The LHCb Trigger System

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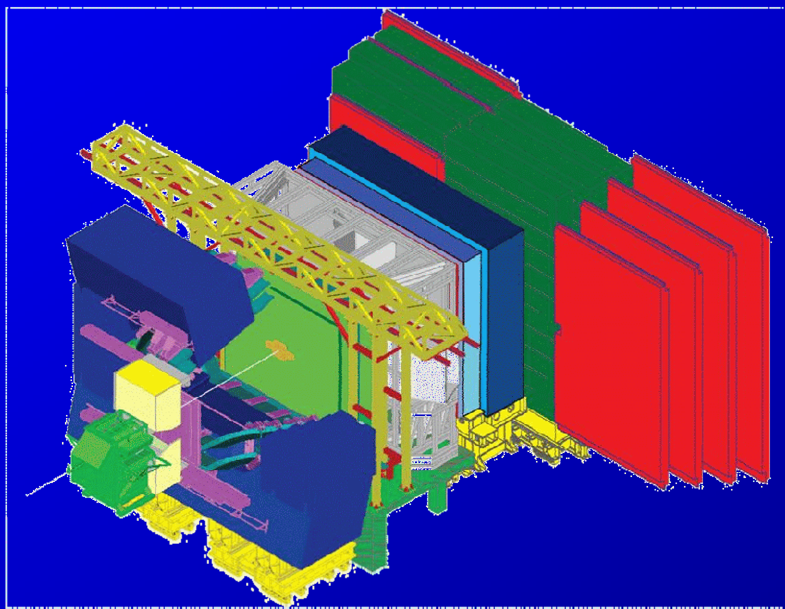
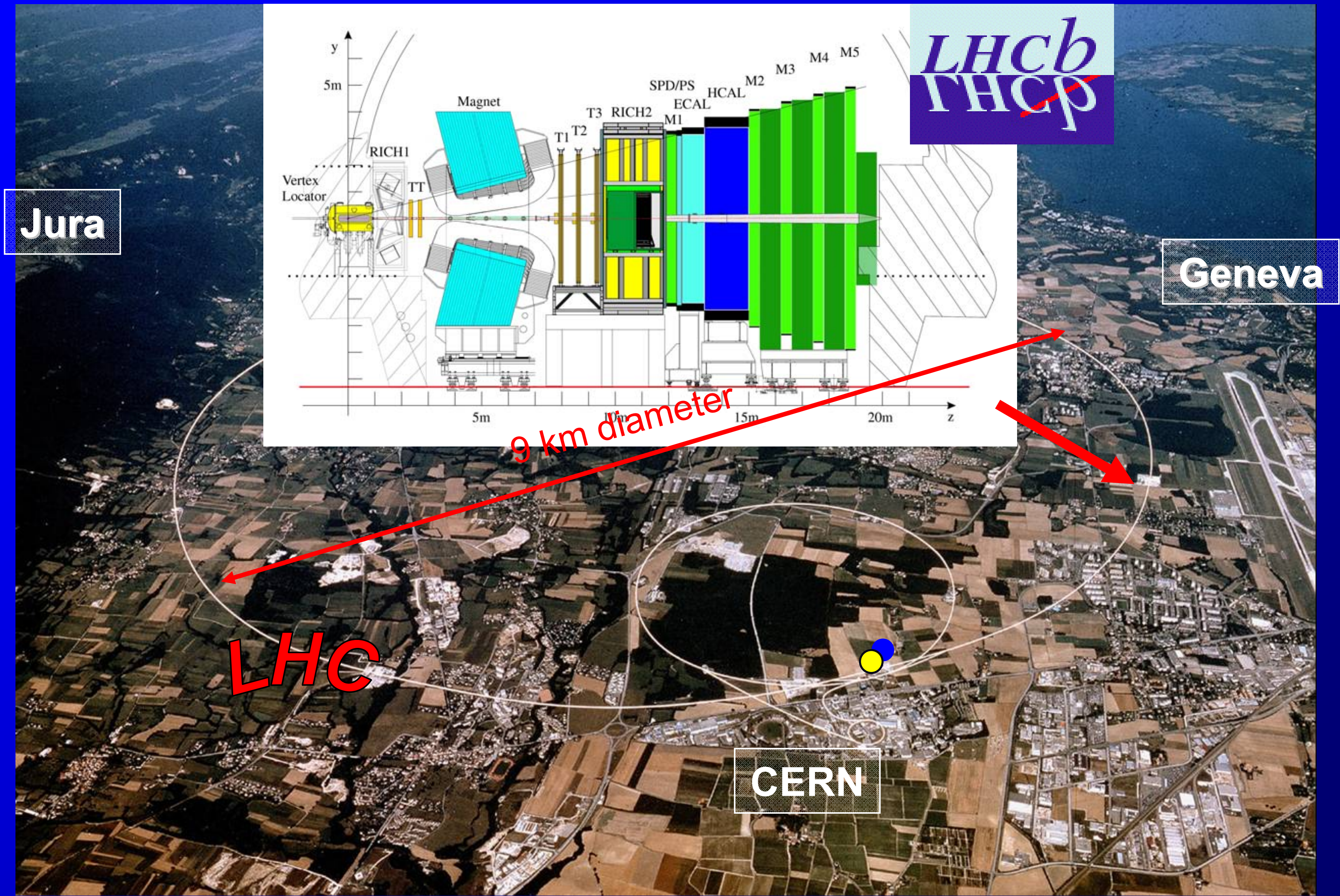
On behalf of the LHCb Collaboration

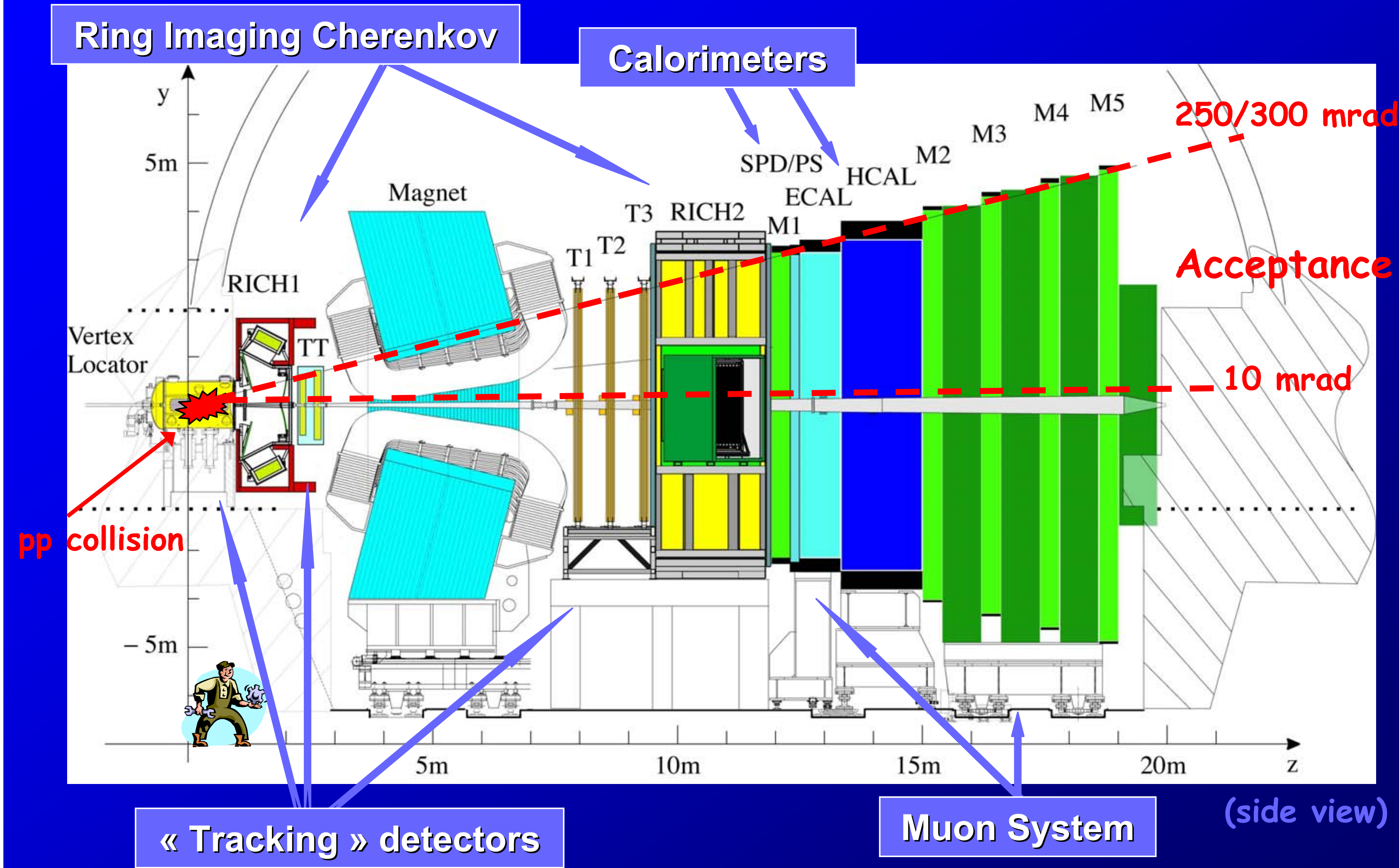
Beauty 2006, Oxford, UK   25th-29th Sep 2006



- 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


Jura
Geneva
CERN
LHC
9 km diameter
LHCb
Vertex Locator
RICH1
TT
Magnet
T1
T2
T3
RICH2
SPD/PS
ECAL
HCAL
M1
M2
M3
M4
M5
y
5m
z
5m
10m
15m
20m

LHCb Detector



(side view)

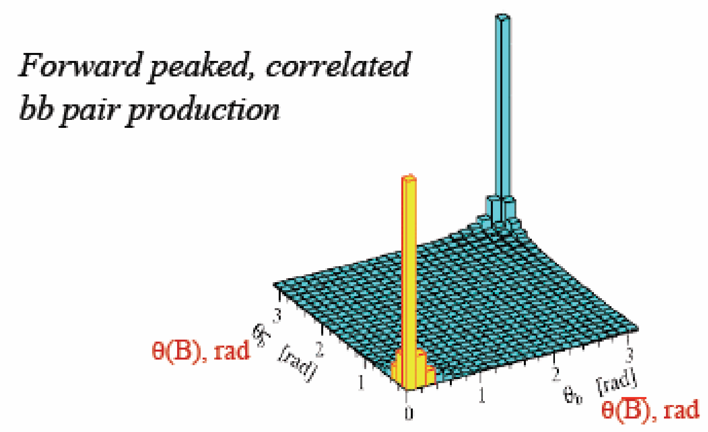
Trigger Strategy & Overview

- LHC(b) Environment
- Trigger Overview & Strategy

LHC(b) Environment

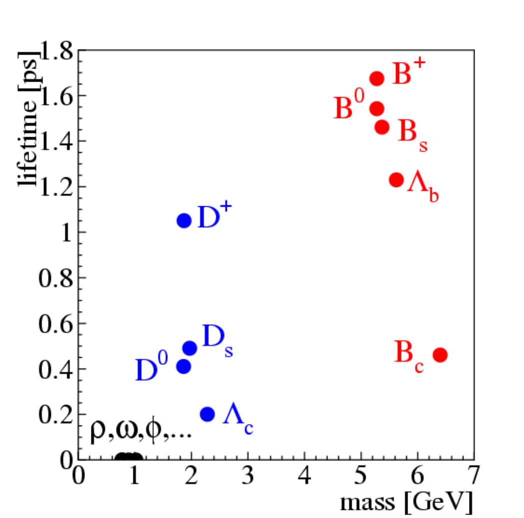
LHC environment

- pp collisions at E_{CM} = 14 TeV
- t_{bunch} = 25 ns ↔ bunch crossing rate = 40 MHz
- <L> = 2×10^{32} cm^{-2} s^{-1} @ LHCb interaction region
  - ↪ 10-50 times lower than for ATLAS/CMS



Cross sections

Physical quantity	Value	Event rate	Yield / year
σ total	~ 100 mb		
σ visible	~ 60 mb	~ 12 MHz	
σ (c-cbar)	~ 3.5 mb	~ 700 kHz	~ 7×10^{12} pairs
σ (b-bbar)	~ 0.5 mb	~ 100 kHz	~ 10^{12} pairs



B-hadrons are heavy and long-lived !

Expected B-signal rates

- branching ratios ~ 10^{-9} – 10^{-4}
  - ➔ 10 – 10^6 events / year ?

Trigger Overview

pp collisions

12 MHz

Level-0

- ✓ custom hardware
- ✓ high E_T particles
- ✓ partial detector information

1 MHz

HLT

- ✓ CPU farm -> software trigger
- ✓ high E_T / IP particles
- ✓ full detector information

~2 kHz

Storage

- ✓ event size ~35 kb

Trigger Strategy

Be alert !

Two-level Trigger

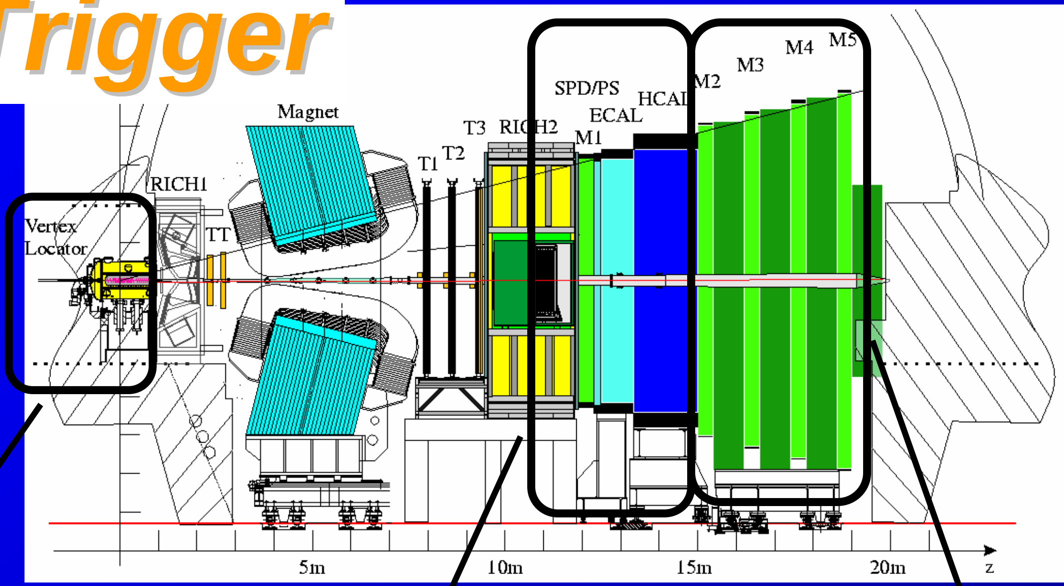
L0 high E_T / P_T particles

- hardware trigger, sub-detector specific implementation
- pipelined operation, fixed latency of 4 μs
- (minimum bias) rate reduction ~12 MHz -> 1 MHz

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

- algorithms run on large PC farm with ~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 -> 2 kHz
- estimated event size ~ 30kb

Level-0 Trigger



Pile-up system

Calorimeter

Muon system

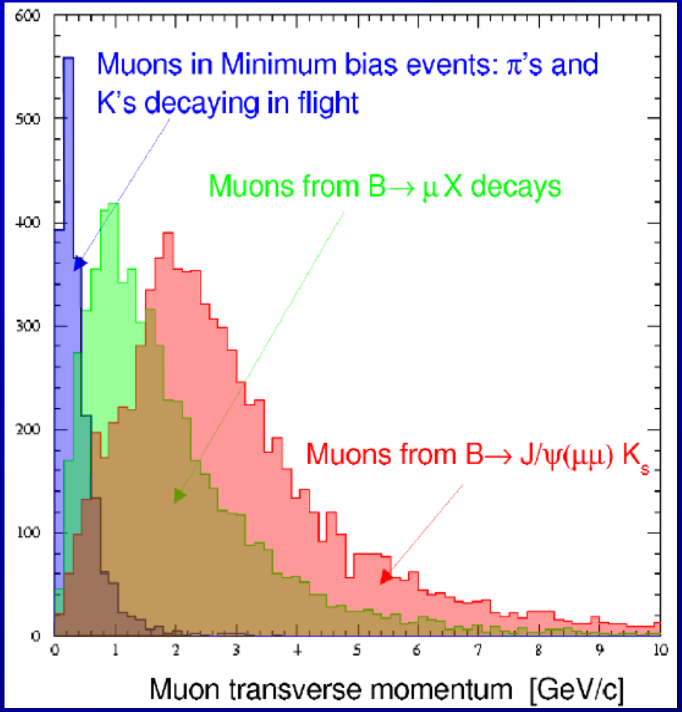
L0 Decision unit

L0DU report

1 MHz

L0 Strategy

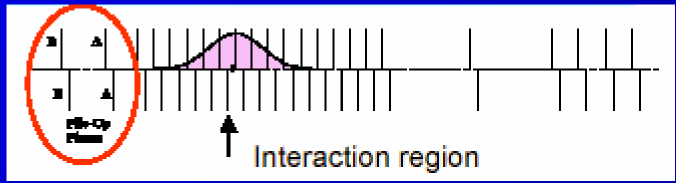
- select high E_T / P_T particles ← L0 thresholds on E_T / P_T of candidates
  - hadrons / electrons / photons / π^0's / muons
- reject complex / busy events ← global event variables
  - more difficult to reconstruct in HLT
  - take longer to reconstruct in HLT
- reject empty events ← global event variables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



L0 Pile-up System

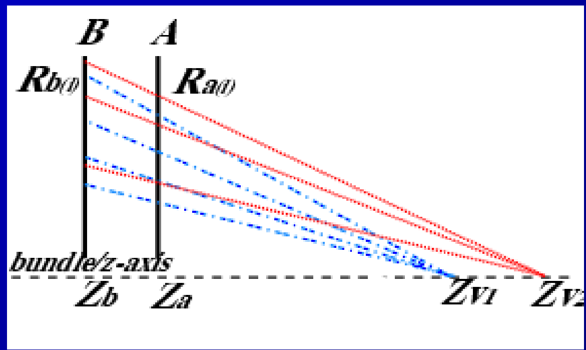
Detector components

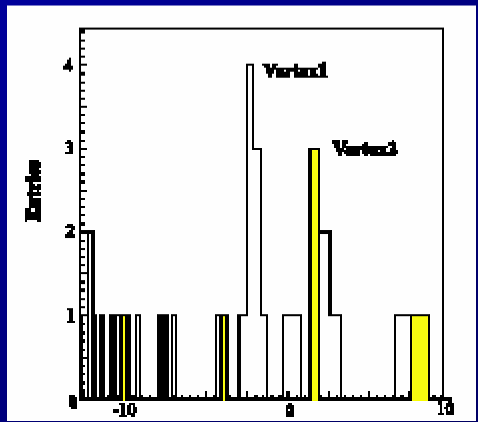
- 2 silicon planes upstream of nominal IP, part of the Vertex Locator (VELO)



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 ~60% and purity ~95%

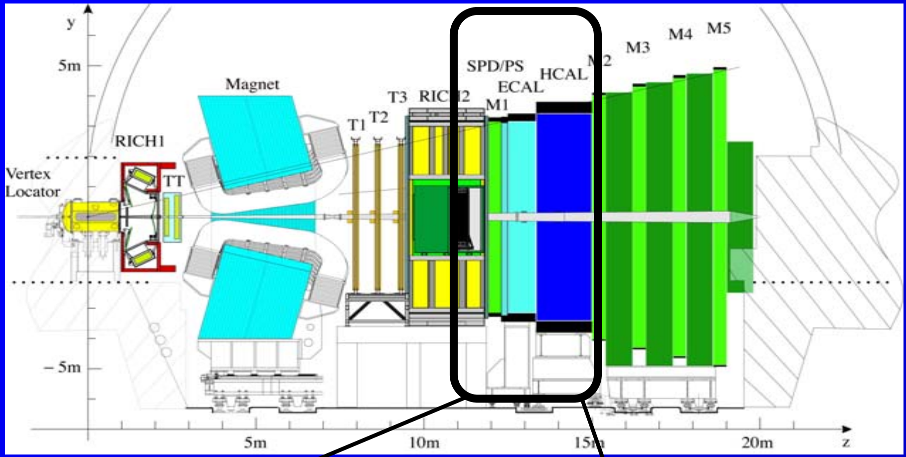




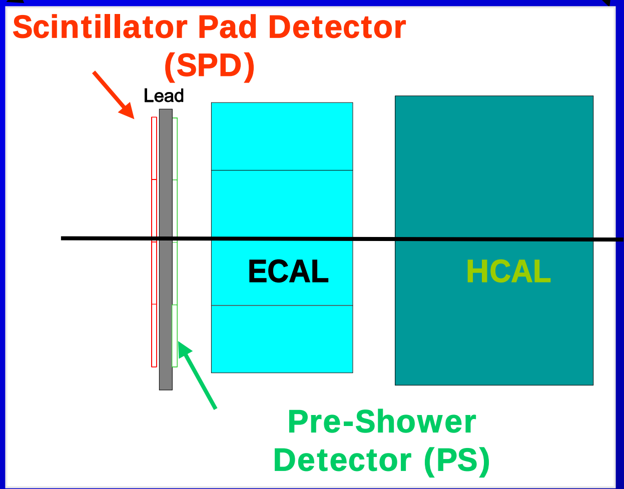
Output for L0DU

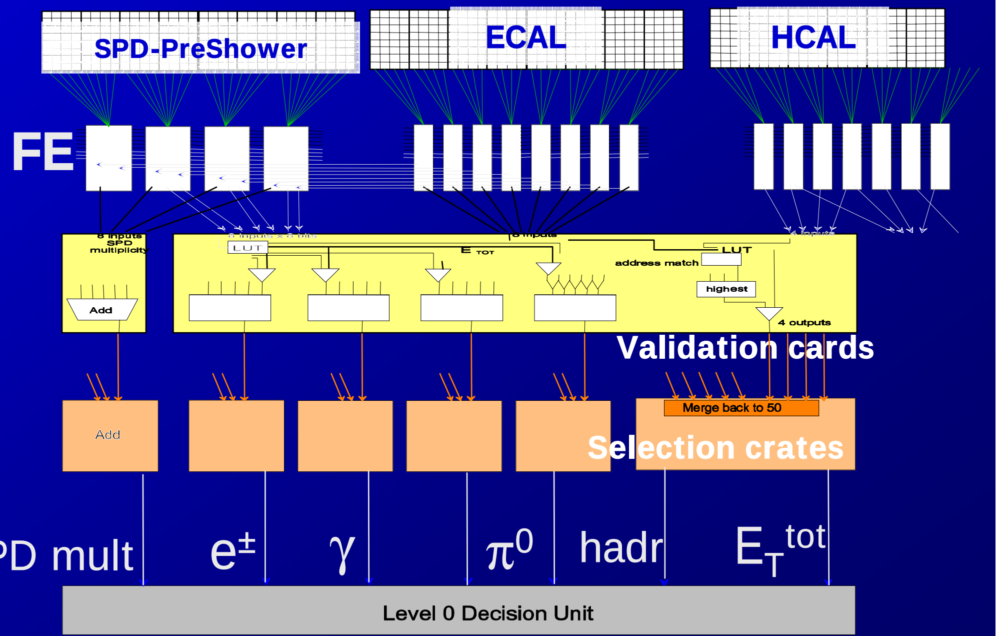
- pile-up system (hit) multiplicity
- number of tracks on second peak/vertex

L0 Calorimeter Trigger (1/2)



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





L0 Calorimeter Trigger (2/2)

Strategy

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

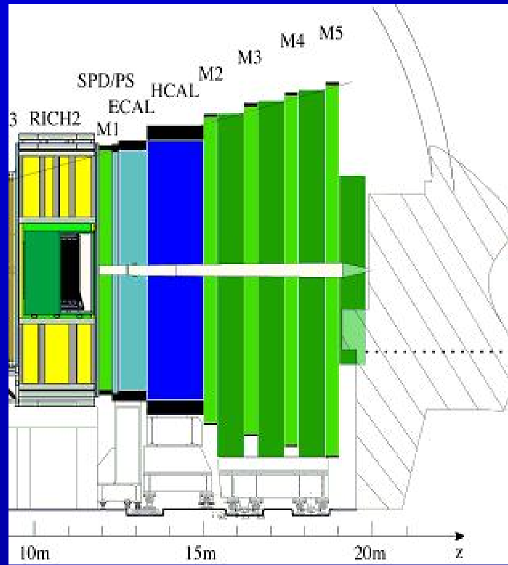
Output for L0 Decision Unit (L0DU)

- highest-E_T candidate of each type
  - ↪ hadron / e / γ / 2 π^0's ("local" and "global")
- global event variables
  - ↪ total E_T in HCAL <-> rejection of empty events
  - ↪ SPD hit multiplicity <-> rejection of busy events

L0 Muon Trigger

Detector components

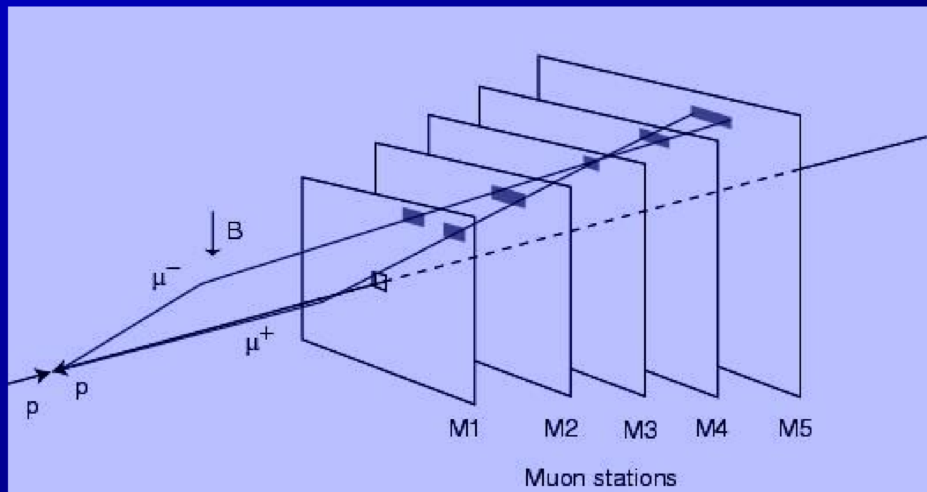
- M1 – M5 muon stations (4 quadrants each)



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):

  σ_p/p ~ 20% for b-decays



Output for L0DU

- 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, γ, 2 π^0's

Muon system

- 2 μ 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

1 MHz

L0DU report

L0 Decision Unit (2/2)

GLOBAL EVENT VARIABLES applied first …

Global event cuts	Cut	Rate (MHz)	
ΣE_T	5.0 GeV	~ 8.3	~ 7
SPD multiplicity	280 hits	~ 13	
Tracks in 2nd vertex	3		
Pile-up multiplicity	112 hits		

Redundancy:
Sub-triggers overlap

… and then cuts on the E_T / P_T CANDIDATES

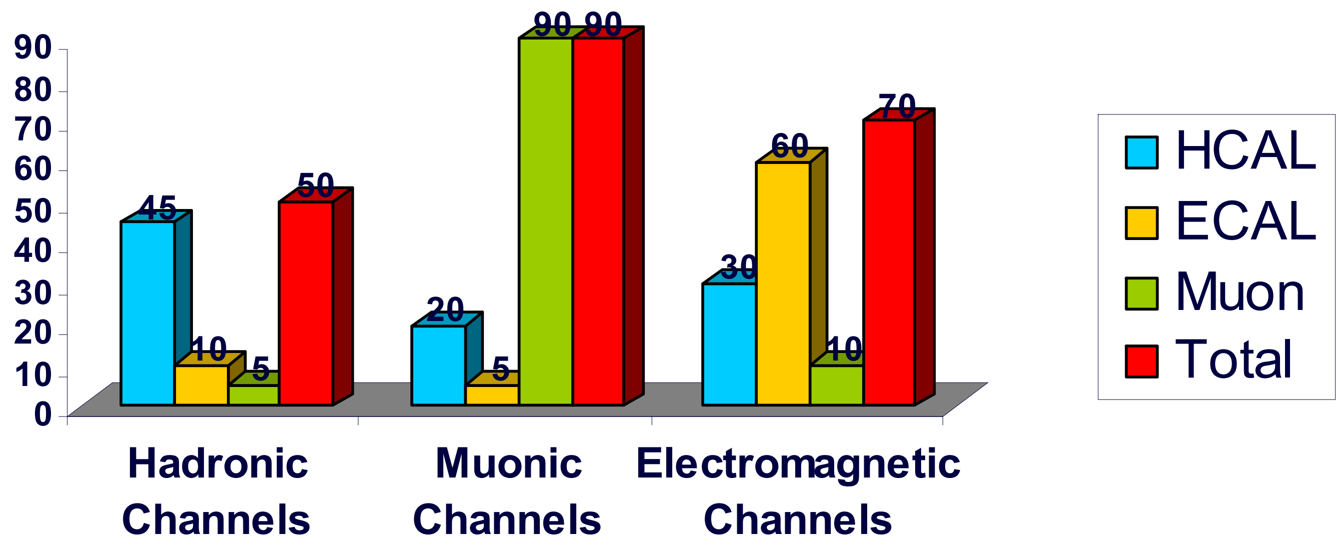
Trigger	Threshold (GeV)	Approx. rate (kHz)	
Hadron	3.6	700	700
Electron	2.8	100	280
Photon	2.6	130	
π^o local	4.5	110	
π^o global	4.0	150	
Muon	1.1	110	160
Di-muon	1.3	150	

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

L0 Performance

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



Hadronic	Muonic	Electromagnetic
$B_s \to D_s \pi$ $B \to \pi\pi$	$B \to J/\Psi(\mu\mu)\, K_s$ $B \to K^* \mu\mu$	$B \to K^* \gamma$ $B \to J/\Psi(ee)\, K_s$

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

High Level Trigger

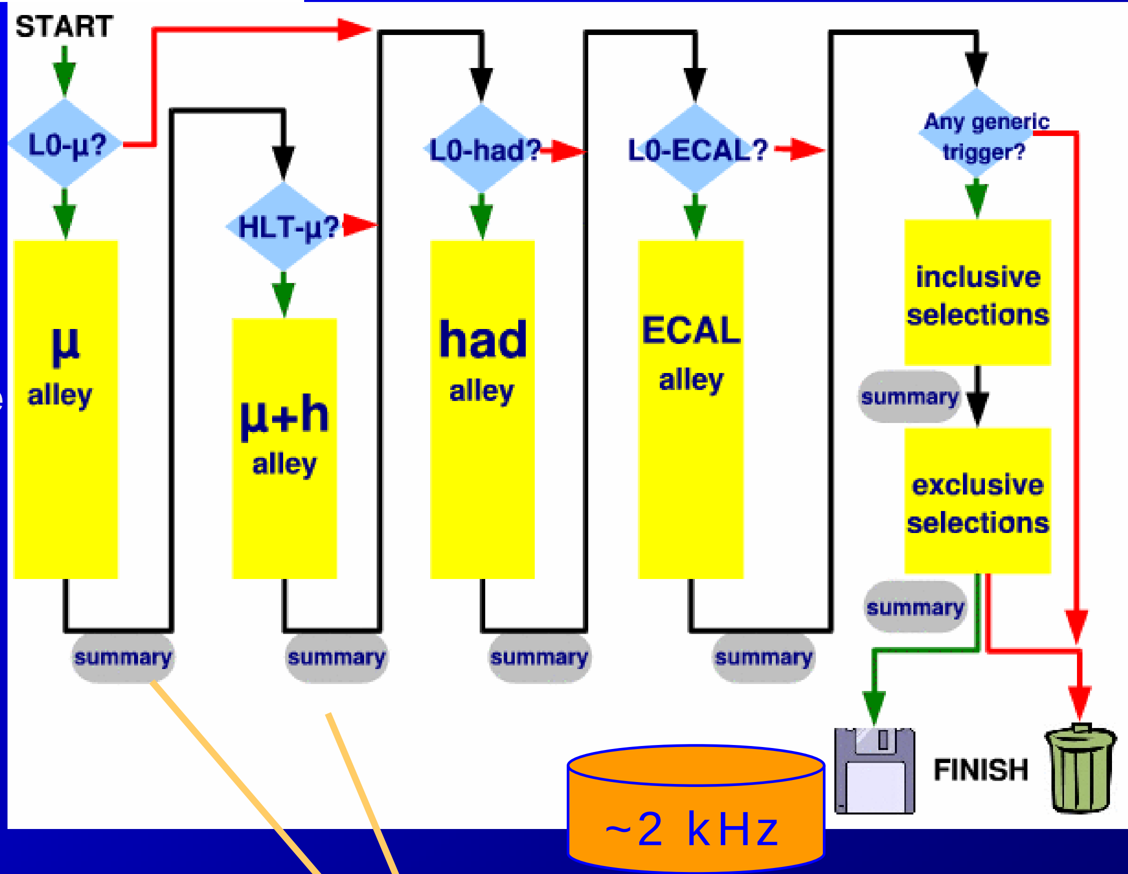
Strategy

Independent alleys:

Follow the L0 triggered candidate

→ ***Muon, Muon + Hadron,***

***Hadron, ECal* streams**



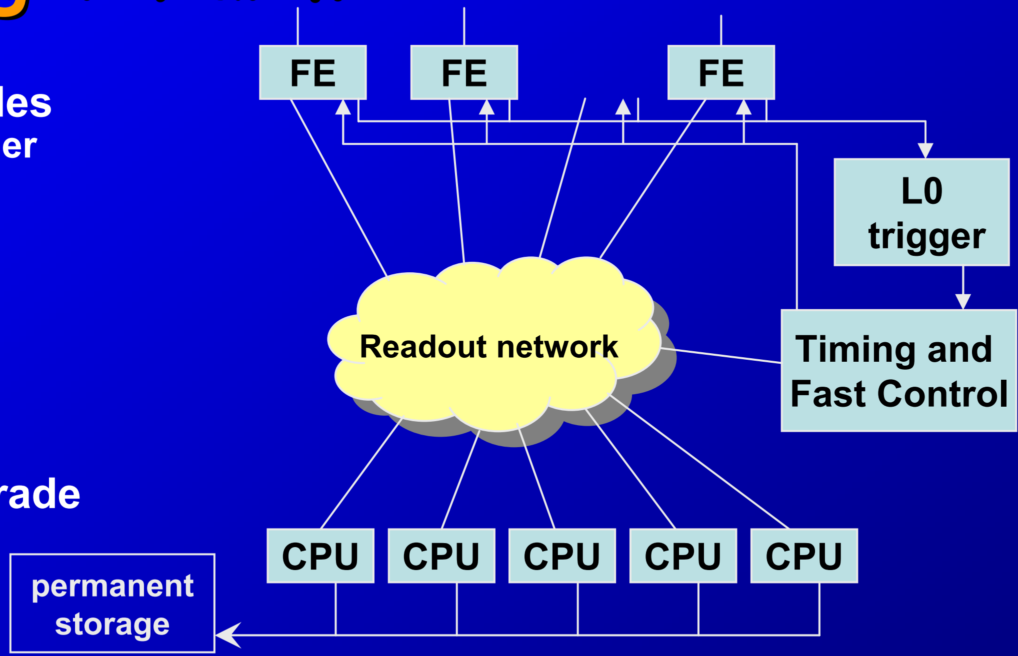
Partial Reconstruction:

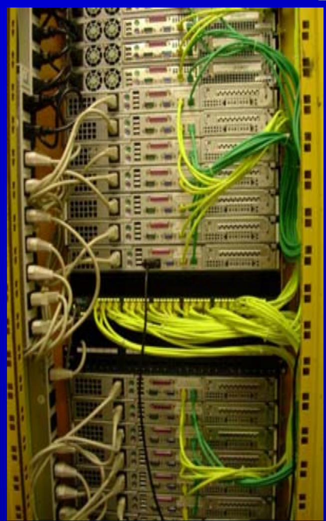
- A few tracks selected per alley (cuts e.g. on P_T, Impact Parameter, mass)
- full reconstruction done at the end of the alleys

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

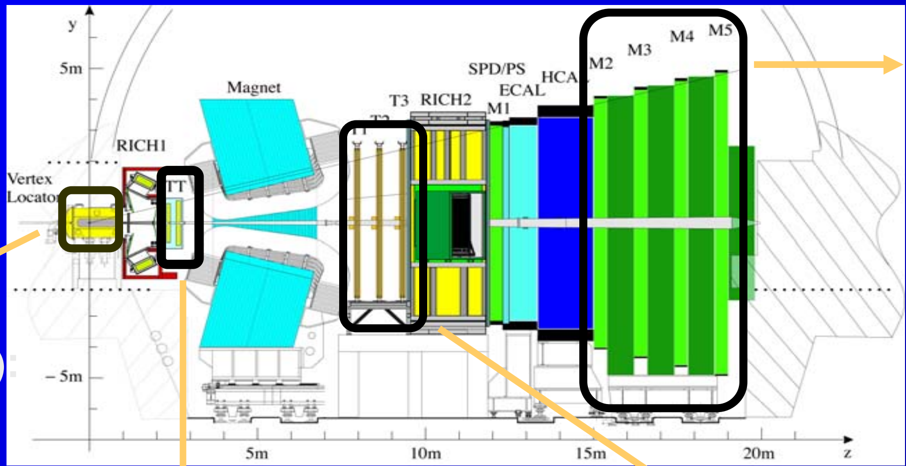




HLT algos CPU time tested on a real farn
→ will fit in the size of the farm foreseen

HLT Tracking / Reconstruction

~ 70 tracks/event after L0



Muon stations:

σ_p/p ~ 20% standalone

σ_p/p ~ 5% matched with VELO tracks

Standalone muons

VErtex LOcator (VELO):

RΦ geometry

Trigger Tracker (TT):

σ_p/p ~ 20-40 %

(using B-field before magnet)

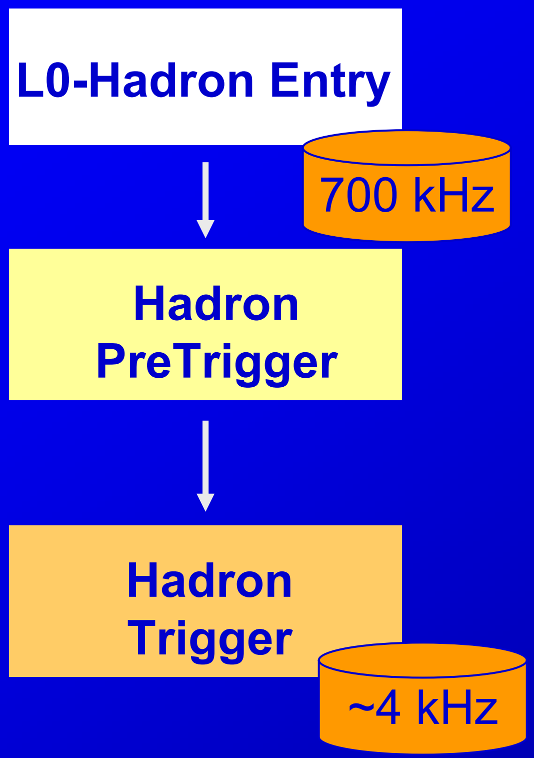
Tracker stations (T):

σ_p/p ~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
  - **$\sigma_Z \sim 60\ \mu m$, $\sigma_{X,Y} \sim 20\ \mu m$**
- Select tracks with IP>150μm
- Measure P_T adding hits in Trigger Tracker: **$\sigma_p/p \sim 20\text{-}40\%$**

Hadron Trigger

- Select tracks with |IP|>100μm
- Measure P_T using Tracking Stations: **$\sigma_p/p \sim 1\%$**
- Make secondary vertices

Hadron Alley - Performance

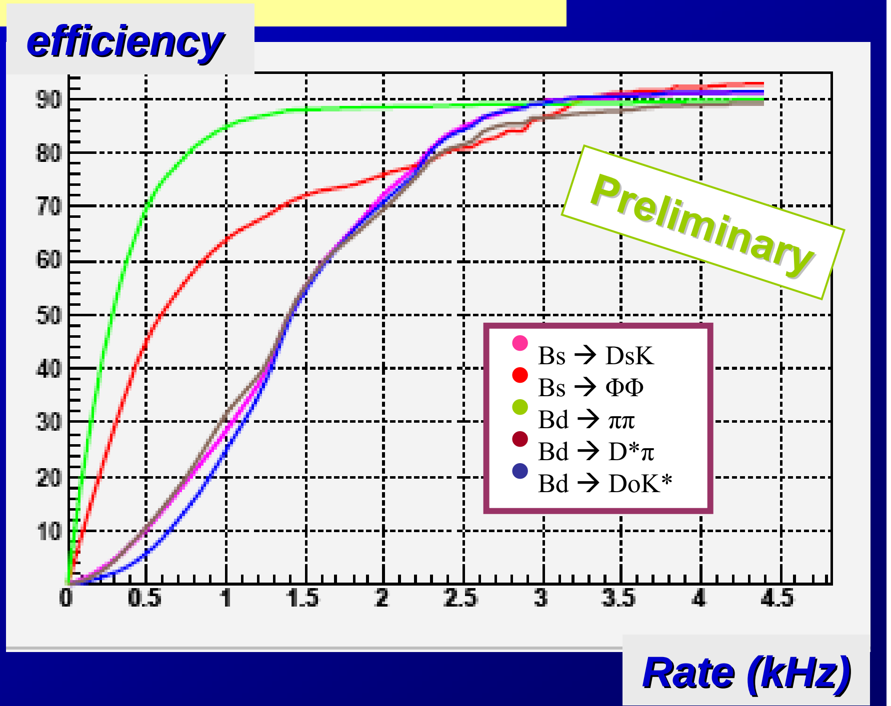
Hadron PreTrigger

- Single hadron: IP>150µm, P_T>2.5 GeV
- Double hadron :IP>150µm, P_{T1}>1.1 GeV, P_{T2}>0.9 GeV
- 14% b content
- Signal efficiency:
  - ~80% for e.g. B→ππ, B_s->D_sK

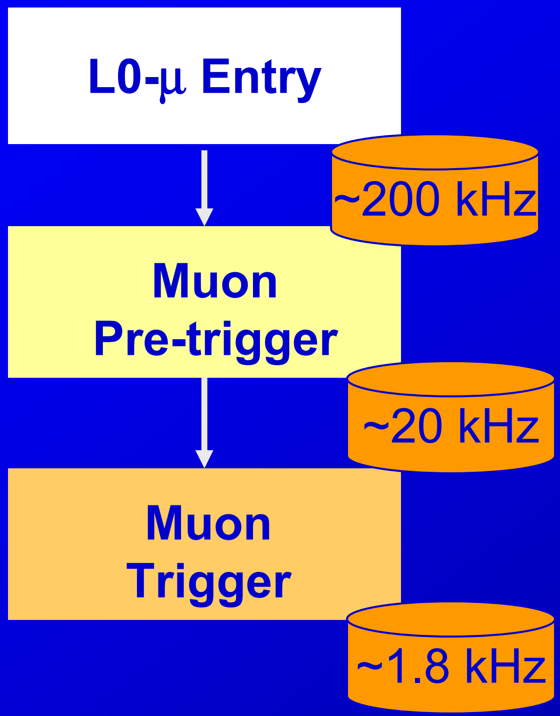
Hadron Trigger

- |IP|>100 µm, P_T> 1GeV
- Make 2 track vertices:
  - Dist. Of Closest Approach < 200 µm
- vertex "pointing" to PV
- 48% b content, 17% c content
- Signal efficiency: ~90% B_s→D_sK, B→ππ

~4 kHz



Muon Alley - Strategy



Muon PreTrigger

- Standalone μ reconstruction: **σ_p/p ~ 20%**
- VELO tracks reconstruction
- Primary vertex reconstruction
- Match VELO tracks and muons: **σ_p/p ~ 5%**

Muon Trigger

- Tracking of VELO track candidates in the downstream T stations: **σ_p/p ~ 1%**
- Refine μ identification:

  match long (VELO-T) tracks and muons

Muon Alley – Performance

~20 kHz

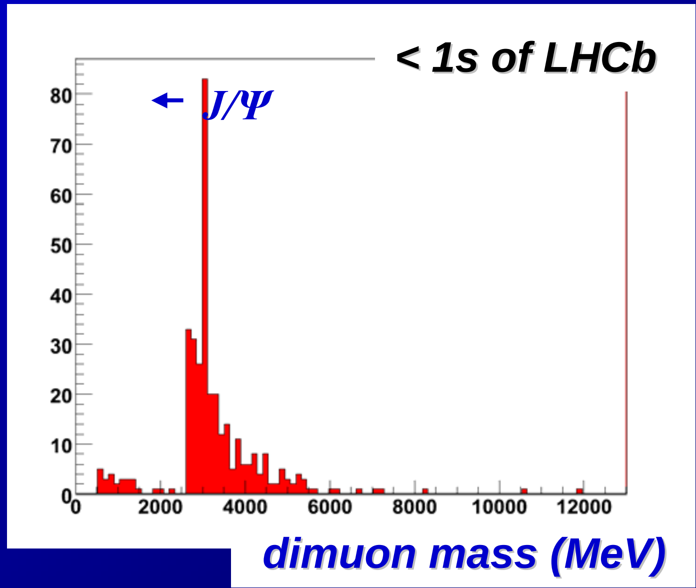
Muon PreTrigger

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

Muon Trigger

- Single muon
  - P_T> 3GeV and IPS> 3
  - $B \to \mu$ content 60%
- Dimuon
  - mass >0.5GeV and IP>100µm
  - J/ψ: mass>2.5GeV (no IP cut!)
- Signal efficiency: ~87%

~1.8 kHz

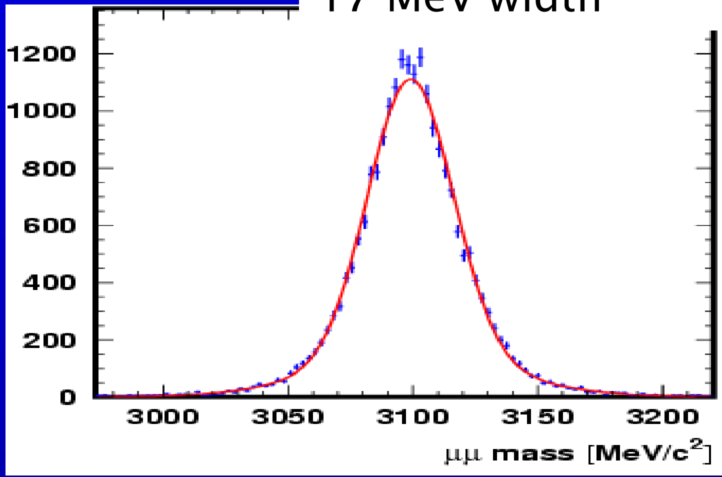


Inclusive Streams

Strategy

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

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



D* inclusive stream

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

~250 Hz

Muon Inclusive streams

- **Single Muon:** enhanced b-sample: $B \to \mu X$
  - 70% B-purity, enables trigger-check on unbiased other B-meson
  - Could be used for studying the tagging performance
- **Dimuon:**
  - J/Ψ, $\Psi(2S)$, etc.
  - Propertime resolution studies from prompt J/Ψ 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

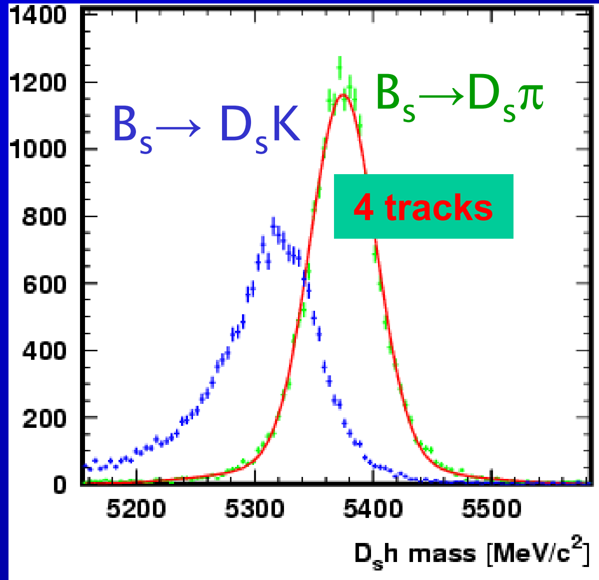
- Use common available reconstructed and selected particles (D_s, D^0, K^*, Φ,..)
- Wide B-mass windows (typically ~ 500 MeV)
- Efficiency: e.g. ~90% for $B \to \pi\pi$

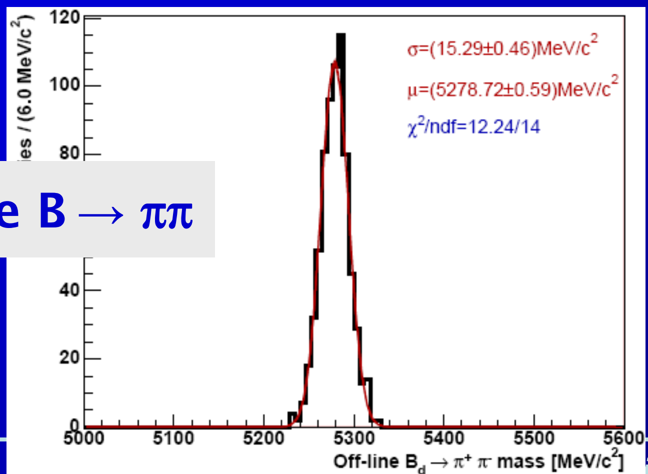
~200 Hz

π, K → $\phi \to KK$, $D_s \to KK\pi$

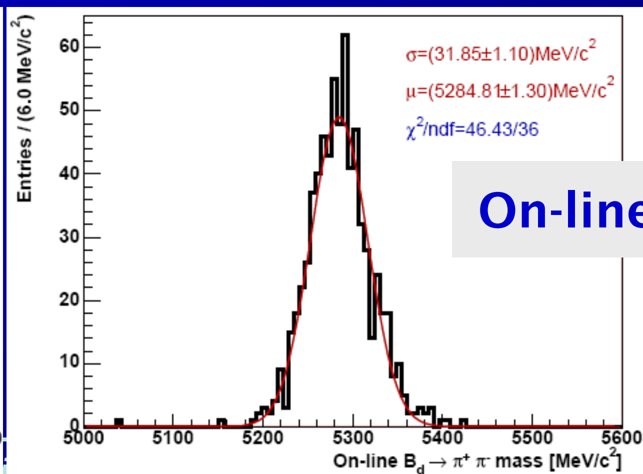
$\phi \to KK$ → $B_s \to \phi\gamma$, $B_s \to \phi\phi$

$D_s \to KK\pi$ → $B_s \to D_s\pi$





Off-line $B \to \pi\pi$



On-line $B \to \pi\pi$

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