High precision probes for new physics through CP-violating measurements at LHCb

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Introduction

LHCb is a 2^{nd} generation precision experiment following Tevatron and the B-factories

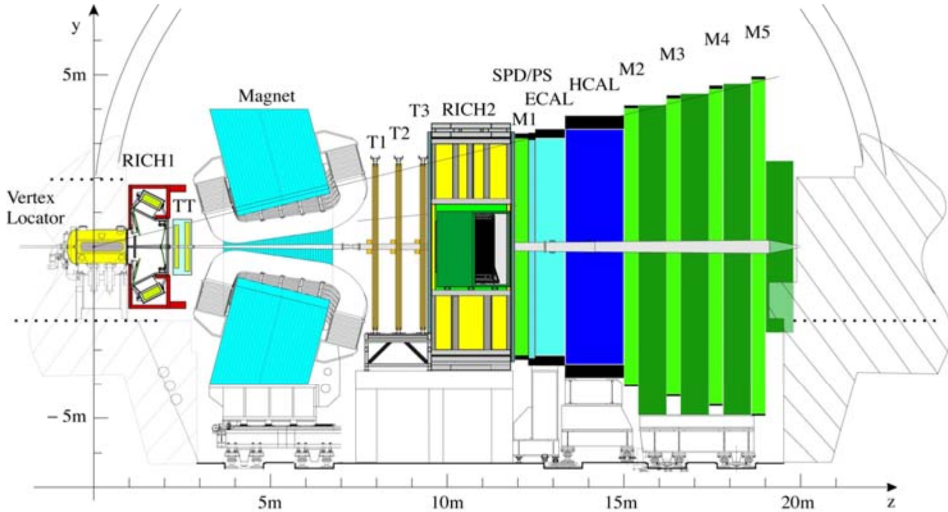
- **b -> c transitions: extensively studied and in good agreement with SM**
- **b -> s transitions: limited knowledge, room for NP effects**
- **Precision measurements available for CKM parameters, allowing strong constraints on SM, but γ still poorly measured.**
- **Collection of large sample of b (c) hadrons at LHC allows extensive study in a wide set of channels.**

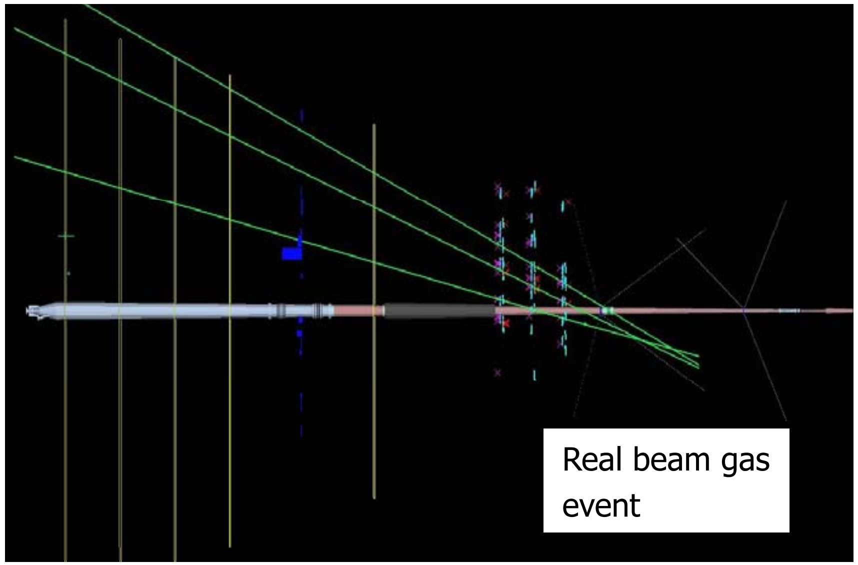
- B_s mixing
- γ with trees
- γ with loops
- Mixing and CPV in charm

- Rare decays - see Hugo Ruiz presentation
- Early LHCb results - see Abraham Gallas presentation

LHCb in a nutshell

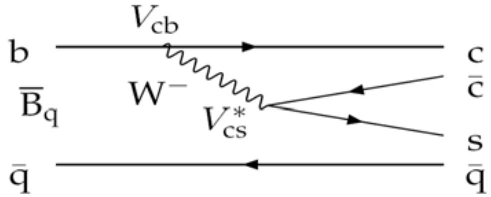
- High statistics:
  - $\mathcal{L}$ ~ 2×10^{32} cm^{-2} s-1
  - σ_{bb} ~ 500 μb at 14 TeV
  - ~ 10^{12} bb year (2 fb^{-1})
  - $B^{\pm}$, B^0, B_s, B_c, Λ_b …
- Tracking:
  - Mass resolution: $\sigma_{B(D)}$ ~ 15(7) MeV
  - B vertex resolution: σ_z ~ 200 μm
  - Proper time resolution: σ_τ ~ 40 fs
- Particle identification:
  - π/K separation over 2 GeV < p < 100 GeV
- Trigger:
  - First level (L0) High p_T hadron trigger



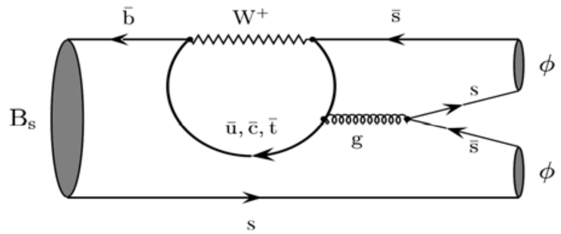


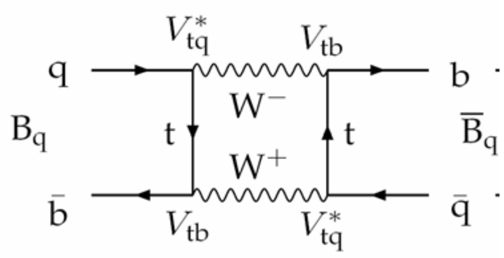
B_s phase Φ_s

B_s -> J/Ψ φ dominated by tree
NP can enter through mixing

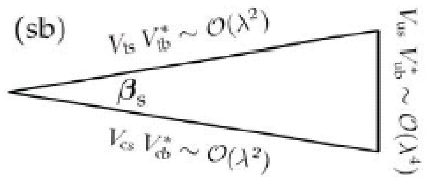


B_s -> φφ dominated by a penguin
NP can enter through mixing
and/or penguin





- The observable is $\Phi_s = \Phi_{SM} + \Phi_{NP}$
- In SM
  - $\Phi_S(B_s \to J/\Psi\ \phi) = -2\beta_s = -0.0368 \pm 0.0017$
  - $\Phi_s(B_s \to \phi\phi) = 0$



$$\beta_s = \arg\left(-\frac{V_{ts}V^*_{tb}}{V_{cs}V^*_{cb}}\right)$$

Tevatron results:		
D0	$2\beta_s = -0.57^{+0.24}_{-0.30}$	with 2.8 fb^{-1}
CDF	$-2\beta_s$ = [0.32,2.82] @ 68%CL	with 1.35 fb^{-1}

In presence of NP the mixing phase
Is modified and can probe NP in the
mixing (Φ_M^{NP}) and/or the penguin (Φ_D^{NP}).

$$\Phi(B_s^0 \to J/\psi\phi) = -2\beta_s + \Phi_M^{NP}$$

$$\Phi(B_s^0 \to \phi\phi) = \Phi_M^{NP} - 2\Phi_D^{NP}$$

B_s phase Φ_s (2)

$\surd_s$ can be extracted from CP time-dependent asymmetry in decay rates :

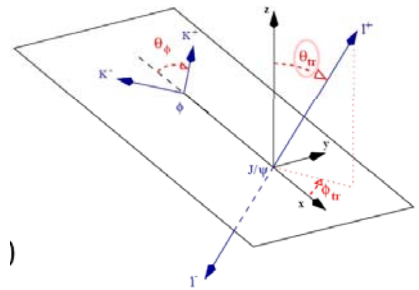
$$A_{CP} = \frac{n_f \sin(\Phi_s)\sin(\Delta m_s t)}{\cos(\Delta\Gamma_s t/2) - n_f \cos(\Phi_s)\sinh(\Delta\Gamma_s t/2)}$$

with $n_f = \pm 1$ CP eigenstate

Would like to use pure CP eigenstates such as

$B_s \rightarrow J/\Psi\, \eta$, $B_s \rightarrow J/\Psi\, \eta'$, $B_s \rightarrow \eta_c\, \Phi$, $B_d \rightarrow D_s^+\, D_s^-$

But low yield and high background

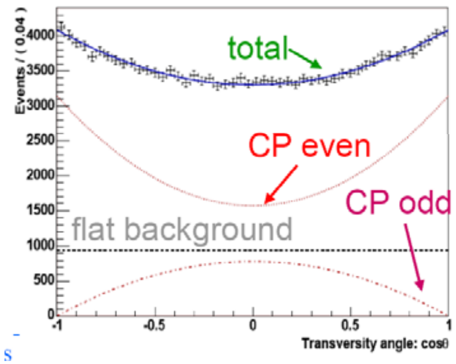


B_s -> $J/\Psi\ \phi$ has a nice signature and large yield

small background

but is a mixture of CP = +1 and CP = -1 states

requires an angular analysis to disentangle the two states



Combined D0 and CDF 2.2 σ from SM (ICHEP08)

B_s phase Φ_s (3)

Decay	Yield (2 fb^{-1})	$\sigma(\phi_s)$
$J/\psi\ \eta_{\gamma\gamma}$	8.5 k	0.109
$J/\psi \eta_{\pi\pi\pi}$	3 k	0.142
$J/\psi\ \eta'_{\pi\pi\eta}$	2.2 k	0.154
$J/\psi\ \eta'_{\rho\gamma}$	4.2 k	0.08
$\eta_c\ \phi$	3 k	0.108
$D_s^+\ D_s^-$	4k	0.133
All CP eig	-	0.046
$J/\psi\ \phi$	115k	0.03

B_s -> $\Phi\ \Phi$

Similar analysis yields 3.4k events (2 fb^{-1}) with an expected sensitivity on Φ_s

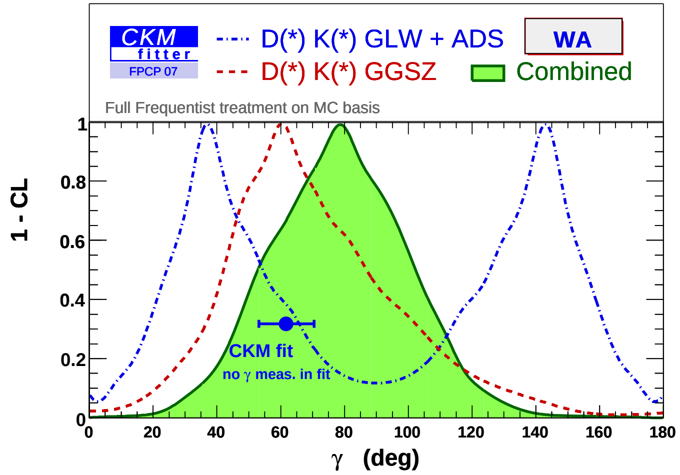
$\sigma(\Phi_s) \sim 0.125$

Angle γ

- γ plays a unique role in flavour physics
  - Can be measured through tree diagrams and those involving loops
- Trees
  - Benchmark for SM
  - Time integrated (GLW, ADS, Dalitz/GGSZ) and/or time dependent strategies
- Loops
  - Sensitive to NP
- Measured at B factories
- A full test of SM and unitarity requires:

  σ_γ ~ a few degrees

  measurement in $B^\pm$, B^0 and B_s

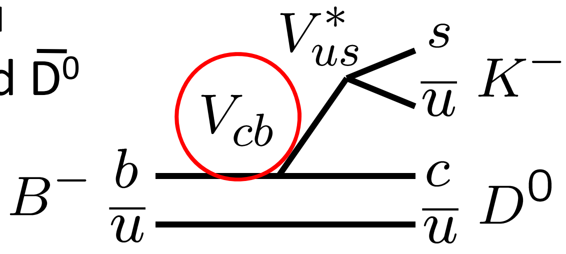


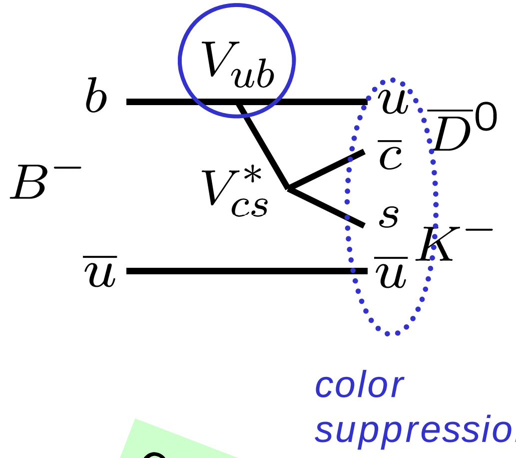
$\gamma = 77° + 30° - 32°$

γ from trees: B -> DK

- Interfere decays b→c with b→u to final states common to D^0 and $\bar{D}^0$

$$\frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)} = r_B e^{i\delta_B} e^{-i\gamma}$$





GLW method:

f_D is a CP eigenstate common to D^0 and $\bar{D}^0$: $f_D = K^+K^-, \pi^+\pi^-, \ldots$

Measure: $B \to D^0 K$, $B \to D^0 K^*$, $B \to D_1 K$

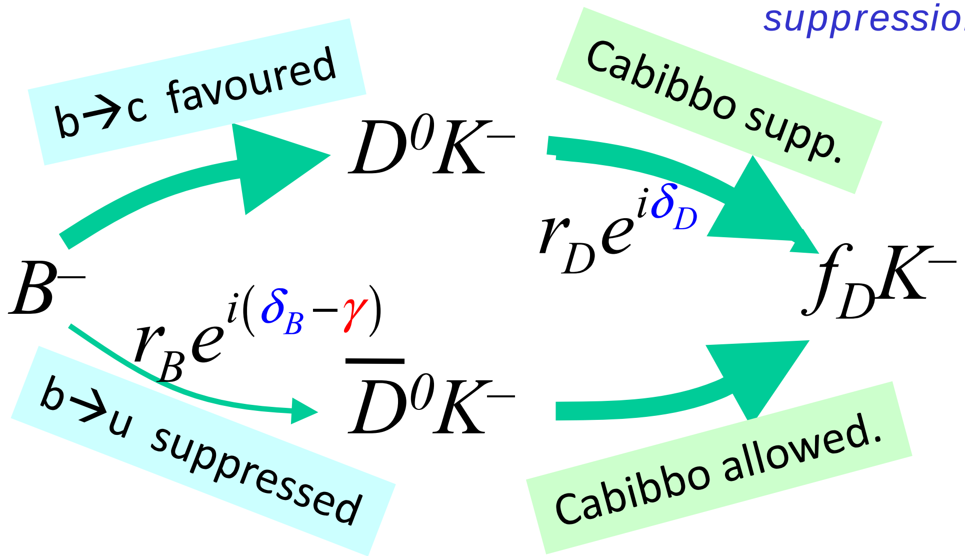
- Large event rate; small interference
- Measurement r_B difficult

ADS method:

Use common flavour state $f_D = (K^+ \pi^-)$

Note: decay $D^0 \to K^+\pi^-$ is double Cabibbo suppressed

- Lower event rate; large interference



Decay time **in**dependent analysis

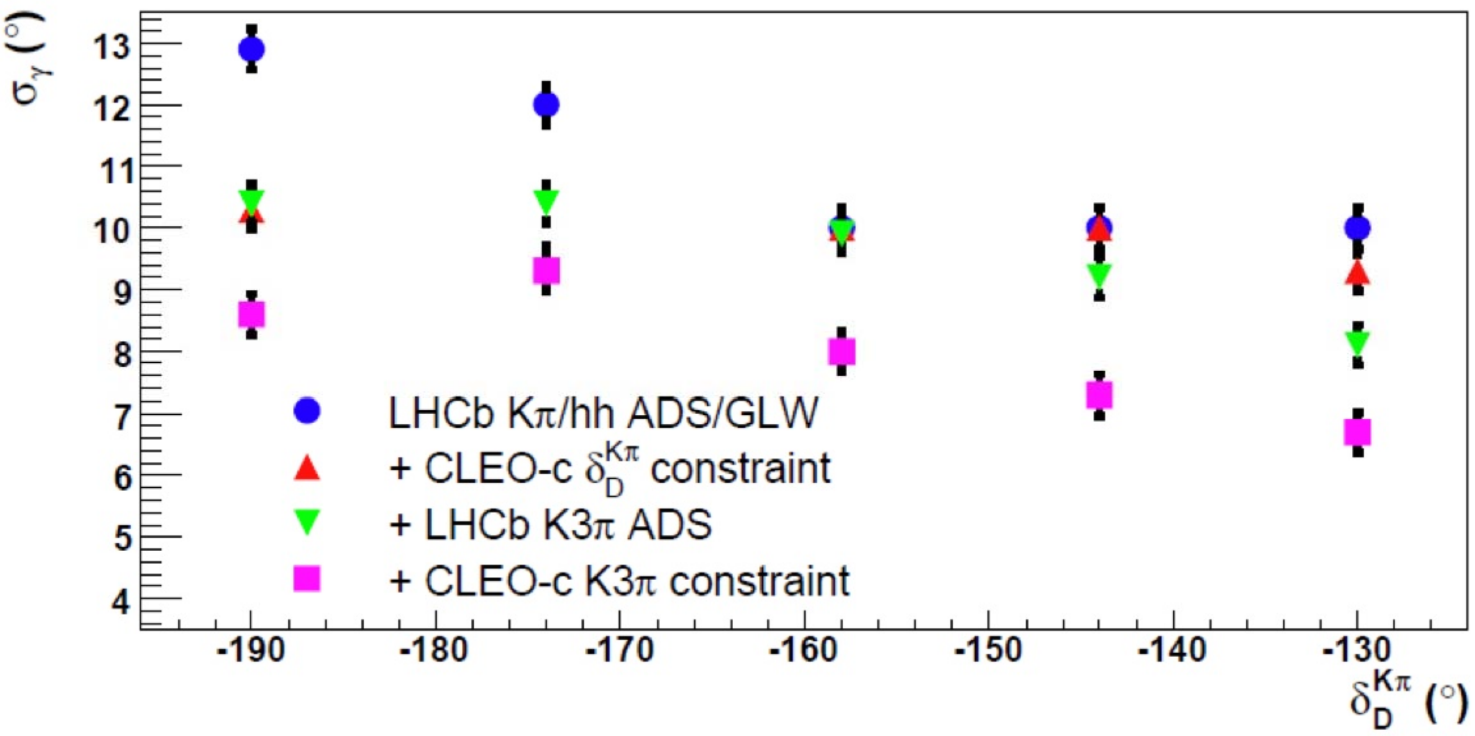
γ from trees: $B^{\pm} \to D(hh) K^{\pm}$

- ADS and GLW
- 6 rates, 5 unknown parameters
- Assuming:
  - $\gamma = 60°$
  - $r_B = 0.10$
  - $\delta_B = 130°$ (PDG)
  - $r_D = 0.0616$ (PDG)
  - δ_D centered at 158° (ADS requires -180 shift w.r.t. published δ_D from CLEO-c)

Channel	Yield (2 fb^{-1})	B/S
$B^+ \to D(K\pi) K^+$ Favoured	28 k	0.6
$B^+ \to D(K\pi) K^+$ Suppressed	650	1.2
$B^+ \to D(KK) K^+$ Favoured	3k	1.2
$B^+ \to D(\pi\pi) K^+$ Suppressed	1k	3.6

σ_γ = 10.8° – 12.7° depending on δ_D

γ from trees: Combining all ADS - GLW



σ_γ = 7° – 9.5°

γ from trees: $B^{\pm} \to D(K_s\pi^+\pi^-) K^{\pm}$

- $K_s\ \pi^+\ \pi^-$ Dalitz plot contain a CP-violating contribution from the decay path sensitive to γ
- Two different method of analysis
  - Unbinned fit based on amplitude model
  - Model independent binned fit using $\psi(3770)$ results on D decays.
- Background suppressed with RICH and momentum cut
- Yield ~ 5k per year

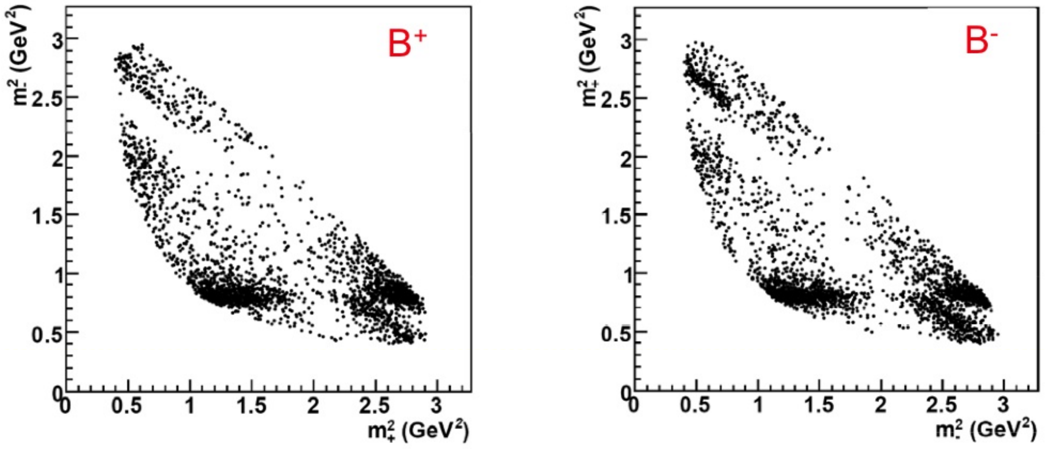
Statistical uncertainty

σ_γ = 9.8° Amplitude model

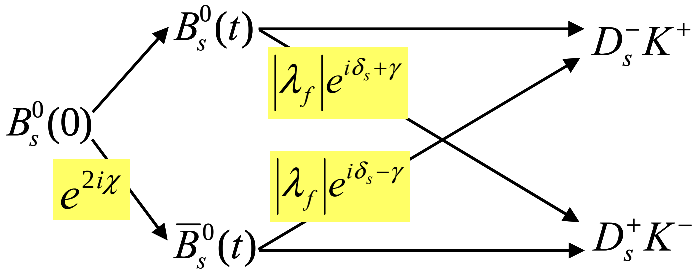
σ_γ = 12.8° Binned fit

Amplitude model also affected by uncertainty due to the model. Latest BaBar analysis estimate 7°

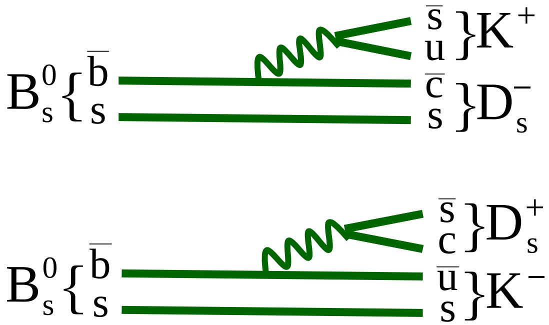
Binned fit affected by finite statistics in Ψ sample, estimated 2°.

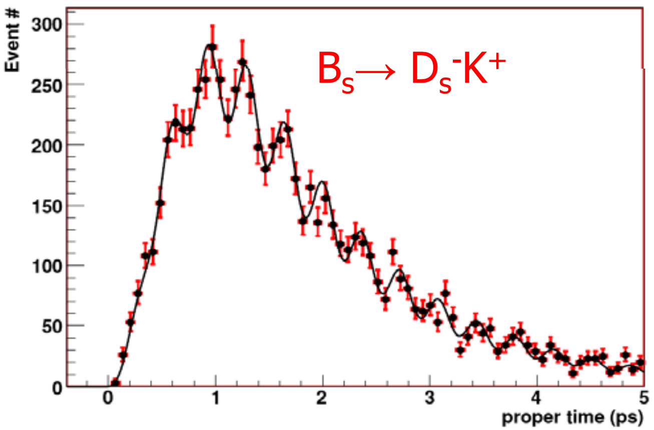


γ from trees: B_s -> D_s K



- Interference between tree decays via mixing
- Insensitive to NP
- Measures $\gamma + \Phi_s$ (Φ_s measured from B_s->J/Ψ φ)
- Include B_s ->D_s π to determine Δm_s and tagging dilution
- Simultaneous fit to both decays
- Assuming $\gamma = 60°$ and $\Delta m_s = 17.5\ ps^{-1}$



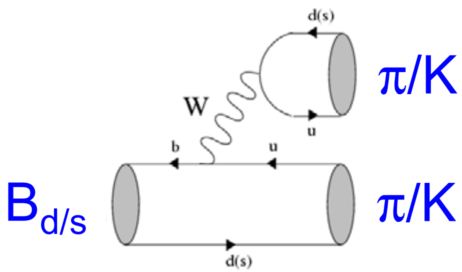


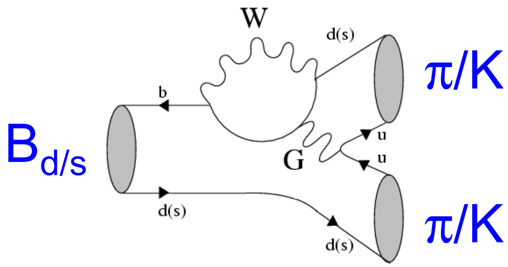
Channel	Yield (2 fb^{-1})	B/S
$B^s \to D_s K$	6.2 k	0.7
$B^s \to D_s \pi$	140 k	0.2

σ_γ = 10.3°

γ from loops: B -> hh

Interference between tree and penguin diagrams





Measure time-dependent CP asymmetries for $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$

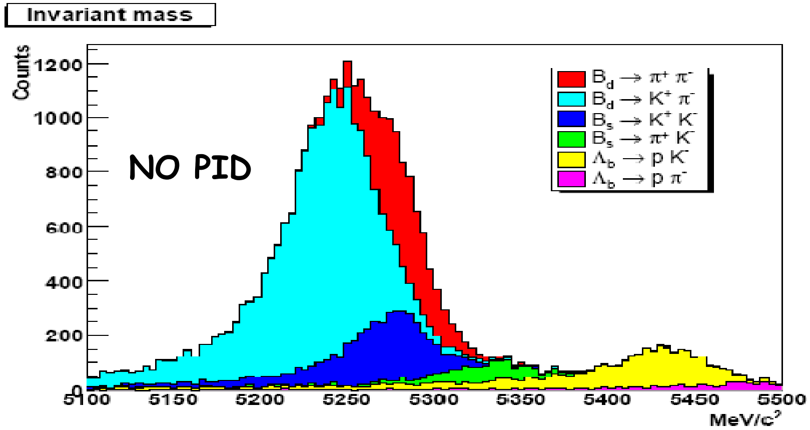
$$A_f^{CP}(t) = \frac{A_f^{dir}\cos\Delta m t + A_f^{mix}\sin\Delta m t}{\cosh\left(\frac{\Delta\Gamma t}{2}\right) - A_f^{\Delta}\sinh\left(\frac{\Delta\Gamma t}{2}\right)}$$

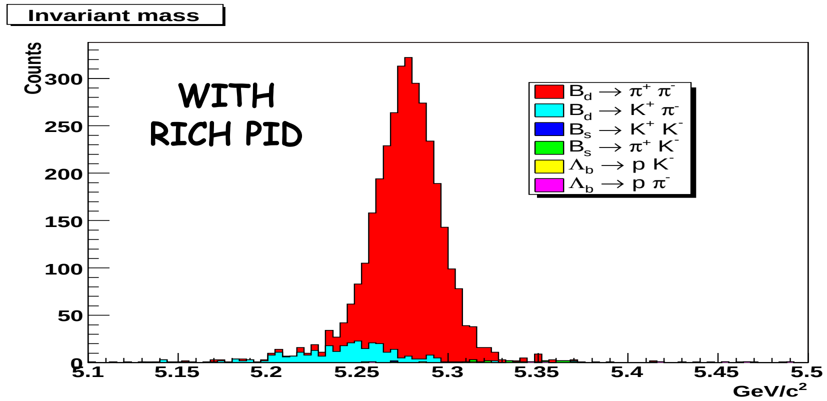
$$A_{mix}^{\pi\pi} = f_1(d,\theta,\sin\phi_d) \quad ; \quad A_{dir}^{\pi\pi} = f_2(d,\theta,\sin\gamma)$$

$$A_{dir}^{KK} = f_3(d',\theta',\sin\gamma) \quad ; \quad A_{mix}^{KK} = f_4(d',\theta',\sin\phi_s)$$

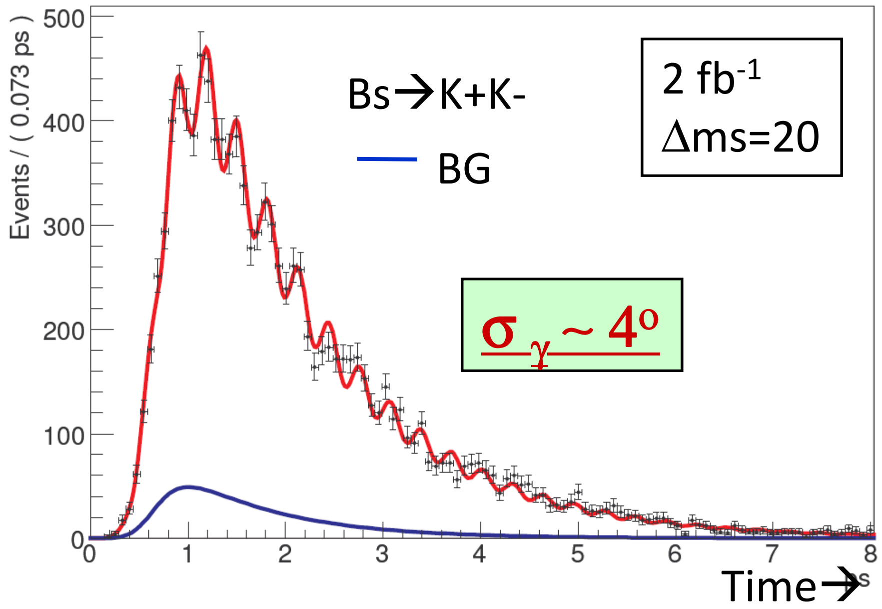
- Assume U-spin flavour symmetry (d $\Leftrightarrow$ s) $d = d'$ and $\theta = \theta'$
- Take ϕ_d from $B_d \to J/\psi\, K_s$ and ϕ_s from $B_S \to J/\psi\, \phi$ solve for γ
- 4 observables , 3 unknowns

γ from loops: B -> hh (2)





Channel	Yield (2 fb^{-1})	B/S
$B_s \to KK$	36 k	< 0.06
$B^0 \to \pi\pi$	36 k	0.5



Different ways to measure γ

B mode	D mode	Method	Parameter	σ_γ 2fb^{-1}
$B_s \to D_s K$	$KK\pi$	tagged, $A^{CP}(t)$	γ-ϕ_s	9°-12°
$B^+ \to D K^+$	$K\pi$,$KK/\pi\pi$	counting, ADS+GLW	γ	11°-13°
$B^+ \to D K^+$	$K_s\pi\pi$	Dalitz, GGSZ	γ	10°-13°
$B^+ \to D K^+$	$KK\pi\pi$	4 body Dalitz	γ	18°
$B^0 \to D K^{*0}$	$K\pi$,KK,$\pi\pi$	counting, ADS+GLW	γ	5°-12°
$B \to \pi\pi$,KK	-	tagged, $A^{CP}(t)$	γ / ϕ_d / ϕ_s	4°

σ_γ 2fb^{-1}

δ_{B° (°)	0	45	90	135	180
Combined B^+/B^0 (ADS+GLW)	**4.6°**	**7.6°**	**6.3°**	**7.1°**	**4.6°**
+ model independent Dalitz	**4.1°**	**5.1°**	**4.8°**	**5.1°**	**3.9°**

Combining with time dependent measurements a global sensitivity with tree decays only in 2 fb^{-1} **$\sigma_\gamma \sim 4°$**

Charm physics – Trigger and yields

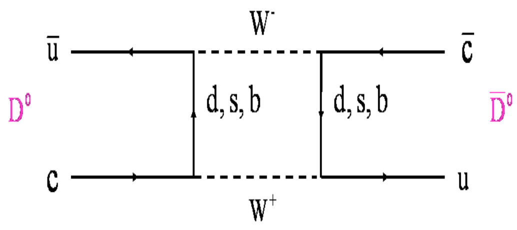
- Dedicated $D^* \to D^0$ (hh) π trigger stream
- Loose cuts on hadrons pt, IP, D0 mass, D* - D0 mass difference
    - RICH information not used in the trigger
    - Present selection favours D* coming from B decays
- Estimated yields for secondary D^0 for 2 fb^{-1}
    - $D^0 \to K^- \pi^+$ (right sign) 12.4 M
    - $D^0 \to K^+ \pi^-$ (wrong sign) 46.5 K
    - $D^0 \to K^+ K^-$ 1.6 M
    - $D^0 \to \pi^+ \pi^-$ 0.5 M

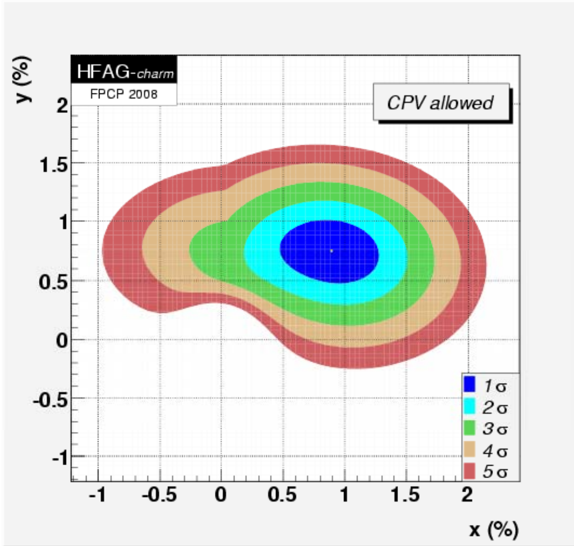
Similar amounts expected for prompt production.

Charm physics - D^0 mixing

$$x = \frac{M_1 - M_2}{\Gamma} \qquad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$

Sensitive to NP in the box diagram loop





Time-dependent D0 mixing with wrong-sign $D^0 \to K^+\pi^-$ decays

$\sigma_{stat}(x'^2) \sim 0.14 \times 10^{-3}$, $\sigma_{stat}(y') \sim 2 \times 10^{-3}$ with 2 fb^{-1}

D unambiguously tagged at production by the sign of the slow π in the D* decay

Recently observed at BaBar Belle and CDF

$x = 0.89^{+0.26}_{-0.27}$ %

$y = 0.75^{+0.17}_{-0.18}$ %

Charm physics – Direct CP violation

- Direct CP violation can be measured in $D^0 \rightarrow KK$ lifetime asymmetry

$$A_{CP} = \frac{\Gamma(D^0 \to KK(\pi\pi)) - \Gamma(\overline{D}^0 \to KK(\pi\pi))}{\Gamma(D^0 \to KK(\pi\pi)) + \Gamma(\overline{D}^0 \to KK(\pi\pi))}$$

- ACP$<10^{-3}$ in SM, up to 1% with New Physics
- current HFAG (average Belle, BaBar, CDF): ACP = -0.16 ± 0.23

	Data set	$N(K^-K^+)$	$A_{CP}(K^-K^+)(\%)$
Belle	$540\,\mathrm{fb}^{-1}$	120×10^3	$-0.43 \pm 0.30 \pm 0.11$
BaBar	$386\,\mathrm{fb}^{-1}$	130×10^3	$0.00 \pm 0.34 \pm 0.13$
CDF	$123\,\mathrm{pb}^{-1}$	16×10^3	$2.0 \pm 1.2 \pm 0.6$
HFAG Avg			-0.16 ± 0.23

Expect σ_{stat}(ACP) ~ 0.001 with 2 fb^{-1}

Conclusions

LHCb is a heavy flavour precision experiment searching for New Physics in CP Violation and rare decays

CP Violation: 2 fb^{-1} (1 year)

- γ from trees: 4°
- γ from loops: ≈ 10°
- B_s mixing phase: 0.023