New Physics at Belle II
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New Physics in $\bar{B} \to D^{(*)} \tau \bar{\nu}$

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B decays with “tau lepton” are now significant:

1. Deviation between SM prediction & experimental result

3.5σ **from** $\bar{B} \to D\tau\bar{\nu}$ **and** $\bar{B} \to D^*\tau\bar{\nu}$

2. What about NP search ?

2HDM cannot compensate the deviation

3. Observables available in future at Belle2

Promising improvement at Belle2

Content

1. Deviation

- Experiment
- SM prediction ／ 2HDM

2. NP search

- Model independent analysis
- NP models

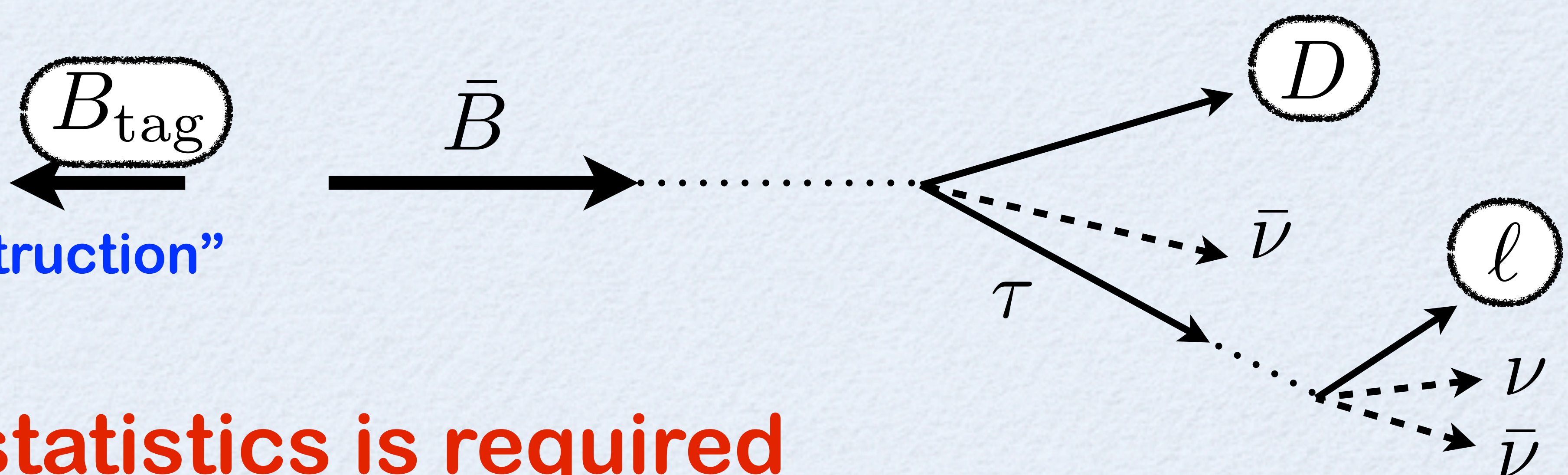
3. Observables at Belle2

- NP analyzer
- q^2 distribution ／ Test of discriminative potential at Belle2

Deviation

Experiment

- It is challenging to measure tauonic B meson decays, because 2 or more neutrinos appear in the final state.
- At B factory, however, reconstructing the opposite B meson we can compare the properties of the remaining particles to those expected for signal and background.

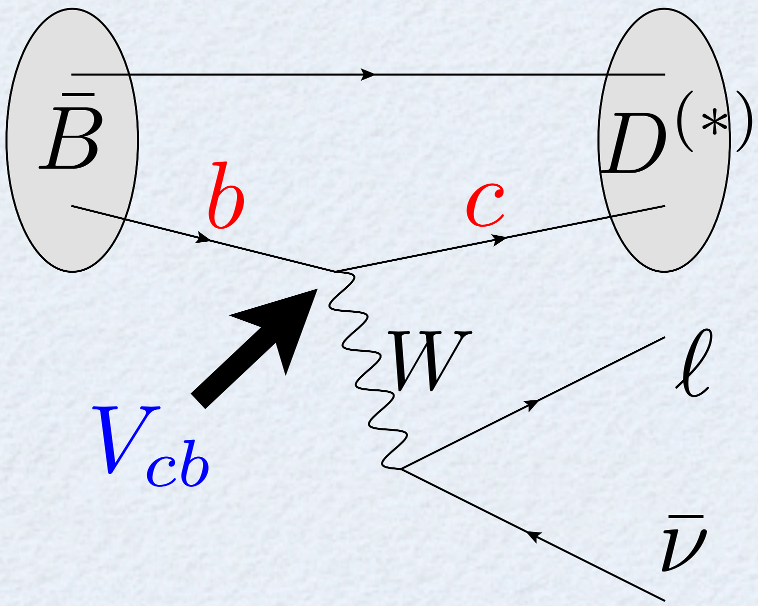


“Full reconstruction”

Large statistics is required even for tree level process

SM prediction

- **Tree level process from V_{cb} in the SM**



$$\mathcal{B}(\bar{B} \to D\tau\bar{\nu}) \propto |V_{cb}|^2 \mathcal{G}(1)^2 \times \{\text{function of } \rho_1^2 \}$$

$$\mathcal{B}(\bar{B} \to D^*\tau\bar{\nu}) \propto |V_{cb}|^2 \mathcal{F}(1)^2 \times \{\text{func. of } \rho_{A_1}^2,\ R_1(1),\ R_2(1) \}$$

$(\mathcal{G},\ \mathcal{F},\ \rho^2,\ R)$ are FF parameters

- **Measurement**

V_{cb} & FF parameters are obtained by a fit to distributions of $\bar{B} \to D^{(*)}\ell\bar{\nu}$ for $\ell = e$ or μ. For an observable of $\bar{B} \to D^{(*)}\tau\bar{\nu}$, normalized decay rate;

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

is used in order to cancel $|V_{cb}|\mathcal{G}(1),\ |V_{cb}|\mathcal{F}(1)$ and reduce FF uncertainties.

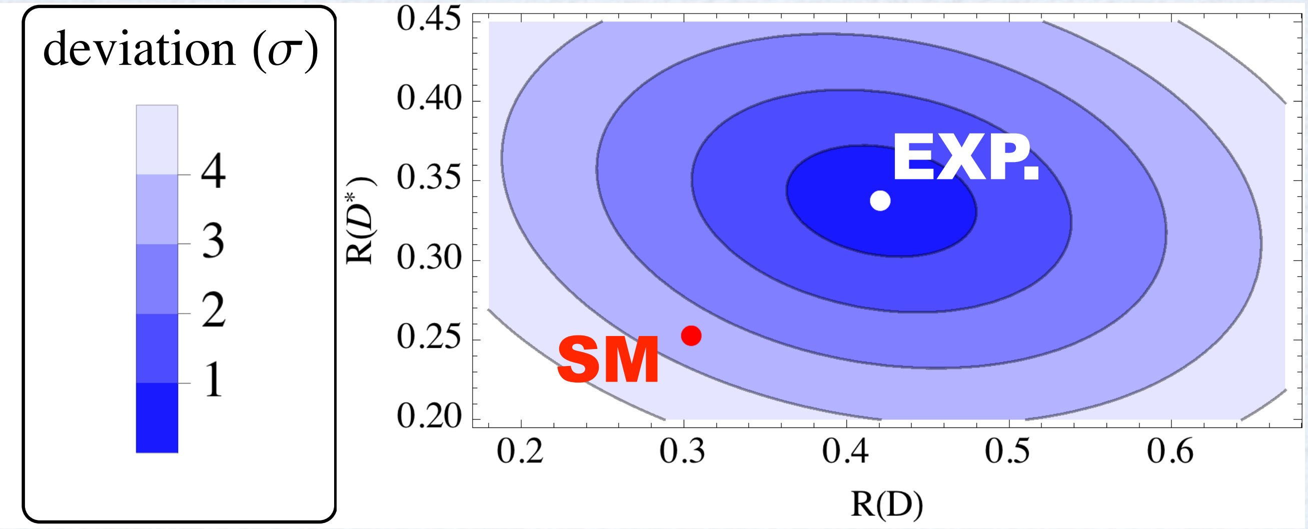
SM prediction

- **Comparison**

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

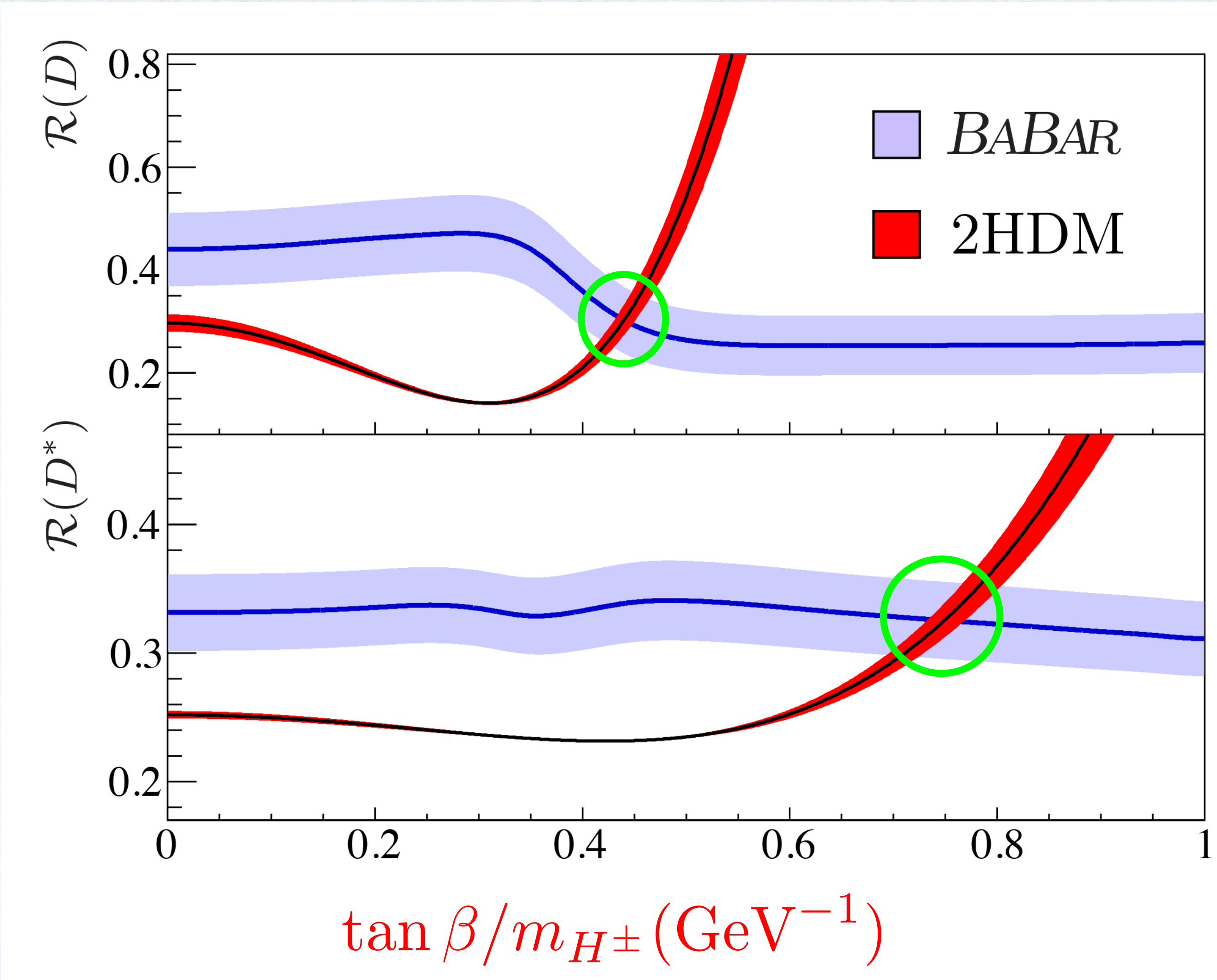
[Belle (our combination), BABAR in arXiv:1205.5442]

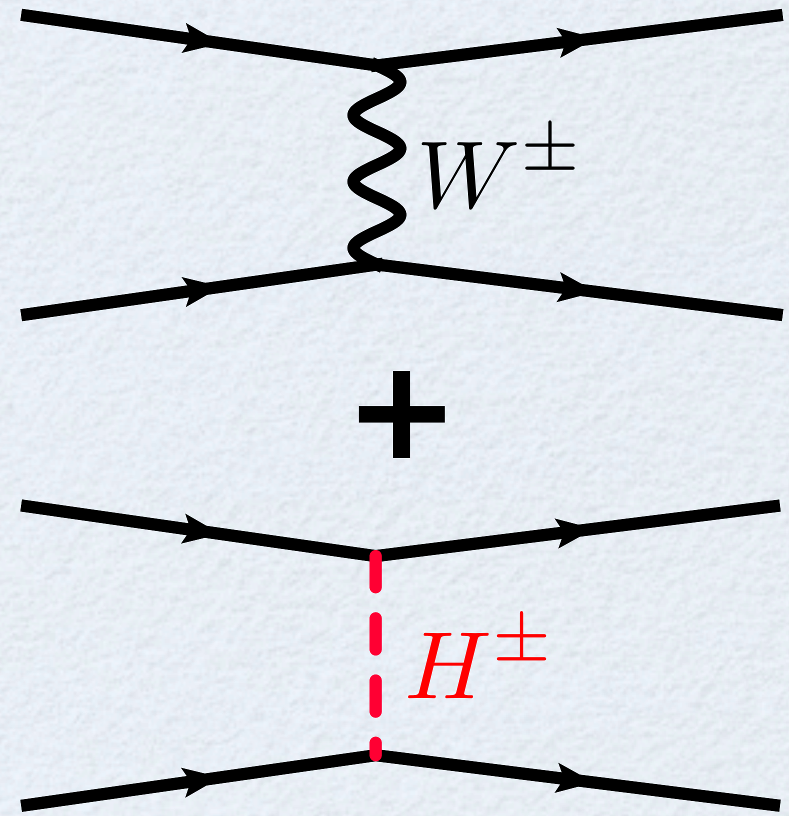
	Belle	BABAR	SM
$R(D)$	0.430 ± 0.091	$0.440 \pm 0.058 \pm 0.042$	0.305 ± 0.012
$R(D^*)$	0.405 ± 0.047	$0.332 \pm 0.024 \pm 0.018$	0.252 ± 0.004
correlation	neglected	-0.27	-



$\sim 3.5\sigma$ **deviation**

2HDM





$$\propto \frac{m_b m_\tau \tan^2\beta}{m_{H^\pm}^2}$$ **(Type II)**

Type-II 2HDM is disfavored at 99.8%CL

[BABAR in arXiv:1205.5442]

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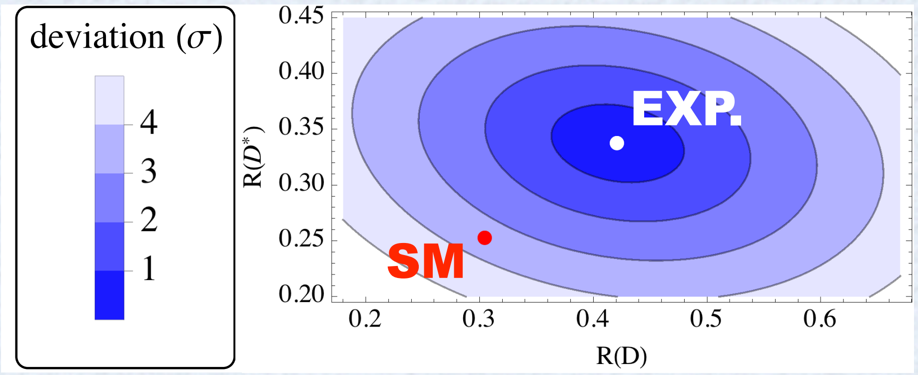
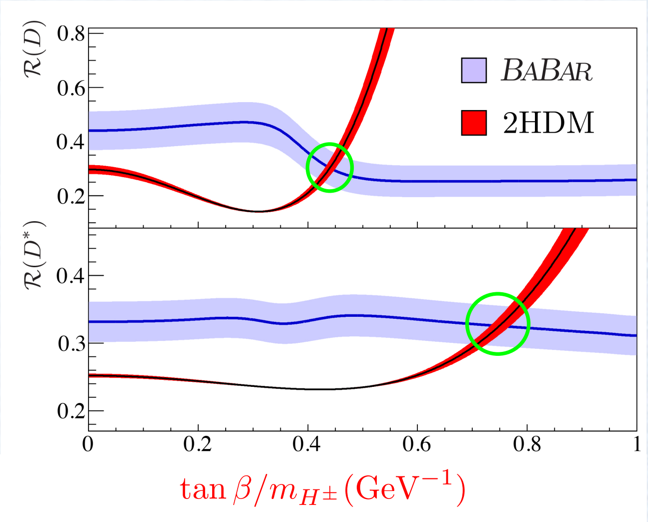




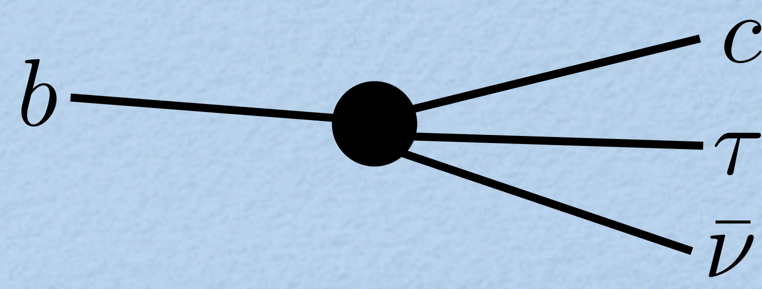
2. NP search

- Model independent analysis
- NP models

3. Observables at Belle2

- NP analyzer
- q^2 distribution ／ Test of discriminative potential at Belle2

NP search



Model independent analysis

$$\mathcal{L}_{\text{eff}} = -2\sqrt{2}G_F V_{cb}\Big[(1 + C_{V_1})\mathcal{O}_{V_1} + C_{V_2}\mathcal{O}_{V_2} + C_{S_1}\mathcal{O}_{S_1} + C_{S_2}\mathcal{O}_{S_2} + C_T\mathcal{O}_T\Big]$$

SM

- **Effective operators** $\mathcal{O}_X$

Vector (1) $\mathcal{O}_{V_1} = \bar{c}_L\gamma^\mu b_L\,\bar{\tau}_L\gamma_\mu\nu_L$

Scalar (1) $\mathcal{O}_{S_1} = \bar{c}_L b_R\,\bar{\tau}_R\nu_L$

Vector (2) $\mathcal{O}_{V_2} = \bar{c}_R\gamma^\mu b_R\,\bar{\tau}_L\gamma_\mu\nu_L$

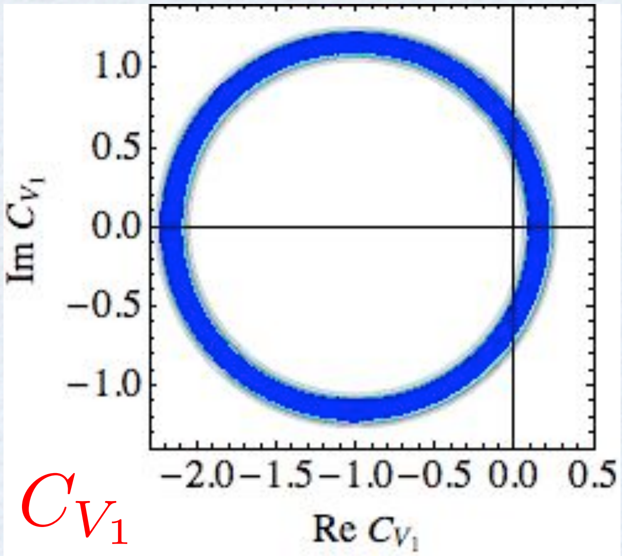
Scalar (2) $\mathcal{O}_{S_2} = \bar{c}_R b_L\,\bar{\tau}_R\nu_L$

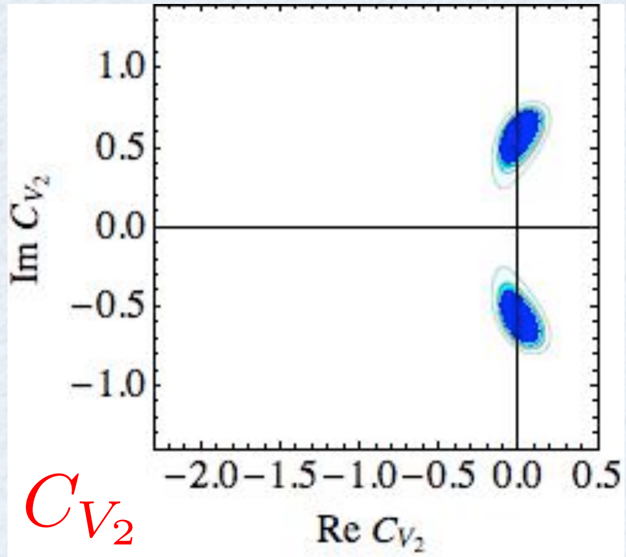
Tensor $\mathcal{O}_T = \bar{c}_R\sigma^{\mu\nu} b_L\,\bar{\tau}_R\sigma_{\mu\nu}\nu_L$

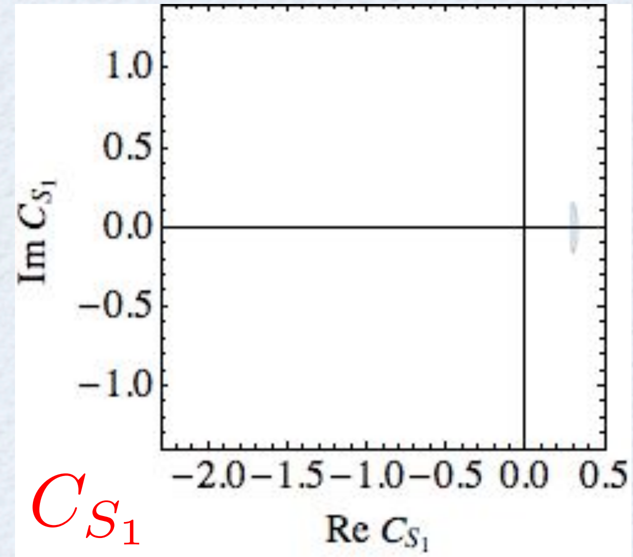
- **Wilson coefficients** C_X

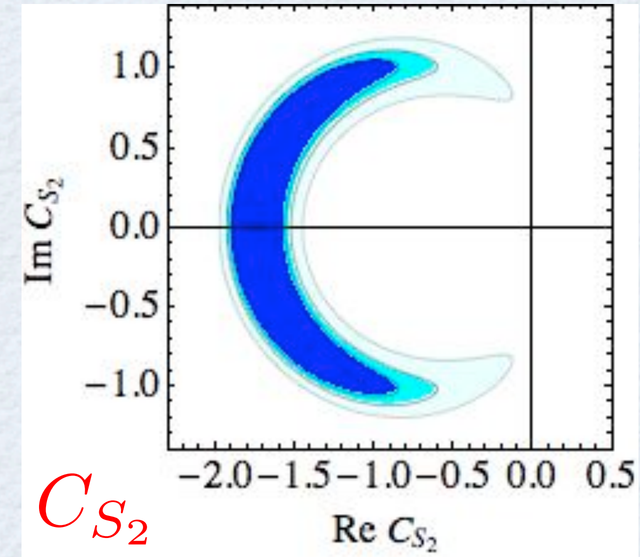
Cx represents “New Physics” contribution normalized by SM contribution

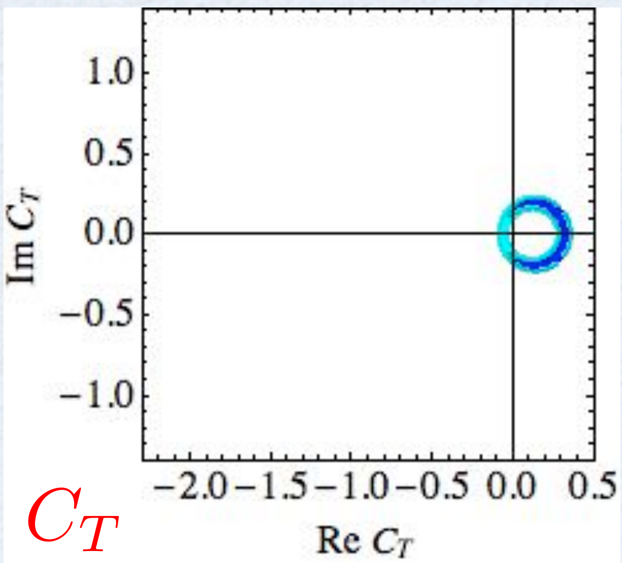
・Allowed region of Cx from R(D) & R(D*) [M.Tanaka&RW, arXiv:1212.1878]











* assuming one operator dominance (ex: $C_{S_2} \neq 0, \text{ others} = 0$)

* using the data which is the average of Belle & BABAR

* allowed at 90%(Light blue), 95%(Cyan), 99%(Dark blue)

・V1, V2, T can explain data within small Cx

・S2 can explain but large Cs_2(~−1.6) is needed

・S1 is not preferred

NP models

[M.Tanaka & RW, arXiv:1212.1878]

2 Higgs Doublet Model

$V_1 \quad V_2 \quad S_1 \quad S_2 \quad T$

- contribute as S1 & S2 type
- type I, II, X, Y cannot explain / type III can

R Parity Violation

$V_1 \quad V_2 \quad S_1 \quad S_2 \quad T$

- S1 type operator is generated, and disfavored
- V1 type is generated, but incompatible with data of $B \to X_s \nu \nu$

Lepto Quark

$V_1 \quad V_2 \quad S_1 \quad S_2 \quad T$

- S1 & V1 type are generated and disfavored as well as RPV
- S2-T types are generated and likely to explain the results

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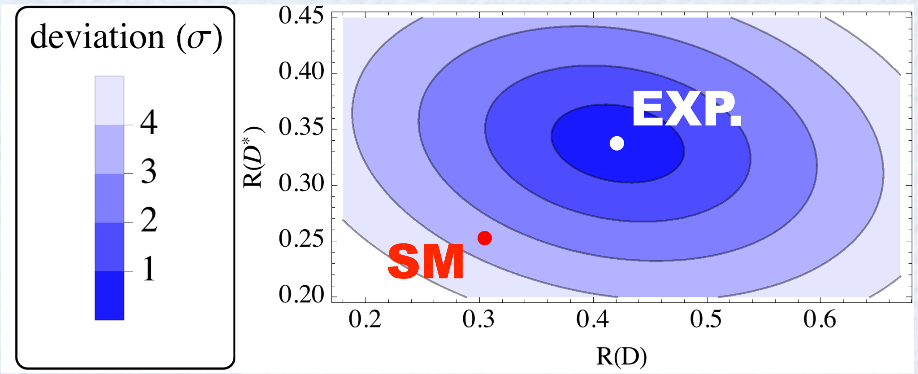

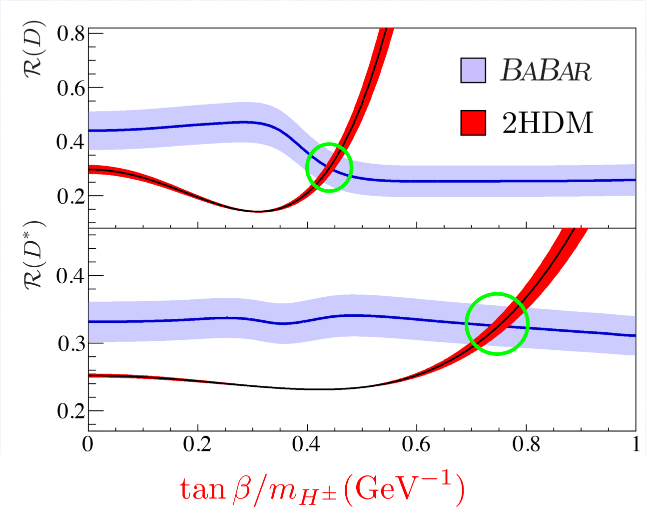

2. NP search

- Model independent analysis
- NP models

・V1, V2, T can explain data within small Cx

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3. Observables at Belle2

- NP analyzer
- q^2 distribution ／ Test of discriminative potential at Belle2

Observables at Belle II

New physics analyzer

- Compared with two body decay like $B \to \tau\nu$,
  many more observables are available in three body decays, $B \to D^{(*)}\tau\nu$

- There are several studies for NP search toward Belle2
  (q^2 distributed and/or integrated)

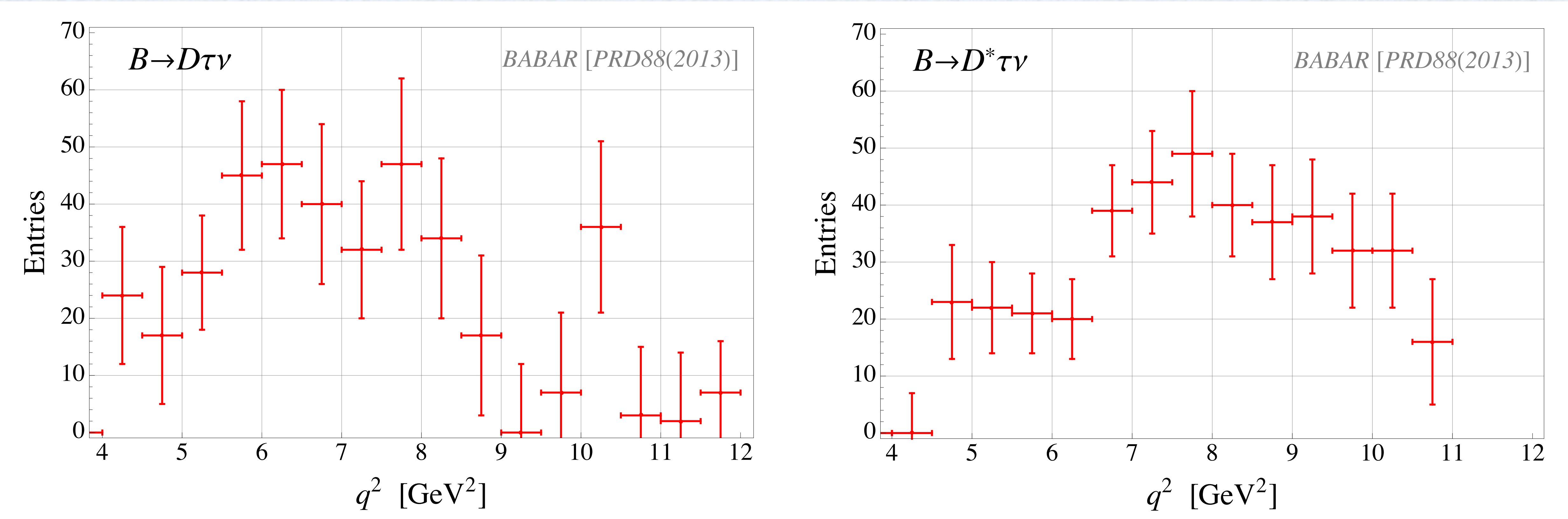
[Fajfer, Kamenik, Nisandzic, Zupan, arXiv:1203.2654]
[Sakaki, Tanaka, arXiv:1205.4908]
[Datta, Duraisamy, Ghosh, arXiv1206.3760]
[Tanaka, Watanabe, arXiv:1212.1878]
[Biancofiore, Colangelo, De Fazio, arXiv:1302.1042]
[Duraisamy, Datta, arXiv:1302.7031, arXiv:1405.3719]
[Sakaki, Tanaka, Tayduganov, Watanabe, arXiv:1309.0301]
[Hagiwara, Nojiri, Sakaki, arXiv:1403.5892]
[Sakaki, Tanaka, Tayduganov, Watanabe, arXiv:1412.3761]

Pick up

q^2 distribution

$$\frac{d\Gamma(\bar{B} \to D^{(*)}\tau\bar{\nu})}{dq^2} \qquad \text{where } q^2 = (p_B - p_{D^{(*)}})^2$$

[BABAR, arXiv:1303.0571]



- p values for the fit

model	$\overline{B} \to D\tau\bar{\nu}$	$\overline{B} \to D^*\tau\bar{\nu}$	$\overline{B} \to (D+D^*)\tau\bar{\nu}$
SM	54%	65%	67%
V_1	54%	65%	67%
V_2	54%	65%	67%
S_2	0.02%	37%	0.1%
T	58%	0.1%	1.0%
LQ$_1$	13%	58%	25%
LQ$_2$	21%	72%	42%

S2 & T are disfavored !

Not conclusive for others

Test of discriminative potential at Belle2

Toward Belle2:

We propose new observable (distribution) for extracting NP signature.

$$R_D(q^2) \equiv \frac{d\Gamma(\bar{B} \to D\tau\bar{\nu})/dq^2}{d\Gamma(\bar{B} \to D\ell\bar{\nu})/dq^2} \times [\text{Normalization factor}]$$

for (our) convenience

ratio of q^2 distributions

$$R_{D^*}(q^2) \equiv \frac{d\Gamma(\bar{B} \to D^*\tau\bar{\nu})/dq^2}{d\Gamma(\bar{B} \to D^*\ell\bar{\nu})/dq^2} \times \left(1 - \frac{m_\tau^2}{q^2}\right)^{-2}$$

We can reduce theoretical uncertainties as is the case with R(D) and R(D*).

Test of discriminative potential at Belle2

Assumption:

1. use the best fitted Cx from the recent results of R(D)&R(D*)
2. prepare/make "faked data for the new distribution" using above
3. evaluate luminosities required to discriminate "data" & "model" by $R_{D^{(*)}}(q^2)$

$\mathcal{L}$ [fb^{-1}]		model						
		SM	V_1	V_2	S_2	T	LQ$_1$	LQ$_2$
"data"	V_1	1170 (270)		10^6 (×)	500 (×)	900 (×)	4140 (×)	2860 (1390)
	V_2	1140 (270)	10^6 (×)		510 (×)	910 (×)	4210 (×)	3370 (1960)
	S_2	560 (290)	560 (13750)	540 (36450)		380 (×)	1310 (35720)	730 (4720)
	T	600 (270)	680 (×)	700 (×)	320 (×)		620 (×)	550 (1980)
	LQ$_1$	1010 (270)	4820 (×)	4650 (×)	1510 (×)	800 (×)		5920 (1940)
	LQ$_2$	1020 (250)	3420 (1320)	3990 (1820)	1040 (20560)	650 (4110)	5930 (1860)	

99.9%CL

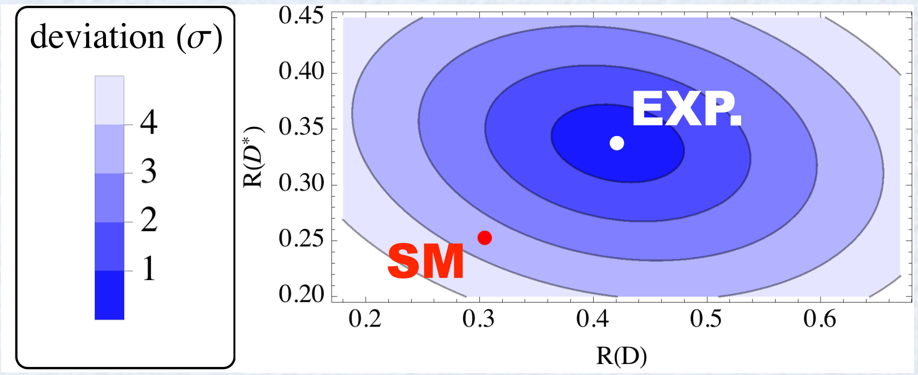
( ) = required luminosity only from R(D)&R(D*)

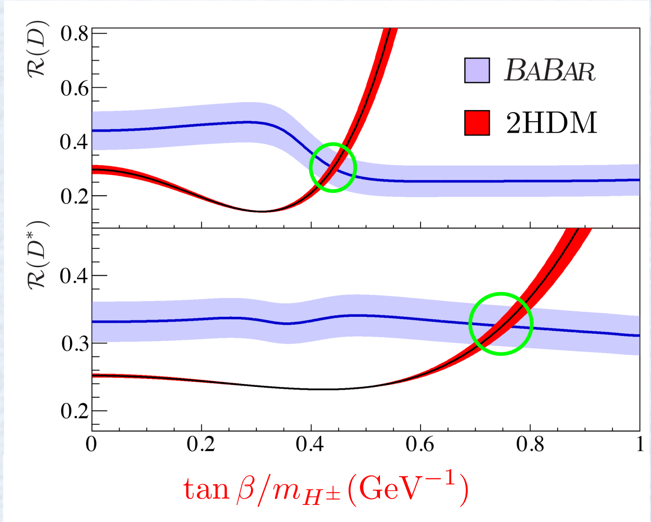
- Some cases can be already tested using present data
- To test LQ, we need 1-6 ab^-1 at Belle2

Summary

1. Deviation

- Experiment
- SM prediction ／ 2HDM





2. NP search

- Model independent analysis
- NP models

・V1, V2, T can explain data within small Cx

・S2 can explain but large Cs2(~-1.6) is needed

・S1 is not preferred

3. Observables at Belle2

- NP analyzer
- q^2 distribution

"data" \ model	SM	V_1	V_2	S_2	T	LQ_1	LQ_2
V_1	■		✘	◎	◎	◎	■
V_2	■	✘		◎	◎	◎	■
S_2	■	○	○		◎	○	○
T	■	◎	◎	◎		◎	○
LQ_1	■	◎	◎	◎	◎		■
LQ_2	■	■	■	○	○	■	

■ R(D(*)) has an advantage

○ Distribution has adv.

◎ possible only from distribution

Back up

$|V_{cb}|$ determination

$\bar{B} \to D\ell\bar{\nu}$

$$\frac{d\Gamma}{dw} = \frac{G_F m_B^5}{48\pi^3} r^3 (1+r)^2 (w^2-1)^{3/2} V_1(w)^2 |V_{cb}|^2$$

$$w = (m_B^2 + m_D^2 - q^2)/(2m_B m_D)$$

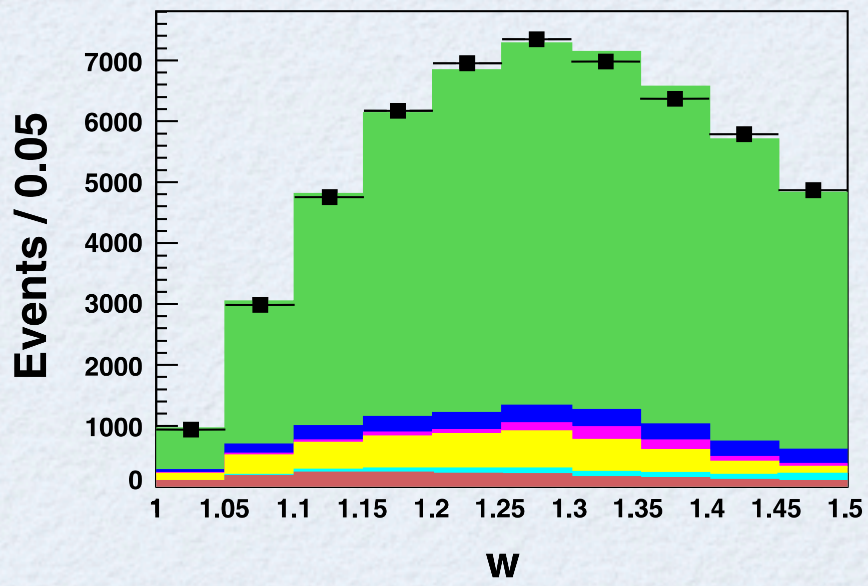
- **Fit the shape (=interaction type) and the hight (=coupling)**

- **Shape is parametrized by HQET** **[Caprini et.al. (1996)]**

Shape : $V_1(w) = V_1(1)\left[1 - 8\rho_1^2 z + (51\rho_1^2 - 10)z^2 - (252\rho_1^2 - 84)z^3\right]$

Hight : $V_1(1)|V_{cb}|$

$$\left(z = \frac{\sqrt{w+1}-\sqrt{2}}{\sqrt{w+1}+\sqrt{2}}\right)$$



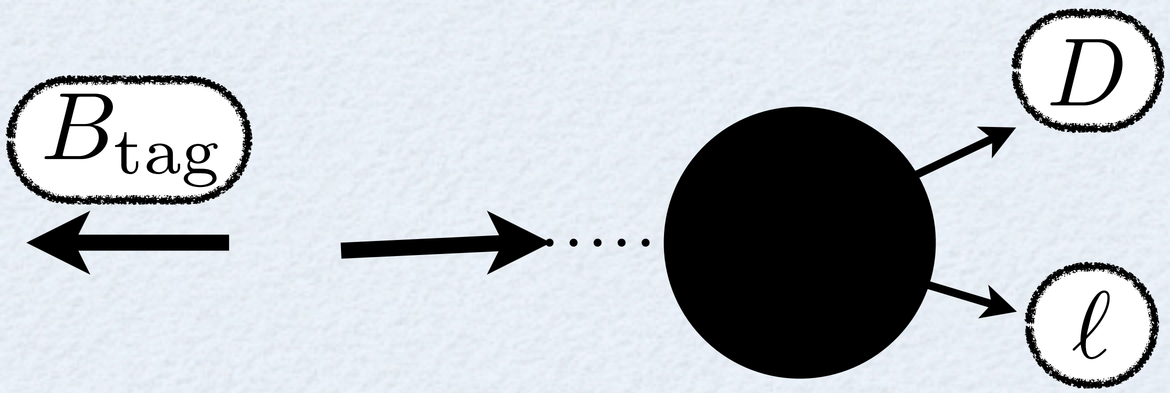
Fit result:

$$V_1(1)|V_{cb}| = (4.26 \pm 0.07 \pm 0.14) \times 10^{-2}$$

$$\rho_1^2 = 1.186 \pm 0.055$$

Experimental analysis @BABAR

[BABAR, arXiv:1205.5442]

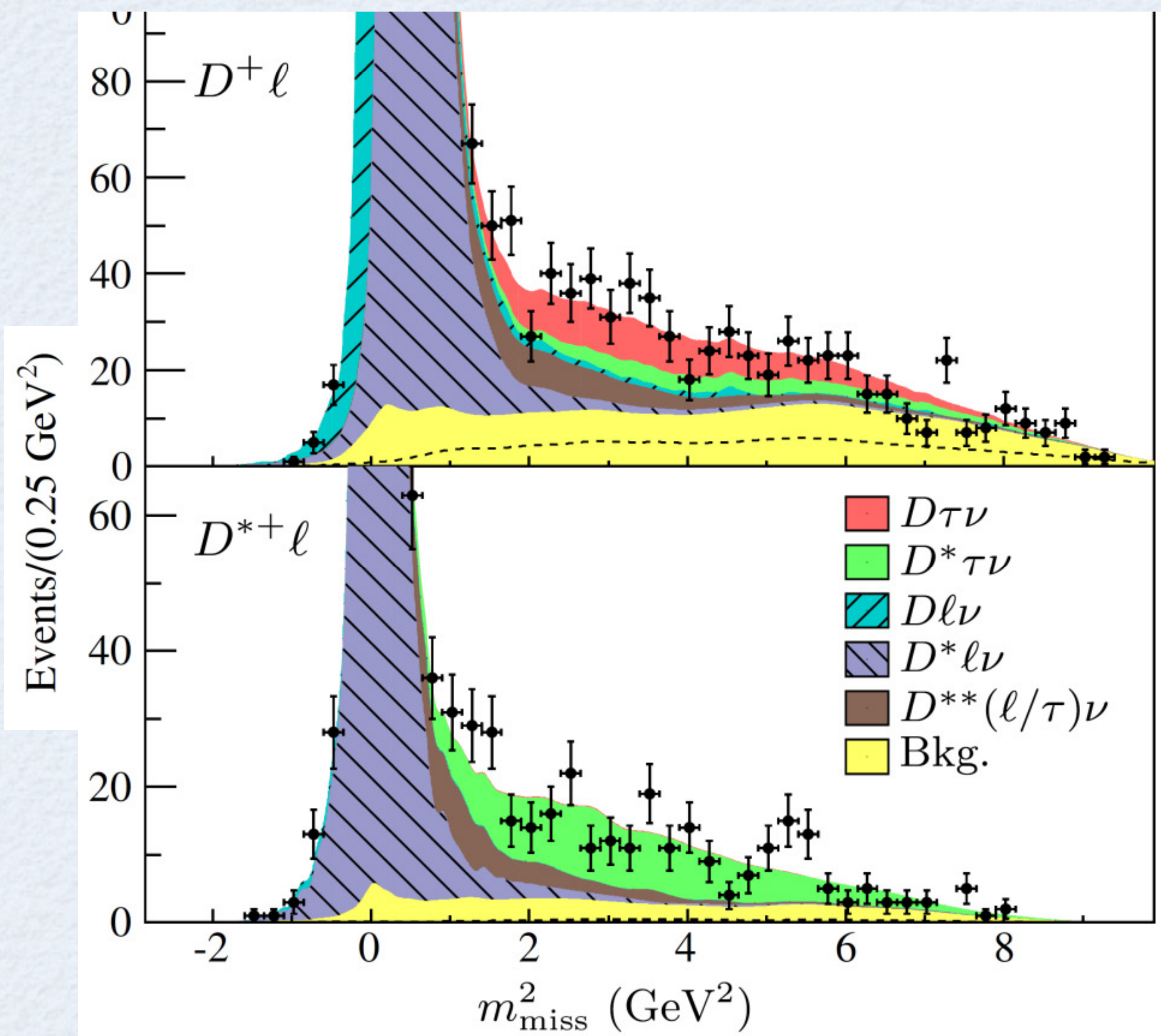


* Decay channel BABAR analyzed:

$$\bar{B} \to D^{(*)}(\tau \to \ell\bar{\nu}\nu)\bar{\nu}$$

* inv. mass of missing particles:

$$m^2_{\rm miss} = (p_{e^+e^-} - p_{\rm tag} - p_{D^{(*)}} - p_\ell)^2$$



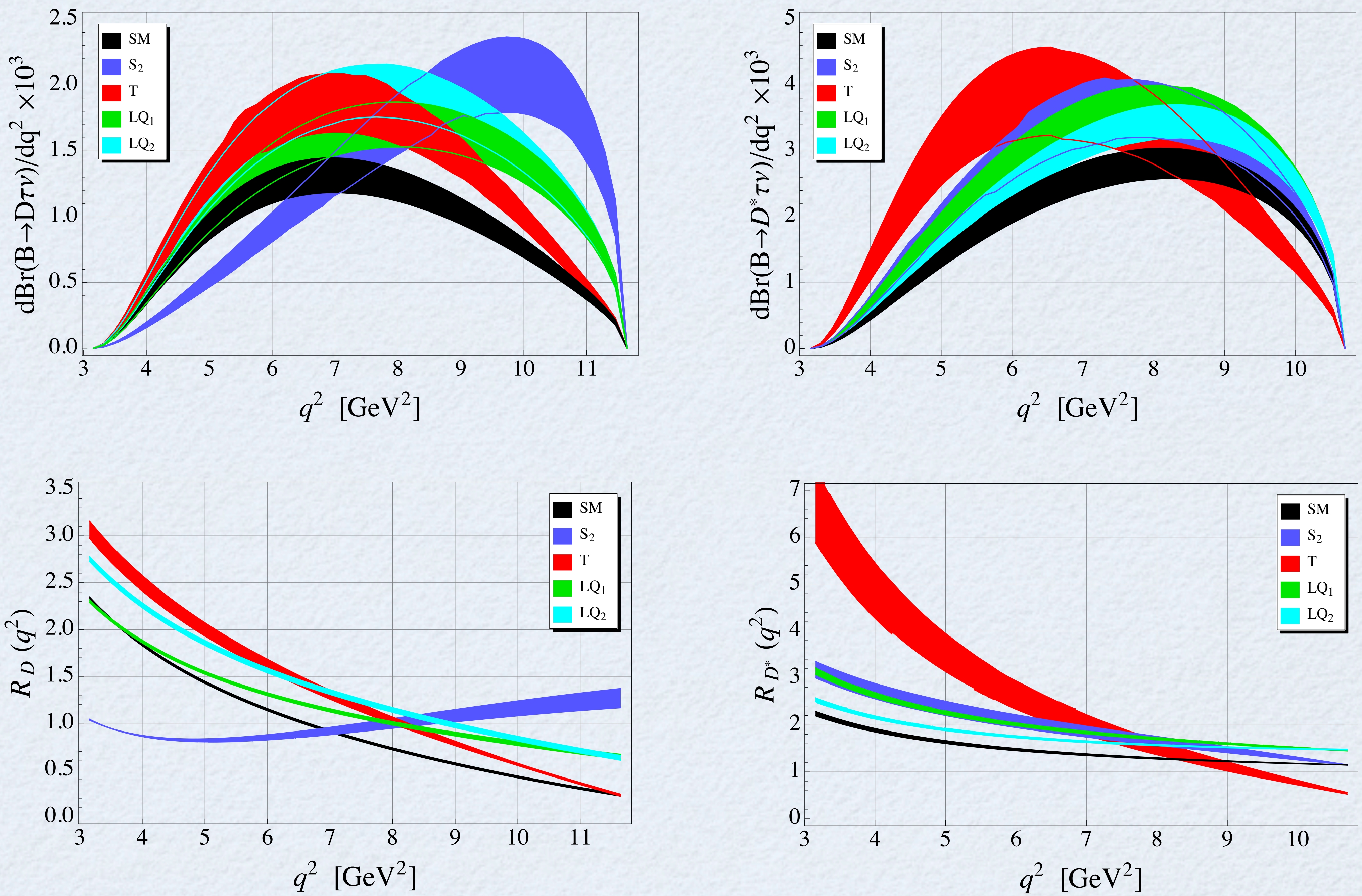
1. $B_{\rm tag}$, $D^{(*)}$, ℓ are identified

2. $m^2_{\rm miss}$ distribution is measured

3. Comparing total event data with expected signal & background, signal event is extracted

Distribution

- **Distribution in NP models using best fitted Cx from R(D(*))**



$$R_D(q^2) \equiv \frac{d\mathcal{B}(\overline{B} \to D\tau\overline{\nu})/dq^2}{d\mathcal{B}(\overline{B} \to D\ell\overline{\nu})/dq^2} \frac{\lambda_D(q^2)}{(m_B^2 - m_D^2)^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^{-2}$$

$$R_{D^*}(q^2) \equiv \frac{d\mathcal{B}(\overline{B} \to D^*\tau\overline{\nu})/dq^2}{d\mathcal{B}(\overline{B} \to D^*\ell\overline{\nu})/dq^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^{-2}$$

Discriminative potential

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99.9%CL

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Setup:

1. divide q^2 region by 16(14) bins in B→D(*)τν as is done by BaBar
2. evaluate covariant matrices of theoretical uncertainties for each model
3. estimate experimental errors taking efficiencies (10^-4) into account

(10^-4 is obtained from BaBar analysis and we assume using this value)