LHCb Performance on $B_{d,s} \to h^+h^-$ Measurements

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INFN Bologna

(for the LHCb Collaboration)

PHYSICS AT LHC

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Overview

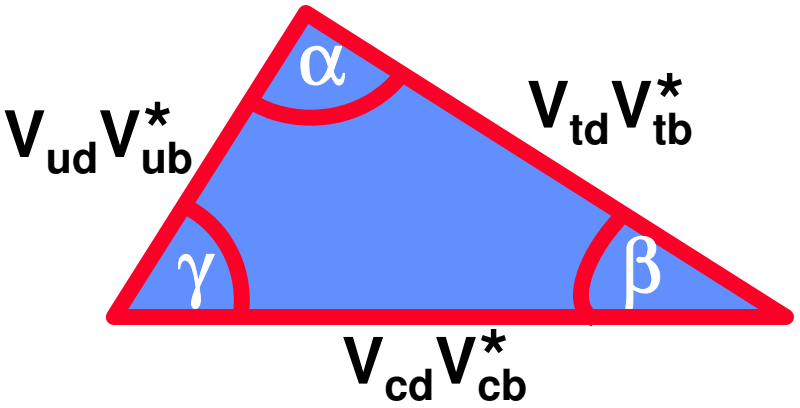
- Physics Motivation
- Event selection
- Sensitivity on CP-violating observables
- Determination of the γ angle of the unitarity triangle
- Conclusions

Physics Motivation

- LHCb can collect large samples of $B_{(d,\,s)} \to h^+h^-$ decays
  - $B_d \to \pi+ \pi-$ $B_d \to K+ \pi-$ $B_s \to \pi+ K-$ $B_s \to K+ K-$
- Due to large penguin contributions the $B_d \to \pi+ \pi-$ channel does no longer provide a clean strategy to extract $\sin(2\alpha)$ …
- … but the combined determination of the $B_d \to \pi+ \pi-$ and $B_s \to K+ K-$ CP asymmetries can be used to extract γ

R. Fleischer, Phys. Lett. B459 (1999)

$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right)$$

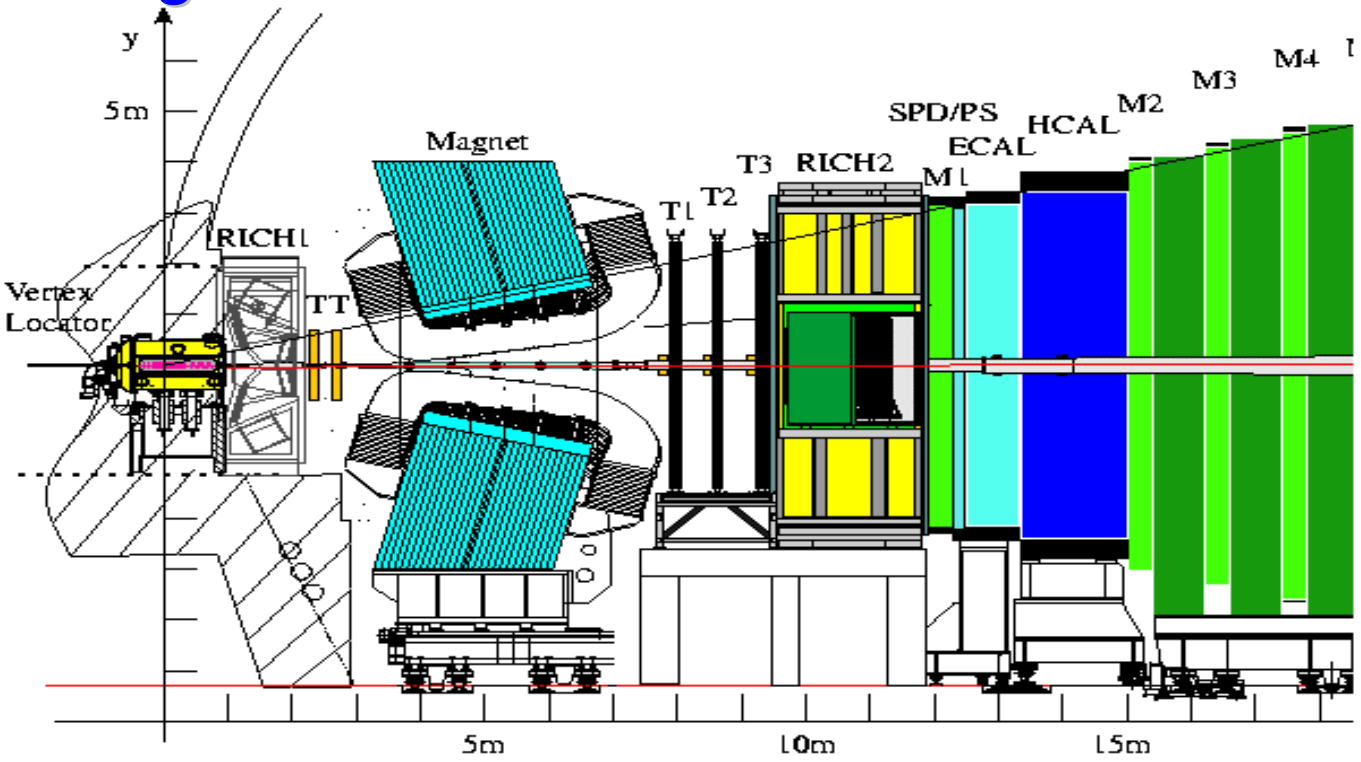


LHCb re-optimized detector

Material reduction:

- Cut the tracking stations by 1/2
- Improved RICH-1 design
- Improved VELO design

Material up to RICH-2 now:
40% X_0 12% λ_I



Event simulation

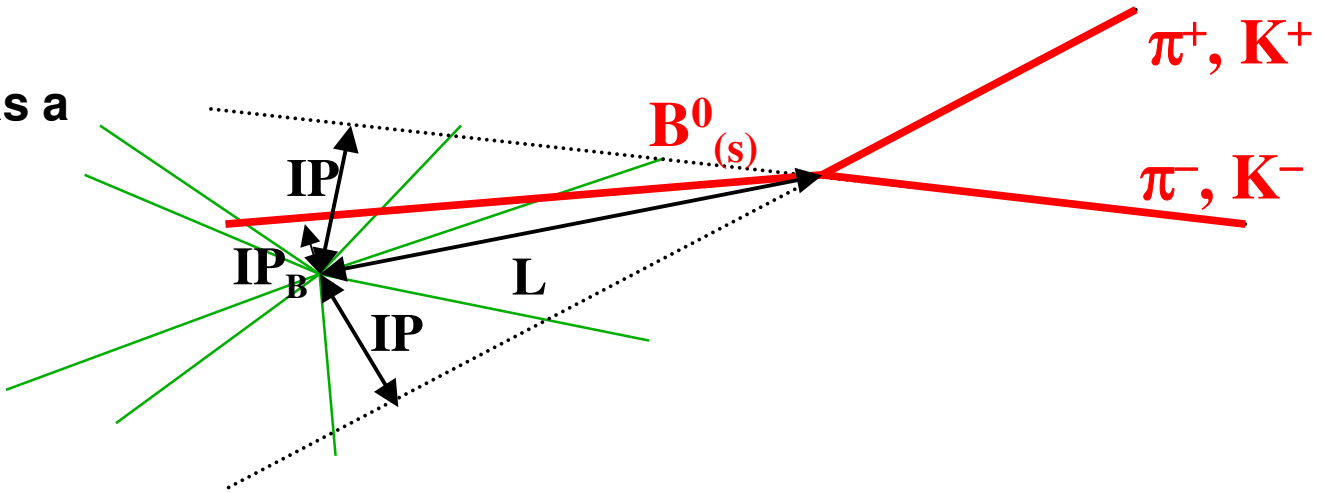
- **Full GEANT simulation**
- **Full Pattern Recognition**
- **Selection cuts optimized separately for each decay under study to maximize efficiency and reject backgrounds**
- **Two sources of background considered**
  - Two-charged-body decays of b-hadrons (particle mis-identification)
  - Inclusive bb decays (combinatorial background)
- **MC samples used:** **size (number of events)**
  - $B_s \rightarrow \pi+ \pi-$ 300k
  - $B_s \rightarrow K+ K-$ 300k
  - $B_d \rightarrow K+ \pi-$ 50k
  - $B_s \rightarrow \pi+ K-$ 50k
  - $\Lambda_b \rightarrow p K-$ 50k
  - $\Lambda_b \rightarrow p \pi-$ 50k
  - inclusive bb 10M

Selection cuts

- **Charged tracks**
  - Each leg identified as a π or K

  Cuts on
  - p
  - max. p_T
  - min. p_T
  - max. IP/σ_{IP}
  - min. IP/σ_{IP}
  - χ^2 of common vertex
- **B candidate:**

  Cuts on
  - p_T
  - IP/σ_{IP}
  - L/σ_L
  - mass



- Assume combinatorial background to be dominated by generic bb events
- With these cuts we can reject all generated bb background also when relaxing mass cut

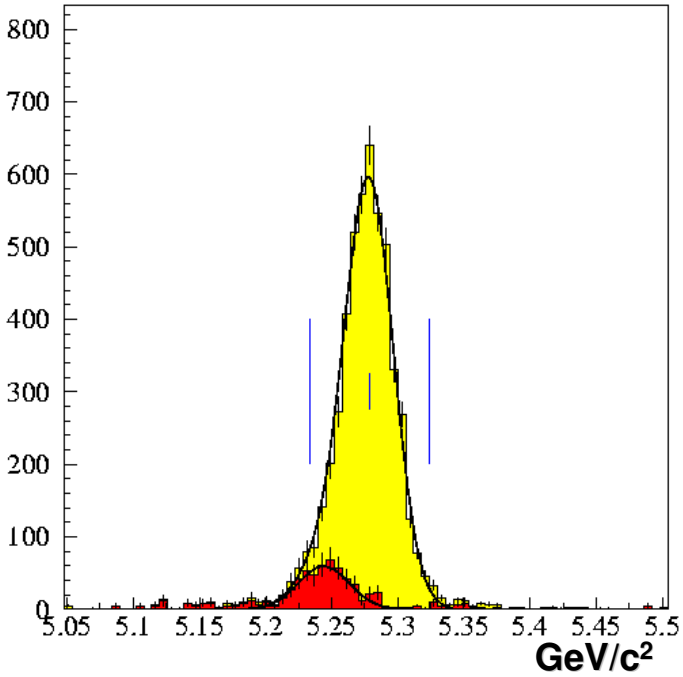
Rejection of two-body background

Relying on

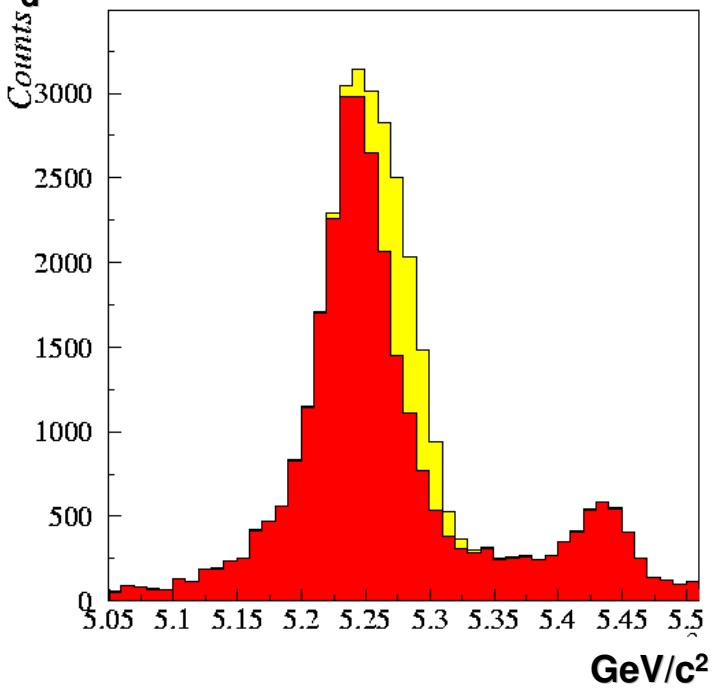
- Particle ID performance (RICH)
- mass resolution (~18 MeV/c^2)

Channel	BR $\times 10^6$	
$B^0 \to \pi^+ \pi^-$	4.8	measured
$B^0 \to K^+ \pi^-$	18.5	measured
$B^0_s \to \pi^+ K^-$	4.8	assumed
$B^0_s \to K^+ K^-$	18.5	assumed
$\Lambda_b \to \pi^- p$	4.8	assumed
$\Lambda_b \to K^- p$	18.5	assumed

$B_d \to \pi+ \pi-$ mass with RICH PID



$B_d \to \pi+ \pi-$ mass without RICH PID



Annual yields and B/S ratios

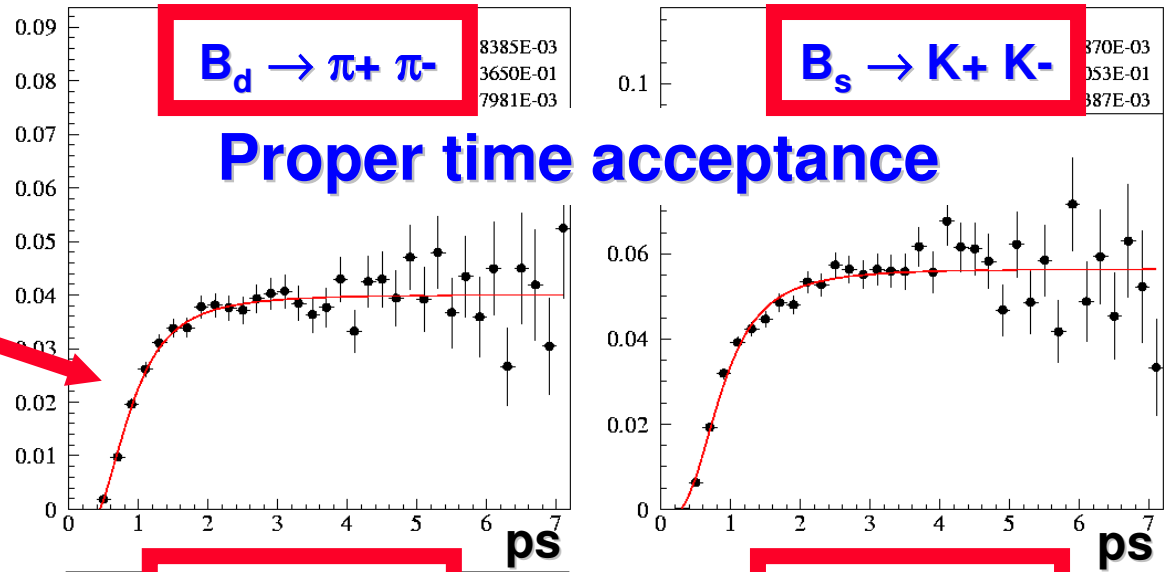
- Annual yields after L0xL1 triggers and offline selection
- B/S include physics and combinatorial background

Event type	B/S (90% CL)	Untagged annual yield
$B_d \rightarrow \pi+ \pi-$	< 0.7	27000
$B_d \rightarrow K+ \pi-$	< 0.35	139000
$B_s \rightarrow K+ K-$	< 0.3	38000
$B_s \rightarrow \pi+ K-$	< 1.6	5400

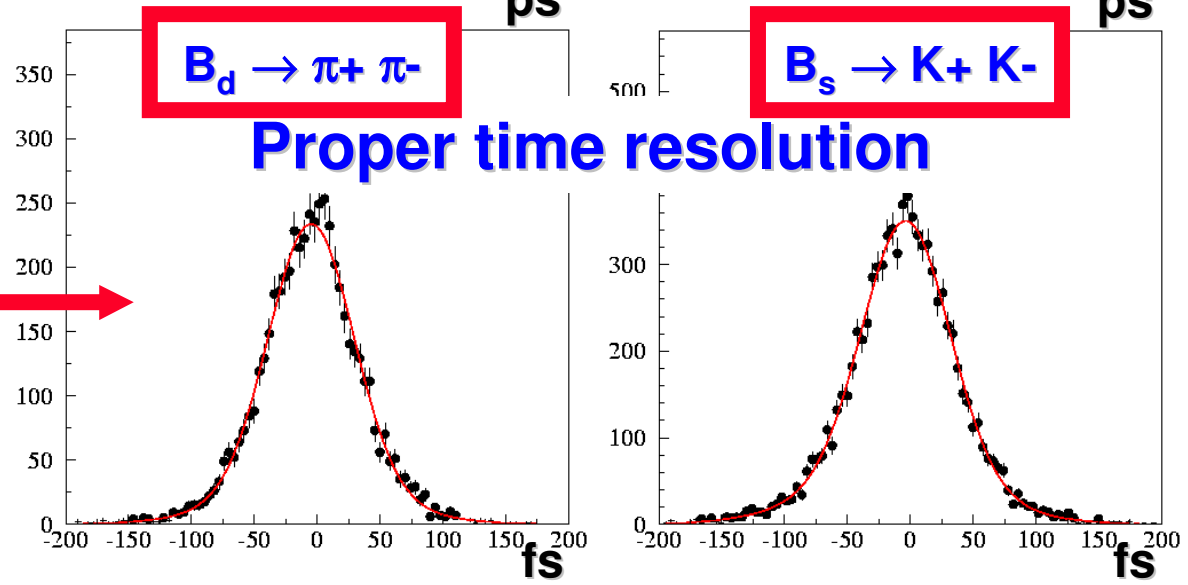
$B_d \to \pi+ \pi-$ $B_s \to K+ K-$

Proper time acceptance and resolution

Acceptance loss due to cuts to reject prompt combinatorics (distance of flight, IP)



Excellent proper time resolution ~40 fs



$B_d \to \pi+ \pi-$ $B_s \to K+ K-$ CP sensitivities

- Tagged event samples generated by means of a fast MC

	$B_d \to \pi+ \pi-$	$B_s \to K+ K-$
Annual event yield	27000	38000
Background-to-signal ratio	0.7	0.3
ΔM (ps^{-1})	0.5	14
Tagging Power εD^2	4%	6%
A_{CP}^{dir}	-0.30	0.16
A_{CP}^{mix}	0.58	-0.17

fast MC inputs

Values used as illustrative example

- Assume identical lifetime for signal and background
- Assume negligible CP violation in the background

Preliminary assumptions: need more study and MC statistics

Max likelihood method to extract CP asymmetries

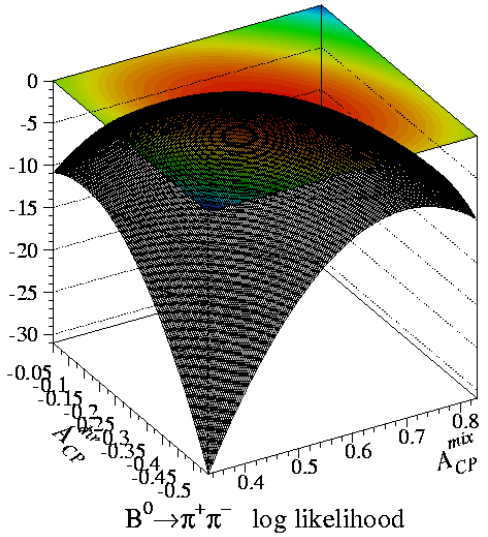
- One year of data taking

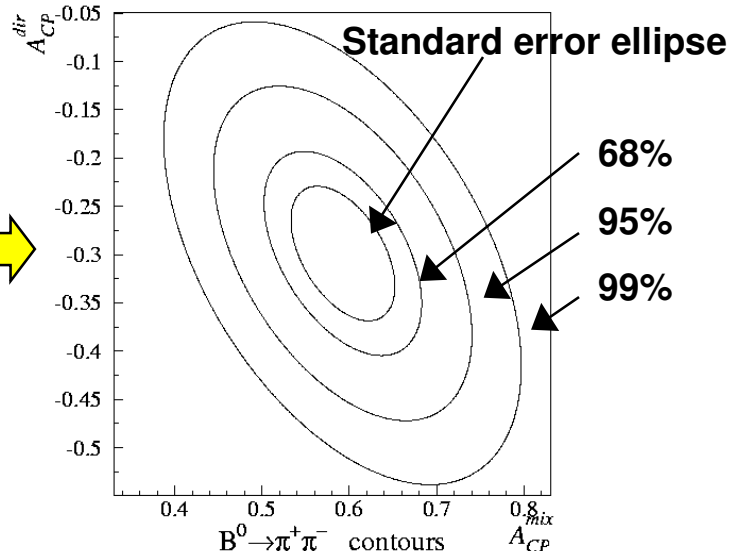
$B^0 \to \pi^+ \pi^-$

$$\sigma(A_{CP}^{dir}) \cong 0.07$$

$$\sigma(A_{CP}^{mix}) \cong 0.06$$

$$Corr\,(A_{CP}^{dir},\ A_{CP}^{mix}) \cong -0.49$$



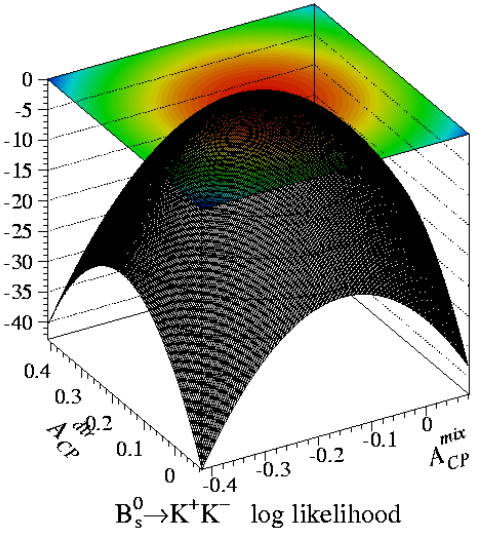


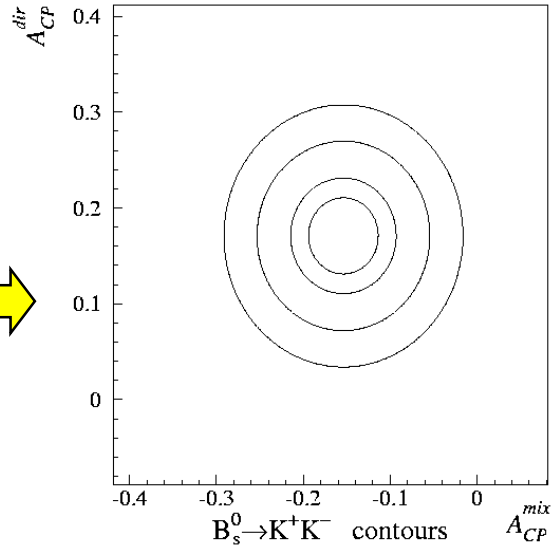
$B_s \to K^+ K^-$

$$\sigma(A_{CP}^{dir}) \cong \sigma(A_{CP}^{mix}) \cong 0.04$$

$$Corr\,(A_{CP}^{dir},\ A_{CP}^{mix}) \cong 0$$

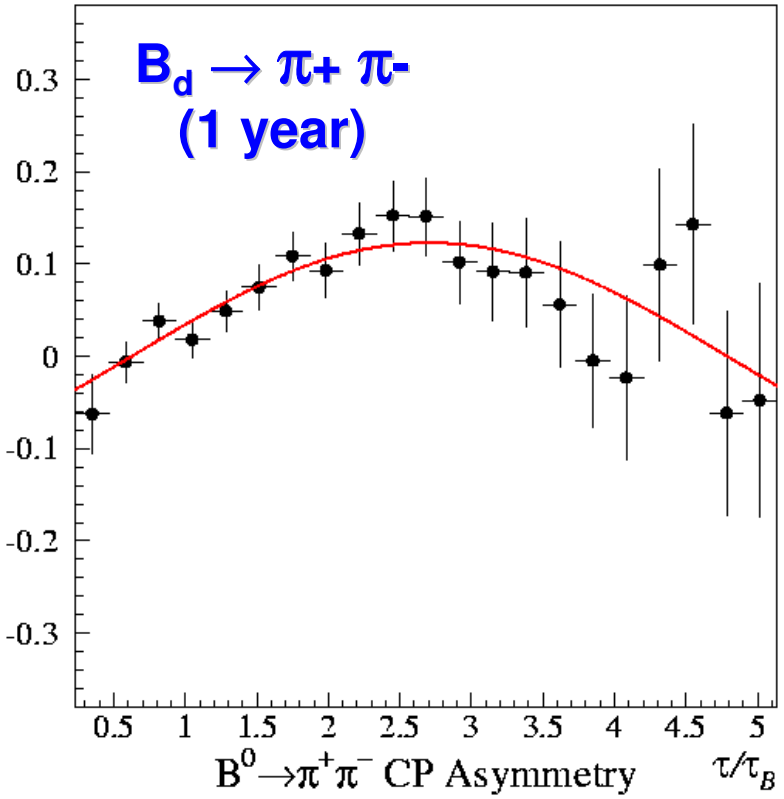
$$@\ \Delta\Gamma_s = 0 \quad \Delta M_s = 14\,ps^{-1}$$

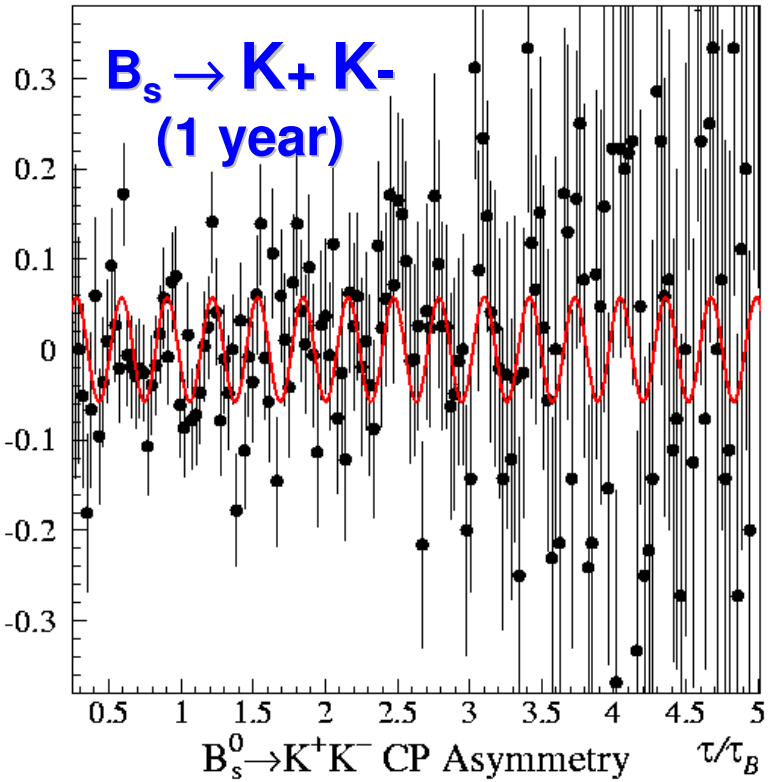




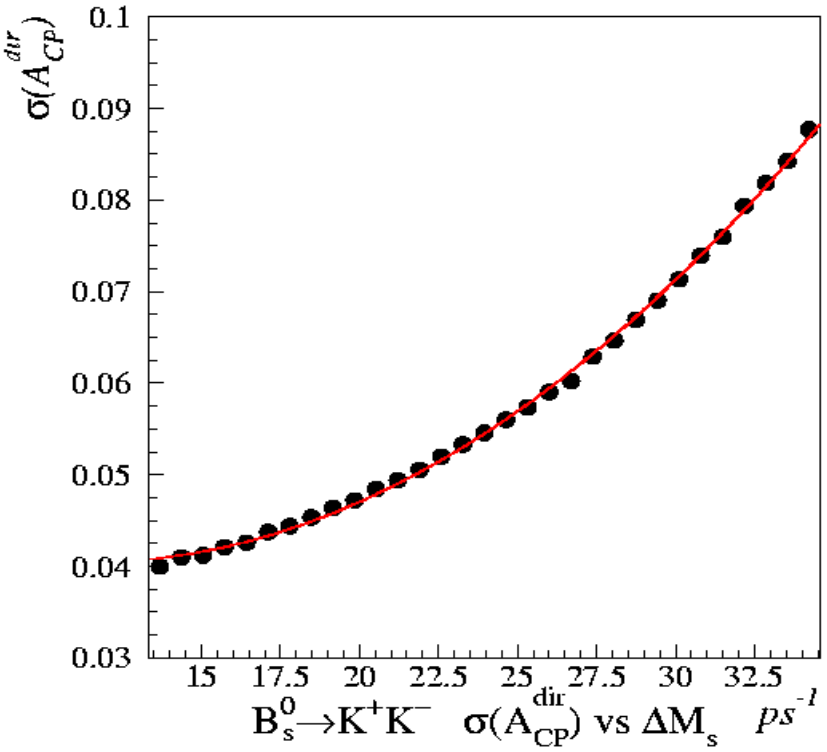
Example of binned asymmetries

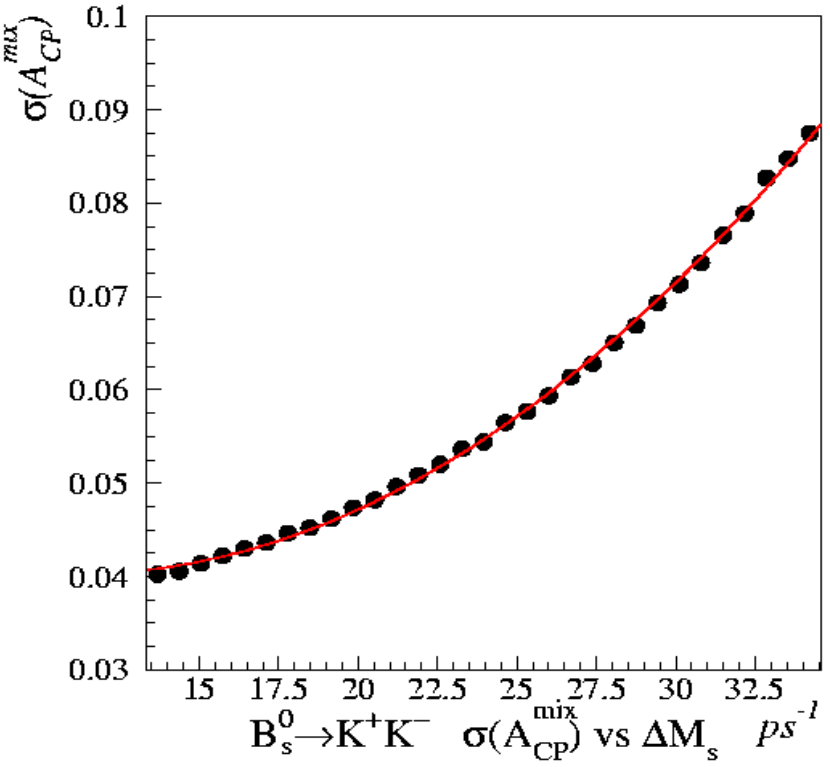
- Results of log likelihood fit superimposed on binned asymmetries





$B_s \rightarrow K+ K-$ Dependence of CP sensitivity on ΔM_s





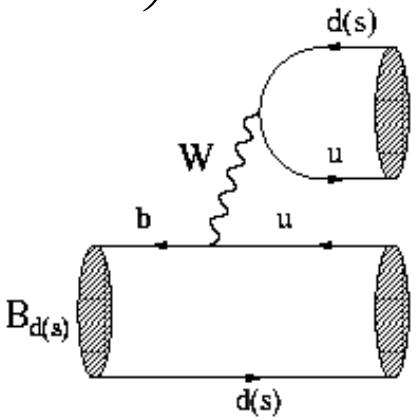
- $\Delta M_s > 14.1\ ps^{-1}$ (PDG 2003, CL 95%)
- Error increases by a factor ~1.7 from ΔM_s=15 ps^{-1} to ΔM_s=30 ps^{-1}

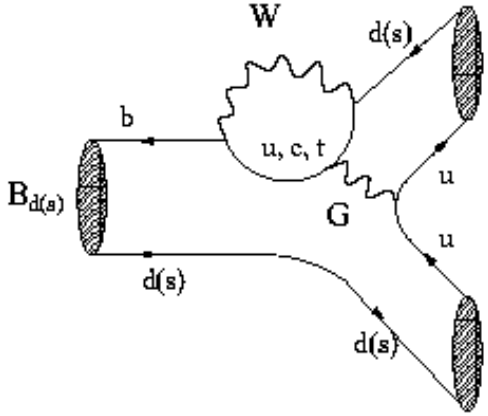
Strategy to extract γ

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

Details in:
R. Fleischer, PLB 459 (1999) 306

$$A_{CP}^{dir}(B_d^0 \to \pi^+\pi^-) = f_1(d, \vartheta, \gamma)$$
$$A_{CP}^{mix}(B_d^0 \to \pi^+\pi^-) = f_2(d, \vartheta, \gamma, \phi_d)$$
$$A_{CP}^{dir}(B_s^0 \to K^+K^-) = f_3(d', \vartheta', \gamma)$$
$$A_{CP}^{mix}(B_s^0 \to K^+K^-) = f_4(d', \vartheta', \gamma, \phi_s)$$





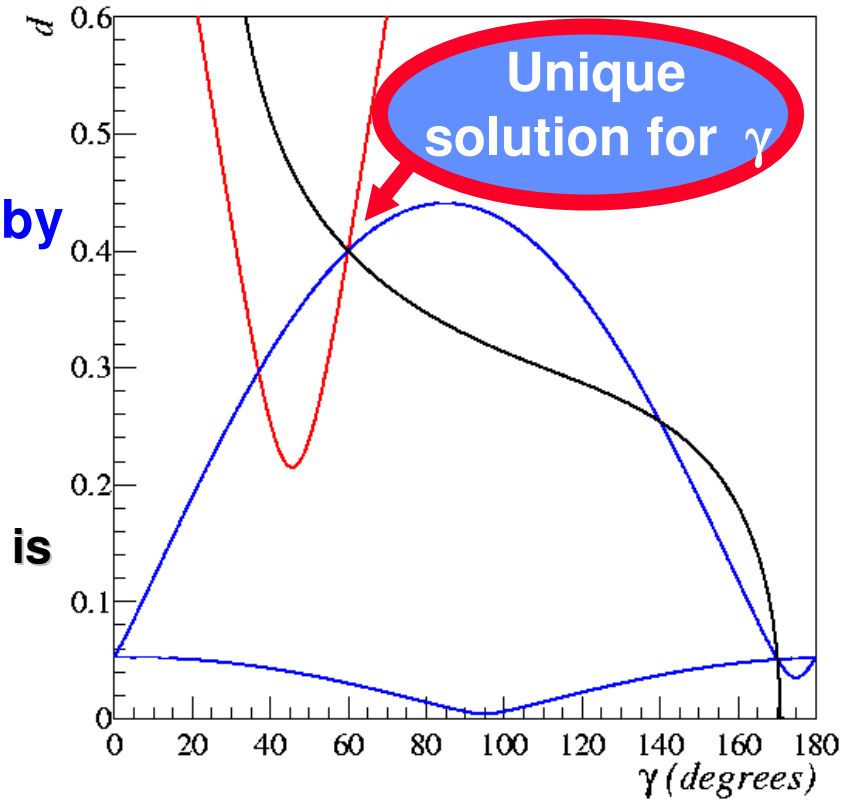
- $d \exp(i\vartheta)$ = function of Tree and Penguin amplitudes in $B_d \to \pi^+\pi^-$
- $d' \exp(i\vartheta')$ = function of Tree and Penguin amplitudes in $B_s \to K^+K^-$
- ϕ_d = B_d mixing phase
- ϕ_s = B_s mixing phase
- γ
- Measuring the four CP-violating observables: 7 unknowns and 4 equations

Using U-spin symmetry of strong interactions

- $B_d \to \pi^+ \pi^-$ and $B_s \to K^+ K^-$ decays are related to each other by interchanging all *d* and *s* quarks.

$$\text{U-spin flavour symmetry} \Rightarrow \begin{cases} d = d' \\ \vartheta = \vartheta' \end{cases}$$

- The mixing phases ϕ_d and ϕ_s are measured by the decays $B_d \to J/\psi\, K_s$ and $B_s \to J/\psi\, \phi$
- Four equations and 3 unknowns
  - Within the validity of U-spin symmetry the system can be solved …
  - … but the size of U-spin symmetry breaking is still an open question



- This illustrative example:

$$\phi_d = 51^\circ \quad \phi_s = 0^\circ \quad d = d' = 0.4$$

$$\vartheta = \vartheta' = 140^\circ \quad \gamma = 60^\circ$$

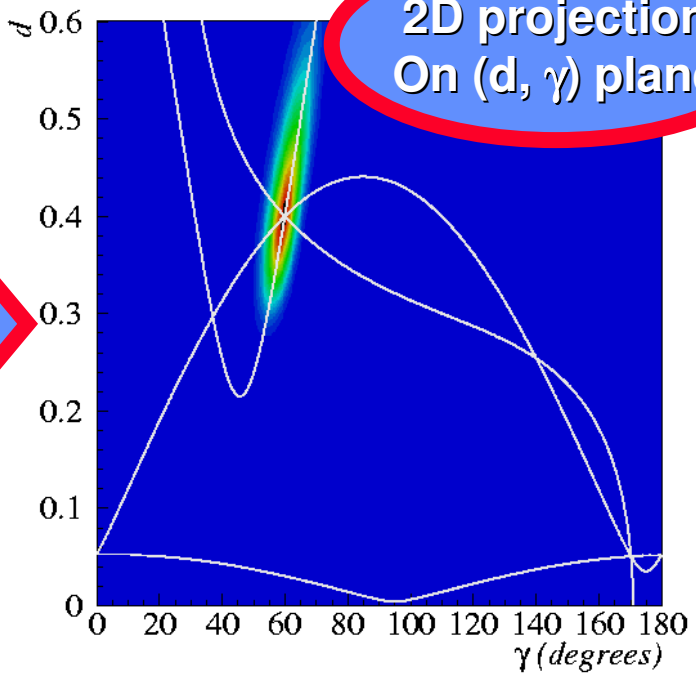
$$A_{CP}^{dir}(B_d) = -0.30 \quad A_{CP}^{mix}(B_d) = 0.58$$

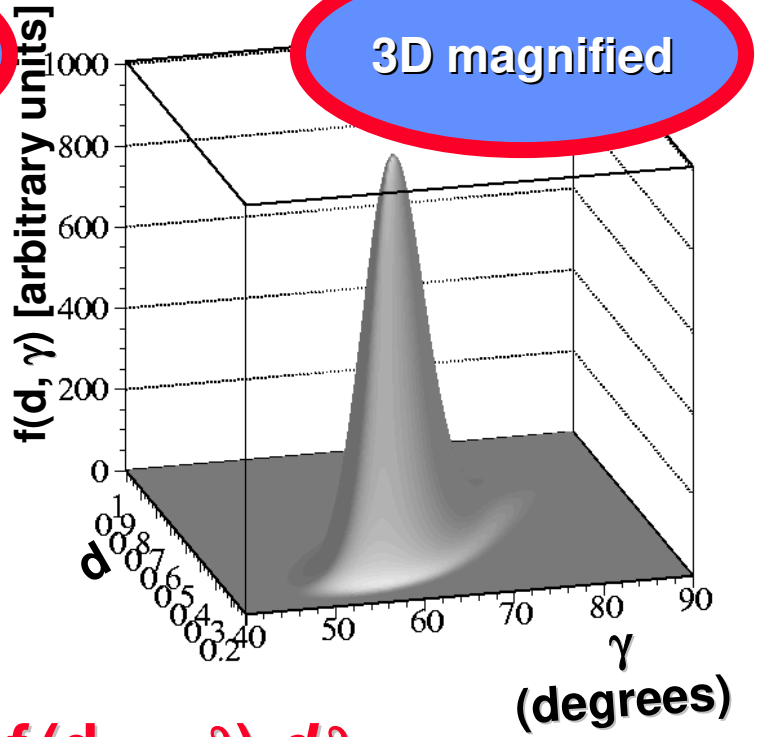
$$A_{CP}^{dir}(B_s) = 0.16 \quad A_{CP}^{mix}(B_s) = -0.17$$

Bayesian approach to determine γ

- Infer a joint p.d.f. $f(d, \gamma, \vartheta)$ by using the four CP asymmetry coefficients as constraints

Joint p.d.f. for d and γ (1 year)



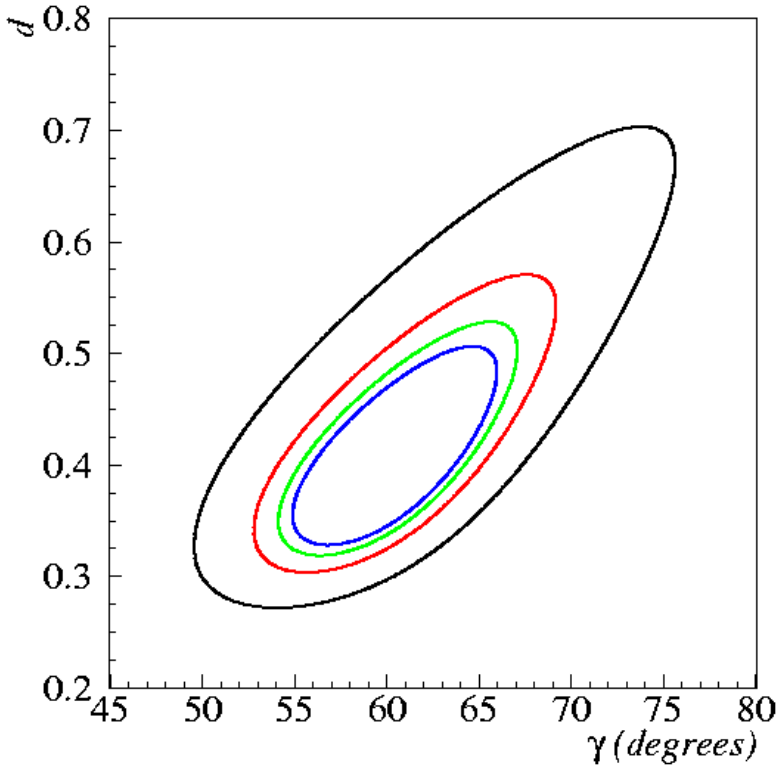


$$f(d, \gamma) = \int f(d, \gamma, \vartheta)\, d\vartheta$$

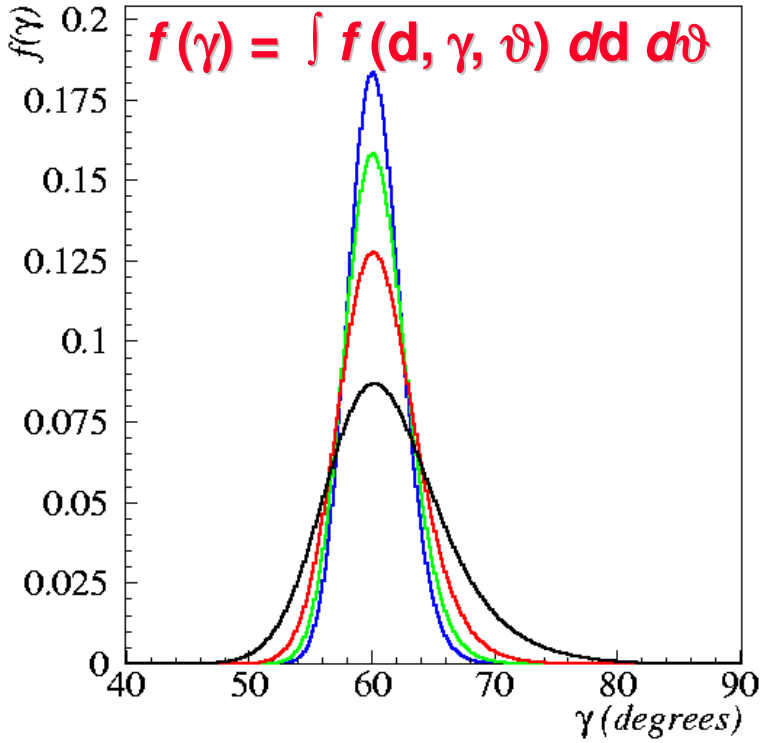
Resolution on γ

1 year
2 years
3 years
4 years

95% confidence region for d and γ



p.d.f. for γ



- **R.M.S. of *f* (γ) after 4 years: 2.2º (for γ = ~60º)**

Conclusions

- The current simulations show large event yields for the decays $B_{d,s} \to h^+h^-$

Event type	B/S (90% CL)	Annual yield
$B_d \to \pi+ \pi-$	< 0.7	27000
$B_d \to K+ \pi-$	< 0.35	139000
$B_s \to K+ K-$	< 0.3	38000
$B_s \to \pi+ K-$	< 1.6	5400

- CP sensitivities for $B_d \to \pi+ \pi-$ and $B_s \to K+ K-$ (one year of data taking)

$B_d \to \pi+ \pi-$

$$\sigma(A_{CP}^{dir}) \cong 0.07$$

$$\sigma(A_{CP}^{mix}) \cong 0.06$$

$$Corr\,(A_{CP}^{dir},\ A_{CP}^{mix}) \cong -0.49$$

$B_s \to K+ K-$

$$\sigma(A_{CP}^{dir}) \cong \sigma(A_{CP}^{mix}) \cong 0.04$$

$$Corr\ (A_{CP}^{dir},\ A_{CP}^{mix}) \cong 0$$

$$@\ \Delta\Gamma_s = 0 \quad \Delta M_s = 14\,ps^{-1}$$

- Combining the $B_d \to \pi+ \pi-$ and $B_s \to K+ K-$ CP measurements it is possible to extract the gamma angle (within U-spin symmetry validity)
- Resolution on γ: 2.2° after 4 years of data taking (for γ = ~60°)