Measurement of The Polarization in $D^0 \rightarrow VV$ Decays On BES-III

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The 10^{th} National Conference of Particle Physics

Outline

1. Introduction
   - Physics Motivations
   - Brief Introduction to Helicity Formalism
2. Data Simulation and Reconstruction
   - Data Sets
   - D^0 Candidate Reconstruction
   - Preparation of Data Samples With Given f_L
3. Extraction of f_L With Artificial Neural Network
   - Configuration and Training of ANN
   - Result and Error Estimation
   - Potential of BES-III on Measuring f_L
4. Maximum Likelihood Fit As Comparison
   - Binned Maximum Likelihood Fit
   - Result from ML Fit

Physics Motivations

- Precise measurement of longitudinal polarization can enhance our understanding of $D^0 \to VV$ decays.
- It will be interesting to compare the results of D^0 and $\bar{D}^0$ decay to a common final state.
- Provide a new method to measure the mixing and CP violating parameters[†].

Possible decay channels on BES-III

- $D^0 \to \bar{K}^{*0}\rho^0$ — $(1.5 \pm 0.33)\%$
- $D^0 \to \bar{K}^{*0}\omega$ — $(1.1 \pm 0.04)\%$
- $D^0 \to K^{*0}\bar{K}^{*0}$ — $\sim\ 0.27\%$

[†] For more information, please refer to I. Dunietz *et al.*, Phys.Rev.D 43, 1991

Decay Amplitudes in Helicity Formalism

The $D^0 \to VV$ decays can be described by three amplitudes, which can be expressed in three different bases:

- In the *partial wave basis*, the amplitudes are related to relative angular momentum L, corresponding to the S, P and D waves.
- In the *helicity basis*, the amplitudes correspond to *helicity eigenstates*, including *longitudinal* $(\lambda = 0)$ part and *transverse* $(\lambda = \pm 1)$ part.

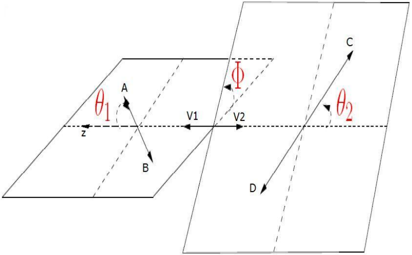
$$\begin{aligned} &\textit{longitudinal}\ (\lambda = 0)\text{: } A_0 = -\tfrac{1}{\sqrt{3}} S + \sqrt{\tfrac{2}{3}} D \\ &\textit{transverse}\ (\lambda = +1)\text{: } A_{+1} = \tfrac{1}{\sqrt{3}} S + \tfrac{1}{\sqrt{6}} D + \tfrac{1}{\sqrt{2}} P \\ &\textit{transverse}\ (\lambda = -1)\text{: } A_{-1} = \tfrac{1}{\sqrt{3}} S + \tfrac{1}{\sqrt{6}} D - \tfrac{1}{\sqrt{2}} P \end{aligned}$$

- To form *CP eigenstates*, the above decay amplitudes can be rewrote in their linear combinations, this is called the *transversity formalism*.

Angular Distribution in Helicity Formalism

Definition (Helicity angle)

- Choose z axis to be along the line of flight of V_1.
- The helicity angle θ_1 in the decay of V_1 is defined as the angle between z and direction of A in rest frame of V_1.
- The helicity angle θ_2 is defined likewise.



General angular distribution:

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_1 d\cos\theta_2 d\phi} = \frac{9}{16\pi}\frac{1}{|A_0|^2+|A_{+1}|^2+|A_{-1}|^2}\Big\{\frac{1}{2}\sin^2\theta_1\sin^2\theta_2(|A_{+1}|^2+|A_{-1}|^2)$$
$$+2\cos^2\theta_1\cos^2\theta_2|A_0|^2+\sin^2\theta_1\sin^2\theta_2[\cos 2\phi\mathcal{R}e(A_{+1}A^*_{-1})$$
$$-\sin 2\phi\mathcal{I}m(A_{+1}A^*_{-1})]-\frac{1}{2}\sin 2\theta_1\sin 2\theta_2[\cos\phi\mathcal{R}e(A_{+1}A^*_0+A_{-1}A^*_0)$$
$$-\sin\phi\mathcal{I}m(A_{+1}A^*_0-A_{-1}A^*_0)]\Big\}$$

Data Sets

Signal sample:

- Decay mode: $\psi(3770) \to D^0 \bar{D}^0$, $D^0 \to (K_S \pi^0)_{\bar{K}^{*0}} (\pi^+ \pi^-)_{\rho^0}$
- $\mathcal{BR}(\psi(3770) \to D^0 \bar{D}^0) \sim 57.2\%$, $\mathcal{BR}(D^0 \to K_S \pi^0 \pi^+ \pi^-) \sim 0.50\%$
- In this analysis, 90K signal events are generated and about 50K events are finally used to create the signal sample.

Background sample:

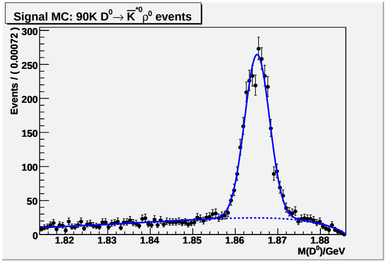
- 3.5M $\psi(3770)$ inclusive decay events are used to build background sample.
- In both signal and background data, the input value of longitudinal polarization fraction (f_L) is 0.33.
- Background and signal samples are generated under BOSS6.3.1.

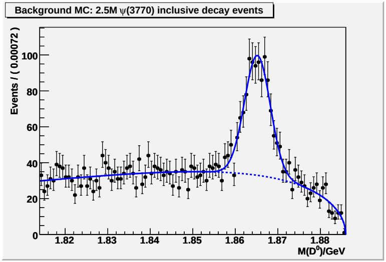
Event Selection

- Good photon cuts:
  $E_\gamma \geq 20MeV; \quad \theta \geq 20^\circ; \quad \phi \geq 20^\circ$
- Use kinematic fit for K_S and π^0 reconstruction:
  $\chi^2(K_S \to \pi^+\pi^-) \leq 500; \quad \chi^2(\pi^0 \to \gamma\gamma) \leq 500$
- Use ParticleID to separate K/π

- Use kinematic fit to reconstruct D^0:
  The $(K_S\pi^0\pi^+\pi^-)$ combination with least $\chi^2(\leq 50)$ is selected.
- Mass window cuts:
  $\Delta M_D = |M_{D_0} - 1.851| \leq 0.012;$
  $\Delta M_K = |M_{\bar{K}^{*0}} - 0.892| \leq 0.12;$
  $\Delta M_\rho = |M_{\rho^0} - 0.771| \leq 0.16;$
  $\Delta M_K^2 + \Delta M_\rho^2 < 0.02;$

D^0 Candidate Reconstruction





- Fitting results of signal sample:
  $M_{D^0} = 1.86514 \pm 0.00007$ GeV
  $\sigma = (2.93 \pm 0.07) \times 10^{-3}$ GeV
  $N_{Sig} = 2451 \pm 62$
  $N_{Bkg} = 1813 \pm 57$
  $\epsilon = 2.72\%$
- Fitting results of inclusive decay sample:
  $M_{D^0} = 1.8652 \pm 0.0002$ GeV
  $\sigma = (3.02 \pm 0.02) \times 10^{-3}$ GeV
  $N_{Sig} = 702 \pm 52$
  $N_{Bkg} = 3090 \pm 71$
- According to the input branch ratio, about 356 events are expected in the signal region. The rest 346 events are mainly the contribution of non-resonant background.

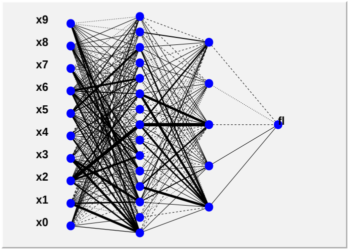
Preparation of Data Samples With Given f_L

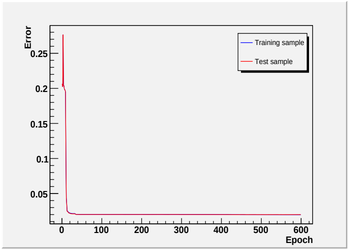
Data sample with different f_L and number of signal events N_S can be created in the following procedure:

- simplified 1-D angular distribution function:

$$\frac{d\Gamma}{d\cos\theta_1} = \frac{3}{4}\left[f_L \cdot 2\cos^2\theta_1 + (1 - f_L)\sin^2\theta_1\right]$$

- Use distribution function at $f_L = 1$ and $f_L = 0$ to make longitudinal and transverse samples respectively.
- The signal events are subtracted from the inclusive decay sample.
- For particular f_L and N_S, randomly select and combine corresponding number of longitudinal, transverse and background events.
- With different seeds for random number, different samples with the same f_L and N_S can be generated.





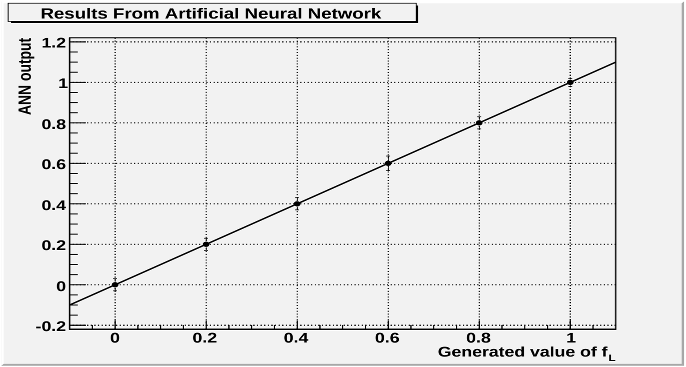
ANN configuration:

- The angular distribution is discretized into 10 bins as the input of ANN.
- Two hidden layers, with 20 and 5 neurons.
- The configuration parameters are preliminarily optimized.

ANN training:

- Training data:
  Set $f_L = 0, 0.01, 0.02, ..., 1.00$, six different data sample are generated and discretized at each f_L value.
- ANN is trained for 600 training cycles

Result and Error Estimation



- The error bar is defined as the standard deviation of ANN output for 100 different data samples at each fixed f_L.
- The data sample used as the ANN input contains approximately 850 signal events.

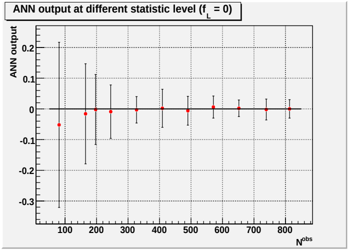
Potential of BES-III on Measuring f_L

- The observable number of events N^{obs} is related to $N(D^0\bar{D}^0)$ by the following formula:

$$N^{obs} = N(D^0\bar{D}^0) \times \epsilon_{tag} \times \mathcal{BR}(D^0 \to (K_S\pi^0)_{\bar{K}^{*0}}(\pi^+\pi^-)_{\rho^0}) \times \epsilon_{Rec}$$

- Taking $\epsilon_{tag} \sim 10\%$, $\mathcal{BR}(D^0 \to \bar{K}^{*0}\rho^0) = 0.50\%$, $\epsilon_{Rec} \sim 2.72\%$, we have:

$$N^{obs} = N(D^0\bar{D}^0) \times 1.36 \times 10^{-5}$$



- With one year of data taking at $\mathcal{L}_{peak}$, we can get about 18×10^6 $D^0\bar{D}^0$ pairs, the according statistical error is ± 0.1.
- In four years of running, about 72×10^6 $D^0\bar{D}^0$ pairs will be collected, therefore the statistical error of f_L would be ± 0.03.

Binned Maximum Likelihood Fit

- ML fit to extract signal yields and f_L
  in case of small signal yields and/or large background
- Likelihood function:

$$\mathcal{L} = \frac{e^{-(N_S+N_B)}}{N_{evt}!} \prod_{i=1}^{N_{evt}} (N_S \mathcal{P}_S + N_B \mathcal{P}_B)$$

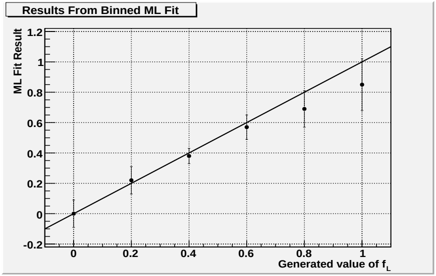
$\mathcal{P}_S$: PDF of signal, generated by theoretical PDF multiplied with detector acceptance

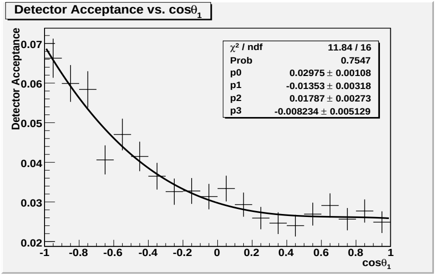
$\mathcal{P}_B$: PDF of background, generated by fitting background with a 3-order polynomial

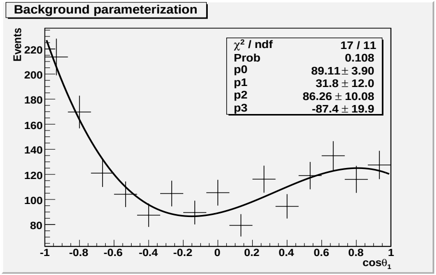
- Fitting variable: currently only $\cos\theta_1$. Other variables including $\cos\theta_2$, ϕ, m_{D_0}, decay time, etc. can also be added in the future analysis.
- Performance of fitter is checked with toy MC data.

Result from ML Fit

- The reconstruction efficiency and background are both fitted with a 3-order polynomial.
- The data sample used in ML fit contains approximately 850 signal events.
- A systematic bias is found at high f_L value.







Summary

- By using either ANN or maximum likelihood fitting, we are able to achieve much better accuracy of polarization measurement (compared with PDG current value) after one year of data taking.
- ANN method requires much less effort concerning reconstruction efficiency and background parametrization, yet gives results with higher accuracy.
- The primary bottleneck of this analysis is the low reconstruction efficiency caused by π^0 in the final states. By switching to charged final states, the result could be greatly improved.

Thank you!

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