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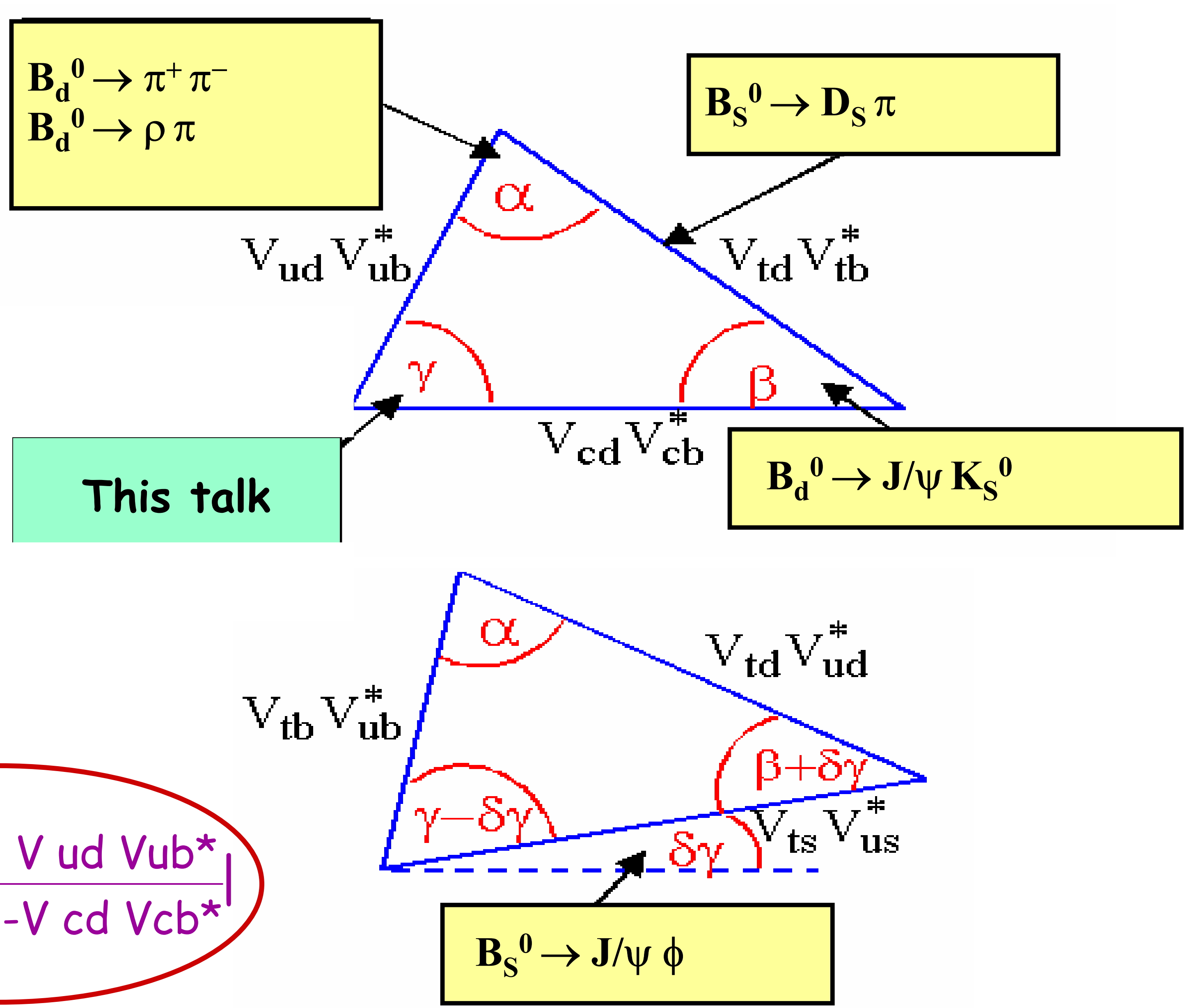
Reaching for γ (present and future)

Unitarity Triangles



$$\gamma = \arg \left| \frac{V_{ud} V_{ub}^*}{-V_{cd} V_{cb}^*} \right|$$

There are a few methods of determining γ

CP violation in Decay

- Rates and asymmetries in $K\pi$ Decays
- Amplitude triangles for $B^{\pm} \rightarrow Dcp^{0}K^{\pm}$ (GLW method) + extensions/modifications

CP violation in Interference of Mixing & Decay

- Time dependent asymmetries in $Bd \rightarrow \pi^{+}\pi^{-}$ and $Bs \rightarrow K^{+}K^{-}$ decays assuming U-spin symmetry
- Time dependent flavor tagged analysis of
  - $Bs \rightarrow DsK^{-}$ decay
  - $Bd \rightarrow D^{*}\pi^{+}$ decay

Data Samples
(present and future)

Results presented today are based on 81.2 fb^{-1}(BaBar) and 78 fb^{-1}(BELLE)
That corresponds to 88 and 85 mln $B\bar{B}$ pairs *(part of data sample)*

Statistics available today at B-factories $\cong$ 300 mln $B\bar{B}$ pairs

In 2006 one expects $\cong$ 1.2 bln $B\bar{B}$ pairs

In 2008 after 1 year of LHCb (and BTeV) operation $\sim$ 10^{12} $b\bar{b}$ pairs

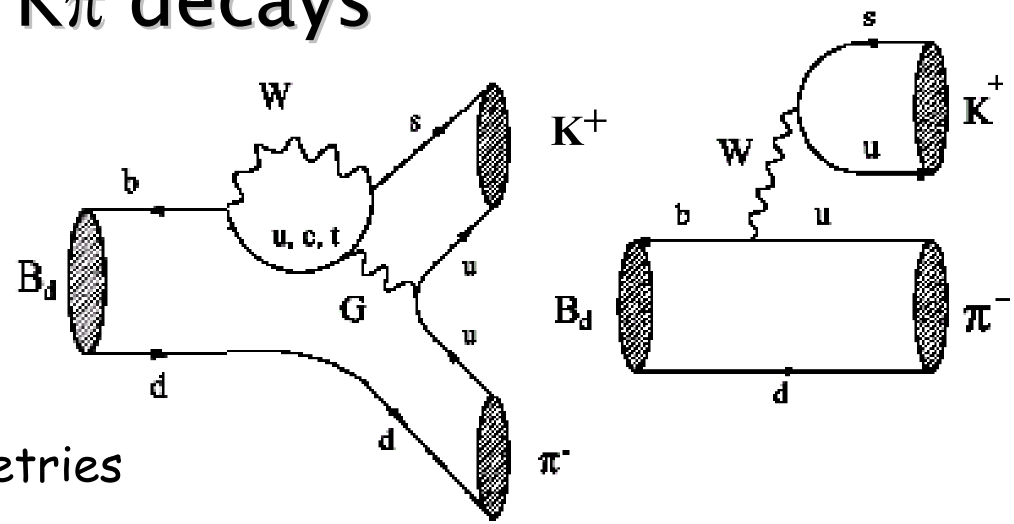
Super B_d-factory: 1.5 to 5 bln of "clean" $B\bar{B}$ events depending on achieved luminosity

γ from $B \rightarrow K\pi$ decays

Significant interference of
tree and penguin amplitudes

$$A_{K\pi} \sim \lambda^2 e^{i\gamma} T + P$$

Expect potentially large CP asymmetries



QCD penguins play the dominant role

Difficulties:

Theoretical
- EW penguins
- SU(3) breaking + (FSI) effects

Experimental
- small BF, $q\bar{q}$ background
- Particle ID is crucial

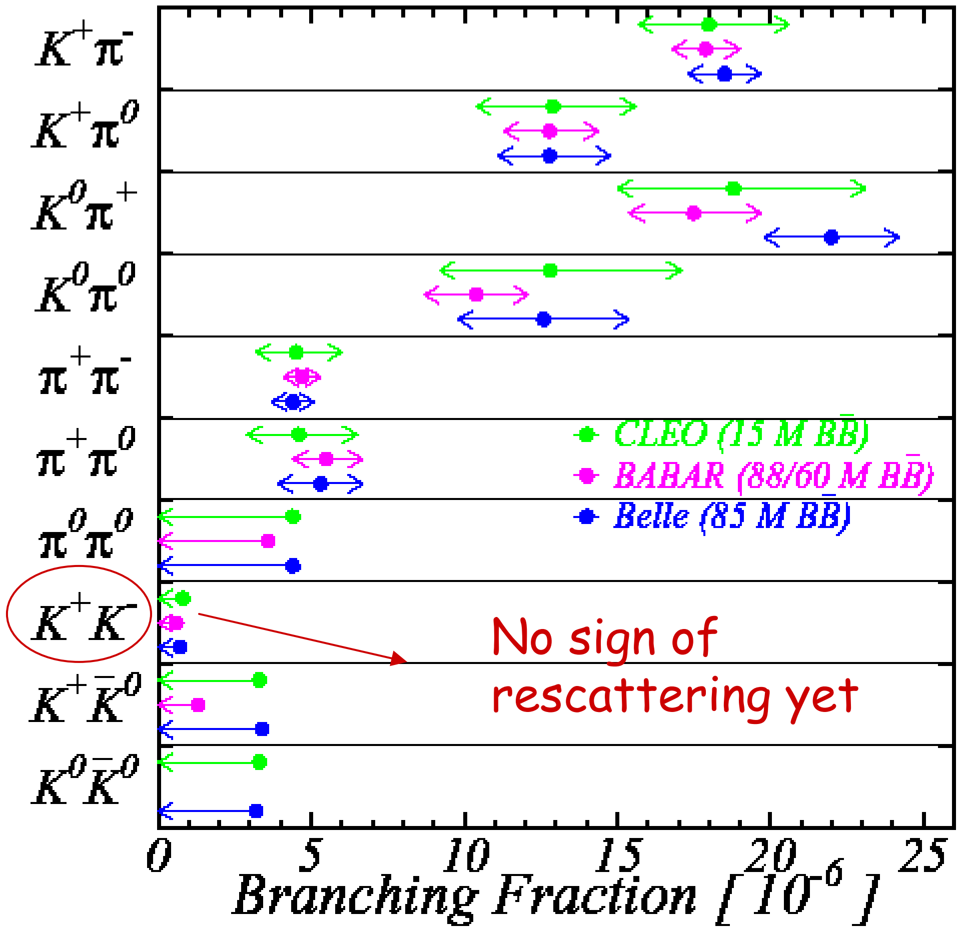
Measurement of the ratios of BF and A_{CP}^{dir} may provide constraints on γ and strong phase δ

Summary of BFs [10^{-6}]

From J.D. Olsen talk at the CKM workshop 2003

Mode	BaBar	BELLE	CLEO	Avg.	$\delta\mathcal{B}/\mathcal{B}$ (%)
$K^+\pi^-$	$17.9 \pm 0.9 \pm 0.7$	$18.5 \pm 1.0 \pm 0.7$	$18.0^{+2.3+1.2}_{-2.1-0.9}$	18.1 ± 0.8	4
$K^0\pi^+$	$20.0 \pm 1.6 \pm 1.0$	$22.0 \pm 1.9 \pm 1.1$	$18.8^{+3.7+2.1}_{-3.3-1.8}$	20.6 ± 1.4	7
$K^+\pi^0$	$12.8^{+1.2}_{-1.1} \pm 1.0$	$12.8 \pm 1.4\,^{+1.4}_{-1.0}$	$12.9^{+2.4+1.2}_{-2.2-1.1}$	12.8 ± 1.1	9
$K^0\pi^0$	$10.4 \pm 1.5 \pm 0.8$	$12.6 \pm 2.4 \pm 1.4$	$12.8^{+4.0+1.7}_{-3.3-1.4}$	11.2 ± 1.4	13
$\pi^+\pi^-$	$4.7 \pm 0.6 \pm 0.2$	$4.4 \pm 0.6 \pm 0.3$	$4.5^{+1.4+0.5}_{-1.2-0.4}$	4.6 ± 0.4	9
$\pi^+\pi^0$	$5.5^{+1.0}_{-0.9} \pm 0.6$	$5.3 \pm 1.3 \pm 0.5$	$4.6^{+1.8+0.6}_{-1.6-0.7}$	5.2 ± 0.8	15
$\pi^0\pi^0$	< 3.6	< 4.4	< 4.4	< 3.6	
K^+K^-	< 0.6	< 0.7	< 0.8	< 0.6	
$K^+\overline{K}^0$	< 2.2	< 3.4	< 3.3	< 2.2	
$K^0\overline{K}^0$	< 1.6	< 3.2	< 3.3	< 1.6	

Comparison of BF



Present precision is dominated by statistical errors
In a few years statistical and systematical errors should become comparable

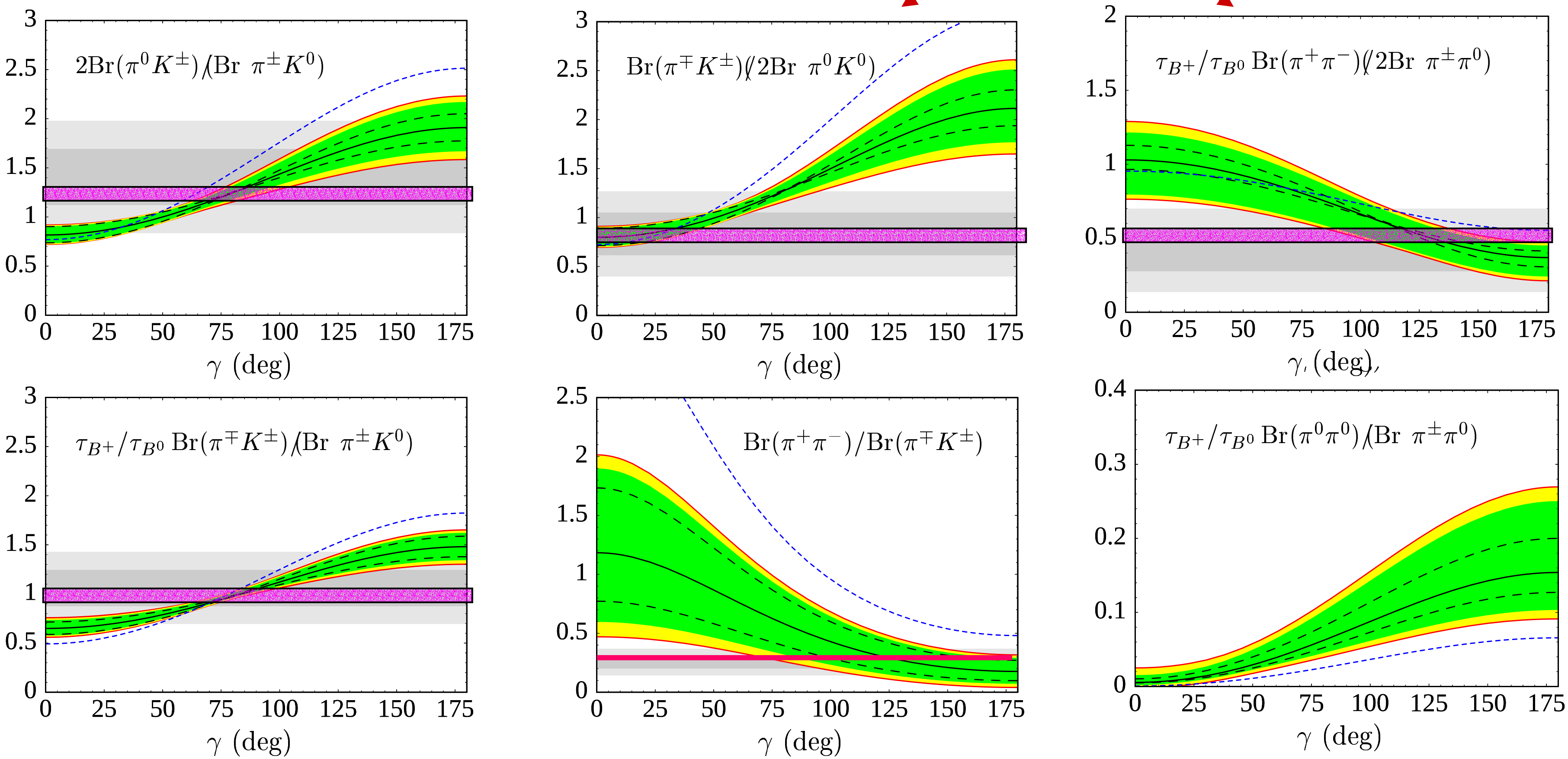
A Specific Model: QCD Factorization

Beneke *et. al.*, Nucl. Phys. B606, 245 (2001)

Data (2001)

Data (2003)

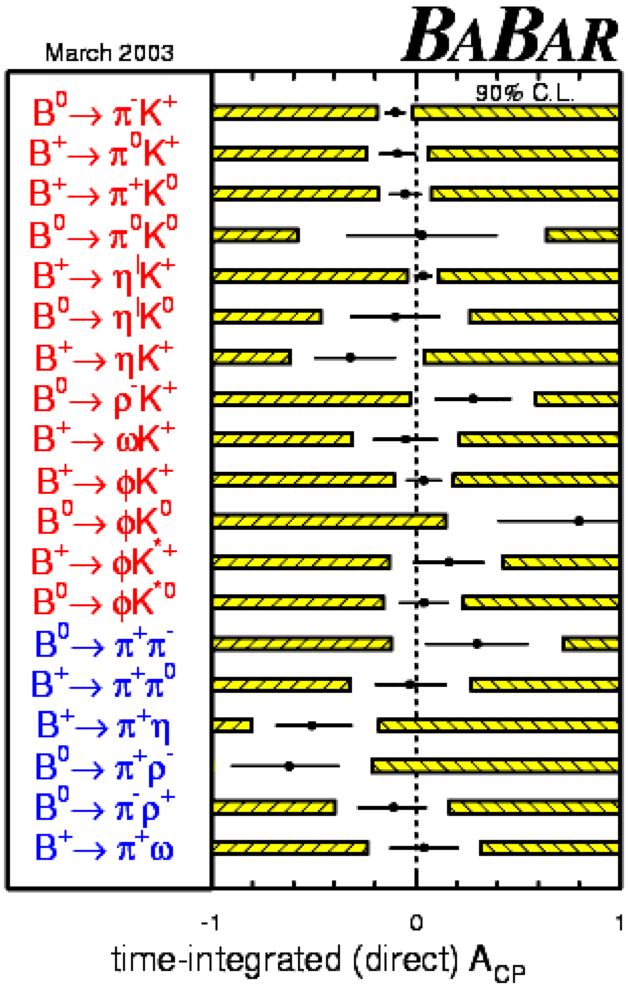
Inconsistent?

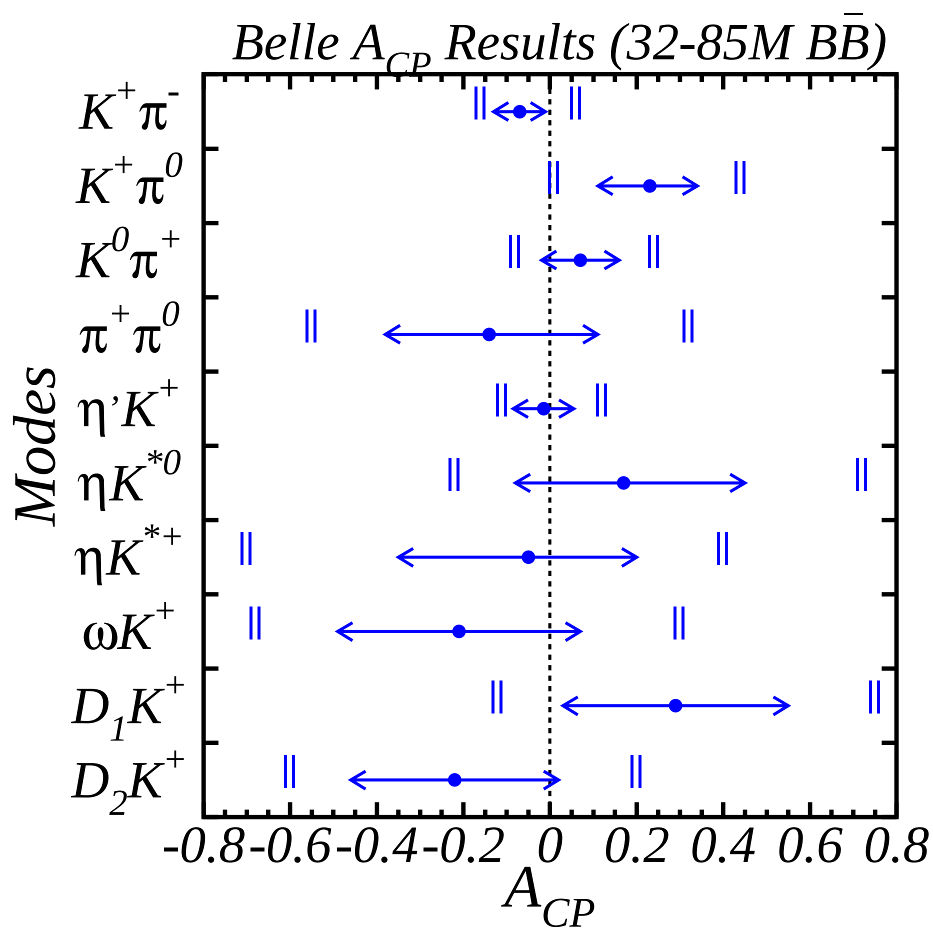


Data start to constrain models

CP asymmetries

(allows one to eliminate dependence on the strong phase δ)

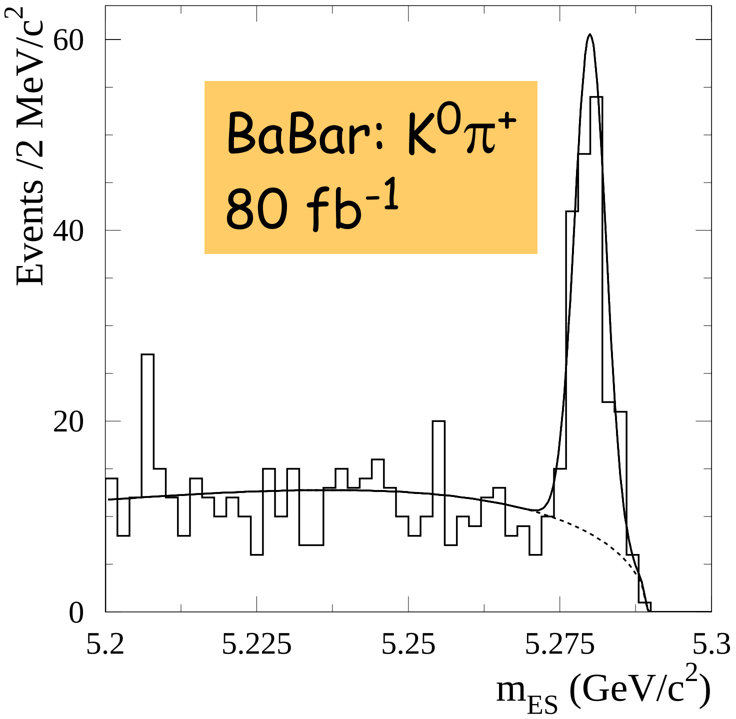




Largest deviations: 2σ each in $K^+\pi^-$(BaBar), $\rho^+\pi^-$(BaBar), and $K^+\pi^0$(Belle)

- In a few years statistical precision in the measurements of Branching Fractions ($B \rightarrow K\pi/\pi\pi$) should reach the level of systematic error, 2-4% depending on decay mode

- Extraction of γ will be dominated by theoretical uncertainties

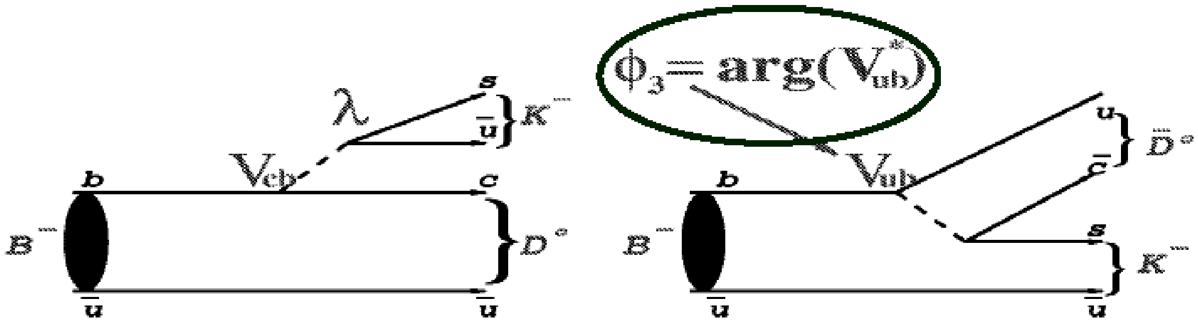


In 1 year BTeV expects:

4600 $K^0\pi^+$ events (with S/B = 1)
62100 $K^-\pi^+$ events (with S/B=20)

Amplitude triangles

- GLW method



Color-favored Color-suppressed

$B^- \rightarrow D_{CP}K^-$ where $D_{CP}=(1/\sqrt{2})(D^0 \pm \overline{D^0})$

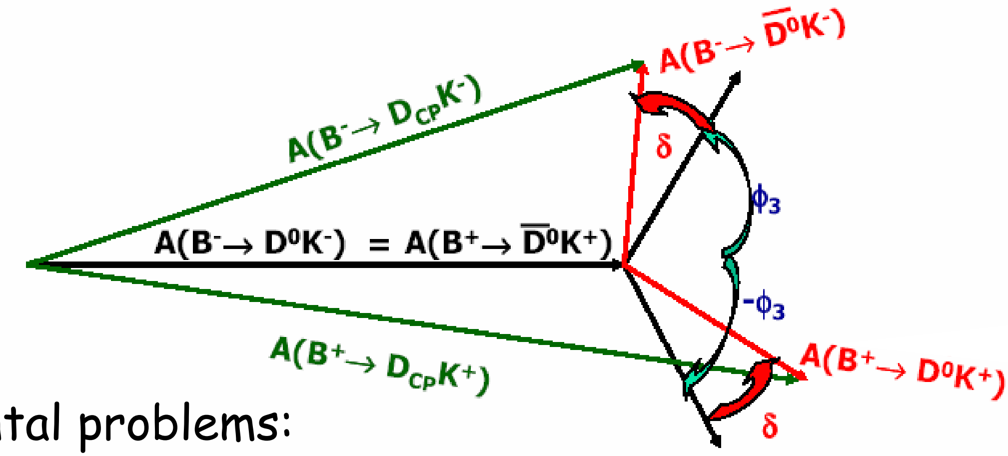
$A(B^- \rightarrow D_{CP}K^-) \approx |A(B^- \rightarrow \overline{D}^0K^-)| + |A(B^- \rightarrow D^0K^-)|e^{i\gamma}e^{i\delta}$

$A(B^- \rightarrow D_{CP}K^+) \approx |A(B^- \rightarrow D^0K^+)| + |A(B^- \rightarrow \overline{D}^0K^+)|e^{-i\gamma}e^{i\delta}$

CP-even states: K+K-, π+π-

CP-odd states: $K_S\pi^0$, $K_S\phi$, $K_S\omega$, $K_S\eta$, $K_S\eta'$

γ can be extracted from the reconstruction of two triangles



Experimental problems:

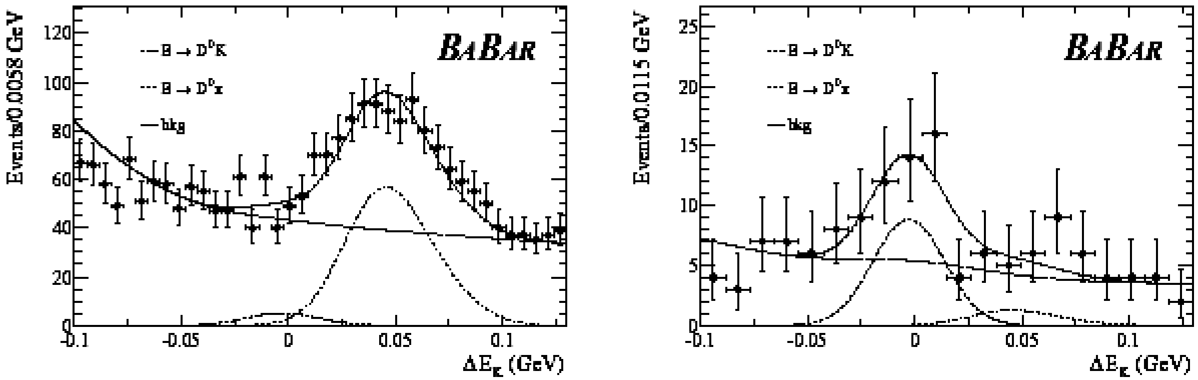
$A(B^- \rightarrow \overline{D}{}^0 K^-)$ is small ⟶ squashed triangles
DCSD lead to the common final states for D^0 and D^0
(color suppressed A is of the same order as color favored × DCSD)

Experimental observables:

$$R_{1,2} = \frac{BF(B^- \rightarrow D_{1,2}K^-)\,/\,BF(B^- \rightarrow D_{1,2}\pi^-)}{BF(B^- \rightarrow D^0K^-)\,/\,BF(B^- \rightarrow D^0\pi^-)} \quad , \quad A_1 \text{ and } A_2$$

allow, in principle, to extract R_{DK^-}, δ and γ

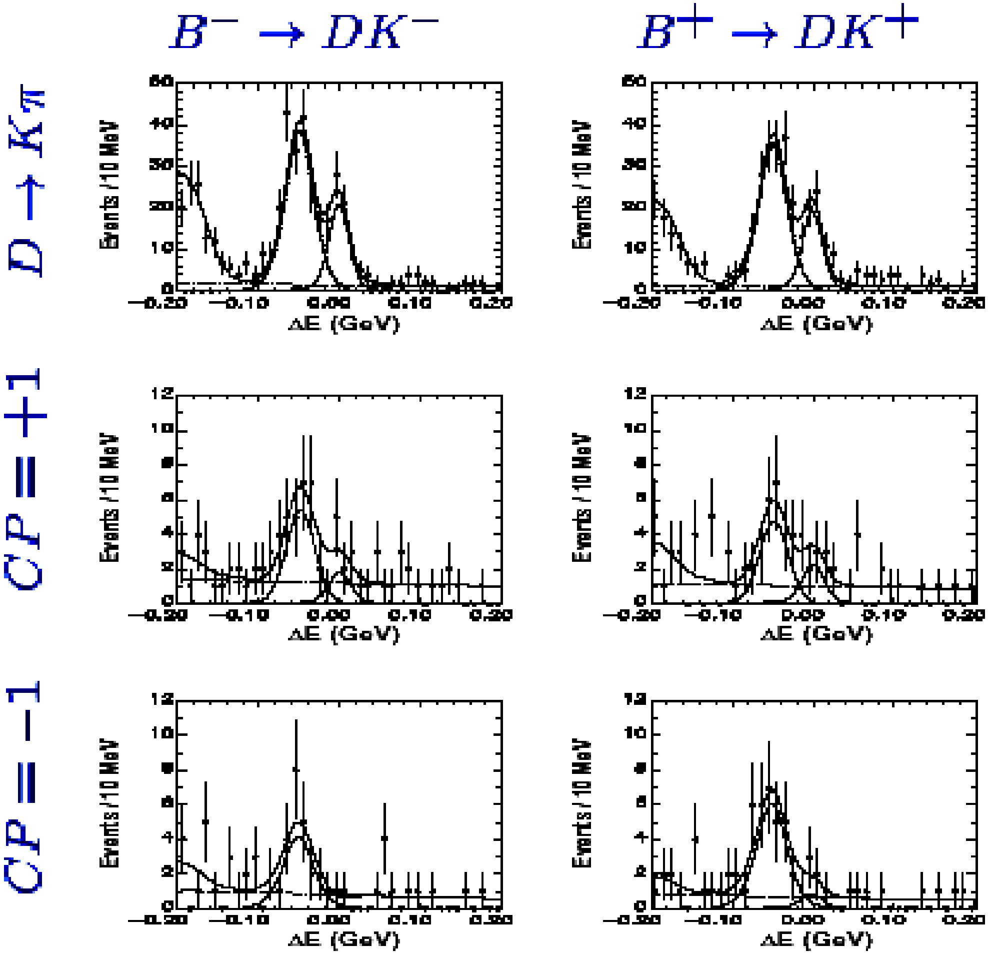
No K/π identification — K-id required



BaBar reconstructed D_1K^-
$\hookrightarrow K^+K^-$

$$R_1 = \frac{(7.4 \pm 1.7 \pm 0.6)\%}{(8.31 \pm 0.35 \pm 0.20)\%}$$

$$A_{D1K^-} = 0.17 \pm 0.23^{+0.09}_{-0.07}$$



BELLE studied both D_1K^- and D_2K^-

$R_1 = 1.21 \pm 0.25 \pm 0.14$
$R_2 = 1.41 \pm 0.27 \pm 0.15$
$A_{D1K^-} = +0.06 \pm 0.19 \pm 0.04$
$A_{D2K^-} = -0.18 \pm 0.17 \pm 0.05$

No constraints on γ possible with this statistics …

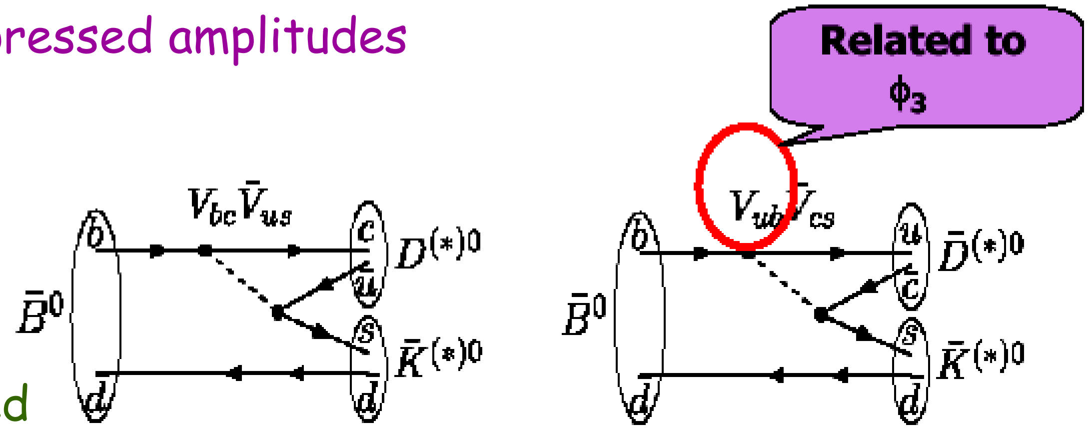
Needed:

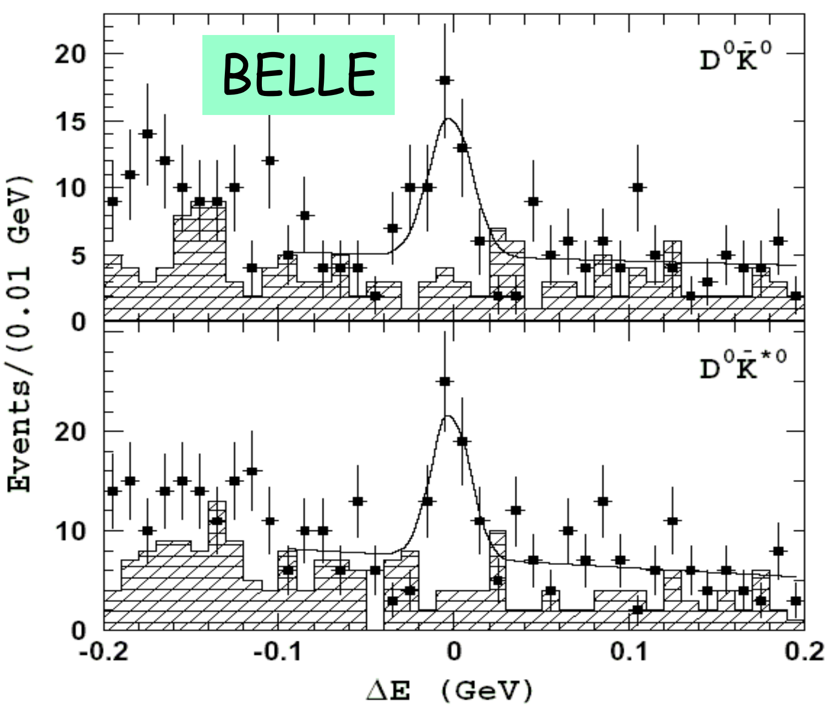
significantly higher statistics
precision measurements of D Branching Fractions

$B^0 \to D^0 K^{(*)0}$ Mode

Two comparable color-suppressed amplitudes

Triangles are not as squashed as in $B^{\pm} \to DK^{\pm}$ case





$BF(\bar{B}^0 \to D^0 \bar{K}^0) = (5.0\ ^{+1.3}_{-1.2} \pm 0.6) \times 10^{-5}$

$BF(\bar{B}^0 \to D^0 \bar{K}^{*0}) = (4.8\ ^{+1.1}_{-1.0} \pm 0.6) \times 10^{-5}$

Hope to see soon $B^0 \to D^0 K^{*0}$ decay

Present Upper Limit is

$BF(B^0 \to D^0 K^{*0}) < 1.8 \times 10^{-5}$

ADS variant of the amplitude triangle approach:

$B^- \to \overline{D}^0[\to f_i]\, K^-$ and $B^- \to D^0[\to f_i] K^-$, $f_i = K^-\pi^+$ or $K^-\pi^+\pi^0$

Use large interference effects
Experimentally challenging since BF of $O(10^{-7})$ are involved

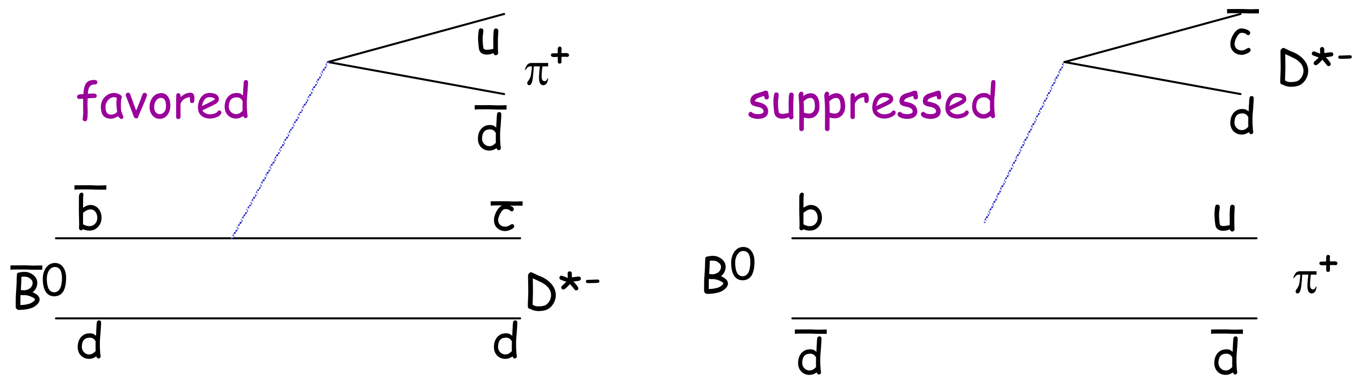
Dalitz plot analysis of $D \to K_S\pi^+\pi^-$ for $B^-\to DK^-$ and $B^+\to DK^+$ decays

$K_S\pi^+\pi^-$ receives contributions from:

$B^-\to D^0K^-$ $D^0\to K^{*-}\pi^+$ $K^{*-}\to K_S\pi^-$
$B^-\to D^0K^-$ $D^0\to K^{*+}\pi^-$ $K^{*+}\to K_S\pi^+$
$B^-\to D^0K^-$ $D^0\to K_S\rho^0$ $\rho^0 \to \pi^+\pi^-$
$B^-\to D^0K^-$ $D^0\to K_S\rho^0$ $\rho^0 \to \pi^+\pi^-$

Enough information to extract γ for any magnitude of δ

$B^0 \to D^{*}\pi^{-}$ Mode



Suppressed/favored $< 10^{-2}$ ➡ Small CP-violating effect expected

Time evolution:

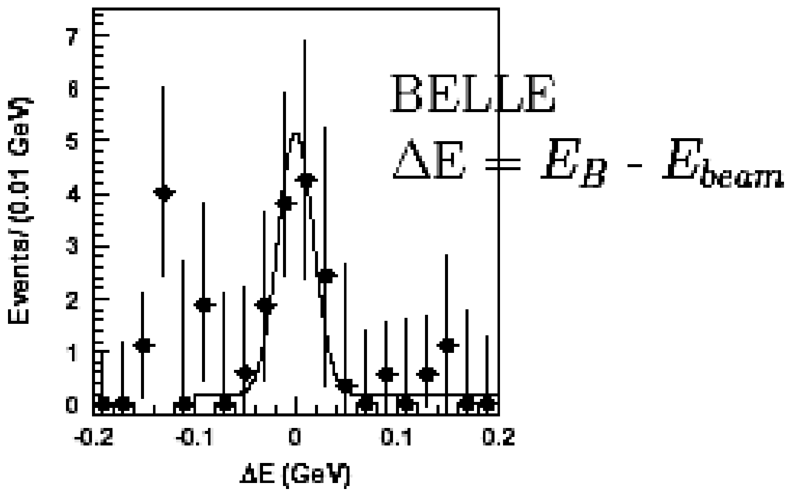
$$\Gamma(B \to D^{*}\pi) \propto (1+R_{D^{*}\pi}{}^2) \pm (1-R_{D^{*}\pi}{}^2)\cos(\Delta m t) \pm 2\, R_{D^{*}\pi}\sin(2\beta+\gamma)\, \sin(\Delta m t)$$

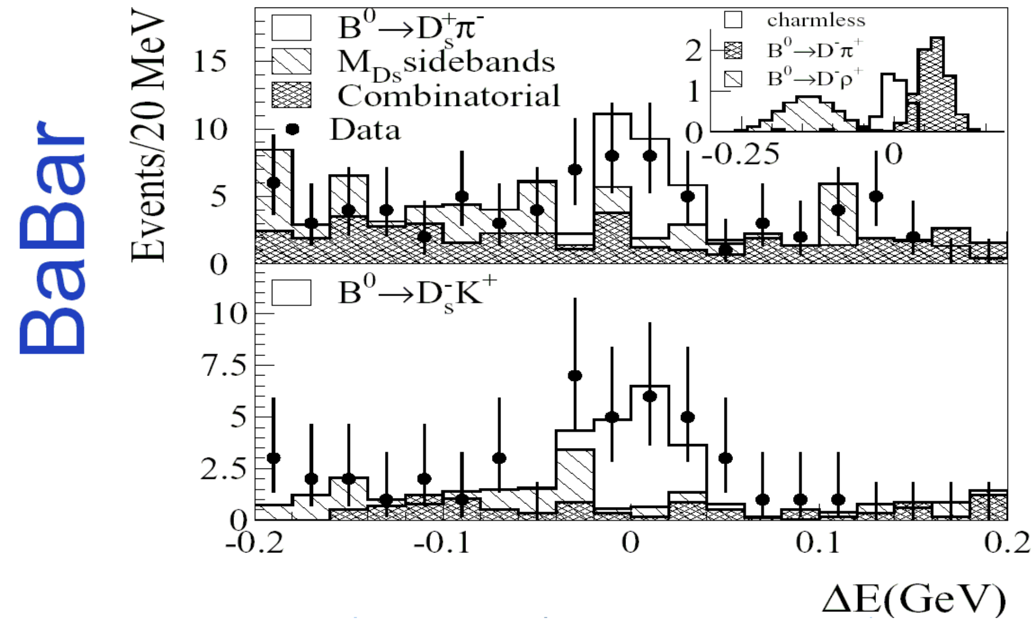
$(2\beta + \gamma)$ is extracted from the measurement of 4 time-dependent asymmetries

$R_{D^{*}\pi}$ can be estimated using $BF(B^0 \to D_s^{+}\pi^{-})$:

$$BF(B^0 \to D_s^{+}\pi^{-}) \approx \frac{BF(B^0 \to D^{*-}\pi^{+})}{\tan^2\Theta_c} \times \frac{f_{Ds}{}^2}{f_{D^*}{}^2} \times R_{D^{*}\pi}{}^2$$

Evidence for $B^0 \to D_s^+ \pi^-$





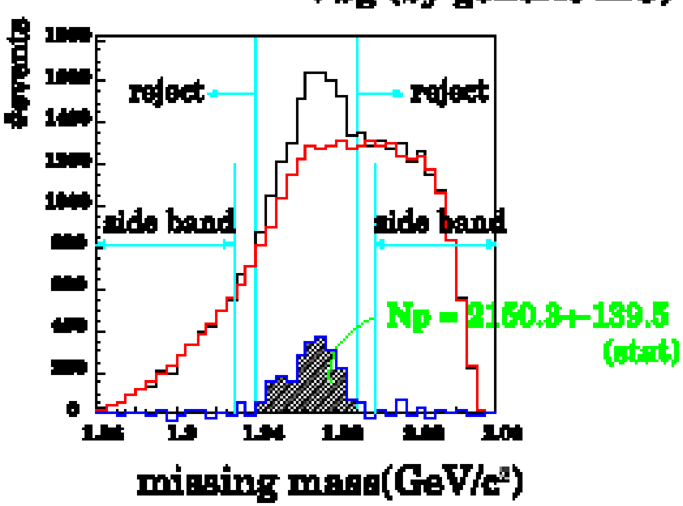
$Br(B^0 \to D_s^+ \pi^-) \times Br(D_s^+ \to \phi \pi^+)$

BaBar	$(1.13 \pm 0.33 \pm 0.21) \times 10^{-6}$
BELLE	$(0.86\,^{+0.37}_{-0.30} \pm 0.11) \times 10^{-6}$

Partial reconstruction

BELLE

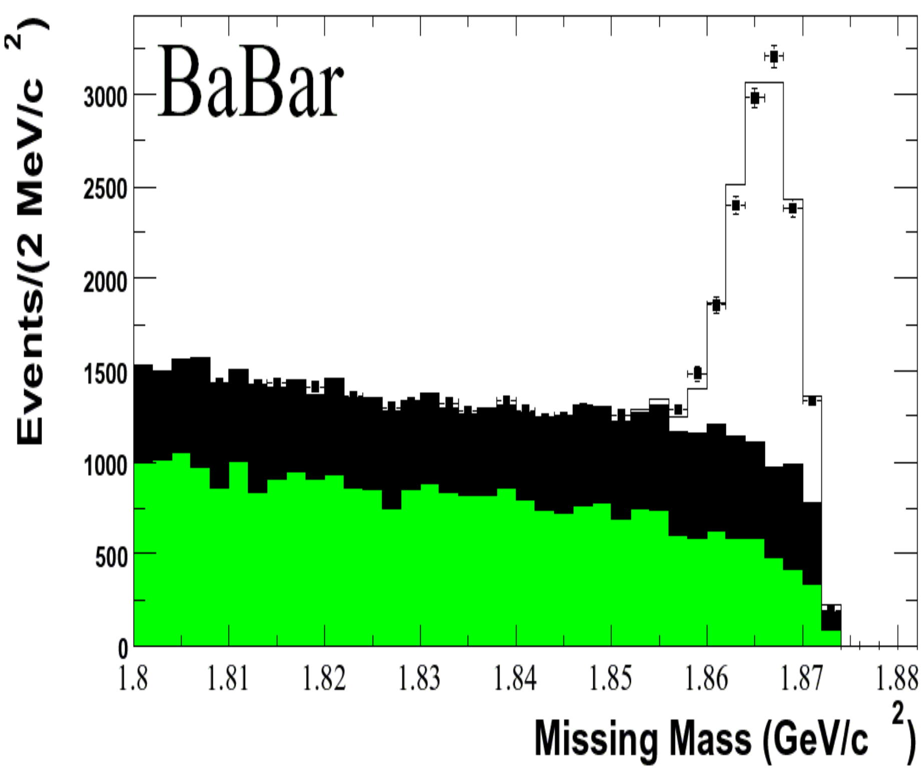
: Data
: signal
: bg (by generic MC)

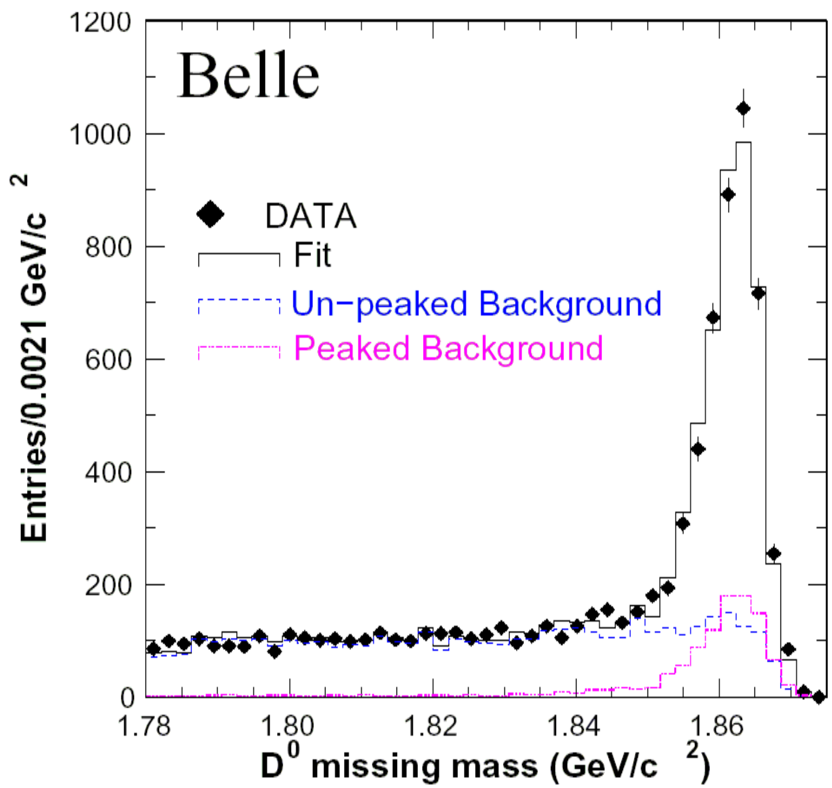


BELLE have measured
$Br(D_s^+ \to \phi \pi^+) = (3.72 \pm 0.39\,^{+0.47}_{-0.39}) \times 10^{-6}$
using full/partial reconstruction method

$R_{D^*\pi} \approx 0.022 \pm 0.007$

$D^{*+}\pi^-$ Data Samples (partial reconstruction)





$\sim$20 fb^{-1}, 6970 ± 240 events

τ_{B^0} = 1.510 ± 0.040 ± 0.041 ps

$\sim$30 fb^{-1} , 3430 ± 80 events

Δm = 0.509 ± 0.017 ± 0.020 ps^{-1}

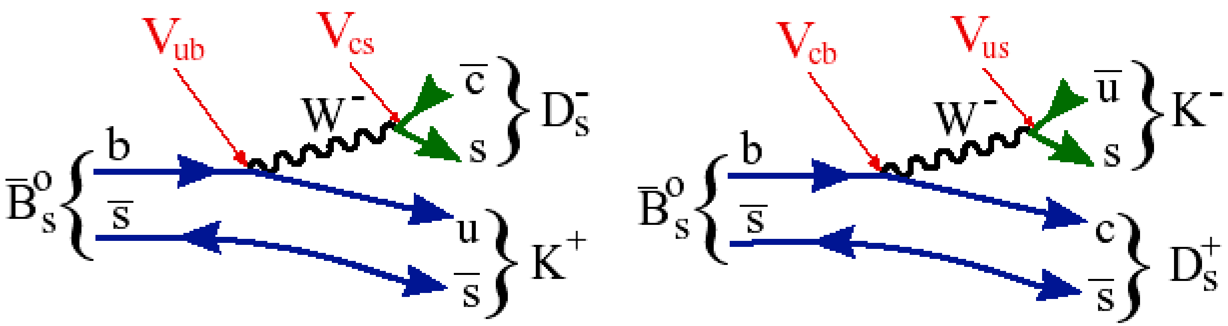
$\delta(\sin(2\beta+\gamma)) \propto \propto 0.15$ for 1000 fb^{-1} T. Gershon (CKM workshop, 2003)

or $\delta(2\beta+\gamma) \propto 10^o$

γ from $B_s \to D^-_s K^+$, $D^+_s K^-$

Same principle as for $B^0 \to D^* \pi^-$
Since $\delta\gamma$ is small → sensitivity should not depend on the value of γ

Two decay modes with comparable amplitudes, $B \sim 10^{-4}$ each



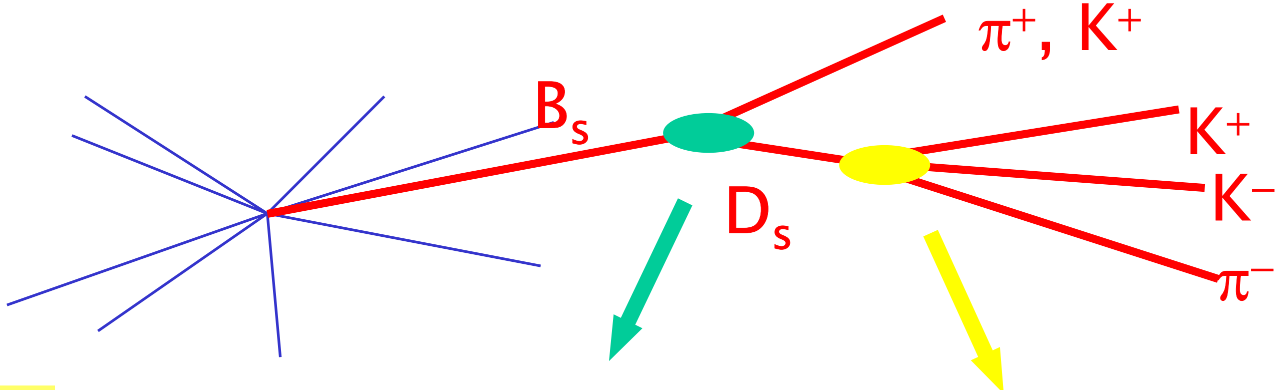
γ can be determined from the measurement of 4 time-dependent asymmetries (assuming that $\delta\gamma$ is fixed from Bs mixing)

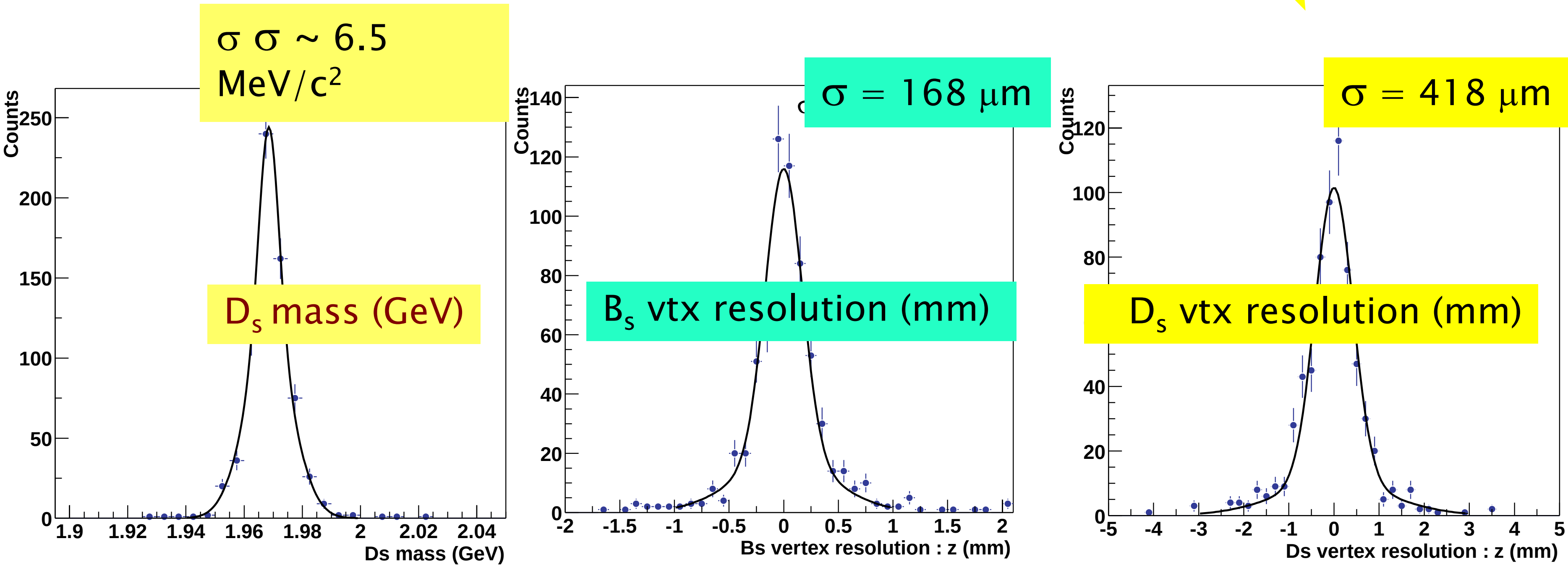
Contribution from NP is unlikely !

Looks as most clean method to measure γ

$B_s \to D_s\pi$, D_sK kinematics at LHCb

72k $D_s^- \pi^+$
8k $D_s^- K^+$

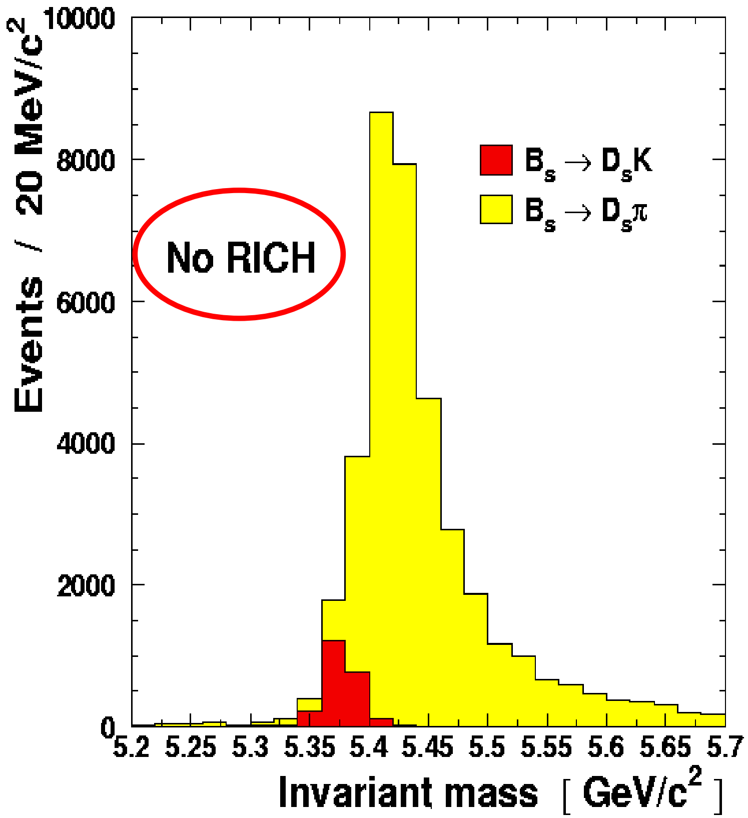


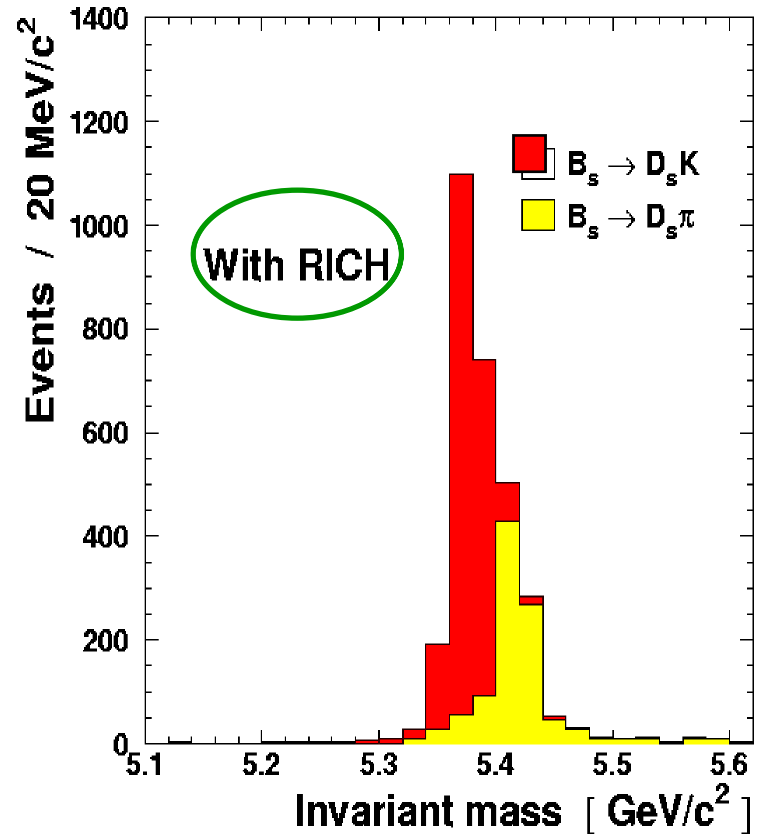


Importance of Particle ID

Needed:

- ✓ Hadronic trigger
- ✓ K/π separation
- ✓ Good proper time resolution

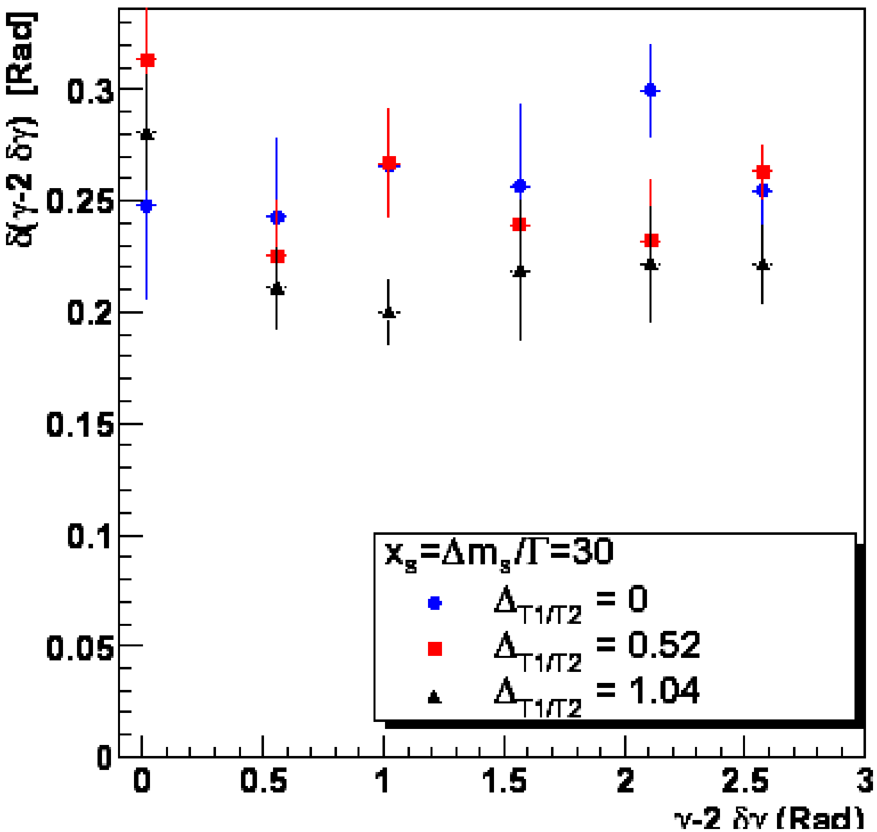




In one year of LHCb running:

8k $B_s \to D_s^{\pm} K^{\pm}$ reconstructed events

Sensitivity slightly depends on strong phase difference Δ(T1/T2) and x_s



Assumptions:

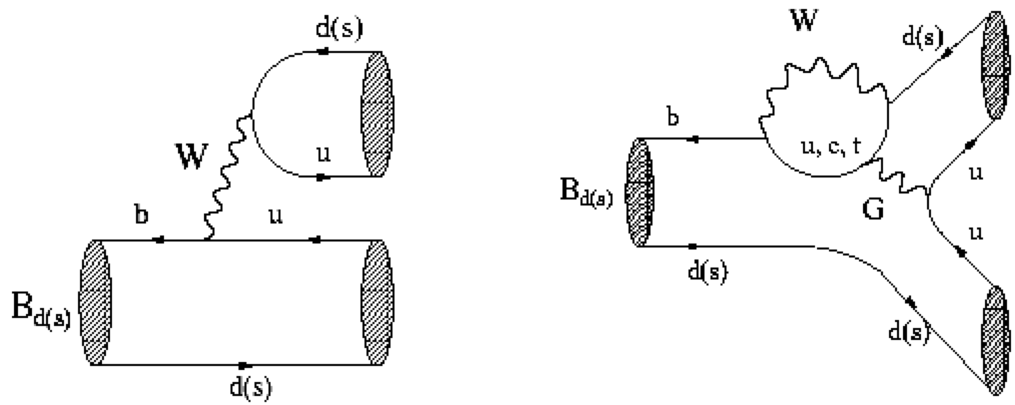
- 3k tagged $Bs \to DsK^-$
- 30% background
- 30% mistag

LHCb:
$\sigma(\gamma) \sim 10°$ for $x_s = 15$
$\sigma(\gamma) \sim 12°$ for $x_s = 30$

BTeV:
$\sigma(\gamma) \sim 8°$

γ from $B_{(s)} \rightarrow \pi\,\pi$, K K

proposed by R. Fleischer



Measure time-dependent asymmetries in $B^0 \rightarrow \pi^+\pi^-$ and $Bs \rightarrow K^+ K^-$ decays to extract γ

$$A^{dir}_{CP}(B^0 \rightarrow \pi^+\pi^-) = function(d, \vartheta, \gamma)$$
$$A^{mix}_{CP}(B^0 \rightarrow \pi^+\pi^-) = function(d, \vartheta, \gamma, \phi_d)$$
$$A^{dir}_{CP}(B_s \rightarrow K^+K^-) = function(d', \vartheta', \gamma)$$
$$A^{mix}_{CP}(B_s \rightarrow K^+K^-) = function(d', \vartheta', \gamma, \phi_s)$$

where $d \times \exp(i\vartheta)$ is a function of T and P amplitudes

Assuming U-spin flavor symmetry: $d=d'$ and $\vartheta=\vartheta'$
γ can be extracted

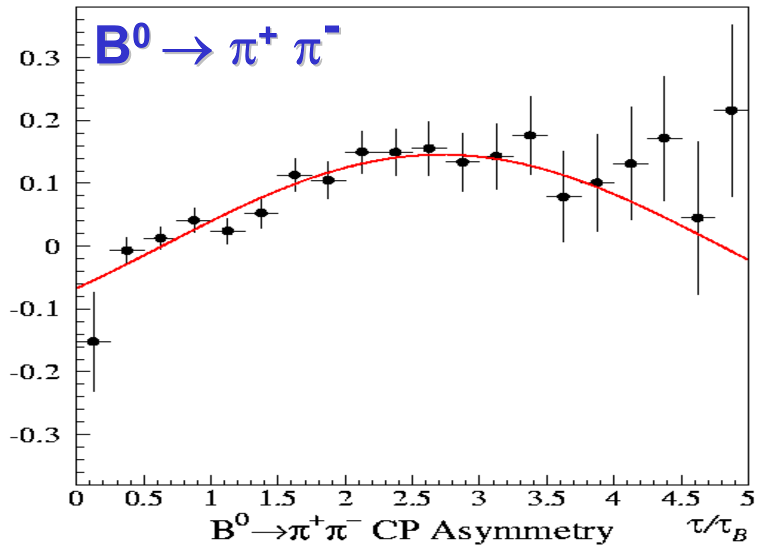
γ from $B_{(s)} \to \pi\,\pi$, K K

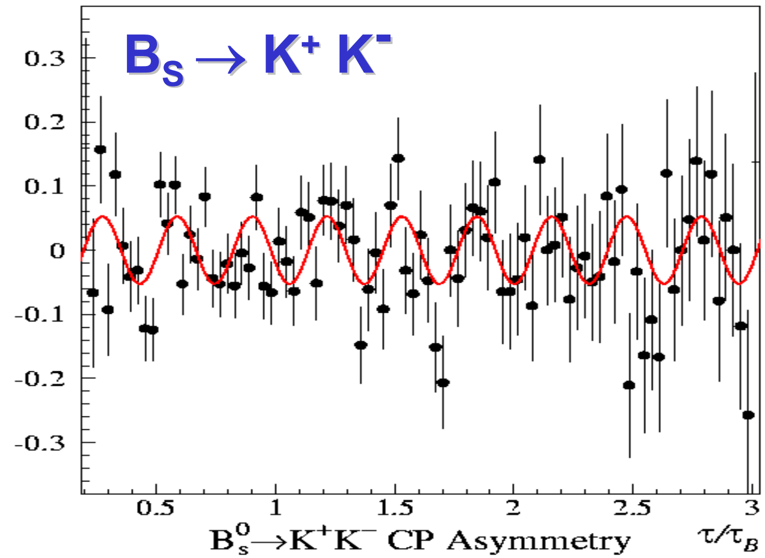
- Evaluation of A_{CP}^{dir} and A_{CP}^{mix} sensitivity

from time-dependent measured asymmetry

$$A_{CP}^{th}(\tau) = \frac{A_{CP}^{dir} \cdot \cos(x \cdot \tau) + A_{CP}^{mix} \cdot \sin(x \cdot \tau)}{\cosh\left(\frac{\Delta\Gamma}{2} \cdot \tau\right) - A_{\Delta\Gamma} \cdot \sinh\left(\frac{\Delta\Gamma}{2} \cdot \tau\right)}$$

input values	$B^0 \to \pi^+ \pi^-$	$B_s \to K^+ K^-$
yield	27k	35k
B/S	0.8	0.55
x_q	0.755	20
εD^2	0.064	0.064
A_{CP}^{dir}	−0.30	0.16
A_{CP}^{mix}	0.58	−0.17
$\Delta\Gamma$	0.0	0.0





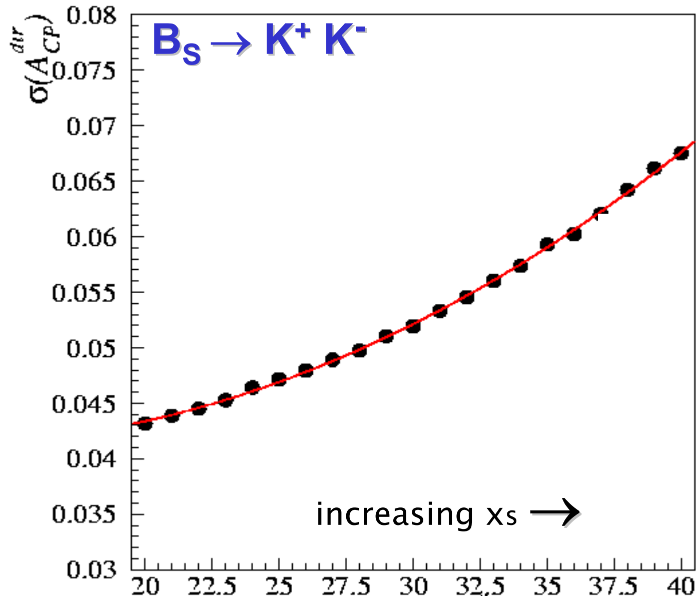
In one year of LHCb operation :

$B^0 \to \pi^+ \pi^-$

$\sigma(A^{dir}) \cong \sigma(A^{mix}) \cong 0.054$

$B_S \to K^+ K^-$

$\sigma(A^{dir}) \cong \sigma(A^{mix}) \cong 0.043$



Sensitivity to γ:

assuming 4 years of data taking

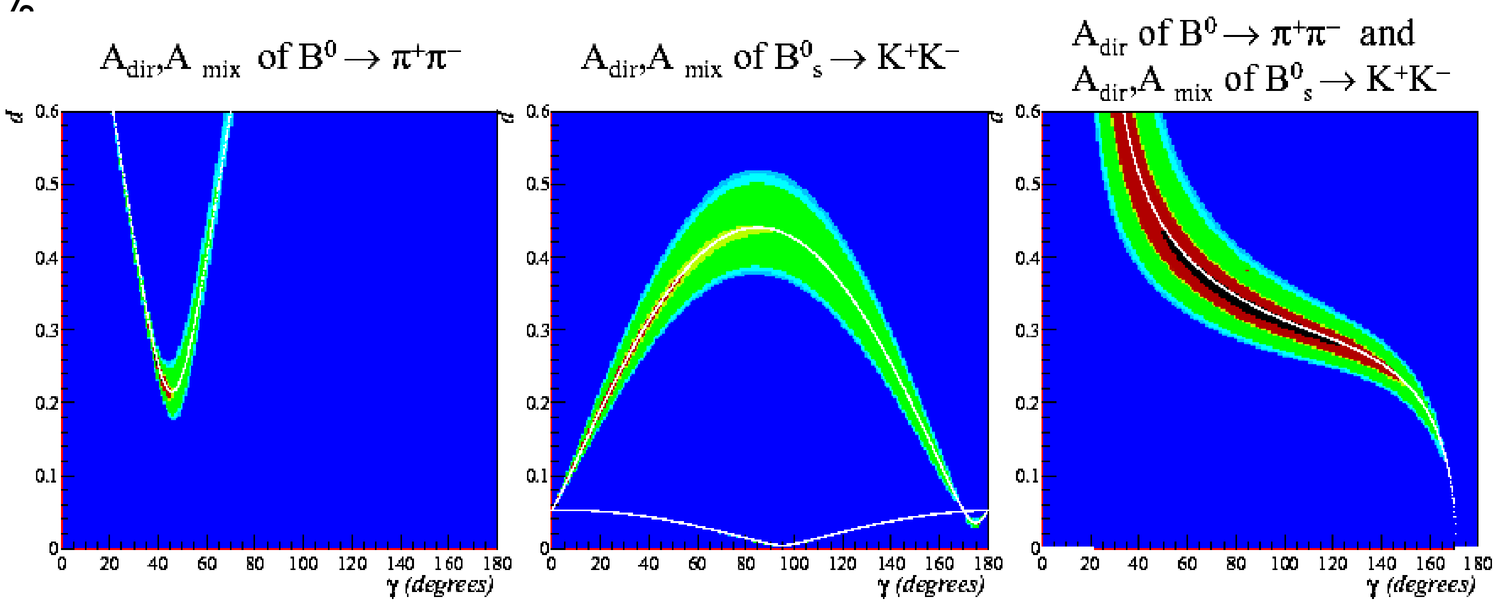
(4x27k Bd→ππ and 4x35k Bs→KK)

B/S = 0.8 and 0.55 correspondingly

tagging: εD^2 = 6.4%

Combining all information:

$\sigma(\gamma) = 2.5^0$



Conclusions

γ can be measured both using CPV in decay (time-integrated) and in the interference of mixing and decay (time-dependent)

(1) Theoretically clean: **b→ c X**

Amplitude triangles

Bs→DsK

Only trees

Trees + loops

(2) Experimentally easier **b → hh** (h = non-c)

Experimental precision on BF already below 10% level

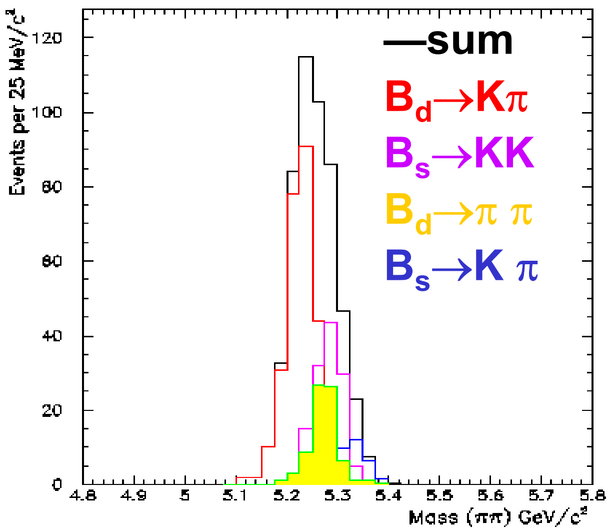
Clear theoretical strategy how to extract γ is still missing

Measurement of rare decays with BF ~ 10^{-7} could help

(1) vs (2) ⇒ **Sensitive probe for New Physics**

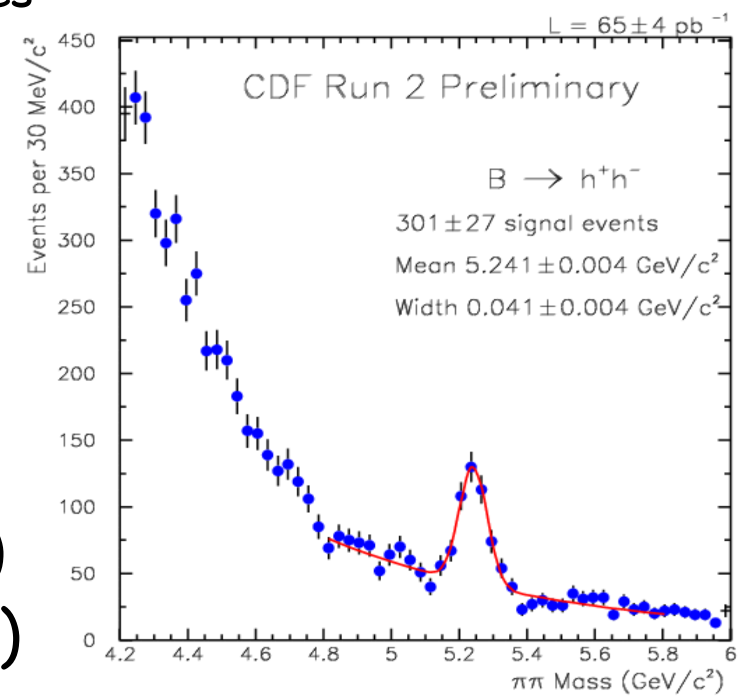
Expectations from CDF Run IIa

$A_{CP} = A_{CP}(dir)\cos(\Delta m \times t) + A_{CP}(mix)\sin(\Delta m \times t)$



ππ/Kπ/KK/πK separation:

Inv. mass ~ 20 MeV/c2
Kinematical variables
dE/dX
ΔMd << ΔMs



RunIIa: $\sigma ACP(dir, mix) \sim 0.2$ ($B_d \to \pi\pi$)
~ 0.1 ($B_s \to KK$)

$\sigma(\gamma) = \pm 10°(stat)$