Measurements of lepton flavour universality in B_c^+ meson decays

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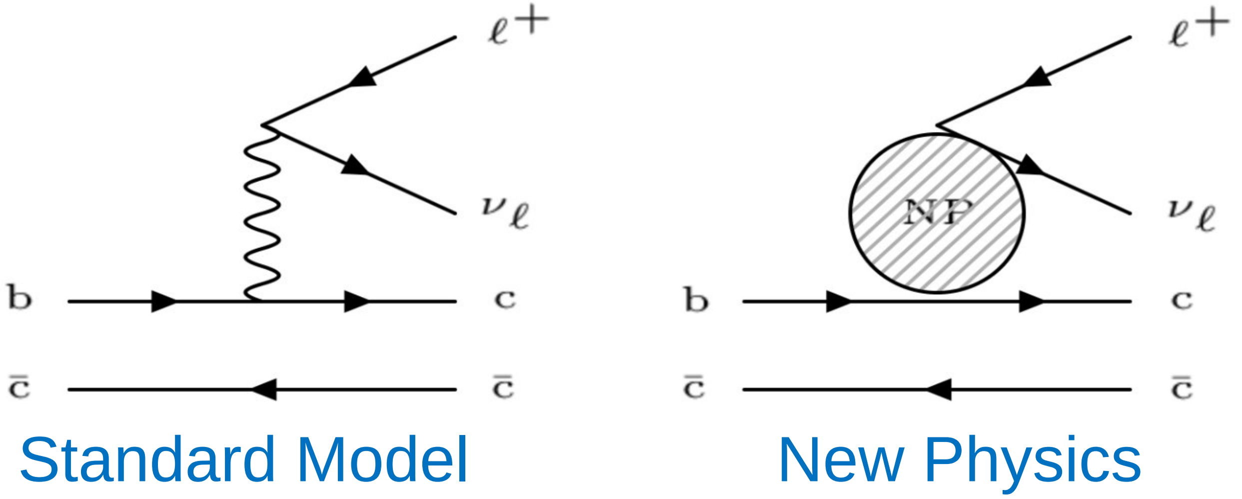
24th October 2024

Author acknowledges support by RSF (grant No. 23-12-00083)

Outline

- Introduction
- Leptonic τ decay cannel
- Hadronic τ decay cannel
- Summary

- In SM the three lepton families have the same couplings for electroweak interactions - Lepton Flavour Universality (LFU)
- A potential observation of LFU violation would be a clear sign of new physics beyond the SM
- Most measurements are consistent with LFU , though there are residual indications of potential violation in b → cτν transitions



Introduction

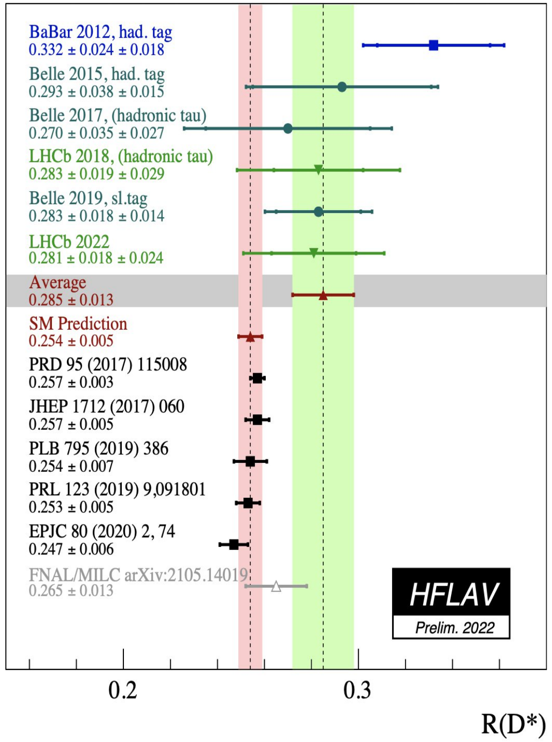
- BaBar, Belle and LHCb collaborations investigated R(D) and R(D^*)

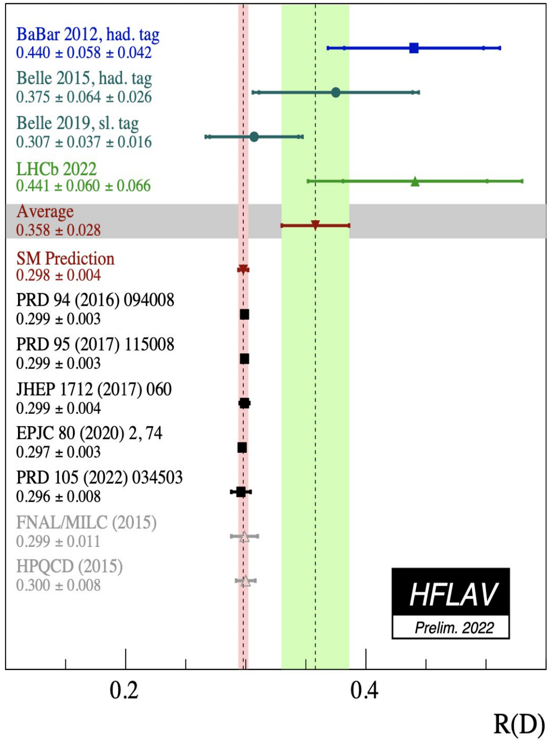
- Combination of both R(D) and R(D^*) measurements is 3.2 σ larger than the SM prediction

- The LHCb Collaboration measured R(J/ψ) = B($B_c^+ \to J/\psi\tau^+\nu_\tau$)/ B($B_c^+ \to J/\psi\mu^+\nu_\mu$) = 0.71 ± 0.17 (stat) ± 0.18 (syst) 2σ deviation w.r.t. SM

Phys. Rev. D 88, 072012 Phys. Rev. D 94, 072007

Phys. Rev. Lett. 115, 159901





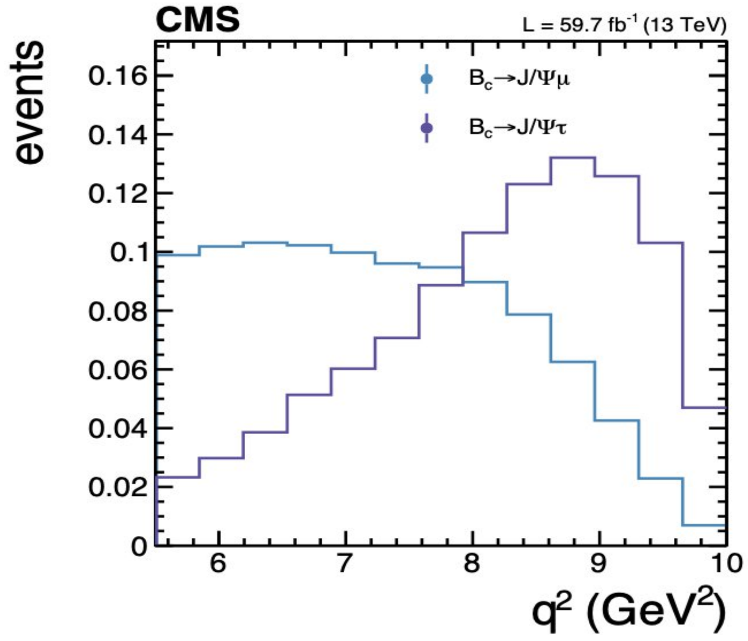
Phys. Rev. Lett. 120, 121801

R(J/ψ) in the $\tau^+ \to \mu^+ \upsilon_\mu \overline{\upsilon}_\tau$ channel

Signal extraction

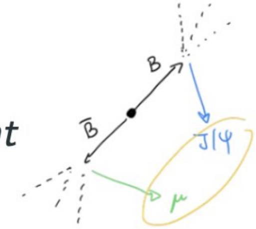
$$R(J/\psi) = \frac{B(B_c \to J/\psi\tau\bar{\nu})}{B(B_c \to J/\psi\mu\bar{\nu})} = \frac{B(B_c \to J/\psi\mu\nu\bar{\nu}\bar{\nu})}{B(B_c \to J/\psi\mu\bar{\nu})}$$

- Measurement uses Run2 2018 CMS data corresponding to an integrated luminosity of 59.7 fb^{-1}
- Similar final states for num. and den. (3μ) - same reconstruction is used
- To infer the p^{B_c} the collinear approximation is used: B_c has the same direction of the visible final state, and $p^{B_c} = \frac{m_B}{m_{reco}} p^{B_c\,\mathrm{reco}}$
- $q^2 = (p^{B_c} - p^{J/\psi})^2$

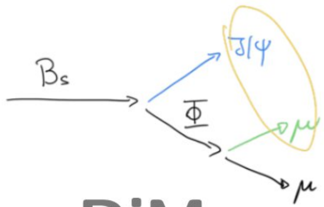


$J/\psi\mu$ background: *dominant*

MC based; normalisation data-driven



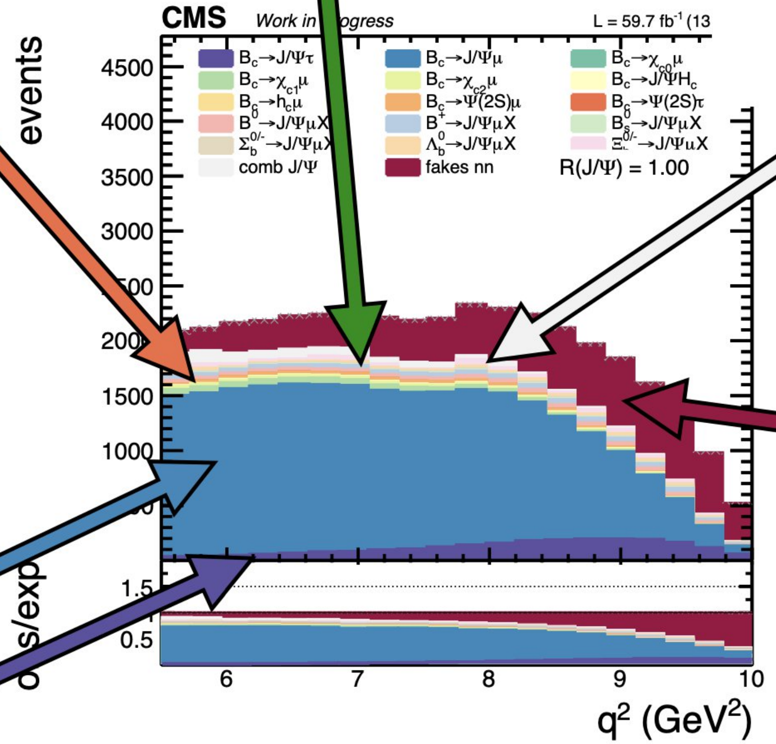
negligible



B_c background:

MC based; normalisation data-driven

- Feeddowns: excited $c\bar{c}$ states to J/ψ
- Other J/ψ+charmed hadron, mostly $B_c \to D_s^{(*)} J/\psi$



DiMuon

Data-driven

Pairs of unrelated muons with m(μμ) close to that of the J/Ψ

Muon fakes

Data-driven anti-isolated μ sideband

J/Ψ + misidentified hadron

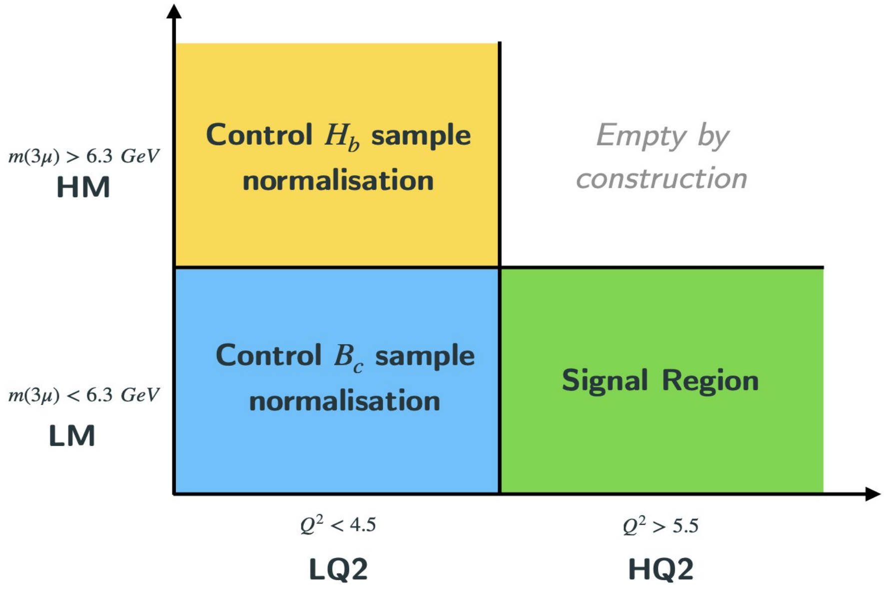
Signals:

Signal μ: $B_c \to J/\psi\mu\nu_\mu$

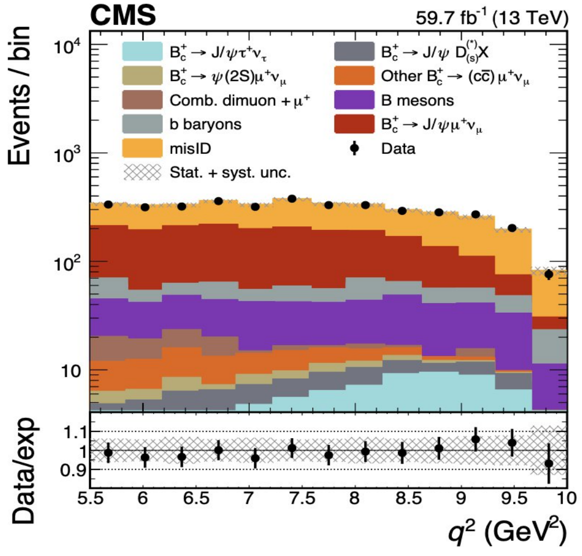
Signal τ: $B_c \to J/\psi\tau\nu_\tau$

Fit strategy

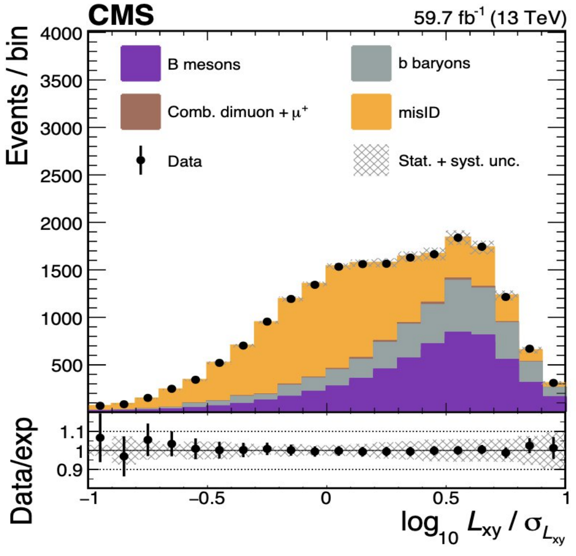
Category pair definitions			Fit observable
$m(3\mu)$	q^2	$\mathrm{IP3D}/\sigma_{\mathrm{IP3D}}$	
$<m_{\mathrm{B}_c^+}$	$>5.5\,\mathrm{GeV}$	<-2 $-1-0$ $0-2$ >2	q^2
$<m_{\mathrm{B}_c^+}$	$<4.5\,\mathrm{GeV}$	<0 >0	$L_{xy}/\sigma_{L_{xy}}$
$>m_{\mathrm{B}_c^+}$	—	—	$L_{xy}/\sigma_{L_{xy}}$



- A binned maximum-likelihood fit is performed simultaneously to all categories
- Several systematic uncertainties are incorporated into the fit as nuisance parameters



Signal region with IP3D/σ_{IP3D} >2



Control region with m(3μ) > m(B_c)

Results

Final result: $R(J/\psi) = 0.17^{+0.18}_{-0.17}$ (stat)$^{+0.21}_{-0.22}$ (sist)$^{+0.19}_{-0.18}$ (theo) = 0.17 ± 0.33

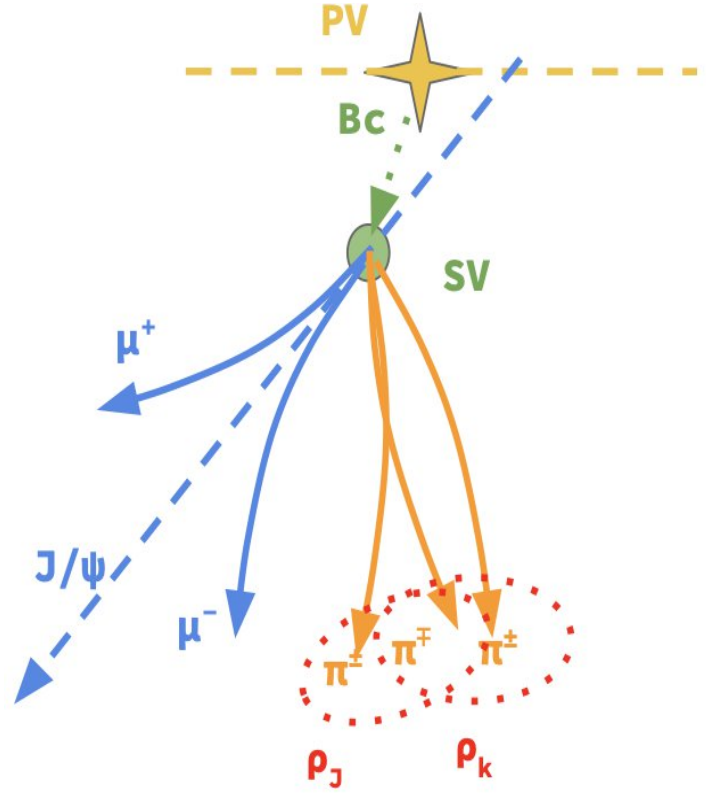
- The result agrees with SM value 0.2582 ± 0.0038 within 0.3σ
- The result is compatible with the LHCb measurement 0.71 ± 0.17 (stat) ± 0.18 (syst) withi 1.3σ

R(J/ψ) in the $\tau^{+} \to \pi^{+}\pi^{-}\pi^{+}(+\pi^{0})\,\overline{\nu}_{\tau}$ channel

Signal extraction

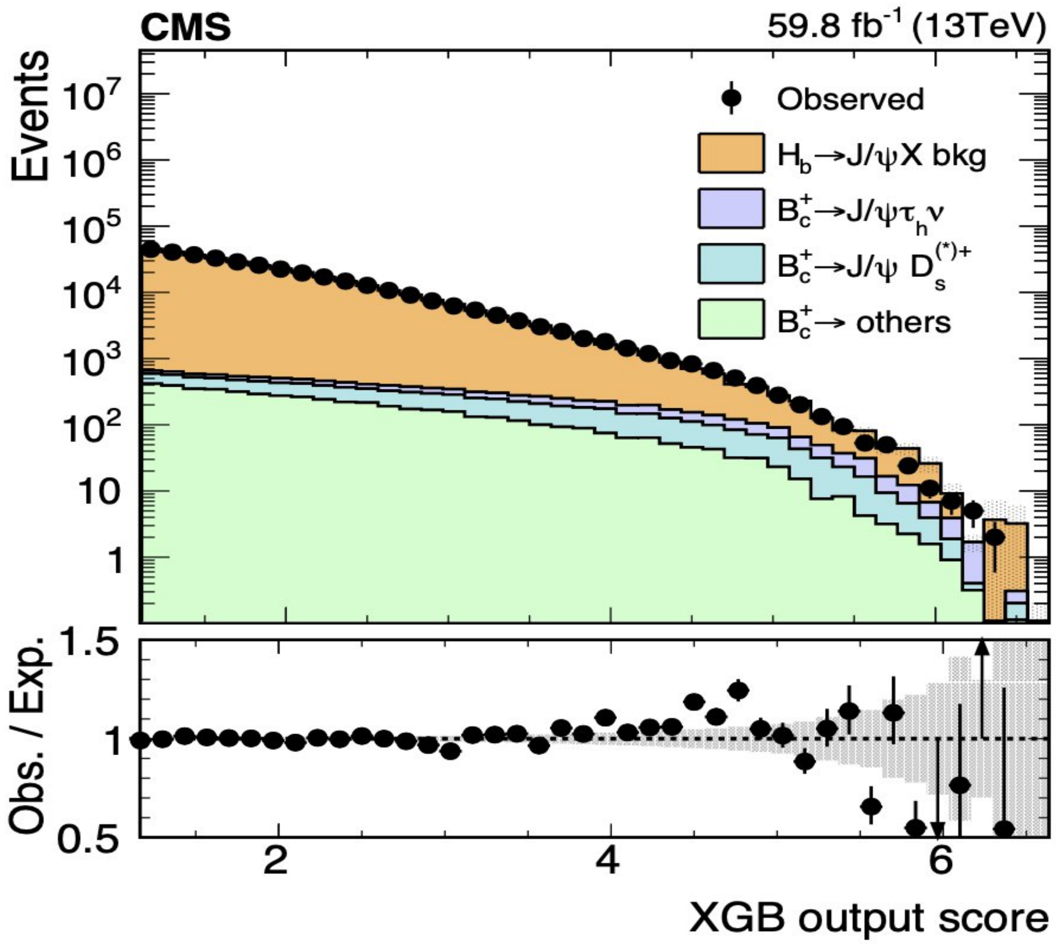
- Analysis is based on Run2 2016-2018 CMS data corresponding to an integrated luminosity of 138 fb^{-1}
- 3 prong tau decays have a good chance to produce an intermediate ρ(770MeV)-resonance (→2π)
- OS pairs as possible ρ(770MeV) combinations: π1+π2; π1+π3; π2+π3
- The unrolled ρ1-ρ2 distribution is used as discriminating variable in the fit for the signal

$$R(J/\psi) = \frac{B(B_c \to J/\psi\tau\bar{\nu})}{B(B_c \to J/\psi\mu\bar{\nu})} = \frac{B(B_c \to J/\psi\pi\pi\pi(+\pi^0)\bar{\nu})}{B(B_c \to J/\psi\mu\bar{\nu})}$$



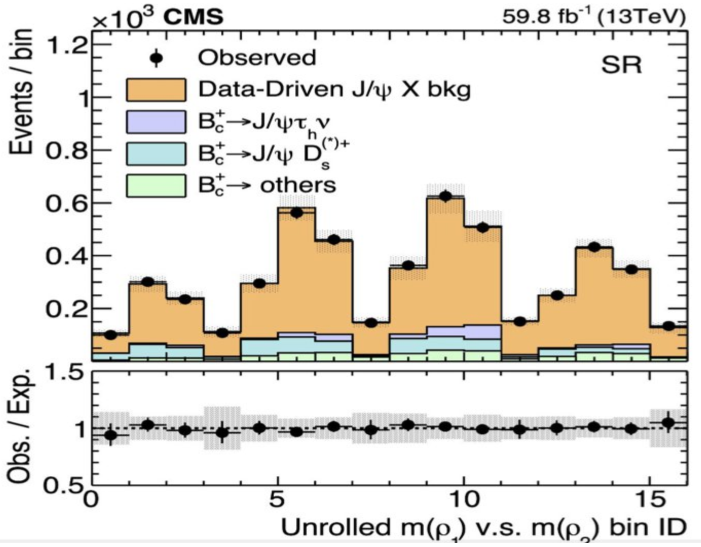
Background estimation

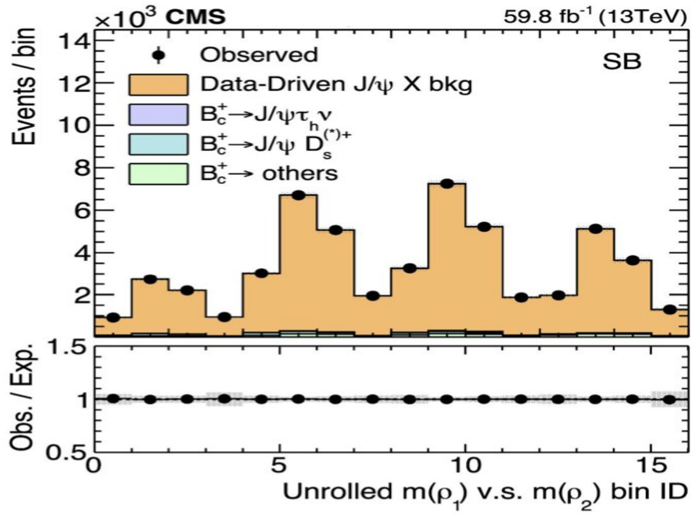
- Signal (estimation based on MC)
- Bc Backgrounds: Bc→J/ψD(*)s (→ 3 prong) (MC)
- Other Bc decays: mainly Bc→J/ψD+(*), Bc→J/ψD+K0(*), Bc→J/ψD0(*)K+ (MC)
- Major background pp->Hadr(b)->J/ψ + X: Non-Bc hadrons producing J/ψ+X final state.Estimated directly in data.



- *The SR is defined as BDT > 4.2 (BDT > 3.5) for the 2017/2018 (2016) data sets.*
- *The SB region is defined as 2.5 < BDT < 3.5 (2 < BDT < 3) for 2017/2018 (2016)*

Fit strategy





- Simultaneous fit is performed with the leptonic τ analysis
- Systematic uncertainties are incorporated into the fit as nuisance parameters
- Fit can treat the common nuisance parameters between two channels

Results

- The leptonic τ analysis uses 2018 data only, therefore R(J/ψ) (2018) is evaluated, by ignoring the 2016 and 2017contributions, and it is measured to be $0.74^{+0.57}_{-0.53}$
- By combining also the contributions from 2016 and 2017:

$$R(J/\psi) = 1.04^{+0.50}_{-0.44}$$

- Final result from overall simultaneous fit (including also the numerator from leptonic analysis):

$$R(J/\psi) = 0.49 \pm 0.25 \text{ (stat)} \pm 0.09 \text{ (sist)}$$

Summary

- The first measurement of R(J/ψ) from general purpose experiment is performed

- For the lepronic τ decay analysis:

  $R(J/\psi) = 0.17 \pm 0.33$

- For the hadronic τ decay analysis:

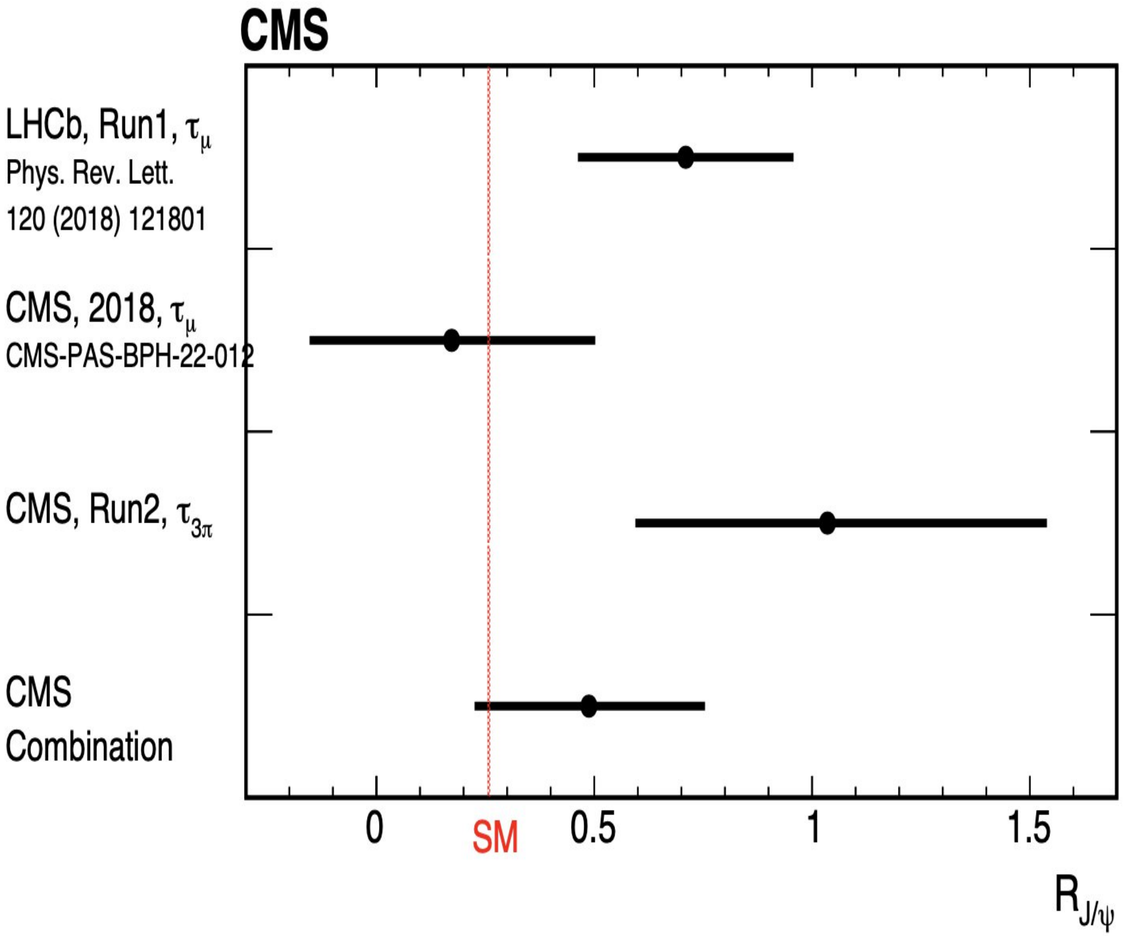
  $R(J/\psi) = 1.04^{+0.50}_{-0.44}$

- Combination of leptonic and hadronic decay modes gives:

  $R(J/\psi) = 0.49 \pm 0.25$ (stat) ± 0.09 (sist)

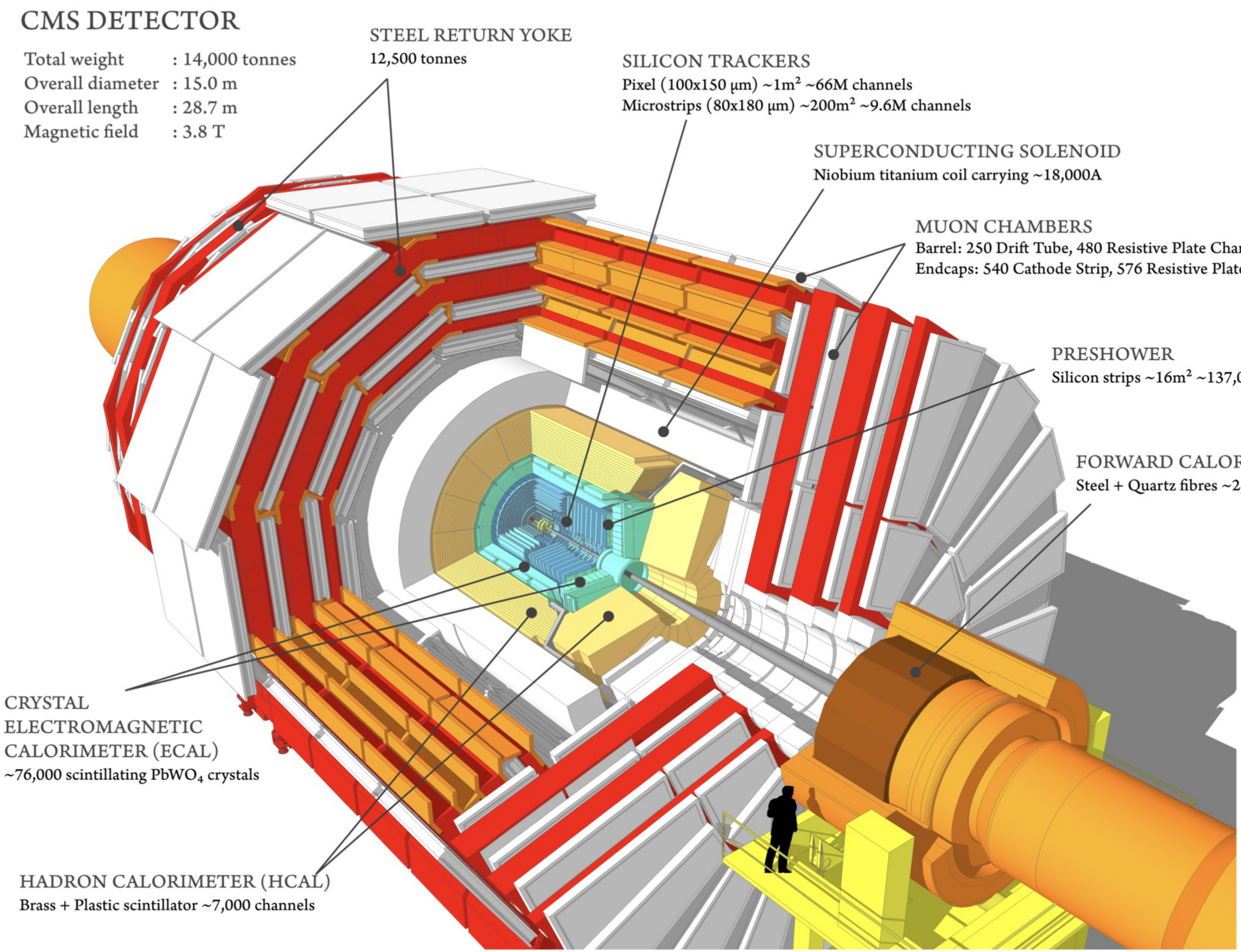
  , which is consistent with the SM within 1σ

- Precision competitive with the current result from LHCb



Backup slides

CMS detector



Systematics - leptonic channel

Contribution	Type	Unc. (10^{-2})
Form factor (theory)	S	19
misID statistical	S (bin-by-bin)	13
misID systematic	N, S	8, 0.7
Finite MC size	S (bin-by-bin)	9
Topological	S	9
Efficiencies	N	6
Total systematic uncertainty		28

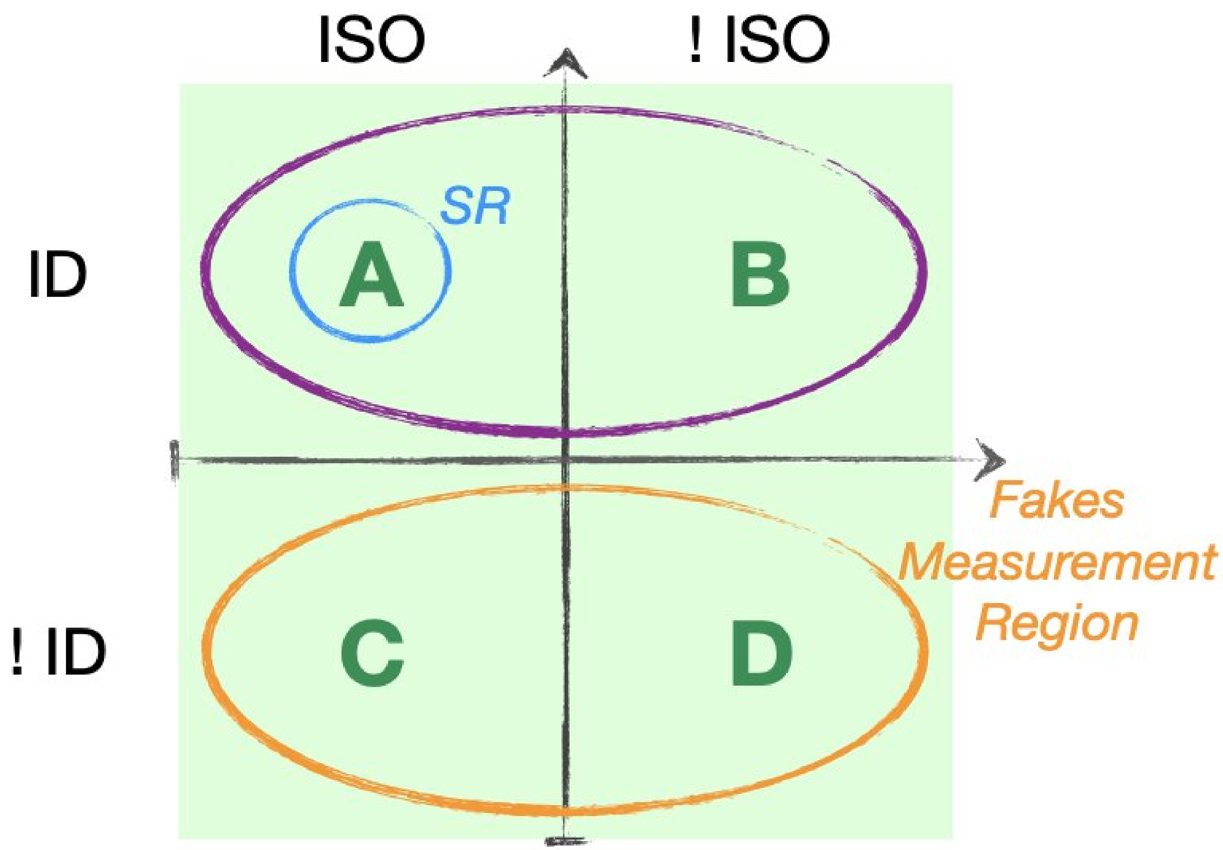
Systematics - hadronic channel

Systematic source	Type	Affected proc.	channel			
			τ_μ 2018	τ_h 2018	τ_h 2017	τ_h 2016
Form factor	shape	$B_c^+ \to J/\psi \ell \nu_\ell$	✓	✓	✓	✓
Tauola modeling	shape	$B_c^+ \to J/\psi \tau^+ \nu_\tau$		✓	✓	✓
B_c^+ decay lifetime	shape	All B_c^+ procs.	✓	✓	✓	✓
$H_b \to J/\psi X$ shape	shape	DD bkg.		✓	✓	✓
Pileup weight	shape	All MC	✓	✓	✓	✓
Missing B_c^+ bkg.	shape	other B_c^+		✓	✓	✓
Bin-by-bin uncertainties	shape	All	✓	✓	✓	✓
Triplet reco. eff.	norm.	$B_c^+ \to J/\psi \tau^+ \nu_\tau$		6.9% (✓)	6.9% (✓)	6.9% (✓)
$B_c^+ \to J/\psi D_s^{(*)}$ normalisation	norm.	$B_c^+ \to J/\psi D_s^{(*)}$	38% (✓)	38% (✓)	38% (✓)	38% (✓)
Other minor B_c^+ normalisation	norm.	other B_c^+		50% (✓)	50% (✓)	50% (✓)
Trigger ($\mu^+\mu^-$)	norm.	All MC	10% (✓)	10% (✓) $\oplus$ 5%	10%	10%
Trigger (track)	norm.	All MC		10%	10%	10%
Trigger (J/ψ)	norm.	All MC		10%	10%	10%
Muon ID	norm.	All MC	4%	4%	4%	4%
Muon Reco	norm.	All MC	4% (✓)	4% (✓)	4%	4%
Bkg. norm.	norm.	DD bkg.		30%	30%	30%
B_c^+ MC norm.	norm.	All B_c^+		5%	30%	30%
Displaced track reco eff.	norm.	All B_c^+		5% (✓)	5% (✓)	5% (✓)

Fakes μ estimate

1. the SoftMva ID = 0 region is used to learn the ”difference” between the $\Delta\beta\mathrm{corriso}\mu3 < 0.2$
and $\Delta\beta\mathrm{corriso}\mu3 > 0.2$ subregions, named region C and D in the scheme;

2.results are then extrapolated to the softMvaID = 1region to find the fakes shape in region A.



Combinatorial J/ψ dimuon background

The Combinatorial Background comes from pairing unrelated muons to form J/ψ candidates.

To estimate this background in SR:

- The dimuon shape is taken from SB and kinematical correction
- The dimuon normalisation is taken from the fit to m(μμ)