Tracking, Vertexing and data handling strategy for the LHCb upgrade

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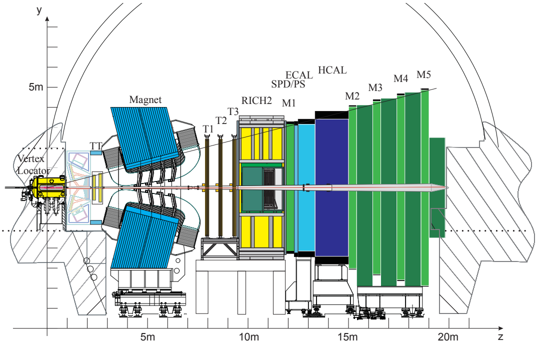
VERTEX 2017

scope I



- Fully equipped forward detector at the LHC
- Approaching 400 papers
- exceeding our own expectations:
  - online calibration and alignment
  - exceeding design pile-up

scope II

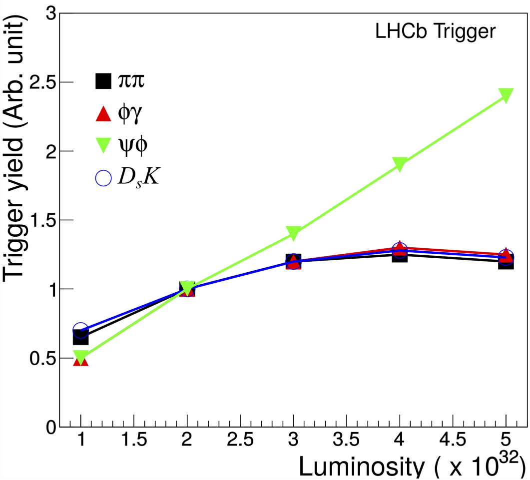
Type	Observable	Current precision	LHCb 2018 (8 fb^{-1})	**Upgrade** (50 fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s(B_s^0 \to J/\psi\phi)$	0.10	0.025	0.008	$\sim$0.003
	$2\beta_s(B_s^0 \to J/\psi\, f_0(980))$	0.17	0.045	0.014	$\sim$0.01
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9}	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
Gluonic penguins	$2\beta_s^{\rm eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	$\sim$10–12°	4°	0.9°	negligible
	$\gamma(B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta(B^0 \to J/\psi K_S^0)$	0.8°	0.6°	0.2°	negligible

`Eur. Phys. Journal C (2013) 73:2373`

- By 2018 important analyses will still be statistically limited
- Theoretical uncertainty smaller than experimental

$\rightarrow$ Significantly more statistics needed

$\Rightarrow$ Go to higher luminosity



what doesn't work

- increased luminosity

$\rightarrow$ events passing hardware trigger

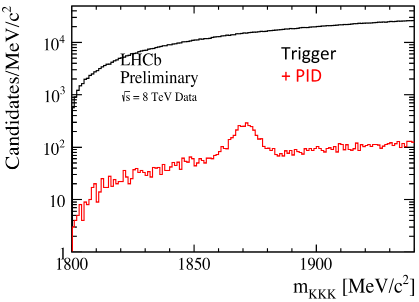
$\rightarrow$ saturating bandwidth

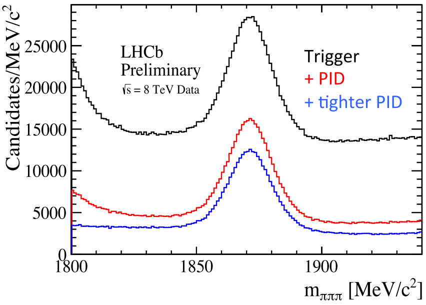
$\rightarrow$ tighten thresholds

$\rightarrow$ loss in efficiency

$\Rightarrow$ no increase in statistics for analyses (depending on the decay channel)

removal of hardware trigger II





- backgrounds from real physics events
- cannot distinguish signal from background w/o RICH PID

$\Rightarrow$ even selection in software

LHCb 2015 Trigger Diagram

40 MHz bunch crossing rate

⇩ ⇩ ⇩

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

450 kHz	400 kHz	150 kHz
$h^\pm$	$\mu/\mu\mu$	e/γ

⇩ ⇩ ⇩

Software High Level Trigger

- Partial event reconstruction, select displaced tracks/vertices and dimuons

⇩

- Buffer events to disk, perform online detector calibration and alignment

⇩

- Full offline-like event selection, mixture of inclusive and exclusive triggers

⇩ ⇩ ⇩

12.5 kHz (0.6 GB/s) to storage

⇒

LHCb Upgrade Trigger Diagram

30 MHz inelastic event rate (full rate event building)

⇩ ⇩ ⇩

Software High Level Trigger

- Full event reconstruction, inclusive and exclusive kinematic/geometric selections

⇩

- Buffer events to disk, perform online detector calibration and alignment

⇩

- Add offline precision particle identification and track quality information to selections

  Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers

⇩ ⇩ ⇩

2-5 GB/s to storage

Luxury problem: MHz signals

Triggers today

Real-time data analysis tomorrow

5

- Selecting and storing full events could work for rare signal
- When dealing with "millions" of good signal events, rejecting background isn't enough to stay within processing bandwidths

Luxury problem: MHz signals

Triggers today

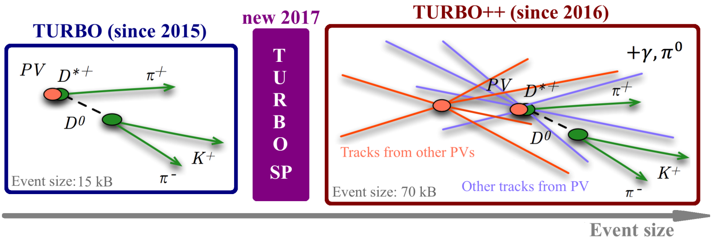
Real-time data analysis tomorrow

5

The TURBO approach

- once a decay is reconstructed (mass, decay time, Dalitz plot) no need to access raw data for analysts
- once a decay is reconstructed in the trigger no need to re-reconstruct offline
- (unaffordable to study raw data for millions of events anyway)

store what you need



10.1016/j.cpc.2016.07.022

per trigger line storage definition

- only decay and nothing else
- decay and selected reconstructed objects
- all *reconstructed* objects (no raw data)
- full raw event

TURBO triggers must be a default for many analyses

Bandwidth division I

- There's always an efficiency vs. event rate tradeoff
- assume: every analysis could max out the full data bandwidth to maximise their *efficiency*
- compromises need to be made
- ideally with little *sensitivity* loss

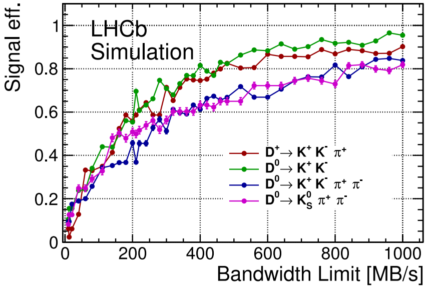
- Genetic algorithm approach
  - Minimise the χ^2 by varying the MVA response for each decay
    - w_i channel weight (= 1.0 here)
    - ε_i channel efficiency
    - $\varepsilon_i^{\max}$ maximum channel efficiency when given the full output BW

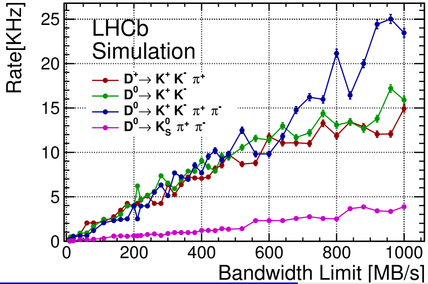
$$\chi^2 = \sum_i^{\text{channels}} \omega_i \times \left(1 - \frac{\varepsilon_i}{\varepsilon_i^{\max}}\right)^2$$

- if sum of all channels exceeds total bandwidth
  $\rightarrow$ assume random dropping of events

LHCb–PUB–2017–006

Bandwidth division II

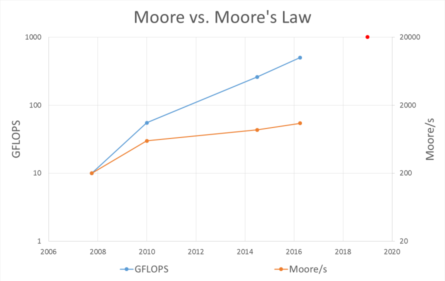




going from maximal bandwidth to restricted bandwidth

- only small efficiency decrease
- “90 % of the data holds 95 % of the statistical power”

“Moore doesn’t obey Moore’s law”

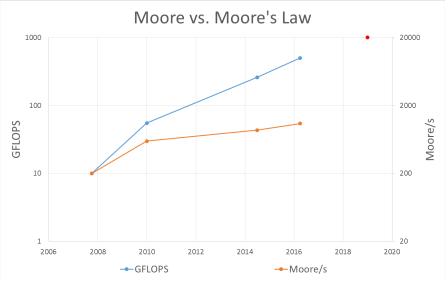


- theoretical computing power of CPUs increases (per second, per Watt, per CHF)
- observed computed trigger decisions does not follow that increase

reasons from a CPU’s point of view I/II

- modern vector units process 2, 4, or 8 inputs at a time
  $\rightsquigarrow$ our software often didn’t use these
  $\rightarrow$ 7/8 of the silicon unused!

“Moore doesn’t obey Moore’s law”



- theoretical computing power of CPUs increases (per second, per Watt, per CHF)
- observed computed trigger decisions does not follow that increase

reasons from a CPU’s point of view II/II

- software not parallelised (just start multiple processes on a multicore machine)
  - ⇝ processes compete for memory
  - ⇝ even multiple instances of the same data (detector geometry)
  - → CPU waits for data instead of computing

overview tracking (stages and types)

parametrised kalman

vectorised kalman

soa/aos

ghost prob

threadded brunel

WG production

conclusion