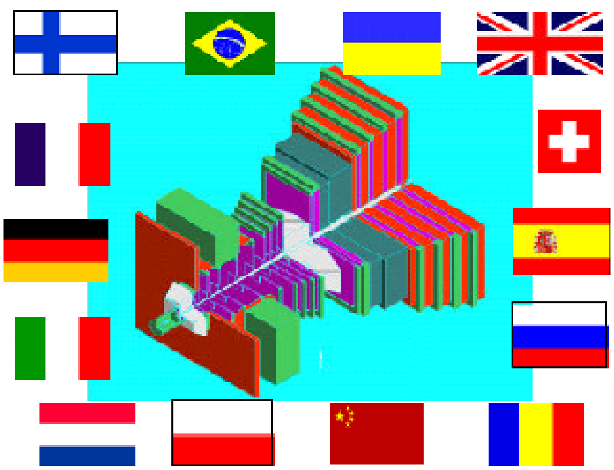
The *LHCB* Experiment
Precise CP Violation Measurements and Rare Decays



Outline
- Motivation
- The LHCb detector
- Physics performance
- Conclusions

João R. T. de Mello Neto

Universidade Federal do Rio de Janeiro

HQ 2k

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Motivations

CP violation is one of the fundamental phenomena in particle physics

CP is one of the less experimentally constrained parts of SM

SM with 3 generations and the CKM ansatz can accomodate CP

CP asymmetries in the B system are expected to be large.

Observations of CP in the B system can:

test the consistency of SM

lead to the discovery of new physics

Cosmology needs additional sources of CP violation other than what is provided by the SM

Standard Model: CKM matrix

The quark electroweak eigenstates are connected to the mass eigenstates by the CKM matrix :

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

phenomenological applications: Wolfenstein parameterization

$$= \begin{pmatrix} 1-\lambda^2/2 & \lambda & -|V_{ub}|e^{-i\gamma} \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ -|V_{td}|e^{-i\beta} & |V_{ts}|e^{i\delta\gamma} & 1 \end{pmatrix}$$

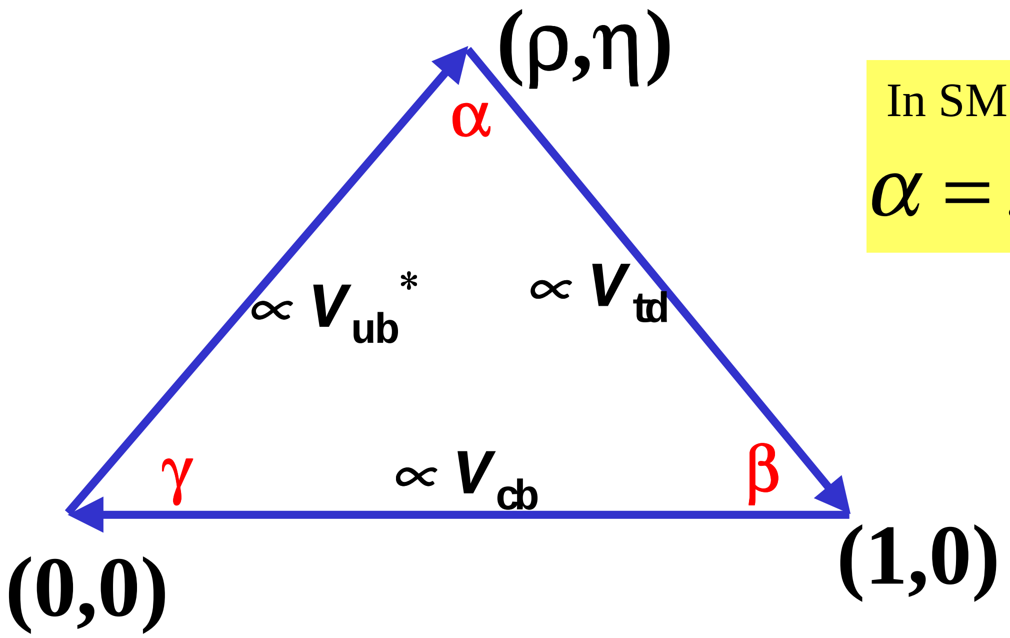
$B_d - \overline{B}_d$ mixing phase

$B_s - \overline{B}_s$ mixing phase

Weak decay phase

Unitarity triangles

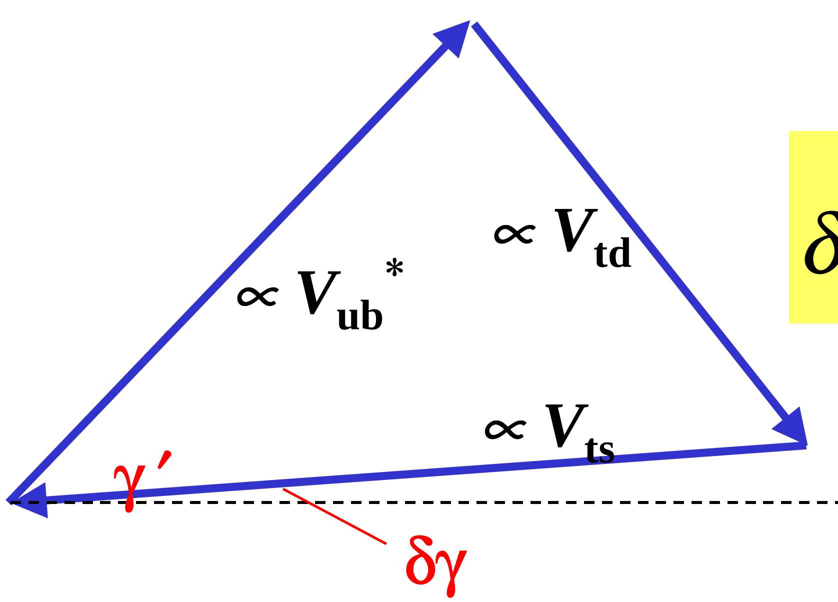
$$V_{td}\,V_{tb}^{*}+V_{cd}\,V_{cb}^{*}+V_{ud}\,V_{ub}^{*}=0$$



In SM:

$$\alpha=\pi-\beta-\gamma$$

$$V_{td}\,V_{ud}^{*}+V_{ts}\,V_{us}^{*}+V_{tb}\,V_{ub}^{*}=0$$



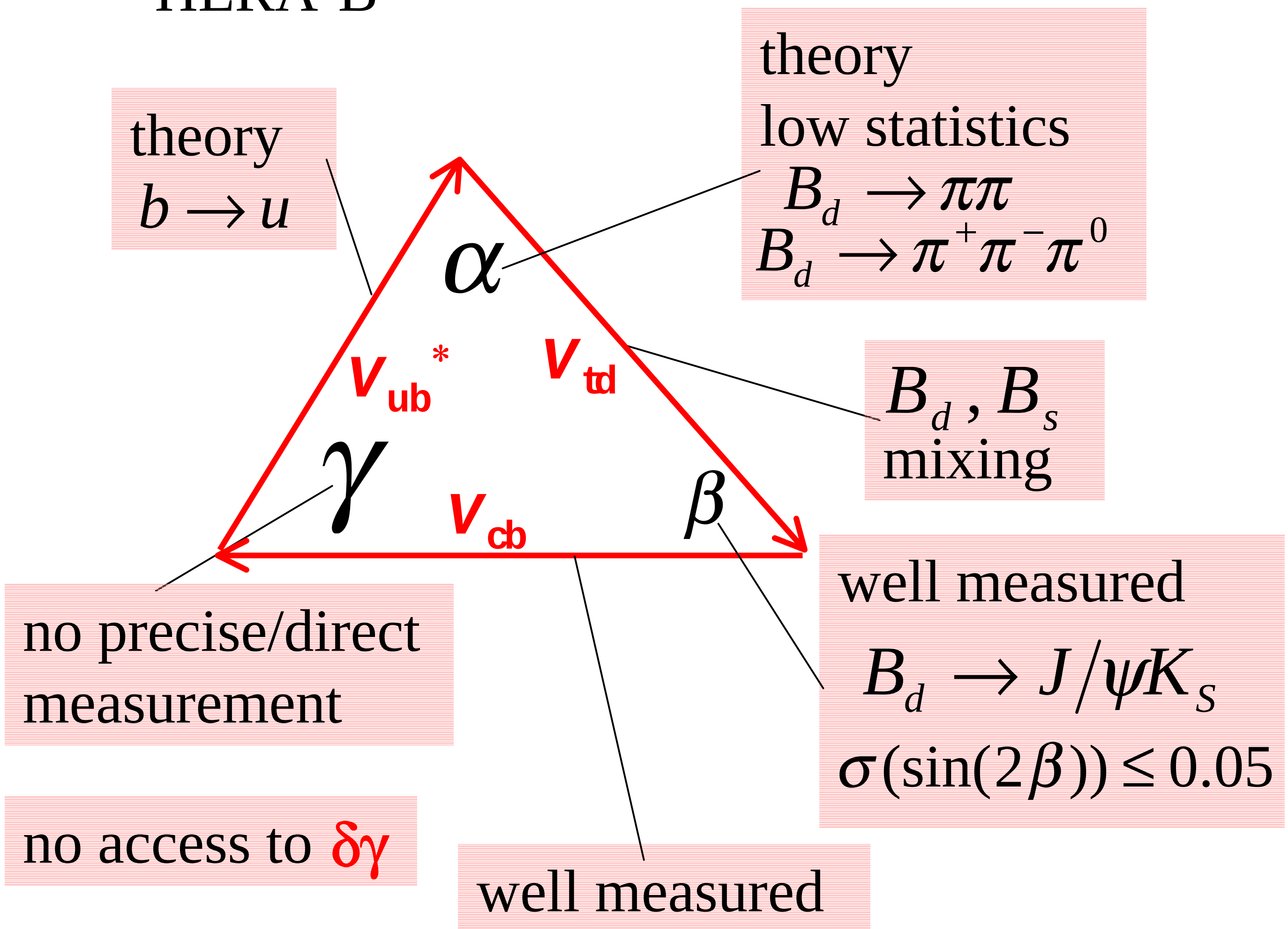
In SM:

$$\delta\gamma=\lambda^{2}\eta\approx 0.03$$

Measurements before LHCb

BaBar, Belle
CDF, D0
HERA-B

Will establish significant evidence for CP violation in the B sector



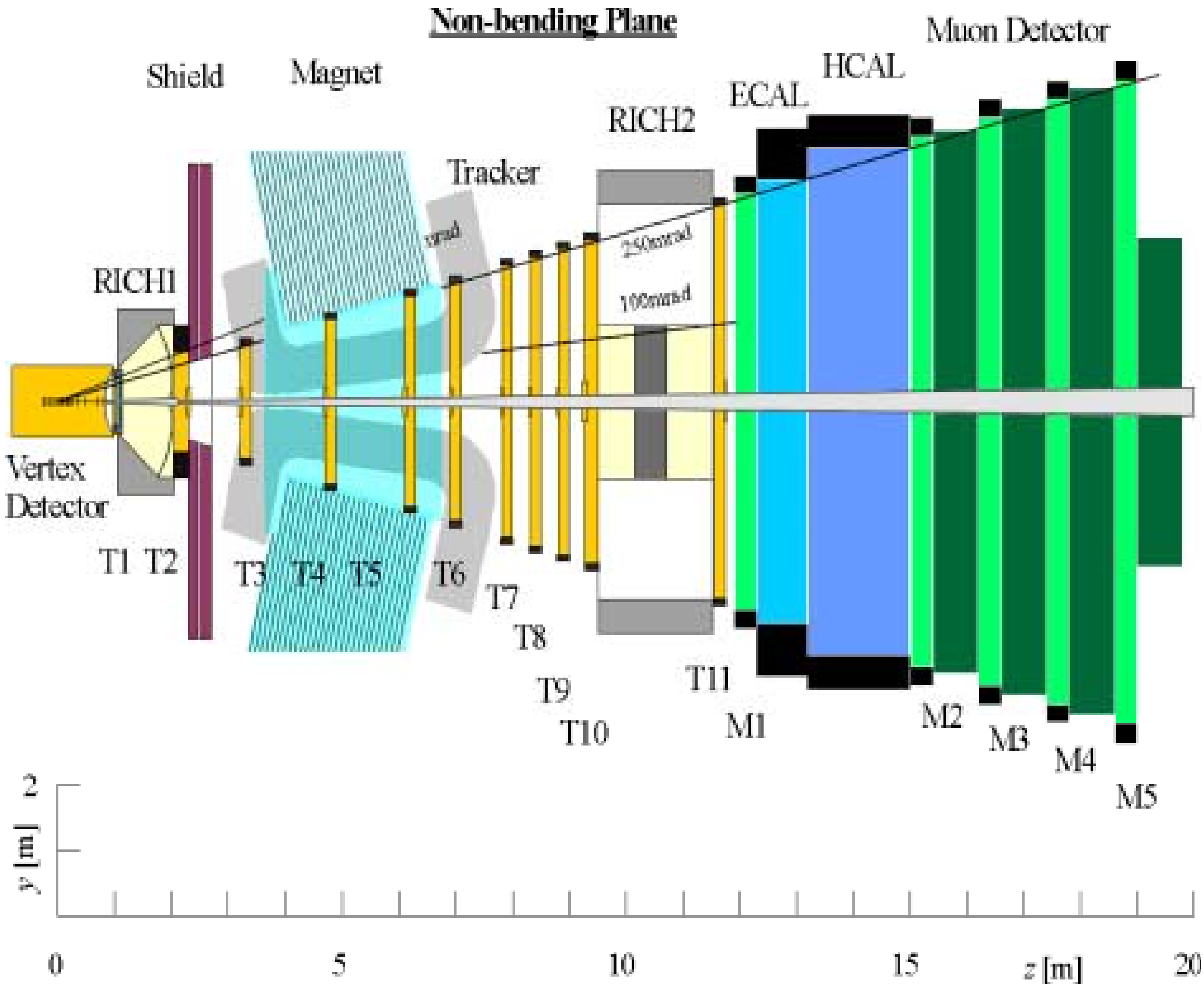
Constraints from the unitarity triangle:

- consistency with the SM (within errors)
- inconsistency with the SM (not well understood)

Next generation of experiments:

- precise measurements in several channels B_d, B_s
- constrain the CKM matrix in several ways

The LHCb Detector



15 mrad < θ < 300 mrad

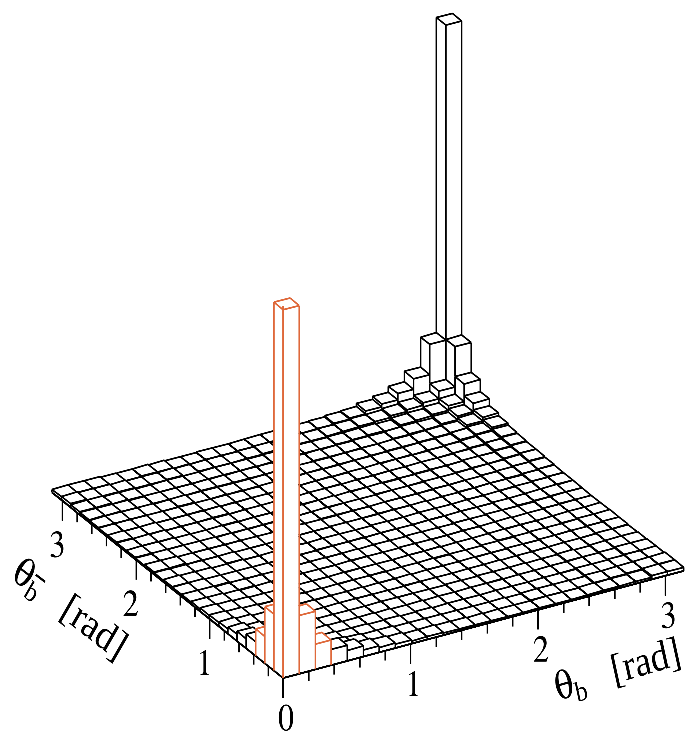
Beam-pipe, radiation

Cost X statistics

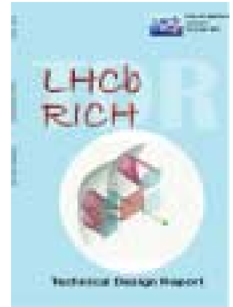
b quark pair produced preferentially at low θ

40% acceptance of pair tagging

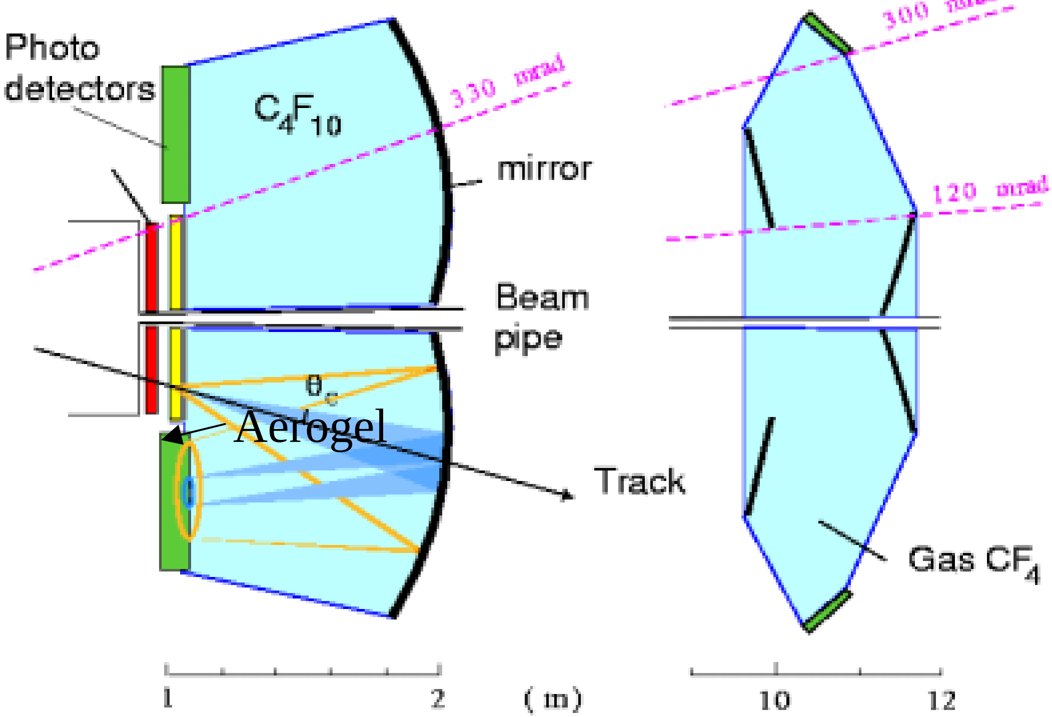
low pt cuts

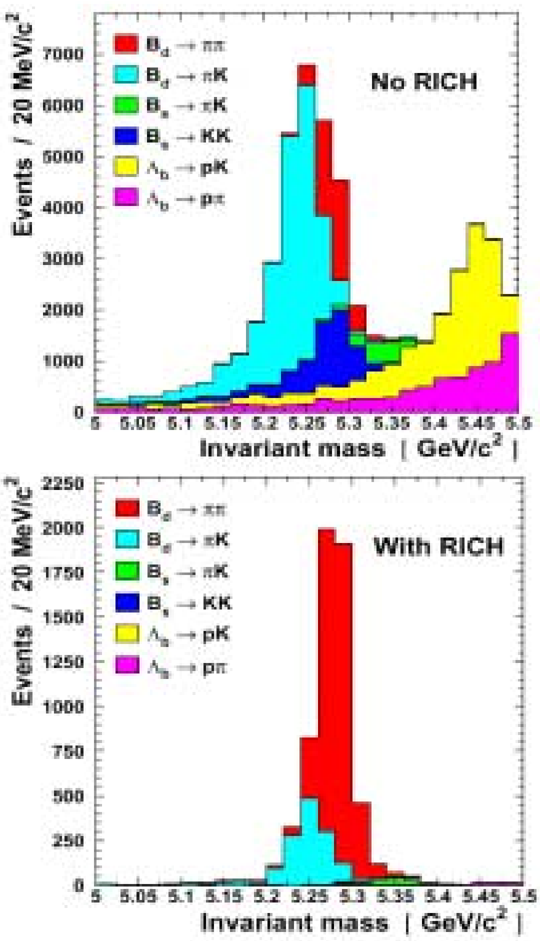


RICH



Essential for hadronic PID



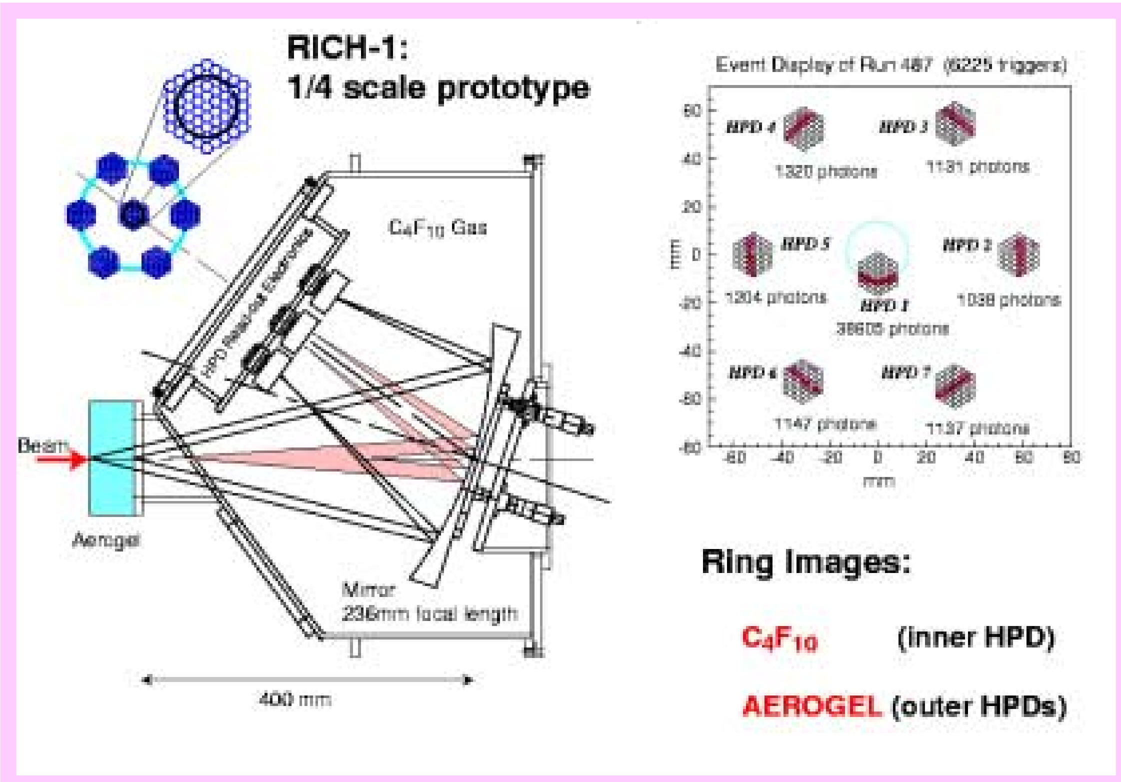


K–π separation > 3 σ
2<p< 100 GeV/c

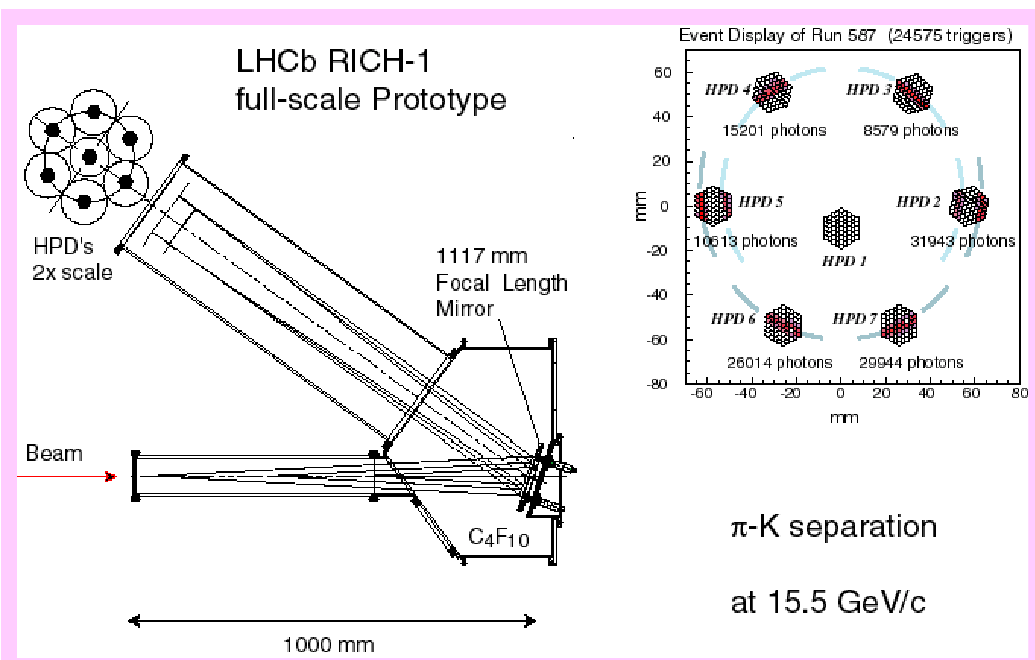
flavour tag with kaons
($b \to c \to K$)

background suppression two body B decay products

RICH Test beam



10 GeV/c
pion beam

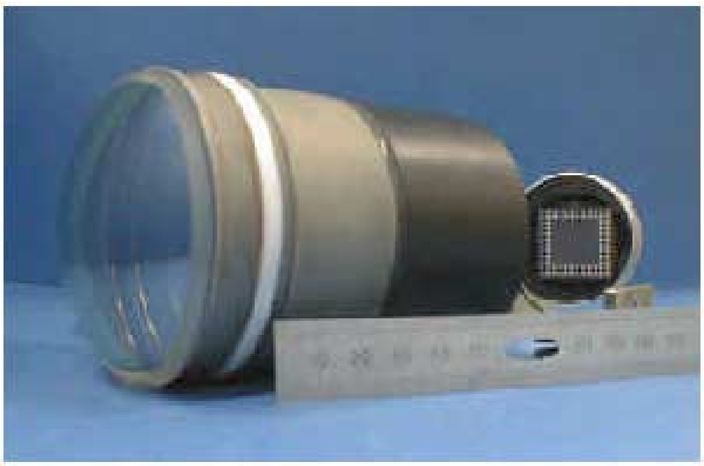


	RICH 1		RICH 2
radiator	Aerogel	C_4F_{10}	CF_4
lenght	5 cm	85 cm	167 cm
n	1.03	1.0014	1.0005
p_π thre. (GeV/c)	0.6	2.6	4.4
p_K thre. (GeV/c)	2.0	9.3	15.6
$\sigma(\theta)$ (mrad)	2.0	1.45	0.58
N pe	6.6	32.7	22.5

RICH HPD

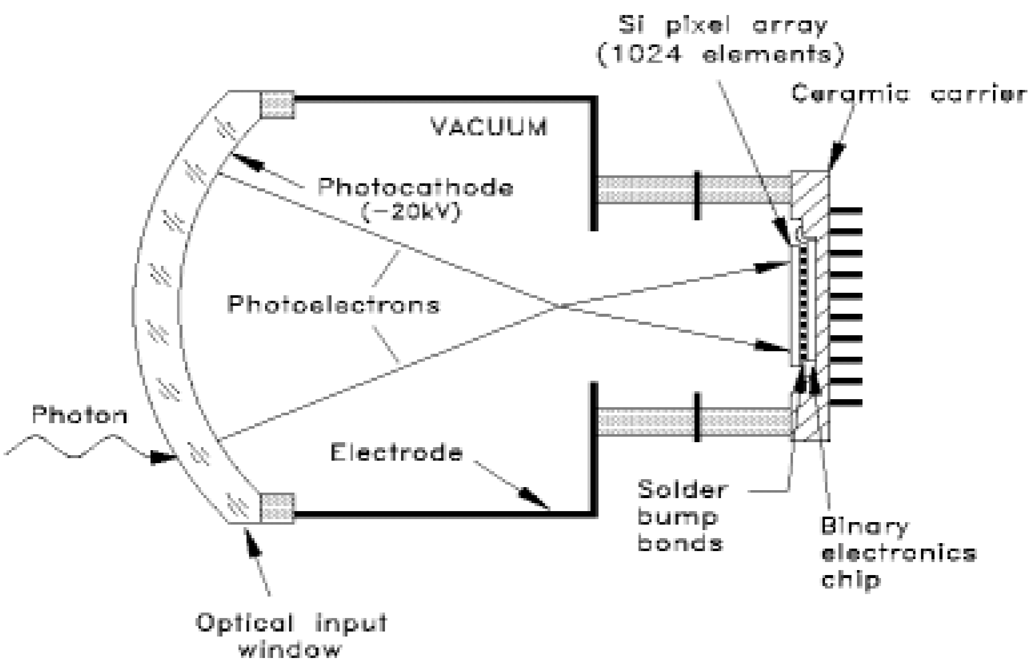
Requirements: 3 m^2 area, 2.5 x 2.5 mm^2 granularity
single photon sensitivity, high Q.E.

Pixel Hybrid PhotoDiode



CERN
DEP (The Netherlands)

diameter: 80 mm
ceramic pin grid array



- 1024 (500μm x 500 μm) Si pixel sensor bump bonded to binary readout electronics (ALICE chip)
- 70% active area coverage (~450 tubes, ~325K channels)

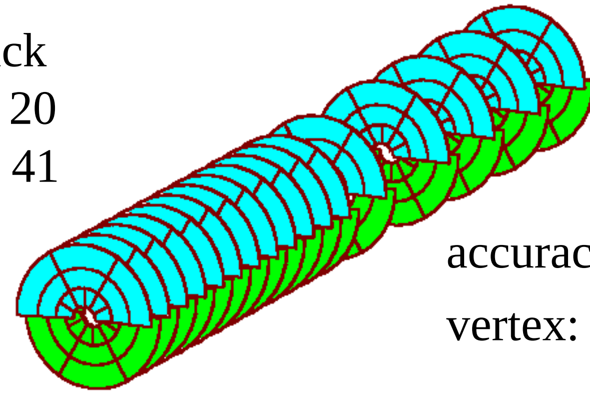
Backup solution: Multianode Photo Multiplier Tube

VErtex LOcator

TDR May 2001

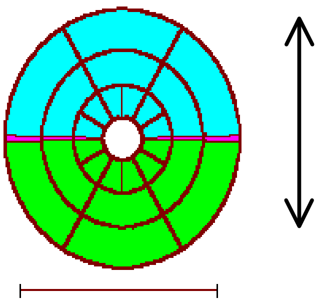
17 Si detectors

- alternate R and ϕ strips
- single sided 220 μm thick
- varying strip pitch from 20 to 40 μm in R and from 41 to 98 μm in ϕ
- 9.5 hits/track

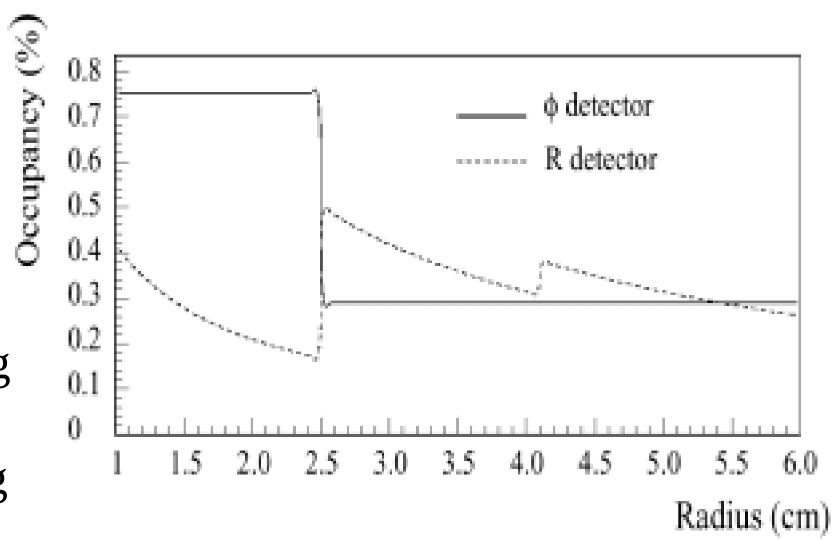


accuracy on primary vertex: **40 μm**

S/B=15



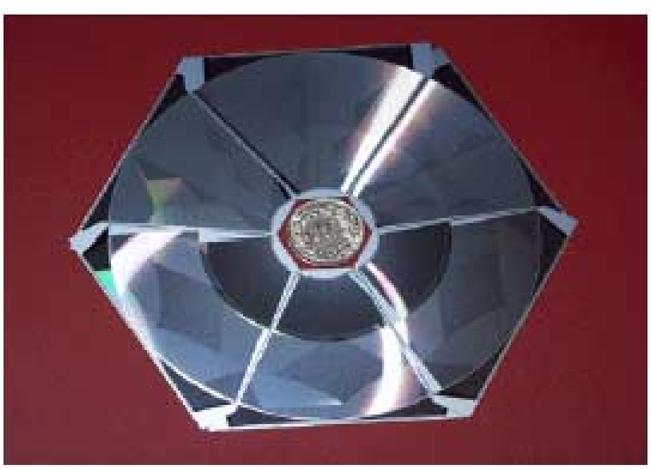
10 cm



Inside beam pipe:

- roman pots
- 8 mm from beam during physics
- retract by 30 mm during beam setup

220000 channels



Prototype: R and ϕ

Decay time resolution:

$$B_s^0 \to D_s K \ (\pi)$$

$$\sigma_t = 43 \text{ fs}$$

$$B_s^0 \to J/\psi\varphi$$

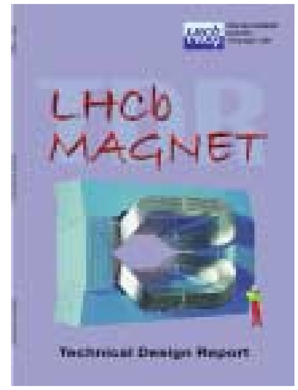
$$\sigma_t = 30 \text{ fs}$$

Magnet and Tracker

Magnet

TDR **approved**

Normal conductor (Al)
BDL = 4 Tm
Power : 4.2 MW
Yoke 1450t



ease the reversal of magnetic field

- study of possible systematic bias
- non-uniformity of detector eff.

Tracker: high particle density near the beam axis

Inner: (40x60 cm^2) triple GEM ,
Si stations

TDR Sept. 2001

TDR March 2001

Outer: straw-tube drift chambers

$$\frac{\sigma_p}{p} = 0.3\%$$

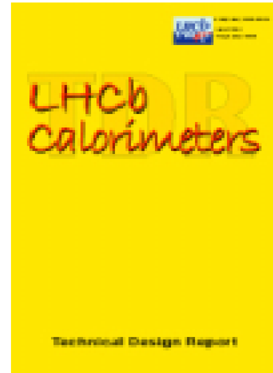
5 - 200 GeV/c

mass resolution:

$$B_d^0 \to \pi\pi \qquad \sigma_m = 15\ \mathrm{MeV/c^2}$$

$$D \to KK\pi \qquad \sigma_m = 4\ \mathrm{MeV/c^2}$$

Calorimeters and Muon



Calorimeter

Pre-shower sandwich Pb - scintillators

ECAL Shashlik type, 25 X_0

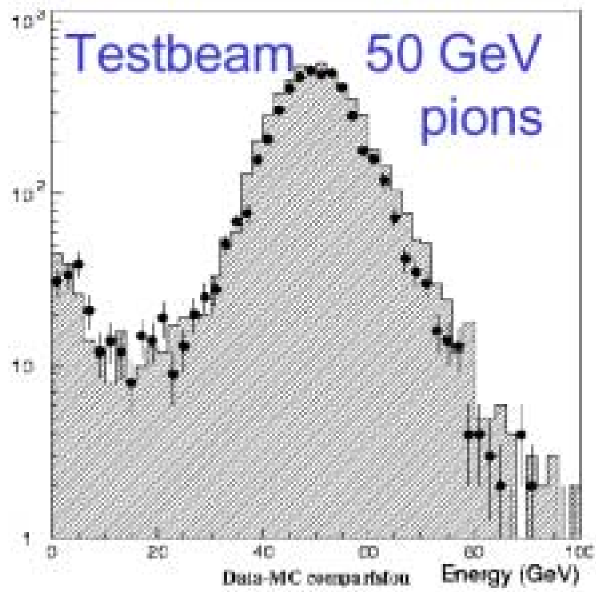
HCAL Fe + scintillating tiles, 5.6λ

R/O by wave-length shifting fibers and PMTs

Energy resolution:

$$\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E}} \oplus 1.5\%$$

$$\frac{\sigma(E)}{E} = \frac{80\%}{\sqrt{E}} \oplus 5\%$$



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Muon

Resistive Plate Chambers (RPC) for moderate flux regions

- time res. 1.3 ns with eff. > 99 in 10 ns time window
- rate capability achieved

Multi Wire Proportional Chamber (MWPC) with anode and/or cathode read out for high flux regions

- time res. < 3 ns with eff. > 99% in 20 ns time window
- perform very well up to rates greater than 100 kHz / cm^2

Trigger

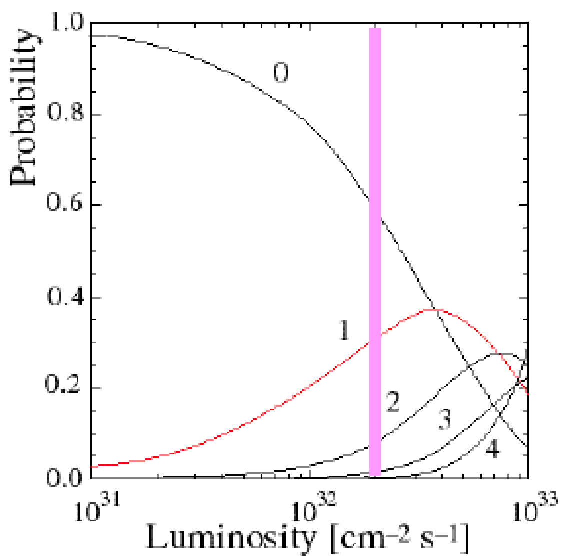
LHC 40MHz

$\sigma_{b\bar{b}}$ ~ 500 μb

$\sigma_{inelast.} / \sigma_{b\bar{b}}$ ~160

TDR January 2002

- efficient
- highly selective
(small branching ratios)



optimal operating point
- number **single** pp colisions
- radiation damage, detector ocupancy, bunch-bunch pile-up, etc.

average running luminosity

2×10^{32} cm^{-2} s^{-1} tuneable

40 MHz

L0

high p_t μ

high p_t e γ

high p_t h

pile-up

muon system

calorimeters

1 MHz

L1

sec vertices

high p_t

Vertex locator

40 kHz

L2/3

refined sec vertices

partial and full reconst. final states

Full detector

200 Hz

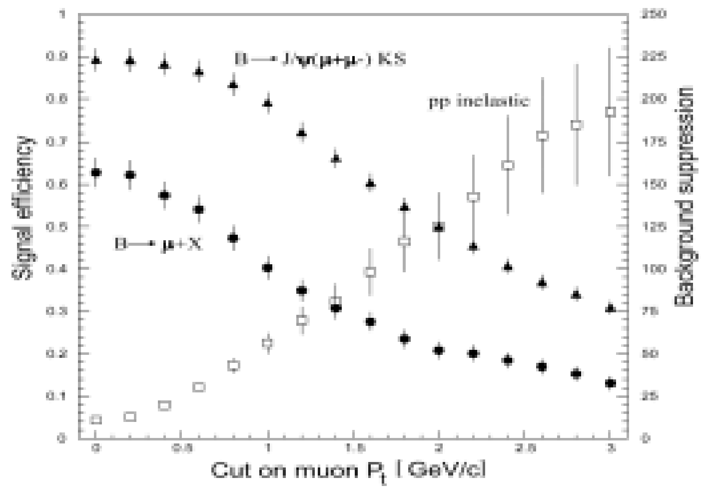
20 Mbytes/s

Trigger

Efficiency reconstructed correctly tagged events	L0(%) μ	L0(%) e	L0(%) h	L0(%) all	L1(%)	L2(%)	Total(%)
$B_d \to J/\psi(ee)K_S$ + tag	17	**63**	17	72	42	81	**24**
$B_d \to J/\psi(\mu\mu)K_S$ + tag	**87**	6	16	88	50	81	**36**
$B_s \to D_s K$ + tag	15	9	**45**	54	56	92	**28**
$B_d \to DK^*$	8	3	**31**	37	59	95	**21**
$B_d \to \pi^+\pi^-$ + tag	14	8	**70**	76	48	83	**30**

trigger efficiencies are ~ 30%

Improvements: L1 will take into account L0 info to take a new decision: will increase efficiency μμ channels



tags (up to now):

μ or **e** from other b-hadron

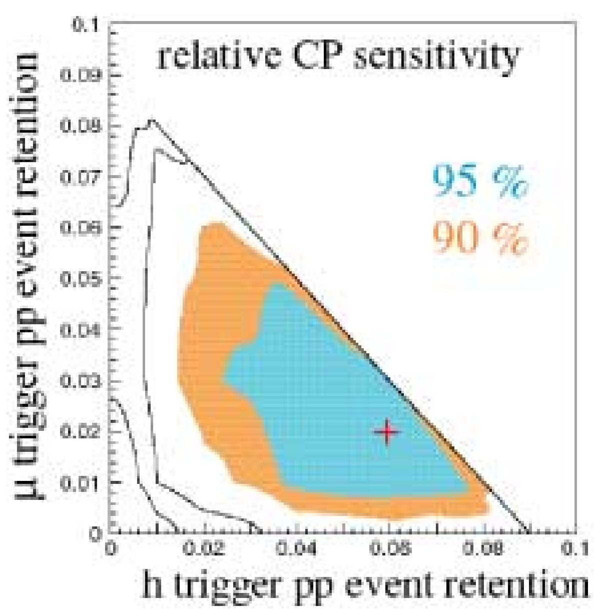
charged **K** from other b-hadron

overall tag efficiency = 40%

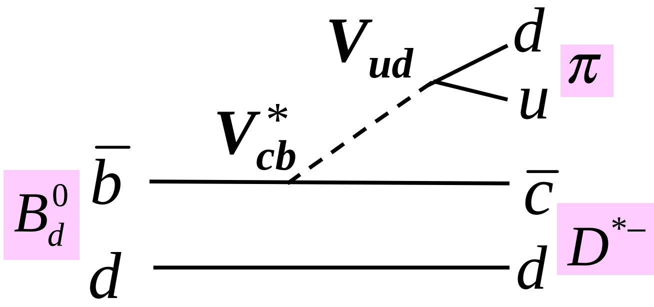
overall mistag rate = 30%

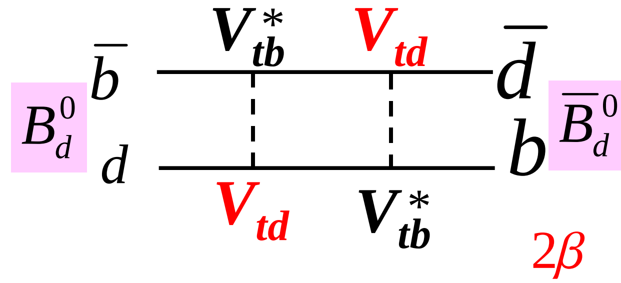
Strategy:

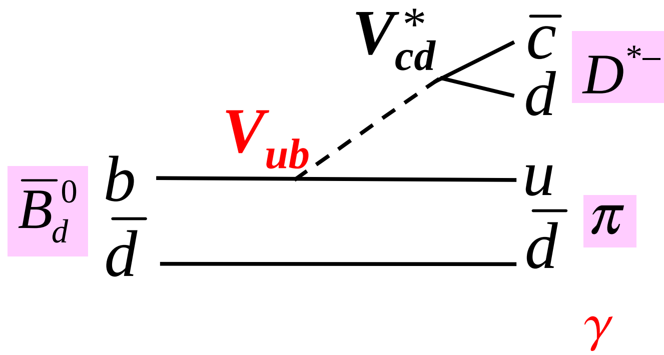
- even selectivity over all levels
- the operating point can be adjusted to the running condition without loss in physics
- does not rely on a particular single component



$2\beta+\gamma$ $\quad B_d^0 \to D^{*-}\pi^+$







four time dependent decay rates:

$$B_d^0 \to D^{*-}\pi^+ \qquad \bar{B}_d^0 \to D^{*-}\pi^+$$
$$\to D^{*+}\pi^- \qquad \to D^{*+}\pi^-$$

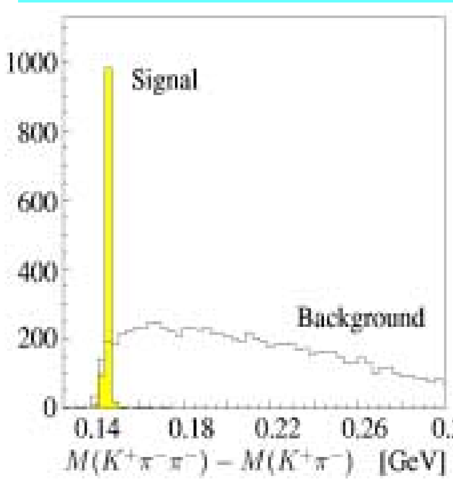
no penguin diagrams:
clean det. of γ

small asymmetry:
V_{ub} suppressed

two asymmetries
- weak phase
- strong phase difference between tree diagrams

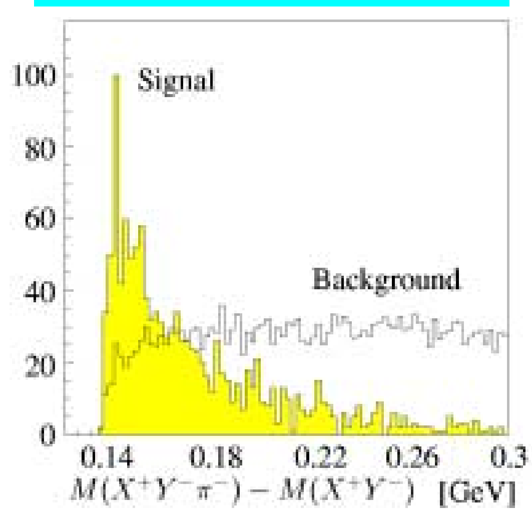
exclusive $D^*\pi$ reconstruction

~ 83k / year S/B ~ 12



inclusive $D^*\pi$ reconstruction

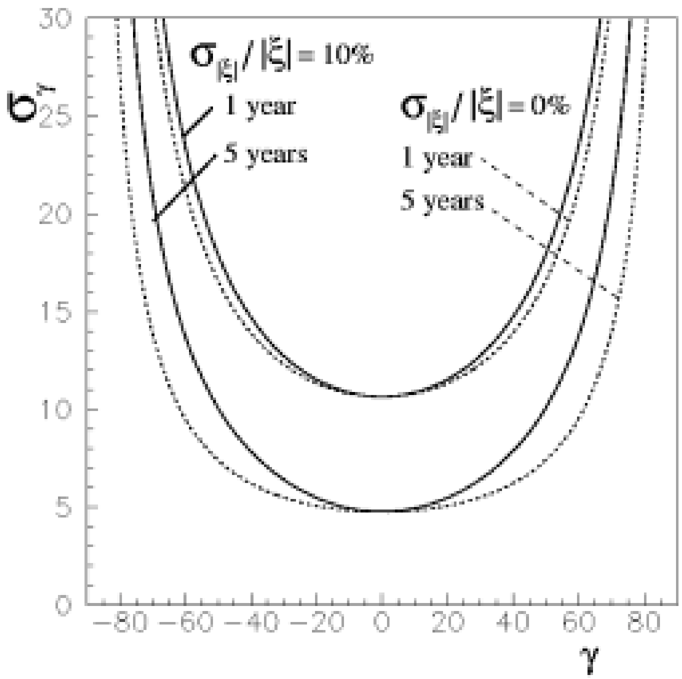
~ 260k / year S/B ~ 3



$2\beta+\gamma$ $B_d^0 \to D^{*-}\pi^+$

uncertainty due to:

$$|\xi| = \left|A(\overline{B}_d^0 \to D^{*+}\pi^-\right| \Big/ \left|A(B_d^0 \to D^{*+}\pi^-\right|$$

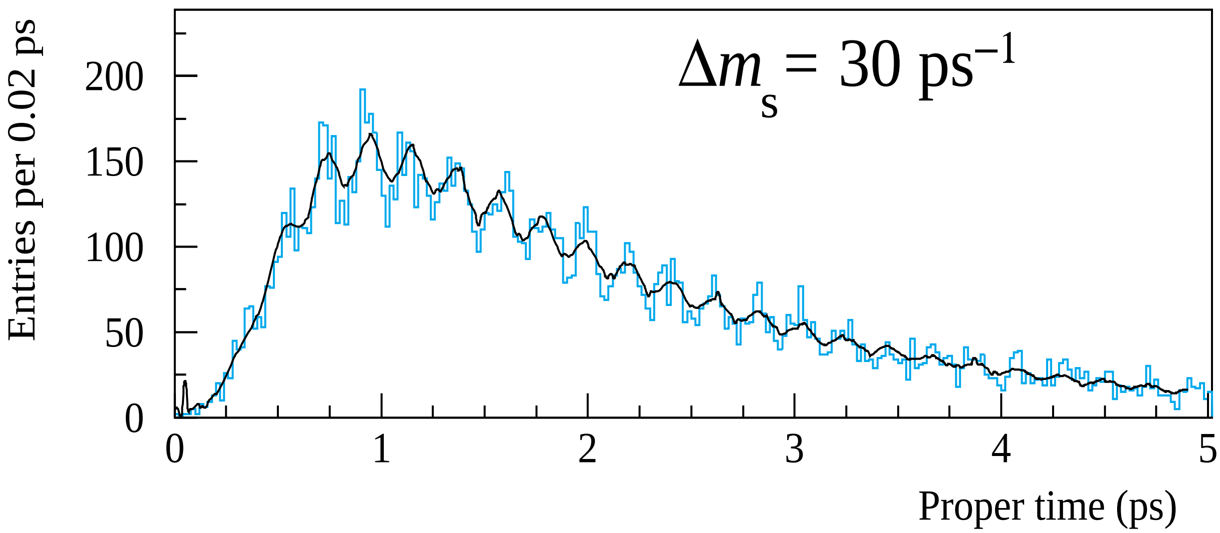


addition of $D^{*-}a_1$ channel: ~ 360k / year

requires full angular analysis

x_s $B_s^0 \to D_s^- \pi^+$

35 k/year tagged events



5σ measurements

$x_s = 75$ ($\Delta m_s =$ 48 ps^{-1})

also a precision measurement of $\Delta\Gamma_s / \Gamma$

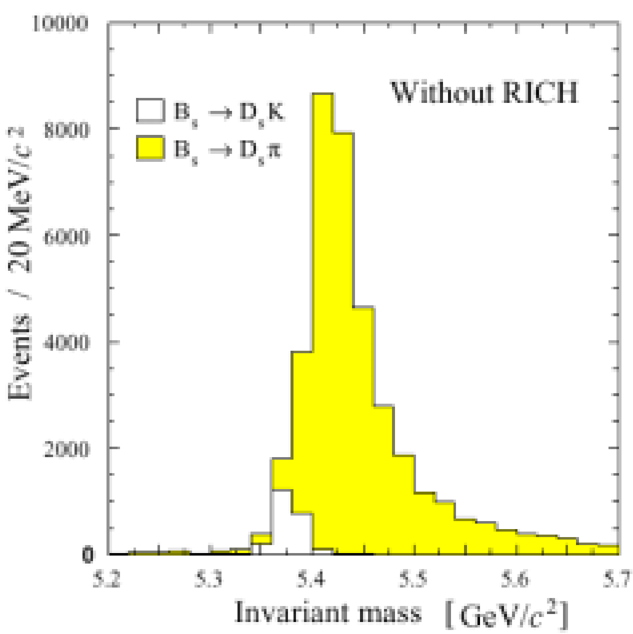
86k/year reconstructed events

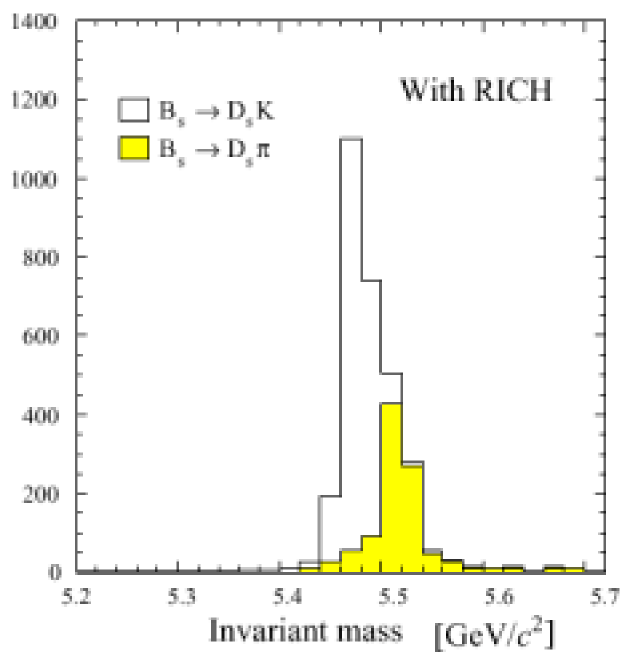
$\sigma(\Delta\Gamma/\Gamma) = 0.05$ $\Delta\Gamma_s / \Gamma = 0.16$

$\gamma - 2\delta\gamma$ $\quad B_s^0 \to D_s^{\pm} K^{\mp}$

Theoretically clean (no pinguins)

Hadron identification: $D_s \pi$ background





Sensitivity to $B_s^0 - \overline{B}_s^0$ oscillations: $\Delta\Gamma_s / \Gamma$, Δm_s

~ 2.5k / year

- reconstructed
- tagged

$\sigma(\gamma - 2\delta\gamma) = 8^o \quad \Delta m_s = 15\,\text{ps}^{-1}$

$\sigma(\gamma - 2\delta\gamma) = 12^o \quad \Delta m_s = 45\,\text{ps}^{-1}$

LHCb (partial) physics summary

Parameter	Channels	events	σ(1 year)	LHCb feature
α	$B_d \to \pi\pi$	5k		
	$\Delta\|P/T\| = 0$		2°-5°	PID, had trig
	$B_d \to \rho\pi$	1.3k	3°- 6°	PID, had trig
$2\beta+\gamma$	$B_d \to D^*\pi$	340k	> 5°	PID, had trig
$\sin(2\beta)$	$B_d \to J/\Psi K_s$	35k	0.021	
$\gamma-2\delta\gamma$	$B_s \to D_s K$	2.4k	6°-13°	PID, had trig, σ_t
γ	$B_d \to DK^*$	400	10°	PID, had trig
$2\delta\gamma$	$B_s \to J/\psi\phi$	370k	0.2°	σ_t
	x_s=20 , μ channel (5 years)			
Bs oscil.				
x_s	$B_s \to D_s\pi$	35k	(up to) 75	had trig, σ_t
Rare Decays				
	$B_s \to \mu\mu$	11	s/b=3.5	σ_t
	$B_d \to K^* \gamma$	26k	s/b=1	photon trigger

New methods for extracting CKM phases have been studied
CERN Yellow Report 2000-004

Other physics topics: B_c mesons, baryons, charm
tau, b production, etc

Conclusions

LHCb is a second generation beauty CP violation experiment

- massive statistics due to large σ_{bb}, efficient trigger for both hadron and lepton
- excelent particle ID
- excelent mass and decay time resolution

Evolving rapidly from the Technical Proposal

Magnet: TDR approved, tendering procedure completed
RICH and Calorimeter TDR's submited
Most of the other TDRs will be submitted in 2001

Construction phase is starting...

Ready to take data in the first day of LHC collision in 2005

LHCb: crucial contribution to the study of CP violation and other rare phenomena in the Standard Model and beyond