Simulation Study of Quasi-Elastic dd Processes at the SPD

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Primary Interest And Challenges

- Spin dependent effects in quasi-elastic polarized (vector and tensor) deuteron collisions - (talk by Yuriy Uzikov this morning)
- Process of interest $d + d \longrightarrow n + p + d$, with a spectator neutron and $p + d$ elastic collision
- Detection signature : two charged tracks of proton and deuteron (no PID), very forward neutrons in the ZDC and no other tracks or energy depositions
- Neutrons in the ZDC with high angular precision but terrible energy resolution ($\frac{\sigma_E}{E} = \frac{50-60\%}{\sqrt{E}} \oplus 8 - 10\%$)
- Typical event generators (Pythia, FTF) do not include such process - **need custom generator**

Resources for The Custom Generator

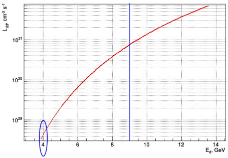
- Calculations are done in Fortran code - Yuriy Uzikov
- Used tool developed by Bell Laboratory : f2c (www.netlib.org) to convert Fortran code to C version
- Compile and produce static library to be loaded in any C/C++ macro and to call methods/subroutines in the code
- Use two methods :
  1. one that gives deuteron s-wave amplitude as function of constituent neutron momenta (in mother rest frame)
  2. another that gives $p + d$ elastic cross-section based on Glauber model

Simulation Strategy

- Start from 4-momenta of two colliding deuterons
- Generate spectator n in the rest frame of fractured deuteron ($p_z > 0$ for convenience) according to the first method - boost n to lab frame (same as the d+d COM frame)
- Accept events for small p_T^n (small angles, reaching ZDC)
- Remaining p scatters elastically off of the other d
- Boost to COM frame of $p + d$, calculate scattering cross-section using second method, accept event according to $|t|$ distribution
- Boost scattered p,d back to lab frame - require p,d tracks reach MVD (polar angle $\geq 7.13^0$)

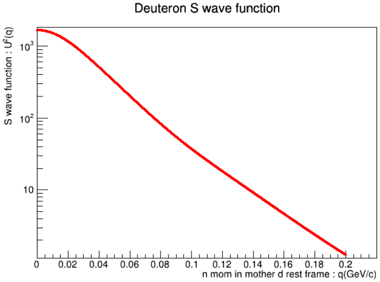
Custom Generator and SpdRoot

- This method is efficient - standalone root macro can generate 1 Million events in less than 10 minutes
- To reconstruct generated events in SpdRoot - using a dummy generator class that will read the results (4-momenta of n,p,d) from text file and pass it on to SpdPrimaryGenerator in the simu script
- Sample features of generated events shown below : $\sqrt{s_{dd}} = 8$ GeV

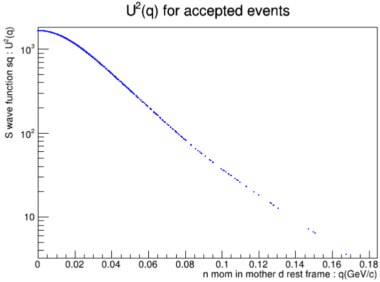


Choice of deuteron collision energy - practically the lowest available

Probability Distributions Used

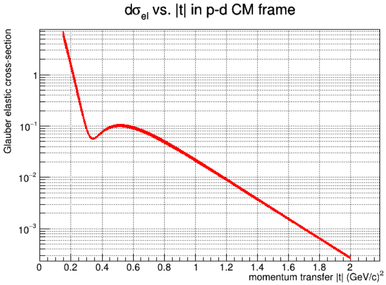


S-wave function squared as a function of p_n in mother rest frame : generated

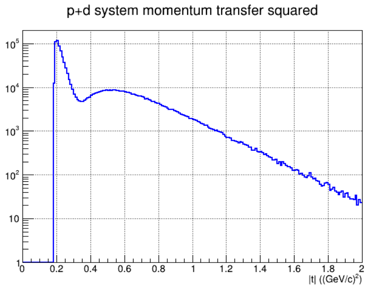


S-wave function squared as function of p_n in mother rest frame : accepted

Probability Distributions Used

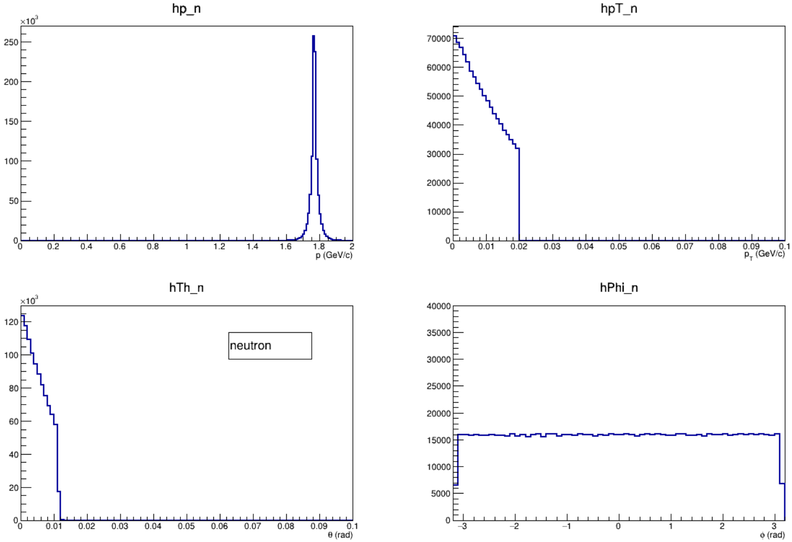


Elastic cross-section as a function of momentum transfer $|t|$ in the $p + d$ COM frame : generated



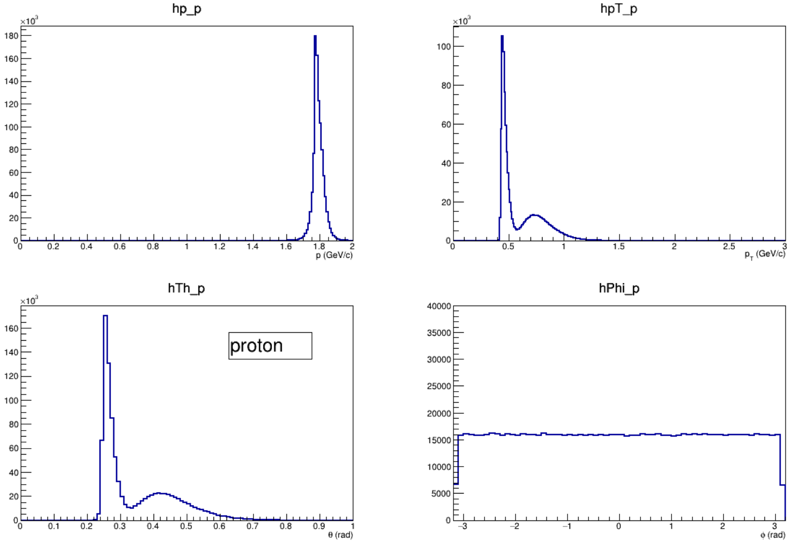
Distribution of momentum transfer $|t|$ in $p + d$ COM frame : accepted

Kinematic Distributions of Generated Neutrons



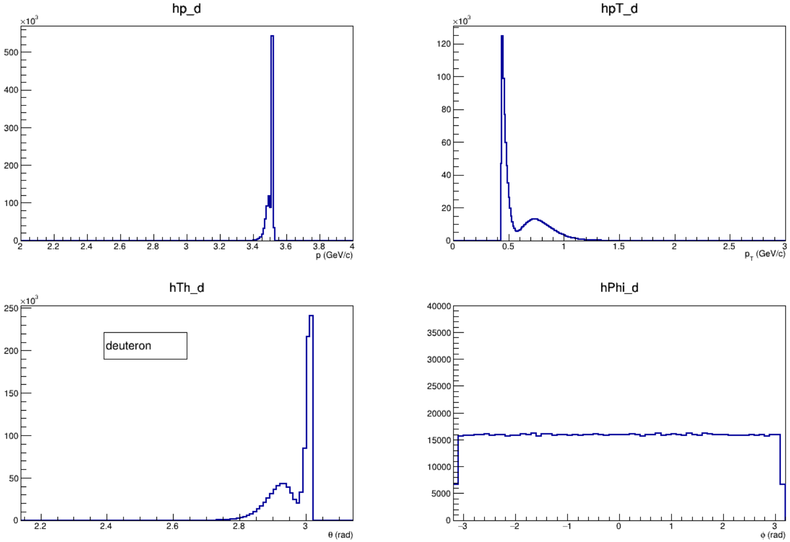
Neutrons in accepted events

Kinematic Distributions of Generated Protons



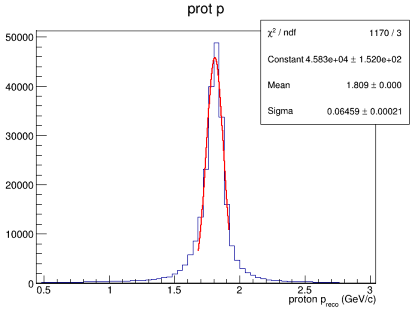
Protons in accepted events

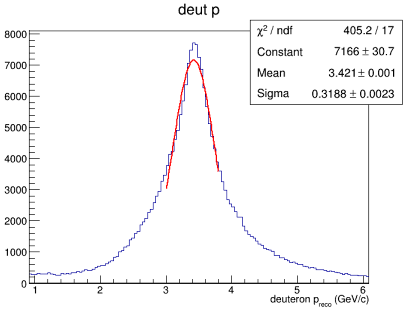
Kinematic Distributions of Generated Deuterons



Deuterons in accepted events

After Reconstruction





Protons : $\sigma_p \sim 65$ MeV/c

Deuterons : $\sigma_p > 320$ MeV/c

Combined detection efficiency $\sim 24\%$

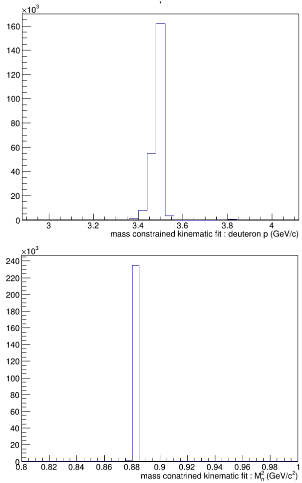
Notice the terrible momentum resolution for deuterons

Some kinematic fit is required for precise knowledge of momenta and momentum transfer $|t|$

Kinematic Fit : First Attempt

- Kinematic fit with invariant mass constraint (FUMILI fit with 'heavy term') - C^{++} code courtesy of V. Kurbatov
- Caveat : assumes 3 particle decay and does NOT take neutron information into account
- Forces p,d momenta to match missing n mass
- Can not distinguish between signal and background - not useful on its own

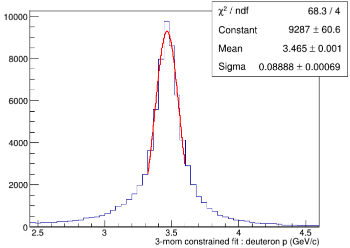
Fitted deuteron momentum

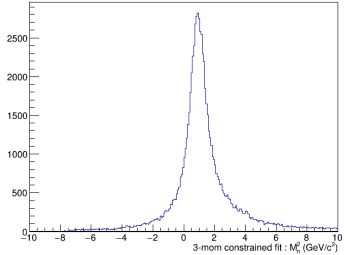


Fitted neutron mass-squared

Kinematic Fit : Second Attempt

Fitted deuteron momentum



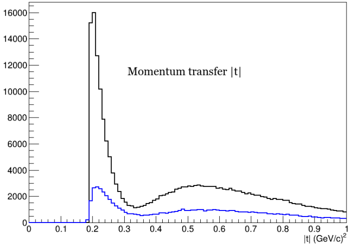


Fitted neutron mass-squared

- Kinematic fit with Lagrange multipliers with 3-momenta constraints(BES-III technique adapted by I. Denisenko)
- Takes into account neutron directions from ZDC
- Distribution of neutron mass - not normalized - can be used for selecting signal from background
- Further fit (may be FUMILI) can be applied AFTER selecting signal events with n,p,d final state

Trouble With Background Study

- FTF event generator included in the current SpdRoot does not generate *d* due to some Geant4 version dependent bug - quick fix generator separately compiled
- Limited $d + d$ at $\sqrt{s_{dd}} = 8$ GeV inelastic data from FTF - does not show any background in the kinematic range of interest - requiring neutron track in ZDC removes most random p-d combinations
- Need to check for background in larger data sets with FTF and Pythia8



Monte Carlo generated and reconstructed and fitted momentum transfer to deuteron

Some Estimates

- FTF generator : $\sigma_{dd}^{inel} \sim 250$ mb
- Pythia8 : $\sigma^{tot} \sim 38$ mb (not very clear, if this is p+p cross-section, nuclear cross-section $\sigma_{dd}^{tot} \sim 160$ mb)
- (Custom) generated signal event : $\sigma_{dd}^{sig} \sim 39.5\ \mu$b
- Assuming $\mathcal{L}_{dd} \sim 4.5 \times 10^{28}$ cm^{-2} s^{-1} for $\sqrt{S_{dd}} = 8$ GeV : PER MONTH ($\frac{10^7}{12}$ s)
  1. 10 billion all d+d events
  2. 1.5 million signal events produced
  3. 74k signal events detected (5% detection efficiency)
- Asymmetries for various spin combinations (vector and tensor) can be measured for the first time in polarized d+d collisions

Summary and To Do List

- We have an efficient method to generate events in the narrow range of phase space we are interested in
- We have (rough) estimates of signal events produced and detected
- Need to test for possible background contamination, so far it looks like a very clean measurement - need large d+d data production to check for level of background under neutron mass peak
- Glauber model predicts $p + d$ elastic cross-section (exponentially) rising at low $|t|$ but we lose low $|t|$ (small scattering angles) events due to lack of MVD in the end cap
- MVD end-cap and/or lower deuteron energy will benefit this study

Thank You