Low energy scattering and cross section data

S. Kopecky

	Z	A	I(π)	c	b_c	b_i	σ_c	σ_i
H	1				−3.7390(11)		1.7568(10)	80.26(6)
		1	1/2(+)	99.985	−3.7406(11)	25.274(9)	1.7583(10)	80.27(6)
		2	1(+)	0.015	6.671(4)	4.04(3)	5.592(7)	2.05(3)
		3	1/2(+)	(12.32 a)	4.792(27)	−1.04(17)	2.89(3)	0.14(4)
He	2				3.26(3)		1.34(2)	0
		3	1/2(+)	0.00014	5.74(7)	−2.5(6)	4.42(10)	1.6(4)
					−1.483(2)*i*	+2.568(3)*i*		
		4	0(+)	99.99986	3.26(3)	0	1.34(2)	0
Li	3				−1.90(2)		0.454(10)	0.92(3)
		6	1(+)	7.5	2.00(11)	−1.89(10)	0.51(5)	0.46(5)
					−0.261(1)*i*	+0.26(1)*i*		
		7	3/2(−)	92.5	−2.22(2)	−2.49(5)	0.619(11)	0.78(3)
Be	4	9	3/2(−)	100	7.79(1)	0.12(3)	7.63(2)	0.0018(9)
B	5				5.30(4)		3.54(5)	1.70(12)
					−0.213(2)*i*			
		10	3(+)	20.0	−0.1(3)	−4.7(3)	0.144(8)	3.0(4)
					−1.066(3)*i*	+1.231(3)*i*		
		11	3/2(−)	80.0	6.65(4)	−1.3(2)	5.56(7)	0.21(7)
C	6				6.6460(12)		5.550(2)	0.001(4)
		12	0(+)	98.90	6.6511(16)	0	5.559(3)	0
		13	1/2(−)	1.10	6.19(9)	−0.52(9)	4.81(14)	0.034(11)
N	7				9.36(2)		11.01(5)	0.50(12)
		14	1(+)	99.63	9.37(2)	2.0(2)	11.03(5)	0.5(1)
		15	1/2(−)	0.37	6.44(3)	−0.02(2)	5.21(5)	0.00005(10)
O	8				5.803(4)		4.232(6)	0.000(8)
		16	0(+)	99.762	5.803(4)	0	4.232(6)	0
		17	5/2(+)	0.038	5.78(15)	0.18(6)	4.20(22)	0.004(3)

V.F. Sears, Neutron News **3** ,1992

Δb in fm	nr of available b_c
$1 < \Delta b < 5$	6
$0.5 < \Delta b < 1$	9
$0.1 < \Delta b < 0.5$	70
$0.05 < \Delta b < 0.1$	98
$0.01 < \Delta b < 0.05$	91
$0.005 < \Delta b < 0.01$	14
$0.001 < \Delta b < 0.005$	23
$0.0005 < \Delta b < 0.001$	3

L. Koester, H. Rauch and E. Seymann, Atom. and Nucl. Data Tables **49**, 65,1991

Transmission ("conventional" and resonance scattering)

Frauenhofer defraction (small angle scattering)

Refraction
Reflection
Interferometry

} Require dynamical scattering theory

Absolute coherence – coherence between incoming and outgoing (scattered) wave, therefore only elastic coherent scattering possible, everything else is referred to as absorption

Relative coherence – coherence between outgoing waves from different scattering centres, therefore both elastic and inelastic coherent scattering is possible

Incoherence – variation in scattering length

$$\left\{-\frac{\hbar^2}{2m}\Delta + V\left(\vec{r}\right)\right\}\psi\left(\vec{r}\right) = E\,\psi\left(\vec{r}\right)$$

$V\left(\vec{r}\right)$ Optical potential $\psi\left(\vec{r}\right)$ Coherent wave

Kinematical theory – Born approximation, therefore ignoring local field , or interparticle multiple scattering

Dynamical theory – derive potential and solve equation rigorously

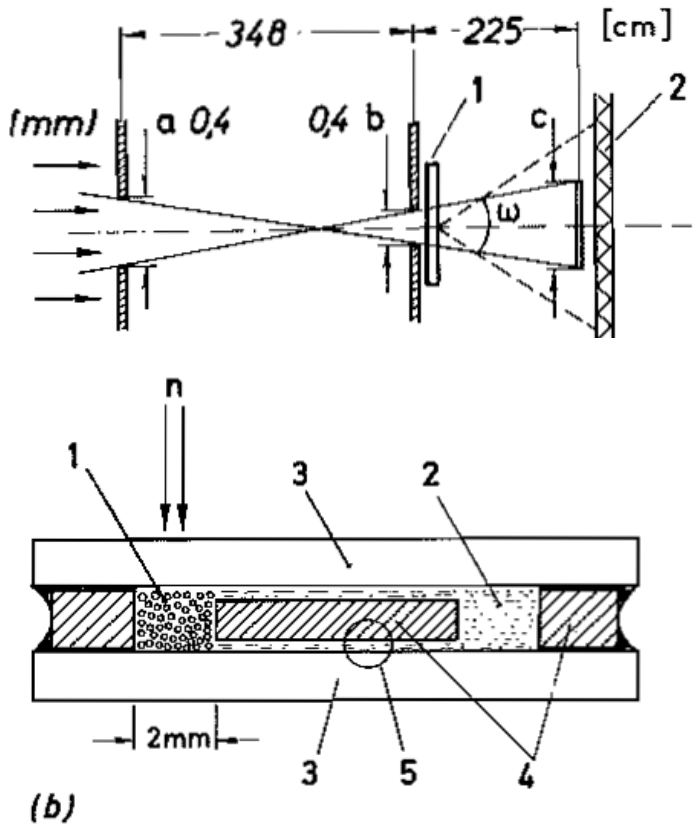
To solve: Impulse Approximation – Fermi Pseudo-potential

$$\left\{-\frac{\hbar^2}{2m}\Delta+V\left(\vec{r}\right)\right\}\psi\left(\vec{r}\right)=E\,\psi\left(\vec{r}\right)$$

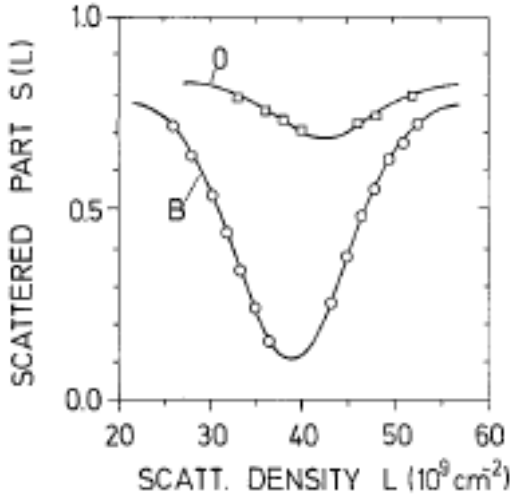
With average potential $\langle V\rangle=\frac{2\pi\hbar^2}{m}Nb$ Refractive index becomes $n^2-1=-\frac{\langle V\rangle}{E}=-\frac{\lambda^2}{\pi}Nb$

When including additional cross section for inelastic and absorption processes σ_a

$$n^2-1=-N\frac{\lambda^2}{\pi}\left\{\pm\left[b^2-\left(\frac{\sigma_a}{2\lambda}\right)^2\right]^{\frac{1}{2}}+i\frac{\sigma_a}{2\lambda}\right\}$$



L. Koester, Springer Tract. Mod. Phys. **80** (1977)

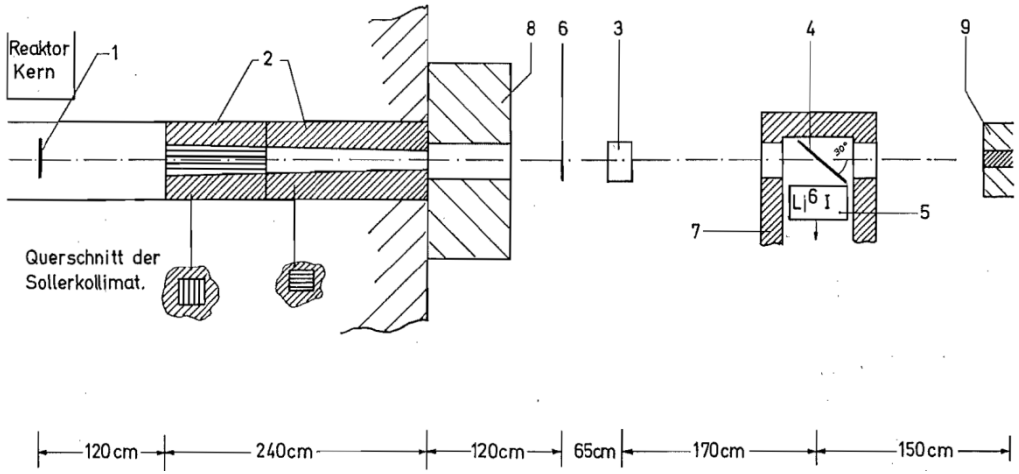


$$S(\Delta) = 1 - \exp\left(-\frac{\Delta^2}{\Gamma^2}\right)$$

$\Delta = Nb_c(\text{powder}) - Nb_c(\text{liquid})$
$\Gamma^{-1} = 2\mu(\lambda R)^2$

2R typical particle dimension
μ particle layers

Reported precision from 10^{-3} to 10^{-2}



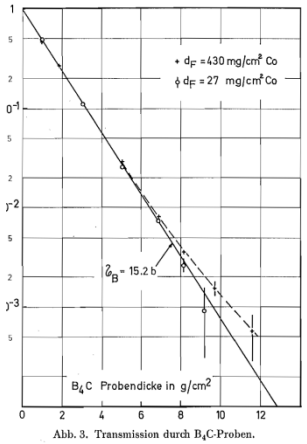
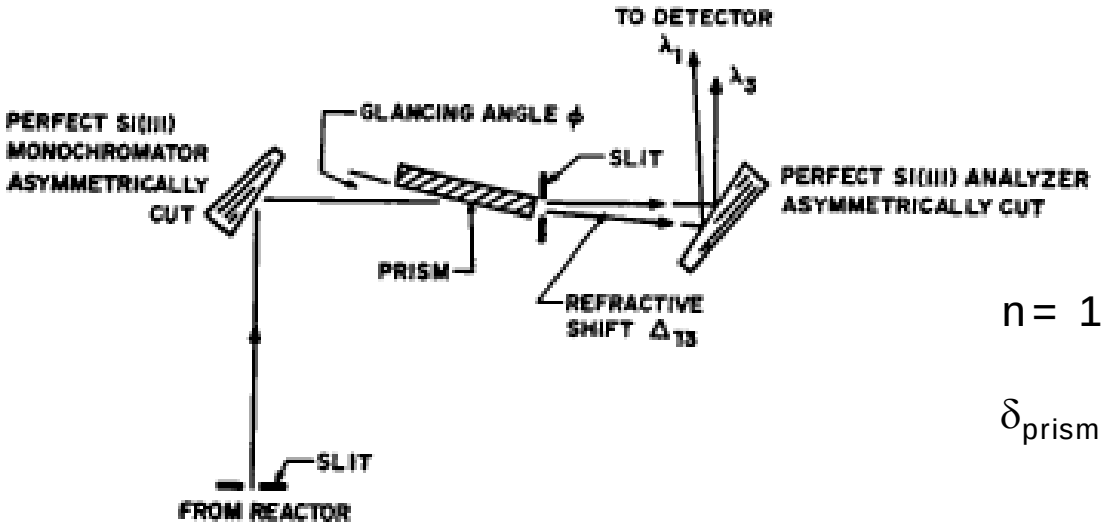


Abb. 3. Transmission durch B_4C-Proben.

Resonance scattering/activation technique allow for improved background conditions

For rhodium and silver resonances, precisions of 5. 10^{-4} have been reported



$$n = 1 - N\lambda^2 b/2\pi = 1-\delta$$

$$\delta_{prism} = 1/2 \sin\Delta_T \sin(2\varphi-\Delta_T) + \delta_{air}$$

C.S. Schneider, Acta Cryst A **32,** 375 (1976)

Measurement of angles of 100-500 μrad with precision of up to 10^{-4}

Derived coherent scattering lengths with precision of up to 10^{-4}

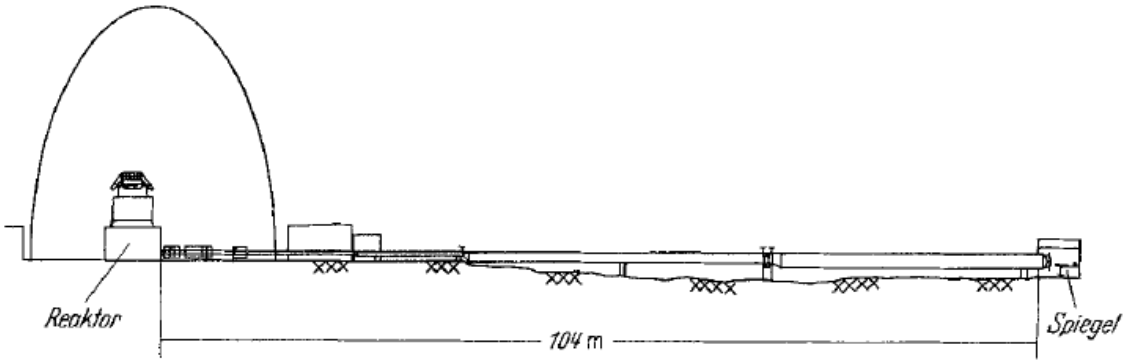
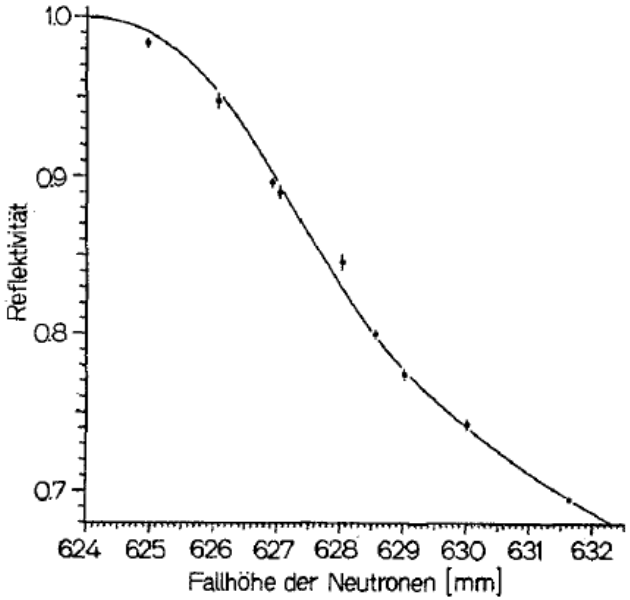


Fig. 1. Ansicht des Schwerkraft-Refraktometers am FRM

L. Koester, ZP **182**, 328 (1965)



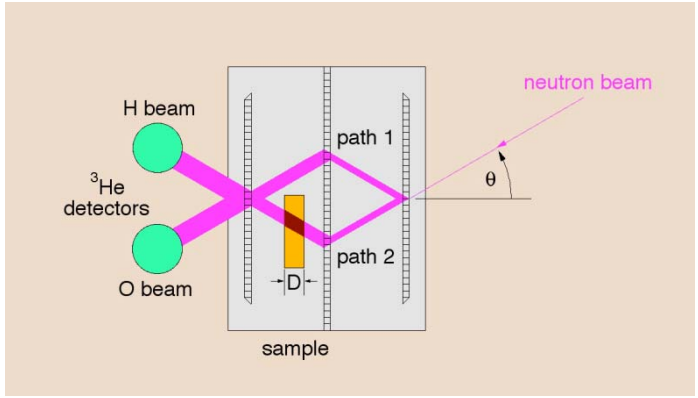
N. Nuecker, ZP **227**, 152 (1969)

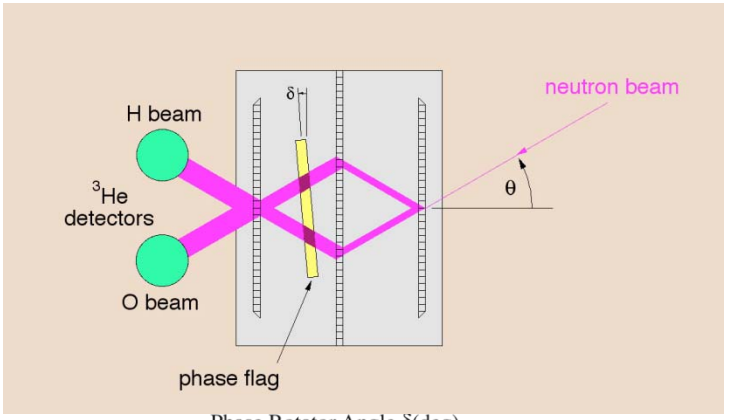
$$h_0 = Nb\frac{2\pi\hbar^2}{gm^2}$$

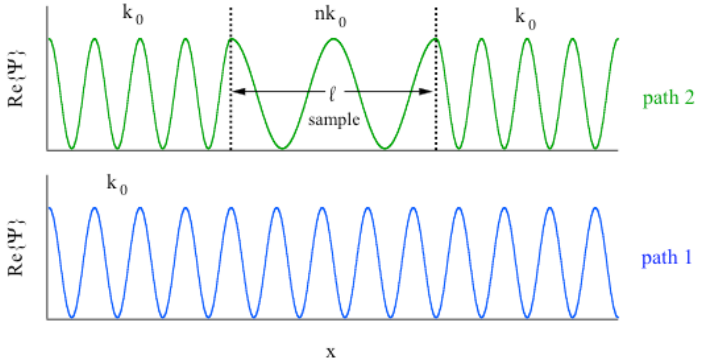
$$r(h,h_0,\gamma) = \left|\frac{1-\left(1-\frac{h_0}{h}+i\frac{A}{h}\right)^{\frac{1}{2}}}{1+\left(1-\frac{h_0}{h}+i\frac{A}{h}\right)^{\frac{1}{2}}}\right|^2$$

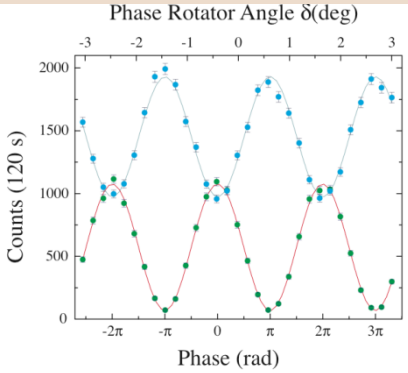
$$A = \gamma\frac{\hbar}{4m}\sqrt{\frac{2}{gh}} \qquad \gamma = N(\sigma_a+\sigma_{inc})$$

Precisions of 1-5 10^{-4} have been reported



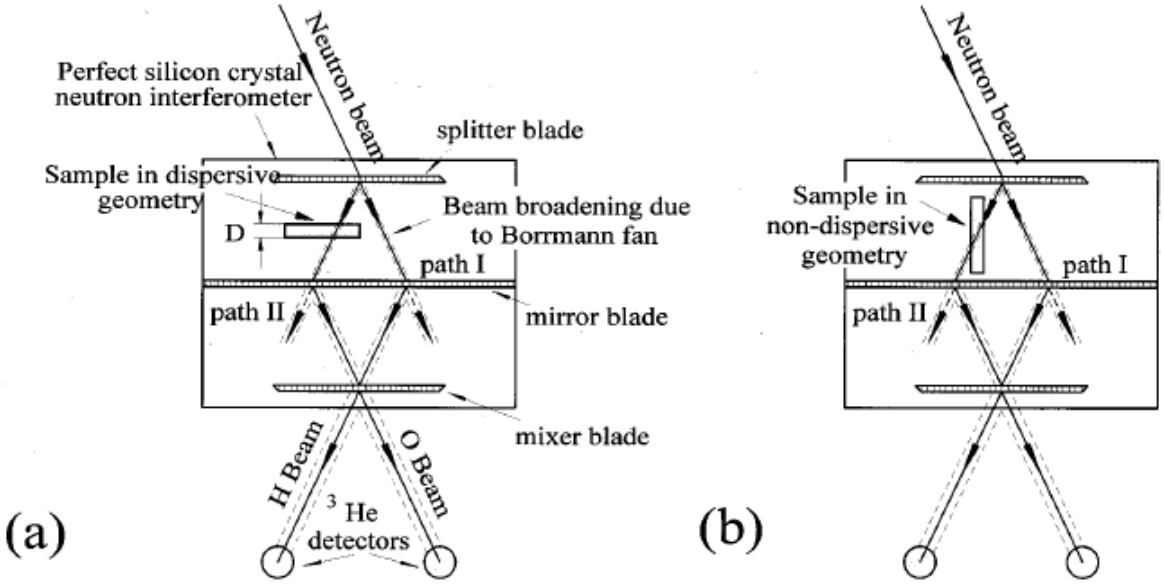






F.E. Wietfeldt, Summer School on fundamental Neutron Physics

Relative phase shift: $\Delta\chi = k_0 l - nk_0 l = Nb\lambda \frac{D}{\cos\theta}$



Ioffe et al, PRA 58, 1475 (1998)

Path length $l = \frac{D}{\cos\theta}$ $l = \frac{D}{\sin\theta}$

Phase shift $\Delta\chi = Nb\lambda\frac{D}{\cos\theta}$ $\Delta\chi = Nb\lambda\frac{D}{\sin\theta} = 2dNbD$

Precision, due to wave-length 10^{-3} Precision better than 10^{-4}

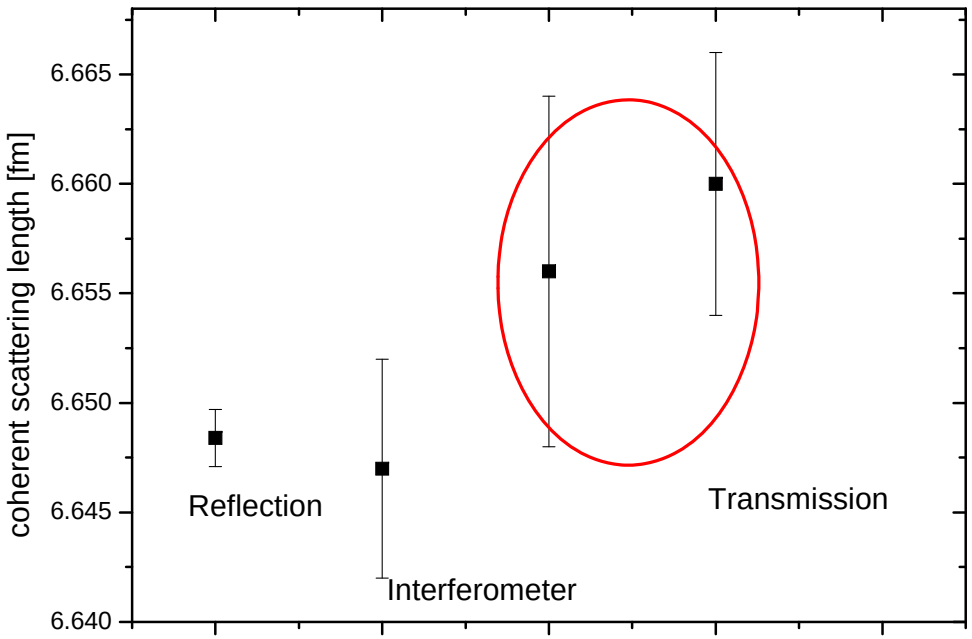
To compare with scattering cross section over a wide energy range:

$$b_c(E) = b_c(1 - \frac{k^2 r_{eff}^2}{6}) - Z(1 - f(E))b_{ne}$$

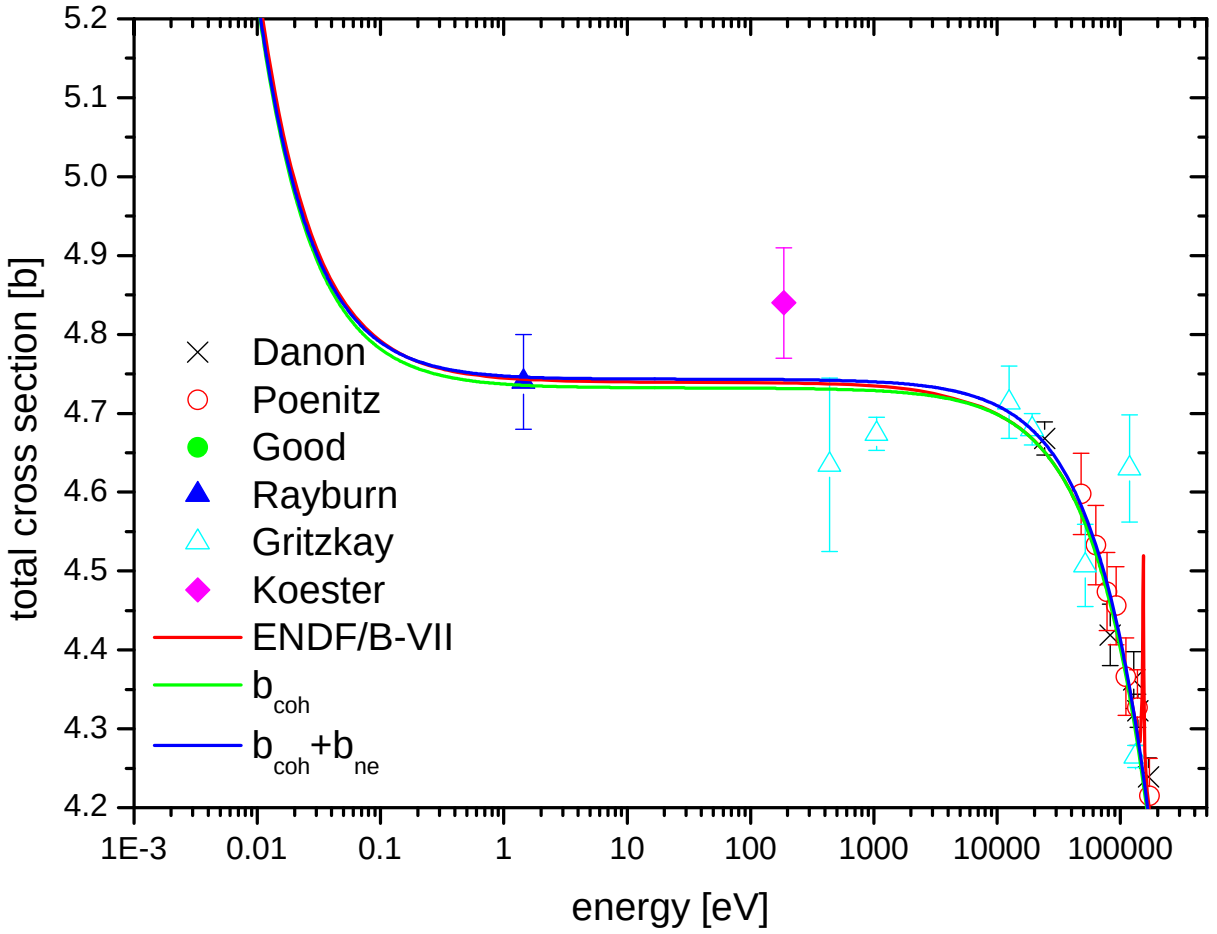
$$\sigma_s = 4\pi b_c^2(E)\left(\frac{A}{A+1}\right)^2\left(1 + \frac{k_b T}{2AE}\right)$$

For simplicity and only guide used: $b_c = \frac{3}{2} r_{eff}$

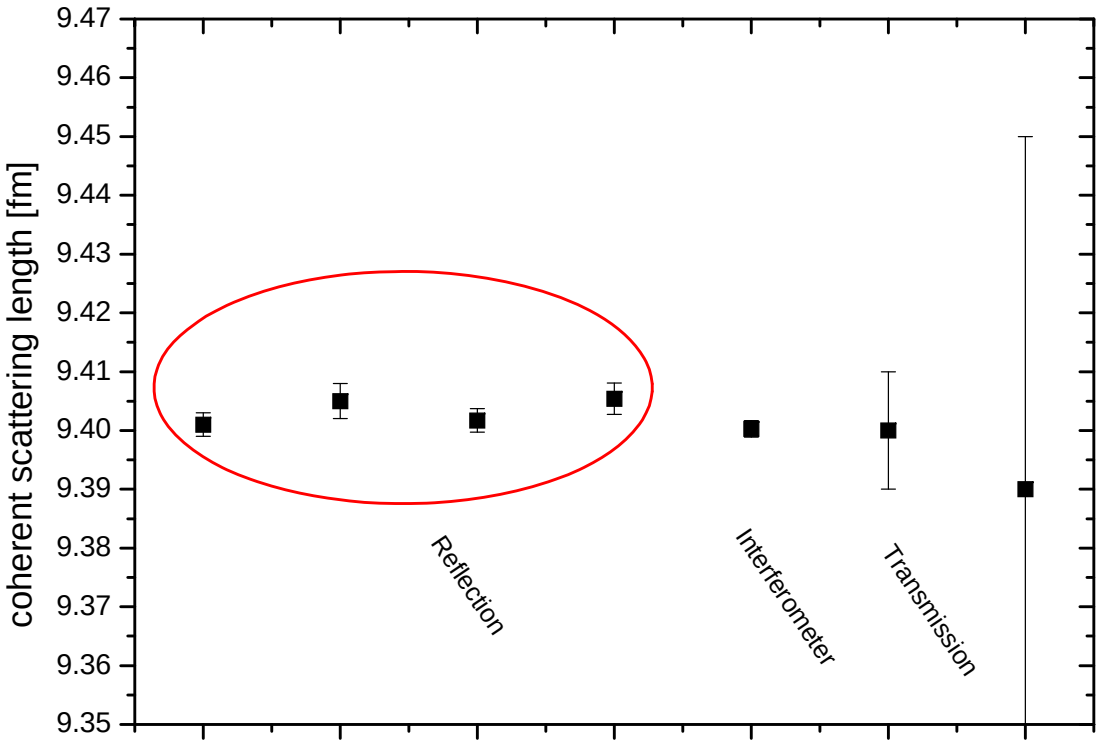
Carbon


coherent scattering length [fm]
6.665
6.660
6.655
6.650
6.645
6.640
Reflection
Interferometer
Transmission

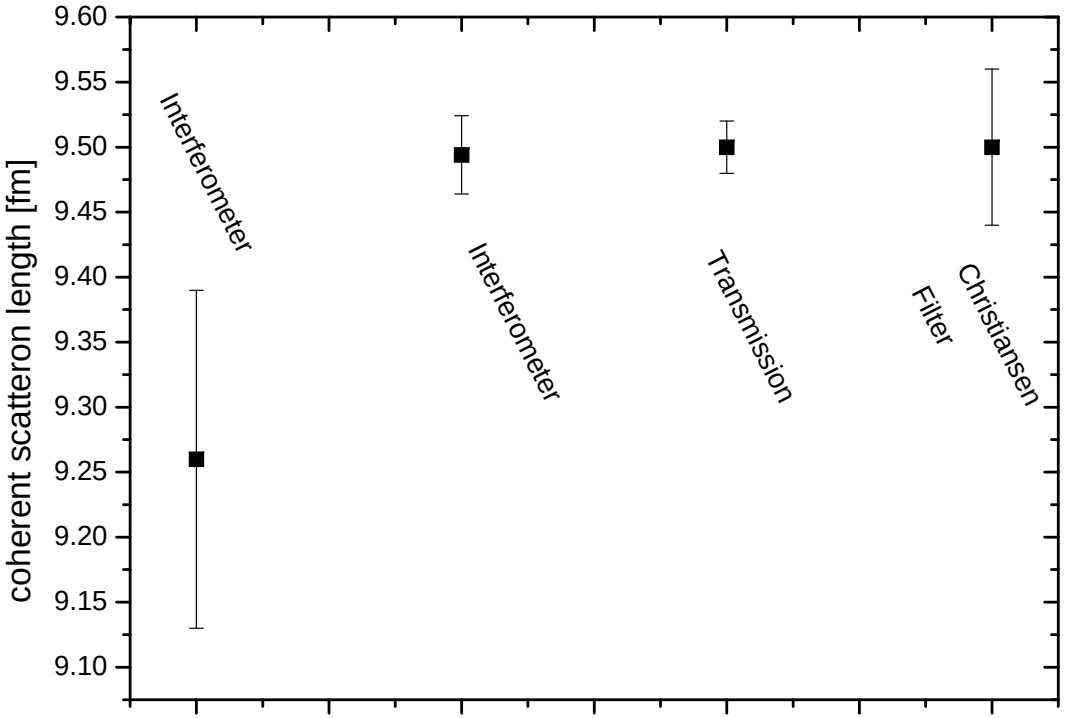
Carbon


total cross section [b]
energy [eV]
5.2
5.1
5.0
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
1E-3
0.01
0.1
1
10
100
1000
10000
100000
Danon
Poenitz
Good
Rayburn
Gritzkay
Koester
ENDF/B-VII
b coh
b coh +b ne

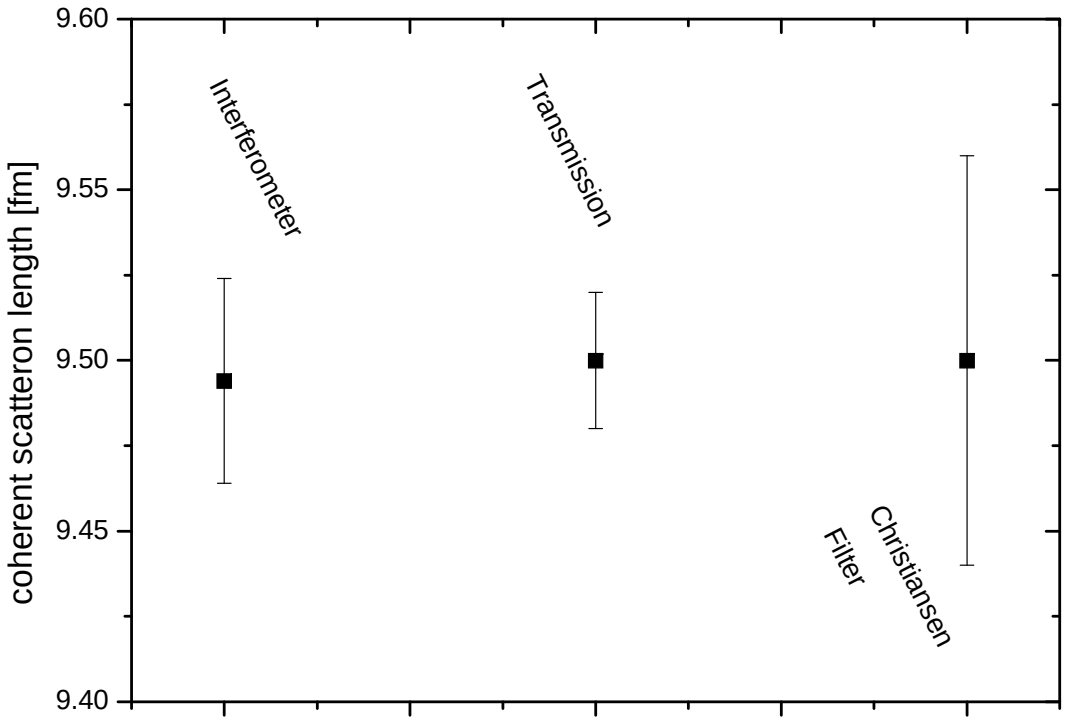
Nat. Pb


coherent scattering length [fm]
9.47
9.46
9.45
9.44
9.43
9.42
9.41
9.40
9.39
9.38
9.37
9.36
9.35
Reflection
Interferometer
Transmission

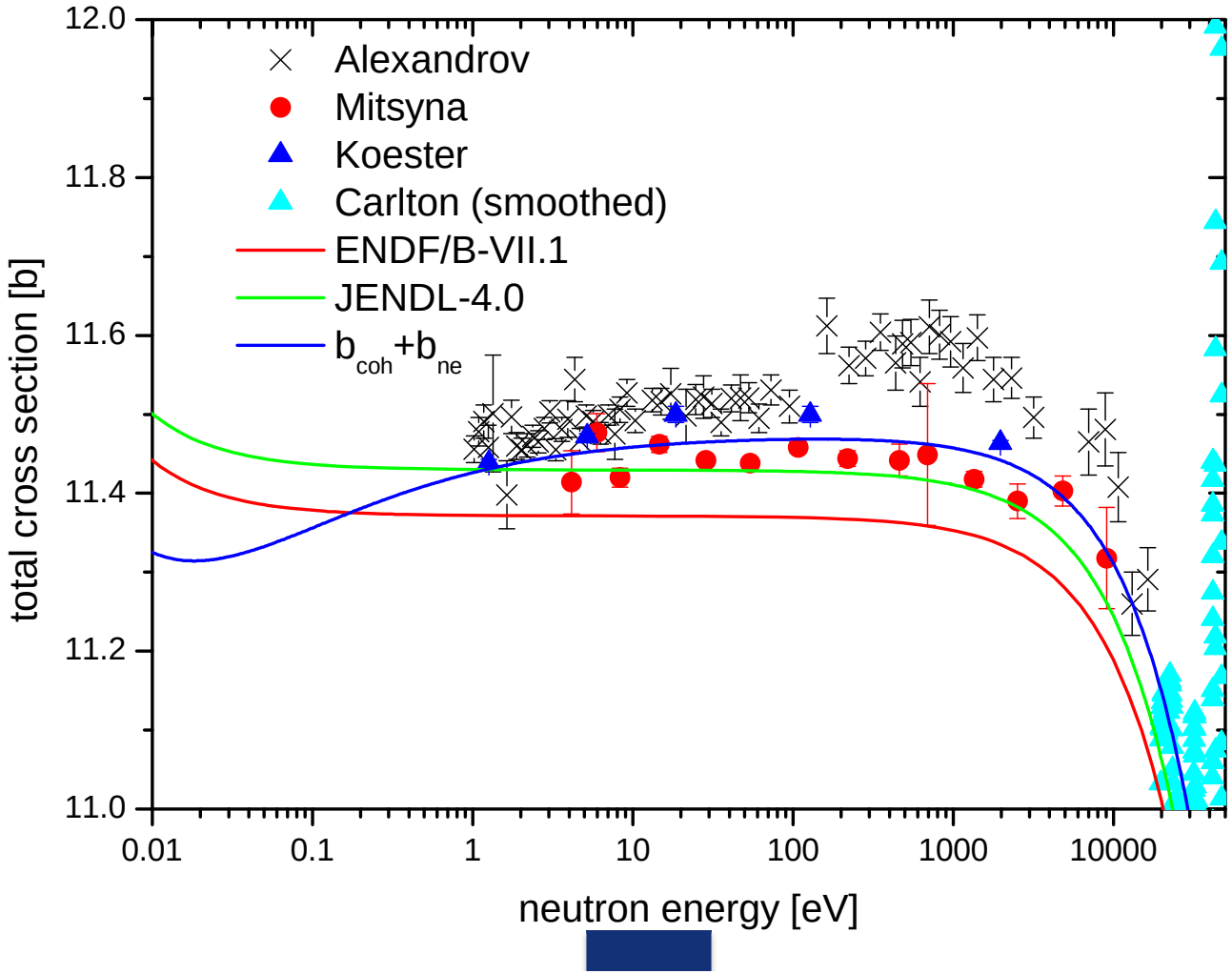
Pb-208

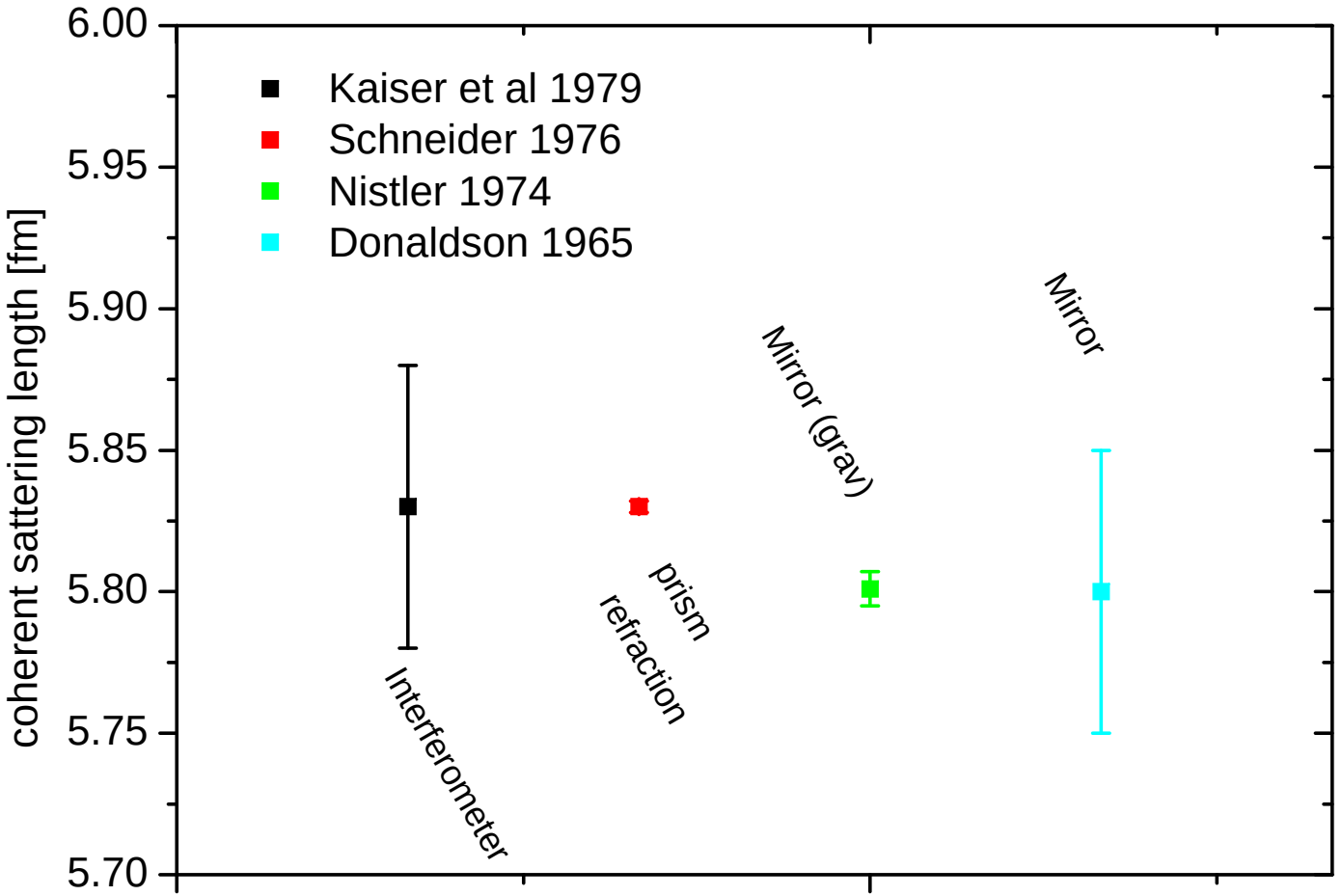

coherent scatteron length [fm]
9.60
9.55
9.50
9.45
9.40
9.35
9.30
9.25
9.20
9.15
9.10
Interferometer
Interferometer
Transmission
Filter
Christiansen

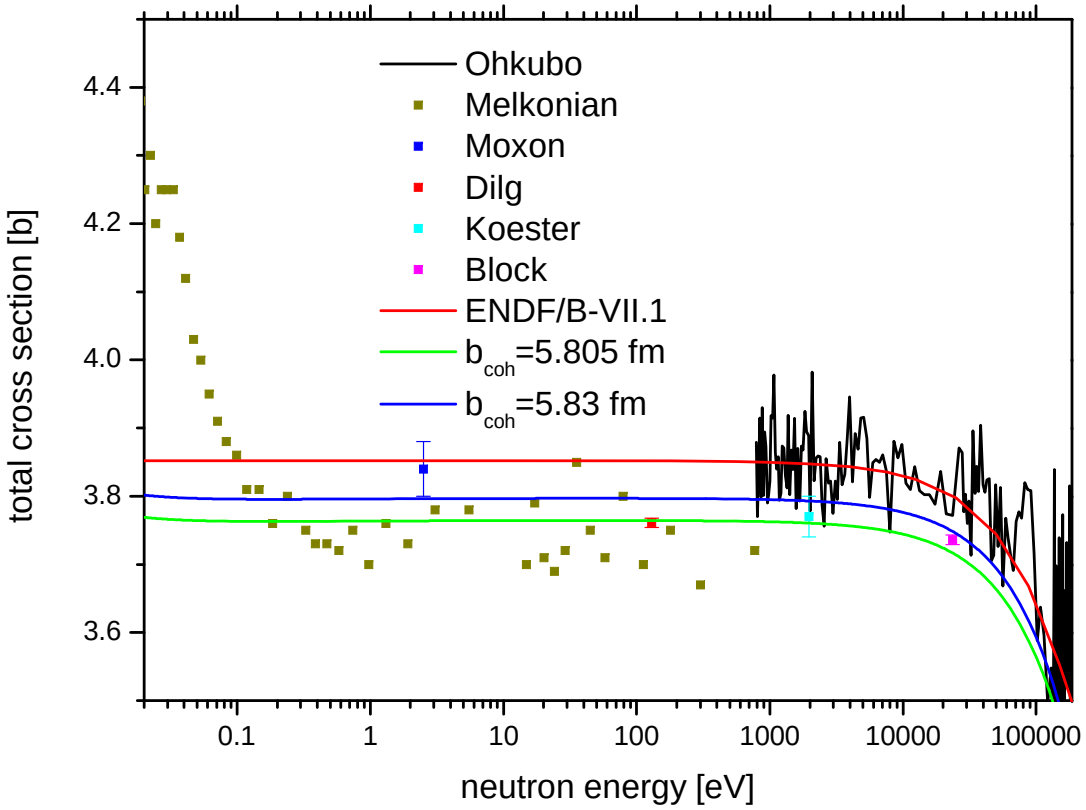
Pb-208

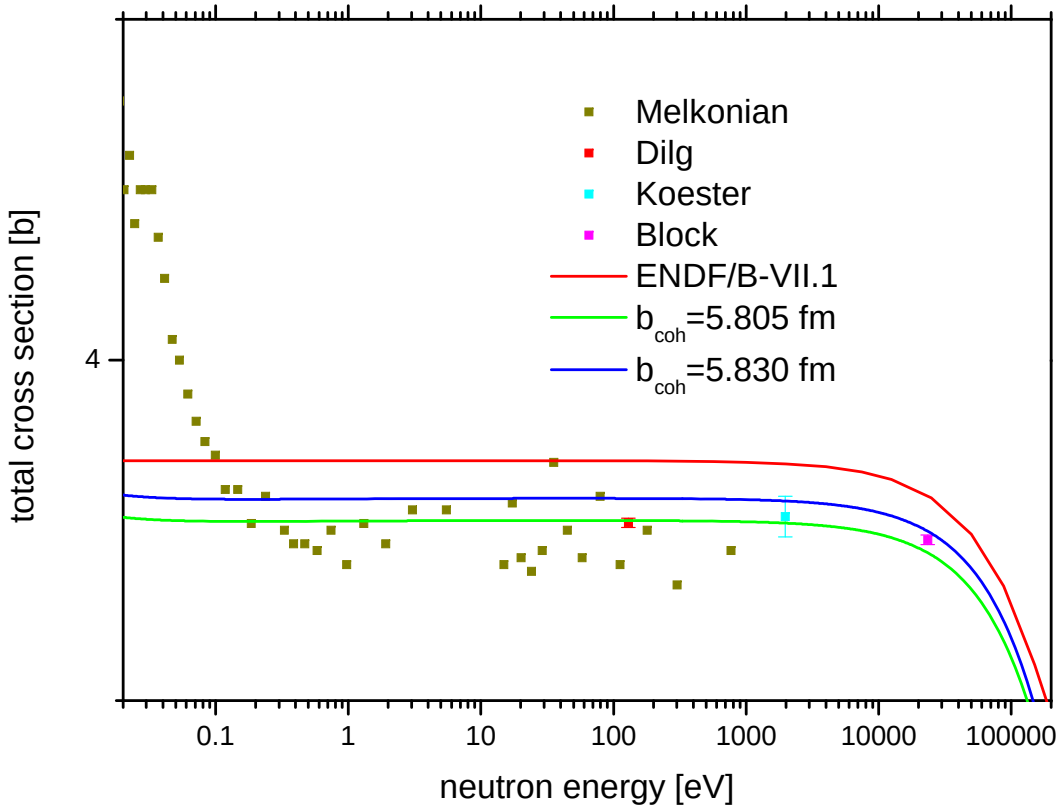

9.60
9.55
9.50
9.45
9.40
coherent scatteron length [fm]
Interferometer
Transmission
Christiansen Filter

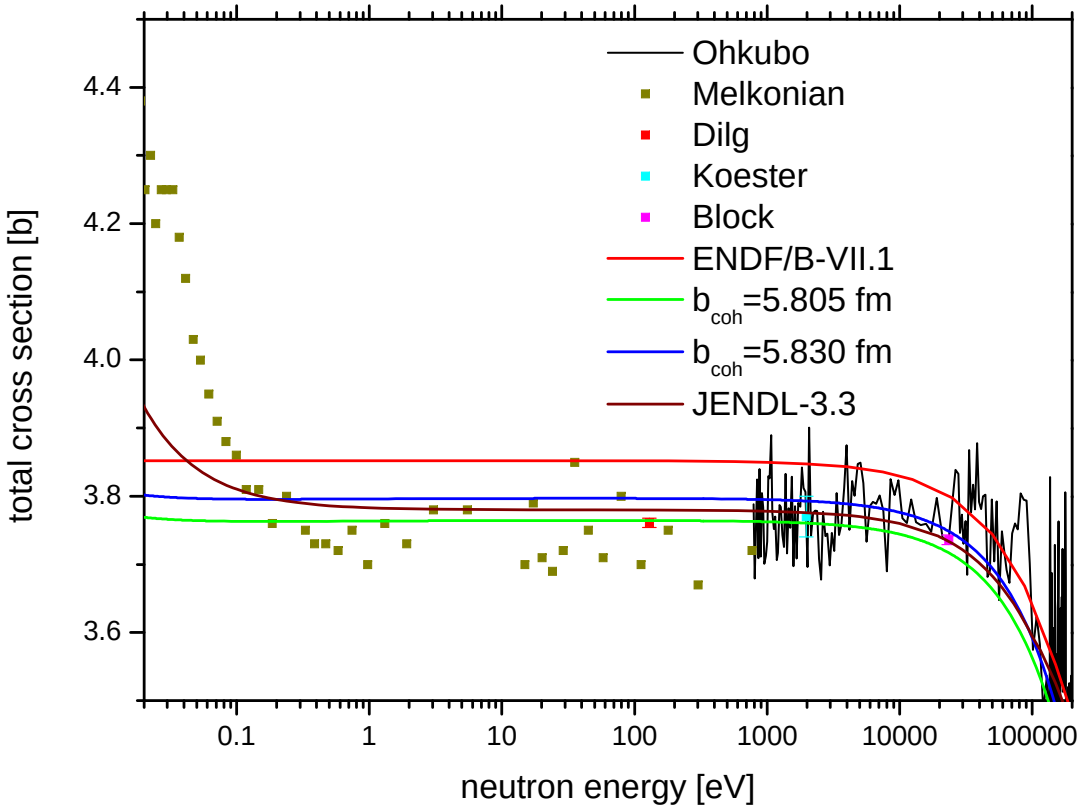
Pb-208


Alexandrov
Mitsyna
Koester
Carlton (smoothed)
ENDF/B-VII.1
JENDL-4.0
b coh +b ne
total cross section [b]
neutron energy [eV]
12.0
11.8
11.6
11.4
11.2
11.0
0.01
0.1
1
10
100
1000
10000

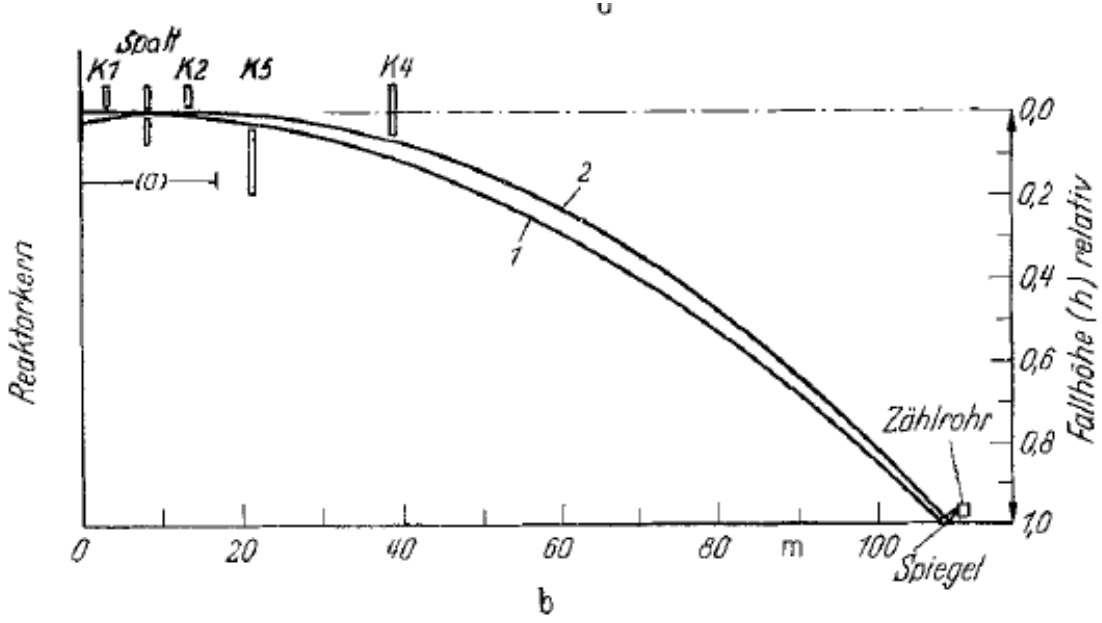

6.00
5.95
5.90
5.85
5.80
5.75
5.70
coherent sattering length [fm]
Kaiser et al 1979
Schneider 1976
Nistler 1974
Donaldson 1965
Interferometer
prism refraction
Mirror (grav)
Mirror


Ohkubo
Melkonian
Moxon
Dilg
Koester
Block
ENDF/B-VII.1
b coh =5.805 fm
b coh =5.83 fm
total cross section [b]
4.4
4.2
4.0
3.8
3.6
0.1
1
10
100
1000
10000
100000
neutron energy [eV]


Melkonian
Dilg
Koester
Block
ENDF/B-VII.1
b_coh=5.805 fm
b_coh=5.830 fm
total cross section [b]
4
0.1
1
10
100
1000
10000
100000
neutron energy [eV]


Ohkubo
Melkonian
Dilg
Koester
Block
ENDF/B-VII.1
b coh =5.805 fm
b coh =5.830 fm
JENDL-3.3
total cross section [b]
4.4
4.2
4.0
3.8
3.6
0.1
1
10
100
1000
10000
100000
neutron energy [eV]

- A large database of precise/accurate coherent scattering lengths is available
- For many light nuclei uncertainties of 10^{-3} are given
- In general uncertainties seem to be reasonable, maybe slightly optimistic
- Can give very useful constraint for fitting cross section data
- O-16
- Case of disagreeing coherent scattering lengths
- Nevertheless they agree within 0.5%


Spalt
K1
K2
K5
K4
(0)
2
1
Reaktorkern
0,0
0,2
0,4
0,6
0,8
1,0
Fallhöhe (h) relativ
Zählrohr
0
20
40
60
80
m
100
Spiegel

b