Physics with LHCb

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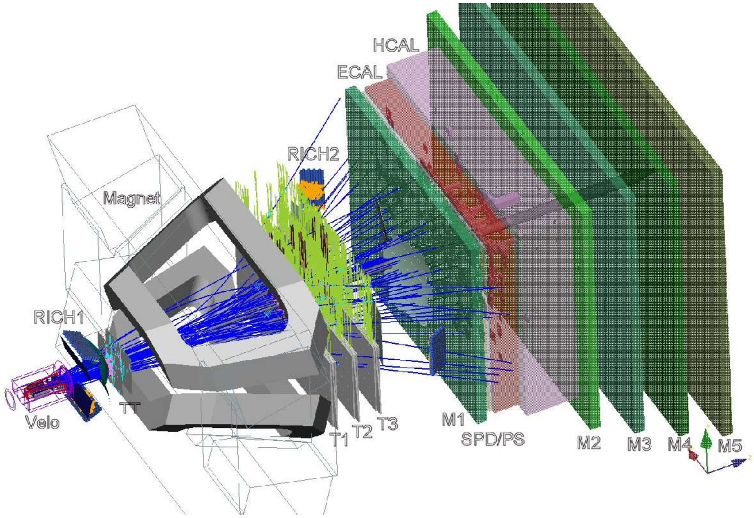
On behalf of the LHCb collaboration



- Introduction
- Ingredients of physics analysis at LHCb
- Physics program
- Summary

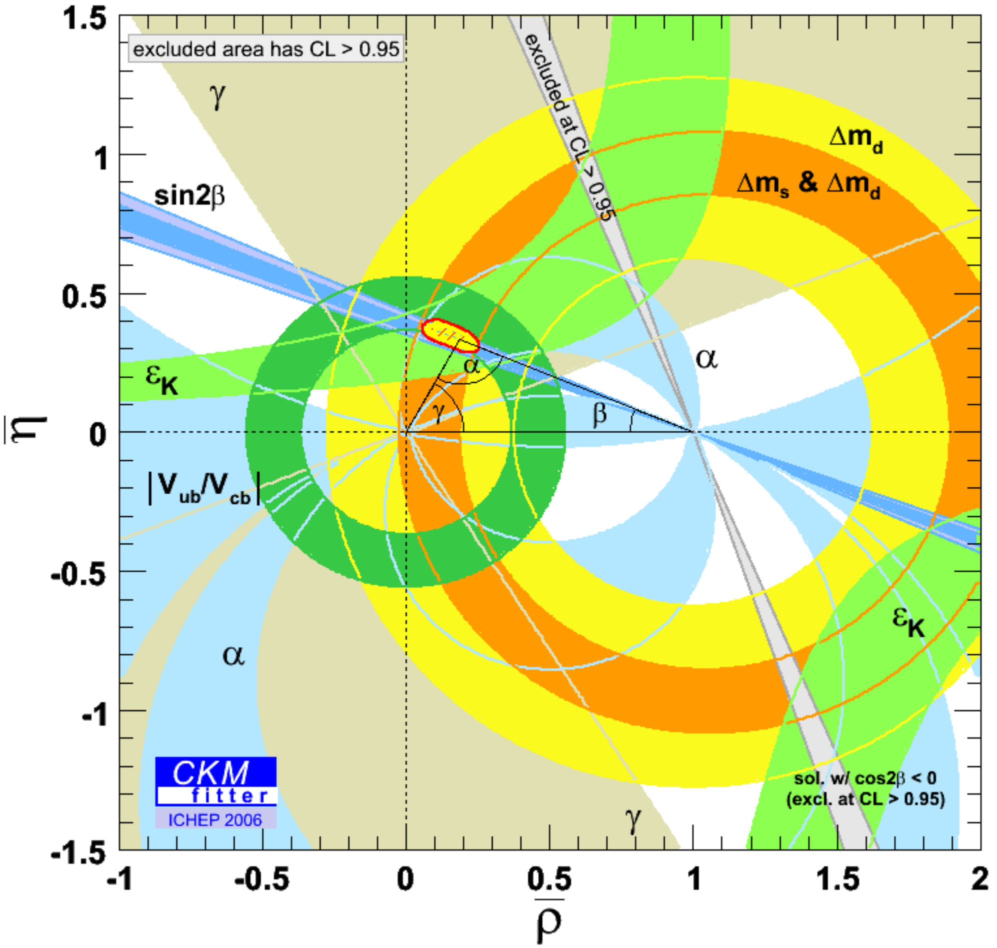
LHC days in Split, 2nd – 7th October 2006

Motivation

- We expect to directly observe new physics at the LHC
  - Cosmological arguments: Dark Matter
  - Hierarchy problem: why is Higgs mass lot less than the Planck scale
- But building and elucidating a model for the new physics will not be easy
- New physics can give rise to new particles in loops
  - Possible deviations from standard model observables
- Indirect measurements can provide complementary information

The State of Play

- All measurements consistent with CKM matrix picture
- Effect of new physics small in the flavour sector is small ?
- Consistency, compare measurement where NP effects expected with tree level measurements
- Clear avenues to explore:
  - Angle γ least constrained
  - CP violation in B_s oscillations



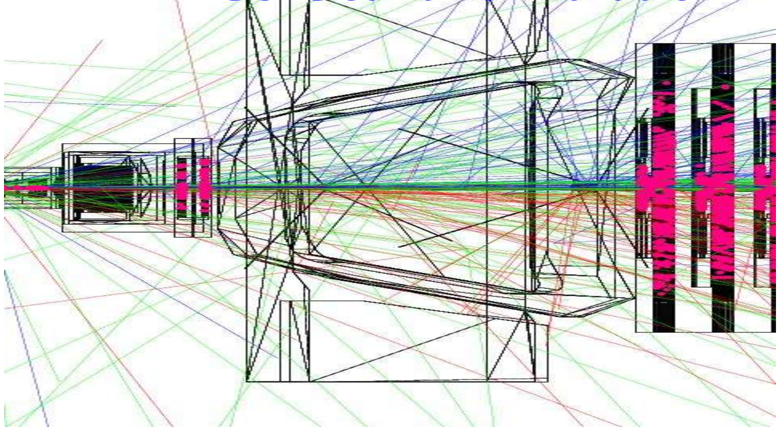
$\sin 2\beta = 0.674 \pm 0.026$

$\alpha = 93^{+11}_{-9}$ degree

$\gamma = 71^{+22}_{-30}$ degree

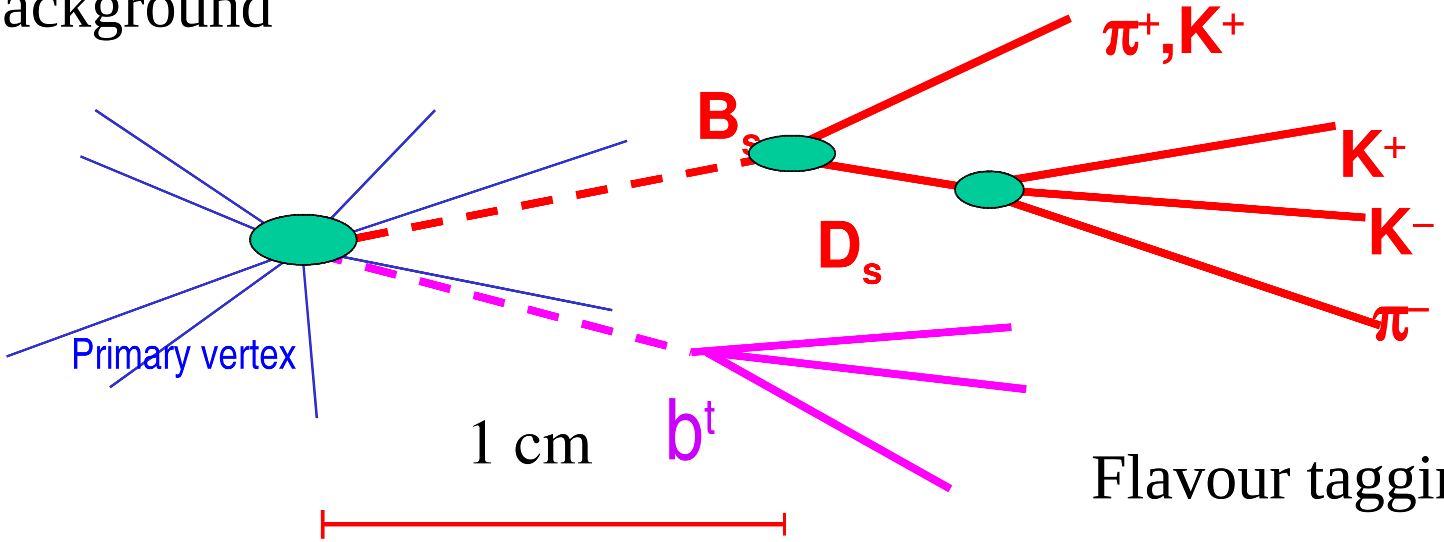
LHCb Requirements

LHCb Geant4 simulation



- Time-dependent measurements
- Working in the harsh enviroment of the LHC
- B events 1 % of the total cross-section
  - Selective trigger need

Mass/pointing constraints to reduce background



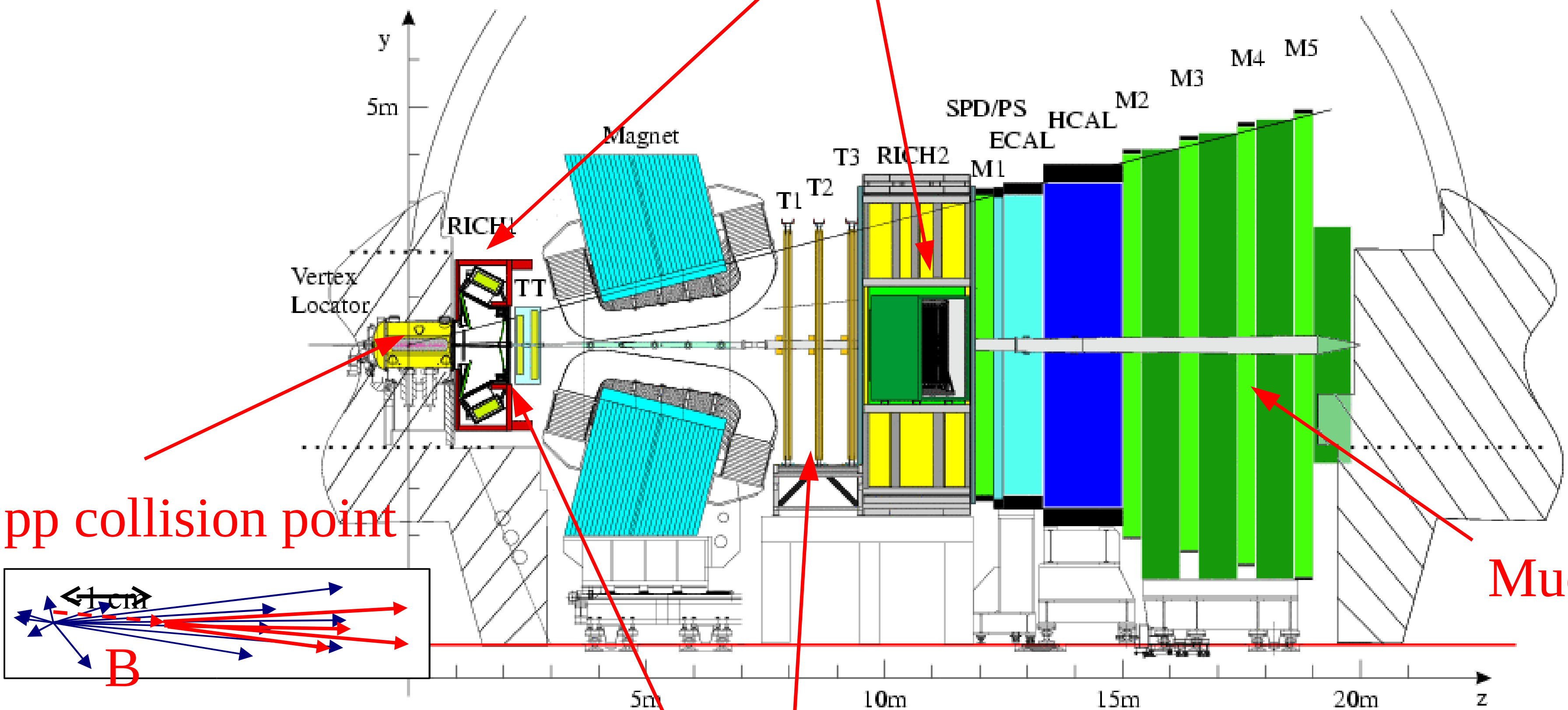
good K/π separation

Flavour tagging

Good primary and secondary vertexing to determine proper time

The LHCb Detector

RICH system for PID



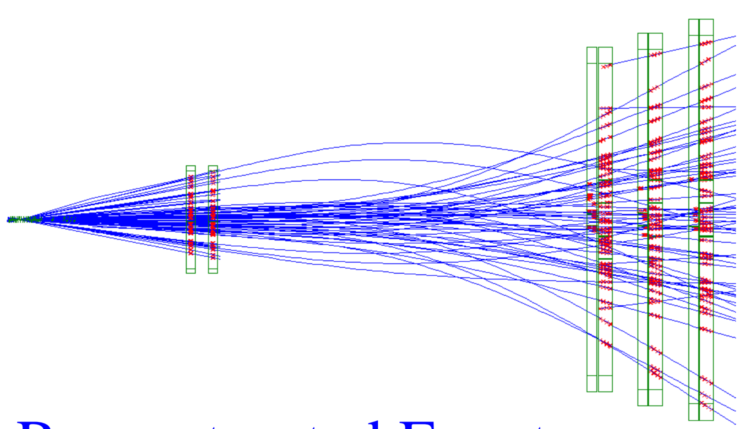
pp collision point

Muon System

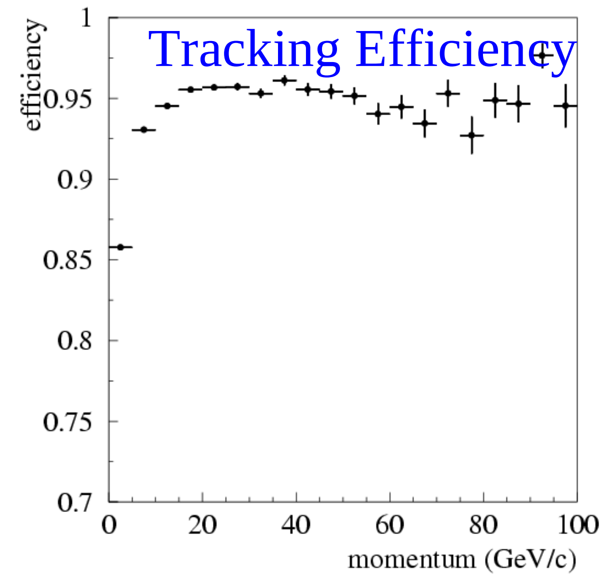
Tracking system

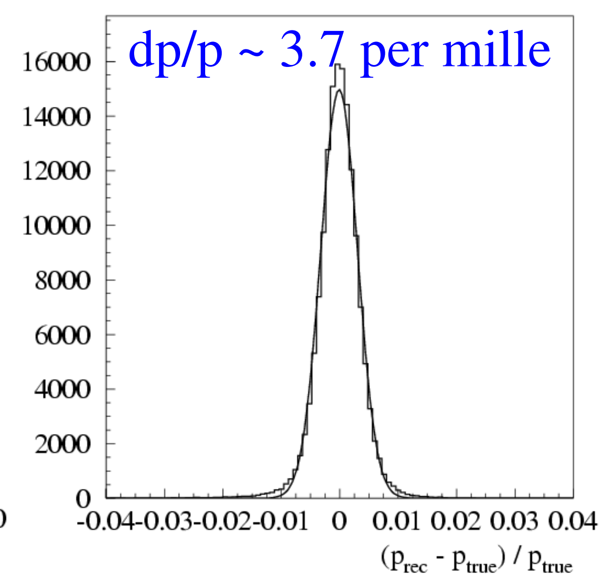
Event Simulation

- Detector perfomance and physics reach obtained with Monte Carlo
- Event generation using Pythia 6.3 with dedicated LHCb tuning
- Detailed GEANT4 simulation of the detector geometry
- Detector response from testbeams and tests of prototypes
- Reconstruction and pattern recognition
- Results using large MC samples generated for Data Challenge in 2004-2005
- Sensitivities are obtained using fast simulations with efficiencies, resolutions and background level from full simulations.

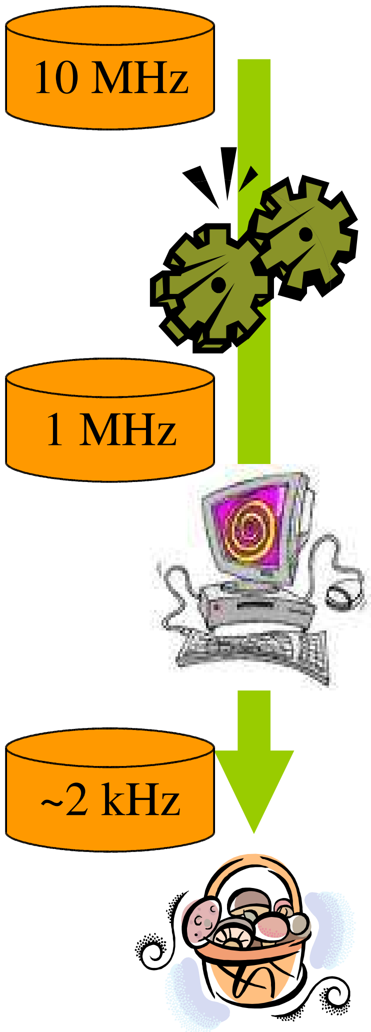


Reconstructed Event





Trigger Strategy



Visible collisions

L = 2 10^{32} cm^{-2} s^{-1}

L0: [hardware]

high Pt particles

calorimeter + muons

4 s latency

HLT [software]

1 MHz readout

~1800 nodes farm

On tape:

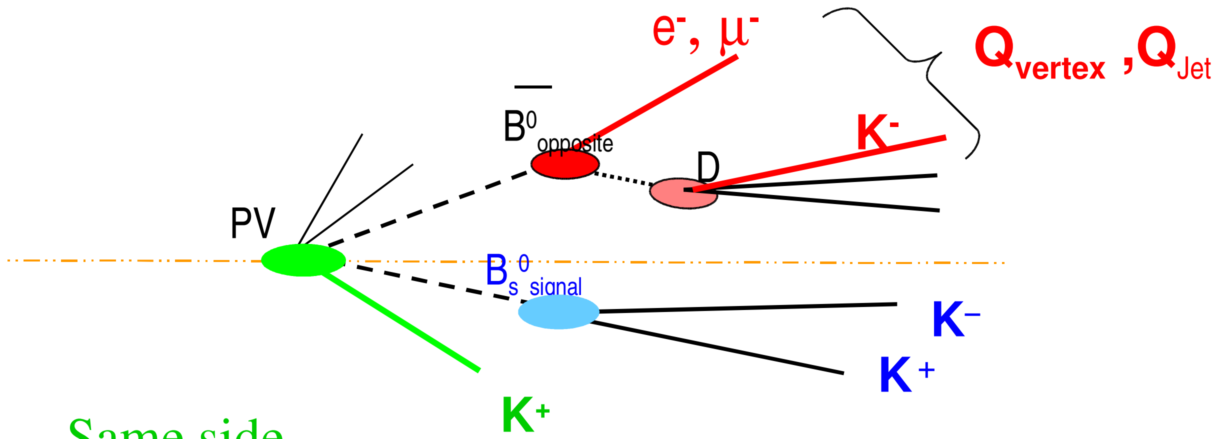
Exclusive selections

Inclusive streams

- Enhance the b content in sample
  - High Pt particles,
  - Displaced tracks
  - Increase b content: from 1% to 50-60%

- Different output streams from HLT
  - 200 Hz are dedicated to the exclusive selections of specific channels
    - Main stream for the core LHCb physics programme
  - Inclusive streams for calibration and data mining:
    - di-muon stream
    - D* stream
    - single muon

Flavour Tagging



Opposite side

- High Pt leptons
- $K^{\pm}$ from b → c → s
- Vertex charge
- Jet charge

Same side

- Fragmentation $K^{\pm}$ accompanying B_s
- $\pi^{\pm}$ from $B^{**} \rightarrow B^{(*)}\pi^{\pm}$

Figure of merit:

$\varepsilon D^2 = \varepsilon(1-2\omega)^2$: tagging power

ε: tagging efficiency

ω: wrong tagging fraction

Tagging power in %		
Tag	B_d	B_s
Muon	1.1	1.5
Electron	0.4	0.7
Kaon opp.side	2.1	2.3
Jet/ Vertex Charge	1.0	1.0
Same side π / K	0.7 (π)	3.5(K)
Combined (Neural Net)	~ 5.1	~9.5

LHCb Physic Program

Dedicated b physics program. Ultimate physics goals:

- Bs mixing parameters: Δm_S, $\Delta\Gamma_S$ and ϕ_S
- α: e.g. with $B_d \rightarrow \pi^0\pi^-\pi^+$
- β: e.g with $B_d \rightarrow J/\psi\, K_S$
- Measurements of with γ using different methods
- Rare decays
  - $B_S \rightarrow \mu\mu$ to the level of the SM prediction
  - Radiative penguin $B_d \rightarrow K^*\gamma$, $B_s \rightarrow \phi\gamma$, $B_d \rightarrow \omega\gamma$
  - Electroweak penguin $B_d \rightarrow K^{*0}\mu^+\mu^-$
- and much more, e.g. B_C, charm physics (oscillations/CP violation)

Angle γ

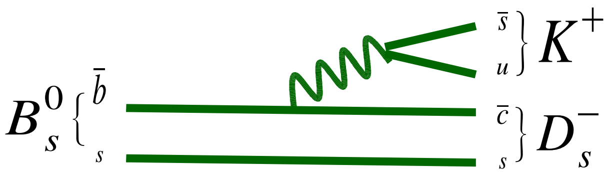
- Least well constrained CKM angle
- LHCb will measure in several channels
  - from $B_s \to D_s K$
  - from $B^0 \to D^0 K^{*0}$
  - from $B^{\pm} \to D K^{\pm}$ using the ADS method
  - $B^+ \to D^0 K^+$ Dalitz ($D^0 \to K_S \pi\pi, K_S KK$)
  - from $B^0 \to \pi^+ \pi^-$ and $B_s \to K^+ K^-$

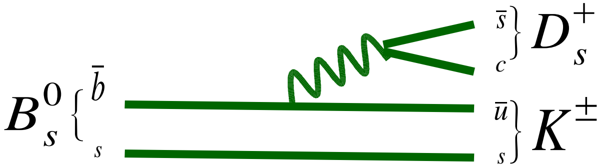
} Standard model γ (first four channels)

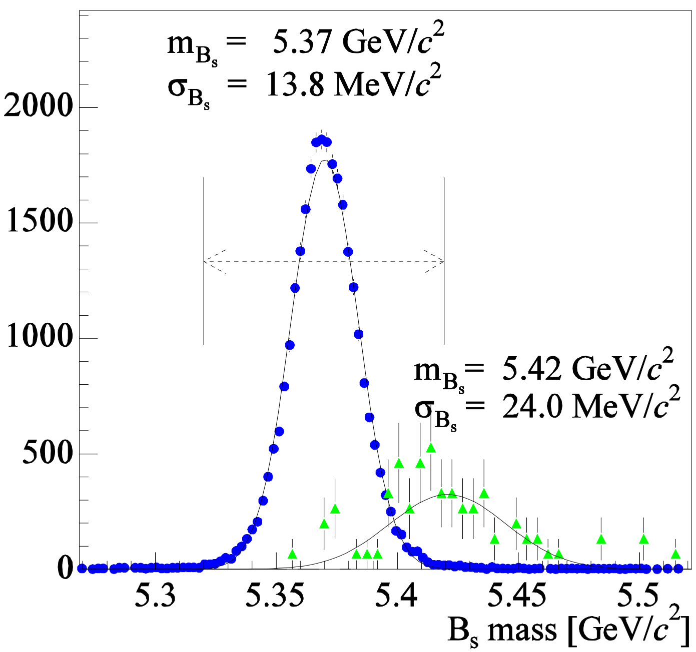
Sensitive to new physics (last channel)

γ from $B_s \rightarrow D_s K$

- Interference between tree level decays via mixing
  - Insensitive to new physics
- Measure $\gamma + \phi_s$
- ϕ_s will be determined from $B_S \rightarrow J/\psi\ \phi$



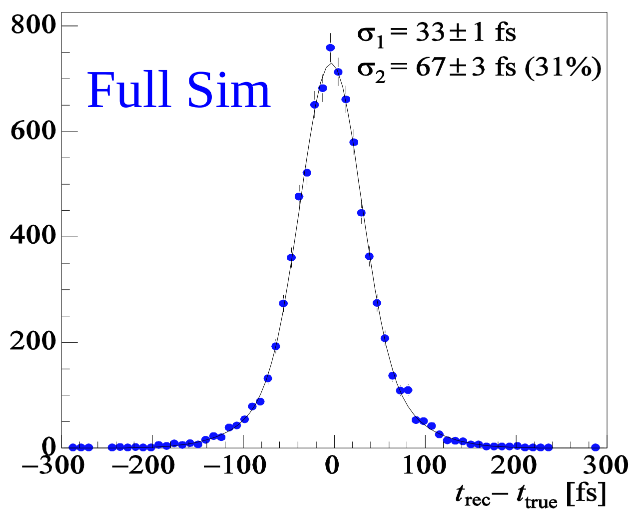


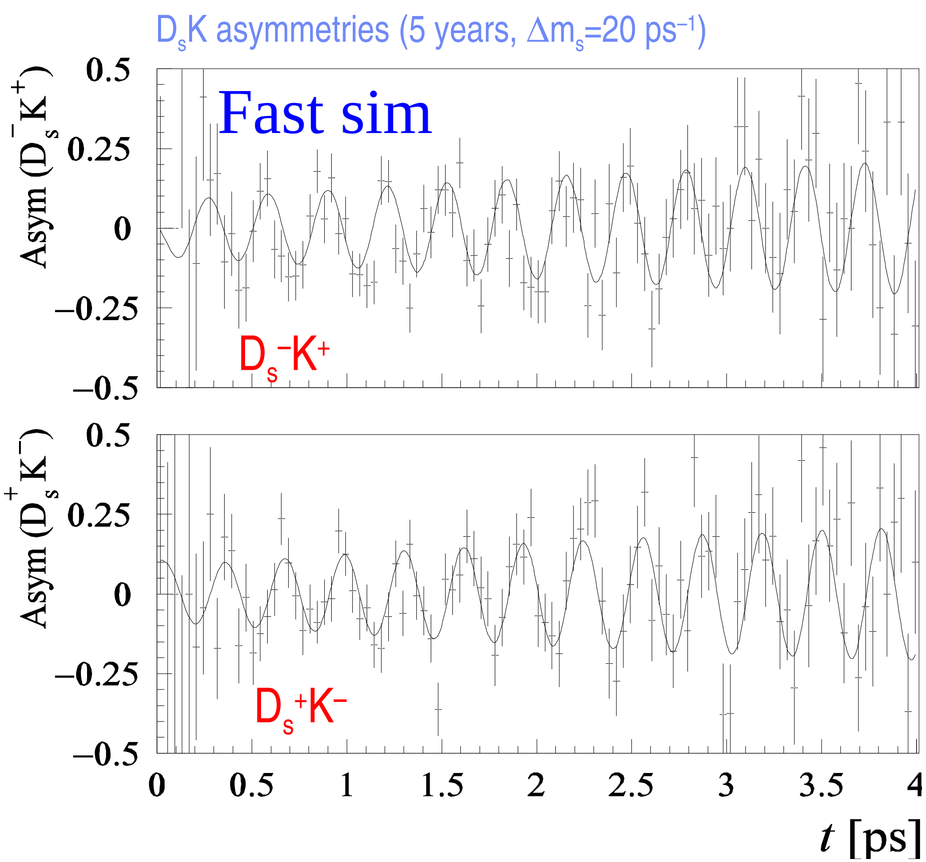


- Main background comes from $B_s \rightarrow D_s\ \pi$
- Factor 10 higher branching ratio
- Suppressed using Kaon identification from RICH
- 5.4 k events expected with $2 fb^{-1}$ (1 year of data)
- Background from $B_s \rightarrow D_s\ \pi < 10$ %
- S/B > 1 at 90% CL

γ from $B_s \to D_s K$

- Measuring the decay asymmetry requires resolving the Bs oscillations
- Excellent proper time resolution from vertex detector





Precision: ~ 13° on γ with $2fb^{-1}$

γ from $B^{\pm} \rightarrow DK^{\pm}$ (ADS Method)

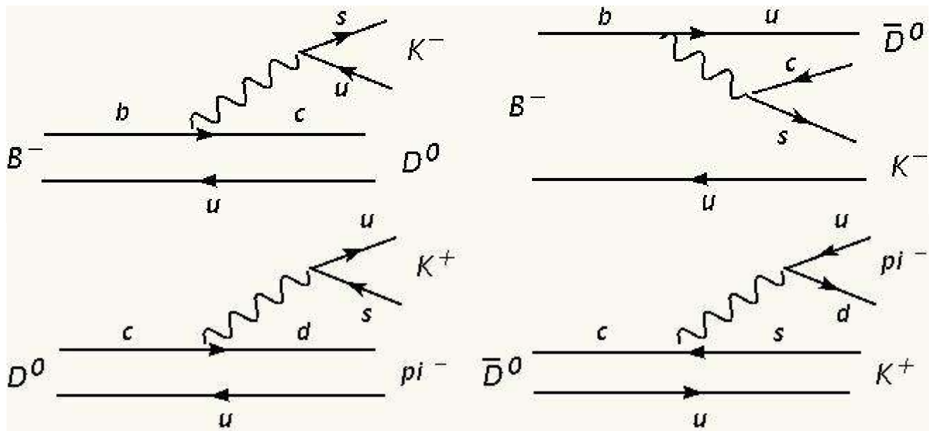
- Measure relative rates of $B^{-} \rightarrow D(K\pi)\,K^{-}$ and $B^{+} \rightarrow D(K\pi)\,K^{+}$
  - Two interfering tree B-diagrams, one colour-suppressed (r_B ~0.077)
  - Two interfering tree D-diagrams, one Double Cabibbo-suppressed ($r_D^{K\pi}$ ~0.06)

Colour allowed

Colour suppressed

Double Cabbibo suppressed

Cabbibo favoured



- For these decays the reversed suppression of the D decays relative to the B decays results in much more equal amplitudes
- Large interference effects
  - Simple counting experiment (no tagging, no proper time) measure:

$$\Gamma(B^- \to (K^-\pi^+)_D K^-) \propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B - \delta_D^{K\pi} - \gamma\right)$$

$$\Gamma(B^- \to (K^+\pi^-)_D K^-) \propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B + \delta_D^{K\pi} - \gamma\right),$$

$$\Gamma(B^+ \to (K^+\pi^-)_D K^+) \propto 1 + (r_B r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B - \delta_D^{K\pi} + \gamma\right)$$

$$\Gamma(B^+ \to (K^-\pi^+)_D K^+) \propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cos\left(\delta_B + \delta_D^{K\pi} + \gamma\right), \quad (4)$$

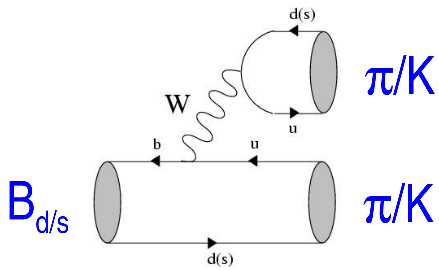
favoured ~60k evts

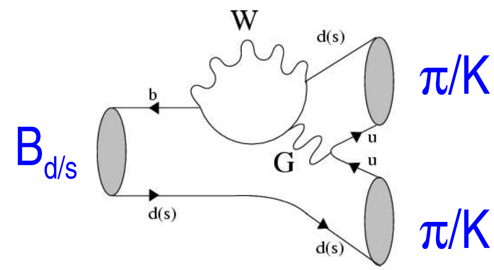
colour suppressed 0.5 k

Precision: 4°- 13° with $2\,fb^{-1}$

γ from $B \to hh$

- $B^0 \to \pi^+\pi^-$ originally proposed for measurement of angle
- But extraction of α is compromised by influence of penguin diagrams





– Measure time-dependent CP asymmetries for $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$

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

– Extract four asymmetries:

$$A_{dir}(B^0 \to \pi^+\pi^-) = f_1(d, \theta, \gamma)$$
$$A_{mix}(B^0 \to \pi^+\pi^-) = f_2(d, \theta, \gamma, \beta)$$
$$A_{dir}(B_s \to K^+K^-) = f_3(d', \theta', \gamma)$$
$$A_{mix}(B_s \to K^+K^-) = f_4(d', \theta', \gamma, \chi)$$

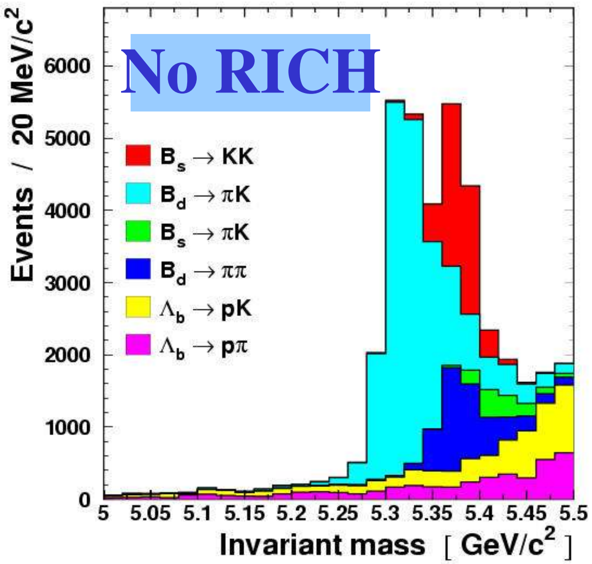
$d e^{i\theta}$ = ratio of penguin and tree amplitudes in $B^0 \to \pi^+\pi^-$

$d' e^{i\theta'}$ = ratio of penguin and tree amplitudes in $B_s \to K^+K^-$

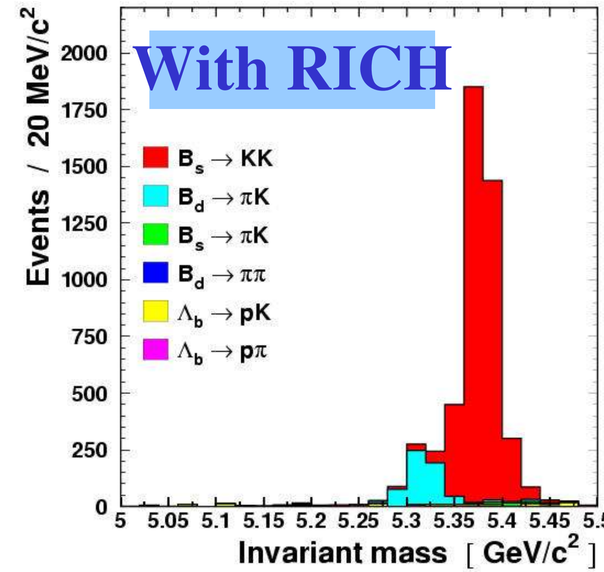
– Assume U-spin flavour symmetry ($d \leftrightarrow s$) $d = d'$ and $\theta = \theta'$

– Take ϕ_d from $B_d \to J/\psi\, K_S$ and ϕ_S from $B_S \to J/\psi\, \phi$ solve for γ

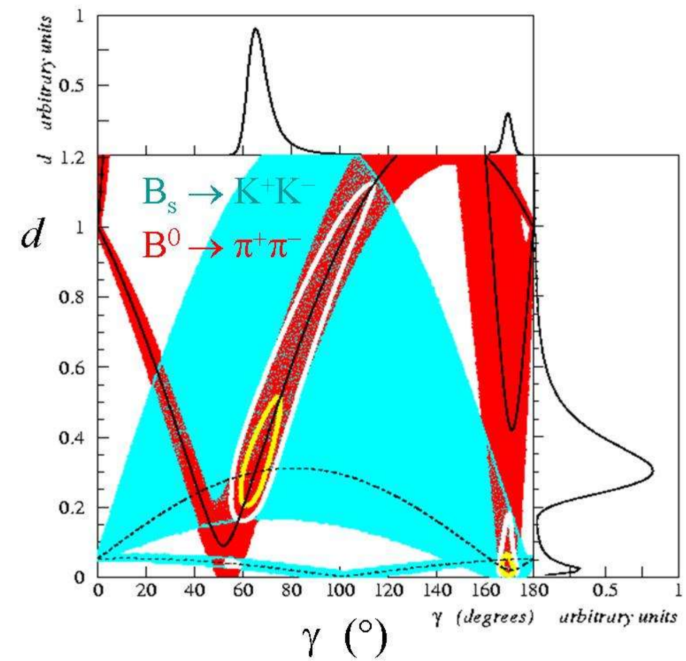
γ from $B \to hh$



Use PID from RICH

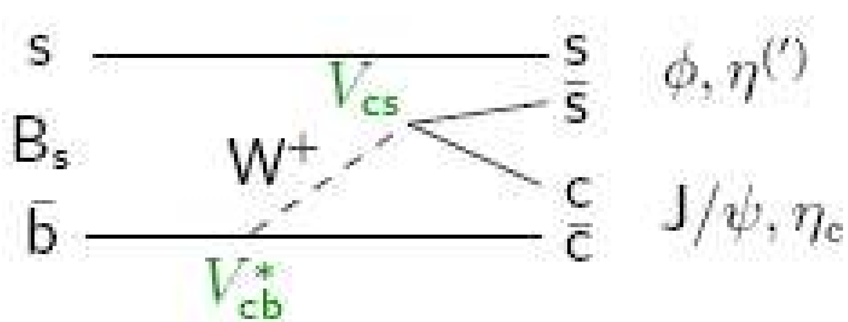


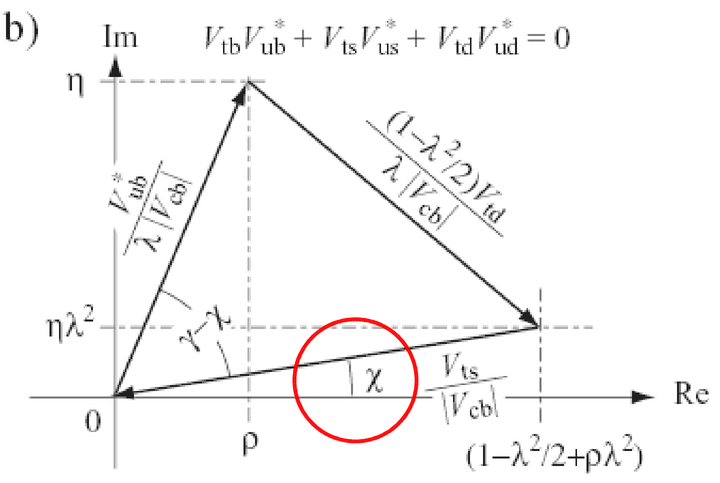
- 26k $B_d \to \pi\pi$ events with 2fb $^{-1}$, B/S<0.7
- 37k $B_s \to KK$ events/year, B/S=0.31±0.1
- $\sigma(\gamma)$ ~ 5^o + uncertainty from U-spin symmetry breaking
- Sensitive to new physics



Measurement of ϕ_s

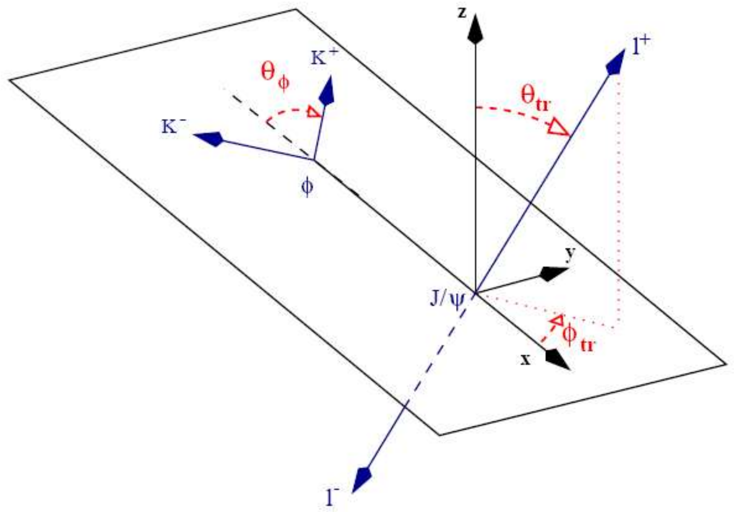
- ϕ_s , Bs oscillation mixing phase
- ϕ_s is small in the standard model: $\phi_s = -\arg(V_{ts}^2) = -2\lambda^2\eta \sim -0.04$ radian
- Sensitive probe for new physics: $\phi_s = \phi_s^{SM} + \phi_s^{NP}$
- ϕ_s is not yet measured: interesting probe of new physics
  - Unconstrained even with Δm_s measurement from CDF
- Measure from time dependent asymmetry measurement in b $\rightarrow$ccs transitions
- For this measurement need Δm_s as input





CP Asymmetry in $B_S \to J/\psi\ \phi$,...

- $B_S \to J/\psi\ \phi$ is the counter part of the golden mode $B_d \to J/\psi\ K_S$
- High yield: 125 k signal events per year (before tagging)
- Vector-Vector final state: Admixture of CP eigenstates
  - Angular analysis needed



- Pure CP eigenstates (e.g. $B_S \to J/\psi\ \eta$) can also be added
  - No angular analysis needed but total statistics low (12k events year)

CP Asymmetry in $B_S \rightarrow J/\psi\ \phi$,...

- Physics reach:

Channels	$\sigma(\phi_s)$ [rad]	Weight $(\sigma/\sigma_i)^2$ [%]
$B_s \rightarrow J/\psi\ \eta(\pi^+\ \pi^-\ \pi^0)$	0.142	2.3
$B_s \rightarrow D_s D_s$	0.133	2.6
$B_s \rightarrow J/\psi\ \eta(\gamma\ \gamma)$	0.109	3.9
$B_s \rightarrow \eta_c \phi$	0.108	3.9
Combined (pure CP eigenstates)	**0.060**	**12.7**
$B_s \rightarrow J/\psi\phi$	0.023	87.3
Combined (all CP eigenstates)	**0.022**	**100.0**

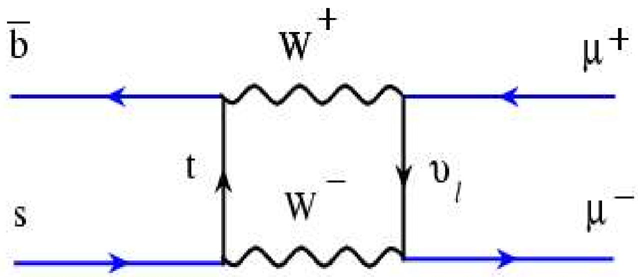
Sensitivity with $2fb^{-1}$, $\Delta m_S = 17.5\ ps^{-1}$, ϕ_S= -0.04 ,$\Delta\Gamma_S/\Gamma_S$ = 0.15

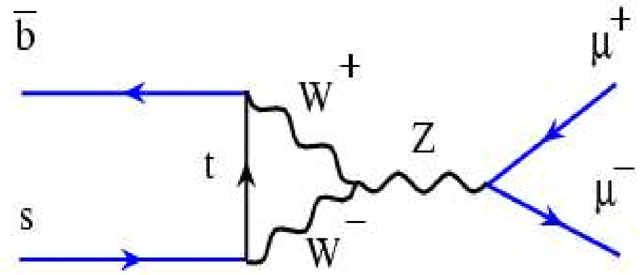
2 σ measurment of standard model value with 2 fb^{-1}

Measurement of $B_s \rightarrow \mu\mu$

- Flavour Changing Neutral Current
  - BR ~ 3.5 10^{-9} in SM, hadronic uncertainities small
  - sensitive to new physics: can be be enhanced in SUSY and other models
  - current limit from Tevatron (CDF): 1.0×10^{-7} at 95% CL

- LHCb expect 17 events 2 fb^{-1}
- No background events selected in sample of 33 million events but estimation limited by statistics
  - b $\rightarrow \mu$, b $\rightarrow \mu$ known to be main source of background





Physics Reach

1 year of LHCb running ($2fb^{-1}$):

	Channel	Yield*	B_{bb}/S	Precision
γ	$B_s \to D_s K$	5.4k	<1	$\sigma(\gamma) \approx 14^\circ$
	$B_d \to \pi\pi$	26k	<0.7	
	$B_s \to KK$	37k	0.3	$\sigma(\gamma) \approx 6^\circ$
	$B_d \to D^0(K^-\pi^+)K^{*0}$	0.5k	<0.3	
	$B_d \to D^0(K^+\pi^-)K^{*0}$	2.4k	<2	$\sigma(\gamma) \approx 8^\circ$
	$B_d \to D_{CP}(K^+K^-)K^{*0}$	0.6k	<0.3	
	$B^- \to D^0(K^-\pi^+)K^-$	60k	0.5	
	$B^- \to D^0(K^+\pi^-)K^-$	2k	0.5	$\sigma(\gamma) \approx 5^\circ$
α	$B_d \to \pi^0\pi^-\pi^+$	14k	0.8	$\sigma(\alpha) \approx 10^\circ$
ϕ_s	$B_s \to J/\Psi\Phi$	125k	0.3	
	$B_s \to J/\Psi\eta$	12k	2-3	$\sigma(\phi_s) \approx 2^\circ$
	$B_s \to \eta_c\Phi$	3k	0.7	
Δm_s	$B_s \to D_s\pi$	80k	0.3	Δm_s up to 68 ps^{-1}
β	$B_d \to J/\Psi K_S$	216k	0.8	$\sigma(\sin 2\beta) \approx 0.022$
rare decays	$B_d \to K^*\mu^+\mu^-$	4.4k	<2.6	C_7^{eff}/C_9^{eff} with 13% error
	$B_s \to \mu^+\mu^-$	17	<5.7	NP search
	$B_d \to K^*\gamma$	35k	<0.7	$\sigma(A_{CP}^{dir}) \approx 0.01$

NP ?

NP ?

NP ?

Physics at Startup

2007: Commisioning with 450 GeV beam

- Detector calibration and alignment

2008: Expect to collect ~ 0.5 fb^{-1}

- Preparations for physics data taking:
  - Commissioning of HLT
  - Completion of momentum and particle ID calibration
- First physics includes:
  - ϕ_S with $B_s \to J/\psi\ \phi$ already with 0.2 fb^{-1} can measure with accuracy of ~ 0.07
  - $B_S \to \mu\mu$ with 0.2 fb^{-1} can exclude to 10^{-8} (same sensitivity as expected at Tevatron in 2009)
  - First CP Measurements: β with $B_d \to J/\psi\ K_S$
  - b and J/ψ production studies

Summary

- LHCb will collect high statistics samples of B hadrons
  - Including Bs and b baryons
- Measure CKM angles with increased precision
  - $\sigma(\gamma) \sim 5°$ with 2 fb^{-1}
- Measure precisely the Bs oscillation parameters
  - ϕ_S to accuracy of 0.02
- Search for rare decays such as $B_S \rightarrow \mu\mu$
- And much more

LHCb offers an excellent opportunity to spot New Physics signals beyond the Standard Model