Flavour Physics at the High Luminosity LHC: LHCb Upgrade II

Ulrik Egede, Monash University
on behalf of the LHCb collaboration

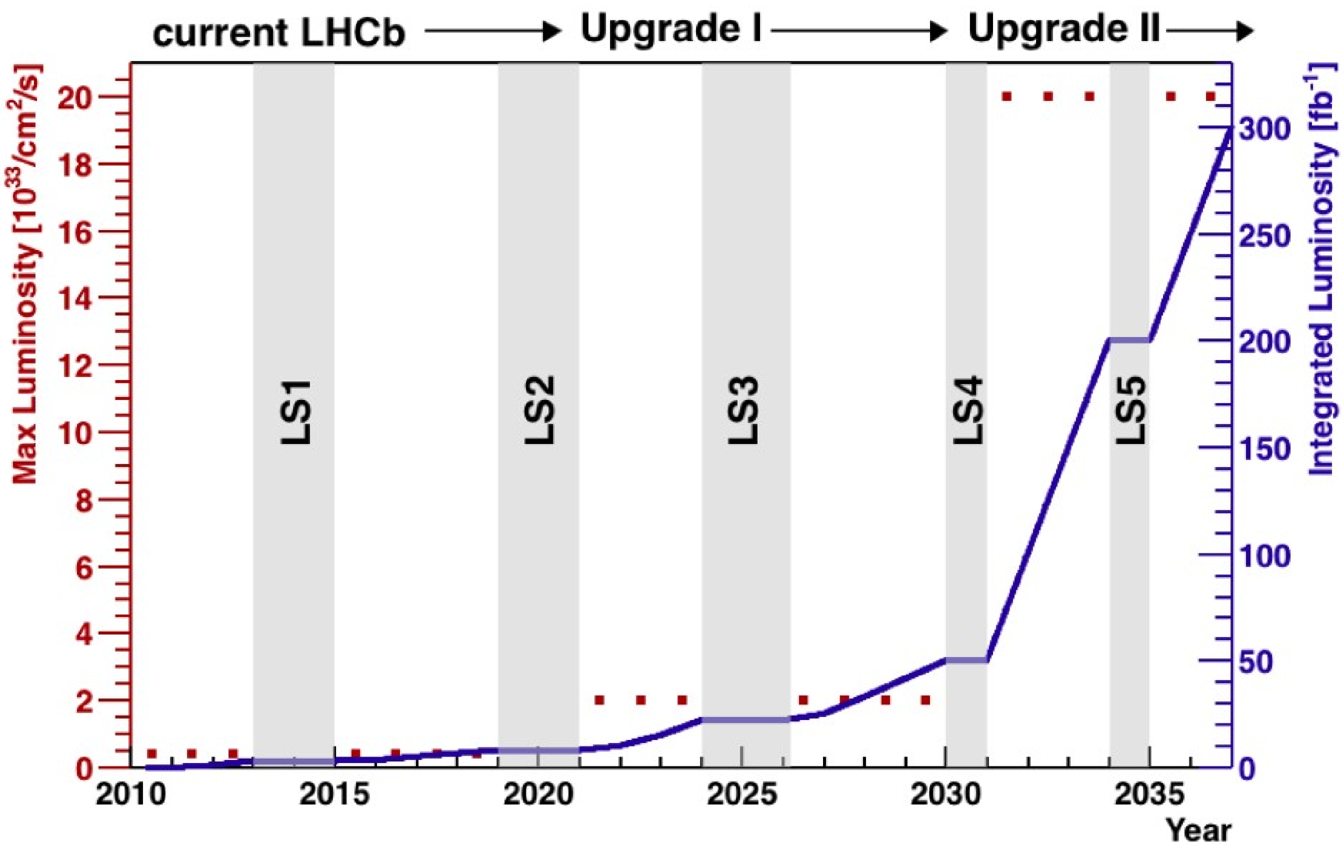
ICHEP 2020

30 July 2020

@UlrikEgede

What is LHCb Upgrade II?

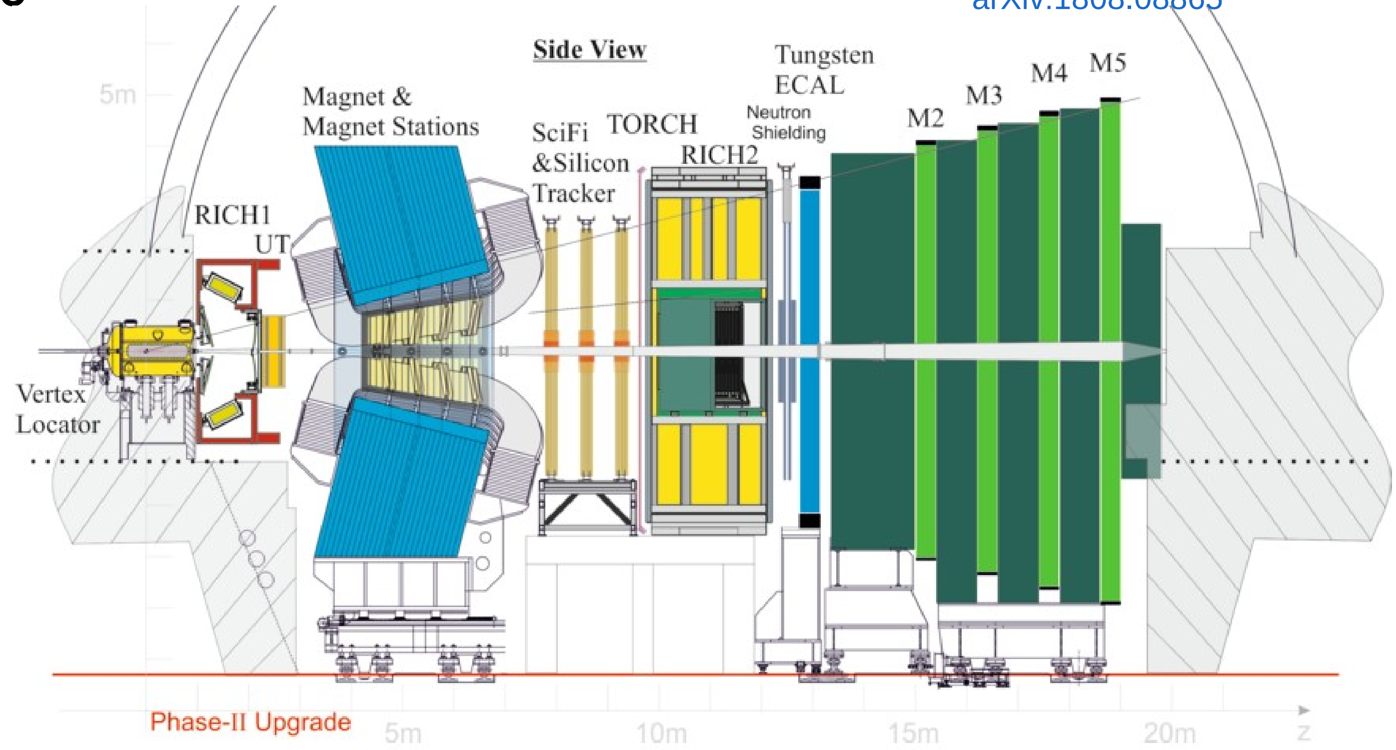
- Currently Upgrade I is under installation
- Upgrade II will come online in 2032
- 30 times current integrated luminosity



What is LHCb Upgrade II?

- Upgrade II will involve changes to nearly all parts of experiment
  - Vertexing
  - Hadron PID
  - Tracking
  - Calorimeter
  - Muon system

arXiv:1808.08865



MONASH University

LHCb Letter of Intent

- Was written in 1995
- Observation of *CP* violation in *B* mesons and B^0_s oscillations the main selling points
- *CP* angle γ would mainly be from time dependent analysis of $B^0_s \rightarrow D^+_s K^-$
- Charm physics only from $B \rightarrow Dl\nu$ decays
- $B^0_s \rightarrow \mu^+\mu^-$ only rare decay
- Λ_b never mentioned

LHCb Letter of Intent

- Was written in 1995
- Observation of *CP* violat… B mesons and B^0_s oscillations th… selling points
- *CP* angle γ would ma… from time dependent ana… of $B^0_s \to D^+_s K^-$
- Charm physics only from … decays
- $B^0_s \to \mu^+\mu^-$ only … decay
- Λ_b ne… mentioned

Done before start-up

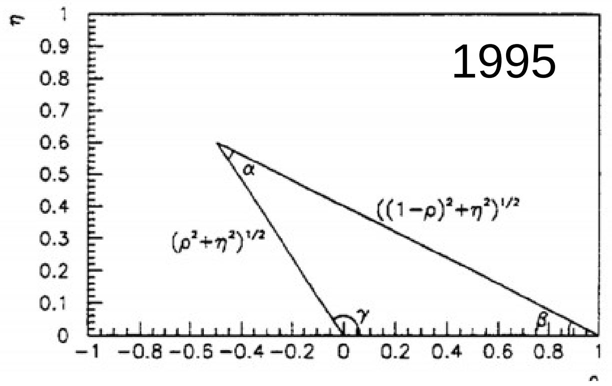
Different method

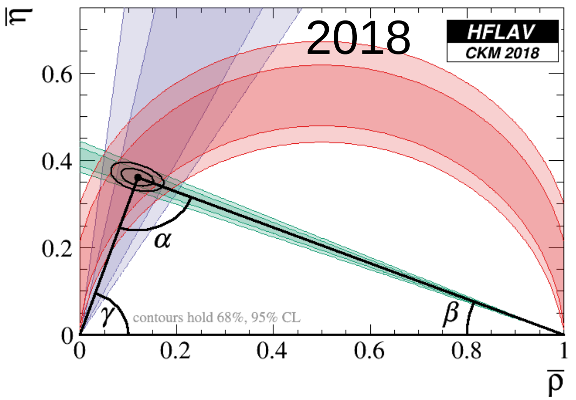
Prompt production

Vastly expanded

What does this mean for Upgrade II

- What we think is the main physics right now might not be what we use the detector for
- Discussing physics is good as a method for comparing and contrasting design options
- The variation in the physics we look for is much smaller
- Results from Belle II, ATLAS and CMS might change our goals dramatically

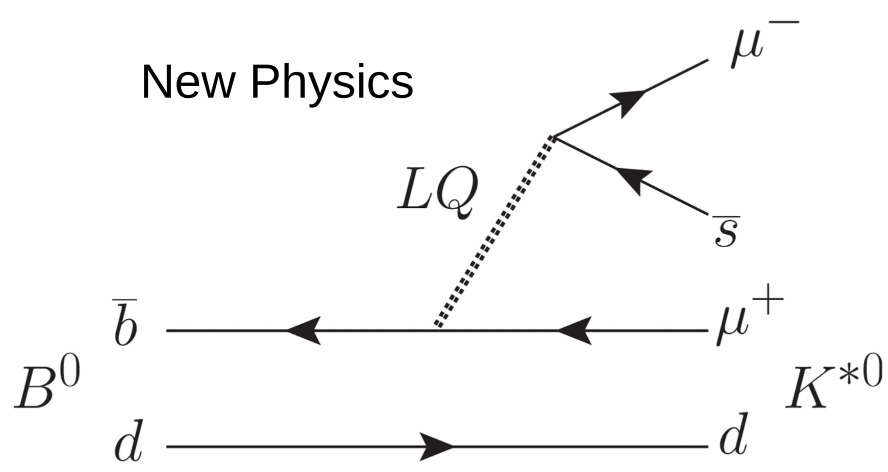




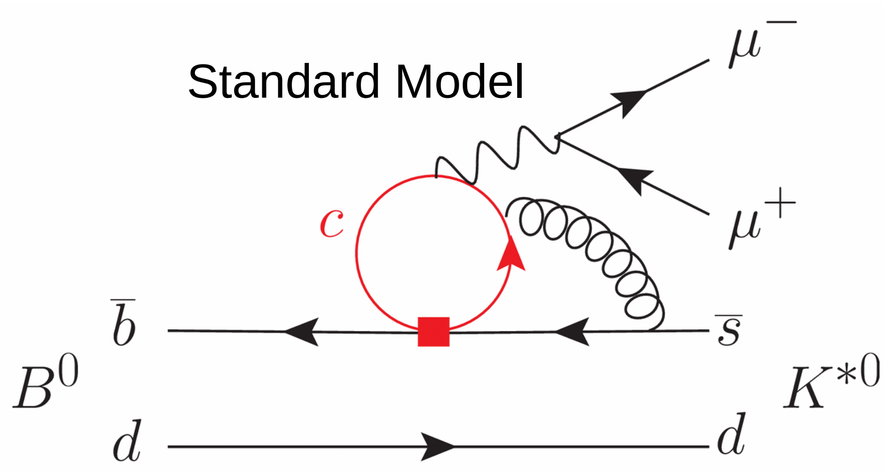
MONASH University

Rare decays

- Current Rare Decay anomalies in $b \rightarrow s\ell^+\ell^-$ decays can't tell us if we have new physics or if there are charm loop effects that we do not understand
- LHCb upgrade II will allow us to go **from**

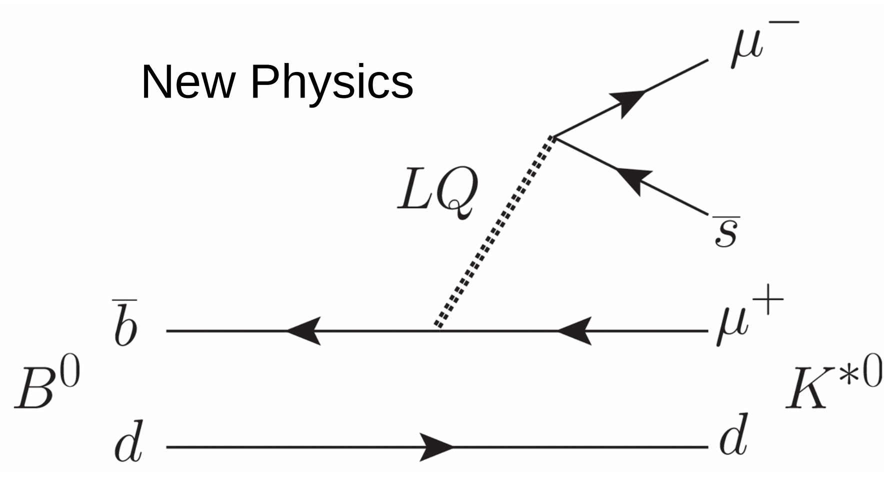


or

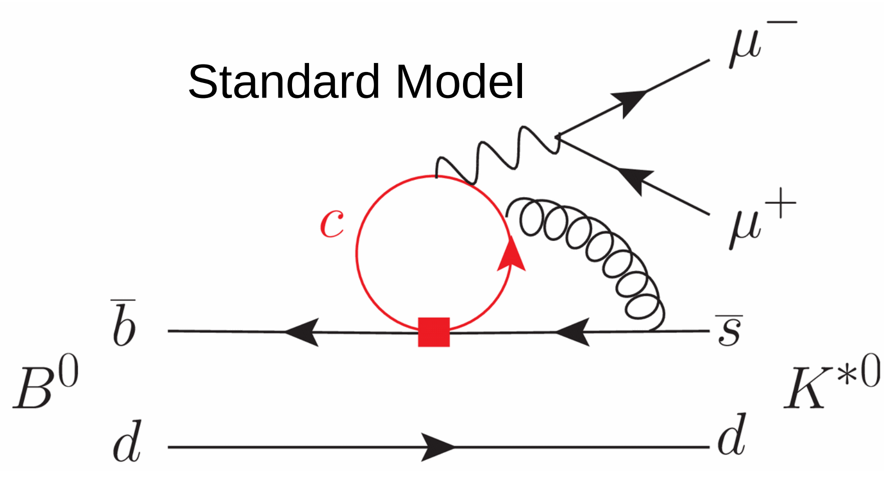


Rare decays

- Current Rare Decay anomalies in $b \rightarrow s\ell^+\ell^-$ decays can't tell us if we have new physics or if there are charm loop effects that we do not understand
- LHCb upgrade II will allow us to go **to**

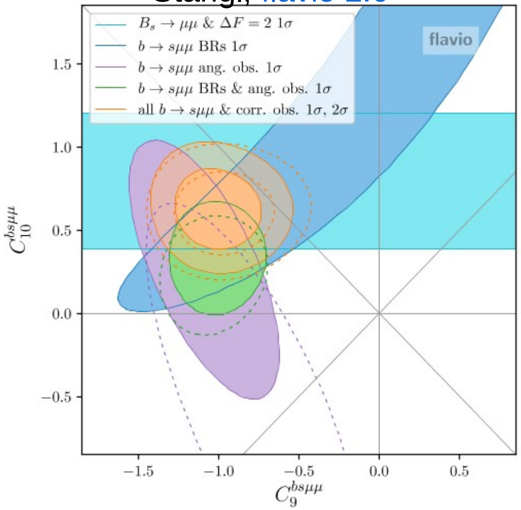


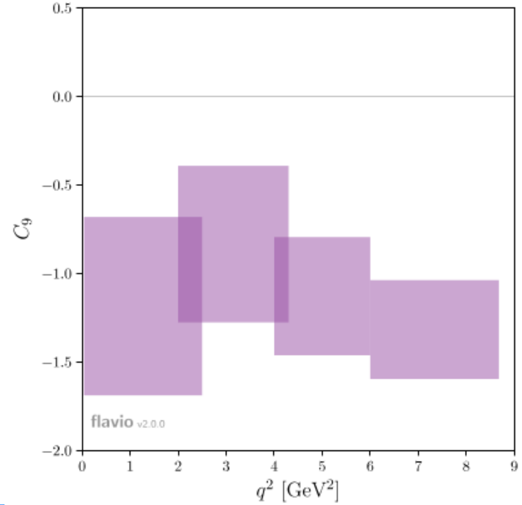
≠



Rare decays

Stangl, flavio 2.0





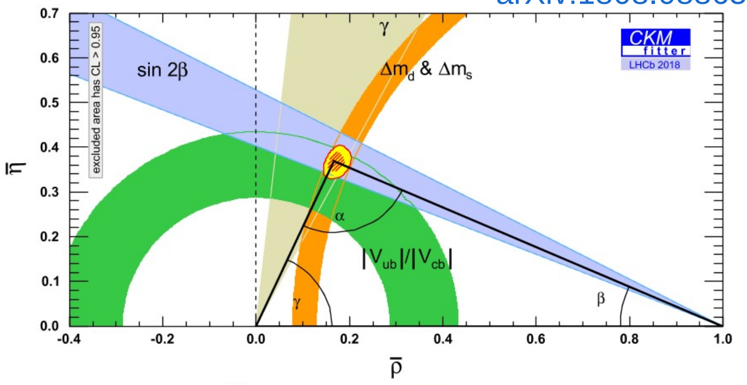
- The “same” NP has to fit all the measurements
- Results here from 2020 consistency analysis of
  - Different decays and observables to same Wilson coefficients
  - Measurement of same Wilson coefficient in different kinematic regions
- Currently just *proof-of-principle* but will be strong constraints with upgrade II when uncertainties go down by ~ factor 5

MONASH University

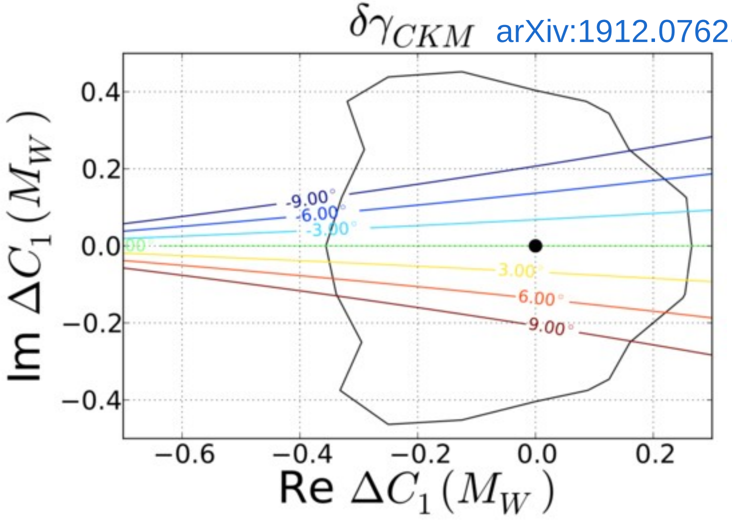
Constraining the Unitary Triangle

- The "common knowledge" that a measurement of γ is a SM measurement, even in the presence of NP is not at all given
- The Wilson coefficients C_1 and C_2 control the non-leptonic tree level decays
- In reality constraints are no better than constraints on C_9 and C_{10} from penguin decays …
- Need to constrain Unitary Triangle without any assumptions

arXiv:1808.08865

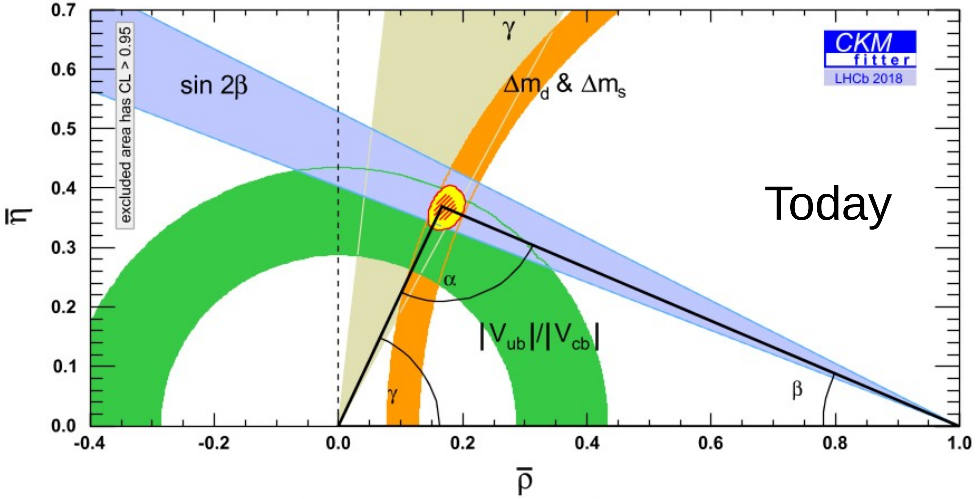


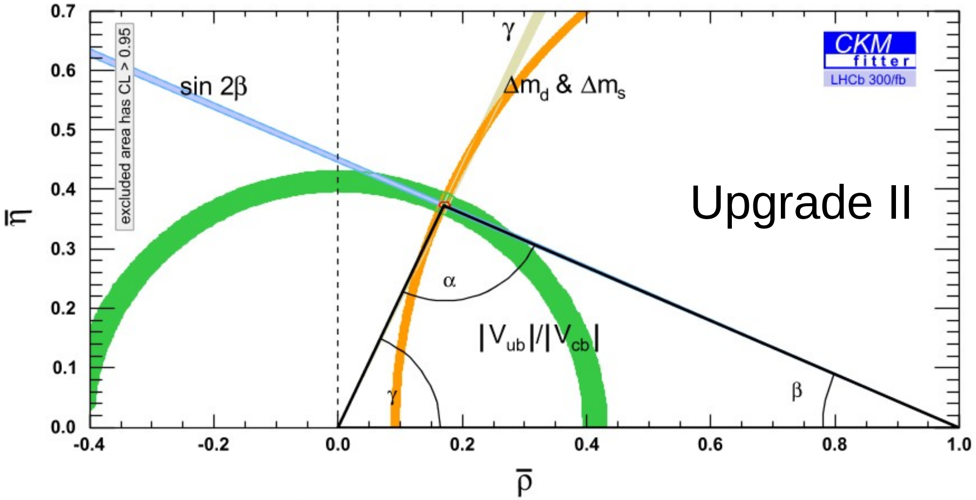
arXiv:1912.07621



Constraining the Unitary Triangle

- Unitary Triangle will impose ever stronger NP constraints



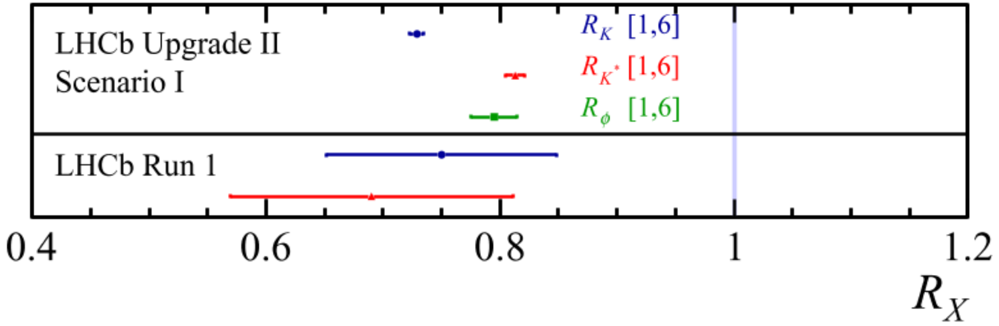


- Two independent measurements of triangle apex
  - ($\Delta m_d/\Delta m_s$, sin 2β) and (V_{ub} , γ)
  - Both pairs require upgrade II for statistics (sin 2β and γ) and time for theory improvements ($\Delta m_d/\Delta m_s$ and V_{ub})

Lepton flavour universality

- Looking for New Physics by comparing decays with muons and electrons a huge challenge
- Calorimeter has to keep current performance with much higher occupancy
- Benefit is in terms of measurements with almost no theoretical uncertainty

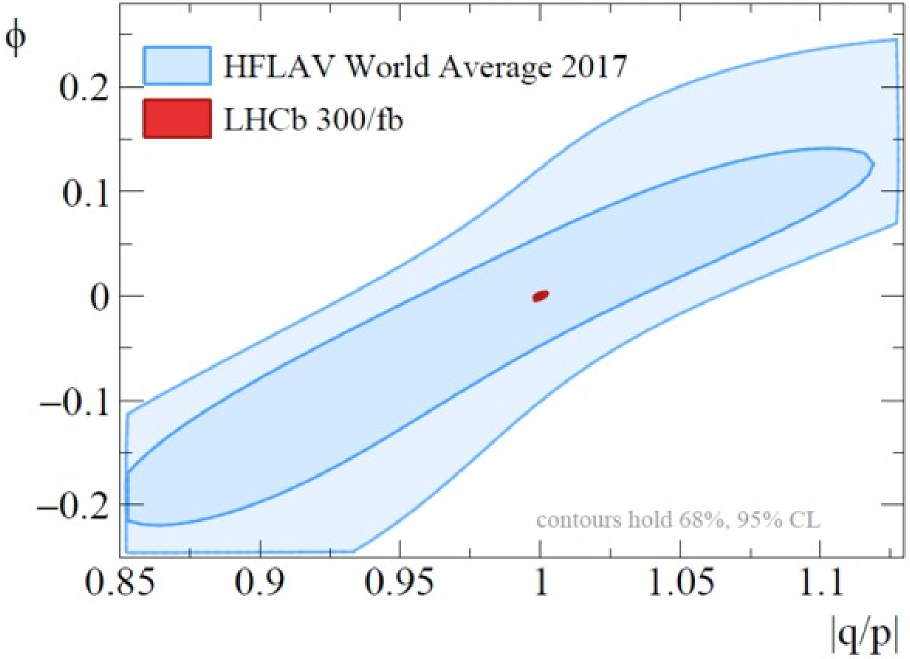
arXiv:1808.08865



Charm CP violation

- Time dependent CP violation in charm serves as an excellent null test for the SM
- Combined with excellent experimental reach this is very promising for upgrade II
- Side stations on magnets for low momentum tracking can improve flavour tagged sample by 20%

arXiv:1808.08865



Conclusion

- The physics case is strong for Upgrade II of LHCb
  - Refer to arXiv:1808:08865 for further details
  - A bit like the research plan for a PhD, it should be seen as a possible direction and not a rule book for what we will do
- The theoretical uncertainties are significant in many areas
  - A mixture of improvements in the theory as well as clever data driven cross checks will keep this under control
- LHCb upgrade II plan is ambitious
  - Compromising might mean that we never even realise what gains we can make

Performance table

arXiv:1808.08865

Table 10.1: Summary of prospects for future measurements of selected flavour observables for LHCb, Belle II and Phase-II ATLAS and CMS. The projected LHCb sensitivities take no account of potential detector improvements, apart from in the trigger. The Belle-II sensitivities are taken from Ref. [608].

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
R_K $(1 < q^2 < 6\,\text{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007	–
R_{K^*} $(1 < q^2 < 6\,\text{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008	–
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05	–
CKM tests					
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [609]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi \phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [610]
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	39 mrad	–	11 mrad	Under study [611]
a_{sl}^s	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%	–
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	34%	–	10%	21% [612]
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**					
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002	–
$R(J/\psi)$	0.24 [220]	0.071	–	0.02	–
Charm					
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [613]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	–
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	–
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	–
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}	–

112