Using Charm Flavour tagger with $D^0 \to K_s K_s$

Sanjeeda Bharati Das[1], Kavita Lalwani[1], Angelo Di Canto[2]
MNIT Jaipur[1], BNL, USA[2]

Belle Analysis Workshop
(17–18 December, 2022)

Today's talk

- **Goal: Measurement of CP Asymmetry in $D^0 \rightarrow K_S K_S$.**
- Explore the prospect of using Charm Flavour Tagger (CFT):
  - Data Sample & Selection Criteria
  - Physics Motivation for CFT
  - Results: Measurement of CFT Metrics with $200 fb^{-1}$ for prompt $D^0 \rightarrow K_S K_S$

Data Sample & Selection Criteria

Trial Sample & Software version:

- MC15ri, 200fb^{-1}
- light-2207-bengal

Selection Criteria :

- *For charged tracks:*
  - *thetaInCDCAcceptance*
  - *dr<0.5 && abs(dz)<2*
  - *[nSVDHits>0] and [nCDCHits>20]*
- *K_S0:merged is used*
  - ***KS_significanceOfDistance >20***
- *For* D^0*:*
  - *Dz_p_CMS > 2.5 GeV/c*
  - *1.7<Dz_M<2.05 GeV/*c^2

Physics Motivation

Experimentally measured quantity is raw asymmetry (A_{raw}) defined as:

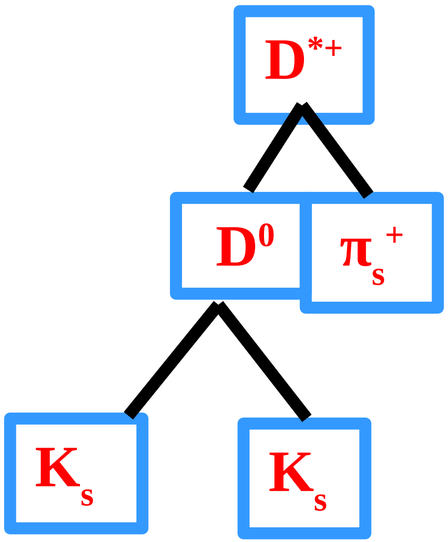
$$A_{raw} \equiv \frac{N(D^0) - N(\bar{D}^0)}{N(D^0) + N(\bar{D}^0)}$$

$N(D^0)$ = *measured yield of* $D^{*+} \to D^0\pi^+, D^0 \to K_S K_S$ *decays*

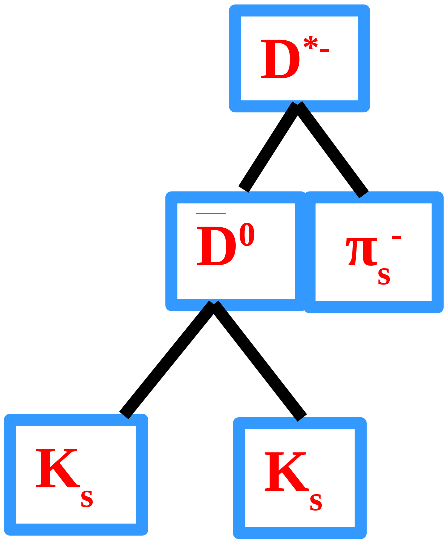
$N(\bar{D}^0)$ = *measured yield of* $D^{*-} \to \bar{D}^0\pi^-, \bar{D}^0 \to K_S K_S$ *decays*

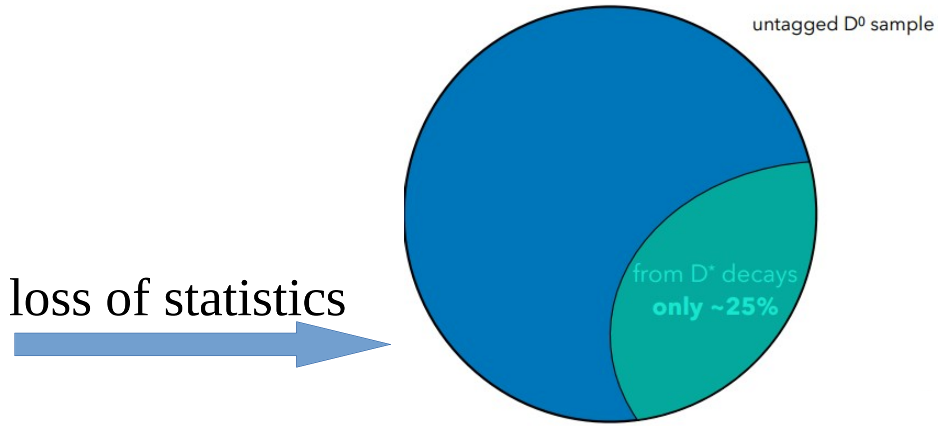
To measure CP Asymmetry, we need to identify (tag) the flavor the D^0 meson. One can usethe charge of the slow pion (π_s).

D^0 Sample



$\bar{D}^0$ Sample





$B(D^0 \to K_S K_S) = (1.321 \pm 0.023 \pm 0.036 \pm 0.044) \times 10^{-4}$ *(Phys. Rev. Lett. 119 171801)*

Due to low branching fraction, it is desirable to have other flavor identifying techniques which can retain statistics in addition to efficient flavour identification.

Charm Flavour Tagger (CFT)

1. **The Charm Flavour Tagger** *is a promising new tool (BELLE2-NOTE-PH-2022-044).*
2. We explore the possibility of using this new tool for our analysis.
3. We expect to considerably increase the statistics
4. CFT metrics and procedure:

tagging efficiency:	$\epsilon_{tag} = \dfrac{R+W}{R+W+U}$
mistag fraction:	$\omega = \dfrac{W}{R+W}$
dilution:	$r = \lvert 1 - 2\omega \rvert$
tagging power:	$\epsilon_{eff} = \epsilon_{tag}(1-2\omega)^2$
tagging decision:	$q = \pm 1$

R (W), U: rightly (wrongly) tagged, untagged D^0 candidates
q: +1 for D^0, -1 for $\bar{D}^0$

Reconstruct Decay

↓

Apply CFT

↓

Additional variables to measure CFT metrics. Eg: *pred flavour, qr,* etc.

CFT Metrics

- The meaning of **tagging efficiency** $\boldsymbol{\varepsilon_{tag}}$ and the **mistag rate** $\boldsymbol{\omega}$ are self explanatory.

- The sensitivity of a measurement that relies on flavor tagging is directly related to the effective **tagging efficiency, or tagging power** ($\boldsymbol{\varepsilon^{eff}_{tag}}$)

$$\varepsilon_{tag}^{eff} = \varepsilon_{tag} r^2 = \varepsilon_{tag}(1-2\omega)^2, \text{where} \qquad r = |1-2\omega| = \frac{R-W}{R+W}$$

is a dilution factor that accounts for candidates that are not correctly tagged.
r = 0 indicates that it is not possible to identify the flavor
r = 1 indicates that the flavor is perfectly known.

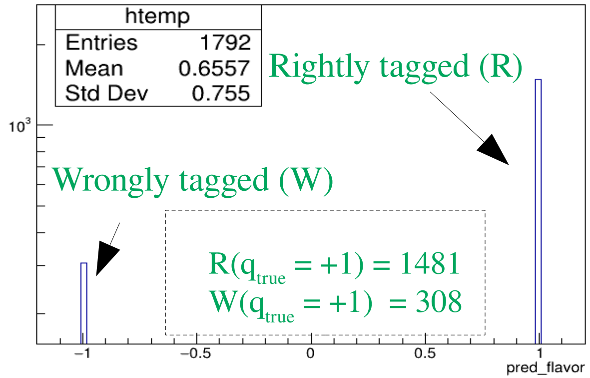
The tagging power represents, in essence, the effective statistical reduction of the sample size when a tagging decision is required.

- tagging efficiency, ε_{tag} , and the mistag rate, ω, can be different for charm and anticharm flavors due to charge-asymmetries in detection and reconstruction and as such $\boldsymbol{\Delta\varepsilon_{tag}}$ and $\boldsymbol{\Delta\omega}$

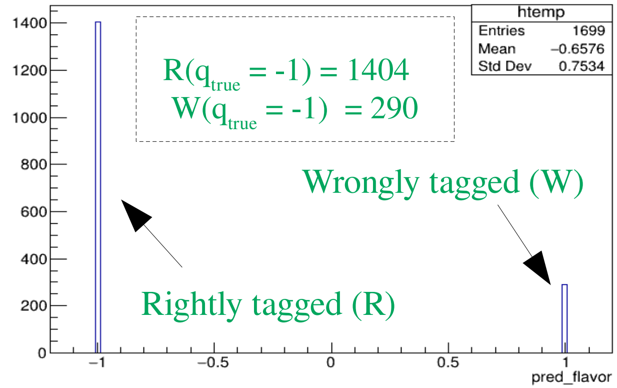
CFT Metrics

pred flavor distributions

Dz_isSignal==1 && Dz_mcPDG==421

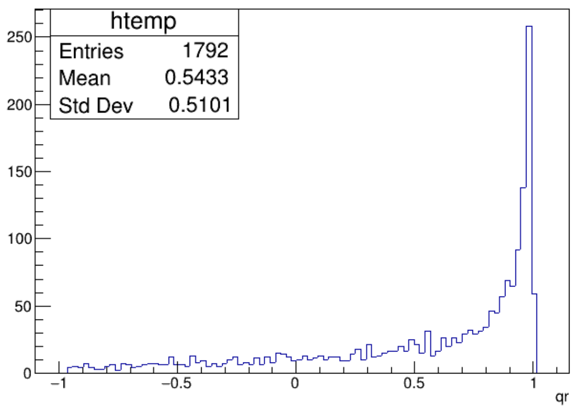


Dz_isSignal==1 && Dz_mcPDG==-421

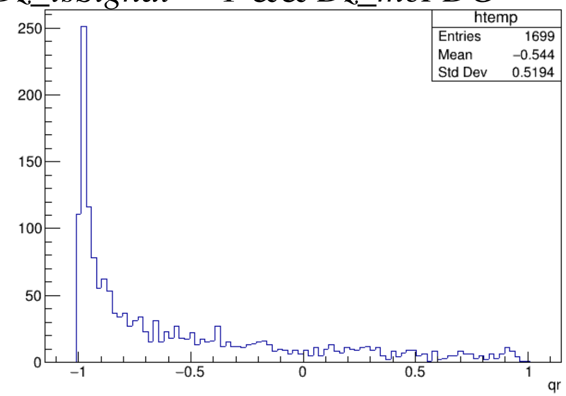


qr distributions

Dz_isSignal==1 && Dz_mcPDG==421



Dz_isSignal==1 && Dz_mcPDG==-421



in a sample of signal D^0 mesons:

$(q_{true} = +1)$ is the fraction of D^0 that are wrongly classified as anti-D0

$(q_{true} = -1)$ is the fraction of anti-D^0 mesons wrongly classified as D0

CFT Metrics (Mistag fraction)

$$fraction\ of\ D^0\ mesons\ that\ are\ wrongly\ classified\ as\ \bar{D}^0:$$

$$\omega(q_{true}=+1)=\frac{W}{R+W}=\frac{308}{1481+308}=17.22\,\%$$

$$fraction\ of\ \bar{D}^0\ mesons\ that\ are\ wrongly\ classified\ as\ D^0:$$

$$\omega(q_{true}=-1)=\frac{W}{R+W}=\frac{290}{1404+290}=17.11\,\%$$

$$Mistag\ fraction\,(\omega)=\frac{\omega(q_{true}=+1)+\omega(q_{true}=-1)}{2}=17.17\,\%$$

$$\Delta\,\omega=0.11\,\%$$

CFT Metrics (Tagging Efficiency, Tagging Power)

Untagged (U) = 8 (***qr!=qr, for no cut on qr***)

U(q_{true} = +1) = 3, U(q_{true} = -1) = 5

$$\varepsilon_{tag}(q_{true}=+1)=\frac{R+W}{R+W+U}=\frac{1481+308}{1481+308+3}=98.33\,\%$$

$$\varepsilon_{tag}(q_{true}=-1)=\frac{R+W}{R+W+U}=\frac{1404+290}{1404+290+5}=99.71\,\%$$

$$tagging\ efficiency=\frac{\varepsilon_{tag}(q_{true}=+1)+\varepsilon_{tag}(q_{true}=-1)}{2}=99.02\,\%$$

$$tagging\ power=\varepsilon_{eff}(1-2\,\omega)^2=42.68\,\%$$

CFT Metrics

CFT Metrics with 200 fb^{-1} ($D^0 \longrightarrow K_s K_s$)

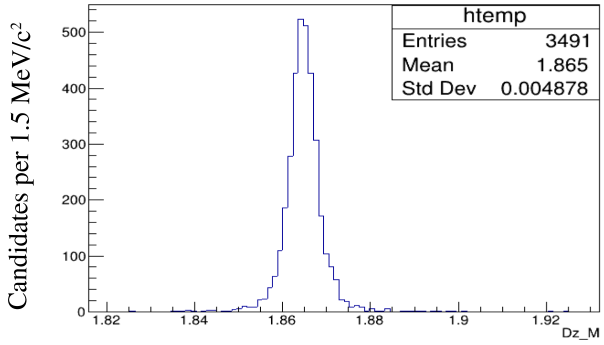
|qr|	Mistag fraction ω (%)	$\Delta\omega = \omega(q_{true} = +1) - \omega(q_{true} = -1)$(%)	tagging efficiency ε_{tag} (%)	tagging power ε^{tag}_{eff} (%)
-	17.17 ± 0.64 %	0.10 ± 1.28 %	99.769 ± 0.084 %	43.02 ± 1.67 %
>0.2	13.71 ± 0.61 %	-0.41 ± 1.23 %	89.699 ± 0.514 %	47.26 ± 1.62 %
>0.4	**10.45 ± 0.58 %**	**0.26 ± 1.17 %**	**78.395 ± 0.697 %**	**49.06 ± 1.51 %**
>0.6	7.16 ± 0.54 %	-0.90 ± 1.08 %	65.294 ± 0.806 %	47.93 ± 1.34 %
>0.8	4.34 ± 0.49 %	-1.67 ± 0.98 %	49.652 ± 0.846 %	41.40 ± 1.13 %

|qr| >0.4 is the optimal cut for maximum tagging power.

M(D^0) distributions

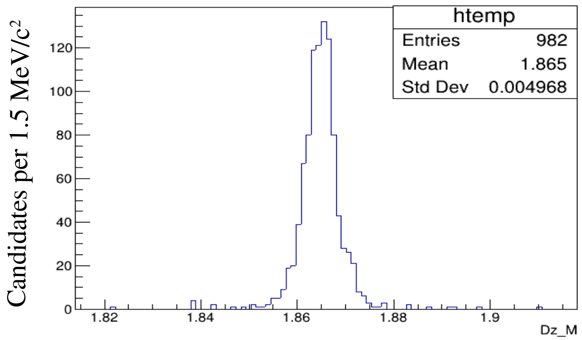
For prompt sample

Dz_isSignal==1



For D* tagged sample

Dst_isSignal==1



Events with CFT:

3491 x tagging power (without *qr* cut)

3491 x 0.43 = **1501**

Increase: (1501-982) /982 ~ 53%

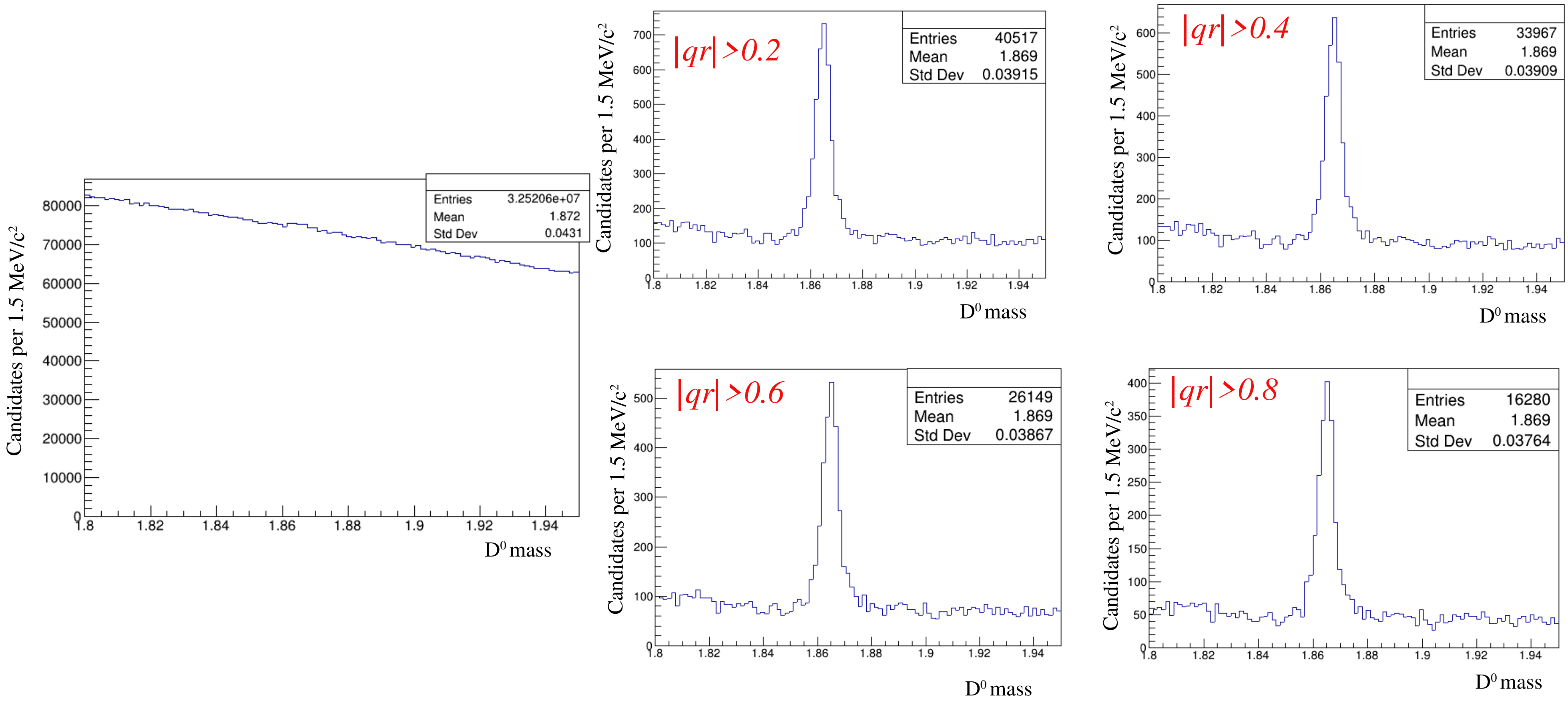
Prompt: $D^0 \longrightarrow K_s K_s$

D* tagged: $D^* \longrightarrow D^0 (K_s K_s)\pi_s$

Effect of |*qr*| criteria, D^0 Mass distributions (Prompt sample)

Simulation

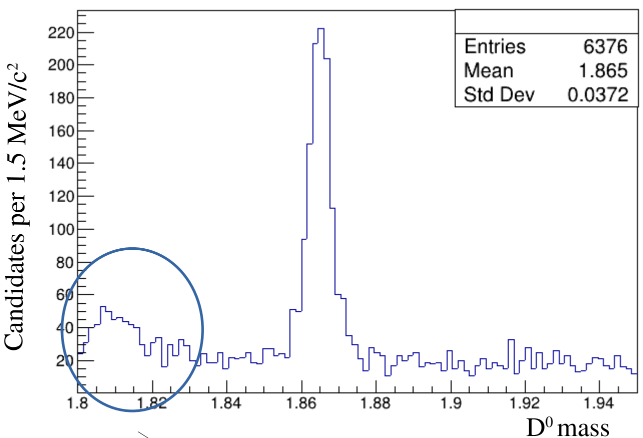
$D^0 \longrightarrow K_s K_s$



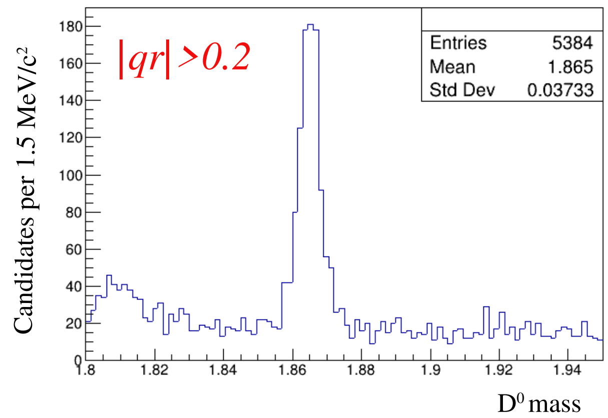
Effect of |*qr*| criteria, D^0 Mass distributions (with D* tagged sample)

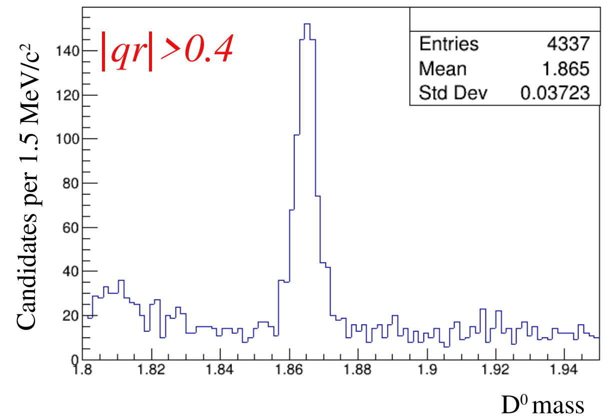
$D^{*} \longrightarrow D^0\,(K_s K_s)\pi_s$

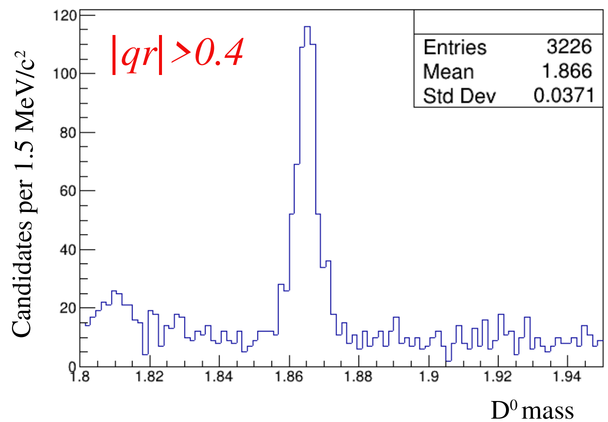
Simulation

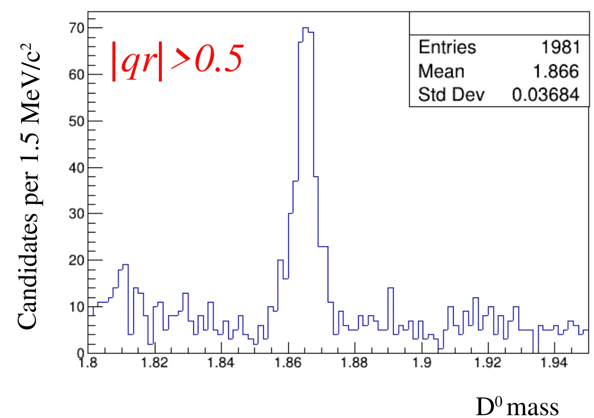


Need to check this peak





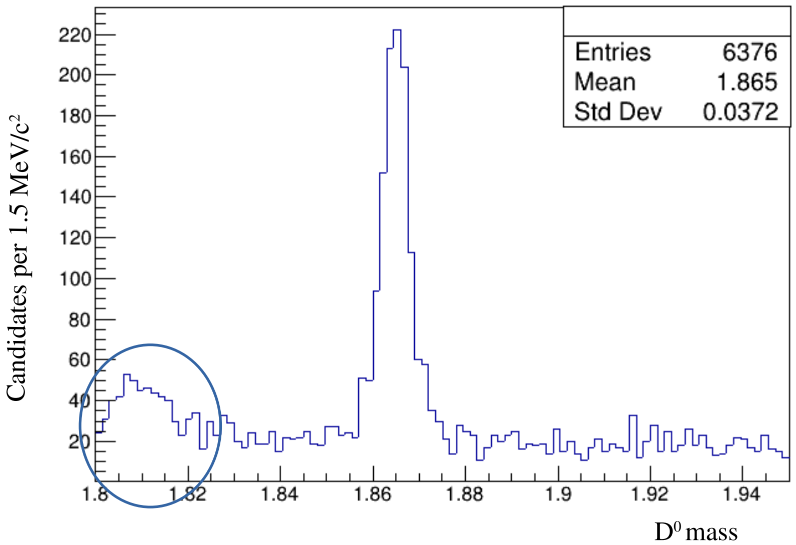




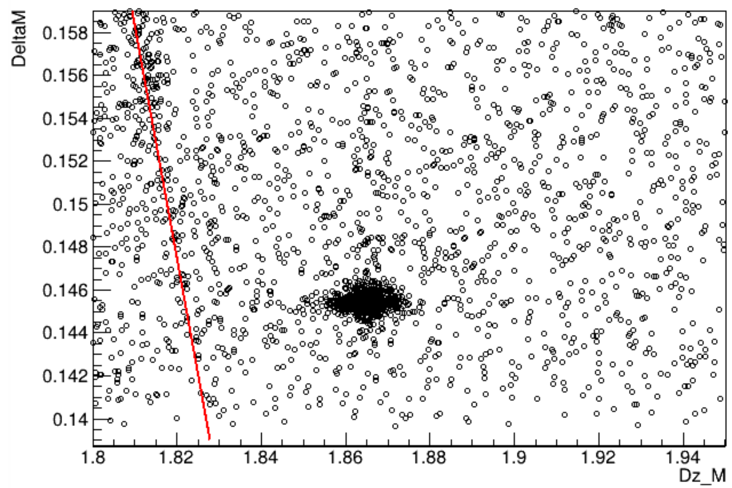
Background in D^0 Mass distribution

Simulation

M(D^0) distribution



Dz_M:DeltaM

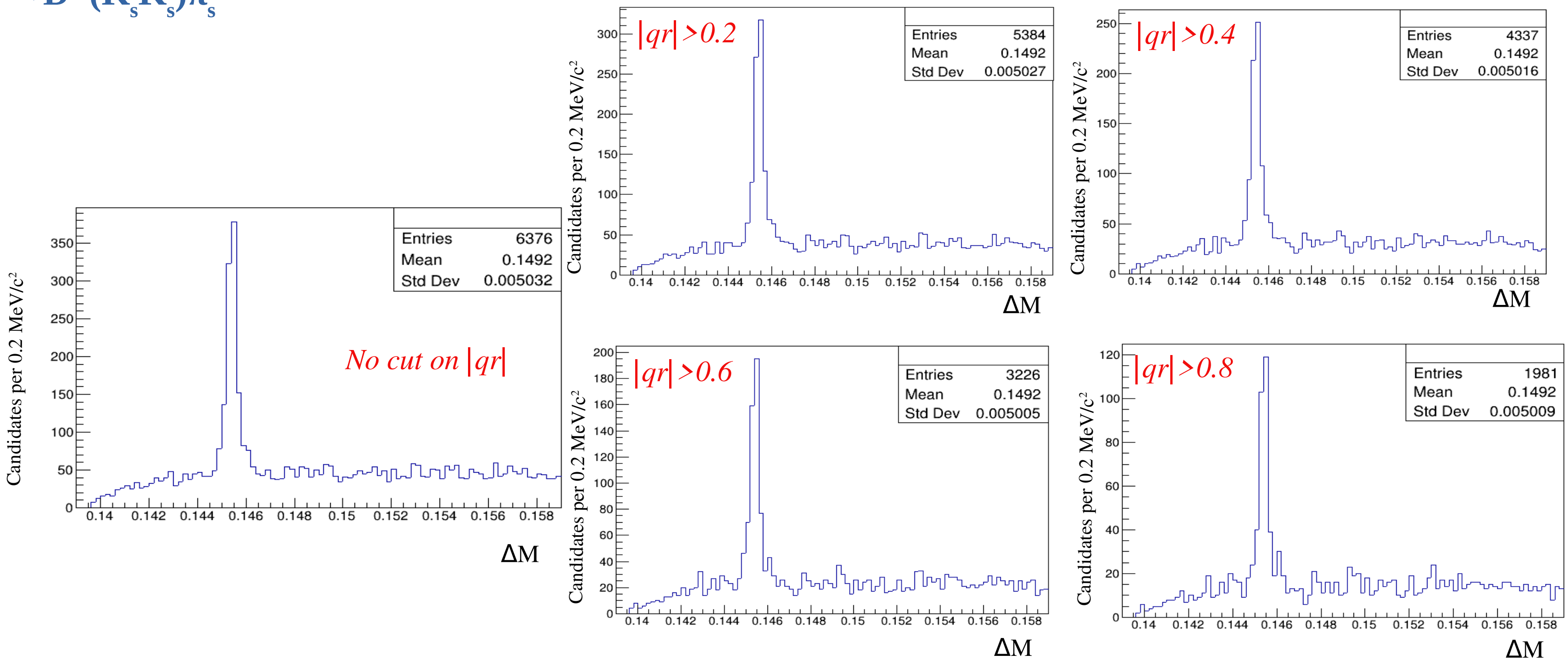


The ‘*shoulder*’ observed in the M(D^0) distribution, is consistent with a contamination from $D_s^+ \to K_s K_s \pi^+$ ($\mathcal{B} = 7.7\times10^{-3}$) decay. The charged pion is used as soft pion candidate.

Effect of |*qr*| criteria, ΔM distributions (with D* tagged sample)

Simulation

$D^{*} \longrightarrow D^{0} (K_s K_s) \pi_s$



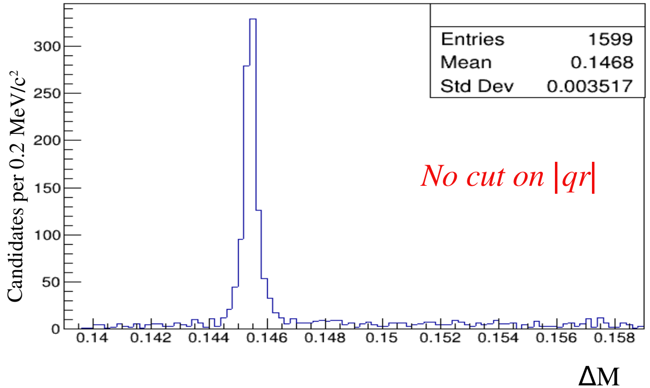
|qr|	**S (Signal)** *Dst_isSignal==1*	**B(Background)** *Dst_isSignal!=1*	**Purity: S/S+B**
-	982	5394	15.40%
>0.2	823	4561	15.29%
>0.4	664	3673	15.31%
>0.6	491	2735	15.22%
>0.8	303	1678	15.30%

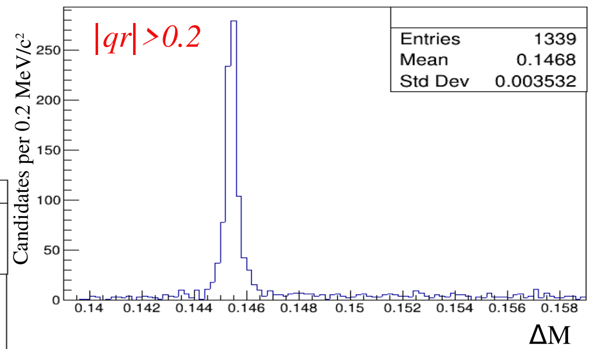
Effect of |*qr*| criteria, ΔM distributions (with D* tagged sample)

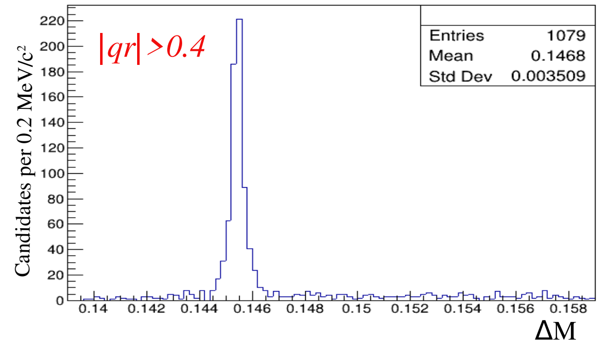
$D^{*} \longrightarrow D^{0} (K_s K_s)\pi_s$

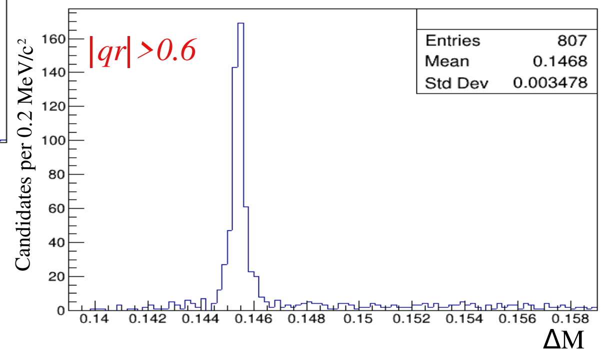
(Signal Window: $1.845 < m(D^0) < 1.885$)

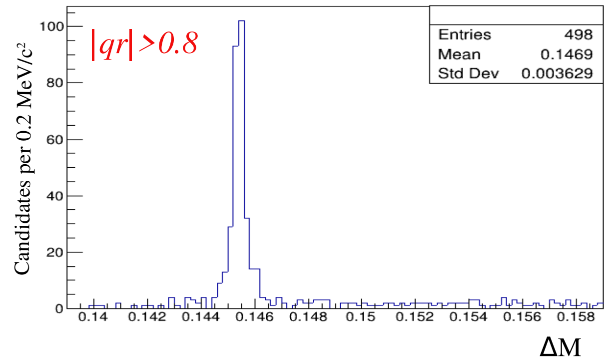
Simulation











|qr|	**S (Signal)** *Dst_isSignal==1*	**B(Background)** *Dst_isSignal!=1*	**Purity: S/S+B**
-	970	629	60.66%
>0.2	813	526	60.72%
>0.4	659	420	61.08%
>0.6	488	319	60.47%
>0.8	302	196	60.64%

Summary

- Charm Flavour Tagger is a promising tool for flavour tagging.
- Observed that the CFT suppressing the backgroung in untagged sample of $D^0 \rightarrow K_S K_S$
- Calculated the CFT Metrics and measured a ~53% increase in statistics in untagged sample of $D^0 \rightarrow K_S K_S$.

Ongoing

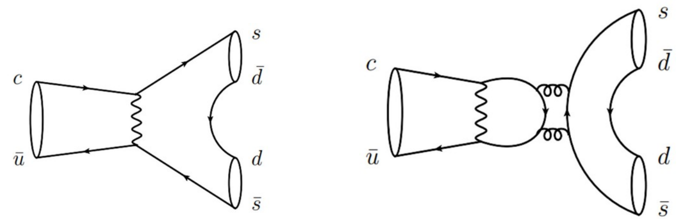
- **Study of signal mode $D^0 \rightarrow K_S K_S$:**

  * Improve the fit for $D^0 \rightarrow K_S K_S$.

Backup Slides

Physics Motivation

- $D^0 \rightarrow K_S K_S$ is a Singly Cabibbo Supressed (SCS) decay which involves the interference of $c\bar{u} \rightarrow s\bar{s}$ and $c\bar{u} \rightarrow d\bar{d}$ transitions.



- Due to this interference, the CP Assymetry (A_{CP}) may be enhanced to an observable level within the Standard Model.

- In Belle, the branching fraction and time-integrated A_{CP} was measured with $D^0 \rightarrow K_s\pi^0$ as the control sample. *(Phys. Rev. Lett. 119 171801)*

$B(D^0 \rightarrow K_S K_S) = (1.321 \pm 0.023 \pm 0.036 \pm 0.044) \times 10^{-4}$

$A_{CP}(D^0 \rightarrow K_S K_S) = (-0.02 \pm 1.53 \pm 0.02 \pm 0.17)\ \%$

- In this analysis, our goal is to measure the time integrated A_{CP} of $D^0 \rightarrow K_S K_S$ using $D^0 \rightarrow K^+K^-$ as the control sample, when we reach the same statistics as Belle.

- The A_{CP} in $D^0 \rightarrow K^+ K^-$ is measured with 0.11% precision [HFLAV] and is expected to improve. *https://hflav-eos.web.cern.ch/hflav-eos/charm/cp_asym/charm_asymcp_19Sep19.html*

- Using $D^0 \rightarrow K^+K^-$ as the control sample will make the analysis much simpler and will reduce the systematic unceraintу.

Methodology

Time integrated A_{CP} is defined as: $A_{CP} \equiv \frac{\Gamma(D^0 \to K_S^0 K_S^0) - \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}{\Gamma(D^0 \to K_S^0 K_S^0) + \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}$ Γ = *partial decay width*

Experimentally measured quantity is raw assymetry (A_{raw}) defined as:

$$A_{raw} \equiv \frac{N(D^0) - N(\bar{D}^0)}{N(D^0) + N(\bar{D}^0)}$$

$N(D^0)$ = measured yield of $D^{*+} \to D^0\pi^+$, $D^0 \to K_S K_S$ decays

$N(\bar{D}^0)$ = measured yield of $D^{*-} \to \bar{D}^0\pi^-$, $\bar{D}^0 \to K_S K_S$ decays

$$A_{raw} \approx A_{FB}^{D^{*+}} + A_{CP} + A_{\varepsilon}^{\pi_s} \text{ (relation between } A_{CP} \text{ \& } A_{raw})$$

$$A_{raw}^{K_sK_s} = A_{FB}^{D^{*+}} + A_{CP}^{K_sK_s} + A_{\varepsilon}^{\pi_s} \to (i)$$

$$A_{raw}^{KK} = A_{FB}^{D^{*+}} + A_{CP}^{KK} + A_{\varepsilon}^{\pi_s} \to (ii)$$

$$\boxed{A_{CP}^{K_sK_s} = (A_{raw}^{K_sK_s} - A_{raw}^{KK}) + A_{CP}^{KK}}$$

$A_{\varepsilon}^{\pi_s}$ = *assymetry of the detection efficiency of the slow pion*

A_{FB} = *forward backward assymetry*