The LHCb Higher Level Trigger and its performance in 2012

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On behalf of the LHCb-HLT Project

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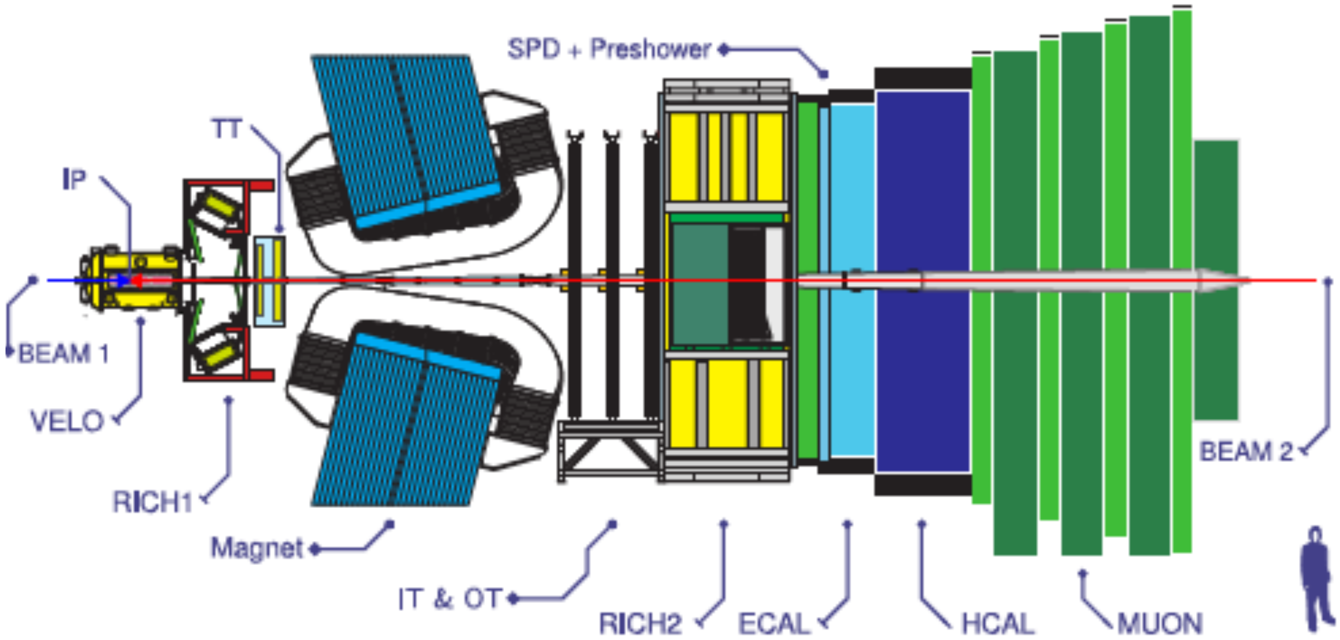
technische universität dortmund

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft
DFG

Experimentelle Physik V
Teilchenphysik

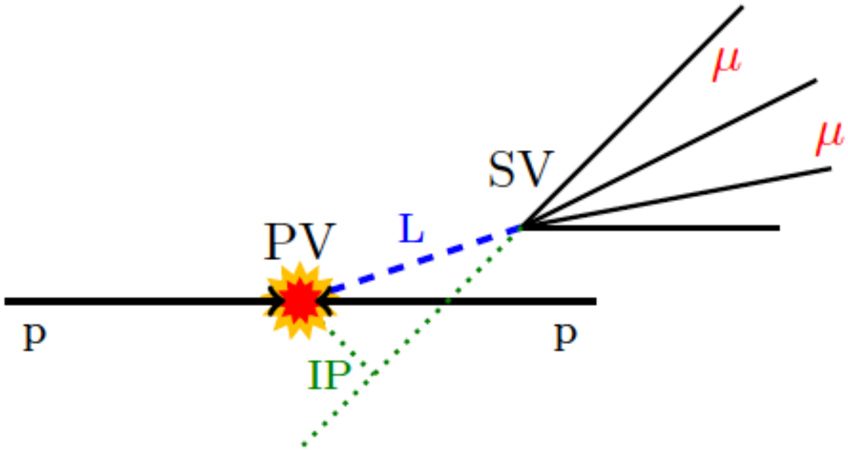
The LHCb Experiment

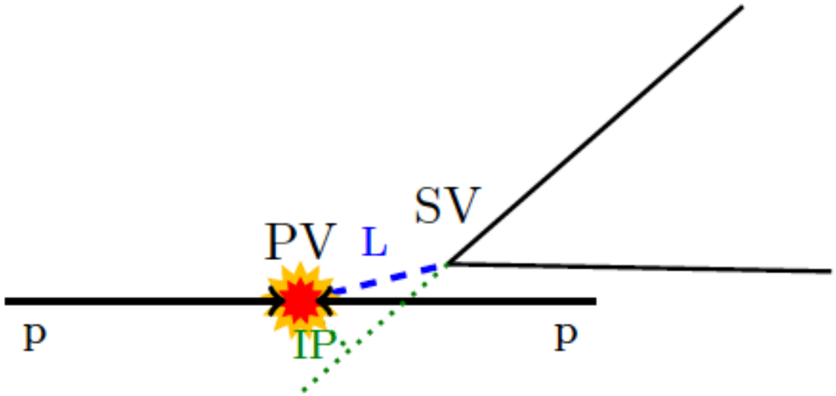
- LHCb: single arm spectrometer at the LHC
  - Precision beauty and charm physics
  - **L= 4 * $10^{32}$$cm^{-2}s^{-1}$** (2* design), **$\mu$~1.6** interactions per bunch crossing



- Extremely large σ_{bb} and σ_{cc} in LHC hadron collisions
  - corresponds to **30kHz $b\bar{b}$ and 600kHz $c\bar{c}$** in acceptance
- Trigger system classifies signal to large extend

Beauty hadrons	Charmed hadrons

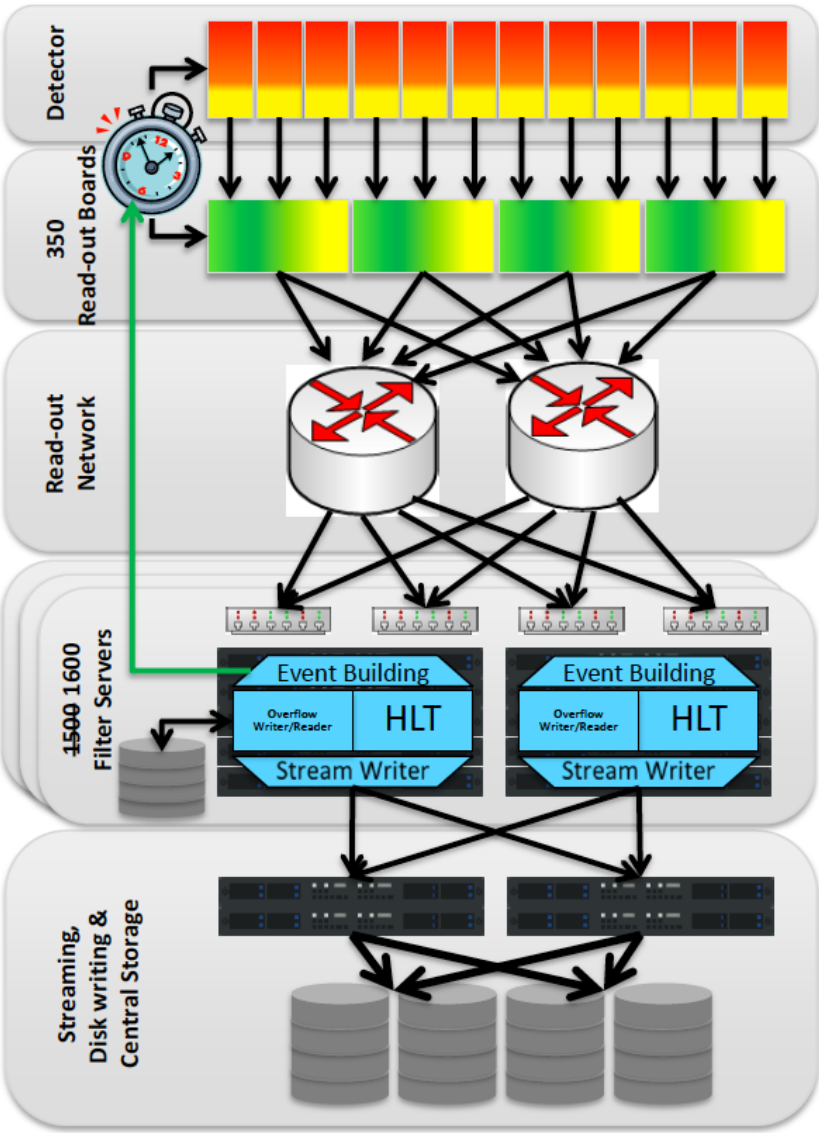




- mass $m(B^+) = 5.28\,\mathrm{GeV}$
  daughter p_T $\mathcal{O}(1\,\mathrm{GeV})$
- lifetime $\tau(B^+) \sim 1.6\,\mathrm{ps}$
  flight distance $\sim 1\,\mathrm{cm}$
- common signature: detached $\mu\mu$
  $B \to J/\psi X$ with $J/\psi \to \mu\mu$

- mass $m(D^0) = 1.86\,\mathrm{GeV}$
  sizeable daughter p_T
- lifetime $\tau(D^0) \sim 0.4\,\mathrm{ps}$
  flight distance $\sim 4\,\mathrm{mm}$
- can be produced in B decays

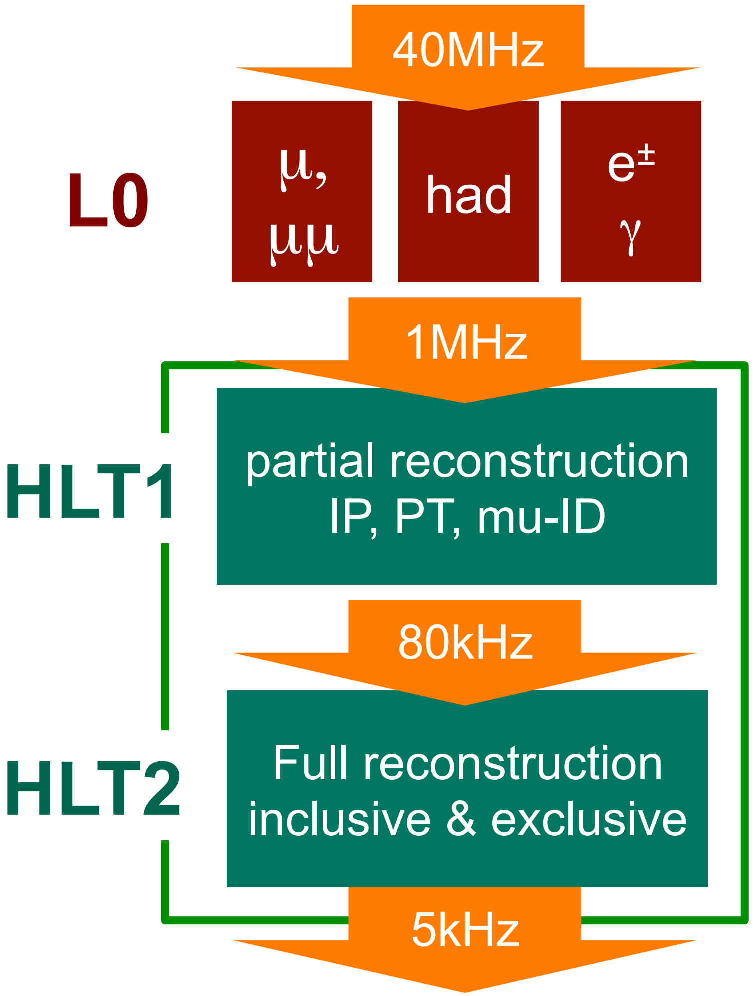
From Front End to Hard Disk



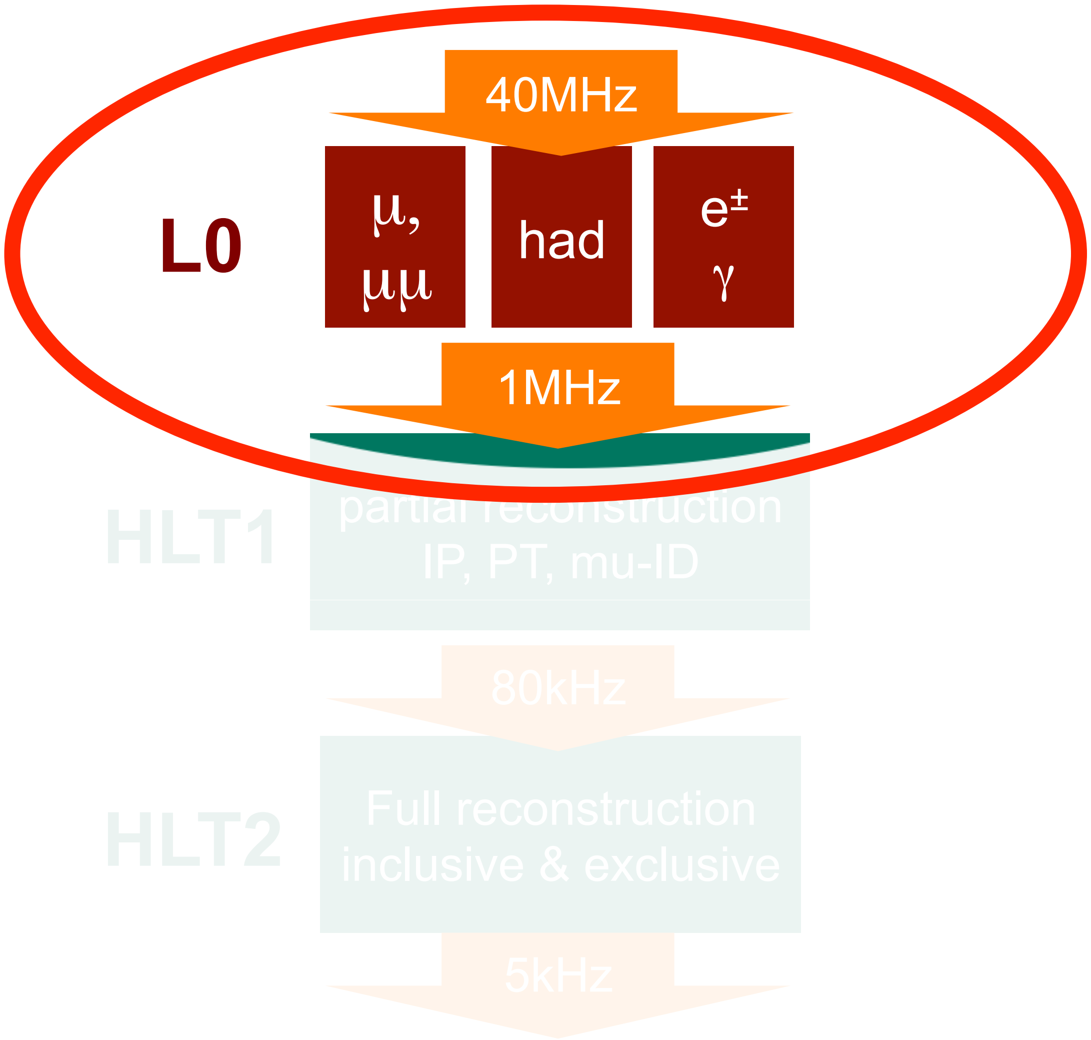
Taken from R. Schwemmer, Mon 13:30

- DAQ
  - Readout rate: 1MHz
  - Total Event size: 50+kB
  - HLT output rate: 5000Hz
  - HLT output bandwidth: 250MB/s
- Architecture
  - Dual core routers
  - Data that can't be processed by the HLT is temporarily stored on local HLT node discs for inter-fill processing

LHCb Trigger Scheme

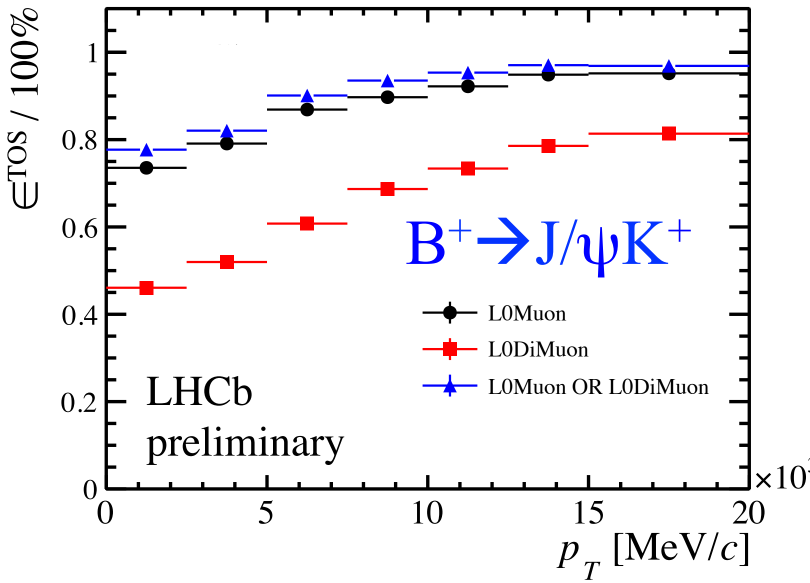


- L0 hardware:
  - Implemented in custom made hardware
  - Decision to front-end in 4μs
- HLT software
  - 29000 logical cores
  - 5 kHz to storage (2kHz incl. B, 2 kHz charm, 1kHz muons)
- Details in JINST 8 (2013) P04022


40MHz
L0
μ, μμ
had
e± γ
1MHz
HLT1
partial reconstruction
IP, PT, mu-ID
80kHz
HLT2
Full reconstruction
inclusive & exclusive
5kHz

- L0 muon trigger
  - Reconstructs muon track segments, Δp/p ~20%
  - L0 muon triggers
    - single muon p_T > 1.76GeV
    - dimuon p_{T1} x p_{T2} > $(1.6\text{GeV})^2$
    - Total muon rate ~400kHz

L0 muon trigger efficiency



Interlude:

Measurement of trigger efficiencies

- Trigger efficiencies are measured **after selection**
  → only **additional inefficiency** due to trigger are shown
- Measured in a data driven way
  (“TISTOS”, generalized tag & probe: JINST 8 (2013) P04022)

L0 hardware trigger: Muons

- L0 muon trigger
  - Reconstructs muon track segments, $\Delta p/p$ ~20%
  - L0 muon triggers
    - single muon p_T > 1.76GeV
    - dimuon p_{T1} x p_{T2} > $(1.6\text{GeV})^2$
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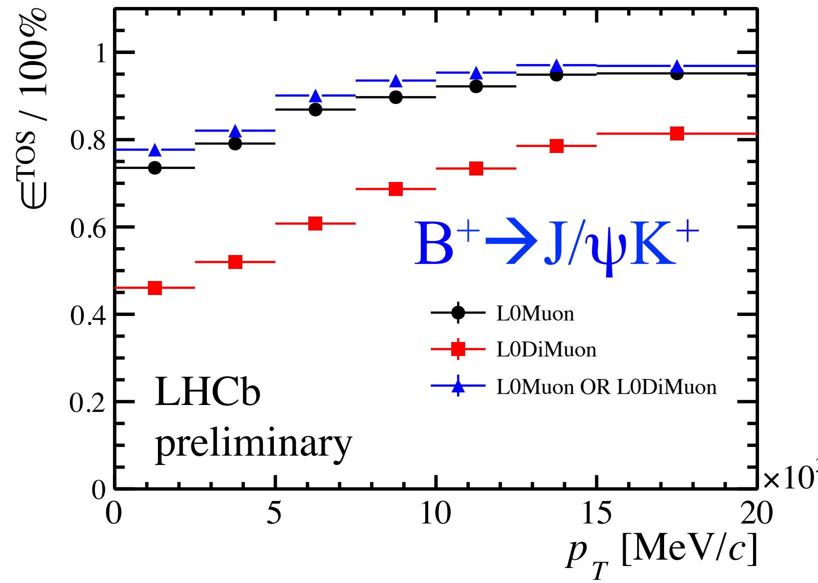
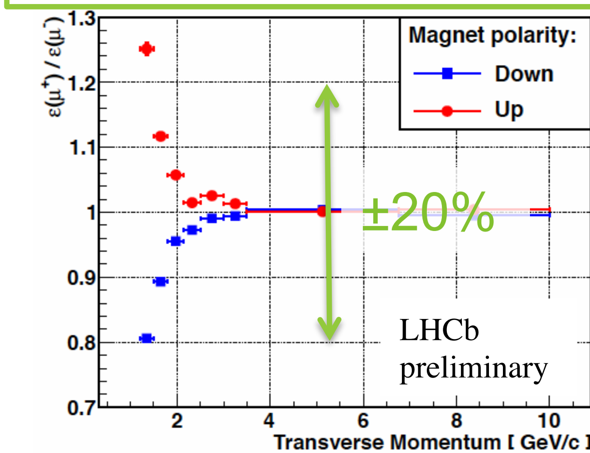
L0 muon trigger efficiency



- L0 charge asymmetry
  - In 2011: ideal geometry used in look-up tables for p_T calculation → charge asymmetry >20%

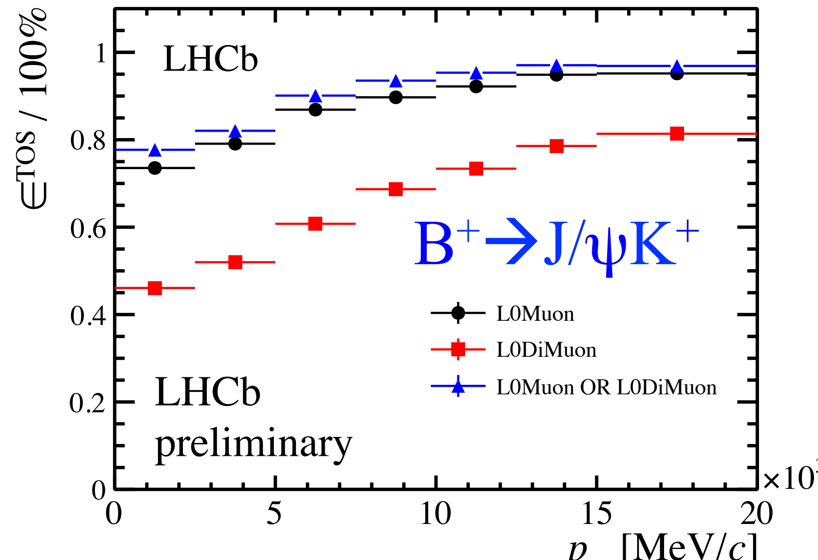
2011 charge asymmetry



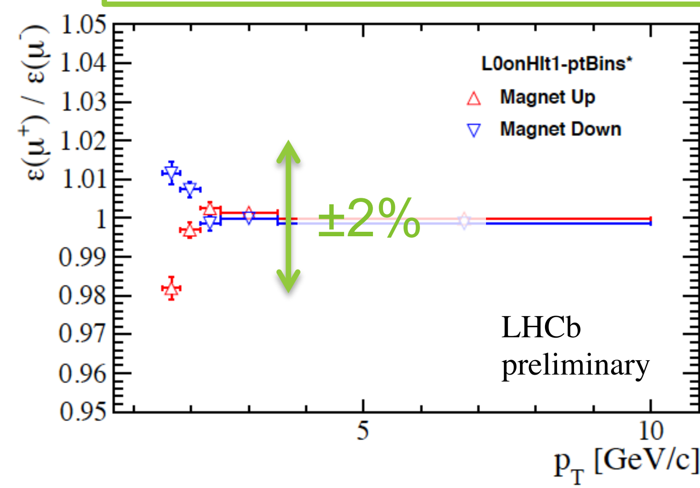
L0 hardware trigger: Muons

- L0 muon trigger
  - Reconstructs muon track segments, $\Delta p/p$ ~20%
  - L0 muon triggers
    - single muon p_T > 1.76GeV
    - dimuon $p_{T1} \times p_{T2}$ > $(1.6\text{GeV})^2$
    - Total muon rate ~400kHz
- L0 charge asymmetry
  - In 2011: ideal geometry used in look-up tables for p_T calculation → charge asymmetry >20%
  - 2012: fill L0 tables from reconstructed track p_T from data → charge asymmetry < 2%

L0 muon trigger efficiency



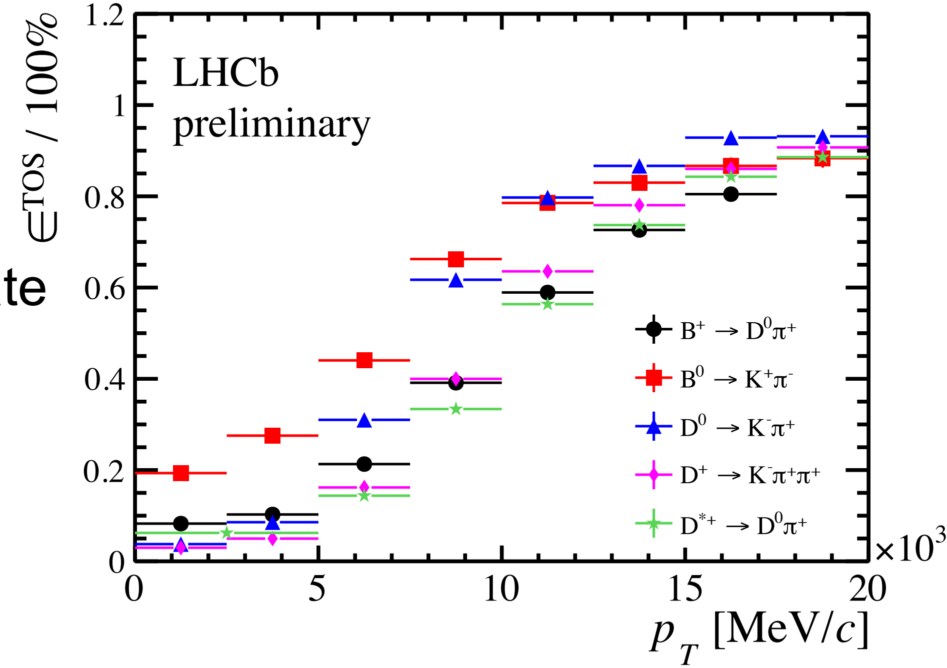
2012 charge asymmetry



L0 hardware trigger: Calorimeter

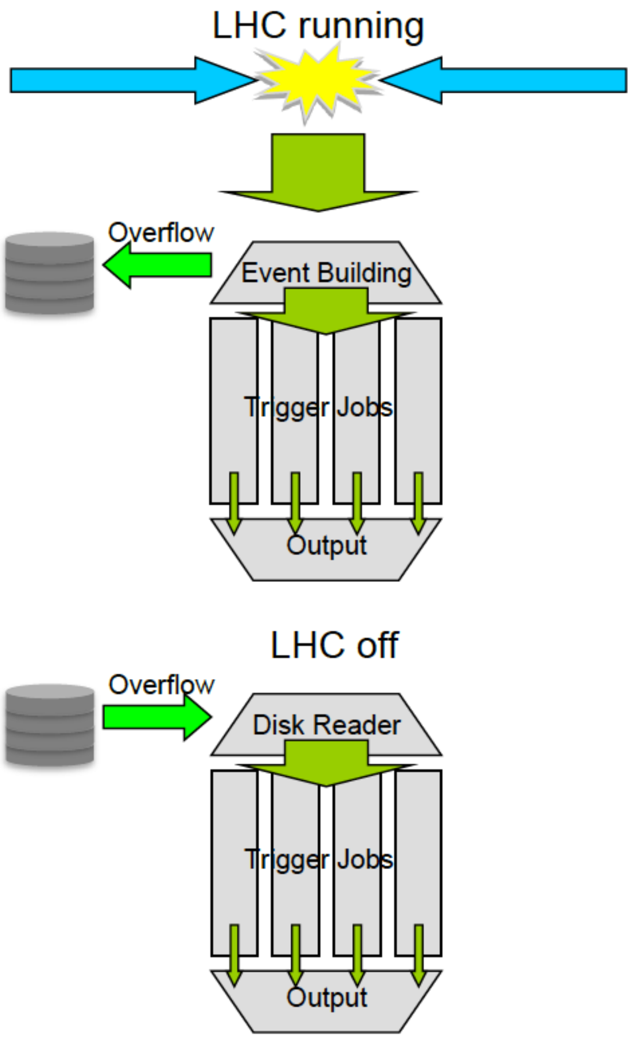
- Hadron trigger
  - Threshold 3.6GeV
- Electron / photon trigger
  - Pre-shower and SPD discriminate between $e^{\pm}$, γ
  - Threshold 3GeV
  - ~80% efficient for radiative $B \rightarrow X\gamma$ decays
- Rates:
  - Total muon rate ~400kHz
  - L0 hadron ~490kHz
  - L0 $e^{\pm}$, γ ~150kHz
  - **Total L0 rate: 0.9MHz**

L0 hadron trigger efficiency



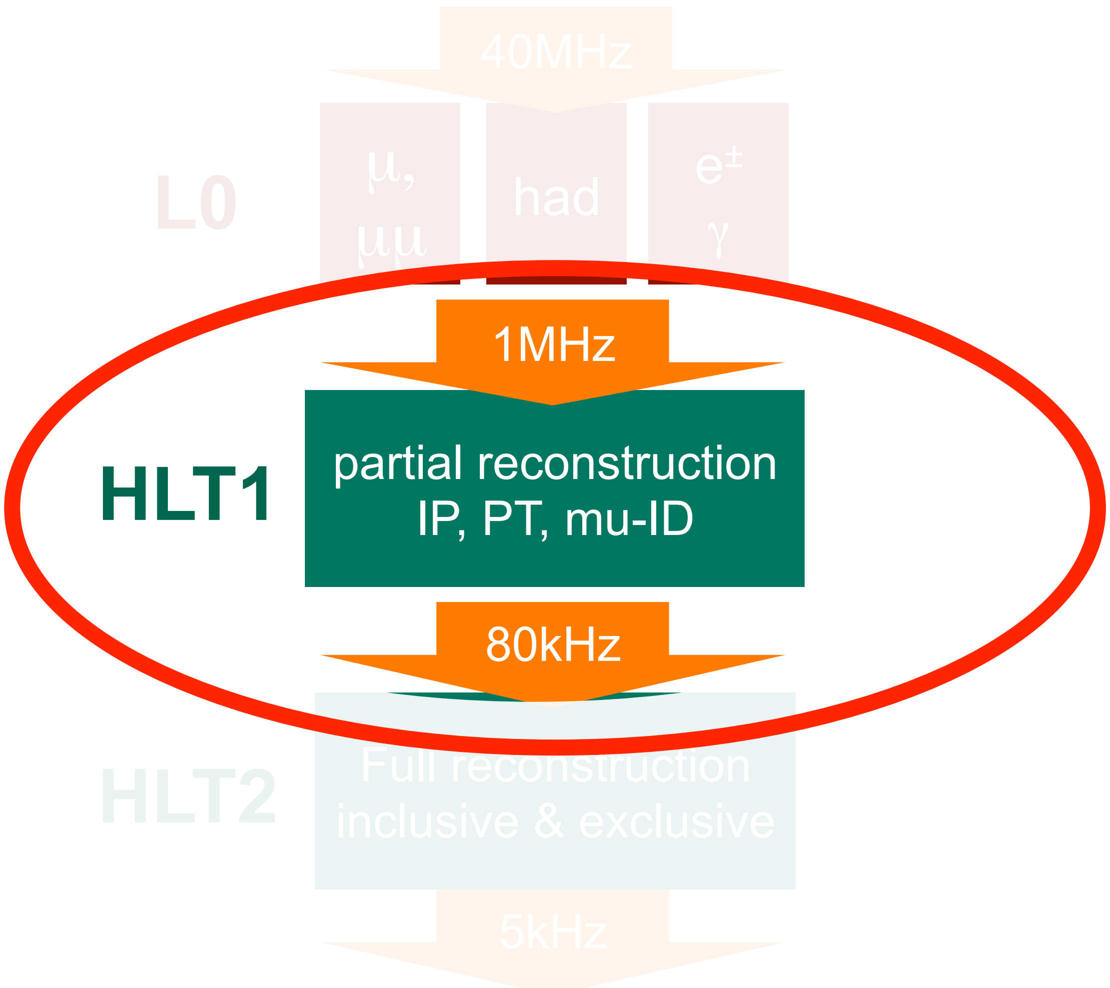
	L0 trigger	Average ϵ^{TOS}
$B^+ \rightarrow J/\psi K^+$	L0-μ or $\mu\mu$	89%
$B^0 \rightarrow K^+\pi^-$	L0-hadron	40%
$D^0 \rightarrow K^-\pi^+$	L0-hadron	27%
$D^0 \rightarrow K^-\pi^+\pi^-\pi^+$	L0-hadron	22%

Interlude: Deferred Trigger

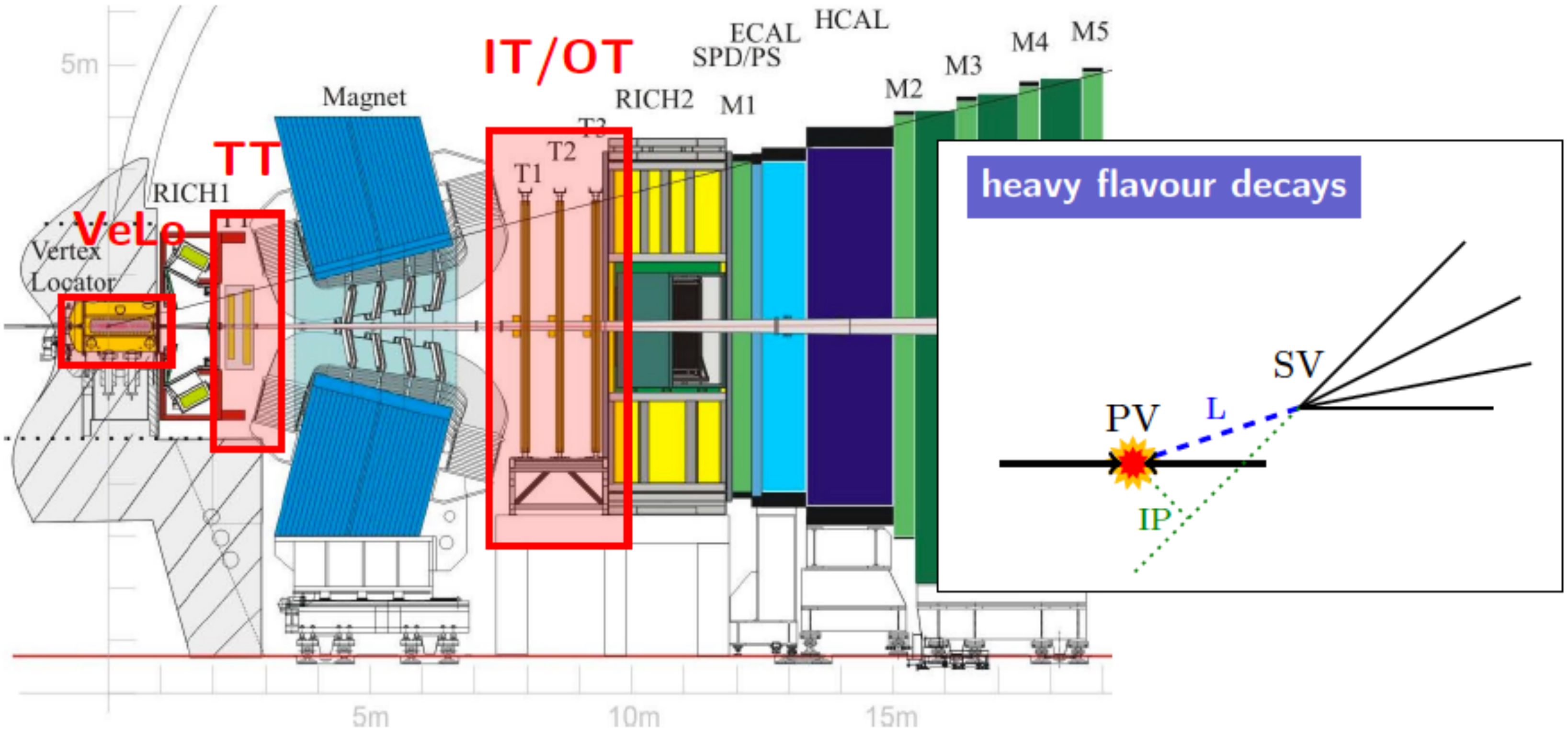


See also M. Frank, Tue 15:45
R. Schwemmer, Mon 13:30

- LHC delivers ~30% of the time stable beams
  → **70% idle time for EFF**
- Principle:
  - >1000 machines equipped with 1-2TB local discs
  - Overcommit Farm by ~20-30%
  - Data that cannot be processed by the HLT is written to local disc
  - Process data in interfill gaps
- **Effective 20% extra CPU** allows to lower tacking thresholds p_T = 500 → 300MeV


40MHz
L0
μ,
μμ
had
e±
γ
1MHz
HLT1
partial reconstruction
IP, PT, mu-ID
80kHz
HLT2
Full reconstruction
inclusive & exclusive
5kHz

HLT1: add tracking information

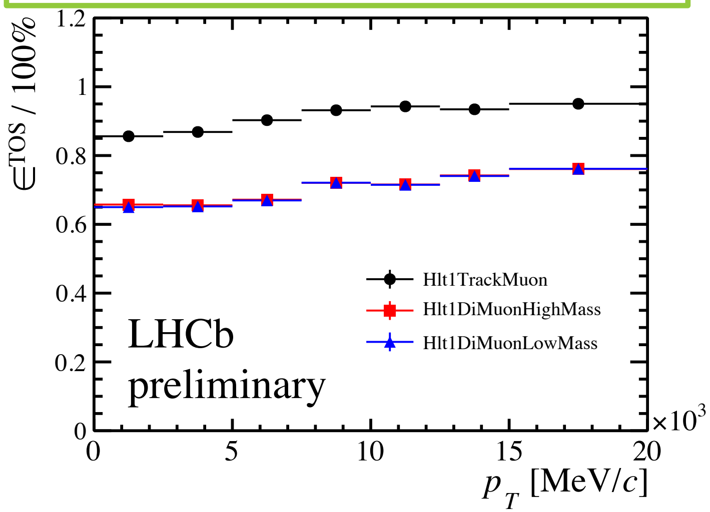


- Track reconstruction in vertex detector (VeLo), reconstruct PVs
- High IP or muon-matched VeLo tracks are selected
- Perform forward tracking, search window size given by min p_T

track	μ	$\mu\mu$	other
min. p_T [GeV]	1.0	0.5	1.6

- HLT1 muon selections with offline-like muon ID
  - Single muon: detached or high p_T
  - Dimuon: detached or high mass ($m_{\mu\mu}$>2.7GeV)

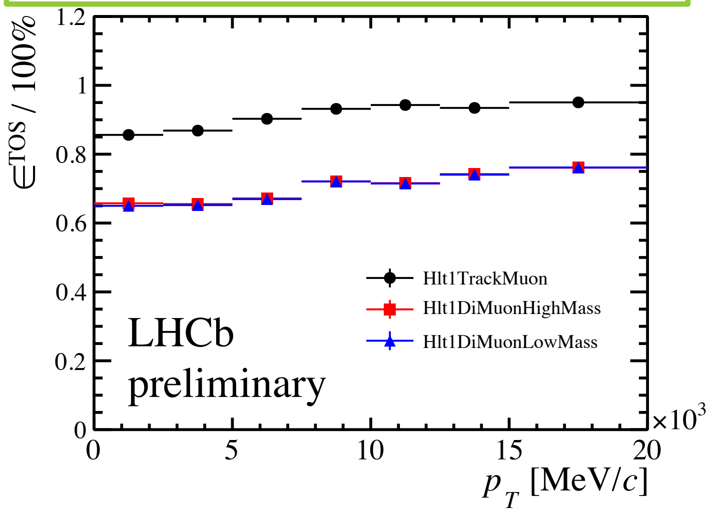
HLT1 muon trigger efficiency



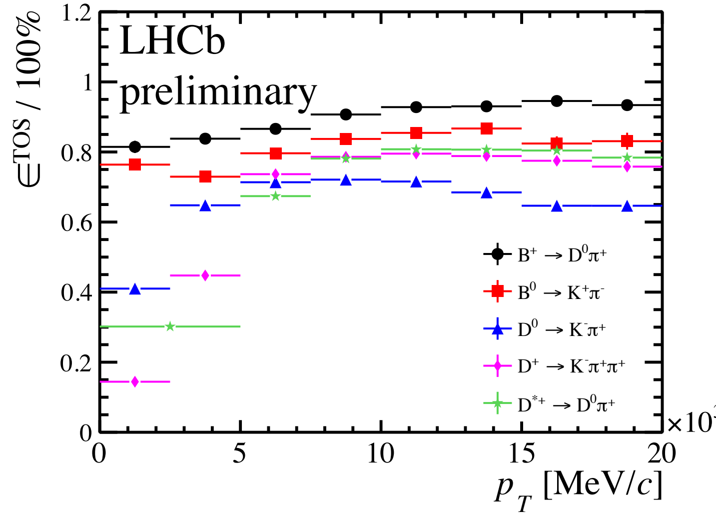
- HLT1 muon selections with offline-like muon ID
  - Single muon: detached or high p_T
  - Dimuon: detached or high mass ($m_{\mu\mu}$>2.7GeV)

- HLT1 inclusive trigger optimized for B decay products
  - Selection: single track with high p_T and vertex separation
  - Version with relaxed cuts for L0 $e^{\pm}$, γ triggers

HLT1 muon trigger efficiency



HLT1 inclusive trigger

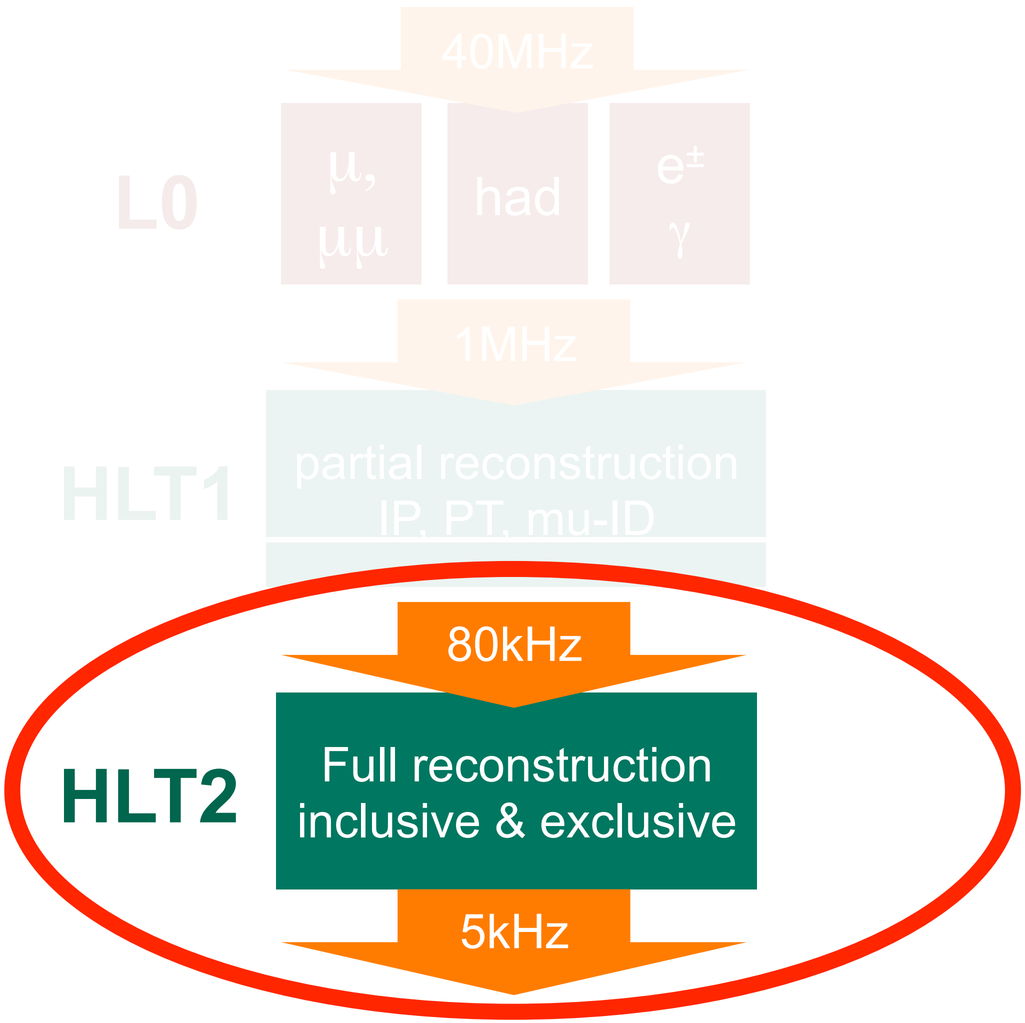


HLT1 Trigger Overview

- HLT1 muon selections with offline-like muon ID
  - Single muon: detached or high p_T
  - Dimuon: detached or high mass ($m_{\mu\mu}$>2.7GeV)
- HLT1 inclusive trigger optimized for B decay products
  - Selection: single track with high p_T and vertex separation
  - Version with relaxed cuts for L0 $e^{\pm}$, γ triggers
- HLT1 output rates:
  - Muons: ~14kHz
  - Inclusive track ~58kHz
  - L0 $e^{\pm}$, γ ~7kHz
  - **Total HLT1 rate ~80kHz**

	HLT1 trigger	Average ε^{TOS}
$B^+ \rightarrow J/\psi K^+$	μ / $\mu\mu$	90 / 69%
$B^0 \rightarrow K^+\pi^-$	Inclusive track	86%
$B^0 \rightarrow D^+\pi^-$		89%
$D^0 \rightarrow K^-\pi^+$		67%
$D^0 \rightarrow K^-\pi^+\pi^-\pi^+$		60%

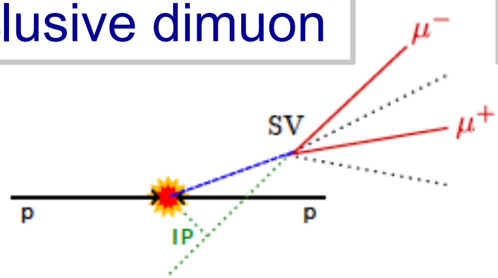
HLT1 output rate tuned to allow HLT2 processing @ max rate


40MHz
L0
μ, μμ
had
e± γ
1MHz
HLT1
partial reconstruction
IP, PT, mu-ID
80kHz
HLT2
Full reconstruction
inclusive & exclusive
5kHz

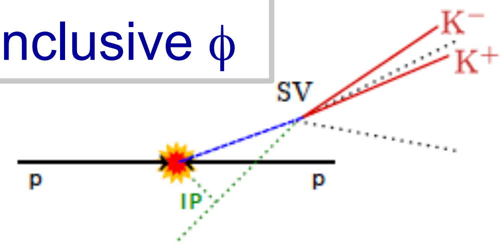
HLT2 full reconstruction

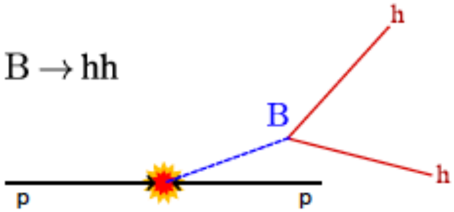
- At HLT2 level, the event is fully reconstructed
  - Reconstruction performance close to offline (p_T>0.3GeV)
  - Extremely powerful, flexible software environment: heavy use of MVA-based selections, staged reconstruction (PID)
  - Combination of inclusive and exclusive selections, e.g.:

Inclusive dimuon

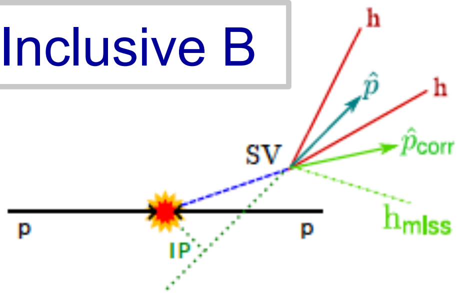


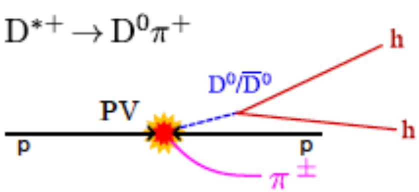
Inclusive ϕ





Inclusive B

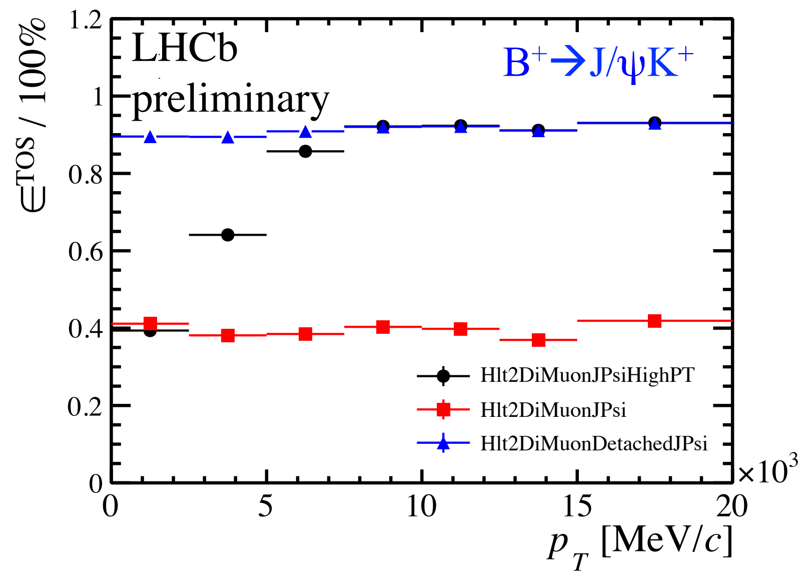




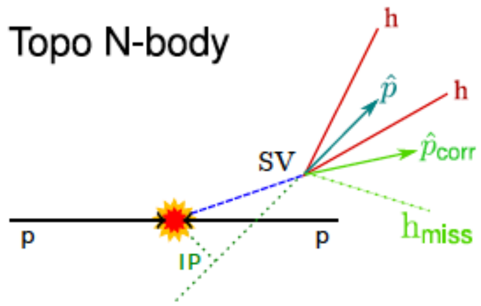
HLT2 Inclusive Dimuon

- Dimuon triggers essential for LHCb physics
  - Muon ID identical to offline [LHCb-DP-2013-001]
  - “Prompt and detached” strategy
    - Prompt lines: no lifetime-biasing cuts, but prescaled (unless high p_T or high $m_{\mu\mu}$)
    - Detached lines use IP cuts to improve purity
  - Total output rate ~1kHz

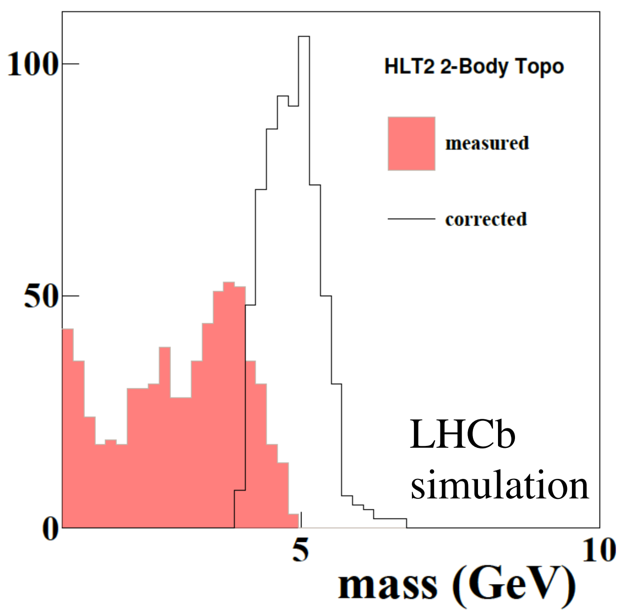
HLT2 muon trigger efficiency



HLT2: Inclusive Beauty trigger I



(corrected) mass



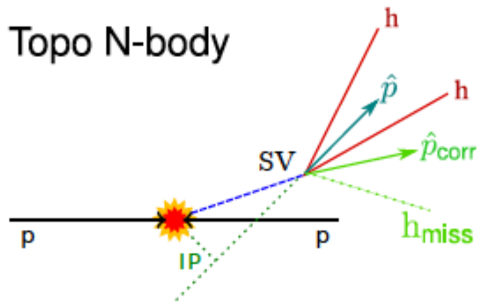
- Inclusive trigger on 2,3,4-body detached vertices
- Primary trigger for B decays to charged tracks
- Uses fast BDT algorithm [JINST 8 (2013) P02013]
- BDT inputs: p_T, $IP\chi^2$, flight distance χ^2, mass and corrected mass

$$m_{corr} = \sqrt{m^2 + |p_{T\,miss}|^2} + |p_{T\,miss}|$$

$p_{T\,miss}$: missing momentum transverse to flight direction

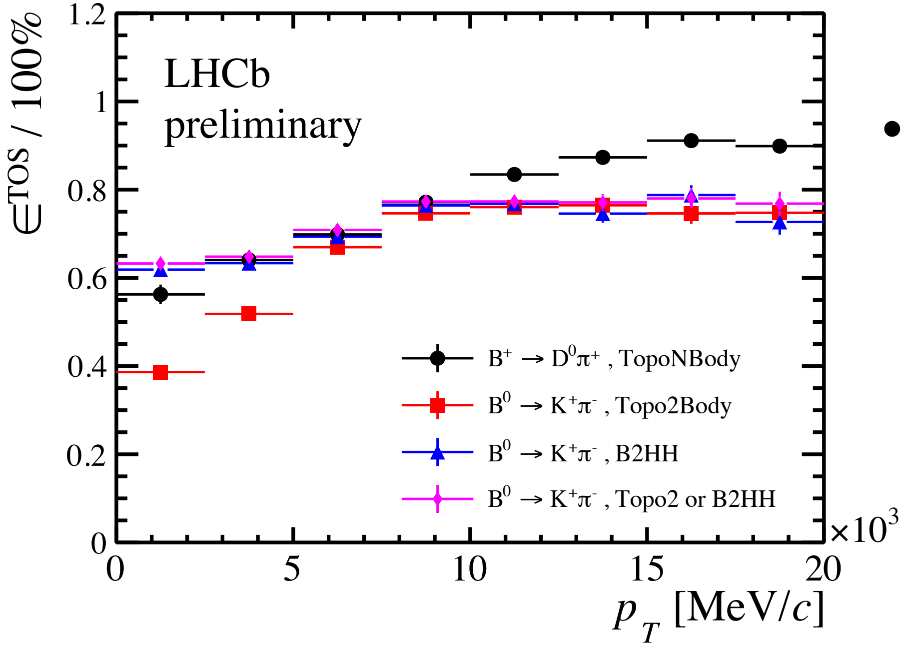
- Very efficient even on partially reconstructed beauty decays

HLT2: Inclusive Beauty trigger II



- Inclusive trigger on 2,3,4-body detached vertices
- Primary trigger for B decays to charged tracks
- Uses fast BDT algorithm [JINST 8 (2013) P02013]

HLT2 inclusive B trigger efficiency



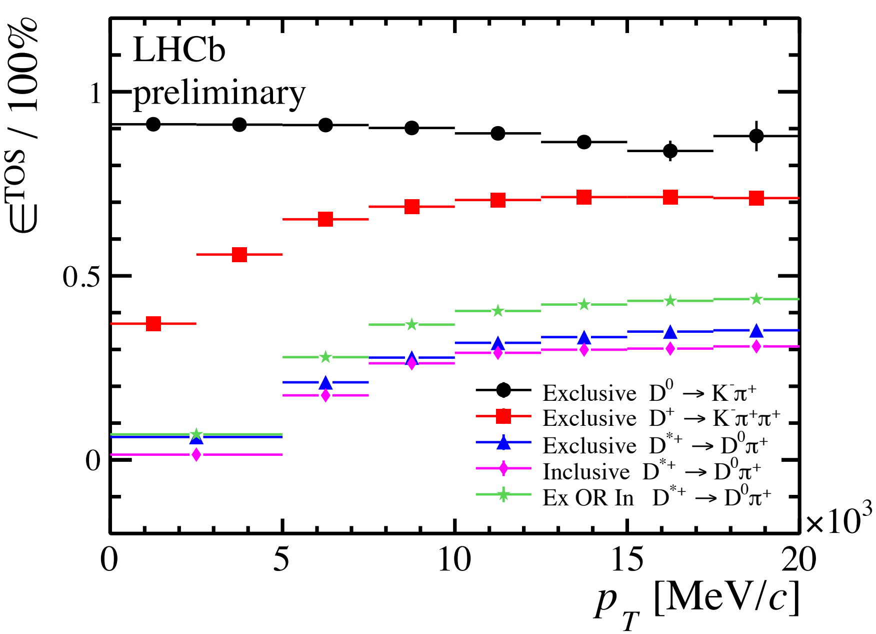
- Output rate: 2kHz (pure beauty signal)
- Efficiencies

	Average ϵ^{TOS}
$B^0 \to K^+\pi^-$	78%
$B^0 \to D^+\pi^-$	76%

Inclusive and Exclusive Charm Triggers

- Promptly produced charm
  - Exclusive selections for hadronic, leptonic and semileptonic decays for both D and Λ^+_c
  - Inclusive trigger for decays $D^{*+} \rightarrow D^0 \pi^+$
    - Requires two decay products of D^0 and a reconstructed slow pion

HLT2 charm trigger efficiency



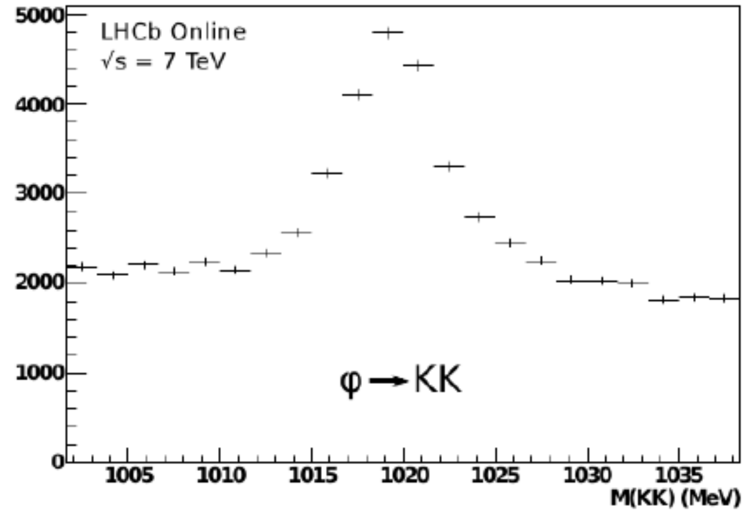
- Output rate: 2kHz (pure charm signal)
- Efficiencies

	Average ϵ^{TOS}
$D^0 \rightarrow K^-\pi^+$	90%
$D^* \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$	26% ($20\%^{excl} + 17\%^{incl}$)

HLT2: Exclusive Triggers

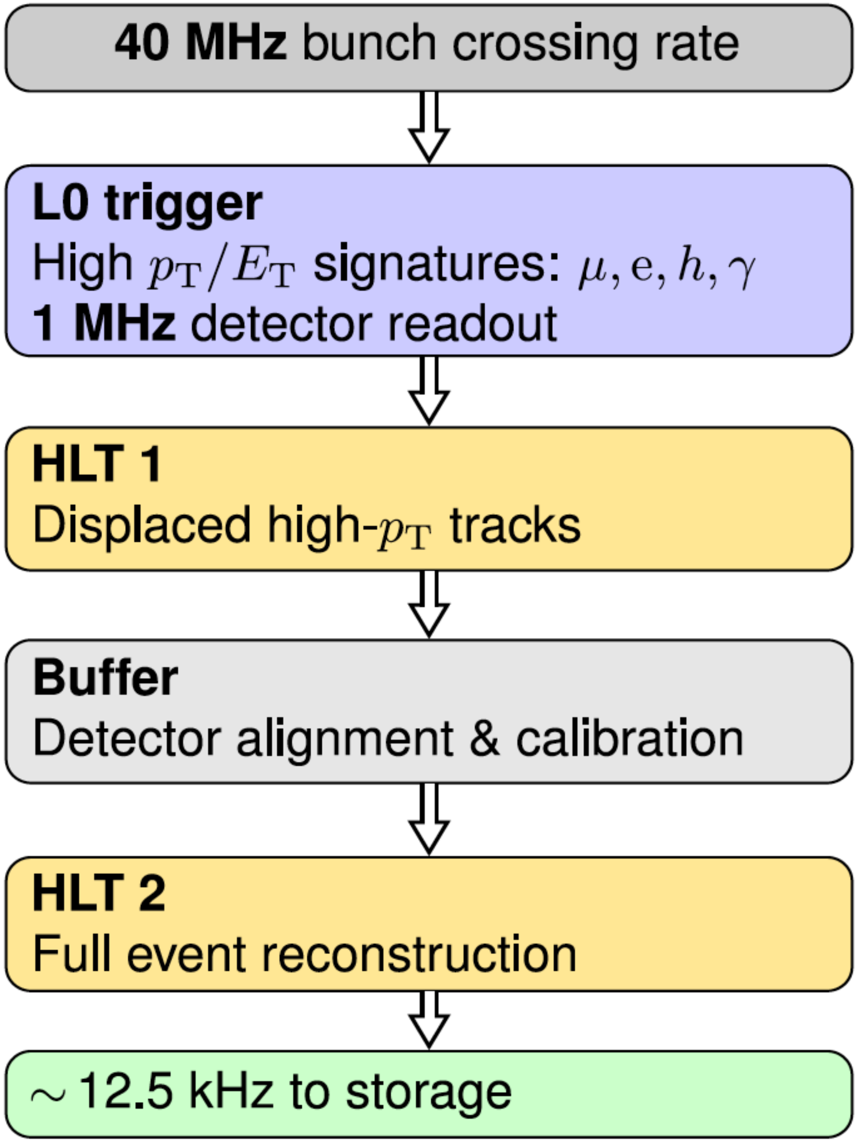
- Modular reconstruction components for CPU intense tasks
  - RICH PID used for proton identification, e.g. in $\phi \rightarrow K^+K^-$ $\Lambda^+_c \rightarrow phh'$
  - Downstream track reconstruction (tracks without Velo hits) used for decays of K_s

HLT2 inclusive ϕ



- Exclusive selections, e.g.
  - Channels with electrons or photons in the final state
  - EW physics (very high p_T $\mu^\pm$ or $e^\pm$)
  - Low multiplicity forward physics
  - Very displaced vertices


The Future
NEXT EXIT



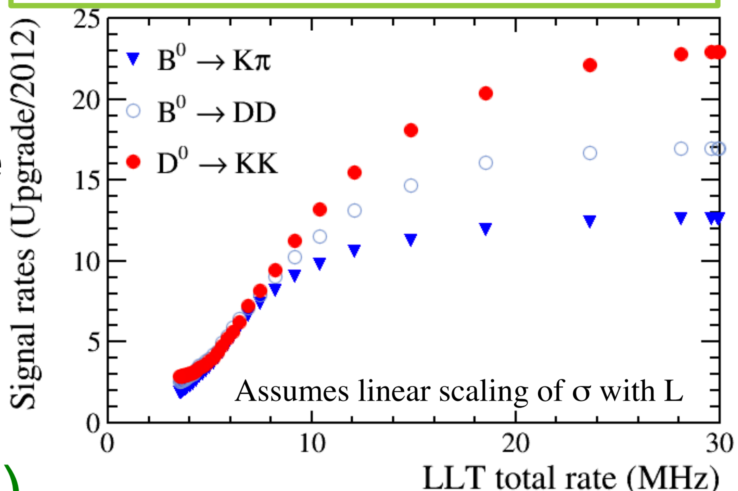
- Decouple HLT2 from HLT1
  - Buffer events after HLT1
  - Allows detector calibration and alignment online
  - Make trigger more compatible with offline
- Allows the use of selection level cuts in the trigger
  - E.g. full RICH PID → allows to separate Cabbibo suppressed charm decays from favoured ones

See also S. Neubert, Poster and M. Frank, Tue 15:45

LHCb Upgrade: 2018++

- **LHCb upgrade goal: collect >5fb^{-1} per year for 10 years with a more efficient and flexible trigger and improved detector performance**
  - Current p_T based hardware trigger system will saturate
- Key point: remove 1MHz detector readout bottleneck
  - Upgrade detector and DAQ to readout at 40MHz
  - Full software trigger building on architecture for LHC run II
  - ~20kHz output to storage
- Initially use LLT to reduce input rate
  - As farm and DAQ size increases, LLT progressively loosened
- **Large gains for hadronic triggers** (and keep excellent muonic triggers)

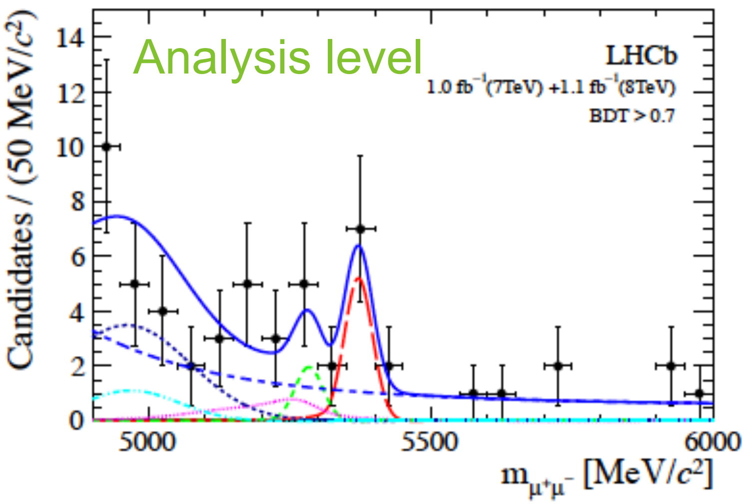
Signal yield upgrade / 2012



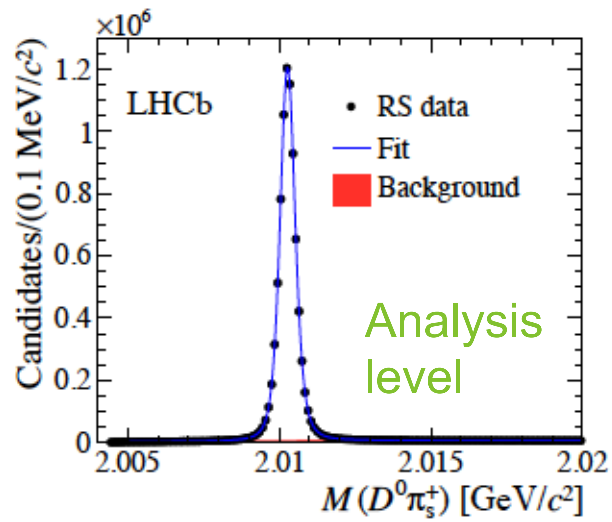
Summary

- LHCb trigger has been very successful in 2011 and 2012
- Covers a wide range of physics channels

Trigger rarest B-decay
with high efficiency

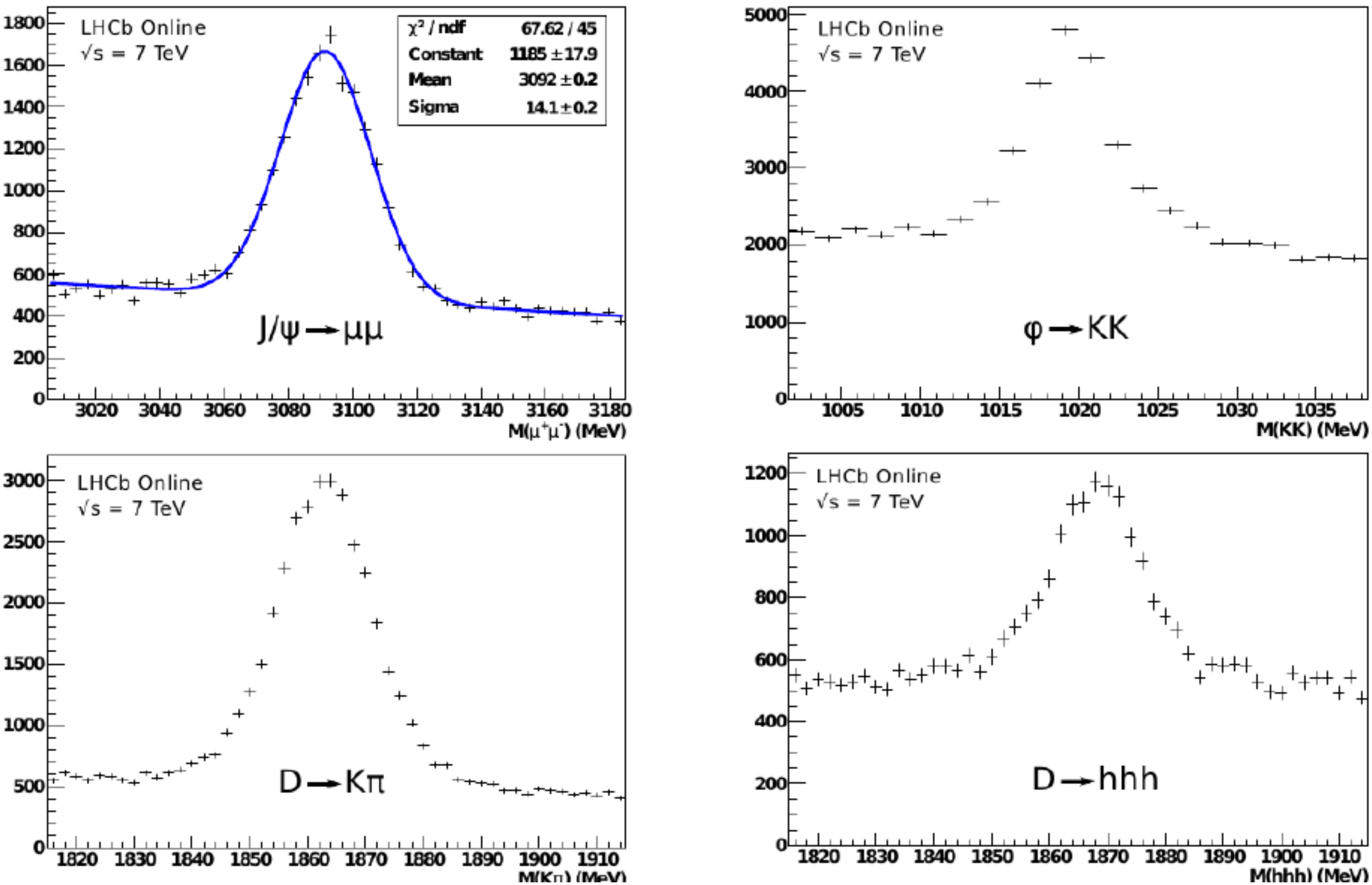


Huge charm sample
with excellent purity



- Flexible implementation in software
  - Allows to quickly adapt to running conditions
  - Deferred triggering: optimize resources for mean-, not peak usage
- Major upgrade of LHCb and its trigger planned for 2018


STOP


LHCb Online
√s = 7 TeV
χ² / ndf 67.62 / 45
Constant 1185 ± 17.9
Mean 3092 ± 0.2
Sigma 14.1 ± 0.2
J/ψ → μμ
M(μ⁺μ⁻) (MeV)
LHCb Online
√s = 7 TeV
φ → KK
M(KK) (MeV)
LHCb Online
√s = 7 TeV
D → Kπ
M(Kπ) (MeV)
LHCb Online
√s = 7 TeV
D → hhh
M(hhh) (MeV)