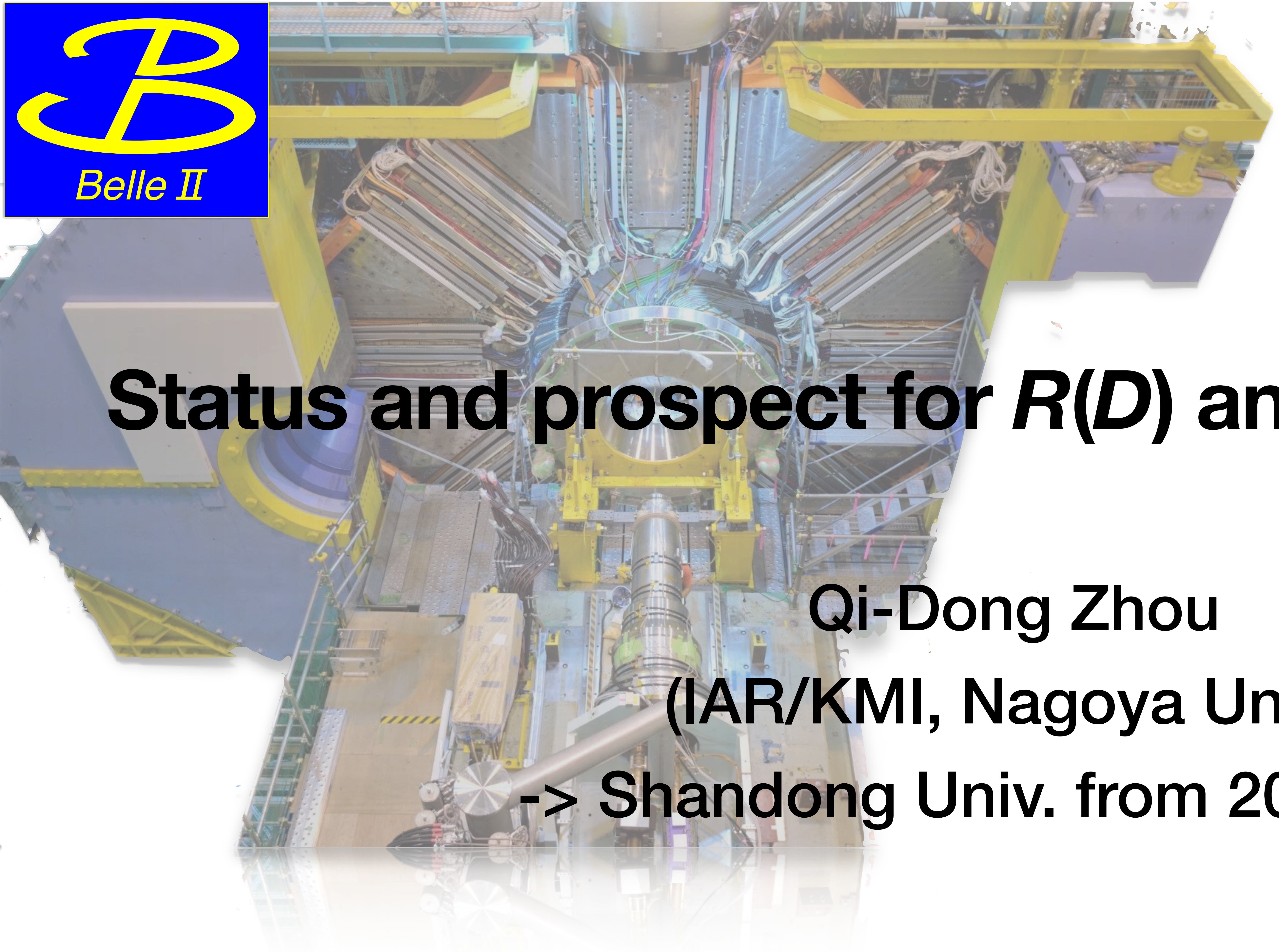


Status and prospect for *R*(*D*) and *R*(*D**) at Belle II

Qi-Dong Zhou

(IAR/KMI, Nagoya Univ.)

-> Shandong Univ. from 2023 May

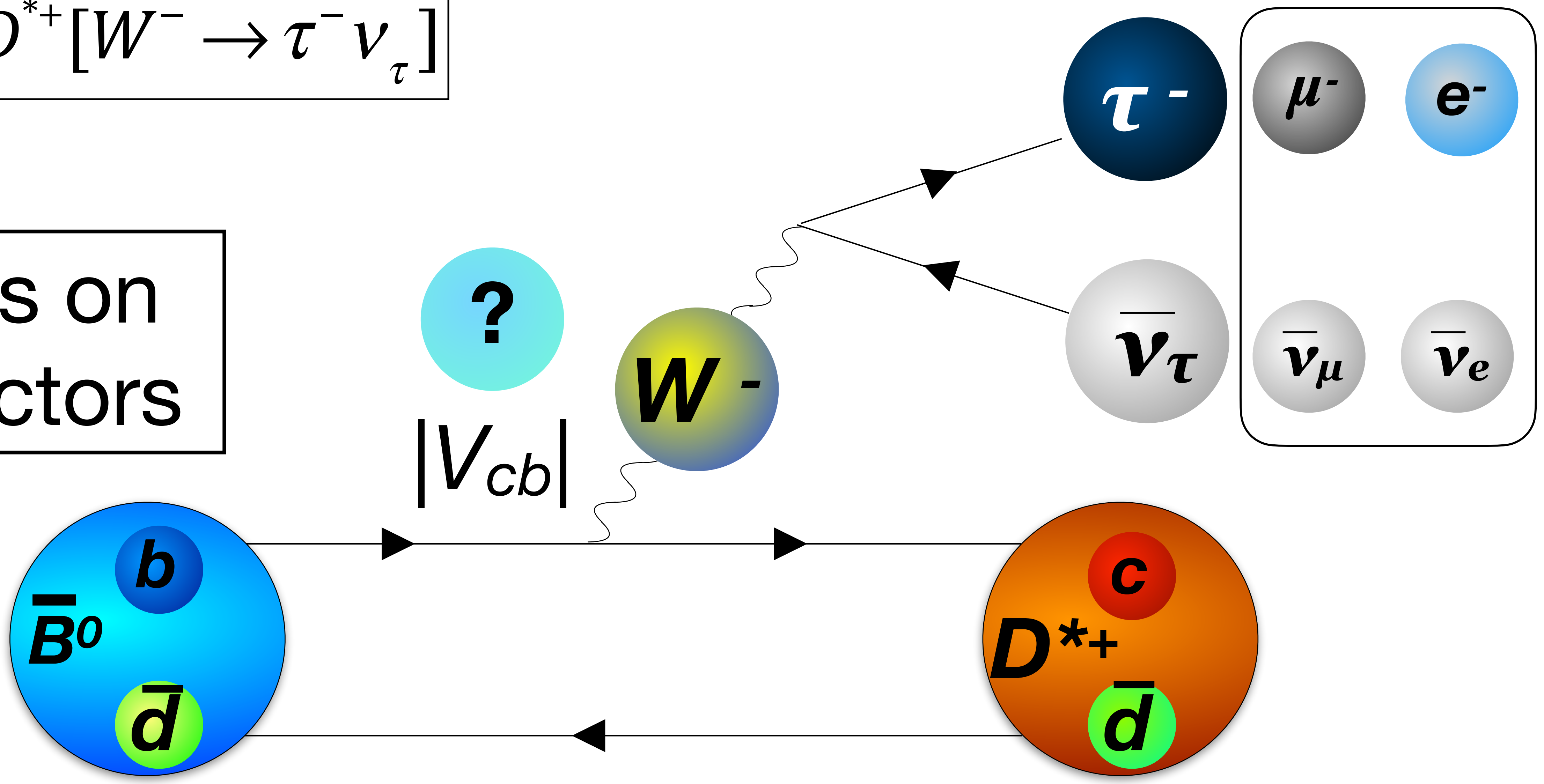
Mar. 29 - 30, 2023, Nagoya University

B1 Heavy Flavor and Dark Matter Joint Unit Symposium

Semi-tauonic *B* decay: $B \to D^{(*)}\tau\nu$

$\overline{B}^0 \to D^{*+}[W^- \to \tau^- \overline{\nu}_\tau]$

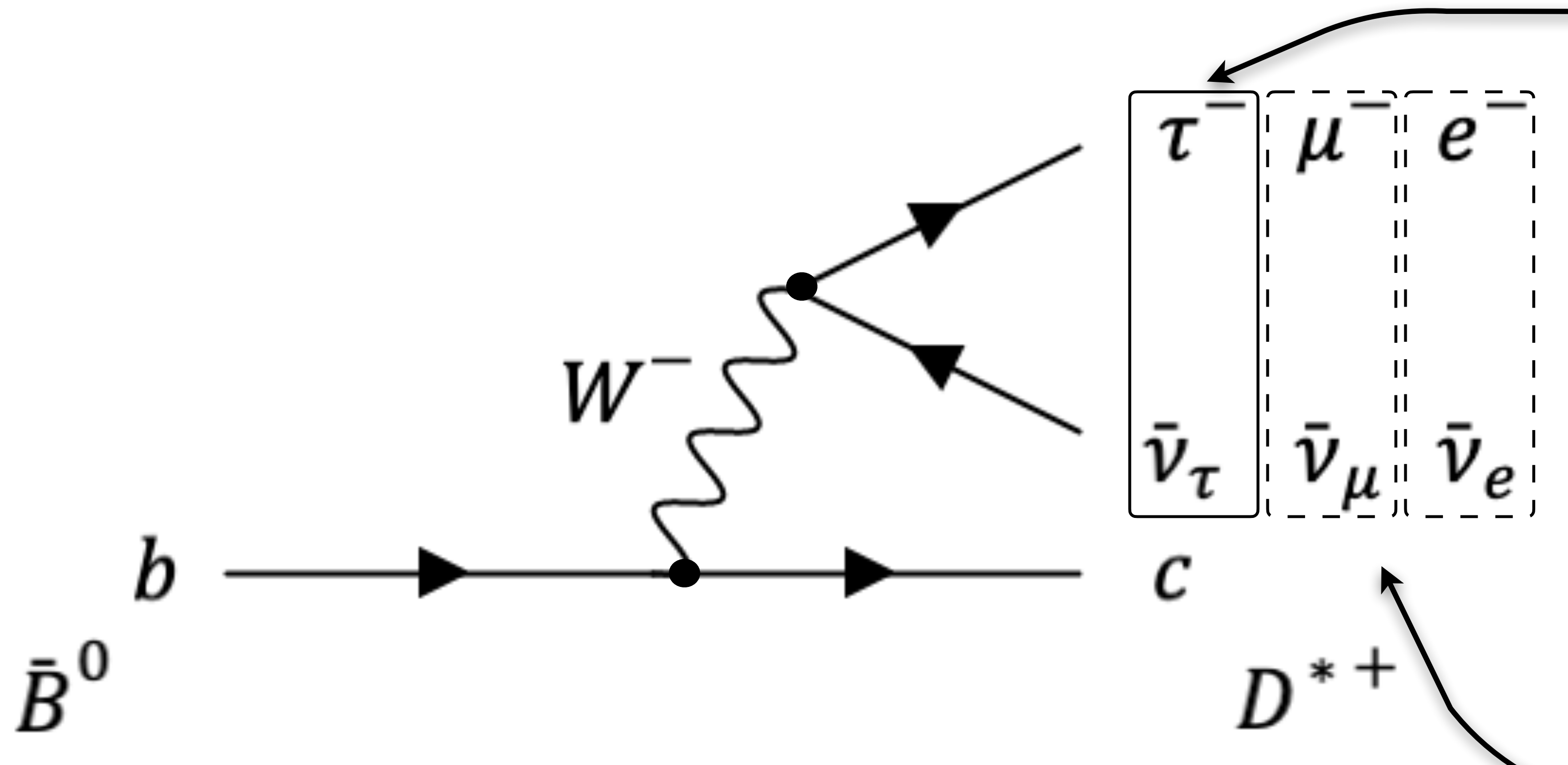
Sizable uncertainties on $|V_{cb}|$ and the form factors



- Universality of the lepton coupling to the *W* gauge boson (Symmetry)
  - Lepton Flavor Universality (LFU) is fundamental theory of Standard Model (SM)

- $B \to D^{(*)}\tau\nu$ sensitive to New physics (NP) because the massive 3rd generation *b* quark and τ lepton are involved
  - Flavor-dependent coupling to fermions could violates LFU

$R(D)$ and $R(D^*)$ anomaly



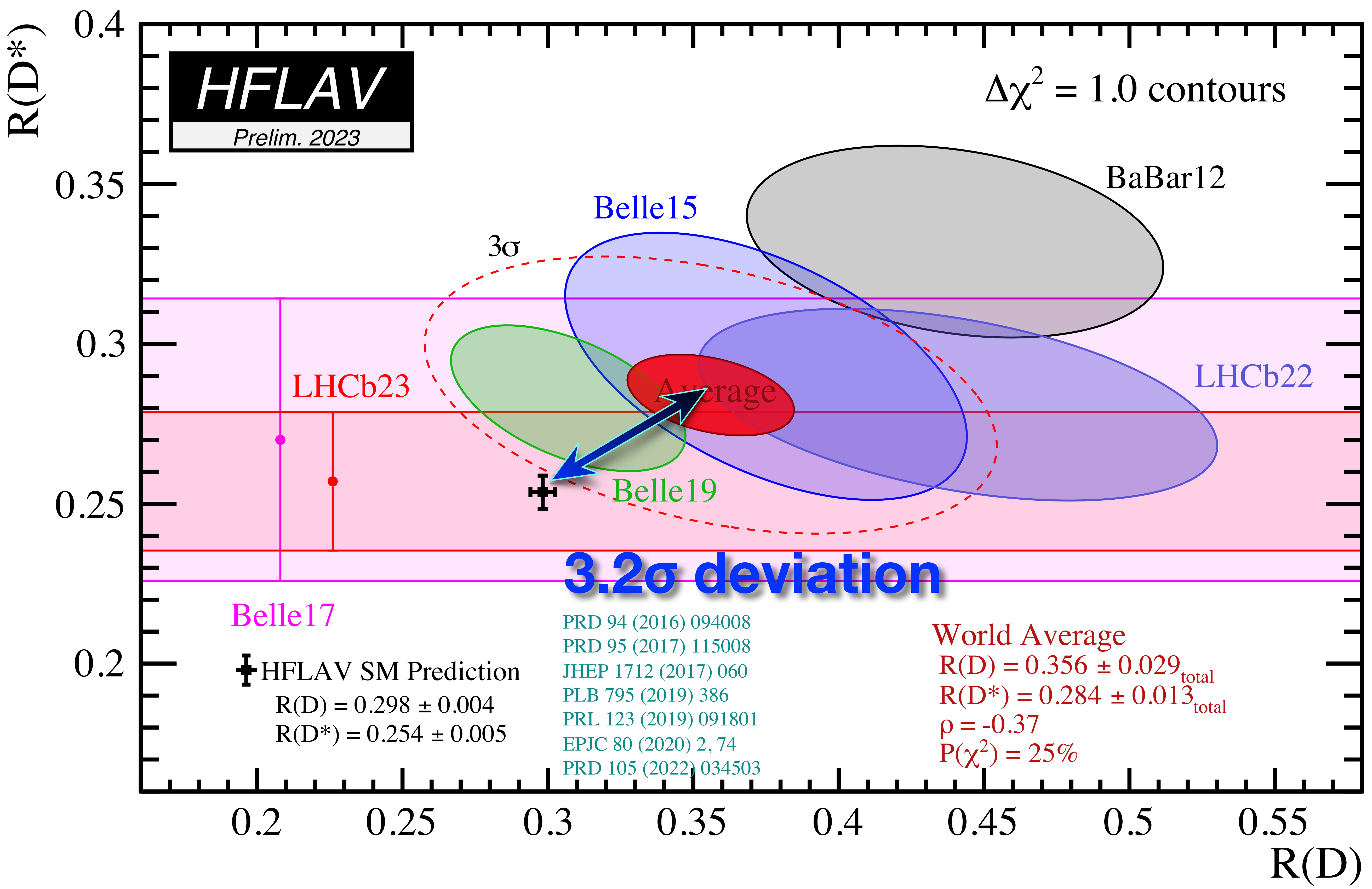
$$R(D^{(*)}) = \frac{Br(\bar{B}^0 \to D^{(*)+}\tau^-\bar{\nu}_\tau)}{Br(\bar{B}^0 \to D^{(*)+}\ell^-\bar{\nu}_\ell)}$$

- Ratio of branch fractions cancel out most of the uncertainties on $|V_{cb}|$, form factors and the experimental systematics
- Charged lepton mass changes kinematics and modifies form factors in the hadronization
- QED corrections depend on lepton velocity (τ vs. ℓ (e, μ))

Experiment	Tag method	τ decay	Correlation(stat/syst/total)	$R(D)$	$R(D^*)$
Babar '12	Hadronic	$\ell\nu\nu$	-0.45/-0.07/-0.27	0.440 ± 0.058 ± 0.042	0.332 ± 0.024 ± 0.018
Belle '15	Hadronic	$\ell\nu\nu$	-0.56/-0.11/-0.49	0.375 ± 0.064 ± 0.026	0.293 ± 0.038 ± 0.015
LHCb '15	-	$\mu\nu\nu$		-	0.336 ± 0.027 ± 0.030
Belle '16	Semileptonic	$\ell\nu\nu$		-	0.302 ± 0.030 ± 0.011
Belle '17	Hadronic	$\pi\nu,\rho\nu$		-	$0.270 \pm 0.035\ ^{+0.028}_{-0.025}$
LHCb '18	-	$\pi\pi\pi\nu$		-	0.283 ± 0.019 ± 0.029
Belle '20	semileptonic	$\ell\nu\nu$	-0.53/-0.51/-0.51	0.307 ± 0.037 ± 0.016	0.283 ± 0.018 ± 0.014
LHCb '22	-	$\mu\nu\nu$	-0.49/ /-0.43	0.441 ± 0.060 ± 0.066	0.281 ± 0.018 ± 0.024
LHCb '23	-	$\pi\pi\pi\nu$		-	0.257 ± 0.012 ± 0.018
Average	-	-	-0.37	0.356 ± 0.029	0.284 ± 0.013
SM				0.298 ± 0.004	0.254 ± 0.005

$R(D)$ and $R(D^*)$ anomaly

	Correlation	$R(D)$	$R(D^*)$
Average	-0.37	0.358 ± 0.029	0.284 ± 0.013
SM		0.298 ± 0.004	0.254 ± 0.005



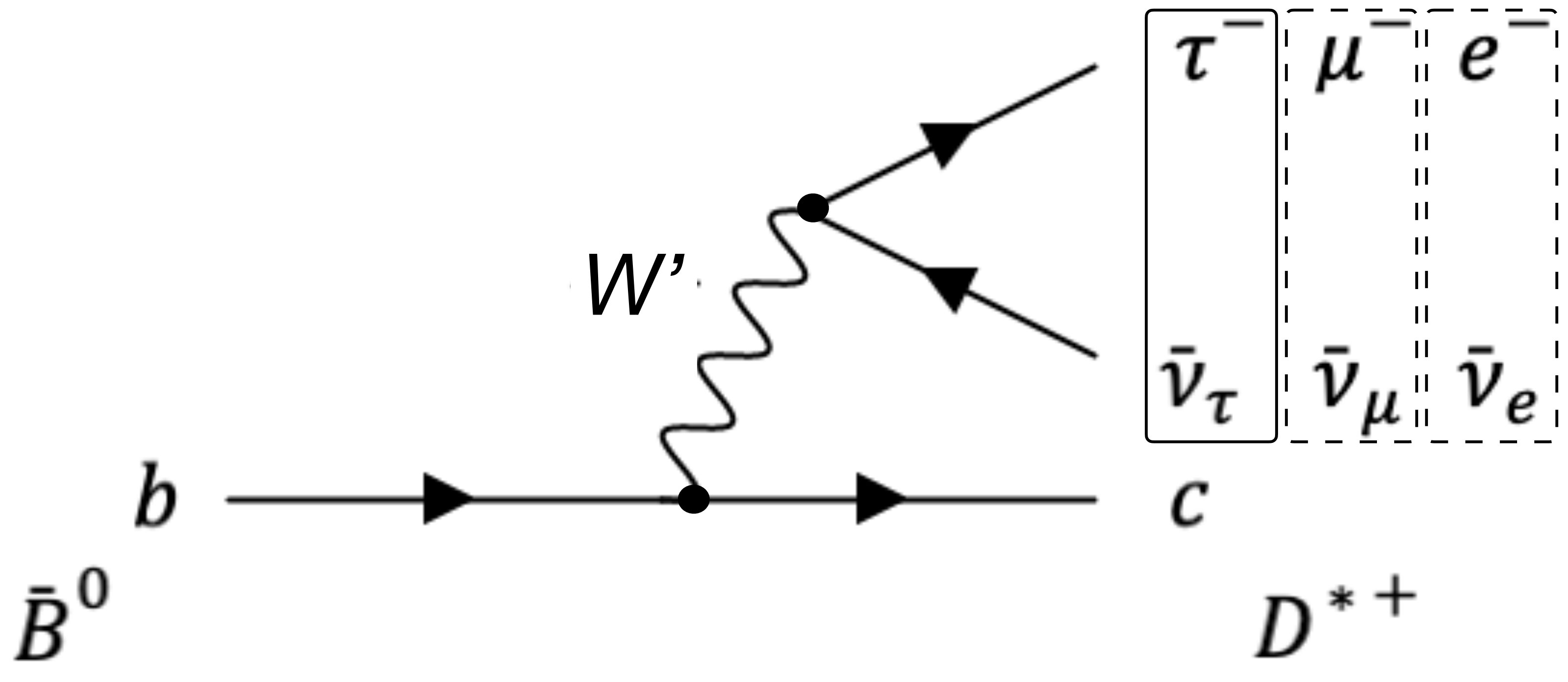
3.8σ —> 3.1σ —> 3.3σ —> 3.2σ —> 3.2σ

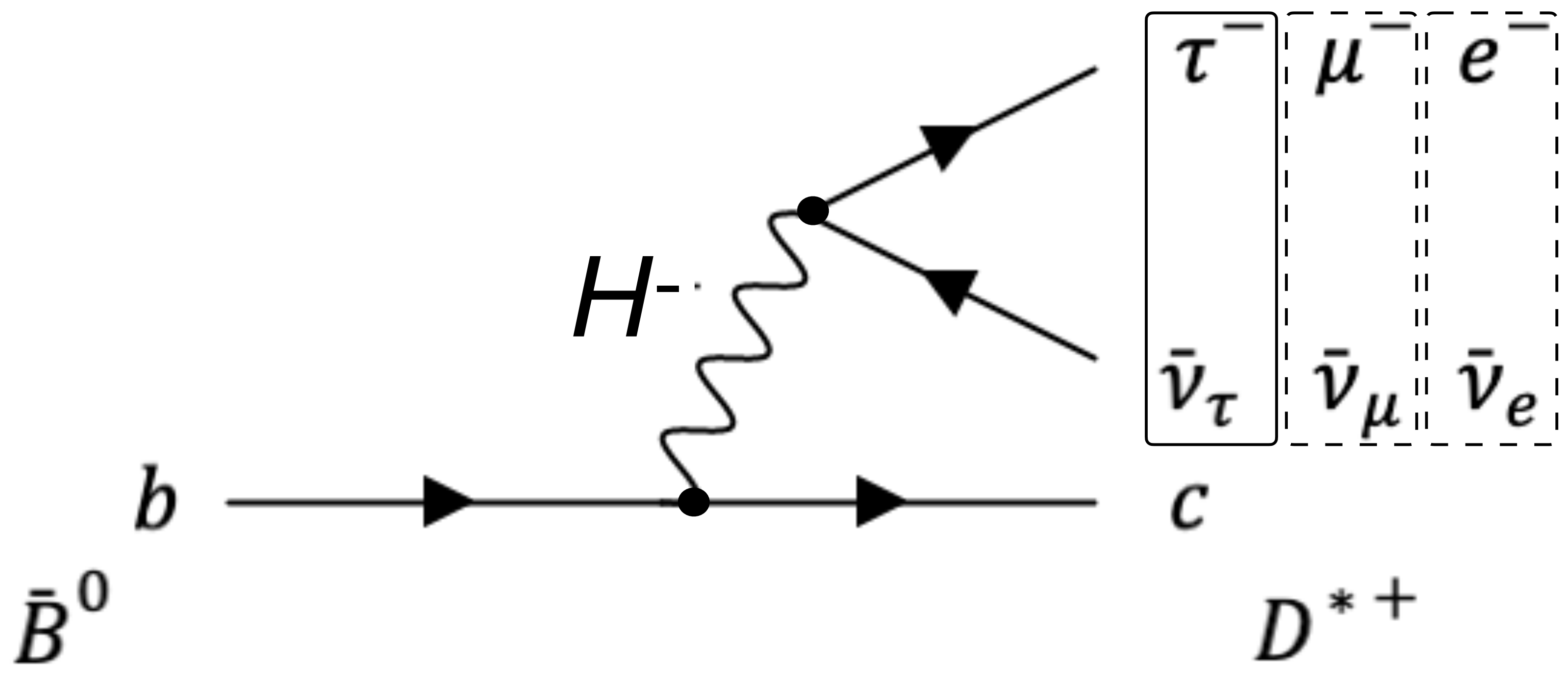
LHCb18 Belle19 2021 LHCb22 LHCb23

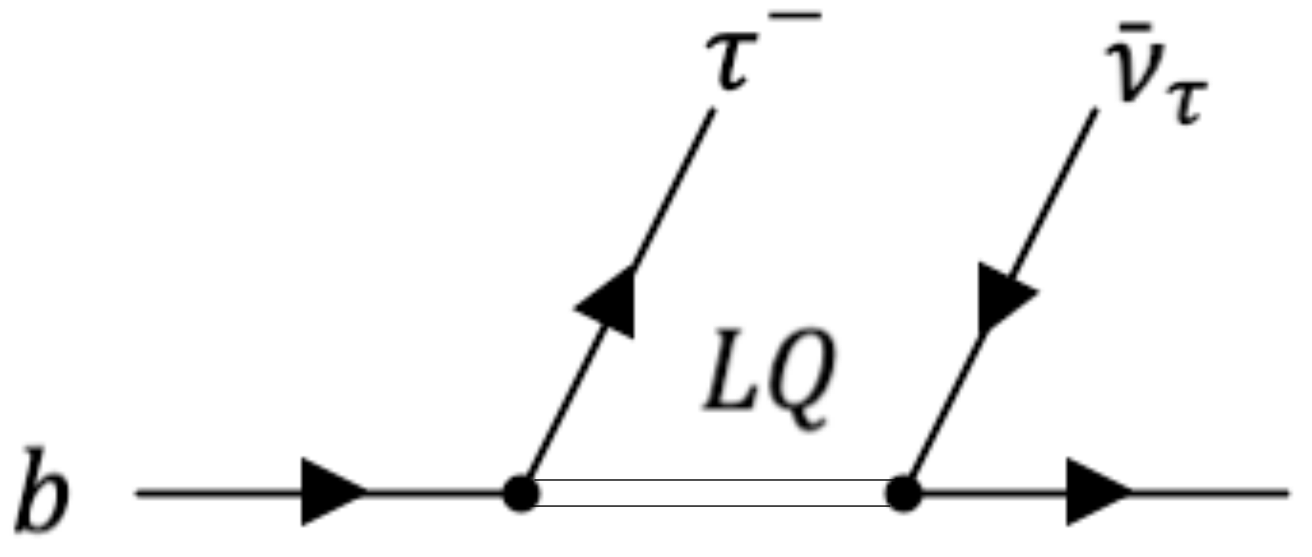
New physics scenarios

In general, there are three typical candidates to explain the deviations observed in $R(D^{(*)})$

- Heavy vector bosons
  - Constrained from $W' \to \tau\nu$ and $Z' \to \tau\tau$ search
- Charged Higgs
  - Constrained from $B_c \to \tau\nu$ and $H^{\pm} \to \tau\nu$,still allowed
  - Previously, it was rejected by $B_c \to \tau\nu$ measurement, however, recovered by recalculating the Bc lifetime.
    arxiv:2201.06565
- Leptoquark
  - $gg \to LQ\ LQ^*$, still broad parameter regions are allowed

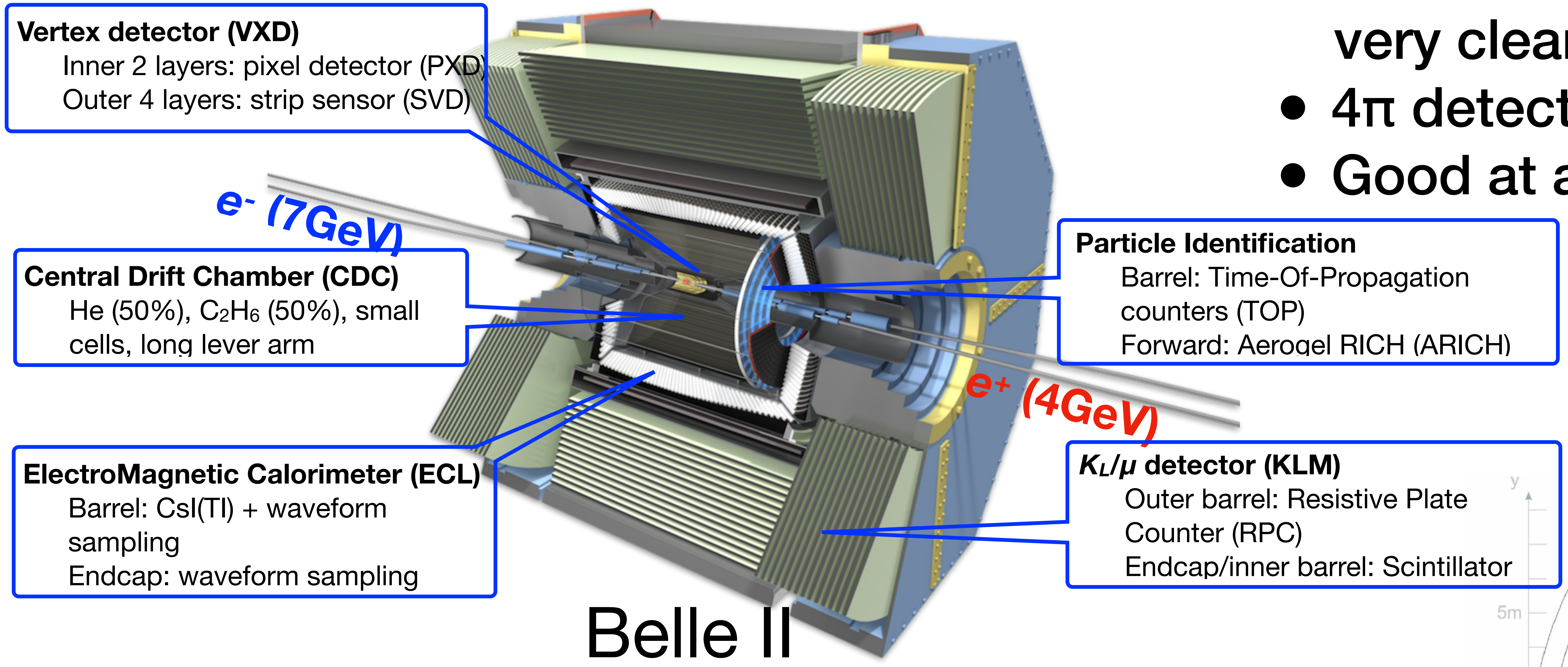






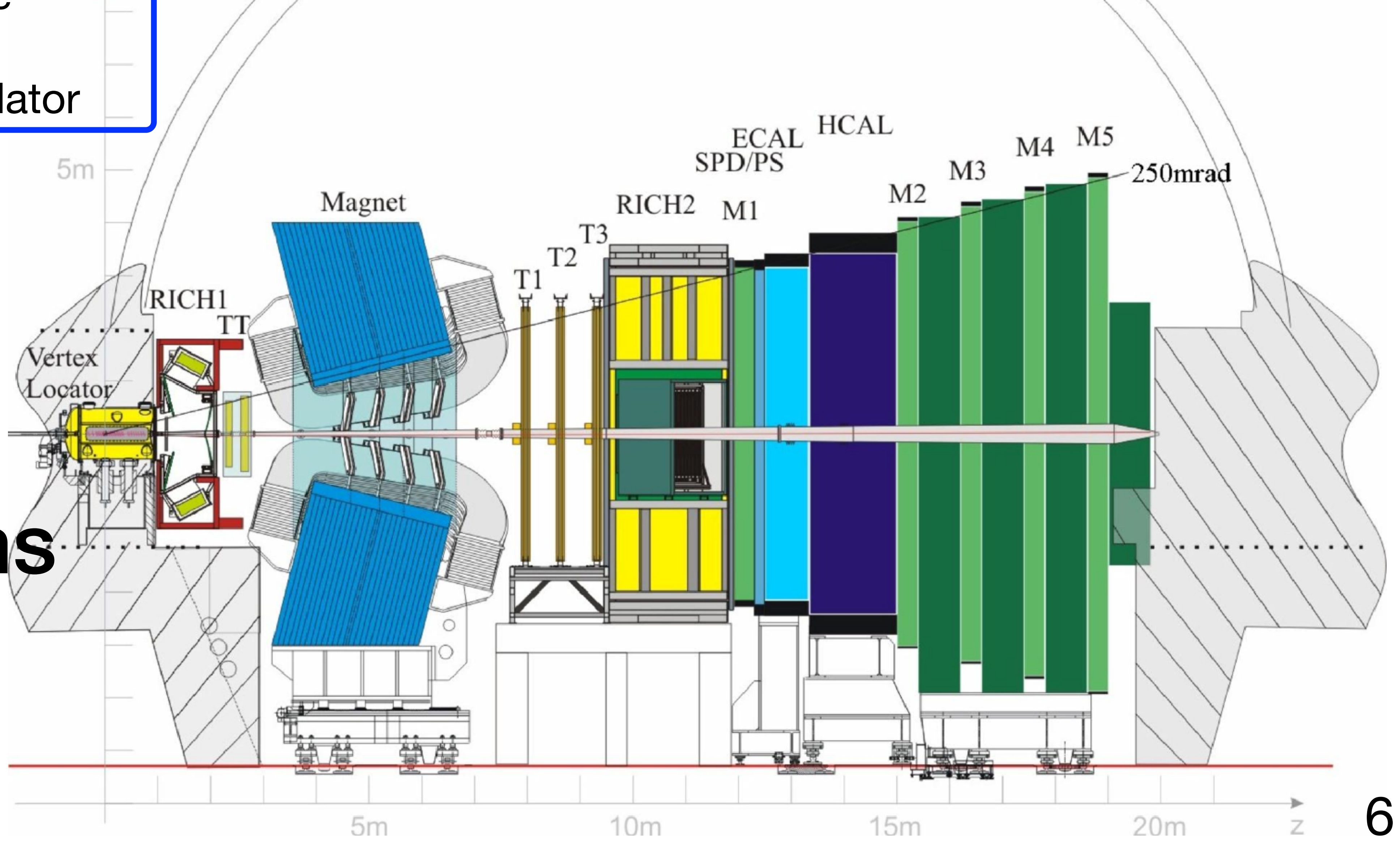
$R(D)$ and $R(D^*)$ experiments

- Experiments at B factory
  - $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$:
    very clean and well-known initial state
  - 4π detector surrounding the IP
  - Good at also measuring neutrals, π^0, γ



Belle II

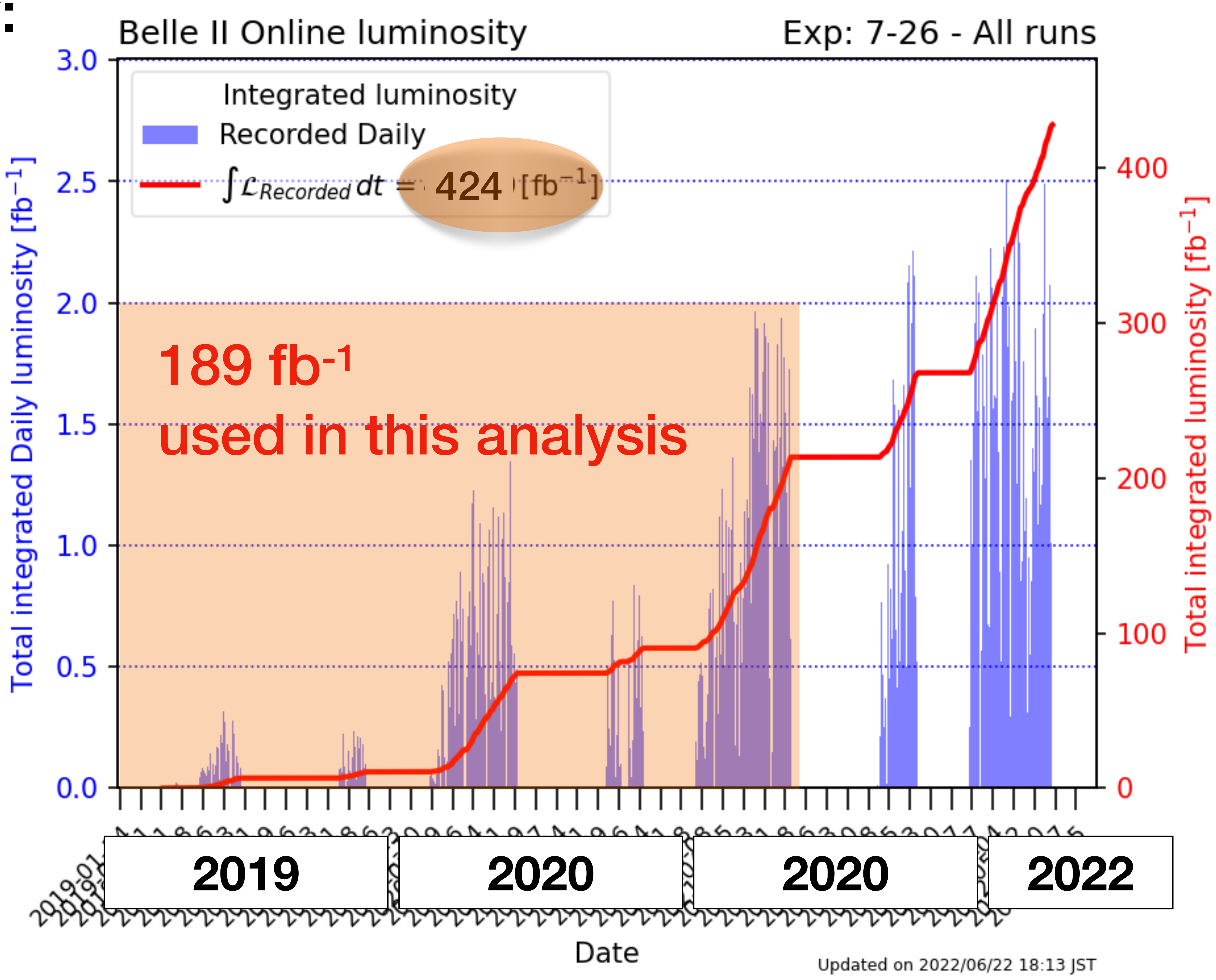
LHCb



- LHCb
  - Large amount of b hadrons produced in p-p collisions
  - Single arm detector covers forward region
  - Large boost, good separation of vertices

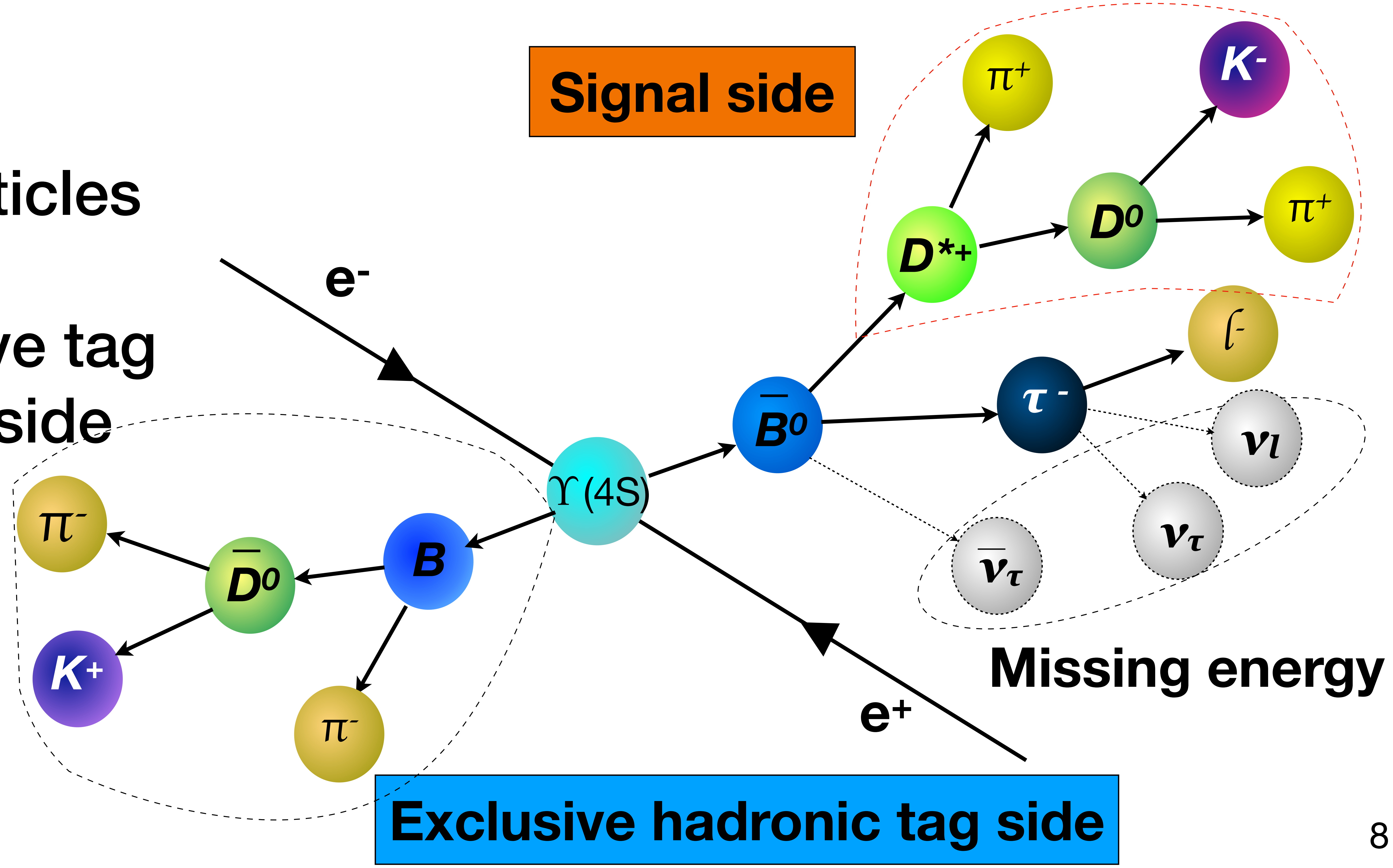
Data set for $R(D^*)$ measurement at Belle II

- World's highest instantaneous luminosity:
  L = 4.7 x 10^{34} cm^{-2} s^{-1}
  KEKB record: 2.1 x 10^{34} cm^{-2} s^{-1}
- Belle II data taking efficiency ~90%
- 424 fb^{-1} until Long Shutdown (LS) 1, ~363 fb^{-1} on $\Upsilon(4S)$
  - Belle: 1 ab^{-1}
- First $R(D^*)$ measurement at Belle II using 189 fb^{-1} data-set targeting the end of spring 2023
  - K. Kojima, et al., Nagoya-KEK group



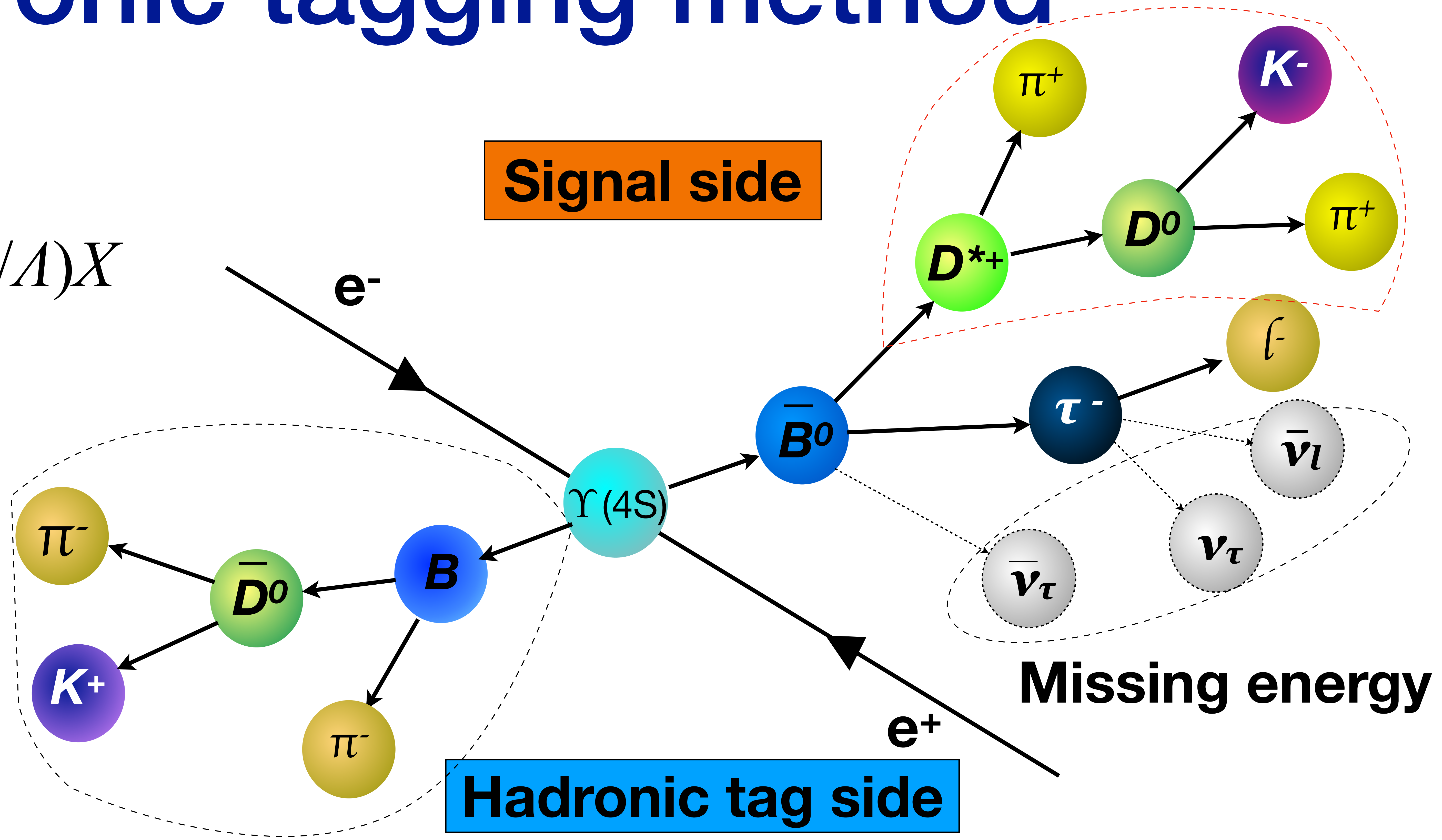
Tagging methods

- B tagging is necessary to measure $B \to D^* \tau \nu$, $B \to D^* l \nu$ ($\nu \geq 2$) simultaneously
- <u>Hadronic tag</u>
  - <u>Exclusive tag</u>
    - Fully reconstruct $B \to D^{(*)}(/J/\psi/\Lambda)X$
    - Tagging efficiency 0.2~0.4%
    - less background
  - <u>Inclusive tag</u>
    - Reconstruct tag *B* with all particles except signal *B*
    - Higher efficiency than exclusive tag
    - Low purity, need clean signal-side final state
- <u>Semileptonic tag</u>
  - Reconstruct $B \to D^{(*)} l \nu$
  - Tagging efficiency ~0.5%
  - More background



Exclusive hadronic tagging method

- Hadronic tag
  - Exclusive tag
    - Fully reconstruct $B \to D^{(*)}(/J/\psi/\Lambda)X$
    - Tagging efficiency 0.2~0.4%
    - less background



- Fully reconstruct one of the *B* mesons (*B* tag), possible to measure momentum of other *B* meson (*B* signal)
- Indirectly measure missing momentum of neutrinos in signal *B* decays
- $M^2_{\text{miss}} = (p_{\text{beam}} - p_{B\text{tag}} - p_{D^{(*)}} - p_\ell)^2$
- E_{ECL} unassigned neutral energy in the calorimeter $E_{\text{ECL}} = \sum_i E_i^\gamma$

} Fitting variables for yields determination

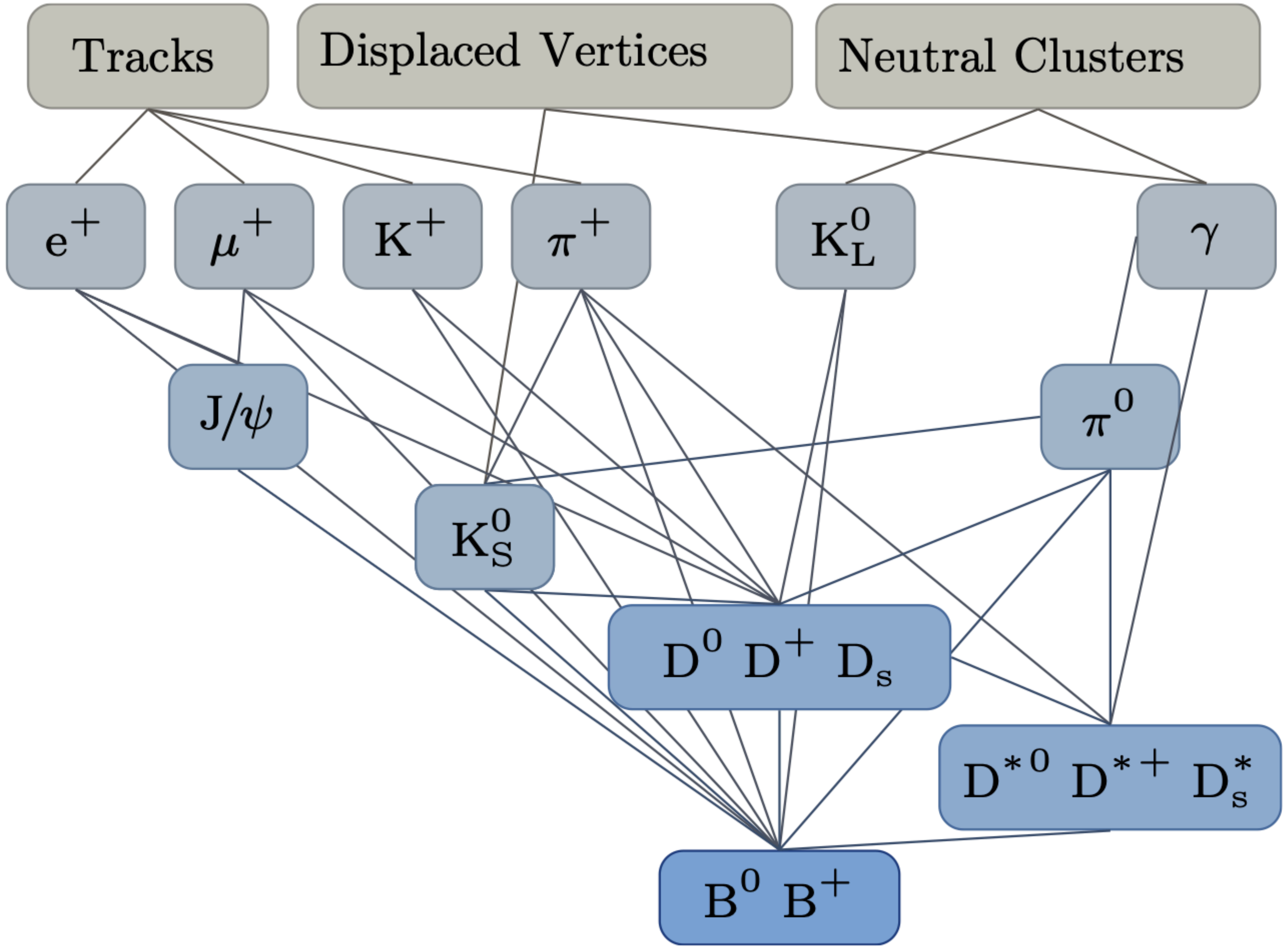
Hadronic tag reconstruction at Belle II

- Hadronic tagging reconstruction : Full Event Interpretation (FEI) trained 200 Boost Decision Tree (BDT) to reconstruct ~100 decay channels, ~10,000 *B* decay chains
  - ε=0.30% for $B^{\pm}$
  - ε=0.23% for B^{0}

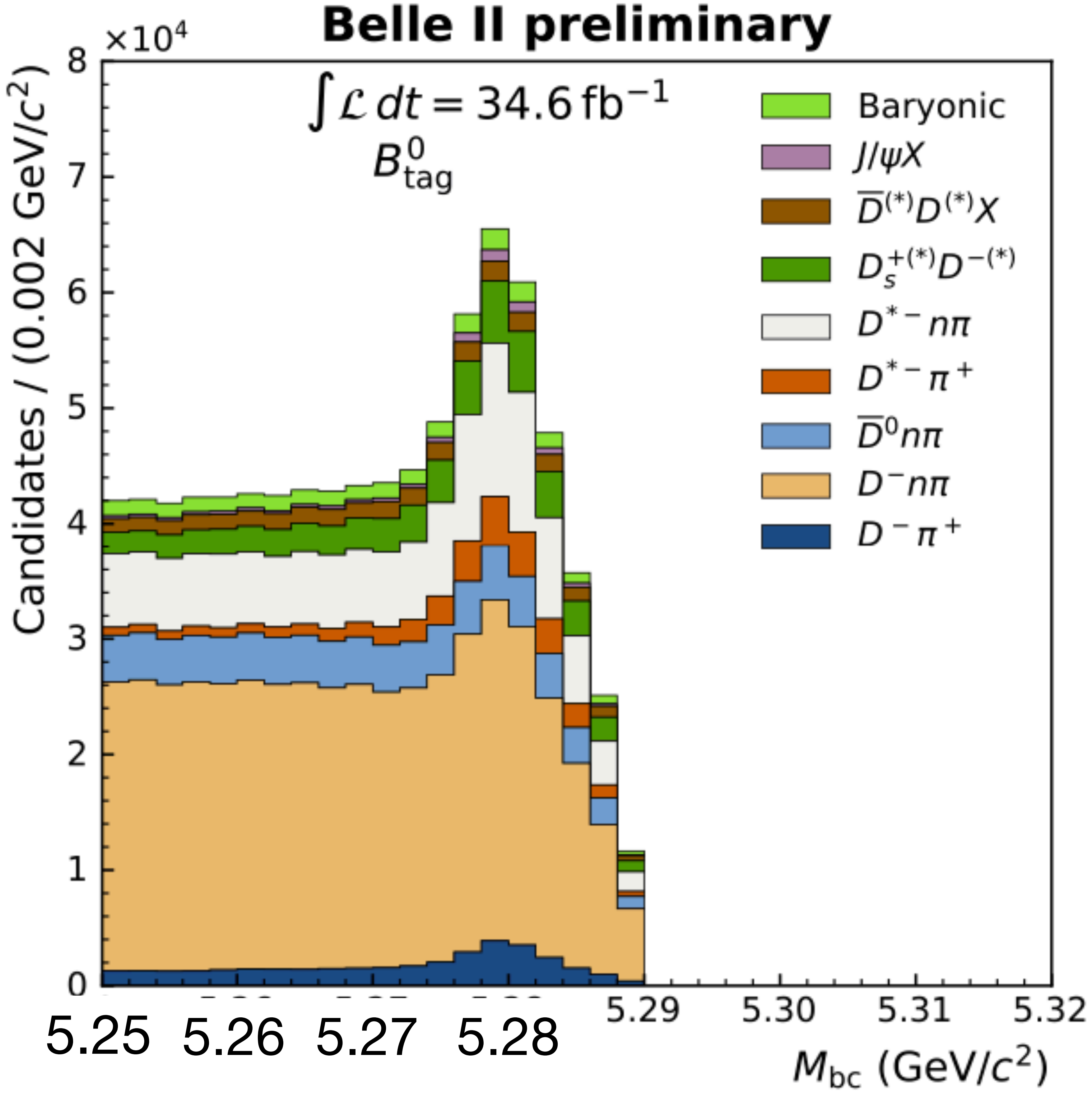
10-30%

- ε=0.28% for $B^{\pm}$ @Belle
- ε=0.18% for B^{0} @Belle

Comp. and Soft. For Big Sci. 3, 6 (2019)



arXiv:2008.06096

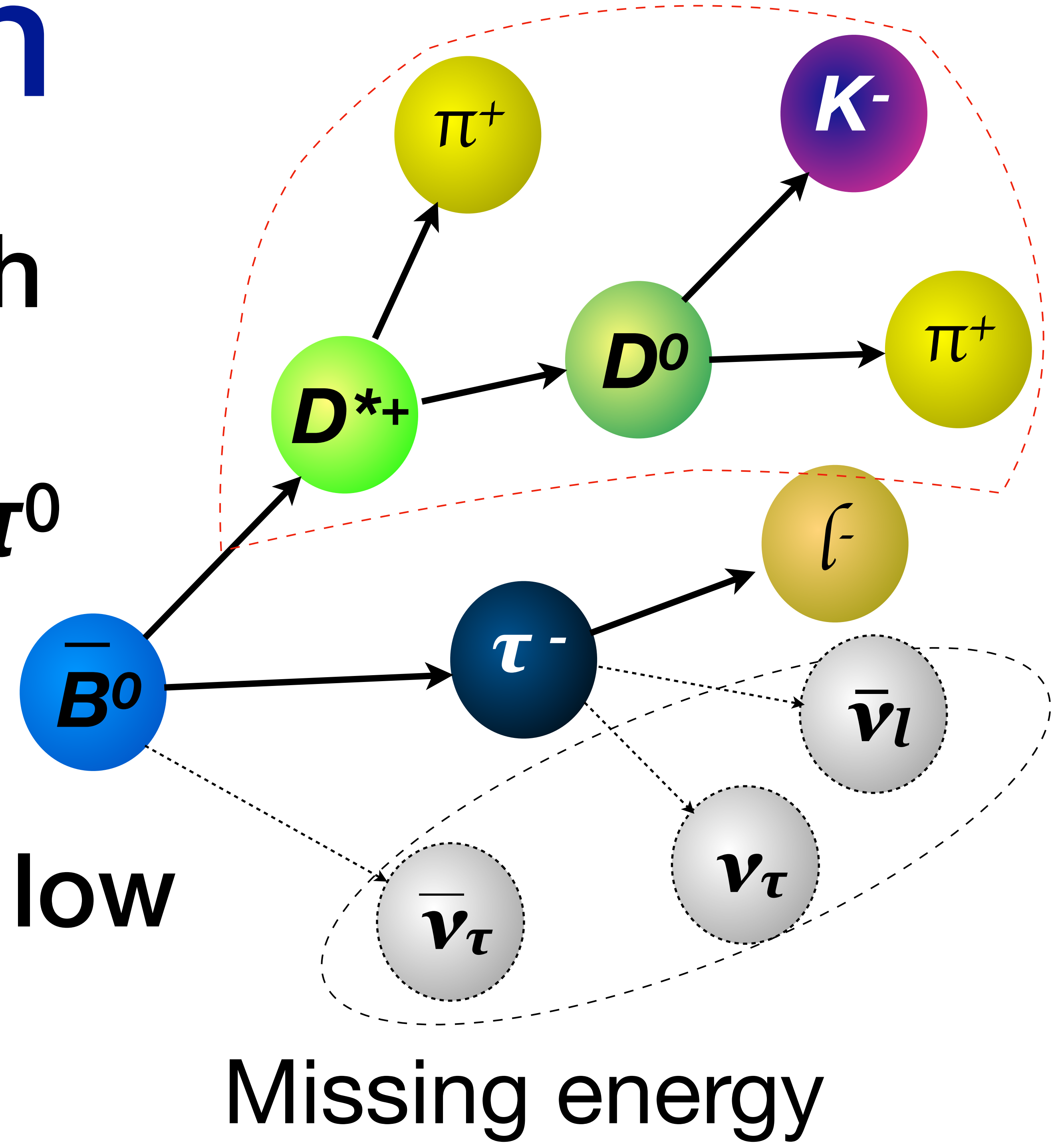


$$m_{\rm bc} = \sqrt{(E^{*}_{\rm beam})^2 - (p^{*}_{B})^2}$$

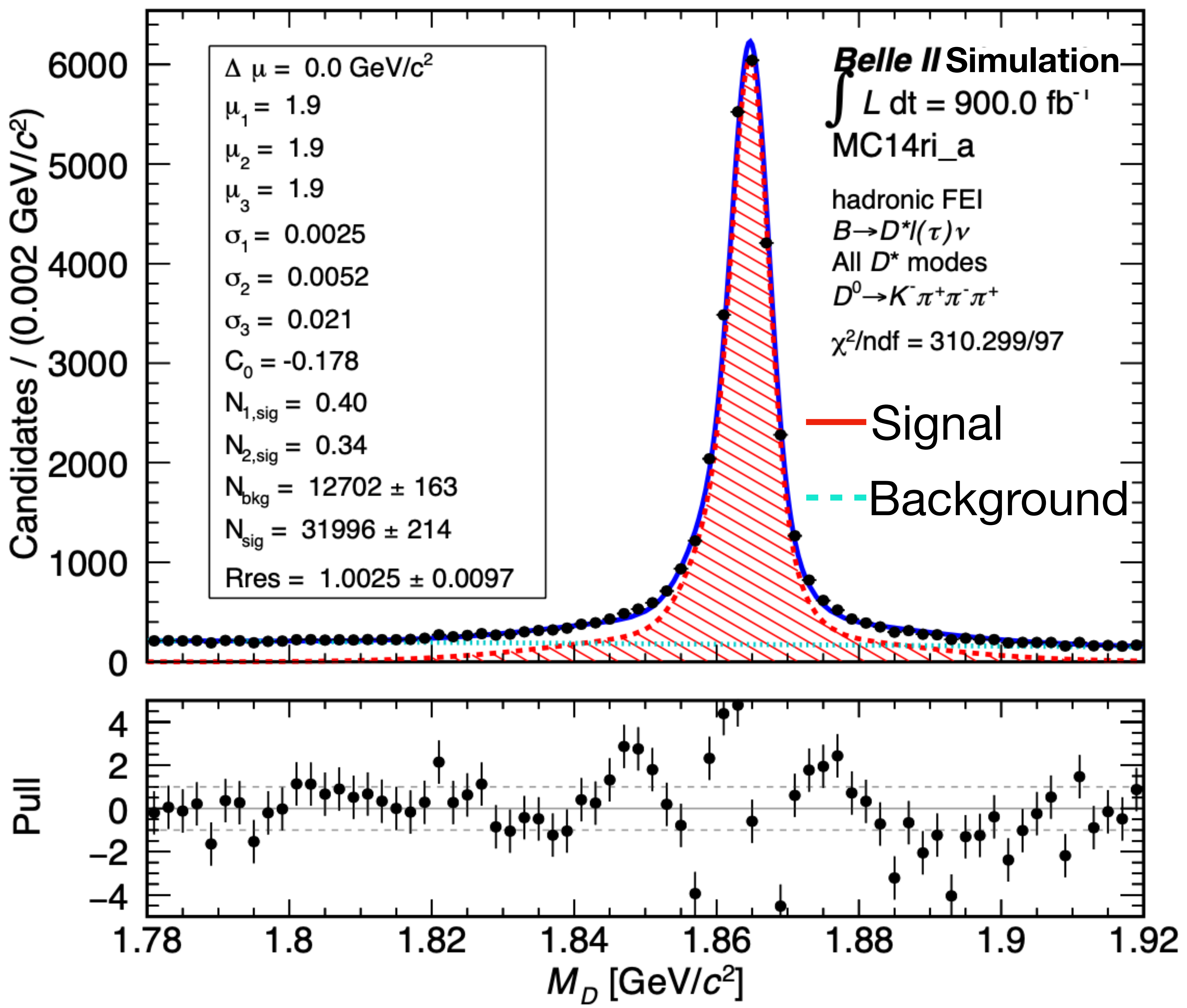
Signal side reconstruction

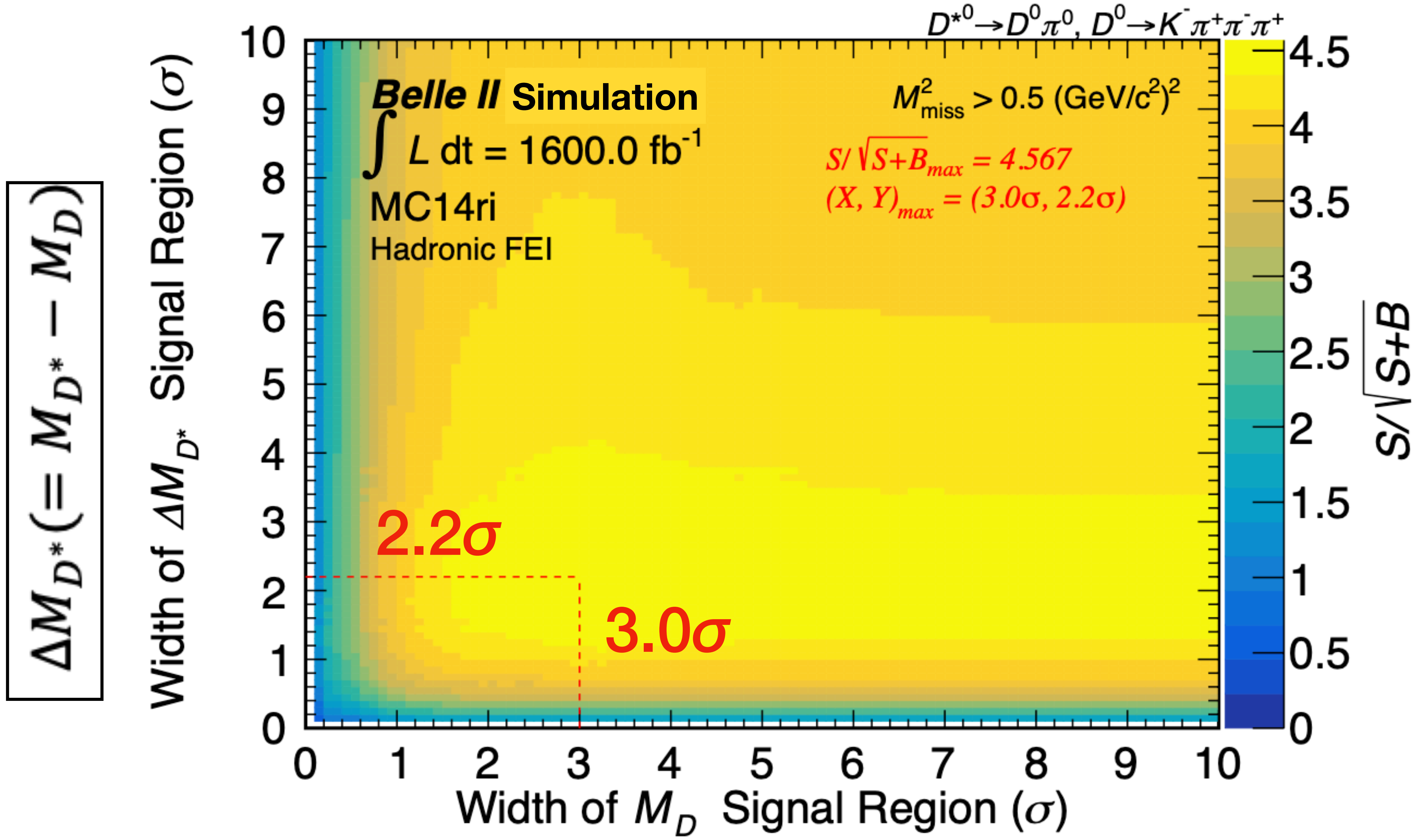
D^* decays	D decays
$D^{*+} \to D^0\pi^+$	$D^0 \to K^-\pi^+\pi^0$
	$D^0 \to K^-\pi^+\pi^-\pi^+$
	$D^0 \to K^0_S\pi^+\pi^-\pi^0$
	$D^0 \to K^-\pi^+$
	$D^0 \to K^0_S\pi^+\pi^-$
	$D^0 \to K^0_S\pi^0$
	$D^0 \to K^-K^+$
	$D^0 \to \pi^+\pi^-$
$D^{*+} \to D^+\pi^0$	$D^+ \to K^-\pi^+\pi^+$
	$D^+ \to K^0_S\pi^+$
	$D^+ \to K^-K^+\pi^+$
	$D^+ \to K^0_S K^+$
$D^{*0} \to D^0\pi^0$	$D^0 \to K^-\pi^+\pi^0$
	$D^0 \to K^-\pi^+\pi^-\pi^+$
	$D^0 \to K^0_S\pi^+\pi^-\pi^0$
	$D^0 \to K^-\pi^+$
	$D^0 \to K^0_S\pi^+\pi^-$
	$D^0 \to K^0_S\pi^0$
	$D^0 \to K^-K^+$
	$D^0 \to \pi^+\pi^-$

- Reconstruct $B \to D^*\tau\nu$ and $B \to D^*l\nu$ with same selections
- *D* meson reconstruct with $K^\pm$, $\pi^\pm$, K_s, π^0
  - 8 D^0 modes (Br ~36%)
  - 4 D^+ modes (Br ~12.3%)
- *D** meson reconstruct with D^+/D^0 and low momentum π^+/π^0
  - $D^{*+} \to D^0\pi^+/D^+\pi^0$ (Br ~98%)
  - $D^{*0} \to D^0\pi^0$ (Br ~65%)
- τ lepton reconstruct with $\ell(e, \mu)\bar{\nu}\nu$
- Both neutral and charged $B^\pm/B^0$ mesons reconstruct with D^{*+}/D^{*0} and $\tau/\ell = (e, \mu)$



Improvement of reconstruction at Belle II



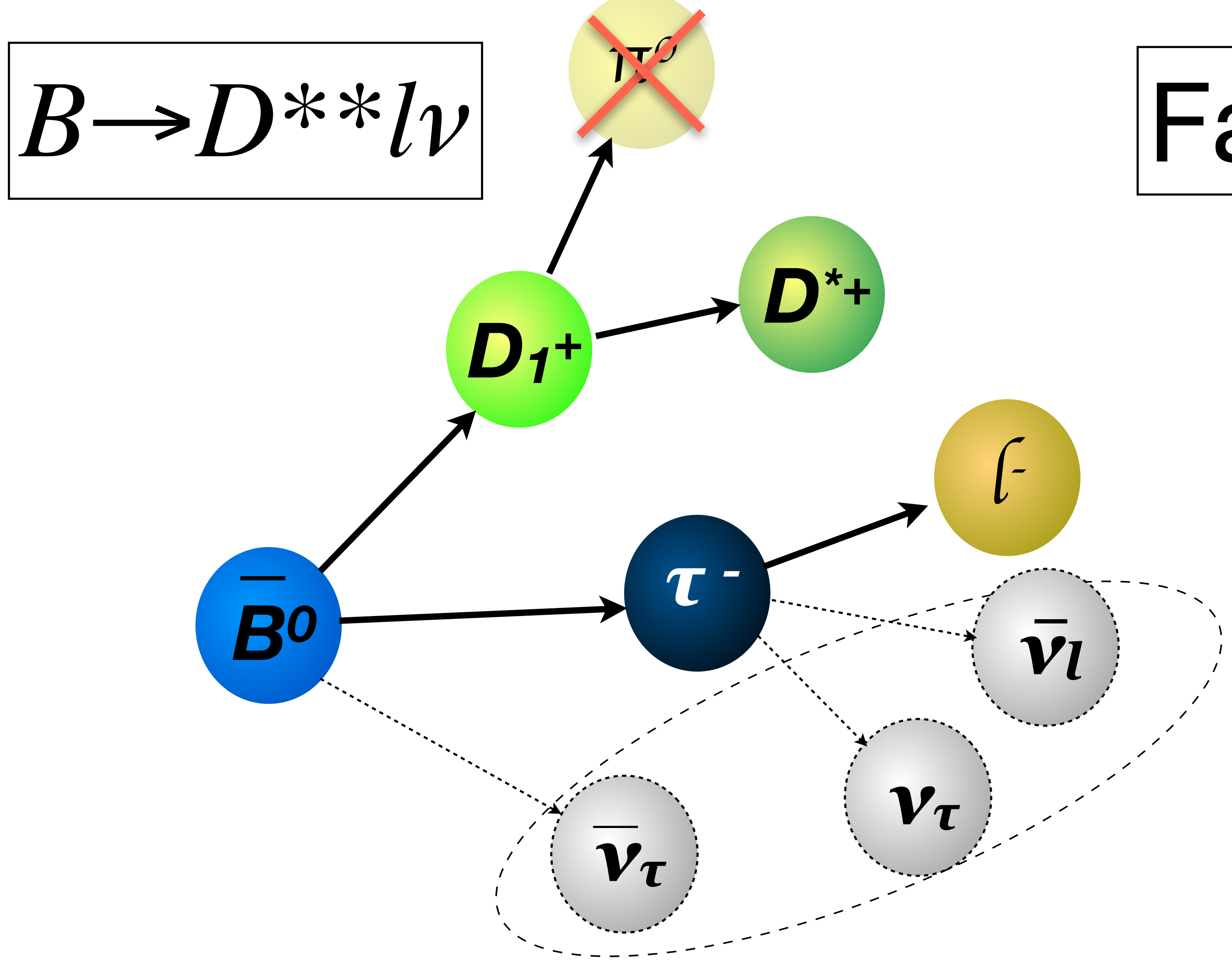


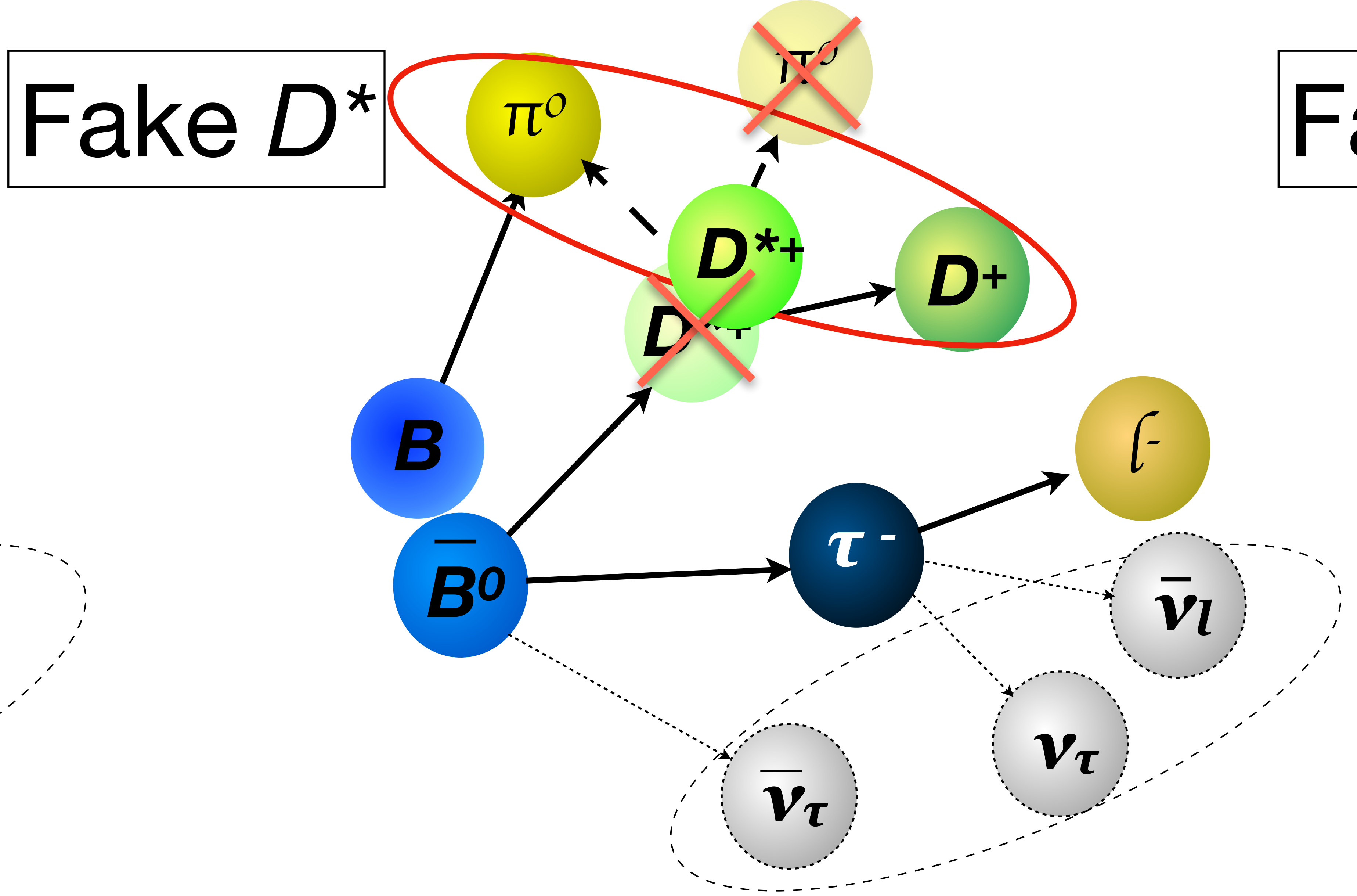
- Improve the reconstruction methodology at Belle II
  - Keep reasonably large reconstruction candidates
  - Found the maximum of FOM $N_{\text{signal}} / \sqrt{N_{\text{signal}} + N_{\text{background}}}$, by scanning the optimal selections
  - Improve 35% of FOM vs. Belle ’15 hadronic tag $R(D^{(*)})$ analysis

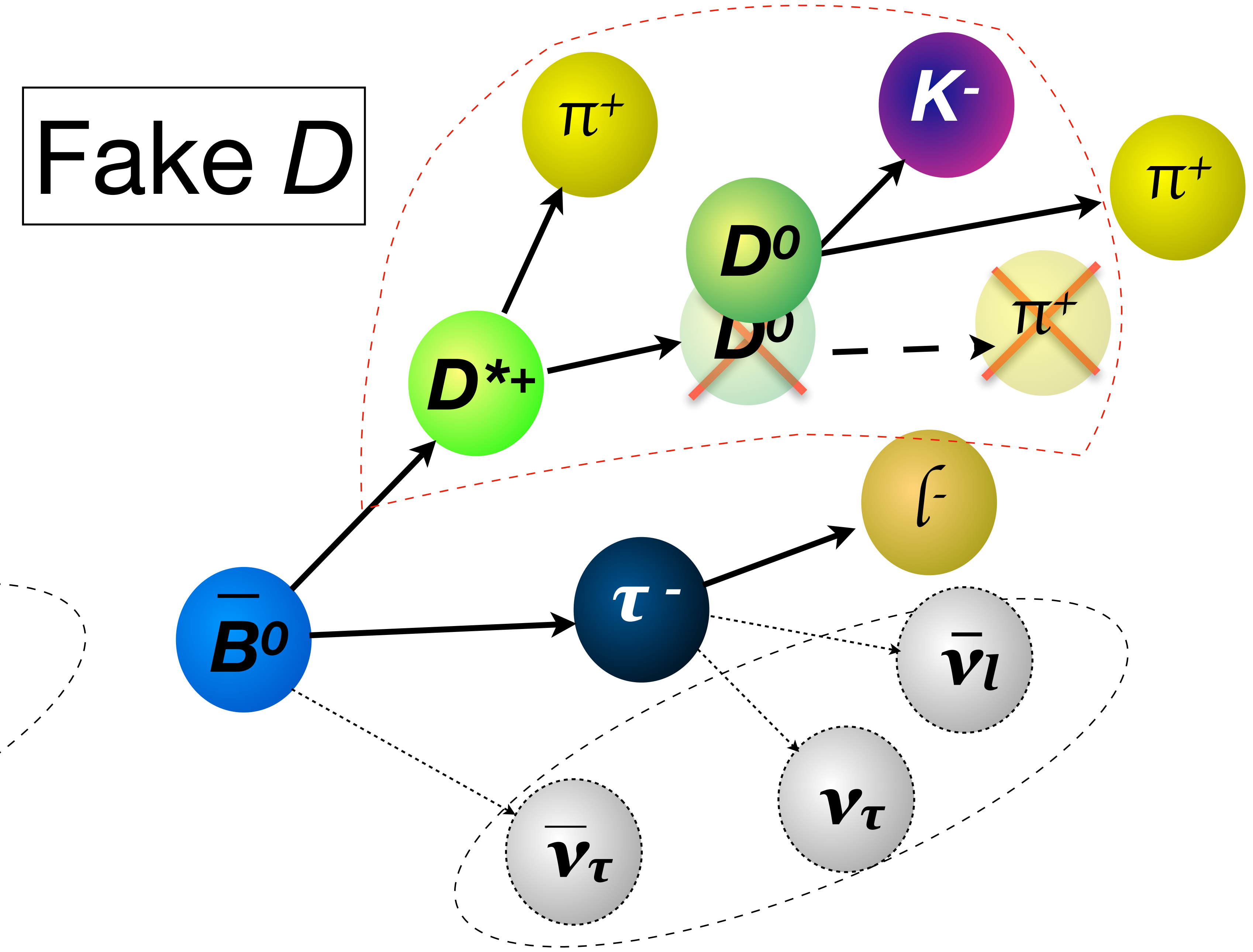
Dominant backgrounds

- Fraction of survived *B* candidates in each category after event selections are estimated based on Belle II MC simulation

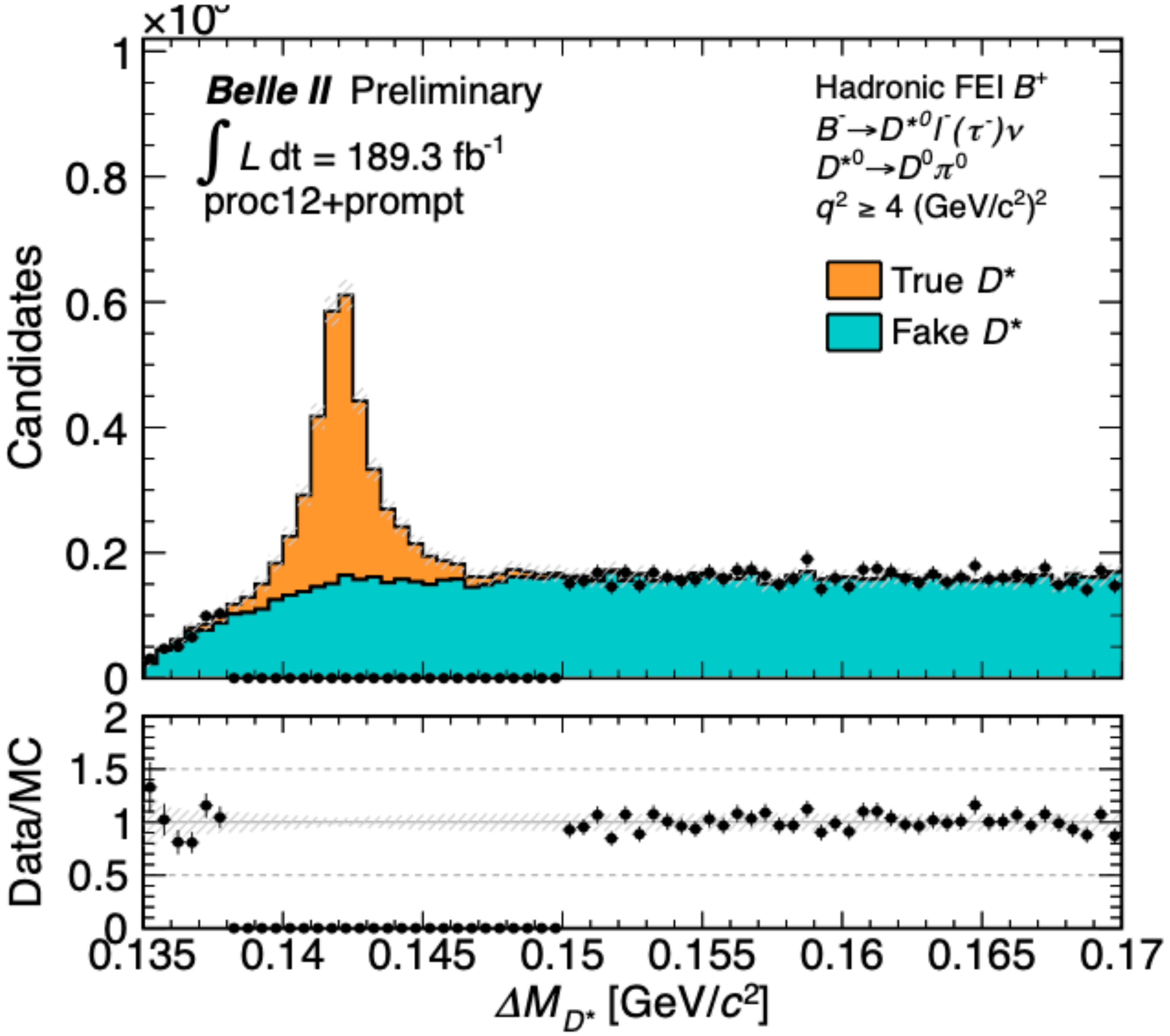
B condidates	$B \to D^* \tau \nu$	$B \to D^* l \nu$	Background Truth $D^{(*)}$	Background Fake $D^{(*)}$
			$B \to D^{**} l \nu$, $B \to D^{(*)} X$, B^0<->$B^{\pm}$, …	
B^0	2.7%	65.5%	12.5%	19.2%
$B^{\pm}$	1.7%	34.7%	5.9%	57.8%



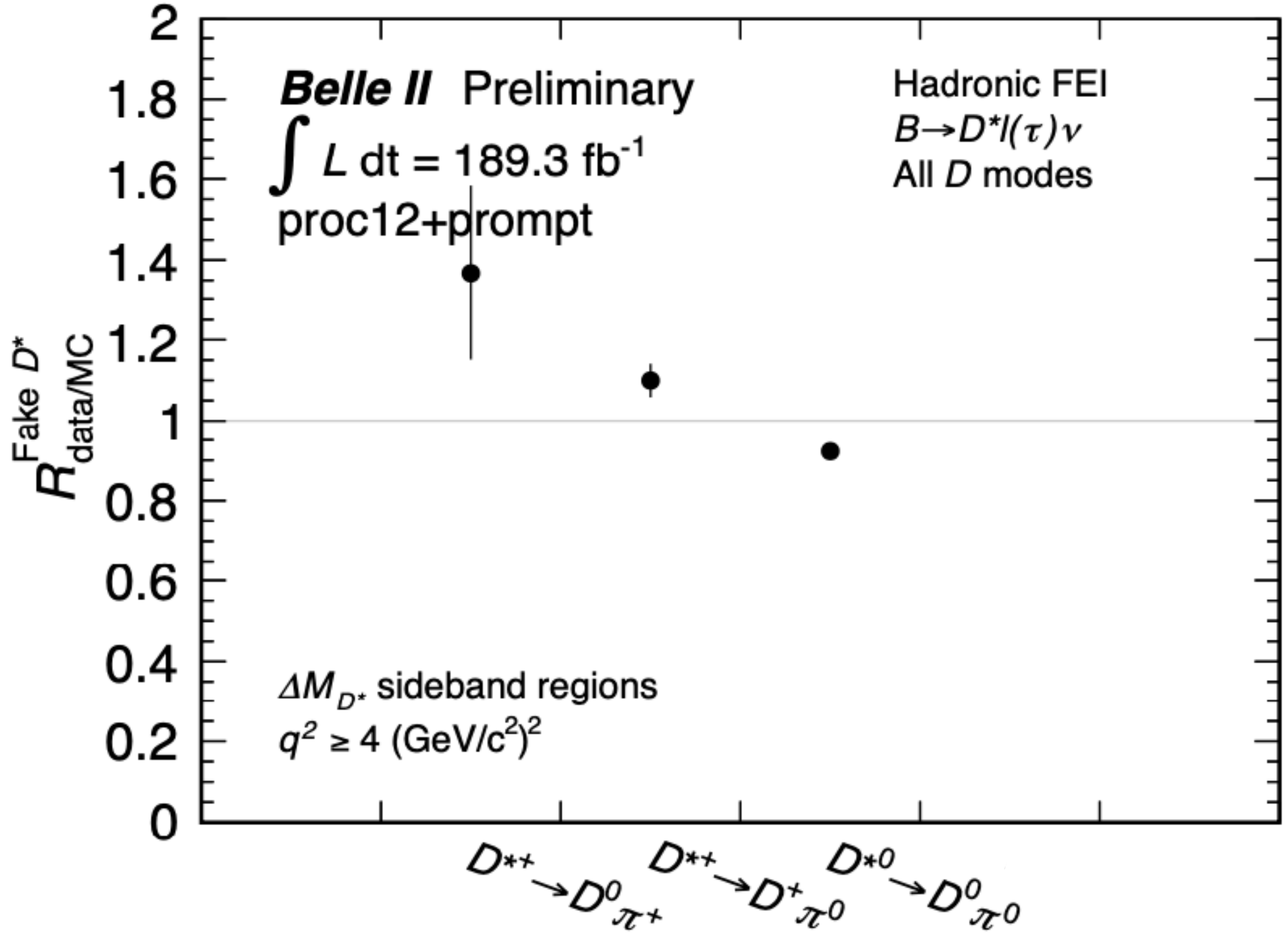




Calibration of fake D^* background on ΔM_{D^*} sideband



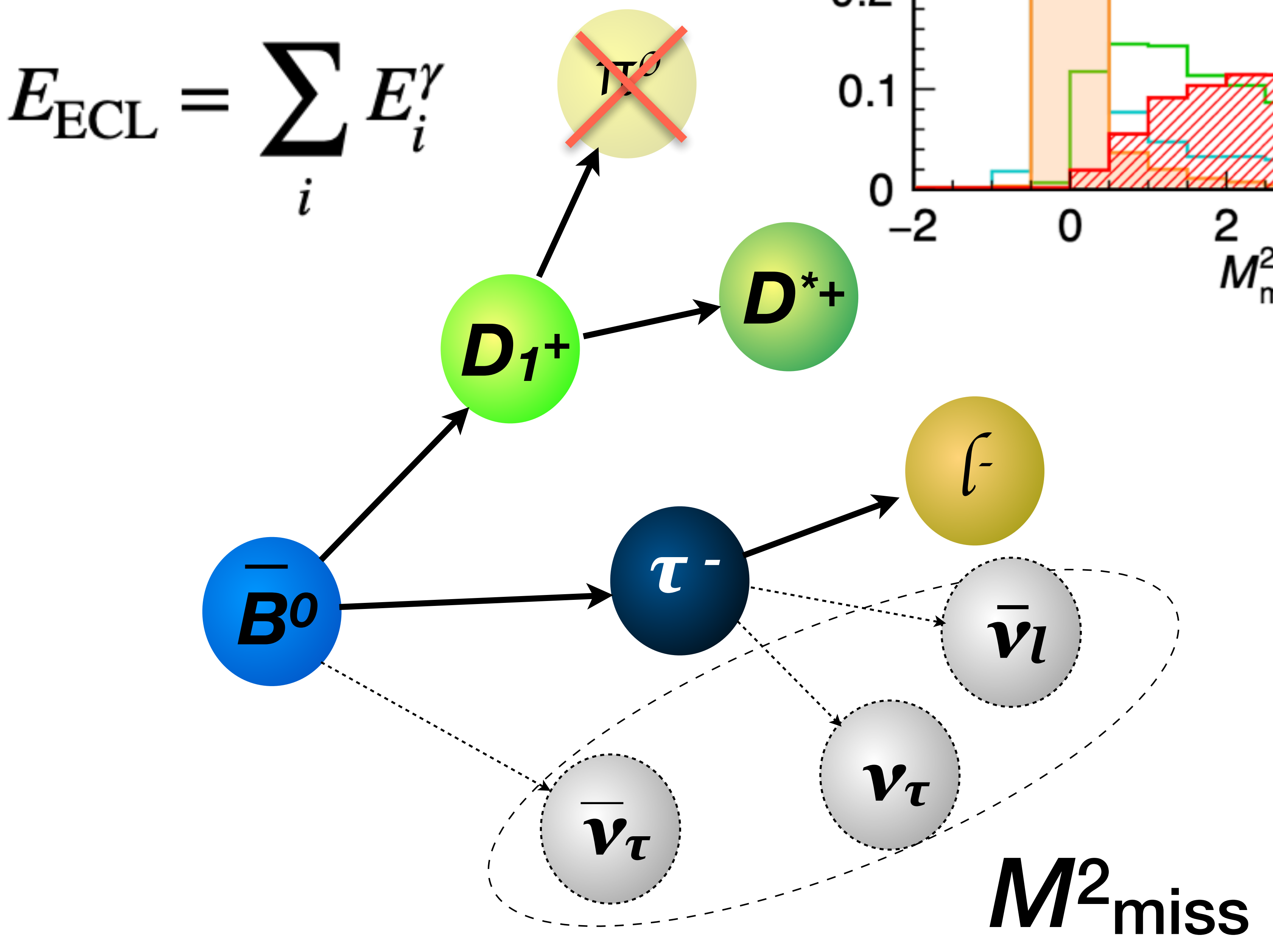
$$\Delta M_{D^*}(= M_{D^*} - M_D)$$

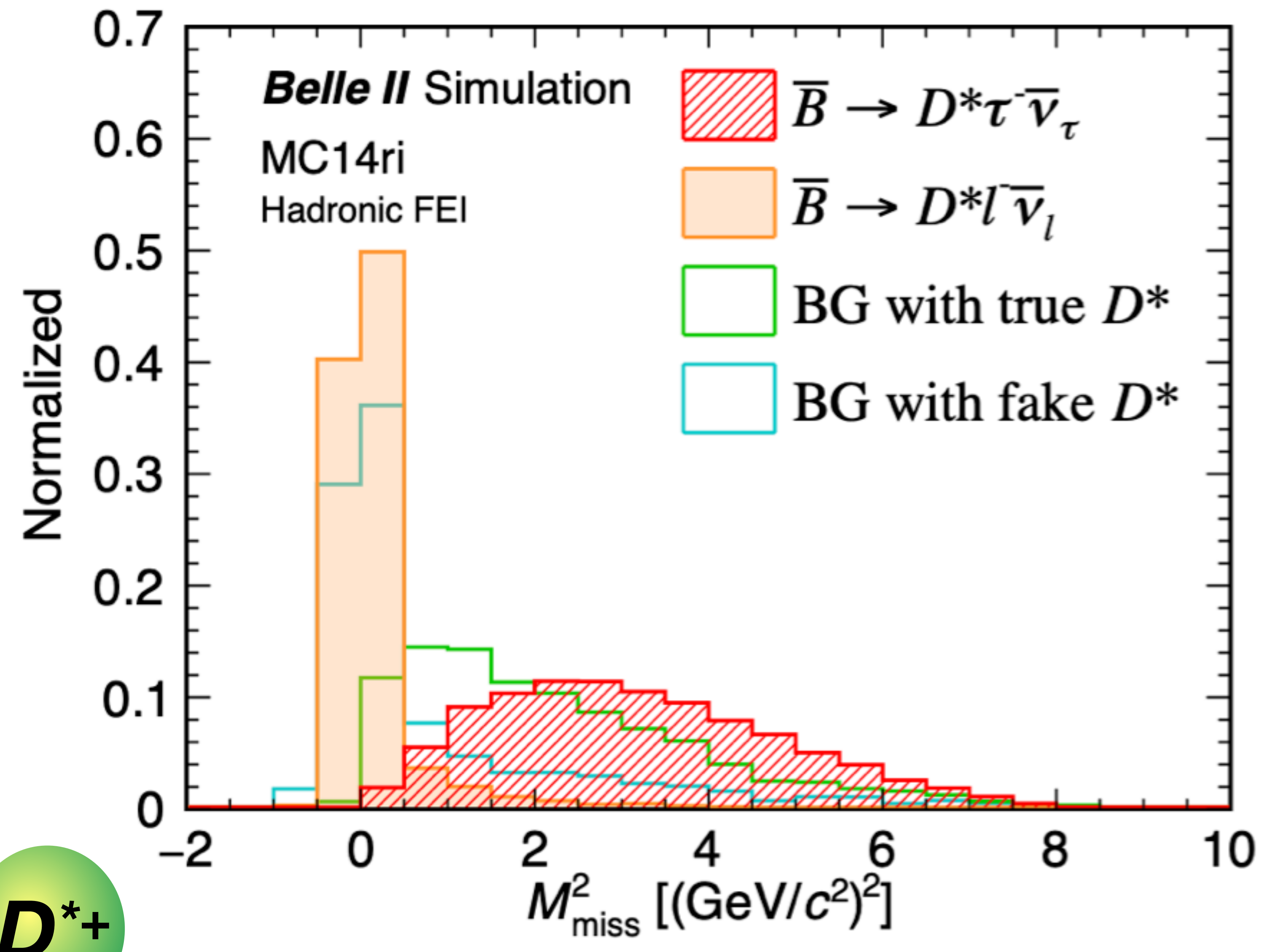


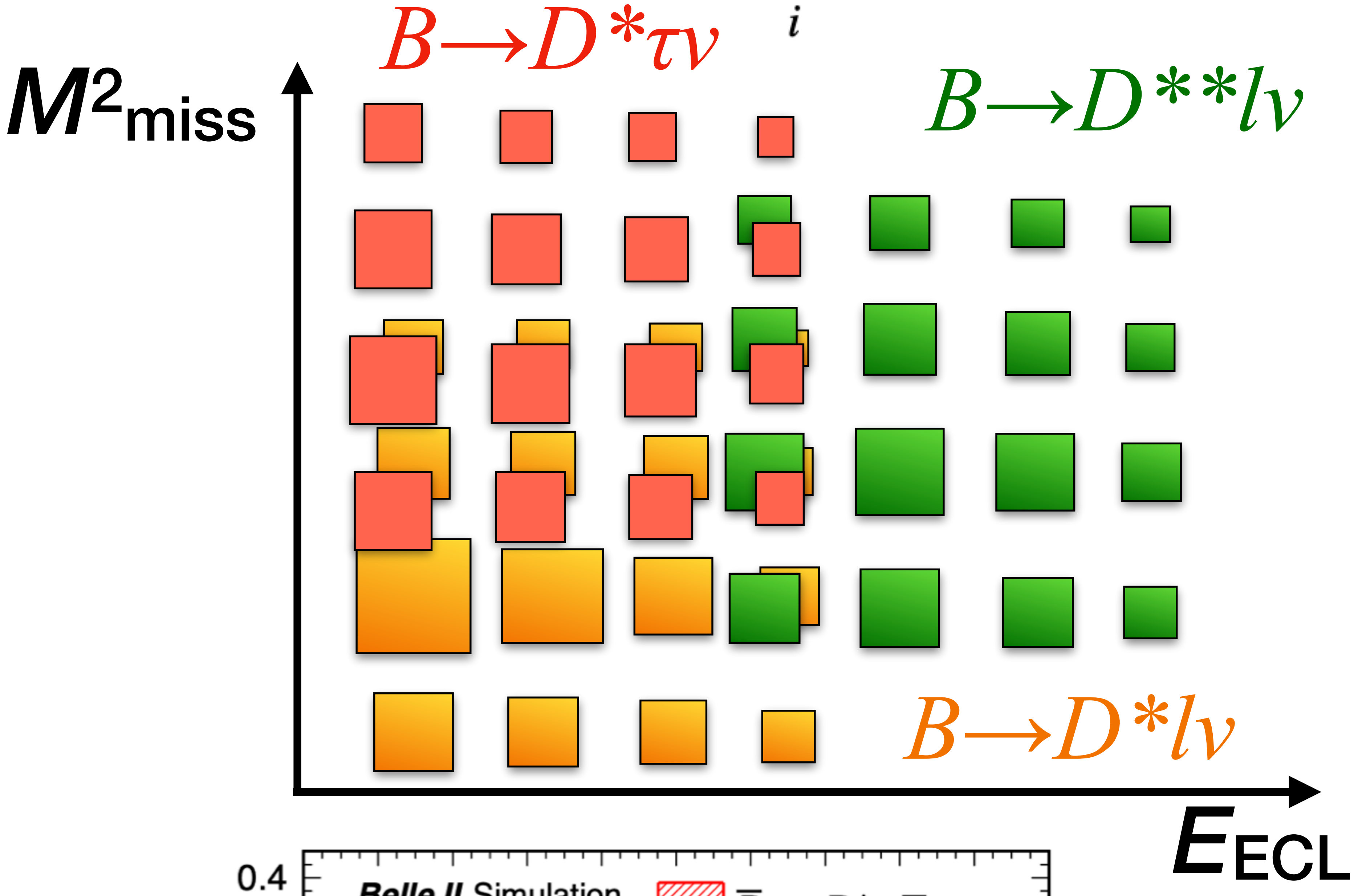
- Estimate the most dominate background (fake D^*) using ΔM_{D^*} sideband
  - Fit ΔM_{D^*} distribution at sideband, threshold or Chebychev functions
  - Obtain a calibration factor

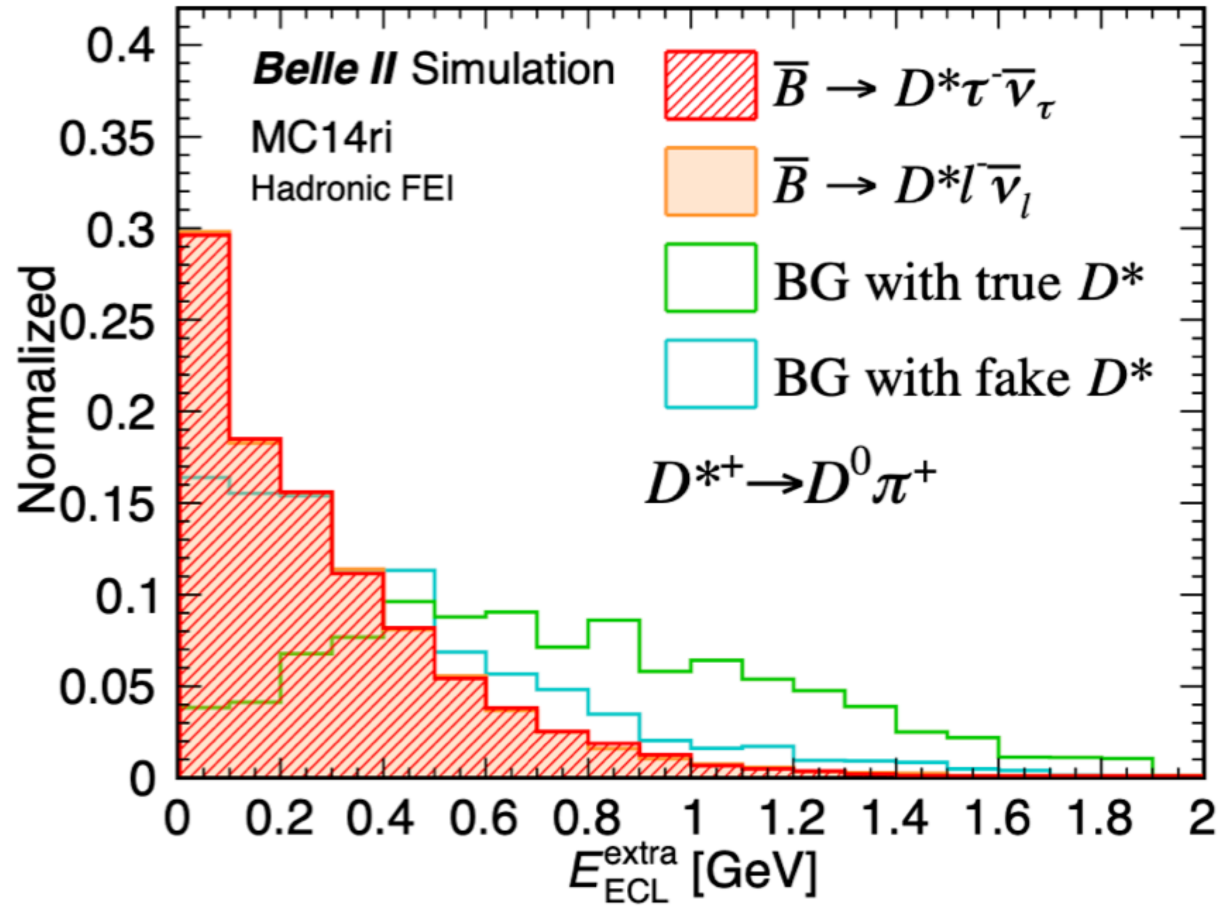
Fitting methodology and variables

- Extracting $B \rightarrow D^* \tau \nu$, $B \rightarrow D^* l \nu$ yields by a two-dimensional simultaneously fit
  - $M^2_{miss} = (p_{beam} - p_{Btag} - p_{D(*)} - p_l)^2$
  - E_{ECL} unassigned neutral energy in the calorimeter $E_{ECL} = \sum_i E_i^\gamma$









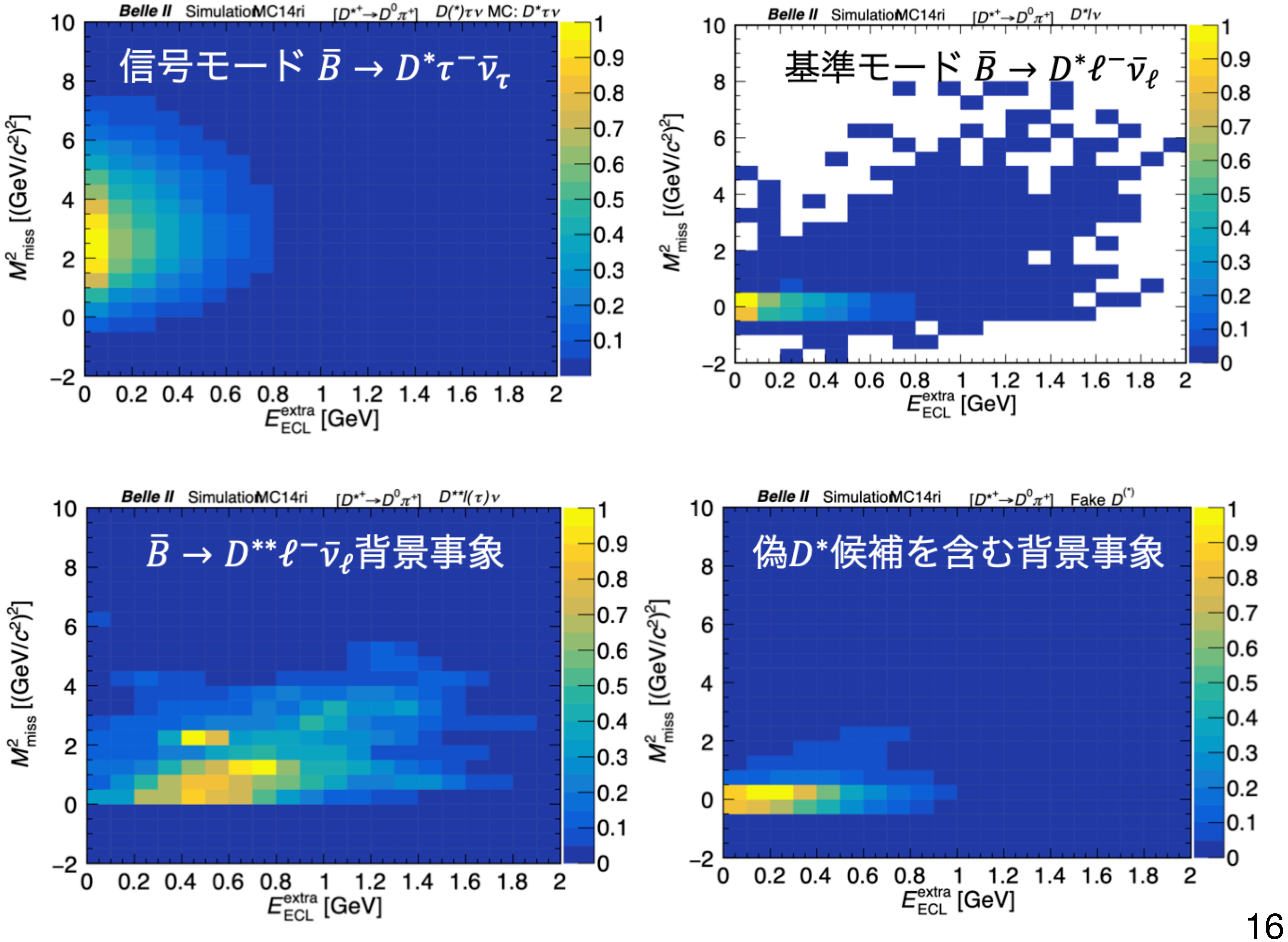
Fit configuration

- PDFs in two dimensions with uniform 24 M^2_{miss} bins and 20 E_{ECL} bins after kernel density estimation
- $R(D^*)$ obtained by simultaneous fits among three D^* modes

	Signal mode $\bar{B} \to D^* \tau^- \bar{\nu}_\tau$
	Signal mode $\bar{B} \to D^* \tau^- \bar{\nu}_\tau$ with misidentified lepton from τ
	Normalization mode $\bar{B} \to D^* \ell^- \bar{\nu}_\ell$
	Normalization mode $\bar{B} \to D^* \ell^- \bar{\nu}_\ell$ with misidentified lepton
Backgrounds with true D^*	$\bar{B} \to D^{**} \ell^- \bar{\nu}_\ell$
	Hadronic B decays
	$B^0 \leftrightarrow B^\pm$ tag misidentification
	$q\bar{q}$ $(q = u, d, s, c)$
Background with fake D^*	

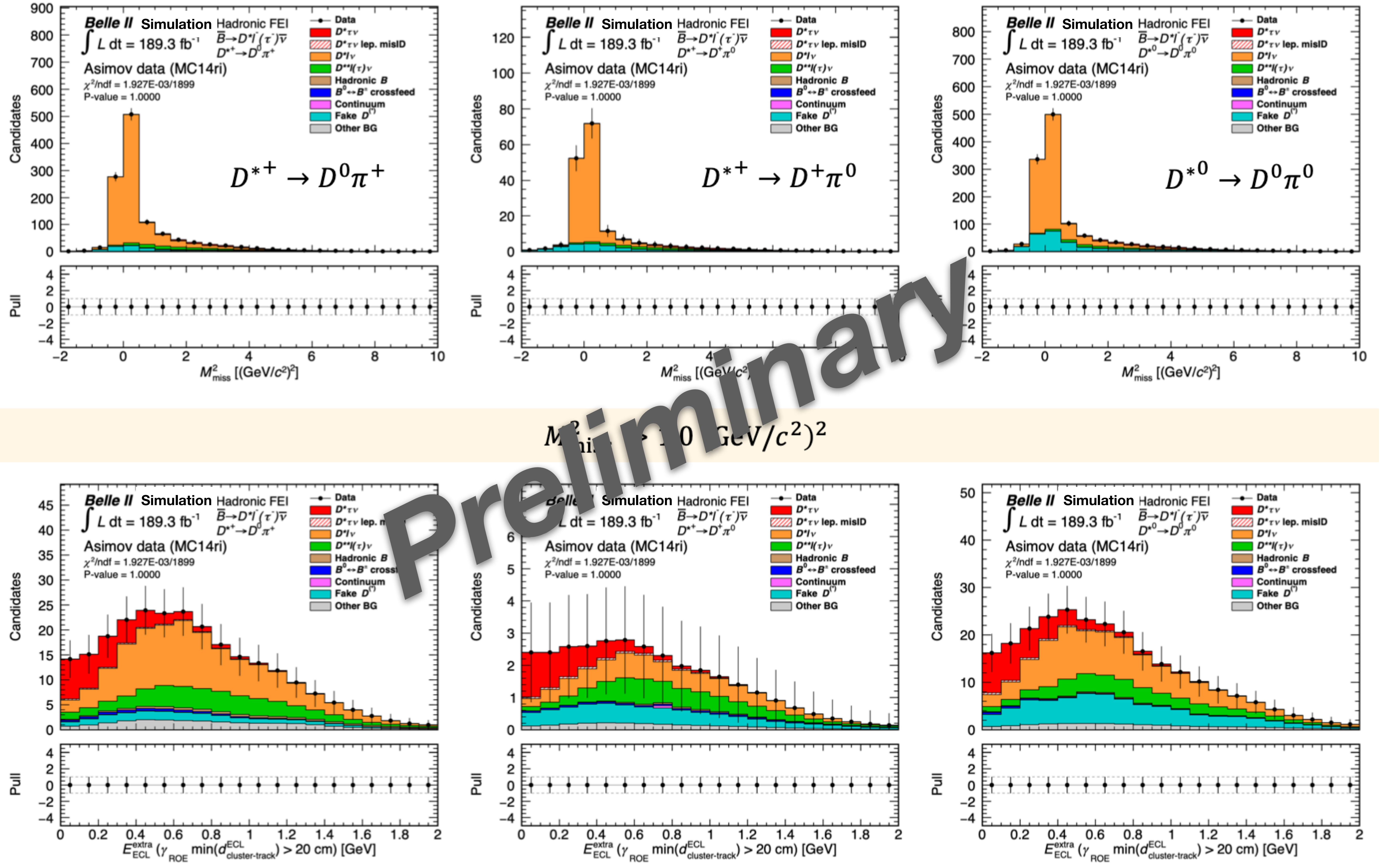
Constrain yields with sidebands

Fixed with MC yields



Belle II $R(D^*)$ sensitivity at 189 fb^{-1}

- Producing Asimov MC data set with 189 fb^{-1} based on PDF where $R(D^*)$ = 0.254 (SM expectation)
- The fit returns $R(D^*)$ = 0.254, statistical uncertainty is +17/-16% at 189 fb^{-1}
- Belle '15 statistical uncertainty is 13% (15%@ $R(D^*)$ = 0.254)



$$R(D^*) = 0.254^{+0.046\,(+18\%)}_{-0.043\,(-17\%)} \quad {}^{+0.043\,(+17\%)}_{-0.040\,(-16\%)}$$

Preliminary systematic uncertainties

- Each source of the uncertainty changes the PDF shape, consequently modify the fitted $R(D^*)$ value

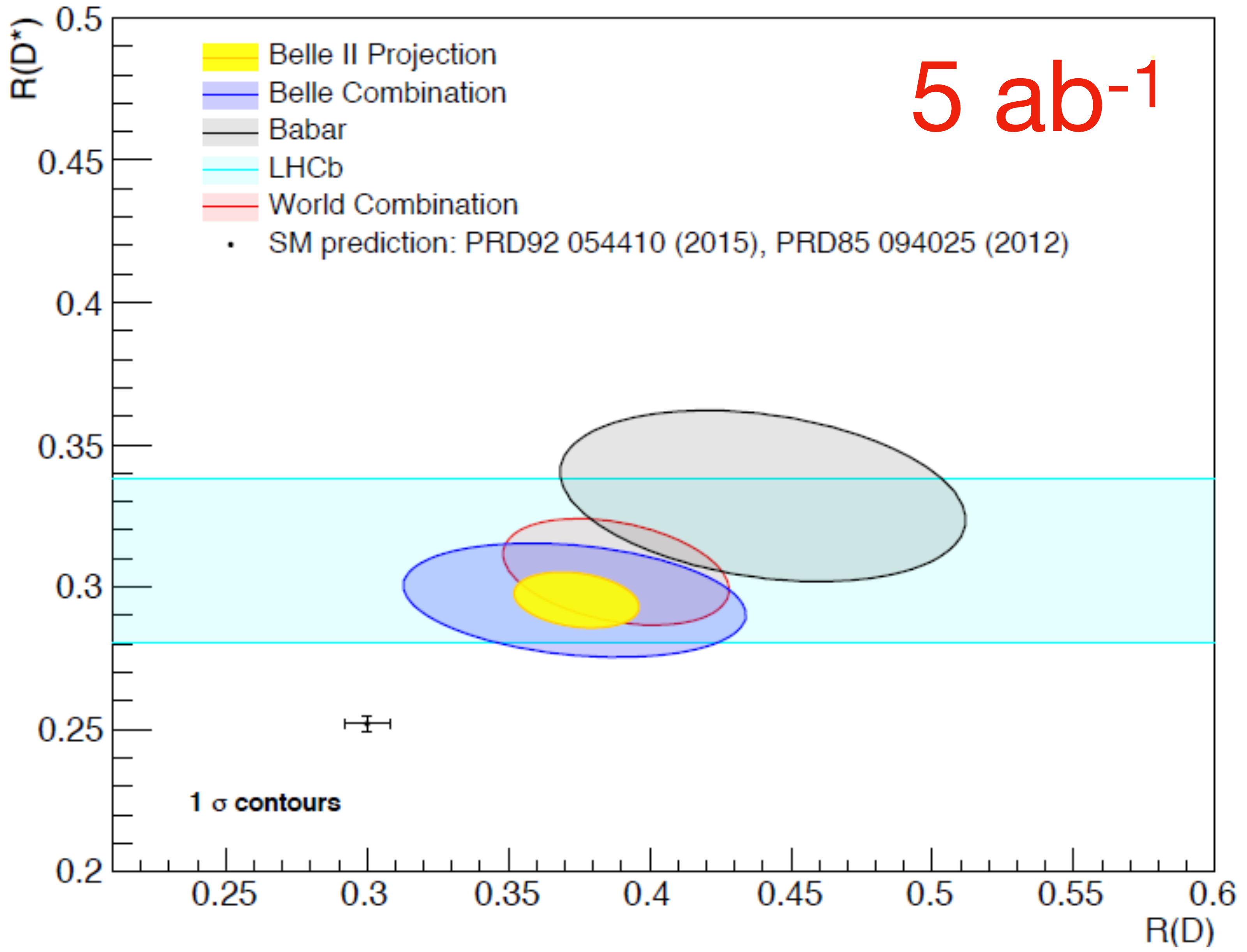
Source	Uncertainty	
Statistical uncertainty	+0.043 -0.040	+17% -16%
MC statistics	+0.010 -0.007	+4.1% -2.7%
$B \to D^{**} l \nu$ branching ratios	+0.012 -0.010	+2.7% -1.9%
…		

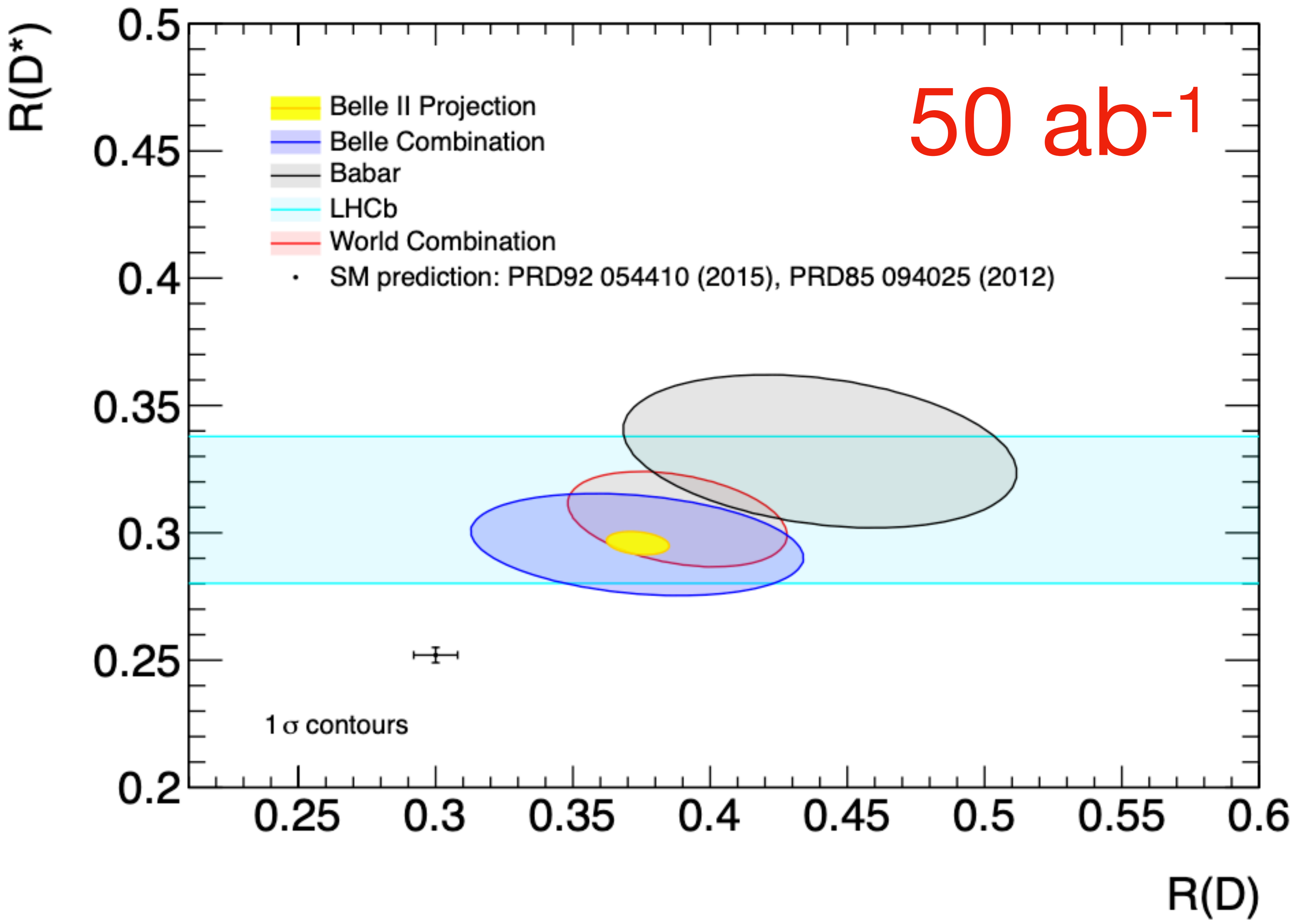
Statistical uncertainty dominated

- Currently, finalize the systematics uncertainty
  - Especially, checking the $B \to D^{**} l \nu$ modeling

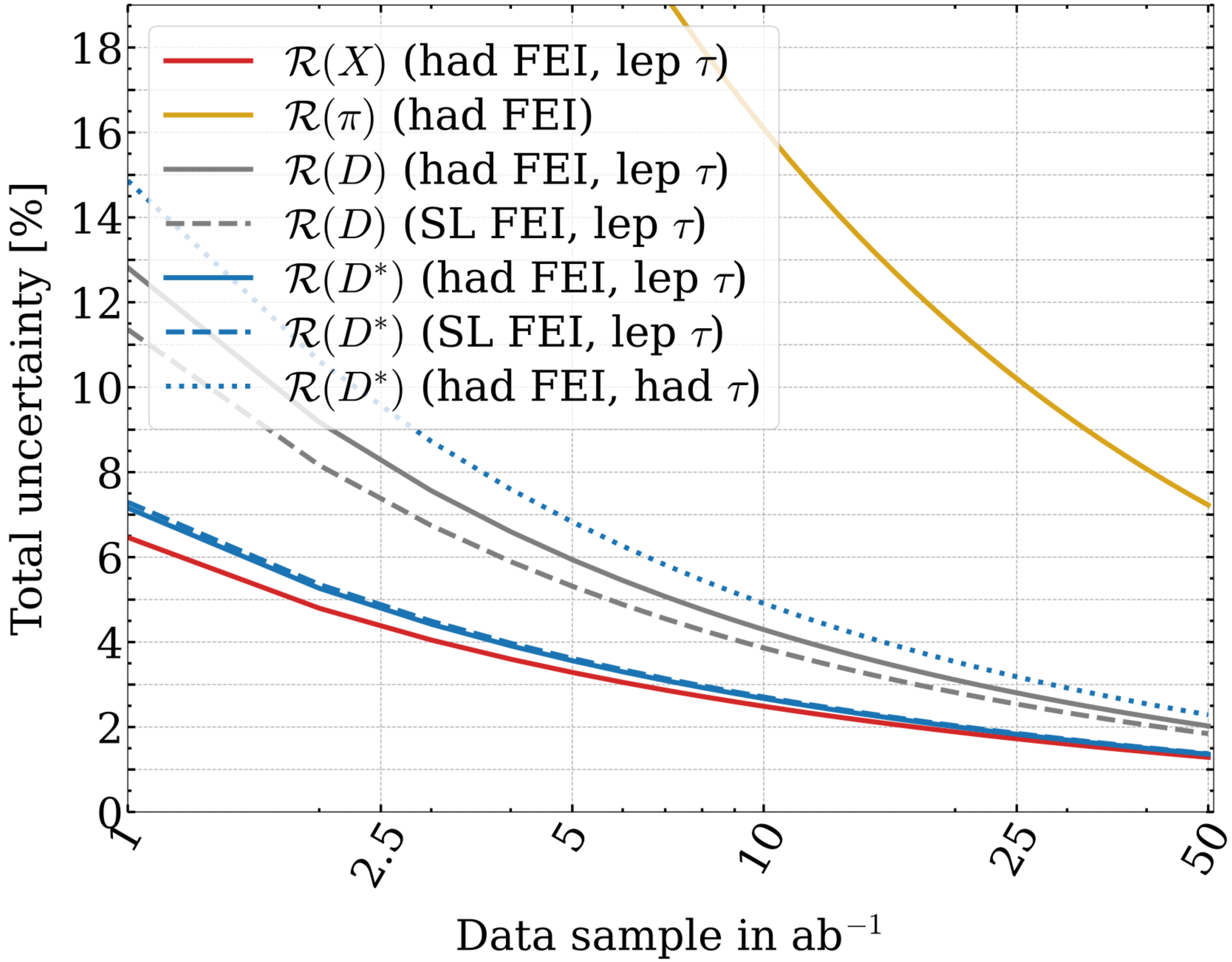
Expected sensitivity of $R(D^*)$ at Belle II

The Belle II Physics Book, PTEP 2019, 123C01





arXiv:2207.06307



Others $R(D)$ and $R(D^*)$ measurements at Belle II

- $R(D)$ and $R(D^*)$ measurements with semileptonic tag
    - Reconstruct $B \to D^{(*)} l \nu$ with semileptonic FEI
    - Tagging efficiency ~0.5%
    - More background
  - Sensitivity study been done with clean D^* mode
  - A publication with 363 fb^{-1} data targeting this summer

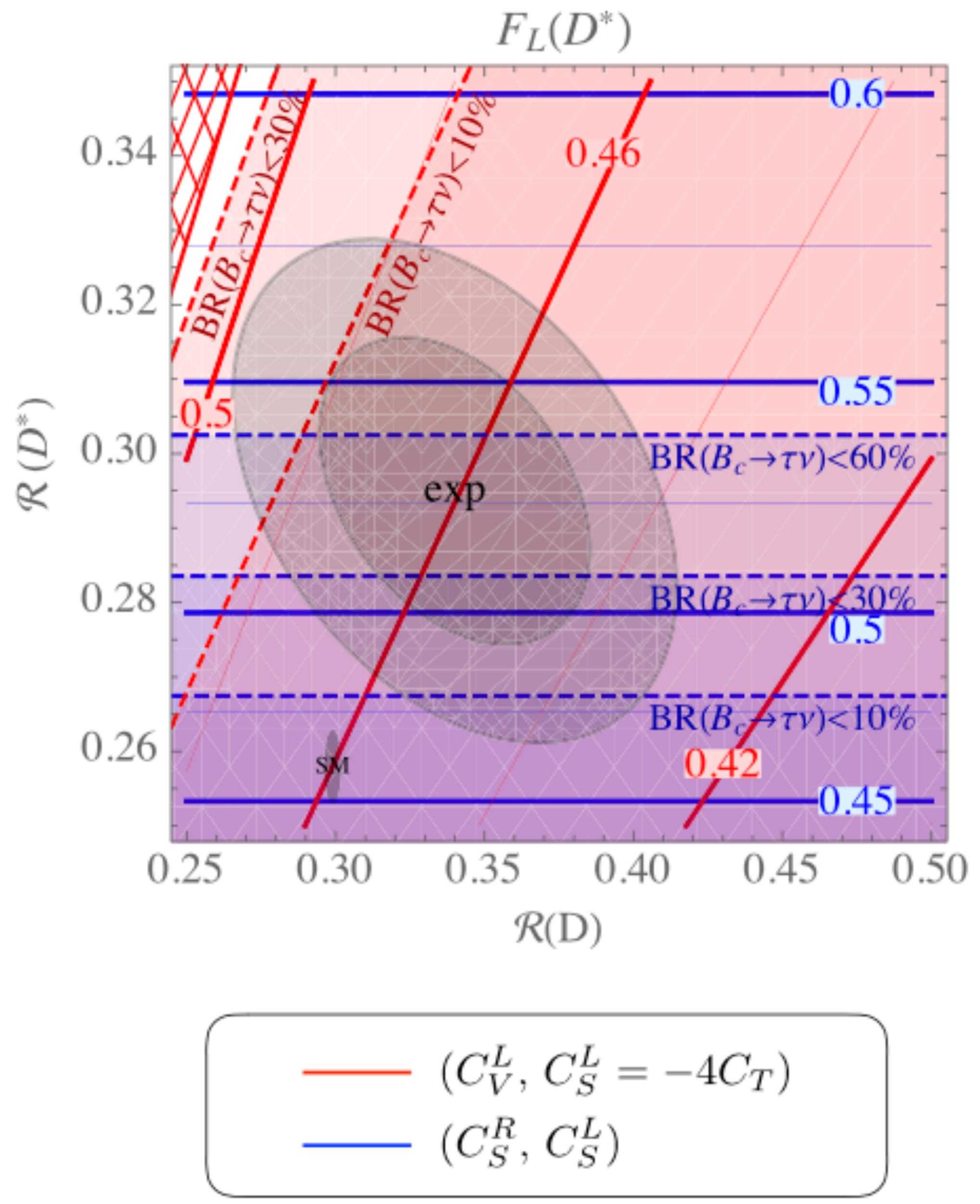
- $R(D^*)$ vs $P_\tau(D^*)$ measurements with hadronic FEI tag
  - Hadronic 1-prong τ decays
  - Sensitivity study of $R(D^*)$ been done with clean D^* mode
  - A publication with 363 fb^{-1} data targeting this winter

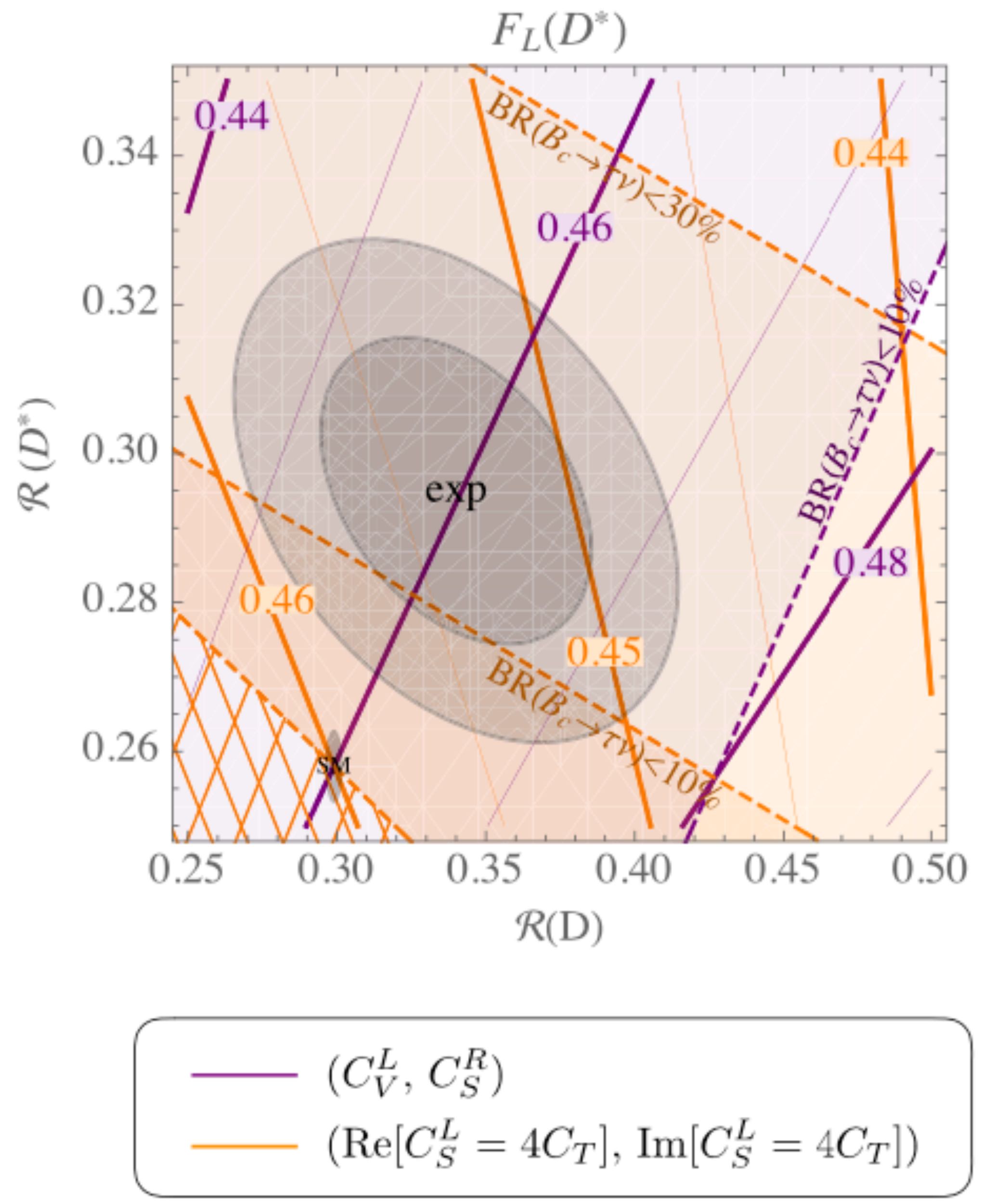
Variables for testing new physics

T. Kitahara @ 4th KMI school

[Iguro, **TK**, Watanabe, 2210.10751]

		Spin	Charge	Operators	R_D	R_{D^*}	LHC	Flavor
	$H^\pm$	0	$(\mathbf{1}, \mathbf{2}, 1/2)$	O_{S_L}	✓	✓	$b\tau\nu$	$B_c \to \tau\nu$, $F_L^{D^*}$, P_τ^D, M_W
LQ	S_1	0	$(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$	O_{V_L}, O_{S_L}, O_T	✓	✓	$\tau\tau$	ΔM_s, P_τ^D, $B \to K^{(*)}\nu\nu$
LQ	$\mathrm{R}_2^{(2/3)}$	0	$(\mathbf{3}, \mathbf{2}, 7/6)$	O_{S_L}, O_T, (O_{V_R})	✓	✓	$b\tau\nu$, $\tau\tau$	$R_{\Upsilon(nS)}$, $P_\tau^{D^*}$, M_W
LQ	U_1	1	$(\mathbf{3}, \mathbf{1}, 2/3)$	O_{V_L}, O_{S_R}	✓	✓	$b\tau\nu$, $\tau\tau$	$R_{K^{(*)}}$, $R_{\Upsilon(nS)}$, $B_s \to \tau\tau$
LQ	$\mathrm{V}_2^{(1/3)}$	1	$(\bar{\mathbf{3}}, \mathbf{2}, 5/6)$	O_{S_R}	✓	2σ	$\tau\tau$	$B_s \to \tau\tau$, M_W

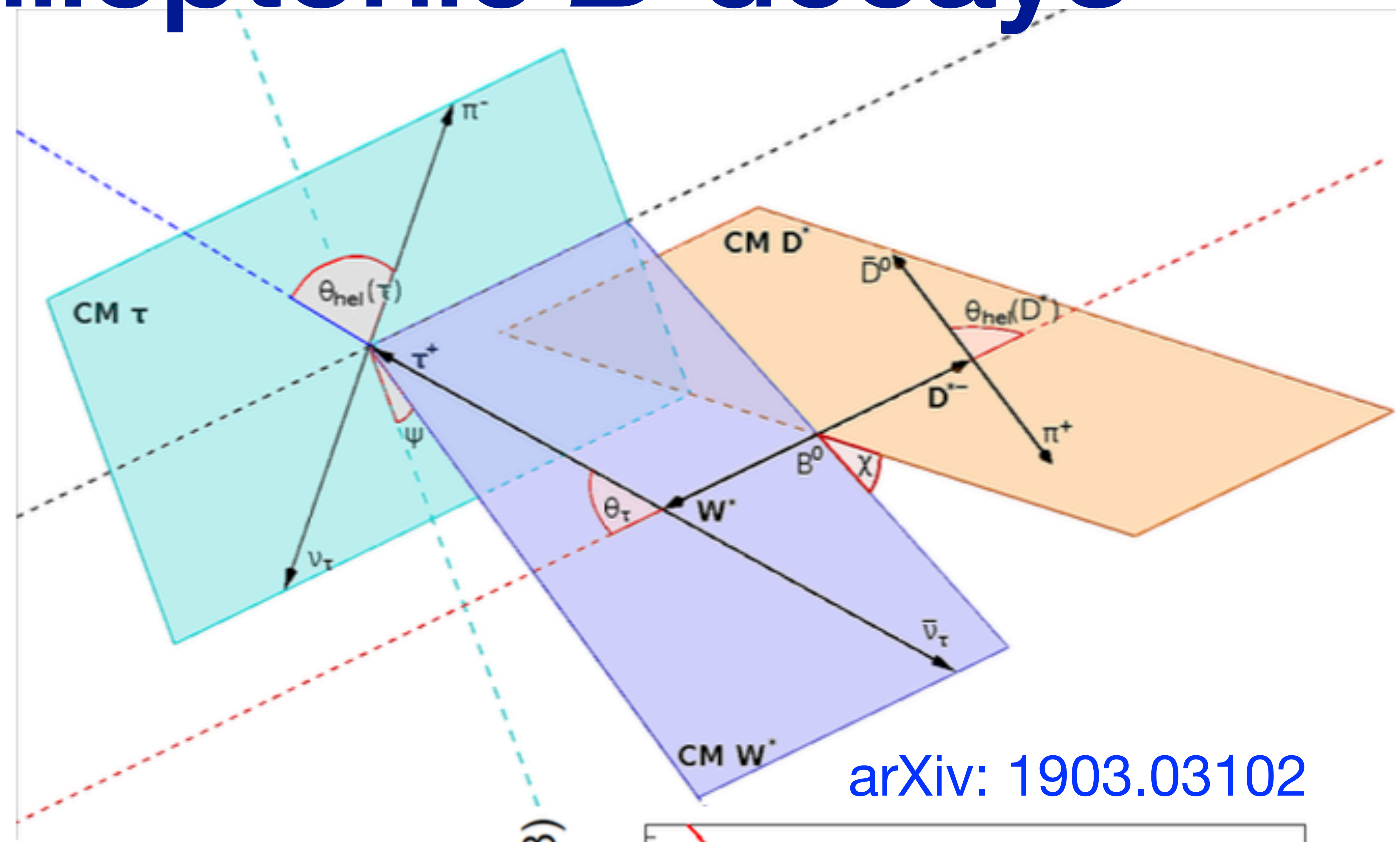




D^{*-} polarization in semileptonic B decays

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{\rm hel}} = \frac{3}{4}(2F_L^{D^*}\cos^2\theta_{\rm hel} + (1 - F_L^{D^*})\sin^2\theta_{\rm hel})$$

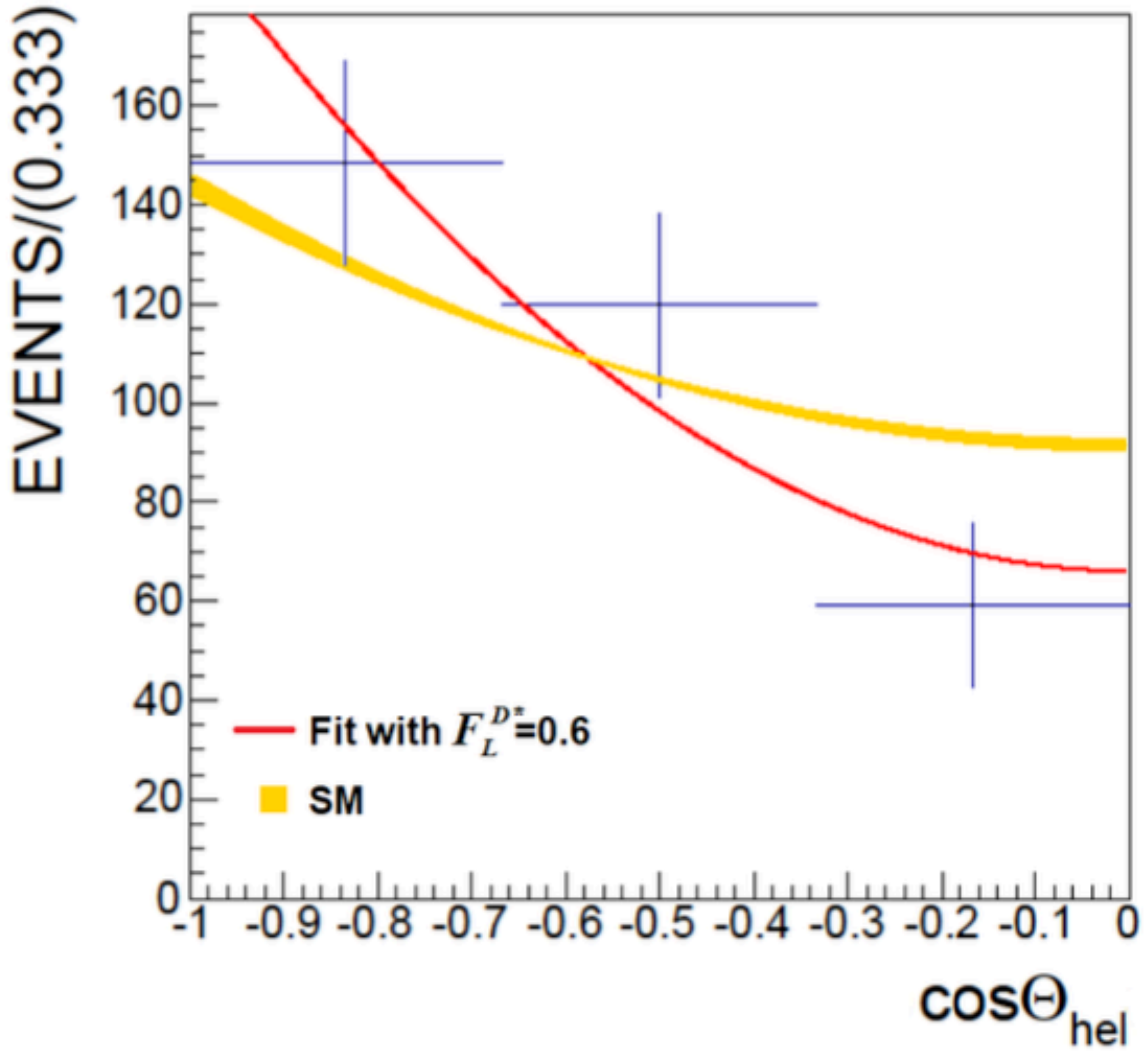
$$F_L^{D^*} = \frac{\Gamma(D_L^*)}{\Gamma(D_L^*)+\Gamma(D_T^*)}$$



- Belle measured the D^{*-} polarization in the decay of $B\rightarrow D^*\tau\nu$, with inclusive tagging based on full Belle data-set (772 M BBbar)
- Result only published on arXiv, NOT to a journal paper

$$F_L^{D^*} = 0.60 \pm 0.08(\text{stat}) \pm 0.04(\text{sys})$$

arXiv: 1903.03102



- Belle II 363 fb-1 data, will have sensitivity for measurement of $F_L^{D^*}$
- Low momentum of charged pion efficiency on forward and backward side is a challenge point.

Measurement of $R_{D^{(*)}}(q^2)$

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

- q^2 specific systematic analysis
  - Cancel the uncertainties both from experimental and theoretical side.
- Has not been measured yet
- Already have sensitivity to rejecting some of the NP, with 363 fb^{-1}

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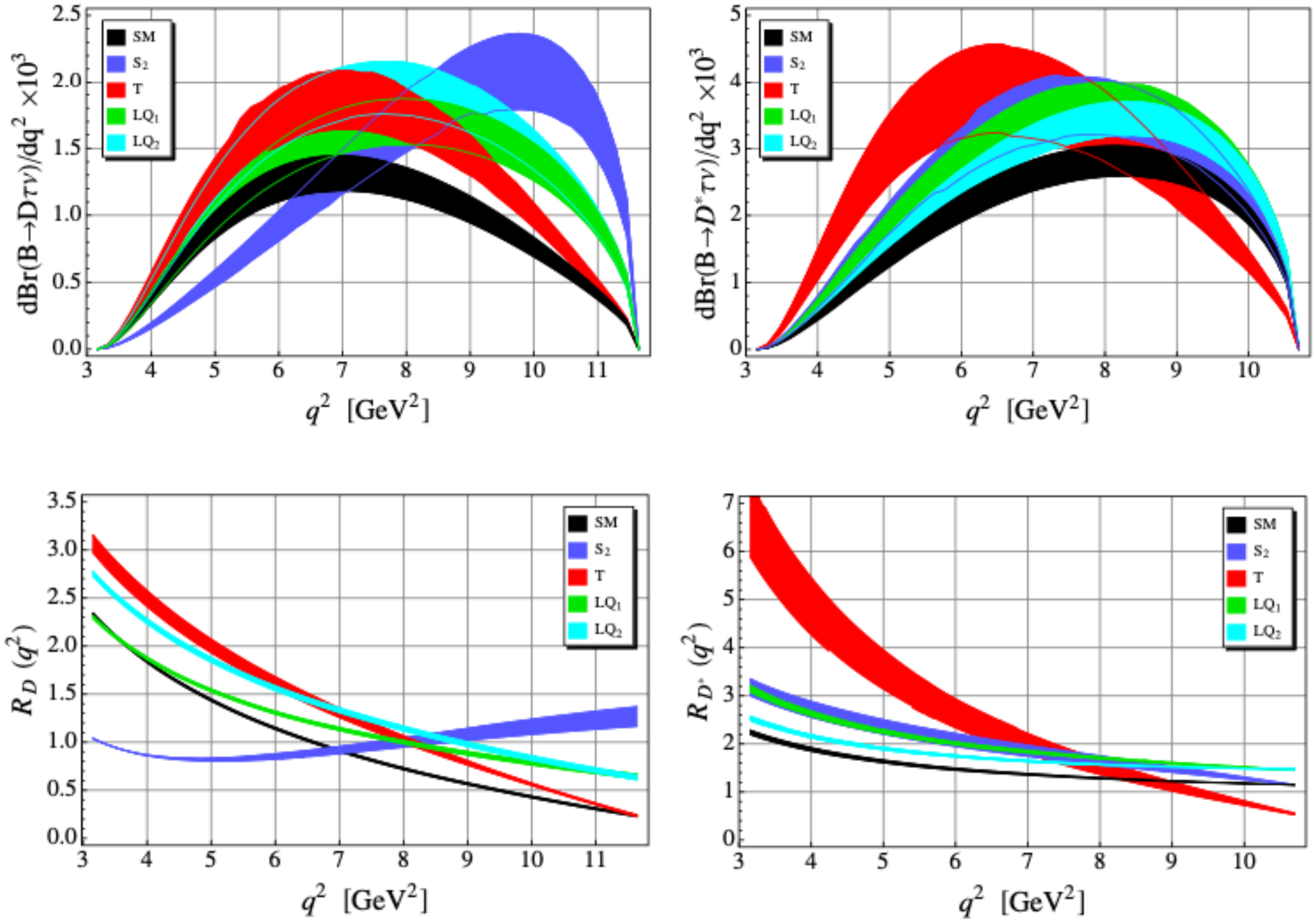
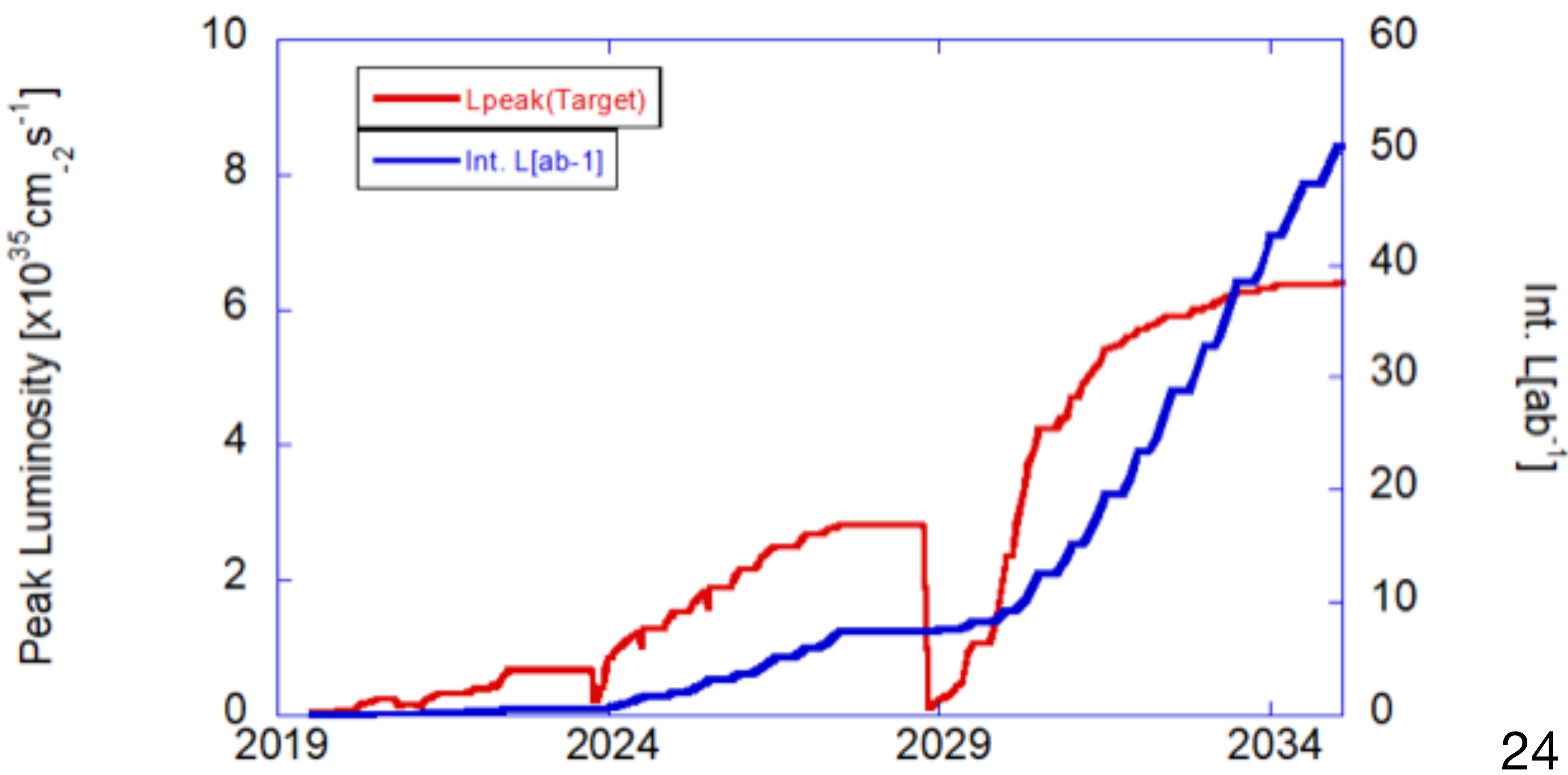


Summary and prospects

- $R(D^*)$ shows 3.2σ deviation between experimental average value and standard model prediction
  - Hint of Lepton Flavor Universality Violation

- Measurement of $R(D^*)$ with hadronic tagging based on 189 fb^{-1} Belle II data
  - Established the analysis framework
  - Selection optimization improve FOM by 35% compare to Belle ’15 analysis
  - Expected statistical uncertainty is +17/-16% at 189 fb^{-1}
  - Evaluated most of the systematic uncertainty, <- statistical uncertainty dominated with 189 fb^{-1} data

- First $R(D^*)$ measurement at Belle II using 189 fb^{-1} data-set targeting the end of spring 2023
- New observables, e.g. $F_L^{D^*}$, $R_{D^{(*)}}(q^2)$ have sensitivity to NP will 363 fb^{-1}



Backup

Statistics estimation for D^{*-} polarization measurement

bellenote1369

$B^0 \to D^{*-}\tau^+\nu_\tau$

$D^{*-} \to \bar{D}^0\pi^-$ Br. 67.7%

$\bar{D}^0 \to K^+\pi^-$, $\bar{D}^0 \to K^+\pi^-\pi^0$, $\bar{D}^0 \to K^+\pi^-\pi^+\pi^-$ Br. 26.6%

$\tau^+ \to e^+\nu_e\bar{\nu}_\tau$, $\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$, $\tau^+ \to \pi^+\bar{\nu}_\tau$ Br. 46.3%

decay chain	$-1<\cos\theta_{hel}(D^*)<-0.67$			$-0.67<\cos\theta_{hel}(D^*)<-0.33$			$-0.33<\cos\theta_{hel}(D^*)<0.$		
All	110.6	188.2	6.4	95.3	170.2	5.8	74.1	132.2	5.2

- B->D* tau nu @ Belle
  - D* l (206), D*pi (74), total (280)

Yield in Belle II MC after full Belle II selection	291.2
Yield in Belle II MC after full Belle-like selection	146.1
Ratio (Belle II sel./Belle-like sel.)	(2.00)

B Br. 50%
D* Br. 67.7%
D Br. 36.4% / 26.6%
Tau Br. 35.2% / 46.3%

- B->D* tau nu @ Belle II 189 fb^{-1}
  - D* l (98), D*pi (31), total (129)

- B->D* tau nu @ Belle II 363 fb^{-1}
  - D* l (188), D*pi (59), total (247) [$total_{+\rho}$ (382)]

Statistics for $R_{D^{(*)}}$ (q^2)

TABLE II. Luminosity required to discriminate various simulated "data" and tested model sets at 99.9% C.L. using $R_{D^{(*)}}(q^2)$ or $R(D^{(*)})$ (in parentheses). A constant efficiency is assumed.

$\mathcal{L}$ [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)	

Babar 426 fb^{-1}

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Decay	N_{sig}	N_{norm}	$\varepsilon_{sig}/\varepsilon_{norm}$	$\mathcal{R}(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)(\%)$	Σ_{stat}	Σ_{tot}
$B^- \to D^0\tau^-\bar{\nu}_\tau$	314 ± 60	1995 ± 55	0.367 ± 0.011	$0.429 \pm 0.082 \pm 0.052$	$0.99 \pm 0.19 \pm 0.12 \pm 0.04$	5.5	4.7
$B^- \to D^{*0}\tau^-\bar{\nu}_\tau$	639 ± 62	8766 ± 104	0.227 ± 0.004	$0.322 \pm 0.032 \pm 0.022$	$1.71 \pm 0.17 \pm 0.11 \pm 0.06$	11.3	9.4
$\bar{B}^0 \to D^+\tau^-\bar{\nu}_\tau$	177 ± 31	986 ± 35	0.384 ± 0.014	$0.469 \pm 0.084 \pm 0.053$	$1.01 \pm 0.18 \pm 0.11 \pm 0.04$	6.1	5.2
$\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$	245 ± 27	3186 ± 61	0.217 ± 0.005	$0.355 \pm 0.039 \pm 0.021$	$1.74 \pm 0.19 \pm 0.10 \pm 0.06$	11.6	10.4
$\bar{B} \to D\tau^-\bar{\nu}_\tau$	489 ± 63	2981 ± 65	0.372 ± 0.010	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.10 \pm 0.04$	8.4	6.8
$\bar{B} \to D^*\tau^-\bar{\nu}_\tau$	888 ± 63	11953 ± 122	0.224 ± 0.004	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.10 \pm 0.06$	16.4	13.2

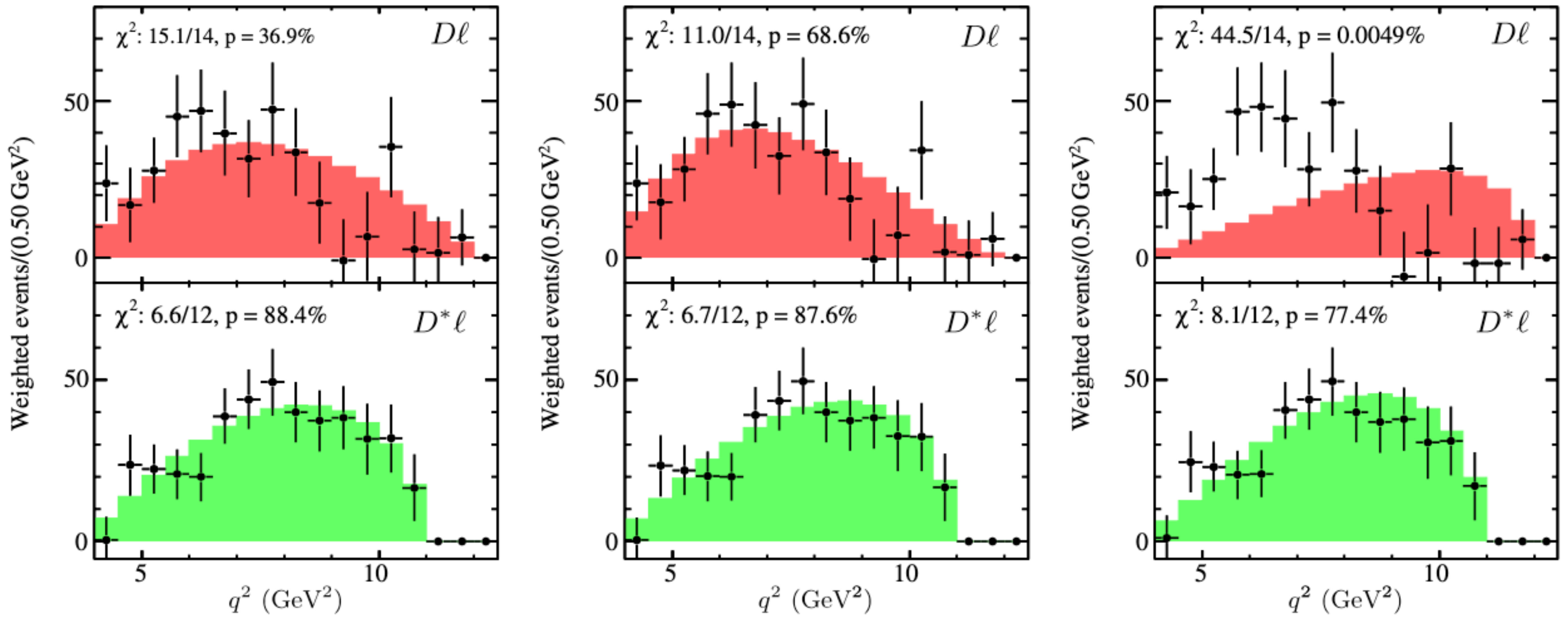
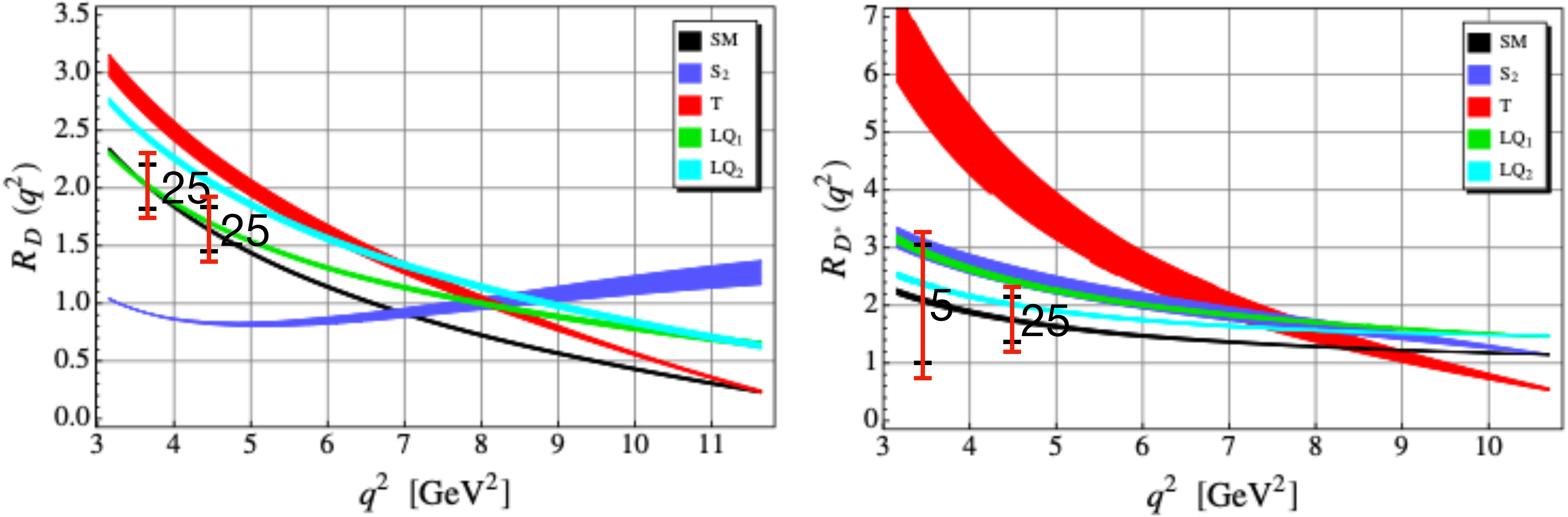


FIG. 23 (color online). Efficiency corrected q^2 distributions for $\bar{B} \to D\tau^-\bar{\nu}_\tau$ (top) and $\bar{B} \to D^*\tau^-\bar{\nu}_\tau$ (bottom) events with $m^2_{miss} > 1.5$ GeV^2 scaled to the results of the isospin-constrained fit. Left: SM. Center: $\tan\beta/m_{H^\pm} = 0.30$ GeV^{-1}. Right: $\tan\beta/m_{H^\pm} = 0.45$ GeV^{-1}. The points and the shaded histograms correspond to the measured and expected distributions, respectively. The B^0 and B^+ samples are combined and the normalization and background events are subtracted. The distributions are normalized to the number of detected events. The uncertainty on the data points includes the statistical uncertainties of data and simulation. The values of χ^2 are based on this uncertainty.

Analysis of $R_{D^{(*)}}(q^2)$

PHYSICAL REVIEW D 91, 114028 (2015)



- Only plot the size of statistical error
- Only add systematic error to be 7% from last page
- Systematic error relate to q^2 not added yet

τ-μ LFU in Υ(2s) Decays at Belle

If new physics involving in $B \to D^{(*)}\tau\nu$ by considering the absence of light right-hand neutrinos

- Correlated processes: $t \to c\tau^+\tau^-$ decay, $B_c \to \tau\nu$ decay, $\Lambda_b \to \Lambda_c \tau\bar{\nu}$ decay, and $b\bar{b}/c\bar{c} \to \tau\tau$ scattering

$$\Gamma_{\Upsilon \to \ell\ell} = 4\alpha^2 e_q{}^2 \frac{|\Psi(0)|^2}{M^2}(1 + 2m^2{}_\ell/M^2)\sqrt{1 - 4m^2{}_\ell/M^2}$$

$$\Longrightarrow R_{\tau\mu} = \frac{\Gamma_{\Upsilon \to \tau\tau}}{\Gamma_{\Upsilon \to \mu\mu}} = \frac{(1 + 2m^2{}_\tau/M_\Upsilon{}^2)\sqrt{1 - 4m^2{}_\tau/M_\Upsilon{}^2}}{(1 + 2m^2{}_\mu/M_\Upsilon{}^2)\sqrt{1 - 4m^2{}_\mu/M_\Upsilon{}^2}}$$

$V(nS)$	SM prediction	Exp. value $\pm\sigma_{stat} \pm \sigma_{syst}$
$\Upsilon(1S)$	$0.9924 \pm \mathcal{O}(10^{-5})$	$1.005 \pm 0.013 \pm 0.022$
$\Upsilon(2S)$	$0.9940 \pm \mathcal{O}(10^{-5})$	$1.04 \pm 0.04 \pm 0.05$
$\Upsilon(3S)$	$0.9948 \pm \mathcal{O}(10^{-5})$	$1.05 \pm 0.08 \pm 0.05$
$\psi(2S)$	$0.390 \pm \mathcal{O}(10^{-4})$	0.39 ± 0.05

Table 1. Experimental results and SM predictions for $R^V_{\tau/\ell}$.

J. High Energ. Phys. 06, 019 (2017)

Recently, measurement at Babar based on the Υ(3s) data-set

Using a 26.9 fb^{-1} data sample collected at the Υ (3S) and 78.3 fb^{-1} data sample at the Υ (4S) to describe the continuum, *BABAR* measures:

$$R_{\tau\mu} = \frac{\mathcal{B}(\Upsilon(3S) \to \tau^+\tau^-)}{\mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-)} = 0.9662 \pm 0.0084_{stat} \pm 0.014_{syst}$$

$$= 0.9662 \pm 0.016 tot$$

This measurement is 6 x more precise than CLEO's result and is within 2σ of the SM value of 0.9948

J. M. Roney @ BEAUTY 2020

τ-μ LFU in Υ(2s) Decays at Belle

Total Integrated Luminosity (fb^{-1}) Belle

Exp	Y4S/Off	Y1S/Off	Y2S/Off	Y3S/Off	Y5S/Off	Scan	Total
7-27	140.747/15.621	0/0	0 /0	0/0	0/ 0	0.281(1S)	156.38
7-65	702.623/79.366	5.745/1.815	0/0	2.922/0.246	23.182/1.73	0.029(1S)/0.076(3S)/6.518(5S)	824.533
31-55	457.911/51.915	0/0	0 /0	2.922 / 0.246	23.182/ 0	0.076(3S)/0.168(5S)	536.42
61-73	104.704/21.918	5.745/1.815	24.913/1.708	0 /0	97.879/1.73	0.029(1S)/0.024(2S)/27.406(5S)	288.088
31-73	562.615/73.833	5.745/1.815	24.913/1.708	2.922/0.246	121.061/1.73	0.029(1S)/0.24(2S)/27.574(5S)	824.507
7-73	702.623/89.454	5.745/1.815	24.913/1.815	2.922/0.246	121.061/1.73	0.029(1S)/0.24(2S)/0.076(3S)/27.574(5S)	980.417

The Υ(2S) on-resonance sample collected by BaBar (Belle) is about ~ 10 (16) times larger than CLEO's sample. The Υ(3S) on-resonance sample collected by BaBar (Belle) is about ~ 20 (2) times larger than CLEO's sample. Analyzing these existing data sets will allow to reduce each of the statistical uncertainties to roughly 1 – 2 percent.

We estimate that a total uncertainty of about 1% can be obtained by analyzing the existing data. Future measurement in Belle II can further reduce this uncertainty. Assuming that the important systematical error is governed by the limited statistics, we estimate that reaching a $\sigma_{sys} = 0.4\%$ for $R^{\Upsilon(1S)}$, Belle II would require integrated luminosity of L ~ 1/ab τ/μ at the Υ(3S) energy

Targeting a publication with Belle data-set

- Roughly schedule: preliminary result next Moriond 2022

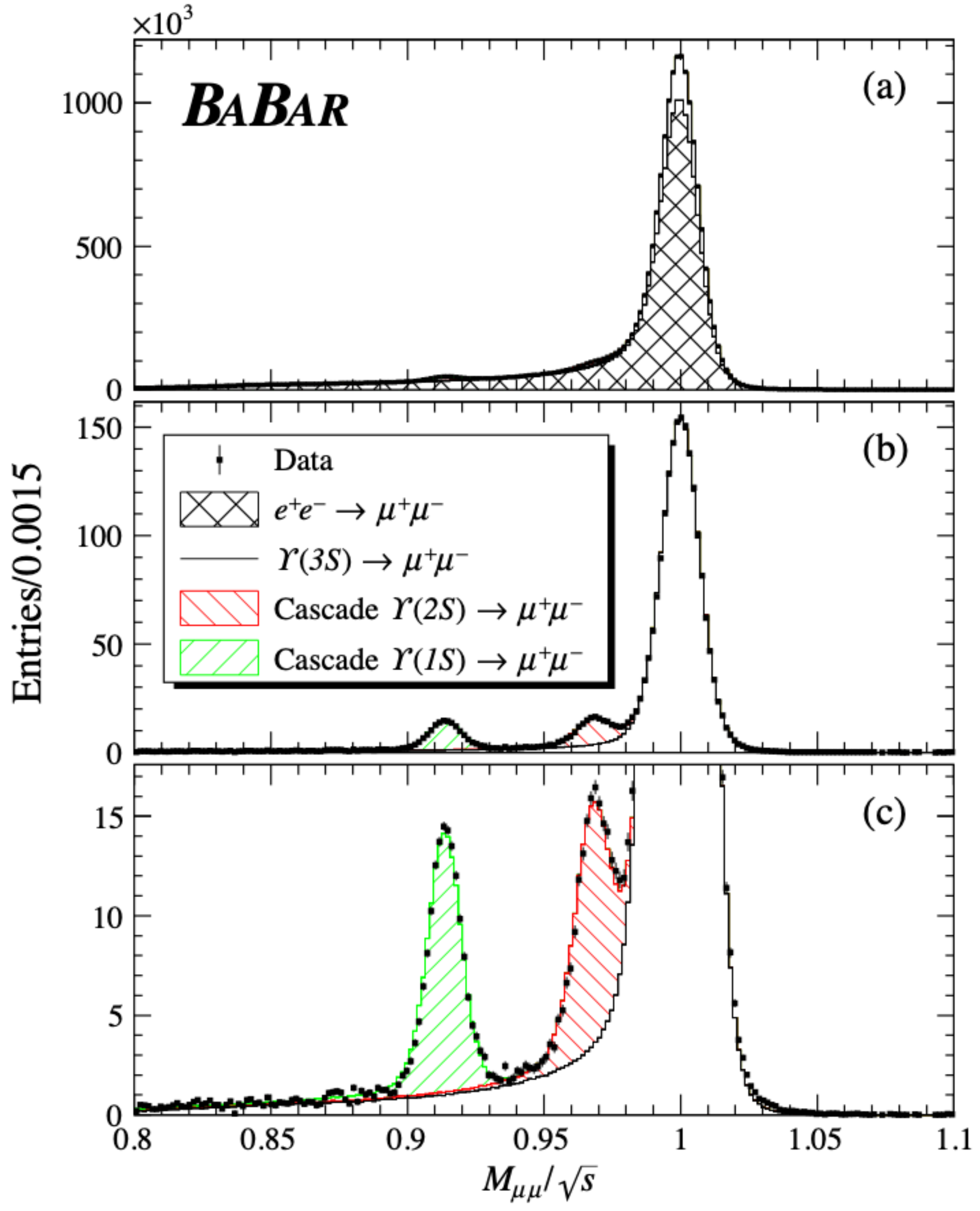


FIG. 3. The result of the template fit to the Υ(3S) data in the $M_{\mu\mu}/\sqrt{s}$ variable. In (a) all events are shown, in (b) and (c) the dominant continuum $e^+e^- \to \mu^+\mu^-$ background is subtracted, and (c) is a magnified view of (b) to better show cascade decays and the radiative-tail region.

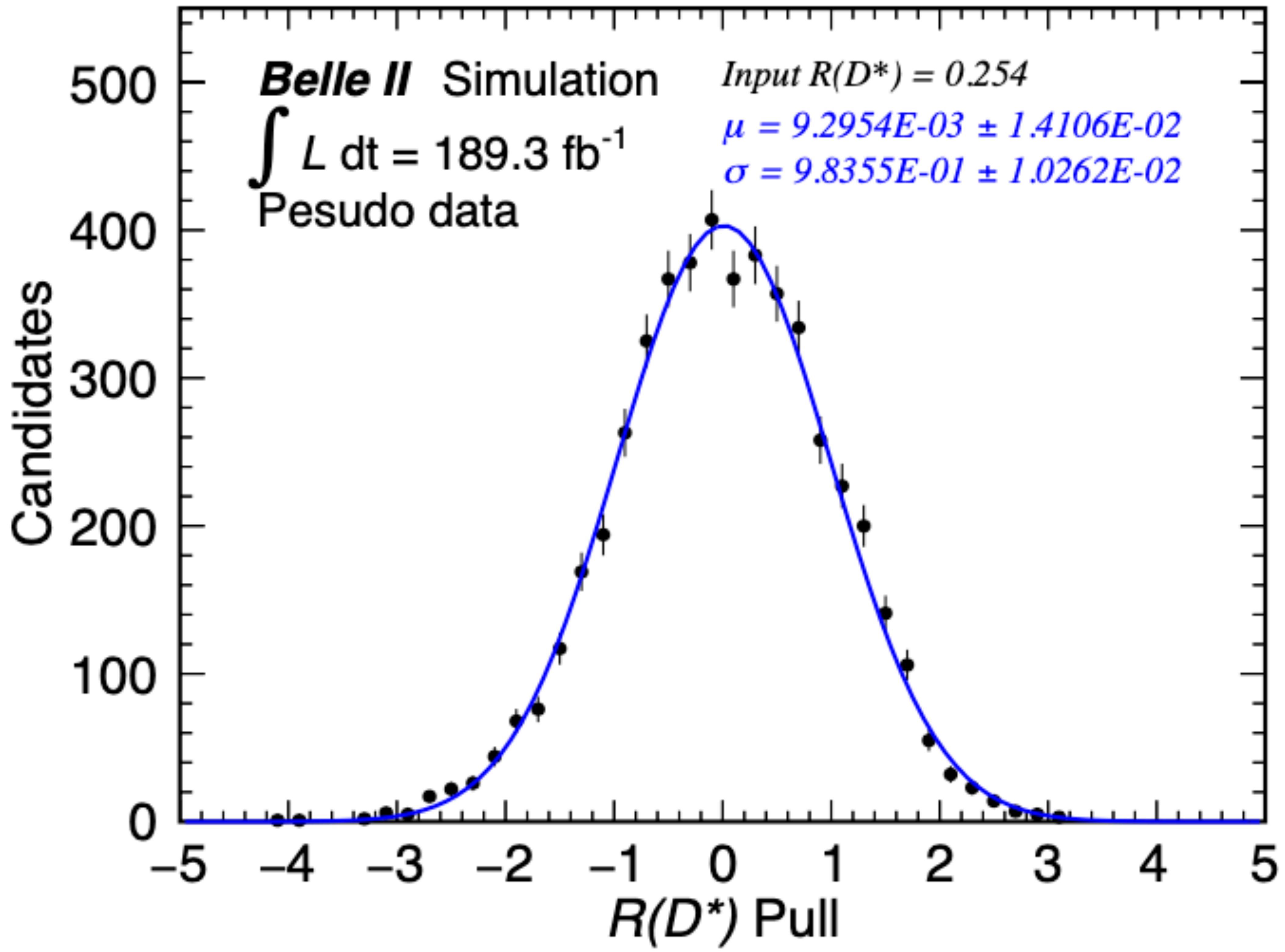
Reconstruction selections

			Category
B_{tag}		$\mathcal{P}_{B_{tag}} > 0.001$ and $M_{bc,B_{tag}} > 5.27\ \mathrm{GeV}/c^2$ and $-0.15 < \Delta E_{B_{tag}} < 0.1\ \mathrm{GeV}$	Tag B meson
`good track`		$dr < 2.0$ and $\lvert dz\rvert < 4.0$ and $p_t > 0.1\ \mathrm{GeV}/c$	Tracks
# of tracks		The number of good tracks > 4	
π^+, K^+ from D		[`good track`] and nCDCHits > 20 and $\mathcal{P}_K^{\mathrm{binary}} > 0.1$, $\mathcal{P}_\pi^{\mathrm{binary}} > 0.1$	Hadrons
π^0		`pi0:eff40_May2020` and γ:$\lvert$clusterTiming$\rvert < 200$ ns	
K_S^0		`KS0:merged` and significanceOfDistance > 3 (before B_{sig} vertex fit)	
D		$1.78 < M_D < 1.92\ \mathrm{GeV}/c^2$	
γ_{low}		`gamma:eff40_May2020` and $\lvert$clusterTiming$\rvert < 200$ ns	Neutrals
π^0_{slow}		`pi0:eff50_May2020` and γ:$\lvert$clusterTiming$\rvert < 200$ ns	
π^+_{slow}		$dr < 2.0$ and $\lvert dz\rvert < 4.0$ and $p > 0.05\ \mathrm{GeV}/c$	
D^*		$0.130 < \Delta M_{D^*} < 0.170\ \mathrm{GeV}/c^2$ ($0.100 < \Delta M_{D^*} < 0.190\ \mathrm{GeV}/c^2$) for $D^{*+}(D^{*0})$	
e, μ		[`good track`] and $\mathcal{P}_\mu^{\mathrm{global}} > 0.9$, $\mathcal{P}_e^{\mathrm{global}} > 0.9$	Leptons
B_{sig} vertex fit		1. `treeFit('B0(B+):sig', conf_level=0.0, ipConstraint=False, updateAllDaughters=True, massConstaint=[K_S0, pi0], path=path)`	← Constraint $D^{(*)}$ daughter's masses to improve $D^{(*)}$ selections
		2. `treeFit('B0(B+):sig', conf_level=-1.0, ipConstraint=False, updateAllDaughters=True, massConstaint=[D*0, D*+, D0, D+, K_S0, pi0], path=path)`	← Constraint $D^{(*)}$ masses additionally to improve M^2_{miss} resolution
ROE	Charged	$\lvert dr\rvert < 5.0$ and $\lvert dz\rvert < 20.0$ and $p_t > 0.1\ \mathrm{GeV}/c$ and nCDCHits > 0	Vertex
	Neutral	`gamma:eff40_May2020` and $\lvert$clusterTiming$\rvert < 200$ ns	Neutrals of Rest of event
		roeCharge == 0 and ROE_nTracks == 0	

Fitter validation with pseudo data

- Producing 5000 random pseudo data set with 189 fb^{-1} based on PDF where *R*(*D**) = 0.254 (SM expectation)
- The fitter performance confirmed by *R*(*D**) pull distribution
- Linearity check of fitter has also been confirmed based on Asimov fit method, by scanned input *R*(*D**) in the range of 0.05 to 2.0

↑ Eur.Phys.J.C71:1554,2011



$\mu = 0.009 \pm 0.014$

$\sigma = 0.984 \pm 0.010$