

Measurement of branching fractions and direct CP asymmetries for B meson decays to quasi-two body charmless final states



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Overview

- Motivation
- Analysis Technique
- $B^0 \rightarrow \eta K^0$
- $B^+ \rightarrow \eta \rho^+, B^+ \rightarrow \eta' \pi^+$
- $B^0 \rightarrow \eta \omega$
- $B^0 \rightarrow a_1^+(1260) \pi^-$
- Conclusion

Motivation

- We look to processes dominated by **penguin loops** ($b \rightarrow s$) or **CKM-suppressed decay tree diagrams** ($b \rightarrow u$)



Rare Decays

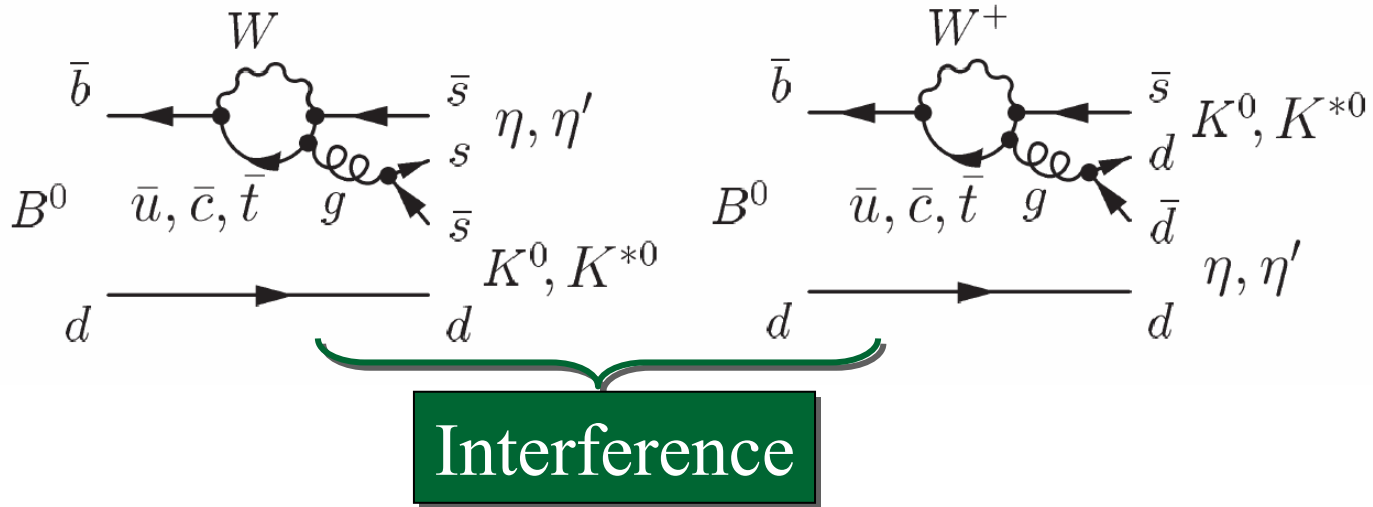
- An optimal place for measurements sensitive to new physics (new contributions to the penguin amplitude beyond the SM)
- Check of QCD Factorization, Perturbative QCD, Flavour SU(3)

Analysis Technique

- Unbinned Maximum Likelihood (ML) Fit
- Kinematic and event shape variables
- Apply loose cuts to keep side-bands for background fitting
- Main background: $e^+e^- \rightarrow q\bar{q}$ continuum ($q = u, d, s, c$).
When necessary also a $B\bar{B}$ background PDFs in fit
- Extract from ML fits:
yields, charge asymmetries, efficiencies
- Several Crosschecks: “Toy MC” experiments, control samples, cut&count analysis,...

$B^0 \rightarrow \eta K^0$

CKM-suppressed process, **dominated by penguin**
 $b \rightarrow s$ transitions



Interference between two penguin diagrams and the known η/η' mixing angle conspire to:

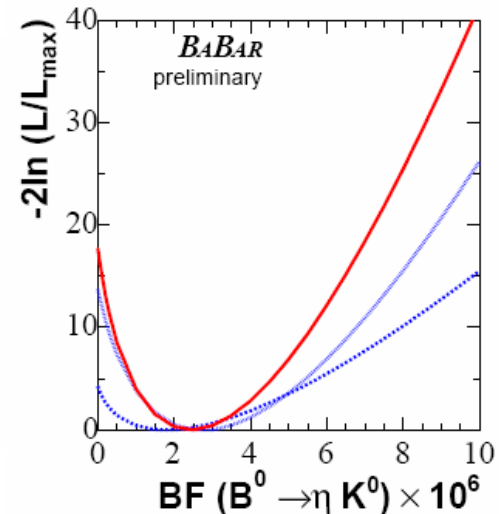
enhance $\eta'K^+$, $\eta'K^0$, ηK^{*+} , ηK^{*0}

suppress ηK^+ , ηK^0 , $\eta'K^{*+}$, $\eta'K^{*0}$

Lipkin, PLB 254,
247 (1991)

$B^0 \rightarrow \eta K^0$

Mode	Y	ϵ (%)	$\prod \mathcal{B}_i$ (%)	S σ	\mathcal{B} (10^{-6})
$\eta_{\gamma\gamma} K^0$	19^{+8}_{-7}	29	14	3.7	$2.7^{+1.1}_{-1.0}$
$\eta_{3\pi} K^0$	6^{+5}_{-4}	22	8	2.1	$1.8^{+1.6}_{-1.1}$
ηK^0				4.2	$2.5 \pm 0.8 \pm 0.1$

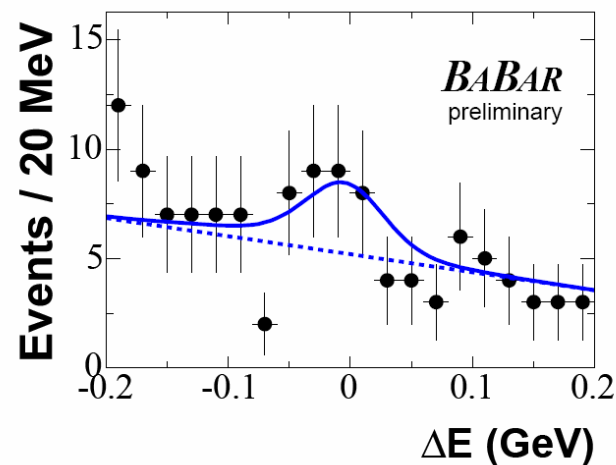
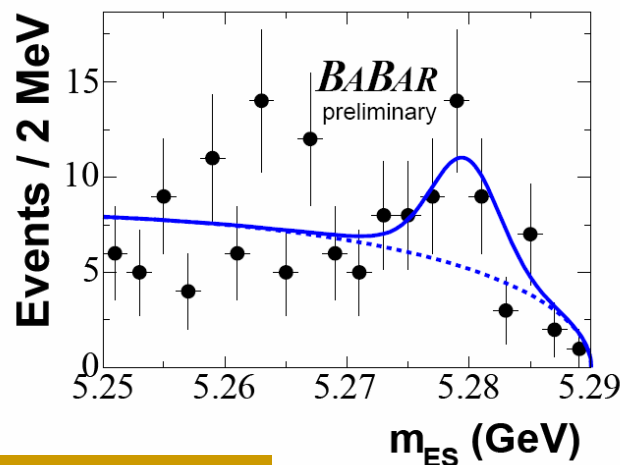


182 million of $B\bar{B}$ pairs (preliminary)

$$m_{ES} = \sqrt{\frac{1}{4}s - \mathbf{p}_B^{*2}}$$

$$\Delta E = E_B^* - \frac{1}{2}\sqrt{s}$$

$\Upsilon(4S)$ frame.



See [hep-ex/0408058](https://arxiv.org/abs/hep-ex/0408058)

$B^0 \rightarrow \eta K^0$

Mode	$S(\sigma)$	$\mathcal{B}(10^{-6})$	90% UL (10^{-6})	\mathcal{A}_{ch} (%)
$B^+ \rightarrow \eta' K^+$	> 10	$76.9 \pm 3.5 \pm 4.4$		$0.04 \pm 0.05 \pm 0.01$
$B^0 \rightarrow \eta' K^0$	> 10	$60.6 \pm 5.6 \pm 4.6$		
$B^+ \rightarrow \eta K^+$	6.1	$3.4 \pm 0.8 \pm 0.2$		$-0.52 \pm 0.24 \pm 0.01$
$B^0 \rightarrow \eta K^0$	4.2	$2.5 \pm 0.8 \pm 0.1$		
$B^+ \rightarrow \eta' K^{*+}$	1.9	$6.3^{+4.0}_{-3.6} \pm 1.8$	< 14	
$B^0 \rightarrow \eta' K^{*0}$	2.1	$4.1^{+2.1}_{-1.8} \pm 1.2$	< 7.6	
$B^+ \rightarrow \eta K^{*+}$	9.0	$25.6 \pm 4.0 \pm 2.4$		$0.13 \pm 0.14 \pm 0.02$
$B^0 \rightarrow \eta K^{*0}$	11.0	$18.6 \pm 2.3 \pm 1.2$		
$B^+ \rightarrow \eta \pi^+$	7.9	$5.3 \pm 1.0 \pm 0.3$		$-0.44 \pm 0.18 \pm 0.01$

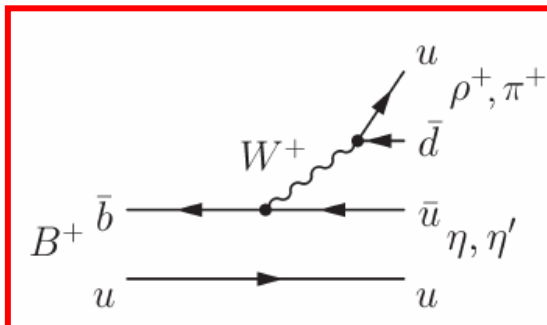
**New measurement with 182 million of $B\bar{B}$ pairs (preliminary).
Other measurements with 89 million of $B\bar{B}$ pairs.**

**Now observed by BaBar
PRL 92, 061801 (2004)**

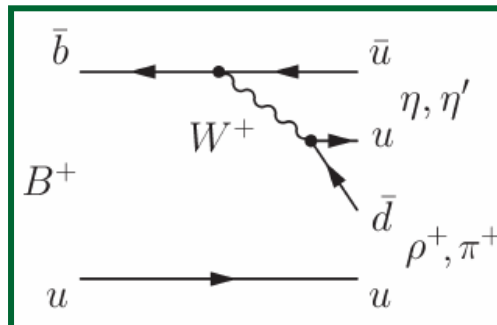
**Predicted large charge asymmetry
Chiang et al., hep-ph/0307395**

$B^+ \rightarrow \eta \rho^+, B^+ \rightarrow \eta' \pi^+$

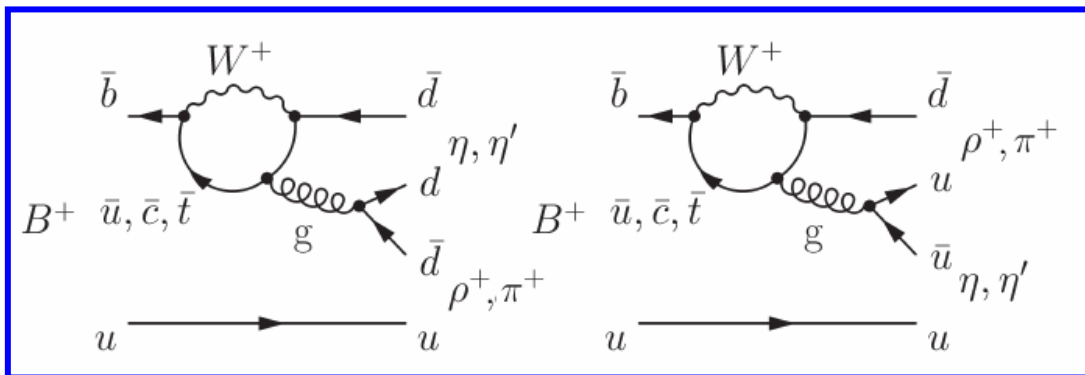
dominant



color suppressed



CKM suppressed



CKM-suppressed $b \rightarrow u$ amplitudes may interfere significantly with penguin amplitudes \rightarrow possibly large direct CP violation

Bander et al., PRL 43, 242 (1979); Dighe et al., PRL 79, 4333 (1997)

$$\mathcal{A}_{ch} = \frac{\Gamma^- - \Gamma^+}{\Gamma^- + \Gamma^+}$$

$$\Gamma^\pm = \Gamma(B^\pm \rightarrow f^\pm)$$

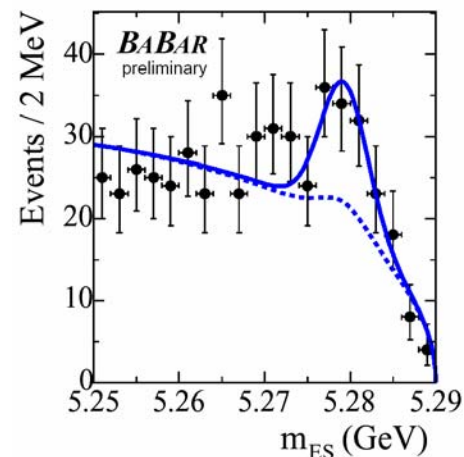
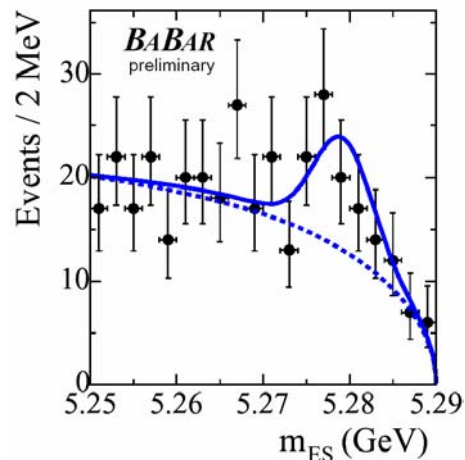
$B^+ \rightarrow \eta \rho^+, B^+ \rightarrow \eta' \pi^+$

New measurements with $182 \cdot 10^6 B\bar{B}$ pairs (preliminary).

See [hep-ex/0408058](https://arxiv.org/abs/hep-ex/0408058)

Mode	Y	ϵ (%)	$\prod \mathcal{B}_i$ (%)	S σ	\mathcal{B} (10^{-6})	\mathcal{A}_{ch}^{qq} (%)	\mathcal{A}_{ch} (%)
$\eta_{\gamma\gamma} \rho^+$	110^{+31}_{-29}	16	39	3.2	$8.1^{+2.9}_{-2.7}$	0.2 ± 0.5	20 ± 23
$\eta_{3\pi} \rho^+$	53^{+19}_{-17}	11	23	2.8	$9.7^{+4.3}_{-3.0}$	-0.1 ± 0.8	-18 ± 32
$\eta \rho^+$				4.2	$8.6 \pm 2.2 \pm 1.1$		$7 \pm 19 \pm 2$
$\eta'_{\eta\pi\pi} \pi^+$	55^{+12}_{-11}	27	18	4.9	$5.4^{+1.4}_{-1.3}$	-0.4 ± 1.4	19 ± 21
$\eta'_{\rho\pi} \pi^+$	30^{+15}_{-14}	18	30	1.2	$1.9^{+1.6}_{-1.4}$	-1.2 ± 0.9	47 ± 44
$\eta' \pi^+$				4.8	$4.2 \pm 1.0 \pm 0.5$		$24 \pm 19 \pm 1$

$\eta \rho^+$



$\eta' \pi^+$

$B^0 \rightarrow \eta\omega$ and other Isoscalar Pairs

Mode	$S(\sigma)$	$B(10^{-6})$	90% UL (10^{-6})	90% UL (10^{-6}) CLEO
$\eta\eta$	0.0	$-0.9^{+1.6}_{-1.4} \pm 0.7$	2.8	18
$\eta\eta'$	0.3	$0.6^{+2.1}_{-1.7} \pm 1.1$	4.6	27
$\eta'\eta'$	0.4	$1.7^{+4.8}_{-3.7} \pm 0.6$	10	47
$\eta'\omega$	0.0	$-0.2^{+1.3}_{-0.9} \pm 0.7$	2.8	60
$\eta\omega$	2.2	$1.2 \pm 0.6 \pm 0.2$	2.3	12
$\eta\phi$	0.0	$-1.4^{+0.7}_{-0.4} \pm 0.2$	1.0	9
$\eta'\phi$	0.8	$1.5^{+1.8}_{-1.5} \pm 0.4$	4.5	31
$\phi\phi$	0.3	$0.3^{+0.7}_{-0.4} \pm 0.1$	1.5	12

Measurements done with $89 \cdot 10^6 B\bar{B}$ pairs (subm. to PRL: hep-ex/0403046)

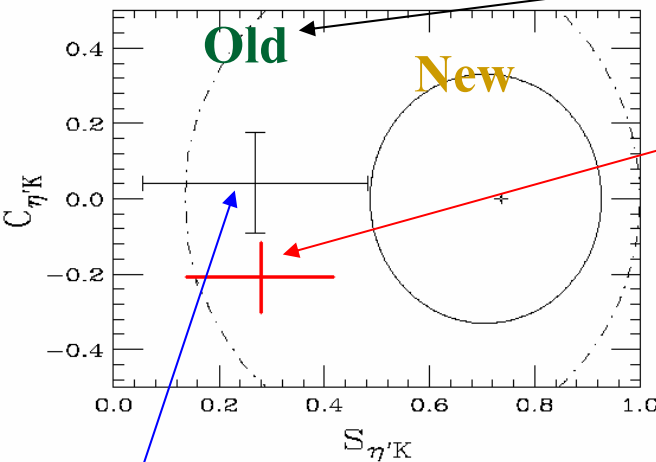
Remeasurement done with $182 \cdot 10^6 B\bar{B}$ pairs (preliminary) (See hep-ex/0408058)

Improved upper limits. Very interesting for calculation of upper bound of ΔS in B^0 decay modes with penguins (SU(3))

Correlated Bounds on (S,C)

In time-dependent analysis and penguin dominated B^0 decays we measure (SU(3)): $\Delta S = S \pm \sin 2\beta$ (where S is the coefficient of sin term and C of the cos term in the time-evolution of the system)

New ULs on decays to isoscalar pairs allow a great improvement relative to previous bounds



Our new measurement: $S = 0.27 \pm 0.14 \pm 0.03$
in $\eta'K^0$ $C = -0.21 \pm 0.10 \pm 0.03$
(see F. Blanc talk, this conf.)

Gronau, Rosner, Zupan hep-ph/0403287
Grossman et al., PRD68 ,015004 (2003)

Old mean BaBar-Belle results

$$B^0 \rightarrow a_1^+ \pi^- \left(a_1^+ \rightarrow (\pi^+ \pi^-)_{\rho, \sigma} \pi^+ \right)$$

- Rare decay with a BF not yet measured.
- This decay can be used to study CP asymmetry for an independent measurement of $\sin 2\alpha$.
- But first we have to measure the BF to see if there is any signal.
- Analysis done with a statistics of $124 \cdot 10^6 B\bar{B}$ pairs.
- Simple analysis done in Quasi-2-Body approximation. Needed Dalitz plot analysis in order to distinguish a_1 from other similar mass resonances ($a_2(1320)$, $\pi(1300)$). Analysis in progress.

$$B^0 \rightarrow a_1^+ \pi^- \left(a_1^+ \rightarrow (\pi^+ \pi^-)_{\rho, \sigma} \pi^+ \right)$$

Preliminary Results:

Observation of this decay, stat. sign. $> 10 \sigma$

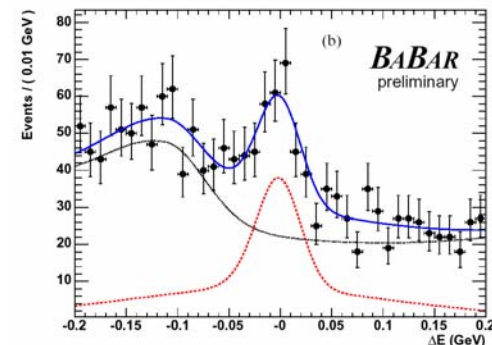
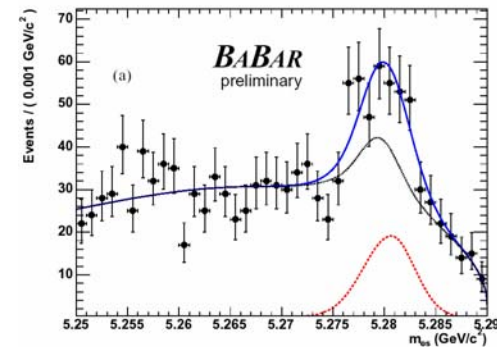
Yield 472 ± 46

$$\text{Br}(B^0 \rightarrow a_1^+ \pi^-) = (42.6 \pm 4.2_{\text{stat}} \pm 4.1_{\text{syst}}) 10^{-6}$$

\swarrow
 \searrow
 \rightarrow **3 π**

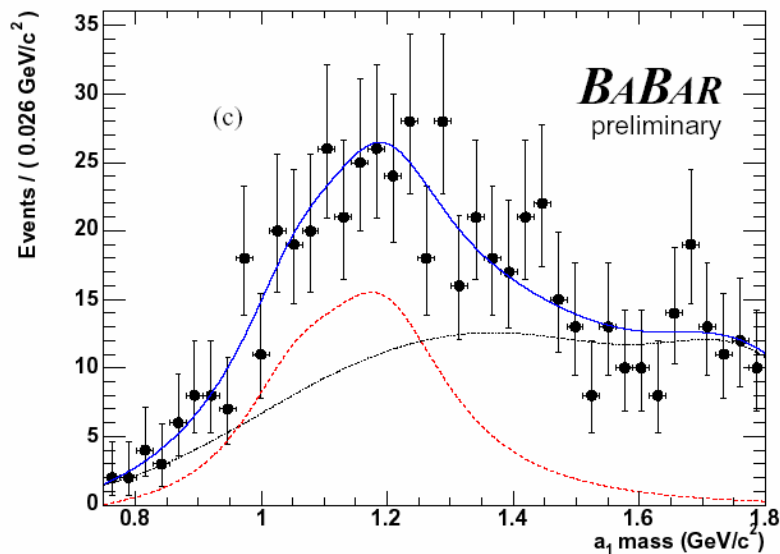
Estimates of the systematic errors (in percent)

Quantity	$a_1^+ \pi^-$
Fit yield	6.3
Fit eff/bias	1.7
Track multiplicity	1.0
Tracking eff/qual	3.2
Number $B\bar{B}$	1.1
SCF	3
$a_1 K$ cross-feed	5
$B \rightarrow 4\pi, \rho\pi\pi$	1.0
MC statistics	1.0
$\cos \theta_{\Gamma}$	1.0
Total	9.6

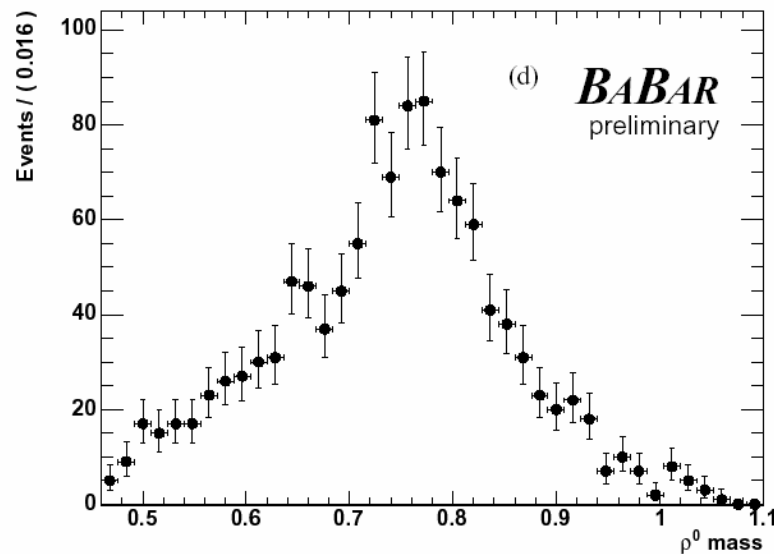


$$B^0 \rightarrow a_1^+ \pi^- (a_1^+ \rightarrow (\pi^+ \pi^-)_{\rho, \sigma} \pi^+)$$

$$m_{a_1} = 1.19 \pm 0.02 \text{ GeV}/c^2 \quad \Gamma_{a_1} = 312 \pm 55 \text{ MeV}/c^2$$



a_1 mass



$(\pi^+ \pi^-)_{\rho, \sigma}$ invariant mass

Conclusion

- First observations of $B^0 \rightarrow \eta' \pi^+, \eta \rho^+, \eta K^0$ and $a_1^+ \pi^-$
- No clear evidence in these decay modes for direct CPV
- Severe tests of factorization models (prediction of BF, charge asymmetry, etc)
Good agreement with the theoretical predictions