Modelling nucleon-nucleus analysing powers with GEANT4

J.R.M. Annand and D.I. Glazier

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This brief document outlines the main features of the polarised nucleon scattering models implemented as an add-on to standard G4 nucleon reaction processes.

Installation instructions are given as an appendix.

1 Introduction

When a polarised nucleon scatters off any nuclear target the spin-orbit potential results in a so-called "up-down" or "left-right" asymmetry. The former results from a nucleon polarised in the horisontal plance while the latter the vertical plane. More precisley the asymmetry takes the form of a $\cos\phi$ distribution where ϕ is the azimuthal angle of the scattered nucleon around the incident momentum and with the zero of the distribution given by the incident polarisation plane :

$$N(\phi) = N_0 \left(1 + A_p P_T \cos\phi\right)$$

here A_p is the "analysing power" of the interaction and it is dependent on the target species, nucleon momentum and scattering angle. P_T is the magnitude of the nucleon polarisation. Often one desires to measure P_T from such scattering reactions. To do so requires prior knowledge of A_p.

In reactions up to several GeV A_p is well determined for nucleon-nucleon scattering and there is a reasonable database for inclusive scattering on Carbon. Everything else is not so well known. Even in the case of protons scattering on carbon the results are not so clear if the experiment is not measuring completely inclusive scattering or if it is sensitve to charge exchange processes. On the other hand what experimental evidence exists tends to suggest quasi-elastic scattering plays a dominant role in reactions where the nucleus is changed. This is particularly clear in charge exchange reactions where the scattered nucleon must have interacted with a nucleon inside the nucleus to exchange its charge with. But would also be enhanced by for example neutron scattering in an active scintillator, where the quasi-elastic scattering on the proton deposits significnalty more energy than elastic scattering on carbon or quasi elastic scattering on a neutron.

Considering these factors it was decided to implement a quasi-elastic model based on the well known free nucleon-nucleon analysing powers to capture the main features of the reaction analysing power. Clearly this does not encapsulate all of the physics and so at the same time standard parameterisations usch as McNaughton have been implemented and can be blended with the quasi-elastic model or used a comparative result.

2 Implementation

The GEANT4 libraries provide state-of-the-art particle tracking algorithms. The primary nucleon interaction models are based upon cascade processes where the nucleon interacts in a series of steps inside the nucleus. The resulting angular distribution was found to agree very well with data in the Sikora analysis. Such models do not consider the polarisation and hence it is necessary to apply an azimuthal distribtution after the final state has been determined. The analysing power for this comes from a parameterisation based on experimental data.

The simplest case is for nucleon-nucleon scattering where the analysing power is well determined by the SAID PWA we use parameterisations of their results to determine the analysing power in these reactions. (Note for charge exchange reactions, this is equivalent to the original nucleon scattering backwards and so the analysing power for the forward charge exchanged nucleon should be taken from backward angles $(180 - \theta)$then multiplied by -1. In this way the charge exchange reaction will have the same sign as the neutral exchange).

For the quasi-elastic process the G4 inelastic model will in general produce multiple nucleons in the final state. We proceed by finding the two most energetic and assume these came from teh quasi-elastic scatter. Then the incident momentum and scatter angle of the most energetic nucleon is used to find the analysing power from the same SAID parameterisations. A new ϕ angle is selected from the polarised distribution and the other reaction products rotated accordingly.

For elastic scattering off larger nuclei the quasi-free approach is not effective and different parameterisatons are needed. Currently we have several proton-Carbon analysing power paramterisations which can be used, although these may include effect other than pure pC elastic scattering.

Similarily for inelastic scattering other paramterisation can be used instead of the quasifree method, Sikora is the most up-to-date.

Note care must be taken over reference frames. The phi angle is selected in the reaction centre of momentum. the z-axis is along the momentum direction, the y-axis momentum X labZ. The user must define the polarisation of the neutron in this frame, so be careful where z-lab is pointing.

2.1 Code

The selection of the analysing power is handled by a new class PolNucleonRotate, which has flags for the different parameterisations that have been coded. This class returns the phi rotation required to put all of the particles in the polarised frame after the scatter.

In addition there is a PolNPRotate class which specifically handles nucleon-nucleon elastic (and quasi) scattering.

2.2 Configuration

There are 4 processes that have to be configured, proton or neutron - elastic or inelastic scattering. The models are setup via the npolPhysicsListMessanger in the run macro:

/Pol/pol/Ay-Process p-elastic
/Pol/pol/Ay-Value 0
/Pol/pol/Ay-Model McNaughton
/Pol/pol/Ay-Process n-elastic
/Pol/pol/Ay-Value 0
/Pol/pol/Ay-Model McNaughton
/Pol/pol/Ay-Process p-inelastic
/Pol/pol/Ay-Value 0
/Pol/pol/Ay-Model McNaughton
/Pol/pol/Ay-Process n-inelastic
/Pol/pol/Ay-Value 0
/Pol/pol/Ay-Model McNaughton

Although nucleon-nucleon (elastic) scattering is taken from SAID by default. In the case you want to use the quasifree model (which will supercede the above configuration options) for the nucleon-nuclear scattering you must use the physics list :

/Pol/physics/Physics QGSP_BIC_POLQF

rather than

/Pol/physics/Physics QGSP_BIC_POL

Note, The Ay-value is used in regions the paramterisations are not valid.

Possible paramterisations other than SAID are (see class NucleonPolRotate for details):

Null, Ladygin, Spinka, McNaughton, Glister, Azhgirey, Sikora

3 npol

The example npol can be used to calculate analysing powers for basic polarimeters. The geoemtry consists of a wall of plastic. The user can set the thickness at run time. To run :

npol macro rootfile targetthick(cm)

macro is the setup macro which will be run and should contain the analysing power configuration options outlined above. targetthick is just the thicness of

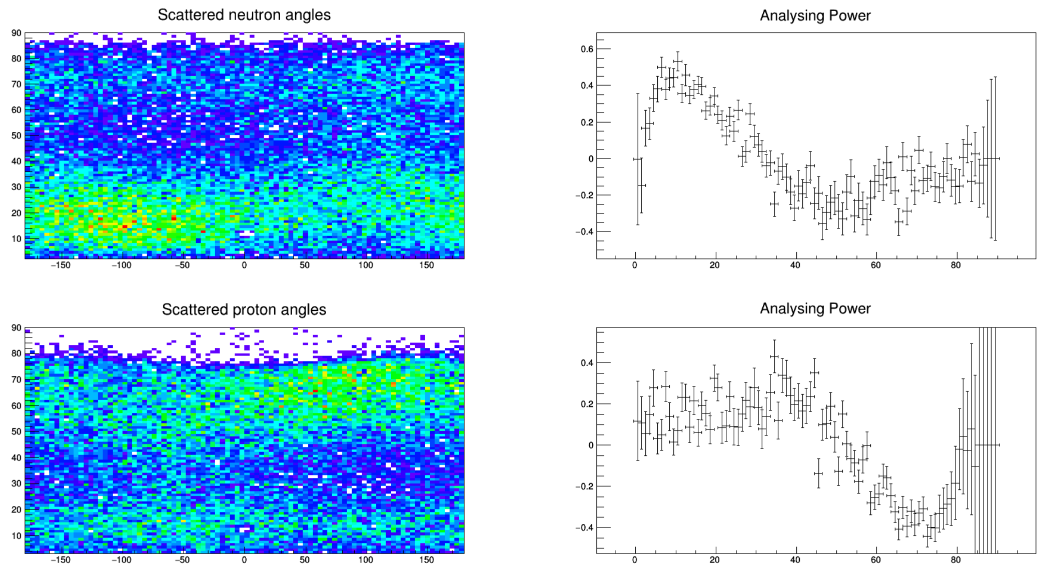

Figure 1: Target geometry : 40cm long, 3cm radius, filled with liquid hydrogen. Fire 2M neutrons, energy = 400 MeV, direction (0.2,0,1) polarisation (1,0,0)

the plastic wall analyser. rootfile is the name of an output file into which will be written a tree containing the incident nucleon, scattered proton and scattered neutron Lorentz vectors. The incident vector is just taken from the particle gun. The scattered vectors are recorded in the npolSteppingAction and they are actualy the Lorentz vectors of the first proton and neutron to leave the analyser (energy above 1MeV).

The rootfile can be analysed to reconstruct the scattering angles and hence the analysing power as a function of scattering angle (and potentially incident momentum). An example of how to do this is given in the ROOT macro Reconstruct.C.

4 Examples

4.1 Scattering in hydrogen target

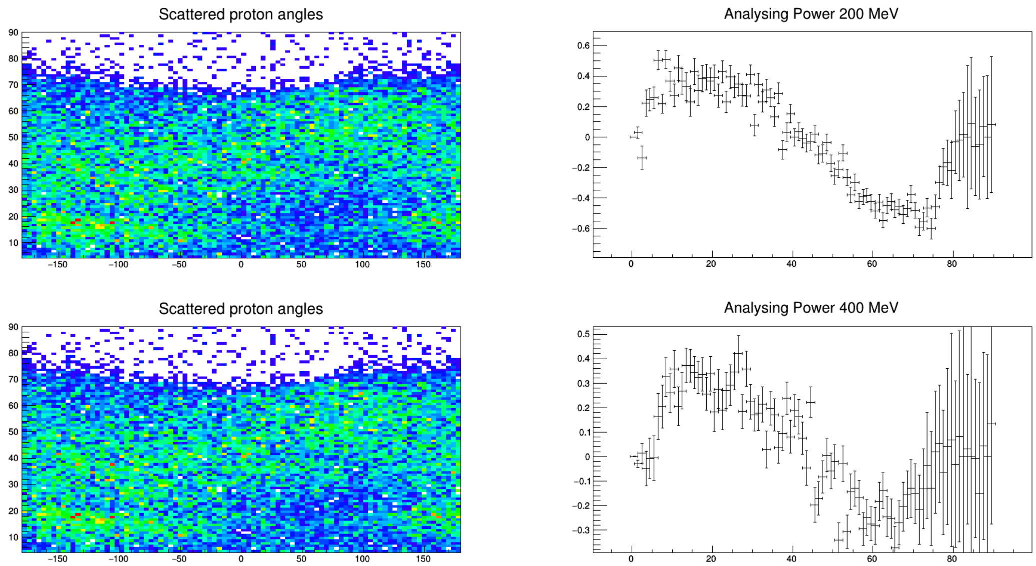

Figure 2: Target geometry : 40cm long, 3cm radius, filled with liquid hydrogen. Fire 2M protons, energy = 200 (top) 400 (bot)MeV, direction (0.2,0,1) polarisation (1,0,0)

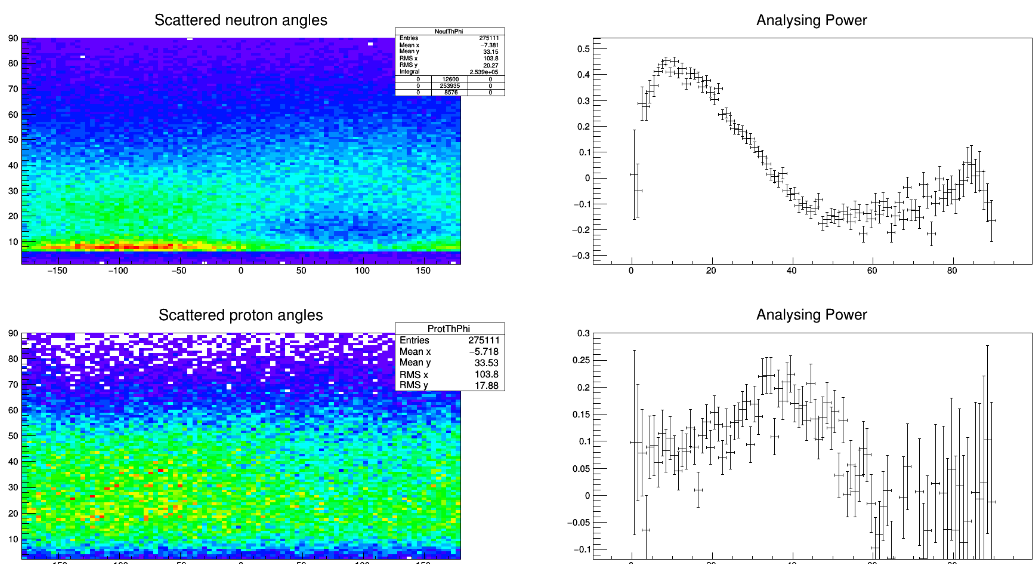

Figure 3: Target geometry : 10cm thick plastic. Fire 2M neutrons, energy = 400 MeV, direction (0.2,0,1) polarisation (1,0,0)