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Thomas Form of the Spin-Dependent Optical Potential and Asymmetry of 20 MeV Polarized Protons*

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ABSTRACT

Recently measured asymmetries produced in the inelastic scattering of 20.3 MeV polarized protons are analyzed in the DWBA collective model approximation. Substantial improvements are observed when the deformed spin-dependent optical potential is of the full Thomas form.

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Previous analyses of inelastic scattering with polarized protons at 18.6 MeV[1] have shown that the influence of the deformed spin-orbit interaction was not obvious although helping, in a limited sense, to reproduce the observed asymmetries. A simple deformed spin-orbit term was used, namely a symmetrized form which gives the following spin-orbit form factor

$$F_{so}^{(L)}(\underset{\sim}{r}) = \left(\frac{\hbar}{m_\pi c}\right)^2 (V_{so} + iW_{so})\, \beta_L^{so}\, \frac{R_{so}}{a_{so}} \times \frac{1}{r}\frac{d}{dr}\frac{d}{dR_{so}} f(x_{so}) \cdot \frac{1}{2}\left[Y_L^{*M}(\hat{r})\,\underset{\sim}{\sigma}\cdot\underset{\sim}{L} + \underset{\sim}{\sigma}\cdot\underset{\sim}{L}\, Y_L^{*M}(\hat{r})\right] \quad (1)$$

In this expression the deformation is mainly introduced in the radial term $f(x_{so})$. The inclusion of the above form factor improved the agreement with observed asymmetries although a larger increase in the spin-orbit strength was necessary. Similar conclusions have been observed from similar work at higher energies[2,3]. It was noted that despite the general improvement in the predicted asymmetries, a descrepancy between theory and experiment at forward scattering angles remained unresolved.

Sherif and Blair[4] have recently pointed out that the deformed spin-dependent interaction of eq. (1)

is an oversimplification, and that a more appropriate form is the full Thomas form

$$F_{so}^{(L)}(\underset{\sim}{r}) = \left(\frac{\hbar}{m_\pi c}\right)^2 (V_{so} + i W_{so}) \beta_L^{so}$$
$$\times \underset{\sim}{\sigma} \cdot \left[\underset{\sim}{\nabla} \left(f(x_{so}) Y_L^{*M}(\hat{r}) \right) \times \underset{\sim}{P} \right] . \qquad (2)$$

The above expression has substantially improved the agreement for forward angle asymmetry of medium energy protons[4,5]. Evidence of the correctness of the full Thomas form has been shown by spin-flip measurements[6,7]. Moreover, it has been very successful in explaining the measured[8] inelastic polarization of high energy protons[9].

Improved data on inelastic scattering of polarized protons should provide a sensitive test of the Thomas form of the deformed spin-dependent interaction. In particular, measurements with lower energy protons are desirable since, as mentioned above, the full Thomas form has lead to substantial improvements in the collective model description of high and medium energy proton scattering; and it should be interesting to see whether the same improvement is achieved at lower energies. Recent data[10] at 20.3 Mev with the Saclay improved polarized beam should be particularly is an oversimplification, and that a more appropriate form is the full Thomas form

$$F_{so}^{(L)}(\underset{\sim}{r}) = \left(\frac{\hbar}{m_\pi c}\right)^2 (V_{so} + i W_{so}) \beta_L^{so} \times \underset{\sim}{\sigma} \cdot [\underset{\sim}{\nabla}(f(x_{so}) Y_L^{*M}(\hat{r})) \times \underset{\sim}{P}] . \quad (2)$$

The above expression has substantially improved the agreement for forward angle asymmetry of medium energy protons[4,5]. Evidence of the correctness of the full Thomas form has been shown by spin-flip measurements[6,7]. Moreover, it has been very successful in explaining the measured[8] inelastic polarization of high energy protons[9].

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The experimental asymmetries will be compared to DWBA collective model predictions using either the simplified form (eq.(1)) or the full Thomas form (eq.(2)) for the deformed spin-dependent interaction. Calculations are carried out using a computer code written for this purpose[5]. We also compare one case with coupled channel calculations carried out with the Oxford code[11]. The nuclei considered here are ^{24}Mg, ^{90}Zr, and ^{92}Zr. The optical model parameters used in the present analysis were obtained by searching on elastic cross section and polarization[10].

In the figures shown, the curves denoted by $U_{s,def}^{(2)} = 0$, are essentially those obtained with the symmetrized form of eq.(1) (see ref.4). Fig.1 shows the asymmetry for the first 2^+ state of ^{24}Mg together with theoretical predictions when the spin-dependent interaction is of the full Thomas form and when it is of the symmetrized form. Also shown is a coupled channel prediction using the symmetrized form (only with slightly smaller β^{so}). The ^{24}Mg nucleus is strongly deformed and the 2^+ state at 1.37 MeV is generally well described as a symmetric rotator. Recent measurements[12] at 49.5 MeV give an asymmetry with two bumps one around 60° and the other at back angle near 110°. The latter is well fitted with the symmetrized form; but the forward one is not at all reproduced by such calculations[13]. It is only when the full Thomas form is used that the forward asymmetry is well reproduced[5]. The situation we have here at 20 MeV is similar in that the second bump (at about 120°) is reproduced by both forms but the forward asymmetry is reproduced only when the full Thomas form is used. The coupled channel prediction may provide a better fit if the Thomas form is adopted in these calculations. The asymmetry for the 4^+ state at 4.12 MeV is poorly reproduced either with or without the full Thomas form and may perhaps require more elaborate calculations.

Figs. 2 and 3 show the asymmetries for the first 2^+ and 3^- states in ^{92}Zr, respectively. The curves are collective model predictions using the symmetrized form and the full Thomas form. A larger spin-orbit deformation is used in these calculations. For the 2^+ state the introduction of the full Thomas form substantially improves the asymmetry at forward angles. The fit is fairly good up to 85°, while at back angles a disagreement with the data remains, although the phase is constantly correct. Similar Behavior is observed for the first 2^+ state in ^{90}Zr.

The fit to the asymmetry for the 3^- state is good with the symmetrized form around 85^o and 140^o and the full Thomas form hardly affects the fit at those angles. Nevertheless, the full Thomas form leads to a definite improvement in the asymmetry for scattering angles less than 50^o. The overall fit to the measured asymmetry is then rather good at all angles when the full Thomas form is used. This is particularly true for the 3^- state in ^{90}Zr.

Our conclusion is that the asymmetry measurements with 20 MeV protons provide strong evidence that the deformed spin-dependent interaction appropriate for collective model description of proton inelastic scattering is of the full Thomas form. This strengthens the evidence already provided by measurements at high and intermediate energies[9,5].

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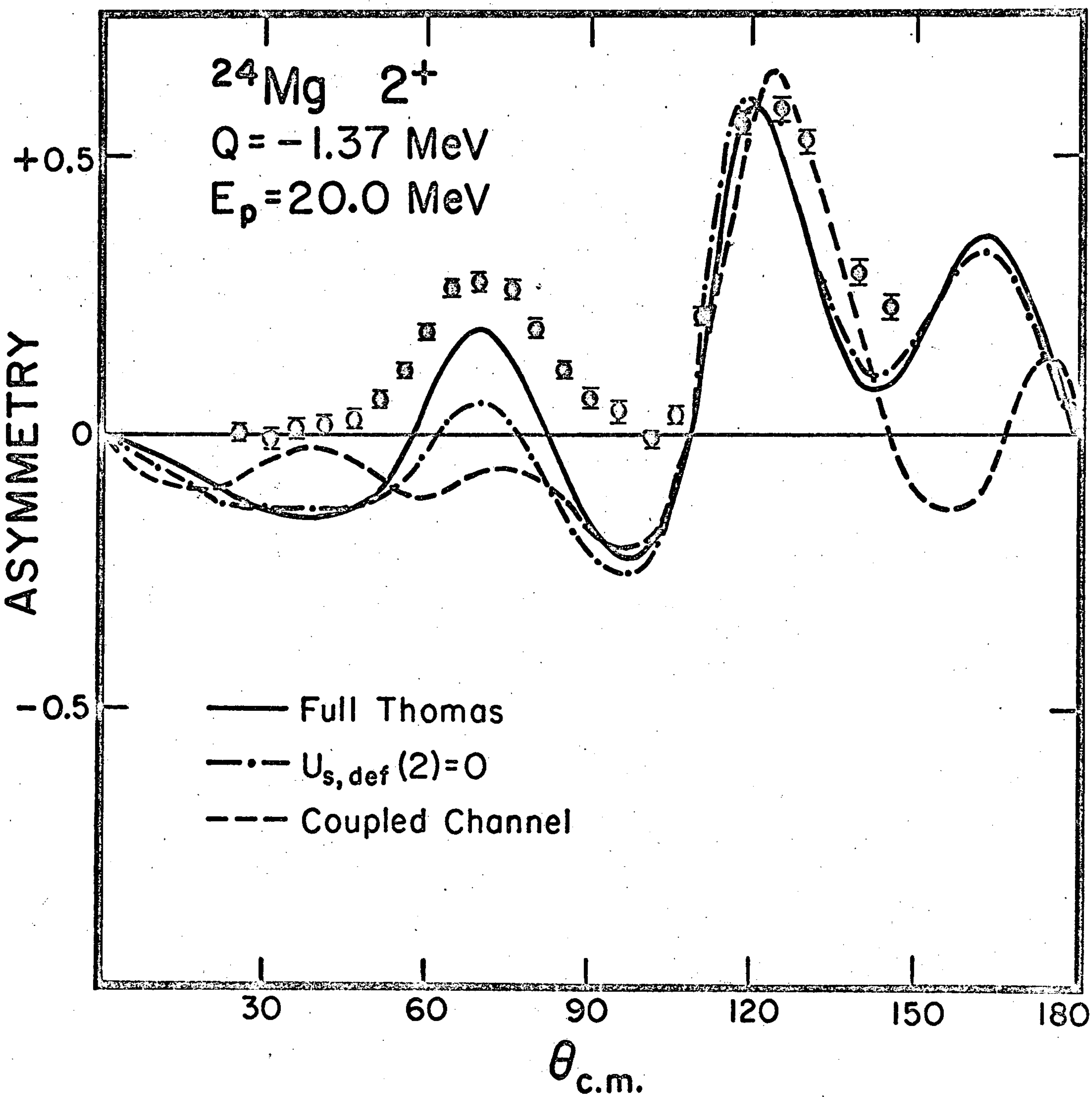
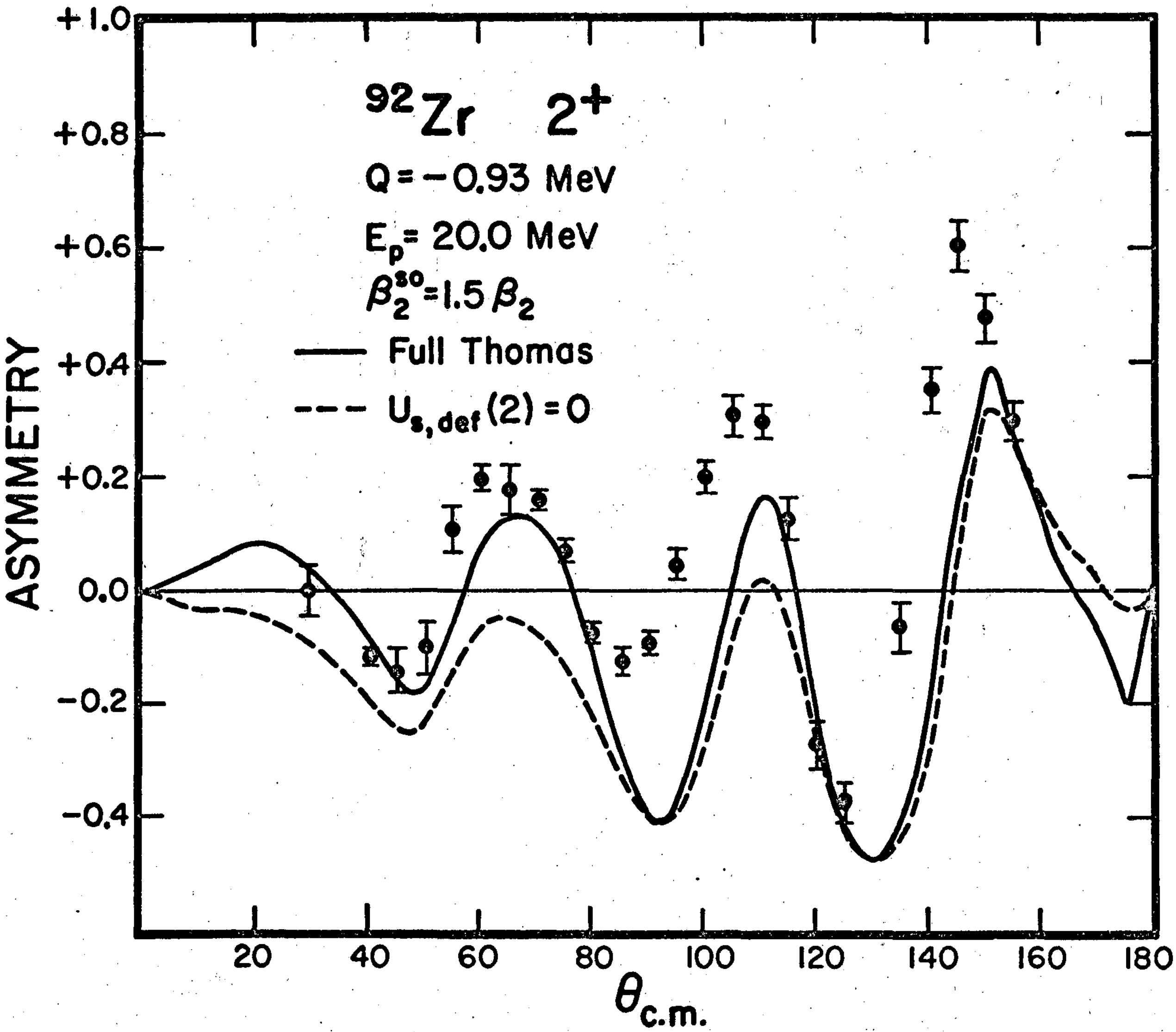


^{24}Mg 2+
Q = -1.37 MeV
E_p=20.0 MeV
+0.5
0
-0.5
ASYMMETRY
Full Thomas
$U_{s,def}(2)=0$
Coupled Channel
30
60
90
120
150
180
$\theta_{c.m.}$

Figure 1



^{92}Zr 2$^+$
Q = −0.93 MeV
E_p = 20.0 MeV
β_2^{so} = 1.5 β_2
Full Thomas
$U_{s,def}(2) = 0$
ASYMMETRY
+1.0
+0.8
+0.6
+0.4
+0.2
0.0
-0.2
-0.4
20
40
60
80
100
120
140
160
180
$\theta_{c.m.}$

Figure 2

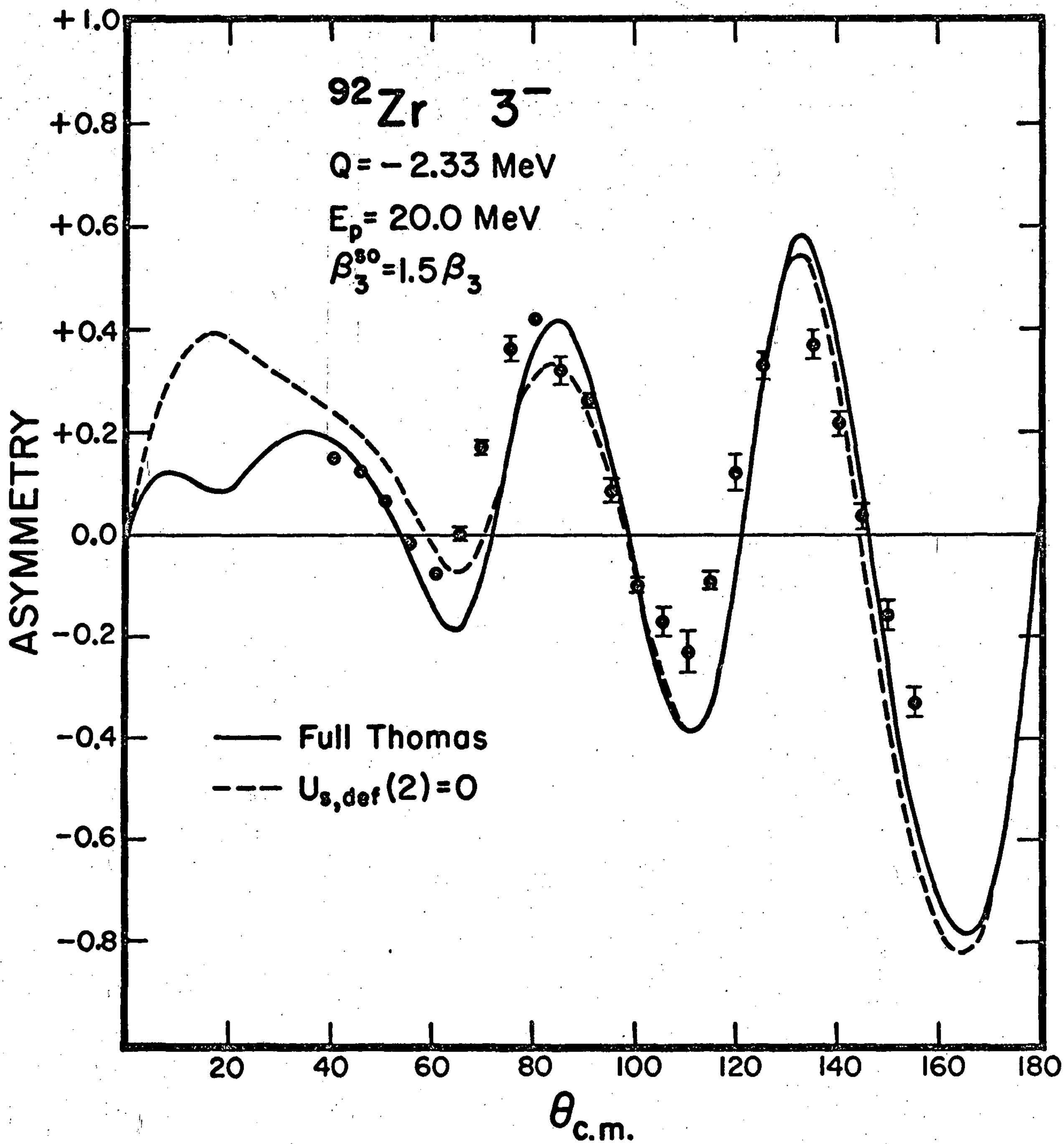

+1.0
+0.8
+0.6
+0.4
+0.2
0.0
-0.2
-0.4
-0.6
-0.8
ASYMMETRY
^{92}Zr 3$^-$
Q = −2.33 MeV
E_p = 20.0 MeV
β_3^{so} = 1.5 β_3
Full Thomas
$U_{s,def}(2) = 0$
20
40
60
80
100
120
140
160
180
$\theta_{c.m.}$

Figure 3

FIGURE CAPTIONS

Fig. 1 Asymmetry for the excitation of the first 2^+ state in ^{24}Mg by 20 MeV protons, together with DWBA fits using either the simplified form or the full Thomas form of the deformed spin-dependent interaction. Also shown is a coupled channel fit.

Fig. 2 Asymmetry for the excitation of the first 2^+ state in ^{92}Zr together with DWBA fits using either the simplified form or the full Thomas form of the deformed spin-dependent interaction.

Fig. 3 Asymmetry for the excitation of the first 3^- state in ^{92}Zr together with DWBA fits using either the simplified form or the full Thomas form of the deformed spin-dependent interaction.

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