

DIRECT CP-VIOLATION IN B DECAYS - EXPERIMENTS



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Direct CP-Violation

- Direct CP Violation – occurs in the decays only

$$A_{CP} = \frac{\Gamma(\bar{B} \rightarrow f) - \Gamma(B \rightarrow \bar{f})}{\Gamma(\bar{B} \rightarrow f) + \Gamma(B \rightarrow \bar{f})}$$

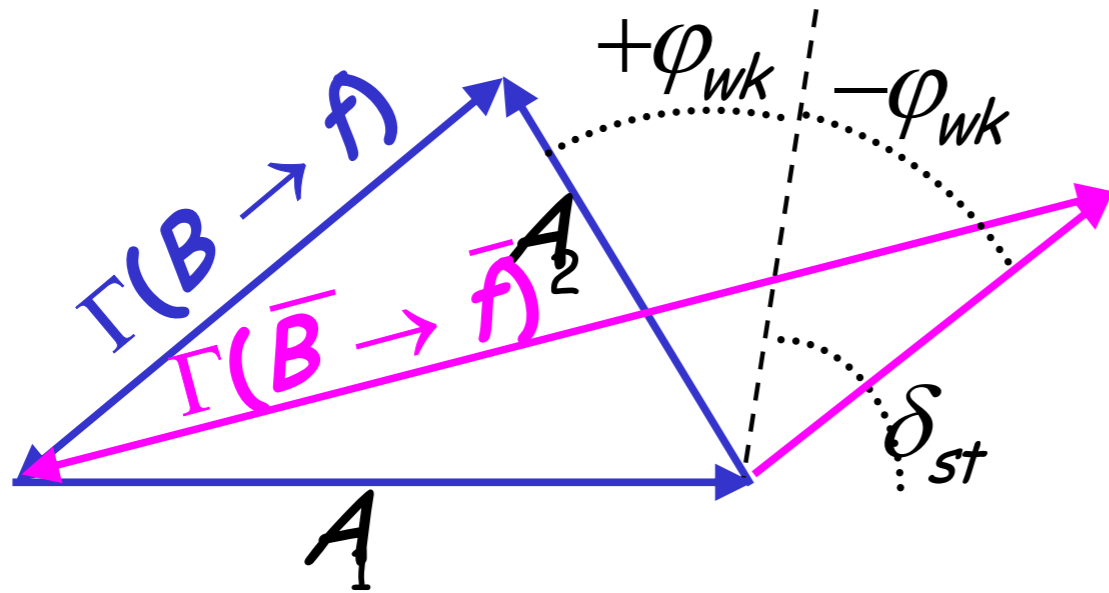
- If produced coherently need to disentangle mixing effects (especially at B-factories)

$$\begin{aligned} A_{CP}(\Delta t) &= \frac{\Gamma_{\bar{B}}(\Delta t) - \Gamma_B(\Delta t)}{\Gamma_{\bar{B}}(\Delta t) + \Gamma_B(\Delta t)} \\ &= \mathcal{S} \sin(\Delta m \Delta t) + \mathcal{A} \cos(\Delta m \Delta t) \end{aligned}$$

$$A(\text{Belle}) = -C(\text{BaBar})$$

Direct CP-Violation in B system

➤ CPV through interference of decay amplitudes



B

$$\Gamma(B \rightarrow f) = |A_1 + A_2 e^{i\varphi_{wk}} e^{i\delta_{st}}|^2$$

$$\Gamma(\bar{B} \rightarrow \bar{f}) = |A_1 + A_2 e^{-i\varphi_{wk}} e^{i\delta_{st}}|^2$$

$$A_{CP} = \frac{\Gamma(\bar{B} \rightarrow \bar{f}) - \Gamma(B \rightarrow f)}{\Gamma(\bar{B} \rightarrow \bar{f}) + \Gamma(B \rightarrow f)} \neq 0 \text{ if } \varphi_{wk} \neq 0 \text{ and } \delta_{st} \neq 0$$

E.g.: $B \rightarrow K^+ \pi^- / K^- \pi^+$

$$A_{CP} = -0.108 \pm 0.024 \pm 0.007$$

BaBar: hep-ex/0608003

$$A_{CP} = -0.093 \pm 0.018 \pm 0.008$$

BaBar: ICHEP06

Difficult to extract CKM information due to strong phase

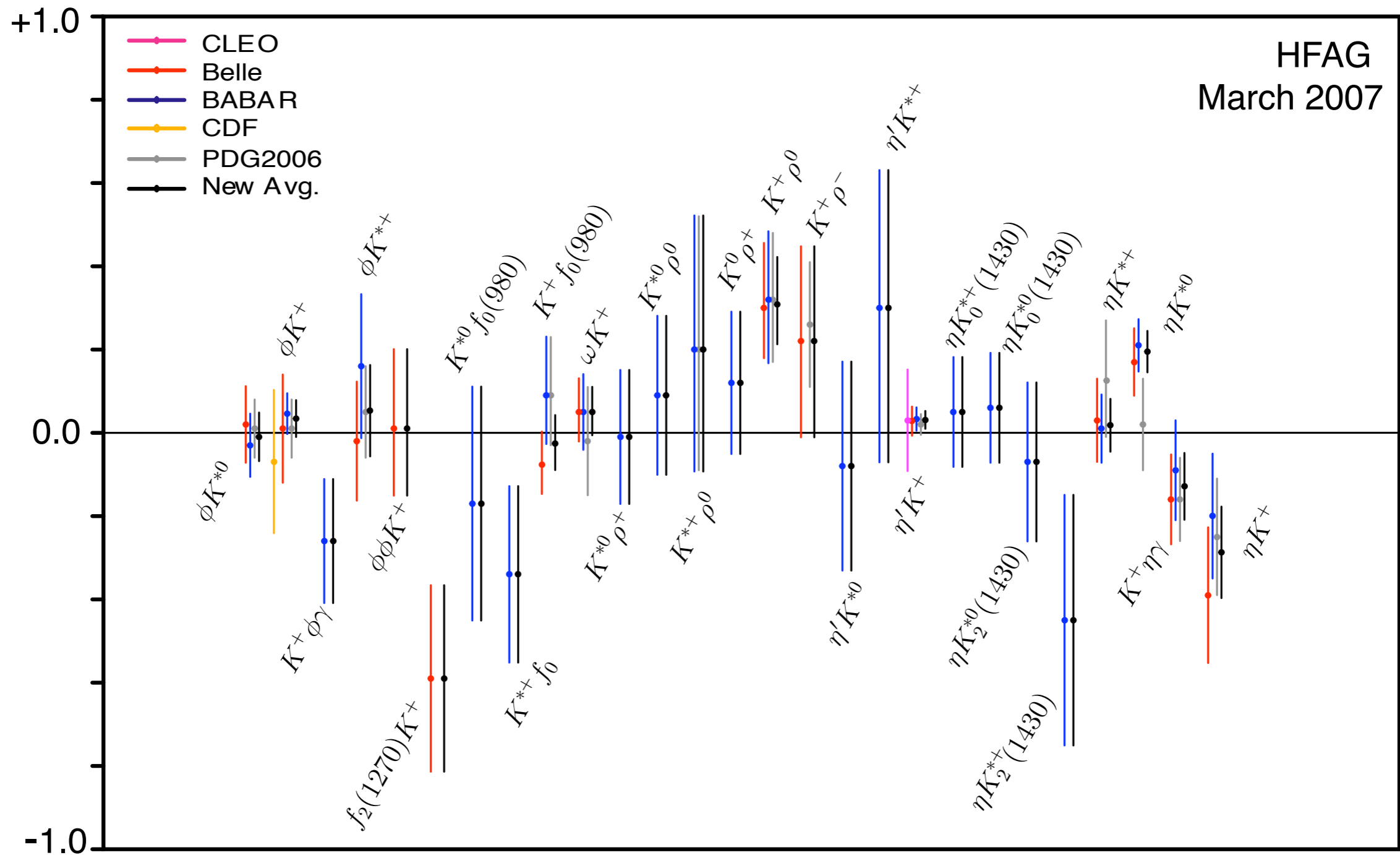


Belle & BaBar Charmless B decays

- **No new results -**
 - all summarised in HFAG 2007 winter
[hep-ex/0704.3575v1](https://arxiv.org/abs/hep-ex/0704.3575v1)
 - previous talk: Michael Gronau
- **Consistent results**
 - no significant variations between experiments
(given number of measurements)
 - statistics limited, improvement still expected

Charmless Kaonic modes with rho...

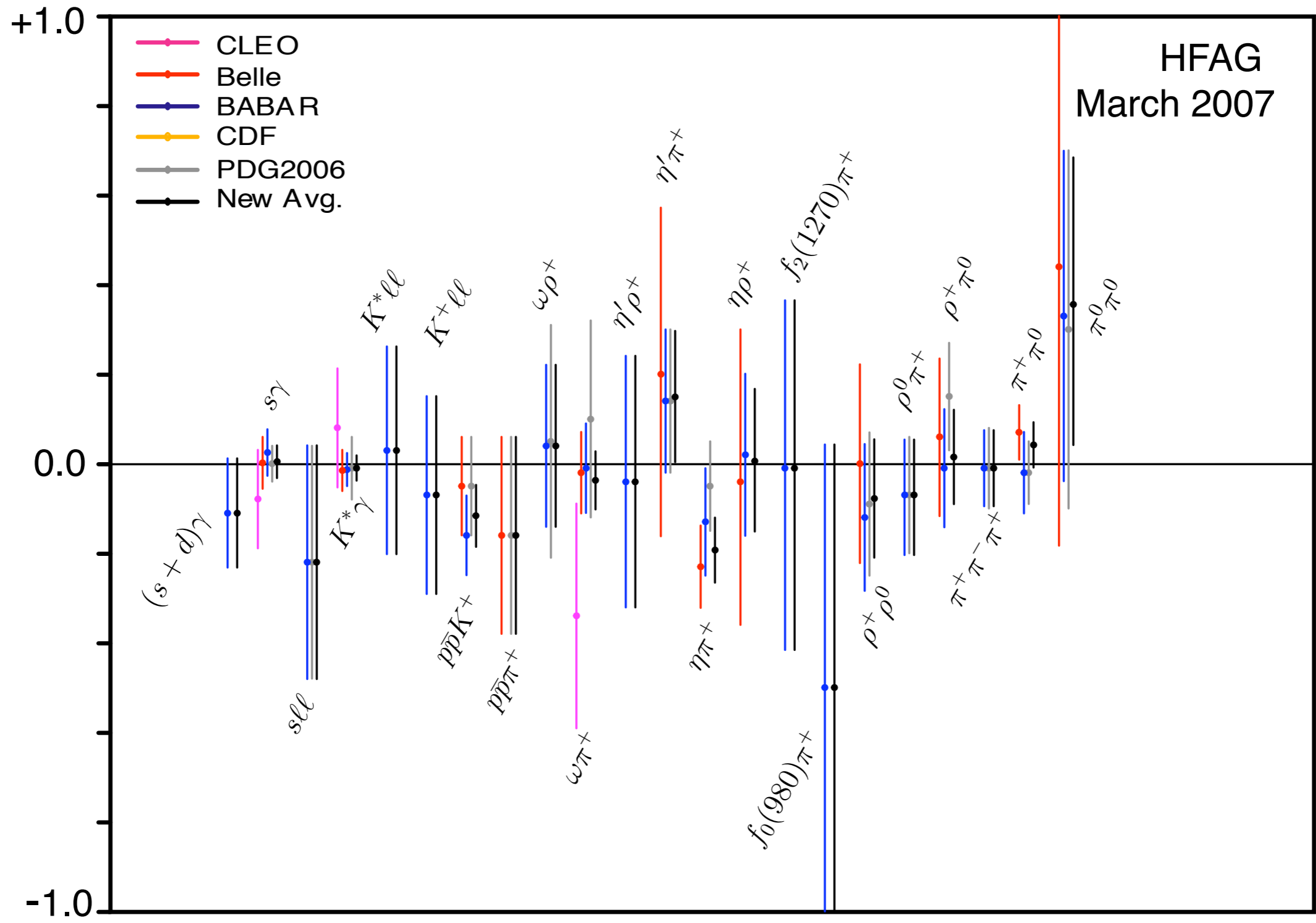
CP Asymmetry in Charmless B Decays





Non-Kaonic Modes

CP Asymmetry in Charmless B Decays



Belle & BaBar $B \rightarrow K\pi$



$\bar{B}^0 \rightarrow K^- \pi^+$

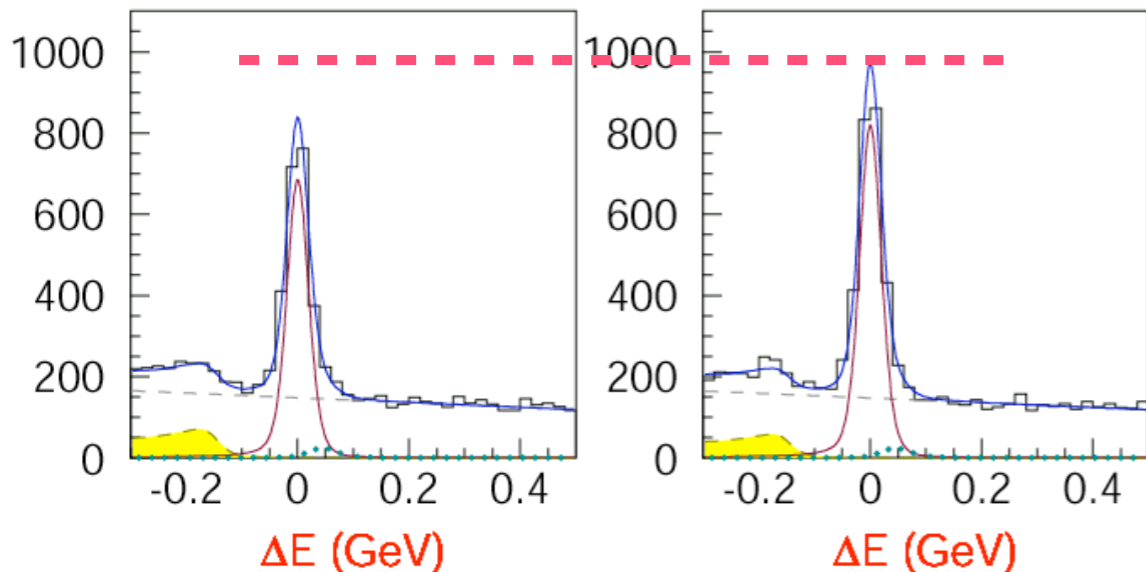
$B^0 \rightarrow K^+ \pi^-$

535 M $B\bar{B}$

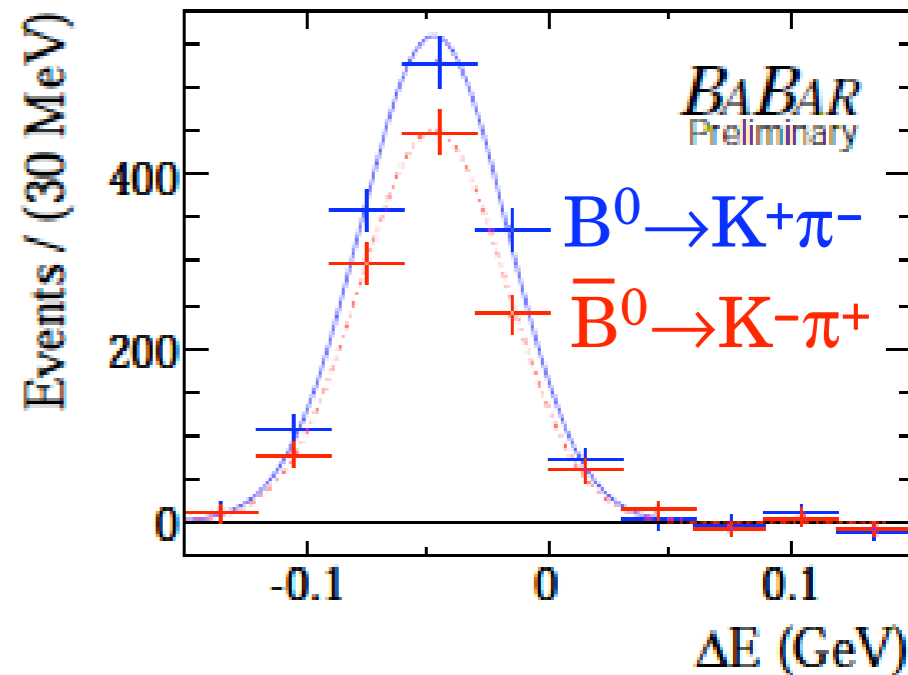


[hep-ex/0607106]

347 M $B\bar{B}$



Evidence
of A_{CP}
in $K^+ \pi^-$



$$A_{CP}(K^+ \pi^-) = -0.093 \pm 0.018 \pm 0.008$$

$$A_{CP}(K^+ \pi^-) = -0.108 \pm 0.024 \pm 0.008$$

$$A_{CP}(K^+ \pi^0) = 0.07 \pm 0.03 \pm 0.01$$

$$A_{CP}(K^+ \pi^0) = 0.016 \pm 0.041 \pm 0.012$$

World average (including CLEO, CDF): $A_{CP}(K^+ \pi^-) = -0.093 \pm 0.015$

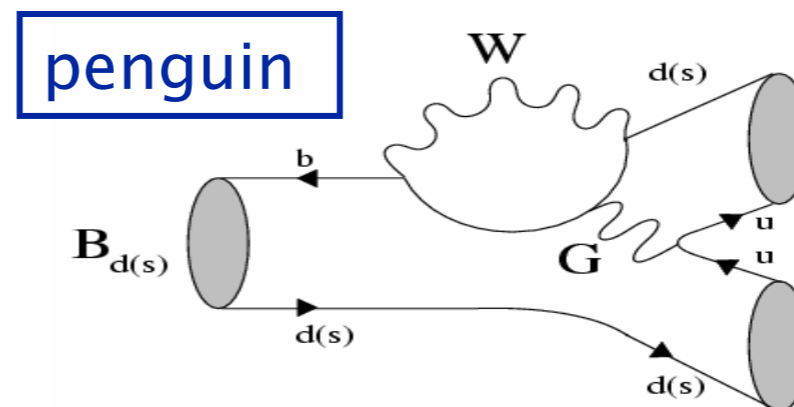
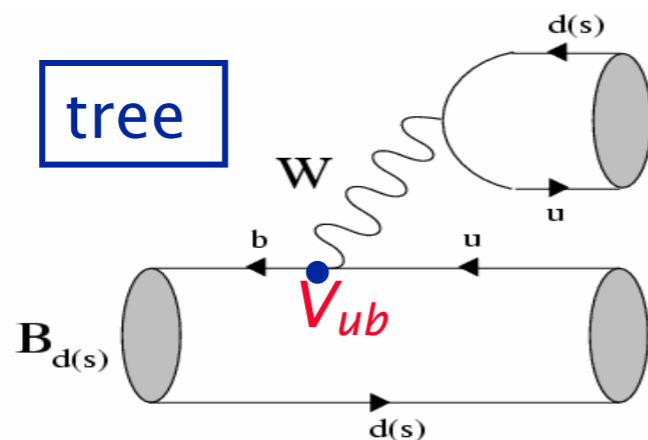
$$A_{CP}(K^+ \pi^0) = 0.047 \pm 0.026$$

$A_{CP}(K^+ \pi^-) \sim A_{CP}(K^+ \pi^0)$ in naïve estimation $>4\sigma$ deviation

still another $K\pi$ puzzle ? (EW penguin like N.P / hadronic effect?)

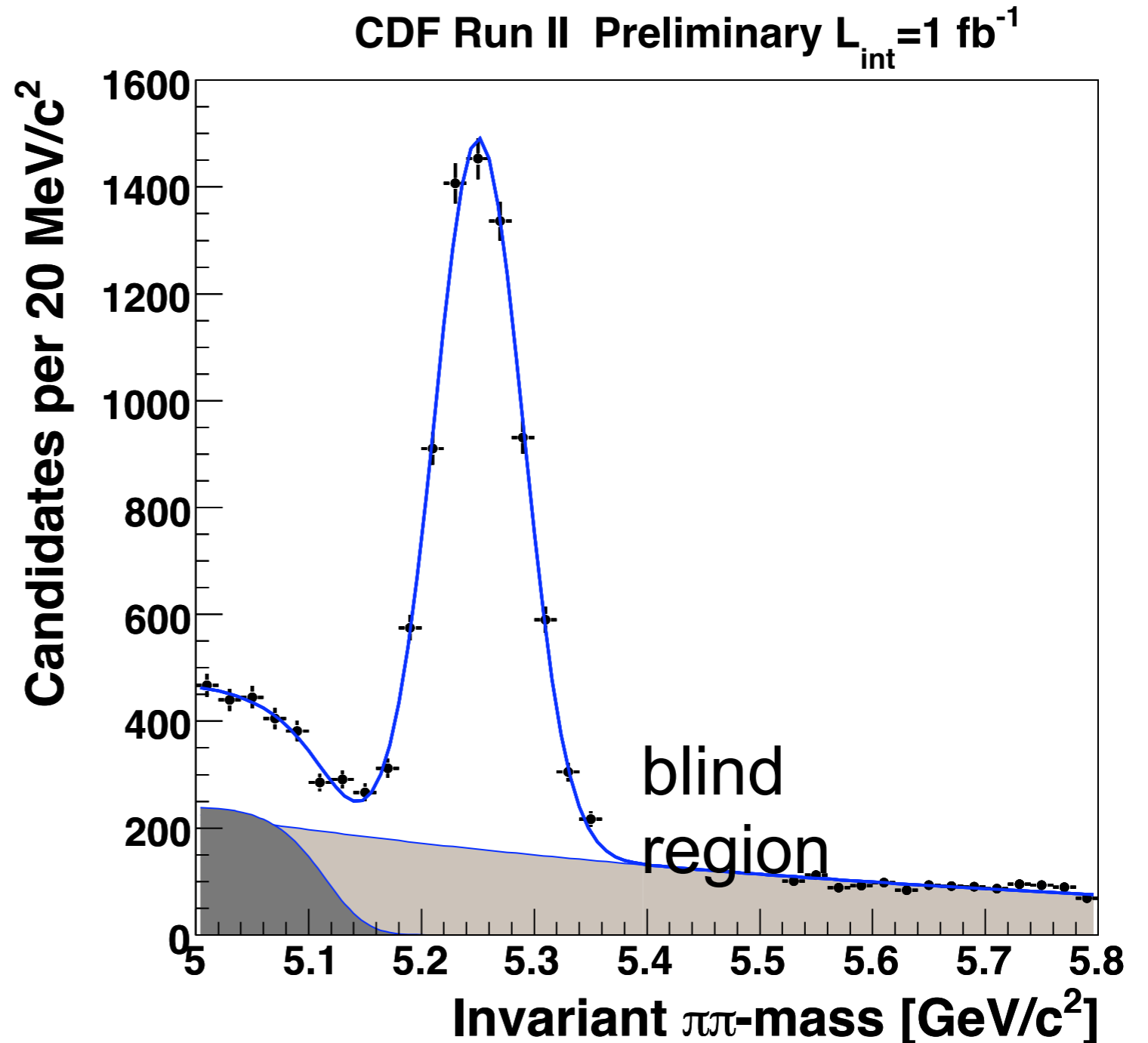
CDF $B \rightarrow hh'$

- Data collected using displaced vertex trigger
 - B_d and B_s produced
 - charmless two body decays
 - currently statistics limited



CDF $B \rightarrow hh'$

- For each $h+h'$ pair passing cuts calculate mass assuming $\pi\pi$ hypothesis
 - Mass resolution ~ 22 MeV
 - multiple decay modes
- Determine signal composition with likelihood fit
 - kinematics & particle ID (dE/dx)

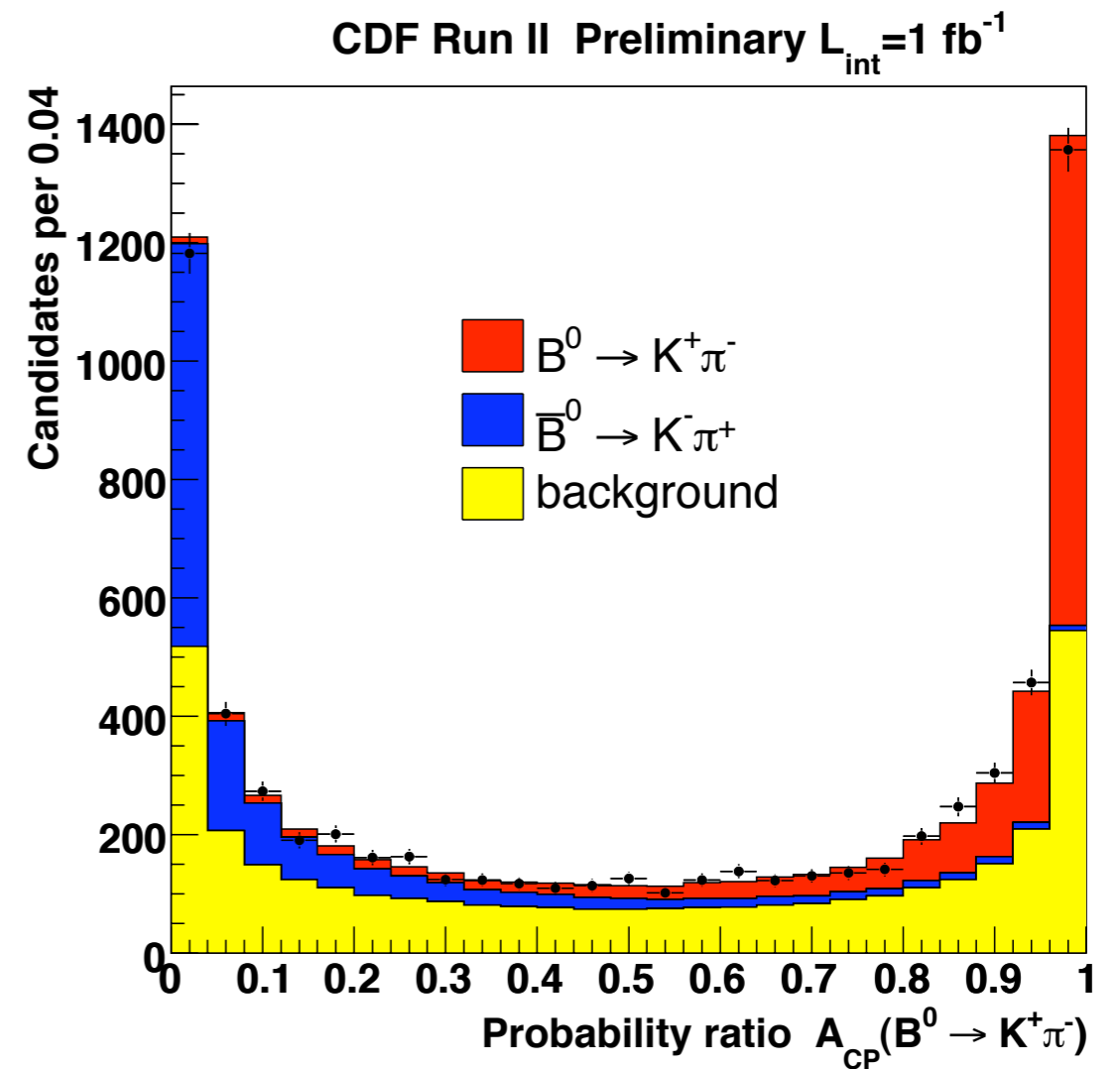
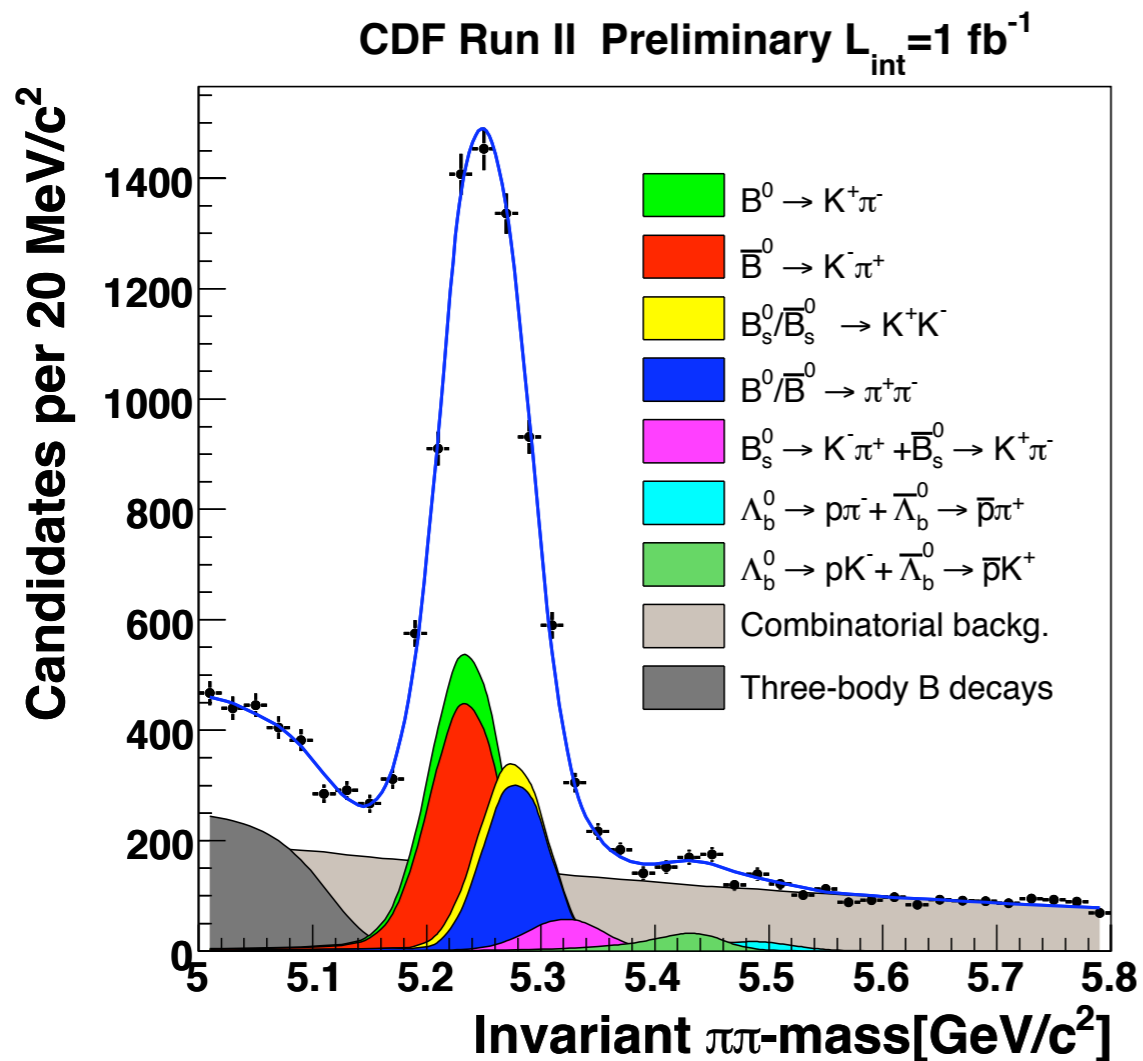


CDF $B_d \rightarrow K^+ \pi^-$

- Loose cuts cuts optimised to measure the direct CP-asymmetry

$$A_{CP}(B_0 \rightarrow K^+ \pi^-)$$

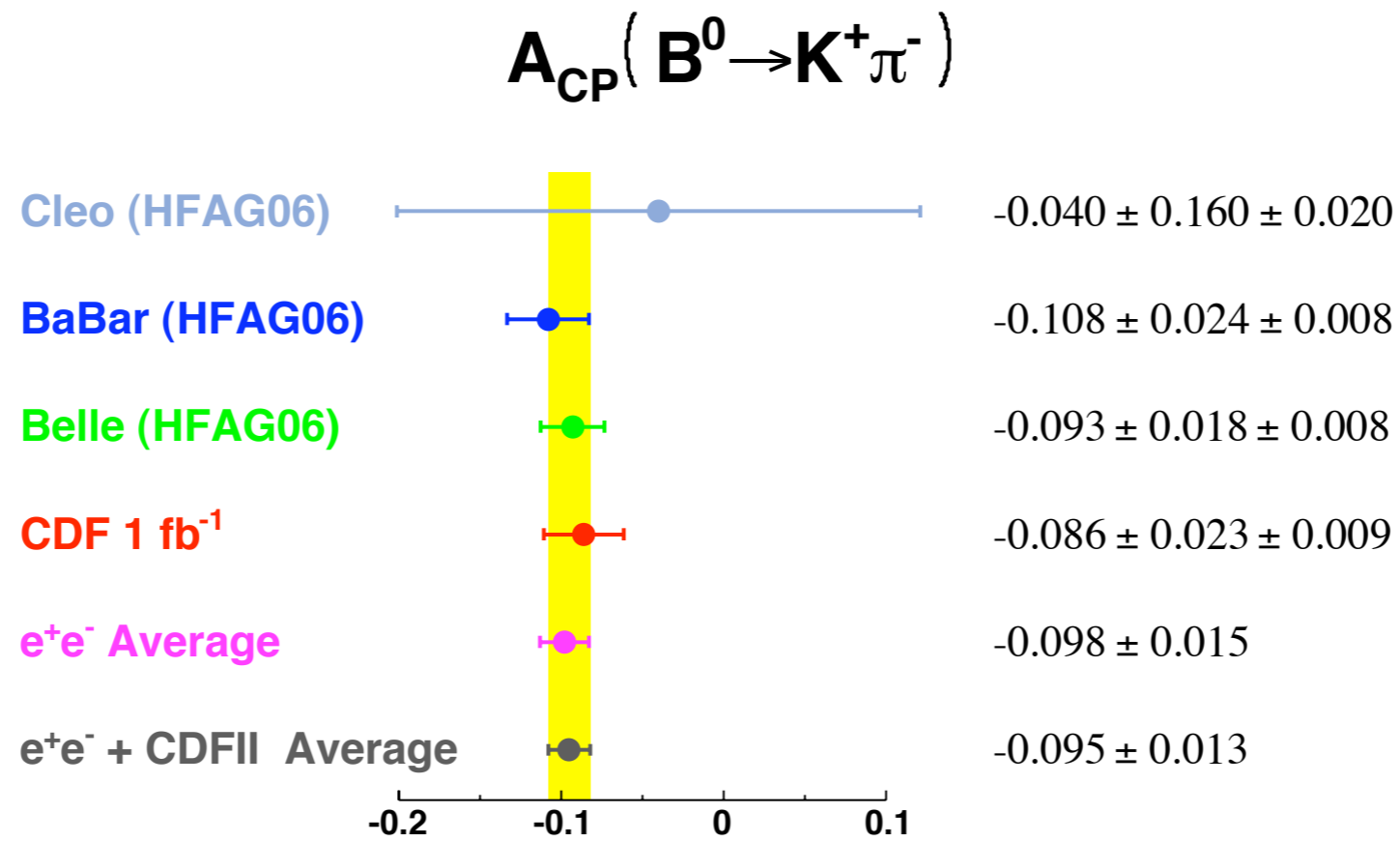
- signal is self-tagging





CDF $B_d \rightarrow K^+ \pi^-$

$$\begin{aligned}
 A_{CP} &= \frac{N(\bar{B}^0 \rightarrow K^- \pi^+) - N(B^0 \rightarrow K^+ \pi^-)}{N(\bar{B}^0 \rightarrow K^- \pi^+) + N(B^0 \rightarrow K^+ \pi^-)} \\
 &= -0.086 \pm 0.023 \text{ (stat)} \pm 0.009 \text{ (syst)} \pm 0.009
 \end{aligned}$$

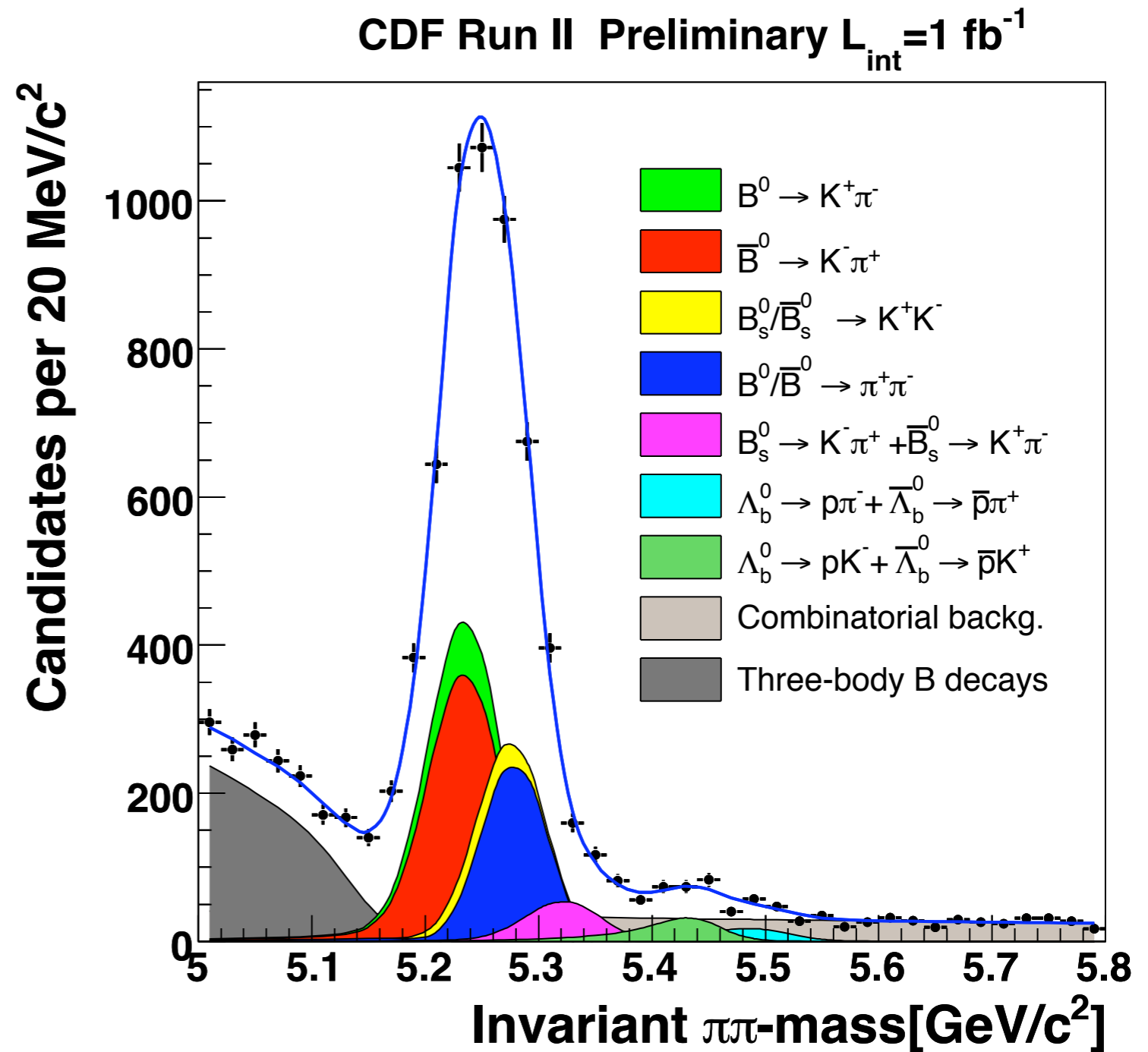


- Now approaching 2 fb⁻¹ of data i.e. roughly doubling statistics
 - significant improvement to come



CDF $B_s \rightarrow K^- \pi^+$

- Tighten cuts for B_s
 - BR Cuts optimised to measure yield best discovery/limit for $B_s \rightarrow K^- \pi^+$
 - Signal is a combination of six modes (three newly observed)
 - $B_0 \rightarrow \pi^+ \pi^- / K^+ \pi^- / B_s \rightarrow K^+ K^-$ already established.



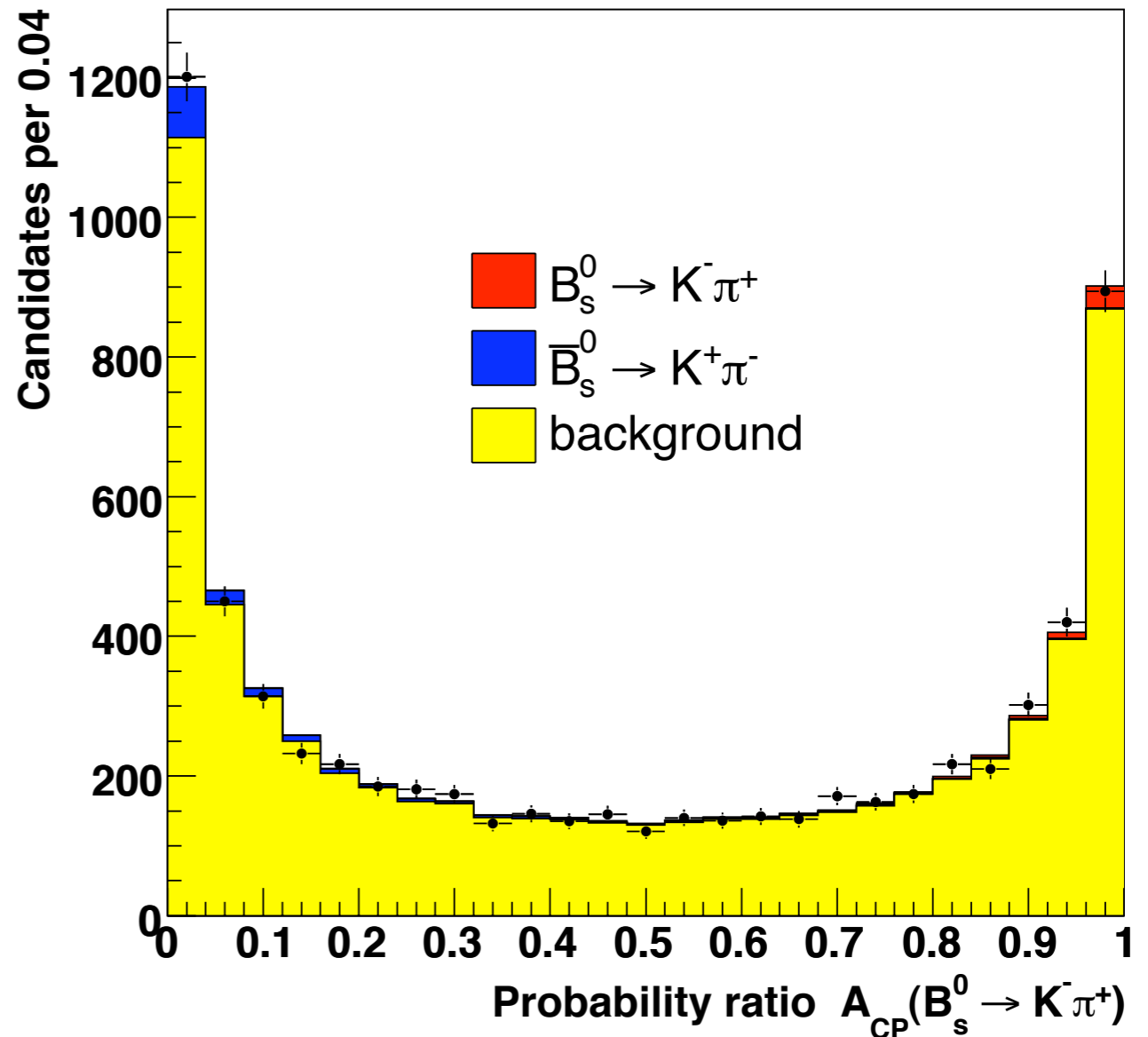
$$N_{\text{raw}} (B_s^0 \rightarrow K^- + \pi^+) = 230 \pm 34 (\text{stat}) \pm 16 (\text{syst}) 0.009$$



CDF $B_s \rightarrow K^- \pi^+$

- Is observed direct CP violation due to new physics?
 - SM prediction of equal violation in $B_s \rightarrow K^- \pi^+$
 - [Lipkin, Phys. Lett. B621:126, 2005],[Gronau&Rosner Phys.Rev. D71 (2005) 074019].
- Expect large $A_{CP} \approx 0.37$ in this mode, sign opposite to A_{CP} ($B_d \rightarrow K^+ \pi^-$)
- Observe 2.5σ effect

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



$$\begin{aligned}
 A_{CP} &= \frac{N(\bar{B}_s^0 \rightarrow K^+ \pi^-) - N(B_s^0 \rightarrow K^- \pi^+)}{N(\bar{B}_s^0 \rightarrow K^+ \pi^-) + N(B_s^0 \rightarrow K^+ \pi^-)} \\
 &= 0.39 \pm 0.15 \text{ (stat)} \pm 0.08 \text{ (syst)}
 \end{aligned}$$

CDF $B_s \rightarrow K^- \pi^+$ and $B_d \rightarrow K^+ \pi^-$

- [Lipkin, Phys. Lett. B621:126, 2005] predicts

$$|A(\bar{B}_d^0 \rightarrow K^- \pi^+)|^2 - |A(B_d^0 \rightarrow K^+ \pi^-)|^2 = |A(\bar{B}_s^0 \rightarrow K^+ \pi^-)|^2 - |A(B_s^0 \rightarrow K^- \pi^+)|^2$$

- Combining the two CDF results:

$$\frac{N(\bar{B}_d^0 \rightarrow K^- \pi^+) - N(B_d^0 \rightarrow K^+ \pi^-)}{N(\bar{B}_s^0 \rightarrow K^+ \pi^-) - N(B_s^0 \rightarrow K^- \pi^+)} = -3.2 \pm 1.6 (\text{stat}) \pm 0.4 (\text{syst})$$

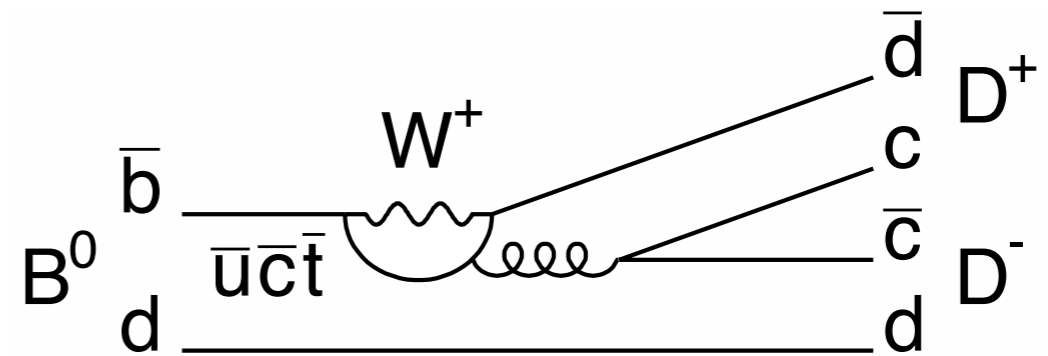
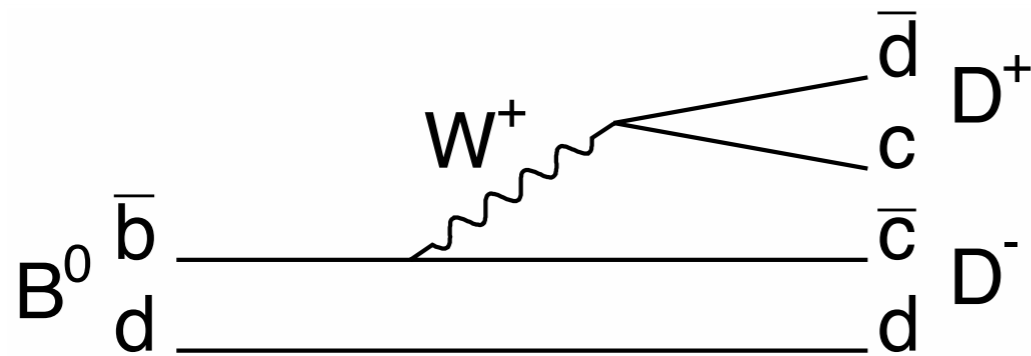
- and using HFAG 2006

$$\frac{|A(\bar{B}_d^0 \rightarrow K^- \pi^+)|^2 - |A(B_d^0 \rightarrow K^+ \pi^-)|^2}{|A(\bar{B}_s^0 \rightarrow K^+ \pi^-)|^2 - |A(B_s^0 \rightarrow K^- \pi^+)|^2} = 0.84 \pm 0.42 (\text{stat}) \pm 0.15 (\text{syst})$$



Belle: $B^0 \rightarrow D^+D^-$

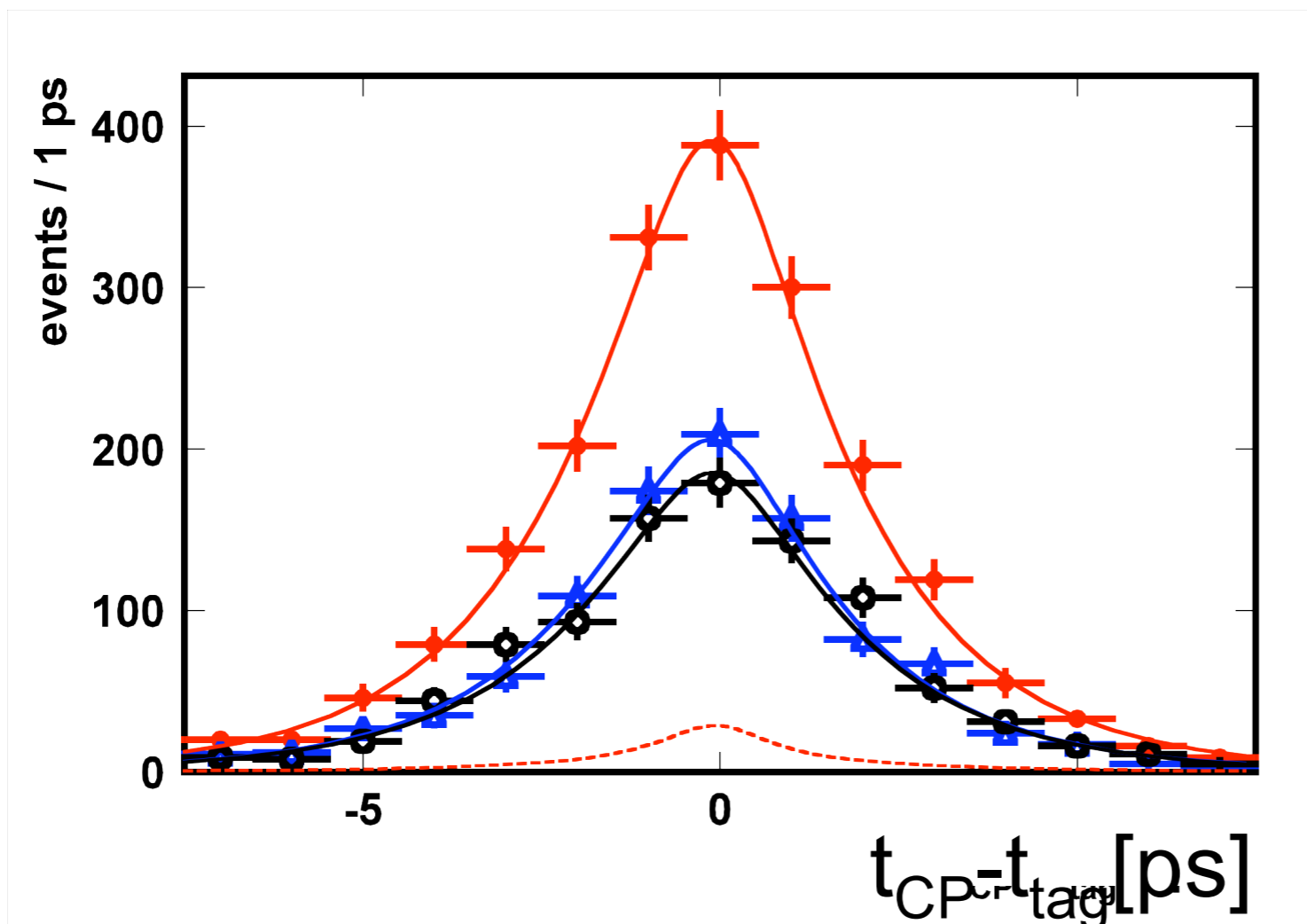
- **Standard Mixing Analysis**
 - expect little or No direct CP violation
 - S, A : CP violation parameters
 - SM expectations: $S \approx -\sin 2\varphi$, $A \approx 3\%$
[Z.Z.Xing, PRD61, 014010 (2000)]



- **$D \rightarrow K\pi\pi$ or $D \rightarrow K_S\pi$**
 - kinematic and id cuts applied

CP-fit to the control sample data

- Control sample of $B^0 \rightarrow D_s^+ D^-$ decays
 - $S = -0.064 \pm 0.094$ (stat) ± 0.012 (syst)
 - $A = 0.091 \pm 0.060$ (stat) ± 0.010 (syst)
- Consistent with $S = A = 0$

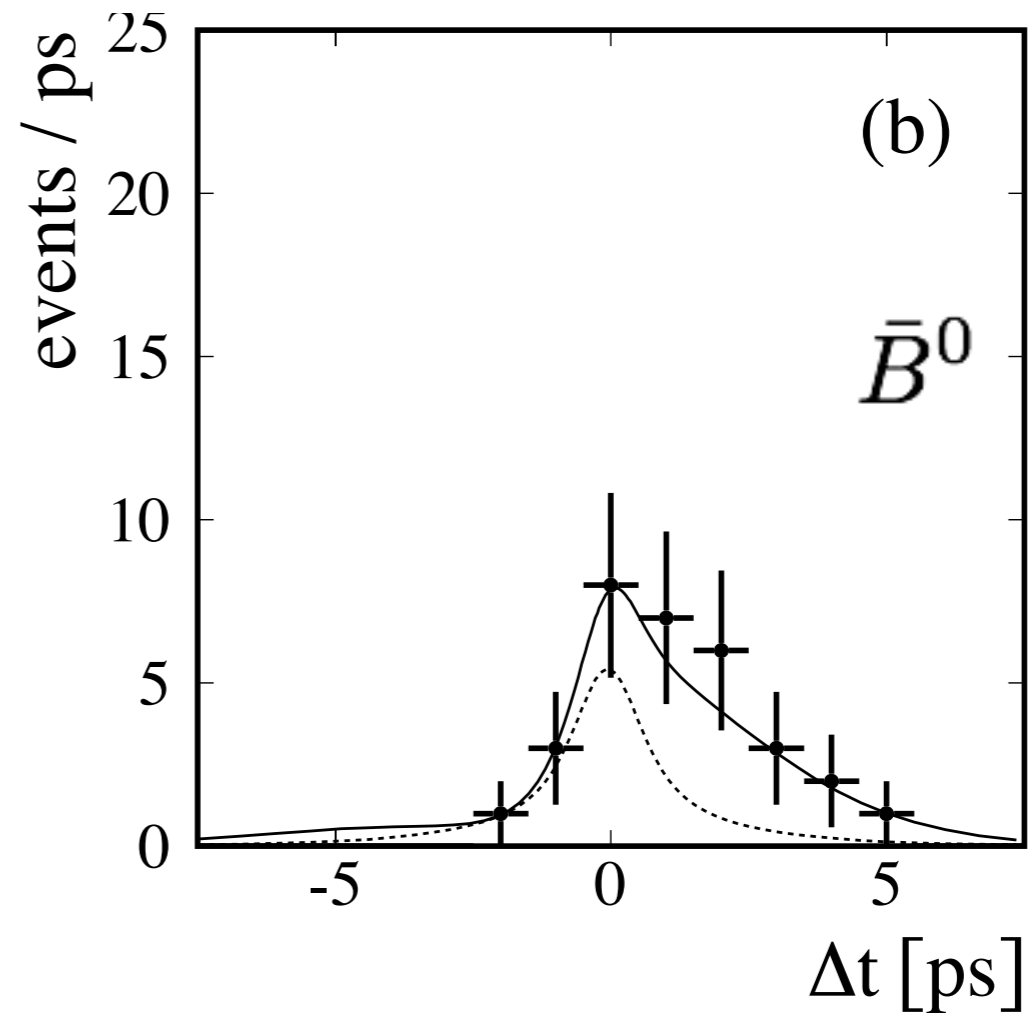
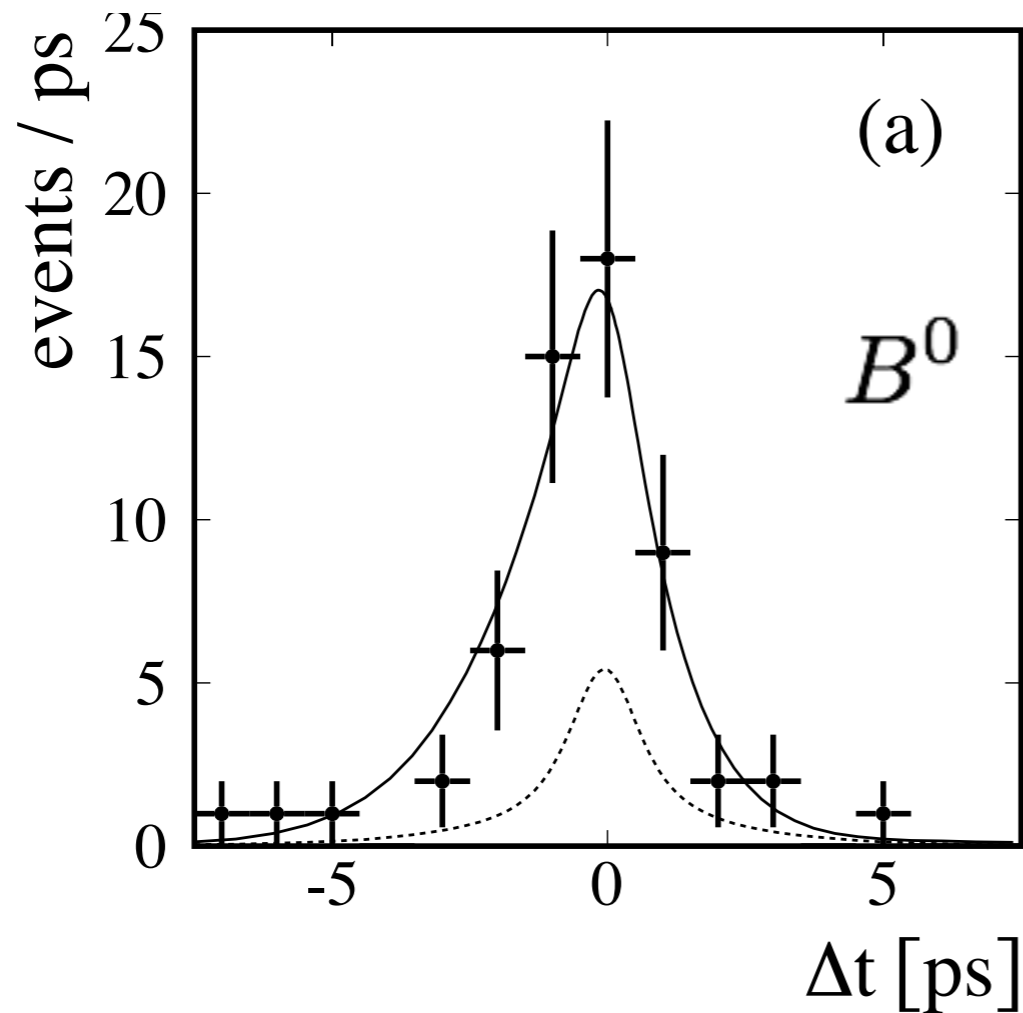


Red: All events
Blue: B0
Black: anti-B0
dashed -
background



Belle: $B^0 \rightarrow D^+D^-$ CP parameters

$$S = -1.13 \pm 0.37 \text{ (stat)} \pm 0.09 \text{ (syst)}$$
$$A = 0.91 \pm 0.23 \text{ (stat)} \pm 0.06 \text{ (syst)}$$

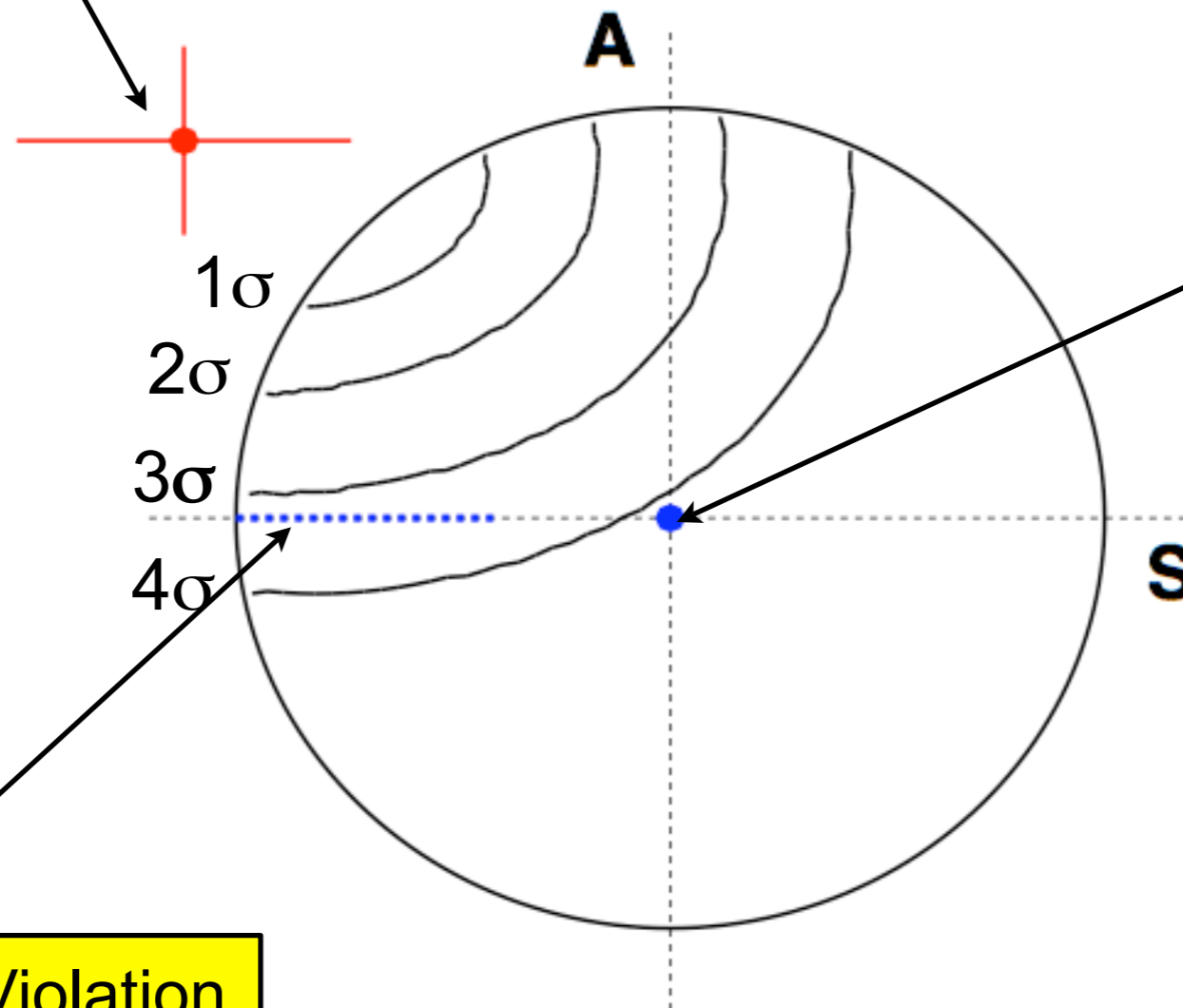


Time Integrated Cross-Check $A = 0.86 \pm 0.32$ (2.7σ)

Belle: $B^0 \rightarrow D^+D^-$ Significance

$$S = -1.13 \pm 0.37 \text{ (stat)} \pm 0.09 \text{ (syst)}$$

$$A = 0.91 \pm 0.23 \text{ (stat)} \pm 0.06 \text{ (syst)}$$



Zero CP Violation
($S=0, A=0$)
excluded at 4.1σ

Zero direct-CP Violation
($A=0$)
excluded at 3.2σ for any
value of S

New BaBar $B^0 \rightarrow D^+D^-$ result

- hep-ex/0705.1190 submitted to PRL 8 May 2007
 - 131 ± 14 $B^0 \rightarrow D^+D^-$ events observed

BaBar

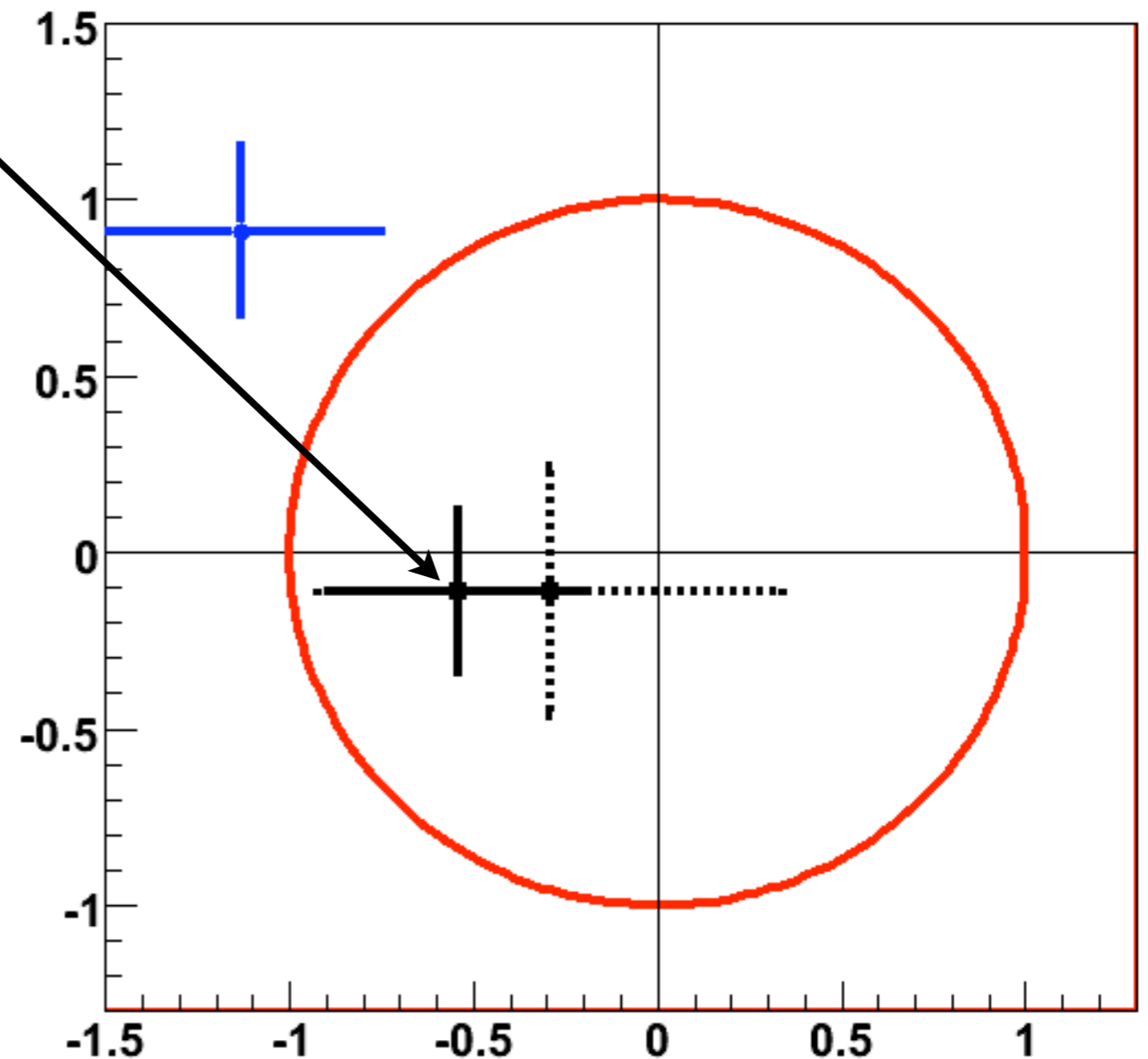
$$S = -0.54 \pm 0.34 \text{ (stat)} \pm 0.06 \text{ (syst)}$$

$$A = -0.11 \pm 0.22 \text{ (stat)} \pm 0.07 \text{ (syst)}$$

Belle

$$S = -1.13 \pm 0.37 \text{ (stat)} \pm 0.09 \text{ (syst)}$$

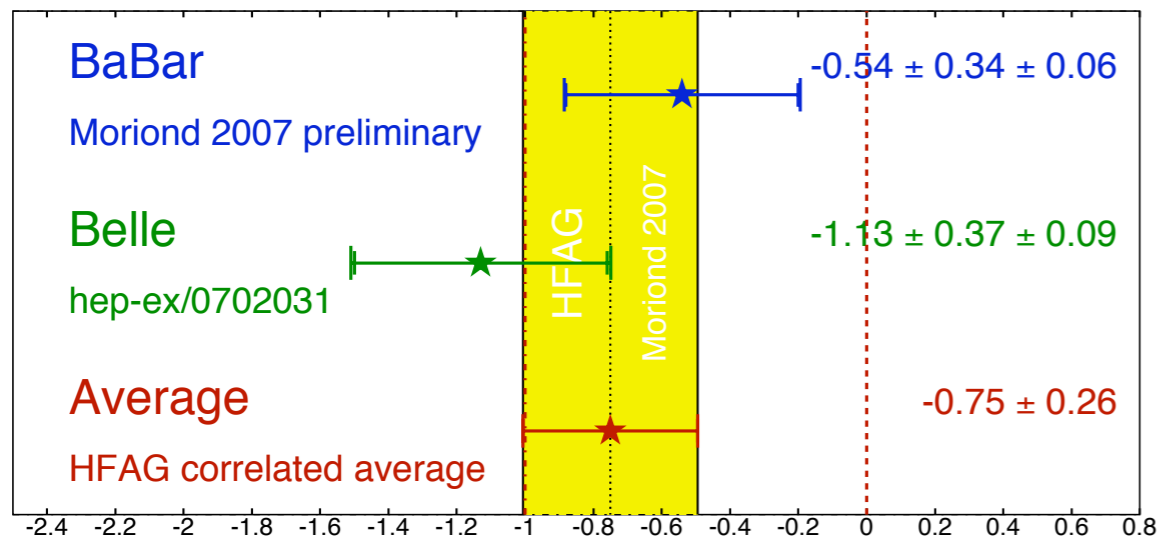
$$A = 0.91 \pm 0.23 \text{ (stat)} \pm 0.06 \text{ (syst)}$$



Comparison with BaBar

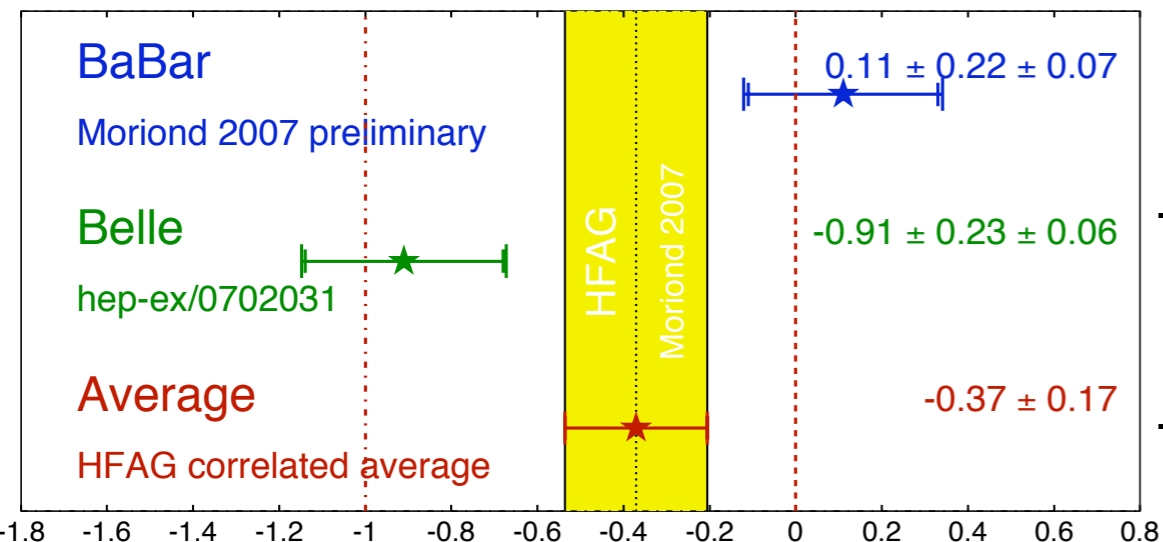
$D^+ D^- S_{CP}$

HFAG
Moriond 2007
PRELIMINARY



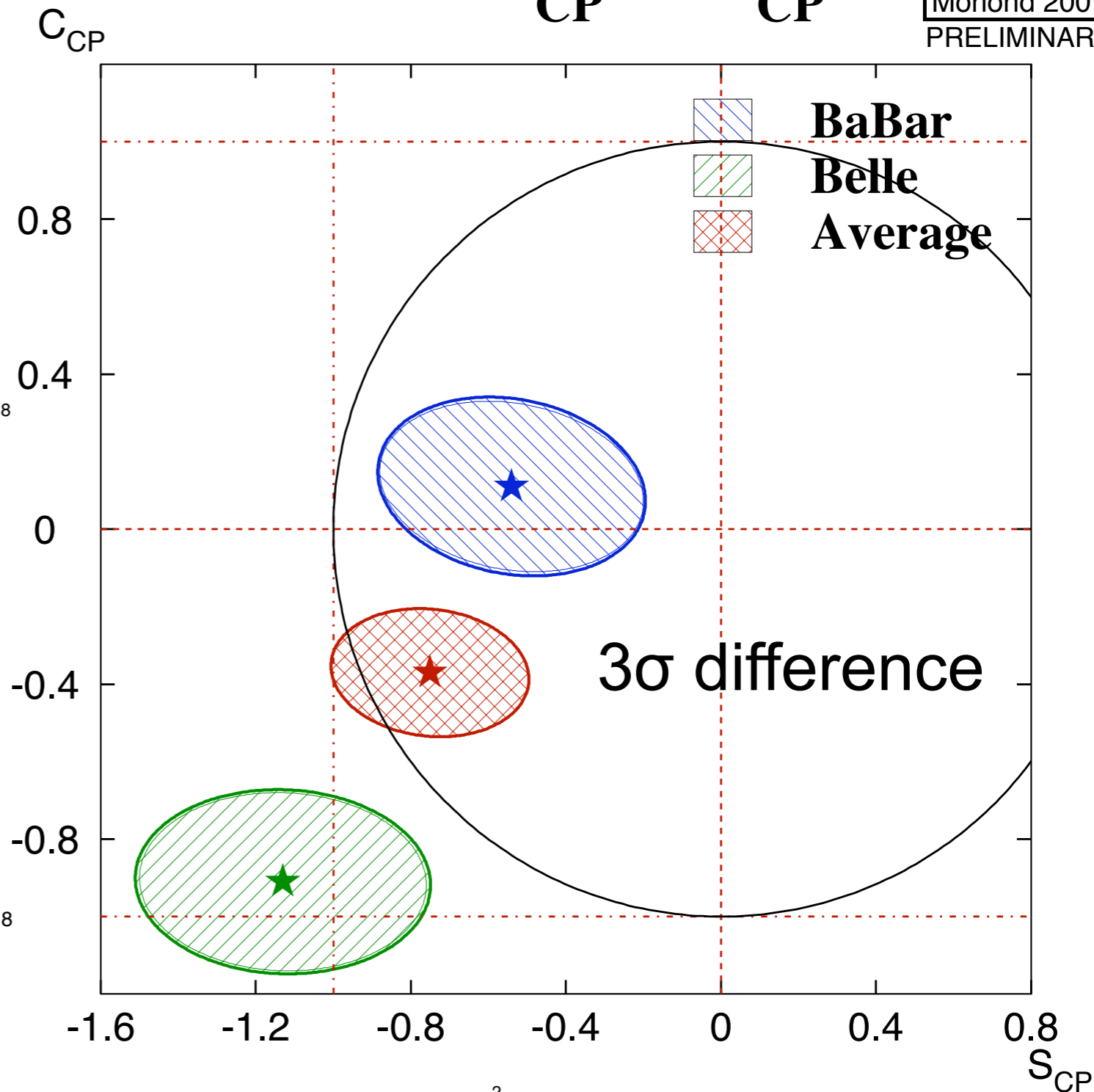
$D^+ D^- C_{CP}$

HFAG
Moriond 2007
PRELIMINARY



$D^+ D^- S_{CP}$ vs C_{CP}

HFAG
Moriond 2007
PRELIMINARY



Average

$$S = -0.75 \pm 0.25$$

$$A = 0.37 \pm 0.17$$

Summary

- Consistent set of results for $B \rightarrow hh'$

- first results for B_s system
- expect more results with increased statistics

$$A_{CP} = \frac{N(\bar{B}_s^0 \rightarrow K^+\pi^-) - N(B_s^0 \rightarrow K^-\pi^+)}{N(\bar{B}_s^0 \rightarrow K^+\pi^-) + N(B_s^0 \rightarrow K^+\pi^-)}$$
$$= 0.39 \pm 0.15 (\text{stat}) \pm 0.08 (\text{syst})$$

- $B \rightarrow D^+D^+$ puzzle

- significant direct CP violation observed by Belle
- no signal seen by BaBar
- large statistical fluctuation
 - await new results