Barrier distribution studies at HIL: influence of dissipation

Giulia Colucci

Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

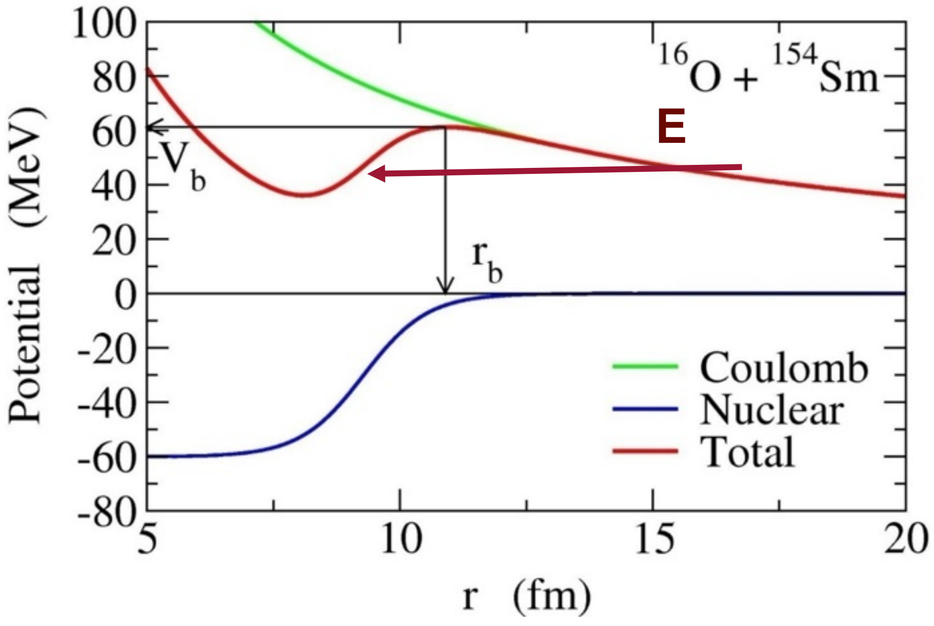
D_{QE} measurements at HIL : $^{20}Ne + ^{90,92}Zr$

D_{QE} of $^{20}Ne + ^{92,94,95}Mo$

Future plans

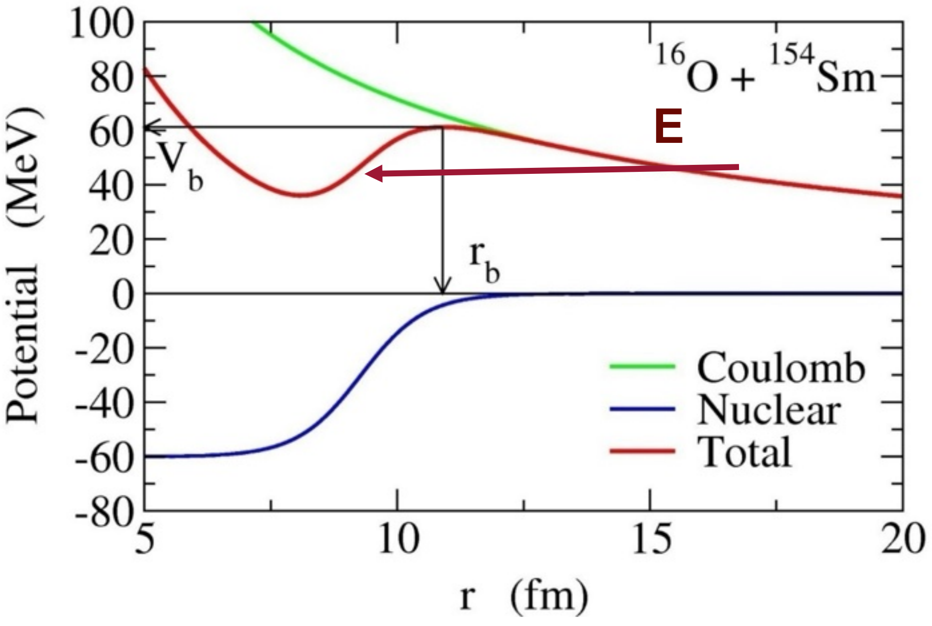
Why nuclear physics?

Two interactions: long range repulsive **Coulomb force** and short range attractive **nuclear force**. Cancellation between the two forces generates **Coulomb barrier**.



K. Hagino, Progress of Theoretical Physics, Vol. **128**, No. 6, (2012)

Two interactions: long range repulsive **Coulomb force** and short range attractive **nuclear force**. Cancellation between the two forces generates **Coulomb barrier**.

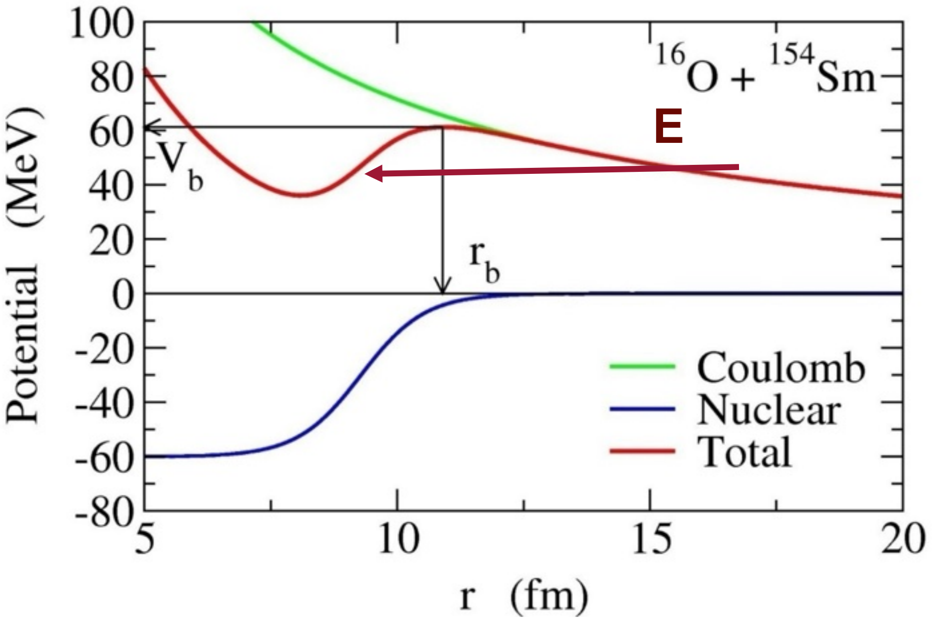


Why near- and sub-barrier fusion?

- Many-particle tunnelling effect
  - → Many types of intrinsic degrees of freedom (collective vibrational, rotational states..)
  - → Beam energy dependence
- Strong interplay between reaction and nuclei structure

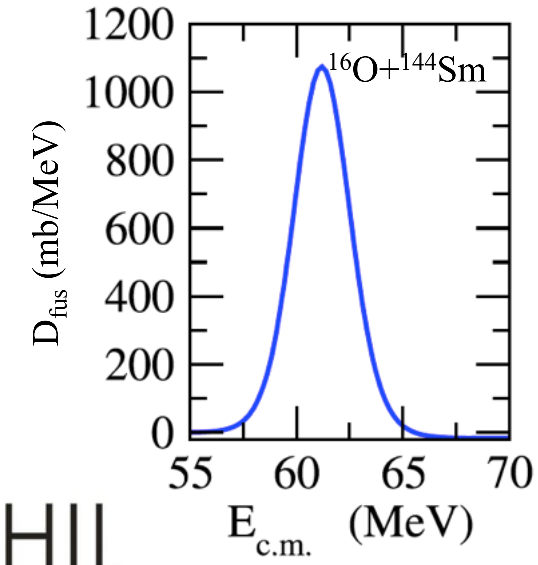
K. Hagino, Progress of Theoretical Physics, Vol. **128**, No. 6, (2012)

Two interactions: long range repulsive **Coulomb force** and short range attractive **nuclear force**. Cancellation between the two forces generates **Coulomb barrier**.



Why near- and sub-barrier fusion?

- Many-particle tunnelling effect
  - Many types of intrinsic degrees of freedom (collective vibrational, rotational states..)
  - Beam energy dependence
- Strong interplay between reaction and nuclei structure



K. Hagino, Progress of Theoretical Physics, Vol. **128**, No. 6, (2012)

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

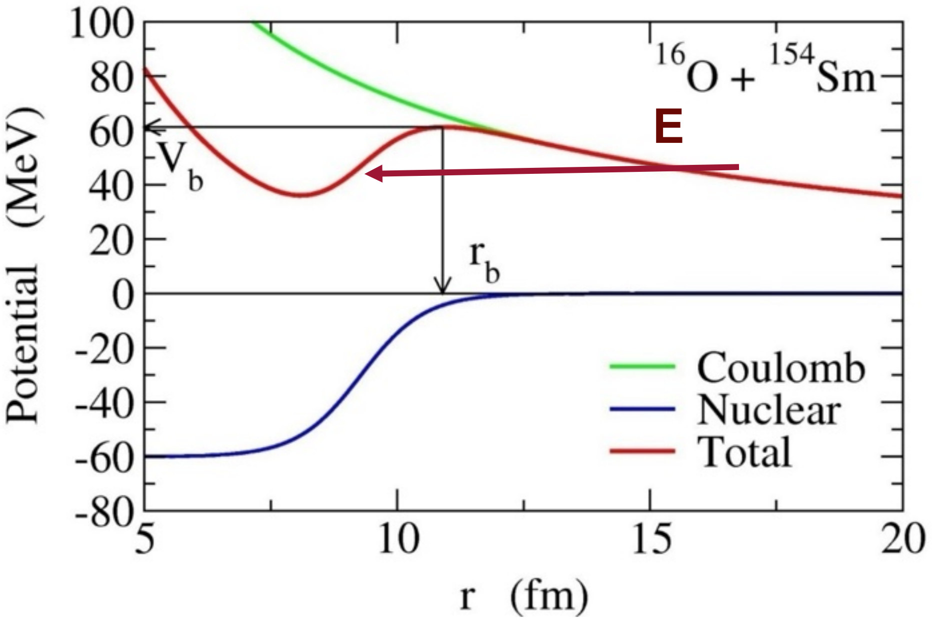
D_{QE} measurements at HIL : ^{20}Ne + ^{90,92}Zr

D_{QE} of ^{20}Ne + ^{92,94,95}Mo

Future plans

Why nuclear physics?

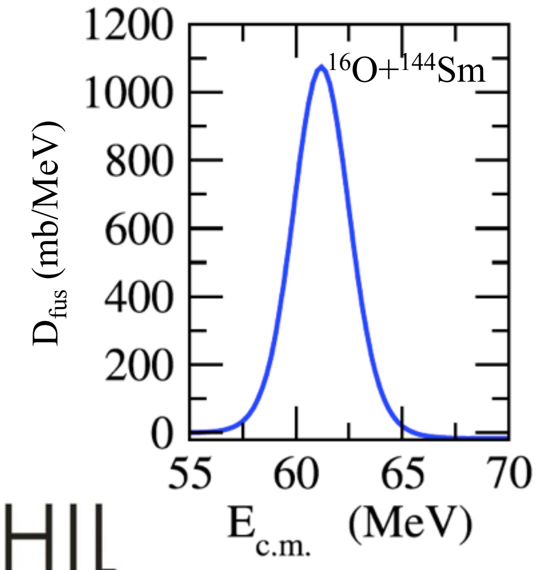
Two interactions: long range repulsive **Coulomb force** and short range attractive **nuclear force**. Cancellation between the two forces generates **Coulomb barrier**.



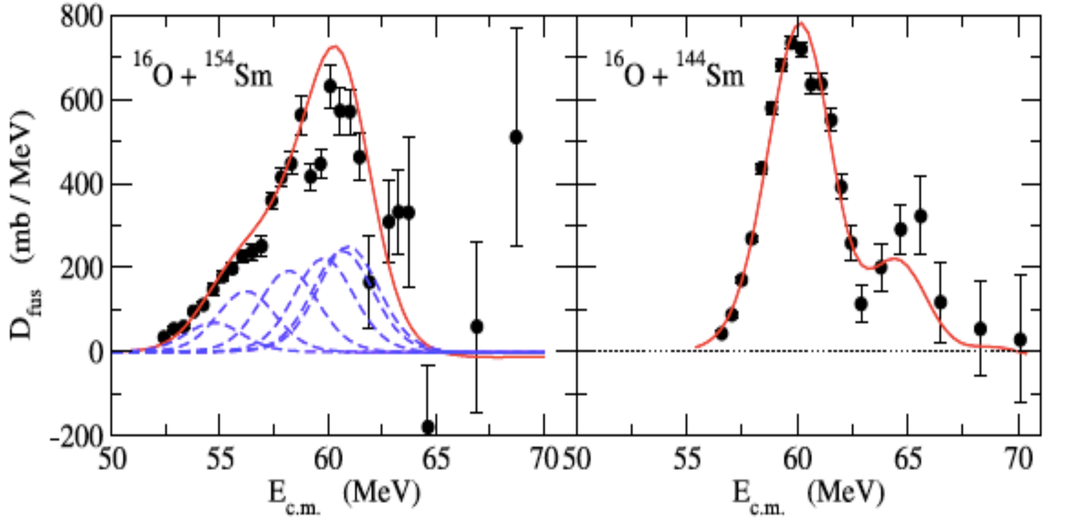
Why near- and sub-barrier fusion?

- Many-particle tunnelling effect
  - → Many types of intrinsic degrees of freedom (collective vibrational, rotational states..)
  - → Beam energy dependence
- Strong interplay between reaction and nuclei structure

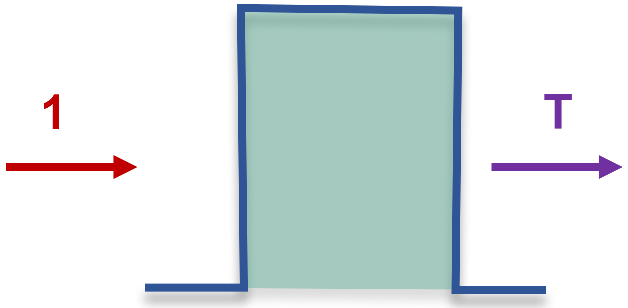
Barrier distributions



Distribution of barriers due to the channel coupling effects

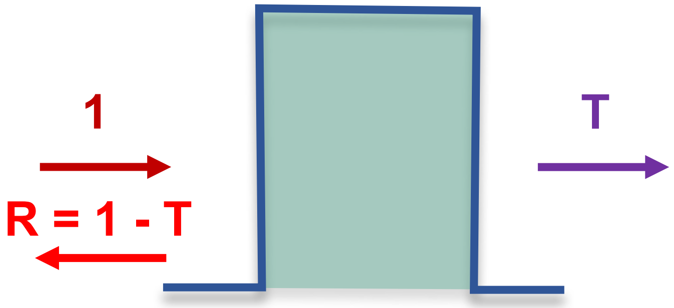


K. Hagino, Progress of Theoretical Physics, Vol. **128**, No. 6, (2012)



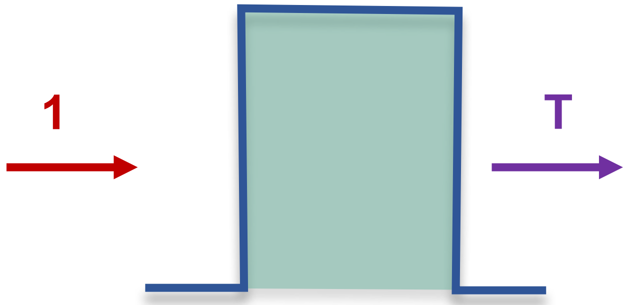
FUSION

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

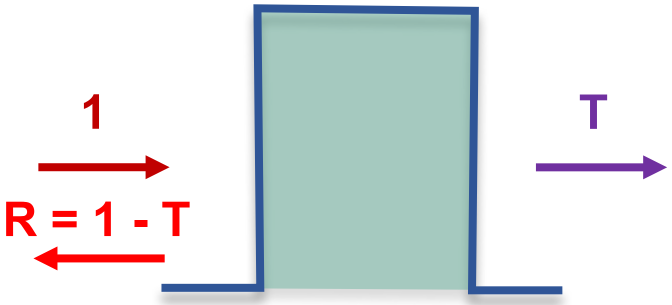


QUASI-ELASTIC

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



FUSION

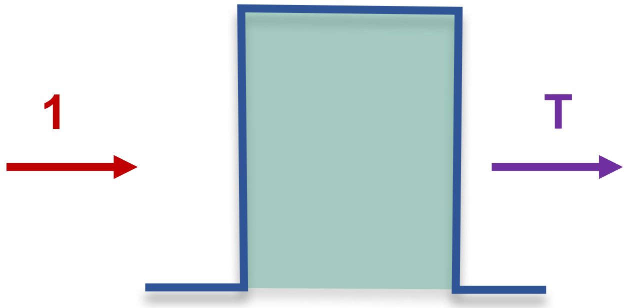


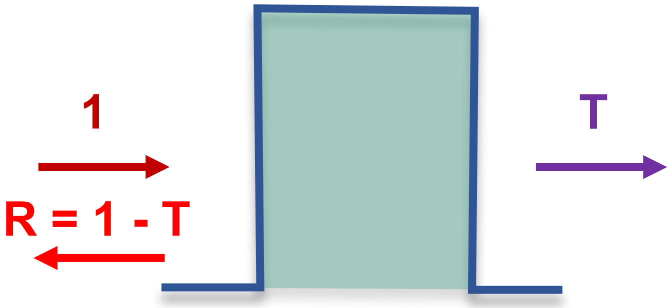
QUASI-ELASTIC

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

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

Theoretically the two approaches are approximately **complementary**





FUSION

QUASI-ELASTIC

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

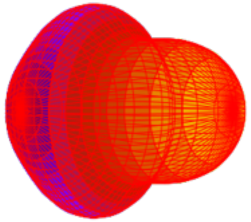
$$D_{QE}(E) = -\frac{d}{dE}\left(\frac{\sigma_{QE}}{\sigma_{Ruth}}\right)$$

Theoretically the two approaches are approximately **complementary**

Coupled Channels (CC) model takes into account strong collective excitations of the participating nuclei

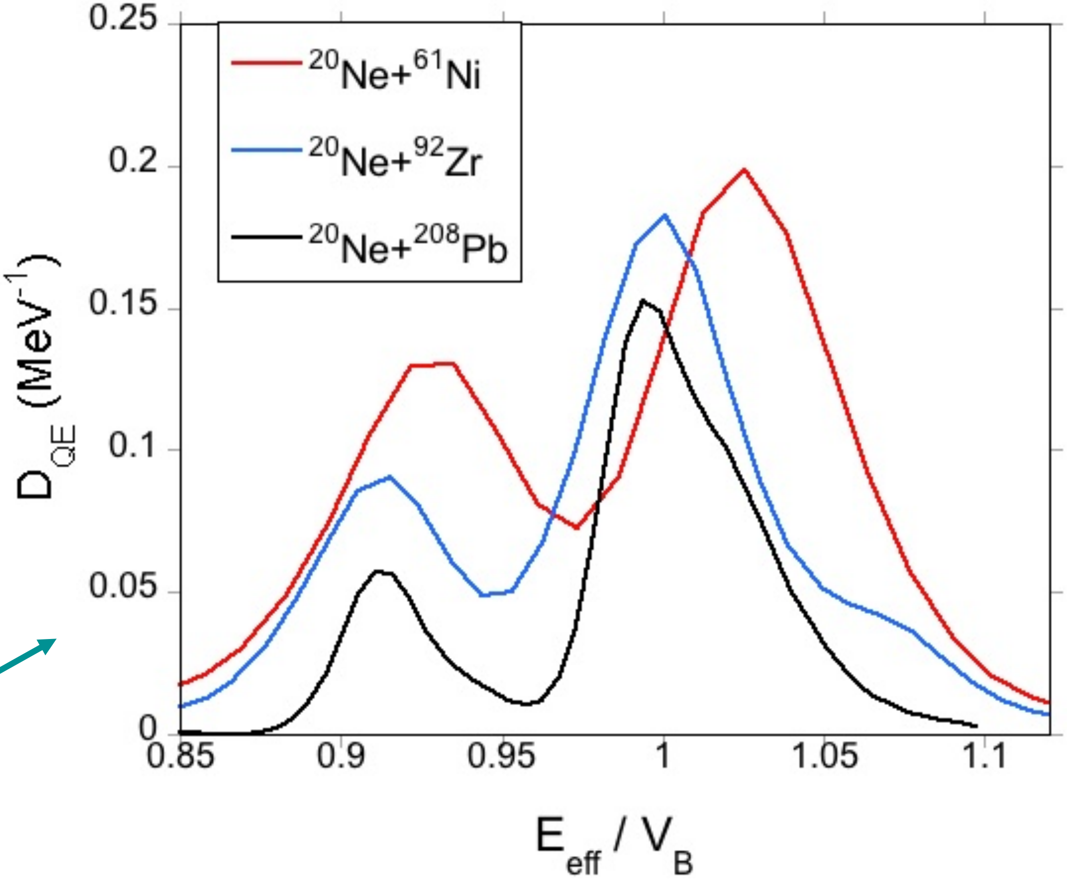
The role of dissipation by a multitude of **non-collective excitations** and different **transfer channels** is much less understood

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

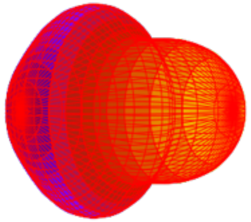


Calculations carried out by the Coupled Channels (CC) method predict the distribution of barriers with a strong "structure" for all ^{20}Ne + X systems

Two peaks structure

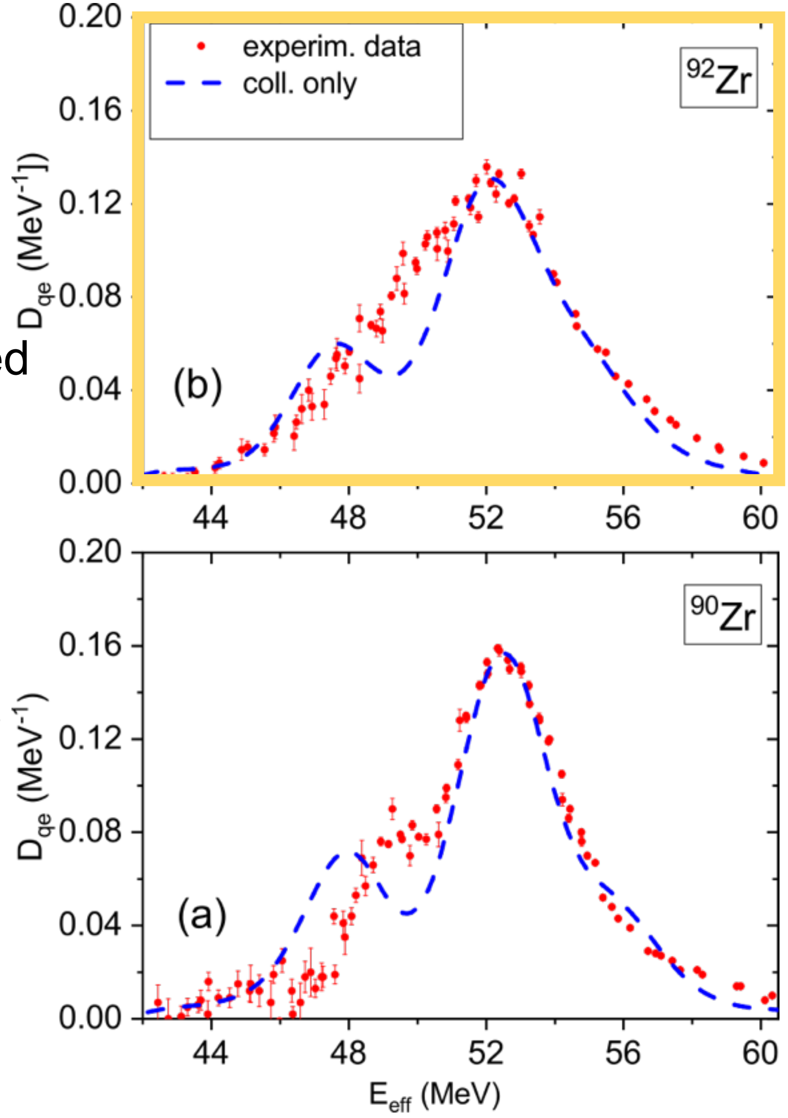


^{20}Ne projectile - strongly deformed nucleus: $\beta_2 = 0.46$, $\beta_3 = 0.39$, $\beta_4 = 0.27$



Experimental D_{QE} have much smoothed structure respect to coupled channels (CC) calculations predictions

Structure disappears for $^{20}Ne + ^{92}Zr$



E. Piasecki et al., Phys. Rev. , C 80 (2009) 054613

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

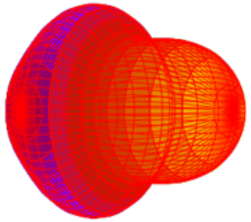
D_{QE} measurements at HIL : $^{20}Ne + ^{90,92}Zr$

D_{QE} of $^{20}Ne + ^{92,94,95}Mo$

Future plans

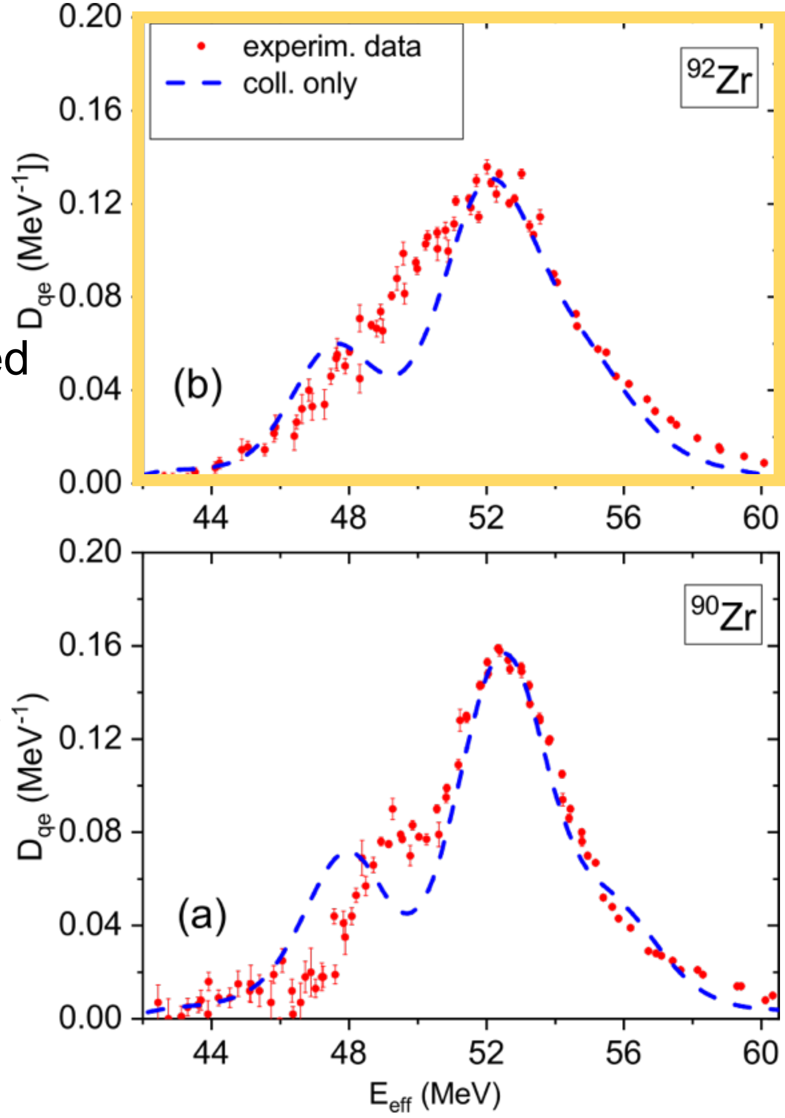
Why nuclear physics?

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

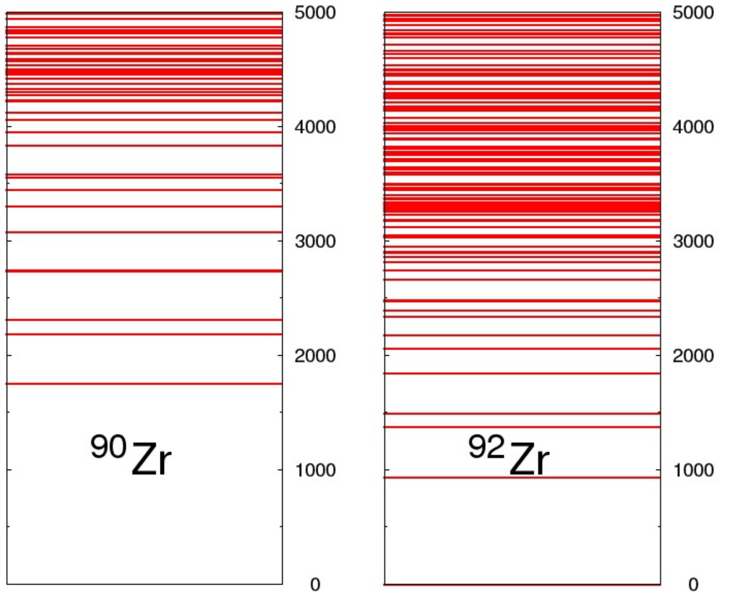


Experimental D_{QE} have much smoothed structure respect to coupled channels (CC) calculations predictions

Structure disappears for $^{20}Ne + ^{92}Zr$



Influence of single particle excitations on the smoothing of the barrier distribution



E. Piasecki et al., Phys. Rev. , C 80 (2009) 054613

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

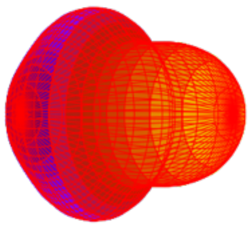
D_{QE} measurements at HIL : ^{20}Ne + $^{90,92}Zr$

D_{QE} of ^{20}Ne + $^{92,94,95}Mo$

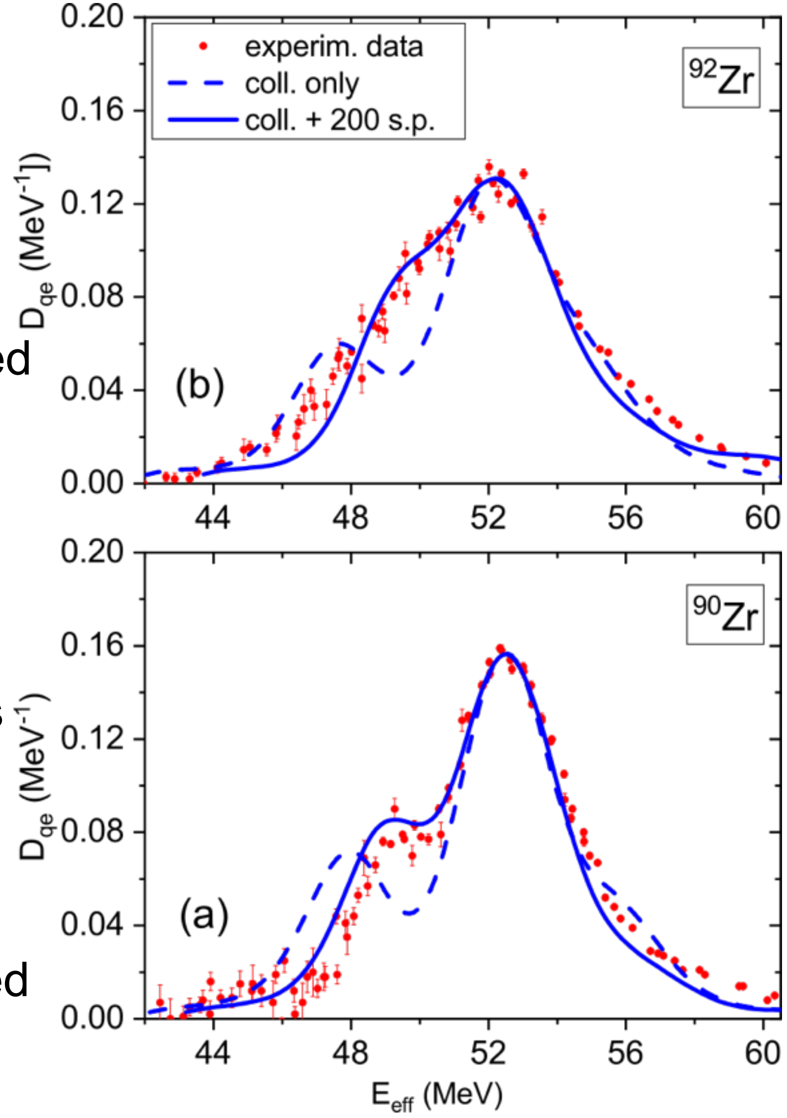
Future plans

Why nuclear physics?

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



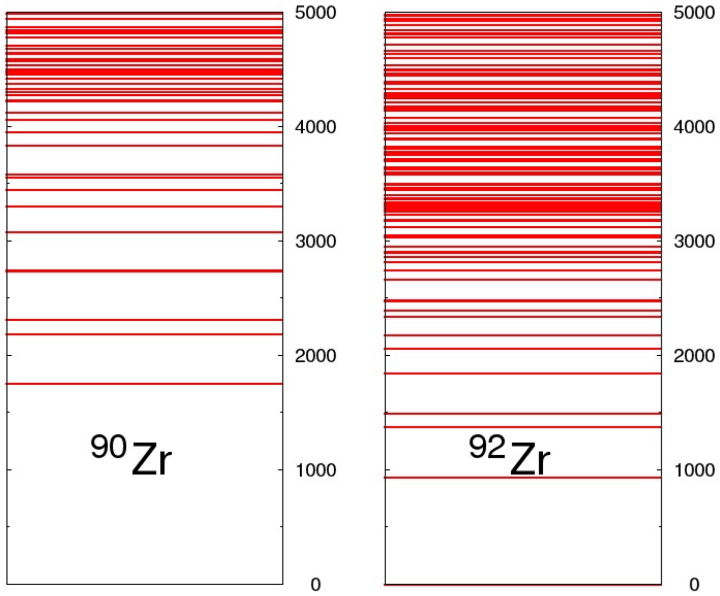
Experimental D_{QE} have much smoothed structure respect to coupled channels (CC) calculations predictions



Structure disappears for ^{20}Ne + ^{92}Zr

Coupling to noncollective included within CC+RMT model

Influence of single particle excitations on the smoothing of the barrier distribution



Dissipation due to the coupling of a multitude of noncollective levels

E. Piasecki et al., Phys. Rev. C 100 (2019) 014616 S. Yusa et al., Phys. Rev. C 82 (2010) 024606 E. Piasecki et al., Phys. Rev. , C 80 (2009) 054613

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

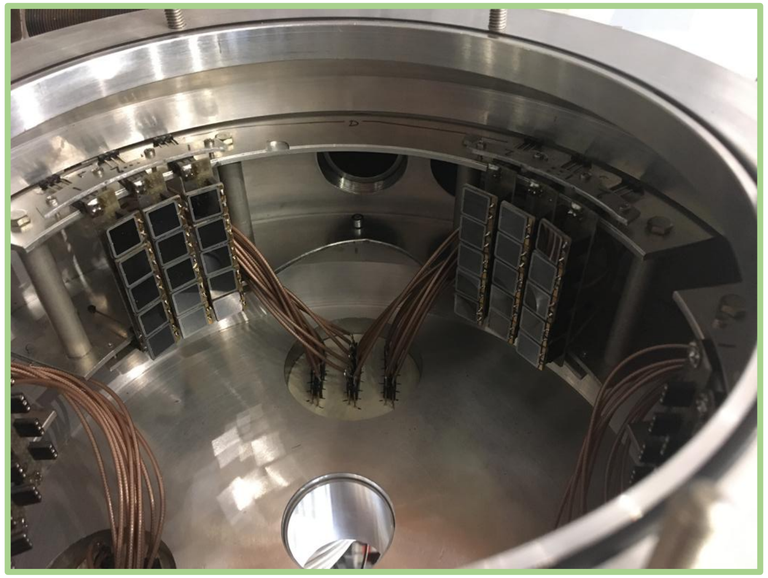
D_{QE} measurements at HIL : ^{20}Ne + ^{90,92}Zr

D_{QE} of ^{20}Ne + ^{92,94,95}Mo

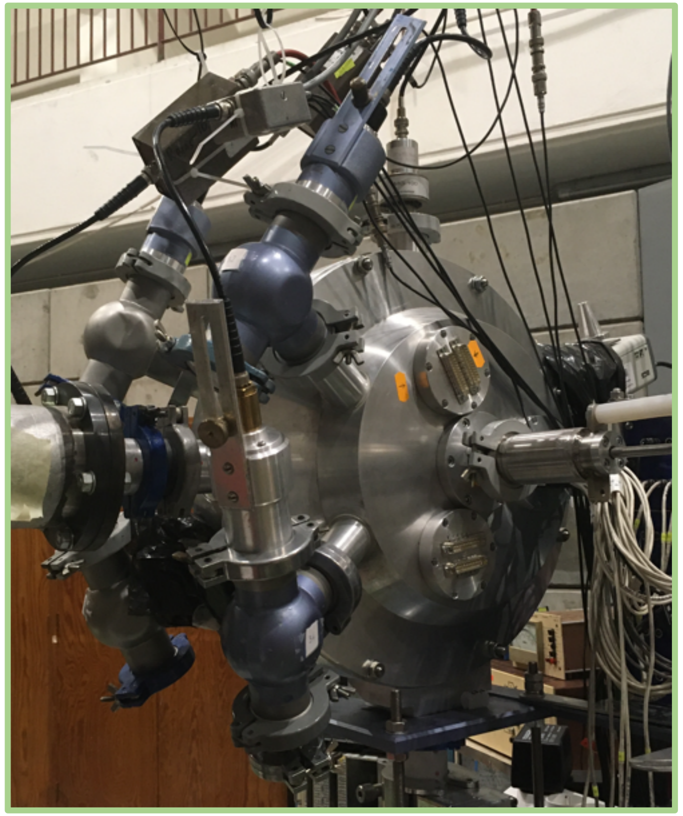
Future plans

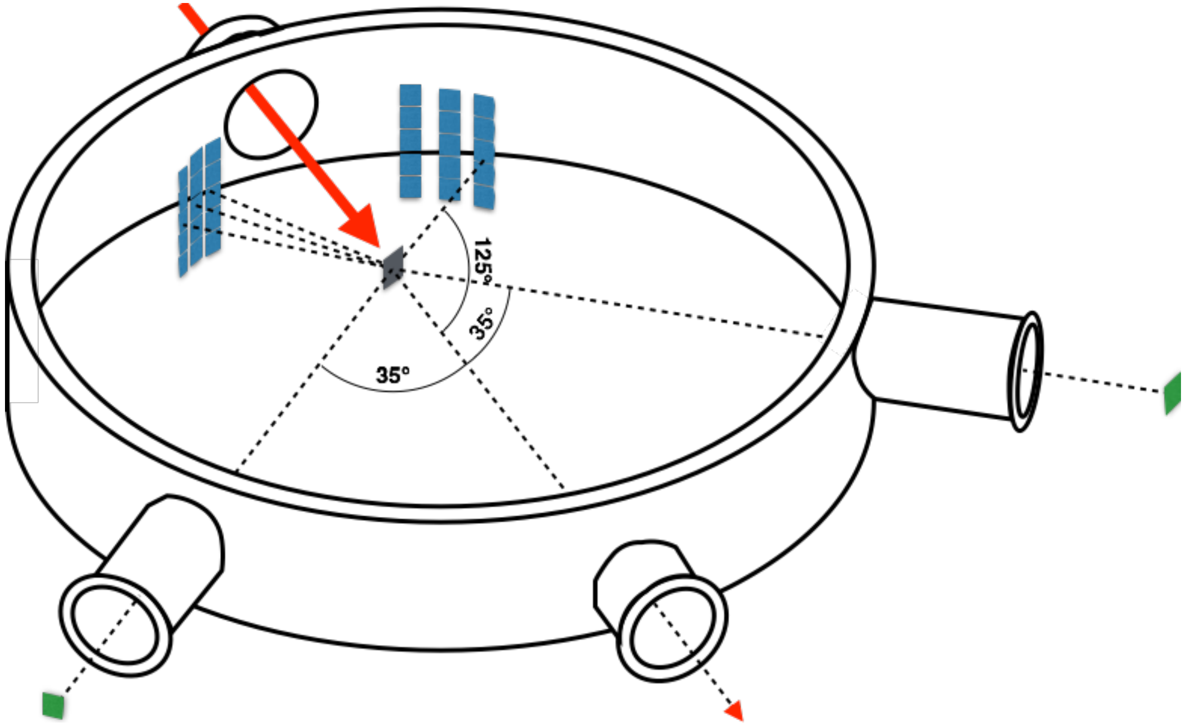
Why nuclear physics?

CUDAC (Coulomb Universal Detector Array Chamber) at HIL



- 30 PIN diodes (1cmx1cm) at the backward angles of 125°, 135°, 145°
- 4 PIN diodes the forward angles of 35°





HIL
Heavy Ion Laboratory

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

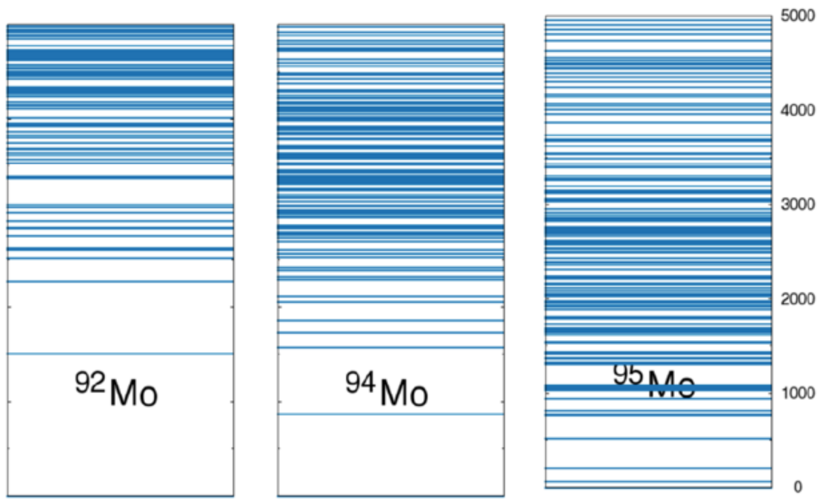
D_{QE} measurements at HIL : $^{20}Ne + ^{90,92}Zr$

D_{QE} of $^{20}Ne + ^{92,94,95}Mo$

Future plans

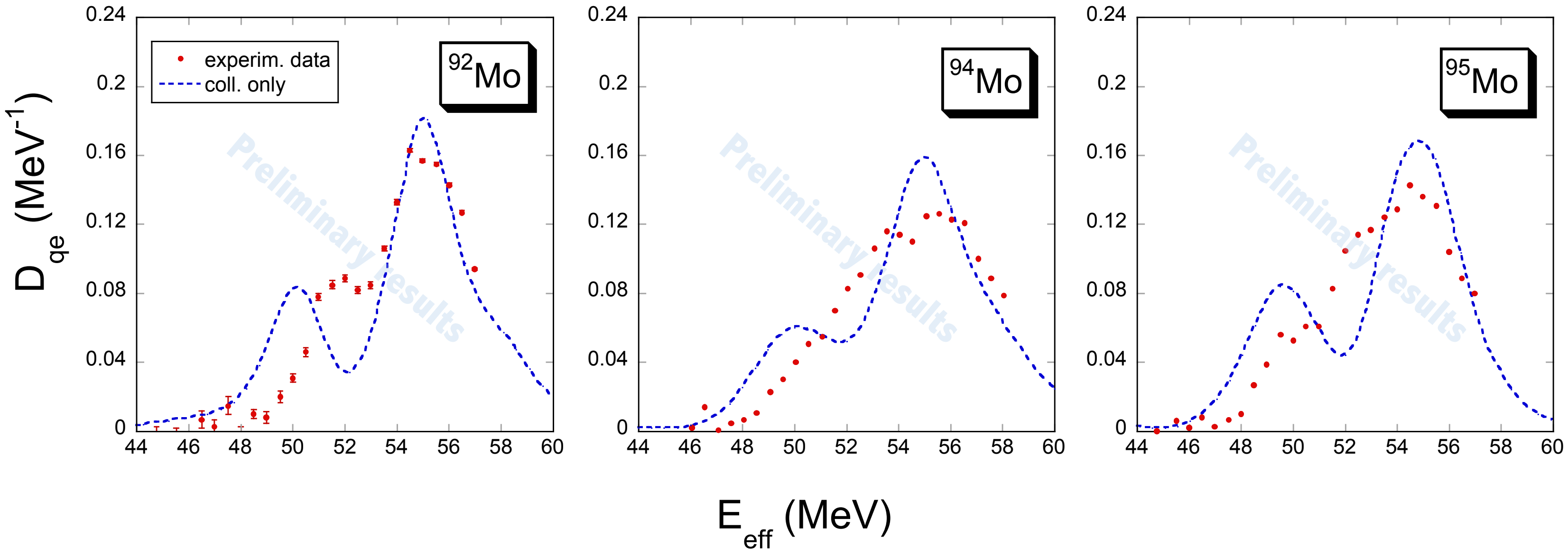
Why nuclear physics?

Quasielastic barrier distribution of $^{20}Ne+^{92,94,95}Mo$



Increasing of dissipation in a "controlled" way: observing the influence of increasing level density on D_{QE}

- Experimental D_{QE} of ^{92}Mo preserves two-peaks structure
- Experimental D_{QE} of ^{95}Mo has much smoothed structure respect to CC calculations, as predicted by CC+RMT model;



Quasielastic barrier distribution of ^{20}Ne+^{92,94,95}Mo

Near barrier fusion reactions

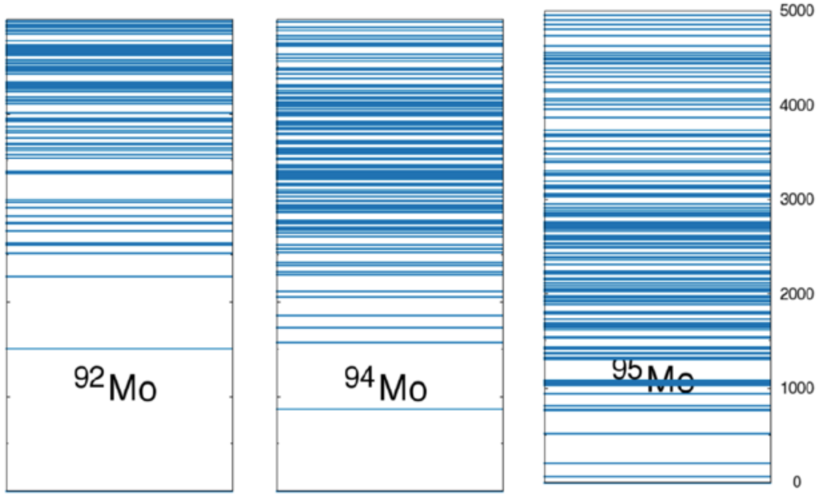
Fusion and quasielastic barrier distributions

D_{QE} measurements at HIL : ^{20}Ne + ^{90,92}Zr

D_{QE} of ^{20}Ne + ^{92,94,95}Mo

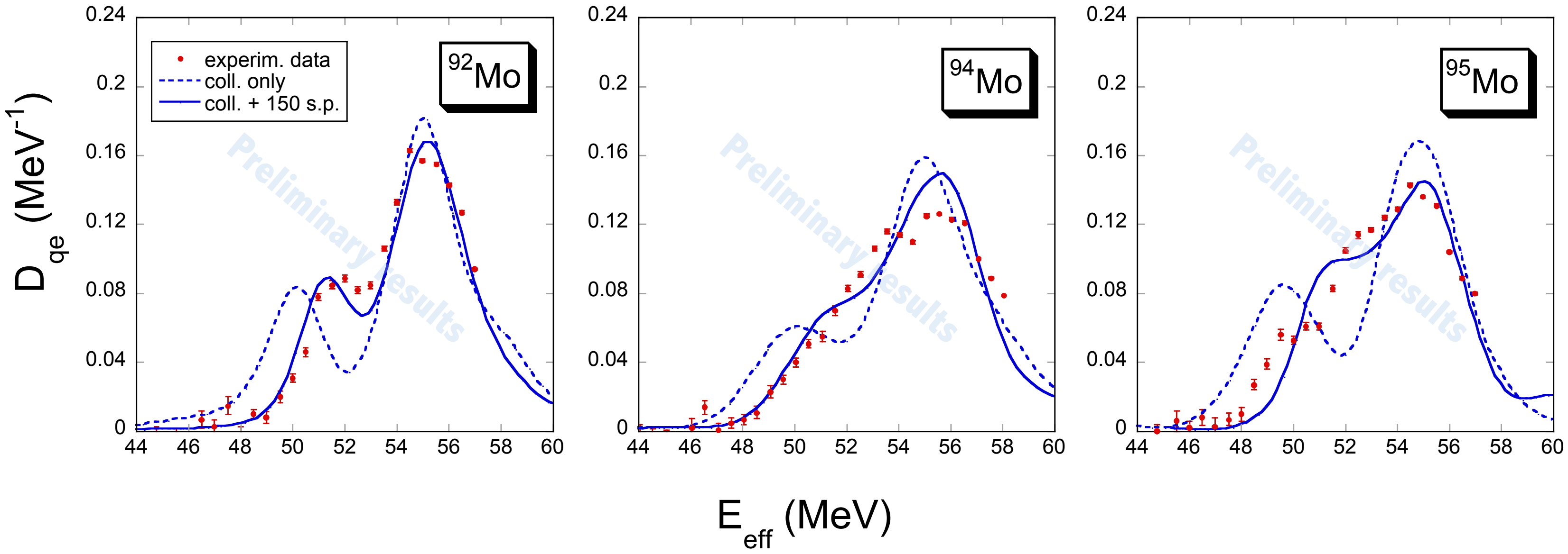
Future plans

Why nuclear physics?



Increasing of dissipation in a “controlled” way: observing the influence of increasing level density on D_{QE}

- Experimental D_{QE} of ^{92}Mo preserves two-peaks structure
- Experimental D_{QE} of ^{95}Mo has much smoothed structure respect to CC calculations, as predicted by CC+RMT model;
- D_{QE} of ^{94}Mo is **smoother** and **wider** with respect to the predicted one from CC and CCRMT.



Possible significant differences in transfer channels between the isotopes.

HIL Heavy Ion Laboratory

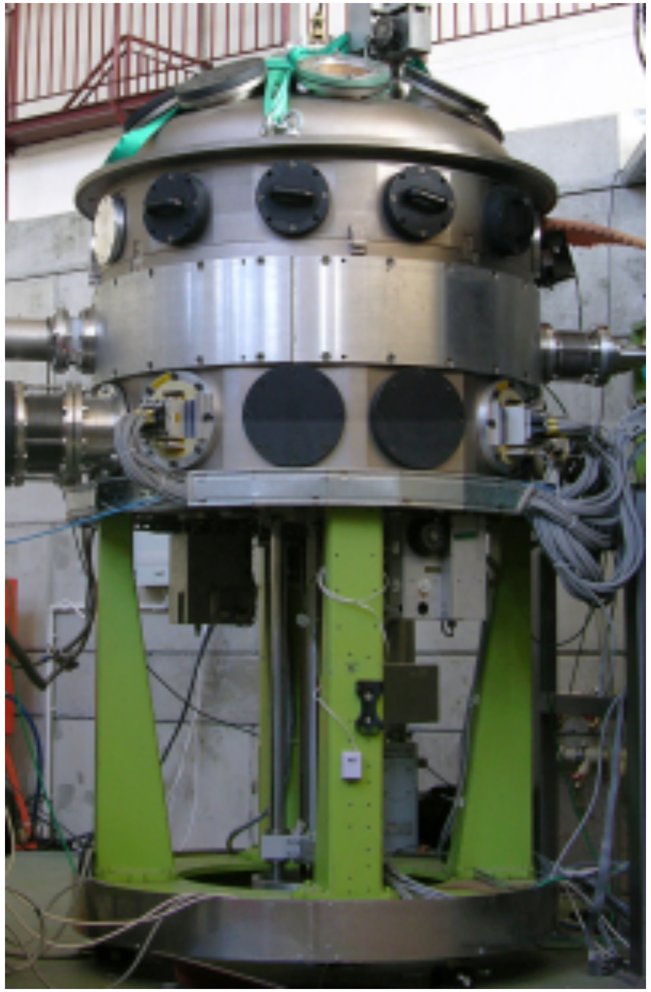
Direct transfer cross-section measurements of the $^{20}Ne+^{92,94,95}Mo$

- Comparison of the transfer cross sections for different transfer reaction of the neighbour isotopes

Direct transfer cross-section measurements of the $^{20}Ne+{}^{92,94,95}Mo$

- Comparison of the transfer cross sections for different transfer reaction of the neighbour isotopes

ICARE - charged particles detector system

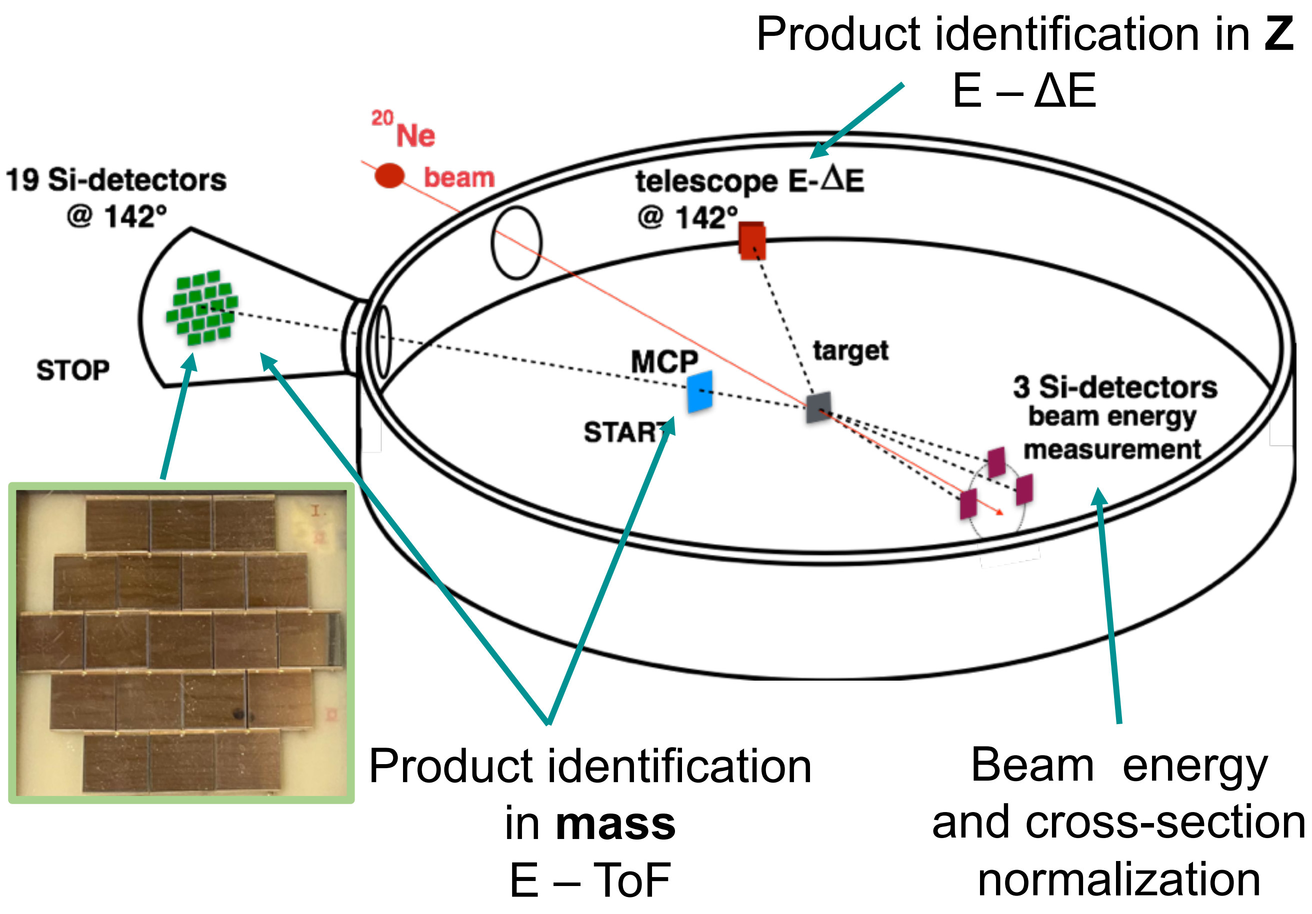


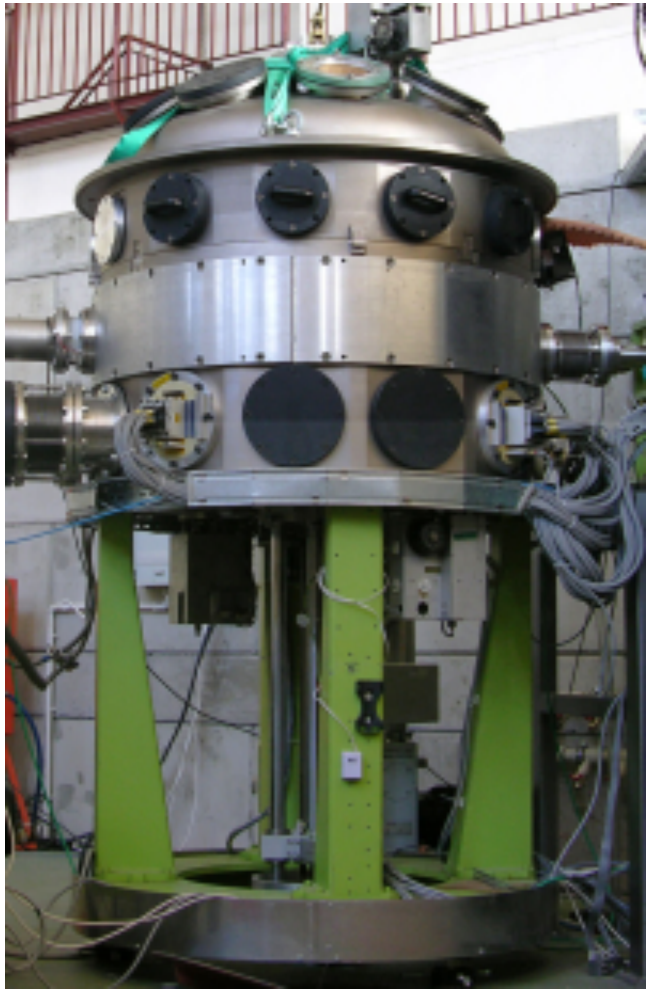
HIL Heavy Ion Laboratory

Direct transfer cross-section measurements of the $^{20}Ne+^{92,94,95}Mo$

- Comparison of the transfer cross sections for different transfer reaction of the neighbour isotopes

ICARE - charged particles detector system



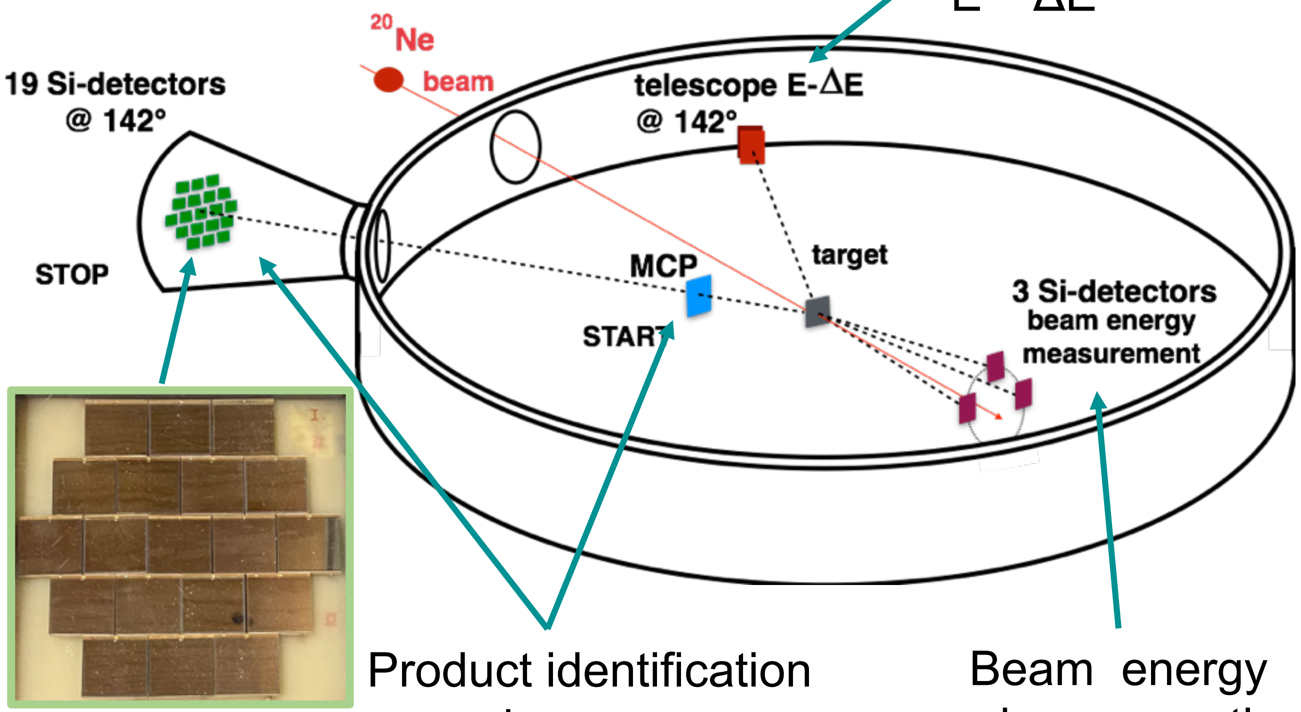


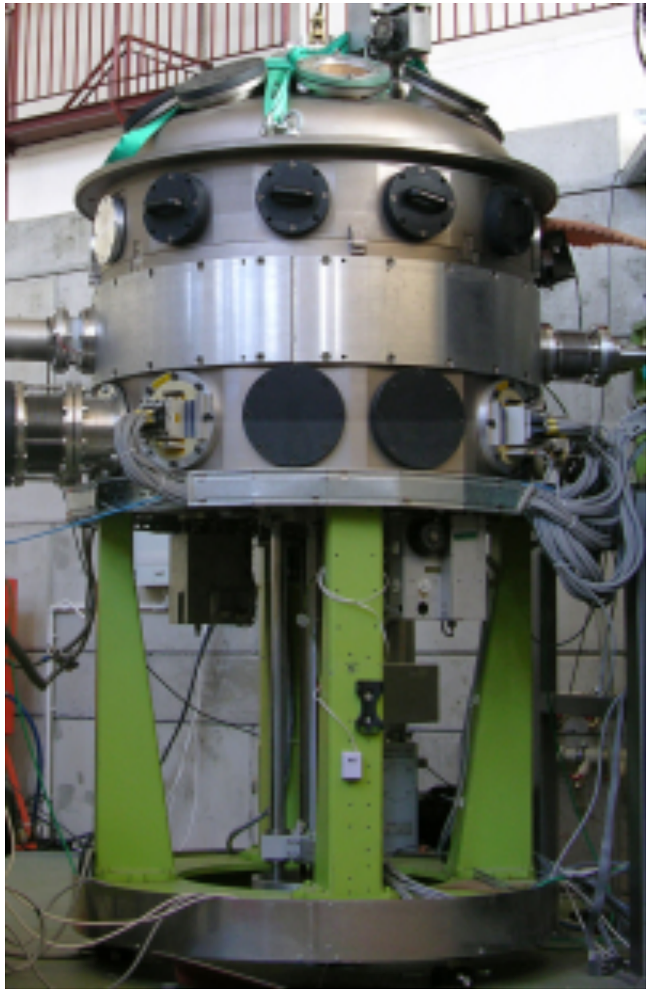
Direct transfer cross-section measurements of the $^{20}Ne+^{92,94,95}Mo$

- Comparison of the transfer cross sections for different transfer reaction of the neighbour isotopes

ICARE - charged particles detector system

Product identification in **Z**
E – ΔE





Product identification
in **mass**
E – ToF

Beam energy
and cross-section
normalization

Experiment will be performed beginning next year

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

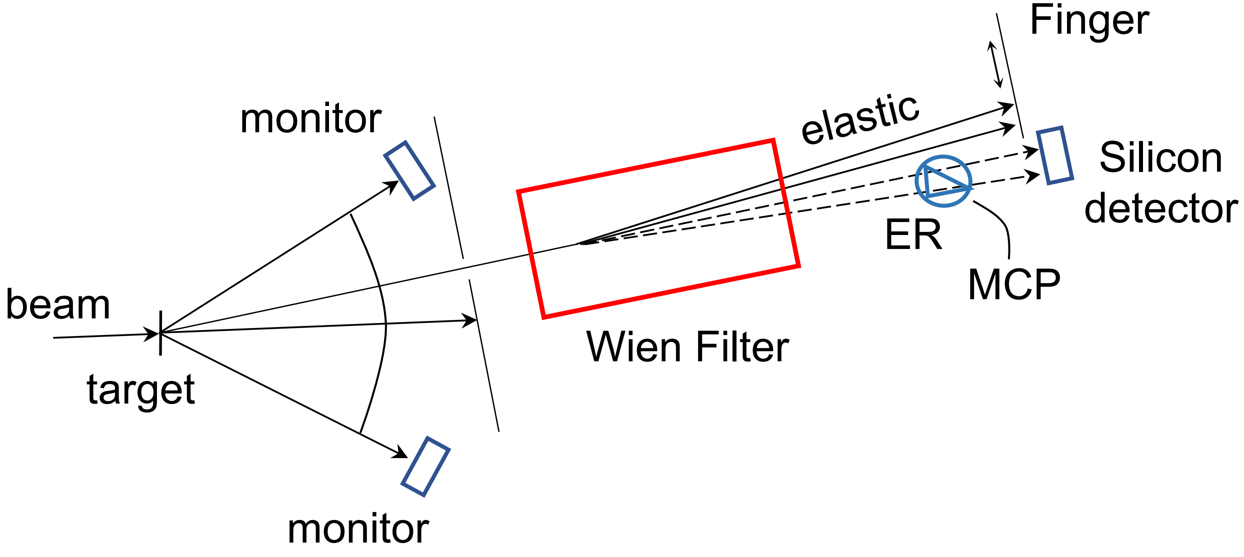
D_{QE} measurements at HIL : ^{20}Ne + ^{90,92}Zr

D_{QE} of ^{20}Ne + ^{92,94,95}Mo

Future plans

Why nuclear physics?

Fusion barrier distribution measurement through the direct detection of evaporation residues



Based on set-up in use at ANU (Australia)

Using a MCP and a Silicon detector

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

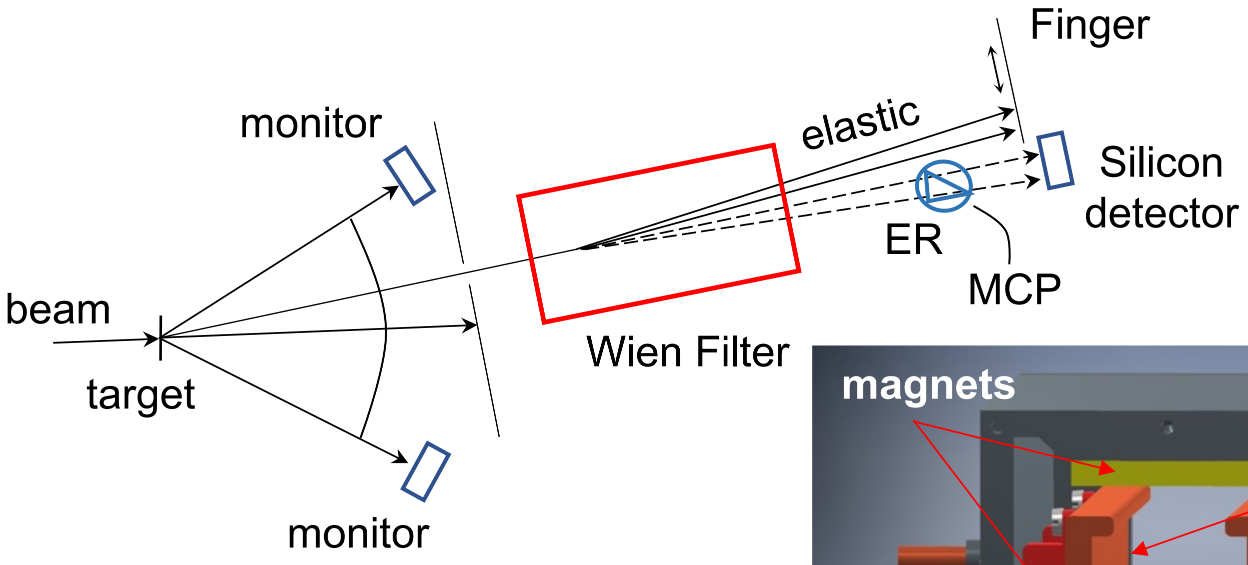
D_{QE} measurements at HIL : $^{20}Ne + ^{90,92}Zr$

D_{QE} of $^{20}Ne + ^{92,94,95}Mo$

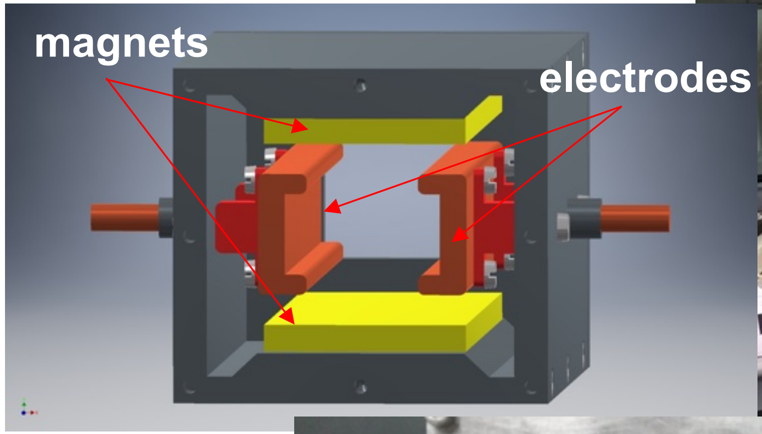
Future plans

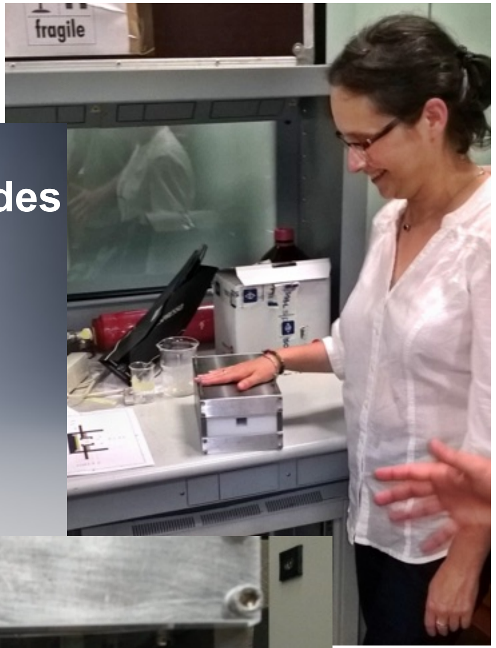
Why nuclear physics?

Fusion barrier distribution measurement through the direct detection of evaporation residues



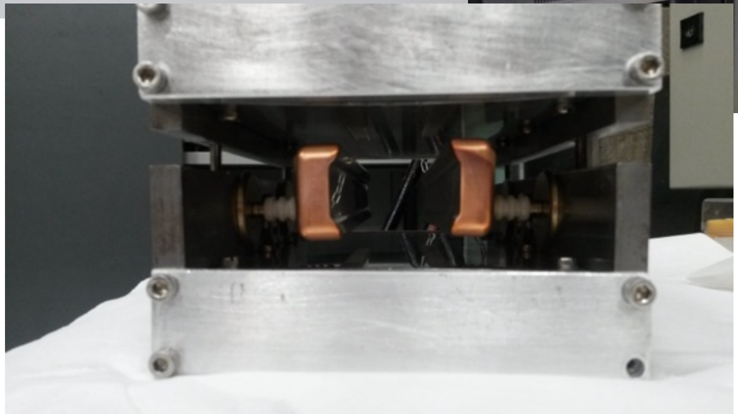
Based on set-up in use at ANU (Australia)
Using a MCP and a Silicon detector





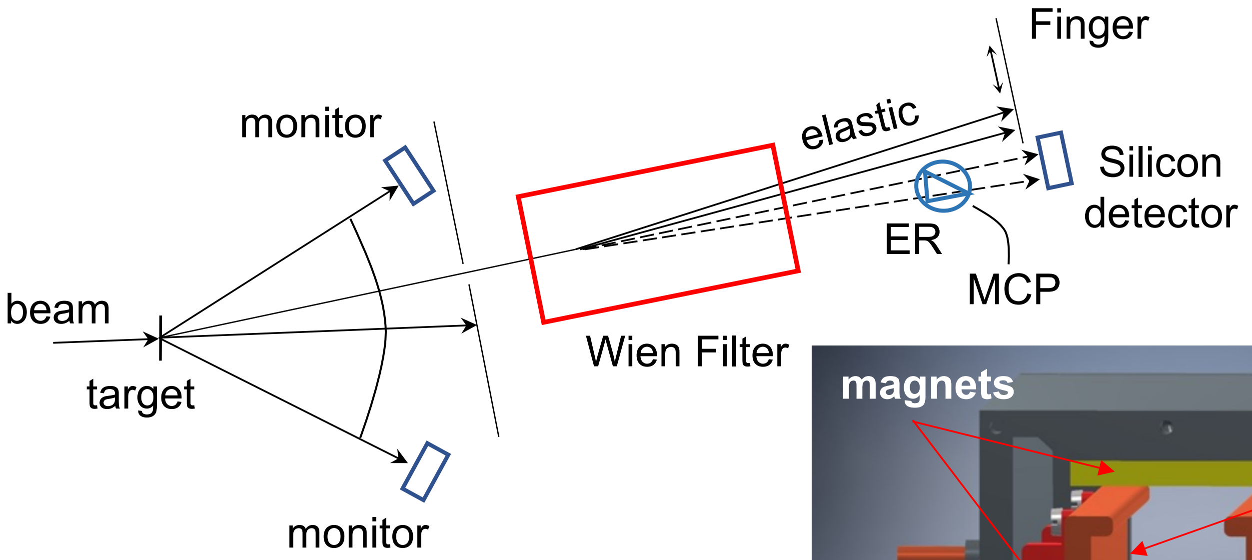
The Wien Filter at LNS

- Dimensions of 106 x 150 x 250 mm^3
- 20 permanent magnets (Sm_2Co_{17}) 41 x 41 x 11 mm^3 (Vacuumshmalze)
- Magnets distance 60 mm
- Magnetic field 1.7 kG
- Electrodes at distance of 44 mm
- Maximum high voltage for each electrode $\pm$20 kV



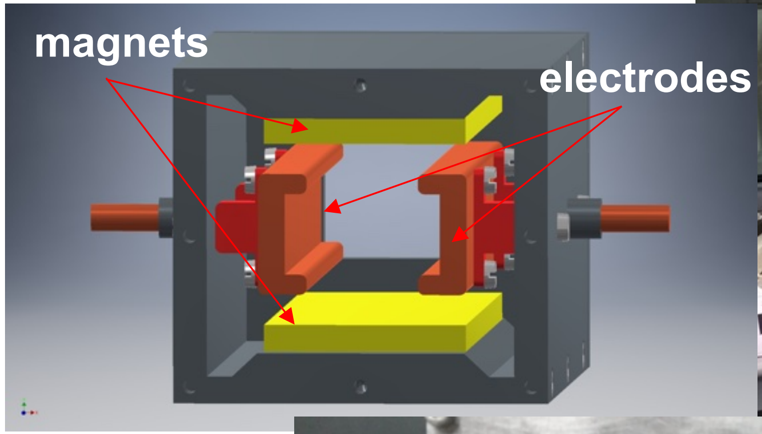
HIL Heavy Ion Laboratory

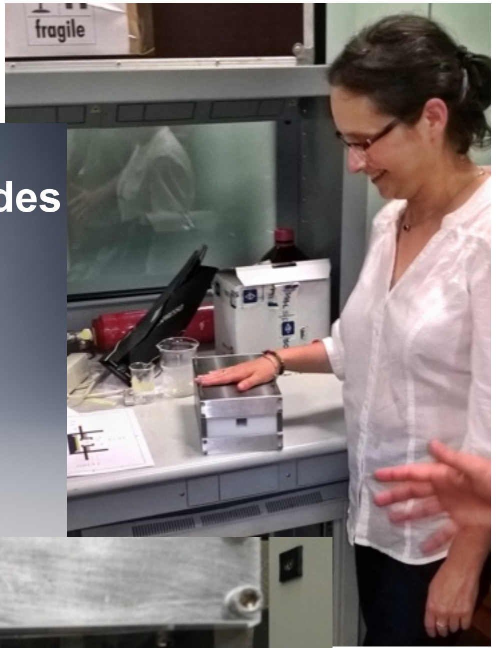
Fusion barrier distribution measurement through the direct detection of evaporation residues

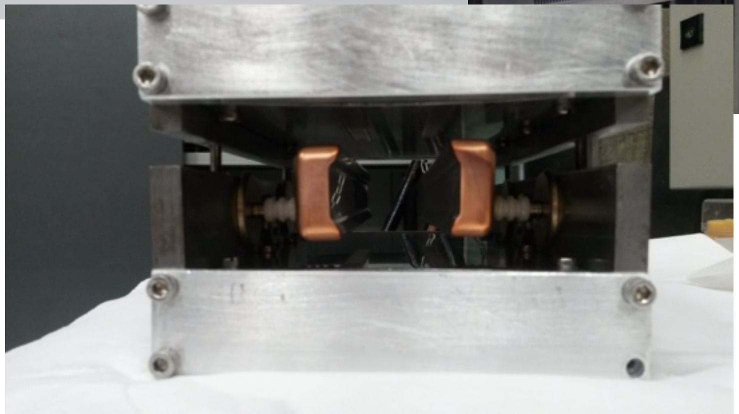


Based on set-up in use at ANU (Australia)
Using a MCP and a Silicon detector

The Wien Filter at LNS







- Dimensions of 106 x 150 x 250 mm^3
- 20 permanent magnets (Sm_2Co_{17}) 41 x 41 x 11 mm^3 (Vacuumshmalze)
- Magnets distance 60 mm
- Magnetic field 1.7 kG
- Electrodes at distance of 44 mm
- Maximum high voltage for each electrode $\pm$20 kV

Experiment will be performed next year

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

D_{QE} measurements at HIL : ^{20}Ne + ^{90,92}Zr

D_{QE} of ^{20}Ne + ^{92,94,95}Mo

Future plans

Why nuclear physics?

- Experimental nuclear physics allows you to follow an experiment in its entire process

  → From detectors' characterization to the experimental and theoretical analysis of the data

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

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

D_{QE} measurements at HIL : $^{20}Ne + ^{90,92}Zr$

D_{QE} of $^{20}Ne + ^{92,94,95}Mo$

Future plans

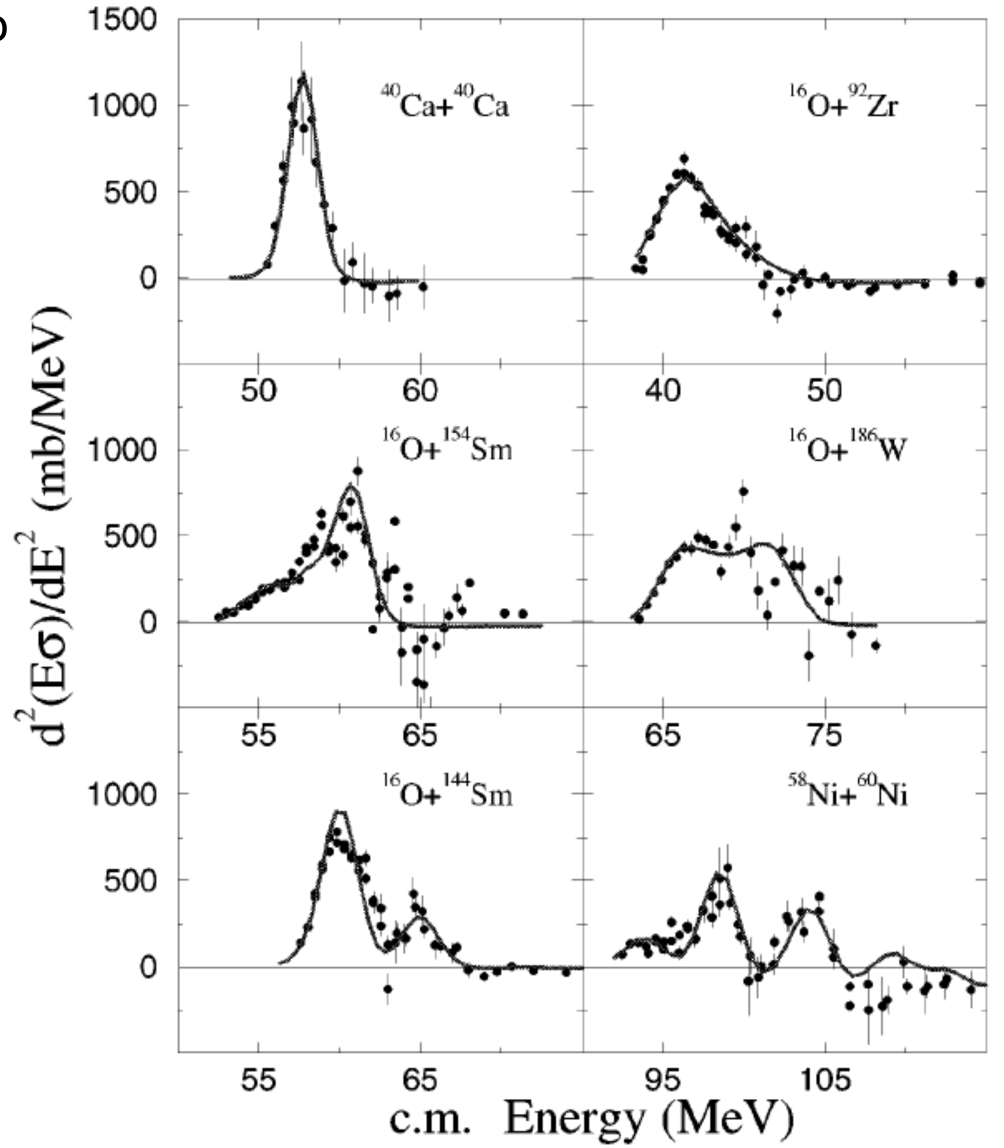
Why nuclear physics?

- Experimental nuclear physics allows you to follow an experiment in its entire process

  → From detectors' characterization to the experimental and theoretical analysis of the data

- Barrier distributions show up significant differences among different systems

  → Fingerprint of the structure of the interacting nuclei and the dynamics of the reaction



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

Near barrier fusion reactions

Fusion and quasielastic barrier distributions

D_{QE} measurements at HIL : ^{20}Ne + ^{90,92}Zr

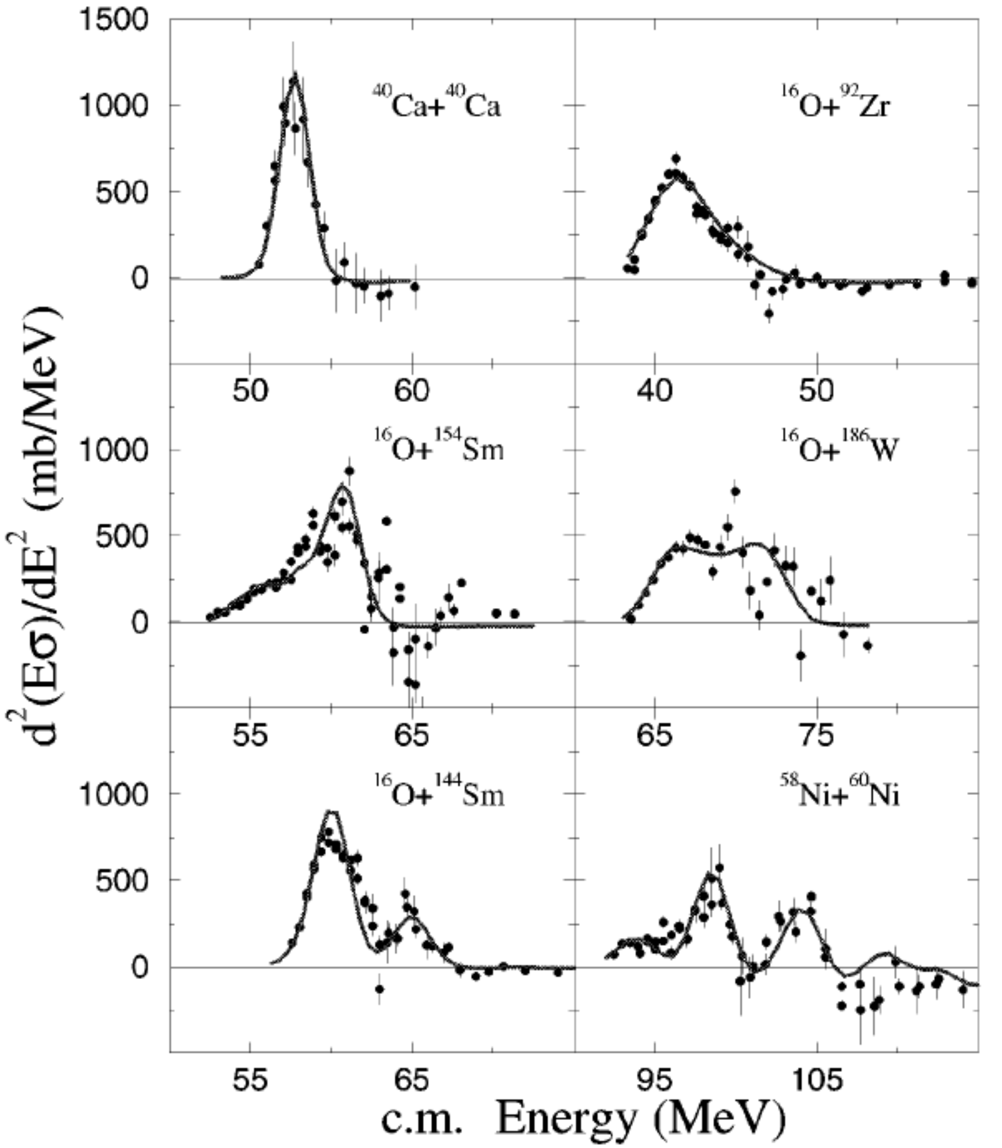
D_{QE} of ^{20}Ne + ^{92,94,95}Mo

Future plans

Why nuclear physics?

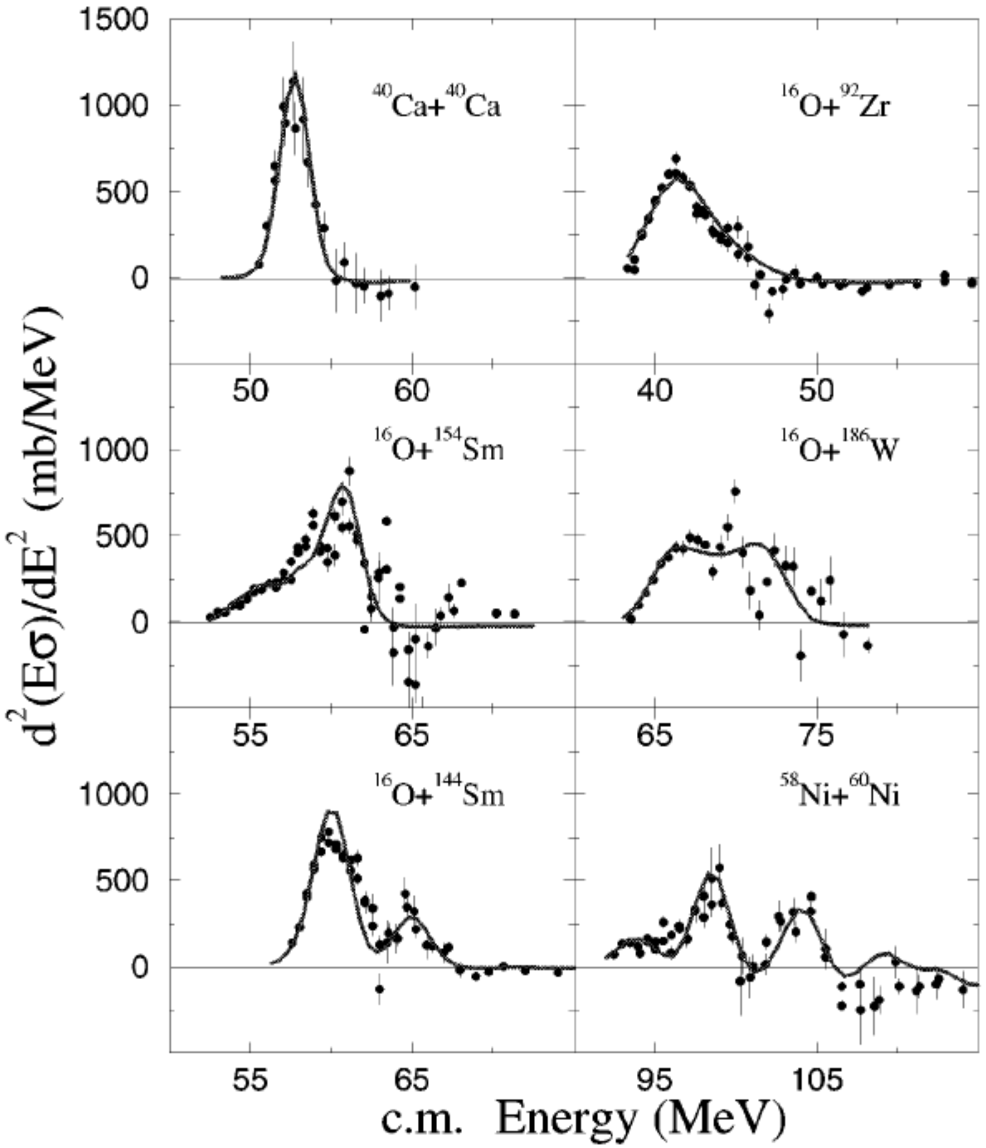
- Experimental nuclear physics allows you to follow an experiment in its entire process
  - From detectors' characterization to the experimental and theoretical analysis of the data
- Barrier distributions show up significant differences among different systems
  - Fingerprint of the structure of the interacting nuclei and the dynamics of the reaction

Dissipation



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

- Experimental nuclear physics allows you to follow an experiment in its entire process
  - From detectors' characterization to the experimental and theoretical analysis of the data
- Barrier distributions show up significant differences among different systems
  - Fingerprint of the structure of the interacting nuclei and the dynamics of the reaction
  - Dissipation
- Availability of new set-up at HIL
  - Fusion barrier distributions studies



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

E. Piasecki, A. Trzcińska, M. Kowalczyk, M. Kisieliński, M. Wolińska-Cichocka, B. Zalewski, J. Choiński, K. Hadyńska-Klęk, G. Jaworski, M. Matuszewski, K. Piasecki, J. Samorajczyk-Pyśk, A. Stolarz, A. Tucholski

Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland

L. Calabretta, G. Cardella, D. Dell'Aquila, E. De Filippo, S. De Luca, F. Favela, E. Geraci, B. Gnoffo, G. Lanzalone, I. Lombardo, C. Maiolino, N. S. Martorana, A. Pagano, E. V. Pagano, S. Pirrone, G. Politi, L. Quattrocchi, D. Rizzo, F. Rizzo, A. Russo, P. Russotto, A. Trifiro, M. Trimarchi, M. Vigilante, C. Zagami

Dip. di Fisica e Astronomia, Università di Catania, and INFN-LNS, Catania, Italy

W. Trzaska, G. Tiurin

University of Jyväskylä, Jyväskylä, Finland

P. Koczoń , Y. Leifels , B. Lommel

GSI, Darmstadt, Germany

P. W. Wen

China Institute of Atomic Energy, Beijing, China

Thank you for your attention

HIL
Heavy Ion Laboratory