Cluster transfer as spectroscopic tool: understanding the reaction process

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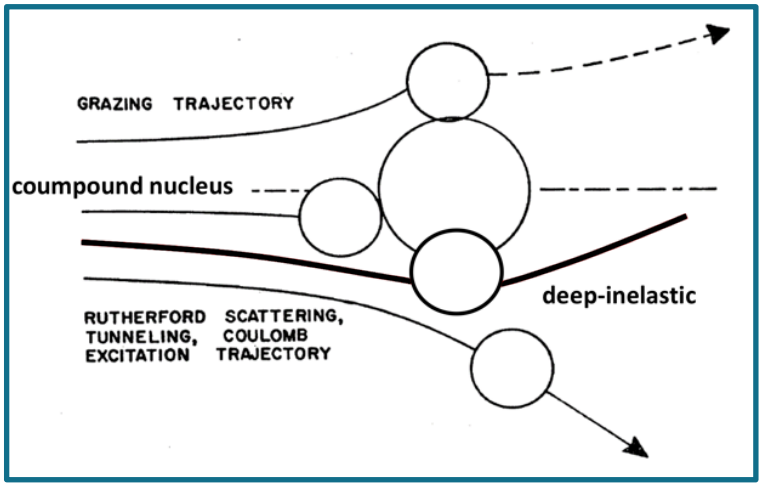
Introduction

Energy regime

Around the Coulomb barrier
(from just below up to ≈2 times above)

Reaction mechanism



Statistical methods

Perturbative methods

Compound nucleus

Deep inelastic

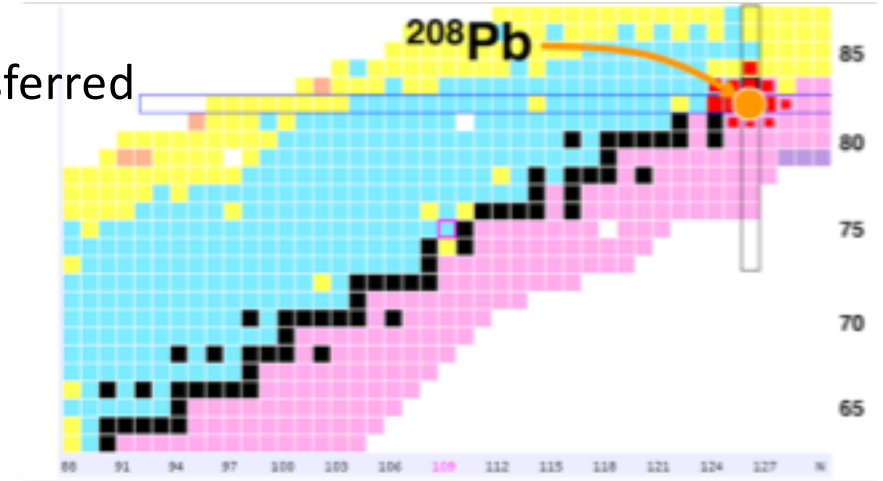
Cluster transfer

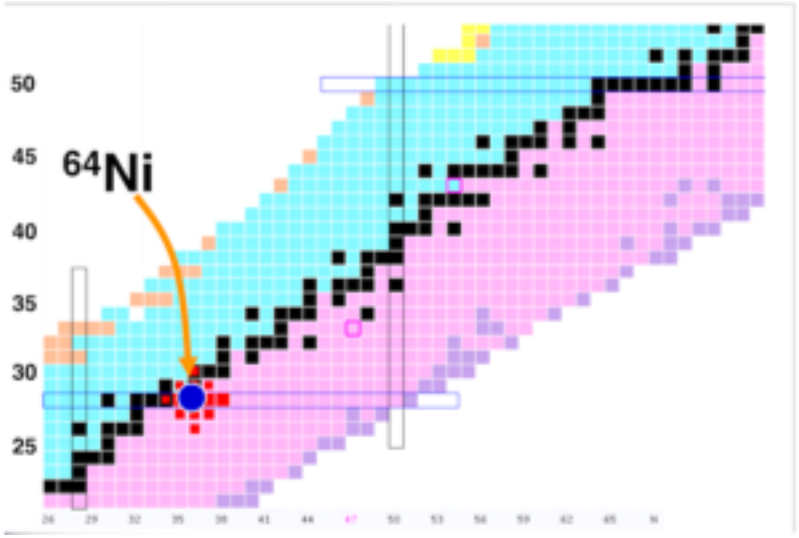
Nucleon transfer

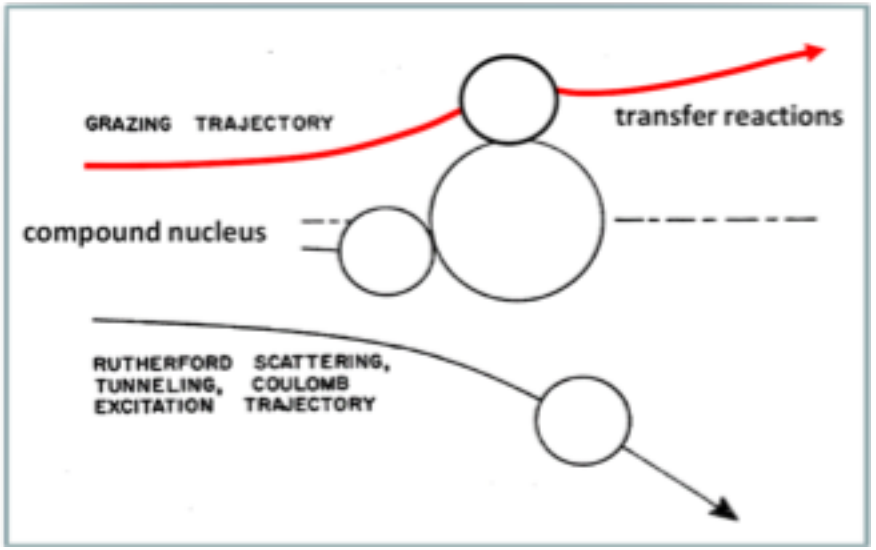
Inelastic and elastic scattering

Nucleon-transfer reactions

- Selectivity of final channel
  Few units of angular momentum transferred
  Provide spectroscopic information
  (single-particle structure)
- Methods:
  Coupled channels, DWBA, CDCC...



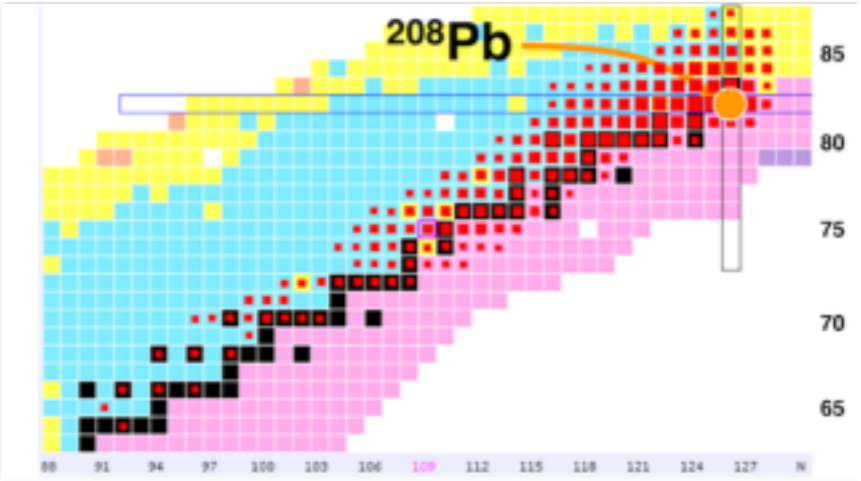


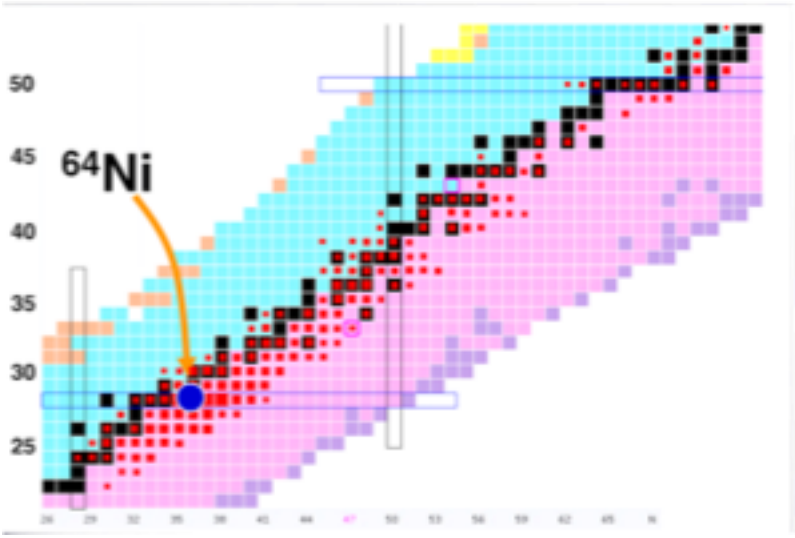


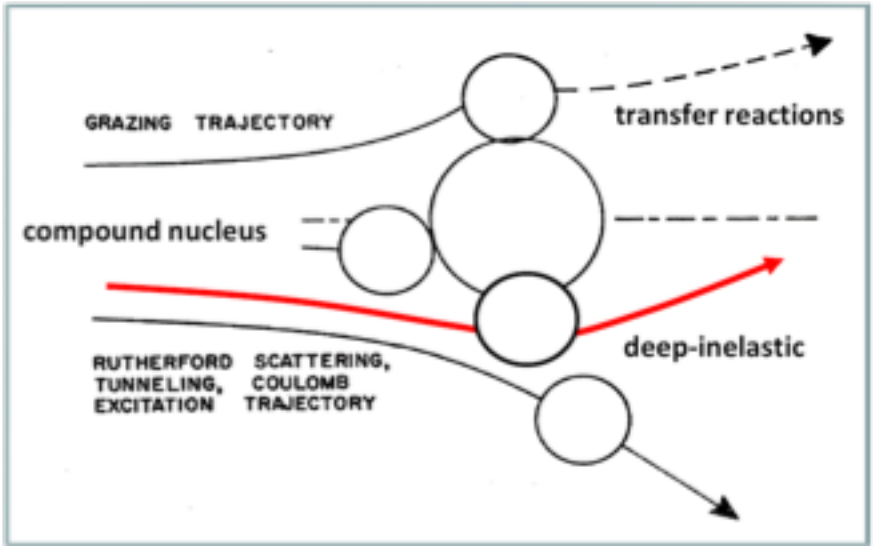
See talk by B. Fornal (EURORIB 2018)

Deep-inelastic reactions

- Access to nuclei otherwise difficult to produce directly
- High angular momentum transfer
- Statistical methods







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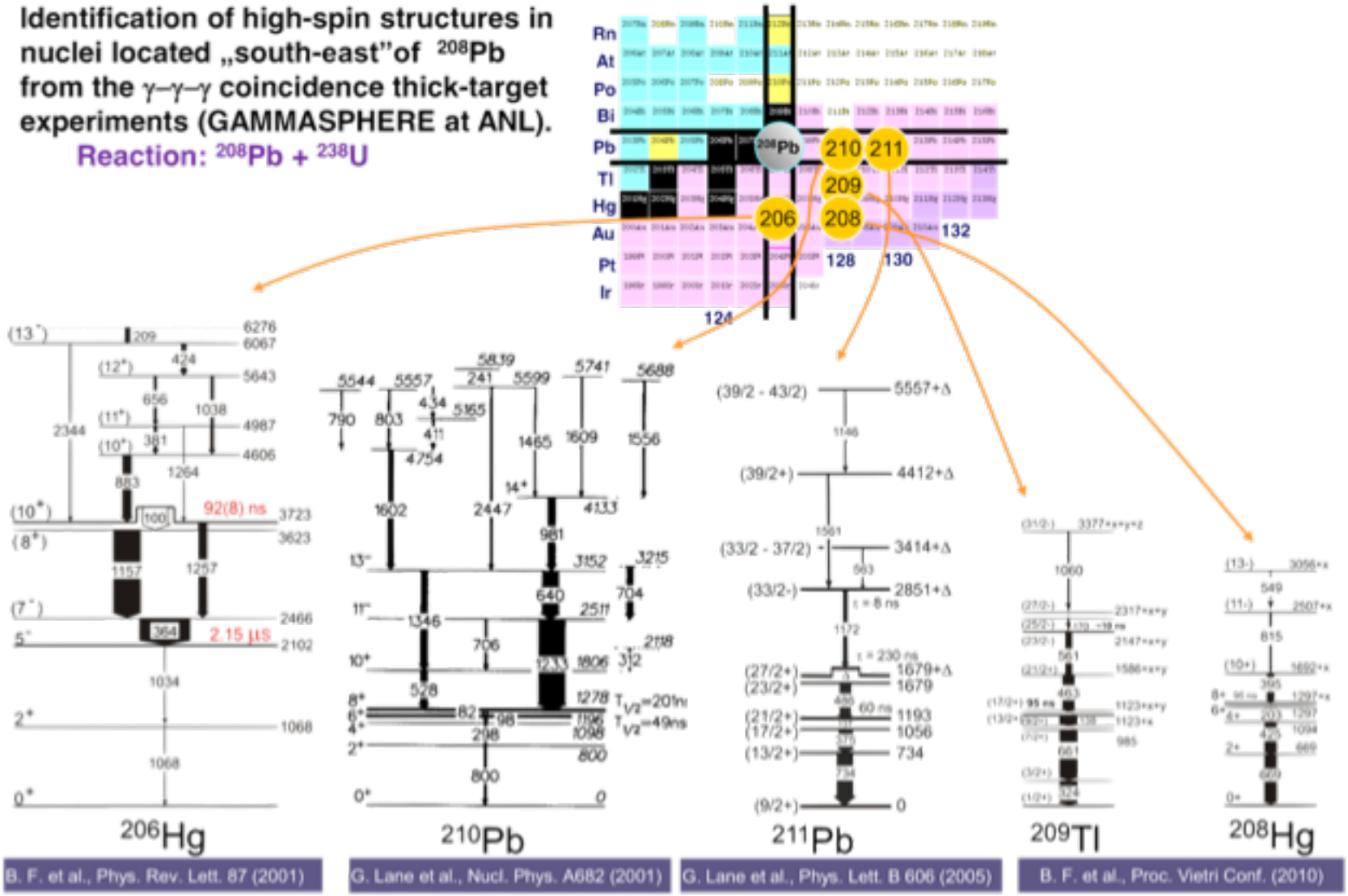
Deep-inelastic reactions

Identification of high-spin structures in nuclei located „south-east"of ^{208}Pb from the γ–γ–γ coincidence thick-target experiments (GAMMASPHERE at ANL).

Reaction: ^{208}Pb + ^{238}U



B. F. et al., Phys. Rev. Lett. 87 (2001) | G. Lane et al., Nucl. Phys. A682 (2001) | G. Lane et al., Phys. Lett. B 606 (2005) | B. F. et al., Proc. Vietri Conf. (2010)

See talk by B. Fornal (EURORIB 2018)

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Deep-inelastic reactions: cross sections

PHYSICAL REVIEW C **89**, 054608 (2014)

Formation of light exotic nuclei in low-energy multinucleon transfer reactions

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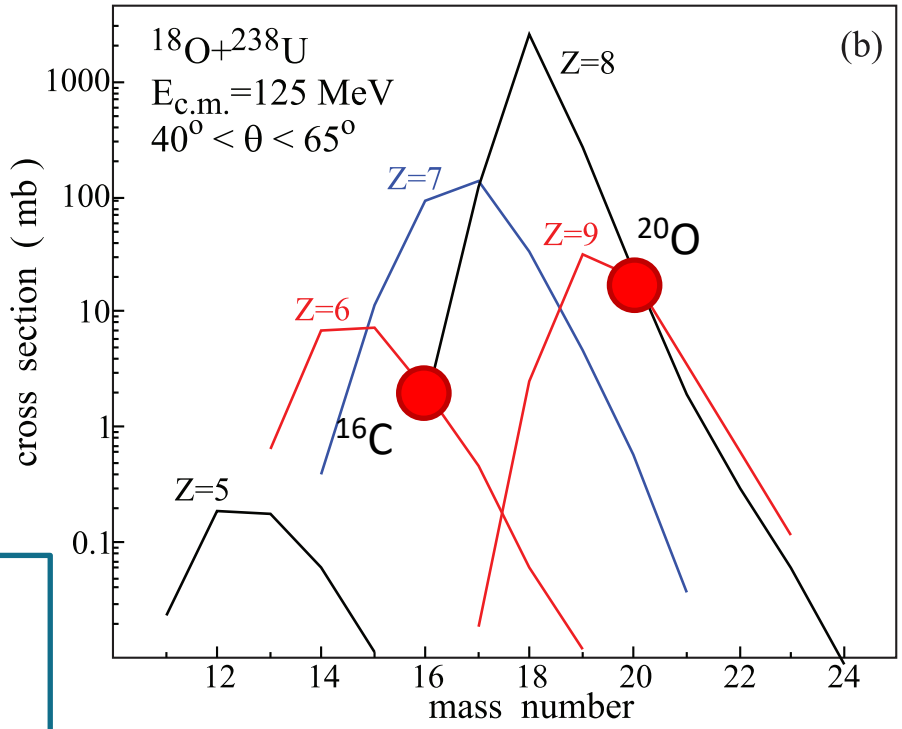
[2]*The Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland*
[3]*Dipartimento di Fisica, University of Milano, Milano, Italy*
[4]*Frankfurt Institute for Advanced Studies, J.W. Goethe-Universität, Frankfurt, Germany*
(Received 13 March 2014; published 9 May 2014)

- Coupled Langevin-type dynamical equations of motion
- Adiabatic multidimensional potential energy surface
- Friction coefficients, inertia parameters, N/Z equilibration, damping



Experiment E656 at GANIL with VAMOS+AGATA+PARIS (July 2017)

See talk by B. Fornal (EURORIB 2018)

Deep-inelastic reactions: cross sections

Physics Letters B 779 (2018) 456–459

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Neutron-rich nuclei produced at zero degrees in damped collisions induced by a beam of ^{18}O on a ^{238}U target

I. Stefan [a,*], B. Fornal [b], S. Leoni [c,d], F. Azaiez [a,1], C. Portail [a], J.C. Thomas [e], A.V. Karpov [i], D. Ackermann [e], P. Bednarczyk [b], Y. Blumenfeld [a], S. Calinescu [h], A. Chbihi [e], M. Ciemala [b], N. Cieplicka-Oryńczak [b,d], F.C.L. Crespi [c,d], S. Franchoo [a], F. Hammache [a], Ł.W. Iskra [b], B. Jacquot [e], R.V.F. Janssens [f,2], O. Kamalou [e], T. Lauritsen [f], M. Lewitowicz [e], L. Olivier [a], S.M. Lukyanov [i], M. Maccormick [a], A. Maj [b], P. Marini [g,3], I. Matea [a], M.A. Naumenko [i], F. de Oliveira Santos [e], C. Petrone [h], Yu.E. Penionzhkevich [i,k], F. Rotaru [h], H. Savajols [e], O. Sorlin [e], M. Stanoiu [h], B. Szpak [b], O.B. Tarasov [i,j], D. Verney [a]

PHYSICAL REVIEW C **96**, 024618 (2017)

Modeling near-barrier collisions of heavy ions based on a Langevin-type approach

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Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia and Dubna State University, 141982 Dubna, Russia
(Received 7 June 2017; published 23 August 2017)

Nuclear Physics **A524** (1991) 121–140
North-Holland

DEEP INELASTIC TRANSFERS

A way to dissipate energy and angular momentum for reactions in the Fermi energy domain

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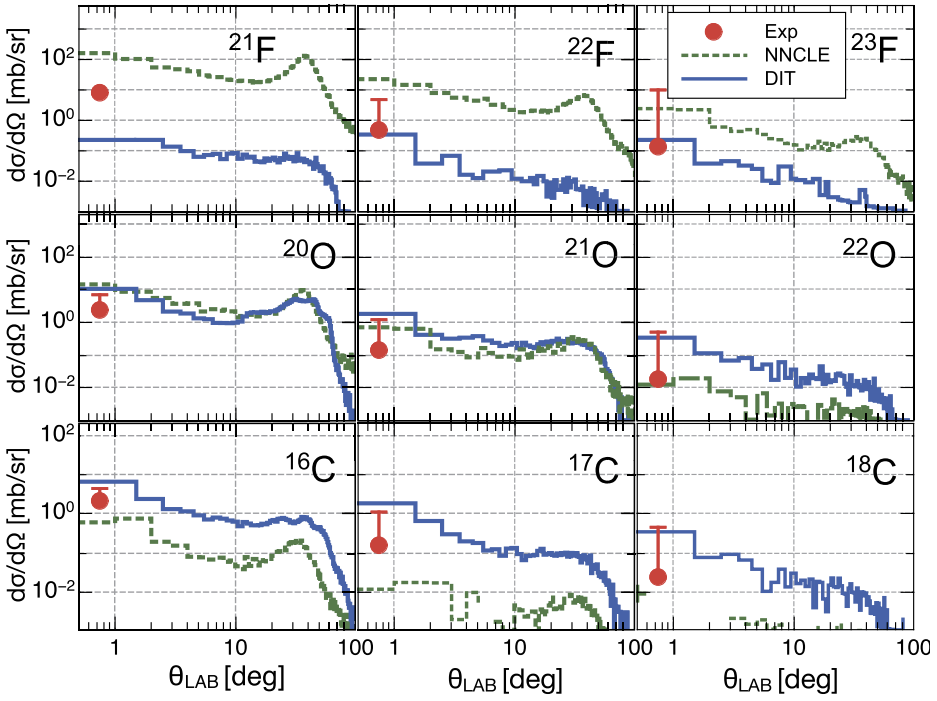
Institut de Physique Nucléaire 91406 ORSAY Cedex, France

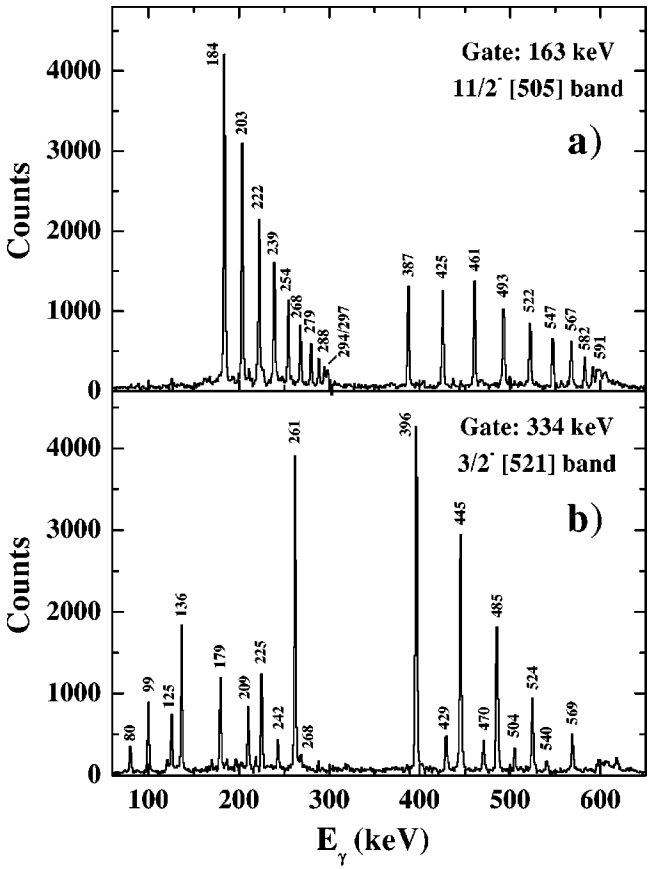
^{18}O+^{238}U at LISE



See talk by B. Fornal (EURORIB 2018)

Cluster-transfer reactions

- Selective, and
- Large angular momentum transfer



^{7}Li-induced reactions

G. D. Dracoulis et al., J. Phys. G: Nucl. Part. Phys. 23, 1191 (1997)
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A. Jungclaus et al., Phys. Rev. C 67, 034302 (2003)
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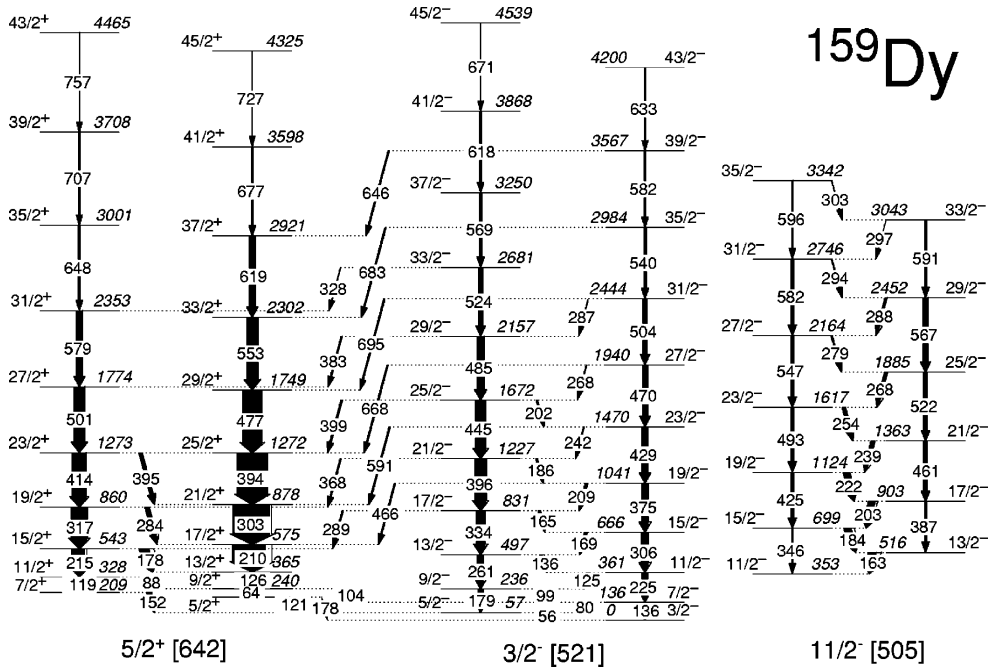
H. Watanabe et al., Phys. Rev. C 79, 024306 (2009)

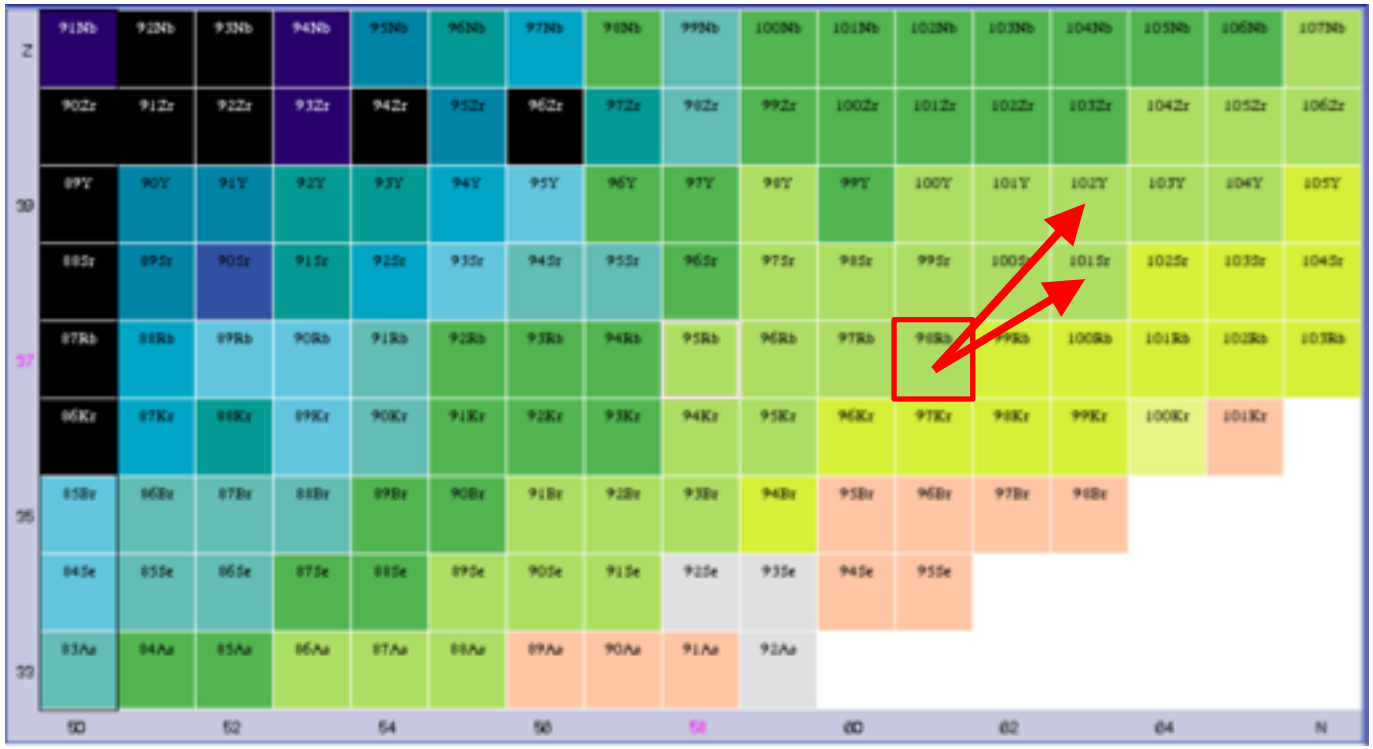


^{7}Li+^{98}Rb at REX-ISOLDE

PHYSICAL REVIEW C **92**, 024322 (2015)

Cluster-transfer reactions with radioactive beams: A spectroscopic tool for neutron-rich nuclei

S. Bottoni,[1,2,3,*] S. Leoni,[1,2,†] B. Fornal,[4] R. Raabe,[3] K. Rusek,[5] G. Benzoni,[2] A. Bracco,[1,2] F. C. L. Crespi,[1,2] A. I. Morales,[2] P. Bednarczyk,[4] N. Cieplicka-Oryńczak,[2,4] W. Królas,[4] A. Maj,[4] B. Szpak,[4] M. Callens,[3] J. Bouma,[3] J. Elseviers,[3] H. De Witte,[3] F. Flavigny,[3,6] R. Orlandi,[3,7] P. Reiter,[8] M. Seidlitz,[8] N. Warr,[8] B. Siebeck,[8] S. Hellgartner,[9] D. Mücher,[9] J. Pakarinen,[10] M. Vermeulen,[11] C. Bauer,[12] G. Georgiev,[13] R. V. F. Janssens,[14] D. Balabanski,[15] M. Sferrazza,[16] M. Kowalska,[17] E. Rapisarda,[17] D. Voulot,[17] M. Lozano Benito,[17] and F. Wenander[17]



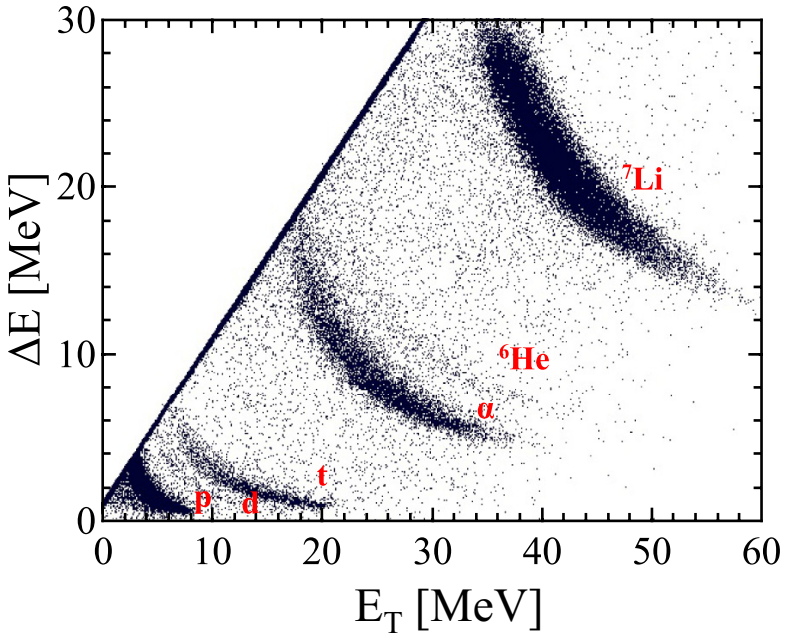
^{98}Rb beam
2.85 MeV/nucleon
2x10^{4} pps
≈1/3 ^{98}Sr contaminant

^{7}Li target (LiF)
1.5 mg/cm^{2}

Detection:
Miniball + CD

Observed channels

- Products flying forward
  → Doppler correction does not need recoil detection
- Detection of α or t
  → identification of channel

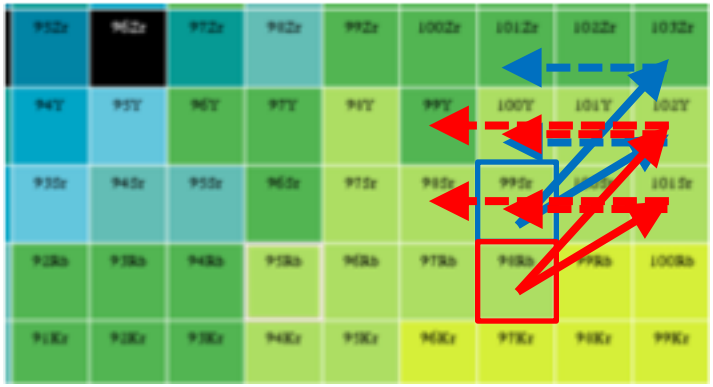


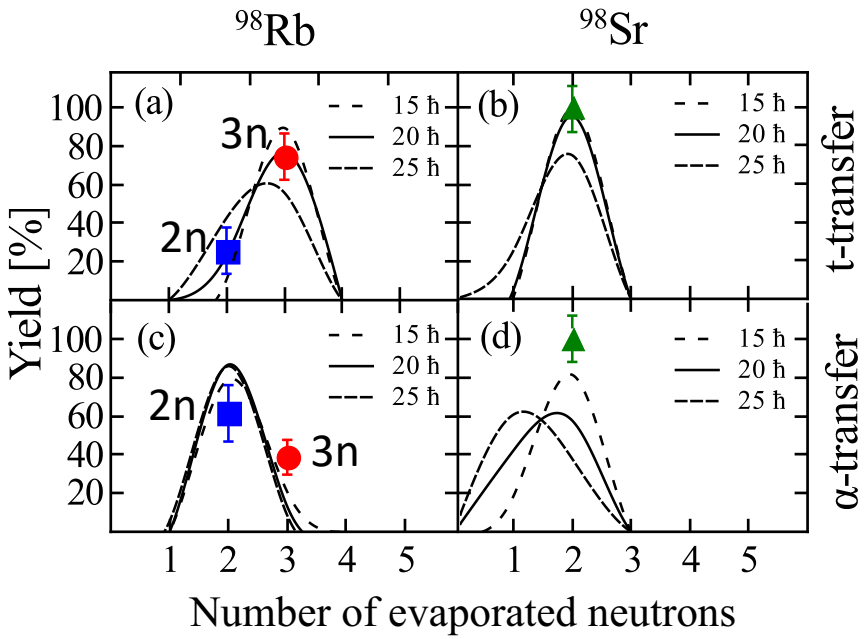
Observed

- Elastic and inelastic
- α and t transfer
- [^{7}Li direct break-up]
- 1n-stripping + break-up
- 1p-stripping
- Fusion (^{105}Zr) -evaporation to ^{100}Zr

Cluster transfer: populated nuclei

(MeV)	t transfer	α transfer
Q_{gg}	13.6	7.6
Q_{opt}	−5.1	−10.4
E^*_{opt}	18.7	18
S.E.	16	10



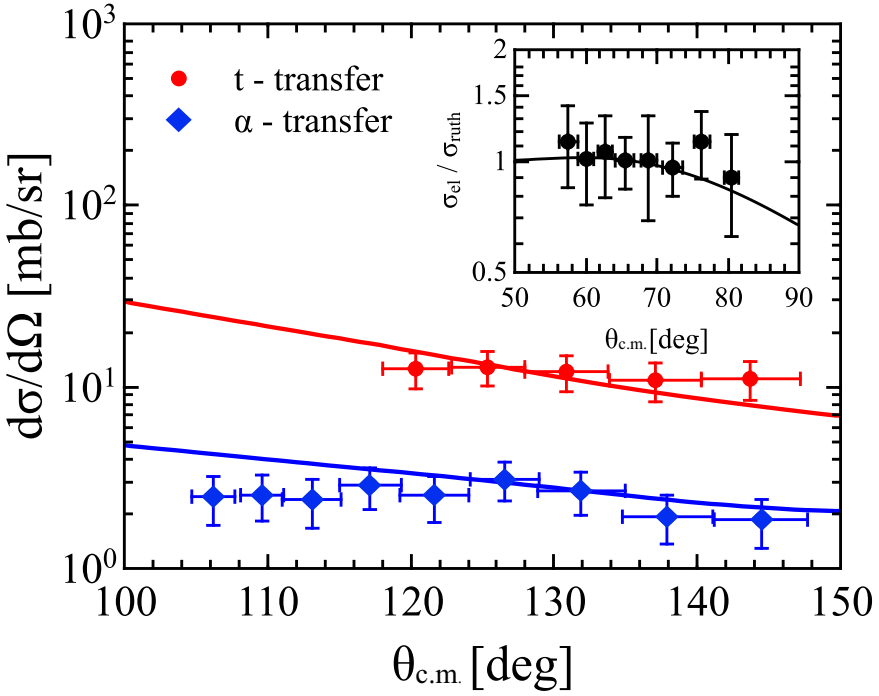


From Cascade:

- Spin in product
  ≈20$\hbar$ for t transfer
  ≈15$\hbar$ for α transfer
- E*, spin in residues
  6 MeV, 16$\hbar$ for 2n
  2 MeV, 9.5$\hbar$ for 3n

Cross sections

- Model: binary process,
  direct transfer of a particle
- Ingredients:
  - optical potentials
    (^{7}Li+^{98}Rb, α+^{101}Sr, t+^{102}Y)
  - models for structure
    → clusters for ^{7}Li and final nuclei
  - binding potentials
    gaussian for ^{7}Li, WS for final nuclei
- Population of states in the continuum:
  <u>weakly-bound approximation</u>
  1-step DWBA with ℓ up to 5



Cross sections

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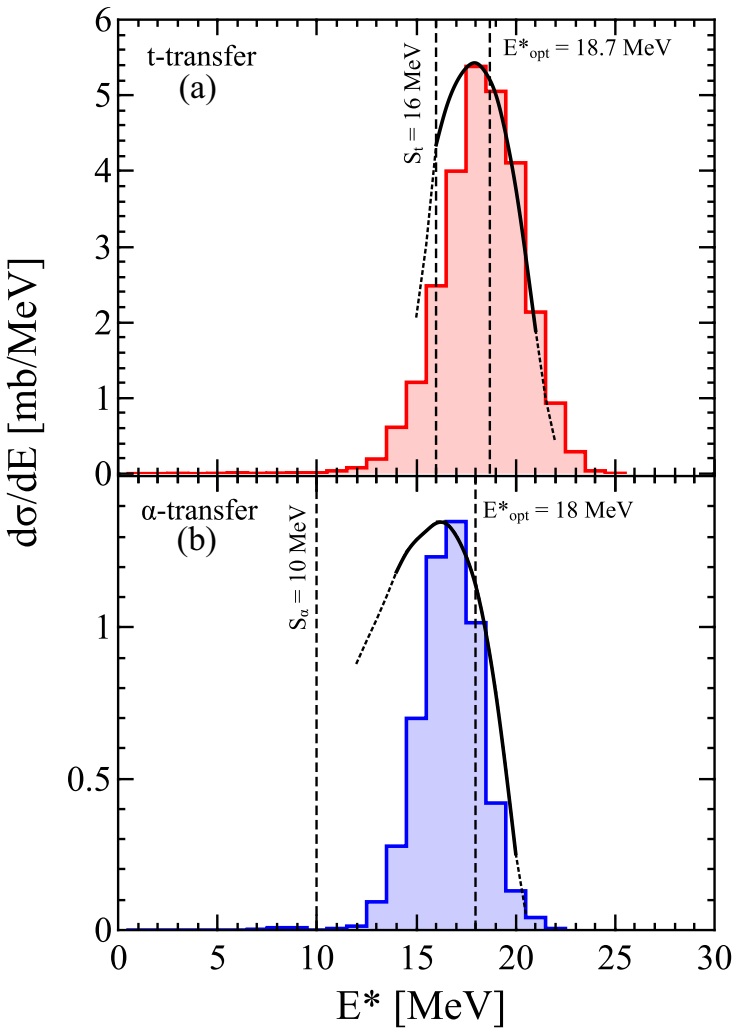
    gaussian for ^{7}Li, WS for final nuclei
- Population of states in the continuum:
  <u>weakly-bound approximation</u>
  1-step DWBA with ℓ up to 5

Satisfactory description of the process in terms of a direct transfer

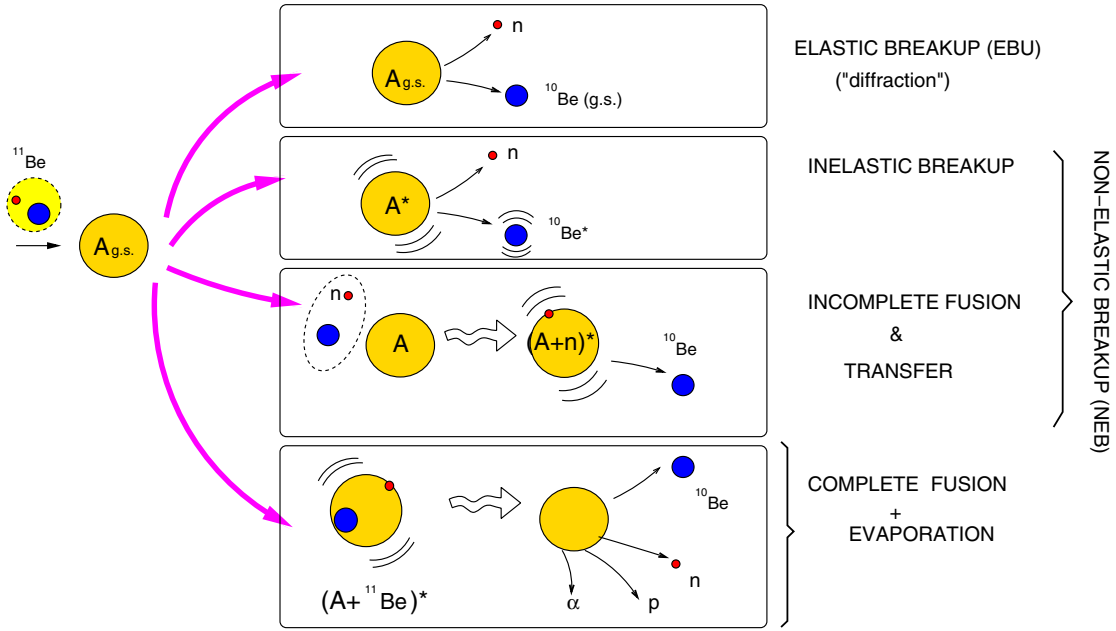


Calculations of α yields: J. Lei & A. Moro

PHYSICAL REVIEW C **95**, 044605 (2017)

Comprehensive analysis of large α yields observed in ^{6}Li-induced reactions

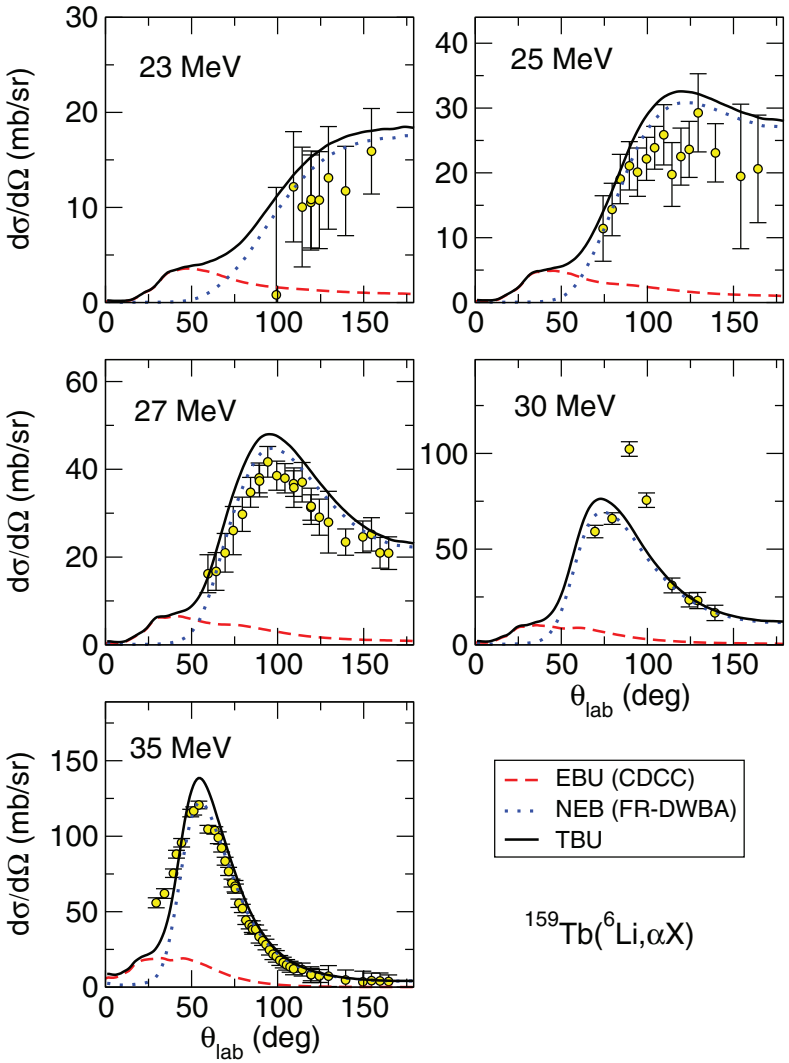
Jin Lei* and Antonio M. Moro†
Departamento de FAMN, Universidad de Sevilla, Apartado 1065, 41080 Sevilla, Spain

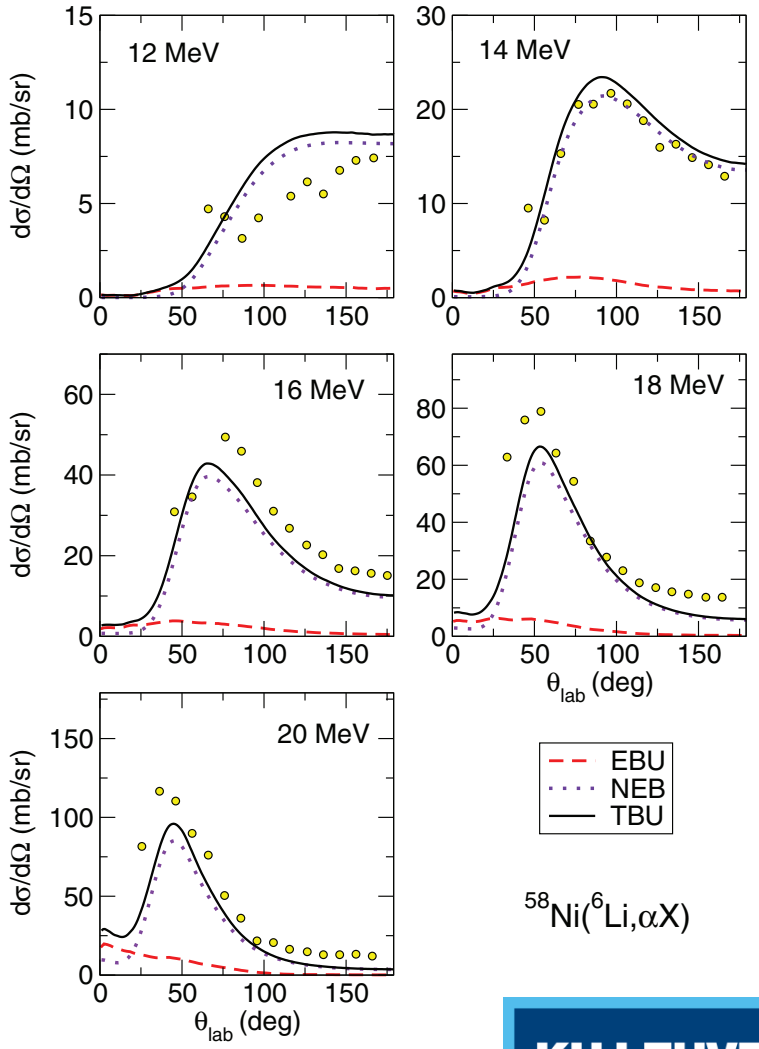


- EBU in CDCC
- NEB in DWBA (Ichimura, Austern, and Vincent model): transfer to the continuum (complex potential) extended to bound states

Calculations of α yields: J. Lei & A. Moro

α yields: dominated by NEB





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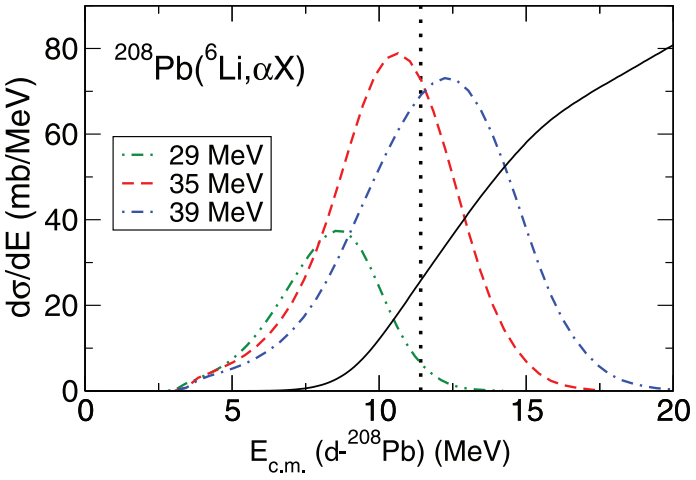
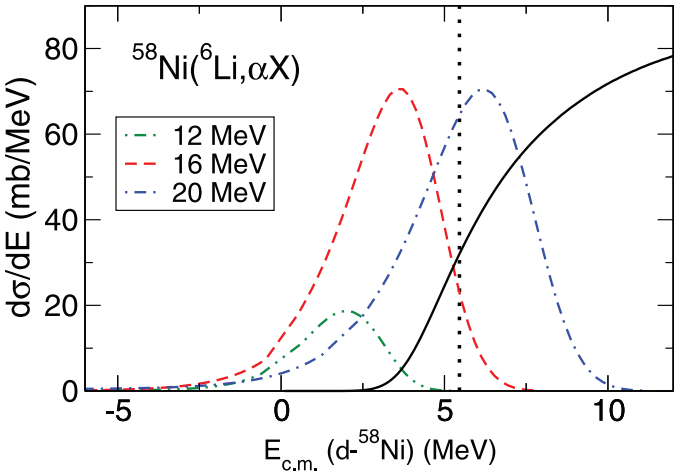
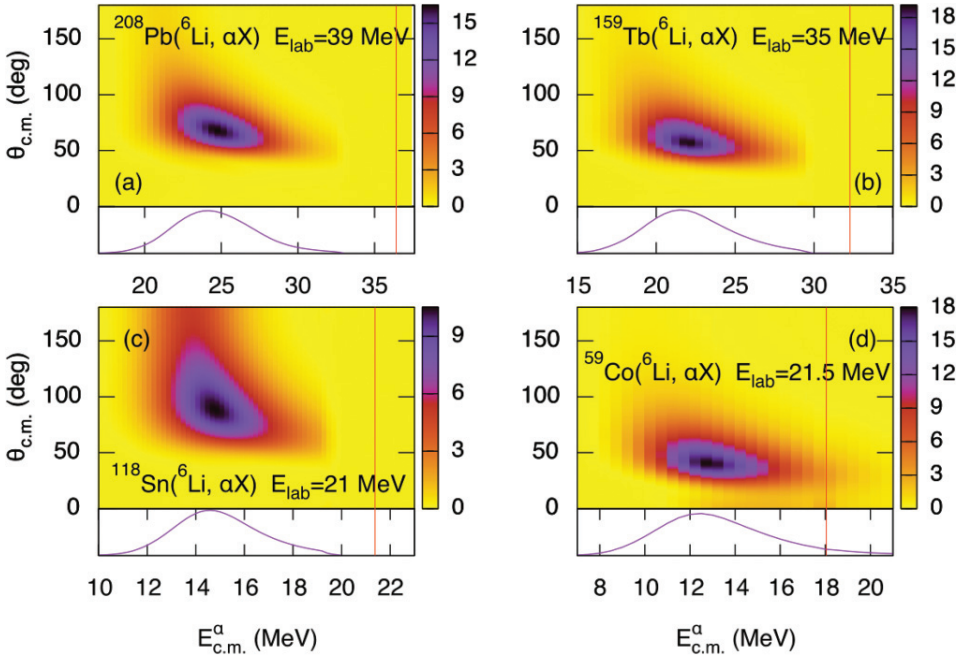
Calculations of α yields: J. Lei & A. Moro







- Very good agreement with data
- Prediction of cross sections in function of E*
  Angular distributions

Summary

- Multinucleon transfer reactions:
  tool to produce & study nuclei, otherwise difficult to access
- Large angular momentum transfer
  → population of high-spin states
- Cluster-transfer reactions:
  - selectivity
  - experimentally “easy”
- Cross sections interpreted in the frame of direct transfer
  Now with predictive power