Role of non-collective excitations in subbarrier fusion reactions

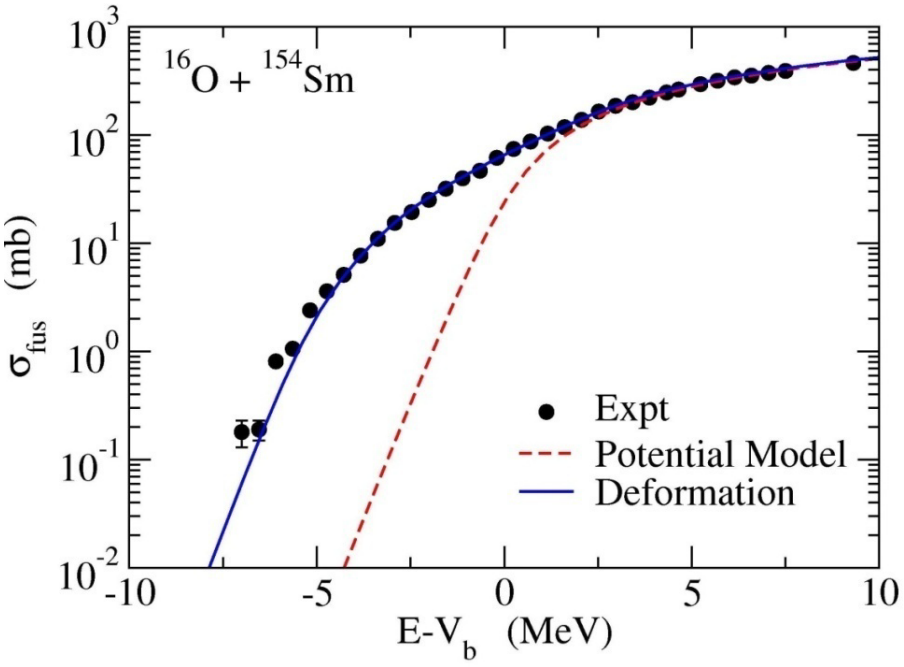
Kouichi Hagino (Tohoku University)
Shusaku Yusa (Tohoku University)
Neil Rowley (IPN Orsay)

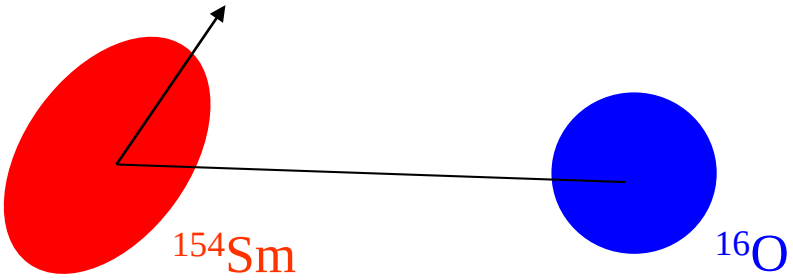
1. *Introduction:*
   Subbarrier fusion and Coupled-channels approach
2. *Indications of non-collective excitations*
3. *$^{16}O+^{208}Pb$ fusion and quasi-elastic scattering*
4. *Summary*

Introduction

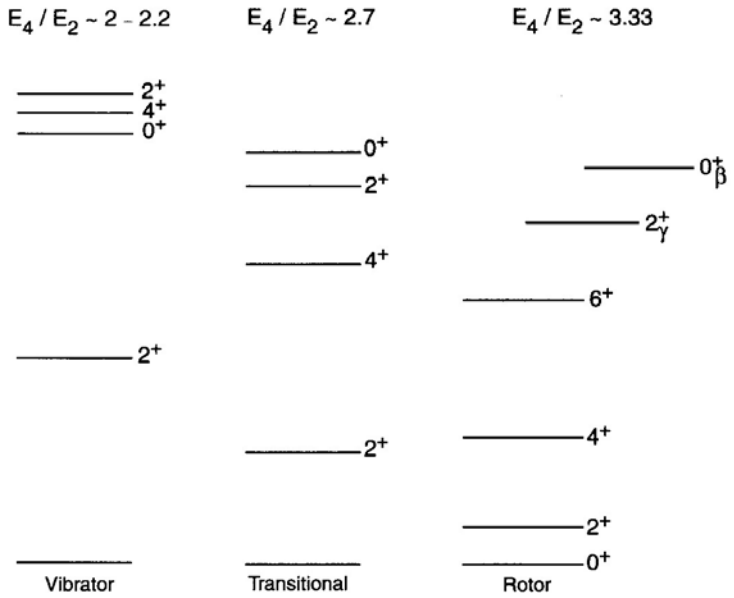
Subbarrier enhancement of fusion cross section

⟺ channel coupling effects



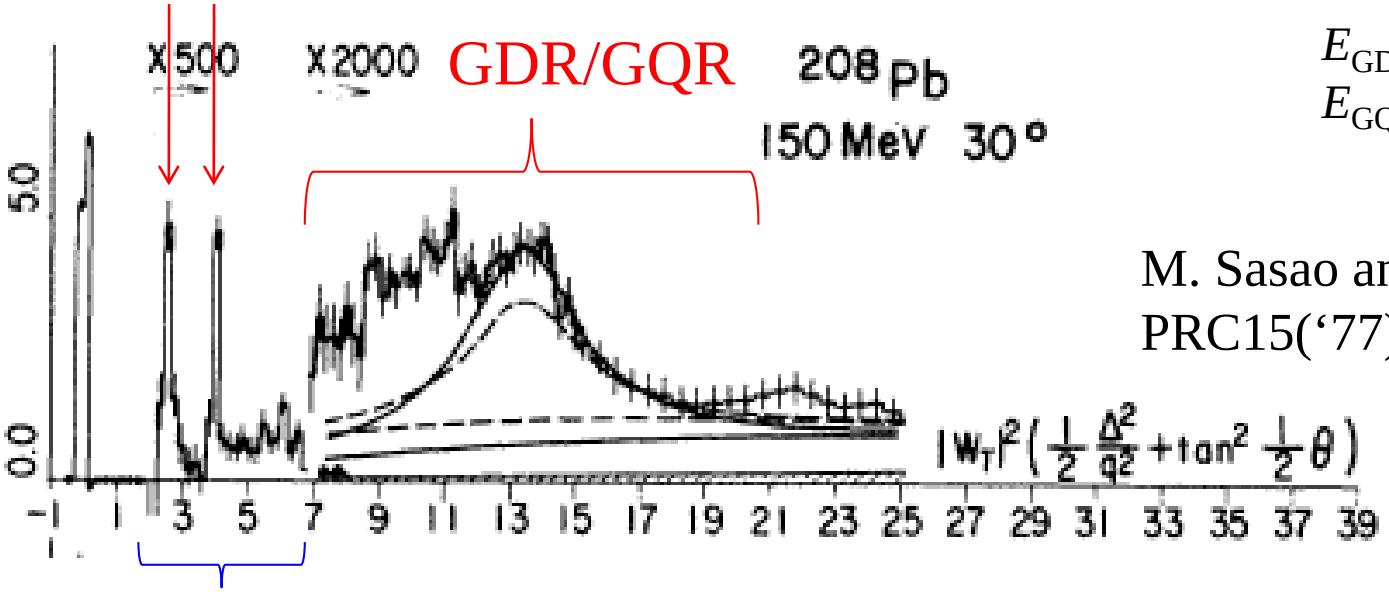


Coupling of the relative motion to collective excitations in the colliding nuclei



typical excitation spectrum: electron scattering data

low-lying collective excitations



low-lying non-collective excitations

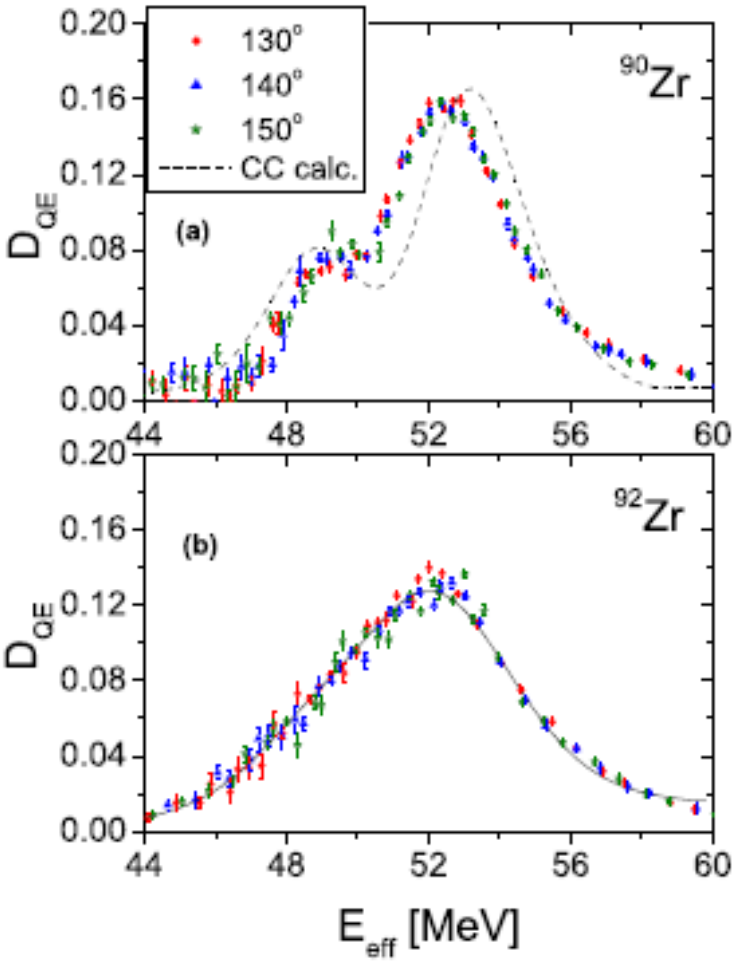
$E_{GDR} \sim 79A^{-1/3}$ MeV
$E_{GQR} \sim 65A^{-1/3}$ MeV

M. Sasao and Y. Torizuka,
PRC15('77)217

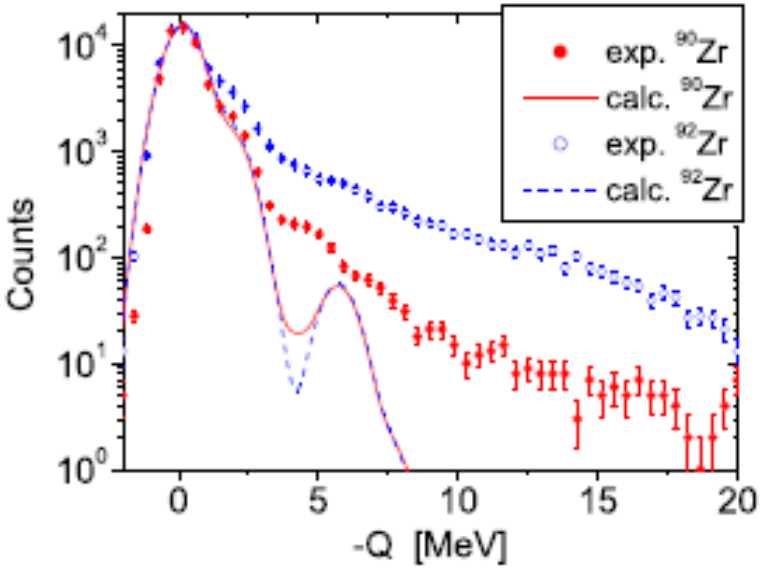
- Giant Resonances: high E_x, smooth mass number dependence
  $\longrightarrow$ adiabatic potential renormalization
- Low-lying collective excitations: barrier distributions,
  strong isotope dependence
- Non-collective excitations: either neglected completely or
  implicitly treated through an absorptive potential

Indications of non-collective excitations : comparison between ^{20}Ne+^{90}Zr and ^{20}Ne+^{92}Zr

$$D_{\mathrm{qel}}(E) = -\frac{d}{dE}\left(\frac{\sigma_{\mathrm{qel}}(E,\pi)}{\sigma_R(E,\pi)}\right)$$



E. Piasecki et al., PRC80('09)054613

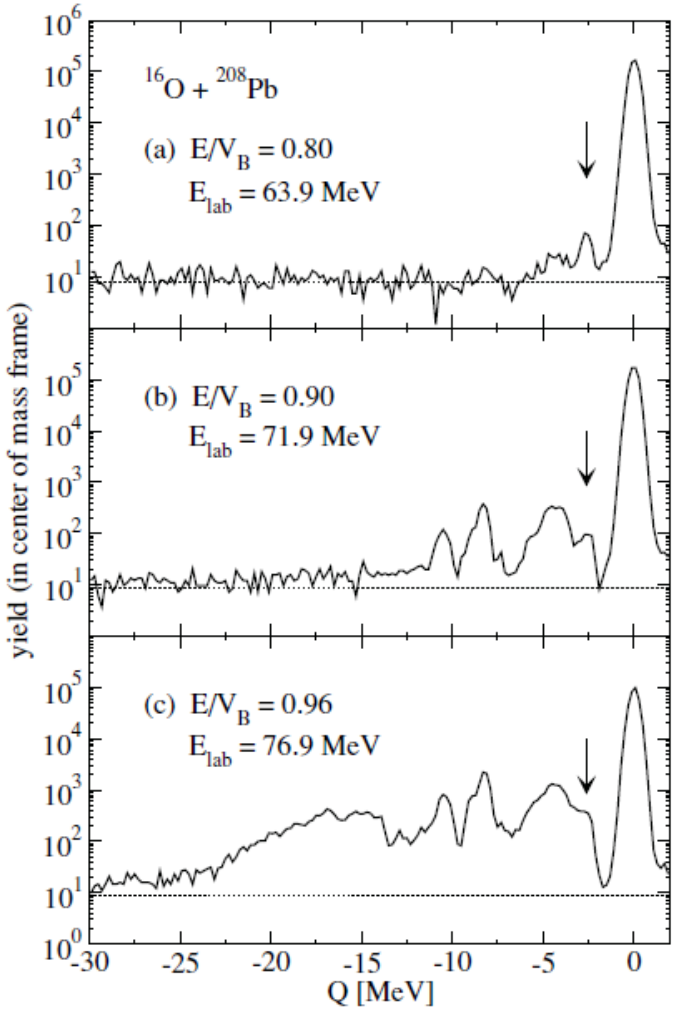


(E_{eff} = 50 MeV)

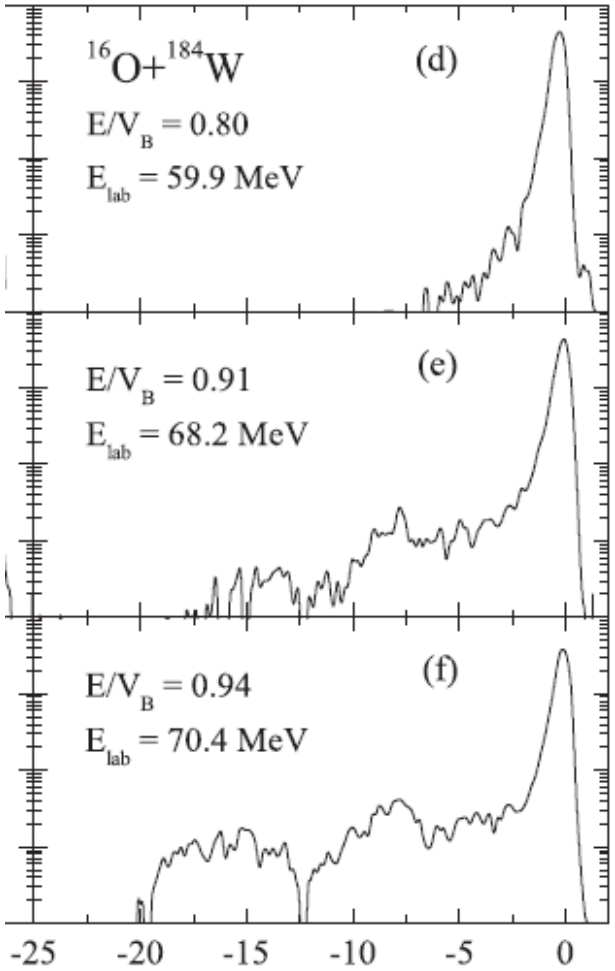
- C.C. results are almost the same between the two systems
- Yet, quite different barrier distribution and Q-value distribution

non-collective excitations?

Q-value distribution from backward scattering:



M. Evers et al.,
PRC78(‘08)034614



C.J. Lin et al.,
PRC79(‘09)064603

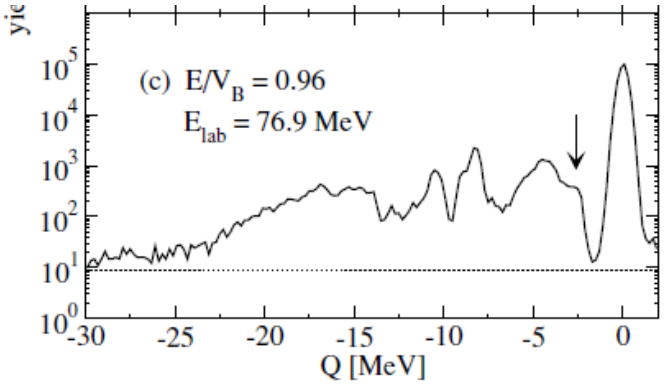
(elastic + collective) peaks + non-collective bumps

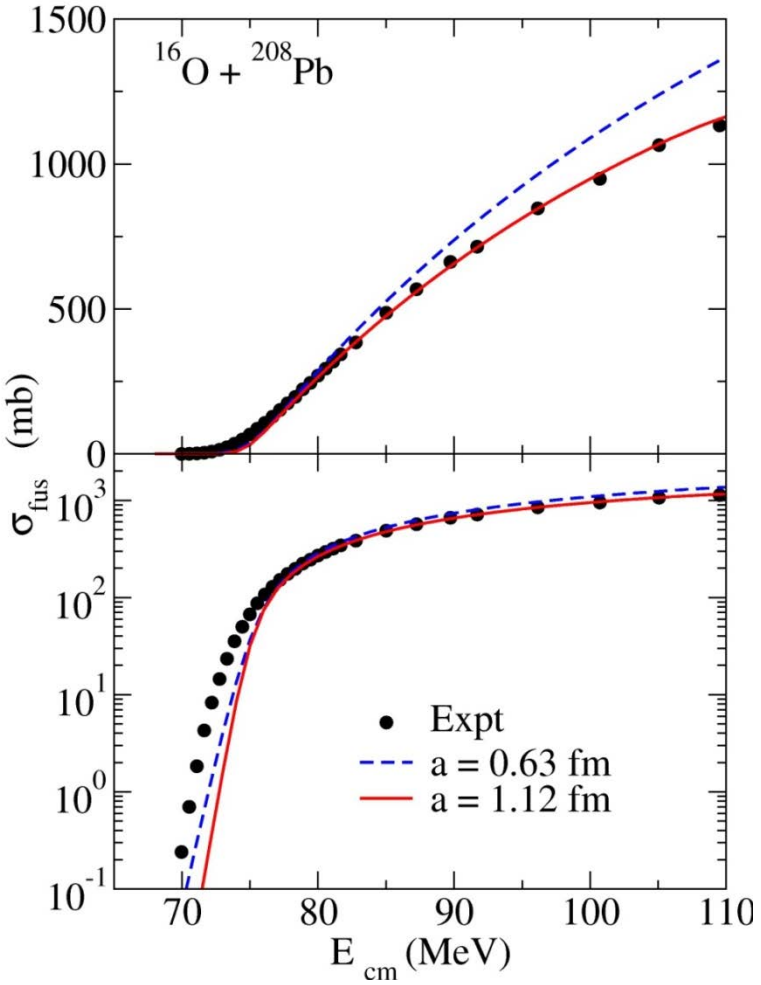
Motivations of this work

- What is the role of non-collective excitations?

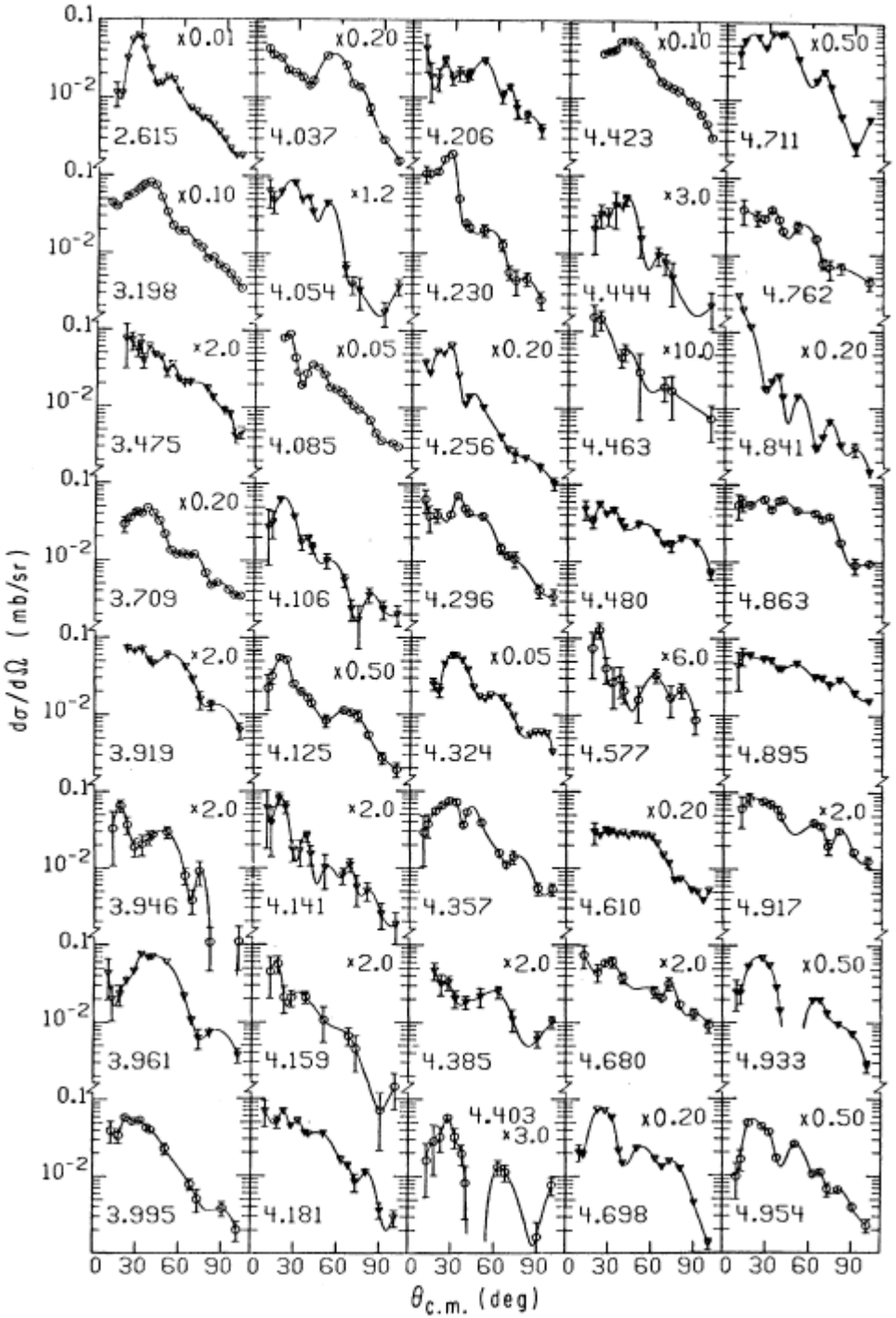
  - ✓fusion reaction
  - ✓quasi-elastic scattering
  - ✓surface diffuseness problem?
  - ✓deep subbarrier hindrance?

- Can we understand the energy dependence of the observed Q-value distribution?





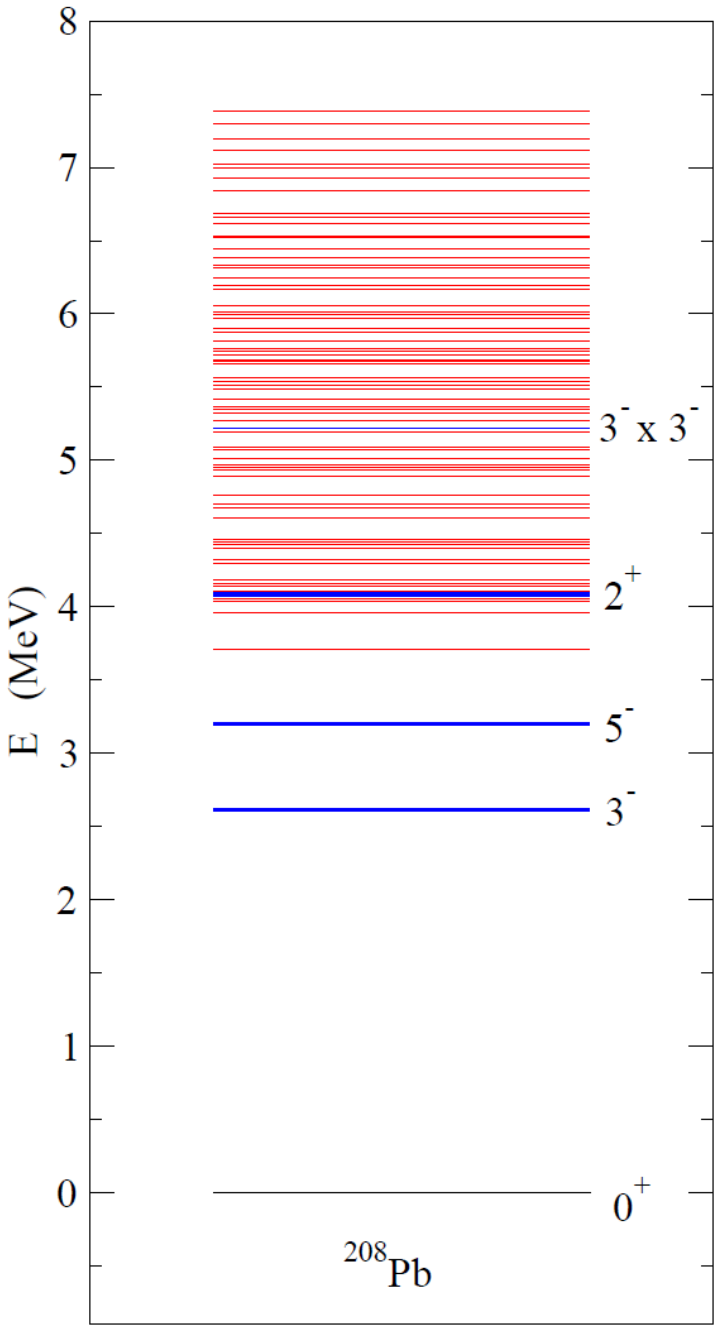
→ ^{16}O + ^{208}Pb reaction



High resolution (p,p') experiment of ^{208}Pb

W.T. Wagner et al., PRC12('75)757

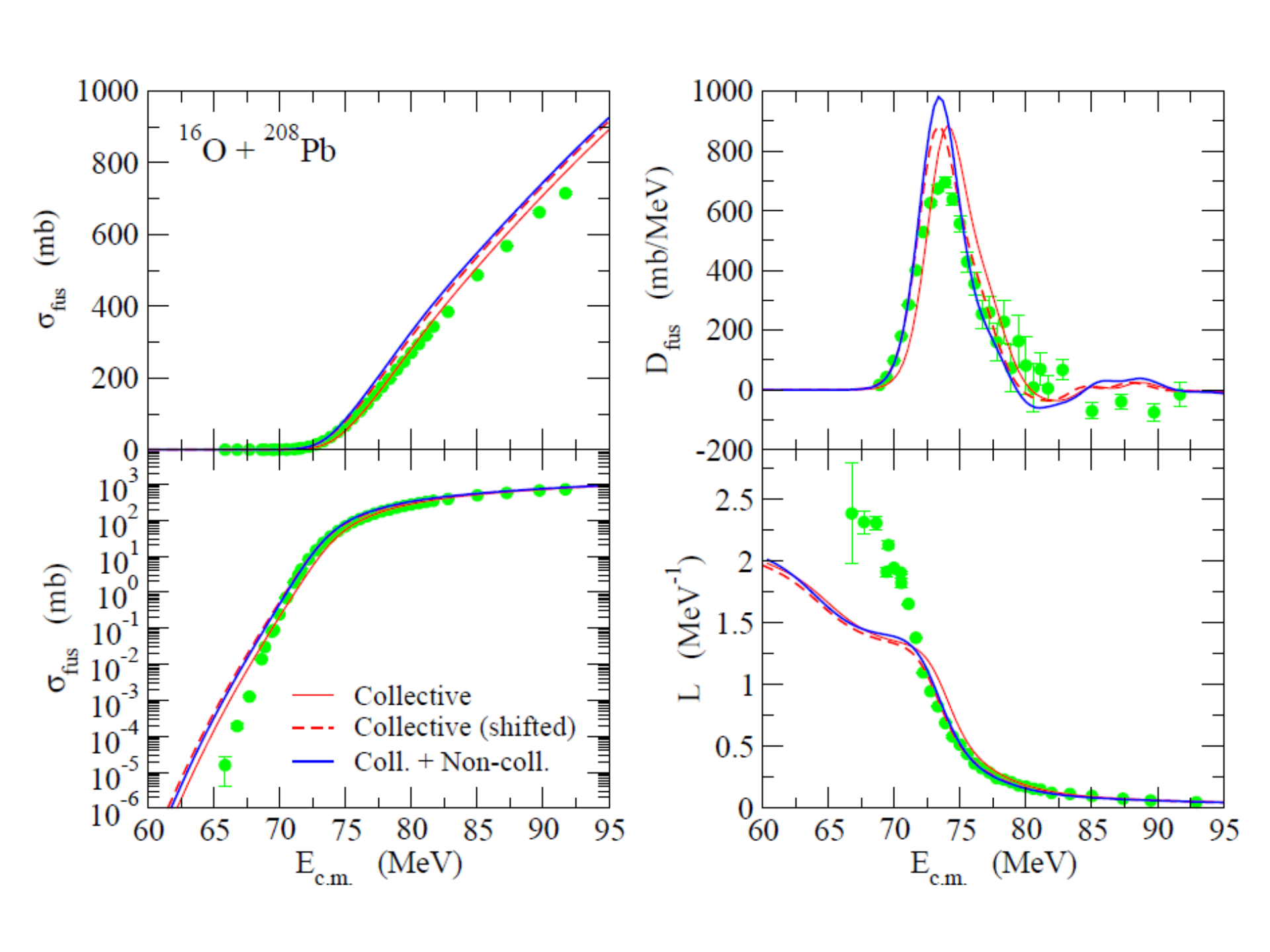
energy resolution: 5-8 keV

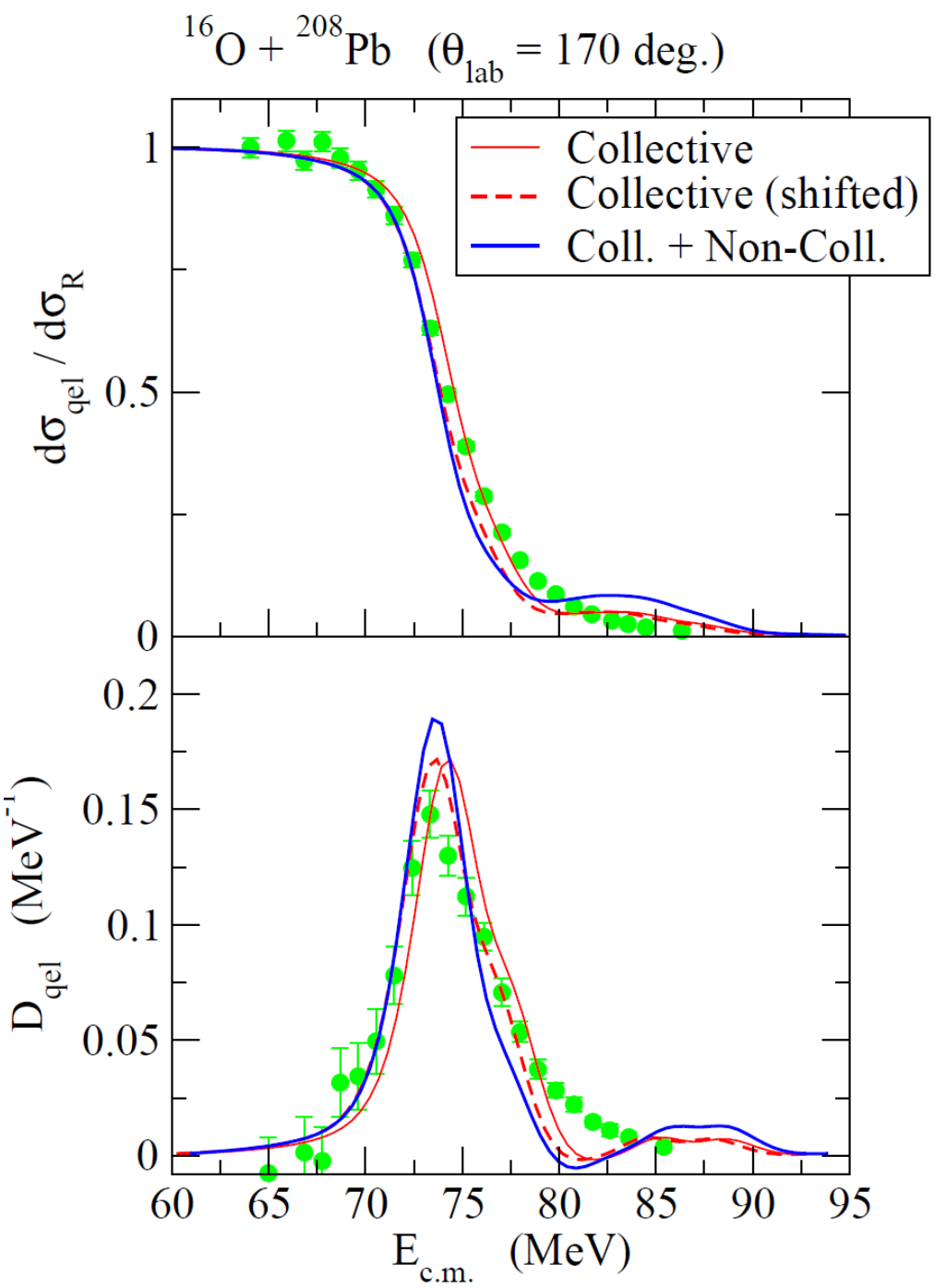


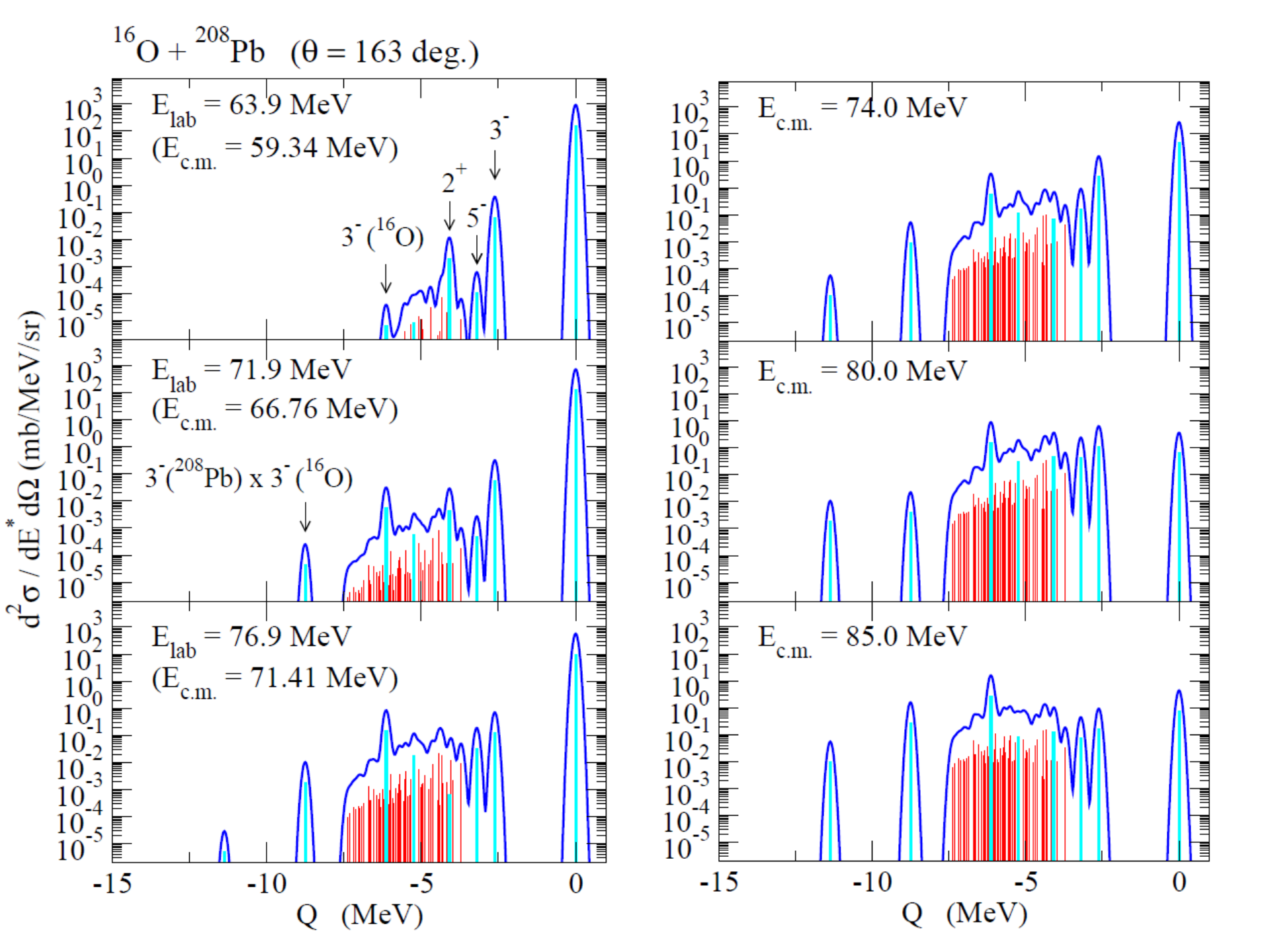
Non-collective states:
weakly coupled, but many levels

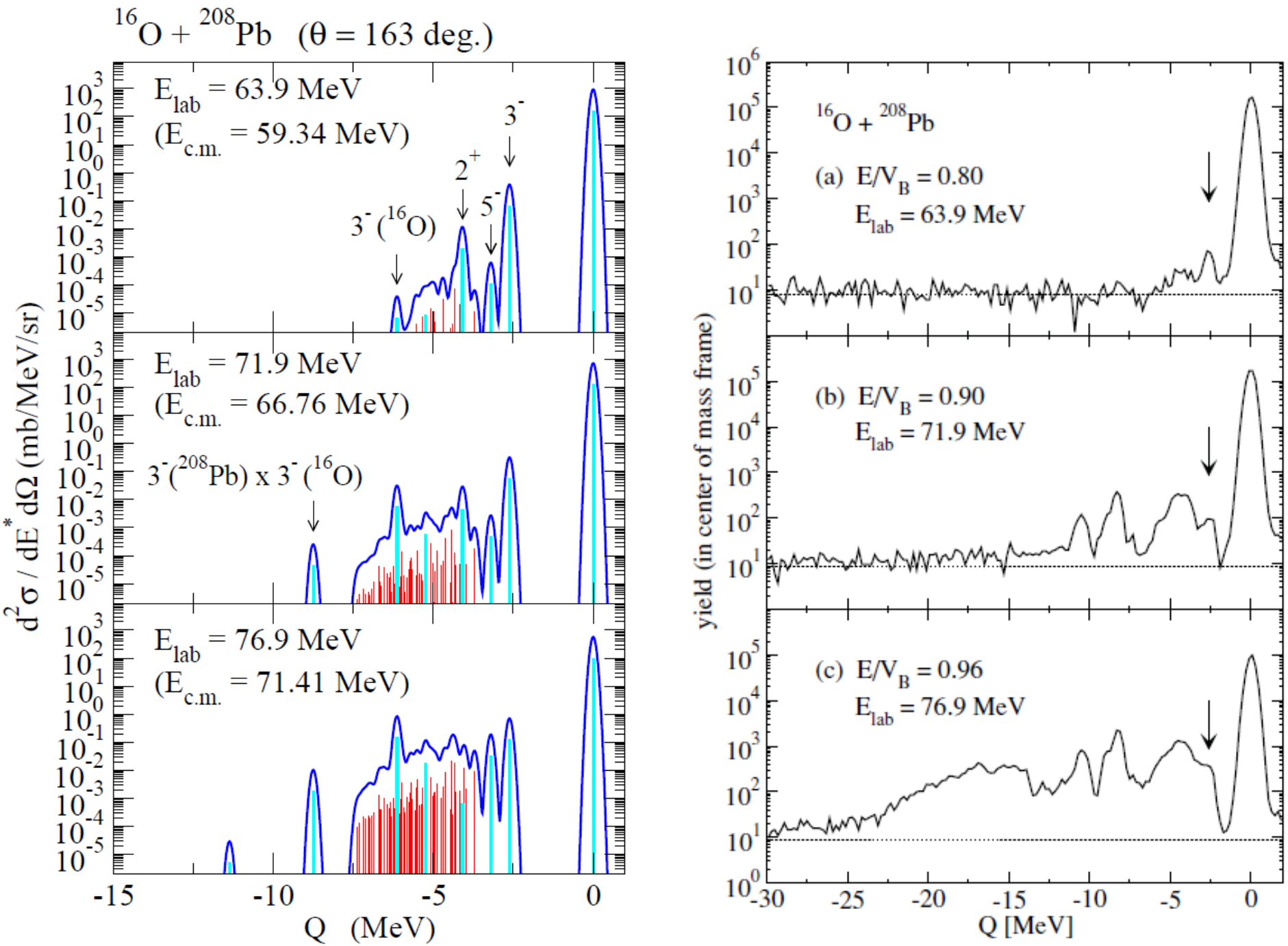
64 non-collective levels up to 7 MeV
nearly "complete" level scheme
both E^* and β_λ

Solve C.C. equations including also these non-collective levels


$^{16}O + ^{208}Pb$
σ_{fus} (mb)
D_{fus} (mb/MeV)
L (MeV^{-1})
$E_{c.m.}$ (MeV)
Collective
Collective (shifted)
Coll. + Non-coll.


^{16}O + ^{208}Pb (θ_{lab} = 170 deg.)
Collective
Collective (shifted)
Coll. + Non-Coll.
$d\sigma_{qel} / d\sigma_R$
D_{qel} (MeV^{-1})
$E_{c.m.}$ (MeV)
0
0.5
1
0.05
0.1
0.15
0.2
60
65
70
75
80
85
90
95


$^{16}O + ^{208}Pb$ (θ = 163 deg.)
E_{lab} = 63.9 MeV
($E_{c.m.}$ = 59.34 MeV)
3^-
2^+
5^-
3^- (^{16}O)
E_{lab} = 71.9 MeV
($E_{c.m.}$ = 66.76 MeV)
3^-(^{208}Pb) x 3^- (^{16}O)
E_{lab} = 76.9 MeV
($E_{c.m.}$ = 71.41 MeV)
$E_{c.m.}$ = 74.0 MeV
$E_{c.m.}$ = 80.0 MeV
$E_{c.m.}$ = 85.0 MeV
$d^2\sigma / dE^*_x d\Omega$ (mb/MeV/sr)
Q (MeV)
Q (MeV)


16O + 208Pb (θ = 163 deg.)
Elab = 63.9 MeV
(Ec.m. = 59.34 MeV)
3-
2+
5-
3- (16O)
Elab = 71.9 MeV
(Ec.m. = 66.76 MeV)
3-(208Pb) x 3- (16O)
Elab = 76.9 MeV
(Ec.m. = 71.41 MeV)
d2σ / dE* dΩ (mb/MeV/sr)
Q (MeV)
16O + 208Pb
(a) E/VB = 0.80
Elab = 63.9 MeV
(b) E/VB = 0.90
Elab = 71.9 MeV
(c) E/VB = 0.96
Elab = 76.9 MeV
yield (in center of mass frame)
Q [MeV]

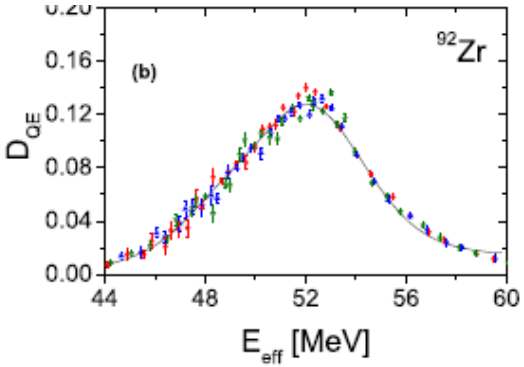
Summary

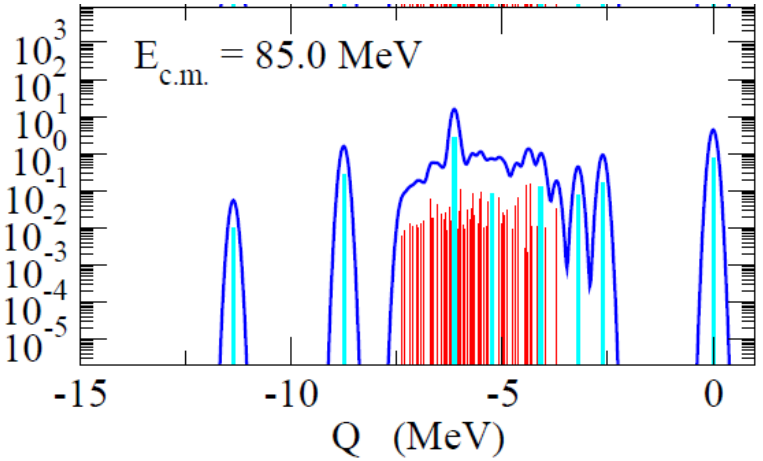
Role of non-collective excitations in $^{16}O + ^{208}Pb$ reaction

- Large scale coupled-channels calculations
- non-collective excitations: adiabatic barrier renormalization
- Energy dependence of fusion cross section: is not altered much
- the second peak (bump) in the barrier distribution: somewhat smeared
- Energy dependence of Q-value distribution: qualitatively good

Future Perspectives

- ✓ $^{20}Ne + ^{90,92}Zr$ systems
- ✓ Quantum mechanical theory for DIC





THE CONTINUOUS SPECTRUM AND THE EXCITATION OF GIANT RESONANCES IN THE REACTION $^{16}O + ^{208}Pb$

R.A. BROGLIA, G. POLLAROLO, A. VITTURI and A. WINTHER
The Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen Ø, Denmark

and

C.H. DASSO and H. ESBENSEN
NORDITA, DK-2100 Copenhagen Ø, Denmark

PLB89(‘79)22