Back of the Envelope: NNbar at ILL

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Idea: exploit Nesvizhesky observation concerning “grazing” incidence reflections

- Use full flux of n beam
- Beam diameter greater than ~ 1m not required

Completely changes experimental geometry for long neutron guide!
4m diameter guide not necessary!

Goal: Minimize the relative phase shift

Phase factors for neutron and anitneutron reflected wave

$$\Psi_r = R\psi_o = \rho_n e^{i\varphi_n} + \rho_{\bar{n}} e^{i\varphi_{\bar{n}}}$$

Reflected neutron wave

Antineutron amplitude

Minimize: $\varphi_n - \varphi_{\bar{n}}$

Maximize : ρ_n

R. Golub and H. Yoshiki, Nucl. Phys. A**501**, 869-876 (1989)

H. Yoshiki and R. Golub, Nucl. Phys. A**536**, 648-668 (1992)

Result...for one material!

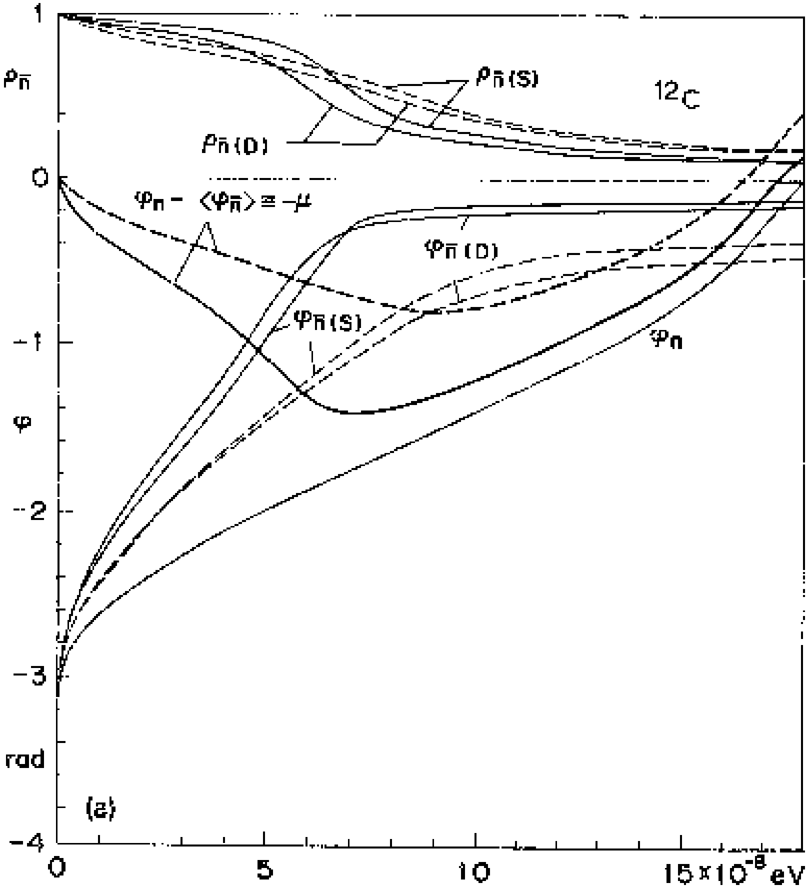

Fig. 2a. Reflectivity $\rho_{\bar n}$ and relative phase change $\varphi_n - \langle\varphi_{\bar n}\rangle$ due to a wall collision on carbon. The solid and dotted lines are for square-well and diffuse potential, respectively. See text for the explanation of S and D whose potential parameters are listed in table 1.

Need to design multilayer with right properties over broad band of $k_\perp$

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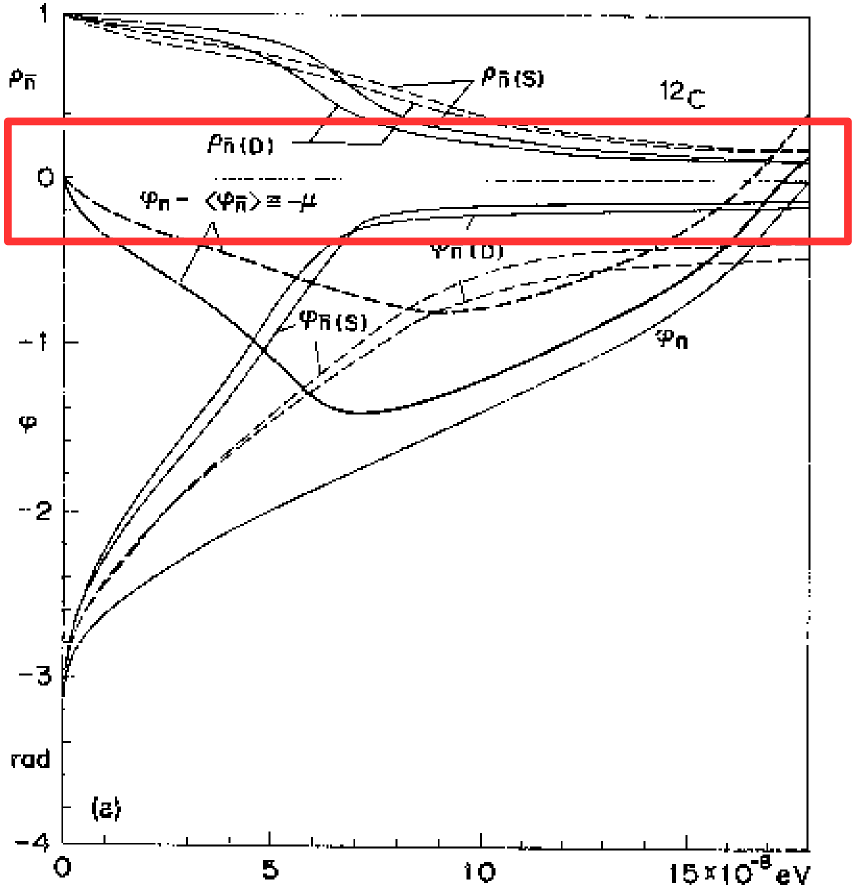

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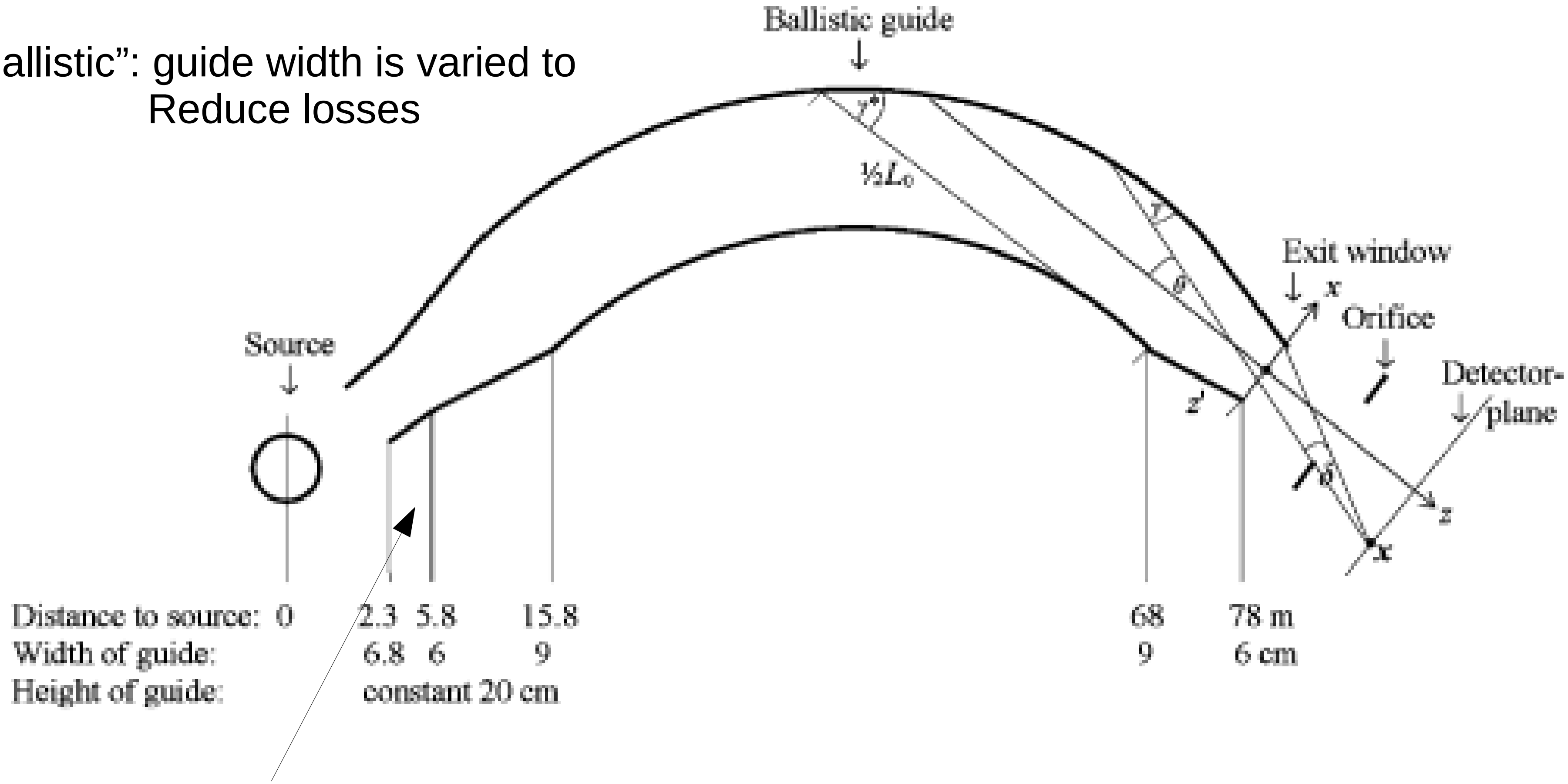
H113 – PF1b

“Ballistic”: guide width is varied to
Reduce losses



Distance to source:	0	2.3	5.8	15.8	68	78 m
Width of guide:		6.8	6	9	9	6 cm
Height of guide:		constant 20 cm				

m=1.2

Horizontal radius of curvature = 4000 m

Losses diminished by $(do/d)^2 \sim 0.5$

Guide vacuum -- 0.01 mbar(?)

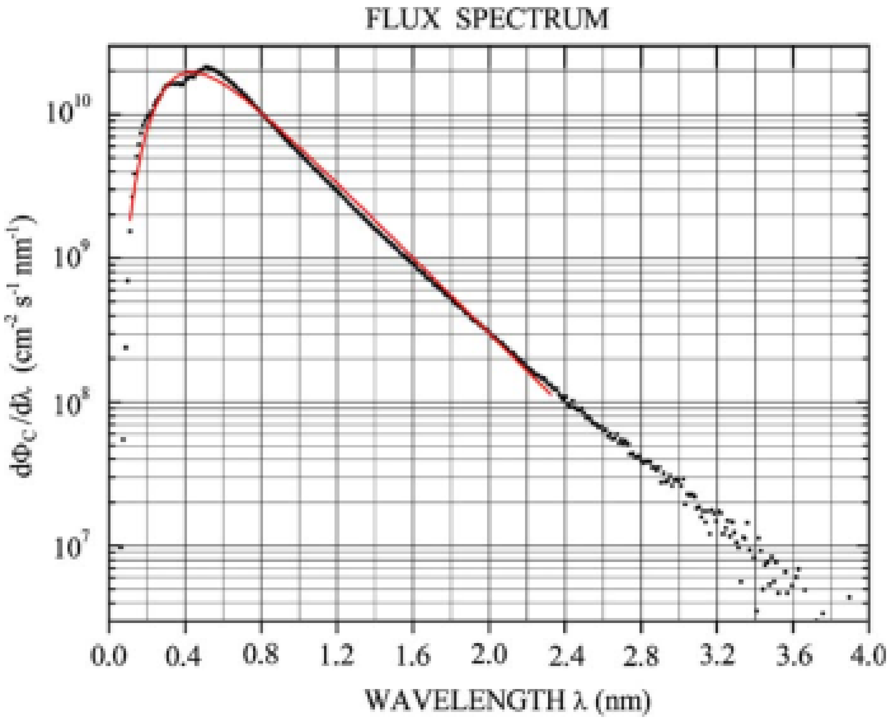


Fig. 4. Absolute neutron capture flux-density spectrum $\partial\Phi_C/\partial\lambda$ averaged over the central $2 \times 2\,\text{cm}^2$ area of the exit window of the H113 guide, measured (dots) and modelled with Eq. (11) (line).

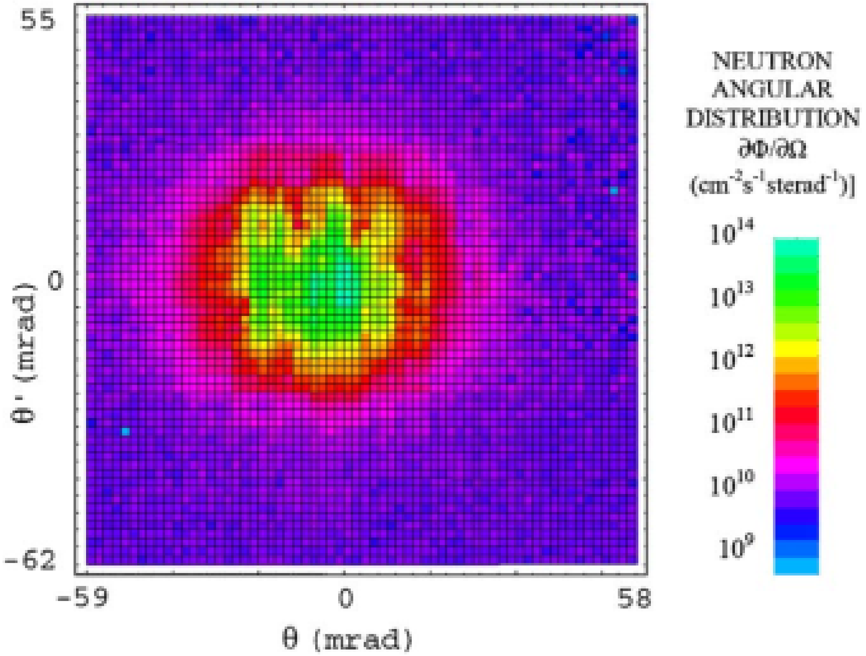


Fig. 5. Neutron angular distribution measured with a CASCADE detector at 1.7 m distance from a pinhole at the centre $x_0 = 0$ of the exit window of the ballistic guide H113. Data are displayed in 64×64 channels. Each channel in this measurement holds a 9-bit time-of-flight spectrum. The small asymmetry in the horizontal distribution appears enhanced due to the logarithmic presentation of the data.

m = 2 guide = 2 x V_F of natural nickel

Mirror constant κ = 0.0035 rad/nm

H113 most likely wavelength = 0.5 nm → max angle = 0.0086 rad (= κλ)

Spectrum “harder” than typical cold guide

From Valery – length of guide where expansion could be performed ~ 50m
detector and dump region 2.5 by ~ 5 m
Total flux 2.2x10^{12} (full guide, measured)
sensitivity

Back of the envelope: adiabatic expansion does not lose flux
Use full beam

Limit: 11 x ILL sensitivity, run for 3 years

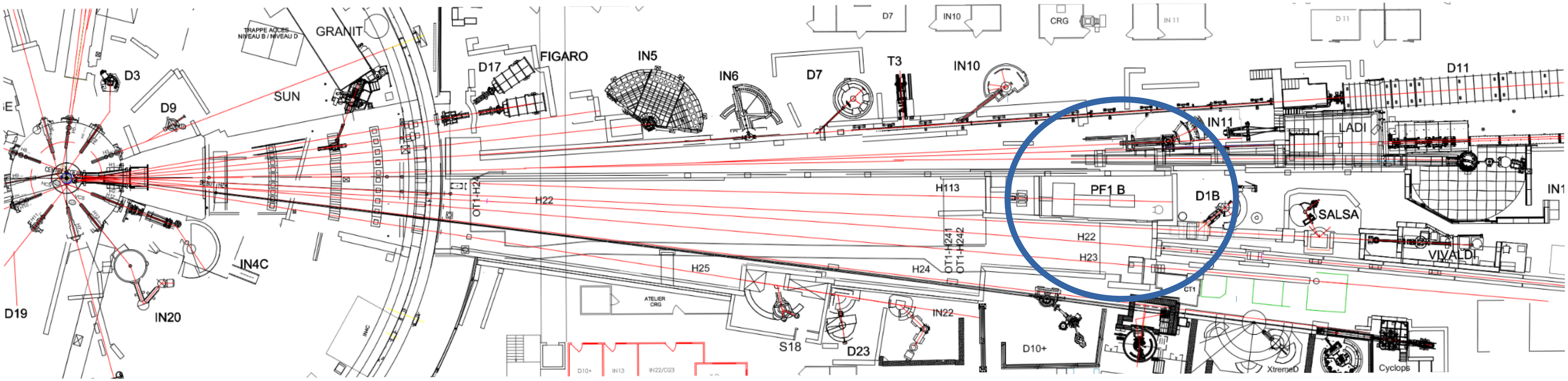
Improvement – 8.6 x 10^{7} s → 5.7 x 10^{8} s (SK – 3 x 10^{8} s)

Interesting increment,complementary to SK!

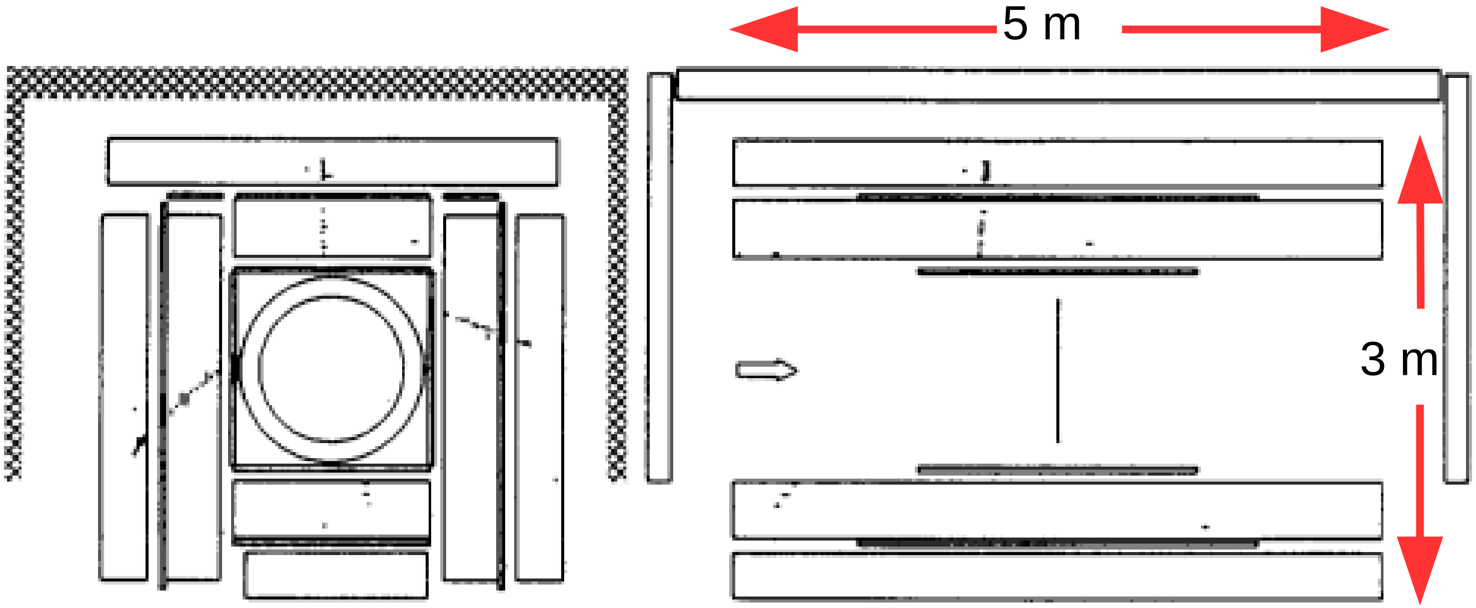
Advantage – new limits, build collaboration, establish expertise

Disadvantages – adiabatic expansion not modeled, dilute ESS limit, still expensive, time scale uncertain, footprint for detector and dump imited...

PF1 B at ILL – Layout



Detector Footprint



Get lost tube –
at least 2 m?

Fig. 3. A typical recorded event. The three orthogonal projections are shown. The black areas on the drawing represent the hitted scintillator counters in the projection orthogonal to the beam axis and the evaluated track crossing point in the scintillators in the other projections. Reported are also the recorded crossing times of the scintillators for the time of flight analysis (I, O for inner, outer sectors; L, R, U, D for left, right, up and down).

Could improve efficiency (1.5 → 1.8)? ILL det eff 0.5

Some Steps We Can Take

- Detailed investigation and optimization of interactions with material guide to minimize phase shift (Mike Snow and Valery Nesvizhevsky)
- Have McStas model – investigate adiabatic expansion
- Refine understanding of impact of **uncertainties** in reflection model
- Understand spin coherence issues…

Working on second bullet...

How to calculate the reflected wave amplitudes?

- We assume that the cold neutron waves are plane waves incident on a standard material potential:

- Solve 1D Schroedinger eqn for wave incident on 1D complex potential Λ...

Reflected wave amplitude

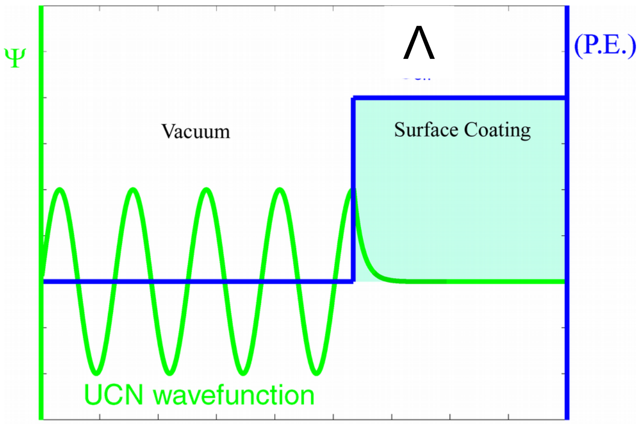
$$\Psi_r = R\Psi_o$$

$$R = \frac{k_\perp - k'}{k_\perp + k'} = \rho e^{i\varphi}$$

complex wave-vector in coating

$$(k')^2=(k_\perp)^2 - \Lambda/h = (k_\perp)^2 - 4\pi Na$$

Material potential: need value for scattering length a



Case where E < U_{eff}

Parameters of interest

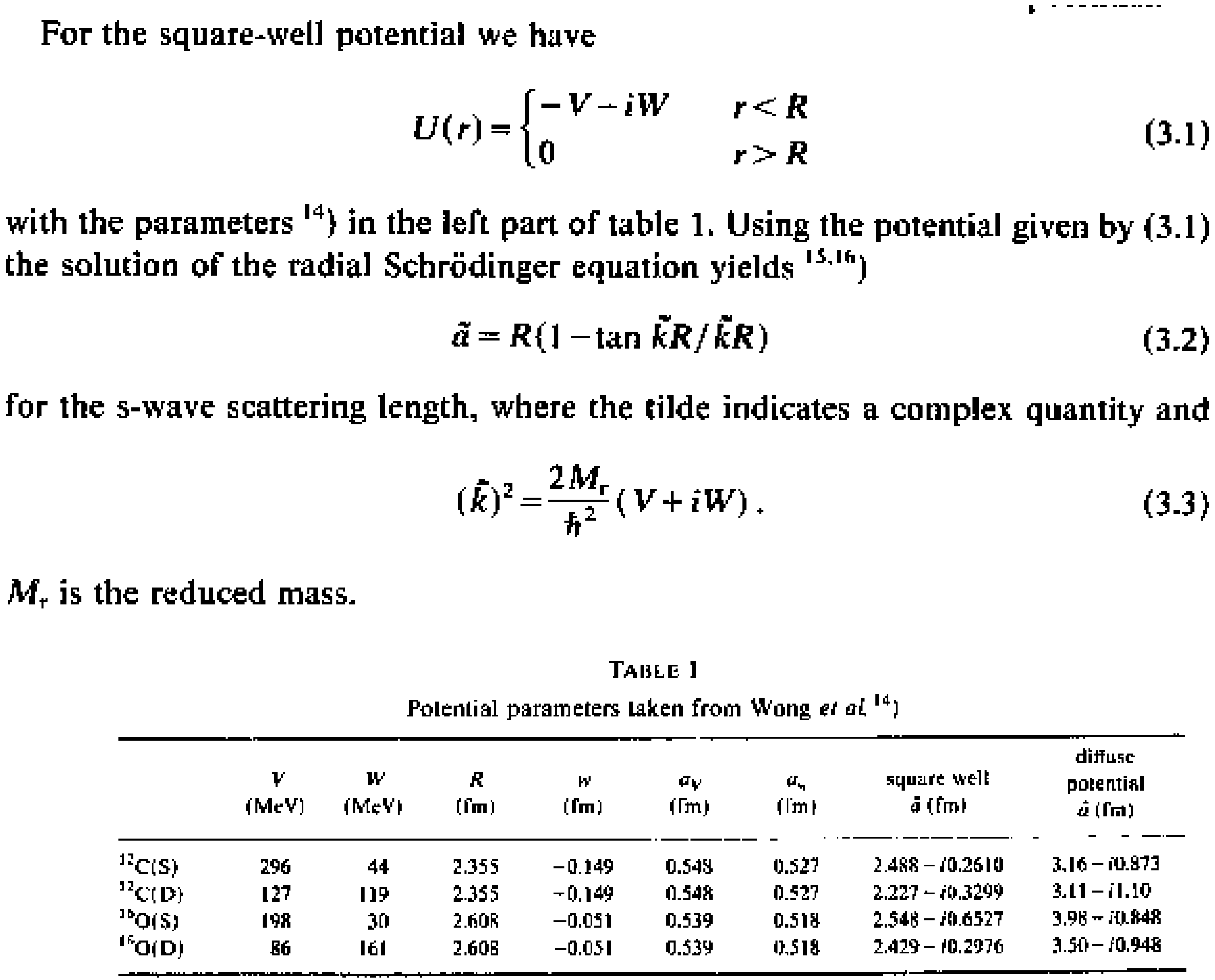
$$\Phi = \arcsin\left(\frac{\mathrm{Im}\left\{ \frac{k_\perp - k'}{k_\perp + k'} \right\}}{\left\| \frac{k_\perp - k'}{k_\perp + k'} \right\|} \right)$$

Phase determined by transverse momentum and scattering lengths!

Neutron scattering for Carbon essentially real (ignore absorption)

$a_n = 6.648$ fm

Get complex scattering length for n from anti-protonic atom analysis
(determined parameters for effective potential)



For the square-well potential we have

$$U(r)=\begin{cases}-V-iW & r<R\\ 0 & r>R\end{cases}\tag{3.1}$$

with the parameters [14] in the left part of table 1. Using the potential given by (3.1) the solution of the radial Schrödinger equation yields [15,16]

$$\tilde{a}=R(1-\tan\tilde{k}R/\tilde{k}R)\tag{3.2}$$

for the s-wave scattering length, where the tilde indicates a complex quantity and

$$(\tilde{k})^2=\frac{2M_r}{\hbar^2}(V+iW)\,.\tag{3.3}$$

M_r is the reduced mass.

TABLE 1

Potential parameters taken from Wong *et al.* [14]

	V (MeV)	W (MeV)	R (fm)	w (fm)	a_V (fm)	a_w (fm)	square well $\tilde{a}$ (fm)	diffuse potential $\hat{a}$ (fm)
^{12}C(S)	296	44	2.355	−0.149	0.548	0.527	$2.488-i0.2610$	$3.16-i0.873$
^{12}C(D)	127	119	2.355	−0.149	0.548	0.527	$2.227-i0.3299$	$3.11-i1.10$
^{16}O(S)	198	30	2.608	−0.051	0.539	0.518	$2.548-i0.6527$	$3.98-i0.848$
^{16}O(D)	86	161	2.608	−0.051	0.539	0.518	$2.429-i0.2976$	$3.50-i0.948$