Study of spin polarization in simulated high energy pp and heavy ion collisions

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Overview

- ⋆ In heavy ion non-central collisions, a large orbital angular momentum is present. It has been shown in [1] that the quarks produced in these collisions are polarized due to the presence of this initial angular momentum.
- ⋆ The presence of this polarisation can be explained using Thomas Precession.
- ⋆ We study the spin polarization in a pp collision at $\sqrt{s}$ = 13 TeV using data generated by PYTHIA. We look at the decay $\Phi \to K^+ + K^-$ and find out the angular distribution of the decay products.

Resonance

Total scattering cross section involving all processes is

$$\sigma_{tot} = \sum_{l=0}^{\infty} \frac{\lambda^2}{2}(2l+1)(1 - Re(\eta_l)) \quad (1)$$

Resonance $\rightarrow$ For $\boxed{\eta_l = -1}$ i.e. $- \rightarrow$ Maximum Cross Section Scattering cross section for resonance becomes

$$\sigma_{sc} = \frac{\pi}{k^2}(2l+1)\frac{\Gamma/2}{(E - E_R)^2 + \Gamma^2/4} \quad (2)$$

This is the **Breit Wigner function**. Γ is the width, E_R is the resonance peak and the coefficient is the yield.

Angular distribution of decay products

The coordinate system is fixed in the beginning as shown below. We work in the rest frame of Φ .

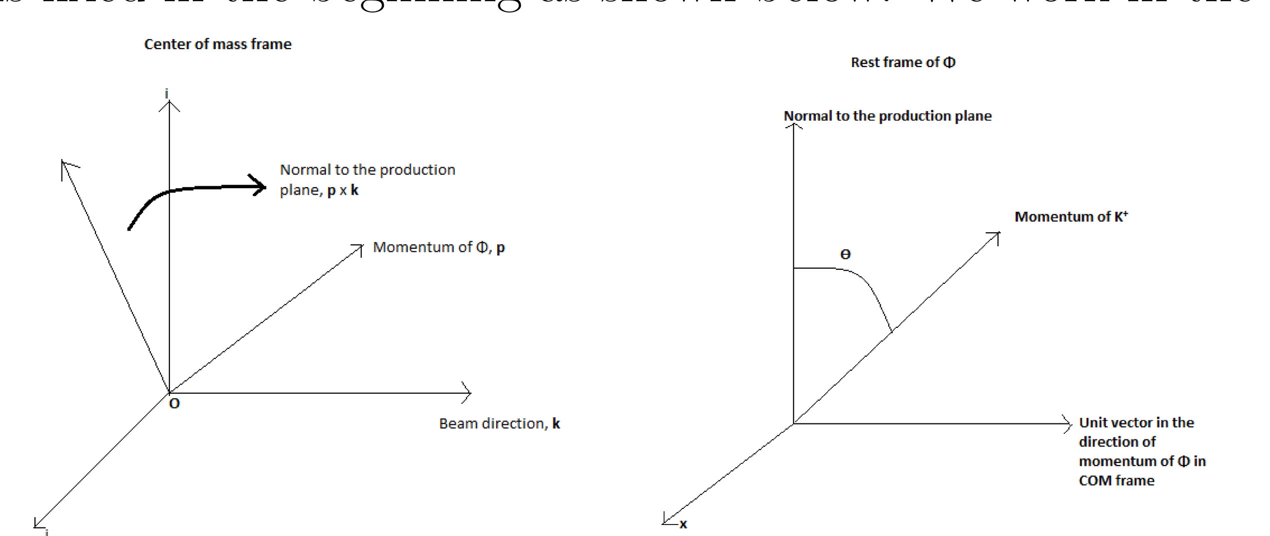


Figure: Choice of coordinate system

$$\boxed{\frac{dN}{dcos\theta} = N_0\left[1 - \rho_{0,0} + \cos^2\theta\,(3\rho_{0,0} - 1)\right]} \quad (3)$$

$\rho_{0,0} = \frac{1}{3}$ if there is no polarisation. Then, $\frac{dN}{d\cos\theta}$ is constant.

Thomas Precession

- ⋆ Relativistic effect arising due to spin orbit coupling.
- ⋆ Present because successive Lorentz transformations don't commute.
- ⋆ Explains anomalous Zeeman effect and fine structure splitting.
- ⋆ Causes precession of the rotating frame with frequency

$$\boxed{\vec{\omega_T} = \frac{\gamma}{\gamma+1}\frac{\vec{F} \times \vec{\beta}}{m_0}} \quad (4)$$

- ⋆ Energy associated $U = -\vec{s}.\omega_T$.

Polarisation

- ⋆ Polarisation $P = \frac{|A_+|^2 - |A_-|^2}{|A_+|^2 + |A_-|^2} = -\frac{\omega_T}{\Delta E_0}$
- ⋆ Recombination of a fast and a slow quark to form hadron.
- ⋆ Density matrix element $\rho_{0,0}$ related to the polarisations of the slow and the fast quarks by [2], [3]

$$\boxed{\rho_{0,0} = \frac{1 - P_{q^s}P_{q^f}}{3 + P_{q^s}P_{q^f}}} \quad (5)$$

- ⋆ $\rho = \frac{1}{3}$ if there is no polarisation

Results

Particle : ϕ || **Rest mass** $= 1019.461 \pm 0.019$ MeV || **Quark Content** $= s\bar{s}$ || **Charge** $= 0$ || **Width** $= 4.266 \pm 0.031$ MeV || **Lifetime** $= (1.55 \pm 0.01) \times 10^{-22}$ s || **Strangeness** $= 0$, **Charmness** $= 0$, **Bottomness** $= 0$ || **Total Spin** $= 1$ || **Isospin** $= 0$ || **Major decay channels:** $\Phi \to K^+ + K^-$ $(0.489 \pm 0.005) \to$ (We used this in our analysis) || $\Phi \to K_L^0 + K_S^0$ (0.342 ± 0.004)

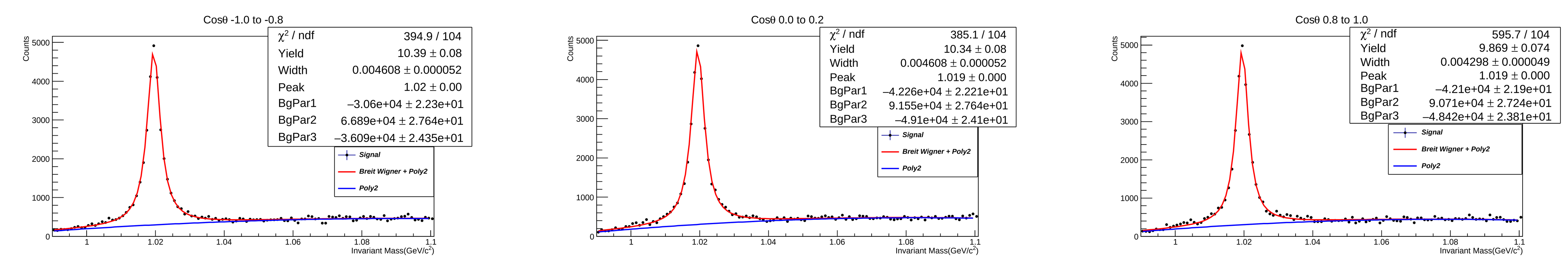
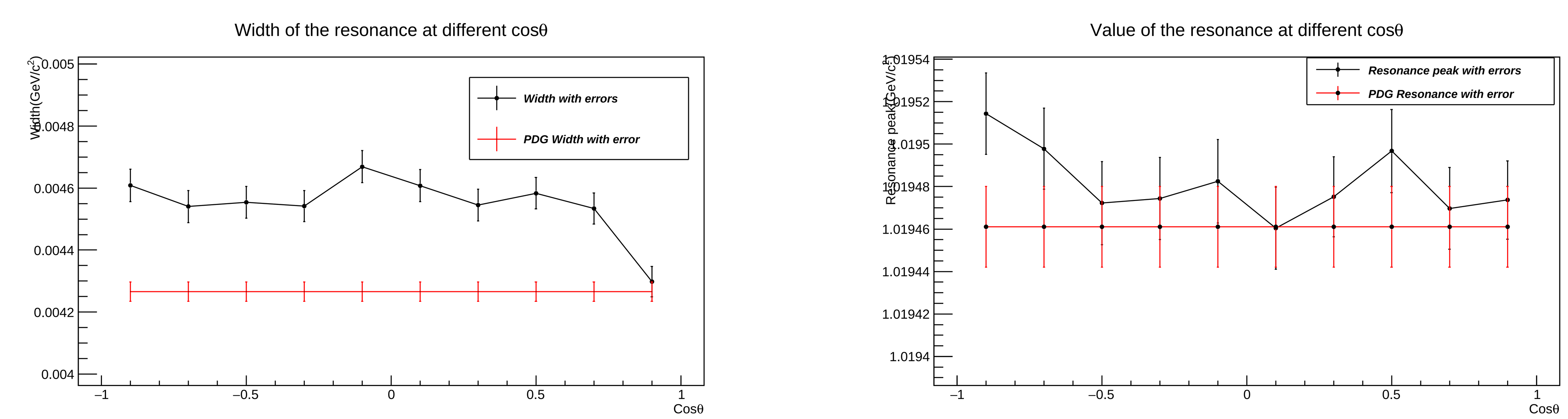


Figure: Invariant mass distribution of $m_{K^+K^-}$ after combinatorial background subtraction fitted with a Briet Wigner + Residual Background function (red line) in different $\cos\theta$ bins, from $\cos\theta$ = -1 to $\cos\theta$ = 1, for pp collisions at $\sqrt{s}$ = 13 TeV. The contribution from residual background is shown by blue line.



(a) (b)

Figure: (a) Width and (b) Mass of the resonance for different $\cos\theta$.

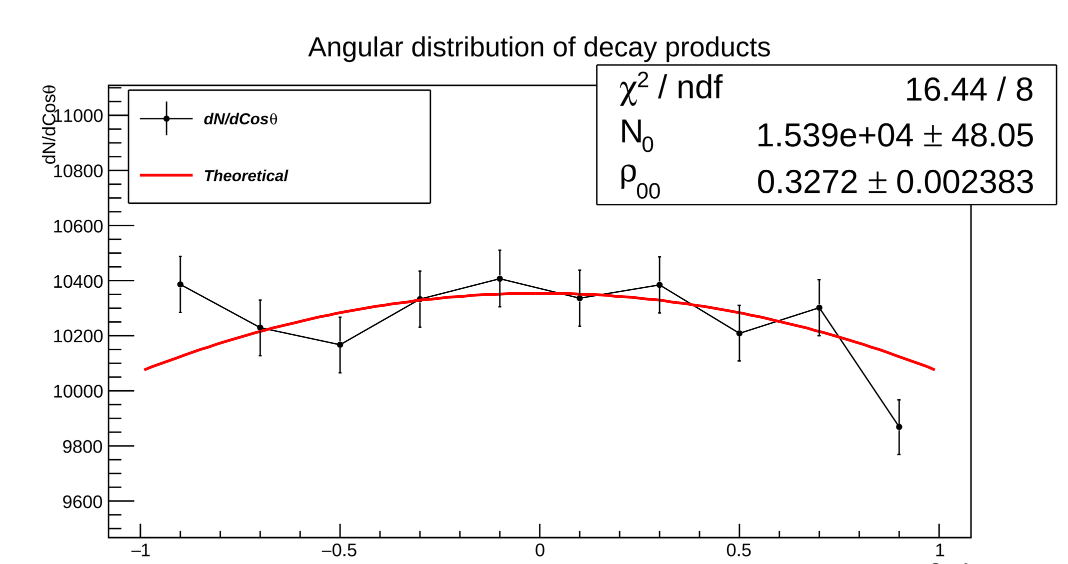


Figure: The angular distribution of the decay particles as a function of $\cos\theta$.

Inferences

- ⋆ For pp collisions, there is no polarisation for Φ as the value of $\rho_{0,0}$ is almost equal to $\frac{1}{3}$.
- ⋆ The data here is generated from PYTHIA from which we don't expect any initial angular momentum. Hence, our result is justified.

References

[1] Z.-T Liang, X.-N Wang, Physical Review Letters, 94, 102301 (2005).

[2] A. Ayala, E. Cuautle, G.H. Corral, J. Magnin and L.M. Montano, Physics Letters B 682 (2010) 408âĂŞ412.

[3] T.A. DeGrand, H.I. Miettinen, Phys. Rev. D 24 (1981) 2419.