First ADS analysis of $B^- \rightarrow D^0 K^- \rightarrow K^- \bar{K}^0$ decays in hadron collisions

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Motivation: CKM $\gamma$ angle measurement

CKM matrix

$$V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

CP violation if $\eta \neq 0$

$\beta \rightarrow u$ transition
B meson system
CKM $\gamma$ angle through $B \to DK$ decays

**CKM matrix**

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \lambda^2 / 2 & \lambda & A\lambda^3 \left( \rho - i\eta \right) \\ -\lambda & 1 - \lambda^2 / 2 & A\lambda^2 \\ A\lambda^3 \left( 1 - \rho - i\eta \right) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

**CP violation if $\eta \neq 0$**

![Diagram of CP violation](image)

**Use of $B \to DK$ decays is the cleanest way to measure $\gamma$:**
- tree-level amplitude only
- tiny theoretical uncertainties

$\gamma$ can be extracted exploiting the interference between the processes $b \to c\bar{s}$ ($B^- \to D^0 K^-$) and $b \to u\bar{c}s$ ($B^- \to \bar{D}^0 K^-$), when $D^0$ and $\bar{D}^0$ decay into the same final state

Favored $b \to c$ transition

$$A_1 \sim V_{cb} V_{us}^* \sim \lambda^3$$

Color suppressed $b \to u$ transition, sensitive to $\gamma$

$$A_2 \sim V_{ub} V_{cs}^* \sim \lambda^3 r_B e^{-i\delta_B} e^{-i\gamma}$$
Current situation of $\gamma$ using $B^- \rightarrow D^0 K^-$

- **GGSZ (Giri-Grossmann-Soffer-Zupan) method** ([PRL78,3257, PRD68,054018])
  that uses the $B^\pm \rightarrow D K^\pm$ decays with the $D^0$ and $\bar{D}^0$ reconstructed into three-body final state. For example the $D^0 \rightarrow K_{s}^{0} \pi^+ \pi^-$
- **GLW (Gronau-London-Wyler) method** ([PLB253,483 PLB265,172])
  that uses the $B^\pm \rightarrow D K^\pm$ decays with $D_{CP}$ decay modes. $D_{CP+} \rightarrow \pi^+ \pi^-, K^+ K^-$
  and $D_{CP-} \rightarrow K_{s}^{0} \pi^0, K_{s}^{0} \omega, K_{s}^{0} \phi$. 
- **ADS (Atwood-Dunietz-Soni) method** ([PRL78,3257; PRD63,036005])
  that uses the $B^\pm \rightarrow D K^\pm$ decays with $D$ reconstructed in the doubly Cabibbo suppressed $D^0 \rightarrow K^+ \pi^-$

$\gamma$ is the least well-known angle of the CKM triangle nowadays.

$\gamma(\text{deg}) = 68 \pm 13 - 14$

$\gamma(\text{deg}) = 76 \pm 11$
ADS method

Direct CP violation in suppressed $B \rightarrow DK$ modes
Interference of “suppressed modes”:

\[ V_{ub} \sim \gamma \]

1) Color suppressed

\[ b \rightarrow c \]

\[ V_{ub} \sim V_{cs} \]

\[ K^- \]

\[ \pi^- \]

They decay into the same final state and they are indistinguishable.

2) Color favored

\[ b \rightarrow s \]

\[ V_{ub} \sim V_{us} \]

\[ K^+ \]

\[ \pi^- \]

\[ \text{Doubly Cabibbo suppressed} \]

\[ f_{col-sup} \text{ large CP-violating asymmetry} \]
**ADS observables**

**Observables**

\[ A_{ADS}(K) = \frac{\mathcal{B}(B^{-} \to [K^{+}\pi^{-}]_{D}K^{-}) - \mathcal{B}(B^{+} \to [K^{-}\pi^{+}]_{D}K^{+})}{\mathcal{B}(B^{-} \to [K^{+}\pi^{-}]_{D}K^{-}) + \mathcal{B}(B^{+} \to [K^{-}\pi^{+}]_{D}K^{+})} \]

Asymmetry of the suppressed modes

\[ R_{ADS}(K) = \frac{\mathcal{B}(B^{-} \to [K^{+}\pi^{-}]_{D}K^{-}) + \mathcal{B}(B^{+} \to [K^{-}\pi^{+}]_{D}K^{+})}{\mathcal{B}(B^{-} \to [K^{-}\pi^{+}]_{D}K^{-}) + \mathcal{B}(B^{+} \to [K^{+}\pi^{-}]_{D}K^{+})} \]

Ratio of suppressed and favored modes

\[ R^{\pm}(K) = \frac{\mathcal{B}(B^{\pm} \to [K^{\mp}\pi^{\pm}]_{D}K^{\pm})}{\mathcal{B}(B^{\pm} \to [K^{\pm}\pi^{\mp}]_{D}K^{\pm})} \]

Ratio of suppressed and favored modes, charge separated. R+ and R- are statistically uncorrelated and sensitive to γ

From theory:

\[ A_{ADS}(K) = 2r_{B}r_{D} \sin(\delta_{B} + \delta_{D})\sin\gamma/R_{ADS}(K) \]

\[ R_{ADS}(K) = r_{D}^{2} + r_{B}^{2} + 2r_{B}r_{D}\cos(\delta_{B} + \delta_{D}) \cos\gamma \]

\[ R^{\pm}(K) = r_{D}^{2} + r_{B}^{2} + 2r_{B}r_{D}\cos(\delta_{B} + \delta_{D} \pm \gamma) \]
Asymmetry of the $\pi$ mode

$$A_{\text{ADS}} = \frac{2r_B r_D \sin(\delta_B + \delta_D) \sin \gamma}{r_D^2 + r_B^2 + 2r_B r_D \cos(\delta_B + \delta_D) \cos \gamma}$$

The maximum value achievable is:

$$A_{\text{ADS}}^{\text{MAX}} = \frac{2r_B r_D}{r_D^2 + r_B^2}$$

For the $K$ mode:
- $r_B(K) \sim 0.1$
  \[ A_{\text{ADS}}^{\text{MAX}}(K) \sim 0.9 \]

For the $\pi$ mode:
- $r_B(\pi) \sim 0.005$
  \[ A_{\text{ADS}}^{\text{MAX}}(\pi) \sim 0.16 \]


Small $CP$-violating asymmetries are possible also for the $\pi$ mode, so we will measure the ADS observables also this mode.
To measure $R_{ADS}$ and $R^\pm$ we need to reconstruct two decay channels:

**"Suppressed" mode**

- Final state is $B^- \rightarrow D(\rightarrow K^+ \pi^-) h^-$
- Color suppressed
- Cabibbo favored

**"Favored" mode**

- Final state is $B^- \rightarrow D(\rightarrow K^- \pi^+) h^-$
- Color favored
- Cabibbo favored

Also the channel with the color suppressed transition of the $B$, followed by the doubly Cabibbo suppressed decay of the $D^0$ has this same final state, but its contribution is negligible.
To measure $R_{ADS}$ and $R^\pm$ we need to reconstruct two decay channels:

**“Suppressed” mode**

Color favored

$doubly~Cabibbo~suppressed$

Color suppressed

Cabibbo favored

**“Favored” mode**

Color favored

Cabibbo favored

Also the channel with the color suppressed transition of the B, followed by the doubly Cabibbo suppressed decay of the $D^0$ has this same final state, but its contribution is negligible.

Final state is

$B^- \rightarrow D(\rightarrow K^+ \pi^-) h^-$

Same sign charge

Final state is

$B^- \rightarrow D(\rightarrow K^- \pi^+) h^-$
In the ADS method we have two observables and four unknowns.

The results has to be combined with other methods to extract $\gamma$.

For example, we can combine ADS and GLW methods, measure all the interesting branching ratios and fit $r_B$, $\delta_B$, $\delta_D$ and $\gamma$.

Or, for example, we can use external inputs for the (well-known) D quantities and fit $r_B$ and $\gamma$. 
Current measurements of the ADS observables

BaBar (467M BB)

(Phys.Rev.D 82, 072006 (2010))

\( \mathcal{R}_{DK} = (1.1 \pm 0.6 \pm 0.2) \times 10^{-2} \)

\( A_{DK} = -0.86 \pm 0.47^{+0.12}_{-0.16} \)

\(~ 20 \) \( B \rightarrow DK \) events,

with a significance of \( \sim 2 \sigma \)
Current measurements of the ADS observables

**BaBar (467M BB)**
(Phys.Rev.D 82, 072006 (2010))

**Belle (772M BB)**
(arXiv:1103.5951v1)

\( \approx 20 \, \text{B} \rightarrow \text{D} \, \text{K} \) events,
with a significance of \( \approx 2\sigma \)

\( \mathcal{R}_{DK} = (1.1 \pm 0.6 \pm 0.2) \times 10^{-2} \)

\( \mathcal{A}_{DK} = -0.86 \pm 0.47 ^{+0.12}_{-0.16} \)

\( \approx 56 \, \text{B} \rightarrow \text{D} \, \text{K} \) events,
with a significance of \( 4.1\sigma \)

\[ \mathcal{R}_{DK} = [1.63^{+0.44}_{-0.41}(\text{stat})^{+0.07}_{-0.13}(\text{syst})] \times 10^{-2} \]

\[ \mathcal{A}_{DK} = -0.39^{+0.26}_{-0.28}(\text{stat})^{+0.04}_{-0.03}(\text{syst}) \]
Current measurements of the ADS observables

BaBar (467M BB) (Phys.Rev.D 82, 072006 (2010))

Belle (772M BB) (arXiv:1103.5951v1)

LHCb (343pb⁻¹) (Preliminary for EPS)

\[ \mathcal{R}_{DK} = (1.1 \pm 0.6 \pm 0.2) \times 10^{-2} \]

\[ A_{DK} = -0.86 \pm 0.47 ^{+0.12}_{-0.16} \]

~ 20 B→DK events, with a significance of ~2σ

Significance of B→DK~4.0σ
First measurement of $A_{ADS}$, $R_{ADS}$ and $R^{\pm}$ at a hadron collider
Analysis overview

• Use the 7fb⁻¹ of data.

• Completely data-driven measurement -- the favored $B \rightarrow D\pi$ mode is used as a model for the suppressed.

• Cuts optimization, to find a significant suppressed peak.

• Invariant mass distribution with the pion mass hypothesis to the track from $B$. --> Need to disentaggle the signal and background contributions with an extended unbinned maximum likelihood fit.

• Efficiency corrections.
Favored and suppressed samples ($L = 7 \text{ fb}^{-1}$)

**Favored** $\bar{B} \rightarrow D(\rightarrow K^- \pi^+) \pi^-$

**Suppressed** $\bar{B} \rightarrow D(\rightarrow K^+ \pi^-) \pi^-$

CDF Run II Preliminary $L_{\text{int}} = 7 \text{ fb}^{-1}$

**Favored decay**

$\bar{B} \rightarrow D_{\text{fav}}^0 \pi^- \rightarrow [K^- \pi^+] \pi^- + \text{c.c.}$

**Suppressed decay**

$\bar{B} \rightarrow D_{\text{sup}}^0 \pi^- \rightarrow [K^+ \pi^-] \pi^- + \text{c.c.}$
Favored and suppressed samples ($L = 7\,\text{fb}^{-1}$)

**Favored $B^- \to D(\to K^- \pi^+)\pi^-$**

**Suppressed $B^- \to D(\to K^+ \pi^-)\pi^-$**

Cuts optimization

- We directly used the CF sample (not MC) selecting the signal ($S$) in $\pm 2\sigma$ of $B \to D\pi$ peak and the background ($B$) in $[5.4, 5.8]$ range
- We maximized the quantity $\frac{S}{1.5 + \sqrt{B}}$ (arXiv:0308063v2)

Crucial step toward the DCS modes
**Optimized selection**

**$D^0$ candidate**

Cuts on:
- the invariant mass
- veto on the swapped identity of the D decay products
- angular distribution
- the decay length wrt B to remove $B \rightarrow 3$ body decays
- particle identification of tracks from $D^0$ to remove $D^0 \rightarrow \pi \pi$ events
Optimized selection

**B candidate**

Cuts on:
- decay length wrt primary vertex
- impact parameter
- angle between momentum and decay length
Optimized selection

**B candidate**

Cuts on:
- decay length wrt primary vertex
- impact parameter
- angle between momentum and decay length

**isolation**

\[
I(B) = \frac{p_T(B)}{p_T(B) + \sum_i p_T(i)}
\]

- 3D vertex quality, obtained with the 3D silicon-tracking, to:
  - resolve multiple vertices along the beam direction
  - reject fake tracks.

Background reduces \(\times 2\), small inefficiency on signal (<10%).
Favored and suppressed after cut optimization

Favored \( B^- \rightarrow D(\rightarrow K^- \pi^+) \pi^- \)

Suppressed \( B^- \rightarrow D(\rightarrow K^+ \pi^-) \pi^- \)

CDF Run II Preliminary \( L_{\text{int}} = 7 \text{ fb}^{-1} \)

**Favored decay**
\[
B^- \rightarrow D_{\text{fav}}^0 \pi^- \rightarrow [K^- \pi^+] \pi^- + \text{c.c.}
\]

**Suppressed decay**
\[
B^- \rightarrow D_{\text{sup}}^0 \pi^- \rightarrow [K^+ \pi^-] \pi^- + \text{c.c.}
\]

Events per 10 MeV/c^2

Signal region
Fit procedure

$B^- \rightarrow DK^-$ signal overlaid in the tail of the $B^- \rightarrow D\pi^-$. Use of an extended unbinned maximum likelihood fit (combined on favored and suppressed modes) to separate them.

We used:

- mass information
- particle identification ($dE/dx$ with $K-\pi$ separation: $1.5\sigma$ for $p > 2$ GeV/c)

Common parameters between favored and suppressed:

- ratio between $N(B^- \rightarrow D^{*0} \pi^-)/N(B^- \rightarrow D^0 \pi^-)$
- combinatorial background pdf
To reject most of the physics backgrounds, we narrow the fit windows, starting from $5.17 \text{ GeV/c}^2$.

After a MC study, we found that the most significant background contributions are:

- $B^- \rightarrow D^{0*} \pi^-$, $D^{0*} \rightarrow D^{0} \gamma/\pi^0$ for both favored and suppressed
- for the suppressed only:
  - the inclusive $B^- \rightarrow D \rightarrow X h^-$
  - the three body $B^- \rightarrow K^- \pi^+ \pi^-$
  - the $B^0 \rightarrow D_0^{*+} l^{+} \nu_l$

All contributions are modeled using MC simulation and included in the fit.
Results: favored reconstruction

\[ B^+ \rightarrow \bar{D}(\rightarrow K^+ \pi^-) \pi^+ \]

CDF Run II Preliminary \( L_{\text{int}} = 7 \text{ fb}^{-1} \)

\[ B^- \rightarrow \bar{D}(\rightarrow K^- \pi^+) \pi^- \]

CDF Run II Preliminary \( L_{\text{int}} = 7 \text{ fb}^{-1} \)

Yield \( (B \rightarrow D_{\text{fav}}K) = 1461 \pm 57 \ (7 \text{ fb}^{-1}) \)

Yield \( (B \rightarrow D_{\text{fav}}\pi) = 19774 \pm 145 \ (7 \text{ fb}^{-1}) \)
Results: suppressed reconstruction

\[ B^+ \rightarrow D(K^- \pi^+) \pi^+ \]

\[ B^- \rightarrow D(K^+ \pi^-) \pi^- \]

CDF Run II Preliminary \(L_{\text{int}} = 7 \text{ fb}^{-1}\)

Yield (\(B \rightarrow D_{\text{sup}}K\)) = 32 ± 12 (significance = 3.2 \(\sigma\) (with syst))

Yield (\(B \rightarrow D_{\text{sup}}\pi\)) = 55 ± 14 (significance = 3.6 \(\sigma\))
Results: suppressed reconstruction

\[ B^+ \rightarrow D(\rightarrow K^- \pi^+) \pi^+ \]

\[ B^- \rightarrow D(\rightarrow K^+ \pi^-) \pi^- \]

CDF Run II Preliminary \( L_{\text{int}} = 7 \text{ fb}^{-1} \)

Significance for a non-null \( A_{\text{ADS}}(K) \) value is \( 2.2\sigma \)
Results: the observables

First measurement of $A_{ADS}$, $R_{ADS}$ and $R^\pm$ at a hadron collider.

Results are corrected for different reconstruction efficiency of: $K^+/K^-$, $\pi^+/\pi^-$ and $K^+\pi^-/K^-\pi^+$

Final results:

$$R_{ADS}(\pi) = (2.8 \pm 0.7 \text{ (stat.)} \pm 0.4 \text{ (syst.)}) \cdot 10^{-3}$$

$$R_{ADS}(K) = (22.0 \pm 8.6 \text{ (stat.)} \pm 2.6 \text{ (syst.)}) \cdot 10^{-3}$$

$$A_{ADS}(\pi) = 0.13 \pm 0.25 \text{ (stat.)} \pm 0.02 \text{ (syst.)}$$

$$A_{ADS}(K) = -0.82 \pm 0.44 \text{ (stat.)} \pm 0.09 \text{ (syst.)}$$

$A_{ADS}(K)$ is 2.2$\sigma$ far from zero.

$$R^+(\pi) = (2.4 \pm 1.0 \text{ (stat.)} \pm 0.4 \text{ (syst.)}) \cdot 10^{-3}$$

$$R^+(K) = (42.6 \pm 13.7 \text{ (stat.)} \pm 2.8 \text{ (syst.)}) \cdot 10^{-3}$$

$$R^-(\pi) = (3.1 \pm 1.1 \text{ (stat.)} \pm 0.4 \text{ (syst.)}) \cdot 10^{-3}$$

$$R^-(K) = (3.8 \pm 10.3 \text{ (stat.)} \pm 2.7 \text{ (syst.)}) \cdot 10^{-3}$$

(CDF public note 10615)
Comparing the observables...

...the results are in agreement and compatible with other experiments.

\[ B \rightarrow D\pi \]

- **BABAR** (PRD10.072006)
- **Belle** (arXiv:1103.3951)
- **CDF II**
- **AVG** (HESG)

\[ B \rightarrow D\pi \] \[ R_{ADS}(\pi) \]

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\[ B \rightarrow DK \]

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- **CDF II**
- **LHCb** (EPS preliminaries)

\[ B \rightarrow DK \] \[ R_{ADS}(K) \]

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\[ B \rightarrow DK \] \[ A_{ADS}(K) \]

- **BABAR** (PRD10.072006)
- **Belle** (arXiv:1103.3951)
- **CDF II**
- **LHCb** (EPS preliminaries)

Yellow band is the old average.

Results are combined with other methods to obtain \( \gamma \) measurement.
CDF program on $\gamma$: GLW result

The ADS measurement belongs to a broader program of CDF for measuring $\gamma$ from trees.

Recently published the GLW measurement using 1 fb$^{-1}$ of data (Phys.Rev.D81:031105,2010)

Direct CP violation in $B\rightarrow D_{CP+}(\rightarrow K\bar{K}/\pi\pi)$ K modes

Yield ($B\rightarrow D_{CP+}K$) $\sim$ 90 (1 fb$^{-1}$)
Conclusions

• CDF performed:
  • first measurement of $A_{\text{ADS}}$, $R_{\text{ADS}}$ and $R^{\pm}$ at a hadron collider using 7 fb$^{-1}$.
    • Evidence of suppressed $D_{\pi}$ and $DK$ signals
    • $A_{\text{ADS}}(K)$ at 2.2$\sigma$ different from zero
  • first measurement of $A_{\text{CP}^+}$ and $R_{\text{CP}^+}$ at a hadron collider using 1 fb$^{-1}$.

• Significantly contribute to global knowledge of $\gamma$

• CDF demonstrated the capability of hadron collider with $B$ to charm decays, getting competitive results with B-factories.
BACK-UP
The Tevatron

Good performances on Run II:
- peak $L_{\text{inst}} = 3.5 - 4 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$
- delivering 2.5 fb$^{-1}$/year

Tevatron is great for rare B decay searches:
- **Large $b$ production cross section**
  (x1000 times larger than $e^+e^-$ B factories)
- **All B species** are produced ($B^0$, $B^+$, $B_s$, $\Lambda_b...$)
The Tevatron

Tevatron is great for rare B decay searches:

- **Large b production cross section**
  (x1000 times larger than e⁺e⁻ B factories)
- **All B species** are produced (B⁰, B⁺, Bₛ, Λ_b,...)

But:

- The **total inelastic x-section** is a factor 10³ larger than \( \sigma(b\bar{b}) \)
- The **BRs** of rare b-hadron decays are \( O(10^{-6}) \) or lower

Interesting events must be extracted from a high track multiplicity environment

Detectors need to have:

- **Very good tracking** and vertex resolution and highly selective trigger

Good performances on Run II:

- peak \( L_{\text{inst}} = 3.5-4 \times 10^{32}\text{cm}^{-2}\text{s}^{-1} \)
- delivering 2.5 fb⁻¹/year

tot delivered \( L_{\text{int}} > 11.5 \text{ fb}^{-1} \)
The CDF II detector

TRACKING system:

• DRIFT CHAMBER
  96 layers (|\eta|<1)
  \rightarrow 1.5\sigma \pi/K separation by dE/dx

• SILICON TRACKER
  7 layers (1.5-22cm from beam pipe)
  \rightarrow I.P. resolution 35 \mu m at 2 GeV
  \rightarrow \sigma(p_T)/p_T^2 \sim 0.015\% (c/GeV)

TRACKING TRIGGER system:

• Chamber track processor at L1, 2D tracks in COT, p_T > 1.5 GeV

• Silicon Vertex Trigger at L2, 2D tracks p_T > 2 GeV,
  Impact Parameter measurement (trigger on events containing long lived particles)
Fit procedure

Use of an extended unbinned maximum likelihood fit (combined on favored and suppressed modes) to separate signals contribution.

\[
\mathcal{L} = \prod_{k} \frac{\mu^N}{N!} e^{-\mu} [f_{\text{sig}} \mathcal{F}_{\text{sig}} + (1 - f_{\text{sig}}) \cdot \mathcal{F}_{\text{back}}]
\]

\(F_{\text{sig}}\) = sum of \(B^{-} \rightarrow D^{0} \pi^{-}\), \(B^{-} \rightarrow D^{*0} \pi^{-}\) and \(B^{-} \rightarrow D^{0} K^{-}\) likelihood

\(F_{\text{back}}\) = sum of combinatorial and physics background likelihood

We used:
- mass information
- particle identification (dE/dx with K-π separation: 1.5 \(\sigma\) for p > 2 GeV/c)

Common parameters between favored and suppressed:
- ratio between \(N(B^{-} \rightarrow D^{*0} \pi^{-})/ N(B^{-} \rightarrow D^{0} \pi^{-})\)
- combinatorial background pdf
Implementation of a Likelihood FIT using masses and particle identification (dE/dx) information to determine the signal composition.

\[ \text{K}^+ - \pi \text{ separation: } 1.5 \sigma \text{ for } p > 2 \text{ GeV/c} \]
Results: physics background

Physics background for DCS:

<table>
<thead>
<tr>
<th>Decay</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^- \rightarrow D^0 \pi^-, D^0 \rightarrow D^0 \gamma/\pi^0$</td>
<td>$2 \pm 1$</td>
</tr>
<tr>
<td>$B^- \rightarrow D^0 \pi^-, D^0 \rightarrow X$</td>
<td>$100 \pm 10$</td>
</tr>
<tr>
<td>$B^- \rightarrow D^0 K^-, D^0 \rightarrow X$</td>
<td>$3 \pm 3$</td>
</tr>
<tr>
<td>$B^- \rightarrow K^- \pi^+ \pi^-$</td>
<td>$11 \pm 3$</td>
</tr>
<tr>
<td>$B^0 \rightarrow D_0^{*-} e^+ \nu_e$</td>
<td>$5 \pm 3$</td>
</tr>
</tbody>
</table>

CDF Run II Preliminary $L_\text{int} = 7$ fb$^{-1}$

$B^+ \rightarrow \bar{D}_{\text{sup}}^0 \pi^+ \rightarrow [K^- \pi^+] \pi^+$

$B^+ \rightarrow \bar{D}_{\text{sup}}^0 \pi^+ \rightarrow [K^- \pi^+] \pi^+$

$B^+ \rightarrow \bar{D}_{\text{sup}}^0 \pi^+ \rightarrow [K^+ \pi^-] \pi^-$

$B^+ \rightarrow \bar{D}_{\text{sup}}^0 \pi^+ \rightarrow [K^+ \pi^-] \pi^-$
- dE/dx we varied the shapes of the PID pdfs according to the full matrix correlation

- Combinatorial and physics background: we varied the shapes of the mass pdfs

- efficiency of K+/K-, π+/π-, K+π-/K−π+ reconstruction. The latter is estimated on our data
ADS: Likelihood

\[ \mathcal{L} = \mathcal{L}_{CF^+} \cdot \mathcal{L}_{CF^-} \cdot \mathcal{L}_{DCS^+} \cdot \mathcal{L}_{DCS^-} \]

\[
\mathcal{L}_{CF^+} = \prod_i^{N_{\text{events}}} \left[ (1 - b_{CF^+}) \cdot \left( f^{CF^+}_\pi \cdot \text{pdf}_\pi(M, ID) + c^+ \cdot f^{CF^+}_\pi \cdot \text{pdf}_{D^*}(M, ID) \right) + \left( 1 - f^{CF^+}_\pi - c^+ \cdot f^{CF^+}_\pi \right) \cdot \text{pdf}_K(M, ID) \right] + b_{CF^+} \cdot \text{pdf}_{\text{comb}}(M, ID)
\]

\[
\mathcal{L}_{DCS^+} = \prod_i^{N_{\text{events}}} \left[ (1 - b_{DCS^+}) \cdot \left( f^{DCS^+}_\pi \cdot \text{pdf}_\pi(M, ID) + c^+ \cdot f^{DCS^+}_\pi \cdot \text{pdf}_{D^*}(M, ID) \right) + \left( 1 - f^{DCS^+}_\pi - c^+ \cdot f^{DCS^+}_\pi \right) \cdot \text{pdf}_K(M, ID) \right] + b_{DCS^+} \cdot \left( f^+_\pi \cdot \text{pdf}_\pi^{[X]}(M, ID) + f^+_K \cdot \text{pdf}_K(M, ID) + f^+_0 \cdot \text{pdf}_0(M, ID) \right) + (1 - f^+_\pi - f^+_K - f^+_0) \cdot \text{pdf}_{\text{comb}}(M, ID)
\]

- \( \text{pdf}_i(M, ID) = \text{pdf}_i(M) \cdot \text{pdf}_i(ID) \)
- **Fitted parameters**
  - \( b_{CF, DCS} \) = background fraction for CF and DCS
  - \( f_{\pi, CF, DCS} = B^{-} \rightarrow D^0 \pi^{-} \) fraction for CF and DCS signal
  - \( c = f_{B^+} / f_{\pi} \) (equal for CF and DCS)
  - \( f_{[X]}^{\pi} \) = fraction of \( B^{-} \rightarrow D^0 \pi^{-}, D^0 \rightarrow X \) in DCS reconstruction (constrained from MC)
  - \( f_{[X]}^{K} \) = fraction of \( B^{-} \rightarrow D^0 K^{-}, D^0 \rightarrow X \) in DCS reconstruction (constrained from MC)
  - \( f_{K^{\pi\pi}} \) = fraction of \( B^{-} \rightarrow K^{-} \pi^{+} \pi^{-} \) in DCS reconstruction (constrained from MC)
  - \( f_{B^0} \) = fraction of \( B^0 \rightarrow D^{*-} e^+ \nu \) in DCS reconstruction (constrained from MC)

Analogous expressions for negative charges.
CDF program on $\gamma$

The ADS measurement belongs to a broader program of CDF for measuring $\gamma$ from trees.

Recently published the **GLW measurement** using 1 fb$^{-1}$ of data (Phys. Rev. D81:031105, 2010)

The **GLW method**

- Direct CP violation in $B \rightarrow D_{CP}K$ modes
  
  ($D_{CP+} \rightarrow \pi^+\pi^-, K^+K^-$ and $D_{CP-} \rightarrow K^0_s\pi^0, K^0_s\omega, K^0_s\phi$.)

- very clean method

- small asymmetry, sensitivity to $\gamma$ proportional to $r_B$

The observables

\[
R_{CP\pm} = \frac{\Gamma(B^- \rightarrow D_{CP\pm}^0K^-) + \Gamma(B^+ \rightarrow D_{CP\pm}^0K^+)}{[\Gamma(B^- \rightarrow D^0K^-) + \Gamma(B^+ \rightarrow D^0K^+)]/2}
\]

\[
A_{CP\pm} = \frac{\Gamma(B^- \rightarrow D_{CP\pm}^0K^-) - \Gamma(B^+ \rightarrow D_{CP\pm}^0K^+)}{\Gamma(B^- \rightarrow D_{CP\pm}^0K^-) + \Gamma(B^+ \rightarrow D_{CP\pm}^0K^+)}
\]

From theory:

\[
R_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\gamma
\]

\[
A_{CP\pm} = 2r_B \sin\delta_B \sin\gamma/R_{CP\pm}
\]

3 independent equations

($A_{CP+}R_{CP+} = -A_{CP-}R_{CP-}$)

and 3 unknowns ($r_B, \gamma, \delta_B$)