B-Physics Potential of ATLAS, CMS, LHCb and BTeV

Neville Harnew
University of Oxford

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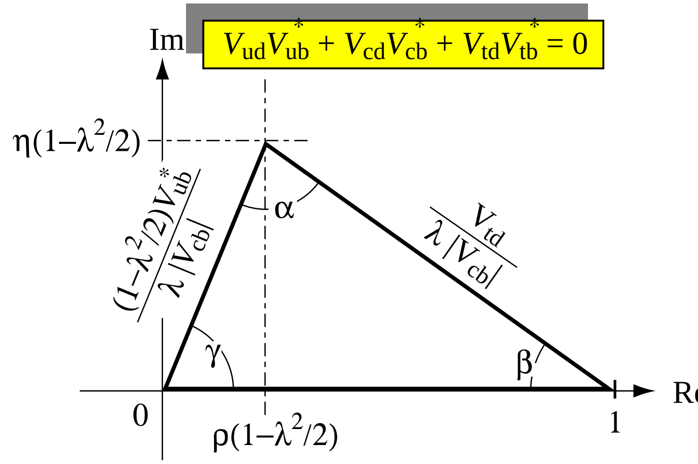
Outline

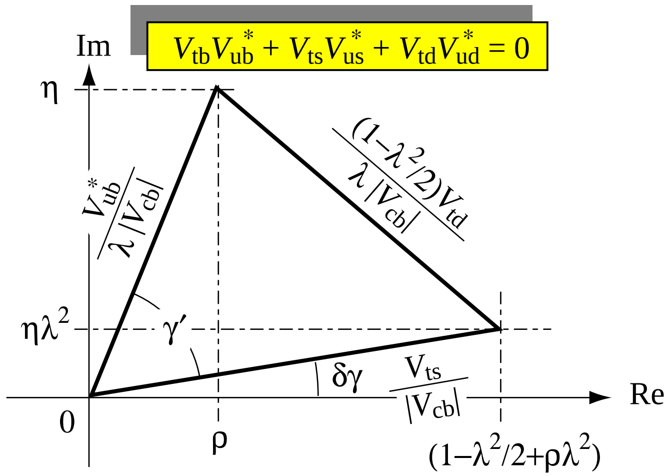
- Introduction
- The 2nd Generation experiments :
  LHCb, B-TeV, ATLAS, CMS.
- Precision measurements :
  CP-violation, rare B decays.
- Performance summary

Introduction

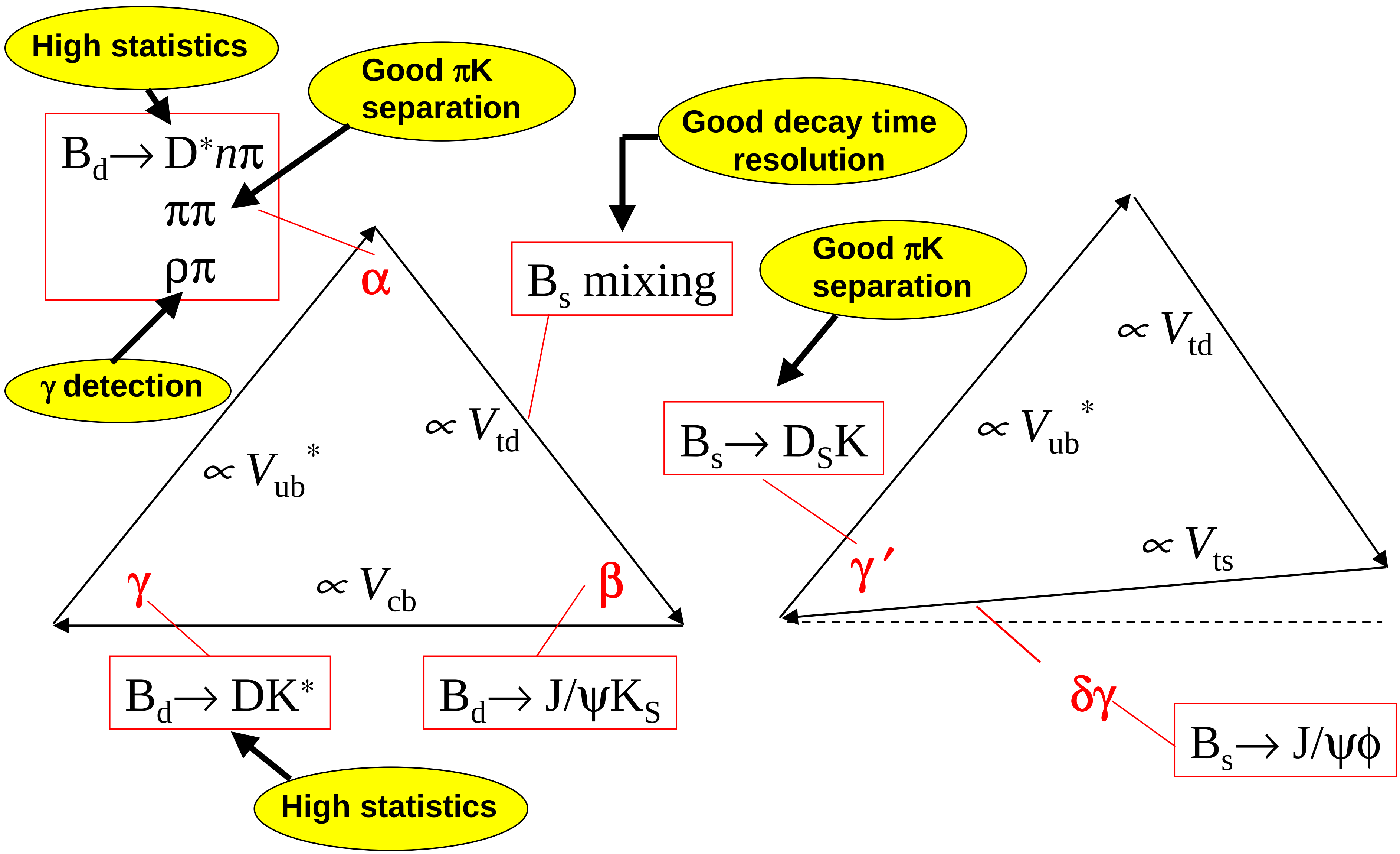
Before 2005 various experiments will explore the unitarity triangle :

- **sin 2β well measured by BaBar/Belle/ HERA-B/CDF/D0 perhaps to ~ 0.03 - 0.05**
- **Side opposite γ : known assuming B_s mixing is measured by (SLD/LEP?) CDF/D0**
- **Side opposite β : significant hadronic error**
- **sin 2α measured - but with poor statistical precision and significant theoretical uncertainties**
- **γ no good or direct measurement**





Decay modes to measure triangle parameters



Either : **Inconsistency in 'gold plated' measurements (eg. β and mixing side)**

Or : **Hint of inconsistency, or inconsistency with less precise data (eg. α, kaon asymmetries)**

Or : **Measurements consistent with SM interpretation**

In all cases, next generation experiments at LHC/Tevatron will need to make precise investigation of CP violation

- **Precision measurements : same parameters in previously measured channels**
- **Different channels (theoretically clean but not necessarily easiest experimentally) : cross checks of same parameters**
- **New parameters : eg. What is γ ?**
- **B_s sector : relatively unexplored by Phase 1**

Comparison of the LHC and the Tevatron experiments

	Tevatron	LHC	
Energy / collision mode	2.0 TeV $\bar{p}p$	14.0 TeV pp	
$b\bar{b}$ cross section	~ 100 μb	~ 500 μb	
Inelastic cross section	~ 50 mb	~ 80 mb	
Ratio $b\bar{b}$ / inelastic	0.2%	0.6%	
Bunch spacing	132 ns	25 ns	
	BTeV	**LHCb**	**ATLAS / CMS**
Detector configuration	Two-arm forward	Single-arm forward	Central detector
Running luminosity	2 x 10^{32} cm^{-2}s^{-1}	2 x 10^{32} cm^{-2}s^{-1}	$\leq$ 1 x 10^{33} cm^{-2}s^{-1}
$b\bar{b}$ events per 10^7 sec	2 x 10^{11} x accept.	1 x 10^{12} x accept.	$\leq$ 5 x 10^{12} x accept.
<Interactions/crossings>	~ 2.0	0.5 (~30% single int.)	~ 2.3

Advantages of forward detector geometry

- $b\bar{b}$ production sharply peaked forward-backward

- At LHC, low luminosity is sufficient ($2.0 \times 10^{32}\ cm^{-2}s^{-1}$)

→ Less radiation

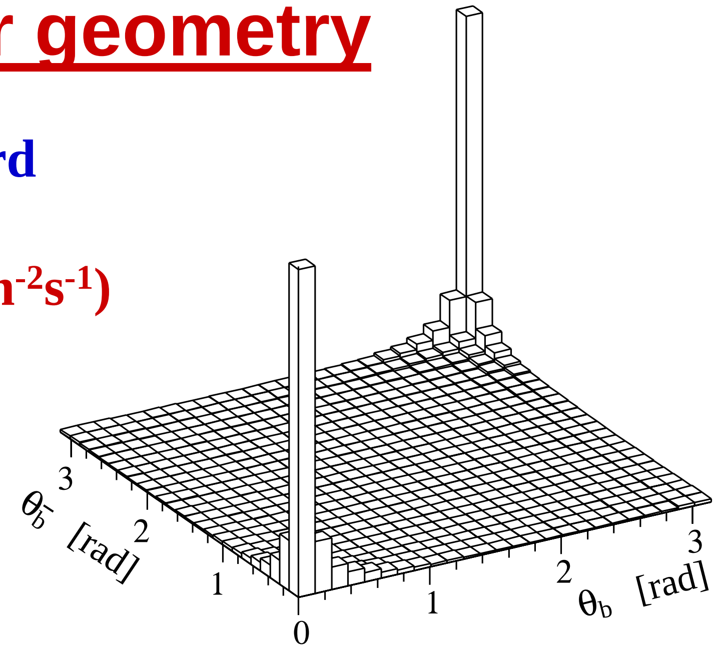
→ >80% triggered events single interactions

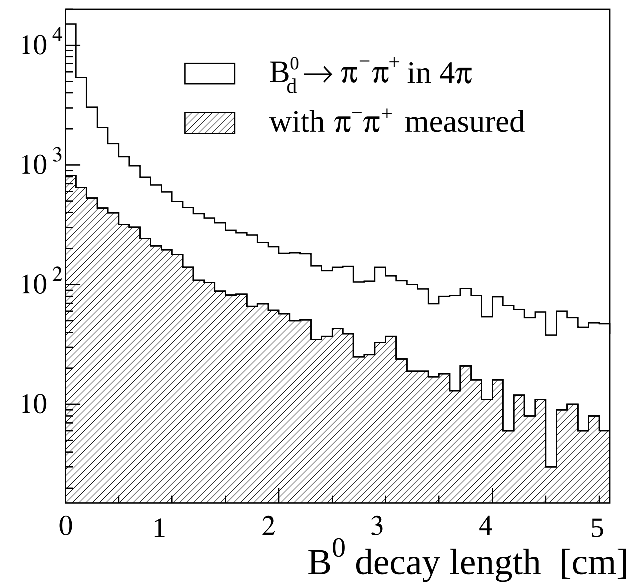
- Vertex detector close to interaction region.

→ $< p_B >_{Accepted}$ ~ 80 GeV/c at LHC

→ Mean flight path of B's ~7 mm

- Open geometry allows for easy installation and maintenance

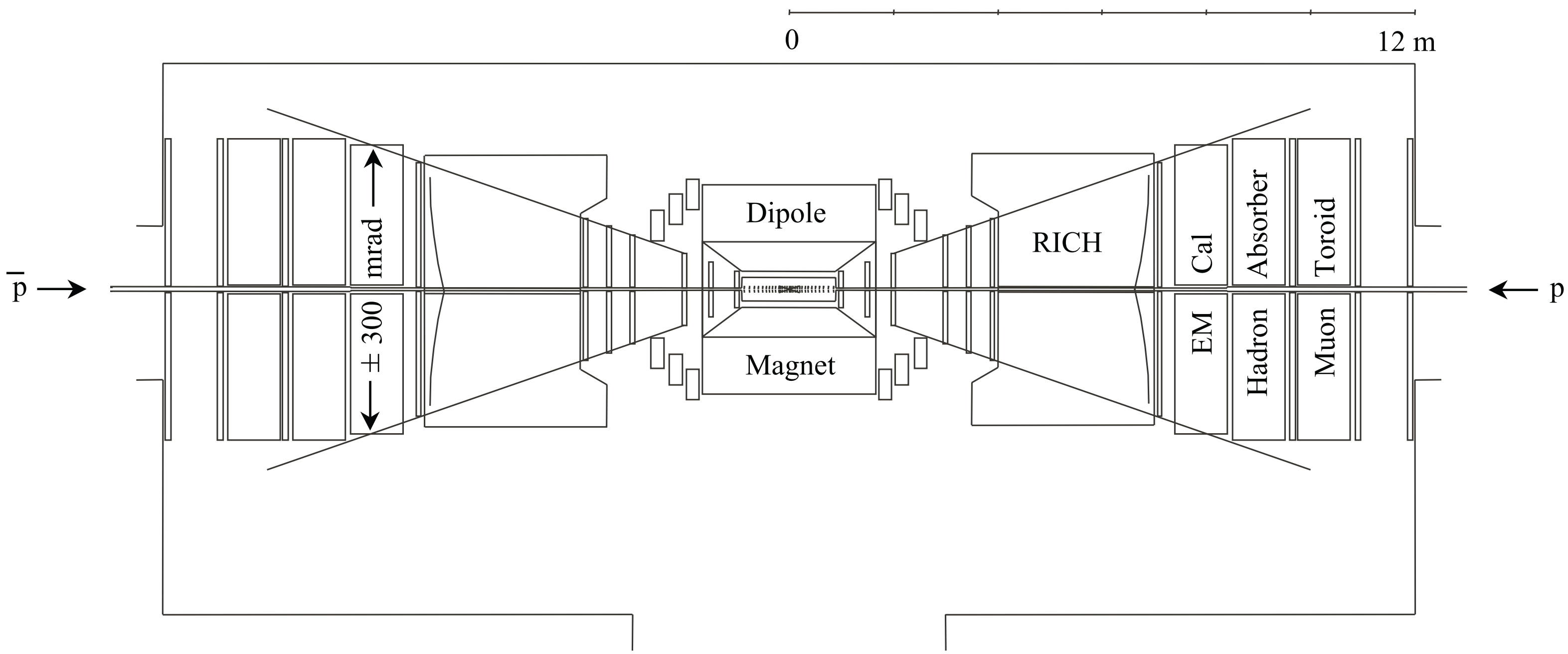




Disadvantages

- Minimum bias also peaks forward
- High occupancy, high track density

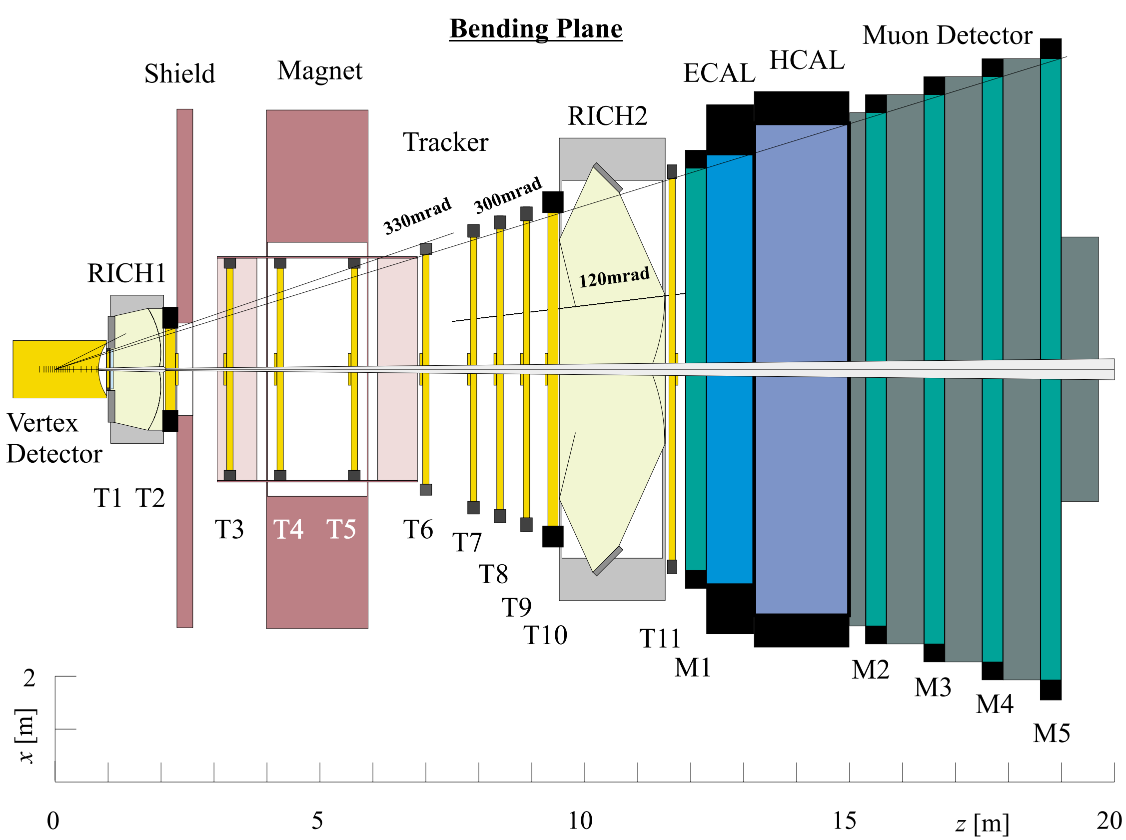
The BTeV Detector



Key design features

- Forward double arm spectrometer
- Precision pixel vertex detector inside dipole B field ($\int B.dL=5.2$ Tm)
- Vertex trigger at first level
- Single RICH detector for particle ID
- Lead tungstate EM calorimeter for γ and π^0 reconstruction

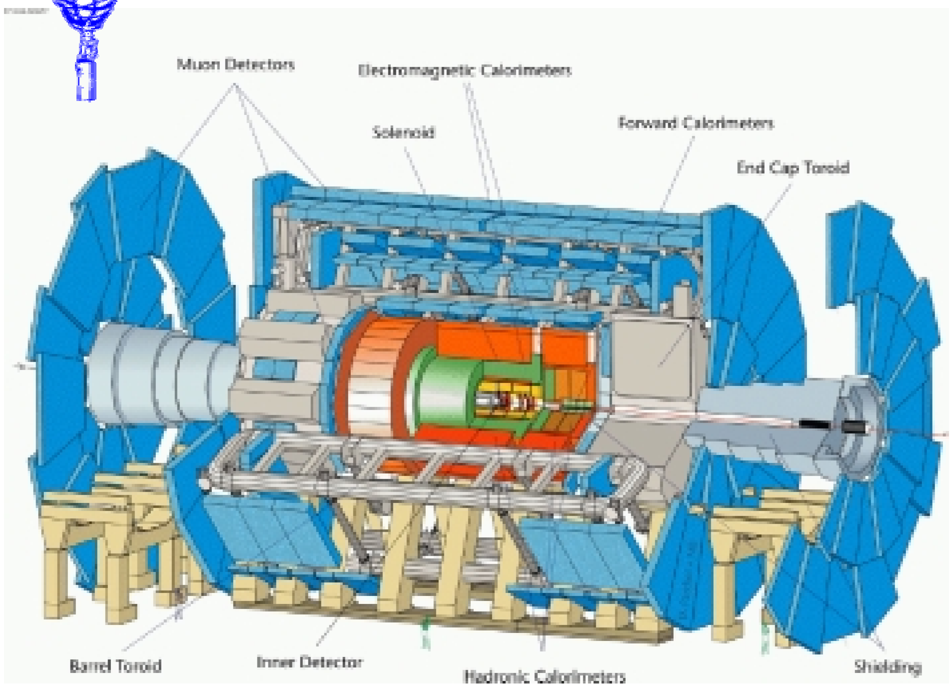
The LHCb Detector



Key design features

- Forward single arm spectrometer
- Precision Si-strip vertex detector
- Efficient 4 Level trigger incl. L1 vertex trigger
- Two RICH detectors for particle ID
- Hadron & EM calorimetry
- Designed to run at low LHC lumi ($2x10^{32}cm^{-2}s^{-1}$)

The ATLAS/CMS Detectors



Central general-purpose detectors :

- **Tracking up to $|\eta| < 2.5$**
- **Specialist B triggers operating at lumi $\leq 1x10^{33}$ $cm^{-2}s^{-1}$**

Importance of efficient triggering

BTeV

Three levels :-

L1: Pioneering pixel vertex trigger (132ns pipelined)

L2,L3: Software triggers

LHCb

Four levels :-

L0: "High" p_T μ, e, hadron (p_T~1-2 GeV/c)

L1: Vertex trigger

L2, L3: Software triggers

ATLAS/CMS

Three levels :-

L1: High p_T μ, & cal (p_T~ 5-6 GeV/c)

L2,L3: Software triggers

No vertex trigger

Level-1 vertex-trigger efficiencies

	BTeV	LHCb
$B^0 \to J/\psi\ K_s^0\ (\mu\mu)$	50%	50%
$B^0 \to \pi^+\ \pi^-$	55%	48%
$B_s^0 \to D_s^- K^+$	70%	56%

Tagging efficiencies typically 40%

Wrong tag fractions typically 30%

Total trigger efficiency (L0-L3) typically 30% , for reconstructable evnts.

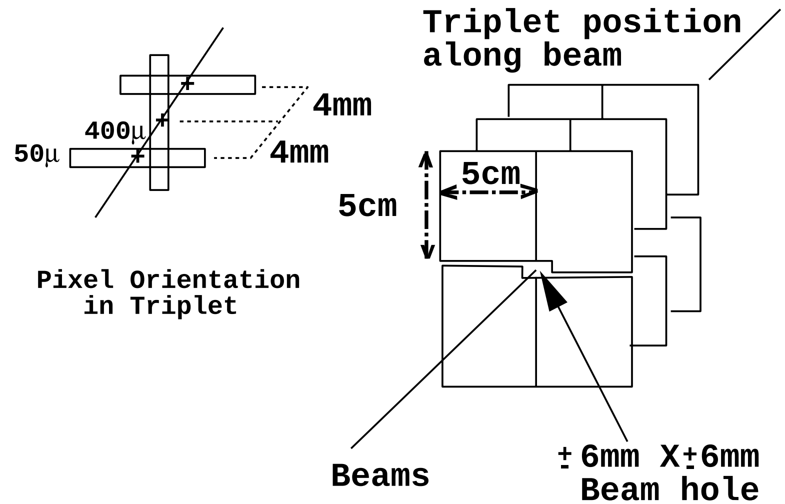
BTeV Pixel Detector

Why pixels ?
- Good signal to noise
- Good spatial resolution, 5-10μm
- Low occupancy
- Radiation hard

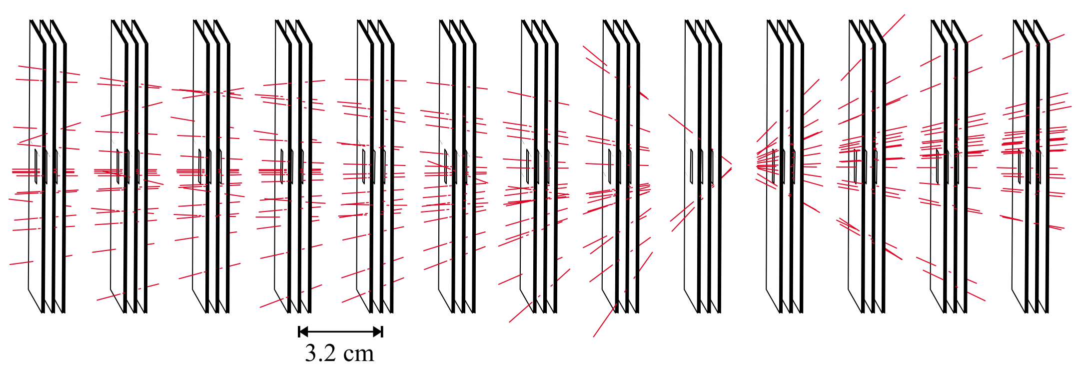
Special Features
- Used in the Level-1 trigger
- Located in the B field

Disadvantage
- Large radiation length (~$1X_0$)

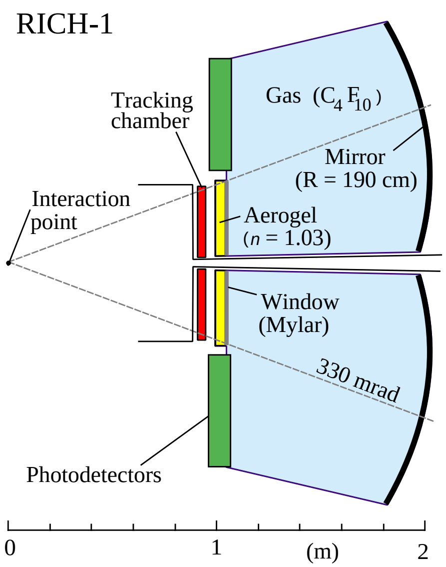
The BTeV Baseline Pixel Detector

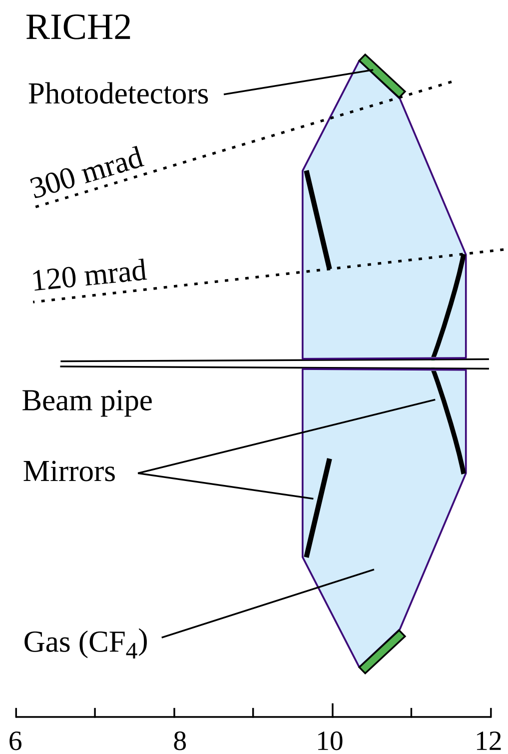


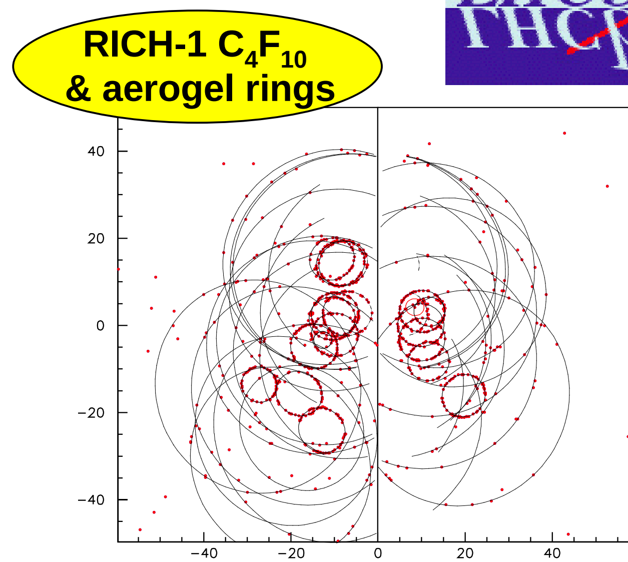
$B \rightarrow \pi^+\pi^-$ event in the vertex detector

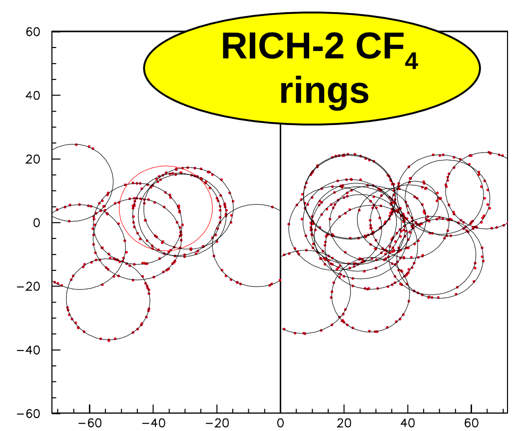


Importance of Particle ID (RICH detectors)



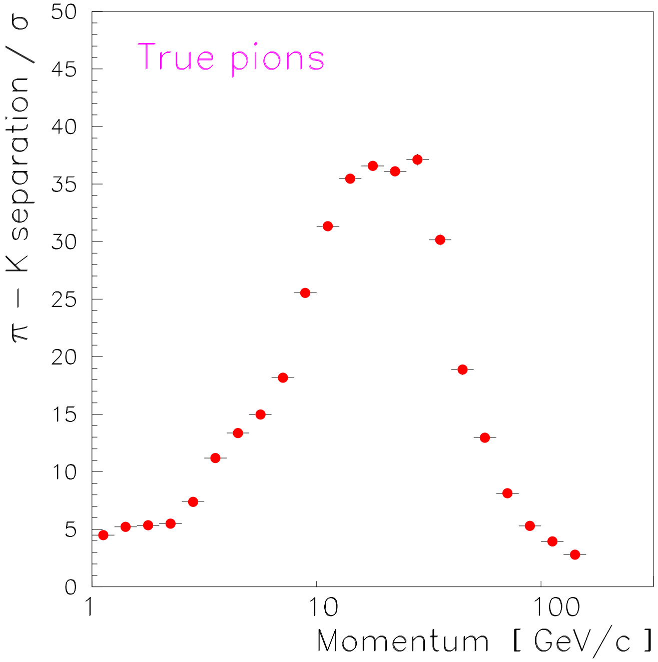






	Aerogel	C4F10	CF4
π threshold	0.6 GeV/c	*2.6 GeV/c*	*4.4 GeV/c*
K threshold	*2.0 GeV/c*	*9.3 GeV/c*	*15.6 GeV/c*

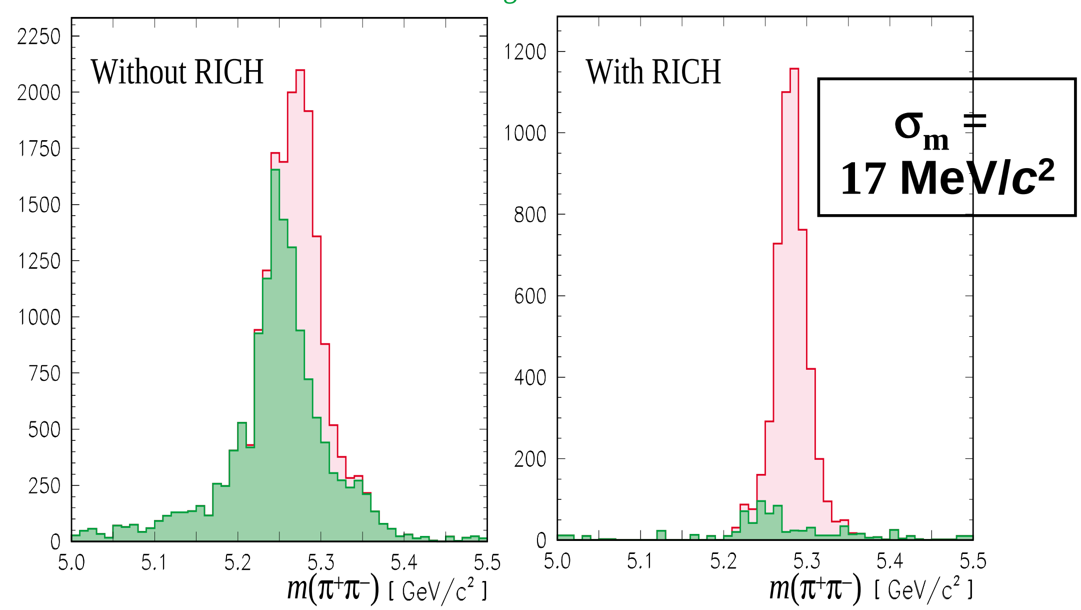
Reducing background in $B_d \rightarrow \pi^+\pi^-$



$B_d \rightarrow \pi^+\pi^- \sim 0.8\times10^{-5}$, $\rightarrow K^\pm\pi^\mp = 1.5\times10^{-5}$

$B_s \rightarrow K^+K^- = 1.5\times10^{-5}$, $\rightarrow K^\pm\pi^\mp = 0.7\times10^{-5}$

eff. = 85%



3σ separation for
1 < p < 150 GeV/c

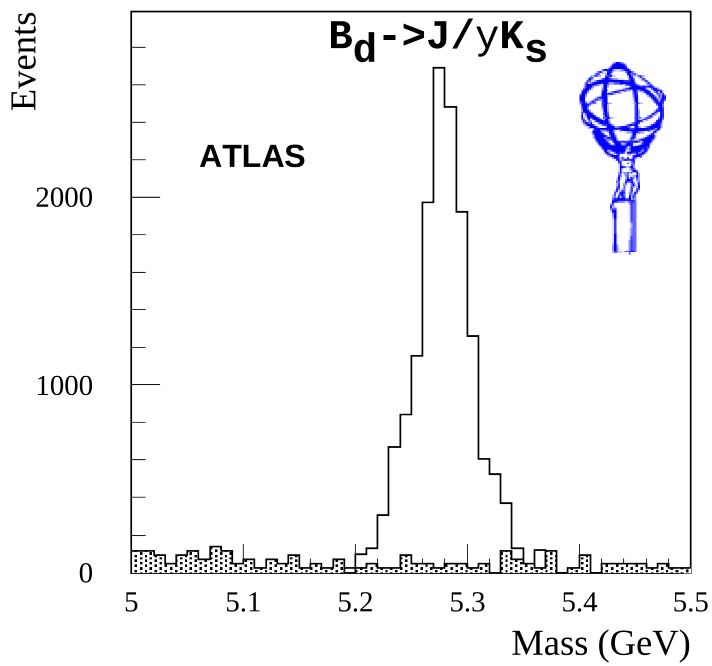
BTeV : One RICH
3 < p < 70 GeV/c

Softer B momentum spectrum

$B_d \rightarrow J/\Psi\, K_s$ decay

Pure mixing:

$$A(t) = \frac{N(B_d^0 \to J/\psi K_s^0) - N(\overline{B}_d^0 \to J/\psi K_s^0)}{N(B_d^0 \to J/\psi K_s^0) + N(\overline{B}_d^0 \to J/\psi K_s^0)} = -\sin(2\beta)\sin(\Delta m t)$$



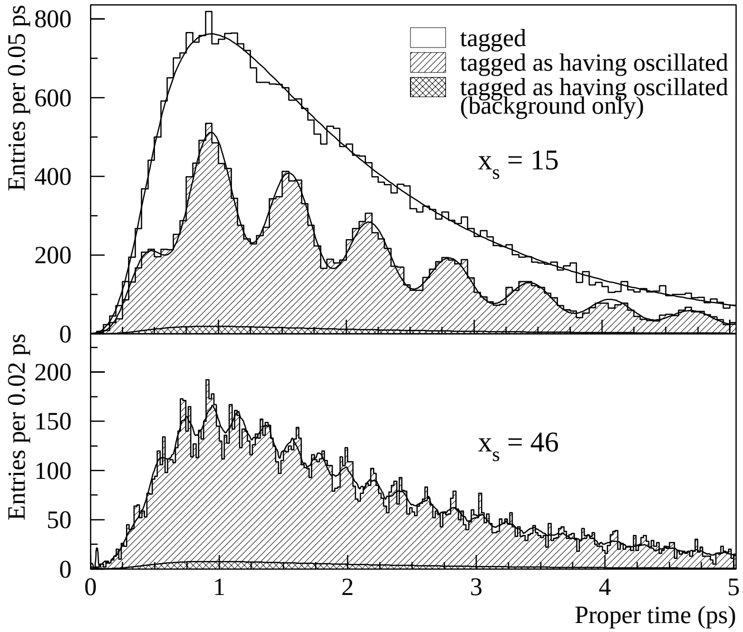
Here the General Purpose Detectors compare quite well with the forward detectors (high p_T muon triggers).

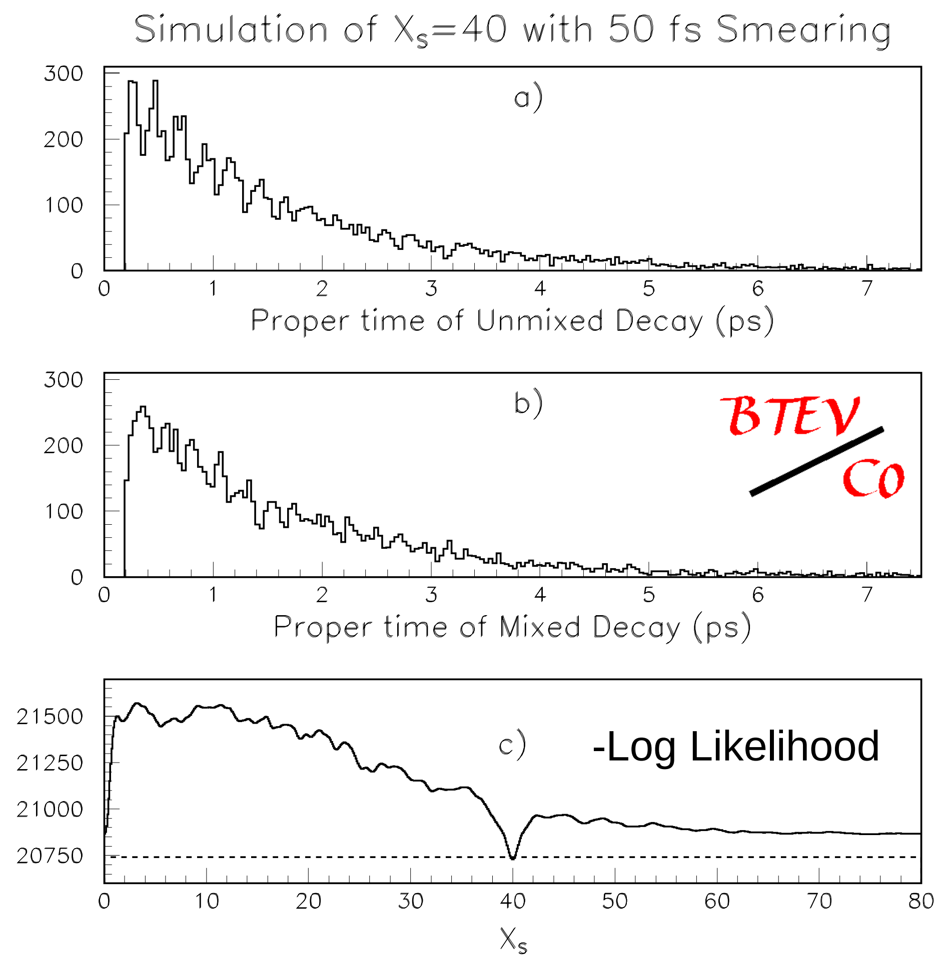
Sensitivities per year :

	σ(sin 2β)
BTeV	0.021
LHCb	0.011 to 0.017
ATLAS	0.021
CMS	0.025

Xs Reach

$B_s \rightarrow D_s^- \pi^+ , \bar{B}_s \rightarrow D_s^+ \pi^-$





	Xs reach (10^7s/year)
BTeV	60
ATLAS	*46*
CMS	*48*
LHCb	*75*

$B_d^0 \rightarrow D^0 K^{*0}$ decay

Determination of γ from the measurement of 6 time-integrated decay rates :

$B_d \rightarrow D^0 K^{*0}$, $B_d \rightarrow \overline{D}^0 K^{*0}$, $B_d \rightarrow D^0_{CP=+1} K^{*0}$

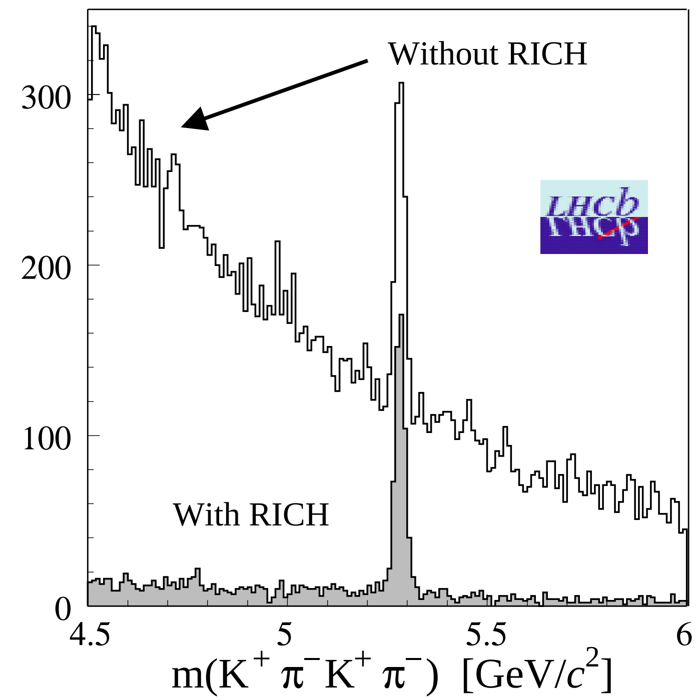
$\overline{B}_d \rightarrow \overline{D}^0 \overline{K}^{*0}$, $\overline{B}_d \rightarrow D^0 \overline{K}^{*0}$, $\overline{B}_d \rightarrow D^0_{CP=+1} \overline{K}^{*0}$

→ $K^+\pi^-$ → $K^-\pi^+$ → K^+K^-, $\pi^+\pi^-$

Visible BR's $\sim 10^{-8} \rightarrow 10^{-7}$

Measurement only possible with forward detector with particle ID (LHCb, BTeV)

$B_d \rightarrow \overline{D}^0 K^{*0}$ signal



LHCb sensitivity per year : $\sigma(\gamma) = 10^o$

$B^- \rightarrow D^0 K^-$ decay

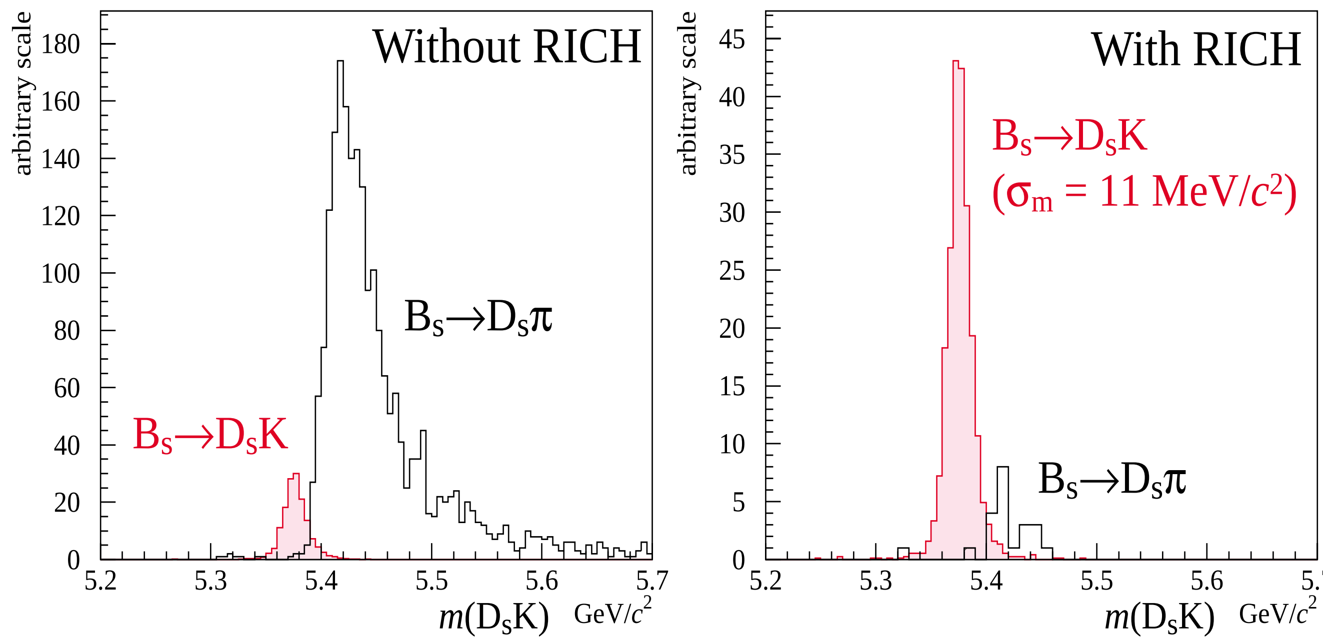
Determination of γ from the measurement of 9 time-integrated decay rates :

Interference of the decays $B^- \rightarrow D^0 K^-$, $B^- \rightarrow \overline{D}^0 K^-$ where D^0, $\overline{D}^0 \rightarrow$ same final state

BTeV sensitivity per year : $\sigma(\gamma) = 13^o$

$\overset{(-)}{B}{}_s^0 \to D_s^- K^+ , D_s^+ K^-$ decays

Measurement of $(\gamma - 2\delta\gamma)$ from the measurement of 4 time-dependent decay rates :



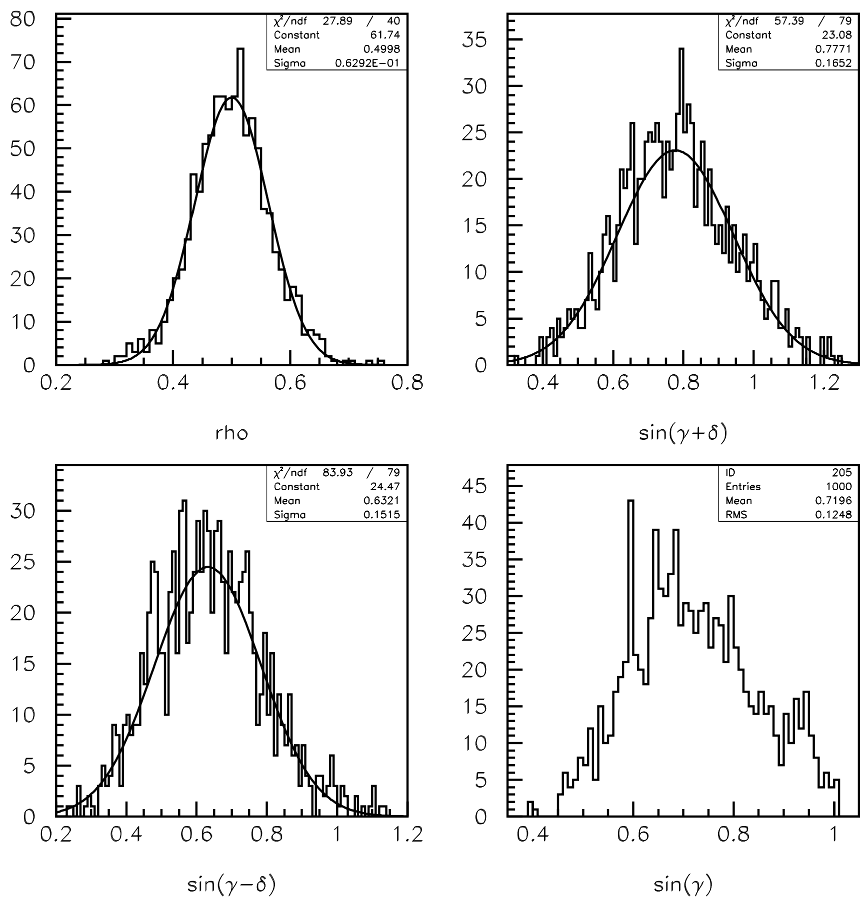
Sensitivities per year :

	$\sigma(\gamma-2\delta\gamma)$
BTeV	11°
LHCb	$6\text{-}13^{\circ}$

Depends on $\gamma-2\delta\gamma$ and strong phase diff.

Fitting γ in $B_s^0 \to D_s^- K^+$ (BTeV)

BTEV / CO



1000 “experiments”
Input values :

$\rho = 0.5$; $\sin(\gamma+\delta) = 0.771$;
$\sin(\gamma-\delta) = 0.629$; $\gamma = 45^{o}$

Result of fit :

$$\gamma = 46^{+11^{o}}_{-9^{o}}$$

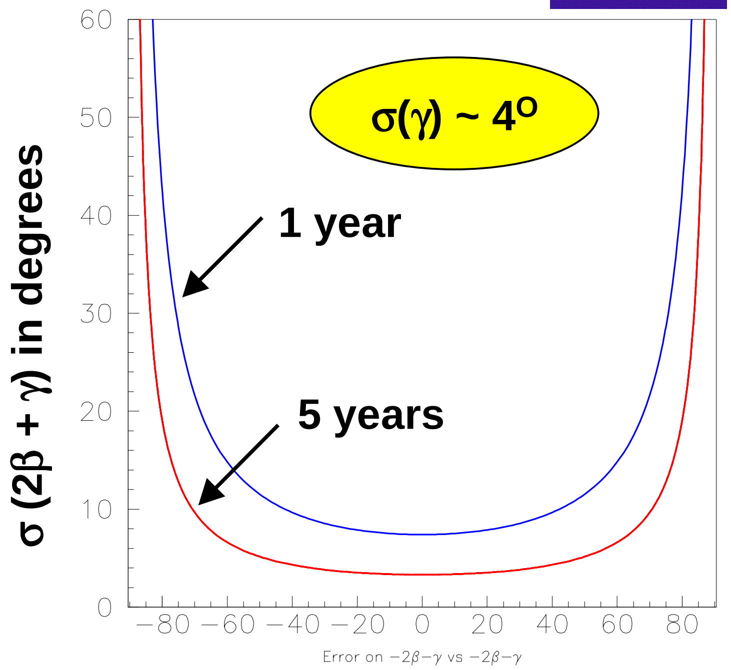
Estimated error on γ

Extraction of $(2\beta+\gamma)$

$B_d \rightarrow D^{*-}\pi^+ , D^{*+}\pi^-$

- **4 Time-dependent decay rates**
- **Relies on efficient hadron trigger**
- **Need large statistics (CP asymmetry very small)**

  - **Inclusive D* reconstruction ~ 270 k events/year with S/B~7**
  - **Add D^*a_1 channels ~ 320 k events/year**

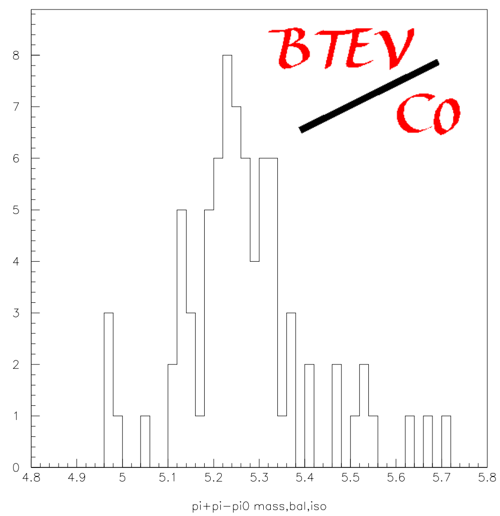


$(2\beta + \gamma)$ in degrees

No strong phase difference assumed

$B_d \rightarrow \rho\pi$ reconstruction

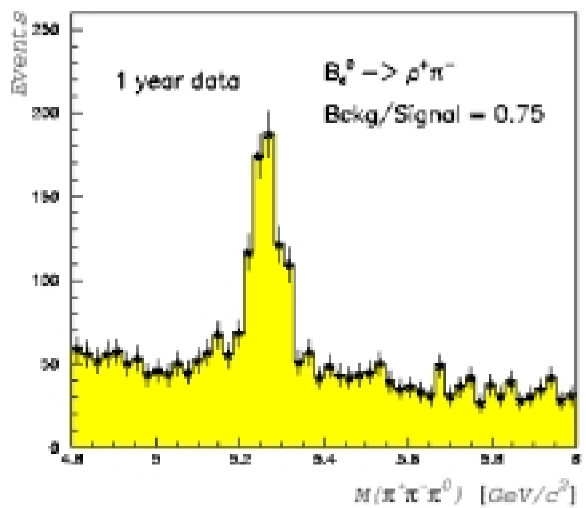
Measurement of the angle α

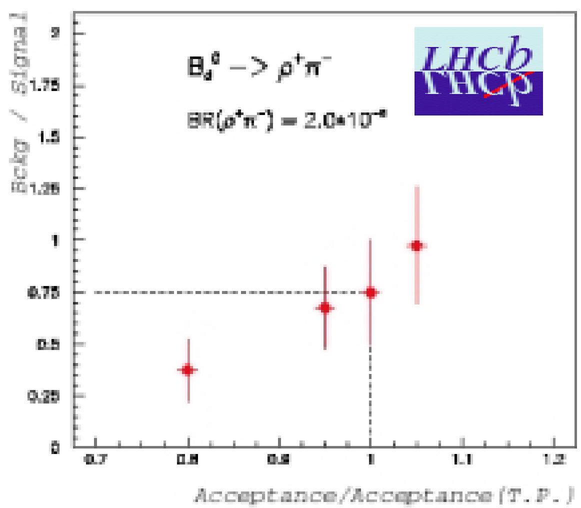


BTeV mass resolution $B_d^0 \rightarrow \pi^+\pi^-\pi^0$

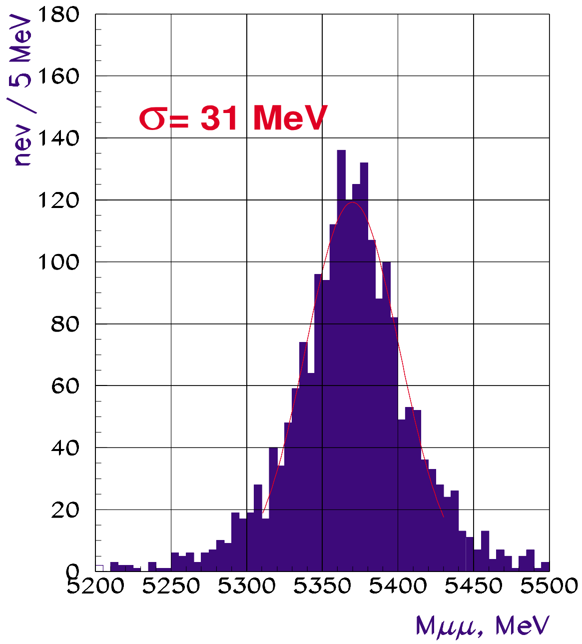
2800 tagged $B_d^0 \rightarrow \rho^+\pi^-$ events per year obtained

BTeV : lead tungstate calorimetry :
LHCb : Shashlik EM calorimetry :
~2% / sqrt(E) + 0.6%   vs. 10% / sqrt(E) + 1.5%





Rare decays



Muon trigger :
2 μ's with p_T > 4.3 GeV
$|\eta| < 2.4$

$$B_s \rightarrow \mu^+\mu^-$$

Standard Model BR ~ 3.5×10^{-9}

Here the General Purpose Detectors have an advantage : high p_T di-muon triggering at high (1×10^{34}) luminosity.

CMS : 100 fb^{-1} (10^7s at 10^{34} $cm^{-2}s^{-1}$) :
26 signal events
6.4 events background

Performance summary

Sensitivities per year :

Measurement	Channel	BTeV	LHCb	ATLAS	CMS
sin(2β)	**$B^0 \to J/\psi\ K_s^0$**	0.021	0.011 to 0.017	0.021	0.025
sin(2α)	**$B^0 \to \pi^+ \pi^-$** (assuming no penguin)	0.06	0.05	0.10	0.17
	$B^0 \to \rho\pi \to \pi^+ \pi^- \pi^0$			--	--
2β + γ	**$B^0 \to D^{*+} \pi^-$**		9^o	--	--
γ - 2δγ	**$B_s^0 \to D_s^- K^+$**	11^o	6^o to13^o	--	--
γ	**$B_d^0 \to D^0 K^*$**		10^o	--	--
γ	**$B^- \to D^0 K^-$**	13^o		--	--
δγ	**$B_s^0 \to J/\psi\ \Phi$**		0.6^o	0.9^o	
X_s	**$B_s^0 \to D_s^- \pi^+$**	< 60	< 75	< 46	< 48
Rare decays	**$B_s^0 \to \mu^+\mu^-$** (SM. BR. ~3.5×10^{-9})		4.4σ SM signal	4.3σ SM signal	10σ SM signal
	$B_d^0 \to K^* \gamma$	24k evts.	26k evts.	--	--

Summary

- The 2nd Generation CP-violation experiments will provide massive statistics : ~10^{12} $b\bar{b}$ pairs per year.

- LHCb/BTeV will provide :
  - Efficient B triggers
  - Excellent proper time resolution (σ_t ~ 40 - 50 fs)
  - Particle ID.

- The experiments will measure precisely the angles and the sides of the Unitarity Triangle.

A unique opportunity to understand origin of CP violation in framework of SM and BEYOND !