A measurement of deuteron breakup at 49 MeV using Silicon Tracking Telescope.

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Using a proton beam with kinetic energy of 49.3 MeV impinging on a deuterium target only two channels are accessible: $pd \rightarrow pd$ elastic scattering and $pd \rightarrow ppn$ deuteron breakup. The pd elastic scattering was the test channel for the depolarization measurement at COSY February 2008. For this measurement the breakup channel was the background. As described in [1], the Silicon Tracking Telescope (STT) system, with left-right geometry, is optimized to detect charged particles and in particular the pd elastic channel.

A comparative analysis between Monte Carlo and data shows that the STT is also able to identify the deuteron breakup reaction in a so far unexplored kinematical region [4]. Since the neutron is invisible to the STT, in order to identify deuteron breakup it is necessary to detect two stopped protons in the final state. For stopped protons the kinetic energies can be deduced and the missing mass can be calculated using the four-momentum conservation formula (in proton deuteron breakup reactions this should peak at the neutron mass). The information of the process is thus kinematically complete.

Monte Carlo events have been generated, according to February 2008 STT setup, using PLUTO and GEANT code [2]. They are separated into 10^6 elastic events and 10^6 deuteron breakup events. Moreover deuteron breakup simulated events are divided in $5 \cdot 10^5$ neutron spectator, $pd \rightarrow (pp)n$, and $5 \cdot 10^5$ proton spectator, $pd \rightarrow (pn)p$. The condition to detect two protons inside the STT acceptance suppresses the neutron spectator channel, so the analysis is restricted to proton spectator channel, in which the neutron is scattered in the forward direction.

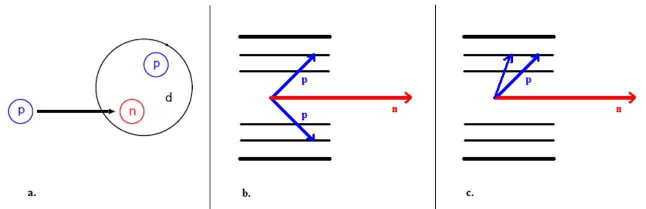

Fig. 1: Proton spectator model scheme. a) shows the initial state in which the proton beam impinges on the neutron of the deuteron target. b) shows the final state in which the neutron is forward emitted and the two protons are scattered at large angles and detected by the STT. In c) is shown a particular final state where the two protons are emitted in the same direction at low relative momentum.

The analyzed data have been taken from three test runs (136, 260, 262) of February 2008 data taking [3]. In the real data, it is necessary to disentangle particles coming from elastic scattering and the ones coming from deuteron breakup using all kinematical information. Since at this energy two final states are possible, by the exclusion of overconstrained elastic events, only breakup events remain. With this aim a double track selection, based on correlations between polar and azimuthal angles has been applied [4]. This coplanarity cut rejects the main concentration of elastic events. But as the deuteron breakup reaction involves three bodies in the final state, the phase space covered is flat and overlaps the elastic phase space and some good events are also inevitably rejected by this cut. A single track cut based on the deposited energy in the detector, discussed in [3], has been applied to reject events with deuteron signal. These two cuts isolate the main concentration of breakup events. Stopped protons are identified by the analysis of STT plots with $\Delta E/E$ method.

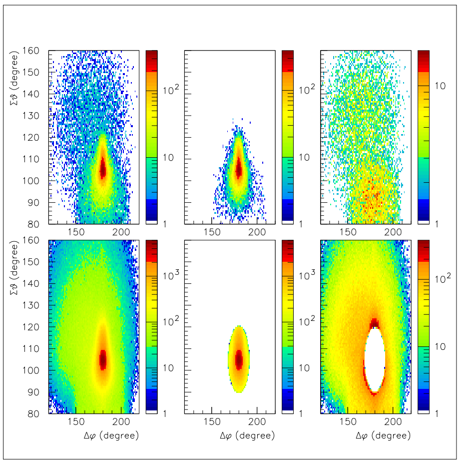

Fig. 2: Non-planarity cut. In the upper panel Monte Carlo data are displayed. Starting from the left: elastic and breakup together, in the middle pure elastic events and on right pure breakup events. In the lower panel the data are shown. From the left: all events without cuts, in the middle the ellipse which contains the majority of elastic events, the right panel shows the application of the non-planarity cut which isolates the main concentration of breakup events.

The reconstruction of breakup events with two stopped tracks has been carried out for four samples, named $2-1$, (see fig:3), $2-2$, $3-1$, $3-2$. The definitions of these samples are based on the number of hits that make up each track. For the case of February 2008 STT setup, a track can be reconstructed using at most three hits. So three types of tracks exist: short track S (one hit per track so the proton reaches the 1^{st} layer of STT), medium track M (two hits which means proton enters the 2^{nd} layer of STT), long track L (three hits, case with a proton stopped in the 3^{rd} layer of STT). The trajectory followed inside the detector by the proton (supposed to be linear) is traced from the hits of the first two layers and, for L track, connected to the third layer hit. In all these cases protons are stopped so the energy is known.

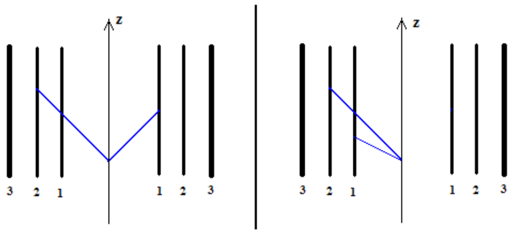

Fig. 3: Sample 2-1 configuration. The two tracks traced by particles can intercept the two opposite side of the detector or intercept the same side of the detector. This can happen also for all other samples.

For a proton stopped in the 1^{st} layer of STT, the track reconstruction procedure is different since only one silicon hit is available. An S track must be considered together with a track composed at least by two hits. This M or L track can be extended until the point of intersection with the incident beam to have the vertex coordinates; after that, the S track is traced connecting the vertex point to the single hit of the particle supposed to be stopped in the 1^{st} layer. To be sure that this particle is really stopped in the 1^{st} layer of STT, its track is forward extended to check if there is an hit at the point in which it intercepts the STT 2^{nd} layer acceptance. If there is an hit on the 2^{nd} layer it means that the particle did not stop in the 1^{st} layer. All the breakup samples listed above are combination of these kind of tracks.

The Missing Mass method could not be applied as a selection criterion in this particular kinematical and energetic range because the background of incorrectly reconstructed events is also distributed around the neutron mass.

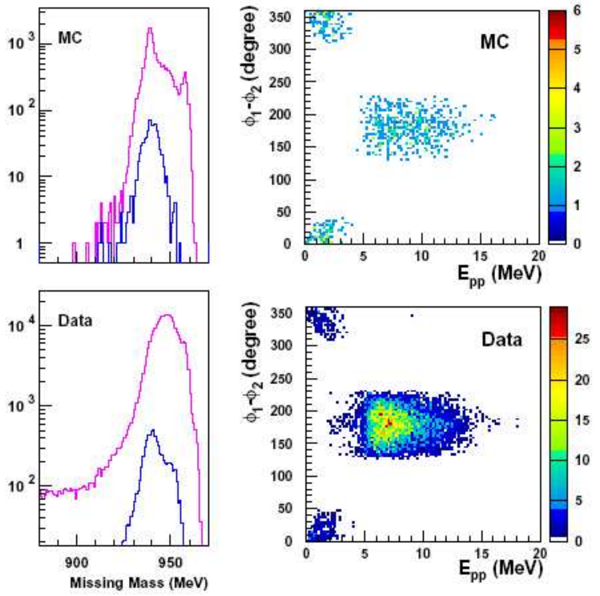

Fig. 4: Missing Mass and azimuthal angles dependence on energy excitation of the di-proton for 2-1 sample. In the upper panel Monte Carlo data and in the lower panel real data are reported. From the left: the magenta line shows the Missing Mass distribution for 2-1 sample for not stopped events, the blue line is the Missing Mass for 2-1 stopped events. The magenta spectrum is broader probably due to the overlap of the deposited energies of the proton and the deuteron. In the right panel two concentrations of events at low E_{pp} are shown. This happens when the two tracks are emitted in the same direction; the one at large E_{pp} realizes when protons hit the two opposite side of the STT. The Monte Carlo events are distributed according pure phase space.

The Missing Mass has been applied only as a control criterion. In general the application of stopped events to the Missing Mass formula generates a more narrow spectra of this function, (see fig:4), and this means that stopped events cuts are quite efficient. The study described in [4] has been developed for a restricted phase space region in which the energy excitation of the pp, di-proton system, E_{pp} is lower then 3 MeV. This corresponds to the cases 3-1 and 2-1 of deuteron breakup reaction with tracks emitted in the same direction, (see fig:4). These events can be analyzed as quasi-elastic scatterings and the di-proton polarization observable A_y^{pp} can be calculated using elastic channel complementary informations.

$$\frac{\sigma^{el}}{\sigma_o^{el}} = 1 + A_y^d \cdot P_B \cdot \cos(\phi^d), \tag{1}$$

where σ^{el} (σ_o^{el}) is the polarized (unpolarized) elastic cross section, P_B the beam polarization and ϕ^d is the deuteron azimuthal angle. A_y^d enters in the definition of the asymmetry parameter ε [3]:

$$\varepsilon^d = P_B \cdot \langle\cos(\phi)^d\rangle A_y^d(\theta), \tag{2}$$

Once ε and A_y are known, the beam polarization can be calcuted. The same procedure can be extended to the quasi-elastic channel, replacing the deuteron with the di-proton system:

$$\varepsilon^{pp} = P_B \cdot \langle\cos(\phi)^{pp}\rangle A_y^{pp}(\theta). \tag{3}$$

since the two channels are measured simultaneously, the beam polarization value in eq.2 and eq.3 is the same and A_y^{pp} can be extracted as:

$$A_y^{pp} = \frac{\varepsilon^{pp}}{\varepsilon^d} \frac{\langle\cos(\phi)^d\rangle}{\langle\cos(\phi)^{pp}\rangle} \cdot A_y^d. \tag{4}$$

The number of identified deuteron breakup events with Energy excitation, $E_{pp} < 3\,MeV$ in three test run are about 800. The statistics of elastic events sufficient for a polarization measurement is of the order of 10^5. The time required for a data taking to obtain 10^5 breakup events for samples 2-1 and 3-1 with $E_{pp} < 3\,MeV$ can be estimated in around 5 days.

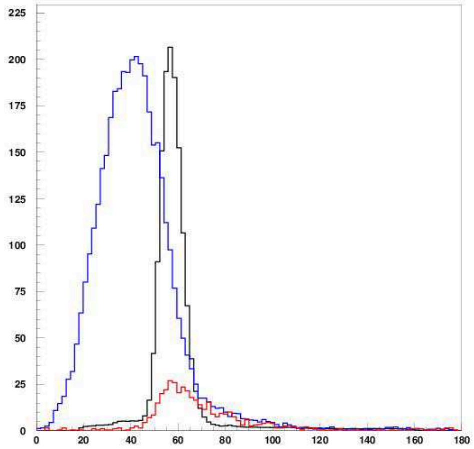

Fig. 5: Black line shows the deuteron polar angle, blue line shows the polar angle of the di-proton system for the 2-1 and 3-1 samples together, red line shows the di-proton polar angle for 2-1 and 3-1 samples with $E_{pp} < 3\,MeV$. The red curve (quasi-elastic channel) overlaps the region occupied by the elastic channel and in this range the calculation of A_y^{pp} can be applied.

References:

[1] A.Mussgiller, Ph.D. thesis, University of Cologne.

[2] M.Tabidze et al., Simulation Results for Depolarization Experiment at 45 MeV.

[3] G.Macharasvili, $p_{\uparrow}d \rightarrow pd$ analysis (EXP_181) Pax Feb-2008 beam time.

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