Cross-section measurements in the Institute of Isotopes

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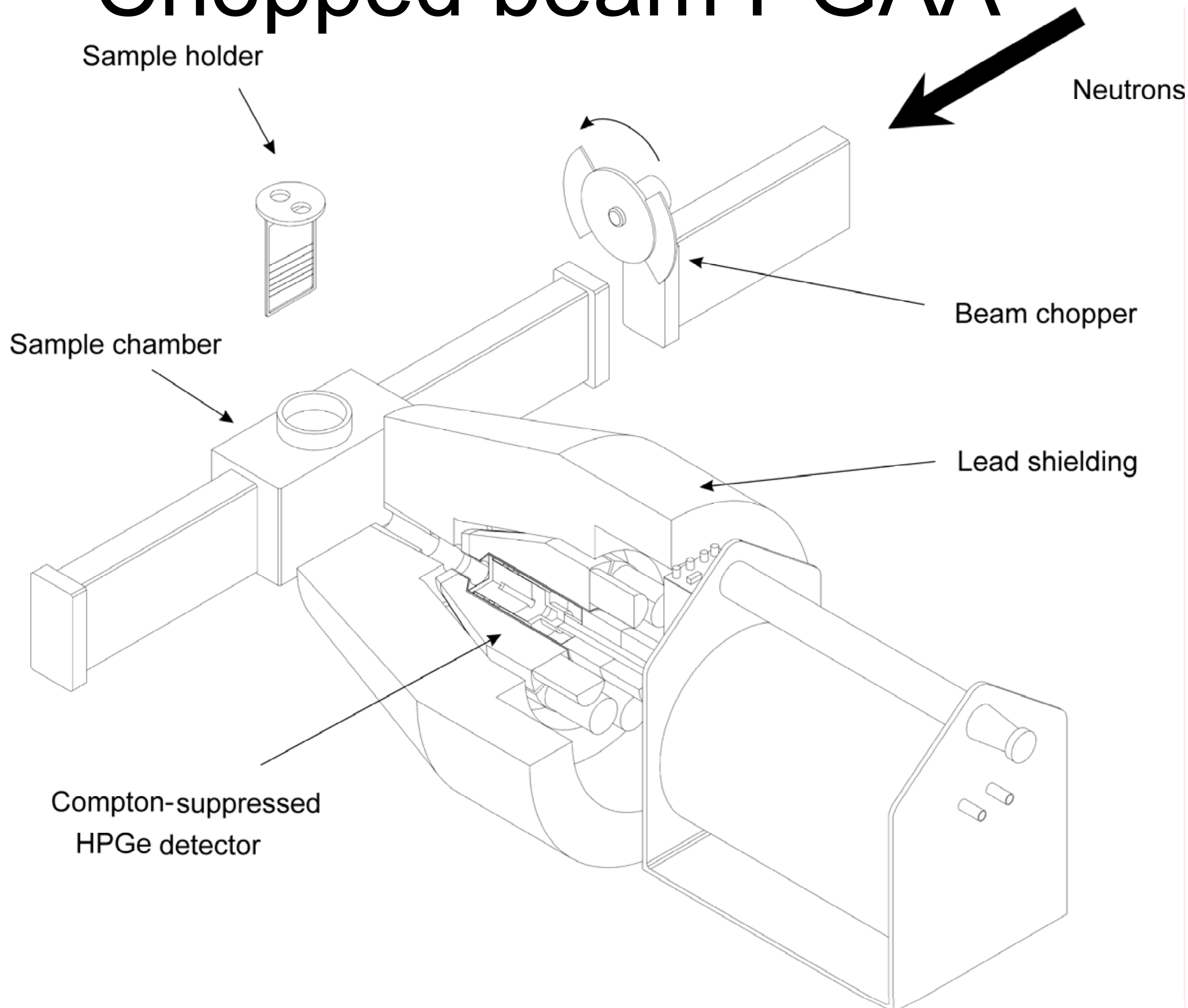
Budapest PGAA facility

- Cold neutron beam
- Pure cold beam until now
  - (for a year f=60,000)
  - Now no direct sight, f=∞
- Beam chopper
- Flux: —2000: 2×10^{6} cm^{-2} s^{-1}
  - 2000—2006: 3×10^{7} cm^{-2} s^{-1}
  - 2007– : 1.2×10^{8} cm^{-2} s^{-1}

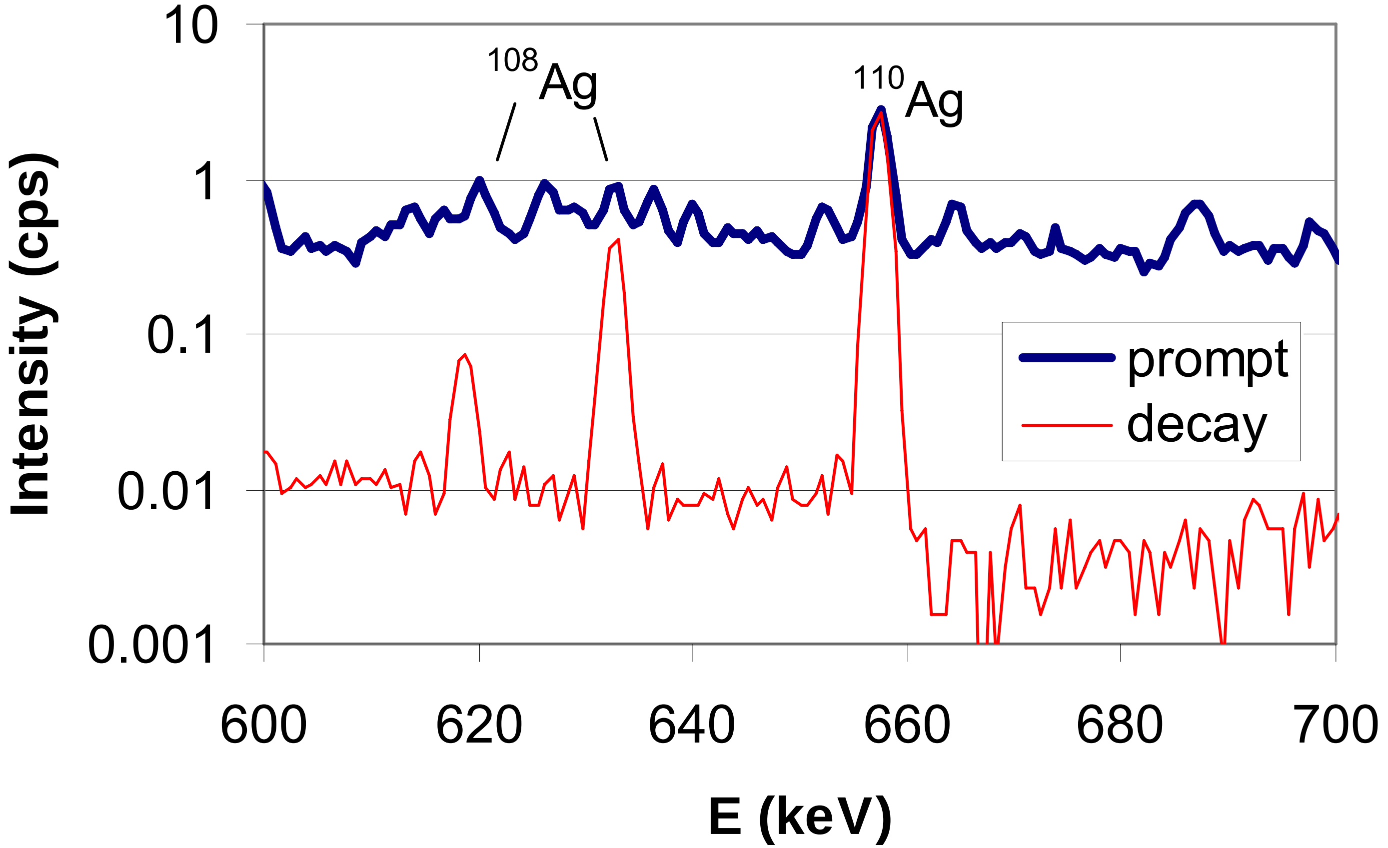
Chopped beam PGAA



Determination of cross-sections (k_0-s) with PGAA

- In-beam measurement
  - Decay peaks appear in prompt spectra
- Chopped beam measurements
  - Decay peaks appear with a higher sensitivity

Prompt and decay spectrum of Ag



Determination of cross-sections (k_0-s) with NAA

- NAA laboratory at Budpest Research Reactor
- András Simonits
- Standard k_0 measurements
  - New software
  - Suspicious cases are better known

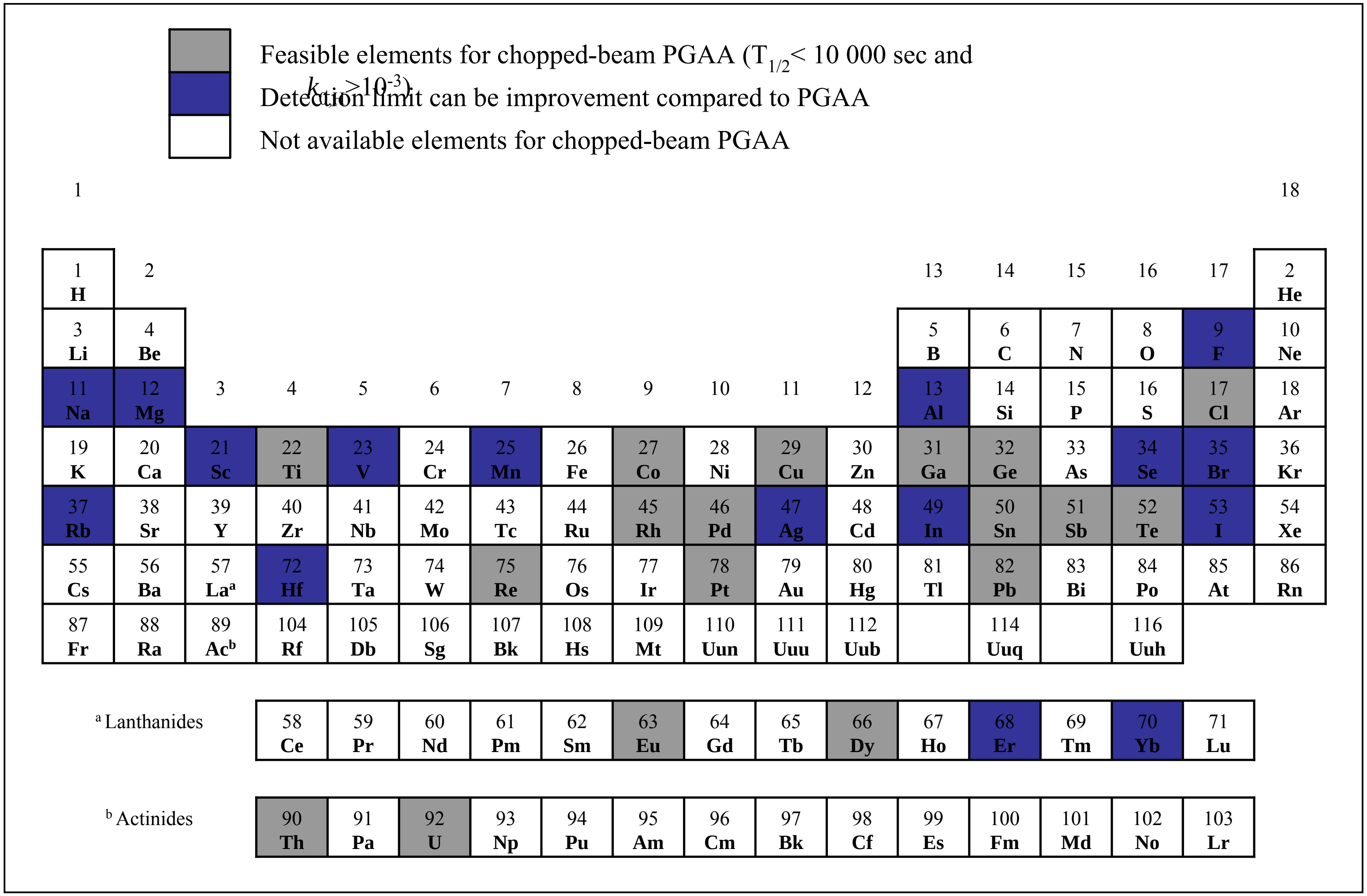
In-beam measurements

k_0-s for short lived nuclides

Final nuclide	Energy (keV)	Half-life	Theoretical k_0	k_0 De Corte *et al*	k_0 Roth *et al*	k_0 in-beam
^{20}F	1633.6	11.03 ± 0.06 s	$(1.06\pm0.05)\times10^{-3}$		$(1.01\pm0.007)\times10^{-3}$	$(1.06\pm0.04)\times10^{-3}$
^{24m}Na	472.28	20.2 ± 0.1 ms	$(4.82\pm0.05)\times10^{-2}$		$(3.63\pm0.02)\times10^{-2}$	$(4.34\pm0.03)\times10^{-2}$
^{28}Al	1778.99	2.2414 ±0.0001 m	$(1.79\pm0.02)\times10^{-2}$	$(1.75\pm0.01)\times10^{-2}$		$(1.80\pm0.02)\times10^{-2}$
^{38m}Cl	671.33	0.715 ±0.003 s	$(6.7\pm1.4)\times10^{-3}$		$(7.95\pm0.14)\times10^{-4}$	$(7.6\pm0.8)\times10^{-4}$
^{46}Sc	142.53	18.7 ± 0.05 s	0.282 ±0.033		0.227±.002	0.226 ± 0.002
^{51}Ti	320.08	5.76 ± 0.01 m	$(3.77\pm0.07)\times10^{-4}$	$(3.74\pm0.04)\times10^{-4}$		$(3.66\pm0.11)\times10^{-4}$
^{52}V	1434.08	3.75 ± 0.01 m	0.2 ± 0.005	0.196 ± 0.002		0.197 ± 0.004
^{56}Mn	846.81	2.5785 ± 0.0006 h	0.5 ± 0.008	0.496 ± 0.030		0.502 ± 0.006
^{60m}Co	1332.5	10.47 ± 0.006 m	$3.3\cdot10^{-3}$			$(3.20\pm0.09)\times10^{-3}$
^{66}Cu	1039.35	5.088 ± 0.011 m	$(1.6\pm0.4)\times10^{-3}$	$(1.86\pm0.009)\times10^{-3}$		$(1.97\pm0.04)\times10^{-3}$
^{77m}Ge	215.48	52.9 ± 0.6 s	$2.69\cdot10^{-5}$			$(2.68\pm0.13)\times10^{-5}$
^{77m}Se	161.92	17.45 ± 0.1 s	0.029±0.001		$(2.57\pm0.001)\times10^{-2}$	$(2.24\pm0.04)\times10^{-2}$

Chopped beam measurements

Periodic table of elements for chopped-beam PGAA



Completed chopped-beam measurements

- ^{20}F, ^{24}Na, ^{28}Al, ^{38}Cl, ^{56}Mn, ^{46}Sc, $^{80,82}Br$, ^{127}I, $^{179m1}Hf$, ^{187}W, $^{86m,88}Rb$, $^{108-110}Ag$
- ^{130}I, ^{100}Tc, U…

Nuclide	*Half-life* (Abs. Unc)*	*Decay Code*	*Comparator Peak, keV*	*Decay Peak Energy, keV*	*Sigma, barn* (Abs. Unc)*	***$k_{0,Au}$* (Rel. unc %)**	*Literature*	*Z-score*
^{20}F	11.163 (8) s	I	C 4945	1633.53	*0.00932 (22)*	**0.00102 (2.5%)**	**9.98E-4 (1.2%)** **1.01E-3 (0.7%)**	0.89 0.44
^{24}Na	14.9590 (12) h	IV/B	S 841	1368.66	*0.527 (11)*	**0.047646 (2.1%)**	**4.68E-02 (0.6%)**	0.80
		IV/B	S 841	2754.13	*0.526 (13)*	**0.047591 (2.5%)**	**4.62E-02 (0.8%)**	1.12
^{28}Al	2.2414 (1) m	I	H 2223	1778.99	*0.233 (3)*	**0.017946 (1.6%)**	**1.75E-02 (0.8%)**	1.38
^{38m}Cl	0.715 (3) s	IV/B	Cl 1951	671.355	*0.0135 (7)*	**0.000791 (5.2%)**	**7.95E-04 (1.7%)**	-0.09
^{38}Cl	37.24 (5) m	IV/B	Cl 1951	1642.5	*0.0345 (21)*	**0.00202 (6.2%)**	**1.97E-03 (1.4%)**	0.42
		IV/B	Cl 1951	2166.90	*0.0478 (23)*	**0.00280 (4.9%)**	**2.66E-03 (1.3%)**	0.99
^{56}Mn	2.5789 (1) h	I	Cl 1951	846.754	*13.20 (18)*	**0.499 (1.6%)**	**4.96E-01 (0.6%)**	0.39
		I	Cl 1951	1810.72	*3.57 (5)*	**0.1351 (1.6%)**	**1.35E-01 (0.4%)**	0.06
		I	Cl 1951	2113.05	*1.92 (4)*	**0.0728 (2.2%)**	**7.17E-02 (0.2%)**	0.70
^{46}Sc	18.75 (4) s	I	S 841	142.528	*4.88 (11)*	**0.225 (2.4%)**	**0.2270 (0.7%)**	-0.37

Nuclide	*Half-life** *(Abs. Unc)*	*Decay Code*	*Comparator Peak, keV*	*Decay Peak Energy, keV*	*Sigma, barn** *(Abs. Unc)*	$k_{0,Au}$ *(Rel. unc %)*	*Literature*	*Z-score*
^{80}Br	4,4205 (8) h/ 17.68 (2) m	IV/A	H 2223	616.3[a]	*0.259 (3)*	**0.00675 (1.5%)**	**6.92E-03 (0.3%)**	-1.64
		IV/A	H 2223	665.8[a]	*0.0469 (11)*	**0.00122 (2.6%)**	**1.22E-03 (0.5%)**	-0.03
^{82}Br	6.13 (5)m/ 35.30 (2) h	IV/B	H 2223	554.348	*0.890 (18)*	**0.02315 (2.2%)**	**2.38E-02 (1.1%)**	-1.15
		IV/B	H 2223	619.106	*0.533 (11)*	**0.01387 (2.3%)**	**1.45E-02 (0.8%)**	-1.88
		IV/B	H 2223	698.21	*0.352 (8)*	**0.00917 (2.4%)**	**9.38E-03 (0.9%)**	-0.89
		IV/B	H 2223	776.50	*1.059 (16)*	**0.02756 (1.7%)**	**2.76E-02 (0.8%)**	-0.08
		IV/B	H 2223	827.8	*0.290 (9)*	**0.00753 (3.3%)**	**7.99E-03 (0.9%)**	-1.78
		IV/B	H 2223	1044.0	*0.335 (9)*	**0.00872 (2.9%)**	**9.14E-03 (0.7%)**	-1.59
		IV/B	H 2223	1317.5	*0.318 (10)*	**0.00828 (3.2%)**	**8.91E-03 (0.4%)**	-2.38
		IV/B	H 2223	1474.9	*0.206 (7)*	**0.00536 (3.7%)**	**5.42E-03 (0.5%)**	-0.31
^{127}I	24.99 (2) m	I	H 2223	442.901	*0.712 (9)*	**0.0117 (1.5%)**	**1.12E-02 (1.7%)**	1.79
		I	H 2223	526.6	*0.0676 (14)*	**0.0011 (2.3%)**	**1.07E-03 (1.4%)**	1.25
^{179m1}Hf	18.67 (4) s	I	Cl 1951	214.341[b]	*15.11 (25)*	**0.176 (2.0%)**	**0.1770 (0.2%)**	-0.29

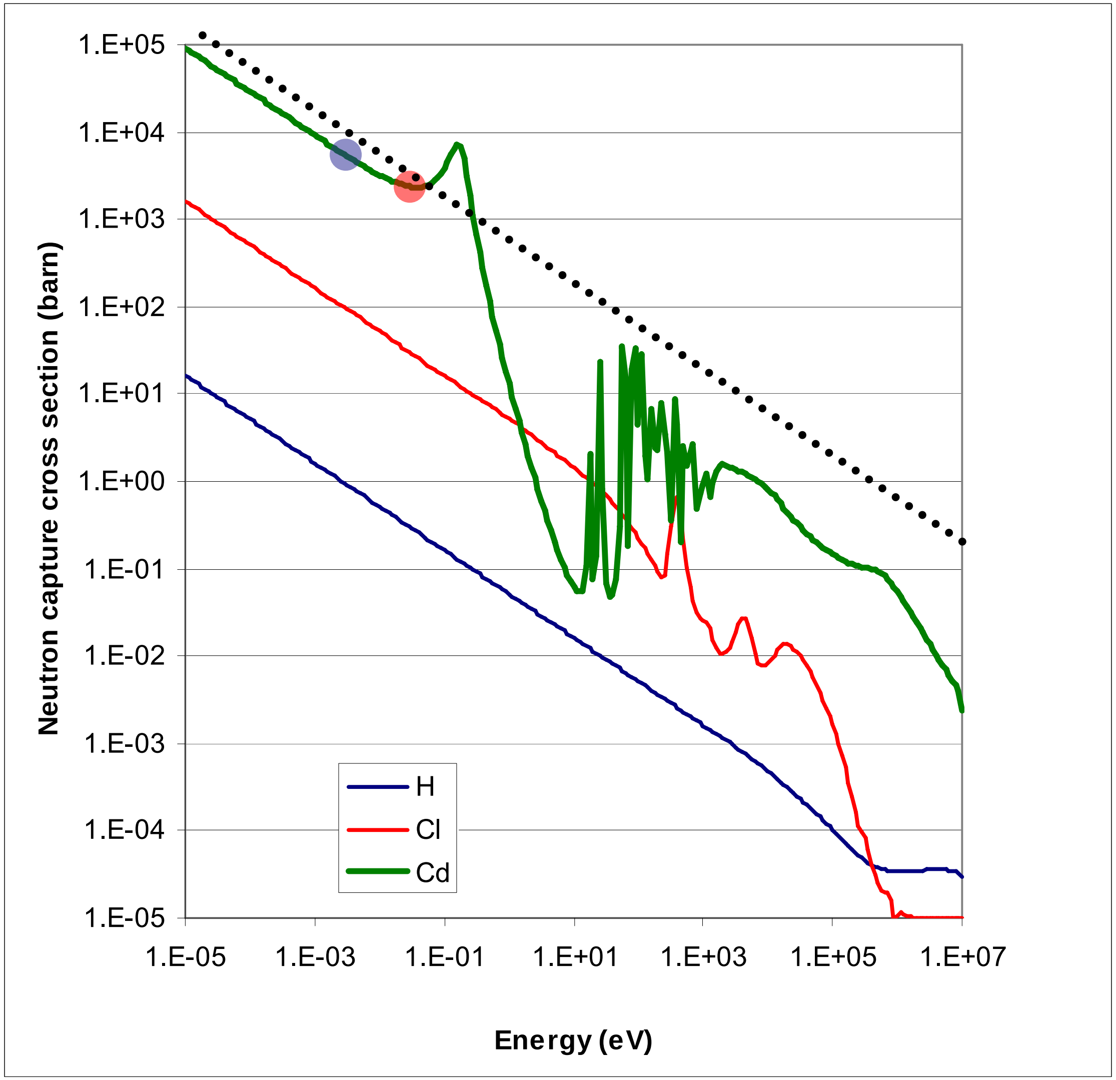
Nuclide	*Half-life* (Abs. Unc)*	*Decay Code*	*Comparator Peak, keV*	*Decay Peak Energy, keV*	*Sigma, barn* (Abs. Unc)*	*$k_{0,Au}$ (Rel. unc %)*	*Literature*	*Z-score*
^{187}W	23.72 (6) h	I	H 2223	134.2[c]	*1.037 (19)*	**0.0117 (1.9%)**	**1.13E-02 (0.7%)**	1.70
		I	H 2223	479.55	*2.64 (4)*	**0.0299 (1.8%)**	**2.97E-02 (1.0%)**	0.28
		I	H 2223	551.5	*0.613 (10)*	**0.00693 (1.8%)**	**6.91E-03 (0.5%)**	0.17
		I	H 2223	618.3	*0.757 (13)*	**0.00856 (1.8%)**	**8.65E-03 (0.7%)**	-0.51
		I	H 2223	625.5	*0.133 (3)*	**0.00151 (2.5%)**	**1.48E-03[d] (–)**	–
		I	H 2223	685.73	*3.35 (6)*	**0.0379 (2.0%)**	**3.71E-02 (0.5%)**	0.99
		I	H 2223	772.9	*0.498 (8)*	**0.00563 (1.8%)**	**5.61E-03 (0.7%)**	0.15
^{86m}Rb	1.017 (3)m	I	H 2223	555.61	*0.04104 (9)*	**0.000999 (2.4%)**	**9.96E-04 (1.6%)**	0.12
^{88}Rb	17.78 (11) m	I	H 2223	898.03	*0.00469 (23)*	**0.00011 (4.9%)**	**1.01E-04 (1.5%)**	2.25
		I	H 2223	1836.00	*0.0068 (4)*	**0.00017 (5.3%)**	**1.57E-04 (1.1%)**	0.95
^{108}Ag	2.37 (1) min	I	H 2223	433.96[e]	*0.087 (4)*	**0.00168 (5.0%)**	**1.59E-03 (2.0%)**	1.05
		I	H 2223	618.86[e]	*0.055 (4)*	**0.00105 (6.8%)**	**9.33E-04 (0.8%)**	1.69
		I	H 2223	632.98[e]	*0.303 (6)*	**0.00585 (2.0%)**	**6.01E-03 (0.8%)**	-1.26
^{110}Ag	24.6 (2) s	I	H 2223	657.50[e]	*1.88 (3)*	**0.03627 (1.7%)**	*1.93 b (2.1%) [6]*	-0.98

Recent measurements

- In-beam
  - Regular: (Zr), (Pt), Rh, Mn, Sb, In, Sc, Sr, (Te), Tl
  - Non 1/v nuclides: Lu, ...
- Chopped-beam:
  - Sc, V, Cu, Se, Rh, In, Sb, Cs

Cross section

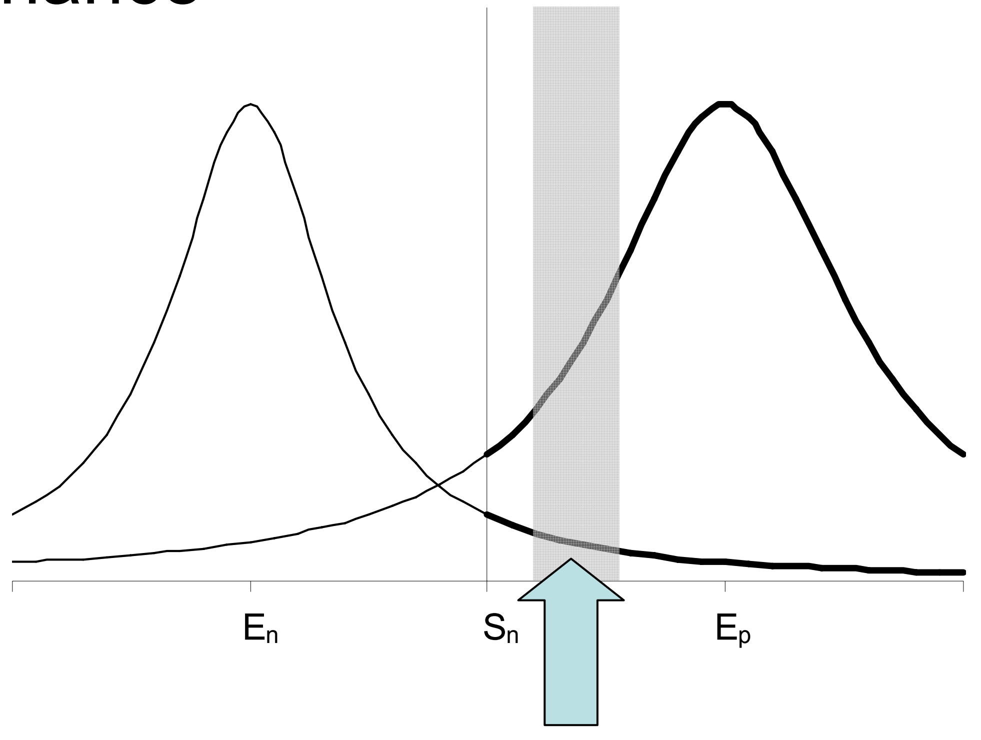
- neutron capture cross section
- at low E: 1/*v* law
- at higher E-s
  - resonances



Low-energy resonances

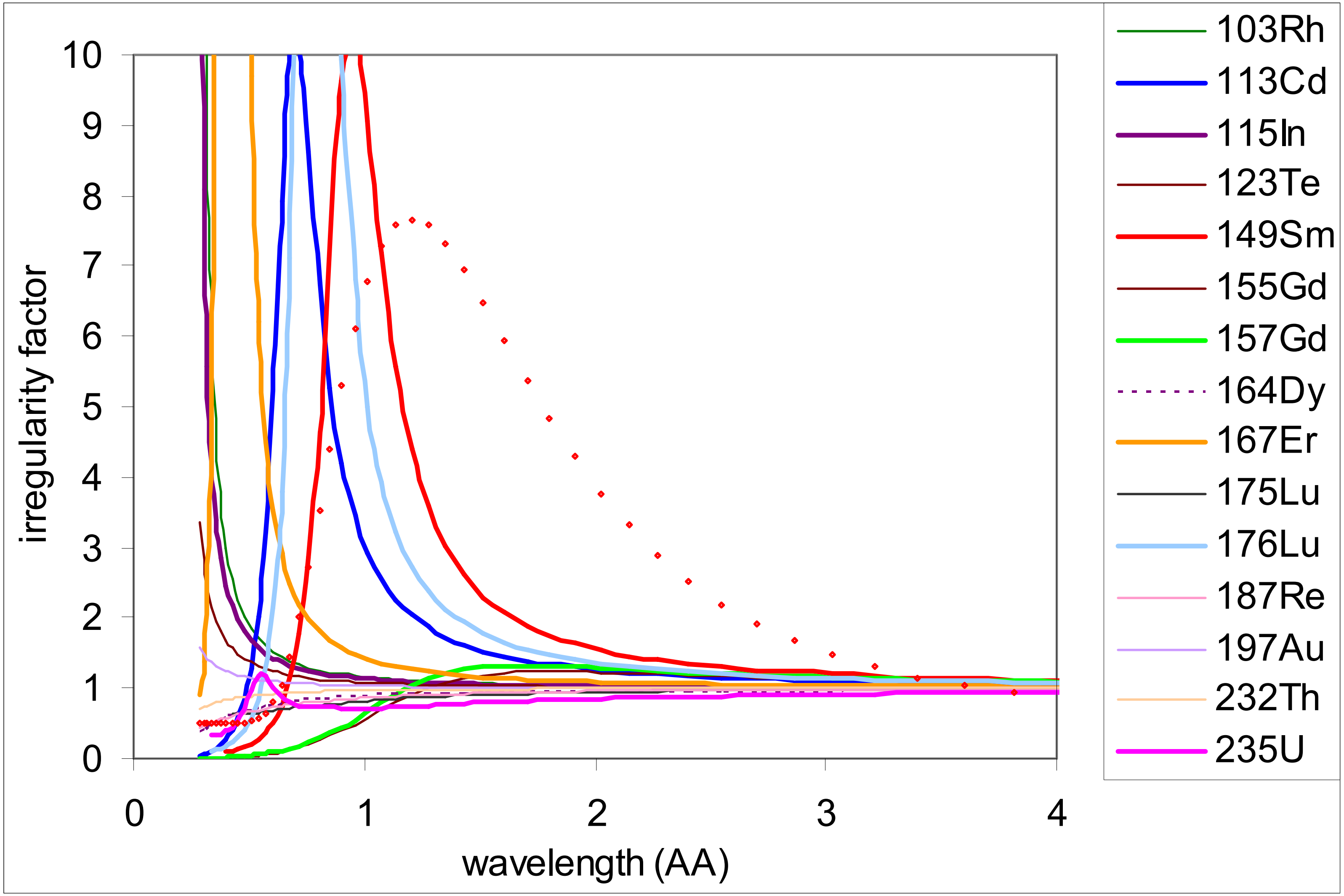
negative resonance

positive resonance



cold and thermal neutron beam

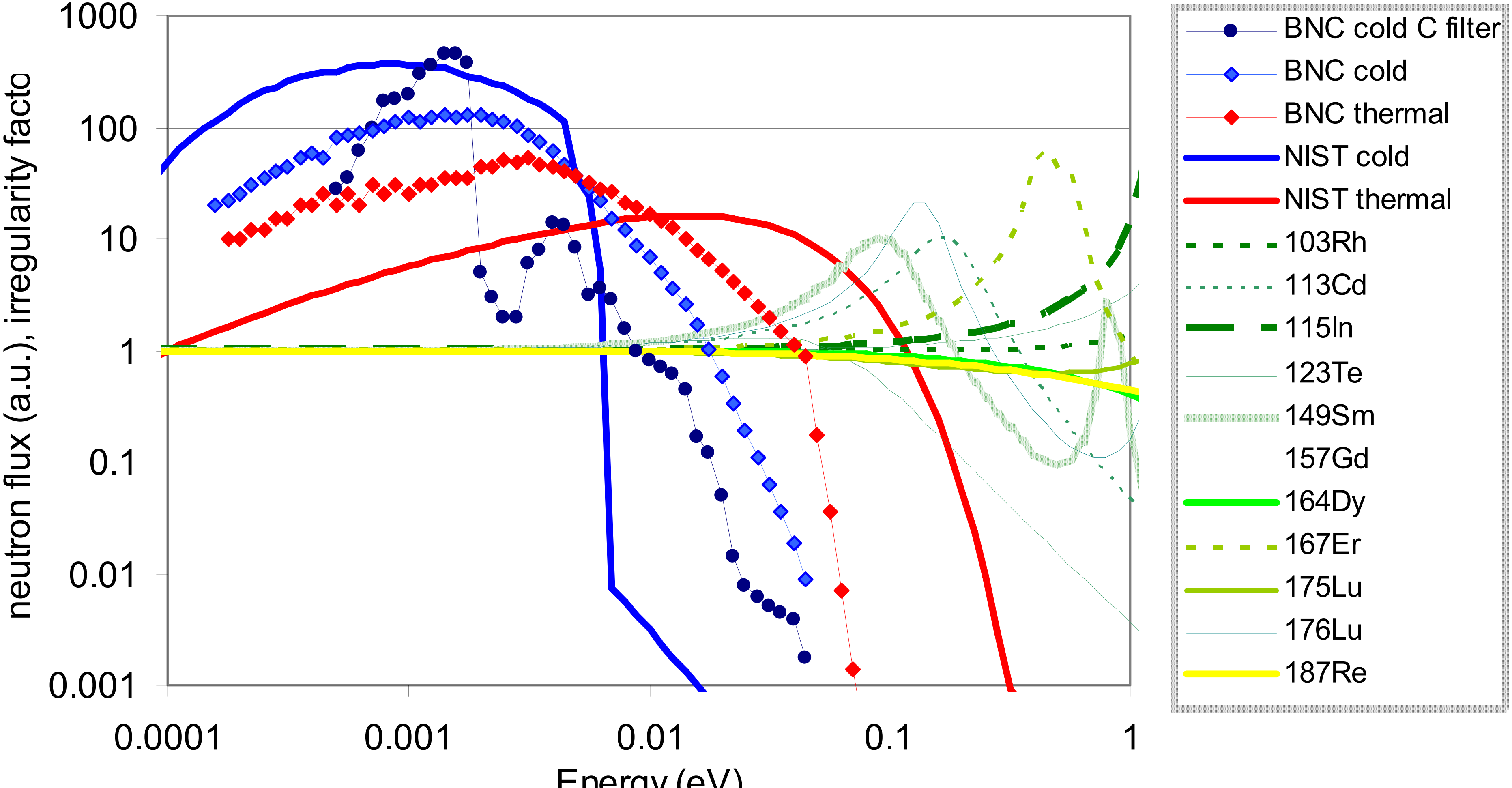
Non-1/*v* behaviour: irregularity



The interference of irregular cross-section with different neutron spectra

- 11 irregular nuclides
  - ^{103}Rh, ^{113}Cd
  - ^{115}In, ^{123}Te
  - ^{149}Sm, ^{157}Gd
  - ^{164}Dy, ^{167}Er
  - ^{175}Lu, ^{176}Lu
  - ^{187}Re
- in 5 different beams
  - NIST thermal
  - NIST cold
  - Budapest thermal
  - Budapest cold
  - Budapest filtered

Neutron spectra & irregularities in σ



Measured *g* factors

	NIST cold (T_{eff} = 17 K)	BNC cold (T_{eff} = 28 K)	BNC therm (T_{eff} = 74 K)	NIST therm (T_{eff} = 320 K)
^{103}Rh	1	1.00(3)		1.17(4)
^{115}In	1	1.00(3)		1.17(5)
^{164}Dy*	1	1.010(6)		1.04(4)
^{167}Er	1	1.09(3)	1.013(23)	1.15(5)
^{176}Lu*	1	1	**1.15(6)**	**2.38(3)**
^{187}Re	1	1.08(5)		0.97(4)

Planned NAA measurements

- Na

Zn	$^{64}Zn(n,\gamma)^{65}Zn$
Rb	$^{85}Rb(n,\gamma)^{86}Rb$
Fe	$^{58}Fe(n,\gamma)^{59}Fe$
Nb	$^{93}Nb(n,\gamma)^{94}Nb$
Ag	$^{109}Ag(n,\gamma)^{110m}Ag$
Ba	$^{130}Ba(n,\gamma)^{131}Ba$
Cs	$^{133}Cs(n,\gamma)^{134}Cs$
Gd	$^{152}Gd(n,\gamma)^{153}Gd$
Sm	$^{152}Sm(n,\gamma)^{153}Sm$
Tm	$^{169}Tm(n,\gamma)^{170}Tm$