Nuclear Cross Sections for Cosmic Rays Astrophysics Theory and Experiments

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Abstract

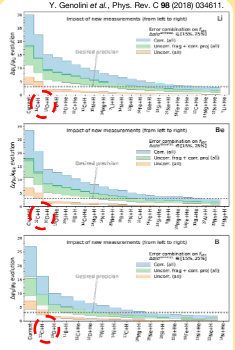
Measurement of nuclear cross section are crucial for astroparticle physics, both for the development of high-accuracy models, and for the understanding of the normalization of nuclei spectra for experimental measurements. For theory the most relevent cross section of nuclei incident over H and He (principal components of the interstellar medium), while for experiments are needed cross section for nuclei incident on passive and active detector material such as C or Al. Given the availability of high energy nuclei beams at the CERN SPS, used since long time for testing of cosmic ray experiments that operate in space, a program for measurement of cross section can be envisioned that can contribute to both fields.

Limitations in Cosmic-Ray Theory from Nuclear Cross Section Knowledge

Interpretation of the behaviour of secondary nuclei CRs (Li, Be, B, …) with respect to primaries (C, O, …), is the key for the understanding of propagation of all CRs in the Galaxy. This understanding is currently limited by the knowledge of their cross-section with the interstellar medium. Among the most important cross section are the ones related to (C,O) + (H,He) → (Li,Be,B) + X.

→ Take home message: to do high-precision modelling of CR physics, for the research of exotic sources, we need a precise description of nuclear XS, that are limiting the prediction power for all CR species.

Y. Genolini *et al.*, Phys. Rev. C **98** (2018) 034611.



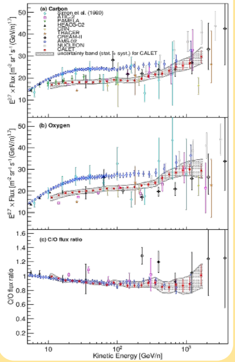
Limitation in Cosmic Ray Experimental Mesurements from Nuclear Cross Section Knowledge

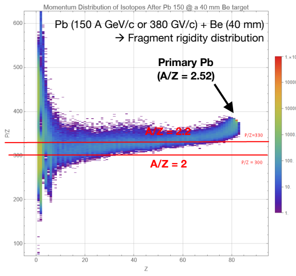
Precision measurement of CRs requires a detailed understanding of the interaction of particles in the detector materials (C, Si, Al, …), in terms of total and spallation XS. A motivation for such a measurement is the apparent disagreement in the measurement of CRs nuclei spectra between different experiments.

Some attempt to solve this discrepancy has been done comparing survival probabilities from MC codes with direct estimations with CR experiment (Q. Yan *et al.*, Nucl. Phys. A **996** (2020) 121712). However, this work does not translate directly to all other experiments.

→ Take home message: direct measurement of CRs needs accurate measurements of nuclear XS of ions on C, Al, …, that are largely incomplete or absent, to do precision measurements of CRs.

O. Adriani *et al.*, Phys. Rev. Lett. **125** (2020) 251102.





SPS Beam-test line H4 @ CERN

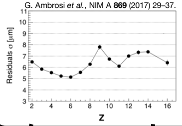
The **H4 beam line** of EHN1 at SPS is a **high-energy**, **high-resolution secondary beam line**. The momentum that can be transported in the experiments is in the range between 40 and 400 AGeV/c (primary). A secondary ion spectrum is produced from collision on target (Be) of high-Z primaries (Pb) accelerated in SPS. The produced fragments can be selected with a magnetic spectrometer with a maximum Δp/p acceptance of **2%**. By approximate conservation ("straight-ahead approximation") of the kinetic energy per nucleus od the nuclear fragments, the selection in rigidity corresponds to a selection of A/Z of the secondary production.

This facility is routinely used for testing of CR experiments (AMS, CALET, DAMPE, HERD, …) for testing of since the 2000s. Many groups active in CRs direct measurement are familiar with it.

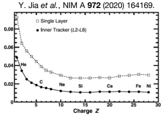
Micro-strip Silicon Sensor

An ideal device that can combine the high-resolution charge and tracking, optimizing the amount of material on the beam line, is the **micro-strip silicon sensor**, which has been employed successfully for this kind of applications (AMS, PAMELA, …).

G. Ambrosi *et al.*, NIM A **869** (2017) 29–37.



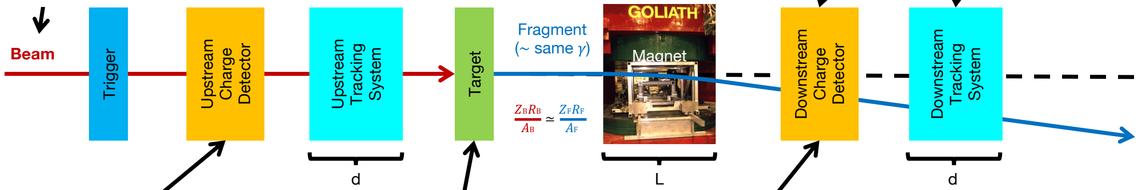
Y. Jia *et al.*, NIM A **972** (2020) 164169.



GOLIATH

operating on the H4 line.
B = up to 1.5 T
L ~ 1m

Proposed XS Measurement Setup



Incoming Beam Characterization

The SPS ion beam secondary is precisely selected in rigidity between 40 and 400 GV with a specified A/Z. An Upstream Charge Detector can be used to establish the Z of the beam particle. By combination of beam setting and Z selection it is possible to select clear samples of incoming elements (as an ex. ^{12}C and ^{16}O). The purity of the incoming beam can be estimated using the whole spectrometer in runs without the target.

Target

A variety of targets should be employed to fulfill the physics program. Just to make an example, C and CH_2 targets can be used both for XS useful for detectors, X+C, or for astrophysics, estimating X+H by subtraction. The beam interacts in the target. Then, a leading ion fragment emerges with approximately the same kinetic energy of the beam.

Charge Change XS

The Downstream Charge Detector establishes the fragment Z. The system **Trigger/Target/Upstream-Downstream Charge Detector** is sufficient to study charge change cross section. This configuration could be important for: 1) a simpler acquisition configuration for development and study; 2) reference for the isotopic channel measurements.

Mass Change XS

The **magnetic spectrometer** composed by the **Magnet**, the **Upstream** and the **Downstream Tracking Systems** allows for the reconstruction of the fragment mass by deflection. Considering two tracking devices constituted by two stations measuring position with a resolution σ = 30 μm at d = 2m, a magnetic field of about B = 1T and a length in the magnet of L = 1m (GOLIATH), for incoming rigidities in the range 40—400 GV the deflection angle is between 0.04–0.4° and the rigidity resolution is σ_R/R = 0.4—4%. The rigidity resolution translates directly into the mass resolution σ_M/M. This resolution seems adequate to judge fragments up to A=10 and above.

Conclusions

Nuclear XS are paramount for CRs Theory and Experiments.

Possible measurement at beam facility already used for testing of CRs experiments can be envisioned, employing already existing technology.

These measurements can be complementary to existing programs.