Probing Cluster Transfer in Peripheral Collisions of ^{40}Ar on ^{64}Ni and ^{58}Ni at 15 MeV/nucleon

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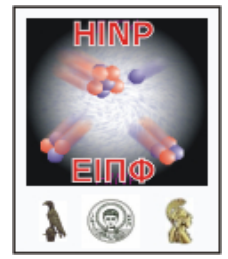


Overview

- Introduction
- Experimental Setup
- Presentation of Theoretical Computational Models
- Comparison of Calculations with Experimental Data
- Summary

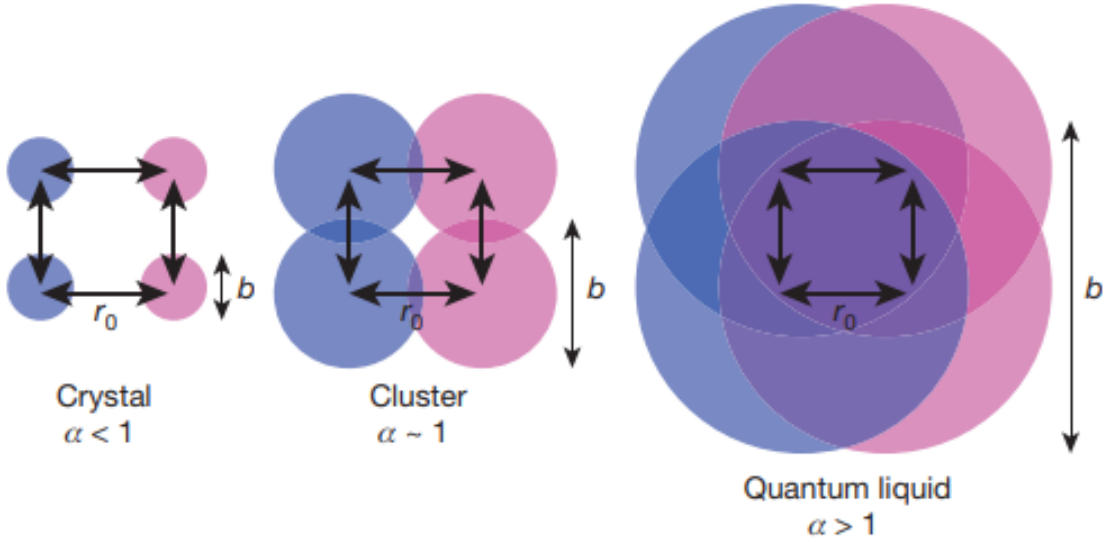
Clustering in Nuclei

- $a = b/r_0$

b :the dispersion of the nucleon wavefunction

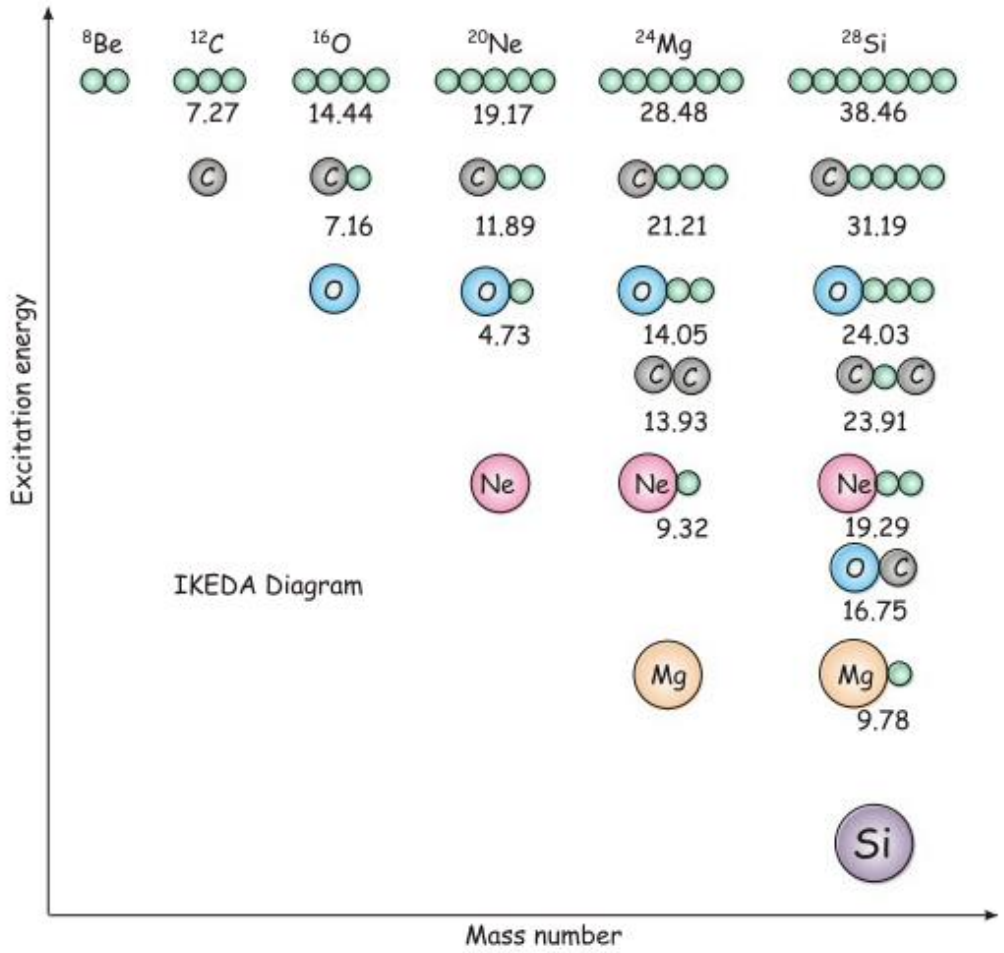
r_0 :the typical distance between nucleons (~ 1.2 fm)

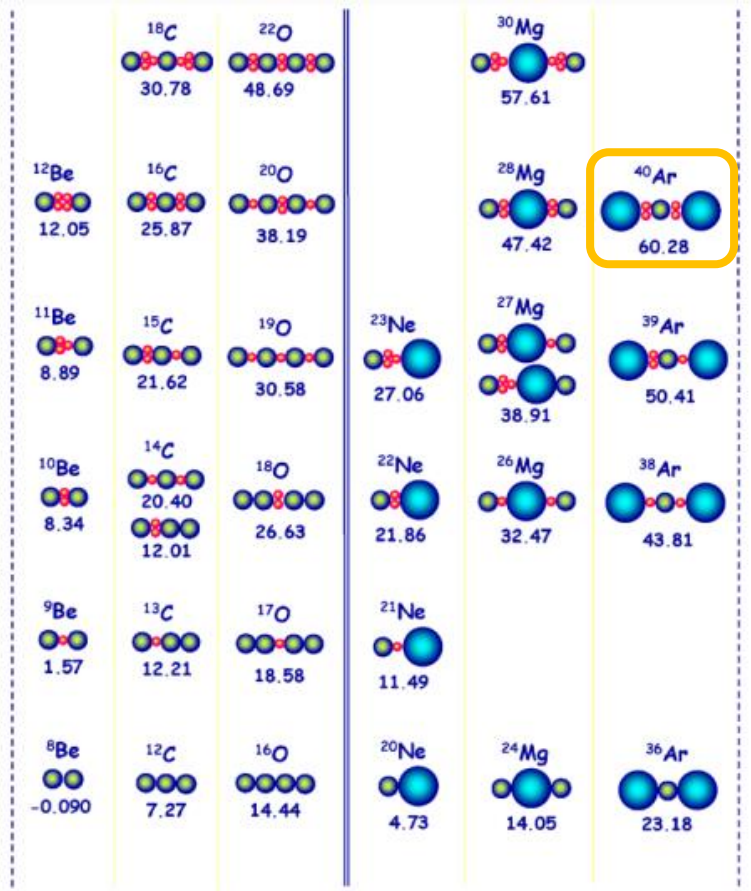
- α < 1: crystalline phase
- α ~ 1: transition to a cluster state
- α > 1 :the nucleons are delocalized, and the nucleus has a quantum liquid structure



Ebran, JP., Khan, E., Nikšić, T. *et al.* How atomic nuclei cluster. *Nature* 487, 341–344 (2012)

Clustering in Nuclei

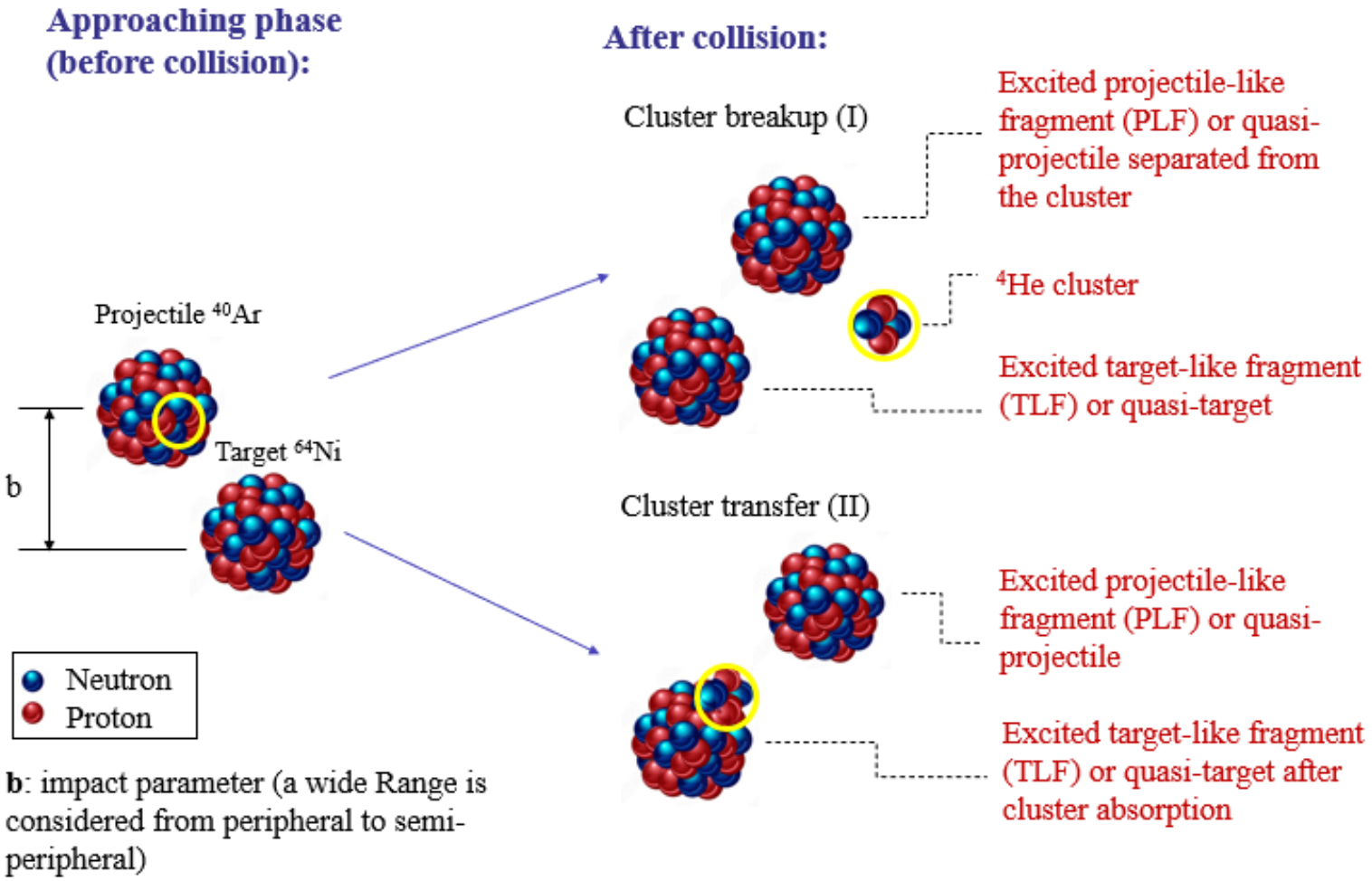




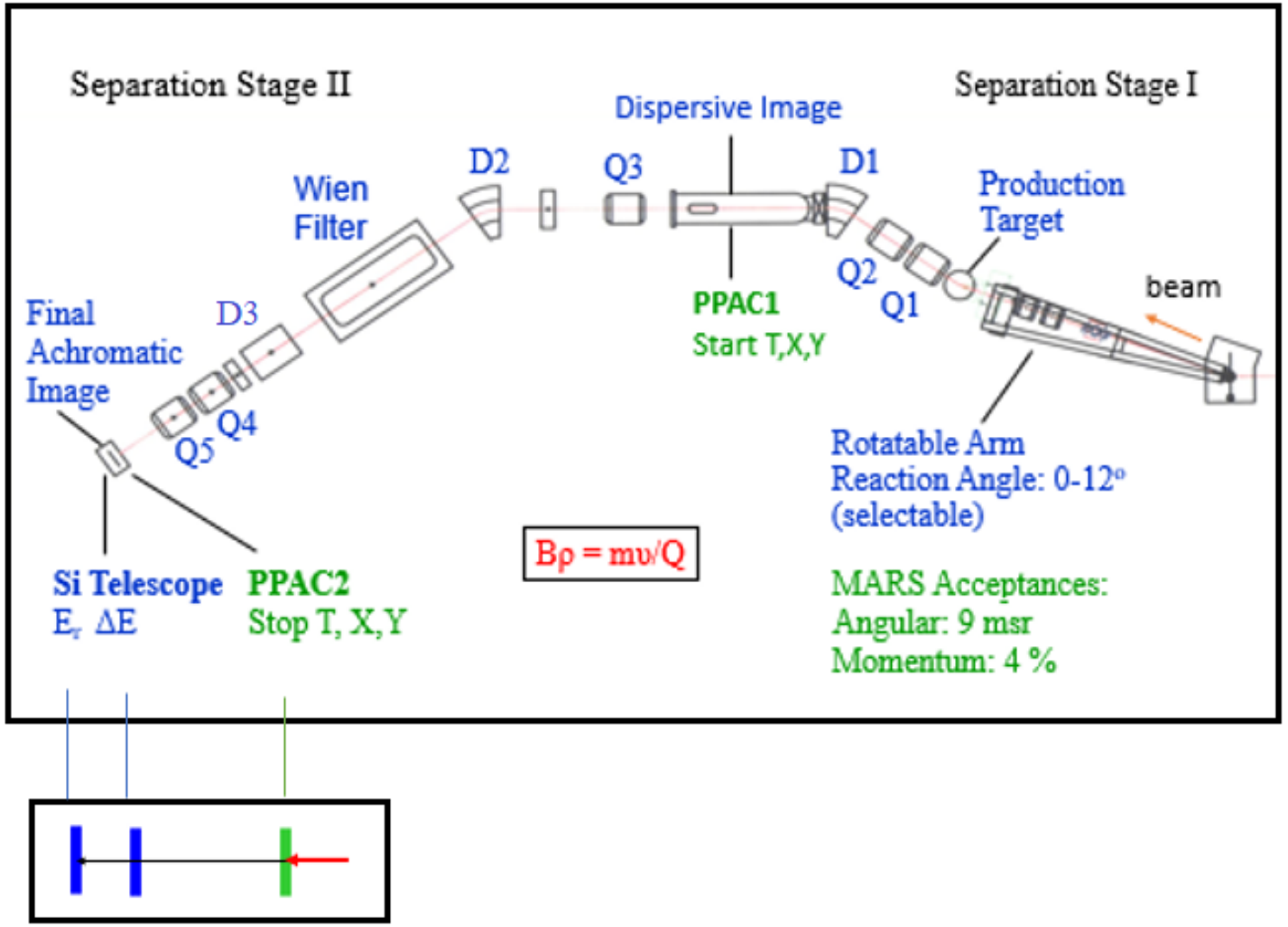
Modified Ikeda Diagram proposed by von Oertzen

M. Freer, Clustering in Light Nuclei; from the Stable to the Exotic. *Springer*, Vol. IV (2014)

Cluster breakup (I) or Cluster transfer (II) in peripheral collisions



MARS Recoil Separator



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

Computational Models

To describe the dynamic stage of the reaction:

- **DIT** (Deep Inelastic Transfer) : Phenomenological Nucleon Exchange Model
- **CoMD** (Constrained Molecular Dynamics) : Microscopic Nuclear Dynamics Model

For the description of the de-excitation of the primary fragments:

- **GEMINI**

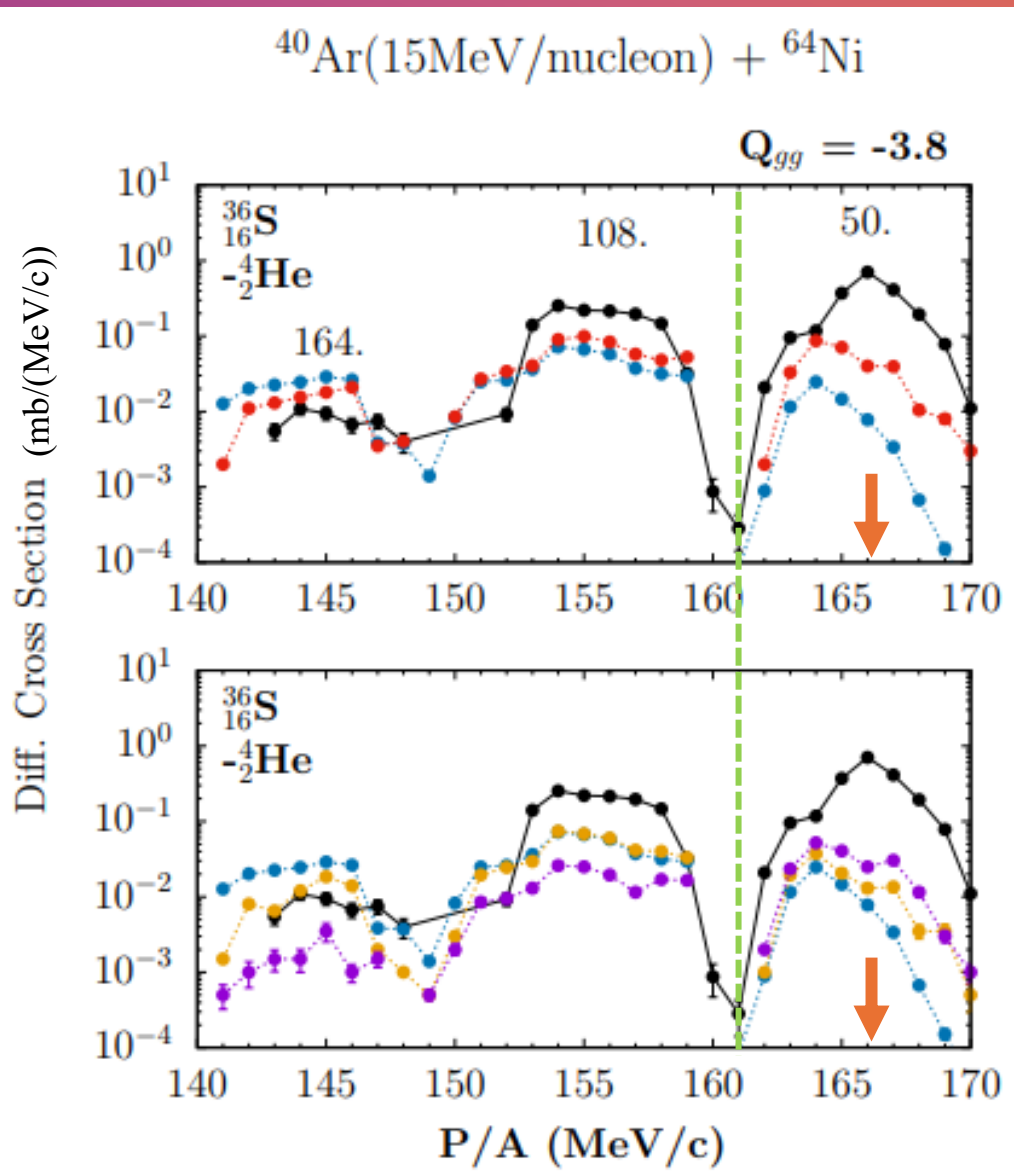
DIT: L. Tassan-Got, C. Stefan, Nucl. Phys. A, 524, 121, (1991)

CoMD: M. Papa et al., Phys. Rev. C, 64, 024612, (2001),

K. Palli, G. A. Souliotis, T. Depastas, et al. Microscopic dynamical description of multinucleon transfer in 40Ar induced peripheral collisions at 15 MeV/nucleon. EPJ Web Conf.,Vol 252 (2021)

GEMINI: R.J. Charity, Phys. Rev. C 82, 014610 (2010)

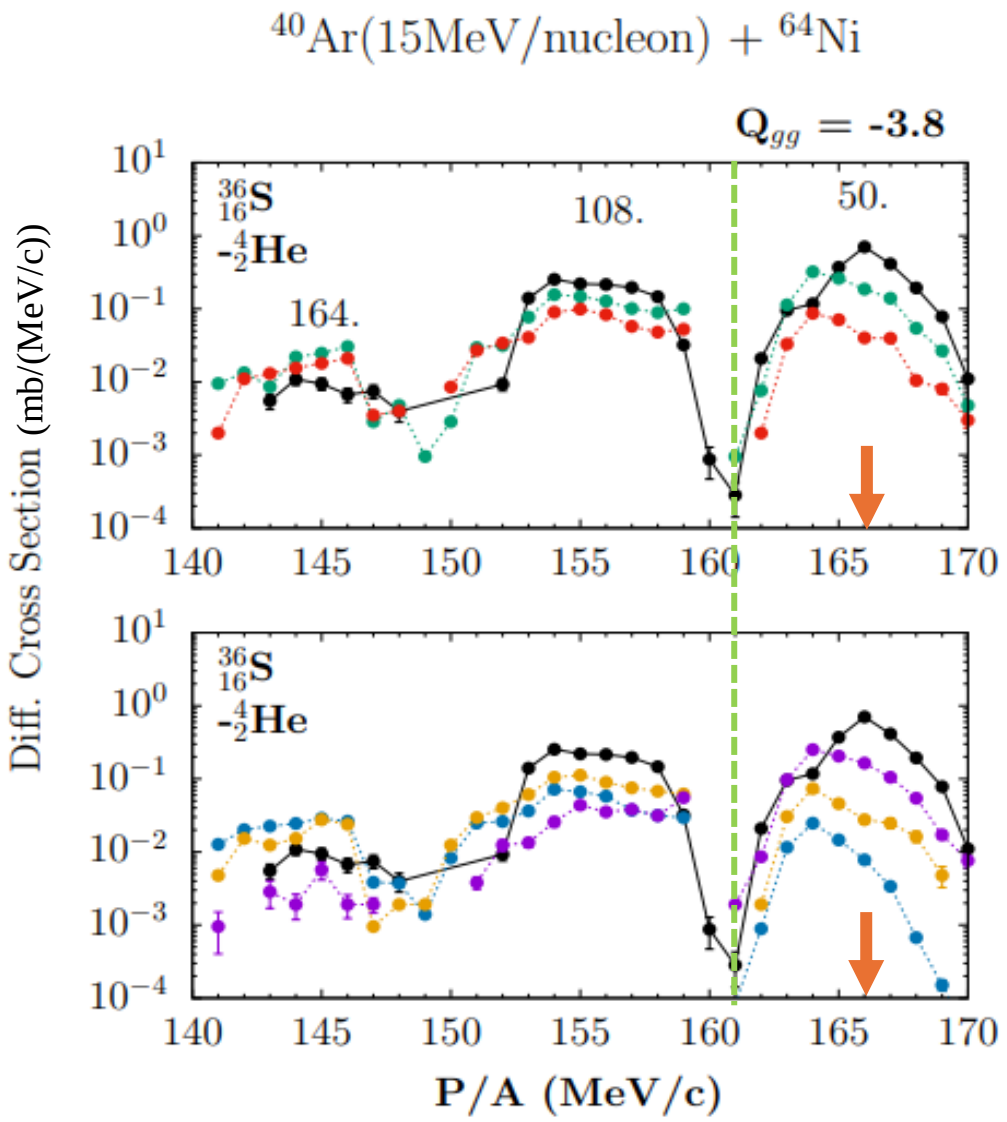
Momentum Distribution of the ^{36}S fragment ($^{40}Ar - \alpha$)



- Experimental Data
- DIT
- Standard CoMD (paulm=87)
- CoMD Nucleon Transfer
- CoMD Nucleon Breakup

$$E^*_{tot} = Q_{gg} - Q$$

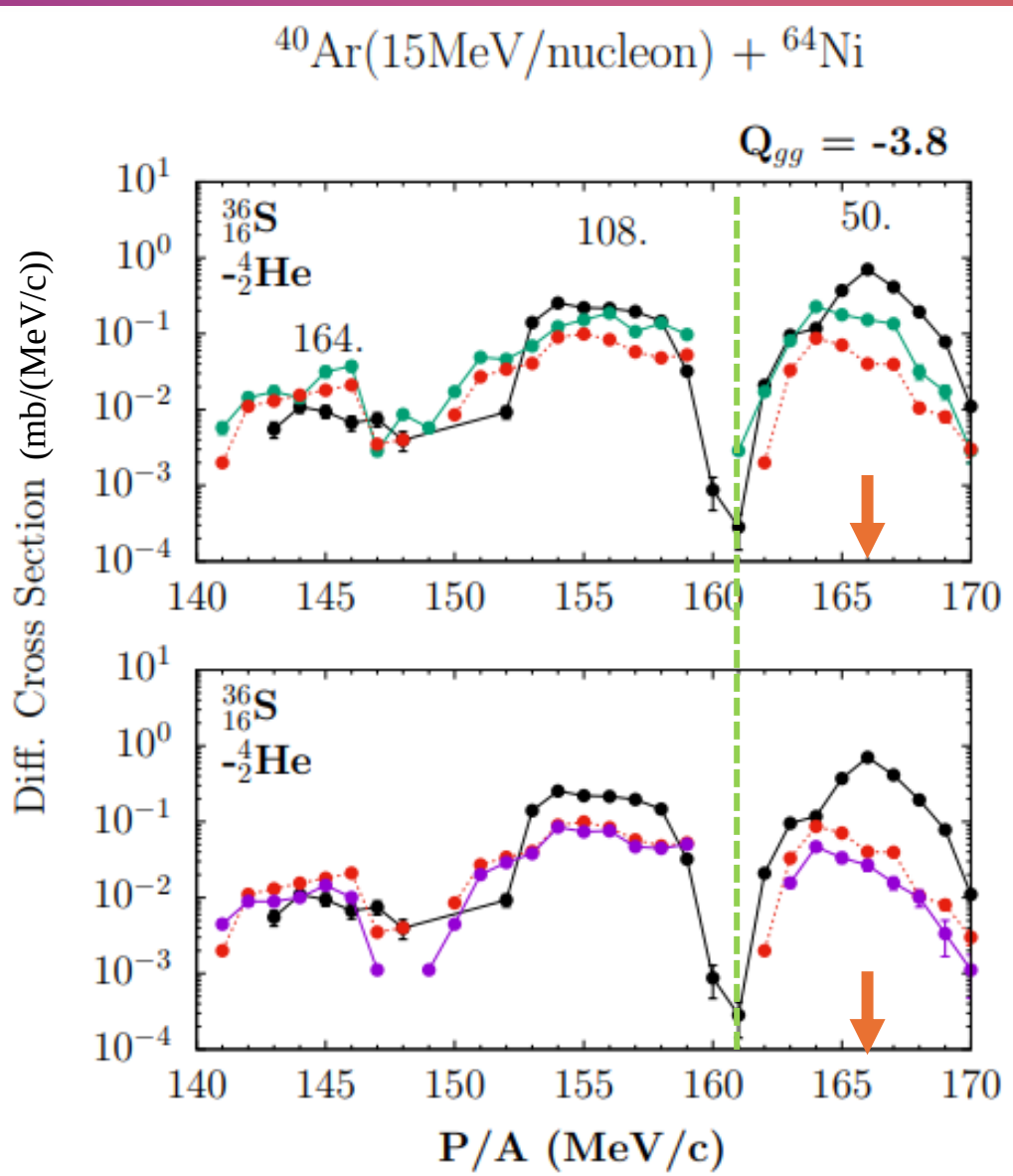
Effect of the Enhanced Pauli Constraint on the CoMD Calculations



- Experimental Data
- DIT
- Standard CoMD (paulm=87)
- CoMD with enhanced Pauli constraint (paulm=80)
- CoMD (paulm=80)/ Nucleon Transfer
- CoMD (paulm=80)/ Nucleon Breakup

S. Ohkubo, Luneburg-lens-like universal structural Pauli attraction in nucleus-nucleus interactions: Origin of emergence of cluster structures and nuclear rainbows, Phys. Rev. C 93, 041303 (2014)

Effect of Compressibility on the CoMD Calculations



- Experimental Data
- Standard CoMD (K=254)
- CoMD (K=200)
- CoMD (K=308)

Summary and Conclusions

- We studied projectile fragments of the reaction ^{40}Ar (15 MeV/nucleon) + ^{64}Ni, with emphasis on the momentum distributions which correspond to the removal of one α-particle from the ^{40}Ar.
- We performed calculations with the DIT and CoMD models, that appear to underestimate the quasi-elastic region of the experimental data.
- We tested the CoMD model under enhanced Pauli constraint. We, also, tested two different compressibilities, K=200 and K=308.
- We tentatively conclude that the observed disagreement may be a signature of cluster breakup or transfer.

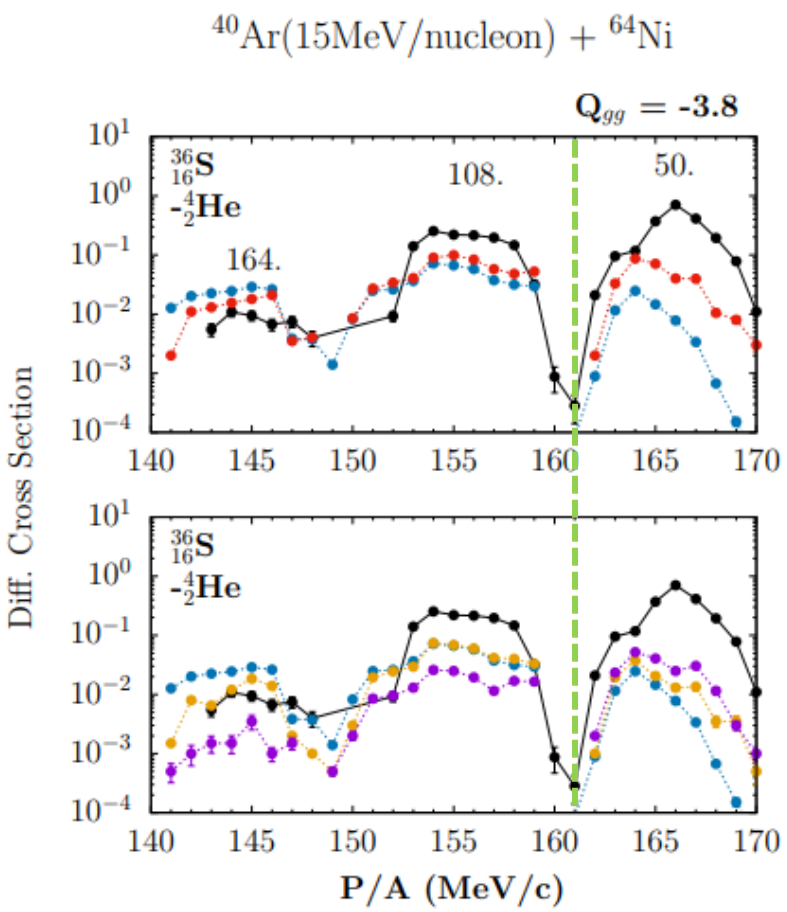
Future Steps

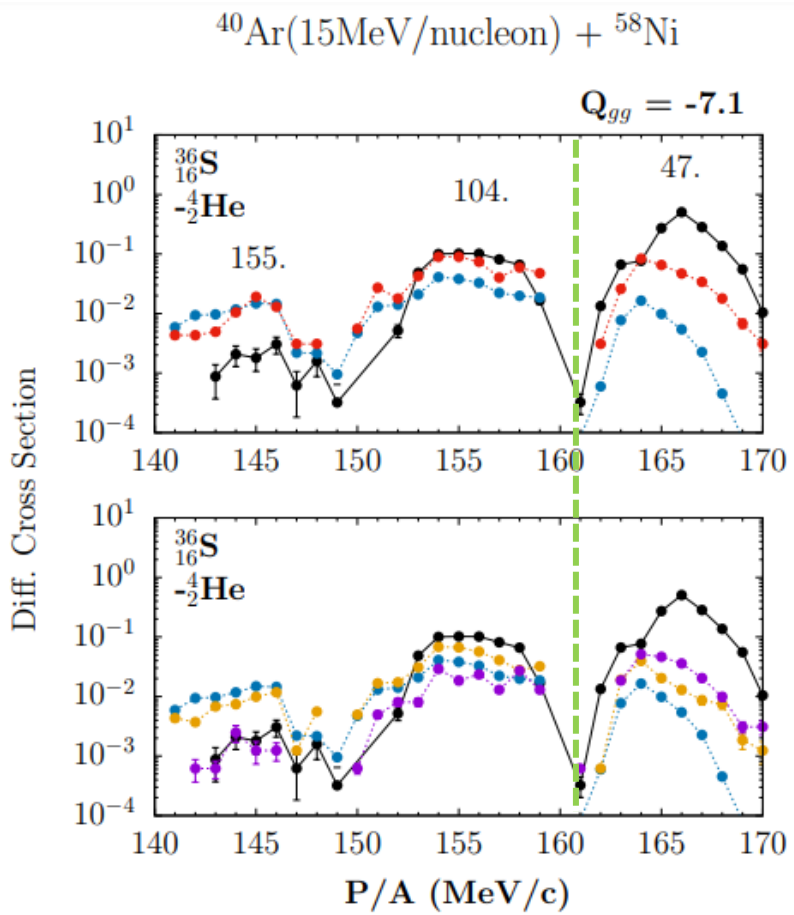
- Further investigation and analysis with the CoMD code, including a study of the time-dependence of alpha-particle formation and transfer
- Comparison of the data with the HaC (Hybrid alpha-Cluster) model
- Further comparisons with other reactions, studied by our group

Thank you for your attention!

Extras

Momentum Distribution of the ^{36}S fragment





- Experimental Data
- DIT
- Standard CoMD (paulm=87)
- CoMD (paulm=87)/ Nucleon Transfer
- CoMD (paulm=87)/ Nucleon Breakup

$E^*_{tot} = Q_{gg} - Q$

Nuclear Reactions in the Fermi Energy Regime (15-35 MeV/nucleon)

- Intermediate reactions between low (E/A < 10 MeV) and high (E/A > 100 MeV) energy reactions
- Existence of competing mechanisms

Momentum distributions:

- Measure of energy dissipation of a reaction
- Information as to the nature of the reaction mechanism

Deep Inelastic Transfer Model (DIT)

Approximation stage

- Nuclei are considered to be spheres moving along Coulomb orbits

Interaction stage

- Binuclear system formation
- Nucleon transfer during the overlap of their potentials
- Production of primary excited fragments

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

Constrained Molecular Dynamics Model (CoMD)

- Semi-Classical Quantum Molecular Dynamics Model
- Nuclei are considered Gaussian wavepackets
- Pauli's prohibitory principle via restriction to phase space
- Study of stage potential in a time interval of 600 fm/c ($\sim 2 \times 10^{-21} s = 2\ zs$)
- Impact parameter range: 0-14 fm

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

Standard parameters of computational models for the reaction ^{40}Ar (15 MeV/nucleon) + ^{64}Ni, ^{58}Ni

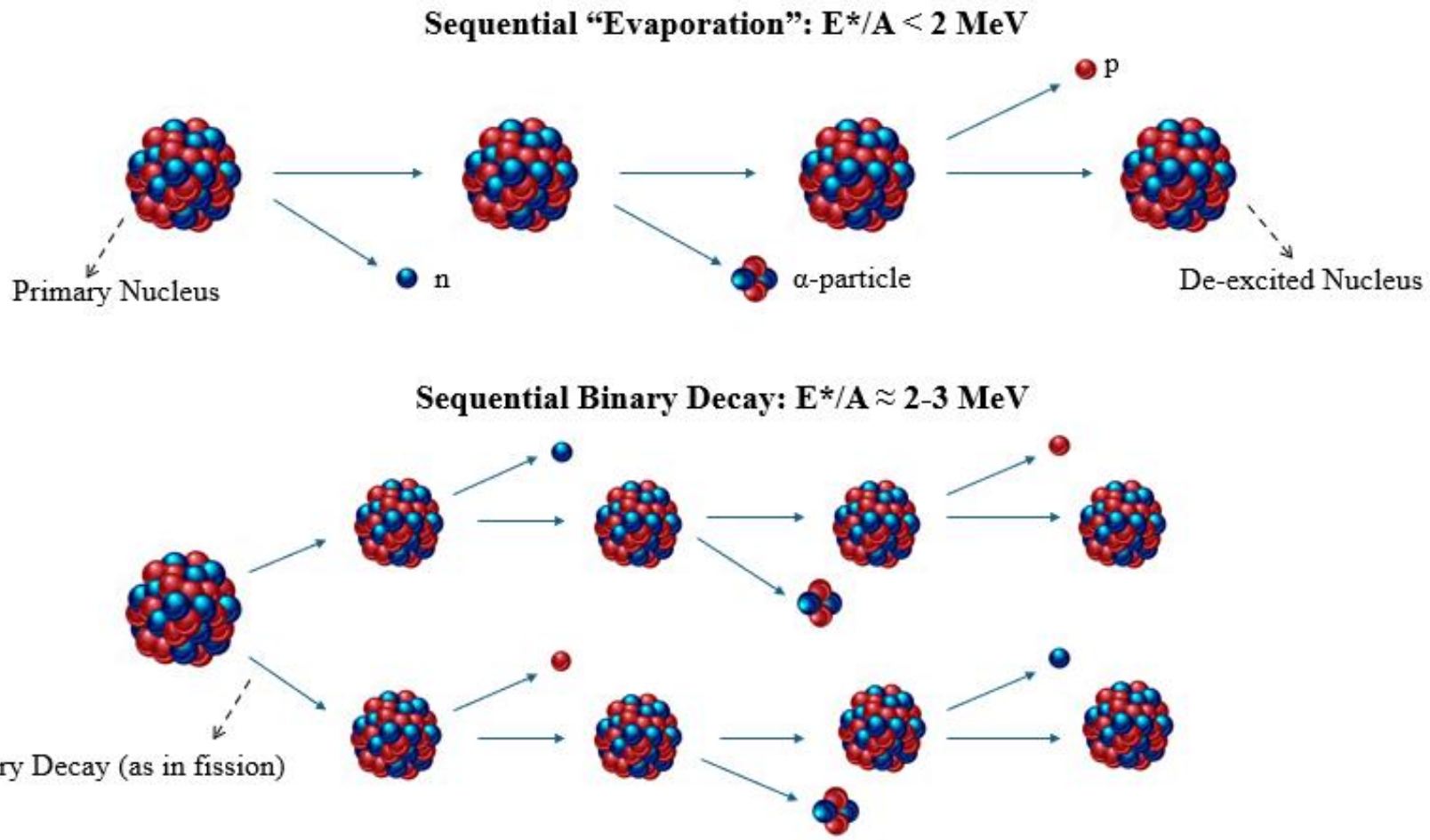
Standard DIT

- Reduction of the excitation energy of primary fragments by 15%

Standard CoMD

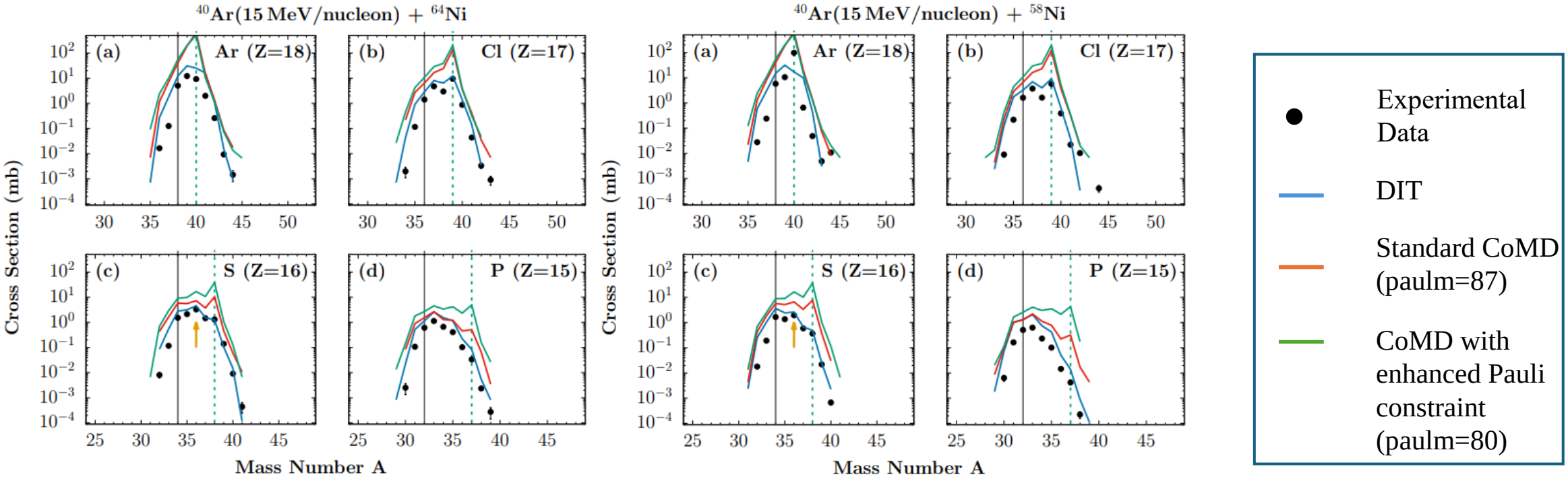
- No reduction of the excitation energy of primary fragments
- Pauli constraint setting with parameter paulm=87
- Nuclear matter compressibility setting with parameter K=254

GEMINI



R.J. Charity, Phys. Rev. C 82, 014610 (2010)

Mass Distributions of the reaction ^{40}Ar (15 MeV/nucleon) + ^{64}Ni, ^{58}Ni



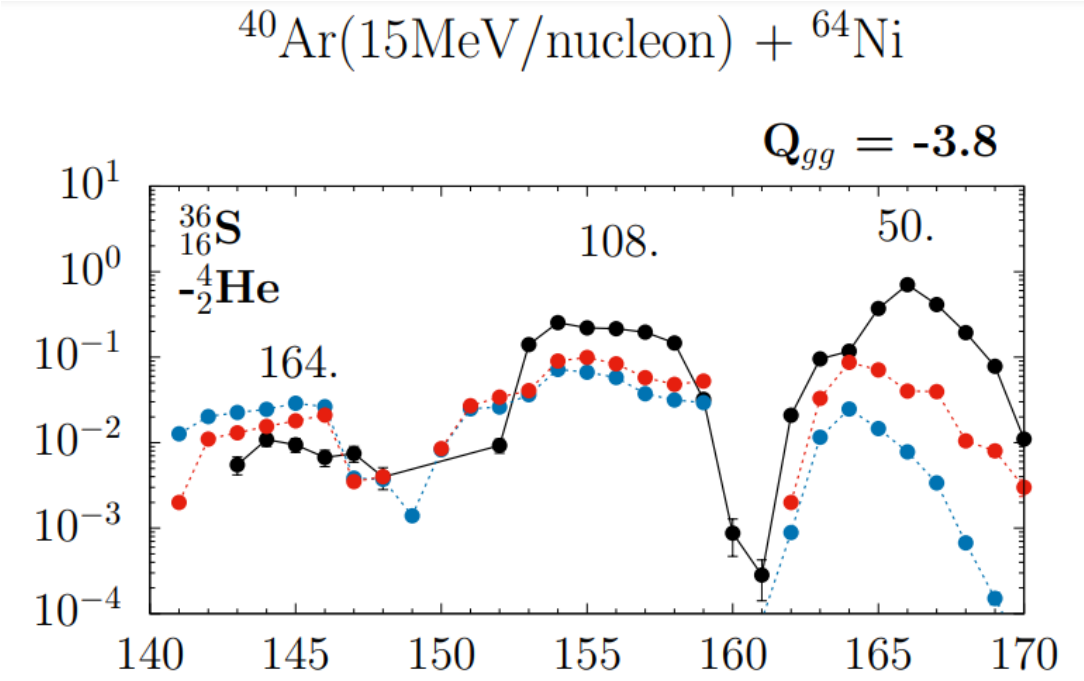
Experimental Data:

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

Momentum distributions of the reaction ^{40}Ar (15 MeV/nucleon) + ^{64}Ni, ^{58}Ni

Two regions are observed:

- Quasi-elastic peaks, corresponding to primary fragments of direct reactions
- “Dips”, which are a result of the software “gating”
- Broad peaks (inelastic peaks) corresponding to products that have been stripped of extra nucleons during their de-excitation



Each panel shows the distribution for different calculations performed.