Strange Hypernuclei : A Project with START Program Student

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START Progam Project

- STdent Advanced Research Training (START) program at JINR
- Maksim Davydov from Lomonosov Moscow State University
- Session : Summer 2022
- Worked on simulation studies of $d + d$ at SPD Stage I energies to look for strange hypernuclei signature

Strange Hypernuclei

- Jean-Marc Richard et al. (Phys. Rev. C **91** 014003) discussed 'lightest neutral hypernuclei with strangeness -1 and -2'
- No stable hypernuclei of baryon number $A = 2$
- For $A = 3$, ${}^{3}_{\Lambda}H = (n, p, \Lambda)$ is measured and there is claim for ${}^{3}_{\Lambda}n = (n, n, \Lambda)$
- HypHI experiment (at GSI) observed ${}^{6}_{\Lambda\Lambda}He$ and it generates interest in $S = -2$ systems i.e. ${}^{4}_{\Lambda\Lambda}n$
- Paper investigates stability and possible production mechanism in deuteron-deuteron scattering
- Physics st Stage 1 document, article no. 11 (by the authors of the paper) suggests possible measurements at SPD

Production of ${}^{4}_{\Lambda\Lambda}n$ (T-particle)

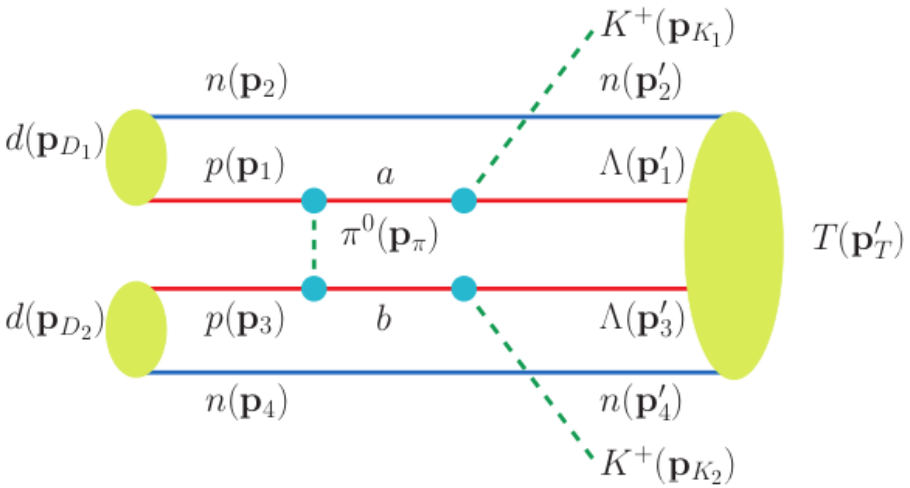

Figure 1: Possible T particle production in $d + d$ scattering

- Production of strange hypernuclei T associated with two positive kaons
- Signature of K^+K^+ is supposed to be clean with very little background
- Wave function of ground state is 'nontrivial' and 'strongly model-dependent'
- Composite particle ($nn\Lambda\Lambda$) with two s quarks

Predicted Cross-sections

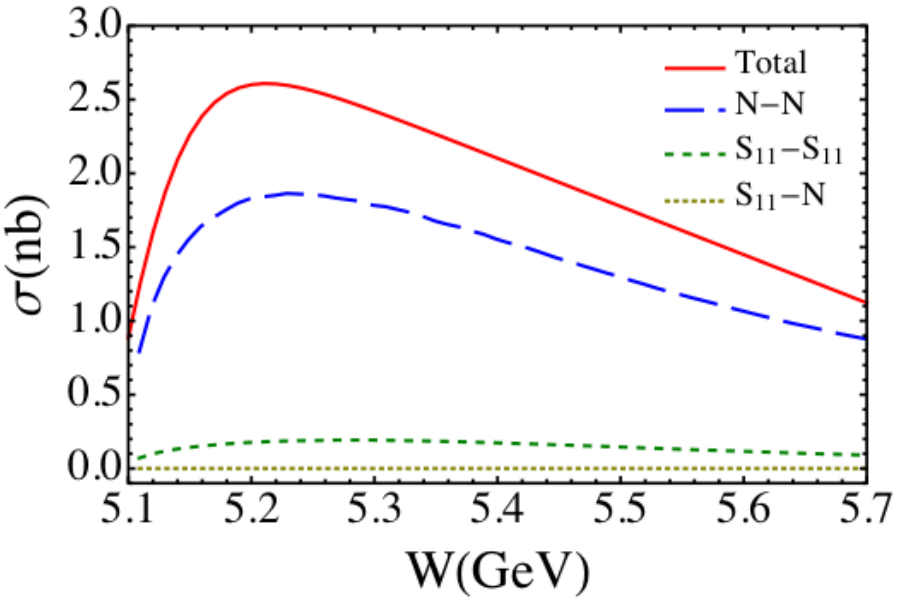

Figure 2: Leading order cross-section prediction

- Lines from top are : nucleon Born terms, double $S_{11}(1535)$ excitations, one Born - one $S_{11}(1535)$ excitation
- Total cross-section (nb) as function of collision energy
- Notice how sharply the cross-section falls at the low end

Stage I Measurement Proposal

- Proposal assumes SPD Stage-I $d + d$ collision energy $E_{cm} = 6.7$ GeV and luminosity $L_{avg} = 10^{29}\ cm^{-2}\ s^{-1}$
- At $E_{cm} = 6.7$, leading order cross-section ~ 0.2 nb
- Estimated events in one year of data $N = \sigma \times L = 630$
- By current estimate, stage-I $d + d$ peak luminosity $L = 10^{30}\ cm^{-2}\ s^{-1}$, an order higher (Good)
- Current estimate $d + d$ collision energy up to 4.5 GeV/n
- At max $d + d$ energy of 9 GeV, cross-section is too low (Bad)
- For this measurement, obviously, the sweetspot is $E_{cm} = 5.2 - 5.4$ GeV, or 2.6-2.7 GeV/n for $d + d$

Simulation Studies

- Difficulty in choice of event generator
  1. A Multiphase Transport Model (AMPT) - standalone
  2. Fritiof model (FTF) - integrated in SpdRoot
  3. Pythia8 - integrated in SpdRoot (not ideal, but read a few articles saying Pythia can do decent light nuclei collisions)
- Mostly worked with FTFGen and Pythia8, collision energies 5.5 GeV and 7.6 GeV

Production Mechanism : Coalescence

- Composite particle (d, He) creation through coalescence : if constituent hadrons are close enough in momentum space, they 'coalesce' to form larger composites
- Coalescence parameter/momentum (p_0) can be extracted comparing cross-sections in measurements
- As rough estimate, used same coal. mom. (p_0) as in deuteron formation (ref: Phys. Rev. D **98** 023012)
- For multiple constituents, diff. posisblities of coalescence condition

1. avg. mom. diff. of all possible pairs $< p_0$
2. apply for *nn* pair and $\Lambda\Lambda$ pair separately, then apply for two pairs to combine T particle
3. ... other possibilities

Coalescence Parameter (Deuteron)

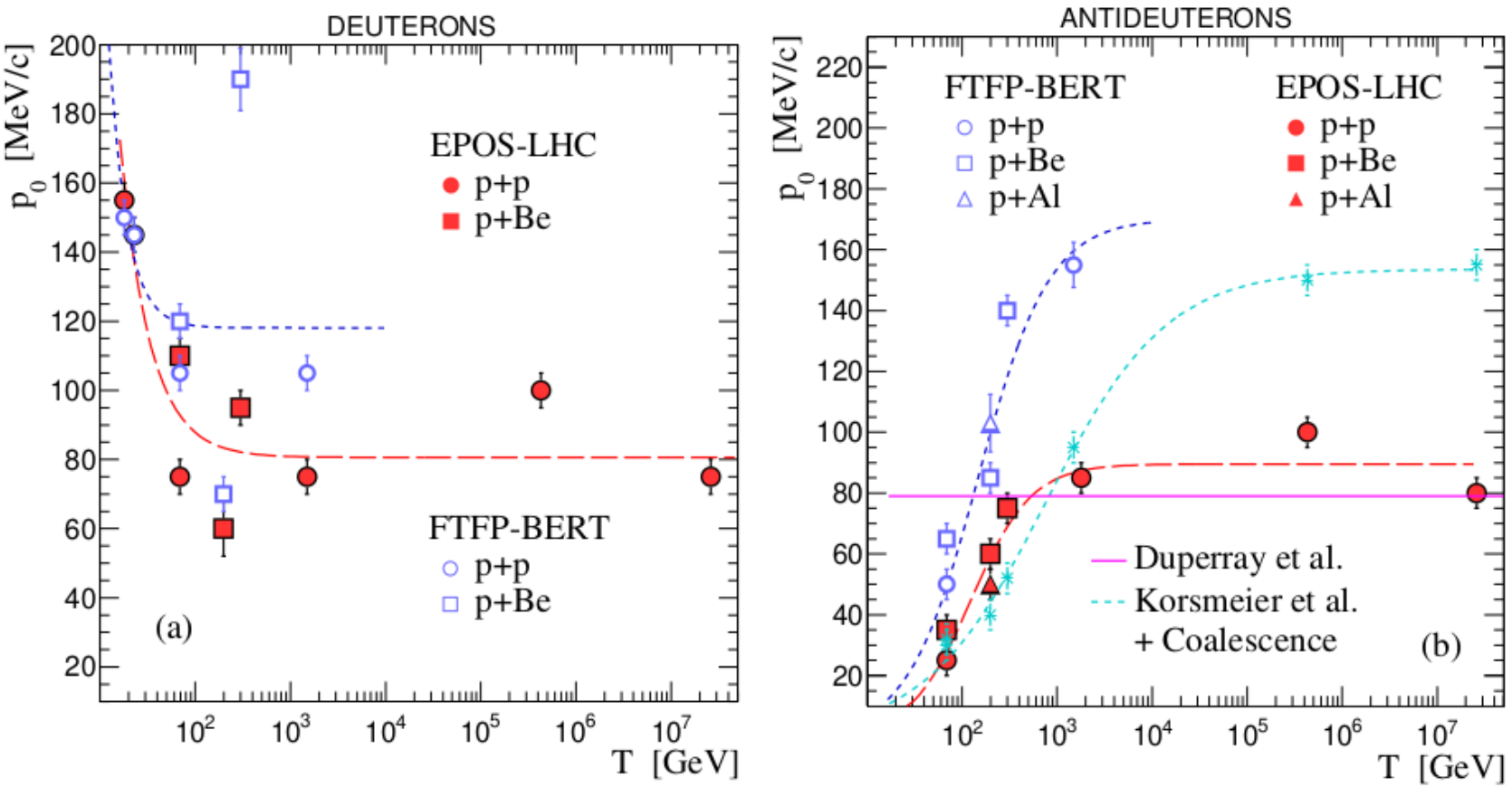

Figure 3: Coalescence parameter/momentum p_0 as function of collision kinetic energy for (anti-)deuterons

Kaon Distributions

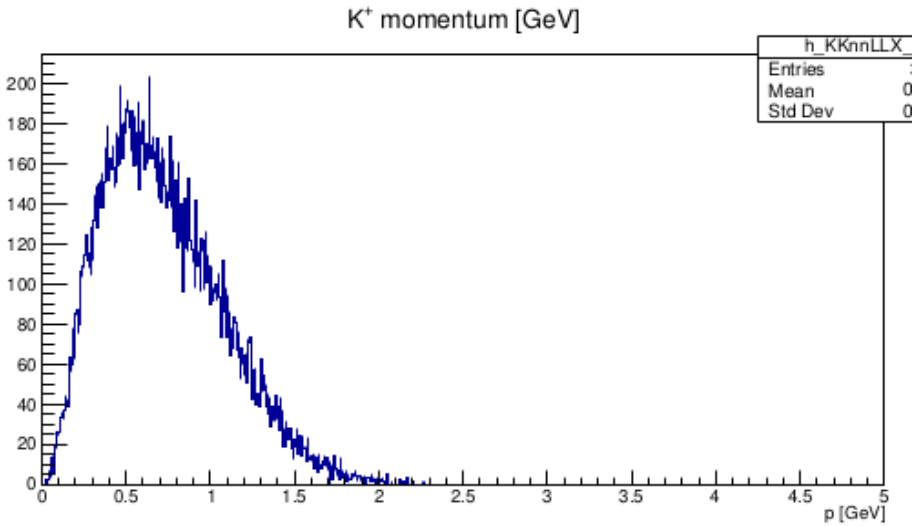

Figure 4: Momentum distribution of kaons in $d + d$ at 5.5 GeV with acoompanying production of n, n, Λ, Λ

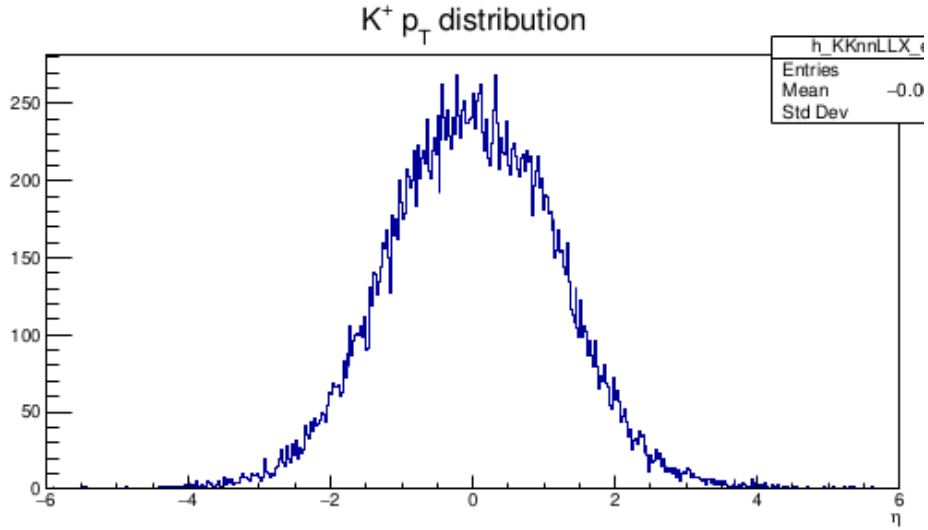

Figure 5: Pseudo-rapidity of kaons in $d + d$ at 5.5 Gev with acoompanying production of n, n, Λ, Λ

Mostly midrapidty kaons, going to barrel parts

Kaon Missing Mass

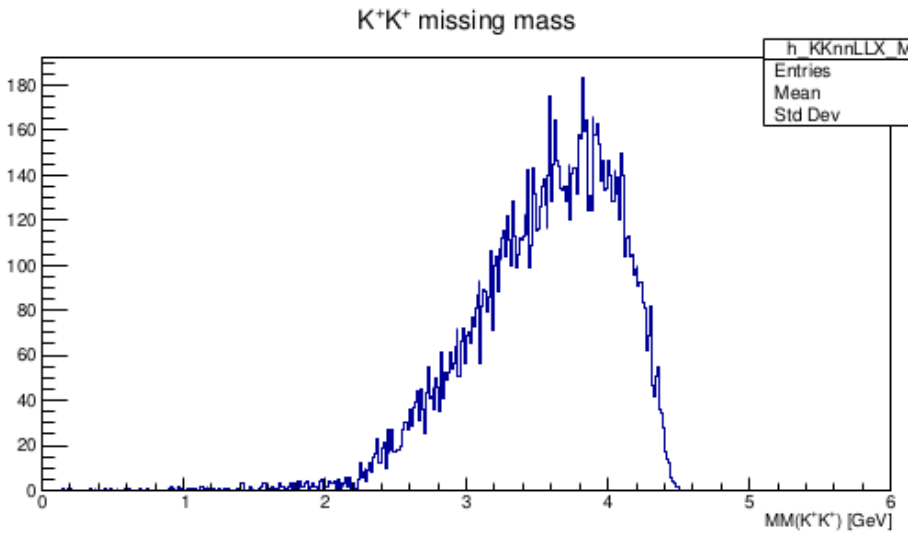

Figure 6: Missing mass of two positive kaons

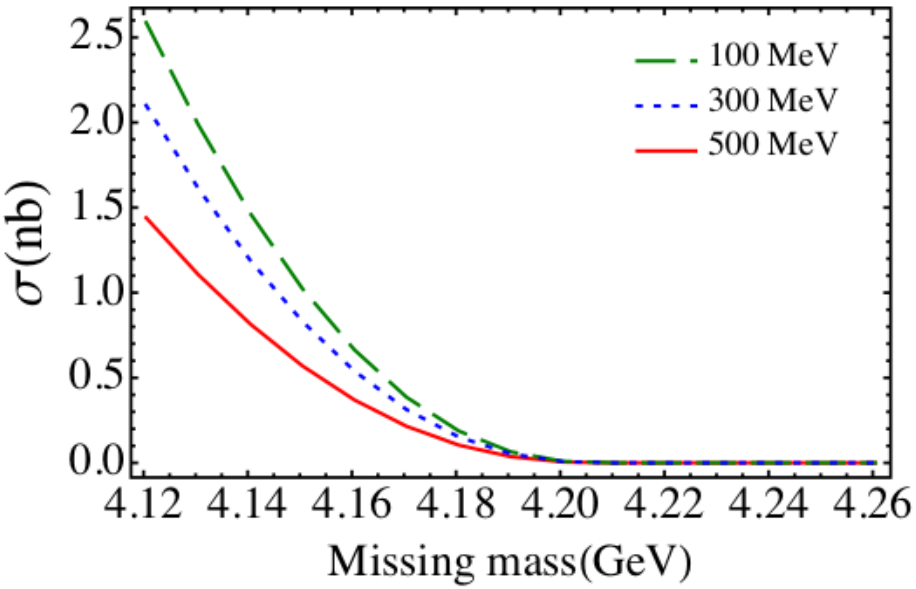

Figure 7: Missing mass for specific momentum of T particle

For stable T-particle production, only relevant part is above threshold ($\sim$ 4.12 GeV)

Kaon Missing Mass

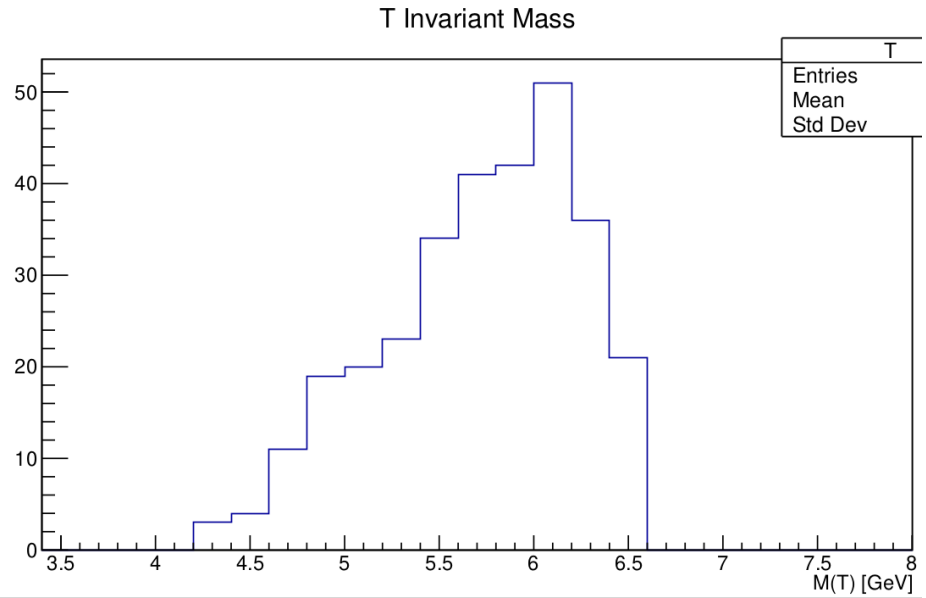

Figure 8: T-particle invariant mass for $d + d$ at 7.6 GeV

- The proposal had some simplictic assumptions
- Other particle created from same events were not considered
- More particles will make missing mass spectra different

Summary

- At suggested $d + d$ energy for peak T-particle production and peak Stage-I luminosity, we expect ~ 60000 such events in a year
- We can operate at this energy for a fraction of a year for decent first measurement if there are demands to operate at other energies
- A prolonged study at this energy, comparison of Pythia-8 and FTFGen performance for $d + d$ are needed (interested student?)
- Need to estimate background : K^+K^+ missing mass spectra above T-particle threshold from events when n, n, Λ, Λ are not produced
- Could be also an interesting study to extract colascence parameter for this composite hypernuclei if measurement is done

Thank You