Fisica del B e violazioni di CP ai futuri collider adronici

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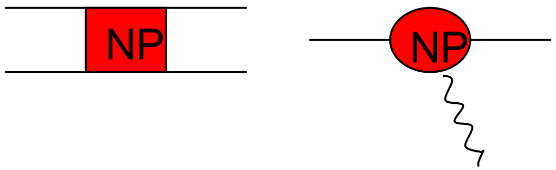
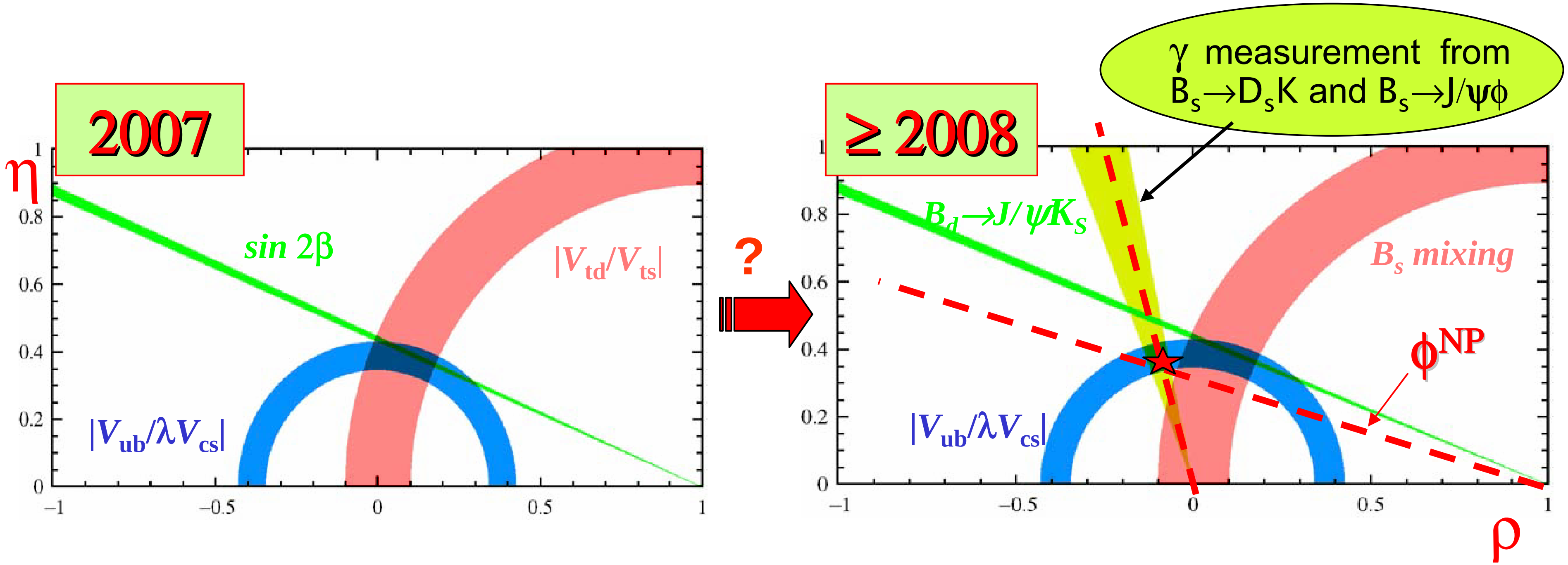
In 2007 several measurements on CKM will be available from B-Factorys and Tevatron

But …

New Physics could still be hidden in mixing or in penguins diagrams





We need to overconstrain the Unitarity Triangles, search for signals of NP measuring several CP phases and look for NP in rare decays

At hadronic colliders a huge $b\bar{b}$ cross section is available

→ High statistics, access to $B_{d,u}$, B_s , b-baryon , B_c

LHC LHCb dedicated exper. ≥ 2007

CMS ATLAS omni-purpose ≥ 2007

TEVATRON BTeV dedicated exper. ≥ 2009 CD0 approval in ‘03
CD1 expected end april

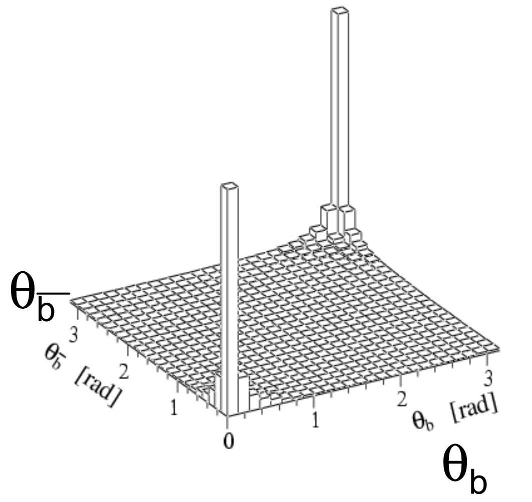
Experimental challenges

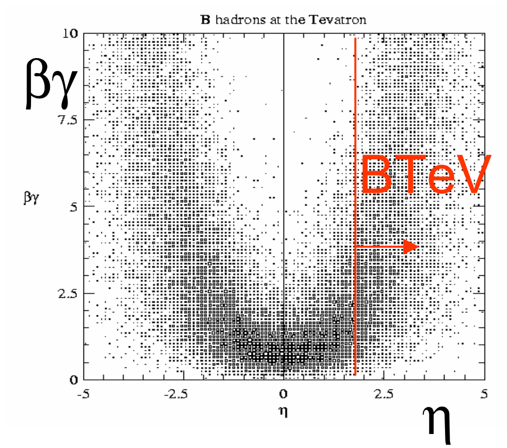
hadronic environment: b produced with wide range of momentum (no stringent constraints as at e+e- colliders), high multiplicity

high rate of background events → trigger is an issue

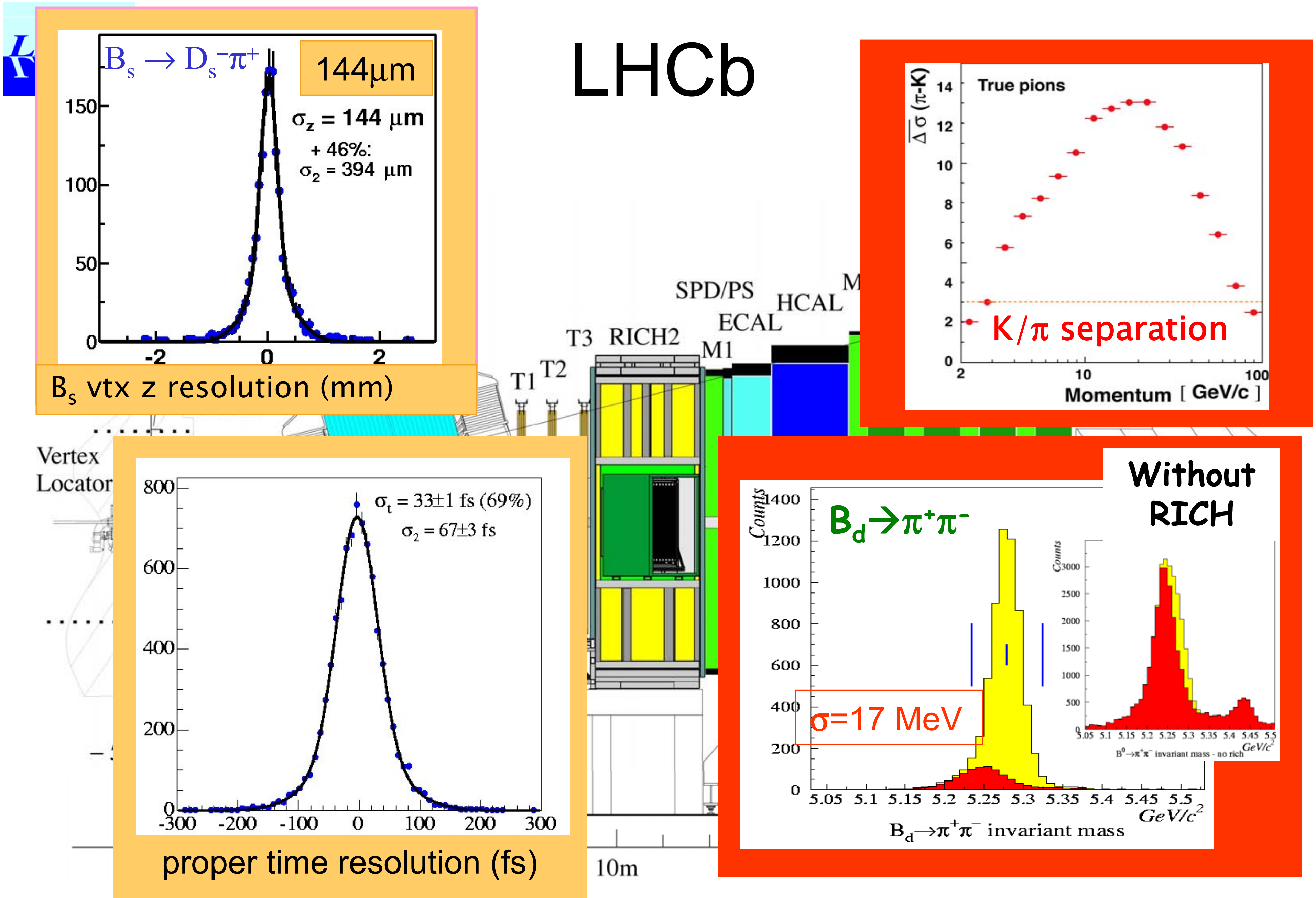
LHC Tevatron

	CMS-ATLAS central det.	LHCb forward det.	BTeV forward det.
√s	14 TeV		2 TeV
σ_{total}	100 mb		67 mb
$\sigma_{inelelastic}$	80 mb		50 mb
σ_{bb}	500 μb		100 μb
L (cm^{-2}s^{-1})	$2\times10^{33}(10^{34})$	2×10^{32}	2×10^{32}
Nbb/year	10^{13}	10^{12}	2×10^{11}
$t_{\text{bunch spacing}}$	25 ns		(132) 396 ns
$W_{\text{bunch crossing}}$	40 MHz		(7.6) 2.5 MHz
σ_z	5 cm		30 cm
$<N_{\text{pp int./bco}}>$	~2.3	0.4	(2) 6





LHCb



$B_s \to D_s^- \pi^+$
144μm
σ_z = 144 μm
+ 46%:
σ_2 = 394 μm
B_s vtx z resolution (mm)
True pions
$\overline{\Delta\sigma}$ (π-K)
K/π separation
Momentum [GeV/c]
SPD/PS
HCAL
ECAL
M1
T3
RICH2
T1
T2
Vertex
Locator
σ_t = 33±1 fs (69%)
σ_2 = 67±3 fs
proper time resolution (fs)
10m
Without
RICH
Counts
$B_d \to \pi^+\pi^-$
σ=17 MeV
$B_d \to \pi^+\pi^-$ invariant mass
GeV/c^2

LHCb trigger

40 MHz

Level-0 — high p_T μ, e, γ, hadrons (~1-3GeV)
Pile-up veto

1 MHz

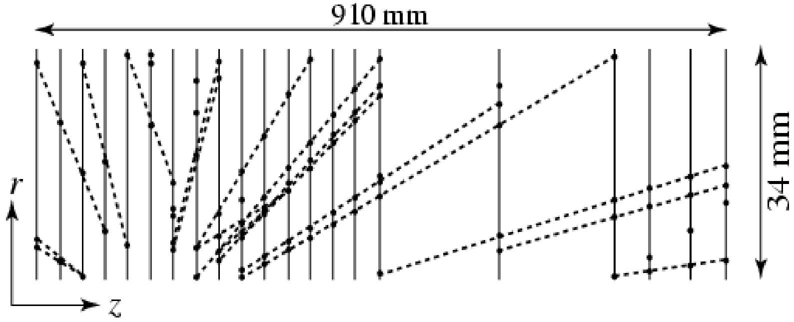
Level-1 — high impact parameter and high p_T tracks

40 kHz

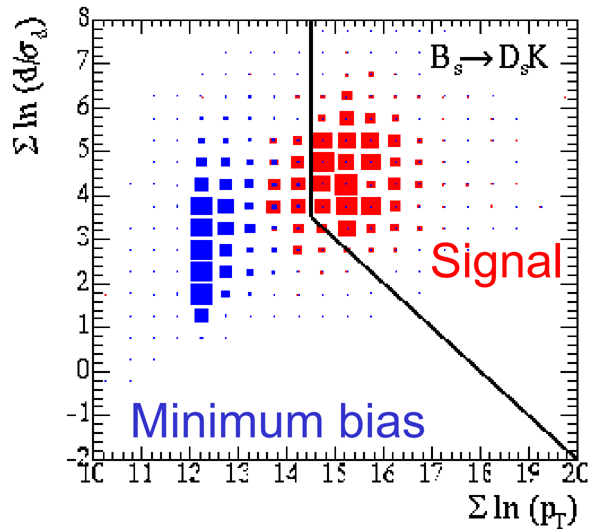
HLT — software on complete event

200 Hz

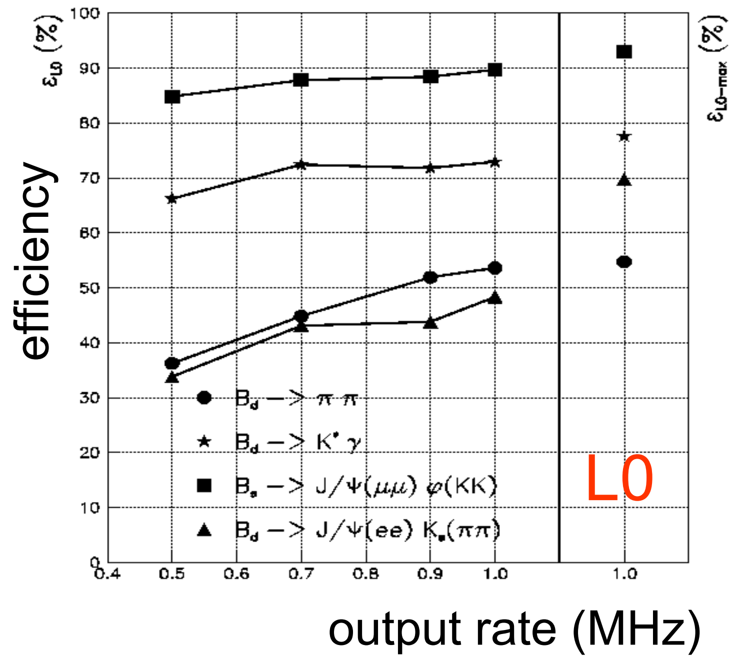
L1

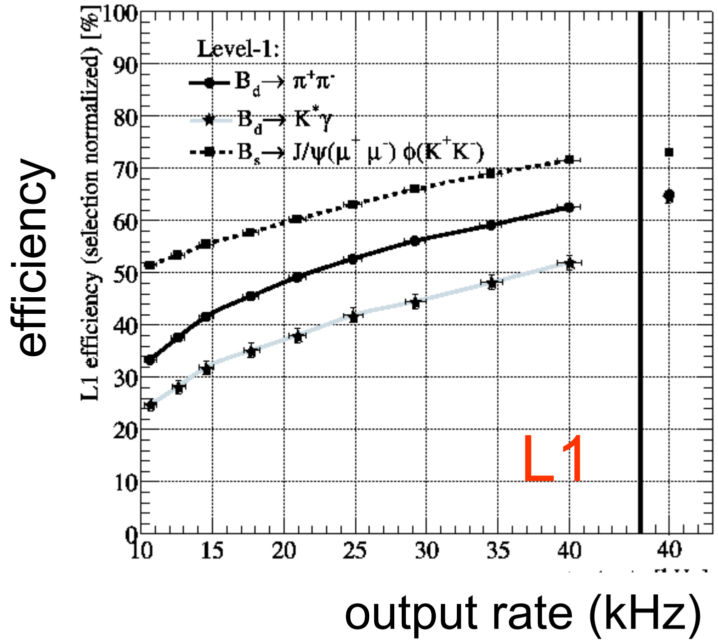


- High speed 2D VELO tracking
  Full 3D tracking and extrapolation to TT for high ip tracks
- p_T measured in 0.15 Tm field



LHCb trigger

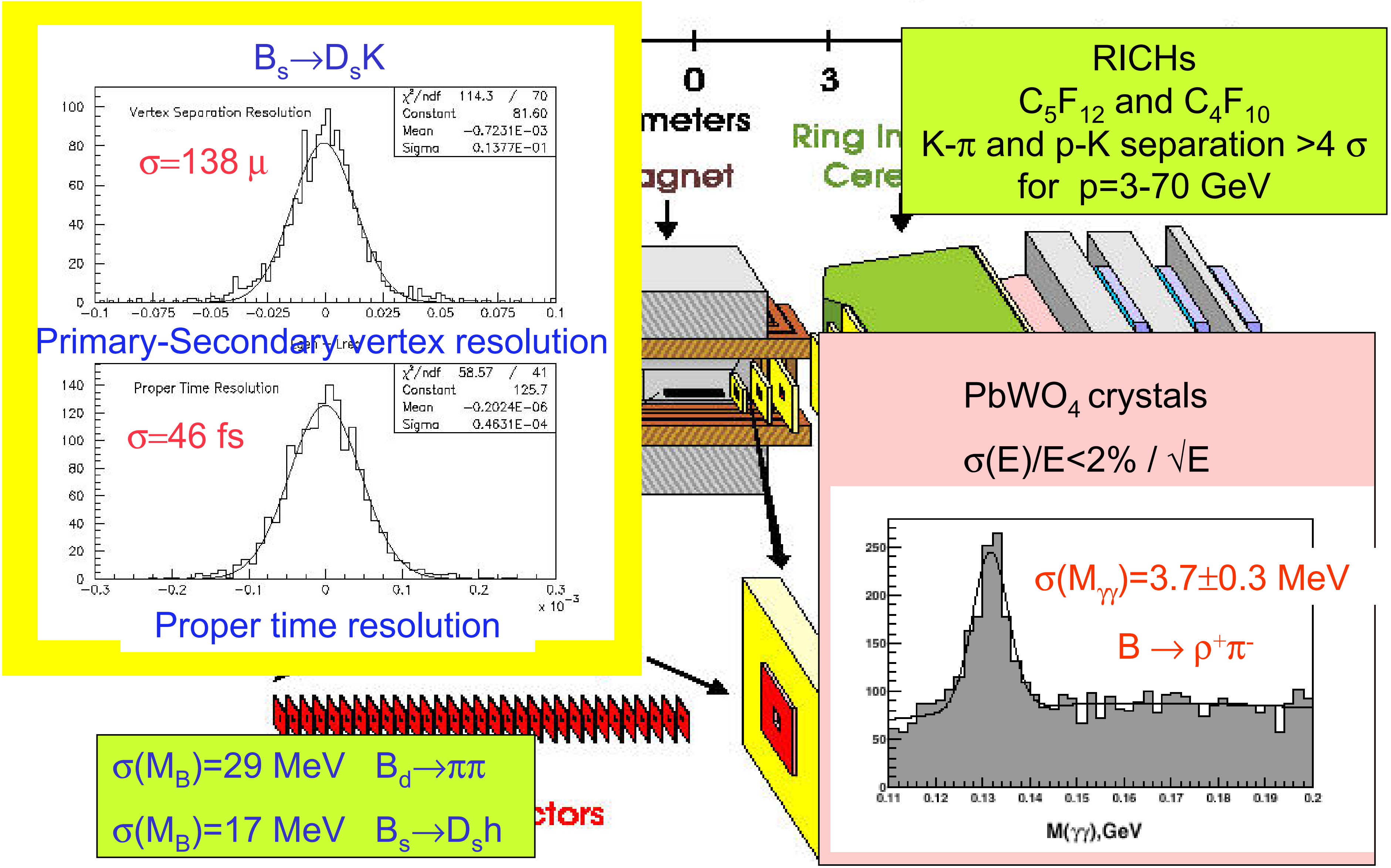




Efficiencies

Decay Channel	ε_{L0} (%)	ε_{L1}(%)	ε_{L0*L1}(%)
$B° \to \pi+\pi-$	**53.6**	62.7	33.6
$B° \to \pi+\pi-\ \pi°$	**77.2**	46.6	36.0
$B° \to D^*-\pi+$	**49.0**	56.0	27.4
$B°_s \to D_s-\pi+$	**49.4**	63.0	31.1
$B°_s \to D_s-K+$	**47.2**	62.6	29.5
$B° \to J/\Psi(\mu\mu)K°_s$	**89.3**	67.7	60.5
$B° \to J/\Psi(ee)K°_s$	**48.3**	54.9	26.5
$B°_s \to J/\Psi(\mu\mu)\Phi(KK)$	**89.7**	71.4	64.0
$B° \to K^*(K+\pi-)\gamma$	**72.9**	51.9	37.8

BTeV Detector Layout



BTeV Trigger

Input (7.6) 2.5 MHz

Level 1 — Vertex trigger + muon trigger

↓ 1/100

Level 2 — Secondary vertex

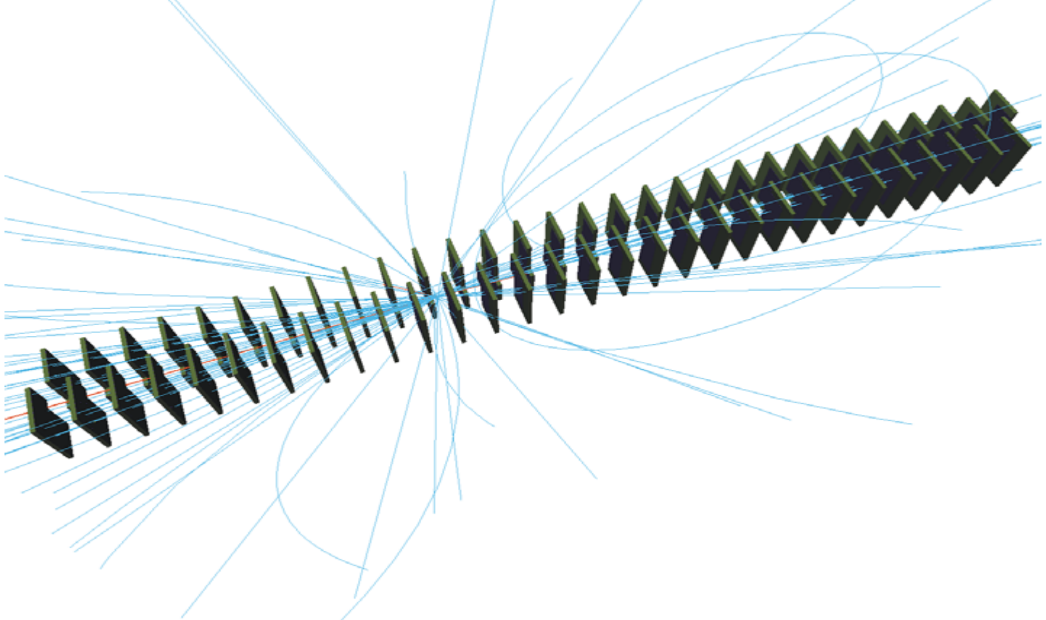
↓ 1/10

Level 3 — Full reconstruction

↓ 1/2

~ 200 MB/s on tape

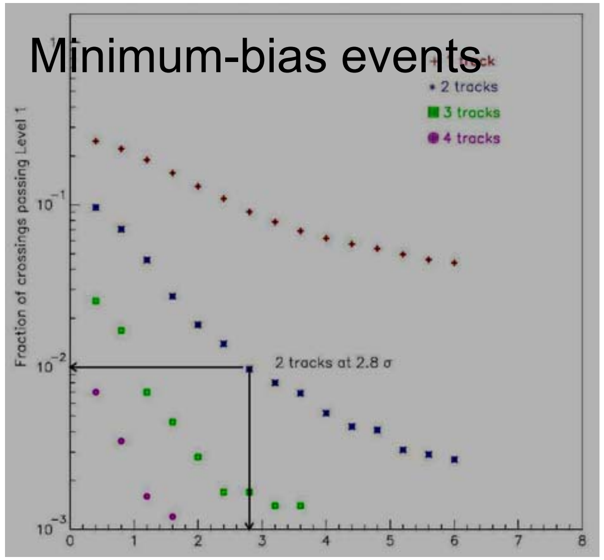
Vertex trigger: based on 3D information from Pixel detector (B_{max}=1.6T field) σ<10μm



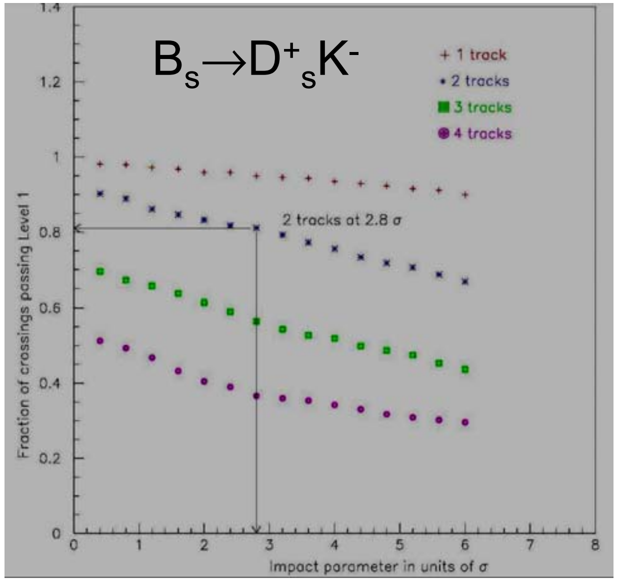
After a procedure of segment finding and vertex finding (3000 FPGA+DSP and micro-processors) measure impact parameter and count number of detached tracks

Requiring ≥2 tracks detached by ≥6σ retains 1% of beam crossings at <N>=2

Channel	LVL1 eff(%)	Channel LVL1	eff(%)
$B \to \pi^+\pi^-$	63	$B^o \to K^+\pi^-$	63
$B_s \to D_sK$	74	$B^o \to J/\psi\ K_s$	50
$B^- \to D^oK^-$	70	$B_s \to J/\psi K^*$	68
$B^- \to K_s\pi^-$	27	$B^o \to K^*\gamma$	40



ip/σ

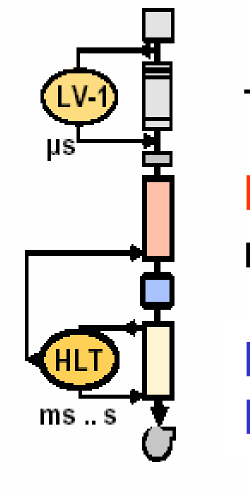


ip/σ

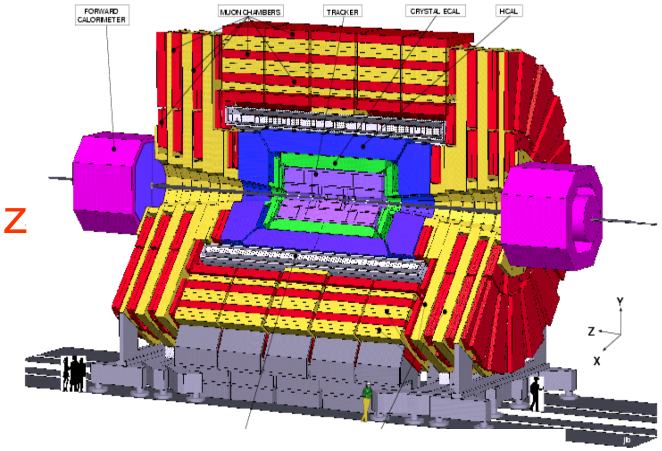
Recent re-evaluation at 396 ns <N>=6 ip≥4σ

Channel	LVL1 eff(%)
$B \to \pi^+\pi^-$	55
$B_s \to D_sK$	70
$B^- \to D^oK^-$	60

CMS



Trigger start up in 2007: 4 DAQ slices → 50kHz



Level-1 designed to cover widest possible range of discovery Physics (Higgs, SuSy ...)

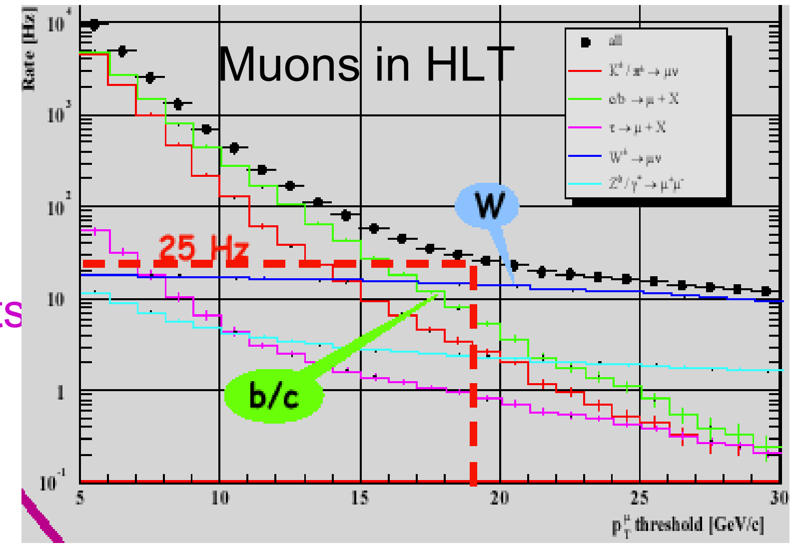
B Physics selection triggered by single or di-muon triggers
Muons are preferred to electrons because of lower trigger threshold

HLT output fixed at100 Hz

30Hz allocated to 1μ,2μ (p_T>19 GeV, p_T>7 GeV)

The content in b /c is too little (~5HZ):
→exploit online tracking to select exclusive b events

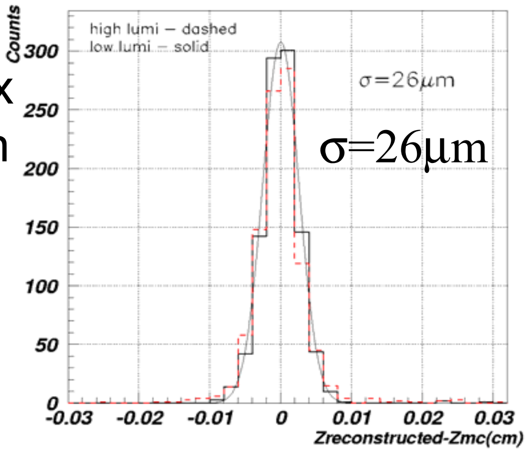
Limited amount of CPU time (~50 msec in 2007):
→ reduce # tracks and # operation/track using regional reconstruction and conditional tracking



Studies on some benchmark channels: $B_s \to \mu\mu$, $B_s \to J/\psi\ \phi$, $B_s \to D_s\pi \to KK\pi\pi$

CMS

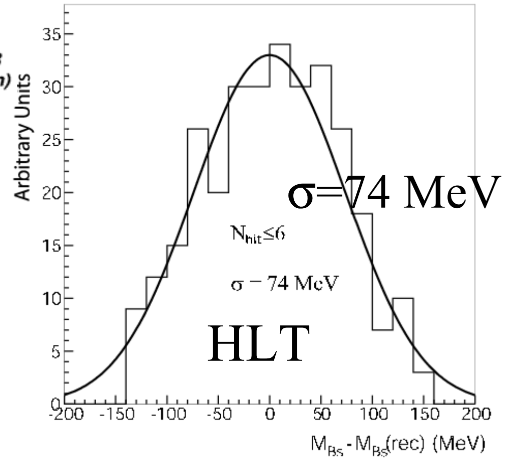
Primary vertex reconstruction Only Pixel Detector

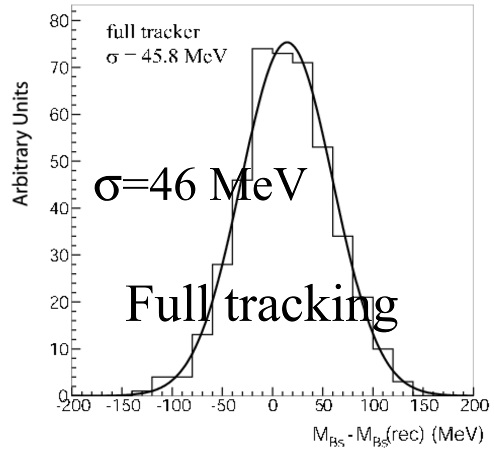


Secondary vertex reconstruction

	$B_s \to \mu\mu$	$B_s \to J/\psi\ \phi$
σ(x) μm	47.5±3.6	55.3 ±0.9
σ(z) μm	71.5 ± 1.3	72.7 ±1.4
CPU time	1.9 ms	3 ms

$B_s \to \mu+\mu-$ B_s mass resolution





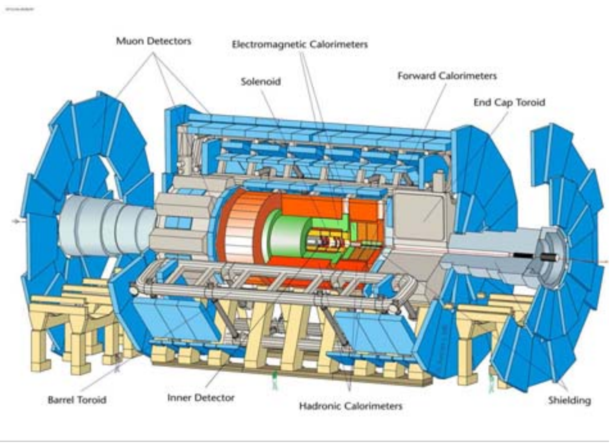
$B_s \to \mu+\mu-$

Lvl-1 ε	HLT ε	Global ε	Events/10fb^{-1}	Trigger rate
15.2%	33.5%	5.1%	47	<1.7 Hz

$B_s \to J/\psi\phi$

Lvl-1 ε	HLT step1 ε	step1 rate	HLT step2 ε	step2 rate	Events/10fb^{-1}
16.5%	13.7%	14.5 Hz	8.7%	<1.7 Hz	83800

ATLAS



Three level Trigger:
40 MHz $\rightarrow$ Level-1 $\rightarrow$ (20 kHz)
$\rightarrow$ Level-2 $\rightarrow$ (1-5 kHz)
$\rightarrow$ Event Filter $\rightarrow$ (200 Hz)

B-physics ‘classical’ scenario: LVL1 muon with $p_T > 6$ GeV, $|\eta| < 2.4$, LVL2 muon confirmation, ID full scan.

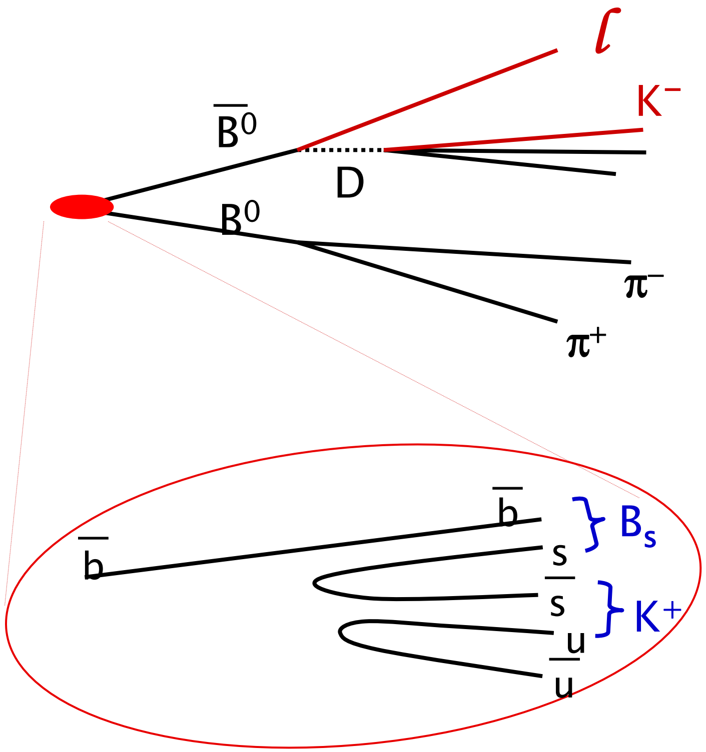
B-physics trigger revised for $L=2\times10^{33}$ $cm^{-2}s^{-1}$ and possibly reduced detector at start-up
Alternatives:

- single muon at LVL1 and additional requirements:
  a second muon $\rightarrow$ $J/\psi(\mu^+\mu^-)$, rare decays like $B \rightarrow \mu^+\mu^-(X)$, etc.
  a Jet or EM RoI $\rightarrow$ hadronic modes e.g. $B_s \rightarrow D_s\,\pi$; electrons, e.g. $J/\psi \rightarrow e^+e^-$
  and reconstruct tracks at LVL2 and EF within RoI
- flexible trigger strategy: start with a di-muon trigger for higher luminosities, add further triggers (hadronic final states, final states with electrons and muons) and/or lower the thresholds later in the beam-coast/for low-luminosity fills.

Promising results, further studies ongoing.

Flavour Tag

The knowledge of the b flavour at birth is essential for the majority of CP measurements



$\varepsilon \equiv$ tagging efficiency

$D \equiv (N_{right} - N_{wrong})/(N_{right} + N_{wrong})$

effective efficiency $\equiv \varepsilon D^2$

Several methods:

Other B
- Lepton
- Kaon
- Vertex charge /Jet charge

Signal B (same side)
- Fragmentation kaon near B_s
- Fragmentation pion near B_d and pion from $B^{**} \rightarrow B\pi$

Flavour tag

LHCb Tag	εD^2 (%)	
Muon	1.0	
Electron	0.4	
Kaon	2.4	
Vertex Charge	1.0	
Same side kaon		2.1
Combined B^0 / B_s	~4	~6

LHCb: results are channel dependent (correlations with trigger and selection)

Same side pion tag under developement

BTeV Tag	εD^2 (%) B_s	εD^2 (%) B^o
muon	1.3	1.2
kaon	5.8	6.0
Jet Charge	4.5	4.8
Same side K/ π	5.7	1.8
Electron	0.9	0.8
Combined B^0 / B_s (no overlap)	13.0	10.0

BTeV partially optimistic results :

No pattern recognition, μ identification
Only $gg \to b\bar{b}$ production process in MC, resulting in b and $\bar{b}$ back to back

CMS / ATLAS

Tag	εD^2 (%)
Muon	~0.7
Electron	~0.5
Vertex Charge	~3.1
Same side pion	~2.2

Physics goals

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

Δm_s from $B_s \to D_s \pi$

CPV measurements: $\sin(2\chi)$ and $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$, $J/\psi\eta^{(')}$

γ from $\begin{cases} B_s \to D_s K \\ B^0 \to \pi\pi \text{ and } B_s \to KK \\ B^0 \to D^0 K^{*0},\ B^+ \to D^0 K^+ \end{cases}$

$2\beta+\gamma$ from $B^0 \to D^* \pi$

$\alpha=\pi-\beta-\gamma$ from $B^0 \to \pi\pi$, $\rho\pi$

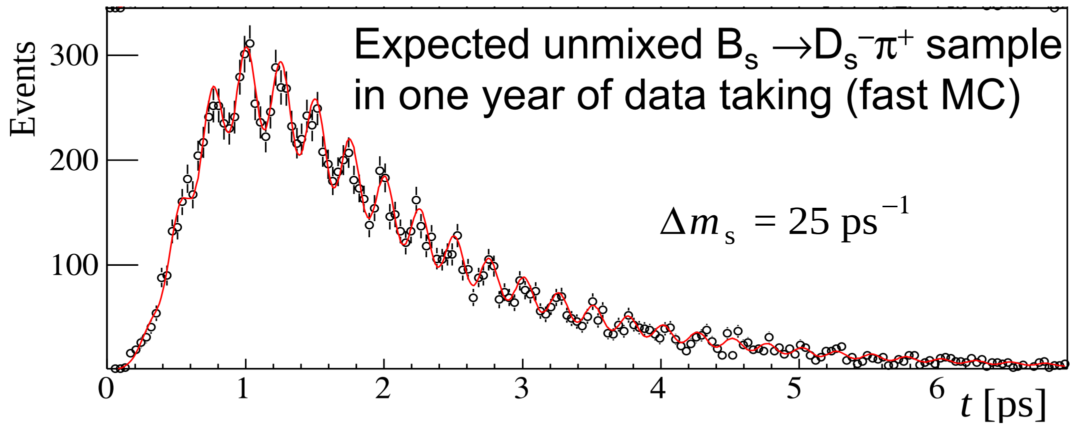
Rare decays: $b \to s\gamma$ penguins

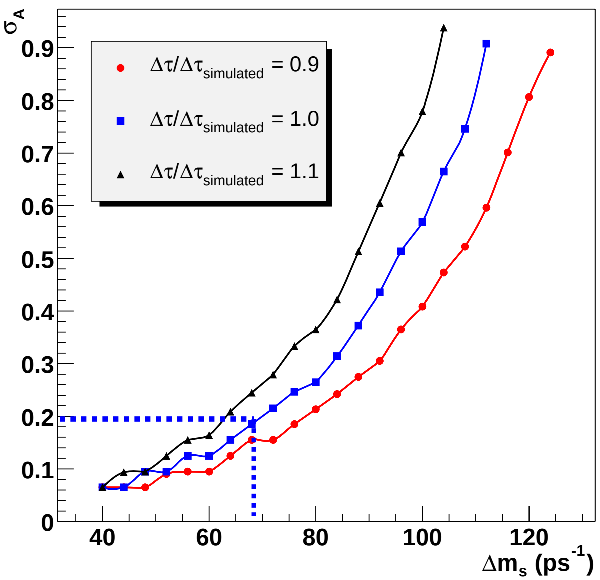
Δm_s from $B_s \rightarrow D_s \pi$

LHCb

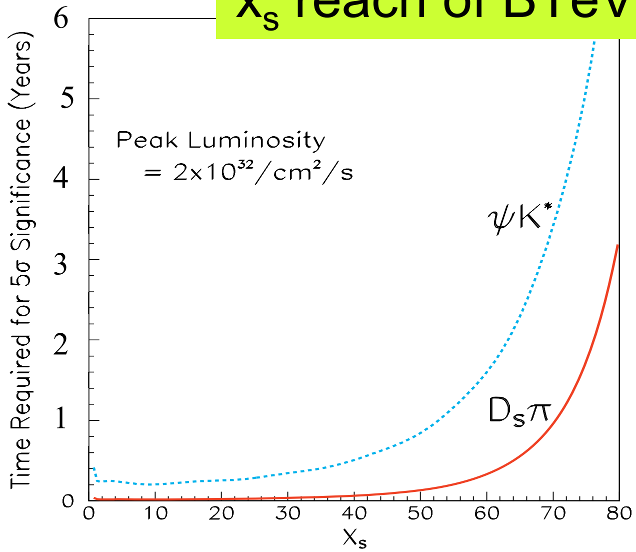
80k events/yr   B/S=0.32
Proper time res. 33 fs (core)

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





x_s reach of BTeV



5σ observation of B_s oscillation up to x_s=80 ps^{-1} in 3.2 yr using $D_s\pi$

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

SM: $\Phi_s = -2\chi = -2\lambda^2\eta \sim -0.04$

High sensitivity to NP contributions in B_s mixing

PS $\to$ VV decay:
3 contributing amplitudes
2 CP even, 1 CP odd
$\Rightarrow$ fit angular distribution of decay states as function of proper time.

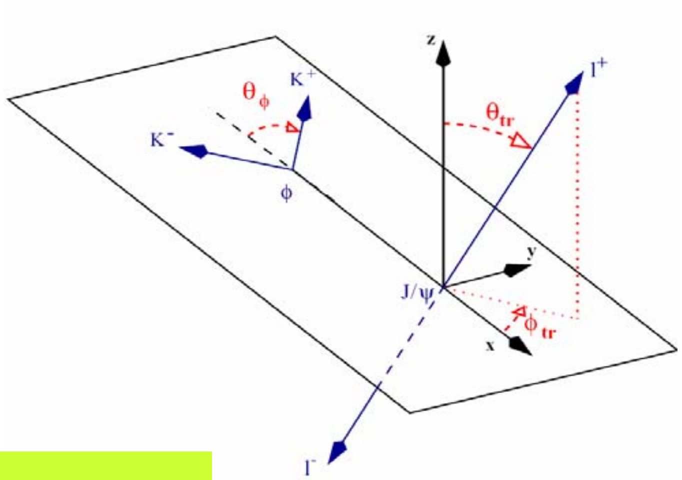
LHCb 100k ($\mu\mu$) events/yr B/S<0.3

proper time res. 38 fs

Δm_s in ps^{-1}	15	20	25	30
$\sigma(\mathcal{A}_{\mathrm{mix}})$	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
$\sigma(\mathcal{A}_{\mathrm{mix}})$	0.059	0.064	0.070
$\sigma(\Delta\Gamma/\bar{\Gamma})$	0.015	0.018	0.019

$\sigma(\Phi_s) \sim$ **3.6°**



BTeV: 10k $B_s \to J/\psi\eta'$ events/yr
3k $B_s \to J/\psi\eta$

CP autostates: simpler analysis

$\sigma(\Phi_s) \sim$ **2.8°**

Critical check:

$$\sin(\chi) = \lambda^2 \frac{\sin\beta \sin\gamma}{\sin(\beta+\gamma)}$$

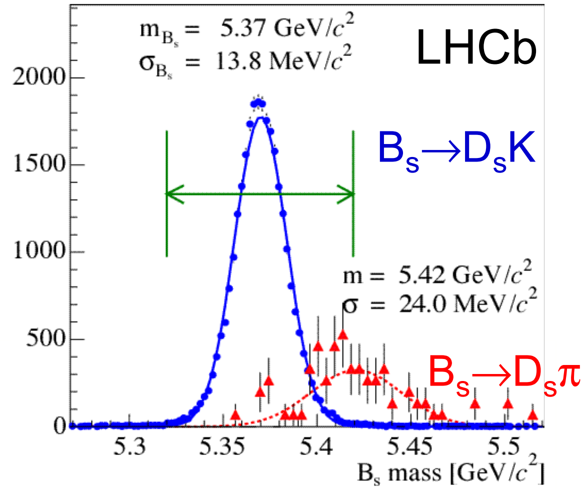
CMS $40 fb^{-1}$

300k events from HLT

$\sigma(\Phi_s) \sim$ **2°**

γ from $B_s \to D_s K$

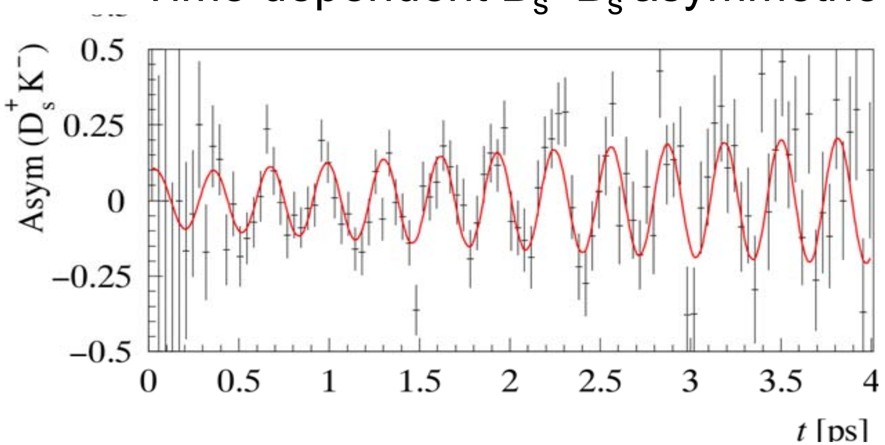
- Measure $\gamma + \phi_s$ from time-dependent rates: $B_s \to D_s^- K^+$ and $B_s \to D_s^+ K^-$ (+ CP-conjugates)
- Use ϕ_s from $B_s \to J/\psi\phi$
- Model independent



LHCb 5.4 k events/ yr B/S<1.0

Δm_s (ps^{-1})	20	25	30
$\sigma(\gamma+\Phi_s)$	14^0	16^0	18^0

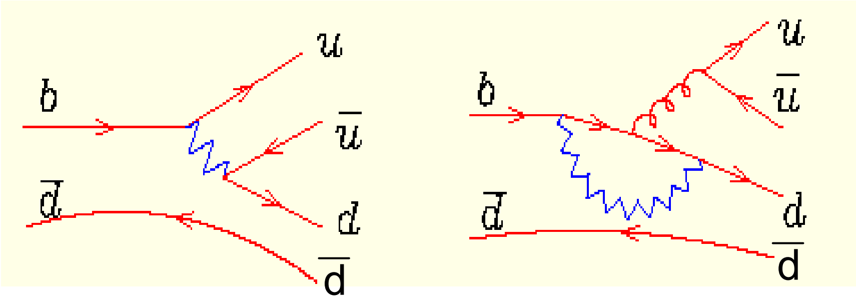
Time dependent $B_s - \overline{B}_s$ asymmetries



BTeV 7.5k events / yr
B/S: 0.14
$\sigma(\gamma+\Phi_s) \sim 8^0$

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

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



Measurement of time-dependent CP asymmetry for both decays

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 $\vartheta = \vartheta'$

$\Phi_s\ (B_s \to J/\psi\phi)$
$\Phi_d\ (B^0 \to J/\psi K_s)$

⇒

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

⇒

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

LHCb

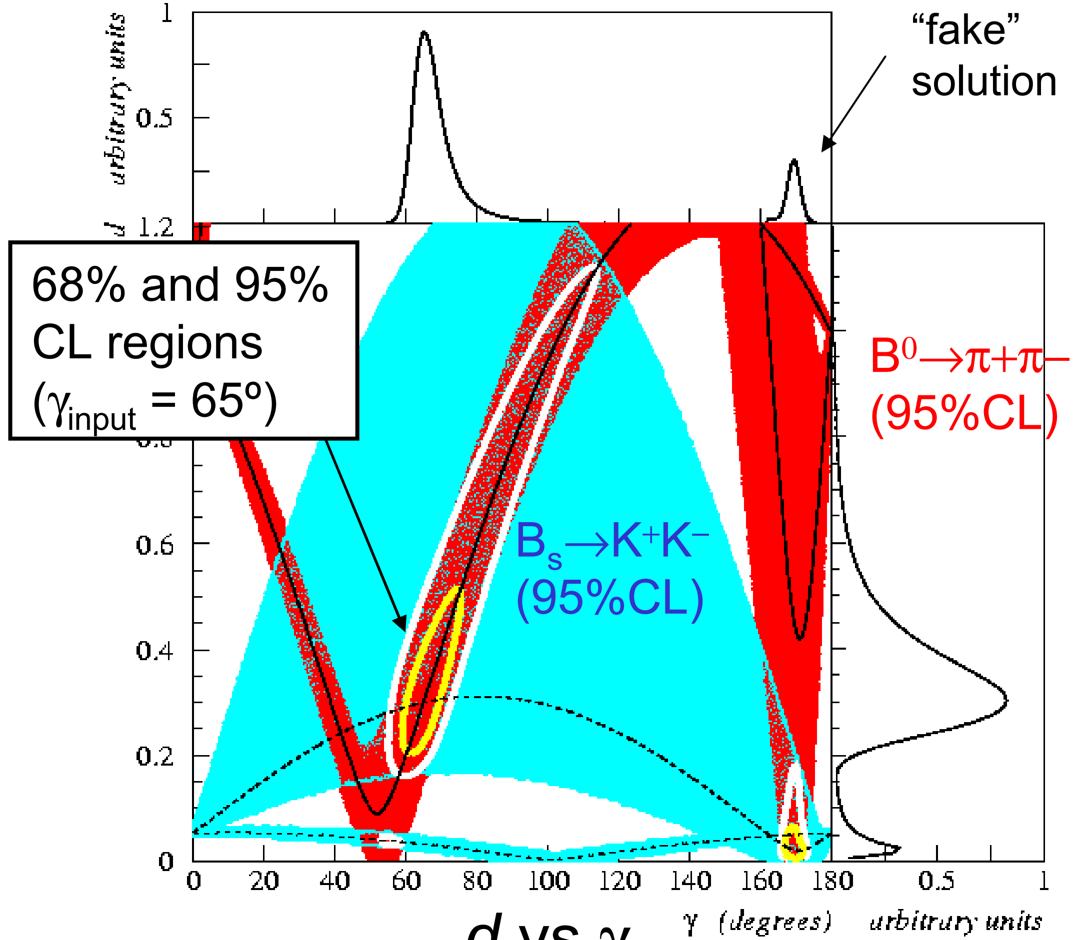
	events/yr	B/S
$B^0 \to \pi^+\pi^-$	26k	<0.7
$B_s \to K^+K^-$	37k	0.31
$B^0 \to K^+\pi^-$	135k	0.16
$B_s \to K^-\pi^+$	5.3k	<1.3

$\sigma(A_{\pi\pi})$~0.06
$\sigma(\gamma)$ = 4–6 deg

BTeV

	events/ yr	B/S
$B^0 \to \pi^+\pi^-$	15k	0.33
$B^0 \to K^+\pi^-$	62k	0.05

$\sigma(A_{\pi\pi})$~0.03



d vs γ

α from $B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$

Time dependent analysis of Dalitz plot to get α independently from penguin contributions

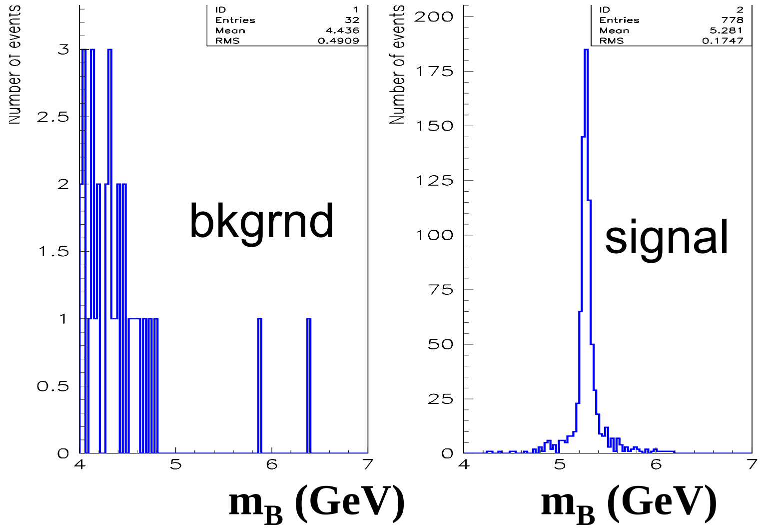
BTeV

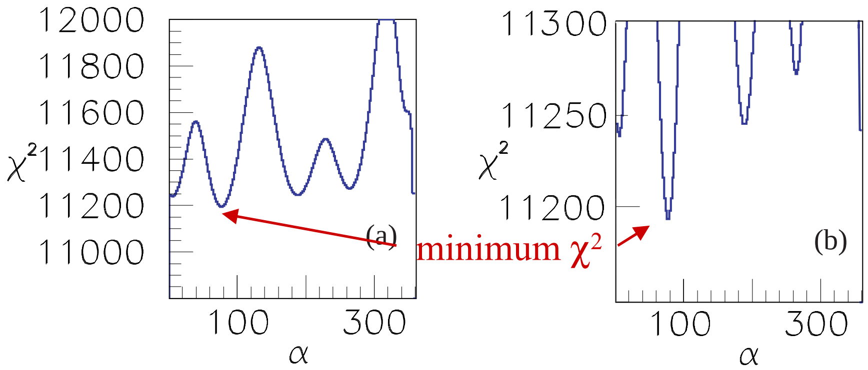
$B^o \to \rho^+\pi^-$ 5.4 k events/yr S/B = 4.1
$B^o \to \rho^o\pi^o$ 0.8 k events/yr S/B = 0.3

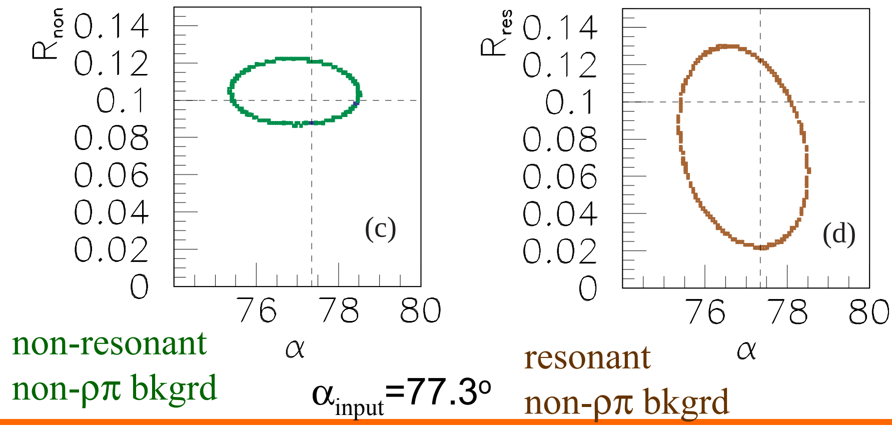
Fit with including resonant and non-resonant background with 1000 tagged events (2 years)

α (gen)	R_{res}	R_{non}	α (rec.)	$\delta\alpha$
77.3°	0.2	0.2	77.2°	1.6°
77.3°	0.4	0	77.2°	1.8°
93.0°	0.2	0.2	93.3°	1.9°
111.0°	0.2	0.2	111.7°	3.9°

$\delta\alpha$ ~2°-4° in 2 years

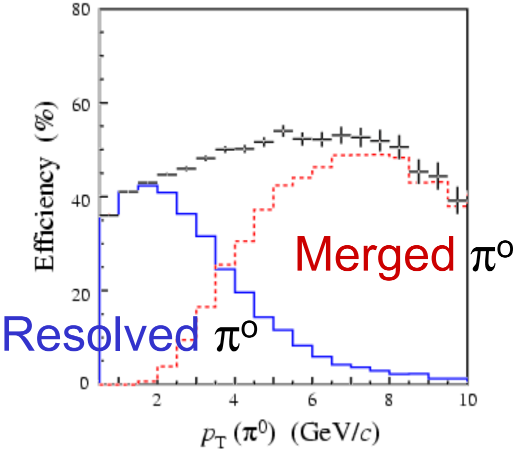






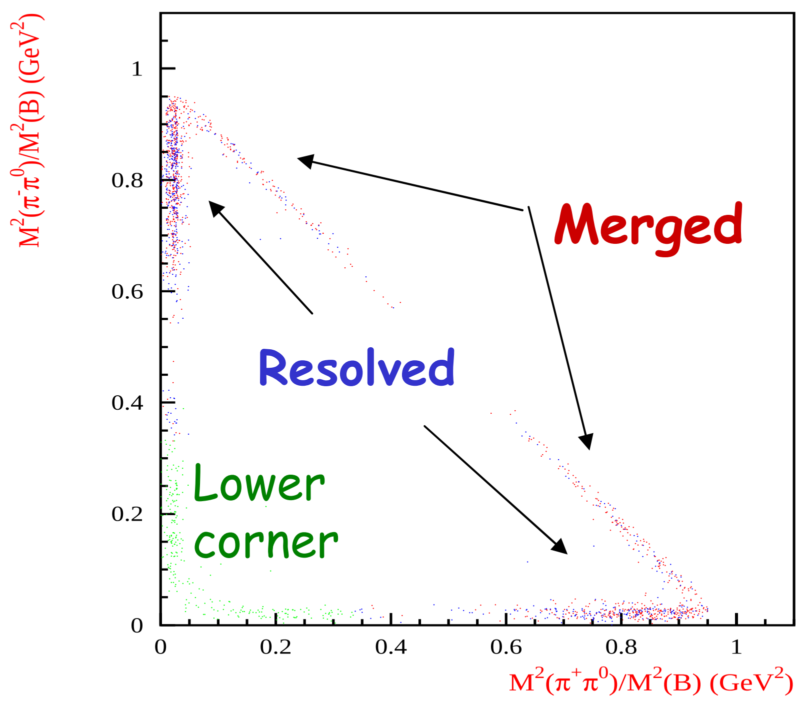
$B^0 \rightarrow \pi^+\pi^-\pi^0$ in LHCb

π^o reconstruction efficiency

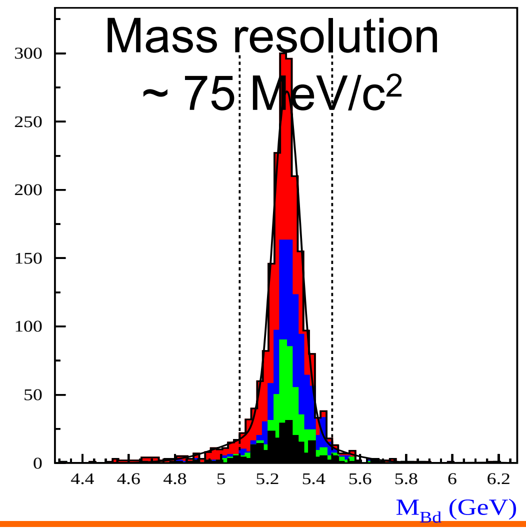


New analysis of $B^0 \rightarrow \pi^+\pi^-\pi^0$ signal and background
2.5 increase of signal yield wrt TDR2003 (new variables, π id, use of multiple collision events…)

Dalitz plot



$B^o \rightarrow K^*(K^+\pi^-)\pi^o/\gamma$ seems the most dangerous specific background. Reduced by a factor 6 to B/S ~6% using K/π separation from RICH



10800 events/yr
B/S<3

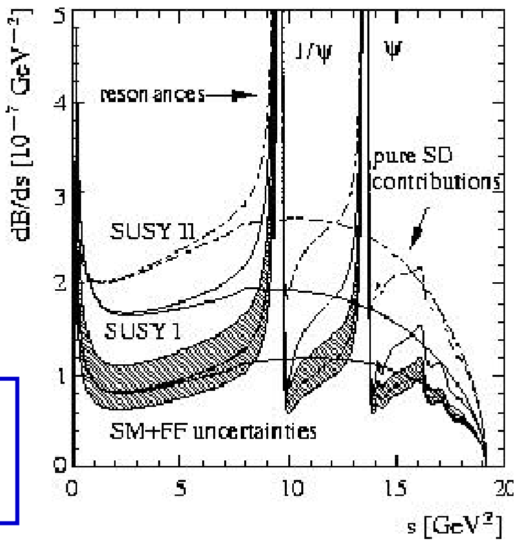
(conservative estimate based on … background events)

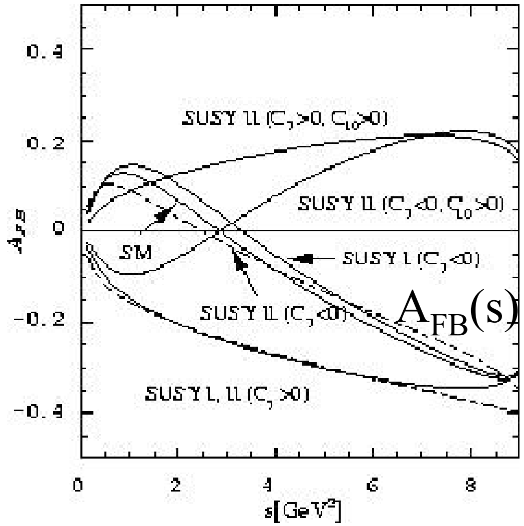
$B^0 \to K^{*0} \mu^+\mu^-$

Sensitivity to **New Physics** in:

μ+μ– invariant mass distribution

μ+μ– forward-backward asymmetry





SM:

BR($B^0 \to K^{*0} \mu^+\mu^-$) = $(1.2 \pm 0.4) \times 10^{-6}$
determination of $|V_{ts}|$ complementary to $\Delta m_s/\Delta m_d$ oscillation measurements

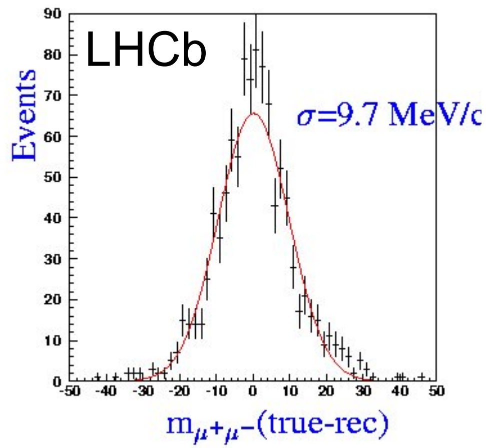
LHCb

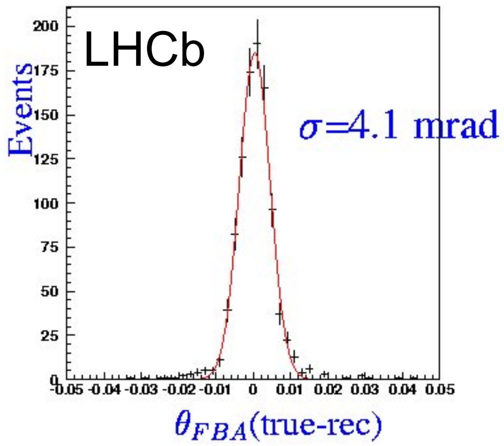
Annual yield (SM): 4.4k B/S <2
σ(BR) ~ 3% σ(A_{CP}) ~ 3%

BTeV

Annual yield (SM): 2.5k B/S=0.1

ATLAS	Yield (30 fb^{-1})	B/S
$B_d^0 \Rightarrow \rho^0\mu\mu$	222	4.3
$B_d^0 \Rightarrow K^*\mu\mu$	1995	0.15
$B_d^0 \Rightarrow \phi^0\mu\mu$	411	0.34





Event Yield

(untagged)

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

Channel	LHCb Yield	LHCb B/S	LHCb Parameter	BTeV Yield	BTeV B/S	BTeV parameter
$B^0 \to \pi^+\pi^-$	26 k	< 0.7	$\sigma(A)$~0.06	15k	0.33	$\sigma(A)$~0.03
$B_s \to K^+K^-$	37 k	0.3	γ~5°	19k	0.15	
$B^0 \to K^+\pi^-$	135 k	0.16		62k	0.05	
$B_s \to D_s^-\pi^+$	80 k	0.3		59k	0.33	
$B_s \to D_s^{-+}K^{+-}$	5.4 k	< 1.0	$\gamma+\Phi_s$~14°	7.5k	0.14	$\gamma+\Phi_s$~8°
$B^0 \to D^0 K^{*0}$	4.5 k	0.3	γ~8°			
$B^0 \to J/\psi(\mu^-\mu^+)K_S$	216 k	0.8	$\sigma(A)$~0.022	168k	0.10	$\sigma(A)$~ 0.017
$B^0 \to J/\psi(e^-e^+)K_S$	26 k	1.0				
$B_s \to J/\psi(\mu^-\mu^+)\phi$	100 k	< 0.3	Φ_s~3.6°			
$B_s \to J/\psi(e^-e^+)\phi$	20 k	0.7				
$B_s \to J/\psi(\mu^-\mu^+)\eta$	7 k	< 5		2.8k	0.07	Φ_s~2.8°
$B_s \to J/\psi(\mu^-\mu^+)\eta'$				9.8k	0.03	
$B^0 \to \rho\pi$	10.8 k	< 3		6.2k	0.24	α~4°
$B^0 \to K^{*0}\gamma$	35 k	< 0.7	$\sigma(A)$~0.01			
$B^0 \to K^{*0}\mu\mu$	4.4 k	< 2.0		2.5k	0.09	
$B^0 \to \phi K_S$	800	< 1.3				
$B_s \to \mu\mu$	17.2	5.7		5.7	7.7	

Conclusion

❖ New experiments at hadronic colliders will offer soon an excellent opportunity to study many different B-meson decay modes with high statistics

- determine precisely the CKM parameters through phase measurements
- spot New Physics by overconstraining the Unitarity Triangles and measure rare decays

❖ The goal will be reached thanks to:

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

❖The main challenge is the trigger

An informal Italian Workshop on B Physics was held in Rome in Feb. 2004 to discuss experiences from running experiments and future ones. This was its first subject. More to come.

Back up

Branching Ratios

$BR(B^0 \to \pi^+\pi^-)$	$(4.4\pm0.9)\ x10^{-6}$	PDG2002
$BR(B^0 \to K^+\pi^-)$	$(1.74\pm0.15)\ x10^{-5}$	PDG2002
$BR(B_s \to K^+K^-)$	$(1.74\pm0.15)\ x10^{-5}$	$= BR(B^0 \to K^+\pi^-)$
$BR(B_s \to \pi^+K^-)$	$(4.4\pm0.9)\ x10^{-6}$	$= BR(B^0 \to \pi^+\pi^-)$
$BR(B_s \to D_s^-\pi^+)$	$(3.0\pm0.4)\ x10^{-3}$	$= BR(B^0 \to D^-\pi^+)$
$BR(B_s \to D_s\ K^\pm)$	$(2.5\pm0.6)\ x10^{-4}$	calcolato
$BR(B^0 \to \pi^+\pi^-\pi^0)$	$2.\ x10^{-5}$	
$BR(B_s \to J/\psi\ \phi)$	$(9.3\pm3.3)\ x10^{-4}$	PDG2002
$BR(B^0 \to K^{0*}\gamma)$	$(4.3\pm0.4)\ x10^{-5}$	PDG2002
$BR(B^0 \to \phi K^0)$	$(8.1\pm3.)\ x10^{-6}$	PDG2002
$BR(B_s \to \mu\mu)$	$3.5\ x10^{-9}$	Ali
$BR(B^0 \to K^{0*}\mu\mu)$	$(1.2\pm0.4)\ x10^{-6}$	Ali

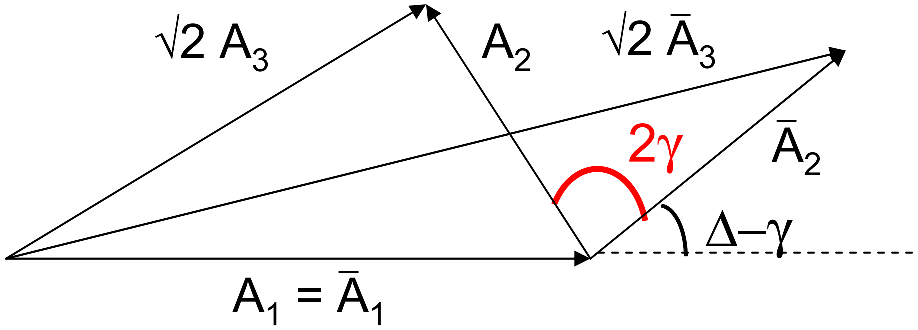
γ from $B^0 \to D^0 K^{*0}$ and $B^0 \to D^0 K^{*0}$

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

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

$1/\sqrt{2} \; (A(B^0 \to D^0 K^{*0}) + A(B^0 \to \overline{D}^0 K^{*0}))$

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



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
$B^0 \to \overline{D}^0 (K^+\pi^-) K^{*0}(K^+\pi^-)$	+ cc	3.4k	0.3
$B^0 \to D_{CP} (KK) K^{*0} (K^+\pi^-)$	+ cc	0.6k	1.4

γ=65°, Δ=0

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

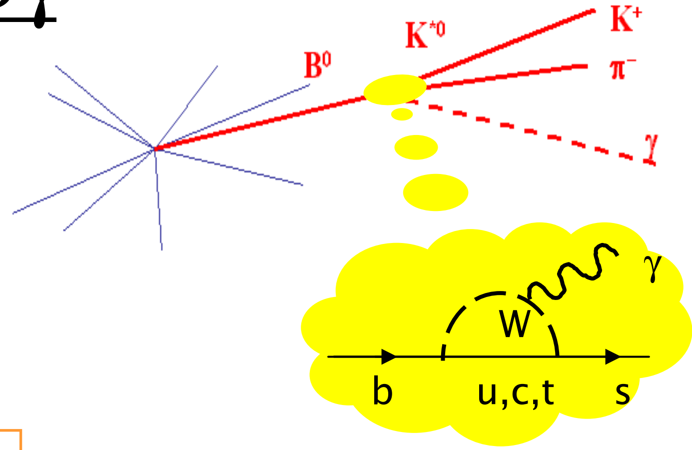
$\sigma(\gamma)$ = 7–8 deg

sensitive to new phase in D_{CP}

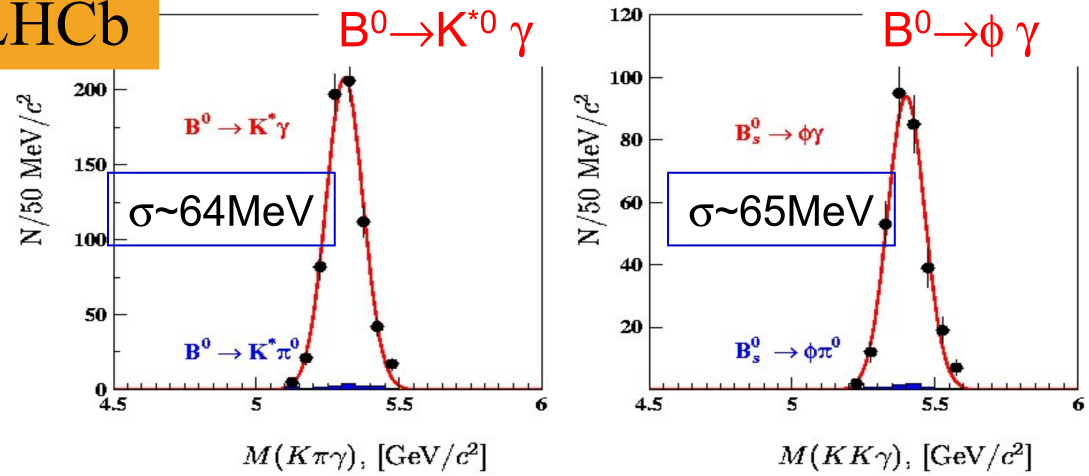
$B^0 \to K^{*0}\gamma$ and $B_s \to \phi\gamma$

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 $B_s \to \phi\gamma$



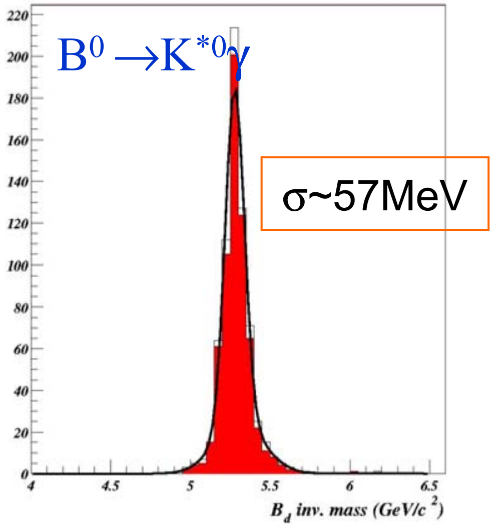
LHCb



	Events/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 (1 year)

ATLAS



10.5k evts 30 fb^{-1} B/S<3.3