Status of B semitauonic analysis at LHCb

Bo Fang[1,2,3], *Liang Sun*[2], *Guy Wormser*[2,3]

Wuhan University[1] & *Paris – Saclay University*[2] & *IJCLab*[3]

First flavor day at IJCLab
27 Oct 2021

Outline

- LFUV and semitauonic B decays

- Details about R(D^*) measurement with hadronic tau decays

- Prospects: growth in statistics and input from BESIII

- Summary

Lepton flavour universality (LFU)

- An approximate lepton ($\ell = e, \mu, \tau$) flavor symmetry among physical observables
- Broken in the Standard Model (SM) only by the charged lepton mass term
- New physics particles coupling to 3rd generation charged lepton can lead to lepton flavour universality violation (LFUV)

Semitauonic B decays as tests of LFUV

- $b \rightarrow c \ell \nu$ transitions : $\quad R(X_c) = \dfrac{BR(X_b \rightarrow X_c \tau \nu_\tau)}{BR(X_b \rightarrow X_c \mu \nu_\mu)}$
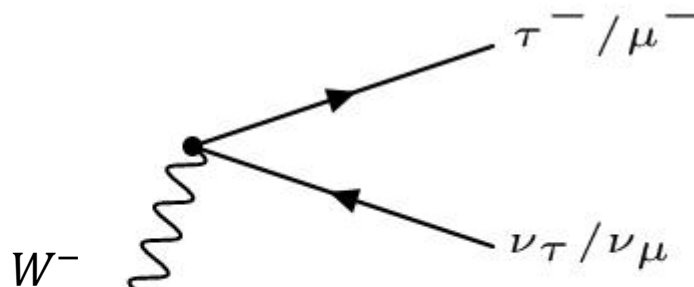
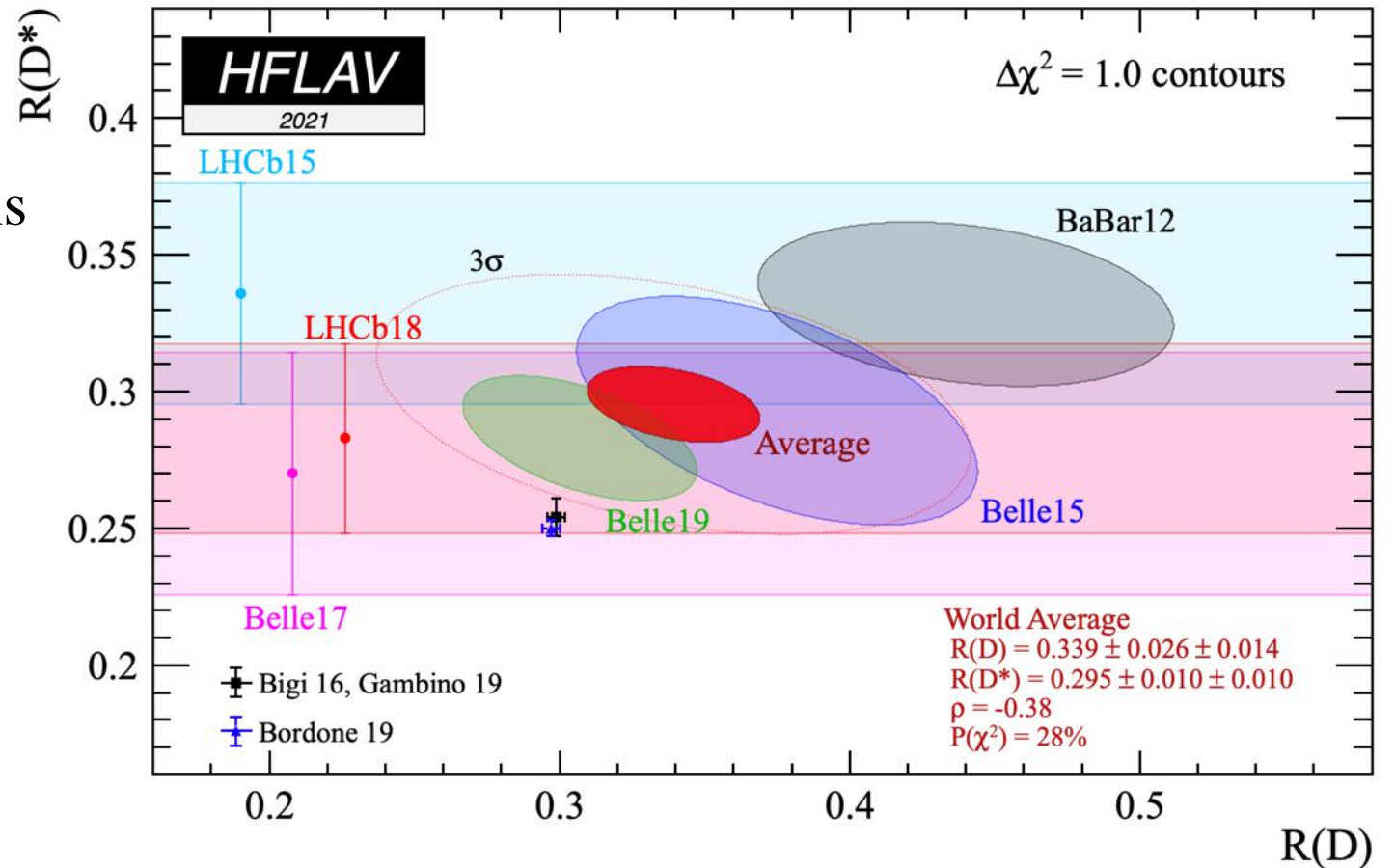e.g. possible contribution from leptoquark [PRL116(2016)081801]
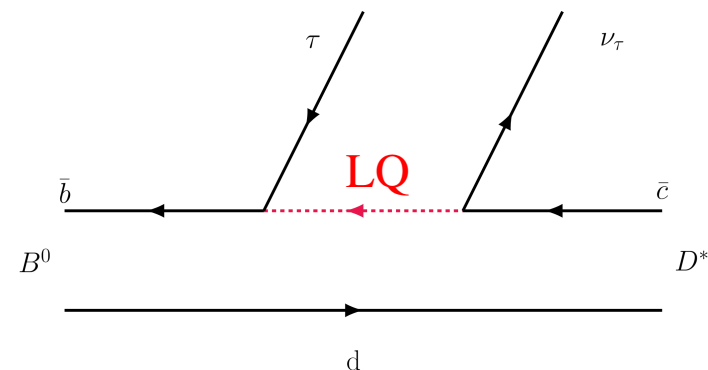
Experimental results about semitauonic B decays

- R(D) and R(D*) combined results:
  3.4σ extension from SM predictions

- R(J/ψ): $B_c^+ \to J/\psi \ell^+ \nu_\ell$
  ~2σ from SM
  [PRL 120, 121801 (2018)]

LHCb15: $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$
[PRL115(2015)111803]

LHCb18: $\tau^+ \to \pi^+ \pi^- \pi^+ (\pi^0) \bar{\nu}_\tau$
[PRL120(2018)171802, PRD97(2018)072013]

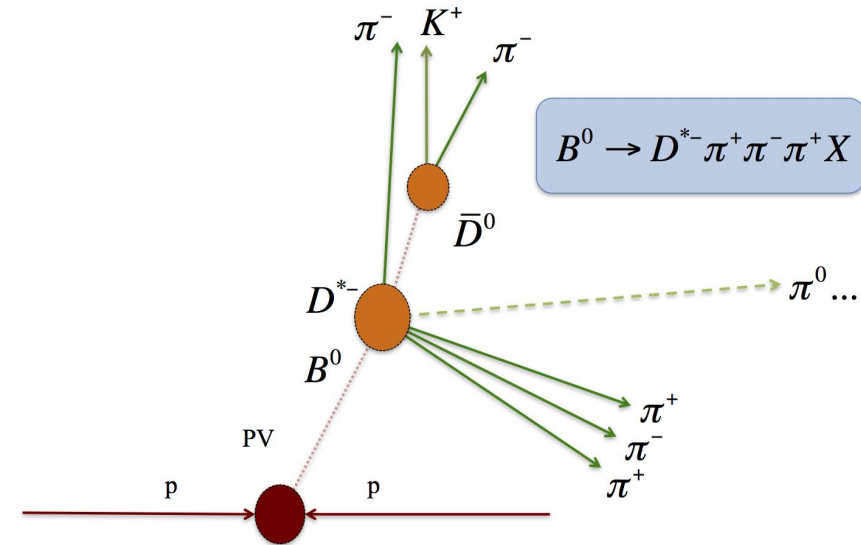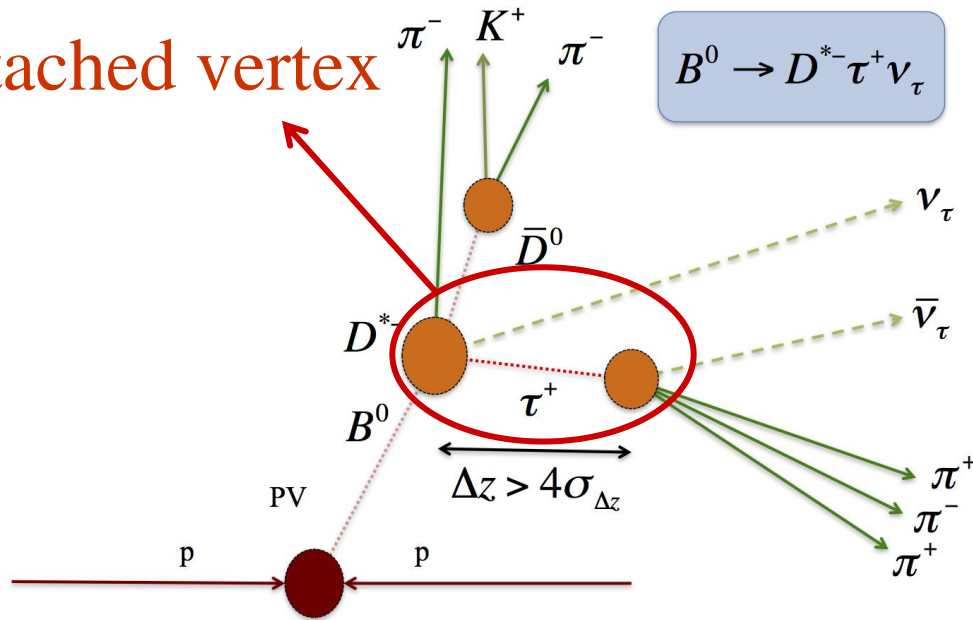All LHCb results based on 3fb^{-1} data from Run1,
updates are on the way!

Details about R(D^*) measurement with hadronic tau decays

Detached vertex

$B^0 \to D^{*-}\tau^+\nu_\tau$

$B^0 \to D^{*-}\pi^+\pi^-\pi^+X$
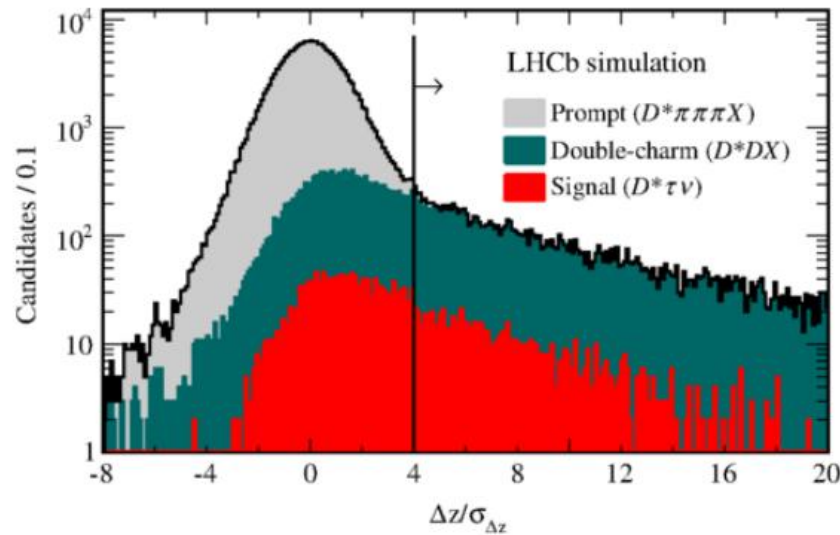
- Advantage for hadraonic tau decays: three prong decays allow for the reconstruction of tau vertex & no background from normal semileptonic decays

- Target measurement: $K(X_c) = \dfrac{BR(B^0 \to D^{*-}\tau^+\nu_\tau)}{BR(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}$. Same charged final states in signal and normalization channels.

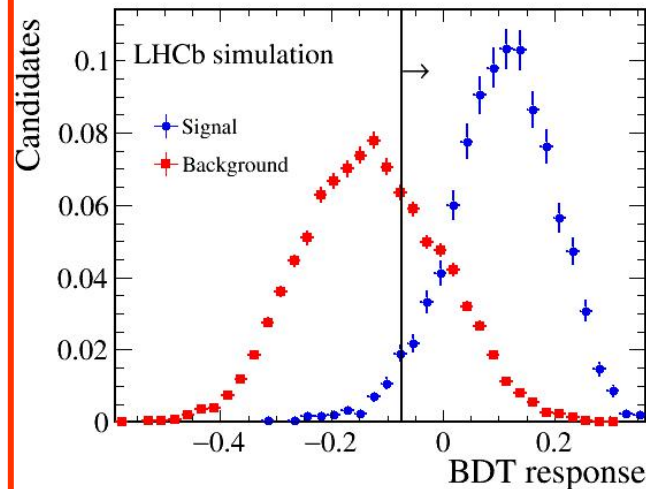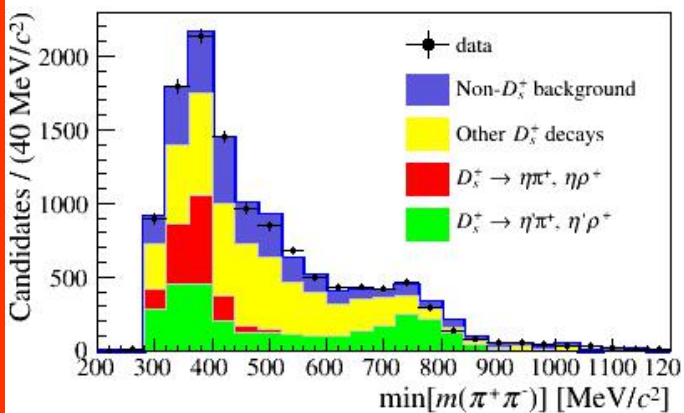# Details about R(D^*) measurement with hadronic tau decays

- Main backgrounds:
  - $B^0 \to D^{*-}\pi^+\pi^-\pi^+ X$
  - $B^0 \to D^{*-}DX (D = D_s^+, D^0, D^+)$

- After the detached vertex cut, the largest background from $B^0 \to D^{*-}\pi^+\pi^-\pi^+ X$ decays is suppressed by ~3 orders of magnitude

While min[m($\pi^+\pi^-$ from τ^+)] will peak at ρ mass (770 MeV)

- The dominant double charm background $B^0 \to D^{*-}D_s^+ X$ is reduced by a boosted decision tree (BDT) based on 3π dynamics and resonant structure
- $B^0 \to D^{*-}D^0 X$ is well constrained by charged-particle isolation method

Details about R(D^*) measurement with hadronic tau decays

- Signal yield determined by a 3D binined template fit
  - q^2 ($\equiv |P_{B^0} - P_{D^*}|^2$)
  - t_τ, τ decay time
  - BDT output (trained to reduce $B^0 \to D^{*-}D_s^+X$ background)

- Templates obtained from simulation and study of control samples

$$\mathcal{R}(D^{*-}) = 0.291 \pm 0.019(\text{stat}) \pm 0.026(\text{syst}) \pm 0.013(\text{ext})$$

1σ above SM prediction
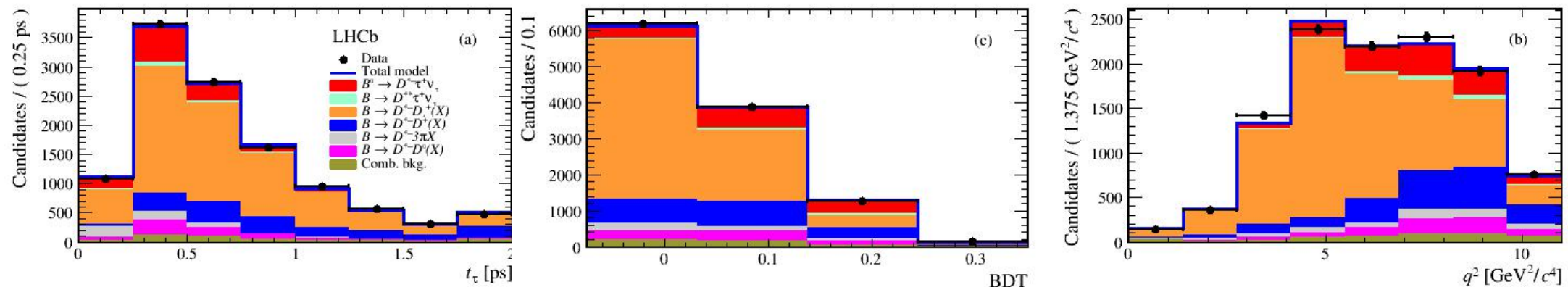
Prospects: growth in statistics

[arXiv:2101.08326]

| Experiment	*BABAR*	Belle	Belle II	LHCb			
				Run 1	Run 2	Runs 3–4	Runs 5–6
Completion date	2008	2010	2031	2012	2018	2031	2041
Center-of-mass energy	10.58 GeV	10.58/10.87 GeV	10.58/10.87 GeV	7/8 TeV	13 TeV	14 TeV	14 TeV
$b\bar{b}$ cross section [nb]	1.05	1.05/0.34	1.05/0.34	$(3.0/3.4)\times10^5$	5.6×10^5	6.0×10^5	6.0×10^5
Integrated luminosity [fb^{-1}]	424	711/121	$(40/4)\times10^3$	3	6	40	300
B^0 mesons [10^9]	0.47	0.77	40	170	580	4,200	32,000
B^+ mesons [10^9]	0.47	0.77	40	170	580	4,200	32,000
B_s mesons [10^9]	-	0.01	0.5	40	140	1,000	7,600
Λ_b baryons [10^9]	-	-	-	90	300	2,200	16,000
B_c mesons [10^9]	-	-	-	1.3	4.4	32	240
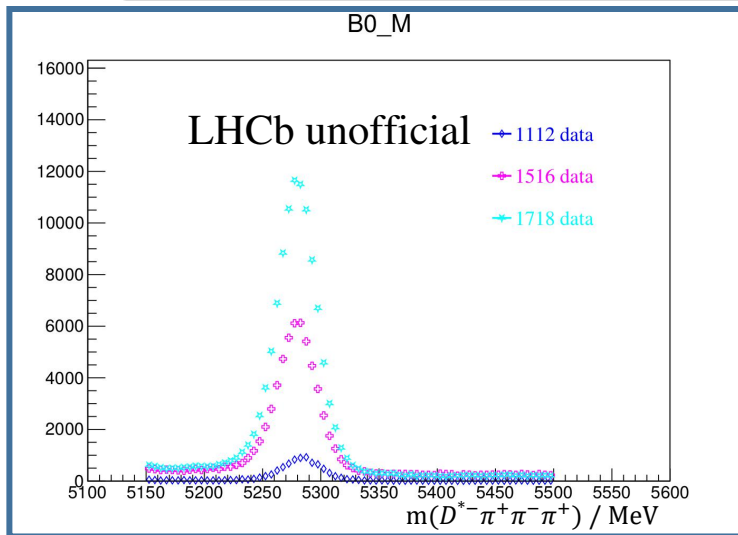
Mass spectrum of reconstructed B^0 from roughly pre-selected $B^0 \to D^{*-}\pi^+\pi^-\pi^+$ candidates

- Hopefully, owing to
  - increase in integrated luminosity
  - larger $\sqrt{s}$ leads to larger production cross section
  - improved trigger and selection

The stat. uncertainty of hadronic R(D^*) can reduce to below 3%

Prospects: input from BESIII

Relative Systematic uncertainties on R(D^*)

| Source	$\delta R(D^{*-})/R(D^{*-})$ [%]
Simulated sample size	4.7
Empty bins in templates	1.3
Signal decay model	1.8
$D^{**}\tau\nu$ and $D_s^{**}\tau\nu$ feeddowns	2.7
$D_s^+ \to 3\pi X$ decay model	2.5
$B \to D^{*-}D_s^+ X$, $B \to D^{*-}D^+ X$, $B \to D^{*-}D^0 X$ backgrounds	3.9
Combinatorial background	0.7
$B \to D^{*-}3\pi X$ background	2.8
Efficiency ratio	3.9
Normalization channel efficiency (modeling of $B^0 \to D^{*-}3\pi$)	2.0
Total uncertainty	9.1

[PRL120(2108)171802, PRD 97(2018)072013]

- Regarding charm mesons decays, need inputs from BESIII
  - Inclusive $D_s^+ \to \pi^+\pi^-\pi^+ X$
  - $\eta\pi, \eta\rho, \eta'\pi, \eta'\rho, \omega\pi, \omega\rho, \phi\pi, \phi\rho$
  - M3π where M is ($\pi^0, \eta, \eta', K^0, \omega, \phi$)

- Cooperations between LHCb and BESIII on this project is ongoing

- These inputs are critical for the complete R(X) program of LHCb

I'm working on the measurement of branching fraction of $D_s^+ \to \pi^+\pi^-\pi^+\eta'$ at BESIII

Prospects: input from BESIII

- Recent result on this project from BESIII:
  - Branching fraction of $D_s^+ \to \pi^+\pi^-\pi^+\eta$
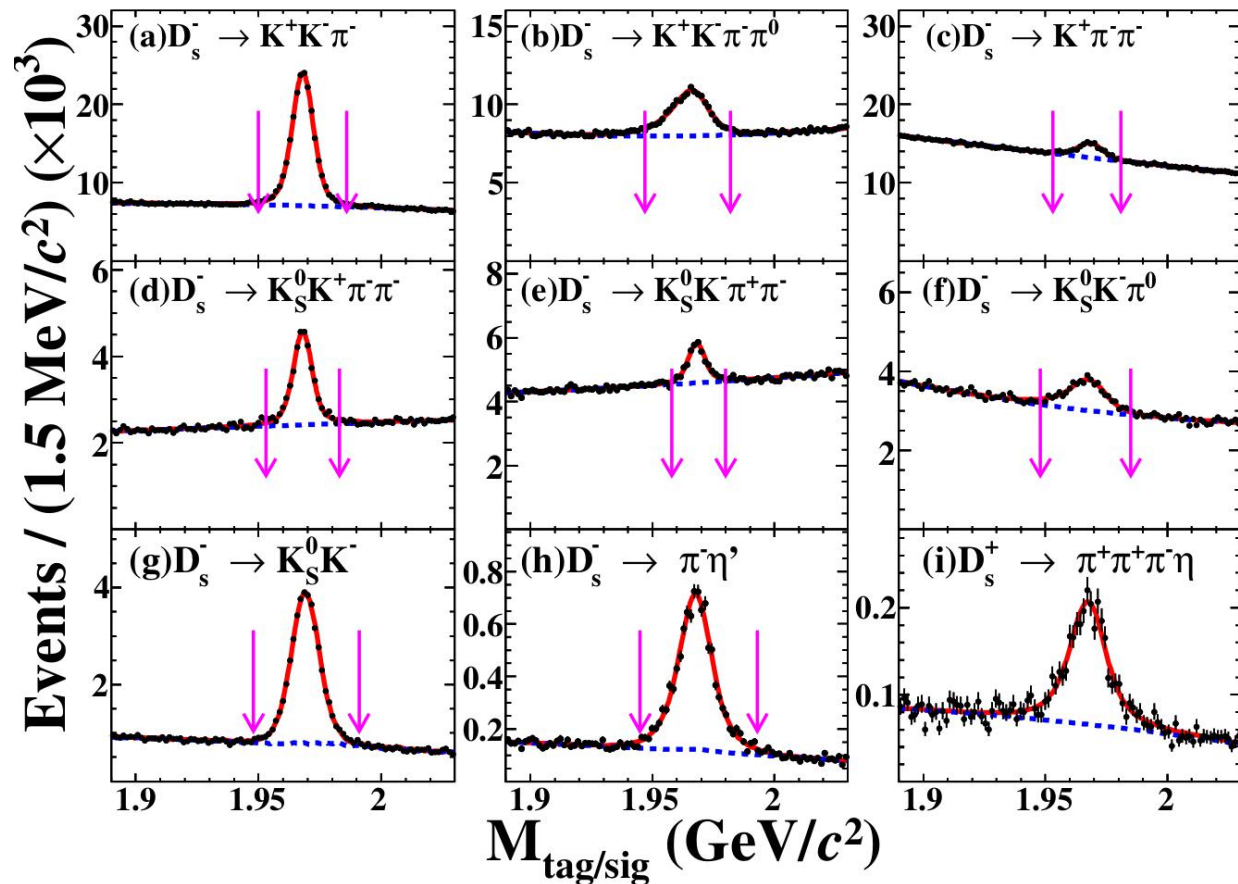
$$\mathcal{B}(D_s^+ \to \pi^+\pi^+\pi^-\eta) = (3.12 \pm 0.13_{\text{stat.}} \pm 0.09_{\text{syst.}})\%$$
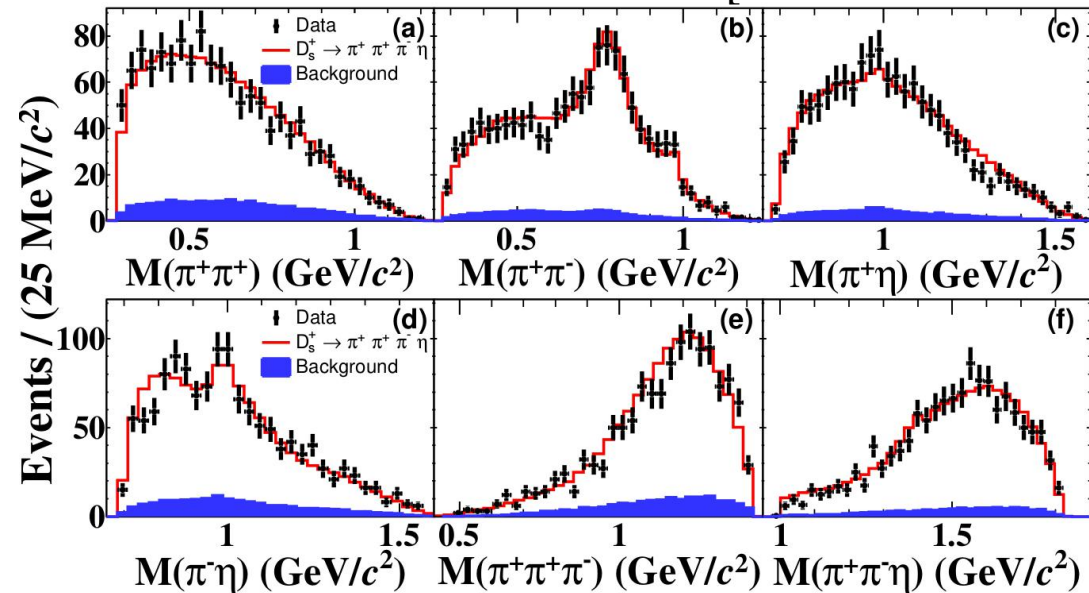

TABLE I: Phases and FFs for various intermediate processes. The first and the second uncertainties are statistical and systematic, respectively.

Amplitude	Phase	FF(%)
$a_1(1260)^+(\rho(770)^0\pi^+)\eta$	0.0(fixed)	$55.4 \pm 3.9 \pm 2.0$
$a_1(1260)^+(f_0(500)\pi^+)\eta$	$5.0 \pm 0.1 \pm 0.1$	$8.1 \pm 1.9 \pm 2.1$
$a_0(980)^+\rho(770)^0$	$2.5 \pm 0.1 \pm 0.1$	$6.7 \pm 2.5 \pm 1.5$
$\eta(1405)(a_0(980)^-\pi^+)\pi^+$	$0.2 \pm 0.2 \pm 0.1$	$0.7 \pm 0.2 \pm 0.1$
$\eta(1405)(a_0(980)^+\pi^-)\pi^+$	$0.2 \pm 0.2 \pm 0.1$	$0.7 \pm 0.2 \pm 0.1$
$f_1(1420)(a_0(980)^-\pi^+)\pi^+$	$4.3 \pm 0.2 \pm 0.4$	$1.9 \pm 0.5 \pm 0.3$
$f_1(1420)(a_0(980)^+\pi^-)\pi^+$	$4.3 \pm 0.2 \pm 0.4$	$1.7 \pm 0.5 \pm 0.3$
$[a_0(980)^-\pi^+]_S\pi^+$	$0.1 \pm 0.2 \pm 0.2$	$5.1 \pm 1.2 \pm 0.9$
$[a_0(980)^+\pi^-]_S\pi^+$	$0.1 \pm 0.2 \pm 0.2$	$3.4 \pm 0.8 \pm 0.6$
$[f_0(980)\eta]_S\pi^+$	$1.4 \pm 0.2 \pm 0.3$	$6.2 \pm 1.7 \pm 0.9$
$[f_0(500)\eta]_S\pi^+$	$2.5 \pm 0.2 \pm 0.3$	$12.7 \pm 2.6 \pm 2.0$

Prospects: estimated precision evolution

[arXiv:2101.08326]
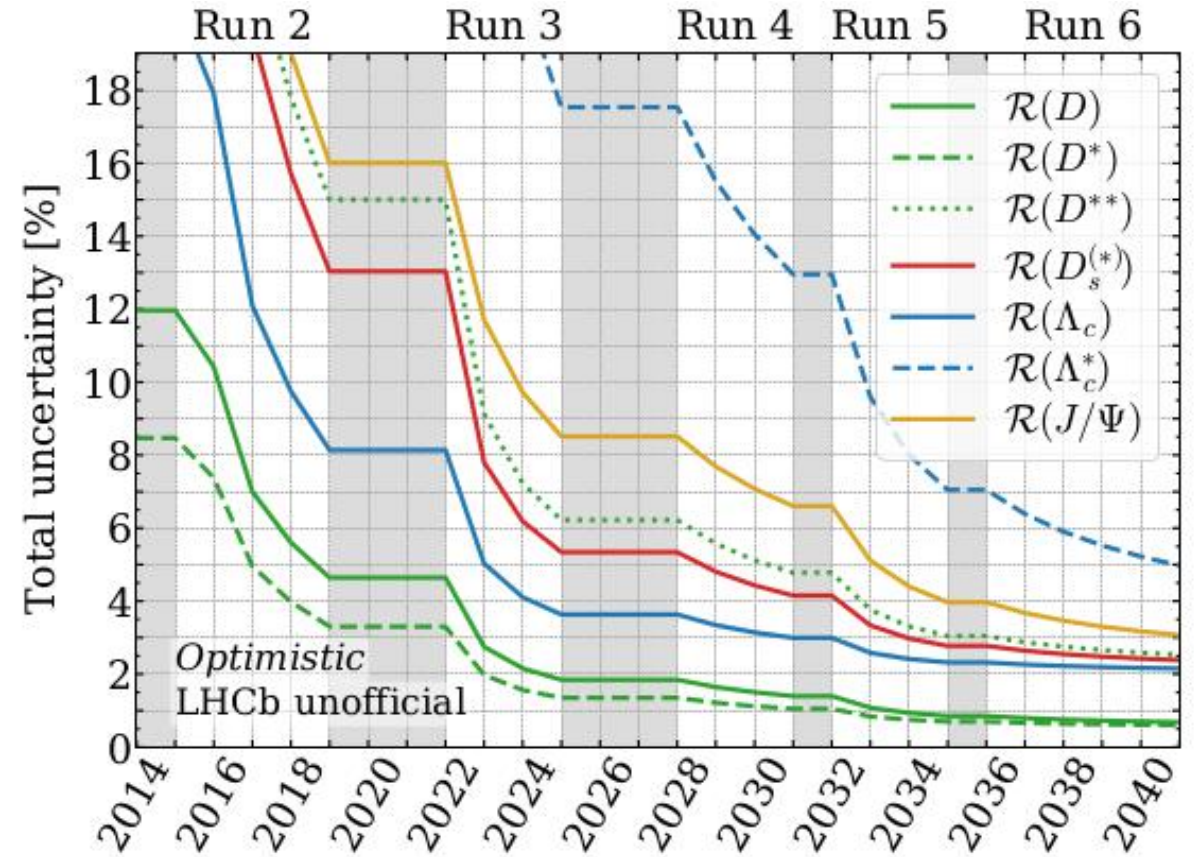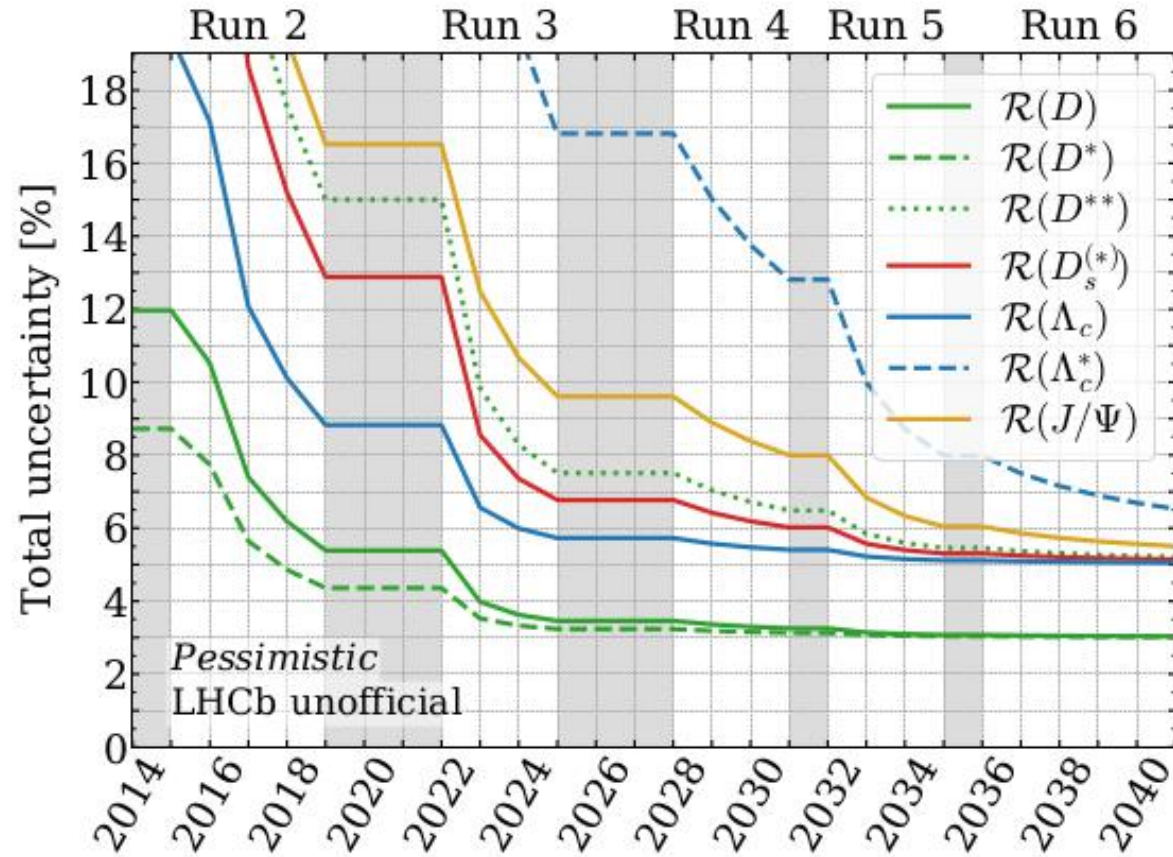
Summary

- LFUV is a hint towards physics beyond SM

- Semitauonic B decays are important tests of LFUV, updates based on larger samples collected by LHCb are ongoing

- Cooperation with BESIII insures critical inputs about charm mesons decays, which will increase the precision of complete R(X) program at LHCb

- My works on both sides:

  - BESIII: measurement of branching fraction of $D_s^+ \to \pi^+\pi^-\pi^+\eta'$

  - LHCb: R(D^*) hadronic measurement using 2017-2018 data samples (4 fb^{-1})

Thank you for listening!

Backup

The LHCb detector

A single-arm forward spectrometer, designed for the study of heavy flavor physics

- Excellent vertex, IP and decay-time resolution
  - $\sigma(IP) \approx 20\mu m$ for high-p_T tracks
  - $\sigma(\tau) \approx 45fs$ for $B_s^0 \to J/\psi\varphi$ and $B_s^0 \to D_s^-\pi^+$ decays
- Very good momentum resolution
  - $\delta p/p \approx 0.5\%$-1% for p $\in$ (0,200) GeV
  - $\sigma(m_B) \approx 24$ MeV for two-body decays
- Hadron and muon identification
  - $\varepsilon_{K\to K} \approx 95\%$ for $\varepsilon_{\pi\to K} \approx 5\%$ up to 100 GeV
  - $\varepsilon_{\mu\to\mu} \approx 97\%$ for $\varepsilon_{\pi\to\mu} \approx 1\%$-$3\%$

- 2<η<5 range(LHCb acceptance): ~3x10^4/s b$\overline{b}$
  pairs@7TeV
  ~x2 yield@13TeV; ~x20 yield for $c\overline{c}$ pairs