B-hadrons: CPV and semileptonic decays

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Tu Dortmund University

LHCP, Paris, June 10, 2021

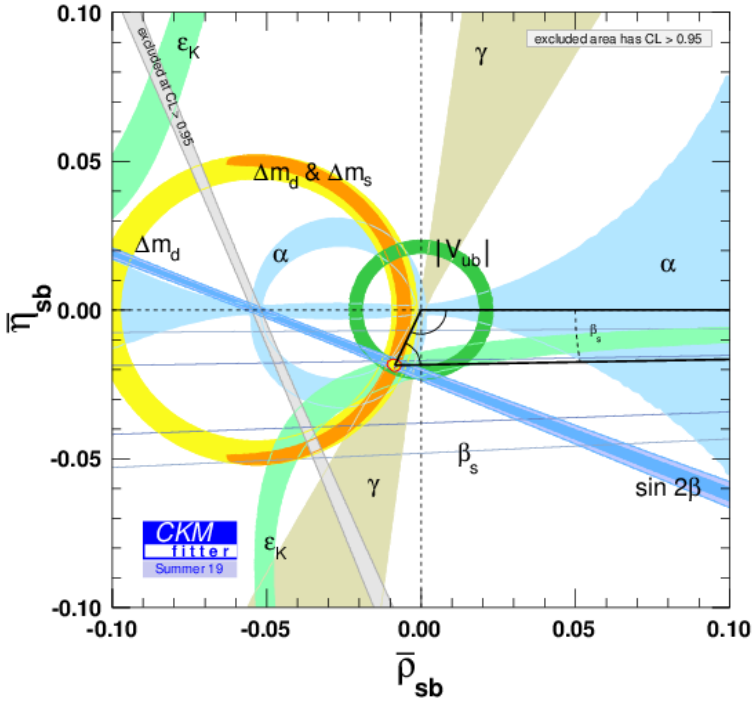
Outline

- **Introduction**
- **CPV in B decays @ LHC**
  - ϕ_{s}
  - γ
  - α
  - $+\ \Delta m_s$
- **Semileptonic Beauty decays @ LHC**
  - $|V_{\mathrm{ub}}|/|V_{\mathrm{cb}}|$

What & Why

- CKM matrix: connects the "weak" and the "mass" states of the quarks
  - Complex and unitary $\rightarrow$ 6 Unitary triangles
  - $V_{\rm ud}V^*_{\rm ub} + V_{\rm td}V^*_{\rm tb} + V_{\rm cd}V^*_{\rm cb} + 1 = 0$

$$V_{\rm CKM} \sim \begin{pmatrix} V_{\rm ud} & V_{\rm us} & |V_{\rm ub}|, \gamma \\ V_{\rm cd} & V_{\rm cs} & |V_{\rm cb}| \\ \Delta m_d, \beta & \Delta m_s, \beta_s & |V_{\rm tb}| \end{pmatrix}$$



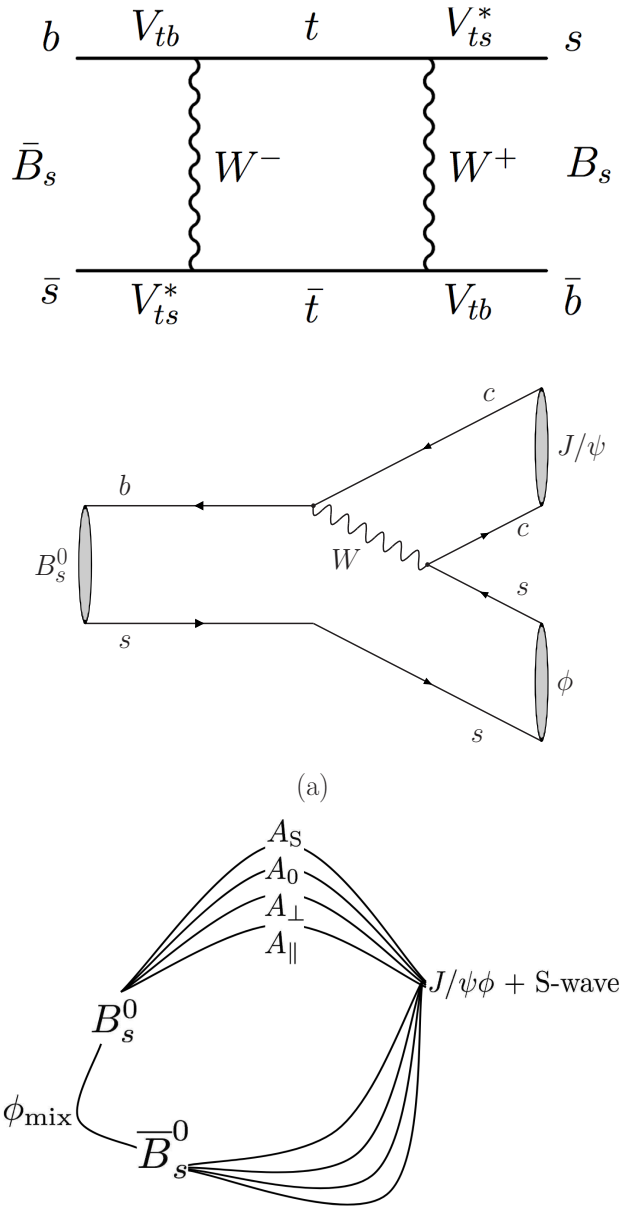
- Beauty decays: excellent terrain to test CKM picture
  - CP violation: CKM complex phase
  - Mixing and Semileptonic rates $\rightarrow$ CKM's amplitudes
    - $+$ Laboratory to study LFU anomalies (Alessandra's Talk on Tuesday)
- Tensions are a clear sign for New Physics

CPV in B decays

ϕ_s with $B_s^0 \to J/\psi\phi$ decays: theory

- CP-violating phase ϕ_s: interference between decay and the mixing of B_s^0 mesons
  - Well-known within SM: $\phi_s^{SM} \simeq -2\beta_s = -36.89^{+0.70}_{-0.81}$ rad [CKMfitter]
  - New Physics contributes to B_s^0 mixing loop
- Golden mode $B_s^0 \to J/\psi\phi$:
  - Large statistics ✓, dominated by trees ✓, access to a wealth of information($\Delta\Gamma_s, \Gamma_s, \lambda, \Delta m_s$, ...)✓
  - Have to control penguin diagrams ✗
  - P→VV decay: admixture of CP odd/even states → angular analysis is needed ✗
  - + S-wave ✗

$$\frac{d\Gamma}{dt\ d\Omega} = \sum_{k=1}^{10} f^k(t, \phi_s, \Delta\Gamma_s, ...) g^k(\theta, \psi, \phi)$$



ϕ_s with $B_s^0 \to J/\psi\phi$ decays: experiment

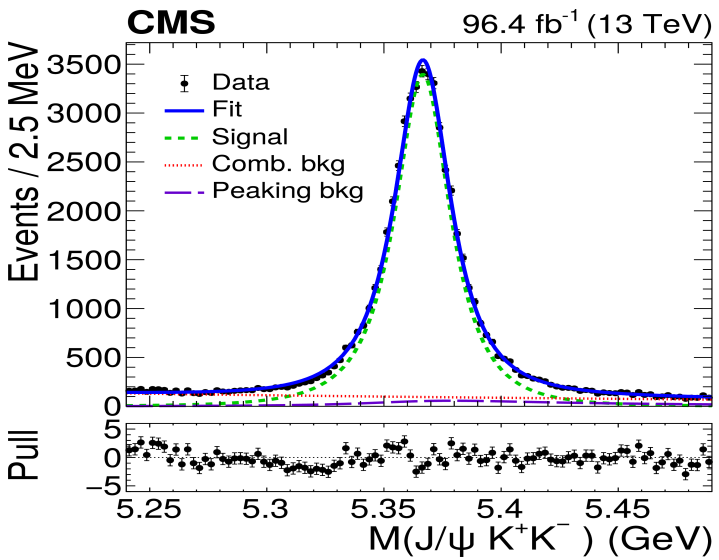
- Statistical sensitivity to ϕ_s:

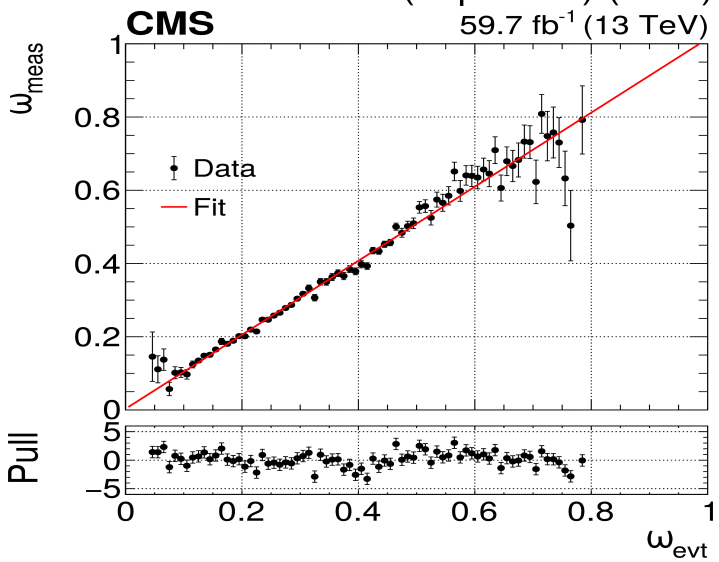
$$\propto \sqrt{\frac{S}{S+B}} \sqrt{\varepsilon_{\rm tag}(1-2\omega)^2}\, e^{-\sigma_t^2 \Delta m_s^2}$$

- Signal purity (trigger constrains versus offline selection)
- Flavour-tagging to infer the flavour at production (smart algorithms versus challenging LHC environment)
- Excellent decay time resolution to solve fast B_s^0 oscillation (vertexing/tracking systems)
  - More details in Vitalii's talk today
- +Systematics: control decay-time and angular efficiencies (detector geometry and analysis cuts)

ϕ_s with $B_s^0 \to J/\psi\phi$ decays @ CMS [Phys. Lett. B 816(2021)136188]

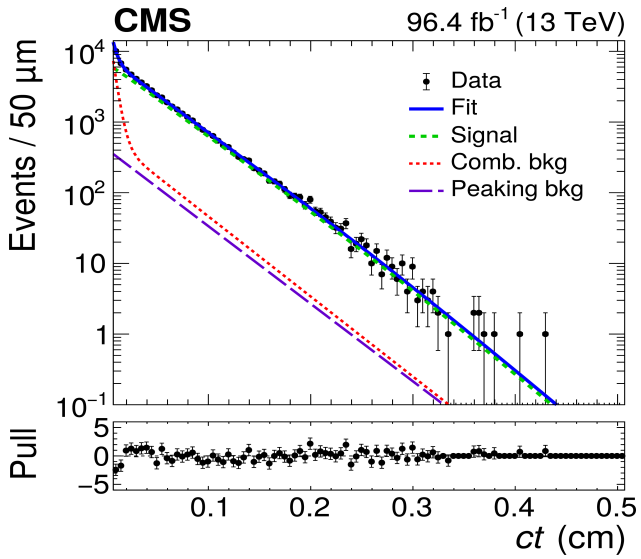
- 2017 + 2018 CMS data = 96.4 fb^{-1}
- Unique trigger: $J/\psi(\mu\mu)$ for the signal + additional tagging muon from $b \to \mu X$
  - $\to$ Low signal yield($\sim$ 50k) but high tagging power
- Flavour tagging using only Opposite-side μ: use novel Deep NN to discriminate against hadronic fakes
  - Another DNN to estimate mistag probability per event, calibrated on data using $B^+ \to J/\psi K^+$ decays
  - Calibrated Tagging power: $(10.5 \pm 0.1)\%$
- Silicon tracking system: $\sigma_t \sim 50 - 70\,\mathrm{fs}$

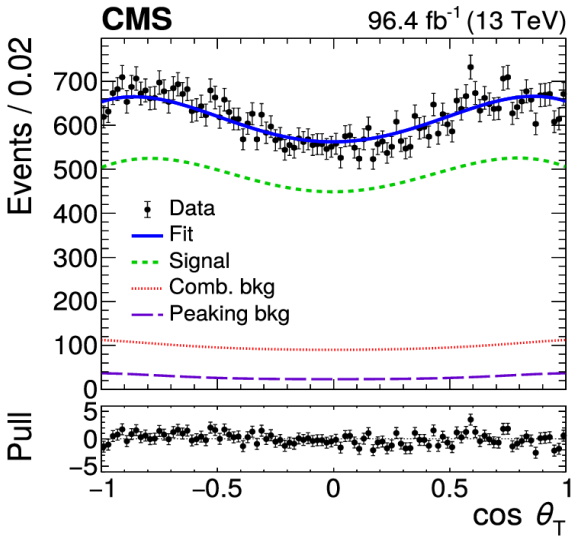


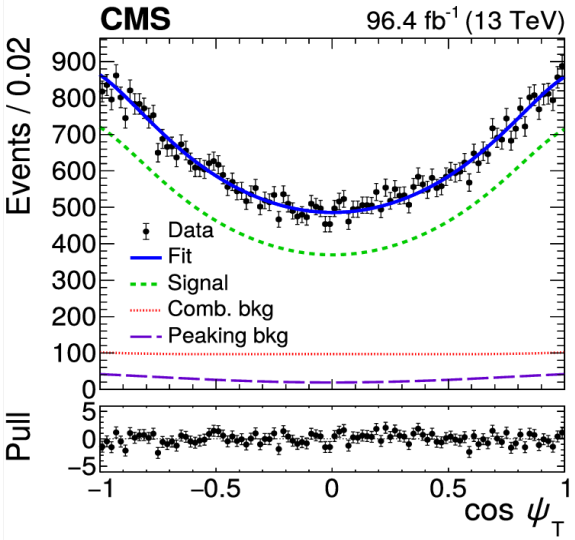


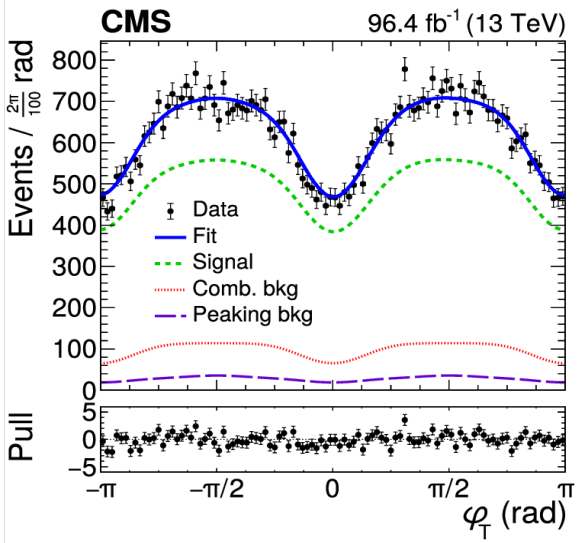
ϕ_s with $B_s^0 \to J/\psi\phi$ decays @ CMS [Phys. Lett. B 816(2021)136188]

- 6-D(3 angles, decay time, mass, mistag probability and decay time error) likelihood fit
- Decay time and angular observables efficiencies: detector geometry and selection
- $\phi_s = -0.011 \pm 0.050(\text{stat.}) \pm 0.010(\text{sys.})$
- Systematic dominated by angular efficiency and model bias





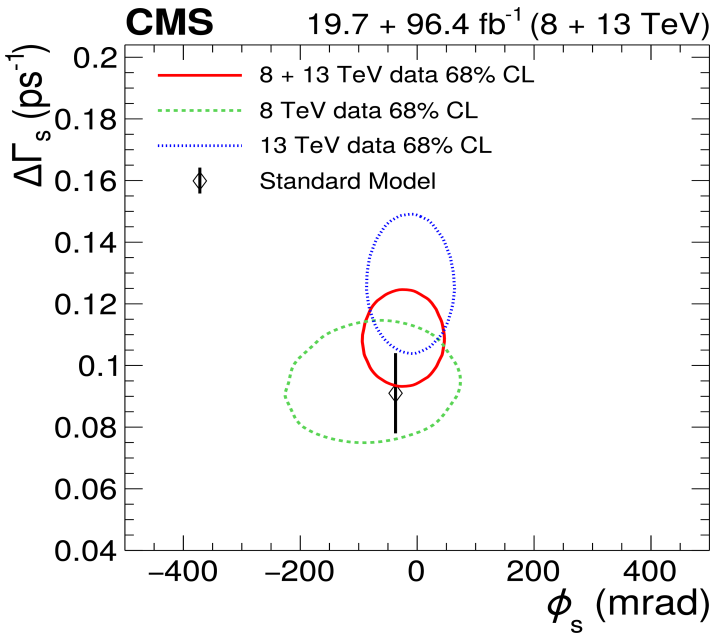




ϕ_s with $B_s^0 \to J/\psi\phi$ decays @ CMS [Phys. Lett. B 816(2021)136188]

- Combine results from current and Run 1 (@$\sqrt{s} = 8\,\mathrm{TeV}$) analyses
- Systematic sources assumed uncorrelated
- Results are in agreement with each other and agree with SM predictions

$$\phi_s = -0.021 \pm 0.045 \text{ rad}\ ,\ \Delta\Gamma_s = 0.1032 \pm 0.0106\,\mathrm{ps}^{-1}$$

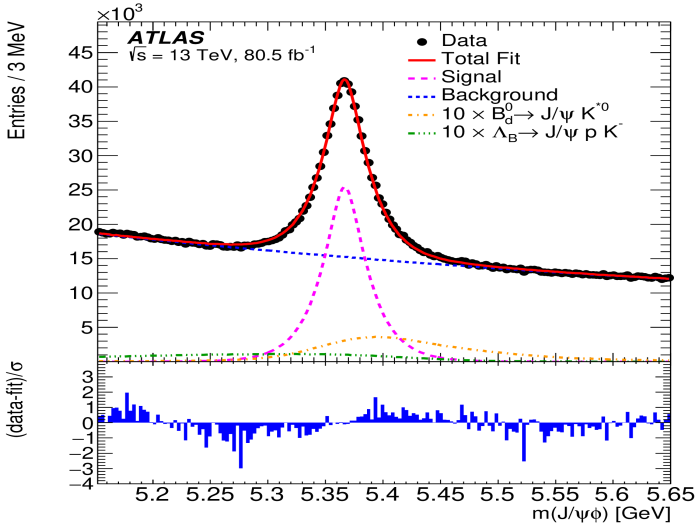


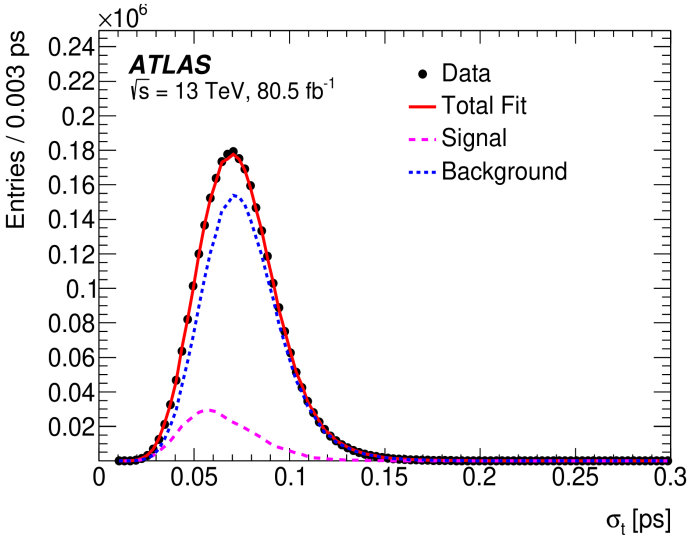
- Full Run 2 analysis is ongoing, possibility to add additional triggers/taggers

More in Adam's talk yesterday

ϕ_s with $B_s^0 \to J/\psi\phi$ decays @ ATLAS Eur. Phys. J. C 81 (2021) 342

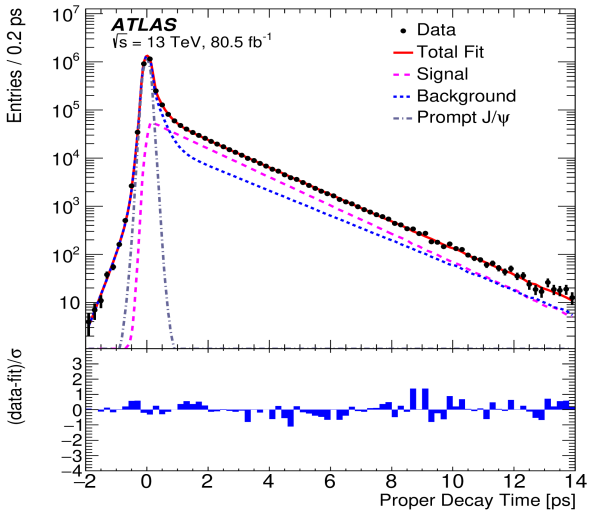
- 2015 – 2017 ATLAS data: $80.5\,\mathrm{fb}^{-1}$@$\sqrt{13}\,\mathrm{TeV}$
- Trigger: two μ candidates making $J/\psi(\mu\mu)$ mass ($\Delta m \sim 50\,\mathrm{MeV}$)
  - "Low" p_T cut, no decay time/impact parameter cuts
  - High signal yield ($\sim$ 45k)
- Flavour tagging using Opposite-side leptons (μ, e) or b-jet-charge tagging
  - Calibrated Tagging power: $(1.75 \pm 0.01)\%$
- Silicon pixels and strips tracker: $\sigma_t \sim 65\,\mathrm{fs}$
- Decay time and angular observables efficiencies: detector geometry and selection

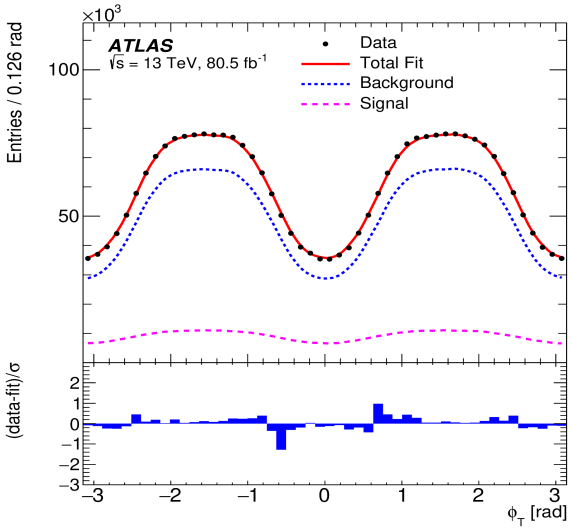


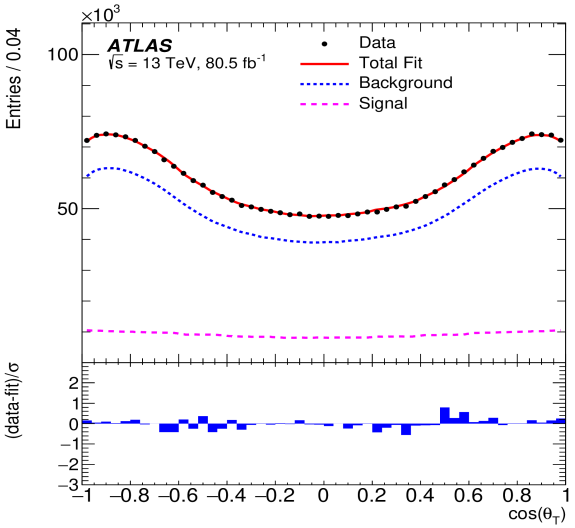


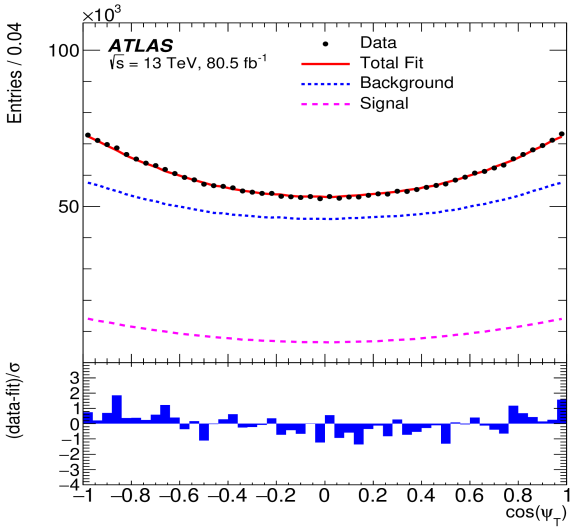
ϕ_s with $B_s^0 \to J/\psi\phi$ decays @ ATLAS Eur. Phys. J. C 81 (2021) 342

- 6-D (3 angles, decay time, mass, mistag probability and decay time error) likelihood fit to extract ϕ_s
- $\phi_s = -0.081 \pm 0.041(\text{stat.}) \pm 0.022(\text{sys.})$
- Systematic dominated by calibration of Flavour tagging(B^+ versus B_s^0 MC size, pile-up dependence)





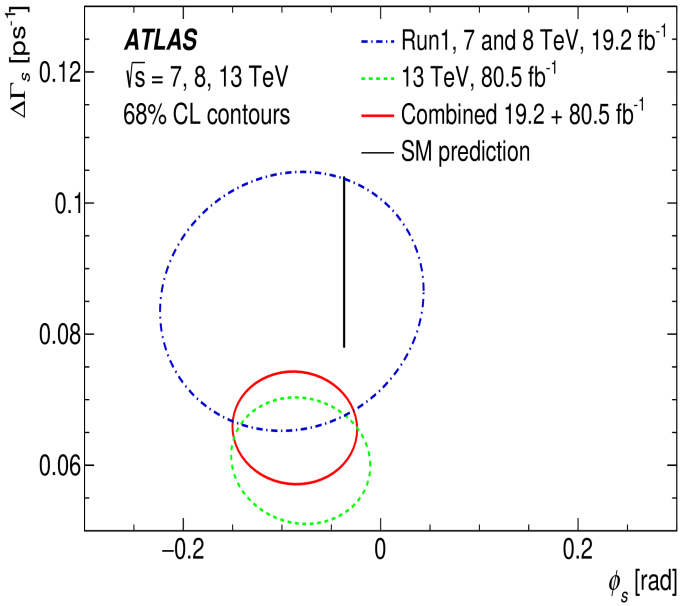




ϕ_s with $B_s^0 \to J/\psi\phi$ decays @ ATLAS Eur. Phys. J. C 81 (2021) 342

- Combine results from current and previous Run 1 analyses @$\sqrt{s} = 8, 7\,\mathrm{TeV}$
- Correlation matrix and correlation of systematic sources are included in the combination
- Results are in agreement with each other and agree with SM predictions

$$\phi_s = -0.087 \pm 0.042 \text{ rad}\ ,\ \Delta\Gamma_s = 0.0641 \pm 0.0049\,\mathrm{ps}^{-1}$$

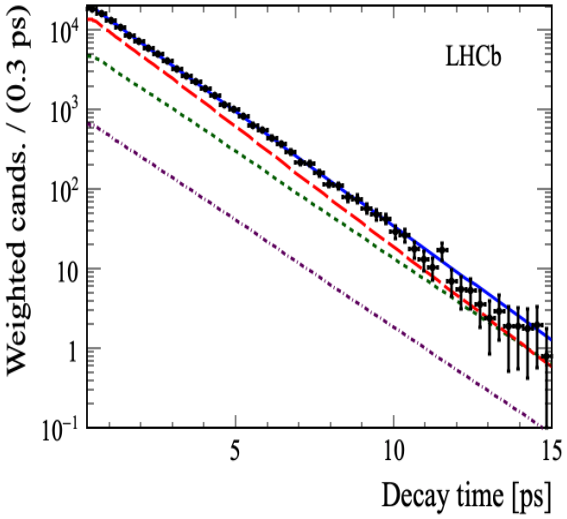


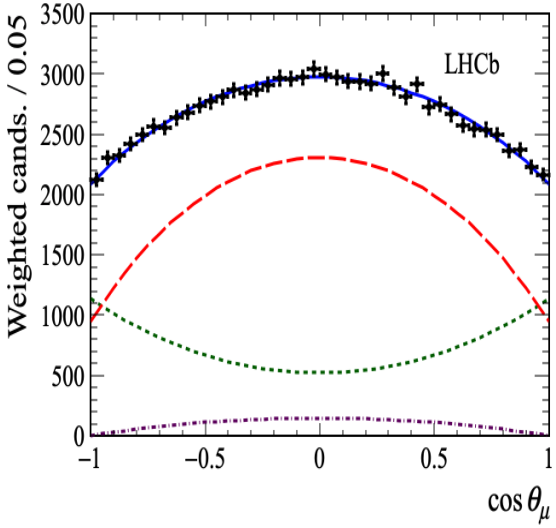
- Full Run 2 analysis is ongoing: additional $60\,\mathrm{fb}^{-1}$

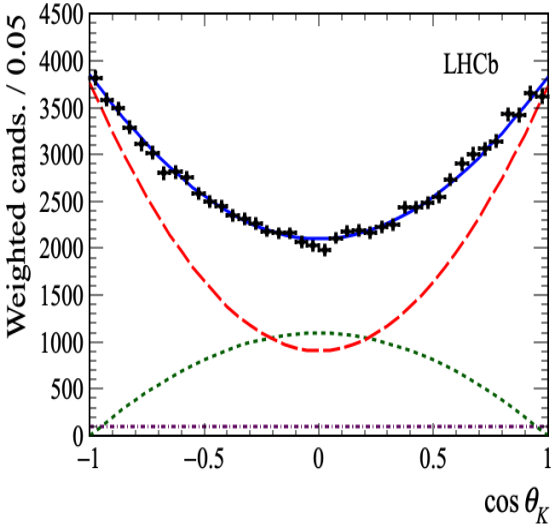
More in Adam's talk yesterday

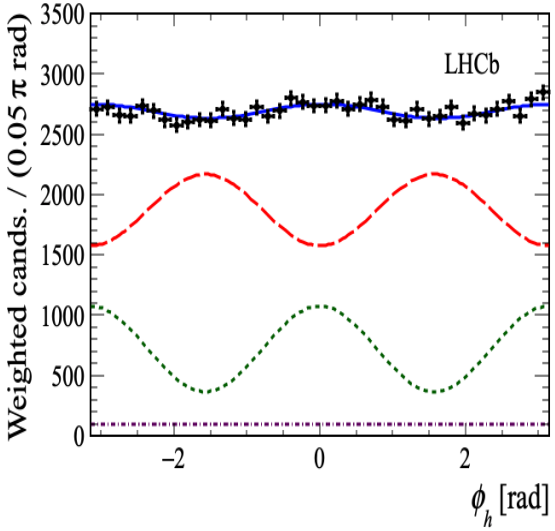
ϕ_s with $B_s^0 \to J/\psi\phi$ decays @ LHCb [Eur. Phys. J. C79 (2019) 706]

- Most recent analysis in $B_s^0 \to J/\psi\phi$ using 2015-2016 data: $4.9\,\mathrm{fb}^{-1}$
  - $\sigma_t \sim 45.5\,\mathrm{fs}$, Tagging power: $(4.73 \pm 0.34)\%$
  - $\phi_s = -0.083 \pm 0.041(\mathrm{stat.}) \pm 0.006(\mathrm{sys.})$
- Combined with Run 1: $\phi_s = -0.080 \pm 0.032$





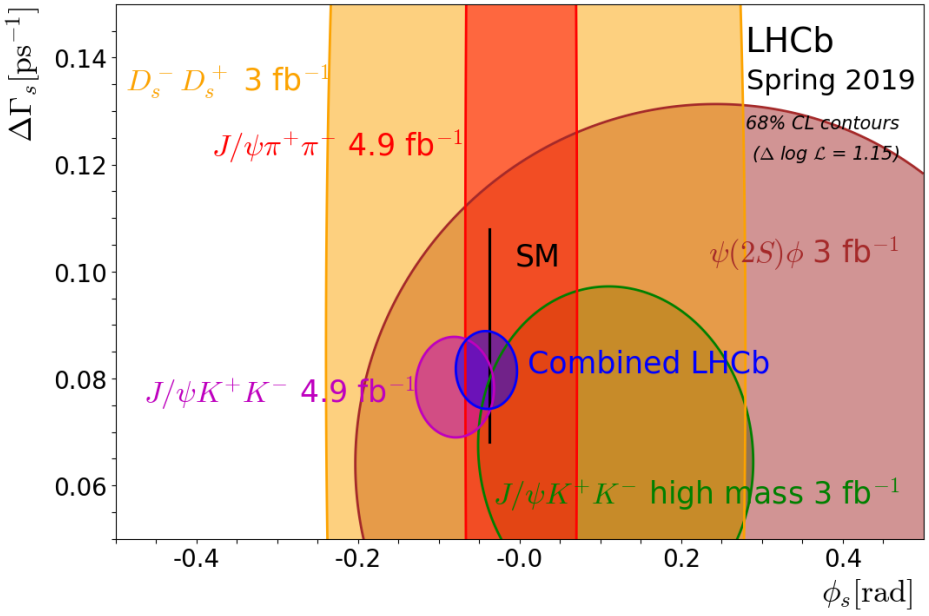




ϕ_s @ LHCb [Eur. Phys. J. C79 (2019) 706]

- Measurements done at LHCb with many different channels:
  - $B_s^0 \to D_s^- D_s^+$(Run 1), $B_s^0 \to \psi(2S)\phi$(Run 1), $B_s^0 \to J/\psi KK$(high mass, Run 1), $B_s^0 \to J/\psi \pi^+\pi^-$(Run 1+2)
- Combination of all measurements from LHCb:

$$\phi_s = -0.041 \pm 0.025 \text{ rad}\ ,\ \Delta\Gamma_s = 0.0813 \pm 0.0048\,\mathrm{ps}^{-1}$$

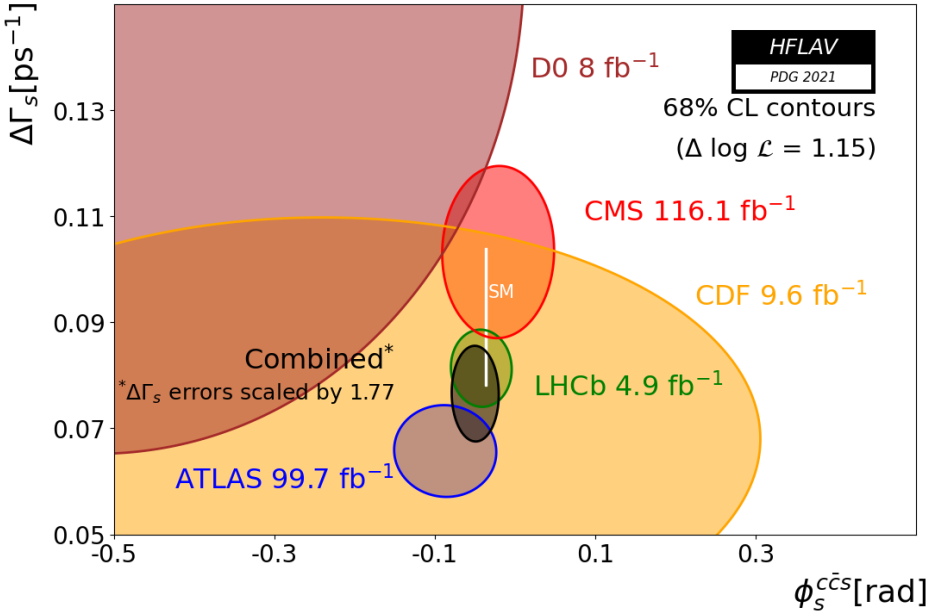


- Full Run 2 analysis is ongoing: additional $\sim 4\,\mathrm{fb}^{-1}$

ϕ_s @ world average from [HFLAV]

- HFLAV performs world average of all available measurements to date

$$\phi_s = -0.041 \pm 0.025 \text{ rad}\ ,\ \Delta\Gamma_s = 0.082 \pm 0.005\,\mathrm{ps}^{-1}$$

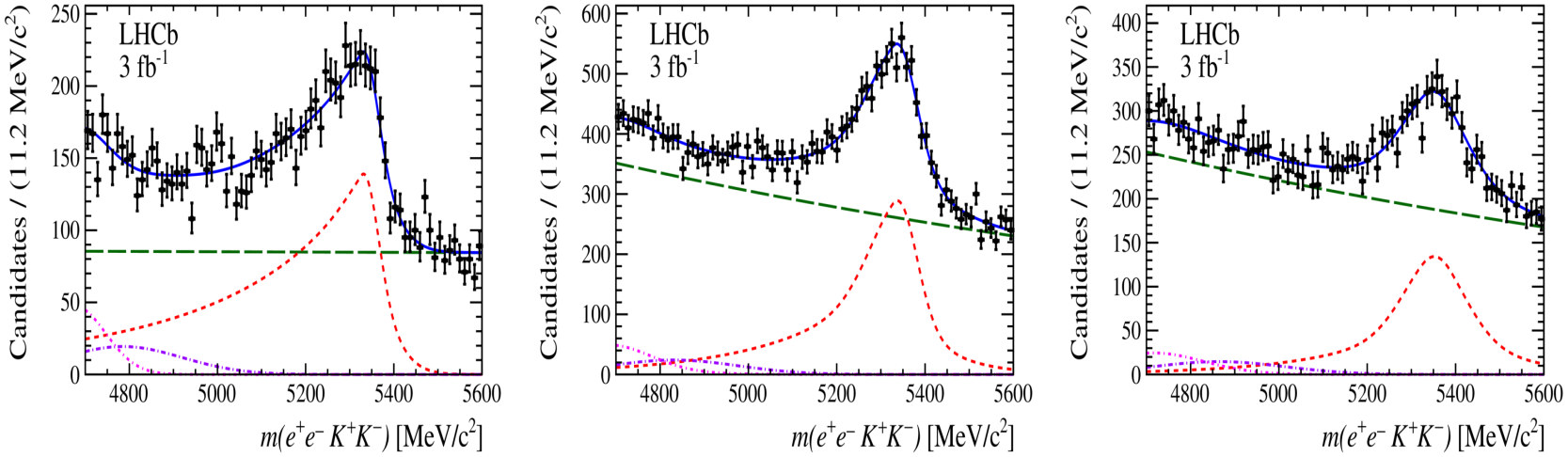


- Combination is statistically dominated
- Consistent with SM and consistent with no CP violation in the interference
- Different "full Run 2" analyses are ongoing $\rightarrow$ expect to improve ϕ_s soon

Bonus: ϕ_s @ LHCb with $B_s^0 \to J/\psi(ee)\phi$ [arXiv:2105.14738, submitted to EPJC]

- Use full Run 1 data at LHCb $\sim$ 13k signal events
- Bremsstrahlung:
  - Degrades $J/\psi(ee)$, B_s^0 mass resolution and trigger efficiency
  - Corrections to e^+e^- pair $\to$ complicate analysis (systematics)
- First time dependent angular analysis with an electron final state

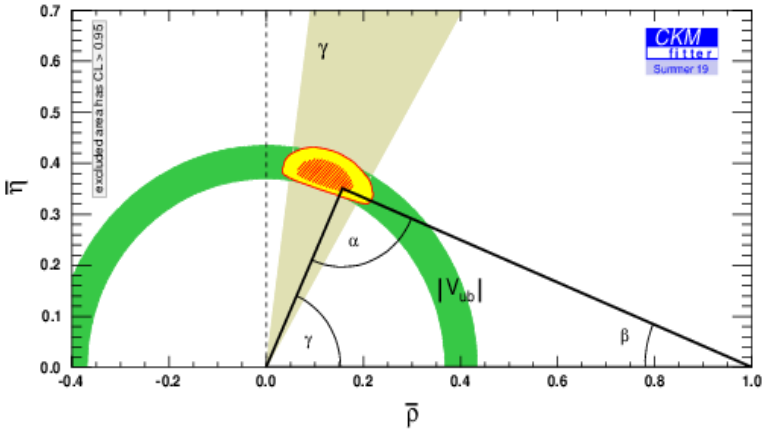
  $\phi_s = 0.00 \pm 0.28 \pm 0.05$ rad , $\Delta\Gamma_s = 0.115 \pm 0.045 \pm 0.011\,\mathrm{ps}^{-1}$
- Result not yet included in HFLAV world average

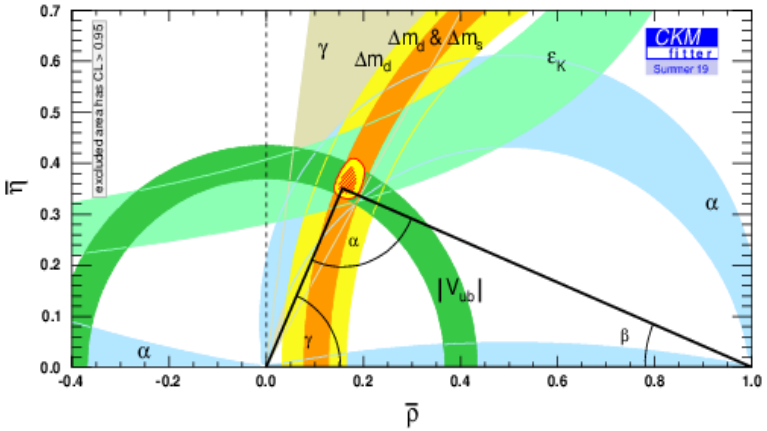


No correction | one correction | both corrected

γ

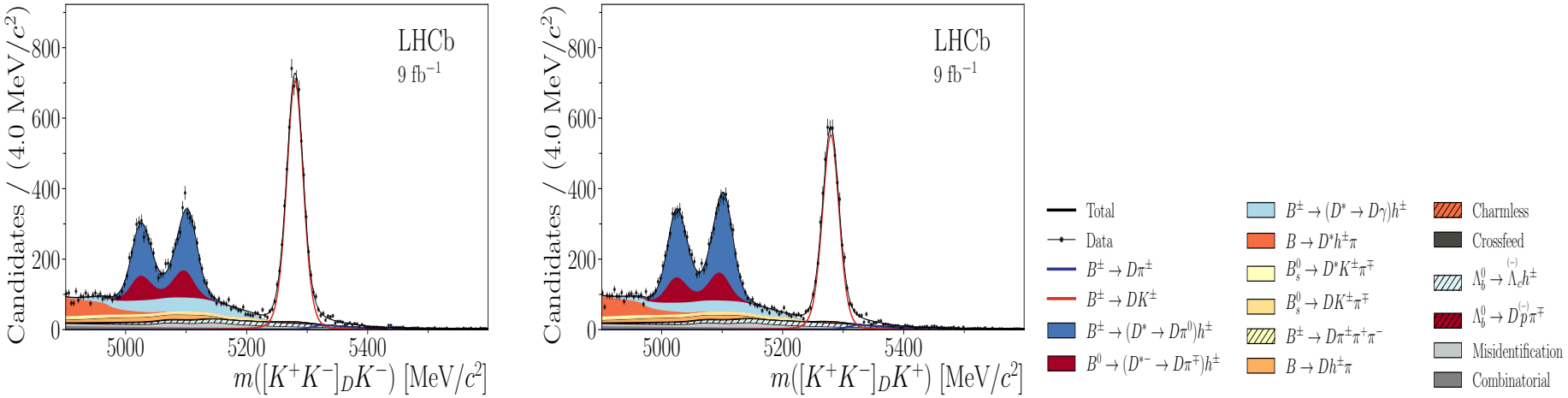
- $\gamma \propto \arg(V_{\mathrm{ub}})$, least known among CKM angles
- Measured via interference $\mathrm{b} \to \mathrm{u}$ and $\mathrm{b} \to \mathrm{c}$ transitions
- γ-tree $= (72.1 \pm 5.4)^{\circ}$ theoretically clean, indirect $\gamma = (65.7^{+1.0}_{-2.5})^{\circ}$
  - Discrepancy would indicate New Physics
- Can be accessed through neutral B mesons but golden modes are B^{+} decays





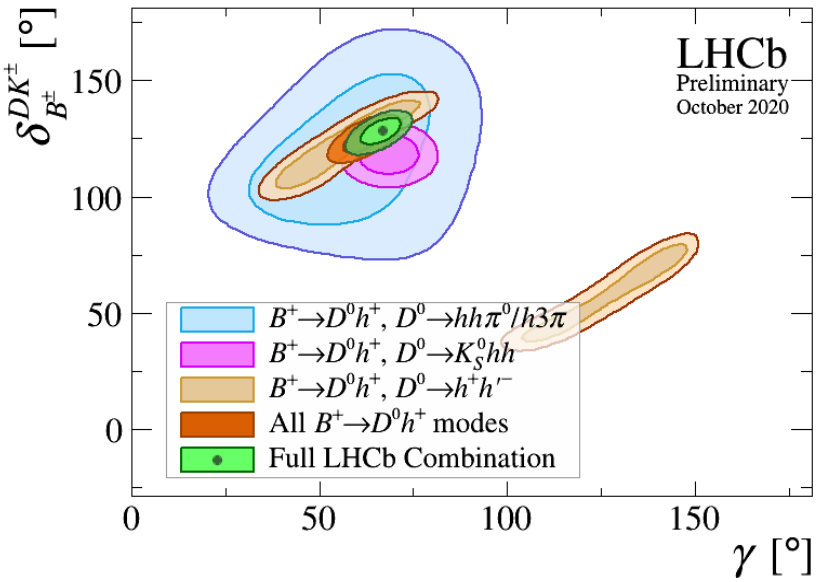
γ with $B^+ \to D^{(*)}h^+$ decays [JHEP 04 (2021) 081]

- γ through Tree-level decays $B^+ \to D^{(*)}h^+$
- Use $D^0 \to K^+K^-, \pi^+\pi^-, K^\pm\pi^\mp + \pi^0$
- Accessed through time-integrated asymmetries between B^+, B^- yields
- Simultaneous fit to 16 different decays using Full Run 2 data set



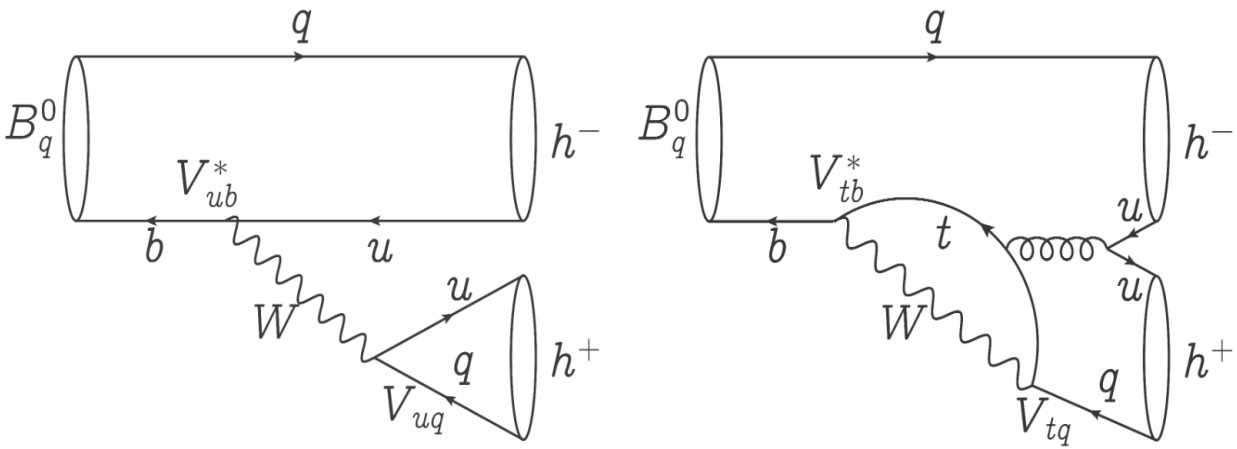
γ with $B^+ \to D^{(*)}h^+$ decays [JHEP 04 (2021) 081]

- Full LHCb combination with previous measurements $\to \gamma = (67 \pm 4)^\circ$
  - Most precise determination to date
  - Compatible with indirect determination of $\gamma (= 65.7^{+1.0}_{-2.5})^\circ$
- More details in Alessandro's Talk yesterday



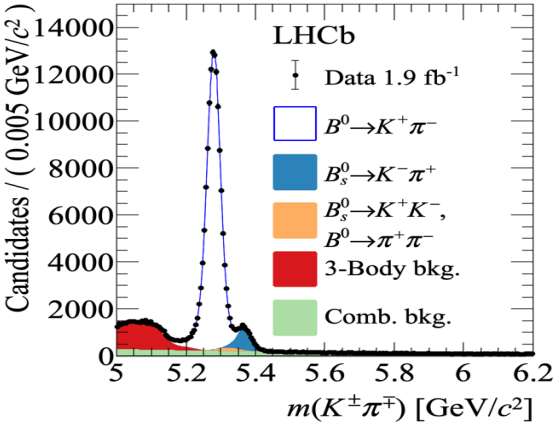
α with $B^0_{(s)} \to h^+h^-$ [JHEP 03(2021)075]

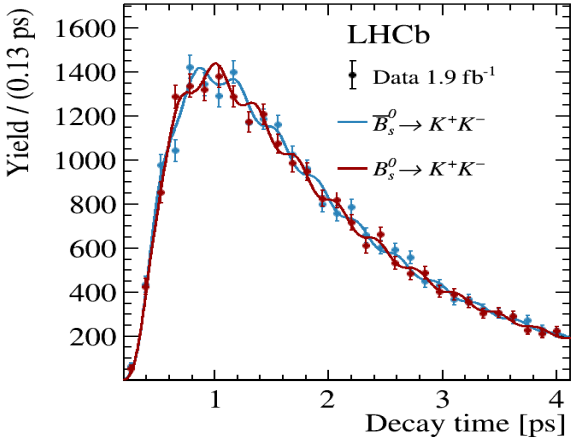
- Decay of neutral B to charmless final states, CP violation in both decay and the interference
- Time dependent CP asymmetries in $B^0_s \to K^+K^-$ and $B^0 \to \pi^+\pi^-$
  - Constrained to α, γ, β_s and direct CP violation
  - Requires: Flavour tagging(4.5% – 5.1%) and decay time resolution($\sim 44\,\mathrm{fs}$)
- $+$ Time-integrated CP in $B^0 \to K^+\pi^-$, $B^0_s \to K^-\pi^+$
  - Access decay-specific CP asymmetry
  - Requires excellent understanding of fine experimental/physics asymmetries(production, detection, PID, etc ...)

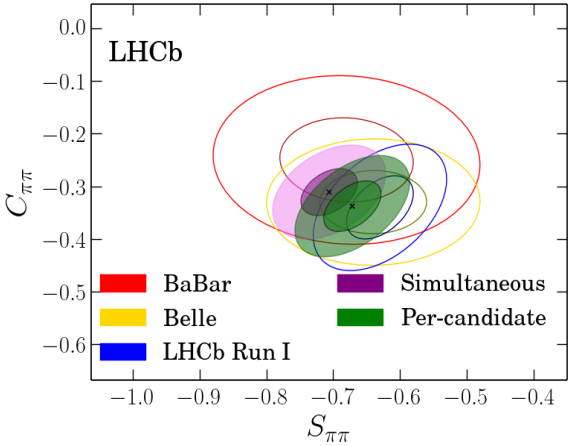


α with $B^0_{(s)} \to h^+h^-$ [JHEP 03(2021)075]

- First observation of time-dependent CP violation in B^0_s decays using $1.9\,\mathrm{fb}^{-1}$ of Run 2 data
- $S_{\pi\pi} = -0.706 \pm 0.042 \pm 0.013,\ S_{KK} = +0.123 \pm 0.034 \pm 0.015$
- $A_{CP}^{B^0 \to K^+\pi^-} = -0.082 \pm 0.003 \pm 0.003,\ A_{CP}^{B^0_s \to K^-\pi^+} = +0.236 \pm 0.013 \pm 0.011$

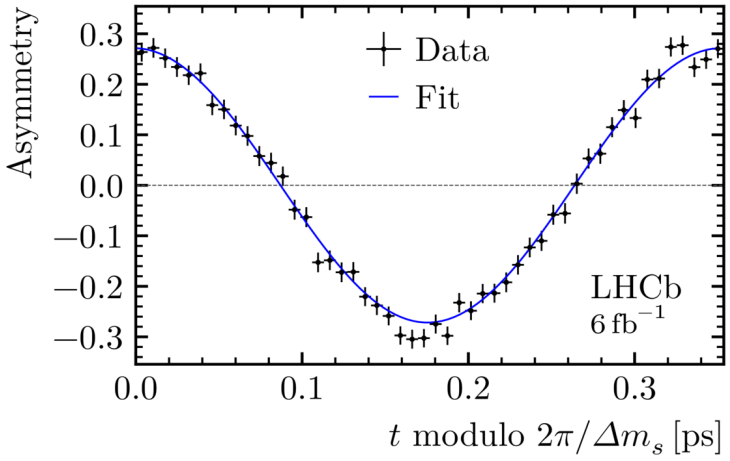


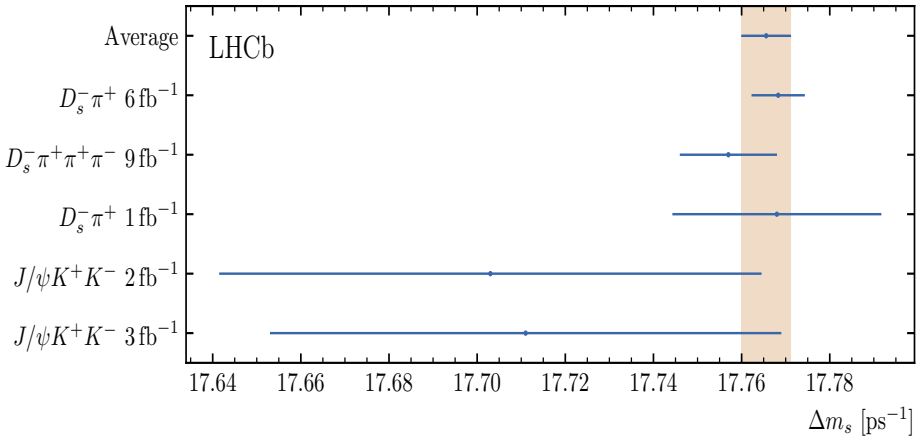




Δm_s with $\mathrm{B_s^0} \to \mathrm{D_s^-}\pi^+$ Full Run 2 [arXiv:2104.04421, submitted to Nature Physics]

- Δm_s oscillation frequency for $\mathrm{B_s^0}$: constrain V_{ts}, input for $\mathrm{B_s^0}$ CPV measurements
- Time-dependent analysis in $\mathrm{B_s^0} \to \mathrm{D_s^-}\pi^+$
  - Requires Flavour tagging($\sim$ 6%) and excellent decay time resolution
  - Full Run 2 data 6 fb^{-1}: $\sim$ 400k events $\rightarrow$ need to control systematics
- Combination of all LHCb measurements: $\Delta m_s = 17.7656 \pm 0.0057\,\mathrm{ps}^{-1}$
- Most precise measurement to date

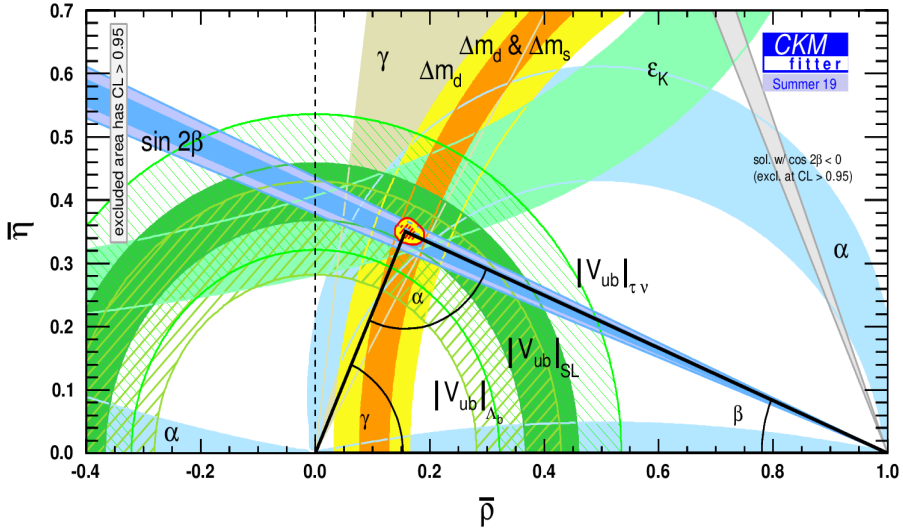


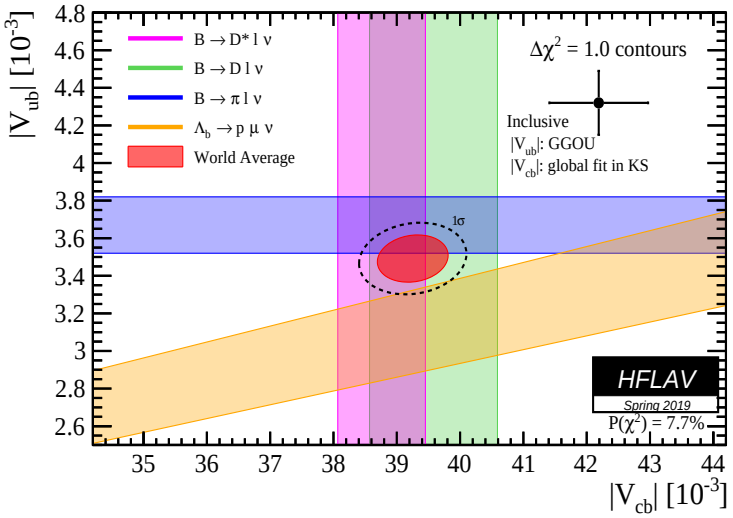


Semileptonic Beauty decays

$|V_{\rm ub}|/|V_{\rm cb}|$: introduction

- $|V_{\rm ub}|, |V_{\rm cb}|$: coupling strength between $\rm b$ and $\rm u$ ($\rm c$) quarks
- Complementary experimental approaches: inclusive versus exclusive
- CKMfitter: uses exclusive + inclusive averages of $|V_{\rm ub}|$ & $|V_{\rm cb}|$ and adds $|V_{\rm ub}|/|V_{\rm cb}|$ from LHCb separately
- HFLAV: Combine all exclusive measurements from LHCb, BaBar and Belle:
  $|V_{\rm ub}| = (3.49 \pm 0.13) \times 10^{-3}$
  $|V_{\rm cb}| = (39.25 \pm 0.56) \times 10^{-3}$
- Inclusive & exclusive measurements are in disagreement ($\sim 3\sigma$)





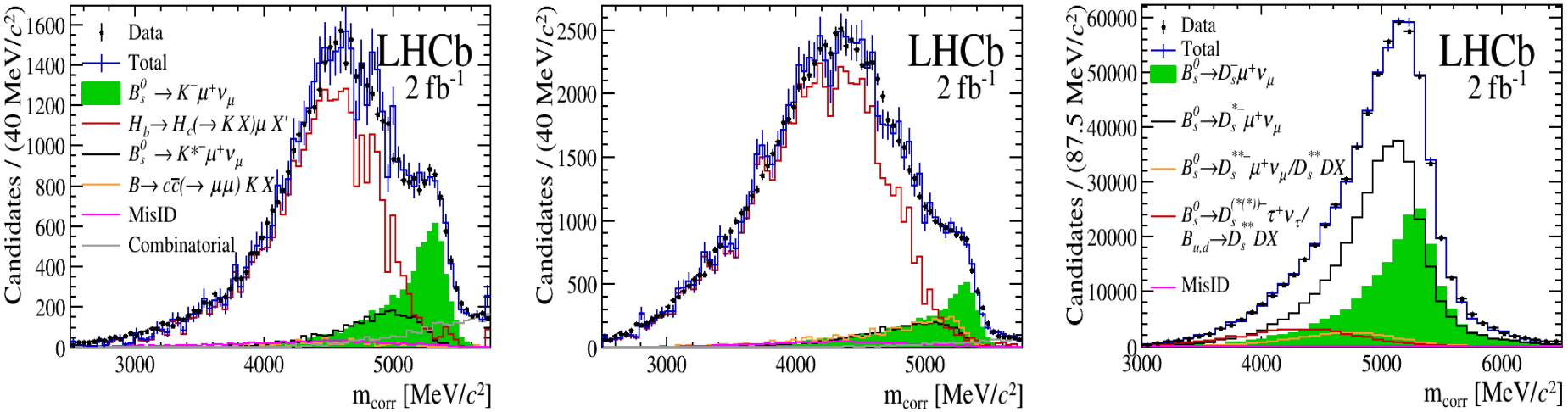
$|V_{ub}|/|V_{cb}|$ in $B_s^0 \to K^- \mu^+ \nu_\mu$ [Phys. Rev. Lett. 126 (2021) 081804]

- Measure of BRs ratio of $B_s^0 \to K^- \mu^+ \nu_\mu$ & $B_s^0 \to D_s^- \mu^+ \nu_\mu$

$$\underbrace{\frac{\mathcal{B}(B_s^0 \to K^- \mu^+ \nu_\mu)}{\mathcal{B}(B_s^0 \to D_s^- \mu^+ \nu_\mu)}}_{\textbf{experiment}} = \frac{|V_{ub}|^2}{|V_{cb}|^2} \times \underbrace{\frac{d\Gamma(B_s^0 \to K^- \mu^+ \nu_\mu)/dq^2}{d\Gamma(B_s^0 \to D_s^- \mu^+ \nu_\mu)/dq^2}}_{\textbf{theory input}}$$

- Theory input is sensitive to q^2: Complementary predictions from LQCD and LCSR
- Using $2\,\mathrm{fb}^{-1}$ of LHCb data: $N_{B_s^0 \to D_s^- \mu^+ \nu_\mu} \sim 200$k, $N_{B_s^0 \to K^- \mu^+ \nu_\mu (\mathrm{low})} \sim 13$k

Low q^2 High q^2

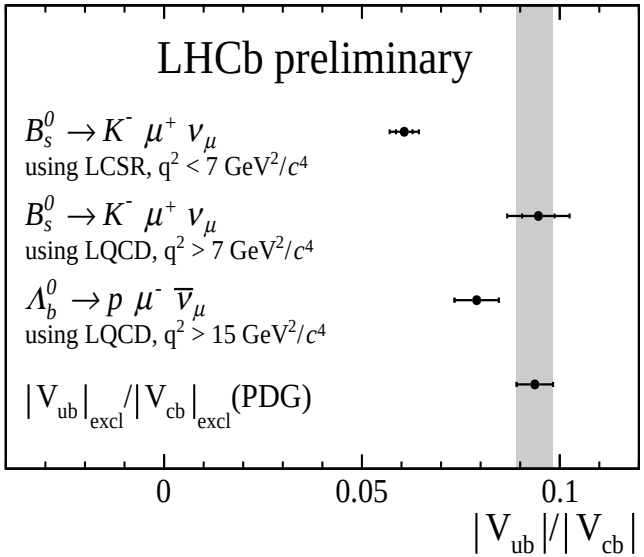


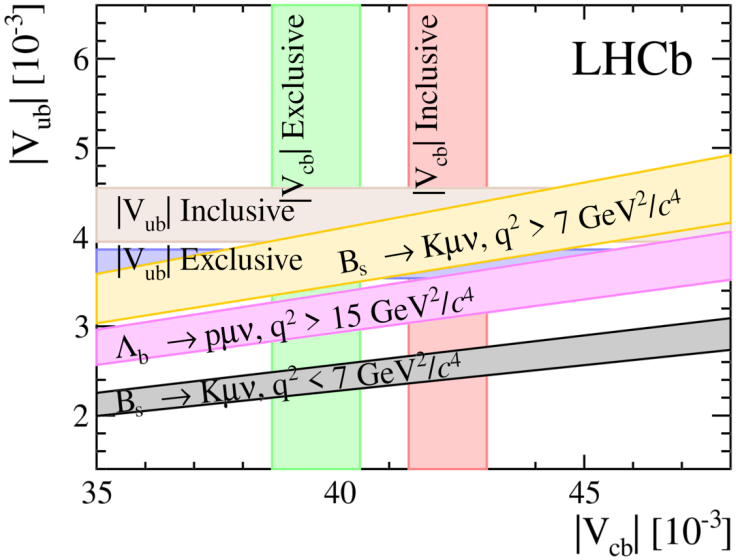
Results: $\mathcal{B}(\mathrm{B_s^0} \to \mathrm{K}^- \mu^+ \nu_\mu)$ [Phys. Rev. Lett. 126 (2021) 081804]

$$\mathcal{B}(\mathrm{B_s^0} \to \mathrm{K}^- \mu^+ \nu_\mu) = (1.06 \pm 0.05(\mathrm{stat}) \pm 0.04(\mathrm{syst}) \pm 0.06(\mathrm{ext}) \pm 0.04(\mathrm{FF})) \times 10^{-4}$$

$$|V_{\mathrm{ub}}|/|V_{\mathrm{cb}}|(\mathrm{low}) = 0.0607 \pm 0.0015(\mathrm{stat}) \pm 0.0013(\mathrm{syst}) \pm 0.0008(\mathrm{D_s}) \pm 0.0030(\mathrm{FF})$$

$$|V_{\mathrm{ub}}|/|V_{\mathrm{cb}}|(\mathrm{high}) = 0.0946 \pm 0.0030(\mathrm{stat})^{+0.0024}_{-0.0025}(\mathrm{syst}) \pm 0.0013(\mathrm{D_s}) \pm 0.0068(\mathrm{FF})$$





- First observation of the golden channel: $\mathrm{B_s^0} \to \mathrm{K}^- \mu^+ \nu_\mu$
- Discrepancy $|V_{\mathrm{ub}}|/|V_{\mathrm{cb}}|(\mathrm{low})$: clash in theory predictions $\to$ solved when measuring full q^2 shape of $\mathrm{B_s^0} \to \mathrm{K}^- \mu^+ \nu_\mu$

Conclusion

- Most precise measurements of ϕ_s using data from LHC experiments
  - Work ongoing from LHCb, ATLAS & CMS to update with the rest of Run 2 data
- Most precise determination of γ angle using a combination of LHCb measurements with charged B^+ decays
  - γ from direct versus indirect measurements are compatible
- First observation of CP violation in $B_s^0 \to K^+K^-$ decays from LHCb
- Most precise measurement of Δm_s in $B_s^0 \to D_s^- \pi^+$ using LHCb's full Run 2 data
- First measurement of $|V_{ub}|/|V_{cb}|$ in $B_s^0 \to K^- \mu^+ \nu_\mu$ decays
  - Great potential to reduce theory uncertainties but first solve theory disagreement using LHCb data
- Run 3 & beyond: constrain CKM picture to unprecedented level with CPV & semileptonics observables Francesca' talk on Monday

Backups

ϕ_s with $B_s^0 \to J/\psi\phi$ decays @ ATLAS: Run 2 results

Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s [rad]	−0.081	0.041	0.022
$\Delta\Gamma_s$ [ps^{-1}]	0.0607	0.0047	0.0043
Γ_s [ps^{-1}]	0.6687	0.0015	0.0022
$\lvert A_\parallel(0)\rvert^2$	0.2213	0.0019	0.0023
$\lvert A_0(0)\rvert^2$	0.5131	0.0013	0.0038
$\lvert A_S(0)\rvert^2$	0.0321	0.0033	0.0046
$\delta_\perp - \delta_S$ [rad]	−0.25	0.05	0.04
Solution (a)			
$\delta_\perp$ [rad]	3.12	0.11	0.06
$\delta_\parallel$ [rad]	3.35	0.05	0.09
Solution (b)			
$\delta_\perp$ [rad]	2.91	0.11	0.06
$\delta_\parallel$ [rad]	2.94	0.05	0.09

ϕ_s with $B_s^0 \to J/\psi\phi$ decays @ CMS: Run 2 results

Parameter	Fit value	Stat. uncer.	Syst. uncer.
ϕ_s [mrad]	-11	± 50	± 10
$\Delta\Gamma_s$ [ps^{-1}]	0.114	± 0.014	± 0.007
Δm_s [$\hbar$ ps^{-1}]	17.51	$^{+0.10}_{-0.09}$	± 0.03
$\lvert\lambda\rvert$	0.972	± 0.026	± 0.008
Γ_s [ps^{-1}]	0.6531	± 0.0042	± 0.0024
$\lvert A_0\rvert^2$	0.5350	± 0.0047	± 0.0048
$\lvert A_\perp\rvert^2$	0.2337	± 0.0063	± 0.0044
$\lvert A_S\rvert^2$	0.022	$^{+0.008}_{-0.007}$	± 0.016
$\delta_\parallel$ [rad]	3.18	± 0.12	± 0.03
$\delta_\perp$ [rad]	2.77	± 0.16	± 0.04
$\delta_{S\perp}$ [rad]	0.221	$^{+0.083}_{-0.070}$	± 0.048

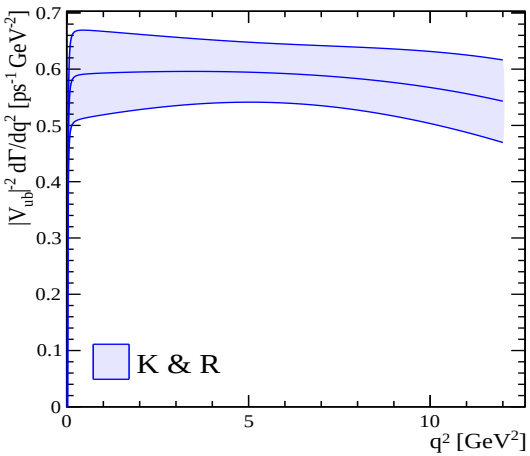
ϕ_s with $B_s^0 \to J/\psi\phi$ decays @ LHCb: Run 2 results

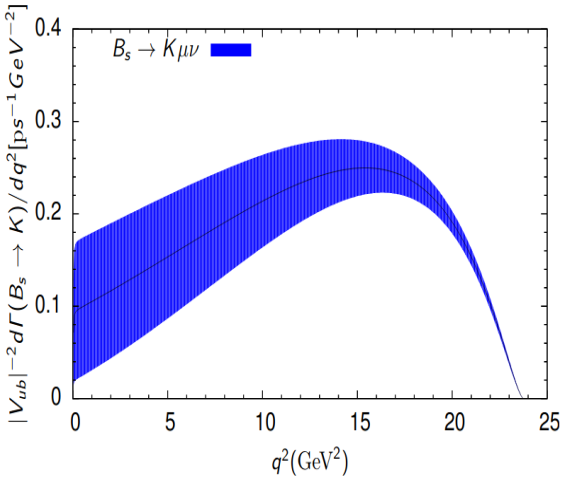
$$\phi_s = -0.083 \pm 0.041 \pm 0.006\,\mathrm{rad}$$
$$|\lambda| = 1.012 \pm 0.016 \pm 0.006$$
$$\Gamma_s - \Gamma_d = -0.0041 \pm 0.0024 \pm 0.0015\,\mathrm{ps}^{-1}$$
$$\Delta\Gamma_s = 0.077 \pm 0.008 \pm 0.003\,\mathrm{ps}^{-1}$$
$$\Delta m_s = 17.703 \pm 0.059 \pm 0.018\,\mathrm{ps}^{-1}$$
$$|A_\perp|^2 = 0.2456 \pm 0.0040 \pm 0.0019$$
$$|A_0|^2 = 0.5186 \pm 0.0029 \pm 0.0023$$
$$\delta_\perp - \delta_0 = 2.64 \pm 0.13 \pm 0.10\,\mathrm{rad}$$
$$\delta_\parallel - \delta_0 = 3.06\,^{+0.08}_{-0.07} \pm 0.04\,\mathrm{rad}.$$

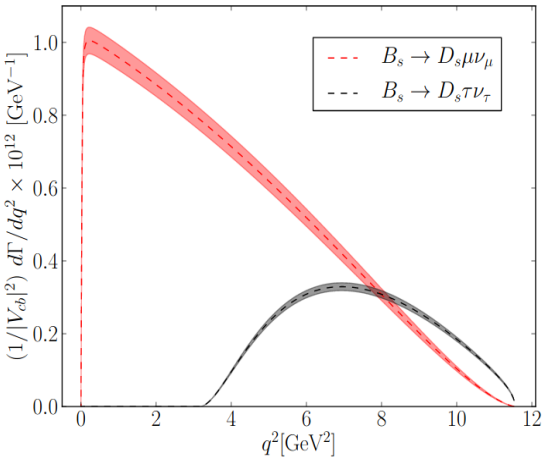
Results: $|V_{\rm ub}|/|V_{\rm cb}|$ ingredients

$$\frac{\mathcal{B}(\mathrm{B_s^0 \to K^- \mu^+ \nu_\mu})_{q^2<7}}{\mathcal{B}(\mathrm{B_s^0 \to D_s^- \mu^+ \nu_\mu})_{\mathrm{Full\ q^2}}} = (1.66 \pm 0.08(\mathrm{stat}) \pm 0.07(\mathrm{syst}) \pm 0.05(\mathrm{D_s})) \times 10^{-3}$$

$$\frac{\mathcal{B}(\mathrm{B_s^0 \to K^- \mu^+ \nu_\mu})_{q^2>7}}{\mathcal{B}(\mathrm{B_s^0 \to D_s^- \mu^+ \nu_\mu})_{\mathrm{Full\ q^2}}} = (3.25 \pm 0.21(\mathrm{stat}) \,^{+\,0.16}_{-\,0.17}(\mathrm{syst}) \pm 0.09(\mathrm{D_s})) \times 10^{-3}$$







JHEP08(2017)112 Phys. Rev. D 100, 034501 (2019) Phys. Rev. D 101, 074513 (2020)

$$\mathrm{FF_K} = 4.14 \pm 0.38\,\mathrm{ps}^{-1}\ ,\ \mathrm{FF_K} = 3.23 \pm 0.46\,\mathrm{ps}^{-1}\ ,\ \mathrm{FF_{D_s}} = 9.15 \pm 0.37\,\mathrm{ps}^{-1}$$

Neutrino reconstruction

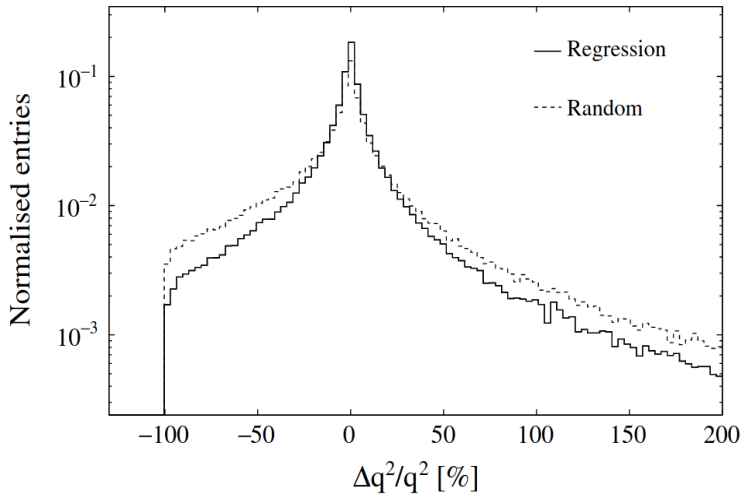
- Transverse component of the neutrino momentum $p_\perp$ is trivial to calculate
- Longitudinal component $p_\parallel$ is determined up to a two-fold ambiguity with the quadratic equation

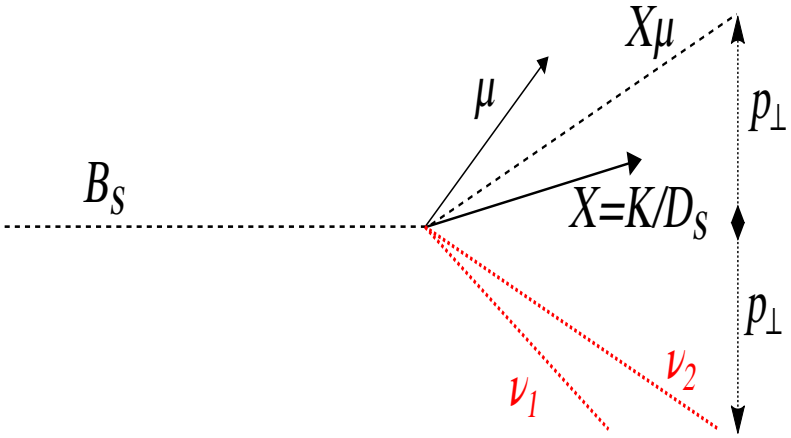
$$p_\parallel = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}, \tag{1}$$

$$\begin{aligned} a &= |2p_{\parallel,X_\mu} m_{X_\mu}|^2, \\ b &= 4p_{\parallel,X_\mu}(2p_\perp p_{\parallel,,X_\mu} - m^2_{miss}), \\ c &= 4p_\perp^2(p^2_{\parallel,X_\mu} + m^2_{\mathrm{B_s^0}}) - |m^2_{miss}|^2, \\ m^2_{miss} &= m^2_{\mathrm{B_s^0}} - m^2_{X_\mu}. \end{aligned} \tag{2}$$

$|V_{ub}|/|V_{cb}|$ @ LHCb: Strategy

- Analysis requires q^2 reconstruction:
  1. Infer P_ν from B_s^0 topology $\rightarrow$ two-fold ambiguity
  2. Use linear regression (JHEP 02 (2017) 021) to choose correct P_ν solution
- $B_s^0 \rightarrow K^- \mu^+ \nu_\mu$ & $B_s^0 \rightarrow D_s^- \mu^+ \nu_\mu$
  - Fit data using "corrected mass"
  - $M_{corr} = \sqrt{M_{X\mu}^2 + p_\perp^2} + p_\perp$
- Similar vetoes to select/reconstruct $B_s^0 \rightarrow K^- \mu^+ \nu_\mu$& $B_s^0 \rightarrow D_s^- \mu^+ \nu_\mu$
  - Use inclusive $D_s^- \rightarrow K^+ K^- \pi^-$ decays





Systematics breakdown

Uncertainty	$\frac{\mathcal{B}(B_s \to K\mu\nu)}{\mathcal{B}(B_s \to D_s\mu\nu)}$ [%]		
	No q^2 sel.	low q^2	high q^2
Tracking	2.0	2.0	2.0
Trigger	1.4	1.2	1.6
Particle ID	1.0	1.0	1.0
m_{corr} error	0.5	0.5	0.5
Isolation	0.2	0.2	0.2
Charged BDT	0.6	0.6	0.6
Neutral BDT	1.1	1.1	1.1
q^2 migration		2.0	2.0
ε gen& reco	1.2	1.6	1.6
Fit template	$^{+2.3}_{-2.9}$	$^{+1.8}_{-2.4}$	$^{+3.0}_{-3.4}$
Total	$^{+4.0}_{-4.3}$	$^{+4.3}_{-4.5}$	$^{+5.0}_{-5.3}$
$\mathcal{B}(\mathrm{D_s^-} \to \mathrm{K^-K^+}\pi^-)$	2.8	2.8	2.8

- Similar contribution to systematic budget from fit and ϵ
- Multiple Systematic sources for fit and ϵ are reducible with larger data sets and simulation samples