DETAILS OF ANALYSIS

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Outline

♦ Aim of the analysis
  i) definition of asymmetry
  ii) extracting the efficiencies of reconstruction

♦ Steps of analysis
  i) motivation of steps
  ii) building and testing the codes
  iii) preliminary measurements
  iv) background study and skimming data

♦ Further steps of analysis, resolution effects
  i) cartoon to explain resolution effects
  ii) how resolution of the detector affects our measurements
  iii) calculating detector resolution functions
  iv) “unfolding” measured momentum distributions

♦ Systematics
Definition of asymmetry

\[ \langle A \rangle = \frac{N_{KL\pi}^{\text{phys}} - N_{KS\pi}^{\text{phys}}}{N_{KL\pi}^{\text{phys}} + N_{KS\pi}^{\text{phys}}} \]

asymmetry in \( D^0 \rightarrow K_L\pi \) and \( D^0 \rightarrow K_S\pi \) from CF, DCS interference

\[ N_{KL\pi}^{\text{phys}} = \int_a^b \eta_{KL\pi}^{\text{rec}}(p)/\epsilon_{KL\pi}(p) \, dp \quad p \equiv p_{K^0}^{\text{lab}} \]

\[ N_{KS\pi}^{\text{phys}} = \int_a^b \eta_{KS\pi}^{\text{rec}}(p)/\epsilon_{KS\pi}(p) \, dp \]

\( \eta_{KL\pi}^{\text{rec}}(p) \): number density of reconstructed \( D^0 \rightarrow K_L\pi \) events in data

\( \eta_{KS\pi}^{\text{rec}}(p) \): number density of reconstructed \( D^0 \rightarrow K_S\pi \) events in data

\( \epsilon_{KL\pi}(p) \): reconstruction efficiency of \( D^0 \rightarrow K_L\pi \)

\( \epsilon_{KS\pi}(p) \): reconstruction efficiency of \( D^0 \rightarrow K_S\pi \)

\([a, b] \): limits on p where similar \([K\pi], [K\pi\pi]\) spectrum expected
Extracting the efficiency of reconstruction

- How to extract reconstruction efficiency $\epsilon_{K_L \pi}(p)$ and $\epsilon_{K_S \pi}(p)$

We make 2 assumptions

$D^0 \rightarrow K^*-(K_L \pi^-)\pi^+$ and $D^0 \rightarrow K^*-(K_S \pi^-)\pi^+$ are generated 1:1

reconstruction efficiencies can be factorised as follows

$\epsilon_{K_L \pi}(p) = \epsilon_{K_L}(p) \times \epsilon(\pi(p))$, $\epsilon_{K_S \pi}(p) = \epsilon_{K_S}(p) \times \epsilon(\pi(p))$

$\epsilon_{K_L \pi \pi}(p) = \epsilon_{K_L}(p) \times \epsilon(\pi(p)) \times \epsilon(\pi(p))$, $\epsilon_{K_S \pi \pi}(p) = \epsilon_{K_S}(p) \times \epsilon(\pi(p)) \times \epsilon(\pi(p))$

it follows that

$r(p) \equiv \frac{\epsilon_{K_L \pi}(p)}{\epsilon_{K_S \pi}(p)} \equiv \frac{\epsilon_{K_L \pi \pi}(p)}{\epsilon_{K_S \pi \pi}(p)} = \frac{\eta_{K_L \pi \pi}^{\text{rec}}(p)}{\eta_{K_S \pi \pi}^{\text{rec}}(p)} : (K_L/K_S)$ relative efficiency
Extracting the asymmetry

We measure the following asymmetries

\[
\langle A \rangle = \frac{\int_a^b \frac{1}{\epsilon_{KS\pi}(p)}[\eta_{KL\pi}^{rec}(p)/r(p)-\eta_{KS\pi}^{rec}(p)] \, dp}{\int_a^b \frac{1}{\epsilon_{KS\pi}(p)}[\eta_{KL\pi}^{rec}(p)/r(p)+\eta_{KS\pi}^{rec}(p)] \, dp}, \text{ averaged over } p_{K_0}^{lab}
\]

\[
A(p) = \frac{\eta_{KL\pi}^{rec}(p)-r(p)\times\eta_{KS\pi}^{rec}(p)}{\eta_{KL\pi}^{rec}(p)+r(p)\times\eta_{KS\pi}^{rec}(p)}, \text{ in bins of } p_{K_0}^{lab}
\]

We extract the asymmetry from the following quantities

Monte Carlo: \( \epsilon_{KS\pi}^{MC}(p) = \frac{\eta_{KL\pi}^{recMC}(p)}{\eta_{KL\pi}^{genMC}(p)} \)

Data: \([a, b], \eta_{KL\pi}^{rec}(p), \eta_{KS\pi}^{rec}(p), r(p) = \frac{\eta_{KL\pi\pi}^{rec}(p)}{\eta_{KS\pi\pi}^{rec}(p)} \)
Motivations of steps of Analysis

- Why do I do what I do?

  How can I use signal Monte Carlo
  i) Build and test codes, devise preliminary selection cuts
  ii) preliminary measurement of limits on momentum \([a, b]\)
  iii) test the assumption of factorisability
  iv) test dependence of relative efficiency \(r\) on different variables

  Why to study Background Monte Carlo
  i) study potential sources of background
  ii) refine and optimise the cuts from signal MC study

Data
skim data and extract all required functions
Systematics
need careful attention to this aspect as we need calibration better than 5 %
Building and testing the codes

- Building the codes
  \( \pi^0 : \text{mdst-pi0} \)
  \( \pi^{\pm} : \text{mdst-charged} \)
  \( K_S^0 : \text{mdst-vec2, } dr > 0.25\text{mm}, z\text{dist} < 1\text{cm}, d\phi < 0.1 \)
    \( dr \to \) vertex and IP separation in plane perpendicular to beam
    \( z\text{dist} \to \) distance between \( \pi^{\pm} \) tracks at \( K_S^0 \) vertex
    \( d\phi \to \) angle between assumed and reconstructed \( K_S^0 \) direction
    in transverse projection to beam
  \( K_L^0 : D^0, K_L^0 \) mass fixed at PDG value, minimum ionisation cut
  \( D^0 : -0.95 < \cos(\theta_{DK}) < 0.2 \)
  \( \theta_{DK} \to K^0 \) flight angle wrt \( D^0 \) boost
  \( D^{*+} \) tag, cut on \( \delta M = (D^{*+} - D^0) \) mass, \( p_{D^{*+}} = \) reconstructed scaled momentum cut
  Inv. mass cuts on \( K_S^0, K^{*-}, D^0(K_s\pi/K_s\pi\pi), \pi^+\pi^-(K\pi\pi) \) system

- Testing the codes
  look at \( D^{*+} \) mass, \( \delta M, \) generated vs reconstructed momentum of
  \( D^{*+}, D^0, K_L^0, K_S^0, K^{*-} \)
Preliminary measurements

- Preliminary measurement of \([a, b]\)
in \([a, b]\) efficiency of kinematical cuts is same for \([K_s\pi]\) and \([K_{S\pi\pi}]\)

\(K_S\) and corresponding \(K_L\) modes: same kinematics

\(K_s\) modes are fully controlled

reconstruct \(D^0 \rightarrow K_S^0\pi \text{ and } D^0 \rightarrow (K_S^0\pi)\pi\)

plot reconstructed \(p_{K_0}^{lab}\) and obtain \(\eta_{K_{S\pi}}^{\text{recMC}}(p)\) and \(\eta_{K_{S\pi\pi}}^{\text{recMC}}(p)\)

take the ratio of \(\eta_{K_{S\pi}}^{\text{recMC}}(p)\) and \(\eta_{K_{S\pi\pi}}^{\text{recMC}}(p)\)
Testing of assumptions

- Factorisability, test \( \epsilon_{K_S\pi\pi}(p) = \epsilon_{K_S}(p) \times \epsilon_{\pi}(p) \times \epsilon_{\pi}(p) \) etc
  
  reconstruct \( D^0 \rightarrow (K_S^0 \pi)^{\pi} \)
  plot reconstructed and generated \( p_{K_S}^{lab} \)
  obtain \( \epsilon_{K_S\pi\pi}(p) = \eta_{K_S\pi\pi}^{MC}(p)/\eta_{K_S\pi\pi}^{genMC}(p) \)
  plot reconstructed and generated momentum of \( K_L^0 \) candidates
  obtain \( \epsilon_{K_S}(p) = \eta_{K_S}^{MC}(p)/\eta_{K_S}^{genMC}(p) \)
  similarly obtain \( \epsilon_{\pi\pm}(p) = \eta_{\pi\pm}^{MC}(p)/\eta_{\pi\pm}^{genMC}(p) \)
  similarly for factorisability in other modes
  
  ??? We don’t rely on MC for \( K_L \) simulation, yet study this in MC ???
  ?? different momentum space for \( K_S\pi\pi, K_S \) and \( \pi\pm ???

- Dependence of \( r \) on different variables
  
  plot \( r = \eta_{K_L\pi\pi}^{recMC}/\eta_{K_S\pi\pi}^{recMC} \) in bins of different variables
  e.g. reconstructed \( p_{K_S}^{lab} \) and \( \theta_{K_S} \)
  study the dependence on these variables
Background Study and skimming data set

- charm background first (skim by using cuts from signal MC)
  reconstruct $D^0 \rightarrow K_L \pi$ with a wide $D^{*+}$ mass scale
  tag decays in evtgen for entire event set
  investigate any other potential background source
  plot reconstructed $D^{*+}$ mass
  for each decay (background) see the number appearing on the $D^{*+}$ mass scale
  refine cuts from signal MC study and optimise cuts
  do for other decay modes

- extend to uds, charge, mixed background sample
  anti-continuum suppression and further refinement of cuts
  extract $\epsilon_{K_S \pi}$ and $[a, b]$ again

- skim data set
  extract $\eta_{KL \pi}^{rec}(p), \eta_{K_S \pi}^{rec}(p), \eta_{KL \pi \pi}^{rec}(p), \eta_{K_S \pi \pi}^{rec}(p)$ and $[a, b]$
Cartoon to explain resolution effects

How momentum distribution is smeared by detector response

Efficiency of reconstruction
How resolution of detector affects our measurements

\[ R(\Delta p_T) \]: probability that amount of smearing is \( \Delta p_T \) (R normalised)
\[ \eta^{\text{gen}}(p_T)dp_T \]: number of events in the bin \( p_T \) (center of bin)
\[ \eta^{\text{gen}}(p_T)R(p - p_T)dp_T \]: number of events from bin \( p_T \) ending up in bin \( p \)
\[ \int_a^b \eta^{\text{gen}}(p_T)R(p - p_T)dp_T \]: total number of events in bin \( p \)
\[ \eta^{\text{convol}}(p) = \int_a^b \eta^{\text{gen}}(p_T)R(p - p_T)dp_T = \eta^{\text{gen}}(p) \otimes R(\Delta p) \]
\[ \eta^{\text{convol}}(p) \times \epsilon(p) = \eta^{\text{rec}}(p) \]
by having resolution function of detector we can ’unfold’ the distribution \( \eta^{\text{rec}}(p) \) after efficiency correction
Redefining the asymmetry

To cancel the resolution effects we have to redefine our asymmetry. The previous definition of asymmetry still contains resolution of detector.

So \( \langle A \rangle = \frac{\int_{a}^{b} \frac{1}{\epsilon_{K}\pi}(p)\left[\eta_{KL}\pi(p)/r(p)-\eta_{KS}\pi(p)\right]}{\int_{a}^{b} \frac{1}{\epsilon_{K}\pi}(p)\left[\eta_{KL}\pi(p)/r(p)+\eta_{KS}\pi(p)\right]} dp } \), averaged over \( p_{K}^{lab} \)

\[ A(p) = \frac{\eta_{KL}\pi(p)/r(p)\times\eta_{KL}\pi(p)}{\eta_{KL}\pi(p)/r(p)\times\eta_{KS}\pi(p)} , \text{ in bins of } p_{K}^{lab} \]

is actually

\[ \langle A(p) \otimes R(p) \rangle = \frac{\int_{a}^{b} [\eta_{KL}\pi(p)/r(p)\epsilon_{K}\pi(p) - \eta_{KL}\pi(p)/\epsilon_{K}\pi(p)] dp }{\int_{a}^{b} [\eta_{KL}\pi(p)/r(p)\epsilon_{K}\pi(p) + \eta_{KL}\pi(p)/\epsilon_{K}\pi(p)] dp } \]

\[ A(p) \otimes R(p) = \frac{\eta_{KL}\pi(p)/r(p)\epsilon_{K}\pi(p) - \eta_{KL}\pi(p)/\epsilon_{K}\pi(p)}{\eta_{KL}\pi(p)/r(p)\epsilon_{K}\pi(p) + \eta_{KL}\pi(p)/\epsilon_{K}\pi(p)} \]

or

\[ \langle A(p) \otimes R(p) \rangle = \frac{\int_{a}^{b} [\eta_{KL}\pi(p) - \eta_{KL}\pi(p)] dp }{\int_{a}^{b} [\eta_{KL}\pi(p) + \eta_{KL}\pi(p)] dp } \]

\[ A(p) \otimes R(p) = \frac{\eta_{KL}\pi(p) - \eta_{KL}\pi(p)}{\eta_{KL}\pi(p) + \eta_{KL}\pi(p)} \]

where \( \eta_{KL}\pi(p)/\epsilon_{K}\pi(p) = \eta_{KL}\pi(p) = \eta_{KL}\pi(p) \otimes R_{KL}\pi(\Delta p) \) and so on find \( R_{KL}\pi(\Delta p) \) etc., ‘unfold’ \( \eta_{KL}\pi(p) \) etc., calculate \( \langle A \rangle , A(p) \)
How to find $R_{KS\pi}(\Delta p)$ etc

- finding $R_{KS\pi}(\Delta p)$
  we have already reconstructed $D^0 \rightarrow KS\pi^0$ in signal MC
  plot $p_{KS\pi}^{\text{rec}} - p_{KS\pi}^{\text{gen}}$
  possibly obtain a gaussian
  fit the gaussian and obtain the width
  talked to Pavel: says recon. efficiency negligible in extracting this resolution

- finding $R_{KL\pi}(\Delta p)$
  Do the same for $D^0 \rightarrow KL\pi^0$ in signal MC
  we don’t rely on MC for $D^0 \rightarrow KL\pi^0$
  talked to Roman, says:
  MC at least gives a good starting point and
  resolution for truly reconstructed events (tagging GenHepEvt)
  ??? Is $D^0 \rightarrow \text{pseudo } KL\pi^0$ a better choice???
How to ’unfold’ $\eta_{KL\pi}^{\text{convol}}(p)$ etc

- Area under convolution is product of area under factors
  Mathematically $\int_{-\infty}^{\infty} f(x) \otimes g(x) \, dx = \int_{-\infty}^{\infty} f(u) \, du \times \int_{-\infty}^{\infty} g(u) \, du$
  for our case $\int_{-\infty}^{\infty} \eta_{KL\pi}^{\text{convol}}(p) \, dp = \int_{-\infty}^{\infty} \eta_{KL\pi}^{\text{gen}}(p) \, dp \times \int_{-\infty}^{\infty} R_{KL\pi}(\Delta p) \, dp$
  since $\int_{-\infty}^{\infty} R_{KL\pi}(\Delta p) \, dp = 1$, we obtain $\int_{-\infty}^{\infty} \eta_{KL\pi}^{\text{gen}}(p) \, dp$ as we know $\eta_{KL\pi}^{\text{convol}}(p)$
  But I am afraid this does not work for finite range $[a,b]$
  and also this may not give $A(p)$, it would only give $\langle A(p) \rangle$

- Fourier transform of convolution is product of Fourier transforms
  mathematically $\mathcal{F}(f \otimes g) = \mathcal{F}(f) \times \mathcal{F}(g)$
  so $\eta_{KL\pi}^{\text{gen}}(p) = \mathcal{F}^{-1}[\frac{\mathcal{F}(\eta_{KL\pi}^{\text{convol}}(p))}{\mathcal{F}(R_{KL\pi}(\Delta p))}]$
residual difference in $p_{K_0}^{lab}$ spectra leads to bias if $\epsilon_{K_L}$ depends strongly on momentum
introduce momentum dependent efficiency for $K_S\pi$ and $K_S\pi\pi$ modes
weight changes linearly from 0 at 'a' to 1 at 'b'
calculate change in ratio of yield, gives estimation of systematics