# Hot Topics from BABAR

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BABAR™

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# Contents

Recent BABAR results:

- $B \to \rho^+ \rho^0$
- $B \to a_1^+ \pi^-$
- T, CP, and CPT studies in B mixing with dileptons
- FCNC search in charm decays
- Flavor-tagged charm in B decays

# $B^{\pm} \to \rho^{\pm}\rho^{0}$

Motivation: member of the B→ρρ isospin family: current most sensitive probe of the UT angle α

Data sample: 232M B-pairs

BABAR preliminary

$$BF = \left(17.2 \pm 2.5_{STAT} \pm 2.8_{SYST}\right)10^{-6}$$

Previous results: (from <100M B-pairs)

Belle, PRL 91, 221801 (2003)

$$BF = \left(31.7 \pm 7.1^{+3.8}_{STAT\,-6.7\,SYST}\right)10^{-6}$$

$$f_L = 0.95 \pm 0.11_{STAT} \pm 0.02_{SYST}$$

$$A_{CP} = 0.00 \pm 0.22_{STAT} \pm 0.03_{SYST}$$

BABAR, PRL 91, 171802 (2003)

$$BF = \left(22.5^{+5.7}_{-5.4\,STAT} \pm 5.8_{SYST}\right)10^{-6}$$

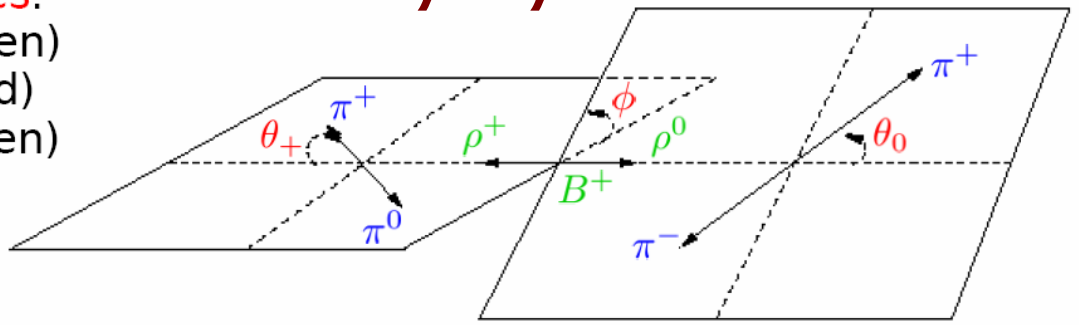
$$f_L = 0.97^{+0.03}_{-0.07\,STAT} \pm 0.04_{SYST}$$

$$A_{CP} = -0.19 \pm 0.23_{STAT} \pm 0.03_{SYST}$$

# $B^{\pm} \to \rho^{\pm}\rho^{0}$

Three partial waves:

- S (L=0, CP even)
- P (L=1, CP odd)
- D (L=2, CP even)

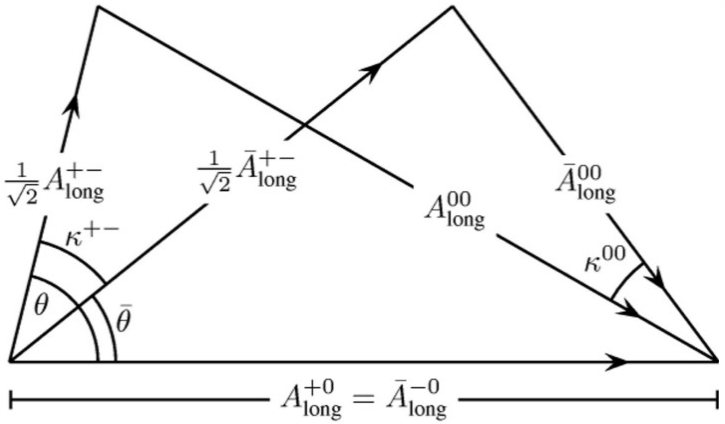



Helicity basis ($\lambda$=0,+1,-1):
the $\lambda$=0 state is a CP-even mixture of S and D waves (longitudinal polarization)
$f_L$ is the fraction of longitudinal component

Analysis simplified by integrating over $\phi$:

$$\frac{1}{\Gamma}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}\cos\theta_+\,\mathrm{d}\cos\theta_0} \propto \frac{1}{4}(1-f_L)\underbrace{\sin^2\theta_+\sin^2\theta_0}_{\text{transverse}} + f_L\underbrace{\cos^2\theta_+\cos^2\theta_0}_{\text{longitudinal}}$$

"polarisation"

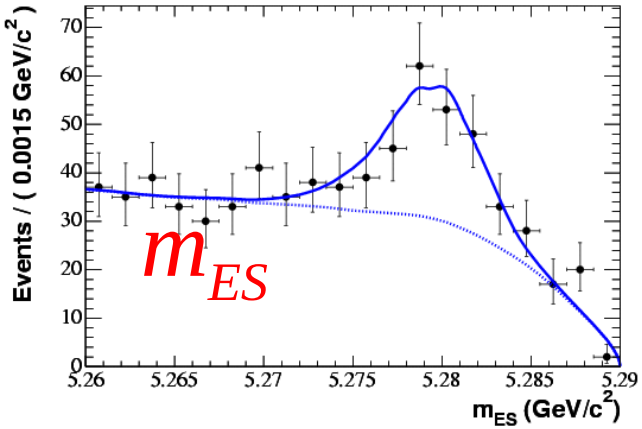



Longitudinal dominance in all observed modes
Isospin analysis (ignoring EW penguins)
Penguin pollution smaller than 2-pion system
Best reach in UT angle $\alpha$

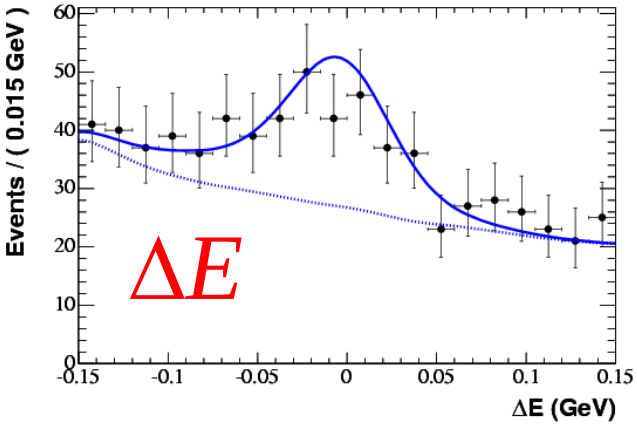
# $B^{\pm} \to \rho^{\pm}\rho^{0}$

Improved analysis, main features:

- PID: proton, electron, kaon veto
- $D^0$ mass veto
- Efficiency: 8.4% (long. pol.), 18.6% (transv. pol.)
- Extended likelihood fit using:
  - $m_{ES}$, $\Delta E$
  - Rho masses and decay angles $\theta$
  - Neural Net (8 variables, B versus continuum)
- Event categories:
  - Signal, reconstructed correctly
  - Signal, self-crossfeed
  - B backgrounds: 16 types
  - Continuum
- Fitted sample: 65,500 events
- Signal yield: 334±46 events




Likelihood-enhanced plots
~1/3 of signal
~0.8% of background




$$BF = \left(17.2 \pm 2.5_{STAT} \pm 2.8_{SYST}\right)10^{-6}$$

$$f_L = 0.96 \pm 0.04_{STAT} \pm 0.05_{SYST}$$

$$A_{CP} = -0.10 \pm 0.14_{STAT} \pm 0.09_{SYST}$$

# $B^0 \to a_1^{\pm}(1260)\pi^{\mp}$

Motivation:

- test of factorization
- poor knowledge of $a_1$ parameters
- possibly UT angle $\alpha$ in future

Data sample: 218M B-pairs

BABAR preliminary (hep-ex/0603050)

$$BF(B^0 \to a_1^{\pm}(1260)\pi^{\mp}) \times BF(a_1^{\pm}(1260) \to \pi^{\pm}\pi^{\mp}\pi^{\pm}) = \left(16.6 \pm 1.9_{STAT} \pm 1.5_{SYST}\right)10^{-6}$$

significance: $9.2\sigma$

Prediction (BSW): few times $10^{-5}$

Previous limits: few times $10^{-4}$ (CLEO, DELPHI)

# $B^0 \to a_1^{\pm}(1260)\pi^{\mp}$

- PID: proton, electron, kaon veto
- Vertex fit cut (at 0.01 probability)
- Efficiency: 11.7%
- Extended likelihood fit:
  - $m_{ES}$, $\Delta E$
  - resonance mass (relativistic B-W, mass-dependent width)
  - Fisher (B versus continuum)
  - Angular variable to distinguish from spin-2 $a_2(1320)$ and spin-0 $\pi(1300)$ – no significant yield found
  - No separation of $(\pi\pi)_\rho\pi$ and $(\pi\pi)_\sigma\pi$ – dominated by $\rho\pi$
- Fitted sample: 35,285 events
- Signal yield: 421±48 events

# $B^0 \to a_1^{\pm}(1260)\pi^{\mp}$

PDG mean $= (1230 \pm 40)\, MeV/c^2$

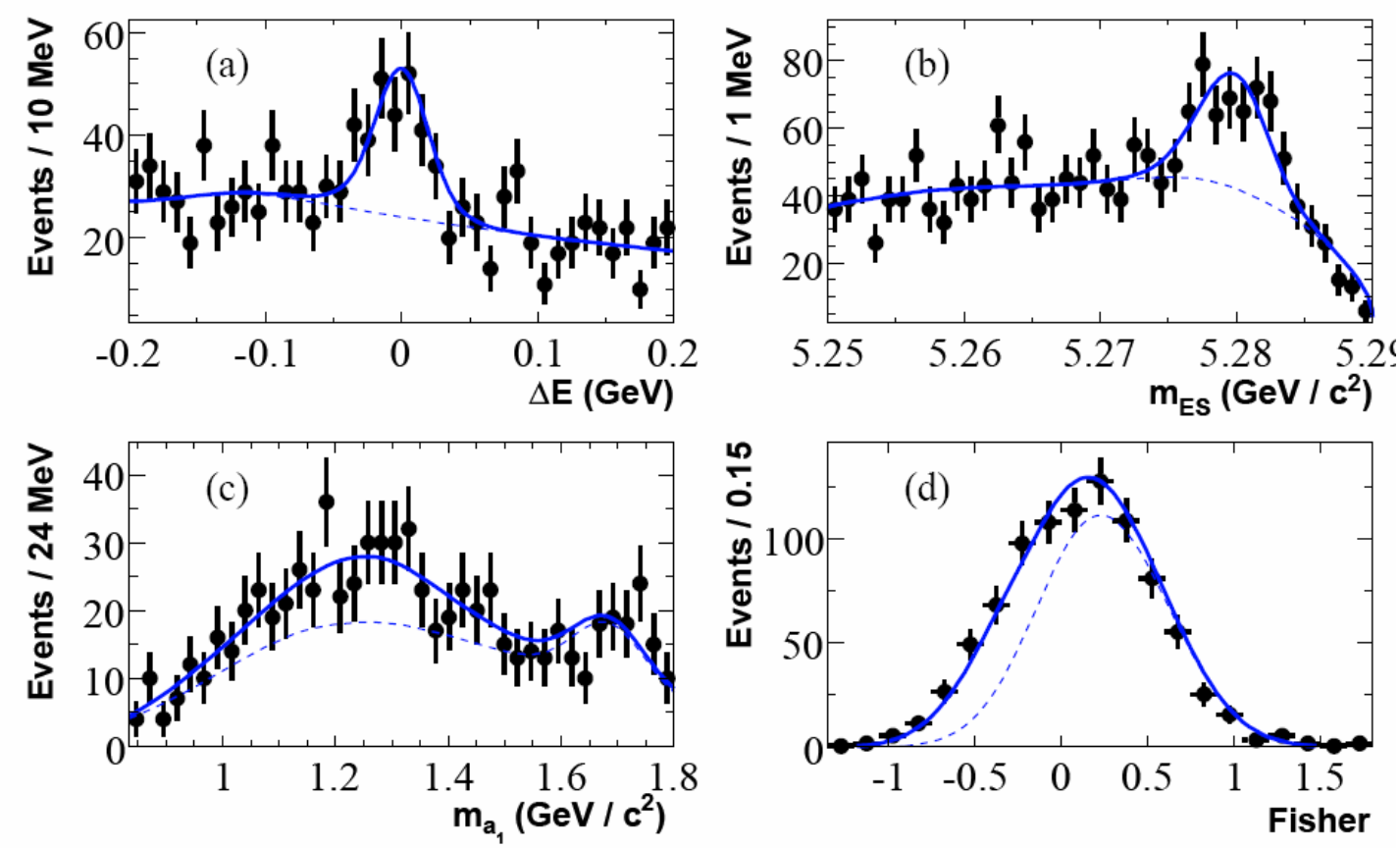
width $= 250 - 600\, MeV/c^2$

$a_1(1260)$ mass: Our result mean $= (1229 \pm 21)\, MeV/c^2$

width $= (393 \pm 62)\, MeV/c^2$

$$BF(B^0 \to a_1^{\pm}(1260)\pi^{\mp}) \times BF(a_1^{\pm}(1260) \to \pi^{\pm}\pi^{\mp}\pi^{\pm}) = (16.6 \pm 1.9_{STAT} \pm 1.5_{SYST})10^{-6}$$

significance: $9.2\sigma$



# Dileptons: T, CP, CPT (hep-ex/0603054)

Physical $B_d$ states:

$$|B_L^0>= p\sqrt{1-z}\,|B^0> +q\sqrt{1+z}\,|\overline{B}^0>)$$
$$|B_H^0>= p\sqrt{1+z}\,|B^0> -q\sqrt{1-z}\,|\overline{B}^0>)$$

$|q/p|\neq 1$ violates CP and T in mixing
$z\neq 0$ violates CP and CPT in mixing

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$$A_{T/CP}(\Delta t)=\frac{N(\ell^+\ell^+)-N(\ell^-\ell^-)}{N(\ell^+\ell^+)+N(\ell^-\ell^-)}\approx 2\left(1-\left|q/p\right|\right)$$

Time-independent asymmetry
Probes CP,T violation in mixing
$|q/p|$ small (~$10^{-3}$) in SM

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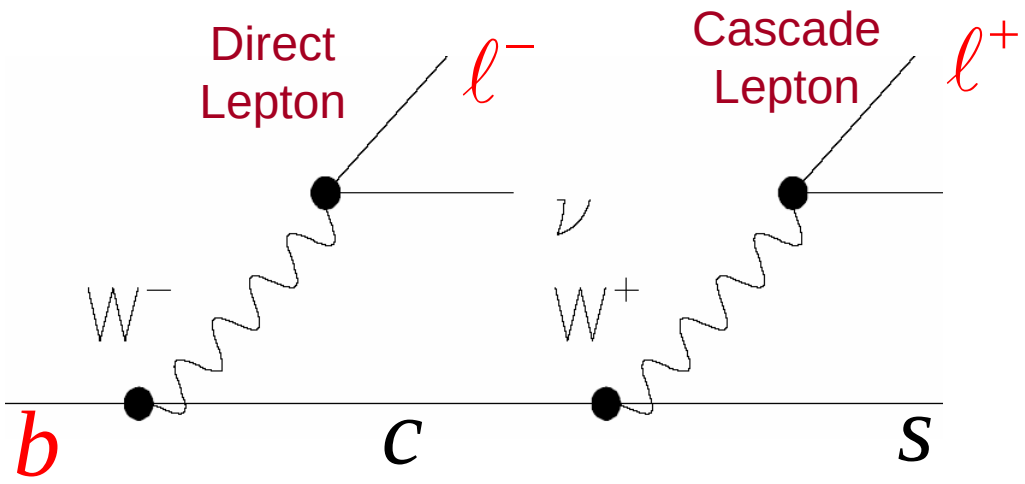
$$A_{CPT/CP}(|\Delta t|) = \frac{N(\ell+,\ell-)(\Delta t<0)-N(\ell+,\ell-)(\Delta t>0)}{N(\ell+,\ell-)(\Delta t<0)+N(\ell+,\ell-)(\Delta t>0)}$$
$$= 2\frac{\mathrm{Re}\,z\sinh(\Delta\Gamma\Delta t/2)-\mathrm{Im}\,z\sin(\Delta m_d\Delta t)}{(1+|z|^2)\cosh(\Delta\Gamma\Delta t/2)+(1-|z|^2)\cos(\Delta m_d\Delta t)}$$

Time-dependent asymmetry
Probes CP,CPT violation in mixing
Sensitive to Imz, $\Delta\Gamma$xRez

# Dileptons: T, CP, CPT




Semileptonic decays: lepton sign determines B flavour at decay time

Need to take into account:

- Cascade leptons
- Charm flight
- All possible combinations

# Dileptons: T, CP, CPT

- Data sample: 232M B-pairs
- Event selection:
  - Fox-Wolfram moments, invariant mass, aplanarity, track multiplicity
  - Tight lepton PID
  - Photon conversion and charmonium veto
- Event types in fit:
  - Signal (both leptons, 81% of B pair events)
  - Direct – cascade leptons from the two B mesons (9%)
  - Direct – cascade leptons from the same B meson (4%)
  - $b \rightarrow \tau \rightarrow (e \text{ or } \mu)$ (3%)
  - Charmonium leptons (3%)

# Dileptons: T, CP, CPT

**Results:**

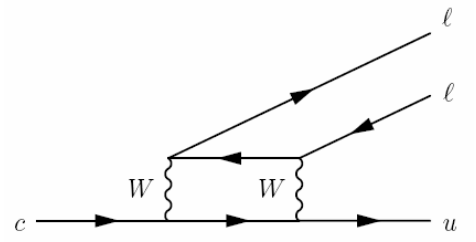
$$
\begin{aligned}
|q/p| - 1 &= (-0.8 \pm 2.7(\text{stat.}) \pm 1.9(\text{syst.})) \times 10^{-3}, \\
\text{Im}\, z &= (-13.9 \pm 7.3(\text{stat.}) \pm 3.2(\text{syst.})) \times 10^{-3}, \\
\Delta\Gamma \times \text{Re}\, z &= (-7.1 \pm 3.9(\text{stat.}) \pm 2.0(\text{syst.})) \times 10^{-3}\, \text{ps}^{-1}
\end{aligned}
$$

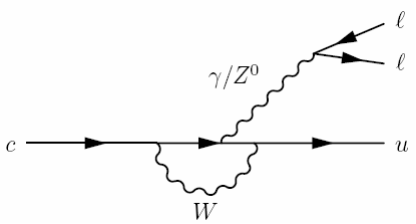
70% correlation

Extensive use of real data control samples

| **Systematic Effects** | $\sigma(\lvert q/p\rvert)$ $(\times 10^{-3})$ | $\sigma(\text{Im}\, z)$ $(\times 10^{-3})$ | $\sigma(\Delta\Gamma \times \text{Re}\, z)$ $(\times 10^{-3}\, \text{ps}^{-1})$ |
|---|---|---|---|
| Ch. asym. of non-$B\overline{B}$ bkg | 0.6 | 0.0 | 0.0 |
| Ch. asym. in tracking | 1.0 | 0.0 | 0.0 |
| Ch. asym. of electrons | 1.4 | 0.0 | 0.0 |
| PDF modeling | 0.3 | 2.5 | 1.2 |
| Fraction of bkg components | 0.2 | 0.4 | 0.1 |
| $\Delta m$, $\tau_{B^0}$, $\tau_{B^\pm}$ and $\Delta\Gamma$ | 0.2 | 1.9 | 1.1 |
| SVT alignment | 0.5 | 0.6 | 1.2 |
| Total | 1.9 | 3.2 | 2.0 |

# Search for FCNC in charm decays



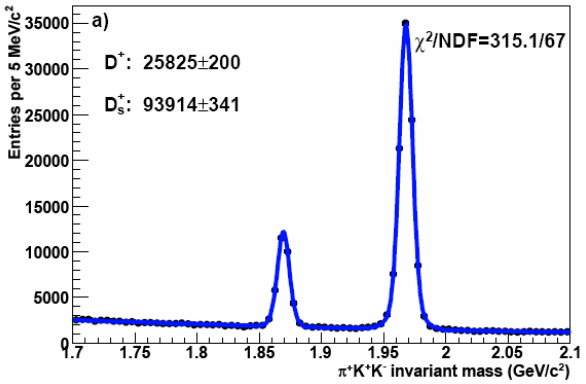




- FCNC: rare decays, ideal for NP searches
- So far big activity in $b\to s\ell\ell$, $b\to s\gamma$, $s\to d\ell\ell$, $s\to d\nu\nu$

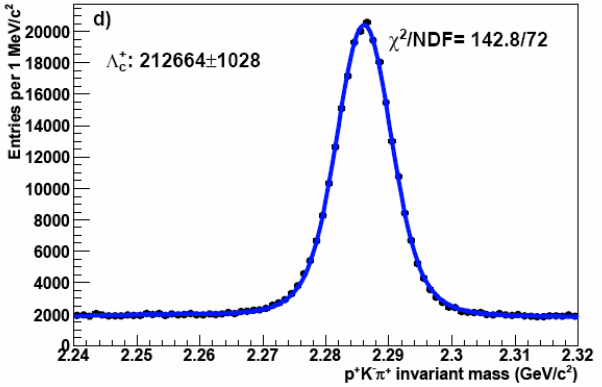
- FCNC in $c\to u\ell\ell$ strongly suppressed by GIM cancellations
- SM expectations for $D\to X_u l^+l^-$ at ~$10^{-8}$
- Intermediate resonances expected at ~$10^{-6}$
- Need to veto resonances in $l^+l^-$ invariant mass
- Example: $BF(D_S^+\to\pi\phi)=(3.6\pm0.9)\times10^{-2}$
  $BF(\phi\to e^+e^-)=(2.98\pm0.04)\times10^{-4}$
  $BF(D_S^+\to\pi\phi,\ \phi\to e^+e^-)\sim10^{-5}$

# Search for FCNC in charm decays

- Data sample: 288fb$^{-1}$
- Channels investigated: $D^+$, $D_S^+$, $\Lambda_c^+$ to ($\pi$, K, p)(ee, $\mu\mu$, e$\mu$)
- Event selection:
  - Tight lepton PID
  - Track counting, event shape: Bhabha, ISR, two-photon rejection
  - Lepton vertex and total energy, momentum: B decays rejection
  - Photon conversion veto
- Normalization modes:
  - Known D decays used for normalization
  - Cancellation of many non-PID systematic errors



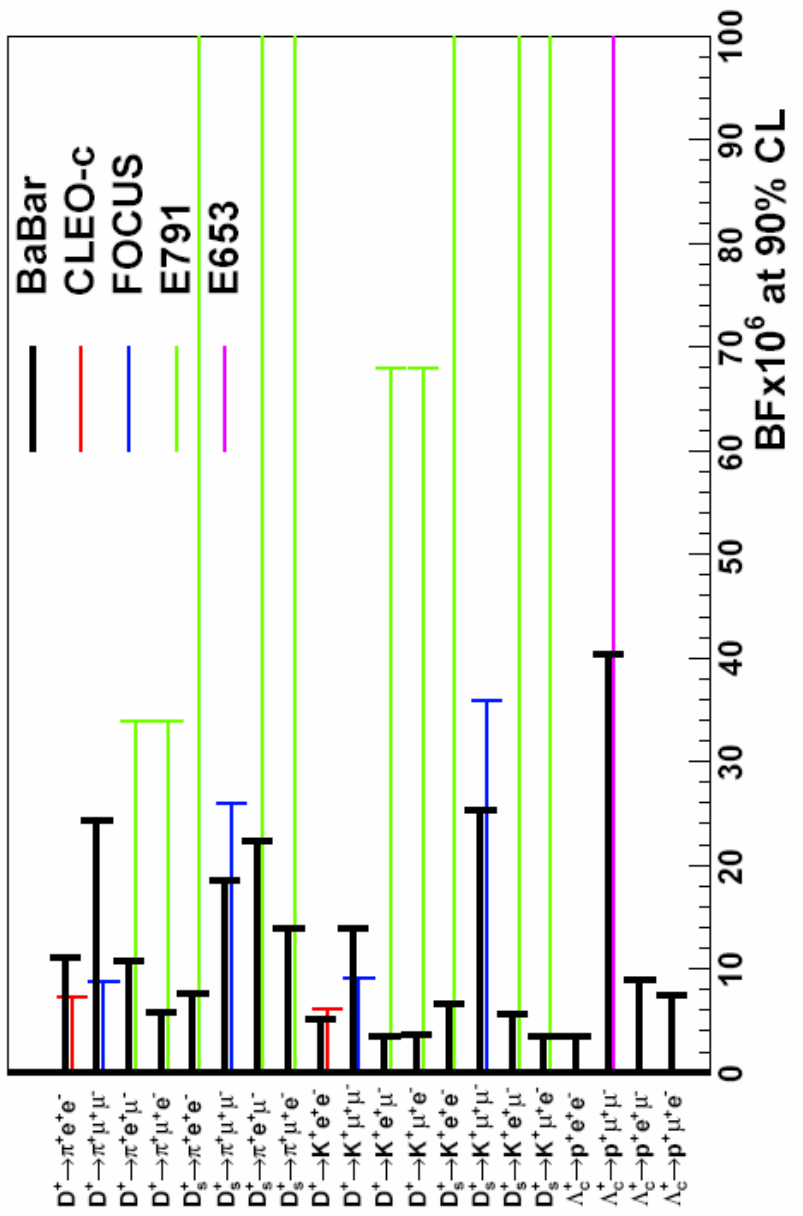

| Decay mode | BF ($\times 10^3$) |
|---|---|
| $D^+ \to \pi^+\phi$ | 6.2±0.6 |
| $D_s^+ \to \pi^+\phi$ | 36±9 |
| $\Lambda_c^+ \to pK^-\pi^+$ | 50±13 |



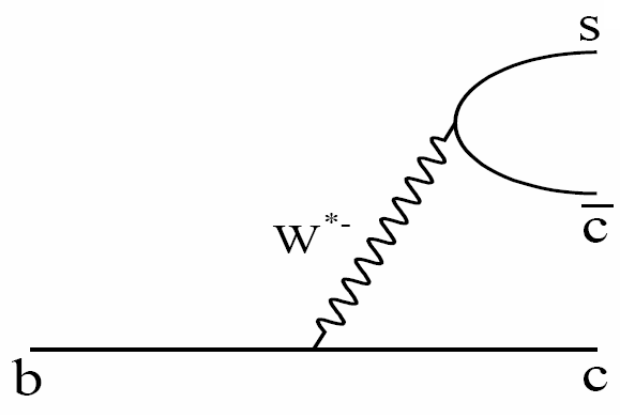
# Search for FCNC in charm decays

## Fit results and upper limits

| Decay mode | Yield (events) | BF$\times 10^6$ (90% CL) |
|---|---|---|
| $D^+ \to \pi^+ e^+ e^-$ | $24.0^{+25.0+3.4}_{-24.1-5.1}$ | $< 11.2$ |
| $D^+ \to \pi^+ \mu^+ \mu^-$ | $1.5^{+20.1+3.4}_{-19.3-2.6}$ | $< 24.4$ |
| $D^+ \to \pi^+ e^+ \mu^-$ | $4.1^{+17.8+3.1}_{-16.3-2.1}$ | $< 10.8$ |
| $D^+ \to \pi^+ \mu^+ e^-$ | $-12.1^{+15.5+3.2}_{-14.8-0.0}$ | $< 5.9$ |
| $D_s^+ \to \pi^+ e^+ e^-$ | $-1.7^{+5.3+0.2}_{-4.6-2.0}$ | $< 7.6$ |
| $D_s^+ \to \pi^+ \mu^+ \mu^-$ | $-9.4^{+5.0+0.2}_{-4.4-1.4}$ | $< 18.5$ |
| $D_s^+ \to \pi^+ e^+ \mu^-$ | $4.8^{+4.7+0.8}_{-3.9-0.3}$ | $< 22.3$ |
| $D_s^+ \to \pi^+ \mu^+ e^-$ | $0.5^{+4.0+1.0}_{-3.3-0.1}$ | $< 13.9$ |
| $D^+ \to K^+ e^+ e^-$ | $5.9^{+8.9+3.8}_{-7.8-0.3}$ | $< 5.2$ |
| $D^+ \to K^+ \mu^+ \mu^-$ | $2.9^{+8.0+0.2}_{-7.0-3.7}$ | $< 14.0$ |
| $D^+ \to K^+ e^+ \mu^-$ | $-3.4^{+6.5+1.0}_{-5.6-0.1}$ | $< 3.6$ |
| $D^+ \to K^+ \mu^+ e^-$ | $-4.4^{+7.1+1.4}_{-6.1-3.0}$ | $< 3.7$ |
| $D_s^+ \to K^+ e^+ e^-$ | $-3.8^{+6.2+1.5}_{-5.3-1.3}$ | $< 6.6$ |
| $D_s^+ \to K^+ \mu^+ \mu^-$ | $5.0^{+6.5+0.1}_{-6.1-0.3}$ | $< 25.4$ |
| $D_s^+ \to K^+ e^+ \mu^-$ | $-3.7^{+5.1+1.4}_{-4.4-1.4}$ | $< 5.6$ |
| $D_s^+ \to K^+ \mu^+ e^-$ | $-6.5^{+4.9+0.2}_{-4.3-1.1}$ | $< 3.6$ |
| $\Lambda_c^+ \to p e^+ e^-$ | $0.9^{+4.1+0.4}_{-3.4-0.1}$ | $< 3.6$ |
| $\Lambda_c^+ \to p \mu^+ \mu^-$ | $6.9^{+4.7+0.3}_{-3.7-0.6}$ | $< 40.4$ |
| $\Lambda_c^+ \to p e^+ \mu^-$ | $0.2^{+2.9+0.5}_{-2.0-0.5}$ | $< 8.9$ |
| $\Lambda_c^+ \to p \mu^+ e^-$ | $-0.2^{+2.5+0.5}_{-1.7-0.9}$ | $< 7.5$ |



# Flavor tagged charm production in B decays

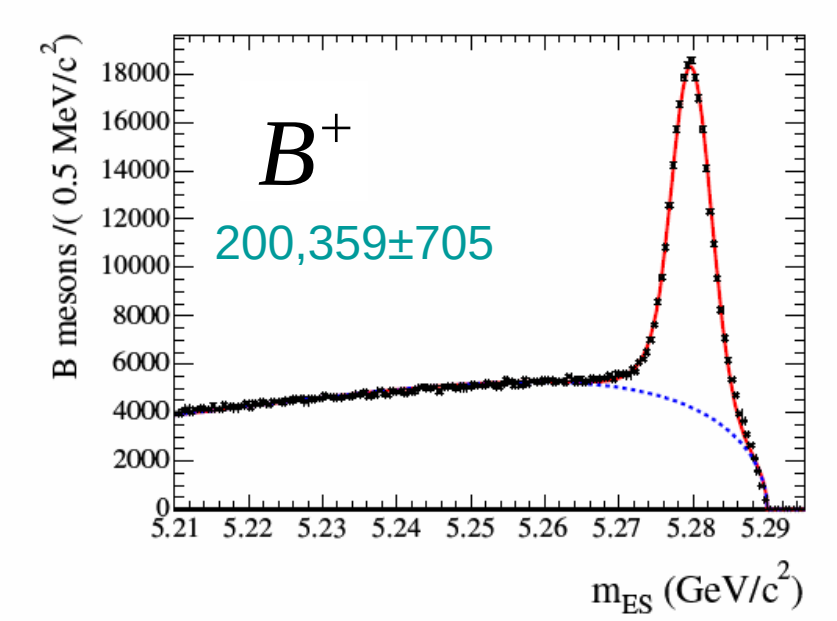


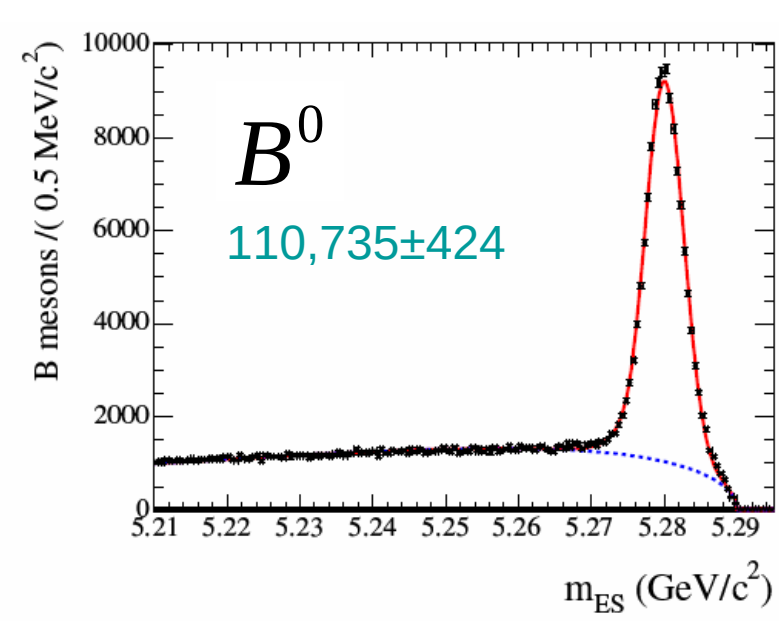

- $b \to c W^{*-}$ : dominant, correlated c production, rate close to 100%
- $W^-$ decays: anti-correlated $\bar{c}$ production, lower rate

- Charm hadrons decay to D, $D_s$, $\Lambda_c$
- Full reconstruction of one B in the event and the charm hadron on the other side allows flavor-specific charm counting
- First results published in PRD 70, 091106(R)
- Improved analysis using 231M B-pairs

# Flavor tagged charm production in B decays

## Fully reconstructed B candidates in $B \to D^{(*)}(\pi,\rho,a_1)$



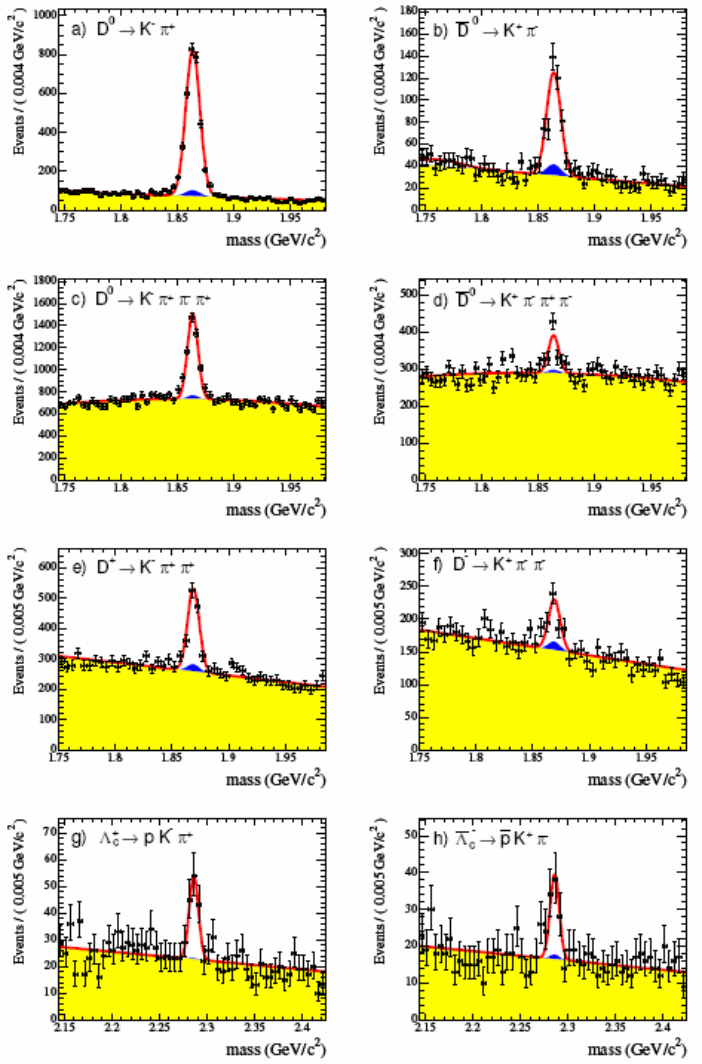




Number of B extracted from fits

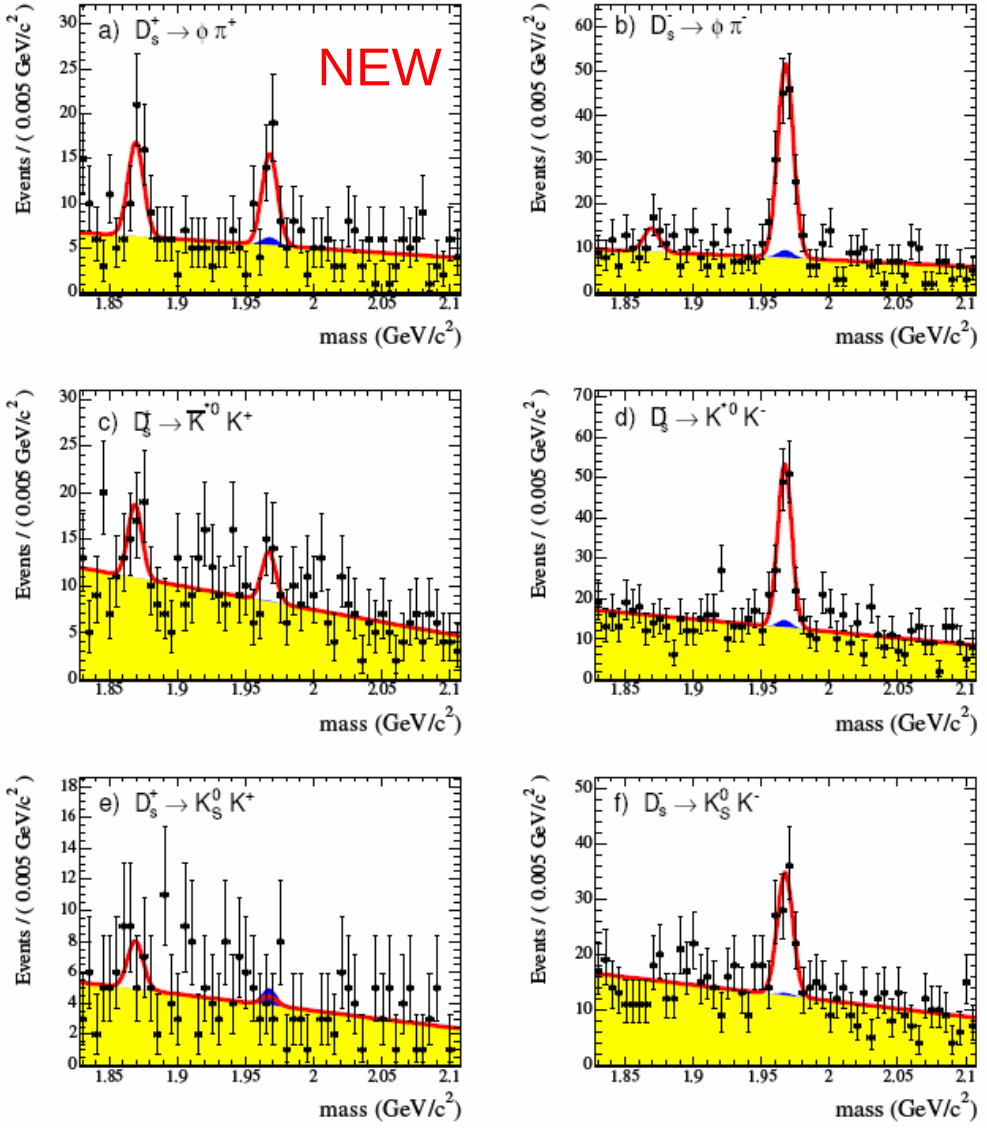
Small neutral (charged) cross-feed estimated from MC (~3%)

# Flavor tagged charm production in B decays

## Charm counting in 2-d likelihood fit ($m_{ES}$, charmed hadron mass)




$B^-$




All disctributions:

Charmed Hadron Mass ($GeV/c^2$)

# Flavor tagged charm production in B decays

## Results: B branching fractions

| | Correlated | | Anticorrelated | |
|---|---|---|---|---|
| $C$ | $\mathcal{B}(B^- \to CX)(\%)$ | $\mathcal{B}(\overline{B}^0 \to CX)(\%)$ | $\mathcal{B}(B^- \to \overline{C}X)(\%)$ | $\mathcal{B}(\overline{B}^0 \to \overline{C}X)(\%)$ |
| $D^0$ | $78.6 \pm 1.6 \pm 2.7^{+2.0}_{-1.9}$ | $47.4 \pm 2.0 \pm 1.5^{+1.3}_{-1.2}$ | $8.6 \pm 0.6 \pm 0.3^{+0.2}_{-0.2}$ | $8.1 \pm 1.4 \pm 0.5^{+0.2}_{-0.2}$ |
| $D^+$ | $9.9 \pm 0.8 \pm 0.5^{+0.8}_{-0.7}$ | $36.9 \pm 1.6 \pm 1.4^{+2.6}_{-2.3}$ | $2.5 \pm 0.5 \pm 0.1^{+0.2}_{-0.2}$ | $2.3 \pm 1.1 \pm 0.3^{+0.2}_{-0.1}$ |
| | | | | $< 3.9$ at 90 % CL |
| $D_s^+$ | $1.1^{+0.4}_{-0.3} \pm 0.1^{+0.2}_{-0.1}$ | $1.5 \pm 0.8 \pm 0.1^{+0.2}_{-0.2}$ | $7.9 \pm 0.6 \pm 0.4^{+1.3}_{-1.0}$ | $10.3 \pm 1.2 \pm 0.4^{+1.7}_{-1.3}$ |
| | | $< 2.6$ at 90 % CL | | |
| $\Lambda_c^+$ | $2.8 \pm 0.5 \pm 0.3^{+1.0}_{-0.6}$ | $5.0 \pm 1.0 \pm 0.5^{+1.8}_{-1.0}$ | $2.1 \pm 0.5 \pm 0.2^{+0.8}_{-0.4}$ | $1.6 \pm 0.9 \pm 0.2^{+0.6}_{-0.3}$ |
| | | | | $< 3.1$ at 90 % CL |

$C$ : charmed hadron

$B^-$

$$N_c^- = 0.968 \pm 0.019 \pm 0.032^{+0.026}_{-0.022},$$
$$N_{\overline{c}}^- = 0.234 \pm 0.012 \pm 0.008^{+0.016}_{-0.012},$$
$$n_c^- = 1.202 \pm 0.023 \pm 0.040^{+0.035}_{-0.029}.$$

$\overline{B}^0$

$$N_c^0 = 0.947 \pm 0.030 \pm 0.028^{+0.035}_{-0.028},$$
$$N_{\overline{c}}^0 = 0.246 \pm 0.024 \pm 0.009^{+0.019}_{-0.014},$$
$$n_c^0 = 1.193 \pm 0.030 \pm 0.034^{+0.044}_{-0.035}.$$

# Summary

New BABAR results presented for:

- $B \to \rho^+ \rho^0$ (improved precision) $(17.2 \pm 2.5_{STAT} \pm 2.8_{SYST})10^{-6}$
- $B \to a_1^+ \pi^-$ (first observation)

$$BF(B^0 \to a_1^{\pm}(1260)\pi^{\mp}) \times BF(a_1^{\pm}(1260) \to \pi^{\pm}\pi^{\mp}\pi^{\pm}) = (16.6 \pm 1.9_{STAT} \pm 1.5_{SYST})10^{-6}$$

- T, CP, and CPT studies in B mixing with dileptons (improved precision and new measurements)

$$|q/p| - 1 \;=\; (-0.8 \pm 2.7(\text{stat.}) \pm 1.9(\text{syst.})) \times 10^{-3}$$

- FCNC search in charm decays (first BABAR results; best limits in 15 channels)
- Flavor-tagged charm in B decays (new results, improved precision)