# B Physics expectations at LHCb

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LISHEP 2006
International School on High Energy Physics
Session C - Wokshop on Collider Physics

# CP Violation before LHC

- New Physics is expected to play a role at LHC, but difficult to be characterized
- SM: CP violation is described by a complex phase in the unitarity CKM matrix. Unitary Triangles

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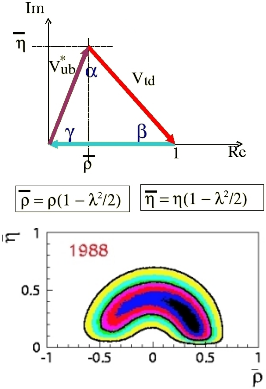

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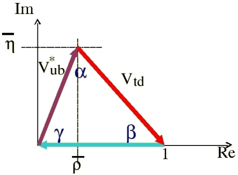


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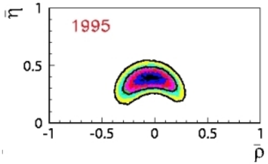


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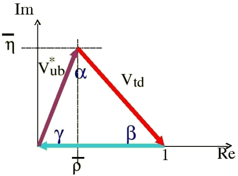


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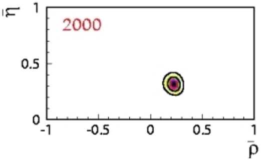

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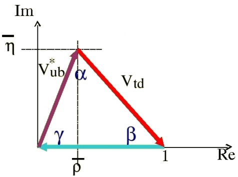


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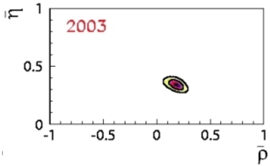

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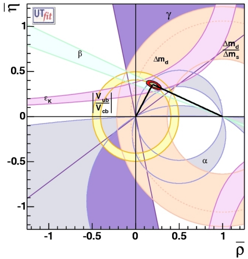
- Belle and Babar

2005



# CP Violation at LHC

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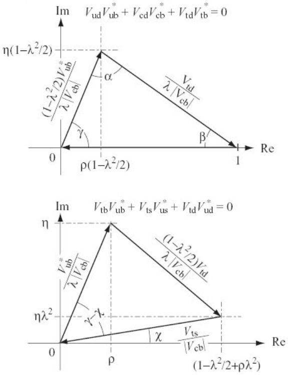
- LHCb precision $\Rightarrow$ 2 Unitary Triangles



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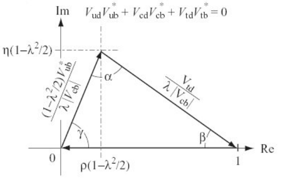
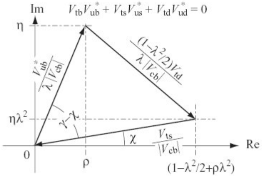
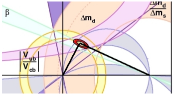
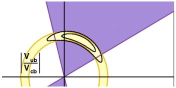
- LHCb precision $\Rightarrow$ 2 Unitary Triangles
- LHCb will over constrain the Triangles



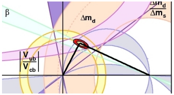
# LHCb Physics Program

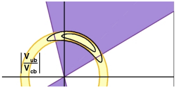



- $\Delta m_s$, $\phi_s$ and $\Delta\Gamma_s$: $B_s \to D_s\pi$, $J/\Psi\Phi$, $J/\Psi\eta$ and $\eta_c\Phi$
- $\alpha$: $B_d \to \pi^0\pi^-\pi^+$
- $\beta$: $B_d \to J/\Psi K_S$ and $B_s \to \Phi K_S$ (penguin)
- $\gamma$
  - $CP_{asym}(t)$: $B_s \to D_s^{\pm}K^{\mp}$ , $K^+ K^-$ and $B_d \to \pi^+\pi^-$
  - Decay Rates: $B_d^0 \to D^0(K^-\pi^+ ; K^+\pi^-; K^+ K^-)K^{*0}$
    $\bar{B}_d^0 \to \bar{D}^0(K^-\pi^+ ; K^+\pi^-; K^+ K^-)\bar{K}^{*0}$
  - Dalitz analysis: $B^{-,0}_{,d} \to D^0(K_s\pi^-\pi^+, K_sK^-K^+)K^{-,*0}$
- Rare Decays
  - Penguins: Radiative: $B_d \to (K^*, \omega)\gamma$, $B_s \to \Phi\gamma$;
    Electroweak $B_d \to K^*\mu^-\mu^+$;
    Gluonic: $B_s \to \Phi\Phi$ and $B_d \to \Phi K_s$
  - Box diagram: $B_s \to \mu^-\mu^+$
- $B_s$, b-baryon Physics, c Physics ...

# LHCb Physics Program (in 15 minutes!)

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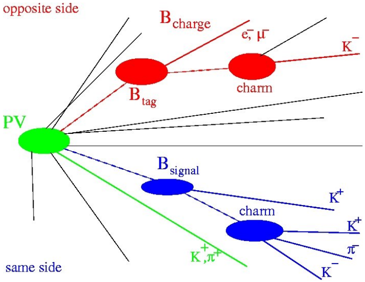
# Flavour Tagging

MC Simulation: 40M $b\bar{b}$ and 70M minimun bias events

## How to know the b-flavor at t=0?

- detecting the flavor of the other B - opposite side: e, $\mu$, K, $B_{charge}$
- using $K^{\pm}$ for $B_s$ or $\pi^{\pm}$ for $B_s$ - same side: $\pi$/K



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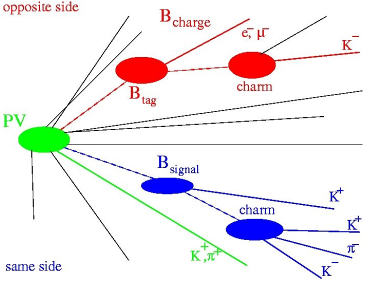
- Tagging power characterized by $\epsilon(1-2\omega)^2$, where $\epsilon$ is the efficiency and $\omega$ the mistag

| | $B_d$ | $B_s$ |
|---|---|---|
| $\epsilon(1-2\omega)^2$ | 4%-5% | 6%-9% |

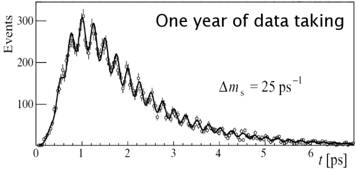


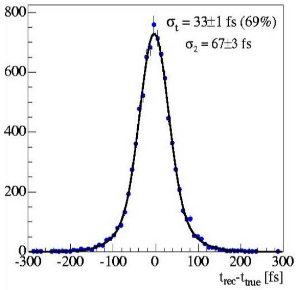
# $B_s$ Oscillation Frequency: $\Delta m_s$

Needed for $B_s$ time dependent CP asymmetries

**$B_s \rightarrow D_s \pi^+$**

- 2 $fb^{-1}$ (one year of data taking)
- can observe $> 5\sigma$ oscillation signal if $\Delta m_s < 68\ ps^{-1}$
- proper time resolution $\approx 35$ fs



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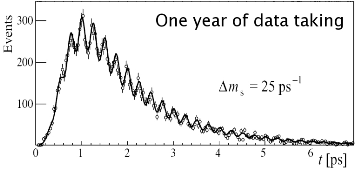
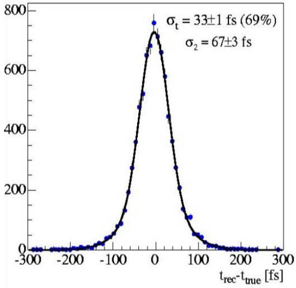
LHCb: if $\Delta m_s$= 20 $ps^{-1}$ $\Rightarrow$

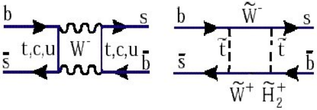
$\sigma_{LHCb}(\Delta m_s)$= 0.01 $ps^{-1}$



# $B_s$ Mixing Phase $\Phi_s$

- CP asymmetry from interference: $B_s \rightarrow J/\Psi\Phi$ and $B_s \rightarrow \overline{B}_s \rightarrow J/\Psi\Phi$. New Physics?
- $B_s$ counter part of the golden mode $B_d \rightarrow J/\Psi\, K_S$ ($\beta$)



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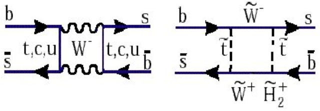
- $B_s$ counter part of the golden mode $B_d \to J/\Psi\ K_S$ ($\beta$)
- Final state is a mixture of CP-even and odd contributions $\to$ angular analysis of decay products required
- Also from pure CP eigenstates: $J/\Psi\eta(\gamma\gamma, \pi^+\pi^-\pi^0), \eta_c\Phi \Rightarrow$ no need of angular analysis, but lower statistics
- Standard Model: $\Phi_s = -2\chi$ = -0.036 $\pm$ 0.003 (CKM fitter)




**10 fb$^{-1}$ - 5 years**

$\sigma(\Phi_s)$ = 0.013

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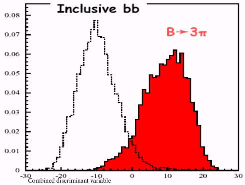
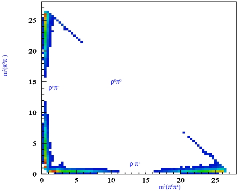
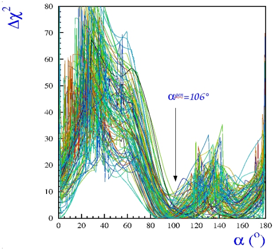
# $\alpha$ from $B_d \to \pi^0\pi^+\pi^-$




- Selection based in a multivariable analysis
- Dalitz plot analysis - Quinn Snyder method



- 14 kevents/year with B/S = 0.8
- 11-parameter likelihood fits in time-dependent Dalitz space



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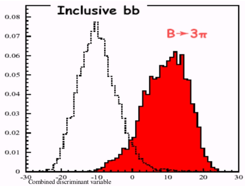


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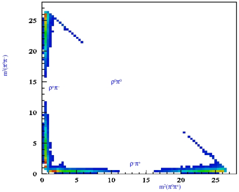


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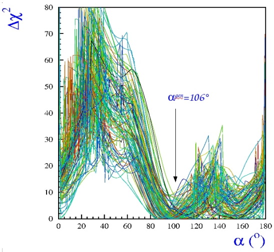


$\alpha_{\text{fit}}$ = (102 $\pm$ 9)$^{o}$

Toy MC - 2 fb$^{-1}$

$\sigma(\alpha) = 10^{o}$

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LHCb

# $\beta$ from $B_d \rightarrow J/\psi K_S$

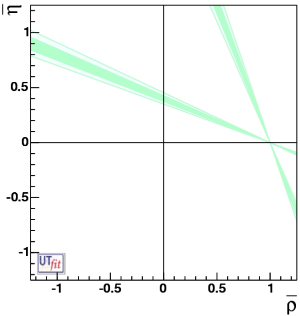
➥ Well measured by Belle and Babar

- ✘ $(\sin 2\beta)_{\text{meas}} = 0.687 \pm 0.032$

in agreement with fitted value

- ✘ $(\sin 2\beta)_{\text{fit}} = 0.738 \pm 0.023$

sin $2\beta$



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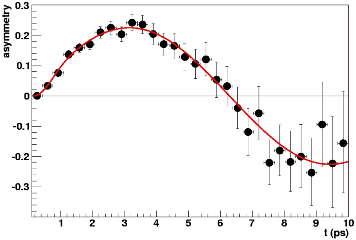
To be measured as a proof of principle

- Well measured by Belle and Babar
  - $(\sin 2\beta)_{meas} = 0.687 \pm 0.032$

  in agreement with fitted value
  - $(\sin 2\beta)_{fit} = 0.738 \pm 0.023$
- 2 $fb^{-1}$ LHCb
  - control channel: $B_d \to J/\Psi\ K^*$
  - 216 kevents
  - $\sigma(\sin 2\beta) = 0.022$

sin $2\beta$




To be compared with values obtained from $b \to s$ penguin

# $\gamma$ from $B_d \to D^0 K^{*0}$ - Gronau-London-Wyler Method

**6 self tagging decays**

$A_1 \equiv A(B_d \to \overline{D}^0\,[K^+\pi^-]\,K^*[K^+\pi^-]) = \overline{A}_1$

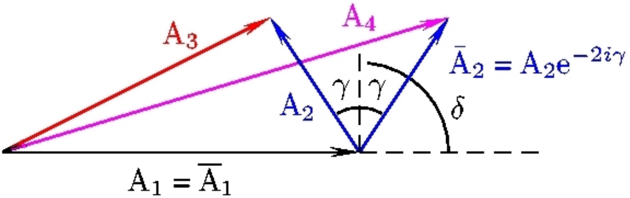
$A_2 \equiv A(B_d \to D^0\,[K^-\pi^+]\,K^*[K^+\pi^-]) = \overline{A}_2 e^{2i\gamma}$

$A_3 \equiv A(B_d \to D_{CP}[KK,\pi\pi]\,K^*[K^+\pi^-])$

$A_4 \equiv A(\overline{B}_d \to D_{CP}[KK,\pi\pi]\,\overline{K}^*[K^-\pi^+])$

- 6 measurements: $A_i$
- $A_3 \neq A_4 \to$ CPV
- $r_B$ - known
- $\delta$ strong phase

A counting experiment: no tagging or proper time needed



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- $A_3 \neq A_4 \to$ CPV
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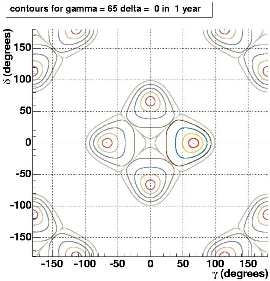
- $\delta$ strong phase
- 8 ambiguities!

Insensitive to new Physics




$$\gamma_{UTFIT} = (71 \pm 16)^o$$
$$\sigma_{1year}(\gamma) = 8^o$$
$$\sigma_{5years}(\gamma) = 4^o$$

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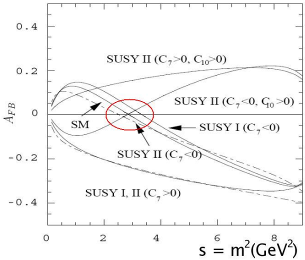
# Rare Decay: $B_d \rightarrow K^{*0}\mu^-\mu^+$

Forward-backward asymmetry $A_{FB}(s)$ in the $\mu\mu$ rest-frame is a sensitive probe to New Physics

- Suppressed decay. $BR_{SM} \approx 10^{-6}$
- 2 $fb^{-1} \rightarrow$ 4.4 kevents with $B/S < 2.6$



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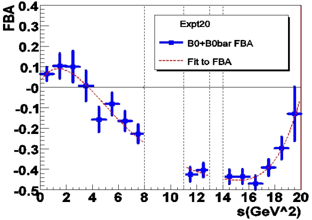
- 10 $fb^{-1}$:
  zero of $A_{FB}$ located to $\pm$ 0.53 $GeV^2$



# LHCb performance with $2fb^{-1}$ (1 year)

| | Channel | Yield | $B_{bb}/S$ | | Precision |
|---|---|---|---|---|---|
| | $B_s \to D_s K$ | 5.4k | $< 1$ | | $\sigma(\gamma) \approx 14^o$ |
| | $B_d \to \pi\pi$ | 26k | $< 0.6$ | Fleicher | $\sigma(\gamma) \approx 6^o$ |
| | $B_d \to K K$ | 37k | 0.3 | | |
| $\gamma$ | $B_d \to D^0(K^+\pi^-) K^*$ | 0.5k | $< 0.3$ | | |
| | $B_d \to \overline{D}^0 (K^-\pi^+) K^*$ | 2.4k | $< 2$ | GLW+D | $\sigma(\gamma) \approx 8^o$ |
| | $B_d \to \overline{D}_{CP} (KK,\pi\pi) K^*$ | 0.6k | $< 0.3$ | | |
| | $B^- \to D^0(K^+\pi^-) K^-$ | 60k | 0.5 | ADS | $\sigma(\gamma) \approx 5^o$ |
| | $B^- \to \overline{D}^0 (K^-\pi^+) K^-$ | 2k | 0.5 | | |
| $\alpha$ | $B_d \to \pi^o\pi^+\pi^-$ | 14k | 0.8 | Snyder Quinn | $\sigma(\alpha) \approx 10^o$ |
| $\beta$ | $B_d \to J/\Psi K_S$ | 216k | 0.8 | | $\sigma(\sin 2\beta) \approx 0.022$ |
| | $B_s \to J/\Psi\Phi$ | 125k | 0.3 | | |
| $\phi_s$ | $B_s \to J/\Psi\eta$ | 12k | 2.3 | | $\sigma(\phi_s) \approx 2^o$ |
| | $B_s \to \eta_c\Phi$ | 3k | 0.7 | | |
| $\Delta m_s$ | $B_s \to D_s\pi$ | 80k | 0.8 | | $\Delta m_s$ up to 68 $ps^{-1}$ |
| | $B_d \to K^*\mu\mu$ | 4.4k | $< 2.6$ | | Zero at $\pm$ 0.53 $GeV^2$ |
| rare decays | $B_s \to \mu\mu$ | 17 | $< 5.7$ | | New Physics search |
| | $B_d \to K^*\gamma$ | 35k | $< 0.7$ | | $\sigma(A_{CP}^{dir}) \approx 0.01$ |

# Conclusions

- $B_d$, $B_u$, $B_s$ and $B_c$ systems studied at an unprecedented level of accuracy
- $B_s - \overline{B}_s$ oscillations measured
- CP angles determined via channels with different sensitivity to NP
- Many measurements of rare decays and CP asymmetries performed
- b-baryon, c Physics ...

# Conclusions

- $B_d$, $B_u$, $B_s$ and $B_c$ systems studied at an unprecedented level of accuracy
- $B_s - \overline{B}_s$ oscillations measured
- CP angles determined via channels with different sensitivity to NP
- Many measurements of rare decays and CP asymmetries performed
- b-baryon, c Physics ...

**2 $fb^{-1}$ (1 year)**

- $\Delta m_s < 68\ ps^{-1}$ ($5\sigma$)
- $\sigma(\Delta m_s) \approx 0.02 ps^{-1}$
- $\sigma(\phi_s) \approx 2^o$
- $\sigma(\alpha) \approx 10^o$
- $\sigma(\beta) \approx 0.9^o$
- $\sigma(\gamma) \approx 5^o$

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LHCb

# Conclusions

LHCb offers an excellent opportunity to spot New Physics signals beyond Standard Model and will be ready in 2007

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