# Weak channels and barrier distributions

*(Tunneling in the presence of environment)*

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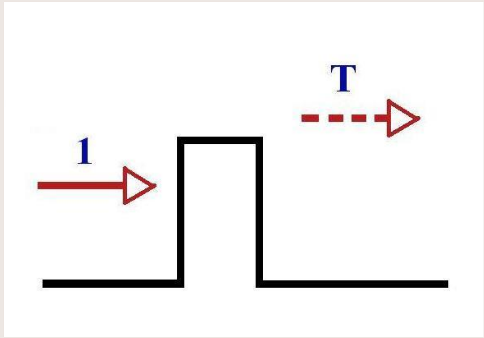
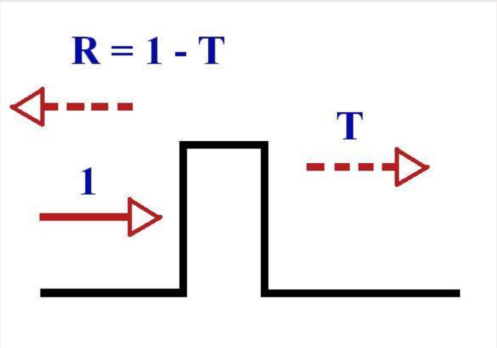
Heavy Ion Laboratory of Warsaw University

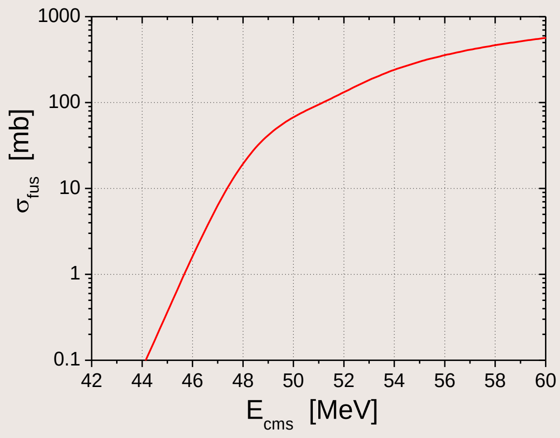
and the „Barriers" collaboration

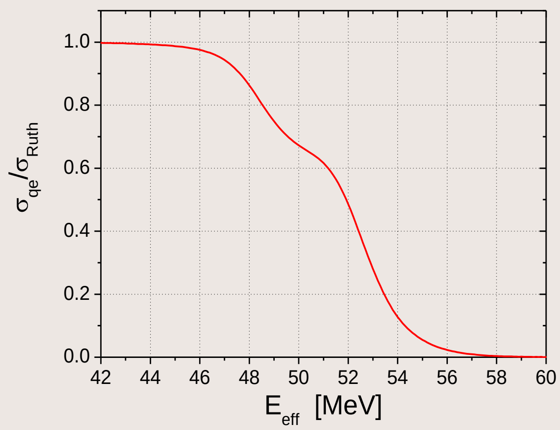
**Tokai, Dec. 2014**

# *Two experimental methods:*



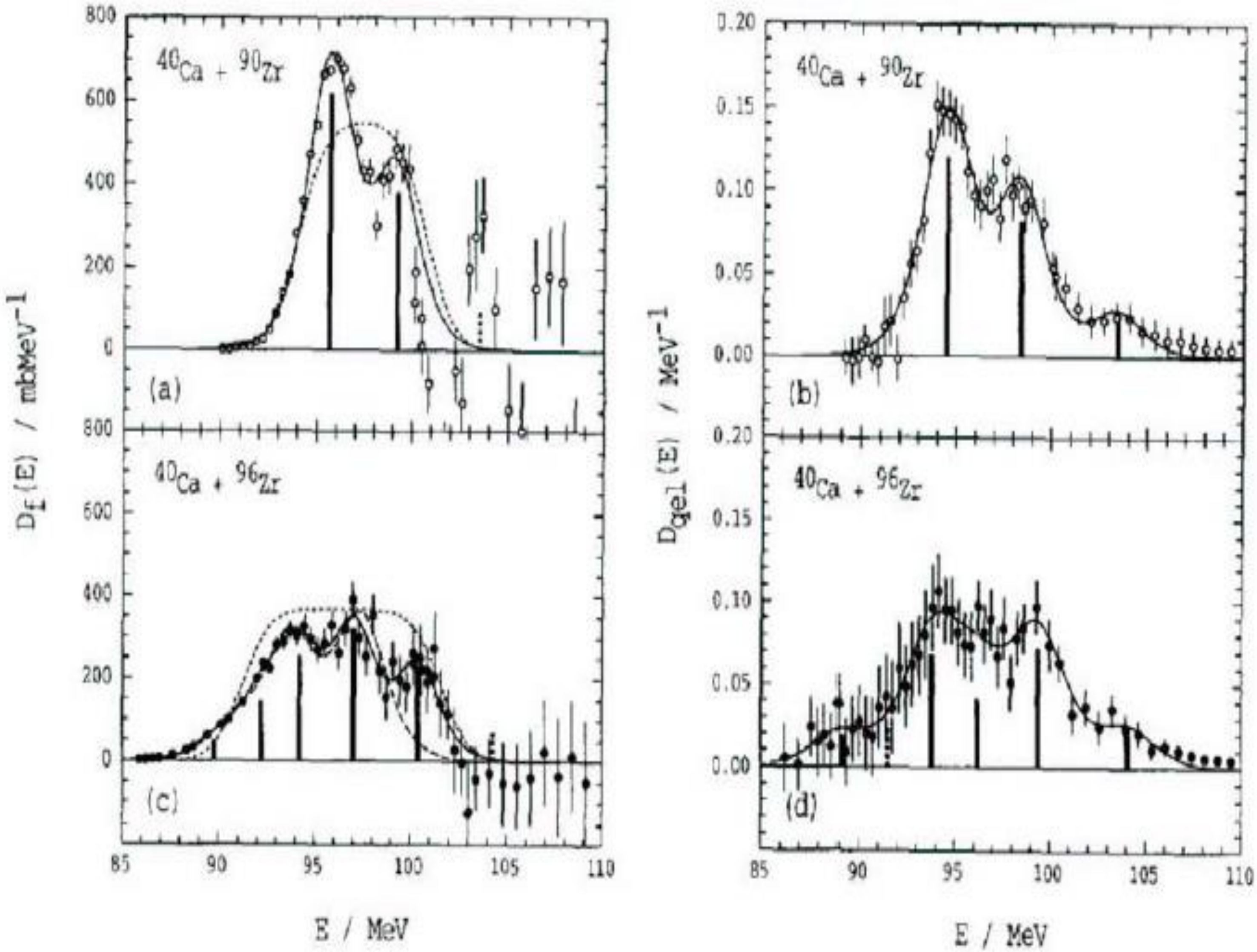




$$D_{fus}(E) = \frac{d^2}{dE^2}\left(E\sigma_{fus}\right)$$

$$D_{qe}(E) = -\frac{d}{dE}\left(\frac{\sigma_{qe}}{\sigma_{Ruth}}\right)$$

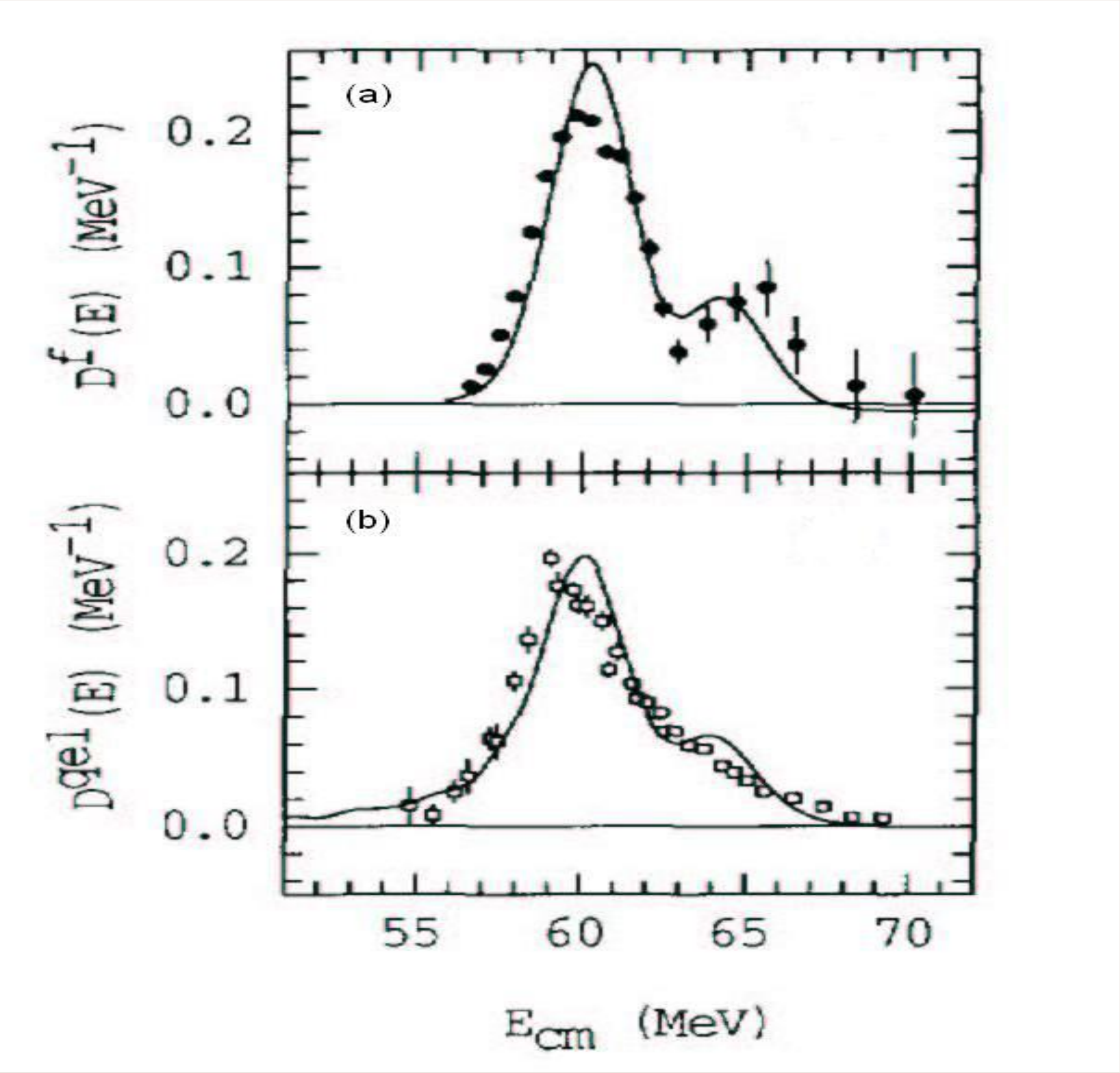
$$E_{eff} = \frac{2E}{1 + cosec(\theta/2)}$$

# Are the methods equivalent?




H.Timmers et al., NP A 633(1998)421

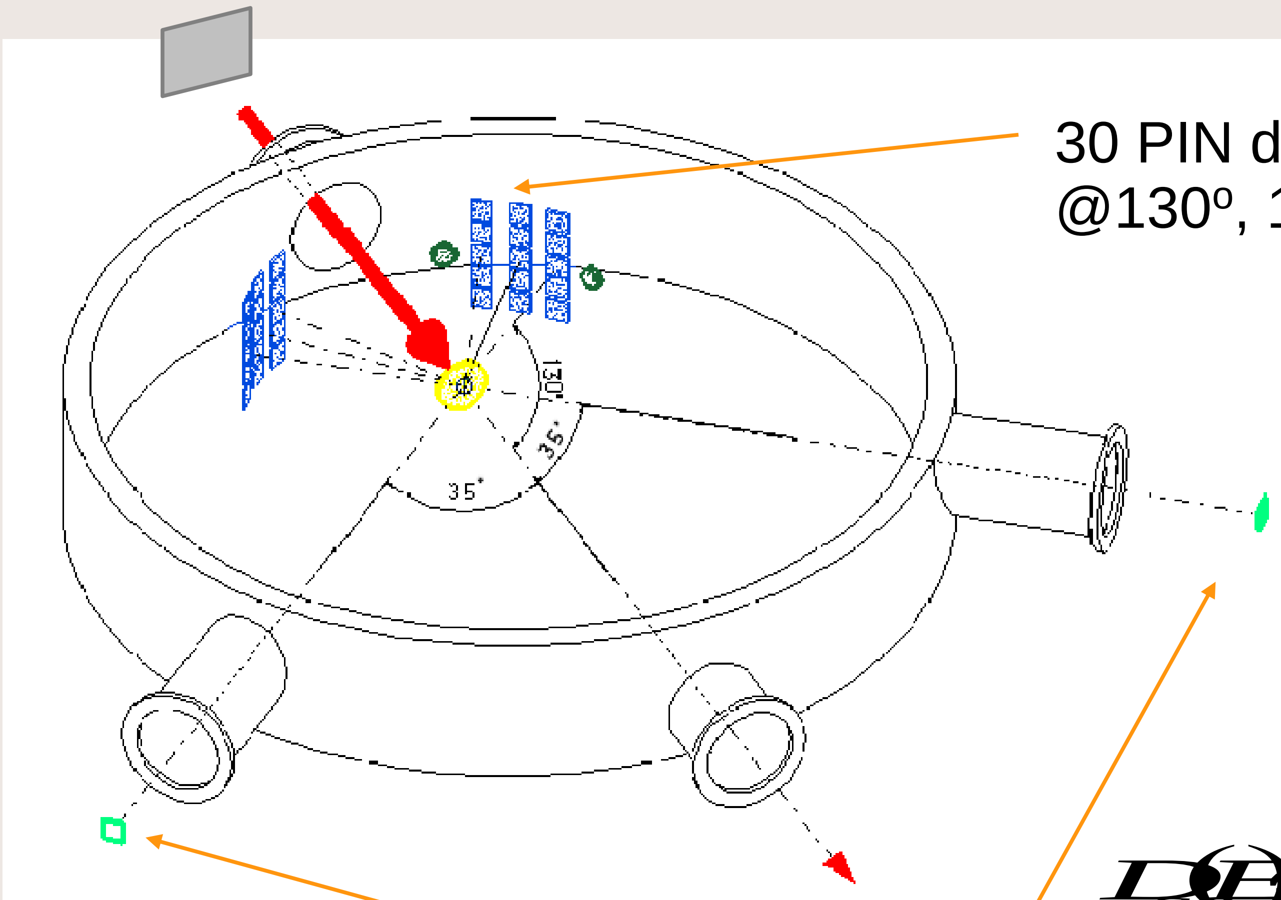
# $^{16}O + ^{144}Sm$




H.Timmers et al., NP. A584(1995)195

# Our experimental set-up

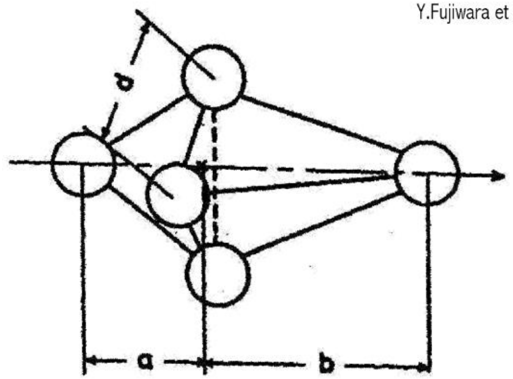
degrader




30 PIN diods 1x1cm @130°, 140°, 150°

2 PIN diods @ 35°

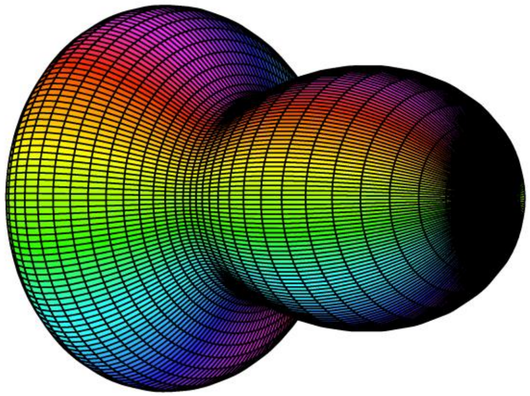
Y.Fujiwara et al., Suppl.Progr.Th.Phys. 68(1980)111




5α configuration of the basis intrinsic wave function in the α-$^{12}$C-α GCM; *d* is the distance between two α in $^{12}$C-like core, and *a* and *b* are treated as the generator coordinates.

**Cluster model**

**Shape of $^{20}$Ne**

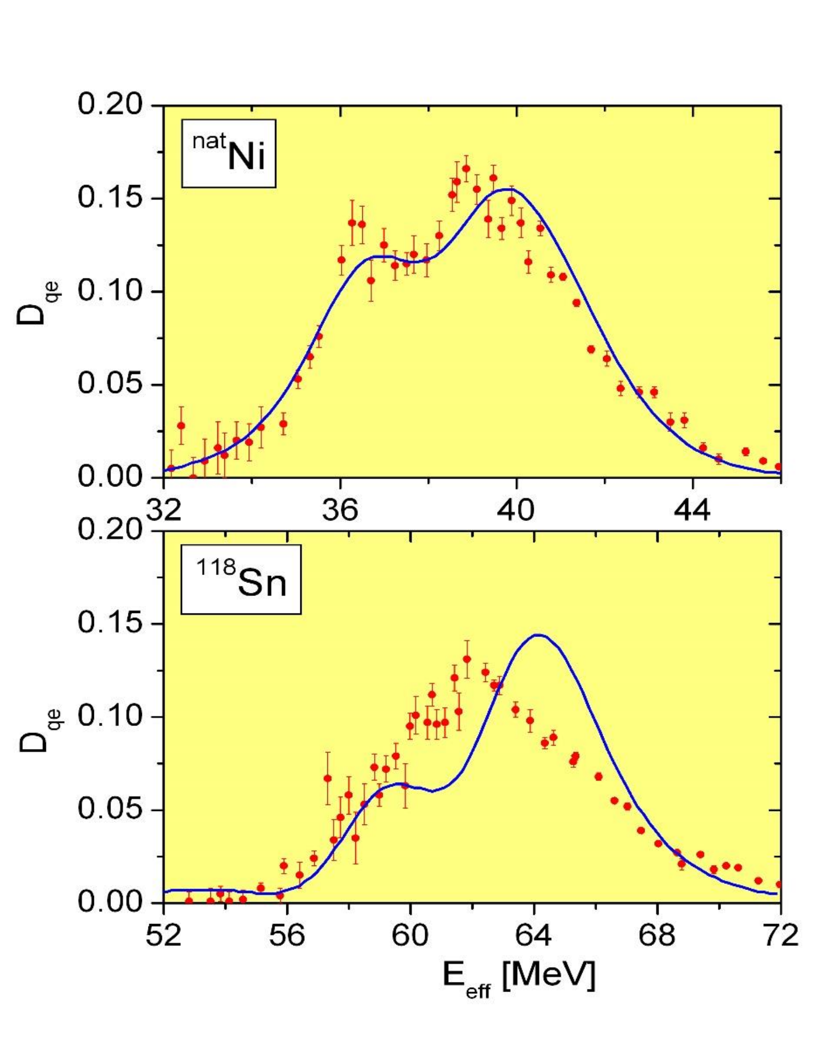


$\beta_2 = 0.46$

$\beta_3 = 0.39$

$\beta_4 = 0.27$

# First measurements – first surprises



*What causes smoothing of structure in the case of the Sn targets?*

*Why in the case of Ni target the structure is clearly seen, being in agreement with theory?*

Hypothesis: p, n, α **TRANSFER** during $^{20}Ne$ scattering

disregarded in the CC calculations

stronger in the Sn than in the Ni case

# *Estimated from systematics*

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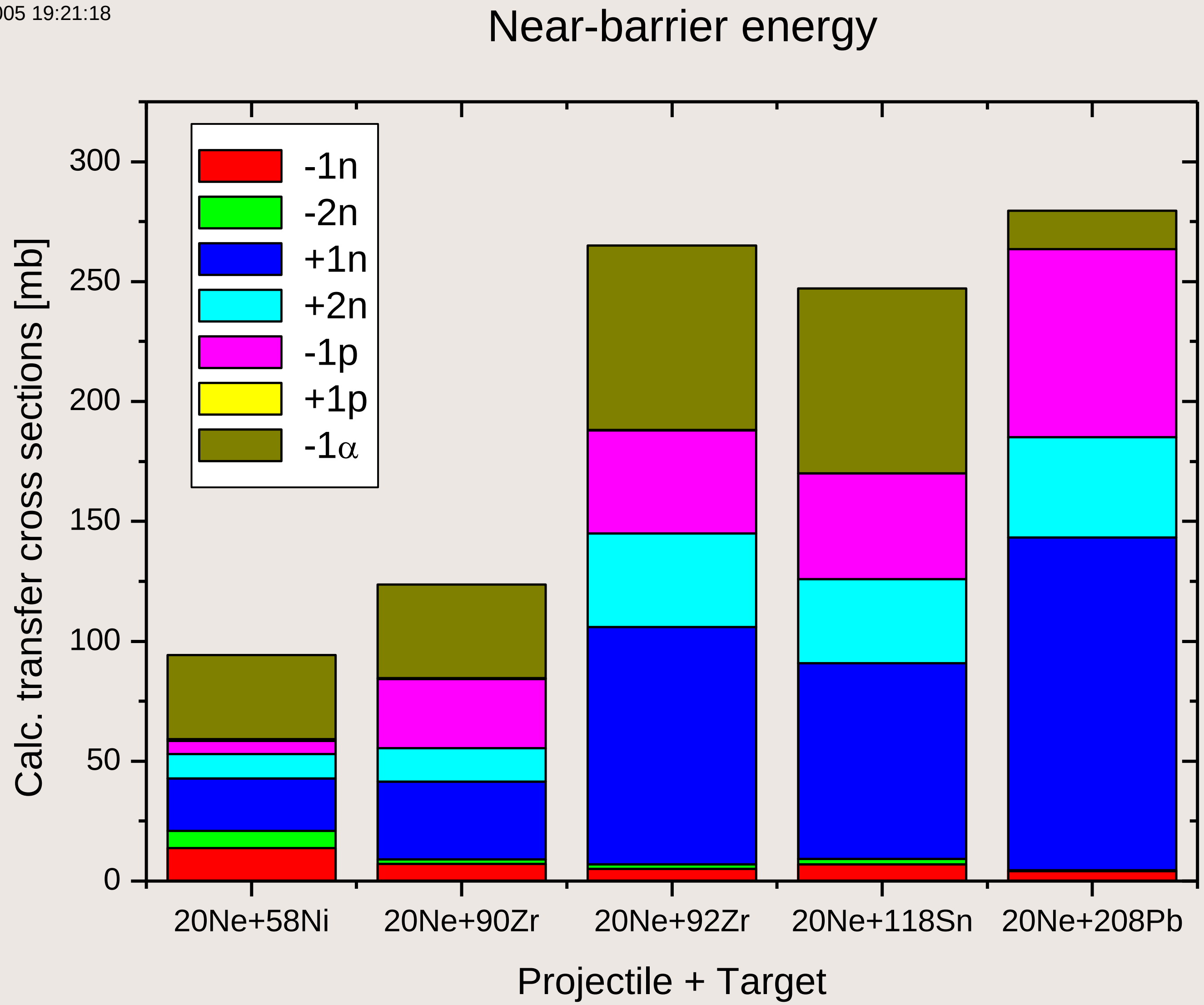


# Expectations & experimental results:

$^{20}Ne + ^{90}Zr$:

**Weak transfer →**

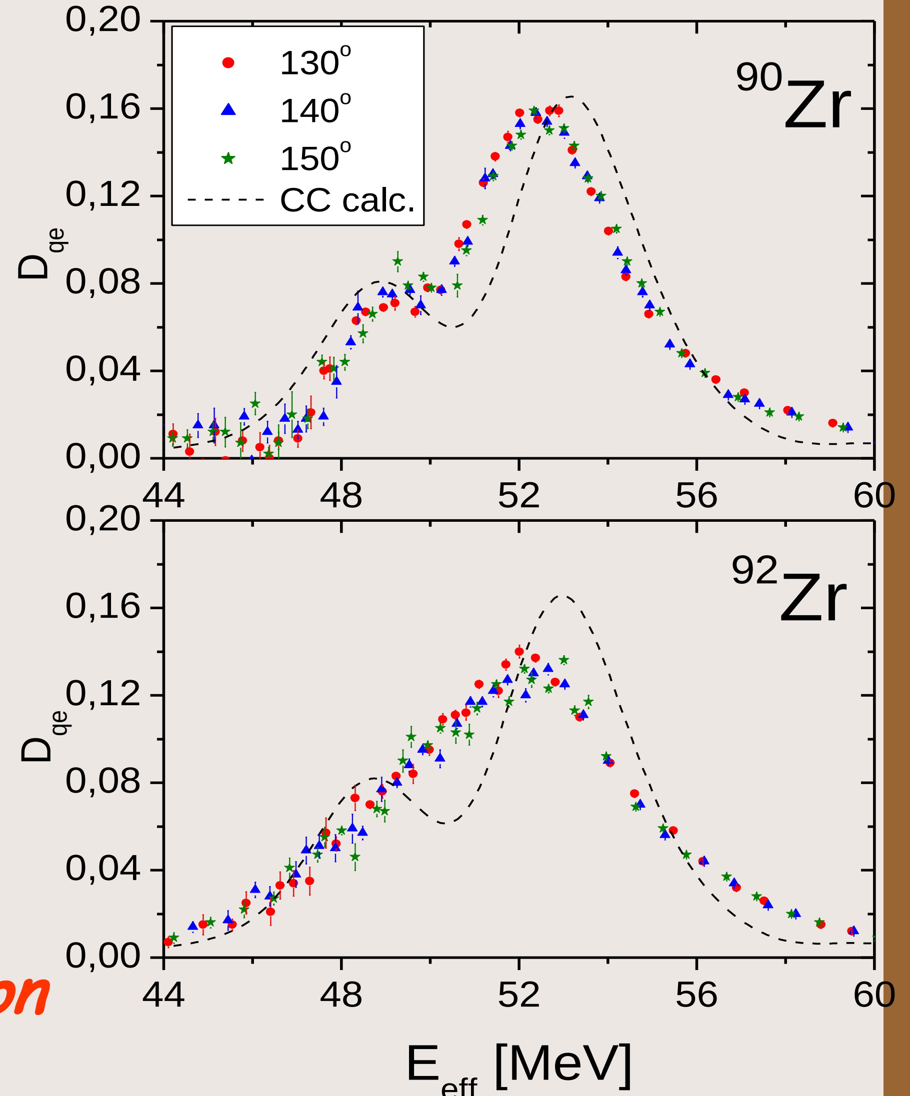
**barrier structure**

$^{20}Ne + ^{92}Zr$:

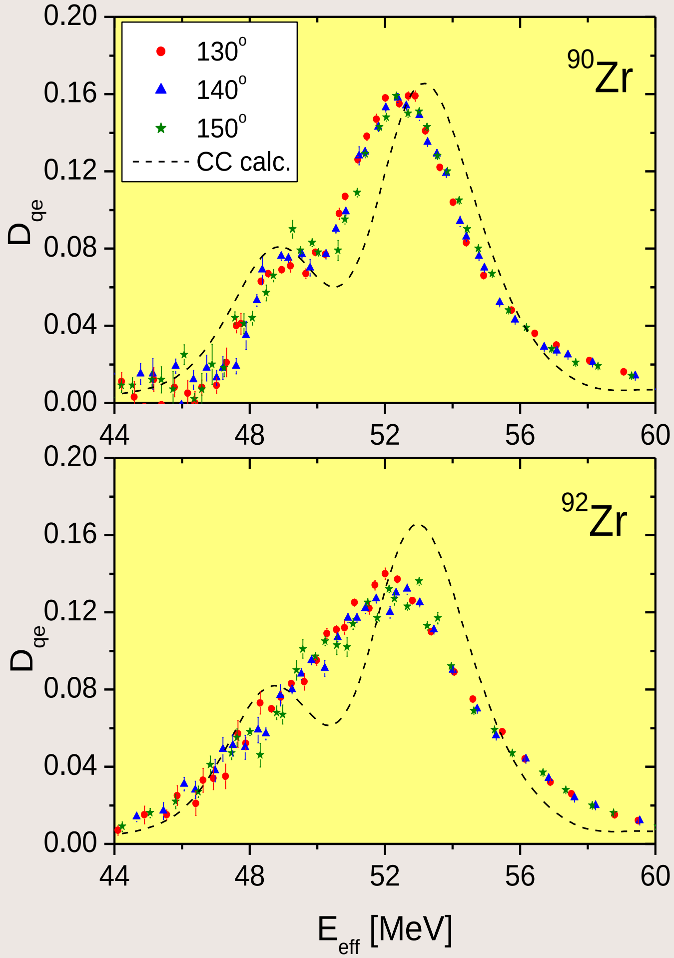
**Stronger transfer →**

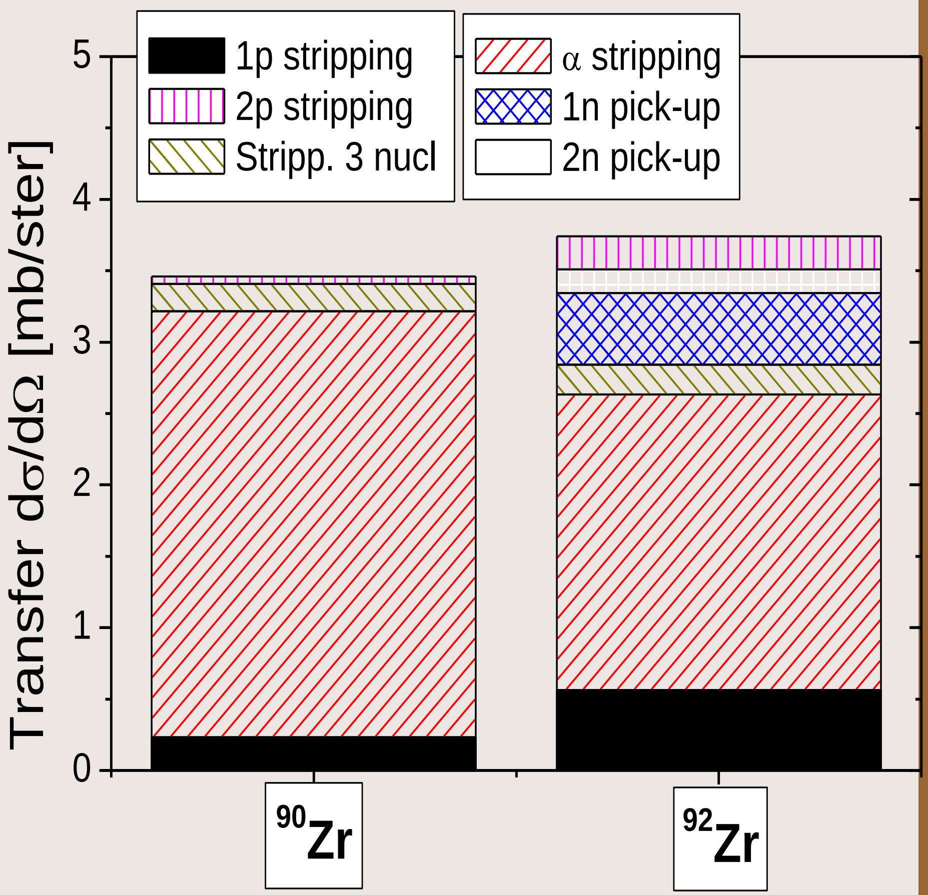
**no structure**

**wider barrier distribution**



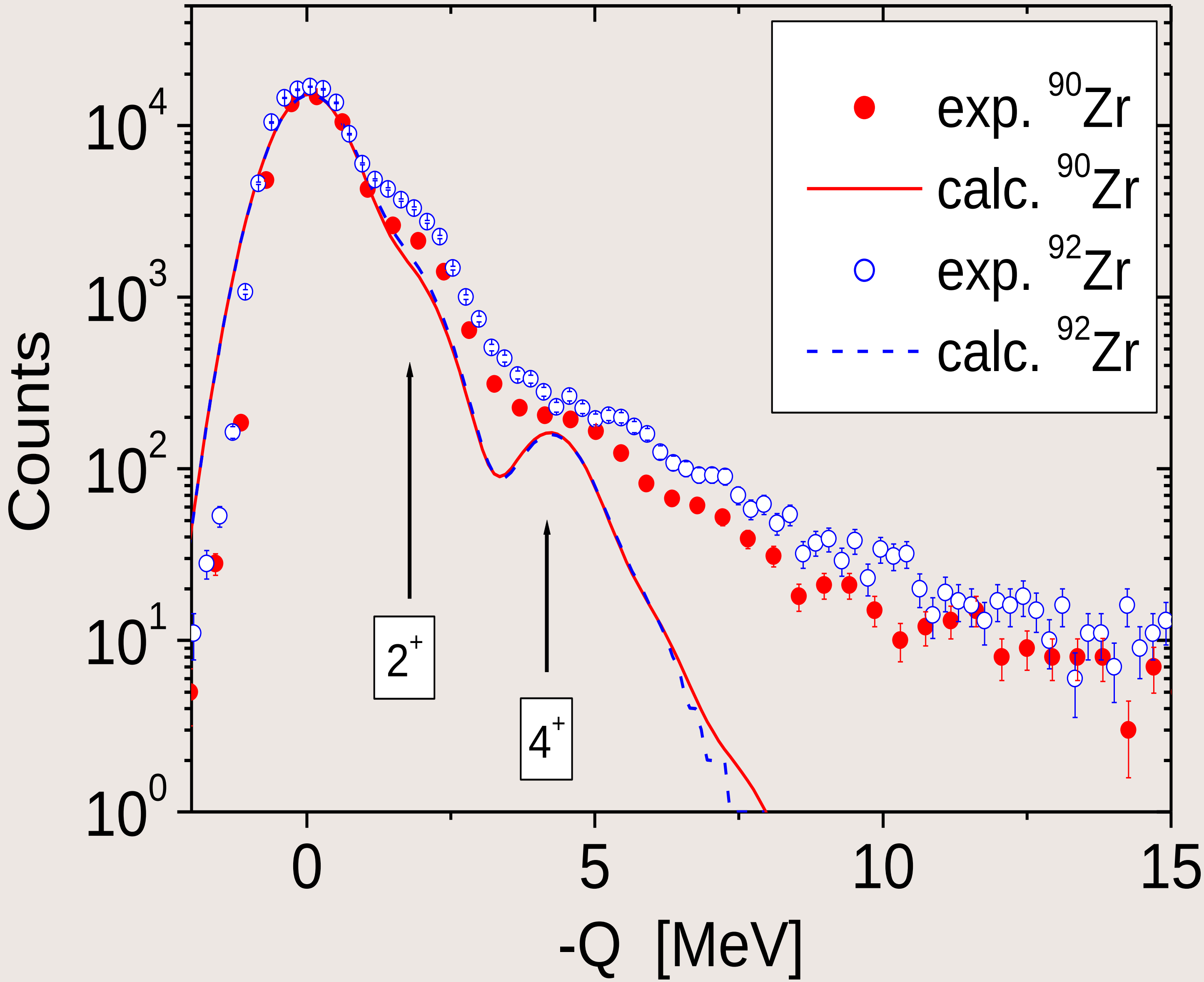

E. Piasecki et al., Phys.Rev. C80 (2009) 054613



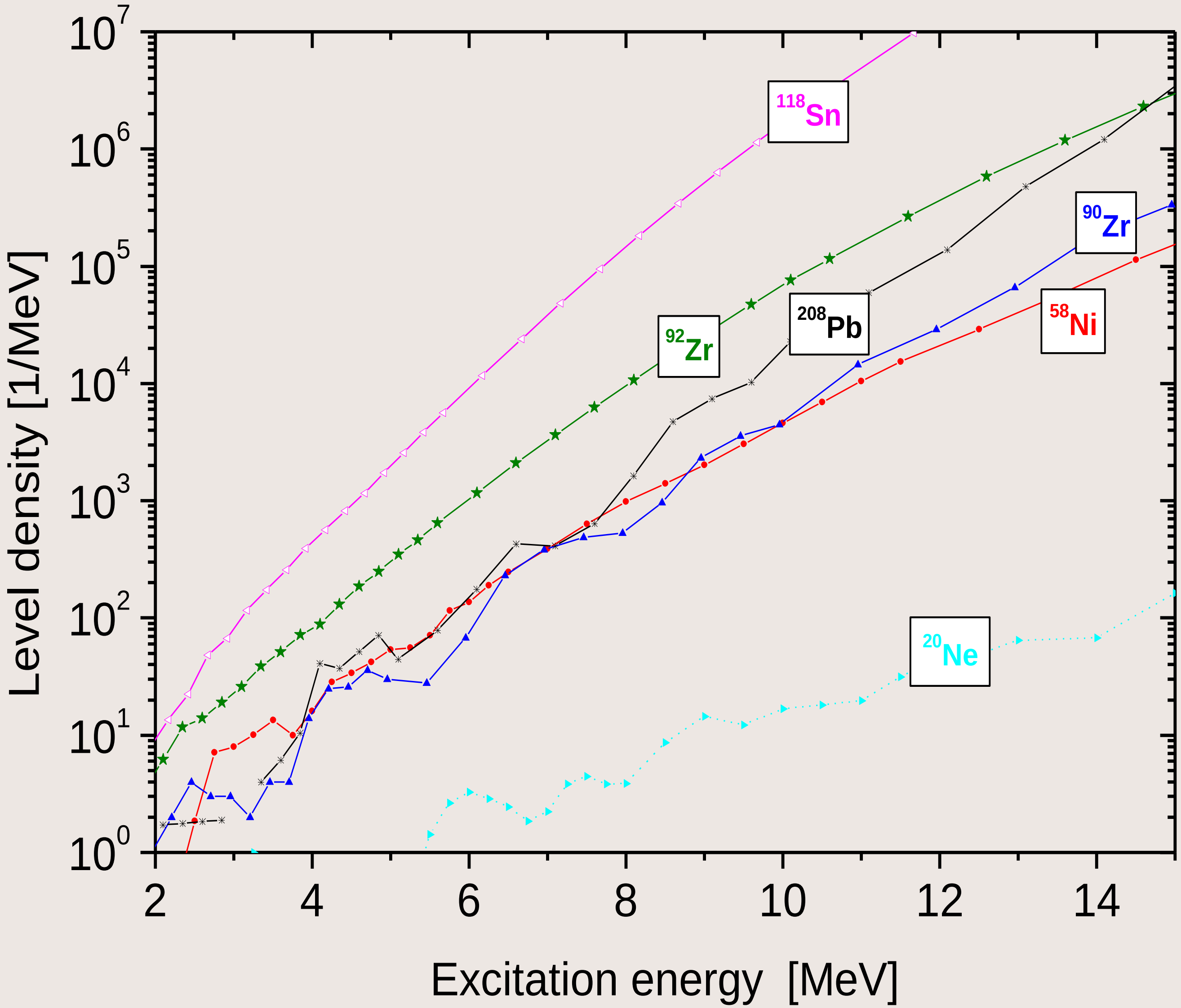




E. Piasecki et al., Phys.Rev. C80 (2009) 054613

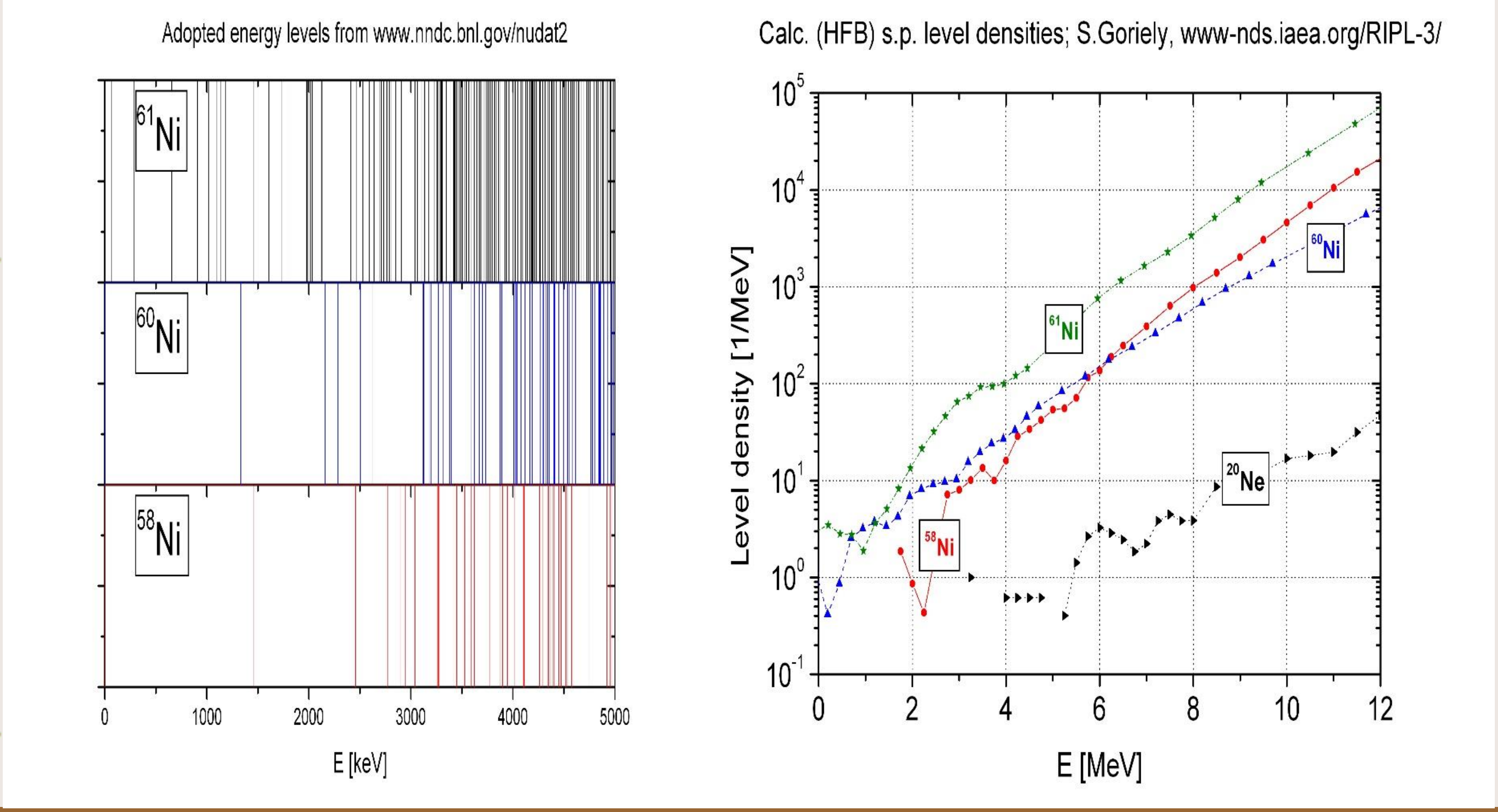
# Non-transfer backscattering $^{20}Ne + ^{90,92}Zr$



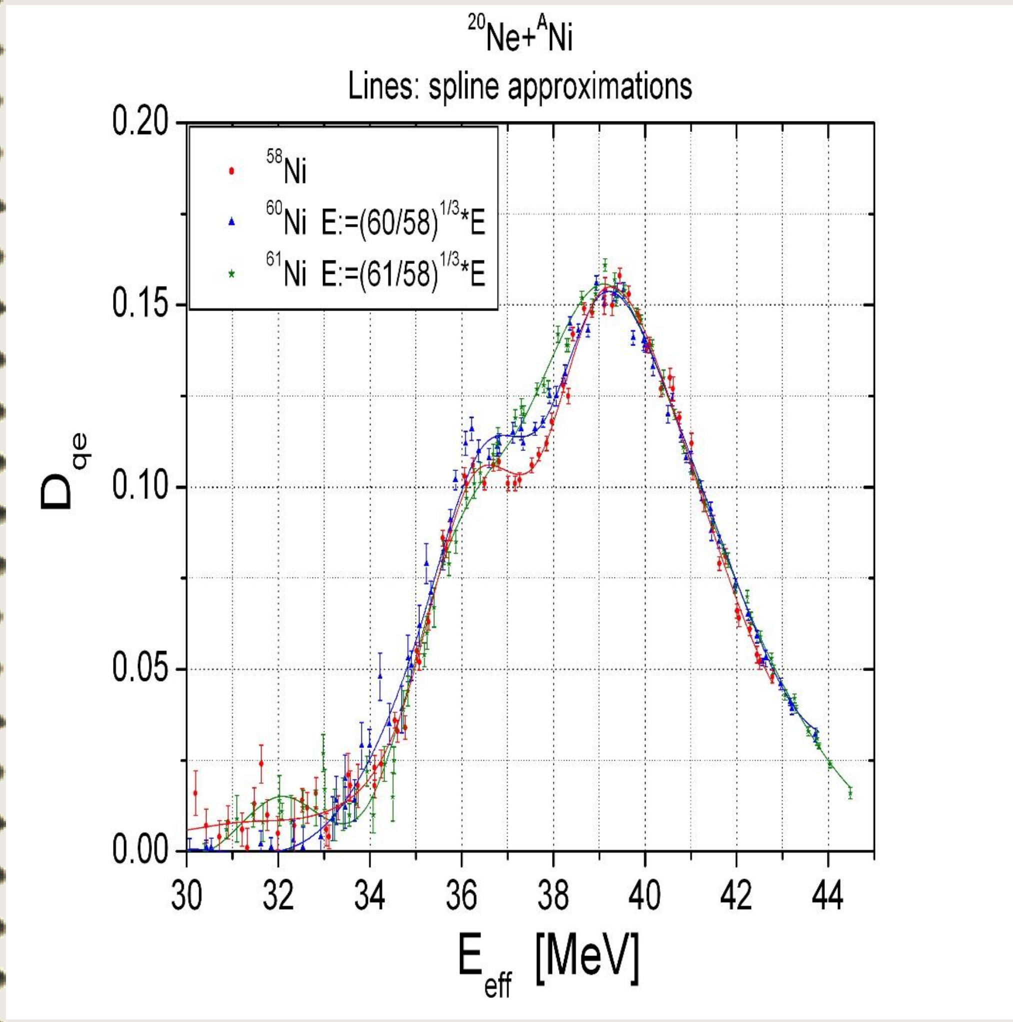
# HFB calculations of s.p. level density

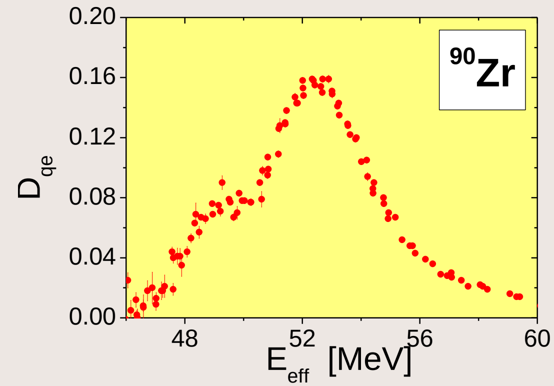


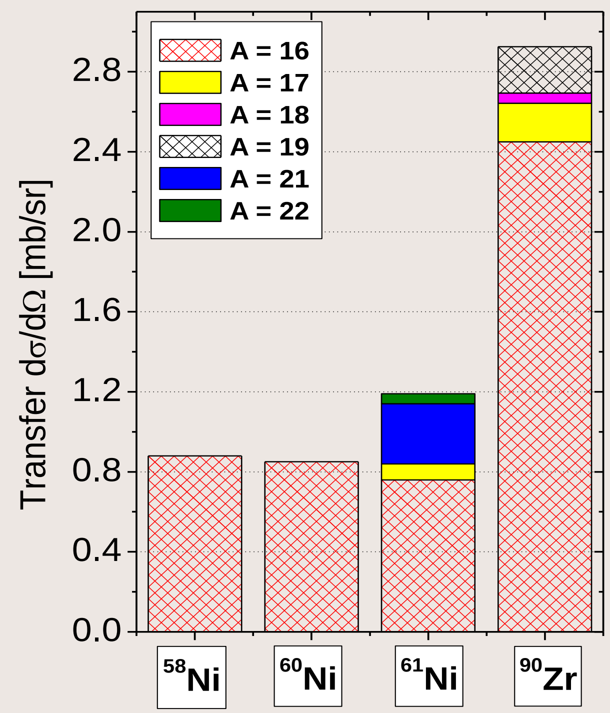
# *Next candidates to study: $^{58,60,61}Ni$*



# $^{20}Ne + ^{58,60,61}Ni$



## We see the limits of the standard CC Method

How to go beyond?

A.Diaz-Torres, Phys. Rev. C82 (2010) 054617

**The Coupled Channels Method using Schrödinger equation describes reversible processes (coherent superposition of a few intrinsic states)**

**Excitation of non-collective levels → irreversible damping of relative motion into many internal degrees of freedom**

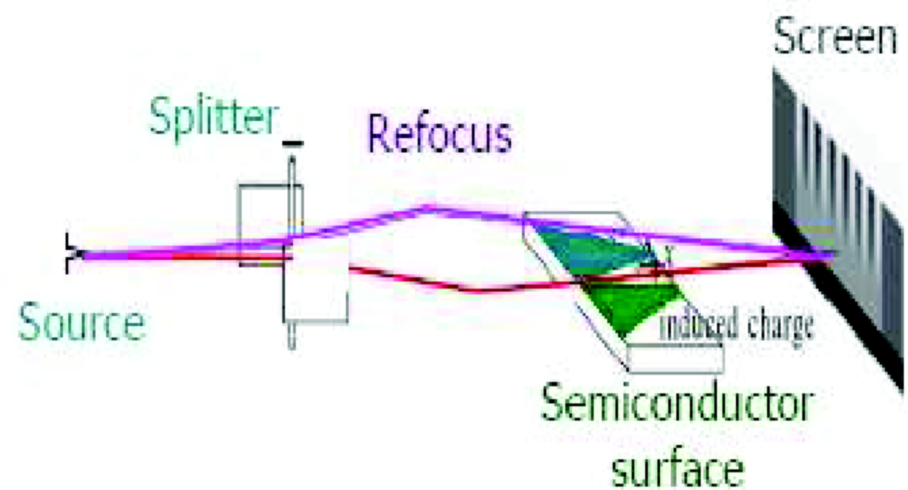
**Moreover, interaction of quantum system with a complex environment results in destruction of the coherent superposition (decoherence)**

**Schrödinger → Lindblad equation**

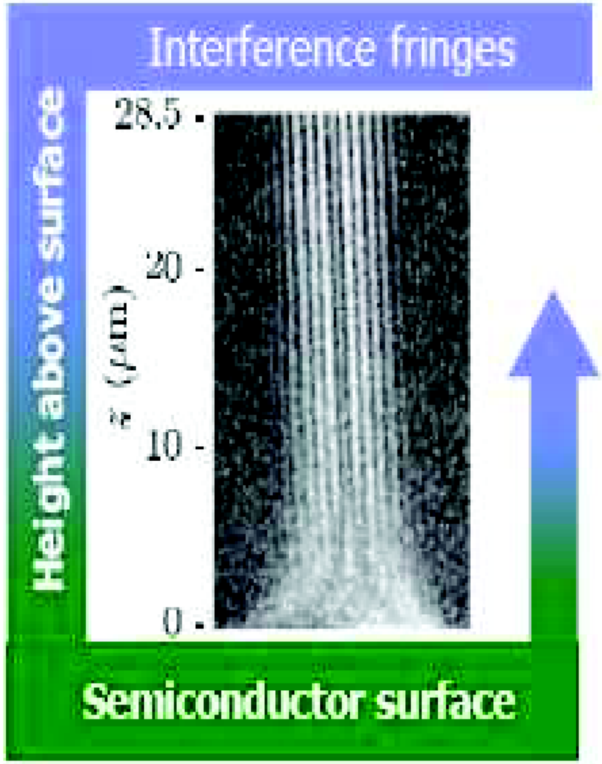
# The Reality of Quantum Decoherence

## Electron entanglement with a surface

Double-slit type experiment with single electrons




Sonnentag & Hasselbach, PRL **98** (2007) 200402

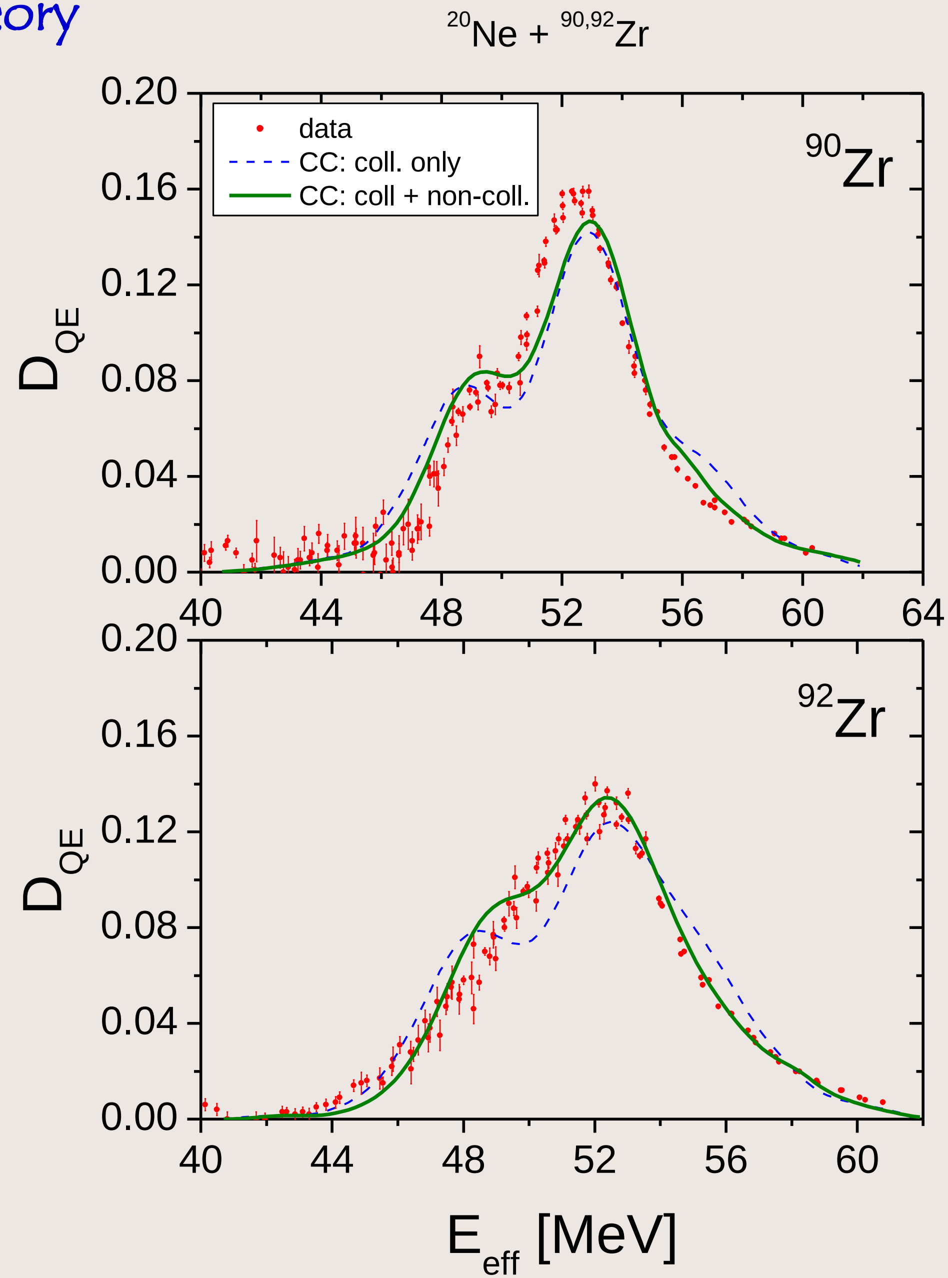



- Decoherence – "dynamical dislocalization of quantum mechanical superpositions"

(H.D. Zeh arXiv:quant-ph/0512078 v2) coherence shared with (lost in) environment

# CC + Random Matrix Theory

S.Yusa, K.Hagino, N.Rowley
Phys. Rev. C88(2013)054621



# Open questions and our planned experiments

1. **Is smoothing seen also in $D_{fus}$?**

   *Determination of $D_{fus}$ for $^{20}Ne + {}^{90,92}Zr$*

2. **What is the beam energy dependence of non-collective excitations and testing the RMT predictions?**

   *Measurement of Q-spectra for $^{20}Ne + {}^{90,92}Zr$ for various $E_{beam}$*

3. **Can „decoherence” be observed for other beams?**

   *Measurement of $D_{qe}$ (& $D_{fus}$?) for $^{24}Mg + {}^{90,92}Zr$*

   *Measurement of transfer cross-section in $^{24}Mg + {}^{90,92}Zr$*

4. **What is the angular distribution of non-collective excitations?**

   *Measurement of Q-spectra in function of scattering angle*

## Conclusions:

- *The weak (non-collective) channels can considerably influence the barrier height distributions*
- *Limits of the standard CC method are seen: nonreversibility results in decoherence phenomenon, what means necessity of coupling Statistical Physics with Quantum Mechanics. Progress in this direction is significant:*
  - **A.Diaz-Torres, Phys. Rev. C82 (2010) 054617**
  - **S.Yusa et al., Phys. Rev. C88 (2013) 054621**

# The BARRIER Collaboration:

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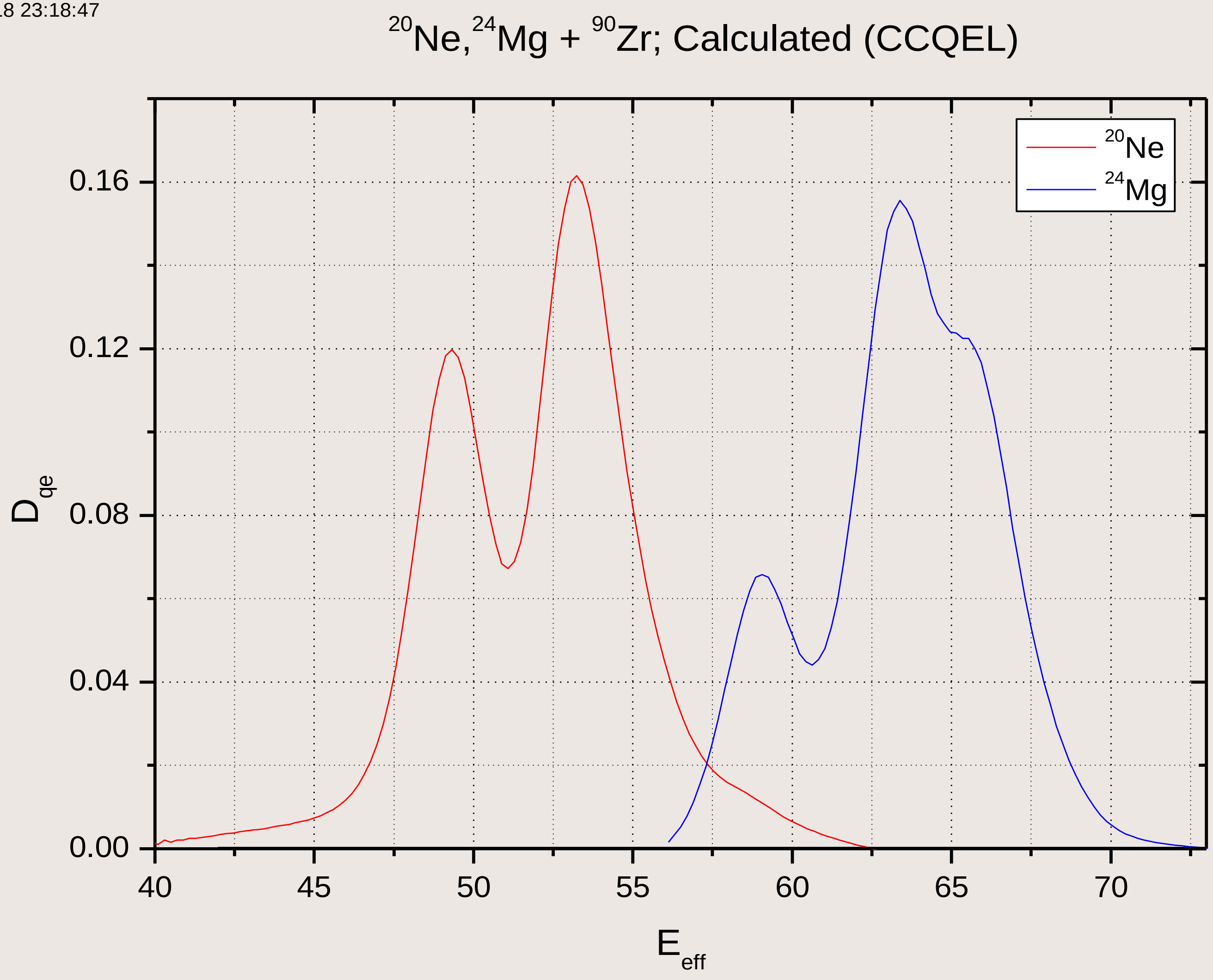
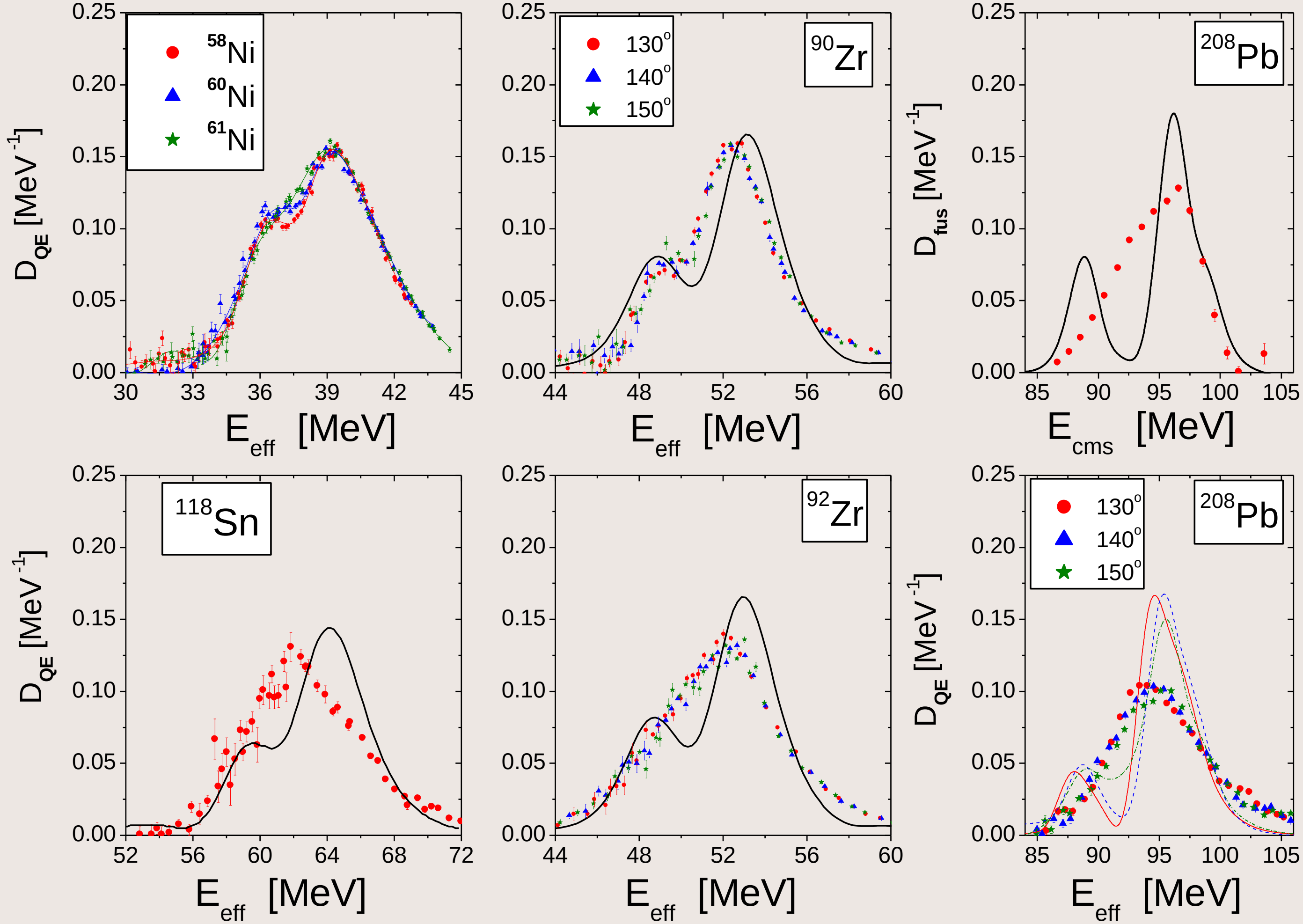
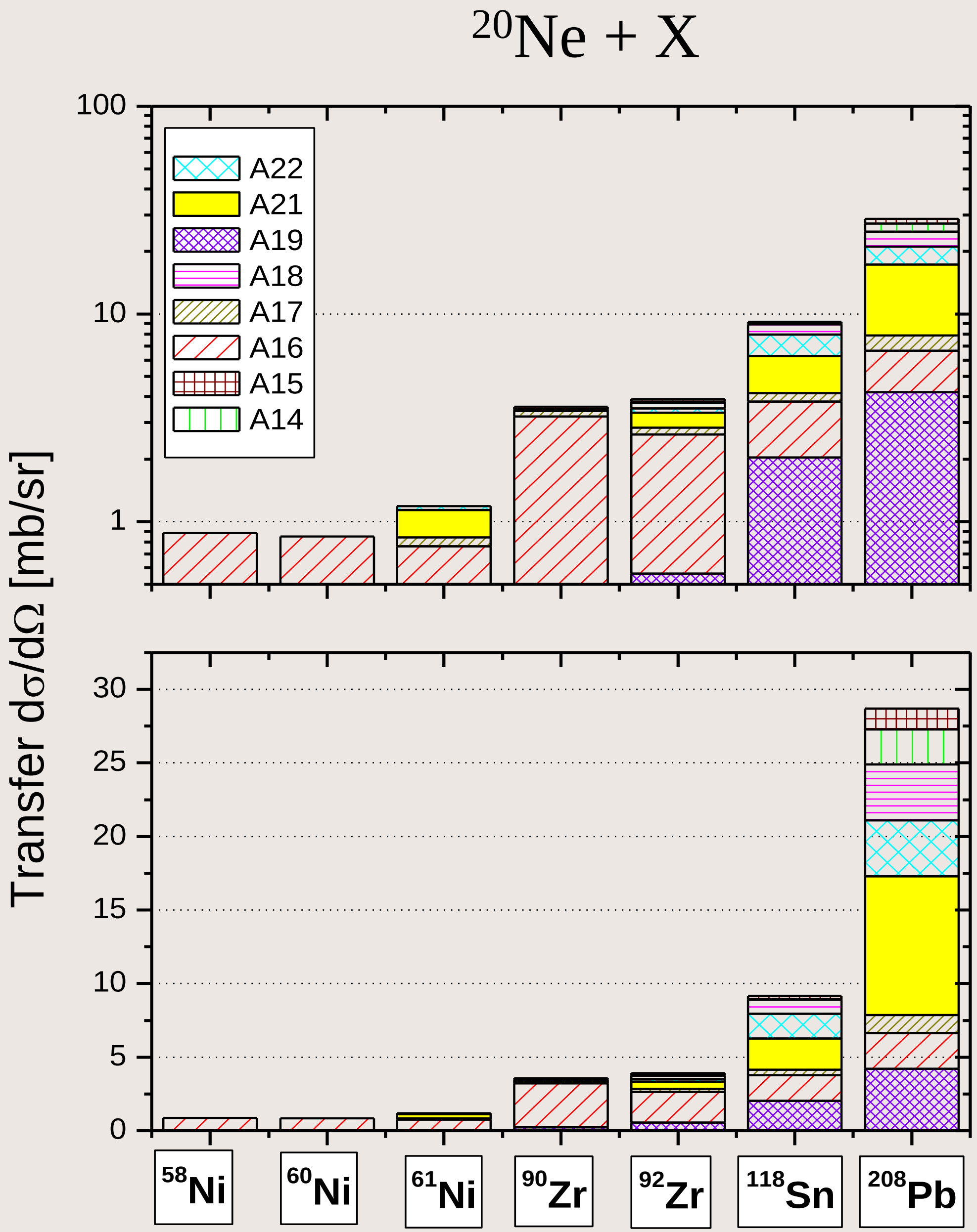


# $^{20}Ne + X$



58Ni
60Ni
61Ni
90Zr
208Pb
118Sn
92Zr
130°
140°
150°
D_QE [MeV^-1]
D_fus [MeV^-1]
E_eff [MeV]
E_cms [MeV]



$^{20}$Ne + X
Transfer dσ/dΩ [mb/sr]
A22
A21
A19
A18
A17
A16
A15
A14
100
10
1
30
25
20
15
10
5
0
$^{58}$Ni
$^{60}$Ni
$^{61}$Ni
$^{90}$Zr
$^{92}$Zr
$^{118}$Sn
$^{208}$Pb