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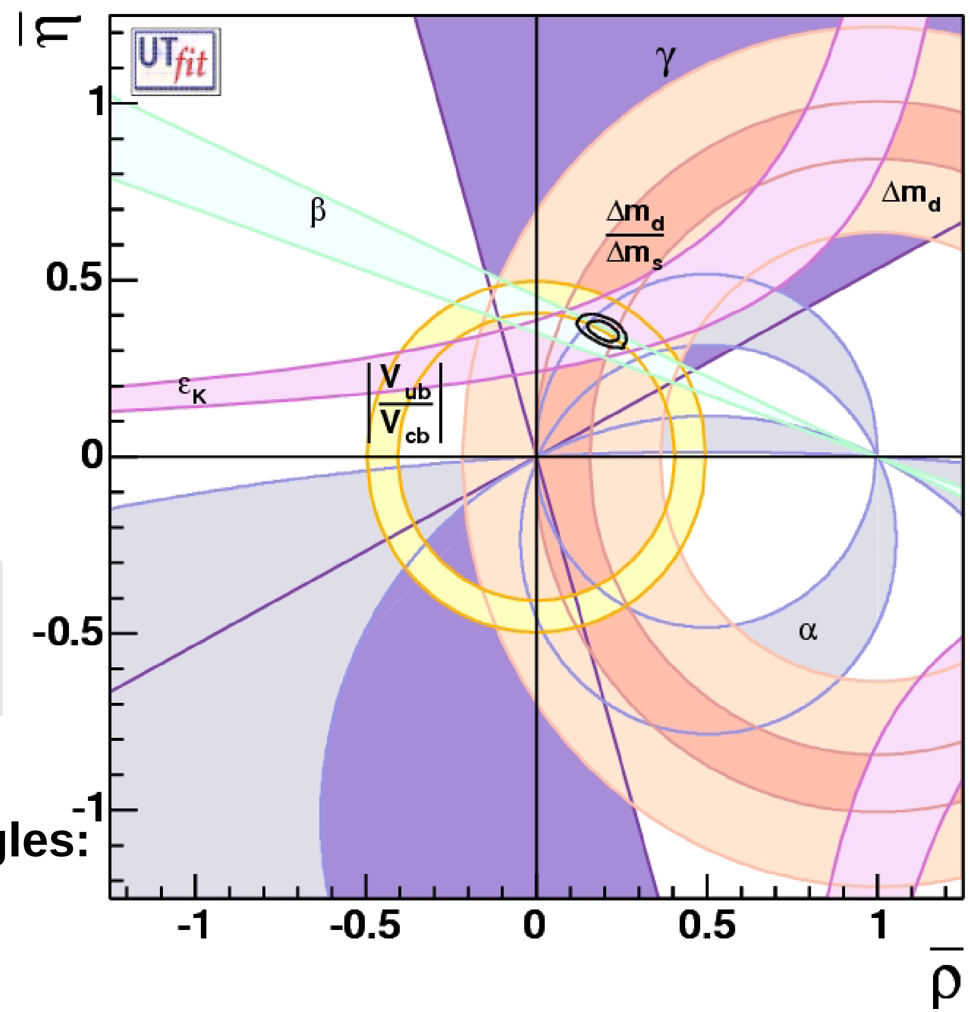
NP in CP-violation at LHC(b)

Current SM fit predicts
(including CDF result on Δm_s)

α = 94.6° ± 4.6°
β = 23.9° ± 1.0°
γ = 61.3° ± 4.5°



Theoretical limitations for the sides:

- Extraction of |Vub|
- Lattice calculation of

$$\xi^2 = \frac{\hat{B}_{B_s} f_{B_s}^2}{\hat{B}_{B_d} f_{B_d}^2}$$

Present experimental precision on angles:

α= +5°/-16°
β = ± 1.0°
γ = ± 30°

Mean values of angles and sides are in desperate agreement with predictions

UT may stay closed for quite some time !!!

To define the apex of UT $\bar{\rho} = \rho \left[1 - \frac{1}{2}\lambda^2\right] \;;\; \bar{\eta} = \eta \left[1 - \frac{1}{2}\lambda^2\right]$

one needs to know at least 2 independent quantities out of 2 sides:

$$R_b = \frac{|V_{ud}V_{ub}^*|}{|V_{cd}V_{cb}^*|} = \sqrt{\bar{\rho}^2 + \bar{\eta}^2} \;;\; R_t = \frac{|V_{td}V_{tb}^*|}{|V_{cd}V_{cb}^*|} = \sqrt{(1-\bar{\rho})^2 + \bar{\eta}^2}$$

and 3 angles: **α, β** and γ

Straightforward strategy to search for NP contribution:

Extract quantities R_b and γ from the *tree-mediated* processes, that are expected to be unaffected by NP, and compare computed values for

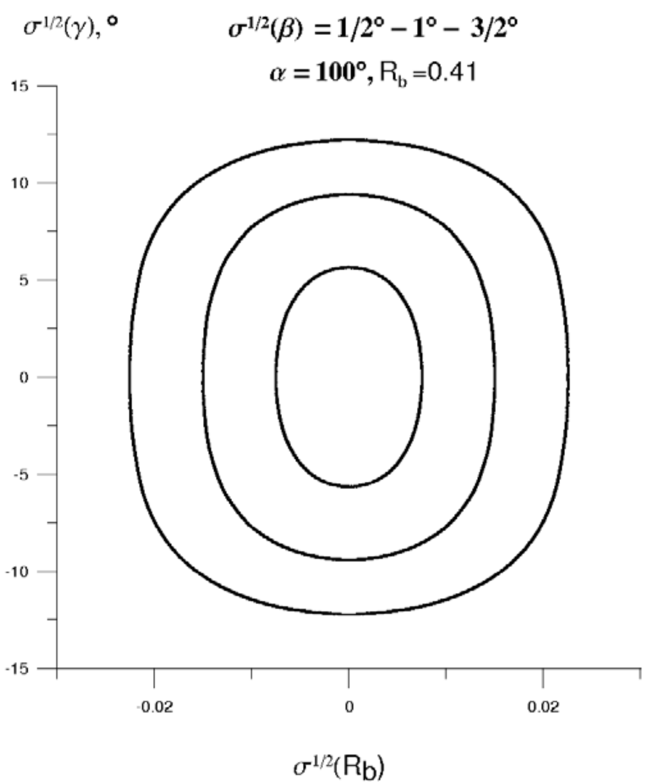
$$R_t = \sqrt{1 + R_b^2 - 2R_b\cos\gamma} \;;\; \cot\beta = \frac{1 - R_b\cos\gamma}{R_b\sin\gamma}$$

with direct measurements in the processes involving loop graphs.

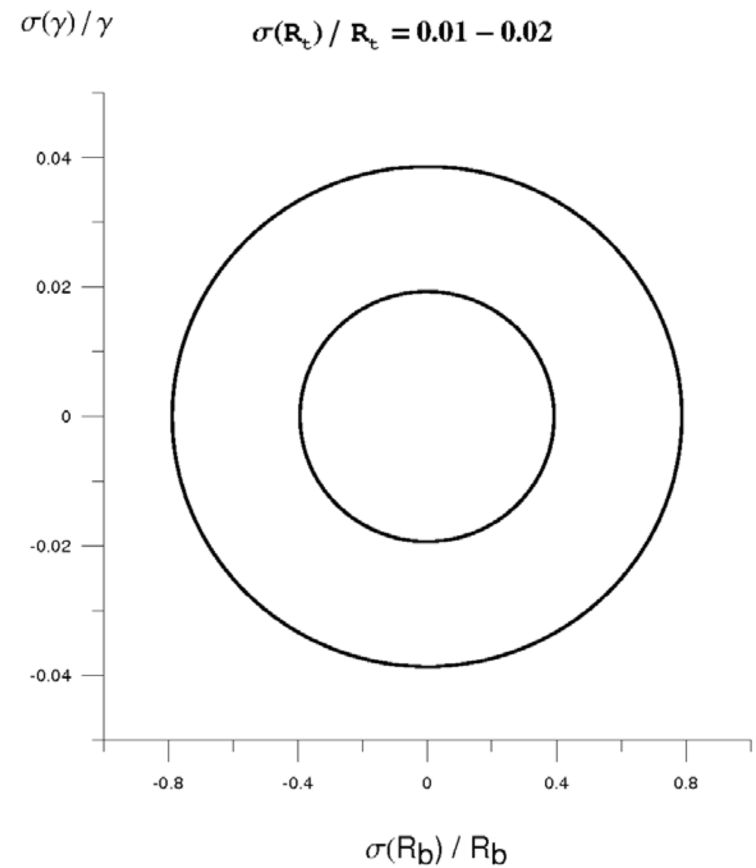
Interpret the difference as a NP signal

Unfortunately such approach has very limited sensitivity to the NP contribution

Due to geometry of UT the dependence of γ on β is rather moderate:



γ is more constrained by R_t. However NP effects may cancel out: R_t is proportional to the ratio of "identical" loop graphs: boxes or penguins



Alternative approach

Measure the same observable in the processes mediated by different topologies: trees, penguins or boxes

Examples:

- ***Penguin vs Box***

$|V_{ts}|$ can be extracted either from the measurement of **$\Delta(m_s)$** or BR($B \to K^*\gamma$). The same applies for |Vtd|

$$\zeta_{K^*}^2 = \frac{|V_{tb}^* V_{ts}|^2_{\Delta M_s}}{|V_{tb}^* V_{ts}|^2_{B\to K^*\gamma}} = 1 \quad \text{(in the SM)}$$

$$\zeta_{K^*}^2 = \frac{3\alpha(1-r_{K^*})^3}{32\pi^2} \cdot \left[\frac{\Delta M_s}{\Gamma(B \to K^*\gamma)}\right] \cdot \left[\frac{m_B^2 |F_1^{B\to K^*}(0)|^2}{\hat{B}_{B_s} f_{B_s}^2}\right] \cdot \kappa$$

, where

$$\kappa = \frac{m_b^2 |C_7(x_t, m_b)|^2}{\eta_B [M_W^2 F_{tt}]}$$

describes short-range effects

Hope that some uncertainties of lattice calculations are cancelled out in the ratio

Tree vs Penguin

Extraction of γ from penguins (through α: $B \rightarrow \pi\pi$, $\rho\pi$ and $\rho\rho$) and various tree topologies

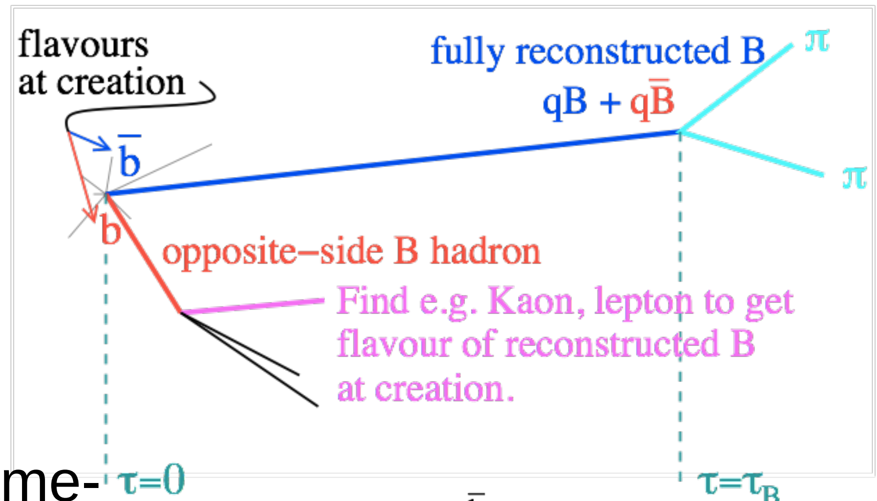
Current experimental precision on γ determined in trees and loops leaves the room of ~ 40 for the difference

Finally, the measurement of the ϕ_S is a very sensitive test of SM !!!

In the rest of the talk LHCb sensitivities to the measurement of β, ϕ_s and γ are presented

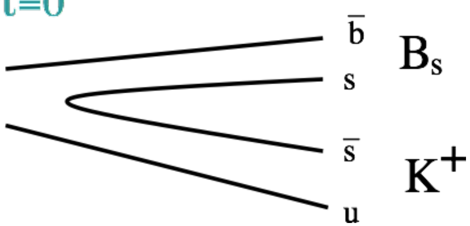
Slides from LHCb talks at the BEACH (M. Musy) and
LHC Physics (J. Rademacker, L.Fernandez and O. Deschamps) conferences

Basic Principle & Tagging.



- Decay products (RICH)
- Decay time ~ flight distance (VELO)
- Flavour at creation - opposite-side or same-side (Bs only) Tagging.

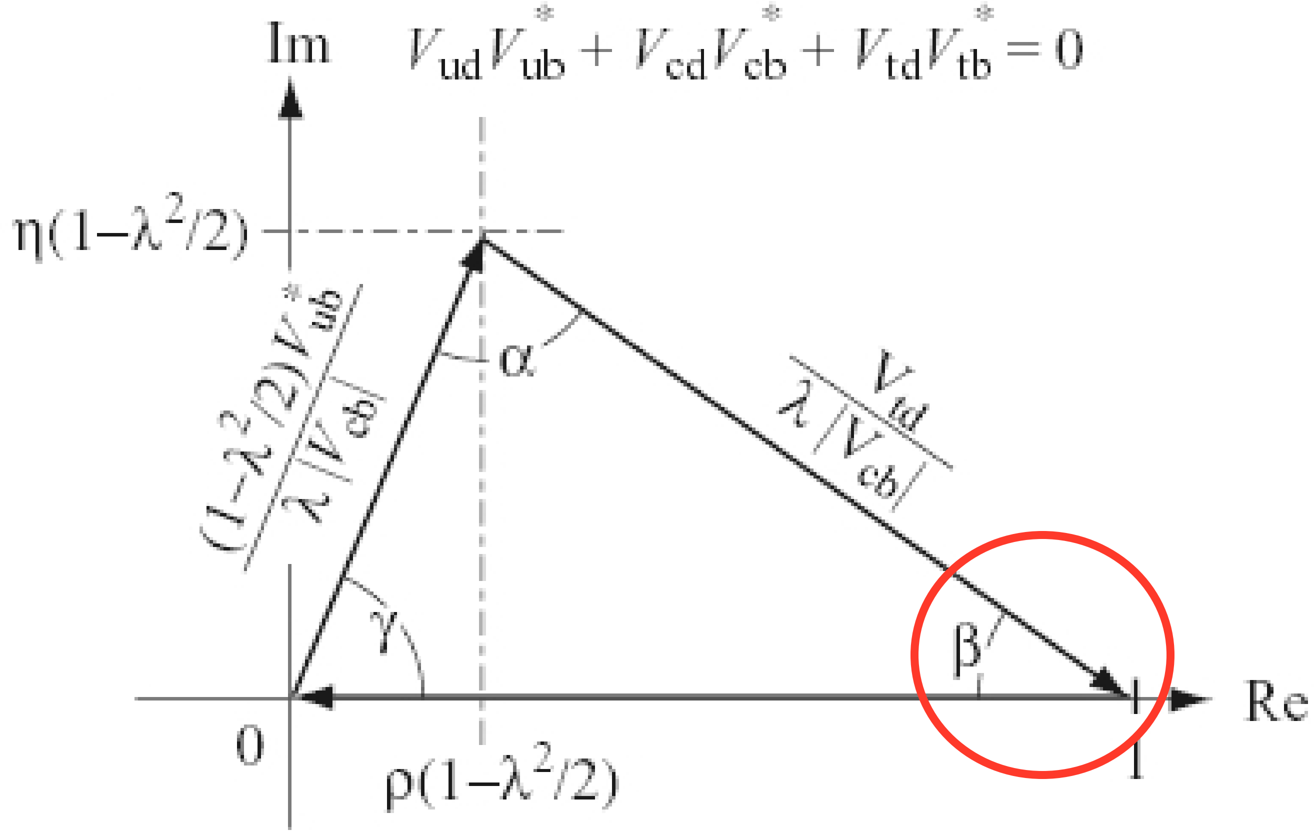
Same-side taggin g



$$\varepsilon_{\text{eff}} = \epsilon D^2 = \epsilon\,(1-\omega)^2 = \begin{cases} \sim 4-5\% & (B_d) \\ \sim 7-9\% & (B_s) \end{cases}$$

N events with tagging efficiency ε and mis-tag fraction ω are statistically equivalent to ε_{eff} perfectly tagged events.

β

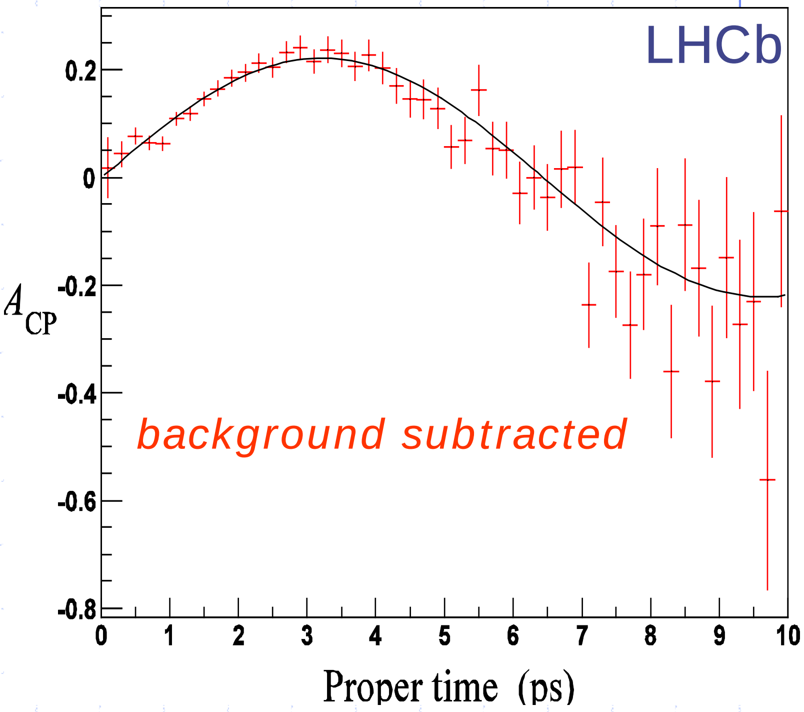

Im
$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$
$\eta(1-\lambda^2/2)$
$\frac{(1-\lambda^2/2)V_{ub}^*}{\lambda|V_{cb}|}$
α
$\frac{V_{td}}{\lambda|V_{cb}|}$
γ
β
0
$\rho(1-\lambda^2/2)$
Re
1

β from $B^0 \to J/\psi K_s$

- The 'gold plated' channel at B-factories already well measured by Babar/Belle
- Still an important measurement:

$$A_{CP}^{th}(t) = A_{CP}^{dir} \cdot \cos(\Delta m_d \cdot t) + A_{CP}^{mix} \cdot \sin(\Delta m_d \cdot t)$$

A_{CP}^{dir} =0 in SM; A_{CP}^{mix} =sin 2β



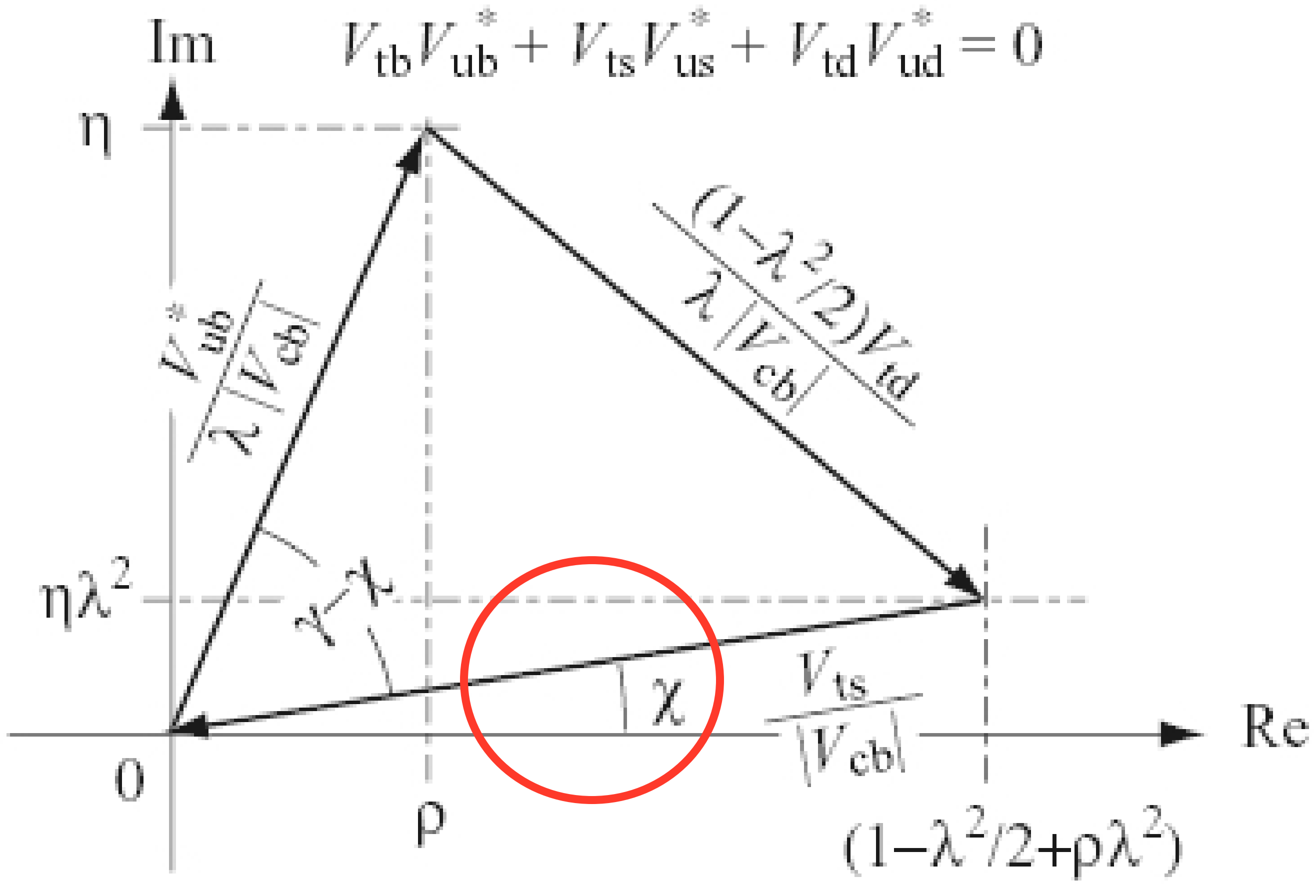
LHCb In one year, 2/fb, with 216k events, σ(sin2β)~0.02, σ(β)~0.6°

Atlas will achieve similar sensitivity with 30/fb

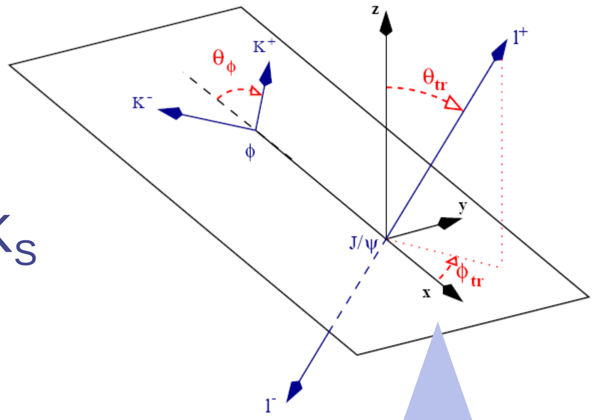
Comparing with other channels may indicate NP in penguin diagrams

Scaling of 1 year sensitivity from $J/\psi K_s$ to ϕK_s:
$\sigma(\sin 2\beta_{eff})$~0.4, Yield:0.8k, B/S<2.4 (preliminary).

ϕ_s


Im
$V_{tb}V_{ub}^* + V_{ts}V_{us}^* + V_{td}V_{ud}^* = 0$
η
$\eta\lambda^2$
$\frac{V_{ub}^*}{\lambda |V_{cb}|}$
$\frac{(1-\lambda^2/2)V_{td}}{\lambda |V_{cb}|}$
γ-χ
χ
$\frac{V_{ts}}{|V_{cb}|}$
Re
0
ρ
$(1-\lambda^2/2+\rho\lambda^2)$

ϕ_s from $B_s \rightarrow J/\psi\phi$ (η,η'...)



$B_s \rightarrow J/\psi\phi$ is the B_s counterpart of $B^0 \rightarrow J/\psi K_S$

- In SM $\phi_S = -2\arg(V_{ts}) = -2\lambda^2\eta \sim -0.04$
- Sensitive to New Physics effects in the B_s-$\overline{B}_s$ system

if NP in mixing $\rightarrow$ $\phi_S = \phi_S(SM) + \phi_S(NP)$

- 2 CP-even, 1 CP-odd amplitudes, angular analysis needed to separate, then fit to ϕ_S, $\Delta\Gamma_S$, CP-odd fraction

Channels used	Yield (10^3/2 fb^{-1})	B/S	$<\delta_\tau>$ (fs)	σ_{mass} (MeV/c^2)
$B_s \rightarrow J/\psi(\mu^-\mu^+)\phi(K^+K^-)$	131	0.12	36	14
$B_s \rightarrow \eta_c(h^-h^+h^-h^+)\phi(K^+K^-)$	3	0.6	30	12
$B_s \rightarrow J/\psi(\mu^-\mu^+)\ \eta(\gamma\gamma)$	8.5	2.0	37	34
$B_s \rightarrow J/\psi(\mu^-\mu^+)\ \eta(\pi^+\pi^-\pi^0(\gamma\gamma))$	3.0	3.0	34	20
$B_s \rightarrow J/\psi\ (\mu^-\mu^+)\ \eta'(\pi^+\pi^-\eta\ (\gamma\gamma))$	2.2	2.0	32	19
$B_s \rightarrow D_s(K^+K^-\pi^-)\ D_s(K^+K^-\pi^+)$	4.0	0.3	56	6

With SM inputs: Δm_s=17.5/ps, ϕ_s=-0.04, $\Delta\Gamma_s/\Gamma_s$ = 0.15 and 2/fb stat:

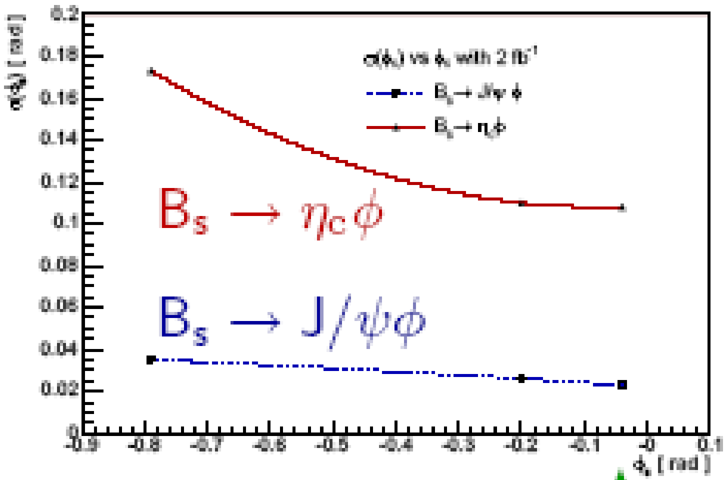
LHCb

Channels	$\sigma(\phi_s)$ [rad]	Weight $(\sigma/\sigma_i)^2$ [%]
$B_s \rightarrow J/\psi\ \eta(\pi^+\ \pi^-\ \pi^0)$	0.142	2.3
$B_s \rightarrow D_s D_s$	0.133	2.6
$B_s \rightarrow J/\psi\ \eta(\gamma\ \gamma)$	0.109	3.9
$B_s \rightarrow \eta_c \phi$	0.108	3.9
Combined (pure CP eigenstates)	**0.060**	**12.7**
$B_s \rightarrow J/\psi\phi$	0.023	87.3
Combined (all CP eigenstates)	**0.022**	**100.0**

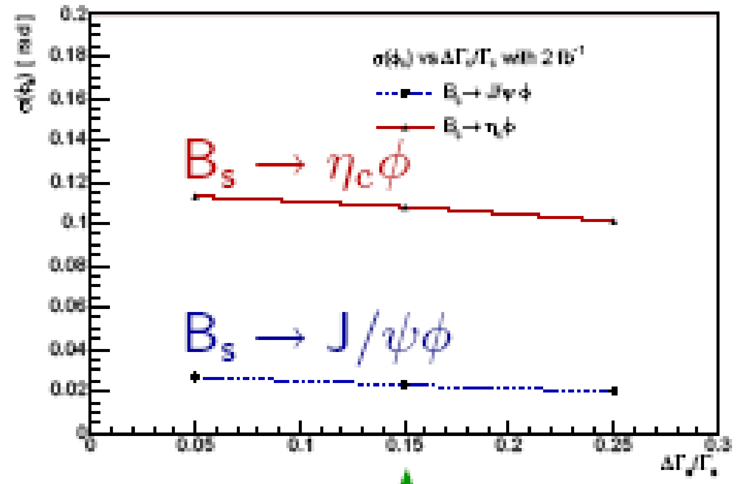
Atlas will reach $\sigma(\phi_s)$ ~ 0.08 (10/fb, Δm_s=20/ps, 90k $J/\psi\phi$ evts)

CMS will reach $\sigma(\phi_s)$ ~ 0.07 (10/fb, on $J/\psi\phi$ evts, no tagging)

$\sigma(\phi_s)$ vs ϕ_s



$\sigma(\phi_s)$ vs $\Delta\Gamma_s/\Gamma_s$



Nominal inputs

Very small dependence on ϕ_s value for $B_s \to J/\psi\phi$

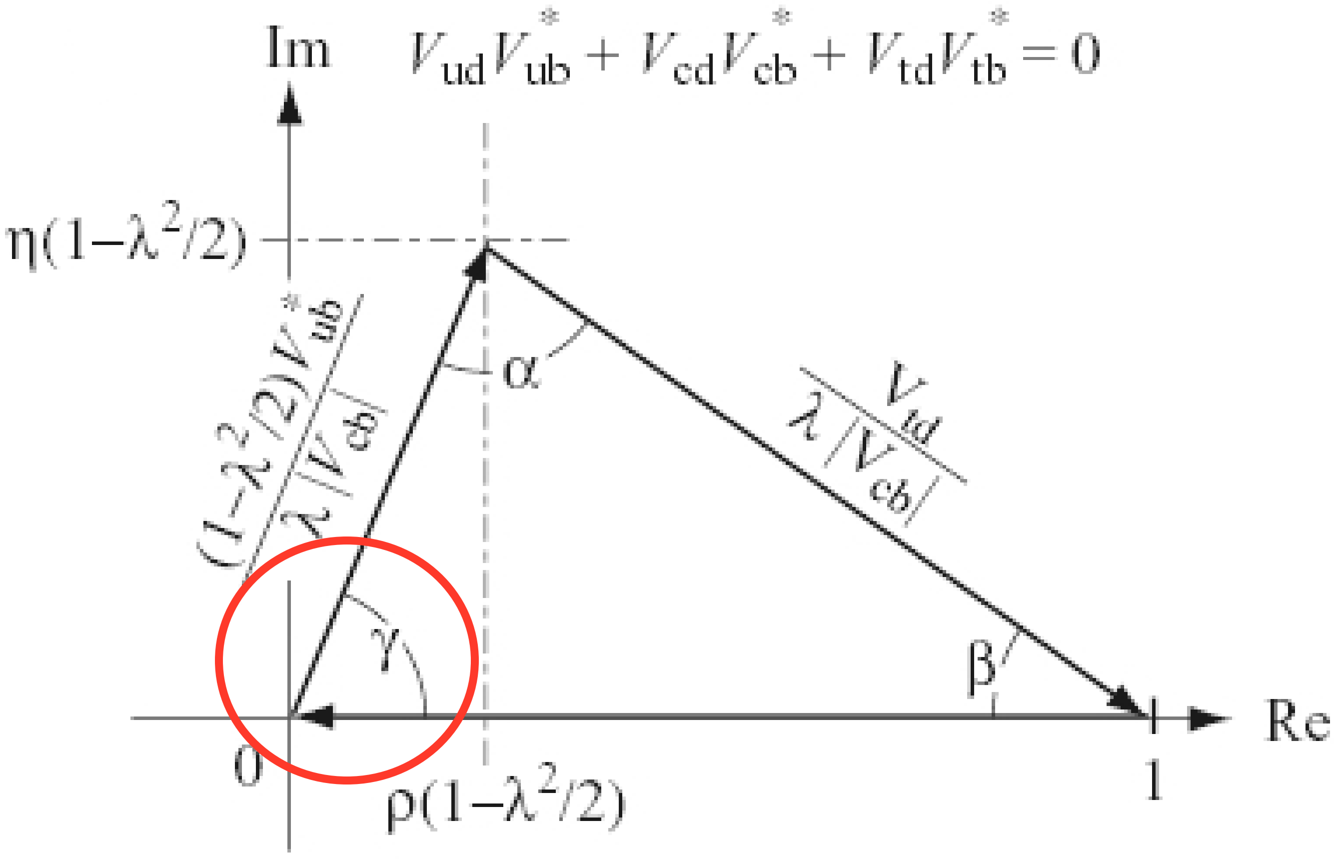
Does not depend on sign of ϕ_s for:

- pure CP eigenstates
- $B_s \to J/\psi\phi$ and one-angle angular analysis

Not very sensitive to $\Delta\Gamma_s/\Gamma_s$ value

Better sensitivity for larger $\Delta\Gamma_s/\Gamma_s$ $\to$ better separation between Γ_L (short lived, CP even) and Γ_H (long lived, CP odd) eigenstates

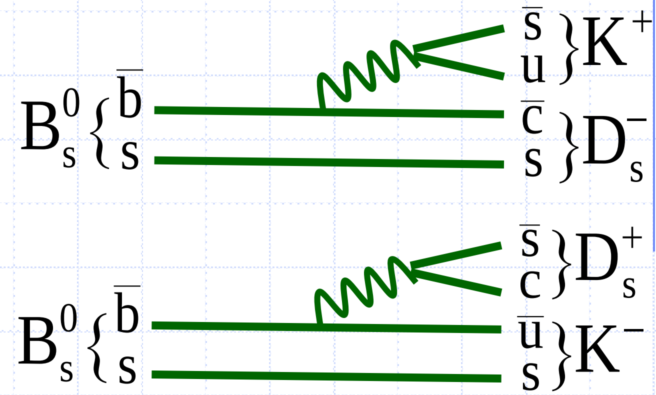
γ



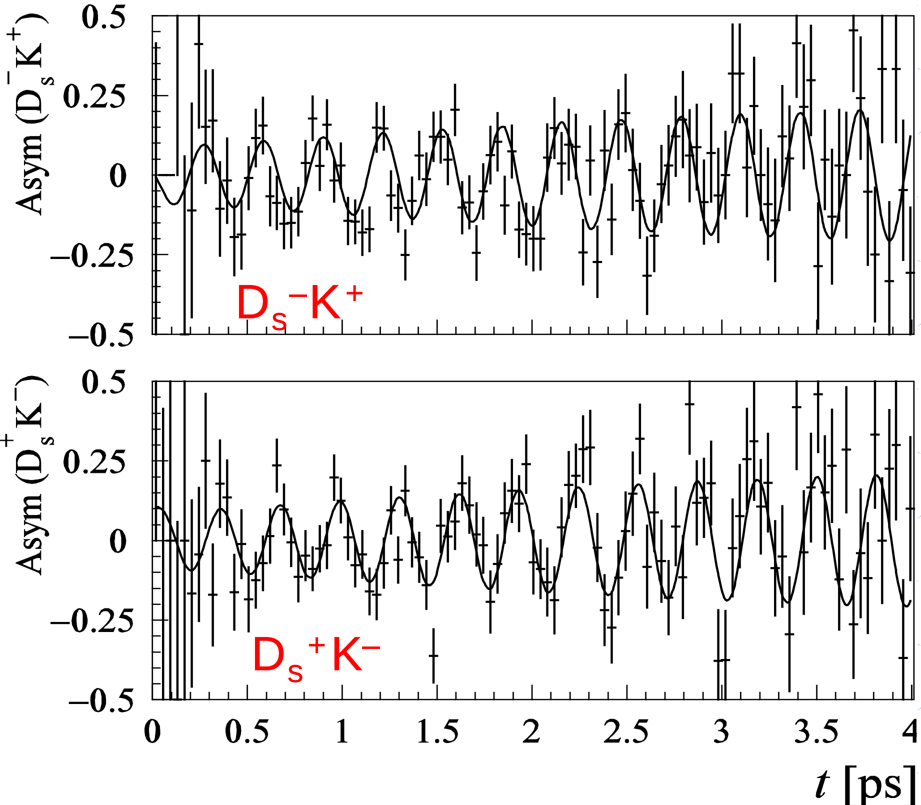
$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$
Im
$\eta(1-\lambda^2/2)$
$\frac{(1-\lambda^2/2)V_{ub}^*}{\lambda|V_{cb}|}$
α
$\frac{V_{td}}{\lambda|V_{cb}|}$
γ
β
0
$\rho(1-\lambda^2/2)$
1
Re

γ from $B_s \to D^{\pm}_s K^{\mp}$

- 2 same order tree level amplitudes ($\propto\lambda^3$) : large asymmetries, *NP components unlikely!*
- From the measurement 4 rates and 2 time-dependent asymmetries one gets $\gamma+\phi_s$ (with ϕ_s from $B_s \to J/\psi\phi$)



$D_s K$ asymmetries (5 years, $\Delta m_s = 20\ ps^{-1}$)



Yield: 5.4k signal events in 2/fb, residual contamination from
$B_s \to D_s\pi$ ~ 10%
S/B > 1 at 90% CL

Precision: $\sigma(\gamma)$ ~ **13°**
(Δm_s = 17.3/ps , -20°<Δ_{strong}<20°)
Discrete ambiguities in γ can be resolved if $\Delta\Gamma_s$ large enough, or using $B^0 \to D\pi$ and U-spin symmetry

γ from B

γ from $B^{\pm}$

- 3 observables, 5 parameters $(\gamma, \delta_B, r_B, \delta_D^{K\pi}, r_D^{K\pi})$, $r_D^{K\pi} \sim 0.06$ known
  add more D-decays to constrain further:

  $D \rightarrow K\pi\pi\pi$ (Cabibbo favoured + DCS)

  ✓ 4 new rates with 2 new parameters, $\delta_D^{K3\pi}$; $r_D^{K3\pi} \sim 0.06$

  $D \rightarrow KK$ (CP eigenstate)

  ✓ 2 new rates, no new unknown: $r_D^{KK} = 1$; $\delta_D^{KK} = 0$

  ➔ 7 relative rates and 5 unknowns: $\gamma, r_B, \delta_B, \delta_D^{K\pi}, \delta_D^{K3\pi}$ (this may come from CLEO-C)

  Precision: $\sigma(\gamma) \sim$ 4 - 13 in 1 year, 2/fb
  depending on $\delta_D^{K\pi}$ ($-25 < \delta_D^{K\pi} < 25$)
  and on $\delta_D^{K3\pi}$ ($-180 < \delta_D^{K3\pi} < 180$)

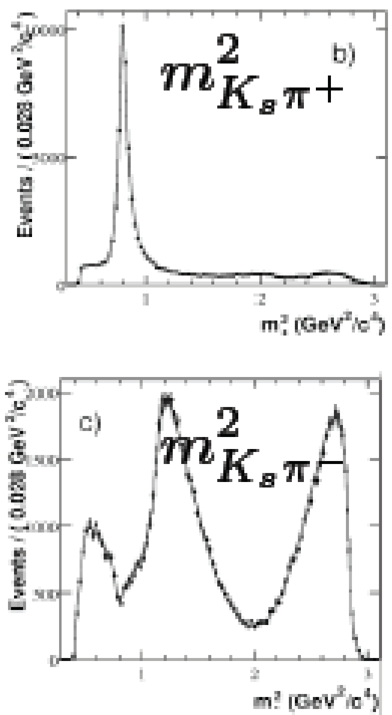
- Extraction of γ via Dalitz study ($D \rightarrow K_s\pi\pi$) is under investigation.

$B^{\pm} \rightarrow (K_s\pi\pi)_{D^0} K^{\pm}$ Dalitz analysis.

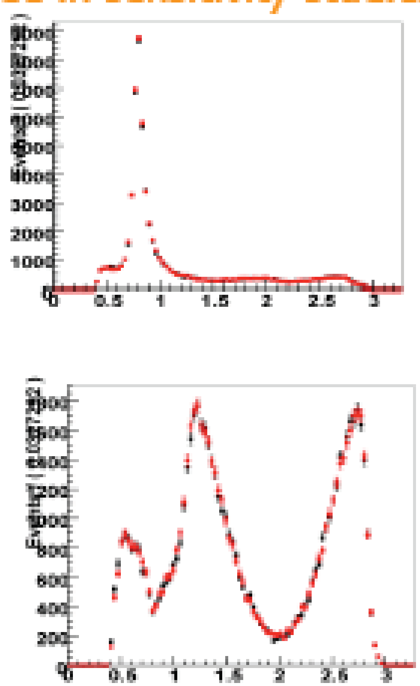
Distribution of kin. variables...

in data at BaBar:

From BaBar's large prompt D sample, not D's from B's used for CPV measurement



...in our implementation of BaBar's isobar Model, used in sensitivity studies:



Detector/yield studies:

- Acc ~flat (within stats)
- ~ 1.3k events/year
- 0.5 < B/S < 3.2 (90% CL)

Sensitivity study

1.3k events, ignoring backg. and detector effects, for γ=60, δ=130, r_B =8%:

$\sigma(\gamma) \sim 16^o$

r_B dependence:

$$\sigma(\gamma) \propto 1/\left(\frac{r_b}{1+r_B^2}\right) \approx 1/r_B$$

We use UTFit's global fit result, r_B= 8%. BaBar/BELLE's value from this channel is closer to 15%.

4 body Amplitude Analysis

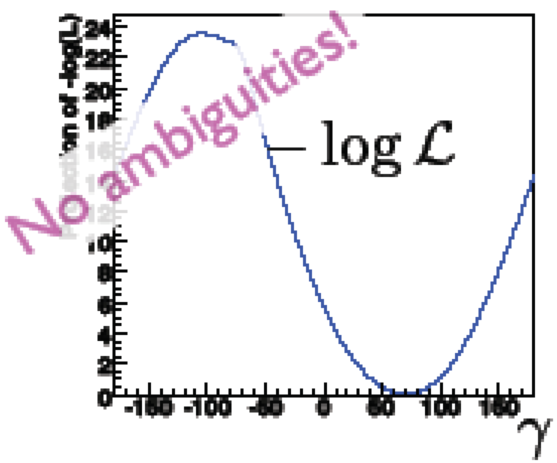
- What works with $\mathrm{D}^0 \rightarrow \mathrm{K_s}\pi\pi$ should also work with $\mathrm{D}^0 \rightarrow \mathrm{K}^+\mathrm{K}^-\pi^+\pi^-$.
- Particularly suitable for LHCb: No neutrals, benefits from K/π separation by LHCb RICH.
- 4 body amplitude analyses are a bit trickier than 3 body:
    - Need 5 instead of 2 parameters to describe kinematics, and phase-space is not flat in m_{ij}^2 parameters.
    - Amplitude structure a bit more complex, with several intermediate states in decay chains.
- But can be done. See FOCUS in Phys.Lett. B610 (2005) 225-234 (hep-ex/0411031) (for D's not from B's)

Amplitude analysis of $B_u^\pm \to (K^+K^-\pi^+\pi^-)_{D^0}K^\pm$

MC input values: $\gamma = 60^o$ $\delta = 130^o, r_B = 8\%$

Fitting 60 toy experiment with 1k events each:

		mean±rms
γ	$=$	$63^o \pm 21^o$
δ	$=$	$130^o \pm 17^o$
r_B	$=$	$8.4\% \pm 2.7\%$



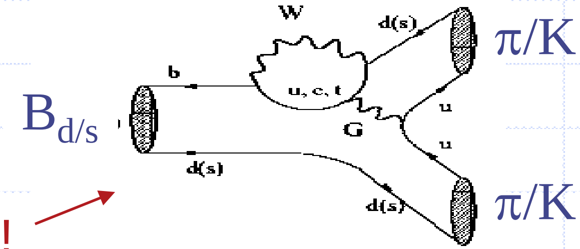
All preliminary, all without background or detector effects

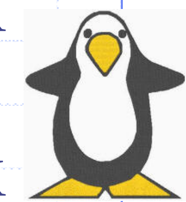
Assuming LHCb yields of 1.5k/year and $r_B = 8\%$, expect $\sigma(\gamma) \sim 20^o$ in 1 year.

High hopes for for ADS-type 4-body channel $B^\pm \to (K\pi\pi\pi)_{D^0}K^\pm$, which has stronger interference, i.e. r_B closer to 1.

LHCb specific yield and sensitivity studies for both channels pending.

γ from $B\to\pi\pi$, $B_s\to KK$





- Large penguin contributions, sensitive to NP!

- Evaluation of A_{CP}^{dir} and A_{CP}^{mix} parameters from time-dependent measured asymmetry depend on γ, mixing phases, and ratio of penguin/tree = $d\,e^{i\theta}$

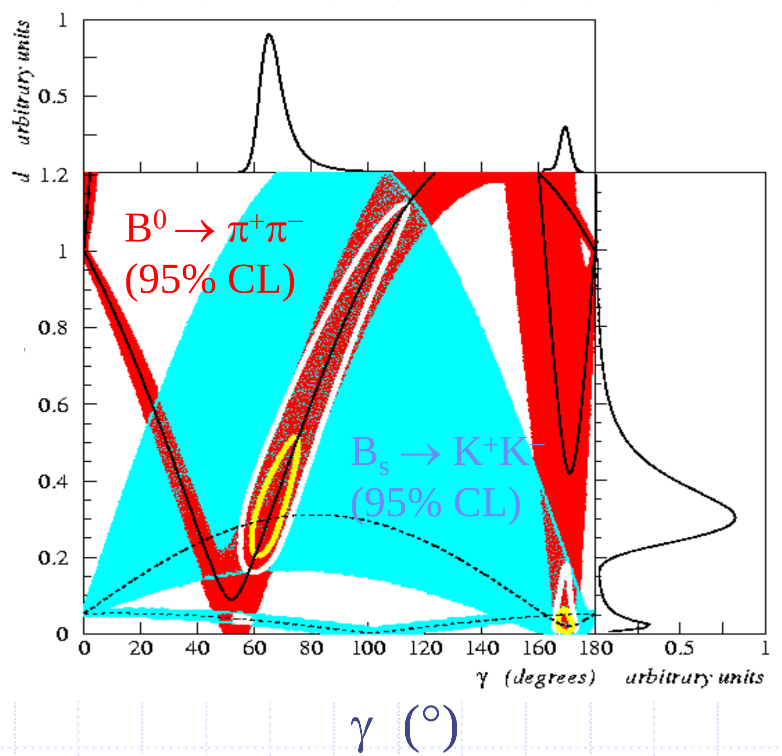
$$A_{CP}^{th}(\tau)=\frac{A_{CP}^{dir}\cdot\cos(x\cdot\tau)+A_{CP}^{mix}\cdot\sin(x\cdot\tau)}{\cosh\left(\frac{\Delta\Gamma}{2}\cdot\tau\right)-A_{\Delta\Gamma}\cdot\sinh\left(\frac{\Delta\Gamma}{2}\cdot\tau\right)}$$

- Assume U-spin symmetry $d_{\pi\pi}=d_{KK}$ $\theta_{\pi\pi}=\theta_{KK}$ (and $\phi_{s,d}$ from $B_s\to J/\psi\phi$, $B\to J/\psi K_s$)

  $\to$ solve for γ

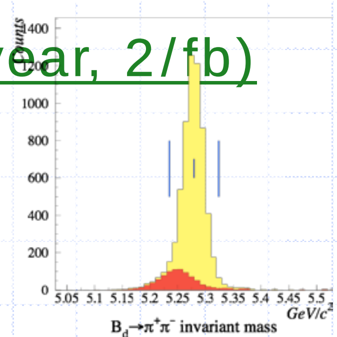
LHCb

Precision: $\sigma(\gamma)$ ~ 5°
(but model dependent)

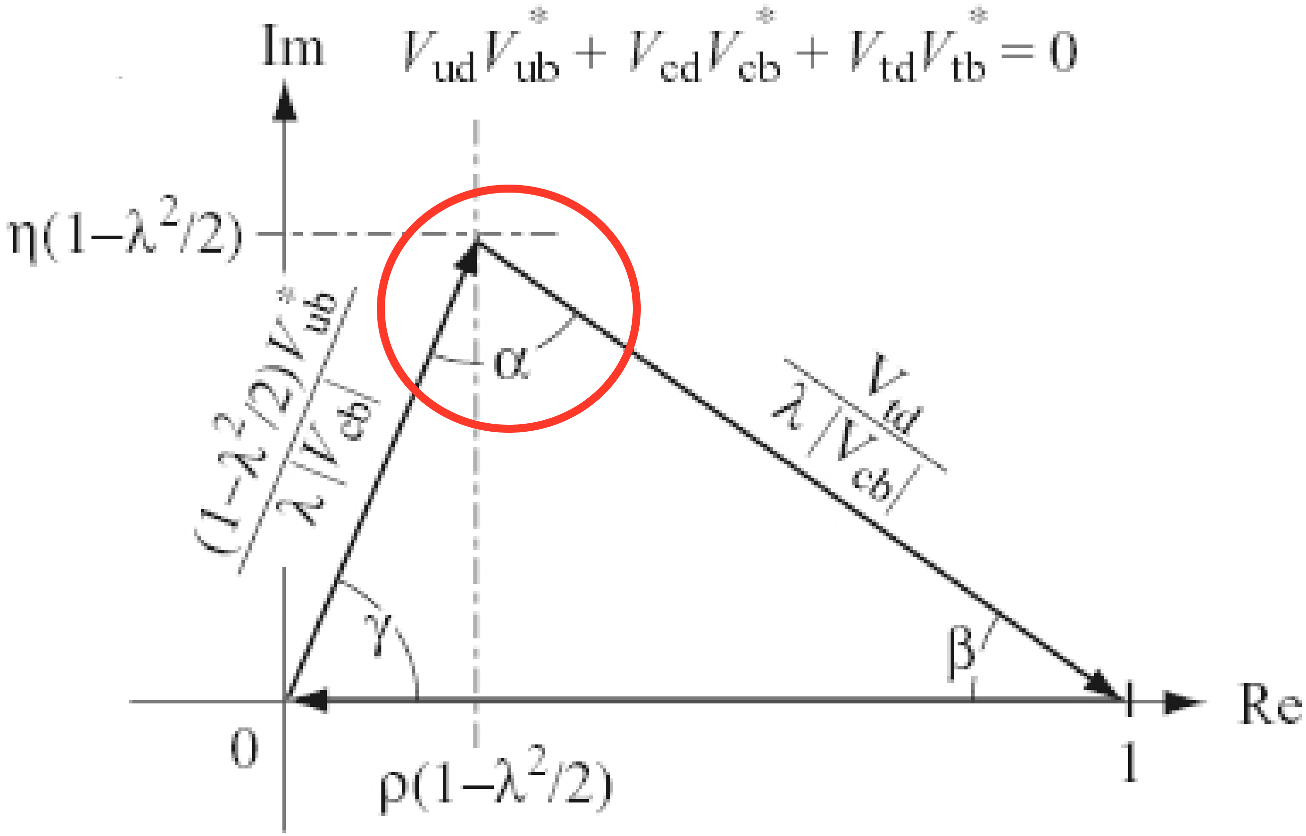


Expected Yield (1year, 2/fb)

- 26k $B^0\to\pi^+\pi^-$,
- 37k $B_s\to K^+K^-$,
- 135k $B^0\to K^+\pi^-$



α

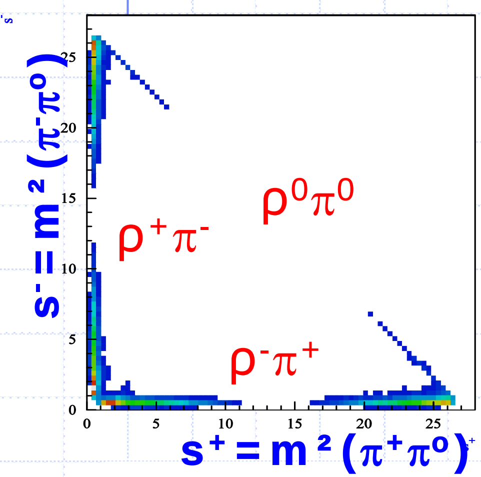


Im
$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$
$\eta(1-\lambda^2/2)$
$\frac{(1-\lambda^2/2)V_{ub}^*}{\lambda|V_{cb}|}$
α
$\frac{V_{td}}{\lambda|V_{cb}|}$
γ
β
0
$\rho(1-\lambda^2/2)$
1
Re

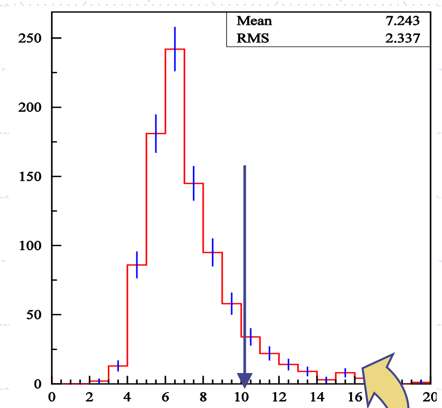
α from $B^0 \to \rho\,\pi$

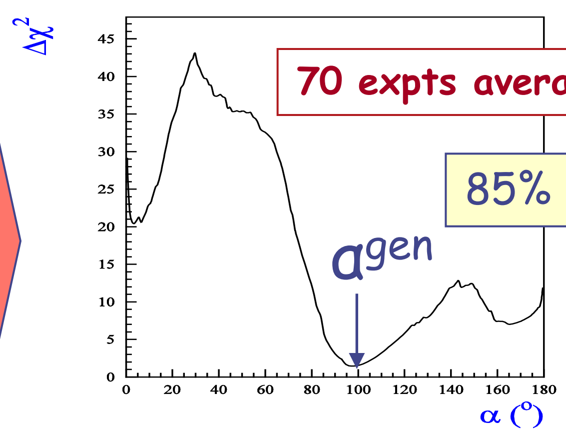
[Snyder,Quinn,1993]

Thanks to the interferences between the transitions $B \to \rho\pi \to \pi^-\pi^0\pi^+$ we can simultaneously extract α with amplitudes and strong phases from the time dependence of the tagged Dalitz plot



- Simulate the experimental effects: resolution, acceptance, wrong tag, … Assume B/S=1 (mix of flat and resonant ρ)
- Maximize the likelihood wrt α^{fit} and the background ratios r^{fit} (12D fit)





70 expts averaged (L=2fb^{-1})

85% converge to the correct solution*

90% of experiments have σ_α < 10°

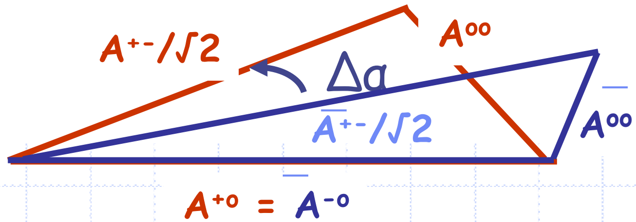
*prob. of mirror solutions decreases with stats, down to ~0.2% for 10/fb

α from $B^0 \to \rho\,\rho$

Measuring the time dependent asymetry of B ➛ $\rho^+\rho^-$ provide $\alpha_{eff} = \alpha + \Delta\alpha$

$$A^{+-}_{\rho\rho}(t) = S^{+-}_{\rho\rho}\sin(\Delta m_d t) - C^{+-}_{\rho\rho}\cos(\Delta m_d t)$$

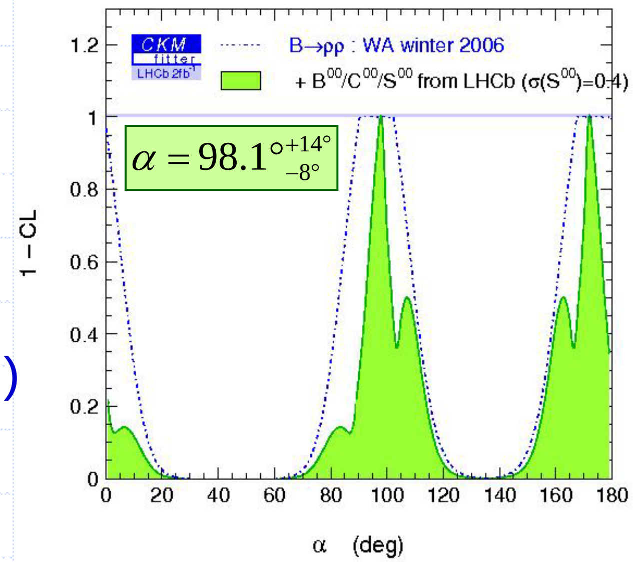
with $$S^{+-}_{\rho\rho} = \sqrt{1 - C^{+-\,2}_{\rho\rho}}\,\sin(2\alpha_{eff})$$



LHCb is not competitive with current B-factory performance in $\rho^+\rho^-$. The main contribution of LHCb to the $\rho\rho$ analysis could be the measurement of the B ➛ $\rho^0\rho^0$ mode

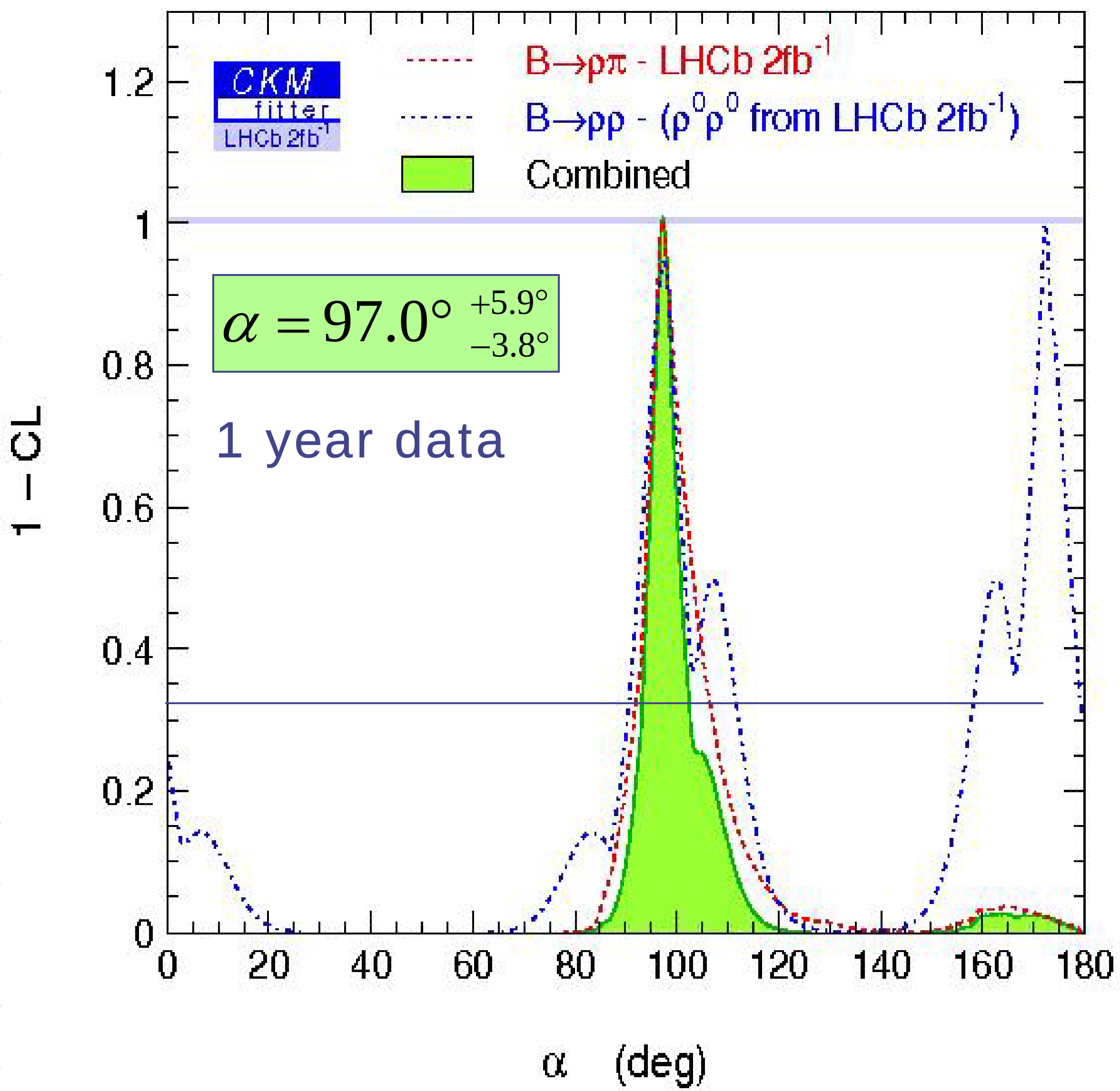
Yields in 2/fb:

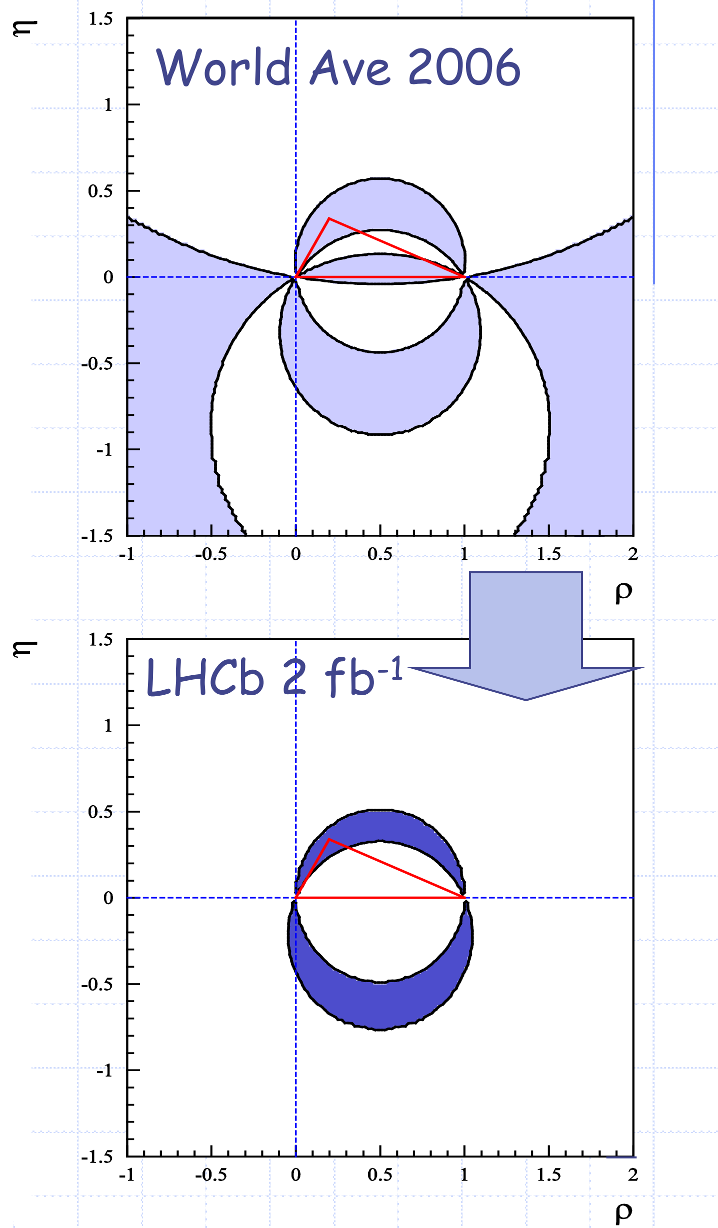
B ➛ $\rho^+\rho^-$: 2k (B/S<5, 90%CL)
$B^\pm$ ➛ $\rho^\pm\rho^0$: 9k (B/S ~ 1)
B ➛ $\rho^0\rho^0$: ~0.5k, assuming a BR=0.5 10^{-6}
(Babar: $B^{00} = (0.54^{+0.36}_{-0.32} \pm 0.19)10^{-6}$)



α from $B^0 \to \rho\pi, \rho\rho$ combined

LHCb





Summary table

Angle	Channel	Yield*	B_{bb}/S	LHC (2/fb)
β	$B_d \to J/\Psi\ K_S$	216k	0.8	$\sigma(\beta) \approx 0.6^\circ$
	$B_d \to \phi\ K_S$	0.8k	<2.4	$\sigma(\beta) \approx 12^\circ$
ϕ_s	$B_s \to J/\Psi\Phi$	125k	0.3	$\sigma(\phi_s) \approx 1.2^\circ$
	$B_s \to J/\Psi\eta$	12k	2-3	
	$B_s \to \eta_c\Phi$	3k	0.7	
γ	$B_s \to D_sK$	5.4k	<1.0	$\sigma(\gamma) \approx 13^\circ$
	$B_d \to \pi\pi$	26k	<0.7	$\sigma(\gamma) \approx 5^\circ$
	$B_s \to KK$	37k	0.3	
	$B_d \to D^0(K^-\pi^+)K^{*0}$	0.5k	<0.3	$\sigma(\gamma) \approx 8^\circ$
	$B_d \to D^0(K^+\pi^-)K^{*0}$	2.4k	<2.0	
	$B_d \to D_{CP}(K^+K^-)K^{*0}$	0.6k	<0.3	
	$B^- \to D^0(K^+\pi^-)K^-$	60k	0.5	$\sigma(\gamma) \approx 4^\circ\text{-}13^\circ$
	$B^- \to D^0(K^-\pi^+)K^-$	2k	0.5	
α	$B_d \to \pi\rho, \rho\rho$	14k	0.8	$\sigma(\alpha) < 10^\circ$

* Untagged annual yield after trigger

Summary

Measurement of ϕ_s with ~1 precision in 1 year

Measurement of γ in trees and loops and check for consistency:

- *Many channels for the tree topologies → expect to reach a few degrees sensitivity in 1 year*

-*The measurement of γ in loops should be possible in $B\rightarrow\rho\pi$ with <10 precision. For the study of $\rho\rho$ final states, the measurement of BR($B\rightarrow\rho^0\rho^0$) together with the measurements of asymmetries at B factories will further improve precision*

If difference is observed we need a model to relate # of degrees in $\Delta\gamma$ to masses and couplings of NP !!!