Interplay between Collider and Flavour Physics
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Exploring CP violation @LHC (mostly LHCb)

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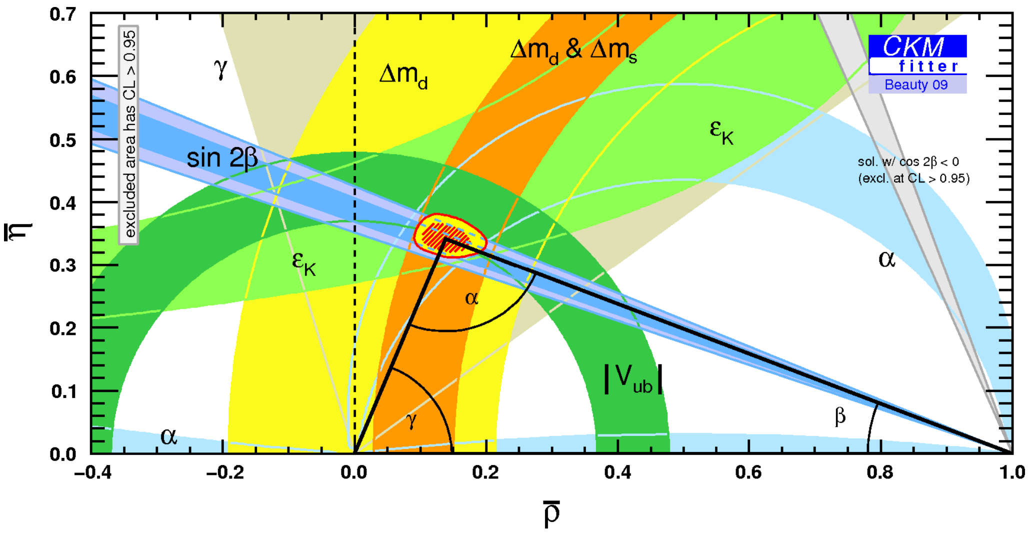
The synergy (or competition?)

- Collider: direct search for new particles
- Flavour physics: indirect search for new couplings beyond the usual Yukawa matrix
  - "unexpected" phenomena in loop processes
    - measurements of decay rates, rate asymmetries, angular distributions, Lorentz structures, …
  - new CP-violating phases beyond CKM
    - precision measurements of CP asymmetries, unitarity angles, CKM elements

This talk!

Status of CKM unitarity test

Measurements of ε_K, UT sides and angles are in astonishing agreement in constraining apex of the “db” UT!



- Stringent constraint on new physics contribution in B_d mixing
- Not everything well measured
- Size of new physics contribution in B_s mixing and b→s penguin decays still unconstrained
- Some hints of discrepancies with the SM await verification with higher precision at LHC.

angle	Direct measurement	Fit (excl. dir. meas.)
α	89.0 [+4.4, -4.2]	92.2 [+6.4, -6.3]
β	21.15 [+0.90, -0.88]	26.5 [+1.3, -1.7]
γ	75 [+19, -25]	67.7 [+4.5, -3.7]

“Anomalies” in b→s transitions

- SM prediction (CKM fitter):

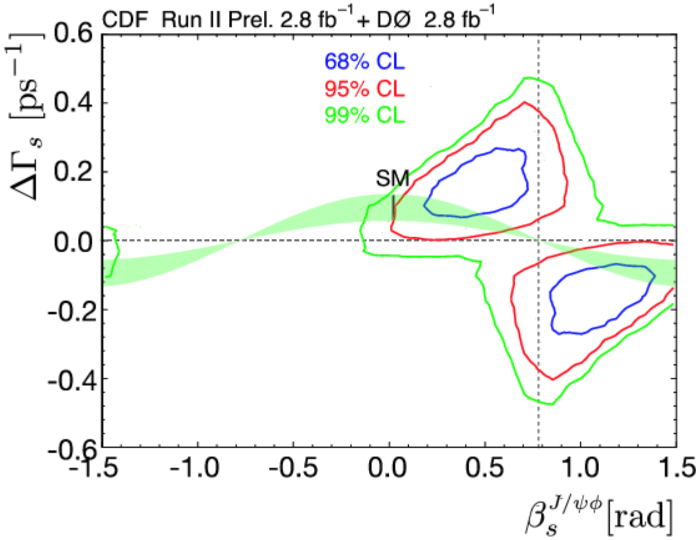
  $\Phi_s = -0.036 \pm 0.002$
- CDF+D0 (2.8fb^{-1} each):

  $\Phi_s \equiv -2\beta_s \in [0.54, 1.18] \cup [1.94, 2.60]$

  at 68% CL

  P-value of SM is 3.4% or 2.12σ

  (CDF public note 9798)

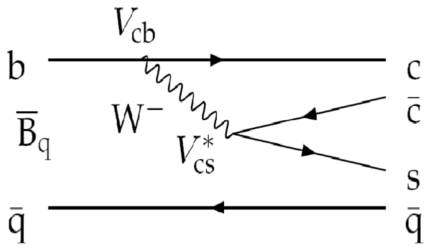


Some puzzles require more understanding of hadronic amplitudes as well as better measurement precision

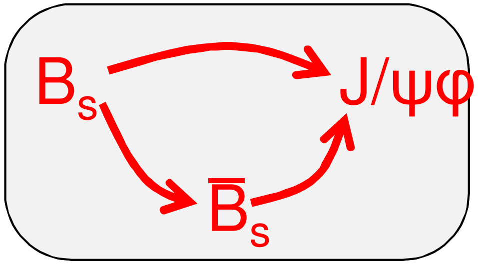
- sin(2β^{eff}) ≈ or ≠ sin(2β) in b→s penguin modes?
- $A_{dir}(B^+ \rightarrow \pi^0 K^+) \neq A_{dir}(B^0 \rightarrow \pi^- K^+)$ at 5 σ

Path1: Search for NP in B_s mixing

$B_s \to J/\psi\phi$ is dominated by a tree diagram, which is free of new physics contribution.

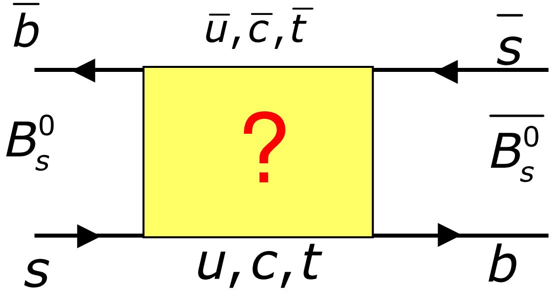


CP violation arising from interference between decay with and without mixing is proportional to the B_s mixing phase Φ_s


$$\begin{tikzcd} B_s \arrow[r] \arrow[d] & J/\psi\phi \\ \overline{B}_s \arrow[ur] & \end{tikzcd}$$

SM value of Φ_s is precisely predicted to be $\Phi_s^{SM} = -0.036 \pm 0.002$

Φ_s is sensitive to CP-violating new physics in $\Delta B=2$ and $\Delta S=2$ operators



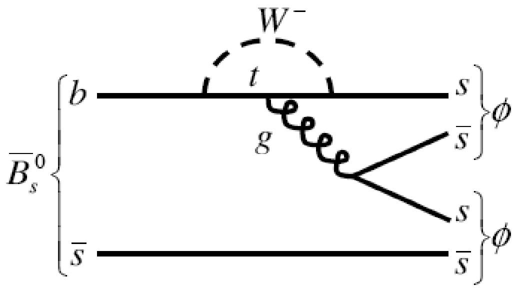
$\Phi_s(J/\psi\phi) = \Phi_s^{SM}$?

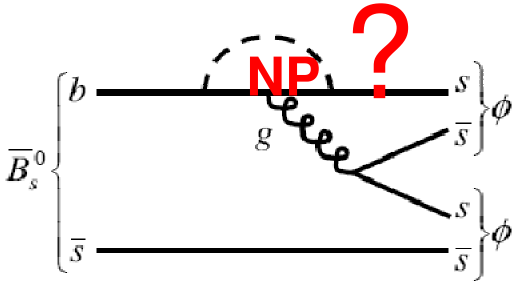
Path 2: Search for NP in b→s penguin

- CP violating new phases in b →s penguin decay $B_s \to \phi\phi$ can make

  $\Phi_s(\phi\phi) \neq 0$

  SM expectation of $\Phi_s(\phi\phi)$ vanishes due to phase cancellation between decay and mixing



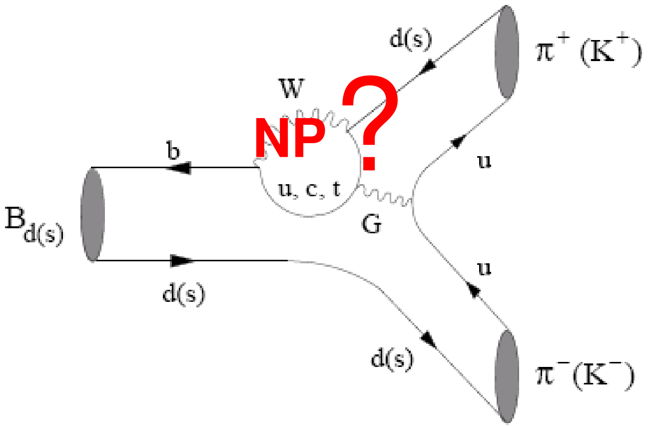


- Similarly, CP violating new phases in b →s penguin diagram for $B_s \to KK$ will make

  γ(loop-induced) ≠ γ(tree-level)

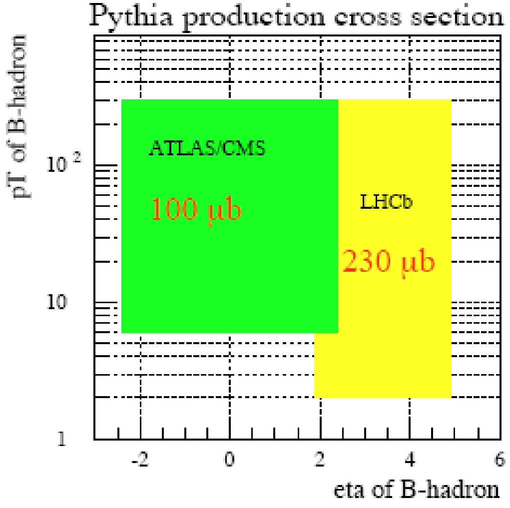
  Loop-induced: B→hh

  Tree level: B→DK, $B_s \to D_sK$

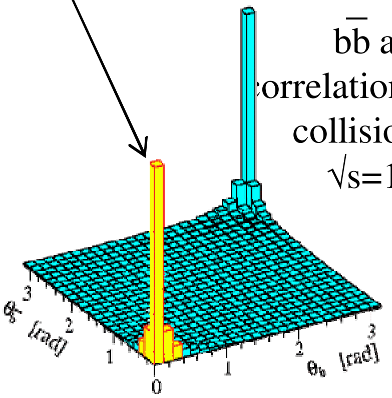


LHC is full of beauty

- ATLAS/CMS:
  - central detectors, $|\eta|<2.5$
  - B physics using high-p_T muon triggers, mostly with modes involving dimuon
- LHCb:
  - designed to maximize B acceptance (within cost and space constraints)
  - forward spectrometer, $1.9 < \eta < 4.9$
  - relying on much softer, lower p_T triggers
  - efficient also for purely hadronic B decays



LHCb sees 40% cross section



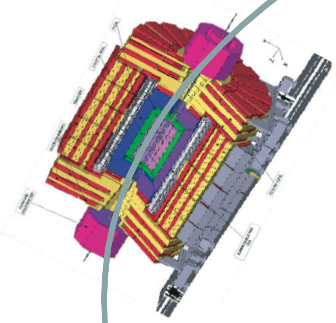
$b\bar{b}$ angular correlation in pp collisions at $\sqrt{s}$=14 TeV

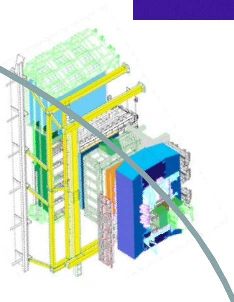
σ_{bb} = 500 μb at 14 TeV→ 10^{12} bb events in

L_{int} = $2fb^{-1}$ (1 nominal year 10^7 s at $2x10^{32}$ $cm^{-2}s^{-1}$)

B_d: B_u: B_s =40%: 40%: 10%

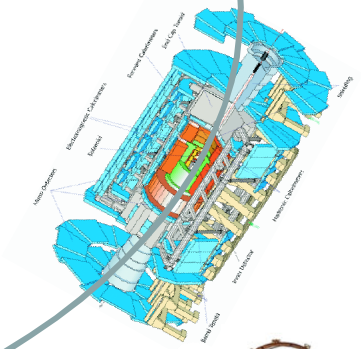
… and beauty pursuers





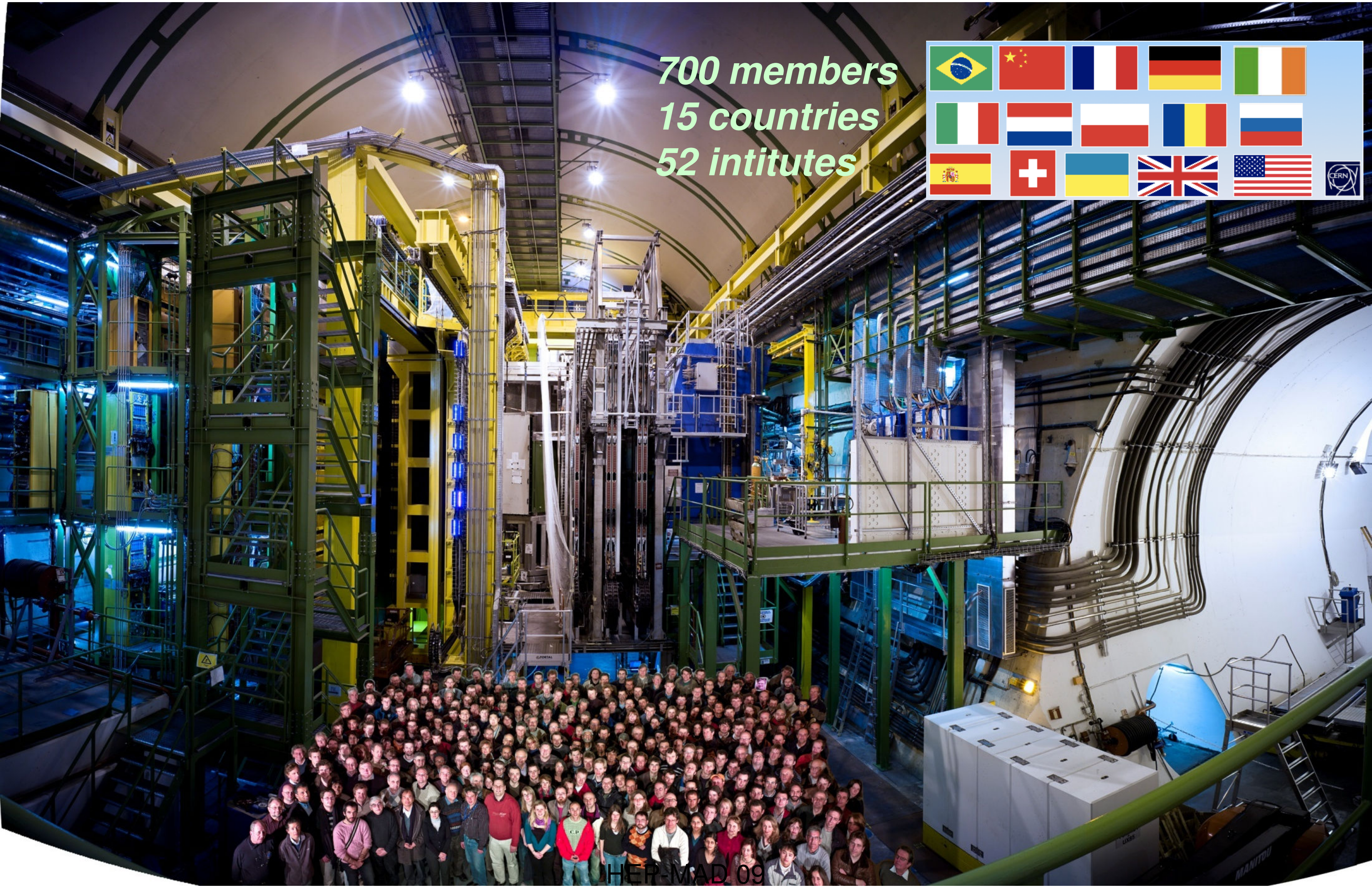
A wide range of precision measurements in B (or charm) decays. Key CP measurements include

1) B_s mixing phase Φ_s from tree-level decay
2) B_s mixing phase Φ_s from penguin decay
3) UT angle γ from tree level decay
4) UT angle γ from loop-induced decay
5)CPV in charm decays



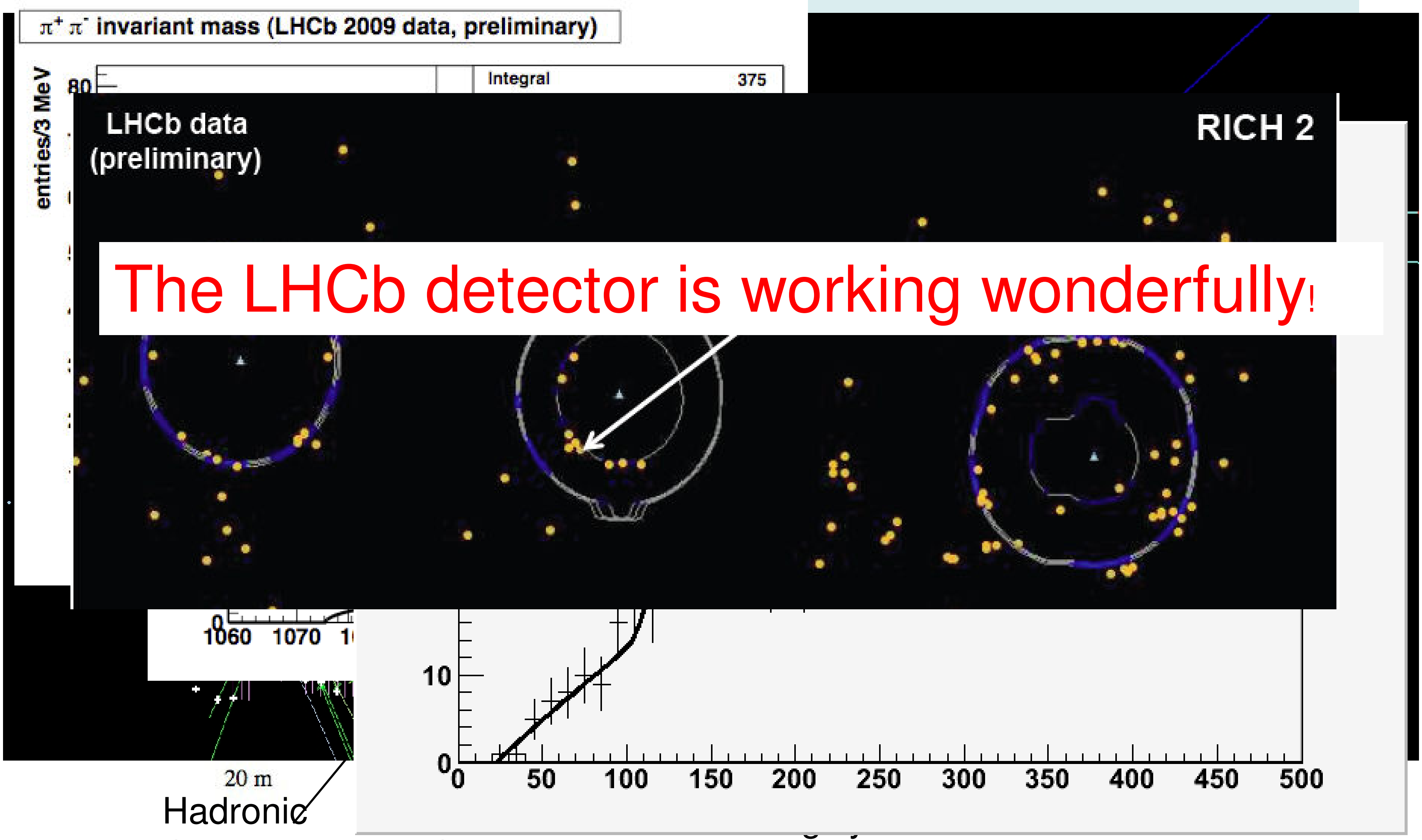
LHCb will measure 1, 2, 3, 4, 5
ATLAS, CMS have sensitivity to 1

The LHCb Collaboration



700 members
15 countries
52 intitutes

LHCb detector



The LHCb detector is working wonderfully!

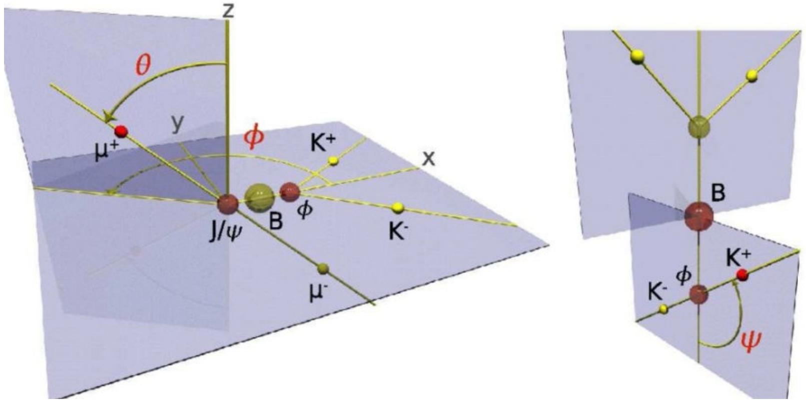
Hadronic
Calorimeter

Calorimeter

Φ_s from $B_s \rightarrow J/\psi(\mu\mu)\phi(KK)$

- Analysis method and sensitivity
- Systematics
- Theoretical uncertainties

Differential rates



P→VV decay : mixture of CP-even (ℓ=0,2) and CP odd (ℓ=1) final states. An angular analysis allows to separate statistically the decay amplitudes.

3 angles $\Omega=(\theta, \phi, \psi)$ to describe the final decay products directions.

Differential decay rate:

$$\frac{d^4\Gamma(\mathrm{B_s^0} \to \mathrm{J}/\psi\phi)}{dt\; d\cos\theta\; d\varphi\; d\cos\psi} \equiv \frac{d^4\Gamma}{dt\; d\Omega} \propto \sum_{k=1}^{6} h_k(t) f_k(\Omega)$$

B_s

$\overline{B}_s$

A_0 (0) → CP even
$A_{||}$ (0) → CP even
$A_\perp$ (0) → CP odd

k	$h_k(t)$	$\bar{h}_k(t)$	$f_k(\theta,\psi,\varphi)$
1	$\lvert A_0(t)\rvert^2$	$\lvert \bar{A}_0(t)\rvert^2$	$2\cos^2\psi(1-\sin^2\theta\cos^2\varphi)$
2	$\lvert A_{\vert\vert}(t)\rvert^2$	$\lvert \bar{A}_{\vert\vert}(t)\rvert^2$	$\sin^2\psi(1-\sin^2\theta\sin^2\varphi)$
3	$\lvert A_\perp(t)\rvert^2$	$\lvert \bar{A}_\perp(t)\rvert^2$	$\sin^2\psi\sin^2\theta$
4	$\Im\{A_{\vert\vert}^*(t)A_\perp(t)\}$	$\Im\{\bar{A}_{\vert\vert}^*(t)\bar{A}_\perp(t)\}$	$-\sin^2\psi\sin 2\theta\sin\varphi$
5	$\Re\{A_0^*(t)A_{\vert\vert}(t)\}$	$\Re\{\bar{A}_0^*(t)\bar{A}_{\vert\vert}(t)\}$	$\frac{1}{\sqrt{2}}\sin 2\psi\sin^2\theta\sin 2\varphi$
6	$\Im\{A_0^*(t)A_\perp(t)\}$	$\Im\{\bar{A}_0^*(t)\bar{A}_\perp(t)\}$	$\frac{1}{\sqrt{2}}\sin 2\psi\sin 2\theta\cos\varphi$

Time dependences

$$|A_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \cos\Phi \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin\Phi \sin(\Delta m_s t)\right]$$

$$|A_\parallel(t)|^2 = |A_\parallel(0)|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \cos\Phi \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin\Phi \sin(\Delta m_s t)\right]$$

$$|A_\perp(t)|^2 = |A_\perp(0)|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + \cos\Phi \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - \sin\Phi \sin(\Delta m_s t)\right]$$

$$\Im\{A_\parallel^*(t)A_\perp(t)\} = |A_\parallel(0)||A_\perp(0)|e^{-\Gamma_s t}\left[-\cos(\delta_\perp - \delta_\parallel)\sin\Phi \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp - \delta_\parallel)\cos\Phi \sin(\Delta m_s t)\right]$$

$$\Re\{A_0^*(t)A_\parallel(t)\} = |A_0(0)||A_\parallel(0)|e^{-\Gamma_s t}\cos\delta_\parallel\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \cos\Phi \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin\Phi \sin(\Delta m_s t)\right]$$

$$\Im\{A_0^*(t)A_\perp(t)\} = |A_0(0)||A_\perp(0)|e^{-\Gamma_s t}\left[-\cos\delta_\perp \sin\Phi \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin\delta_\perp \cos(\Delta m_s t) - \cos\delta_\perp \cos\Phi \sin(\Delta m_s t)\right]$$

High sensitivity to Φ when B/$\bar{B}$ initial state is determined by flavour tagging

Some sensitivity to Φ from untagged analysis

Depend on 8 physics parameters: Φ, Γ_s, $\Delta\Gamma_s$, Δm_s, $R_\perp$, $R_\parallel$, $\delta_\perp$, $\delta_\parallel$

$$\Phi = \Phi^{\mathrm{SM}} + \phi_s^\Delta \qquad R_\perp = \frac{|A_\perp(0)|^2}{|A_\perp(0)|^2 + |A_\parallel(0)|^2 + |A_0(0)|^2}$$

$$\Gamma_s = \frac{\Gamma_L + \Gamma_H}{2} \qquad R_\parallel = \frac{|A_\parallel(0)|^2}{|A_\perp(0)|^2 + |A_\parallel(0)|^2 + |A_0(0)|^2}$$

$$\Delta\Gamma = \Gamma_L - \Gamma_H \qquad \delta_\perp = \arg(A_\perp(0)A_0^*(0))$$

$$\Delta m_s = M_H - M_L \qquad \delta_\parallel = \arg(A_\parallel(0)A_0^*(0))$$

Parameter extraction method

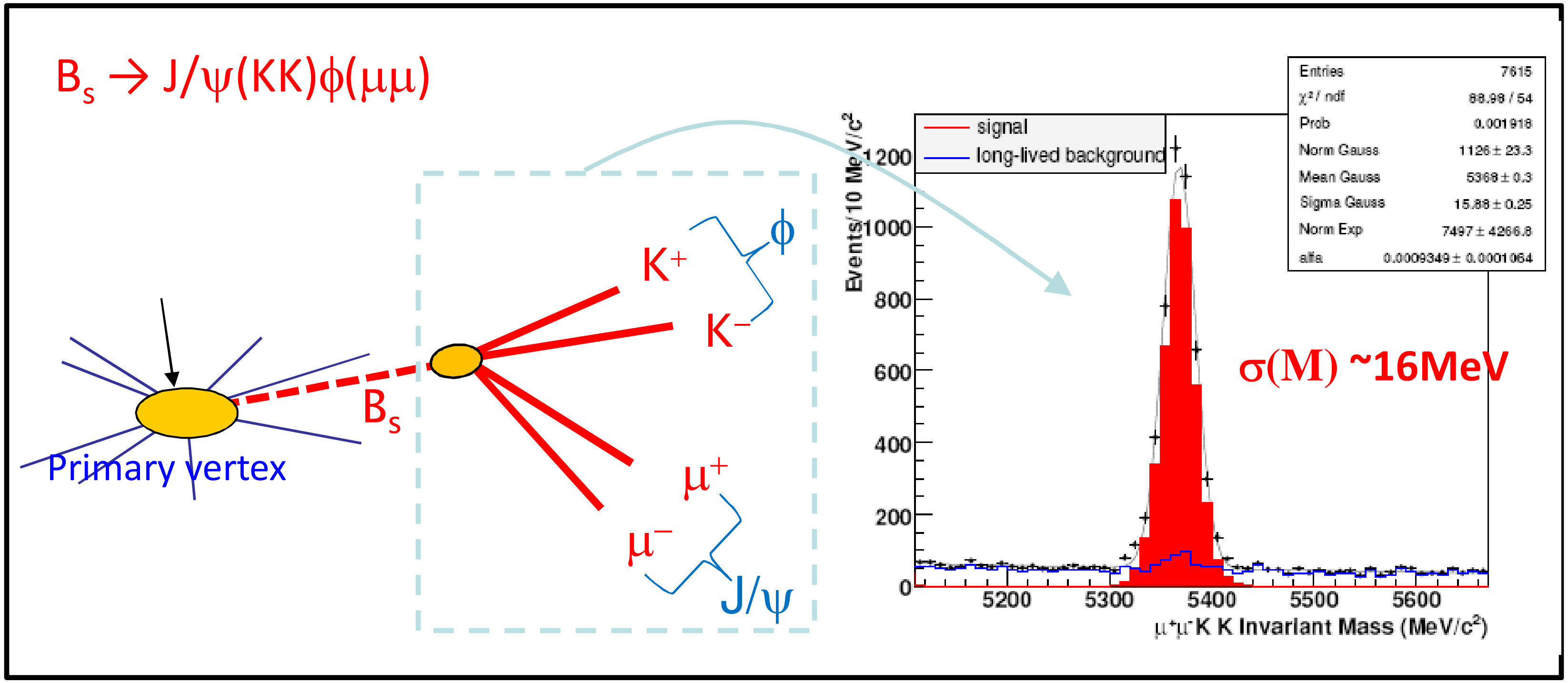
- Unbinned maximum likelihood fit
- Input
  - B_s invariant mass: to separate signal and background
  - angles $\Omega=(\theta, \phi, \psi)$: to separate different CP eigenstates
  - B flavour tag: pin down initial state of the decay
  - proper decay time: to extract Φ_s from its distribution
- Output
  - physics parameters $\Phi, \Gamma_s, \Delta\Gamma_s, \Delta m_s, R_\perp, R_\parallel, \delta_\perp, \delta_\parallel$
  - various detector parameters
- Sensitivity depends on
  - signal yield and background level
  - reconstruction quality of the input variables, particularly proper time and flavour tag

Event reconstruction

- Trigger on dimuon ε~70%
- Baseline event selection maximally preserves proper time and angular distributions
- Unified selection to also select
  - $B_d \rightarrow J/\psi K^*$ to check angular acceptance
  - $B^+ \rightarrow J/\psi K^+$ to calibrate opposite side tagging
- Copious signal yields with relatively low background

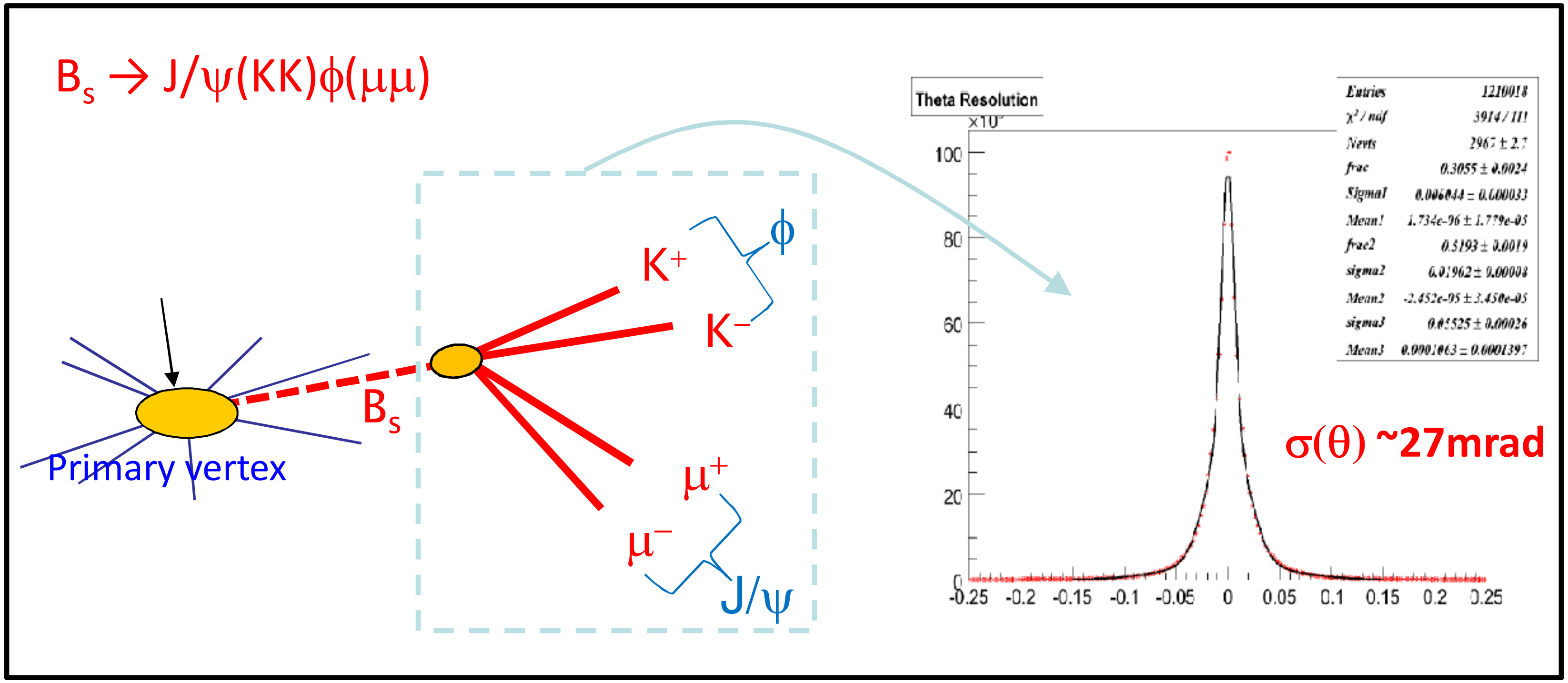
	Yield ($2fb^{-1}$)	B(bb)/S	B(prompt J/ψ)/S
$B_s \rightarrow J/\psi\phi$	117k	0.5	1.6
$B_d \rightarrow J/\psi K^*$	489k	1.5	5.2
$B^+ \rightarrow J/\psi K^+$	942k	0.3	1.6

B mass resolution



Average σ(M) ≈ 16MeV, good for separating signal from background

Angular resolution

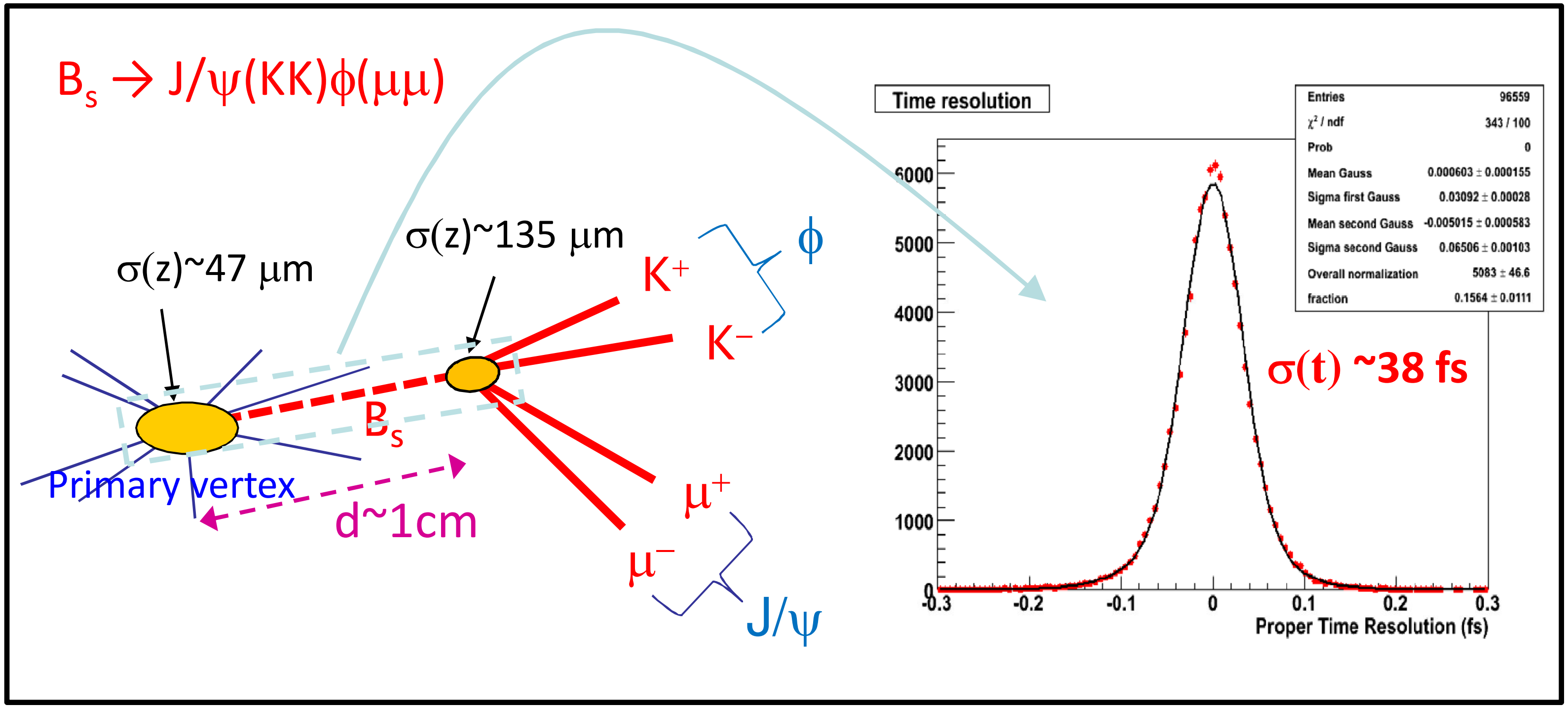

$B_s \rightarrow J/\psi(KK)\phi(\mu\mu)$

$\sigma(\theta)$ ~27mrad

	ψ	ϕ	θ
Resolution (mrad)	20	27	27

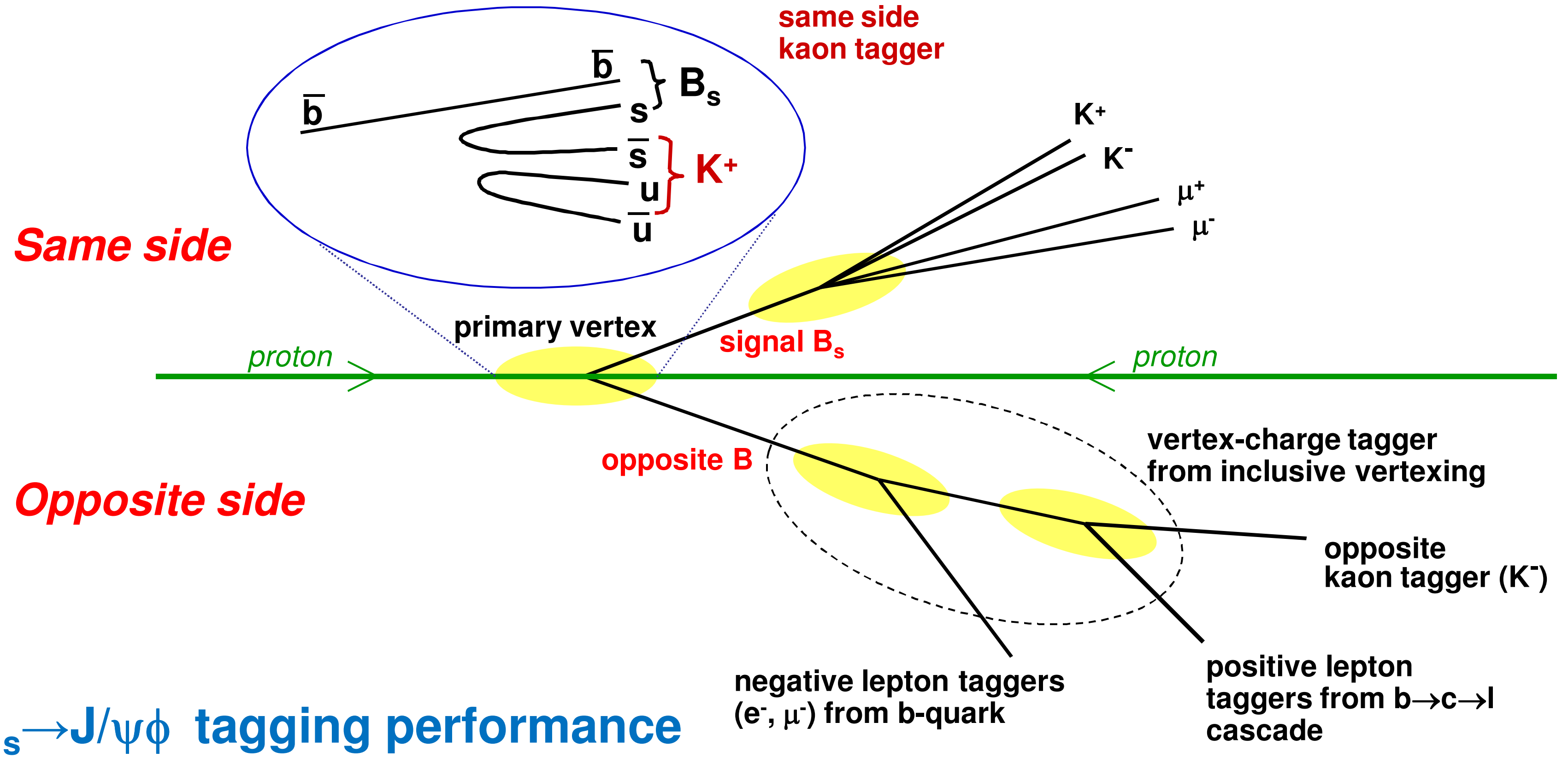
Angular resolution effect negligible

Proper time resolution



Average $\sigma(t) \approx 38\text{fs}$, compared with oscillation period $T = 2\pi/\Delta m_s \approx 314\text{fs}$ for $\Delta m_s = 20\text{ps}^{-1}$

Flavour tagging performance



Same side

same side kaon tagger

Opposite side

vertex-charge tagger from inclusive vertexing

opposite kaon tagger (K^-)

negative lepton taggers (e^-, μ^-) from b-quark

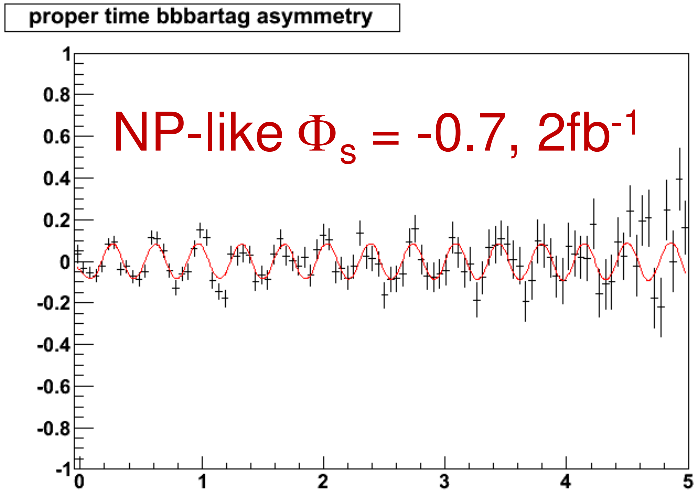
positive lepton taggers from b→c→l cascade

$B_s \to J/\psi\phi$ tagging performance

Tagger	Tag eff.	mistag	$\varepsilon(1-2\omega)^2$
Opposite side	45%	36.5%	3.3%
+ same side	56%	33.3%	6.2%

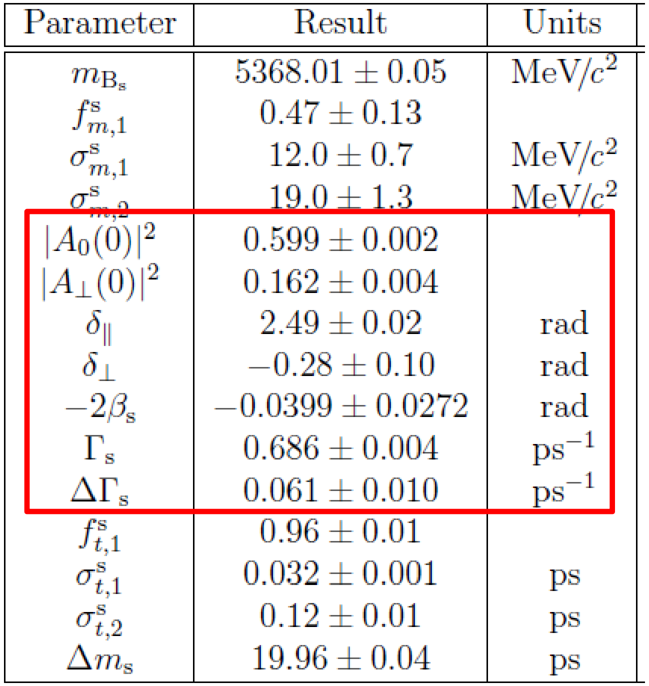
Sensitivity with $2fb^{-1}$

- Estimate sensitivity from fits of toy data samples based on detector performance from full simulation
- SM case sensitivity with $2fb^{-1}$ $\sigma(\Phi_s) \approx 0.03$



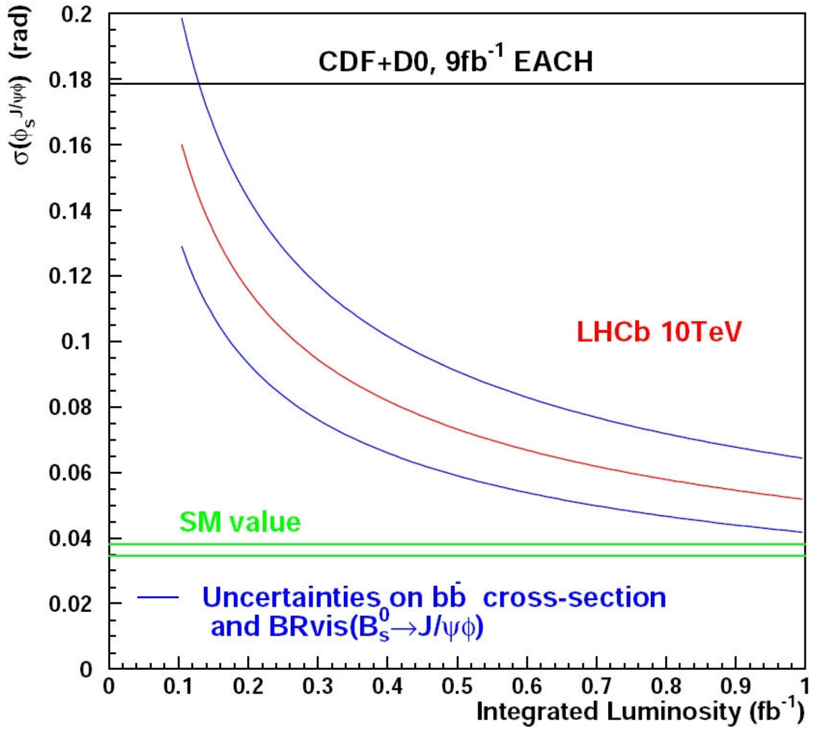
NP-like Φ_s = -0.7, $2fb^{-1}$

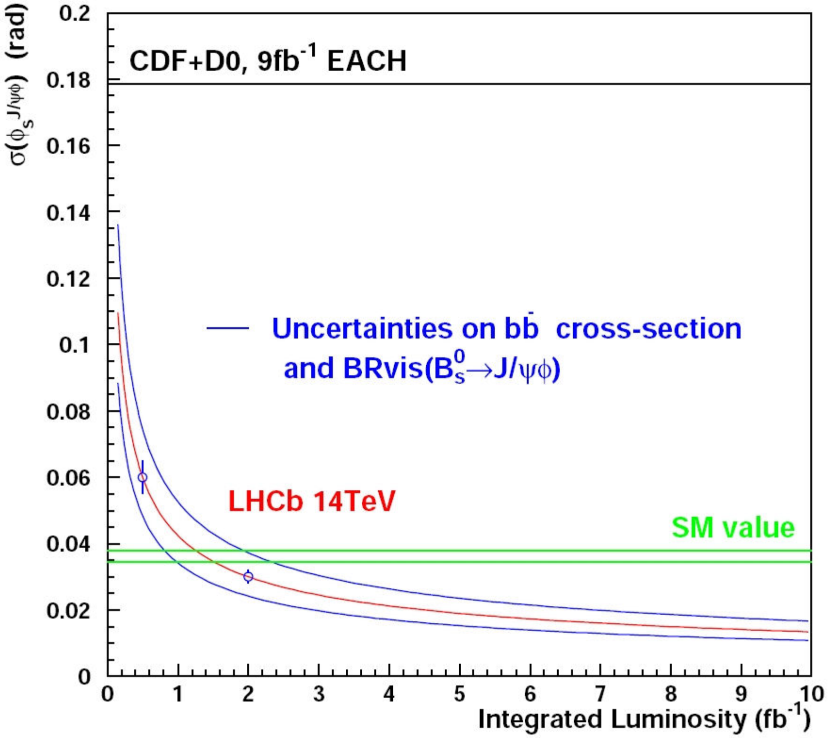
$$A(t) = \frac{\Gamma\left(B^{tag}(t)\right) - \Gamma\left(\overline{B}^{tag}(t)\right)}{\Gamma\left(B^{tag}(t)\right) + \Gamma\left(\overline{B}^{tag}(t)\right)}$$



Parameter	Result	Units
$m_{\mathrm{B_s}}$	5368.01 ± 0.05	MeV/c^2
$f^{\mathrm{s}}_{m,1}$	0.47 ± 0.13	
$\sigma^{\mathrm{s}}_{m,1}$	12.0 ± 0.7	MeV/c^2
$\sigma^{\mathrm{s}}_{m,2}$	19.0 ± 1.3	MeV/c^2
$\vert A_0(0)\vert^2$	0.599 ± 0.002	
$\vert A_\perp(0)\vert^2$	0.162 ± 0.004	
$\delta_\parallel$	2.49 ± 0.02	rad
$\delta_\perp$	-0.28 ± 0.10	rad
$-2\beta_{\mathrm{s}}$	-0.0399 ± 0.0272	rad
Γ_{s}	0.686 ± 0.004	ps^{-1}
$\Delta\Gamma_{\mathrm{s}}$	0.061 ± 0.010	ps^{-1}
$f^{\mathrm{s}}_{t,1}$	0.96 ± 0.01	
$\sigma^{\mathrm{s}}_{t,1}$	0.032 ± 0.001	ps
$\sigma^{\mathrm{s}}_{t,2}$	0.12 ± 0.01	ps
Δm_{s}	19.96 ± 0.04	ps

Sensitivity versus integrated luminosity





- $0.2 fb^{-1}$:
  - LHCb overtakes Tevatron projection
  - Can observe NP if true value of Φ_s is close to the Tevatron central value (~ -0.8)

ATLAS/CMS performance

	LHCb	**LHCb ($\sqrt{s}$ = 7 TeV)**	**ATLAS**	**CMS**
Integrated luminosity	**$2\ \mathrm{fb}^{-1}$**	**$0.3\ \mathrm{fb}^{-1}$**	**$0.15\ \mathrm{fb}^{-1}$** [a]	**$10\ \mathrm{fb}^{-1}$**
$B_s \to J/\psi\varphi$ signal events	117k	8k	1.14k [a]	110k
bb background/signal ratio	0.5		~ 5.5 [a]	0.33
B_s mass resolution	16 MeV/c^2		61 MeV/c^2 [a]	14 MeV/c^2 [b]
Proper-time resolution	38 fs		152 fs [a]	78 fs [c]
Flavour tagging εD^2	6.2%		4.6% [c]	–
$\sigma_{stat}(\Phi_s)$	**0.030**	**0.12**		

[a] Early data analysis performance
[b] J/ψ mass constrained
[c] A. Dewhurst, talk at Beauty 2009

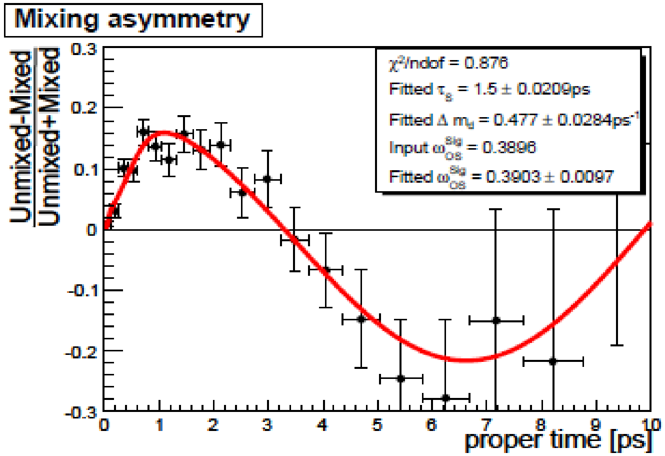
ALTAS: CERN-OPEN-2008-020
CMS: PHYSICS TDR 2006
LHCb: CERN-LHCb-2009-025
CERN-LHCb-2009-021, CERN-LHCb-

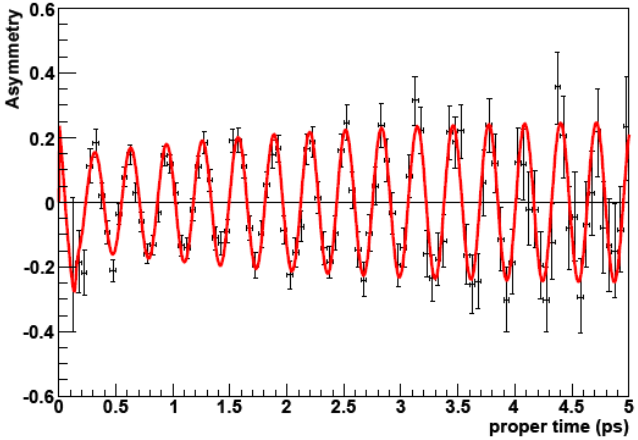
Systematics under control

- Flavour tagging
  - Will be measured in control channels
  - If mistag ~ 0.34±0.01 → $\Delta\Phi_s/\Phi_s = 7\%$
  - Can float mistag in fit to avoid systematics
- Angular acceptance
  - Check correction method in control channel
  - If distortion ~ 5% → $\Delta\Phi_s/\Phi_s = 7\%$
- Proper time resolution
  - Obtain proper time error scale factor to from prompt J/ψ events
  - If 10% error on scale factor → $\Delta\Phi_s/\Phi_s = 5\%$
  - Bias in $\Delta\Phi_s/\Phi_s$ can be absorbed when mistag is floated
- Background
  - Use sidebands to learn or subtract background

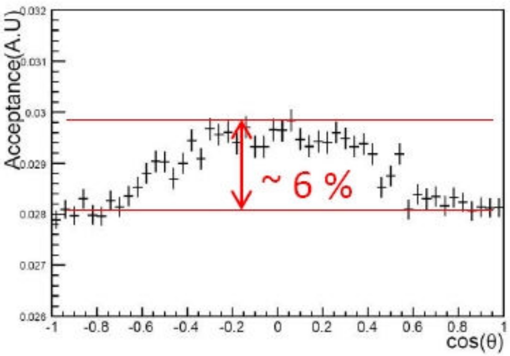
Flavour tagging calibration

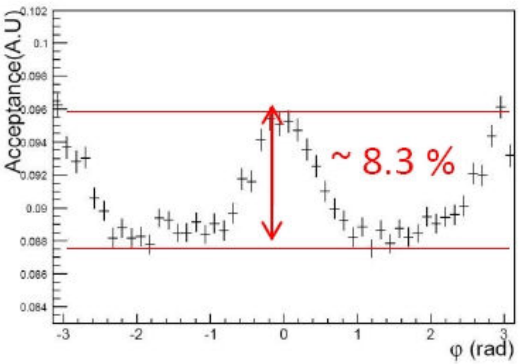
- Calibrate opposite side tagger mistag rate
  - $B_d \rightarrow J/\psi K^*$ oscillations
  - $B^+ \rightarrow J/\psi K^+$
- Calibrate same side tagger mistag rate
  - $B_s \rightarrow D_s \pi$ oscillations

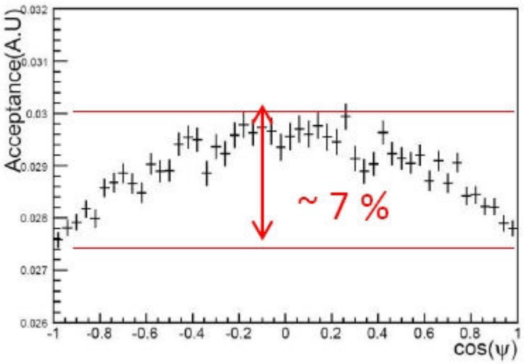




Angular acceptance

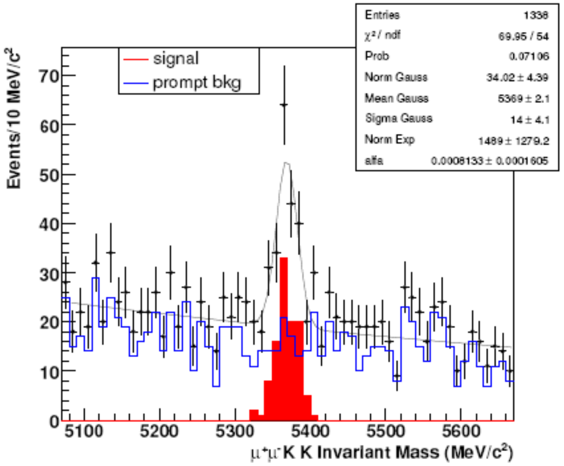


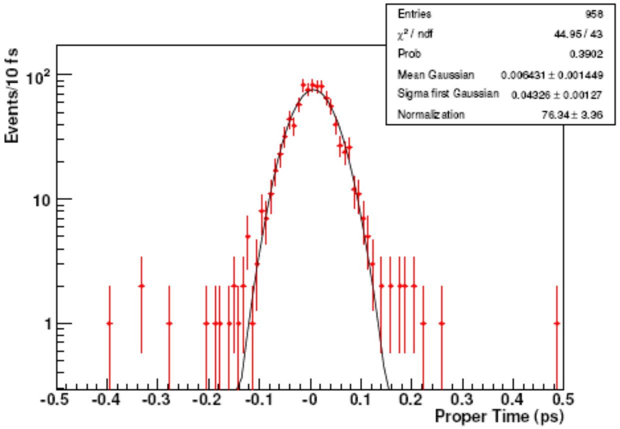




- Angular distortion <10% according to full simulation
- Can be corrected taking into account
  - Detector geometrical acceptance
  - P and P_T cuts on final state particles
  - Final state particle reconstruction efficiencies
- Correction method will be validated in $B_d \rightarrow J/\psi K^*$

Background

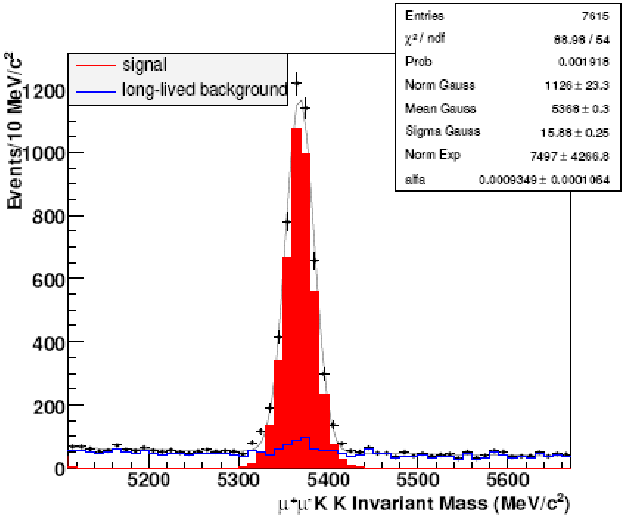


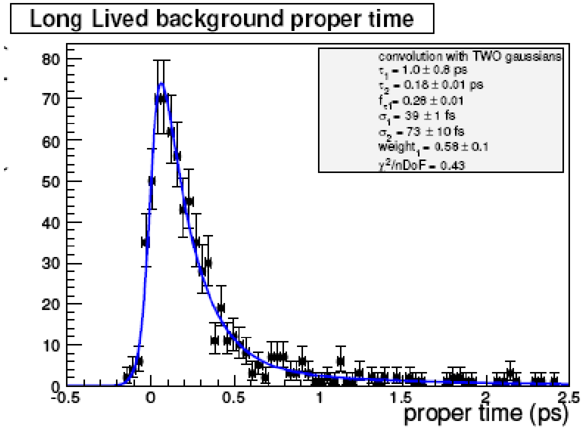


Methods to controol:

1) learn background time-angular distributions from mass sidebands;

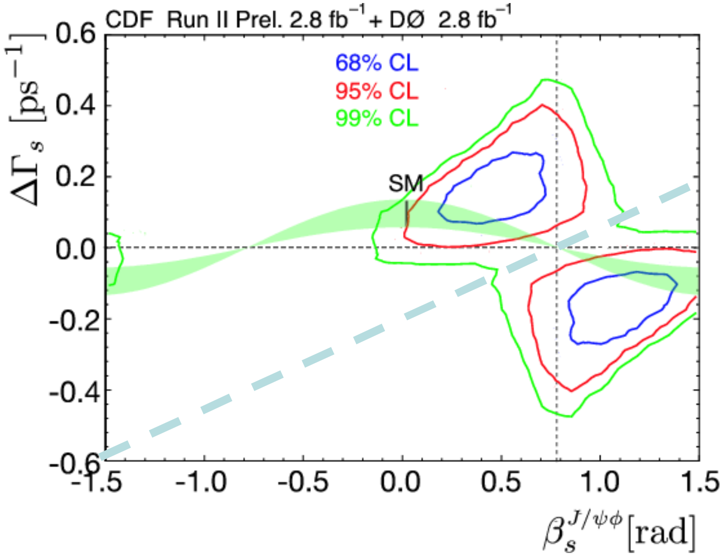
2) background subtraction





Theory issues

- Possible K^+K^- S-wave pollution
- Removing ambiguity in Φ_s



Choosing one side reduces half of the allowed parameter space!

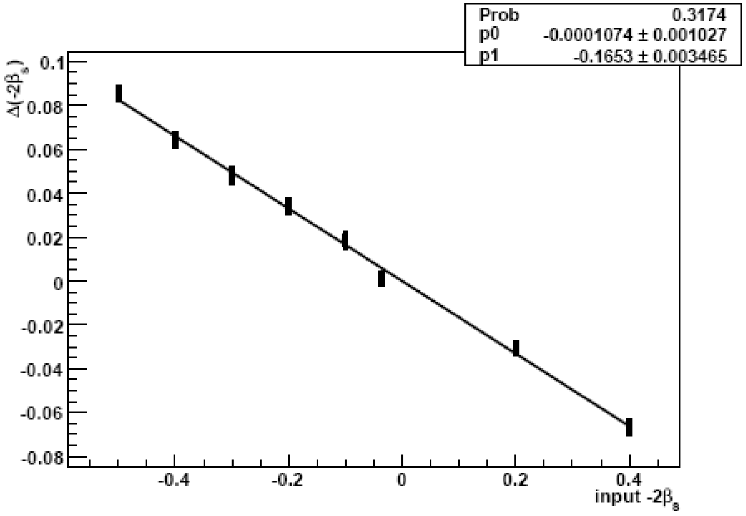
- DCS loop contributions in $b \rightarrow c\bar{c}s$ decays

S-wave

[Y. Xie, P. Clarke, G. Cowan, F. Muheim, JHEP 0909:074,2009]

- Sizeable K^+K^- S-wave (f_0 or non-resonant) is possible
- Neglecting a 5-10% S-wave contribution introduces a ~10% bias in Φ_s
- Including the S-wave slightly increases the statistical error but removes bias

Bias in Φ_s from neglecting a 10% KK S-wave contribution versus Φ_s . A linear dependence Is observed.



Promising prospect to measure Φ_s in $B_s \to J/\psi\, f_0(\pi\pi)$. [S. Stone and L. Zhang PRD 79 (2009) 074024]

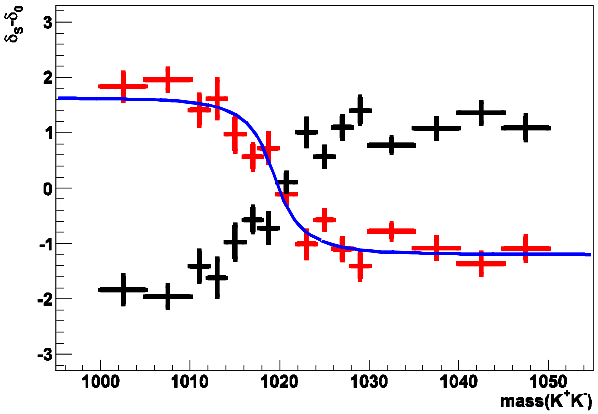
Remove ambiguity in Φ_s

[Same paper by Y. Xie et al.]

two-fold ambiguity in Φ_s

$$\left(\delta_{//}-\delta_0,\delta_\perp-\delta_0,\delta_S-\delta_0,\Phi_s,\Delta\Gamma_s\right)\Leftrightarrow$$
$$\left(\delta_0-\delta_{//},\pi+\delta_0-\delta_\perp,\delta_0-\delta_S,\pi-\Phi_s,-\Delta\Gamma_s\right)$$

Two branches when plotting δ_S-δ_0 versus m(KK)



Blue: simulated dependence
Red: physical solution
Black: mirror solution

The branch falling rapidly across the ϕ(1020) resonance mass region provides the physical solution

~0.5fb^{-1} at LHCb, 10% S-wave, true Φ_s = -0.0368

$$\sin\Phi_s = -0.043 \pm 0.05$$
$$\cos\Phi_s = +1.05 \pm 0.08$$

Loop contributions

- Are doubly Cabibbo-suppressed loop contributions in $b \to c\bar{c}s$ decays negligible?
  - Yes. Effect of SM DCS contributions on mixing induced CP asymmetry is only at 10^{-3} level

  [M. Gronau, J. L. Rosner, PLB 672 (2009) 349 and references therein]
  - No. SM long distance hadronic penguin contributions can cause $\mathcal{O}(-10\%)$ effect on mixing induced CP asymmetry

  [S. Faller, R. fleischer, T. Mannle, PRD 79 (2009) 014005]
  - You need to consider loop contributions any way as new physics can enter both B_s mixing and $b \to c\bar{c}s$ decay amplitudes

  [A. datta, S. Khali, PRD 80 (2009) 075006]

  [C. Chiang et al., arXiv:0910.2929]

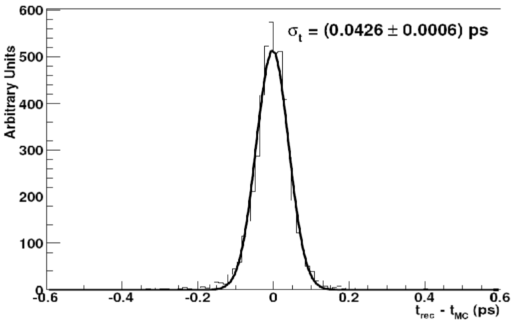
Questions to theorists

- If a small but significant deviation from the usual SM prediction of Φ_s =-0.0368 is measured, how can we tell if it is due to new physics or SM loop contributions?
- If a large deviation from the SM prediction is measured, how can we distinguish if it is due to new physics in B_s mixing or in decay? Do we need to?
- Will it be necessary for experiments to measure direct and mixing-induced CP asymmetries for each polarisation? Or measuring a single Φ_s is sufficient?
- What other measurements are needed to resolve these issues?

Φ_s From $B_s \rightarrow \phi(KK)\phi(KK)$

$B_s \rightarrow \phi\phi$ selection

- $BR[B_s \rightarrow \phi\phi] = [24 \pm 2.1(stat) \pm 2.7(syst) \pm 8.2(BR)] x10^{-6}$
  from CDF, EPS'2009
- Hadronic trigger (E_T and IP cuts), less efficient than lepton trigger: $\varepsilon \approx 22\%$
- Use PID and kinematic offline cuts
  - Signal yield 4.6k per $2fb^{-1}$
  - $B_{bb}/S < 2.4$ at 95%
    in 50MeV B mass window
- Proper time resolution 43fs
- Tagging efficiency ~60%, mistag~30%



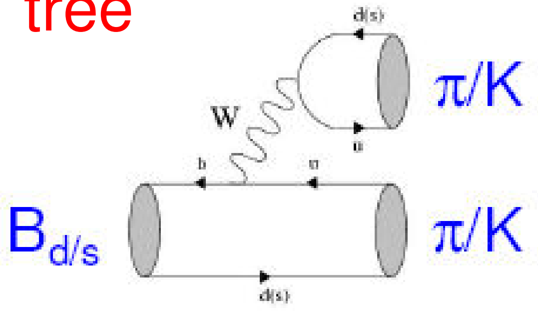
$B_s \rightarrow \phi\phi$ sensitivity

- Analysis strategy: null test of SM
  - assume no NP, and extract an effective $\Phi_s(\phi\phi)$
  - compare with SM expectation $\Phi_s(\phi\phi) = 0$
- Sensitivity $\sigma(\Phi_s(\phi\phi)) \sim 0.06$ with $10 fb^{-1}$ CERN-LHCb-PUB-2009-02
  - Current combined BaBar/Belle uncertainties:

    $\sigma(S(\phi K_S)) = 0.17$, $\sigma(S(\eta' K_S)) \sim 0.07$
- Measurements with 0.2-0.5 fb^{-1}
  - Relative branching ratio and polarization
- Similar channel $B_s \rightarrow K^{*0}(K\pi)\overline{K}^{*0}(K\pi)$ under investigation
  - 7.6k per $2 fb^{-1}$ with B/S = 1 (trigger not included)

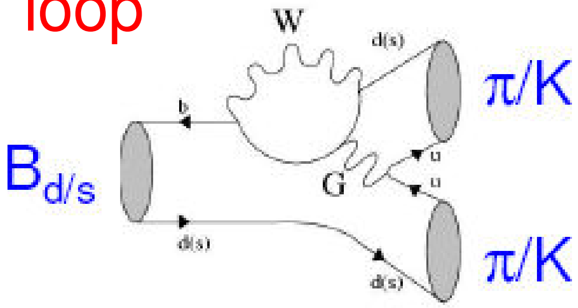
γ from loops

tree



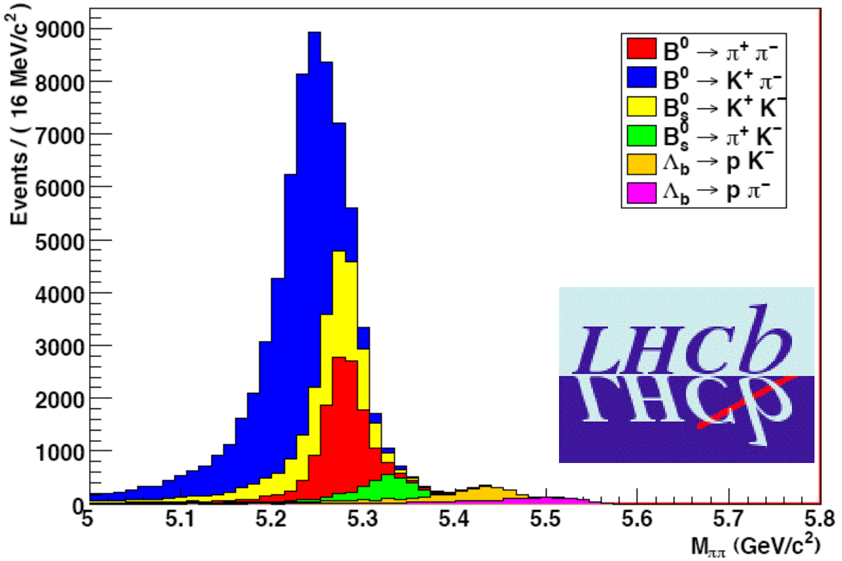
$B_{d/s}$ π/K π/K

loop



$B_{d/s}$ π/K π/K

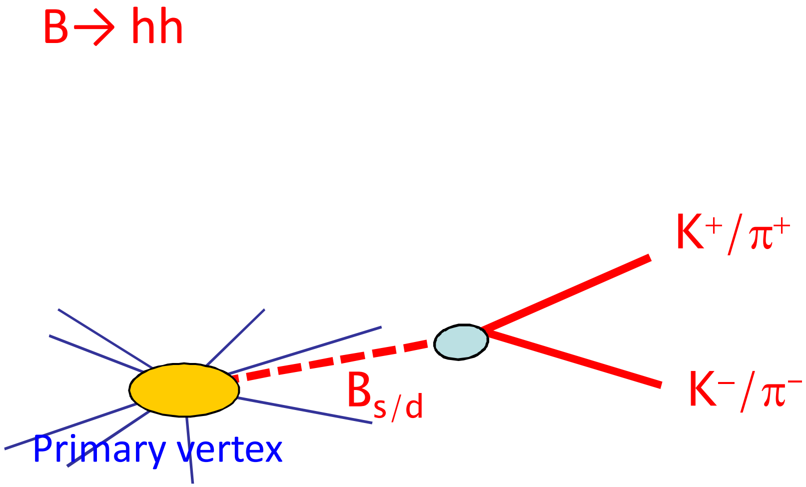
B→hh selection

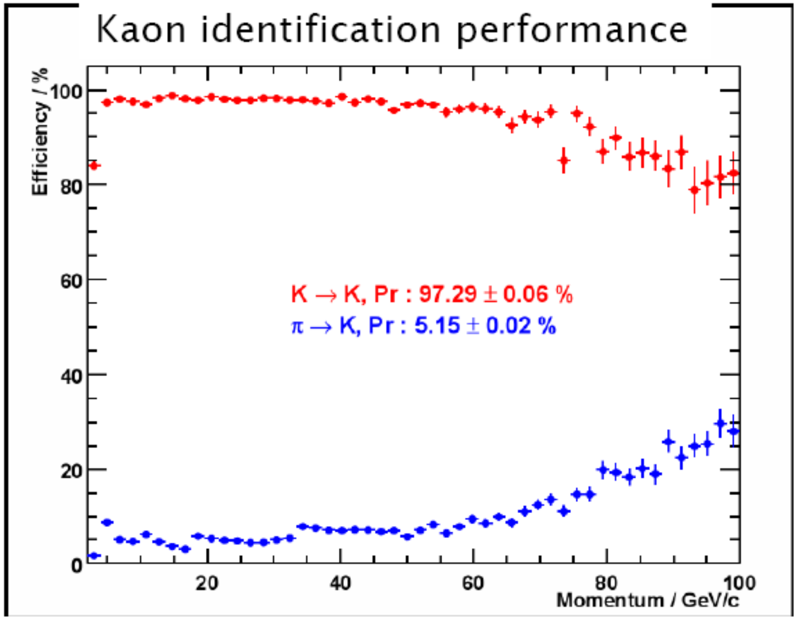


- Reconstruct all B→hh modes under the ππ hypothesis
- Use their different distributions of ππ mass and PID variables in fit to statistically separate them for extraction of physics parameters

Decay mode	f_{hadr} [%]	$\mathcal{BR}$ $\times 10^6$	ϵ_{sel} [%]	$\epsilon_{trig/sel}$ [%]	ϵ_{tot} [%]	Annual yield
$B^0 \to \pi^+\pi^-$	40.3 ± 0.9	5.16 ± 0.22	3.95 ± 0.05	35.8 ± 0.6	1.41 ± 0.03	$58.8\,k$
$B^0 \to K^+\pi^-$	40.3 ± 0.9	19.4 ± 0.06	3.84 ± 0.04	36.1 ± 0.3	1.39 ± 0.02	$216.6\,k$
$B_s^0 \to \pi^+K^-$	10.1 ± 0.9	5.27 ± 1.17	3.83 ± 0.07	37.0 ± 1.0	1.42 ± 0.04	$15.1\,k$
$B_s^0 \to K^+K^-$	10.1 ± 0.9	25.8 ± 4.2	3.69 ± 0.05	37.4 ± 0.5	1.38 ± 0.02	$71.9\,k$
$\Lambda_b \to p\pi^-$	9.2 ± 1.5	3.1 ± 0.9	3.36 ± 0.06	36.8 ± 1.1	1.24 ± 0.04	$7.0\,k$
$\Lambda_b \to pK^-$	9.2 ± 1.5	5.0 ± 1.2	3.32 ± 0.05	35.7 ± 0.7	1.18 ± 0.03	$10.9\,k$

Particle identification





Good PID performance is essential for this analysis

Extraction of γ

Simplified description of method

- Measure time dependant asymmetries for $B_d \rightarrow \pi\pi$ and $B_s \rightarrow KK$ to determine A_{dir} and A_{mix}

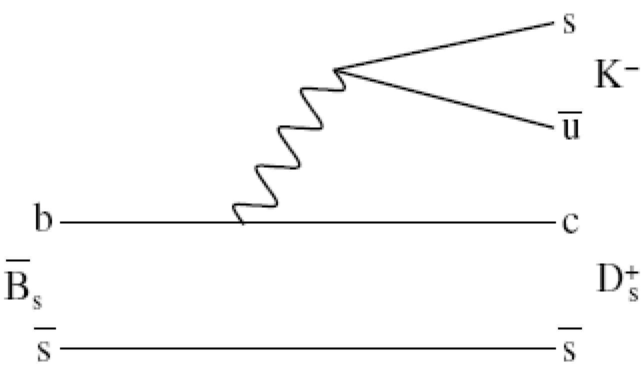
$$A_{CP}(t) = A_{dir} \cos(\Delta m\, t) + A_{mix} \sin(\Delta m\, t)$$

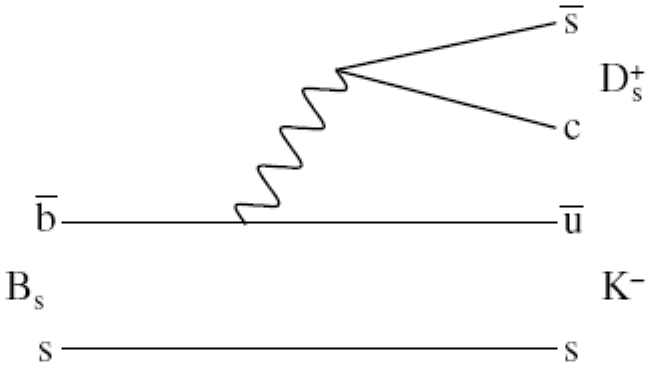
- A_{dir} and A_{mix} depend on
  - γ
  - Mixing phases ϕ_d or ϕ_s
  - Penguin/Tree=$de^{i\theta}$
- Use ϕ_d and ϕ_s from $J/\psi\phi$ and $J/\psi K_s$
- U-spin symmetry: $d_{\pi\pi}=d_{KK}$, $\theta_{\pi\pi}=\theta_{KK}$
- 4 observables, 3 unknowns: solve for γ

The actual analysis uses more modes and have more observables, allowing to take into account U-spin symmetry breaking effect.

$\sigma(\gamma)$ = 7° with 2 fb^{-1}

CERN-LHCb-PUB-2009-029


s
K⁻
ū
b
c
$\bar{B}_s$
D_s^+
$\bar{s}$
$\bar{s}$


$\bar{s}$
D_s^+
c
$\bar{b}$
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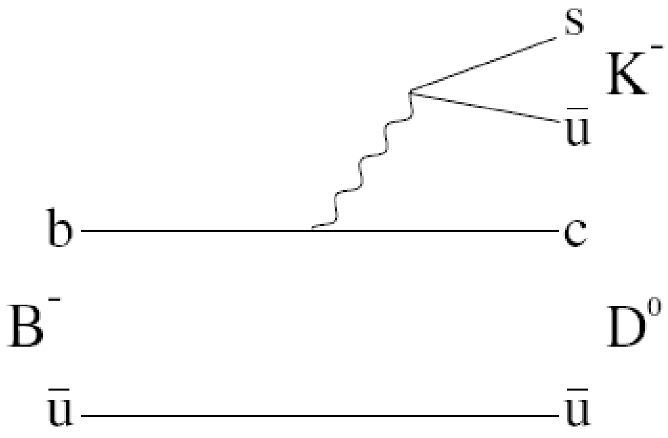
B_s
K⁻
s
s

γ from tree


s
K⁻
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B⁻
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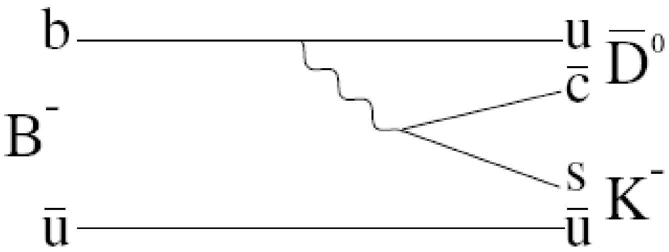

b
u
$\bar{D}^0$
c̄
B⁻
s
K⁻
ū
ū

γ from tree sensitivity

- Many modes in two categories
  - Time-dependent analysis: $B_s \rightarrow D_s K$, $B \rightarrow D^* \pi$
  - Time-integrated analysis (Dalitz, ADS): $B \rightarrow DK^{(*)}$

Combined $\sigma(\gamma) = 4\text{-}5°$ with 2 fb^{-1}

CERN–LHCb-PUB-2009-029

- Measurement not affected by NP and can be used to test NP by comparing with
  - indirect measurement with current error

    $\sigma(\gamma) < 5°$
  - measurement of γ from loops with expected error

    $\sigma(\gamma) = 7°$

CP violation in charm decays

- Observation of CP violation in charm system is a clear signature of new physics
- Very high statistics at LHCb
  - D* tagged trigger provides 42k $D^0 \to KK$ events per pb^{-1}
- Unprecedented sensitivity even with first data
  - D^0 mixing and CP violation in mixing

Two body lifetime ratio measurement

$\sigma(y_{CP}) \sim 1.1 \times 10^{-3}$ @100pb^{-1} [SM<10^{-3}]

$$y_{CP} = \frac{\tau(D^0 \to K^- \pi^+)}{\tau(D^0 \to K^- K^-, \pi^+ \pi^-)} - 1$$

  - Direct CP violation in singly Cabibbo-suppressed charm decays ($D^0 \to KK$, D^+ -> $KK\pi$)

Advertisement

Most numbers for LHCb in this talk are taken from CERN-LHCb-PUB-2009-029, which will be made public and submitted to arXiv soon.

“Road map for selected key measurements from LHCb”

(The LHCb Collaboration)

Chapter 1: Introduction

Chapter 2: The Tree-level determination of gamma

Chapter 3: Charmless charged two-body B decays

Chapter 4: Measurement of mixing-induced CP violation in B_s → J/psiphi

Chapter 5: Analysis of the decay B_s → mu mu

Chapter 6: Analysis of the decay B0 → K* mu mu

Chapter 7: Analysis of B_s → phi gamma and other radiative B decays

Summary

- Great prospects to find CP violating new physics at the LHC in
  - measurement s of Φ_s in tree-level and loop decays
  - measurements of γ in tree-level and loop decays
  - measurement of CP violation in charm decays
- Experiments very well prepared in all aspects
  - detectors, event reconstruction and final physic analysis
- Theory experiment interplay crucial for good understanding of related theoretical issues
  - The LHC is running and exciting time is coming, possibly as early as 2010, with

    new physics discovered at LHCb in $B_s \rightarrow J/\psi\phi$ using 0.2fb^{-1}

Backup slides

Decay amplitudes

- $B_s \rightarrow J/\psi\phi$ described by Breit-Wigner amplitudes

Blatt-Weisskopf form factors ≈ constant

$$A_\lambda\left(B_s \rightarrow J/\Psi\phi\right) = r_\lambda e^{id_\lambda} \frac{1}{M_\phi^2 - M_{KK}^2 - iM_\phi\Gamma_\phi} \boxed{F_B F_\phi}$$

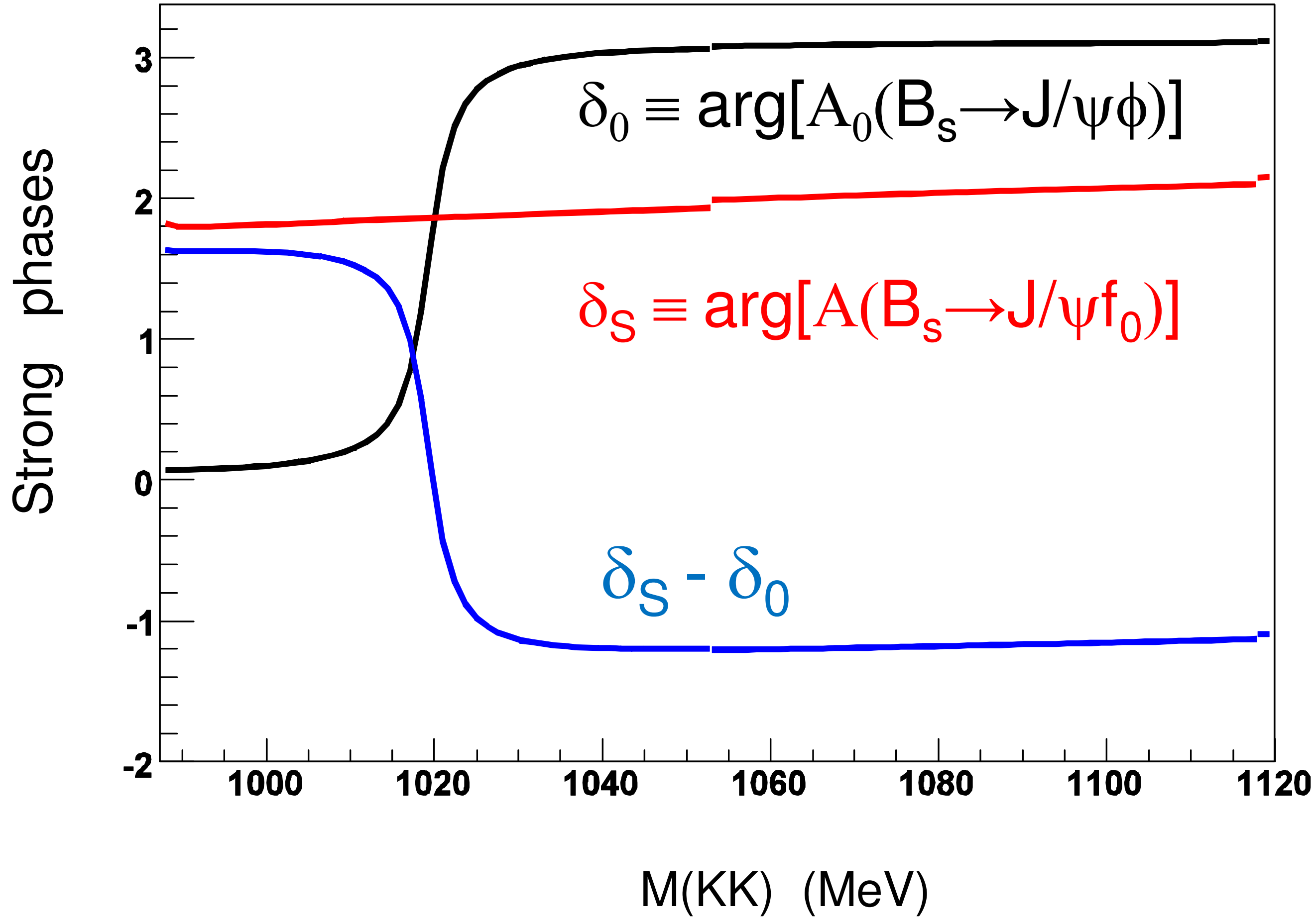
- $B_s \rightarrow J/\psi f_0$ described by a coupled-channel Breit-Wigner amplitude

Blatt-Weisskopf form factors ≈ constant

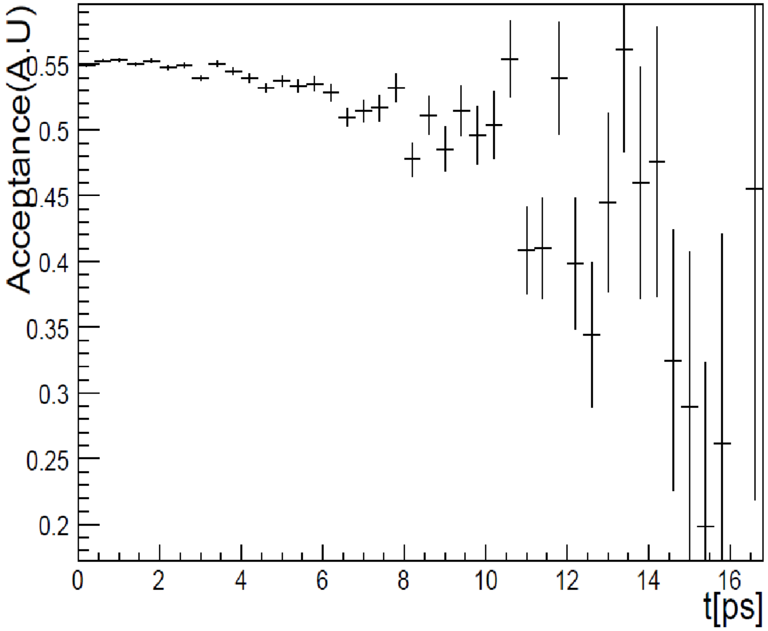
$$A\left(B_s \rightarrow J/\Psi f_0\right) = r_S e^{id_S} \frac{1}{M_{f_0}^2 - M_{KK}^2 - i\left(g_1\rho_{\pi\pi} + g_2\rho_{KK}\right)} \boxed{F_B F_{f_0}}$$

$$\rho_{\pi\pi/KK} = \sqrt{1 - 4M_{\pi/K}^2 / M_{KK}^2}$$

Dependences of strong phases on KK mass

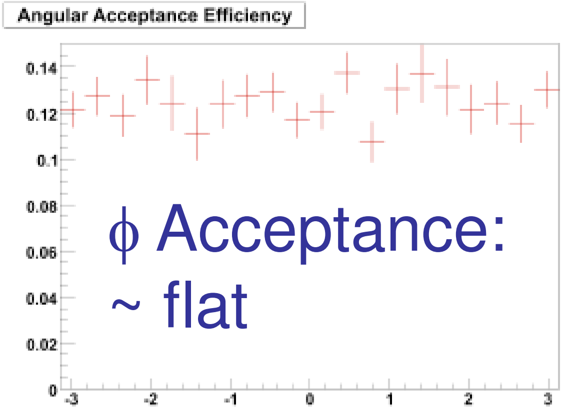


Proper time acceptance

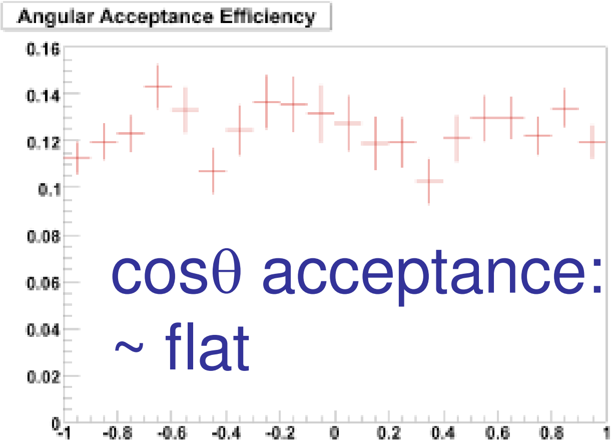


$B_s \to J/\psi\phi$ reconstruction efficiency slightly decreases with proper time.
Can be learned from $B_d \to J/\psi K^*$

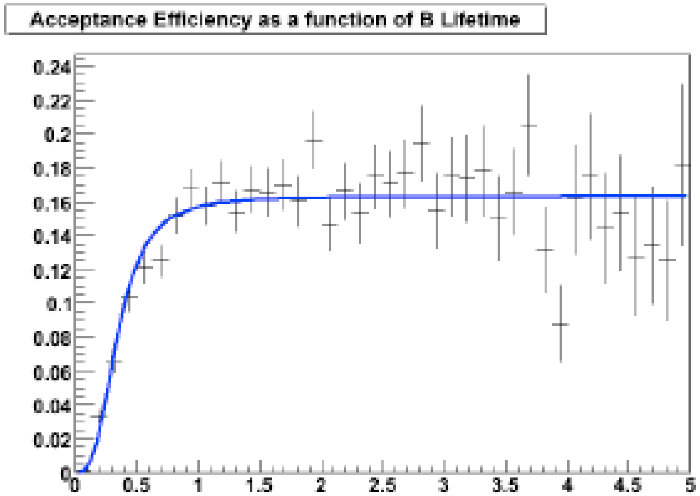
$B_s \rightarrow \phi\phi$ acceptances



ϕ Acceptance:
~ flat



cosθ acceptance:
~ flat



Time acceptance needs correction.
$\Phi_s(\phi\phi)$ not sensitive to time acceptance