Performance of the LHCb trigger and its upgrade

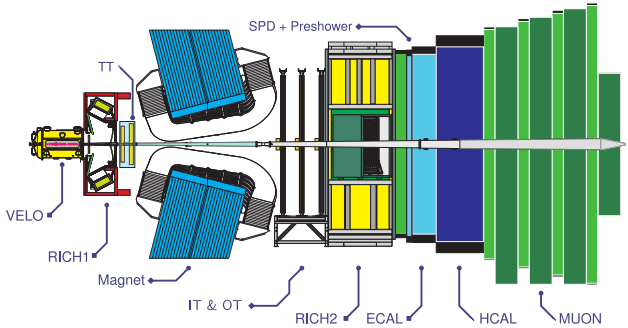
Instrumentation for Colliding Beam Physics 2014

Tim Head for the LHCb collaboration

CERN

1 March 2014

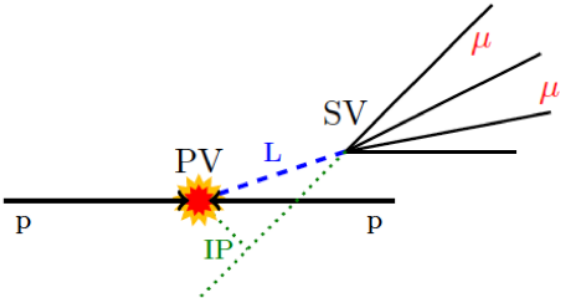
The LHCb Detector



- LHCb is a single-arm ($2 < \eta < 5$) spectrometer at the LHC
  - Precision beauty and charm physics: CP violation, rare decays, heavy flavour production
- σ_{bb} and σ_{cc} are extremely large at the LHC
  - 30 kHz $b\bar{b}$ and 600 kHz $c\bar{c}$ in LHCb acceptance!

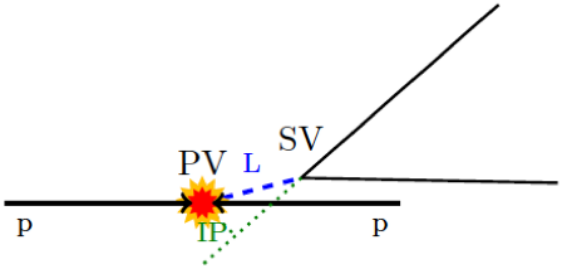
Heavy Flavour Signatures

Beauty hadrons



- B^+ mass 5.28 GeV, daughter p_T $\mathcal{O}(1\,\text{GeV})$
- lifetime ≈ 1.6 ps ⇒ flight distance ≈ 1 cm
- common signature: detached $\mu\mu$

Charmed hadrons



- D^0 mass 1.86 GeV, sizeable daughter p_T
- lifetime ≈ 0.4 ps ⇒ flight distance ≈ 4 mm
- can be produced in B decays

LHCb Trigger Scheme

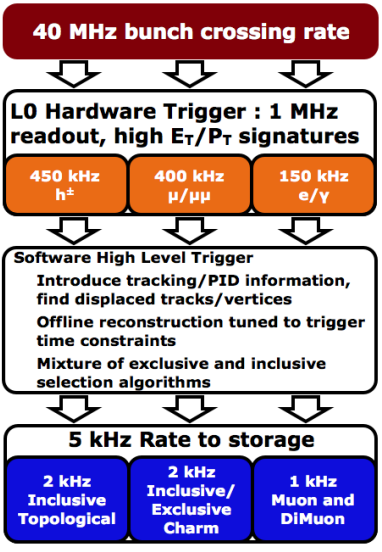
Level 0

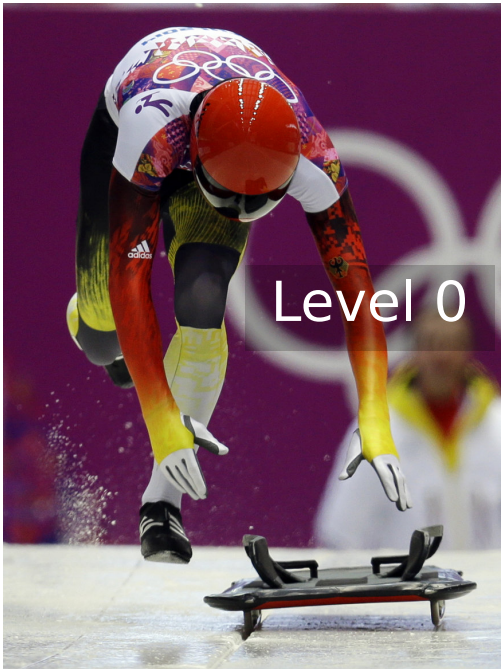
- implemented in custom made hardware
- decisions made in 4 μs

High Level Trigger

- implemented exclusively in software
- extremely flexible
- 29000 logical cores
- writes 5 kHz to storage (2 kHz incl B, 2 kHz incl charm, 1 kHz muons)

Details in JINST 8 (2013) P04022




Level 0

Muon Based L0 Triggers

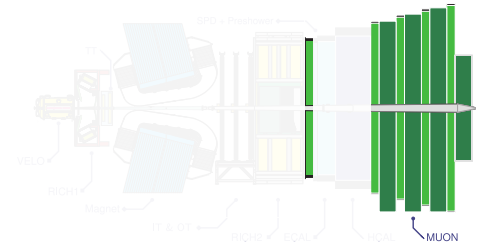
Reconstructs muon track segments

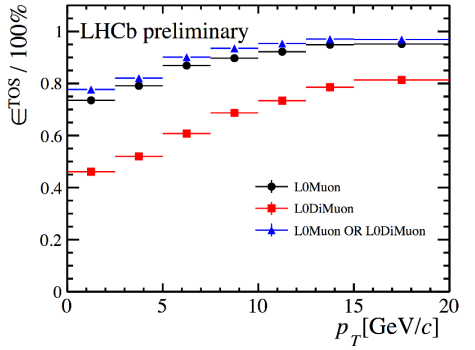
- $\Delta p/p \approx 20\%$

Two L0 muon triggers:

- single muon, $p_T > 1.76\,\text{GeV}$
- dimuon, $p_{T1} \times p_{T2} > (1.6\,\text{GeV})^2$
- total rate $\approx 400\,\text{kHz}$

Typically over 90% efficiency





Calorimeter Based L0 Triggers

Select high E_T hadrons, electrons and photons

- Preshower and SPD discriminate between electrons and photons

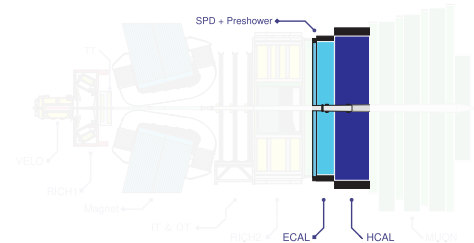
L0 hadron trigger:

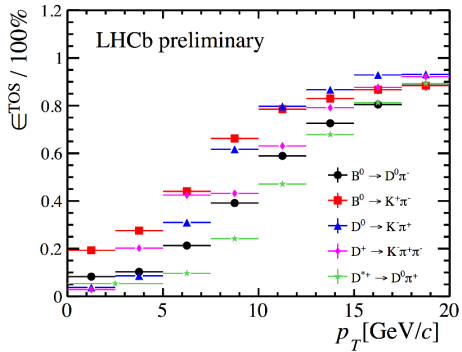
- threshold 3.6 GeV
- rate ≈ 490 kHz

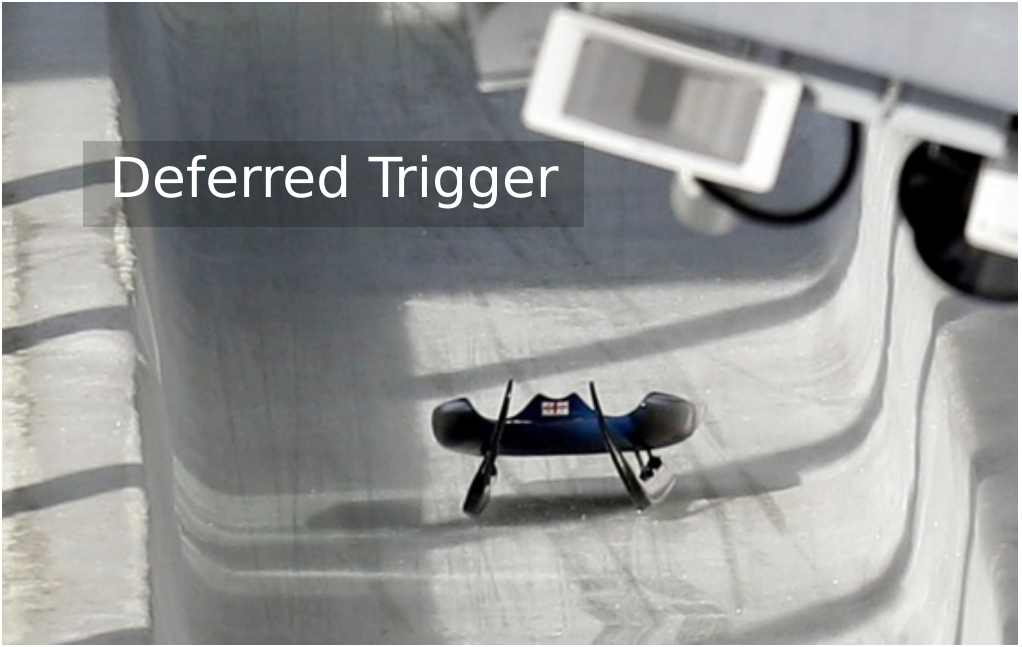
L0 electron, photon:

- threshold 3 GeV
- rate ≈ 150 kHz
- ≈ 80% efficient for $B \to X\gamma$

Total L0 rate ≈ 1 MHz





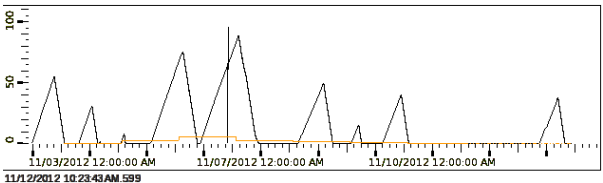

Deferred Trigger

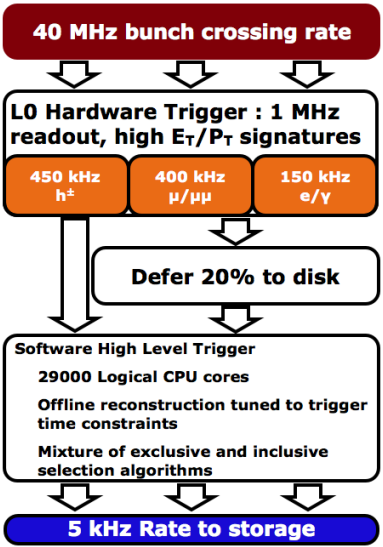
Deferred Trigger

- LHC “only” delivers collisions 30% of the time
  - trigger farm idle for 70% of the time!
- in total farm has ≈ 1 PB storage which is not being used

$\Rightarrow$ overcommit HLT by $20-30\%$ and catch up during the breaks

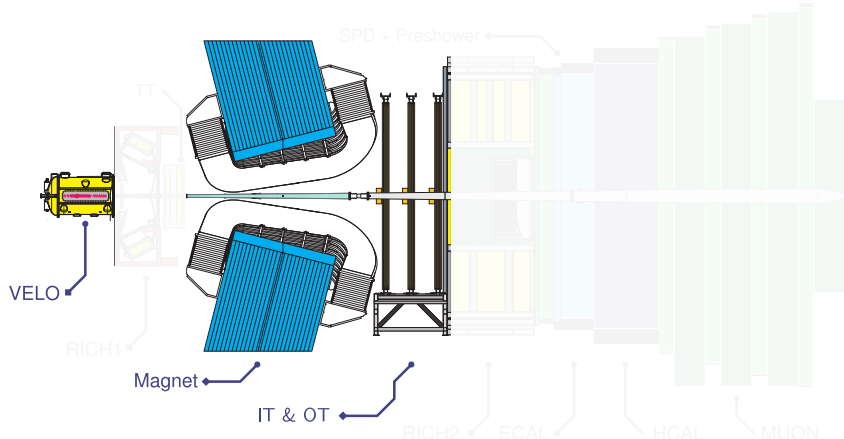
- Gains 20% extra CPU time
  - lower track reconstruction thresholds ($p_T = 500 \rightarrow 300$ MeV)!





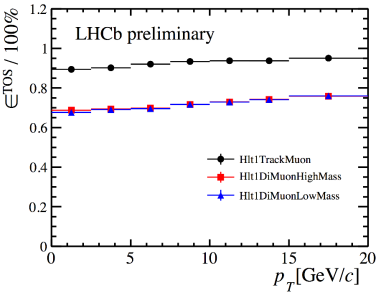

SOCHI
HLT 1

First Stage of the High Level Trigger



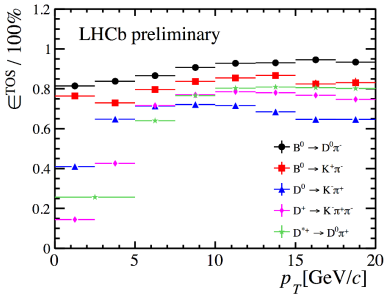
- Reconstruct all Velo tracks and perform PV finding
- Tracks with large IP or matched to a L0 muon are “upgraded”
  - measure momentum using tracking stations after the magnet

First Stage of the High Level Trigger (cont)



Muon lines

- high p_T or large lifetime



Inclusive line

- single track with large IP and high p_T

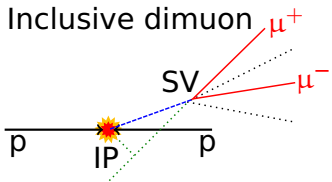
HLT1 output rates:

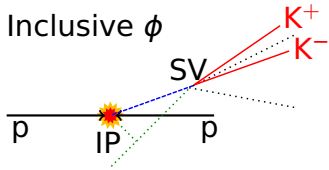
- Muons ≈ 14 kHz
- Inclusive ≈ 58 kHz
- **Total** ≈ 80 kHz

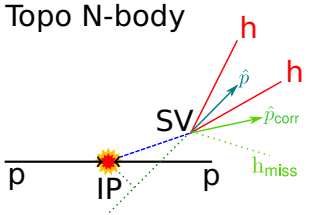
Tuned to maximise HLT2 CPU usage

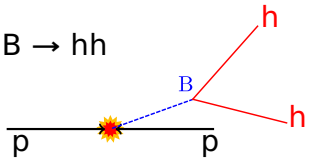
HLT 2

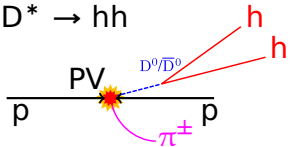
Second Stage of the High Level Trigger







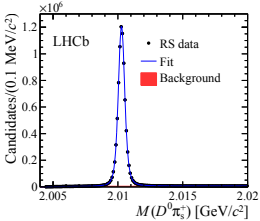


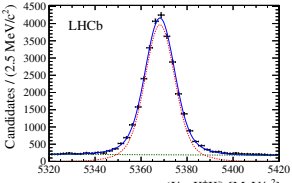


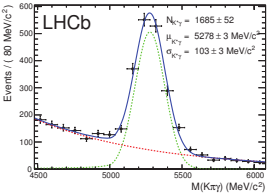
- Full offline like event reconstruction!
- Extremely powerful, flexible software environment
- Combining inclusive and exclusive selections
- **Main trigger is MVA-based**

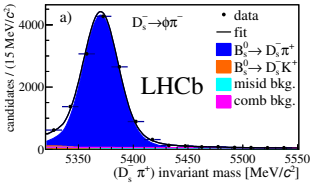
Trigger Performance

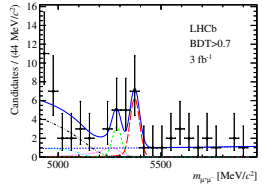
	Hadronic		Dimuon	Radiative
	$D \to hhh$	$B \to hh$	$B^+ \to J/\psi K^+$	$B^0 \to K^* \gamma$
L0 [%]	27	62	93	85
HLT | L0 [%]	42	85	92	67
HLT × L0 [%]	11	52	84	57

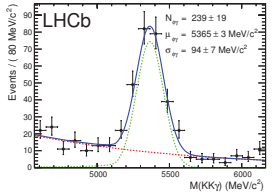






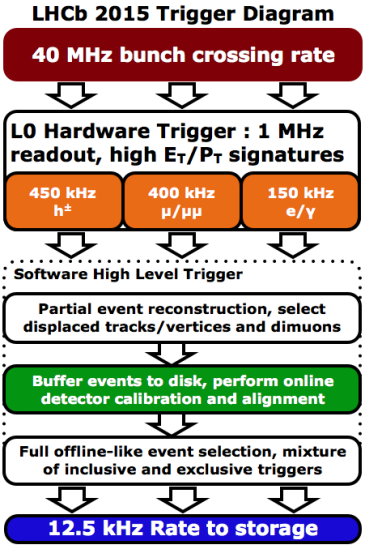







JAMAICA
The Future

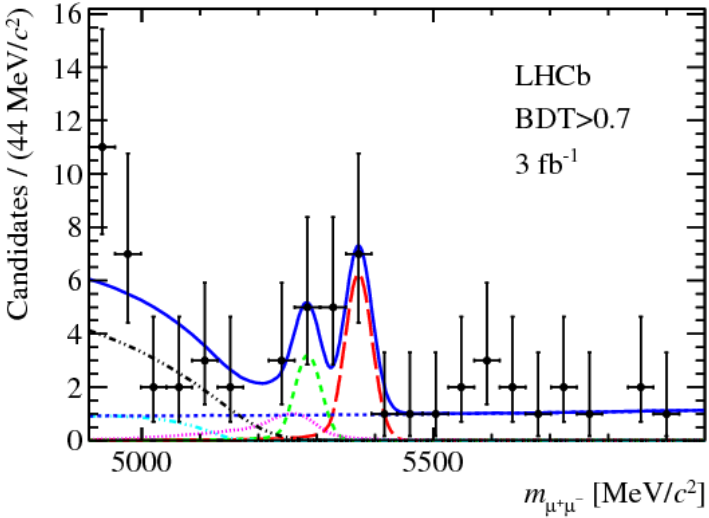
Developments for 2015



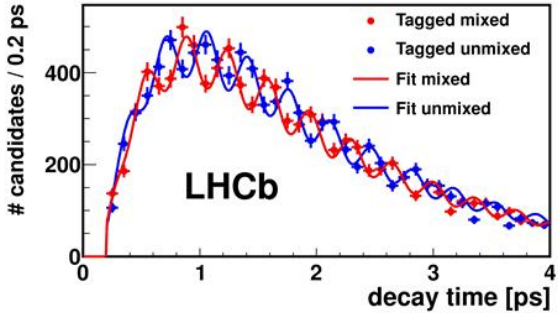
- Decouple HLT2 from HLT1
  - by buffering events after HLT1
- Align and calibrate detector
- Run offline-like reconstruction in HLT2
- Can now use full RICH PID
  - separate Cabbibo suppressed charm decays from favoured ones
- Larger output rate achieved by parking data

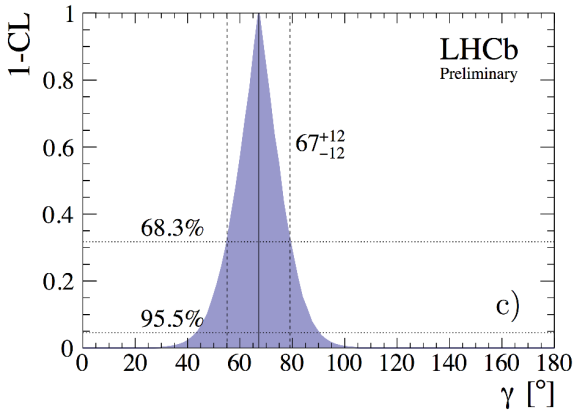

The Future’s Future

For Rare Decays

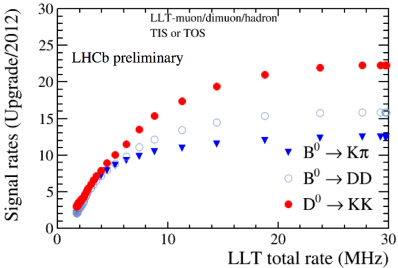


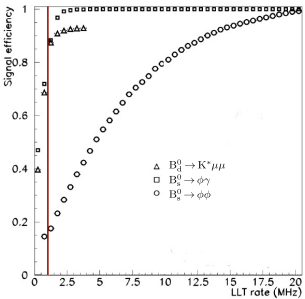
Hadronic Beauty





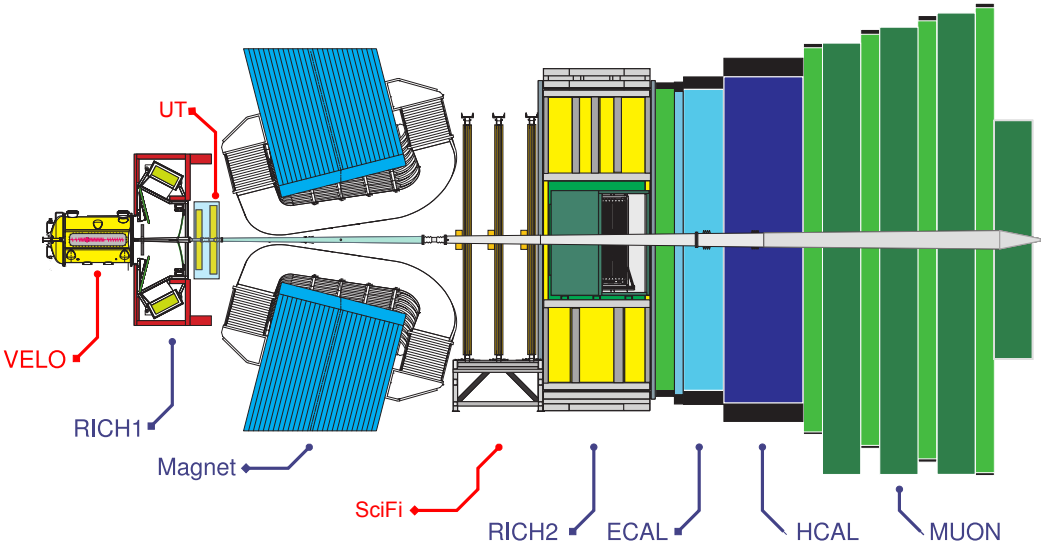
LHCb @ 40MHz



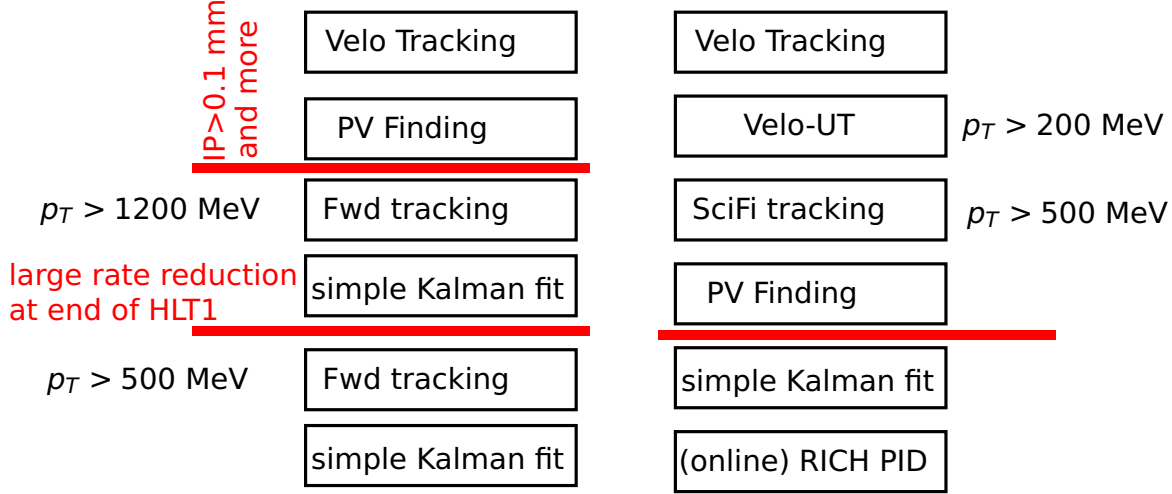


- To take advantage of running at $L = 2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, we need to read out every event!
  - L0 trigger limited to 1 MHz output ⇒ bottleneck
- Replace L0 with Low Level Trigger, replace sub-detectors and DAQ
- Large gains to be made for hadronic triggers
- As trigger farm grows progressively loosen LLT cuts until eventually full rate is delivered to a fully software based trigger.

The Upgraded LHCb Experiment



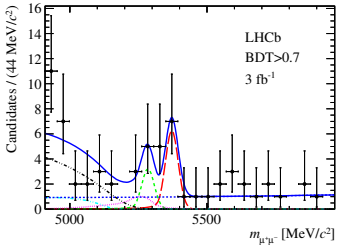
HLT 2012 vs 2020

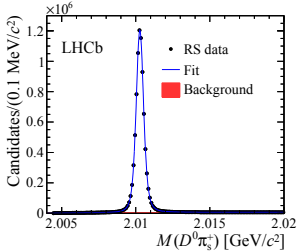


Provide an environment which is of the same sophistication and quality as “offline”

Closing Ceremony

- The LHCb trigger system is extremely successful!





- The LHCb trigger system is extremely sophisticated
  - can react quickly to changes in running conditions
  - deferred triggering to boost recorded physics
  - use MVAs already in the trigger
- For 2020 LHCb will have a truly upgraded trigger
  - goal is to be able to do physics with the output of the trigger