Measurements of the Charmed Mesons Hadronic Branching Ratios at 4.03 GeV

A Direct Measurement of

the Absolute Branching Ratio

$Br(D^0 \to K^- \pi^+)$

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Introduction

- $Br(D^0 \to K^-\pi^+)$ and $Br(D^+ \to K^-\pi^+\pi^+)$ are important to D physics and B physics.
  1. It's the normalization constant of BR for other D decay modes.
  2. $b_{quark} \to (\approx 1.3) c_{quark}$
  3. The element of CKM: $|V_{cs}|, |V_{cd}|, |V_{bd}|$
- Measurements of $Br(D^0 \to K^-\pi^+)$ from other experiments:
  1. MarkIII (at $\psi(3770)$, using double tag method).
  2. ALEPH, CLEO, AUGUS etc. (at High Energy region, using decay chain $D^{*+} \to \pi^+ D^0$,searching for the soft pion).

  There is a little difference between the result from MarkIII and that from High Energy experiments.
- BES has collected $22pb^{-1}$ data at 4.03 GeV. Base on this data sample, we got $\approx 8000 D^0$ tags and $\approx 2700 D^+$ tags .
  1. D meson may be produced via several procedures. ($D\overline{D^*}, D^*\overline{D^*}, D\overline{D}$, including Charged and Neutral channels).
  2. The decay of D^{*+} will cause the 'mixing' of D^0 and D^+.
  3. Kinematical fit could not be used in analysis.
  4. Difficulty to detect the soft pions.

Single Tags and Double Tags

Table 1. The observation possibility of single-tags and double-tags at 4.03 GeV

Tags \ Modes		$D\overline{D^*}$		$D^*\overline{D^*}$		$D\overline{D}$	
		$D^0\overline{D^{*0}}$	D^-D^{*+}	$D^{*0}\overline{D^{*0}}$	$D^{*-}D^{*+}$	$D^0\overline{D^0}$	D^+D^-
Single Tags	D^0	$2\varepsilon_i B_i$	$\varepsilon_i B_i B_0^+$	$2\varepsilon_i B_i$	$2\varepsilon_i B_i B_0^+$	$2\varepsilon_i B_i$	0
	D^+	0	$\varepsilon_{1i} B_i + \varepsilon_{2i} B_i (1 - B_0^+)$	0	$2\varepsilon_i B_i (1 - B_0^+)$	0	$2\varepsilon_i B_i$
Double Tags	D^0 vs $\overline{D^0}$	$\varepsilon_{ii} B_i B_i$ $2\varepsilon_{ij} B_i B_j$	0	$\varepsilon_{ii} B_i B_i$ $2\varepsilon_{ij} B_i B_j$	$\varepsilon_{ii} B_i B_i (B_0^+)^2$ $2\varepsilon_{ij} B_i B_j (B_0^+)^2$	$\varepsilon_{ii} B_i B_i$ $2\varepsilon_{ij} B_i B_j$	0
	D^+ vs D^-	0	$\varepsilon_{ii} B_i B_i (1 - B_0^+)$ $2\varepsilon_{ij} B_i B_j (1 - B_0^+)$	0	$\varepsilon_{ii} B_i B_i (1 - B_0^+)^2$ $2\varepsilon_{ij} B_i B_j (1 - B_0^+)^2$	0	$\varepsilon_{ii} B_i B_i$ $2\varepsilon_{ij} B_i B_j$
	D^0 vs D^-	0	$\varepsilon_{ij} B_i B_j B_0^+$	0	$2\varepsilon_{ij} B_i B_j (1 - B_0^+) B_0^+$	0	0

$$B_0^+ = Br(D^{*+} \to \pi^+ D^0)$$

Event selection

Single (charged) track selection

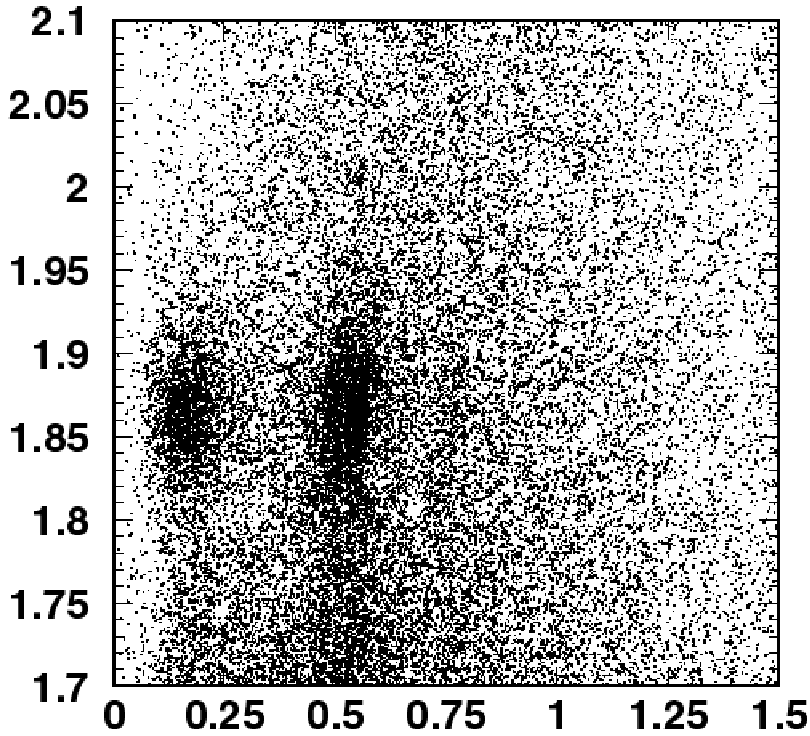
- $|\cos\theta| < 0.85$, to insure reliable MDC measurement.
- $|V_{xy}| < 1.2cm, |V_z| < 15cm$, tracks are required to be inside the interaction region.
- MFIT=2, −19, −9

Particle Identification

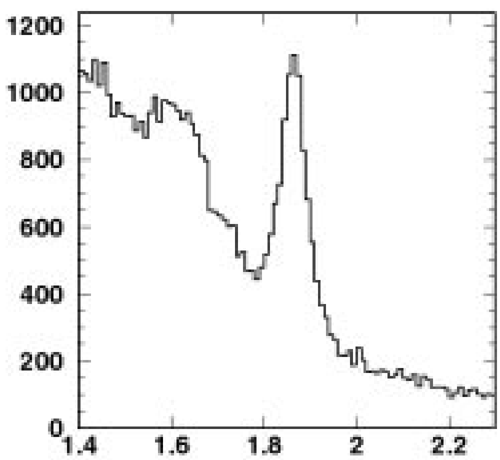
- Pions and Kaons are required to have a relative likelihood ($CL(type)$) greater than 1% for mass hypothesis, according to TOF and dE/dx information.
- More strictly cut for Kaons : $CL(K) > CL(\pi)$.

Singleton D tags Selection

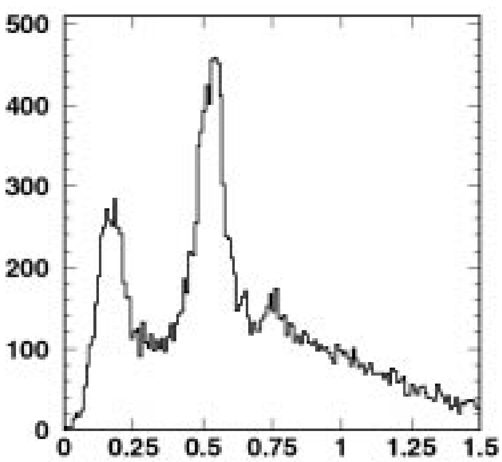
- D production At 4.03 GeV:
  1. $D\overline{D^*}$ (charged and neutral)
  2. $D^*\overline{D^*}$ (charged and neutral)
  3. $D\overline{D}$ (charged and neutral)
- These procedures could be identified by the momentum distribution of the D-tag candidate.



$m_{K\pi}$ vs $p_{K\pi}$



$m_{K\pi}$ (under 3 $p_{K\pi}$ peak)



$p_{K\pi}$ (near D^0 mass peak)

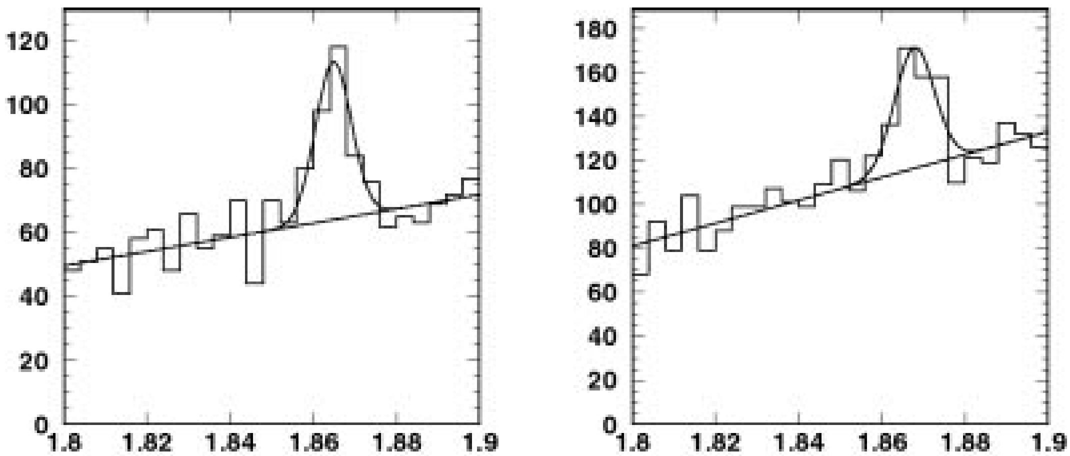
Fig1. $m_{K\pi}$ and $p_{K\pi}$ distribution

Fig1. shows that $D\overline{D^*}$ and $D^*\overline{D^*}$ have large productions at 4.03 GeV. A fine momentum cut is applied to select D^0 and D^+ tags.

Mode	$D\overline{D^*}$	$D^*\overline{D^*}$
D^0	$0.42 < p < 0.64$	$0.06 < p < 0.26$
D^+	$0.42 < p < 0.64$	$0.04 < p < 0.24$

Table 2. Momentum cuts for D^0 and D^+ tags

- The production of $D\overline{D}$ are very low, it will be discard in further analysis.



$\psi(4030) \to (K^-\pi^+) + X$ $\quad$ $\psi(4030) \to (K^-\pi^+\pi^+) + X$

$M_{K\pi} = M_X$ $\quad$ $M_{K\pi\pi} = M_X$

134 ± 40 events $\quad$ 164 ± 46 events

Fig2. $M_{K\pi}$ and $M_{K\pi\pi}$ distribution via $D\overline{D}$ production

- Three D decay modes are selected in this analysis, they are: $D^0 \to K^-\pi^+, D^0 \to K^-\pi^+\pi^+\pi^-, D^+ \to K^-\pi^+\pi^+$. The invariant mass distributions are shown in Figure 3.

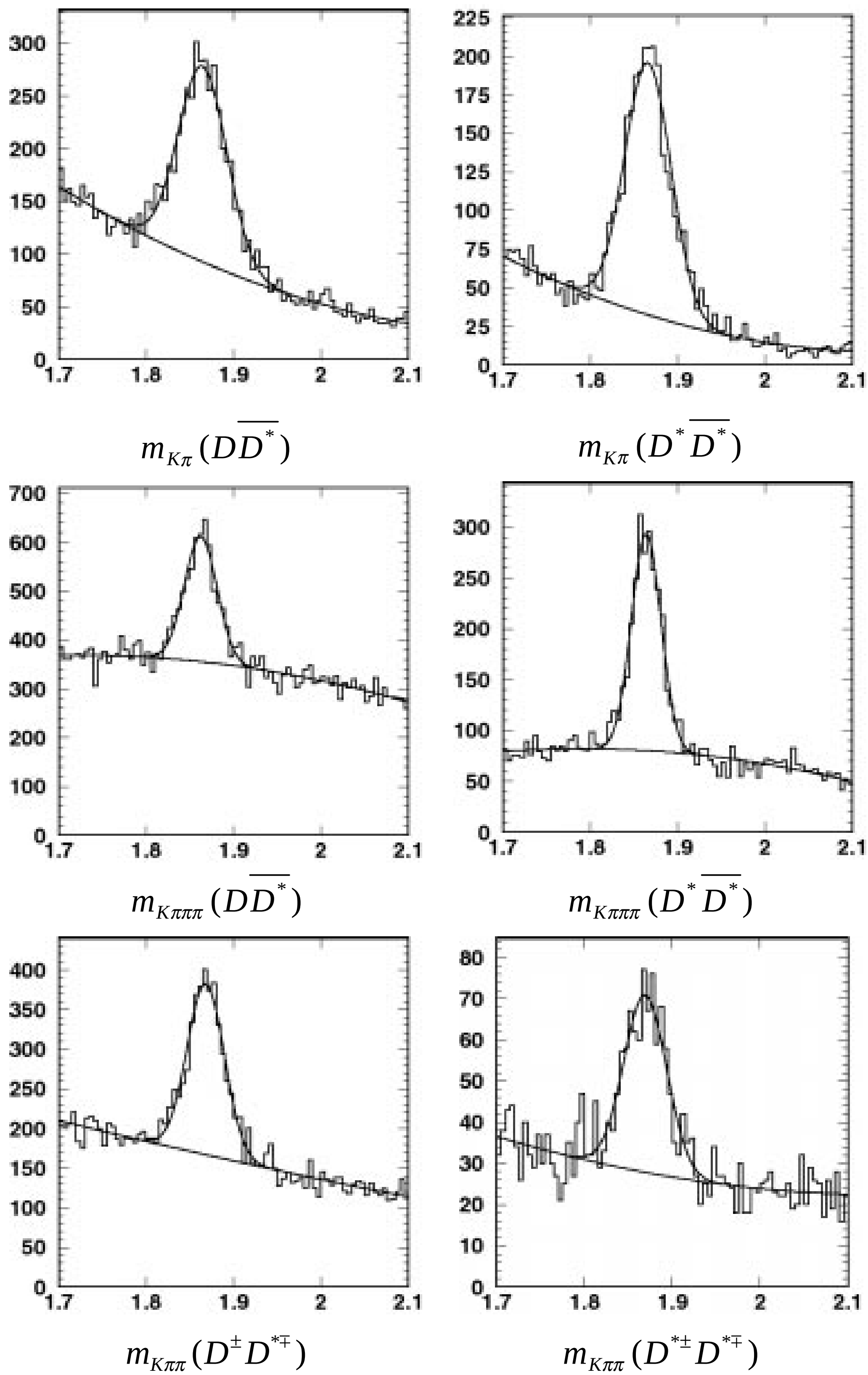


Fig 3. Invariant mass distributions for D Tag candidates

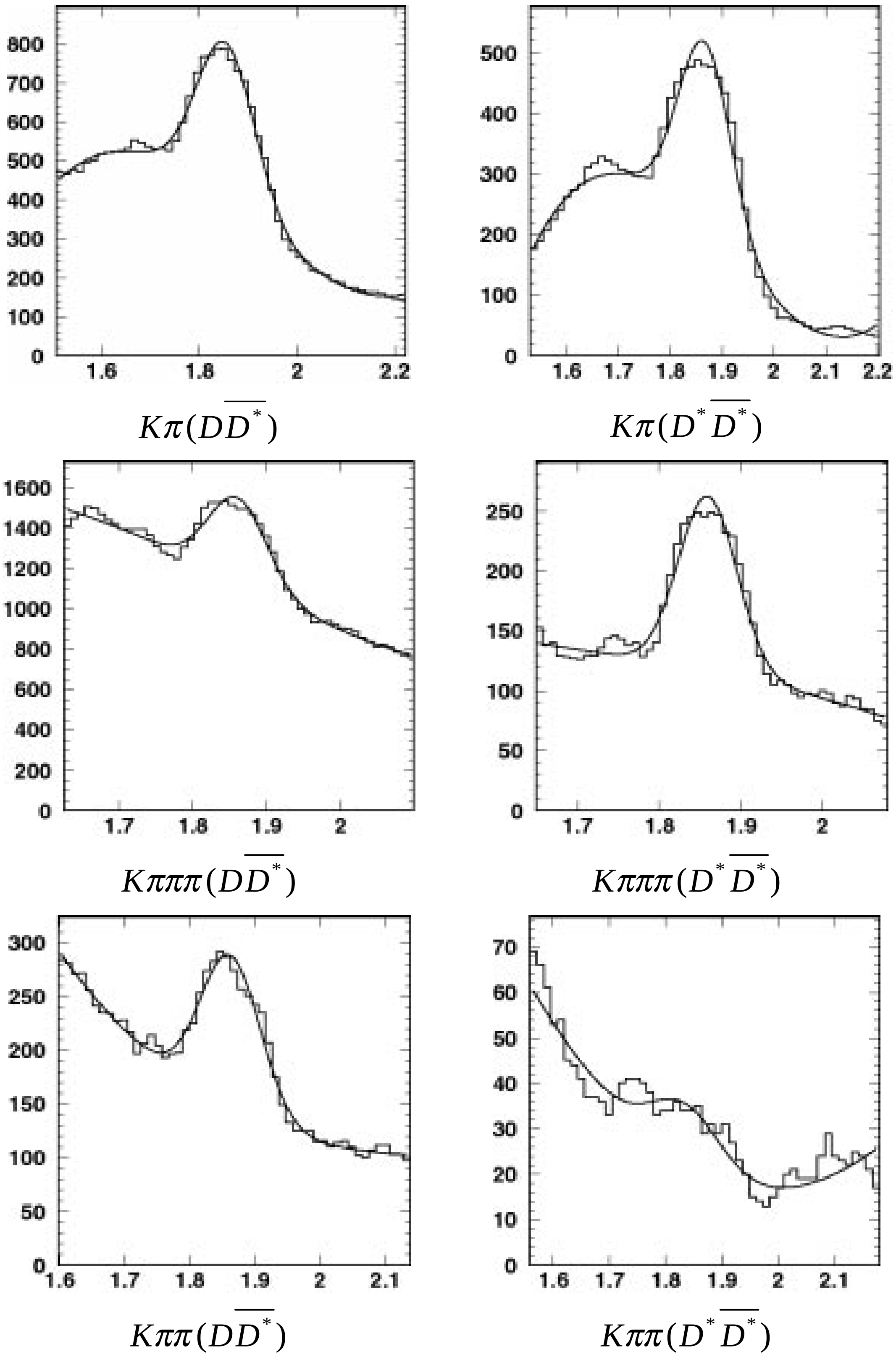
Double Counting Correction

- Multi-entries:
  1. Particle misidentification
  2. Wrong combination
  3. Really double-tag events

- Keep 1 entry per event

- To evaluate the double counting ratio in signal region, a fine scan on single-tag mass plot was employed in following way:
  1. Center = $\leftarrow M_D \rightarrow$
  2. Size = $3\sigma_{M_D}$
  3. Step = $0.5\sigma_{M_D}$

- Same procedure for MC data



Double Counting Distribution

Tags		$K\pi$	$K\pi\pi\pi$	$K\pi\pi$
$D\overline{D^*}$	M_D	1.8647	1.8626	1.8684
	σ_{M_D}	0.0280	0.0186	0.0212
	Total Counting	2600 ± 101	2374 ± 132	2290 ± 108
	D.C. Ratio	15.4%	17.7%	6.2%
	Net Counting	2200 ± 103	1954 ± 136	2147 ± 109
$D^*\overline{D^*}$	M_D	1.8662	1.8641	1.8694
	σ_{M_D}	0.0265	0.0169	0.0244
	Total Counting	2168 ± 59	1799 ± 66	526 ± 52
	D.C. Ratio	14.4%	8.0%	2.1%
	Net Counting	1856 ± 60	1654 ± 67	515 ± 52

Double Tags Selection

- Loosening Momentum CUT:

1. For D^0 Tags:

$$0.06GeV/c < p < 0.34GeV/c$$

$$0.40GeV/c < p < 0.70GeV/c$$

2. For D^+ Tags

$$0.04GeV/c < p < 0.26GeV/c$$

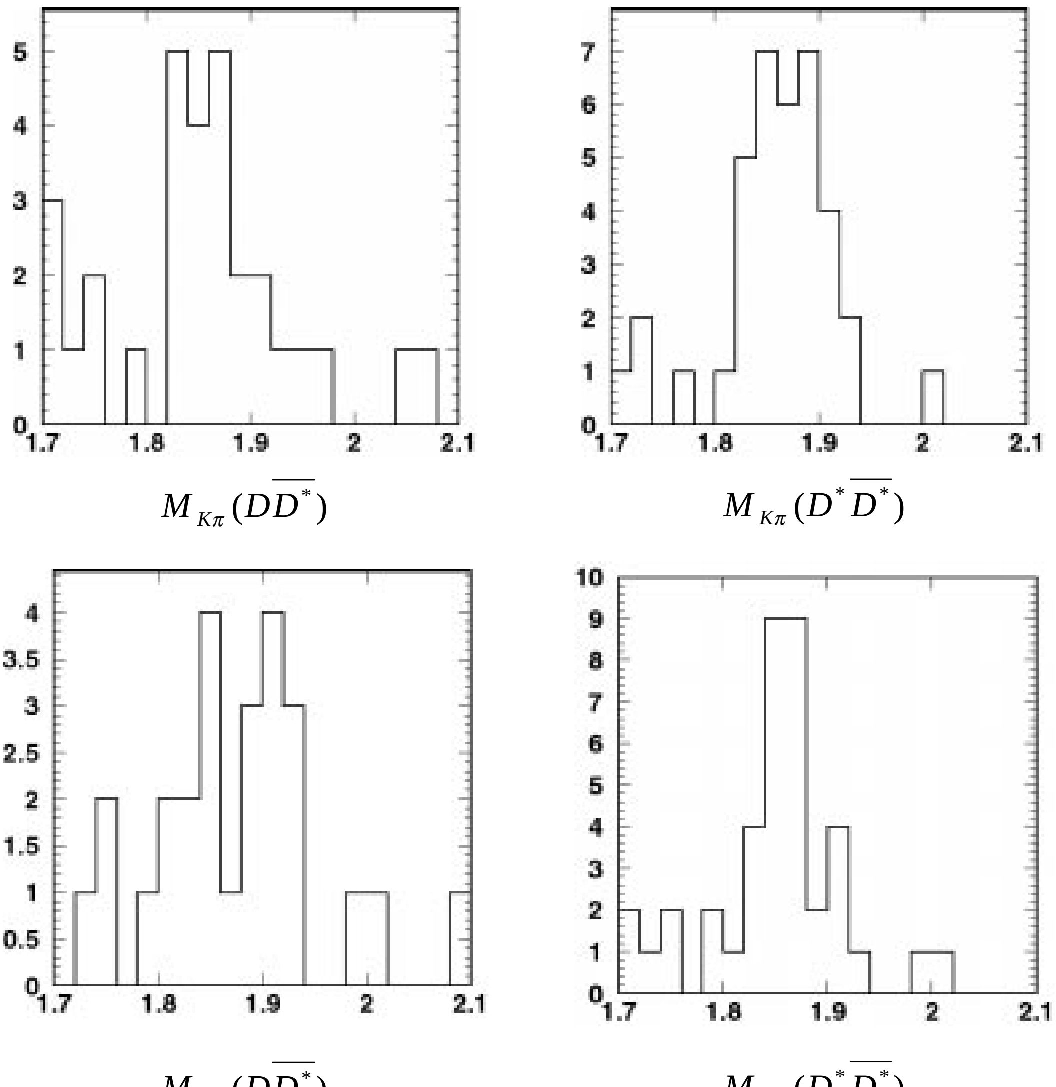
$$0.42GeV/c < p < 0.64GeV/c$$

- Tag side Mass CUT:

$$|M_{tag} - M_D| < 3\sigma_{M_D}$$

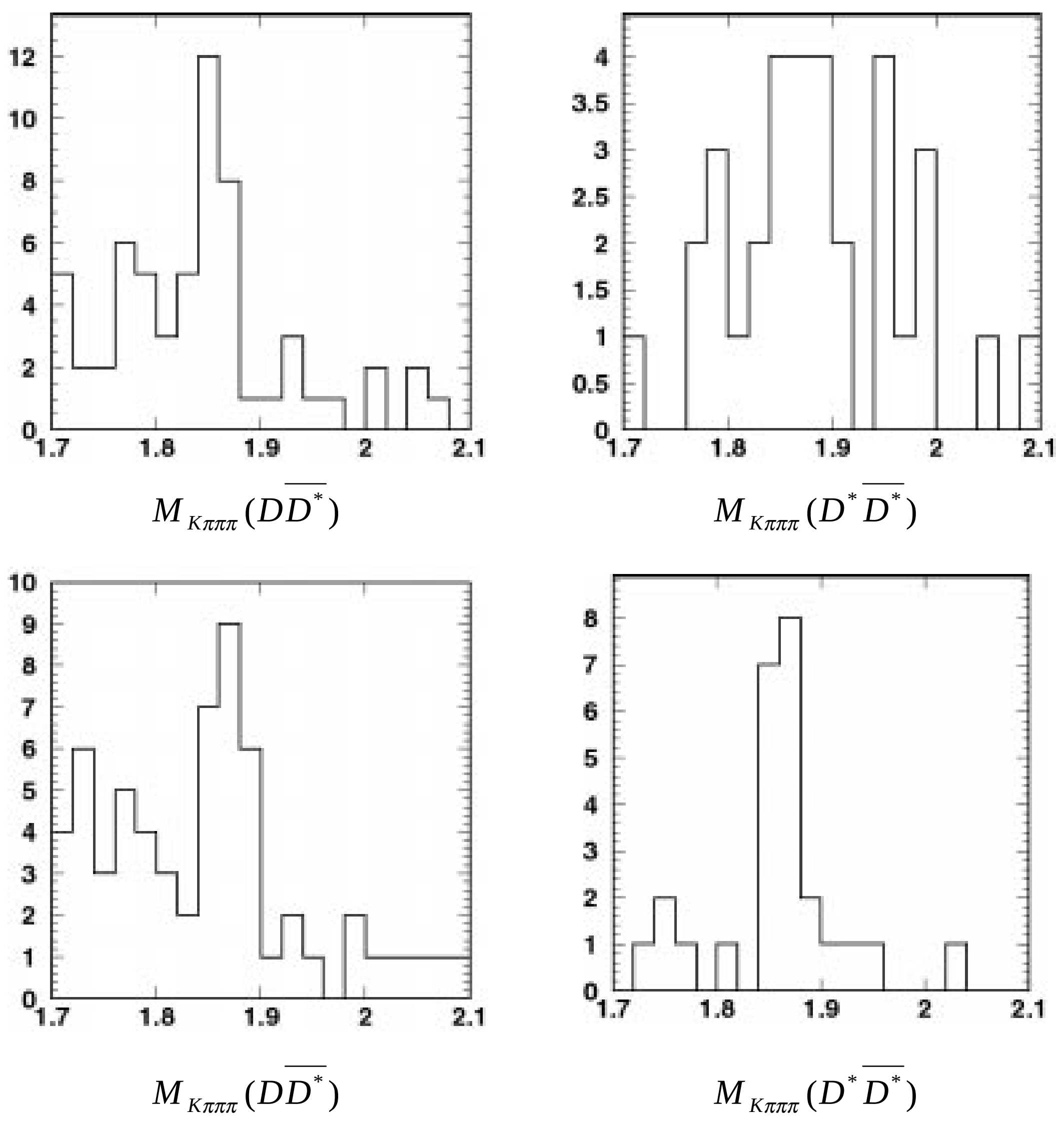
M_D, σ_{M_D}, is taken from the Single Tags mass plot fit.

- Charm Balance is required.

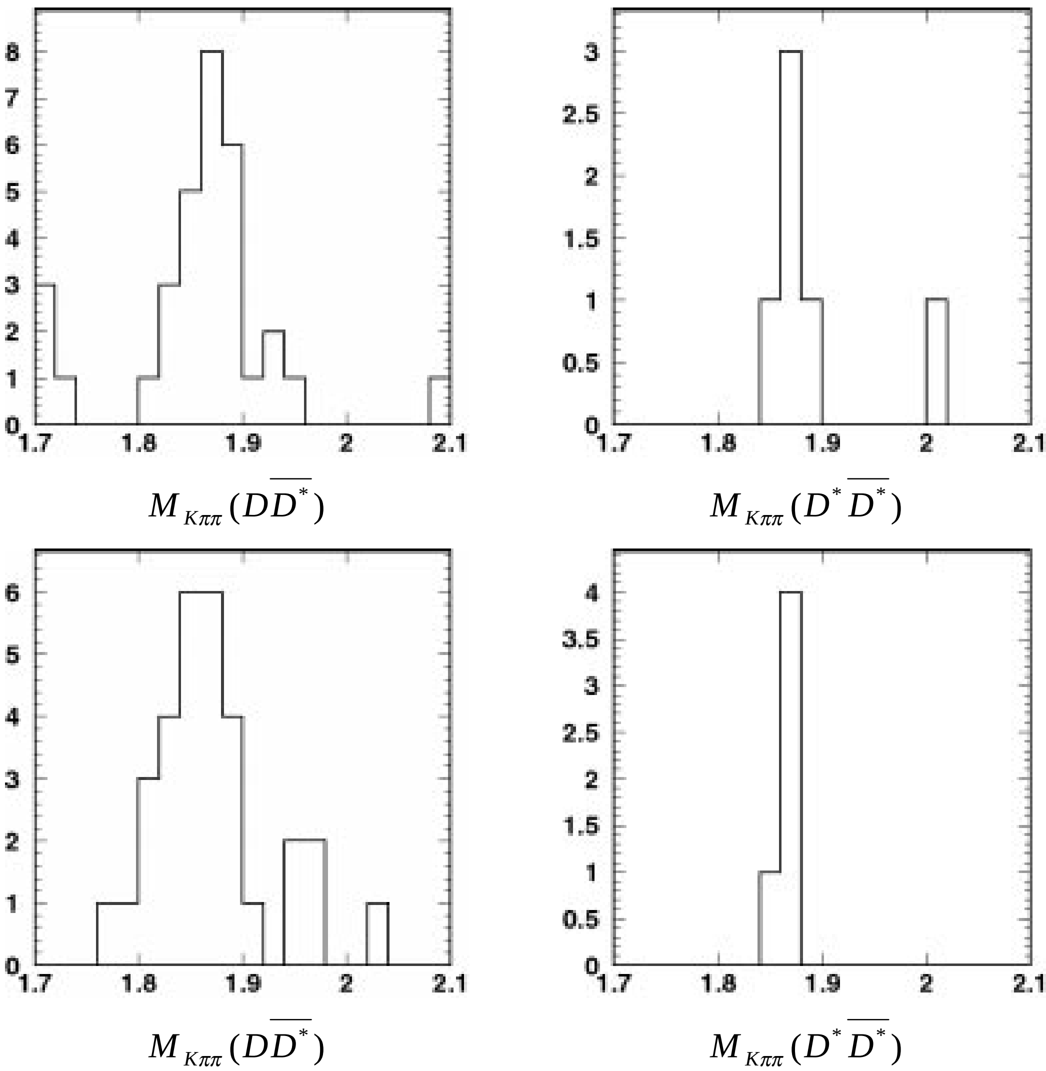


$M_{K\pi}(D\overline{D^*})$
$M_{K\pi}(D^*\overline{D^*})$
$M_{K\pi}(D\overline{D^*})$
$M_{K\pi}(D^*\overline{D^*})$

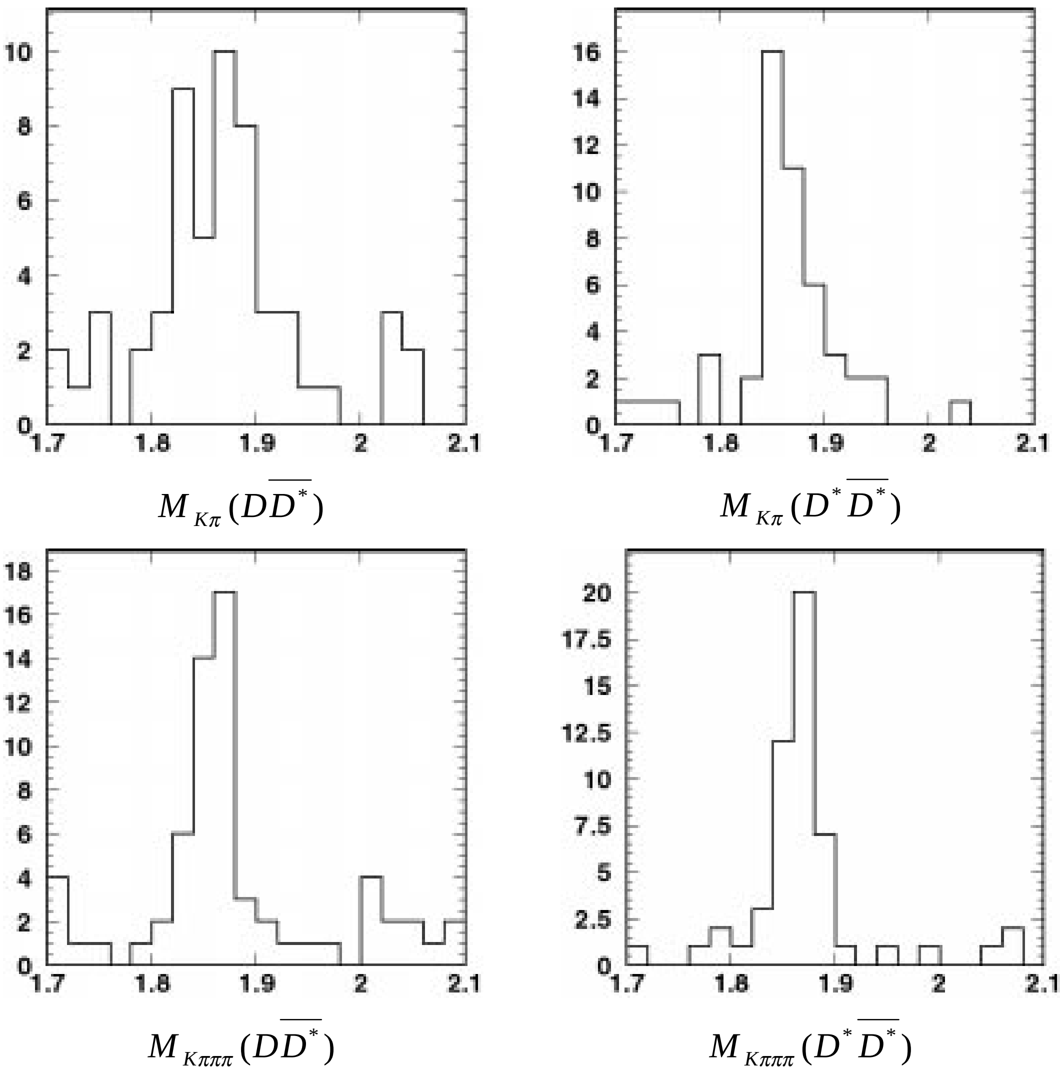
$K^-\pi^+$ vs $K^+\pi^-$



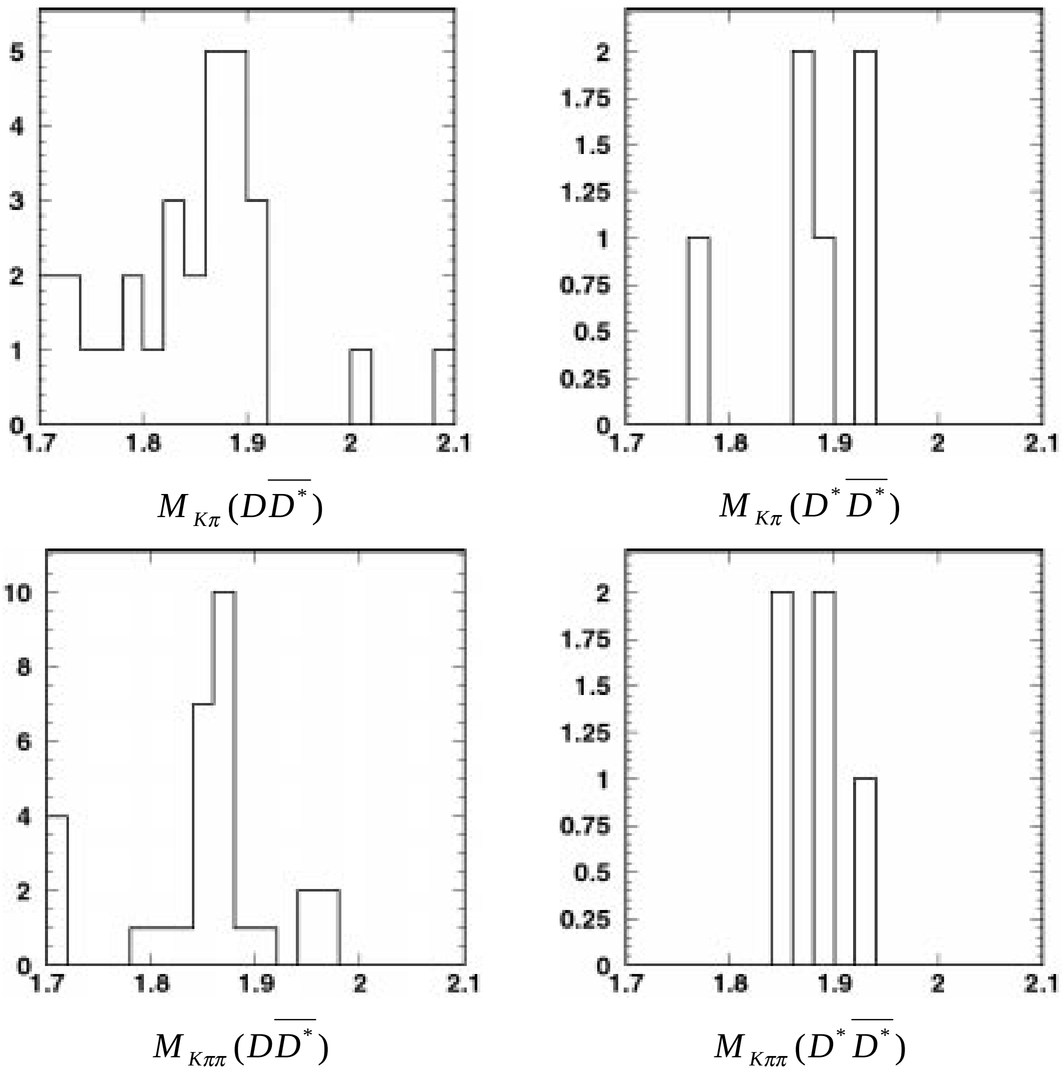
$K^-\pi^+\pi^+\pi^-$ vs $K^+\pi^-\pi^-\pi^+$



$K^-\pi^+\pi^+$ vs $K^+\pi^-\pi^-$

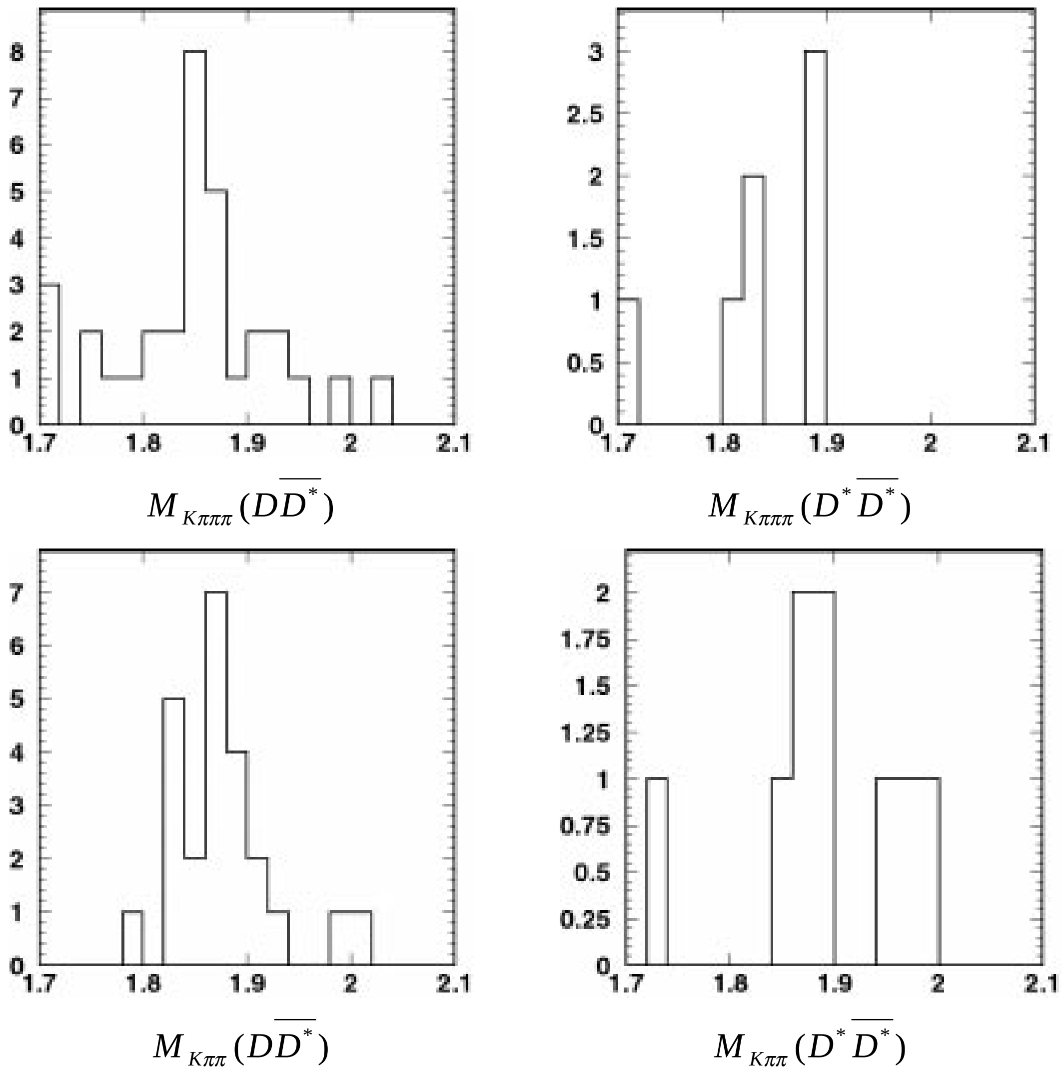


$K^-\pi^+$ vs $K^+\pi^-\pi^-\pi^+$



$M_{K\pi}(D\overline{D^*})$
$M_{K\pi}(D^*\overline{D^*})$
$M_{K\pi\pi}(D\overline{D^*})$
$M_{K\pi\pi}(D^*\overline{D^*})$

$K^-\pi^+$ vs $K^+\pi^-\pi^-$



$K^-\pi^+\pi^+$ vs $K^+\pi^-\pi^-\pi^+$

Monte Carlo efficiency

- BES $D\overline{D^*}$, $D^*\overline{D^*}$ generator + full detector simulation at 4.03 GeV.

- Single-tags:
  1. Tag side: specified Mode via D or $\overline{D^*}$
  2. Recoil side: cocktail (all possible modes, *Br* according to PDG data).
  3. Double Counting correction was made.

- Double-tags:
  1. Tag side: specified Mode via D or $\overline{D^*}$
  2. Recoil side: specified Mode via D or $\overline{D^*}$

$Br(D^0 \to K^- \pi^+)$ **Measurement**

Data are splinted into 2 samples ($D\overline{D^*}$, $D^* \overline{D^*}$)

1. $D\overline{D^*}$

Let

$$N_0 = N_{D^0 \overline{D^{*0}}} = L \cdot \sigma_{D^0 \overline{D^{*0}}}$$

$$N_c = N_{D^+ D^{*-}} = L \cdot \sigma_{D^+ D^{*-}}$$

The observed Single-tags(S) and Double-tags(D) can be expressed as:

$$S_i^0 = 2N_0 \varepsilon_i B_i + N_c \varepsilon_i B_i B_0^+$$

$$S_i^c = N_c \varepsilon_i B_i + N_c \varepsilon_i B_i (1 - B_0^+)$$

$$D_{ij}^{00} = f_{ij} N_0 \varepsilon_{ij} B_i B_j$$

$$D_{ij}^{cc} = f_{ij} N_c \varepsilon_{ij} B_i B_j (1 - B_0^+)$$

$$D_{ij}^{0c} = N_c \varepsilon_{ij} B_i B_j B_0^+$$

where ,

$$B_0^+ = Br(D^{*+} \to \pi^+ D^0)$$

$$f_{ij} = \begin{cases} 1 & i = j \\ 2 & i \neq j \end{cases}$$

2. $D^* \overline{D^*}$

Let

$$N_0 = N_{D^{*0}\overline{D^{*0}}} = L \cdot \sigma_{D^{*0}\overline{D^{*0}}}$$
$$N_c = N_{D^{*+}D^{*-}} = L \cdot \sigma_{D^{*+}D^{*-}}$$

The observed Single-tags(S) and Double-tags(D) can be expressed as:

$$S_i^0 = 2N_0\varepsilon_i B_i + 2N_c\varepsilon_i B_i B_0^+$$
$$S_i^c = 2N_c\varepsilon_i B_i(1 - B_0^+)$$
$$D_{ij}^{00} = f_{ij}(N_0 + N_c(B_0^+)^2)\varepsilon_{ij}B_i B_j$$
$$D_{ij}^{cc} = f_{ij}N_c\varepsilon_{ij}B_i B_j(1 - B_0^+)^2$$
$$D_{ij}^{0c} = 2N_c\varepsilon_{ij}B_i B_j B_0^+(1 - B_0^+)$$

where ,

$$B_0^+ = Br(D^{*+} \to \pi^+ D^0)$$
$$f_{ij} = \begin{cases} 1 & i = j \\ 2 & i \neq j \end{cases}$$

In final, all single-tags and double-tags are employed in a χ^2 minimization fit :

$$\chi^2 = \sum_i \frac{(S_{measure}^i - S_{pre}^i)^2}{\sigma_{S_{measure}^i}^2} + \sum_{ij} \frac{(D_{measure}^{ij} - D_{pre}^{ij})^2}{\sigma_{D_{measure}^{ij}}^2}$$

Results

$$Br(D^0 \to K^-\pi^+) = (3.9 \pm 0.5 \pm 0.3)\%$$
$$Br(D^0 \to K^-\pi^+\pi^+\pi^-) = (8.0 \pm 1.1 \pm 0.5)\%$$
$$Br(D^+ \to K^-\pi^+\pi^+) = (9.6 \pm 3.0 \pm 0.8)\%$$

$$Br(D^{*+} \to \pi^+ D^0) = (57 \pm 10 \pm 4)\%$$

$$N_{D^0\overline{D^{*0}}} = (5.69 \pm 1.23) \times 10^4$$
$$N_{D^{*+}D^-} = (5.23 \pm 1.55) \times 10^4$$

$$N_{D^{*0}\overline{D^{*0}}} = (4.91 \pm 0.92) \times 10^4$$
$$N_{D^{*+}D^{*-}} = (1.88 \pm 0.47) \times 10^4$$

The fit yields a χ^2 of 6.65 for 10 degrees of freedom

$D\overline{D^*}$

Double Tags	$K^-\pi^+$	$K^-\pi^+\pi^+\pi^-$	$K^-\pi^+\pi^+$
$K^+\pi^-$ (fit)	14 ± 5 17	35 ± 7 33	15 ± 6 16
$K^+\pi^-\pi^-\pi^+$ (fit)		14 ± 6 19	17 ± 5 16
$K^+\pi^-\pi^-$ (fit)			22 ± 5 22
Single Tags (fit)	2200 ± 103 2270	1954 ± 136 1754	2147 ± 109 2155

$D^*\overline{D^*}$

Double Tags	$K^-\pi^+$	$K^-\pi^+\pi^+\pi^-$	$K^-\pi^+\pi^+$
$K^+\pi^-$ (fit)	25 ± 6 18	38 ± 7 35	5 ± 3 6
$K^+\pi^-\pi^-\pi^+$ (fit)		13 ± 5 18	5 ± 3 5
$K^+\pi^-\pi^-$ (fit)			5 ± 3 4
Single Tags (fit)	1856 ± 60 1839	1654 ± 67 1684	515 ± 52 515

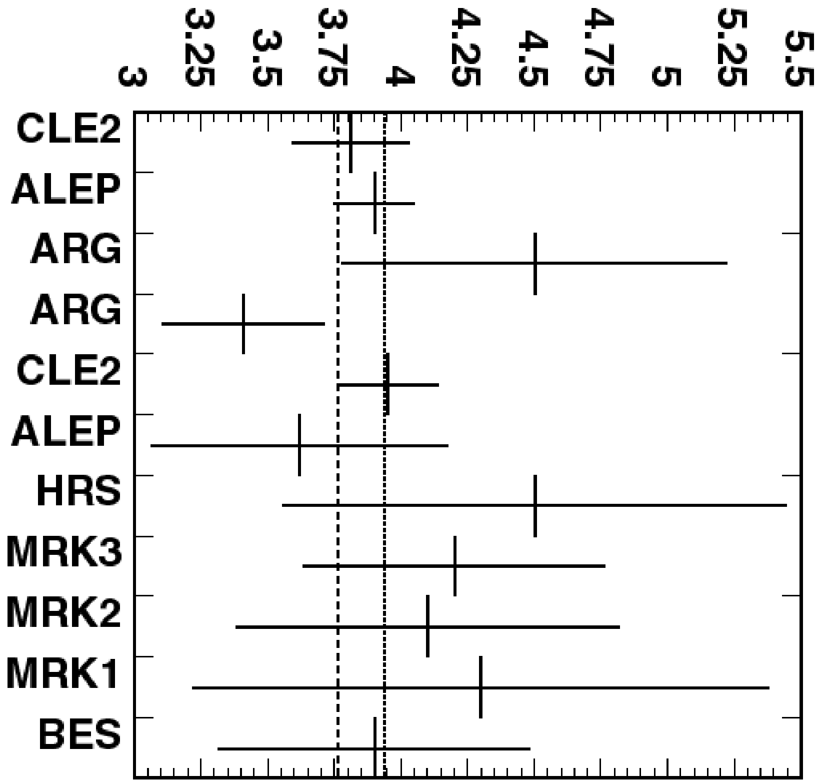
Systematic Error

- Uncertainty in events selection : 3~7%
  1. Single track selection
  2. Particle identification
  3. Double counting correction
  4. Momentum CUT
  5. Sideband subtraction (Double-tags)

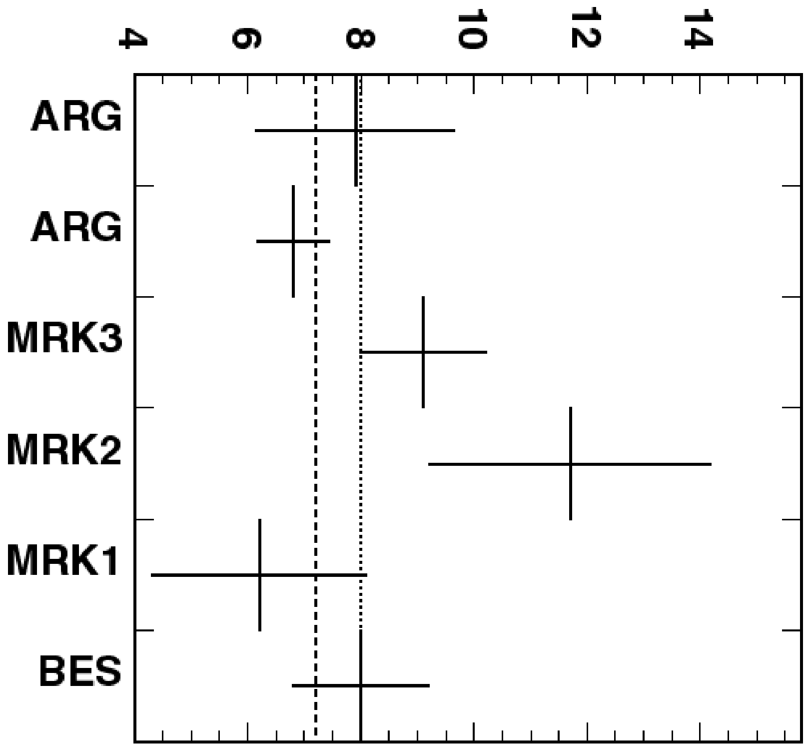
- Uncertainty in detection efficiency: ~5%

List of systematic errors

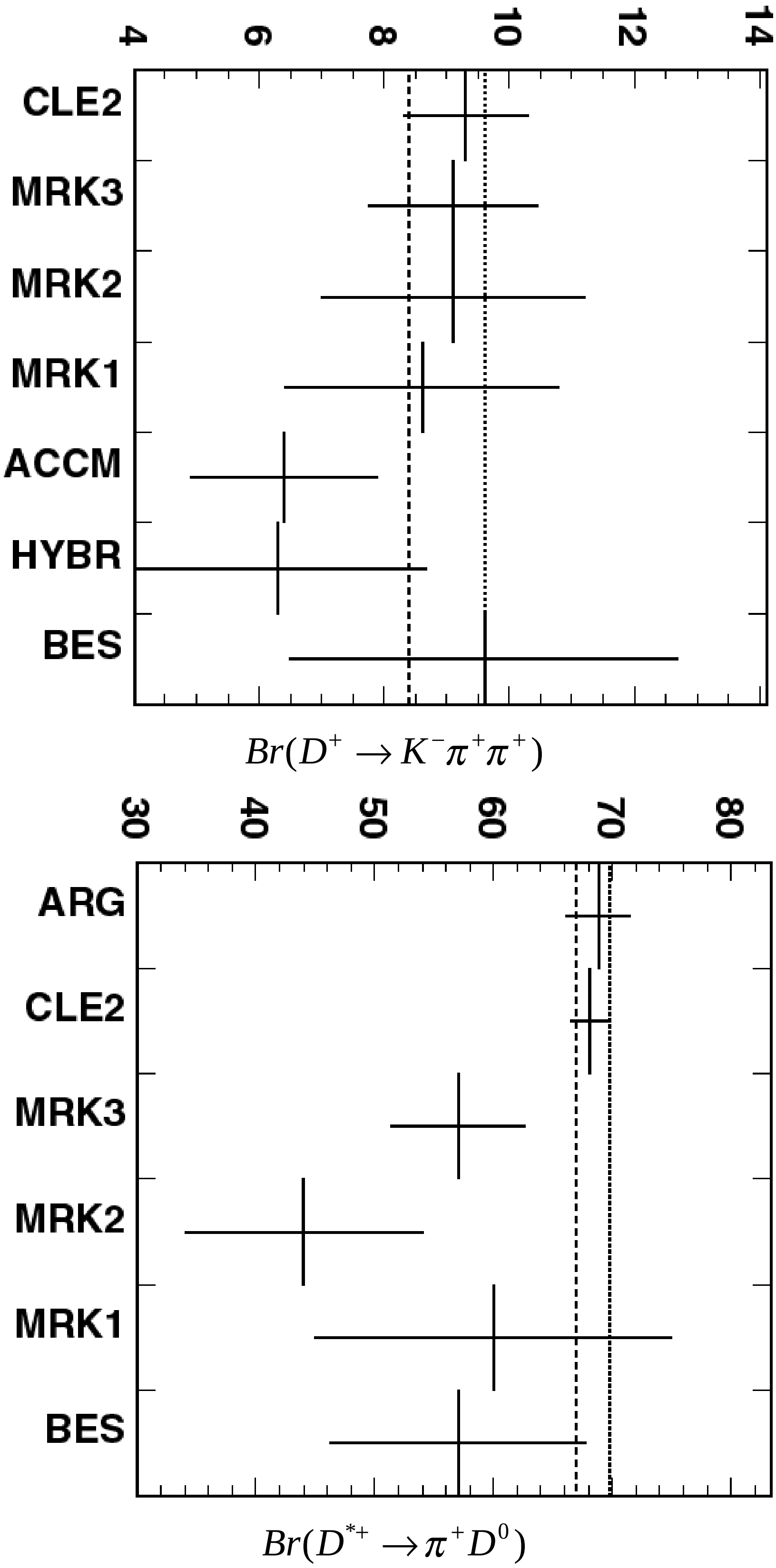
Term / Br	Events Selection	Detection Efficiency	Total (%)
$Br(D^0 \to K^- \pi^+)$	0.2	0.2	0.3
$Br(D^0 \to K^- \pi^+ \pi^+ \pi^-)$	0.3	0.4	0.5
$Br(D^+ \to K^- \pi^+ \pi^+)$	0.6	0.5	0.8
$Br(D^{*+} \to \pi^+ D^0)$	3.0	2.9	4.0



$Br(D^0 \to K^- \pi^+)$



$Br(D^0 \to K^- \pi^+ \pi^+ \pi^-)$



4
6
8
10
12
14
CLE2
MRK3
MRK2
MRK1
ACCM
HYBR
BES
$Br(D^+ \to K^- \pi^+ \pi^+)$
30
40
50
60
70
80
ARG
CLE2
MRK3
MRK2
MRK1
BES
$Br(D^{*+} \to \pi^+ D^0)$