Imperial College London

LHCb prospects

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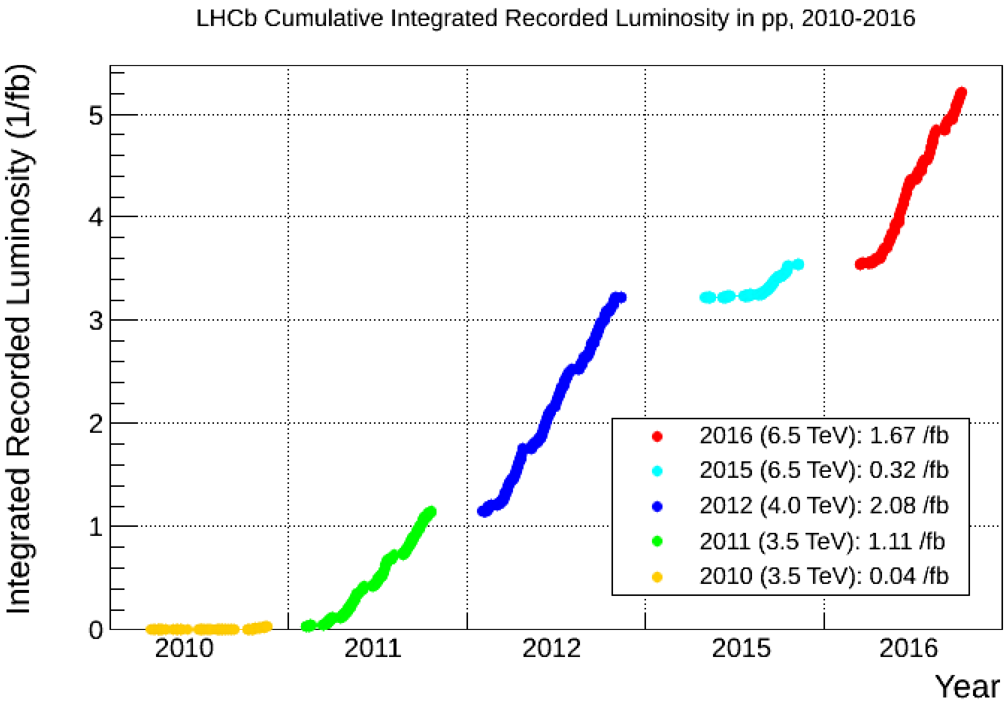
Instant workshop on B meson anomalies, CERN
17-19 May 2017

What we currently have in hand

Nearly all papers from LHCb so far are only including data from 2011 and 2012, corresponding to 3 fb^{-1} @ 7/8 TeV.

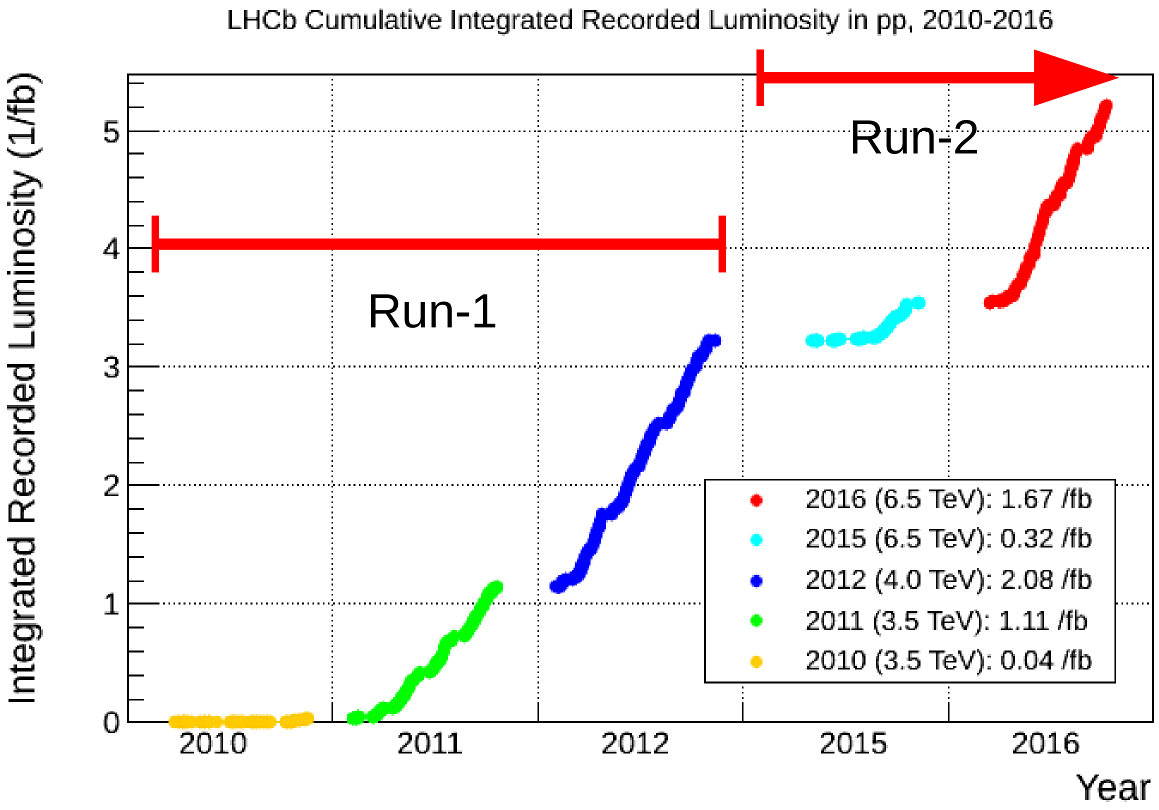
Notable exceptions are

- The latest $B \to \mu\mu$ paper that include (partial) 2016 data as well
- Cross section papers



What we currently have in hand

The Run-2 data is taken with $\sqrt{s}$ = 13 TeV where b-hadron cross section is nearly twice as high.



The future of LHCb

The current detector configuration will be used until end of Run-2 (2018)

- ~ factor 5 on Run-1 yield

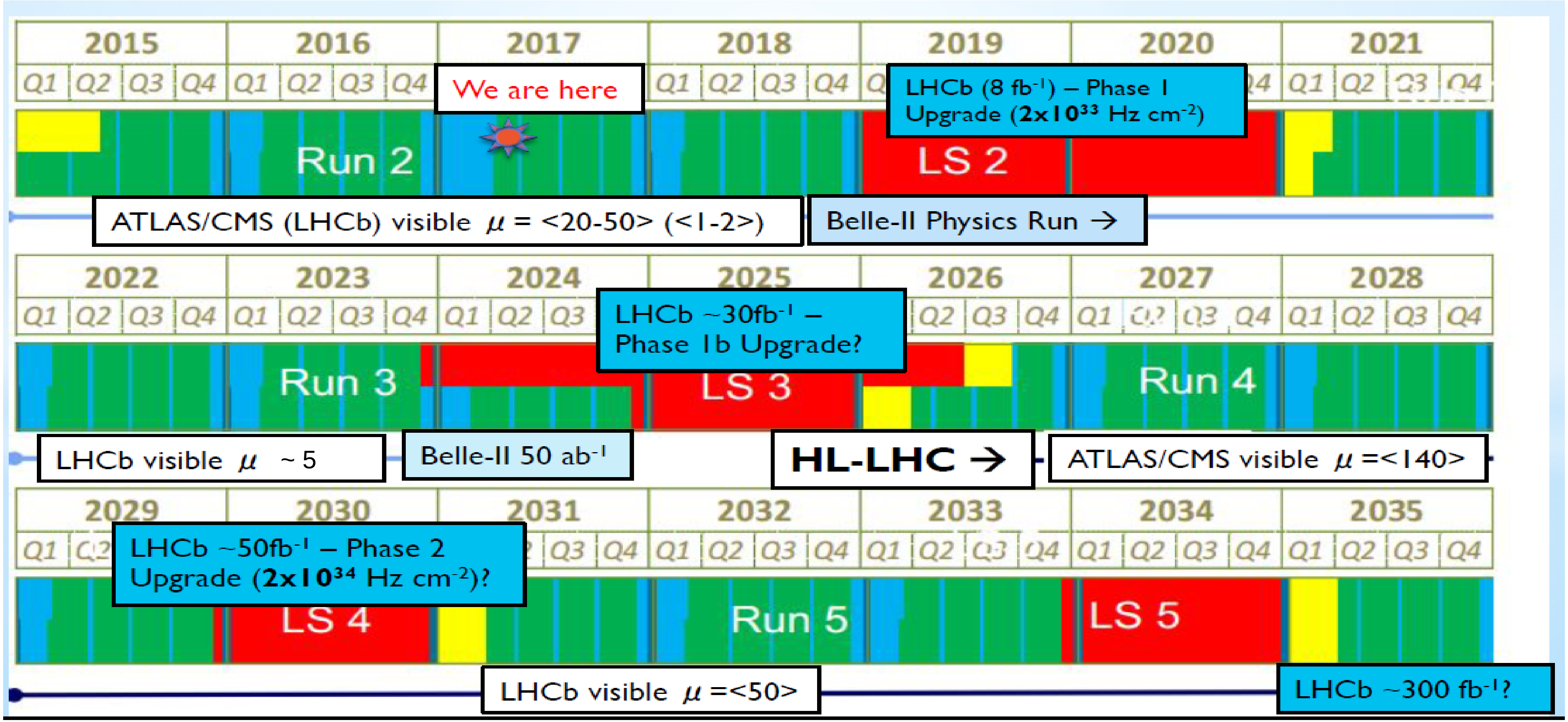
The LHCb upgrade will take data for 6 years from 2021

- ~ factor 25
- This ignores trigger improvements

A proposed LHCb upgrade phase-II will take data after 2030

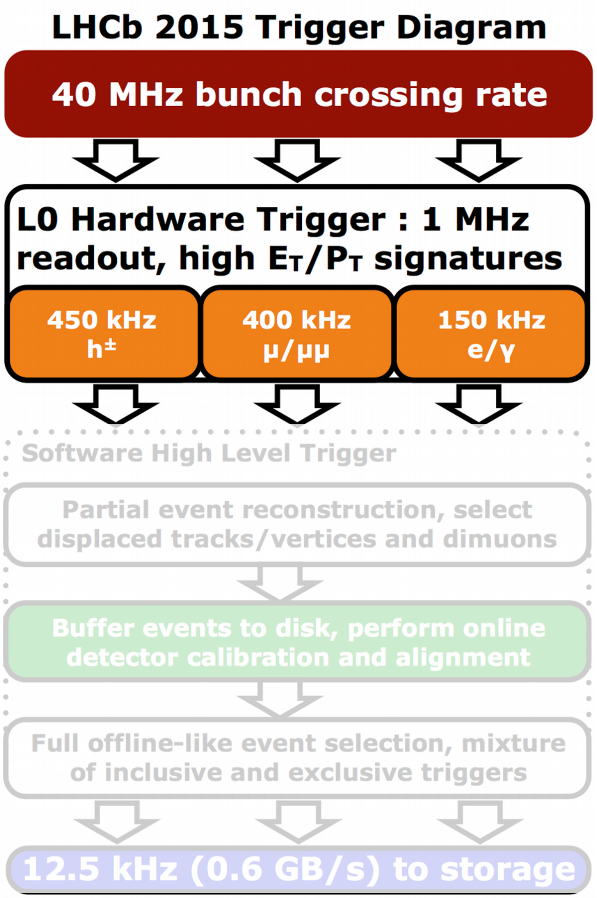
- ~ factor 200

Timing


2015
2016
2017
2018
2019
2020
2021
We are here
Run 2
LS 2
LHCb (8 fb^{-1}) – Phase I Upgrade (**2x10^{33}** Hz cm^{-2})
ATLAS/CMS (LHCb) visible μ = <20-50> (<1-2>)
Belle-II Physics Run →
2022
2023
2024
2025
2026
2027
2028
Run 3
LS 3
Run 4
LHCb ~30fb^{-1} – Phase Ib Upgrade?
LHCb visible μ ~ 5
Belle-II 50 ab^{-1}
HL-LHC →
ATLAS/CMS visible μ =<140>
2029
2030
2031
2032
2033
2034
2035
LS 4
Run 5
LS 5
LHCb ~50fb^{-1} – Phase 2 Upgrade (**2x10^{34}** Hz cm^{-2})?
LHCb visible μ =<50>
LHCb ~300 fb^{-1}?

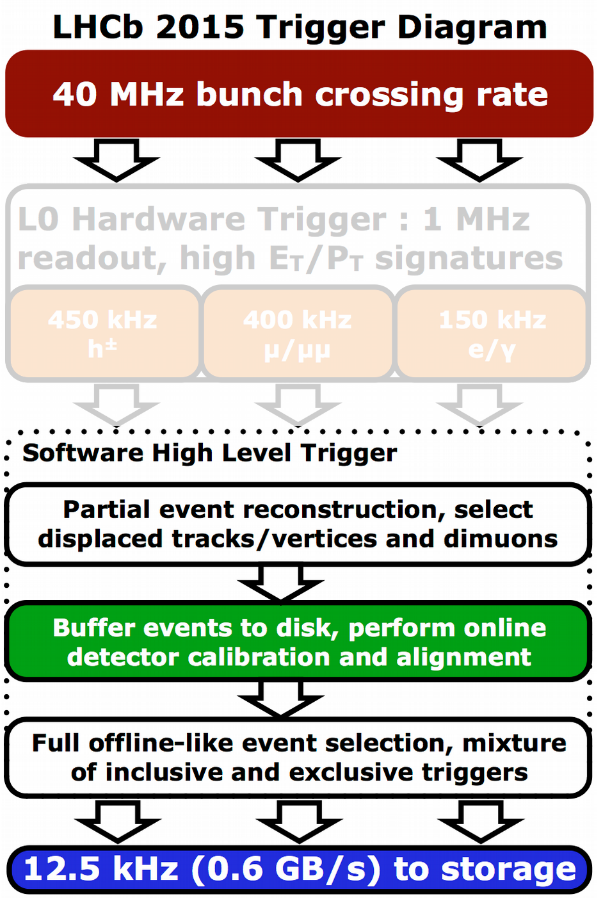
Data taking for rest of Run-2

- Inflexibility of trigger
  - The first (hardware) level of the current trigger is limited to 1 MHz
  - Only very simple decisions can be made
    - Occupancy
    - Transverse energy of single muon/electron/hadron
  - Any increase in one category leads to decrease in another
    - Only minor changes for rest of Run-2



Data taking for rest of Run-2

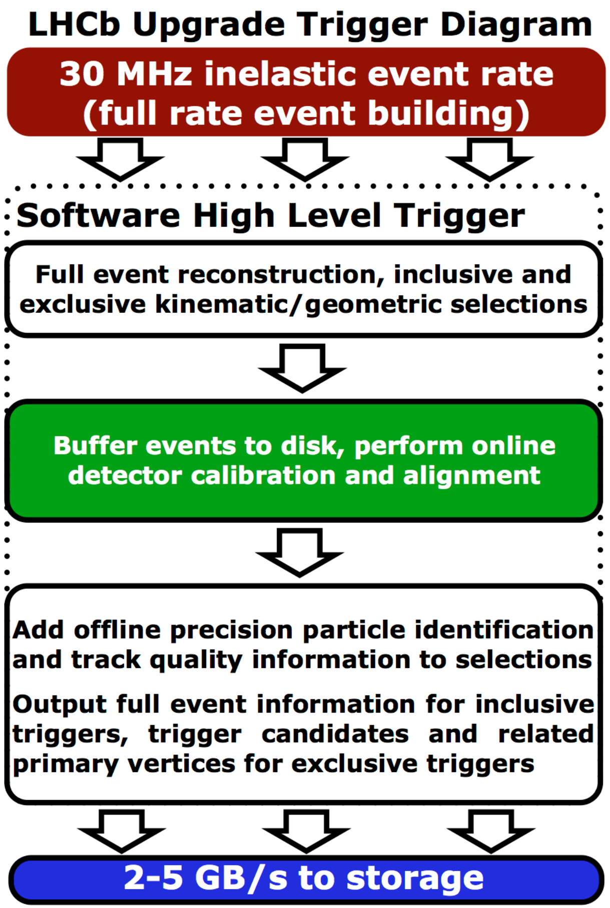
- Flexibility of trigger
  - The (software) High Level Trigger has full flexibility
    - Clever algorithms can make efficiency go up for all categories
    - Storing reduced information allows for increasing overall output rate
  - If looking for new signatures they might need explicit implementation here – think ahead!



Data taking in upgrade

In the upgrade the trigger will be based fully in software

- Will in particular benefit hadronic final states and long lived particle searches
- Improvements to final states with electrons less explored yet
- Efficiencies for final states with muons roughly unchanged



LHCb as a multipurpose experiment

LHCb has moved far beyond just being a heavy flavour experiment

- Rare light meson decays, e.g. $K^0_s \rightarrow \mu^+\mu^-$
- Electroweak precision measurements, $\sin^2\theta_W$
- Exotic hadronic states, Pentaquarks
- Search for long lived particles, $B \rightarrow \chi K^*$, $\chi \rightarrow \mu^+\mu^-$
- Central Exclusive Production, J/ψ production
- Heavy ions, pPb, PbPb

The trigger in the upgrade will dramatically improve some of these possibilities

Potential for discovery of NP

For a given prospective measurement, we need to ask the questions

- What level of statistical accuracy could be expected?
- How will experimental systematics be controlled?
- What are the theoretical uncertainties and can they be reduced?
- How can everything be cross checked?
- Do we know SM parameters well enough?

From answers conclude if measurement is actually interesting

- There are still plenty of interesting measurements

Direct discovery

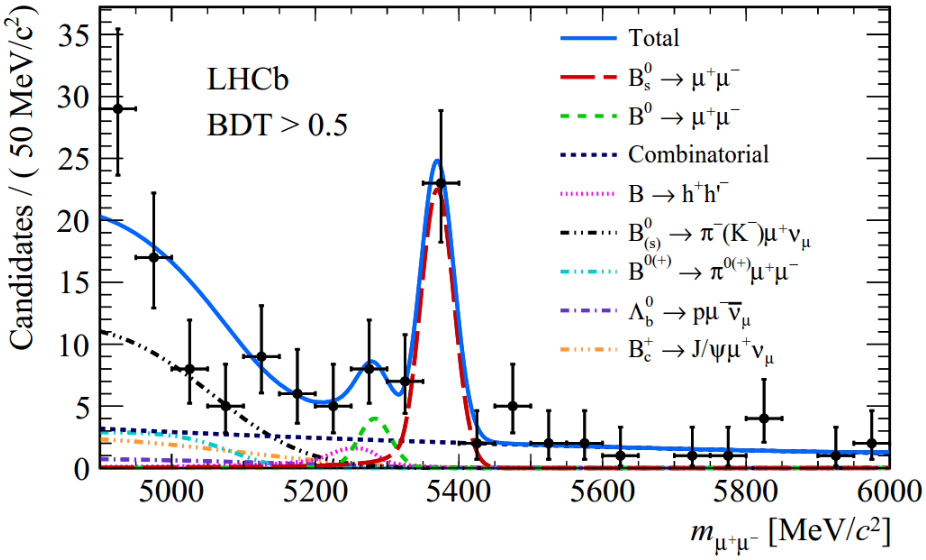
$B \to \mu^+\mu^-$

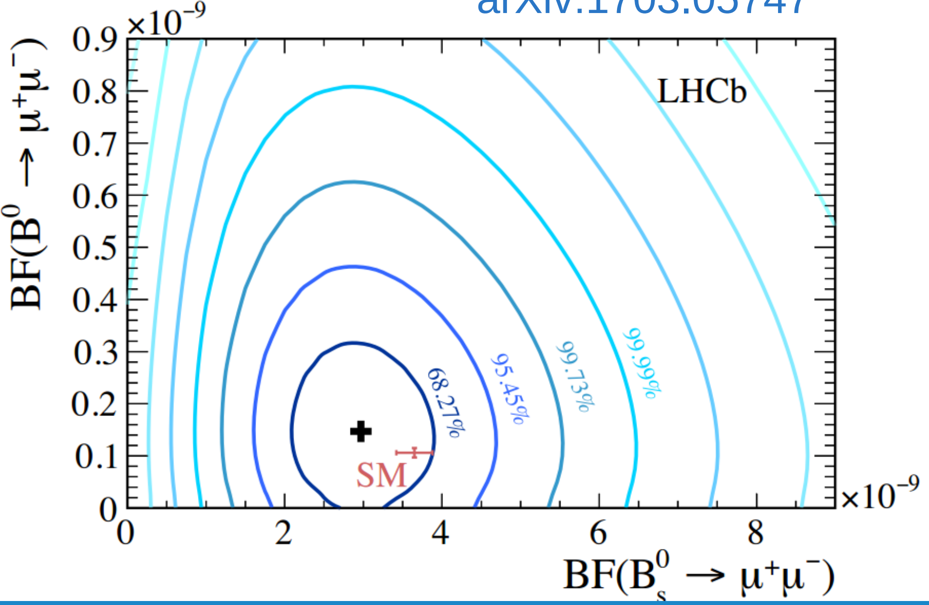
Latest analysis performed with 4.4 fb^{-1}

For $B^0_s \to \mu^+\mu^-$, BF = $(3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$ 7.8σ significant

No evidence of $B^0 \to \mu^+\mu^-$, BF < 3.4×10^{-10} @ 95% CL

arXiv:1703.05747





$B \to \mu^+\mu^-$

For Run II, the clear goal is observation of $B^0 \to \mu^+\mu^-$, yield ~ x 2.5 up on present

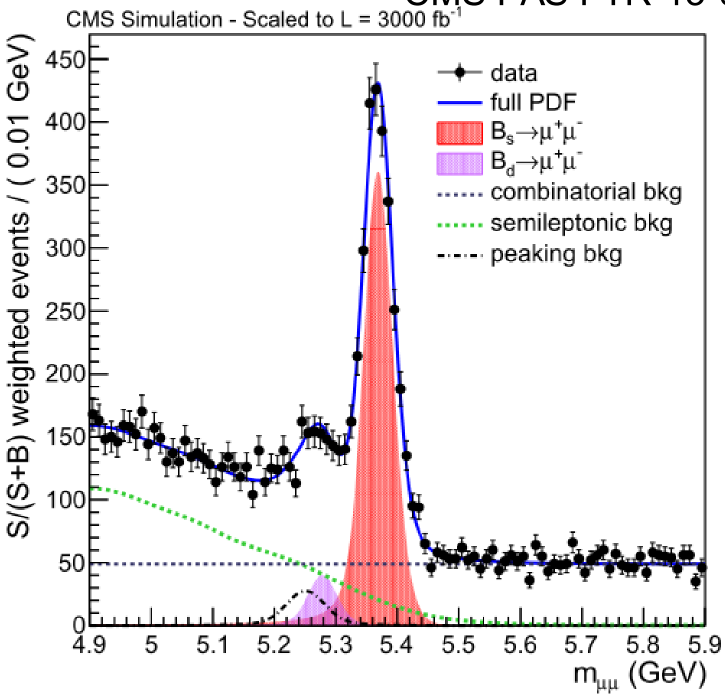
In the far future:

- LHCb upgrade: 35% accuracy on ratio
- CMS upgrade at full 3 ab^{-1}: 21%
  - Need to keep peaking backgrounds under control

$B^0_s \to \tau^+\tau^-$ interesting for FCCee

- Would need **huge** enhancement to be visible in LHCb (current limit 7 x 10^{-3})

CMS PAS FTR-13-016

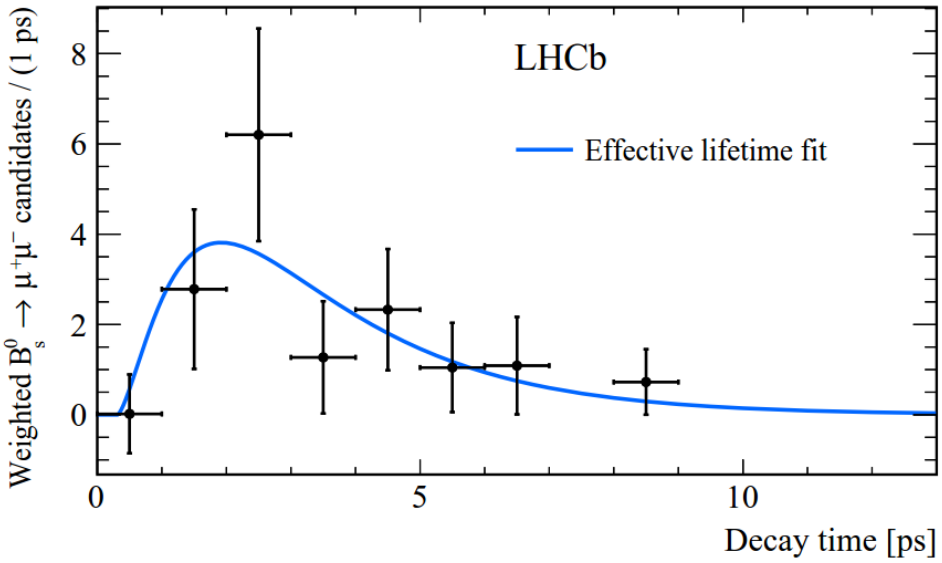


$B \to \mu^+\mu^-$

Is the decay $B^0_s \to \mu^+\mu^-$ *CP*-even or *CP*-odd?

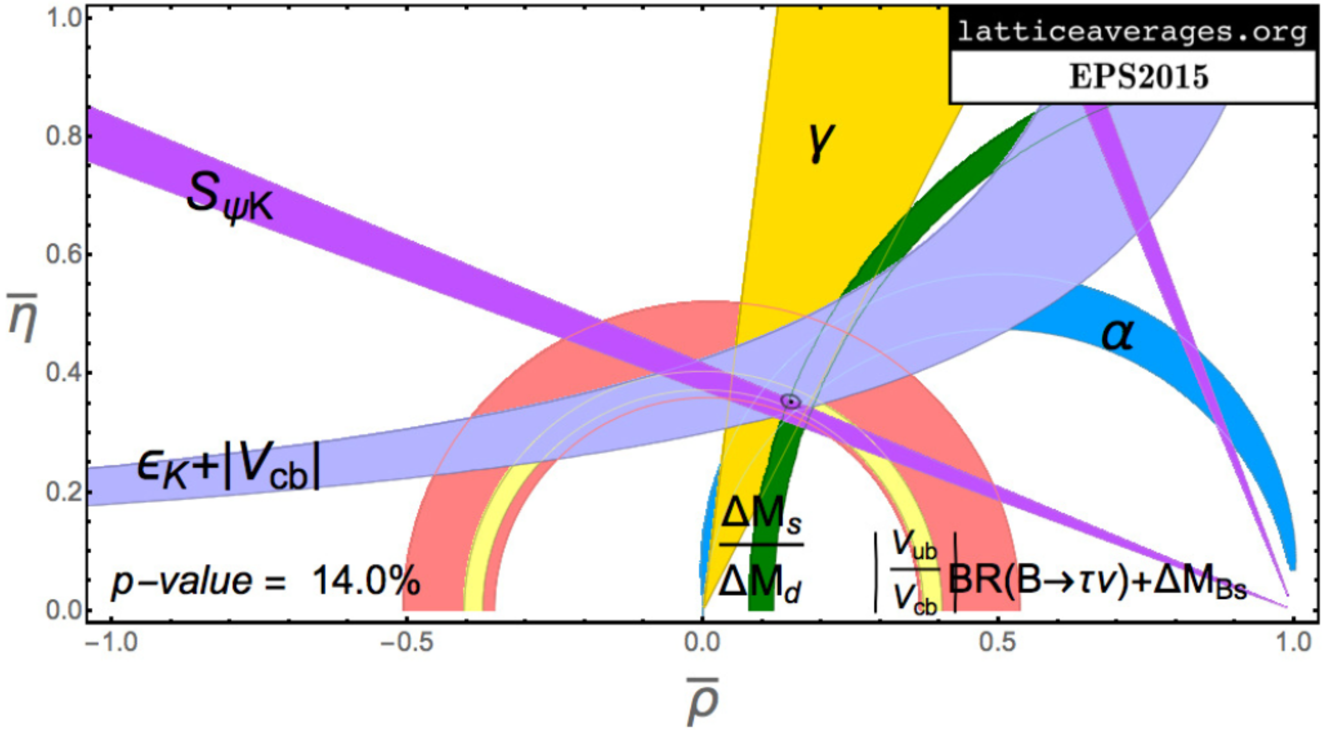
- The two weak eigenstates of the B^0_s differ by about 12% in effective lifetime ($\Delta\Gamma/\Gamma \sim 0.12$)
- The two states are almost purely CP-even and CP-odd
  - Measurement of effective lifetime in $B^0_s \to \mu^+\mu^-$ is a measure of the CP of the decay.
- $\tau(B^0_s \to \mu^+\mu^-) = 2.04 \pm 0.44 \pm 0.05$ ps
  - Need 300 fb^{-1} to make important measurement

arXiv:1703.05747



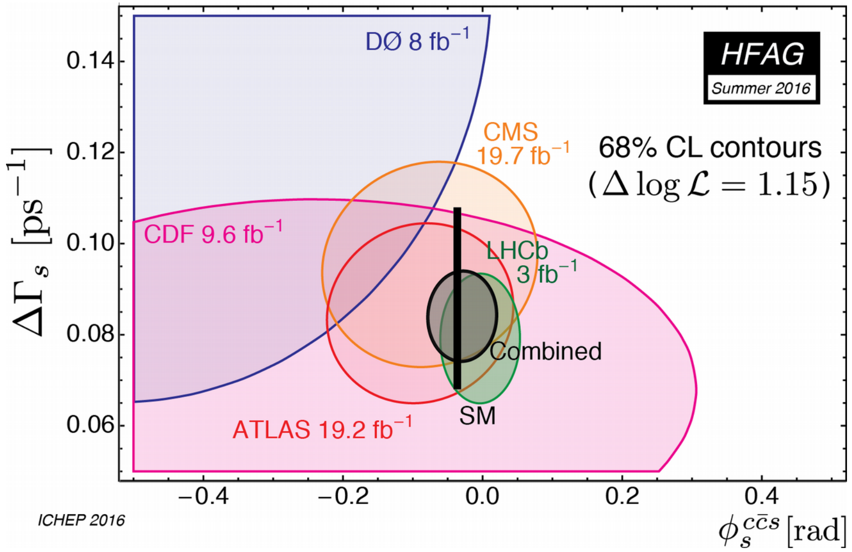
No heavy flavour *CP* violation anomalies?

The global CKM fits do not show any anomalies



No heavy flavour *CP* violation anomalies?

Still scope for NP to show up in B^0_s oscillations



The theoretical uncertainty is still small compared to experimental uncertainty

Are we so close that NP could not be discovered in CPV from this?

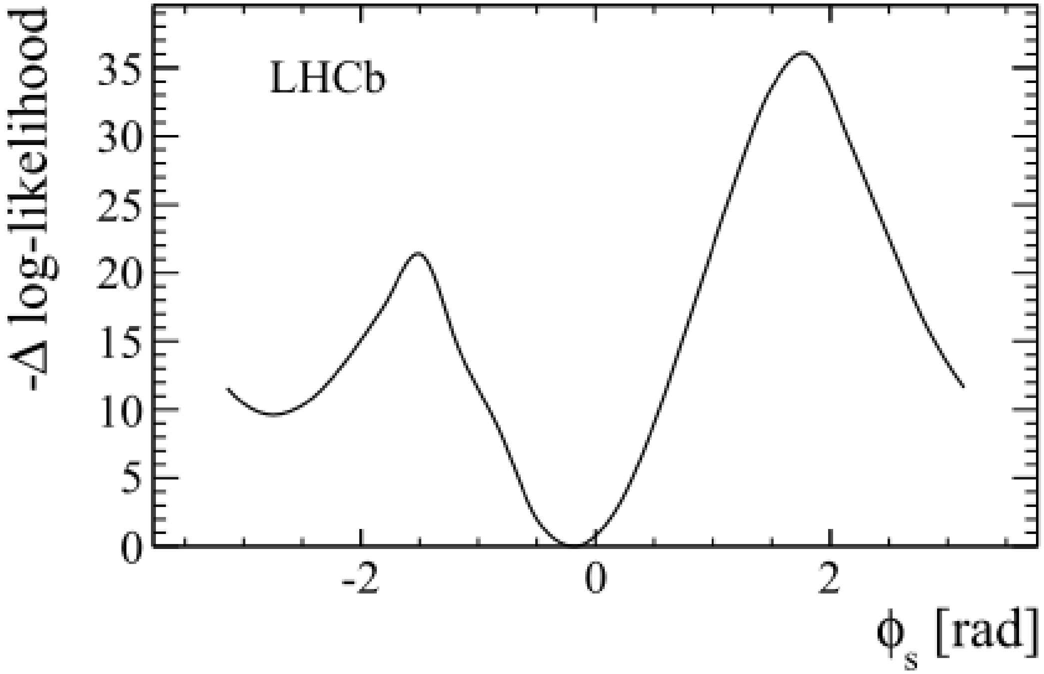
CP violation in gluonic penguins

Current status of LHCb $B^0_s \to \varphi\varphi$ measurement

No significant CP violation observed

SM prediction is for zero CPV

LHCb : PRD 90 (2014) 5, 052011



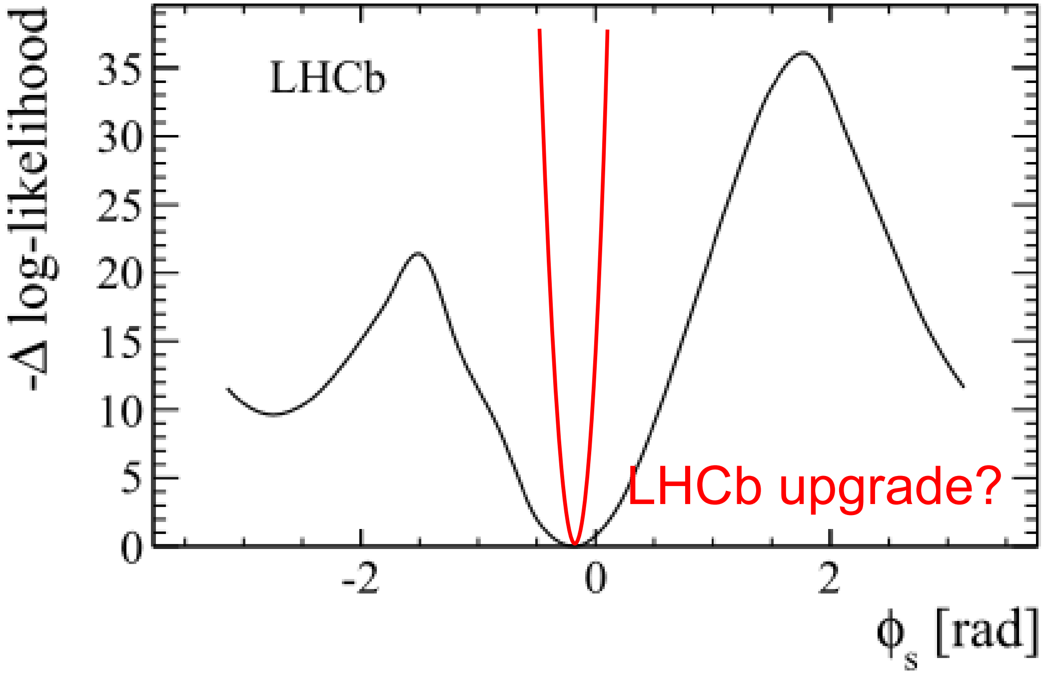
$$\phi_s = -0.17 \pm 0.15\,(\text{stat}) \pm 0.03\,(\text{syst}) \;\; \text{rad}$$

CP violation in gluonic penguins

LHCb upgrade will bring precision on this down to 0.02

Same level as the current theoretical uncertainty

LHCb : PRD 90 (2014) 5, 052011



The indirect view

The improved measurement of SM parameters might lead us to discovery of New Physics

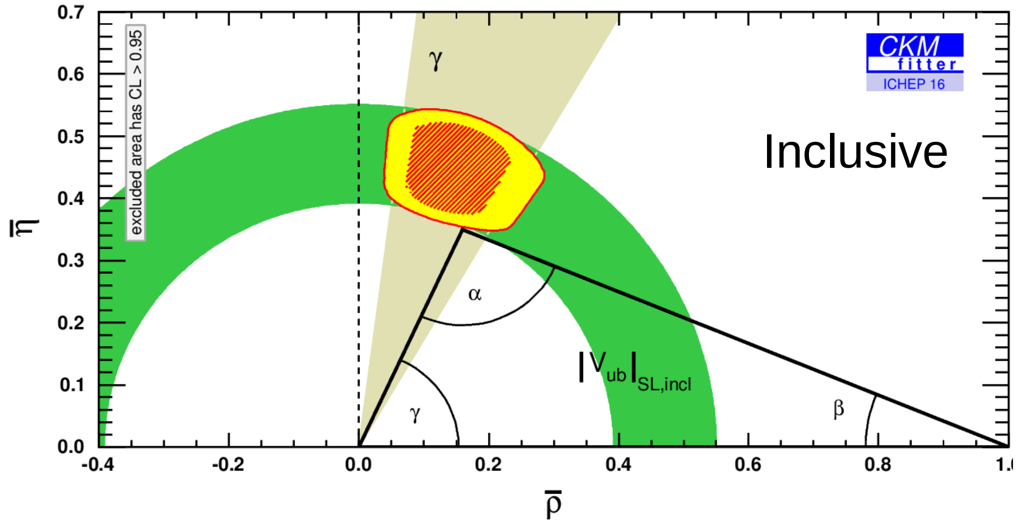
There are key measurements that we can improve

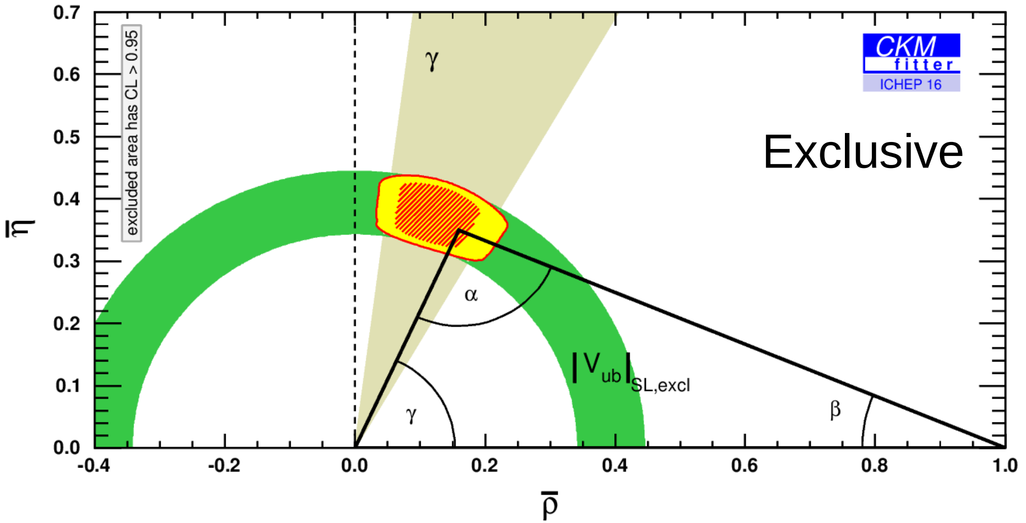
The need to resolve the problem with $|V_{ub}|$

The measurement of $|V_{ub}|$ hides an internal inconsistency between

Inclusive measurement : $B \rightarrow X_u \mu^+ \upsilon$

Exclusive measurement : $B^0 \rightarrow \pi^- \mu^+ \upsilon$, $\Lambda_b \rightarrow p \mu^+ \upsilon$



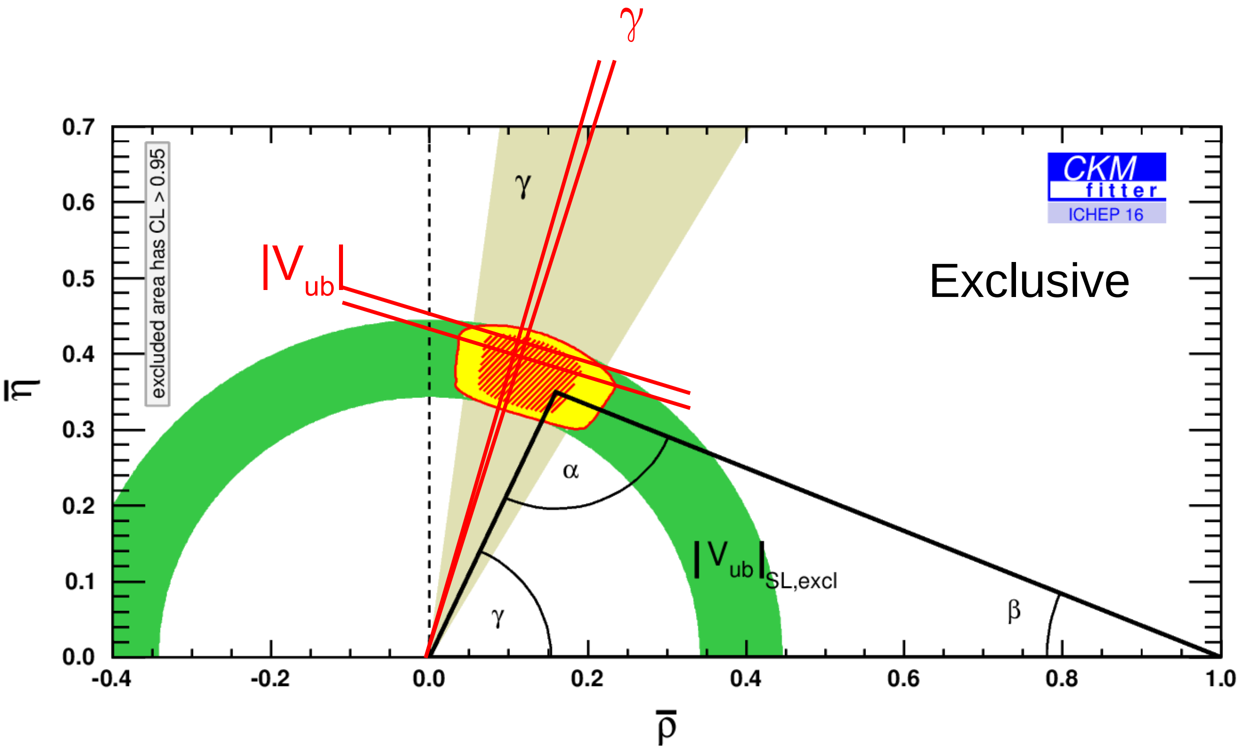


Improve $|V_{ub}|$

We are working on exclusive measurement of $|V_{ub}|$ from $B^0_s \to K^- \mu^+ \nu$

- Better understood normalisation compared to $\Lambda_b \to p \mu^+ \nu$
- Lattice calculation of form factors good

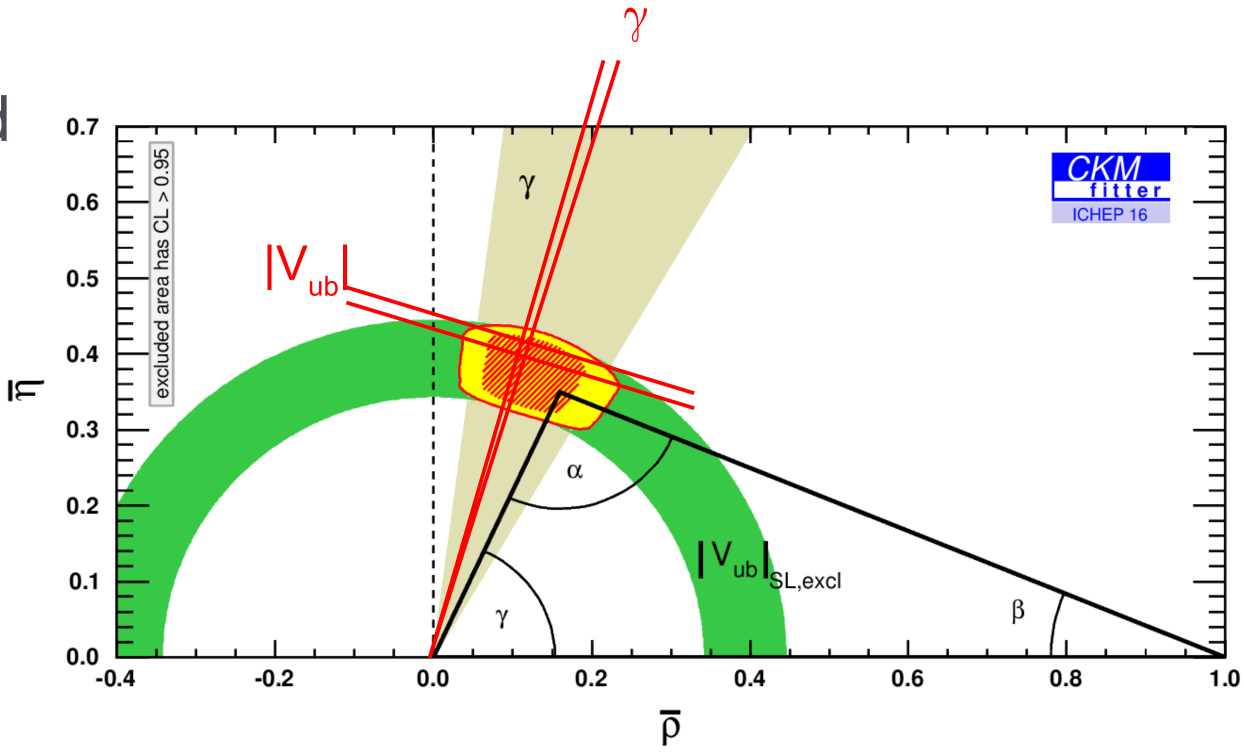
Some ideas about inclusive measurement from B_c decays



Improve γ

The CP angle γ will be improved to around 1° at end of LHCb upgrade, and to 0.4° at end of phase 2

Sets precise points to compare against $\Delta m_s/\Delta m_d$, penguin measurements and sin 2β



Normalisations

Many of the experimental measurements depends on normalisation with respect to other modes

LHCb : arXiv:1606.04731

$$\mathcal{B}(B^0 \to K^*(892)^0 \mu^+ \mu^-) = (0.904\,^{+0.016}_{-0.015} \pm 0.010 \pm 0.006 \pm 0.061) \times 10^{-6},$$

where the uncertainties, from left to right, are statistical, systematic, from the extrapolation to the full q^2 region and due to the uncertainty of the branching fraction of the normalisation mode.

Should we normalise penguin decays to semileptonic decays instead, like $B^+ \to D^0 \mu^+ \upsilon$

Another example is $\Lambda_c^+ \to pK^+\pi^-$

Discrepancy between Belle and BES measurement large systematic for $\Lambda_b \to p\mu^+\upsilon$

Making the pieces fit

If NP is there, we need to understand its properties

- $B^+ \to \pi^+\mu^+\mu^-$ BF compared to $B^+ \to K^+\mu^+\mu^-$
  - Can help us understand if NP observes minimal flavour violation
- Search for $B^+\to K^+e^+\mu^-$, $B^+\to K^+\tau^+\mu^-$
  - Is NP flavour diagonal in lepton sector
- Measure R_K and R_{K^*} in $b\to d$ transitions, $B\to K^{(*)}l^+l^-$
  - Does NP depend on quark sector
- Measure $B^+\to p\bar{p}\tau^+\nu$ relative to $B^+\to p\bar{p}\mu^+\nu$
  - Does new physics care about $b\to c$ vs. $b\to u$ transitions?

Conclusion

If NP is there for discovery in Flavour Physics, we have a rich programme ahead of us to understand it!