



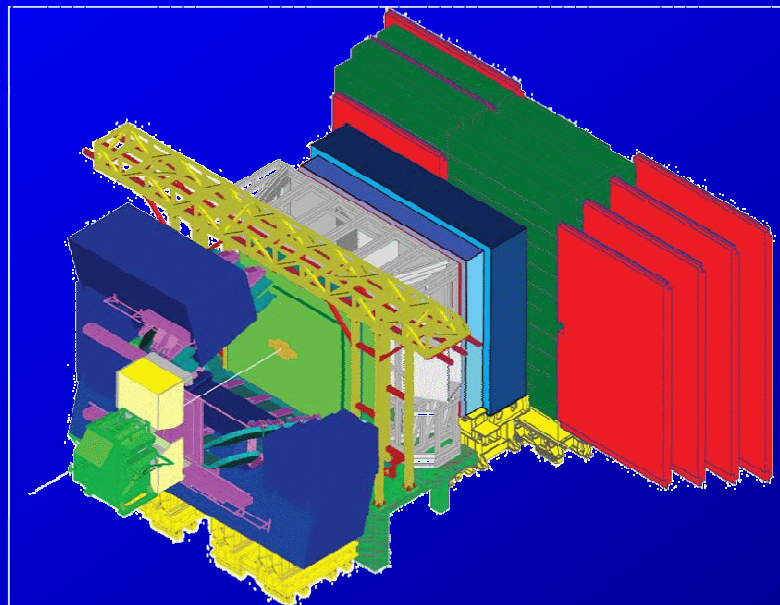
# The LHCb Trigger System



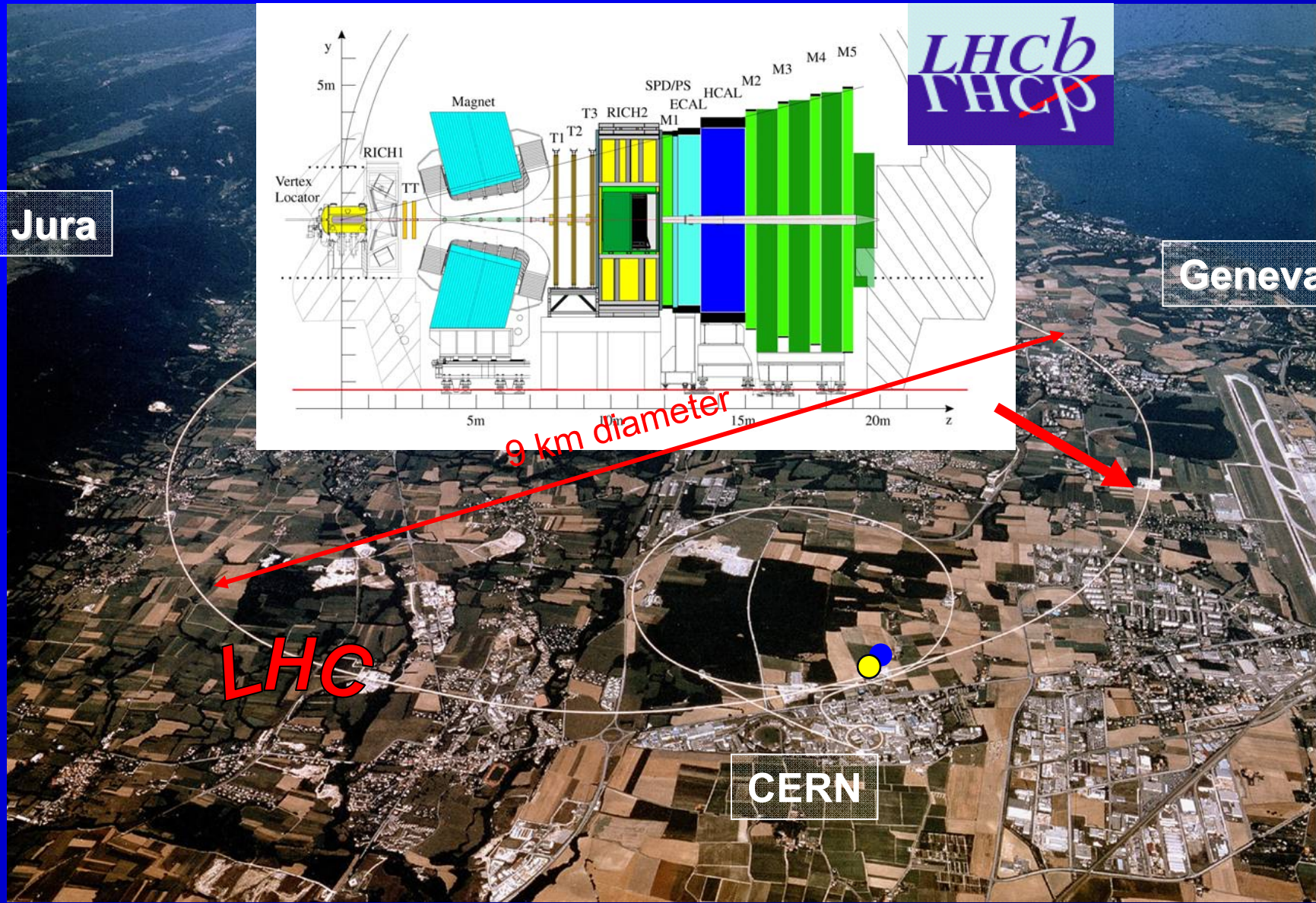
Eduardo Rodrigues  
NIKHEF

*On behalf of the LHCb Collaboration*

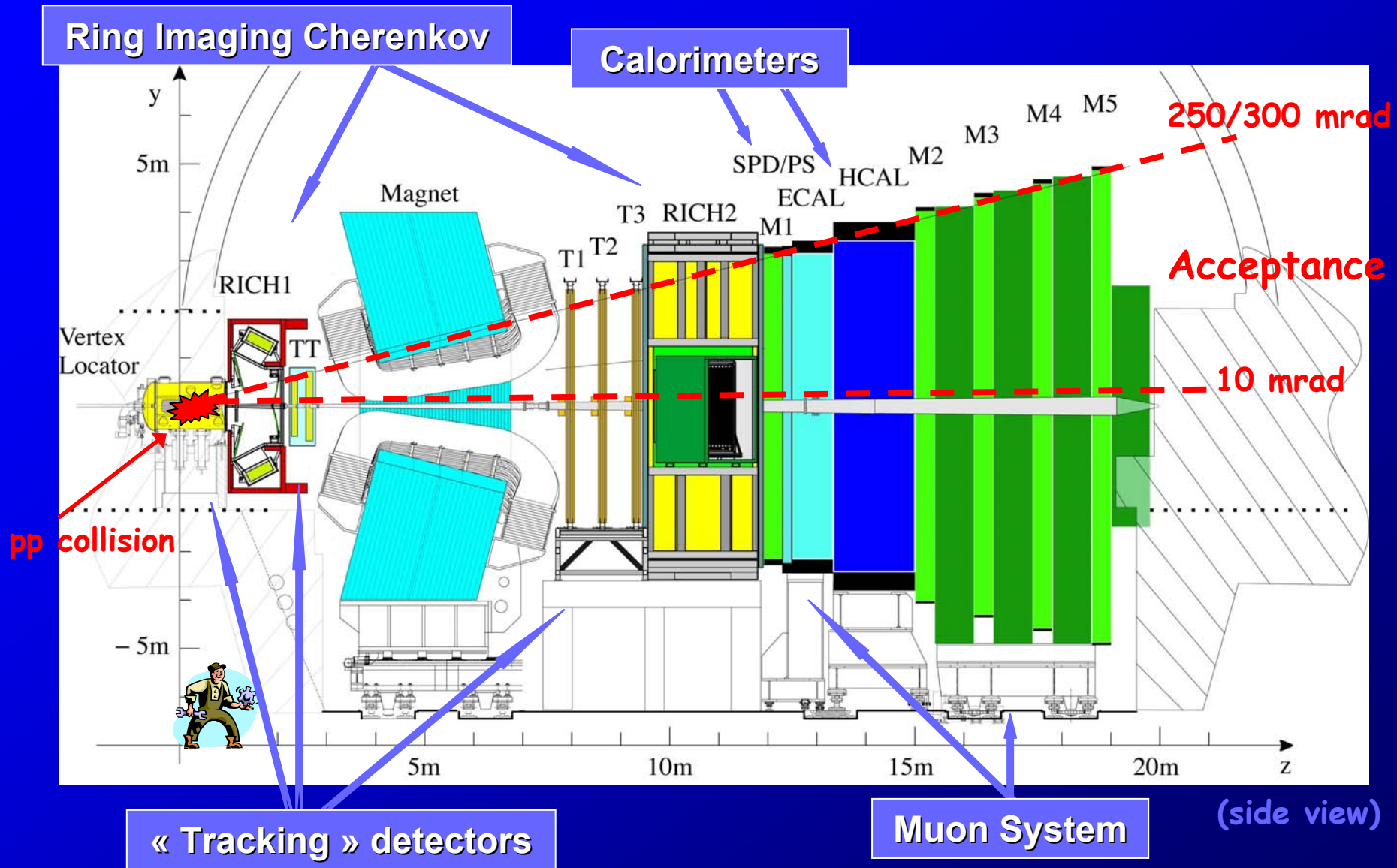
Beauty 2006, Oxford, UK 25<sup>th</sup>-29<sup>th</sup> Sep 2006



- LHCb Experiment and Detector
- Trigger strategy and overview
- Hardware trigger: Level-0  
components, decision unit, performance
- Software trigger: High Level Trigger  
farm, alleys, exclusive and inclusive  
strategies, decision, performance
- Outlook



# LHCb Detector



# ***Trigger Strategy & Overview***

- **LHC(b) Environment**
- **Trigger Overview & Strategy**

# LHC(b) Environment

## LHC ENVIRONMENT

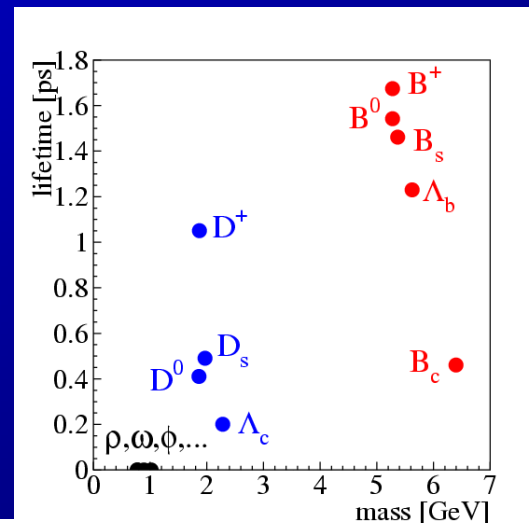
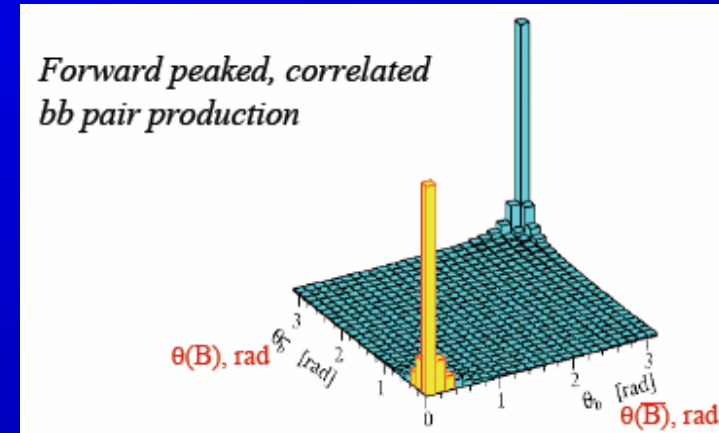
- pp collisions at  $E_{\text{CM}} = 14 \text{ TeV}$
- $t_{\text{bunch}} = 25 \text{ ns} \leftrightarrow$  bunch crossing rate = 40 MHz
- $\langle L \rangle = 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$  @ LHCb interaction region
  - ↳ 10-50 times lower than for ATLAS/CMS

## CROSS SECTIONS

| Physical quantity | Value                 | Event rate             | Yield / year                  |
|-------------------|-----------------------|------------------------|-------------------------------|
| $\sigma$ total    | $\sim 100 \text{ mb}$ |                        |                               |
| $\sigma$ visible  | $\sim 60 \text{ mb}$  | $\sim 12 \text{ MHz}$  |                               |
| $\sigma$ (c-cbar) | $\sim 3.5 \text{ mb}$ | $\sim 700 \text{ kHz}$ | $\sim 7 \times 10^{12}$ pairs |
| $\sigma$ (b-bbar) | $\sim 0.5 \text{ mb}$ | $\sim 100 \text{ kHz}$ | $\sim 10^{12}$ pairs          |

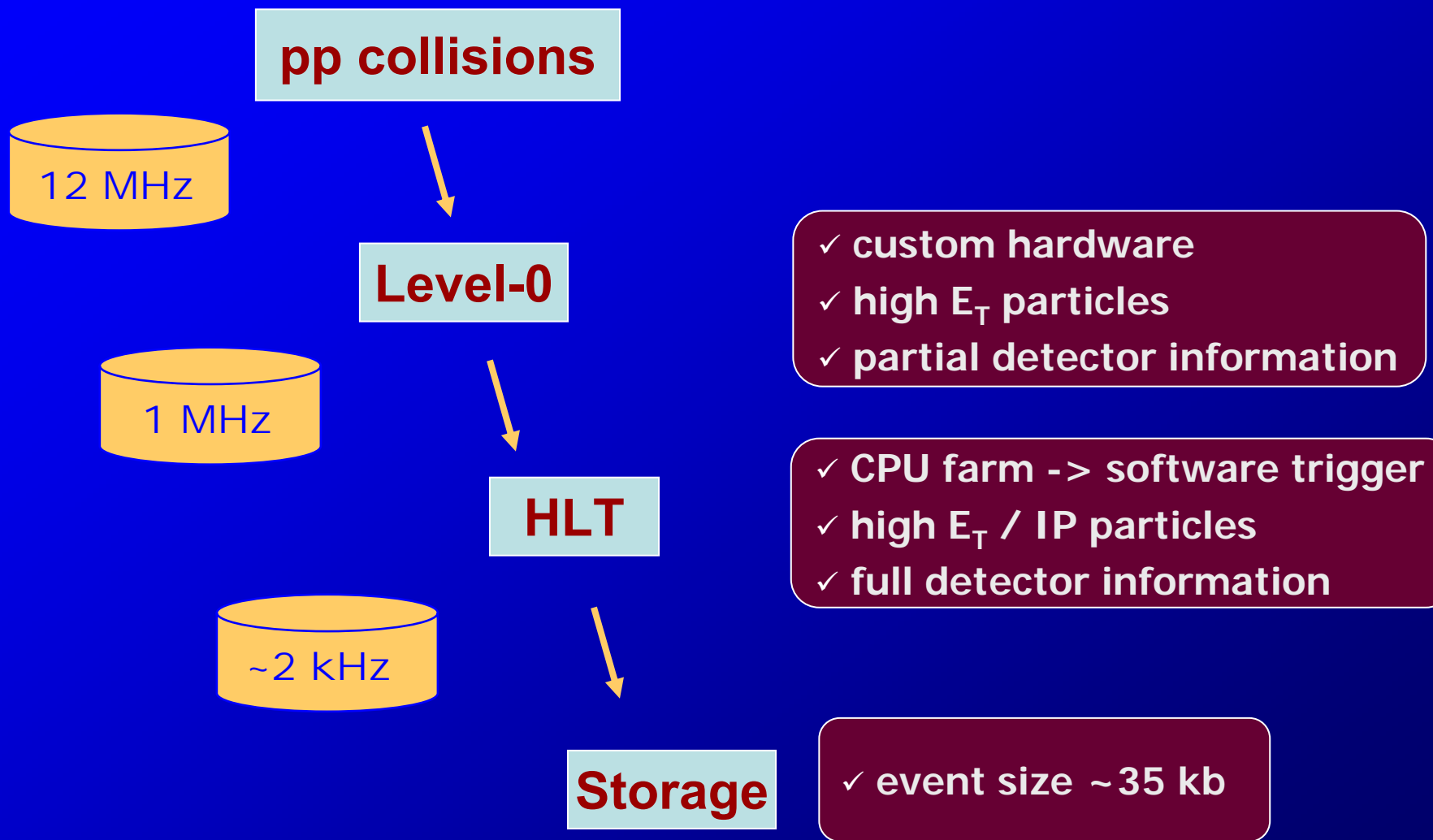
## EXPECTED B-SIGNAL RATES

- branching ratios  $\sim 10^{-9} - 10^{-4}$
- ➔  $10 - 10^6$  events / year ?



**B-hadrons are heavy and long-lived !**

# Trigger Overview



# Trigger Strategy

## Two-level Trigger

### L0 high $E_T$ / $P_T$ particles

- hardware trigger, sub-detector specific implementation
- pipelined operation, fixed latency of 4  $\mu$ s
- (minimum bias) rate reduction  $\sim 12$  MHz  $\rightarrow$  1 MHz

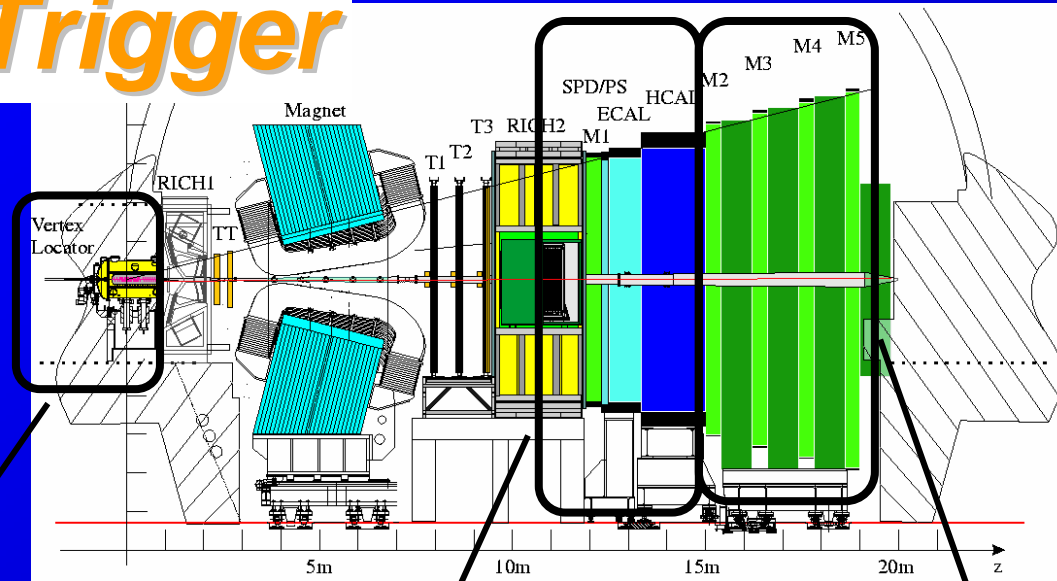
Be alert !



### HLT: high $E_T/P_T$ & high Impact Param. particles & displaced vertices & B-mass & ...

- algorithms run on large PC farm with  $\sim 1800$  nodes
- several trigger streams to exploit and refine L0 triggering information
- software reconstruction on part/all of the data
  - ↳ tracking / vertexing with accuracy close to offline
- selection and classification of interesting physics events
  - ↳ inclusive / exclusive streams
- rate reduction 1 MHz  $\rightarrow$  2 kHz
- estimated event size  $\sim 30$ kb

# Level-0 Trigger



Pile-up system

Calorimeter

Muon system

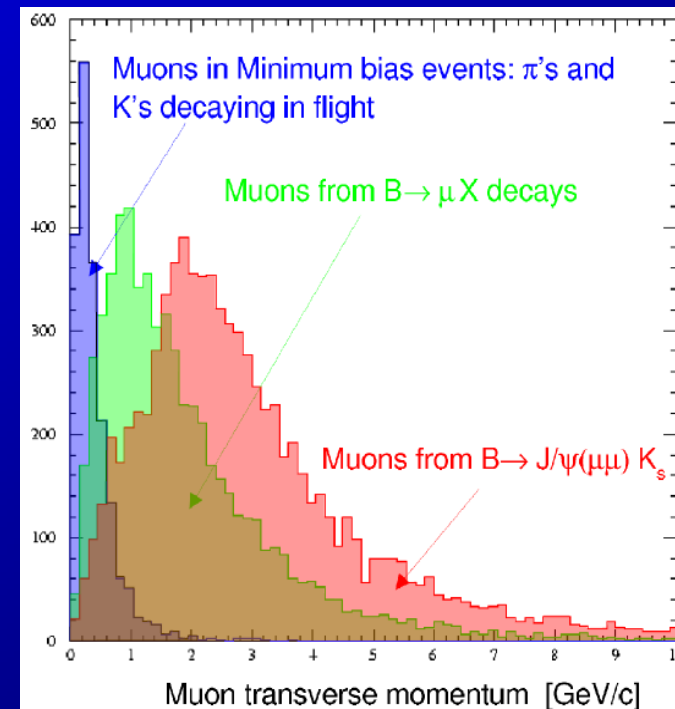
L0 Decision unit

L0DU report

1 MHz

# L0 Strategy

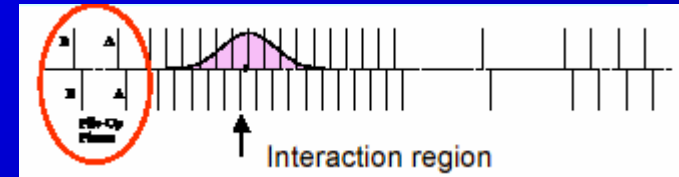
- **select high  $E_T$  /  $P_T$  particles** ← L0 thresholds on  $E_T$  /  $P_T$  of candidates
  - ↳ hadrons / electrons / photons /  $\pi^0$ 's / muons
- **reject complex / busy events** ← global event variables
  - ↳ more difficult to reconstruct in HLT
  - ↳ take longer to reconstruct in HLT
- **reject empty events**
  - ↳ uninteresting for future analysis



# LO Pile-up System

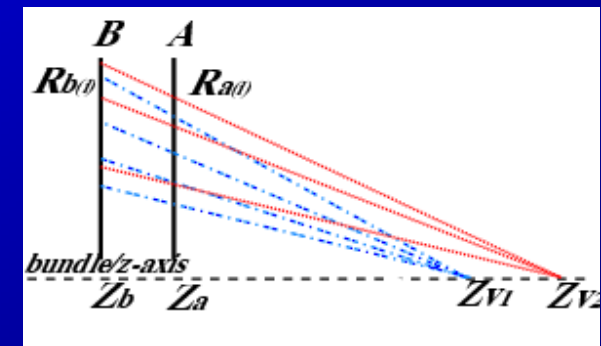
## DETECTOR COMPONENTS

- 2 silicon planes upstream of nominal IP, part of the Vertex Locator (VELO)



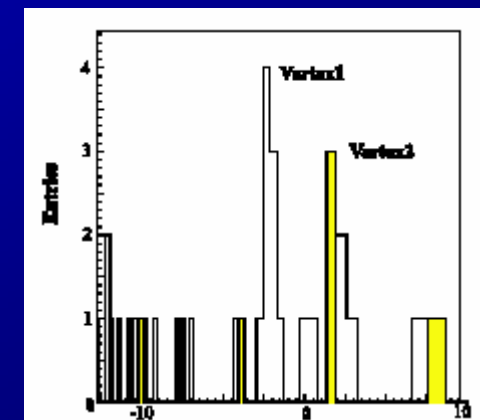
## STRATEGY: *identify multi-PV events*

- calculate  $z$  of vertices for all combinations of A & B
- find highest peak in histogram of  $z$
- remove hits contribution to that peak
- find the second highest peak
  - ↳ 2-interactions crossings identified with efficiency  $\sim 60\%$  and purity  $\sim 95\%$

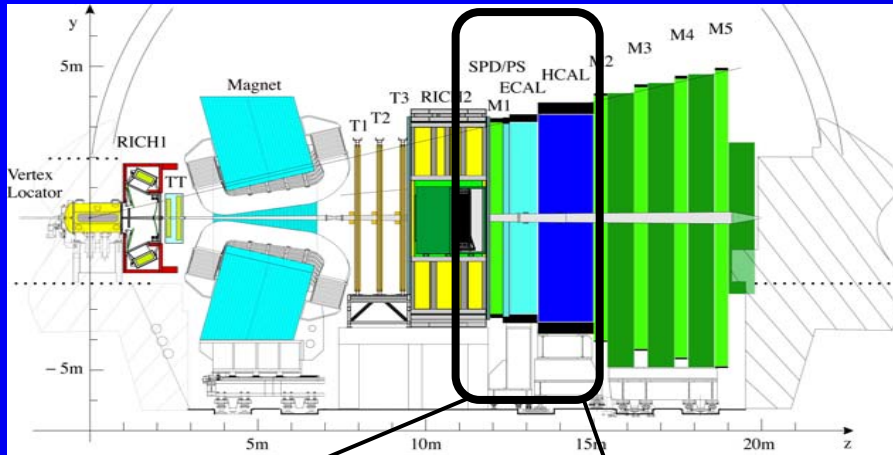


## OUTPUT FOR LODU

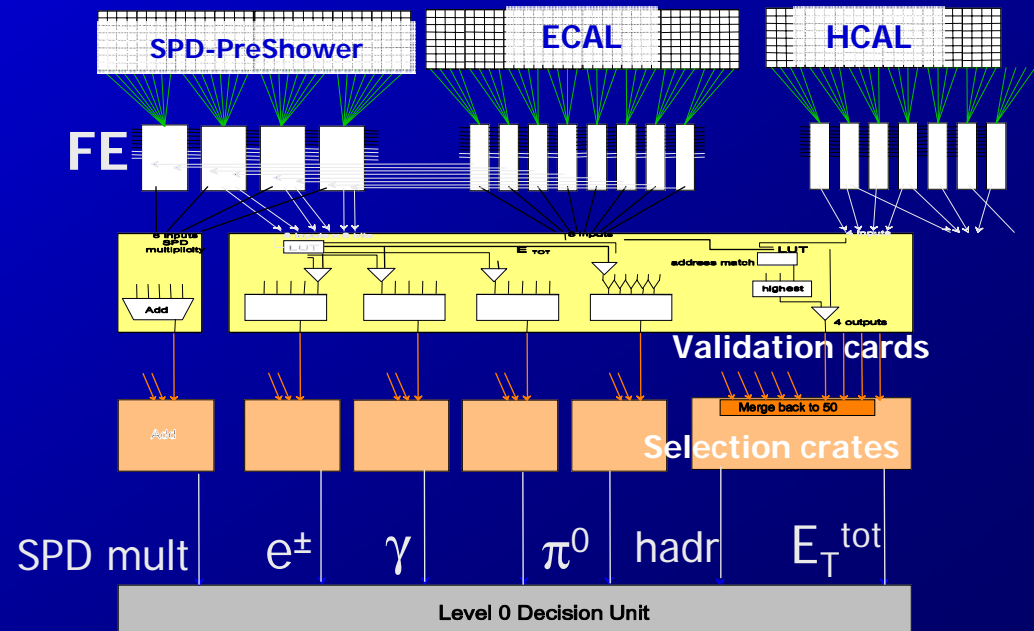
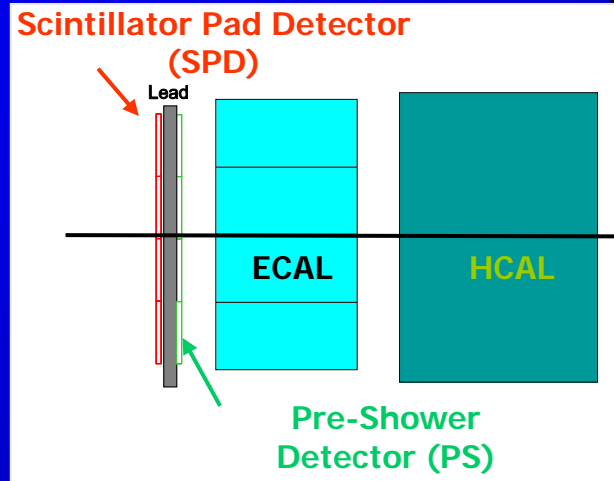
- pile-up system (hit) multiplicity
- number of tracks on second peak/vertex



# LO Calorimeter Trigger (1/2)



- ECAL and HCAL
  - ECAL: ~6000 cells, 4x4 to 12x12 cm<sup>2</sup>
  - HCAL: ~1500 cells, 13x13 to 26x26 cm<sup>2</sup>
- Scintillator Pad Detector (SPD)
- Preshower (Prs)



# LO Calorimeter Trigger (2/2)

## STRATEGY

- identify high- $E_T$  hadrons / e's /  $\gamma$ 's /  $\pi^0$ 's using all 4 sub-detectors:
  - ECAL and HCAL
    - ↳ large energy deposits  $\leftrightarrow$   $E_T$  in 2x2 cells
  - Scintillator Pad Detector (SPD) & Preshower (Prs)
    - ↳ used for charged/electromagnetic nature of clusters, respectively (PID)

## OUTPUT FOR LO DECISION UNIT (LODU)

- highest- $E_T$  candidate of each type
  - ↳ hadron / e /  $\gamma$  / 2  $\pi^0$ 's ("local" and "global")
- global event variables
  - ↳ total  $E_T$  in HCAL  $\leftrightarrow$  rejection of empty events
  - ↳ SPD hit multiplicity  $\leftrightarrow$  rejection of busy events

# LO Muon Trigger

## DETECTOR COMPONENTS

- M1 – M5 muon stations (4 quadrants each)

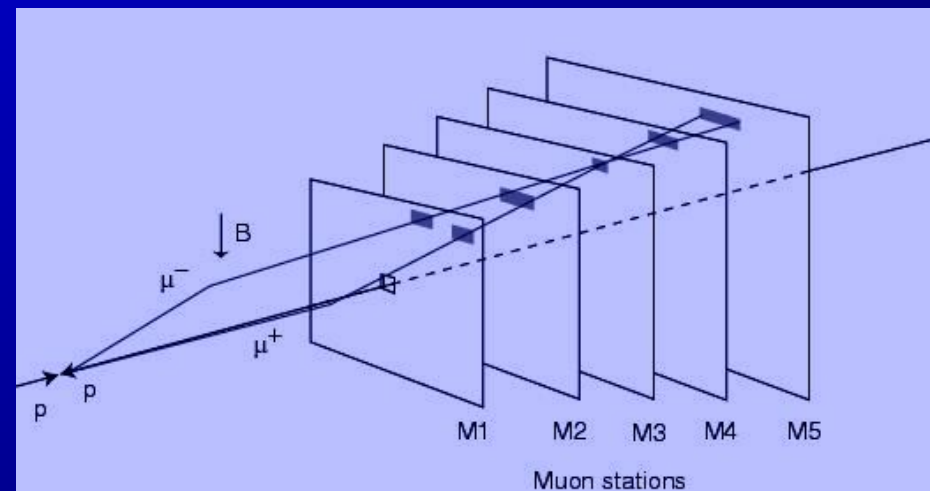
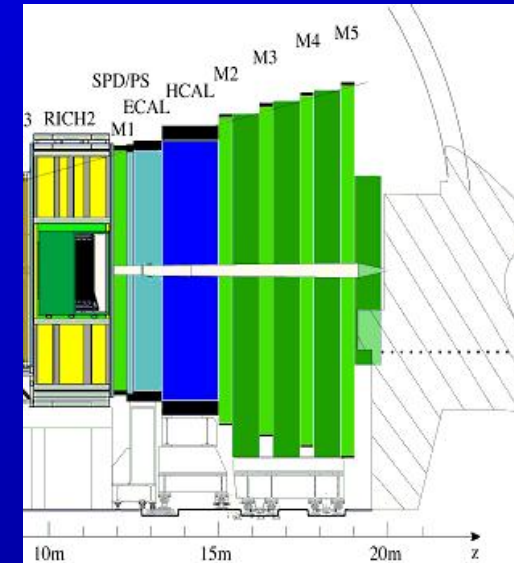
## STRATEGY

- straight-line search in M2–M5  
and extrapolation to M1 for momentum determination
- momentum determination from M1-M2  
assuming muons from primary vertex  
(using a look-up table):

$$\sigma_p/p \sim 20\% \text{ for } b\text{-decays}$$

## OUTPUT FOR LODU

- 2 muon candidates  
per each of the 4 quadrants



# L0 Trigger Hardware Status

- for general status / commissioning of LHCb:  
see Lluís Garrido's / Gloria Corti's talks

## L0 TRIGGER

- commissioning due to start early 2007  
→ ready for end of Summer 2007
- L0 candidates selection/validation cards ready for production



## MUON SYSTEM FOR L0

- chambers production and tests progressing well (tests with cosmics also performed)
- chambers installation to start now in October ...
- full L0-muon trigger electronics chain being tested

## CALORIMETER FOR L0

- all CAL parts installed; ECAL & HCAL being commissioned, SPD, Prs will follow ...
- L0-CAL trigger tests with realistic configuration in Autumn '06

# L0 Decision Unit (1/2)

## Calorimeter

- total  $E_T$  in HCAL
- SPD multiplicity
- highest-  $E_T$  candidates:  
h, e,  $\gamma$ ,  $2 \pi^0$ 's

## Muon system

- 2  $\mu$  candidates  
per each of 4 quadrants

## Pile-up system

- total multiplicity
- # tracks in second peak



**L0 Decision unit**

- cuts on global event variables
- thresholds on the  $E_T$  candidates

**L0DU report**

1 MHz

# LO Decision Unit (2/2)

## GLOBAL EVENT VARIABLES applied first ...

| Global event cuts                | Cut      | Rate (MHz) |     |
|----------------------------------|----------|------------|-----|
| $\Sigma E_T$                     | 5.0 GeV  | ~ 8.3      | ~ 7 |
| SPD multiplicity                 | 280 hits | ~ 13       |     |
| Tracks in 2 <sup>nd</sup> vertex | 3        |            |     |
| Pile-up multiplicity             | 112 hits |            |     |

Redundancy:  
Sub-triggers overlap



## ... and then cuts on the $E_T / P_T$ CANDIDATES

| Trigger        | Threshold (GeV) | Approx. rate (kHz) |     |
|----------------|-----------------|--------------------|-----|
| Hadron         | 3.6             | 700                | 700 |
| Electron       | 2.8             | 100                | 280 |
| Photon         | 2.6             | 130                |     |
| $\pi^0$ local  | 4.5             | 110                |     |
| $\pi^0$ global | 4.0             | 150                | 160 |
| Muon           | 1.1             | 110                |     |
| Di-muon        | 1.3             | 150                |     |

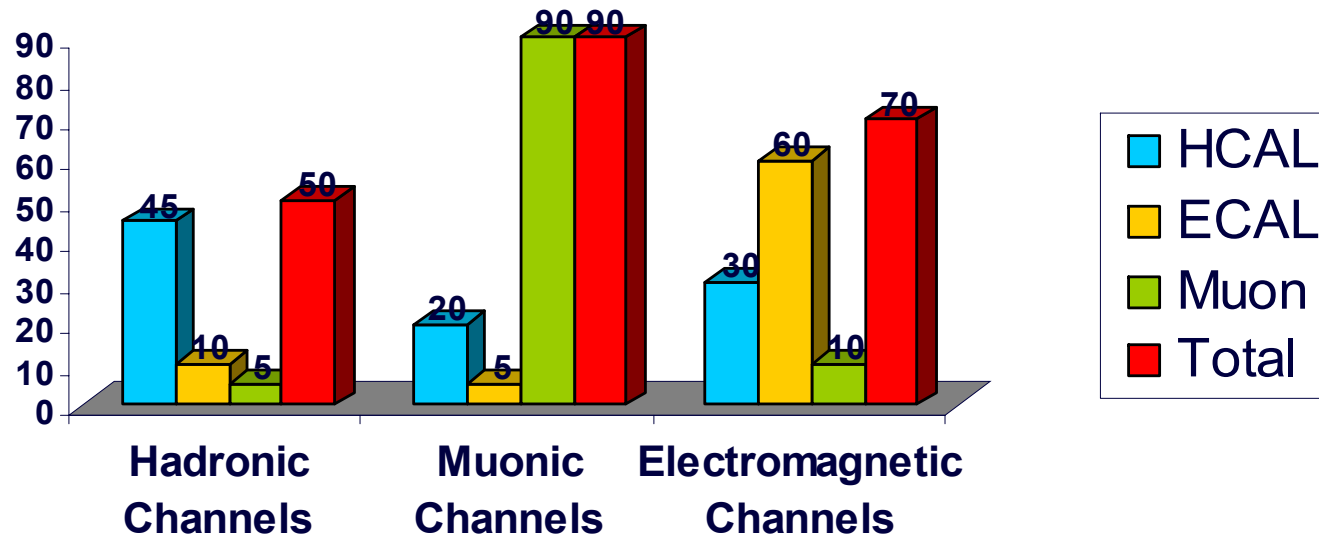
### Di-muon trigger is special

- not subject to the global event selection
- $P_{T^{\mu\mu}} = P_{T^{\mu 1}} + P_{T^{\mu 2}}$  with  $P_{T^{\mu 2}} = 0$  possible
- “tags” clean B-signatures



# LO Performance

Dedicated sub-triggers most relevant for each « channel type »



| Event composition  | b-bbar (%) | c-cbar (%) |
|--------------------|------------|------------|
| Generated, visible | 1.1        | 5.6        |
| after L0           | 3.0        | 10.6       |

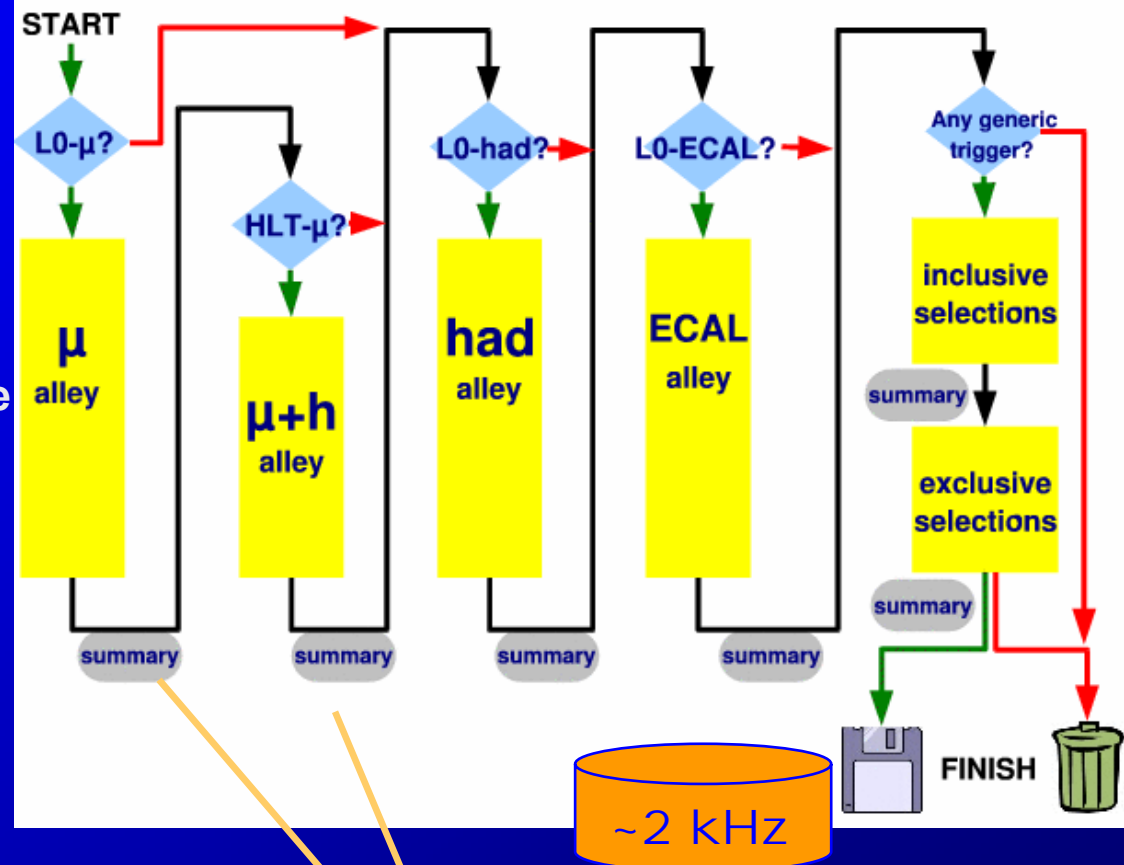
# High Level Trigger

## STRATEGY

### INDEPENDENT ALLEYS:

Follow the L0 triggered candidate

→ Muon, Muon + Hadron,  
Hadron, ECal streams



### Partial Reconstruction:

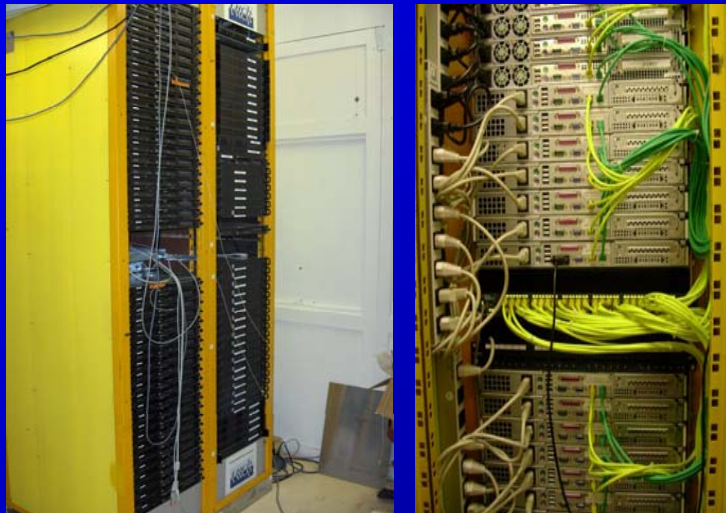
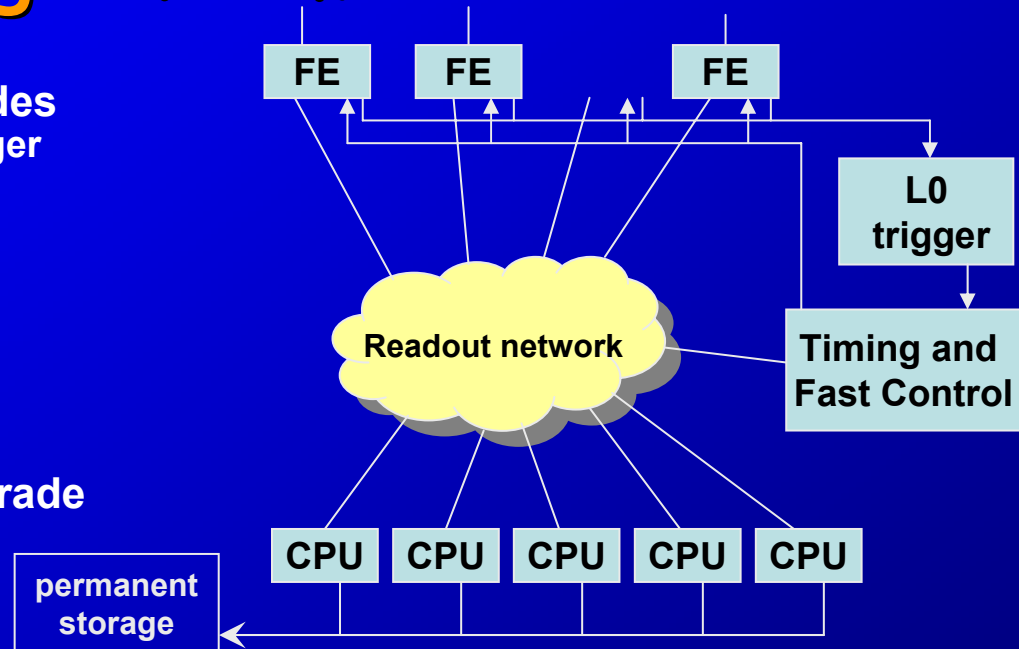
- A few tracks selected per alley (cuts e.g. on  $P_T$ , Impact Parameter, mass)
- full reconstruction done at the end of the alleys

### Summary Information:

decision, type of trigger fired, info on what triggered

# Trigger Farm

- ❖ Event Filter Farm with ~1800 nodes (estimated from 2005 Real-Time Trigger Challenge)
- ❖ Sub-divided in 50 sub-farms
- ❖ Readout from Level-0 at 1 MHz  
↳ 50 Gb/s throughput
- ❖ Scalable design ↔ possible upgrade

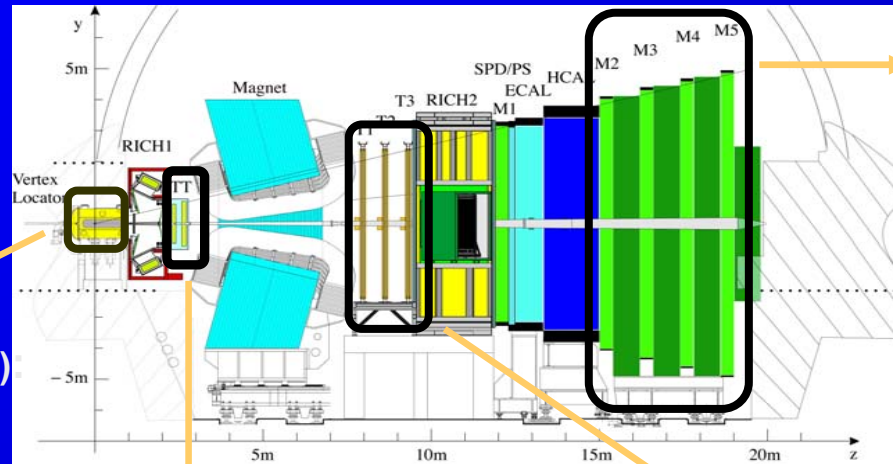


HLT algos CPU time tested on a real farm  
→ will fit in the size of the farm foreseen

# HLT Tracking / Reconstruction

~ 70 tracks/event  
after L0

Vertex LOcator (VELO)  
*RΦ geometry*



Muon stations:

$\sigma_p/p \sim 20\%$  *standalone*  
 $\sigma_p/p \sim 5\%$  *matched with VELO tracks*

*Standalone muons*

Trigger Tracker (TT):

$\sigma_p/p \sim 20-40\%$   
(using B-field before magnet)

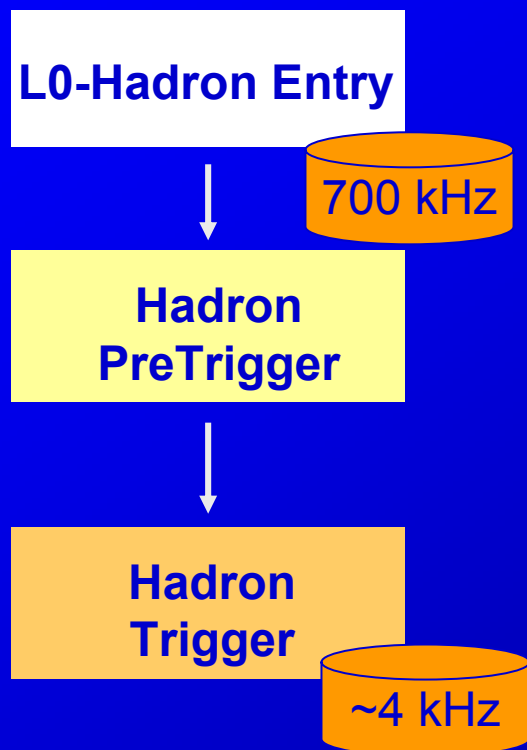
Tracker stations (T):

$\sigma_p/p \sim 1\%$

## RECONSTRUCTION STRATEGY

- Do reconstruction with VELO and select tracks with Impact Parameter
- Fast measurement of  $P_T$  (use TT or match VELO tracks with the muon stations)
- Refine  $P_T$  measurement (use T stations)

# Hadron Alley - Strategy



## HADRON PRETRIGGER

- Reconstruct VELO Tracks and Primary Vertices
  - $\sigma_z \sim 60 \mu\text{m}$ ,  $\sigma_{x,y} \sim 20 \mu\text{m}$
- Select tracks with  $IP > 150 \mu\text{m}$
- Measure  $P_T$  adding hits in Trigger Tracker:  
 $\sigma_p/p \sim 20\text{-}40\%$

## HADRON TRIGGER

- Select tracks with  $|IP| > 100 \mu\text{m}$
- Measure  $P_T$  using Tracking Stations:  $\sigma_p/p \sim 1\%$
- Make secondary vertices

# Hadron Alley - Performance

## HADRON PRETRIGGER

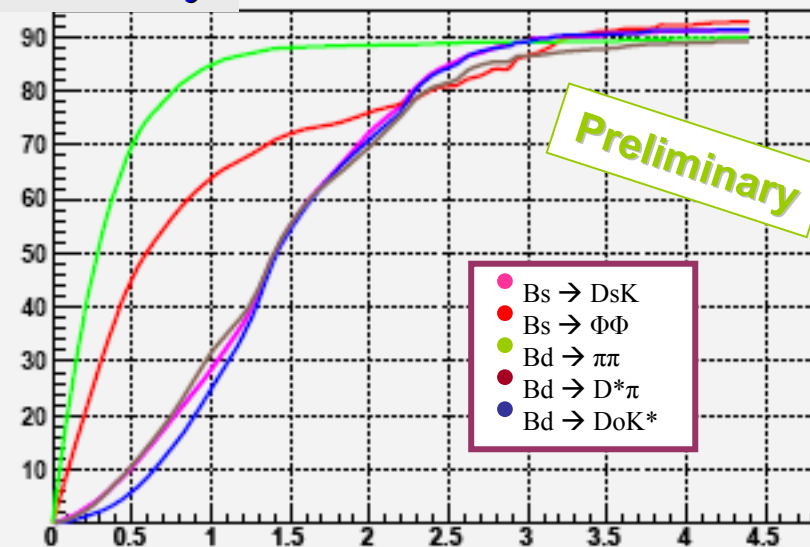
- Single hadron:  $IP > 150 \mu\text{m}$ ,  $P_T > 2.5 \text{ GeV}$
- Double hadron :  $IP > 150 \mu\text{m}$ ,  $P_{T1} > 1.1 \text{ GeV}$ ,  $P_{T2} > 0.9 \text{ GeV}$
- 14% b content
- Signal efficiency:
  - ~80% for e.g.  $B \rightarrow \pi\pi$ ,  $B_s \rightarrow D_s K$

## HADRON TRIGGER

- $|IP| > 100 \mu\text{m}$ ,  $P_T > 1 \text{ GeV}$
- Make 2 track vertices:
  - Dist. Of Closest Approach  $< 200 \mu\text{m}$
- vertex "pointing" to PV
- 48% b content, 17% c content
- Signal efficiency: ~90%  $B_s \rightarrow D_s K$ ,  $B \rightarrow \pi\pi$

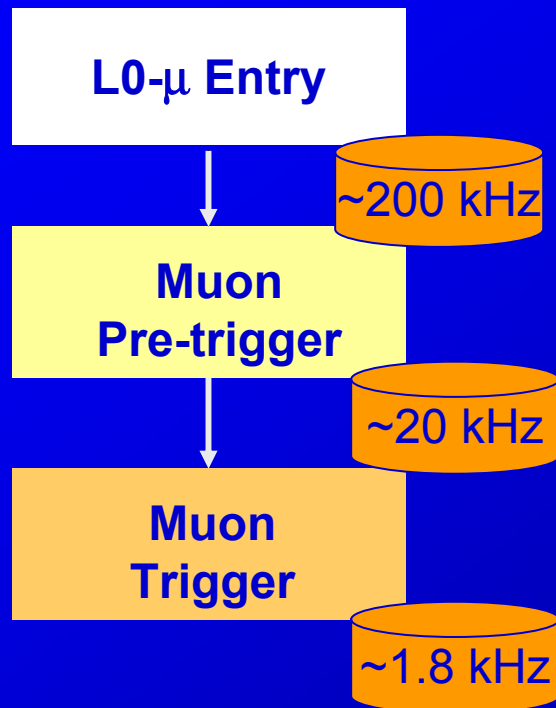
~4 kHz

efficiency



Rate (kHz)

# Muon Alley - Strategy



## MUON PRETRIGGER

- Standalone  $\mu$  reconstruction:  $\sigma_p/p \sim 20\%$
- VELO tracks reconstruction
- Primary vertex reconstruction
- Match VELO tracks and muons:  $\sigma_p/p \sim 5\%$

## MUON TRIGGER

- Tracking of VELO track candidates in the downstream T stations:  $\sigma_p/p \sim 1\%$
- Refine  $\mu$  identification:  
match long (VELO-T) tracks and muons

# Muon Alley - Performance

## MUON PRETRIGGER

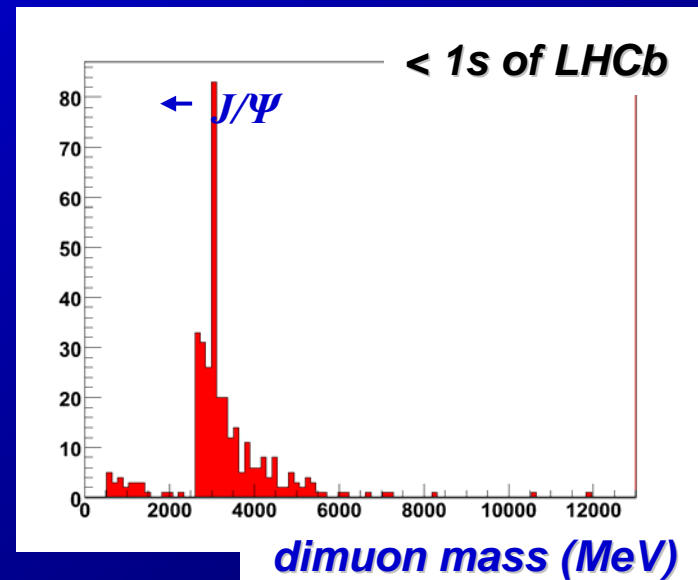
~20 kHz

- $b \rightarrow \mu$  ~11%
- Signal efficiency: ~88%

## MUON TRIGGER

~1.8 kHz

- Single muon
  - $P_T > 3\text{GeV}$  and  $\text{IPS} > 3$
  - $B \rightarrow \mu$  content 60%
- Dimuon
  - mass  $> 0.5\text{GeV}$  and  $\text{IP} > 100\mu\text{m}$
  - $J/\psi$ : mass  $> 2.5\text{GeV}$  (no IP cut!)
- Signal efficiency: ~87%



# Inclusive Streams

## STRATEGY

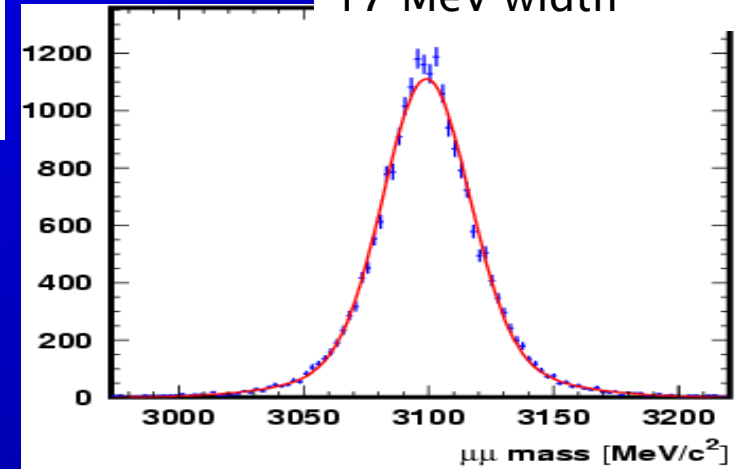
- Full tracking reconstruction at a few kHz
- Select Inclusive streams (e.g.  $D^*$ ,  $D_s$ ,  $\Phi$ , ...)

## $D^*$ INCLUSIVE STREAM

- Clear signal of  $D^{*+} \rightarrow D^0(K^-\pi^+)\pi^+$
- With very high statistics
- Useful to calibrate Particle Identification

~250 Hz

$J/\psi$  from  $B \rightarrow J/\psi K_S$  :  
17 MeV width



## MUON INCLUSIVE STREAMS

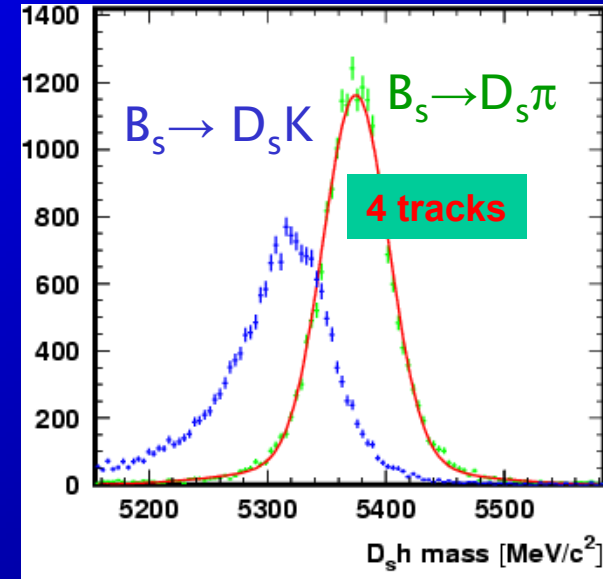
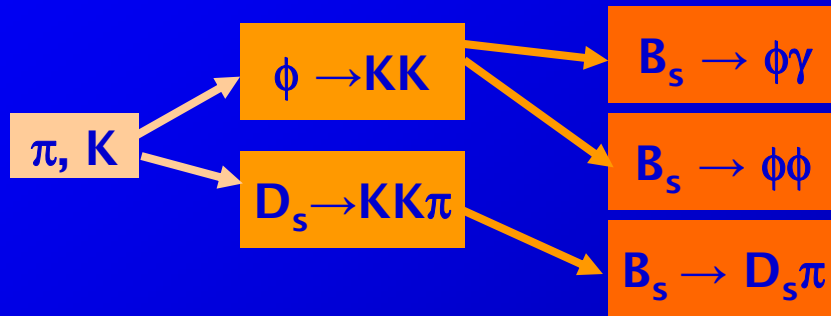
- **Single Muon:** enhanced b-sample:  $B \rightarrow \mu X$ 
  - 70% B-purity, enables trigger-check on unbiased other B-meson
  - Could be used for studying the tagging performance
- **Dimuon:**
  - $J/\Psi$ ,  $\Psi(2S)$ , etc.
  - Proptime resolution studies from prompt  $J/\Psi$  events
  - Use narrow mass to study alignment, momentum calibration due to B-field
  - Select a di-muon with no lifetime bias!

# Exclusive Selections

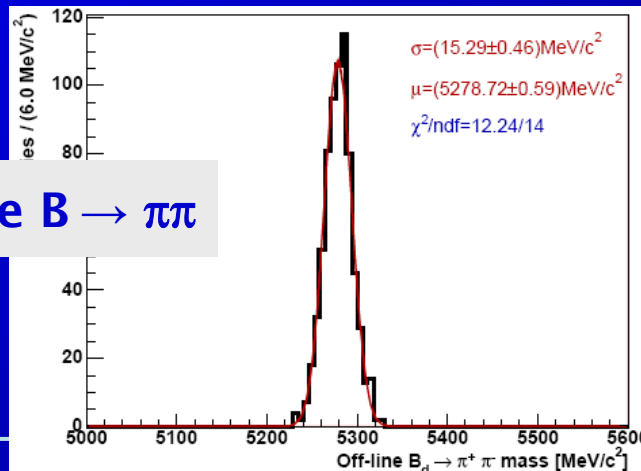
## EXCLUSIVE SELECTIONS

- Use common available reconstructed and selected particles ( $D_s$ ,  $D^0$ ,  $K^*$ ,  $\Phi$ ,...)
- Wide B-mass windows (typically  $\sim 500$  MeV)
- Efficiency: e.g.  $\sim 90\%$  for  $B \rightarrow \pi\pi$

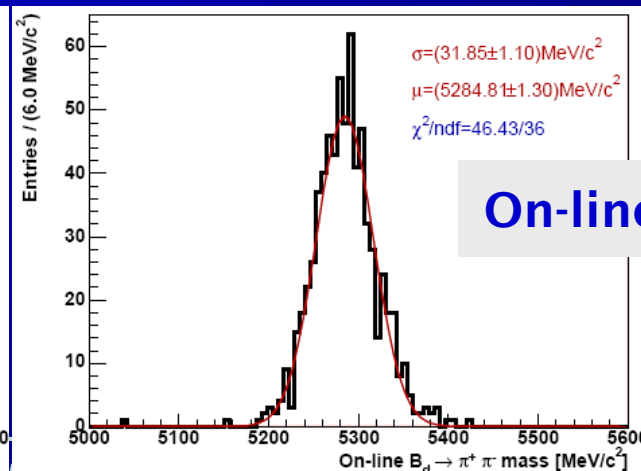
$\sim 200$  Hz



Off-line  $B \rightarrow \pi\pi$



On-line  $B \rightarrow \pi\pi$



# Outlook

## ❖ LHCb TRIGGERS IN GOOD SHAPE

### ❖ LEVEL-0

- ❖ strategy well defined
- ❖ good performance for B-decays
- ❖ rather flexible, robust, with built-in redundancy
- ❖ production of hardware components well under way
- ❖ commissioning early 2007

### ❖ HLT

- ❖ strategy details being finalized
- ❖ exploitation of Level-0 triggering information
- ❖ high efficiency for B-decays
- ❖ flexible and robust