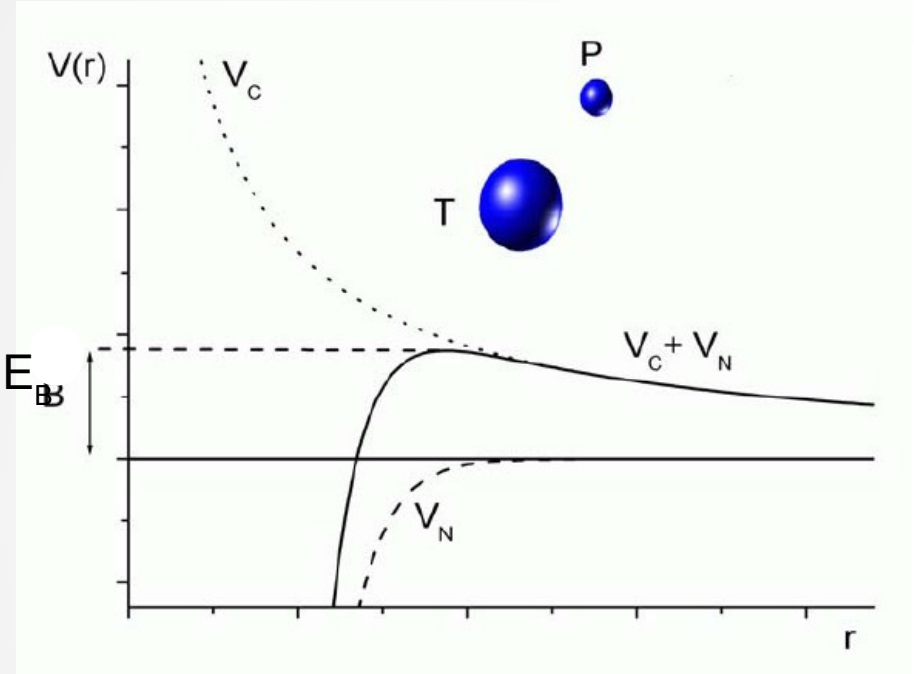
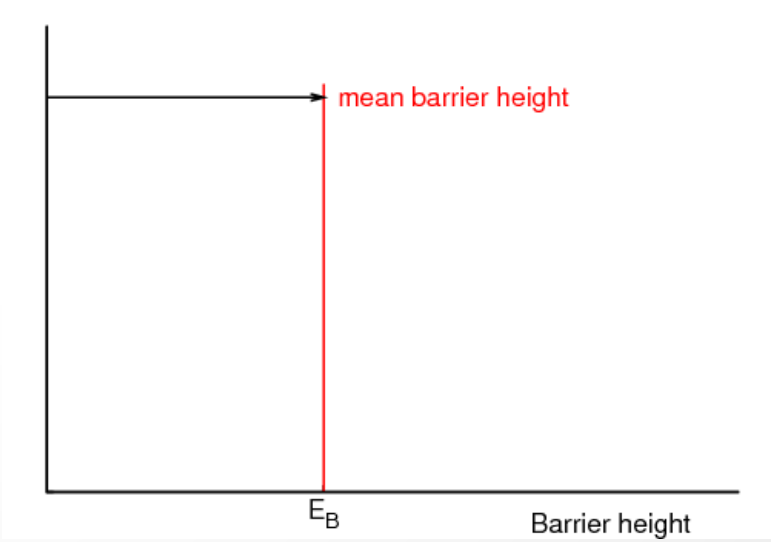
Quasi-elastic barrier distributions studies: influence of weak channels

Agnieszka Trzcińska

Heavy Ion Laboratory
University of Warsaw
for
BARRIERS collaboration

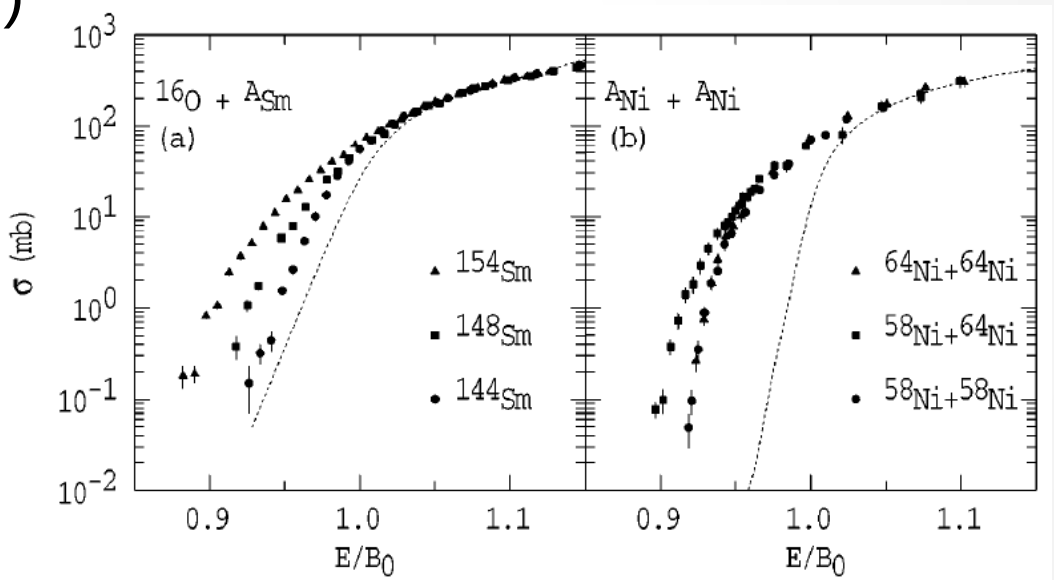
Coulomb barrier height (single barrier)





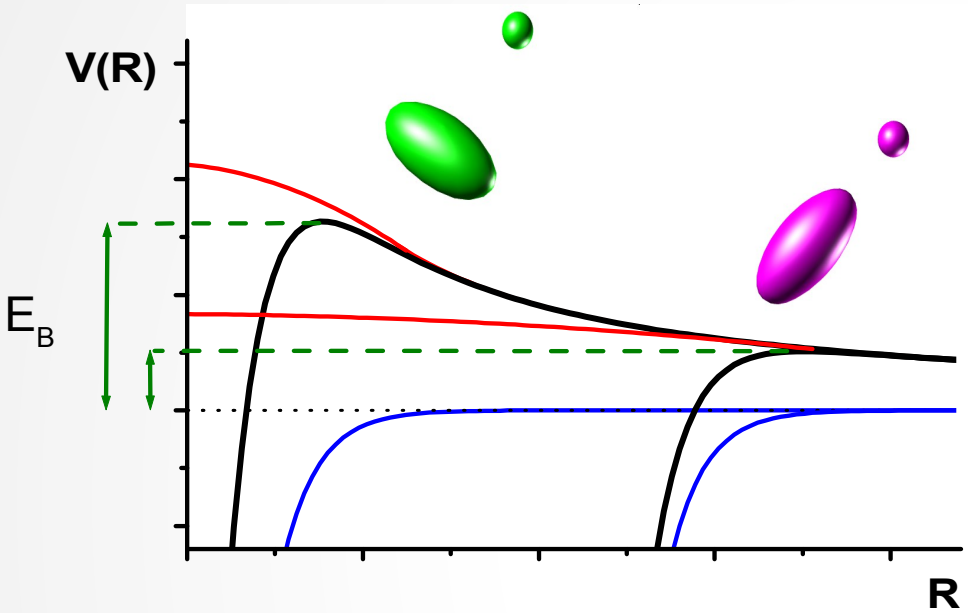
From single barrier to barrier distribution

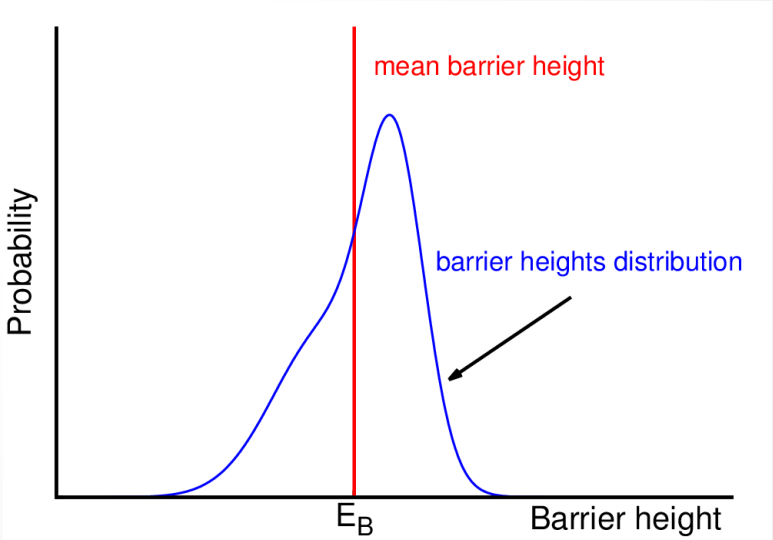
- Single Barrier Model – good description of fusion cross sections for light nuclei
- Observation of <u>fusion enhancement</u> for heavier systems below barrier (e.g. ^{16}O + ^{A}Sm)



- Good description of fusion cross section with several barriers emerging from couplings to many reaction channels → barriers distribution

Coulomb barrier height distribution



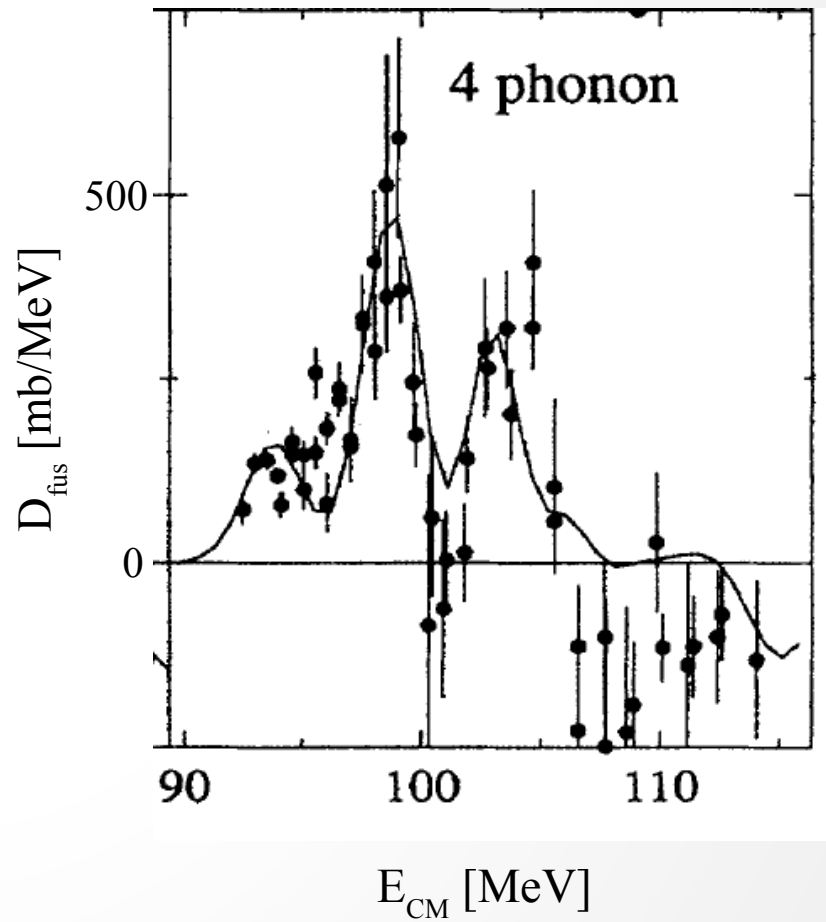


Barrier height distribution

A “structure” in BHD appears

not only for deformed nuclei: $^{58}Ni + ^{60}Ni$

the nature of the phenomenon is quantum



A. M. Stefanini *et al.*, Phys. Rev. Lett. 74 (1995) 864

Motivation

- A tunneling through a barrier – a fundamental phenomenon essential in many domains (physics, chemistry, biology, technology):
  in nuclear physics – studies of fusion phenomenon

- An environment has an influence on a tunneling.
  In nuclear physics: environment = nuclear structure which influences nuclear reaction channels and their couplings

- Barrier heights distribution reflects these couplings

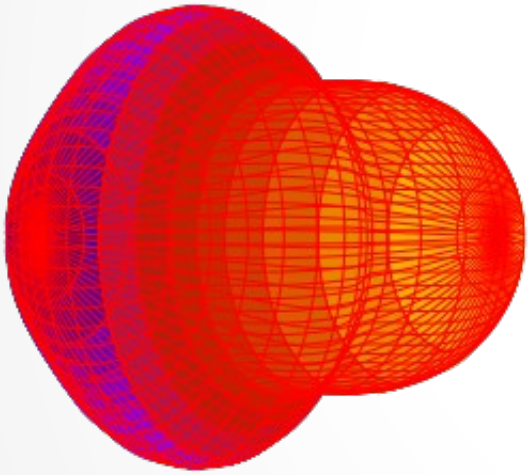
- Test of the “standard” Coupled Channels Method – where most often only strong channels are taken into account (*)

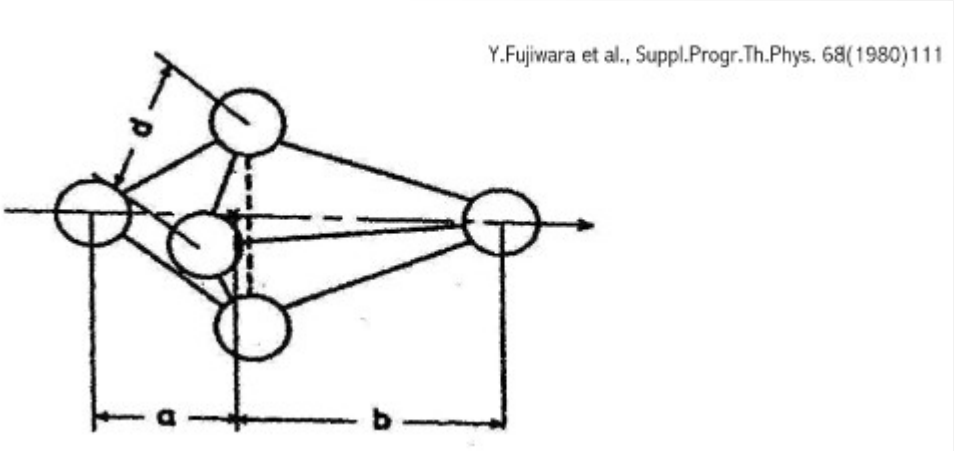
(*) strong channels = channels connected with ***collective excitations***

Program of barrier distribution studies

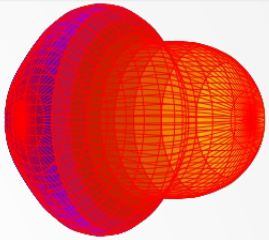
- projectile: ^{20}**Ne** – strongly deformed nucleus:

  $\beta_2 = 0.46$, $\beta_3 = 0.39$, $\beta_4 = 0.27$





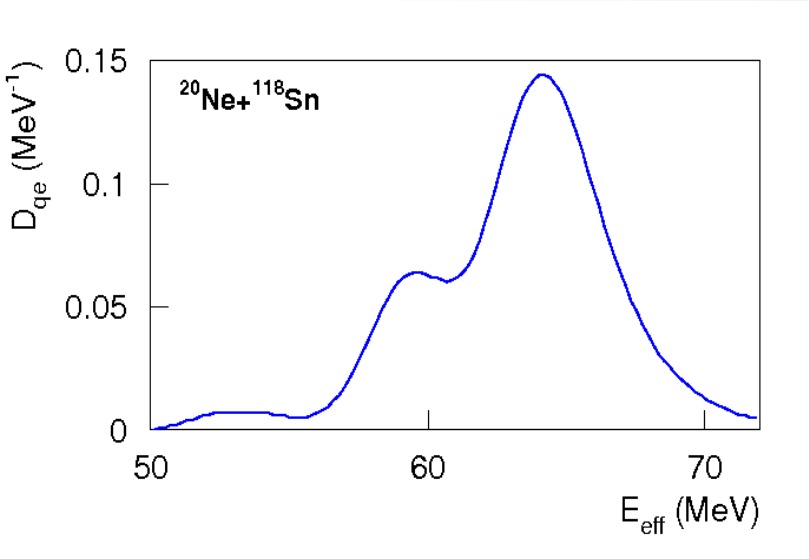
Program of barrier distribution studies



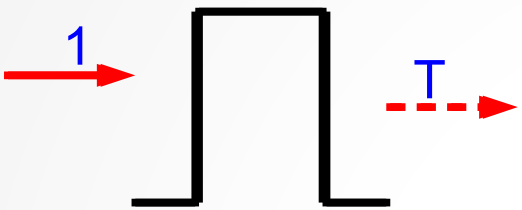
- projectile: **^{20}Ne** – strongly deformed nucleus:

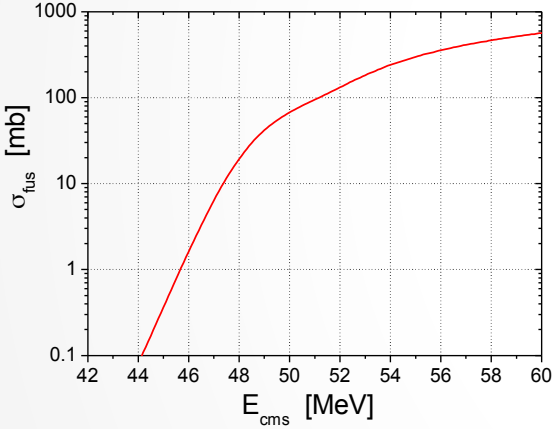
  $\beta_2 = 0.46$, $\beta_3 = 0.39$, $\beta_4 = 0.27$

- Coupled Channels Method predicts **"structured" barrier height distribution** for systems **^{20}Ne+X**



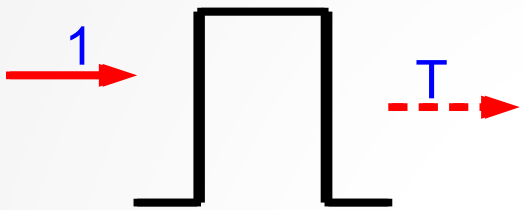
Methods of barrier height distributions experimental determination

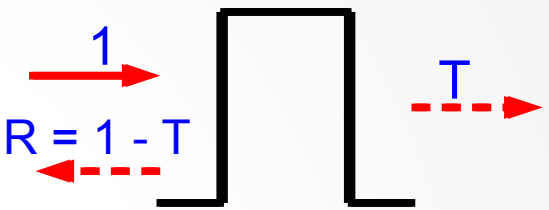


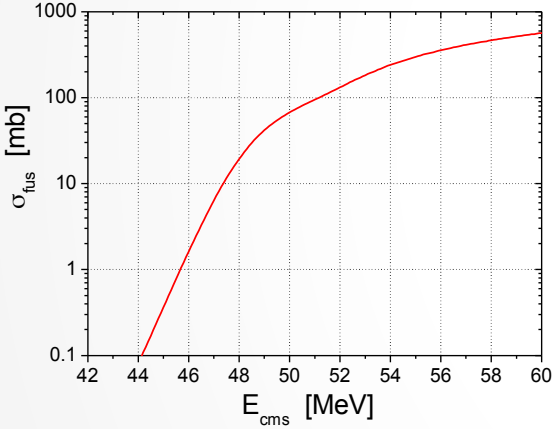


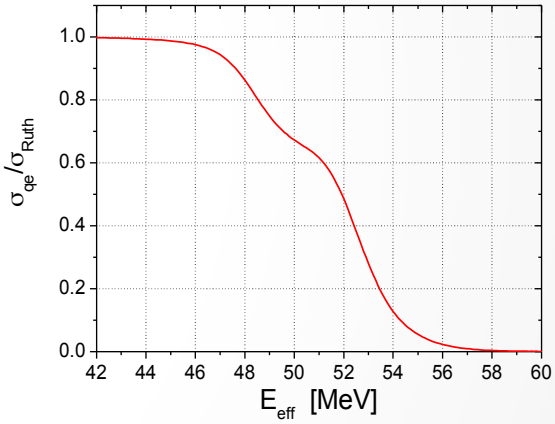
$$D_{fus}(E) = \frac{d^2}{dE^2}\left(E\sigma_{fus}\right)$$

Methods of barrier height distributions experimental determination







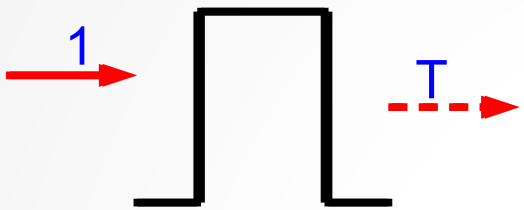


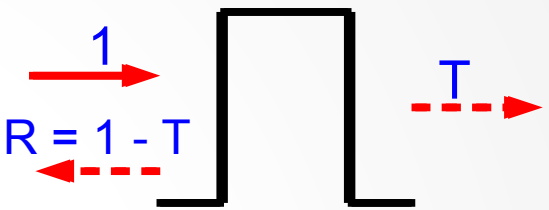
$$D_{fus}(E) = \frac{d^2}{dE^2}\left(E\sigma_{fus}\right)$$

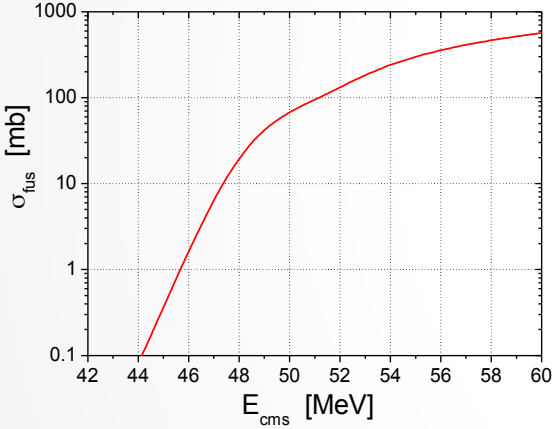
$$D_{eq}(E) = -\frac{d}{dE}\left(\frac{\sigma_{qe}}{\sigma_{Ruth}}\right)$$

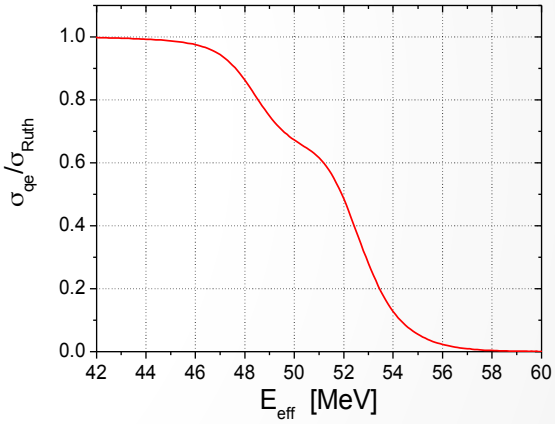
where $E_{eff} = \dfrac{2E}{1 + cosec(\theta/2)}$

Methods of barrier height distributions experimental determination







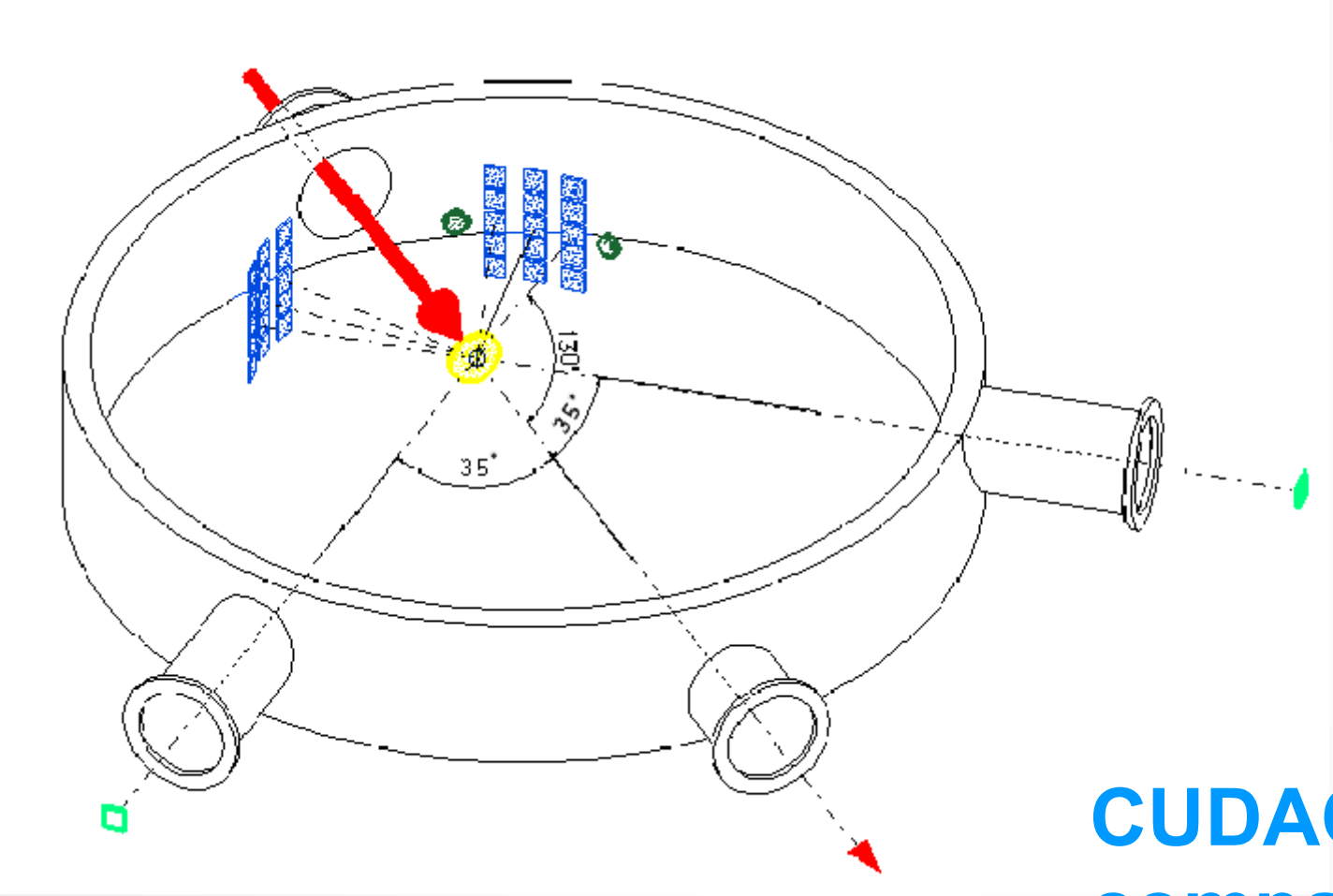


$$D_{fus}(E) = \frac{d^2}{dE^2}\left(E\sigma_{fus}\right)$$

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

Aproximate equivalence of both methods is shown in L.F. Canto *et al.*, Phys. Rep. 424 (2006)1

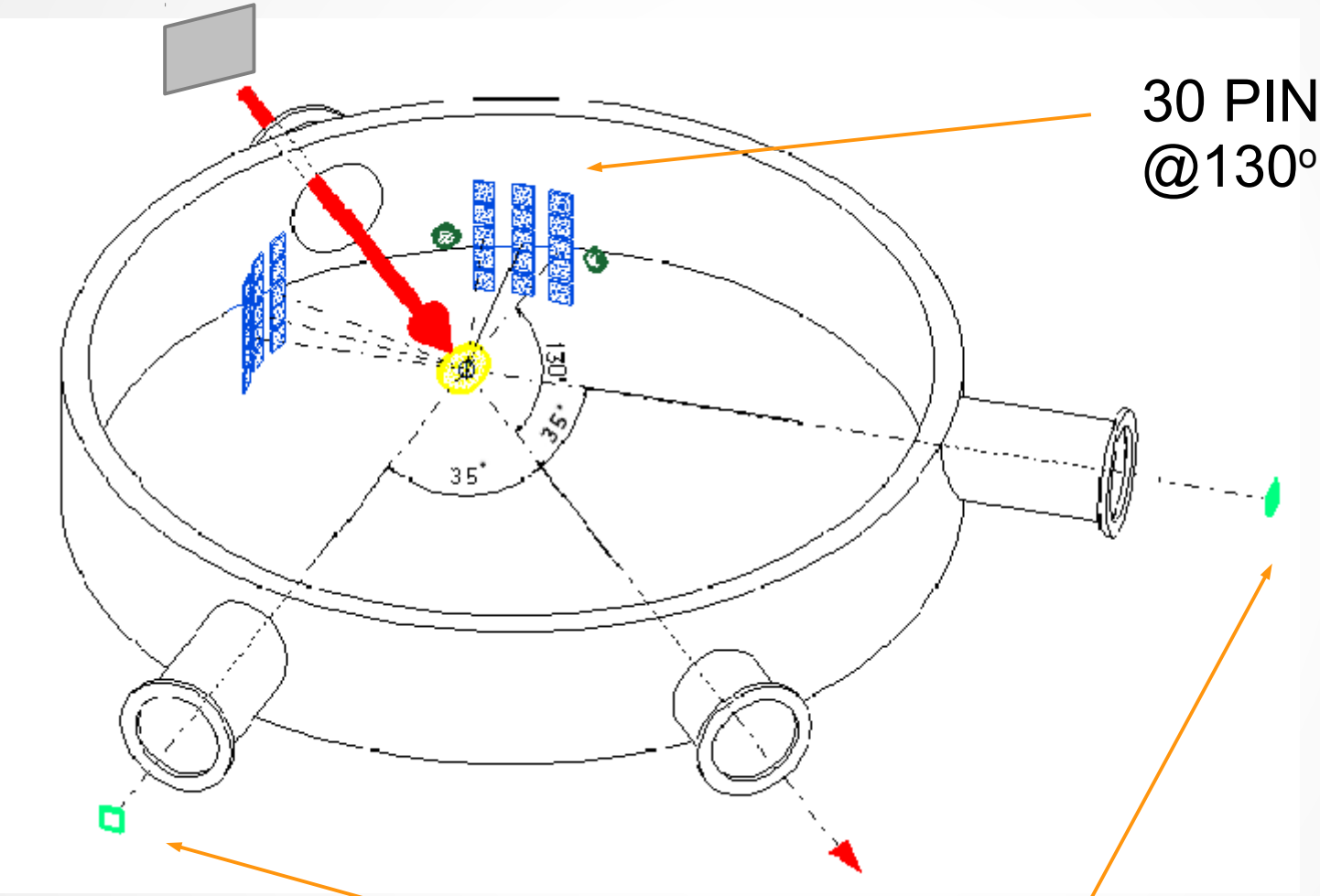
Experimental set-up



CUDAC:
compact chamber
(diameter 40 cm)

Experimental set-up

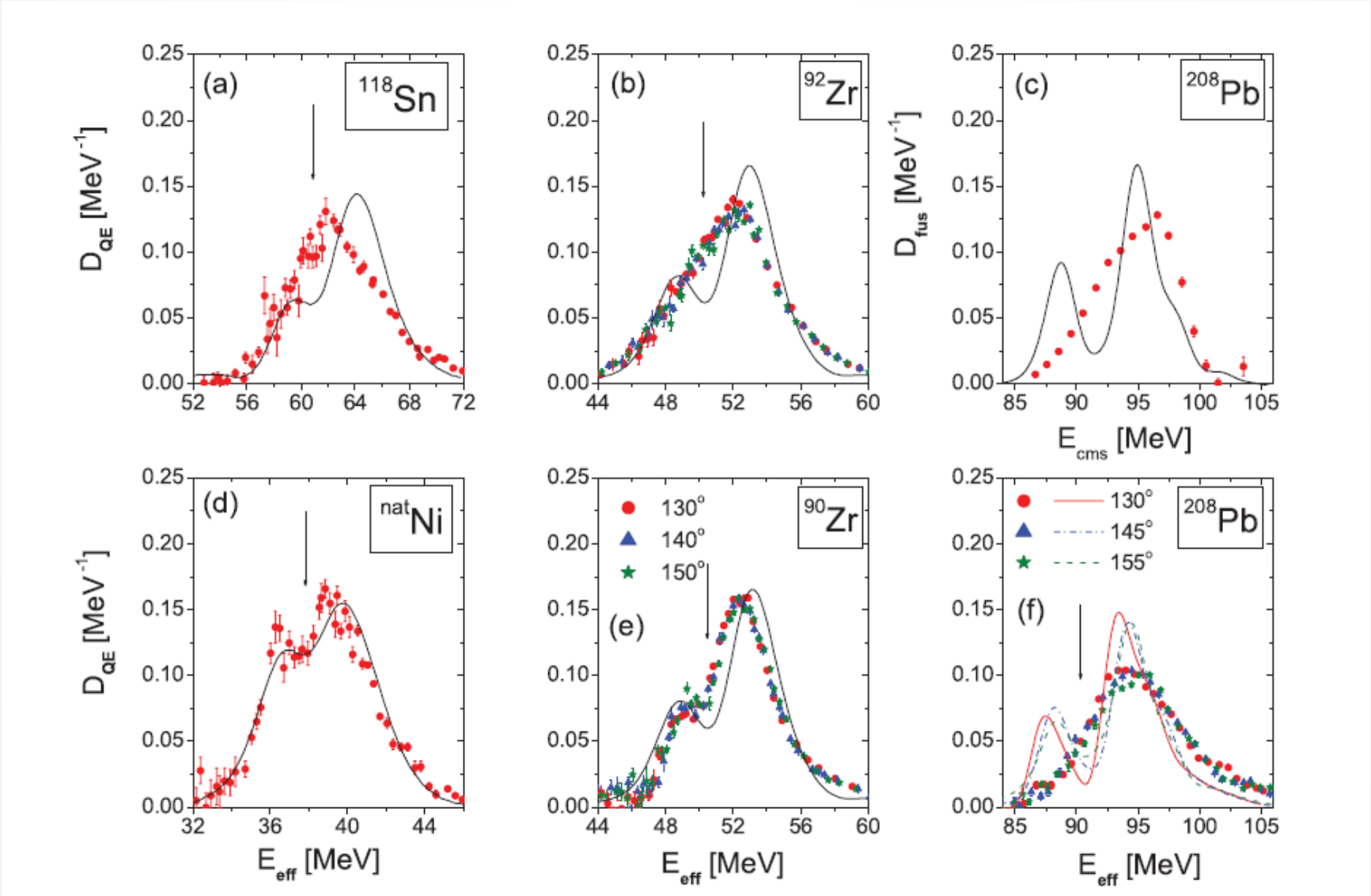
degrader



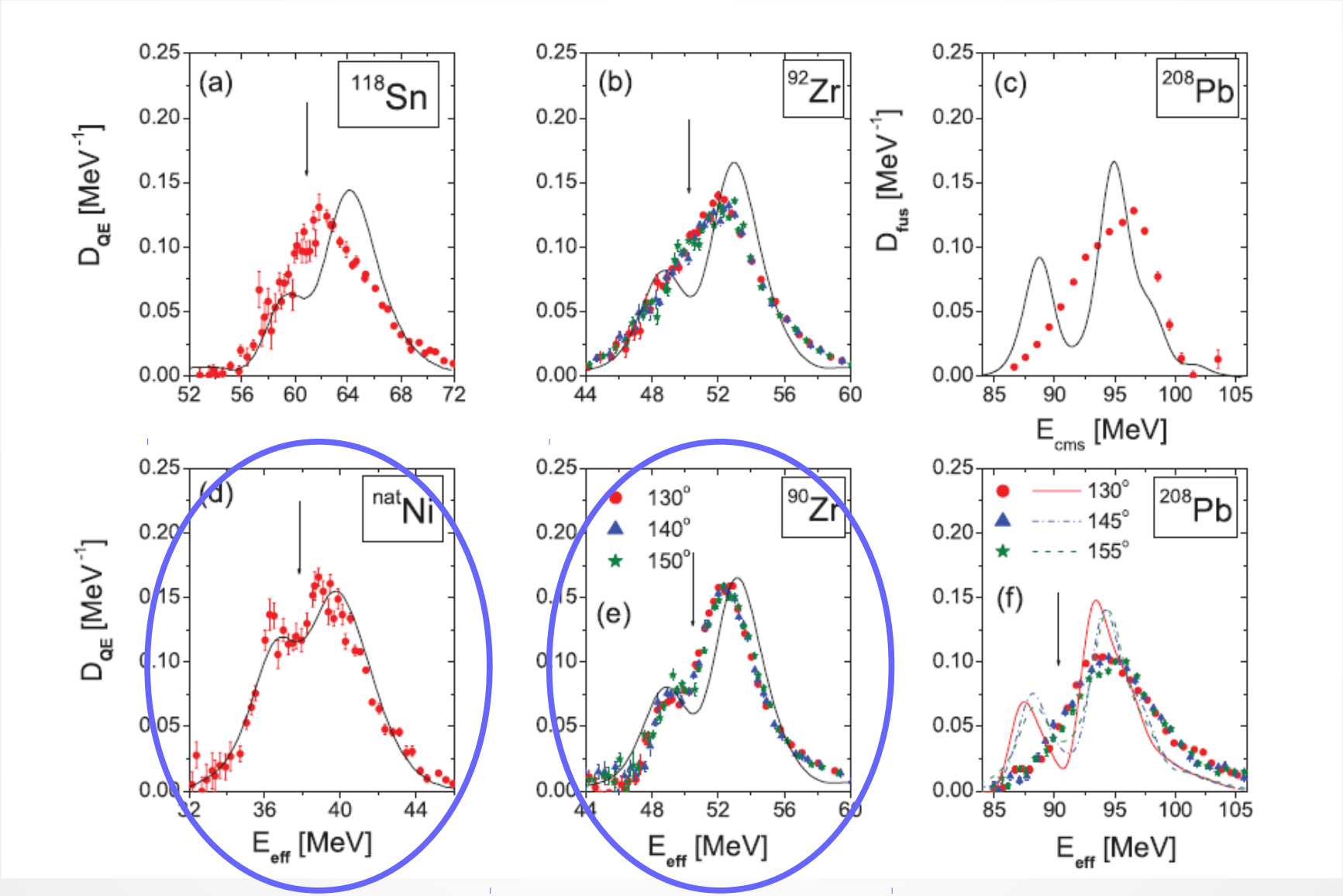
30 PIN diods 1x1cm
@130°, 140°, 150°

2 PIN diods @ 35°

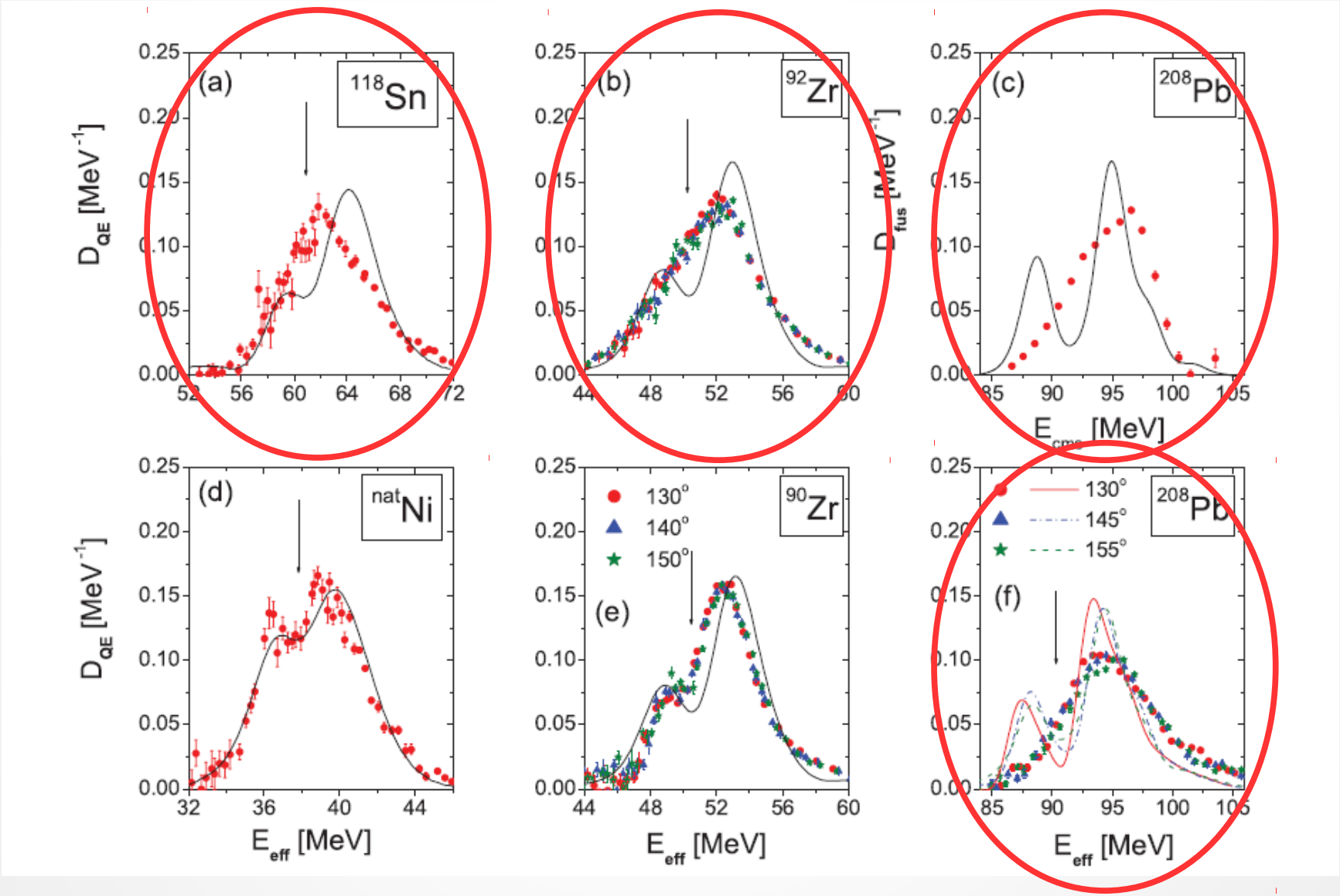
Compilation of **barrier height distributions** measured with ^{20}**Ne** projectile



Compilation of **barrier height distributions** measured with ^{20}**Ne** projectile



Compilation of **barrier height distributions** measured with ^{20}**Ne** projectile



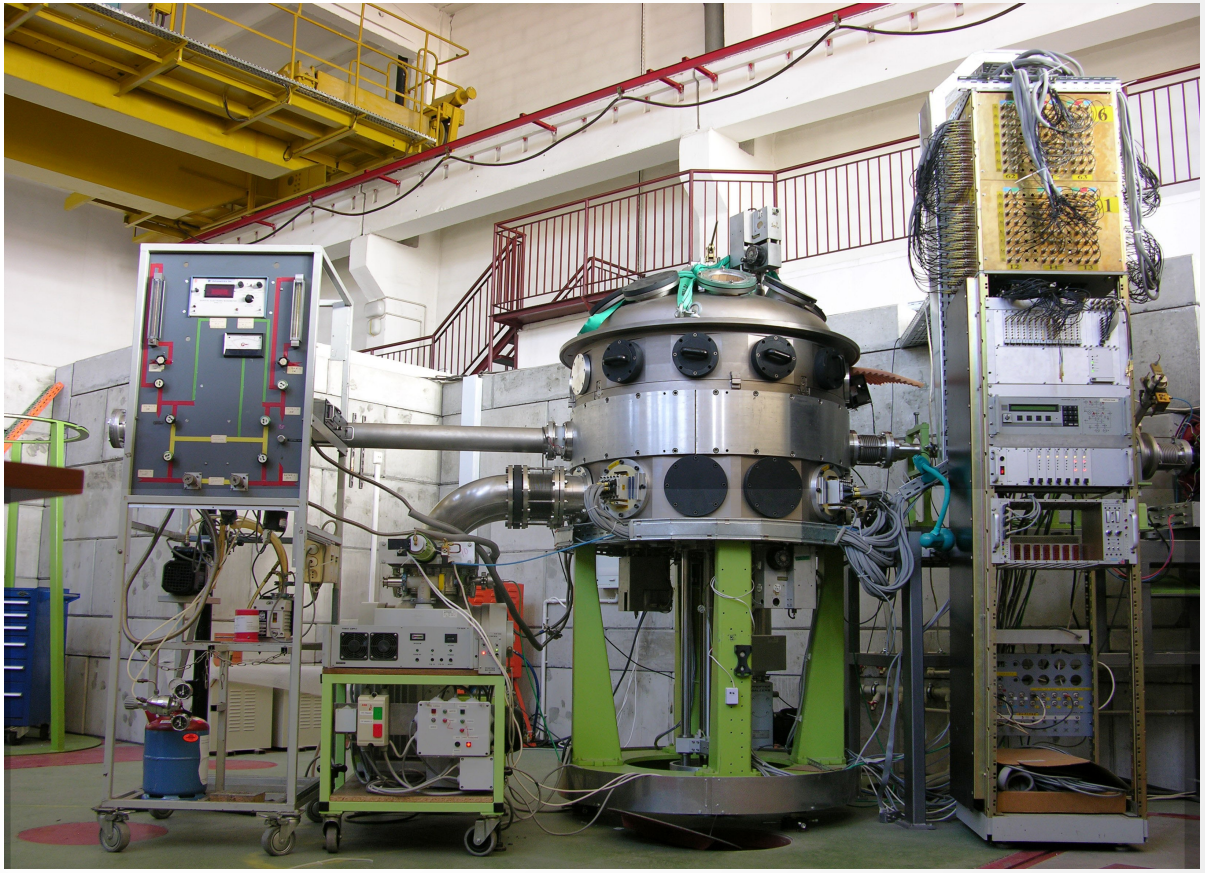
Possible explanation for difference between CC calculations and experimental data

- weak reaction channels? not taken into account in CC calculations e.g. transfer α, n, ...

- check of the hypothesis: measurements of transfer cross sections

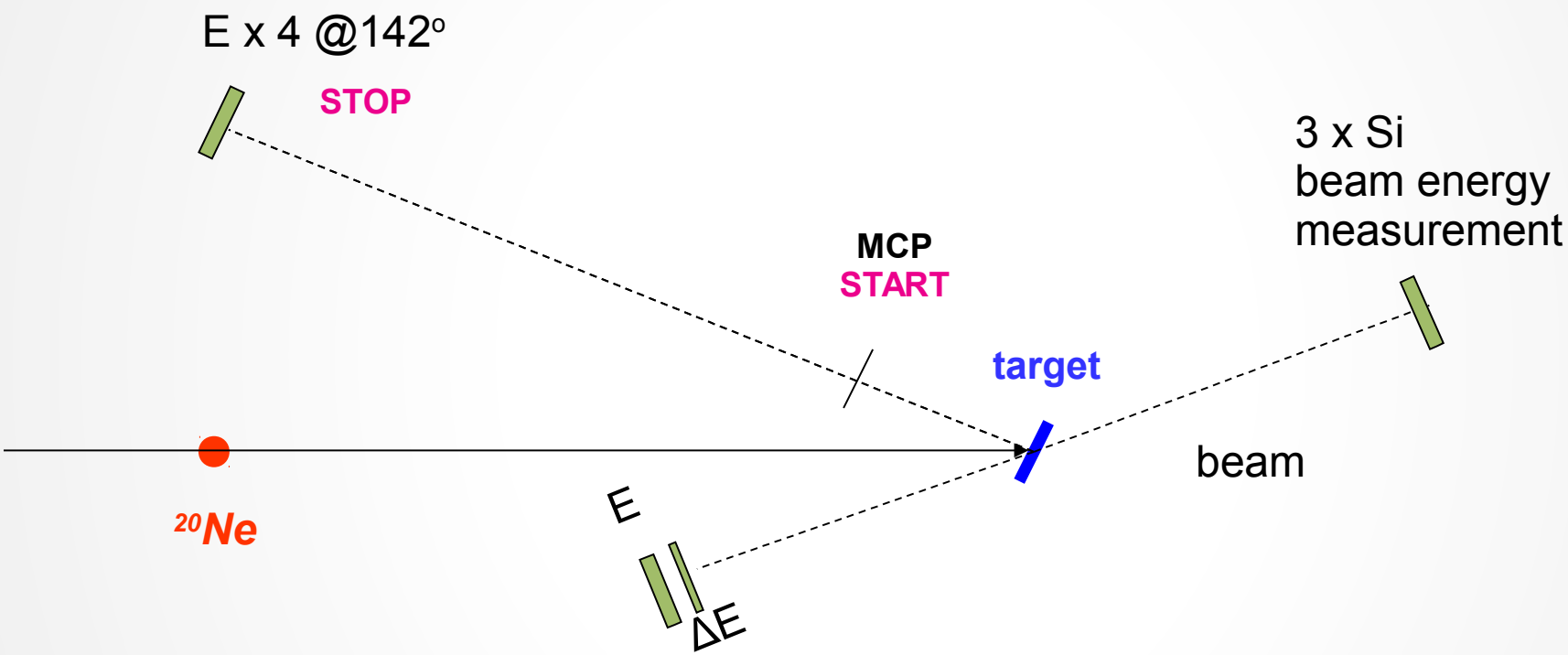
Measurement of transfer cross sections

- performed at HIL, ICARE scattering chamber employed

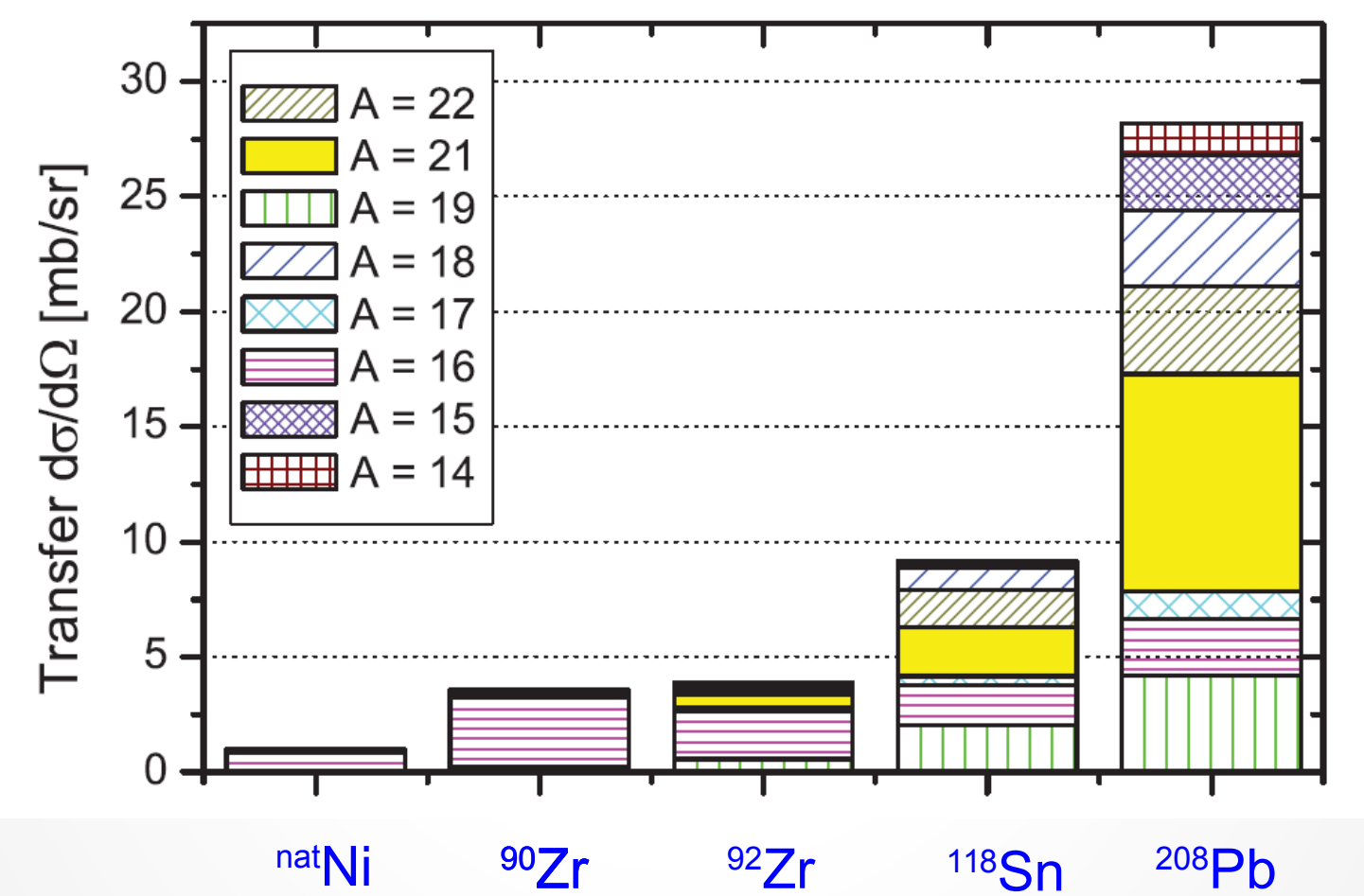


- product identification:
  - mass: E – ToF
  - charge: E – ΔE

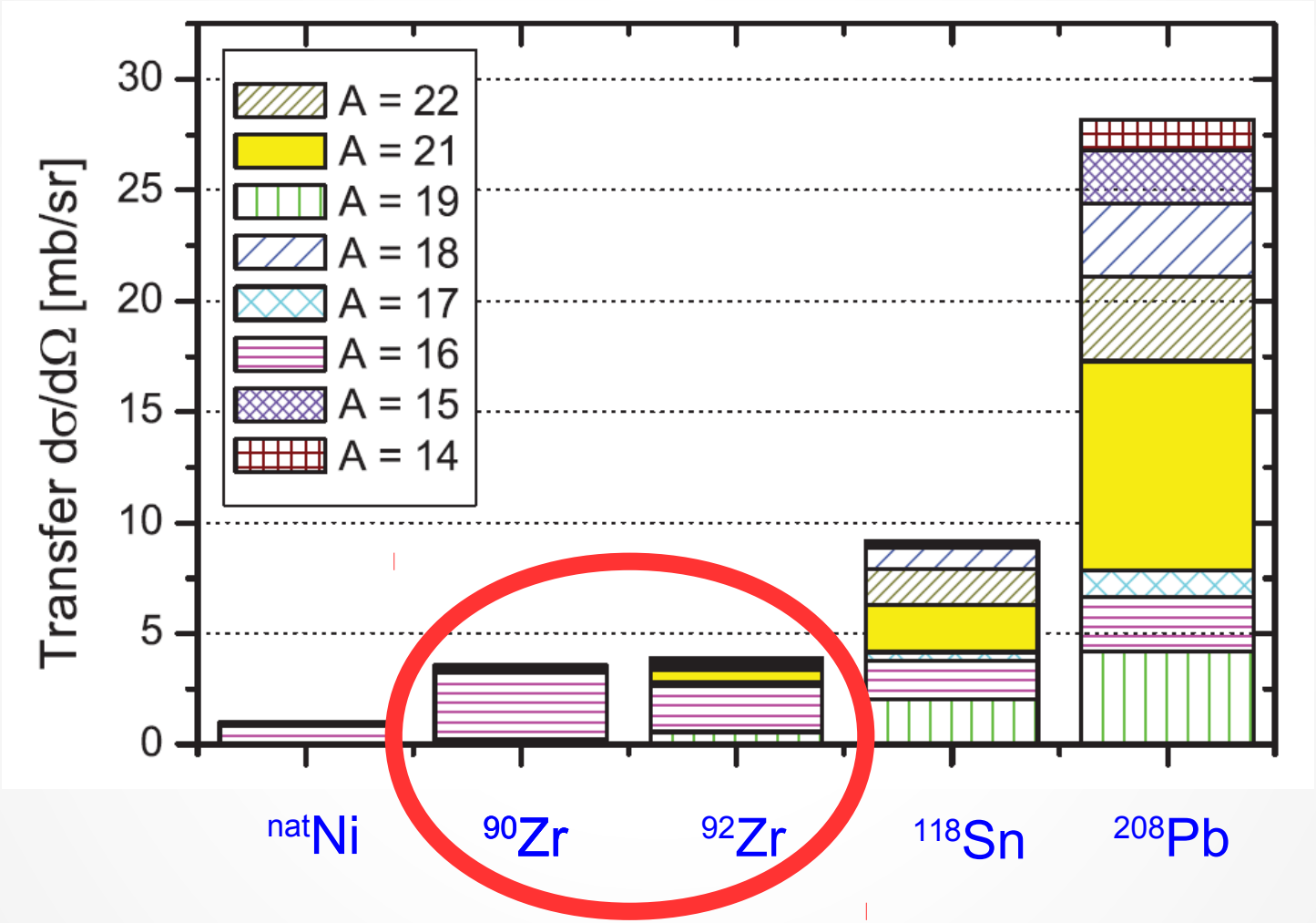
Experimental set-up



Measured transfer cross sections



Measured transfer cross sections



Possible explanation for difference between CC calculations and experimental data

- weak reaction channels? not taken into account in CC calculations e.g. transfer α, n...

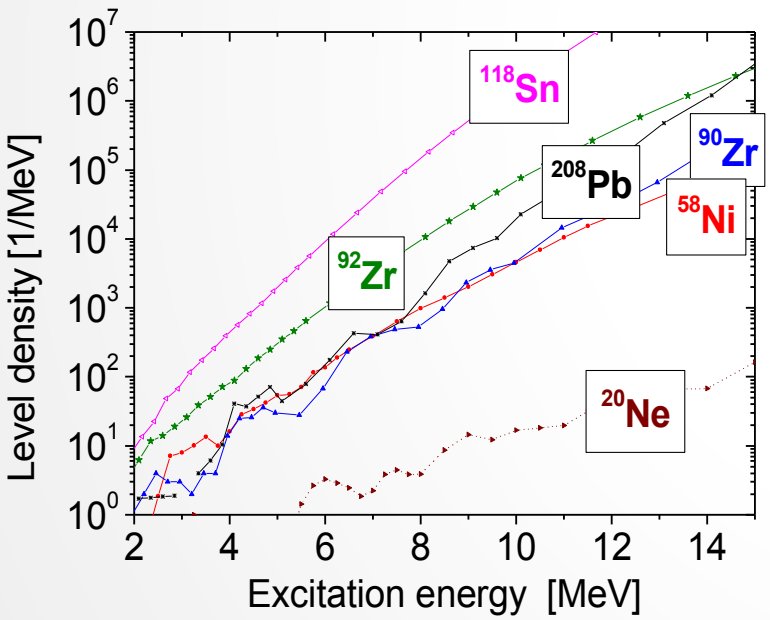
not for all cases

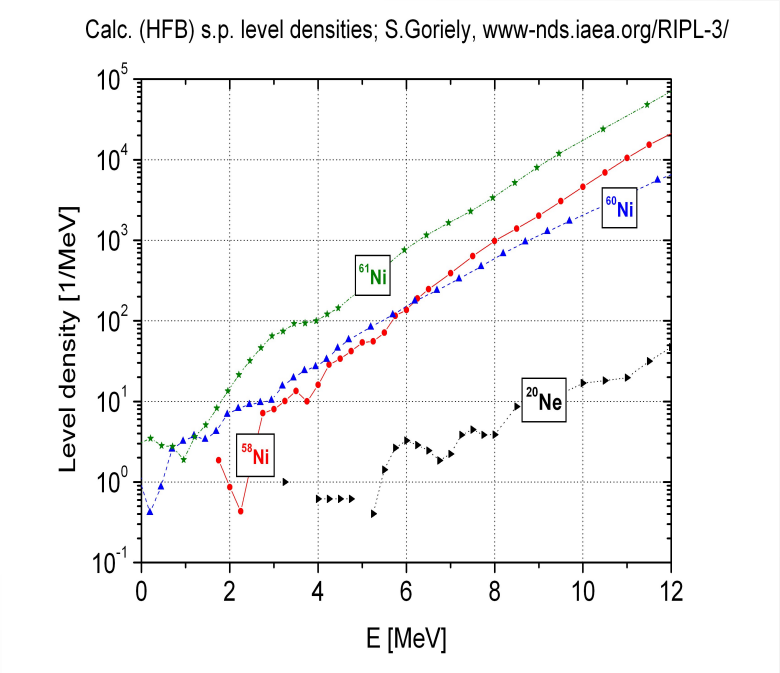
- weak reaction channels: non-collective (single particle) excitation?

Noncollective excitations?

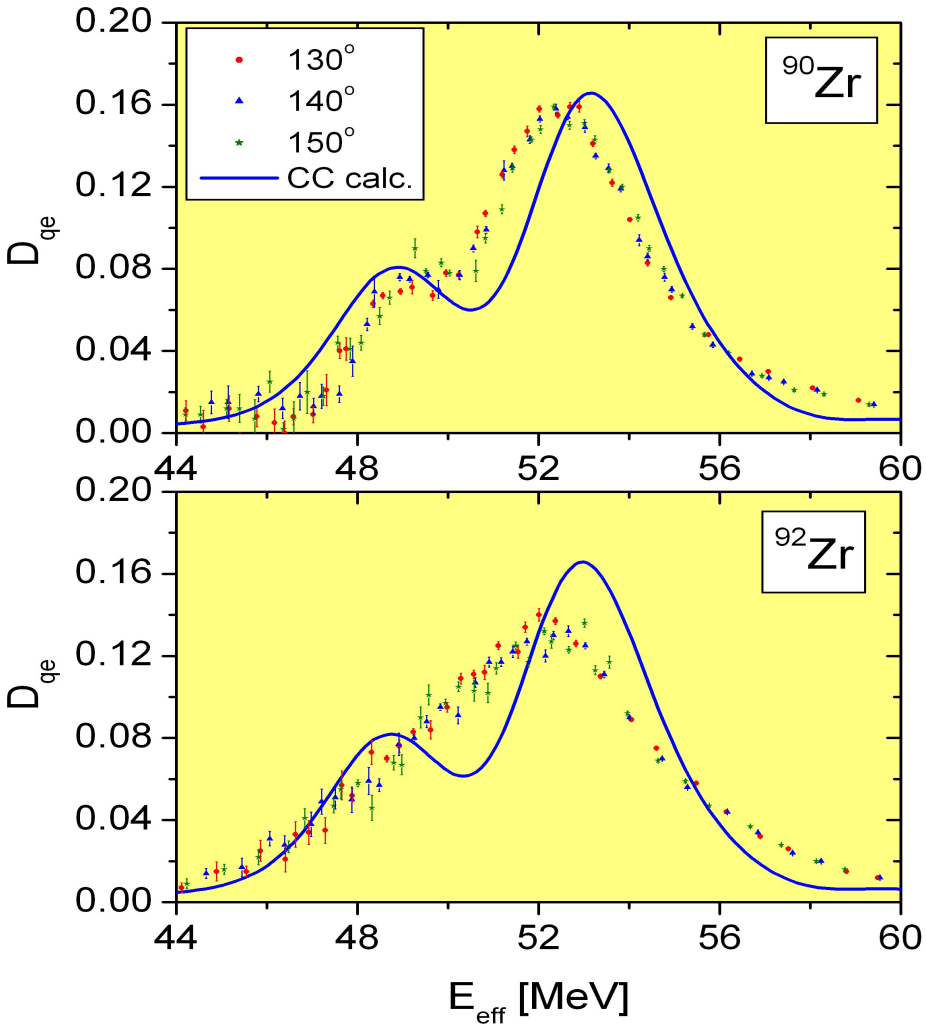
^{90}Zr, ^{92}Zr and ^{58}Ni, ^{60}Ni, ^{61}Ni

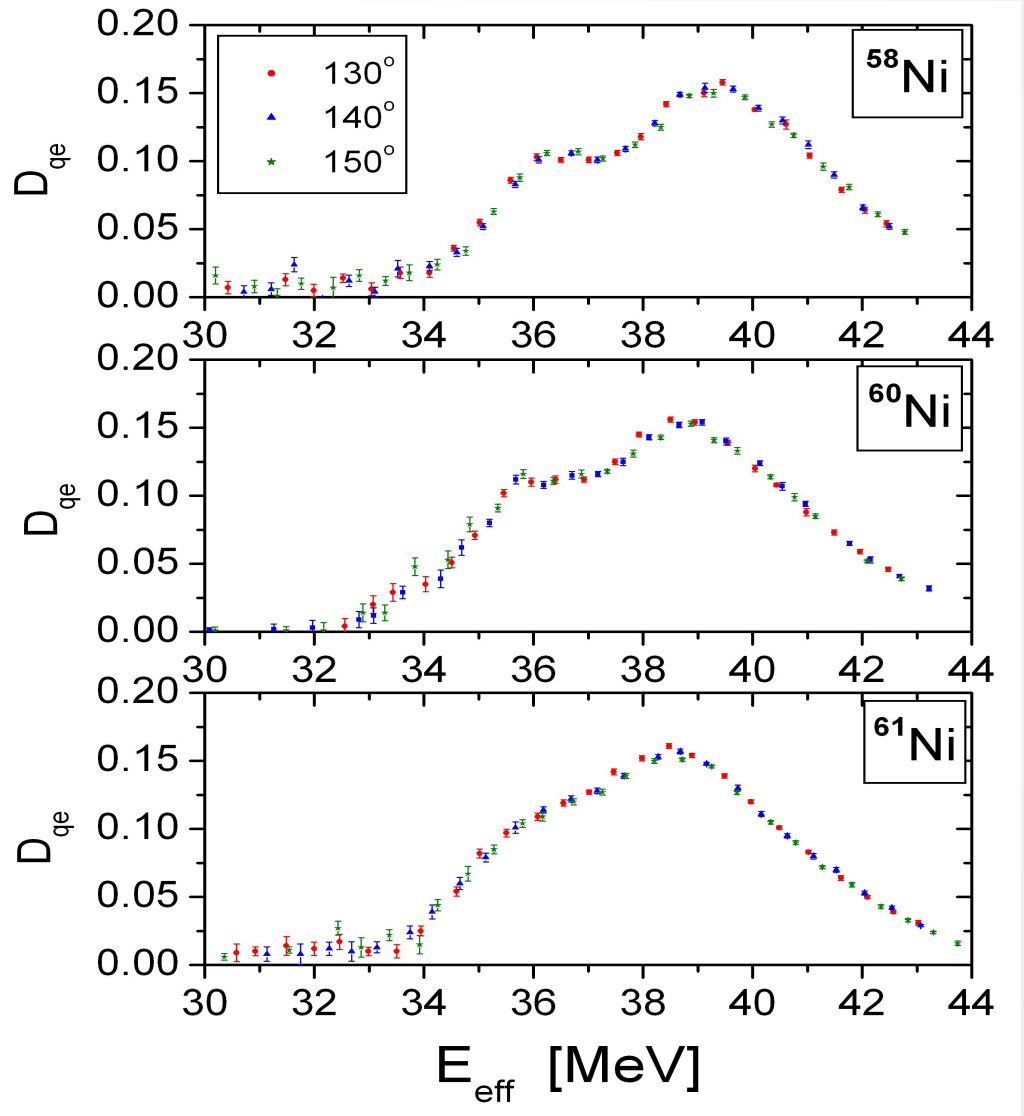
- isotopes differ by levels density





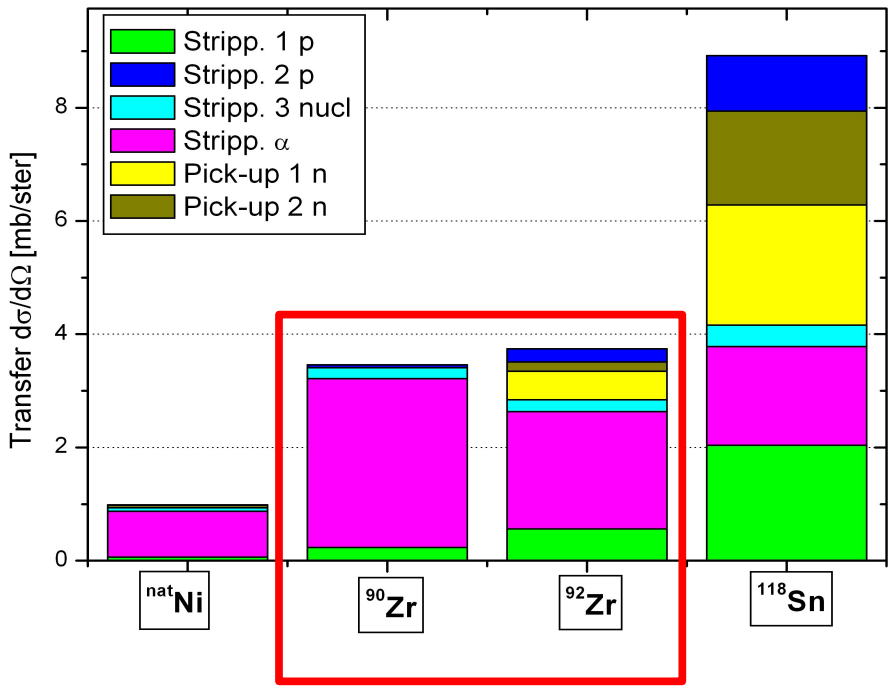
D_{qe} – experimental results

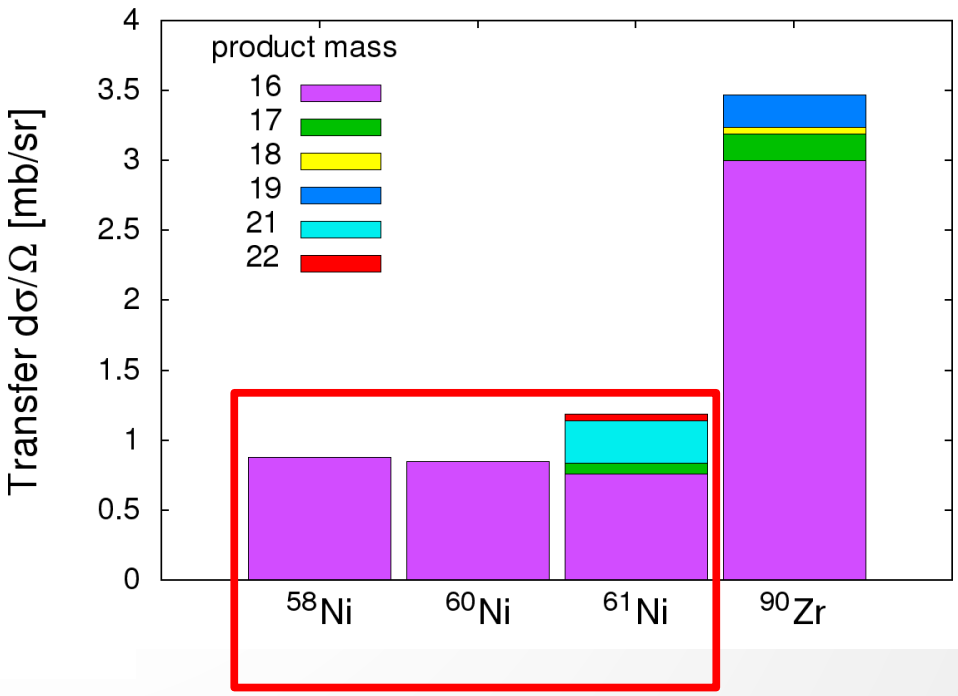




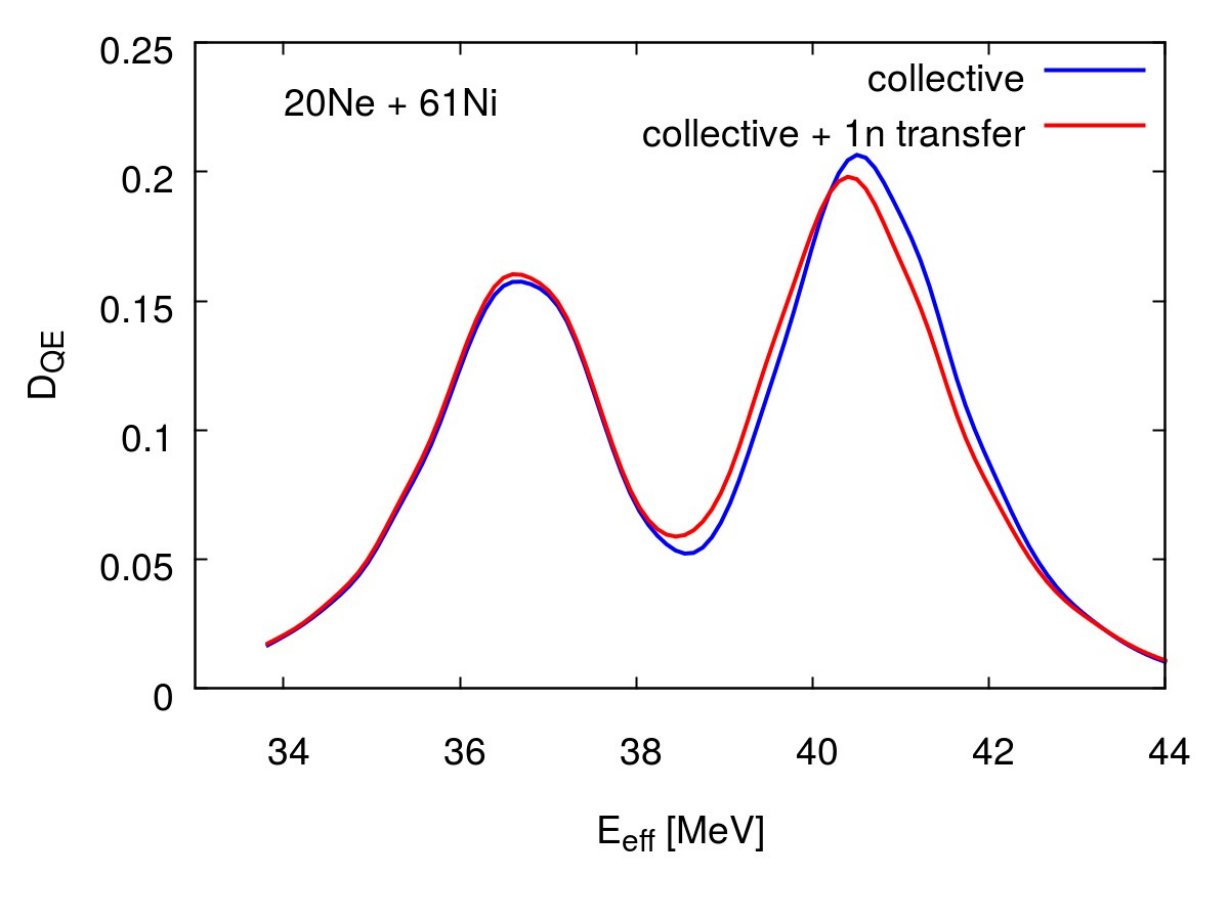
Transfer cross sections

Transfer cross sections measured at 142° with beam energy around Coulomb barrier





1n transfer – CC calculations



influence of 1n transfer on D_{QE} is marginal

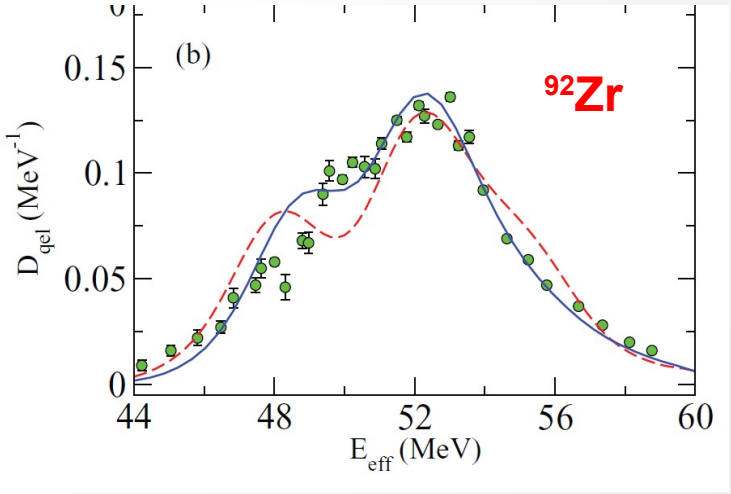
Role of non-collective excitations

- 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)
- Dissipative (decoherent) dynamics → beyond the standard CC model

How to take into account non-collective excitations?

- irreversible dynamics: A.Diaz-Torres
- CC + random matrix theory: S. Yusa, K. Hagino

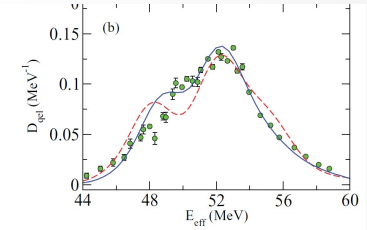
  PRC 88 (2013) 054621 ← ^{20}Ne + ^{90,92}Zr
  PRC 88 (2013) 044620



How to take into account non-collective excitations?

- irreversible dynamics: A.Diaz-Torres
- CC + Random Matrix Theory (RMT) : S. Yusa, K. Hagino

  PRC 88 (2013) 054621 ← ^{20}Ne + ^{90,92}Zr
  PRC 88 (2013) 044620



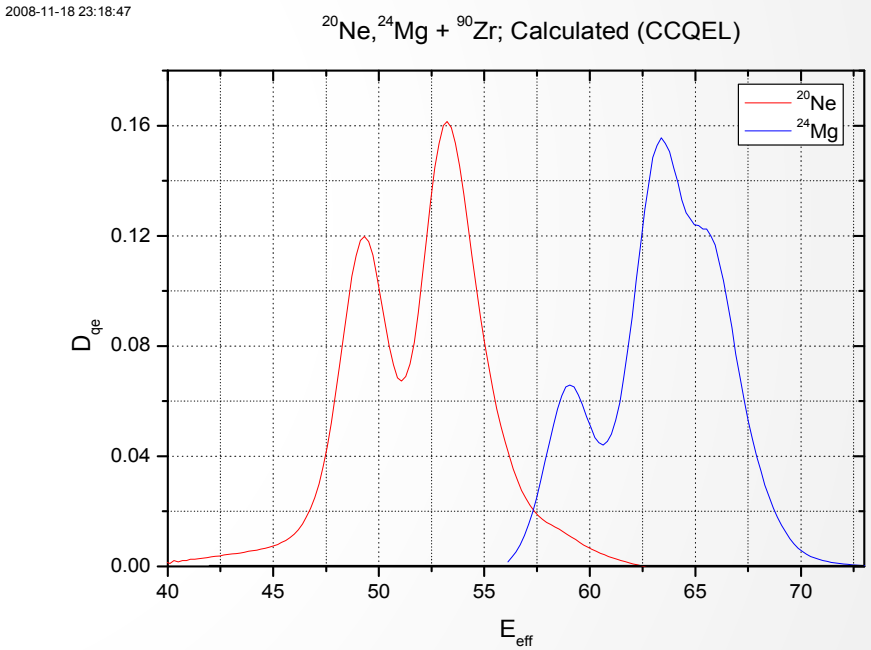
- new improved CC+RMT calculations for ^{20}Ne + ^{90,92}Zr and ^{20}Ne + ^{58,60,61}Ni in progress
  - preliminary results very promising

Summary & conclusions

- The weak reaction channels can considerably influence the barrier height distribution via:
  - transfers (^{208}Pb)
  - non-collective single particle exctiations (^{61}Ni, ^{92}Zr)
- Single particle levels are excited during nuclear reactions → nuclear intrinsic degrees of freedom act as environment for nuclear reaction → coupling to environment → dissipation

Future plans

- near future: studies of barrier height distribution using Mg projectile – accepted proposal @ LNS Catania (tandem beam, CHIMERA chamber)



- further future: measurement of barrier height distribution for ^{20}Ne+^{92}Zr systems employing fusion method

Thank you for your attention

The Barrier Collaboration

University of Warsaw: J.Jastrzębski, A.Kordyasz, M.Kowalczyk, M.Kisieliński, M.Palacz, K.Piasecki, E.Piasecki, K.Rusek, A.Stolarz, Ł.Świderski, A.Trzcińska

Białystok University: T.Krogulski

Institute of Nuclear Physics (Kraków): S.Kliczewski. R. Siudak

Technische Universitat (Darmstadt): M.Mutterer

GSI (Darmstadt): P.Koczoń, B.Lommel

Radium Institute (St. Petersburg): S.Kchlebnikov, G.Tyurin

University of Jyvaskyla: W.Trzaska, M. Sillanpää

Tohoku University: K.Hagino

IPN (Orsay): N.Rowley

Kharkiv University: E.Koshchiy

Ntl. Centre for Nucl. Research (Świerk): N.Keeley, I.Strojek

LNL (Legnaro): A.Stefanini

LNS (Catania): P.Russotto

JINR (Dubna): S.Smirnov, T.Loktev

Institute of Nuclear Physics Almaty/Tanta University (Egypt) : A.Amar

This is the end...