SL decays of B meson, R(D) and R(D*) anomaly

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Outline

1. B -> D* lν decays, R(D) and R(D*) anomaly

2、 New measurements from Belle and LHCb

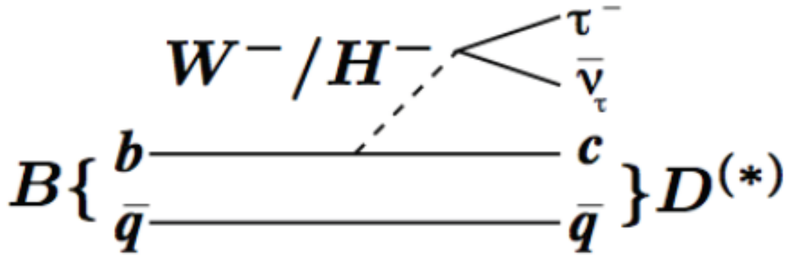
3、 R(D) and R(D*), the pQCD prediction

4. Summary

1. $B \to D^{(*)} l\nu$ decays, R(D) and R(D*) anomaly

SemiLeptonic B/B_s decays

- BABAR measurements:
  PRL 109, 101802 (2012);
  Evidence for an Excess of
  B \to D^(*) \tau \nu Decays



$$\mathcal{R}(D) \equiv \frac{\mathcal{B}(B \to D\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B \to Dl^-\bar{\nu}_l)} = 0.440 \pm 0.072,$$

$$\mathcal{R}(D^*) \equiv \frac{\mathcal{B}(B \to D^*\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B \to D^*l^-\bar{\nu}_l)} = 0.332 \pm 0.030,$$

SM predictions are:

$$R(D) = 0.297 \pm 0.017,$$

$$R(D^*) = 0.252 \pm 0.003$$

3.4σ deviation from SM(HQET) !

1. Some authors, however, try to understand the measured $R(D^{(*)})$ in SM:
   - In RQ model[10] (MPL A27,1250183(2012)) ;
   - By using the FFs computed in lattice QCD [8] (PRL 109, 071802(2012)) ;
   - By maximally employing the experimental information on the relevant FFs from the data of $B \to D l \bar{\nu}_l$ [18] (hep-ph1301.1167) .

But they all failed to explain the BaBar's $R(D^{(*)})$ anomaly.

- Semileptonic decays of B/Bs decays with τ lepton in the final state are sensitive to charged Higgs
- The ratios of the branching ratios R(D) and R(D*) are both theoretically and experimentally clean !

- **BaBar's anomaly of R(D), R(D*) are very hot topics since May 2012 !**

- J.P.~Lees , et al. BABAR Collab., PRL 109, 101802 (2012); 引用已经超过**200**次！

2. New measurements from Belle and LHCb

◆ Belle new data:

T.Kuhr, talk given at FPCP 2015;

M.Huschel, ph.D Thesis, 2015.01

Belle, 1507.03233v2 [hep-ex];

$$R = 0.375^{+0.064}_{-0.063} \pm 0.026$$
$$R^* = 0.293^{+0.039}_{-0.037} \pm 0.015 \,.$$

◆LHCb:
1506.08614

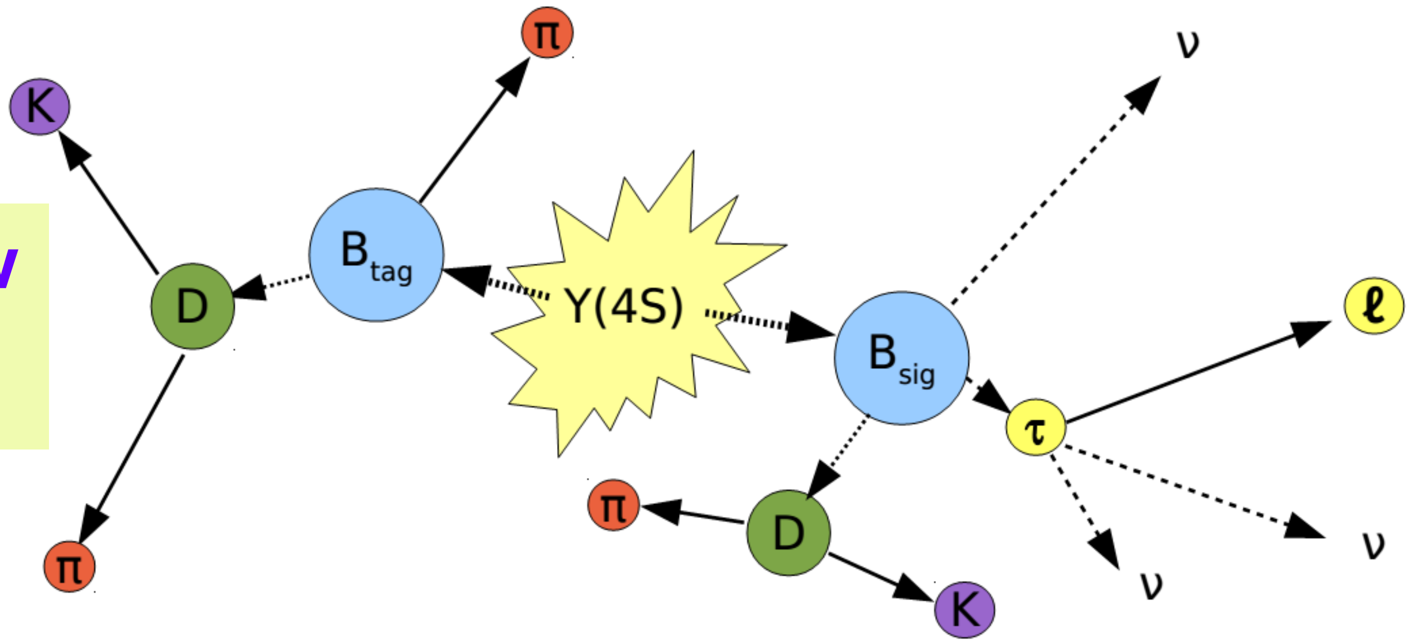
Measurement of the ratio of branching fractions $\mathcal{B}(\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau)/\mathcal{B}(\overline{B}^0 \to D^{*+}\mu^-\overline{\nu}_\mu)$

R(D*)=0.336±0.027±0.030

The LHCb collaboration[†]

Abstract
The branching fraction ratio $\mathcal{R}(D^*) \equiv \mathcal{B}(\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau)/\mathcal{B}(\overline{B}^0 \to D^{*+}\mu^-\overline{\nu}_\mu)$ is measured using a sample of proton-proton collision data corresponding to 3.0 fb^{-1} of

Belle new data:



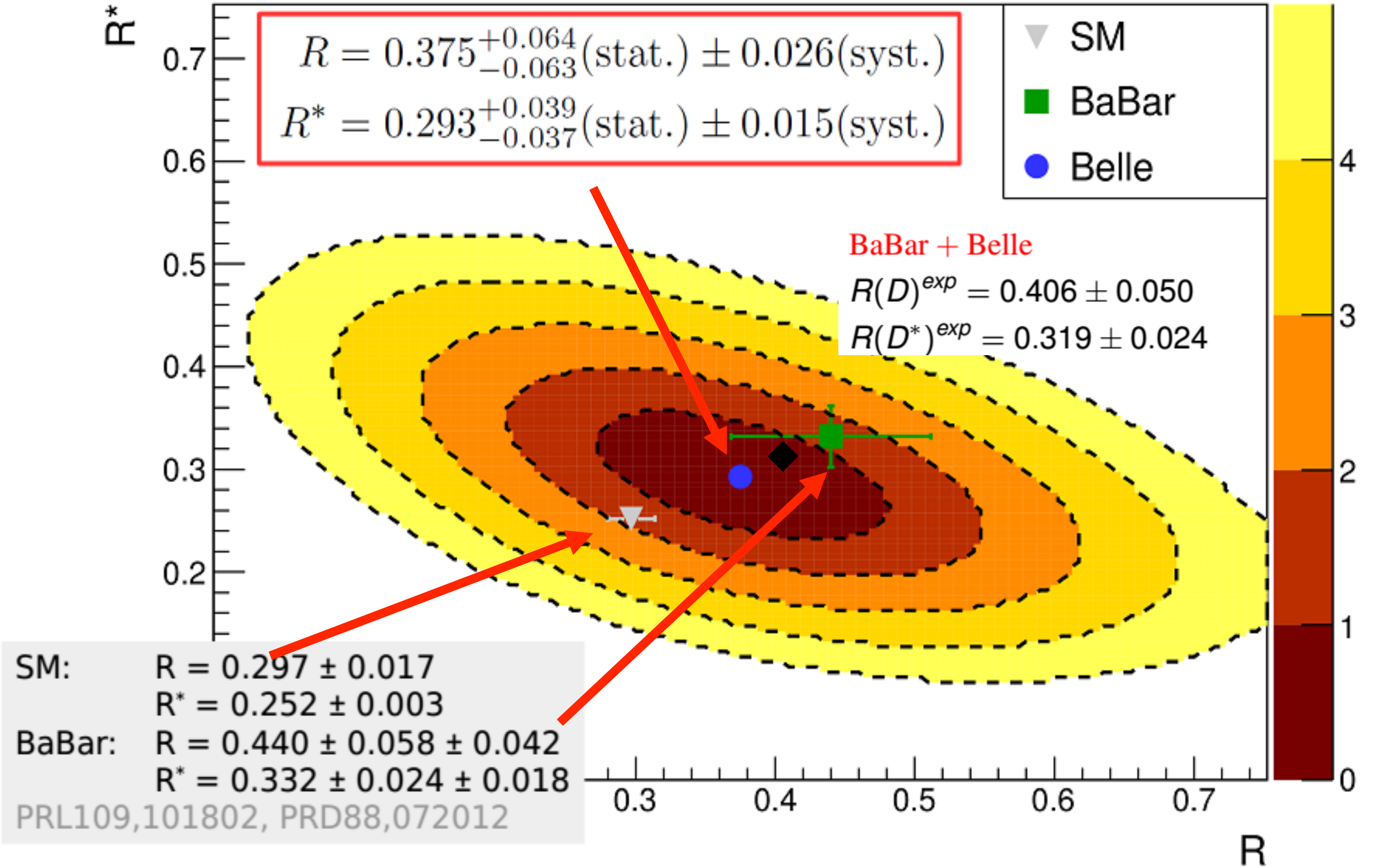
◆ **Belle new results using its full data:**

--- Tag B determines charge and momenta of signal B

--- All remaining particles must come from signal B

--- Not possible at hadron colliders

◆ BaBar + Belle, T. Kuhr, FPCP2015, May 2015, Japan



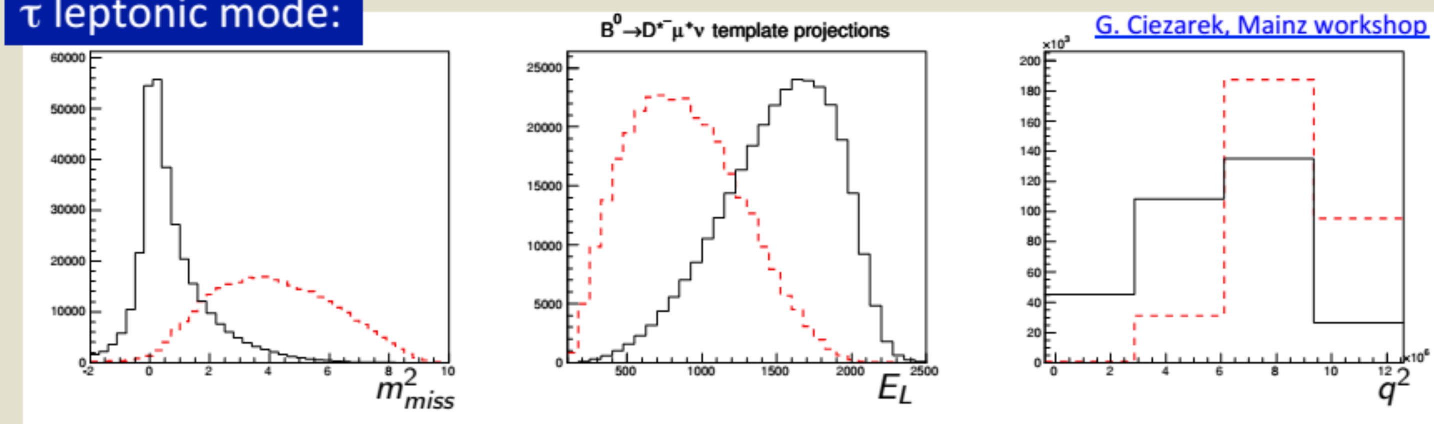
◆ C.Bozzi, talk given at B2Tip, Crakow, 2015.04.17

$B \to D^* \tau \nu$ at LHCb

- Experimentally challenging due to **additional neutrino(s)**
- Two tau decay modes being studied:

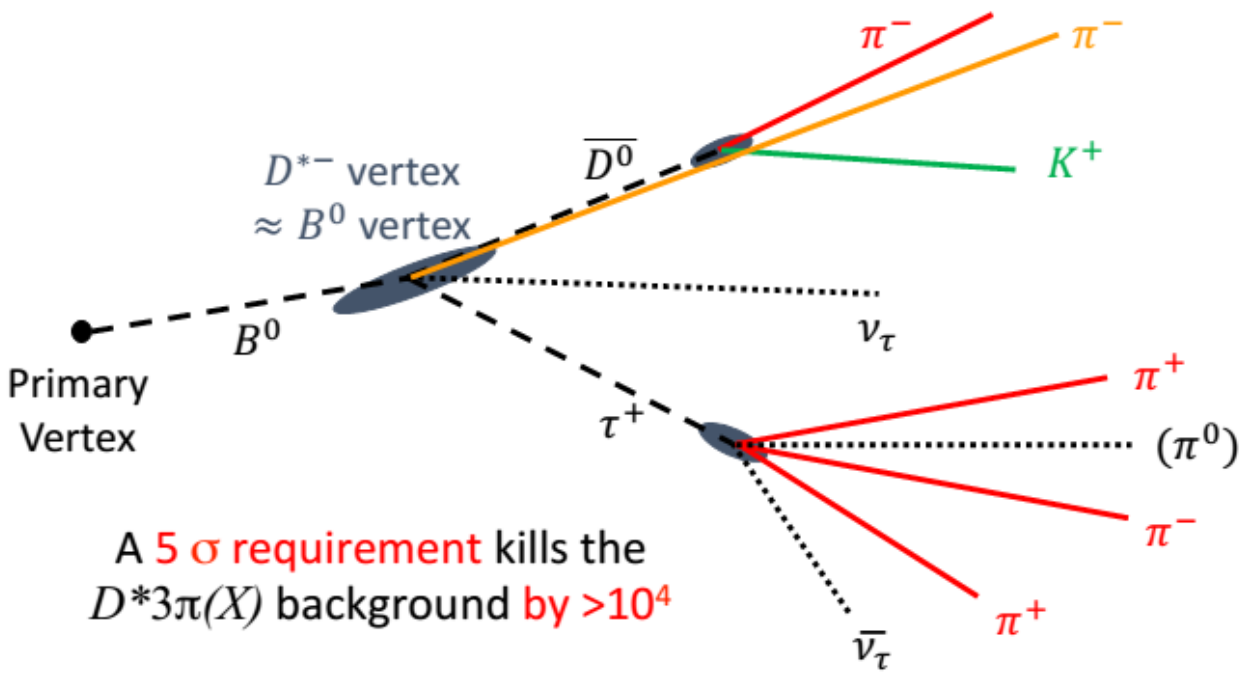
  leptonic: $\tau \to \mu \nu_\mu \nu_\tau$ 3-prong: $\tau \to 3\pi(\pi^0)\nu_\tau$
- Main backgrounds: **partially reconstructed B decays**
  - D*(*)μν, D*3πX, D*D(s)(*)X…
  - use **isolation criteria** (MVA) and/or **τ flight length**
- Find and fit distributions which differentiate **signal** and **background**.

τ leptonic mode:



$B \to D^* \tau \nu$, with $\tau \to 3\pi(\pi^0)$

- Doing semileptonic physics **without leptons in the final state!**
- The $B \to D^* \tau \nu$ decay, with $\tau \to 3\pi(\pi^0)$ leads to a ***$D^*3\pi(X)$* final state**
- Nothing is more common than this final state in a typical B decay
- $Br(B \to D^*3\pi(X))$ / $Br(B \to D^*\tau\nu;\ \tau \to 3\pi(\pi^0)\nu)_{SM}$ **~100**
- Suppress with ***inverted vertex topology***



A 5 σ requirement kills the $D^*3\pi(X)$ background by >10^4

- C.Bozzi, talk given at B2Tip, Crakow, 2015.04.17;
  G.Ciezarek, talk given at FPCP 2015, May 2015;
  R.Aaij et al., LHCb Collab. 1506.08614

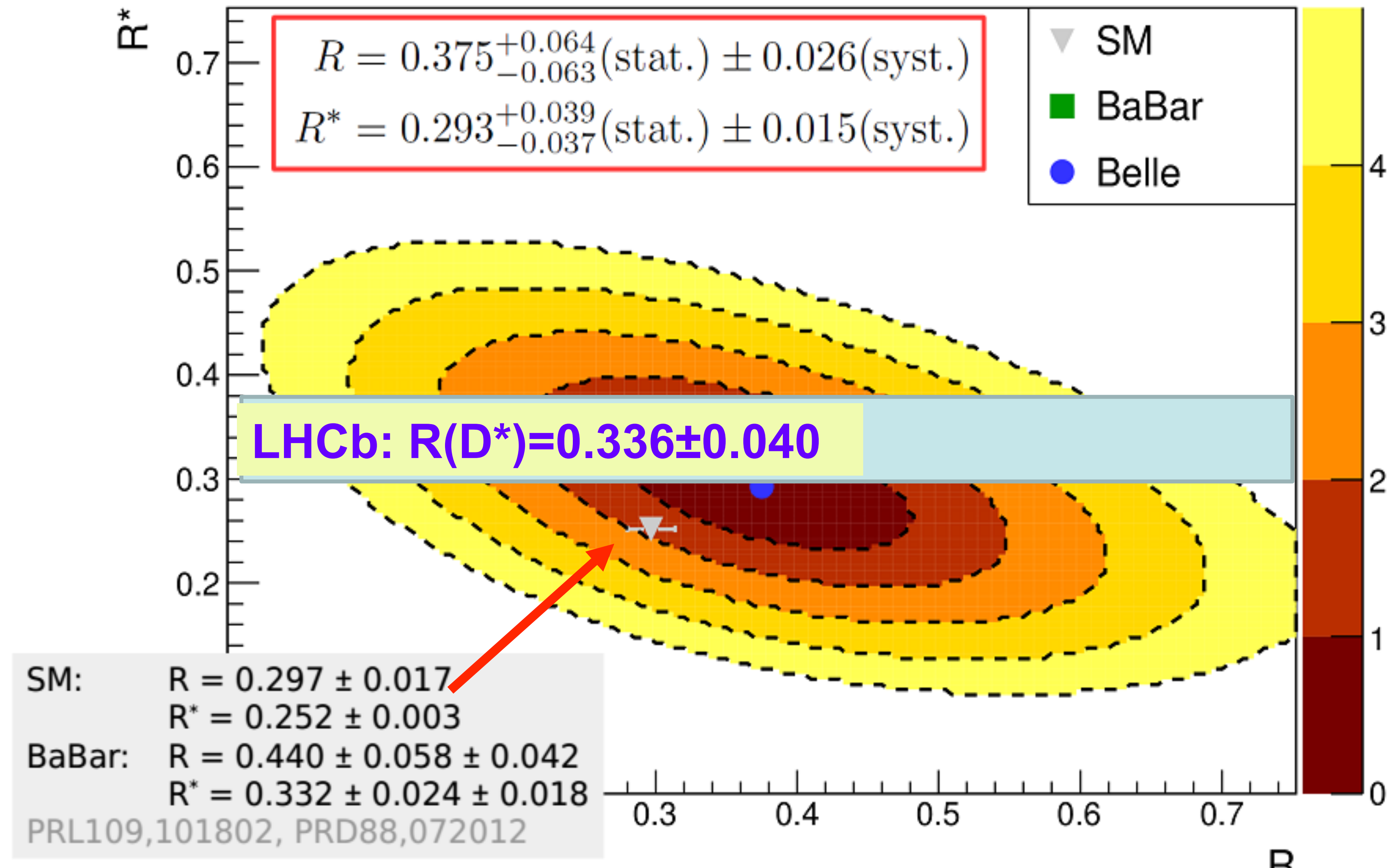
$B \to D^* \tau \nu$ at LHCb

R(D*)=0.336±0.027±0.030

- Decays with taus in the final state look promising. For $B \to D^* \tau \nu$:
  - Leptonic mode: same level of precision (~10%) as B Factories
  - 3-prong mode: aiming at statistical precision at the 5% level. Current limitation due to the large error (11% PDG 2014) on the normalisation $Br(B^0 \to D^* 3\pi)$. New measurement needed!

- $B \to D^* \tau \nu$: First measurement of any $B \to \tau X$ decay at a hadron collider
  - Consistent with past measurements, competitive precision
  - Agreement with SM at 2.1σ level

◆ LHCb, Measurements of R(D*), 1506.08614 [hep-ex]



3. R(D) and R(D^*), pQCD predictions

3.1 R(D) and R(D*) in the pQCD approach

- Y.Y. Fan, W.F. Wang, S. Cheng, and Z.J. Xiao

  Chin.Sci.Bull. 59 (2014) 125; 1301.6246 [hep-ph]
- First SM interpretation for BaBar's anomaly!

Chin. Sci. Bull. (2014) 59(2):125–132
DOI 10.1007/s11434-013-0049-9
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Semileptonic decays $B \rightarrow D^{(*)} l\nu$ in the perturbative QCD factorization approach

Ying-Ying Fan · Wen-Fei Wang · Shan Cheng · Zhen-Jun Xiao

Received: 23 November 2013 / Accepted: 29 November 2013 / Published online: 2 January 2014

- Differential decay rates for B meson decays:

  The blue curve: pQCD predictions;
  The red curve: The HQET predictions;

- Similar but with a little difference !

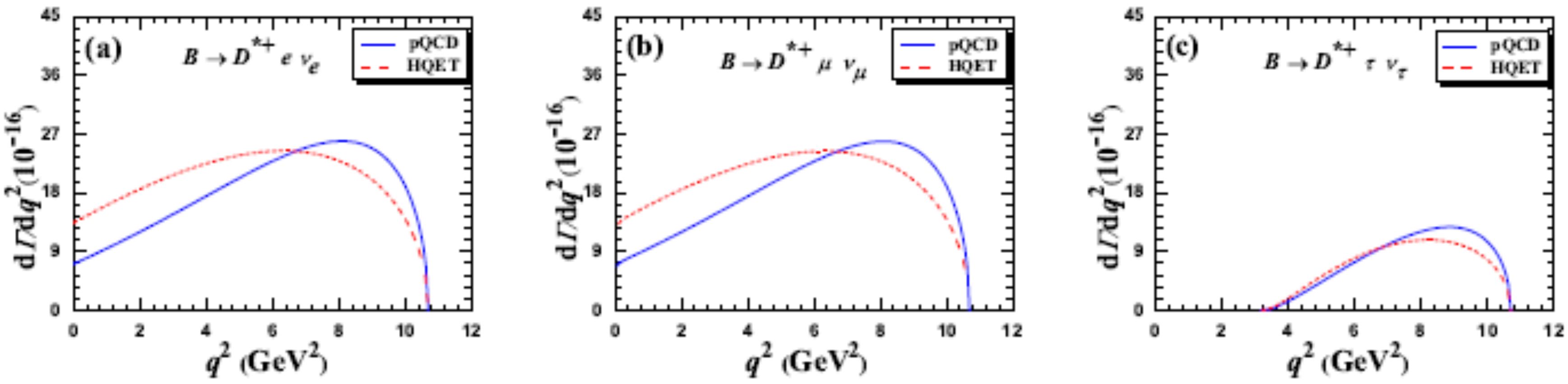


FIG. 2. The q^2-dependence of $d\Gamma/dq^2$ for $B \to D^{*+} l^- \bar{\nu}_l$ with $l = e, \mu, \tau$ in the pQCD approach (the solid curves), or in the HQET (the short-dashed curves). Here $q^2_{\rm max}$ = 10.69 GeV^2.

Table: pQCD predictions for BRs of $B \to D^{(*)}\tau^-\bar{\nu}_\tau$ and $B \to D^{(*)}l^-\bar{\nu}_l$ decays where l^- stands for e^- or μ^-. The WA from PDG 2012 [25], and BaBar measured values in Refs. [1, 26, 27].

Channel	pQCD(%)	PDG(%)[25]	BaBar(%)
$\bar{B}^0 \to D^+\tau^-\bar{\nu}_\tau$	$1.07^{+0.44}_{-0.34}$	1.1 ± 0.4	1.01 ± 0.22
$\bar{B}^0 \to D^+l^-\bar{\nu}_l$	$2.51^{+1.17}_{-0.86}$	2.18 ± 0.12	2.15 ± 0.08
$B^- \to D^0\tau^-\bar{\nu}_\tau$	$1.17^{+0.47}_{-0.38}$	0.77 ± 0.25	0.99 ± 0.23
$B^- \to D^0l^-\bar{\nu}_l$	$2.71^{+1.26}_{-0.93}$	2.26 ± 0.11	2.34 ± 0.14
$\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$	$1.67^{+0.48}_{-0.46}$	1.5 ± 0.5	1.74 ± 0.23
$\bar{B}^0 \to D^{*+}l^-\bar{\nu}_l$	$5.56^{+1.83}_{-1.62}$	4.95 ± 0.11	4.69 ± 0.34
$B^- \to D^{*0}\tau^-\bar{\nu}_\tau$	$1.82^{+0.52}_{-0.50}$	2.04 ± 0.30	1.71 ± 0.21
$B^- \to D^{*0}l^-\bar{\nu}_l$	$6.03^{+1.97}_{-1.75}$	5.70 ± 0.19	5.40 ± 0.22

Table: The pQCD predictions for the six R(X)-ratios, other SM predictions [2, 4, 5], and the measured values.

Ratio	pQCD	SM [2]	SM[4]	SM[5]	BaBar [1]
$R(D^0)$	$0.432^{+0.021}_{-0.024}$	$--$	$--$	$--$	0.429 ± 0.097
$R(D^+)$	$0.426^{+0.025}_{-0.022}$	$--$	$--$	$--$	0.469 ± 0.099
$R(D^{*0})$	$0.302^{+0.011}_{-0.016}$	$--$	$--$	$--$	0.322 ± 0.039
$R(D^{*+})$	$0.300^{+0.012}_{-0.015}$	$--$	$--$	$--$	0.355 ± 0.044
$\mathcal{R}(D)$	0.429 ± 0.023	0.296	0.316	0.315	0.440 ± 0.072
$\mathcal{R}(D^*)$	$0.301^{+0.012}_{-0.015}$	0.252	$--$	0.260	0.332 ± 0.030

(iii) For the four isospin-unconstrained ratios $R(D^0)$, $R(D^+)$, $R(D^{*0})$ and $R(D^{*+})$, the pQCD predictions agree well with the BaBar measured values.

(iv) For the two isospin-constrained ratios $R(D)$ and $R(D^*)$, the pQCD predictions agree well with BaBar's measurements.

3.2 R(D) and R(D*) in "pQCD + Lattice QCD input"

arXiv:1505.07169

The $B \to D^{(*)} l \nu_l$ decays in the pQCD approach with the Lattice QCD input

Ying-Ying Fan[1], Zhen-Jun Xiao[2] [a], Ru-Min Wang[1], and Bing-Zhong Li[1]

[1] *College of Physics and Electronic Engineering, Xinyang Normal University, Xinyang, Henan 464000, P. R. China*
[2] *Department of Physics and Institute of Theoretical Physics, Nanjing Normal University, Nanjing, Jiangsu 210023, P. R. China*

(Dated: May 28, 2015)

In this paper, we studied the semileptonic decays $B \to D^{(*)} l^- \bar{\nu}_l$ by using the the "pQCD+Lattice QCD" method. We made the extrapolation for the six relevant form factors by using the values obtained from the pQCD factorization approach in the lower region of $0 \leq q^2 \leq m_\tau^2$, but the Lattice QCD input at the end-points q^2_{max}. We then calculated the branching ratios $\mathcal{B}(B \to D^{(*)} l^- \bar{\nu}_l)$ and the ratio $R(D)$ and $R(D^*)$. From our numerical results we found that (a) the "pQCD+Lattice QCD" predictions for the branching ratios $\mathcal{B}(B \to D^{(*)} l^- \bar{\nu}_l)$ agree well with the measured values within one standard deviation; and (b) the "pQCD+Lattice QCD" predictions for the ratios $R(D^{(*)})$ are $R(D) = 0.337^{+0.038}_{-0.037}$ and $R(D^*) = 0.269^{+0.021}_{-0.020}$, the deviation of these new predictions from the averaged BaBar and Belle measurements is about 2.1σ.

◆ Some points about this work

1 The Th.predictions strongly depend on the value and their q^2 dependence of the relevant FFs.

2 The classical method is the HQET (see S.Fajfer's papers)

3 For the calc of form factors, pQCD are reliable in the low q^2 region only, one has to make the extrapolation for FF to the high q^2 region by using the "pole model param.", this is the major source of uncertainty!

4 The FFs can be evaluated reliably in q^2_{max} by using the Lattice QCD method !

5 We take the Lattice QCD predictions at q^2_{max} as input to improve the extrapolation !

◆ Effects of the Lattice QCD input on the form factors

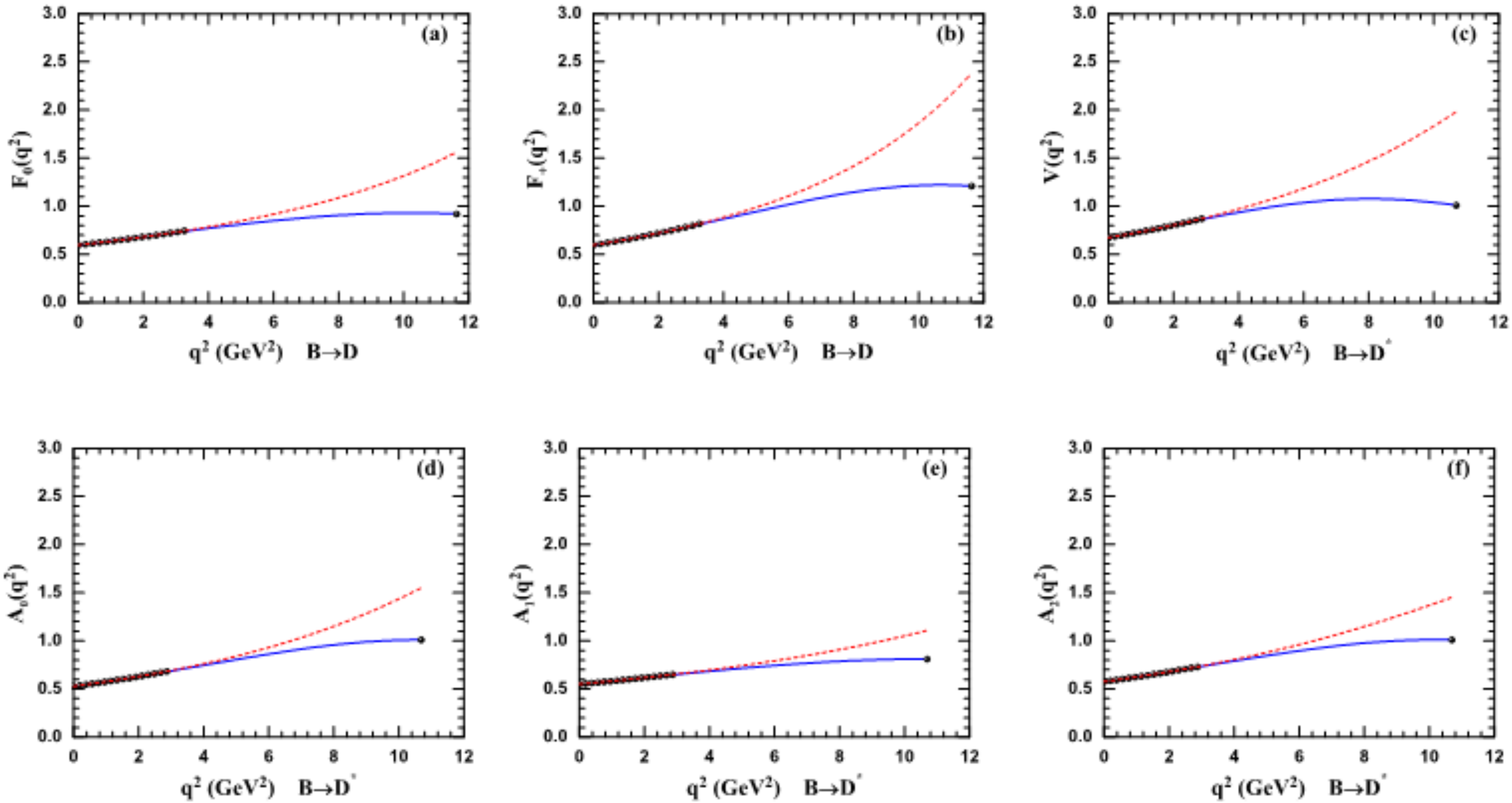


FIG. 1. The theoretical predictions for the q^2-dependence of the six form factors in the pQCD approach (the dashed curves), the pQCD plus Lattice-QCD input (solid curves).

◆ Effects of the Lattice QCD input on the form factors

-- J.A.Baily et al., FermiLab Lattice and MILC Collab. PRD 85, 114502 (2012)
PRD 89, 114504 (2014); Pos Lattice2010: 311 (2010).

-- D.M.de Divitis et al., NPB 807, 373 (2009)

pQCD+Lattice

Form Factors	$F(0)$	$F(q^2_{max})$	$F'(q^2_{max})$
$F_0^{B\to D}$	$0.60^{+0.15}_{-0.12}$	0.92 ± 0.02	1.56 ± 0.25
$F_+^{B\to D}$	$0.60^{+0.15}_{-0.12}$	1.21 ± 0.02	$2.37^{+0.38}_{-0.33}$
$V^{B\to D^*}$	$0.67^{+0.15}_{-0.13}$	1.01 ± 0.02	$1.98^{+0.20}_{-0.21}$
$A_0^{B\to D^*}$	$0.53^{+0.11}_{-0.10}$	1.01 ± 0.02	$1.55^{+0.14}_{-0.24}$
$A_1^{B\to D^*}$	$0.55^{+0.12}_{-0.10}$	0.81 ± 0.02	1.11 ± 0.13
$A_2^{B\to D^*}$	$0.58^{+0.13}_{-0.11}$	1.01 ± 0.02	$1.45^{+0.18}_{-0.19}$

pQCD only

◆ Effects of the Lattice QCD input on the form factors

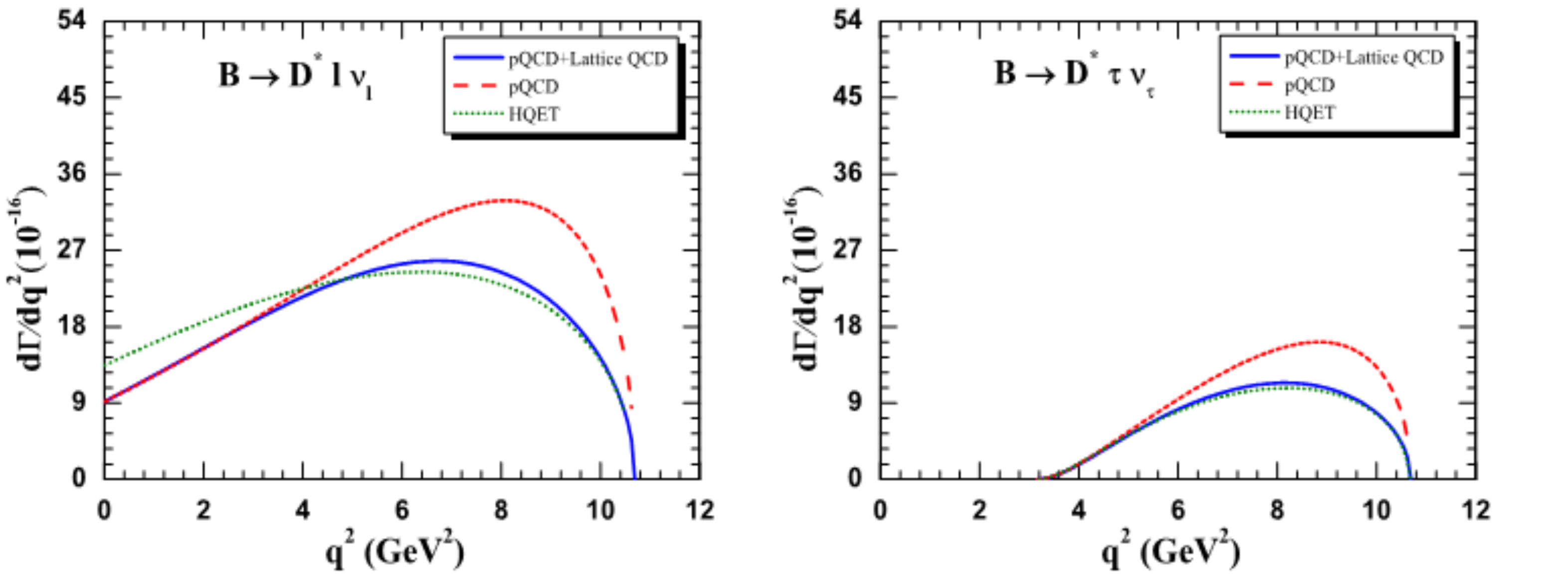


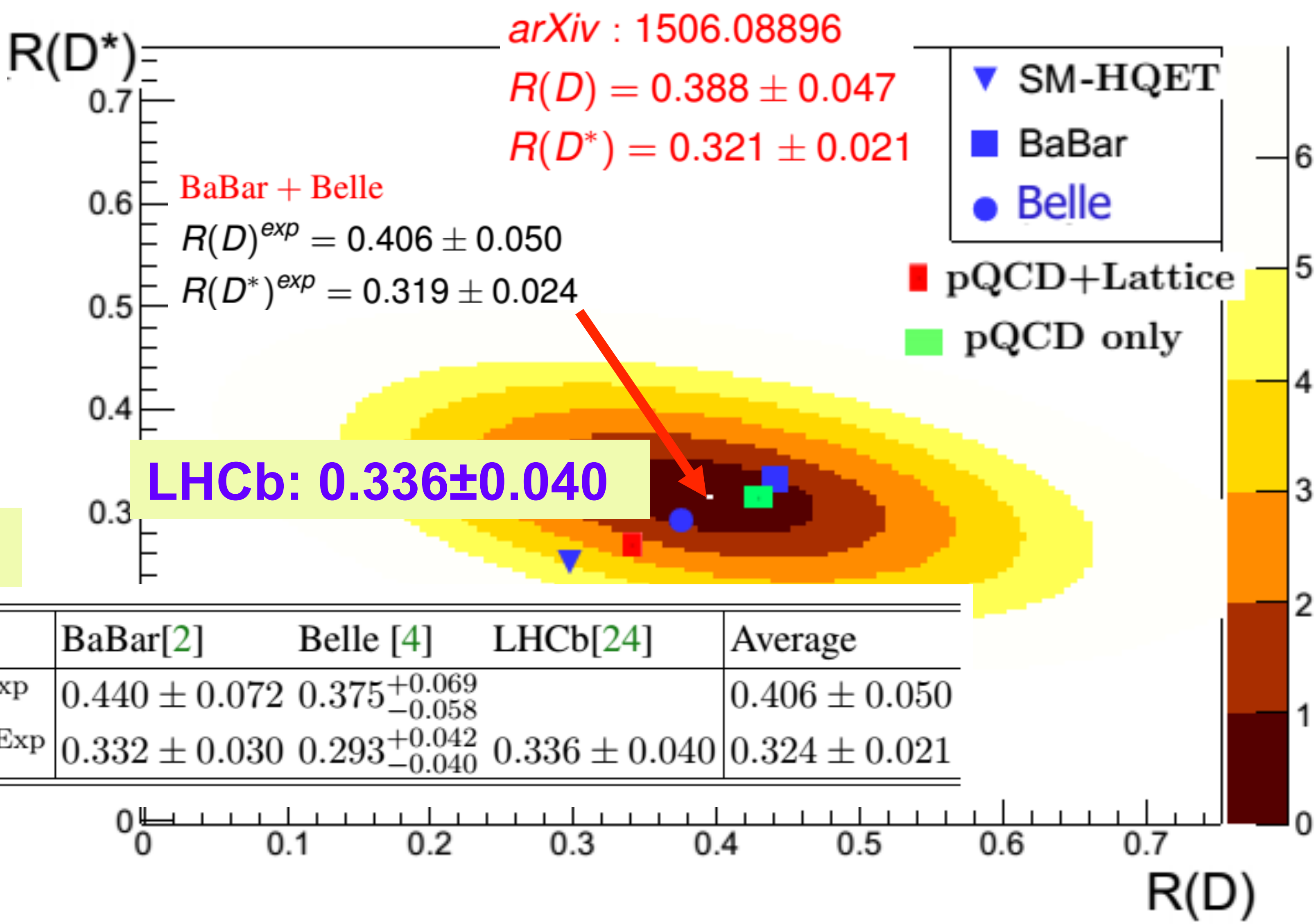
FIG. 2. The theoretical predictions for the q^2-dependence of $d\Gamma/dq^2$ for $B \to D^* l^- \bar{\nu}_l$ $l = (e, \mu)$ and $B \to D^* \tau^- \bar{\nu}_\tau$ decays in the pQCD approach (the dashed curves), the "pQCD + Lattice-QCD" method (solid curves), and the traditional HQET method (the dots curves). Here $q^2_{max} = 10.69$ GeV^2.

pQCD+Lattice

$$R(D) = 0.337^{+0.038}_{-0.037}$$
$$R(D^*) = 0.269^{+0.021}_{-0.020}$$

Th. predictions

Ratio	pQCD[15]	pQCD+Lattice	HQET[5]
$\mathcal{R}(D)^{\rm SM}$	$0.430^{+0.021}_{-0.026}$	$0.337^{+0.038}_{-0.037}$	0.296 ± 0.016
$\mathcal{R}(D^*)^{\rm SM}$	$0.301^{+0.013}_{-0.013}$	$0.269^{+0.021}_{-0.020}$	0.252 ± 0.003



LHCb: 0.336±0.040

Exp

Ratio	BaBar[2]	Belle [4]	LHCb[24]	Average
$\mathcal{R}(D)^{\rm Exp}$	0.440 ± 0.072	$0.375^{+0.069}_{-0.058}$		0.406 ± 0.050
$\mathcal{R}(D^*)^{\rm Exp}$	0.332 ± 0.030	$0.293^{+0.042}_{-0.040}$	0.336 ± 0.040	0.324 ± 0.021

3.3、Some works for SL B/Bs/Bc decays in pQCD approach

- The semileptonic decays B/Bs → (π,K)(l^+ l^-,lν,νν) in the pQCD approach beyond the leading-order,
  Wen-Fei Wang, Zhen-Jun Xiao, Phys.Rev.D86, 114025 (2012);

- SL decays Bc → (\eta_c,J/\Psi) l ν in the pQCD approach
  W.F. Wang, Y.Y. Fan and Z.J. Xiao, Chin.Phys.C37, 093102 (2013).

- SL decays Bs → (η,η',G)(ll,lν,νν) in the pQCD approach beyond the LO
  W.F. Wang, Y.Y. Fan, M. Liu and Z.J. Xiao, Phys.Rev.D87, 097501 (2013);

- Study of Bs → (Ds^+,Ds^{*+}) l^- ν decays in the pQCD factorization approach,
  Y.Y. Fan, W.F. Wang, and Z.J. Xiao, Phys.Rev.D89, 014030 (2014).

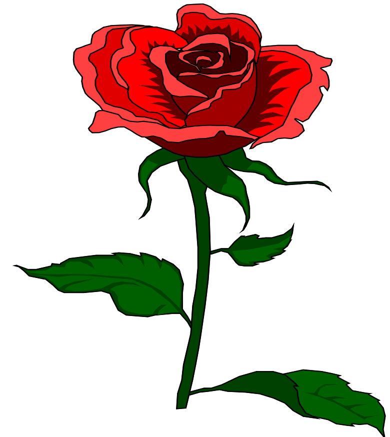
- The SL decays of B/Bs meson in the pQCD approach: A short review
  Z.J. Xiao et al., Chin.Sci.Bull. 59 (2014) 3787-3800.

- The semileptonic decays Bc → D(s)^(*)(lν,ll,νν) in the pQCD approach
  W.F. Wang, X.Yu, C.D. Lu, Z.J. Xiao, Phys.Rev.D90,094018 (2014);

4、Summary

- Based on the pQCD factorization approach, we can provide an self-consistent SM interpretation for R(D)-R(D*) anomaly.
- With the "pQCD + Lattice input" methods, the extrapolation of the form factors from the low to high q^2 are improved.
- LHCb and Super-B leading the precision frontier, precision measurements for the Brs, angles, CPV etc will become true in the near future!
- High precision measurements will play an important role in testing the SM or to find the signals of NP !

Thank you !



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