LHCb Status & Outlook

US-LHC Users Association Annual Meeting 2019

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on behalf of the LHCb collaboration

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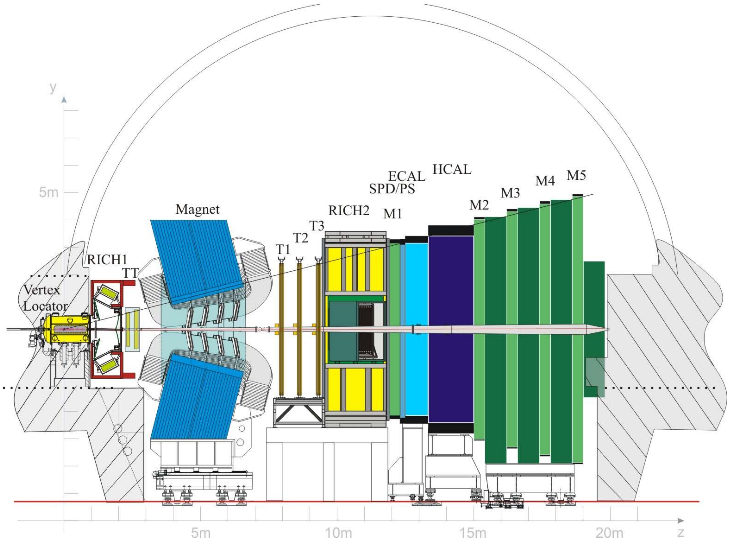
Overview

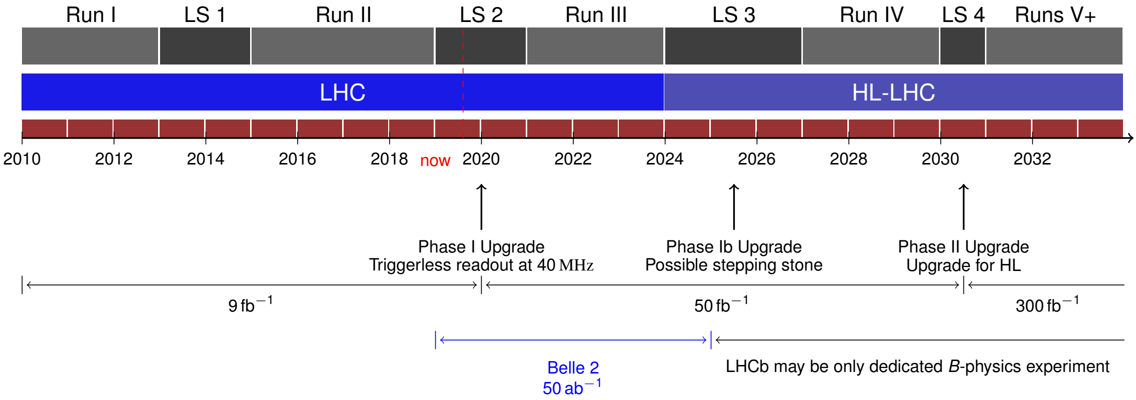
- LHCb has a broad physics programme
- Increasingly functioning as “a GPD in the forward region”
- Will highlight a selection of results from the last year
- Many topics not covered
  - *e.g.* CEP, heavy ions, fixed target...

The LHCb detector



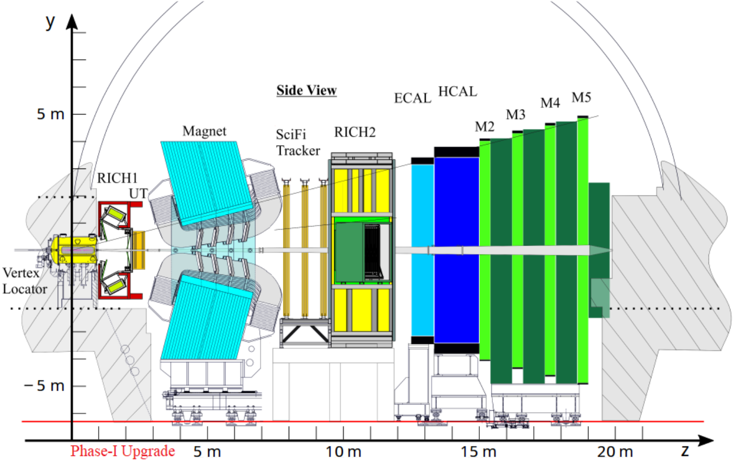
- Instrumentation in the forward region ($2 < \eta < 5$)
- Excellent secondary vertex reconstruction
- Precise tracking before and after magnet
- Good PID separation up to $\sim 100\,\text{GeV}/c$

LHCb timeline



The LHCb detector: phase 1 upgrade

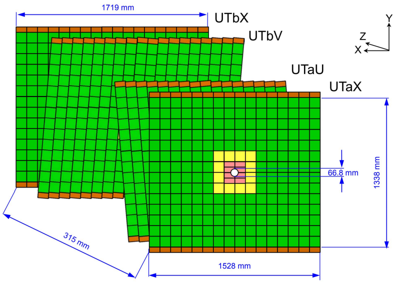
CERN-LHCC-2012-007

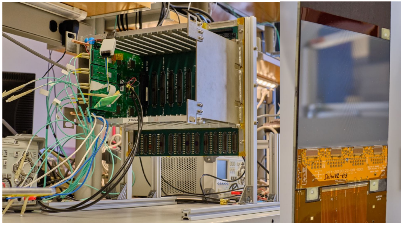


- Triggerless readout at 40 MHz
- New vertex locator
- New tracking (UT, SciFi)

Phase 1 upgrade : Upstream Tracker

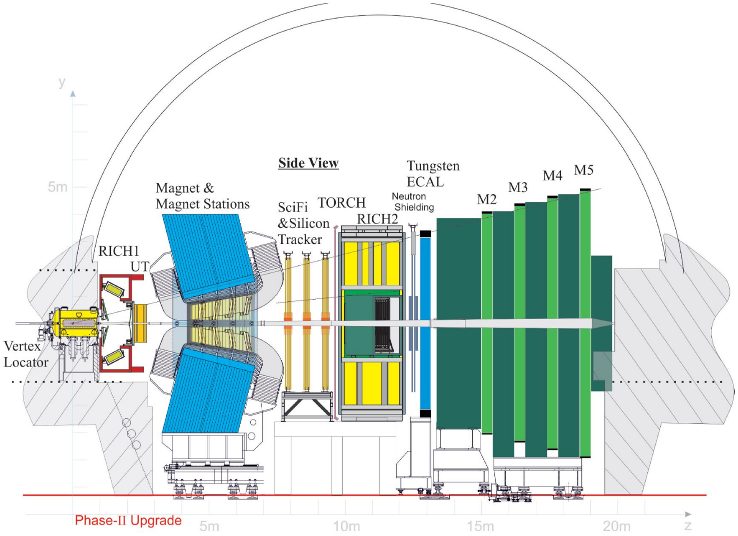
- Upgraded silicon tracker to replace TT
  - Finer granularity
  - Improved coverage
  - Lower material budget
- First major LHCb construction contribution from US
  - Bare stave construction complete
  - Sensor QA almost finished
  - ASIC design validated in test beam
  - Off-detector electronics validated in slice test, now in production
  - Aim to install first half at LHCb by March 2020
  - Contributions from Syracuse, Maryland, Cincinnati, Michigan & MIT





The LHCb detector: phase 2 upgrade

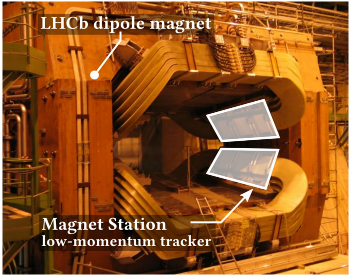
CERN-LHCC-2017-003

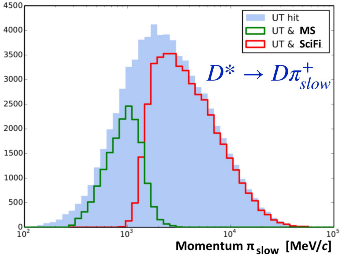


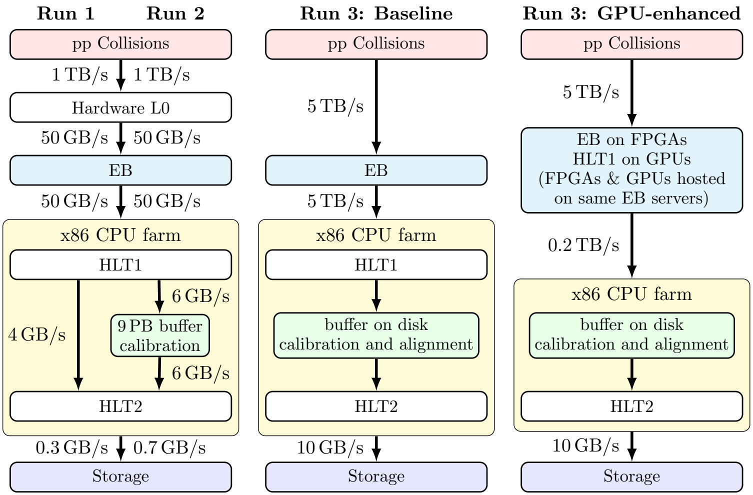
- Tracking in magnet
- ECAL upgrade
- TORCH for PID or ToF
- Replace HCAL with shielding
- Some changes could happen as part of phase 1b

Phase 2 upgrade : Magnet Stations

- Slow particles swept out by magnet
- Significant gains at low momentum by instrumenting sides of magnet
- Particularly useful for gluon saturation studies
- Recommended for inclusion in Phase 1b ugrade
- Los Alamos leading design and construction



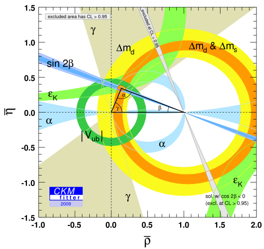


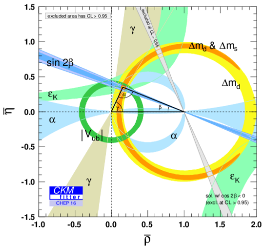


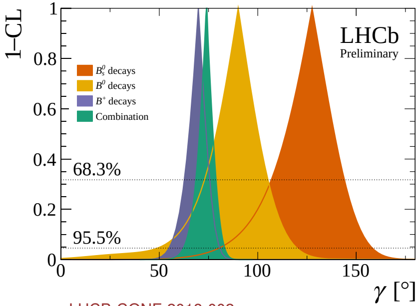
- Hardware trigger to be removed from Run III
- Option to move to a GPU-based HLT1 with GPUs installed on the Event Builder servers
- Demonstrated technical feasibility modulo integration tests that are underway
- May be adopted by LHCb for Run III

CP violation and CKM elements

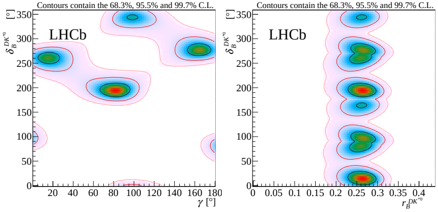
- LHC era has seen marked improvements in key measurements (upper→lower)
- But deviations from the CKM quark-mixing mechanism continue to elude detection
- Uncertainties on “tree” quantities still give room for new physics in loops
- Key goal to improve precision on less well-determined SM measurements, γ and $|V_{ub}|$
- Compare these “baseline” results to loop-dominated processes to search for NP
  - Continue to improve key loop-process measurements such as ϕ_s, Δm_s and Δm_d



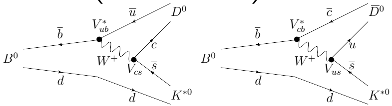




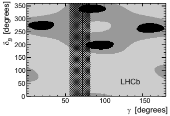
LHCB-CONF-2018-002



- γ measured at tree level $\to$ SM measurement
- LHCb average dominated by $B^+ \to DK^+$ decays
- $B^0 \to DK^{*0}$ decay pathways both colour suppressed
  - Larger r_B *cf.* $B^+ \to DK^+$ (~ 0.3 vs ~ 0.1)
- New analysis uses a larger dataset for 2-body GLW/ADS modes
- Includes 4-body GLW/ALS-like modes for first time
- First observations of $B^0 \to D(\pi^+K^-)K^{*0}$ and $B^0 \to D(\pi^+\pi^-\pi^+\pi^-)K^{*0}$



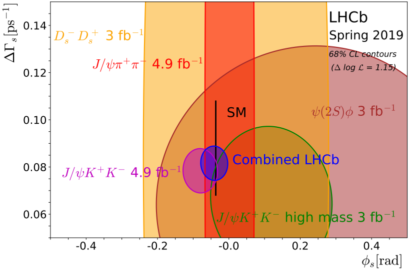
Previously:
(39.4 %, 86.5 % CL contours)



PR**D90** (2014) 112002

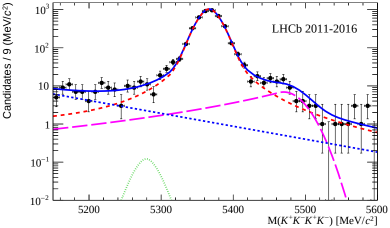
- ϕ_s small in SM, may be enhanced by NP
- $B_s^0 \to J/\psi\,\phi$ decays studied in data from 2015-16
- Single most precise measurement of ϕ_s to date
- Other channels, *e.g.* $B_s^0 \to J/\psi\,\pi^+\pi^-$, also utilised
- LHCb combination consistent with SM predictions

$$-0.041 \pm 0.025$$



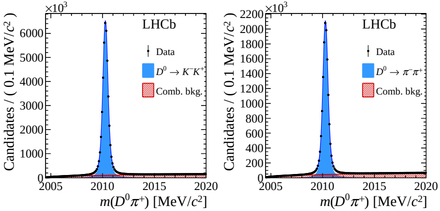
- $\phi_s^{s\bar{s}s} \approx 0$ in SM, small mixing & decay phases cancel
- New analysis of $B_s^0 \to \phi\phi$ decays in 2011-16 data
- Most precise single measurement of $\phi_s^{s\bar{s}s}$ to date

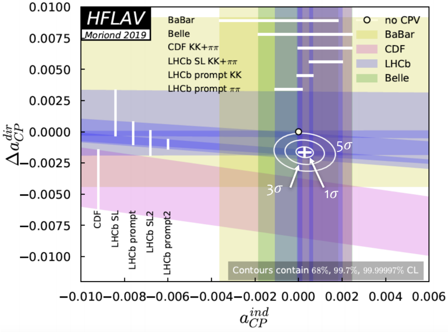
$$-0.073 \pm 0.115 \pm 0.027$$



- Upper limit (90% CI) on rate of $B^0 \to \phi\phi$ decay

$$\mathcal{B}(B^0 \to \phi\phi) < 2.7 \times 10^{-8}$$



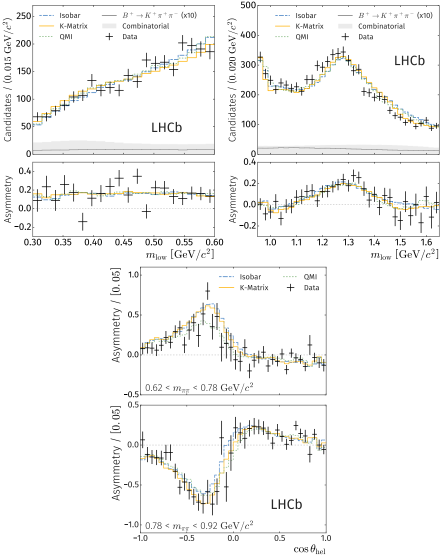


- Study CPV in up-type quarks
- Measure ΔA_{CP} between K^+K^- and $\pi^+\pi^-$ to control systematics
- LHCb combination gives 5.3σ significance of CPV
- First observation of (direct) CP violation in charm decays
- Global average now inconsistent with "no CPV" at more than 5σ

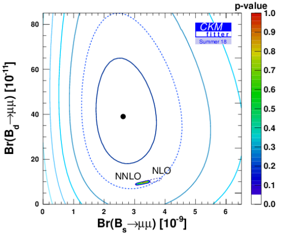
$$a_{CP}^{\text{ind}} = (0.028 \pm 0.026)\%$$
$$\Delta a_{CP}^{\text{dir}} = (-0.164 \pm 0.028)\%$$

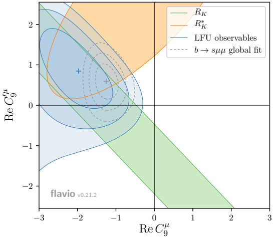
CPV in $B^+ \to \pi^+\pi^+\pi^-$ decays

- Charmless b-decays have tree- and loop-level contributions with similar amplitudes
- Dalitz plot analysis of $\sim 20\,000$ $B^\pm \to \pi^\pm\pi^\pm\pi^\mp$ decays recorded in Run I
- CPV previously seen in a model-independent analysis of this dataset
- Three different models considered for S-wave
- Significant CPV observed in low-$m_{\pi^+\pi^-}$ S-wave, the $a_2(1270)$ resonance and in interference between S- and P-wave contributions
- No CPV observed in $\rho - \omega$ mixing
- Does not directly inform on SM or NP parameters but offers further insight into CPV in multi-body decays



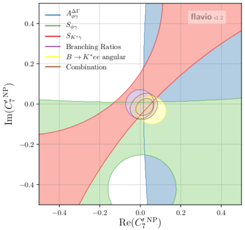
Rare decays and anomalies

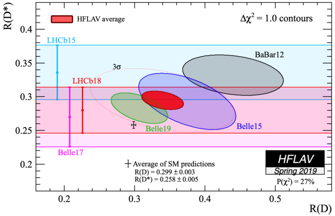




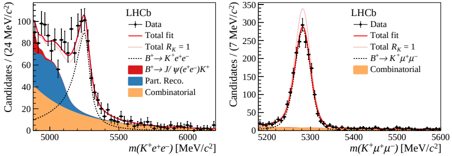
PR **D122** (2019) 222001

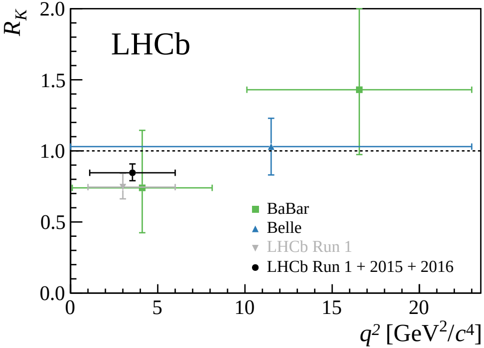
- Rare or forbidden SM processes sensitive to new physics contributions
- Many anomalies in current results
  - P_5', R_K, R_D^*, etc
- Analyses typically limited by statistics
- Exciting prospects for Run III+



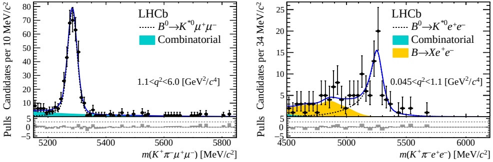


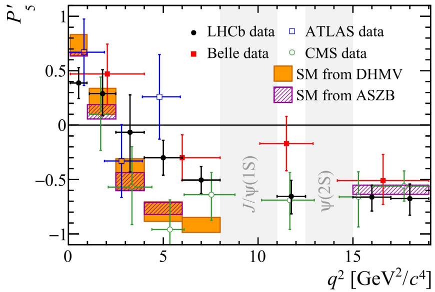
- Analysis of $B^+ \to K^+\ell^+\ell^-$ updated with $5\,\text{fb}^{-1}$ of data
- Total uncertainty on R_K in $1.1 < q^2 < 6.0\,\text{GeV}^2/c^4$ reduced by $\sim 40\,\%$
- Central value also moved towards SM prediction
  - 2.5σ discrepancy *cf.* 2.6σ in Run I
- Still statistically dominated
- More data needed

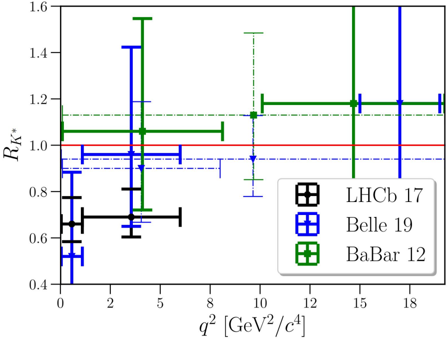




- Analyses of $B^0 \to K^{*0}\ell^+\ell^-$ give access to both R_{K^*} and angular quantities
- Run I analyses show interesting anomalies, *e.g.* R_{K^*}, P_5'
- Analyses on Run II data still to come



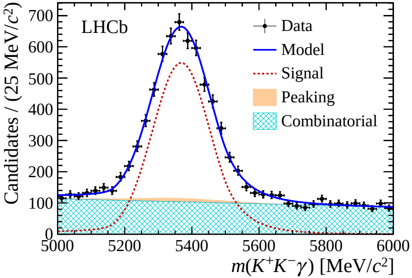


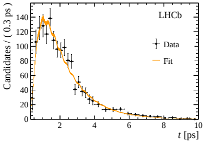


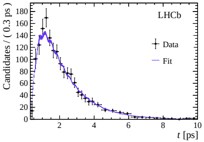
Radiative decays

PRL **123** (2019) 081802

PRL **123** (2019) 031801



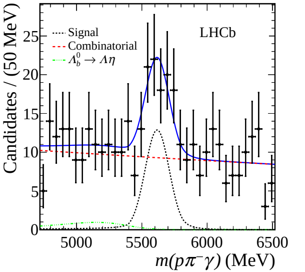




- Updated study of $B_s^0 \to \phi\gamma$ decays
- First measurement of CPV parameters $S_{\phi\gamma}$ and $C_{\phi\gamma}$
- Updated measurement of $\mathcal{A}^{\Delta}_{\phi\gamma}$
- Results consistent with SM at 1.3, 0.3, and 1.7σ

- First observation of $\Lambda_b^0 \to \Lambda\gamma$ using 2016 data
- Normalised to $B^0 \to K^{*0}\gamma$

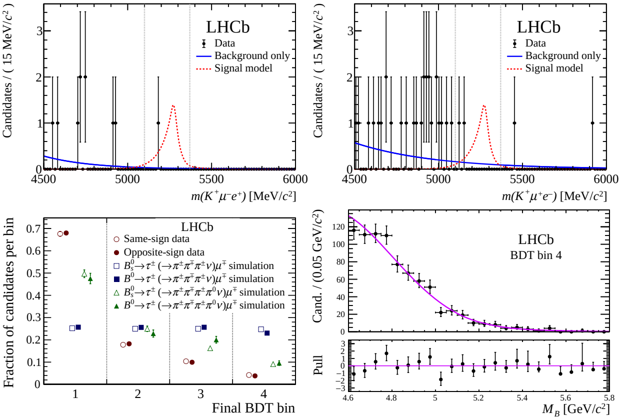
$$\mathcal{B} = (7.1 \pm 1.5 \pm 0.6 \pm 0.7) \times 10^{-6}$$

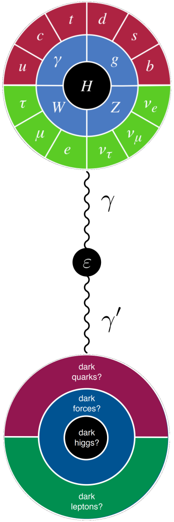


- Charged LFV negligible in SM
- Would be clear evidence of BSM physics
- Searches for $B^+ \to K^+ e^\pm \mu^\mp$ and $B^0_{(s)} \to \tau^\pm \mu^\mp$ in Run I data
- New best limits set on branching fractions

$$
\begin{aligned}
\mathcal{B}(B^+ \to K^+ \mu^- e^+) &< 7.0(9.5) \times 10^{-9} \\
\mathcal{B}(B^+ \to K^+ \mu^+ e^-) &< 6.4(8.8) \times 10^{-9} \\
\mathcal{B}(B^0_s \to \tau^\pm \mu^\mp) &< 3.4(4.2) \times 10^{-5} \\
\mathcal{B}(B^0 \to \tau^\pm \mu^\mp) &< 1.2(1.4) \times 10^{-5}
\end{aligned}
$$

at 90 (95) % confidence level



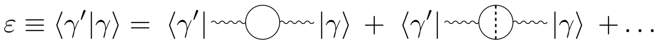


$$\alpha' = \varepsilon^2 \alpha_{\mathrm{EM}}$$

- New physics may well be disconnected from SM up to GUT scale
- If a dark sector couples to ours at some scale, photon can mix with a dark photon
- May interact either via a particle carrying both charges or through GUT-scale interaction between sectors
- Search for massive dark photon decays to $\mu^+\mu^-$ in this "few-loop" regime

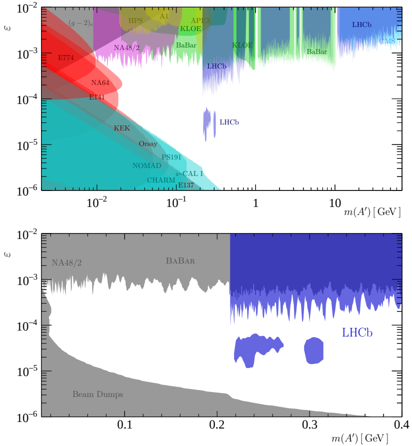
e.g, particle carrying both EM and dark-EM charge

e.g, GUT near the Planck scale

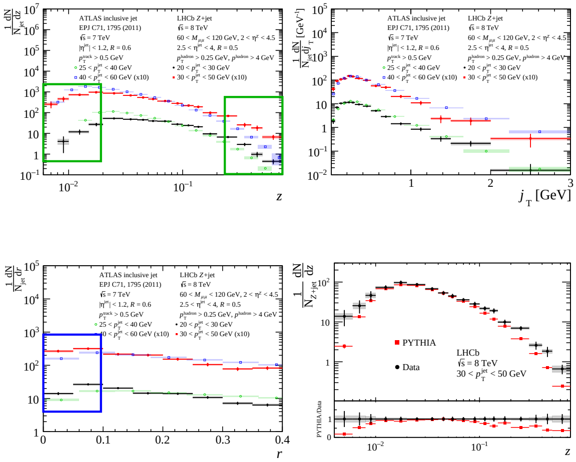


$\varepsilon \sim \mathcal{O}(10^{-3})$ $\varepsilon \sim \mathcal{O}(10^{-5})$

- New analysis extends previous LHCb searches for dark photon decays to $\mu^+\mu^-$
- Factor $3\times$ increase in luminosity
- Search for prompt $\mu^+\mu^-$ limited by $\gamma^* \to \mu^+\mu^-$ background
  - Vertex-constrained fit improves resolution at low $m(\mu^+\mu^-)$
  - Isolation requirements reduce background at higher mass
- Search for long-lived A' uses vertex resolution to reduce background
  - Dominant backgrounds from material interaction, b-decays to multiple muons and K^0_S decays
- Exclusion region expected to be significantly increased with Run III analysis



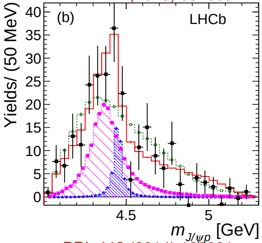
Hadron production in Z^0-tagged jets



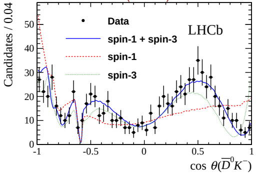
- Production of charge hadrons studied in jets in 2012 data
- First studies of jet hadronisation in forward direction and in jets produced with a Z^0
- *cf.* mid-rapidity jets, more collimated in both z and r
  - More similar to ATLAS γ+jet
  - Suggests effect due to quark-dominated jets
- *cf.* simulation, more high-momentum hadrons

Spectroscopy and production

PRL **117** (2016) 082003

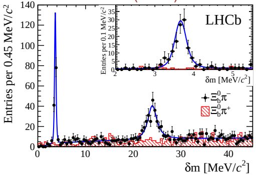


PRL **113** (2014) 162001

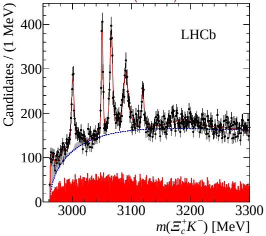


- Many new states and decays observed
- Many serendipitous discoveries
- In particular, LHC provides a unique environment to study *b*-baryons
  - First evidence of *CP* violation in Λ_b^0 decays
  - First observation of pentaquarks

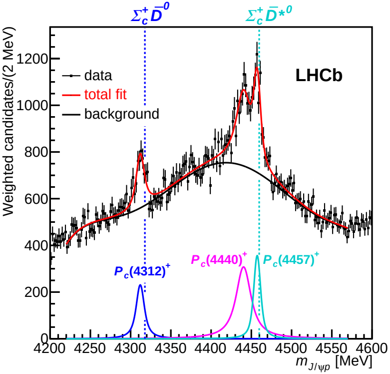
PRL **114** (2015) 062004



PRL **118** (2017) 182001



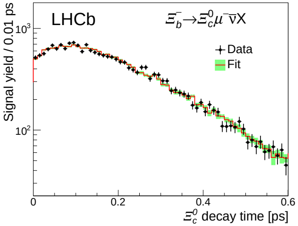
Pentaquarks

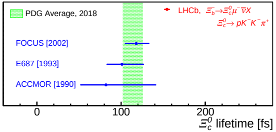


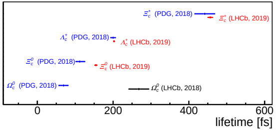
- Hidden-charm pentaquarks first observed in 6D amplitude analysis of $\Lambda_b^0 \to J/\psi pK^-$ decays
- Latest analysis uses $9\times$ larger dataset to perform 1D mass fit
- Previously observed resonance resolved into two separate states
- New narrow state observed, $P_c(4312)^+$
- Near-threshold masses hint at molecular structures
- Also expect relatively narrow $\Sigma_c^{*+}\bar{D}^{(*)0}$ states
- For $P_c(4312)^+$ and $P_c(4457)^+$, thresholds within widths of peaks
  - Possible virtual states, arXiv:1904.10021
- Updated 6D amplitude analysis required to identify broad states or assign J^P

c-baryon lifetimes

PR **D100** (2019) 032001





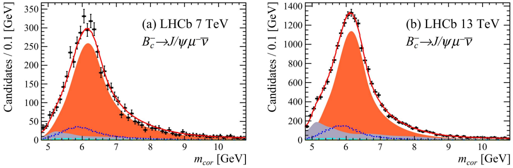


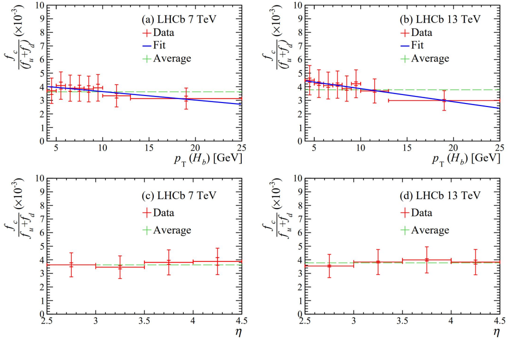
- Properties of charm baryons effective tests of higher-order corrections to HQE
- Lifetimes of Λ_c^+, Ξ_c^0 and Ξ_c^+ baryons last measured almost 20 years ago
- Recent LHCb measurement of Ω_c^0 lifetime $4\times$ larger than previous average PRL **121** (2018) 092003
- Reconstruct baryons produced in semimuonic decays of *b*-baryons and decaying to hadronic final states
- Λ_c^+ and Ξ_c^- consistent with previous averages
- Ξ_c^0 shows 3.3σ discrepancy

B_c^+ production

- $\frac{f_c}{f_u+f_d}$ determined from $B_c^+ \to J/\psi\,\mu^-\overline{\nu}$ decays
- Analysis performed at $\sqrt{s} = 7\,\mathrm{TeV}$ and $13\,\mathrm{TeV}$
- Normalised to inclusive B^0 and B^+ semimuonic rates
- Production asymmetry consistent with zero

$$\frac{f_c}{f_u+f_d} = (3.63 \pm 0.08 \pm 0.12 \pm 0.86) \times 10^{-3} \text{ at } 7\,\mathrm{TeV}$$
$$\frac{f_c}{f_u+f_d} = (3.78 \pm 0.04 \pm 0.15 \pm 0.89) \times 10^{-3} \text{ at } 13\,\mathrm{TeV}$$





Summary

- Run I & II datasets continue to provide new results
  - Both in flavour physics and beyond
- Work to upgrade the detector for Run III+ continues in parallel
- Many more exciting results to come...