OBSERVATION OF THE RARE CHARMED B DECAY,

\[ B_d^0 \rightarrow D^{(*)+} \alpha^- \]

AT THE BABAR EXPERIMENT

ON FINDING A NEEDLE IN A HAYSTACK
SEARCH FOR THE RARE B DECAY \[ B^0_d \rightarrow D^{(*)+} a^-_0 \]

Contents

- BaBar and CP violation
- Physics goals and production mechanism
- Analysis
  - Optimization of signal selection
  - Setup of three dimensional likelihood fit
  - Results
- Interpretation and outlook

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PEP II's LINAC is 1.9 miles long: longest building in the world!!
BABAR and anti-matter

- BaBar at PEPII collider, SLAC ('99-'08)
- Focus on measurements of CP violation: differences between matter/anti-matter
- Run at $e^+e^-$ collisions at $Y(4S)$:
  clean coherent B-meson production
- (On tape 526.5 million $\bar{B}B$ pairs)

![Graph showing mass distribution with peaks at $1S$, $2S$, $3S$, and $4S$ states, with $BB$ threshold and $Y(4S)$ indicated.]
CP violation in electroweak decays (1)

Quark changes flavor due to weak interaction

3x3 flavor changing currents

\[
\begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\]

Cabibbo-Kobayashi-Maskawa (CKM) matrix
CP violation in electroweak decays (1)

\[
\begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
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\end{pmatrix}
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Cabibbo-Kobayashi-Maskawa (CKM) matrix

CKM Matrix must be unitary (conservation of probability):

- 9 equations (6 triangles)
- 4 free parameters, (3 magnitudes + 1 complex phase)
CP violation in electroweak decays (1)

Cabibbo-Kobayashi-Maskawa (CKM) matrix

\[ \begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
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V_{td} & V_{ts} & V_{tb}
\end{pmatrix} \]

CKM Matrix must be unitary (conservation of probability):

- 9 equations (6 triangles)
- 4 free parameters, (3 magnitudes + 1 complex phase)

Relative magnitudes:

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CP violation in electroweak decays (2)

\[ V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \]

Cabibbo-Kobayashi-Maskawa (CKM) matrix

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CP violation in electroweak decays (2)

- **W^+**
  - $q = u, c, t$
  - $V_{qq'}$
  - $q' = d, s, b$

**Unitarity Triangle**

- $V_{ud}V_{ub}^*$
- $V_{td}V_{tb}^*$
- $V_{cd}V_{cb}^*$

**Cabibbo-Kobayashi-Maskawa (CKM) matrix**

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

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CKM angles

- Over-constraining CKM triangle powerful test of Standard Model
CKM angles

- Over-constraining CKM triangle
  powerful test of Standard Model
Over-constraining CKM triangle powerful test of Standard Model

CKM angle $\gamma$ least constrained by measurements
$\alpha = 88 \pm 5^\circ, \beta = 22 \pm 5^\circ, \gamma = 77 \pm 30^\circ$

Measured through time dependent interference in $B$ decays

Current measurements through
$B^0 \rightarrow D^{*+}\pi^- $ and $B^0 \rightarrow D^{*+}\rho^-$

$B^0 \rightarrow D^{*+}a_0^-$ could be more sensitive

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Same initial and final state.
Weak phase difference gives \( \sin(2\beta + \gamma) \).
Asymmetry amplitude to phase given by the amplitude ratio.

Oscillation process where anti B meson changes in B meson

CKM angle \( 2\beta \)

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**Sensitivity to CKM angle $\gamma$**

- Same initial and final state.
- Weak phase difference gives $\sin(2\beta + \gamma)$.
- Asymmetry amplitude to phase given by the amplitude ratio.

Asymmetry amplitude: 

$$ \frac{A_I}{A_{II}} \propto \frac{V_{ub}^* V_{cd}}{V_{cb} V_{ud}} \times \frac{F_{B \to a_0}}{F_{B \to D}} \times \frac{f_D}{f_{a_0}} \approx 0.04 \times 1 \times 200 $$

Weak decay constants (MeV):

- $D^+$
- $D^{**}$
- $\pi^+$
- $\rho^+$
- $a_0^+$
- 200
- 300
- 130
- 200
- 1.1

Asymmetry amplitude to CKM phase is large for $B^0 \to D^{*+} a_0^-$. However, we also have less events because of low branching ratio.
So how large is the branching ratio? I

Using

\[ \langle Da_0 | B \rangle = \langle D | 0 \rangle \times \langle a_0 | B \rangle \]

amplitude small
due to \( V_{ub} \sim 10^{-6} \)
So how large is the branching ratio? II

Using
\[ \langle Da_0 | B \rangle = \langle D | 0 \rangle \times \langle a_0 | B \rangle \]

amplitude small due to Vub \( \sim 10^{-6} \)

W decay constants:

\[
\begin{align*}
&D^+ &D^{**} &a_0^* \\
&200 &300 &1.1
\end{align*}
\]

Using
\[ \langle Da_0 | B \rangle = \langle a_0 | 0 \rangle \times \langle D | B \rangle \]

amplitude small due decay constant \( \sim 10^{-6} \)
In short…

It means we use factorization principles.

No interactions between produced mesons XY.

Non-factorizing terms (with interactions produced mesons)
usually small …..

…. but not in case of $B^0 \rightarrow D^{(*)+}a_0^-$

Naïve prediction: $3 \times 10^{-6}$

Including calculable non-factorizing terms: $6 \times 10^{-6}$
**Punch line is:**
We search for the $B^0 \rightarrow D^{(*)+} a_0^-$ decay
We are looking for a needle in a haystack.

If we don’t find it
✓ we can eliminate non-factorizing QCD scenario’s

If we do
✓ we can eliminate other non-factorizing QCD scenario’s
✓ measure CKM angle $\gamma$ with high precision (potentially)
Decay reconstruction

- Lineshape width of $a_0$ uncertain: PDG 50 - 100 MeV
- Setup selection no criteria linewidth: a priori select $B^0 \rightarrow D(\ast)^+ \eta \pi^-$ events
- Use likelihood fit to discriminate resonant from non-resonant decay
- 6 $D$ decay modes for statistics selection and fit separate; different S/B
- Non-resonant $B^0 \rightarrow D(\ast)^+ \eta \pi^-$ decays not measured before: interesting on its own!

\[ B^0 \rightarrow D^+ a_0^- \]
\[ a_0^{22} \Gamma M \]
\[ D^+ \rightarrow K^+ \pi^+ \pi^- \]
\[ K_s^0 \pi^+ \]
\[ B^0 \rightarrow D^{*+} a_0^- \]
\[ D^{*+} \rightarrow D^0 \pi^+ \]
\[ D^0 \rightarrow K^+ \pi^- \]
\[ K^+ \pi^- \pi^0 \]
\[ K^+ \pi^- \pi^+ \pi^- \]
\[ K_s^0 \pi^- \pi^+ \]

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Signal selection optimization

- Defined 30 discriminatory observables
  - Particle properties $m/p/E$
  - Decay lengths $(D/K_s)$
  - Event shape
  - Utilize angular properties in decay

- 27 for event selection / 3 for likelihood fit

- Cuts are optimized while branching ratio is unknown!!
  - Using significance:
    $$SL = \frac{\varepsilon_S}{(n\sigma/2) + \sqrt{B}}$$
  - Desired observation
  - Significance
  - Signal selection efficiency
  - Background events

- Simultaneous optimization searches for highest $SL$
  - Using rectangular box cuts

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Punzi (2003) physics/0308063
Unbinned likelihood fit in 3 dimensions

1. $M_{ES}$ beam energy substituted mass, $m_{ES} = \sqrt{E_{beam}^* - P_B^2}$
   signal peaks at B mass, background as Argus shape

2. $\Delta E$ energy difference, $\Delta E = E^* - E_{beam}^*$
   signal peaks at 0, background flat

3. $M_{\eta\pi}$ invariant mass,
   resonant signal is Breit-Wigner, non resonant as phase space with kinematics
PDF shapes signal

peaks at B mass

Centered at 0

Breit-Wigner at $a_0$ mass

$M_{ES}$  $\Delta E$  $M_{\eta\pi}$

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PDF shapes non-resonant signal

$M_{ES}$  $\Delta E$  $M_{\eta\pi}$

peaks at B mass

Centered at 0

spin 0 phase space
PDF shapes background

\[ M_{ES} \quad \Delta E \quad M_{\eta \pi} \]

Combinatorics + kinematics green: peaking background

Blue: combinatorics green: peaking background

Peaking bkg not uniform

Used as control sample!

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PDF shapes summary

$B^0 \rightarrow D^+ \alpha_0^-$

$B^0 \rightarrow D^+ \eta \pi^-$

background

Shape parameters determined on MC and fixed in the fit to data
Adding the different $D$ decay modes

5 parameters fitted in likelihood fit for every $D$ decay mode:
1. (# resonant signal events) $\text{BR(reshaonant)}$
2. (# non-resonant signal events) $\text{BR(non-reshaonant)}$
3. # $D_s$ events
4. # BB background events
5. # qq background events

Combine $D^+$ and $D^{*+}$ decay modes
1. Simultaneous fit of branching ratios of $B^0 \rightarrow D^+ a_0^-$ and $B^0 \rightarrow D^+ \eta \pi^-$
2. Other 3 parameters fitted individually.

\[
\frac{\mathcal{B}(B \rightarrow D a_0) \times \mathcal{B}(a_0 \rightarrow \eta \pi)}{N_{\text{obs},i} \times N_{BB} \times B(D)_i \times \varepsilon_{\text{eff},i}} = \frac{1}{N_{BB} \times B(D)_i \times \varepsilon_{\text{eff},i}}
\]

$B^0 \rightarrow D^+ a_0^-$
$D^+ \rightarrow K^+ \pi^+ \pi^-$
$K_s^0 \pi^+$

$B^0 \rightarrow D^{*+} a_0^-$
$D^{*+} \rightarrow D^0 \pi^+$
$D^0 \rightarrow K^+ \pi^-$

$K^+ \pi^- \pi^0$ $K^+ \pi^- \pi^0 \pi^-$ $K_s^0 \pi^- \pi^+$

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Combined Fit Result

Full projection

$B^0 \rightarrow D^{**} a_0^-$
$B^0 \rightarrow D^{**} \eta \pi^-$
$B^0 \rightarrow D^{**} D_s^-$
Combined Fit Result

\[ B^0 \rightarrow D^{*+} a_0^- \]
\[ B^0 \rightarrow D^{*+} \eta \pi^- \]
\[ B^0 \rightarrow D^{*+} D_s^- \]
Combined Fit Result

$B^0 \rightarrow D^{*+} a_0^-$
$B^0 \rightarrow D^{*+} \eta \pi^-$
$B^0 \rightarrow D^{*+} D_s^-$

Full projection

$M_{ES}$ signal reg

$M_{\eta \pi}$ signal reg

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Combined Fit Result

$B^0 \rightarrow D^{**+} a_0^-$

$B^0 \rightarrow D^{**+} \eta \pi^-$

$B^0 \rightarrow D^{**+} D_s^-$

Full projection

$M_{ES}$ signal reg

$M_{\eta \pi}$ signal reg

$M_{ES}$ side region
Combined Fit Result

- $B^0 \rightarrow D^{**} a_0^-$
- $B^0 \rightarrow D^{**} \eta\pi^-$
- $B^0 \rightarrow D^{**} D_s^-$

Full projection

$M_{ES}$ signal reg

$M_{\eta\pi}$ signal reg

$M_{ES}$ side region

Graphs showing distributions for different decay modes with fitted distributions and data points.
Systematic uncertainties

- Determined using:
  - Full Monte Carlo studies
  - Toy Monte Carlo studies
  - Data sample itself
  - Control sample $B^0 \rightarrow D(\ast)^+ D_s^-$

- Largest uncertainties due to $a_0$ line-shape and selection validations
### Systematic uncertainties

Determined using:
- Full Monte Carlo studies
- Toy Monte Carlo studies
- Data sample itself
- Control sample

#### Largest uncertainties due to $a_0$ line-shape and selection validations

<table>
<thead>
<tr>
<th>Source</th>
<th>$D^\pm$ modes</th>
<th>$D^{*\pm}$ modes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$D$chI $D$chII</td>
<td>$D$stI $D$stII $D$stIII $D$stIV</td>
</tr>
<tr>
<td>bias offset (a.v.)</td>
<td>2.7 1.8</td>
<td>1.3 0.5 0.9 0.5</td>
</tr>
<tr>
<td>observed branching ratio</td>
<td>$2.7 \cdot 10^{-6}$</td>
<td>$4.0 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$\Gamma_{a_0}$ (a.v.)</td>
<td>$5.3 \cdot 10^{-8}$</td>
<td>$4.5 \cdot 10^{-8}$</td>
</tr>
<tr>
<td>$m_{a_0}$ (a.v.)</td>
<td>$3.2 \cdot 10^{-7}$</td>
<td>$3.8 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>$m_{\eta^{\pi}}$ eff. (a.v.)</td>
<td>$2.9 \cdot 10^{-7}$</td>
<td>$3.7 \cdot 10^{-7}$</td>
</tr>
</tbody>
</table>

### Table: Resonant signal specific errors

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<td>$D$chI $D$chII</td>
<td>$D$stI $D$stII $D$stIII $D$stIV</td>
</tr>
<tr>
<td>bias offset (a.v.)</td>
<td>8.3 8.2</td>
<td>3.7 2.5 4.6 3.0</td>
</tr>
<tr>
<td>observed branching ratio</td>
<td>$8.4 \cdot 10^{-8}$</td>
<td>$6.7 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>$\Gamma_{a_0}$ (a.v.)</td>
<td>$5.6 \cdot 10^{-8}$</td>
<td>$5.4 \cdot 10^{-8}$</td>
</tr>
<tr>
<td>$m_{a_0}$ (a.v.)</td>
<td>$5.3 \cdot 10^{-7}$</td>
<td>$1.4 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$m_{\eta^{\pi}}$ eff. (a.v.)</td>
<td>$7.2 \cdot 10^{-7}$</td>
<td>$8.0 \cdot 10^{-7}$</td>
</tr>
</tbody>
</table>

### Table: Non-resonant signal specific errors

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<tbody>
<tr>
<td></td>
<td>$D$chI $D$chII</td>
<td>$D$stI $D$stII $D$stIII $D$stIV</td>
</tr>
<tr>
<td>number of B events</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>$B$ counting (%)</td>
<td></td>
<td></td>
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<tr>
<td>fractional $D$ decay</td>
<td></td>
<td></td>
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<tr>
<td>$D^{(*)\pm}$ decay (%)</td>
<td>3.6 4.1</td>
<td>2.1 4.6 3.4 25.8</td>
</tr>
<tr>
<td>efficiency</td>
<td></td>
<td></td>
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<tr>
<td>$\pi^0$ ID (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K^0_S$ ID (%)</td>
<td></td>
<td></td>
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<tr>
<td>$\eta$ ID (%)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>tracking (%)</td>
<td>5.4 4.2</td>
<td>5.5 5.4 8.2 5.6</td>
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<tr>
<td>selection (%)</td>
<td>10</td>
<td>10</td>
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</table>
Profile likelihood

D* meson modes

$B_d^0 \rightarrow D^{**} a_0^-$

$B_d^0 \rightarrow D^{**} \eta \pi^-$

5.3$\sigma$

8.2$\sigma$

$(5.93^{+1.64+2.22}_{-1.48-1.52}) \times 10^{-5}$

$(33.91^{+5.47+6.80}_{-5.11-5.14}) \times 10^{-5}$
Combined Fit Result

$B^0 \rightarrow D^{+} a_0^-$
$B^0 \rightarrow D^{+} \eta \pi^-$
$B^0 \rightarrow D^{+} D_s^-$

Full projection
Combined Fit Result

- $B^0 \rightarrow D^+ a_0^-$
- $B^0 \rightarrow D^+ \eta \pi^-$
- $B^0 \rightarrow D^+ D_s^-$

Full projection

$M_{ES}$ signal reg

$M_{\eta \pi}$ signal reg

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Combined Fit Result

Full projection

$M_{ES}$ signal reg

$M_{\eta\pi}$ signal reg

$M_{ES}$ side region

$B^0 \rightarrow D^+ a_0^-$

$B^0 \rightarrow D^+ \eta \pi^-$

$B^0 \rightarrow D^+ D_s^-$
Combined Fit Result

- $B^0 \rightarrow D^+ a_0^-$
- $B^0 \rightarrow D^+ \eta\pi^-$
- $B^0 \rightarrow D^+ D_s^-$

Full projection

$M_{ES}$ signal reg

$M_{\eta\pi}$ signal reg

$M_{ES}$ side region

$B^0 \rightarrow D^+ a_0^-$

$B^0 \rightarrow D^+ \eta\pi^-$

$B^0 \rightarrow D^+ D_s^-$
Profile likelihood

D* meson modes

\[ B_d^0 \rightarrow D^{*+}a_0^- \]

5.3\(\sigma\)

\[
(5.93^{+1.64+2.22}_{-1.48-1.52}) \cdot 10^{-5}
\]

\[ B_d^0 \rightarrow D^{*+}\eta\pi^- \]

8.2\(\sigma\)

\[
(33.91^{+5.47+6.80}_{-5.11-5.14}) \cdot 10^{-5}
\]

D meson modes

\[ B_d^0 \rightarrow D^+a_0^- \]

4.4\(\sigma\)

\[
(-0.11^{+0.93+0.29}_{-0.67-0.76}) \cdot 10^{-5}
\]

\[ B_d^0 \rightarrow D^+\eta\pi^- \]

\[
(13.41^{+3.54+2.42}_{-3.25-1.94}) \cdot 10^{-5}
\]

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Profile likelihood

D* meson modes

\[ B_d^0 \to D^{*+} a_0^- \]

5.3\( \sigma \)

\[ (5.93^{+1.64+2.22}_{-1.48-1.52}) \cdot 10^{-5} \]

\[ B_d^0 \to D^{*+} \eta\pi^- \]

8.2\( \sigma \)

\[ (33.91^{+5.47+6.80}_{-5.11-5.14}) \cdot 10^{-5} \]

D meson modes

\[ B_d^0 \to D^+ a_0^- \]

4.4\( \sigma \)

\[ (-0.11^{+0.93+0.29}_{-0.67-0.76}) \cdot 10^{-5} \]

\[ B_d^0 \to D^+ \eta\pi^- \]

\[ (13.41^{+3.54+2.42}_{-3.25-1.94}) \cdot 10^{-5} \]

< 2.3 \cdot 10^{-5} @ 90\% c.l.

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Intermediate results

- Branching ratio of $B^0 \rightarrow D^{(*)+}a_0^-$ predicted (3-6) $10^{-6}$

- Analysis setup
  - Data selection optimization using ~30 variables
  - Likelihood fit in 3 observables

- Measured branching ratios
  - Non-resonant $B^0 \rightarrow D^+\eta\pi^-\ 1.3\ 10^{-5}$ at 4 $\sigma$ (46 events)
  - $B^0 \rightarrow D^{*+}\eta\pi^-\ 3.4\ 10^{-5}$ at 8 $\sigma$ (76 events)
  - Resonant $B^0 \rightarrow D^{*+}a_0^-\ 6.0\times10^{-5}$ at 5 $\sigma$ (30 events)
  - $B^0 \rightarrow D^+a_0^-\ >\ 2.3\times10^{-5}$ at 90 % CL

- Not enough for time-dependent analysis needed to measure $\gamma$ (?)
We measure $B^0 \rightarrow D^{*+} a_0^-$ at $6.0 \times 10^{-5}$ at $5 \sigma$ (30 events).

Naïve factorization model predicts $3 \times 10^{-6}$.

Including some QCD diagrams upper limit at $6 \times 10^{-6}$.

Restrictions on both naïve factorizable diagrams strict!
We measure $B^0 \to D^{*+}a_0^-$ $6.0 \times 10^{-5}$ at 5 $\sigma$ (30 events)

Naïve factorization model: $3 \times 10^{-6}$

Adding QCD diagrams: upper limit $6 \times 10^{-6}$

Restrictions on both naïve factorizable diagrams strict!

For naïve calculation we need to know:

CKM $V_{ub}$ $V_{cd}$ $V_{cb}$ $V_{ud}$

W decay $f_D$ $f_a_0$

B decay $F_{B \to D}$ $F_{B \to a}$

All well known or strong upper limit

Ratio I/II measured in time-dependent analysis (cosine term)
Rescattering

Possible rescattering through $D\alpha_1 \leftrightarrow D^*\alpha_0$

Not calculated, comparison with $D\rho \leftrightarrow D^*\pi$ gives order $10^{-6}$

Kinematic arguments: easily would be at order $10^{-5}$

Same CKM phase gamma!
Conclusion

- Branching ratio of $B^0 \to D^{(*)+}a_0^-$ predicted $(3-6) \times 10^{-6}$

- Analysis setup
  - Data selection optimization using $\sim 30$ variables
  - Likelihood fit in 3 observables

- Measured branching ratios
  - Non-resonant $B^0 \to D^+\eta\pi^-$: $1.3 \times 10^{-5}$ at 4 $\sigma$ (46 events)
    $B^0 \to D^{*+}\eta\pi^-$: $3.4 \times 10^{-5}$ at 8 $\sigma$ (76 events)
  - Resonant $B^0 \to D^{*+}a_0^-$: $6.0 \times 10^{-5}$ at 5 $\sigma$ (30 events)
    $B^0 \to D^+a_0^-$: $> 2.3 \times 10^{-5}$ at 90 % CL

- Not enough for time-dependent analysis needed to measure $\gamma$ (?)

- Time dependent analysis will give insight to high BF
CKM UT current status
Restrictions on both naïve factorizable diagrams strict!

QCD factorizable diagrams upper limit at $6 \times 10^{-6}$, factor 10 too low!

Possible rescattering through $D_1 \leftrightarrow D^*a_0$ not calculated, comparison with $D_0 \leftrightarrow D^*\pi$ gives order $10^{-6}$ but should be larger!! Easily would be at order $10^{-5}$. 
Per cycle:

- Evaluates significance level in given search area with cuts placed on all other variables.
- New, optimized, cut is placed in direction of the highest SL.
- All variables are evaluated in single cycle
\[a_0\] suppression mechanism

**G parity suppressed/second class current**

- Weak current has \(V-A\) behaviour
  
  - ‘natural’ spin-parity meson couple to \(V\), ‘unnatural’ to \(A\)

- \(G \equiv C e^{i\pi l_2}\)

- First class currents: \(G^+\) and \(V\), or \(G^-\) and \(A\)

- Second class currents: \(G^-\) and \(V\), or \(G^+\) and \(A\)

- \(a_0\) doubly suppressed; by CVC and \(G\) parity violating

<table>
<thead>
<tr>
<th>(X)</th>
<th>(\pi^\pm)</th>
<th>(a_1^\pm(1260))</th>
<th>(b_1^\pm(1235))</th>
<th>(a_0^\pm(980))</th>
<th>(\rho^\pm)</th>
<th>(\eta)</th>
</tr>
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<tbody>
<tr>
<td>(m_X) [MeV]</td>
<td>139.6</td>
<td>1230</td>
<td>1229.5</td>
<td>984.7</td>
<td>775.5</td>
<td>547.5</td>
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<tr>
<td>(G)</td>
<td>(-)</td>
<td>(-)</td>
<td>(+)</td>
<td>(-)</td>
<td>(+)</td>
<td>(+)</td>
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<td>(J^P)</td>
<td>0(^-)</td>
<td>1(^+)</td>
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<td>0(^+)</td>
<td>1(^-)</td>
<td>0(^-)</td>
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<td>weak coupling</td>
<td>(A)</td>
<td>(A)</td>
<td>(A)</td>
<td>(V)</td>
<td>(V)</td>
<td>n.a.</td>
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<td>FCC or SCC</td>
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<td>FCC</td>
<td>SCC</td>
<td>SCC</td>
<td>FCC</td>
<td>FCC</td>
</tr>
<tr>
<td>(f_X) [MeV]</td>
<td>131</td>
<td>238 [20]</td>
<td>(\sim 0.6 [20])</td>
<td>(\sim 1.6)</td>
<td>210</td>
<td>n.a.</td>
</tr>
</tbody>
</table>
- $S/\sqrt{B}$ – does not behave well for low numbers of $S$ (prefers $0.1/0.01$ over $10/2$)
- $S/\sqrt{S+B}$ – depends on BR!