Physics Performance

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On behalf of the LHCb collaboration

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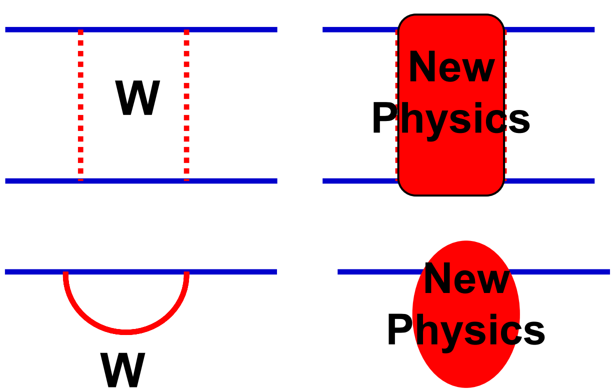
Physics Goals

At 2×10^{32} cm^{-2}s^{-1} $\Rightarrow 10^{12}$ $b\bar{b}$ pairs produced / yr

- CPV measurements in many decay channels:
  - pure hadronic and multi-body final states.
  - new decay channels in particular B_s decays
- precise determination of CKM elements: measurement of $b\to u+W$ (tree) phase
- **overconstraining** the Unitarity Triangles: disentangle the tree phases from phases of oscillations (loops) and penguins
- Study rare and loop-suppressed decays

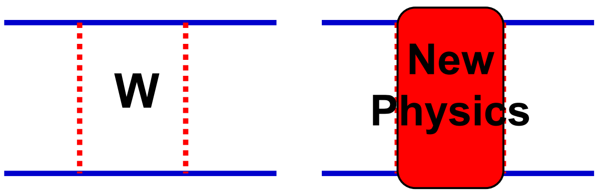
Search and filter-out effects of New Physics

2β	$B^0 \to J/\psi(\mu\mu)K$
$2\beta + \gamma$	$B^0 \to D^{*-}\pi^+$
γ	$B^0 \to D^0 K^{*0}$
β and γ	$B^0 \to \pi^+\pi^-$ $B_s \to K^+K^-$
$\gamma - 2\chi$	$B_s \to D_S K$
2χ	$B_s \to J/\psi(\mu\mu)\phi$
$\alpha=\pi-\beta-\gamma$	$B^0 \to \pi^+\pi^-$, $\rho\pi$



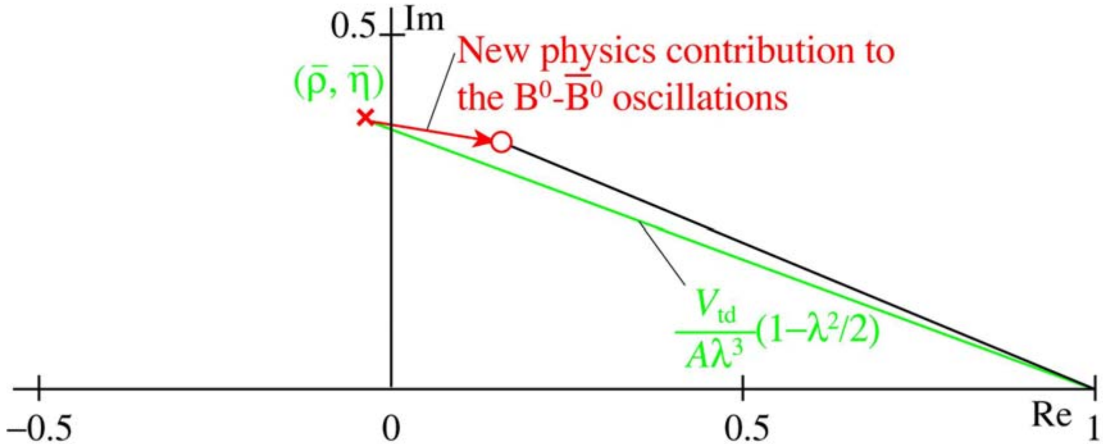
Example: New Physics in B mixing

$B_{(s)}\bar{B}_{(s)}$ mixing phase:



$$\Phi_d = 2\beta + \Phi_d^{NP}$$

$$\Phi_s = 2\chi + \Phi_s^{NP}$$

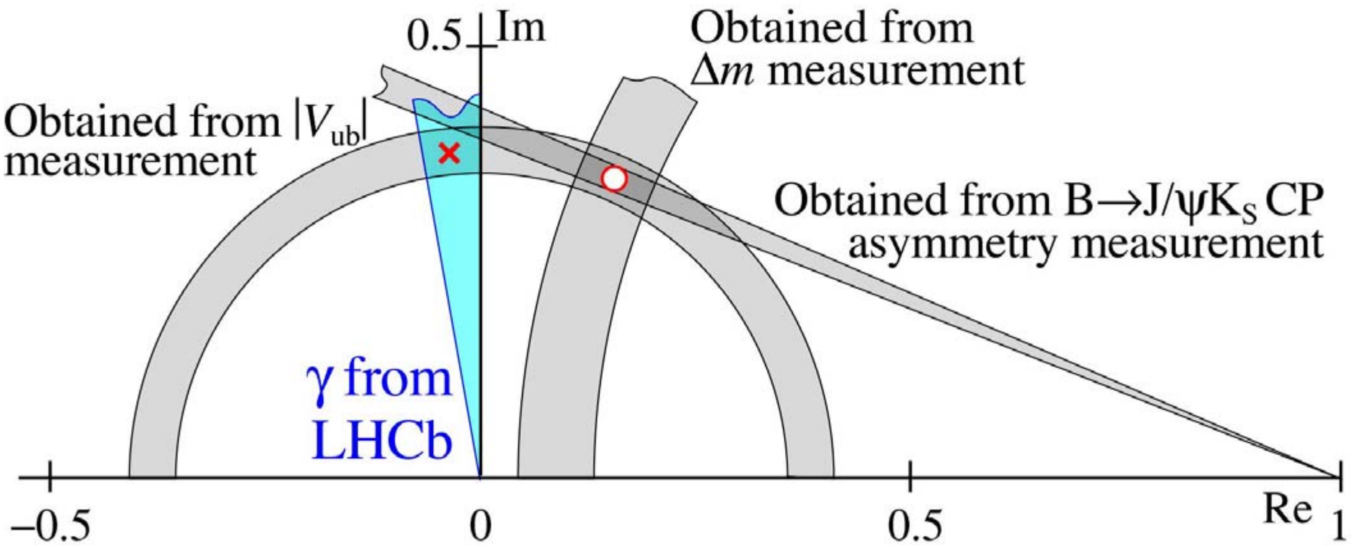


<u>Observation of new phase:</u>

CPV in	$B^0 \to J/\psi\, K_s$	$\sin(2\beta+\Phi_d^{NP})$
	$B^0 \to D^*\pi$	$\sin(2\beta+\Phi_d^{NP}+\gamma)$
	$B_s \to J/\psi\phi$	$\sin(2\chi+\Phi_s^{NP})$
	$B_s \to D_s K$	$\sin(2\chi+\Phi_s^{NP}+\gamma)$
Rate of	$B^0 \to D^0 K^{*0}$, $\bar{D}^0 K^{*0}$, $D^0_{CP} K^{*0}$	γ

Redundant measurements necessary to disentangle CKM phases from New Physics

Discovery Potential



In 1 year: e.g. $\gamma(B^0 \rightarrow D^0K^{*0})$: $\pm 7^0$

$\sin\phi_d(B^0 \rightarrow J/\psi K_s)$: ± 0.022 ⇐ ≤ $\int^{2007}$ BABAR+BELLE

"reference channel"

Monte Carlo Simulation

Full Geant 3.2 simulation:

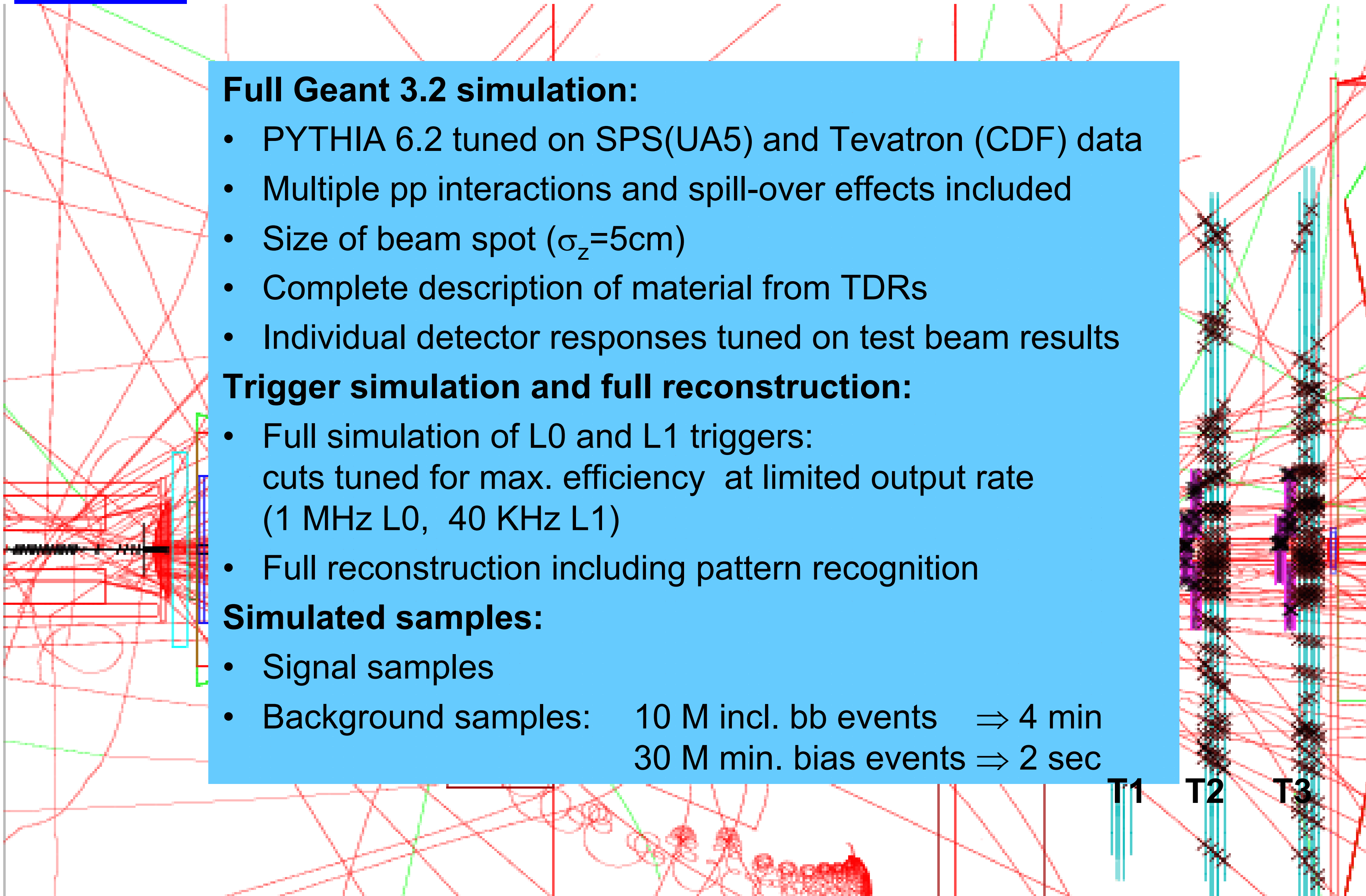
- PYTHIA 6.2 tuned on SPS(UA5) and Tevatron (CDF) data
- Multiple pp interactions and spill-over effects included
- Size of beam spot (σ_z=5cm)
- Complete description of material from TDRs
- Individual detector responses tuned on test beam results

Trigger simulation and full reconstruction:

- Full simulation of L0 and L1 triggers:
  cuts tuned for max. efficiency at limited output rate
  (1 MHz L0, 40 KHz L1)
- Full reconstruction including pattern recognition

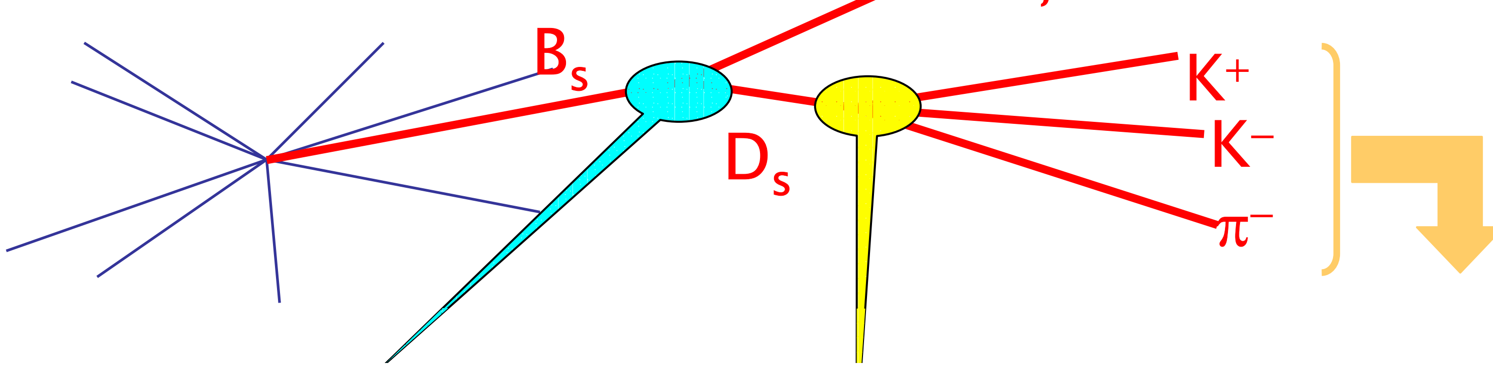
Simulated samples:

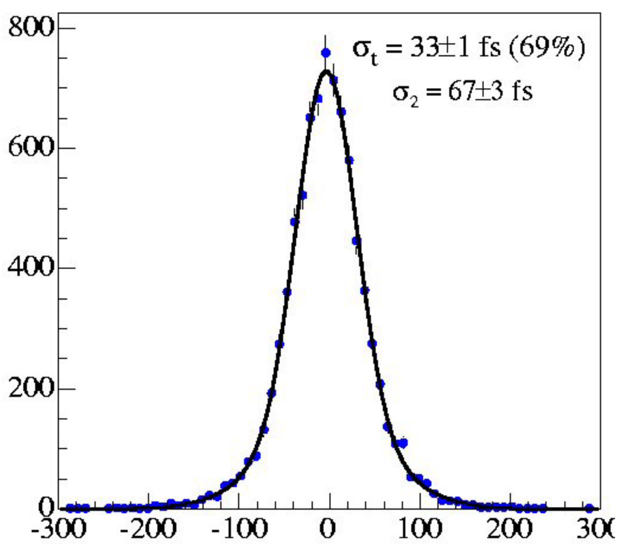
- Signal samples
- Background samples: 10 M incl. bb events $\Rightarrow$ 4 min
  30 M min. bias events $\Rightarrow$ 2 sec



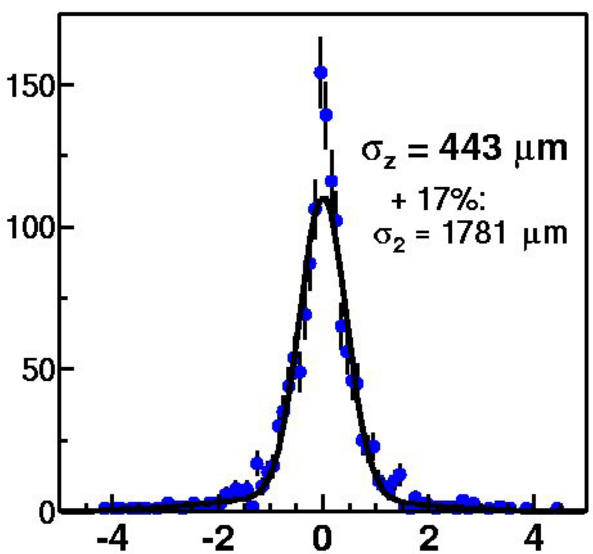
Detector Performance

$B_s \rightarrow D_s^- \pi^+ (K^+)$

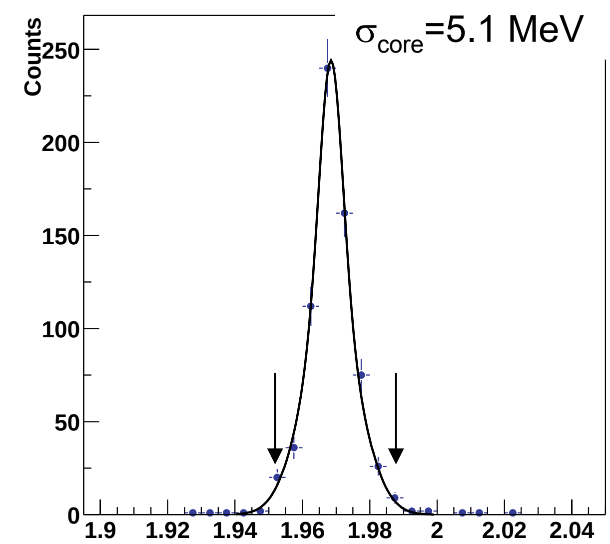




Proper time resolution (fs)



D_s vtx z resolution (mm)

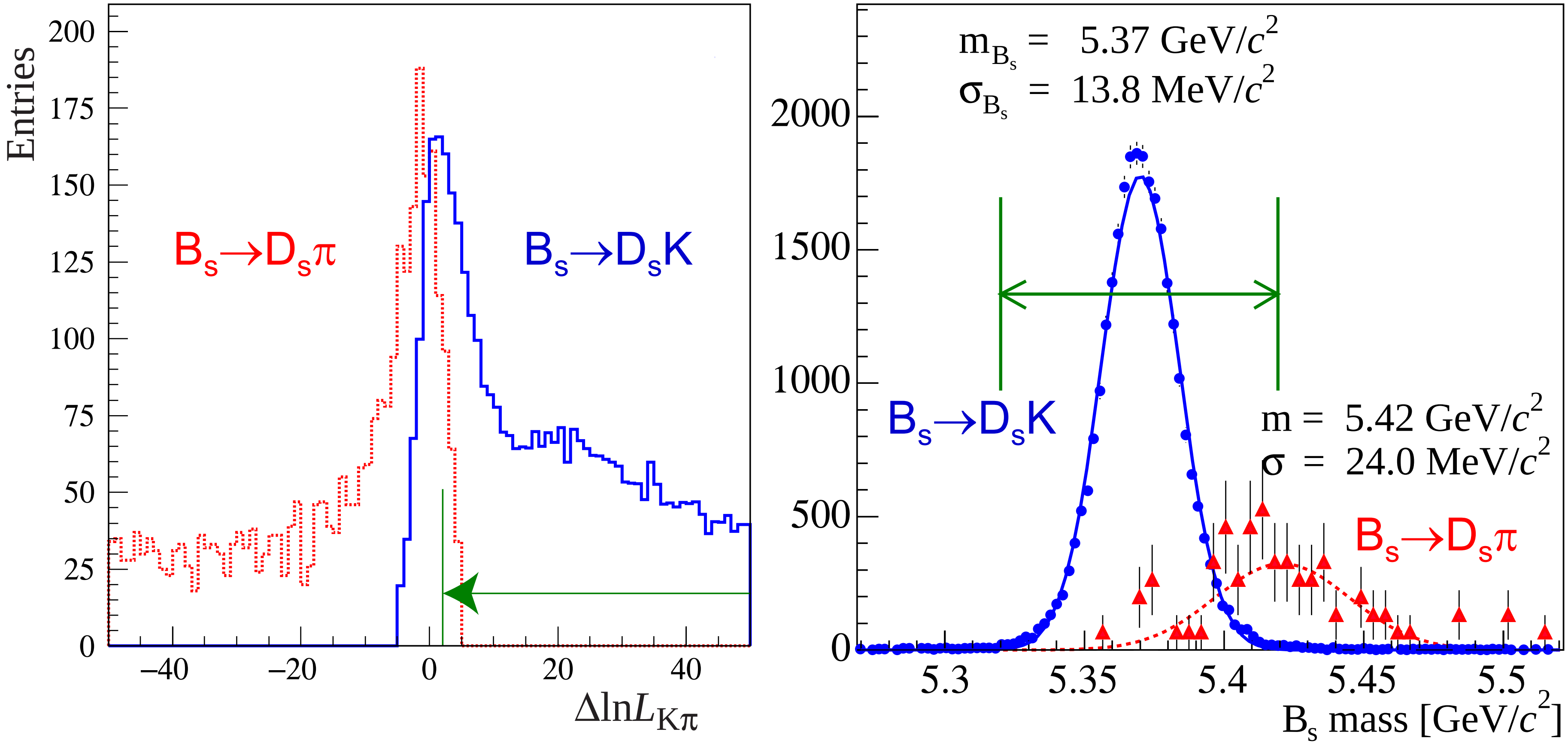


D_s mass (GeV)

$B_s \to D_s\pi$ / $B_s \to D_sK$ Separation

$B_s \to D_s^-\pi^+$ is a physics background for $B_s \to D_s^{-+} K^{+-}$

- $BR(B_s \to D_s^-\pi^+) / BR(B_s \to D_s^{-+}K^{+-}) \sim 12$
- $\varepsilon(B_s \to D_s^-\pi^+) / \varepsilon(B_s \to D_s^{-+}K^{+-}) = 1\%$ after PID and mass cuts



Event Yield (untagged)

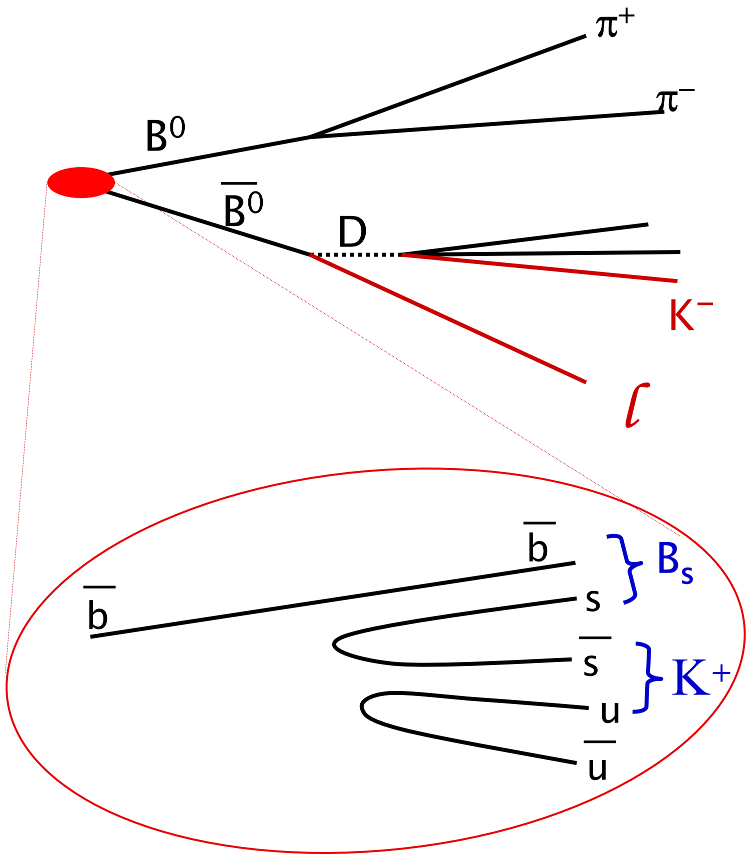
1 year (10^7s) at L = 2×10^{32} cm^{-2} s^{-1}

Channel	ε_{Trig} (L0+L1)	ε_{tot}	Yield	B/S
$B^0 \rightarrow \pi^+\pi^-$	34 %	0.69 %	26 k	< 0.7
$B^0 \rightarrow K^+\pi^-$	33 %	0.94 %	135 k	0.16
$B_s \rightarrow K^-\pi^+$	37 %	0.55 %	5.3 k	< 1.3
$B_s \rightarrow K^+K^-$	31 %	0.99 %	37 k	0.3
$B_s \rightarrow D_s^-\pi^+$	31 %	0.34 %	80 k	0.3
$B_s \rightarrow D_s^{-+}K^{+-}$	30 %	0.27 %	5.4 k	< 1.0
$B^0 \rightarrow J/\psi(\mu^-\mu^+)\, K_S$	61 %	1.39 %	216 k	0.8
$B^0 \rightarrow J/\psi(e^-e^+)\, K_S$	27 %	0.16 %	26 k	1.0
$B_s \rightarrow J/\psi\, (\mu^-\mu^+)\phi$	64 %	1.67 %	100 k	< 0.3
$B_s \rightarrow J/\psi\, (e^-e^+)\phi$	28 %	0.32 %	20 k	0.7
$B^0 \rightarrow \rho\pi$	36 %	0.03 %	4.4 k	< 7
$B^0 \rightarrow K^{*0}\gamma$	38 %	0.16 %	35 k	< 0.7
$B_s \rightarrow \phi\gamma$	34 %	0.22 %	9.3 k	< 2.4

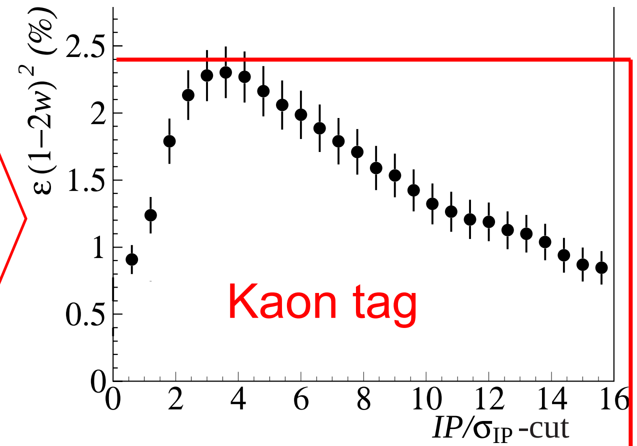
norm. to $4\pi \rightarrow \varepsilon_{tot} = \varepsilon_{det}{}^* \varepsilon_{rec/det}{}^* \varepsilon_{sel/rec}{}^* \varepsilon_{Trig} = 0.12 \times 0.92 \times 0.18 \times 0.34$

(for $B^0 \rightarrow \pi^+\pi^-$)

Flavour Tagging



Tagging tracks: large impact par.



- Lepton
- Kaon
- Vertex charge
- Fragmentation kaon near B_s

(Lepton, Kaon, Vertex charge: other B)

Tag	ε_{Tag} (%)	w (%)	ε_{eff} (%)
Muon	11	35	**1.0**
Electron	5	36	**0.4**
Kaon	17	31	**2.4**
Vertex Charge	24	40	**1.0**
Frag. kaon (B_s)	18	33	**2.1**
Combined B^0 (decay dependent:			**~4**
Combined B_s trigger + select.)			**~6**

Physics Sensitivity

Reference measurements: $\sin(2\beta)$ from $B^0 \rightarrow J/\psi K_s$

Δm_s from $B_s \rightarrow D_s \pi$

CPV measurements: $\sin(2\chi)$ and $\Delta\Gamma_s$ from $B_s \rightarrow J/\psi\phi$

γ from:
- $B_s \rightarrow D_s K$
- $B^0 \rightarrow \pi\pi$ and $B_s \rightarrow KK$
- $B^0 \rightarrow D^0 K^{*0}$

Radiative decays: $b \rightarrow s\gamma$ penguins

<u>CP reach evaluation:</u> all numbers for 1 yr

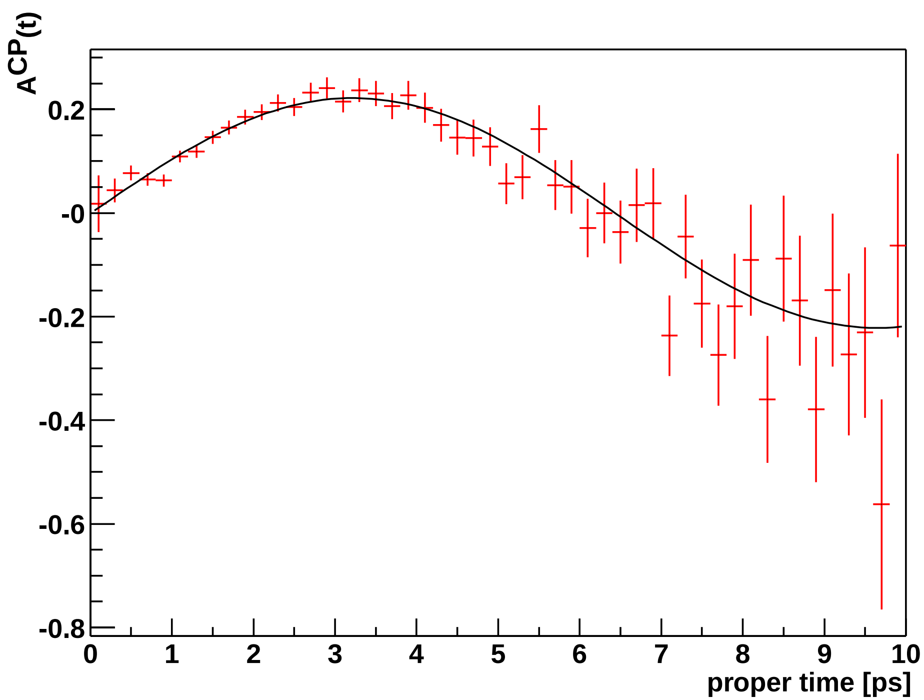
- Generate many fast MC samples
  - Signal efficiencies (including tagging) as well as background levels and shapes taken from full simulation studies
- extract physics parameter from each sample
  - for CP asymmetries, fit together a second fast MC sample of flavour-specific decays to extract the mistag “from the data”

$\sin\phi_d$ in $B \to J/\psi K_s$

$$A_{CP}^{th}(t) = A_{CP}^{dir} \cdot \cos(\Delta m_d \cdot t) + A_{CP}^{mix} \cdot \sin(\Delta m_d \cdot t)$$

$A^{dir} \neq 0 \Rightarrow$ New Physics beyond SM

$\sin\Phi_d = \sin(2\beta)$



Annual $B^0 \to J/\psi(\mu\mu)K_s$ yield: 216k

Background:	B/S	0.8
Tagging probability:		45 %
Mistag probability w:		37 %

MC simulation of many experiments:

$\sigma(\sin(\phi_d)) = 0.022$

("measurement" of mistag rate w through simulated $B^0 \to J/\psi(\mu\mu)K^*$ evts)

Δm_s with $B_s \to D_s^+(KK\pi)\pi^-$

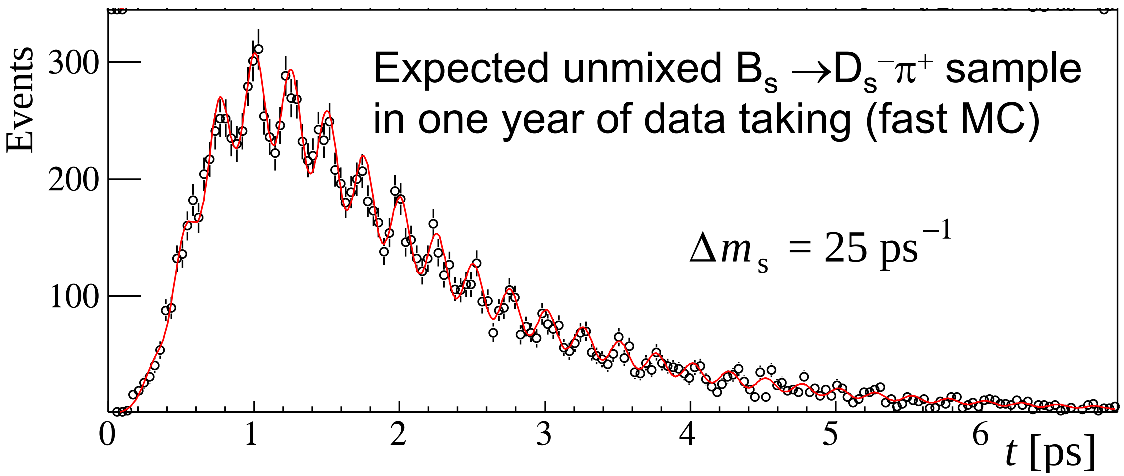
Annual event yield: 80k

Background B/S: 0.32

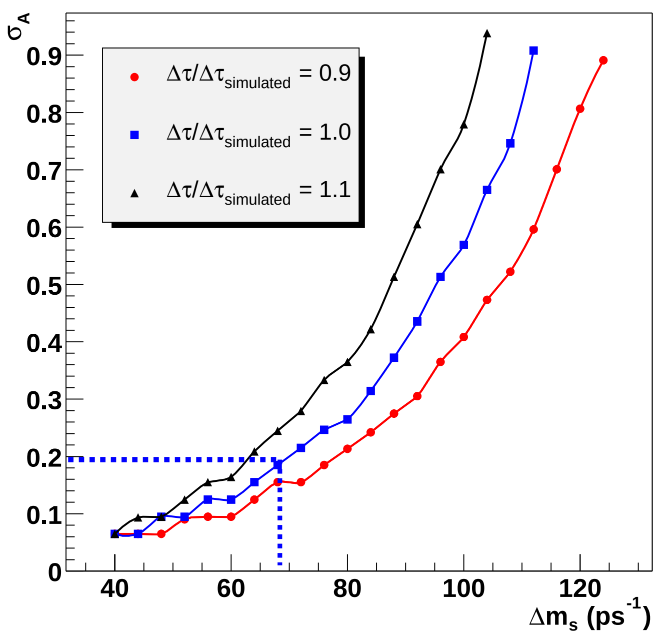
Tagging probability: 55 %

Mistag probability w: 33 %

Proper time res. 33 fs (core)



Statistical precision / yr				
Δm_s (ps^{-1})	15	20	25	30
$\sigma(\Delta m_s)$	0.009	0.011	0.013	0.016



5σ observation of B_s oscillation: 68 ps^{-1} / yr

error σ_A of oscillation amplitude

Φ_s and $\Delta\Gamma_s$ with $B_s \to J/\psi\Phi$

The "gold plated decay" of B_s:

SU(3) analogue of $B_d \to J/\psi K_s$

A_{CP} in SM $\Rightarrow$
$\Phi_s = -2\chi = -2\lambda^2\eta \sim -0.04$

event yield ($\mu\mu$) / yr:	100k
background B/S:	<0.3
tagging efficiency	50%
Mis-tag rate:	33%
proper time resolution	38 fs

Δm_s in ps^{-1}	15	20	25	30
$\sigma(\mathcal{A}_{\text{mix}})$	0.057	0.064	0.075	0.088
$\sigma(\Delta\Gamma/\bar{\Gamma})$	0.018	0.018	0.018	0.018

$\Delta\Gamma/\Gamma$	0	0.1	0.2
$\sigma(\mathcal{A}_{\text{mix}})$	0.059	0.064	0.070
$\sigma(\Delta\Gamma/\bar{\Gamma})$	0.015	0.018	0.019

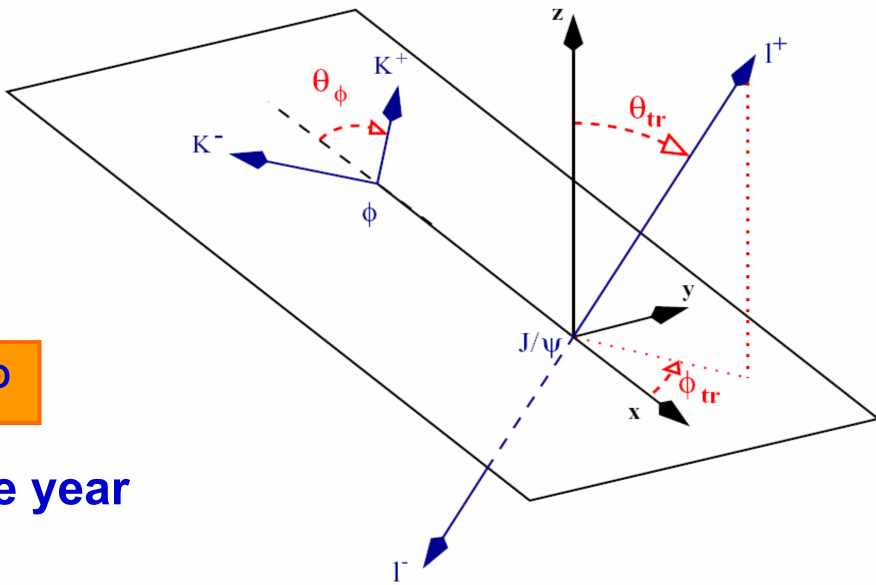
$\sigma(\chi) \sim 2^{\circ}$

If $\Delta\Gamma/\Gamma$ is ~0.1, can do a 5σ discovery in one year

Problem: PS $\to$ VV

3 contributing amplitudes
2 CP even, 1 CP odd

$\Rightarrow$ fit angular distribution of decay states (transversity angle θ_{tr}) as function of proper time.

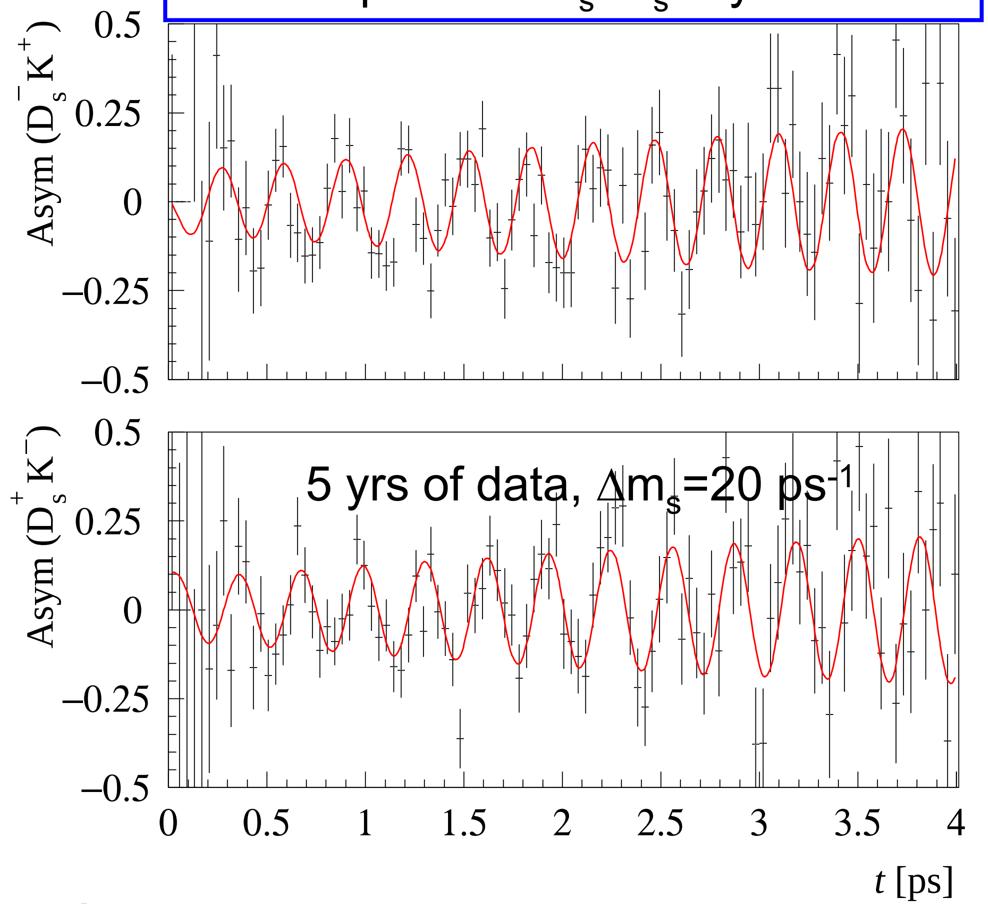


γ from $B_s \to D_s^{-+} K^{+-}$

- Interference between 2 tree diagrams due to B_s mixing
- Measure $\gamma + \phi_s$ from time-dependent rates:
  $B_s \to D_s^- K^+$ and $B_s \to D_s^+ K^-$
  (+ CP-conjugates)
- Use ϕ_s from $B_s \to J/\psi\phi$

event yield ($\mu\mu$) / yr:	5.4k
background B/S:	<1.0
tagging efficiency	54%
Mistag rate w: (extract from $B_s \to D_s \pi$)	33%

Time dependent $\overline{B}_s$–B_s asymmetries



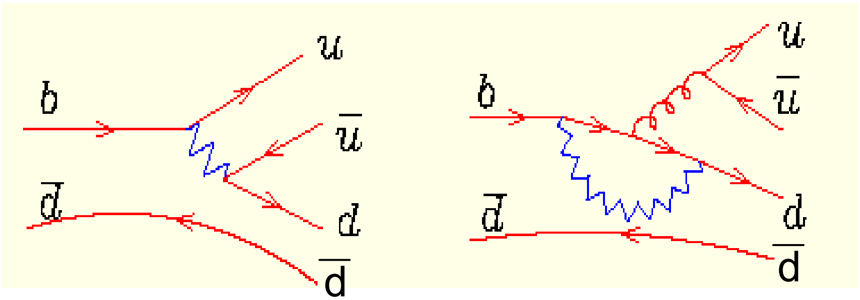
Δm_s	20	25	30
$\sigma(\gamma+\Phi_s)$	14^0	16^0	18^0

After 1 year,
if $\Delta\Gamma s/\Gamma s$ = 0.1,
$55 < \gamma < 105^O$
$-20 < \Delta T1/T2 < 20^O$

No theoretical uncertainty; insensitive to new physics in B mixing

γ from $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$

In both decays large $b \to d(s)$ penguin contributions to $b \to u$:



Measurement of time-dependent CP asymmetry for both decays
$\Rightarrow$ A^{dir} and A^{mix} w/ strong phase contribution of unknown magnitude

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

Method proposed by R. Fleischer:

- use $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$ together
- exploit U-spin flavour symmetry for P/T ratio described by d and ϑ

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

U-spin symmetry: $d = d'$ and $\vartheta = \vartheta'$

Φ_s ($B_s \to J/\psi\phi$)
Φ_d ($B^0 \to J/\psi K_s$)

4 measurements (CP asymmetries) and 3 unknown (γ, d and ϑ) $\to$ can solve for γ

γ from $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$

$A^{dir}_{\pi\pi}$, $A^{mix}_{\pi\pi}$, A^{dir}_{KK} , A^{mix}_{KK} and **w** (mistag), $\boldsymbol{A_{\pi K}}$**,,** $\boldsymbol{A_{\pi K}}$**,,** $\boldsymbol{\Delta\Gamma}$**,** $\boldsymbol{\Delta m}$**,** $\boldsymbol{\Gamma}$**, m** and τ resolutions (17 par.) from fit to:

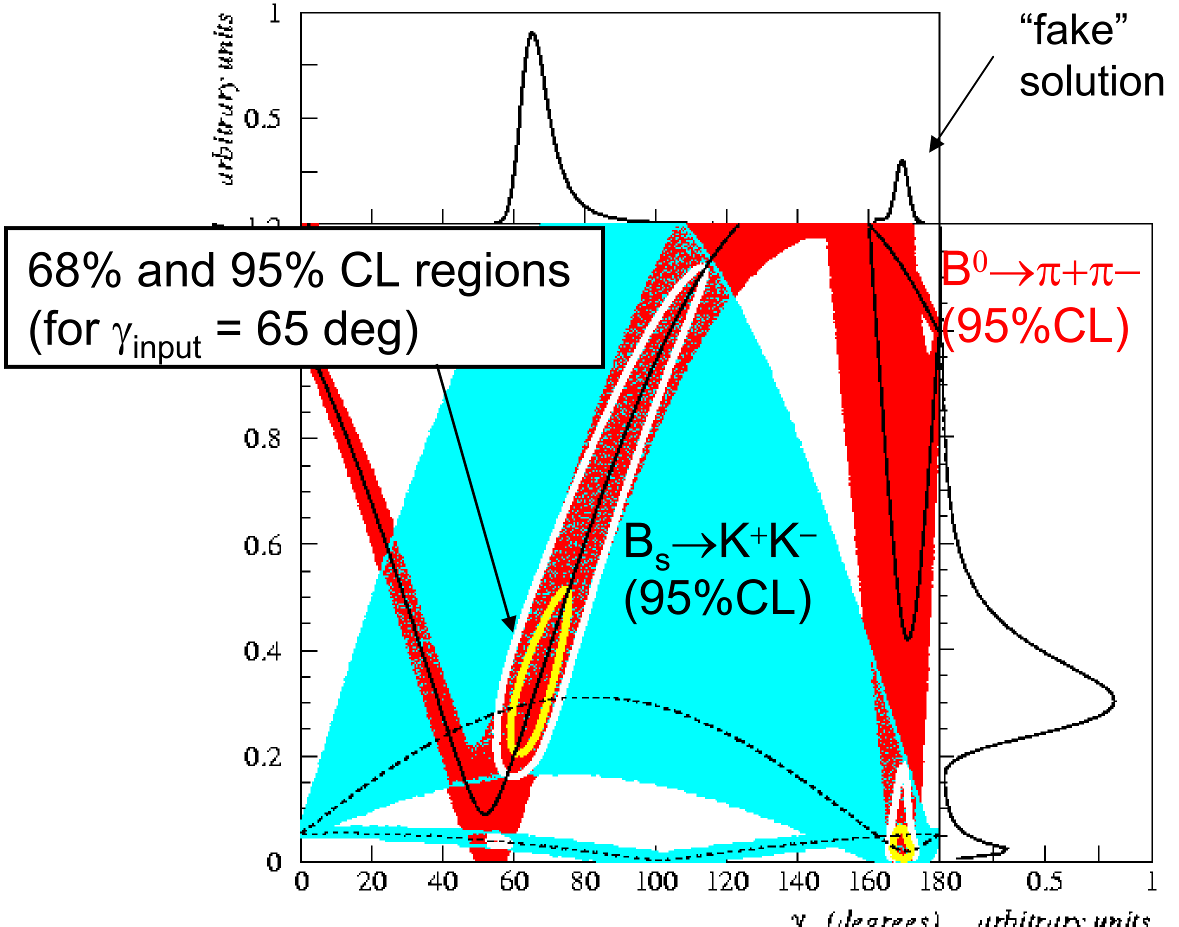
- $B^0 \to \pi^+\pi^-$ (26k / yr)
- $B_s \to K^+K^-$ (37k / yr)
- $B^0 \to K^+\pi^-$ (135k / yr)
- $B_s \to K^-\pi^+$ (5.3k / yr)

$\Rightarrow$ **p.d.f. F(*d*, ϑ, γ)**

If Δm_s= 20 ps^{-1}, $\Delta\Gamma_s/\Gamma_s$=0.1, d =0.3, ϑ= 160 deg, 55 < γ < 105 deg:

$\sigma(\gamma)$ = 4–6 deg

U-spin symmetry assumed; sensitive to new physics in penguins



d vs γ

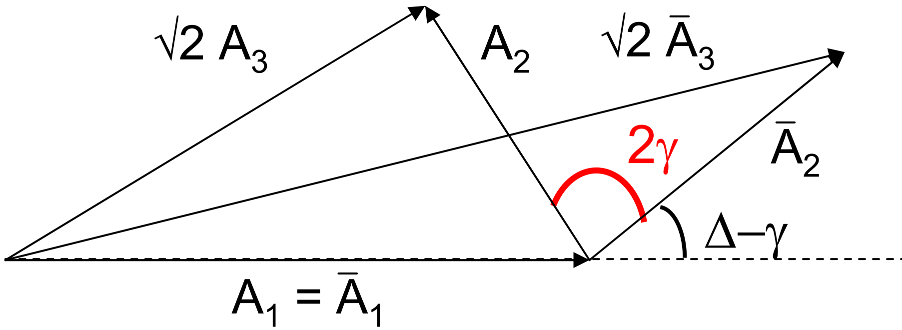
γ from $B^0 \to D^0 K^{*0}$ and $B^0 \to \bar{D}^0 K^{*0}$

Variant of the Gronau-Wyler method proposed by I.Dunietz:

$A(B^0 \to D_{CP} K^{*0}) = A_3 =$

$1/\sqrt{2}\ \left(A(B^0 \to D^0 K^{*0}) + A(B^0 \to \bar{D}^0 K^{*0}) \right)$

$1/\sqrt{2}\ \left(A_1 + |A_2|\, e^{i(\Delta+\gamma)} \right)$



together with CC decays $\Rightarrow$ two triangle relations for amplitudes

Measure 6 decay rates:

		yield/yr	B/S
$B^0 \to D^0 (K^-\pi^+) K^{*0}(K^+\pi^-)$	+ cc	0.5k	1.8
$B^0 \to \bar{D}^0 (K^+\pi^-) K^{*0}(K^+\pi^-)$	+ cc	3.4k	0.3
$B^0 \to D_{CP} (KK) K^{*0} (K^+\pi^-)$	+ cc	0.6k	1.4

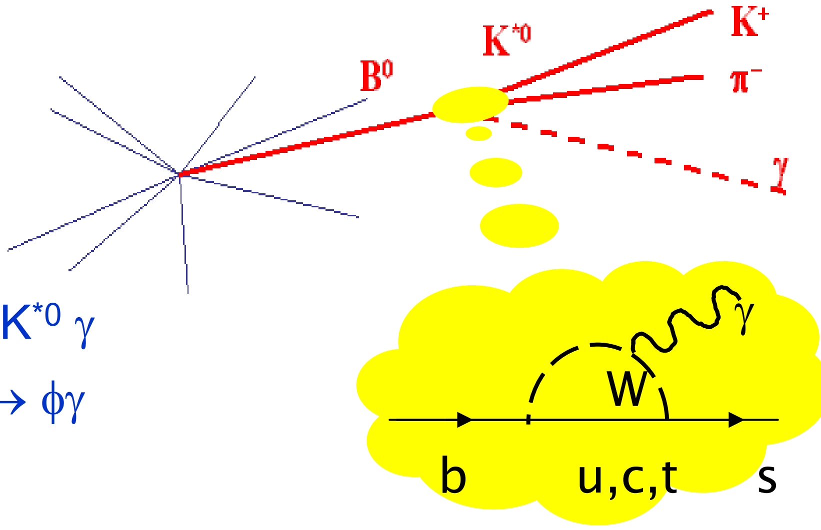
$\gamma = 65^o$, $\Delta = 0$

$55 < \gamma < 105$ deg
$-20 < \Delta < 20$ deg

$\sigma(\gamma) = 7\text{–}8$ deg

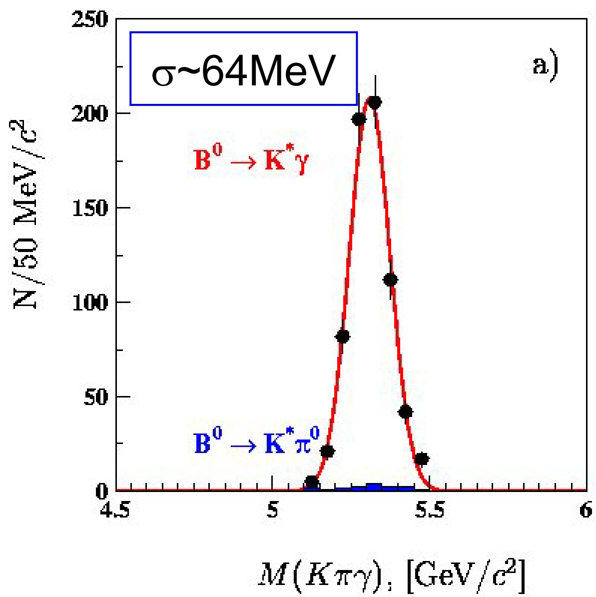
sensitive to new phase in D_{CP}

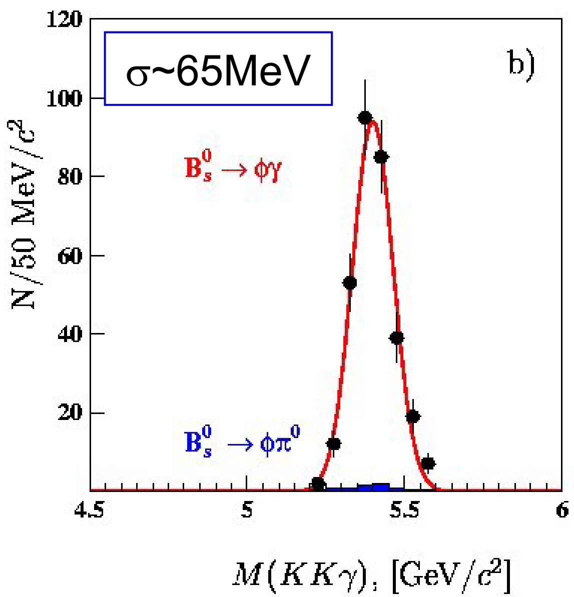
$B^0 \to K^{*0}\gamma$ and $B_s \to \phi\gamma$



In SM:

- loop-suppressed $b \to s\gamma$ transitions
- BR($B^0 \to K^{*0}\gamma$) = $(4.3 \pm 0.4)\ 10^{-5}$
- expected direct CP violation <1% for $B^0 \to K^{*0}\gamma$
- expected CP violation in mixing ~0 for $B_s \to \phi\gamma$





	1 yr	B/S
$B^0 \to K^{*0}\ (K^+\pi^-)\ \gamma$	35k	<0.7
$B_s \to \phi\ (K^+K^-)\ \gamma$	9.3k	<2.4

$\sigma(A_{CP})$ ~ 0.01 (1year)

$B^0 \to K^{*0}\ \mu^+\mu^-$

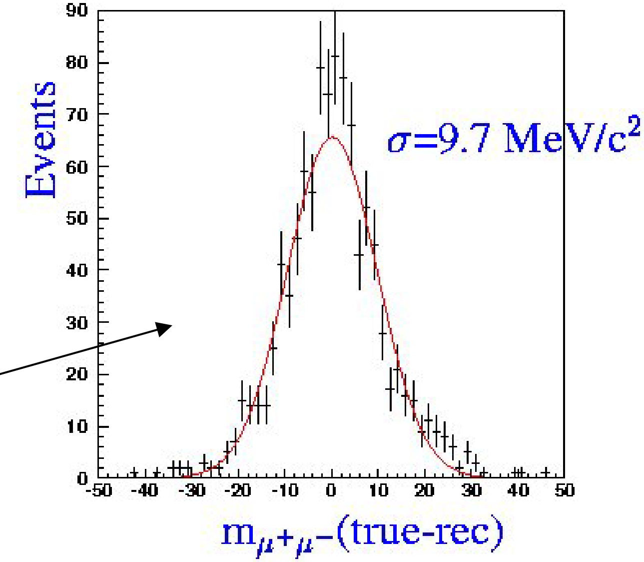
SM:

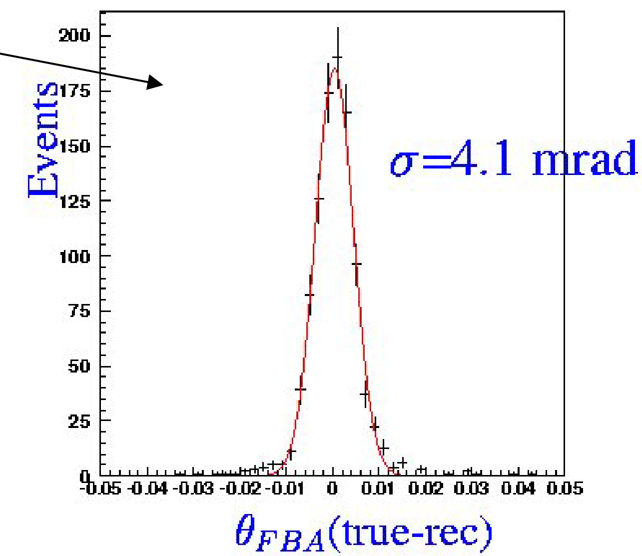
$BR(B^0 \to K^{*0}\ \mu^+\mu^-) = (1.2 \pm 0.4) \times 10^{-6}$

$\Rightarrow$ Measurement determines $|V_{ts}|$

Variables sensitive to **New Physics:**

- $\mu^+\mu^-$ invariant mass distribution
- $\mu^+\mu^-$ forward-backward asymmetry
  $\theta_{FBA} = \angle\ (\mu^+$, B direction in $\mu^+\mu^-$ CMS)





Annual yield (SM):	4.4k
Efficiency:	0.7%
Background (B/S)	<2

$\sigma(BR) \sim 3\%$

$\sigma(A_{CP}) \sim 3\%$

Conclusion

LHCb can study many different B-meson decay modes with high precision

- excellent particle identification capability
- excellent mass and decay-time resolution

LHCb can fully exploit the large B-meson yields at LHC from the start-up

- flexible, robust and efficient trigger
- design luminosity of $2x10^{32}$ is lower than typical LHC luminosity

LHCb detector will be ready for data taking in 2007 at LHC start-up

- detector production is on schedule
- installation of detectors will start end of next year

LHCb will offer soon an excellent opportunity to

- determine precisely the CKM parameters through phase meas.
- spot New Physics by overconstraining the Unitarity Triangles