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Experimentelle Physik V
Teilchenphysik

LHCb Trigger and Online TDR: Trigger Section

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LHCC Detector Upgrade Review,
3. June 2014

LHCb Trigger and Online TDR: Trigger Section

- 8 Sections, 33 pages
  - Event anatomy
  - Trigger sequence
  - Global event cuts
  - Low level trigger algorithms
  - Track reconstruction and particle identification
  - Trigger selections and efficiencies
  - Robustness
  - Project organisation

Main part of TDR

Upgrade trigger strategy

30 MHz inelastic collisions

Full Software Trigger

LLT (optional)
Event builder farm

15 – 30 MHz

Full track reconstruction
Event filter farm

1 – 2 MHz

Track fit
RICH particle ID
Inclusive and exclusive selections

20 – 100 kHz to storage

Upgrade trigger strategy

Baseline strategy:
reconstruct all tracks at
full inelastic collision rate

Allows offline like
selections without
trigger simplifications

30 MHz inelastic collisions

Full Software Trigger

~~LLT (optional)~~
~~Event builder farm~~

~~15~~ – 30 MHz

Full track reconstruction
Event filter farm

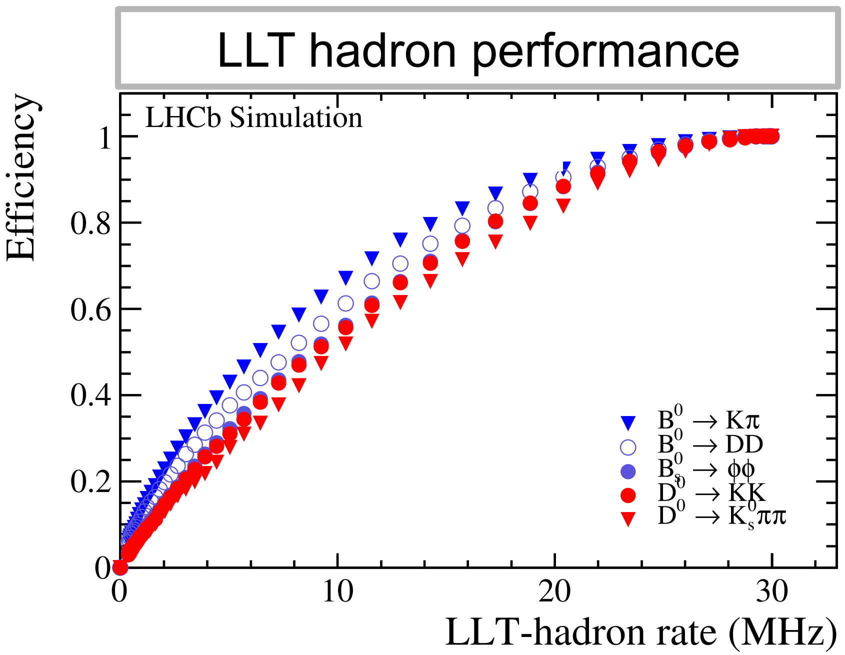
1 – 2 MHz

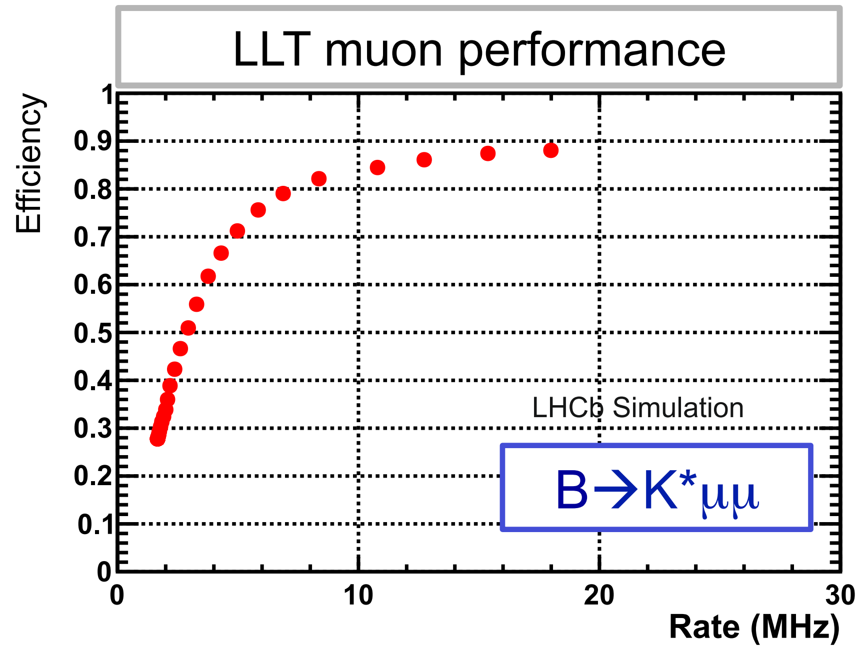
Track fit
RICH particle ID
Inclusive and exclusive selections

20 – 100 kHz to storage

Low Level Trigger

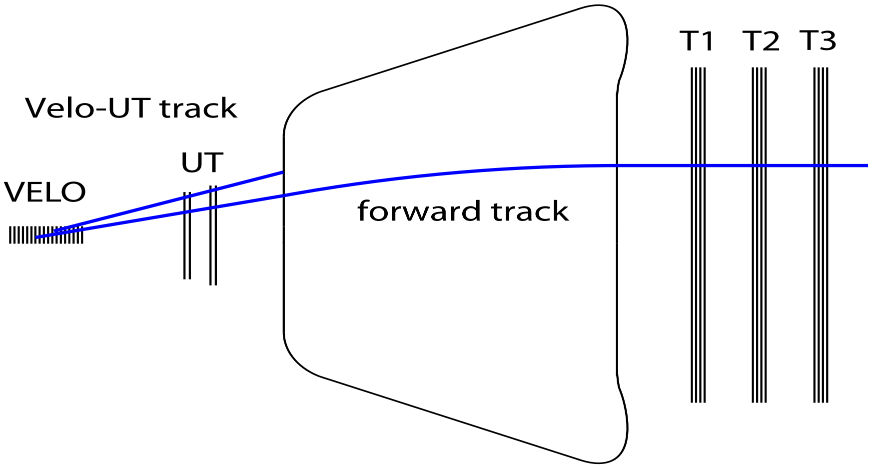
- Detector readout at full rate (30 MHz inelastic collisions)
  - Low Level Trigger as optional hardware filter kept as backup
    → scalable output between 15 – 30 MHz





- A natural place to run the software LLT are the event-builder nodes. The remaining CPU power on them gives about 2 ms
- Baseline strategy is to run without LLT

Tracking sequence in the trigger

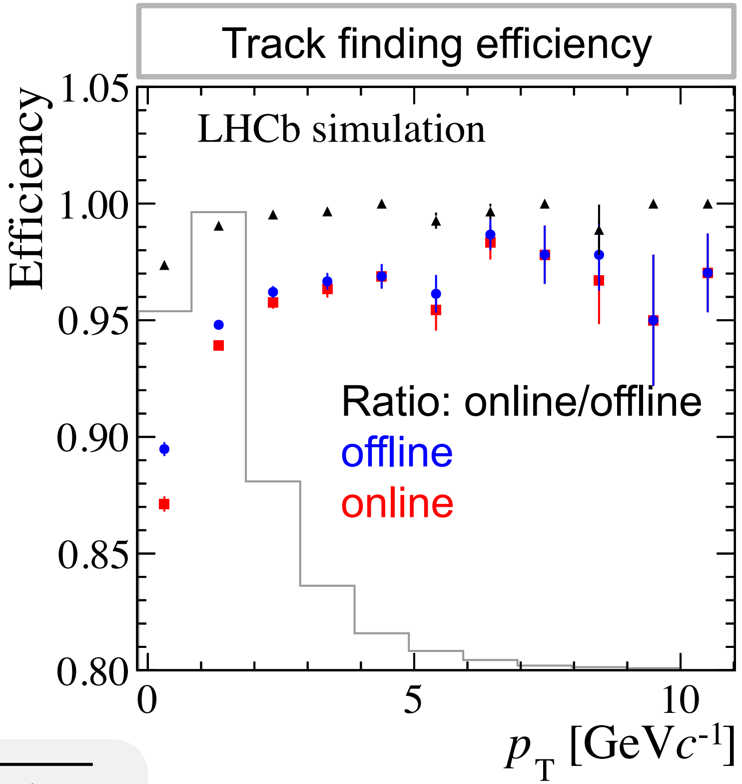


Offline	Upgrade HLT
VELO tracking	VELO tracking
VELO-UT	VELO-UT $p_T >$ 200 MeV/c
Forward reco $p_T >$ 70 MeV/c	Forward reco $p_T >$ 500 MeV/c
PV finding	PV finding
	Trigger cuts to reduce rate to 1 MHz
	Muon ID
Full Kalman Fit	Simplified Kalman Fit
Global PID	Online RICH PID

- Do offline like full track reconstruction at 30 MHz
  → all tracks with PT>500 MeV reconstructed
- Inclusion of UT in tracking significantly speeds up tracking sequence
- Particle ID (also RICH based) and Kalman filter based fit at 1 MHz
- Partial reconstruction approach maintained as backup

Track finding efficiencies

- Typical B-daughter tracks have PT>500 MeV
  → efficiency to find in trigger ~98.7% relative to offline



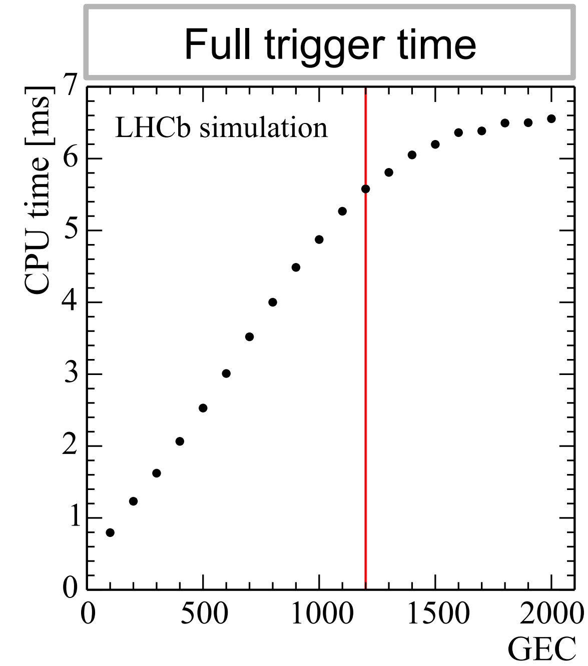
	no GEC	GEC=1200	relative
Ghost rate	10.9%	5.9%	-
long	42.7%	42.9%	50.4%
long, from B	72.5%	72.8%	80.3%
long, $p_T > 0.5\,\mathrm{GeV}/c$	86.9%	87.4%	97.2%
long, from B, $p_T > 0.5\,\mathrm{GeV}/c$	92.3%	92.5%	98.7%

Track finding CPU cost

- Remove busiest events with global event cut (GEC, calorimeter multiplicities)
  - GEC not necessary, but useful

- CPU budget Event Filter Farm: 13 ms

- Full tracking sequence uses only 40% of budget
  - Efficient “knobs” to tune CPU time available (backup)
  - Beahviour Vs. multiplicity under control



Tracking Algorithm	CPU time[ms] No GEC	CPU time[ms] GEC = 1200
VELO tracking	2.3	2.0
VELO-UT tracking	1.4	1.3
Forward tracking	2.5	1.9
PV finding	0.40	0.38
Total @29 MHz		5.6
Total	6.6	5.4

Hardware assisted tracking?

- A concentrated effort was made to perform the first tracking steps on FPGA's [LHCb-PUB-2014-026]
- Retina inspired algorithm, feasibility of track reconstruction at 40 MHz demonstrated (Latency ~1 μs, cost just below 1 MCHF)
- Review with internal and external experts to compare full software trigger and hardware assisted trigger
  - M. Elsing, J. Lefrancois, P. Vande Vyvre:

    Full software trigger:
    "The reviewers were impressed by the results presented and the spectrum of studies shown, including the demonstrated flexibility and robustness of the approach. "

    Hardware assisted (TPU):
    "The cost for the TPU is estimated to be 940 kCHF, which does not provide a significant cost benefit with respect to an all software based trigger, even taking the uncertainties of the computing technology evolution into account. The reviewers therefore support the baseline decision for an all software based trigger as the best solution for the LHCb upgrade."

Selections

- Up front track reconstruction allows 1-stage trigger selections, that are very close to the final analysis selections

- The output bandwidth of the trigger is defined in the Upgrade Letter of Intend to 2 GB/s (20 kHz)
  - Limitation of output rate is given by offline computing resources
  - Show potential gains in physics performance for increased output rates (5 GB/s and 10 GB/s as benchmark scenarios)

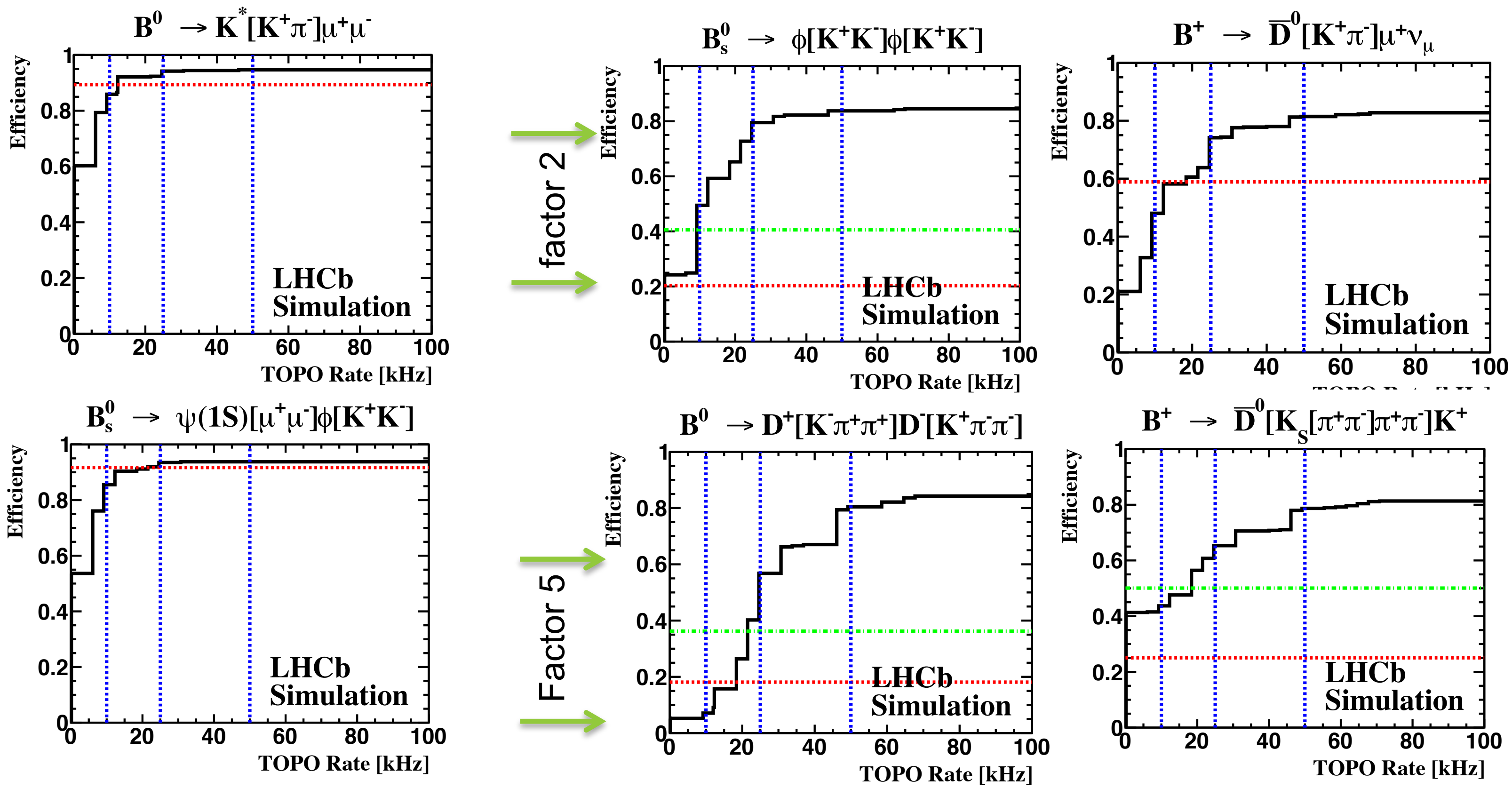
- Several alternatives to reduce the burden to offline computing
  - streaming of data
  - Reduced data formats

  → Commissioned in Run 2, final decision on output rate in 2018

Inclusive beauty trigger

- Newly tuned, BDT based inclusive beauty trigger (very similar to main beauty "Topological" trigger in Run 1)
  - Timing: 0.1 ms per event.
  - At 25 – 50 kHz large efficiency gains over Run 1

Efficiencies are for full trigger chain



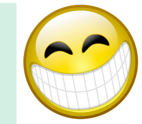
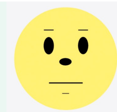
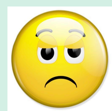
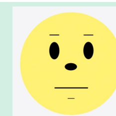
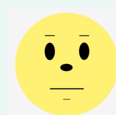
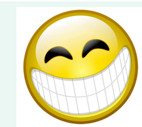
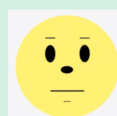
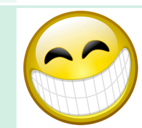
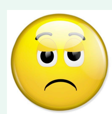
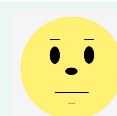
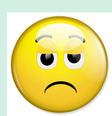
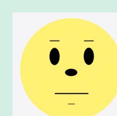
red (green): Run I efficiency (x2)

LHCb-PUB-2014-031

Exclusive selections

- Efficiency of core beauty channels will be boosted with exclusive selections
  - e.g. $B_s \rightarrow \phi\phi$: 95% efficiency relative to offline, <10 Hz rate
- Full track reconstruction allows "**lifetime unbiased**" selections
  - Avoid any cuts that bias lifetime distributions (minimize systematics)
  - E.g. $B \rightarrow h^+h^-$ or $D \rightarrow h^+h^-$
    - timing O(0.1-0.2 ms)
    - Rate: 100 Hz ($B \rightarrow K^+K^-$) – a few kHz $D \rightarrow h^+h^-$
      → limited triggers possible for 20 kHz output, full program for increased rate
- Charm physics, "Problem" are **signal rates around 6 MHz**
  - Only few golden exclusive selections possible in 20 kHz (much more restricted than in Run 1 or 2)
  - Increased output rate would allow extensive program

Selection summary

	2 GB/s (20 kHz)	5 GB/s (50 kHz)	10 GB/s (100 kHz)
Exclusive beauty			
Inclusive beauty	 		
Inclusive di-muon			
Lifetime unbiased			
Charm: exclusive			
Charm: inclusive			
Exotics			

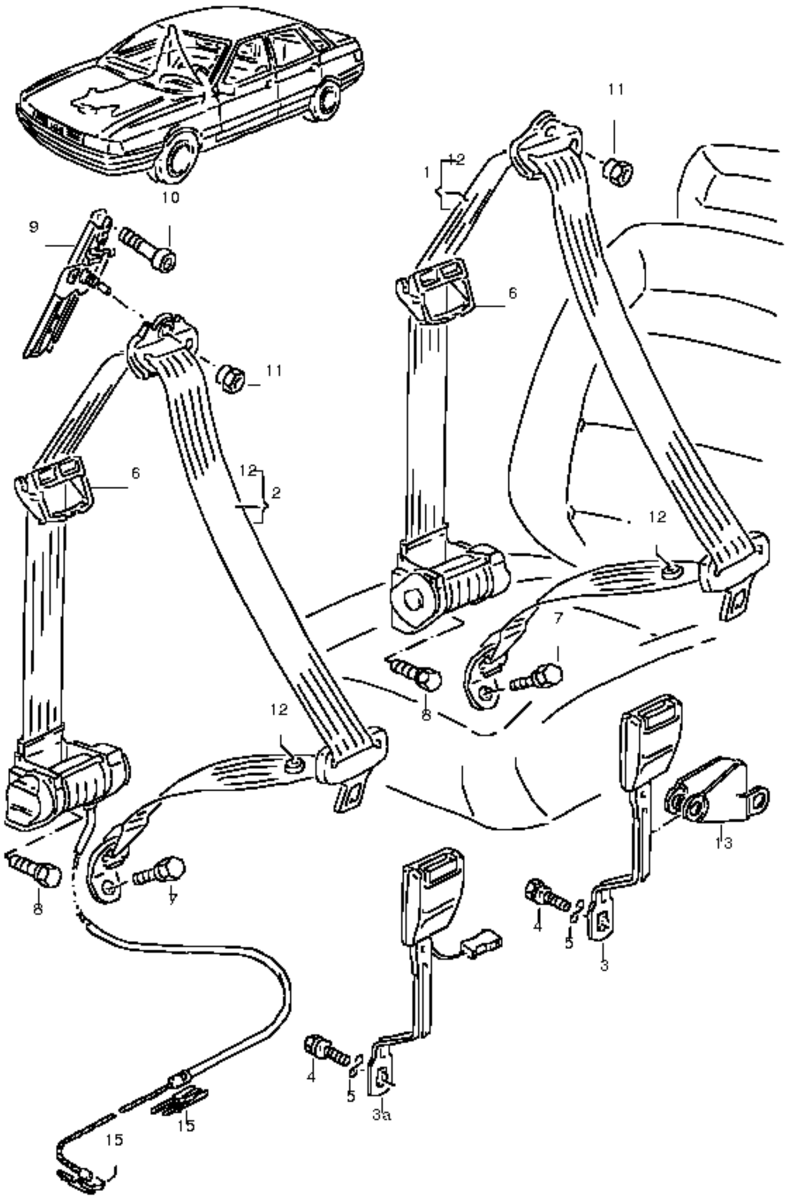
- Approximate equal rate allocated for beauty and charm
- Large gains possible when output rate increased above 2GB/s

Summary

- Full software HLT: offline-like track reconstruction at 30 MHz
  - 98.7% of all offline tracks (PT>500 MeV) for 40% of the CPU budget
- Allows trigger selection (almost) identical to offline
  - High signal efficiencies and low biases on observables
  - Output bandwidth: shown to fit in 2 GB/s (20 kHz)
    → large gains in physics possible if we can increase the bandwidth

	LHCb Run 1	LHCb Run 2	LHCb Run 3
Energy / Luminosity	7-8 TeV / 2-4 * 10^{32}	13 TeV / 4 * 10^{32}	14TeV / 2 * 10^{33}
Visible IA rate	13 MHz	13 MHz	30 MHz
Input rate HLT	1 MHz	1 MHz	30 MHz
Full track reconstruction rate	80 kHz	1 MHz	30 MHz
RICH PID rate	O(100 Hz)	150 kHz	1 MHz
Rate to storage	2 - 5 kHz	12.5 kHz	20 kHz

Backup

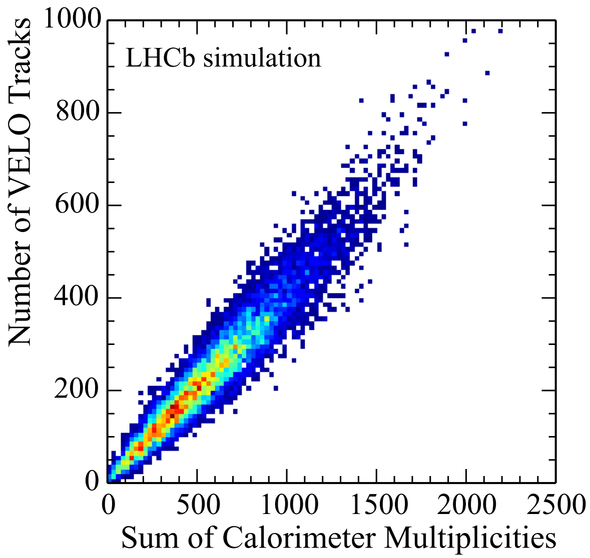


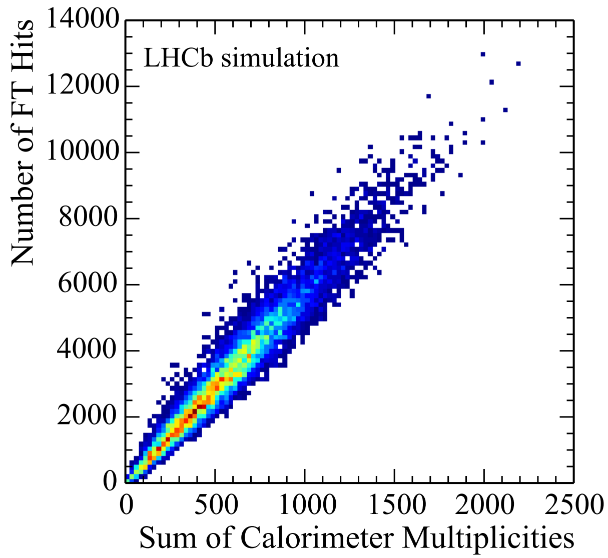
Selection overview

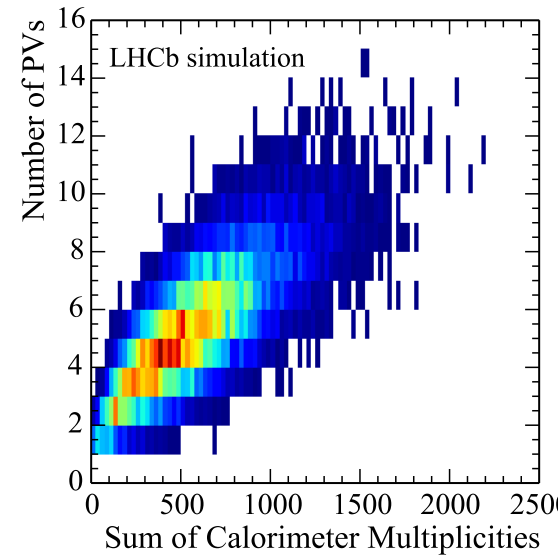
- For the TDR: define 3 bandwidth scenarios
  - 2GB/s (20kHz)
    - Rather efficient Topo (10kHz), ~Run 1 performance
    - Tight beauty exclusives
    - Only few exclusive golden charm selections
  - 5GB/s (50kHz)
    - Much improved Topo (20kHz), efficiency: *1.5 SL, *2-4 had
    - Enough room for exclusives, LT unbiased
    - Charm: exclusives & tight inclusives (remember: 6MHz of charm)
  - 10GB/s (100kHz)
    - Comfortable Topo (50kHz), hadronic efficiency improved
    - Charm: exclusives & inclusives, also LT unbiased (better than 2012)
    - Room for “exotics” like strange or tau- physics

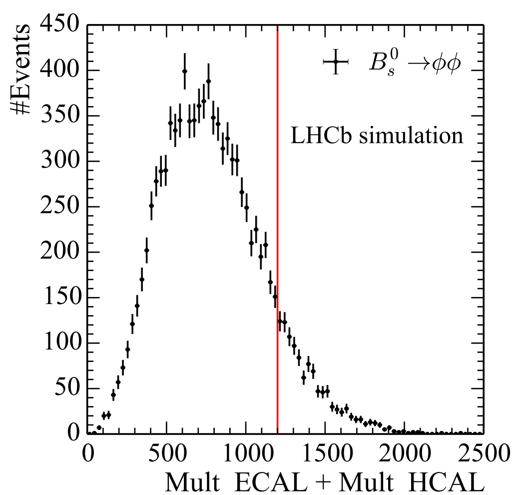
Selection	Output Rate (kHz)		
Topological	10	20	50
Lifetime unbiased	1	4	5
Exclusive beauty	ϵ	1	3
Inclusive di-muon	–	–	2
Charm	9	20	40
Total	20	50	100
Bandwidth [GBs^{-1}]	2	5	10

Global Event Cuts

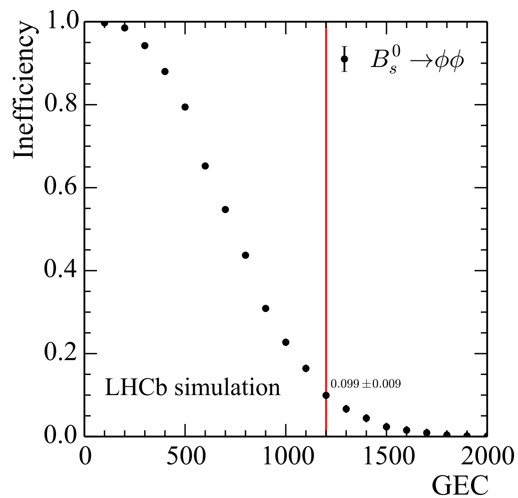








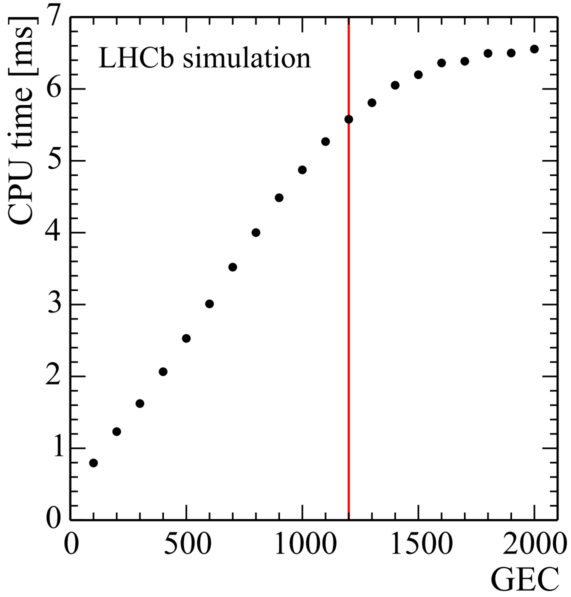
(a) Event distribution for $B_s^0 \to \phi\phi$.



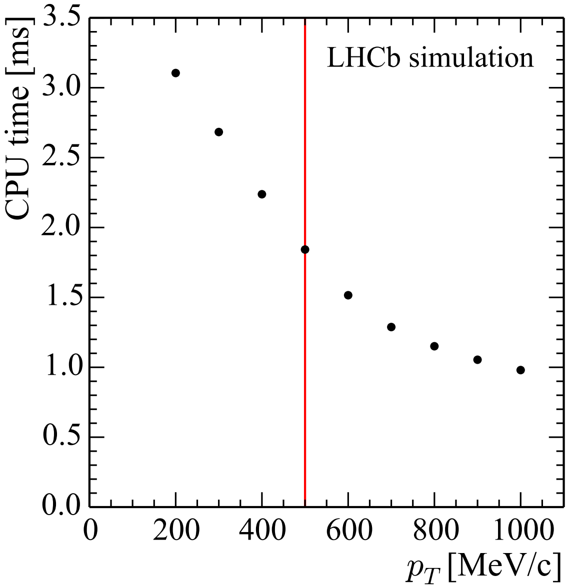
(b) GEC inefficiency on $B_s^0 \to \phi\phi$.

CPU time tunable: PT and GEC

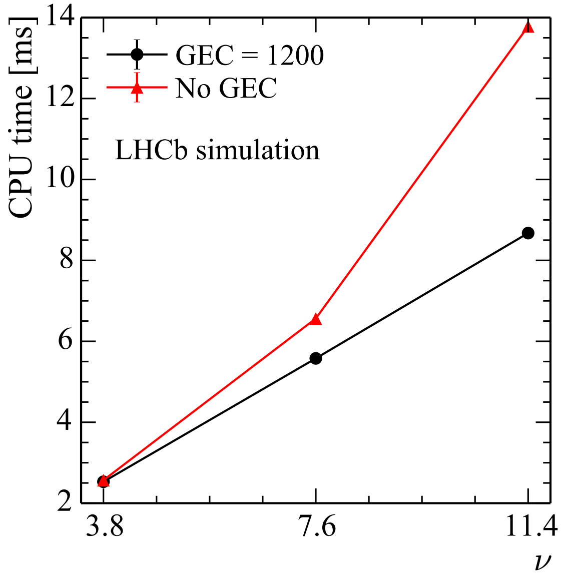
Full trigger time, forward PT 500



Forward track reconstruction time, GEC1200



Trigger time vs Luminosity



- Efficient knobs to tune the CPU time are available
  - Pt cut above 500 costs little in hadronic B (or Bs2mm), but hurts charm
  - GEC removes most busy events
- Behaviour vs Luminosity / multiplicity under control