Study of Inclusive Decay $\bar{D}^0 \to K_S^0 X$

Indian Institute Of Science Education And Research Mohali

Neetesh Mudgal , Vishal Bhardwaj , Karim Trabelsi

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Study Of Inclusive Decay $\bar{D}^0 \rightarrow K_S^0 X$

- Tension in the $R(D^{(*)})$ measurements
- First measurement of $R(X)$ in Belle II
- Introduction
- Analysis
- Fitting procedure
- K_S^0 yield using the sPlot
- Summary

Motivation

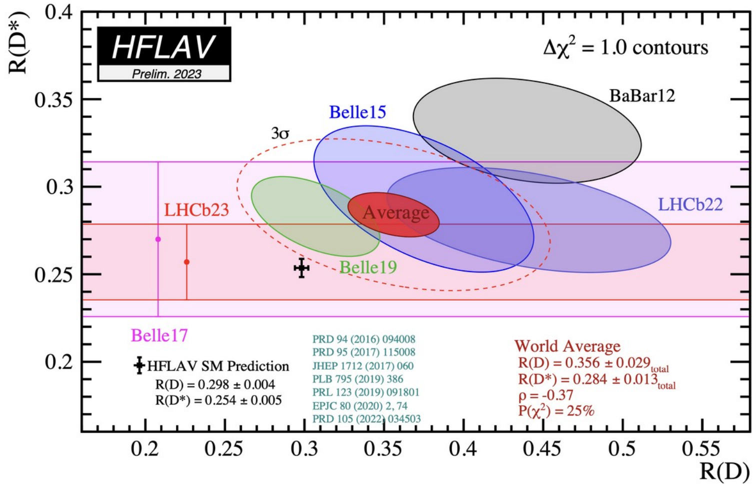
- Lepton flavour universality (LFU) is a fundamental symmetry of the Standard Model.
- Any violation of LFU is thus a clear indication of new physics.
- To probe this, physics community has shown interest in the semileptonic B-decays
- and measured an observable $R(D^{(*)})$ in different experiments.

- The obervable $R(D^{(*)})$ is defined as

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{*} \tau \nu_{\tau})}{\mathcal{B}(B \to D^{*}\, l \nu_{l})} \qquad ; \; l = e, \mu$$

This has been measured by BaBar, Belle, LHCb, Belle II and gives a combine resultof nearly 3σ tension with the SM

†SM prediction	†World average
$R(D) = 0.298 \pm 0.004$	$R(D) = 0.356 \pm 0.026 \pm 0.014$
$R(D^{*}) = 0.254 \pm 0.005$	$R(D^{*}) = 0.284 \pm 0.010 \pm 0.010$



†R(D) and R(D*) averages from the HFLAV collaboration

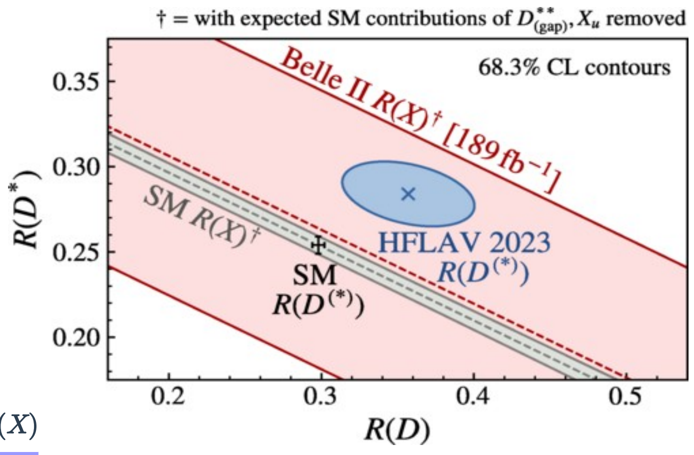
†. Heavy Flavour Averaging Group Collaboration, 2023

First measurement of $R(X)$ in Belle II

- There is inlcusive way to adress LFU using the the observable $R(X)$. X is hadronic final state that originate mostly from $b \to c\tau\nu$.

$$R(X) = \frac{B(B \to X\,\tau\nu_\tau)}{B(B \to X\,l\nu_l)} \quad ; l = e, \mu$$

- Belle II has obtained the first measurement for the tau-to-light-lepton ratio of inclusive semileptonic B-meson using 189 fb^{-1} data that is $R(X)$.
- This result is in agreement with the standard model.



‡Constraint on $R(D^{(*)})$

$R(X) = 0.228 \pm 0.016 \pm 0.036$

‡.Belle II Collaboration Phys. Rev. Lett. 132, 211804

SM prediction,
$R(X) = 0.223 \pm 0.005$

Muslem Rahimia and K. Keri Vosb,J. High Energy Phys. 11 (2022) 007

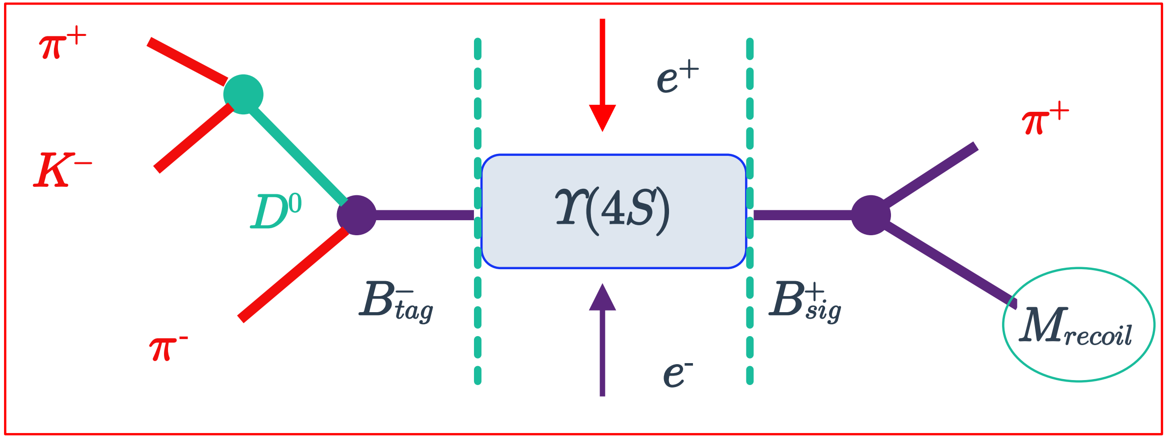
‡**Some of statistical and systematic uncertainties in $R(X)$**

source	e(%)	μ(%)
Experimental sample size	8.8	12.0
Lepton identification	2.8	5.2
$Xl\nu$ branching fractions	7.0	10.0

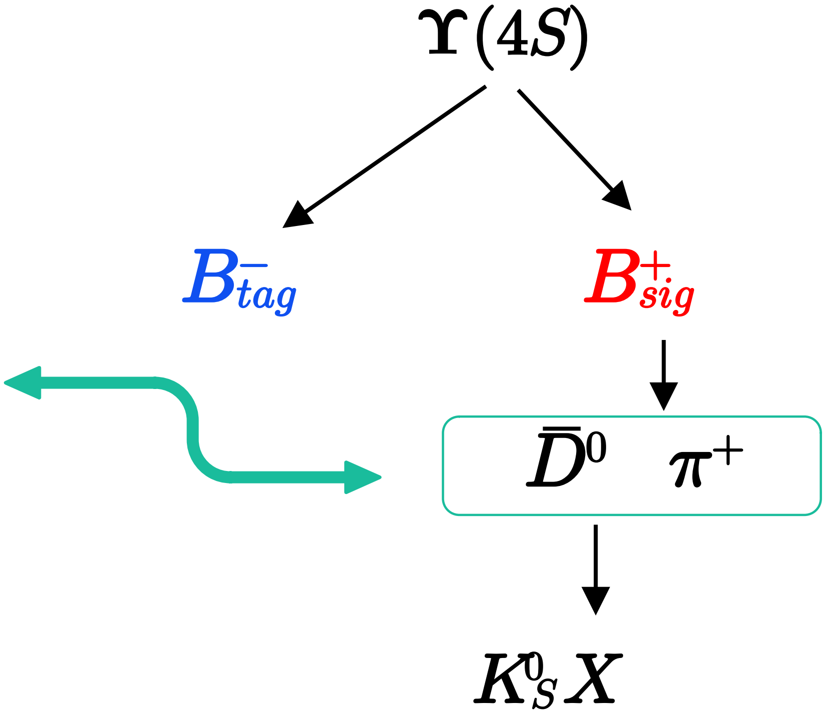
- As X includes charm hadrons D, D^*, D^{**} that decay in to the channel containing the leptons, pions,kaons, which can be misidentified.
- Secondary decay of X are source of background, responsible to increase the uncertainty(systematic) in $Xl\nu$ branching fraction.
- There is a way to improve the systematics uncertainty by studying the inclusive decay of $\bar{D}^0$.
- For this we are doing the analysis to find the branching fraction of inclusive decay mode $\bar{D}^0 \to K^0_S\,X(anything)$.
- This will be first time measurement in Belle II.

Introduction

- At SuperKEKB e^+e^- is collided and produce the $\Upsilon(4S)$ resonance that decays into $B^+B^-(B^0\bar{B}^0)$ pairs. For our inclusive study, hadronic B-tagging is used to tag one $B(B^-)$ and other (B^+) is in signal side.
- One of the daughters of signal side B^+ is π^+. Then using the kinematic information of $B_{tag}(B^-)$ and π^+, we find the mass spectrum of recoil part that is M_{recoil}.



Hadronic B-tagging



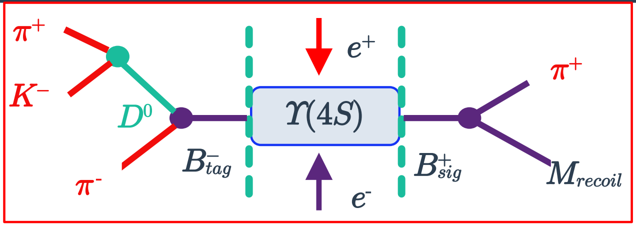
Decay Chain

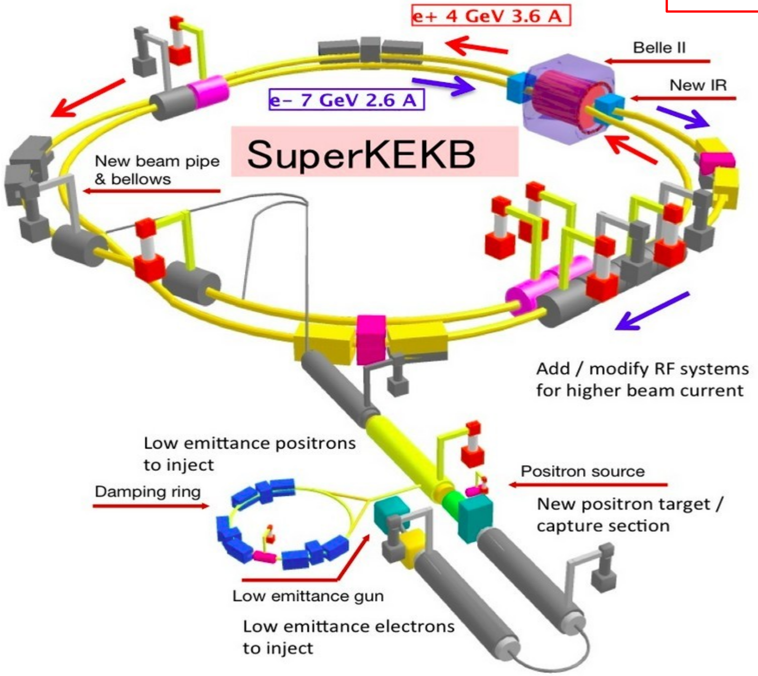
$$M_{recoil} = [(\Delta E)^2 - ((\Delta p_x)^2 + (\Delta p_y)^2 + (\Delta p_z)^2)c^2]^{1/2}$$

ΔE = Energy difference of B^-_{tag} and π^+

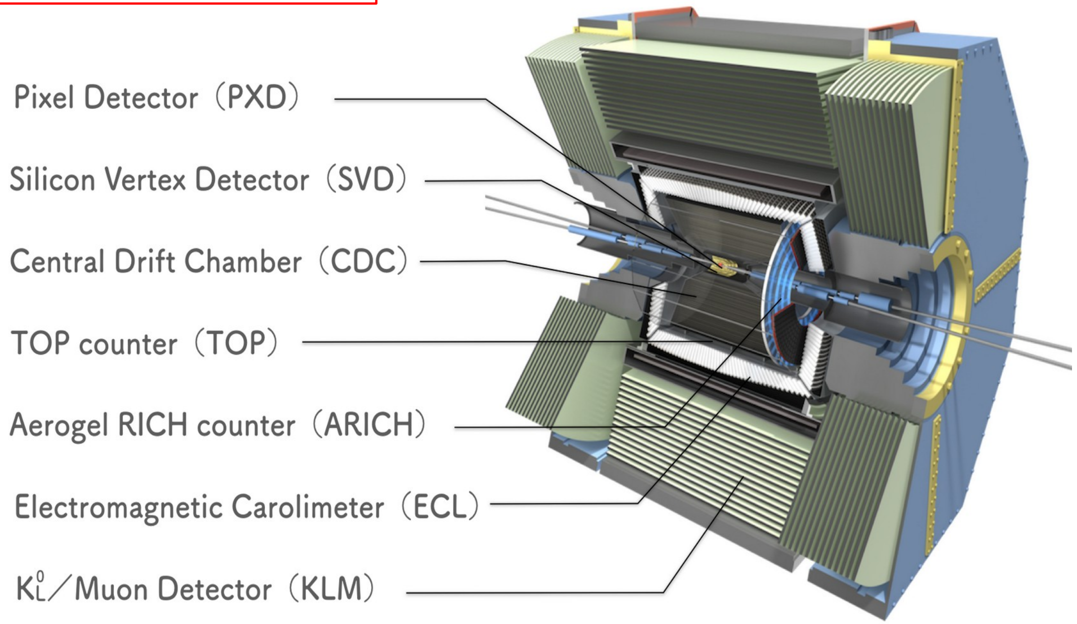
Δp_i = Difference in spatial momentum for B^-_{tag} and π^+ $(i = x, y, z)$

SuperKEKB and Belle II





SuperKEKB *collider Image © arXiv:1609.01806v1*



Belle II *detector Image © www.kek.jp*

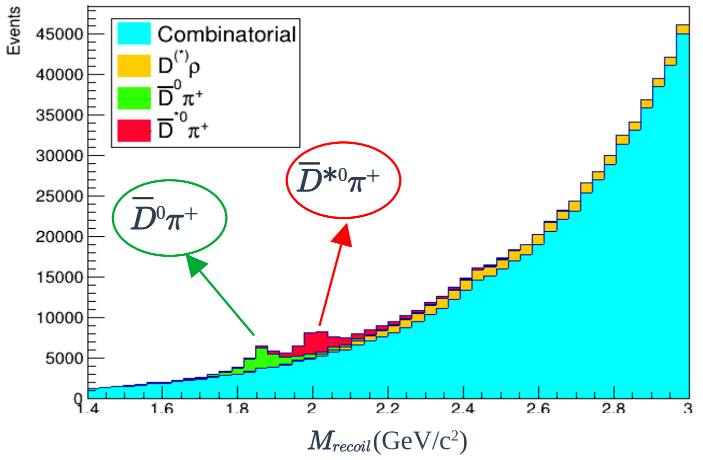
Analysis

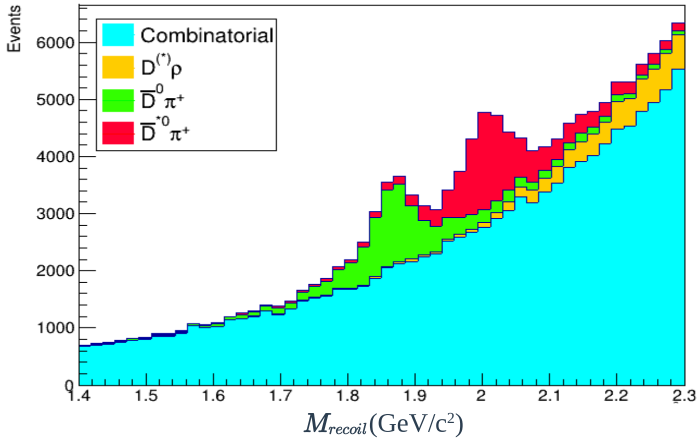
- Inclusive study of $\bar{D}^0 \to K_S^0 X$ using the hadronic B-tagging.
- One of $B(B^-)$ is reconstructed through pre-defined hadron decays.
- For this analysis, 400 fb^{-1} generic Monte-Carlo sample is used.
- Using the kinematics information of B_{tag}^- and π^+, recoil mass(M_{recoil}) is reconstructed in the centre of mass frame of $\Upsilon(4S)$.
- Signal peaks are in the lower mass spectrum region and for having stable fit in further analysis, mass range of recoil $[1.4, 2.3]$ GeV/c^2 is chosen.
- There are four components: Two signal peaks ($\bar{D}^0\pi^+$ and $\bar{D}^{*0}\pi^+$), continuum background and contribution from partially reconstructed $B \to D^{(*)}\rho$ decays

$$M_{recoil} = [(\Delta E)^2 - ((\Delta p_x)^2 + (\Delta p_y)^2 + (\Delta p_z)^2)c^2]^{1/2}$$

ΔE = Energy difference of B_{tag} and π^+

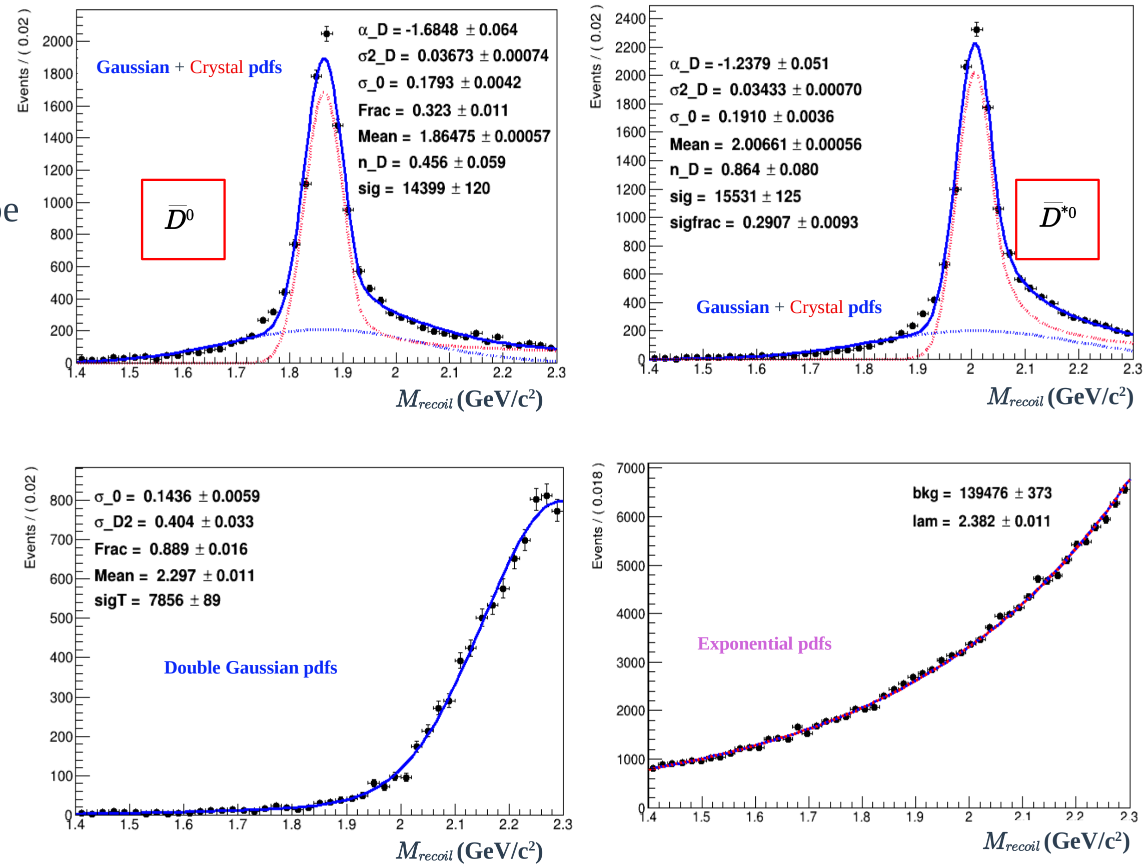
Δp_i = Difference in spatial momentum for B_{tag} and π^+ $(i = x, y, z)$





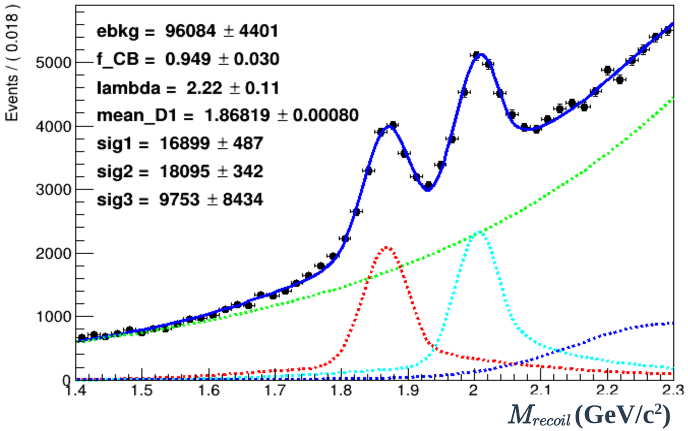
Fitting Procedure:

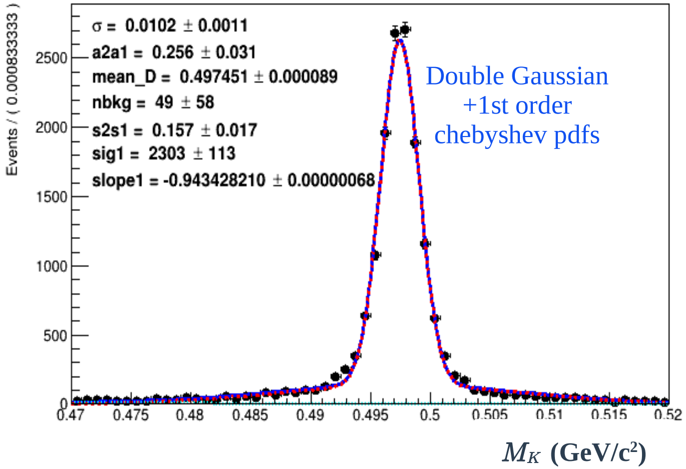
- Fitting plots for the signal and background extracted from mass spectrum of recoil.
- Both of the signals $\bar{D}^0\pi^+$ and $\bar{D}^{*0}\pi^+$ are of similar shape hence both the signals are defined by common pdfs **(Gaussian+Crystal ball)**.
- For Continuum background **Exponential** pdf is used.
- Background coming from partialy reconstructed $D^{(*)}\rho$ decay, is fitted by **double gaussian** pdf.
- After extraction of signal and background, total fitting of M_{recoil} is done.



Fitting and K_S^0 yield using sPlot

- In total fitting we fixed all tail parameters for the signal pdf (**Gaussian + Crystal ball**) except the mean, and for the background we floated the slope(**lambda**) parameter of the **exponential** pdfs.
- A fudge factor parameter (**f_CB**) is included in order to account for possible MC-Data difference.
- After extracting the yield of all signals from spectrum of M_{recoil}, we find the yield of K_S^0 in range $1.4 < M_{recoil} < 2.3$ GeV/c^2.
- Yield of K_S^0 is extracted from the signal $\bar{D}^0$ using sPlot technique.
- In sPlot technique weights are assigned to all the events, then using these weights yield of K_S^0 is estimated in signal region.





Yield of $\bar{D}^0\pi^+$(**sig1**) = 16899±487
Yield of $\bar{D}^{0*}\pi^+$(**sig2**) =18095±342
Yield of continuum background(**ebkg**)=96084±4401
Yield of higher $D^{(*)}\rho$ decays(**sig3**)=9753±8434

After scaling up to 400 fb^{-1}

total no. Of K_S^0 $= 4474 \pm 150$

Conclusion: Branching fraction of $\bar{D}^0 \rightarrow K_S^0 X = 0.330 \pm 0.011$,
Which has 3% statistical uncertainty with Belle II only.

Summary

- We did the inclusive study of $\bar{D}^0 \to K_S^0 X$ decay mode using the 400 fb^{-1} .
- In this we use the hadronic B tagging and B^+ decay is considered in signal side.
- Than using the kinematics information of B^-_{tag} we find the signal of $\bar{D}^0\pi^+$ channel which further in to $K_S^0 X$ decays.
- After this we use the *sPlot* technique to extract the yield of K_s^0 that is following the $\bar{D}^0 \to K_S^0$ X .
- Calculate the branching fraction of $\bar{D}^0 \to K_S^0 X$.
- Further we will validate this result by using the generated level information of K_S^0 .
- We will do the branching fraction calculation in bin of the K_S^0 momentum .

Thank You

Backup

Pre-Selection cut

The following are the pre-selection cuts for FEI (tag-side),and signal side M_{recoil} reconstrucion. These are the standard FEI cuts those are recommended.

B-tag side cuts:

- $M_{bc} > 5.27\, GeV/c^2$
- $-0.15 < |\Delta E| < 0.1\, GeV$
- FEI signal probability > 0.001

Selection of pion cuts:

- $|dr| < 1\, cm$ and $|dz| < 3\, cm$
- $L_{K/\pi} < 0.9$ and $muonID < 0.9$ and $electronID < 0.9$

Best Candidate Selection:

- Highest FEI signal probability
- The highest π momentum in CMS frame

Definition of B_{tag}'s ROE mask:

- Track : $|dr| < 2\, cm, |dz| < 4\, cm, p_t > 0.2\, GeV/c$
  thetaInCDCAcceptance
- ECL : $E > 0.008\, GeV, 0.03\, GeV, 0.06\, GeV$ in front, barrel and end-cap regions, respectively.$|clusterTiming| < 200$, $clusterNhits > 1.5\, and\, 0.2967 < clusterTheta < 2.6180$

M_{recoil} Cut:

- After B-tagging : $1.4 < M_{recoil} < 3.0\ GeV/c^2$
- For selecting the signal : $1.4 < M_{recoil} < 2.3\ GeV/c^2$

K_s^0 Cut:

- A list of K_s^0 is filled which is made up of $\pi^+\pi^-$ with the with the mass cut on K_s^0 (0.47,0.52) GeV/c^2