The LHCb experiment: status and physics program

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FPCP Paris, 2-6 June 2003

The LHCb experiment

- LHCb is a forward one-arm spectrometer dedicated mainly to study CP violation and rare B decays at LHC

Check consistency of the **Standard Model** :
precision measurements of angles and sides of the CKM triangle

Search for **New Physics** :
rare and SM forbidden decays of b particles

Present status

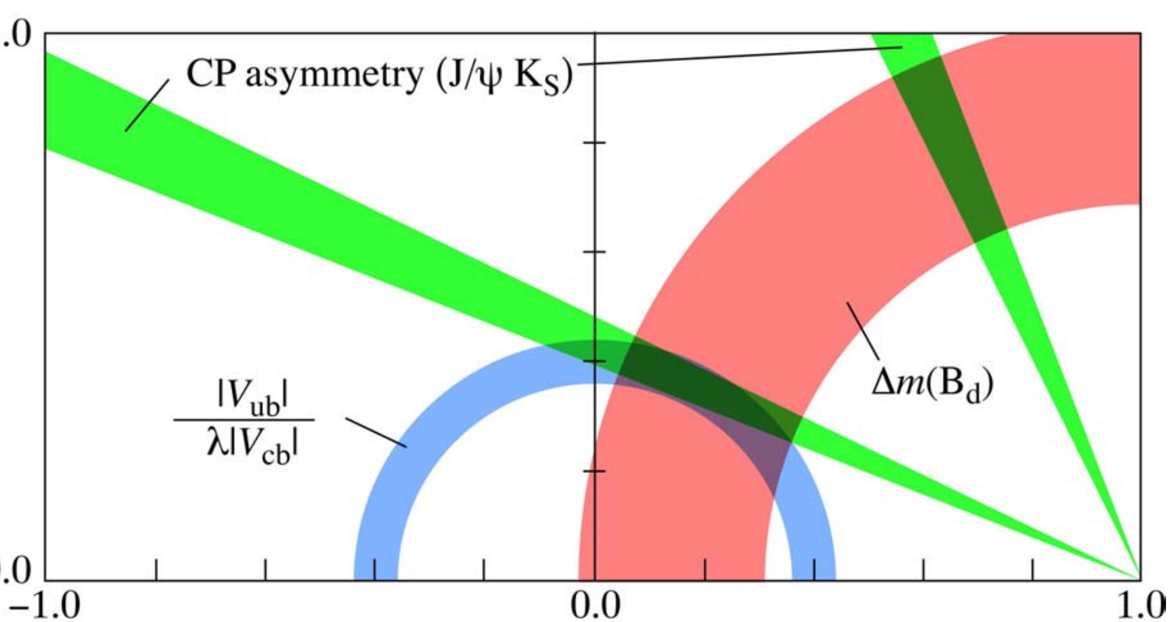
The triangle

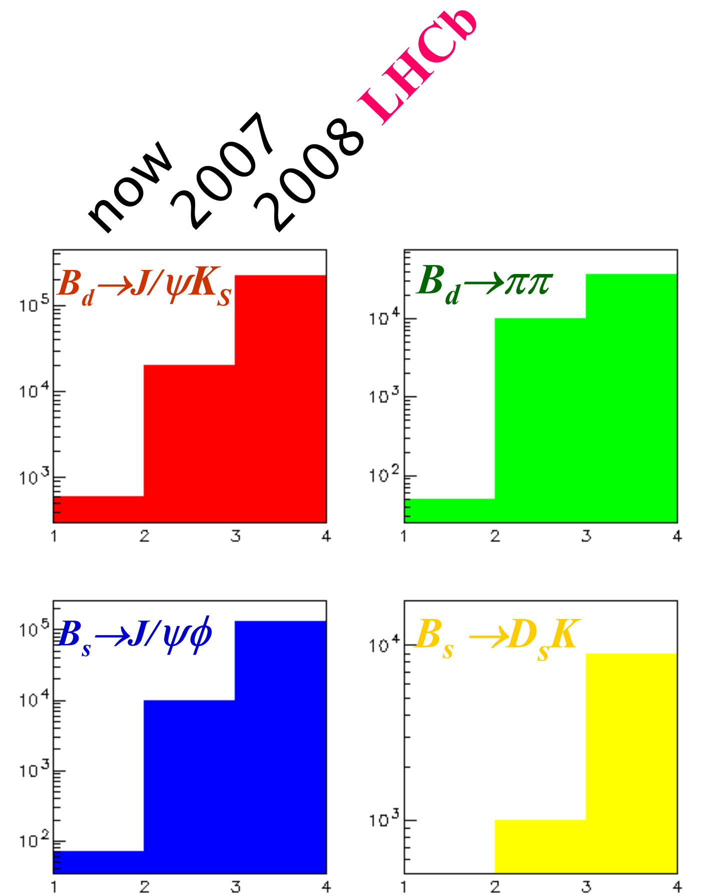
Consistency of the Standard Model (assumed to determine the vertex) and the direct measurement of **sin2β** from B-factories

$|V_{cb}|$ from $B \to H_c X$ decays $\to A$

$|V_{ub}|$ from $B \to H_u \ell \nu$ decays $\to \rho^2 + \eta^2$

B_d-B_d mixing, $\Delta m_d \to (1-\rho)^2 + \eta^2$

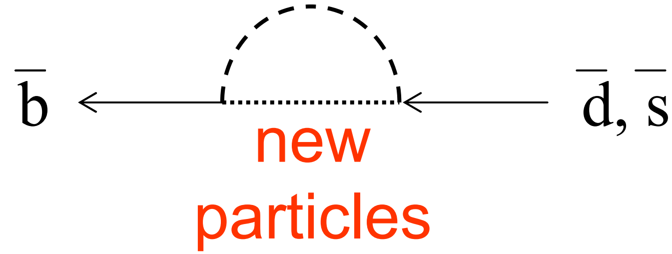




New physics

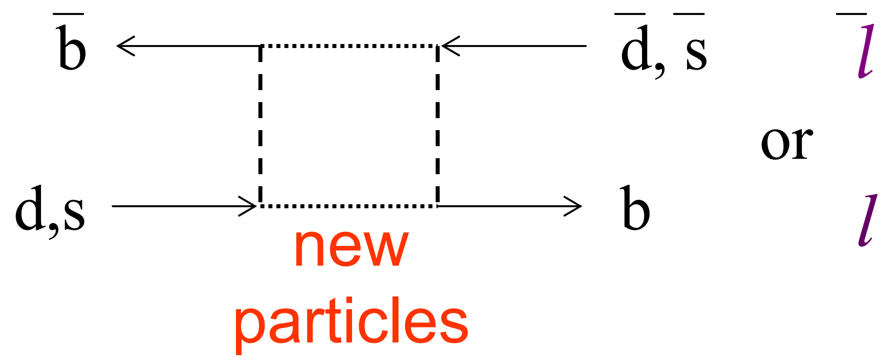
$\Delta b = 1$: **Decays**

➡ through **penguin**

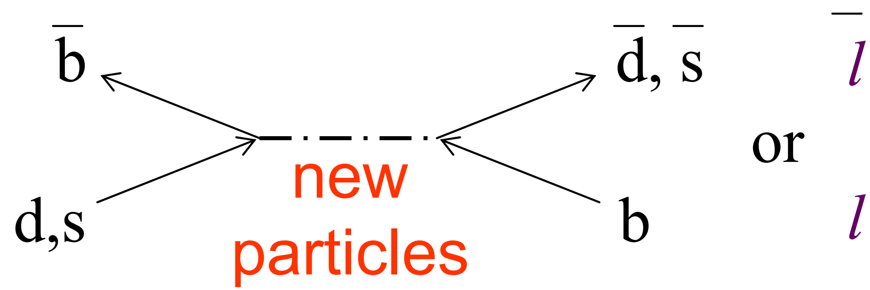


$\Delta b = 2$: **Oscillations**

➡ through **box**



➡ through **tree**



The Standard Model tree process not affected.

b at the LHC machine

(IP1,IP5)

E_{cm}	14 TeV
$L (cm^{-2} s^{-1})$	2×10^{32} (10-100)
σ (bb)	500 μb
σ (inel)	80 mb
#bb-pairs	10^{12} /year
b fraction	5×10^{-3}
f	40 MHz
t_{bunch}	25 ns
z primary	5 cm
inter/xing	0.4 (2-20)

→ Luminosity locally controlled

→ All types of b-hadrons
B_u , B_d , B_s , B_c , Λ_b , Σ_b , Ξ_b,...
with large boost of the hadron

b - physics at LHC

Crucial **tasks** of a detector:

- **triggering**
- **particle ID** (K/π/p/e/μ)
  - **identification of exclusive final states**
  - **tagging**
- **background rejection**
- **decay time resolution**

Aperture

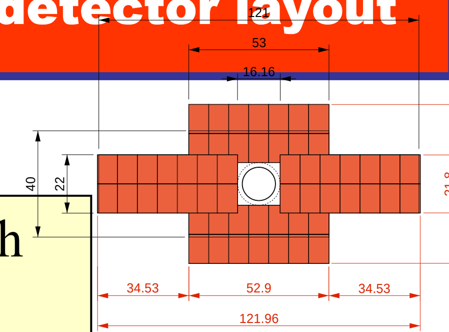
1.5 < | η

Dipole magnet :

- Warm trapezoidal coils
- pole shape following the acceptance
- ∫ Bdl = 4 T

LHCb detector layout

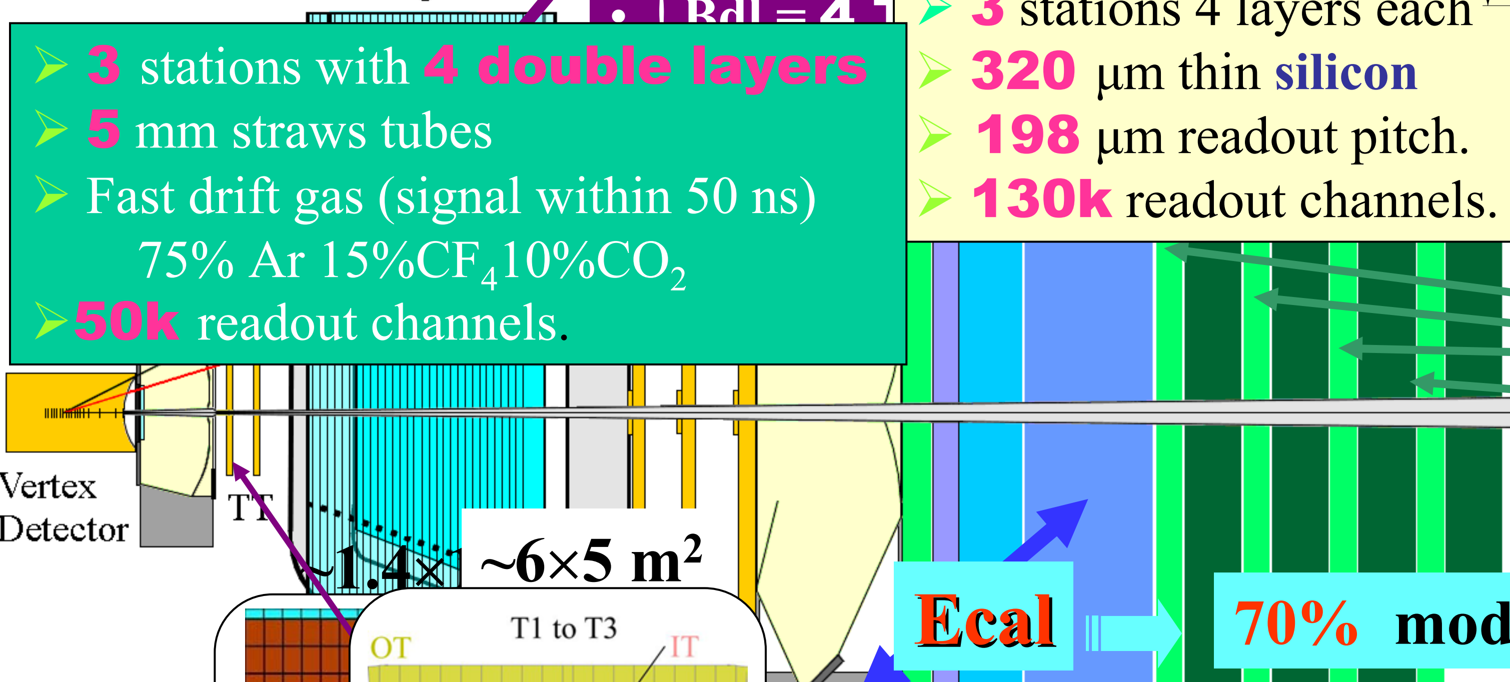
Inner Tracker



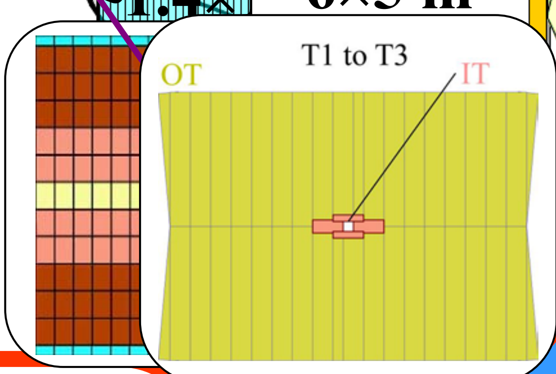
- 3 stations 4 layers each
- 320 μm thin silicon
- 198 μm readout pitch.
- 130k readout channels.

Outer Tracker

- 3 stations with 4 double layers
- 5 mm straws tubes
- Fast drift gas (signal within 50 ns)
  75% Ar 15%$CF_4$10%CO_2
- 50k readout channels.



~6×5 m²



μ chambers
MWPCs

Ecal

70% modules produced

- Shashlik type
  (66layers 2mm Pb/4mm scintillator)
- Transverse granularity 4,6,12 cm cells
- ~6000 channels , 25 X_o
- σ/E ~ 10%/sqrt(E)

40% X_o ; 12% λ_I

1468 ce

σ/E ~

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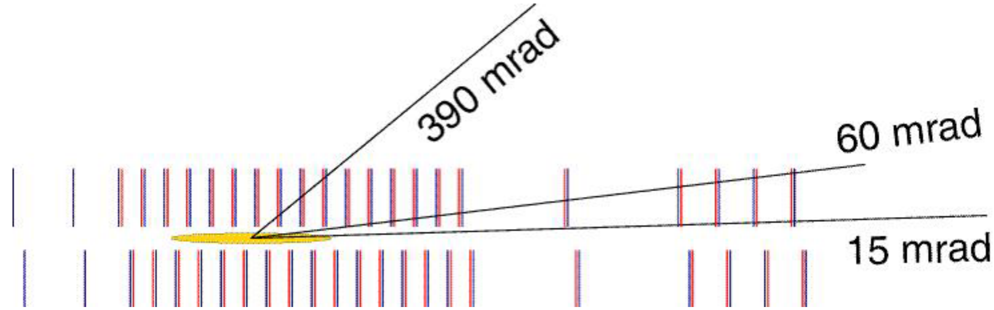
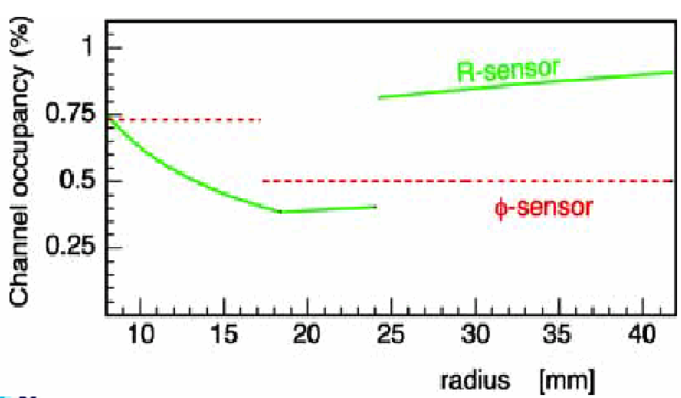
The LHCb Vertex Locator

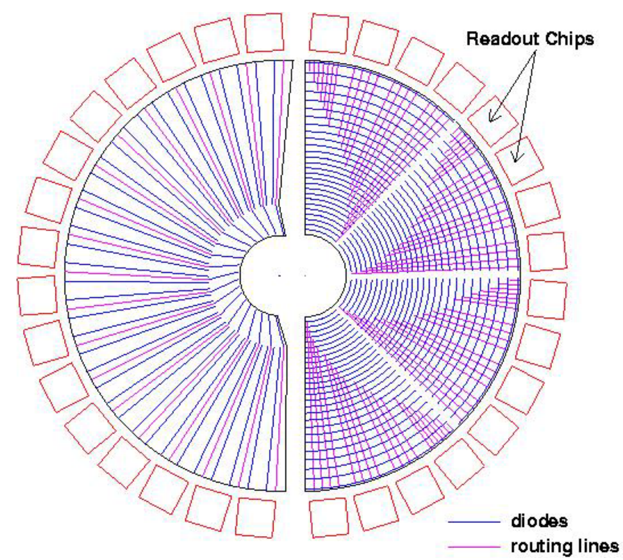
- low occupancy
- Si area : 0.32 m^2
- $\#X_o$: 0.18
- σ_t : 43 fs
- # channels : 172 k

21 stations



$$\sigma_{IP} = 17\,\mu m + \frac{32\,\mu m}{p_T}$$





Tracking performance

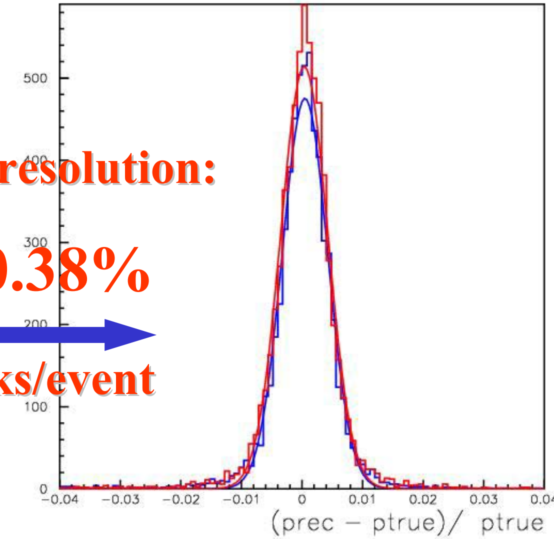
Average efficiency = 92 %
Efficiency for p>5GeV >95%

Ghost rate p_T>0.5 GeV ~ 7%.

Momentum resolution:

$\Delta p/p$=0.38%

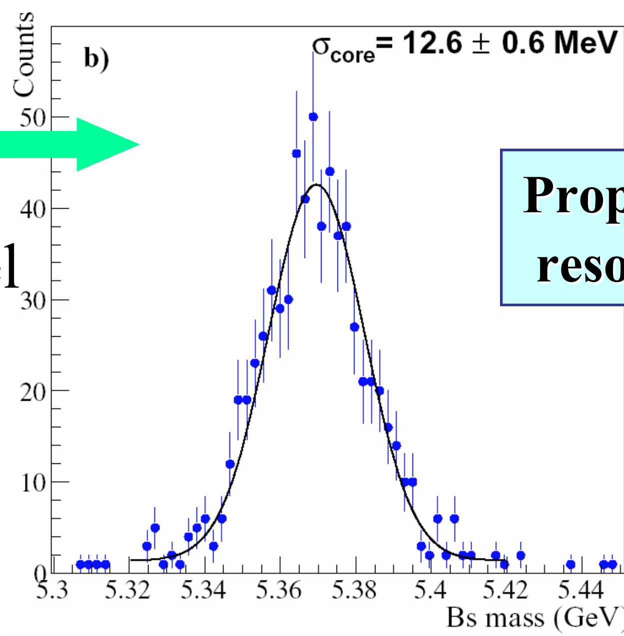
<N> = 27 tracks/event



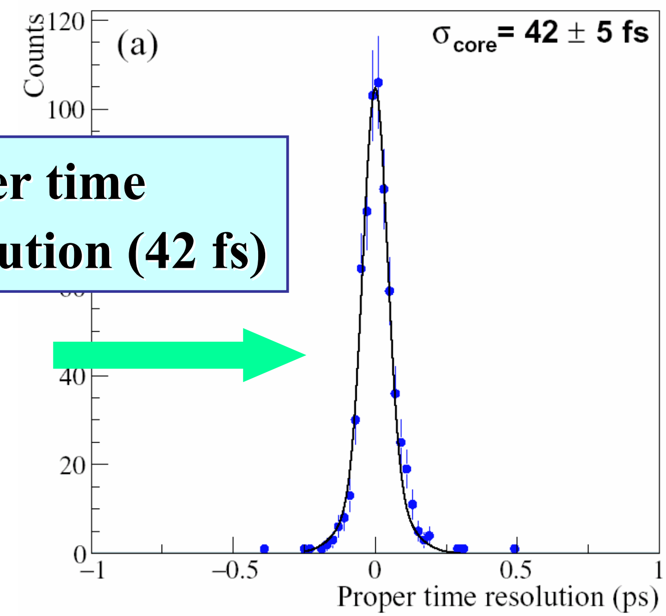
Mass resolution (~13 MeV)

for the decay channel

$B_s \rightarrow D_s\, \pi^+$
$\quad \hookrightarrow KK\pi$



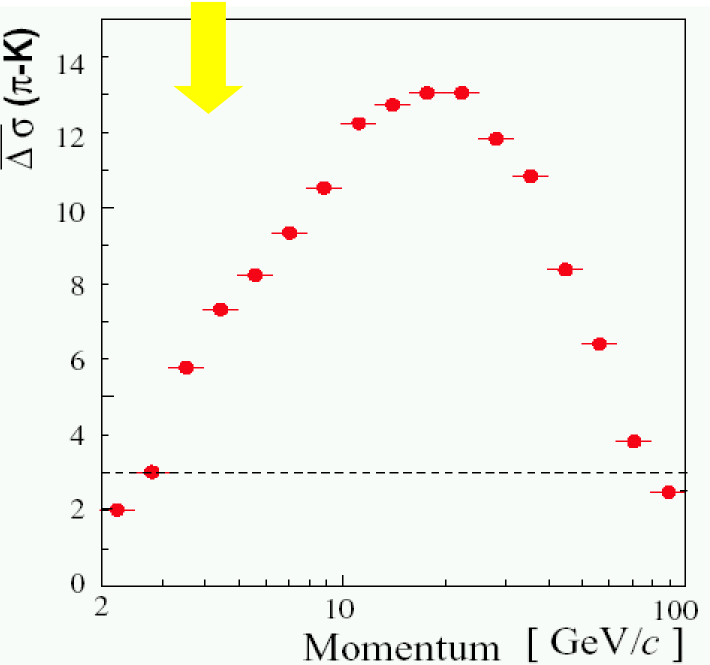
Proper time resolution (42 fs)

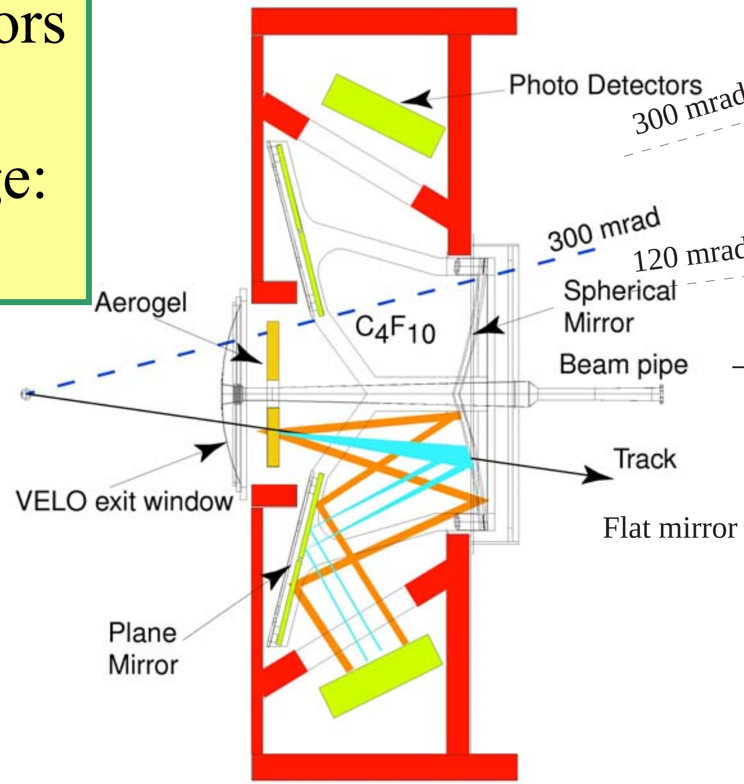


The RICH of LHCb

2 detectors with **3** radiators (aerogel, C_4F_{10}, CF_4) cover momentum range: 2 - 100 GeV

K–π separation



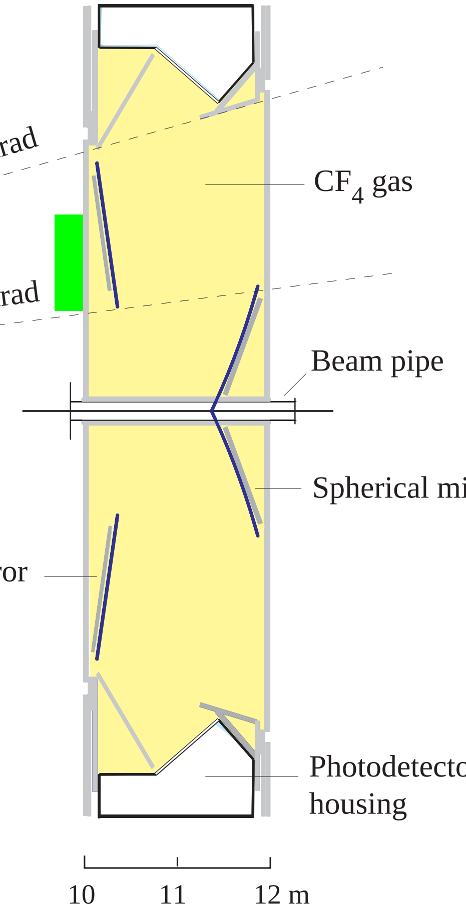


RICH 1

(25-300 mrad)

5 cm aerogel

4 m^3 C_4F_{10}



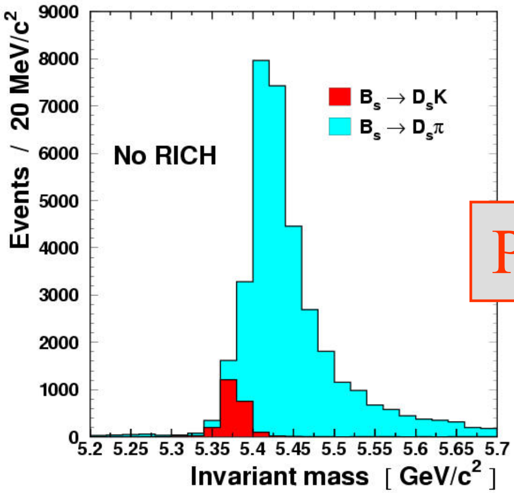
RICH 2

(15-120 mrad)

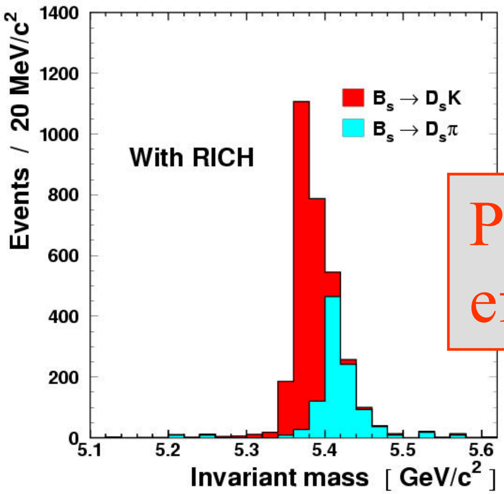
100 m^3 CF_4

Physics with Particle Identification

$B_s \rightarrow D_s K$

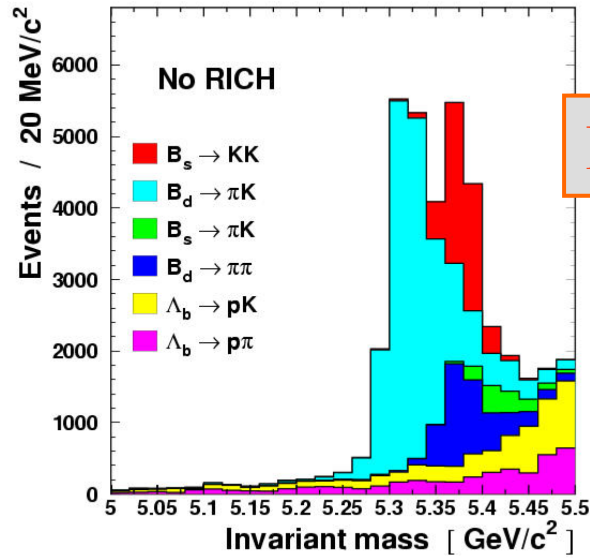


Purity=**7.0**%

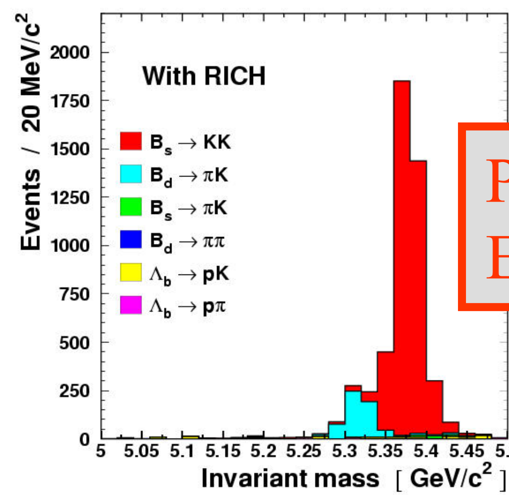


Purity=**66**%
efficiency=**88**%

$B_s \rightarrow K^+K^-$



Purity=13%



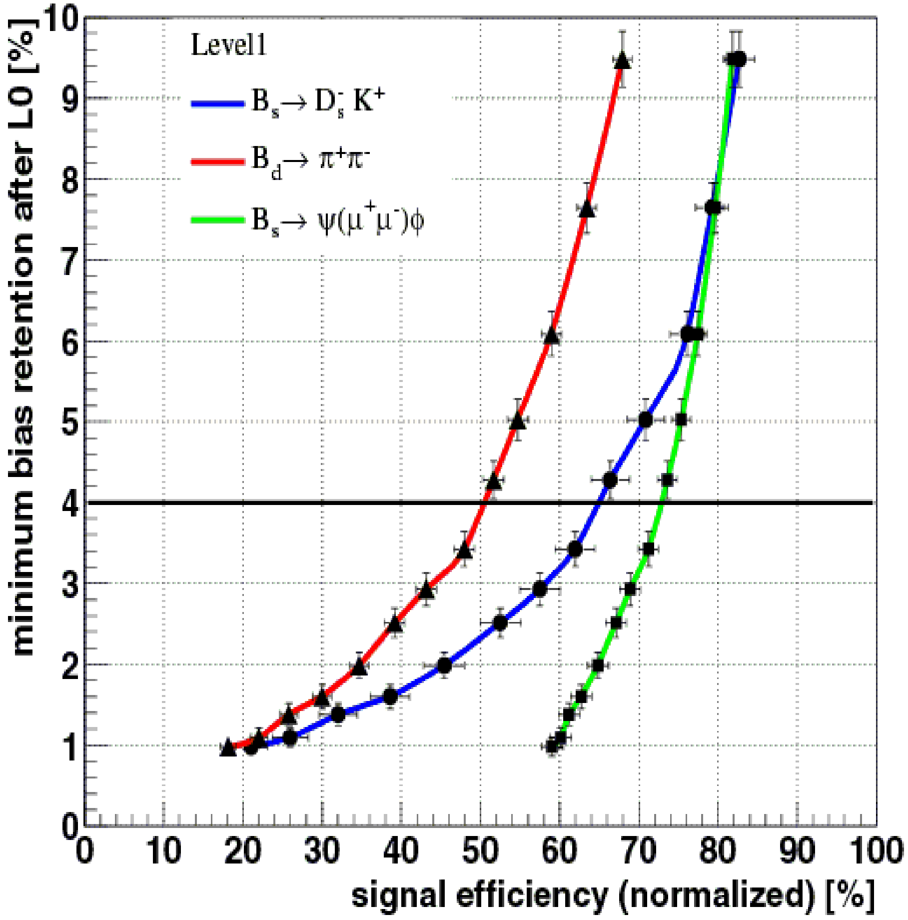
Purity=84%
Efficiency=79%

LHCb Trigger

	subdetectors		
Level-0	Calorimeters Muon Pile-up veto	**40 MHz**	p_T of e, μ, h, γ
Level-1	VELO Trigger Tracker Level-0	**1 MHz**	Impact parameter Rough p estimate (~20%)
Higher Levels	all the detector	**40 KHz**	final state reconstruction
	data log	**200 Hz**	

LHCb L1 trigger

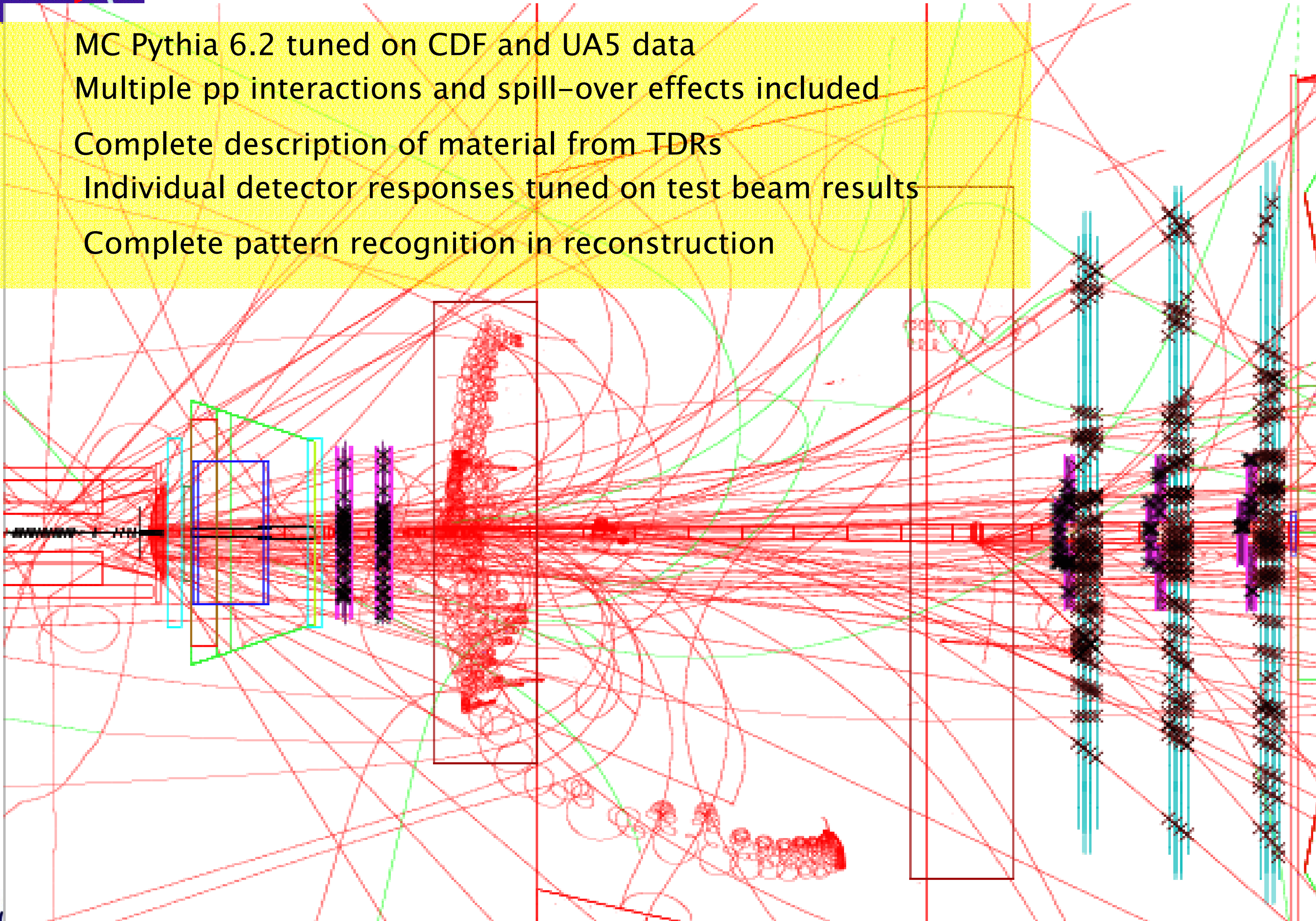
Performance in B decays



- trigger robust and flexible
- hadron trigger fundamental for hadronic final states
- trigger efficiencies L0xL1 20 % - 70%

Simulated b$\bar{b}$ events

- MC Pythia 6.2 tuned on CDF and UA5 data
- Multiple pp interactions and spill-over effects included
- Complete description of material from TDRs
- Individual detector responses tuned on test beam results
- Complete pattern recognition in reconstruction



Event yield in LHCb

1 year = **2 fb $^{-1}$** ($L = 2 \times 10^{32}$ cm^{-2}s^{-1})

Yield calculated taking into account :

- Geometrical acceptance, detection efficiency, material
- L0 and L1trigger efficiencies (including pile-up veto)
- Reconstruction efficiencies (tracking, calorimeters, PID)
- Selection cuts efficiency to identify the final state

Channel		Yield
$B^0 \to \pi^+\pi^-$		**27 k**
$B^0 \to K^+\pi^-$		**115 k**
$B_s \to K^+K^-$		**35 k**
$B_s \to D_s^-\pi^+$		**72 k**
$B_s \to D_s^-K^+$		**8 k**
$B_s \to J/\psi\,(\mu^-\mu^+)\phi$		**109 k**
$B_s \to J/\psi\,(e^-e^+)\phi$		**19 k**
$B^0 \to J/\psi(\mu^-\mu^+)\,K_S$		**119 k**
$B^0 \to K^{0*}\gamma$		**20 k**

more background simulated events are necessary to optimize selection criteria vs background rejection

Measuring γ

4 ways of determining γ

- Time dependent analysis of $B_s \rightarrow D^+_s K^-$ (tagged)
- Rate difference between $B^- \rightarrow D^o K^-$ and $B^+ \rightarrow D^o K^+$ (untagged)

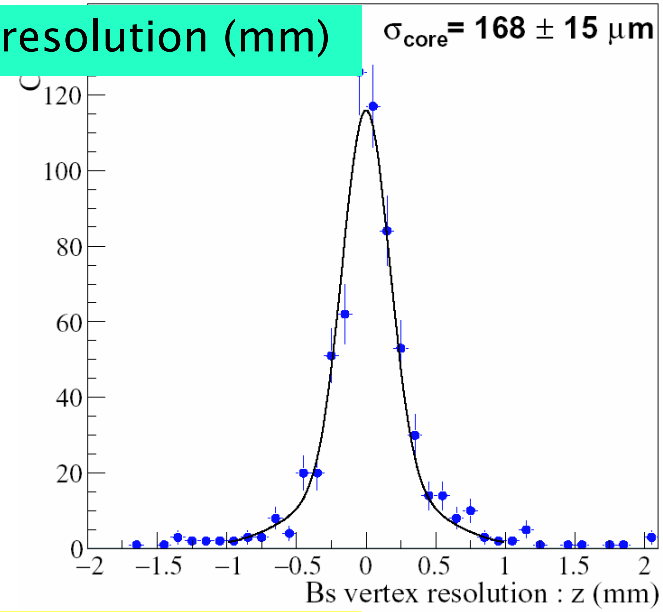
model independent

- Rate measurements in $K^o \pi^\pm$ and $K^\pm \pi^\mp$ (Fleisher-Mannel) or rates in $K^o \pi^\pm$ and asymmetry in $K^\pm \pi^o$ (Neubert-Rosner, Beneke et al) .
- Measure time dependent asymmetries in (Fleischer,Martinelli) $B^o \rightarrow \pi^+ \pi^-$ and $B_s \rightarrow K^+ K^-$ **symmetric d ⟺ s**

dependence on hadronic assumptions in the different calculations

Measuring γ with $B_s \to D_s^{\pm}K^{+}$

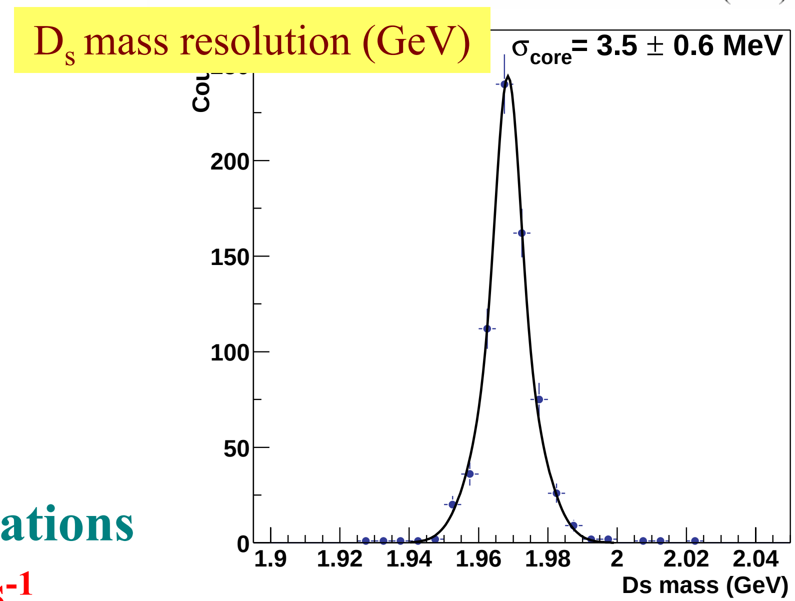
- must be separated from $B_s \to D_s^{-}\pi^{+}$ (~15 times larger Br)
- hadronic trigger, K/π separation, proper time resolution are fundamental
- gets $\gamma - 2\delta\gamma$ (needs $2\delta\gamma$ from $B_s \to J/\Psi\ \Phi$)
- In one year of data (2 fb^{-1}) 8k $D_s K$ and 72k $D_s \pi$



expected sensitivity:

$\sigma(\gamma) \sim 10^0$ for $\Delta m_s = 20\ ps^{-1}$
$\sigma(\gamma) \sim 12^0$ for $\Delta m_s = 30\ ps^{-1}$

depending on amplitudes, strong phases, γ, Δm_s, $\Delta\Gamma/\Gamma$

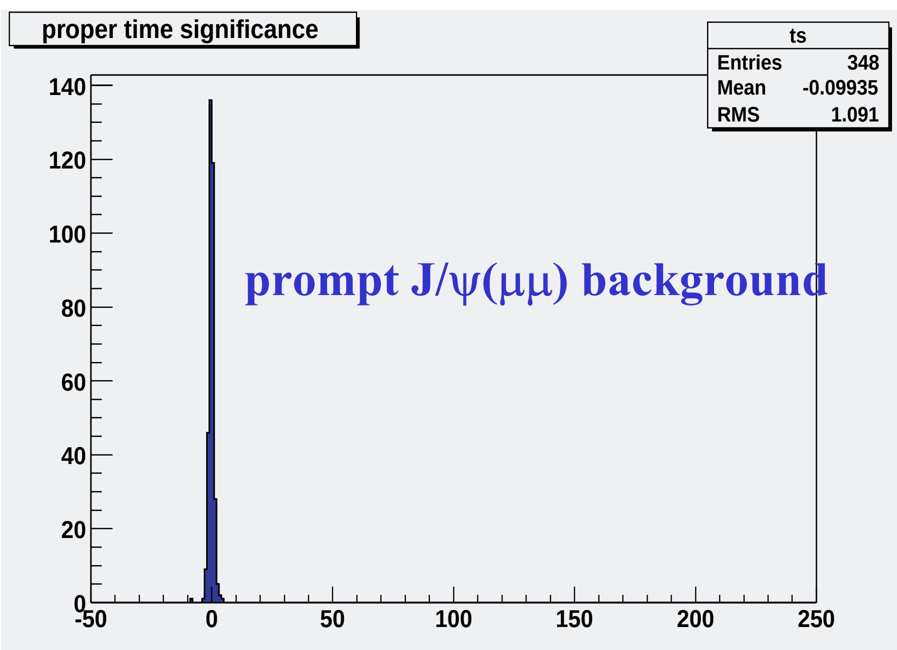


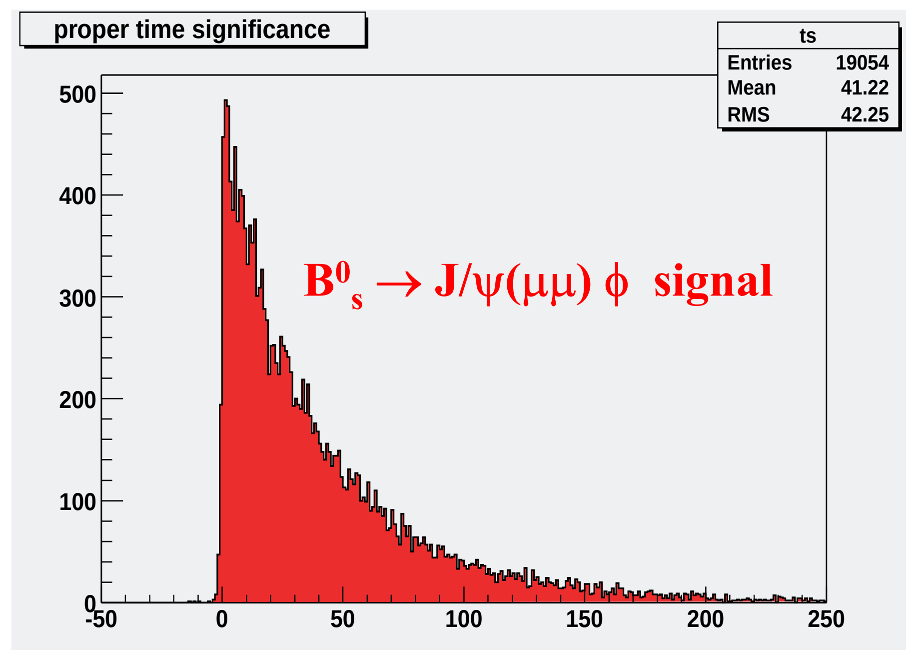
$B_s \to D_s^{-}\pi^{+}$ measure B_s oscillations Δm_s up to ~ 60 ps^{-1}

Study of $B^0_s \to J/\psi\ \phi$ → $(\mu\mu\ K^+K^-)$

- CP asymmetries determine $-2\delta\gamma$ (very small in Standard Model but sensitive to New Physics). **And also Δm_s and $\Delta\Gamma_s$**
- Must be separated from prompt J/Ψ production

  (possible with $0.1 < B/S < 0.4$ at 90% CL)





Study of $B^0_s \to J/\psi\ \phi$ → ($\mu\mu\ K^+K^-$)

- **Needs angular analysis to disantangle CP-odd and CP-even states**

- **In one year of data (2 fb^{-1})**

  109k $J/\Psi\ \Phi$ ($\mu\mu$) **and 19k $J/\Psi\ \Phi$** (ee)

expected sensitivity:

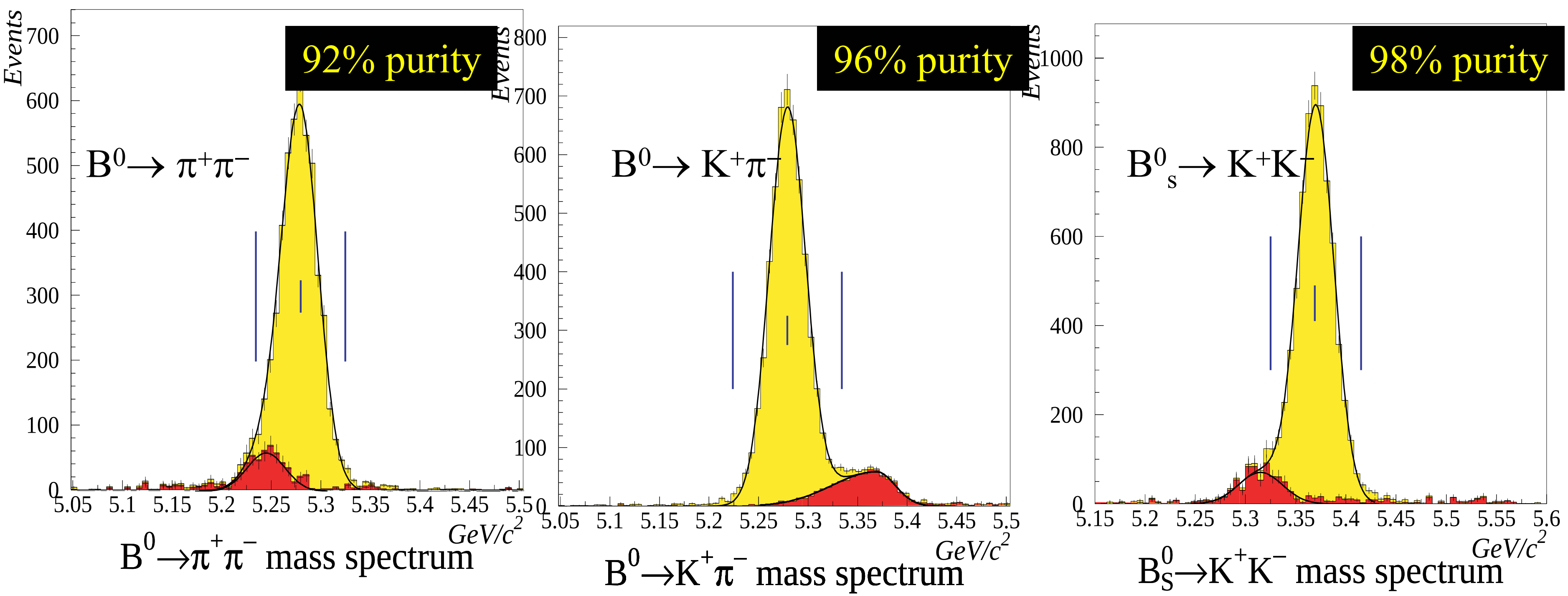
$\sigma(2\delta\gamma) \sim 2^0$ for $\Delta m_s = 20\ ps^{-1}$

also $B^0_s \to \Phi\Phi$ $B^0_s \to J/\Psi\ \eta$ $B^0_s \to \eta_c\Phi$ probe $\delta\gamma$

(under study in LHCb)

Measuring γ with $B_{(s)} \to \pi\,\pi$, $K\,\pi$, $K\,K$

- **Relies on hadronic trigger, excellent K/π separation, mass resolution**
- **Select B candidates with p_T, IP/σ, L, mass cuts**
- **Combinatorial bb bckgr. can be rejected (S/B > 1)**



$\sigma(\gamma) \sim 3^0$ for $x_s = 20$

Present estimate of LHCb Physics reach

These numbers are being updated, and more channels studied, in the re-optimization of the LHCb detector to be concluded in September 2003

1 year data ⟹ 2 fb^{-1}

	Channel	Yield	Precision
β	$B_d \to J/\psi K_s$	119 k	$\sigma(\beta) \approx 0.6^o$
γ	$B_s \to D_s K$ $B_d \to \pi\pi$, $B_s \to KK$	8 k 27 k, 35 k	$\sigma(\gamma) \approx 10^o$ $\sigma(\gamma) \approx 3^o$
α	$B_d \to \pi^+\pi^-$	27 k	$\sigma(\alpha) \approx 5^o - 10^o$
$2\delta\gamma$	$B_s \to J/\psi\, \phi$	128 k	$\sigma(2\delta\gamma) \approx 2^o$
$\lvert V_{td}/V_{ts} \rvert$	$B_s \to D_s\pi$	72 k	Δm_s up to 58 ps^{-1}
rare decays	$B_d \to K^* \gamma$	20 k	

Conclusions

- **The present** of **b**-physics is already very rich
  - **B-factories (BaBar, Belle, CLEO), Tevatron, + (LEP, SLC)**
- **The future** :

  Next generations of **dedicated** experiments at hadron machines will have order of 10^{12} $b\bar{b}$ pairs per year with dedicated trigger and particle ID

LHCb is a unique opportunity to measure precisely angles and sides of the CP triangle and to understand the origin of CP violation in the SM and beyond

LHCb installation starts in 2005

data taking starts in 2007

Back-up slides

LHCb TRIGGER

channel	L0 (%) μ	e	h	γ	all	L1(%)	Total (%)
$B^0_s \rightarrow J/\psi(\mu\mu)\,\phi$	90	5	30	3	93	73	68
$B^0_s \rightarrow J/\psi(ee)\,\phi$	7	36	24	4	52	43	23
$B^0_s \rightarrow D_s K$	8	5	37	2	44	65	29
$B^0_d \rightarrow K^* \gamma$	6	28	30	47	82	33	27
$B^0_d \rightarrow \pi^+ \pi^-$	7	9	55	3	61	51	31