“Possible origin(s) of RD(*) flavor anomalies"

Amarjit Soni
HET-BNL

6th International Conference on New Frontiers in Physics (ICNFP 2017)
08/26/17

Based in part on 1704.06659 With Wolfgang Altmannshofer and Bhupal Dev & in progress [ADS’]

Anomalies galore!

- RD(*)
- RK(*)
- ……
- g -2…T.Blum on the lat~04
- ……
- DCP(K->pi pi) epsilon': obsession….for a long^3 time

  216[PRL 2015] => ~720 now => ~1200

[2.1σ (2.9σ?) => ??] …..some months

Today's primary focus: RD(*)

Outline

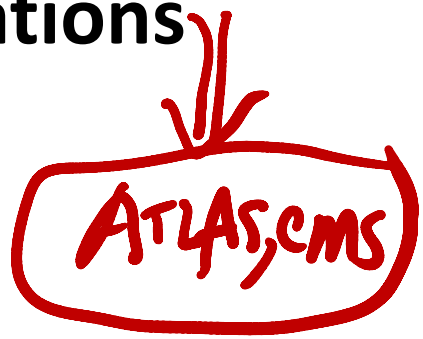
- **Recapitulate: expt situation**
- **Assess Theory: SM predictions**
- **Model independent collider implications**
- **Assuming deviation is real:**

An interesting BSM origin

A minimal setup

Constraints on it

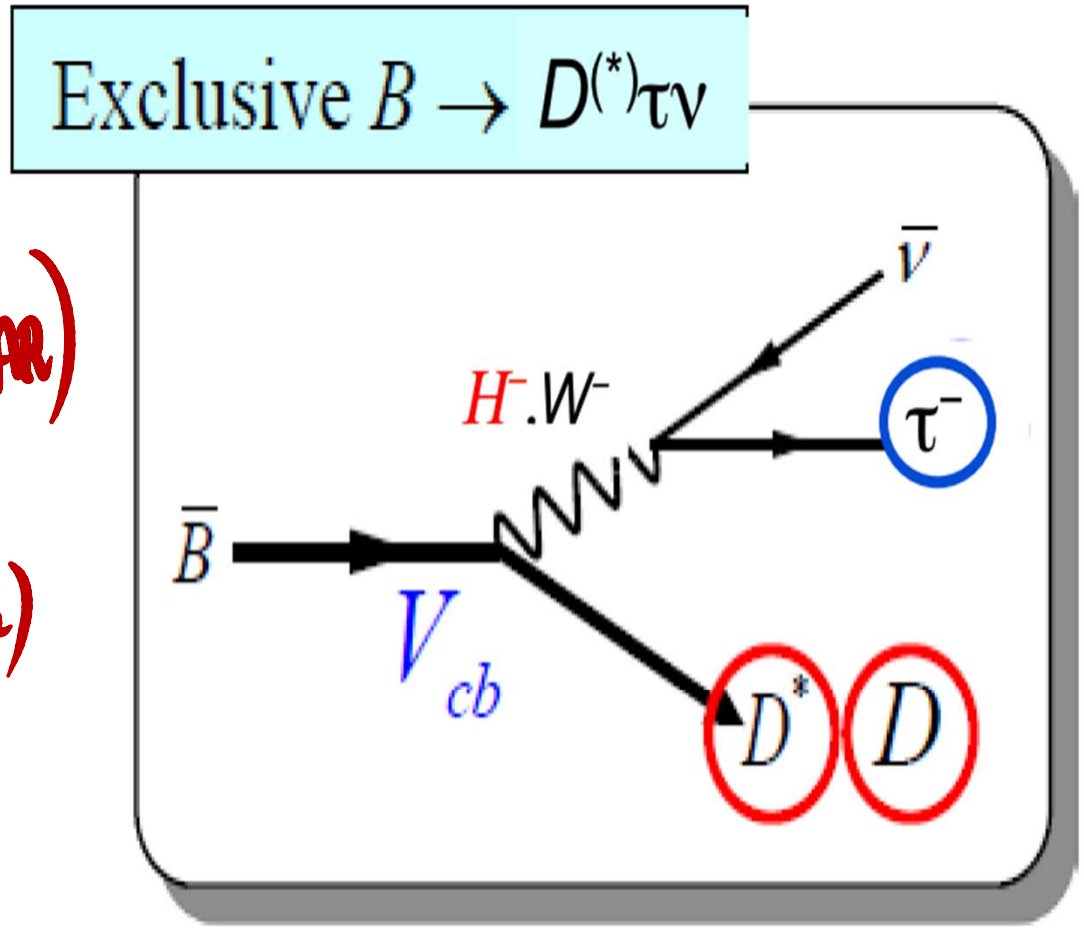
- **Summary & Outlook**



RA LUTH (BABAR)

'CP May 2012

(HEFEI, China)



MANUEL FRANCO

SEVILLA

PhD Thesis

Independent of Vcb!

- To test the SM Prediction, we measure

$$R(D) = \frac{\Gamma(\bar{B} \to D\tau\nu)}{\Gamma(\bar{B} \to D\ell\nu)} \qquad R(D^*) = \frac{\Gamma(\bar{B} \to D^*\tau\nu)}{\Gamma(\bar{B} \to D^*\ell\nu)}$$

Leptonic τ decays only

Several experimental and theoretical uncertainties cancel in the ratio!

- BB events are fully reconstructed:

PHYSICAL REVIEW D VOLUME 56, NUMBER 9 1 NOVEMBER 1997

Improving constraints on $\tan\beta/m_H$ using $B \to D\tau\bar{\nu}$

Ken Kiers* and Amarjit Soni†
Department of Physics, Brookhaven National Laboratory, Upton, New York 11973-5000
(Received 12 June 1997)

We study the q^2 dependence of the exclusive decay mode $B \to D\tau\bar{\nu}$ in type-II two Higgs doublet models (2HDM's) and show that this mode may be used to put stringent bounds on $\tan\beta/m_H$. There are currently rather large theoretical uncertainties in the q^2 distribution, but these may be significantly reduced by future measurements of the analogous distribution for $B \to D(e,\mu)\bar{\nu}$. We estimate that this reduction in the theoretical uncertainties would eventually (i.e., with sufficient data) allow one to push the upper bound on $\tan\beta/m_H$ down to about 0.06 GeV^{-1}. This would represent an improvement on the current bound by about a factor of 7. We

Form factors: B=>D vs B=>D*

- **For B to D [0- to 0-] due to Parity,**

Only vector current contributes: 2 form factor of which, contribution of one is prop. to lepton mass

For B to D* both vector and axial vector conribute;

Now 4 FF, again contribution of one FF is

prop. to lepton mass

Semi-leptonic (exclusive) form factors Basics

$$H_{int} = \frac{G_F}{\sqrt{2}} \left[J_\mu^{had} + J^\mu_{lep} \right] V_{if}^{CKM}$$

$$\to V^\mu + A^\mu \equiv \bar{u}\gamma_\mu b + \bar{u}\gamma_\mu\gamma_5 b$$

$$\langle \pi(p_f) | J_\mu^h | B(p_i) \rangle = (p_i + p_f) f_+(q^2) + (p_i - p_f) f_-(q^2)$$

$$= f_+(q^2) \left[(p_i + p_f)^\mu + \frac{m_f^2 - m_i^2}{q^2} (p_i - p_f)^\mu \right] +$$

$$f_0(q^2) \frac{m_B^2 - m_A^2}{q^2} (p_f - p_i)^\mu ; \quad q \equiv p_f - p_i$$

- S.L. decays involving a $\tau^{\pm}$ have an additional helicity amplitude (for D

$$\frac{d\Gamma_\tau}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |\mathrm{p}| q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^2 \left[\left(|H_{++}|^2 + |H_{--}|^2 + |H_{00}|^2\right) \left(1 + \frac{m_\tau^2}{2q^2}\right) + \frac{3}{2} \frac{m_\tau^2}{q^2} |H_t$$

For $D\tau\nu$, only H_{00} and H_t contribute!

- To test the SM Prediction, we measure

$$R(D) = \frac{\Gamma(\overline{B} \to D\tau\nu)}{\Gamma(\overline{B} \to D\ell\nu)} \qquad R(D^*) = \frac{\Gamma(\overline{B} \to D^*\tau\nu)}{\Gamma(\overline{B} \to D^*\ell\nu)}$$

Leptonic τ decays only

Several experimental and theoretical uncertainties cancel in the ratio!

- BB events are fully reconstructed:
  - full reconstruction of hadronic B decay: Btag (tag efficiency improved)
  - reconstruction of $D^{(*)}$ and $e^{\pm}$ or $\mu^{\pm}$ (extend to lower momenta)
  - no additional charged particles
  - kinematic selections: $q^2 > 4$ GeV^2

Decay	N_{sig}	N_{norm}	$R(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)\,(\%)$	$\Sigma_{tot}(\sigma$
$D^0\tau^-\overline{\nu}_\tau$	314 ± 60	1995 ± 55	$0.429 \pm 0.082 \pm 0.052$	$0.99 \pm 0.19 \pm 0.13$	4.7
$D^{*0}\tau^-\overline{\nu}_\tau$	639 ± 62	8766 ± 104	$0.322 \pm 0.032 \pm 0.022$	$1.71 \pm 0.17 \pm 0.13$	9.4
$D^+\tau^-\overline{\nu}_\tau$	177 ± 31	986 ± 35	$0.469 \pm 0.084 \pm 0.053$	$1.01 \pm 0.18 \pm 0.12$	5.2
$D^{*+}\tau^-\overline{\nu}_\tau$	245 ± 27	3186 ± 61	$0.355 \pm 0.039 \pm 0.021$	$1.74 \pm 0.19 \pm 0.12$	10.4
$D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	6.8
$D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	13.2

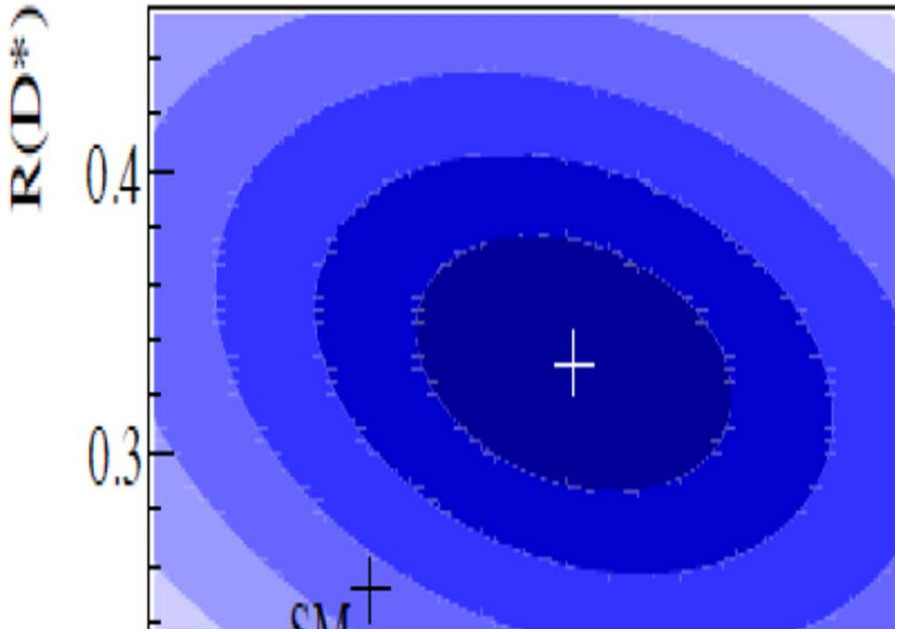
omparison with SM calculation:

4HTH

	R(D)	R(D*)
BABAR	0.440 ± 0.071	0.332 ± 0.029
SM	0.297 ± 0.017	0.252 ± 0.003
Difference	**2.0 σ**	**2.7 σ**

Combined 3.4σ

BABAR



ne combination of the two measurements
0.27 correlation) yields χ^2/NDF=14.6/2,
Prob. = 6.9 x10-4 !!

A charged Higgs (2HDM type II) of spin 0 couples to the τ and will only affect H_t

$$H_t^{\mathrm{2HDM}} = H_t^{\mathrm{SM}} \times \left(1 + \frac{\tan^2\beta}{m_{H^\pm}^2} \frac{q^2}{1 \mp m_c/m_b}\right)$$

- for $D\tau\nu$

+ for $D^*\tau\nu$

This could enhance or decrease the ratios R(D*) depending on $\tan\beta/m_H$

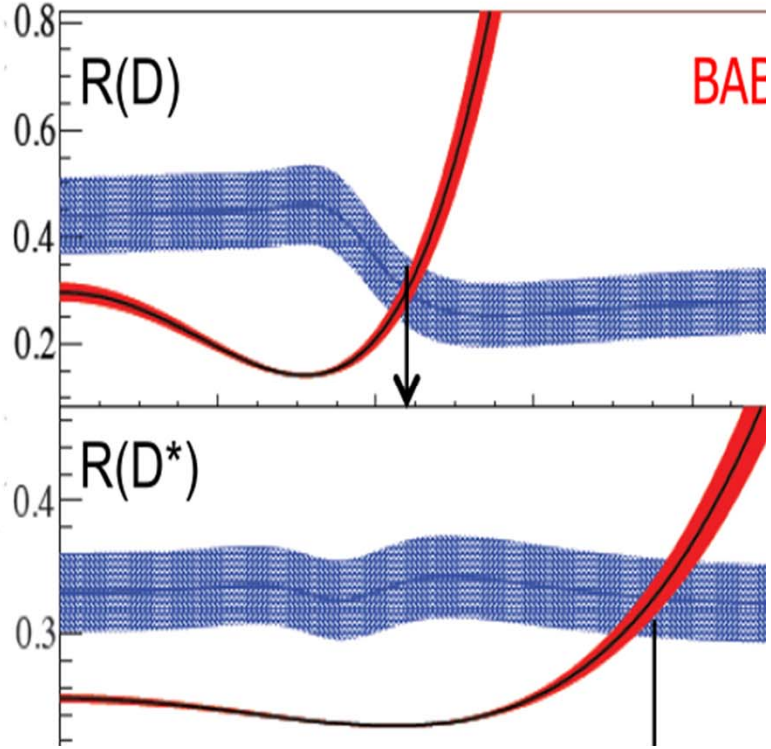
We estimate the effect of 2DHM, accounting for difference in efficiency, and its uncertainty

The data match 2DHM Type II at

$\tan\beta/m_H = 0.44 \pm 0.02$ for R(D)

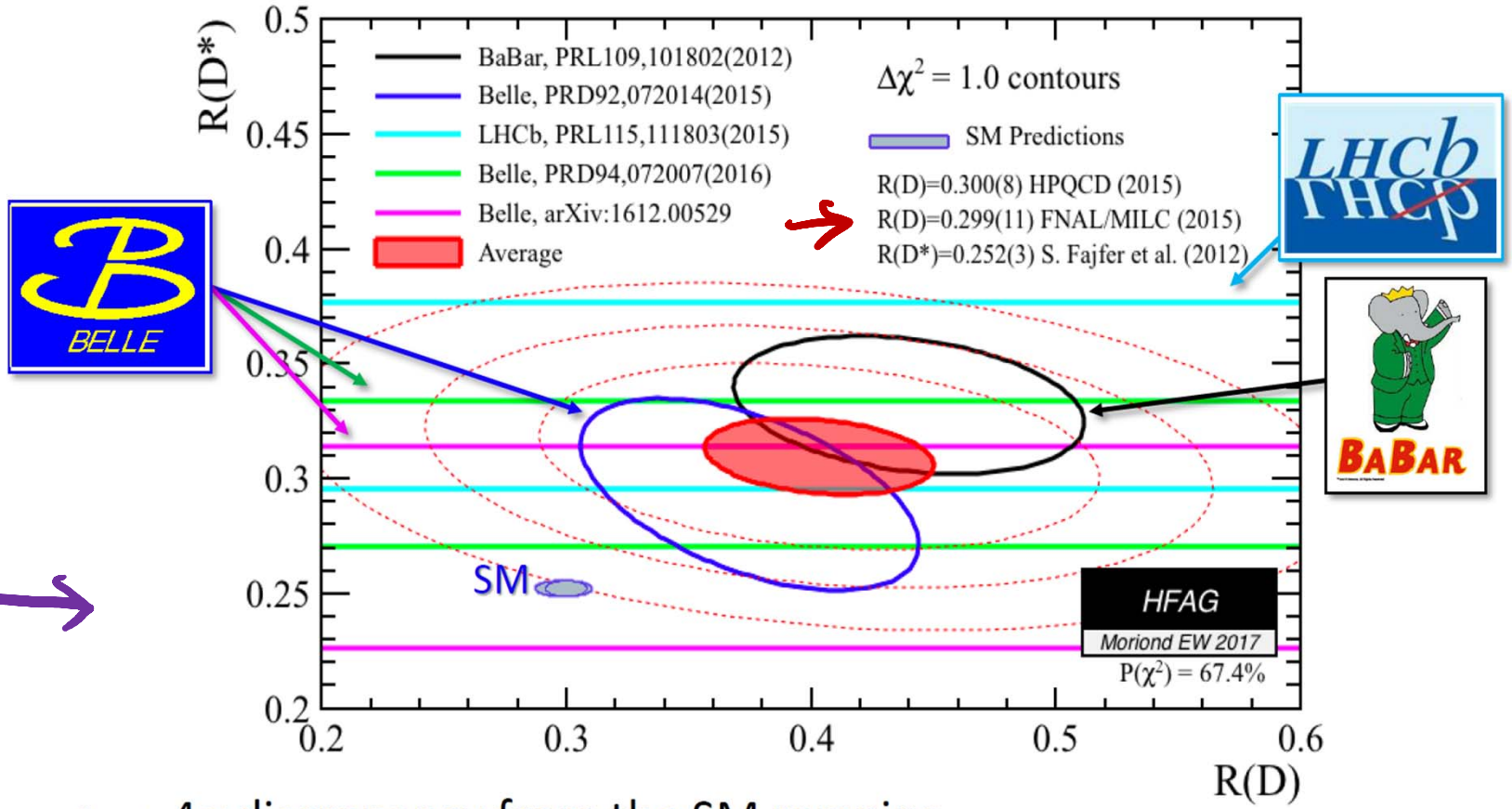
$\tan\beta/m_H = 0.75 \pm 0.04$ for R(D*)

However, the combination of R(D) and R(D*) excludes the Type II 2HDM in the full $\tan\beta$-m_H parameter space with a probability



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

Hirose [BELLE]@EW
MORIOND Mar. 2017



- ~4σ discrepancy from the SM remains
  - All the experiments show the larger $R(D^{(*)})$ than the SM
- More precise measurements at Belle II and LHCb are essential

Belle deviations quite mild

PDG2016

Table 39.1: Area of the tails α outside $\pm\delta$ from the mean of a Gaus distribution.

α	δ	α	δ
0.3173	1σ	0.2	1.28σ
4.55×10^{-2}	2σ	0.1	1.64σ
2.7×10^{-3}	3σ	0.05	1.96σ
6.3×10^{-5}	4σ	0.01	2.58σ
5.7×10^{-7}	5σ	0.001	3.29σ
2.0×10^{-9}	6σ	10^{-4}	3.89σ

Concern on experiments

- **Main concern reg. experiments is contamination from higher D**-like resonances….it is exceedingly important to measure these BGs as model calculations are not reliable**
- **B=> τ ν is intimately intertwined with RD(*)**

as stressed in Nandi + Patra +AS:1605.07191, but unfortunately for now stats are very poor

- **Nevertheless recall that infact BABAR had also claimed for past many years weak BSM indications in B=>tau nu; BELLE originally said yes but later no on with more data and further analysis asserted consistency with SM.**
- **Bearing that (slight) tension in mind, it is noteworthy that Belle measurements of RD and RD* persistently have found consistency with SM within ~1.5 σ and milder discrepancy with SM compared to BABAR and to LHCb**

Concern on Experiments

- **Leptonic decays: τ=> μνν…total 3 ν's in event**
- **Higher D** etc resonances….use of theo models for subtraction of these backgrounds is fraught with danger…..Backgrounds should be measured experimentally for reliable estimate of errors**
- **Note LHCb new result june 2017: B=>D* τ ν; τ =>3π+ν**
- **Consistent with the SM at ~1-σ=> heightens anxiety about D**….contaminations in τ=> μνν**
- **Similarly new Belle result with hadronic tau decay**

With only 1 ν…….consistent with SM well within 1 sigma!

LHCb Seminar CERN 6/6/17

World average

- Using BR($B^0 \to D^* \mu\nu$) = (4.93 ± 0.11)% [PDG-2016] we measure:

  R(D*) = 0.285 ± 0.019(stat) ± 0.025(syst) ± 0.014(ext)

- In combination with the muonic LHCb measurement:

  R(D*) = 0.336 ± 0.027 ± 0.030,

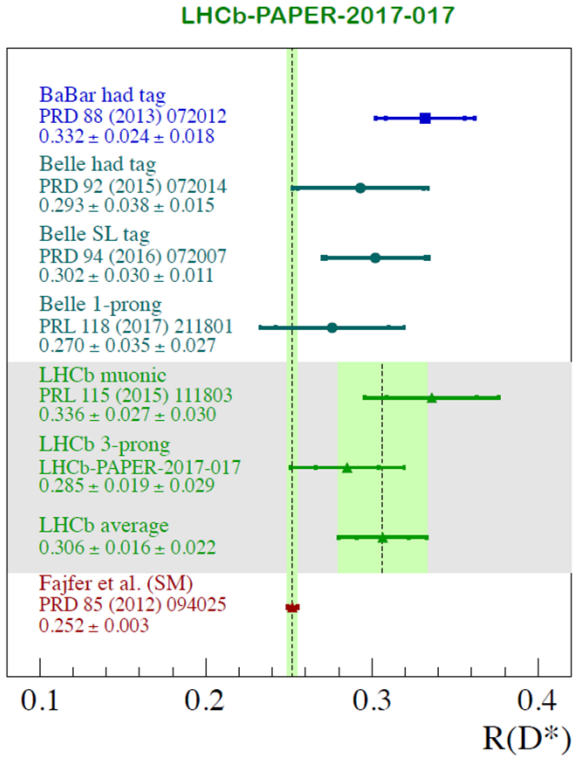
  the LHCb average is:

  - $R_{LHCb}(D^*) = 0.306 \pm 0.016 \pm 0.022$
  - 2.1σ above the SM.

- Naïve new WA:
  - R(D*) = 0.305 ± 0.015
  - 3.4σ above the SM.

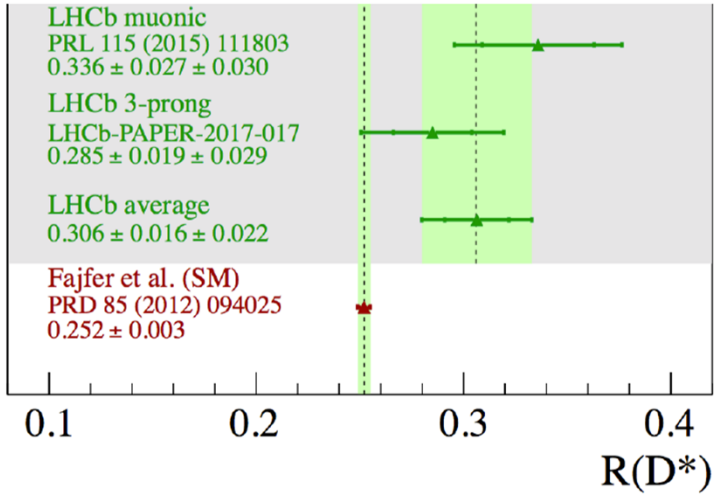
- Naïve R(D)/R(D*) combination at 4.1σ from SM.

Total of 6



Conclusions

- We have measured the ratio $K_{had}(D^*)=BR(B^0\to D^{*-}\tau\nu)/BR(B^0\to D^{*-}3\pi)$ using the $3\pi(\pi^0)$ hadronic decay of the τ lepton.
- The result regarding R(D*) is compatible with all other measurements and with the SM, having the smallest statistical error.
- This analysis was made possible due to the unique LHCb capabilities for separating secondary and tertiary vertices with excellent resolution.



Results

BELLE QED'S July 2017

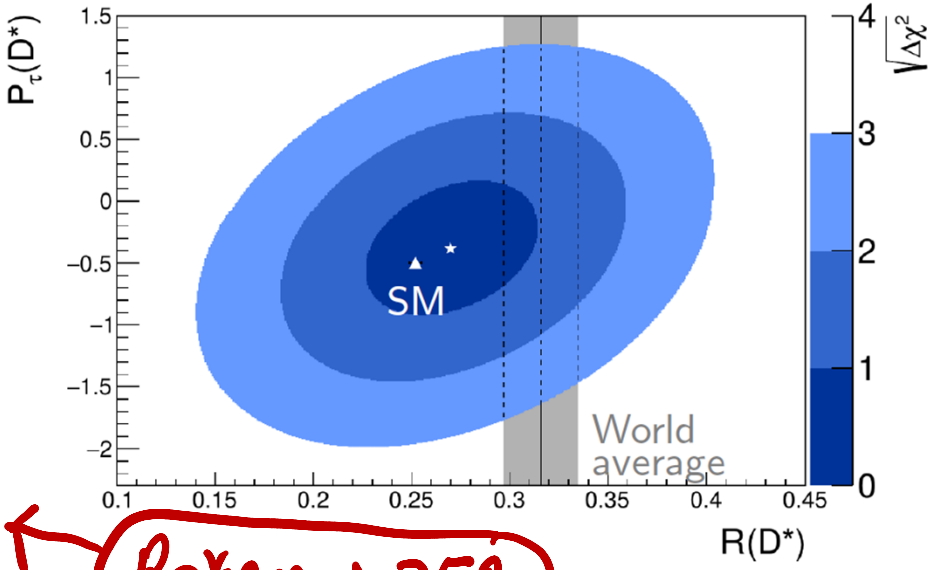
- $\mathcal{R}(D^*)$ can be calculated as before from extracted yields
- Polarisation from forward/backward asymmetry

$\tau \to h_{odd} + \nu$

$$\frac{\epsilon_{norm}}{\epsilon_{sig}} = 0.97 \pm 0.02\ (B^{\pm}, \tau \to \pi\nu)$$
$$= 1.21 \pm 0.03\ (B^0, \tau \to \rho\nu)$$
$$= 3.42 \pm 0.07\ (B^{\pm}, \tau \to \rho\nu)$$
$$= 3.83 \pm 0.12\ (B^0, \tau \to \rho\nu)$$

Result

$$\mathcal{R}(D^*) = 0.270 \pm 0.035^{+0.028}_{-0.025}$$
$$P_\tau(D^*) = -0.38 \pm 0.51^{+0.21}_{-0.16}$$



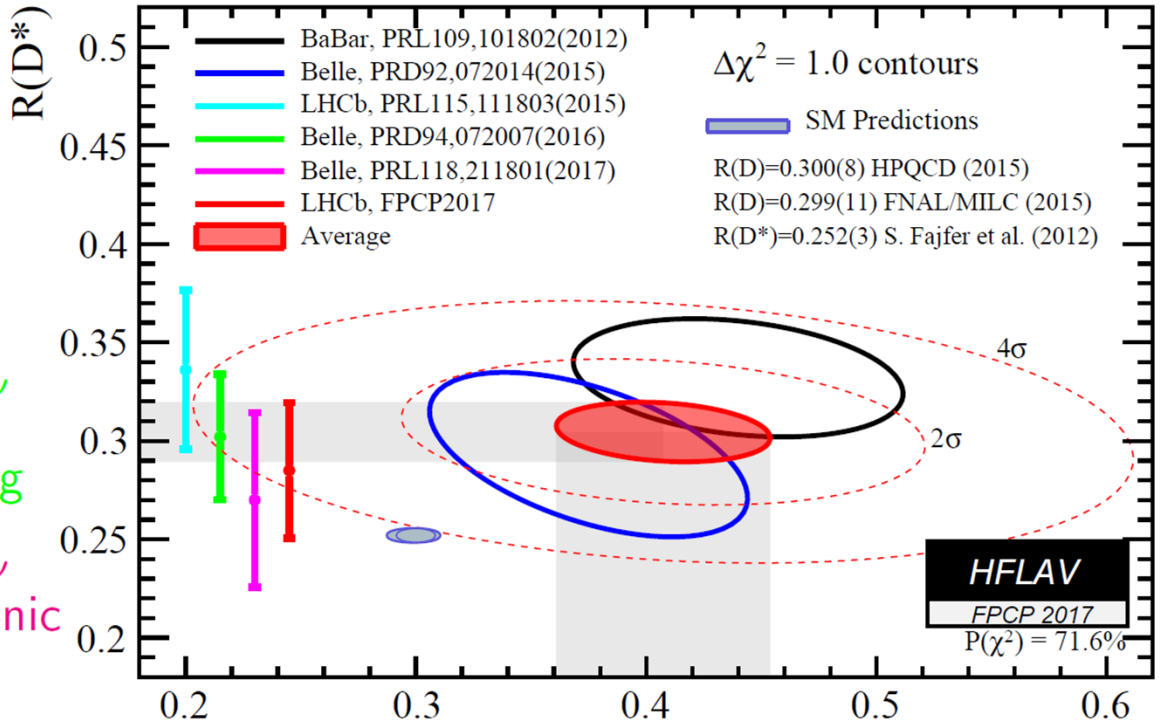
$R_{D^*SM} \sim .258$

- Consistent with SM and previous measurements!
- Error can be reduced in Belle II

New status of $\mathcal{R}(D^*)$

$B \to D^* \tau \nu$ with semi-leptonic tag

$B \to D^* \tau \nu$ with hadronic τ decays



Combined measurement of $\mathcal{R}(D)$ and $\mathcal{R}(D^*)$

Excess still 4σ: central value moved towards SM;

on $\mathcal{R}(D^*)$, discrepancy increased from 3.0σ to 3.4σ

REGARDING (SM) THEORY

Concerns on SM-theory

- **Good news is that lattice[FERMI-MILC] study largely confirms pheno calculations for R_D [our RBC-UKQCD; witzel et al needs some more months; hope for another effort at BNL-centric]**
- **For B=>D* no complete lattice study so far; 4 rather than 2 FF and D* is unstable…..Thus, from the lattice perspective, anticipate appreciately larger errors than for B=>D**
- **Therefore, O(1%) errors in RD* (and in fact smaller than in RD) are difficult to understand; lattice results should come in some months**
- **Meantime recent phenomenological study of** Bernlochner, Ligeti, Papucci and Robinson, 1703.05330 [and even more recently…is/are very timely and greatly appreciated.

D. Bigi, Gambino, Schacht @ EPS

- **For now, for RD*, we take central value from Bernlochner et al but unlike them we take full spread between two cen values i.e. with the famous**

$$R_D^{\rm SM} = 0.299 \pm 0.003 \;\; R_{D^*}^{\rm SM} = 0.257 \pm 0.005$$

Bernlochner, Ligeti, Papucci and Robinson, 1703.05330

Scenario	$R(D)$	$R(D^*)$	Correlation
$L_{w=1}$	0.292 ± 0.005	0.255 ± 0.005	41%
$L_{w=1}$+SR	0.291 ± 0.005	0.255 ± 0.003	57%
NoL	0.273 ± 0.016	0.250 ± 0.006	49%
NoL+SR	0.295 ± 0.007	0.255 ± 0.004	43%
$L_{w\geq 1}$	0.298 ± 0.003	0.261 ± 0.004	19%
$L_{w\geq 1}$+SR	$\mathbf{0.299 \pm 0.003}$	$\mathbf{0.257 \pm 0.003}$	44%
th:$L_{w\geq 1}$+SR	0.306 ± 0.005	0.256 ± 0.004	33%
Data [9]	0.403 ± 0.047	0.310 ± 0.017	-23%
Refs. [48, 52, 54]	0.300 ± 0.008	—	—
Ref. [53]	0.299 ± 0.003	—	—
Ref. [34]	—	0.252 ± 0.003	—

SM prediction

we took RDX = 0.257 ± .005

Fajfer, Kamenik, Nisandzic, PRD'12

TABLE IV. The $R(D)$ and $R(D^*)$ predictions for our fit scenarios, the world average of the data, and other theory predictions. The fit scenarios are described in the text and in Table I. The bold numbers are our most precise predictions.

Very timely & useful phenomenological study by BLPR 2017

Overview on Sources of Uncertainty

preliminary results

SCHACHT EPS

- Our analysis leads to a central value $R(D^*) = 0.258$.
  - ➥ Very good agreement to [BLPR, 1703.05330].

Error due to experimental error of measurement of $B \to D^* l\nu$.

$$\delta R(D^*) = 0.005$$

Theory error due to sum rule parameters.

$$\delta R(D^*) = 0.002$$

Theory error due to higher order effects.

$$\delta R(D^*) = {}^{+0.007}_{-0.006}$$

Total Result (Experiment: $0.310 \pm 0.015 \pm 0.008$ (HFAG, [1612.07233]))

$$R(D^*) = 0.258^{+9}_{-8}$$

$\sim 4\%$

SUMMARY OF THEORETICAL CALCULATIONS

R(D)=0.300(8) HPQCD (2015)

R(D)=0.299(11) FNAL/MILC (2015) *

My Take Now

0.299 ± 0.003 BERNLOCHNER et al 2017

$\mathbf{0.299 \pm 0.003}$ D. BIGI et al 2017

R(D*)=0.252(3) S. Fajfer et al. (2012)

$\mathbf{0.257 \pm 0.003}$ Bernlochner et al

$R(D^*) = 0.258^{+9}_{-8}$ BIGI et al EPS July

$R_{D^*} \sim .258 \pm .020$

FOR RD* CENTRAL VALUE OF BEST THEORY ESTIMATE APPEARS BIT LOWER THAN ALL ~6 MEASUREMENTS!

+2 for R_D

Bottom line

- **NP or not depends critically not just on precise experiment but also reliable SM prediction from the lattice is mandatory….familiar story**

- **Experimental results often attained at huge cost can only be used effectively, if commesurate theory predictions are available…….mantra for past several decades**

Anomalies galore!

- RD(*)
- RK(*)
- ……
- g -2
- ……
- epsilon': my lattice effort ~35 years!

  216[PRL 2015] => ~720 now => ~1200

[2.1σ (2.9σ?) => ????] …..some months

LATTICE is vital for all!

MODEL INDEPENDENT IMPLICATIONS OF RD(*) ANOMALIES FOR [LHC] COLLIDER EXPERIMENTS

- **In a nut-shell B-experiments seem to find anomalous behavior in the underlying b=>c tau nu**
- **This necessarily [by XSym] implies there should be analogous anomaly in g + c => b tau nu…=>pp => b tau nu**

- ***Thus it immediately leads to inescapable search channels for possible NP at the high energy frontier for ATLAS & CMS and these are urgently urged***

Implications of anomaly for colliders

At low energies, the effective 4-fermion Lagrangian for the quark-level transition $b \to c\tau\bar{\nu}$ in the SM is given by

$$-\mathcal{L}_{\text{eff}} = \frac{4G_F V_{cb}}{\sqrt{2}} (\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu_\tau) + \text{H.c.}, \quad (4)$$

SM

BSM

DIM-6 OPS

"V"

"S"

$$\mathcal{O}_{V_{R,L}} = (\bar{c}\gamma^\mu P_{R,L} b)(\bar{\tau}\gamma_\mu P_L \nu) \quad (5)$$

$$\mathcal{O}_{S_{R,L}} = (\bar{c} P_{R,L} b)(\bar{\tau} P_L \nu), \quad (6)$$

$$\mathcal{O}_T = (\bar{c}\sigma^{\mu\nu} P_L b)(\bar{\tau}\sigma_{\mu\nu} P_L \nu). \quad (7)$$

SKIP 4 NOW

Backgrounds and such

- **Anomaly implies BSM signals in pp=> b tau nu..with tau => l + nu's….FOR ATLAS, CMS!**
- **There is SM contribution too[though suppressed by Vcb~0.04] but in addition there is potentially a huge background from W+j with about ~1% misidentification of light jets as b's…At 13TeV, SM+BG (with cuts)XS=1.5pb**
- **signal XS for Vector (scalar) case for Λ/[1TeV]~ gNP~1 is about 1.1(1.8)pb @13TeV …With 300/fb may b probe to ~ 4TeV …Moreover, distinctive kinematic distributions can b exploited with say ptb >100 GeV, Mbl>200 GeV to enhance searched for higher mediator masses** ~ 5 TeV

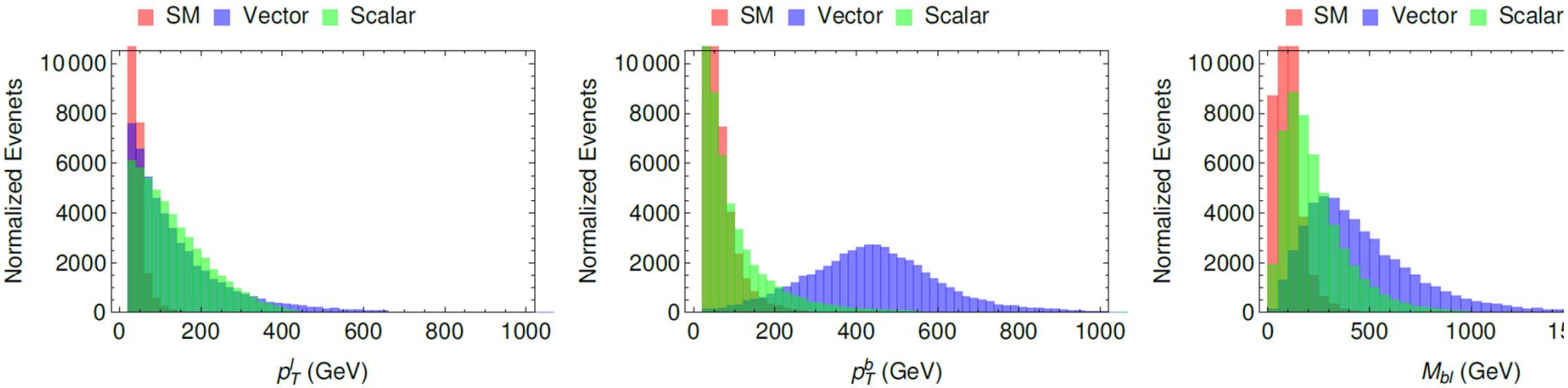


FIG. 1. Kinematic distributions for $pp \to b\tau\nu \to b\ell + \not{E}_T$ signal (vector and scalar) and SM background. We have he total number of events to be the same for all three cases to make a fair comparison of the distributions. Tl corresponds to Eq. (4), whereas the scalar and vector cases correspond to the operators given in Eqs. (6) and (5) r where we have chosen the new physics scale $\Lambda = 1$ TeV for illustration.

EXPECT DISTINCTIVE NP CONTRIBUTIONS IN COLLIDERS

ANOMALY: POSSIBLY A HINT FOR (NATURAL) SUSY-WITH RPV

- **ASSUMING the anomaly is REAL & HERE TO STAY [BIG ASSUMPTION due to caveats mentioned]**
- **Anomaly involves simple tree-level semi-leptonic decays**
- **Also b => tau (3rd family)**
- **Speculate: May be related to Higgs naturalness**
- **Perhaps 3rd family super-partners(a lot) lighter than other 2 gens > proton decay concerns may not be relevant=> RPV ["natural" SUSY as argued also in Brust, Katz, Lawrence and Sundrum 1110.6670 …….]**
- **Collider signals tend to get a lot harder than (usual-RPC) SUSY**

RPV_3 preserves gauge coupling unification irrespective of # of effective gens. 1, 2 or 3.

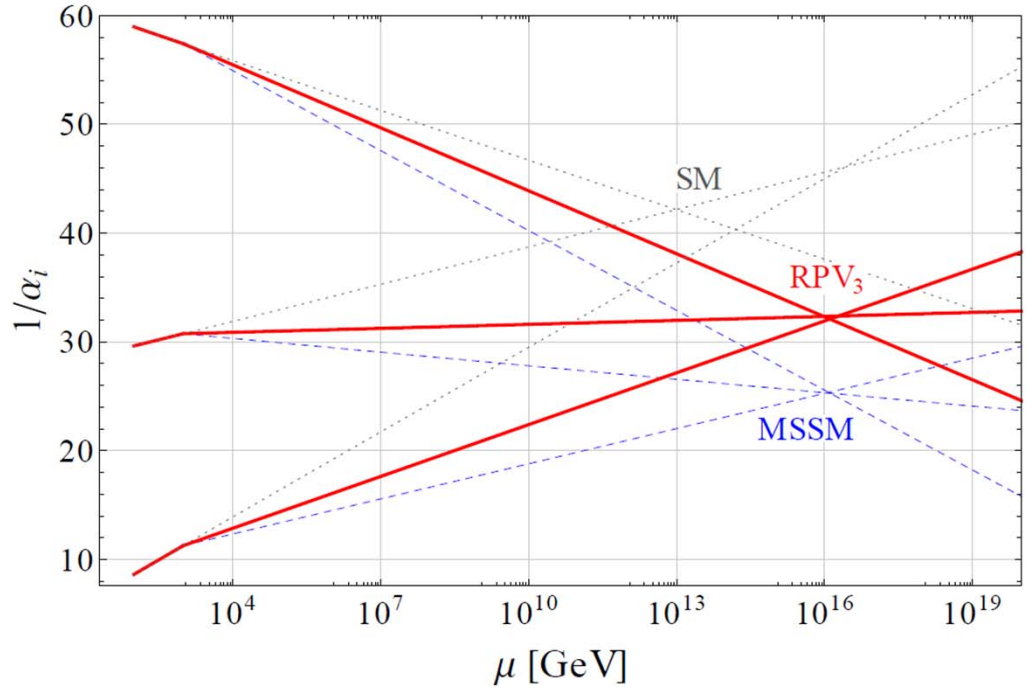


FIG. 2. RG evolution of the gauge couplings in the SM, MSSM and with partial supersymmetrization.

Unification scale M_X stays same, only value of coupling shifts

For pheno relevant terms:

C also Deshpande + He,1608.04817 (but with key diffs)

$$\mathcal{L} = \lambda'_{ijk}\left[\tilde{\nu}_{iL}\bar{d}_{kR}d_{jL} + \tilde{d}_{jL}\bar{d}_{kR}\nu_{iL} + \tilde{d}^*_{kR}\bar{\nu}^c_{iL}d_{jL} - \tilde{e}_{iL}\bar{d}_{kR}u_{jL} - \tilde{u}_{jL}\bar{d}_{kR}e_{iL} - \tilde{d}^*_{kR}\bar{e}^c_{iL}u_{jL}\right] + \text{H.c.}$$

RPV_3 interaction

Dim-6

$$\mathcal{L}_{\text{eff}} \supset \frac{\lambda'_{ijk}\lambda'^*_{mnk}}{2m^2_{\tilde{d}_{kR}}}\left[\bar{\nu}_{mL}\gamma^\mu\nu_{iL}\bar{d}_{nL}\gamma_\mu d_{jL} - \nu_{mL}\gamma^\mu e_{iL}\bar{d}_{nL}\gamma_\mu\left(V^\dagger_{\text{CKM}}u_L\right)_j + \text{h.c.}\right] - \frac{\lambda'_{ijk}\lambda'^*_{mjn}}{2m^2_{\tilde{u}_{jL}}}\bar{e}_{mL}\gamma^\mu e_{iL}\bar{d}_{kR}\gamma_\mu d_{nR}\,,$$

→ for $R_{D^{(*)}}$

NOTE: ITS SM-like!

CONSTRAINTS

BABAR Phy Book '97

Table 13-6. *Model-dependent effects of new physics in various processes.*

Model	*CP* Violation B^0_d–$\overline{B}^0_d$ Mixing	*CP* Violation Decay Ampl.	Rare Decays	D^0–$\overline{D}^0$ Mixing
MSSM	$\mathcal{O}(20\%)$ SM Same Phase	No Effect	$B \to X_s\gamma$ – yes $B \to X_s l^+ l^-$ – no	No Effect
SUSY – Alignment	$\mathcal{O}(20\%)$ SM New Phases	$\mathcal{O}(1)$	Small Effect	Big Effect
SUSY – Approx. Universality	$\mathcal{O}(20\%)$ SM New Phases	$\mathcal{O}(1)$	No Effect	No Effect
R-Parity Violation	Can Do	Everything	Except Make	Coffee
MHDM	$\sim$ SM/New Phases	Suppressed	$B \to X_s\gamma$, $B \to X_s\tau\tau$	Big Effect
2HDM	$\sim$ SM/Same Phase	Suppressed	$B \to X_s\gamma$	No Effect
Quark Singlets	Yes/New Phases	Yes	Saturates Limits	$Q = 2/3$
Fourth Generation	$\sim$ SM/New Phases	Yes	Saturates Limits	Big Effect
LRM – $V_L = V_R$	No Effect	No Effect	$B \to X_s\gamma$, $B \to X_s l^+ l^-$	No Effect
– $V_L \neq V_R$	Big/New Phases	Yes	$B \to X_s\gamma$, $B \to X_s l^+ l^-$	No Effect
DEWSB	Big/Same Phase	No Effect	$B \to X_s\ell\ell$, $B \to X - s\nu\overline{\nu}$	Big Effect

though in many cases further data may limit the available parameter space. In the more exciting eventuality that the results are not consistent with Standard Model predictions, the full pattern of the discrepancies both in rare decays and in *CP*-violating effects will help point to the preferred extension, and possibly rule out others. In either case there is much to be learned.

constraints

- Direct searches via $pp \to \tilde{b}\tilde{b} \to \tau^+\tau^- t\bar{t}$

Indirect constraints considered due B=>τ ν; π τ ν; π(K) ν ν….
Also B_C =>τν….

To a/c (within 1σ) of expt for RD(*) needs largish λ'333 ~1 – 2 range with quite heavy sbottoms but such large couplings develop landau pole below GUT scale.We require couplings stay perturbative below GUT so with λ'333 < ~1 ,

⇒TAKE HOME: This version of RPV is actually (surprisingly) well constrained
⇒RD(*) can only be partly explained

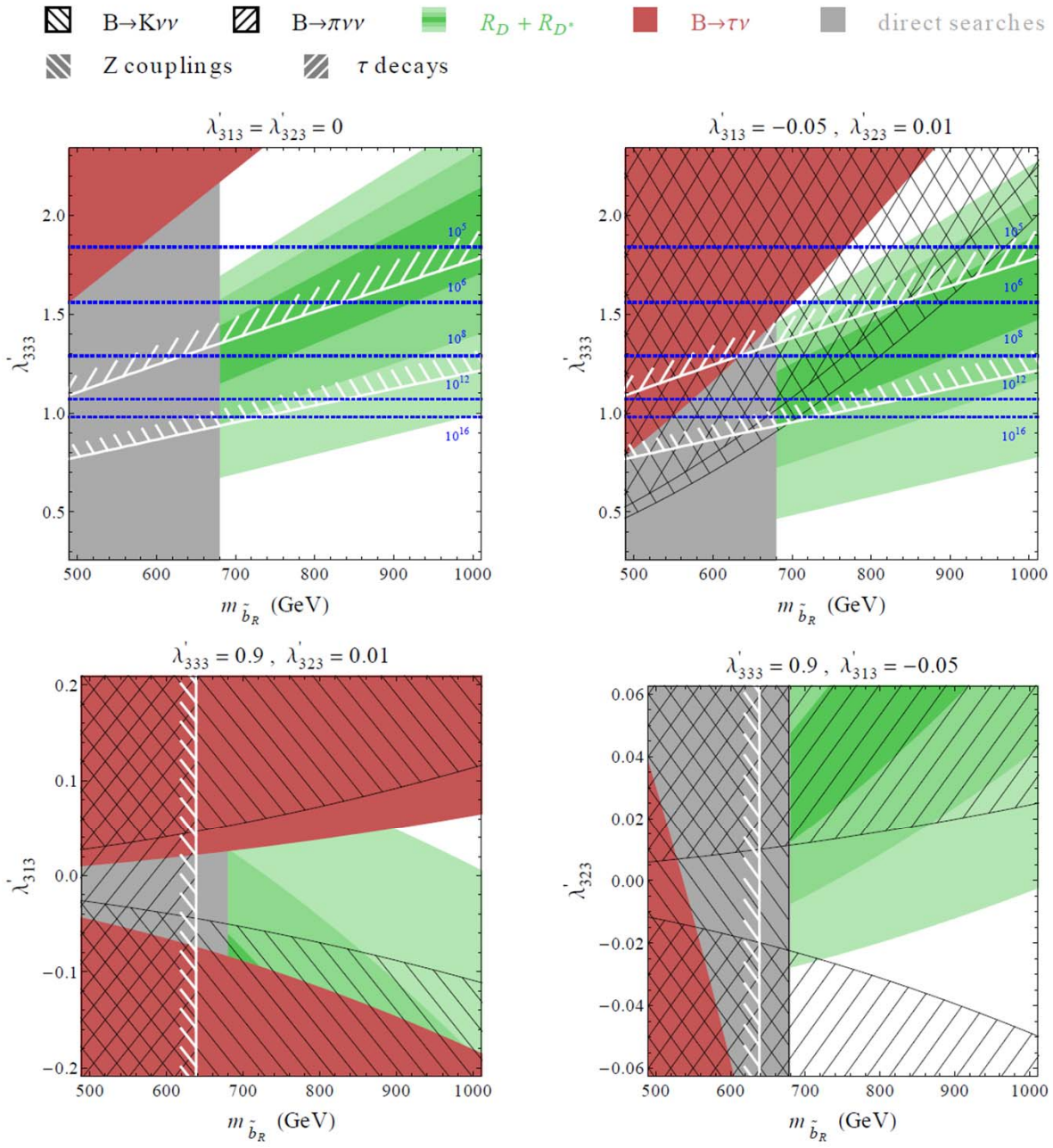
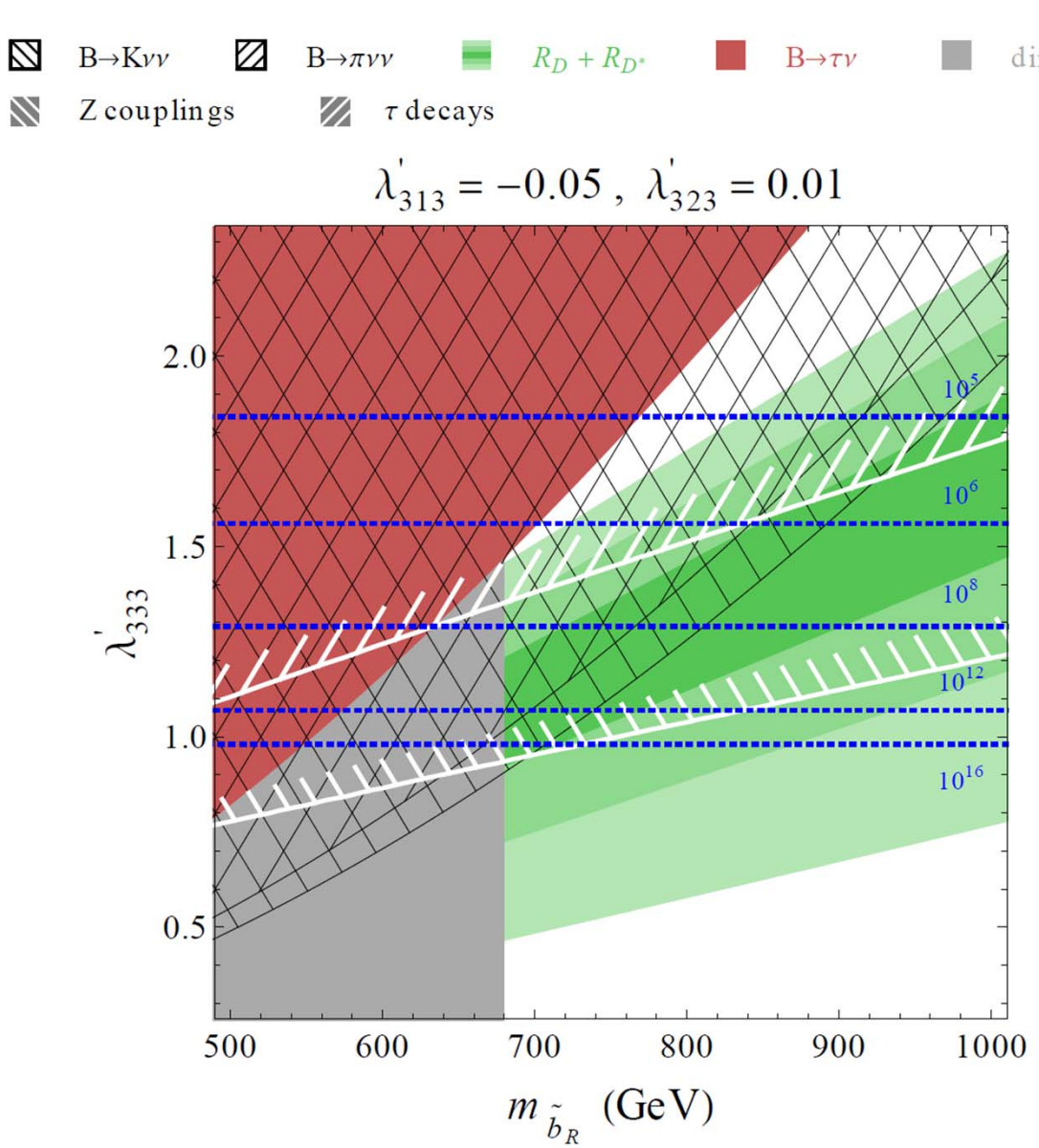


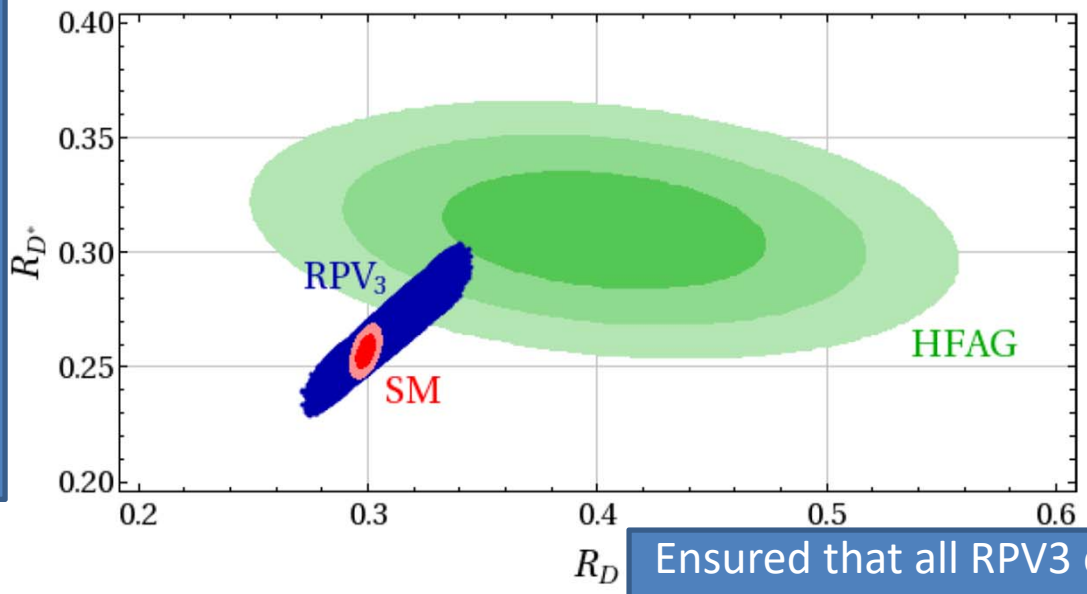
FIG. 3. RPV parameter space satisfying the $R_{D(*)}$ anomaly and other relevant constraints.



Constraints imposed

FIG. 3. RPV parameter space satisfying the $R_{D(*)}$ anomaly and other relevant constraints.

RPV3 allows
RD=(.272-.347)
RD*=(.229-.305)



HFAG dec2016
RD=.403+-.040+-.024
RD*=.310+-.015+-.008
LHCb 06/06/17
RD* 0.305

Ensured that all RPV3 couplings stay perturbative up to GUT

FIG. 4. The SM predictions (red), experimental world average

RPV(blue) region obtained by scanning with sbottom mass 680-1000Gev, $0<\lambda_{333}<2; |\lambda_{323}|<0.1; |\lambda_{313}|<0.3$ + all constraints…….

Summary and Outlook

- **Semi-leptonic B-decays are claimed to indicate ~4.1 sigma deviation from SM**
- ***IMMEDIATE & URGENT IMPLICATION: ATLAS, CMS ought to vigorously search for BSM in : b m ν and in t m***
- **Expt BG from higher D** etc resonances a concern and should b measured; tau detection via hadronic modes should be given very high priority as its much less susceptible to D** contaminations**
- ***More independent theory effort on and off lattice for determination of SM value for RD* are urgently needed***
- **More info from expts on R(D), R(D*), R(π), R(ρ), analogous Bs, B-baryon, B=>τ ν are all urgently needed**
- **Also RD from LHCb as well as Belle would be helpful [since in this case theory is very solid]; *BELLE-II and LHCb-upgrades would of course help a lot***
- **RPV-SUSY effectively involving 3rd gen is economical, minimal and natural and may be an interesting origin of the anomaly [if it persists!]**
- **=> classic large missing energy hunt for SUSY not relevant for that scenario**
- **=> many RPV signatures tend to become rather challenging; therefore, clues can be crucial.**
- **=> our version gives new interesting avenues in b τ ν; t τ …..final states**
- **More studies in progress (inc e,g. RK(*), Bs=>μ μ and much more): see ADS' II**

XTRAS

Lambda' develop landau pole

Overall, we make the following observations: To explain the $R_{D^{(*)}}$ anomaly at the 1σ level, large values of $\lambda'_{333} \sim 1-2$ are required for sbottom masses that are not in conflict with direct searches at the LHC. We find that for such large values of λ'_{333} at the TeV scale, this coupling develops a Landau pole below the GUT scale. In the top panel plots of Figure 3, the position of the Landau pole in GeV is indicated by the dotted blue lines. The position of the pole is obtained by numerically solving the coupled system of 1-loop RGEs of the λ'_{333} coupling from [76], the top Yukawa, and the three gauge couplings in the presence of only one light generation of sfermions. The position of the pole hardly changes when we include all three generations of sfermions. Perturbativity up to the GUT scale requires $\lambda'_{333} \lesssim 1$. Also the Z coupling constraints limits the possible effects in $R_{D^{(*)}}$. In the viable parameter space the $R_{D^{(*)}}$ anomaly can be partially resolved.

$$\frac{g_{Z\tau_L\tau_L}}{g_{Z\ell_L\ell_L}} = 1 - \frac{3(\lambda'_{333})^2}{16\pi^2}\frac{1}{1-2s_W^2}\frac{m_t^2}{m^2_{\tilde{b}_R}} f_Z\left(\frac{m_t^2}{m^2_{\tilde{b}_R}}\right)$$

$$\frac{g_{W\tau_L\nu_\tau}}{g_{W\ell_L\nu_\ell}} = 1 - \frac{3(\lambda'_{333})^2}{16\pi^2}\frac{1}{4}\frac{m_t^2}{m^2_{\tilde{b}_R}} f_W\left(\frac{m_t^2}{m^2_{\tilde{b}_R}}\right) \ ,$$

and the loop functions are given by $f_Z(x) = \frac{1}{x-1} - \frac{\log(x)}{(x-1)^2}$, $f_W(x) = \frac{1}{x-1} - \frac{(2-x)\log(x)}{(x-1)^2}$. In the leading log aprroxima-

Explicitly checked gauge coupling unification in RPV3

Despite the minimality of this setup, one of the key features of SUSY, namely, gauge coupling unification is still preserved, as shown in Fig. 2. Here we show the renormalization group (RG) evolution of the inverse of the

Despite the minimality of this setup, one of the key features of SUSY, namely, gauge coupling unification is still preserved, as shown in Fig. 2. Here we show the renormalization group (RG) evolution of the inverse of the gauge coupling strengths $\alpha_i^{-1} = 4\pi/g_i^2$ (with $i = 1, 2, 3$ for the $SU(3)_c$, $SU(2)_L$ and $U(1)_Y$ gauge groups, where the hypercharge gauge coupling is in SU(5) normalization) in the SM (dotted) and the full MSSM with all SUSY partners at the TeV scale (dashed), and the RPV SUSY scenario with only third generation fermions supersymmetrized at the TeV scale (solid).[6] We find it intriguing that the gauge coupling unification in SUSY occurs regardless of whether only one, two or all three fermion generations are supersymmetrized at low scale, which only shifts the unified coupling value, but not the unification scale. The main reason is that the β-functions receive the dominant contributions from the gaugino and Higgsino sector, so as long as they are not too heavy, the coupling unification feature is preserved, even in presence

AIDA X E-K THESIS: 1ST PHD THESIS (~'89) INITIATING THE USE OF LATTICE METHODS FOR DEDUCING SL FF'S

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Semileptonic decays on the lattice: The exclusive 0^- to 0^- case

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We present our results for the meson form factors of several semileptonic decays. They are computed from the corresponding matrix elements evaluated on the lattice as ratios of Green's functions. The renormalization of the local operators is calculated nonperturbatively. The dependence of the form factors on the four-momentum transfer q^2 is studied by injecting external three-momenta to the initial- and final-state mesons. We study the pseudoscalar decays $K \to \pi l \nu$, $D \to K l \nu$, $D \to \pi l \nu$, $D_s \to \eta l \nu$, and $D_s \to K l \nu$ on different lattices. We also analyze scaling, finite-size, and SU(3)-symmetry-breaking effects. The uncertainties in some lattice parameters, e.g., a^{-1}, as a source of systematic errors in this calculation are discussed.

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Lattice study of semileptonic decays of charm mesons into vector mesons

data before publication. The computing for this project was done at the National Energy Research Supercomputer Center in part under the "Grand Challenge" program and at the San Diego Supercomputer Center.

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We present our lattice calculation of the semileptonic form factors for the decays $D \to K^*$, $D_s \to \phi$, and $D \to \rho$ using Wilson fermions on a $24^3 \times 39$ lattice at $\beta = 6.0$ with 8 quenched configurations. For $D \to K^*$, we find for the ratio of axial form factors $A_2(0)/A_1(0) = 0.70 \pm 0.16^{+0.20}_{-0.15}$. Results for other form factors and ratios are also given.