LHCb status report

Marco Adinolfi
on behalf of the LHCb collaboration

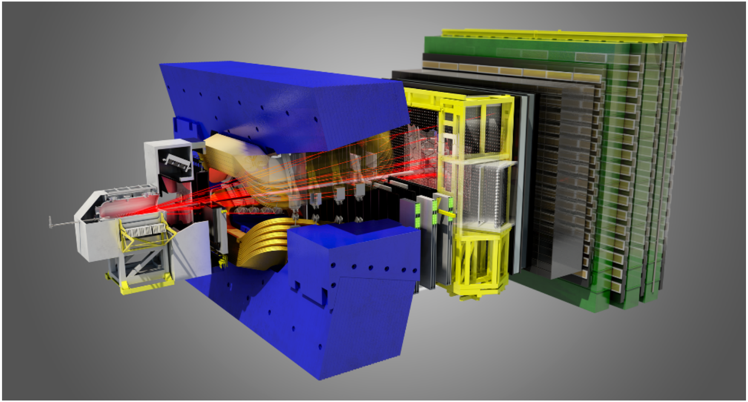
University of Bristol

4 December 2013

Outline

Outline

The LHCb detector



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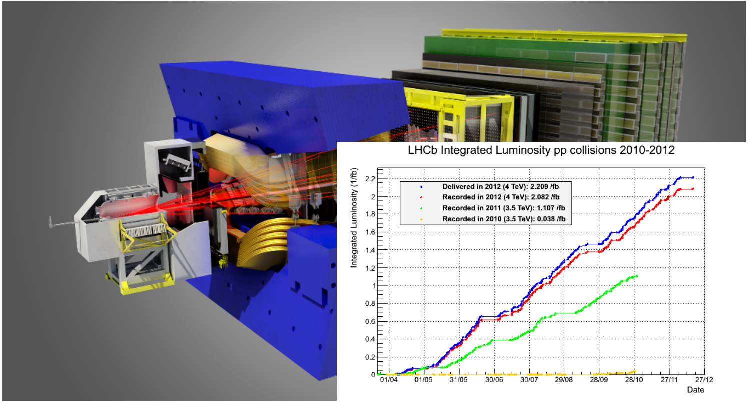
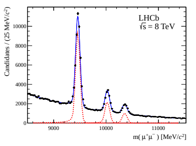


LHCb in a nutshell

TRACKING

$\Delta p/p = 0.4 - 0.6\%$ at 5-100 GeV



J. High Energy Phys. 06 (2013) 064

PID

$\epsilon(K \to K) \sim 95\%$ $\epsilon(\pi \to K) \sim 5\%$

Phys. Lett. B723 (2013) 44-53

CALO

$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\% - ECAL$

$\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\% - HCAL$

Nucl. Phys. B 874 (2013) 663-678

MUON

$\epsilon(\mu \to \mu) \sim 97\%$ $\epsilon(\pi \to \mu) \sim 1 - 3\%$

Phys. Lett. B 725 (2013) 15-24

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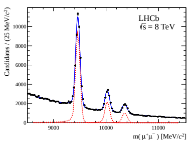

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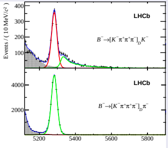

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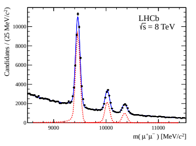

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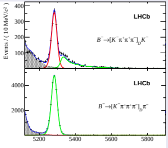

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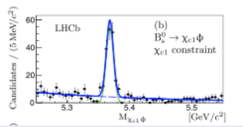

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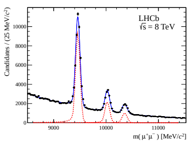

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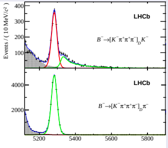

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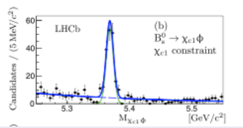

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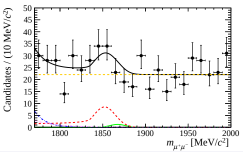
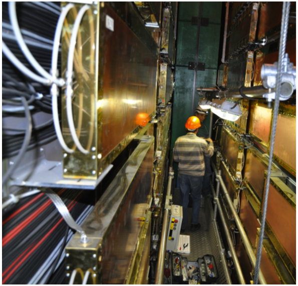


Phys. Lett. B 725 (2013) 15-24

LS1 Status

- LS1 program achieved so far:
  - Significant consolidation of infrastructure: powering, cooling, gas.
  - Maintainance, repair and consolidation work for MUON, OT, IT and TT.
  - Two months delay in magnet consolidation because of procurement and technical difficulties - work ongoing.
  - 610 IMPACT work packages.
  - 350 visits, 4050 visitors (w-o open days).
- Program for 2014:
  - Exchange of part of the RICH1 and RICH2 HPD.
  - ECAL monitoring system exchange.
  - Continuation of MUON consolidation.
  - Reinstallation of the vacuum chamber with lighter supports foreseen for June.
- Conclusion:
  - The work is progressing as expected.
  - Expected to be completed in 2014 as scheduled.

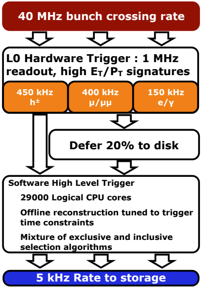
Magnet consolidation



M2-M5 maintainance

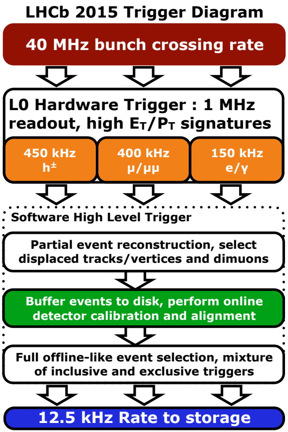
HLT splitting

Deferred trigger in 2012



- Software trigger performed in 2 steps: HLT1 and HLT2.
- HLT2 processes only events passing HLT1: it has a lower input rate and can run more time consuming code.
- So far HLT1 and HLT2 run in a single process.

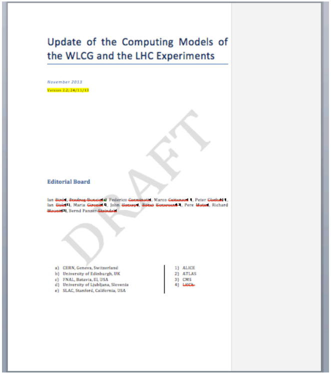
HLT splitting



- Completely separate the HLT1 and HLT2 steps in 2 different processes.
- Allows fully deferring HLT2 and perform online detector alignment/calibration before running it.

Computing news

- Re-stripping of 2011 and 2012 data
  - Bug fixes and new selection criteria added.
  - One more round foreseen for early 2014.


Update of the Computing Models of the WLCG and the LHC Experiments

November 2013

DRAFT

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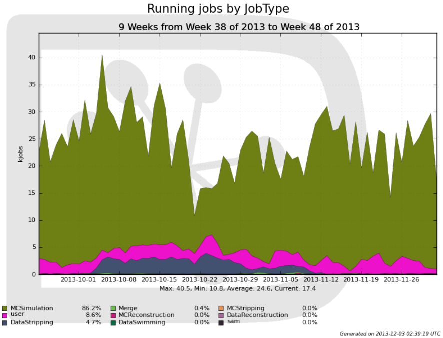
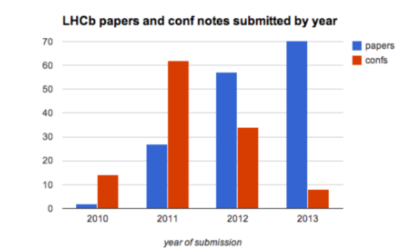


- Computing model updated and new document released with the other experiments.

Outline

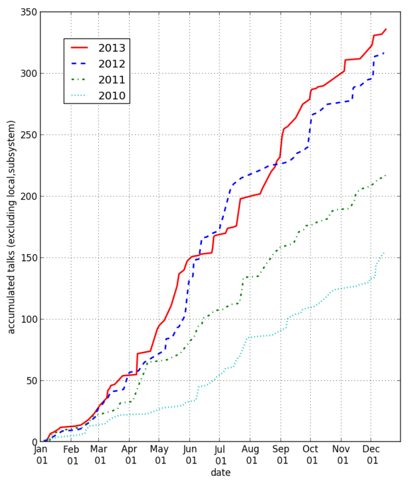
LHCb physics output

Physics publications



161 papers in total.

Talks at conferences



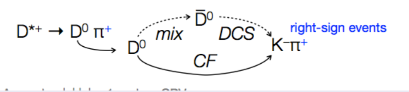
Recent LHCb papers

Measurement of D^0–$\bar{D}^0$ mixing parameters and search for CP violation using $D^0 \to K^+\pi^-$ decays	arXiv:1309.6534
Observation of $\bar{B}^0_{(s)} \to J/\psi f_1(1285)$ decays and measurement of the $f_1(1285)$ mixing angle	arXiv:1310.2145
Search for the decay $D^0 \to \pi^+\pi^-\mu^+\mu^-$	arXiv:1310.2535
Search for the doubly charmed baryon Ξ^+_{cc}	arXiv:1310.2538
Measurement of CP violation in the phase space of $B^\pm \to K^+K^-\pi^\pm$ and $B^\pm \to \pi^+\pi^-\pi^\pm$ decays	arXiv:1310.4740
Measurements of indirect CP asymmetries in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays	arXiv:1310.7201
Search for CP violation in the decay $D^+ \to \pi^-\pi^+\pi^+$	arXiv:1310.7953
Study of forward Z+jet production in pp collisions at $\sqrt{s}$ = 7 TeV	arXiv:1310.8197
Studies of beauty baryon decays to D^0ph^- and $\Lambda_c^+h^-$ final states	arXiv:1311.4823

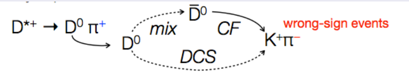
Measurement of D^0–$\bar{D}^0$ mixing parameters ...

Exploit the interference between mixing and doubly-Cabibbo suppressed decay amplitudes.

Right-sign



Wrong-sign



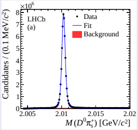
Assuming the mixing parameters $|x|, |y| \ll 1$ and no CP violation:

$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)} = R_D + \sqrt{R_D} y' t + \frac{x'^2 + y'^2}{4} t^2$$

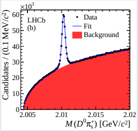
where x' and y' are a linear combination of x and y.

Measurement of D^0–$\bar{D}^0$ mixing parameters ...

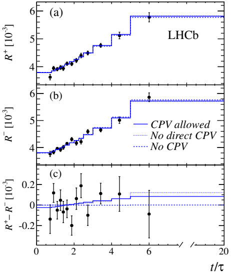
Right-sign ∼ 54M

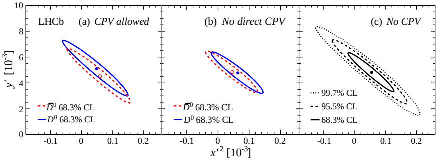


Wrong-sign ∼ 228k



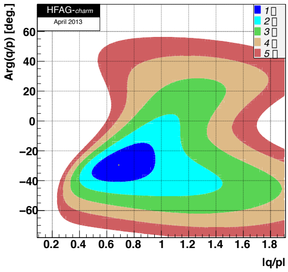
Most systematics cancel in the ratio, remaining accounted for in the time dependent fit.



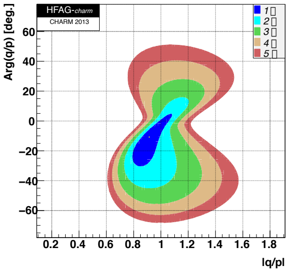


- $0.75 < |q/p| < 1.23$ at 68.3% confidence level.
- Most precise determination from a single experiment.
- No evidence of CP violation found.

Impact of LHCb results on D^0 mixing



HFAG average before LHCb results



HFAG average after LHCb results

Search for CP violation in the decay $D^+ \to \pi^-\pi^+\pi^+$

- 3-body decays have rich resonance structures with interfering amplitudes modulated by strong-phase variations across the phase-space.
- Search of localized asymmetries can provide information on CPV.
- Study the Cabibbo suppressed $D^+ \to \pi^-\pi^+\pi^+$ decay.
- Use $D_s^+ \to \pi^-\pi^+\pi^+$ as control channel.

Binned method

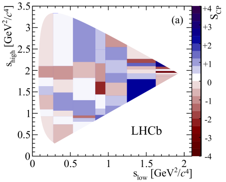
Measure the significance S^i_{CP} of the difference of D^+ and D^- in bins of the Dalitz plot.

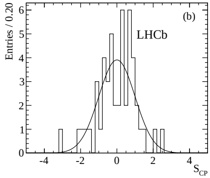
Unbinned method

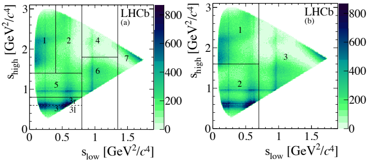
kNN nearest neighbor to compare D^+ and D^- Dalitz plot distributions.

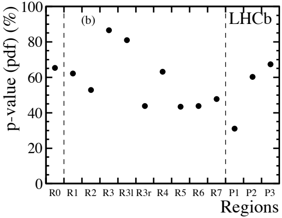
- Data selection common to both methods.
- Analysis carried out on 1 fb^{-1} data.

Search for CP violation in the decay $D^+ \to \pi^-\pi^+\pi^+$







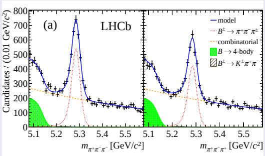


- In absence of localized asymmetries S_{CP} follows a Gaussian distribution.
- CPV can be detected as a deviation.
- All results show statistical agreement between the D^+ and D^- samples.

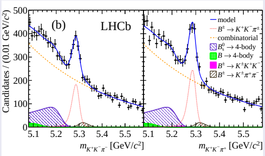
- kNN method applied with 2 possible region definitions.
- The p-values for the CPV hypothesis are all above 20% consistent with no CP asymmetry.

Measurement of CPV in the phase space of $B^{\pm} \to K^{+}K^{-}\pi^{\pm}$ ...

$B^{\pm} \to \pi^{+}\pi^{-}\pi^{\pm}$



$B^{\pm} \to K^{+}K^{-}\pi^{\pm}$



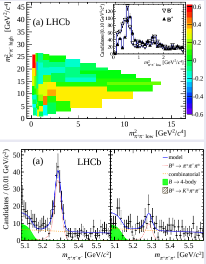
- 1.0 fb^{-1} from 2011.
- $N(\pi\pi\pi) = 4904 \pm 148$ $A_{raw} = 0.124 \pm 0.020$
- $N(KK\pi) = 1870 \pm 133$ $A_{raw} = -0.143 \pm 0.040$
- $A_{CP} = A_{raw} - A_D - A_P$
- $A_P(B^{\pm})$ measured from $B^{\pm} \to J/\psi K^{\pm}$
- A_D previously measured by LHCb: PLB713 (2012) 186

$$A_{CP}(\pi\pi\pi) = 0.117 \pm 0.021(stat) \pm 0.009(sys) \pm 0.007(J/\psi K)\ 4.9\sigma$$

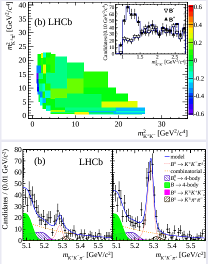
$$A_{CP}(KK\pi) = -0.141 \pm 0.040(stat) \pm 0.018(sys) \pm 0.007(J/\psi K)\ 3.2\sigma$$

Measurement of CPV in the phase space of $B^{\pm} \to K^{+}K^{-}\pi^{\pm}$...

$B^{\pm} \to \pi^{+}\pi^{-}\pi^{\pm}$



$B^{\pm} \to K^{+}K^{-}\pi^{\pm}$



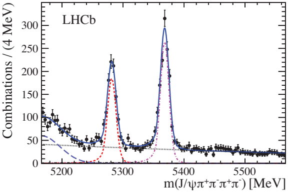
- $s\,\bar{s}$ resonant contribution strongly suppressed for $B^{\pm} \to K^{+}K^{-}\pi^{\pm}$.
- Asymmetries not uniformly distributed.
- A very large negative asymmetry is localized in the low $K^{+}K^{-}$ invariant mass region: $m^2_{K^+K^-} < 1.5\,\mathrm{GeV}^2/c^4$.
- A large positive asymmetry is measured for $m^2_{\pi\pi\mathrm{low}} < 0.4\,\mathrm{GeV}^2/c^4$ $m^2_{\pi\pi\mathrm{high}} > 15\,\mathrm{GeV}^2/c^4$:

$$A_{CP}(\pi\pi\pi\ \mathrm{local}) = 0.584 \pm 0.082(stat) \pm 0.027(sys) \pm 0.007(J/\psi\,K)$$
$$A_{CP}(KK\pi\ \mathrm{local}) = -0.648 \pm 0.070(stat) \pm 0.013(sys) \pm 0.007(J/\psi\,K)$$

- Evidence of large direct CP violation observed.
- Interference between intermediate states does not seem to justify the results for $B^{\pm} \to K^{+}K^{-}\pi^{\pm}$.

Observation of $\bar{B}^0_{(s)} \to J/\psi f_1(1285)$ ...

Large sample of $B^0_{(s)} \to J/\psi\,\pi\pi\pi\pi$ identified in 3 fb^{-1} data.

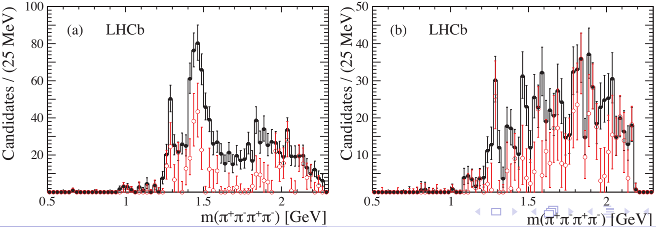


$$N_{\bar{B}^0_s} = 1197 \pm 41$$

$$N_{\bar{B}^0} = 836 \pm 39$$

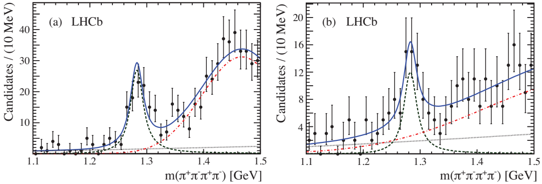
- Clear signals at 1285 MeV/c^2 with structure at higher mass.
- Angular distribution of J/ψ studied to probe the spin of the four-pion state

$\bar{B}^0_s$ $\bar{B}^0$



Observation of $\bar{B}^0_{(s)} \to J/\psi f_1(1285)$...

$N_{\bar{B}^0_s} = 110.2 \pm 15.0 \ 7.6\sigma$ $N_{\bar{B}^0} = 49.2 \pm 29.5 \ 5.4\sigma$



First observation of $f_1(1285)$ in b-hadron decays.

$$\frac{\mathcal{B}(\bar{B}^0_s \to J/\psi\, f_1(1285))}{\mathcal{B}(\bar{B}^0_s \to J/\psi\, \pi^+\pi^-)} = (3.82 \pm 0.52^{+0.29}_{-0.32})\%$$

$$\frac{\mathcal{B}(\bar{B}^0 \to J/\psi\, f_1(1285))}{\mathcal{B}(\bar{B}^0 \to J/\psi\, \pi^+\pi^-)} = (2.32 \pm 0.54 \pm 0.11)\%$$

$$\frac{\mathcal{B}(\bar{B}^0 \to J/\psi\, f_1(1285))}{\mathcal{B}(\bar{B}^0_s \to J/\psi\, f_1(1285))} = (11.6 \pm 3.1^{+0.7}_{-0.8})\%$$

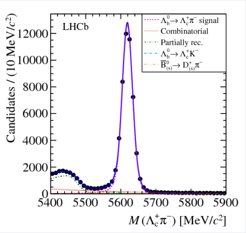
Assuming $f_1(1285)$ is a mixed $q\,\bar{q}$ state the mixing angle Φ is measured:

$$|f_1(1285)\rangle = \cos\Phi \frac{|u\bar{u}\rangle + |d\bar{d}\rangle}{\sqrt{2}} - \sin\Phi |s\bar{s}\rangle \quad ; \quad \Phi = \pm(24.0^{+3.1+0.6}_{-2.6-0.8})^\circ$$

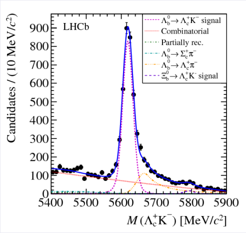
Studies of beauty baryon decays...

- Study $\Lambda_c^+\pi^-$, $\Lambda_c^+K^-$, $D^0p\pi^-$, and D^0pK^- spectra.
- Measure yields of Ξ_b and Λ_b both in Cabibbo favored and Cabibbo suppressed channels:

$\Lambda_b \to \Lambda_c^+\pi^-$



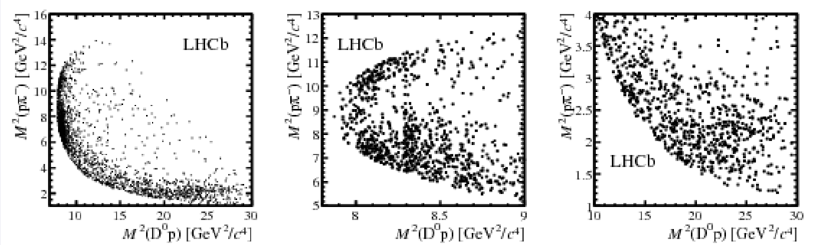
$\Lambda_b \to \Lambda_c^+K^-$



Studies of beauty baryon decays...

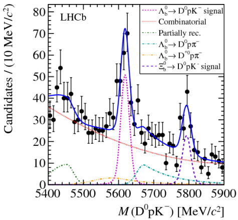
- Efficiency calculated separately for selection, PID and phase-space.
- PID efficiency is data driven as much as possible, remaining components measured from simulation

$D^0 p\pi$ Dalitz plots



- Non zero spin particles involved in initial and final states.
- Angular corrections found to be negligible.

Studies of beauty baryon decays...



- First observation of $\Xi_b \to D^0pK^-$ and of $\Lambda_b \to D^0pK^-$
- $m_{\Xi_b} - m_{\Lambda_b} = 174.8 \pm 2.4 \pm 0.5\,\mathrm{MeV}/c^2$
- $m_{\Xi_b} = 5794.3 \pm 2.4 \pm 0.7\,\mathrm{MeV}/c^2$

$$R_{\Lambda_b^0\to D^0p\pi^-} \equiv \frac{\mathcal{B}(\Lambda_b^0 \to D^0p\pi^-)\times\mathcal{B}(D^0\to K^-\pi^+)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-)\times\mathcal{B}(\Lambda_c^+\to pK^-\pi^+)} = 0.0806 \pm 0.0023 \pm 0.0035,$$

$$R_{\Lambda_b^0\to D^0pK^-} \equiv \frac{\mathcal{B}(\Lambda_b^0 \to D^0pK^-)}{\mathcal{B}(\Lambda_b^0 \to D^0p\pi^-)} = 0.073 \pm 0.008\,^{+0.005}_{-0.006},$$

$$R_{\Lambda_b^0\to \Lambda_c^+K^-} \equiv \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+K^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-)} = 0.0731 \pm 0.0016 \pm 0.0016,$$

$$R_{\Xi_b^0\to D^0pK^-} \equiv \frac{f_{\Xi_b^0}\times\mathcal{B}(\Xi_b^0 \to D^0pK^-)}{f_{\Lambda_b^0}\times\mathcal{B}(\Lambda_b^0 \to D^0pK^-)} = 0.44 \pm 0.09 \pm 0.06,$$

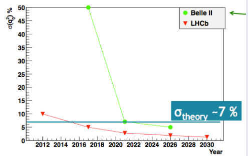
$$R_{\Xi_b^0\to \Lambda_c^+K^-} \equiv \frac{\mathcal{B}(\Xi_b^0 \to \Lambda_c^+K^-)\times\mathcal{B}(\Lambda_c^+\to pK^-\pi^+)}{\mathcal{B}(\Xi_b^0 \to D^0pK^-)\times\mathcal{B}(D^0\to K^-\pi^+)} = 0.57 \pm 0.22 \pm 0.21,$$

Outline

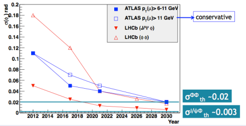
Why an upgrade?

Expected precisions on several Heavy Flavour related quantities from ECFA workshop, Aix-les-Bain Octobr 2013.

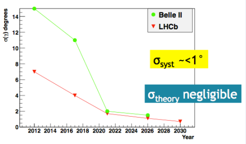
q_0^2 from $B \to K^\star l^+ l^-$



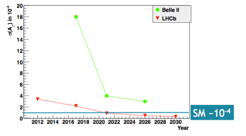
Φ_s from $B_s^0 \to \Phi\Phi$ and $B_s^0 \to J/\psi\,\Phi$



γ from tree decays

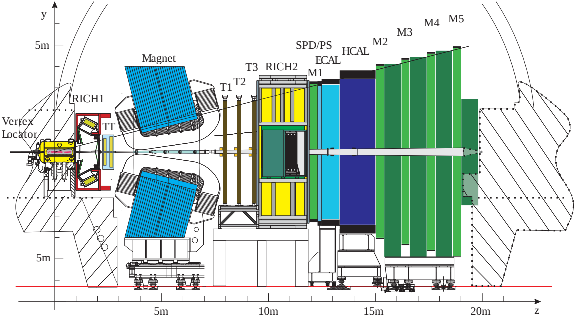


A_Γ from $D^0 \to h^+ h^-$



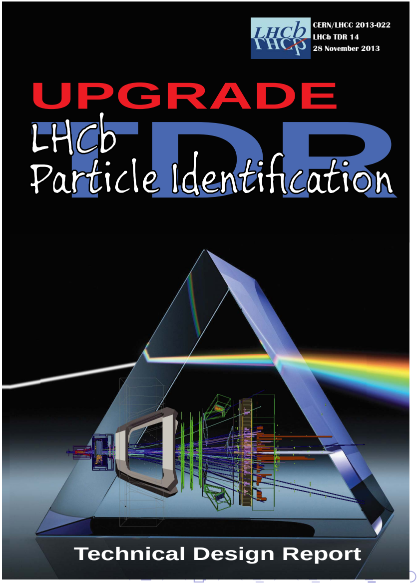
LHCb upgrade more sensitive than competition for key flavour physics observables

LHCb Upgrade

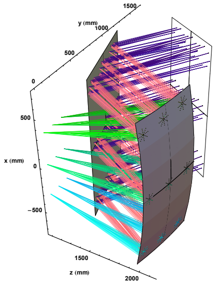


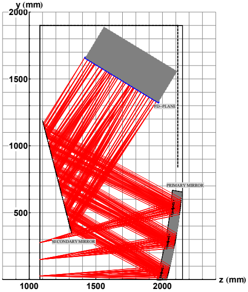
- Luminosity: $2 \times 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$
- 40 MHz readout with software base trigger running on a PC farm.

LHCb Upgrade TDR's



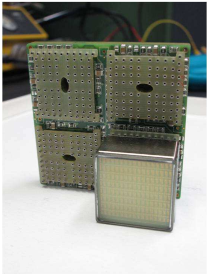
RICH optical design





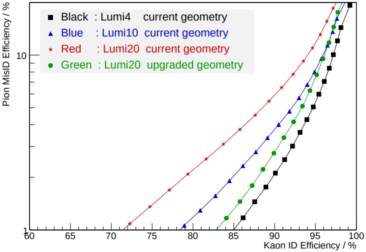
- Overall structure still based on 2 detectors
- Remove aerogel from RICH 1 $\Longrightarrow$ reduced maximum ring size and increase of Cherenkov photons by about 15%.
- Focal length of spherical mirrors increased by a $\approx \sqrt{2}$ $\Longrightarrow$ halved occupancy and reduced aberration.
- Distance between spherical and plane mirrors also increased $\Longrightarrow$ further increase in Cherenkov photons.
- Tilt of spherical mirrors reduced $\Longrightarrow$ reduced aberration.

RICH PD & performance



- Baseline R11265 Hamamatsu MaPMT.
- 8×8 pixel, 26.2 mm square device.

- $3.9 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ current geometry
- $10.0 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ current geometry
- $20.0 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ current geometry
- $20.0 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ updated geometry

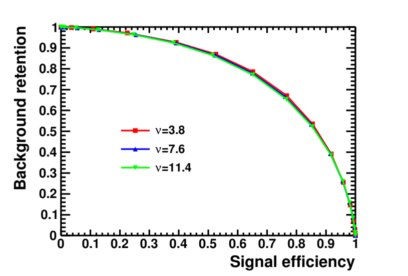


Calorimeter

- Maintain the same photo-multipliers: reduce gain by factor 5 to increase their lifetime.
- Change in electronics to compensate the reduced gain.
- Degradation with radiation will require replacement of the innermost part of ECAL.

- Remove SPD and PS.
- Pile-up
- $\Longrightarrow$ change in reconstruction.

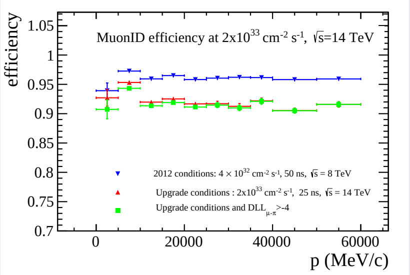
Photon efficiency for various luminosities



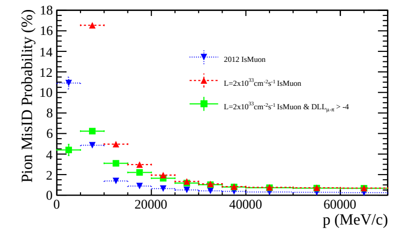
MUON

- New off-detector electronics with 40 MHz readout.
- Removal of station M1.
- Additional shielding around the beam pipe in front of M2.
- Change in identification algorithm needed to recover increased misidentification.

μ id. efficiency



μ misidentification



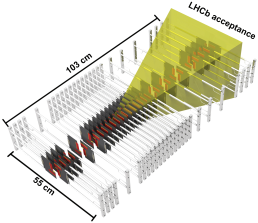
VELO requirements

Physics performance

- Fast and robust reconstruction with excellent IP resolution at $20.0 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.
- First measured point as close as possible to interaction point: $\Longrightarrow$ as close to the beam as $\pm$ 5.1 mm.
- Material in acceptance kept at minimum.
- Geometric acceptance $> 99\%$ for track within $\pm 2\sigma_{lumi} = \pm 126\,\mathrm{mm}$.

Sensors

- Hottest sensor exposed to fluence of $8 \times 10^{15} 1\,\mathrm{MeV}\,n_{\mathrm{eq}}\mathrm{cm}^{-2}$ after 50 fb^{-1}.
- Must be able to withstand 1000 V.
- Will be kept at $<$ -20 °C.



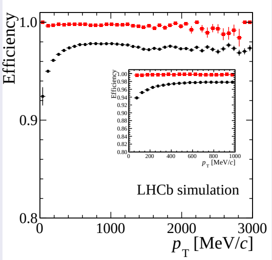
ASIC

- Output rate up to 15.1 Gbit/s.
- Power consumption $\leq$ 3 W.

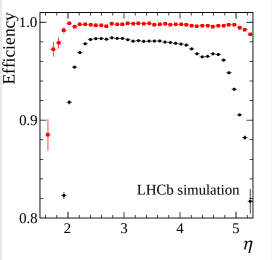
VELO performance: pattern recognition

- $B^0 \to K^{*0}\mu^+\mu^-$ events at $\mathcal{L} = 20.0 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.
- Improved efficiency and ghost rate compared to current VELO.
- Flatter efficiency over p, p_T, η, ϕ...
- Comparison between current (black) and upgraded (red).

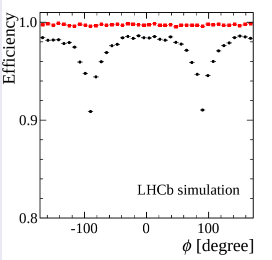
Efficiency vs. p_T



Efficiency vs. η



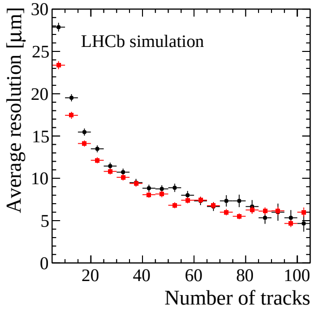
Efficiency vs. Φ



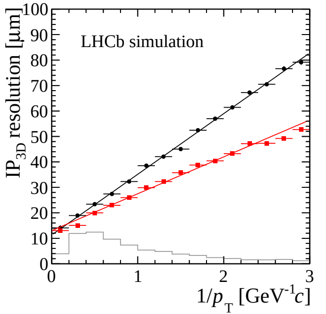
VELO performance: primary vertex and IP

- $B^0 \to K^{\star 0}\mu^+\mu^-$ events at $\mathcal{L} = 20.0 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.
- PV and IP resolution after full reconstruction.
- Intercept of IP resolution vs $1/p_\mathrm{T}$ similar for current (black) and upgraded (red). Slope reduced significantly.

PV resolution in X



IP resolution



Outline

Conclusions

- LHCb continues to produce a wealth of high-quality physics results.
- Full dataset of 3 fb^{-1} not yet fully exploited.
- At the same time work is in progress to prepare for Run 2.
- VELO and PID TDR submitted to LHCC: major milestones on upgrade for achieved.