimental data for all systems

Fe-56 projectiles on O-16 targets



For some systems data for all energy regions are missing

For all systems data are missing for:

Very-low (Coulomb barrier) and energies

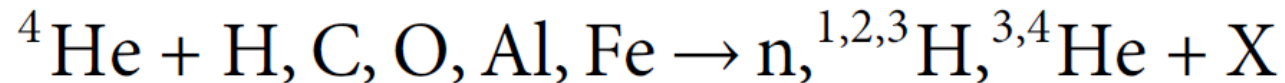
Slowing down process (G4 e.g. has no tracking cuts)

Very high (> 1.5 GeV/u) energies

Thick shieldings

What cross section data are needed?

- Helium-projectile, isotopic double-differential, cross sections for the production of neutrons and light ions



- Total reaction cross sections for some important systems for space radiation protection
- Total reaction cross sections for very-low and very-high energy ranges for all systems

Thanks to



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- Marco Durante
- Felix Horst
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- Uli Weber

And the rest of my group

- John Norbury



- Laura Bagnale



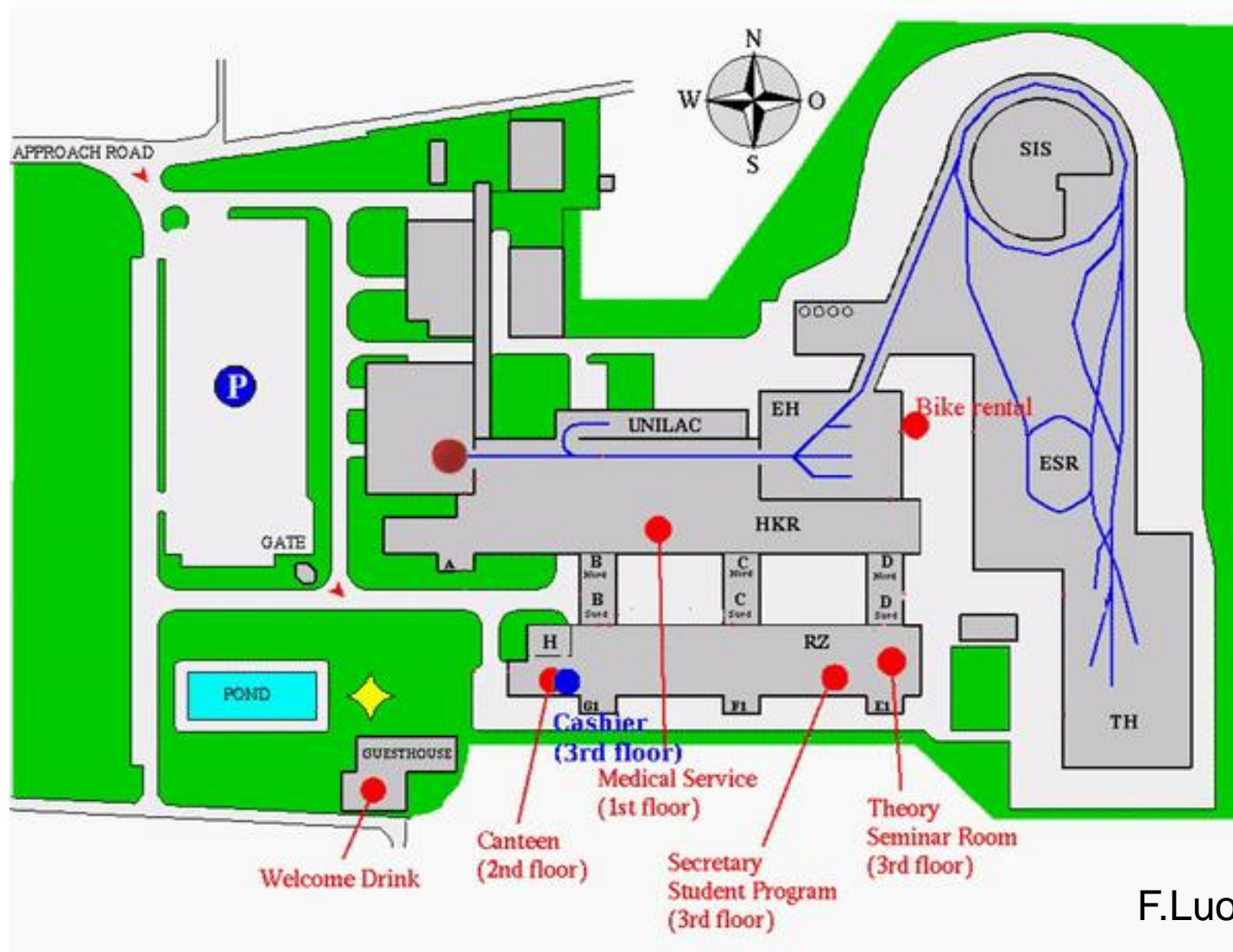
- Anastasiia Quarz



- Giovanni Santin



Thank you for your attention!



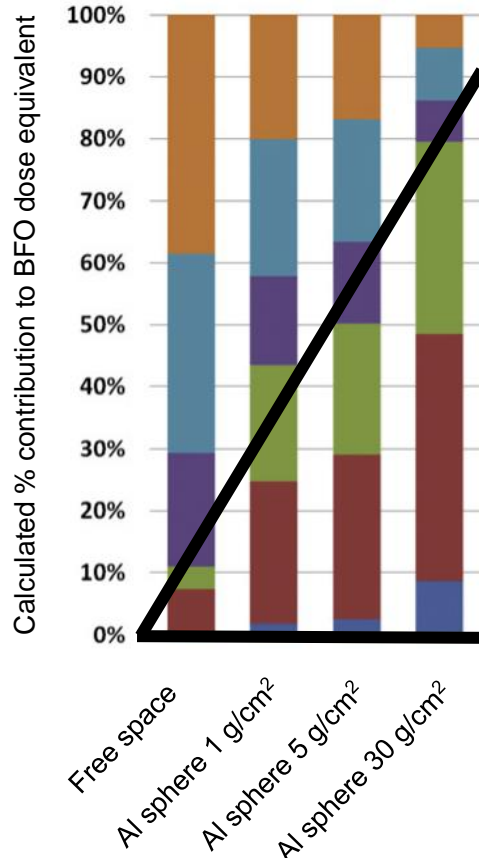
F.Luoni@gsi.de

Why neutrons and light ions?

Helium-projectile, isotopic double-differential, cross sections for the production of neutrons and light ions

■ Z = 0 ■ Z=1 ■ Z=2 ■ 3≤Z≤10 ■ 11≤Z≤20 ■ 21≤Z≤28

Walker *et al.*, Adv. Space Res. (2013)



- They dominate dose equivalent for thick shielding
- For their production and transport specifically $\partial^2\sigma/\partial E\partial\Omega$ are needed as they scatter at large angles (full 3D transport methods)
- Intercode comparison not satisfactory
- Benchmarking of recently collected experimental data with available transport codes not satisfactory
- Data are missing

Norbury *et al.*, Frontiers in Physics (2020)

