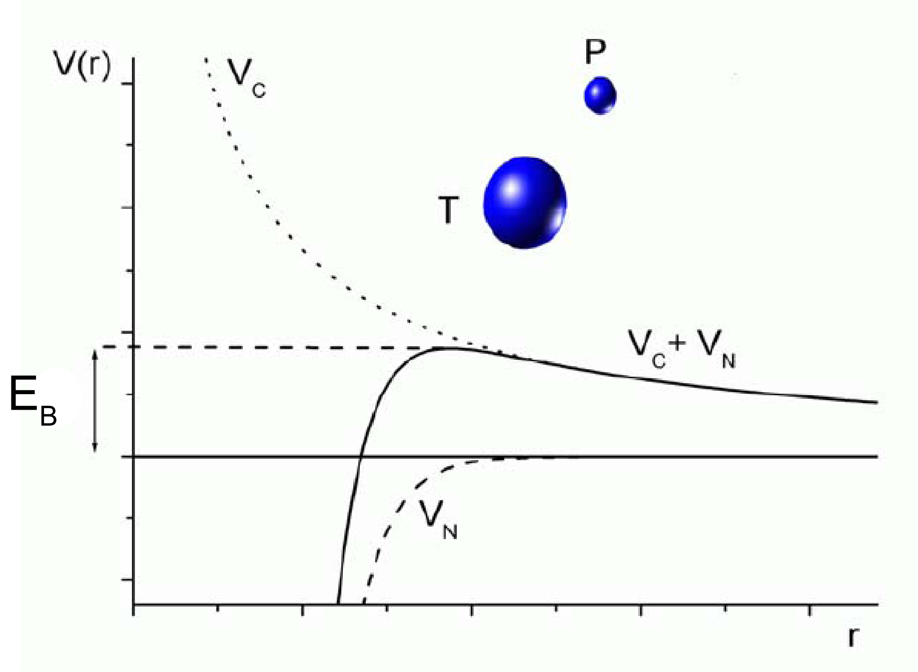
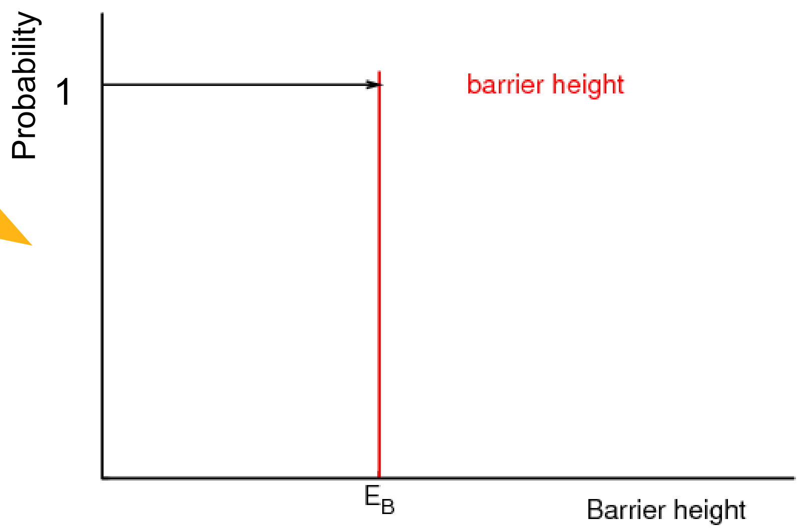
Barrier distributions

Fusion studies

A. Trzcińska for BARRIERS collaboration

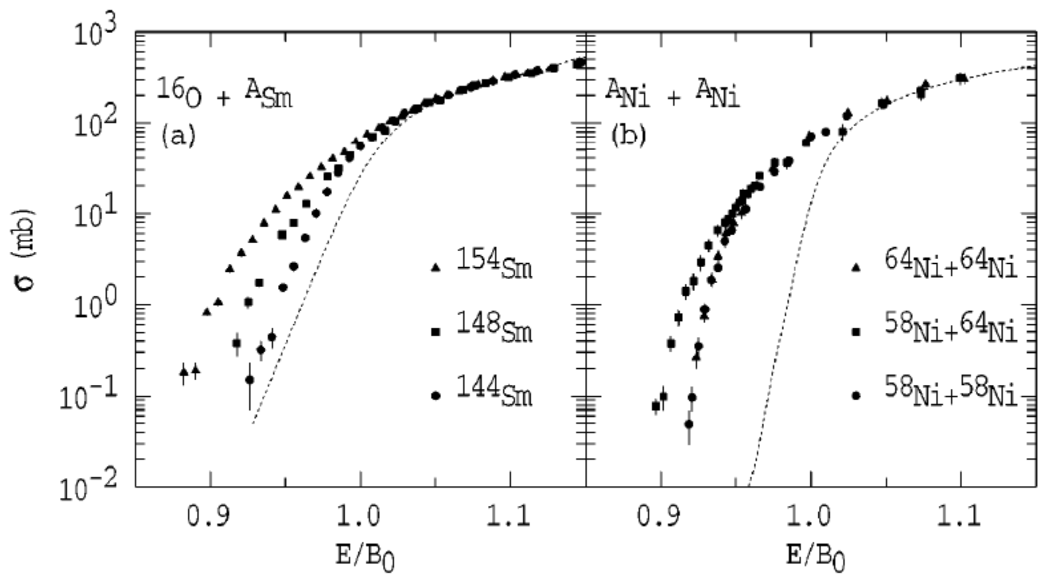
Coulomb barrier height (single barrier)





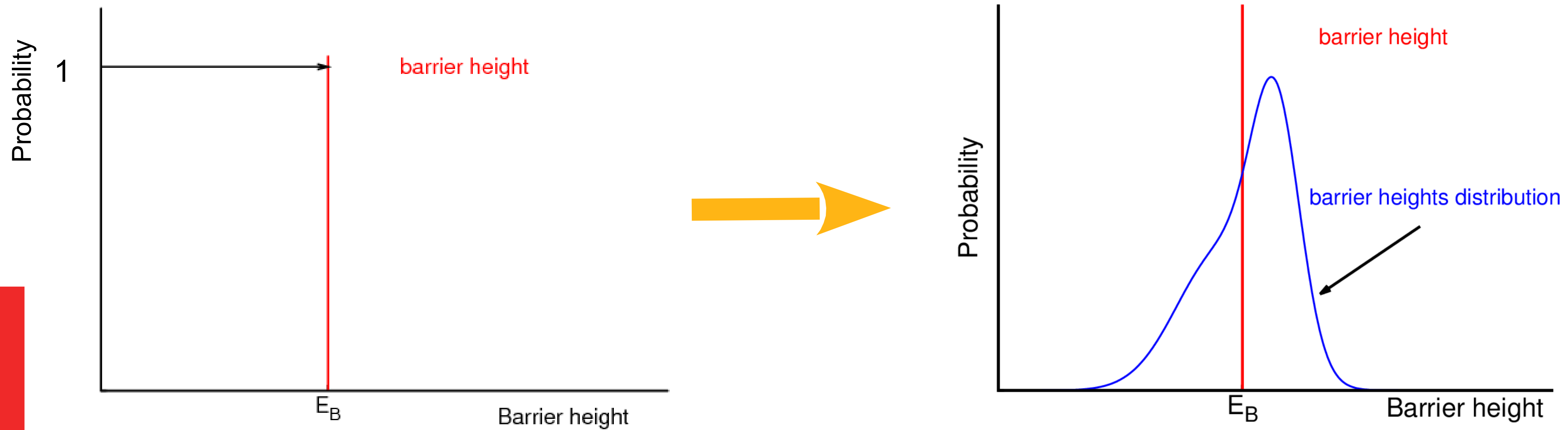
From single barrier to barrier height distribution

- 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. $^{16}O + {}^{A}Sm$)



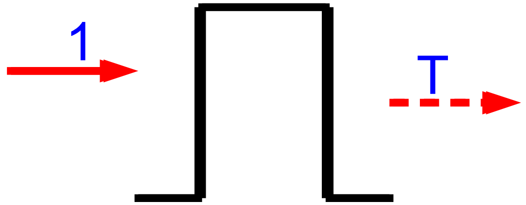
- Good description of fusion cross section with several barriers emerging from <u>couplings to many reaction channels → barrier distribution</u>

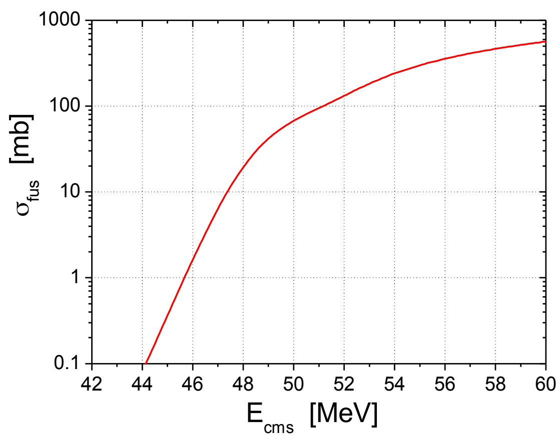
From single barrier to barrier height distribution



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

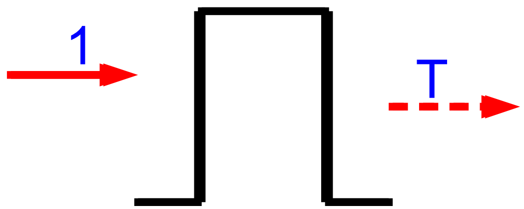
Experimental determination of barrier height distributions

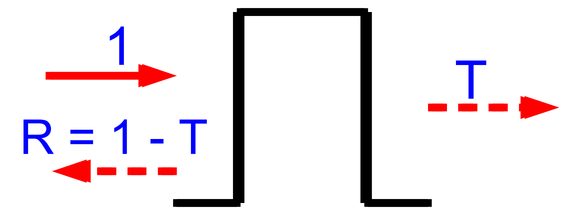


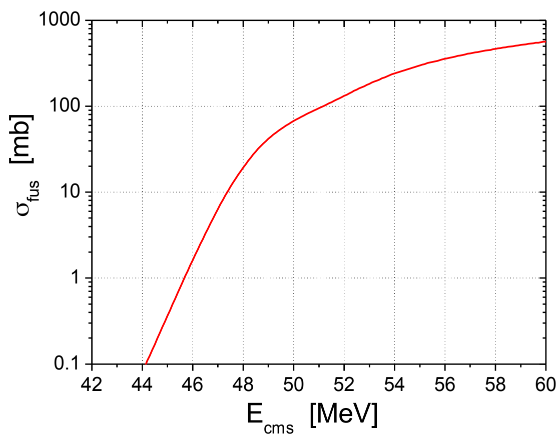


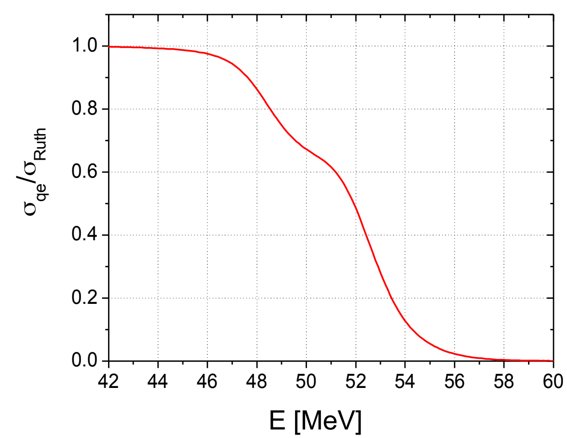
$$D_{fus}(E) = \frac{d^2}{dE^2}\left(E\sigma_{fus}\right)$$

Experimental determination of barrier height distributions







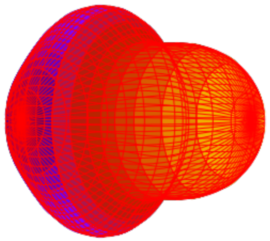


$$D_{fus}(E) = \frac{d^2}{dE^2}(E\sigma_{fus})$$

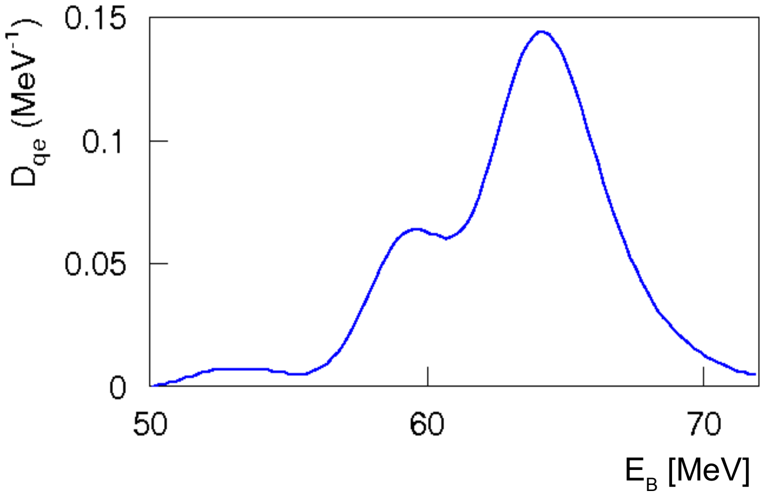
$$D_{qe}(E) = -\frac{d}{dE}\left(\frac{\sigma_{qe}}{\sigma_{Ruth}}\right)$$

BD studies @ HIL (so far)

- projectile: ^{20}**Ne** – strongly deformed nucleus:
  $\beta_2 = 0.46$, $\beta_3 = 0.39$, $\beta_4 = 0.27$

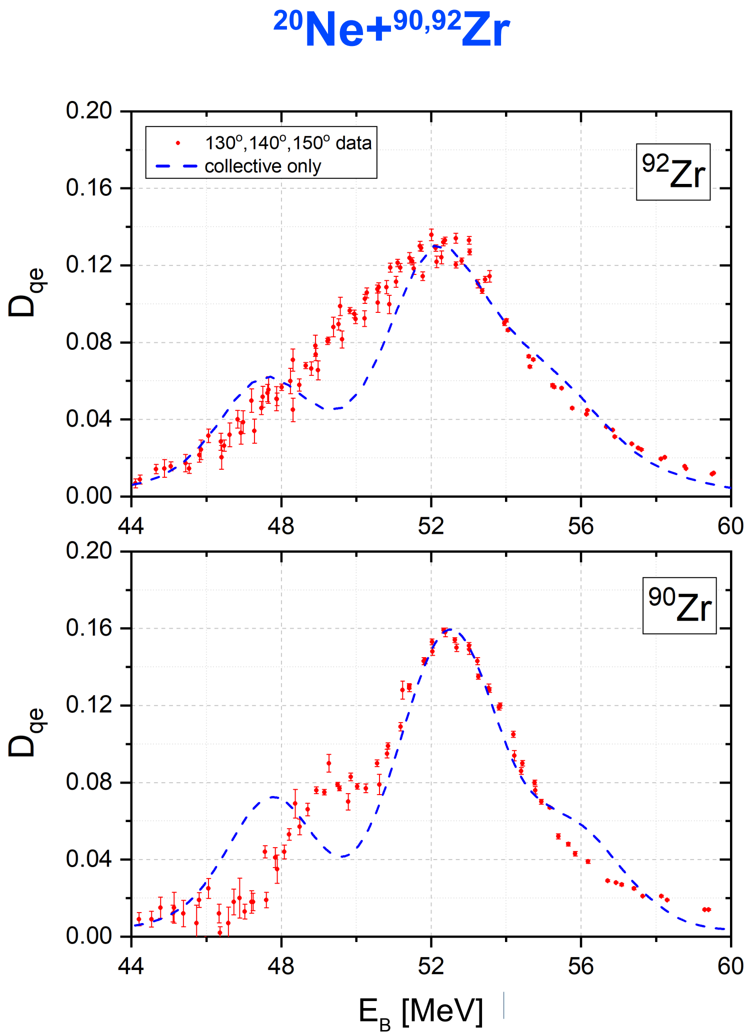


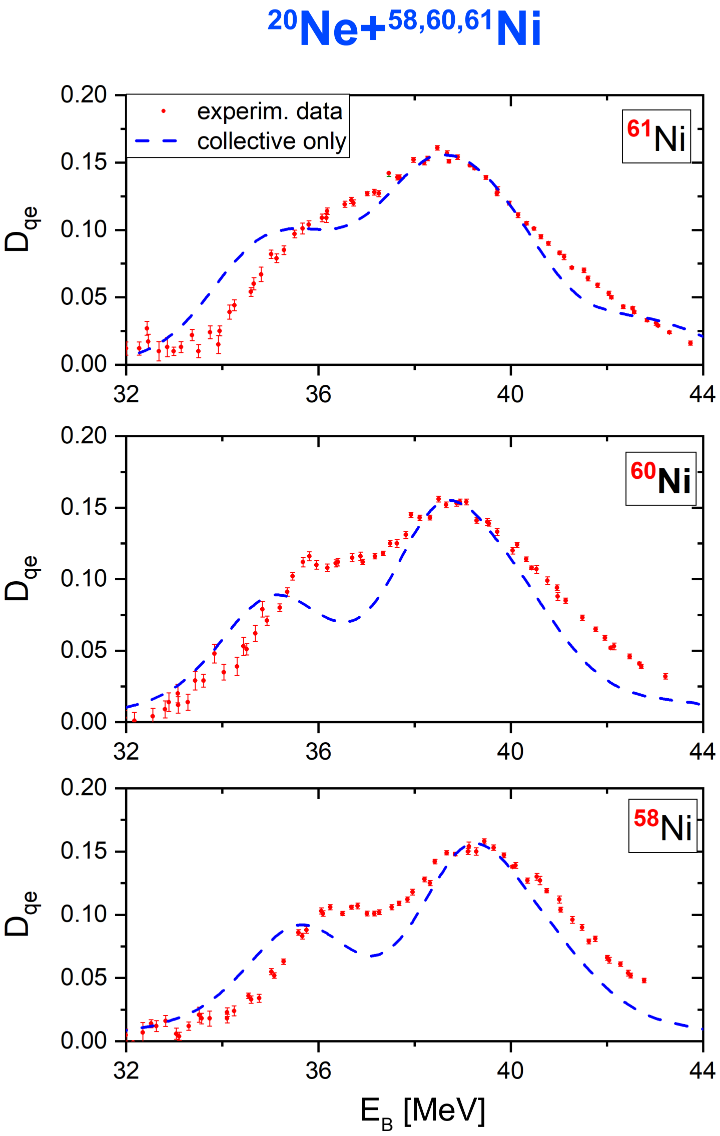
- Coupled Channels Method predicts **“structured” barrier height distribution** for systems ^{20}**Ne+X**



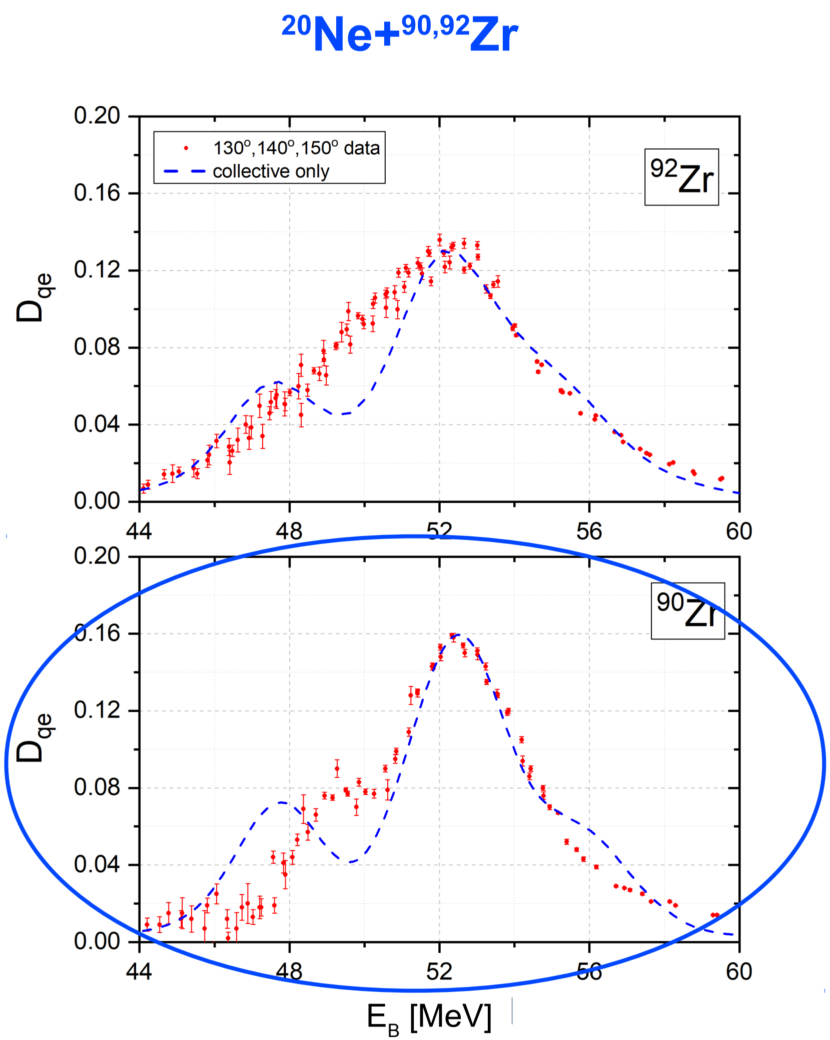
- ^{20}Ne – can be accelerated in cyclotron

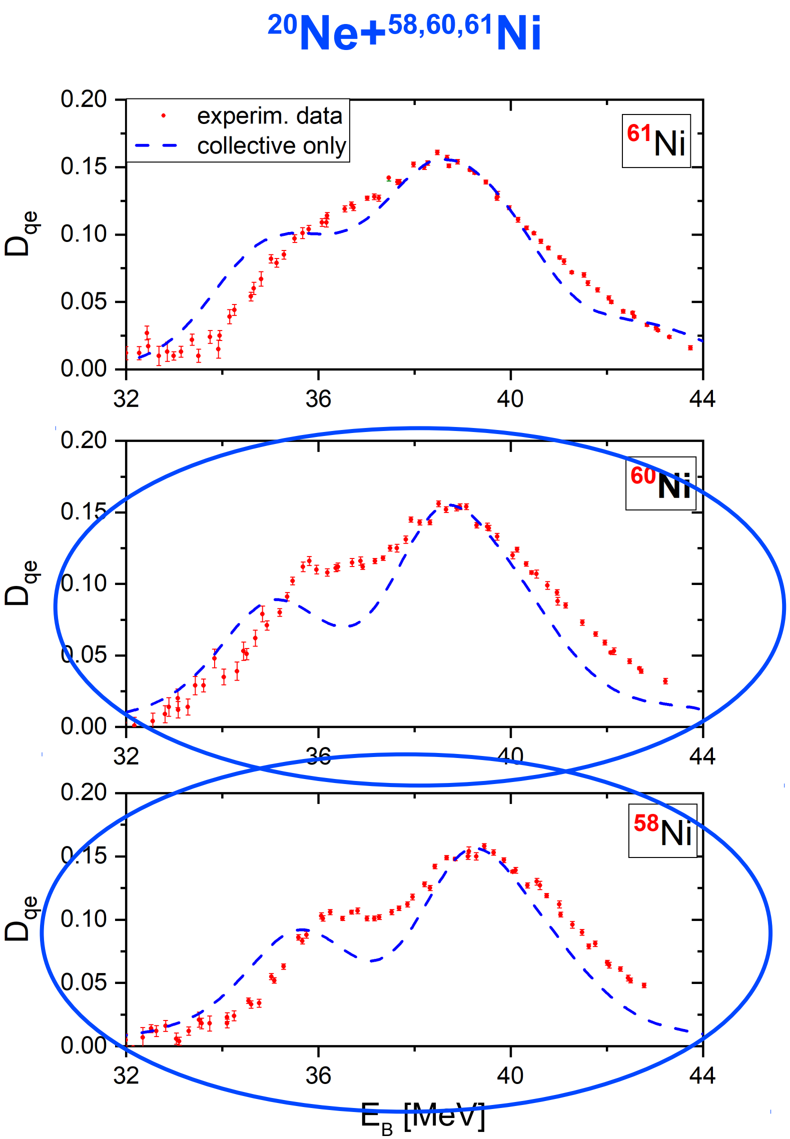
D_{qe} – intriguing experimental results



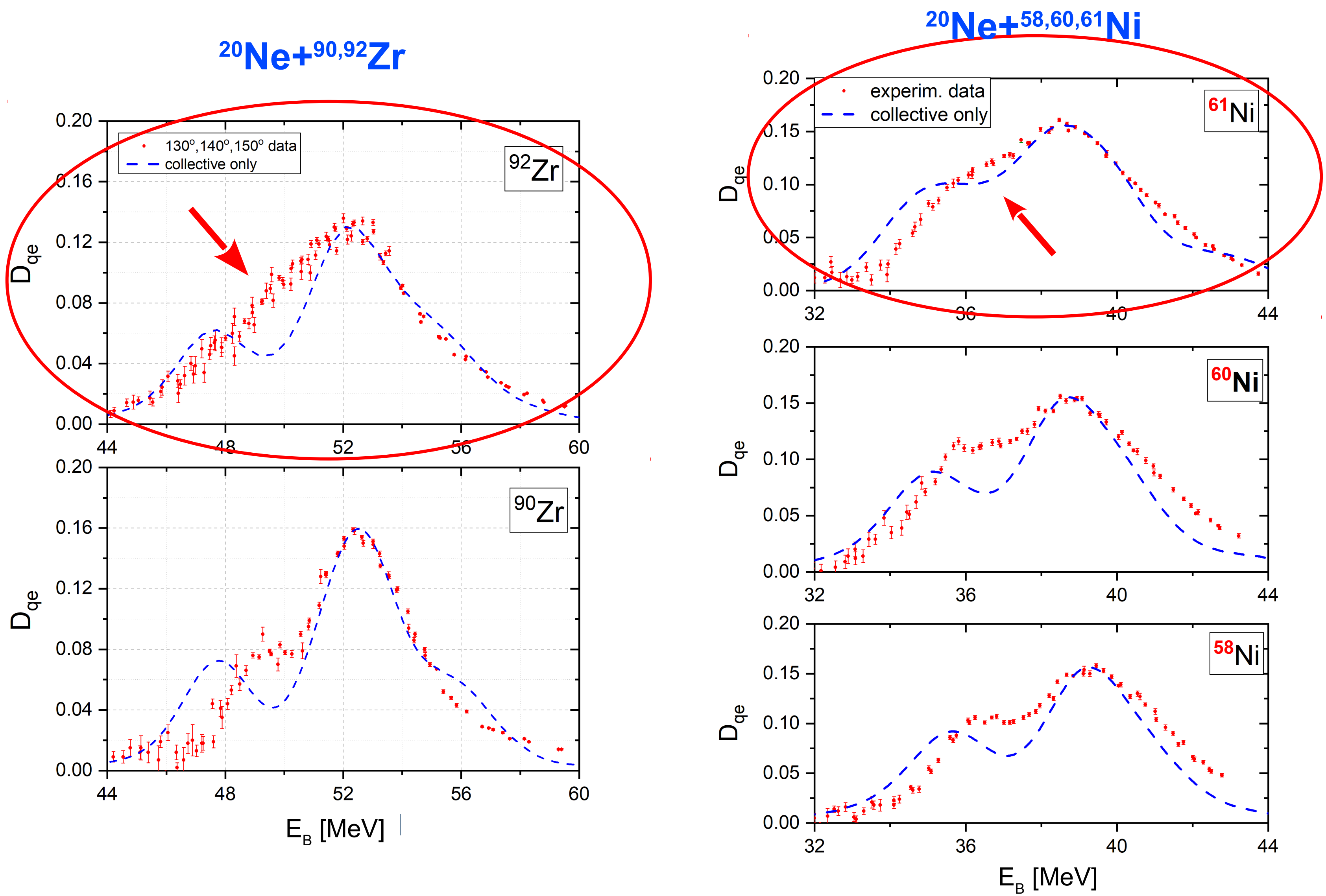


D_{qe} – intriguing experimental results





D_{qe} – intriguing experimental results



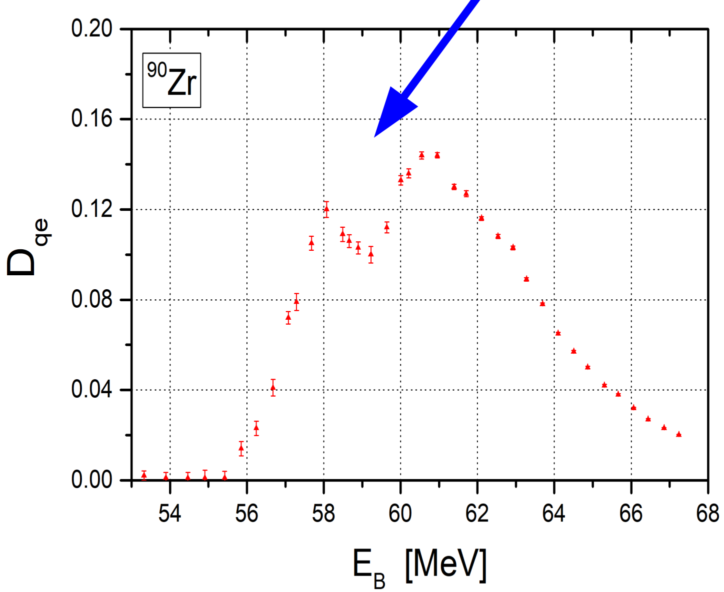
D_{qe} – intriguing experimental results

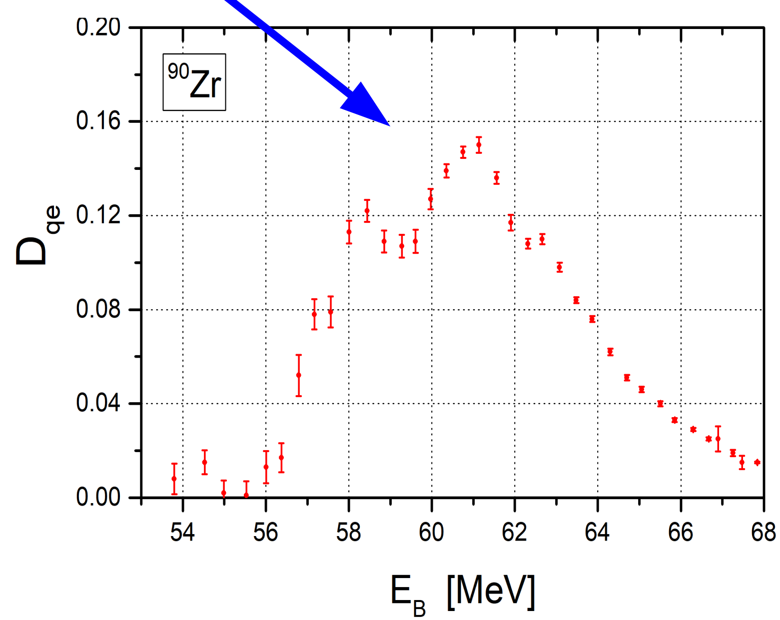
$^{24}Mg + ^{90,92}Zr$ @ LNS Catania

$^{24}Mg + ^{90,92}Zr$; Θ_{cms} = **142°**

$^{24}Mg + ^{90,92}Zr$; Θ_{cms} = **155°**

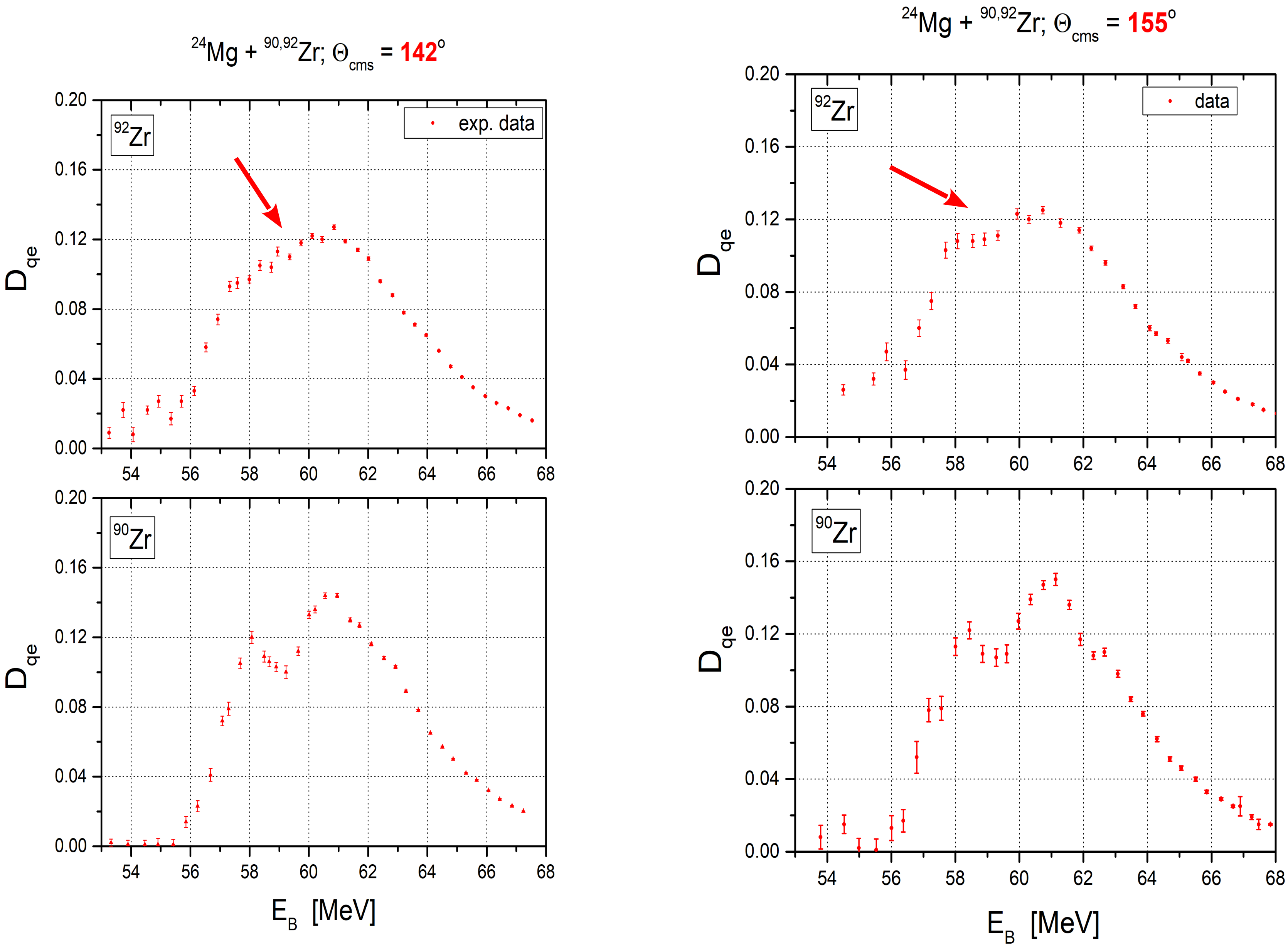
structure – collective excitation of projectile





D_{qe} – intriguing experimental results

$^{24}Mg + ^{90,92}Zr$ @ LNS Catania



Explanation of difference between CC calculations and experimental data?

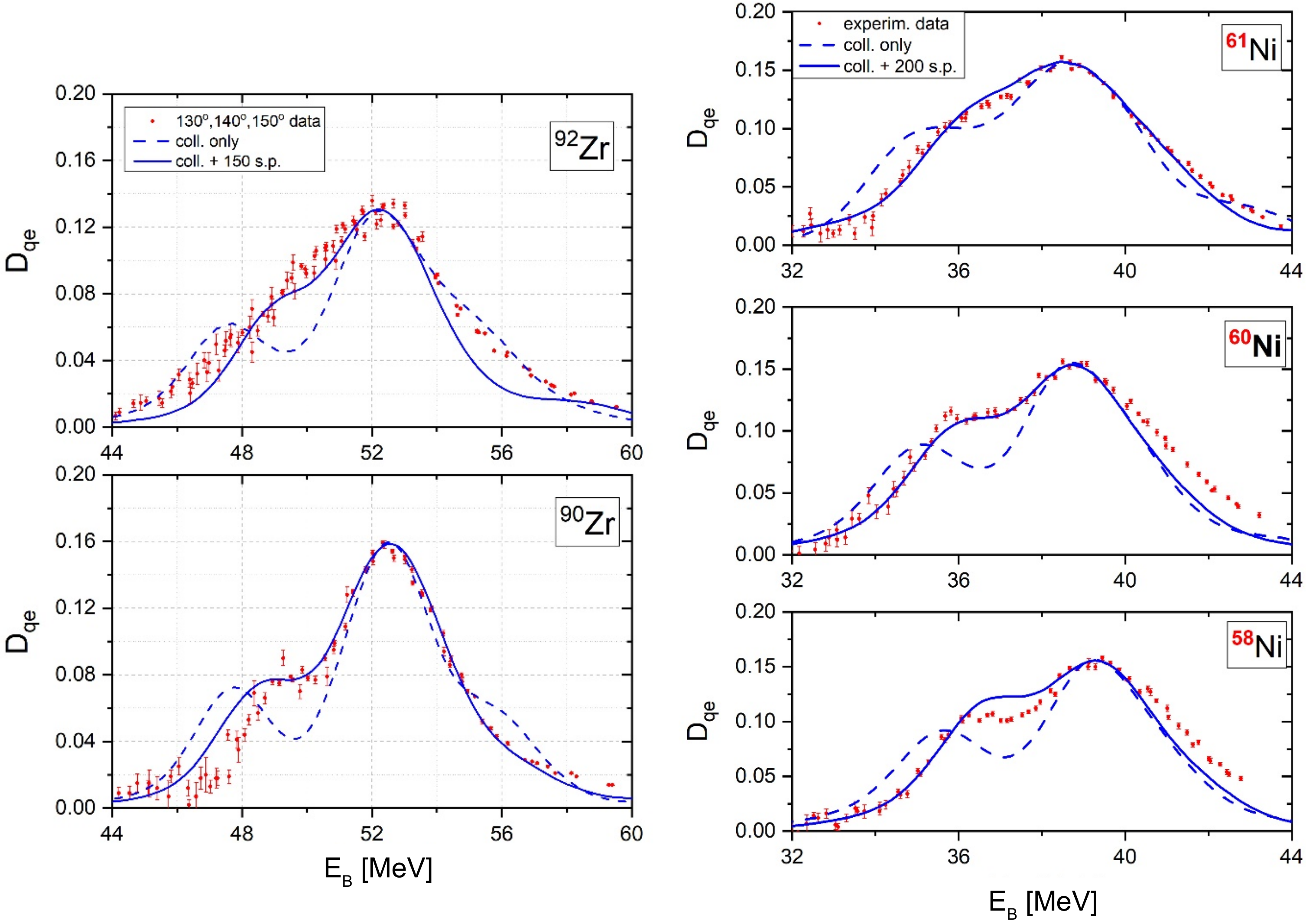
- weak reaction channels not taken into account in CC calculations: in the case of ^{92}Zr, ^{61}Ni - single particle excitations: more numerous that in ^{90}Zr, $^{58,60}Ni$

- consequence of this phenomenon: irreversible damping of relative motion into many internal (collective and non-collective) degrees of freedom → dissipation → in quantum systems dissipation results in destruction of the coherent superposition (decoherence)

- experimental results „triggered" new theoretical approaches:
  - combining CC (Coupled Channels method) + RMT (Random Matrix Theory)
  - replacing the stationary Schrödinger equation by Lindblad equation

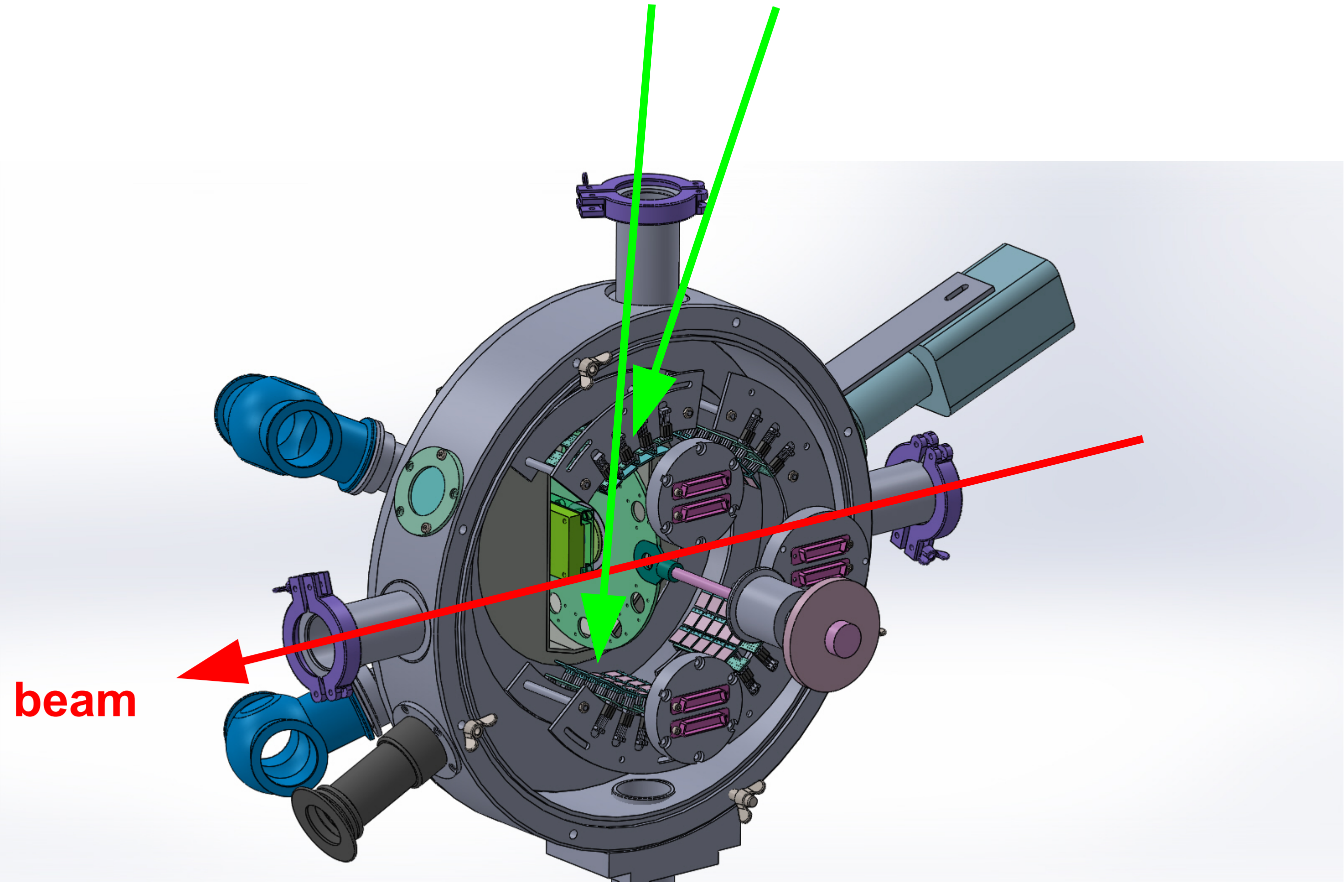
CC+RMT calculations- first results

for all systems only 1 parameter fitted



Future plans and possibilities: back-scattering experiments

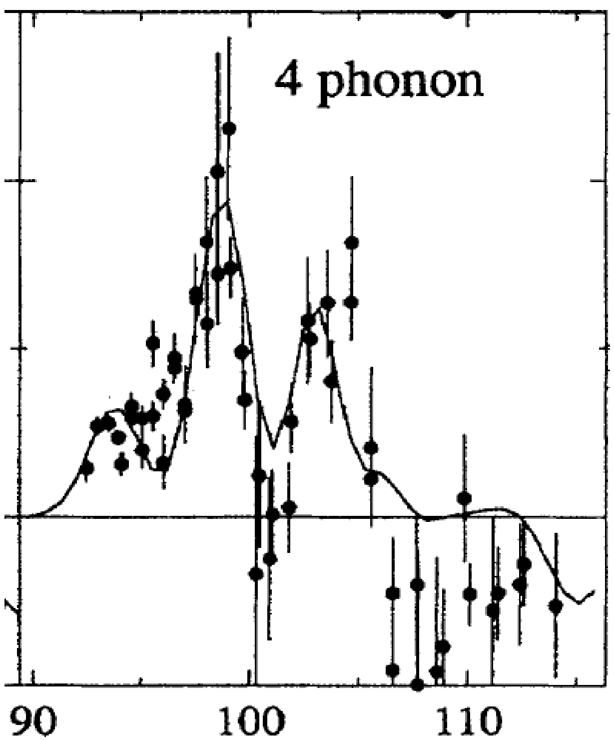
new chamber for back-scattering experiments: improved, with possibility of back-scattering measurement for ~symmetrical systems

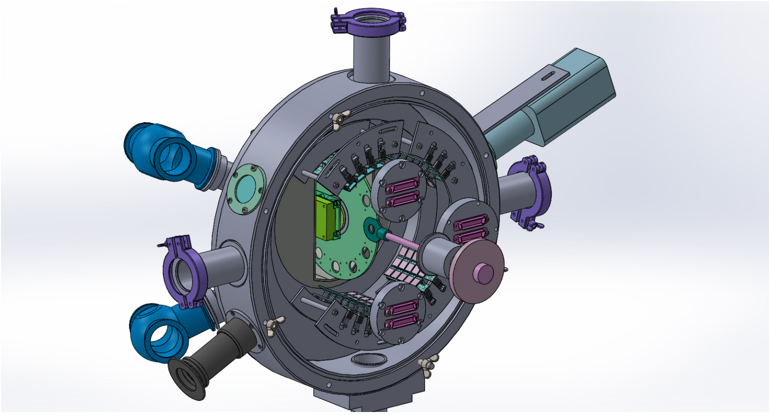


Future plans and possibilities: back-scattering experiments

new chamber for back-scattering experiments: improved, with possibility of back-scattering measurement for ~symmetrical systems

idea of measuring the $^{58}Ni+^{60}Ni$ case with back-scattering method





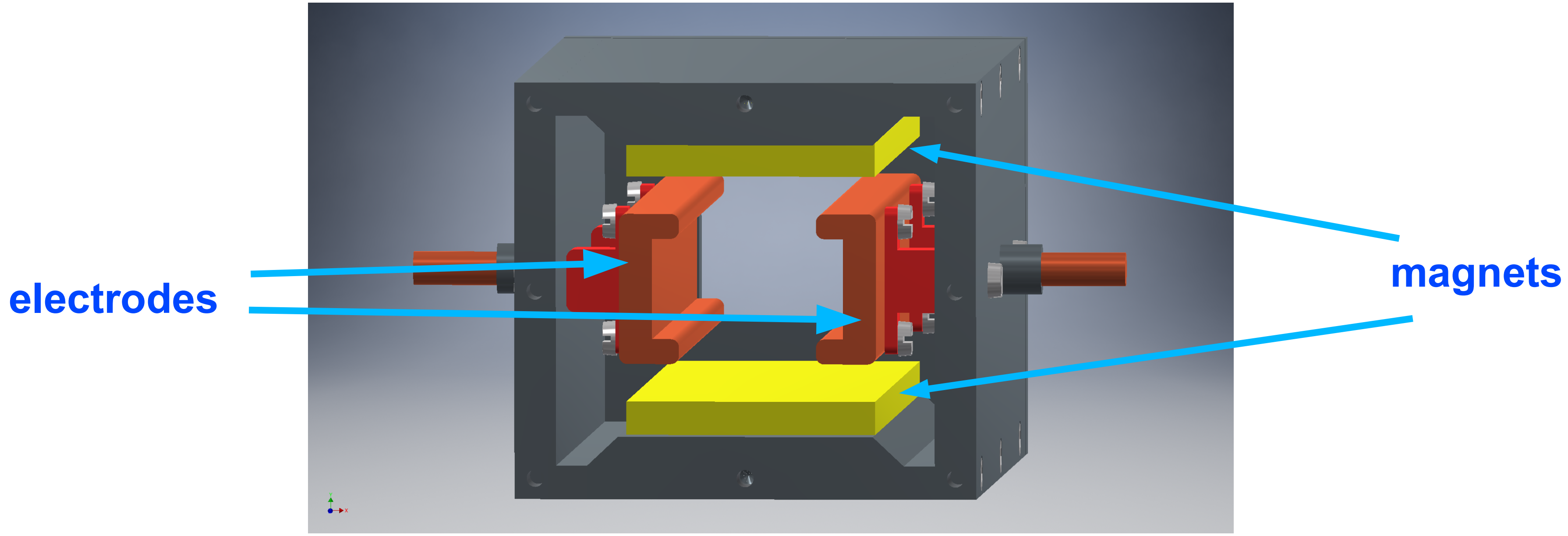
A. M. Stefanini *et al.*, Phys. Rev. Lett. 74 (1995) 864

***Ni** beam required*

Future plans and possibilities: fusion measurements

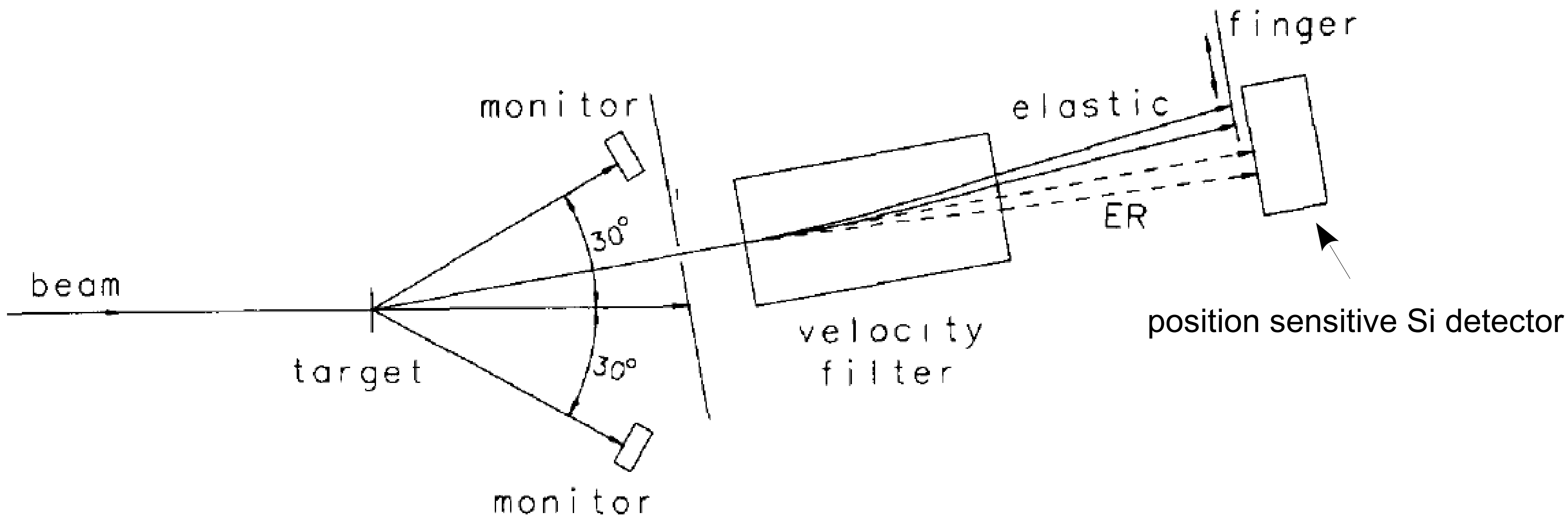
velocity filter (Wien Filter)

- compact (~25x15 cm, ~18 kg) device built in collaboration with LNS Catania; under tests in 2018 and 2019



- possibility to bring to HIL and install in ICARE chamber (some modification/extension of the chamber will be needed)

Future plans and possibilities: fusion measurements

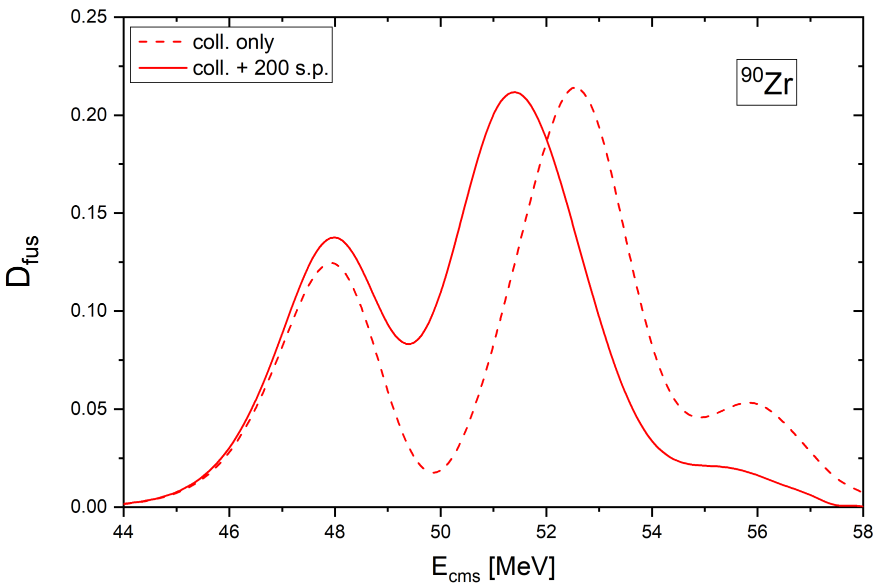


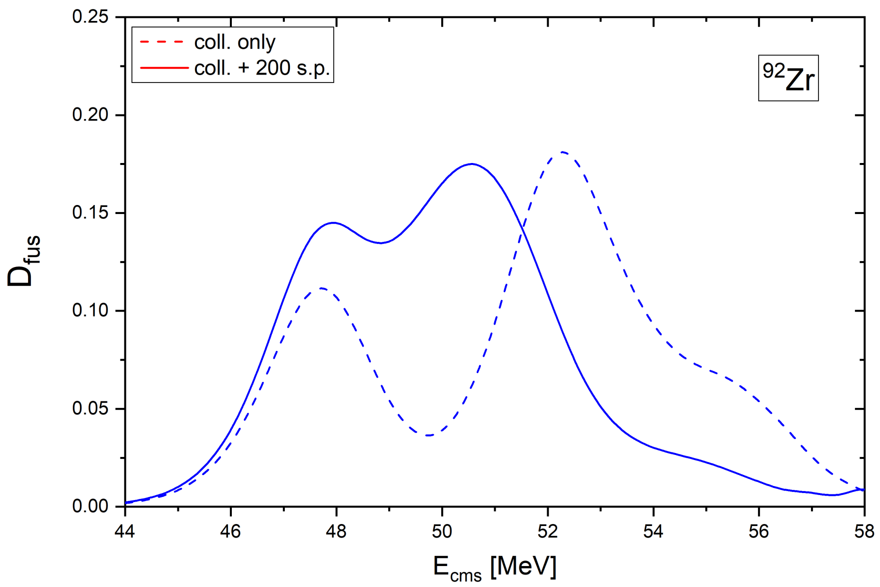
- direct measurements of $\sigma_{fus}(E)$ and D_{fus}

- continuation influence of dissipation on fusion process studies

Future plans and possibilities: fusion measurements – what new?

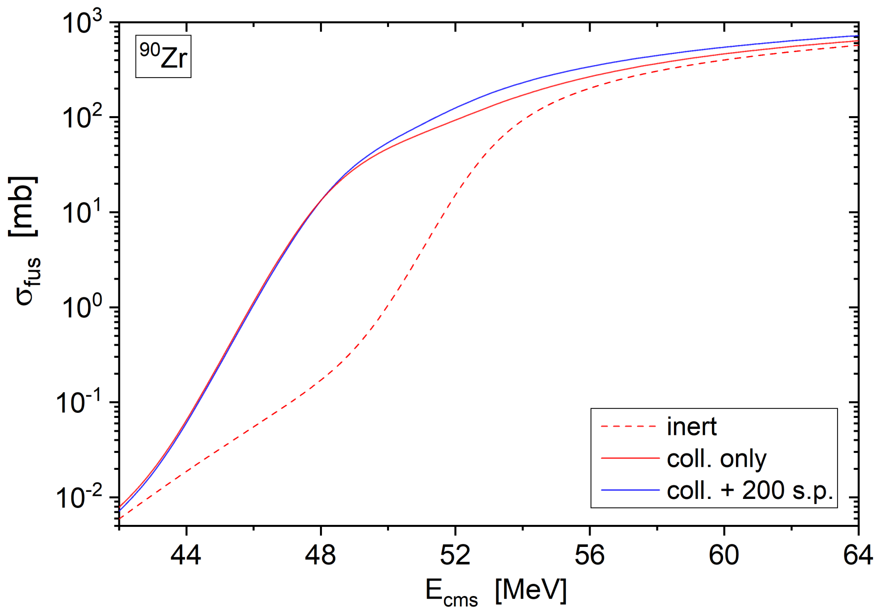
^{20}Ne + ^{90,92}Zr:
measurement of D_{fus} – confirmation of the observation for D_{qe} (disspation in ^{92}Zr) ?

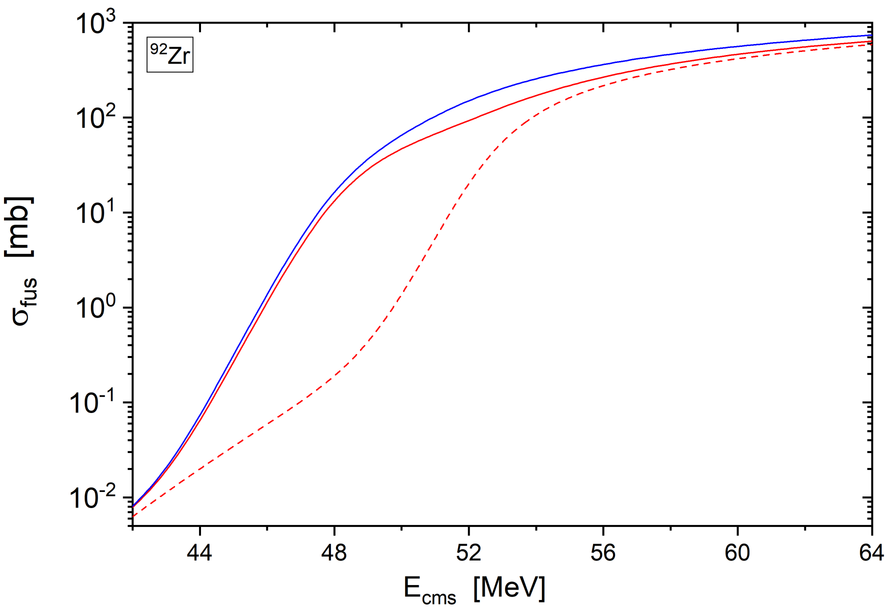




Future plans and possibilities: fusion measurements – what new?

^{20}Ne + ^{90,92}Zr:
measurement of $\sigma_{fus}(E)$

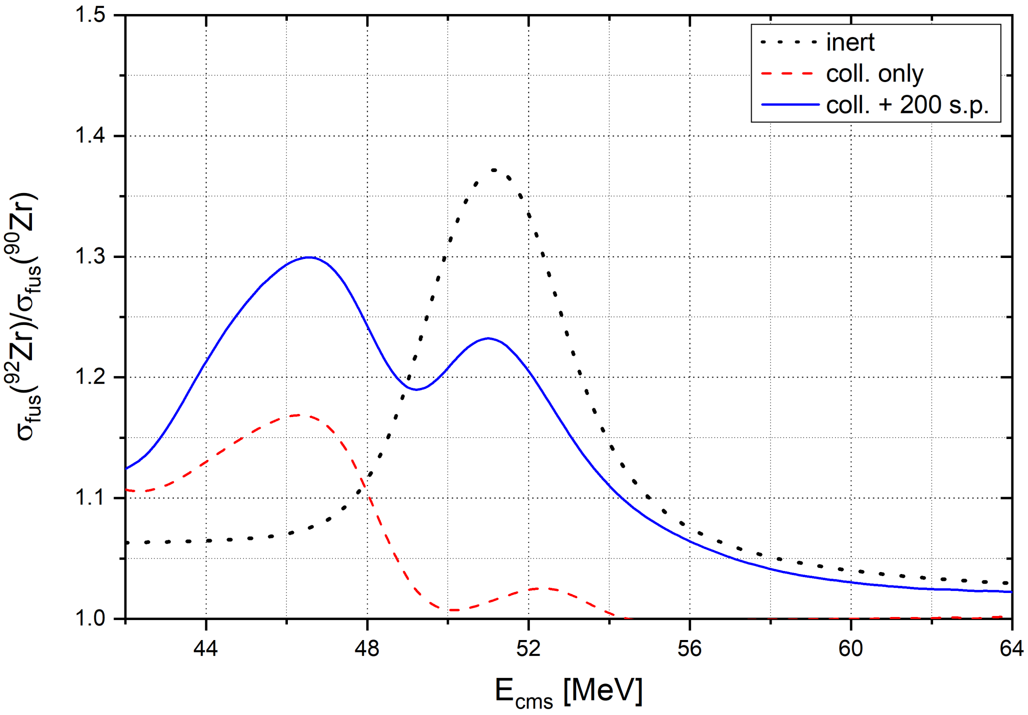




Future plans and possibilities:
fusion measurements – what new?

$^{20}Ne + ^{90,92}Zr$:

measurement of $\sigma_{fus}(E)$



Summary

- Barrier distribution studies show that weak but numerous excitations can influence the fusion.
- This observation triggered new theoretical approaches to describe the fusion ([a] RMT+CC, [b] non-stationary equation)
- Future plans:
    - measurements of semi-symmetrical systems with back-scattering method;
    - direct fusion measurements with velocity filter (after tests in LNS Catania, installing filter @HIL and modification ICARE chamber): studies of dissipation effect on $\sigma_{fus}(E)$ and D_{fus}
    - further CC+RMT improving and calculations

The Barrier Collaboration

University of Warsaw: J.Jastrzębski, A.Kordyasz, M.Kowalczyk, M.Kisieliński, K.Piasecki, E.Piasecki, A.Stolarz, Ł.Świderski, A.Trzcińska, M.Wolińska-Cichocka, D.Wójcik

Białystok University: T.Krogulski

Institute of Nuclear Physics (Kraków): S.Kliczewski

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): G.Cardella, E.De Filippo, D.Dell'Aquila, S.De Luca, B.Gnoffo, G.Lanzalone, I.Lombardo, C.Maiolino, N.S.Martorana, S.Norella, A. Pagano, E.V.Pagano, M.Pappa, S.Pirone, G.Politi, L.Quattrocchi, F.Rizzo, P.Russotto, A.Trifiro, M.Trimarchi, M.Vigilante,

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

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

National Institute for Physics and Nuclear Engineering, Magurele, Romania: C.Bordeanu

China Institute of Atomic Energy, Beijing, China: H.Jia, C.Lin, H.Zhang

Dziękuję za uwagę