LFNU @ LHCb

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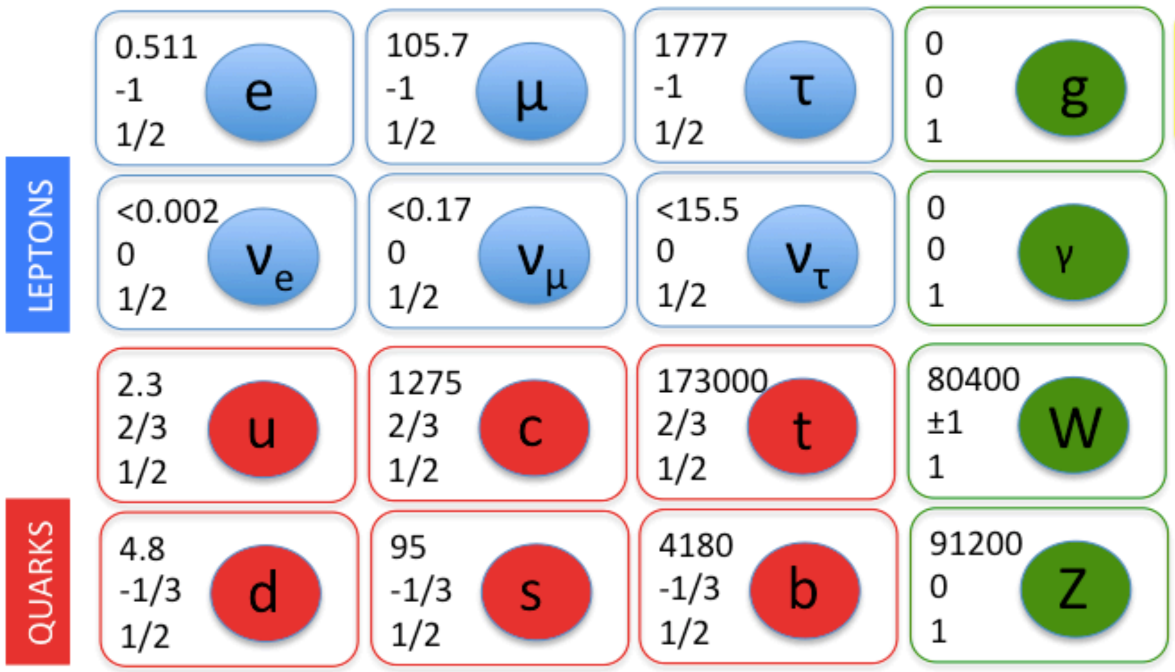
TAU - 2018, AMSTERDAM

LFNU - Introduction

Lepton flavour non-universality:
Couplings between the gauge bosons and the leptons are independent of the lepton generation

LFU is an accidental symmetry of SM that is only broken by the Yukawa term in the SM Lagrangian
=> BR can only differ due to the masses of leptons

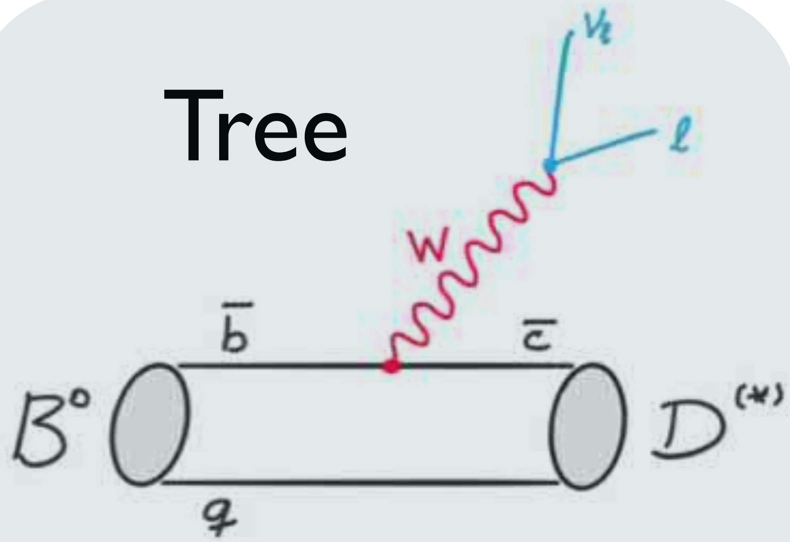
Some Beyond-SM theories predict a non-universal coupling between the three quark and lepton families, e.g. Z' , leptoquark
Testing the LFU hypothesis is fundamental
=>A violation of LFU would be a clear sign of New Physics (NP)



LFNU - B decays

the focus of this talk

Tree



$R(D^{(*)})$

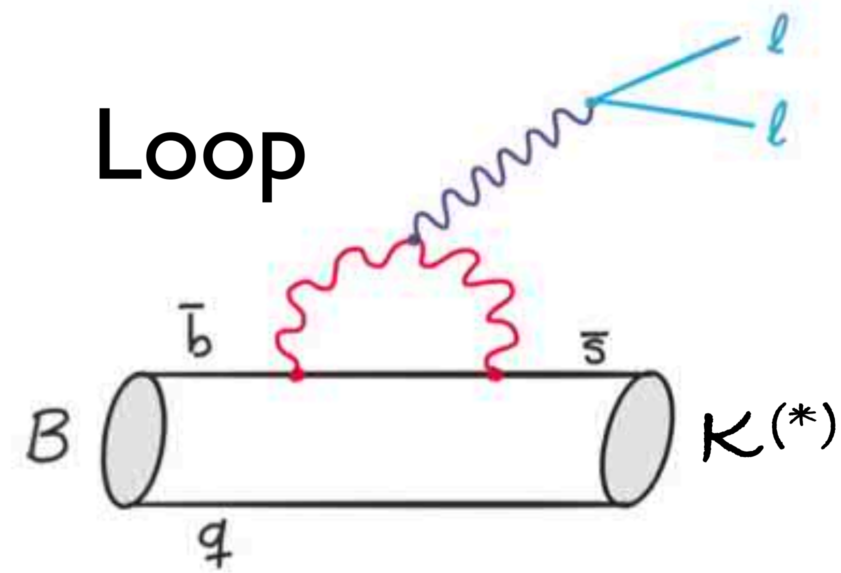
τ versus μ,e ratios

$$R(D^*) = \frac{B \to D* \tau \upsilon}{B \to D* \mu \upsilon}$$

R(D*) = 0.258±0.005

J. High Energ. Phys. (2017) 2017: 60.

Loop



$R(K^{(*)})$

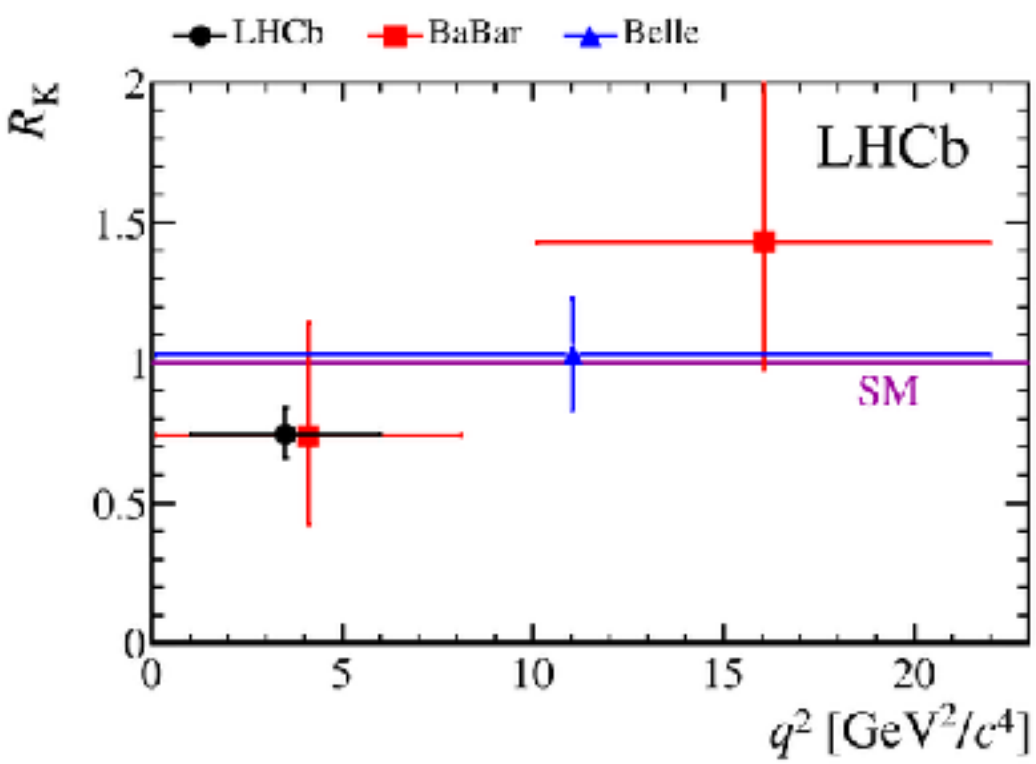
μμ versus ee ratios

$$R(K) = \frac{B \to K\mu\mu}{B \to Kee}$$

R(K) ~ 1 σ(10^{-2}) in SM

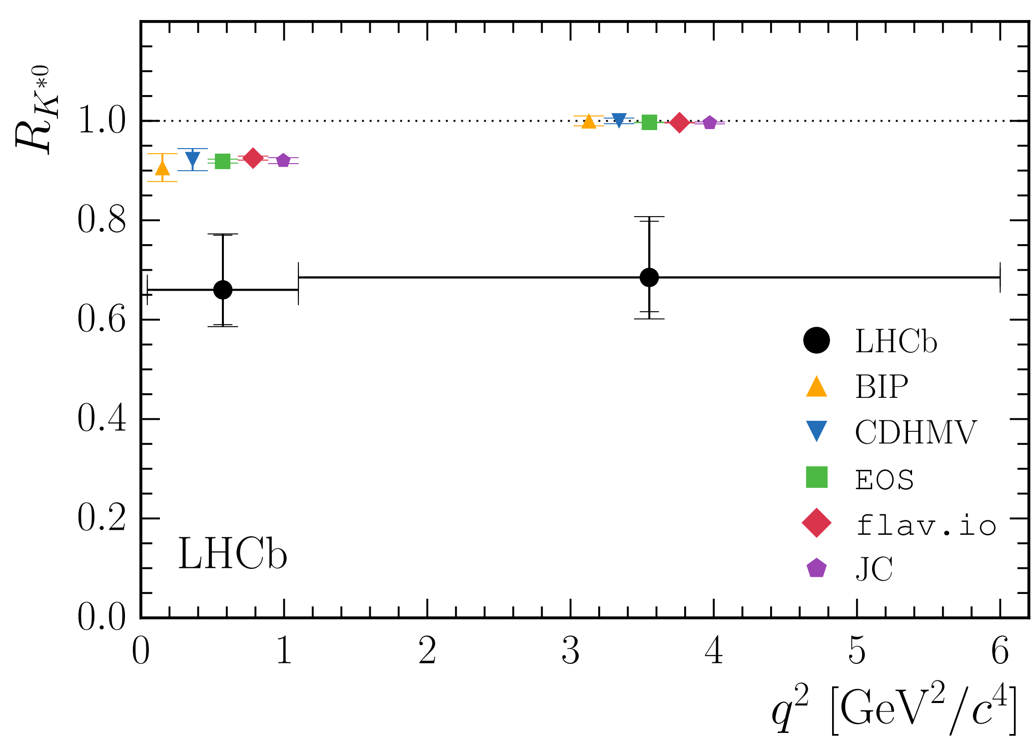
[Eur.Phys.J. C76 (2016) no.8, 440]

R(K)/R(K*)



[Phys. Rev. Lett. 113, 151601 (2014)]

$$R_K = 0.745^{+0.090}_{-0.074}\,(\text{stat}) \pm 0.036\,(\text{syst})$$

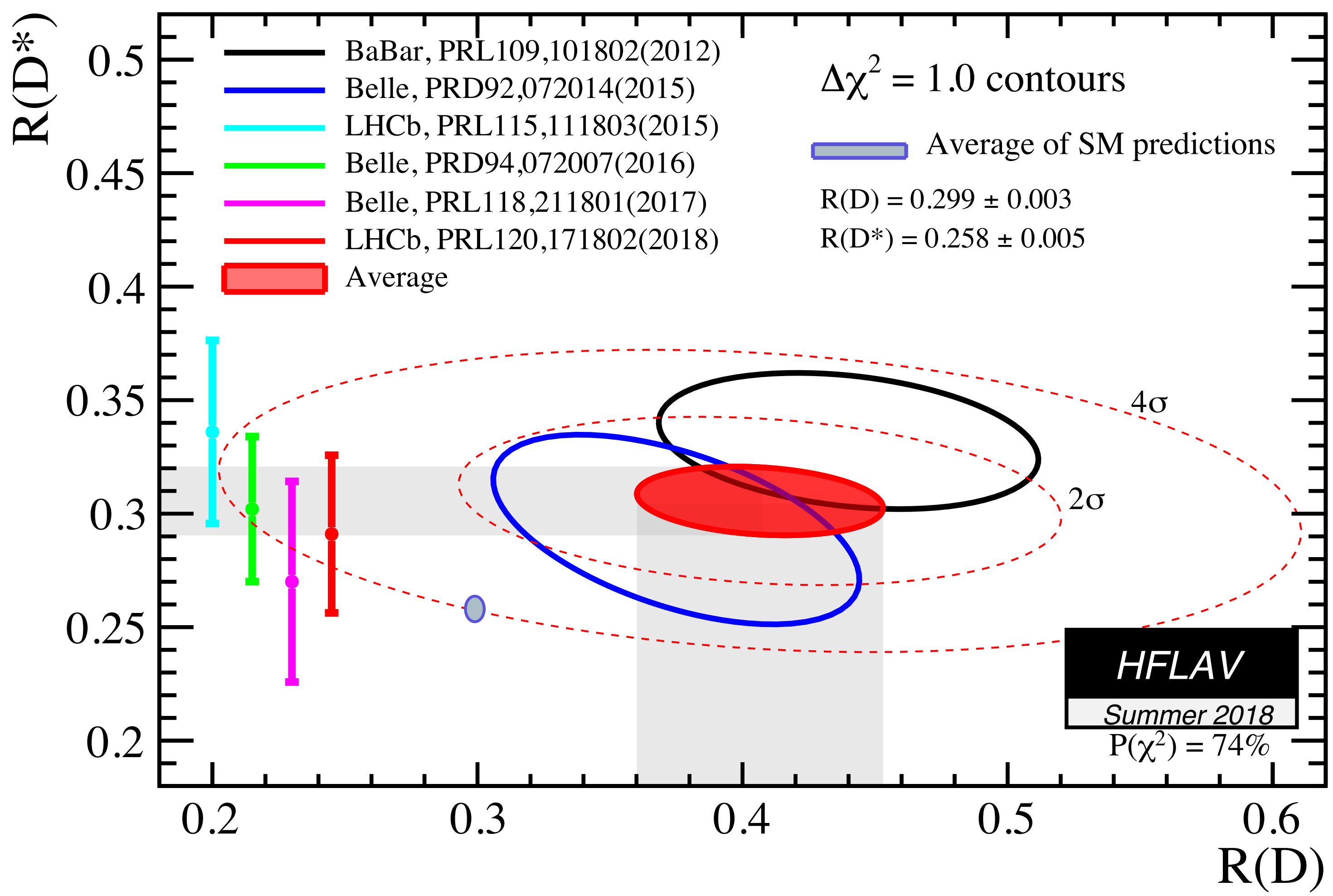


[JHEP 08 (2017) 055]

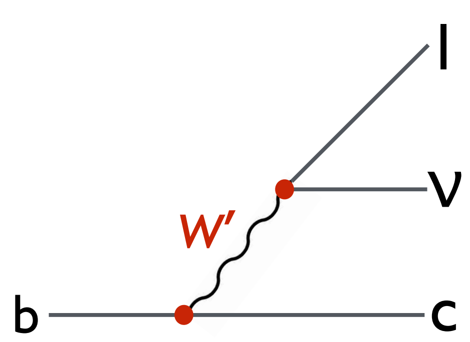
	low-q^2	central-q^2
$R_{K^{*0}}$	$0.66\ ^{+\ 0.11}_{-\ 0.07} \pm 0.03$	$0.69\ ^{+\ 0.11}_{-\ 0.07} \pm 0.05$
95.4% CL	$[0.52, 0.89]$	$[0.53, 0.94]$
99.7% CL	$[0.45, 1.04]$	$[0.46, 1.10]$

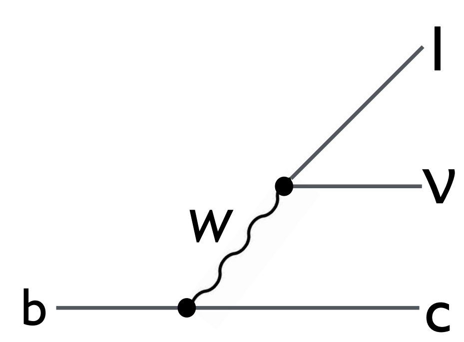
See also the talk of
Maarten van Veghel
on LFV

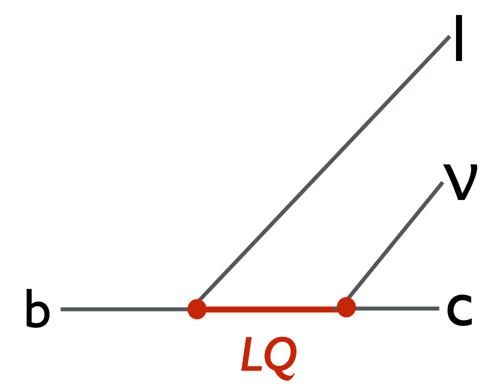
LFNU - Semi-leptonic B decays



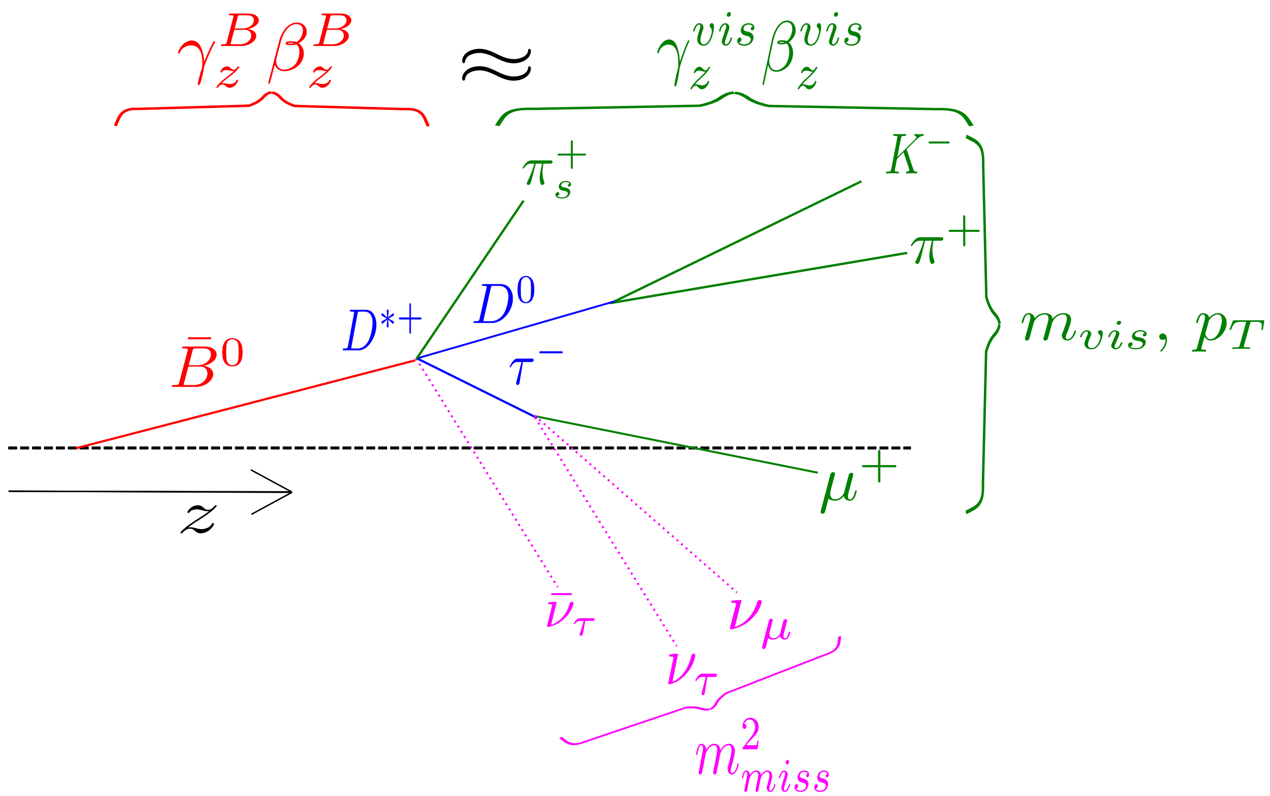
Tension with SM in R(D) vs R(D*) ~ 4 σ → new physics at tree-level?



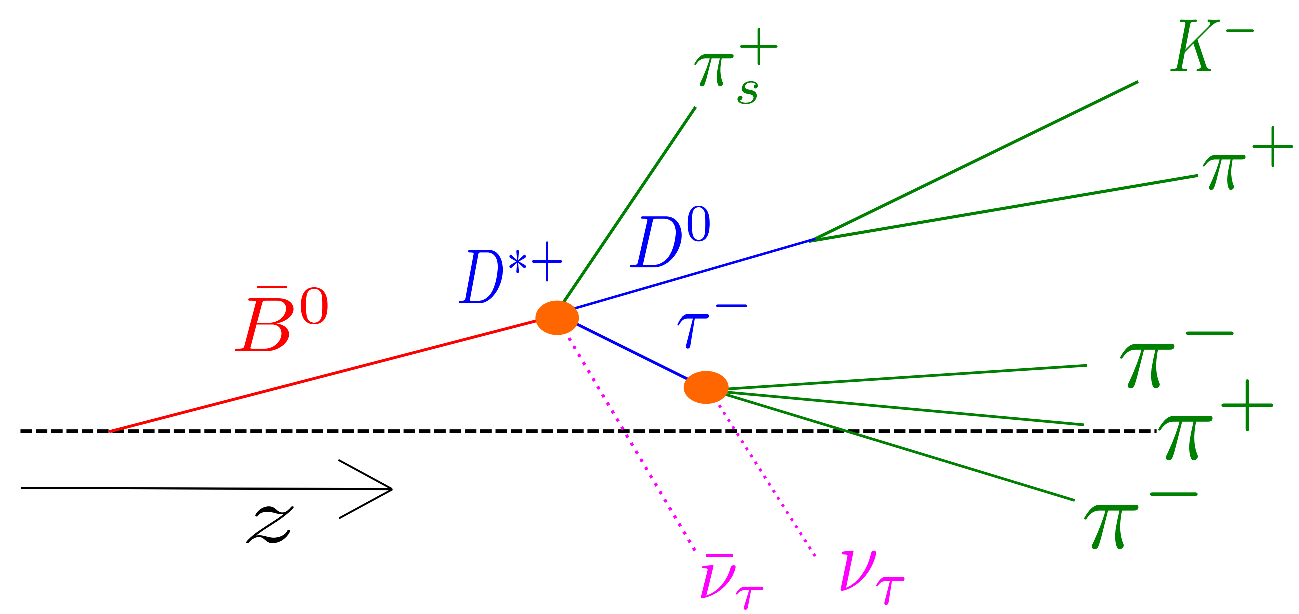




LFNU - Semi-leptonic B decays at LHCb



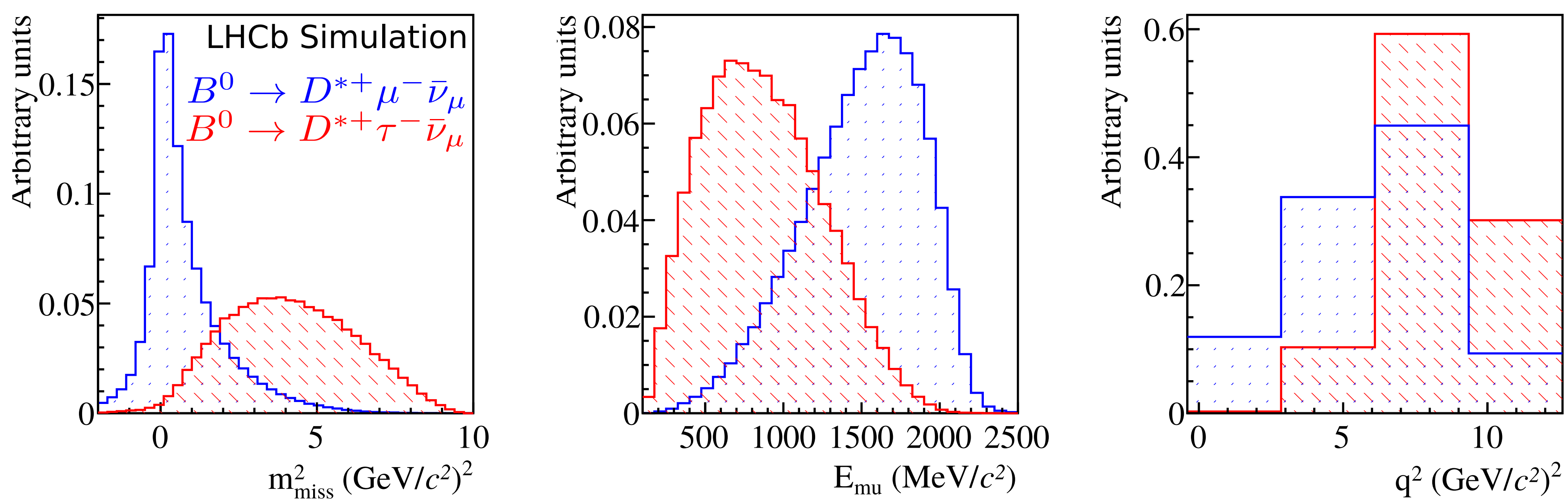
μ-channel



hadronic channel

Muonic R(D*) method

Phys. Rev. Lett. 115, 111803 (2015)



3D fit using templates

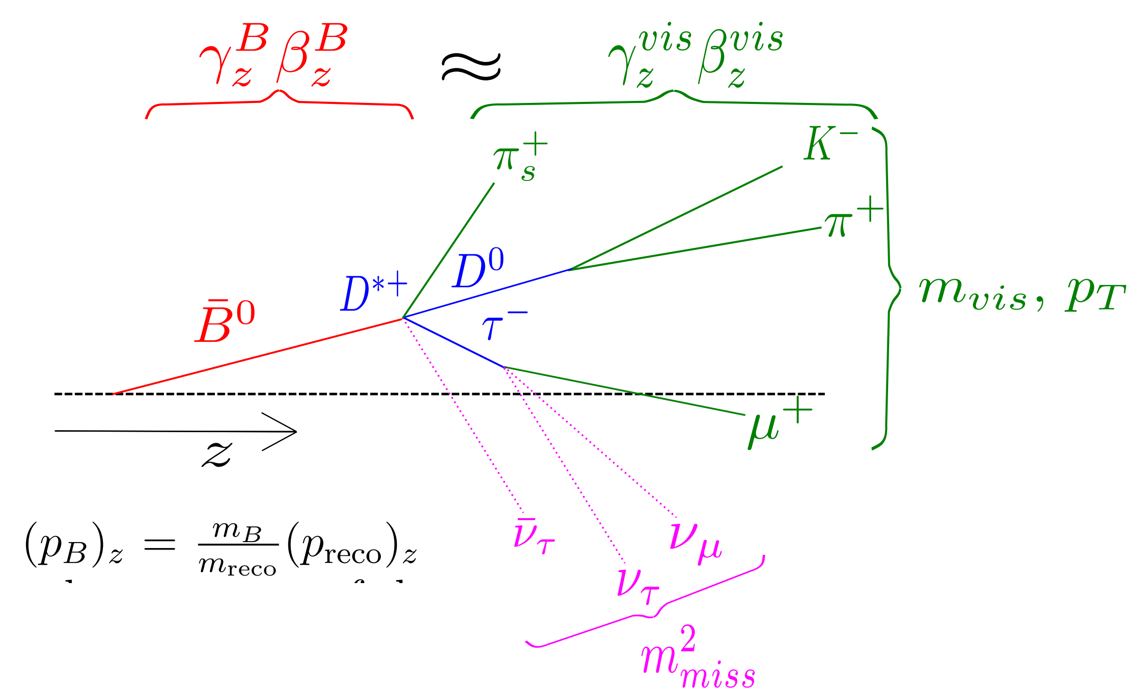
- μ mis-ID and combinatorial taken from data
- simulation used for other contributions

Largest backgrounds:

B → D**μν

B→D*+Xc,Xc →Xμν

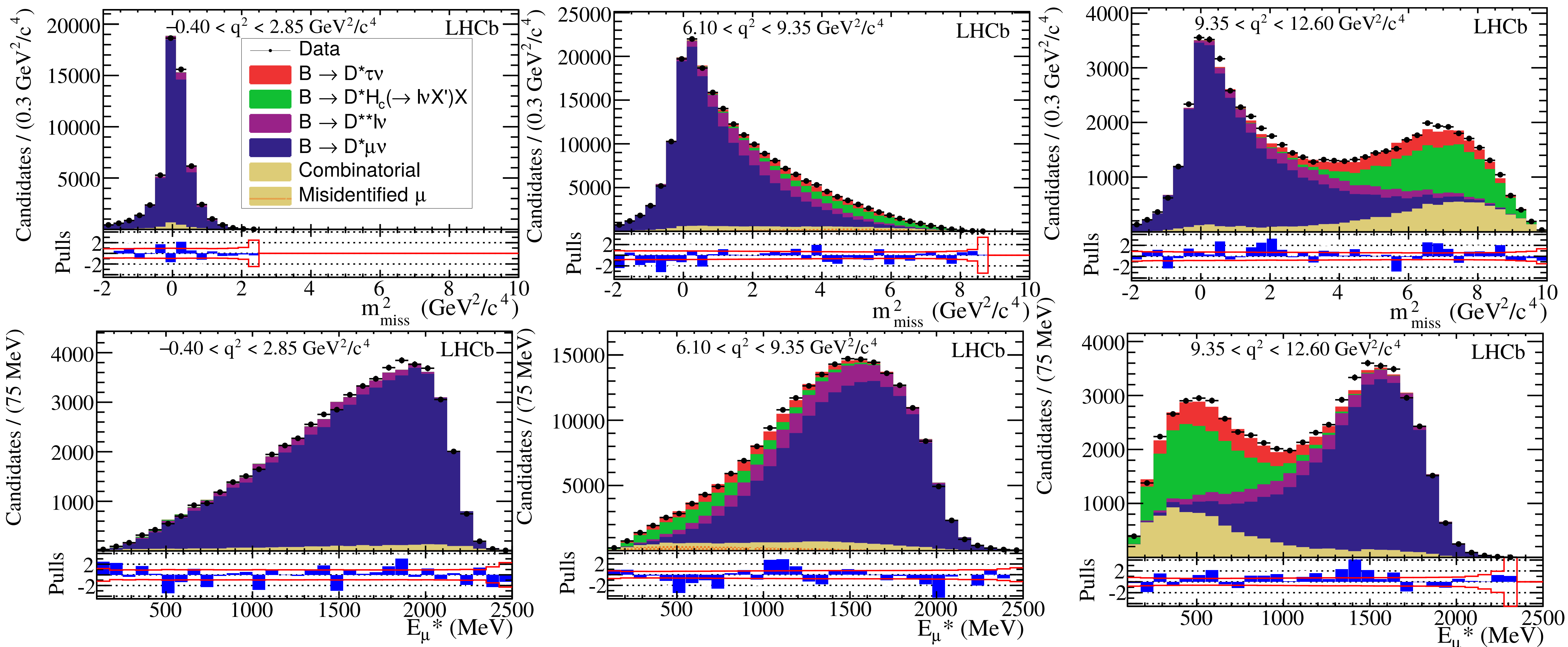
- Reduced with charged isolation variable



Muonic R(D*) results

Phys. Rev. Lett. 115, 111803 (2015)

Run 1, $3\,\mathrm{fb}^{-1}$:



$$R(D^*) = 0.336 \pm 0.027(stat) \pm 0.030(syst)$$

$2.1\,\sigma$ deviation from SM prediction

Muonic R(D*) systematics

Phys. Rev. Lett. 115, 111803 (2015)

largest systematics

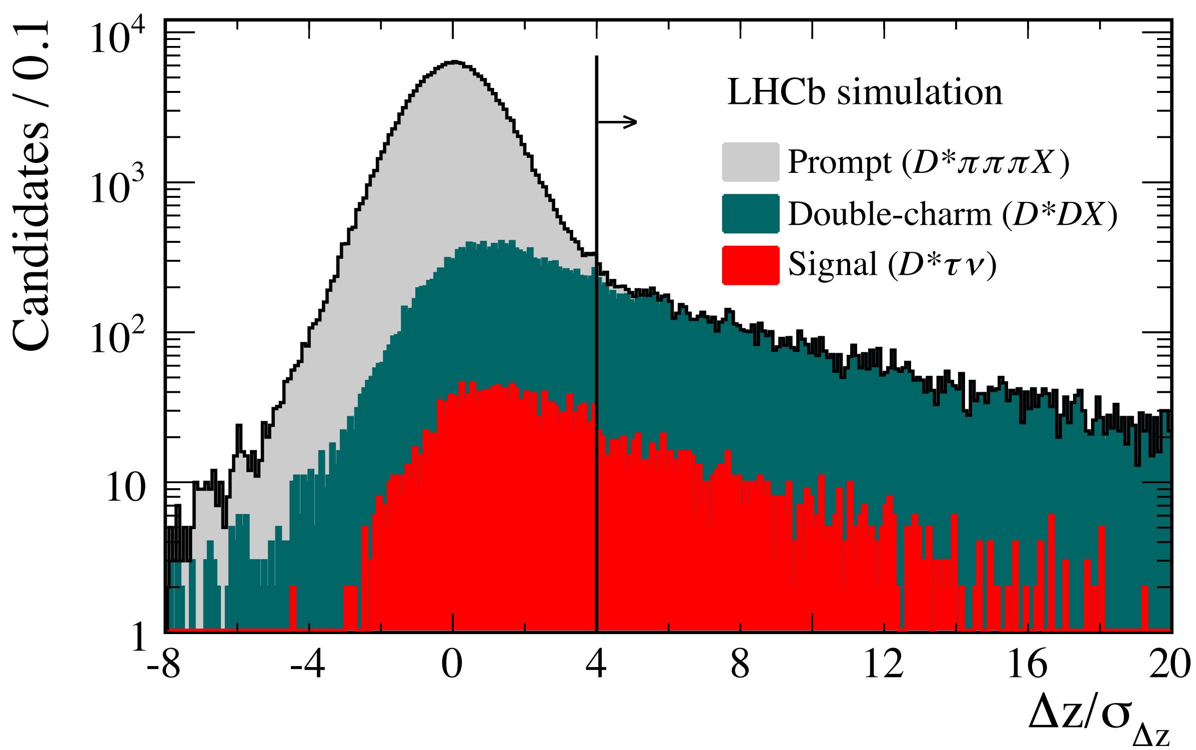
Mis-identified muon template uncertainty taken from use of 2 different unfolding methods on control samples.

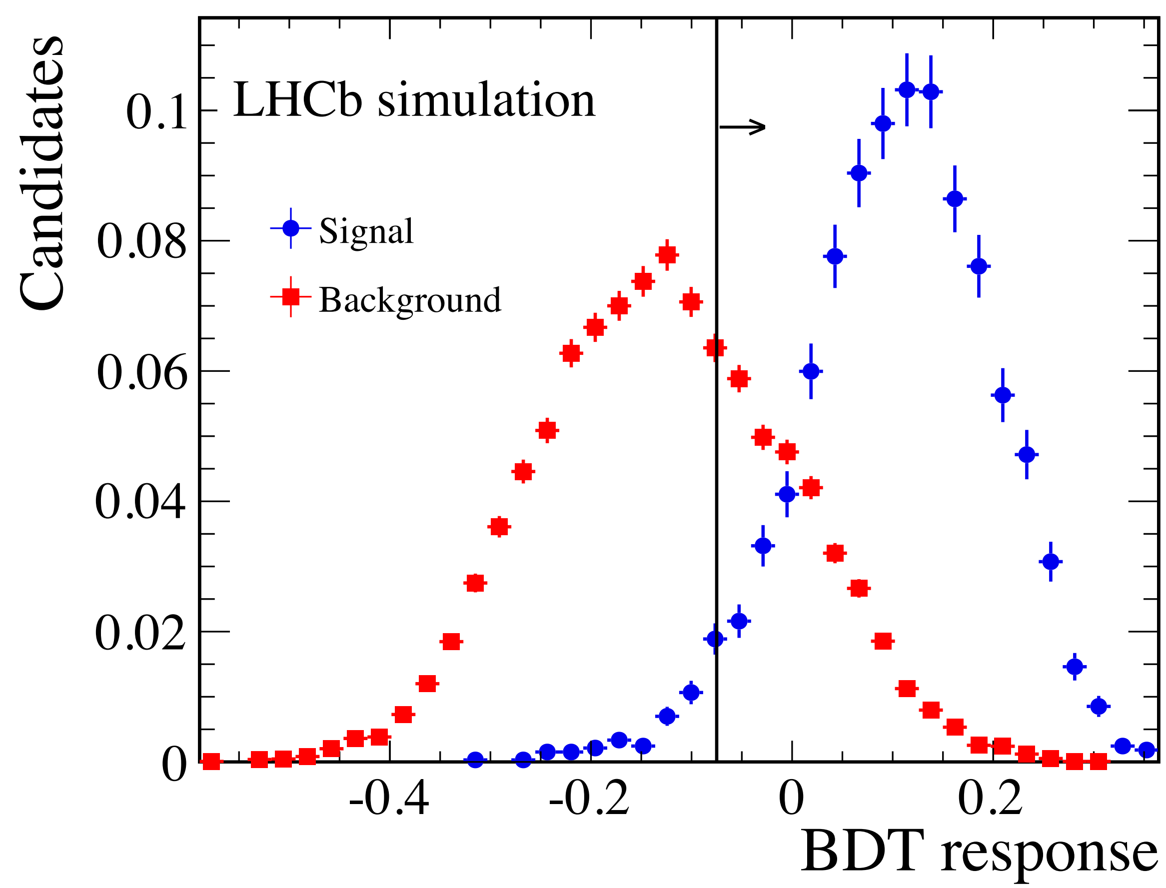
=> will be reduced. All major uncertainties driven by simulation or data control sample sizes.

Model uncertainties	**Absolute size ($\times 10^{-2}$)**
Simulated sample size	2.0
Misidentified μ template shape	1.6
$\overline{B}^0 \to D^{*+}(\tau^-/\mu^-)\overline{\nu}$ form factors	0.6
$\overline{B} \to D^{*+}H_c(\to \mu\nu X')X$ shape corrections	0.5
$\mathcal{B}(\overline{B} \to D^{**}\tau^-\overline{\nu}_\tau)/\mathcal{B}(\overline{B} \to D^{**}\mu^-\overline{\nu}_\mu)$	0.5
$\overline{B} \to D^{**}(\to D^*\pi\pi)\mu\nu$ shape corrections	0.4
Corrections to simulation	0.4
Combinatorial background shape	0.3
$\overline{B} \to D^{**}(\to D^{*+}\pi)\mu^-\overline{\nu}_\mu$ form factors	0.3
$\overline{B} \to D^{*+}(D_s \to \tau\nu)X$ fraction	0.1
Total model uncertainty	**2.8**
Normalization uncertainties	**Absolute size ($\times 10^{-2}$)**
Simulated sample size	0.6
Hardware trigger efficiency	0.6
Particle identification efficiencies	0.3
Form-factors	0.2
$\mathcal{B}(\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau)$	< 0.1
Total normalization uncertainty	**0.9**
Total systematic uncertainty	**3.0**

Hadronic R(D*) method

Phys. Rev. D 97, 072013 (2018)





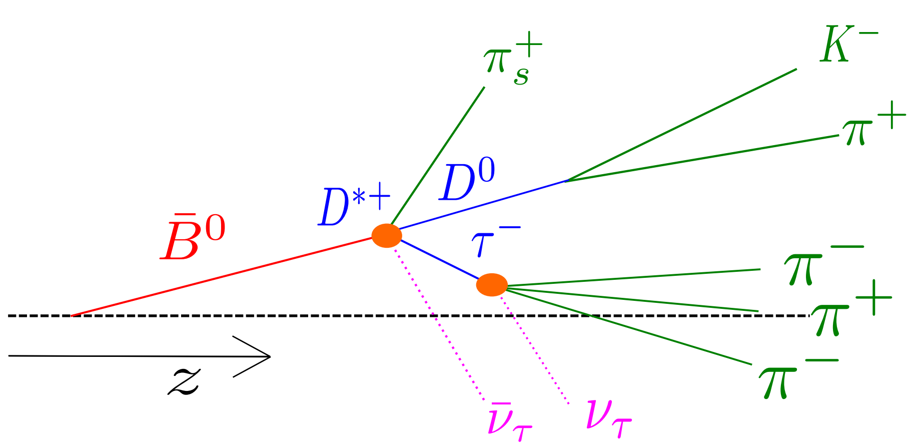
Major backgrounds:

B → D*πππX.

- removed with a flight distance requirement on the τ

B → D*Xc(→πππX)

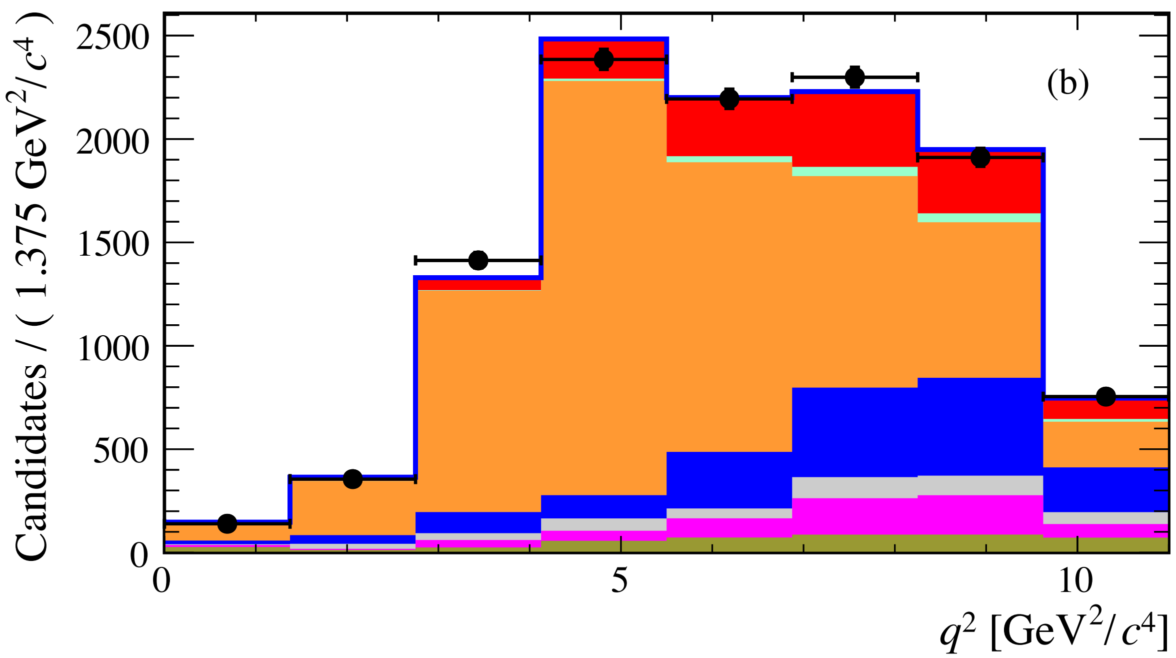
- distinguished with multivariate discriminator

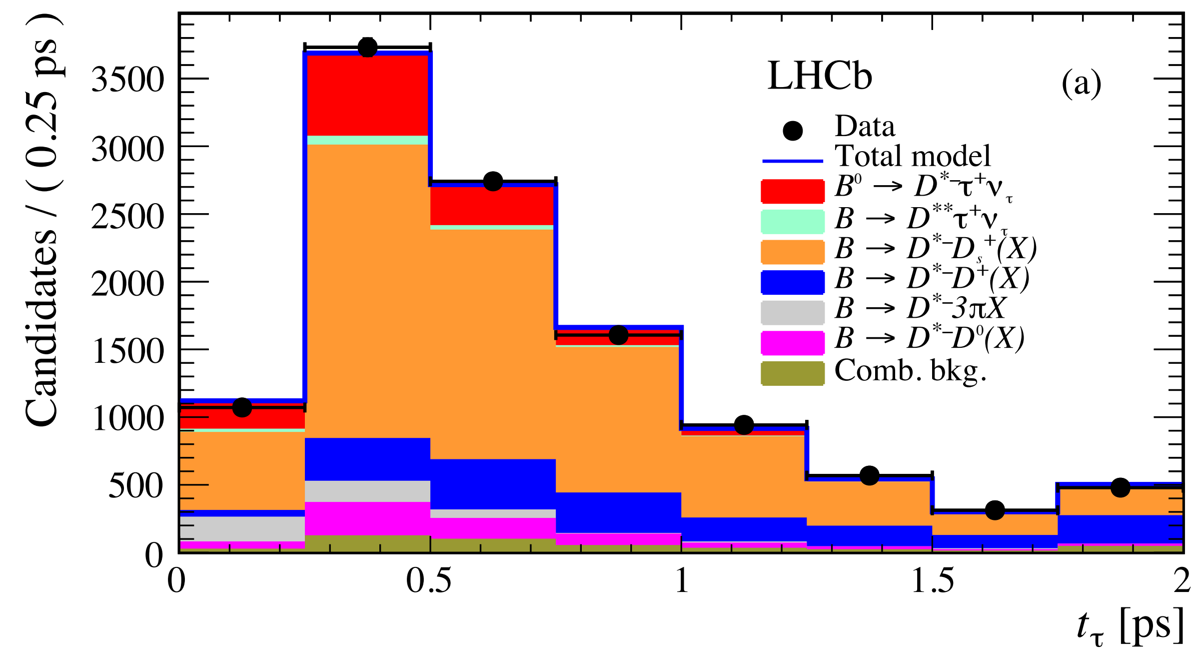


Hadronic R(D*) results

[Phys. Rev. D 97, 072013 (2018)]

Run 1, $3\,\mathrm{fb}^{-1}$. Fit q^2, t_τ, BDT classifier:

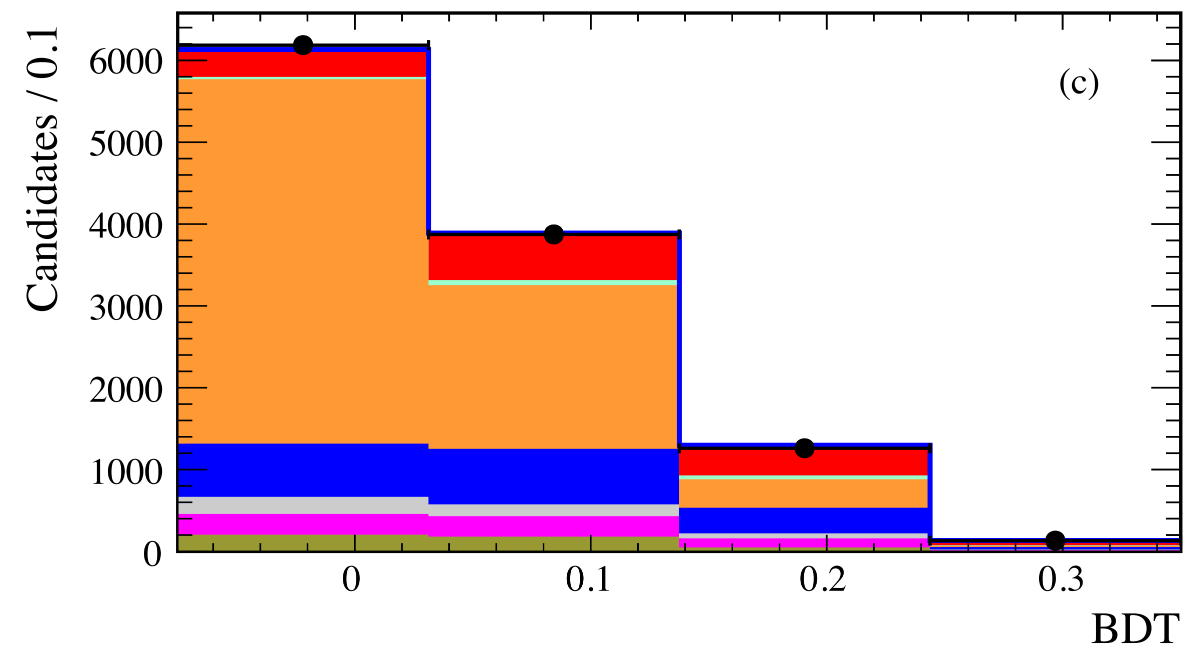




B->D*Ds(X) control sample used to determine necessary fit fractions

$$N_{\rm sig} = 1296 \pm 86 \;\; B^0 \to D^{*-}\tau^+\nu_\tau \text{ decays}$$

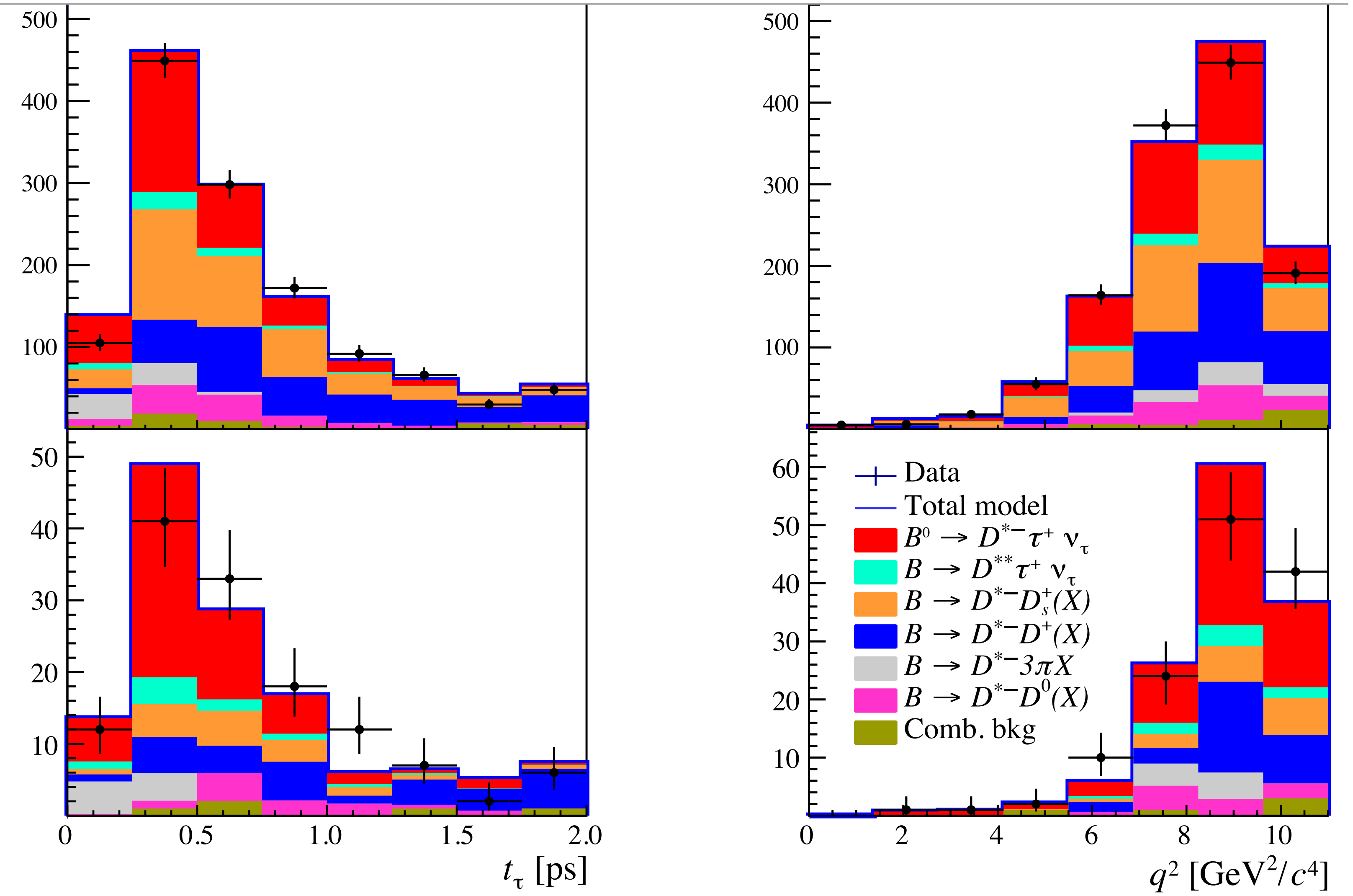
17808 candidates found in the control sample



Hadronic R(D*) results

[Phys. Rev. D 97, 072013 (2018)](#)

2 highest BDT bins



B->D*3π & B->D*μν BR taken from PDG & HFLAV respectively

$$\mathcal{K}(D^{*-}) = 1.97 \pm 0.13\,(\text{stat}) \pm 0.18\,(\text{syst})$$

$$\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau) = (1.42 \pm 0.094\,(\text{stat}) \pm 0.129\,(\text{syst}) \pm 0.054\,(\text{ext})) \times 10^{-2}$$

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

Hadronic R(D*) systematics

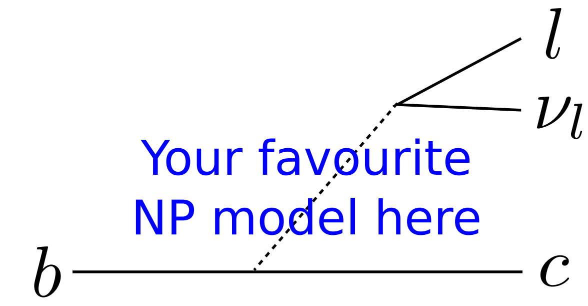
Phys. Rev. D 97, 072013 (2018)

	Contribution	Value in %
Contributions above 2%:	$B \to D^{**}\tau^+\nu_\tau$	2.3
	$D_s^+ \to 3\pi X$ decay model	2.5
	D_s^+, D^0 and D^+ template shape	2.9
	$B \to D^{*-}D_s^+(X)$ and $B \to D^{*-}D^0(X)$ decay model	2.6
	$D^{*-}3\pi X$ from B decays	2.8
	Size of simulation samples	4.1
	Online selection	2.0
	Offline selection	2.0
	Normalization channel efficiency (modeling of $B^0 \to D^{*-}3\pi$)	2.0
Including everything	Total uncertainty	9.1

Main message (apart from R(D*) is a hard measurement to make):

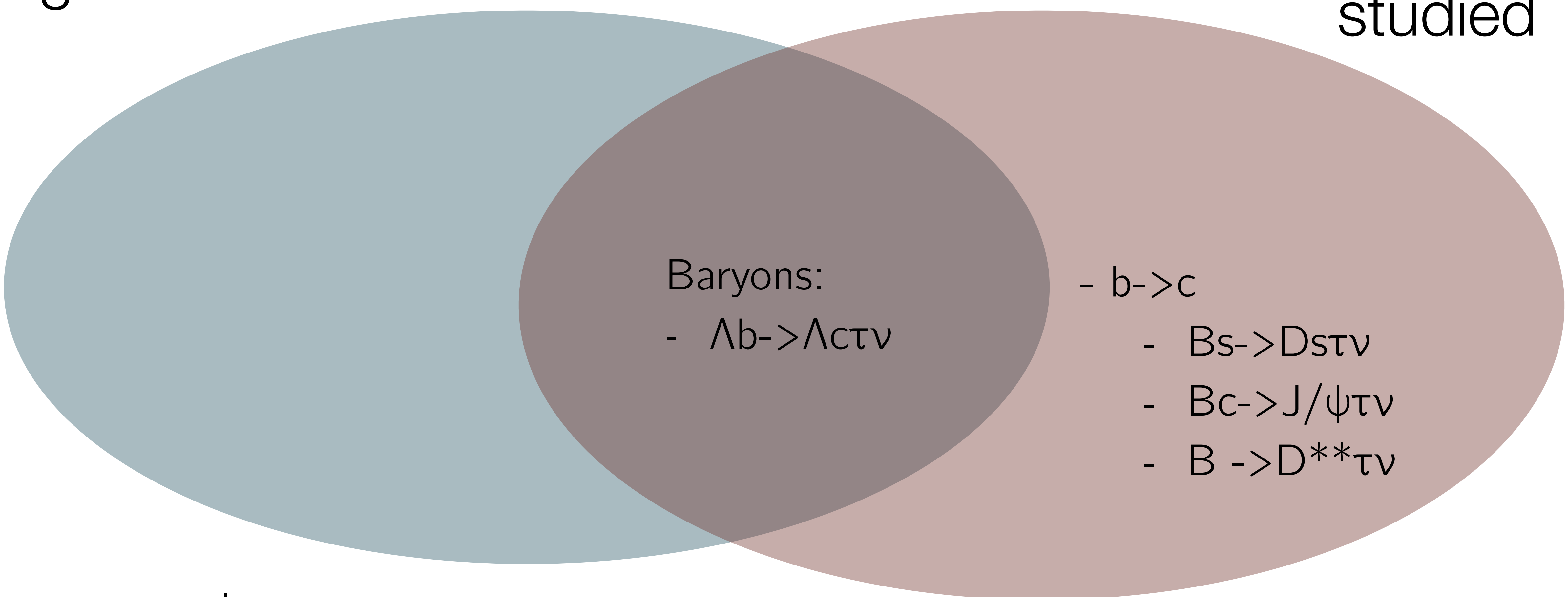
While it is systematics limited, the systematics will be improved

On the todo list…



high stats

theoretically studied



- b->u
  - Flavour structure probes
  - Λb->pτν
  - B->ppτν
  - B->ρτν

R(J/ψ)

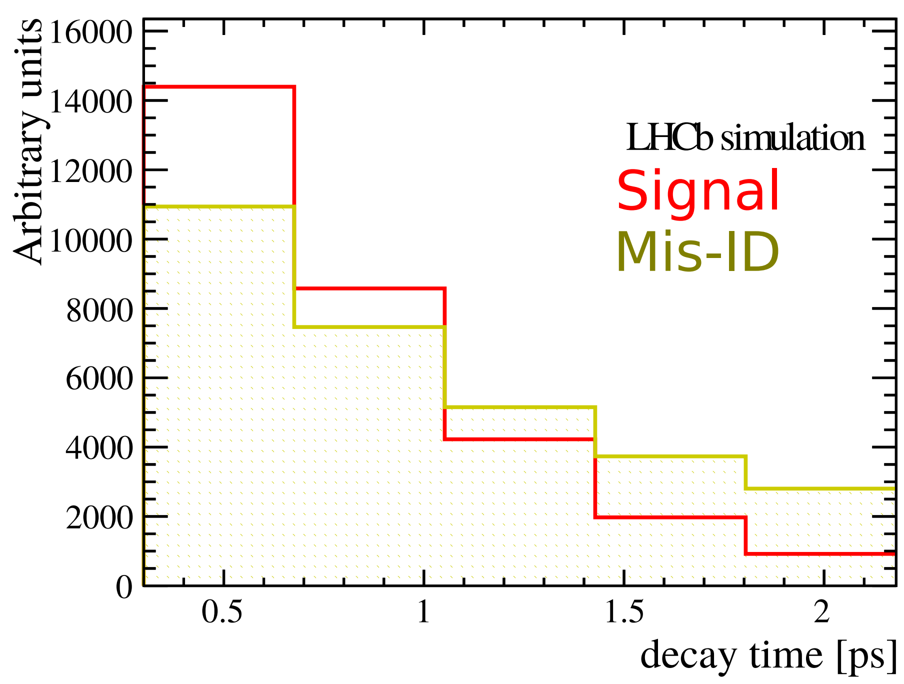
Phys. Rev. Lett. 120, 121801 (2018)

$$R(J/\psi) = \frac{\mathcal{B}(B_c^+ \to J/\psi\, \tau^+ \nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi\, \mu^+ \nu_\mu)} \qquad \tau^+ \to \mu^+ \overline{\nu}_\tau \nu_\mu$$

SM expectation 0.25 – 0.28 (probes same physics as R(D*))

- Phys. Lett. B452 (1999) 129, arXiv:hep-ph/0211021,
- Phys. Rev. D73 (2006) 054024, Phys. Rev. D74 (2006) 074008

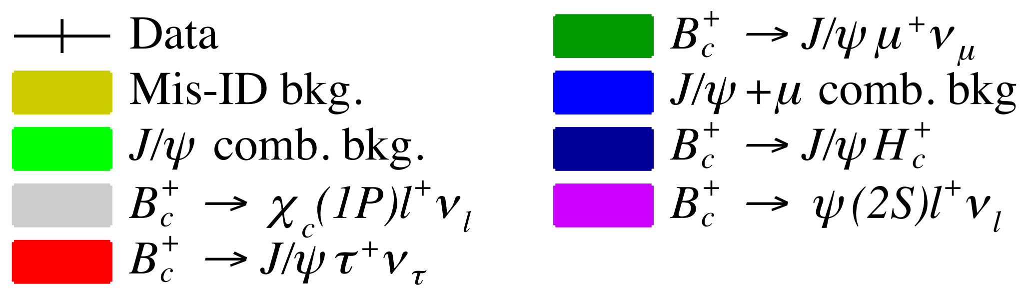
Only measurement is from LHCb



Difference wrt R(D*): use of the decay time in the fit to determine the signal

Complication wrt R(D*): unknown form factors so estimated from fit to enriched sample of the normalisation mode.

R(J/ψ) - results



3D template fit:

$$R(J/\psi) = 0.71 \pm 0.17 \pm 0.18$$

Inclusion of decay time helps distinguish mis-ID background

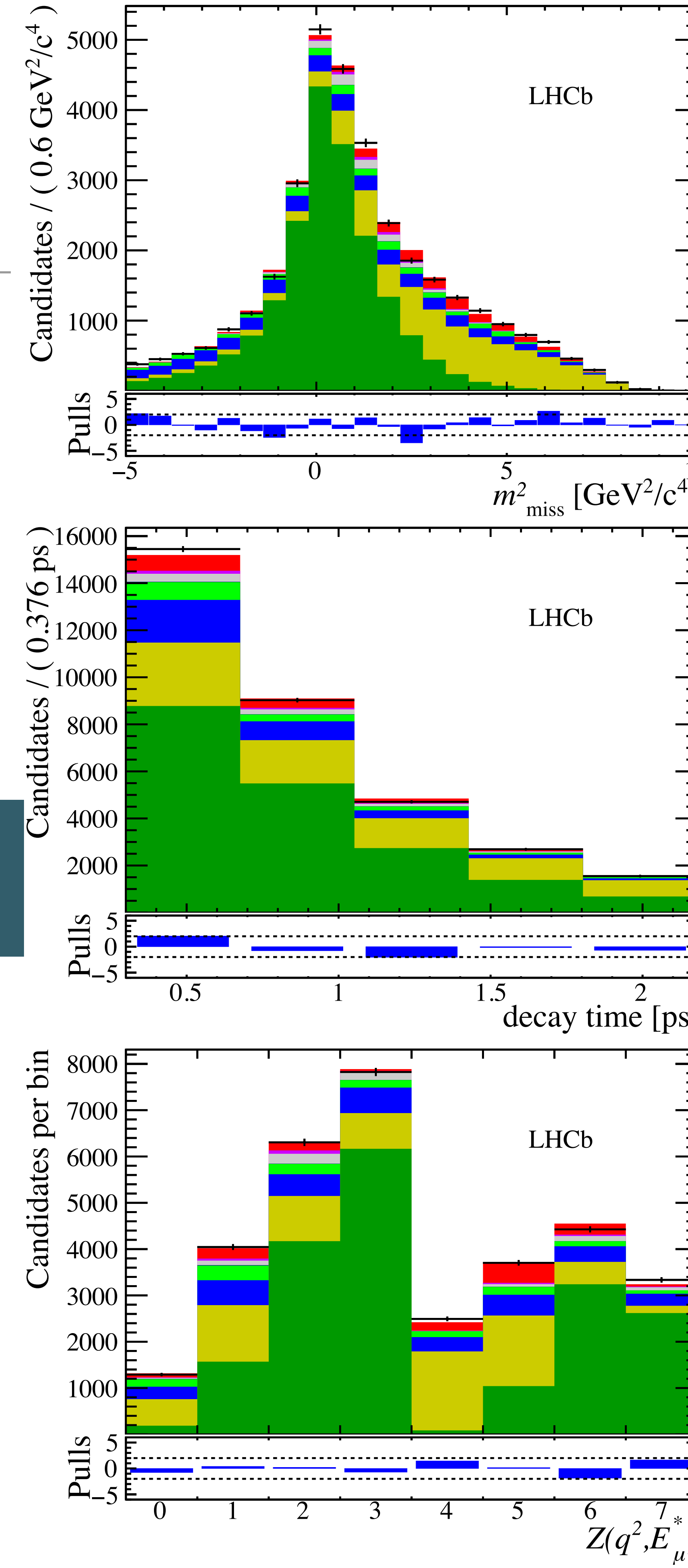
Compatible with SM at 2 σ.

First evidence of decay $B_c^+ \to J/\psi \tau^+ \nu_\tau$

Largest systematics from $B_c \to J/\psi$ form-factor and limited simulation sample size - both can be improved.

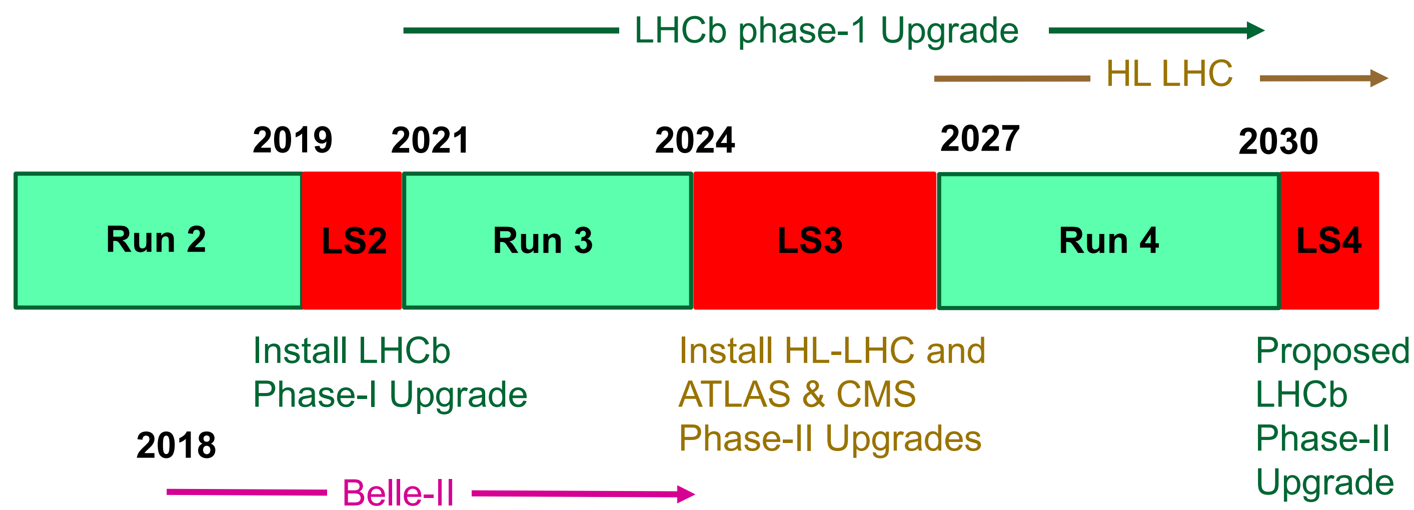
Lattice form-factor calculation is on the way

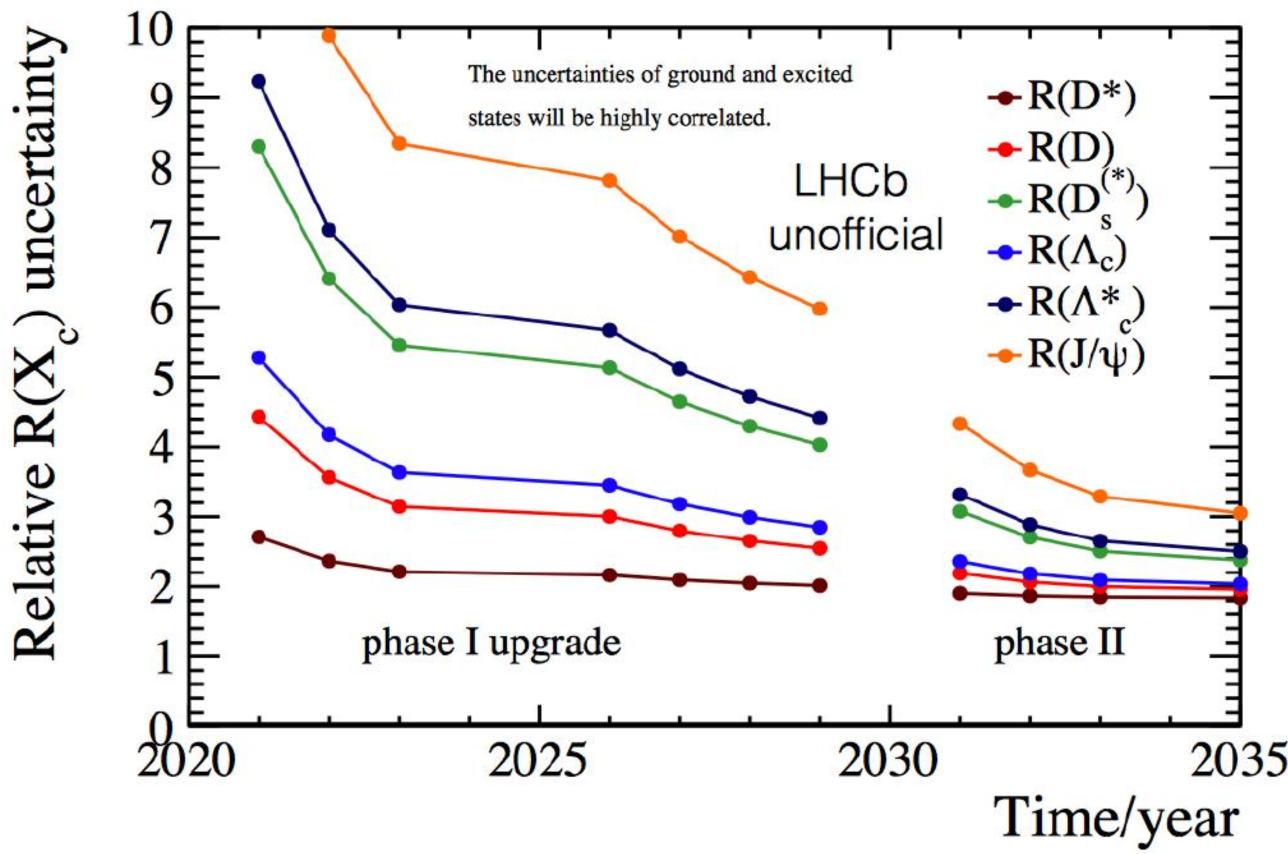
Phys. Rev. Lett. 120, 121801 (2018)



Prospects for the future

Upgrade I:
CERN-LHCC-2012-007
Upgrade II:
CERN-LHCC-2017-003





Improvement in the plot assumes:

- More simulated events
- theory input
- experimental input

arXiv:1808.08865

Summary

Presented IMO some of the most interesting results in the field.

Tensions are present (all above SM predictions) that need to be resolved or understood.

Systematics are a continual challenge but we haven't reached the end yet so as always...

Backup

Backup: hadronic R(D*) control samples

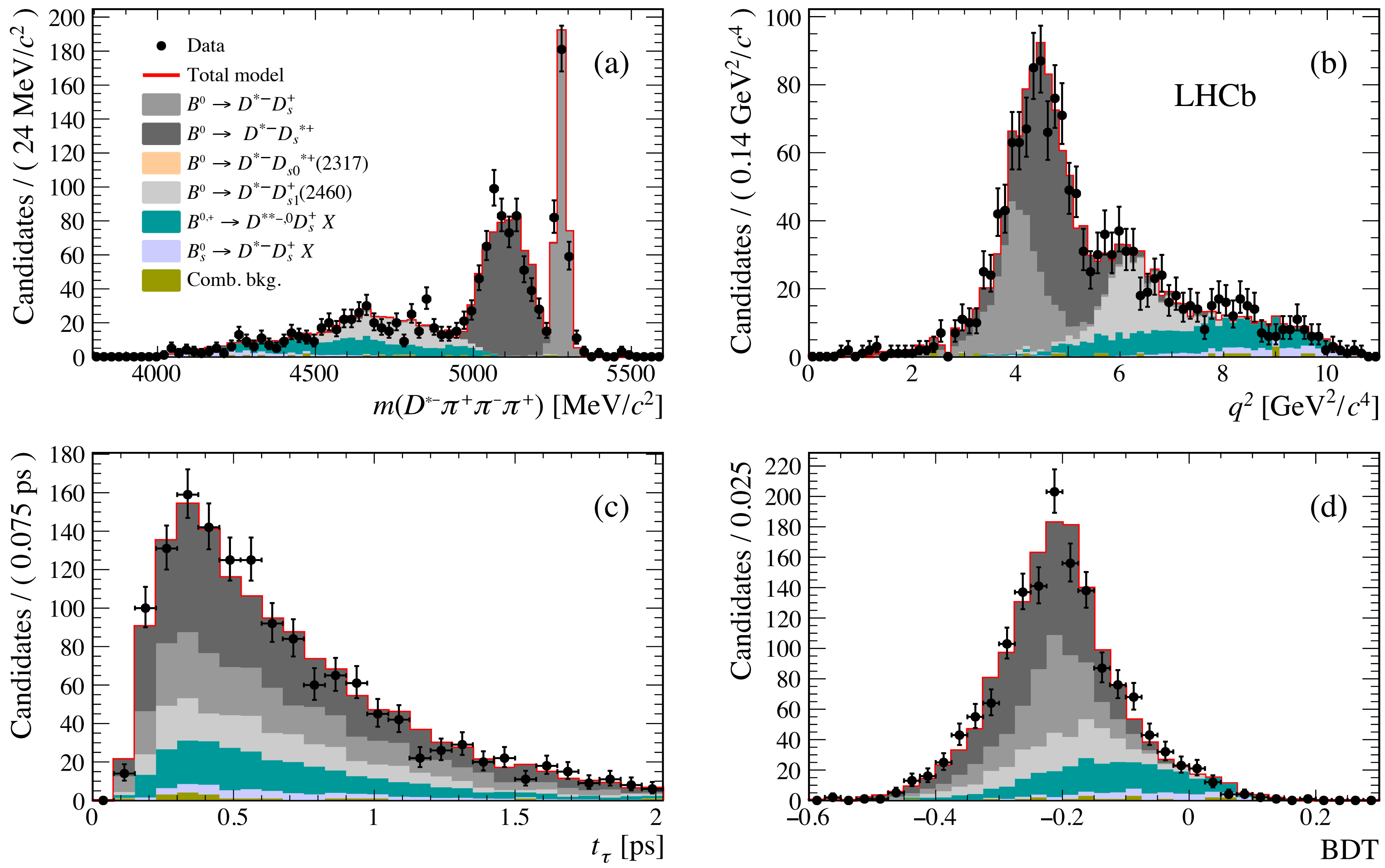


Figure 14: Results from the fit to data for candidates containing a $D^{*-}D_s^+$ pair, where $D_s^+ \to 3\pi$. The fit components are described in the legend. The figures correspond to the fit projection on (a) $m(D^{*-}3\pi)$, (b) q^2, (c) 3π decay time t_τ and (d) BDT output distributions.