Results of total cross-section measurements of the $^{87}Rb(p,\gamma)^{88}Sr$ reaction

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Motivation

Two different **neutron-capture processes** are accountable to produce most of the elements heavier than iron, namely the slow (s) and the rapid (r) neutron-capture process. About 30 – 35 stable, neutron-deficient nuclei – the so-called **p nuclei** [1] – are bypassed by these two processes.

These nuclei are predominantly produced in the **γ process**, which consists of different combinations of **photodisintegration reactions**, e.g. (γ,n) responsible for crossing the valley of stability, (γ,p) or (γ,α), on mainly unstable r- or s-process seed nuclei.

For **statistical model calculations**, nuclear physics input parameters – e.g., cross sections, nuclear level densities, and γ-ray strength functions – below the Coulomb barrier must be known with high precision.

Therefore, measurements in the **Gamow window** are of utmost importance.

(p,γ) Reactions at N=50

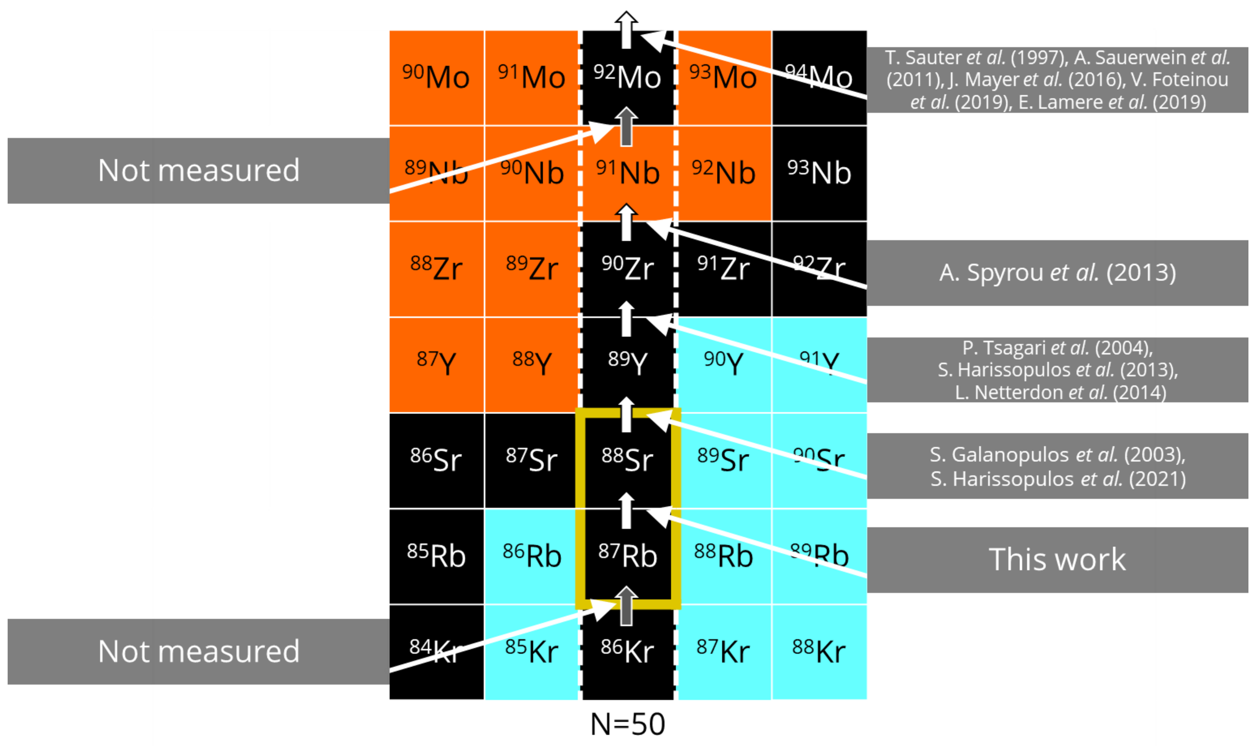

Fig. 1: Measured (p,γ) reactions – symbolized with the upward pointing arrows – in the A=90 mass region, where the reaction of interest is located in the N=50 isotonic chain.

- Interest in systematic studies along the N=50 isotonic chain – shell closure
- First measurement of $^{87}Rb(p,\gamma)^{88}Sr$ reaction
- ^{91}Nb – short-lived radionuclide – influences production of ^{92}Nb – produced in the p process [1]

Target details

- ^{87}Rb melting point $T_m \approx 40°C$
- Rb_2CO_3 melting point $T_m \approx 840°C$, evaporated on a gold backing, highly hygroscopic
- Areal density is $0.73(7)\,\frac{\mu g}{cm^2}$

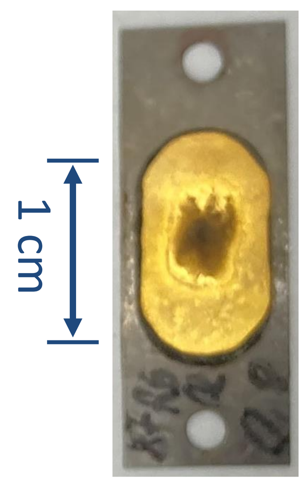

Fig. 2: ^{87}Rb target with the prominent beam spot.

Experimental Details

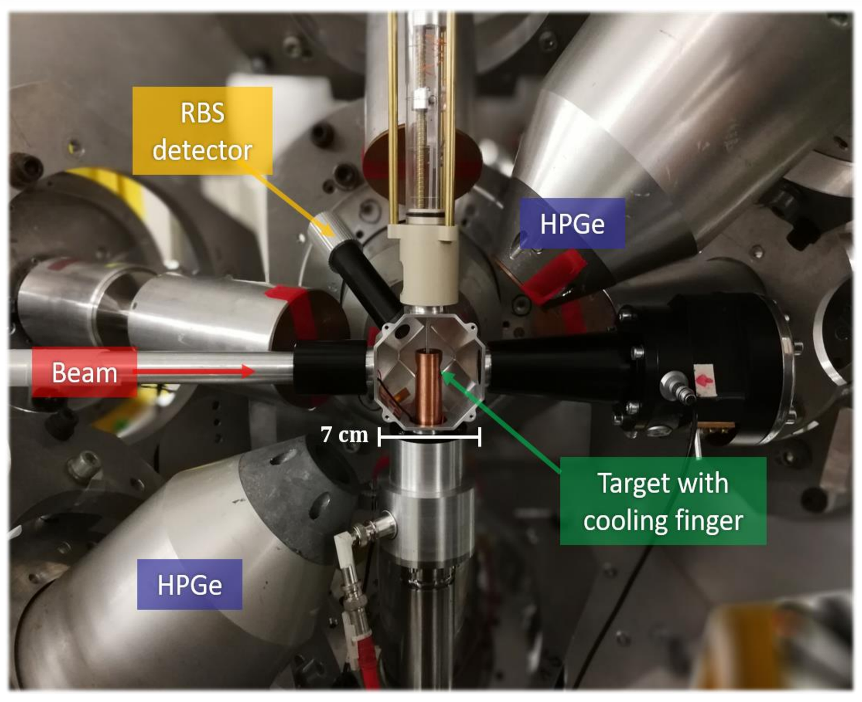

Fig. 3: Target chamber used for the in-beam method inside of HORUS in Cologne [2].

In-beam method

- Create highly excited compound nucleus
- Observation of transitions to the ground state to determine the total cross section
- Observation of de-excitation of the entry state to determine partial cross sections
- Information on the γ–ray strength function obtained by comparing the partial cross-sections to statistical model calculations [3,4]

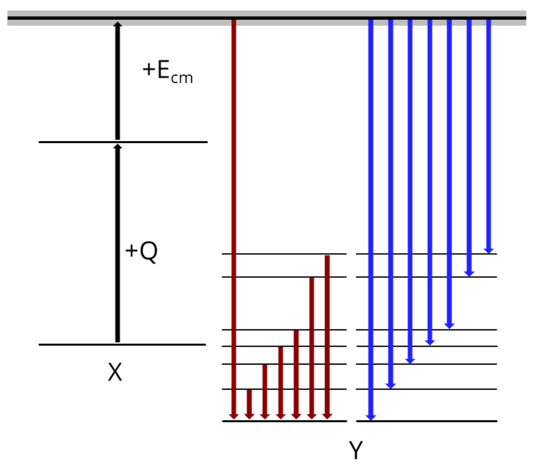

Fig. 4: Schematic figure of the in-beam method with transitions to the ground state and de-excitations of the entry state.

Astrochamber@HORUS

- Proton beam provided by 10 MV FN Tandem accelerator in Cologne
- Target chamber with a silicon detector installed in HORUS [2] which consists of up to 14 HPGe detectors
- Five different angles with respect to the beam axis, allows to measure angular correlations and perform γγ-coincidence measurements.

Transitions to the ground state

Transitions observed in γ-ray spectra of the $^{87}Rb(p,\gamma)^{88}Sr$ reaction are shown in dark red in Fig. 6. The transition in dotted red was not investigated directly but indirectly via the transition shown in blue. The thickness of the arrows represents the contribution to the ground-state.

In Fig. the different contributions to the population of the ground state from different excited states are shown for every proton-beam energy.

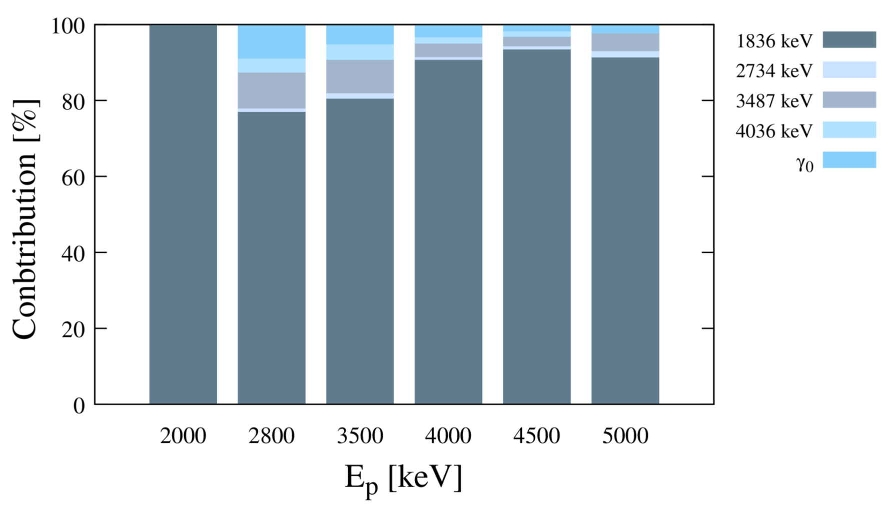

Fig. 5: The different contributions to the population of the ground state from different excited states. About 80% originate from the de-excitation of the first 2+ state.

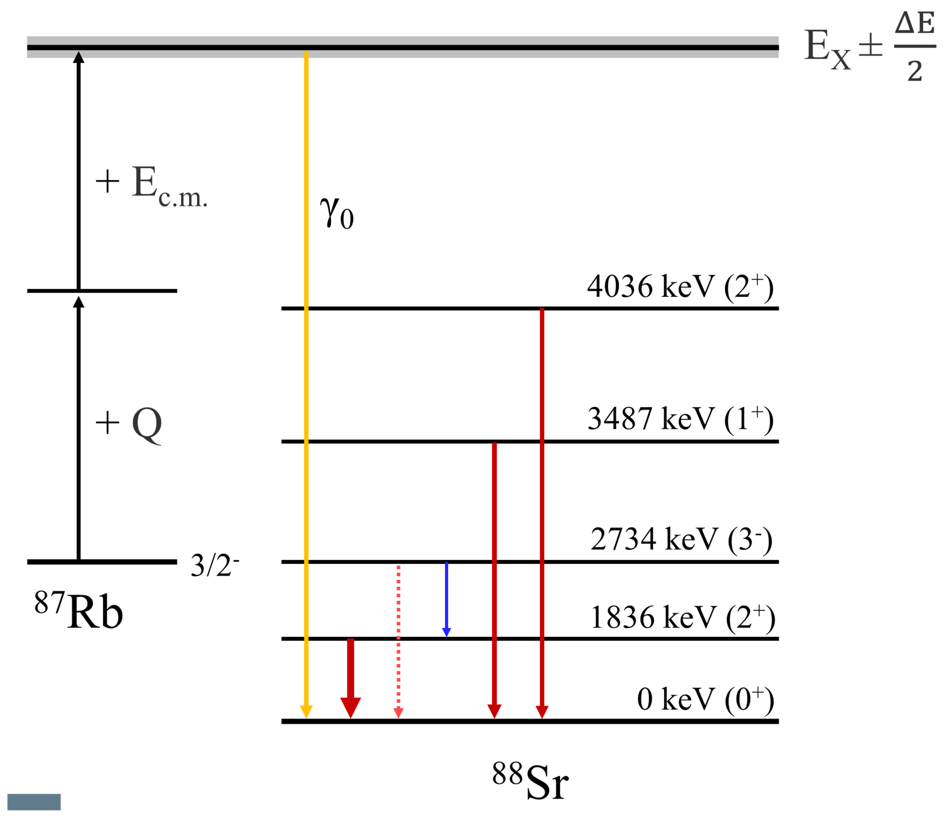

Fig. 6: Level scheme of the $^{87}Rb(p,\gamma)$ reaction [5]. The observed γ-ray transitions to the ground state are shown in dark red.

Proton beam properties

Energy [keV]	Current [nA]	Time [h]
2000	620	14.8
2800	610	20.3
3500	430	9.9
4000	360	11.8
4500	170	8.2
5000	140	15.6

γ-ray Spectra

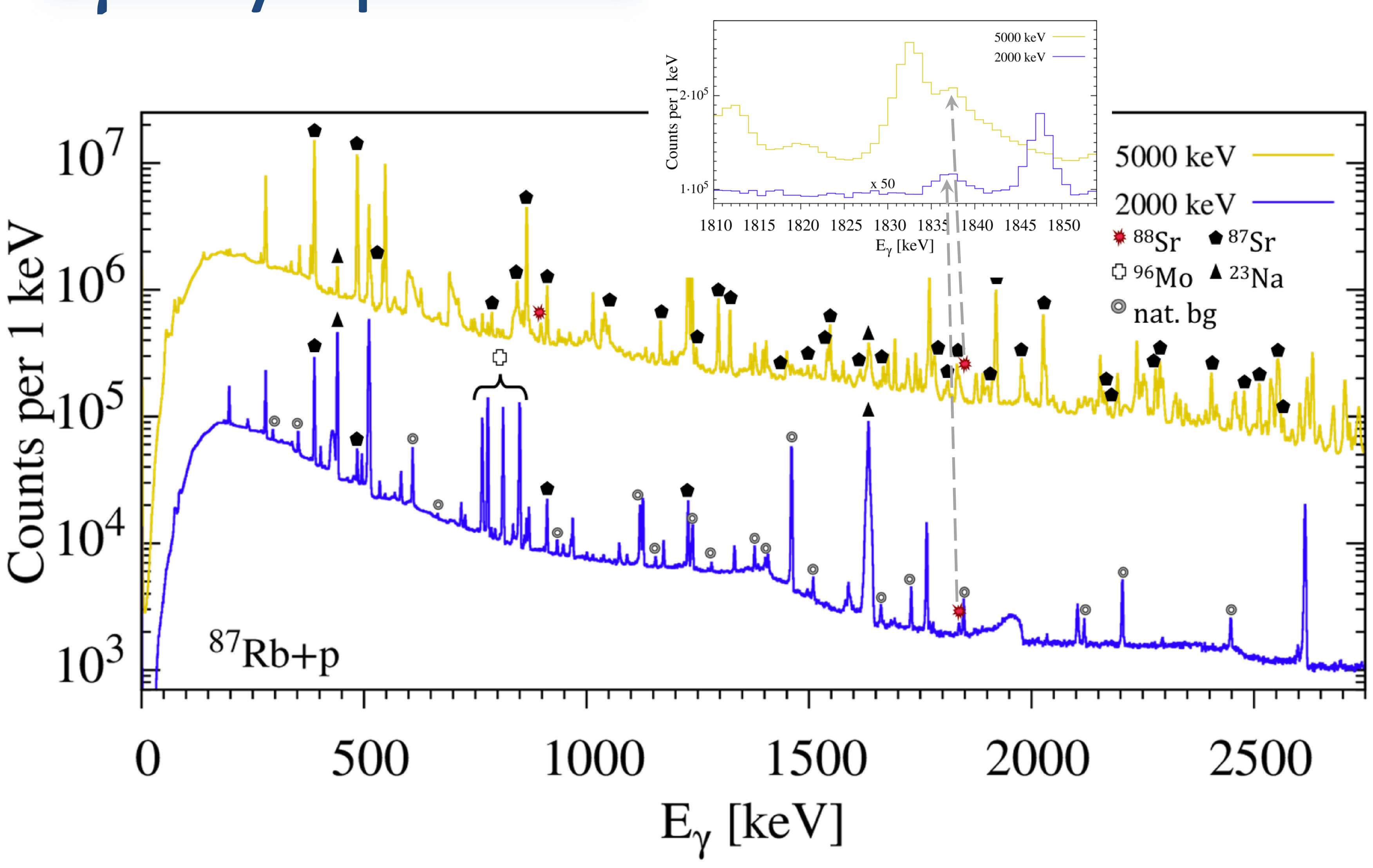

Fig. 7: Comparison of γ-ray spectra obtained at beam energies of E_p = 2000 keV and 5000 keV.

- Higher beam-induced background and more transitions of the (p,n) product are visible for E_p = 5000 keV for similar irradiation time.
- At E_p = 2000 keV small contributions of contaminations in the target material are visible due to lower beam-induced background.
- At higher beam energies the γ-ray spectra become increasingly complex, and a precise reconstruction of the peak origin is challenging.

Results

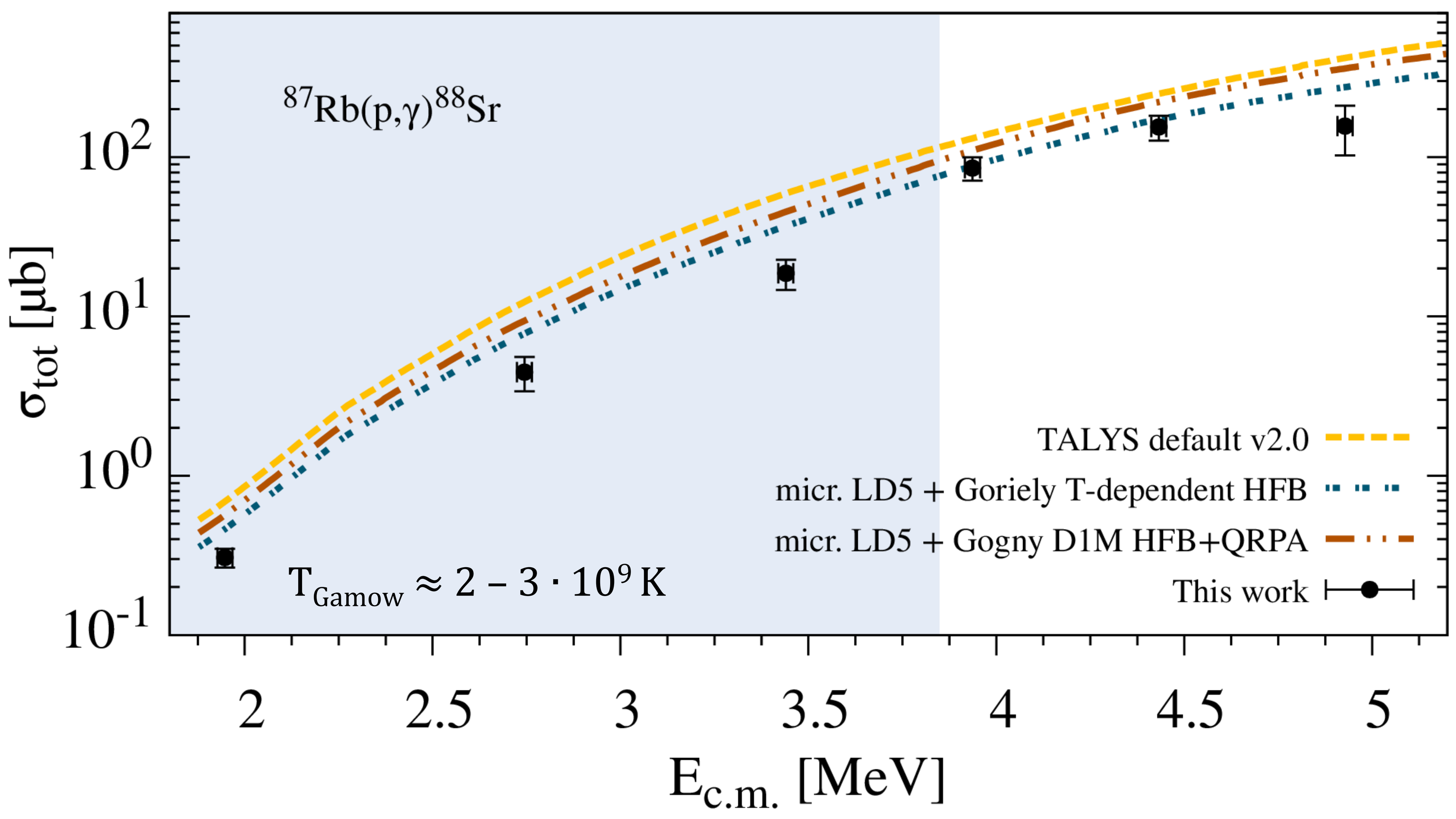

Fig. 8: $^{87}Rb(p,\gamma)^{88}Sr$ reaction cross-sections compared to theoretical Talys [6] model calculations.

- The microscopic level densities (Skyrme force) from the combinatorial model by Hilaire and Goriely (micr. LD5) [7] proved their predictive power [3,4].
- Two different γ-ray strength functions – the temperature-dependent Skyrme-Hatree-Fock-Bogoliubov model [8] and the Gogny-Hatree-Fock-Bogoliubov model [9] – have been used additionally for comparing experiment and theory.
- A good agreement between experiment and theory has been found.

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