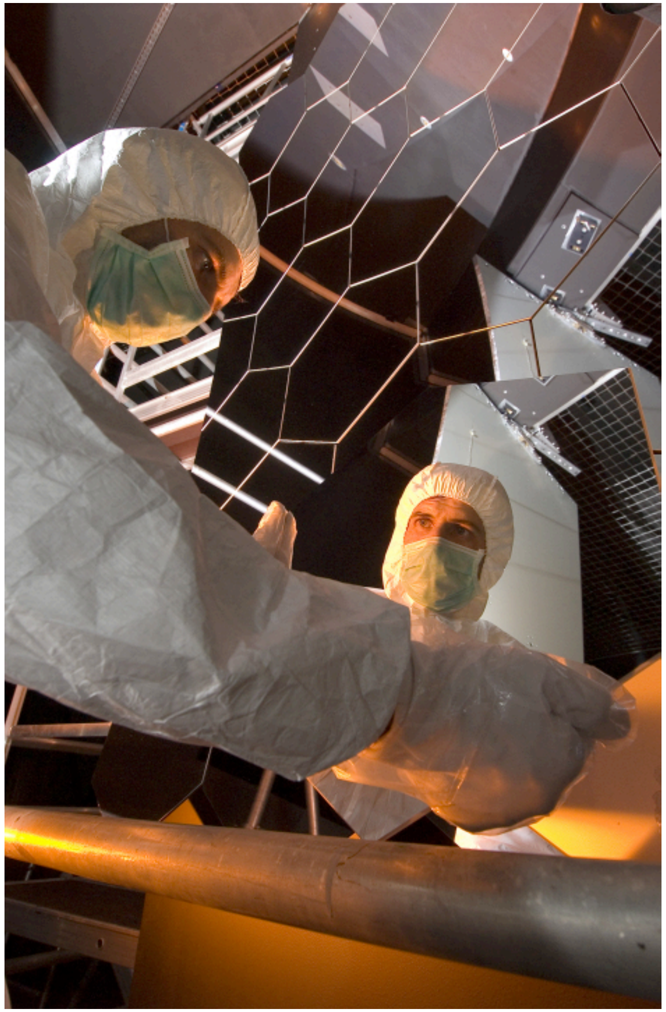
The CKM angle γ at LHCb

- Intro & Status
- Measuring γ with time-dependent decay rate asymmetries in $\{B_d \rightarrow \pi\pi + B_s \rightarrow KK\}$, $B_s \rightarrow D_s K$.
- Measuring γ using time-integrated $B^\pm \rightarrow DK^\pm$.



Physics at the LHC, Krakow,
3-8 July 2006

Jonas Rademacker on behalf of LHCb

The angle γ in SM

$$\begin{array}{ccc} \text{CKM matrix} & \text{order in } \lambda = 0.22 & \text{phases up to } \mathcal{O}(\lambda^3) \\ \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} & \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix} & \begin{pmatrix} 1 & 1 & e^{-i\gamma} \\ 1 & 1 & 1 \\ e^{-i\beta} & 1 & 1 \end{pmatrix} \end{array}$$

- Up to 3rd order in λ, there are only two non-zero phases in the CKM matrix, β and γ. But they can be accessed in different ways.

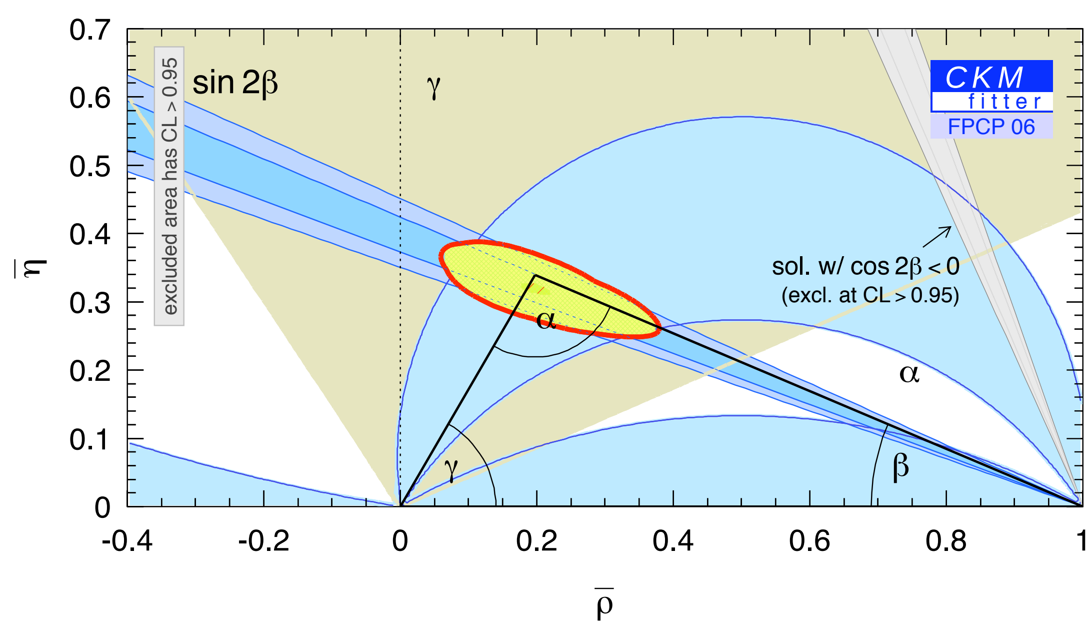
- Convention: Measurements using charmless B_d decays, like $B_d \to \pi\pi$, that are sensitive to 2β+2γ = 2(π-α), are "α measurements" (prev. talk). Others like $B_d \to D\pi$ (sensitive to 2β+γ), are "γ measurements" (this talk).

- More phases appear at higher order (next talk).

Status of γ

- Current constraints (CKM Fitter, based on Moriond 06)
  - From $\mathrm{B}^{\pm} \to \mathrm{DK}^{\pm}$
    $\gamma = 63^{o}{}^{+35^o}_{-25^o}$
  - Including $\mathrm{B_d} \to \mathrm{D}\pi$
    $\gamma = 71^{o}{}^{+22^o}_{-30^o}$
  - Combined fit excluding γ measurements:
    $\gamma = 59.8^{o}{}^{+4.9^o}_{-4.2^o}$

Constraints on the apex of the Unitarity triangle from direct measurements of α, β, γ only.



γ from time-dependent decay rate asymmetries

Extract phase-difference between two decay paths from amplitudes in time-dependent decay rate asymmetries.

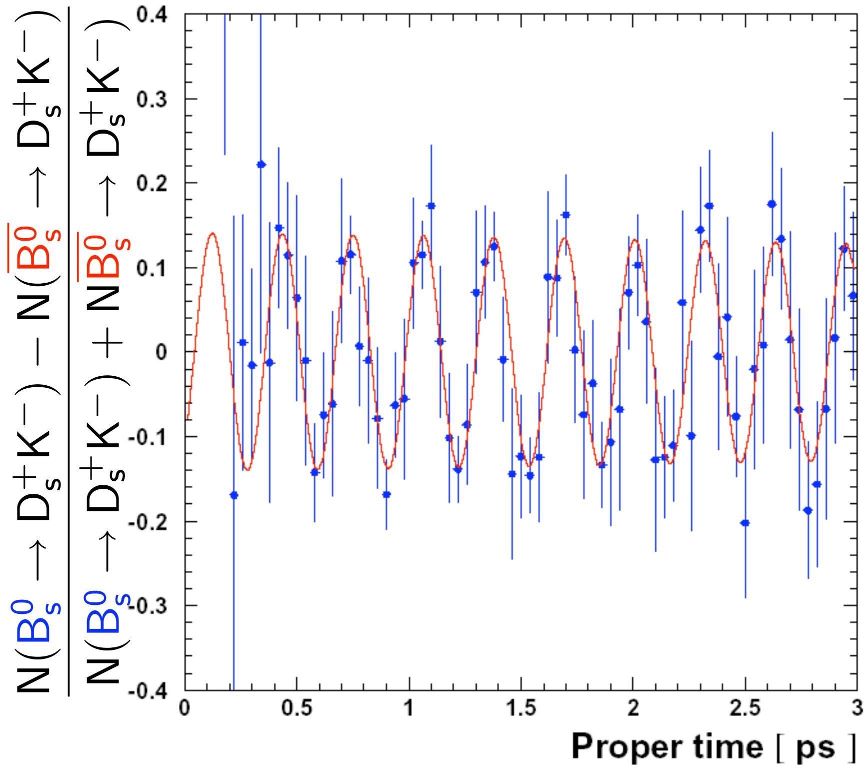
$$\begin{tikzcd}
 & \overline{B}_{d,s} \arrow[dr, "r e^{-i(\gamma+\delta_{\text{strong}})}"] & \\
B_{d,s} \arrow[ur, dash, "e^{-i\phi_{d,s}}"] \arrow[rr, bend right] & & D_{d,s}\pi/K
\end{tikzcd}$$

This example is sensitive to:

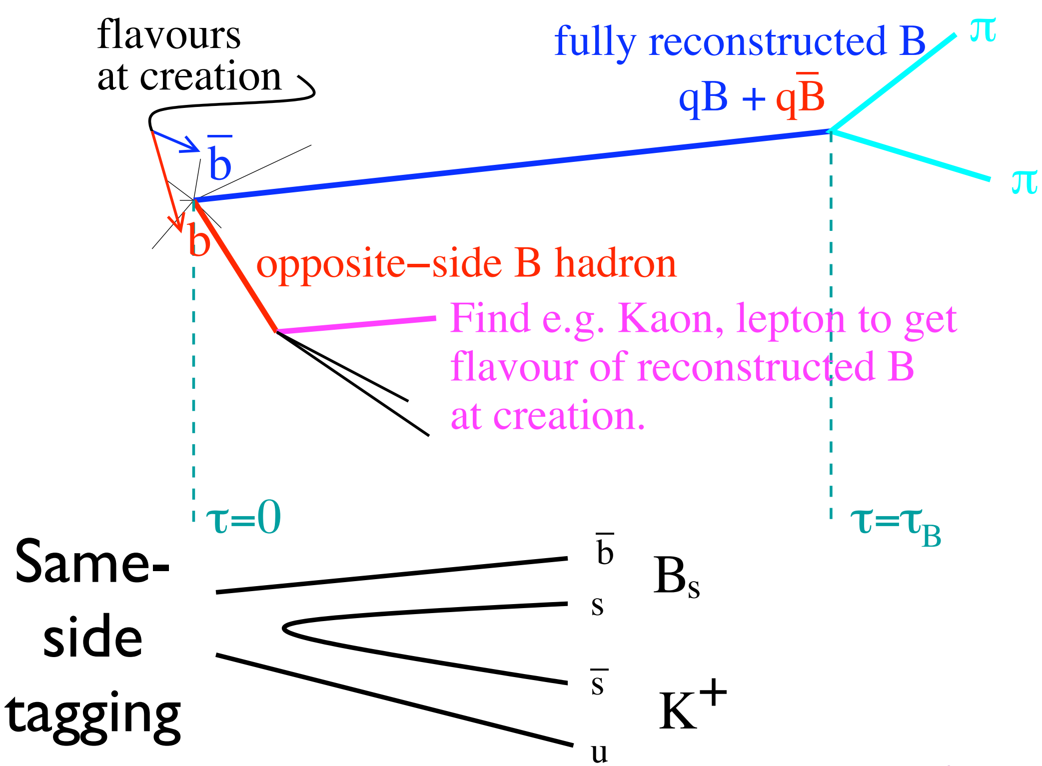
$$\sin(\phi_{s,d} + \gamma + \delta_{\text{strong}})$$

$$\sin(-(\phi_{s,d} + \gamma) + \delta_{\text{strong}})$$

In SM: $\phi_d = 2\beta, \quad \phi_s = -2\delta\gamma$



Basic Principle & Tagging.



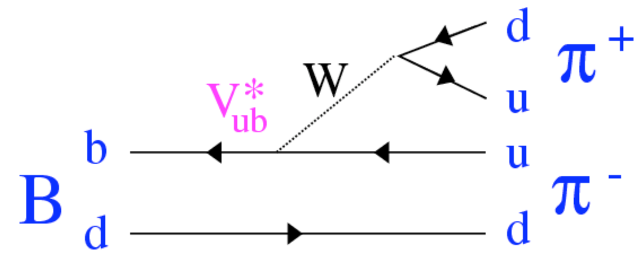
- Decay products (RICH)
- Decay time ~ flight distance (VELO)
- Flavour at creation - opposite-side or same-side (Bs only) Tagging.

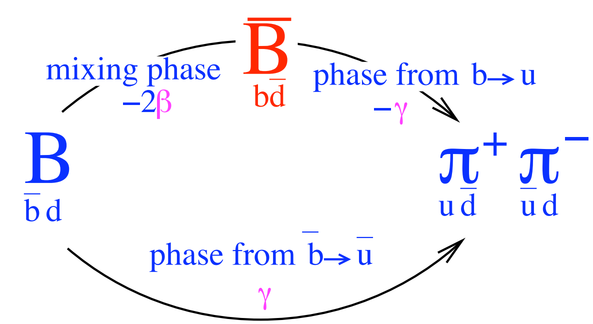
$$\varepsilon_{\text{eff}} = \epsilon D^2 = \epsilon\,(1-\omega)^2 = \begin{cases} \sim 4-5\% & (B_d) \\ \sim 7-9\% & (B_s) \end{cases}$$

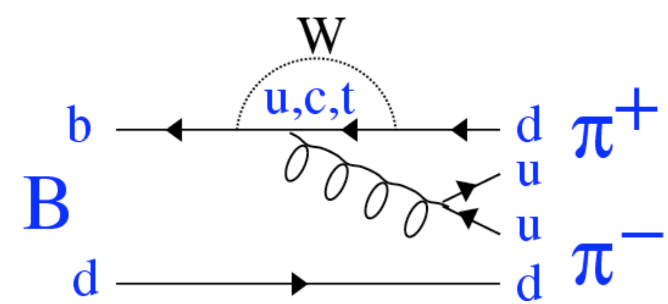
N events with tagging efficiency ϵ and mis-tag fraction ω are statistically equivalent to ε_{eff} perfectly tagged events.

γ from $B_d \to \pi\pi$, $B_s \to KK$

- If there were only the tree-contribution, $B_d \longrightarrow \pi\pi$ would measure 2(β + γ), i.e. 2α.
- But there are penguins. They complicate things, but provide sensitivity to new physics.
- Disentangle Penguin and Tree contribution by combined B_d, B_s analysis. Assumes U-spin (d↔s) symmetry of strong interaction.







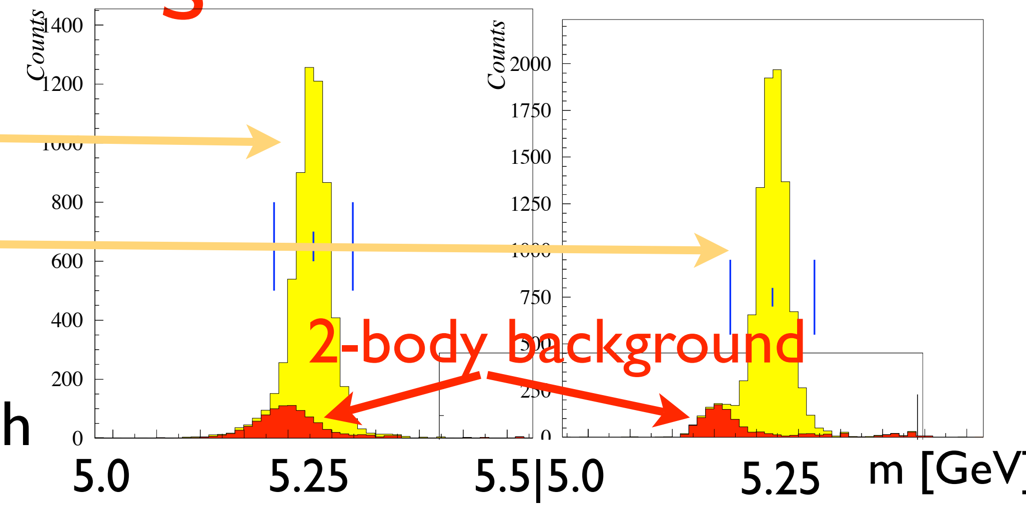
γ from $B_d \to \pi\pi$, $B_s \to KK$

- Expected yields:

  $26k \quad B_d \to \pi^+\pi^-$

  $37k \quad B_s \to K^+K^-$

  $135k \quad B_d \to K^+\pi^-$

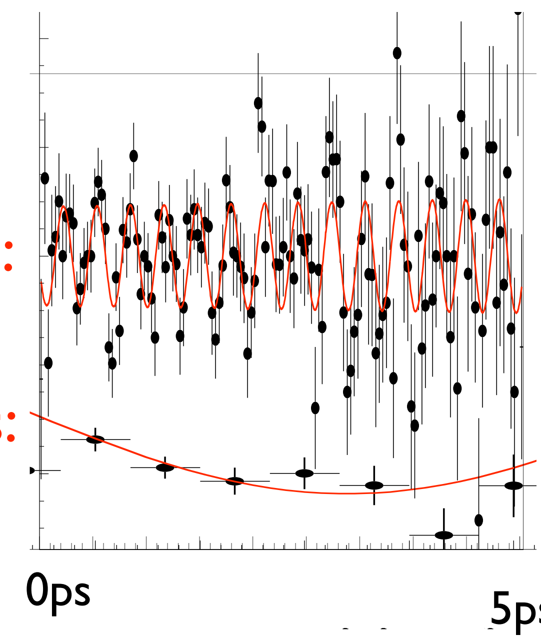


- RICH crucial to distinguish decay modes.

- VELO provides the excellent time resolution needed to resolve fast Bs oscillation. σ(τ) ~ 40 fs, ~10% of Bs oscillation period.

B_s-oscillations:

B_d-oscillations:

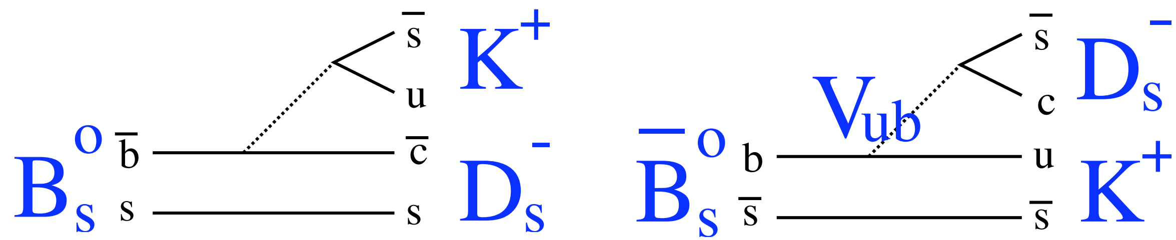


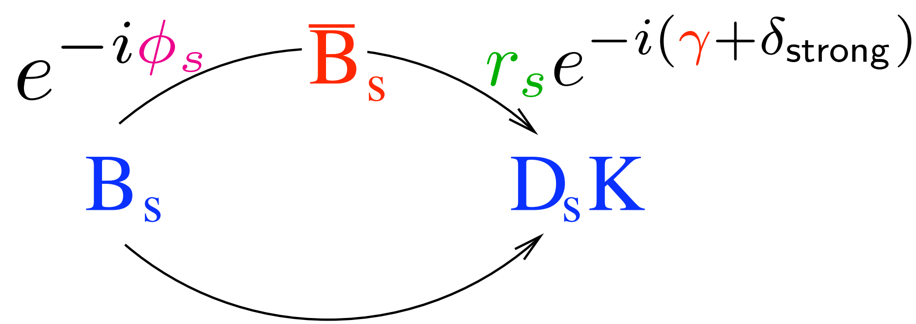
- After 1 year: σ(γ) ~5°

γ from $B_s^0 \to D_s K$

- Tree-only, no penguins.
- In contrast to $B_d \to D\pi$, decay amplitudes are of similar magnitude - large interference effects.
- No external constraints needed to extract $\phi_s + \gamma$.
- Sufficient numbers of Bs only available at LHC.
- Benefits from some of LHCb's finest features, the RICH and the VELO.

Interference between 2 decay amplitudes of similar magnitude.





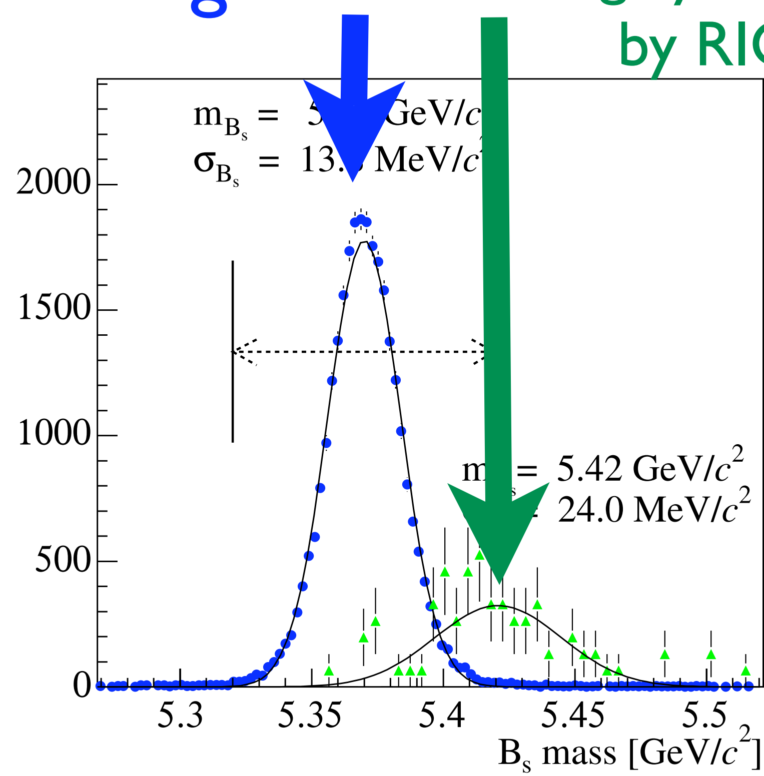
Sensitive to $\phi_s + \gamma$, where ϕ_s is the mixing phase in the B_s system. In SM: $\phi_s \approx 0$

γ from $B_s^0 \rightarrow D_s K$

- Dominant Background: $B_s \rightarrow D_s \pi$ with 10x larger BR.
- K-π separation provided by LHCb's RICH cleans up data sample.
- Expect 5.4k events/ year, with S/B > 2

Signal

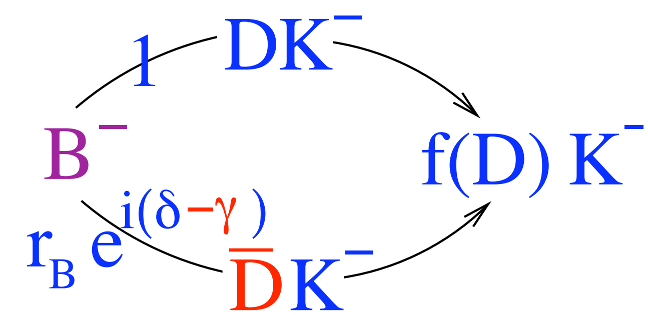
$B_s \rightarrow D_s \pi$, ~10x larger BR, highly suppressed by RICH



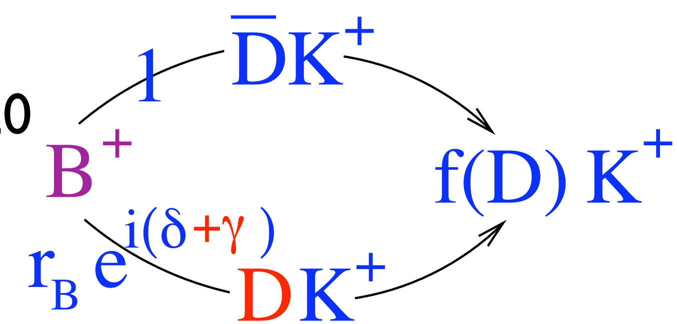
$\sigma(\gamma) \approx 13^\circ$ within 1 year for Δm=17.3/ps

γ from $B^{\pm} \longrightarrow DK^{\pm}$

- Use interference between $B^{\pm} \rightarrow D^0K^{\pm}$ and $B^{\pm} \rightarrow \bar{D}^0K^{\pm}$ where D^0 and $\bar{\mathrm{D}}^0$ decay to the same final state f_D.



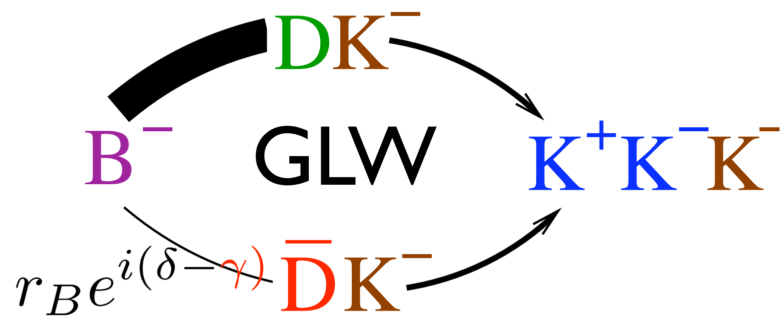
- No time measurement - simple.
- No tagging - boosts statistical power per event by factor of **~10-20**



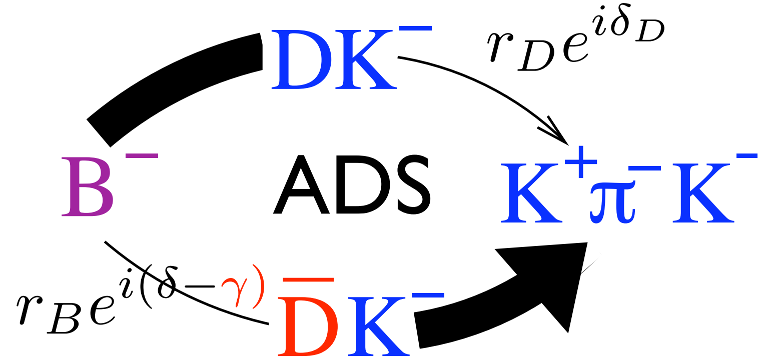
- $\frac{\langle B^- \rightarrow \bar{D}^0 K^- \rangle}{\langle B^- \rightarrow D^0 K^- \rangle} = r_B e^{i(\delta - \gamma)}$

γ from $B^{\pm} \rightarrow DK^{\pm}$

- f(D) can be a CP-eigenstate (GLW) - advantage: $\dfrac{\langle D^0 \rightarrow f_{CP} \rangle}{\langle \bar{D}^0 \rightarrow f_{CP} \rangle} = 1$



- ADS: Favoured B decay goes with the Cabbibo suppressed D decay. Interfering Amplitudes of similar size lead to larger interference effects.



2 body K^+K^-, $\pi^+\pi^-$, $K\pi$

3 body $K_S\pi^+\pi^-$ $K_SK^+K^-$

4 body $K^+K^-\pi^+\pi^-$ $K^+\pi^-\pi^+\pi^-$

Extracting γ by counting $B^{\pm} \rightarrow DK^{\pm}$ event rates

- Extract γ simply by counting event numbers.
- Asymmetries can be very large with ADS, e.g:

$$\frac{\Gamma\left(B^{-} \rightarrow D(K^{-}\pi^{+})K^{-}\right) - \Gamma\left(B^{+} \rightarrow D(K^{+}\pi^{-})K^{+}\right)}{\Gamma\left(B^{-} \rightarrow D(K^{-}\pi^{+})K^{-}\right) + \Gamma\left(B^{+} \rightarrow D(K^{+}\pi^{-})K^{+}\right)} \approx 0.4$$

Expected performance at LHCb, 1 year:

$$\left.\begin{array}{l} \bullet\ 60\mathrm{k}\ \mathrm{K}\pi, \\[2ex] \bullet\ 60\mathrm{k}\ \mathrm{K}\pi\pi\pi\ ^{\dagger} \\[2ex] \bullet\ 8\mathrm{k}\ \mathrm{KK}, \pi\pi \end{array}\right\} \sigma(\gamma) \approx 4^{o} - 14^{o}$$

(stat only)

(exact value depends on input parameters)

† Using simplified model ignoring resonant structure.

3-body D decays and Dalitz Plots

There are many paths from

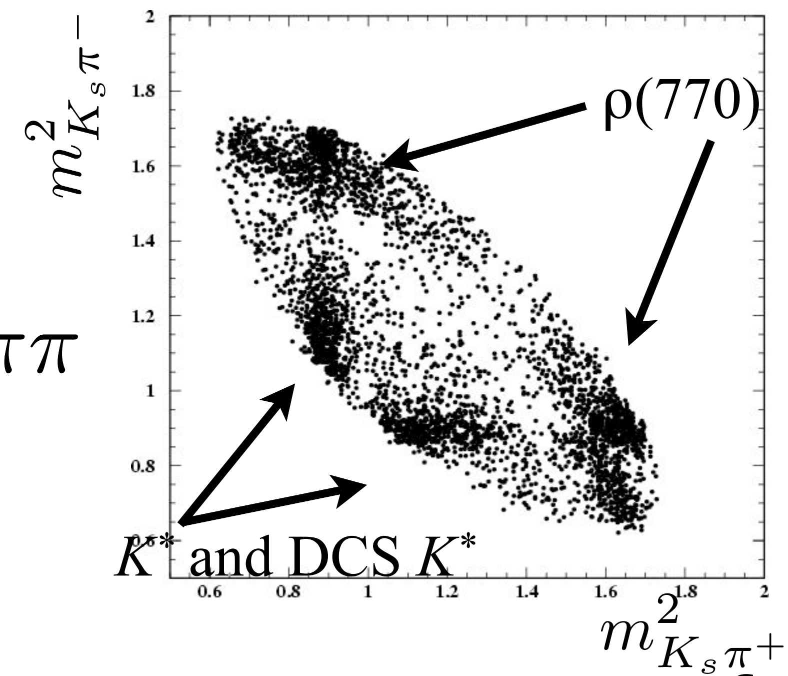
$\mathrm{D^0}$ to $\mathrm{K_s}\pi\pi$

3-body decay fully parametrised by 2 parameters. LHCb-generator study:

$\mathrm{D}^0 \longrightarrow$

Intermediate state	Amplitude $\lvert c_j \rvert$	Phase δ_j (°)
$K^*(892)^+\pi^-$	1.656 ± 0.012	137.6 ± 0.6
$K^*(892)^-\pi^+$	$(14.9 \pm 0.7) \times 10^{-2}$	325.2 ± 2.2
$K_0^*(1430)^+\pi^-$	1.96 ± 0.04	357.3 ± 1.5
$K_0^*(1430)^-\pi^+$	0.30 ± 0.05	128 ± 8
$K_2^*(1430)^+\pi^-$	1.32 ± 0.03	313.5 ± 1.8
$K_2^*(1430)^-\pi^+$	0.21 ± 0.03	281 ± 9
$K^*(1680)^+\pi^-$	2.56 ± 0.22	70 ± 6
$K^*(1680)^-\pi^+$	1.02 ± 0.2	103 ± 11
$K_S\rho^0$	1.0 (fixed)	0 (fixed)
$K_S\omega$	$(33.0 \pm 1.3) \times 10^{-3}$	114.3 ± 2.3
$K_S f_0(980)$	0.405 ± 0.008	212.9 ± 2.3
$K_S f_0(1370)$	0.82 ± 0.10	308 ± 8
$K_S f_2(1270)$	1.35 ± 0.06	352 ± 3
$K_S\sigma_1$	1.66 ± 0.11	218 ± 4
$K_S\sigma_2$	0.31 ± 0.05	236 ± 11
non-resonant	6.1 ± 0.3	146 ± 3

$\longrightarrow \mathrm{K_s}\pi\pi$



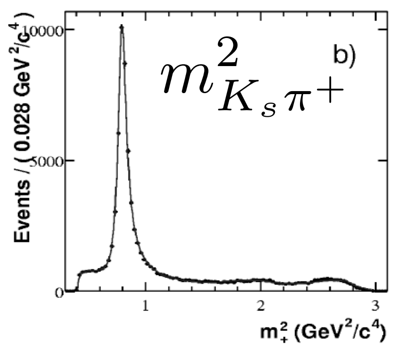
- Every point in Dalitz plot ~ different decay channel, with different strong phase δ.
- The ***shape*** of the Dalitz plot is fitted, not the absolute numbers of B+, B-, no need to know production ratio.
- Same idea applies to $\mathrm{B_u} \rightarrow \mathrm{D(KK\pi\pi)K}$, $\mathrm{B_u} \rightarrow \mathrm{D(K\pi\pi\pi)K}$.

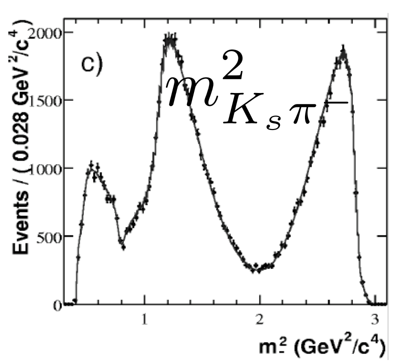
$B^{\pm} \rightarrow (K_s\pi\pi)_{D^0}K^{\pm}$ Dalitz analysis.

Distribution of kin. variables...

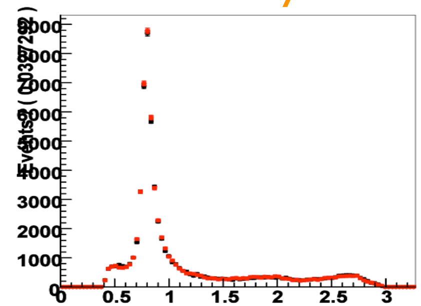
in data at BaBar:

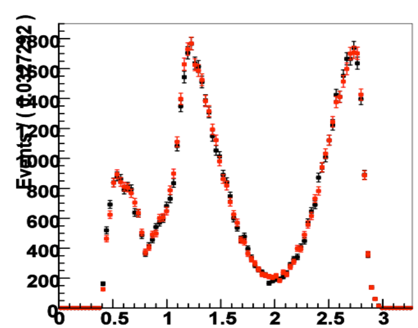
From BaBar's large prompt D sample, not D's from B's used for CPV measurement





...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

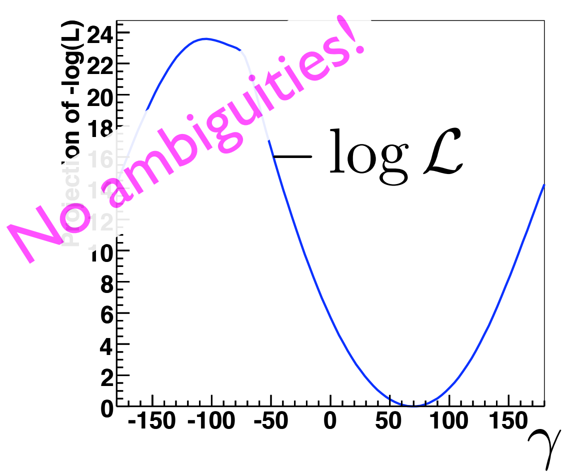
- What works with $\mathrm{D}^0 \to \mathrm{K_s}\pi\pi$ should also work with $\mathrm{D}^0 \to \mathrm{K}^+\mathrm{K}^-\pi^+\pi^-$.
- Particularly suitable for LHCb: No neutrals, benefits from K/π separation by LHCb RICH.
- 4 body amplitude analyses are a bit trickier than 3 body:
  - Need 5 instead 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: $\gamma = 60^o \quad \delta = 130^o, r_B = 8\%$

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 $B_d^0 \to D(\pi K, KK, K\pi)K^*$

All $B^\pm \to DK^\pm$ analyses can also be done with $B_d^0 \to DK^*$
$K^* \to K^+\pi^-$ tags beauty flavour.
Time-integrated decay rates measure γ.

LHCb performance for in one year:

Mode (+ cc)	Yield	S/B_{bb} (90%CL)
$B^0 \to D^0\ (K^+\pi^-)\ K^{*0}$	3.4k	> 2
$B^0 \to D^0\ (K^-\pi^+)\ K^{*0}$	0.5k	> 0.3
$B^0 \to D^0_{CP}\ (K^+K^-)\ K^{*0}$	0.6k	> 0.3

From $B_d^0 \to D(2-\mathrm{body})K^*$
expect precision on γ of ~8°

Conclusions

LHCb can access γ in many different ways, some more and some less sensitive to New Physics. Typical precision: 5–15 deg in one year.

Some γ-sensitive channels at LHCb:

Channel		Tree only	Peng	
$B_d^0 \to \pi^+\pi^-$	U − spin		$\surd$	NP in penguins?
$B_s^0 \to K^+K^-$				
$B_d^0 \to \rho^+\pi^-$	measures		$\surd$	
$B_d^d \to \rho\rho$	$\alpha \equiv \pi - \beta - \gamma$		$\surd$	
$B_d^0 \to D^{*\pm}\pi^{\mp}$		$\surd$		SM-γ
$B_s^0 \to D_s^{\pm}K^{\mp}$		$\surd$		
$B^{\pm} \to D^0(K\pi, KK, \pi K)K^{\pm}$		$\surd$		Sensitive to NP in D-mixing, otherwise SM-γ
$B_d^0 \to D^0(K\pi, KK, \pi K)K^{*0}$		$\surd$		
$B^{\pm} \to D^0(K_s\pi\pi)K^{\pm}$		$\surd$		
$B^0 \to D^0(K_s\pi\pi)K^*$	(study in progress)	$\surd$		
$B^{\pm} \to D^0(KK\pi\pi)K^{\pm}$	(study in progress)	$\surd$		
$B^{\pm} \to D^0(K\pi\pi\pi)K^{\pm}$	(study in progress)	$\surd$		

This will thoroughly over-constrain the SM description of CP violation and quark mixing, hopefully breaking it, certainly severely restricting the parameter space for possible New Physics models.

Backup

Observables and Parameters in $B_s^0 \to D_s K$.

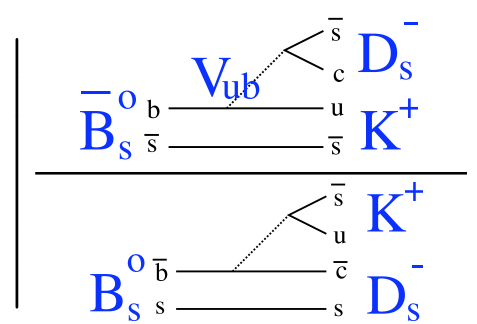
$$A_{D_s^+K^-}(t) = \frac{B_s^0 \to D_s^+K^- - \overline{B_s^0} \to D_s^+K^-}{B_s^0 \to D_s^+K^- + \overline{B_s^0} \to D_s^+K^-}$$

$$= \frac{C_s \cos(\Delta m_s t) + S_s \sin(\Delta m_s t)}{\cosh(\Delta\Gamma_s t/2) - A_{\Delta\Gamma} \sinh(\Delta\Gamma_s t/2)}$$

$$C_s = -\left(\frac{1 - r_s^2}{1 + r_s^2}\right)$$

$$S_s = \frac{2r_s}{1 + r_s^2} \sin(\phi_s + \gamma - \delta)$$

$$A_{\Delta\Gamma} = \frac{2r_s}{1 + r_s^2} \cos(\phi_s + \gamma + \delta)$$

$r_s =$ 

$\phi_s = B_s$ mixing phase ≈ 0 in SM

$\delta =$ strong phase

$\gamma =$ what we're after

For CP-conjugate $A_{D_s^- K^+}$, swap signs of weak phases ϕ and γ.

Conclusions

LHCb can access γ in many different ways, some more and some less sensitive to New Physics. Typical precision: 5–15 deg in one year.

Some γ-channels at LHCb:

Channel	Tree	Peng
$\left.\begin{matrix} B^0_d \to \pi^+\pi^- \\ B^0_s \to K^+K^- \end{matrix}\right\}$ U − spin		$\surd$
$B^0_d \to D^{*\pm}\pi^\mp$	$\surd$	
$B^0_s \to D^\pm_s K^\mp$	$\surd$	
$B^\pm \to D^0(K\pi, KK, \pi K)K^\pm$	$\surd$	
$B^0_d \to D^0(K\pi, KK, \pi K)K^{*0}$	$\surd$	
$B^\pm \to D^0(K_s\pi\pi)K^\pm$	$\surd$	
$B^0 \to D^0(K_s\pi\pi)K^*$ (study in progress)	$\surd$	
$B^\pm \to D^0(KK\pi\pi)K^\pm$ (study in progress)	$\surd$	
$B^\pm \to D^0(K\pi\pi\pi)K^\pm$ (study in progress)	$\surd$	

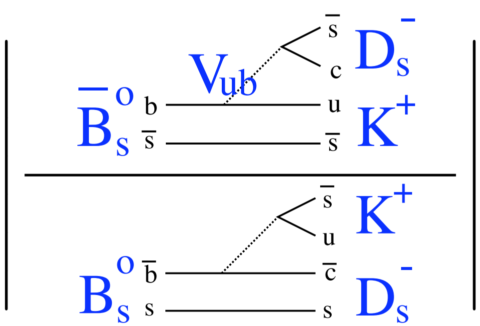
This, together with the α measurements that measure essentially the same CKM parameter (but with different sensitivity to New Physics), will thoroughly over-constrain the SM description of CP violation and quark mixing, hopefully breaking it, certainly putting strong limits on the parameter space for New Physics.

Observables and Parameters in $B_s^0 \to D_s K$.

$$A_{D_s^+K^-}(t) = \frac{B_s^0 \to D_s^+K^- - \overline{B_s^0} \to D_s^+K^-}{B_s^0 \to D_s^+K^- + \overline{B_s^0} \to D_s^+K^-}$$
$$= \frac{C_s \cos(\Delta m_s t) + S_s \sin(\Delta m_s t)}{\cosh(\Delta\Gamma_s t/2) - A_{\Delta\Gamma} \sinh(\Delta\Gamma_s t/2)}$$

$$C_s = -\left(\frac{1-r_s^2}{1+r_s^2}\right) \quad S_s = \frac{2r_s}{1+r_s^2}\sin(\phi_s + \gamma - \delta) \quad A_{\Delta\Gamma} = \frac{2r_s}{1+r_s^2}\cos(\phi_s + \gamma + \delta)$$

$r_s =$



$\phi_s = B_s$ mixing phase ≈ 0 in SM

$\delta =$ strong phase

$\gamma =$ what we're after

For CP-conjugate $A_{D_s^- K^+}$, swap signs of weak phases ϕ and γ.

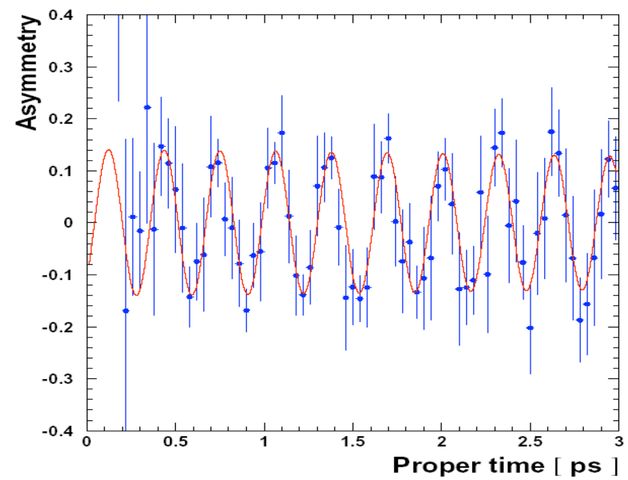
γ from $B_s^0 \to D_s K$ and $B_d \to D^{(*)}\pi$

Penguin free, hence insensitive to New Physics. Measures SM-γ, a benchmark for other measurements

As for α, use interference between two decay paths to a common final state.

$e^{-i\phi_s}$ $\overline{B}_{d,s}$ $r e^{-i(\gamma+\delta_{\text{strong}})}$

$B_{d,s}$ $D_{d,s}\,\pi/K$



Not a CP eigenstate. Measure two time-dependent asymmetries, one for each final state. CPV is in the difference between the 2.

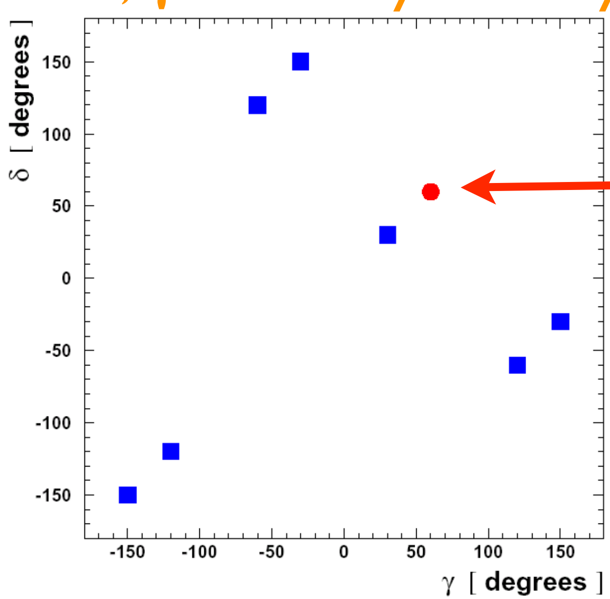
Details: Aleksan, Dunietz, Kayser, Z. Phys C 54 (1992) 653.

Ambiguities

Fit to asymmetry is sensitive to $\sin\left(\pm\left(\phi_s + \gamma\right) + \delta\right)$ leaving an 8-fold ambiguity in γ, δ

Untagged decay rates depend on $\sinh(\Delta\Gamma_s t/2)\cos\left(\pm\left(\phi_s + \gamma\right) + \delta\right)$
Helps resolve ambiguities (effectiveness will depend on precision, can only work for Bs where ΔΓ is large)

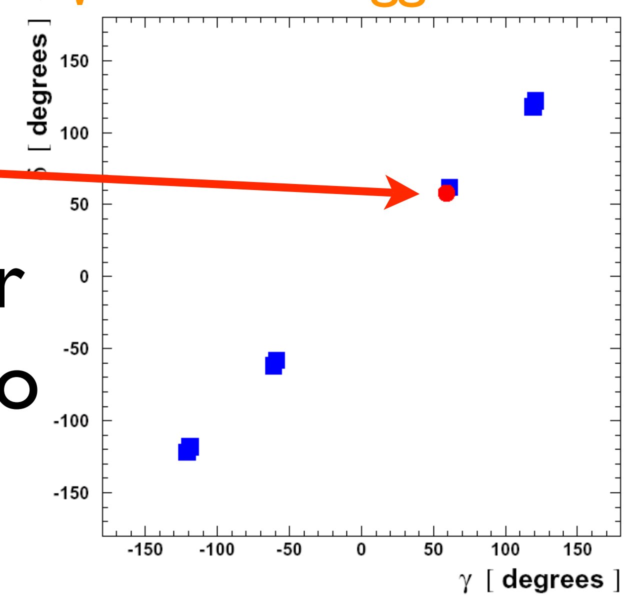
δ, γ from asymmetry



true solution

Illustration for δ=60, γ=60, no errors.

δ, γ from untagged rates

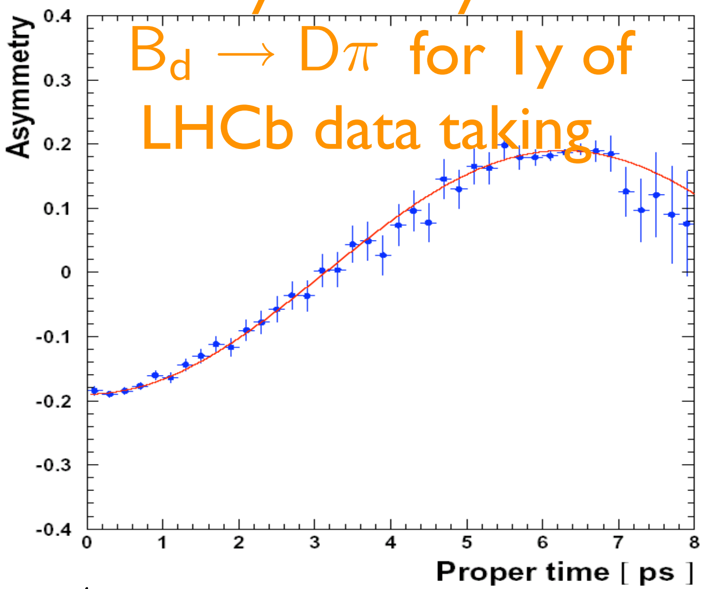


γ from $B_d \to D^{(*)}\pi$

- The U-spin (swap d↔s) partner of $B_s \to D_sK$
- Larger BR, more events, e.g. > 200k pa, S/B>3, for $B_d \to D^o(K\pi)\pi$.
- But: Interfering amplitudes differ hugely in magnitude:

$$r_d = \left|\frac{A(B_d \to D^+\pi^-)}{A(\overline{B_d} \to D^+\pi^-)}\right| \ll 1$$

  - Less sensitivity to γ per event.
  - In contrast to Bs case, r is too small to be constrained sufficiently from fit to C. Need to get it from elsewhere.



$$A_{B_d \to D\pi} = C_d \cos(\Delta m_d t) + S_d \sin(\Delta m_d t)$$

$$C_d = -\left(\frac{1-r^2}{1+r^2}\right)$$

$$S_d = \frac{2r}{1+r^2}\sin(\phi_d + \gamma - \delta)$$

Combining $B_{d,s} \to D_{d,s}\{\pi, K\}$ to resolve ambiguities:

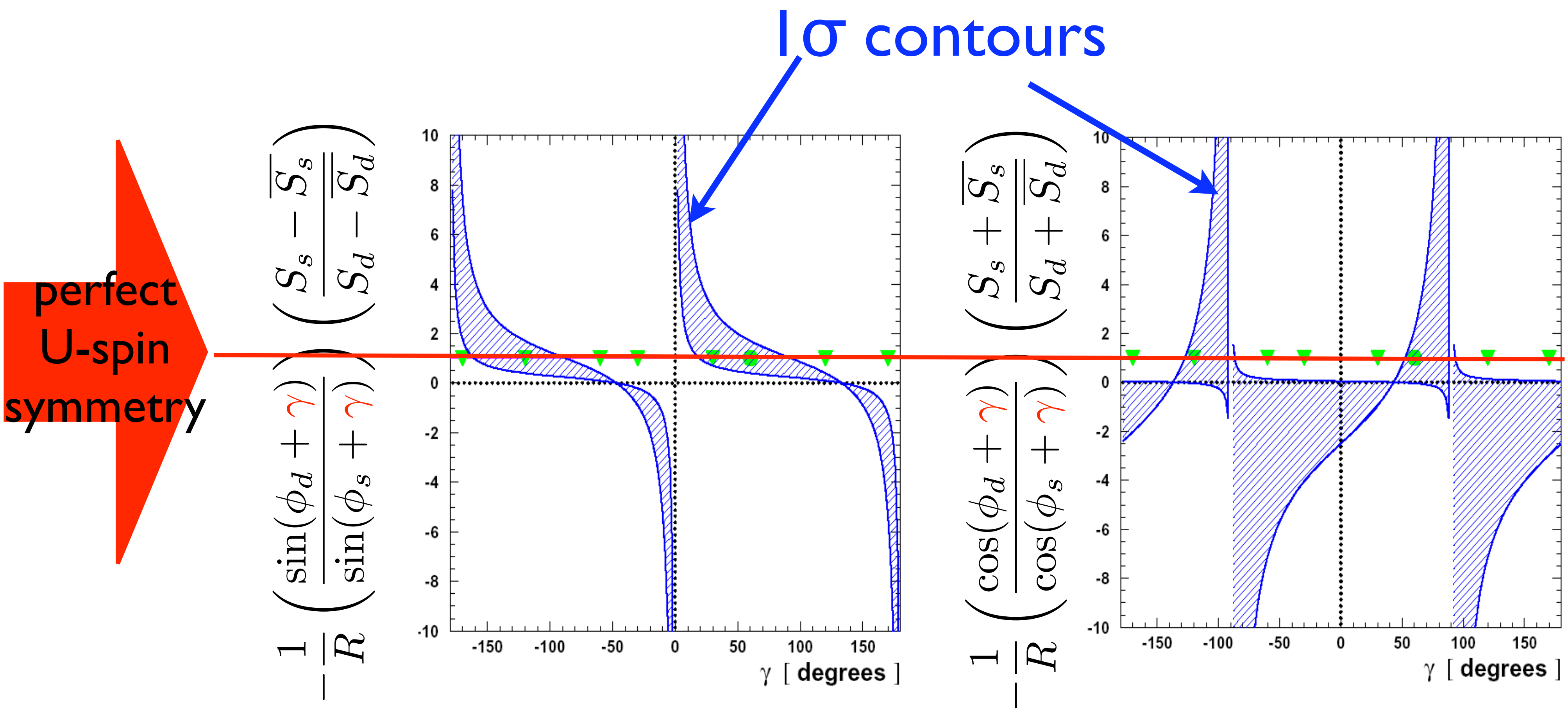
The following expressions are exactly 1 if we assume the strong interaction is symmetric under s↔d quark swap (U-spin symmetry):

$$1 = -\frac{1}{R}\left(\frac{\sin(\phi_d+\gamma)}{\sin(\phi_s+\gamma)}\right)\left(\frac{S_s-\overline{S_s}}{S_d-\overline{S_d}}\right) = -\frac{1}{R}\left(\frac{\cos(\phi_d+\gamma)}{\cos(\phi_s+\gamma)}\right)\left(\frac{S_s+\overline{S_s}}{S_d+\overline{S_d}}\right)$$

Amplitude of sine-term in $A(D^+\pi^-)$ ... and same for CP-conjugate Asymmetry.

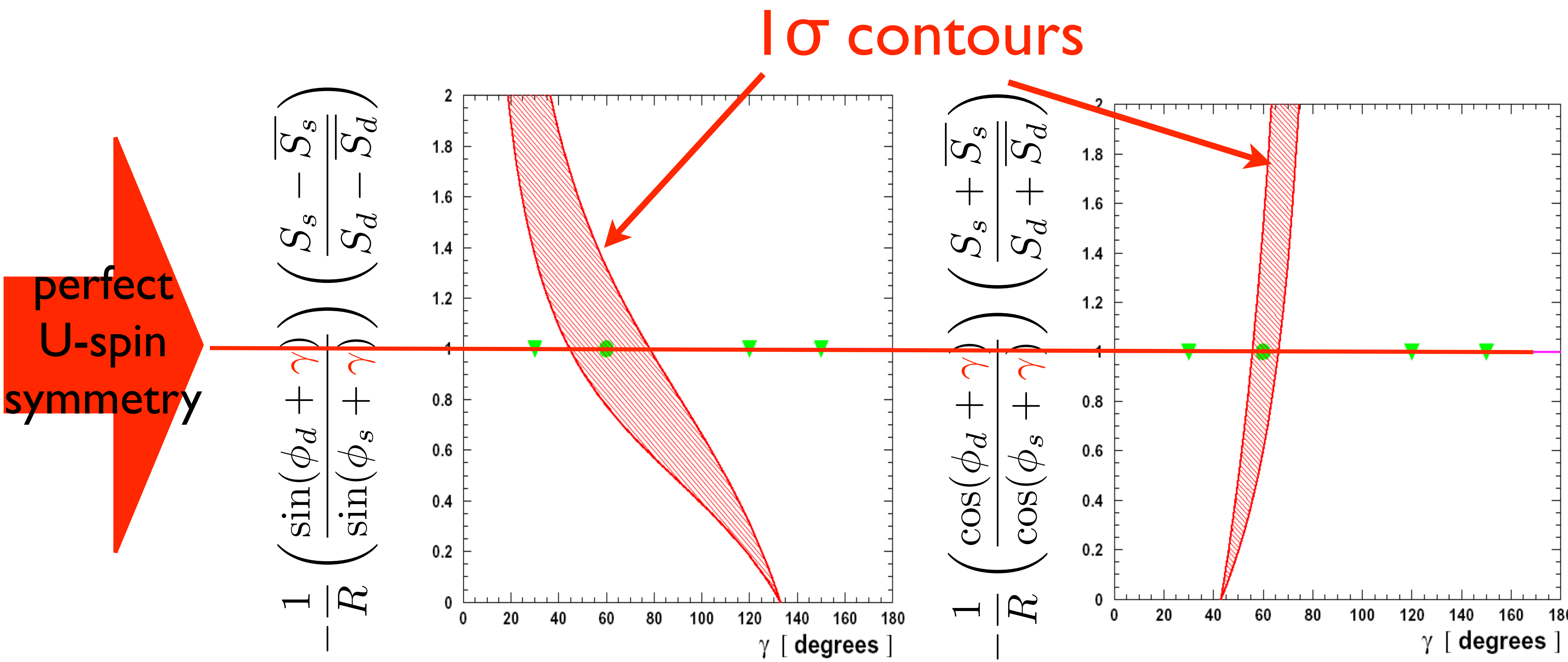
$R = \left(\frac{1-\lambda^2}{\lambda^2}\right)\left(\frac{1+r_d^2}{1+r_s^2}\right)$ can be extracted from data (to 10%-15% in 1y). No need to know r_d.

Combined $B_{d,s} \to D_{d,s}\{\pi, K\}$ to resolve ambiguities (1year)



After 1 year for γ=60, δ=60, ϕ_s=0 ϕ_d=47

Combined $B_{d,s} \to D_{d,s}\{\pi, K\}$ to resolve ambiguities (5 years)

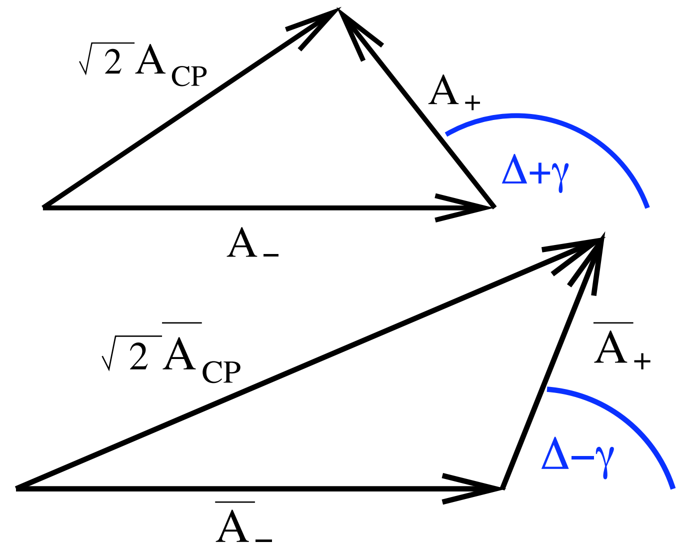


After 5 years, showing positive solutions only, for

γ=60, δ=60, ϕ_s=0 ϕ_d=47

γ from $B_d^0 \to DK^*$ and $B^\pm \to DK^\pm$.

- K* or K+ tag beauty flavour.



- Measure 3+3 decay rates:

$$\Gamma_+ = \Gamma\left(B^0 \to D^0(\pi^+K^-)K^{*0}\right)$$
$$\Gamma_- = \Gamma\left(B^0 \to \bar{D}^0(K^+\pi^-)K^{*0}\right)$$
$$\Gamma_{CP} = \Gamma\left(B^0 \to D^0_{CP}(K^+K^-)K^{*0}\right)$$

and CP-conj: $\bar{\Gamma}_+, \bar{\Gamma}_-, \bar{\Gamma}_{CP}$

- Use: $A(B_d \to D_{CP}K^*) = A(B_d \to \frac{1}{\sqrt{2}}(D^0 + \overline{D^0})K^*)$

- Extract γ from:

$$\Gamma_+ = \bar{\Gamma}_- \equiv g_1, \quad \Gamma_- = \bar{\Gamma}_+ \equiv g_2$$
$$\Gamma_{CP} = \frac{g_1 + g_2}{2} + \sqrt{g_1 g_2}\cos(\Delta + \gamma)$$
$$\bar{\Gamma}_{CP} = \frac{g_1 + g_2}{2} + \sqrt{g_1 g_2}\cos(\Delta - \gamma)$$

More about the method in: Gronau, Wyler, Phys. Lett. B 265 (1991) 172; Dunietz, Phys. Lett. B 270 (1991) 75.

BRs, Yields of 3 and 4 body Dalitz channels

$D^0 \to \ldots$	B.R.	
$K_S\pi^+\pi^-$	2.9%	BaBar/Belle
$K_SK^+K^-$	0.51%	new gamma channel
$K^+K^-\pi^+\pi^-$	0.25%	new gamma channel, this talk
$K^+\pi^-\pi^+\pi^-$	7.5%	new Dalitz channel

4 body channels promising for an experiment like LHCb:

o Only charged particles in final state, no Ks.

o Kaons can be identified by RICH.

LHCb yield p.a.: ~1.5k KKππ, 60k Kπππ (~1-2k doubly Cabbibo supr.)

(Yields are *guesstimates* based on yields in LHCb reopt TDR (CERN/LHCC 2003-040) for topologically similar channels, and B.R.s)

Details on 2body channels in LHCb-2005-066.

event yields

Table 1: Examples of the LHCb physics reach in 2 fb^{-1}. Branching ratios are products of the B and D (or J/ψ)and K^{*o} (or ϕ) rates into modes used in the simulation. Reactions between two lines are used together.

Process	$\mathcal{B} \times 10^{-6}$	# of Events	B/S	Parameter	Error or (Value)
$B^o \rightarrow \pi^+\pi^-$	4.8	26,000	<0.7	γ	6°
$B_s \rightarrow K^+K^-$	18.5	37,000	0.3		
$B_s \rightarrow D_s^{\pm}K^{\mp}$	10	5,400	<1	γ	14°
$B_s \rightarrow D_s^+\pi^-$	120	80,000	0.3	Δm (ps^{-1})	(68)
$B^o \rightarrow \overline{D}^0(K^+\pi^-)K^{*o}$	1.2	3,400	<0.5	γ	8°
$B^o \rightarrow D^0(K^-\pi^+)K^{*o}$	0.2	500	<3.4		
$B^o \rightarrow D^0(K^+K^-)K^{*o}$	0.19	590	<2.9		
$B_s \rightarrow J/\psi\phi$	31	120,000	<0.3	ϕ_s	2°
$B^o \rightarrow K^*\mu^+\mu^-$	0.8	4,400	< 2		

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

MC input values: $\gamma = 60^o$ $\delta = 130^o, r_B = 0.15$

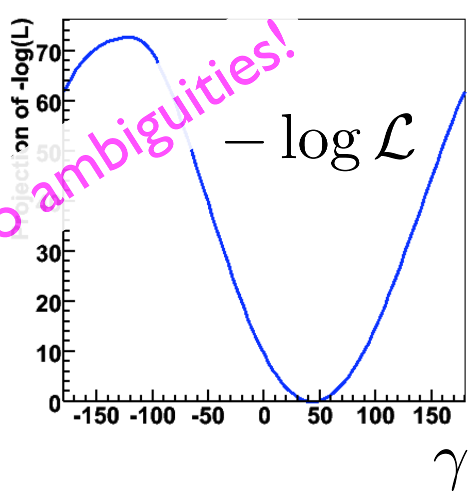
Fitting 100 toy experiment with 1k events each:

$$\gamma = 60^o \pm 10^o$$
$$\delta = 128^o \pm 10^o$$
$$r_B = 15\% \pm 2\%$$

Fitting 10k events:

Result from a single toy experiment.

$$\gamma = 64.6^o \pm 3.1^o$$
$$\delta = 132.5^o \pm 3.1^o$$
$$r_B = 15.0\% \pm 0.7\%$$



With guessed LHCb yields (~1.5k/year), expect $\sigma(\gamma) \sim 10^o$ after 1 year.
High hopes for for ADS-type 4-body channel $B^\pm \to (K\pi\pi\pi)_{D^0}K^\pm$

All preliminary, all without background or detector effects

γ from $B_d^0 \to DK^*$

- Same idea as for charged B decays. Here, K* tags beauty flavour.
- To extract all unknowns, need to measure 3 decay rates:

$$\begin{aligned}\Gamma_+ &= \Gamma\left(B^0 \to D^0(\pi^+K^-)K^{*0}\right)\\ \Gamma_- &= \Gamma\left(B^0 \to \bar{D}^0(K^+\pi^-)K^{*0}\right)\\ \Gamma_{CP} &= \Gamma\left(B^0 \to D^0_{CP}(K^+K^-)K^{*0}\right)\end{aligned}$$

- ...and their CP-conjugates $\bar{\Gamma}_+, \bar{\Gamma}_-, \bar{\Gamma}_{CP}$
- Extract γ from

$$\Gamma_+ = \bar{\Gamma}_- \equiv g_1, \quad \Gamma_- = \bar{\Gamma}_+ \equiv g_2$$

$$\begin{aligned}\Gamma_{CP} &= \frac{g_1+g_2}{2} + \sqrt{g_1 g_2}\cos(\Delta+\gamma)\\ \bar{\Gamma}_{CP} &= \frac{g_1+g_2}{2} + \sqrt{g_1 g_2}\cos(\Delta-\gamma)\end{aligned}$$

LHCb performance 1year, detailed study:

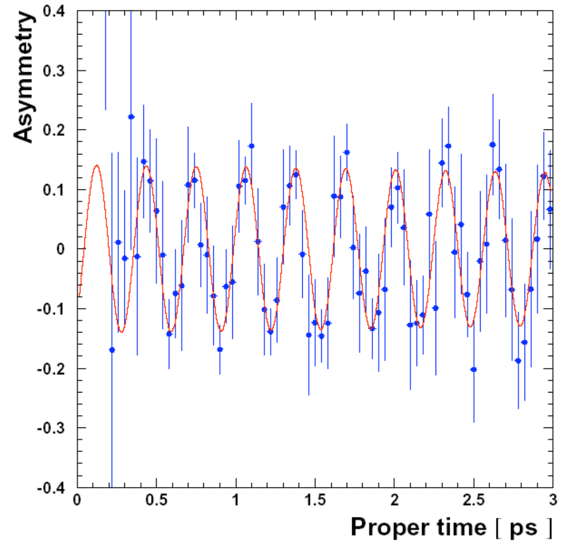
- 3.6k evts for $\Gamma_+, \bar{\Gamma}_+$
- 0.52k evts for $\Gamma_-, \bar{\Gamma}_-$
- 0.31k evts for $\Gamma_{CP}, \bar{\Gamma}_{CP}$
- $\sigma(\gamma) = 13^o$ (For $\gamma = 65^o, \Delta = 0^o$)

More about the method in: Gronau, Wyler, Phys. Lett. B 265 (1991) 172; Dunietz, Phys. Lett. B 270 (1991) 75.

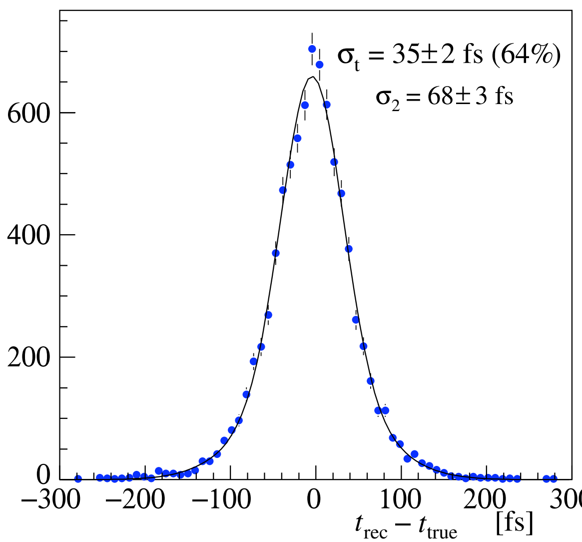
γ from $B_s^0 \to D_s K$

- Extract γ from time-dependent decay rate asymmetries.
- Requires excellent time resolution - VELO provides it.
- ... and tagging. Expect $\varepsilon D^2 \approx 6\%$ i.e. 100 Bs events at LHCb are worth ~6 perfectly tagged events.

Fast Bs oscillations....



... require excellent time resolution



σ(τ) ~50fs, 7% of oscillation period for Δm = 17.3/ps

From $B_s \to D_s K$ we expect to achieve:

σ(γ) ≈13° within 1 year for Δm=17.3/ps