Charge Pickup Reaction Cross Section for Neutron-Rich *p*-Shell Isotopes at 900*A* MeV

Jichao Zhang (寂潮 张)

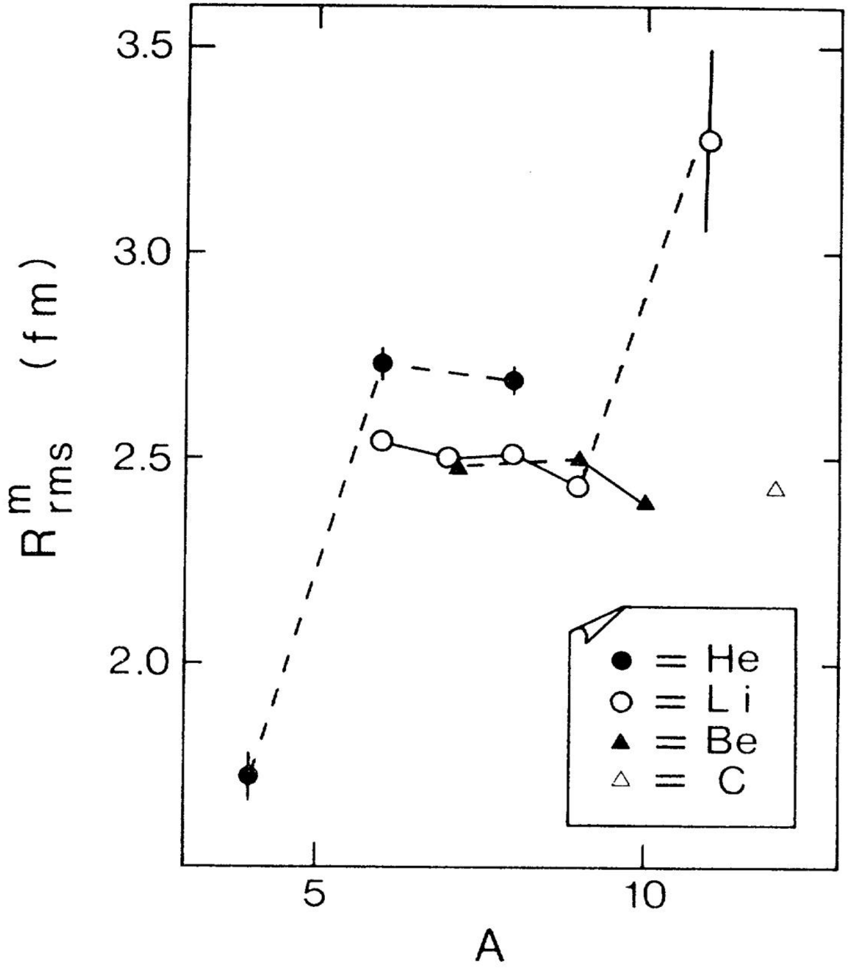
(RCNP, the University of Osaka/School of Physics, Beihang University)

Collaborators: B.H. Sun, I. Tanihata, and GSI experiment group

Charge pickup reaction— An “unpicked pearl”

沧海遗珠

I. Tanihata, *et al*., PRL, 1985



Interaction cross section ~ *Rm*

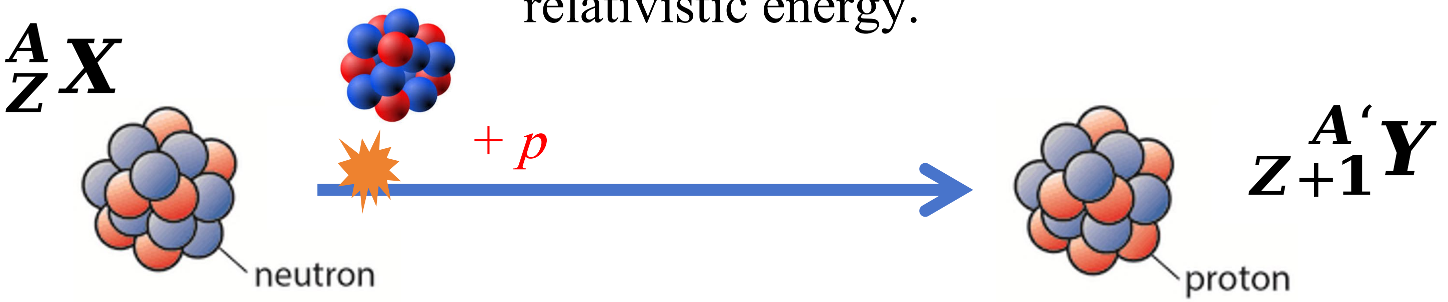
neutron skin, halo

Charge-changing cross section ~ *Rp*

etc.

and, the “unpicked” Charge pickup cross section

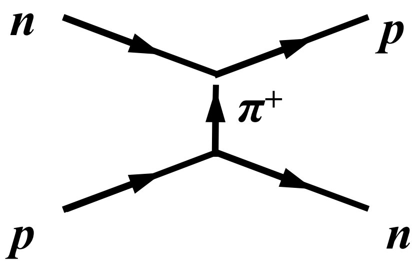
——the projectile gains a proton in the collision at relativistic energy.



Charge pickup reaction

The projectile **gains a proton** in the collision— a process historically known as **charge pickup**

Direct Charge Exchange

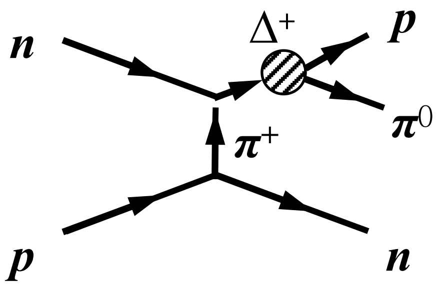


Dominated by charge exchange processes when E >100 MeV/nucleon

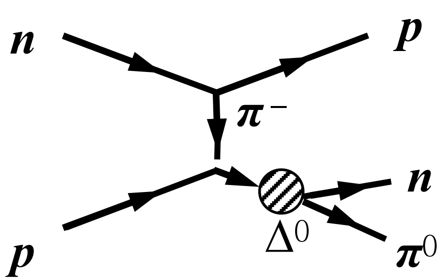
Correlated with Gamow-Teller (GT) transitions

H. Lenske, *et al*., PPNP 2019

Δ Resonance



Projectile excitation



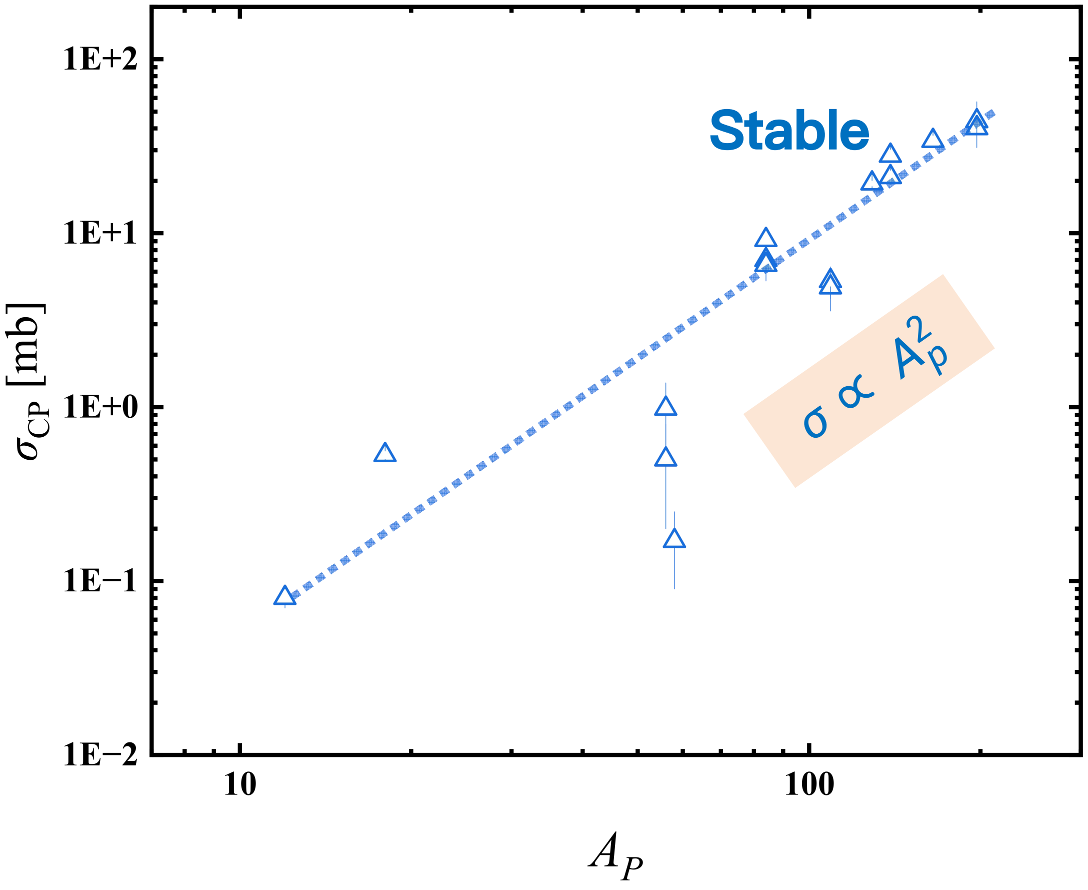
Target excitation

(p,n) from Δ resonance

J. L. Rodríguez-Sánchez, *et al.*, PRC, 2022

Past systematics of stable nuclei

E >700 MeV/nucleon



- **Literature data: 1980s~2000s,**
  Stable nuclides with 10 < A < 200 on several targets at 0.7~2 GeV/nucleon

Mass dependence

$$\sigma_{\mathrm{CP}} = 1.7 \cdot 10^{-4}\ \gamma_{PT}\ A_P^2 \quad [\mathrm{mb}]$$

Target dependence

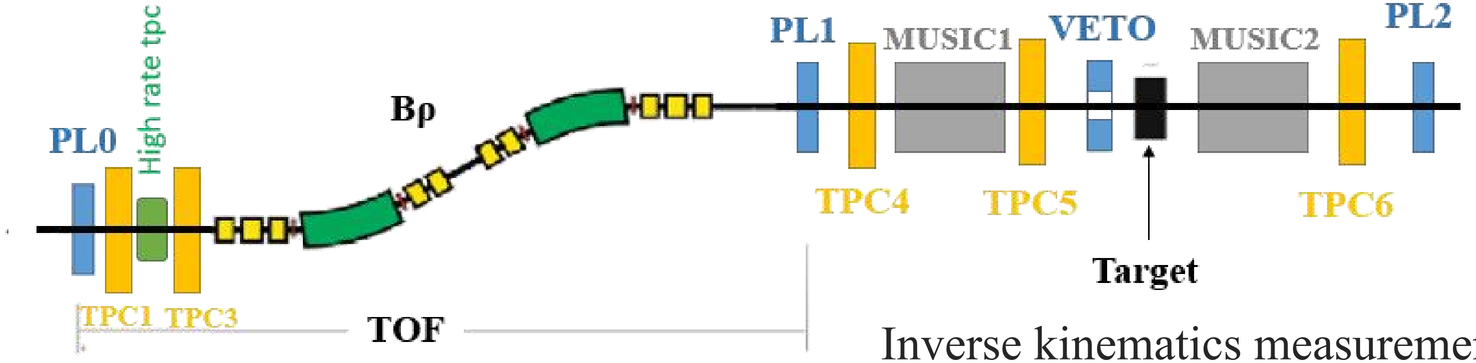
$$\gamma_{PT} = A_P^{1/3} + A_T^{1/3} - 1.0$$

Typical peripheral collision

Ren, *et al.*, PRC, 1989

Olson *et al.*, PRC24(1981)1529; Olson *et al.*, PRC28(1983)1602; Gerbier *et al.*, PRL60(1988)2258; Ren *et al.*, PRC39(1989)1351; Summer *et al.*, PRC52(1995)1106; Nilsen *et al.*, PRC50(1994)1065; Cummings *et al.*, PRC42(1990)2508

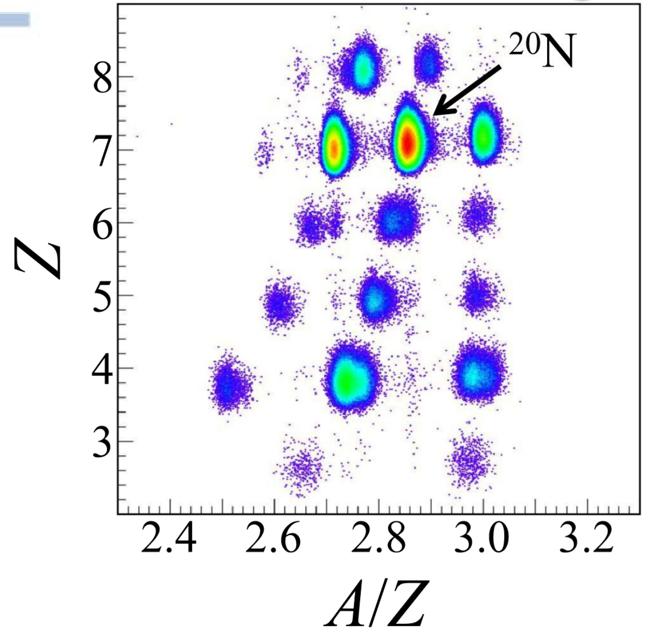
New $^{A}Z(p,xn)Z+1$ measurement



Inverse kinematics measurement

$B\rho - \Delta E -$ TOF method

Before reaction target

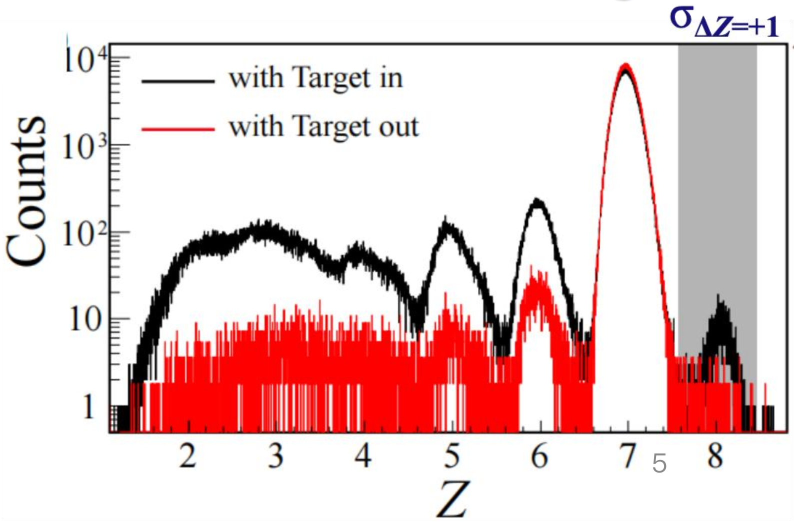


- Primary Beam:
  ^{22}Ne @ 1 GeV/u
  ^{40}Ar @ 1 GeV/u
- Target: C(4, 2.5 g/cm^2), CH_2(3.6 g/cm^2)
- PID of RIBs: Bρ-dE-TOF
- Z-identification: Music1&2
- Beam tracking: TPCs

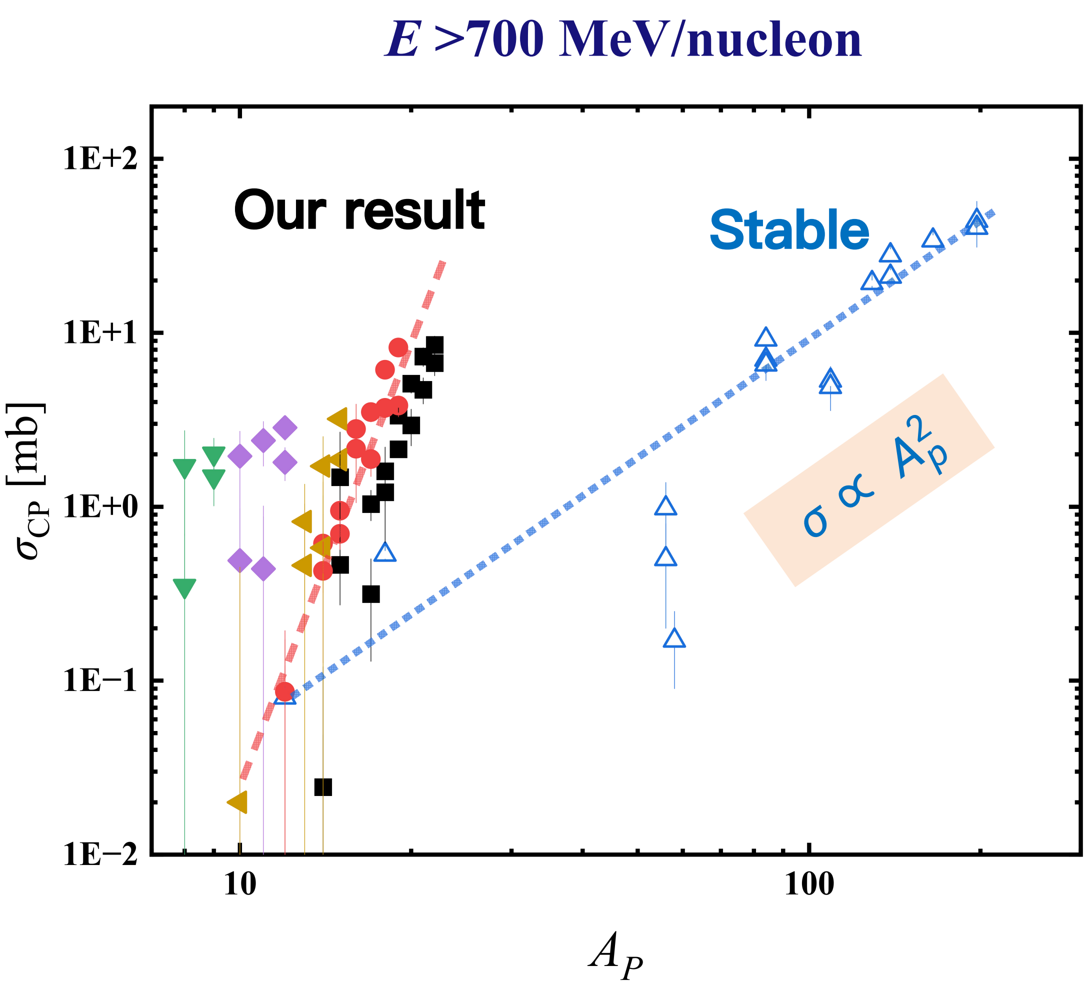
We analyse the charge pickup cross sections of **24 *p*-shell nuclei** (^{8,9}Li, $^{10-12}$Be, $^{10,13-15}$B, $^{12,14-19}$C, $^{14,15,17-22}$N) at about **900*A* MeV** on **carbon and hydrogen** targets in FRS, GSI.

Published in J.C. Zhang, B.H. Sun, I. Tanihata, et al., *Phys. Rev. X* 15, 031004, 2025

After reaction target



Different behaviors of neutron-rich and stable nuclei



■ **Literature data: 1980s~2000s,**

Stable nuclides with 10 < A < 200 on several targets at 0.7~2 GeV/nucleon

$$\sigma_{\mathrm{CP}} = 1.7 \times 10^{-4} \gamma_{PT} A_P^2 \qquad \gamma_{PT} = A_P^{1/3} + A_T^{1/3} - 1.0$$

Ren, et al., PRC, 1989

■ **New data:**

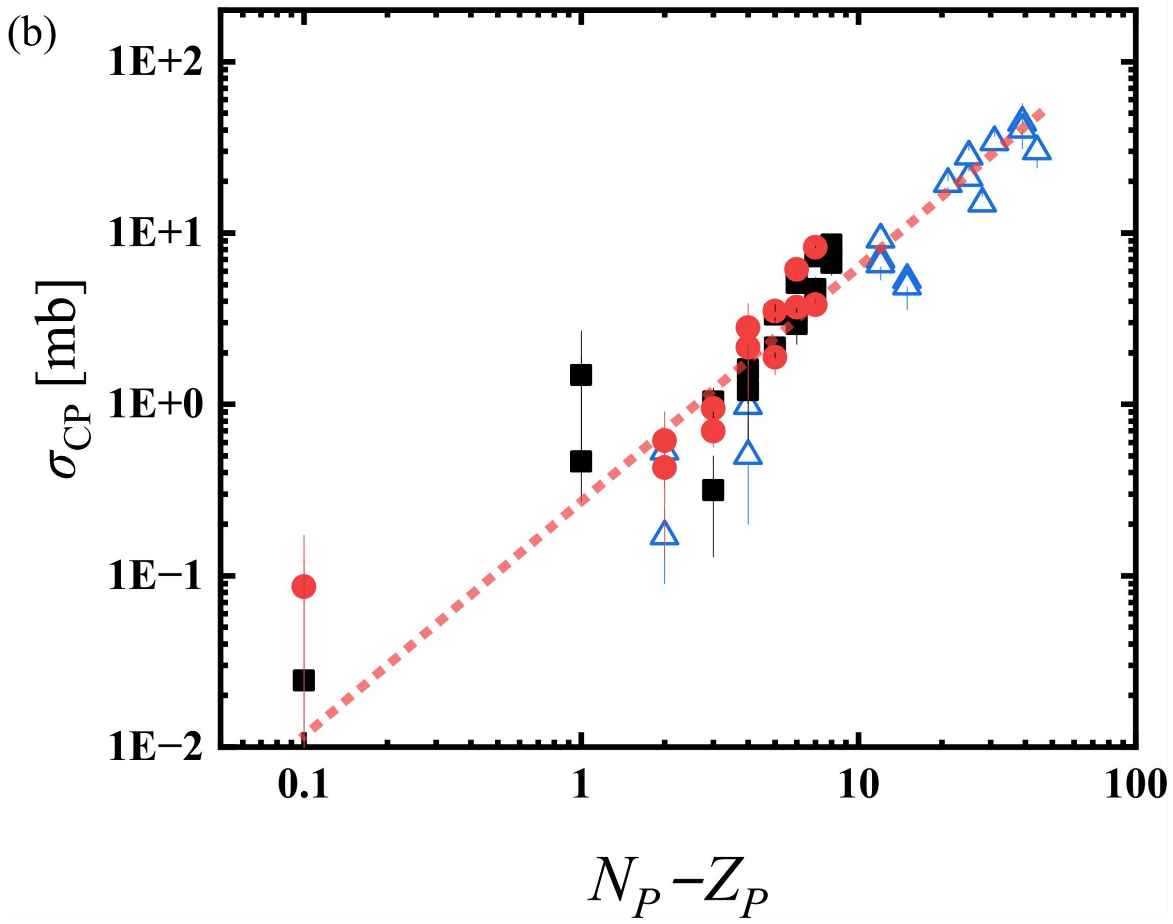
24 *p*-shell isotopes (^{8,9}Li, $^{10\text{–}12}$Be, $^{10,13\text{–}15}$B, $^{12,14\text{-}19}$C, $^{14,15,17\text{–}22}$N), include stable and neutron-rich on C/H targets at ~900 MeV/nucleon

J.C. Zhang, et al., PRX, 2025

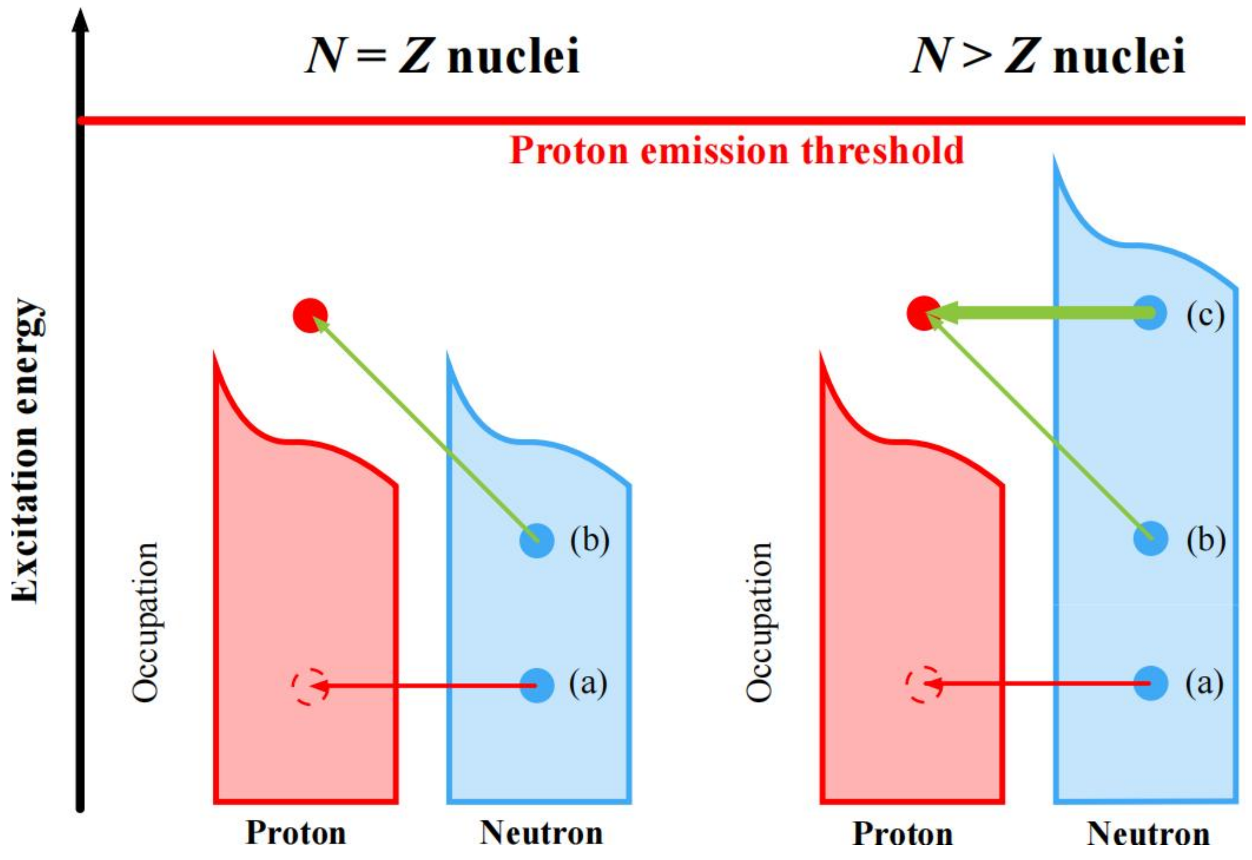
■ **Finding:**

The neutron-to-proton flip probability grows far more rapidly with neutron number than previously believed!

Role of isospin asymmetry



Neutron-proton imbalance (**isospin asymmetry**) plays a key role



As the isospin asymmetry increases, the superallowed transition channel opens up

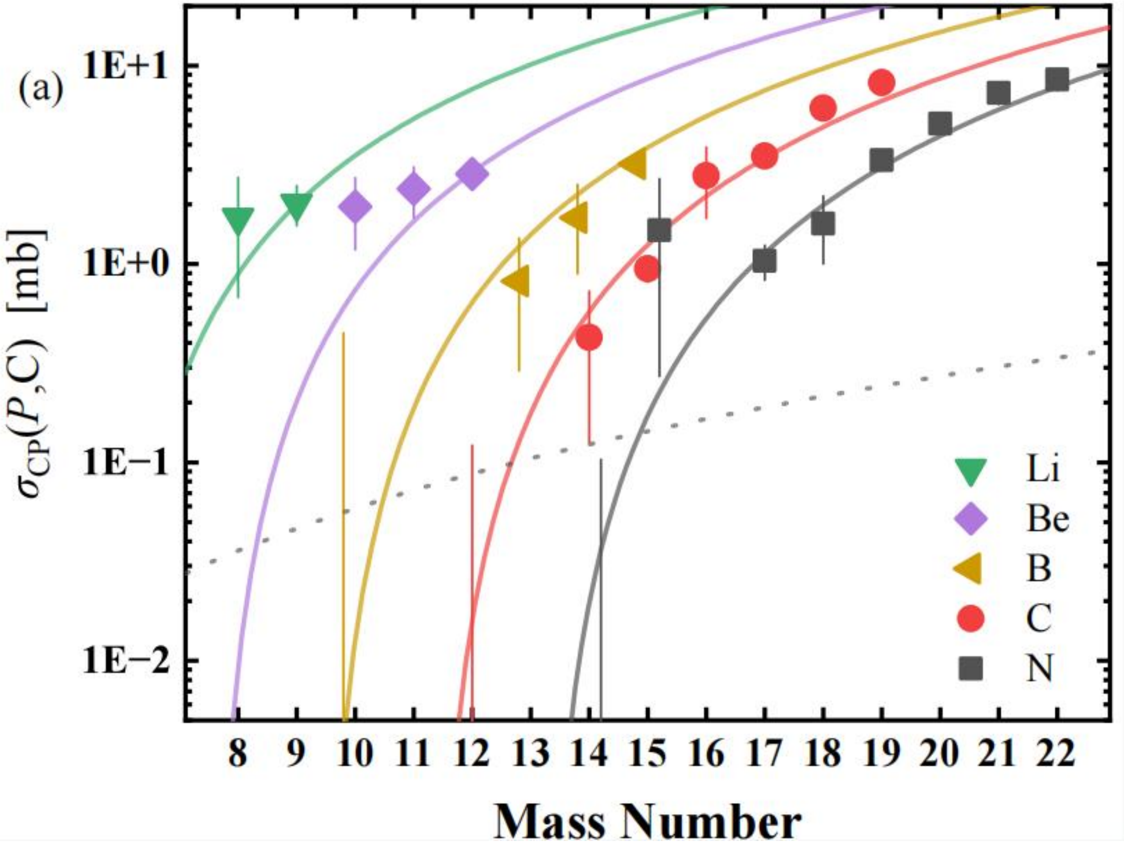
A new empirical formula

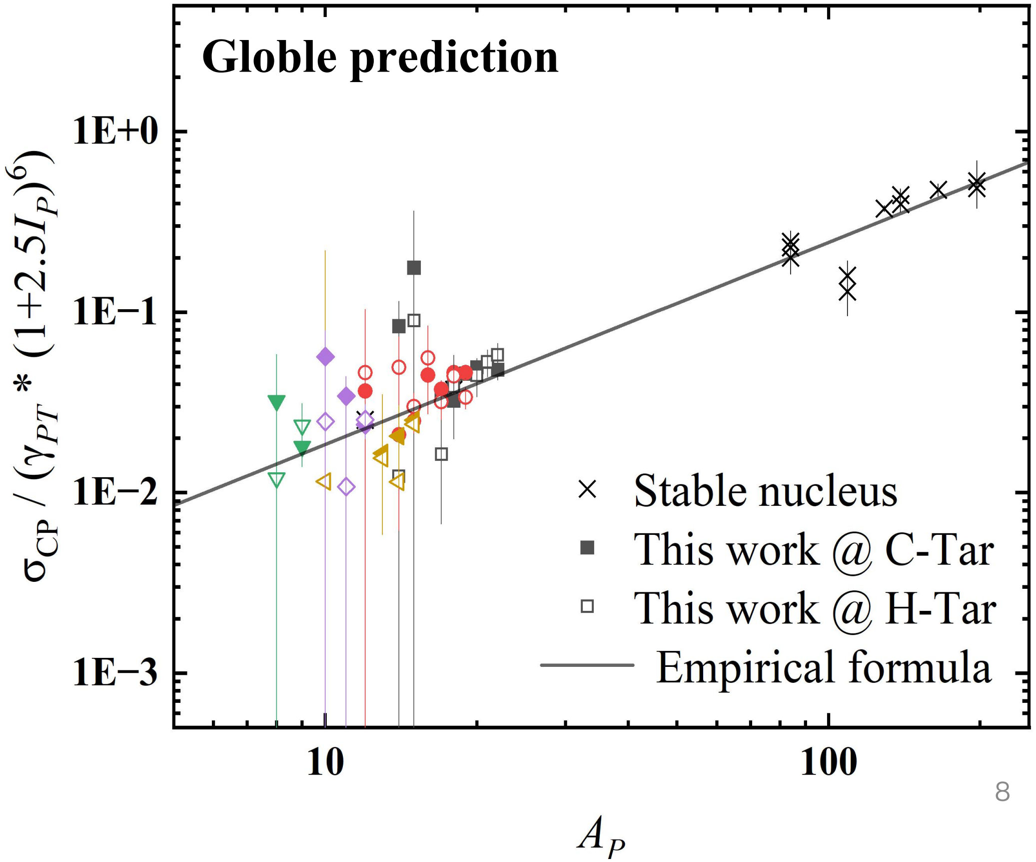
$$\sigma_{\Delta Z=+1} = 1.4 \cdot 10^{-3} \ \ (A_P^{1/3} + A_T^{1/3} - 1.42) \ \ A_P^{1.12} \ \ \left(1 + 2.5\frac{N_P - Z_P}{A_P}\right)^6 \ \ [\mathrm{mb}]$$

Target dependence

Mass dependence

Isospin asymmetry dependence





An important supplement to nuclear databases

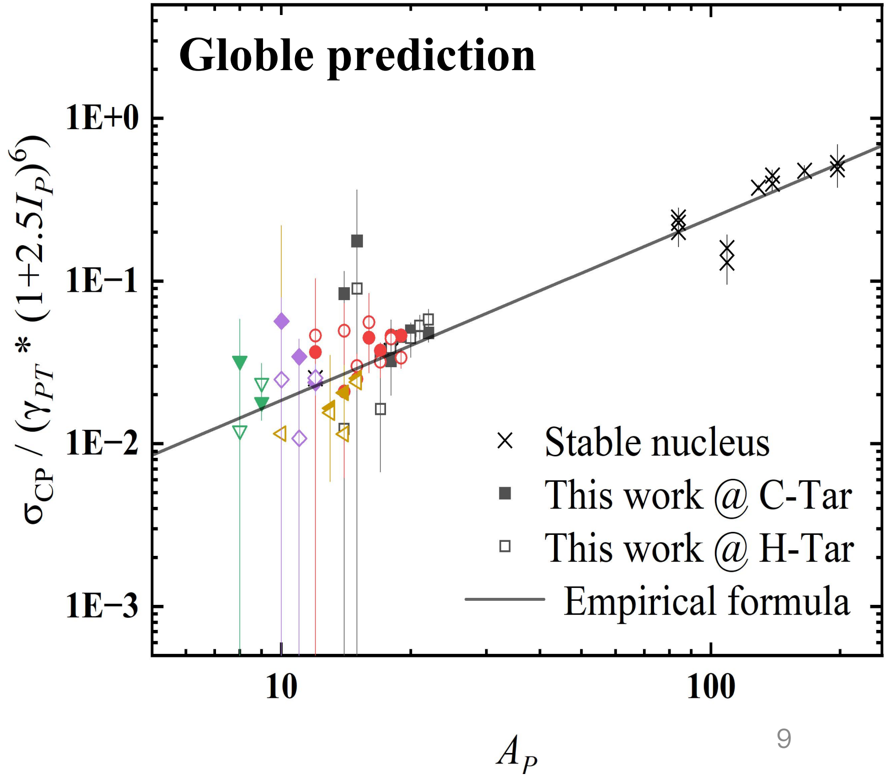
$$\sigma_{\Delta Z=+1} = 1.4\cdot 10^{-3} \ (A_P^{1/3} + A_T^{1/3} - 1.42) \ A_P^{1.12} \left(1 + 2.5\frac{N_P - Z_P}{A_P}\right)^6 \ [\mathrm{mb}]$$

Target dependence

Mass dependence

Isospin asymmetry dependence

It holds practical implications for rare isotope production and enhancing nuclear astrophysics simulations!



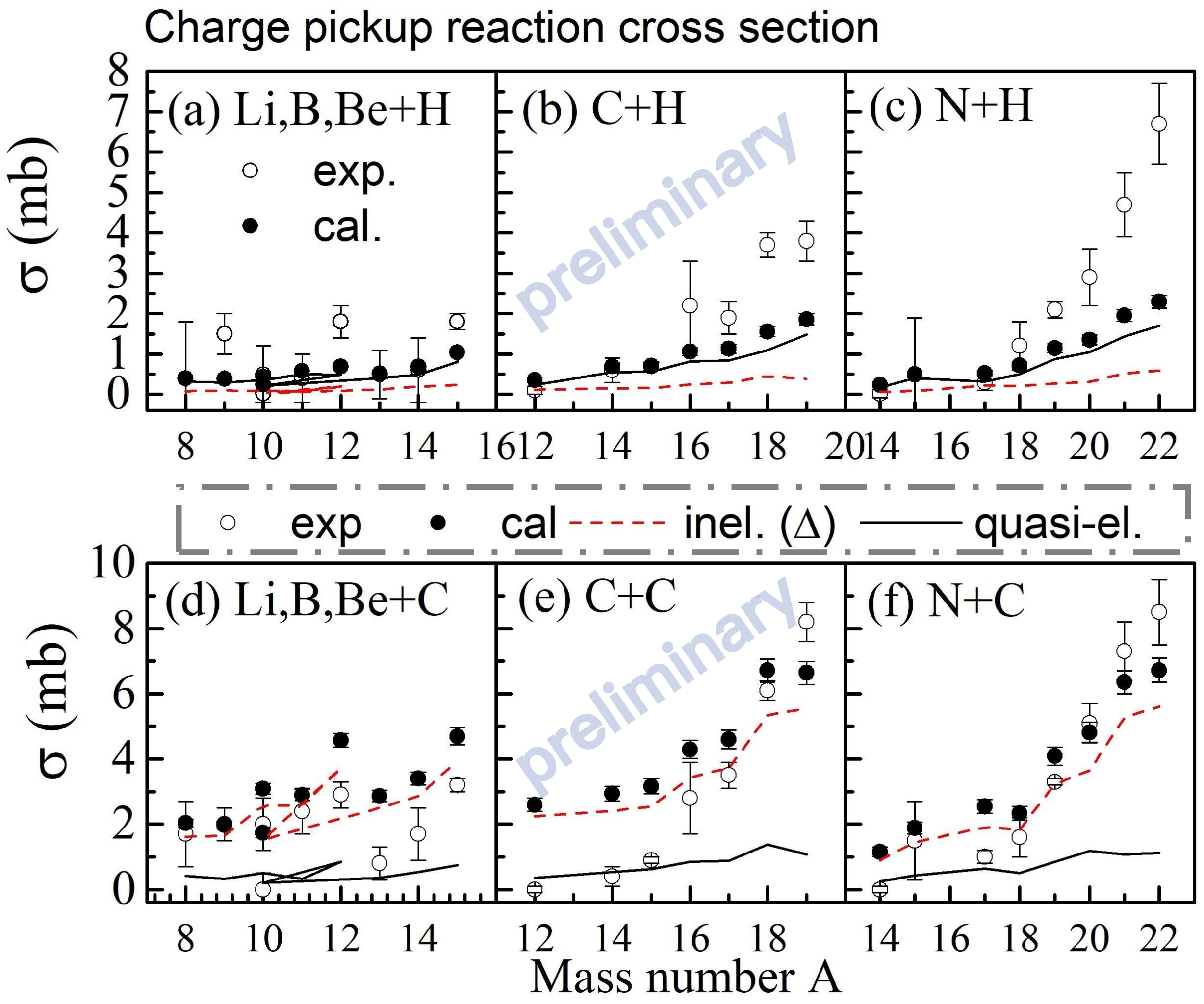
Future direction:

By integrating theoretical research,
we can explore potential experimental mechanisms.

Using the **IQMD+GEMINI** model,
we can partially reproduce the experiments conducted on the C target.

Furthermore, Our goal is to establish some relationships between the charge pickup cross sections and certain important physical quantitys.

Courtesy of Prof. Jun Su (Sun Yet-Sen U.)



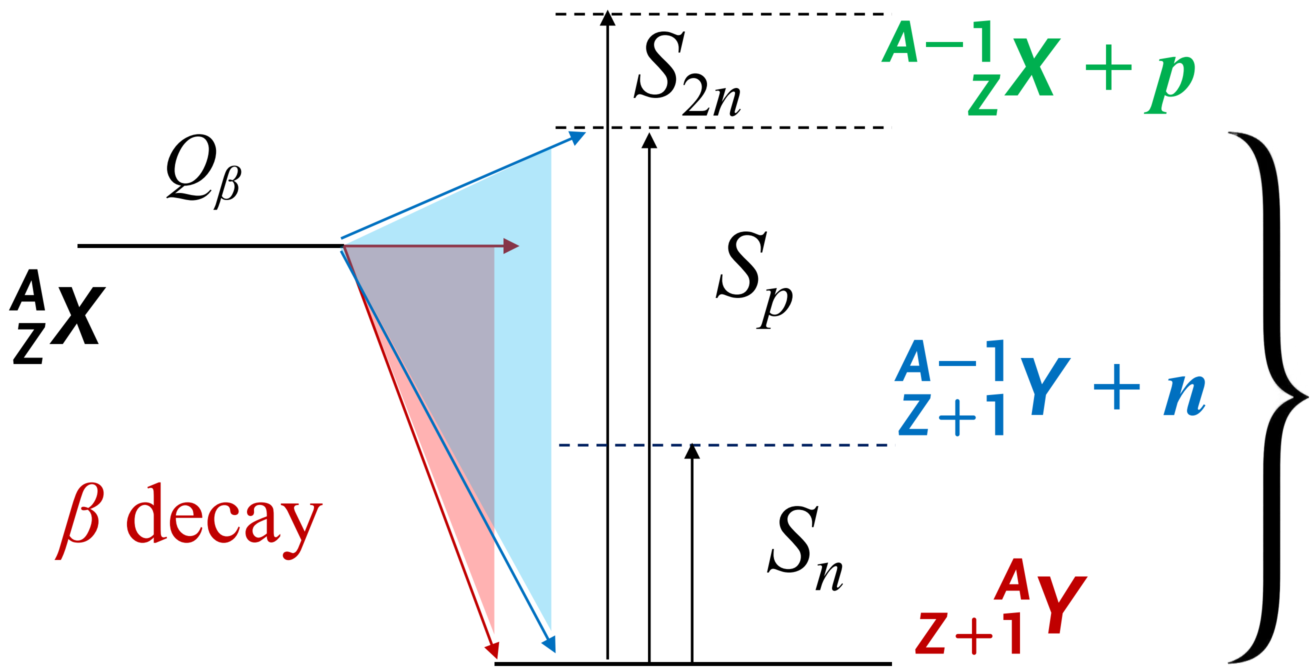
Future direction:

Further systematic measurements:

Medium mass nuclides, Neutron-deficient nuclide, Energy dependence (lower and higher)

An exceptional tool for systematic study:

Neutron skin thickness —> Halo structure, Total β transition strength, etc.

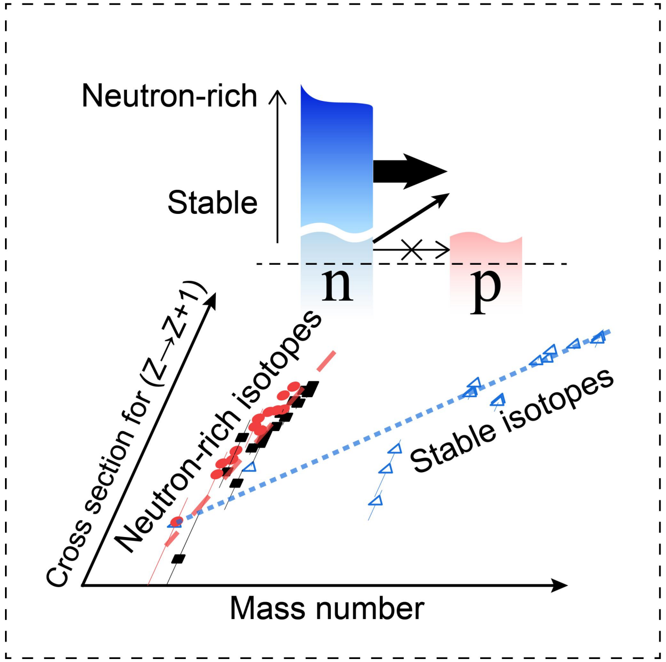


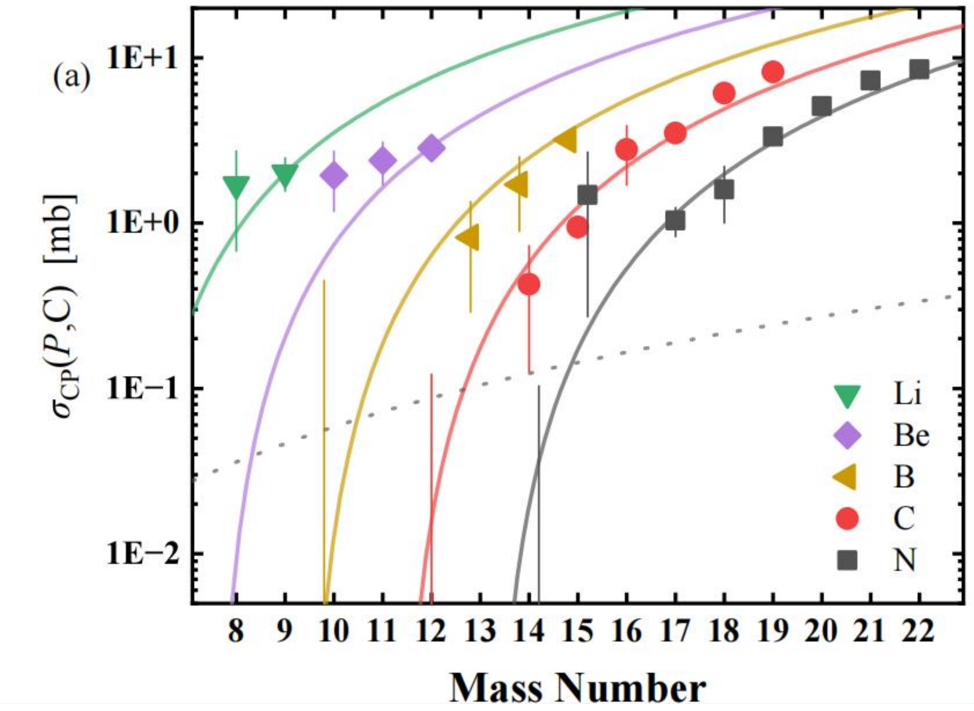
Charge exchange reactions provide rare access to total β decay strength (beyond Q_β), crucial for understanding the long-standing B(GT) quenching problem.

Total Charge exchange $\propto \sum_{g.s.}^{S_p} B(\mathrm{GT})$

Summary:

New **neutron-to-proton conversion** in light nuclear reactions at relativistic energies **rises exponentially with neutron number**, challenging prior understanding and allowing for refined nuclear reaction and astrophysics predictions.





J.C. Zhang, B.H. Sun, I. Tanihat, *et al.*, PRX, 2025

Thanks to all our collaborators!

Charge Pickup Reaction Cross Section for Neutron-Rich *p*-Shell Isotopes at 900*A* MeV

J.-C. Zhang,[1,2] B.-H. Sun,[1,*] I. Tanihata,[1,2,†] S. Terashima,[1] F. Wang,[1] R. Kanungo,[3,4] C. Scheidenberger,[5,6,7] F. Ameil,[5] J. Atkinson,[3] Y. Ayyad,[8] S. Bagchi,[9] D. Cortina-Gil,[8] I. Dillmann,[5,6] A. Estradé,[3,5] A. Evdokimov,[5] F. Farinon,[5] H. Geissel,[5,6,‡] G. Guastalla,[5] R. Janik,[10,‡] S. Kaur,[3,11] R. Knöbel,[5] J. Kurcewicz,[5] Yu. A. Litvinov,[5] M. Marta,[5] M. Mostazo,[8] I. Mukha,[5] C. Nociforo,[5] H. J. Ong,[2] S. Pietri,[5] A. Prochazka,[5] B. Sitar,[10] P. Strmen,[10,‡] M. Takechi,[5] J. Tanaka,[2] J. Vargas,[8] H. Weick,[5] and J. S. Winfield[5,‡]

[1]*School of Physics, Beihang University, Beijing 100191, China*
[2]*Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki Osaka 567-0047, Japan*
[3]*Astronomy and Physics Department, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*
[4]*TRIUMF, Vancouver, British Columbia V6T 4A3, Canada*
[5]*GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany*
[6]*Justus-Liebig University, 35392 Giessen, Germany*
[7]*Helmholtz Research Academy Hesse for FAIR (HFHF), GSI Helmholtz Center for Heavy Ion Research, Campus Giessen, 35392 Giessen, Germany*
[8]*Universidad de Santiago de Compostela, E-15706 Santiago de Compostella, Spain*
[9]*Department of Physics, Indian Institute of Technology (Indian School of Mines) Dhanbad, Jharkhand 826004, India*
[10]*Faculty of Mathematics and Physics, Comenius University, 84215 Bratislava, Slovakia*
[11]*Department of Physics and Atmospheric Science, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada*

Thanks for your listening!