B_d and B_s Mixing at LHCb

On behalf of the LHCb Collaboration

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Physics at the LHC, Vienna
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- ☆ CP Violation
- ☆ B-$\overline{B}$ Asymmetry
- ☆ LHCb simulation
- ☆ Oscillations and Phases
- ☆ Summary

The CKM Matrix: Unitarity Triangles

- ☆ Standard Model description of CP violation based on the CKM matrix
  - CP violation appears only in the charged current weak interaction of quarks

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

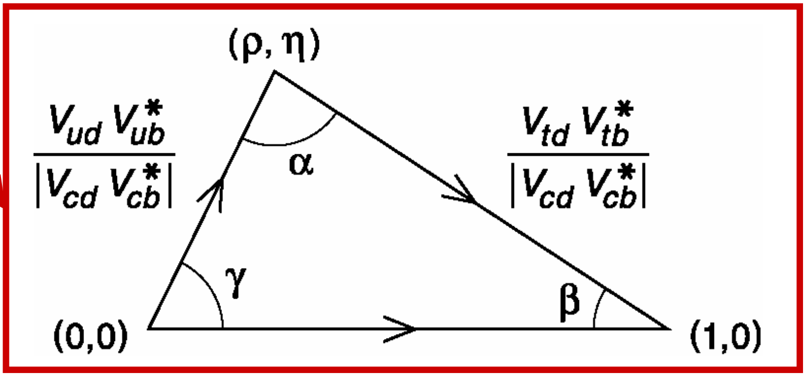
"Complex" phase

$$\boxed{V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0}$$

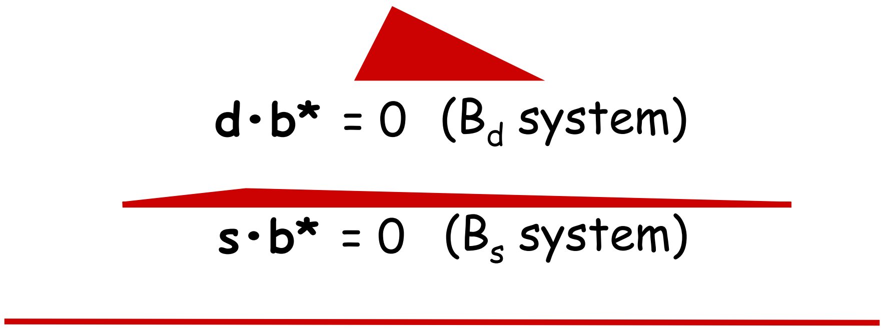
$\lambda = V_{us} = \sin(\theta_{Cabibbo}) = 0.22$

$A = V_{cb}/\lambda^2 = 0.83$

$\rho - i\eta = V_{ub} / A\lambda^3$



This unitarity relation is drawn in the ρ-η complex plane as a triangle



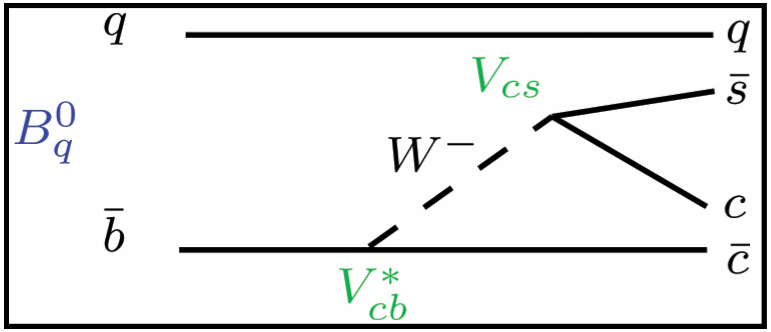
$d \cdot b^* = 0$ (B_d system)

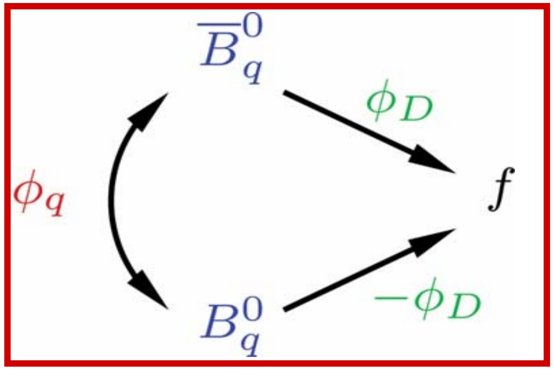
$s \cdot b^* = 0$ (B_s system)

$d \cdot s^* = 0$ (K system)

$\bar{b}\to\bar{c}c\bar{s}$ Transitions: Decays to CP eigenstates

- ☆ Decays dominated by only one CKM phase:
  $\phi_D \equiv -\arg[V^*_{cb}V_{cs}]$ → small

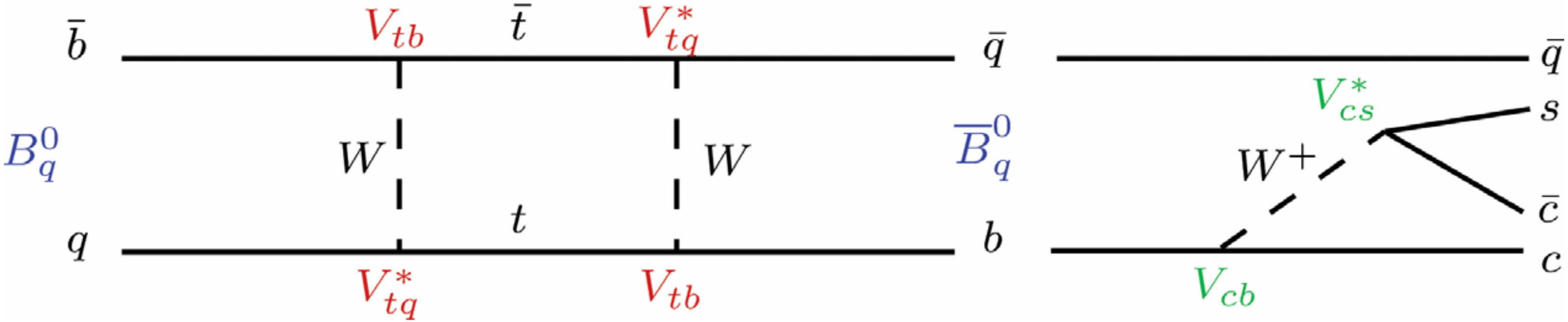




- ☆ Due to the mixing, the flavour states B^0_q-$\overline{B}^0_q$ can either remain unchanged and decay to f, or oscillate into each other, …

- ☆ "Mixing-induced" $\not{C}\not{P}$ arises from a phase difference (ϕ_{CKM}) between the weak mixing phase $\phi_q \equiv 2\arg[V^*_{tq}V_{tb}]$ and the tree phase $\phi_D \equiv -\arg[V^*_{cb}V_{cs}]$ (q=d,s)

$$\boxed{\phi_{CKM} = \phi_q - 2\,\phi_D \approx \phi_q \neq 0,\ \pi}$$



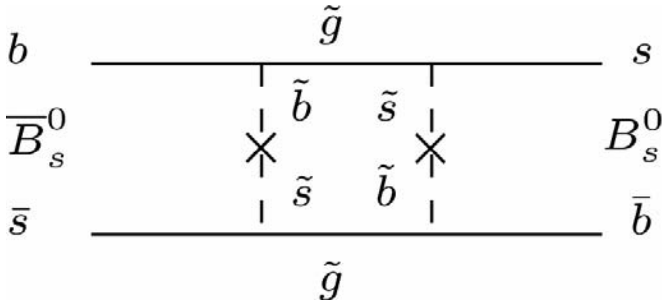
New Physics

- ☆ B_d-system: $\phi_d \equiv 2\arg[V^*_{td}V_{tb}]$ well measured ($\sin(\phi_d) = 0.7$)
- ☆ B_s-system: $\phi_s \equiv 2\arg[V^*_{ts}V_{tb}]$ not measured yet ($\sin(\phi_s^{SM}) \sim -0.04$)
  - Cannot be measured at B-factories working at $\Upsilon(4s)$

  → "Highway" towards New Physics

- ☆ SUSY contribution (mainly induced by gluino exchange) to the B^0_s-$\overline{B^0}_s$ transitions could drastically change the SM prediction

  (P. Ball et al., hep-ph/0311361)



  - $\sin(\phi_s) \sim -1$ (SM: $\sin(\phi_s) \sim -0.04$)
  - $\Delta m_s = (10 - 10^4)\ ps^{-1}$ (SM: $\Delta m_s = 20\ ps^{-1}$)

- ☆ Up-type singlets models (quark mixing matrix $(3+n_u)\mathrm{x}3$)

  (J.A. Aguilar-Saavedra et al., hep-ph/0406151)

  - $\sin(\phi_s) \sim \lambda \sim 0.22$

CP measurements in LHCb

- ☆ The study of CP violation implies measurement of time-dependent decay asymmetry between the B^0 and the $\overline{B^0}$ into CP eigenstates

$$\mathcal{A}_{\mathrm{CP}}^{obs}(t) \equiv \frac{R\left(\overline{B^0}(t) \to f_{CP}\right) - R\left(B^0(t) \to f_{CP}\right)}{R\left(B^0(t) \to f_{CP}\right) + R\left(\overline{B^0}(t) \to f_{CP}\right)}$$

t : Proper time
R : Measured decay rate
$f_{CP} = \overline{f}_{CP}$

- ☆ Tagging ⇨ dilution of the theoretical asymmetry by a factor $D = (1-2\omega)$
(In case of perfect resolution and no bkg)

$$\mathcal{A}_{\mathrm{CP}}^{obs}(t) = D \cdot \mathcal{A}_{\mathrm{CP}}^{th}(t)$$

To estimate LHCb performances to the tagging and physics parameters
→ need of a full MC simulation:

- Generation of minimum bias p-p, incl. pile-up and spill-over ($\sqrt{s}$ = 14TeV) → Pythia 6.2
- Decay of unstable particles → QQ
- Tracking and detector response → *Geant 3*

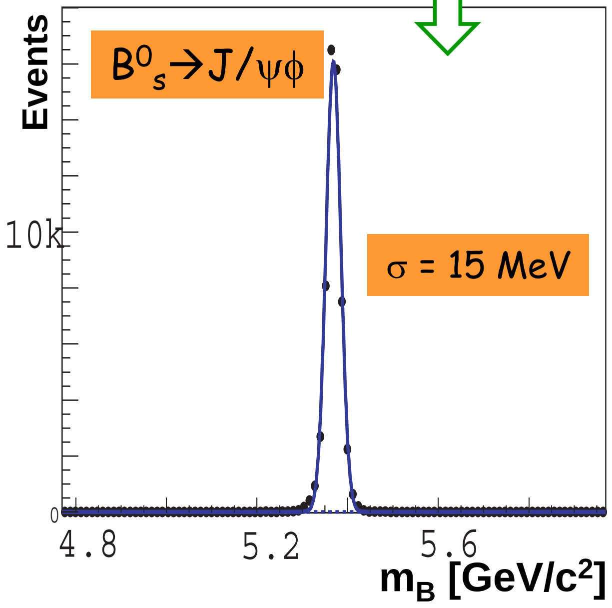
Reconstruction at LHCb

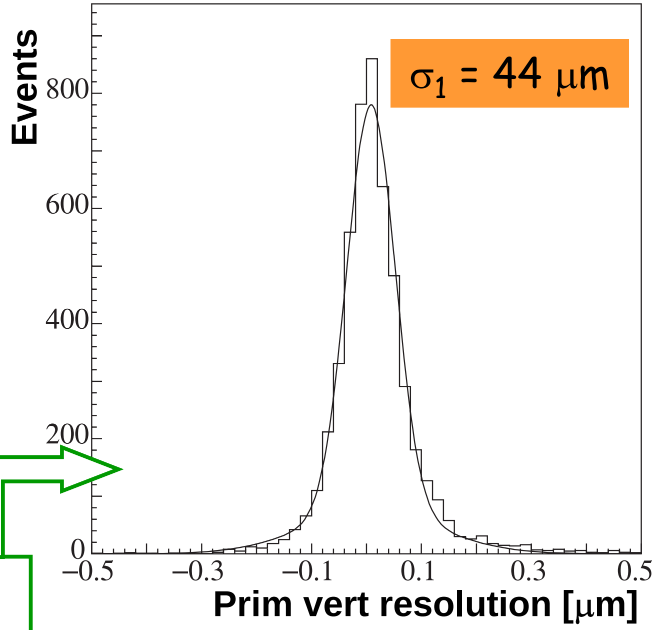
- ☆ Precise reconstruction needed for mixing parameters measurements

B^0 mass peak resolution after selection:

~ 15 MeV/c² for charged final states

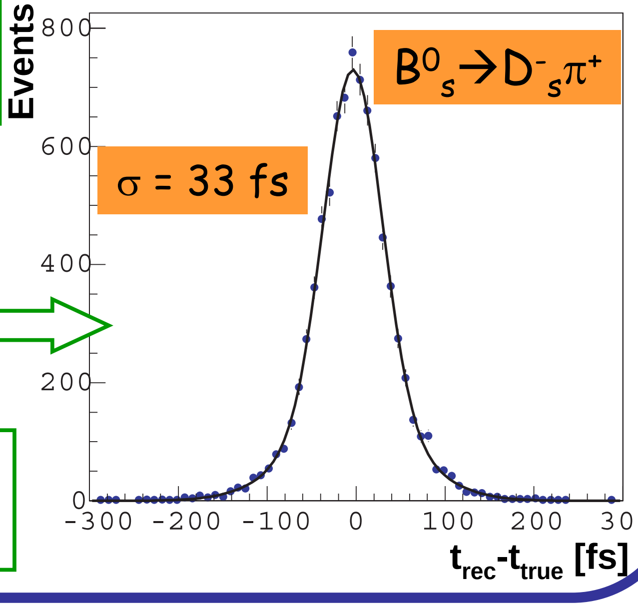
~ 40 MeV/c² for photons + charged final states





Vertex resolutions:

- σ(prim vert z) ~ 44 μm
- σ(decay vert z) < 180 μm



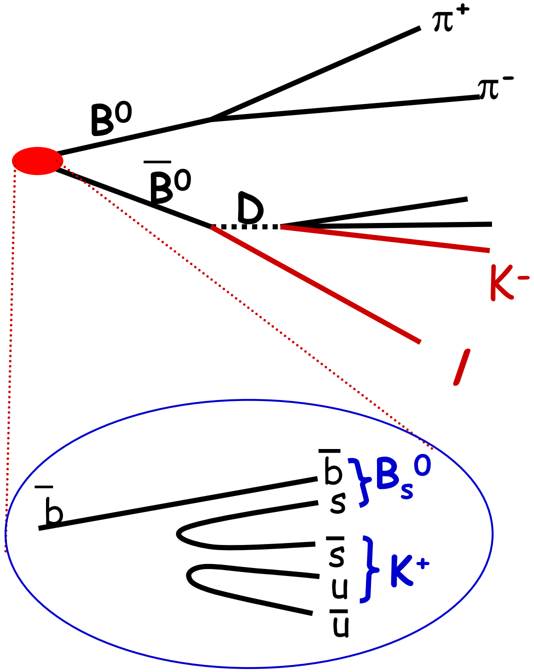
Proper time resolution: ~ 40 fs

- Precise enough to resolve the fast B^0_s-$\overline{B^0}_s$ oscillation

Flavour Tagging

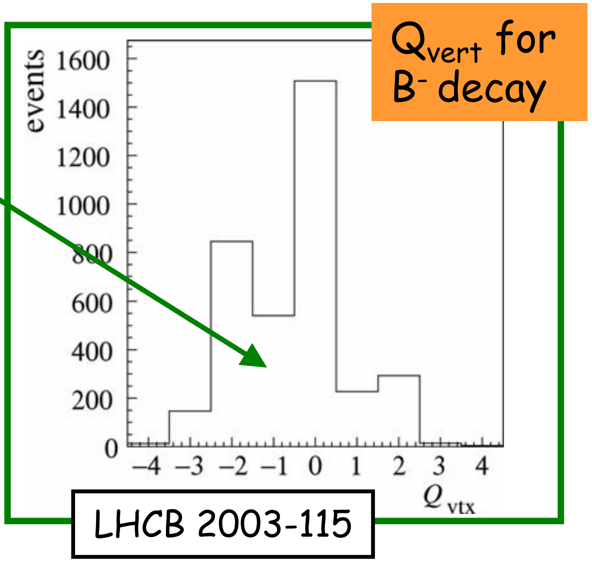
Knowledge of B initial flavour is essential for any $\not{C}\!\not{P}$ measurements

- affects statistical and systematic precision



Current LHCb Tagging strategy:

- ☆ opposite side lepton tag (b → *l*)
- ☆ opposite side kaon tag (b → c → s)
- ☆ same side kaon tag (for B^0_s only)
- ☆ opposite B vertex charge tagging



Q_{vert} for B^- decay

LHCB 2003-115

Expected improvements (DC04):

- ☆ add a same side pion tag (ε_{eff}~0.8%)
- ☆ improve bkg rejection for e, μ channels
- ☆ add a same side pion tag (B^0_d, B^{**}_d)
- ☆ Improve same side kaon tag including B^{**}_s
- ☆ improve inclusive secondary vertex reconstruction (separating b↔c vertices)

Flavour Tagging

effective efficiency:

$\varepsilon_{eff} = \varepsilon_{tag}(1-2\omega)^2$

☆ Tagging efficiency : ε_{tag}

☆ Wrong tag fraction (if there is a tag) : ω

Channel	ε_{tag} (%)	ω (%)	ε_{eff} (%)
$B^0_d \rightarrow \pi^+\pi^-$	41.8 ± 0.7	34.9 ± 1.1	3.8 ± 0.5
$B^0_d \rightarrow K^+\pi^-$	43.2 ± 1.4	33.3 ± 2.1	4.8 ± 1.0
$B^0_d \rightarrow J/\psi(\mu\mu)K^0_S$	45.1 ± 1.3	36.7 ± 1.9	3.2 ± 0.8
$B^0_d \rightarrow J/\psi(\mu\mu)K^{*0}$	41.9 ± 0.5	34.3 ± 0.7	4.1 ± 0.3
$B^0_s \rightarrow K^+K^-$	49.8 ± 0.5	33.0 ± 0.8	5.8 ± 0.5
$B^0_s \rightarrow \pi^+K^-$	49.5 ± 1.8	30.4 ± 2.6	7.6 ± 1.7
$B^0_s \rightarrow D^-_s\pi^+$	54.6 ± 1.2	30.0 ± 1.6	8.7 ± 1.2
$B^0_s \rightarrow D^\mp_s K^\pm$	54.2 ± 0.6	33.4 ± 0.8	6.0 ± 0.5
$B^0_s \rightarrow J/\psi(\mu\mu)\phi$	50.4 ± 0.3	33.4 ± 0.4	5.5 ± 0.3

For B^0_d system → ε_{eff} ~ 4%

For B^0_s system → ε_{eff} ~ 6%

Values used for the sensitivity studies

LHCB 2003-115

Decays of Interest

☆ Channels used in this talk to study the oscillations amplitudes at LHCb:

$B_d^0 \to J/\Psi(\mu^+\mu^-)\ K^{*0}(K^+\pi^-)$	$\Delta m_d\ , \omega_d$
$B_d^0 \to J/\Psi(\mu^+\mu^-)\ K_s^0$	$\Delta m_d\ , \omega_d,\ \sin 2\beta$
$B_s^0 \to D_s^-(K^+K^-\pi^-)\ \pi^+$	$\Delta m_s, \omega_s, \frac{\Delta\Gamma_s}{\Gamma_s}$
$B_s^0 \to J/\Psi(\mu^+\mu^-)\ \phi(K^+K^-)$	R_T, $\Delta m_s, \omega_s, \frac{\Delta\Gamma_s}{\Gamma_s},\ \sin\phi_s$
$B_s^0 \to J/\Psi(\mu^+\mu^-)\ \eta(\gamma\gamma)$	$\Delta m_s, \omega_s, \frac{\Delta\Gamma_s}{\Gamma_s},\ \sin\phi_s$
$B_s^0 \to \eta_c(4h)\ \phi(K^+K^-)$	$\Delta m_s, \omega_s, \frac{\Delta\Gamma_s}{\Gamma_s},\ \sin\phi_s$

Frequencies

Phases

SM mixing parameters:

$\Delta m_d \sim 0.5\ ps^{-1}$,	$\Delta m_s \sim 20\ ps^{-1}$,
$\Delta\Gamma_d/\Gamma_d \sim 0$,	$\Delta\Gamma_s/\Gamma_s \sim 10\%$,
$\sin 2\beta \sim 0.7$,	$\sin\phi_s \sim -0.04$

Full MC Simulation Results

☆ Values obtained from full MC simulation for the decays of interest

	ε_{tot} (in %)	Yield (10^3/y)	$\sigma(m_B)$ (MeV)	$\sigma(\tau)$ (fs)	B/S
$B^0_d \to J/\psi K^{*0}$	1.5	670	15	na	0.17
$B^0_d \to J/\psi K^0_s$	1.4	216	11	43	0.67
$B^0_s \to D^-_s \pi^+$	0.34	80	14	33	0.32
$B^0_s \to J/\psi \phi$	1.7	100	15	38	< 0.3*
$B^0_s \to J/\psi \eta$	0.46	7	33	45	< 1.6*
$B^0_s \to \eta_c \phi$	0.08	3	13	33	< 0.8*

Improvements since the TDR

CERN/LHCC 2003-030

- ε_{tot}: total signal efficiency (with trigger, without tagging)
- B/S estimated from inclusive $b\bar{b}$ events (*: 90% CL upper limit)

Sensitivity Studies

- Sensitivities of LHCb to the CP observables are assessed using fast toy MC experiments
  - efficiencies and resolutions from the full simulation
  - Systematic effects monitored from data (control channels without ~~C~~R)

- Unbinned maximum likelihood fit used (except for $B^0 \rightarrow J/\psi K^0_s$ – binned)

$$\mathcal{L} = \prod_{events} \left[f_i^{sig} \mathcal{R}_i^{sig} + (1 - f_i^{sig}) \mathcal{R}_i^{bkg} \right]$$

  - f^{sig}: probability to have signal, R: the observed decay rates

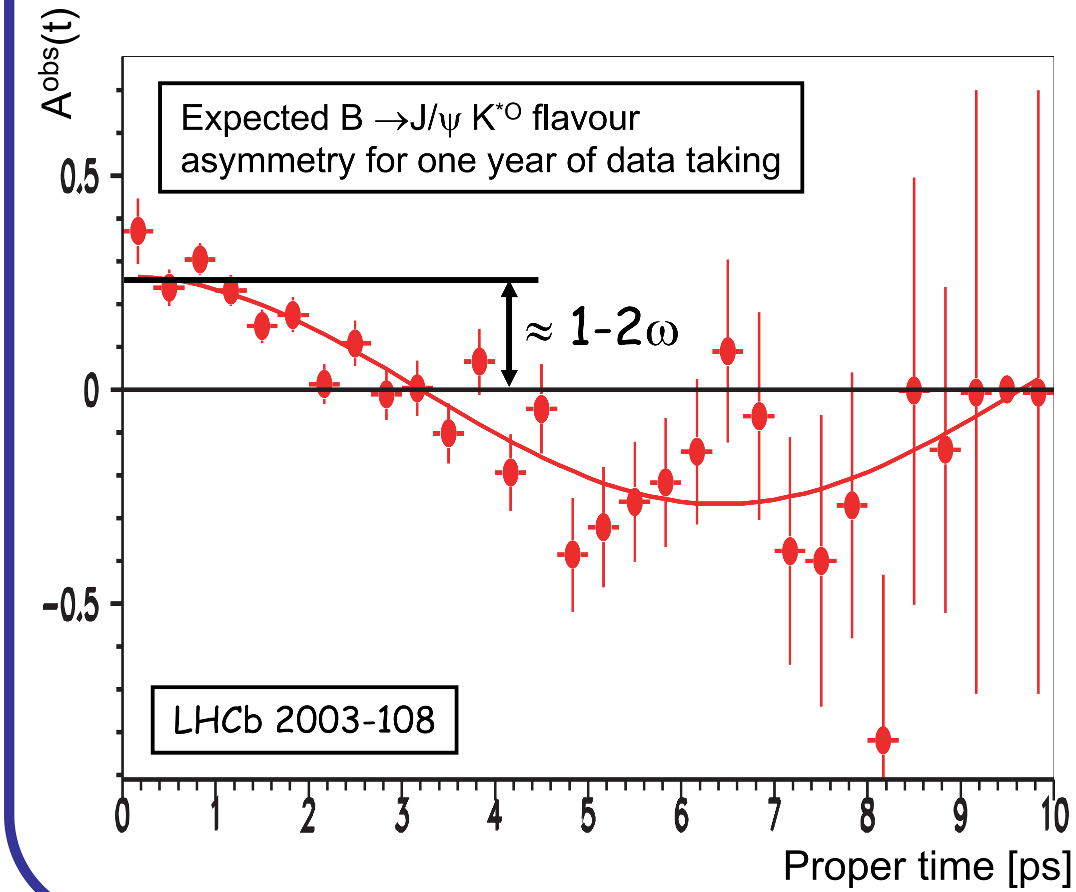
- Decay rates are
  - convoluted with proper-time resolution or/and
  - weighted with acceptance

- Focus on $\sin(\phi_s)$: real challenge for mixing measurements and searches for NP

Δm_d with $B^0_d \to J/\psi K^{*0}$

$\Delta\Gamma_d \sim 0$

$$\mathcal{A}^{obs}_{B^0_d \to J/\psi K^{*0}}(t) = (1-2\omega)\cdot\cos(\Delta m_d t)$$



Imperfect flavour tagging *dilutes* the asymmetry!

- ☆ Flavour specific channel used to study systematics - no ~~CP~~ expected
- ☆ Also used to check the LHCb tagging method – tagged by kaon charge

Control channel

Used to extract ω

$$\boxed{\omega = (36.5 \pm 1.0)\ \%}$$

Error propagated to the other sensitivities - systematics

Golden Decay Mode: $B^0_d \to J/\psi\, K^0_S$

$\Delta\Gamma_d \approx 0$
$\phi_D \approx 0$

Time-dependent *CP* asymmetry

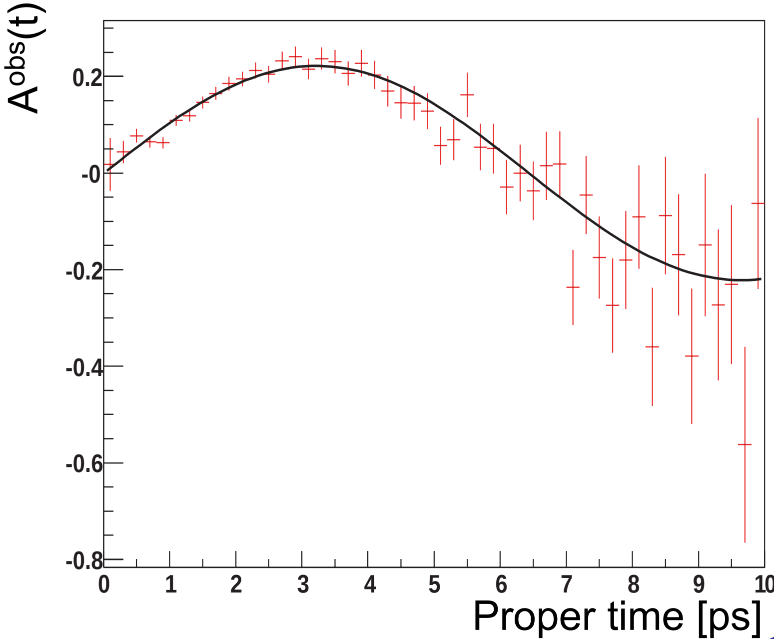
$$\mathcal{A}^{obs,CP}_{B^0_d \to J/\psi K^0_s}(t) = (1 - 2\omega) \cdot \sin 2\beta \cdot \sin(\Delta m_d t)$$

- ☆ Theoretically the cleanest way to measure β
- ☆ Large and well known asymmetry serves mainly as calibration
- ☆ 200 experiments performed corresponding to 1 year each
- ☆ LHCb sensitivity to $\sin(2\beta)$ in one year – 216k events

  $\sigma_{LHCb}(\sin 2\beta) = 0.022$
- ☆ World average in 2006

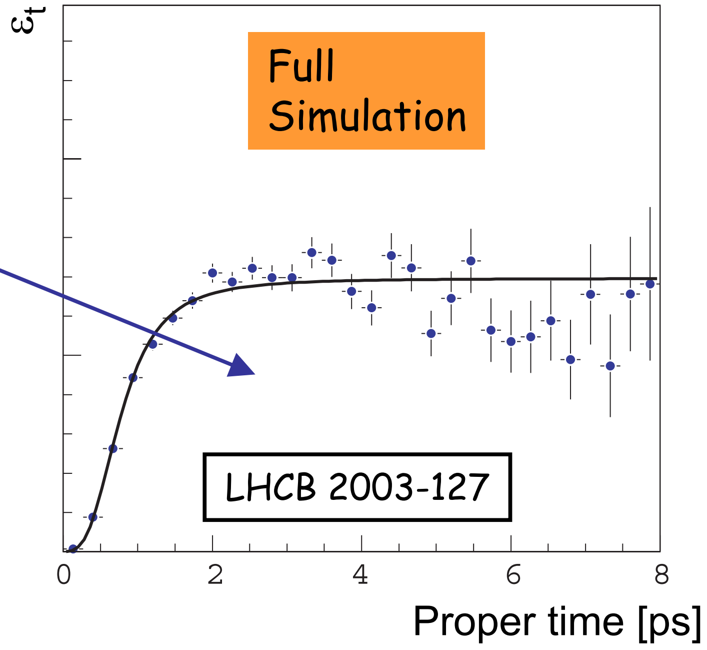
  $\sigma_{World}(\sin 2\beta) \sim 0.02$
- ☆ What can LHCb bring to $\sin 2\beta$?
  - STATISTICS
  - Comparing with other channels, may indicate NP in penguin diagrams

Typical asymmetry fit (1 year)

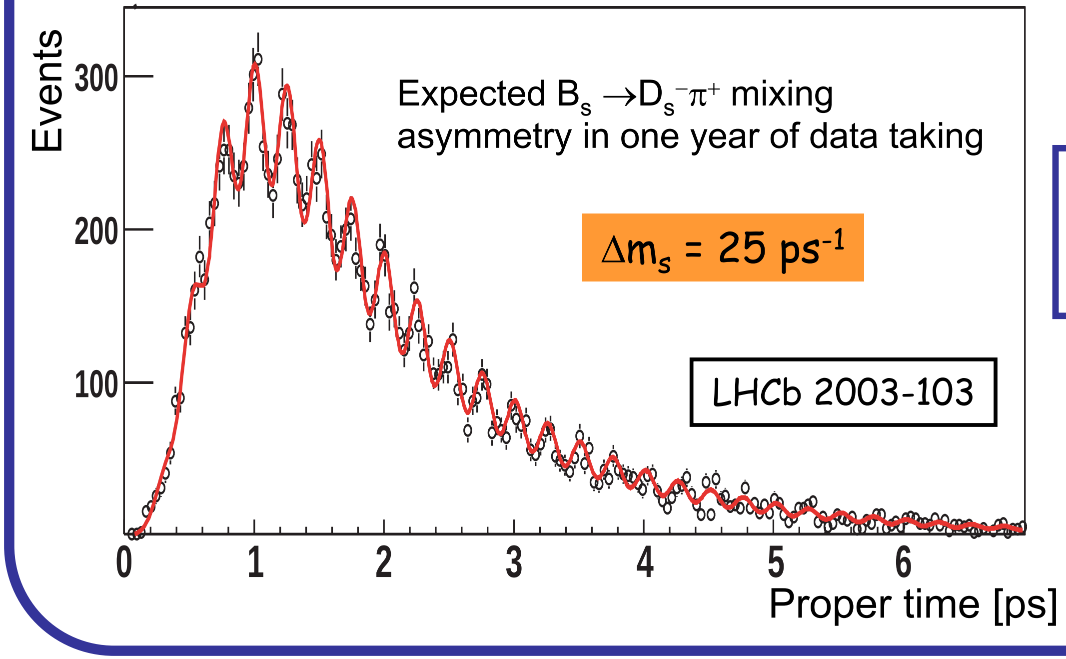


Δm_s with $B^0_s \rightarrow D^-_s \pi^+$

- ☆ Terra Incognita
- ☆ $B^0_s \rightarrow D^-_s\pi^+$: flavour specific decay
- ☆ Likelihood scaled by a time dependent efficiency (acceptance)



$$\mathcal{A}^{obs}_{B^0_s \rightarrow D^-_s \pi^+}(t) = -(1-2\omega) \cdot \frac{\cos(\Delta m_s t)}{\cosh\left(\frac{\Delta\Gamma_s}{2} t\right)}$$



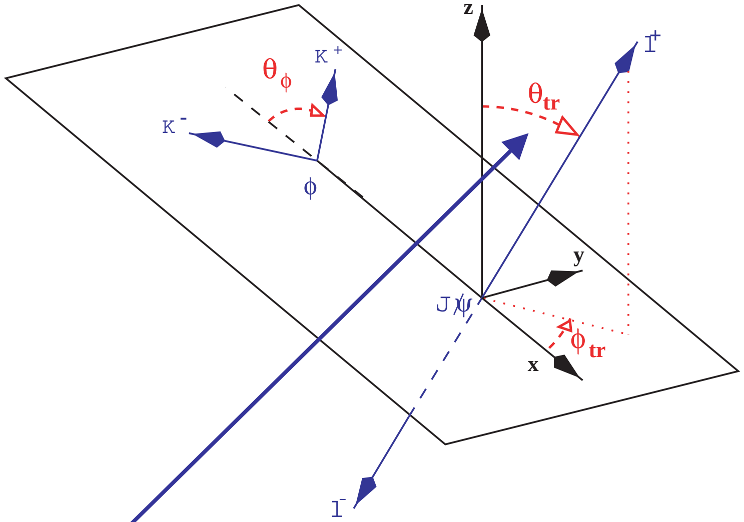
This channel allows the extraction of the parameters Δm_s, $\Delta\Gamma_s$ and ω

In one year, >5σ, for $\Delta m_s < 68$ ps^{-1}

→ Well beyond the SM prediction (14.8 – 26 ps^{-1})

$B^0_s \to J/\psi\,\phi$: Sensitivity Studies

- ☆ B^0_s counterpart of $B^0_d \to J/\psi\, K^0_S$ → measures ϕ_s →Terra incognita
- ☆ The final state is an admixture of CP eigenstates
  - – f = 0, ||: CP-even configuration, $\eta_f = +1$
  - – f = ⊥ : CP-odd configuration, $\eta_f = -1$
- ☆ Linear polarization amplitudes are introduced:
  - – $A_f(t)$ for f=0, ||, ⊥
  - – The fraction of CP-odd is defined as $R_T \equiv |A_\perp(0)|^2 / \sum_f |A_f(0)|^2 \sim 20\%$
- ☆ The one-angle θ_{tr} distribution enables to disentangle the different CP eigenstates

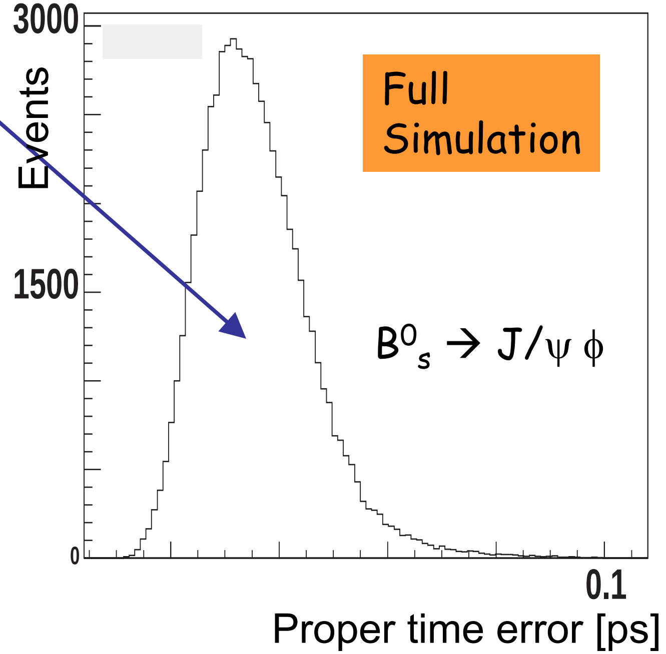


θ_{tr}: Angle between the positive charged lepton and the φ decay plane

$$\frac{d\Gamma(t)}{d(\cos(\theta_{tr}))} \propto \left[|A_0(t)|^2 + |A_\parallel(t)|^2\right]\frac{3}{8}(1+\cos^2\theta_{tr}) + |A_\perp(t)|^2\,\frac{3}{4}\sin^2\theta_{tr}$$

Description for $B^0_s \to J/\psi\,\phi$ Fit

- Due to fast oscillations, need to be very sensitive to proper time
  - Precise proper-time measurements are needed
  - → A computed per-event lifetime error is used in the fast simulation such that an experimental uncertainty is assigned to each generated event



- The transversity angle $\cos(\theta_{tr})$ for $B^0_s \to J/\psi\,\phi$ is introduced
  - angular distribution of the two vector-mesons in the final state

- Physics parameters:
  - extracted using an "unbinned maximum" likelihood fit to
    - the proper time
    - the mass distribution
    - and the transversity angle for $B^0_s \to J/\psi\,\phi$

- Fit simultaneously maximized with the control sample $B^0_s \to D^-_s \pi^+$, which allows the determination of Δm_s, $\Delta\Gamma_s/\Gamma_s$, ω

Fit Procedure for $B^0_s \to J/\psi\ \phi$

1. The mass distributions are fitted and the per-event signal probability is determined, based on the reconstructed mass
2. The sidebands are used to determine the background parameters
3. In the signal window, the physics parameters are fitted:

Δm_s, $\Delta\Gamma_s/\Gamma_s$, $1/\Gamma_s$, ω, ϕ_s and R_T

- ☆ Determined by $B^0_s \to J/\psi\ \phi$ and $B^0_s \to D^-_s \pi^+$
- ☆ Completely determined by $B^0_s \to J/\psi\ \phi$

☆ Likelihood:

$$\mathcal{L} = \prod_{events} \mathcal{L}_m \mathcal{L}_{\theta_{tr}} \mathcal{L}_t$$

☆ $\mathcal{L}_m \propto \begin{cases} \text{Gaussian for signal} \\ \text{Exponential for bkg} \end{cases}$

☆ $\mathcal{L}_t \propto$ Decay rates (incl. res)

$$\boxed{\mathcal{L}_{\theta_{tr}} = R_T \frac{1-\cos^2\theta_{tr}}{2} + (1-R_T)(1+\cos^2\theta_{tr})}$$

☆ 1000 toy experiments, each corresponding to 1 year of LHCb, are performed

Expected Sensitivities for ϕ_s

For one given final state

Time-dependent *CP* asymmetry

$$\mathcal{A}^{obs,CP}_{B^0_s\to J/\psi\phi}(t) = -(1-2\omega)\frac{\eta_f \sin(\phi_s)\sin(\Delta m_s t)}{\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \eta_f\cos(\phi_s)\sinh\left(\frac{\Delta\Gamma_s t}{2}\right)}$$

- ☆ $B^0_s \to J/\psi\,\eta$, $B^0_s \to \eta_c\phi$: increase the sensitivity to ϕ_s
  - Decays to pure CP-eigenstates (CP-even)
  - Same physics, but no angular analysis needed

Sensitivity (1 year)	$\sigma(\Delta\Gamma_s/\Gamma_s)$	$\sigma(\phi_s)$ [rad]
$B^0_s \to J/\psi\,\phi$	0.018	0.06
$B^0_s \to J/\psi\,\eta$	~ 0.025	~ 0.1
$B^0_s \to \eta_c\phi$	~ 0.025	~ 0.1
Combined ϕ_s sensitivity		~ 0.05

Preliminary results

- ☆ Statistical sensitivity to ϕ_s after five years of LHCb data taking
  → $\sigma(\phi_s)$ ~ 0.02, with ϕ_s ~ 0.04 in the SM

Summary

- ☆ We have presented the way to extract the phases and frequencies at LHCb using the channels:
  - $B^0 \rightarrow J/\psi\ K^{*0}$, $B^0 \rightarrow J/\psi\ K^0_s$, $B^0_s \rightarrow D^-_s\ \pi^+$, $B^0_s \rightarrow J/\psi\ \phi$, $B^0_s \rightarrow J/\psi\ \eta$, $B^0_s \rightarrow \eta_c\phi$

- ☆ The sensitivities after one year to the parameters of interest are:
  - Δm_s $> 5\sigma$ for $\Delta m_s < 68\ ps^{-1}$
  - $\sigma_{LHCb}(\sin 2\beta)$ ~ 0.022 (in 2006, world average: ~0.02)
  - $\sigma_{LHCb}(\sin\phi_s)$ ~ 0.05

- ☆ LHCb contribution to these parameters (after one year of running):
  - Reduce $\sin 2\beta$ uncertainties
  - Measure very precisely Δm_s → First steps in B_s-mixing physics
  - If Δm_s is within the SM expectations, no need of $2fb^{-1}$ to measure it
  - Determine $\sin\ \phi_s$
    - to 2σ within 5 years if SM
    - to 4σ within 1 year if $\sin\ \phi_s \sim \lambda$

B^0_s - $\overline{B^0}_s$ system is a prime candidate for the discovery of new physics

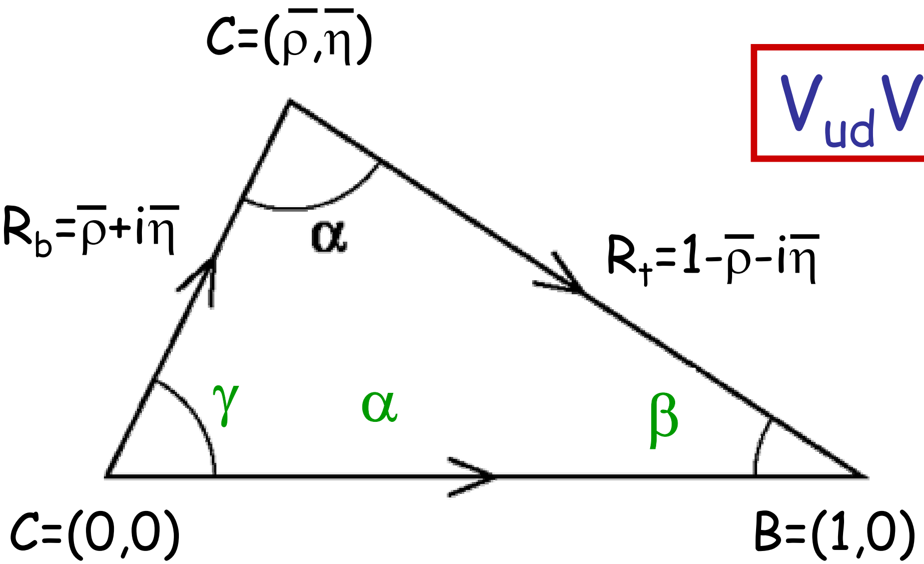
BACK-UP SLIDES

BACK-UP
SLIDES

BKP: Measurements of the Unitary Triangle

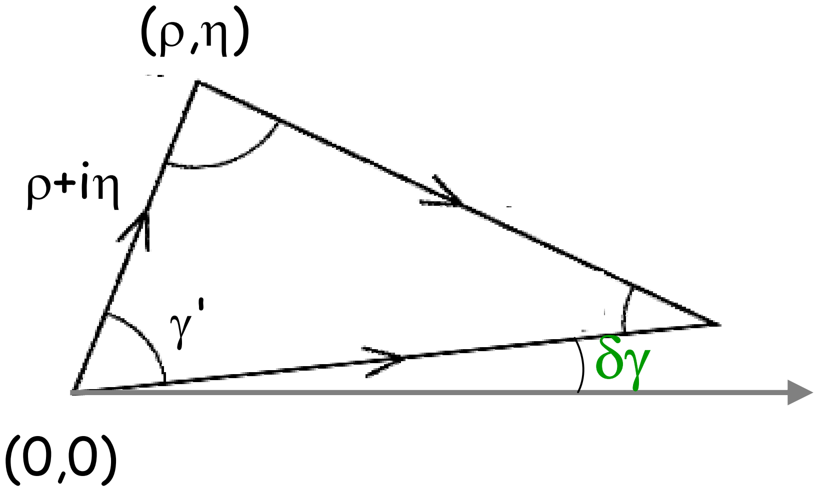
- α $B\rightarrow\rho\pi$ gives access to $\sin2\alpha$ as well as $B\rightarrow\pi\pi$ but the last one requires the knowledge of the "penguin pollution", which can be extracted from $B\rightarrow K\pi$.
- β The B^0-B^0 mixing phase ϕ_B (= 2β) can be extracted from $B\rightarrow J/\psi K^0_s$ and similar channels. Also $B\rightarrow\phi K^0_s$ allows the measurement of 2β but it appears in a penguin loop. This difference can show signs of a new physics if both measurement don't give the same results.
- γ This angle cannot be measured directly but it can be extracted from the $B\rightarrow D^*\pi$ channel, which depend on $\gamma+\phi_B$ using ϕ_B from the measurement described above, or from $B_s\rightarrow D_sK$ which is sensitive to $\gamma+\phi_{Bs}$.
- $\delta\gamma$ The B_s mixing phase ϕ_{Bs} is equal to $-2\delta\gamma$ and can be extracted from $B^0_s\rightarrow J/\psi\eta$ or $B^0_s\rightarrow J/\psi\phi$.
- $|R_b|$ This is the length of the CA side of the unitary triangle, It corresponds to the ratio $|V_{ub}|/|V_{cb}|$. Both the numerator and the denominator can be obtained from inclusive semileptonic B decays.
- $|R_t|$ This is the most difficult element to measure. $|R_t|=1/\lambda^*|V_{td}|/|V_{cd}|$ in which the problematic therm is V_{td}. At the LHC the most efficient way to extract it is through the ratio of the branching fraction of $B\rightarrow llX_d$ and $B\rightarrow llX_s$, which is $|V_{td}|^2/|V_{cd}|^2(1+\text{corrections})$ and thus requires $|V_{ts}|$ known.

BKP: Unitary Triangles



$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$

$$V^*_{ud}V_{td} + V^*_{us}V_{ts} + V^*_{ub}V_{tb} = 0$$



BKP: Tagging Power Characterisation

- The measured asymmetry is diluted by the wrong tag fraction.
- The tagging efficiency is also important (no tags means no physics)
- The best combination of these values arises when looking at the statistical uncertainty of the real asymmetry:

$$\mathcal{A} = \frac{\mathcal{A}^m}{1-2\omega} \quad \Rightarrow \quad \sigma_{\mathcal{A}} = \frac{\sigma_{\mathcal{A}^m}}{1-2\omega}$$

$$\mathcal{A}^m = \frac{R^m - \bar{R}^m}{R^m + \bar{R}^m} \quad \Rightarrow \quad \sigma^2_{\mathcal{A}^m} = \left(\frac{\partial \mathcal{A}^m}{\partial R^m}\right)^2 \sigma^2_{R^m} + \left(\frac{\partial \mathcal{A}^m}{\partial \bar{R}^m}\right)^2 \sigma^2_{\bar{R}^m}$$

$$\sigma^2_{\mathcal{A}^m} = \frac{4R^m\bar{R}^m}{(R^m+\bar{R}^m)^3}$$

At this point, one should note that: $1-\mathcal{A}^{m2} = \dfrac{4R^m\bar{R}^m}{(R^m+\bar{R}^m)^2}$

Thus:

$$\left.\begin{aligned}\sigma^2_{\mathcal{A}^m} &= \frac{1-\mathcal{A}^{m2}}{R^m+\bar{R}^m} = \frac{1-\mathcal{A}^{m2}}{N^m} = \frac{1-\mathcal{A}^{m2}}{\epsilon_{tag}N} \\ \sigma_{\mathcal{A}} &= \frac{\sqrt{1-\mathcal{A}^{m2}}}{\sqrt{\epsilon_{tag}}\sqrt{N}(1-2\omega)} \propto \frac{1}{\sqrt{\epsilon_{tag}}(1-2\omega)}\end{aligned}\right\} \epsilon_{eff} = \epsilon_{tag}(1-2\omega)^2$$

Which states that we need to maximize the effective tagging efficiency

BKP: Angular distribution

- ☆ In $B^0_s \rightarrow J/\psi\, \phi$ the final state is an admixture of CP eigenstates
  - $f = 0, ||$: CP-even configuration, $\eta_f = +1$
  - $f = \perp$: CP-odd configuration, $\eta_f = -1$
- ☆ Linear polarization amplitudes corresponding to the different configurations are introduced (hep-ph 9804293, hep-ph 0012219): $A_f(t)$ for $f=0, ||, \perp$
  - The fraction of CP-odd is defined as $R_T \equiv |A_\perp(0)|^2 / \sum_f |A_f(0)|^2 \sim 20\%$
- ☆ Each of the $|A_f(t)|^2$ corresponds to an ordinary decay rate of a pure CP eigenstate for a $\bar{b} \rightarrow \bar{c}c\bar{s}$ transition (for a given η_f value)
- ☆ Assuming that $\cos(\phi_s) \approx 1$, we get the following analytical decay rates
  - For initially pure B^0_s

$$\begin{aligned} |A_f(t)|^2 &= |A_f(0)|^2 \left[e^{-\Gamma_L t} + e^{-\Gamma_s t} \sin(\phi_s) \sin(\Delta M_s t)\right], \quad f = 0, || \\ |A_\perp(t)|^2 &= |A_\perp(0)|^2 \left[e^{-\Gamma_H t} - e^{-\Gamma_s t} \sin(\phi_s) \sin(\Delta M_s t)\right] \end{aligned}$$

  - For initially pure $\overline{B^0}_s$

$$\begin{aligned} |\bar{A}_f(t)|^2 &= |A_f(0)|^2 \left[e^{-\Gamma_L t} - e^{-\Gamma_s t} \sin(\phi_s) \sin(\Delta M_s t)\right], \quad f = 0, || \\ |\bar{A}_\perp(t)|^2 &= |A_\perp(0)|^2 \left[e^{-\Gamma_H t} + e^{-\Gamma_s t} \sin(\phi_s) \sin(\Delta M_s t)\right] \end{aligned}$$

Note: there is no CP violation in the decay rates

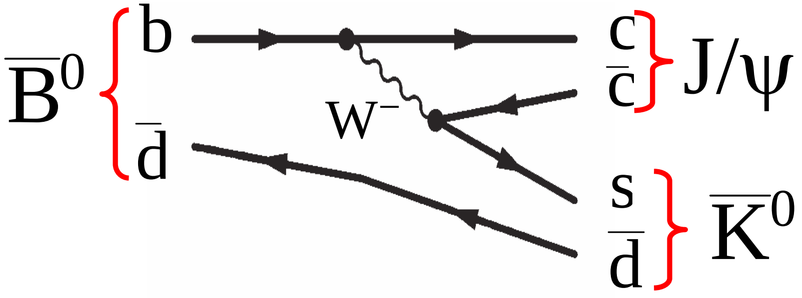
Systematic uncertainties

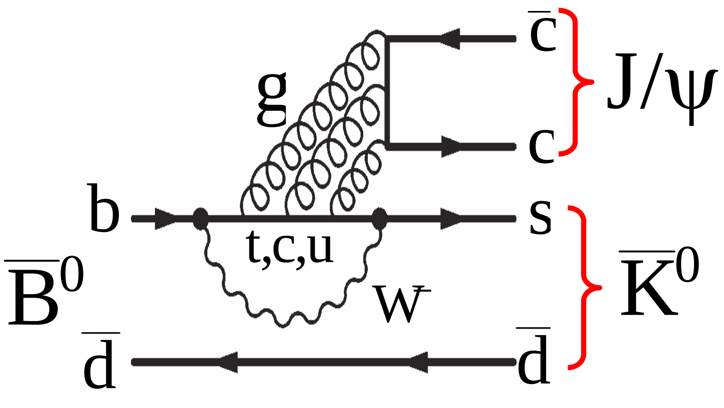
- ☆ The systematic errors due to acceptance, detection efficiency, decay-time resolution, production asymmetries, tagging performance and trigger efficiency must be well understood.
- ☆ Possible sources of systematic uncertainty:
  - Asymmetry of b vs $\bar{b}$ production
  - Detector efficiencies which depend on charge
    - can bias tagging efficiencies
    - can fake CP asymmetries
  - CP asymmetry also in background processes

- ☆ Alternate runs, swapping the orientation if the magnetic field
- ☆ Use control samples available with high statistics:
  - $B_s \rightarrow D_s \pi$ 80k events/year
  - $B^0 \rightarrow J/\psi K^*$ 670k events/year
  - $B^\pm \rightarrow J/\psi K^\pm$ 1700k events/year

  → Control sample sometimes too different from the signal sample !!!
- ☆ Study CP asymmetries in the B mass side bands

BKP: Are we sure that $S(J/\psi\, K_S) = \sin(2\beta)$??





$$A\left(B \to J/\psi\, K\right) = \underbrace{V_{cb}V_{cs}^*}_{\propto \lambda^2}\left(T + P^c - P^t\right) + \underbrace{V_{ub}V_{us}^*}_{\propto \lambda^4}\left(P^u - P^t\right)$$

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$V_{ub}V_{us}^* + V_{cb}V_{cs}^* + V_{tb}V_{ts}^* = 0$$

Leading penguin contribution has *same* weak phase as tree
➔Extraction of sin(2β) from J/ψK_S is
"theoretically clean"

BKP: Monte Carlo simulation

- ☆ Physics potential is estimated using "Data challenges", i.e. "big" number of simulated events

- ☆ 2003: 67M events
  - 10M bb events (~4 minutes of data taking !)
  - Pythia, QQ, GEANT3

- ☆ 2004: 180M events simulation and analysis in a distributed way (Grid)
  - Started in May, already >50M events produced
  - Pythia, EvtGen, GEANT4
  - >3000 jobs running in parallel all over the world

- ☆ Digitization, trigger and reconstruction are simulated using full detector response, based on test beam data