Λ^0 Polarization and its relation with Nucleonic Resonances

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ABSTRACT

In the sequential reactions pp →pN*, N* →Λ^0K⁺, Λ^0 polarization vector is proportional to that of N*. This result is valid whatever the value of the spin of N* and for both, conserving-parity and non-conserving-parity decays. Besides, for the particular case of N* having spin ½, N* and Λ^0 production planes coincide each other. Based on these results, a technique to evidence nucleonic resonances in pp → pΛ^0K⁺ is established independently of the mechanism responsible of that reaction.

INTRODUCTION

Polarization studies contribute to understand the spin dependence of hadronic interactions. In particular, hyperons polarization is an open problem which has been taken up using different phenomenological approaches; from all the hyperons, Λ^0 is the most studied in both theoretical and experimental analysis and some clues have been established about the origin of its polarization; for instance, in exclusive ***pp*** reactions, **Λ^0 polarization seems to be related to its production mechanism[1,2].** Polarization vector, defined in a frame where the particle is at rest, measures the spin expectation value. Formally, polarization vector is defined as[3]

$$\vec{P} = \frac{\langle \vec{S} \rangle}{S}.$$

We carried out a study of the connection between the polarization of nucleonic resonances ***N**** and that for ***Λ^0***. Using only kinematical information of the reaction ***pp → pΛ^0K⁺***, we establish a method to isolate resonant events in that reaction.

POLARIZATION VECTOR IN STRONG INTERACTIONS

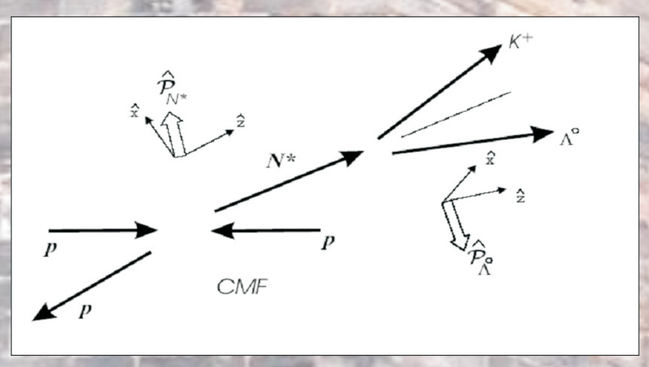


*Figure 1: Frames used in the reactions **pp →pN*, N* → Λ^0K⁺**. Restrictions over polarization vectors are explicitly shown.*

The sequential reactions ***pp → pN*, N* → Λ^0K⁺*** are strong interactions and hence, they follow time reversal and parity symmetries, which restrict spin directions and angular distributions of the produced particles. From ***both*** of these symmetries the next basic statement can be proved:

Statement 1. *In **pp → pN*, N* → Λ^0K⁺**, the spin of N* must point along its production-plane normal. Spin of Λ^0 must point along the normal to **its own** production-plane.*

Production plane for **N*** is defined by its momentum and that of beam proton, ***in contrast*** to Λ^0 production plane, which is defined by its momentum and that for **N*** (See Fig. 1).

RELATION BETWEEN N* AND Λ^0 POLARIZATION VECTORS

In ***N* → Λ^0K⁺***, when **N*** has spin ½, Λ^0 polarization is related to that of **N*** through the following equations[3,4]:

General expression from Lee and Yang for violating-parity decays:

$$\vec{P}_{\Lambda^0} = \frac{\left(\alpha + \vec{P}_{N^*}\cdot\hat{p}\right)\hat{p} + \beta\left(\vec{P}_{N^*}\times\hat{p}\right) + \gamma\hat{p}\times\left(\vec{P}_{N^*}\times\hat{p}\right)}{1+\alpha\vec{P}_{N^*}\cdot\hat{p}},$$

With α=β=0 and γ = +1 :

$$\vec{P}_{\Lambda^0} = \left(\vec{P}_{N^*}\cdot\hat{p}\right)\hat{p} + \hat{p}\times\left(\vec{P}_{N^*}\times\hat{p}\right).$$

With α=β=0 and γ = -1 :

$$\vec{P}_{\Lambda^0} = \left(\vec{P}_{N^*}\cdot\hat{p}\right)\hat{p} - \hat{p}\times\left(\vec{P}_{N^*}\times\hat{p}\right).$$

According to Statement 1, component of Λ^0 polarization along its motion direction is zero and hence, the term in the above equations must be zero, implying the following assertion[3]:

Statement 2. *In **pp → pN*, N* → Λ^0K⁺**, when N* has S=1/2, the production plane of N* and the production plane of Λ^0 are the same.*

When ***N**** has spin higher that 1/2, the **general** relation between polarization vectors is as follows[3]:

$$\vec{P}(\Lambda^0) = \left(\frac{1+(2S+1)\gamma}{2(S+1)}\right)\vec{P}(N^*)$$

This expression was obtained after an integration of the Λ^0 polarization vector over the Λ^0 angular distribution using the method of pure states and it coincides with that reported in literature[5] for the case when ***N**** has S=3/2. The above relation implies the following statement:

Statement 3. *Polarization vector of Λ^0, when it is integrated over the angular distribution of Λ^0 measured in the **N*** rest frame, is proportional to polarization vector of **N****.

NUCLEONIC RESONANCES IN pp → pΛ^0K⁺

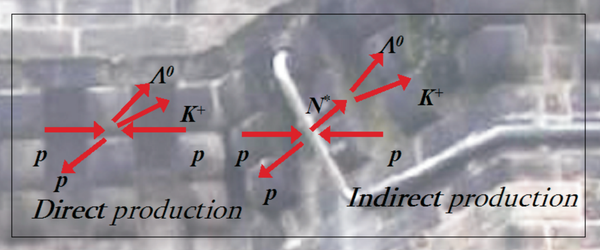


*Figure 2: Mechanisms of production for Λ^0 in the reaction **pp →pΛ^0K⁺**.*

Indirect production of Λ^0 refers to the case when it is created by means of the decay of one resonance (See Fig. 2). Known nucleonic resonances decaying in **Λ^0K⁺** channel are broad (typical widths are 100-200 *MeV*) and they are located inside of a short range of masses (from 1650 until 2200 *MeV*/c²).

This causes they overlap, making difficult the characterization of them, i. e., **it is hard a clear identification of each resonance in a partial wave analysis**. Known resonances have been observed in ***πp*** reactions (Analisis of resonances from ***pp*** reactions were not conclusive[6]). We propose a technique to isolate resonant events as follows:

Using Statement 3, the angle between ***Λ^0*** and ***N**** production planes can be ***calculated*** using the expression:

$$\hat{n}_{N^*}\cdot\hat{n}_{\Lambda^0} = \frac{\vec{P}_{N^*}\cdot\vec{P}_{\Lambda^0}}{\left|\vec{P}_{N^*}\cdot\vec{P}_{\Lambda^0}\right|} = \pm 1$$

This angle can be ***measured*** independently of the energy of ***N**** taking into account that:

$$\hat{n}_{N^*} = \frac{\vec{p}_{beam}\times\vec{p}_{N^*}}{\left|\vec{p}_{beam}\times\vec{p}_{N^*}\right|}, \quad \hat{n}_{\Lambda^0} = \int d\Omega_{\Lambda^0}\frac{\vec{p}_{N^*}\times\vec{p}_{\Lambda^0}}{\left|\vec{p}_{N^*}\times\vec{p}_{\Lambda^0}\right|}.$$

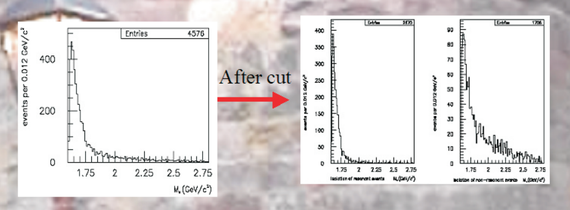
Using the previous considerations a plot of $(\hat{n}_{N^*}\cdot\hat{n}_{\Lambda^0})$ *vs* $M_{\Lambda^0K^-}$, where $M_{\Lambda 0K+}$ is the invariant mass of (***Λ^0K⁺***) would reveal the presence of resonant states of the proton by means of a concentrations of events near of $\hat{n}_{N^*}\cdot\hat{n}_{\Lambda^0} = \pm 1$, in contrast to non-resonant states, which would be uniformly distributed along all the values of $\hat{n}_{N^*}\cdot\hat{n}_{\Lambda^0}$ because non-resonant states don't have definite spin nor parity. In a more practical way, this method can be implemented in an experimental analysis by imposing a cut in the variable $\hat{n}_{N^*}\cdot\hat{n}_{\Lambda^0}$ as follows:

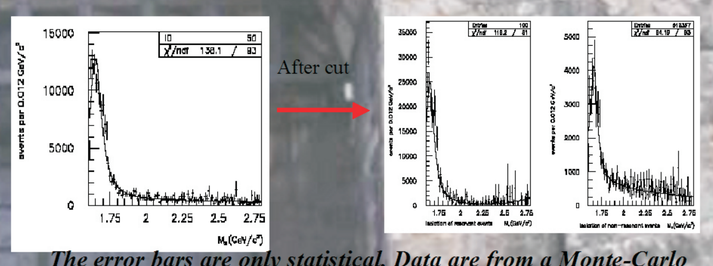
$a)\ \hat{n}_{N^*}\cdot\hat{n}_{\Lambda^0} \geq 0.999$ **or** $\hat{n}_{N^*}\cdot\hat{n}_{\Lambda^0} \leq 0.999$ ***Resonant events (principally).***

$b)\ -0.999 \leq \hat{n}_{N^*}\cdot\hat{n}_{\Lambda^0} \leq 0.999$ ***Non-resonant events.***

This technique was implemented in a Monte-Carlo simulation designed for E690 spectrometer. This experiment measures diffractive reactions[2]. This type of reactions are characterized by a low-mass enhancement which can be confused with a resonant signal.

The sample reconstructed after passing of E690 detector simulator. Note the **similarity between the spectrum of the resonant sample and the non-resonant sample**. This feature is due to the sample comes from a diffractive reaction.





The error bars are only statistical. Data are from a Monte-Carlo simulation using the information of E690 spectrometer.

This figure shows the fits of an equation with a Breit-Wigner shape plus an exponential shape to data. **The isolation of resonant events doesn't depend on the shape of the non-resonant part.**

CONCLUSIONS[7]

We have established a technique evidencing resonances which is based in a relation between the polarization of one resonance ***N**** and that for ***Λ^0*** in the exclusive sequential reactions ***pp→ pN*, N*→ Λ^0K⁺***. Our analysis shows that the method proposed to isolate resonant events works independently of the parameterization used to describe the non-resonant part (direct production of ***Λ^0***). Present results can be easily generalized to study and isolate fermionic resonances in other reactions where parity is conserved in the production and decay of such resonances.

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