Hot fusion studies at the BGS with light projectiles and ^{238}U targets

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Preliminary results from a systematic study of hot fusion reactions with ions from ^{22}Ne through ^{31}P and ^{238}U targets

LBNL Heavy Element Group

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Ken Gregorich	

Postdoc:

Liv Stavsetra	(^{244}Pu Targets)

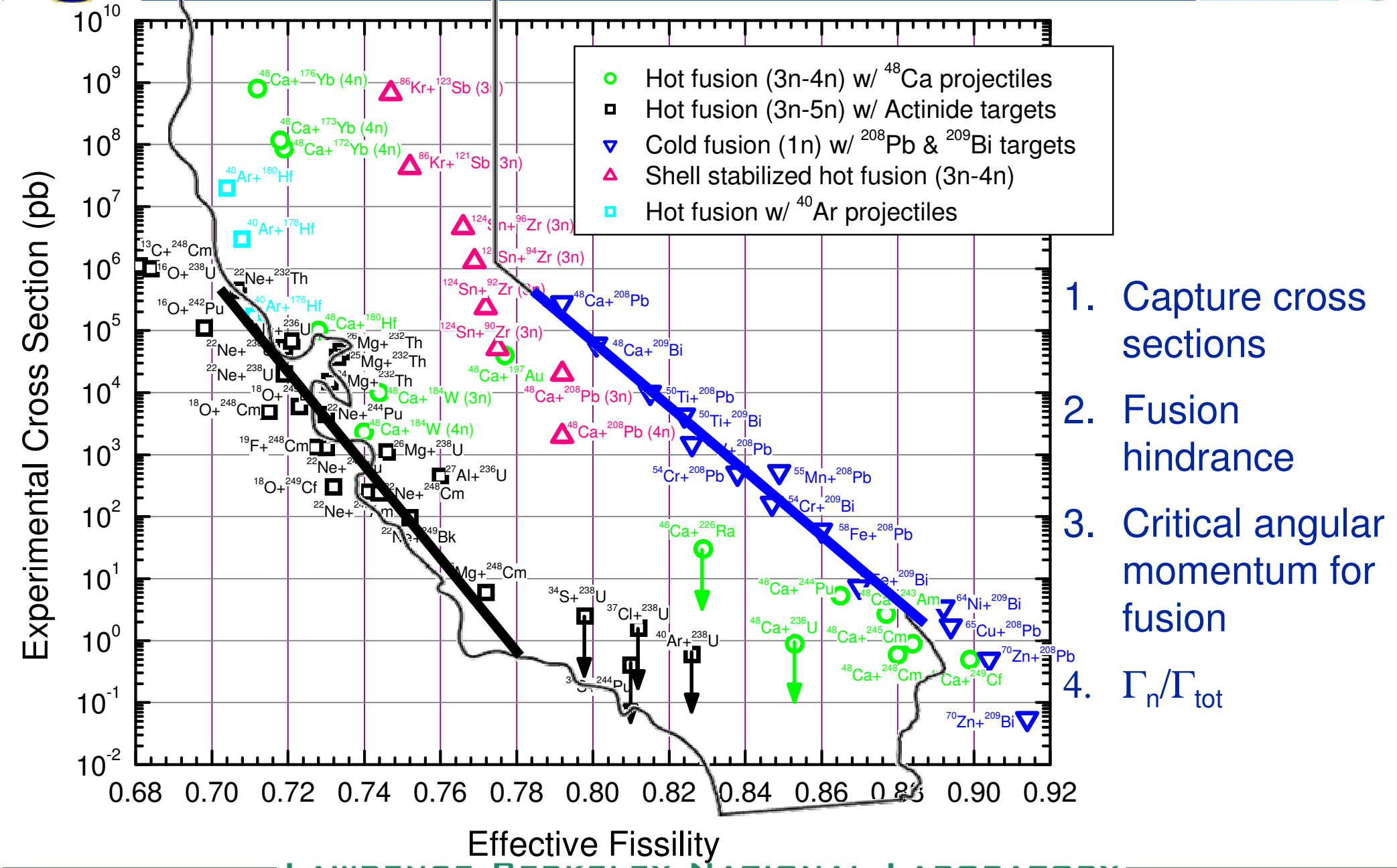
Graduate Students:

Irena Dragojevic	(Cold fusion)
Mitch Andre Garcia	(Gas phase chemistry)
Jacklyn Gates	(Hot fusion; Db extraction chemistry)
Sarah Nelson	(Cold fusion)

Collaborators

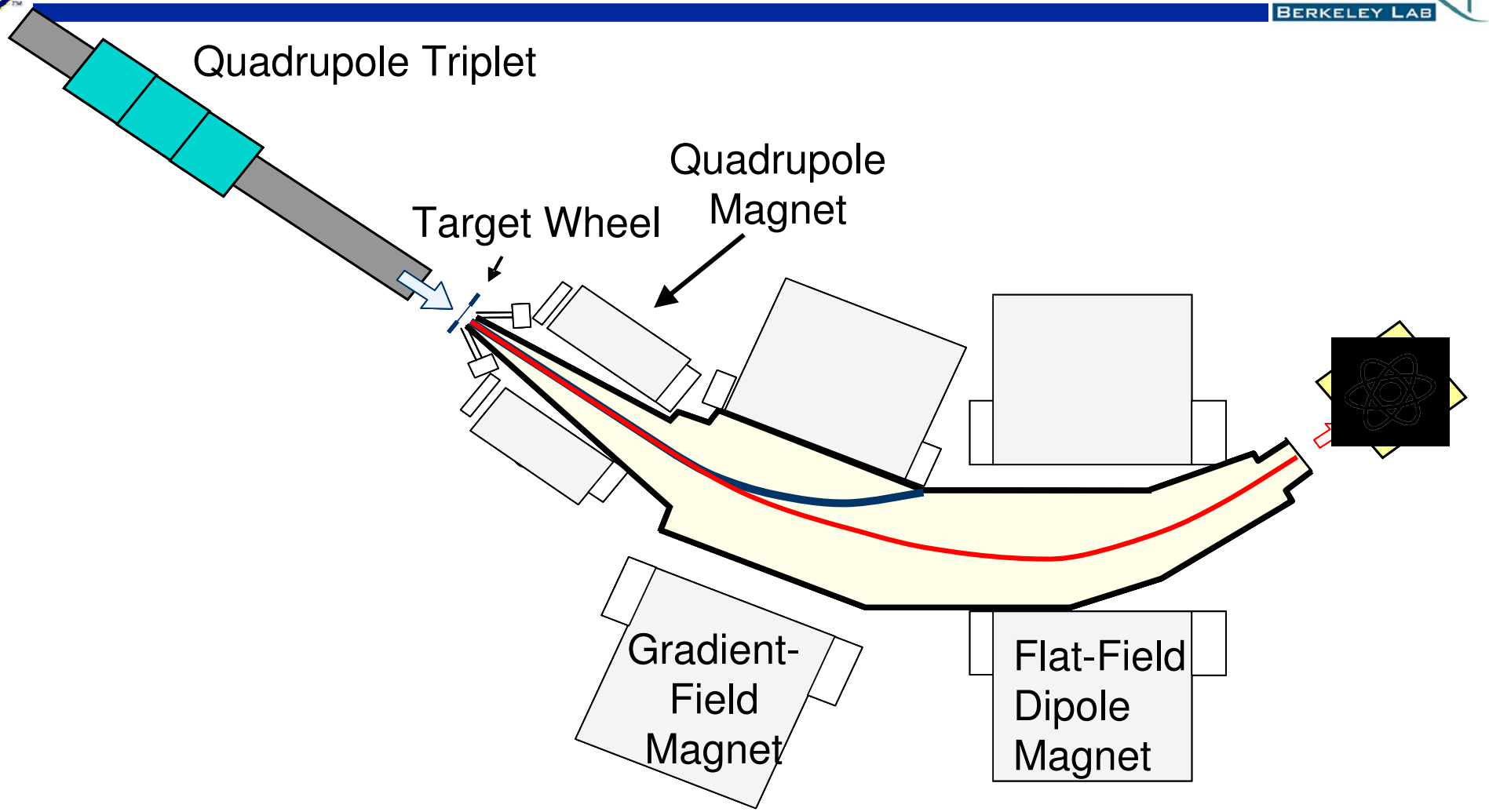
OSU, PSI/Bern, GSI, TUM, ANL

What Can We Learn from a Systematic Study of Compound Nucleus Reactions with ^{238}U targets?



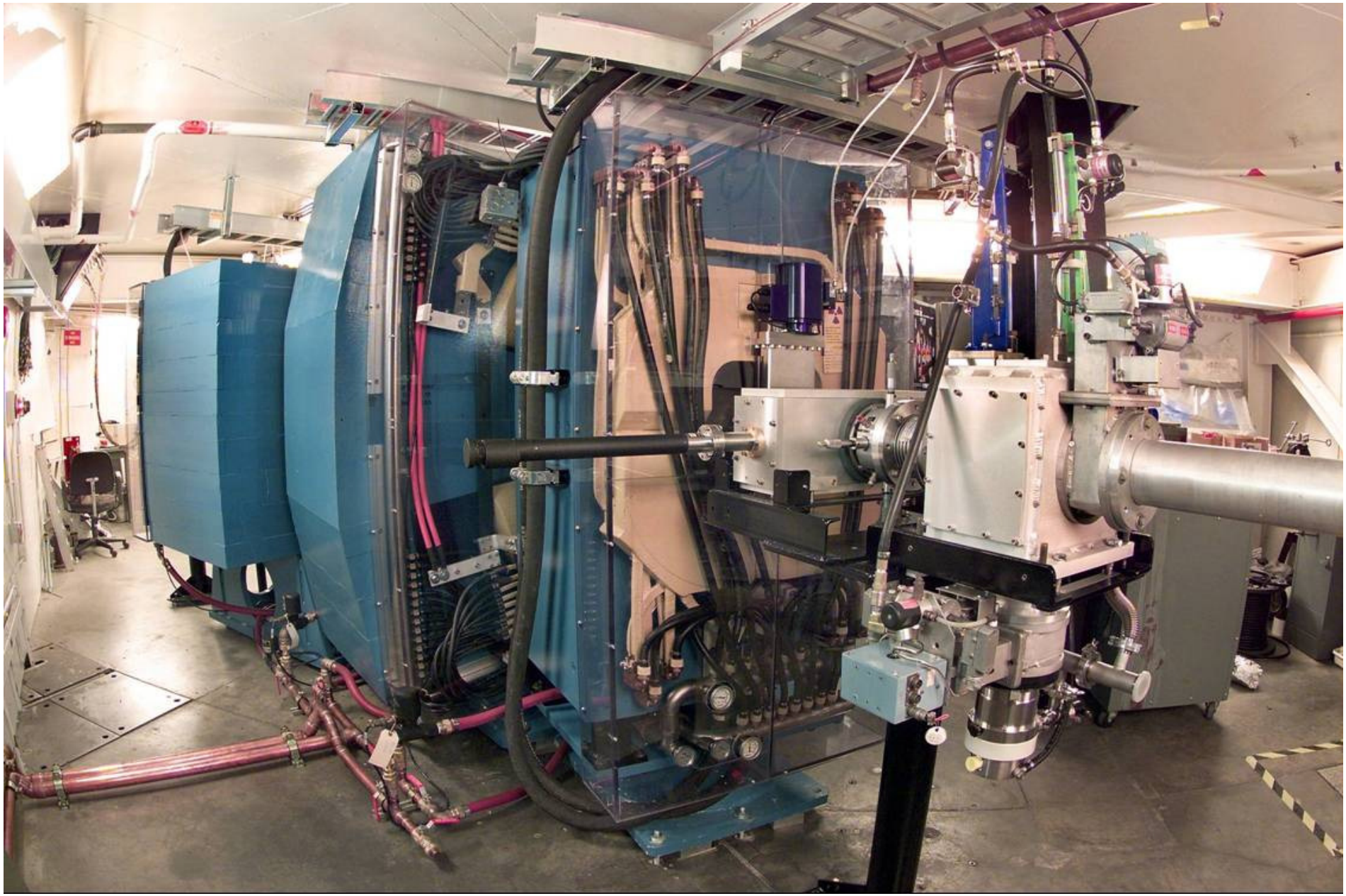
1. Capture cross sections
2. Fusion hindrance
3. Critical angular momentum for fusion
4. Γ_n/Γ_{tot}

Berkeley Gas-filled Separator

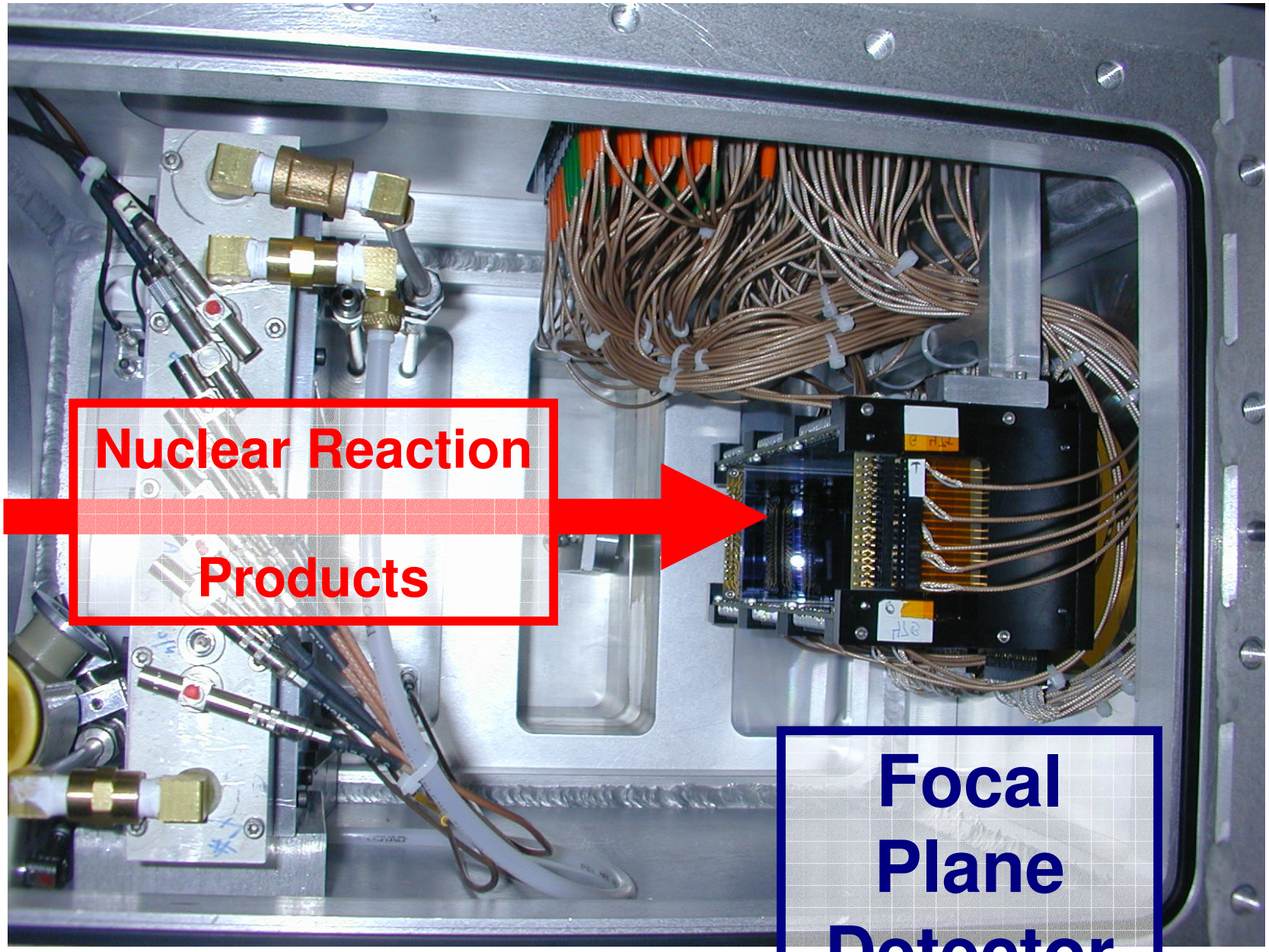


- ☑ Large acceptance: 45 msr (± 9° vertical, ±4.5° horizontal
  - ⇨ High transmission (Ni+Pb: ~70%; Mg+U: 15-18%)
- ☑ Large bend angle: 70°
  - ⇨ Large dispersion: 2 cm/(% Bρ)

BGS



Detector Setup



Systematic Study with ^{238}U targets
and neutron rich projectiles from ^{18}O to ^{31}P

^{238}U(^{18}O,xn)$^{256-x}$Fm (results from radiochemical experiments of Donets et al.)

^{238}U(^{19}F,xn)$^{257-x}$Md (results from radiochemical experiments of Donets et al.)

^{238}U(^{22}Ne,xn)$^{260-x}$No (0.158 mg/cm^2 UF_4 targets, six-point excitation function completed)

chopped beam, measured nobelium alpha singles during beam pause

^{238}U(^{23}Na,xn)$^{261-x}$Lr (0.158 mg/cm^2 UF_4 targets, three-point excitation function completed)

chopped beam, EVR-alpha correlations measured (EVR during beam pulse, alpha during pause)

^{238}U(^{26}Mg,xn)$^{264-x}$Rf (0.471 mg/cm^2 UF_4 targets, six-point excitation function completed)

DC beam short EVR-SF correlations for ^{260}Rf and ^{258}Rf.
chopped beam for ^{259}Rf, EVR during beam pulse, ^{259}Rf alpha during pause

^{238}U(^{27}Al,xn)$^{265-x}$Db (0.471 mg/cm^2 UF_4 targets, three-point excitation function completed)

DC beam, EVR-Db alpha shut off beam to search for Lr daughter alpha

^{238}U(^{30}Si,xn)$^{268-x}$Sg (0.471 mg/cm^2 UF_4 targets, four-point excitation function completed)

DC beam, EVR-Sg shut off beam to search for Rf daughter alpha

^{238}U(^{31}P,xn)$^{269-x}$Bh (cross sections too small?)

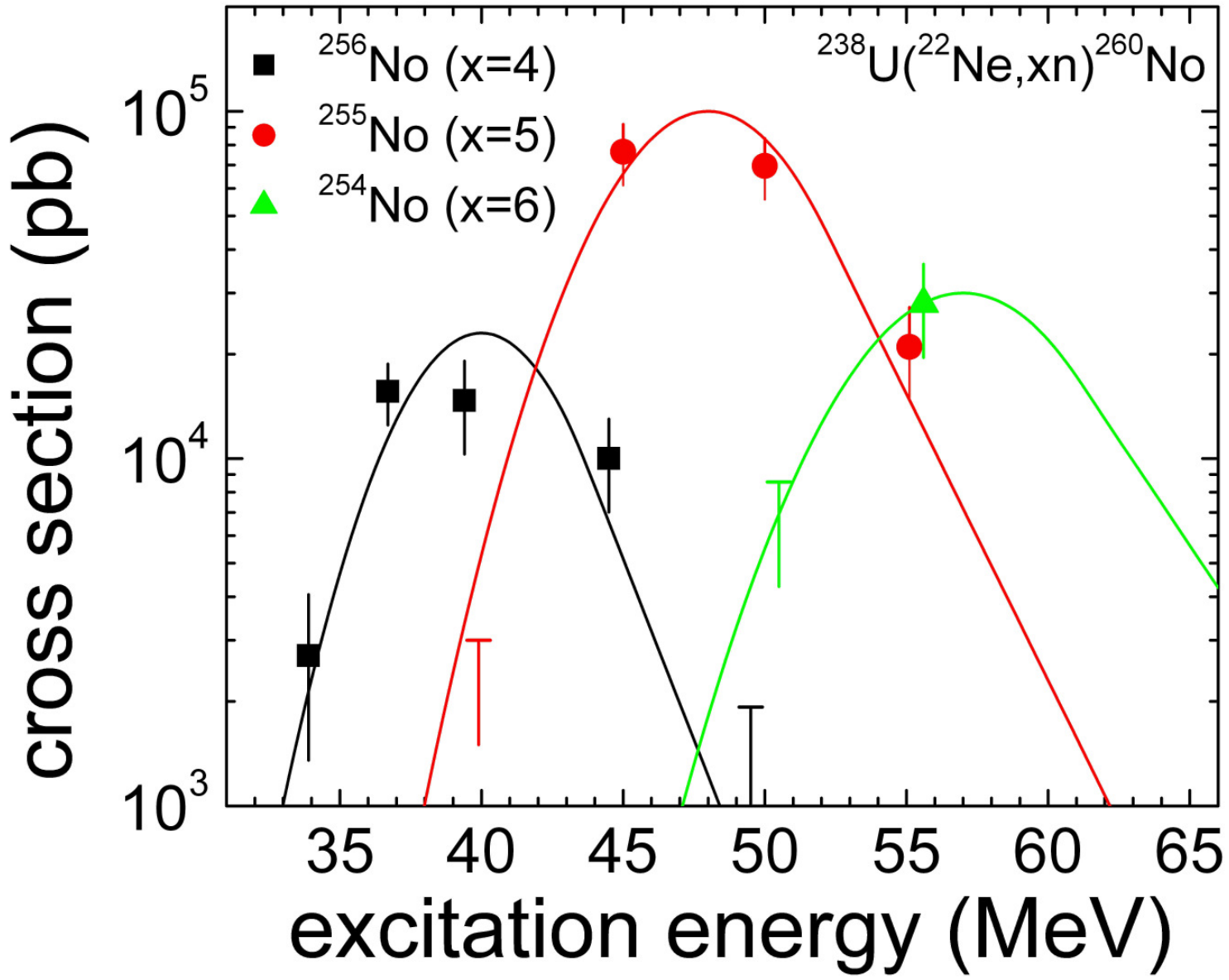
^{238}U(^{34}S,xn)$^{272-x}$Hs (upper limit from DGFRS)

^{238}U(^{37}Cl,xn)$^{275-x}$Mt (~1.6 pb upper limit was not sensitive enough)

DC beam, EVR with MWPC signal, alpha w/o MWPC, beam shutoff to search for daughters

^{238}U(^{40}Ar,xn)$^{278-x}$Ds (0.7 pb upper limit from SHIP)

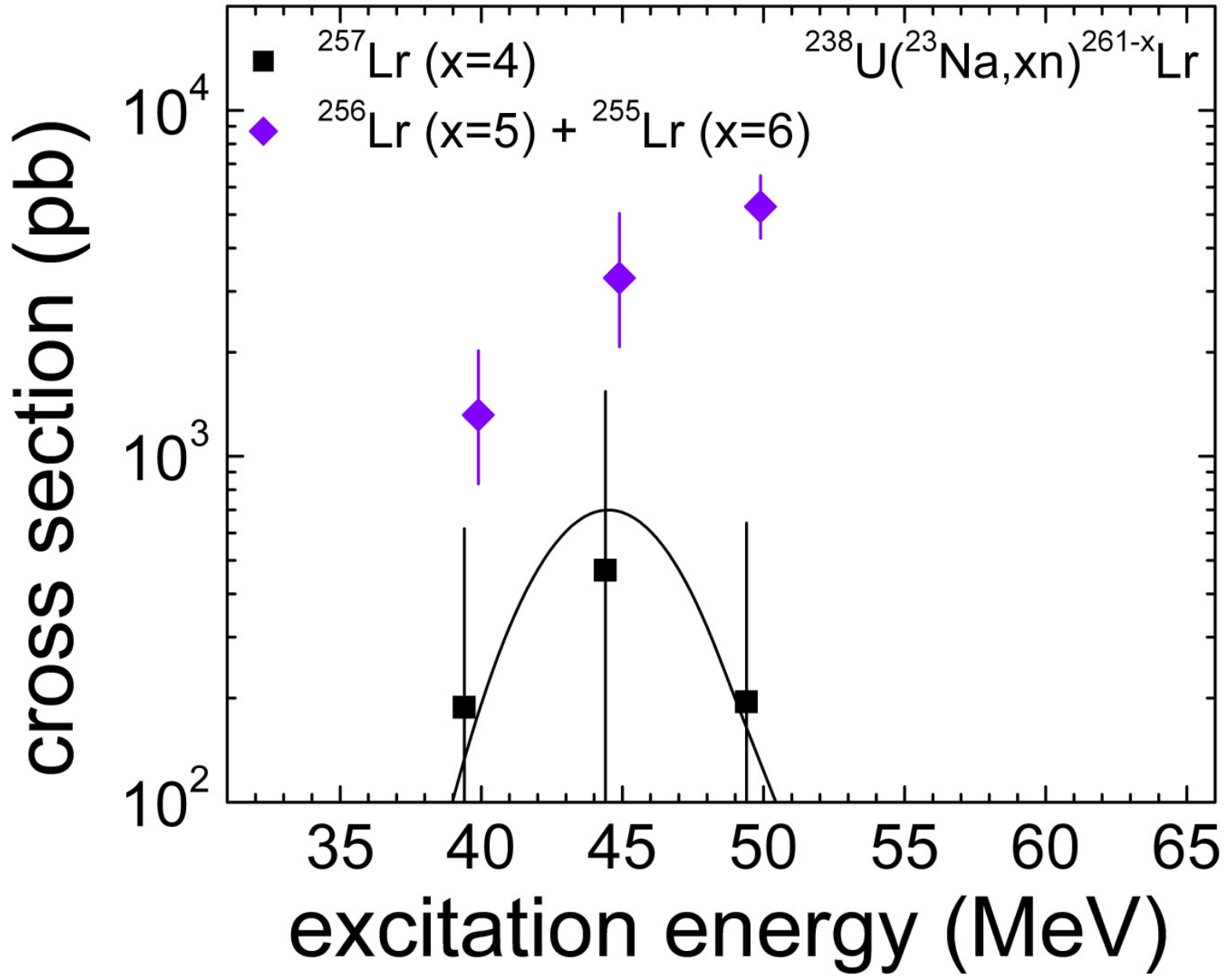
$^{238}U(^{22}Ne,xn)^{260-x}No$



Notes:

1. All data have been normalized by 1.34 to correct for portion of the excitation function missing the detector
2. Separation of ^{255}No and ^{254}No is difficult
3. ^{256}No peak has interference from ^{213}Po

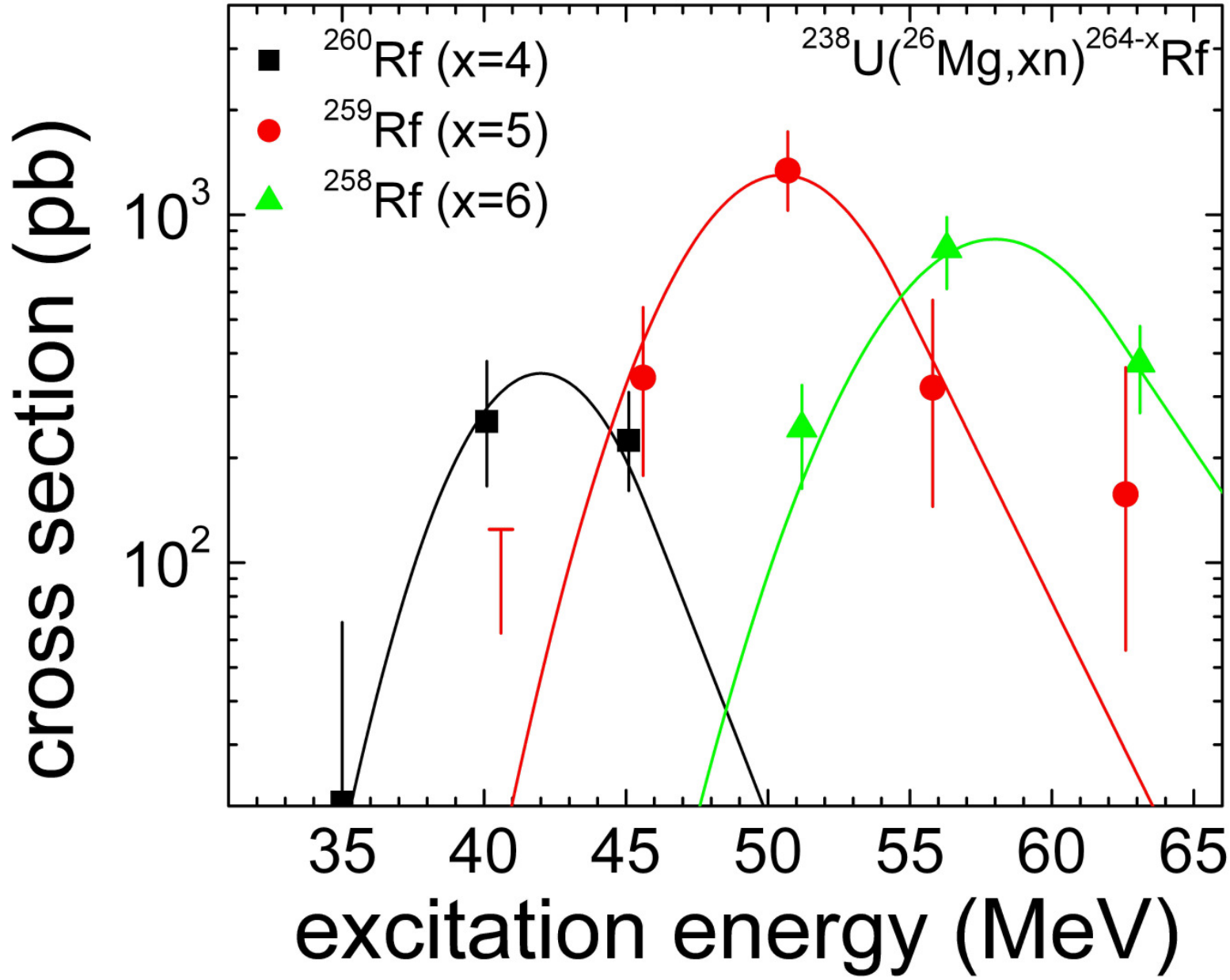
$^{238}U(^{23}Na,xn)^{261-x}Lr$



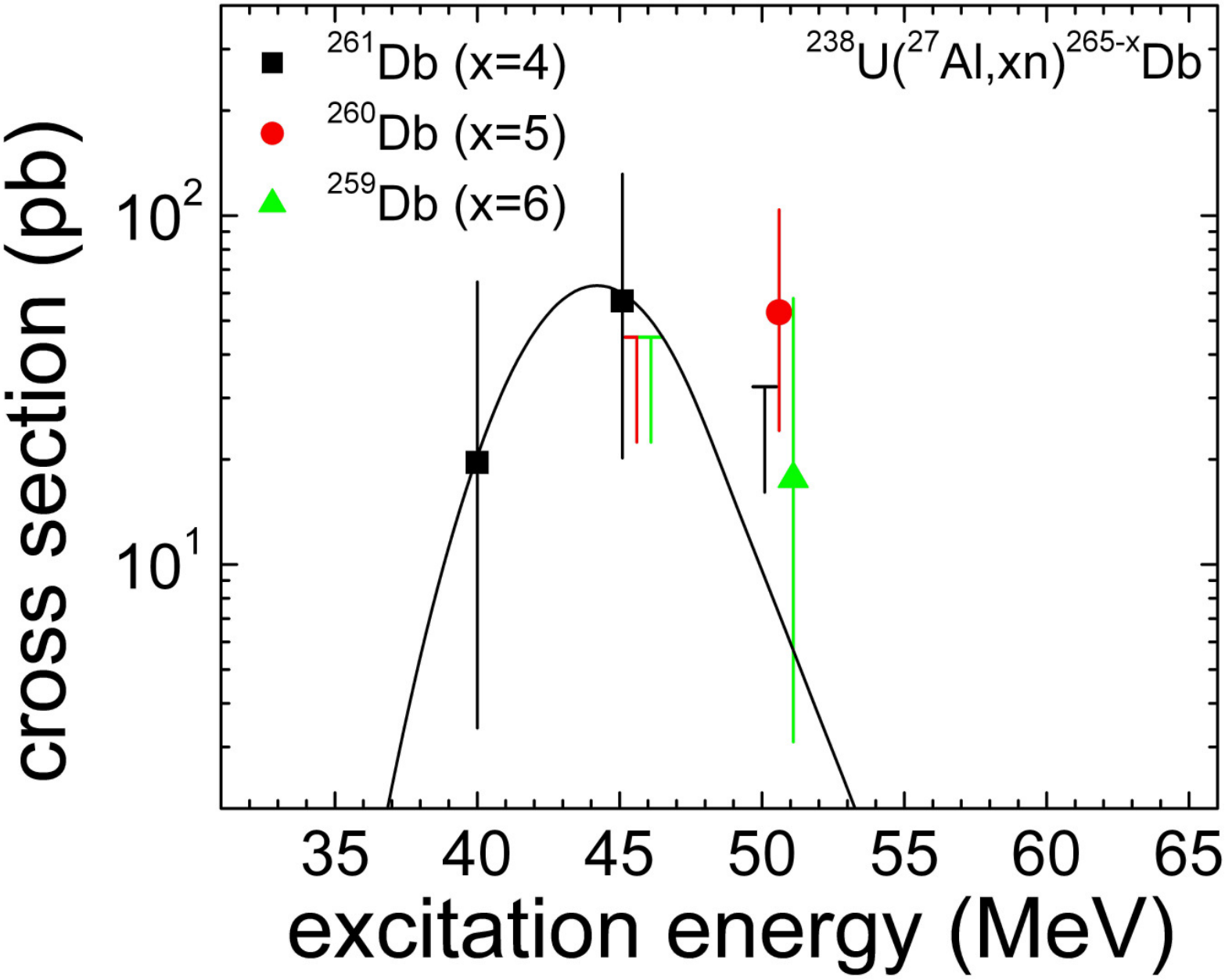
Notes:

1. Could not distinguish between ^{254}Lr and ^{255}Lr, so cross sections are the sum of 5n and 6n exit channels

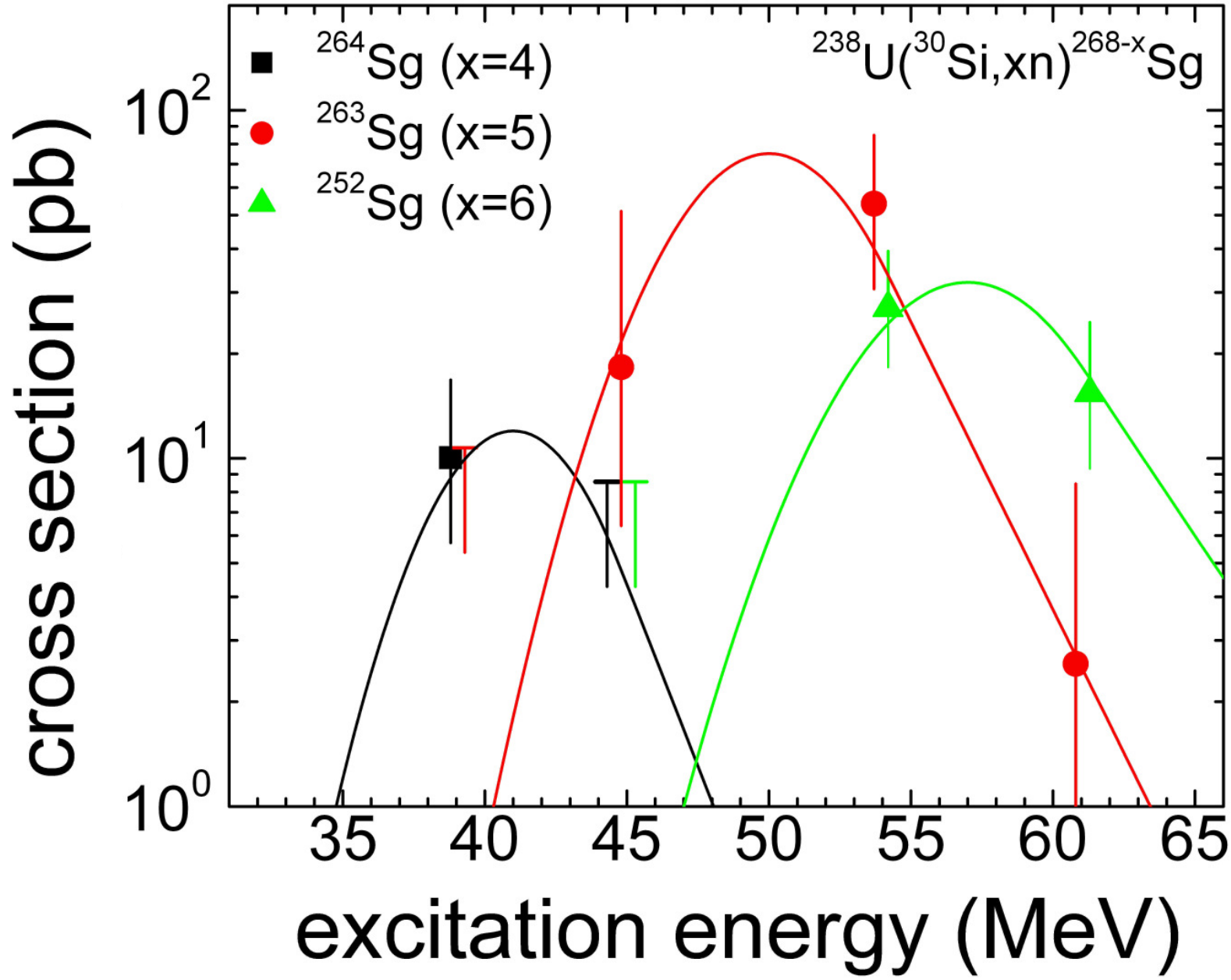
$^{238}U(^{26}Mg,xn)^{264-x}Rf$



$^{238}U(^{27}Al,xn)^{265-x}Db$

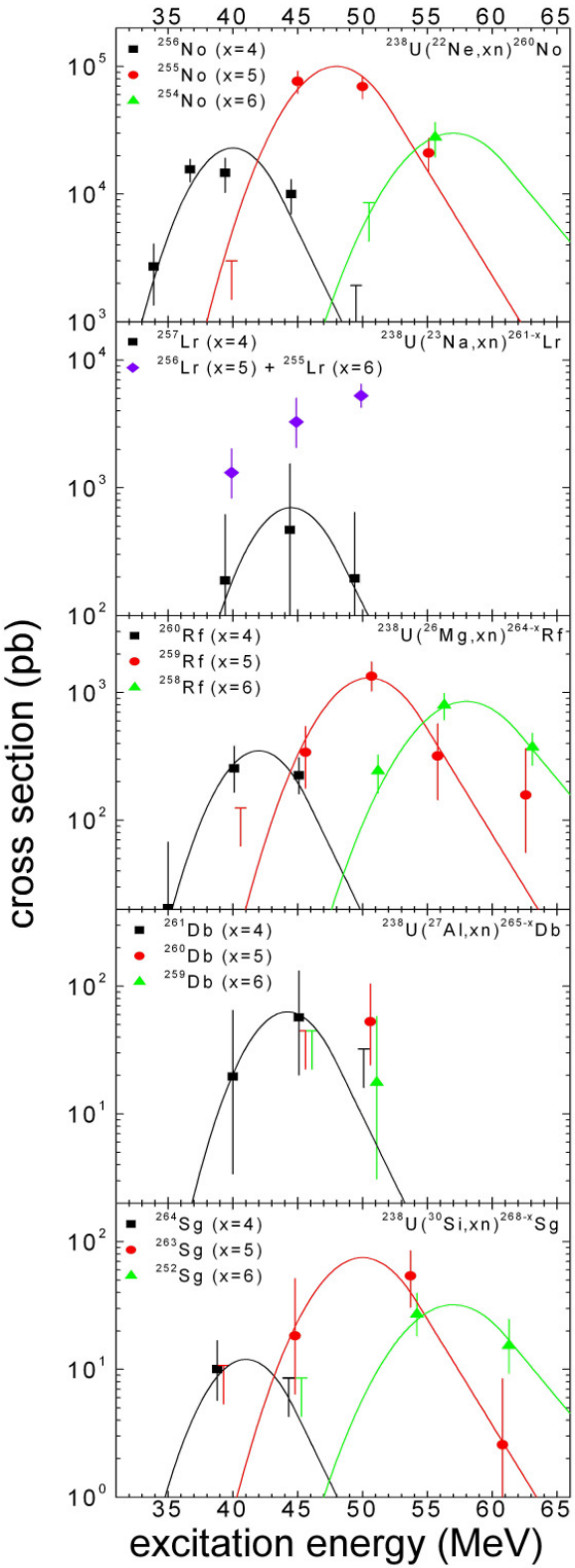


$^{238}U(^{30}Si,xn)^{268-x}Sg$



Notes:

1. ^{264}Sg decays via SF 37^{+27}_{-11} ms
2. ^{262}Sg $t_{1/2}$ is 15^{+5}_{-3} ms (previous value $6.9^{+3.8}_{-1.8}$ ms)
3. 13±8% SF branch in ^{263}Sg measured



^{238}U(^{22}Ne,xn)$^{260-x}$No

^{238}U(^{23}Na,xn)$^{261-x}$Lr

^{238}U(^{26}Mg,xn)$^{264-x}$Rf

^{238}U(^{27}Al,xn)$^{265-x}$Db

^{238}U(^{30}Si,xn)$^{268-x}$Sg

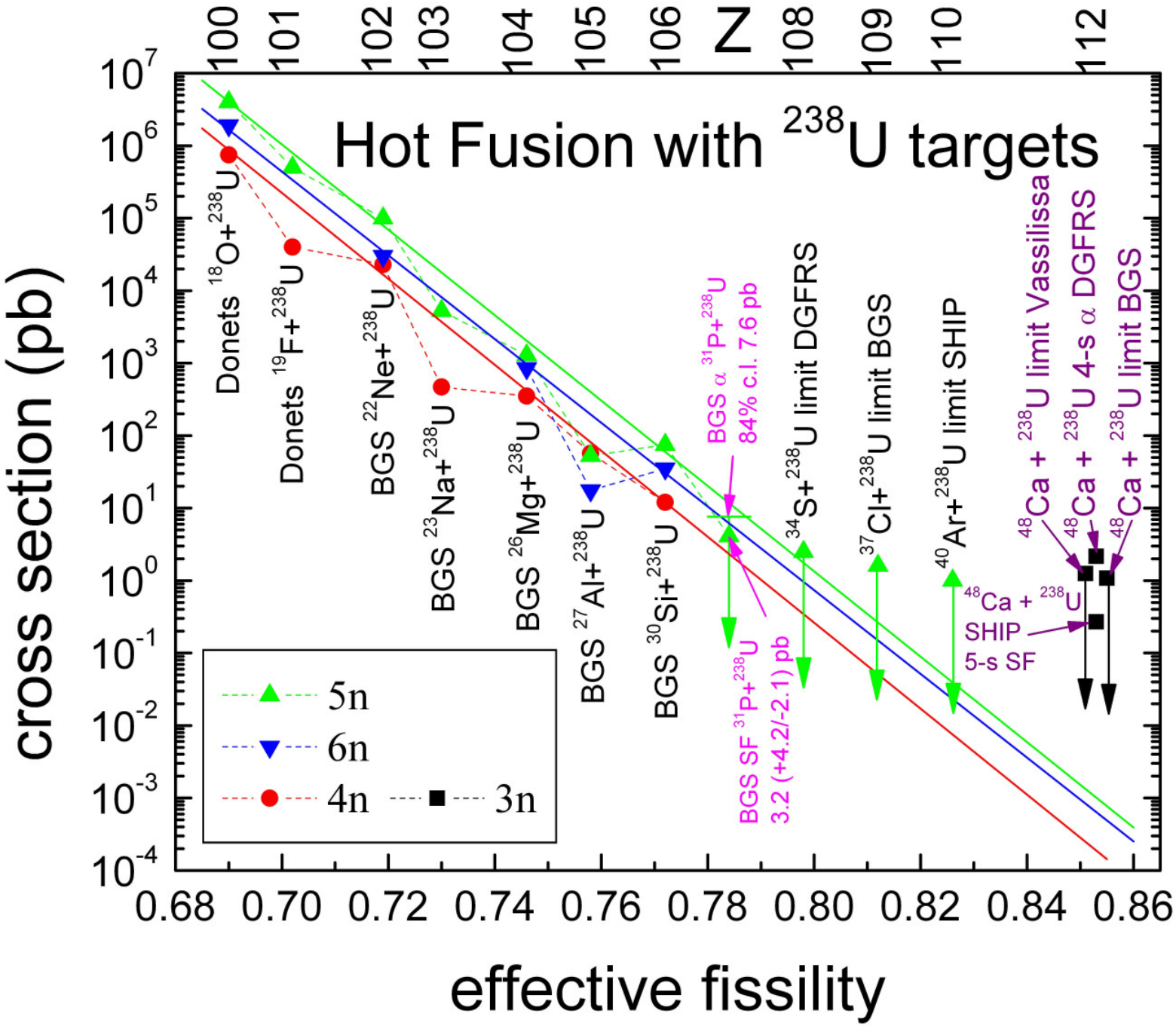
x = 4n
x = 5n
x = 6n

Notes:

1. Excitation functions measured for 4,5 and 6n of even-Z projectiles
2. Partial excitation functions for odd-Z projectiles
3. 6n is wider then 5n which is wider than 4n
4. Ratios of 4n/5n and 5n/6n remain constant

PRELIMINARY DATA:

Still changing weekly!

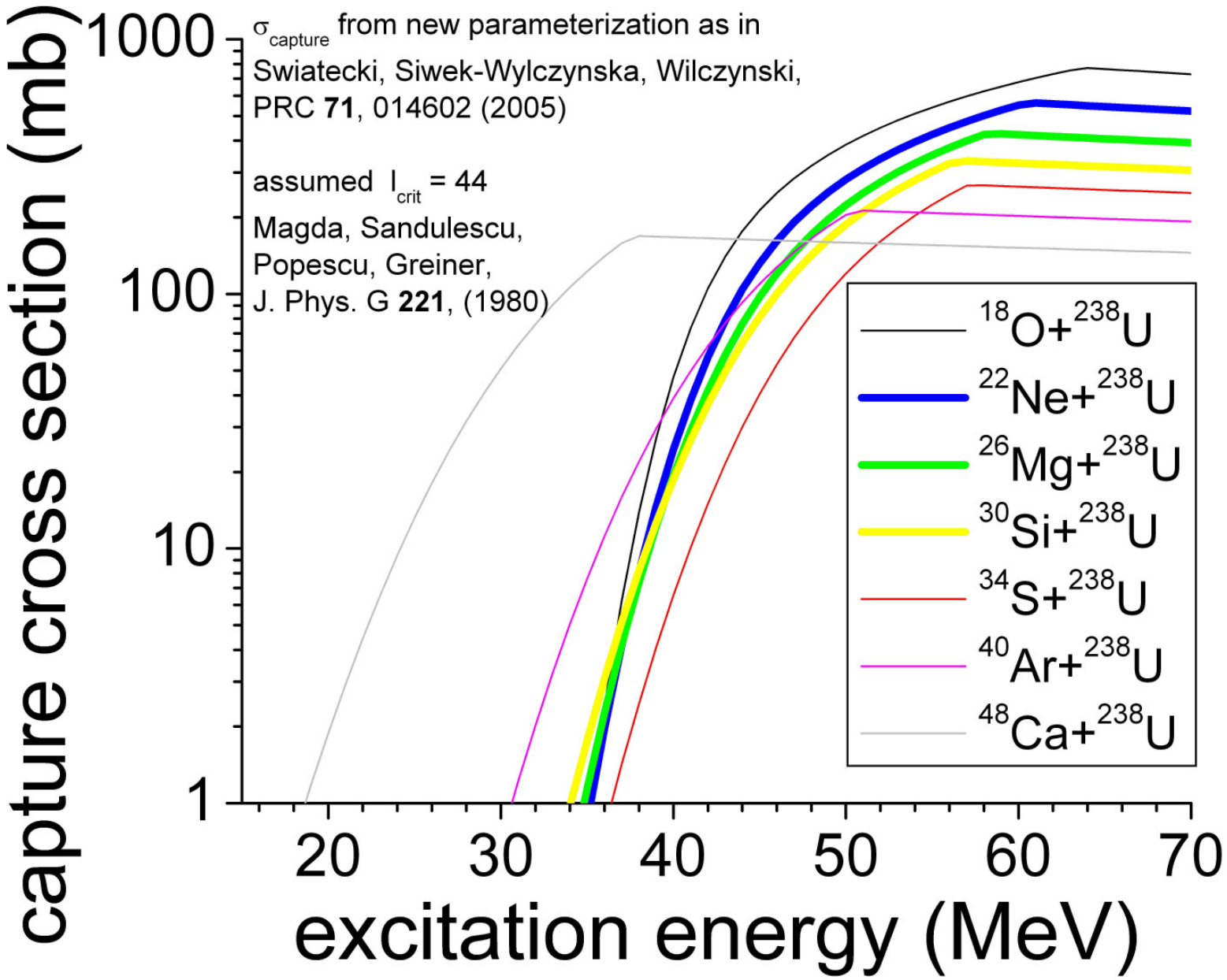


Notes:

1. Lines are fits to even-Z projectile points
2. 5n always highest
3. 6n lower by factor of 3
4. 4n lower by factor of 6

PRELIMINARY DATA:

Still changing weekly!



Γ_n/Γ_{tot} Calculations

- EXTREMELY PRELIMINARY: still changing daily!

$$\frac{\Gamma_n}{\Gamma_{tot}}(49\text{MeV}) = \frac{\sigma_{5n}(49\text{MeV})}{\sigma_{4n}(41\text{MeV})}\frac{\sigma_{fus}(41\text{MeV})}{\sigma_{fus}(49\text{MeV})}$$

$$\frac{\Gamma_n}{\Gamma_{tot}}(57\text{MeV}) = \frac{\sigma_{6n}(57\text{MeV})}{\sigma_{5n}(49\text{MeV})}\frac{\sigma_{fus}(49\text{MeV})}{\sigma_{fus}(57\text{MeV})}$$

Reaction	Γ_n/Γ_{tot} (57 MeV)	Γ_n/Γ_{tot} (49 MeV)
$^{18}O+^{238}U$	1.11	0.28
$^{22}Ne+^{238}U$	0.66	0.16
$^{26}Mg+^{238}U$	0.53	0.32
$^{30}Si+^{238}U$	1.02	0.21

Hot Fusion with ^{238}U Targets Summary and outlook

Conclusions:

- Preliminary results from a systematic study of hot fusion reactions with ions from ^{22}Ne through ^{31}P and ^{238}U targets
- 5n cross section always highest
- Cross sections show exponential decrease with increasing Z
- Odd-even effect increases with increasing Z?
- Systematics can be applied to reactions with other actinide targets

Future Experiments:

- Complete ^{238}U(^{31}P,xn)$^{269-x}$Bh
- Search for ^{238}U(^{26}Mg,3n)^{261}Rf to assess possibilities for production of n-rich nuclides
- "Test to destruction" with small target wheel ^{40}Ar+^{208}Pb