Workshop on

Standard Model Physics (and more) at the LHC

b physics production subgroup

CERN

14 January 1999

LHCb

" A Large Hadron Collider Beauty Experiment for Precision Measurement of CP Violation and Rare Decays "

G.Corti

Layout of the talk

General considerations

Luminosity, Acceptance, ...

The LHCb spectrometer

Simulation

Generator, Spectrometer

Vertex Detector

Main Tracking

Particle ID

Calorimeter, RICH

Tagging

Trigger

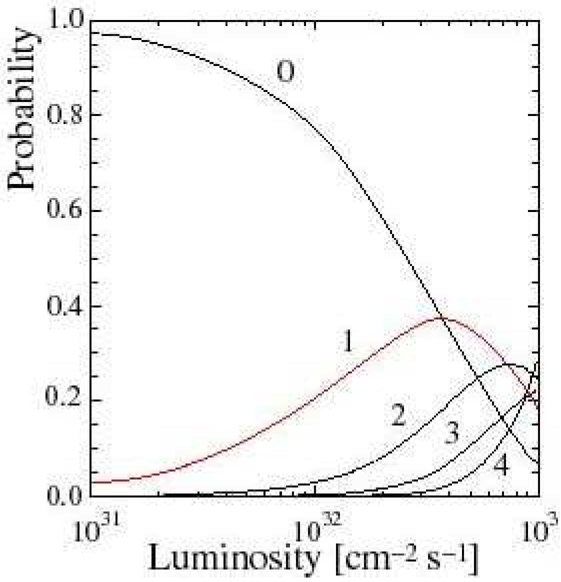
Exploit potential of LHC for b physics

$$\sigma_{b\bar{b}} = 500\,\mu\text{b}$$

At LHCb chosen running luminosity

$$L_{ave} = 2\,\text{x}\,10^{32}\,\text{cm}^{-2}\text{s}^{-1}$$

$$N_{b\bar{b}}^{prod} = 10^{12}\ /\ year$$



Number of bunch crossing with single pp interaction

Radiation Damage

Detector Occupancy

All B hadron species produced (B_s)

Many different decay channels, both hadronic and leptonic final states

Detector requirement/characteristics

Robust and flexible trigger for different b decays

High p_T hadrons

High p_T leptons

Displaced decay vertices

Good Mass resolution

Background

Good proper time resolution

Background

CP asymmetry in B_s

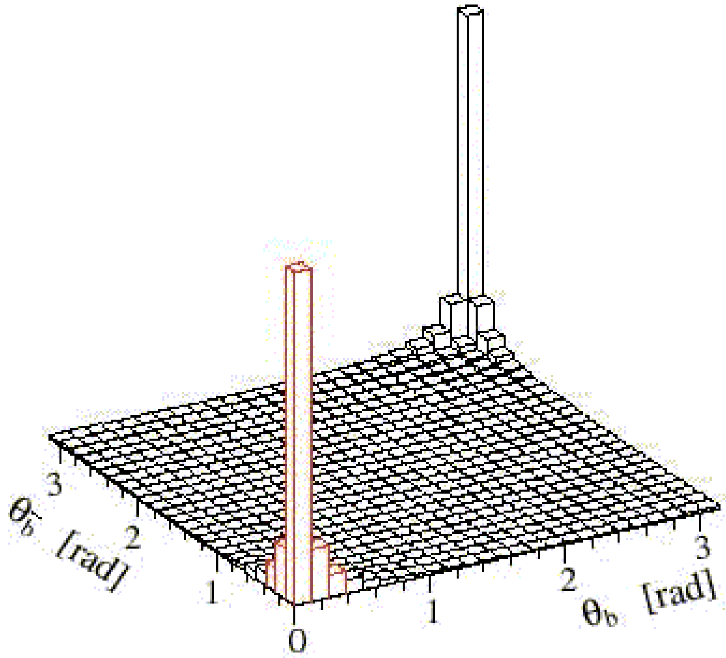
Particle Identification

Background (π / K separation)

Tagging (μ , e , K)

π^o reconstruction

Single arm forward spectrometer



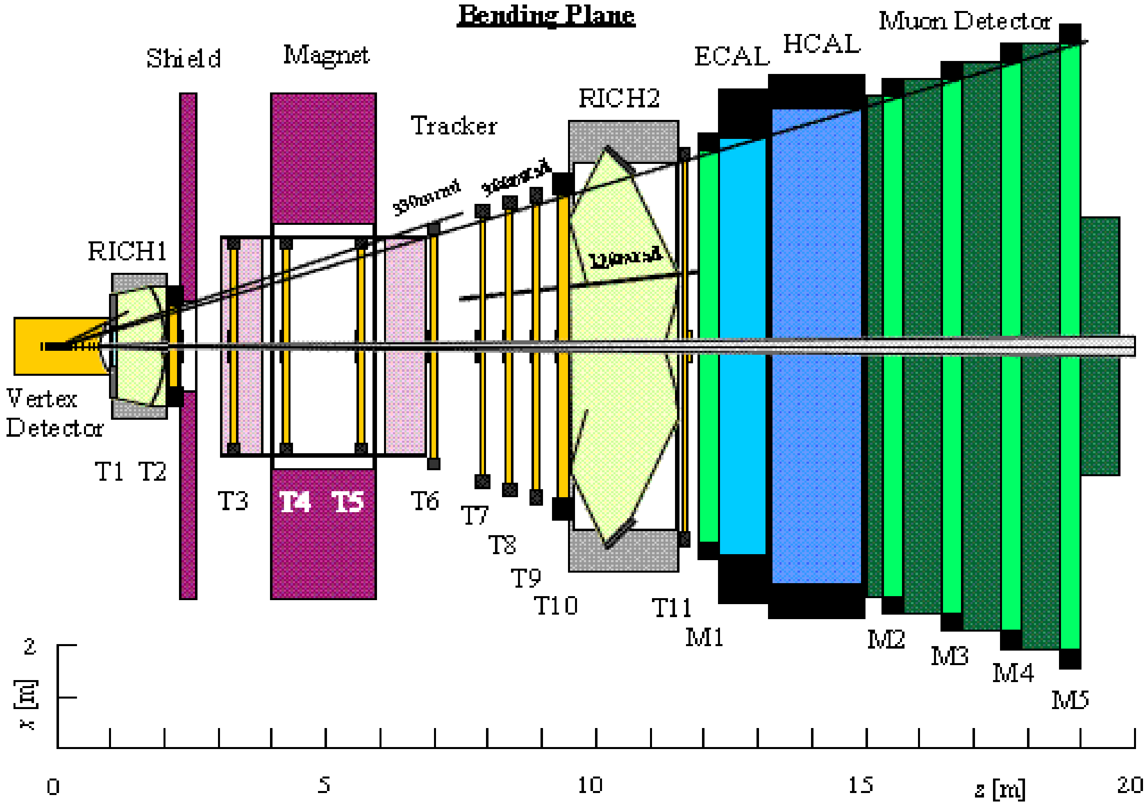
θ_{min} = ~15 mrad (beam pipe and radiation)

to

θ_{max} = ~300 mrad (cost)

i.e. η = ~1.88 to ~4.89

LHCb Detector



Vertex Detector: Silicon Microstrip

Main Tracking System:

MSGC or MCSC (inner) + Honeycombs (outer)

Muon: Cathode Pads and Multigap Resistive Pads

RICH system (3 radiators):

π - K separation at >3σ for

$1 \text{ GeV}/c < p < 150 \text{ GeV}/c$

(K tag) $(B_d \to \pi^+\pi^-)$

Calorimeters:

Preshower + ECAL (Shashlik) + HCAL(Scintillating-tile)

Generator for physics studies and optimizations

Pythia 5.72 / Jetset 7.4

Default values for parameters

Minimum bias events

MSEL = 1

$$f_i f_j \rightarrow f_i f_j$$

$$f_i \bar{f}_i \rightarrow f_k \bar{f}_k$$

$$f_i \bar{f}_i \rightarrow gg$$

$$f_i g \rightarrow f_i g$$

$$gg \rightarrow f_k \bar{f}_k$$

$$gg \rightarrow gg$$

b events

MSEL = 5

$$f_i \bar{f}_i \rightarrow Q_k \bar{Q}_k$$

$$gg \rightarrow Q_k \bar{Q}_k$$

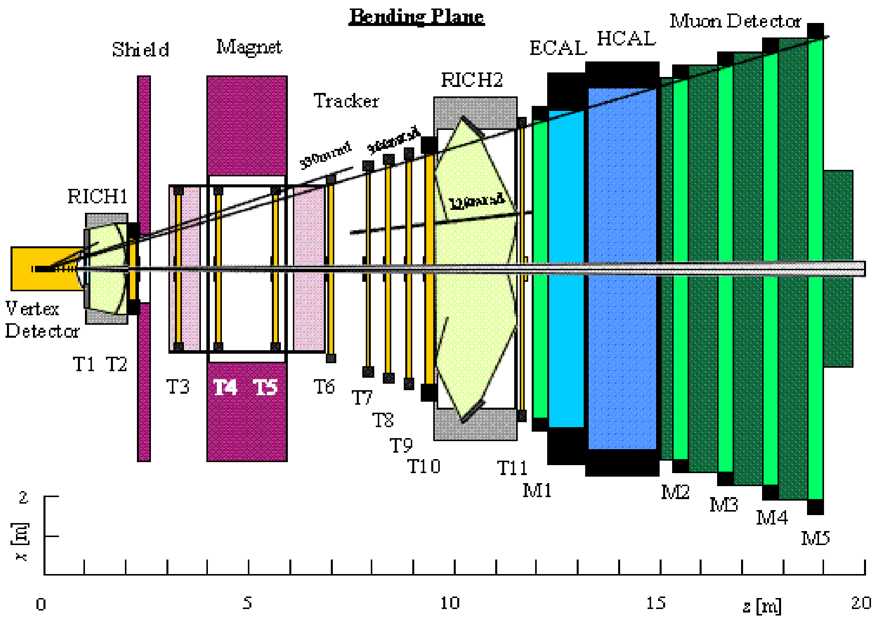
Detector description

GEANT 3.21

including all secondary interactions

Cuts: $e,\gamma = 1\,MeV$ HCAL, Shields: 500 MeV

$h,\mu = 10\,MeV$



All physics studies were performed with FULL GEANT

Physics background were estimated using 10^6 generic $b\bar{b}$

Reconstruction

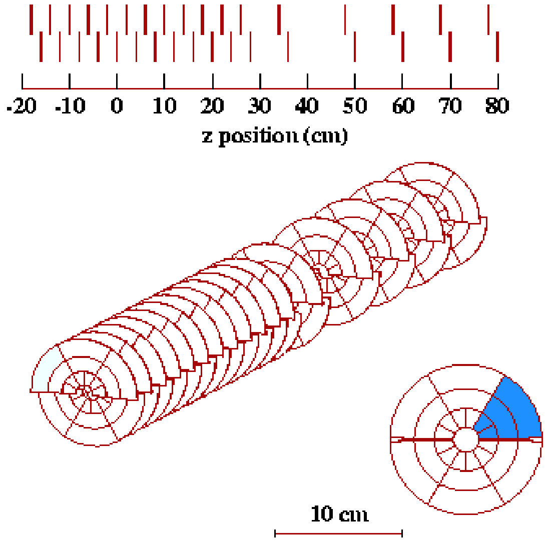
lower level triggers simulation includes pattern recognition

"offline" event reconstruction does not, but studies done separately confirm the results (details in detectors descriptions)

Vertex Detector

Impact parameter determination, good vertex and proper time resolution

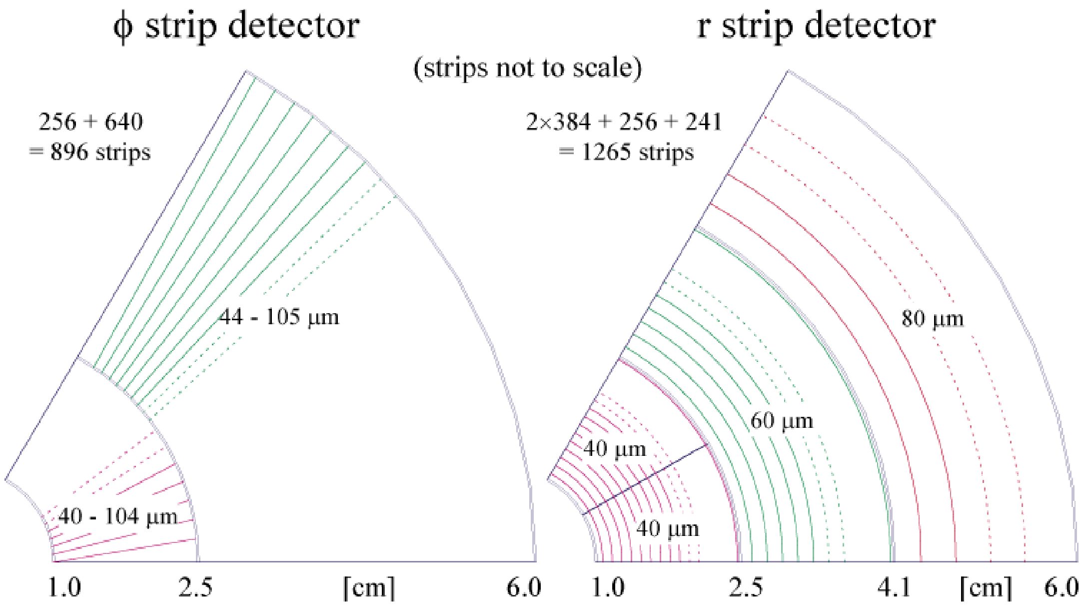
L1 and higher level triggers



Si Strip detector in LHC vacuum as close as possible to the beams,
1cm during physics

Interaction region spread in beam direction $\sigma_z \approx 5cm$

17 stations distributed along 1 m with separate r and ϕ detectors



Natural geometry for fast impact parameter determination in forward region and more homogenous strip occupancy

Simulation:

Support structures are included

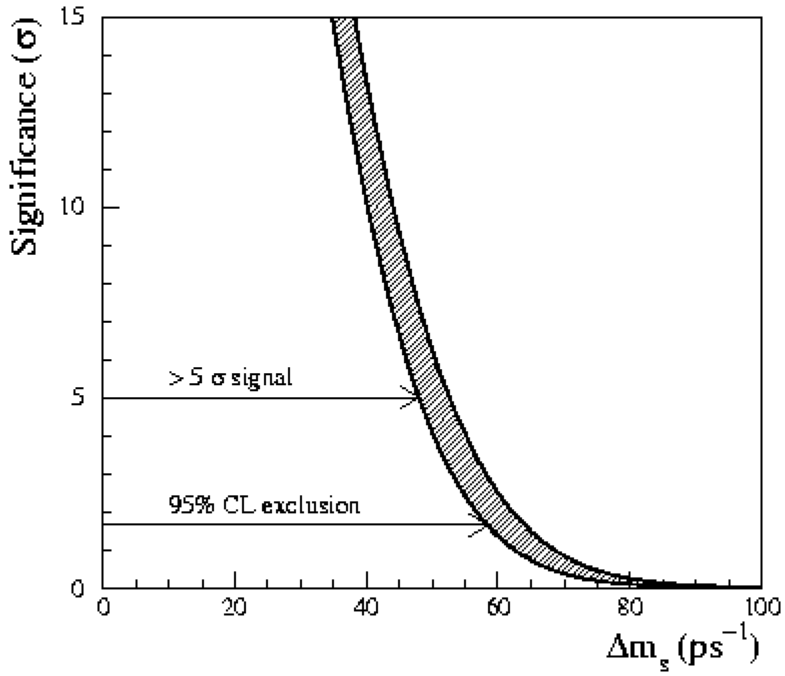
Track Kalman fit combined with main tracker

In L1 trigger full pattern recognition

Performance:

Impact parameter resolution for high momentum tracks ~ 40 μm

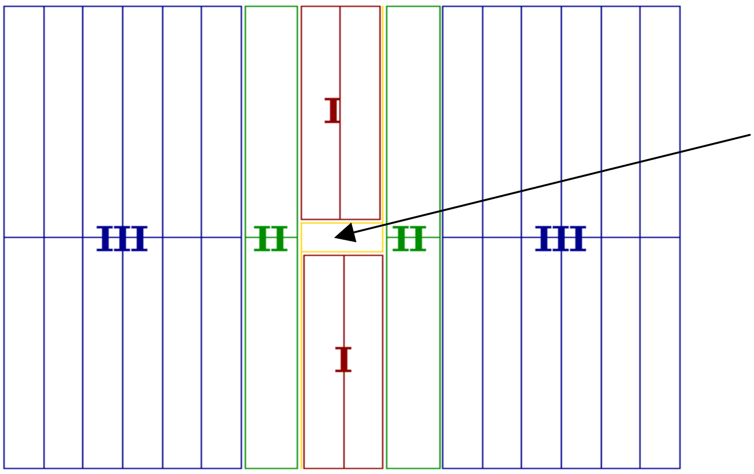
Proper time resolution for $B_s \rightarrow D_s\pi$ ~ 40 fs



Main Tracker

Efficient reconstruction and precise momentum measurement
Higher level triggers

Modular Design to keep all cell occupancies < 10%
Multilayer orientations (0°, +/- 5° stereo)



Inner Tracker:
Size 40 x 60 cm^2
High granularity

Outer Tracker:
Strawtube-like drift chambers (Honeycombs)
Resolution: < 200 μm

Tracking Reconstruction:
Kalman filter fit with vertex and main tracker combined

Perfomance:

$\delta p/p$ = 0.3 %, constant between 5 GeV/c and 200 GeV/c

Mass resolution:

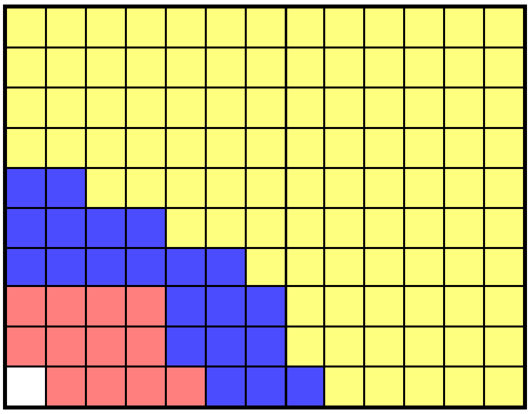
Δm_B = 15.2 MeV/c^2 in $B_d \rightarrow \pi^+\pi^-$
Δm_D = 4.2 MeV/c^2 in $D_S \rightarrow K^+K^-\pi^-$ from B_S decays

Electromagnetic Calorimeter

Measure e and γ energy

π^{o} reconstruction

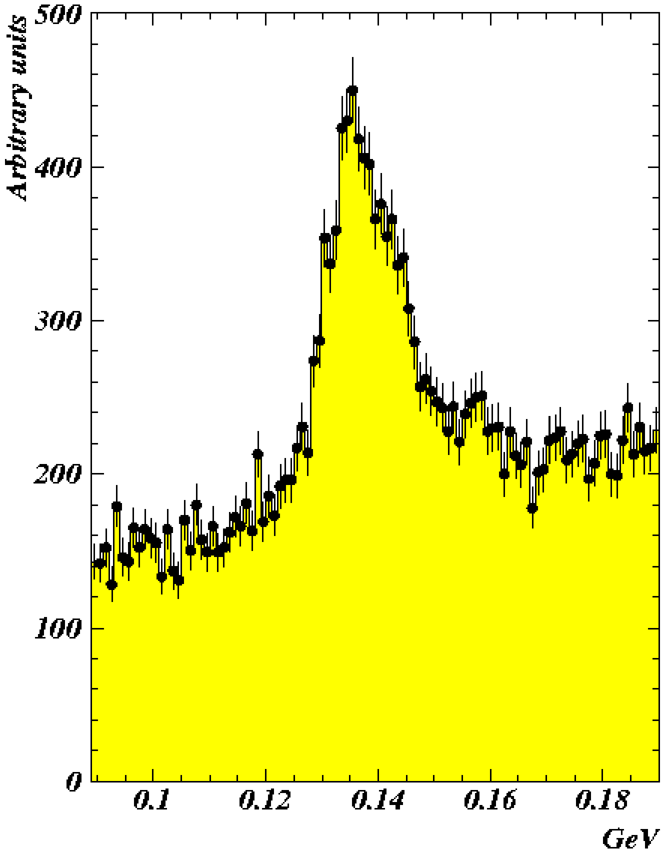
L0 trigger



Modest energy resolution

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

Hole dimensions (64x64 cm^2) for radiation damage



Variable transverse granularity to ensure reconstruction efficiency and low occupancy

Essential for reconstruction of π^0

RICH

π/K separation to suppress "same-topology" background and for tagging

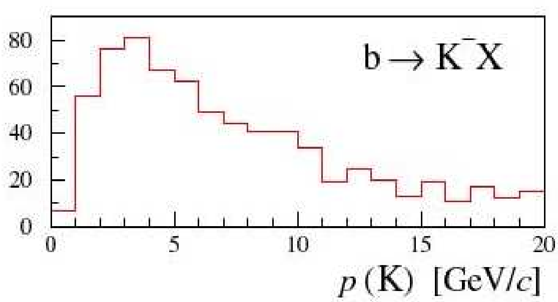
Momentum range:

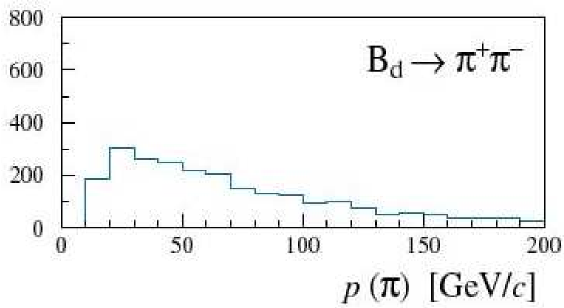
p_{min} = ~ 1 GeV/c

(Kaon tag)

p_{max} = ~ 150 GeV/c

(2-body B decay products)





Upstream RICH

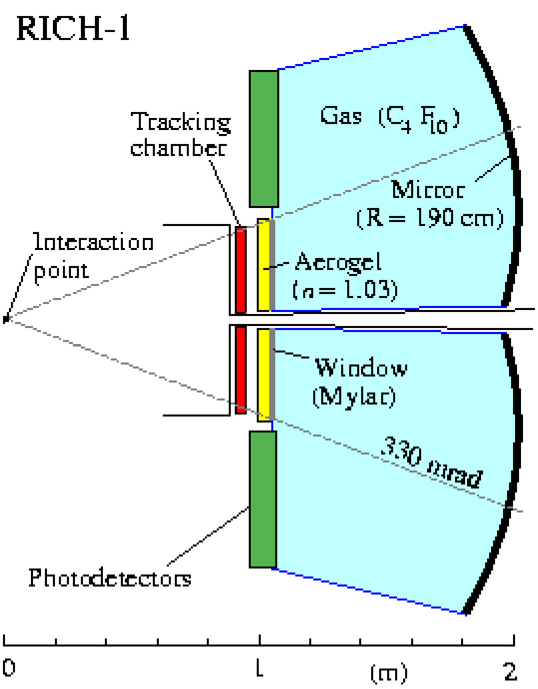
Aerogel , C_4F_{10}

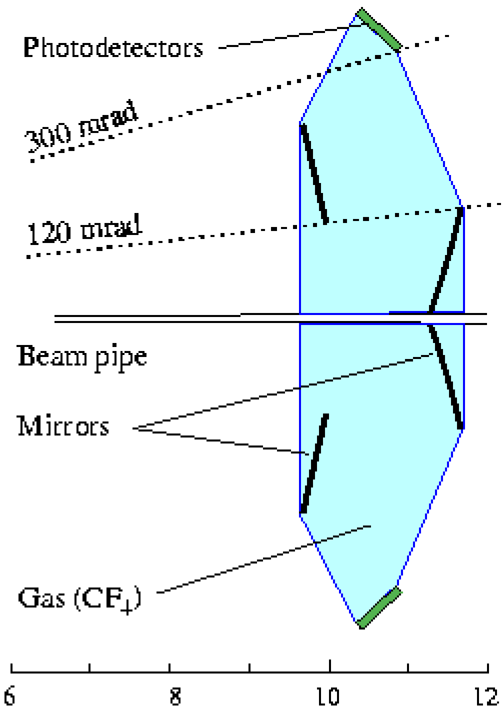
1 < p < 70 GeV/c

Downstream RICH

CF_4

20 < p < 150 GeV/c



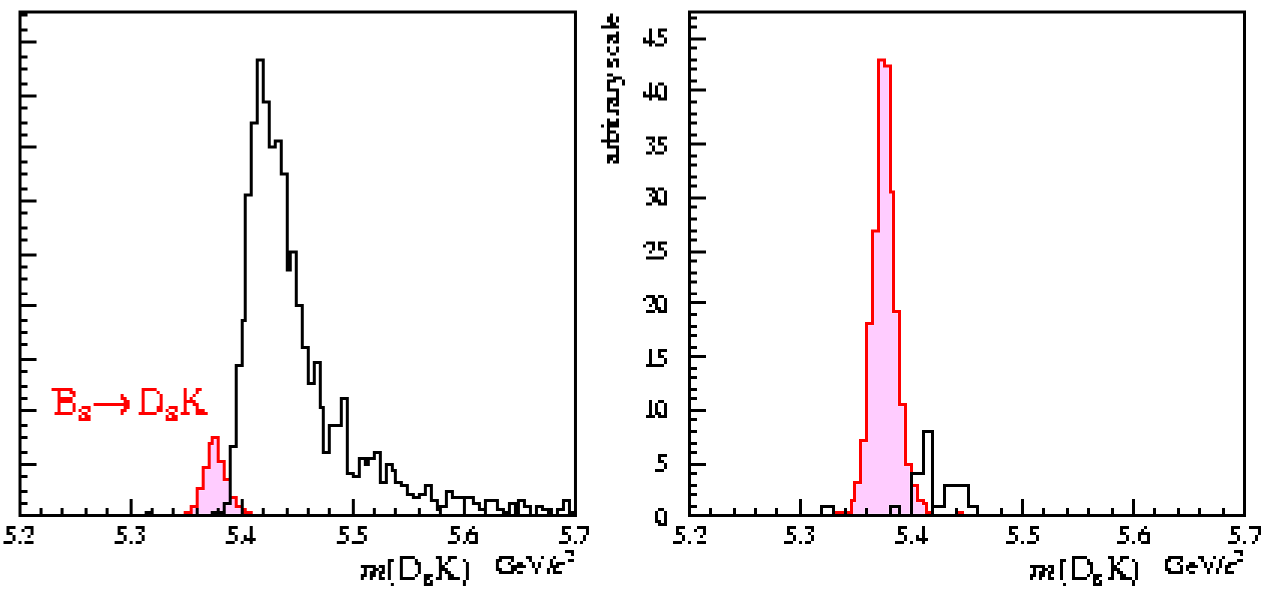


Simulation:

For physics studies parametrized angular resolutions of the measured Cherenkov angles are used to calculate probabilities for e, μ, π, K and p hypothesis

$B_s \rightarrow D_s K$

Without RICH With RICH

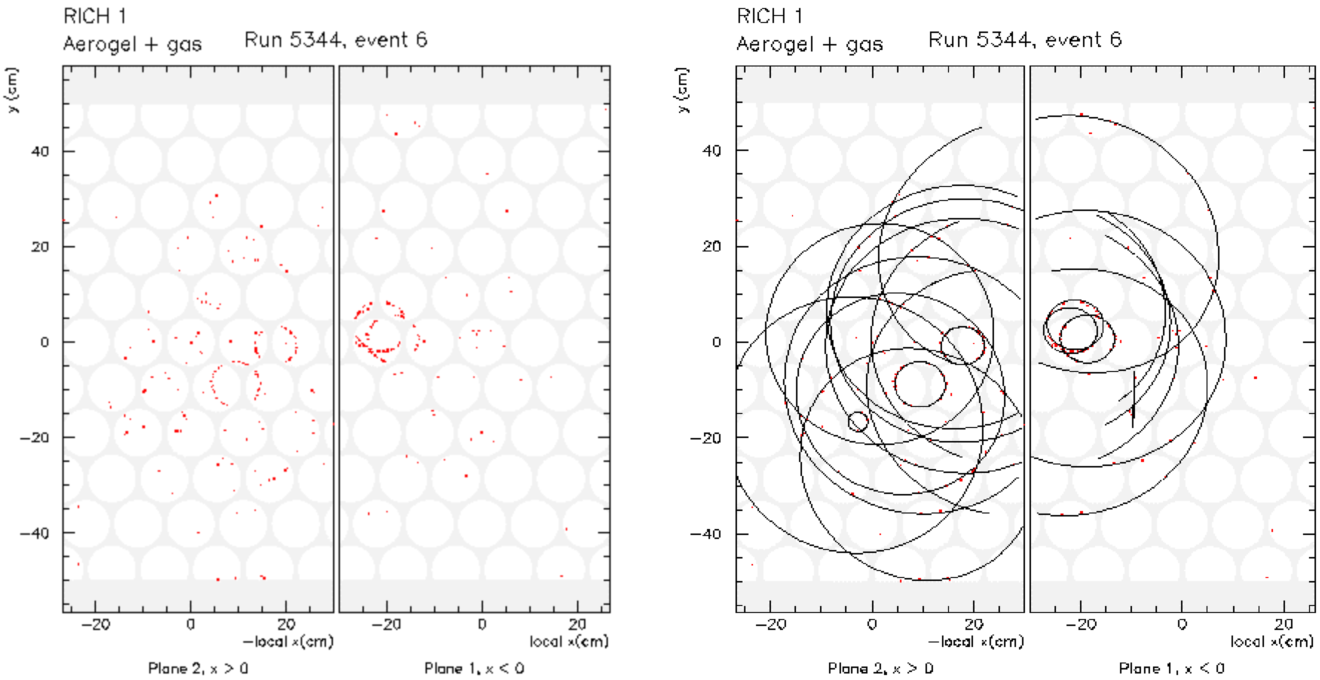


Full pattern recognition studies to verify the efficiency of the method have been performed

Full pattern recognition:

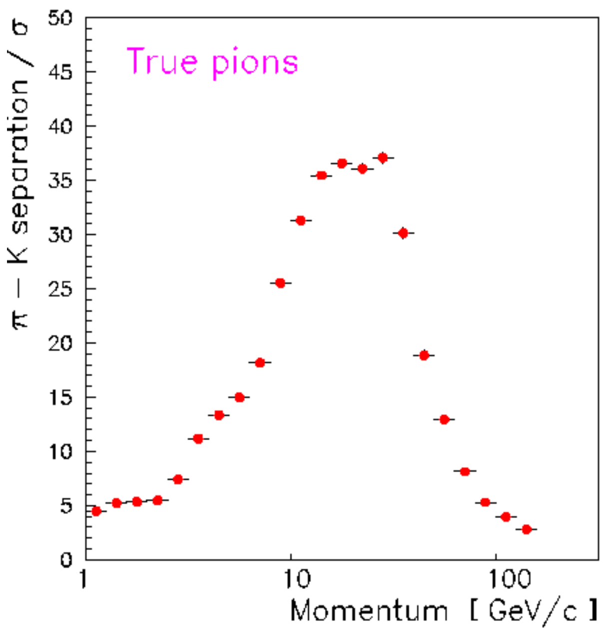
typical events are complicated, BUT ...

Maximize global likelihood of all combinations of hits, reconstructed tracks and particle hypotheses in both RICHes



High purity and efficiency

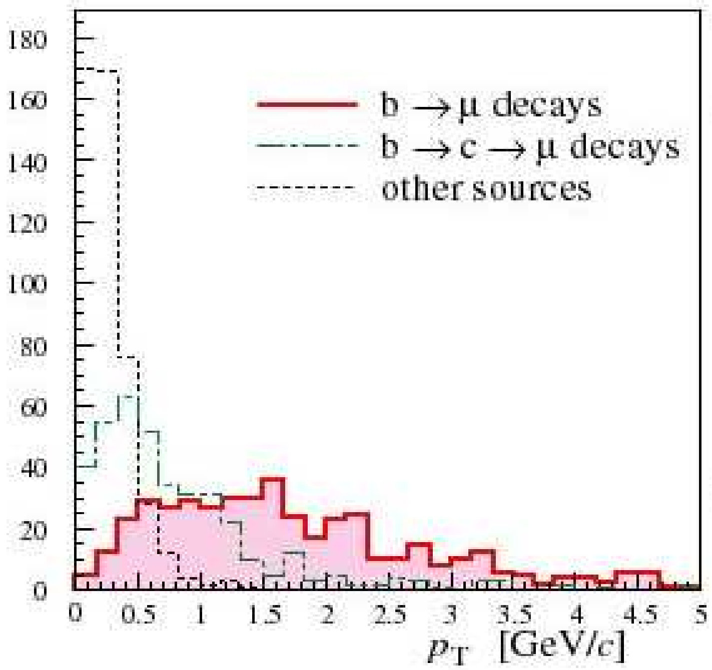
Excellent π / K separation



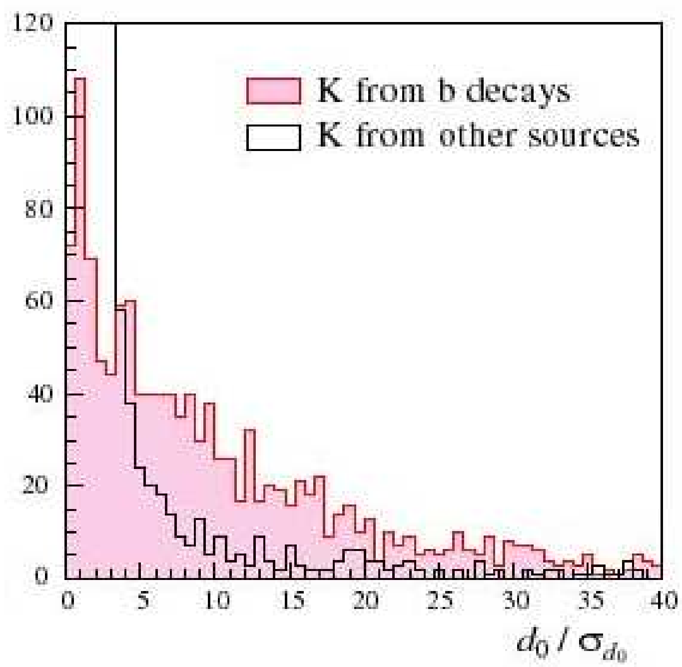
Flavour tagging:

Based on the decay products from accompanying b-hadron

$$b\bar{b} \to B^0$$
$$\quad \hookrightarrow \quad l^- \quad + X$$
(high p_T)



$$b\bar{b} \to B^0$$
$$\quad \hookrightarrow \quad K^- \quad + X$$
(large impact parameter)



$$\varepsilon_{tag} = 0.4$$

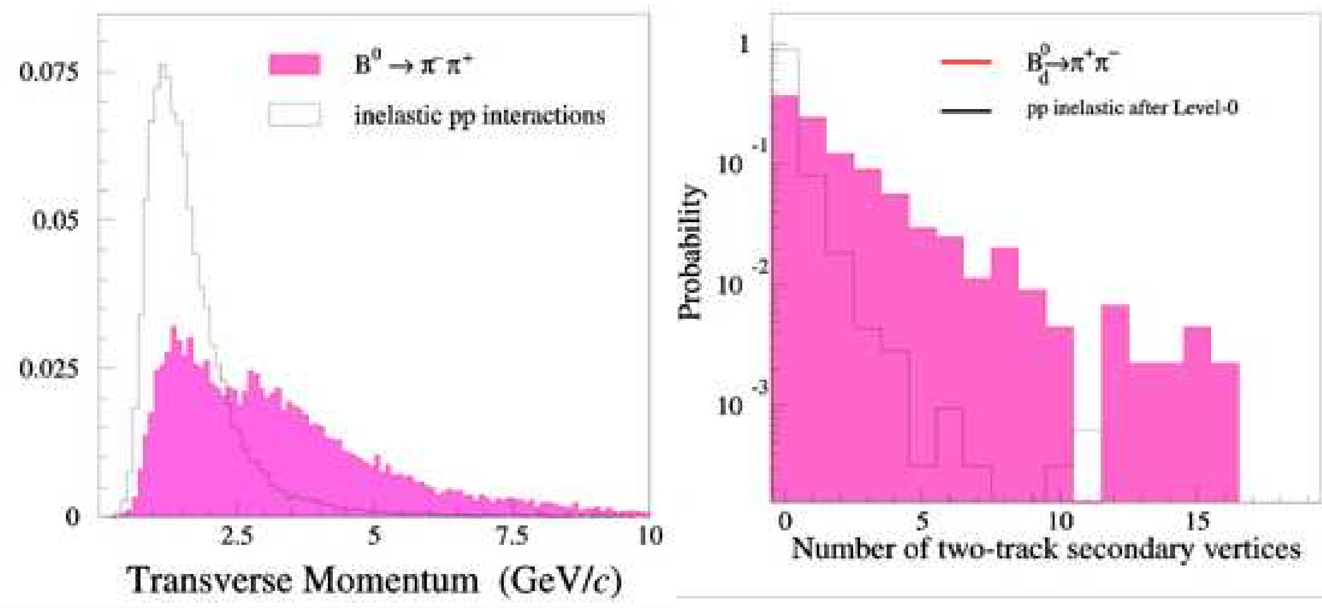
$$\omega_{tag} = 0.3$$

Trigger:

$$\sigma_{\rm inel} = 80\,{\rm mb} \qquad \sigma_{\rm inel} / \sigma_{b\bar{b}} = 160$$

$$\tau_{\rm bx} = 25\,{\rm ns}$$

Efficient: High p_T leptons and hadrons
Detached decay vertices



Flexible: Multilevel with different ingredients

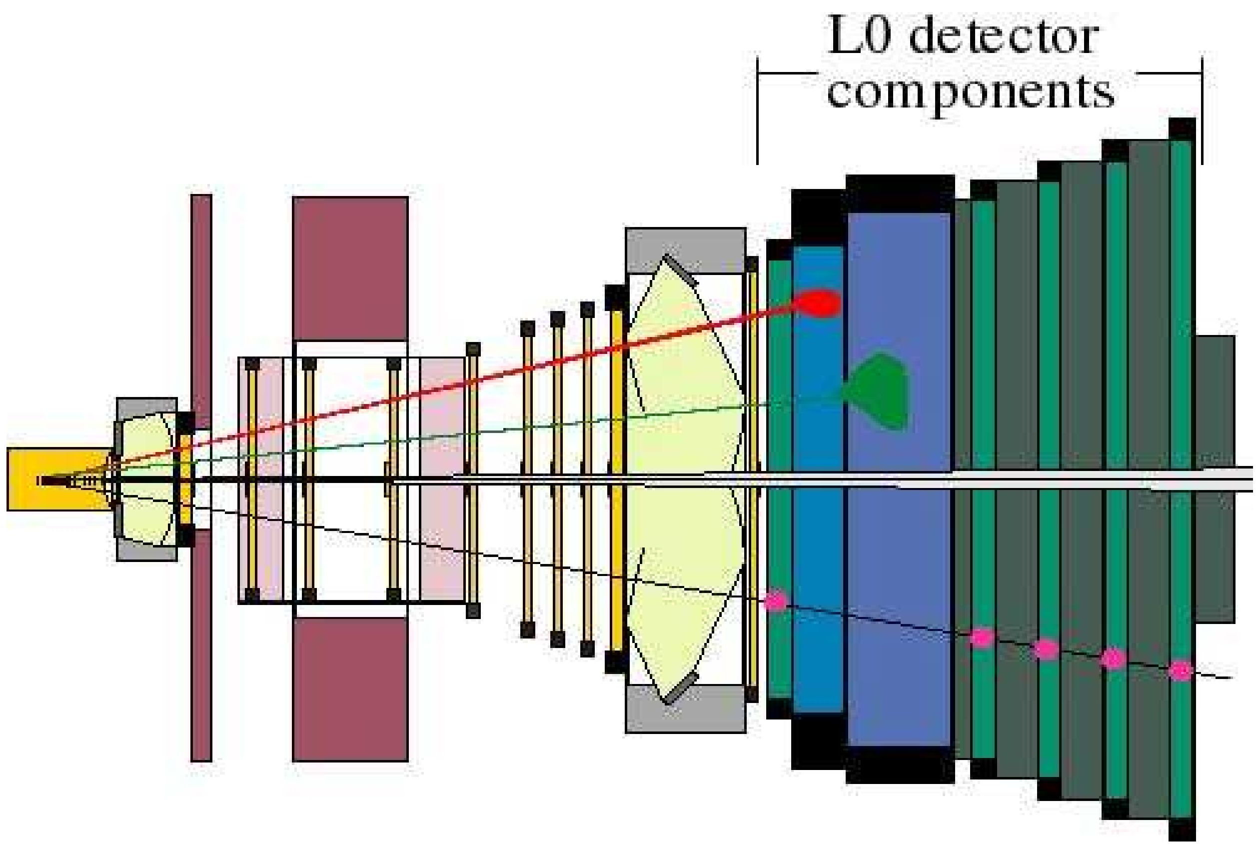
Robust: Evenly spread selectivity over all the levels

Trigger (L0)

Level	Characteristics	Sub-detector	
Level-0	high p_T		in-put
	:e	ECAL	40 MHz
	:h	E+HCAL	
	:μ	Muon	
	:γ	ECAL	latency
	pile-up	Pile-up	3.2 μs

60k channels

on-detector $\rightarrow$ off-detector electronics (1 TB/s)



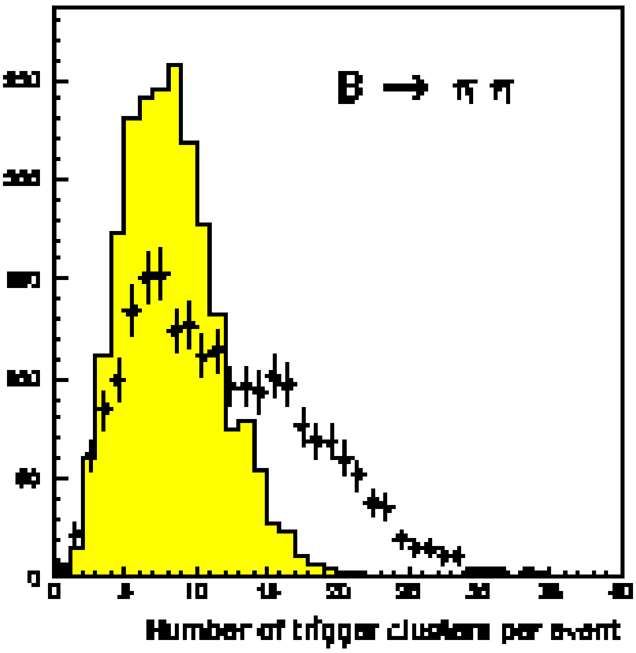
Charged particle multiplicity and p_T spectrum depend on the generator

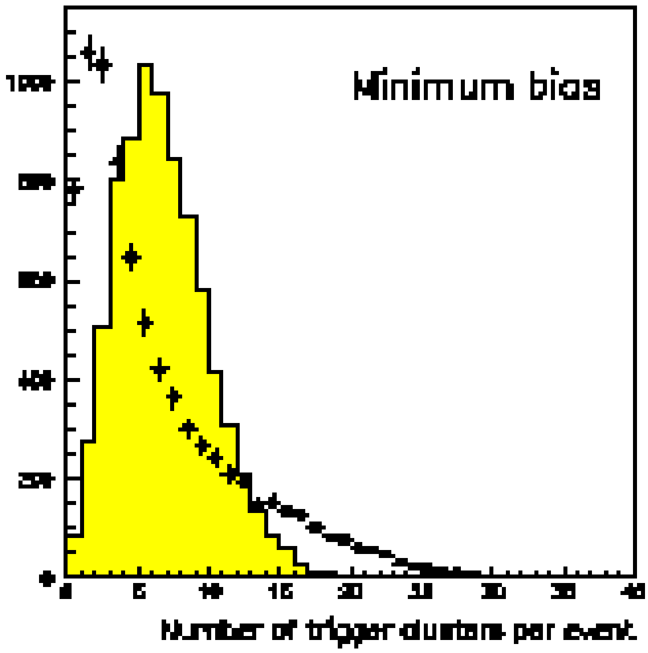
Proton structure function (CTEQ4M, MRSG, GRV94HO, etc...)

NEW

Multiple Interaction Model

$b\bar{b}$ production (MSEL = 1)



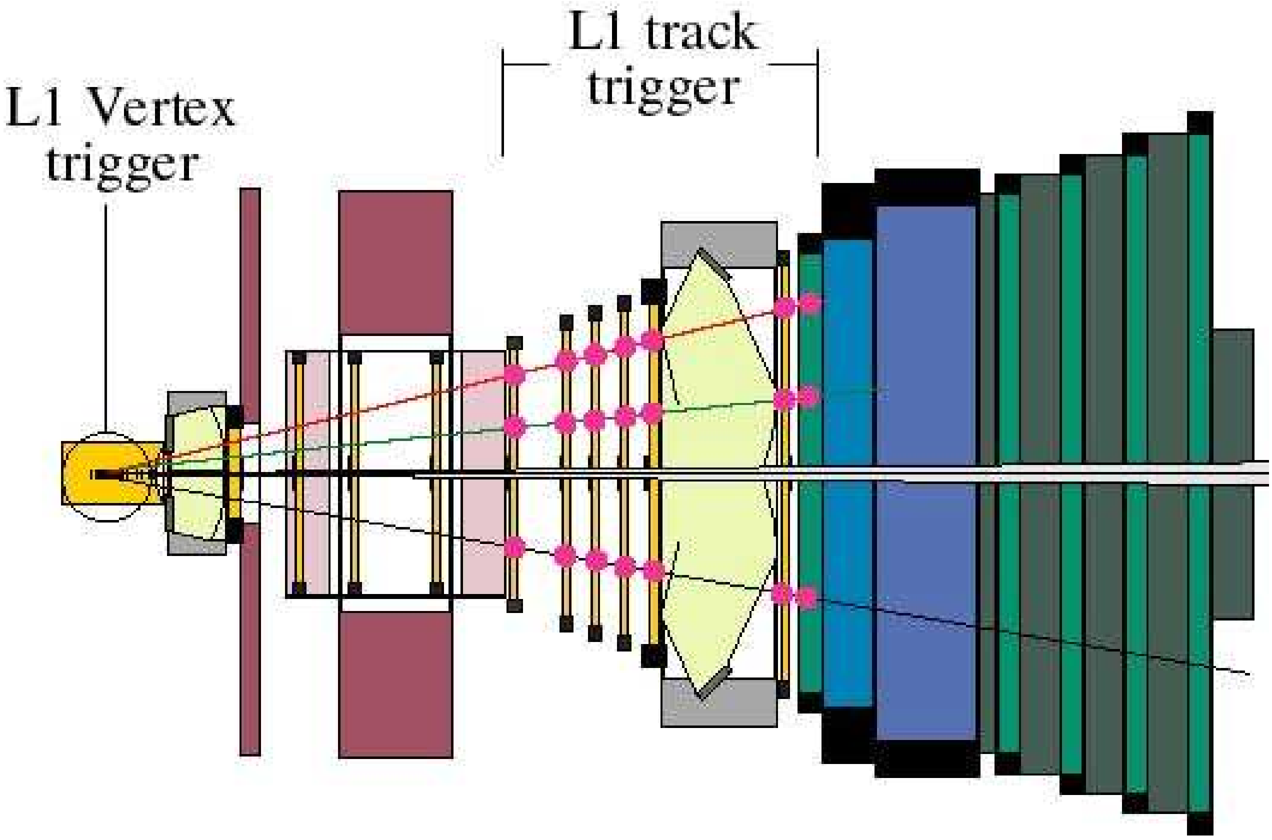


	Minimum Bias Retention			
	3%	6%	10%	
hadron $B_d^0 \to \pi^+\pi^-(acc)$	33%	45%	54%	**old**
	36%	49%	60%	**new**
	1%	2%	3%	
electron $B \to e + X(acc)$	20%	28%	33%	**old**
	20%	28%	33%	**new**
muon $B \to \mu + X(4\pi)$	8%	12%	14%	**old**
	9%	13%	15%	**new**

Trigger (L1)

Level	Characteristics	Sub-detector	
Level-1	sec. vertices high p_T	Vertex Trackers+L0-Seed	1 MHz <256 μs
			220k

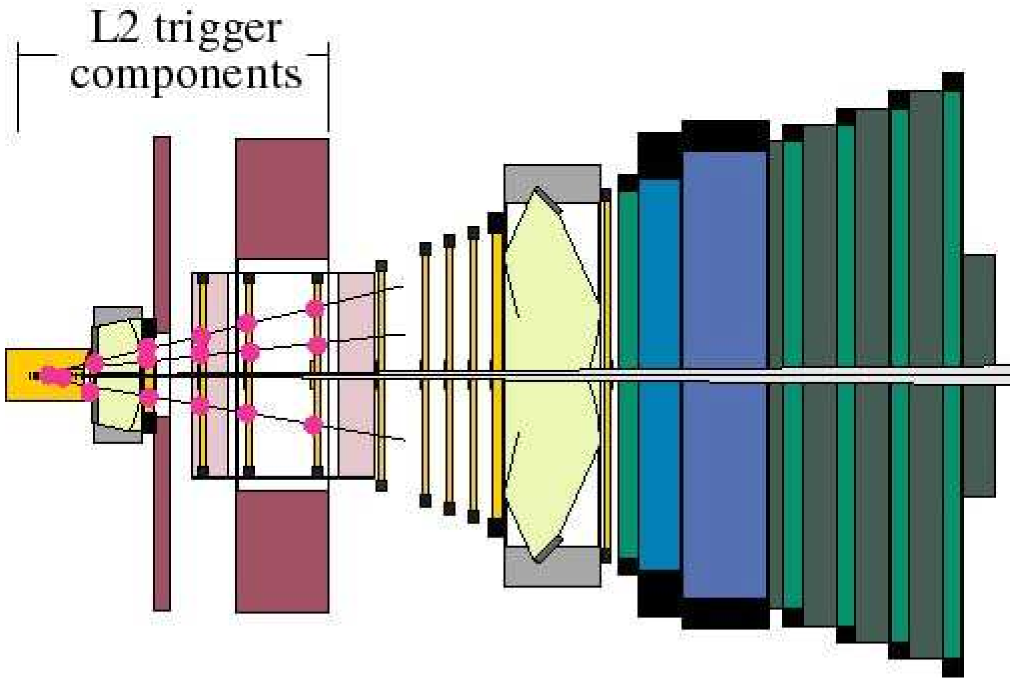
off-detector → event buffer (2-4 GB/s)



Full pattern recognition for L0 and L1 triggers

Trigger (L2,L3)

Level	Characteristics	Sub-detector	
Level-2	refined sec. Vertices	Vertex + Trackers	40 kHz 10 ms
Level-3	partial and full reconstruction of final states	All	5 kHz 200 ms To tape = 200 Hz



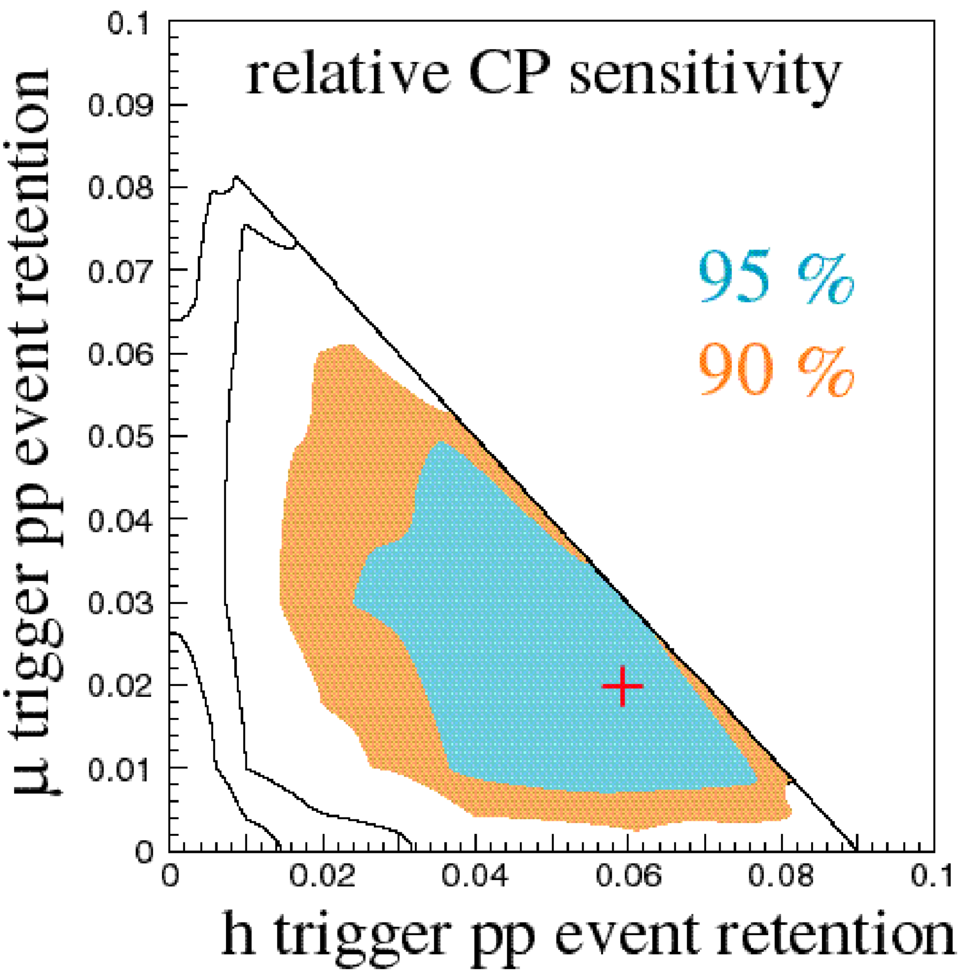
Trigger does not rely on a particular single component

its operating point can be adjusted to the running conditions without loss in physics

Example: thresholds for the L0 trigger

Retention of $\mu + e + h = 0.09$

$$B_d^0 \to \pi^+\pi^-$$



LHCb Trigger Efficiency (%)
for reconstructed and 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 efficiency are ~ 30%

hadron trigger is important for hadronic final states

lepton trigger is important for final states with leptons

Some numbers ….

$\sigma_{inel} = 80\text{mb}$ $\sigma_{b\bar{b}} = 500\mu\text{b}$

$L_{ave} = 2\,\text{x}\,10^{32}\ \text{cm}^{-2}\text{s}^{-1}$

	Visible Br. fraction	Offline Reconstruction (1 year)
$B_d^0 \to J/\psi\, K_s + \text{tag}$	$3.6\text{x}10^{-5}$	56k
$B_s^0 \to D_s^- K^+ + \text{tag}$	$8.1\text{x}10^{-6}$	2.1k
$B_s^0 \to D_s^- \pi^+ + \text{tag}$	$1.2\text{x}10^{-4}$	35k
$B_d^0 \to \overline{D}^0 K^{*0}$	$3.3\text{x}10^{-7}$	337
$B_d^0 \to \pi^+\pi^- + \text{tag}$	$0.7\text{x}10^{-5}$	6.9k
$B_d^0 \to K^+\pi^-$	$1.5\text{x}10^{-5}$	33k
$B_d^0 \to \rho^+\pi^- + \text{tag}$	$1.8\text{x}10^{-5}$	551
$B_d^0 \to K^{*0}\gamma$	$3.2\text{x}10^{-5}$	26k
$B_s^0 \to J/\psi\phi + \text{tag}$	$5.4\text{x}10^{-5}$	44k