

The Physics potential of LHCb: CP violation and rare decays in the beauty sector at LHCb

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The Physics Potential of LHCb:

CP violation and rare decays in the beauty sector at LHC

R. Le Gac[†]
on behalf of the LHCb Collaboration

1. Motivation
2. Methods
3. LHCb detector
4. Physics performances
5. Status and Conclusions

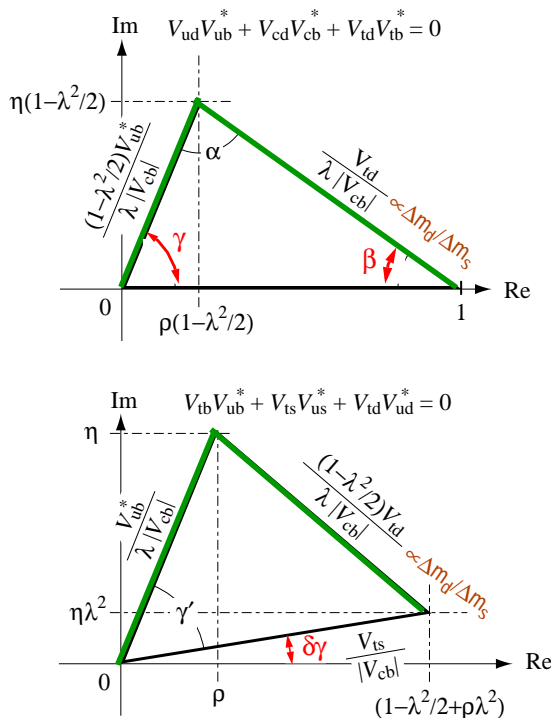
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MOTIVATION

- Standard Model accommodates CP violation through the CKM matrix. This mechanism has to be validated.

Unitarity property of the matrix → Unitarity Triangles (UT):



- Currently the UT is weakly constrained (ϵ , $|V_{ub}|$, $|V_{cb}|$, Δm_d)
- Will be improved in ~2005:
 - Δm_s ? (HERA-b, CDF/D0)
- CP violation in the B_d system:
 - β (BaBar, Belle, CDF/D0, HERA-b)
 - α ? (BaBar, Belle, HERA-b)
- Significant theoretical uncertainties on the length of the sides

- LHCb will measure:

- CP violation in the B_s system
- all phases: β , γ , $\delta\gamma$, $(\beta+\gamma)$,...
- one side: Δm_s

➔ Over-constrain the unitarity triangles.

Understand CP violation in the framework of the Standard Model.

MOTIVATION ...

- **2nd motivation is related to the evolution of the Universe.**
The disappearance of the antimatter component requires CP violation.
But, the CP violation from the Standard Model is too small.
 - ↳ **Additional sources of CP violation are needed.**
They might find their origin in supersymmetric models
- **LHCb is a promising place to study new physics.**
Complementary approach to ATLAS and CMS.
- **LHCb will measure:**
 - The phase β, γ using different decay modes.
 - Branching ratio of rare decays such as: $B_s \rightarrow \mu^+\mu^-$, $B_{d,s} \rightarrow K^{*0}\mu^+\mu^-, \dots$

These measurements couple with the unitarity checks of the CKM matrix will allow to pin down the details of new physics.

2.

**Experimental methods
to determine
 β , γ , $(\beta+\gamma)$, $\delta\gamma$,...**

TIME DEPENDENT DECAY RATE ASYMMETRY

●
$$A_{CP}(\tau) = \frac{\Gamma(B_{d,s}^0 \rightarrow f_{CP})(\tau) - \Gamma(\bar{B}_{d,s}^0 \rightarrow f_{CP})(\tau)}{\Gamma(B_{d,s}^0 \rightarrow f_{CP})(\tau) + \Gamma(\bar{B}_{d,s}^0 \rightarrow f_{CP})(\tau)} \neq 0 \Leftrightarrow \begin{cases} \text{CP Violation} \\ \text{CP}|B^0\rangle = |\bar{B}^0\rangle \\ \text{CP}|f_{CP}\rangle = \pm|f_{CP}\rangle \end{cases}$$

●
$$A_{CP}(\tau) \equiv \begin{matrix} \text{B}^0 \\ \text{B}^0 \end{matrix} \begin{matrix} \xrightarrow{\text{orange}} \\ \xrightarrow{\text{green}} \end{matrix} \begin{matrix} f_{CP} \\ \bar{B}^0 \end{matrix} \equiv \pm \sin[\underbrace{2(\phi_M + \phi_D)}_{\text{orange}}] \sin(\Delta m \tau)^\dagger$$

$B_d^0 \rightarrow J/\psi K_s$	2β		Visible BR 3.6×10^{-5}
$B_d^0 \rightarrow \pi^+ \pi^-$	$2\beta + 2\gamma$	$\left \frac{P}{T} \right , \delta_{P/T}$	0.7×10^{-5}
$B_s^0 \rightarrow J/\psi \phi$	$2\delta\gamma$	$\left \frac{A(\text{CP} = +1)}{A(\text{CP} = -1)} \right , \delta_1, \Delta\Gamma_s$	5.4×10^{-5}

†. When more than one amplitude contributes to the decay: $A_{CP}(\tau) = A_{f_{CP}}^{dir} \cos(\Delta m \tau) + A_{f_{CP}}^{mix} \sin(\Delta m \tau)$

TIME DEPENDENT DECAY RATE ASYMMETRY...

- When the final state is not a CP eigenstate:

			Visible BR
$B_S^0 \rightarrow D_S^\pm K^\mp$	$-2\delta\gamma + \gamma$	$\left \frac{T_1}{T_2} \right , \delta_{T_1/T_2}$	0.9×10^{-5}
$B_d^0 \rightarrow D^{*\pm} \pi^\mp$	$2\beta + \gamma$	$\left \frac{T'_1}{T'_2} \right , \delta_{T'_1/T'_2}$	6.7×10^{-5}
$B_S^0 \rightarrow D_S^- \pi^+$		$\Delta m_S, \Delta \Gamma_S$	12×10^{-5}

OTHER METHODS...

- Dalitz plot analysis:

$B_d^0 \rightarrow \rho\pi \rightarrow \pi^+\pi^-\pi^0$	$\beta+\gamma$	$T^{+-}, T^{00}, P^{+-}, P^{-+}$	Visible BR 5.5×10^{-5}
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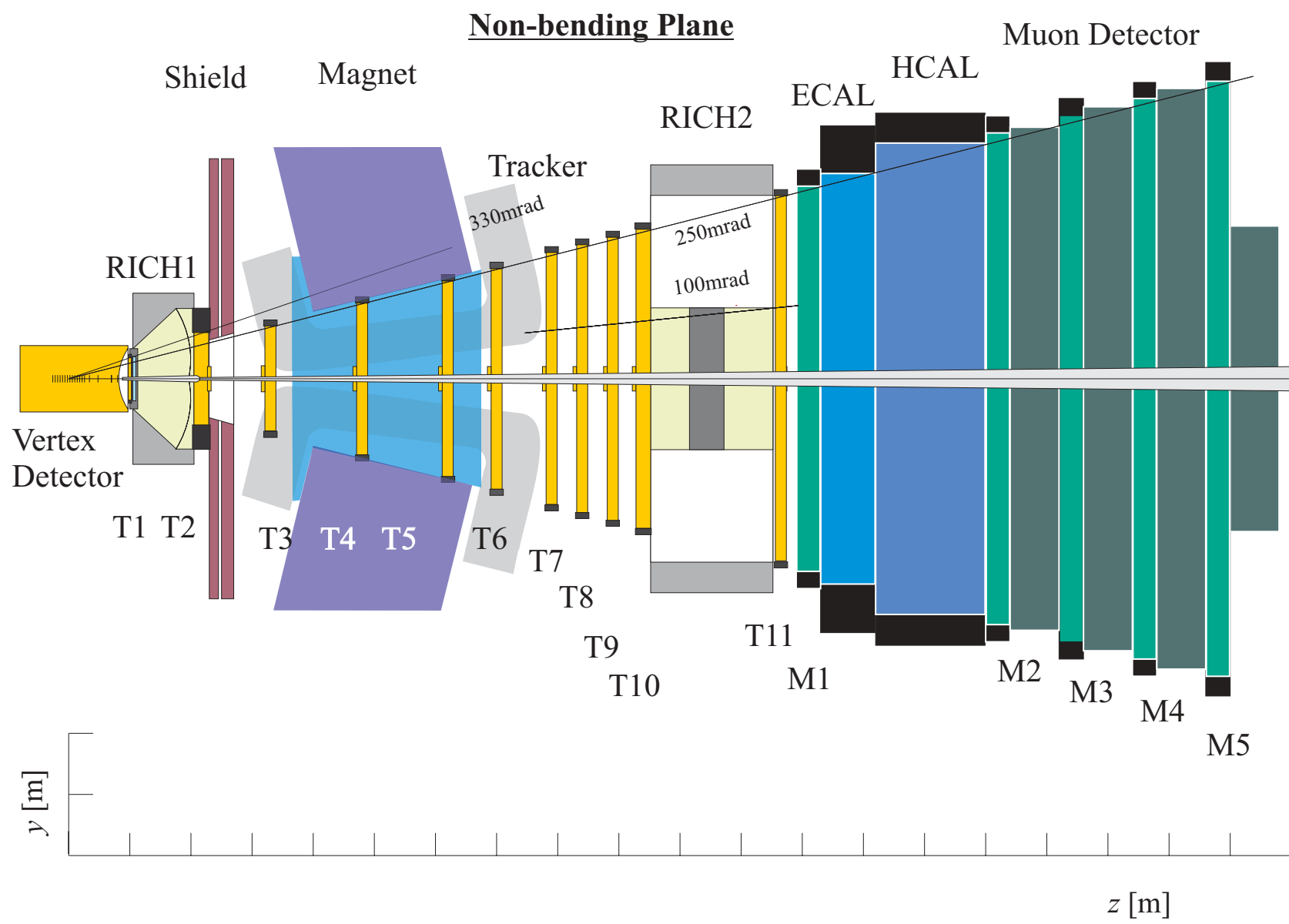
- Branching ratio measurements:

$B_d^0 \rightarrow \begin{cases} \bar{D}^0 K^{*0} \\ D^0 K^{*0} + \text{c.c.} \\ D_1 K^{*0} \end{cases}$	γ	δ_4	Visible BR $10^{-8} - 10^{-7}$
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- New strategies are proposed to measure γ .
They are under evaluation.

3.

LHCb detector...



LHCb DETECTOR PERFORMANCES

- **Particle identification [RICH]:**

- K/π separation $> 3\sigma$ in the momentum range of the experiment

- **Resolutions [Vertex detector, Tracking chambers]:**

- Momentum $\approx 0.3\%$
- Impact parameter $\approx 40 \mu\text{m}$
- Decay-time $\approx 0.03 \tau_B$ (43 fs)

- **Tagging:**

- Efficiency (K, e, μ) $\approx 40\%$
- Dilution factor $\approx 40\%$

RUNNING CONDITIONS

Low Luminosity: $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

- **Tunable locally although ATLAS and CMS work at high luminosity**
 - Ensures long physics programme
 - Guarantees physics results from the beginning of LHC
- **Clean event:**
 - ~ 0.3 interactions/BC
- **Highest statistics of B's ever collected:**
 - 4.5×10^{11} $B_d + \bar{B}_d$ produce per year
 - 1.3×10^{11} $B_s + \bar{B}_s$ produce per year

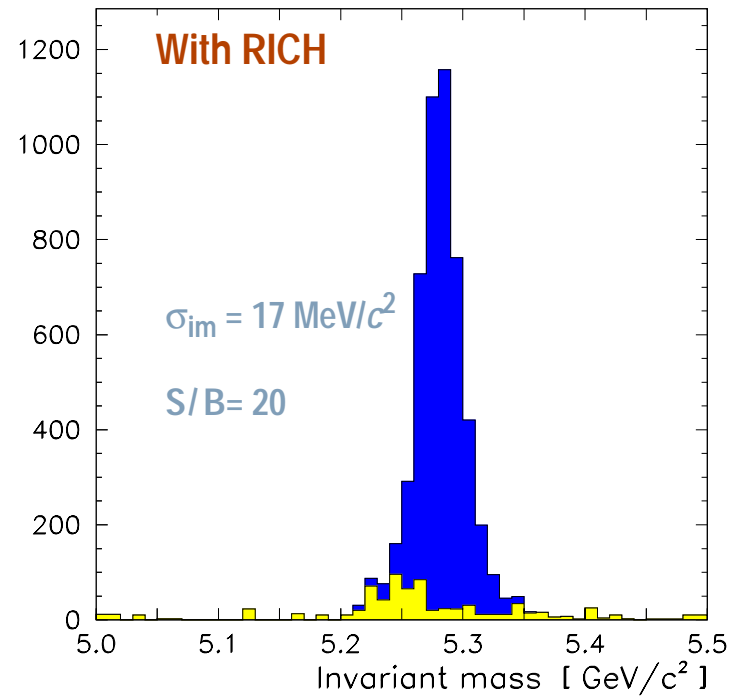
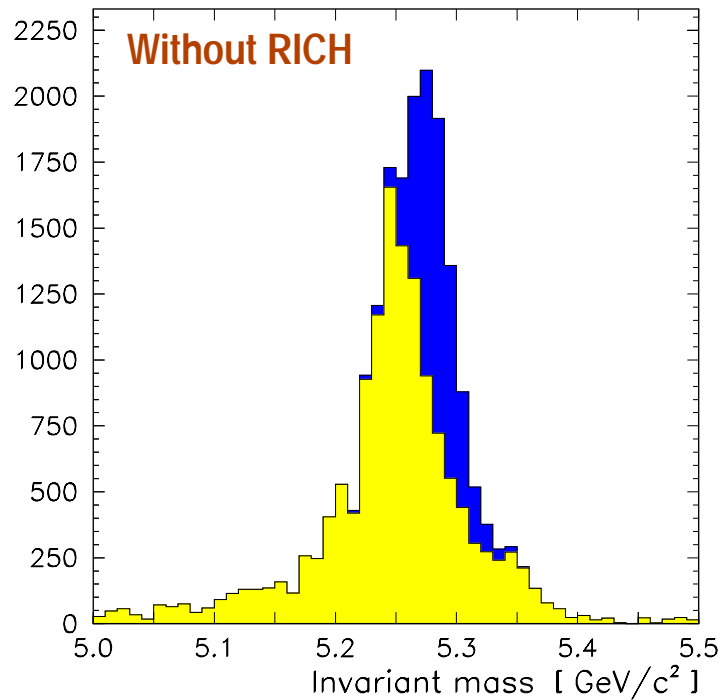
4.

Physics performances...

$$B_d \rightarrow \pi^+ \pi^- (\beta + \gamma)$$

Importance of particle identification

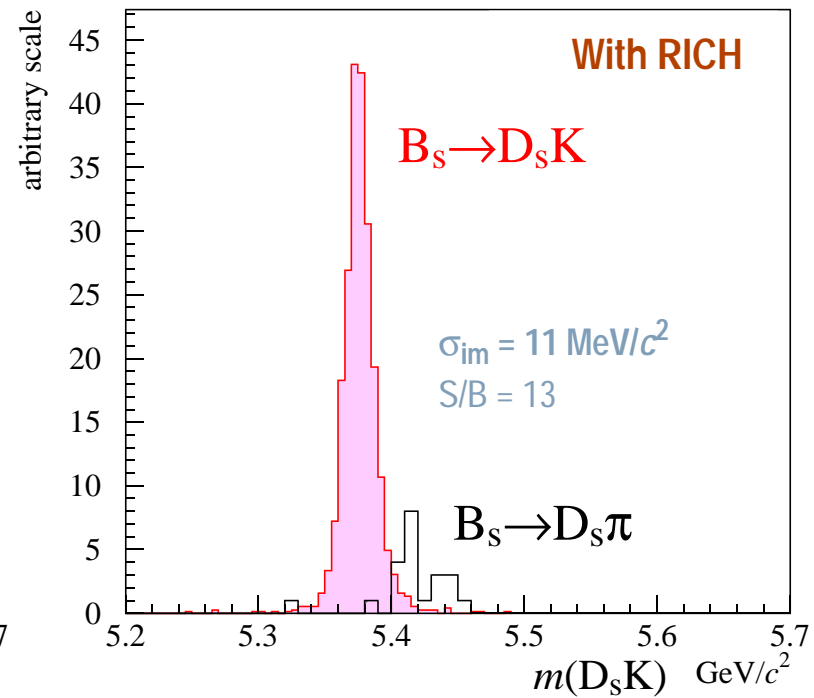
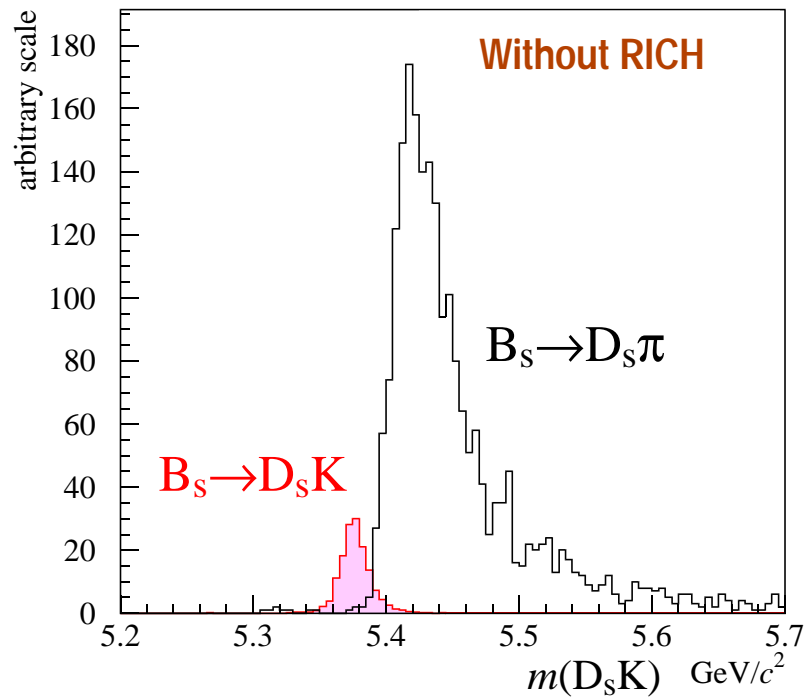
Branching ratio: $B_d \rightarrow \pi^+ \pi^- = 0.7 \times 10^{-5}$, $\rightarrow K^\pm \pi^\mp = 1.5 \times 10^{-5}$
 $B_s \rightarrow K^+ K^- = 1.5 \times 10^{-5}$, $\rightarrow K^\pm \pi^\mp = 0.7 \times 10^{-5}$



$$B_s \rightarrow D_s K (\gamma - 2\delta\gamma)$$

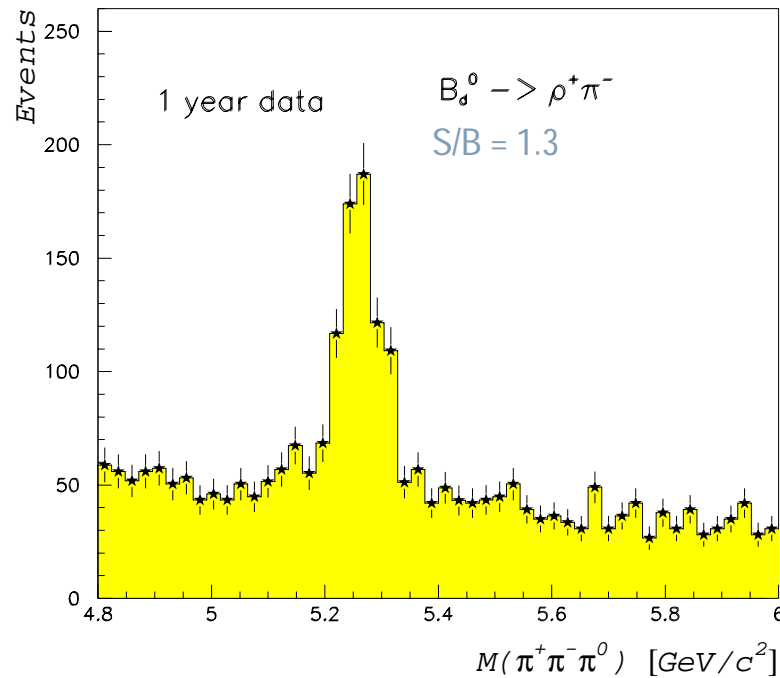
Major background: $B_s \rightarrow D_s \pi$ (No CP violation)

Importance of particle identification and mass resolution



$$B_d \rightarrow \rho\pi \rightarrow \pi^+\pi^-\pi^0 \quad (\beta+\gamma), |P|, |T|, \dots$$

Importance of π^0 reconstruction

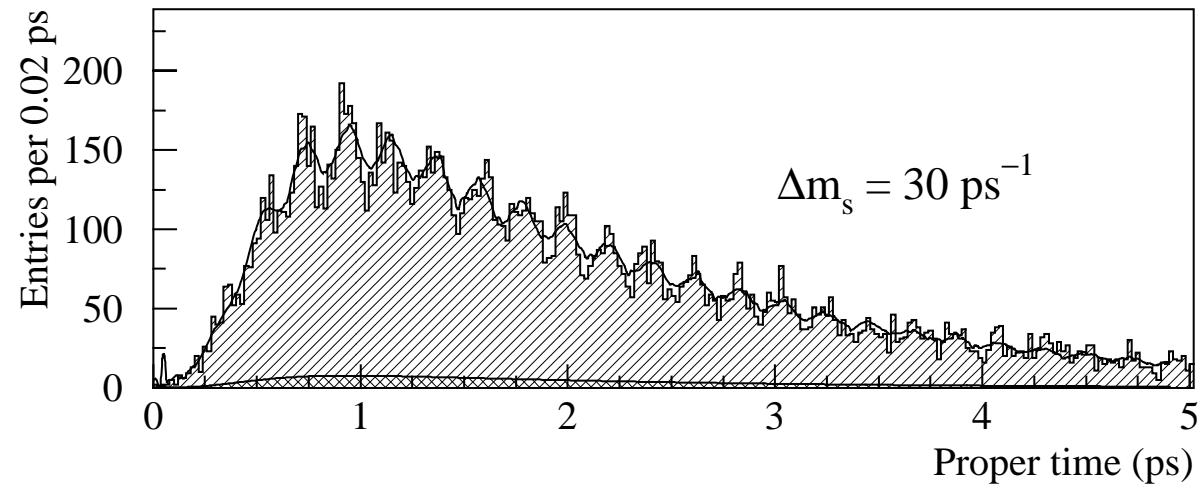


Events per year:

$B_d \rightarrow \rho^+\pi^-$	~ 1000	(Br 4.4×10^{-5})
$B_d \rightarrow \rho^-\pi^+$	~ 200	(Br 1.0×10^{-5})
$B_d \rightarrow \rho^0\pi^0$	~ 100	(Br 0.1×10^{-5})

$$B_S \rightarrow D_S \pi (\Delta M_S, \Delta \Gamma_S)$$

Importance of decay-time resolution



- ➔ Measurement of Δm_s with a significance > 5 , up to 48 ps^{-1} ($\chi_S=75$)
Standard Model expectation: $14.3\text{--}26 \text{ ps}^{-1}$

SUMMARY OF THE PERFORMANCES

Sensitivity per year of data taking:

LHCb Lum= 2×10^{32}			
$B_d^0 \rightarrow J/\psi K_S$	$\sigma(\sin 2\beta)$	0.02	when $\beta = 20^\circ$
$B_d^0 \rightarrow \pi^+ \pi^-$	$\sigma(A^{\text{dir}})$	0.07	
	$\sigma(A^{\text{mix}})$	0.09	
	$\sigma(\beta + \gamma)$	$\sim 2^\circ$	If $ P/T = 0.20 \pm 0.02$ when $\alpha = 90^\circ$ and $\delta = 30^\circ$
$B_d^0 \rightarrow \rho \pi$	$\sigma(\beta + \gamma)$	$2^\circ - 5^\circ$	Preliminary: Backg. not included in the fit Depends on the value of $\beta + \gamma$
$B_d^0 \rightarrow D^{*\pm} \pi^\mp$	$\sigma(2\beta + \gamma)$	$\sim 9^\circ$	when $ 2\beta + \gamma < 25^\circ$
$B_S^0 \rightarrow J/\psi \phi$	$\sigma(\delta\gamma)$	$0.6^\circ - 1.4^\circ$	depends on the value of Δm_S SM expectation: $\sim 1^\circ$
$B_S^0 \rightarrow D_S^\pm K^\mp$	$\sigma(\gamma - 2\delta\gamma)$	$6^\circ - 13^\circ$	Depends on the value of: • $\gamma - 2\delta\gamma$ • strong phase shift difference
$B_d^0 \rightarrow D^0 K^{*0}$	$\sigma(\gamma)$	$4^\circ - 19^\circ$	Depends on the value of: • γ • strong phase shift difference

$B_S^0 \rightarrow D_S^\pm \pi^\mp$	x_S reach	<75	Significance > 5
$B_S^0 \rightarrow \mu^+ \mu^-$	S/\sqrt{B}	~ 6	SM expectation BR = 3.5×10^{-9}

$B_d^0 \rightarrow K^{*0} \gamma$	$ V_{ts} $	26×10^3 evts.	
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5.

Status and conclusions...

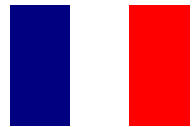
The *LHCb* Experiment



Brazil



Finland



France



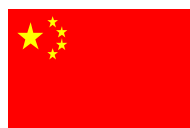
Germany



Italy



Poland



PRC



Netherlands



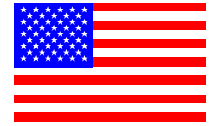
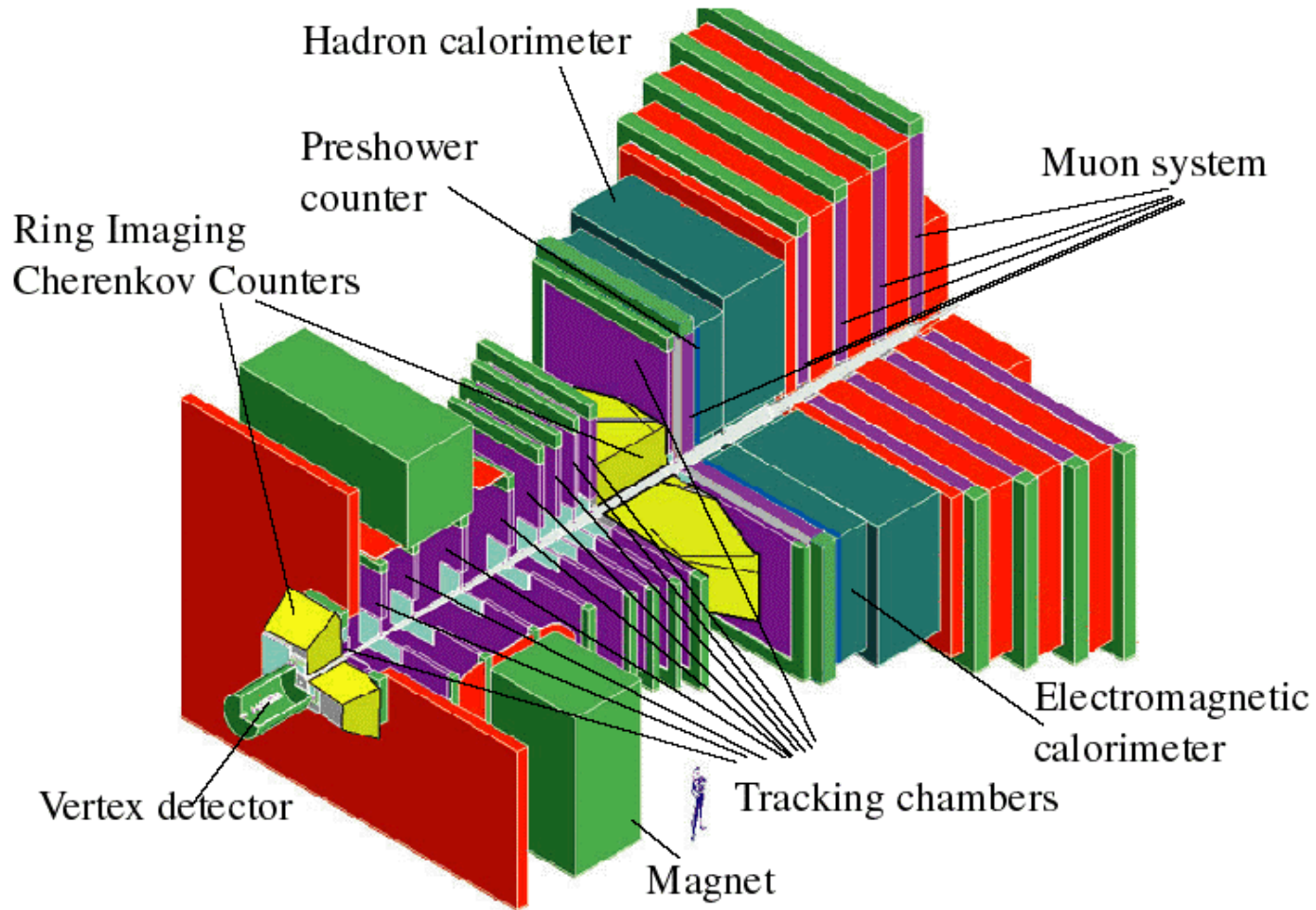
Romania



Russia



Spain



USA



Ukraine



UK



Switzerland

STATUS AND PLANS

- Technical Proposal approved in September 98

- Preparing Technical Design Reports:

- Magnet
 - RICH
 - Calorimeter
 - Outer tracker
 - Muon
 - Vertex
 - Inner tracker
 - Trigger + DAQ
- end 99 ✓
- from now on to 2002
-

- Construction: 2001–2003

- Ready for the first collision of the LHC

CONCLUSIONS

- LHCb is an opportunity to understand the CP violation in the framework of the Standard Model and BEYOND.
- LHCb fully exploit the physics from the beginning of the LHC