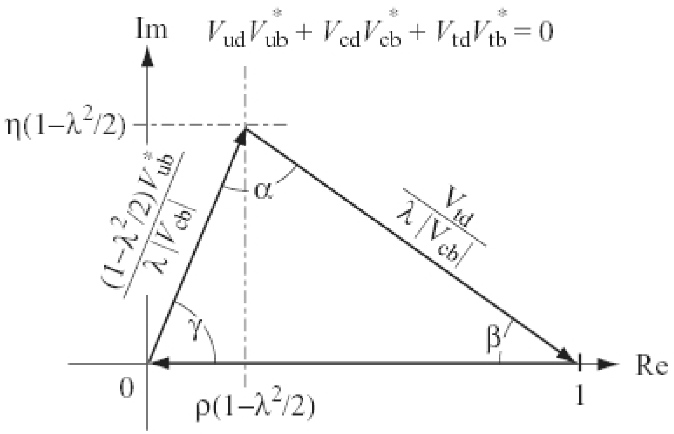
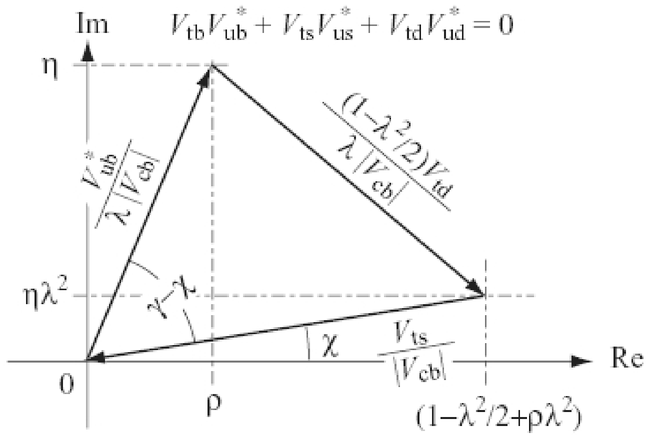
Beach2006
7th International Conference on
Hyperons Charm and Beauty Hadrons
Lancaster 2–8th July 2006

Potential for precise Unitarity Triangle angles measurements in LHC





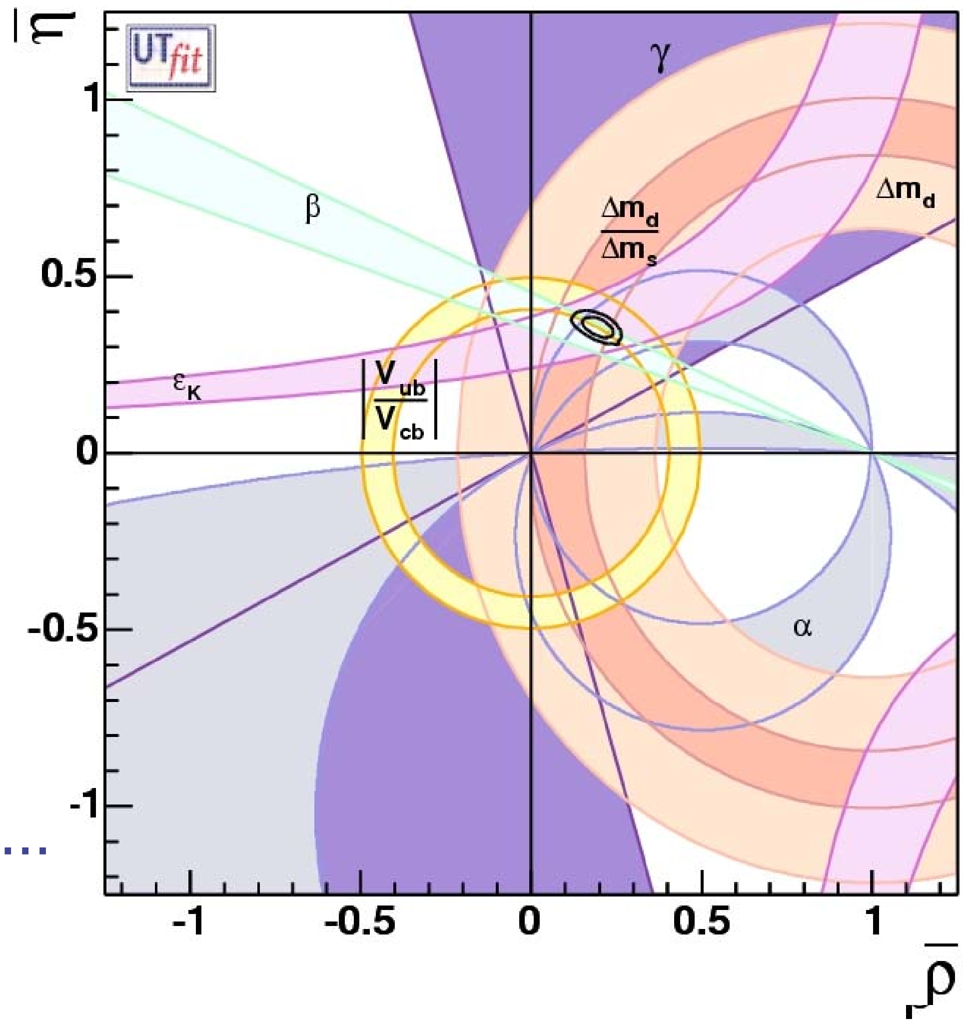
Marco Musy, University of Milano Bicocca

Motivations

Current SM fit predicts
(including CDF result on Δm_s)

$\alpha = 94.6° \pm 4.6°$
$\beta = 23.9° \pm 1.0°$
$\gamma = 61.3° \pm 4.5°$
$\phi_s = \ \ 2.1° \pm 0.2°$

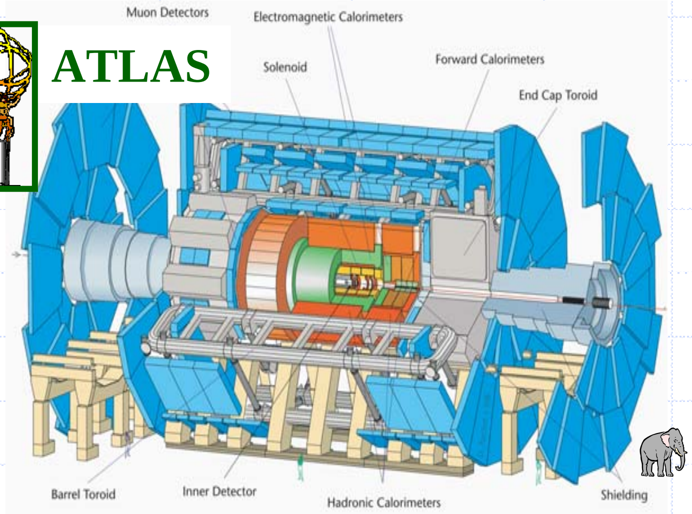
Desperately consistent…



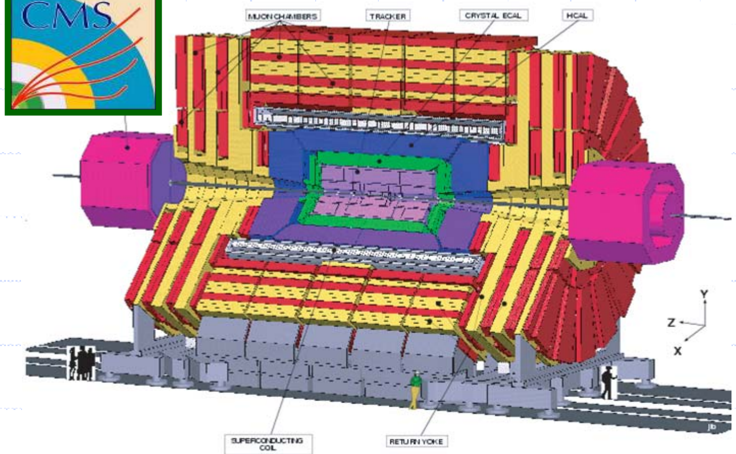
But: New particles may show up in loop diagrams, overconstrain will allow to disentangle SM components from the New Physics ones → <u>need very high precision</u>!

LHC experiments with a B in the menu

ATLAS



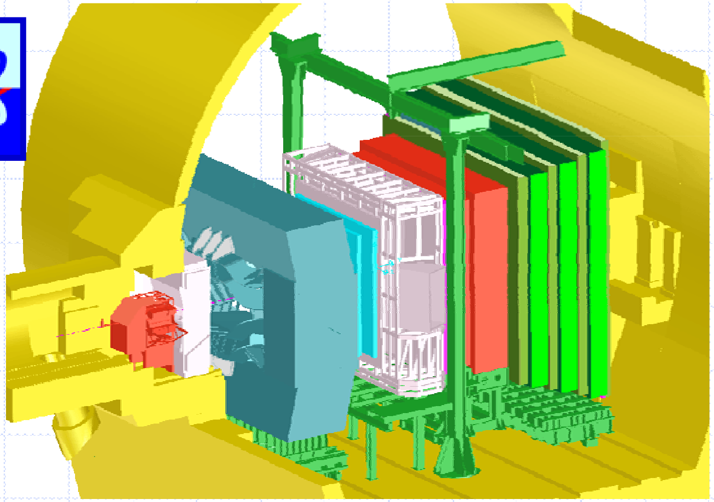
CMS

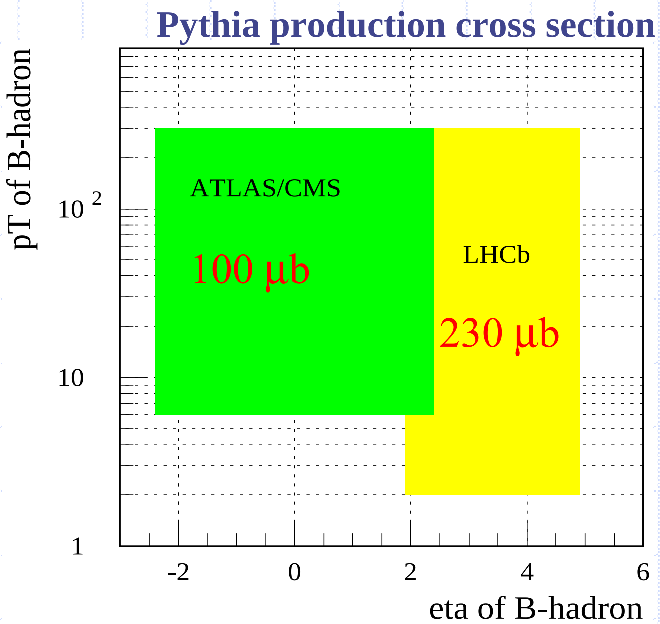


B physics using high-p_T muon, mostly with modes involving dimuons.

B physics dedicated experiment:

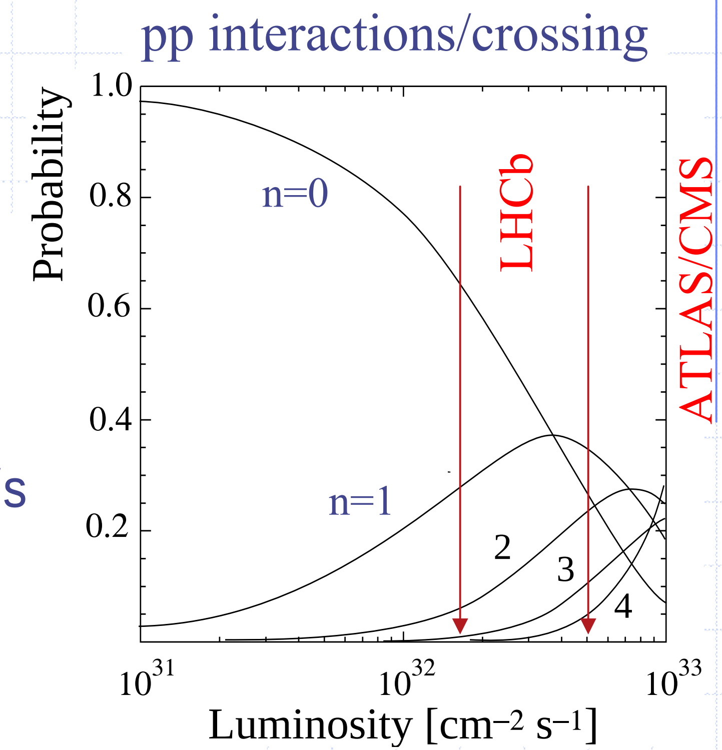
LHCb





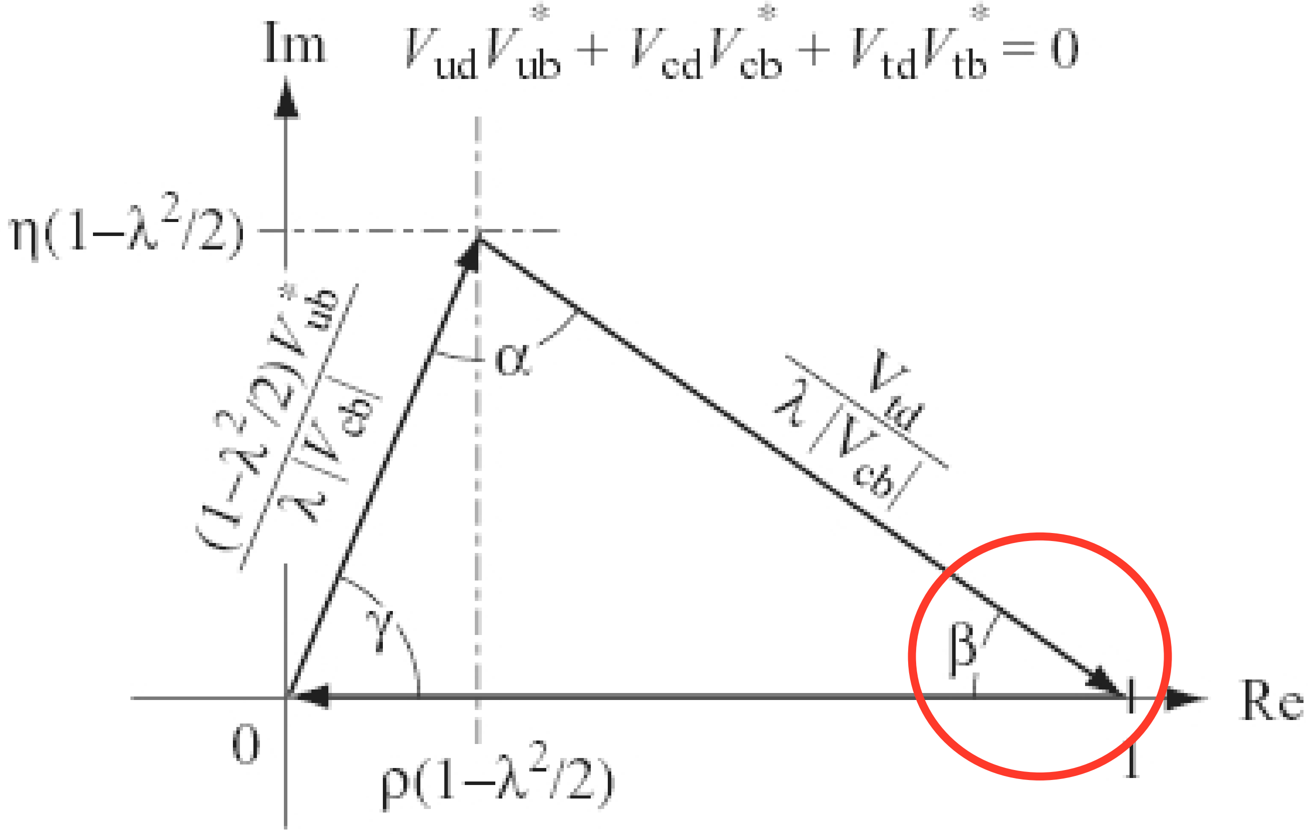
Trigger & Tagging

- **Atlas**: B trigger output rate: 10-15 Hz, Tagging ε_{eff}: ~4%
  CMS: 5 Hz inclusive + ~1 Hz exclusive
  will both run a few years at $L<2\times10^{33}/cm^2/s$ with n(pileup)<5, after that n ~ 25
  LHCb: $L\sim2\times10^{32}/cm^2/s$, n(pileup)~0.5
  Tagging ε_{eff}: 4% - 5%(B_d) 7% - 9%(B_s)
  Trigger output:



Rate	Event type	Use for physics	Use for calibration/systematics
200 Hz	Exclusive B	B (core program)	Control channels (tagging, ...)
600 Hz	High mass dimuon	130 Hz of $B\rightarrow J/\psi X$	Tracking
300 Hz	D*	65 Hz D* (mixing + CPV)	Hadron PID
900 Hz	Inclusive b (e.g. $b\rightarrow\mu$)	550 Hz of B (data mining)	Trigger

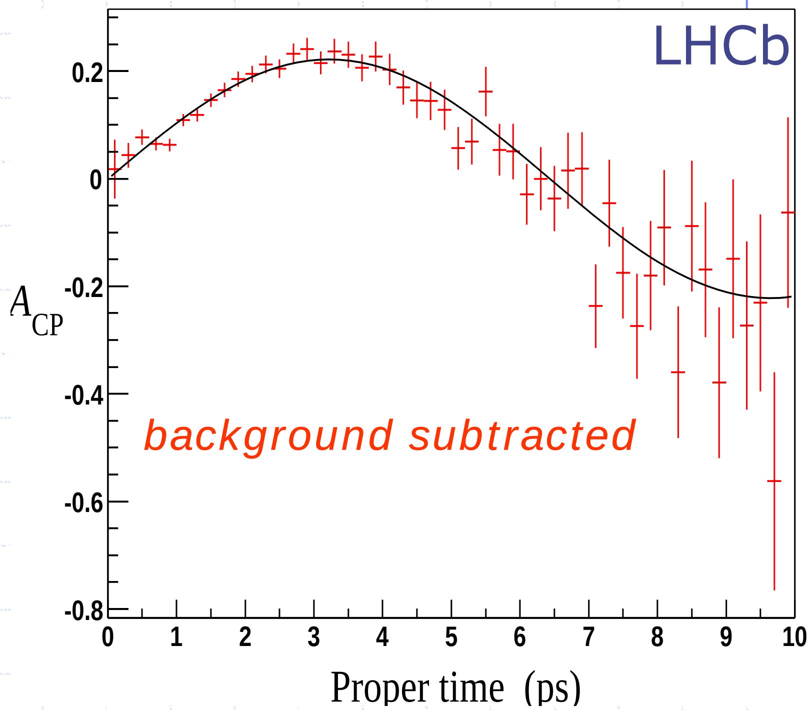
β



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
$\rho(1-\lambda^2/2)$
1
Re

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

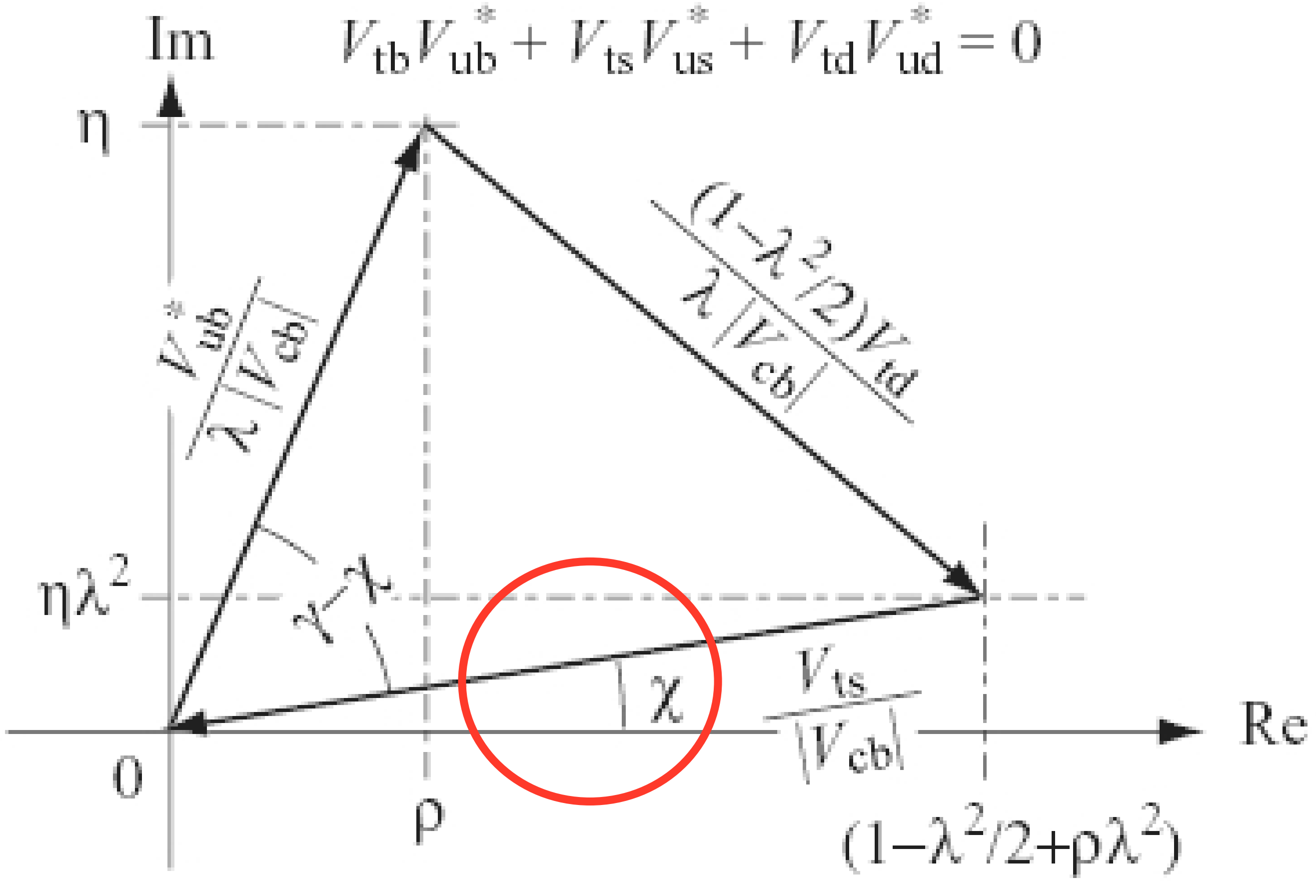
LHCb In one year, 2/fb, with 216k events, σ(sin2β)~0.02, σ(β)~0.6°

Atlas will achieve similar sensitivity with 30/fb

Comparing with other channels may indicate NP in penguin diagrams

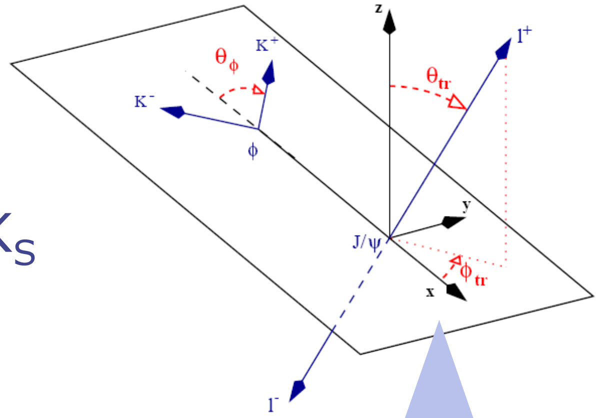
Scaling of 1 year sensitivity from $J/\psi K_s$ to ϕK_s:
$\sigma(\sin 2\beta_{eff})$~0.4, Yield:0.8k, B/S<2.4 (preliminary).

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 $B_s \to J/\psi\phi$ (η,η'…)



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

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

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

- 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)
$B_s \to J/\psi(\mu^-\mu^+)\phi(K^+K^-)$	131	0.12	36	14
$B_s \to \eta_c(h^-h^+h^-h^+)\phi(K^+K^-)$	3	0.6	30	12
$B_s \to J/\psi(\mu^-\mu^+)\ \eta(\gamma\gamma)$	8.5	2.0	37	34
$B_s \to J/\psi(\mu^-\mu^+)\ \eta(\pi^+\pi^-\pi^0(\gamma\gamma))$	3.0	3.0	34	20
$B_s \to J/\psi\ (\mu^-\mu^+)\ \eta'(\pi^+\pi^-\eta\ (\gamma\gamma))$	2.2	2.0	32	19
$B_s \to D_s(K^+K^-\pi^-)\ D_s(K^+K^-\pi^+)$	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
R_T=0.2 and 2/fb stat:

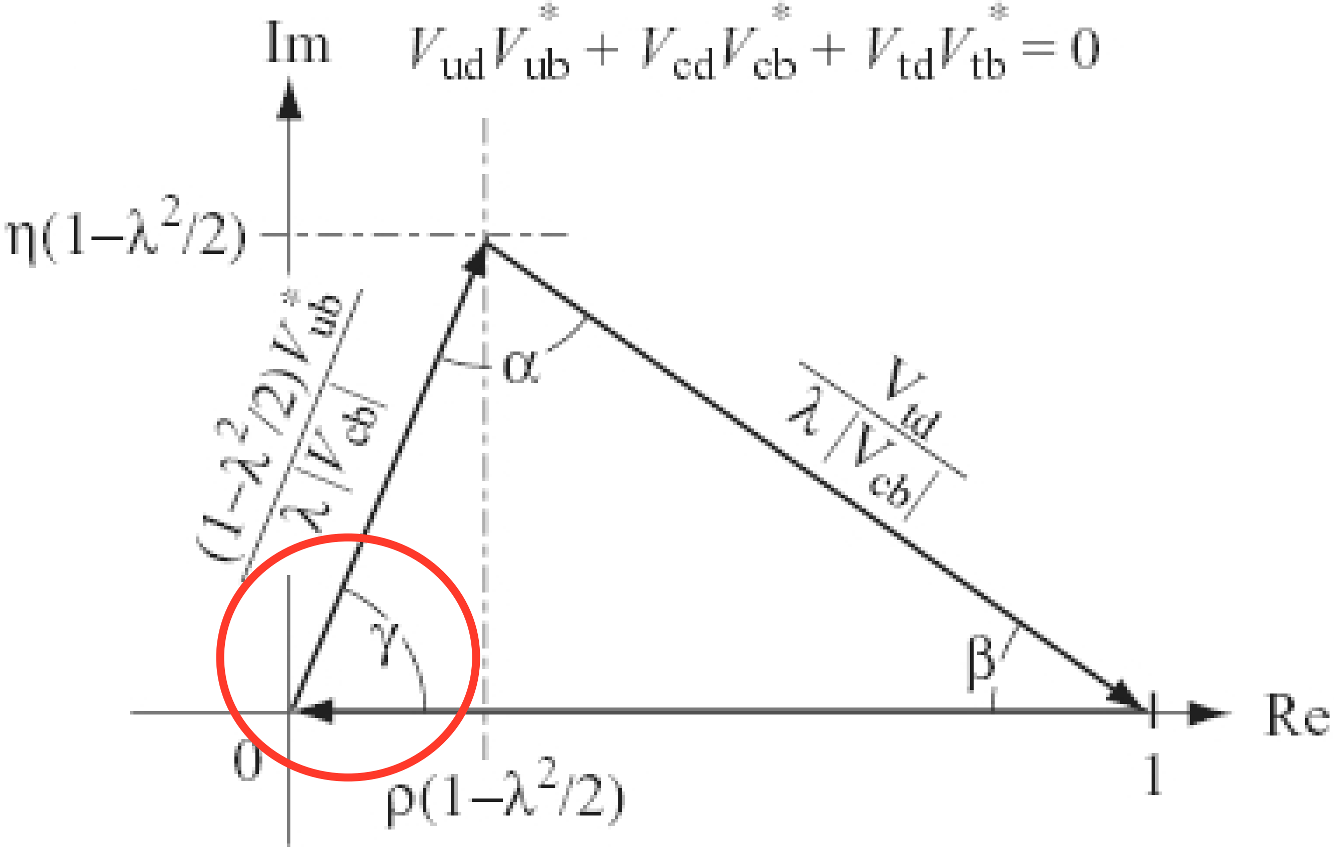
LHCb

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

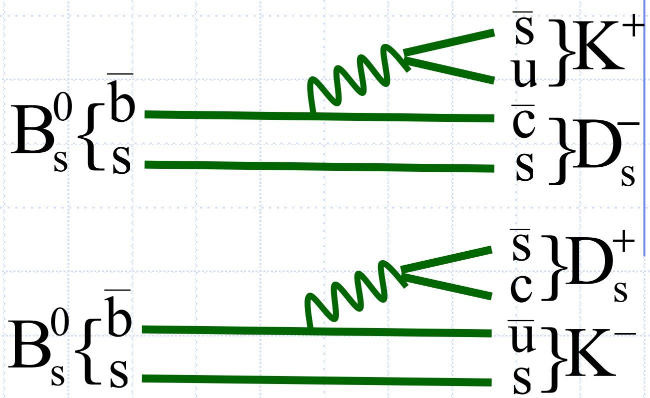
γ



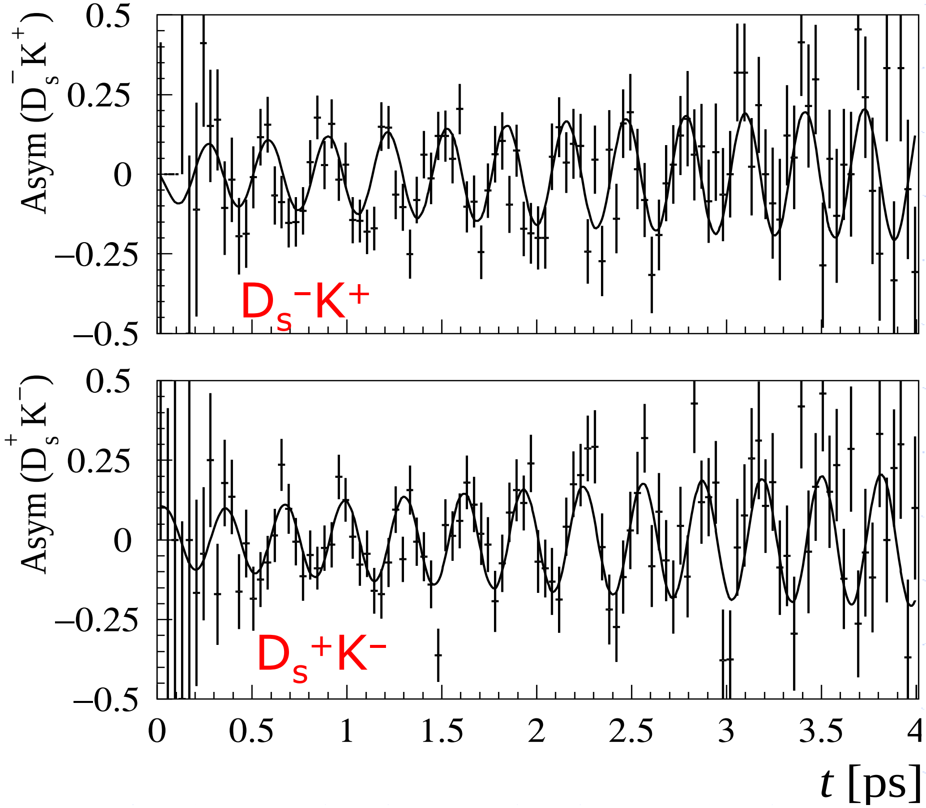
Im
$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$
$\eta(1-\lambda^2/2)$
$\frac{(1-\lambda^2/2)V_{ub}^*}{\lambda|V_{cb}|}$
α
$\frac{V_{td}}{\lambda|V_{cb}|}$
γ
β
Re
0
$\rho(1-\lambda^2/2)$
1

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_sK asymmetries (5 years, Δm_s=20 ps^{-1})

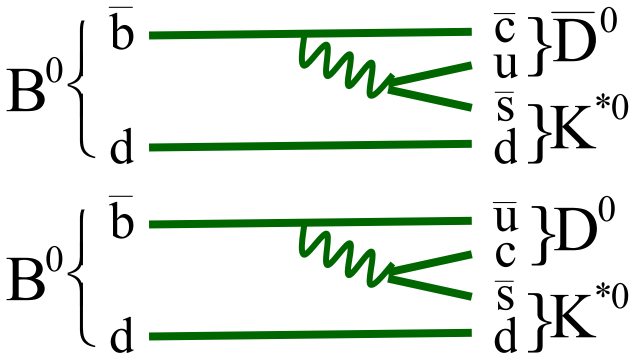


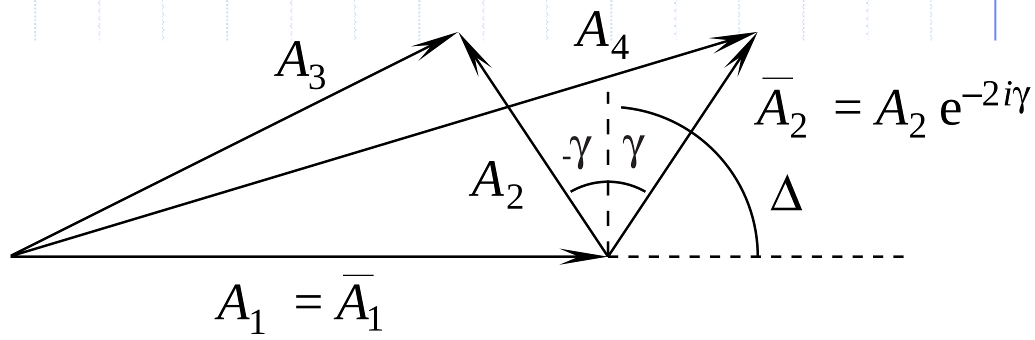
Yield: 5.4k signal events in 2/fb, residual contamination from $B_s \to D_s\pi$ ~ 10%
S/B > 1 at 90% CL

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 $B^0 \to D\pi$

γ from $B^0 \rightarrow D^0 K^*$

[Phys. Lett. B270, 75 (1991)]





$A_1 = A(B^0 \rightarrow \bar{D}^0 K^{*0})$: b→c transition, phase 0

$A_2 = A(B^0 \rightarrow D^0 K^{*0})$: b→u transition, phase $\Delta+\gamma$

$A_3 = \sqrt{2}\, A(B^0 \rightarrow D_{CP} K^{*0}) = A_1 + A_2$, because $D_{CP} = (\bar{D}^0 + D^0)/\sqrt{2}$

- Measuring 6 decay rates *(self-tagged* and *time-integrated)* allows extraction of γ

LHCb

Modes (+CP conj.)	Yield (2/fb)	S/B_{bb} (90%CL)
$B^0 \rightarrow D^0 (K^+\pi^-) K^{*0} (K^+\pi^-)$	3.4 k	> 2.0
$B^0 \rightarrow D^0 (K^-\pi^+) K^{*0} (K^+\pi^-)$	0.5 k	> 0.3
$B^0 \rightarrow D^0_{CP} (K^+K^-) K^{*0} (K^+\pi^-)$	0.6 k	> 0.3

Precision: $\sigma(\gamma) \sim 8°$ (in 1 year, 2/fb, for $55° < \gamma < 105°$, $|\Delta| < 20°$)

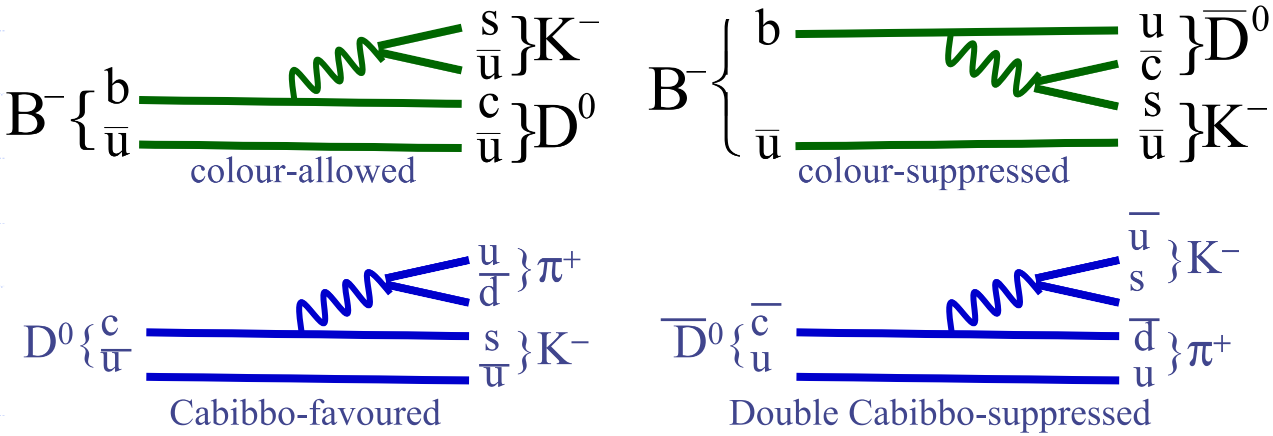
γ from $B^{\pm} \to D K^{\pm}$

[Atwood, Dunietz, Soni method]

New value

- Measure relative rates of $B^{-} \to D(K\pi) K^{-}$ and $B^{+} \to D(K\pi) K^{+}$
  - Two interfering tree B-diagrams, one colour-suppressed ($r_B \sim 0.077$)
  - Two interfering tree D-diagrams, one Double Cabibbo-suppressed ($r_D^{K\pi} \sim 0.06$)

  → large interference because of similar amplitudes!



Weak phase diff.: γ
Magnitude ratio: r_B
Strong phase diff.: δ_B

Magnitude ratio: $r_D^{K\pi}$
Strong phase diff.: $\delta_D^{K\pi}$

measure:

$$\Gamma(B^- \to (K^-\pi^+)_D K^-) \propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B - \delta_D^{K\pi} - \gamma\right)$$

$$\Gamma(B^- \to (K^+\pi^-)_D K^-) \propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B + \delta_D^{K\pi} - \gamma\right),$$

$$\Gamma(B^+ \to (K^+\pi^-)_D K^+) \propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B - \delta_D^{K\pi} + \gamma\right)$$

$$\Gamma(B^+ \to (K^-\pi^+)_D K^+) \propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B + \delta_D^{K\pi} + \gamma\right).$$

favoured ~60k evts

suppressed ~0.5k evts

- 2 observables, 5 parameters ($\gamma, \delta_B, r_B, \delta_D^{K\pi}, r_D^{K\pi}$), $r_D^{K\pi}$ ~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, $\delta_D^{K3\pi}$; $r_D^{K3\pi}$ ~0.06

  D $\rightarrow$ KK (CP eigenstate)

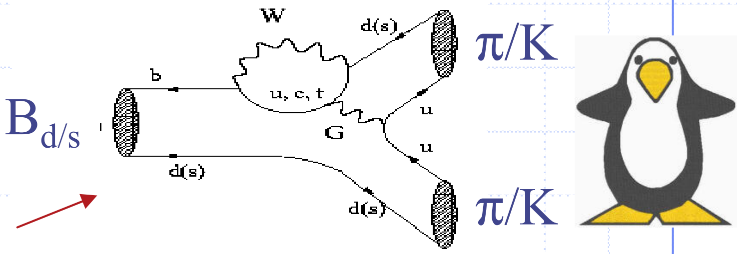
  - ✓ 2 new rates, no new unknown: $r_D^{KK} = 1$; $\delta_D^{KK} = 0$

➔ 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.

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 = $d\, e^{i\theta}$

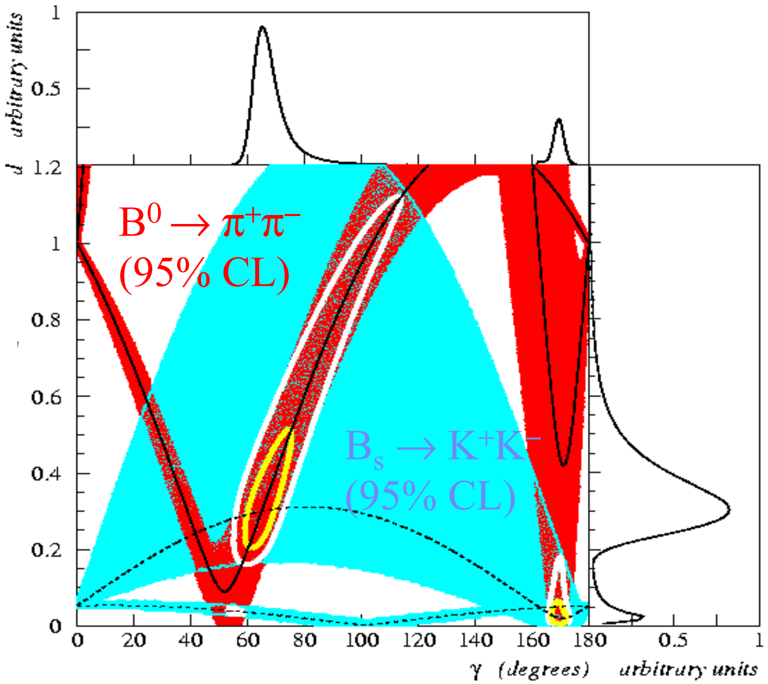
$$A_{CP}^{th}(\tau) = \frac{A_{CP}^{dir} \cdot \cos(x \cdot \tau) + A_{CP}^{mix} \cdot \sin(x \cdot \tau)}{\cosh\left(\frac{\Delta\Gamma}{2} \cdot \tau\right) - A_{\Delta\Gamma} \cdot \sinh\left(\frac{\Delta\Gamma}{2} \cdot \tau\right)}$$

- 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

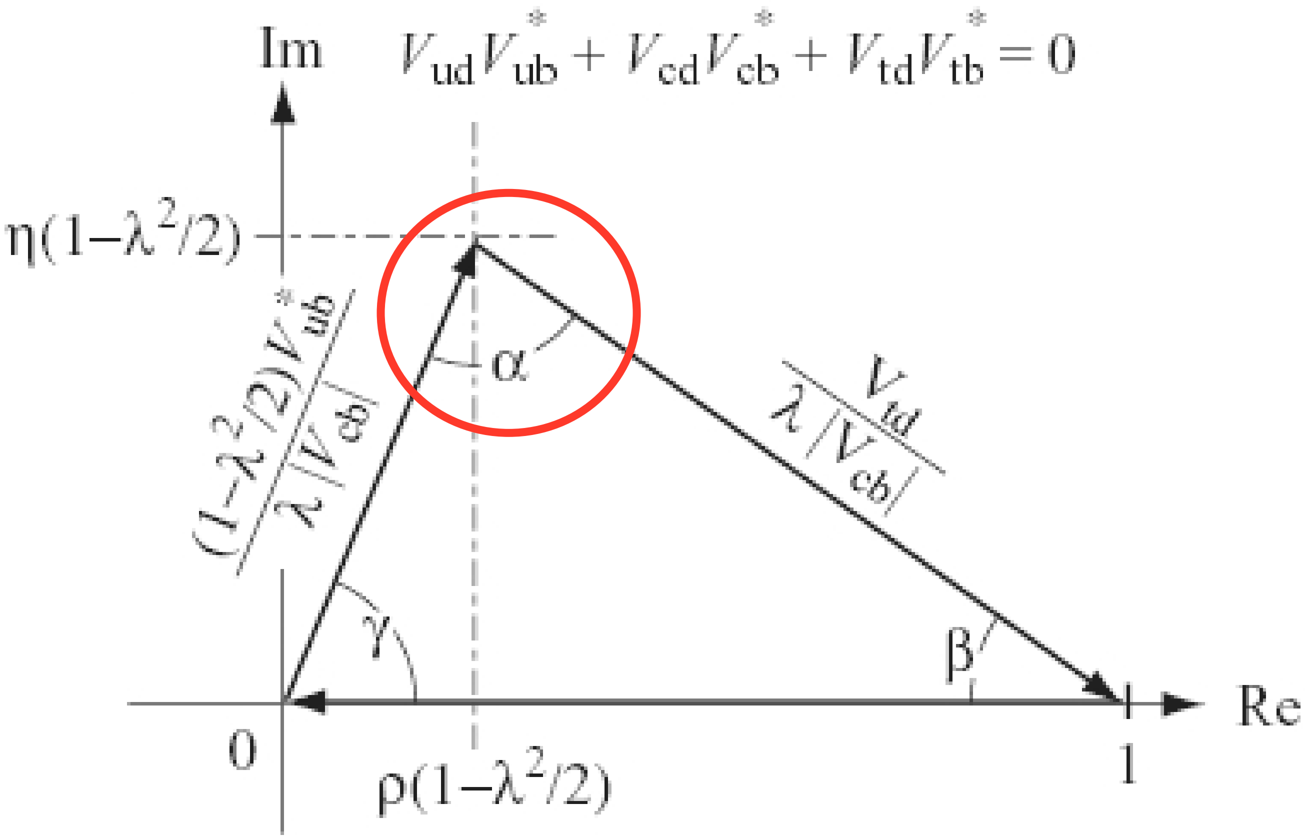
Precision: $\sigma(\gamma) \sim 5°$
(but model dependent)

Expected Yield (1year, 2/fb)
- 26k $B^0 \to \pi^+\pi^-$,
- 37k $B_s \to K^+K^-$,
- 135k $B^0 \to K^+\pi^-$



γ (°)

α

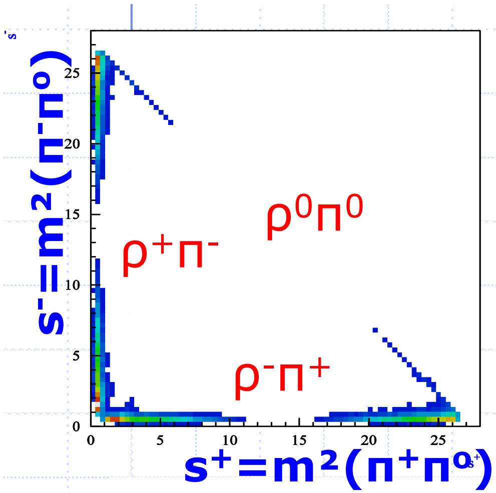

Im
$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$
$\eta(1-\lambda^2/2)$
$\frac{(1-\lambda^2/2)V_{ub}^*}{\lambda|V_{cb}|}$
α
$\frac{V_{td}}{\lambda|V_{cb}|}$
γ
β
0
$\rho(1-\lambda^2/2)$
1
Re

α from $B^0 \to \rho\,\pi$

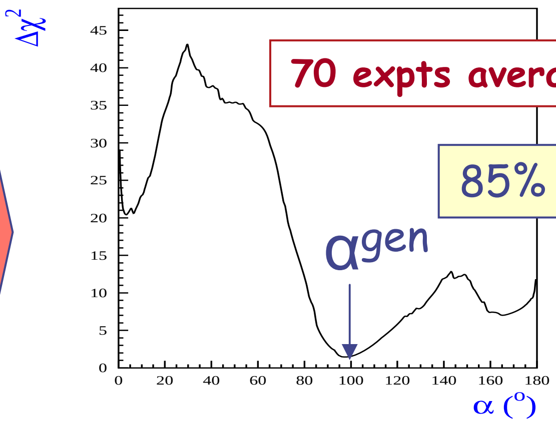
LHCb

[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

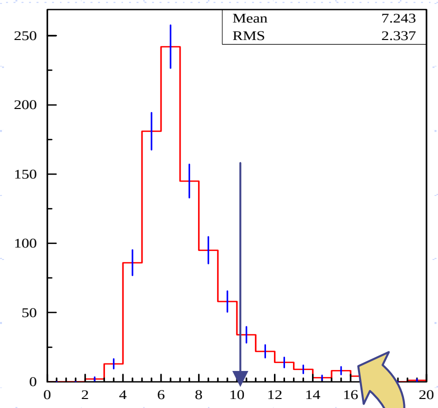


- ❑ Simulate the experimental effects: resolution, acceptance, wrong tag, … Assume B/S=1 (mix of flat and resonant ρ)
- ❑ Maximize the likelihood wrt α^{fit} and the background ratios r^{fit} (12D fit)



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

85% converge to the correct solution*



90% of experiments have $\sigma_\alpha < 10°$

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

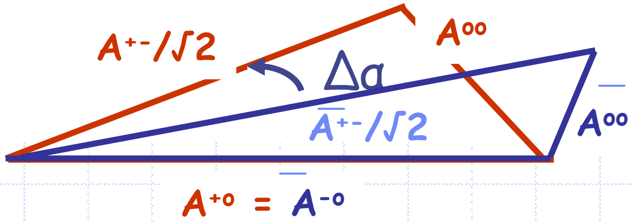
LHCb

α from $B^0 \rightarrow \rho\,\rho$

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 $S_{\rho\rho}^{+-} = \sqrt{1 - C_{\rho\rho}^{+-\,2}}\,\sin(2\alpha_{eff})$



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

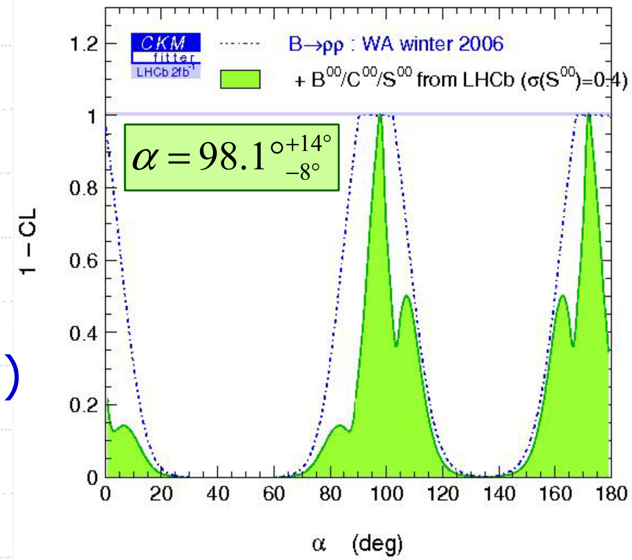
Yields in 2/fb:

B ➛ $\rho^+\rho^-$: 2k (B/S<5, 90%CL)

$B^\pm$ ➛ $\rho^\pm\rho^0$: 9k (B/S ~ 1)

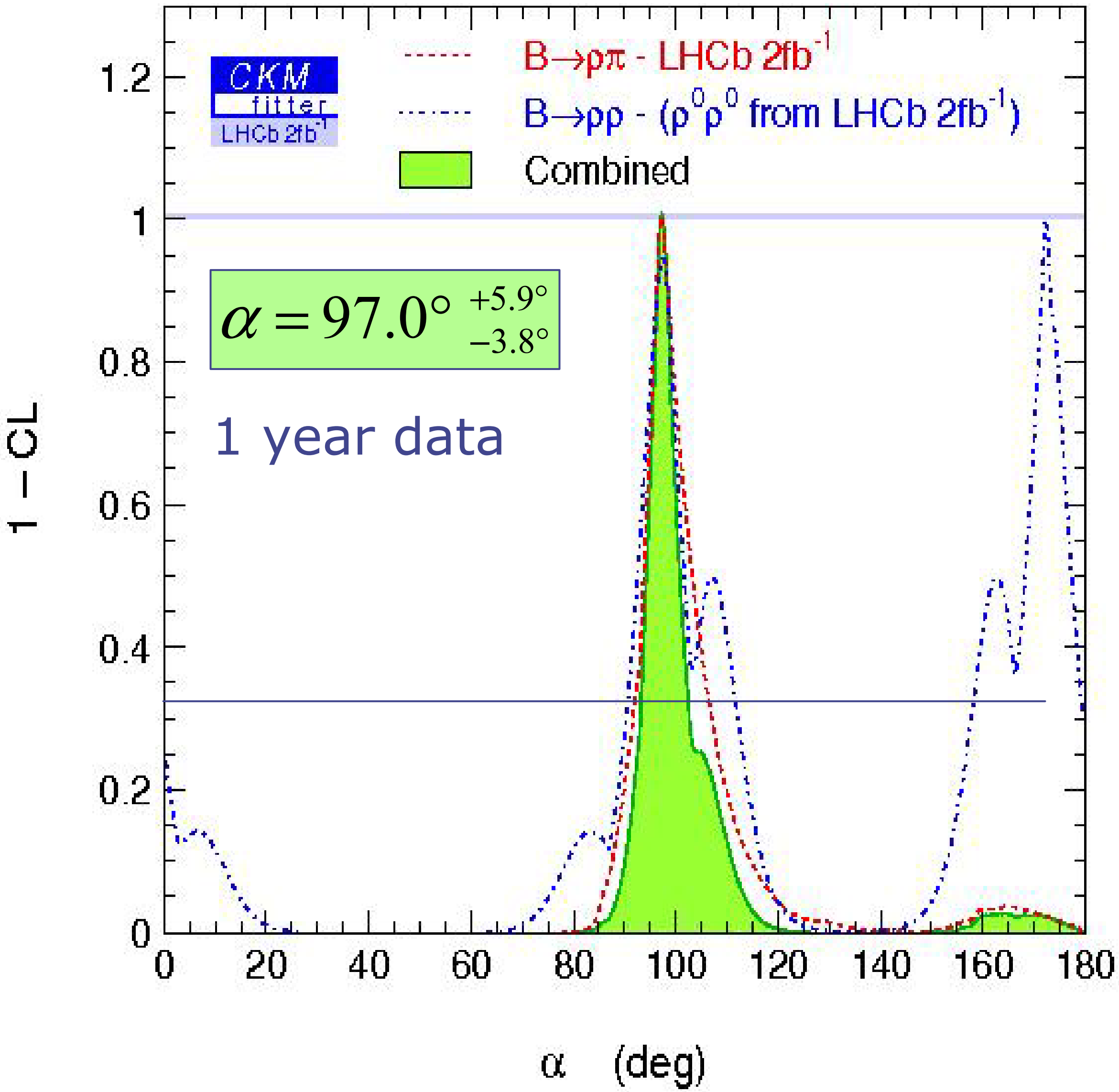
B ➛ $\rho^0\rho^0$: ~0.5k, assuming a BR=0.5 10^{-6}

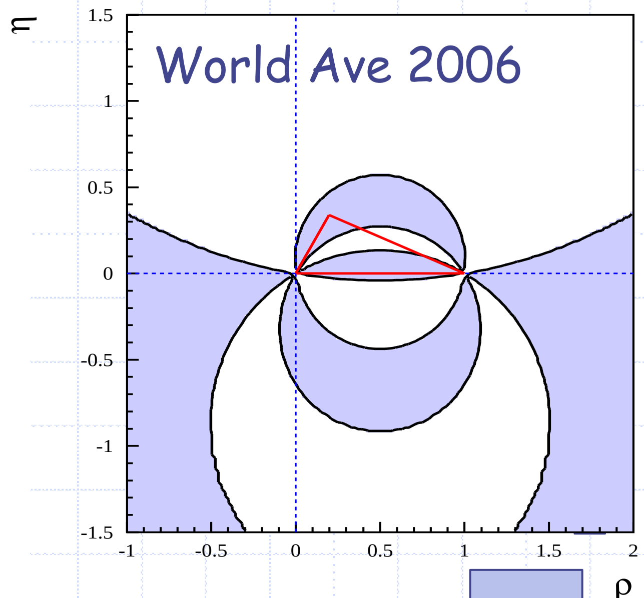
(Babar: $B^{00} = (0.54^{+0.36}_{-0.32} \pm 0.19)10^{-6}$)

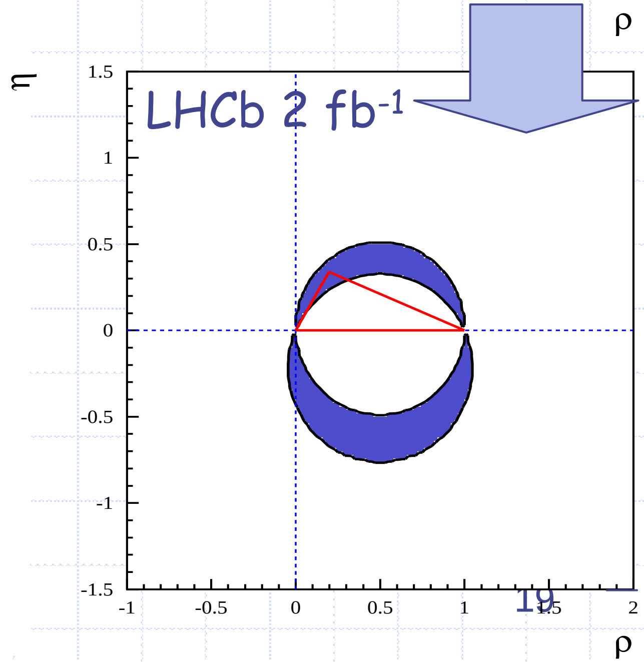


α from $B^0 \rightarrow \rho\pi, \rho\rho$ combined

LHCb







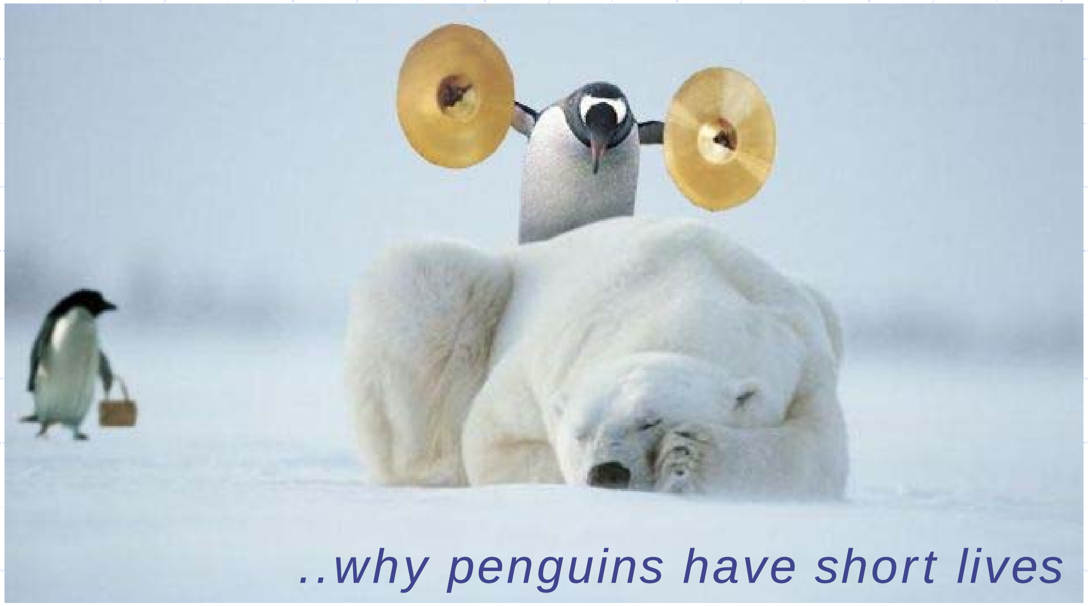
Summary table

Angle	Channel	Yield*	B_{bb}/S	LHC (2/fb)	Theoretical limit
β	$B_d \to J/\Psi\ K_S$	216k	0.8	$\sigma(\beta) \approx 0.6^\circ$	$\sigma(\beta) \sim 0.2^\circ$
	$B_d \to \phi\ K_S$	0.8k	<2.4	$\sigma(\beta) \approx 12^\circ$	$\sigma(\beta) \sim 2^\circ$
ϕ_s	$B_s \to J/\Psi\Phi$	125k	0.3	$\sigma(\phi_s) \approx 1.2^\circ$	$\sigma(\phi_s) \sim 0.2^\circ$
	$B_s \to J/\Psi\eta$	12k	2-3		
	$B_s \to \eta_c\Phi$	3k	0.7		
γ	$B_s \to D_sK$	5.4k	<1.0	$\sigma(\gamma) \approx 13^\circ$	$\sigma(\gamma) \ll 1^\circ$
	$B_d \to \pi\pi$	26k	<0.7	$\sigma(\gamma) \approx 5^\circ$	if U-spin symmetry
	$B_s \to KK$	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	$\sigma(\gamma) \approx 4^\circ$-$13^\circ$	$\sigma(\gamma) \ll 1^\circ$
	$B^- \to D^0(K^-\pi^+)K^-$	2k	0.5		
α	$B_d \to \pi\rho,\ \rho\rho$	14k	0.8	$\sigma(\alpha) < 10^\circ$	$\sigma(\alpha) \sim 1^\circ$

* Untagged annual yield after trigger

Conclusion

- LHC experiments will allow to measure the Unitarity Triangle very precisely
- loop processes in the flavour sector will probe high energy scale!



..why penguins have short lives