Multinucleon transfer reactions and proton transfer channels

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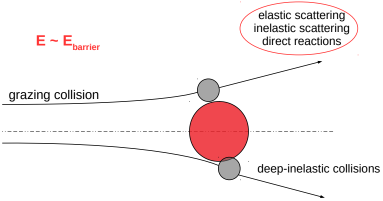
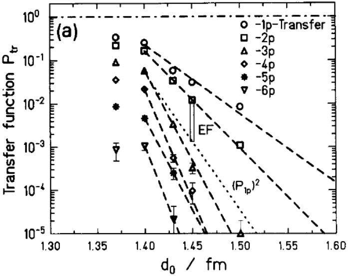
Multinucleon transfer reactions and pair transfers

- Two-particle transfer processes are an ideal tool to study the dynamical aspects of pairing correlations
- **Heavy ion transfer reactions:**
  - **Advantages:** simultaneous comparison of $\pm$nn, $\pm$pp and $\pm$np pairs; transfer of "many" pairs
- **Enhancement coefficients:** the ratio of the actual cross section to the prediction of models using uncorrelated states
  - **Drawbacks:** all existing studies involve inclusive cross sections at energies higher than the Coulomb barrier and at angles forward of the grazing

L. Corradi, G. Pollarolo, S. Szilner, J. Phys. G 36 (2009) 113101





J. Speer et al, PLB 259 (1991) 4

Reactions above the barrier

- many open channels - transfer process governed by:
  - optimum Q-value
  - nuclear structure properties

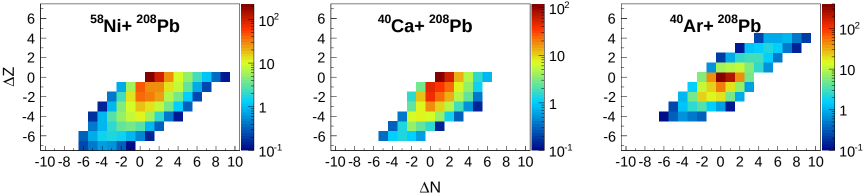
Change of population pattern from neutron-poor to neutron-rich projectiles

Open channels for **stable projectiles:**

- p stripping (-xp)
- n pick-up (+xn)

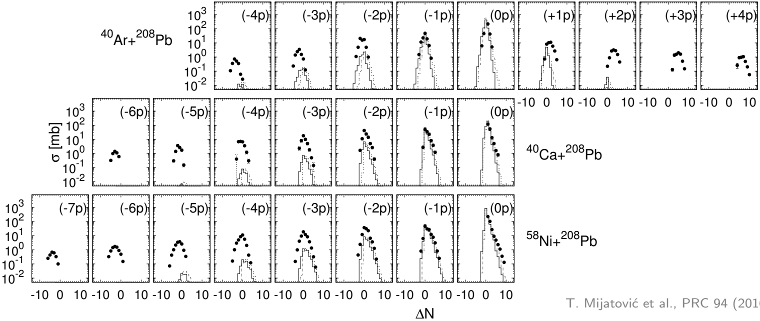
Open channels for **n-rich projectiles:**

- p pick-up (+xp)
- n stripping (-xn)



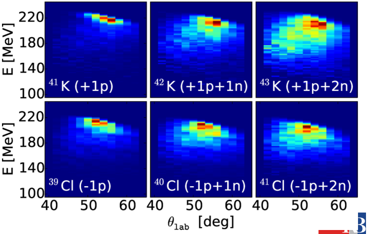
T. Mijatović et al., PRC 94 (2016) 064616

Reactions above the barrier: QE and DIC

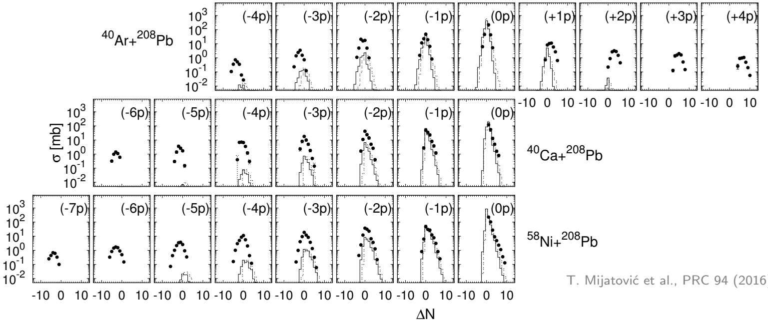


T. Mijatović et al., PRC 94 (2016) 064616

- heavy ions: presence of both QE and DIC components
- large TKEL more important for p transfer channels
- secondary processes may play a major role in the final mass distribution



Reactions above the barrier: QE and DIC



T. Mijatović et al., PRC 94 (2016) 064616

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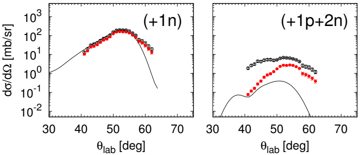
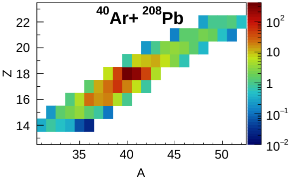
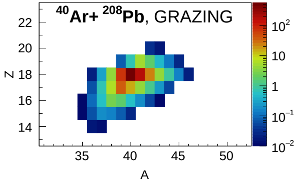
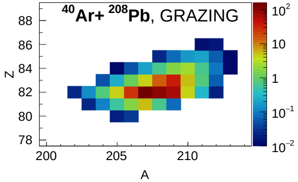


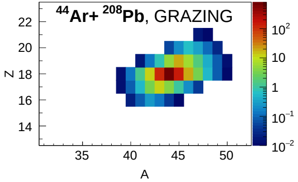
Heavy partner

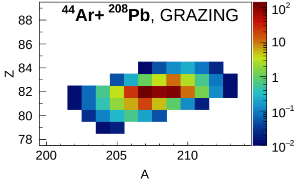






- light partner: **+p-n** channels
- heavy partner: **-p+n** channels





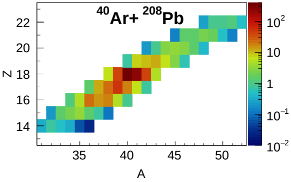
see Poster No. 151

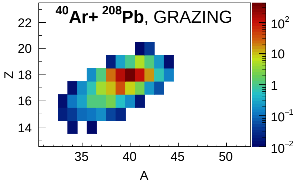
new opportunities with radioactive beams: ^{94}Rb+^{208}Pb, 6.2 MeV/A

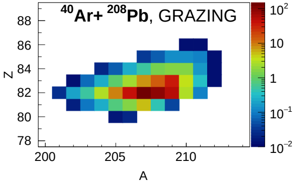
Study of the neutron-rich region in the vicinity of ^{208}Pb via multinucleon transfer reactions

Petra Čolović (RBI, Zagreb, Croatia)

Heavy partner







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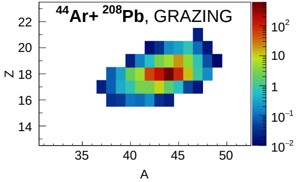

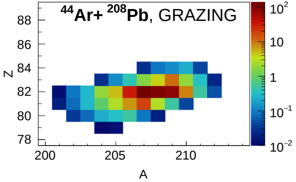

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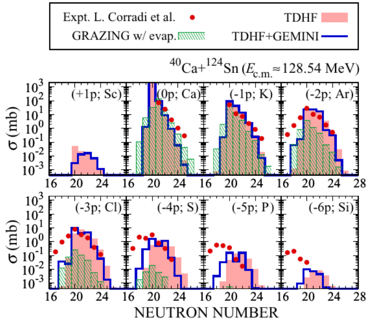
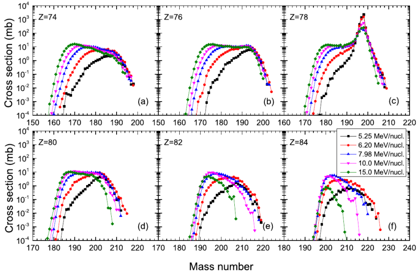
Other calculations



K. Sekizawa and K. Yabana, PRC 88 (2013) 014614



Cheng Li, et al., PRC 99 (2019) 024602

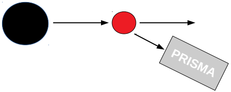
- TDHF: previous talk by **K. Sekizawa**
  C. Simenel, A.S. Umar, Progress in Part. and Nucl. Phys. 103 (2018) 19, K.Sekizawa PRC 96 (2017) 014615
- Langevin-type approach: next talk by **V. Saiko**
  V. Zagrebaev, W. Greiner PRL 101 (2008) 122701; PRC 83 (2011) 044618; A.V.Karpov and V.V.Saiko, PRC 96 (2017) 024618
- quantum molecular dynamics model
  Cheng Li, et al., PRC 99 (2019) 024602
- experimentally important to disentangle different effects (DIC and evaporation) to be able to understand proton transfer channels

Reactions below the Coulomb barrier

Advantages:
- reduced number of open channels
- very narrow Q-value distributions: no evaporation effects
- probe nucleon-nucleon correlations as close as possible to the ground to ground states

However, there are problems:
- cross sections very small for transfer channels
- angular distributions are backward peaked
- direct kinematics $\Longrightarrow$ low kinetic energy $\Longrightarrow$ difficult identification in A, Z and Q-value

Reactions below the Coulomb barrier



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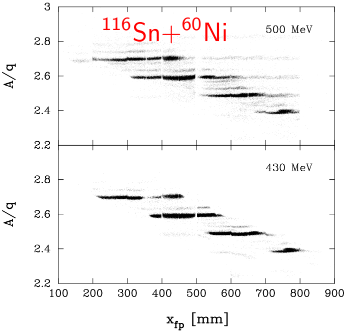
Solution - inverse kinematic measurements:
- forward focused $\Longrightarrow$ high detection efficiency
- high kinetic energy $\Longrightarrow$ good energy and mass resolution



- background free spectra

$\rightarrow$ ratio of transfer channel to elastic channel to 10^{-4}

Proton channels below the barrier

- proton pair transfer studies so far performed **above** the Coulomb barrier
- experimental data very scarce - cross sections drop off rapidly
- large modification in the trajectories of entrance and exit channels due to the modification of the Coulomb field
- the single-particle level density less studied and the corresponding single-particle form factors less known
- theoretically very challenging to reproduce

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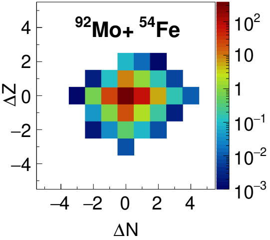
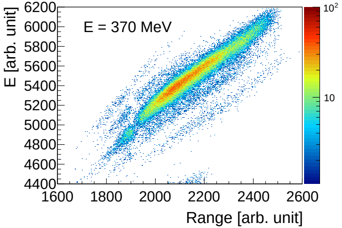
^{92}Mo+^{54}Fe

proton-rich system

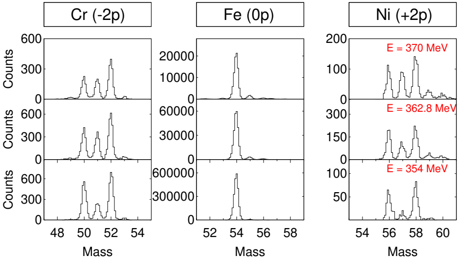
$E_{\mathrm{lab}} = 340 - 370$ MeV

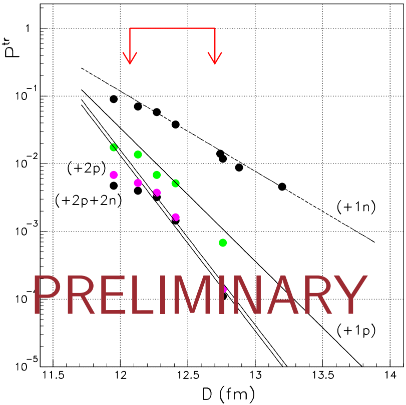
$\theta_{\mathrm{lab}} = 22^{\circ}$





^{92}Mo+^{54}Fe masses and transfer probabilities

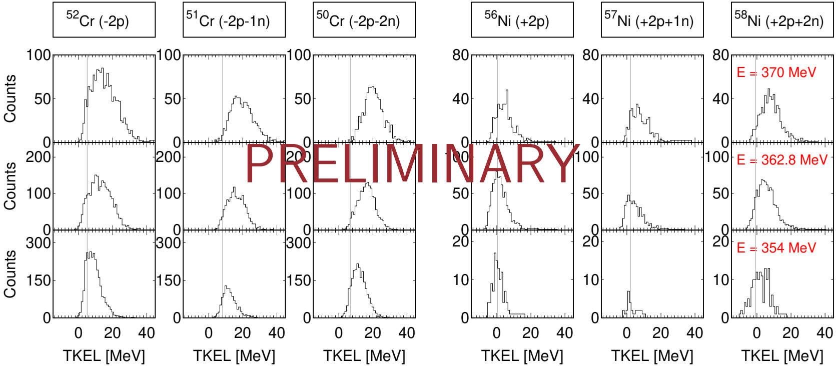




- mass distribution at different bombarding energies
- the yield of the 2p transfer channels are similar to those of the 2p+2n transfer channel
- the cross sections derived by integrating the whole TKEL distributions

TKEL

- below the barrier TKEL gets more narrow and closer to the Q_{gs}

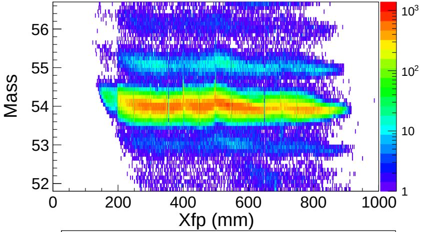


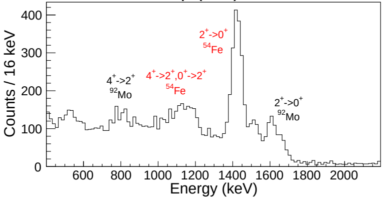
γ-particle coincidences

New measurement: *Nucleon-nucleon correlations in $^{54}Fe+^{92}Mo$ probed via γ-particle coincidences*

PRISMA+LaBr$_3$ array

$E_{\mathrm{lab}} = 230$ MeV, $\theta_{\mathrm{lab}} = 62^\circ$





will be used to extract the strength distribution for different isotopes

analysis ongoing

Summary

- Transfer reactions with heavy ions are a powerful tool to investigate reaction mechanism and structure properties of nuclei.
- Transfer of several nucleons at the same time - possibility to study relative role of transfer of one particle and pair.
- Better understanding of proton transfer channels crucial.
- Results need to be corroborated with population strength of excited states.
- New challenges: Pair transfer channels - radioactive beams with SPES
  - Nuclear properties of the very neutron rich regions, where shell evolution is an open question.
  - How pairing interaction is modified in the nuclear medium - inputs by measurements of nucleon transfer reactions to specific nuclear states.

Thank you!

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