The influence of the 2-neutron elastic transfer on the fusion of $^{42}Ca + ^{40}Ca$

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Several measurements exploited the concept of a fusion barrier distribution, to identify the nature of couplings responsible for cross section enhancements

double-closed shell

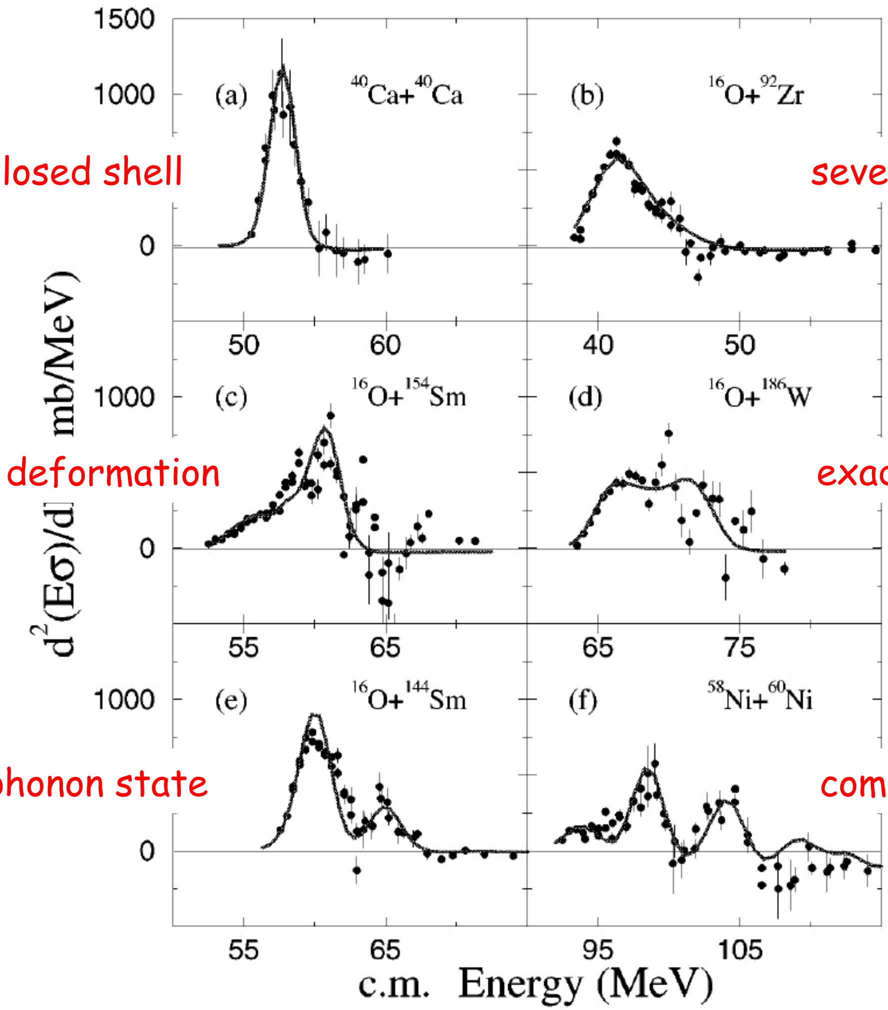
several phonon couplings

prolate deformation

exadecapole deformation $\beta_4<0$

target phonon state

complex surface vibrations

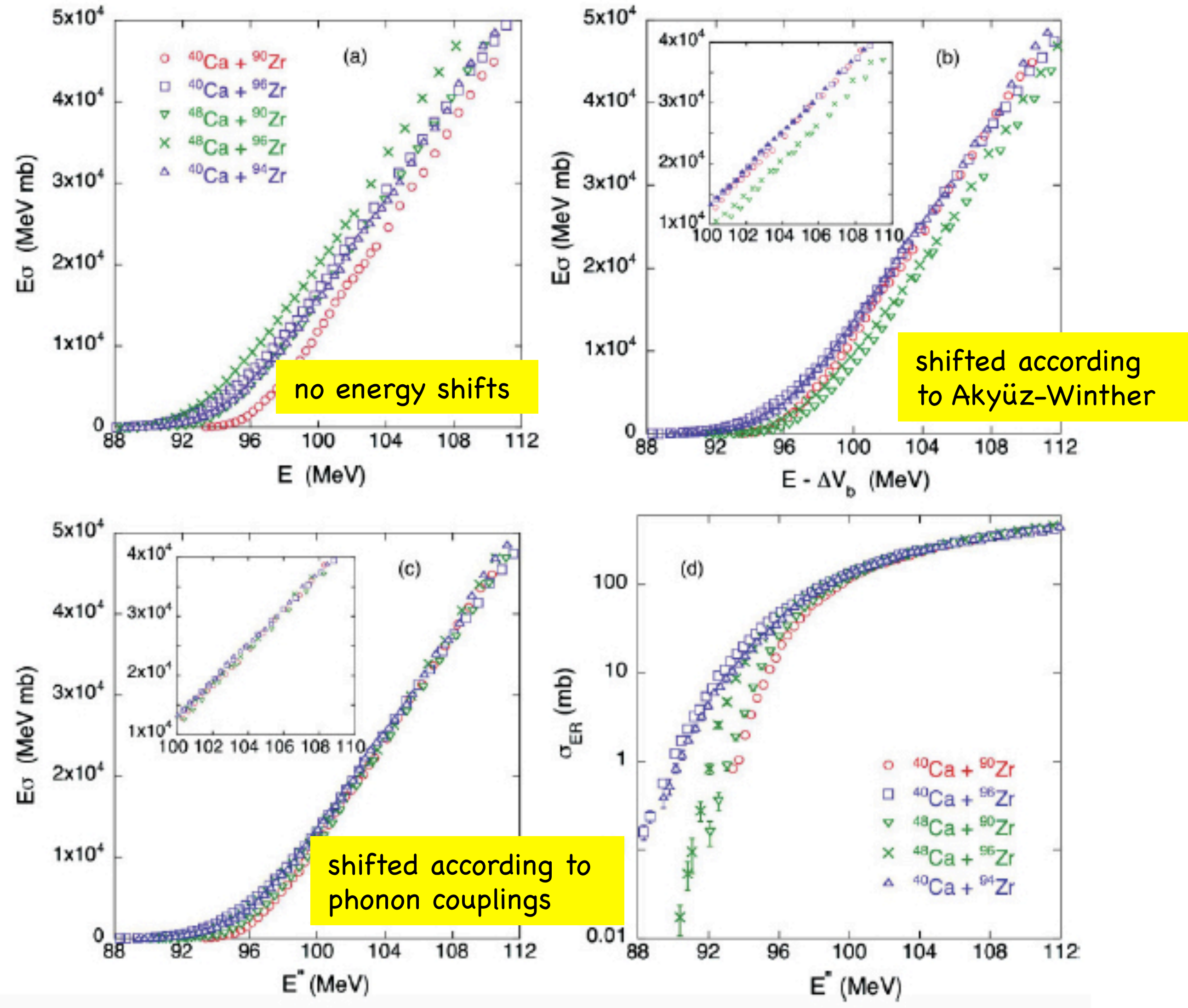


M.Dasgupta e al., Annu. Rev. Nucl. Part. Sci. 48, 401 (1998)

… but identifying the effect of coupling to transfer channels has often been elusive, when deduced from comparing with calculations.

Coupling to transfer is clear only in the cases where the experimental evidence is conclusive in itself.

Transfer couplings in the Ca + Zr systems



A.M.S. et al., PRC 76, 014610 (2007)

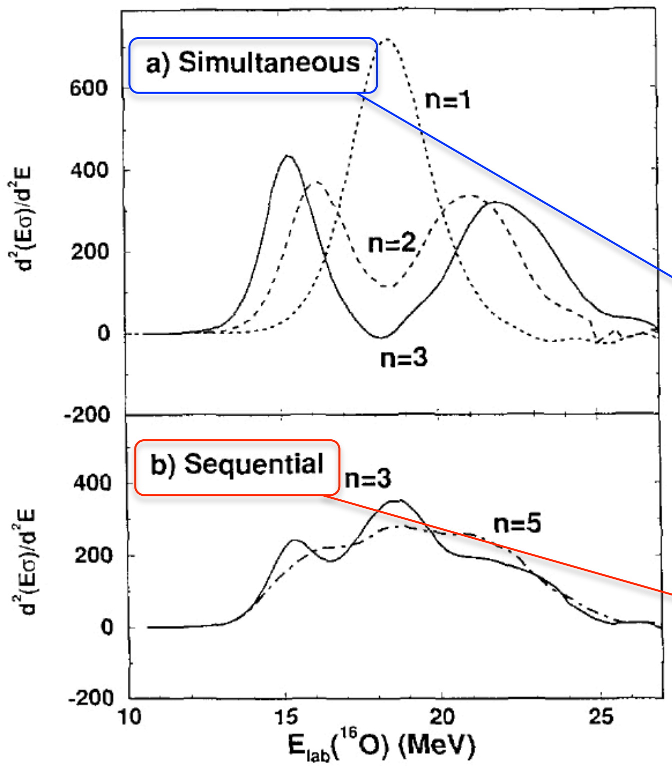
A particular case

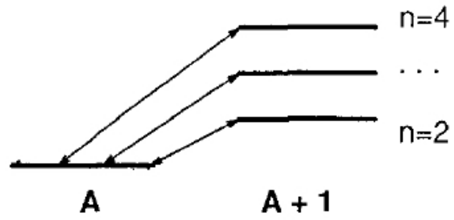
A striking fusion barrier distribution is predicted for strong coupling to a single channel with zero Q-value.

One expects a roughly symmetric distribution with **two peaks**, one on each side of the original uncoupled Coulomb barrier.

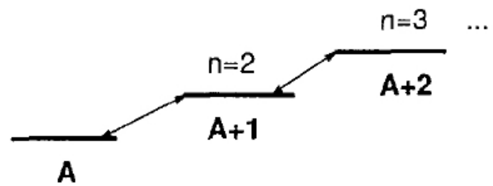
Simultaneous and sequential transfer with Q=0

(model calculations using the code FRESCO)





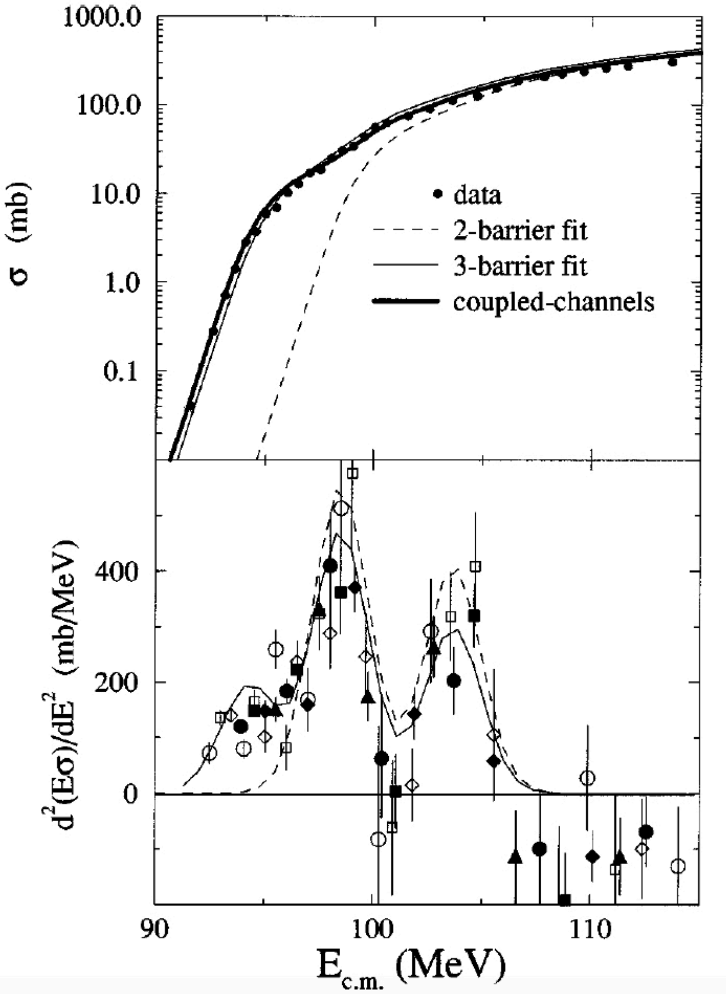
Two peaks for any number of simultaneous transfer channels



The number of peaks is equal to the number of channels

N. Rowley, I.J. Thompson and M.A. Nagarajan, PLB 282 (1992) 276

The investigation of $^{58}Ni+^{60}Ni$ was performed to evidence the coupling to the 2-neutron elastic transfer channel

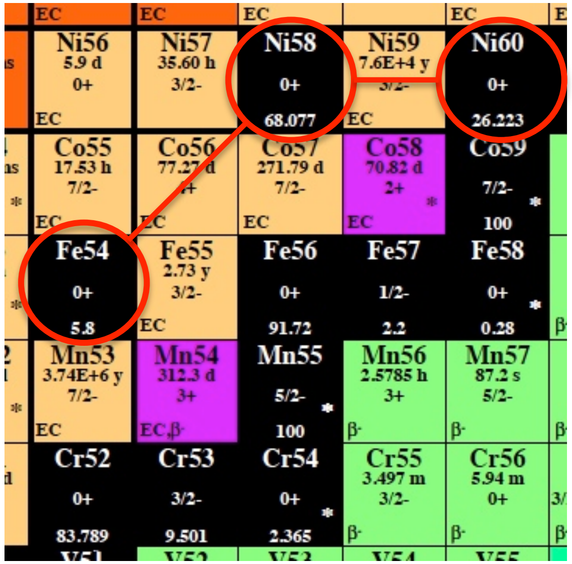


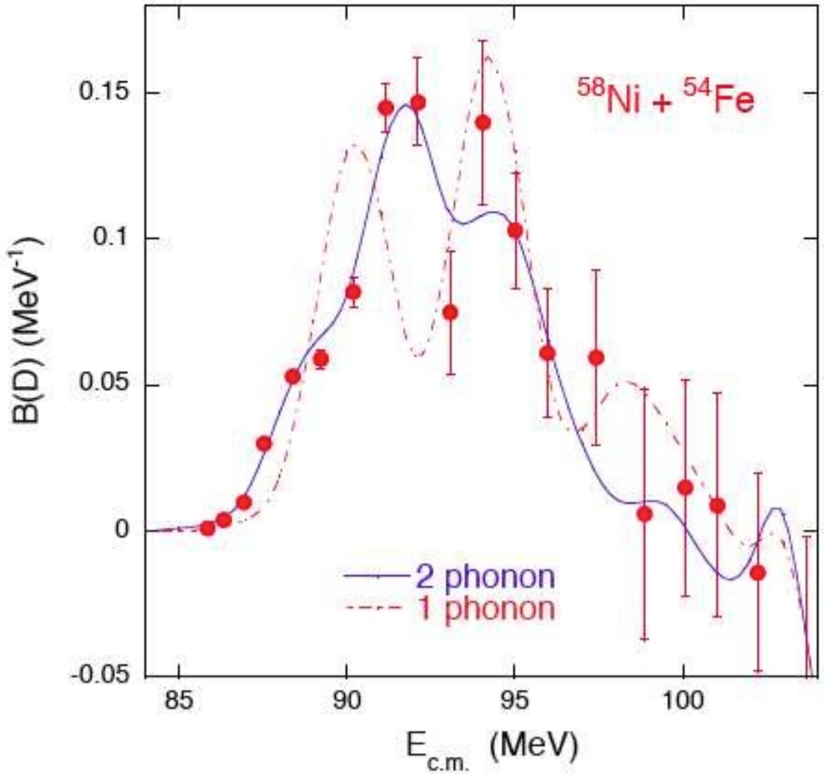
... but the barrier distribution with several well-defined peaks could only be explained by multi-phonon couplings !

the effect of 2n elastic transfer was found to be relatively unimportant

A.M.S. et al., PRL 74, 864 (1995)

The barrier distribution of ^{58}Ni + ^{54}Fe





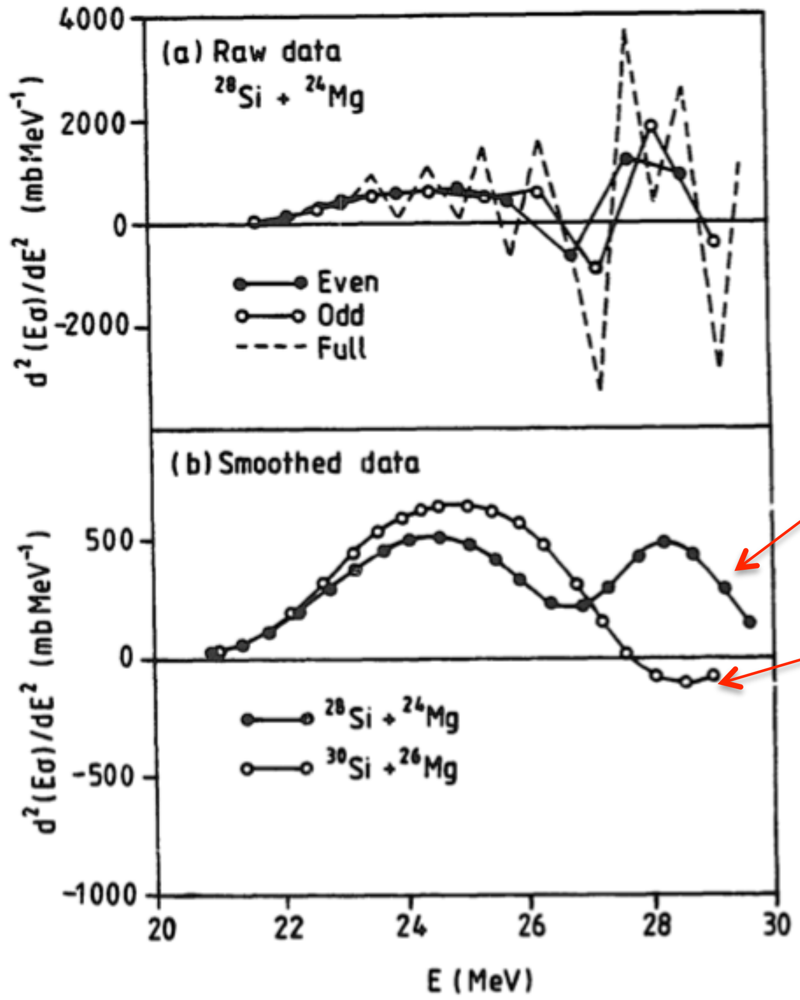
The complex structure closely resembles the BD of ^{58}Ni + ^{60}Ni, and it is nicely reproduced by CC calculations.

The fusion dynamics is dominated by low-energy surface modes.

Little space is left for the possible influence of the alpha-elastic transfer.

A two-peak distribution in ^{28}Si + ^{24}Mg, as the consequence of elastic alpha transfer ?

N.Rowley, Nucl.Phys. A538, 205c (1992)
data from A.Morsad et al., PRC 41, 988 (1990)



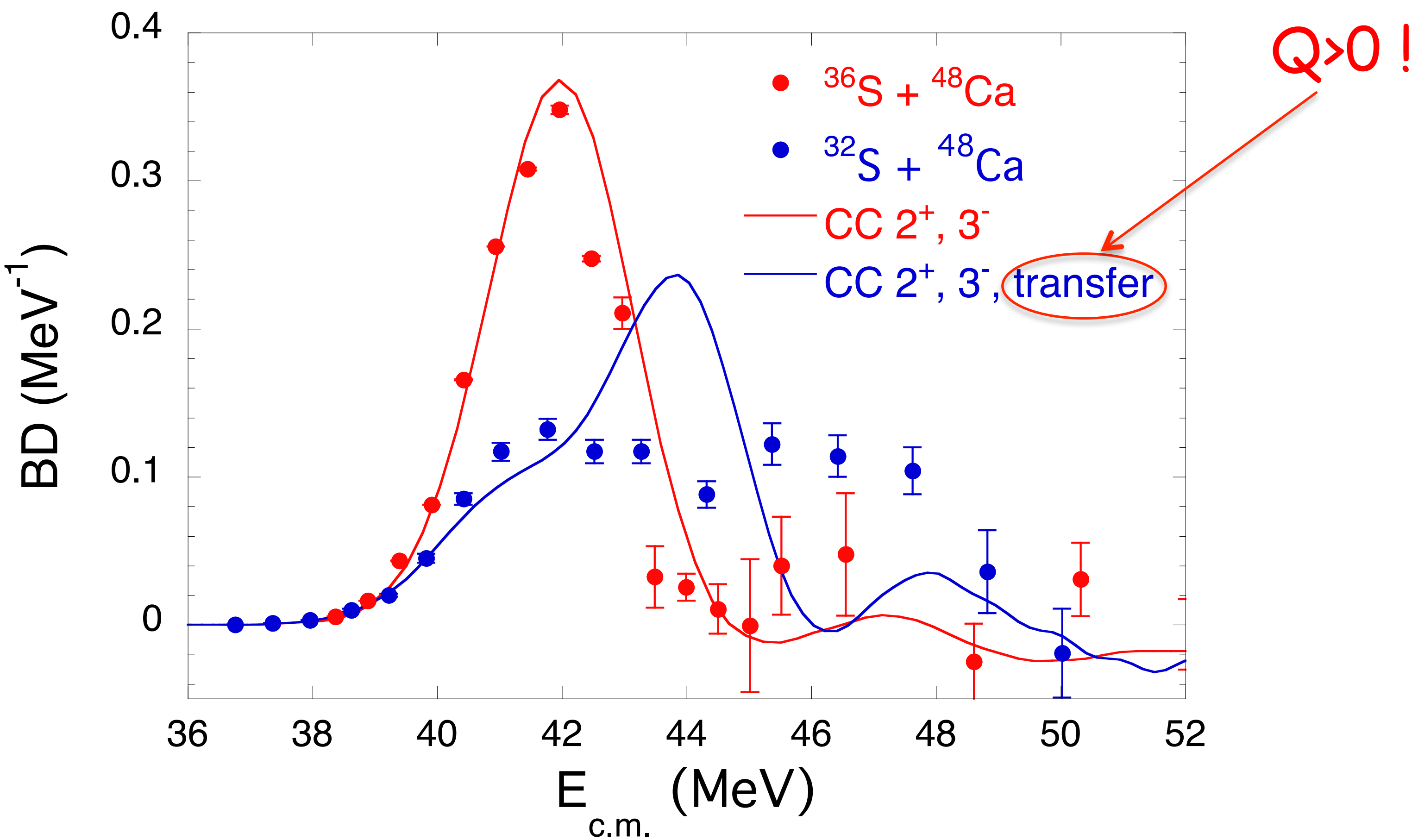
^{28}Si + ^{24}Mg

^{30}Si + ^{24}Mg

A clear case of a symmetric distribution with two peaks has never been observed, probably because low-lying surface vibrations have a dominant role in most systems.

Fusion barrier distributions of $^{32,36}S + ^{48}Ca$

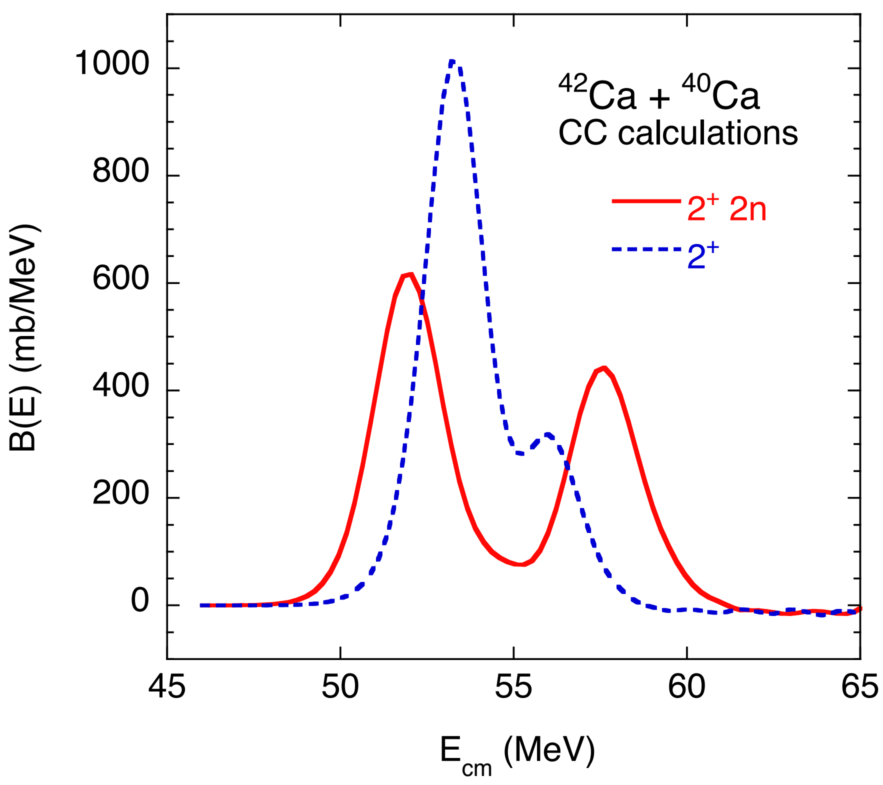
Strong transfer couplings produce a wide and flat barrier distribution, even if Q≠0

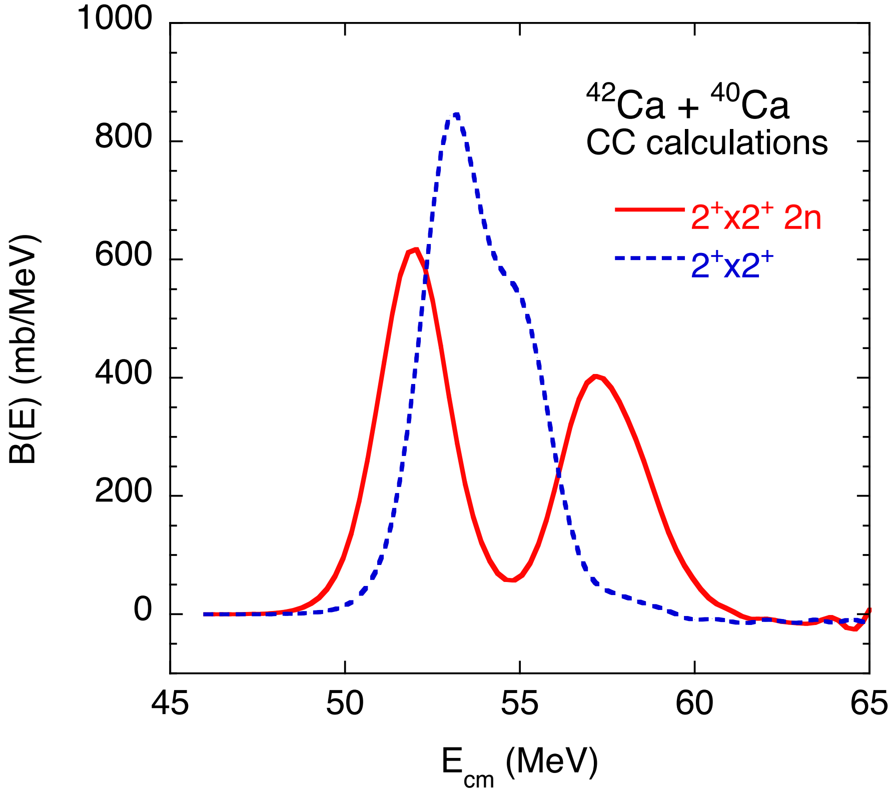


G.Montagnoli et al., PRC 87, 014611 (2013)

We decided to investigate the case of ^{42}Ca + ^{40}Ca

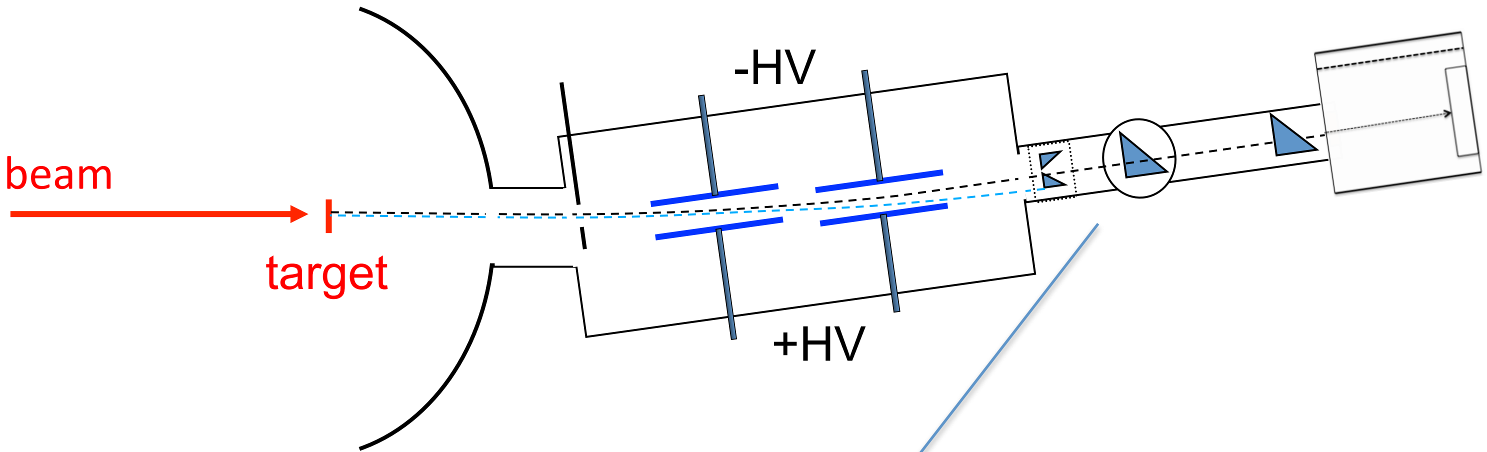
the chance to observe a two-peak B(E) largely depends on the coupling strength of the 2n elastic transfer, which is actually unknown.

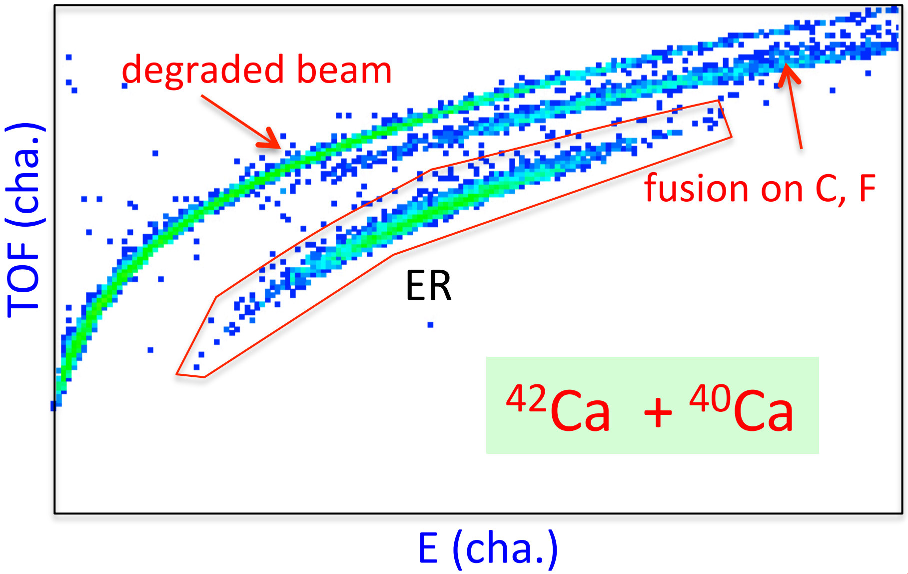


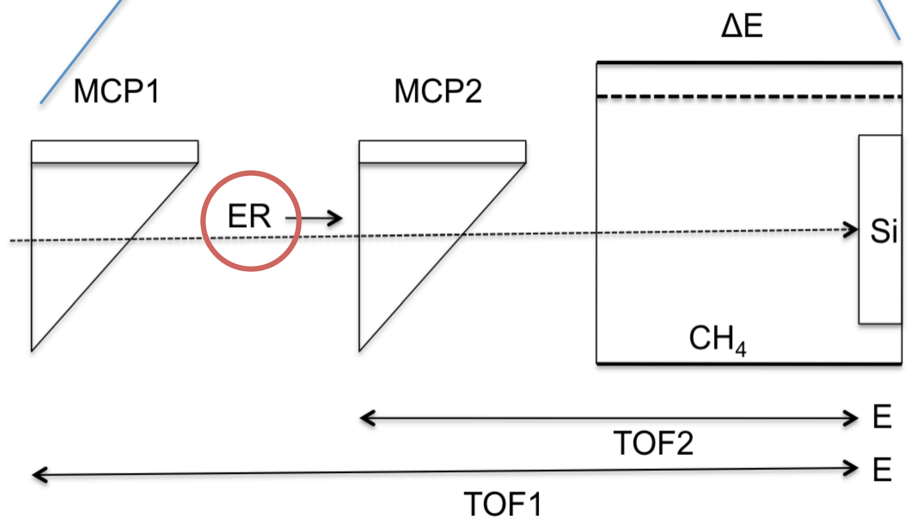


- *CC calculations including the quadrupole mode of ^{42}Ca, and the 2-neutron elastic transfer channel.*
- do the high-energy 3^- states simply renormalize the potential and "rigidly" shift the B(E) ?

The electrostatic beam deflector and the detector telescope at LNL

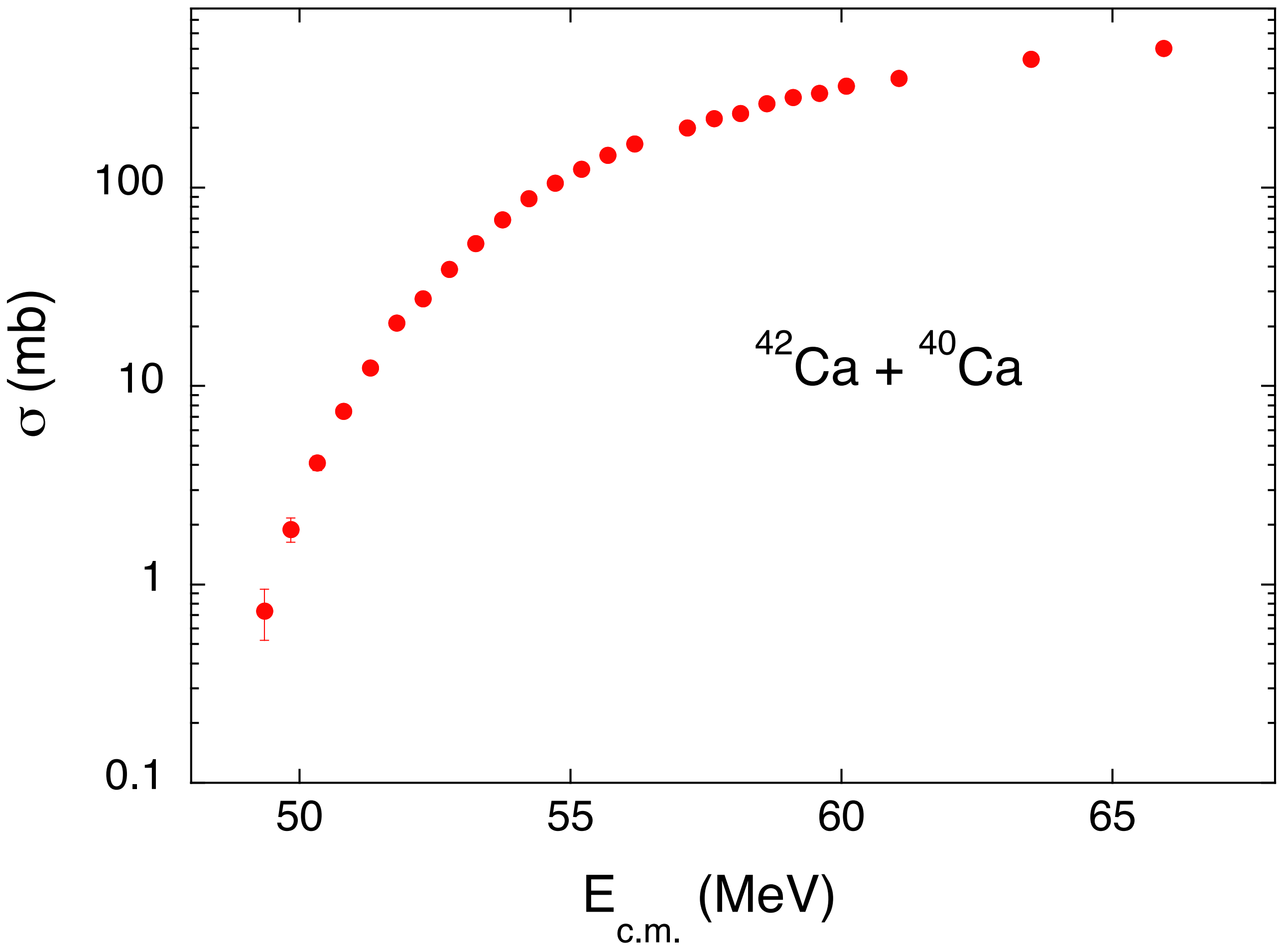




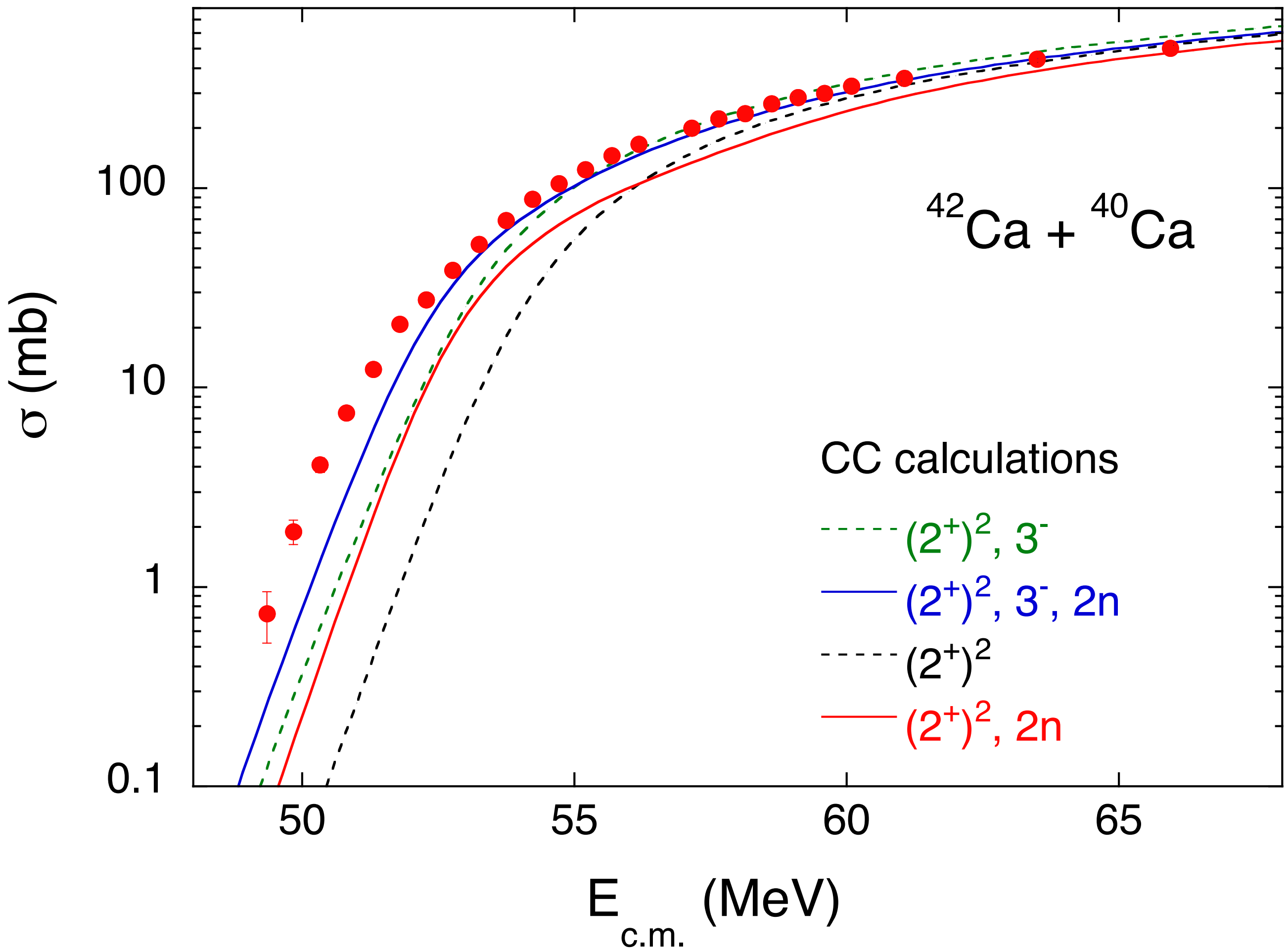


(lowest measurable cross section ≈ 0.5-1 μb)

The measured fusion excitation function



The measured fusion excitation function compared to CC calculations



Woods-Saxon potential

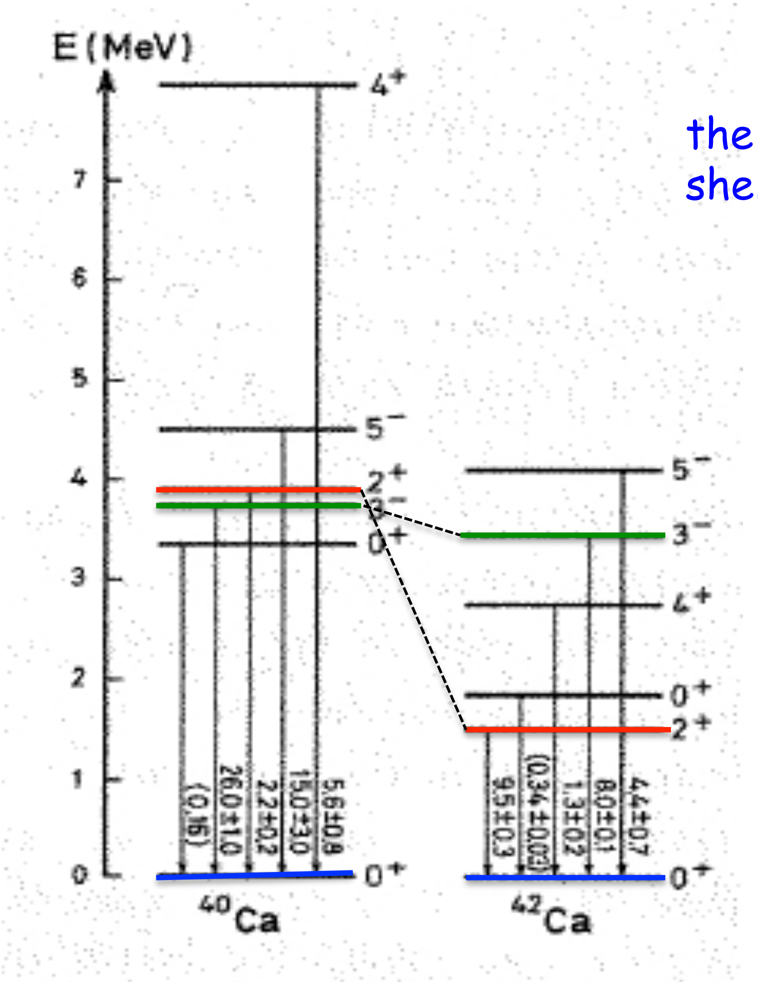
V_0 = 88.71 MeV
r_0 = 1.14 fm
a = 0.65 fm

This gives a barrier

V_b = 54.4 MeV
R_b = 9.85 fm

(very near to the Akyüz Winther barrier)

The low-lying structure of ^{40}Ca and ^{42}Ca



the two neutrons of ^{42}Ca occupy the $1f_{7/2}$ and $2p_{3/2}$ shells above the magic numbers Z=N=20

	I^{π}	E_x(MeV)	β_C	β_N
^{40}Ca	2+	3.905	0.12	0.11
	3-	3.747	0.41	0.28
^{42}Ca	2+	1.525	0.25	0.19
	3-	3.447	0.30	0.16

The schematic two-neutron transfer form-factor

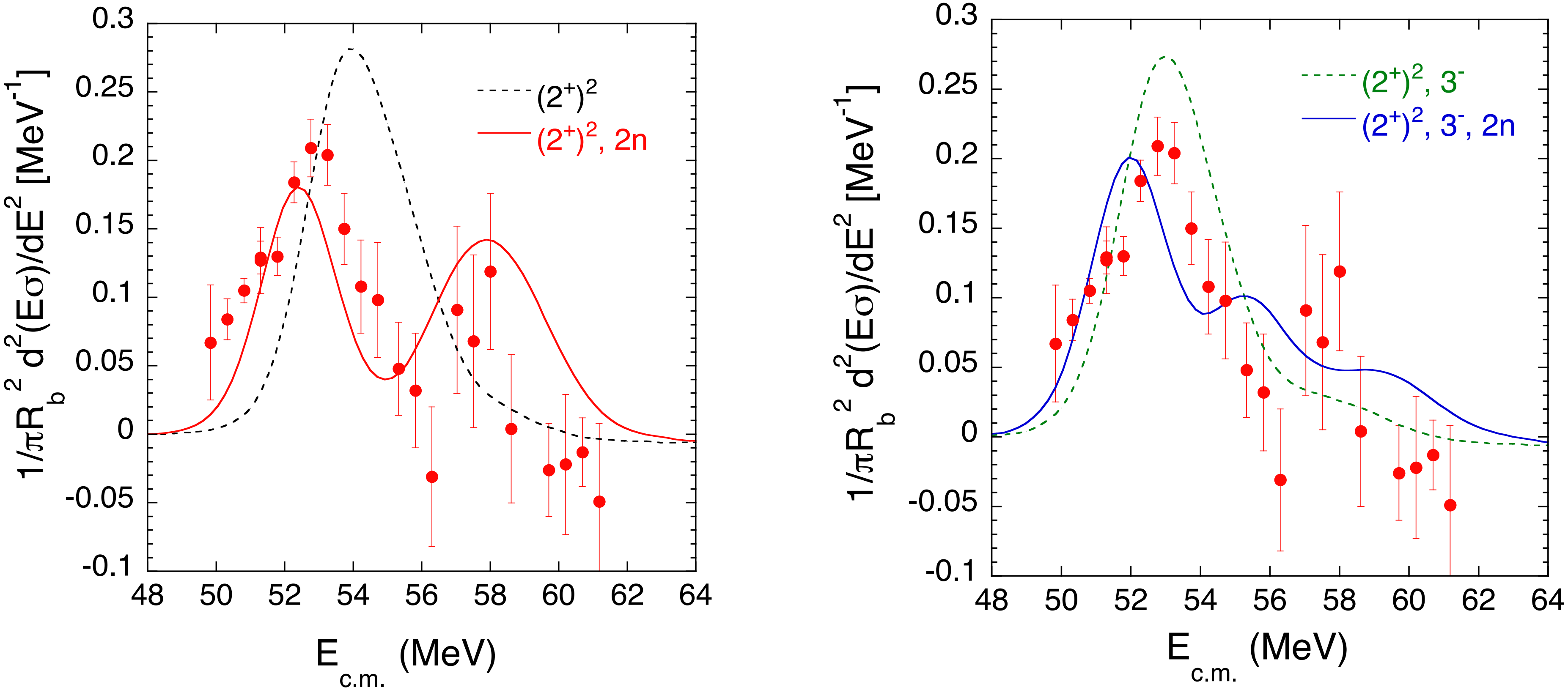
The effect of two-nucleon pair-transfer is simulated by the form factor

$$F_t(r) = -\sigma_t \frac{dU(r)}{dr}$$

C. H. Dasso and A. Vitturi, Phys. Lett. B 179, 337 (1986)

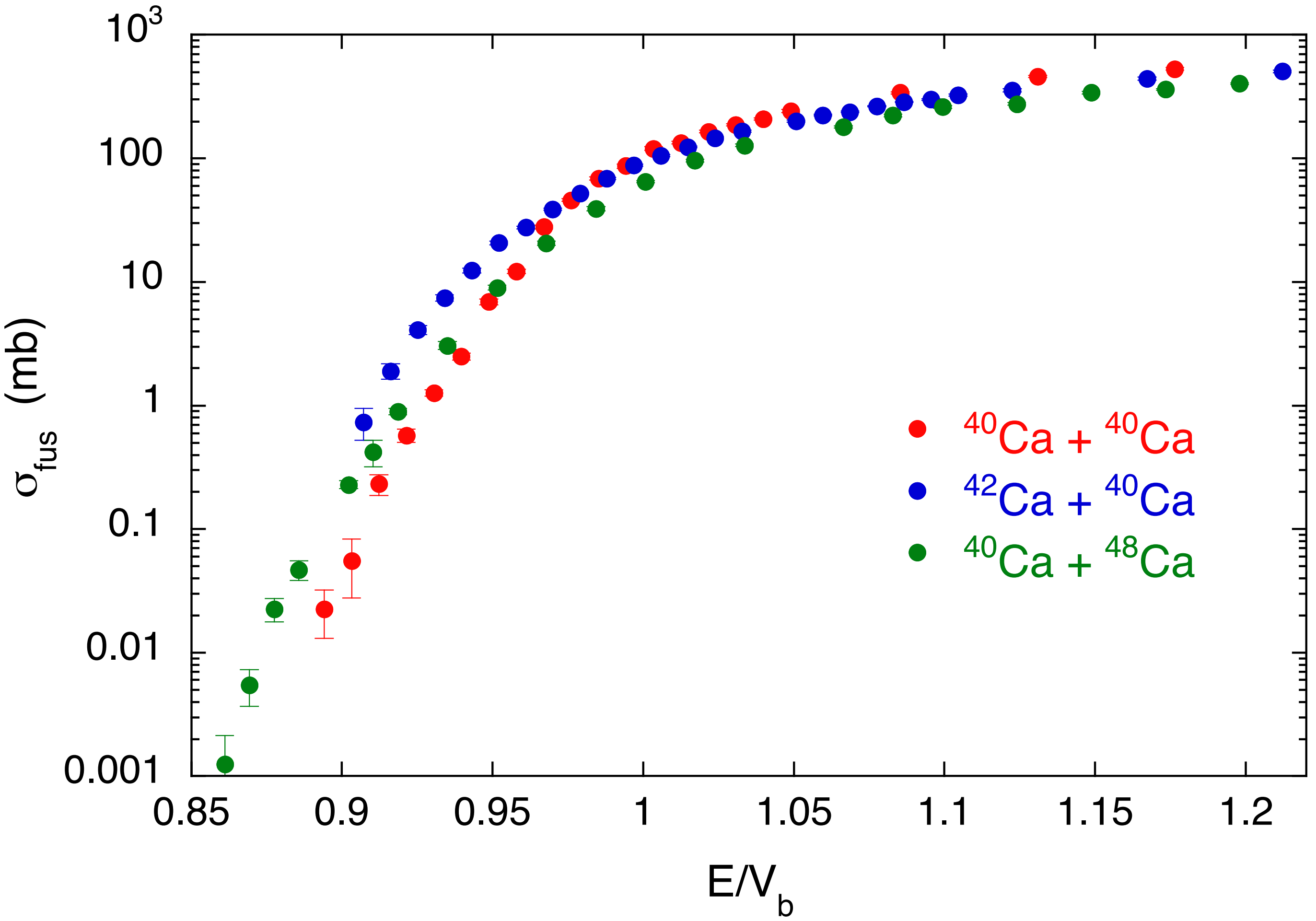
where the strength σ_t of the pair transfer is treated as an adjustable parameter.
In this case we have used σ_t = 0.39 fm best fitting the existing fusion data on $^{40}Ca+^{48}Ca$
The Q-value is taken as zero, obviously, for the elastic transfer.

Barrier distributions and coupled-channel calculations

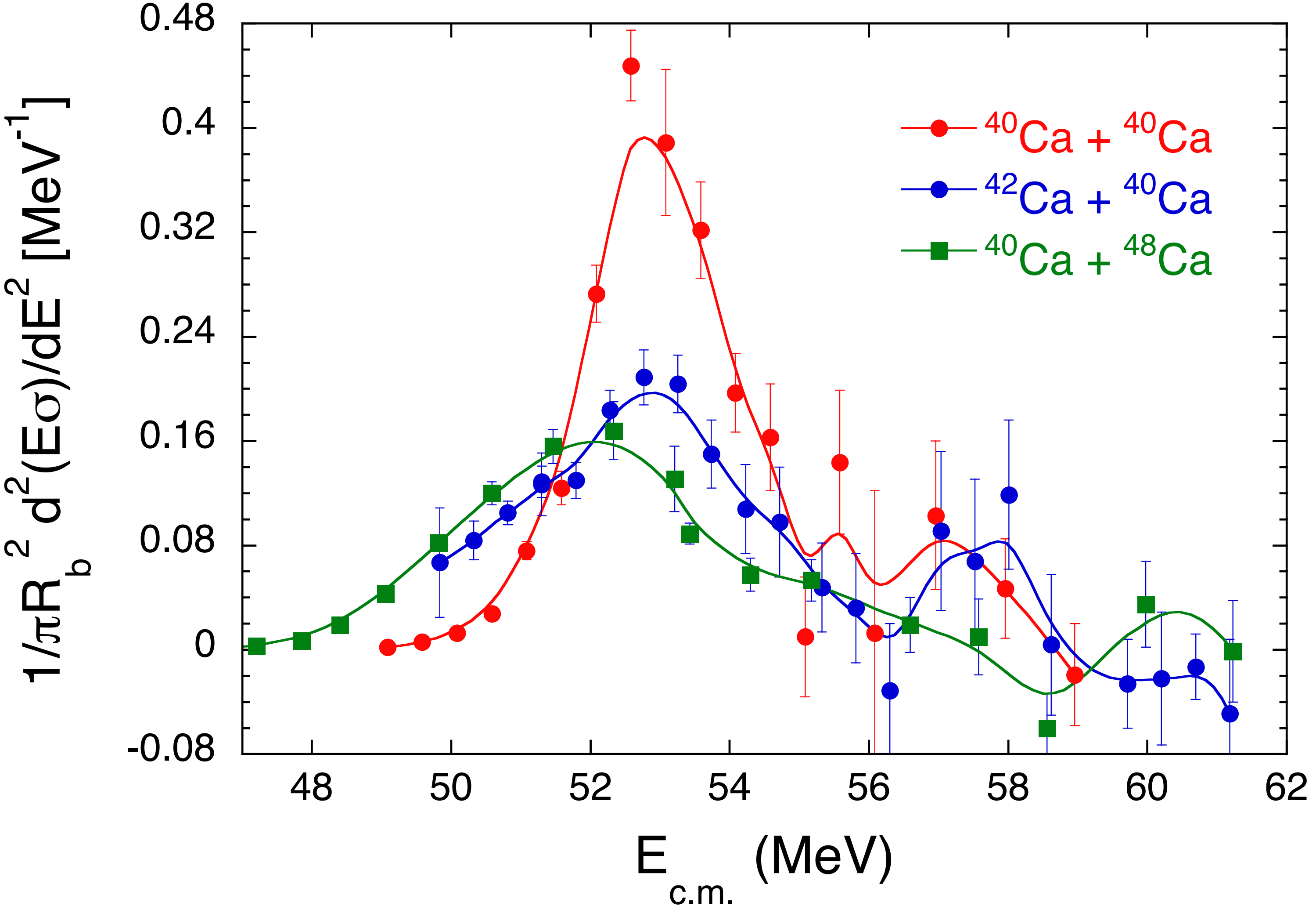


Coupling to octupole vibrations "complicate" the picture !

Comparison of excitation functions



Barrier distributions in several Ca + Ca systems



Summary

- We have measured the near- and sub-barrier fusion excitation function of $^{42}Ca + ^{40}Ca$, where no previous data on the fusion cross sections existed
- The energy step and the statistical errors of the measurements are small enough to allow extracting the barrier distribution BD with good accuracy
- The observed BD clearly shows a double-peak structure, and it is tempting to associate this feature with the elastic 2n-transfer
- The octupole vibrations (very strong in ^{40}Ca) do not essentially influence the shape of the barrier distribution if no transfer coupling is considered. The simple two-peak structure is lost when the 2n transfer is additionally included
- Transfer couplings are important in $^{42}Ca + ^{40}Ca$, but the evidence of an elastic two-neutron transfer is marginal. CC predictions are based only on a schematic (approximate) formulation of the 2n transfer form-factor.

End