

# The LHCb Trigger: present and future.

Roel Aaij

Nikhef, Amsterdam,  
on behalf of the LHCb collaboration

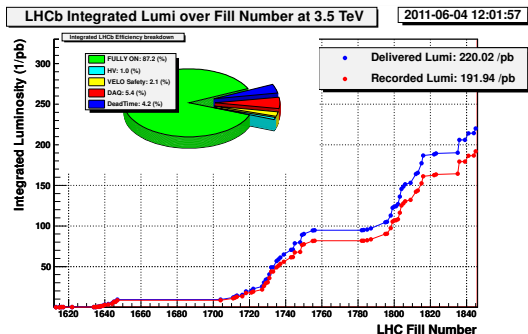
June 10th, 2011



- 1 LHCb in 2010 and 2011
- 2 The Current LHCb Trigger.
- 3 Performance of the Current Trigger.
- 4 The Future LHCb Trigger.
- 5 Conclusions

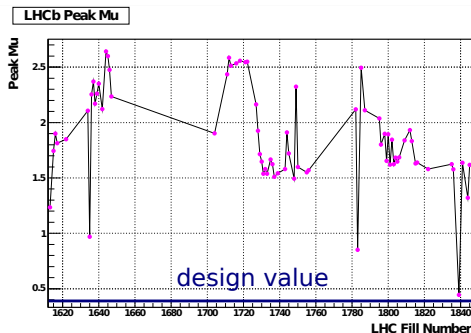
# Luminosity and pile-up

- Luminosity reached  $3 * 10^{32} \text{cm}^{-2} \text{s}^{-1}$
- $\sim 200 \text{pb}^{-1}$  recorded.
- $\mathcal{O}(150\%)$  of design luminosity with  $\mathcal{O}(35\%)$  of the bunches.
- $\sim 1.5 - 2.5$  pp interactions per visible event, close to the foreseen values for the LHCb upgrade.

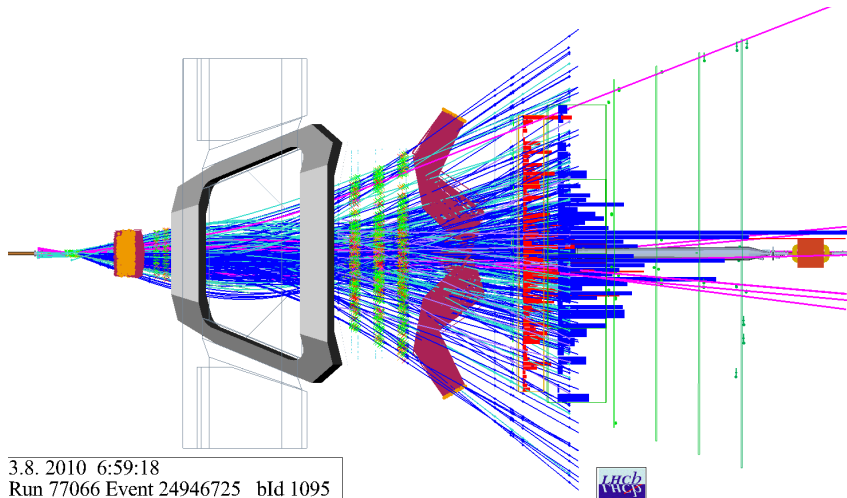


# Luminosity and pile-up

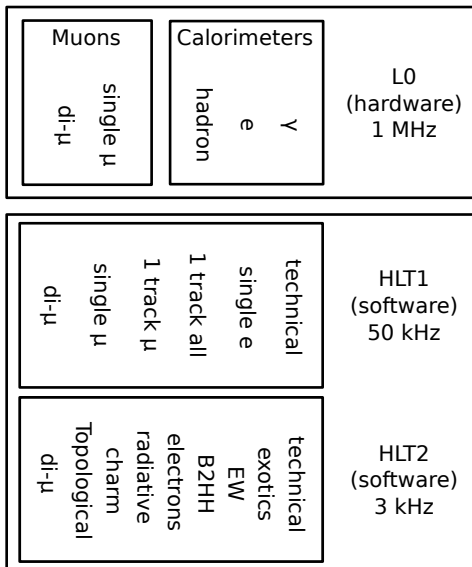
- Luminosity reached  $3 * 10^{32} \text{cm}^{-2} \text{s}^{-1}$
- $\sim 200 \text{pb}^{-1}$  recorded.
- $\mathcal{O}(150\%)$  of design luminosity with  $\mathcal{O}(35\%)$  of the bunches.
- $\sim 1.5 - 2.5$  pp interactions per visible event, close to the foreseen values for the LHCb upgrade.



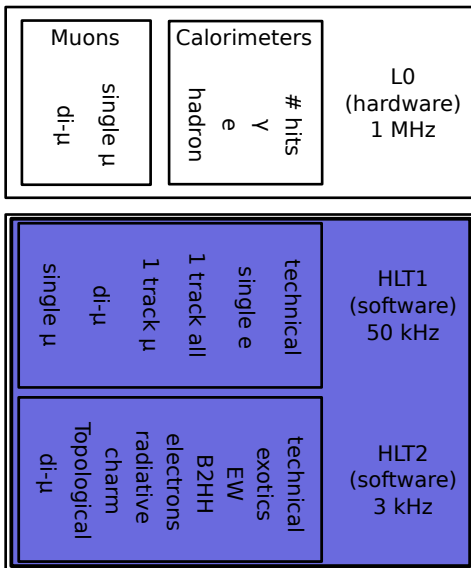
# Event Display



# Trigger Setup

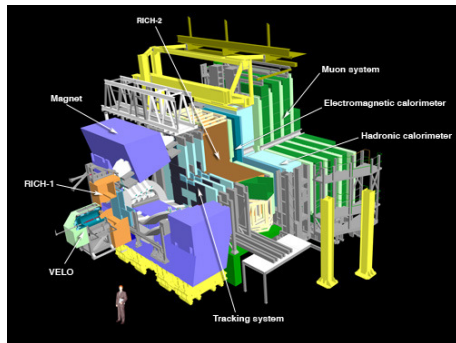


# Trigger Setup



# LHCb Subdetectors in the Trigger.

- Vertex Detector
  - Seed track reconstruction
  - PV reconstruction
- Tracker
  - Momentum determination
- Calorimeters
  - L0 triggers
  - $e, \gamma$  identification
- Muon detector
  - $\mu$  identification



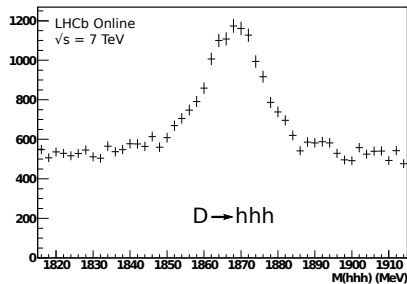
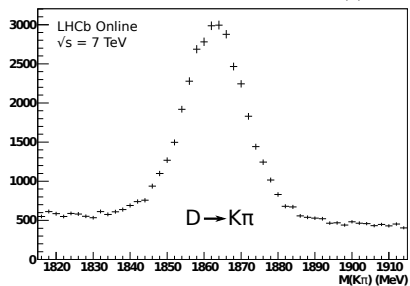
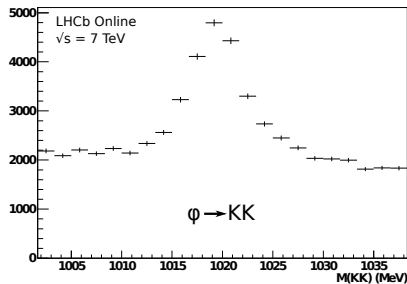
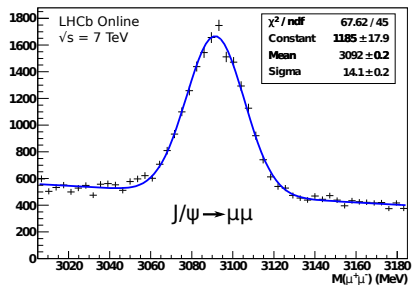


# Efficiency Determination on Data

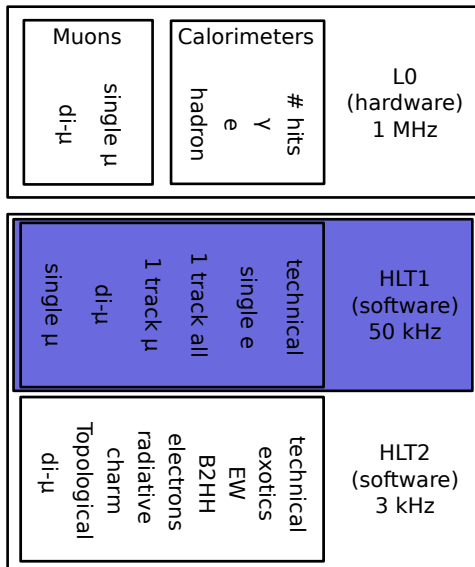
- All trigger candidates are stored in the raw event.
- This allows a comparison with offline candidates.
- If an offline candidate was also flagged by the trigger it is On Signal (OS).
- If the candidate is not required to fire the trigger it is Independent of Signal (IS).
- The efficiency of a trigger line is then given by:

$$\epsilon = \frac{N_{IS\&OS}}{N_{IS}}$$

## Online Monitoring

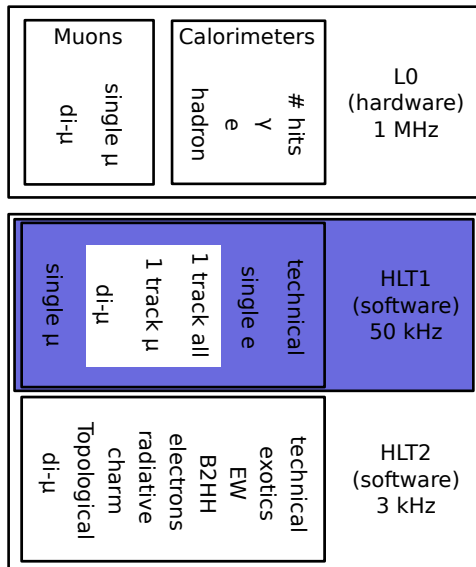


# Trigger Setup: HLT1



- Tight CPU budget (12 ms).
- Inclusive approach.
- Reconstruction and selection interleaved.

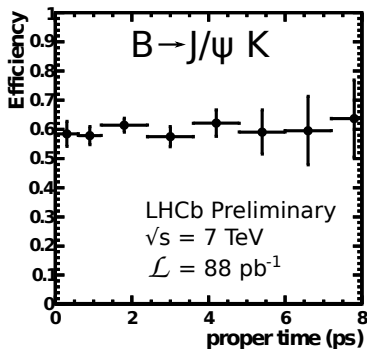
# Trigger Setup: HLT1



- Tight CPU budget (12 ms).
- Inclusive approach.
- Reconstruction and selection interleaved.

# HLT1 DiMuon Triggers

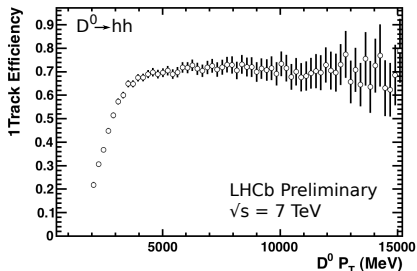
- Start from L0 muon or dimuon.
- Match Velo tracks to muon hits assuming  $P_{min} = 6\text{GeV}$ .
- Determine and cut on momentum.
- Fit tracks; cut hard on track  $\chi^2$ .
- Make dimuons; cut on mass.
- Straightforward and unbiased.
- 5 kHz output.



# HLT1 Single Track Hadron Triggers

“Every  $B$ -decay includes at least 1 good quality track with high impact parameter,  $P$  and  $P_T$ ”.

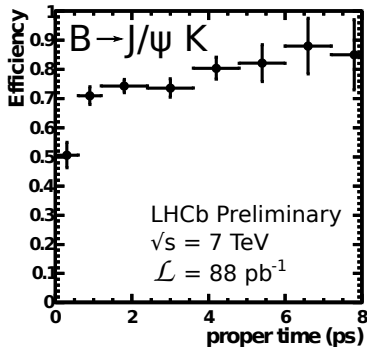
- Start from any L0 decision.
- Find good quality Velo tracks with high IP.
- Determine and cut on momentum.
- Fit tracks; cut hard on track  $\chi^2$ .
- Extremely inclusive.
- 40 kHz output.



# HLT1 Single Track Hadron Triggers

“Every  $B$ -decay includes at least 1 good quality track with high impact parameter,  $P$  and  $P_T$ ”.

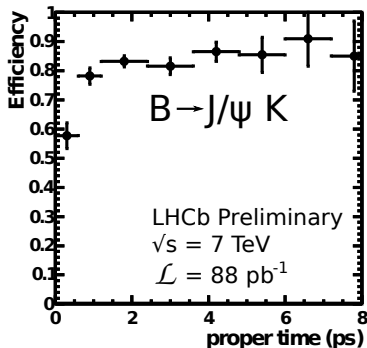
- Start from any L0 decision.
- Find good quality Velo tracks with high IP.
- Determine and cut on momentum.
- Fit tracks; cut hard on track  $\chi^2$ .
- Extremely inclusive.
- 40 kHz output.



# HLT1 Single Track Muon Trigger

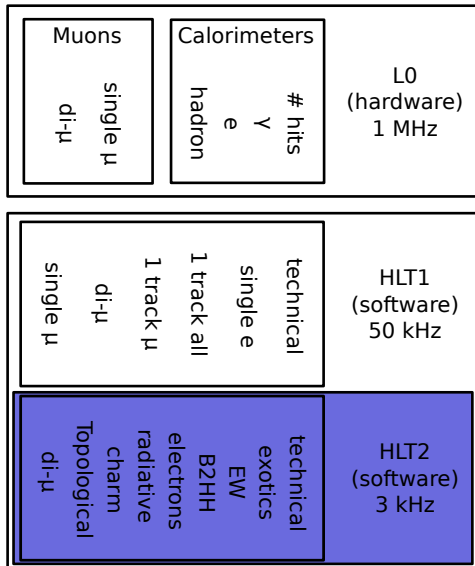
Combine muon matching with the single track principle to allow looser  $P$ ,  $P_T$  and  $IP$  cuts.

- Start from L0 muon or dimuon.
- Find Velo tracks with high IP.
- Match Velo tracks to muon hits assuming  $P_{min} = 6\text{GeV}$ .
- Determine and cut on momentum.
- Fit tracks; cut hard on track  $\chi^2$ .
- 5 kHz output.



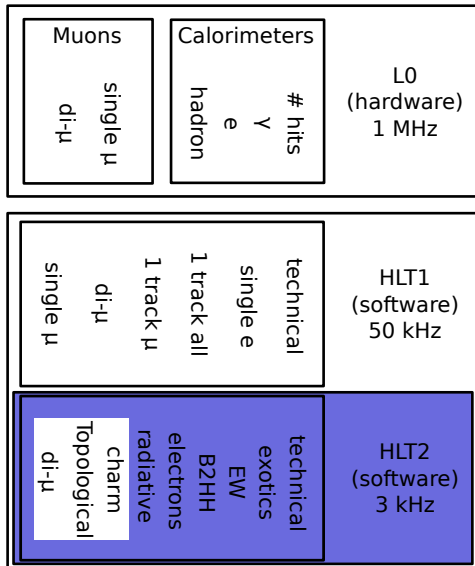


# Trigger Setup: HLT2



- Global track reconstruction.
- Other reconstruction on demand.
- Inclusive and exclusive selections.

# Trigger Setup: HLT2

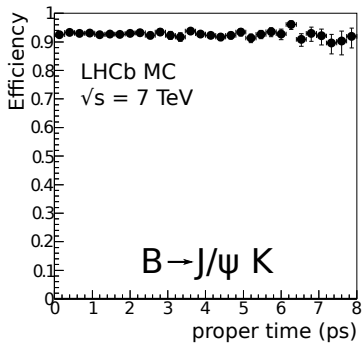


- Global track reconstruction.
- Other reconstruction on demand.
- Inclusive and exclusive selections.

# HLT2 Inclusive Triggers: Dimuon

Many key LHCb physics channels use dimuons:  $B_s \rightarrow \mu^+ \mu^-$ ,  $B \rightarrow J/\psi X$ ,  $J/\psi$ . Making the trigger selection as unbiased as possible and as close to offline as possible simplifies analysis.

- Steady configuration over 2010 and 2011.
- Use offline muon id.
- 93% efficient for  $B \rightarrow J/\psi X$ .
- 900 Hz combined muon output.



# HLT2 Inclusive Triggers: Topological (2010)

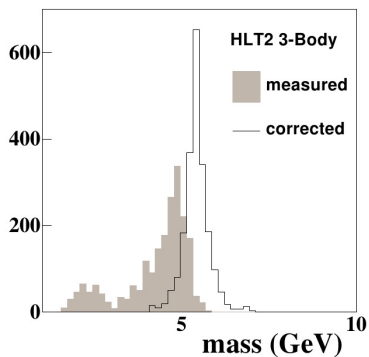
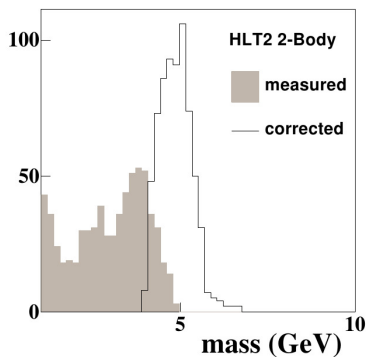
The topological trigger is designed to trigger on decays of  $B \rightarrow$  anything by exploiting common  $B$ -decay properties. A cut based approach was used in 2010.

- Track  $\chi^2_{dof}$ ,  $IP\chi^2$
- $P_{T,min,max}$ ,  $\sum P_T$
- Flight Distance  $\chi^2$
- $\sum IP\chi^2$
- DOCA
- 2-, 3- and 4-body variants.
- 80-90% efficient.
- Good background rejection.
- Main 2010 trigger for  $B \rightarrow$  hadrons.

$$M_{corr} = \sqrt{M^2 + |P_{T,miss}|^2} + |P_{T,miss}|,$$

where  $P_{T,miss}$  is the missing momentum transverse to the flight direction of the  $B$  and accounts for missing daughters.

## Corrected Mass



$M_{corr}$  of  $B^0 \rightarrow K^* \mu^+ \mu^-$  trigger candidates.

# HLT2 Inclusive Triggers: Topological (2011-)

This year's conditions required the background to be reduced by a factor three. To keep or even improve upon 2010 efficiencies, MVA became a requirement.

A Boosted Decision Tree is a good option, but how to:

- Protect the BDT from using small regions of phase space.
- Ensure common properties of  $B$ -decays are used.
- Mitigate online vs. offline differences.
- Create a sufficiently fast implementation.

# HLT2 Inclusive Triggers: Topological (2011-)

Use a BDT with discretised variables: the “[Bonsai Boosted Decision Tree](#)”, forcing the BDT to split only at predefined values.

- Use most of the 2010 variables.
- Choose discretisation using physics, resolutions and common  $B$ -decay properties.

# HLT2 Inclusive Triggers: Topological (2011-)

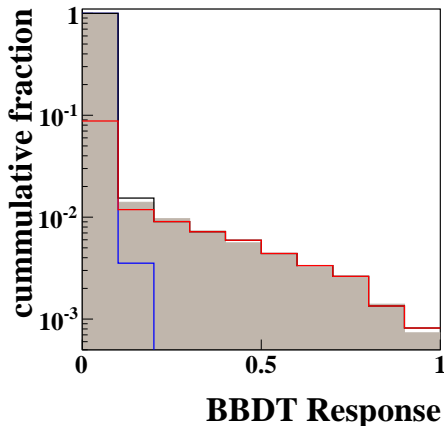
Use a BDT with discretised variables: the “[Bonsai Boosted Decision Tree](#)”, forcing the BDT to split only at predefined values.

- Use most of the 2010 variables.
- Choose discretisation using physics, resolutions and common  $B$ -decay properties.
- Efficiencies at least as good as 2010 Topo.
- Background reduced by a factor 3.
- Allows the semi-infinite number of BDT if statements to be converted to a 1-D array of response values with fast look-up.
- 1 kHz combined output.



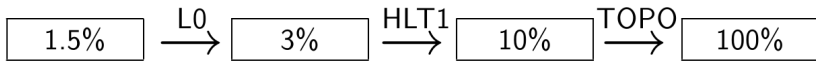
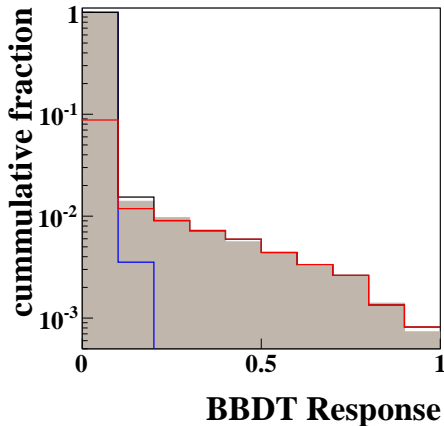
# HLT2 Inclusive Triggers: Topological (2011-) (MC)

- Minbias data (grey)
- Inclusive b MC (red)
- Inclusive c MC (blue)
- LHCb cross-section used to normalise MC to data.



# HLT2 Inclusive Triggers: Topological (2011-) (MC)

- Minbias data (grey)
- Inclusive b MC (red)
- Inclusive c MC (blue)
- LHCb cross-section used to normalise MC to data.
- MC signal purity:



# HLT2 Exclusive Triggers: Charm

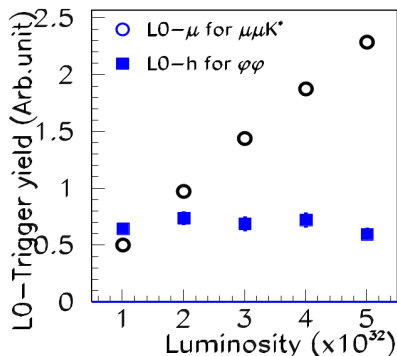
Triggers for charm decays face a specific set of challenges. Momentum cuts to speed up the general reconstruction severely affect efficiencies and acceptances in the Dalitz plane. Since branching ratios are generally high, the focus is on avoiding biases and acceptance effects.

The absence of RICH based PID in the trigger and high combinatorial backgrounds due to the softer charm decays make inclusive strategies untenable.

This is overcome by using a 2-stage approach, first selecting good 2-body combination to reduce rates, followed by an extra reconstruction step to recover softer tracks and a final exclusive reconstruction.

# Limitations of the Current Trigger

- The current L0 trigger is at the limit of enriching capabilities for hadronic events.
- The only way out is to upgrade the detector to full 40MHz readout.



# LHCb Upgrade: Physics Case

The target luminosity for the current LHCb detector is  $\sim 5\text{fb}^{-1}$ . Many interesting physics goals can be reached in the forward direction with an upgraded LHCb detector and a target luminosity of  $\sim 50\text{fb}^{-1}$ .

- Measure unitarity angle  $\gamma$  to  $< 1^\circ$  to match theory improvements.
- Charm CPV below  $10^{-4}$ .
- Measure  $\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)$  to a precision of  $\sim 10\%$  of SM value.
- Measure  $2\beta_s$  to a precision of  $< 20\%$  of SM value.

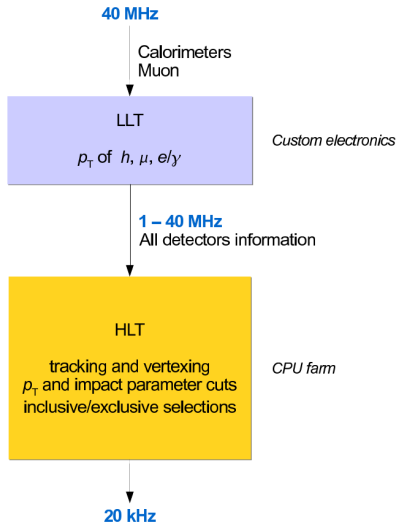
# LHCb Upgrade: Physics Case

The target luminosity for the current LHCb detector is  $\sim 5\text{fb}^{-1}$ . Many interesting physics goals can be reached in the forward direction with an upgraded LHCb detector and a target luminosity of  $\sim 50\text{fb}^{-1}$ .

- Measure unitarity angle  $\gamma$  to  $< 1^\circ$  to match theory improvements.
- Charm CPV below  $10^{-4}$ .
- Measure  $\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)$  to a precision of  $\sim 10\%$  of SM value.
- Measure  $2\beta_s$  to a precision of  $< 20\%$  of SM value.
- Search for  $\sim 1\text{GeV}$  Majorana neutrinos in  $D$  and  $B$  decays.
- Search for exotic long-lived particles.
- Measure  $A_{FB}$  to a statistical precision of  $\sim 0.0004$ .

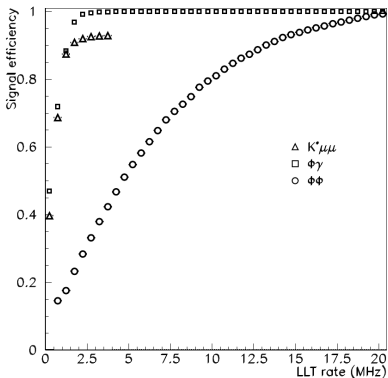
# Upgrade Trigger Strategy

- Use Low Level Trigger to allow staging of farm input.
- Baseline HLT1: single track triggers.
- Baseline HLT2: Topological + (Detached) DiMuons.
- Additional HLT2: Charm + exclusive selections.



# Upgrade Trigger Performance (MC)

Allowing the LLT rate to go up to 20MHz significantly improves efficiencies for hadronic  $B$ -decays.

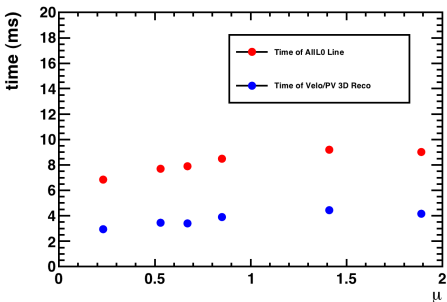


Signal efficiencies versus maximum allowed LLT rate.

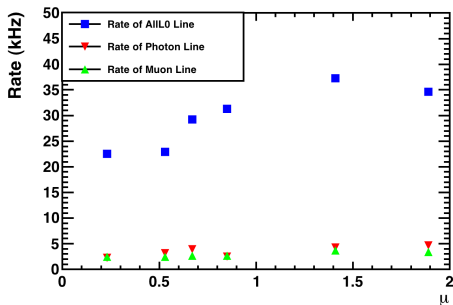


# Upgrade Trigger Performance

LHCb has been run at a pile-up similar to what is foreseen for the upgrade. This allows the use of minimum bias data to evaluate trigger performance for the upgrade in terms of CPU usage and output rates.



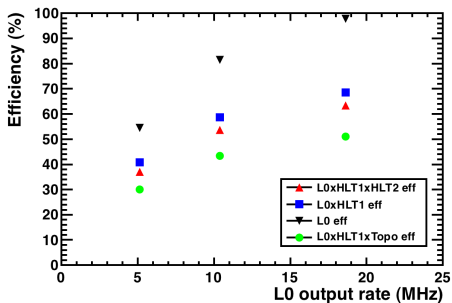
Single track trigger time at different values of  $\mu$ .



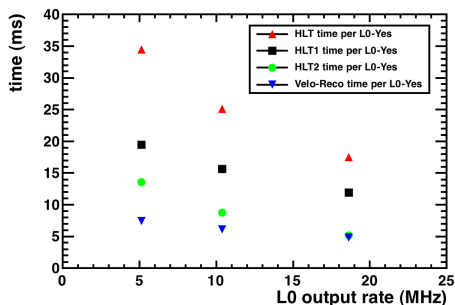
Single track trigger rate at different values of  $\mu$ .

# Upgrade Trigger Performance

LHCb has been run at a pile-up similar to what is foreseen for the upgrade. This allows the use of minimum bias data to evaluate trigger performance for the upgrade in terms of CPU usage and output rates.



$B_s \rightarrow \phi\phi$  trigger efficiency at different LLT rates.



HLT time consumption at different LLT rates.

# Conclusions and Prospects

- Excellent performance of LHC and LHCb.
  - LHC attained it's 2010 target for instantaneous luminosity and is well underway for 2011.
  - $37.5\text{pb}^{-1}$  on tape in 2010;  $200\text{pb}^{-1}$  so far this year.
- The inclusive strategy for HLT1 and HLT2 shows excellent efficiencies and performance across the board.
- High efficiencies for charm, hadronic- and leptonic  $B$ -decays; the trigger basically outputs pure signal.
- Running LHCb at high pile-up has shown that the current HLT implementation is ready for the upgrade.
- The flexibility of the software trigger has proved and will prove to be crucial to adapt to changing running conditions and optimise the physics yield, now and for the upgrade.

# Other Talks on LHCb

- Calorimeter Performance, F. Machefert
- RICH, D. Perego
- RICH performance, A. Papanestis
- TORCH, N. Harnew
- Velo Performance, T. Latham
- Silicon Tracker Performance, J. Luisier
- LHCb Online System, B. Jost
- Detector Upgrade, A.A. Gallas Torreira

## TCK



Random image containing TCK (Trigger Configuration Key).

# BACKUP

# Trigger Configuration

Since the trigger is such a crucial part of LHCb data taking and therefore of any analysis, information about its configuration is of equally crucial importance. This is addressed by fixing all configurations upon creation and using a hashing technique to map each configuration to a 32 bit number, the Trigger Configuration Key (TCK).

- Know at any point in time the trigger configuration which triggered an event.
- Ensures reproducibility of the behaviour of any trigger configuration.
- Configuration of the event filter farm using a single setting.
- Easy inspection of trigger configurations.

# BDT definition.

Discretise BDT variables using:

$\Delta x_{min} > \delta_x$  for all  $x$  on all leaves where:

$$\delta_x = \min \{ |x_i - x_j| : x_i, x_j \in x_{discrete} \}$$

- $x_{discrete}$  is chosen such that  $\delta_x > \sigma_x^{LHCb}$
- $x_{discrete}$  is also chosen according to common  $B$ -decay properties.