LHCb In Run 3: Looking Forward

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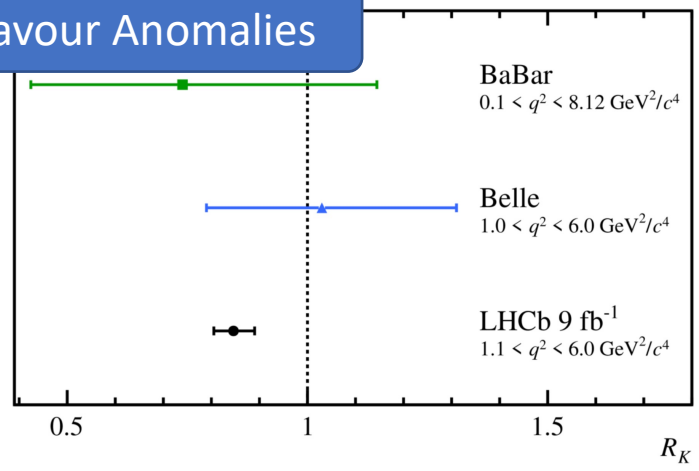
On behalf of LHCb-UK

24th November 2021

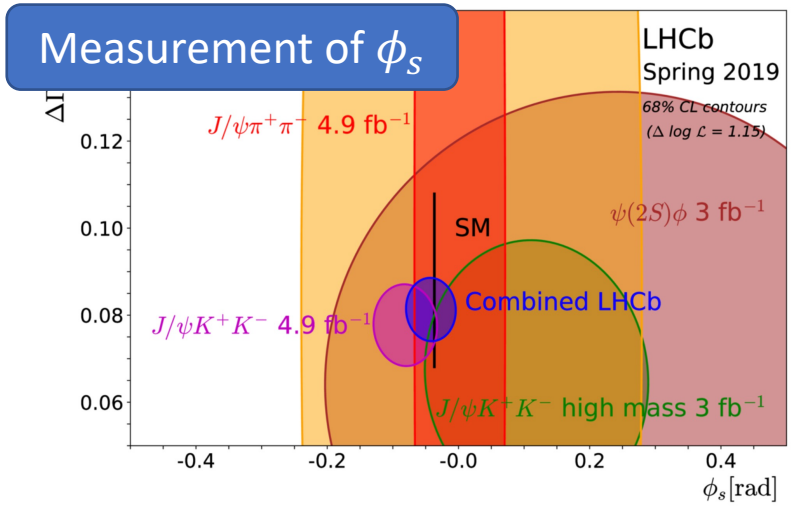
Some highlights from Run 1+2 – Flavour Physics …

600 Physics Papers
and
~50,000 Citations

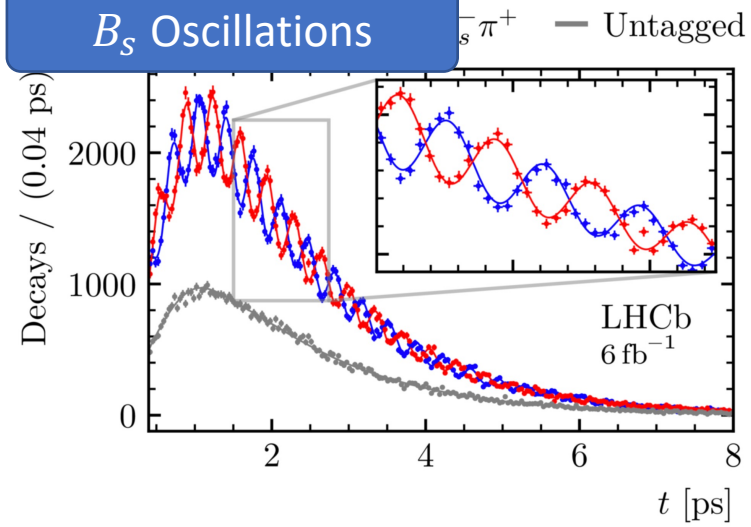
Flavour Anomalies



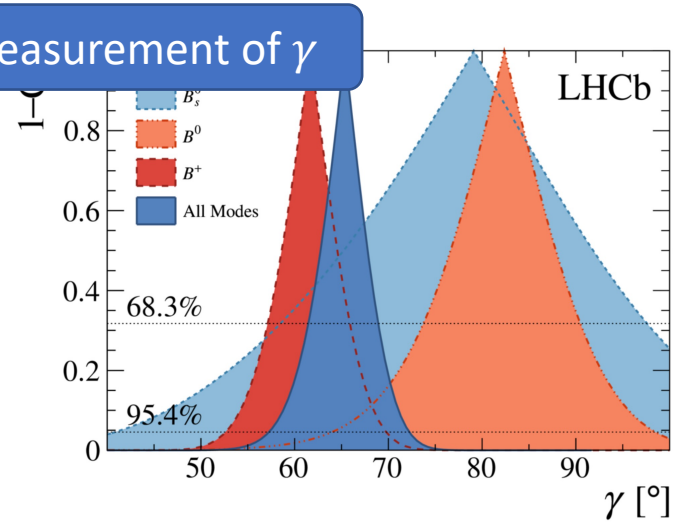
Measurement of ϕ_s



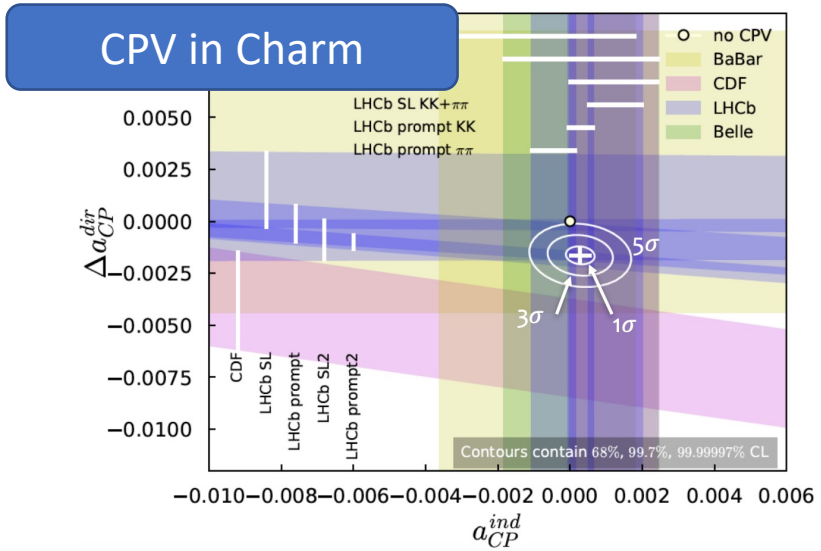
B_s Oscillations



Measurement of γ

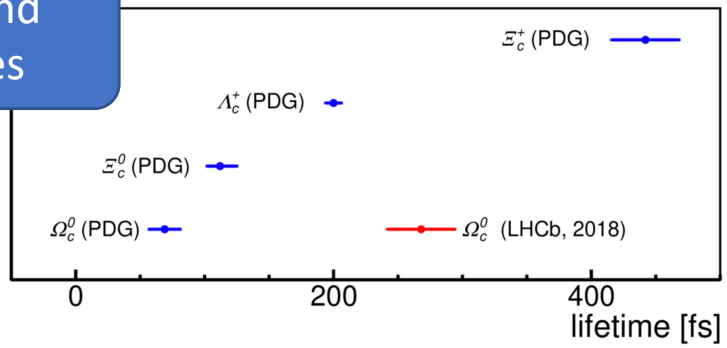


CPV in Charm

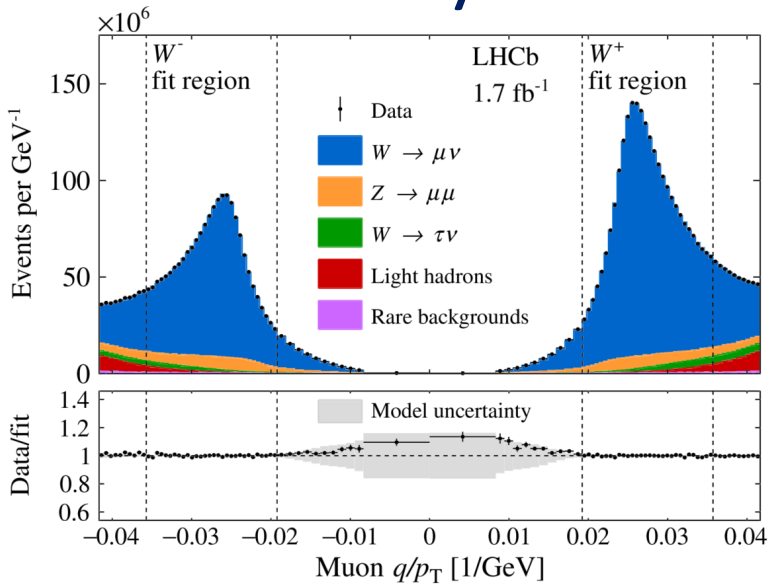


Some highlights from Run 1+2 – … and beyond

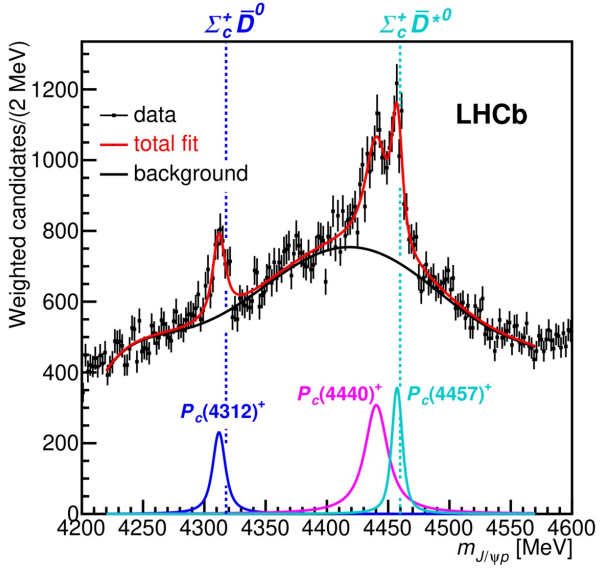
Spectroscopy and Lifetime Studies



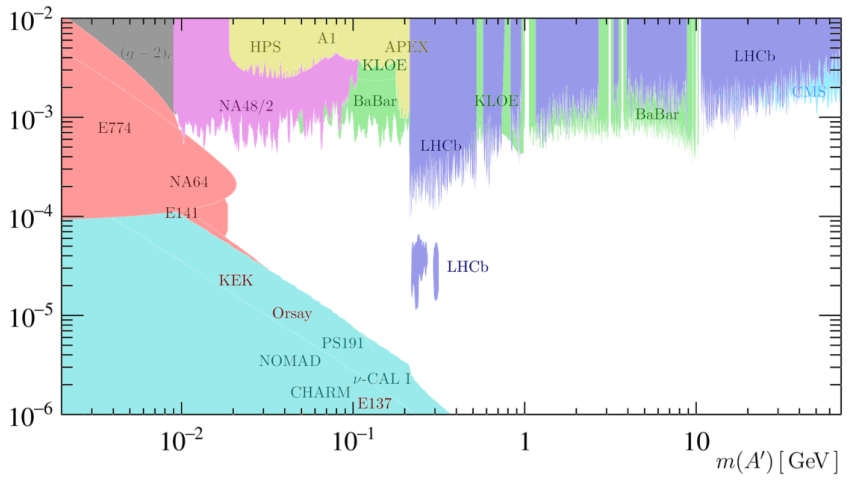
Standard Model Measurements



Pentaquarks and Tetraquarks



World's Best Limits on Dark Photons



Where do we go from here?

- LHCb have used Long Shutdown 2 to install our first major detector upgrade.
- On track for physics / data-taking in early 2022.
- Upgrade allows experiment to run with five times the instantaneous luminosity of Run 2.
- LHCb aiming to have collected at least 23 / fb by the end of Run 3.
  - includes 6 / fb collected in Run 2, and 3 / fb in Run 1.

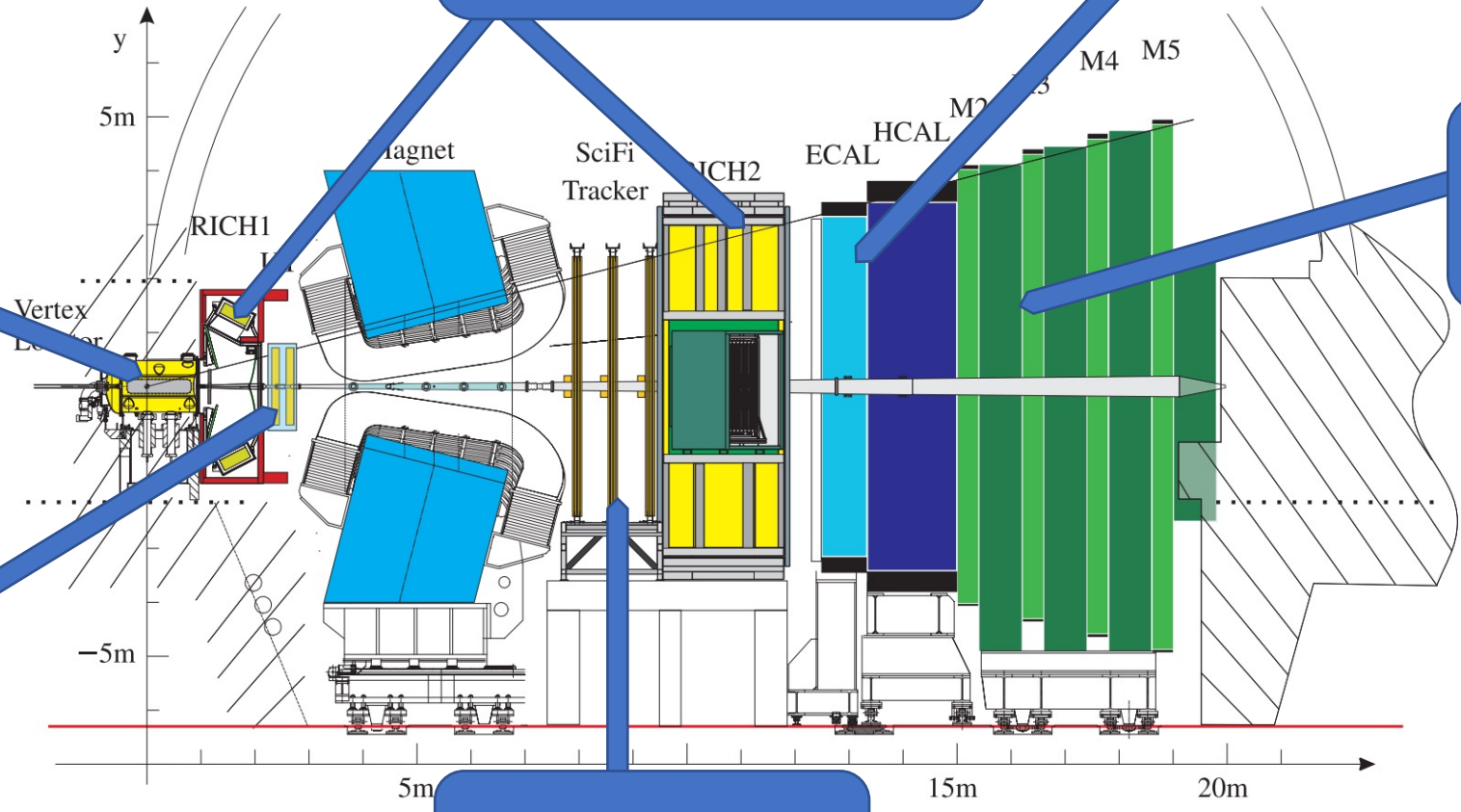
LHCb Upgrade

New RICH1
New readout and photon detectors for RICH2

Calorimeters:
Preshower (PS) and Scintillating Pad Detector (SPD) removed
Reduce PMT Gain, new readout

New PIXEL Vertex Locator (VELO)

Muon:
Remove M1
New readout



New Upstream Tracker (UT)

New Scintillating Fibre Tracker (SciFi)

New trigger paradigm

30 MHz > 1 MHz

- LHCb will readout the full detector in every event (at 30 MHz)
  - Level-0 Hardware Trigger now removed.
- Trigger now entirely software-based, enabling more sophisticated approach earlier in event selection process.
  - Run 1 + 2 hardware approach was based on simple detector signals to reduce rate to 1 MHz before events reach software trigger.
  - eg requiring hadron with $E_T > 3.5$ GeV
  - Software trigger approach enables efficiency gain – typically factor between 3 and 10 for Heavy Flavour channels.
  - First stage of software trigger is GPU based.
- With relatively little additional integrated luminosity, can get very large samples compared to existing datasets.

Rest of this talk

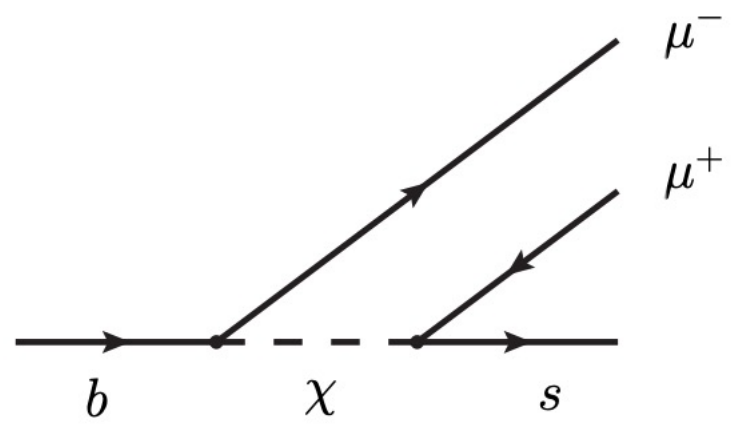
- Some of the exciting measurements possible in Run 3.
- Discussion of the level of precision possible over the next 5 years.
  - Assuming 23 / fb by the end of Run 3 – if the run is extended, our precision will improve.
- Will cover a few measurements of particular interest – far more measurements are exciting than I have time to show, and I have made a personal selection of what to cover.

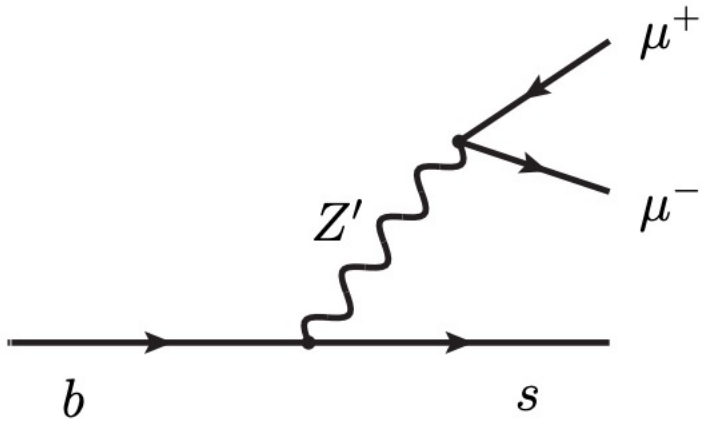
Lepton Flavour Universality Tests

- Provide a precise test of the SM: theoretical prediction is known very well; systematic effects are very small.

$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to J/\psi(\to \mu^+\mu^-)K^+)} \Big/ \frac{\mathcal{B}(B^+ \to K^+e^+e^-)}{\mathcal{B}(B^+ \to J/\psi(\to e^+e^-)K^+)}$$

- Current results show significant deviations from the Standard Model at > 3σ level.
- Significant improvement in precision possible:
  - Current Precision: ~4%
  - Upgrade Precision: ~2%
- Similar improvements in many channels:
  - $K^{*0}ll,\ K^{*+}ll, pKll,\ K_sll$ …

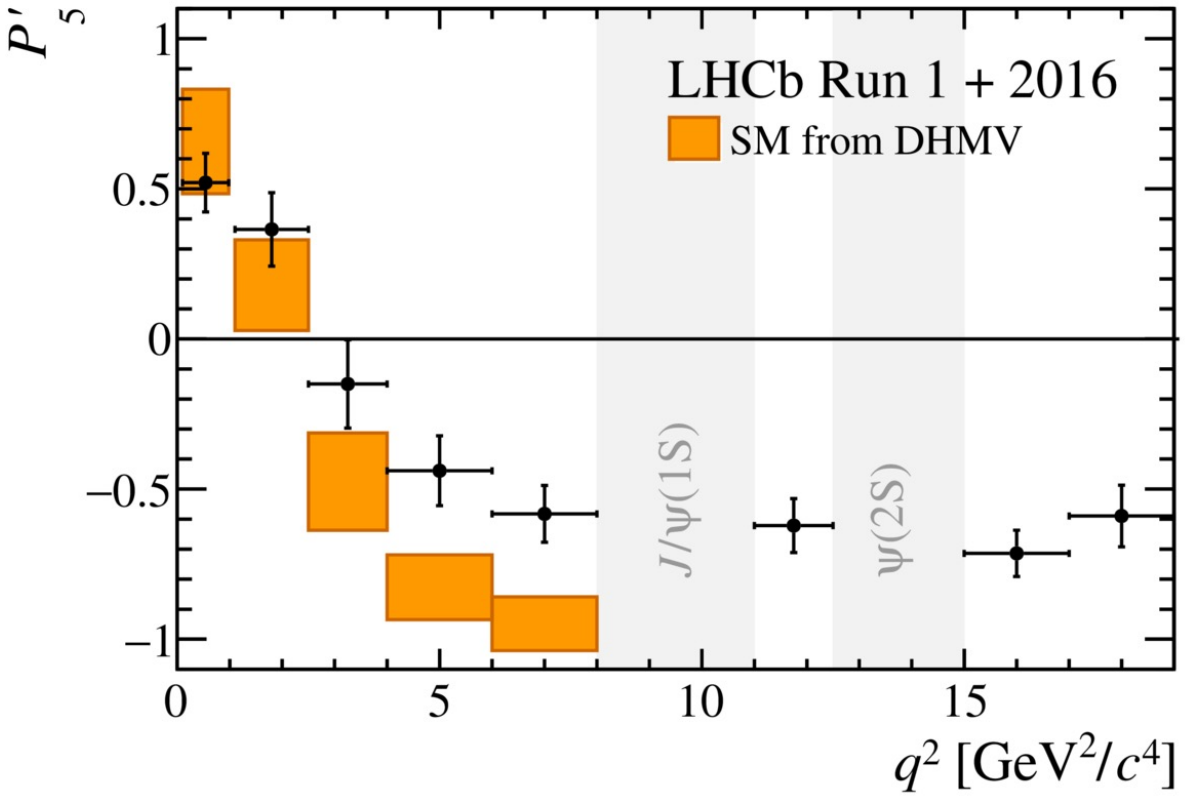


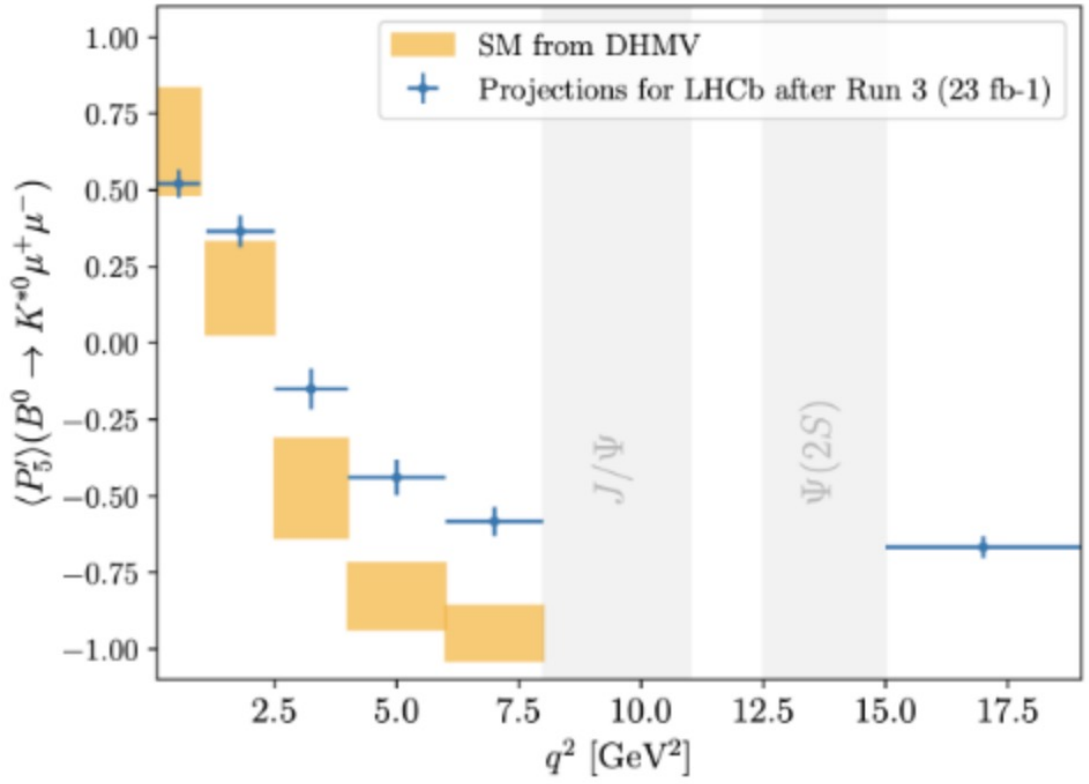


PRL 125 (2020) 011802
Projection Plot from Eluned Smith

Angular Observables in Rare B-meson Decays

- Current results show significant deviations from the Standard Model, both in individual bins and in global fits.





Semileptonic Asymmetries

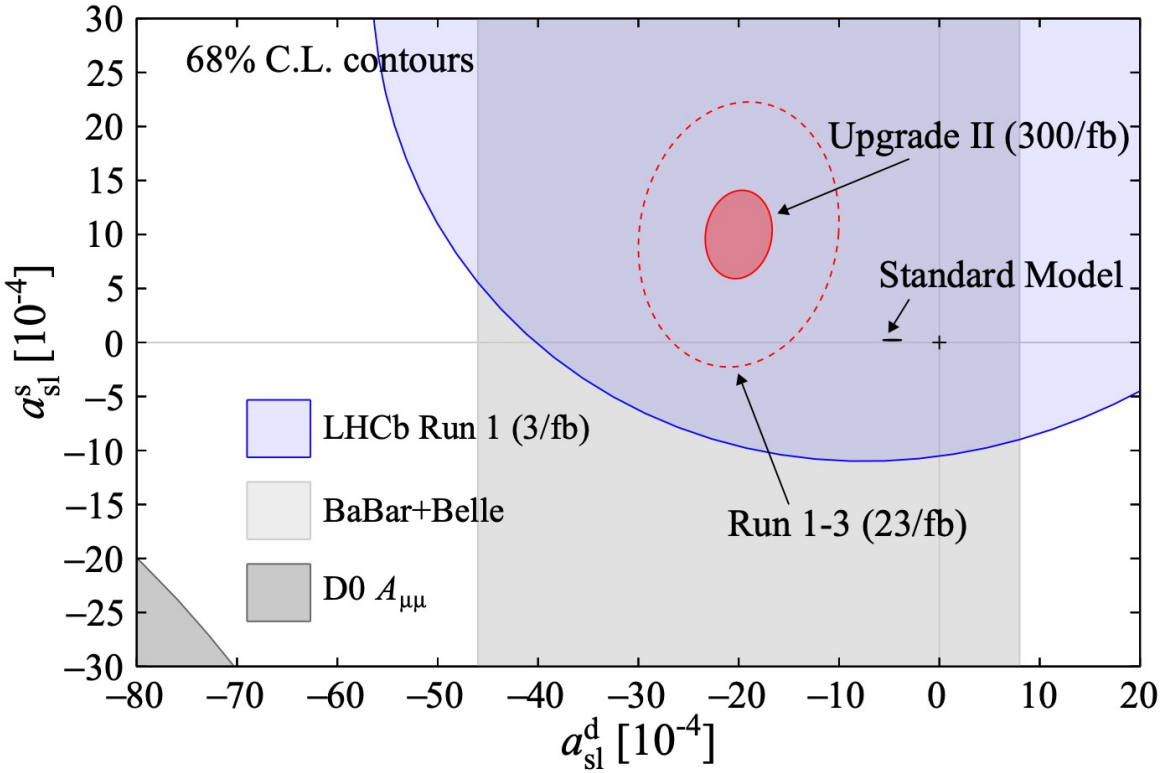
- Measurements of semileptonic asymmetries are sensitive to new sources of CP violation in B-mixing.

$$a^q_{\rm sl} = \frac{\Gamma(\bar{B}^0_q \to f) - \Gamma(B^0_q \to \bar{f})}{\Gamma(\bar{B}^0_q \to f) + \Gamma(B^0_q \to \bar{f})} \approx \frac{\Delta\Gamma_q}{\Delta M_q} \tan\phi^q_{12}$$

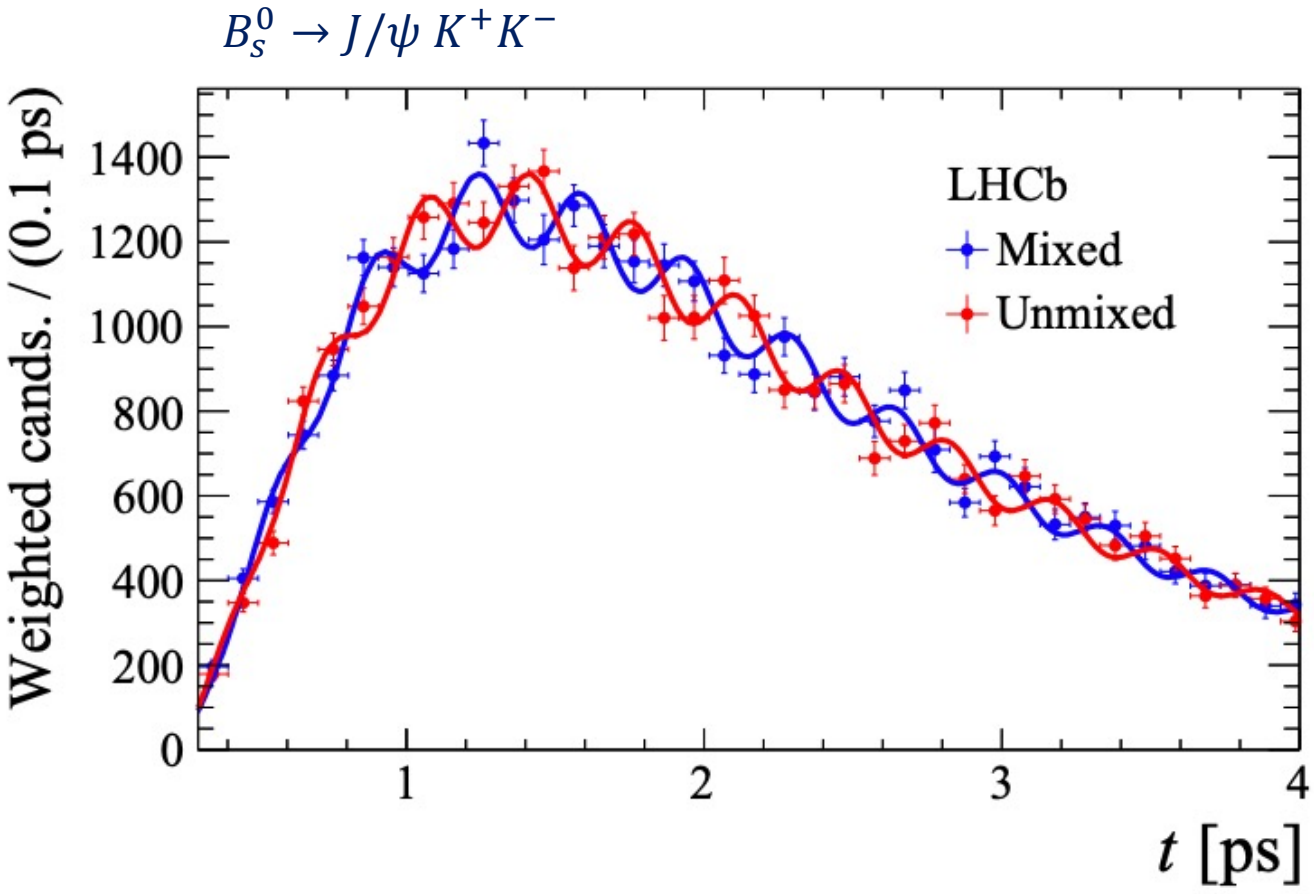
- SM prediction very well known.

- Upgrade will provide an improvement in LHCb measurement by a factor 3-5.

Note: Red ellipse is arbitrarily centred

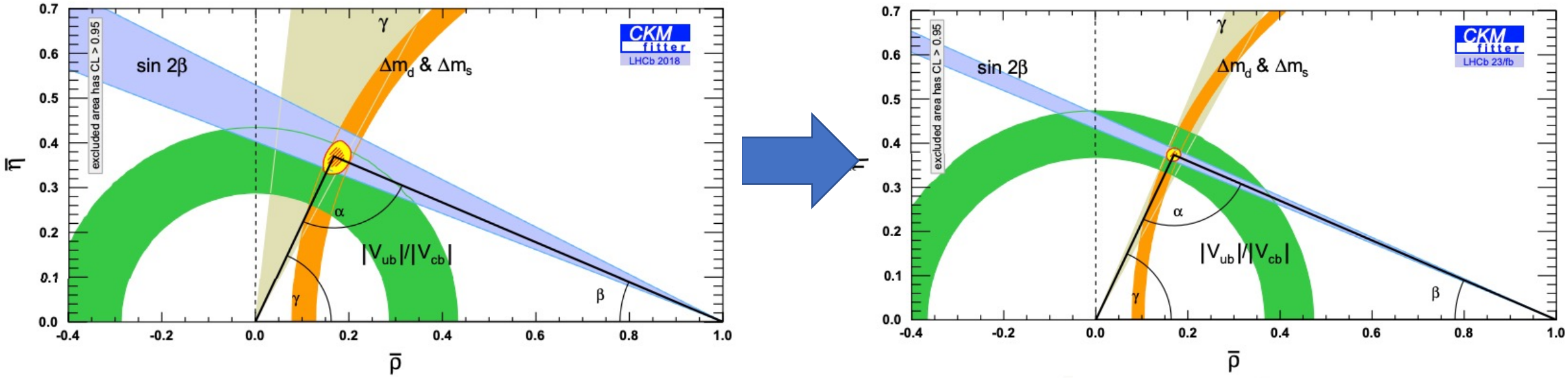


Measuring ϕ_s



- Probe $b \to c\bar{c}s$ transitions, sensitive to $\phi_s = -2\,\beta_s = -2\arg[\frac{-V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}]$
- Precisely known in the Standard Model (-37 ± 1 mrad) from global fits, so provides excellent test for New Physics in B_s^0- $\overline{B_s^0}$ oscillations.
- Current experimental precision (25 mrad) dominated by $B_s^0 \to J/\psi\,\phi$ measurements.
- Expect to achieve precision of 10 mrad using LHCb Upgrade data – chance to see non-zero ϕ_s.

Unitarity Triangle



- Closure of unitarity triangle provides powerful test of potential new physics.
- LHCb Upgrade expected to improve precision in knowledge of key variables by about a factor 2-4.
  - Precision on angle γ will be about 1.5° (current knowledge is ~4°).
  - Similar improvements expected in $\sin 2\beta$ and $|V_{ub}|/|V_{cb}|$

Charm Physics

- LHCb Upgrade perfectly suited here – one in four collisions in the LHCb upgrade will contain a charm meson.
  - can study new channels and improve precision in existing channels
  - uncertainties in key measurements will reduce by a factor 3 by end of Run 3.

Crucial question I: is the LHCb measurement of direct CP violation consistent with the Standard Model?

High precision in a range of channels will probe direct CP violation.

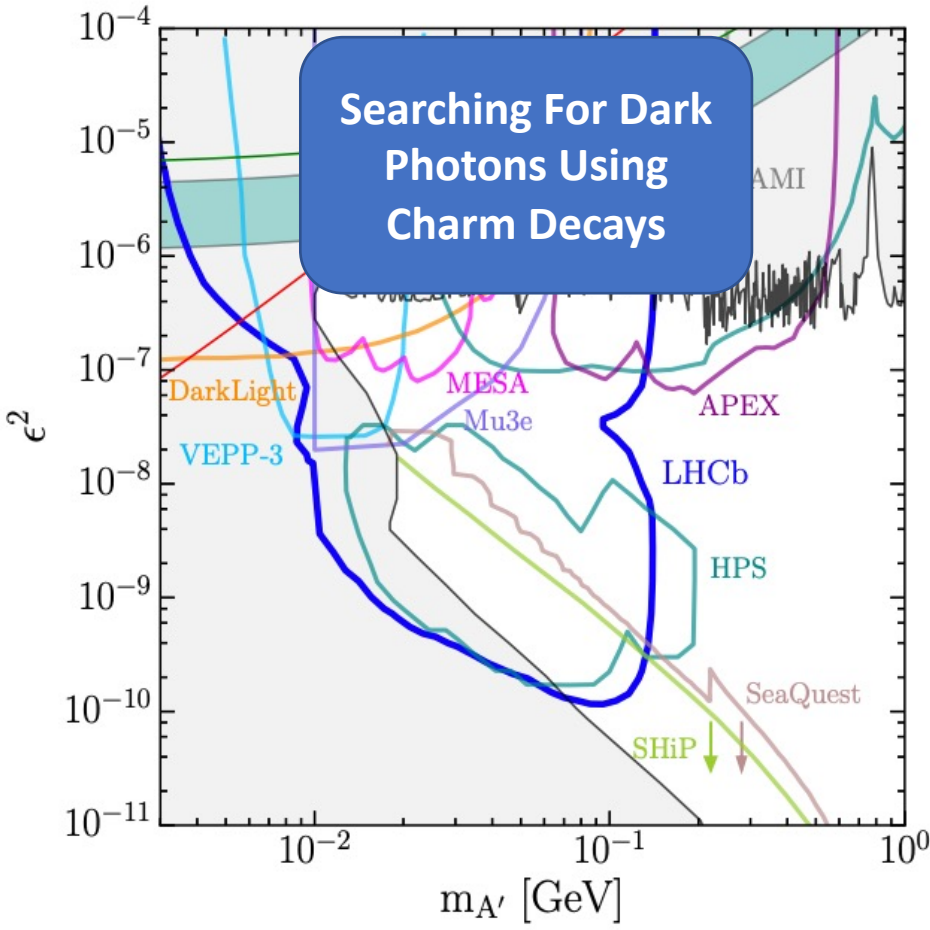
Crucial question II: What level does mixing-induced CP violation occur at in the charm sector?

Any observation in Run 3 will be extremely hard to reconcile with the Standard Model.

Charm physics measurements in LHCb Upgrade will continue to provide a key test of new physics.

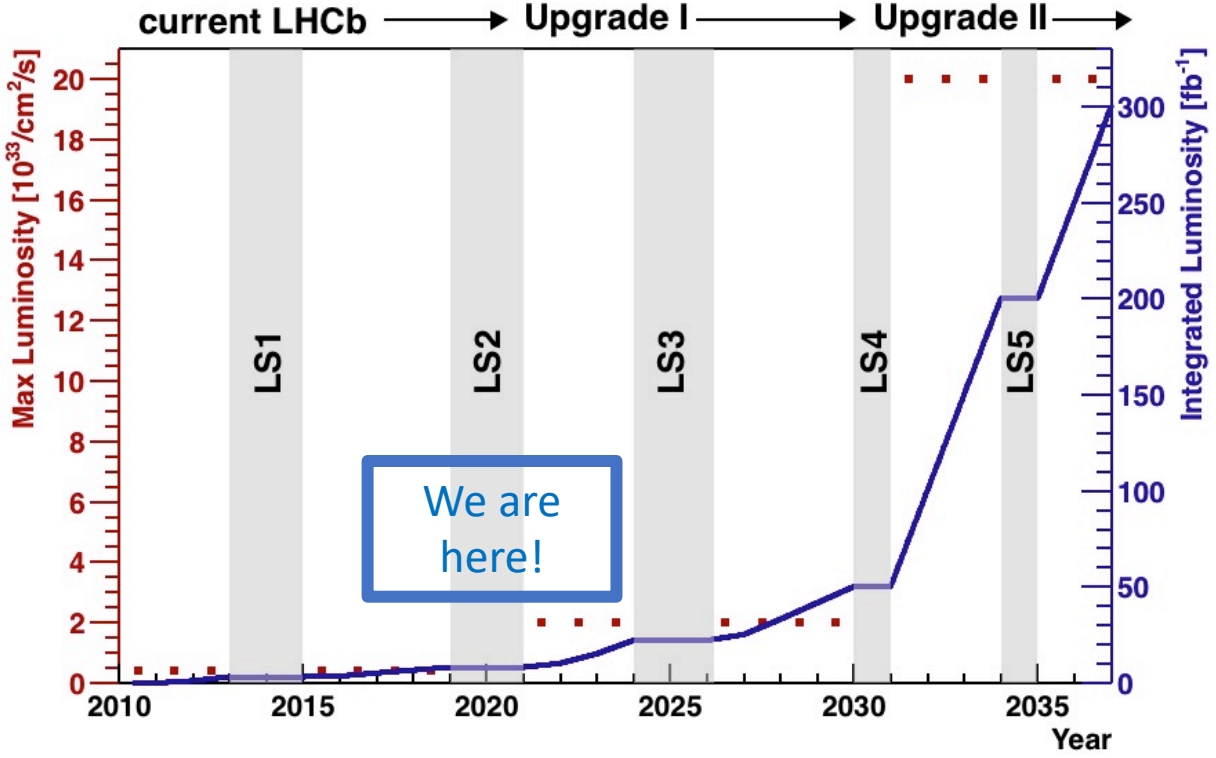
Beyond Flavour

- Spectroscopy
  - Probes of new types of matter – pentaquarks and tetraquarks.
- Standard Model Physics
  - W mass: Aim for 10-20 MeV precision.
  - Weak Mixing Angle: Aim for better precision than best individual measurements at LEP and SLD.
- Exotics
  - World's best limits on dark photon properties between ~10 MeV and ~100 GeV.



Looking Further Forward

- LHCb also proposes a second upgrade at the end of this decade.
- Upgrade II will take LHCb into the high luminosity era and allow the collection of at least 300 / fb.
- Will allow us to explore the full landscape of flavour physics and more at the LHC.



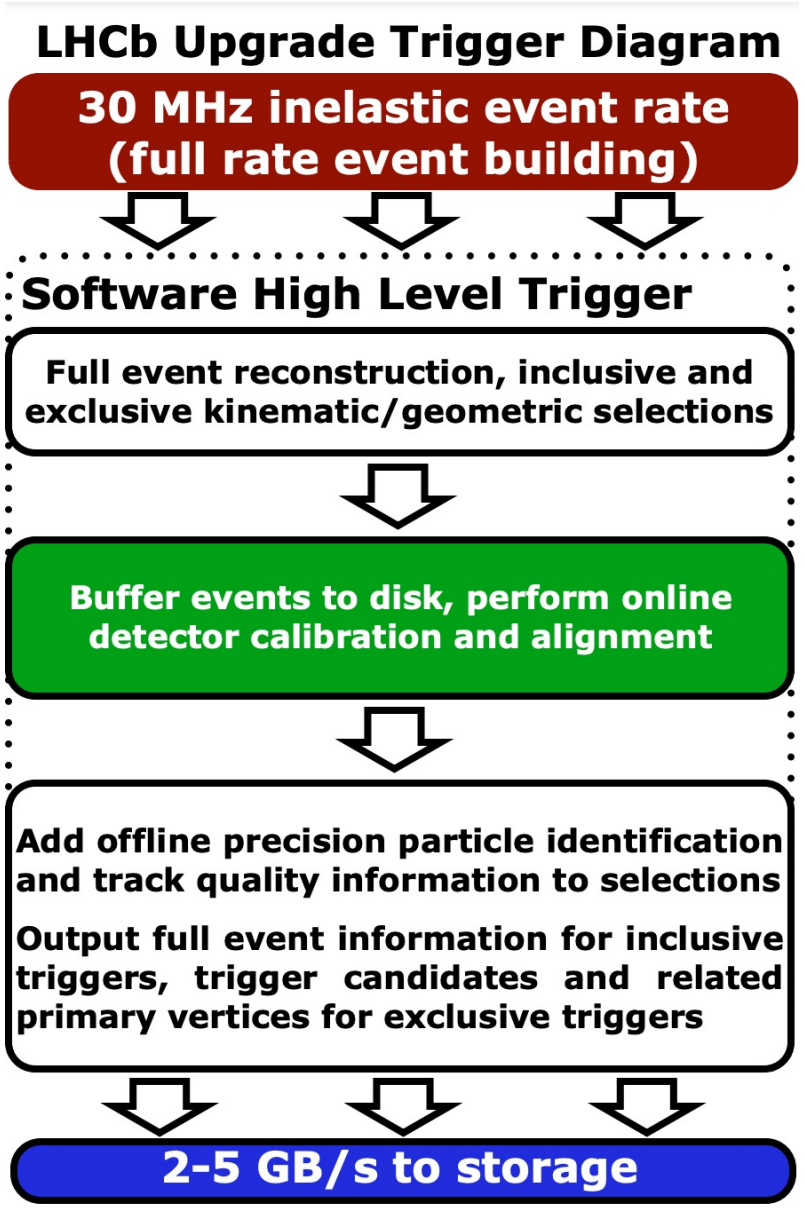
European Strategy Update

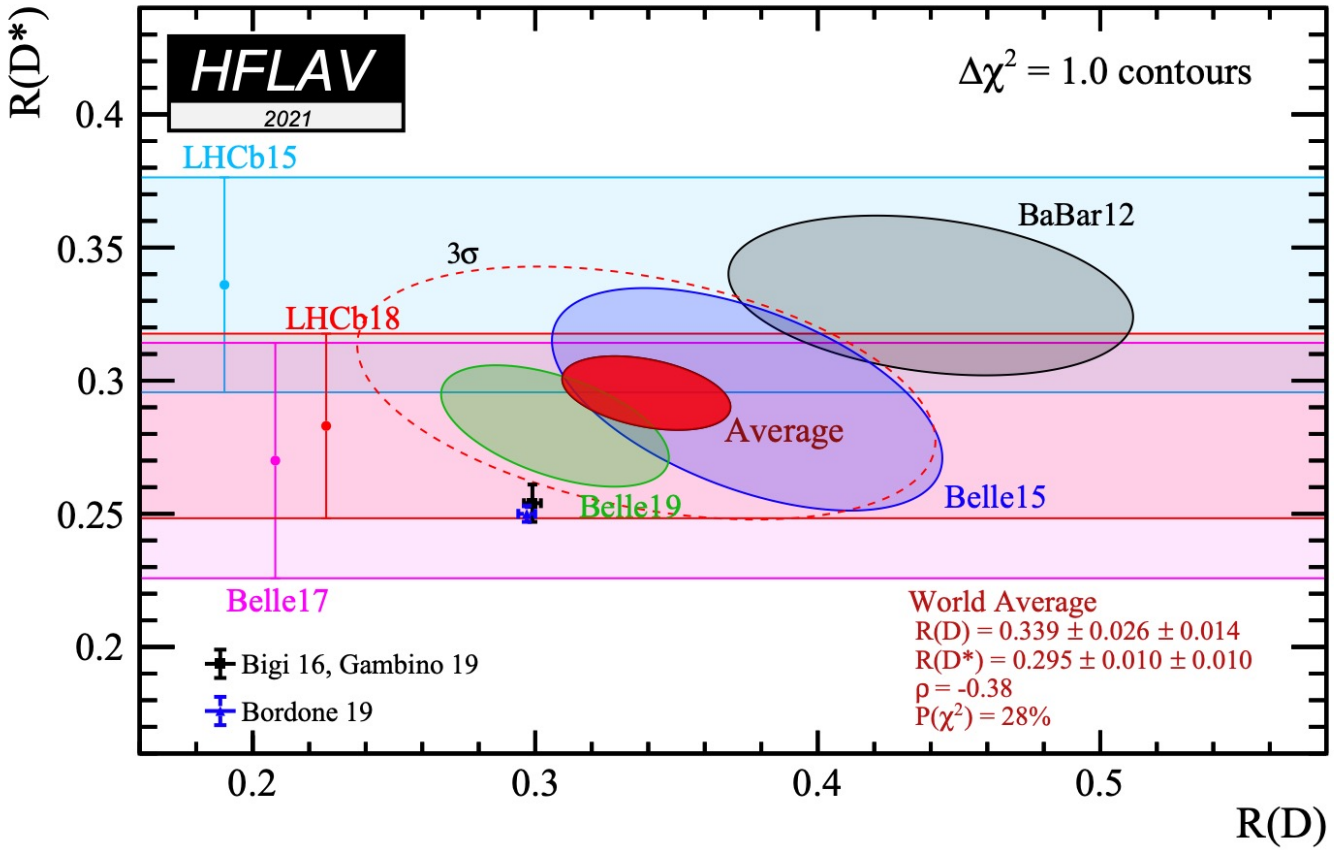
The successful completion of the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques. The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.

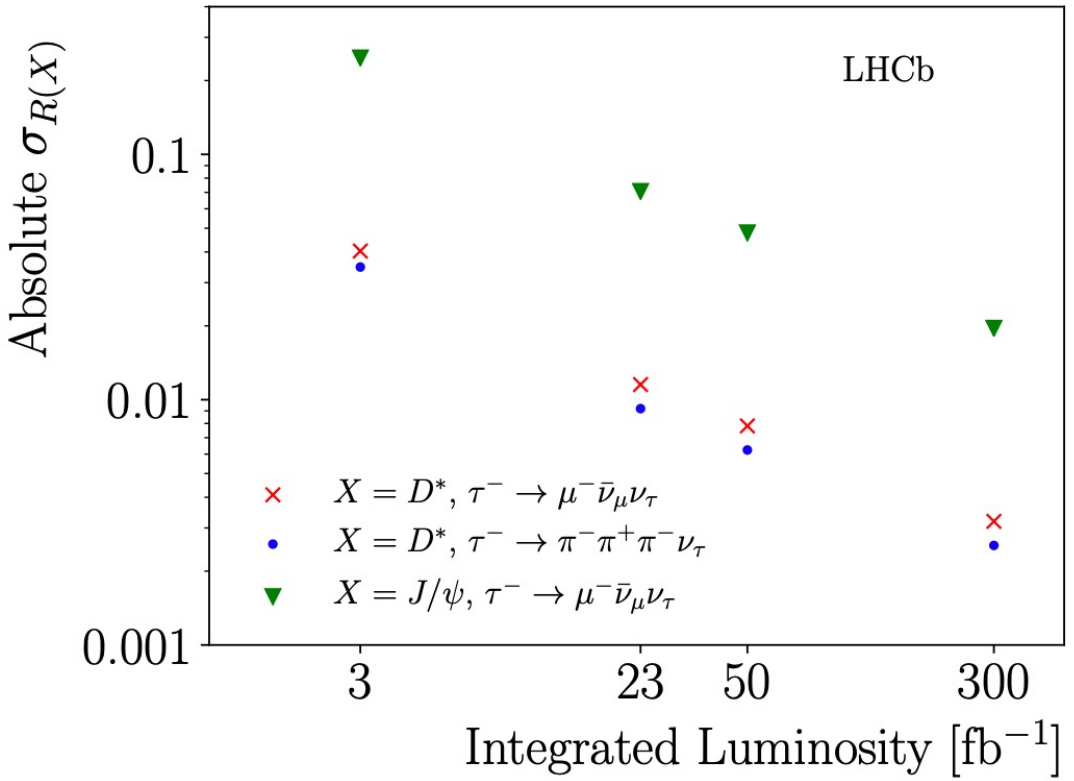
Conclusions

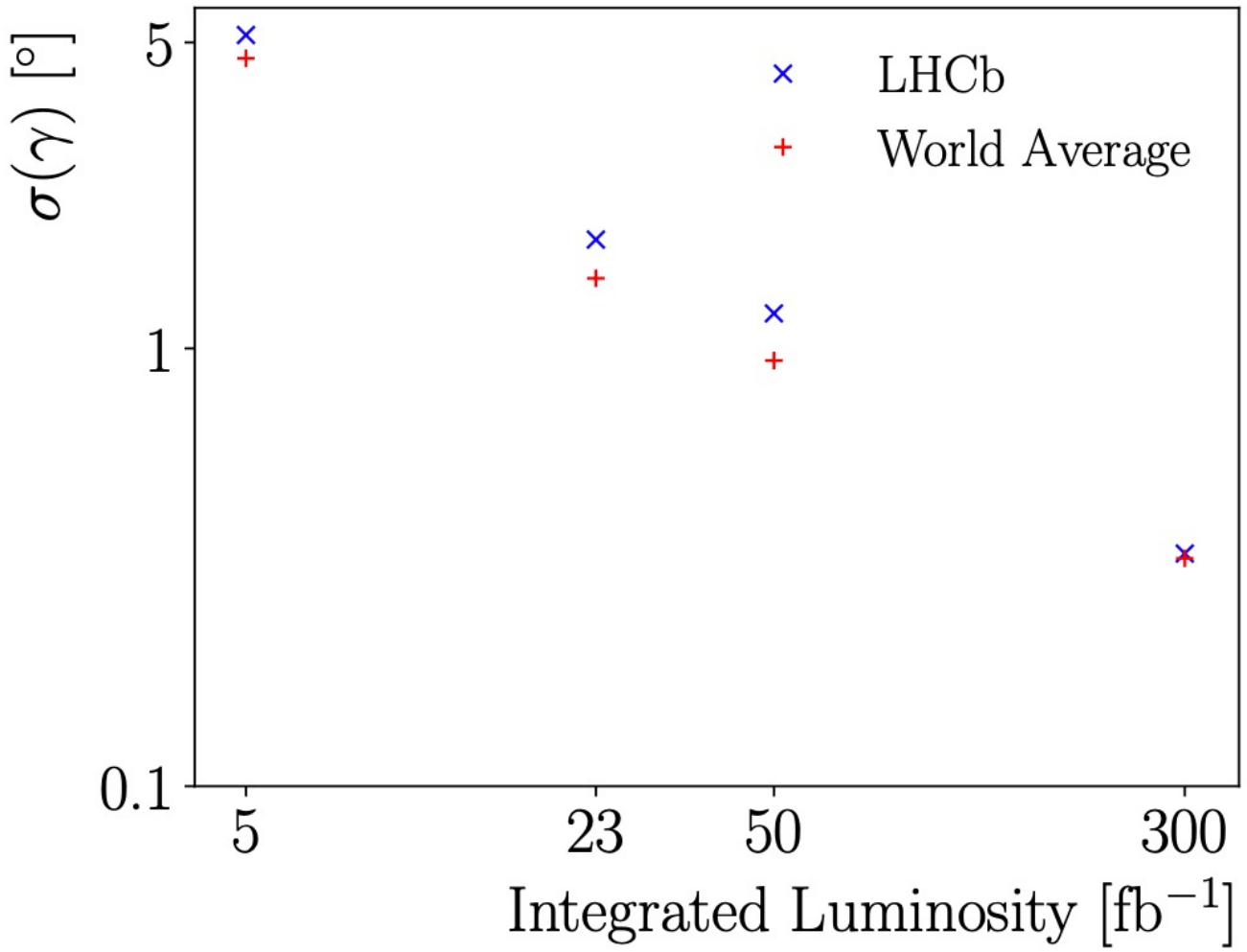
- LHCb has delivered exciting physics results in Runs 1 and 2.
- LHCb currently finishing installation of its upgrade.
- Upgrade will enable large new datasets through this decade.
- Targeting exciting physics results – flavour anomalies, studies of CP violation, and much more!
- Collaboration also proposing a second upgrade at end of this decade to achieve full physics potential of the HL-LHC era.

Backup


LHCb Upgrade Trigger Diagram
30 MHz inelastic event rate (full rate event building)
Software High Level Trigger
Full event reconstruction, inclusive and exclusive kinematic/geometric selections
Buffer events to disk, perform online detector calibration and alignment
Add offline precision particle identification and track quality information to selections
Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers
2-5 GB/s to storage


HFLAV
2021
$\Delta\chi^2 = 1.0$ contours
LHCb15
BaBar12
3σ
LHCb18
Average
Belle19
Belle15
Belle17
World Average
R(D) = 0.339 ± 0.026 ± 0.014
R(D*) = 0.295 ± 0.010 ± 0.010
ρ = -0.38
P(χ²) = 28%
Bigi 16, Gambino 19
Bordone 19
R(D*)
R(D)
0.4
0.35
0.3
0.25
0.2
0.2
0.3
0.4
0.5


LHCb
Absolute $\sigma_{R(X)}$
0.1
0.01
0.001
$X = D^*, \tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$
$X = D^*, \tau^- \to \pi^- \pi^+ \pi^- \nu_\tau$
$X = J/\psi, \tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$
3
23
50
300
Integrated Luminosity [fb^{-1}]


$\sigma(\gamma)$ [°]
5
1
0.1
LHCb
World Average
5
23
50
300
Integrated Luminosity [fb^{-1}]