Studying Hyperon Production With the NuWro Monte Carlo Generator

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What are Hyperons?

▶ Relatives of the proton and neutron containing strange quarks.
▶ Produced in interactions between nucleons and antineutrinos:

\[
\bar{\nu}_l + p \rightarrow l^+ + \Lambda(uds) \quad (1)
\]
\[
\bar{\nu}_l + p \rightarrow l^+ + \Sigma^0(uds) \quad (2)
\]
\[
\bar{\nu}_l + n \rightarrow l^+ + \Sigma^-(dds) \quad (3)
\]

▶ The \( \Sigma^+ \) is generated through final state interactions (FSI).
▶ Study this process using the NuWro Monte Carlo generator, which includes FSI for hyperons.
Measurement Potential

- Few measurements made by past experiments with very limited statistics.
- Model is poorly constrained at present.
- Upcoming experiments will be able to change this, eg. 12,500 events predicted for SBND [1], likely many more in DUNE.

![Graph showing total cross section for Lambda production from free protons compared with existing data from the Gargamelle [2-4], SKAT [5], BNL [6] and FNAL [7] bubble chambers]

**Figure**: Total cross section for Lambda production from free protons compared with existing data from the Gargamelle [2-4], SKAT [5], BNL [6] and FNAL [7] bubble chambers

\(^1\) Full breakdown of data in backup.
Motivations

- Model is derived using SU(3) quark flavour symmetry to find relations to similar processes\(^2\) - sensitive to violations.

- Nuclear effects:
  - Hyperons are not Pauli blocked, can be produced at low energies inside the nucleus.
  - Hyperons should be subject to a potential generated by the nucleus, affects their appearance inside neutron stars [8].
  - Here we include a potential of the form:

\[
V(r) = -30 \text{ MeV} \frac{\rho(r)}{\rho(0)}
\]  

\(^2\)In particular, \(\bar{\nu}_l + n \rightarrow l^+ + p\)
Nuclear Effects

- Study the cross section before and after the application of final state interactions (FSI).
- Prominent FSI effects are the conversion of $\Sigma$ baryons into $\Lambda$ and reabsorption of hyperons by nucleus.

Figure: Differential cross section for production of $\Lambda$ and $\Sigma^0$ from carbon at three neutrino energies.
**Σ⁺ Production**

- **Σ⁺** produced exclusively as a result of FSI.
- Try out a few different nuclear models: Free target (stationary nucleons), global Fermi gas, local Fermi gas.

![Graphs showing differential cross section as a function of the outgoing hyperon kinetic energy.](image)

**(a) Σ⁺ production.**

**(b) Inclusive cross section.**

**Figure:** Differential cross section as a function of the outgoing hyperon kinetic energy. $E_\nu = 1.0$ GeV.
Summary

- Rich phenomenology, very few measurements in existence, but this is expected to change in the near future.
- Lots of nuclear effects to study, predicted to be most prominent for low $Q^2$ events/slow moving hyperons.
- Conversion of $\Sigma$s to $\Lambda$s and reabsorption the most noticeable effects.
Any questions?
References


Backup

![Graph](image_url)

**Figure:** Total cross section for $\Lambda$ production from free nucleons. Data is from the bubble chamber experiments: Gargamelle (green triangle [2], red square [3], black X [4]), SKAT (blue triangle [5]), BNL (white cross [6]), FNAL (pink star [7]).