LHCb upgrade and trigger challenges

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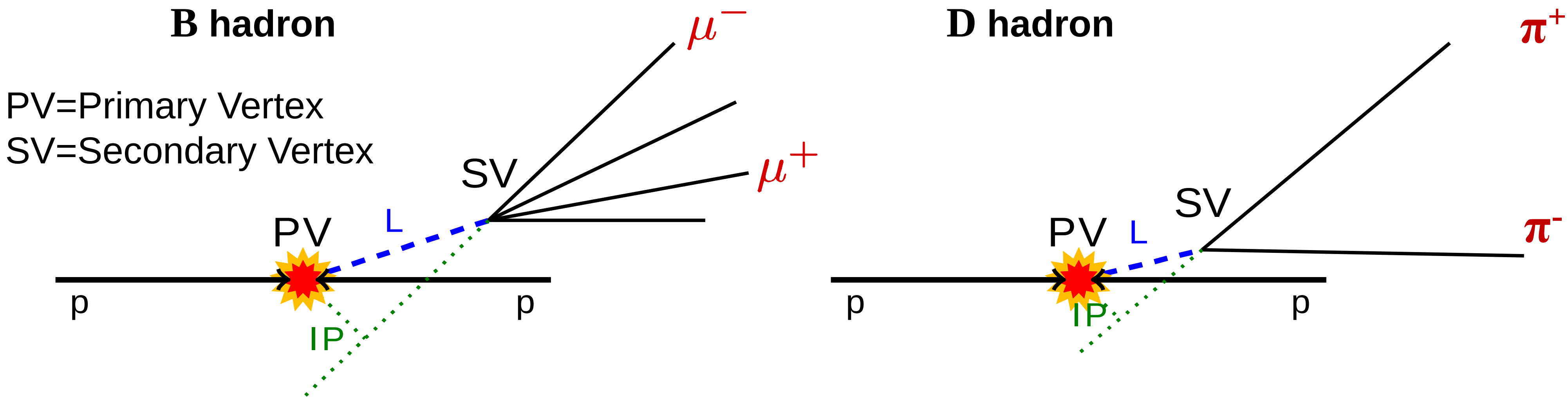
Contents

Aim of LHCb: flavour physics

- **Many open questions of particle physics are associated with flavour:**
  - **Baryon-antibaryon asymmetry**
  - **Quark mass hierarchy**
  - **Cabibbo-Kobayashi-Maskawa matrix structure**
  - **Non zero neutrino mass**
- **Search for New Physics:**
  - **see S. Easo (Tuesday), "Recent LHCb results on rare decays"**
    - **Constraints on supersymmetric Higgs bosons: $B_s \rightarrow \mu^+\mu^-$**
    - **Angular distributions of $B^0 \rightarrow K^{*0}\mu^+\mu^-$ sensitive to helicity structure of NP**
  - **see D.M. Santos (Friday),"Recent LHCb results on CP violation"**
    - **CP violating asymmetries very sensitive to NP: $B_s \rightarrow J/\Psi\ \varphi$ measures B_s mixing phase, charm**
  - **CKM description at sub 10% level**

Flavour Physics at LHC

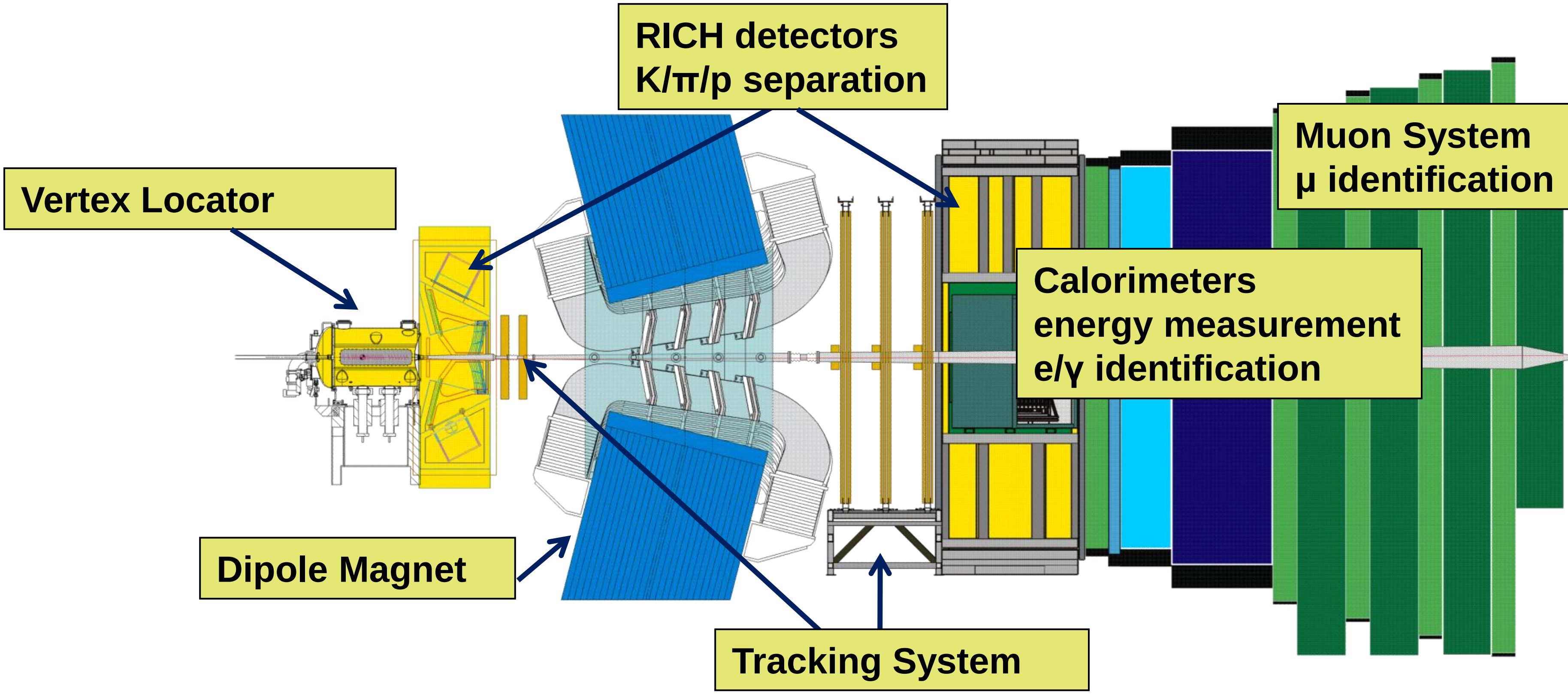
- **Typical decay topologies:**



- **$B^{\pm}$ mass ~ 5.28 GeV, daughter p_T O(1GeV)**
- **τ~1.6 ps, flight distance ~1cm**
- **Signature: detached muons from B→ J/ψ, J/ψ →$\mu^+\mu^-$**
- **D^0 mass ~ 1.86 GeV, appreciable daughter p_T**
- **τ~0.4 ps, flight distance~4mm**
- **Also produced as 'secondary' charm from B decays**

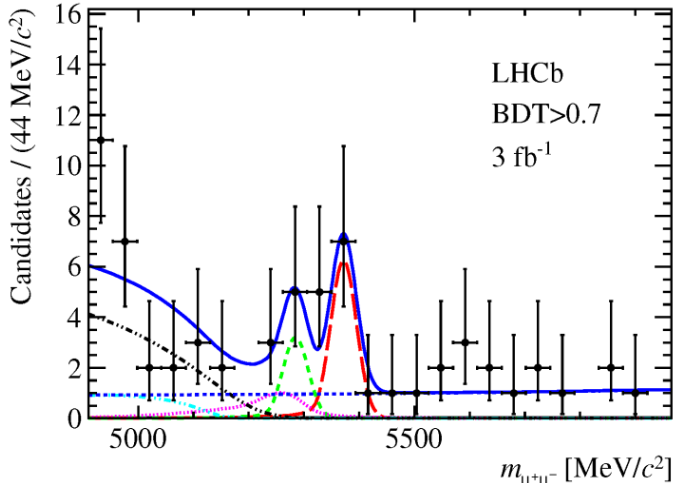
Current LHCb detector

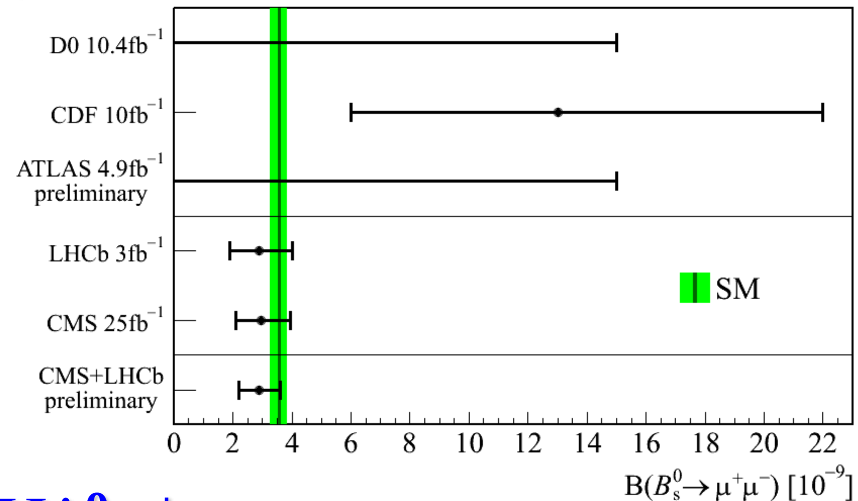
- Forward spectrometer ($2 < \eta < 5$)
- 2% of solid angle, 27% of heavy quark production cross section inside acceptance



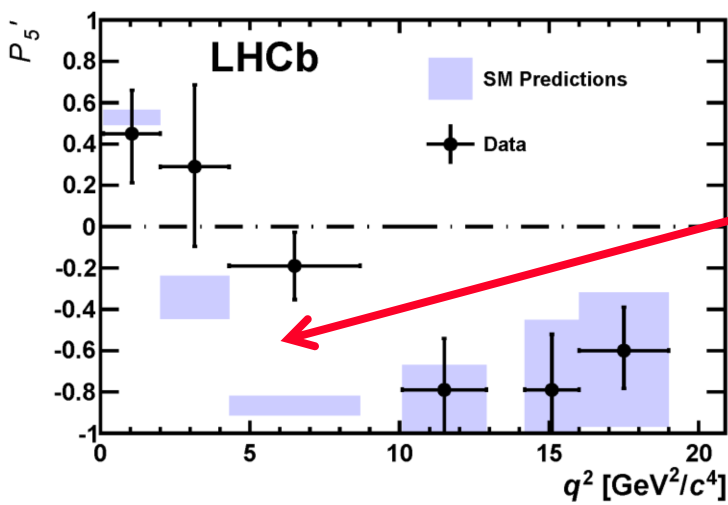
Selected results

- **Measurement of $B_s \to \mu^+\mu^-$ (LHCb-CONF-2013-012)**





- **New observables in $B^0 \to K^{*0}\mu^+\mu^-$**

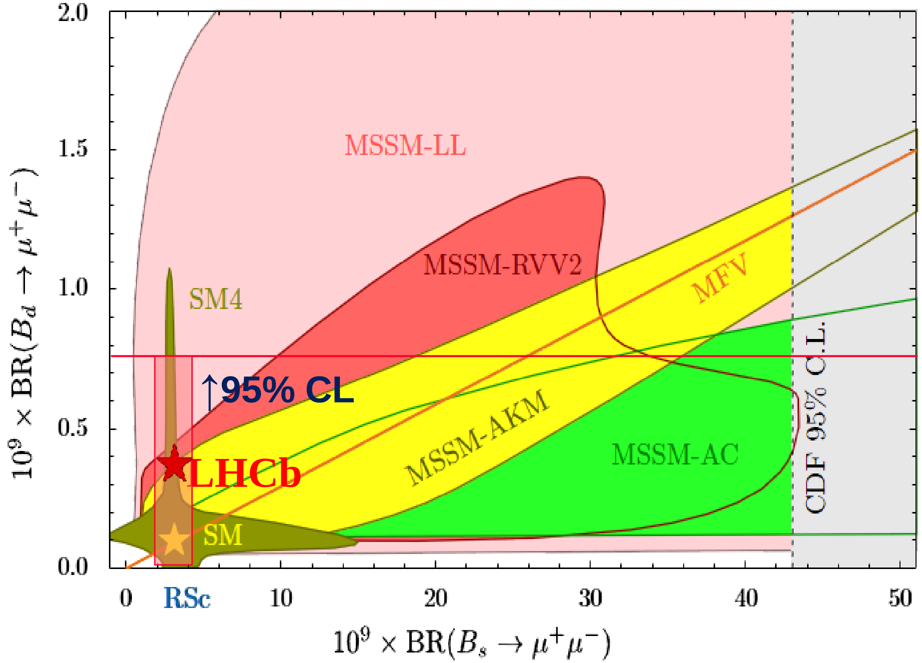


Angular observable "P'$_5$" as function of $\mu^+\mu^-$ invariant mass squared shows local 3.7 σ deviation from SM

arXiv:1308.1707

Many other results

- Constraints on supersymmetry models from $B_{(s)} \to \mu^+\mu^-$



Original plot from D.M. Straub, arxiv:1012.3893

- See Michal Kreps (Monday), "Hadron Spectroscopy at LHCb"
  - **Confirmation & spin measurement of Z(4430). Tetraquark state ($c\bar{c}u\bar{d}$) ? (arXiv:1404.1903)**
- ~200 papers published to date

Why the upgrade?

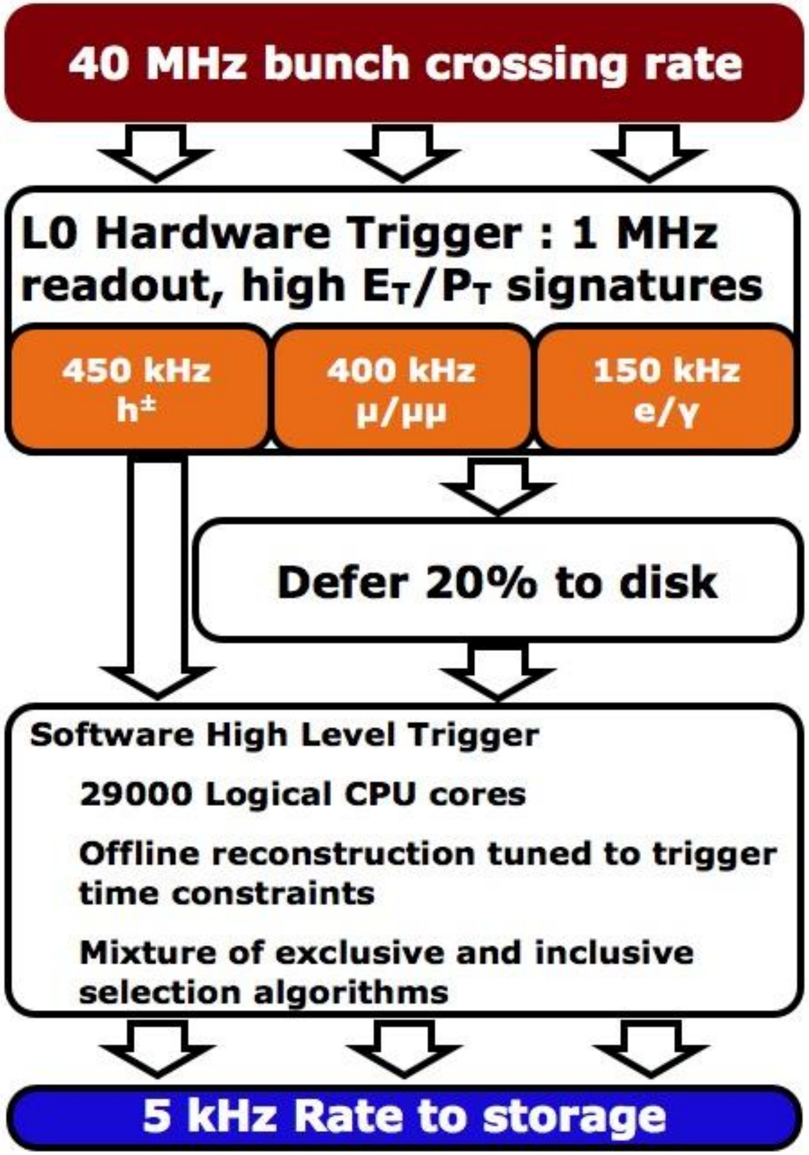
- **LHCb phase 1 (up to 2018):**
  - **After 3 fb^{-1}, the Standard Model description of flavour mixing and CP violation seems confirmed**
  - **Accumulate 8 fb^{-1} at $\mathcal{L}_{inst} = 4{*}10^{32}\ cm^{-2}s^{-1}$ (data doubling in 2015-2018)**
- **To probe NP, higher precision measurements are required**
  - **Sensitivities comparable to theoretical uncertainties (next slide)**
- **At constant luminosity, slow increase in statistical precision, hence**
  - **Run at higher luminosity: $\mathcal{L}_{inst} \leq 2{*}10^{33}\ cm^{-2}s^{-1}$**
  - **Aim: 50 fb^{-1} integrated over 10 years**

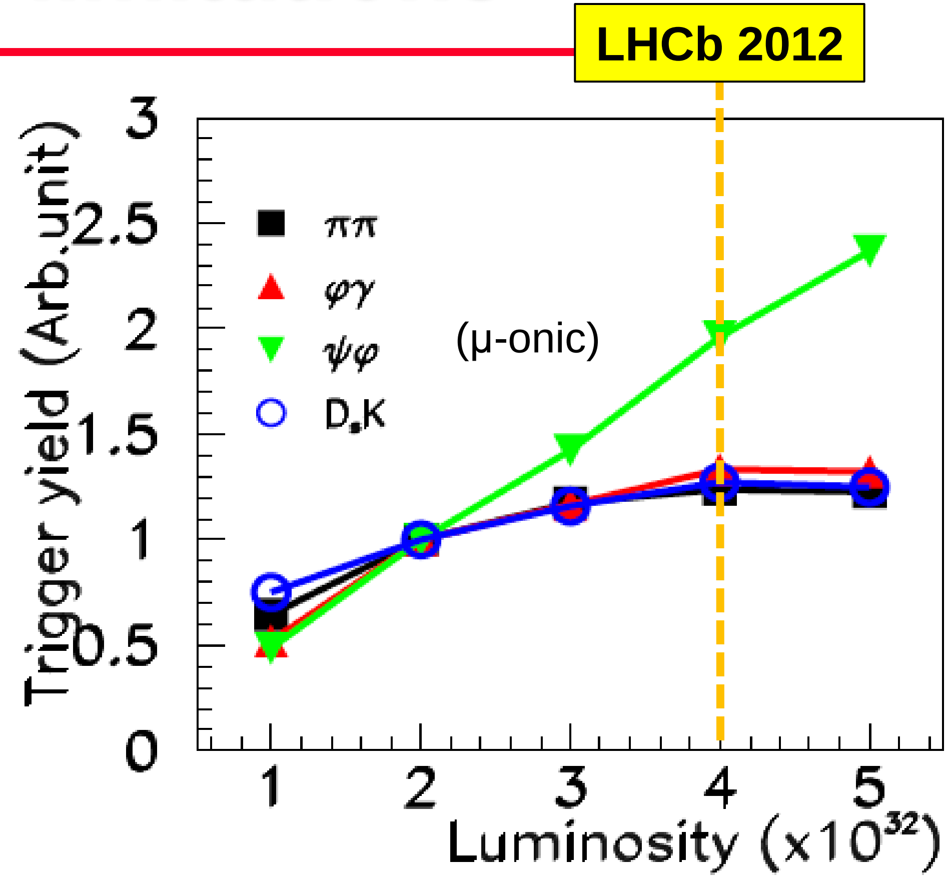
A few LHCb Upgrade physics goals

	2010-2013	2015-2018	2020-2022	2024-…	Theory uncertainty
Integrated lumi	$3\ fb^{-1}$	$8\ fb^{-1}$	$23\ fb^{-1}$	$46\ fb^{-1}$	
$\frac{Br(B_d\to\mu\mu)}{Br(B_s\to\mu\mu)}$	-	110 %	60%	40%	5%
$q_0^2 A_{FB}(B_d \to K^{*0}\mu\mu)$	10%	5%	2.8%	1.9%	7%
$\phi_s(B_s \to J/\psi\phi, B_s \to J/\psi\pi\pi)$	0.05	0.025	0.013	0.009	0.003
$\phi_s(B_s \to \phi\phi)$	0.18	0.12	0.04	0.026	0.02
γ	7°	4°	1.7°	1.1°	negl.
$A_\Gamma(D^0 \to KK)$	$3.4\ 10^{-4}$	$2.2\ 10^{-4}$	$0.9\ 10^{-4}$	$0.5\ 10^{-4}$	-

- **From "Heavy Flavor Physics in the HL-LHC era" Aix-les-Bains ECFA Workshop – Oct 2013**

Current trigger limitations





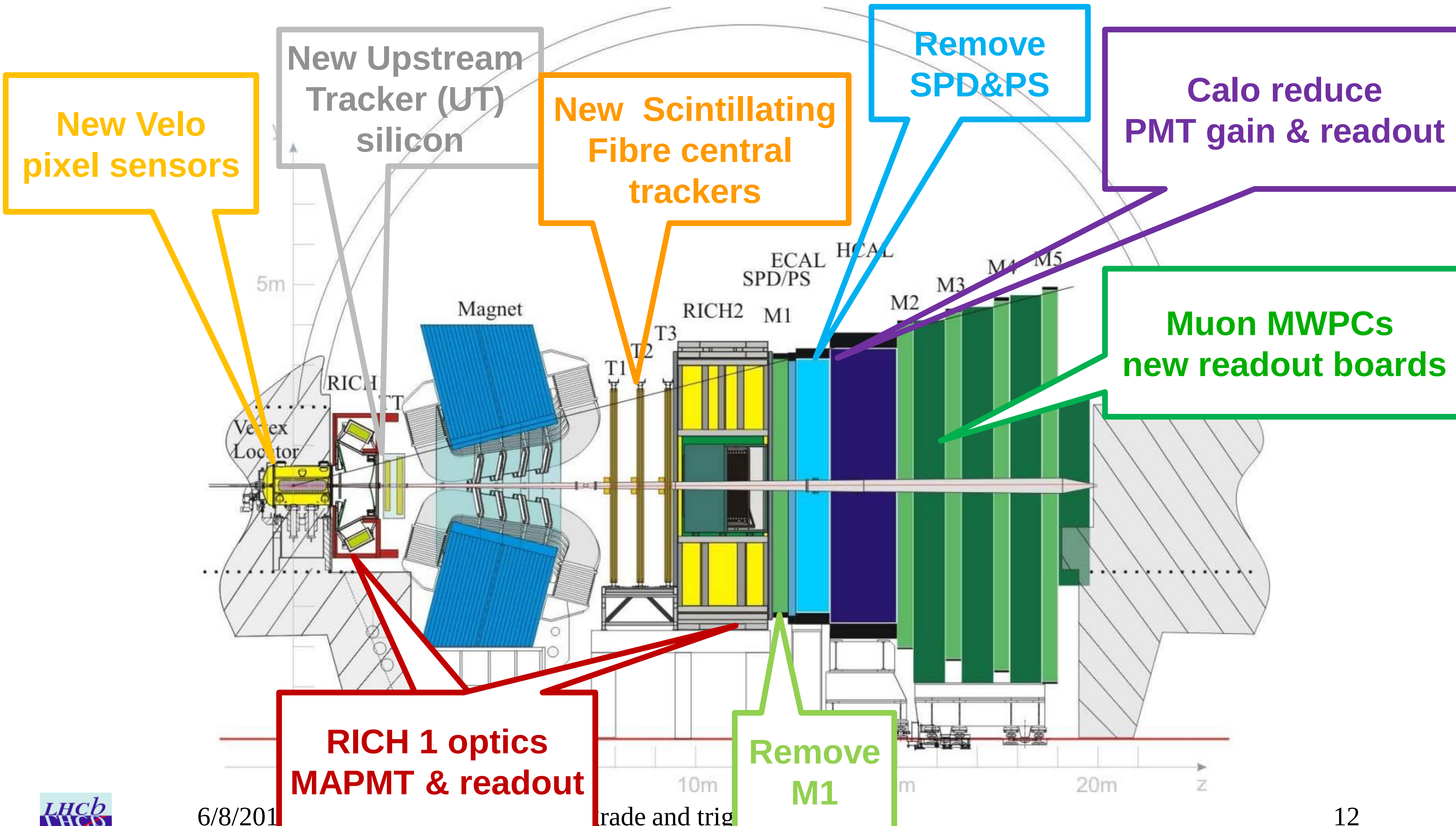
- For higher lumi, E_T thresholds need to be increased
- Yields saturate, no gain beyond $\mathcal{L}_{inst}=2*10^{32}$ for hadronic modes

How & what

- **To increase yields at $\mathcal{L}_{inst}=4*10^{33}$: full software trigger (no L0)**
  - **Increase 10 x for muonic, at least 20 x for hadronic yields (lumi*eff(trig), as compared to 2011)**
  - **Allow fast full reconstruction (more flexible & efficient, also more challenging)**
  - **Initially, run with a hardware Low Level Trigger**
- **Increase current readout from 1MHz → 40 MHz**
  - **can’t read the current detector out beyond 1 MHz**
- **Replace all Front End &Back End electronics**
  - **Detectors with embedded electronics have to be replaced**
- **Apply new technologies to subdetectors**
  - **withstand higher radiation dose and occupancies**
  - **enhance performance**

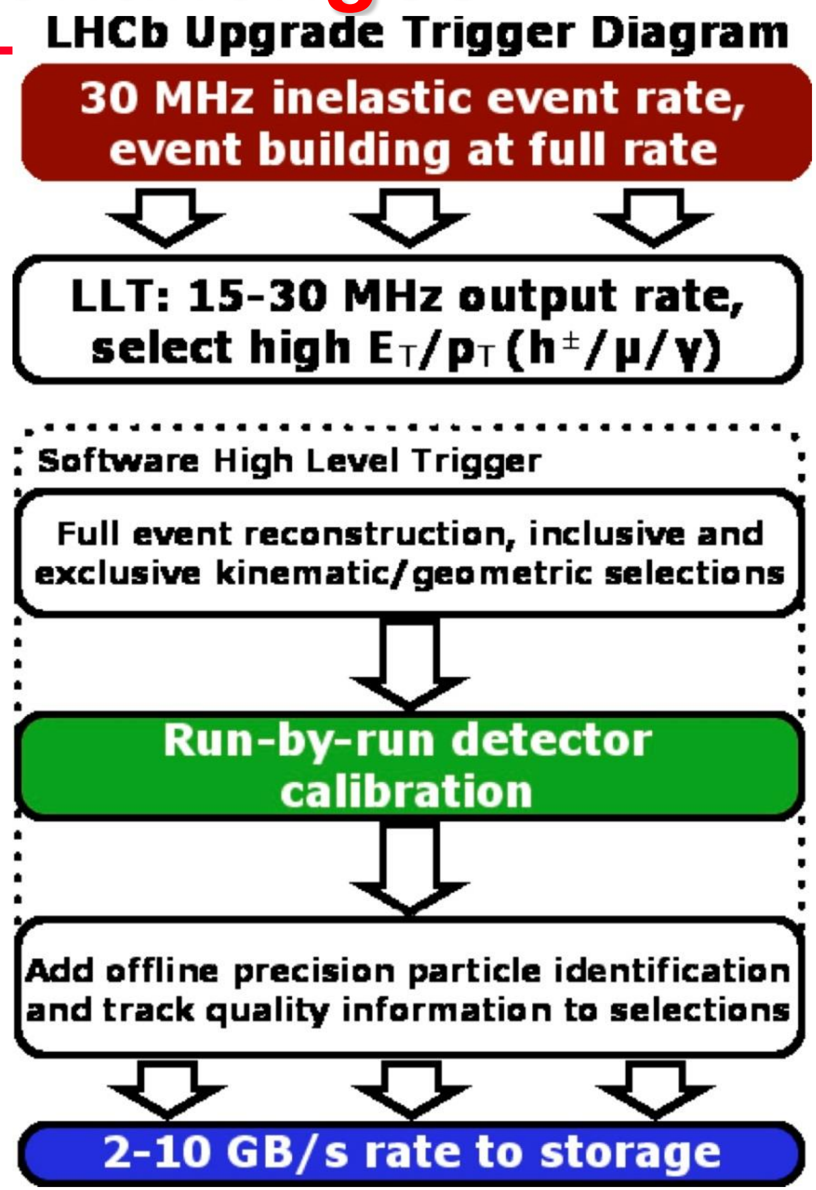
Subdetector upgrades

All subdetectors readout at 40 MHz



Full software trigger challenges

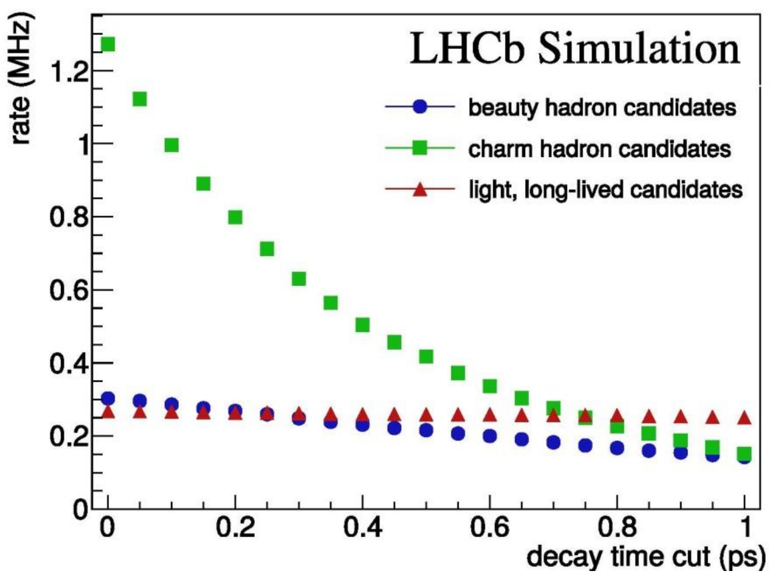
- **Eventsize**
  - ~100 Kb (constraint from readout system)
- **Low Level Trigger**
  - 30 MHz →15-30 MHz
  - Software trigger running on eventbuilder farm
  - Remove when event filter (CPU) farm is complete (1000 nodes)
- **First and second level trigger (HLT1/2) running on Event Filter Farm**
  - CPU budget (13 ms/evt)
  - Output bandwidth (2-10 GB/s)
  - Average pp collisions per bunch crossing ν = 1.6 →7.6; 25 ns bunch separation



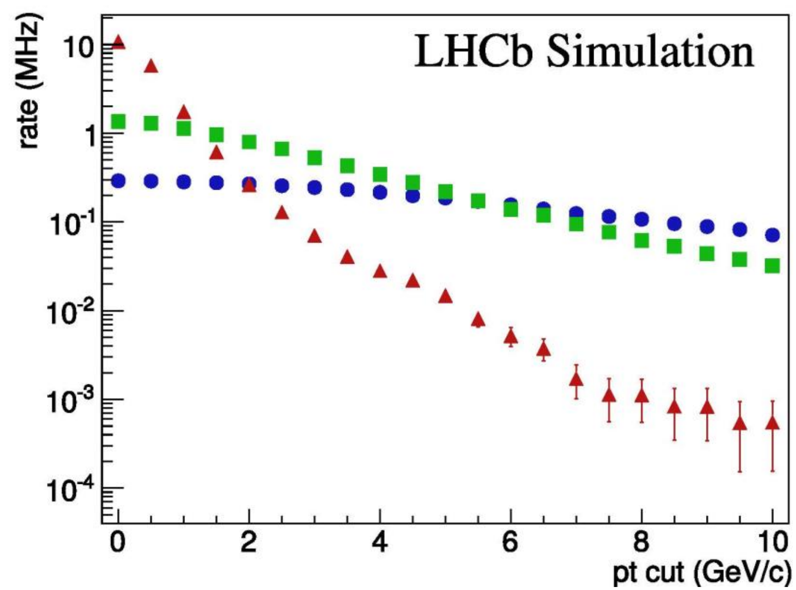
Upgrade conditions (from simulation)

- **Every event contains ~2 light, long-lived hadrons with vertex in Velo**
- **Thus, triggering on displaced vertices is not selective**

Rates as a function of decay time cut for part. reco. candidates

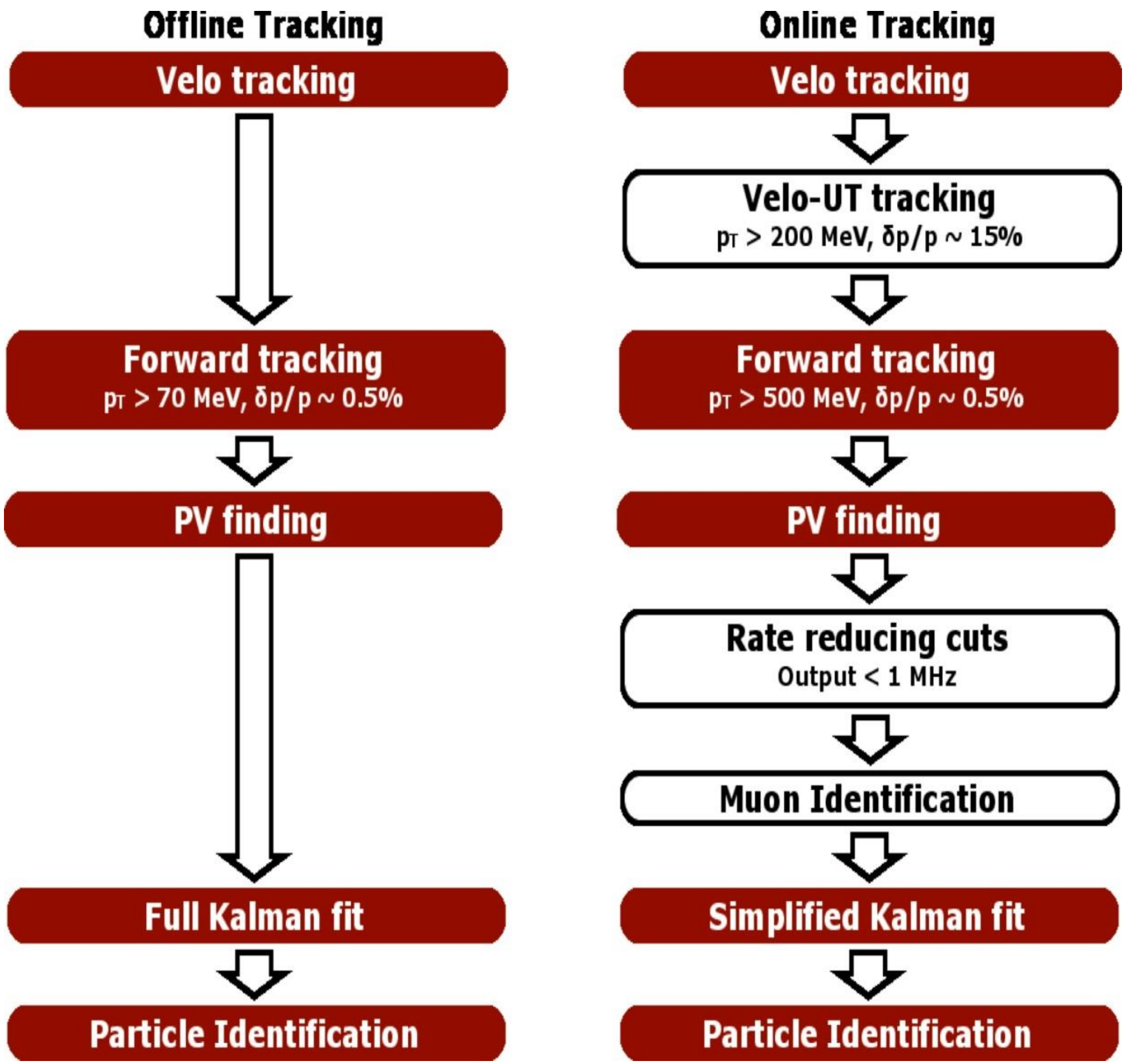


Rates as a function of pT cut for part. reco. candidates



- **Simple cuts (0.2 ps decaytime, 500 MeV p_T) give enormous rates**
- **Upgrade trigger challenge is one of categorisation, not rejection**
- **Use maximum available information to distinguish between signals**
- **See LHCb-PUB-2014-027 (C. Fitzpatrick, V. Gligorov)**

Upgrade trigger strategy



- New Velo pixel and UT reduce the tracking time by 3
  - with SciFi total tracking time in Hlt1: ~ 6 ms
- Offline quality tracking at 30 MHz is possible in software!
- LHCb first collider experiment to operate an all-software trigger at full event rate

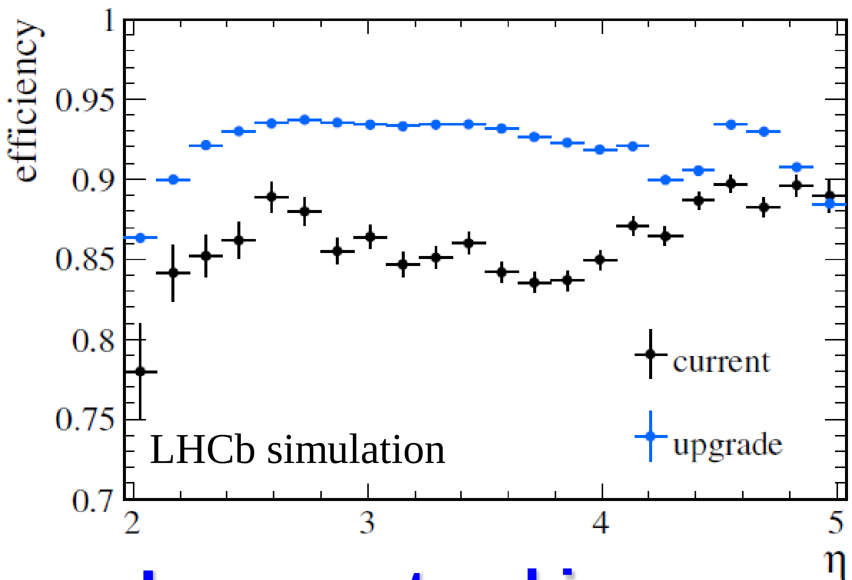
Tracking efficiencies

	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%

- Global Event Cut (GEC): event multiplicity cut also used in Run I
- High efficiency
- See LHCb Tracker Upgrade TDR (LHCb-TDR-015)

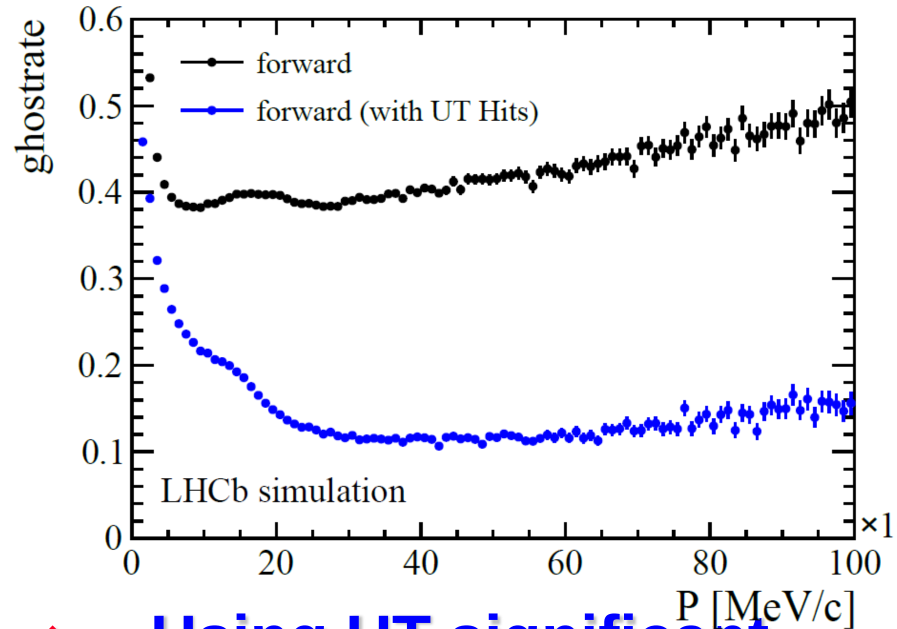
Tracking performance ($B_s \rightarrow \varphi\varphi$)

- **Efficiency**
  - upgrade conditions
  - Current & upgraded T stations



- **Improve tracking performance with SciFi Tracker**

- **Ghost rate**
  - Long tracks without UT and with UT (≥3 hits)



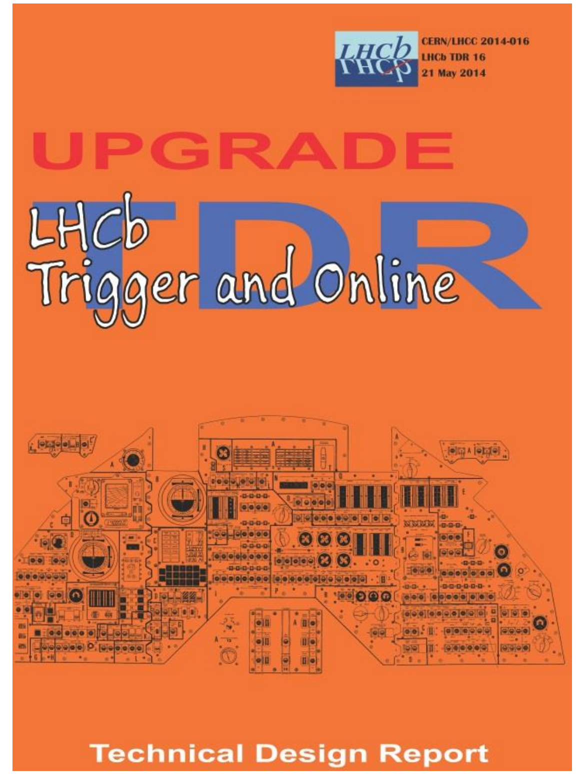
- **Using UT significant reduction in ghost rate**

Trigger selections

- Combination of inclusive (50% b-hadron) and exclusive (mainly charm) trigger selections
- Inclusive selections ("topological trigger")
  - 75-80% efficient for $B^0 \to K^* \mu\mu$
  - 50-70% efficient for $\tau \to 3\mu$
- Exclusive selections
  - Select fully reconstructed "golden" signal decay topologies (e.g. 90% efficient on $B_s \to \varphi\varphi$)
  - Requires more time to compute particles, good combinatorics engine required to combine tracks
  - IP cuts rate
- Lifetime unbiased
  - No vertex displacement requirements; unbiased above minimum decay time cut
  - 60 % efficient on $B \to hh$

Conclusions

- **LHCb upgrade mandatory to probe theoretical uncertainties**
- **Upgrade fully approved, TDRs:**
  - **Tracker TDR LHCC-2014-001**
  - **PID TDR LHCC-2013-022**
  - **Velo TDR LHCC-2013-021**
  - **Trigger and Online TDR LHCC-2014-016 (under approval)**

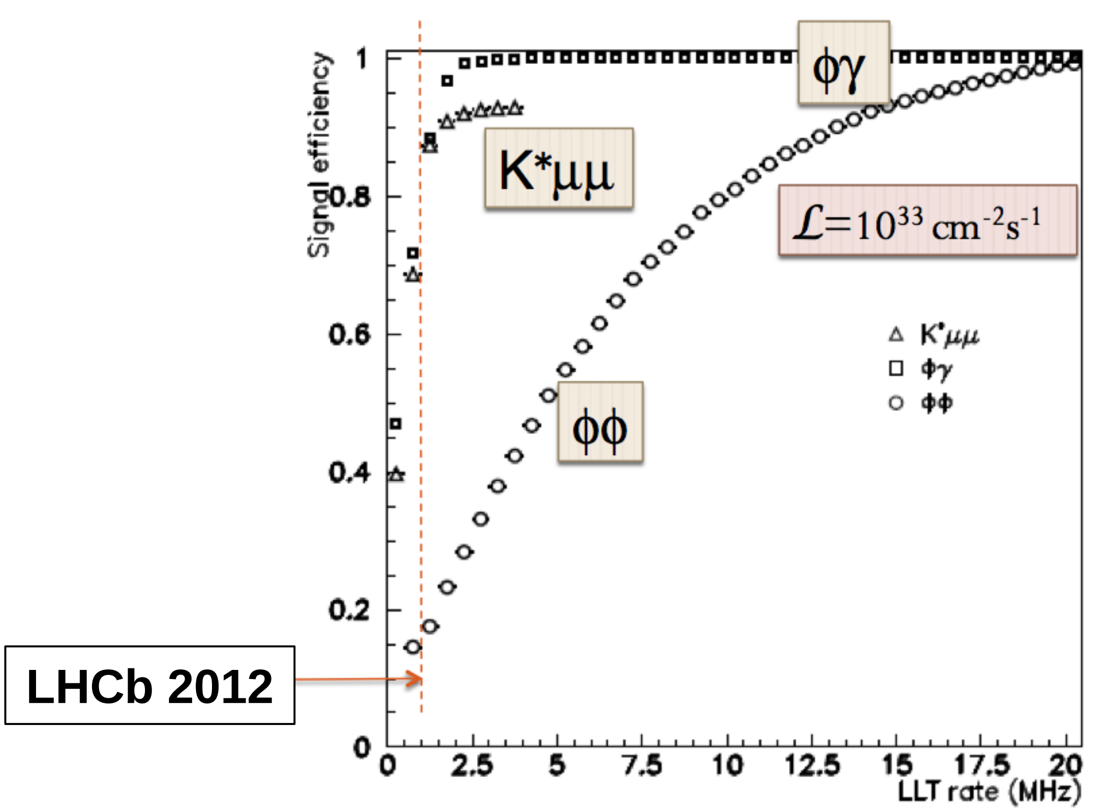


- **LHCb upgrade trigger faces great challenges but will leverage upgraded tracking system**
  - **All tracks available at 30 MHz, no L0 limitation**
  - **Doubling of many signal efficiencies**
  - **Lifetime unbiased beauty and charm selections possible in a hadronic environment**

Backup

Low Level Trigger

- Initially, hardware based LLT to reduce rate to 5-10 MHz
- LLT efficiency for hadron, μ and γ:



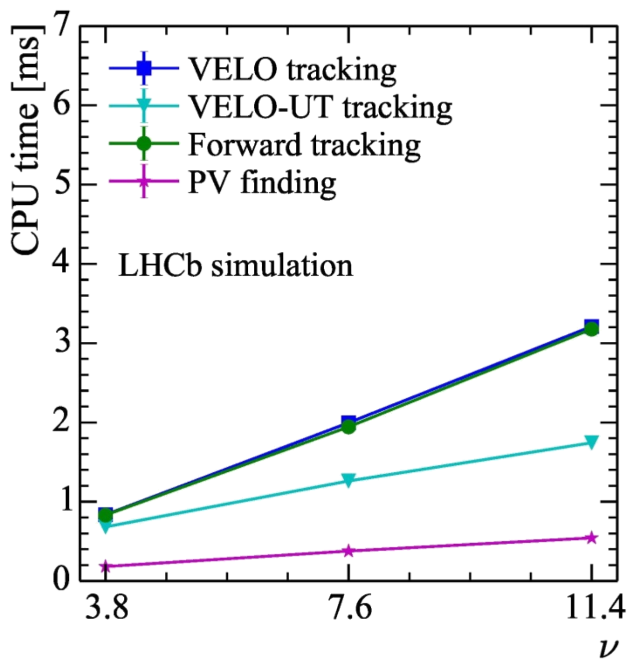
Upgrade conditions

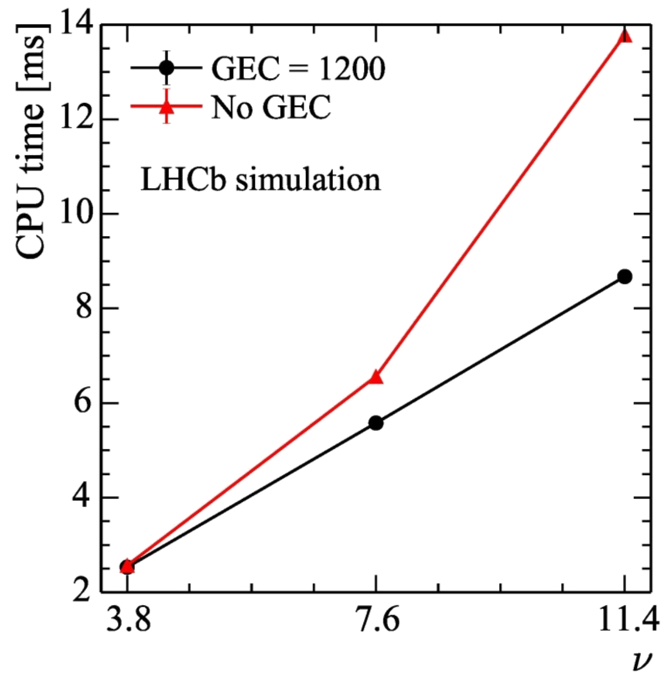
- **Average pp collisions per bunch crossing: ν = 1.6 →7.6**

Run I	per event	with vertex in Velo	Rate (GB/s)
b-hadrons	0.0258±0.0004	0.0029±0.0001	0.9
c-hadrons	0.297±0.001	0.0422±0.0005	3.3
light, long-lived hadrons	8.04±0.01	0.5110±0.002	1.1
Upgrade	per event	with vertex in Velo	Rate (GB/s)
b-hadrons	0.1572±0.0004	0.018740±0.0001	27
c-hadrons	1.4220±0.001	0.21380±0.0005	80
light, long-lived hadrons	33.2910±0.006	2.0840±0.001	26

Tracking time robustness

- Timing of the tracking sequence studied at
  - $\mathcal{L}_{inst} = 1*10^{33}\ cm^{-2}s^{-1}$ (ν = 3.8)
  - $\mathcal{L}_{inst} = 2*10^{33}\ cm^{-2}s^{-1}$ (ν = 7.6, nominal running)
  - $\mathcal{L}_{inst} = 3*10^{33}\ cm^{-2}s^{-1}$ (ν = 11.4)





- Several optimisations can be made to enhance timing and efficiency for different working points