# Helicity distributions

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In $p+p$ collisions at $1.25GeV$, the "helicity angle of $\gamma^*$ in $\Delta$ rest frame" is studied as a useful quantity to characterize the $\Delta$ Dalitz decay process ($\Delta^+ \to pe^+e^-$). It has been studied in this report by the simulation of $pp \to p\Delta^+ \to ppe^+e^-$ at $1.25GeV$. In PLUTO generator, the helicity angle of $\gamma^*$ is defined as in Appendix A and its distribution is implemented as $1+cos^2\alpha$ according to the QED calculation (fig. 1 left panel). But in the experimental data analysis, there is an ambiguity in the

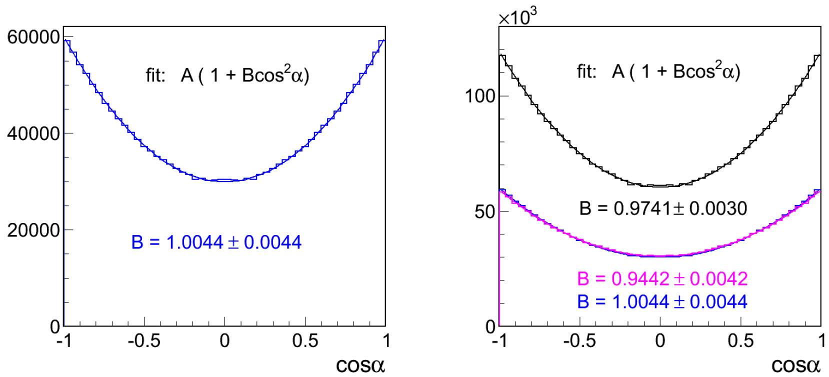


**Fig. 1:** True helicity angle distribution in $4\pi$ fitted with $A(1+Bcos^2\alpha)$. Left panel: only "true $\Delta$", right panel: "true $\Delta$" + "fake $\Delta$"

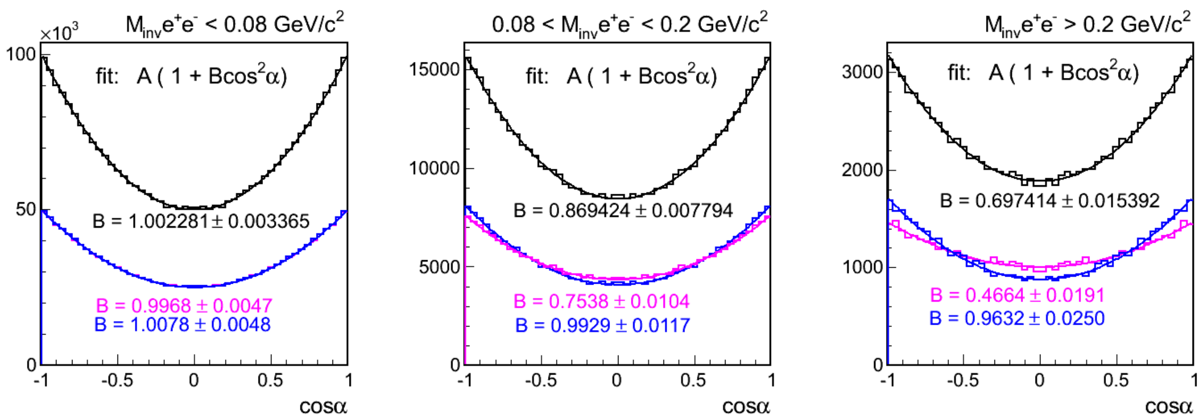


**Fig. 2:** True relicity angle distribution in $4\pi$ fitted with $A(1+Bcos^2\alpha)$ in different mass slices. Blak: total, blue: right proton, pink: wrong proton.

$\Delta$ reconstruction due to unknown origin of proton (from decay or scattering) this therefore causes a problem to define the $\Delta$ reference frame (true $\Delta$ where proton is from decay or fake $\Delta$ where proton is from scattering). Then one will naturally think about the influence on helicity distribution from the "fake $\Delta$". However, taking into account both protons, the helicity distribution is only slightly distorted. For the fake $\Delta$, the anisotropy parameter is 0.94 instead of 1 (fig. 1 right panel). This distortion can be seen more clearly when we draw this distribution in different $e^+e^-$ invariant mass regions, as in fig. 2. The true $\Delta$ contributions keep the anisotropy parameter ($B=1$) while the fake $\Delta$ contributions give

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anisotropy parameters $B < 1$ decreasing with $e^+e^-$ invariant mass. Here we want to point out that, due to the ambiguity of two protons, the helicity distribution is distorted, mainly in the high $e^+e^-$ mass region and the anisotropy parameter for true helicity distribution in $4\pi$ is expected to be only slightly smaller than 1.

In the inclusive $e^+e^-$ analysis, for example in heavy-ion collision, the true helicity can not be retrieved properly because of the impossibility of rebuilding the intermediate resonant state. But a "pseudo helicity" can be calculated, in two different ways A. We will focus in the following on these pseudo helicities and compare them to the true one, in order to choose a definition which keeps most information from true helicity.

Firstly, we compare globally the helicity angle distribtuions using three definitions with only "true Δ". These three variables are correlated which one can understand from the definition, but some differences still exist. As shown in fig.3 in $4\pi$ the 2 pseudo helicities are very similar to the real one but give however slightly smaller anisotropy parameters. Secondly, we compare them in different slices of $e^+e^-$

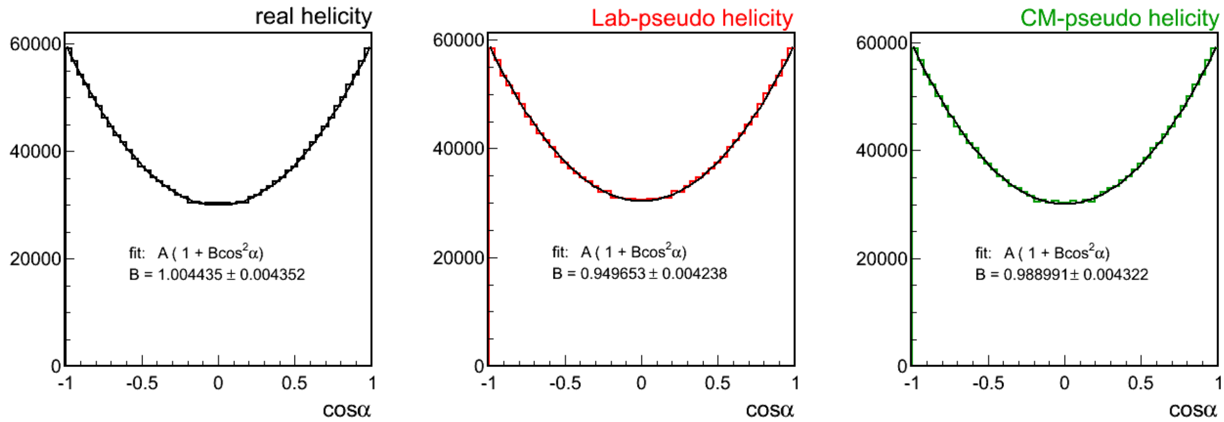


**Fig. 3:** Helicity angle distributions (only "true Δ") in $4\pi$ fitted with $A(1+Bcos^2\alpha)$. Black: real helicity, green: CM-pseudo helicity, red: lab-pseudo helicity

invariant mass regions and introduce the protons in addition. The latter condition will not affect pseudo helicities because the ambiguous protons are not involved in the definition. From fig.4, we see that the pseudo helicities follow the tendency to be more isotropic for higher $e^+e^-$ invariant mass than the real one. The effct is however much smaller for CM-pseudo helicity than for the lab-pseudo helicity. The true, CM-pseudo and lab-pseudo helicity angle are defined precisely and have been studied in p+p at 1.25 GeV in simulation. The true helicity (assuming ambiguity of proton origions) shows a dependence on $e^+e^-$ invariant mass due to the contribution from "fake Δ". It becomes more isotropic as increasing of $e^+e^-$ invariant mass while the same phenomena also has been found for the pseudo helicity distributions as expected.

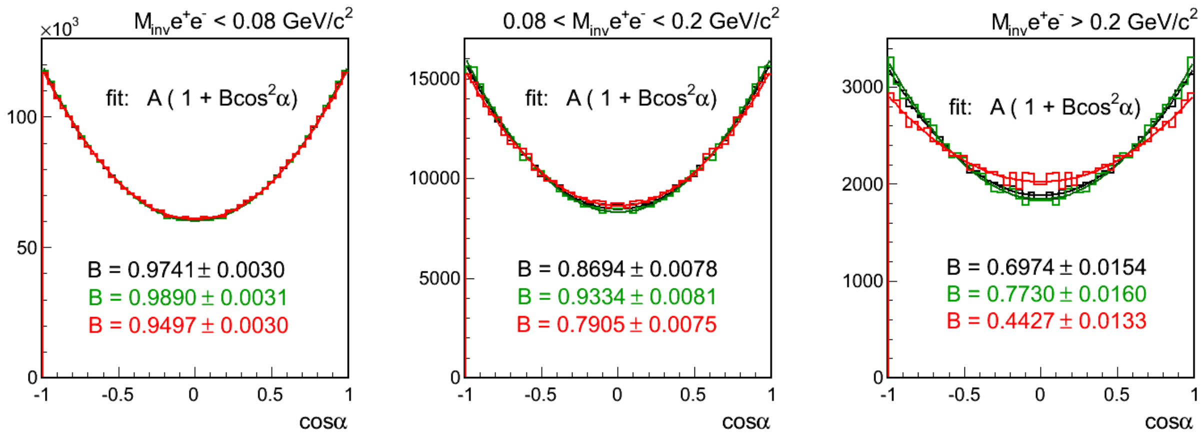


**Fig. 4:** Helicity angle distributions ("true Δ" + "fake Δ") in $4\pi$ fitted with $A(1+Bcos^2\alpha)$ in different $e^+e^-$ invariant mass region. Black: true helicity, green: CM=pseudo helicity, red: lab-pseudo helicity

## 1 For inclusive analysis

The CM-pseudo helicity is recommended for inclusive analysis since it is less sensitive to $e^+e^-$ invariant mass and it is easier to be identified from other isotropically distributed sources than lab-pseudo one.

## 2 For exclusive $pe^+e^-$ analysis

The mass dependence of the true helicity leads us to consider one of the systematic errors introduced from the acceptance correction proceedure, the extrapolation on $e^+e^-$ invariant mass from "pure" Δ region $M_{inv}e^+e^- > 0.14GeV/c^2$ where $B = 0.77$ (fig 5).

In exclusive $pe^+e^-$ analysis, the helicity angle distribution measured by HADES detector is obtained after a whole analysis chain. In order to extract the anisotropy parameter in $4\pi$, the measured spectrum is corrected by all the imposed cuts and by the detector's efficiency and acceptance. The uncertainties from several corrections will be disccussed here, including correction for $e^+e^-$ opening angle cut, extrapolation for $e^+e^-$ invariant mass cut and correction for detector's efficiency and acceptance step by step. Fig 6 shows the correction factors fot each cut as a function of $cos\alpha$ in the left colum,

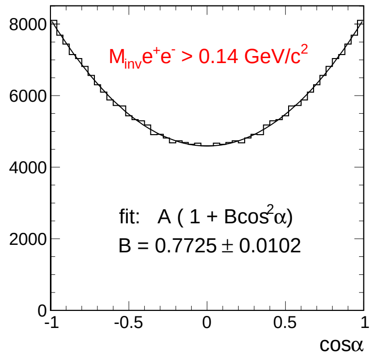


**Fig. 5:** True helicity angle distribution in $4\pi$ fitted with $A(1+Bcos^2\alpha)$ for $e^+e^-$ invariant mass grater than $0.14GeV/c^2$.

together with helicity angle distribution after corresponding cuts on the right side. The first one is $e^+e^-$ opening angle cut: comparing with distribution in $4\pi$ (black solid line in fig. 1), 56% events are cut by this condition but it eliminates more large angles ($cos\alpha$ around 0) than small angles by a factor 1.6 so that the distribution changes to be more peaked. Then the $e^+e^-$ invariant mass cut removed 83% events in addition, but it cuts more small angles which is in a opposite direction of opening angle cut. This results in a global down scaled distribution but whose shape is not very much distorted because of the compensation of these two cuts. After filtering through the detector efficiency and acceptance matrixes, 96% of the left events are cut. The forward and backward angles are strongly distorded therefore the shape of distribution is completely changed.

These three conditions change the helicity distribution: The resolution of $e^+e^-$ opening angle is estimated to be around 3% and invariant mass around 4%, and their distributions are well known as well. We can conclude the uncertainties from these two cuts are very small and can be ignored. The main source of systematic error is no doubt from detector acceptance and efficiency correction because the correction factor is great and it deform strongly the distribution. From left-bottom fig. 6, we can see that the correction factor for small angles are huge and vary steeply. So for these bins, the careful treatment of corrections and well evaluation of errors are extremely important for the further anisotropy parameter fitting.

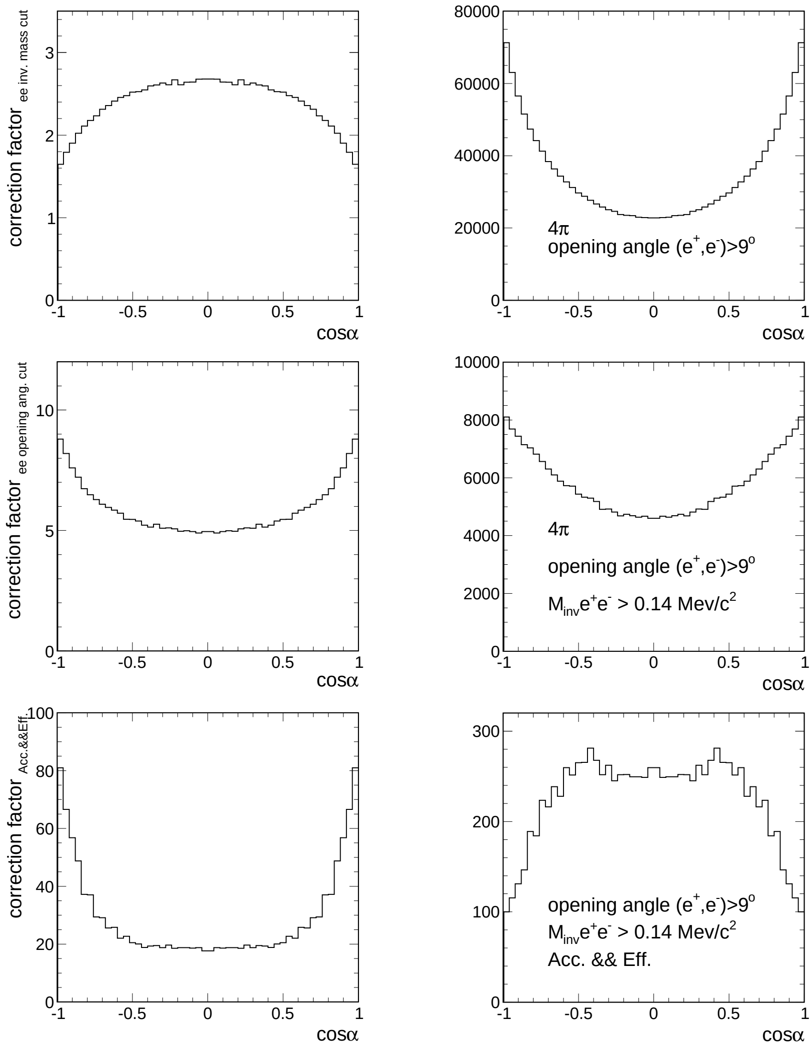


**Fig. 6:** Left: Distribution of correction factors of different imposed cuts and conditions. Right: True helicity angle distributions ("true Δ" + "fake Δ") in $4\pi$ with corresponding conditions.

## Appendices

## A Definition of helicity angle

The definition of real helicity and pseudo helicity are described as following:

(1) Real helicity: HADES helicity definition
- Proton, $e^+$ and $e^-$ detected in lab frame, the other proton is reconstructed by missing mass.

Calculate $\Delta_{detected/reconstructed}$ in lab $= p_{det./rec.} + e^+ + e^-$, and $\gamma^*$ in lab = $e^+ + e^-$.
- $\gamma^*$ boosted to $\Delta^+$ rest frame
- $e^+/e^-$ boosted to the $\Delta^+$ rest frame first, then to the $\gamma^*$ (in $\Delta^+$ rest frame) rest frame.
- Calculate $cos\alpha$, where $\alpha$ is the helicity angle between $e$ and $\gamma^*$as defined above

(2) Lab-pseudo helicity: Pseudo helicity with $\gamma^*$ in lab, $e^+/e^-$ in$\gamma^*$ rest frame:
- $e^+$ and $e^-$ detected in lab frame, reconstruct $\gamma^*$ in lab = $e^+ + e^-$.
- $e^+/e^-$ boosted to the $\gamma^*$ rest frame.
- Calculate $cos\alpha$, where $\alpha$ is the helicity angle between e and $\gamma^*$ as defined above

(3) Pseudo helicity with $\gamma^*$ in total center of mass frame (proton-proton CM), $e^+/e^-$ in $\gamma^*$ rest frame:
- $e^+$ and $e^-$ detected in lab frame, reconstruct $\gamma^*$ in lab = $e^+ + e^-$.
- $e^+/e^-$ boosted to the pp CM rest frame.
- $e^+/e^-$ boosted to pp CM, then to the $\gamma^*$ (in CM frame) rest frame.
- Calculate $cos\alpha$, where $\alpha$ is the helicity angle between e and $\gamma^*$ as defined above