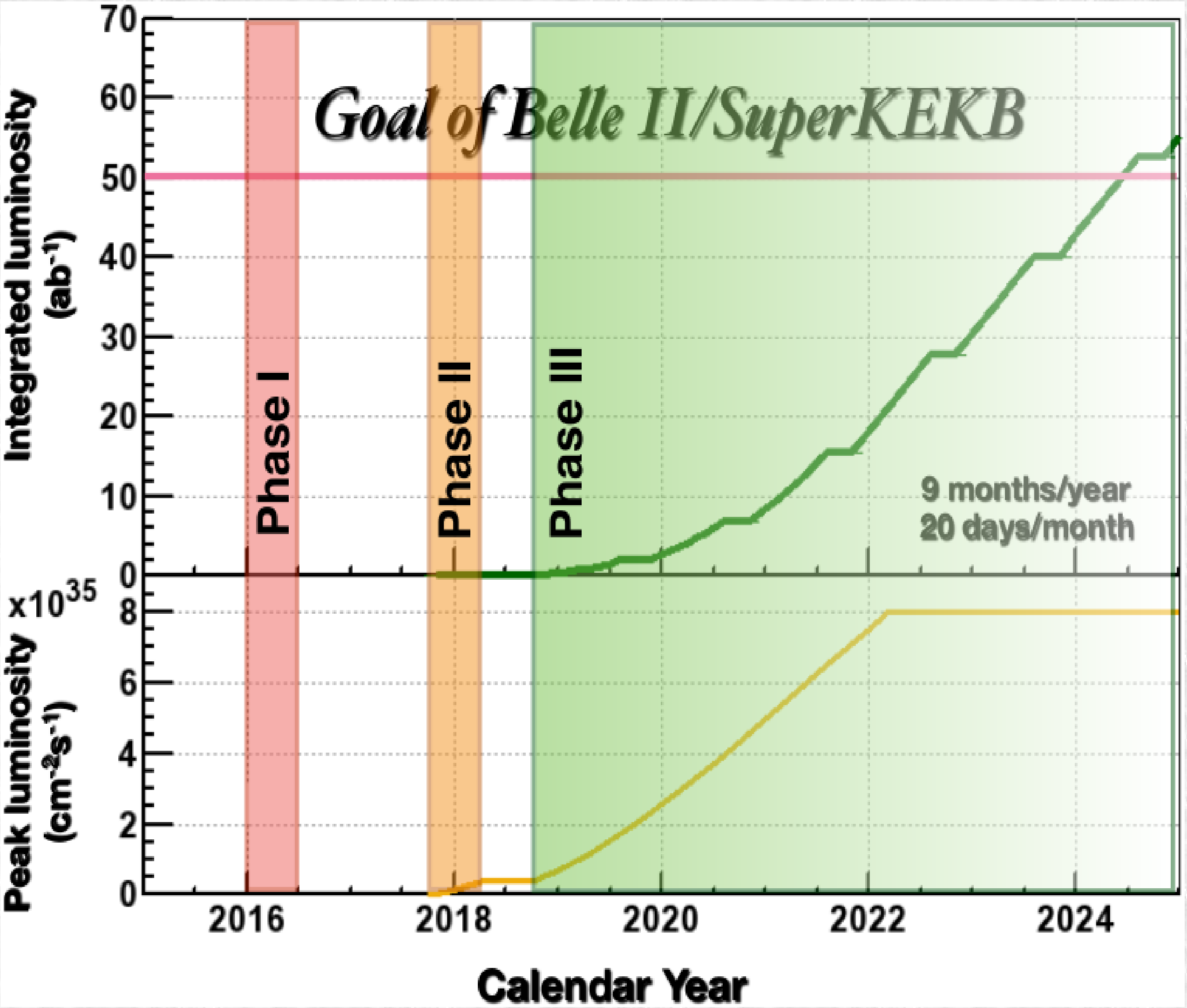
SuperKEKB luminosity /Belle II status & schedule

- Commissioning/operation of Belle II phases:



Phase 3 - **full detector operation by the end 2018**

- 15 ab^{-1} by 2022

Belle II perspective 2019 -2022

A.Bożek
IFJ PAN
Poland

- Current status of flavor physics in B decays related to Belle II
  only B physics
- Some potential development not fully covered yet
  important but not primary, since we are talking about additional topics

Belle II is complementary to the LHC indirect searches :

Well defined initial state

- neutral final states: $\pi^0\pi^0$, $K_S\pi^0(\gamma)$, $K_SK_SK_S$
- final states with missing energy: $\tau\nu$, $D^{(*)}\tau\nu$
- inclusive modes, e.g. $B \to X_S\gamma$, $B \to X_s l^+l^-$

Large B and charm statistics:

Specializes in (very) rare decays to clean final states: $B\to K^*\mu\mu$, $B\to\mu\mu$ and hadronic B decays into charged states

not only complementary but also... competitive

Observables	Belle (2015)	Belle II 50 ab^{-1} 70%@$\Upsilon(4S)$, improved K_S	50 ab^{-1}@$\Upsilon(4S)$	LHCb Run-1	22 fb^{-1}
	$(\sigma_{\rm stat}, \sigma_{\rm sys})$	$(\sigma_{\rm stat}, \sigma_{\rm sys})$	$(\sigma_{\rm stat}, \sigma_{\rm sys})$	$(\sigma_{\rm stat}, \sigma_{\rm sys})$	$(\sigma_{\rm stat}, \sigma_{\rm sys})$
$\sin(2\phi_1)$ in $B \to J/\psi K_S$	(0.023, 0.011)	(0.003, 0.007)	(0.007)	(0.035, 0.020)	(0.012, 0.007#)
$\sin(2\phi_1)$ in $B \to \phi K_S$	(0.14)	(0.018)	(0.015)	(0.30)#	(0.06)
$\sin(2\phi_1)$ in $B \to \eta' K_S$	(0.07, 0.03)	(0.008, 0.008)	(0.009)	–	–

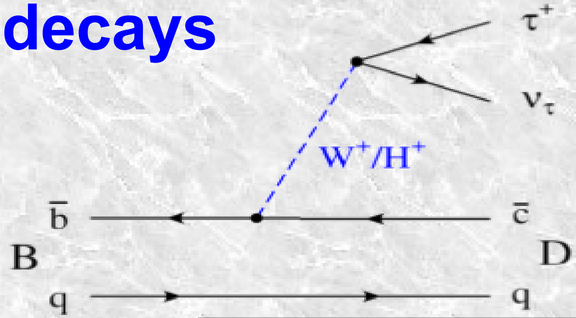
Physics at Belle II

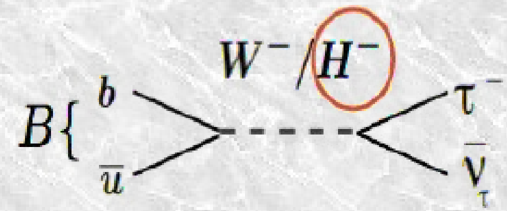
Leptonic and semileptonic decays

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

arXiv:1507.03233 arXiv:hep-ex/1503.05613

Phys. Rev. Lett.99(2007) 191807.
Phys. Rev. D82(2010) 072005.



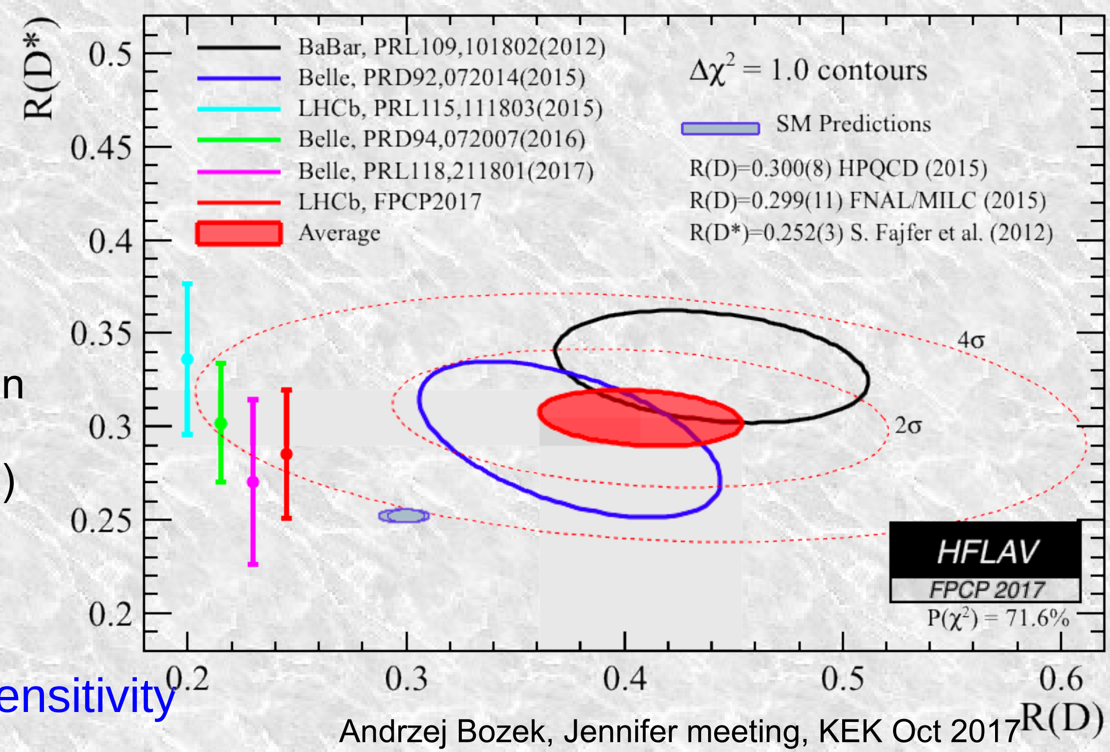


- sensitive to charged scalars
(ex. charged Higgs)
→ BF modification

Sensitivity:	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$R(B \to D\tau\nu)$	$0.440(1 \pm 16.5\%)$	5.6%	3.4%
$R(B \to D^*\tau\nu)$	$0.332(1 \pm 9.0\%)$	3.2%	2.1%
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$96(1 \pm 27\%)$	10%	5%

$B \to D^{(*)}\tau\nu$ is sensitive to the tensor operator

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



- lepton universality test
- the world average value gives 4σ deviation from SM at the moment
- Belle II can reach 3% sensitivity for $R(D^{(*)})$ at 50 at^{-1}

+ Belle II allows for the measurements of τ and D* polarization with good sensitivity

Physics at Belle II

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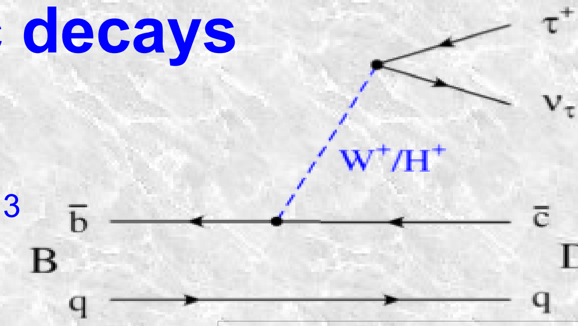

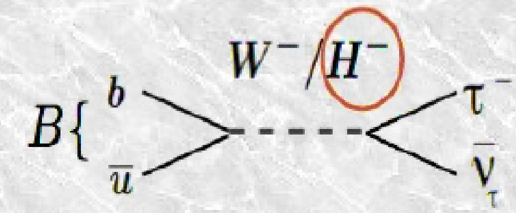

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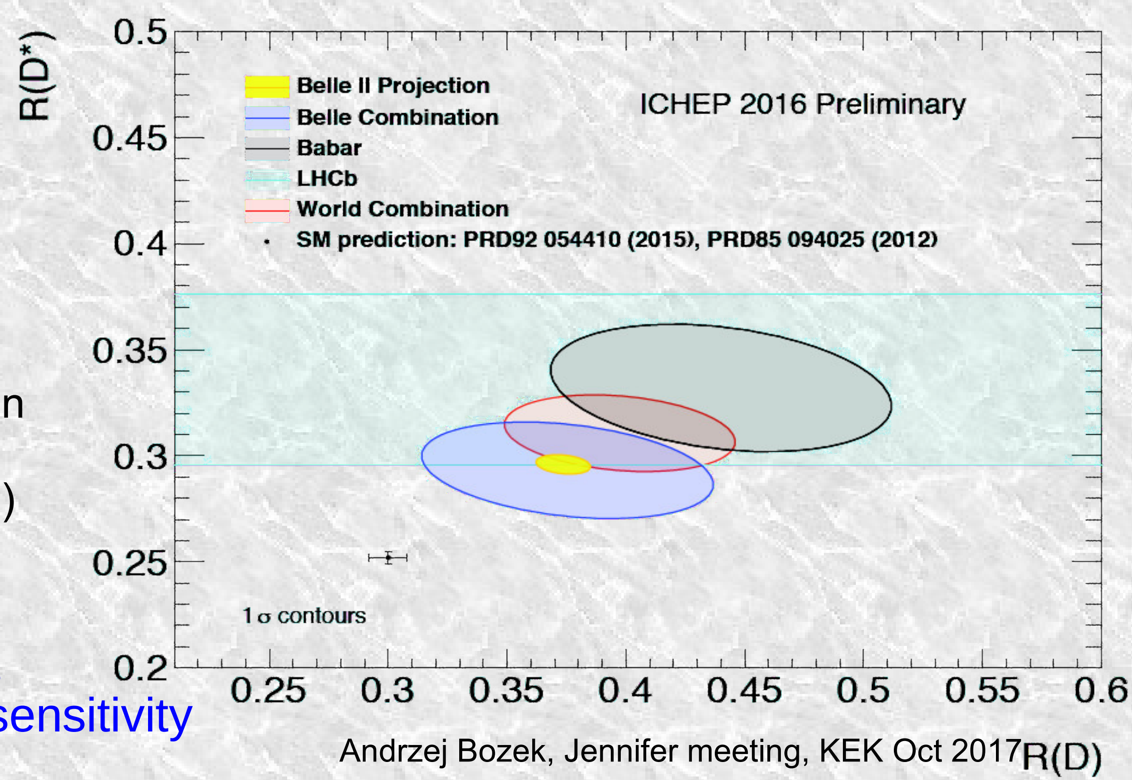

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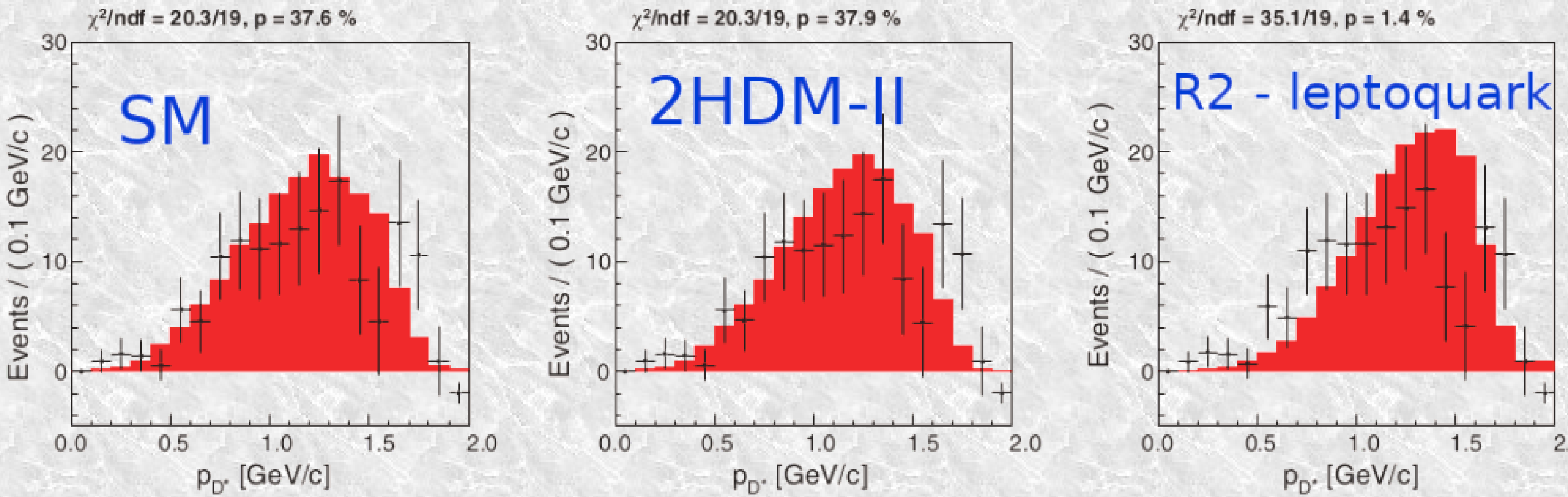
- Belle II can reach 3% sensitivity for R(D$^{(*)}$) at 50 at^{-1}

+ Belle II allows for the measurements of τ and D* polarization with good sensitivity

Momentum spectra to examine NP scenarios

Phys. Rev. D 94, 072007 (2016); semileptonic B_{tag}



- Measured distributions of p_{D*} and p_l consistent with SM but statistically limited
- More observables with more data needed to clarify the situation

The angular observables not yet (fully) explored experimentally.

First measurement of τ polarization in B decays

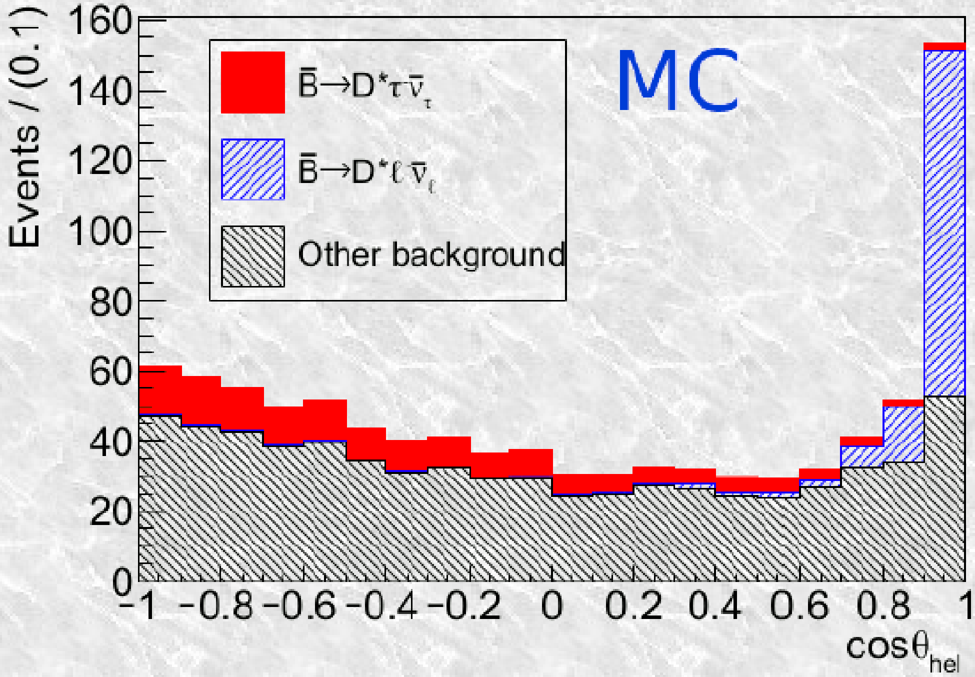
Phys. Rev. Lett. **118**, 211801 (2017)

- **both $\bar{B}^0$ and B^- decays are used; only 2 body τ decays: $\tau \to \pi\nu, \rho\nu$**
- sample divided into two bins of $cos\theta_{\rm hel}$:
  I: $-1 < cos\theta_{\rm hel} < 0$;
  II: $0 < cos\theta_{\rm hel} < 0.8$ (for $\tau \to \pi\nu$)

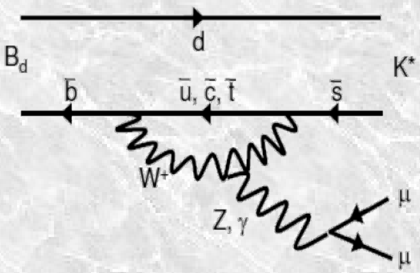
$$P_\tau = \frac{2}{\alpha}\frac{\Gamma_{cos\theta_{\rm hel}>0} - \Gamma_{cos\theta_{\rm hel}<0}}{\Gamma_{cos\theta_{\rm hel}>0} + \Gamma_{cos\theta_{\rm hel}<0}}$$

Experimental challenges

- Distribution of $\cos\theta_{hel}(\tau)$ is modified by:
  - cross-feeds from other τ decays (contribute mainly in the region of $\cos\theta_{hel}(\tau) < 0$)
  - peaking background (concentrated around $\cos\theta_{hel}(\tau) \approx 1$)
- corrections for detector effects: acceptance, asymmetric $\cos\theta_{\rm hel}$ bins, crosstalks between different τ decays
- for $\tau \to \pi(\rho)\nu$ modes combinatorial background from poorly known hadronic B decays

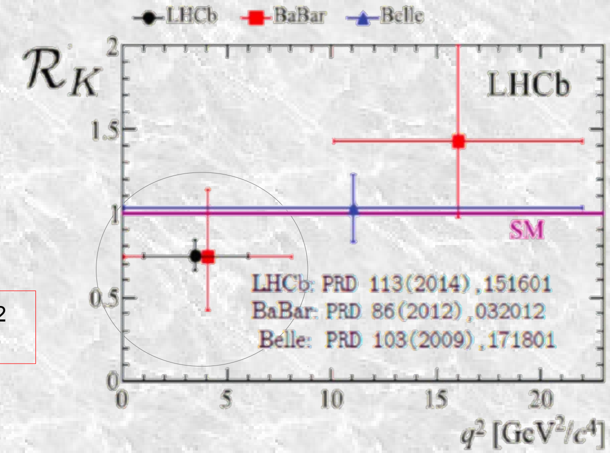


Physics at Belle II



FCNC semileptonic $b \rightarrow s\,ll$ decays

Discrepancies in observables versus the invariant dilepton mass squared (q^2)

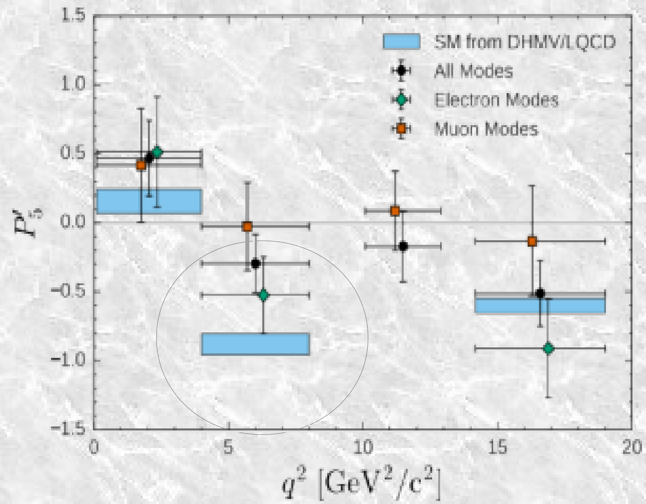


1. LHCb tension for $\mathcal{R}_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ e^+ e^-)} =$

$0.745^{+0.090}_{-0.074} \pm 0.036$ (2.6σ)

$1 < q^2 < 6$ GeV^4/c^2

---> Belle II can handle electron and muon modes with comparable efficiencies, for wide q^2 region



2. for the known P'_5 tension (LHCb), **Belle** observes 2.6σ deviation for μ channel in the lepton-flavor-dependent angular analysis

$4 < q^2 < 8$ GeV^4/c^2

---> Belle II can do:

- isospin comparison of K^{*+} and K^{*0} (or the ground K states)
- inclusive $b \rightarrow X_s ll$ studies (less theoretical uncertainties)

competitive to LHCb !

Andrzej Bozek, Jennifer meeting, KEK Oct 2017

Physics at Belle II

Direct CP violation in B→Kπ decay:

puzzling tension between SM prediction and measurement:

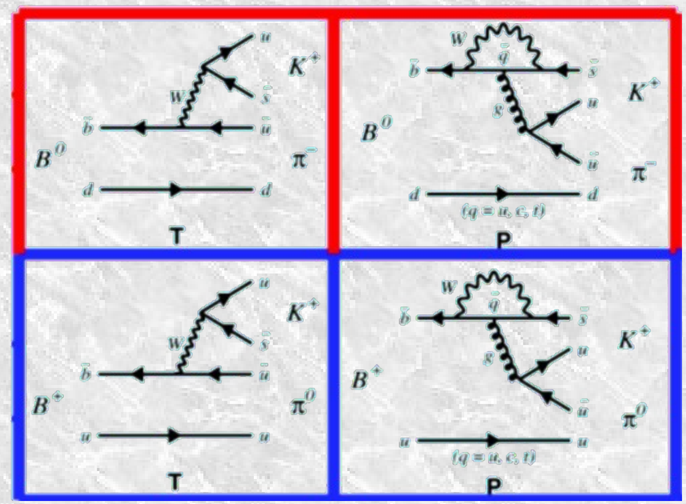
$$\Delta A \equiv A_{CP}^{B^0\to K^+\pi^-} - A_{CP}^{B^+\to K^+\pi^0} =$$

$$= -0.122 \pm 0.022 \text{ (HFAG 2013)} \quad (4\sigma)$$

ΔA $\approx$ 0 in Standard Model, but may be changed:
- due to neglected diagrams
- NP effects

$B^0 \to K^+\pi^-$

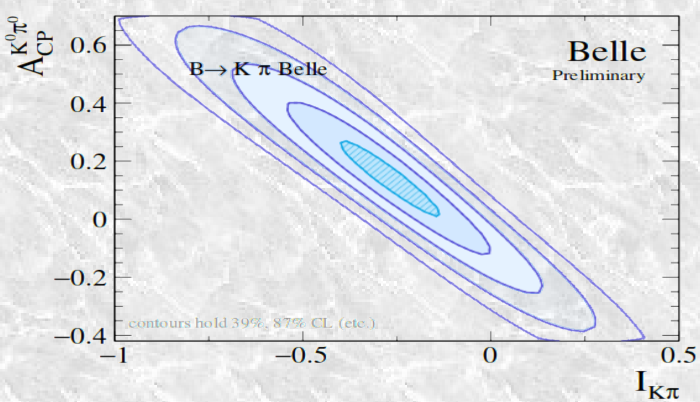
$B^+ \to K^+\pi^0$



Model independent sume rule to test SM

$$A_{CP}^{K^+\pi^-} + A_{CP}^{K^0\pi^+}\frac{\mathcal{B}(B^+\to K^0\pi^+)\tau_{B^0}}{\mathcal{B}(B^0\to K^+\pi^-)\tau_{B^+}} = A_{CP}^{K^+\pi^0}\frac{2\,\mathcal{B}(B^+\to K^+\pi^0)\tau_{B^0}}{\mathcal{B}(B^0\to K^+\pi^-)\tau_{B^+}} + A_{CP}^{K^0\pi^0}\frac{2\,\mathcal{B}(B^0\to K^0\pi^0)}{\mathcal{B}(B^0\to K^+\pi^-)}$$

M. Gronau, PLB 627 (2005) 82, D. Atwood, A. Soni, PRD 58 (1998) 036005



Neutral final states are crucial !!!

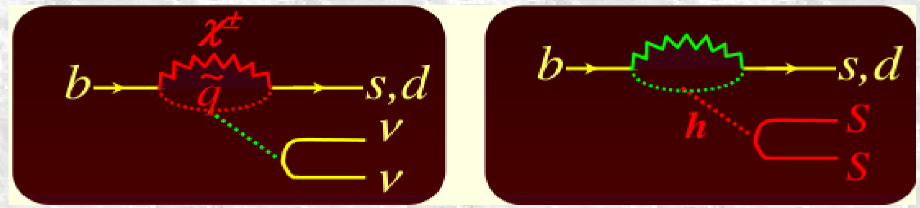
Belle II can measure A(B→K^{0}pi^0) from time-dep. analyses with uncertainty ~ 4%

Physics at Belle II

Electroweak decays with neutrinos $b \to d(s)\nu\nu$

Missing energy modes: $B \to h^{(*)}\nu\nu$

- possible window to light dark matter, not accessible in direct searches



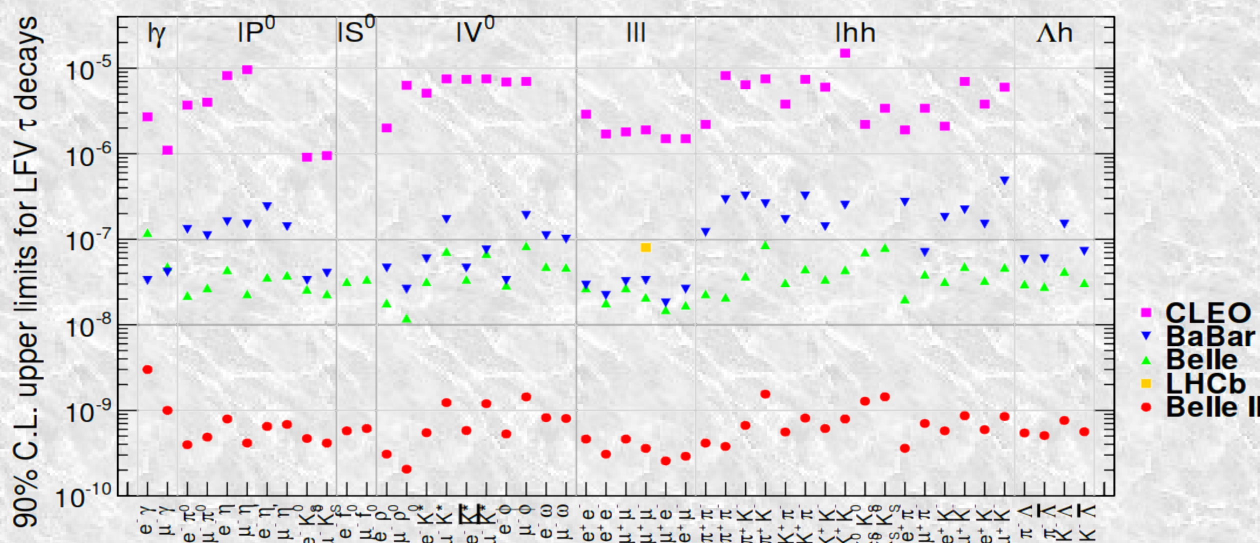
Also a window for SUSY !!!

Mode	$\mathcal{B}$ $[10^{-6}]$	Efficiency Belle $[10^{-4}]$	$N_{\text{Backg.}}$ 711 fb^{-1} Belle	$N_{\text{Sig-exp.}}$ 711 fb^{-1} Belle	$N_{\text{Backg.}}$ 50 ab^{-1} Belle II	$N_{\text{Sig-exp.}}$ 50 ab^{-1} Belle II	Statistical error 50 ab^{-1}	Total Error
$B^+ \to K^+\nu\bar{\nu}$	3.98	5.68	21	3.5	2960	245	23%	24%
$B^0 \to K^0_S\nu\bar{\nu}$	1.85	0.84	4	0.24	560	22	110%	110%
$B^+ \to K^{*+}\nu\bar{\nu}$	9.91	1.47	7	2.2	985	158	21%	22%
$B^0 \to K^{*0}\nu\bar{\nu}$	9.19	1.44	5	2.0	704	143	20%	22%
$B \to K^*\nu\bar{\nu}$ combined							15%	17%

Sources of LFV beyond the SM?

$\tau \to \mu\gamma \qquad \tau \to eee$

Highly suppressed in SM, but in some NP scenarios BF may be expanded to 10^{-10} - 10^{-7}



Physics at Belle II

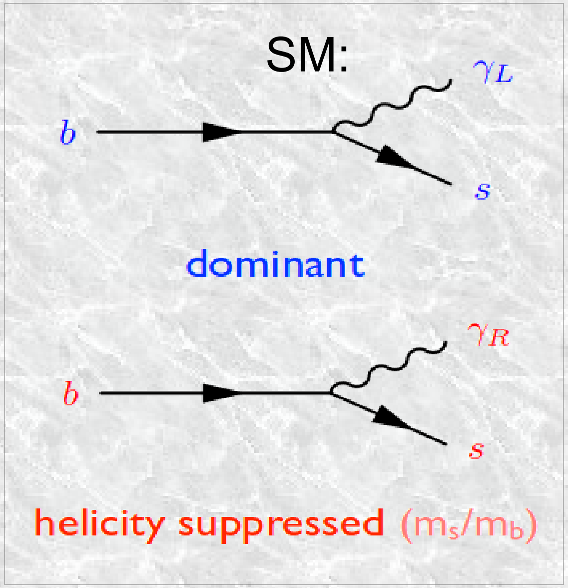
Are there right-handed currents from NP?

- Time-dependent CP Violation in $B \to K^{*0}\gamma$

$$K^{*0} \to K^0_S\,\pi^0$$

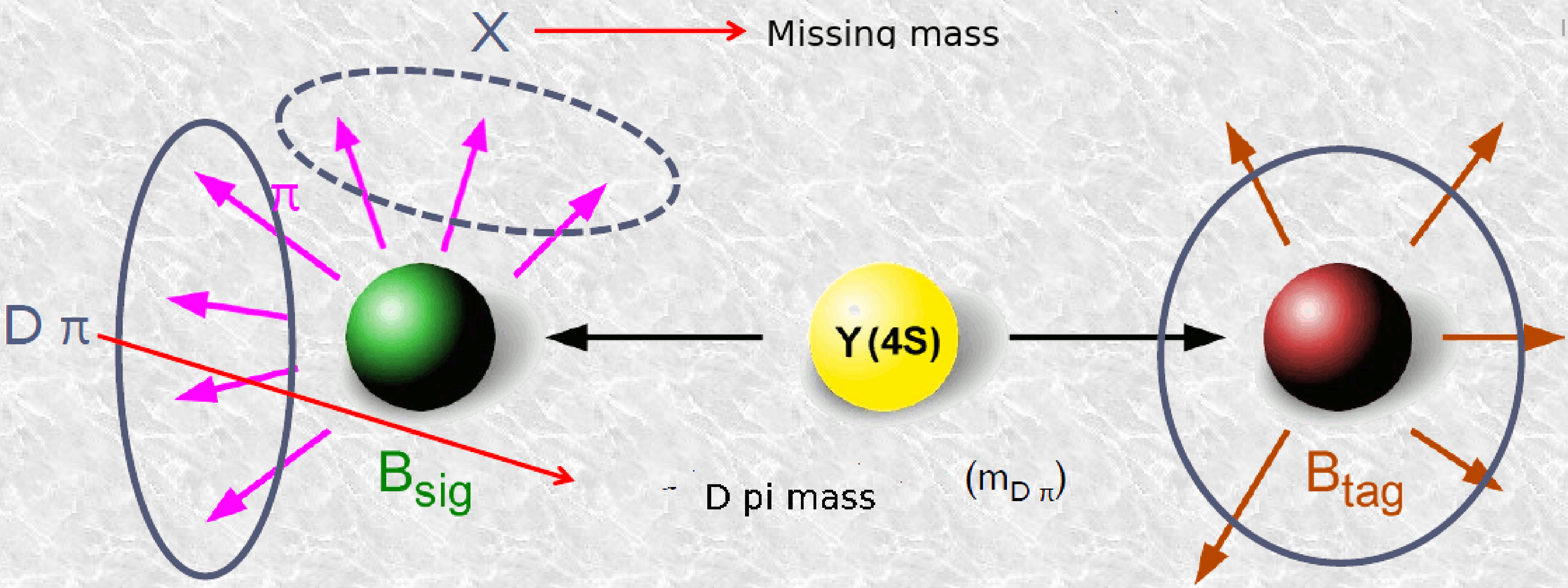
Phys. Rev. Lett.79, 185
Phys. Rev. D71, 076003

no charged tracks from B decay to reconstruct the vertex !!!



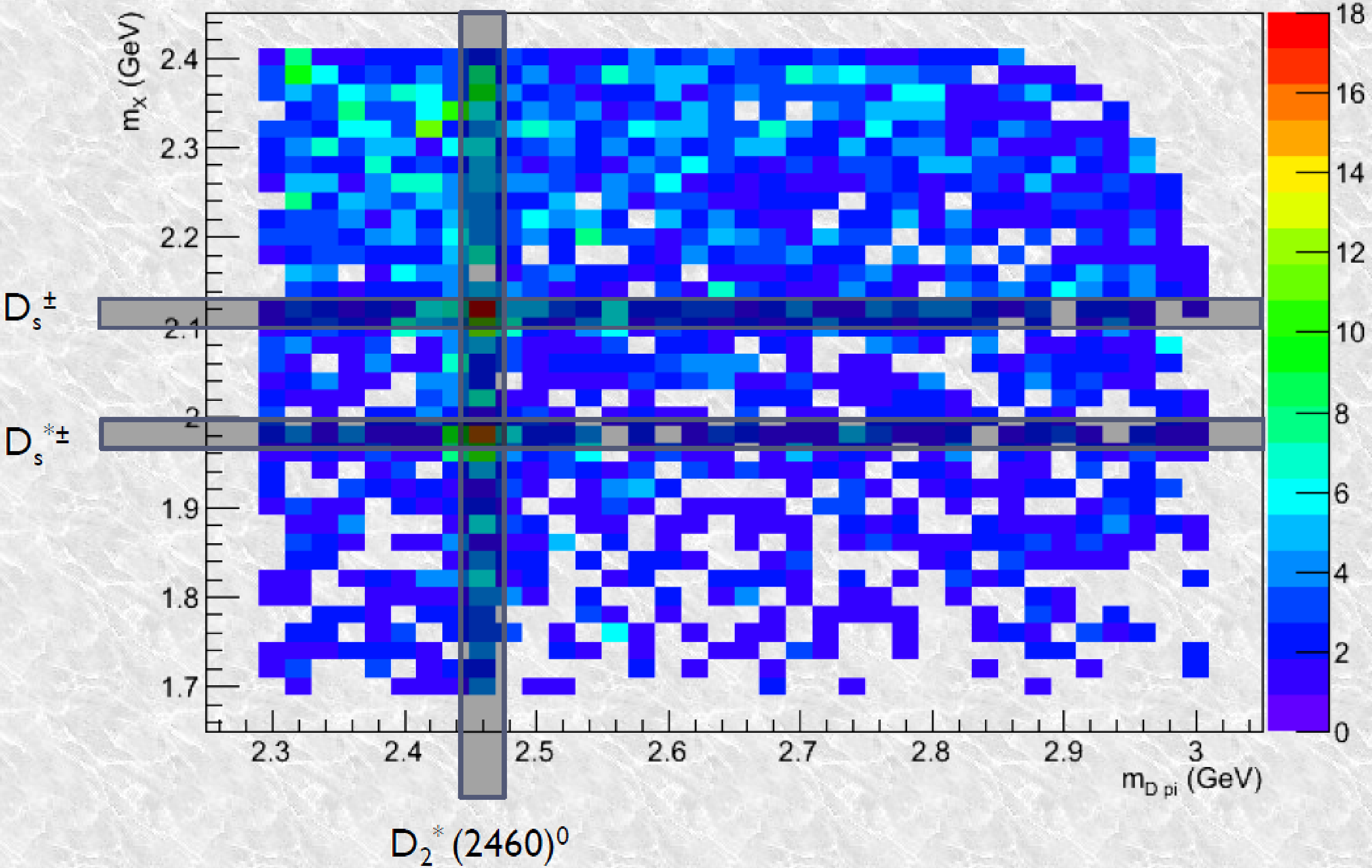
Example D** reconstruction

$$e^+e^- \rightarrow \Upsilon(4s) \rightarrow B\bar{B}$$



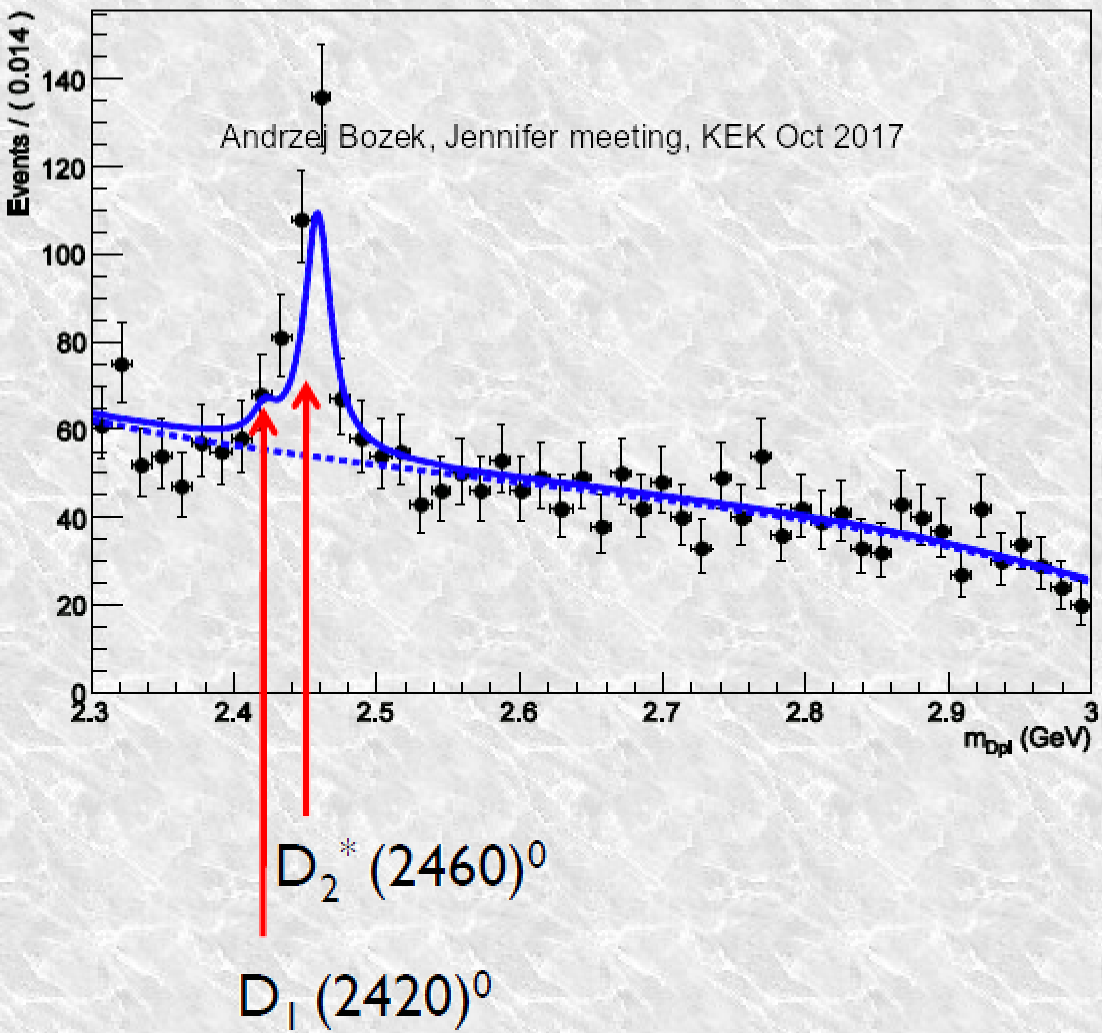
$D = D^0, D^{\pm}, D^{*\pm}, D^{*0}$

Example D** reconstruction



Andrzej Bozek, Jennifer meeting, KEK Oct 2017

Example D** reconstruction



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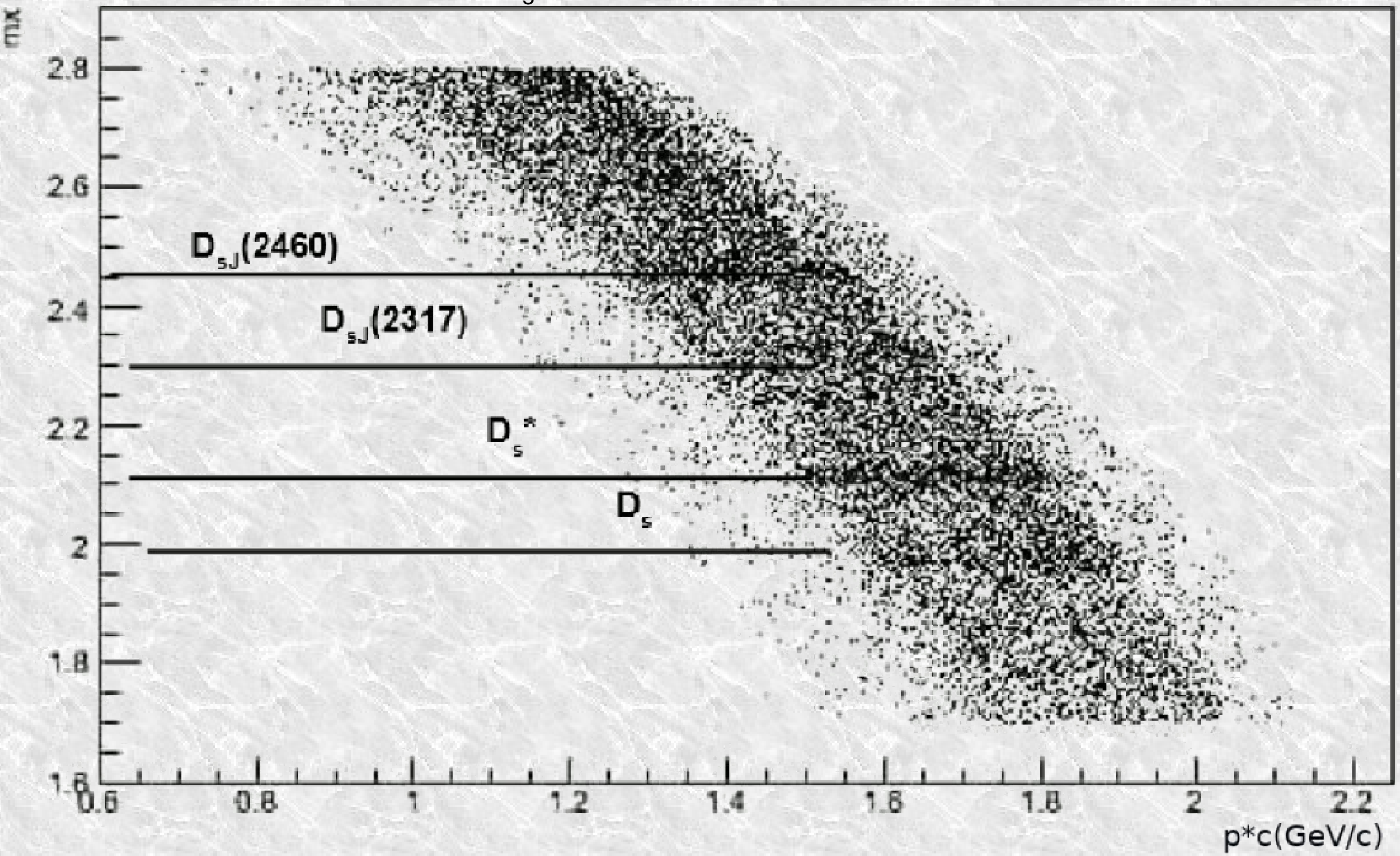
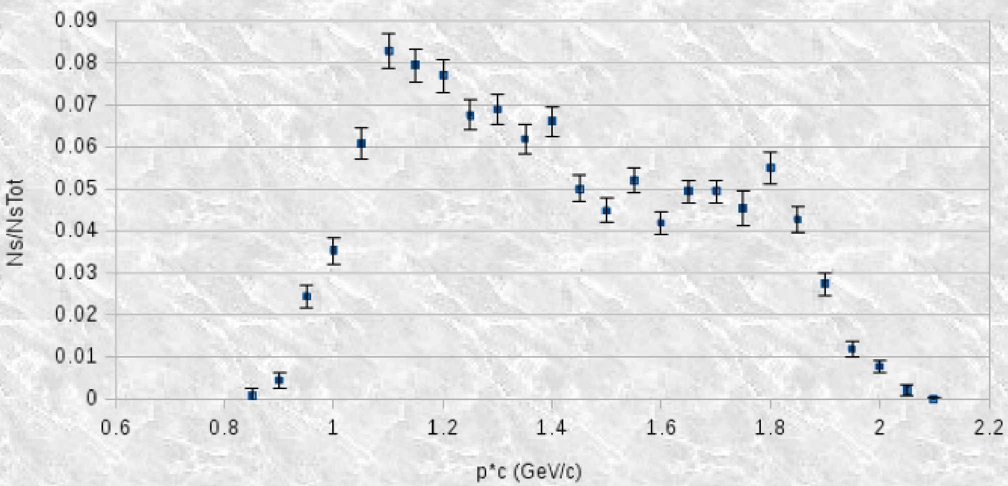
Charm production with tagging

- $B \to D^*D_{sj}$ tagged production
- Tagged with Btag
- We reconstruct only D* and looks inclusively to Dsj
- Instead of reconstruction B momentum based on B_{tag} then reconstruction of missing mass we look at momentum of reconstructed D*
- We can use more efficient partial B_{tag} reconstruction techinques like semileptonic B_{tag}

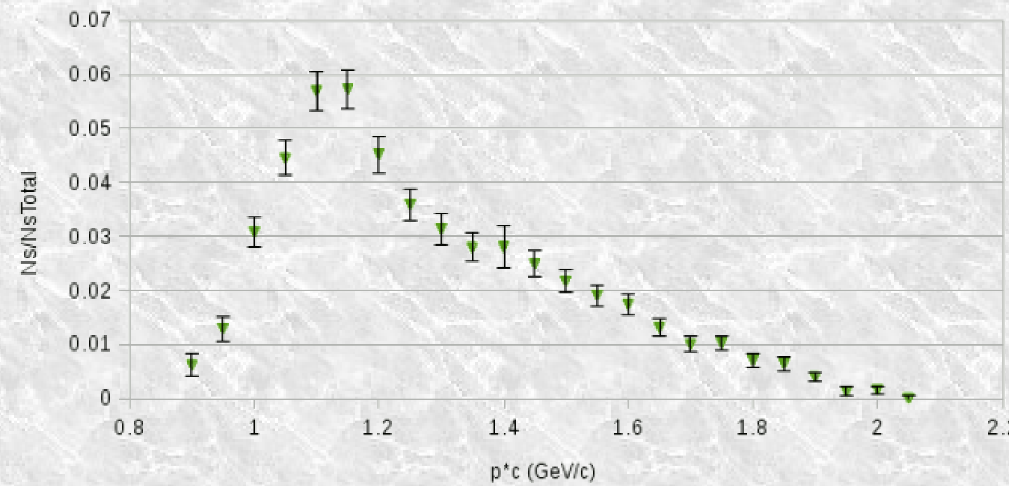


Charm production with tagging

right flavor combination of B_{tag} and D*



wrong flavor combination of B_{tag} and D*



Similar to Babar paper Phys.Rev.D75:072002,2007 (based only on 230 milion BB pairs) on production of D,Ds,Λc but they used momentum in Bsig frame (employing Btag momentum to reconstruct).
In case if we can use semileptonic tag we can improve significantly the statistic.

Direct Acp with tagging

Note fully explored in B factories :

- inclusive reconstruction
- example $B \to DD_{s(J)}^{(*)}h$ Acp measurement
- need for studding properly charge asymmetry in B_{tag}
- with 15 ab^{-1} we can be well below theory predictions

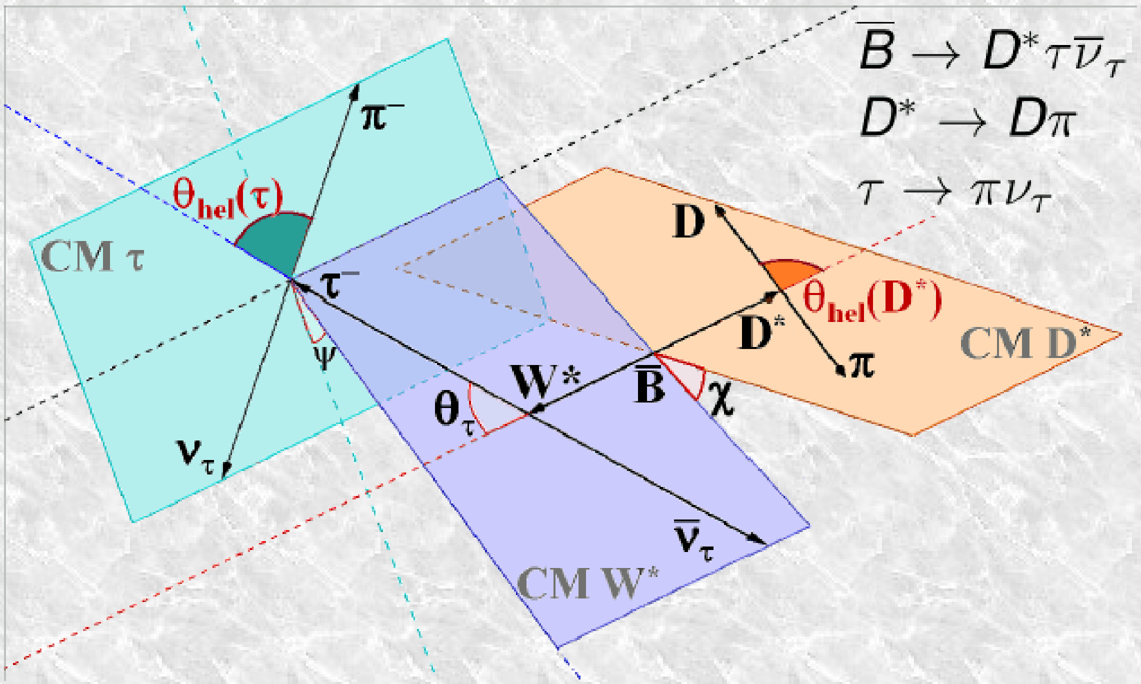
Summary

Additional subjects on top of already explored in Jennifer

- Usage and improvement of tagging techniques
- determination of asymmetry in tagging with high precision
- charm particles production and decays from B (inclusive approach)
- direct Acp with tagging – inclusive reconstruction (?)
- Employing electron and muon excellent reconstruction efficiency
- Bs tagging and inclusive analysis (Y(5s) run before 2022 ?)
-

BACKUP

Kinematic variables describing $B \to D^*\tau\nu$



$\overline{B} \to D^*\tau\overline{\nu}_\tau$
$D^* \to D\pi$
$\tau \to \pi\nu_\tau$

$q^2 \equiv M_W^2$ - effective mass squared of the $\tau\nu$ system
θ_τ - angle between τ&B in W^* rest frame
χ - angle between the $\tau\nu$ and D^* decay planes

$\theta_{\rm hel}(D^*)$ - angle between D&B in D^* rest frame
$\theta_{\rm hel}(\tau)$ - angle between π& direction opposite to W^* in τ rest frame

$$\frac{d\Gamma}{d\cos\theta_{hel}(\tau)} = \frac{1}{2}(1 + \alpha P_\tau \cos\theta_{hel}(\tau))$$

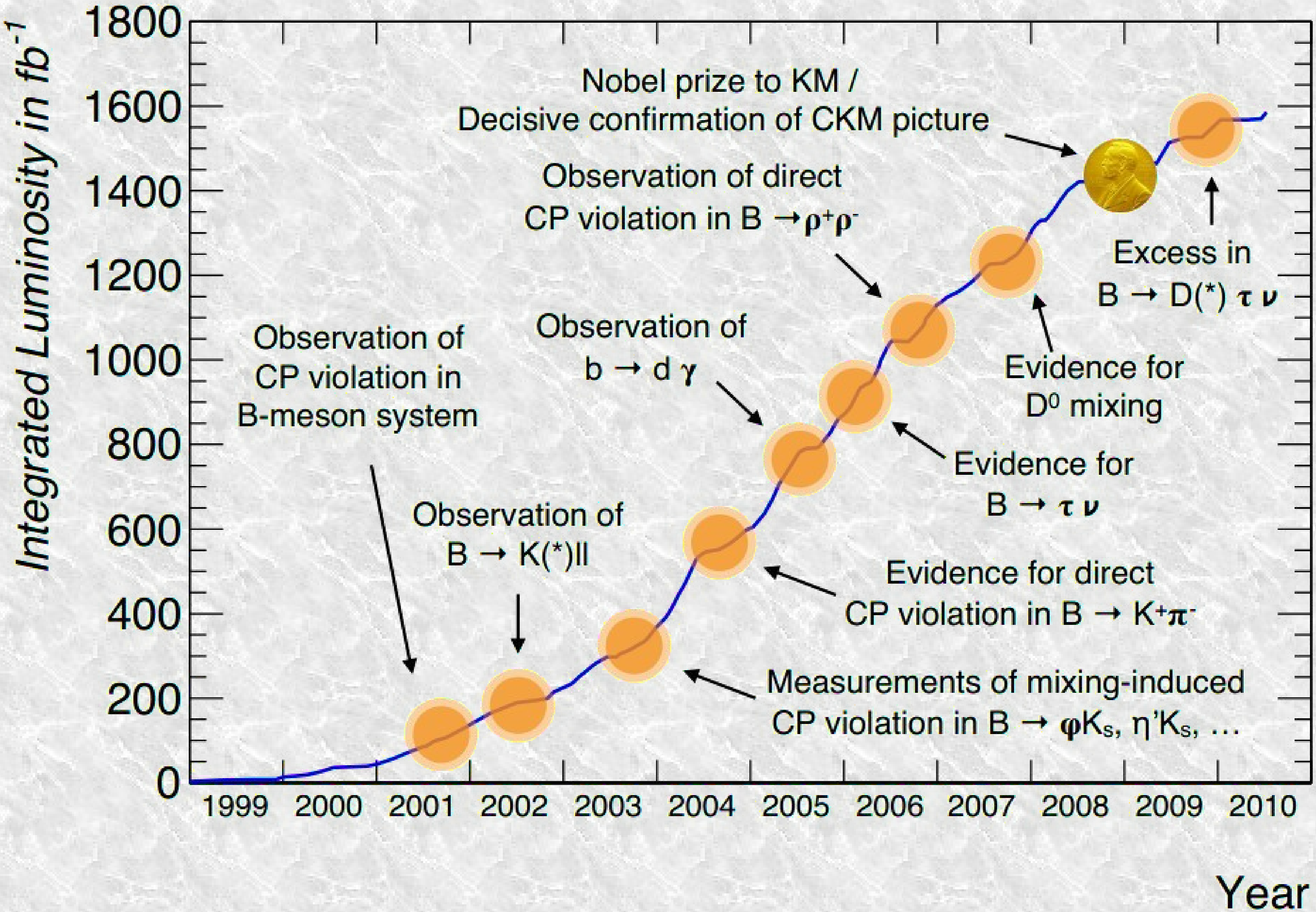
$\alpha = 1.0$ for $\tau \to \pi\nu$; $\alpha = 0.45$ for $\tau \to \rho\nu$

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

M_W^2, M_M^2 and $\cos\theta_{\rm hel}(\tau)$, $\cos\theta_{\rm hel}(D^*)$ can be reconstructed at B-factories with hadronic decays of $B_{\rm tag}$

B Factories achievements

The previous generation of B factories achieved a great success in B (charm, τ) physics studies and explored possible new physics



	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$ [64]	0.012	0.008
	α [°]	85 ± 4 (Belle+BaBar) [24]	2	1
	γ [°]	68 ± 14 [13]	6	1.5
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$ [19]	0.053	0.018
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$ [65]	0.028	0.011
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$ [17]	0.100	0.033
	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$ [66]	0.07	0.04
UT sides	$\lvert V_{cb}\rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 1.8\%)$ [8]	1.2%	
	$\lvert V_{cb}\rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\rm ex.} \pm 2.7\%_{\rm th.})$ [10]	1.8%	1.4%
	$\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\rm ex.} \pm 2.5\%_{\rm th.})$ [5]	3.4%	3.0%
	$\lvert V_{ub}\rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 8.2\%)$ [7]	4.7%	2.4%
Missing E decays	$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	$96(1 \pm 27\%)$ [26]	10%	5%
	$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7 [67]	20%	7%
	$R(B \to D\tau\nu)$	$0.440(1 \pm 16.5\%)$ [29]†	5.6%	3.4%
	$R(B \to D^*\tau\nu)^\dagger$	$0.332(1 \pm 9.0\%)$ [29]†	3.2%	2.1%
	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ [10^{-6}]	< 40 [30]	< 15	30%
	$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$ [10^{-6}]	< 55 [30]	< 21	30%
Rad. & EW penguins	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%
	$A_{CP}(B \to X_{s,d}\gamma)$ [10^{-2}]	$2.2 \pm 4.0 \pm 0.8$ [68]	1	0.5
	$S(B \to K^0_S \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$ [20]	0.11	0.035
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$ [21]	0.23	0.07
	C_7/C_9 $(B \to X_s \ell\ell)$	~20% [36]	10%	5%
	$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7 [42]	0.3	–
	$\mathcal{B}(B_s \to \tau\tau)$ [10^{-3}]	–	< 2 [44]‡	–