Multinucleon Transfer Channels in $^{86}Kr + {}^{64}Ni, {}^{124}Sn$ Peripheral Collisions

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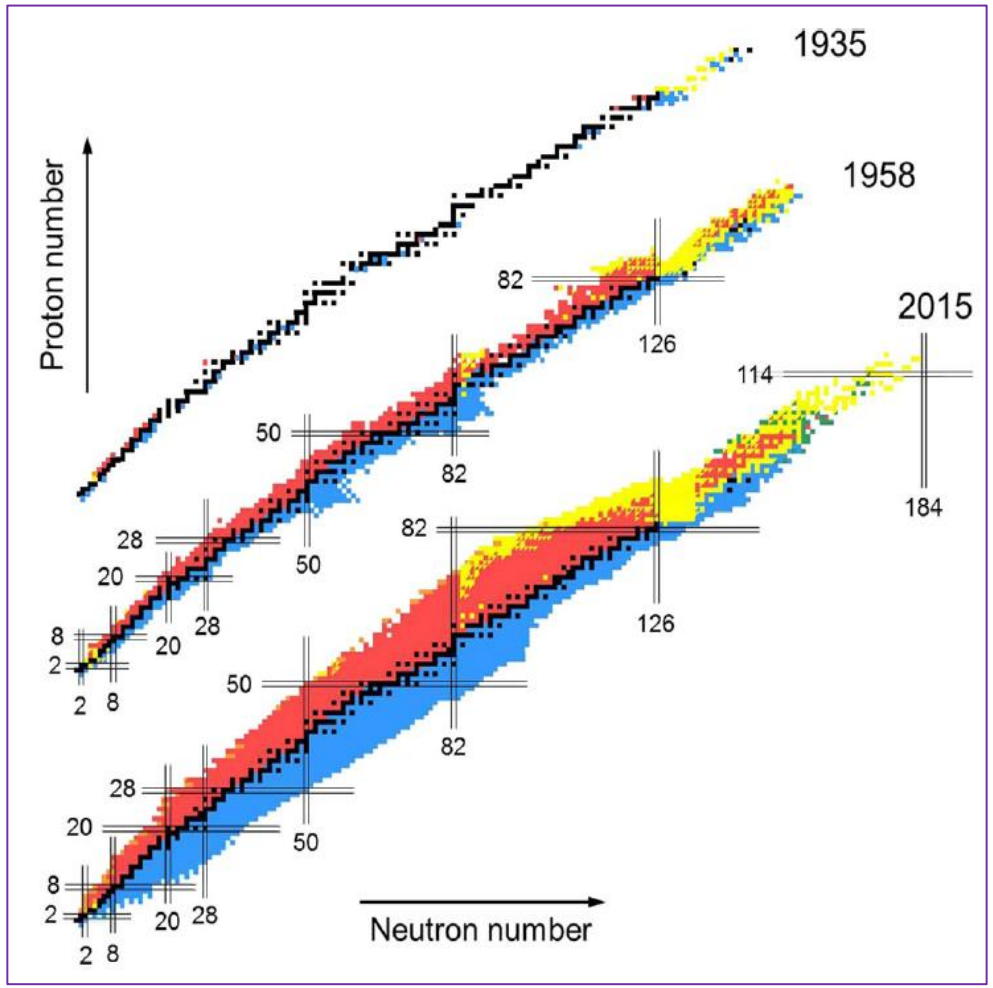
Ioannina, Greece

Overview

- ★ Introduction
- ★ Experimental Data
- ★ Calculations
- ★ Conclusions - Discussion

Nuclear Landscape

<300 stable nuclei
~3300 short lived (radioactive) nuclei synthesized to date



Large region of neutron-rich nuclei remains unexplored (4000-5000 nuclei)

G.G. Adamian et al., Eur. Phys. J. A 56:47 (2020)

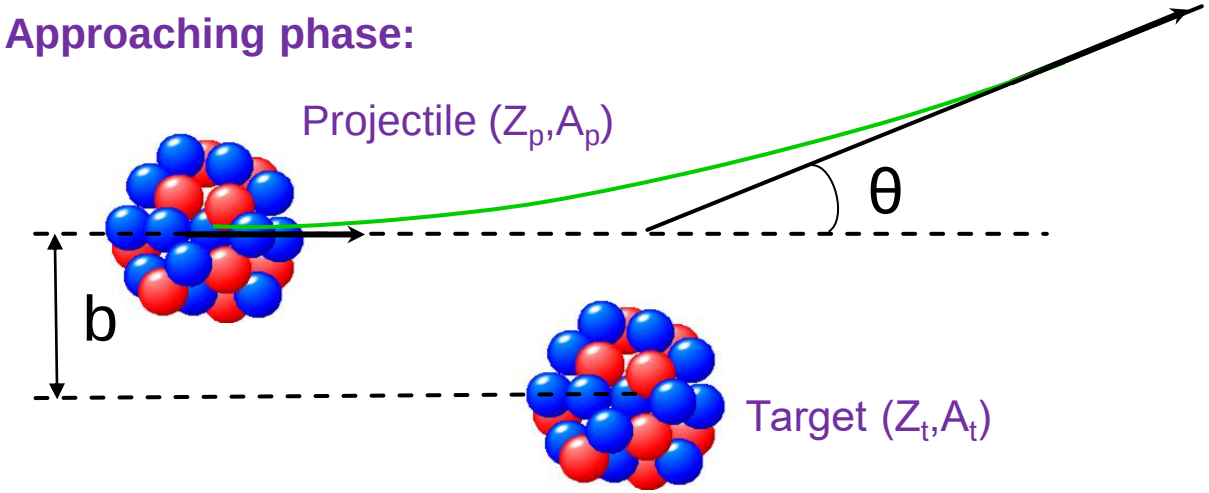
Investigation on multinucleon transfer reactions (MNT)

- ★ Production of neutron rich nuclei
  - ★ Understanding the nuclear structure with increasing N/Z
- ★ Insight into
  - ★ Nucleosynthetic processes (i.e. r-process)
  - ★ Reaction Mechanisms in intermediate energies
  - ★ Equation of state of asymmetrical matter

G.G. Adamian et al., Eur. Phys. J. A 56:47 (2020)

Peripheral Reaction - Deep Inelastic Transfer

Approaching phase:

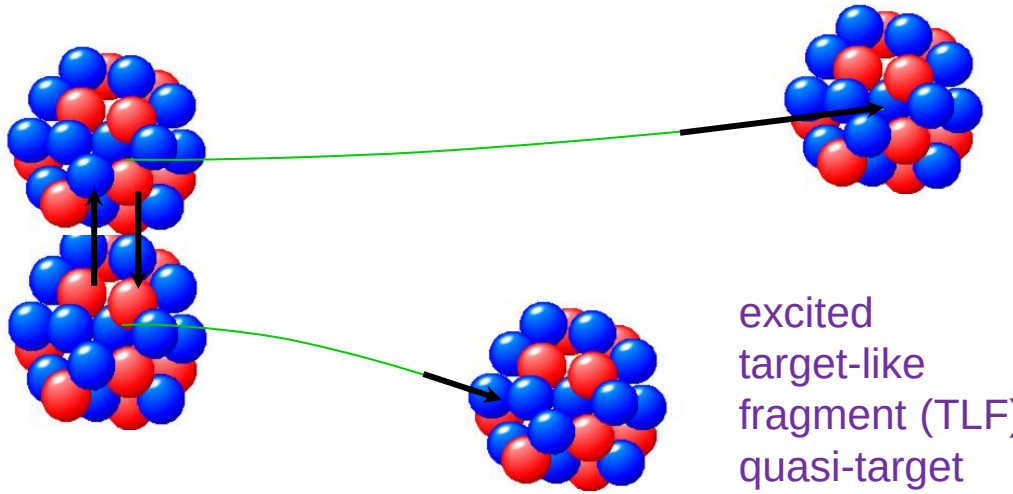


- Neutrons
- Protons

b: impact parameter
θ: scattering angle
Grazing angle, θ_{gr}

Overlap (interaction) phase:

Exchange of nucleons

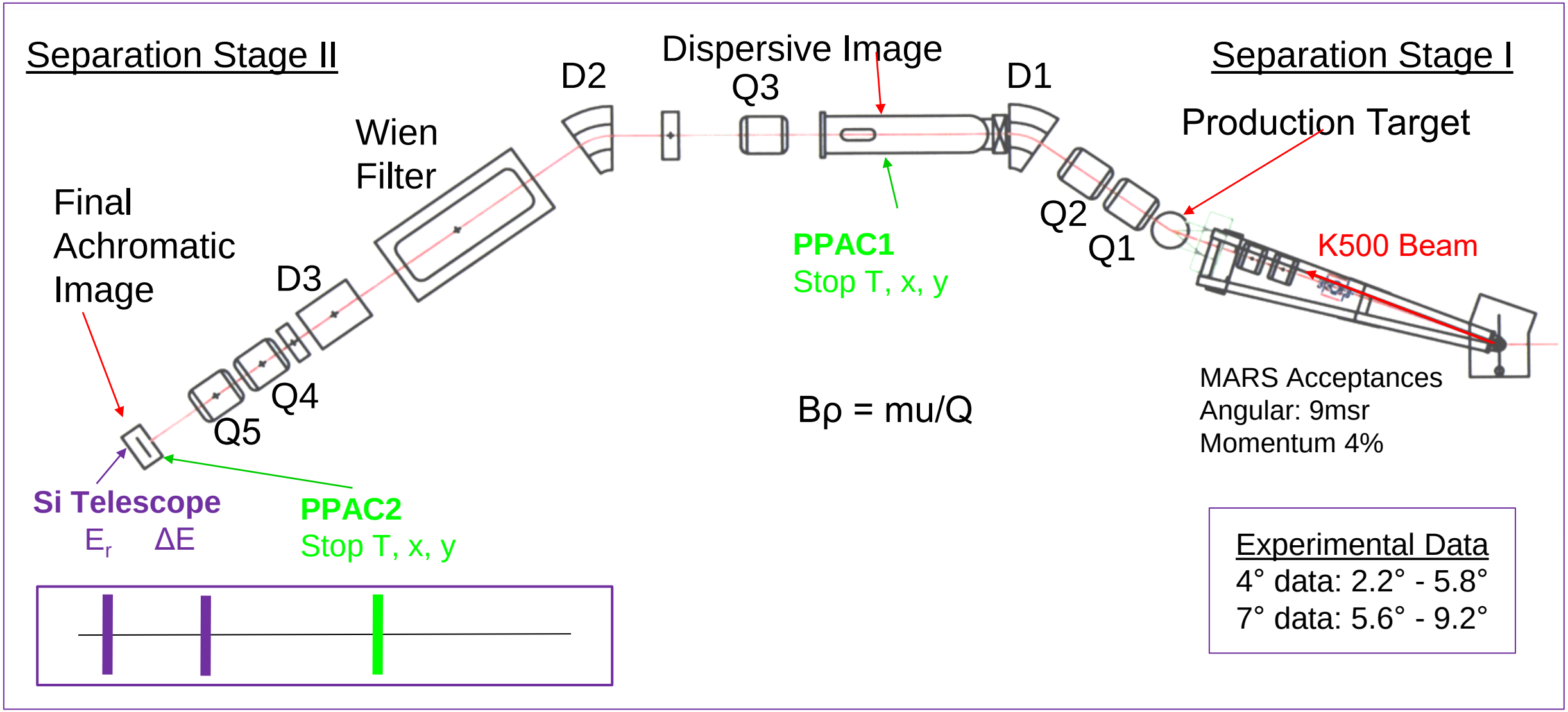


excited projectile-like fragment (PLF) or quasi-projectile

excited target-like fragment (TLF) or quasi-target

L. Tassan-Got and C. Stephan, Nucl. Phys. A 524, 121 (1991)

Momentum Achromat Recoil Separator - MARS



G. A. Souliotis et al., Nucl. Instr. Methods B, 266, 4692 (2008)

Measured Quantities

★ Velocity u (from ToF)
★ Energy Loss, ΔE
★ Residual Energy, E_r
★ Total Energy, $E = \Delta E + E_r$
★ Magnetic Rigidity, Bρ (from position at the dispersive image)

Extracted Quantities

★ Mass-to-charge ratio, A/Q $A/Q \propto B\rho/u$
★ Atomic Number, Z $Z \sim u \cdot \Delta E^{1/2}$
★ Ionic Charge, Q $Q \sim f(E, u, B\rho)$
★ Mass Number, A $A = Q_{int} \bullet A/Q$

Reconstructed (for each angle setting): Fragment Yield Distribution Y(Z, A, u)

G. A. Souliotis, et al., Phys. Rev. C, 84, 064607 (2011)
G. A. Souliotis, S. Koulouris, et al., Nucl. Instrum. Methods A 1031, 166588 (2022)

Reactions Studied with MARS

★ (15 MeV/nucleon) ^{40}Ar + ^{64}Ni, ^{58}Ni (4º data) [1,7]

★ **(15 MeV/nucleon) ^{86}Kr + ^{64}Ni**, ^{58}Ni (**4º** and **7º** data) [2,3,6,8]

★ **(15 MeV/nucleon) ^{86}Kr + ^{124}Sn**, ^{112}Sn (**4º** and **7º** data) [2,3,6]

★ (25 MeV/nucleon) ^{86}Kr + ^{64}Ni (**4º** data) [4,6]

★ **(25 MeV/nucleon) ^{86}Kr + ^{124}Sn**, ^{112}Sn (**4º** data) [5,6]

[1] A. Papageorgiou, G. A. Souliotis et al., J. Phys. G 45, 095105 (2018)
[2] G. A. Souliotis, M. Veselsky et al., Phys. Rev. C, 84, 064607 (2011)
[3] P. Fountas, G. A. Souliotis et al., Phys. Rev. C, 90, 064613 (2014)
[4] G. A. Souliotis, M. Veselsky et al., Phys. Lett. B 543, 163 (2002)
[5] G. A. Souliotis, M. Veselsky et al., Phys. Rev. Lett. 91, 022701 (2003)
[6] O. Fasoula, G. A. Souliotis et al, arXiv: 2103.10688 (nucl-ex 2021)
[7] K. Palli, G. A. Souliotis et al., Eur. Phys. J. WoC 252, 07002 (2021)
[8] O. Fasoula, G. A. Souliotis et al., HNPS Advances in Nuclear Physics vol. 29, pp. 38-44 (2023)

DIT - Deep Inelastic Transfer model (Phenomenological)

★ Peripheral and semi-peripheral collisions

★ Stochastic nucleon exchange

L. Tassan-Got and C. Stephan, Nucl. Phys. A, **524**, 121 (1991)

CoMD - Constrained Molecular Dynamics (Microscopic)

★ Nucleons: Gaussian wavepackets

★ Pauli principle imposed via a phase-space constraint

★ Monte Carlo implementation. Description of the dynamical stage for t = 0-600 fm/c

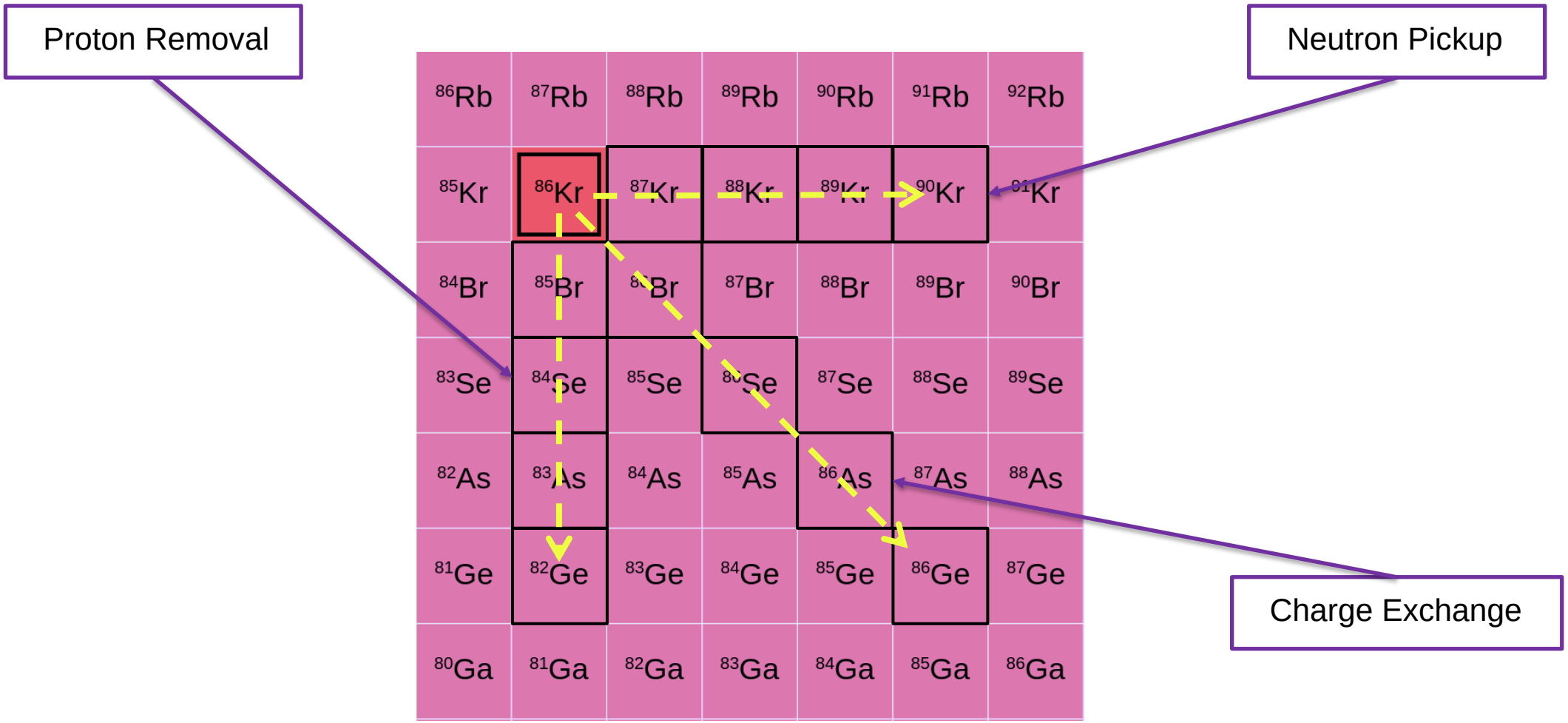
M. Papa, A. Bonasera et al., Phys. Rev. C, **64**, 024612, (2001)

GEMINI - De-excitation

★ Binary decay model

R. J. Charity et.al, Nucl. Phys. A, **483**, 371 (1988), R. J. Charity, Phys. Rev. C **58**, 1073 (1998)

Paths to Neutron Rich Isotopes via MNT



15 MeV/nucleon ^{86}Kr + ^{64}Ni, ^{124}Sn

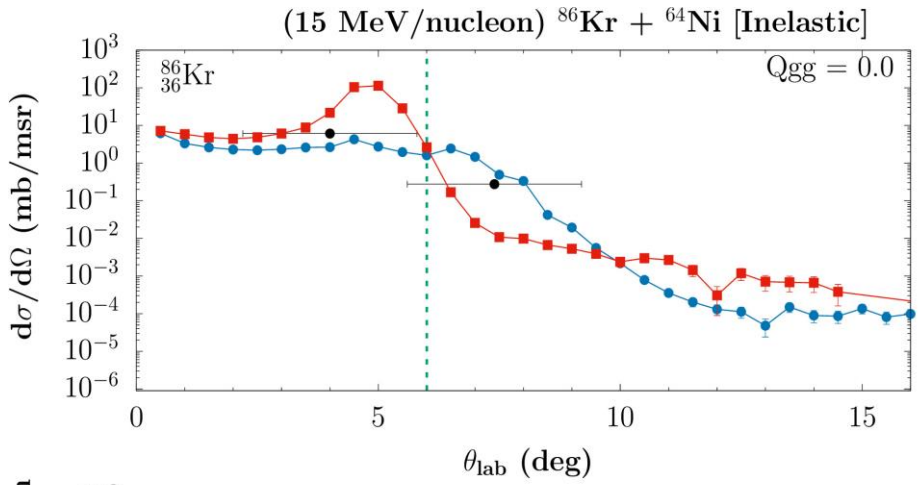
Standard DIT and CoMD Calculations

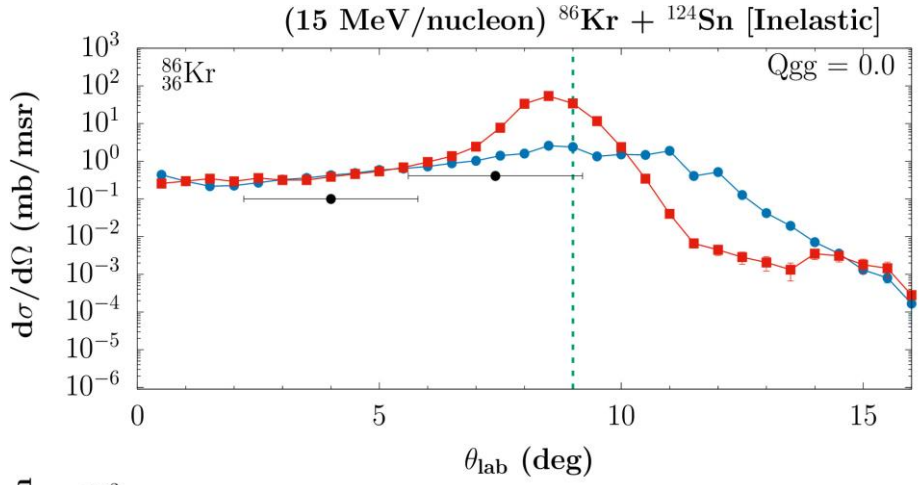
15 MeV/nucleon ^{86}Kr + ^{64}Ni / ^{124}Sn – Inelastic Channel

Angular Distributions

- Exp. Data*
- DIT/Gemini
- CoMD/Gemini
- Grazing angle (θ_{gr})

★ Experimental points
4° and 7°

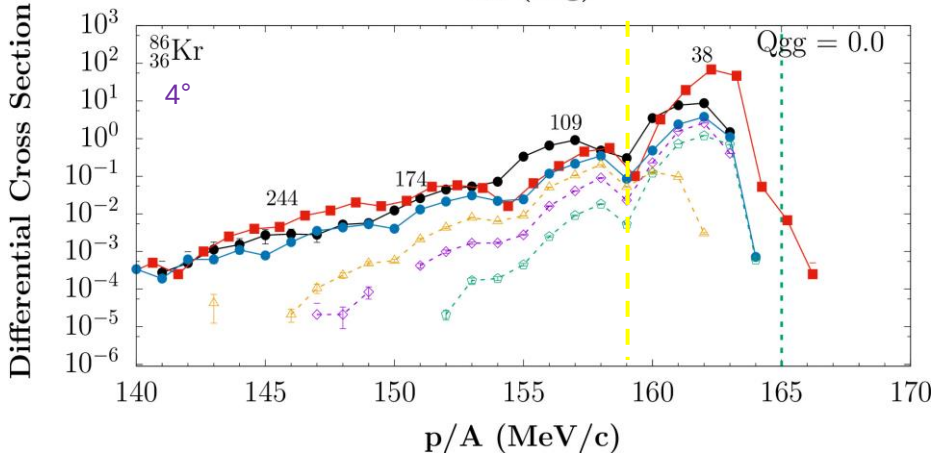


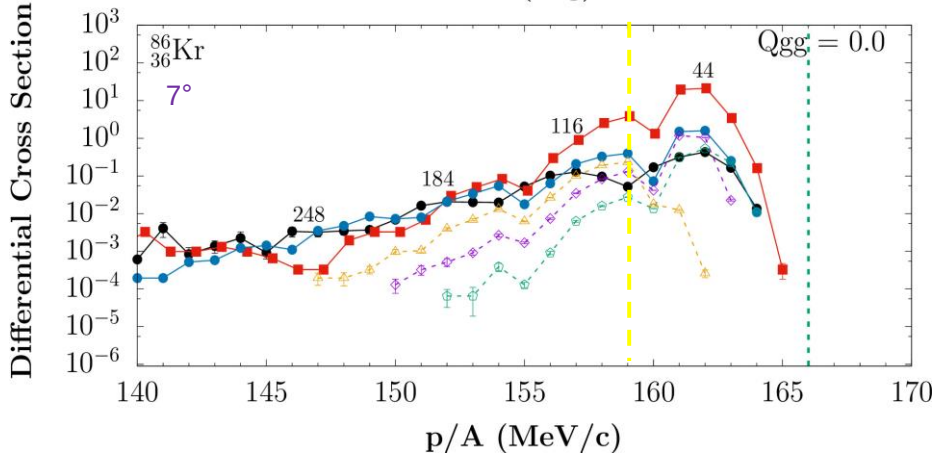


Momentum per Nucleon Distributions

- Exp. Data*
- DIT/Gemini
- CoMD/Gemini
- P/A of beam exiting target

★ Recently extracted from the original experimental data
★ Measured cross sections
Ni: 4° and Sn: 7°
★ Binary Kinematics (Peripheral)
$E^*_{tot} = Q_{gg}-Q_r$, $E_{QP} \approx E^*_{tot}/2$



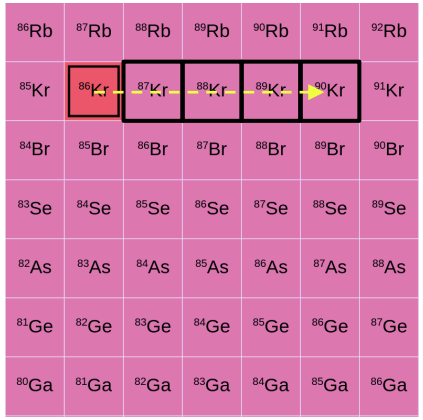


DIT Quasiprojectile (QP) Analysis

- QP – 0N
- QP – 1N
- QP – 2N

*G. A. Souliotis, et al., Phys. Rev. C, 84, 064607 (2011)

15 MeV/nucleon ^{86}Kr + ^{64}Ni / ^{124}Sn – Neutron Pickup Channels



- Exp. Data*
- DIT/Gemini
- CoMD/Gemini
- - - P/A of beam exiting the target

Momentum per Nucleon Distributions

★ Recently extracted from the original experimental data

★ Measured cross sections
Ni: 4° and Sn: 7°

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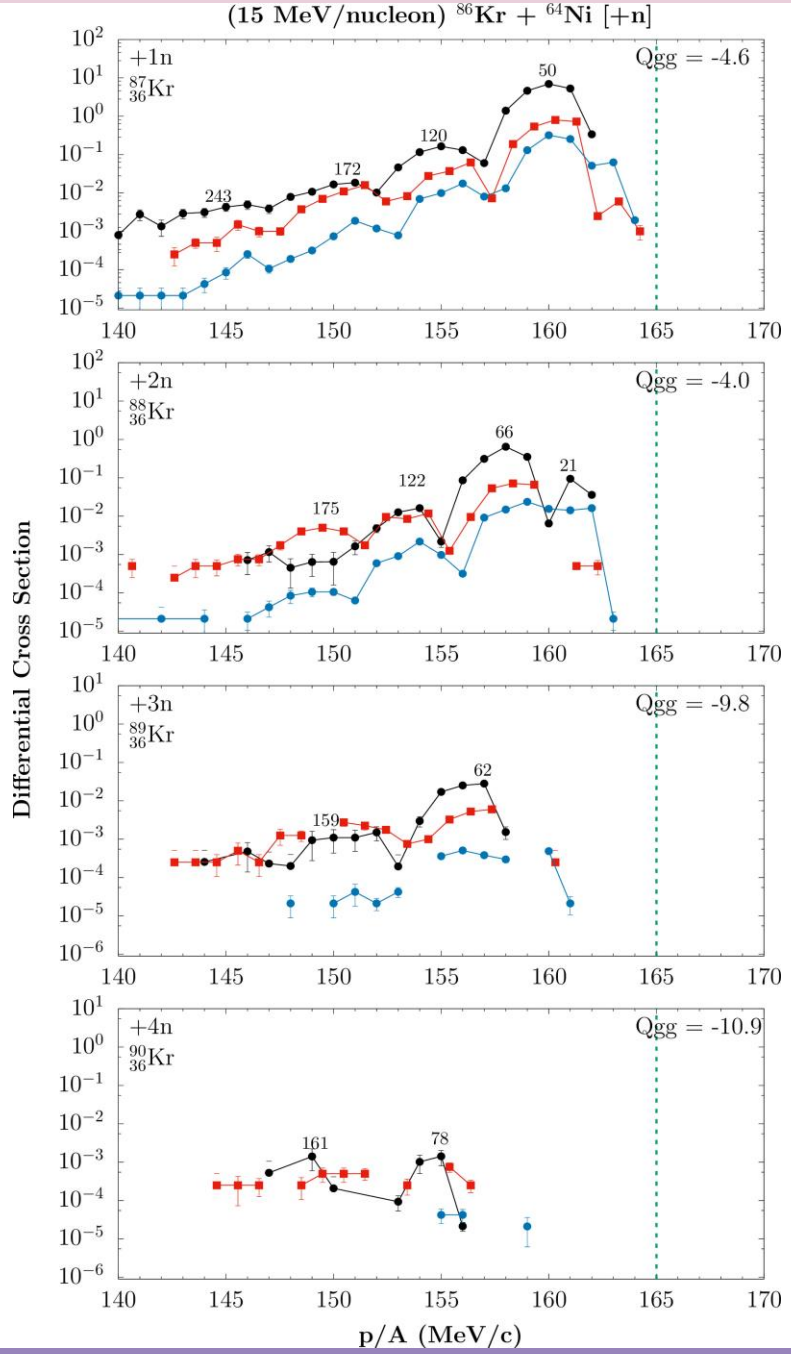
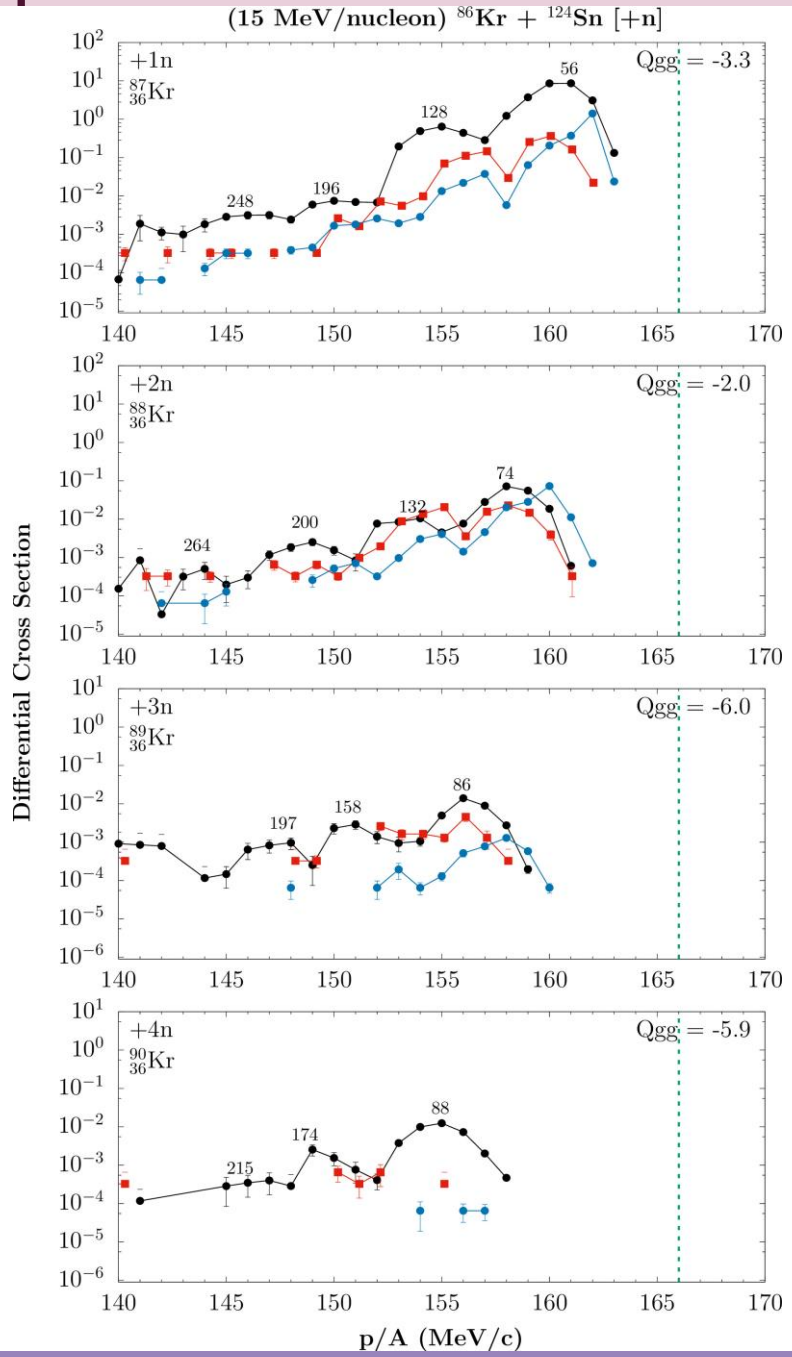
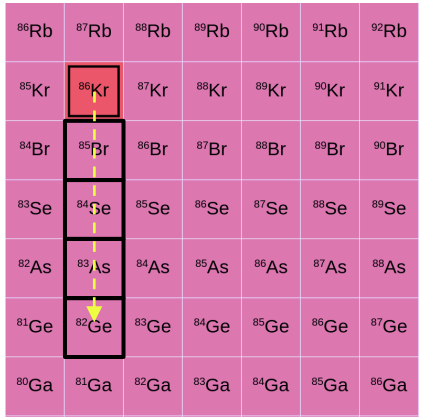
$E^*_{tot} = Q_{gg} - Q_r$, $E_{QP} \approx E^*_{tot}/2$





*G. A. Souliotis, et al., Phys. Rev. C, 84, 064607 (2011)

15 MeV/nucleon ^{86}Kr + ^{64}Ni / ^{124}Sn – Proton Removal Channels



- Exp. Data*
- DIT/Gemini
- CoMD/Gemini
- - - P/A of beam exiting the target

<u>Momentum per Nucleon Distributions</u>

★ Recently extracted from the original experimental data

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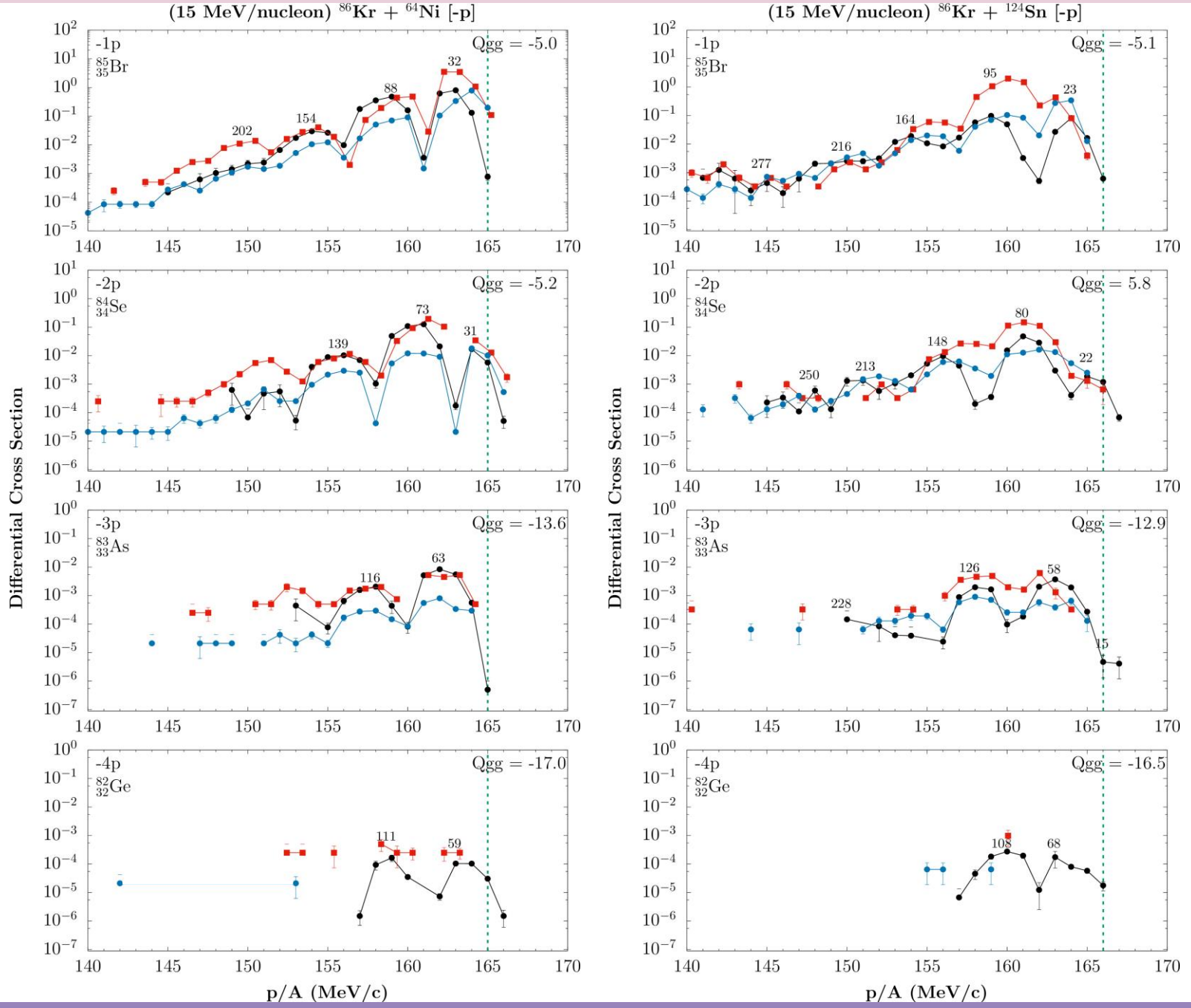
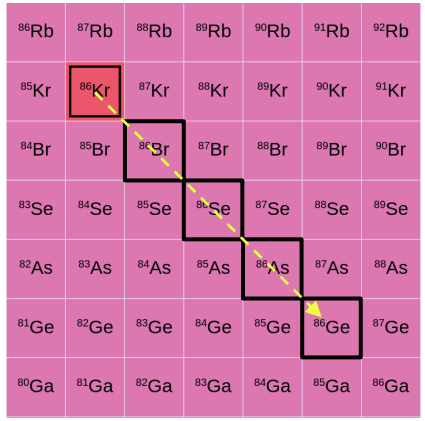


*G. A. Souliotis, et al., Phys. Rev. C, 84, 064607 (2011)

15 MeV/nucleon ^{86}Kr + ^{64}Ni / ^{124}Sn – Multiple Charge Channels



- Exp. Data*
- DIT/Gemini
- CoMD/Gemini
- P/A of beam exiting the target

Momentum per Nucleon Distributions

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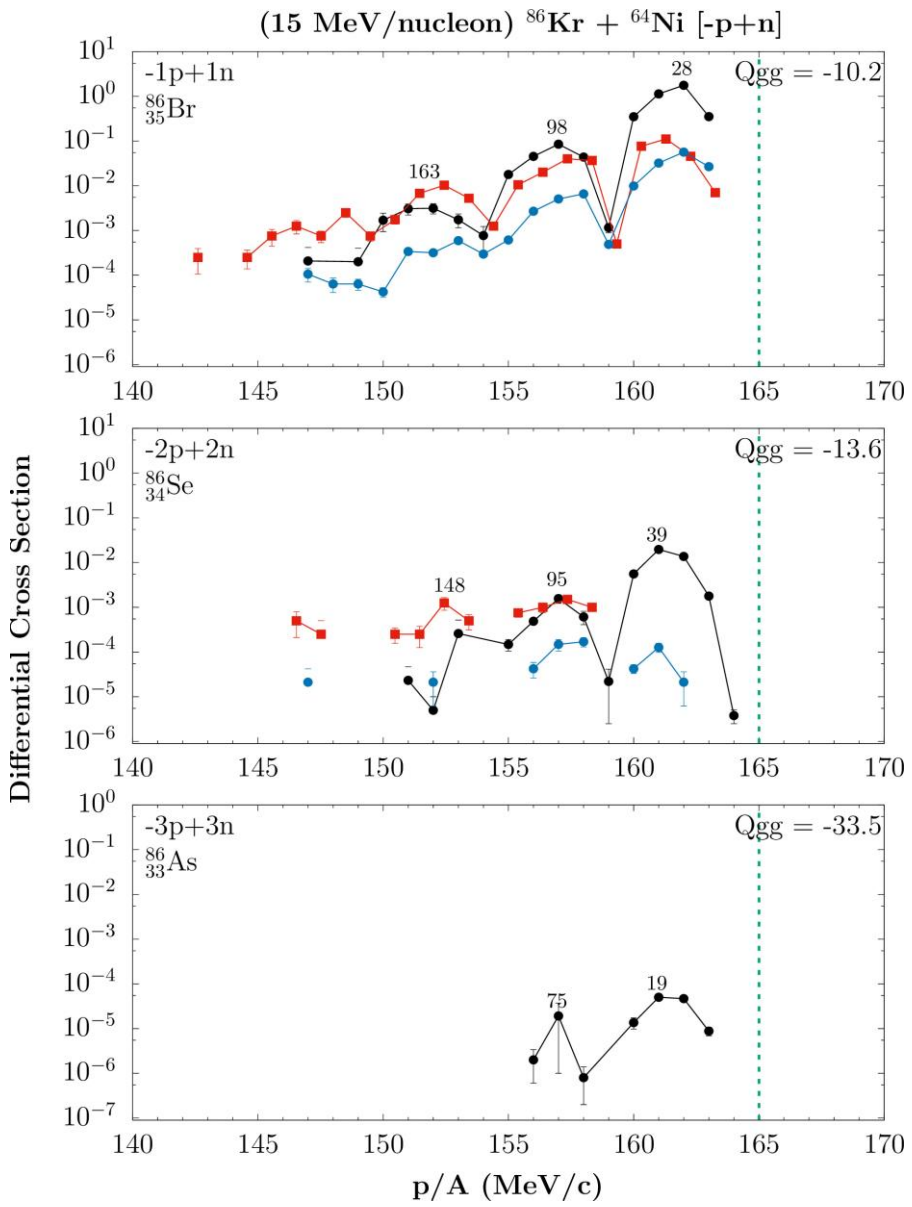

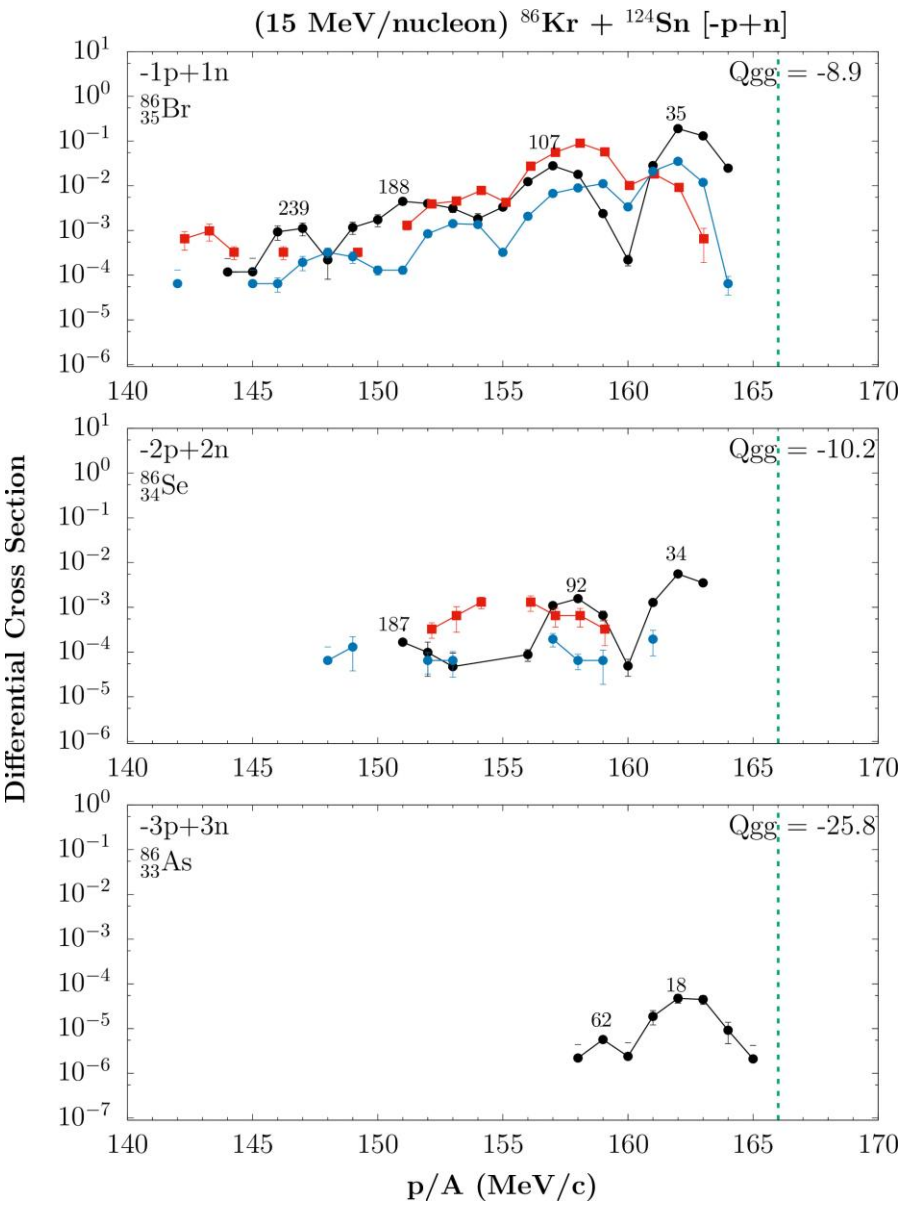

*G. A. Souliotis, et al., Phys. Rev. C, 84, 064607 (2011)

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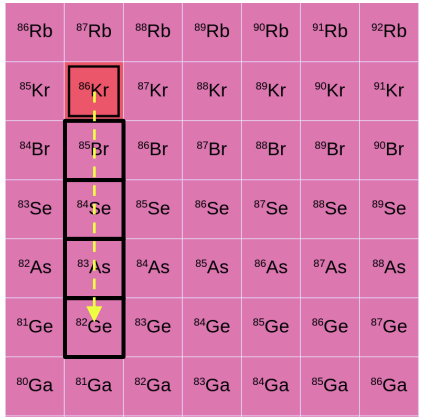

- Exp. Data*
- DIT/Gemini
- CoMD/Gemini
- – – P/A of beam exiting the target

<u>Momentum per Nucleon Distributions</u>

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Sn: 4°

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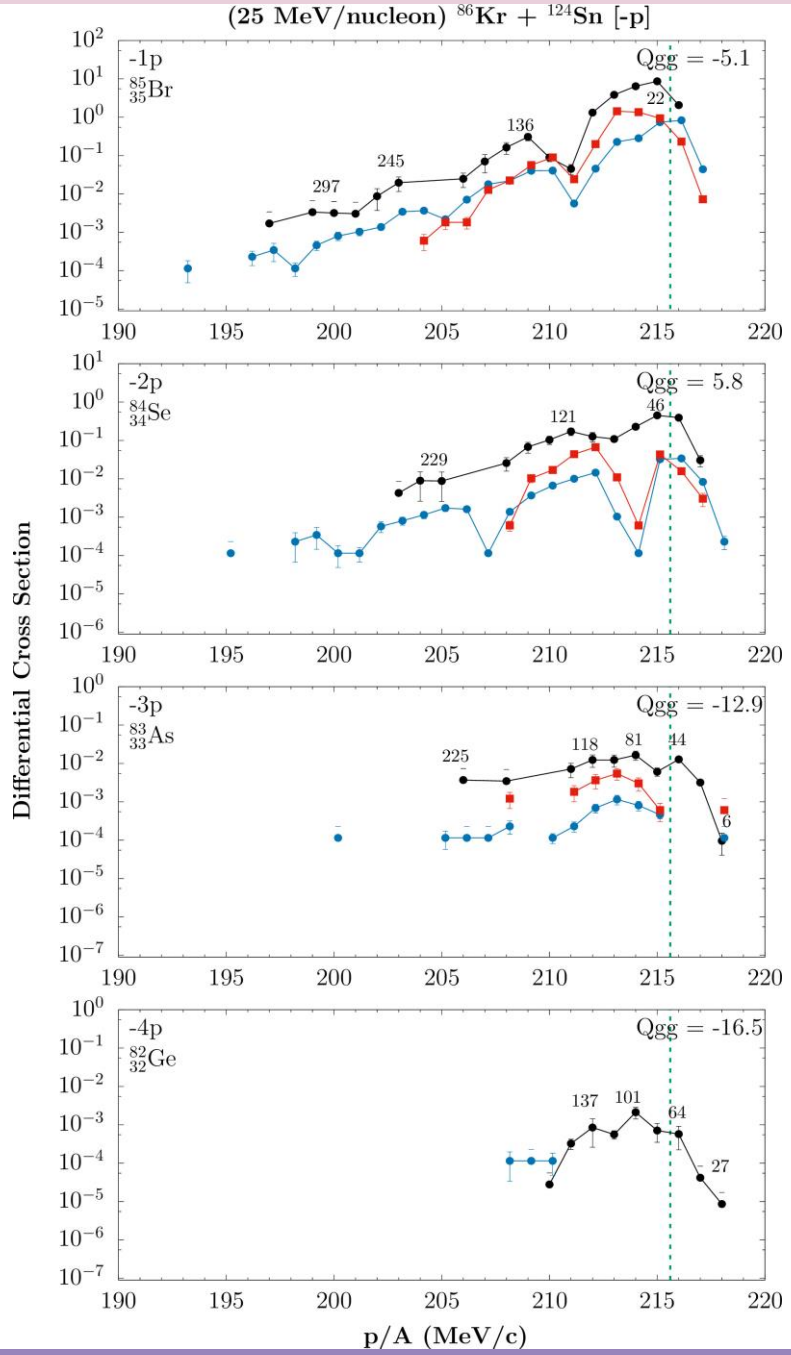

*G.A. Souliotis, et al., Phys. Rev. Lett. 91, 022701 (2003)

So far

★ Systematic studies of reactions of ^{86}Kr beam at 15 MeV/nucleon with targets of ^{64}Ni and ^{124}Sn
★ Extraction of momentum distributions and subsequent kinematic analysis
★ Preliminary comparisons on the 25 MeV/nucleon ^{86}Kr + ^{124}Sn reaction

Future Plans

★ Further detailed calculations with DIT and CoMD models especially for the reactions with the of ^{86}Kr beam at 25 MeV/nucleon
★ Explore the merits of momentum per nucleon and angular distributions studies
★ Decipher the various mechanisms of nuclear reactions at the Fermi energy regime
★ Pathways to neutron rich isotopes

THANK YOU!