Physics at Belle II

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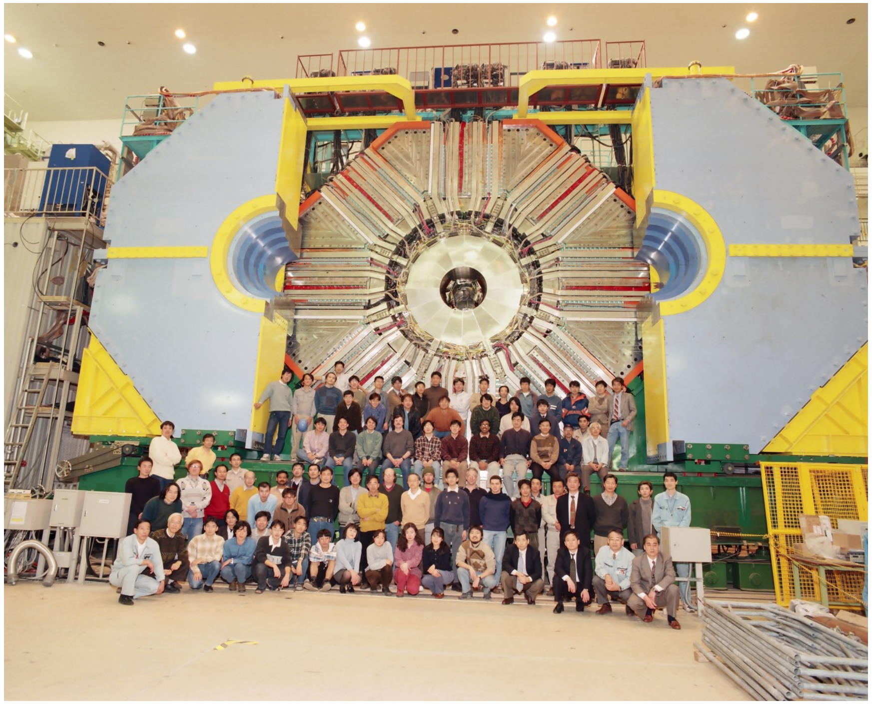
LAL Orsay, March 22nd 2017

De plus Belle...
(more than ever, with renewed vigor)

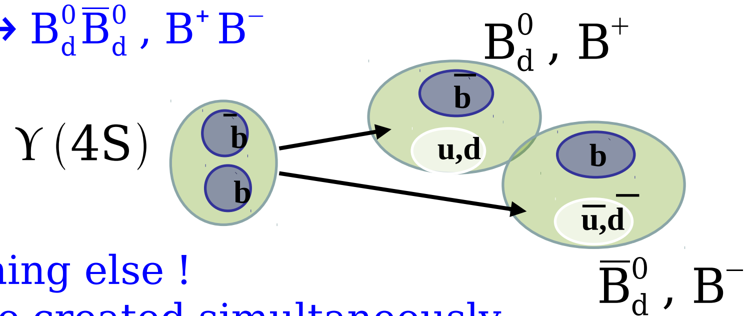


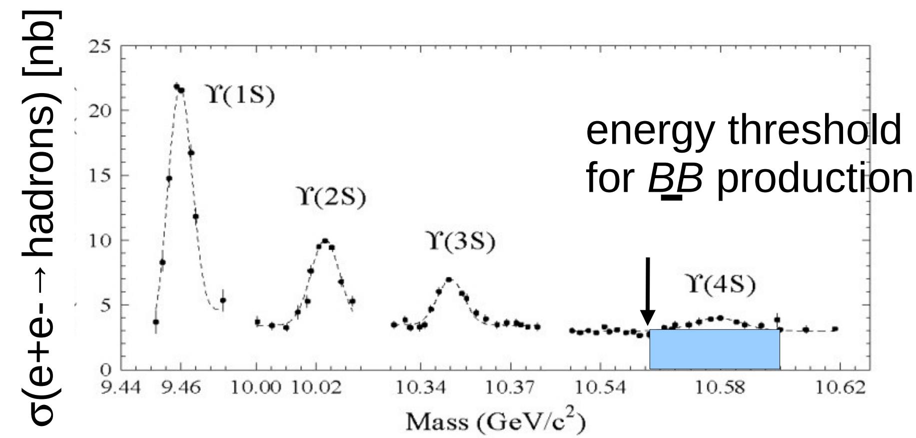
Belle II, a flavour-factory, a rich physics program ...

- We plan to collect 50 ab^{-1} of e^+e^- collisions at (or close to) the $\Upsilon(4S)$ resonance, so that we have:

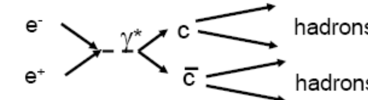
  - **a (Super) B-factory ($\sim 1.1\times 10^9$ $B\bar{B}$ pairs per ab^{-1})**

"on resonance" production
$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B_d^0\bar{B}_d^0,\ B^+B^-$



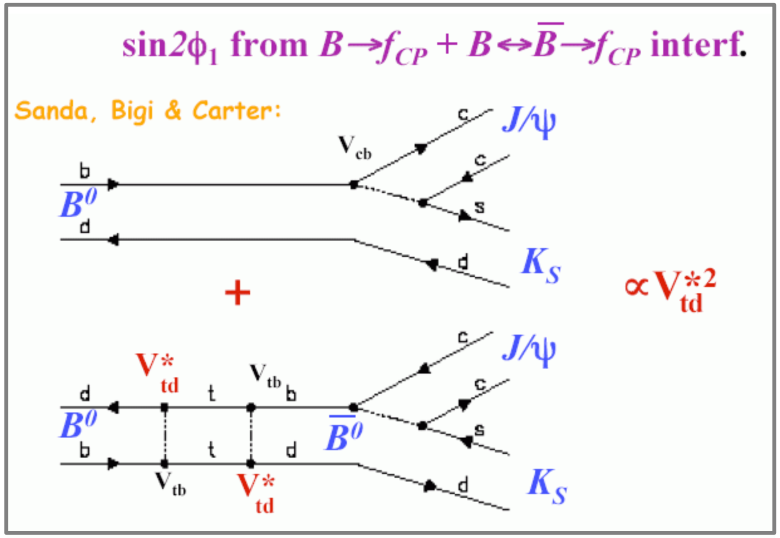


- 2 B's and nothing else !
- 2 B mesons are created simultaneously in a L=1 coherent state

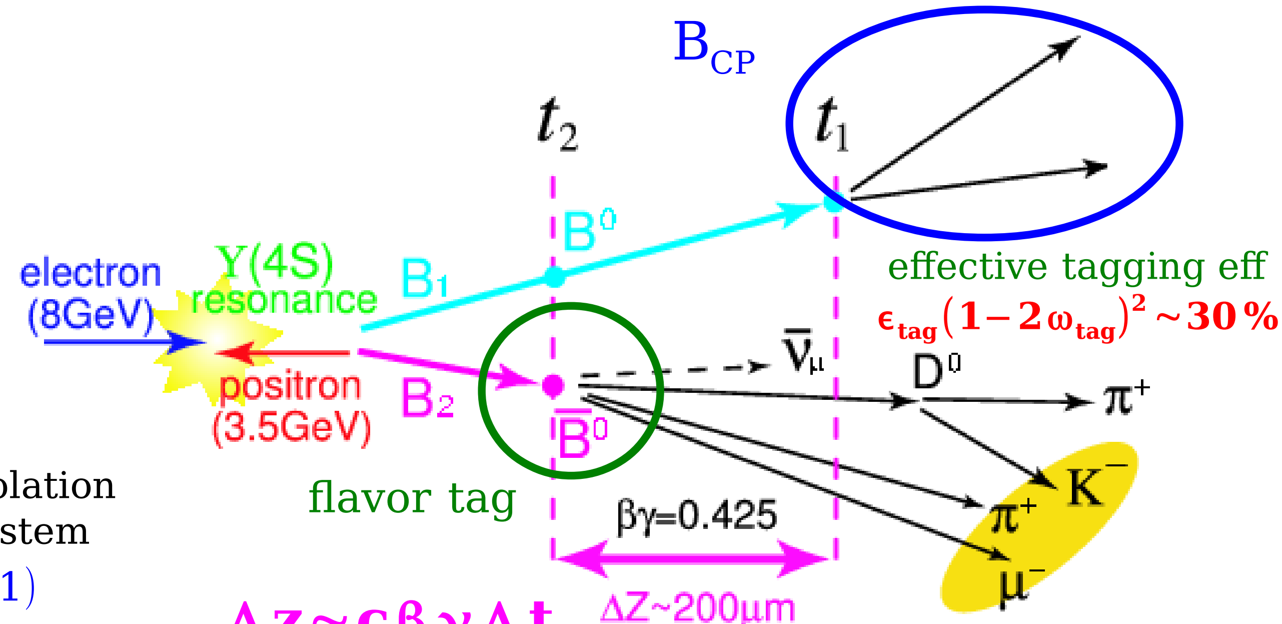


  - **a (Super) charm factory ($\sim 1.3\times 10^9$ $c\bar{c}$ pairs per ab^{-1})**
  - **a (Super) τ factory ($\sim 1.3\times 10^9$ $\tau^+\tau^-$ pairs per ab^{-1})**
  - with Initial State Radiation, effectively scan the range [0.5 – 10] GeV and measure the $e^+e^-\rightarrow$ light hadrons cross section very precisely
  - exploit the clean e^+e^- environment to probe the existence of exotic hadrons, dark photons/Higgs, light Dark Matter particles, ...

Time−dependent CP asymmetries in decays to CP eigenstates



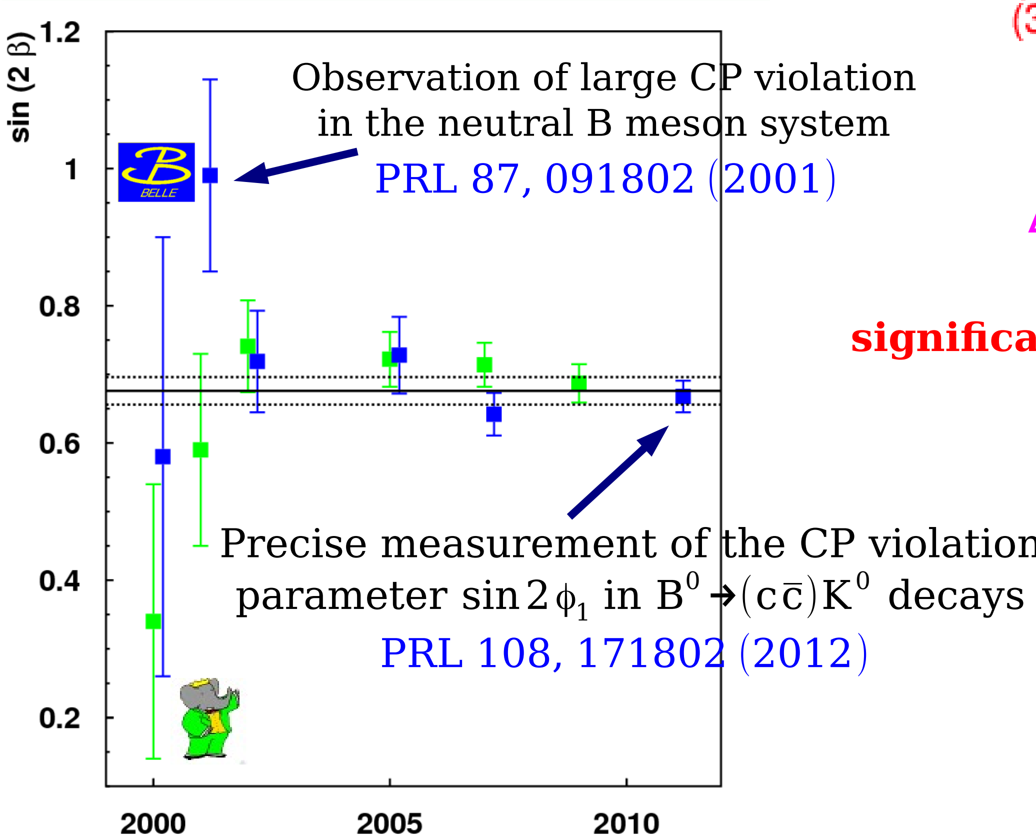
$$\frac{dP_{sig}}{dt}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}\left(1 + q\left(S \sin(\Delta m_d \Delta t) + A \cos(\Delta m_d \Delta t)\right)\right)$$



$\epsilon_{tag}(1-2\omega_{tag})^2 \sim 30\%$

$\Delta z \sim c\beta\gamma\Delta t$

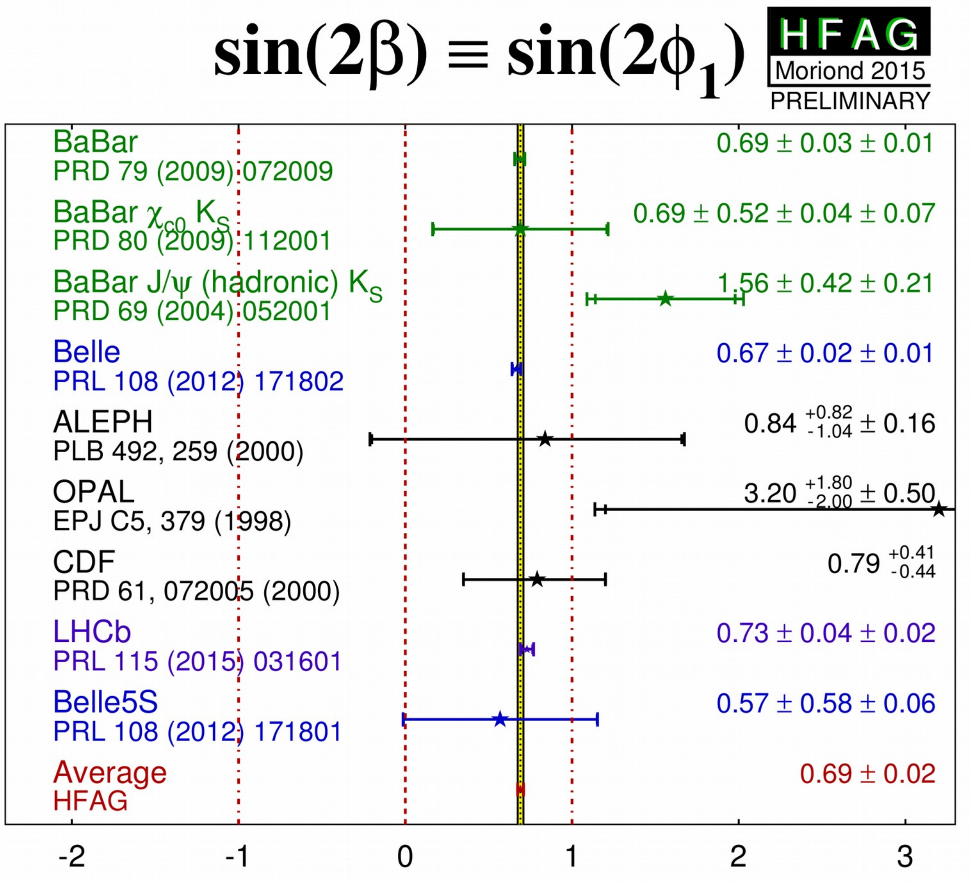
Raison d'être of SVD+PXD
significant resolution improvement for Belle II

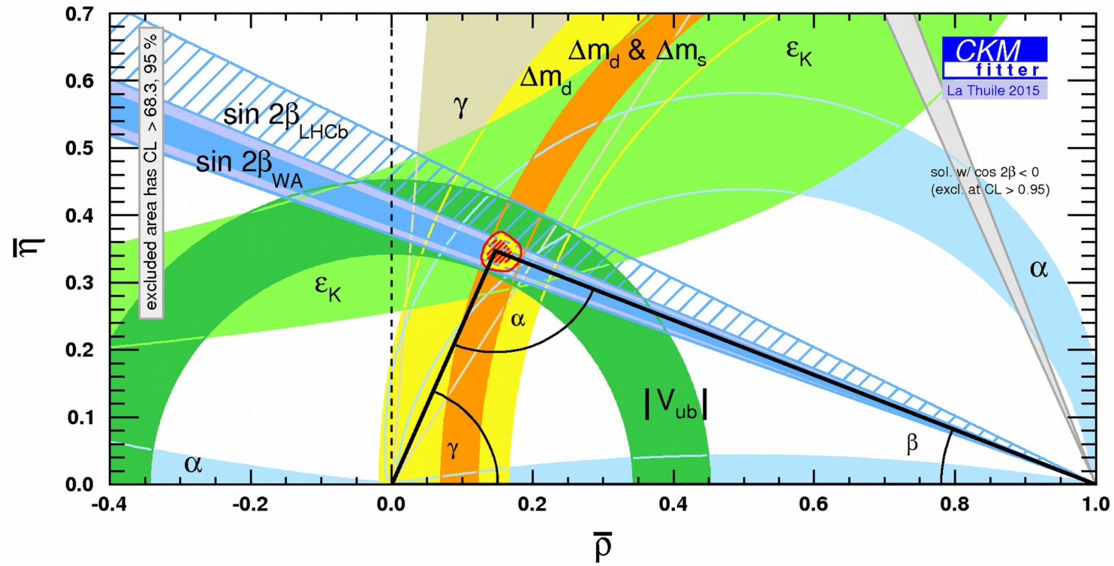


A single irreducible phase in the weak interaction matrix accounts for most of the CPV observed in kaons and B's

Critical role of the B factories in the verification of the KM hypothesis

Measurement of $\sin 2\beta$





WA 2016: $\beta = (21.9 \pm 0.7)^\circ$

$\sin 2\beta$ at Belle II

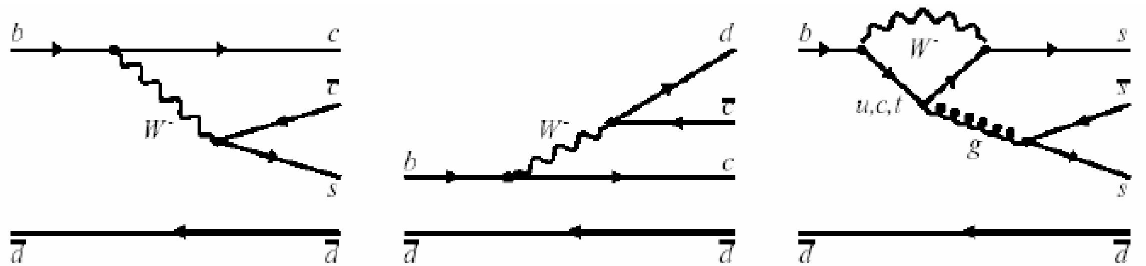
	Belle	Belle II (50 ab^{-1})
S	0.667 ± 0.023 ± 0.012	x.xxxx ± 0.0027 ± 0.0044
A	0.006 ± 0.016 ± 0.012	x.xxxx ± 0.0033 ± 0.0037

anchor of SM

dominated by systematic uncertainties

sin 2β with b→s penguins

dominated by B-factories



$J/\psi K^0_S, \psi(2S)K^0_S, \chi_{c1}K^0_S$, $\eta_c K^0_S, J/\psi K^0_L$, $J/\psi K^{*0}(K^{*0}\to K^0_S\pi^0)$

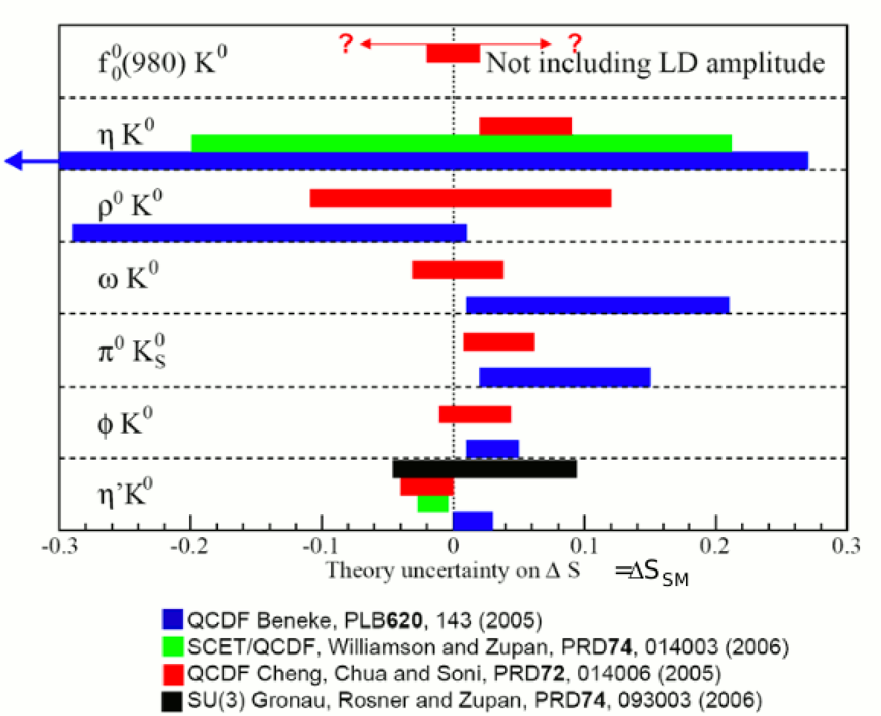
$D^{*+}D^-, D^+D^-$ $J/\psi\pi^0, D^{*+}D^{*-}$

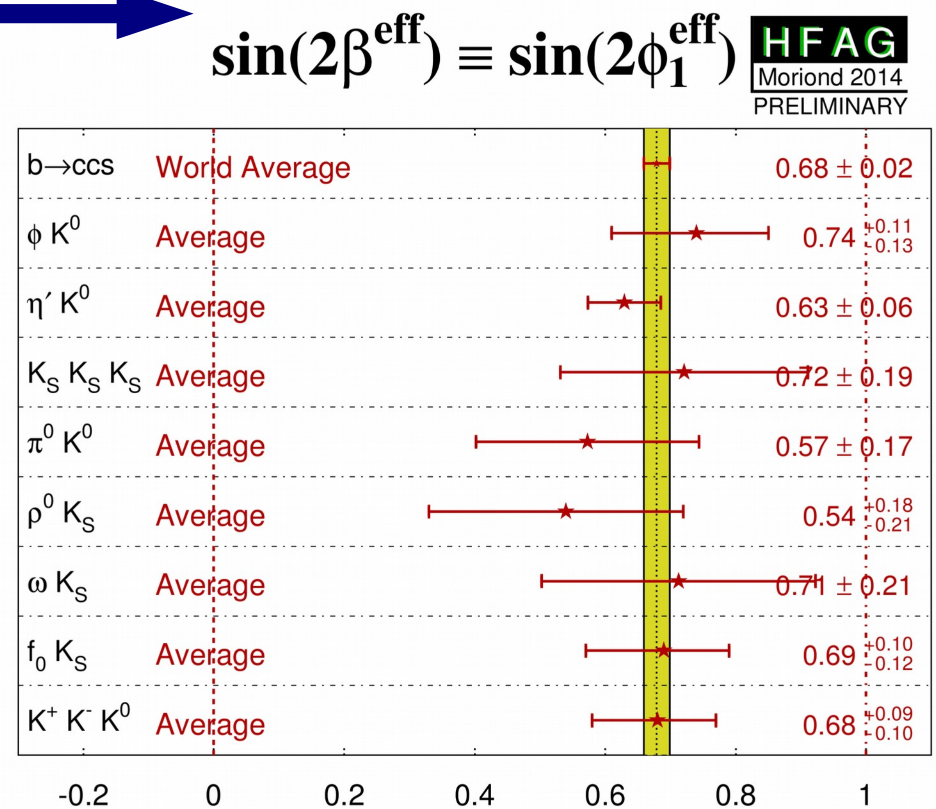
$\phi K^0, K^+K^-K^0_S$, $K^0_S K^0_S K^0_S, \eta' K^0, K^0_S\pi^0$, $\omega K^0_S, f_0(980)K^0_S$

increasing tree diagram amplitude ←

increasing sensitivity to new physics →

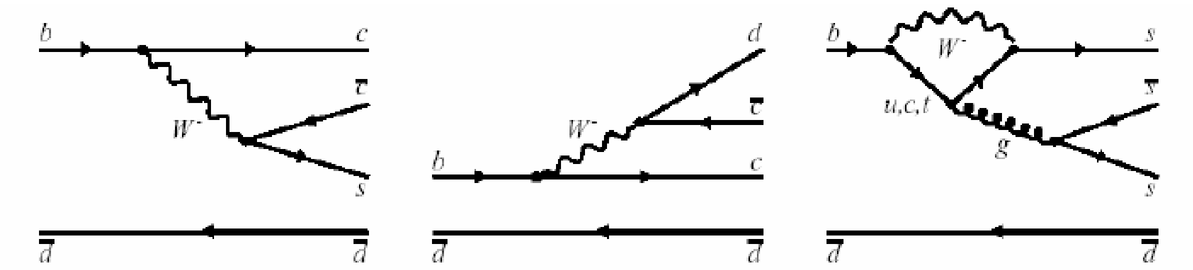
More statistics crucial for mode-by-mode studies





sin 2β with b→s penguins

dominated by B-factories



$J/\psi K_S^0, \psi(2S)K_S^0, \chi_{c1}K_S^0$, $\eta_c K_S^0, J/\psi K_L^0$, $J/\psi K^{*0}(K^{*0} \to K_S^0\pi^0)$

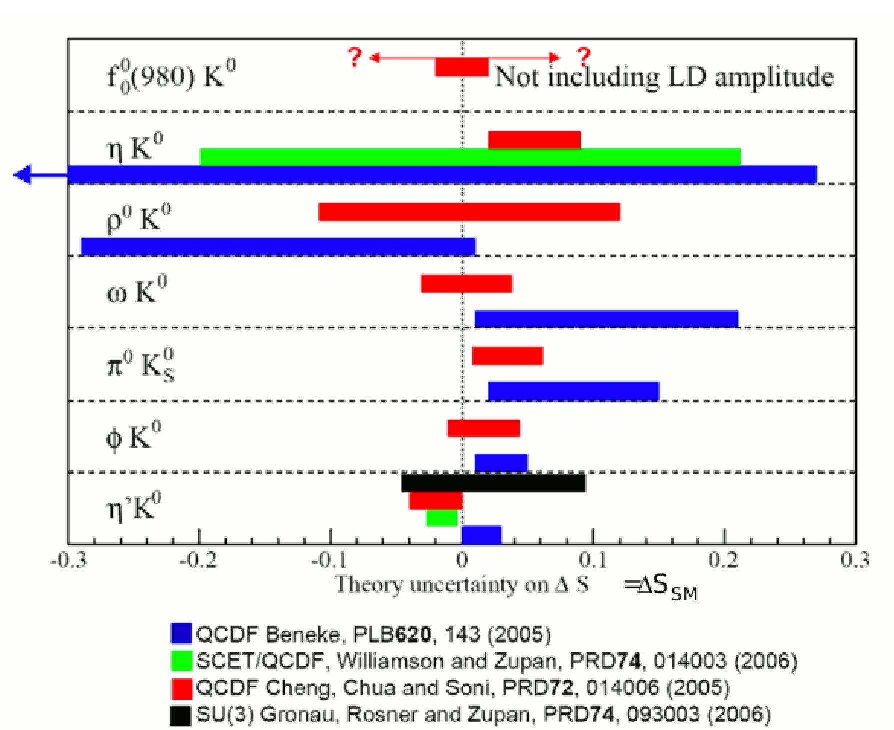
$D^{*+}D^-, D^+D^-$, $J/\psi\pi^0, D^{*+}D^{*-}$

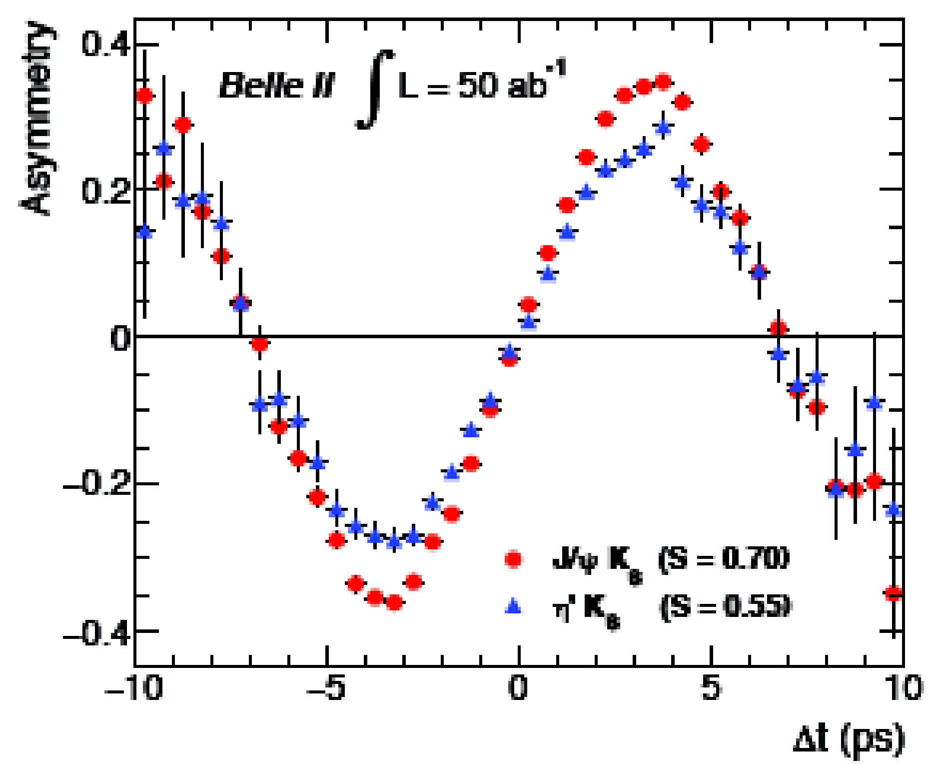
$\phi K^0, K^+K^-K_S^0$, $K_S^0K_S^0K_S^0, \eta' K^0, K_S^0\pi^0$, $\omega K_S^0, f_0(980)K_S^0$

increasing tree diagram amplitude ←

increasing sensitivity to new physics →

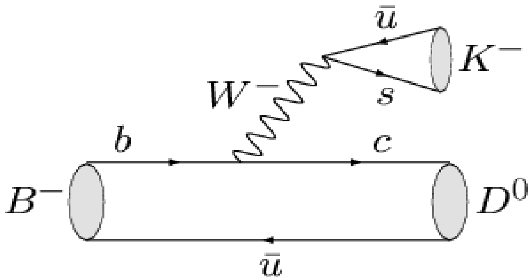
Channel	$\int \mathcal{L}$	Event yield	$\sigma(S)$	$\sigma(A)$
ϕK^0	5 ab^{-1}	5590	0.048	0.035
$\eta' K^0$	5 ab^{-1}	27200	0.027	0.020
ωK_S^0	5 ab^{-1}	1670	0.08	0.06
$K_S\pi^0\gamma$	5 ab^{-1}	1400	0.10	0.12
$K_S\pi^0$	5 ab^{-1}	5699	0.09	0.10





γ measurements from $B^{\pm} \to DK^{\pm}$

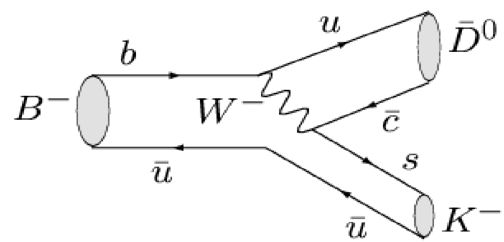
- Theoretically pristine $B \to DK$ approach
- Access γ via interference between $B^- \to D^0 K^-$ and $B^- \to \bar{D}^0 K^-$



color allowed

$B^- \to D^0 K^- \sim V_{cb} V^*_{us}$

$\sim A\lambda^3$



color suppressed

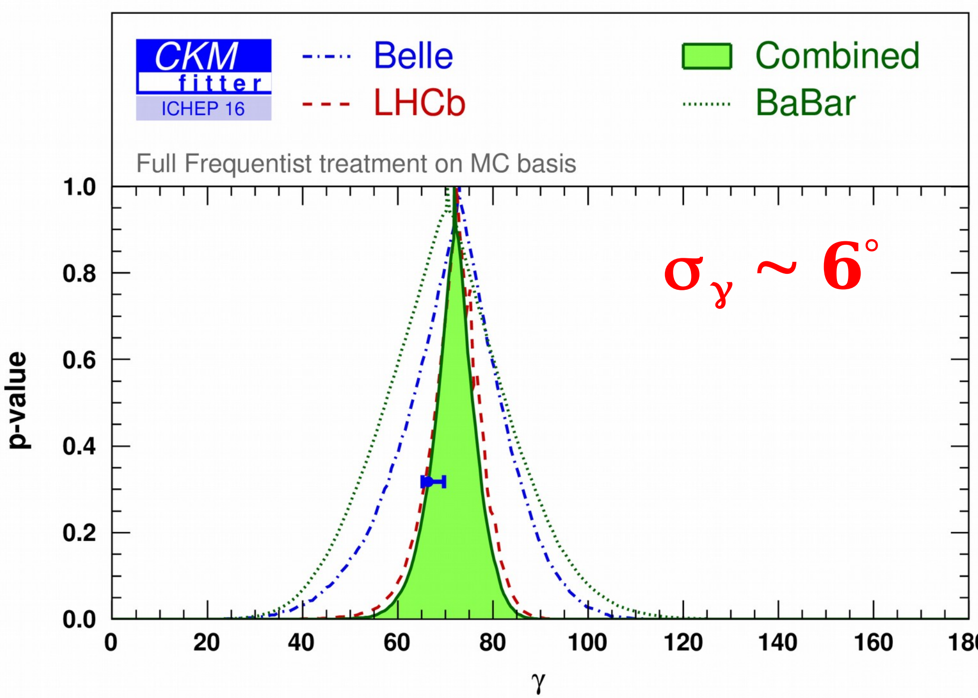
$B^- \to \bar{D}^0 K^- \sim V_{ub} V^*_{cs}$

$\sim A\lambda^3(\rho + i\eta)$

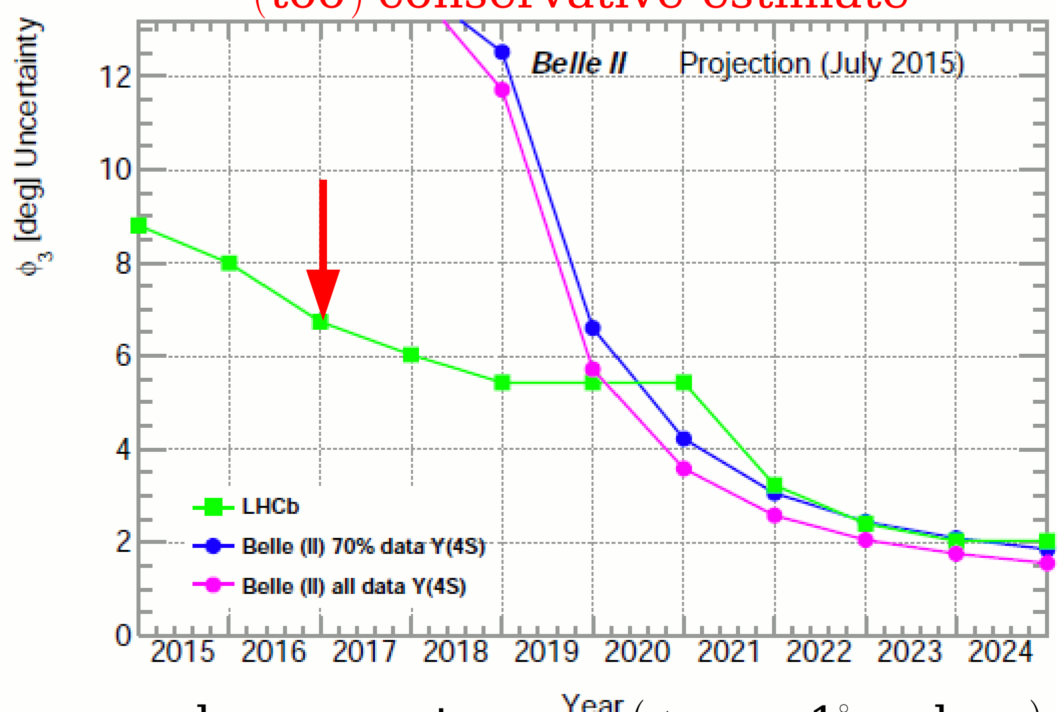
relative weak phase is γ

relative strong phase is δ_B

$r_B \simeq 0.1$



(too) conservative estimate



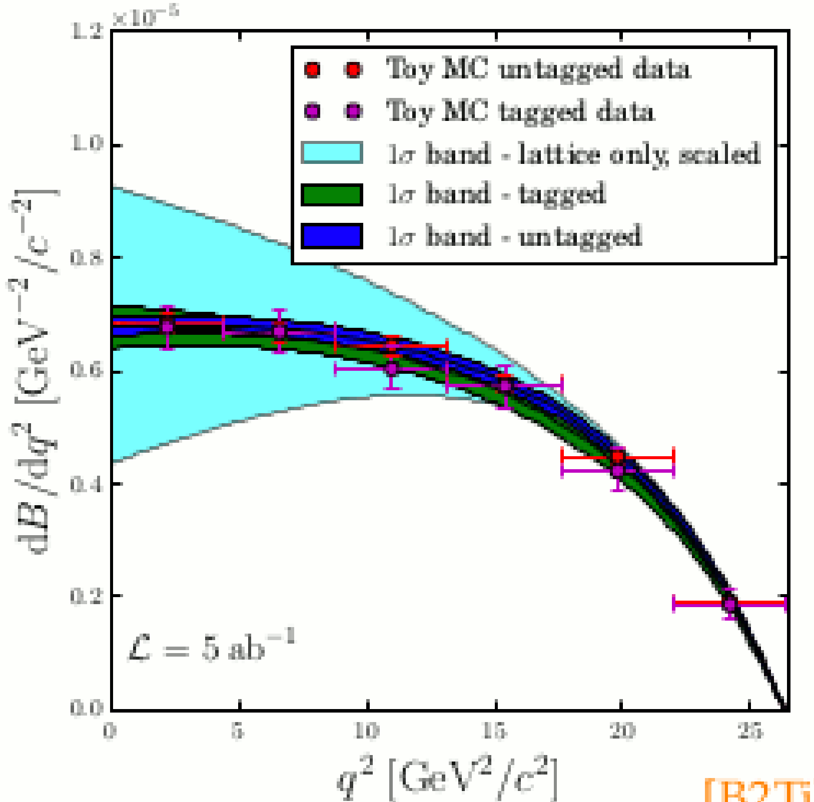
long way to go … ($\to \sigma_\gamma = 1^\circ$ or less)

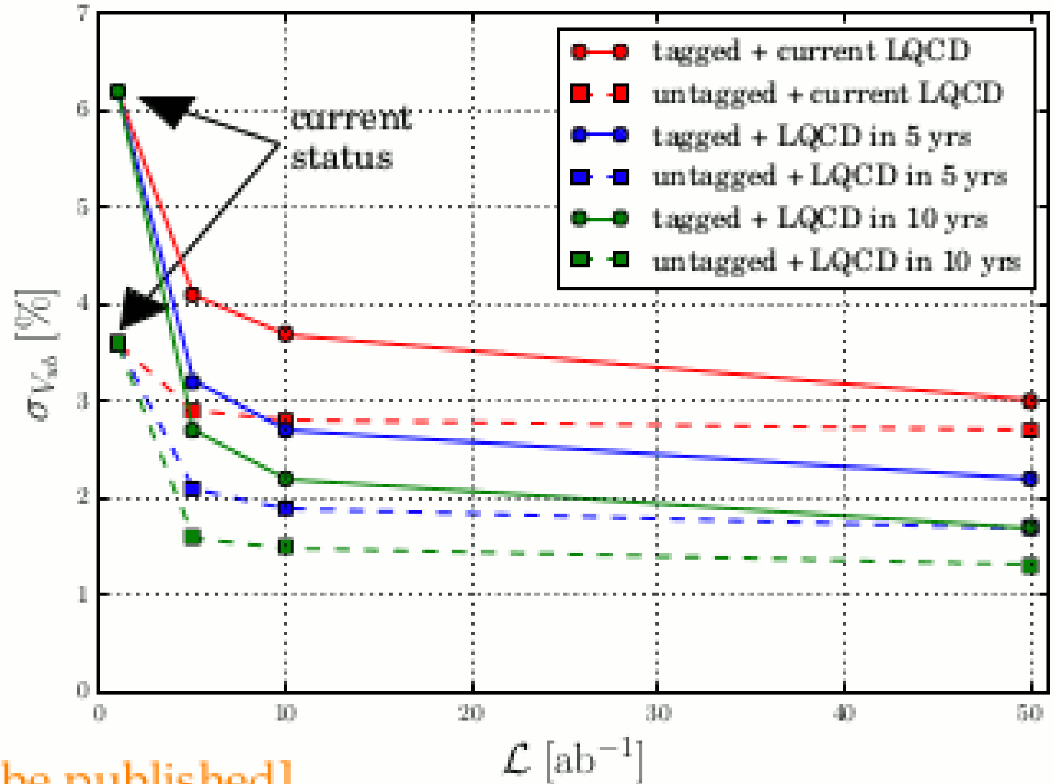
Semileptonic and leptonic

Process	Obser.	Theory	Discovery (ab^{-1})	Sys. limit (ab^{-1})	vs LHCb BESIII	vs Belle	Anomaly	NP
$B \to \pi l \nu_l$	$\|V_{ub}\|$	$\star\star\star$	-	10	$\star\star\star$	$\star\star\star$	$\star\star$	$\star$
$B \to X_u l \nu_l$	$\|V_{ub}\|$	$\star\star$	-	2	$\star\star\star$	$\star\star$	$\star\star\star$	$\star$
$B \to \tau\nu$	$Br.$	$\star\star\star$	2	50	$\star\star\star$	$\star\star\star$	$\star$	$\star\star\star$
$B \to \mu\nu$	$Br.$	$\star\star\star$	5	50	$\star\star\star$	$\star\star\star$	$\star$	$\star\star\star$
$B \to D^{(*)} l \nu_l$	$\|V_{cb}\|$	$\star\star\star$	-	1	$\star\star\star$	$\star$	$\star$	
$B \to X_c l \nu_l$	$\|V_{cb}\|$	$\star\star\star$	-	1	$\star\star$	$\star\star$	$\star\star$	$\star\star$
$B \to D^{(*)} \tau \nu_\tau$	$R(D^{(*)})$	$\star\star\star$	-	5	$\star\star$	$\star\star\star$	$\star\star\star$	$\star\star\star$
$B \to D^{(*)} \tau \nu_\tau$	P_τ	$\star\star\star$	-	15	$\star\star\star$	$\star\star\star$	$\star\star$	$\star\star\star$
$B \to D^{**} l \nu_l$	$\|V_{cb}\|$	$\star$	-	-	$\star\star$	$\star\star\star$	$\star\star$	

$|V_{ub}|$ from $B \to \pi l \nu$ at Belle II

Toy MC studies based on Belle II MC, LQCD forecasts estimated at 5 years (5, 10 ab^{-1}) and 10 years (50 ab^{-1})





[B2TiP, to be published]

$|V_{ub}|^{\pi\ell\nu}$ from simultaneous fit for $\mathcal{L} = 5\ ab^{-1}$, including lattice forecasts and error scaling.

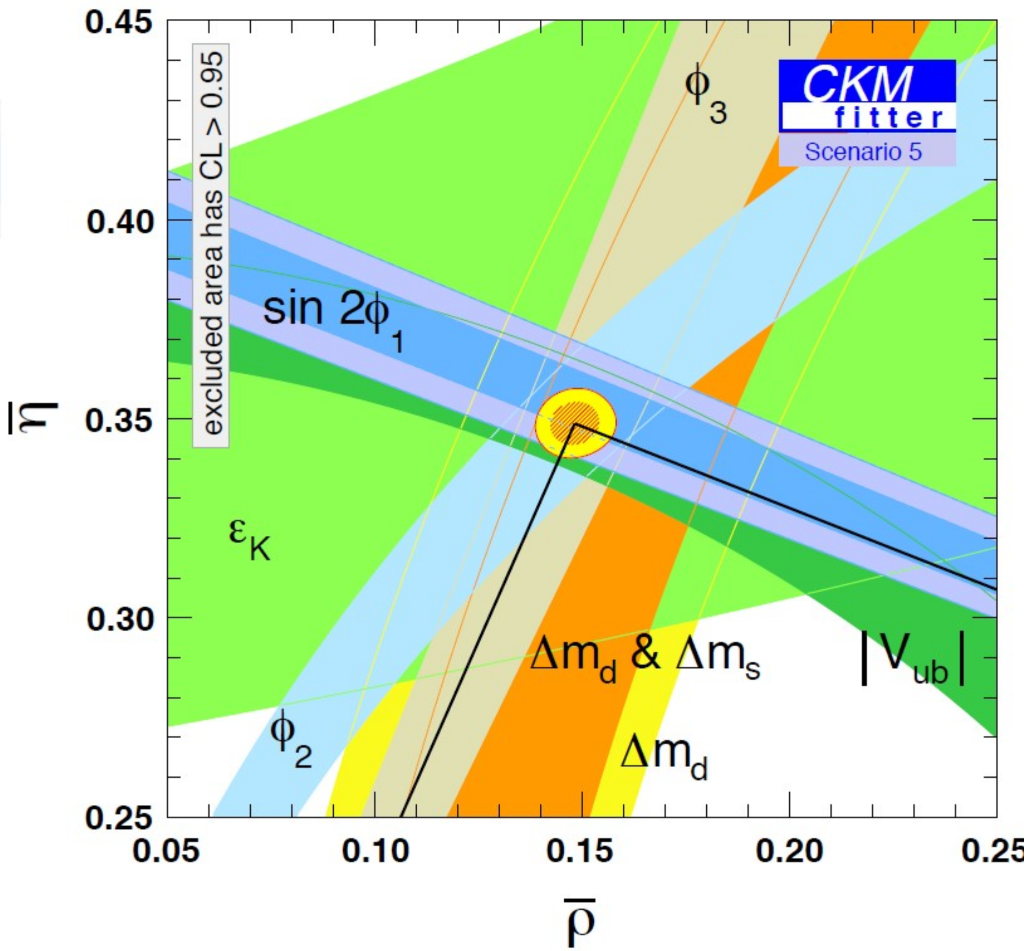
$\delta_{|V_{ub}|^{\pi\ell\nu}}$ estimates for 5, 10 and 50 ab^{-1}:
Tagged: 3.2, 2.7 and 1.7 %
Untagged: 2.1, 1.9 and 1.3 %

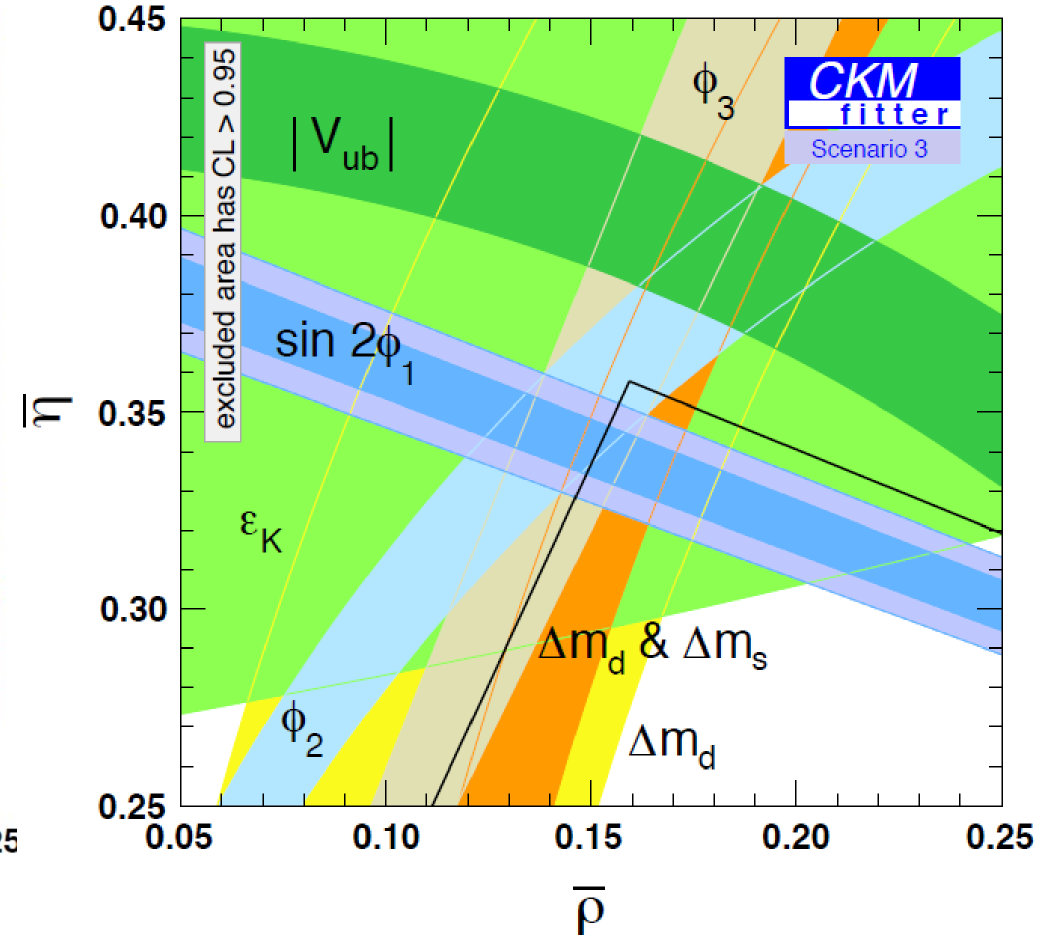
LQCD forecasts: [A. Kronfeld, T. Kaneko, S. Simula]

The Unitarity Triangle in the year 2025

NB: α with couple of degrees @ Belle II

$\Rightarrow$ major updates for $|V_{ub}|$, $\sin 2\beta$, α, γ





Tauonic B decays: $B \to \tau\nu$

$B_{sig} \to \tau\nu$

$\tau \to e\nu\nu,\ \mu\nu\nu,$

$\tau \to \pi\nu,\ \pi\pi^0\nu,\ 3\pi\nu$

(70 % of all τ decays)

B_{tag}

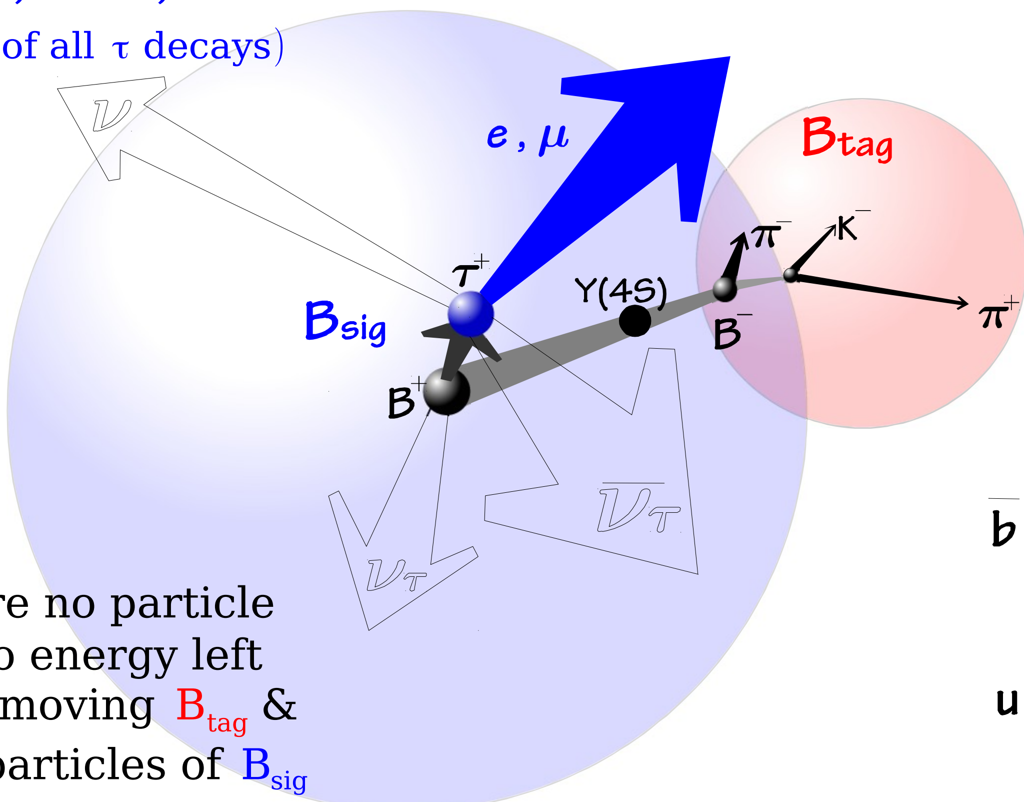
hadronic tag

$B \to D^{(*)}\pi,\ D^{(*)}\rho....$

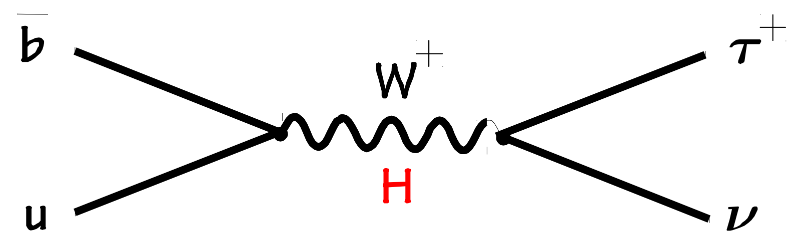
$\epsilon \sim 0.2\,\%$

semileptonic tag

$B \to D^{(*)} l \nu X$



Require no particle and no energy left after removing B_{tag} & visible particles of B_{sig}

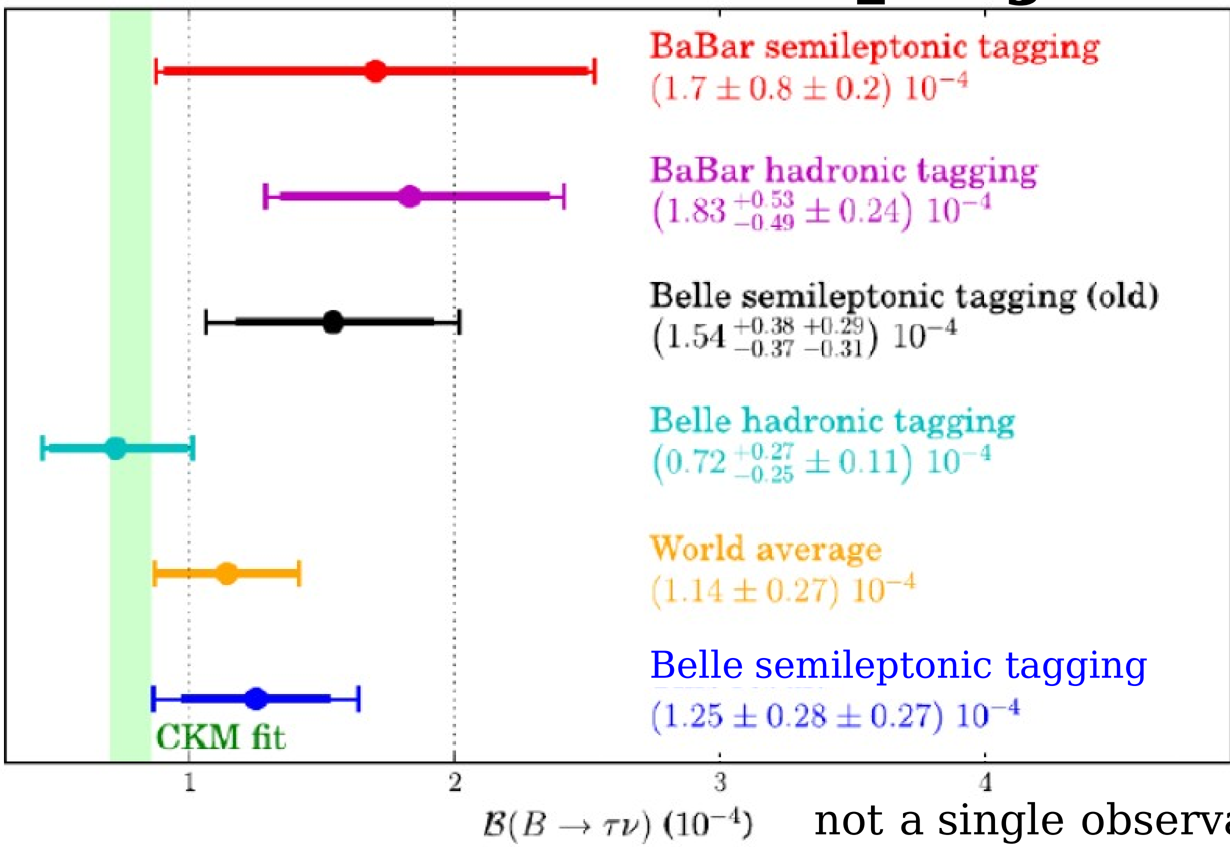


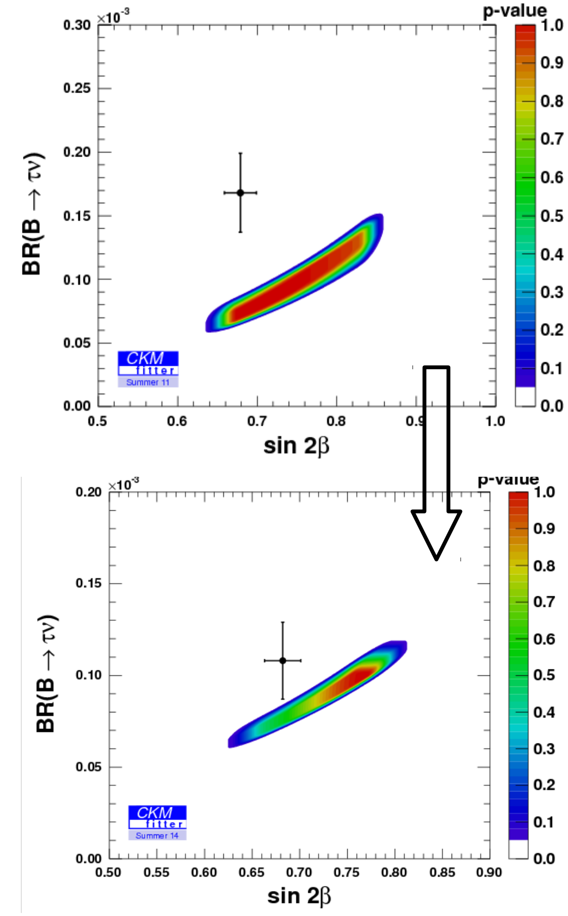
$$2\,\mathrm{HDM}\ (\text{type II}):\ \ \mathcal{B}(B^+ \to \tau^+\nu) = \mathcal{B}_{SM} \times \left(1 - \frac{m_B^2}{m_{H^+}^2}\tan^2\beta\right)^2$$

$$\mathcal{B}_{SM}(B^+ \to \tau^+\nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right) f_B^2 |V_{ub}|^2\ \tau_B$$

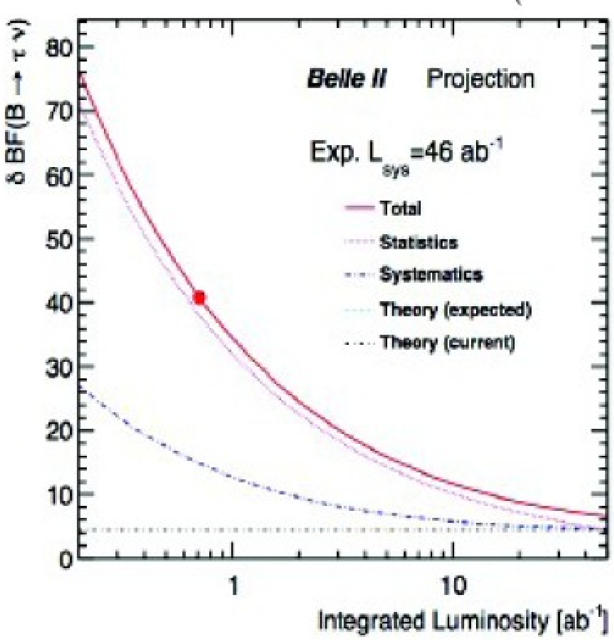
uncertainties from f_B and $|V_{ub}|$ can be reduced to B_B and other CKM uncertainties by combining with precise Δm_d

B→τν status and projections





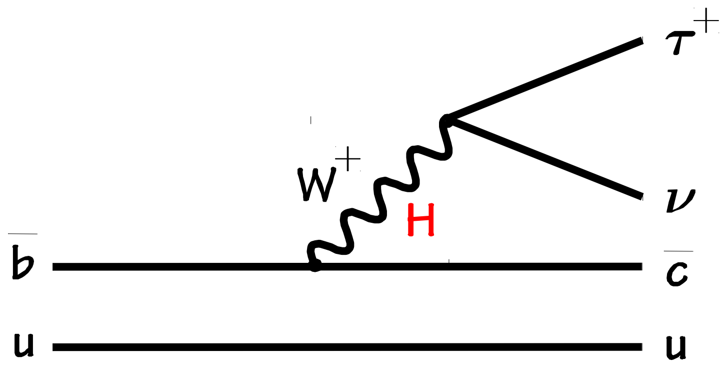
not a single observation ! !



Belle II	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (had. tagged)					
711 fb^{-1}	19.0	(7.1, 2.2)	20.4	2.5	20.5
5 ab^{-1}	7.2	(2.7, 2.2)	7.9	1.5	8.1
50 ab^{-1}	2.3	(0.8, 2.2)	3.2	1.0	3.4
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (SL tagged)					
605 fb^{-1}	12.4	$(9.0,\ ^{+3.0}_{-4.8})$	$^{+15.6}_{-16.1}$	2.5	$^{+15.8}_{-16.2}$
5 ab^{-1}	4.3	$(3.1,\ ^{+3.0}_{-4.8})$	$^{+6.1}_{-7.2}$	1.5	$^{+6.3}_{-7.3}$
50 ab^{-1}	1.4	$(1.0,\ ^{+3.0}_{-4.8})$	$^{+3.4}_{-5.1}$	1.0	$^{+3.6}_{-5.2}$

observation of B→μν is also expected

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



$$R(D^{(*)}) = \frac{BF(B \to D^{(*)} \tau \nu_\tau)}{BF(B \to D^{(*)} l \nu_l)}$$

BaBar

$R(D) = 0.440 \pm 0.058 \pm 0.042$
$R(D^*) = 0.332 \pm 0.024 \pm 0.018$

Belle

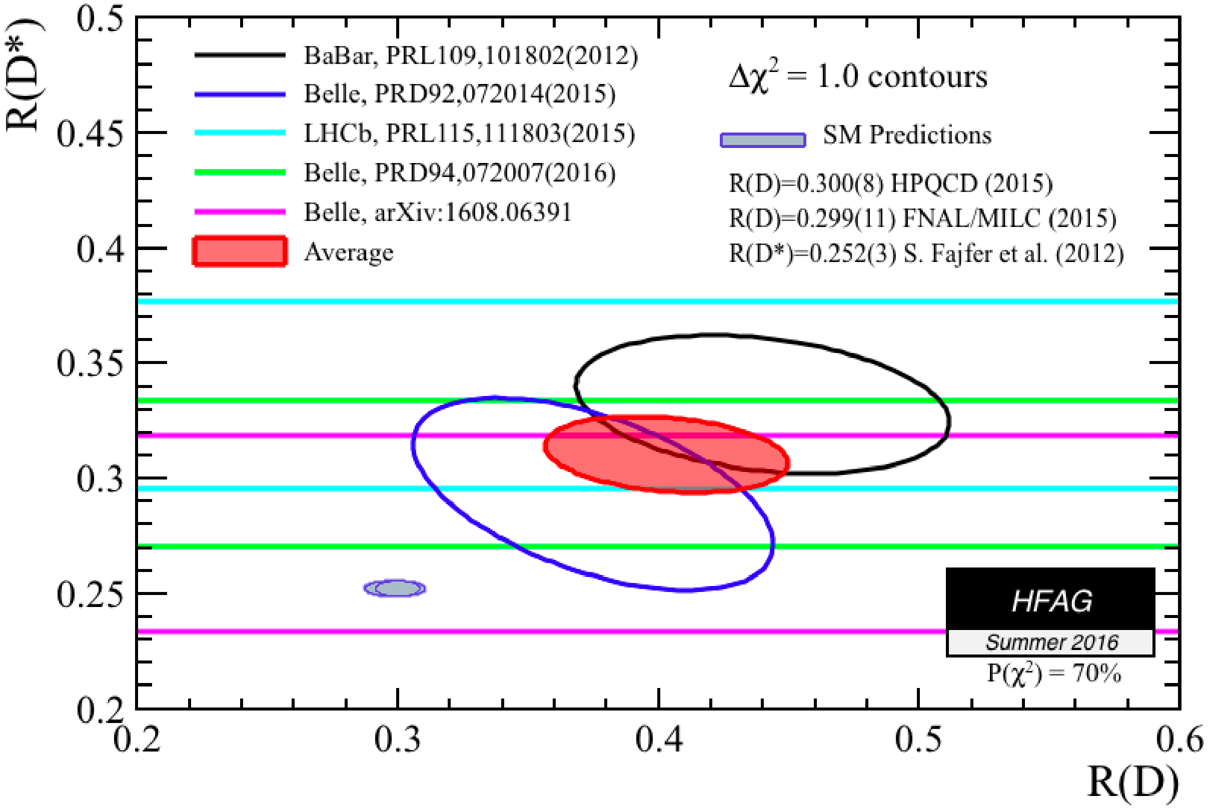
$R(D) = 0.375 \pm 0.064 \pm 0.026$
$R(D^*) = 0.293 \pm 0.038 \pm 0.015$

$R(D^*) = 0.302 \pm 0.030 \pm 0.011$

$R(D^*) = 0.276 \pm 0.034 \, ^{+0.029}_{-0.026}$

LHCb

$R(D^*) = 0.336 \pm 0.027 \pm 0.030$



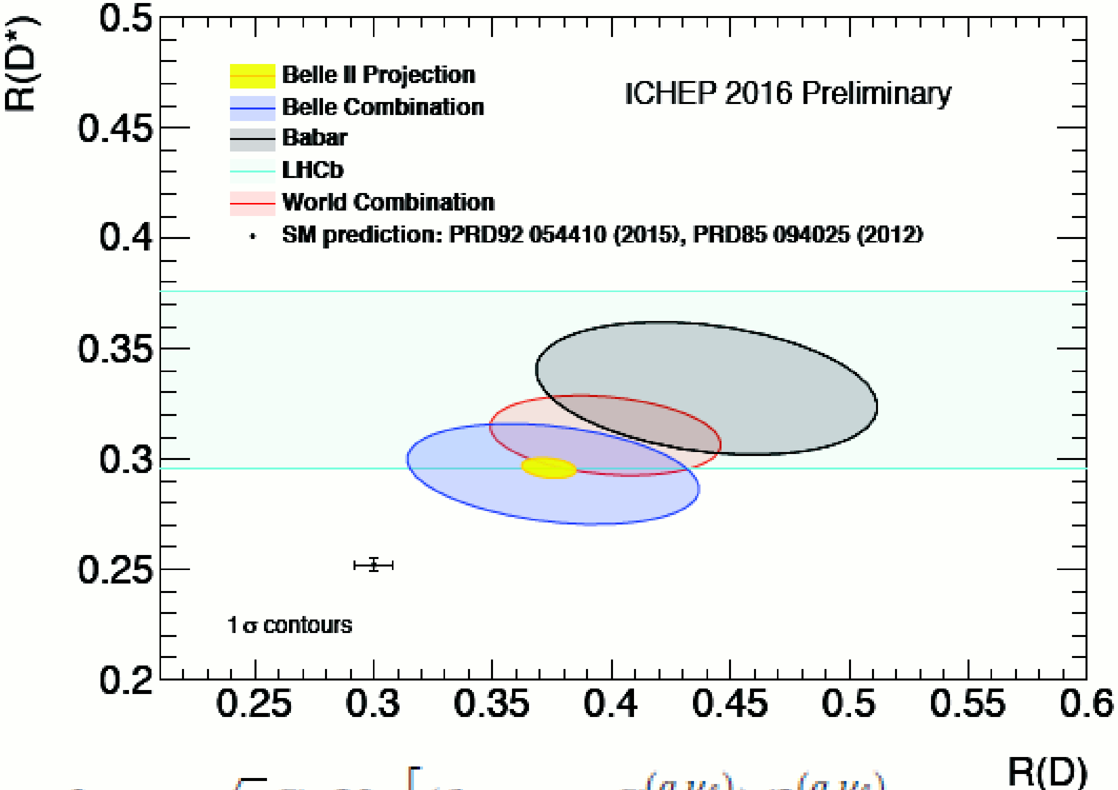
average

$R(D) = 0.403 \pm 0.040 \pm 0.024$
$R(D^*) = 0.310 \pm 0.015 \pm 0.008$

difference with SM predictions is at **3.9** σ level

$\Rightarrow$ more precise measurements needed, more observables (τ polarization ...)

$B \to D^{(*)} \tau \nu$ and other observables

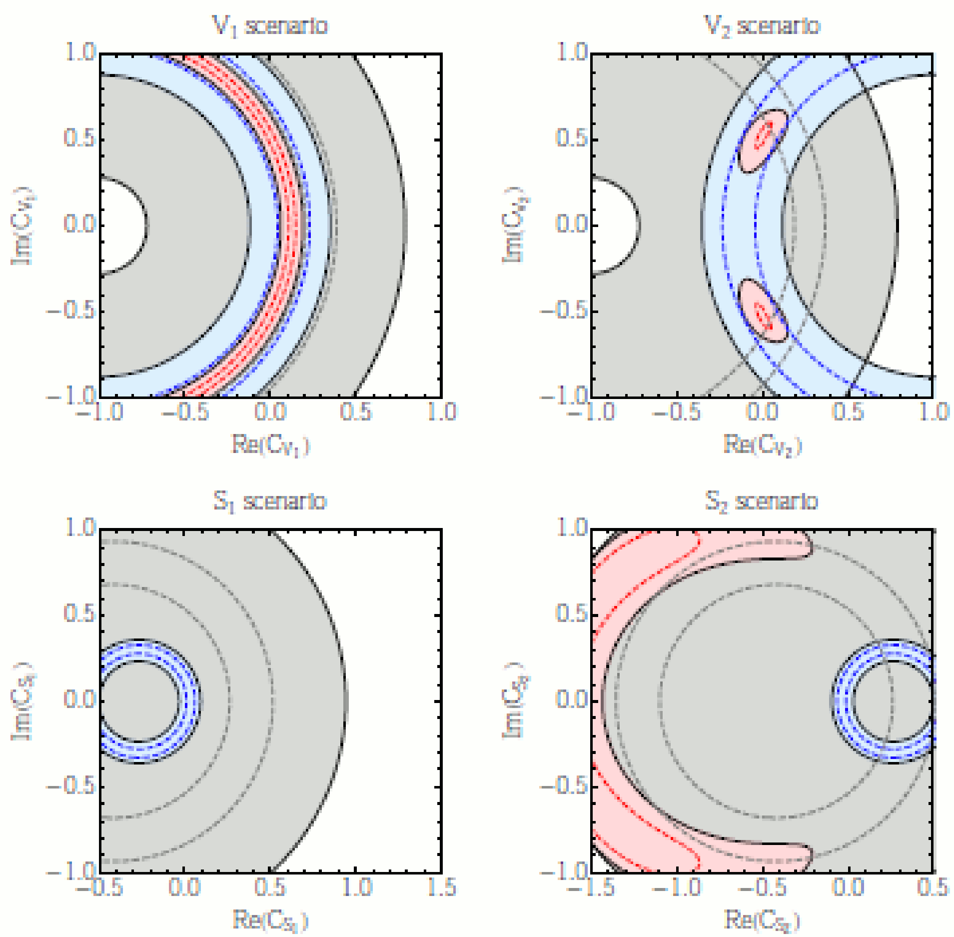


$$R(D^{(*)}) = \frac{B(B \to D^{(*)} \tau \nu)}{B(B \to D^{(*)} l \nu)}, \text{ in red}$$

$$R_{ps} = \frac{\tau_{B^0}}{\tau_{B^-}} \frac{B(B \to \tau^- \nu)}{B(B \to \pi^+ l^- \nu)}, \text{ in blue}$$

$$R(\pi) = \frac{B(B \to \pi \tau \nu)}{B(B \to \pi l \nu)}, \text{ in grey}$$

Dashed: Belle II

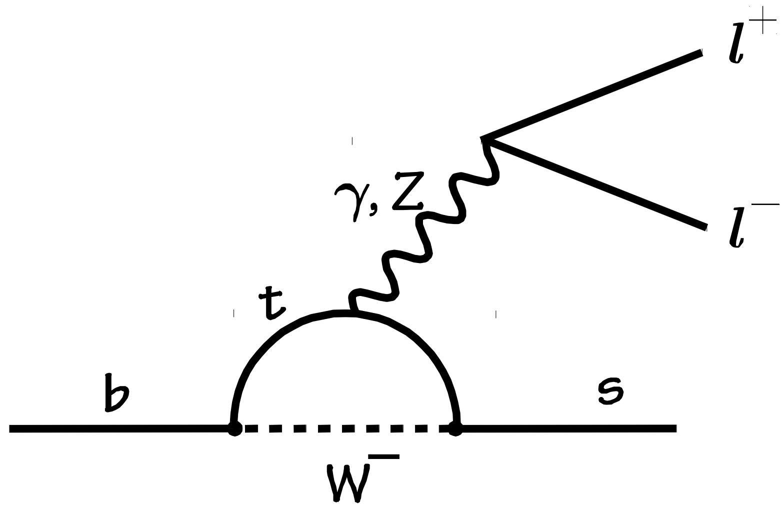


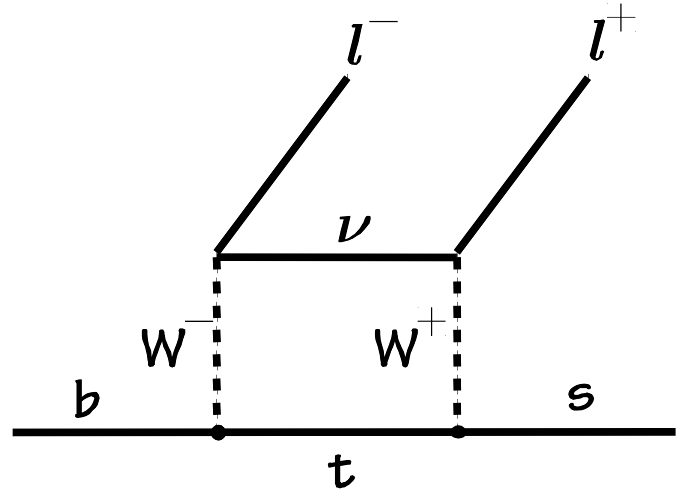
$$-\mathcal{L}_{\rm eff} = 2\sqrt{2} G_F V_{qb} \Big[(\delta_{\nu_\tau,\nu_\ell} + C_{V_1}^{(q,\nu_\ell)}) \mathcal{O}_{V_1}^{(q,\nu_\ell)} + \sum_{X=}^{V_2,S_1,S_2,T} C_X^{(q,\nu_\ell)} \mathcal{O}_X^{(q,\nu_\ell)} \Big],$$

where the four-Fermi operators:

$$\mathcal{O}_{V_1}^{(q,\nu_\ell)} = (\bar{q}\gamma^\mu P_L b)(\bar{\tau}\gamma_\mu P_L \nu_\ell),$$
$$\mathcal{O}_{V_2}^{(q,\nu_\ell)} = (\bar{q}\gamma^\mu P_R b)(\bar{\tau}\gamma_\mu P_L \nu_\ell),$$
$$\mathcal{O}_{S_1}^{(q,\nu_\ell)} = (\bar{q} P_R b)(\bar{\tau} P_L \nu_\ell),$$
$$\mathcal{O}_{S_2}^{(q,\nu_\ell)} = (\bar{q} P_L b)(\bar{\tau} P_L \nu_\ell),$$
$$\mathcal{O}_{T}^{(q,\nu_\ell)} = (\bar{q}\sigma^{\mu\nu} P_L b)(\bar{\tau}\sigma_{\mu\nu} P_L \nu_\ell)$$

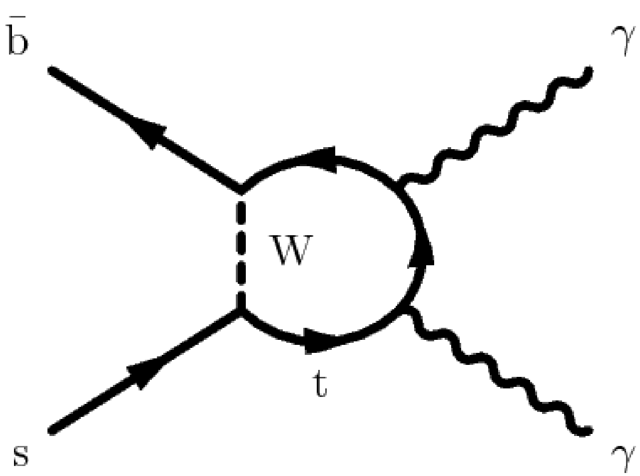
[Details in Watanabe et al, B2TiP theory]

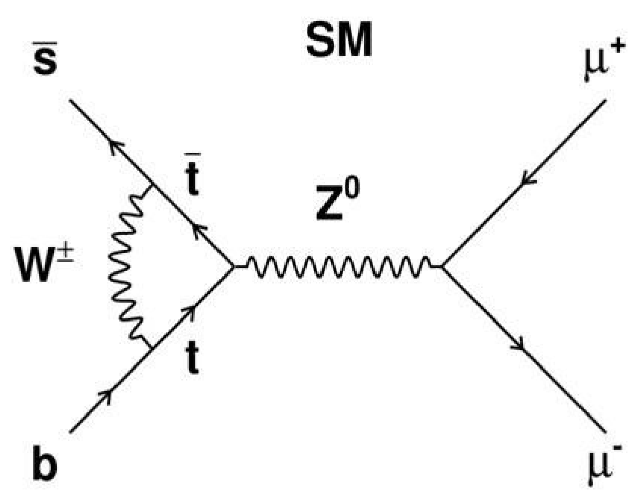




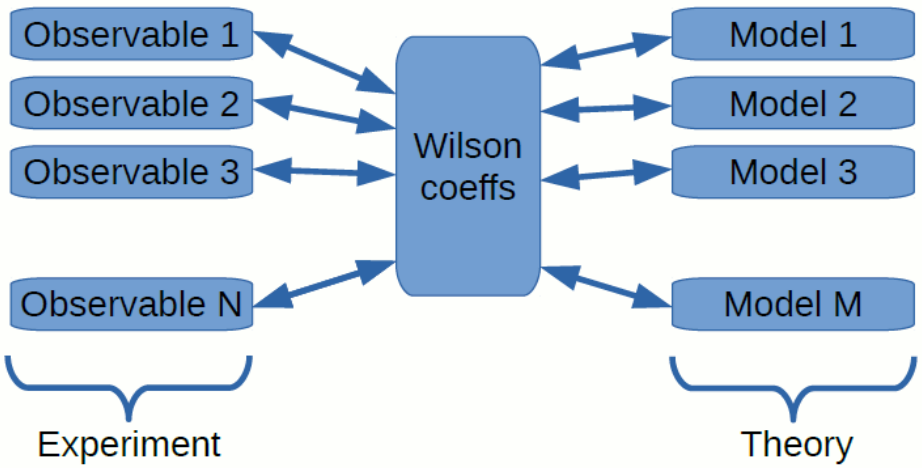
Rare $B_{(s)}$ decays

- FCNC are strongly suppressed in the SM: only loops + GIM mechanism
- Any new particle generating new diagrams can change the amplitudes





Sensitivity to new physics in rare B decays



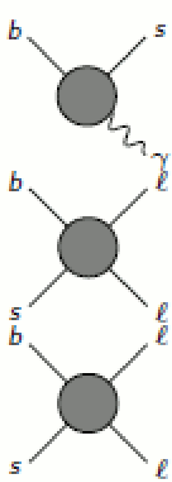
M.Ciuchini et al, arXiv:1512.07157
T.Hurth et al, arXiv:1603.00865
S.Descotes-Genon et al, arXiv:1510.04239...

NP changes short-distance C_i
and/or add new long-distance ops O'_i

- Model-independent description in effective field theory

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{\rm tb} V^*_{\rm ts} \sum_i \underbrace{\mathcal{C}_i \mathcal{O}_i}_{\text{Left-handed}} + \underbrace{\mathcal{C}'_i \mathcal{O}'_i}_{\text{Right-handed, } \frac{m_s}{m_b} \text{ suppressed}}$$

- Wilson coefficients $\mathcal{C}_i^{(\prime)}$ encode short-distance physics, $\mathcal{O}_i^{(\prime)}$ corr. operators

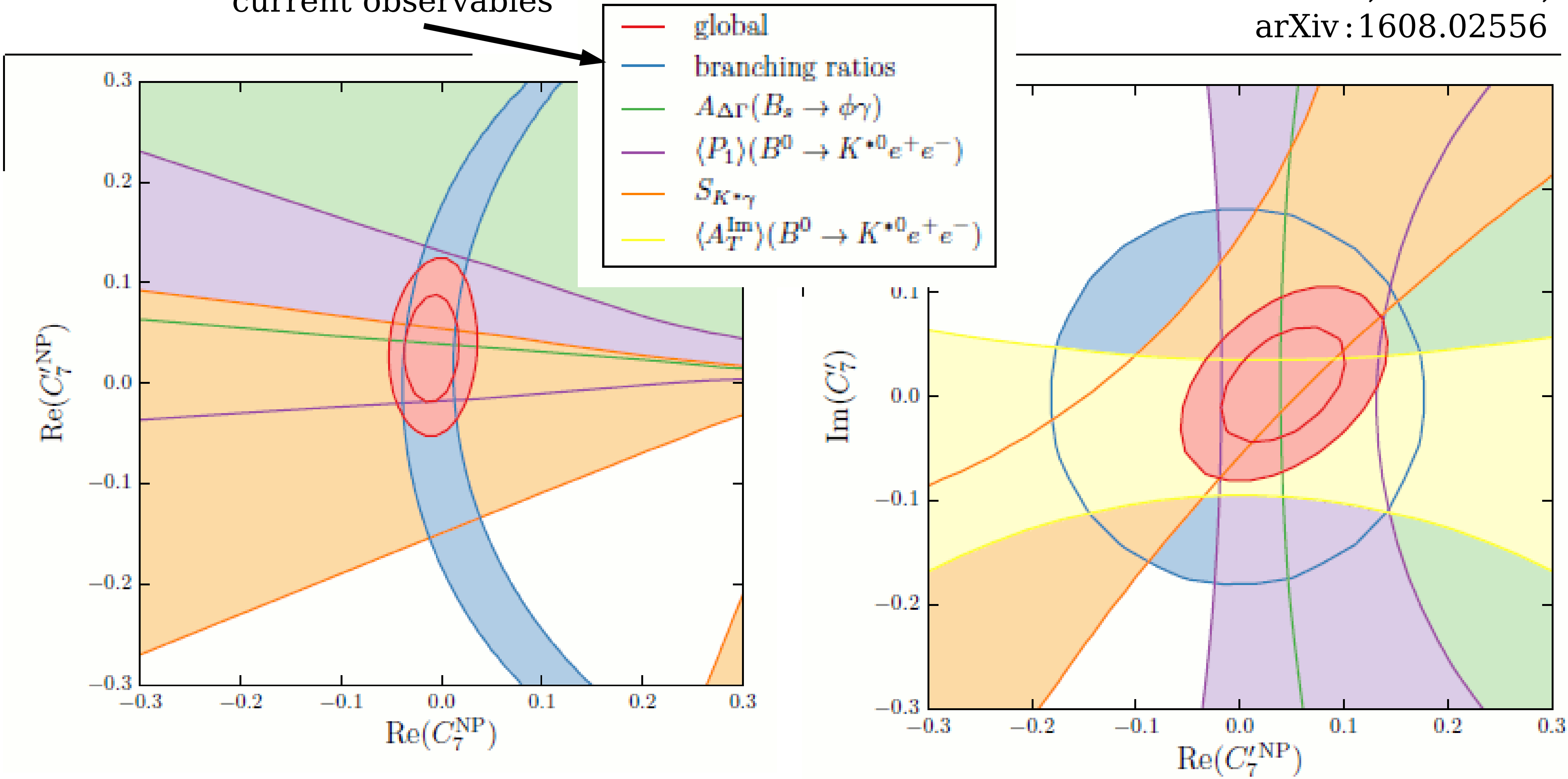


	$b \to s\gamma$	$B \to \mu\mu$	$b \to s\ell\ell$
$\mathcal{O}_7^{(\prime)}$ photon penguin	✓		✓
$\mathcal{O}_9^{(\prime)}$ vector coupling			✓
$\mathcal{O}_{10}^{(\prime)}$ axialvector coupling		✓	✓
$\mathcal{O}_{S,P}^{(\prime)}$ (pseudo)scalar penguin		✓	

Constraints on NP from radiative B decays

A.Paul, D.Straub, arXiv:1608.02556

current observables



- inclusive and exclusive branching ratios strongly constrain NP contributions to the real part of C_7
- more precise measurement of time-dependent CP asymmetry in $B \to K^* \gamma$
- improved measurements of the $B \to K^* e^+ e^-$ angular analysis at very low q^2
- new observables from $B \to K\pi\pi\gamma$, $\Lambda_b \to \Lambda\gamma$

Constraints on NP from radiative B decays

A. Paul, D. Straub, arXiv:1608.02556

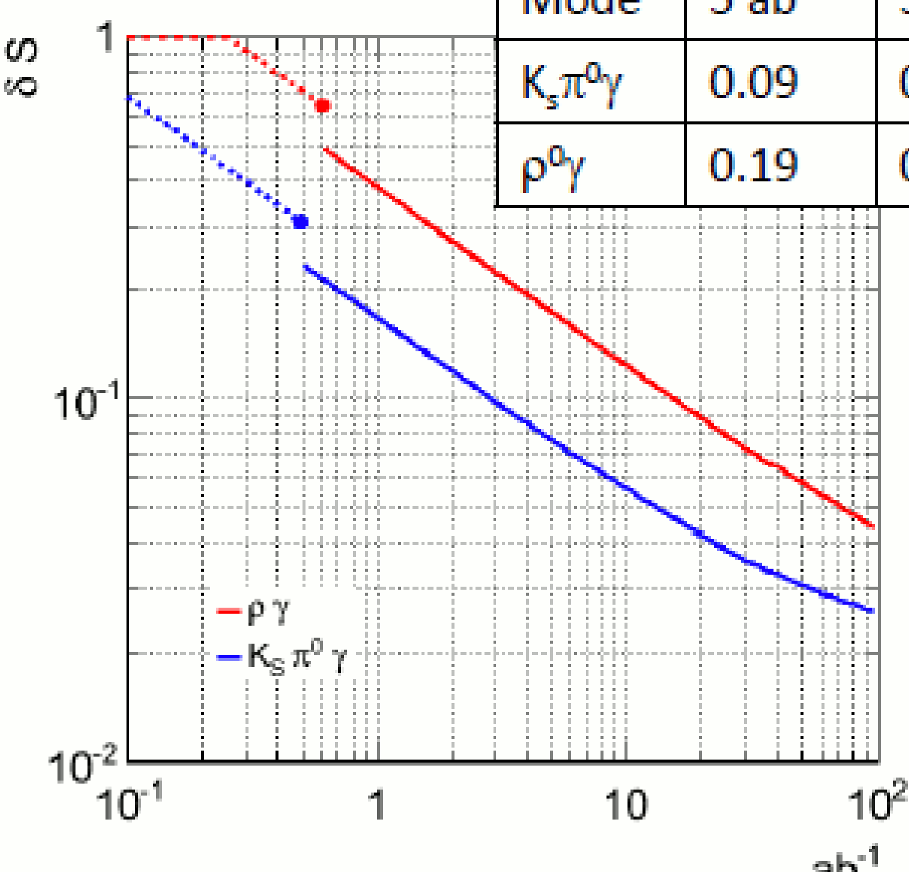
Observable	SM prediction		Measurement	
$10^4 \times \text{BR}(B \to X_s\gamma)_{E_\gamma > 1.6\,\text{GeV}}$	3.36 ± 0.23	[16]	3.43 ± 0.22	[19]
$10^5 \times \text{BR}(B^+ \to K^{*}\gamma)$	3.43 ± 0.84		4.21 ± 0.18	[19]
$10^5 \times \text{BR}(B^0 \to K^{*}\gamma)$	3.48 ± 0.81		4.33 ± 0.15	[19]
$10^5 \times \overline{\text{BR}}(B_s \to \phi\gamma)$	4.31 ± 0.86		3.5 ± 0.4	[43, 44]
$S(B^0 \to K^{*}\gamma)$	-0.023 ± 0.015		-0.16 ± 0.22	[19]
$A_{\text{CP}}(B^0 \to K^{*}\gamma)$	0.003 ± 0.001		-0.002 ± 0.015	[19]
$A_{\Delta\Gamma}(B_s \to \phi\gamma)$	0.031 ± 0.021		-1.0 ± 0.5	[4]
$\langle P_1 \rangle (B^0 \to K^{*}e^+e^-)_{[0.002,1.12]}$	0.04 ± 0.02		-0.23 ± 0.24	[45]
$\langle A_T^{\text{Im}} \rangle (B^0 \to K^{*}e^+e^-)_{[0.002,1.12]}$	0.0003 ± 0.0002		0.14 ± 0.23	[45]

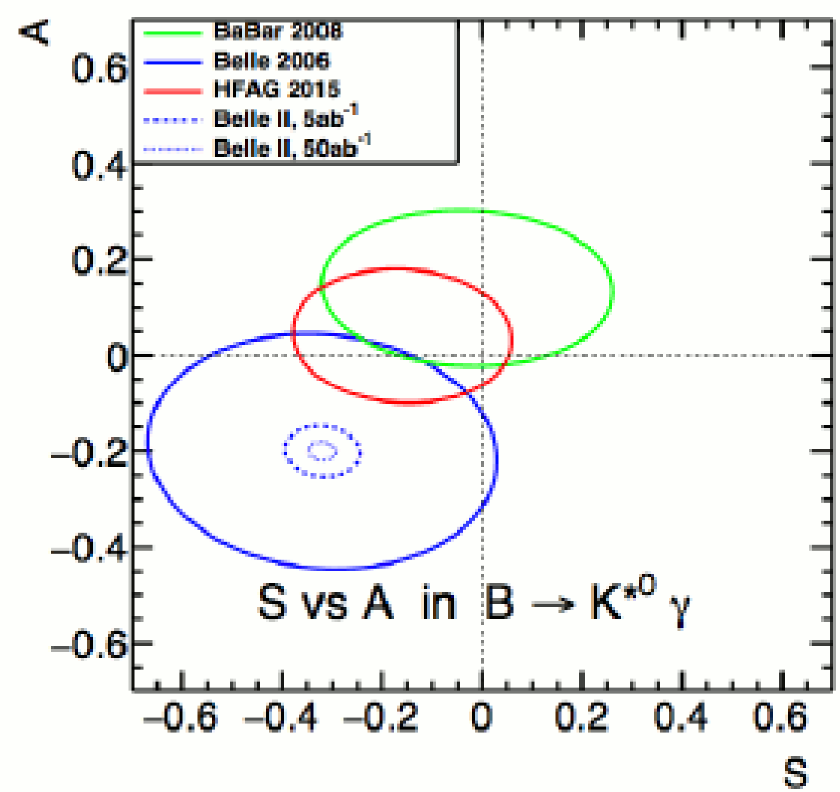
At Belle II, significant improvement in the determination of $A_{CP}(t)$ in $K_S^0\pi^0\gamma$ expected.

- **Belle II SVD larger than Belle (6 → 11.5 cm)**
  ⇒ 30 % more K_S with vertex hits available
- Effective tagging eff. 13 % better

- Expected errors for ***S*** measurements of $K_s\pi^0\gamma$ and $\rho^0\gamma$.

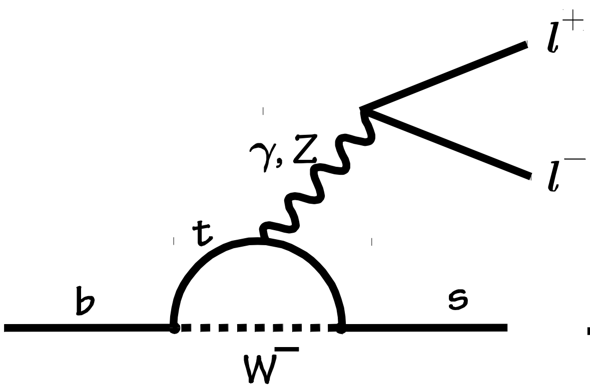
Mode	5 ab^{-1}	50 ab^{-1}
$K_s\pi^0\gamma$	0.09	0.030
$\rho^0\gamma$	0.19	0.064

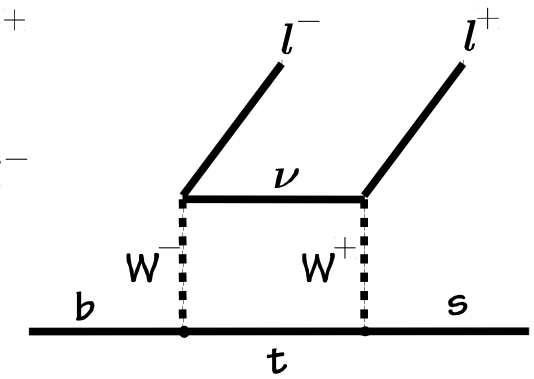




16σ deviation with 50 ab^{-1}.

Electroweak penguins $b \to s l^+ l^-$





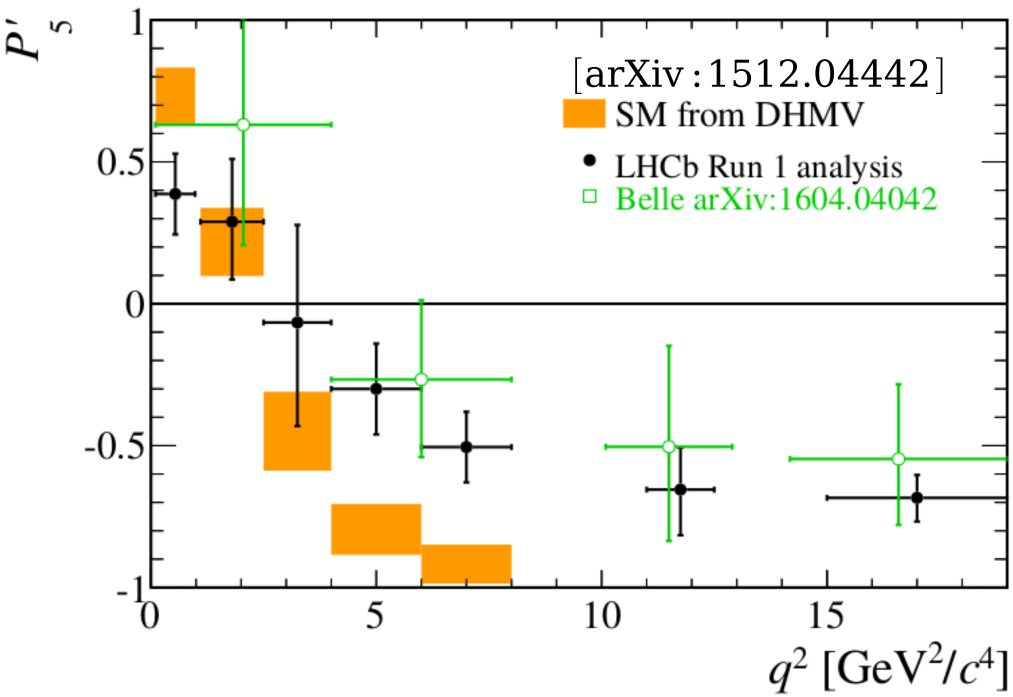
$\Rightarrow$ 2 orders of magnitude smaller than $b \to s \gamma$ but **rich NP search potential**

Many observables:

- Branching fractions
- Isospin asymmetry (A_I)
- Lepton fwd-bwd asymmetry (A_{FB})
- ...

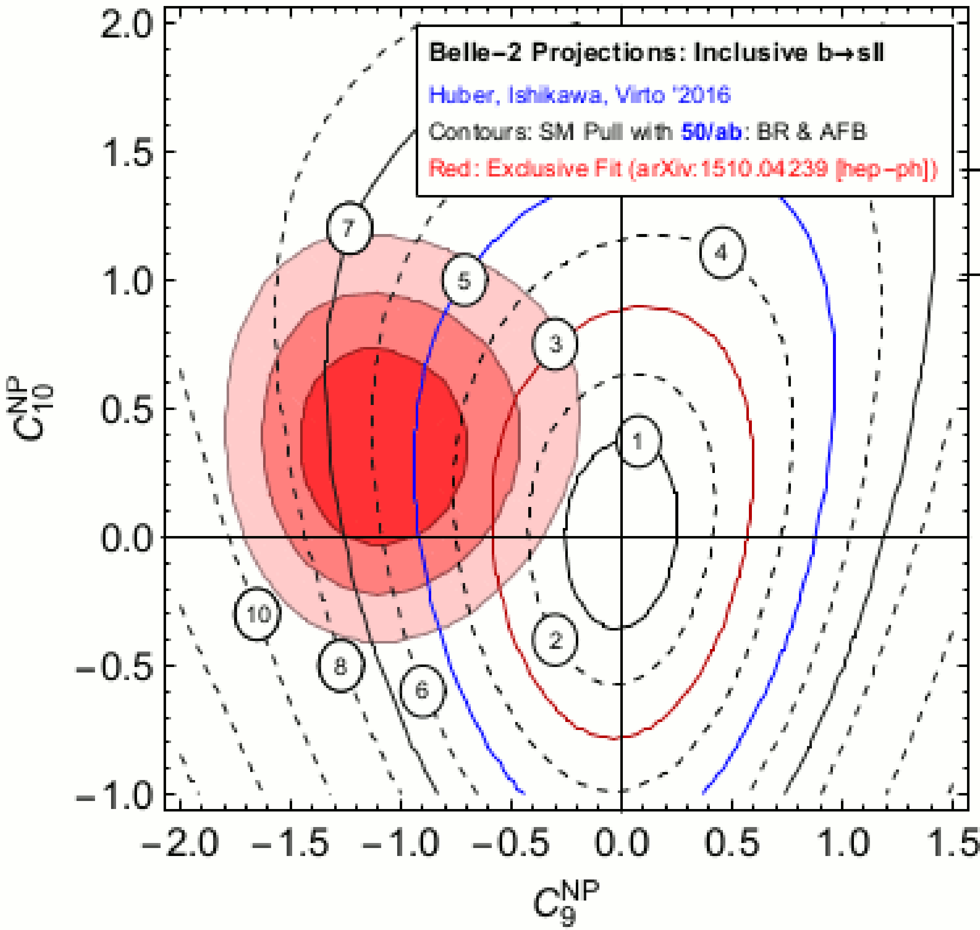
$\Rightarrow$ Exclusive ($B \to K^{(*)} l^+ l^-$), Inclusive ($B \to X_s l^+ l^-$)

- Form-factor independent observable $P'_5 = \dfrac{S_5}{\sqrt{F_L(1-F_L)}}$



- Tension in P'_5 seen with $1\,fb^{-1}$ is confirmed
- Local deviations of 2.9σ and 3.0σ for $q^2 \in [4.0, 6.0]$ and $[6.0, 8.0]$ GeV^2
- Naive combination of the two gives local significance of 3.7σ

Inclusive di-lepton, $B \to X_s l^+ l^-$

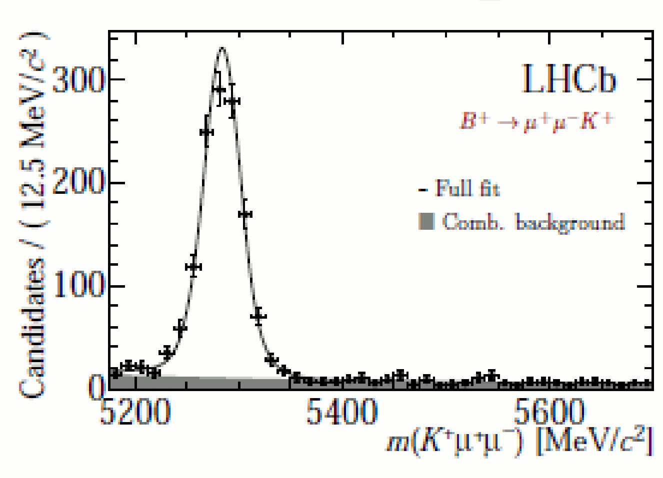


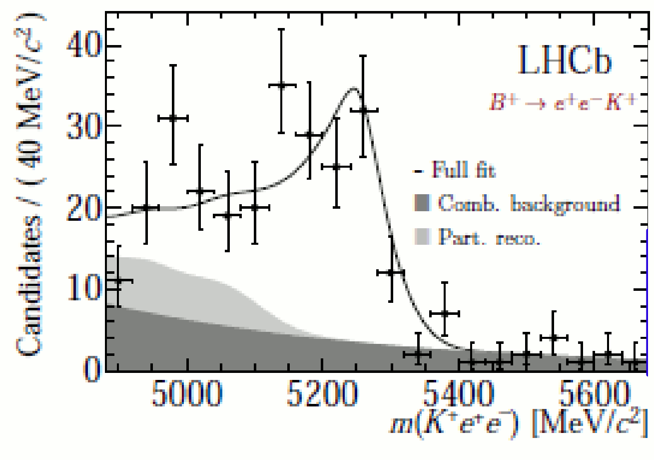
among the most relevant observables:

Process	Obser.	Theory	Discovery (ab^{-1})	Sys. limit (ab^{-1})	vs LHCb BESIII	vs Belle	Anomaly	NP
$B \to X_s l^+ l^-$	R_{X_s}	★★	-	50	★★★	★★★	★★	★★★
$B \to K^{(*)} \nu\nu$	$Br.$	★★★	-	50	★★★	★★★	★	★★
$B \to X_s \gamma$	A_{CP}	★★★	-	8	★★★	★★★		★★
$B \to X_d \gamma$	$Br.$		-	-				
$B \to K_S \pi^0 \gamma$	$S_{K_S \pi^0 \gamma}$	★★	-	50	★	★★★	★	★★★
$B \to \rho\gamma$	$S_{\rho\gamma}$	★★	-	50	★★	★★★		★★★
$B \to K^* l^+ l^-$	P_5'	★★	-	50	★	★★	★★★	★★★
$B \to K e^+ e^-$	$R(K)$	★★★	-	50	★★	★★★	★★★	★★★
$B \to K \tau l$	$Br.$	★★★	-	50	★★	★★★	★★	★★
$B \to K \tau\tau$	$Br.$	★★★	-	50	★★★	★★★	★★	★★
$B \to \nu\nu$	$Br.$	★★★	-	50	★★★	★★★	★★	★★
$B \to X_s \gamma$	$Br.$	★★	-	1	★★★	★	★	★★
$B_s \to \gamma\gamma$	$Br.$	★★	-	5	★★	★★		★★

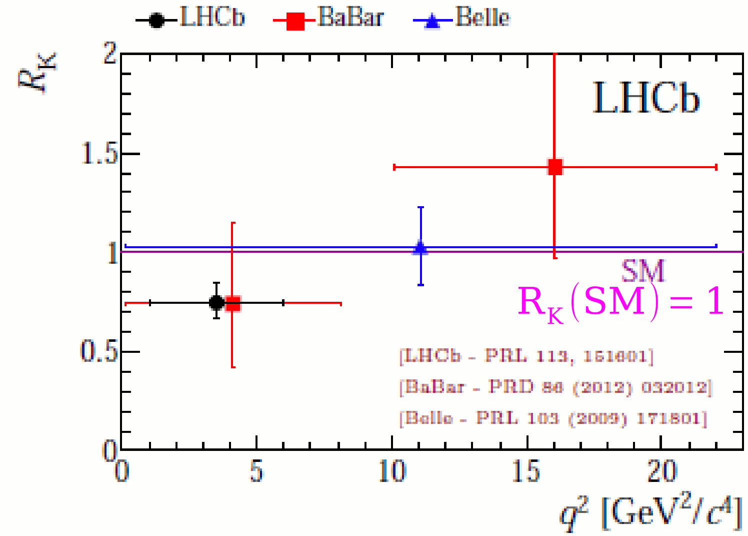
Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$B(B \to X_s \ell^+ \ell^-)$ $(1.0 < q^2 < 3.5\ \mathrm{GeV}^2)$	29%	13%	6.6%
$B(B \to X_s \ell^+ \ell^-)$ $(3.5 < q^2 < 6.0\ \mathrm{GeV}^2)$	24%	11%	6.4%
$B(B \to X_s \ell^+ \ell^-)$ $(q^2 > 14.4\ \mathrm{GeV}^2)$	23%	10%	4.7%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ $(1.0 < q^2 < 3.5\ \mathrm{GeV}^2)$	26%	9.7%	3.1%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ $(3.5 < q^2 < 6.0\ \mathrm{GeV}^2)$	21%	7.9%	2.6%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ $(q^2 > 14.4\ \mathrm{GeV}^2)$	19%	7.3%	2.4%

Test of lepton universality using $b \to s l^+ l^-$ decays





[arXiv:1406.6482]

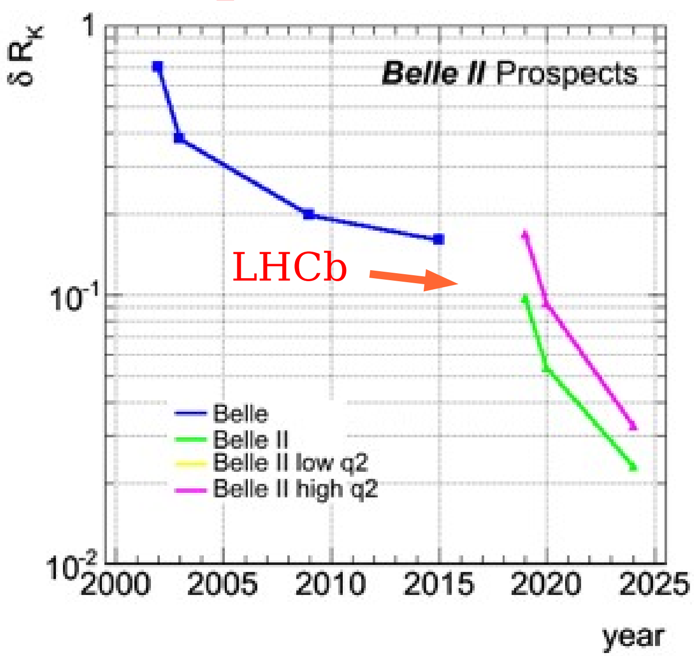


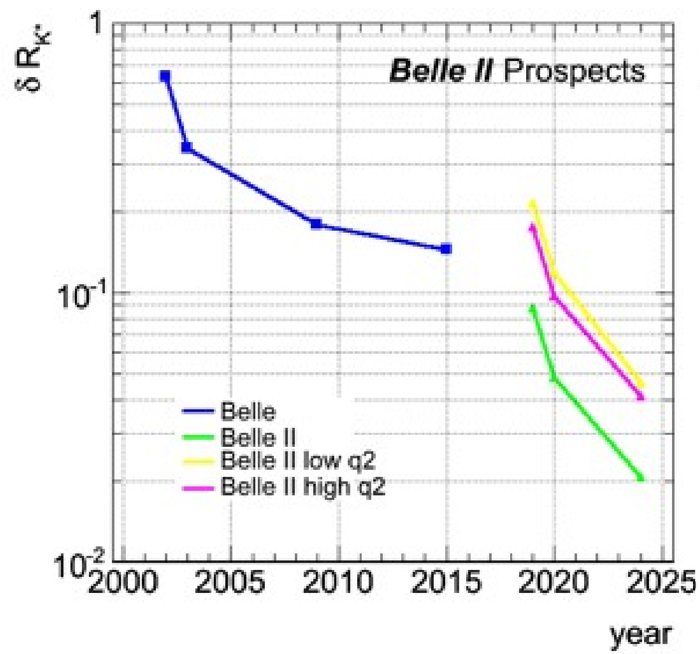
R_K: ratio of branching fractions for $1<q^2<6\,GeV^2/c^4$

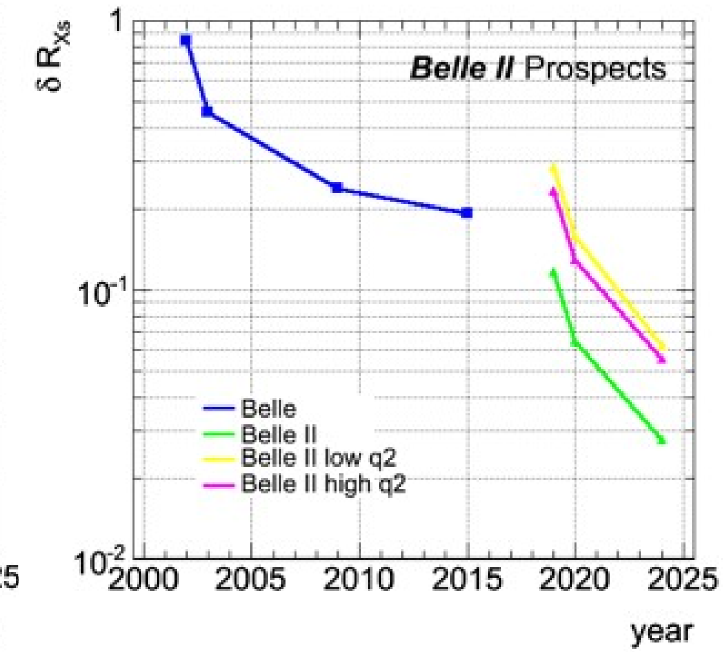
$$\mathbf{R_K = 0.745\,^{+0.090}_{-0.074}(stat) \pm 0.036(syst)}$$

most precise measurement to date is in disagreement with SM at **2.6σ** level

⇒ **Lepton Flavor Non-Universality ?** (effect seems in μμ, not ee)







⇒ great potential also on **LFV B decays**, especially with one τ in final state

cLFV : beyond the Standard Model

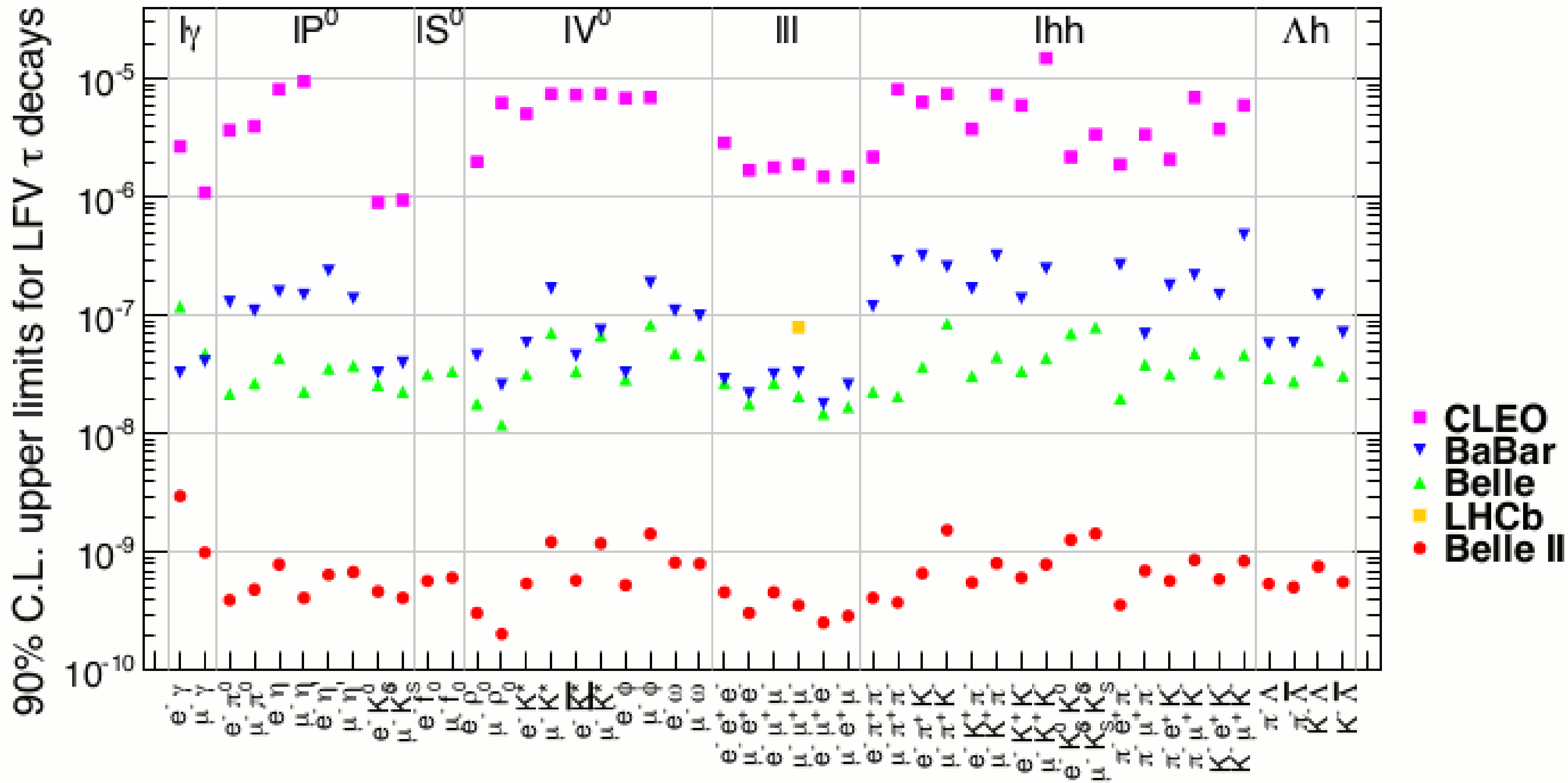
$$\mathcal{B}_{\nu SM}(\tau \to \mu\gamma) = \frac{3\alpha}{32\pi}\left| U^*_{\tau i} U_{\mu i} \frac{\Delta m^2_{3i}}{m^2_W}\right|^2 < 10^{-40}$$

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{C^{(5)}}{\Lambda} O^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} O_i^{(6)} + \ldots$$

Model	Reference	τ→μγ	τ→μμμ
SM+ ν oscillations	EPJ C8 (1999) 513	10^{-40}	10^{-14}
SM+ heavy Maj ν_R	PRD 66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66 (2002) 115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566 (2003) 217	10^{-10}	10^{-7}

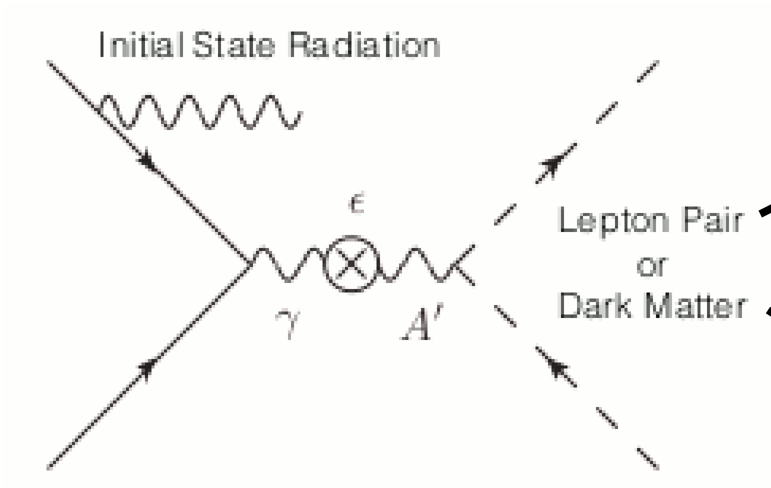
		$\tau\to 3\mu$	$\tau\to\mu\gamma$	$\tau\to\mu\pi^+\pi^-$	$\tau\to\mu K\bar{K}$	$\tau\to\mu\pi$	$\tau\to\mu\eta^{(\prime)}$
4-lepton	$O^{4\ell}_{S,V}$	✓	–	–	–	–	–
dipole	O_D	✓	✓	✓	✓	–	–
lepton-quark	O^q_V	–	–	✓ (I=1)	✓(I=0,1)	–	–
lepton-quark	O^q_S	–	–	✓ (I=0)	✓(I=0,1)	–	–
lepton-gluon	O_{GG}	–	–	✓	✓	–	–
lepton-quark	O^q_A	–	–	–	–	✓ (I=1)	✓ (I=0)
lepton-quark	O^q_P	–	–	–	–	✓ (I=1)	✓ (I=0)
lepton-gluon	$O_{G\tilde{G}}$	–	–	–	–	–	✓

Celis, Cirigliano, Passemar (2014)

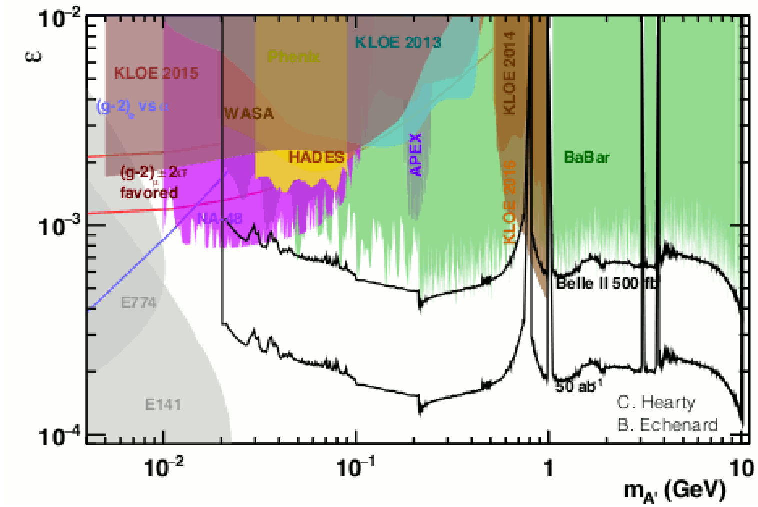


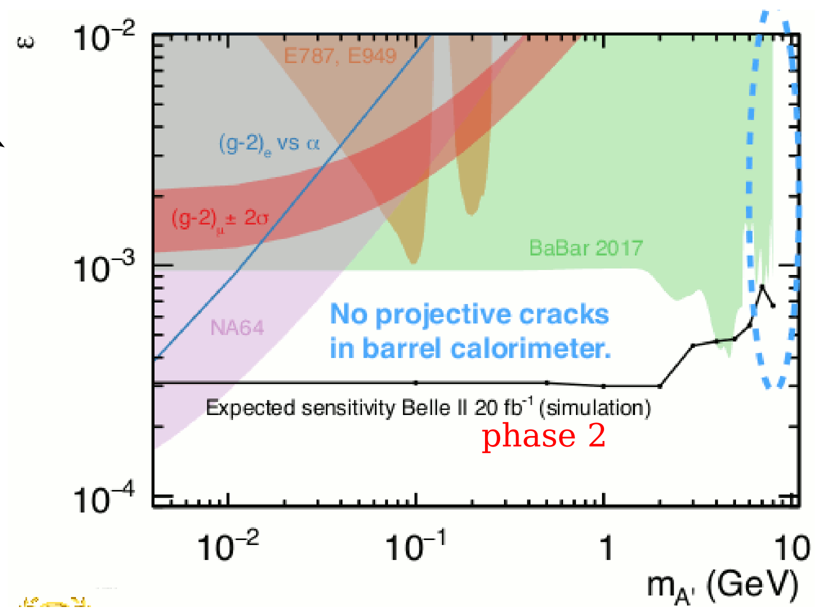
plans for Dark Sector Physics

exploit the clean e^+e^- environment to probe the existence of exotic hadrons, dark photons/Higgs, light Dark Matter particles, ...



dark photon A' mixes with SM photon γ with strength ϵ



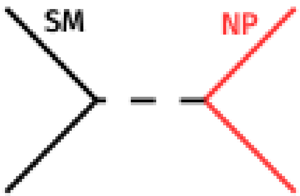


search for a dark photon decaying invisibly, and the search for an axion-like particle may be possible even in "Phase 2"

The case for new physics manifesting in Belle II

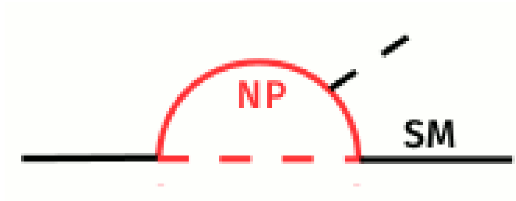
Issues (addressable at a Flavour factory)

energy frontier



limited by beam energy

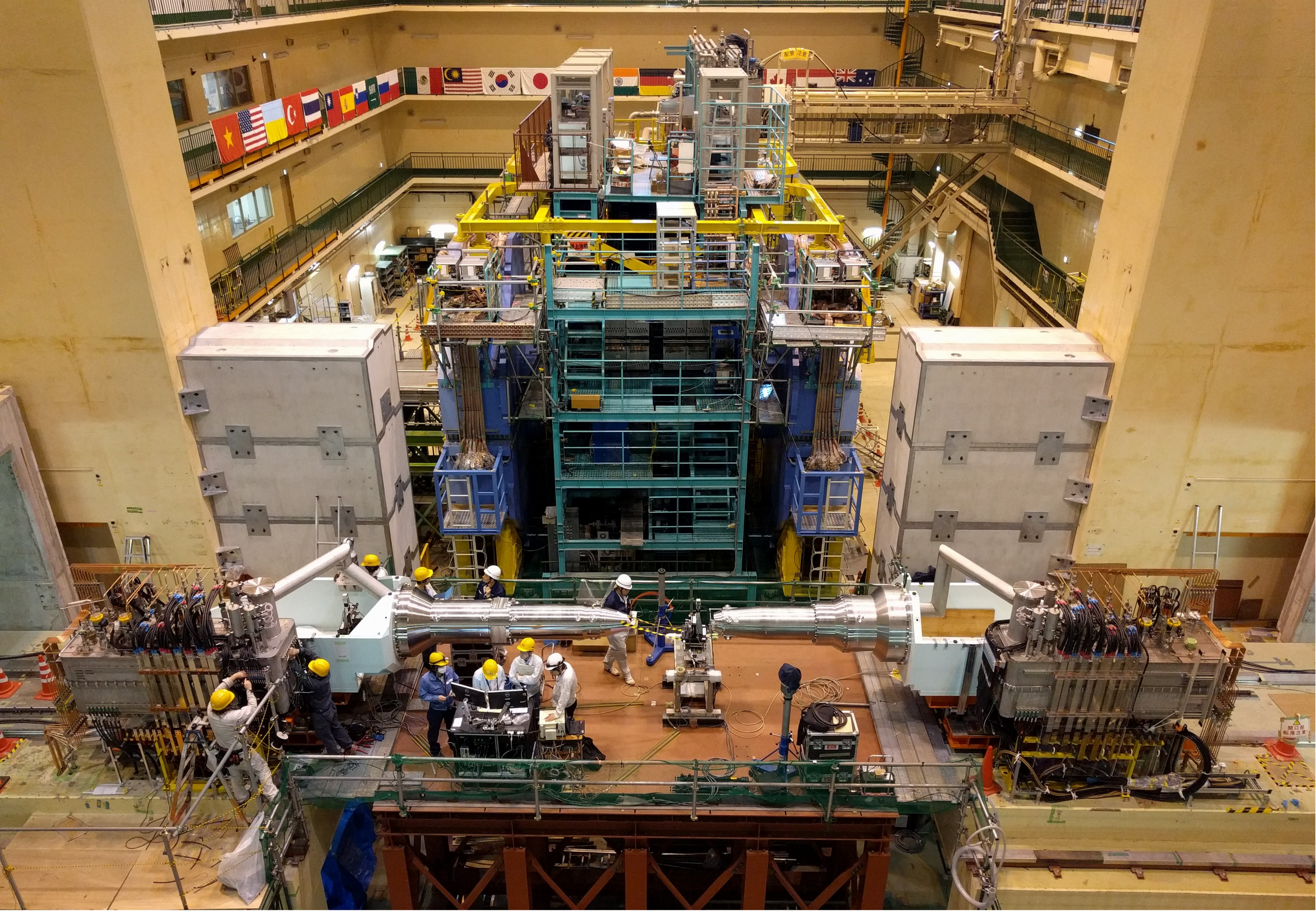
intensity frontier



limited by statistics

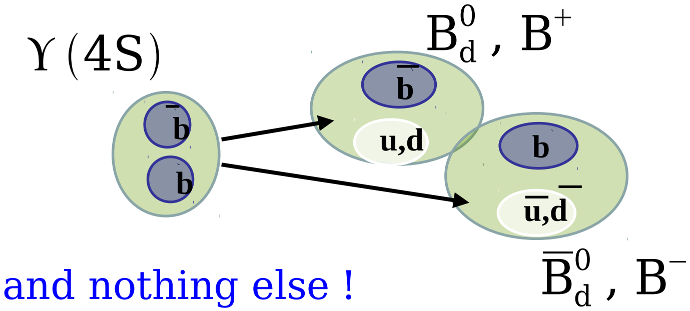
➜ **NP beyond the direct reach of the LHC**

- Baryon asymmetry in cosmology
  ⇒ New sources of CPV in quarks and charged leptons
- Finite neutrino masses
  ⇒ Tau LFV
- Quark and Lepton flavour & mass hierarchy
  ⇒ new symmetry, massive new particles, extended gauge sector
- 19 free parameters
  ⇒ Extensions of SM relate some, (GUTs)
- \+ Puzzling nature of exotic “new” QCD states
- The hidden universe (dark matter)

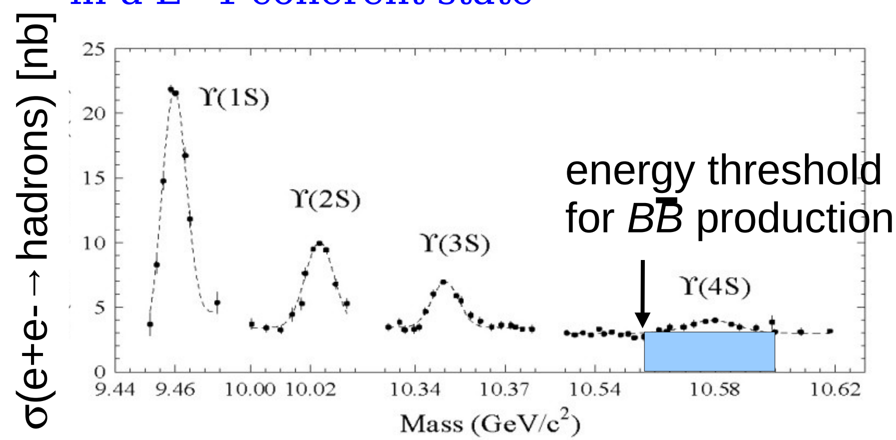


let's roll (-in)...

Belle II, a flavour-factory
A rich physics program…



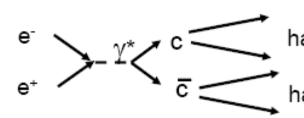
- 2 B's and nothing else !
- 2 B mesons are created simultaneously in a L=1 coherent state



- Studies of CPV in B decays
- $b \to s q \bar{q}$: probe for new sources of CPV
- constraints from the $b \to s\gamma$ observables
- Many more observables in $b \to s l^+ l^-$
- Search for the charged Higgs in the $B \to \tau\nu$, $B \to D^{(*)}\tau\nu$ decays
- Study of D^0-$\bar{D}^0$ mixing
- Search for CPV in D and D_s decays
- Studies of exotic charmonium, tetraquark, pentaquark states
- Studies of new bottomonium-like states
- Search for lepton flavor violation (LFV) in τ decays
- Search for CPV and study of hadronic τ decays
- Light Higgs searches, DM searches…
- …

''on resonance'' production
$e^+e^- \to \Upsilon(4S) \to B_d^0\bar{B}_d^0, B^+B^-$

$\sigma(e^+e^- \to B\bar{B}) \simeq 1.1$ nb ($\sim 10^9$ $B\bar{B}$ pairs)



$\sigma(e^+e^- \to c\bar{c}) \simeq 1.3$ nb ($\sim 1.3\times10^9$ $X_c\bar{Y}_c$ pairs)

ττ production also !

More exotic particles ?

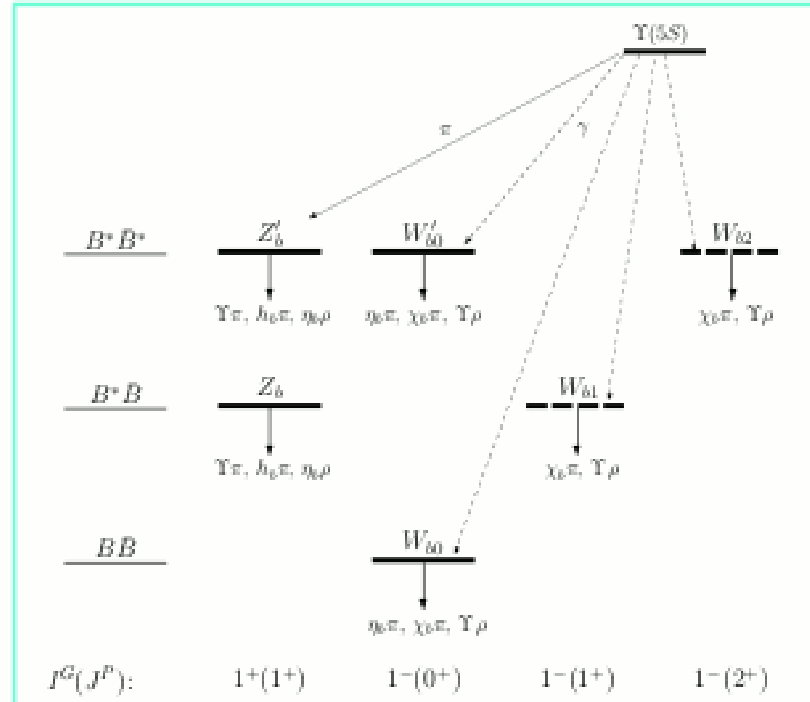
Belle top cited papers:

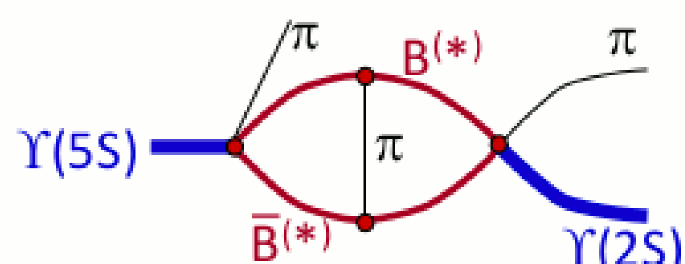
1) Observation of a narrow charmonium-like state in exclusive $B^+ \to K^+ J/\psi \pi^+ \pi^-$ decays – PRL 91, 262001 (2016); — 1269 citations
2) Observation of large CP violation in the neutral B meson system – PRL 87, 091802 (2001); — 831
3) Observation of a resonance-like structure in the $\pi^\pm\psi'$ mass distribution in exclusive $B \to K \pi^\pm \psi'$ decays – PRL 100, 142001 (2008); — 489
4) A measurement for the branching fraction of inclusive $B \to X_s \gamma$ at Belle – PLB 511, 151 (2001); — 427
5) Observation of a near-threshold ω J/ψ mass enhancement in exclusive $B \to K \omega J/\psi$ decays – PRL 94, 182002 (2005). — 414

Many non-anticipated states have been found at Belle, whose nature has not yet been clarified (molecules, tetraquark...)
More surprises in store for Belle II ??

History of Bottomonium-like states @ e^+e^-

- **Belle collected 120 fb^{-1} near Y(5S) and 5.6 fb^{-1} near Y(6S). Y(5S)=Y(10860), Y(6S)=Y(11020)**
- Unexpectedly high rate to $Y(nS)\pi^+\pi^-$ (n=1,2,3), x10^2, at Y(5S)
  - PRL 100, 112001 (2008)
- $\sigma(Y(nS)\pi\pi)$, $\sigma(bb)$ vs CMS energy: "Y(5S)" peaks offset by 9±4 MeV
  - PRD 82, 091106 (2010)
- Bottomonium-like $Z_b^{\pm}(10610)$, $Z_b^{\pm}(10650)$ in 5 channels at Y(5S): $Y(nS)\pi^{\pm}$, $h_b(mP)\pi^{\pm}$ (m=1,2)
  - PRL 108, 122001 (2012)
- Neutral Bottomonium-like $Z_b^0(10610)$ to $Y(nS)\pi^0$ at Y(5S)
  - PRD 88, 052016 (2013)
- $Z_b^{\pm}(10610)$, $Z_b^{\pm}(10650) \to Y(nS)\pi^{\pm}$ amplitude analysis yields $J^P=1^+$
  - PRD 91, 072003 (2015)

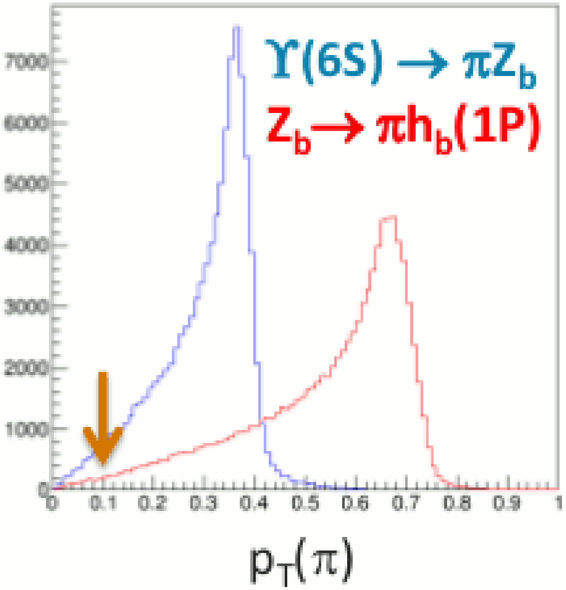


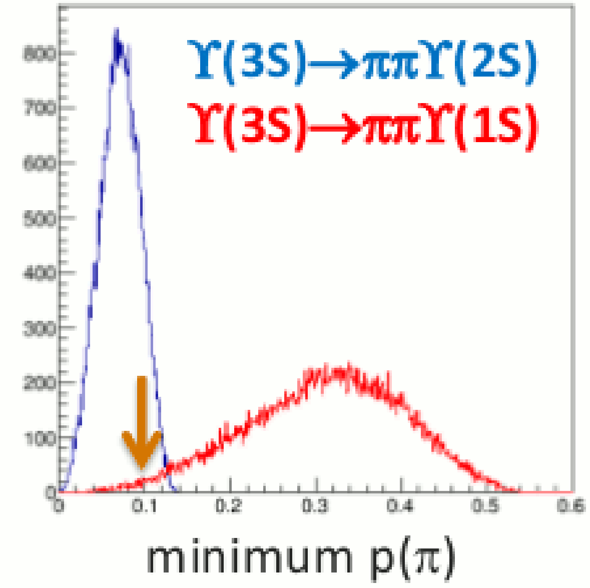


Bottomonium @ Y(6S) in Phase II

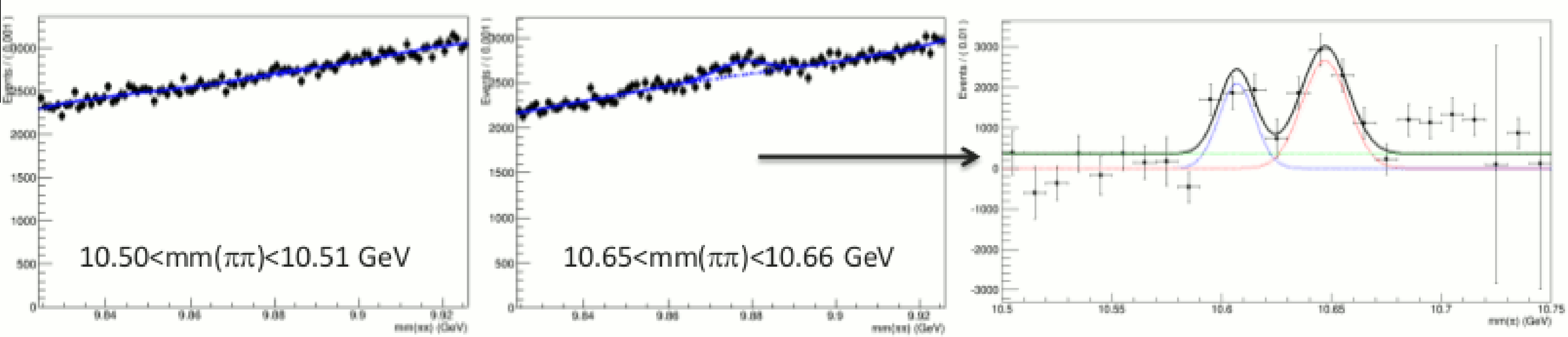
Belle II Full Simulation

- Golden modes via missing mass analysis in phase 2.
  - Y(6S) → π Z_b (π hb(nP))
  - Y(6S) → π Z_b (π Y(pS)(l+l-))
- 95 modes in MC7 covering Y(6S) analyses produced (& analysed) see backup





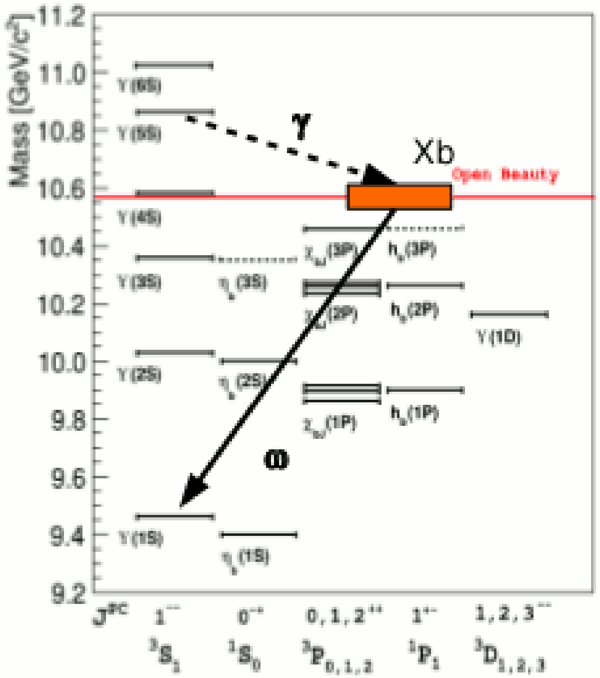
- Proof of principle plots (10 fb^{-1}, 50/50 Z_b split)



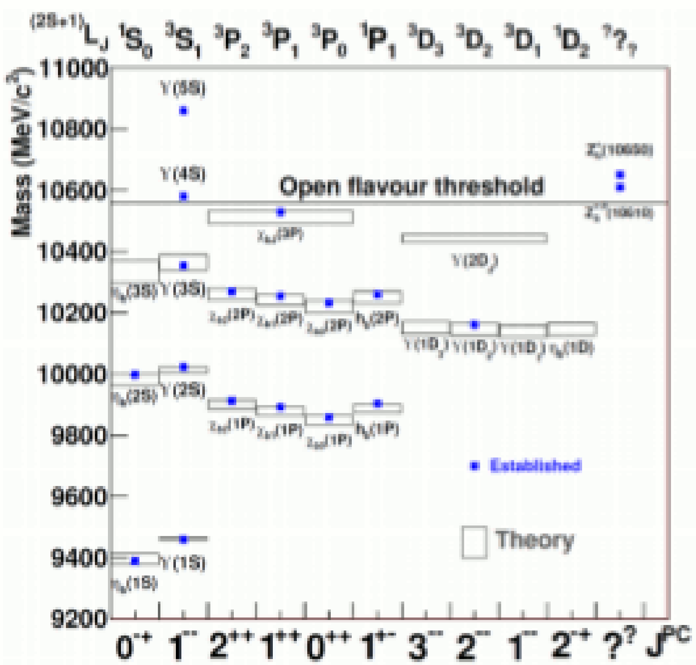
More physics with Υ(6S)

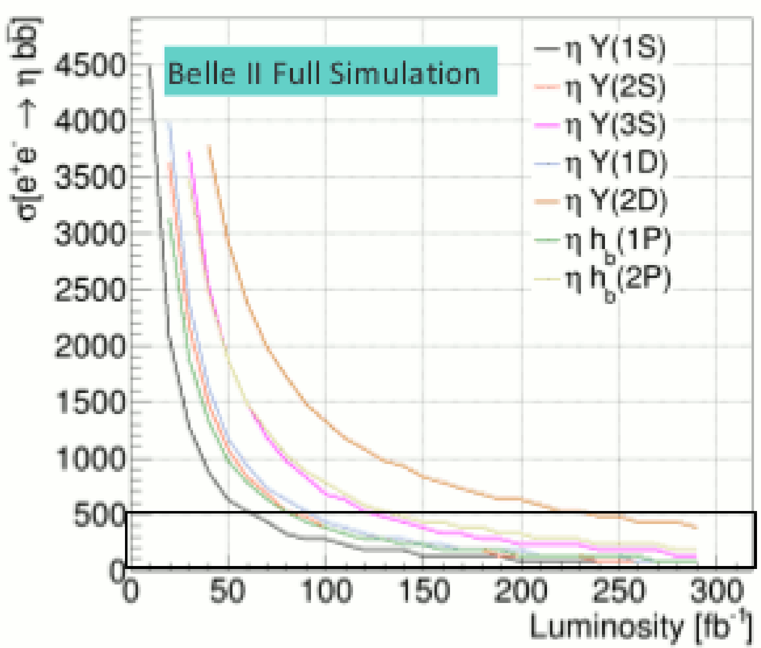
- Other possible states at Υ(6S)

$\Upsilon(6S) \to W_b^0\,\gamma$, $W_b \to \eta_b\pi, \chi_b\pi, \Upsilon\rho$	*
$\Upsilon(6S) \to W_b^0\,\pi^+\pi^-$, $W_b \to \eta_b\pi, \chi_b\pi, \Upsilon\rho$	**
$\Upsilon(6S) \to \gamma X_b\,(\to \omega\,\Upsilon(1S))$	**
$\Upsilon(6S) \to \pi\pi X_b\,(\to \omega\,\Upsilon(1S))$	*
QCD hybrids in BB*	**



- η transitions for accessing below threshold.



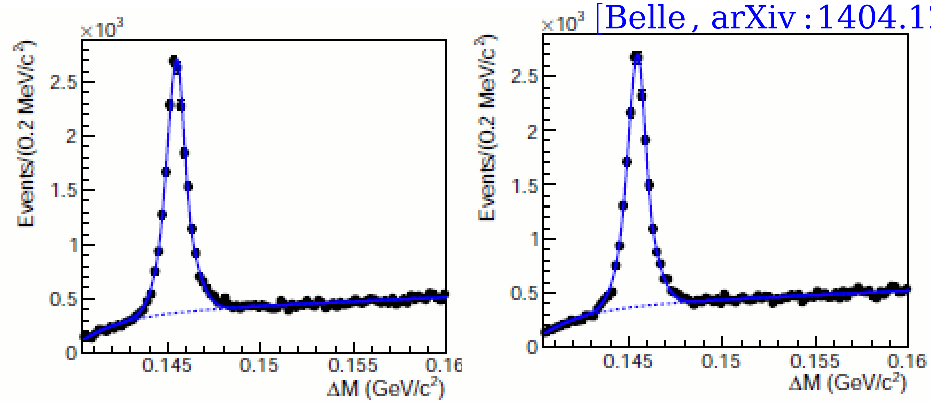


Complementarity in the observables

- $\Delta A_{CP} = A_{CP}(D \rightarrow K^+ K^-) - A_{CP}(D \rightarrow \pi^+ \pi^-)$

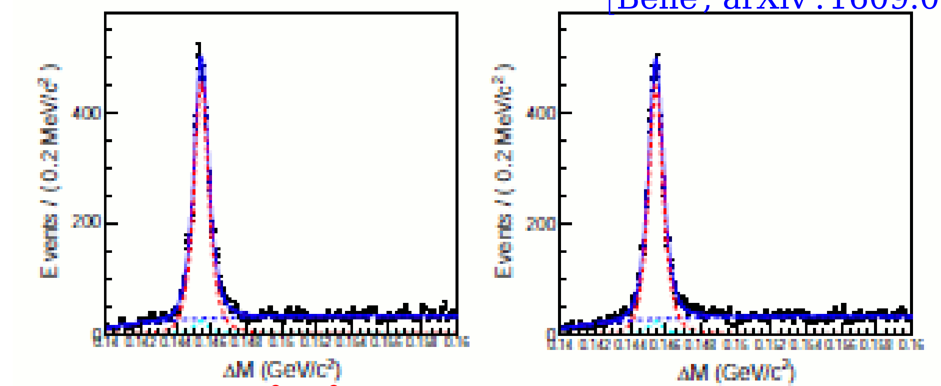
  interpretation in terms of NP require other observables: $A_{CP}(D \rightarrow \pi^0 \pi^0)$, $A_{CP}(D \rightarrow \pi^+ \pi^0)$, $A_{CP}(D \rightarrow K^0_S K^0_S)$, $A_{CP}(D \rightarrow \phi \gamma)$...

[Belle, arXiv:1404.1266]



$A_{CP}(D \rightarrow \pi^0 \pi^0) = (-0.03 \pm 0.64 \pm 0.10)\%$

[Belle, arXiv:1609.06393]



$A_{CP}(D \rightarrow K^0_S K^0_S) = (-0.02 \pm 1.53 \pm 0.17)\%$

- B to charmless 3-body decays...

  interpretation in terms of γ measurement require observables from:

  experimental observables: the decay rates and direct asymmetries for $B^0 \to K^+\pi^0\pi^-$, $B^0 \to K^0\pi^+\pi^-$, $B^0 \to K^+K^0K^-$ and $B^0 \to K^0K^0\overline{K}^0$, and the indirect asymmetries of $B^0 \to K^0\pi^+\pi^-$, $B^0 \to K^+K^0K^-$ and $B^0 \to K^0K^0\overline{K}^0$. *With more observables*

- similarly for $B \rightarrow K\pi$ ($B \rightarrow K^0_S \pi^0$...), isospin analysis for α...

$e^+e^- \rightarrow$ light hadrons

- Long standing discrepancy between theory and experiment in the $(g-2)_\mu$:

E821 Collaboration, PRL **92**, 1618102 (2004)

$$\vec{\mu} = g\,\frac{e\hbar}{2mc}\cdot\vec{S}$$

anomalous magnetic moment

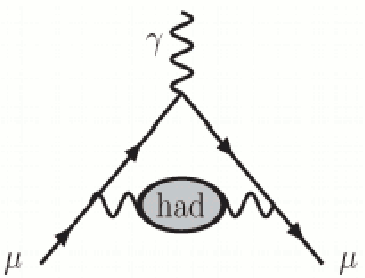
Experiment: $(g-2)_\mu/2 = 11659208.9\ (6.3) \times 10^{-10}$

Theory: $(g-2)_\mu/2 = 11659181.5\ (4.9) \times 10^{-10}$

Discrepancy : $(27.4 \pm 8.0) \times 10^{-10}$

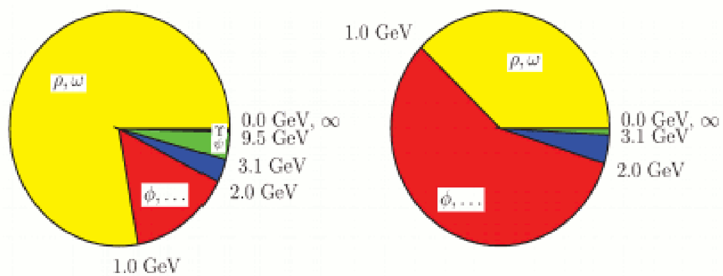
3.5σ discrepancy

- Most of the uncertainty in the theory prediction comes from the hadronic contribution:



"hadronic vacuum polarization"

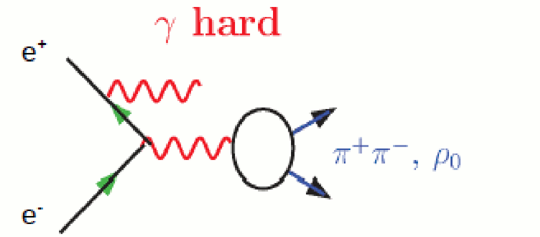
Phys. Rept. **447**, 1-110 (2009)



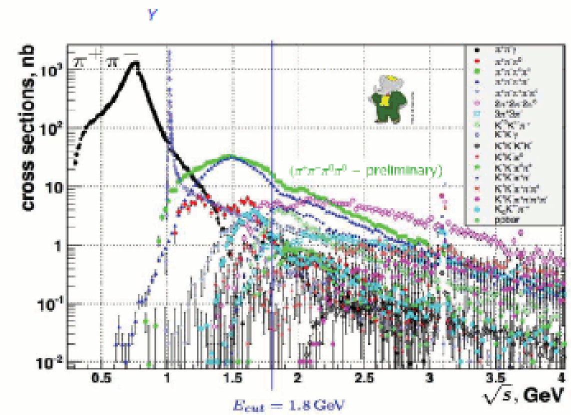
size uncertainty

of the hadronic contribution

- The vacuum polarization is connected to the e^+e^- → hadrons through the optical theorem;
- At the B-factories we can exploit the initial state radiation (ISR) and the large integrated luminosity to effectively have a "scan" at low invariant masses;
- A large number of exclusive final states has been investigated by BaBar;
- Due to trigger limitations, Belle could not participate to the campaign, but this will be an important topic at Belle II!



$$s = M_\phi^2;\ s' = s\,(1-k),\ k = E_\gamma/E_{\text{beam}}$$



Belle(II) LHCb side by side

B-factories

$e^+e^- \to \Upsilon(4S) \to b\bar{b}$

at $\Upsilon(4S)$: 2 B's (B^0 or B^+) and nothing else $\Rightarrow$ clean events

$\sigma_{b\bar{b}} \sim 1\,\mathrm{nb} \Rightarrow 1\ \mathrm{fb}^{-1}$ produces $10^6\ B\bar{B}$

$\sigma_{b\bar{b}}/\sigma_{total} \sim 1/4$

LHCb

$pp \to b\bar{b}X$

production of B^+, B^0, B_s, B_c, Λ_b...

but also a lot of other particles in the event

$\Rightarrow$ lower reconstruction efficiencies

$\sigma_{b\bar{b}}$ much higher than at the $\Upsilon(4S)$

	$\sqrt{s}$ [GeV]	$\sigma_{b\bar{b}}$ [nb]	$\sigma_{b\bar{b}}/\sigma_{tot}$
HERA pA	42 GeV	~30	$\sim 10^{-6}$
Tevatron	2 TeV	5000	$\sim 10^{-3}$
LHC	8 TeV	$\sim 3\times10^5$	$\sim 5\times10^{-3}$
	14 TeV	$\sim 6\times10^5$	$\sim 10^{-2}$

$b\bar{b}$ production cross-section ~ 5× Tevatron , ~ 500,000 × BaBar/Belle !!

$\sigma_{b\bar{b}}/\sigma_{total}$ much lower than at the $\Upsilon(4S)$

$\Rightarrow$ lower trigger efficiencies

B mesons live relativey long

mean decay length $\beta\gamma c\tau \sim 200\,\mu\mathrm{m}$

mean decay length $\beta\gamma c\tau \sim 7\,\mathrm{mm}$

data taking period(s)

[1999-2010]

[run I: 2010-2012, run II: 2015-2018]

(near) future

[Belle II from 2018]

[LHCb upgrade from 2020]

Could it be due to new physics ?

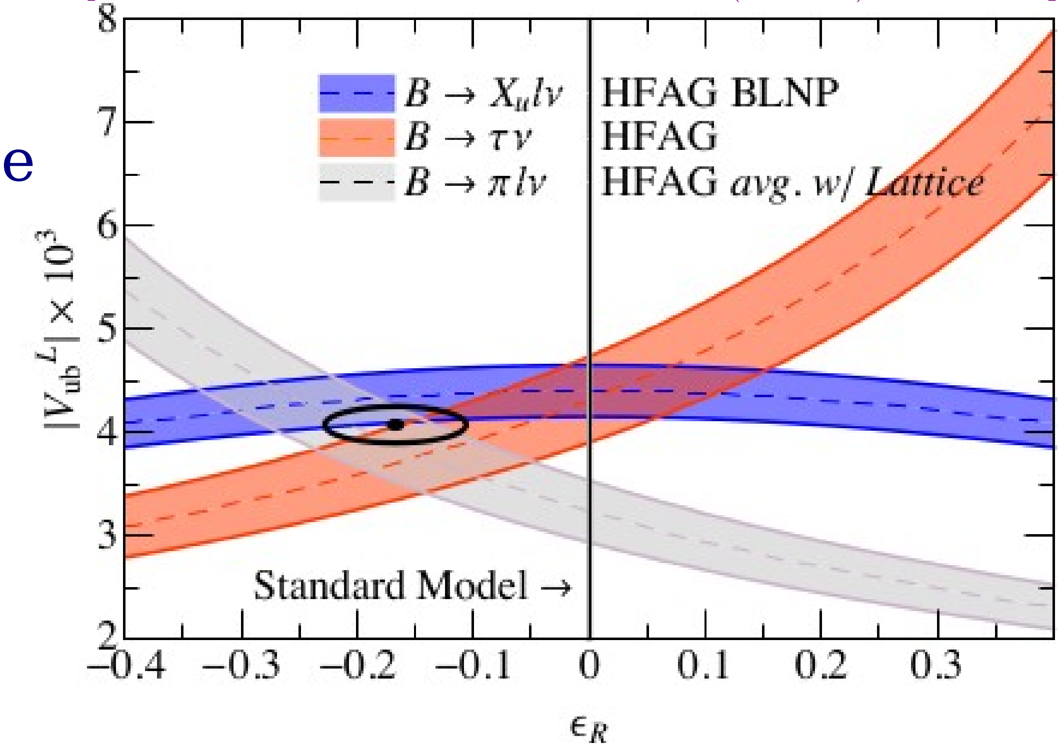
- $B \to \pi l \nu$ is a purely vector current, whereas $B \to X_u l \nu$ is V−A

- Adding right-handed current (V+A), increases vector current but decreases axial-vector current

A negative right-handed current can reduce tension between those two results

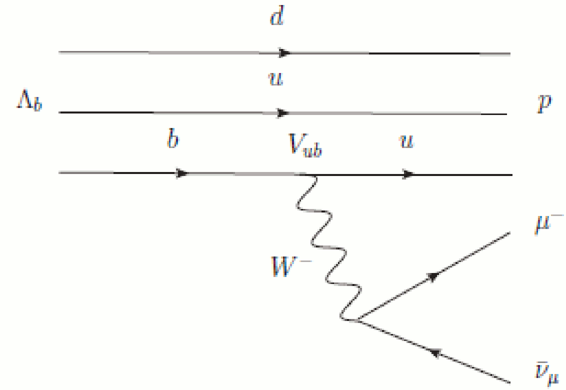
Decay	$\|V_{ub}\| \times 10^3$	ϵ_R dependence
$B \to \pi \ell \bar{\nu}$	3.23 ± 0.30	$1 + \epsilon_R$
$B \to X_u \ell \bar{\nu}$	4.39 ± 0.21	$\sqrt{1 + \epsilon_R^2}$
$B \to \tau \bar{\nu}_\tau$	4.32 ± 0.42	$1 - \epsilon_R$

[F.Bernlochner et al, PRD 90 (2014) 094003]



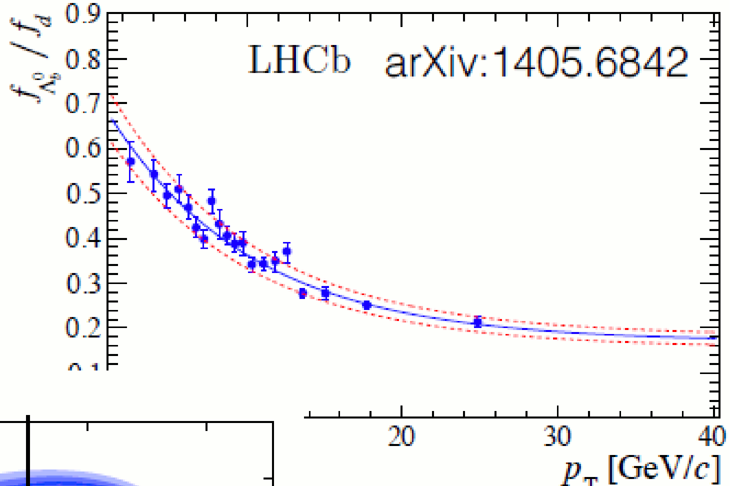
New measurements neeeded, with different approaches also

The decay $\Lambda_b^0 \to p\mu\nu$ arXiv:1504.01568



- The decay $\Lambda_b^0 \to p\mu\nu$ is the baryonic version of $B \to \pi l \nu$
- Cleaner at LHCb as protons are rarer than kaons/pions
- Λ_b^0 baryons not produced at BaBar or Belle experiments but at the LHC produced 1/4 as often as B mesons

⇒ Signature in detector: displaced muon-proton vertex

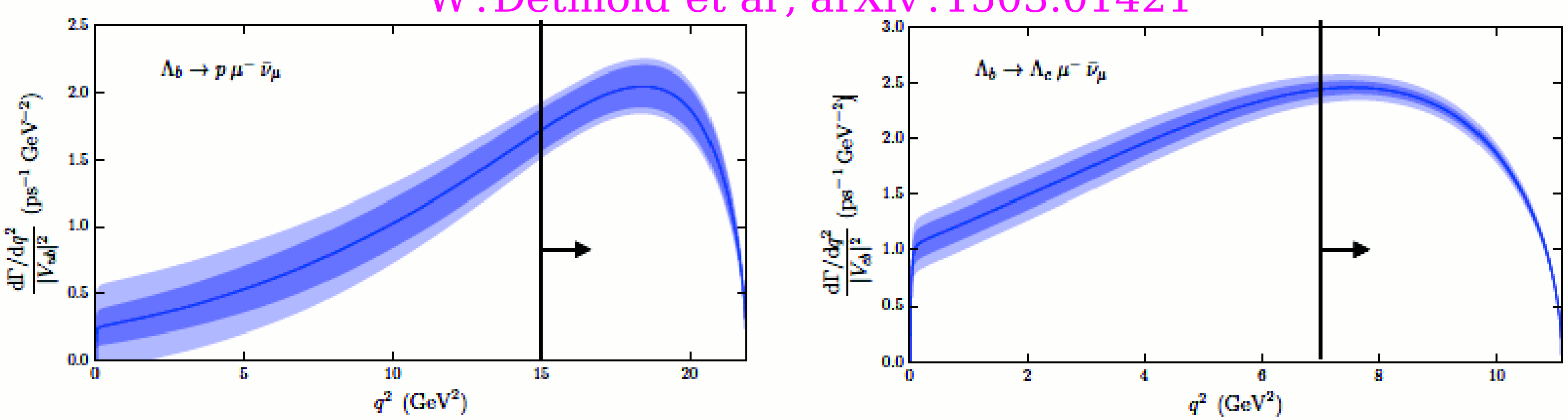


- Normalize signal yield to V_{cb} decay, $\Lambda_b^0 \to \Lambda_c \mu\nu$

⇒ Cancel many systematic uncertainties, including the production rate of Λ_b baryons

- Calculate the branching fraction ratio at high q^2

W.Detmold et al, arXiv:1503.01421



$$\frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,\mathrm{GeV}^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu\nu)_{q^2>7\,\mathrm{GeV}^2}} = \frac{N(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,\mathrm{GeV}^2}}{N(\Lambda_b^0 \to (\Lambda_c^+ \to pK^-\pi^+)\mu\nu)_{q^2>7\,\mathrm{GeV}^2}} \times \frac{\epsilon(\Lambda_b^0 \to (\Lambda_c^+ \to pK^-\pi^+)\mu\nu)_{q^2>7\,\mathrm{GeV}^2}}{\epsilon(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,\mathrm{GeV}^2}} \times \mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$$

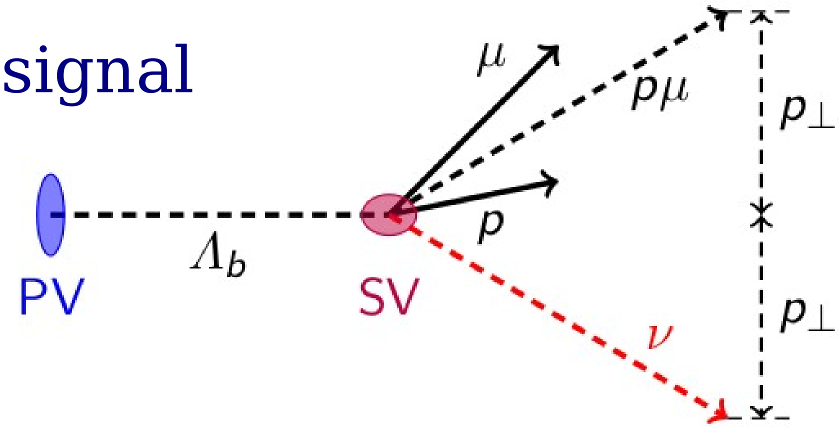
measured precisely by Belle !

Signal fit

arXiv:1504.01568

Corrected mass used to extract the signal

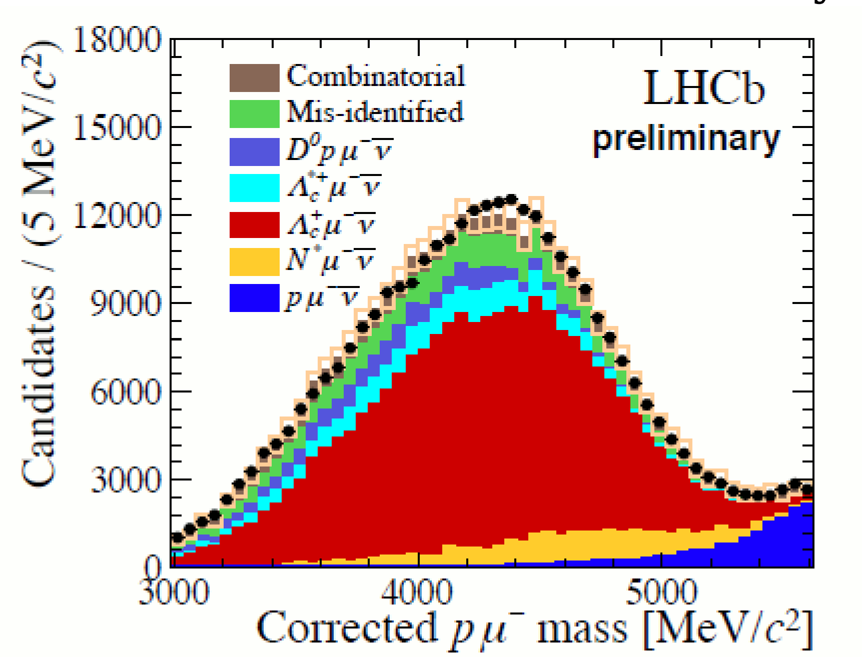
$$M_{corr} = \sqrt{p_\perp^2 + M_{p\mu}^2} + p_\perp$$

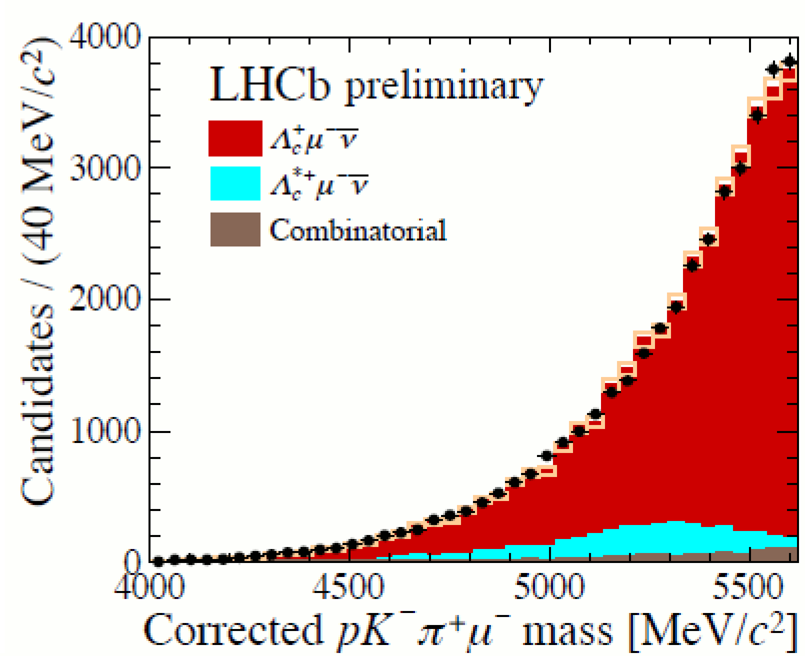


$N(\Lambda_b^0 \to p\mu\nu) = 17{,}687 \pm 733$

First observation of this decay

$N(\Lambda_b^0 \to \Lambda_c(pK)\mu\nu) = 34{,}255 \pm 571$





$$\frac{\mathcal{B}(\Lambda_b \to p\mu^-\overline{\nu}_\mu)_{q^2 > 15\ \mathrm{GeV}^2/c^4}}{\mathcal{B}(\Lambda_b \to \Lambda_c \mu\nu)_{q^2 > 7\ \mathrm{GeV}^2/c^4}} = (1.00 \pm 0.04(stat) \pm 0.08(syst)) \times 10^{-2}$$

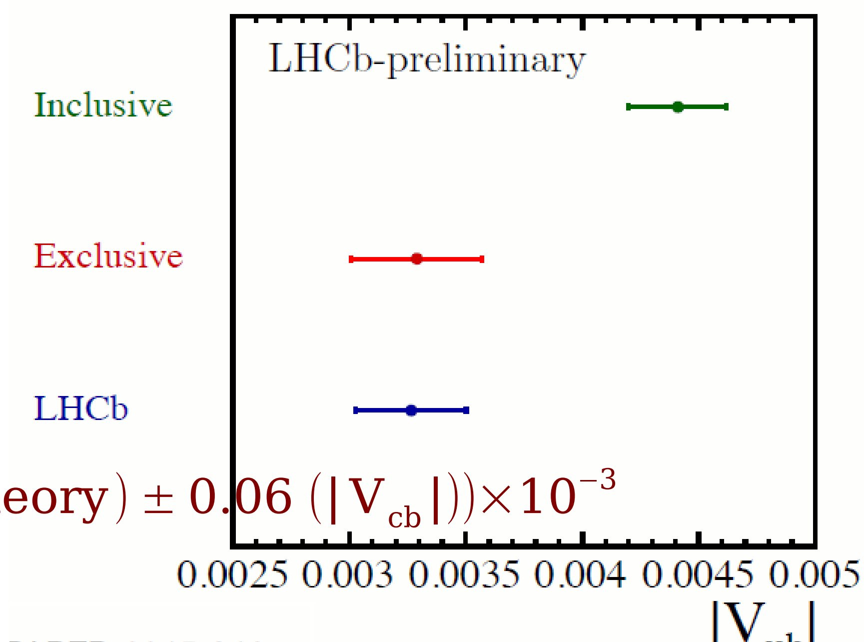
Determining $|V_{ub}|/|V_{cb}|$ arXiv:1504.01568

- Use ratio of differential rates from lattice calculations to calculate the ratio of CKM elements squared:

$$\frac{|V_{ub}|^2}{|V_{cb}|^2} = \frac{\int_{15\ \mathrm{GeV}^2}^{q^2_{\max}} \frac{d\Gamma(\Lambda_b \to p\,\mu^-\bar{\nu}_\mu)}{dq^2} dq^2}{\int_{7\ \mathrm{GeV}^2}^{q^2_{\max}} \frac{d\Gamma(\Lambda_b \to \Lambda_c\,\mu^-\bar{\nu}_\mu)}{dq^2} dq^2} (0.68 \pm 0.07)$$

- leads to: W.Detmold et al, arXiv:1503.01421

$$\frac{|V_{ub}|}{|V_{cb}|} = 0.083 \pm 0.004\,(\mathrm{exp}) \pm 0.004\,(\mathrm{LQCD})$$



$$|V_{cb}| = (3.27 \pm 0.15\,(\mathrm{exp}) \pm 0.17\,(\mathrm{theory}) \pm 0.06\,(|V_{cb}|)) \times 10^{-3}$$

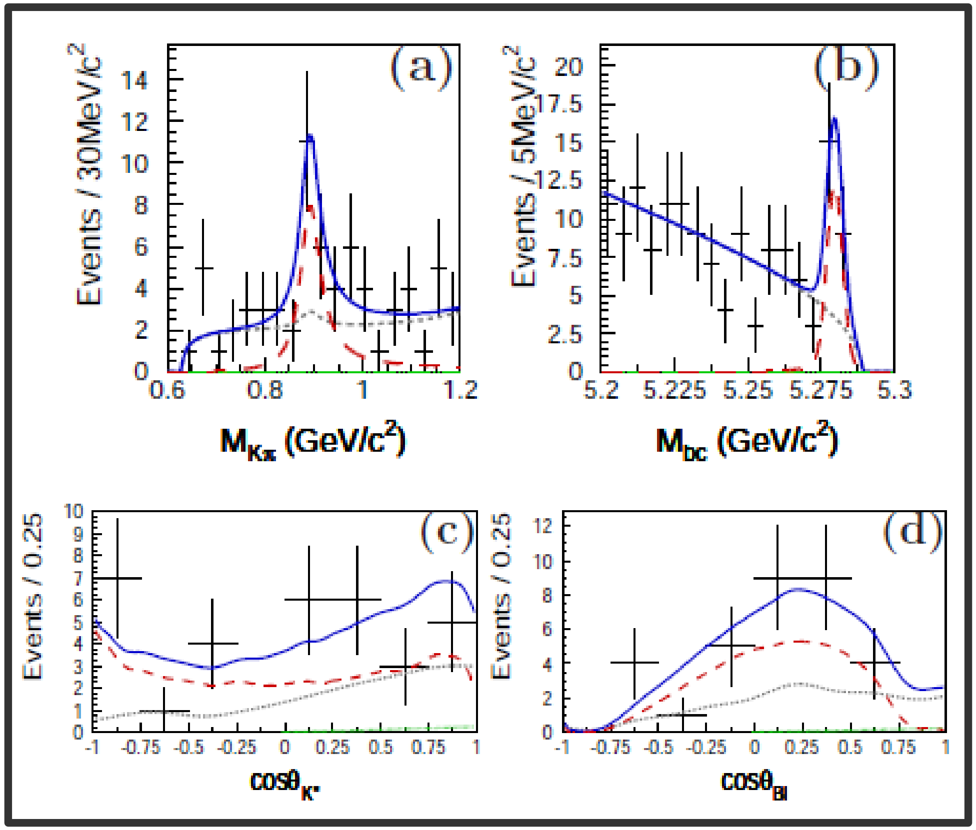
PAPER-2015-013

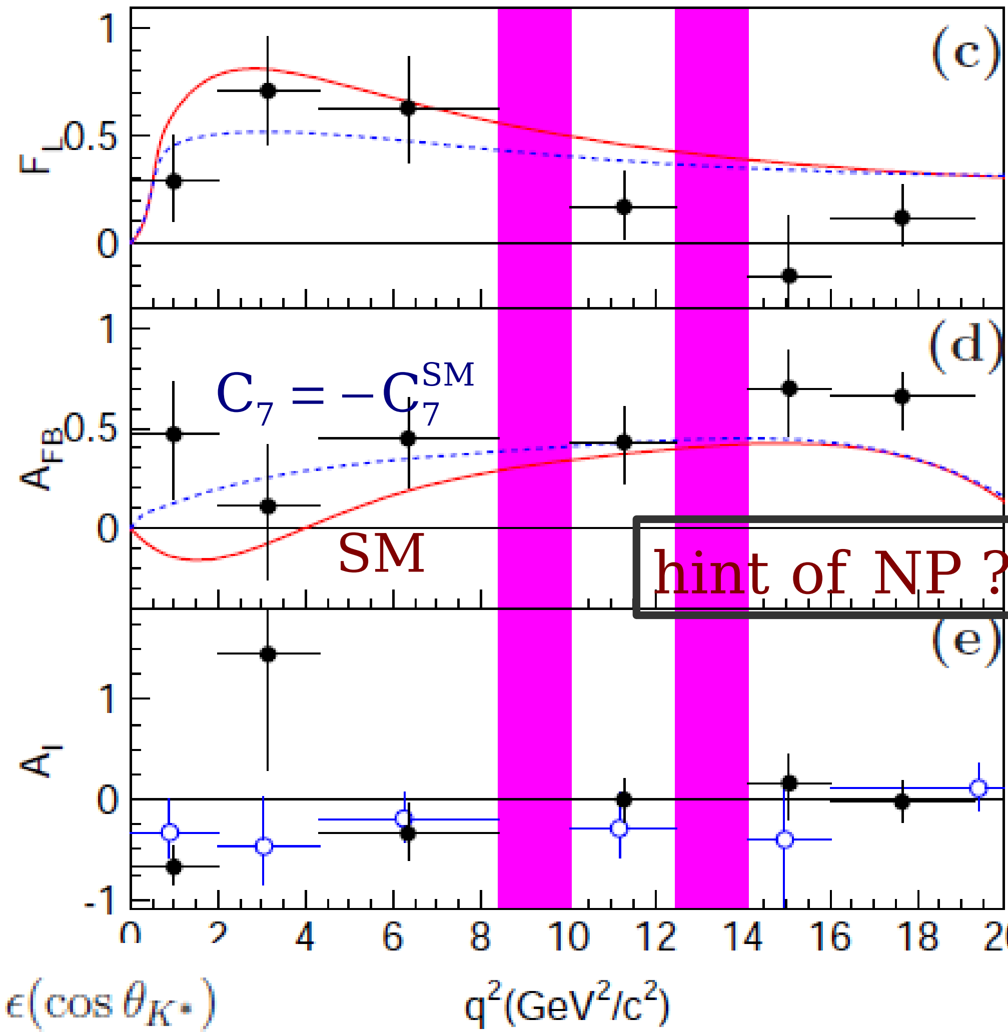
$B \to K^* l^+ l^-$ decays

- Channels: $K^* \to K^+\pi^-$, $K_S^0\pi^+$, $K^+\pi^0$, $l = e$ or μ

[arXiv:0904.0770]

illustration: $q^2 \in [0.0,\ 2,0]$ GeV^2





$$\left[\ \tfrac{3}{2}F_L\cos^2\theta_{K^*} + \tfrac{3}{4}(1-F_L)(1-\cos^2\theta_{K^*})\ \right]\ \times \epsilon(\cos\theta_{K^*})$$

$$\left[\ \tfrac{3}{4}F_L(1-\cos^2\theta_{B\ell}) + \tfrac{3}{8}(1-F_L)(1+\cos^2\theta_{B\ell}) + A_{FB}\cos\theta_{B\ell}\ \right] \times \epsilon(\cos\theta_{B\ell})\ ,$$

$R_{K^*} = 0.83 \pm 0.17 \pm 0.08$

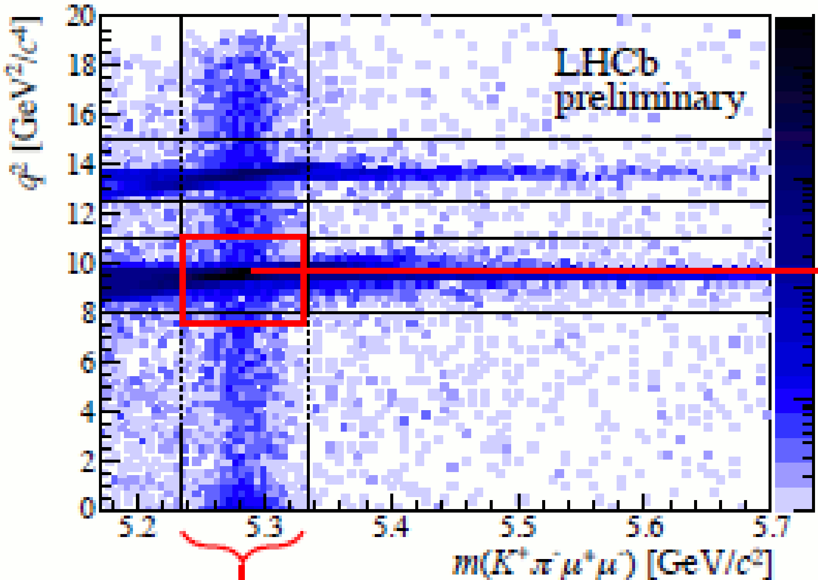
$R_K = 1.03 \pm 0.19 \pm 0.06$

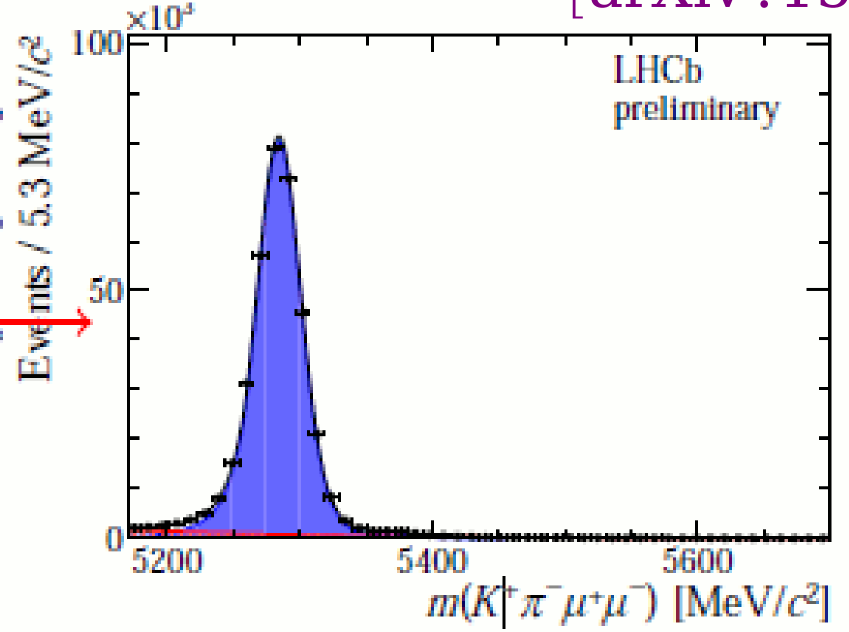
$R_K^{SM} = 1$, $R_{K^*}^{SM} = 0.75$ (photon pole !)

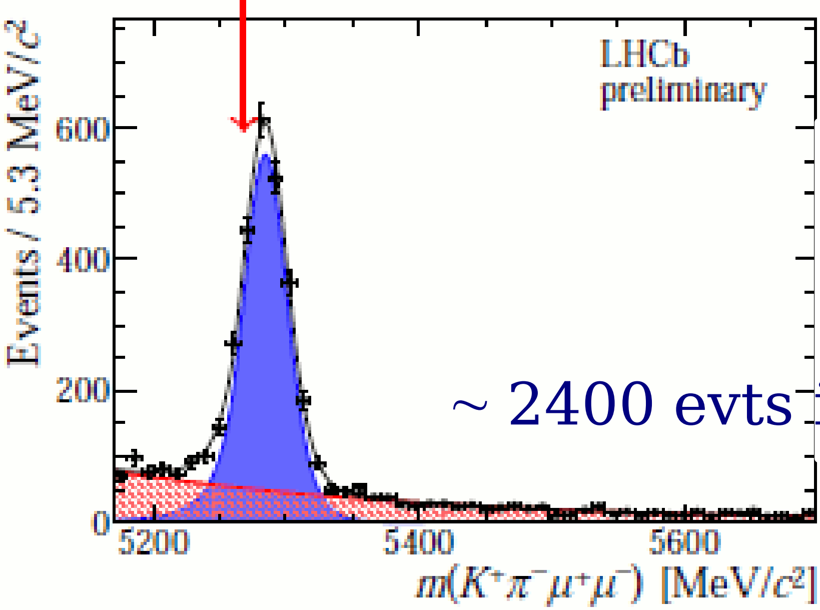
Angular analysis of $B_d^0 \to K^* \mu^+ \mu^-$ decays

- Channel: $B \to K^{*0}(\to K^+ \pi^-)\mu\mu$

[arXiv:1512.04442]







Selection:

BDT to reject combinatorial background

Veto of resonant modes (control modes)

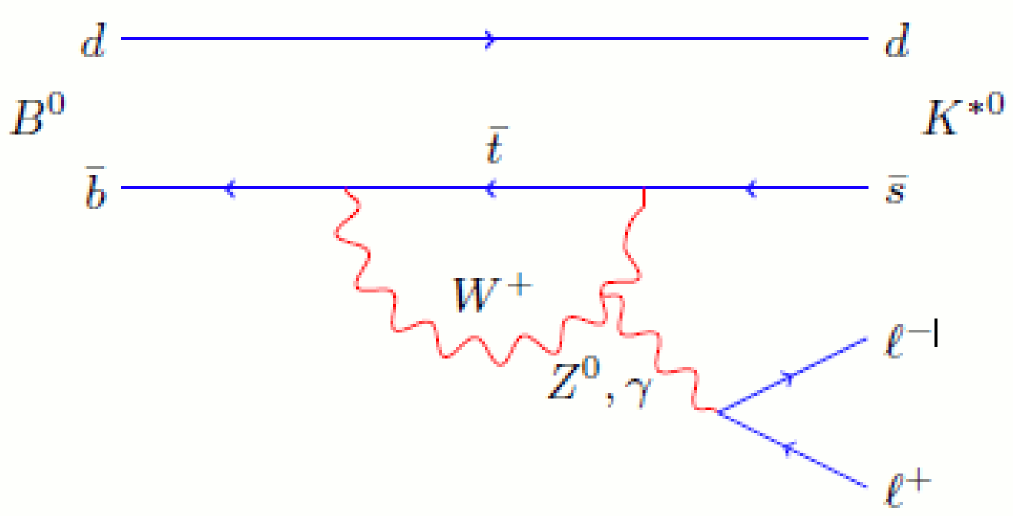
Selection

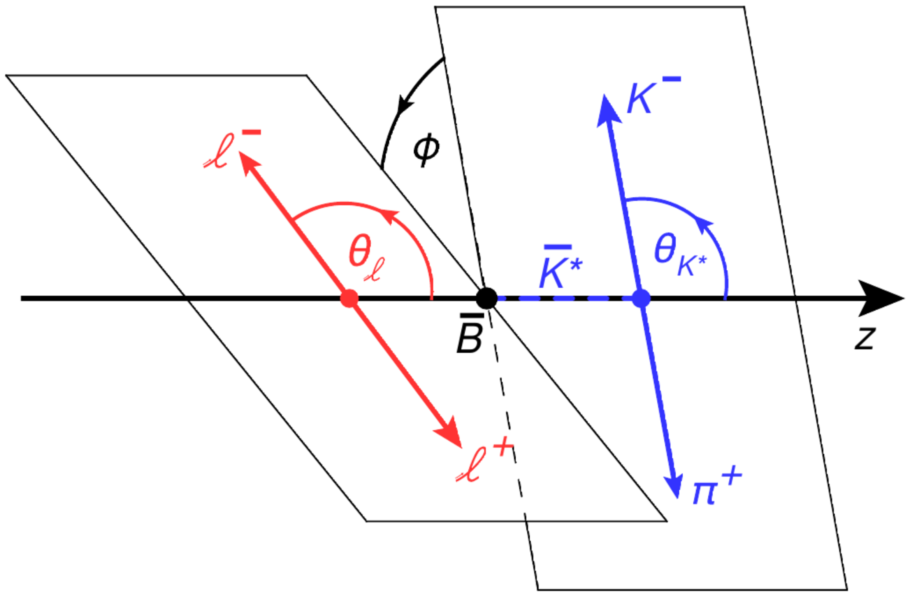
- BDT to reject combinatorial background
- Veto of resonant modes (used as control)

~ 2400 evts in the full q^2 range

Angular analysis of $B_d^0 \rightarrow K^* l^+ l^-$ decays

- Final state described by $q^2 = m_{ll}^2$ and three angles $\Omega = (\theta_l, \theta_K, \phi)$





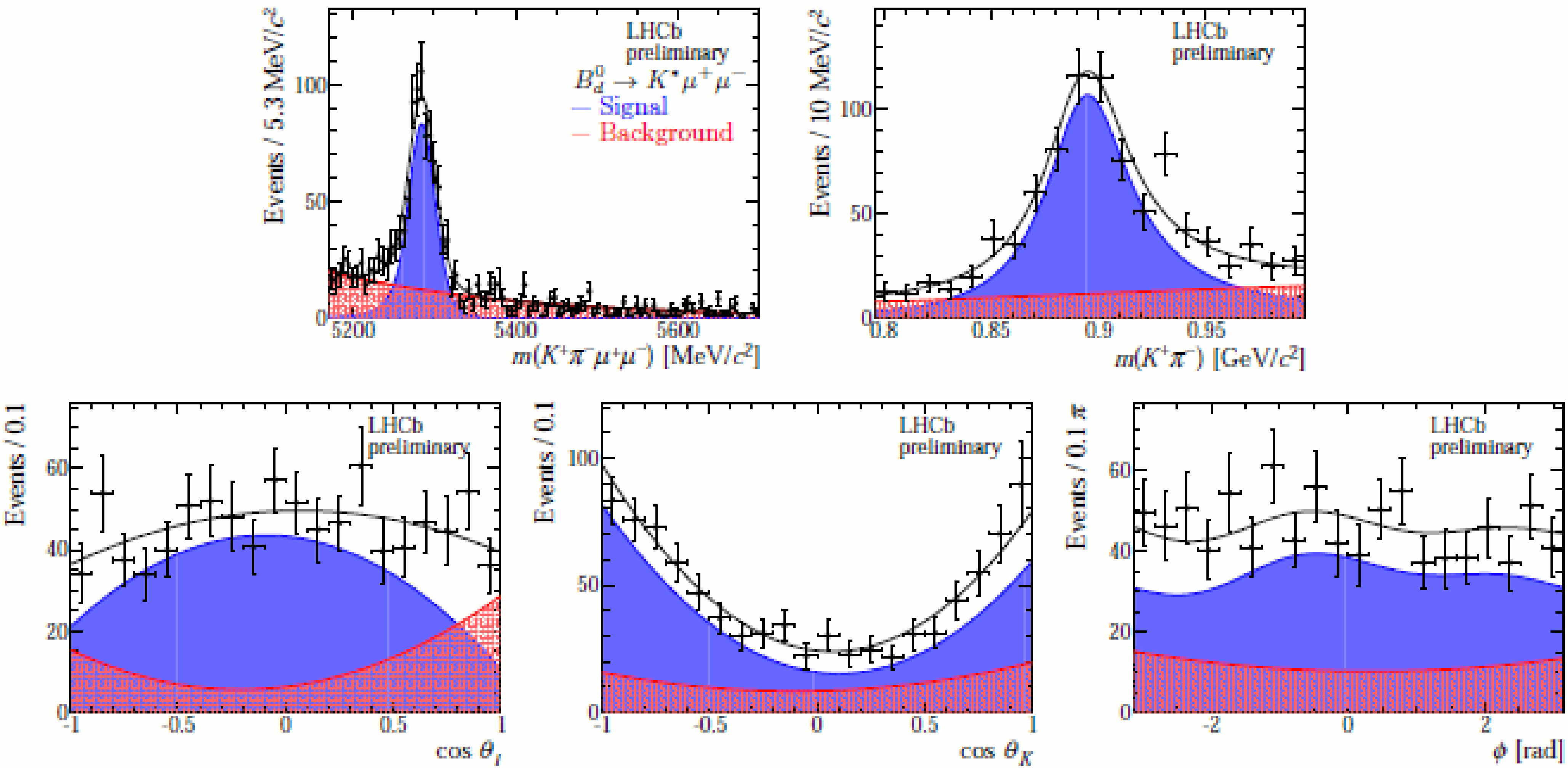
$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_{\mathrm{L}})\sin^2\theta_K + F_{\mathrm{L}}\cos^2\theta_K + \tfrac{1}{4}(1-F_{\mathrm{L}})\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_{\mathrm{L}}\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ \tfrac{4}{3}A_{\mathrm{FB}}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

- F_L, A_{FB}, S_i sensitive to $C_7^{(\prime)}$, $C_9^{(\prime)}$, $C_{10}^{(\prime)}$

Angular analysis of $B_d^0 \to K^* \mu^+ \mu^-$ decays

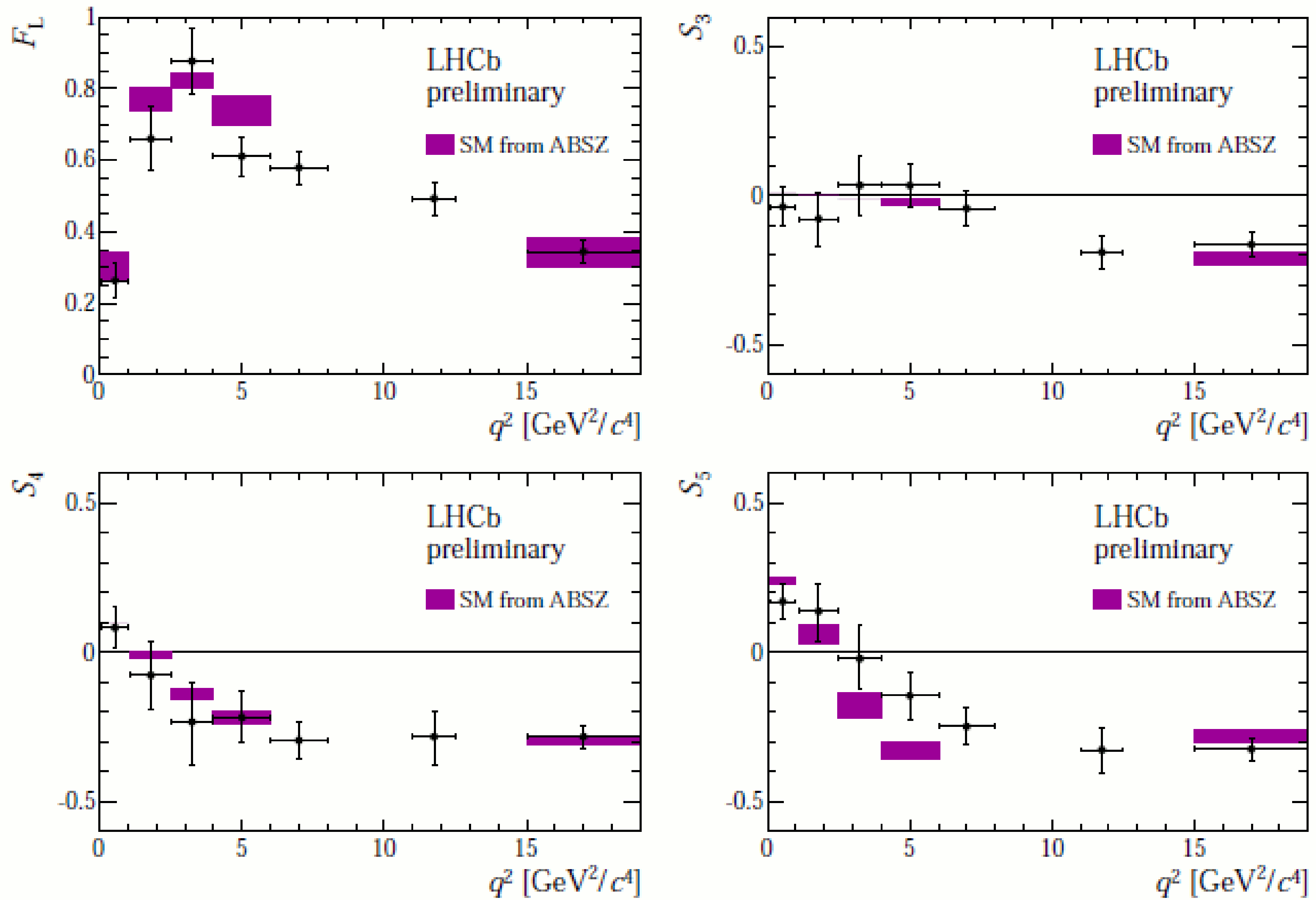
[arXiv:1512.04442]

- Projections of fit results for $q^2 \in [1.1, 6.0]$ GeV^2
- Good agreement of PDF projections with data in every bin of q^2



Angular analysis of $B_d^0 \to K^* \mu^+ \mu^-$ decays

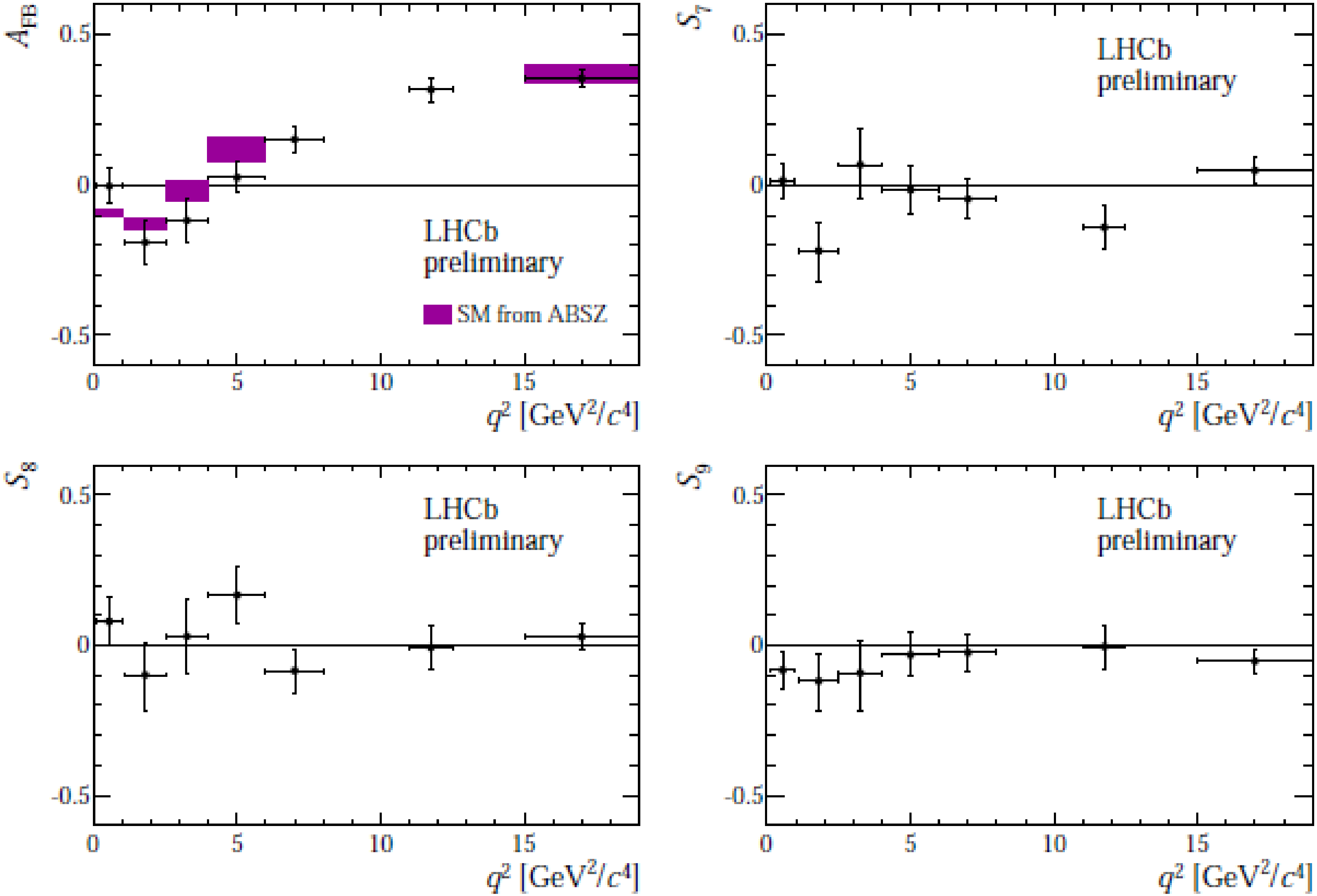
[arXiv:1512.04442]



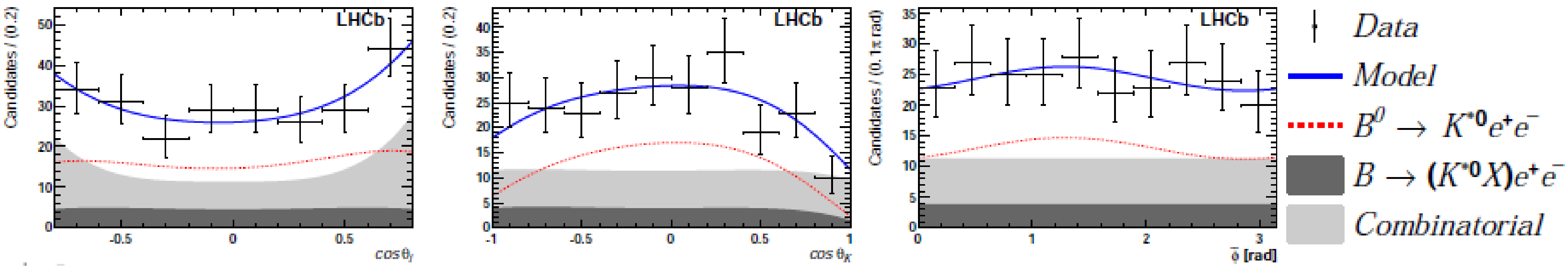
Angular analysis of $B_d^0 \to K^* \mu^+ \mu^-$ decays

[arXiv:1512.04442]

data points systematically lower than SM



Angular analysis of $B_d^0 \to K^* e^+ e^-$ decays [arXiv:1501.03038]

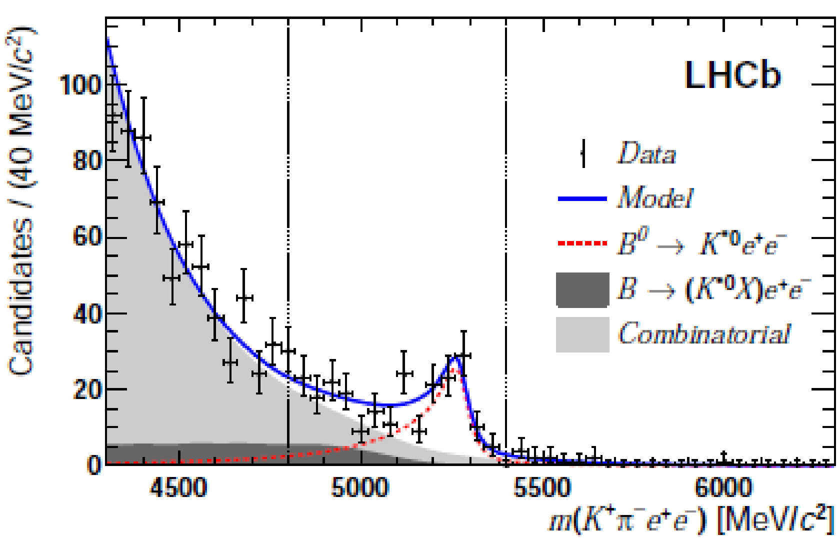


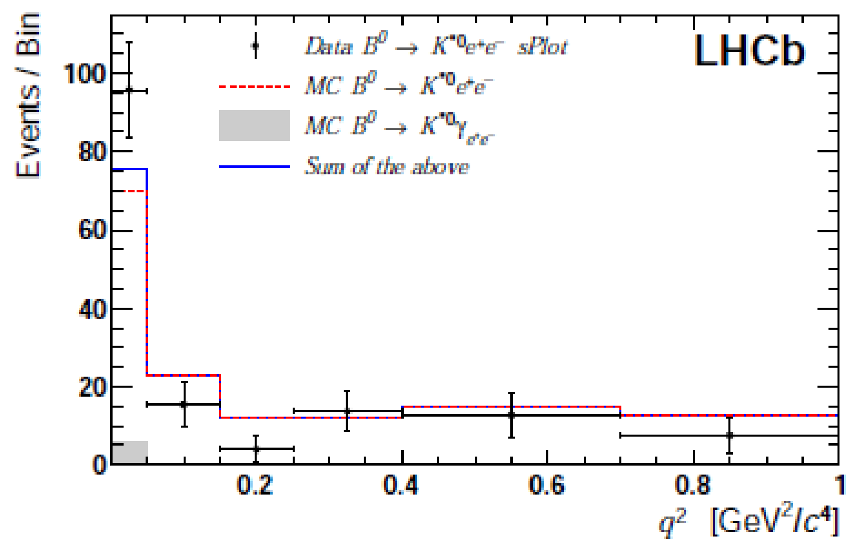
- Measurements in agreement with SM predictions
- Constraints on C_7', complementary with radiative decays

Observable	Measurement	SM prediction†
F_L	$+0.16 \pm 0.06 \pm 0.03$	$+0.10^{+0.11}_{-0.05}$
$A_T^{(2)}$	$-0.23 \pm 0.23 \pm 0.05$	$0.03^{+0.05}_{-0.04}$
A_T^{Re}	$+0.10 \pm 0.18 \pm 0.05$	$-0.15^{+0.04}_{-0.03}$
A_T^{Im}	$+0.14 \pm 0.22 \pm 0.05$	$(-0.2^{+1.2}_{-1.2}) \times 10^{-4}$

S. Jager, J.M. Camalich [arXiv:1412.3283]

- Angular analysis of $B_d^0 \to K^* e^+ e^-$ at very low q^2 ($\in [0.002, 1.120]$ GeV^2)
- Folded angular observables ($\phi = \phi + \pi$ if $\phi < 0$)
- Measurement of F_L, $A_T^{(2)}$, $A_T^{(Im)}$, $A_T^{(Re)}$, sensitive to C_7' as $q^2 \to 0$



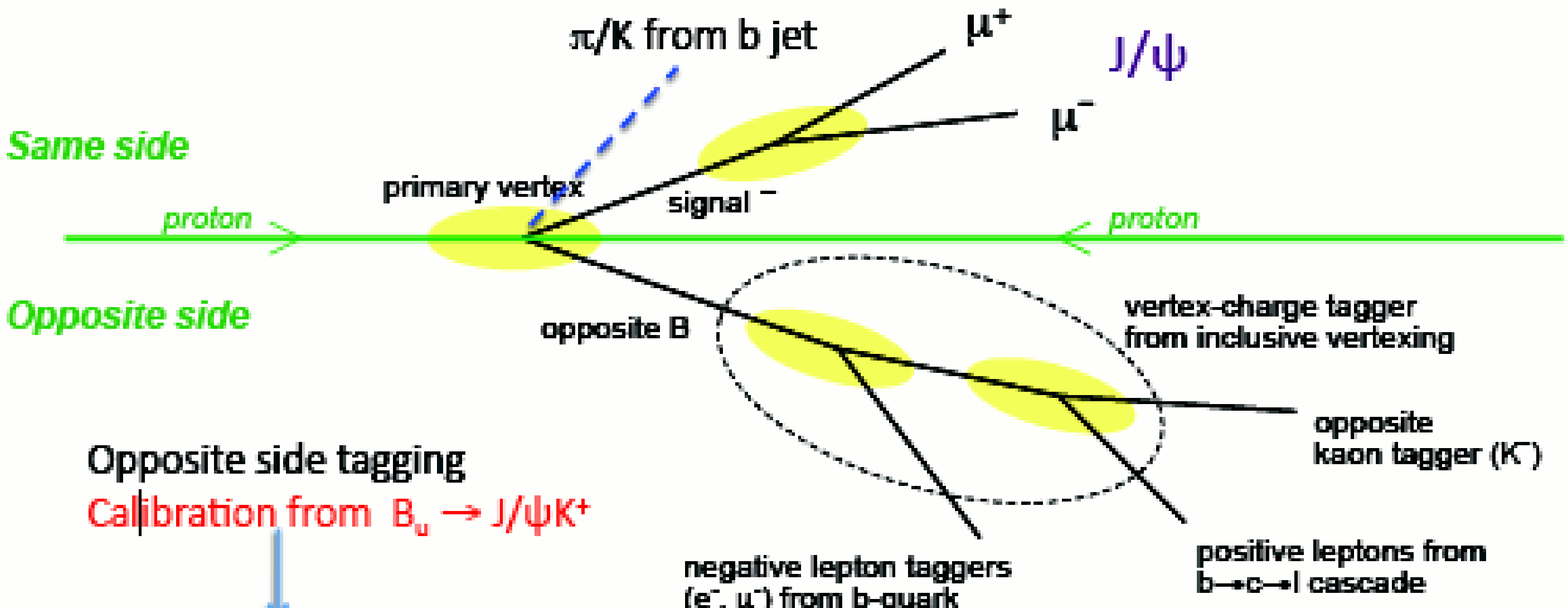


$$A_T^{(Re)} = \frac{4}{3} A_{FB}/(1 - F_L), \quad A_T^{(2)} = \frac{1}{2} S_3/(1 - F_L) \text{ and } A_T = \frac{1}{2} S_9/(1 - F_L)$$

Flavour-Tagging at LHCb

tagging efficiency ε_{tag} ~ 50%
effective mistag ω_{tag} ~ 39%
effective tagging power $\varepsilon_{tag}(1-2\omega_{tag})^2$ ~ 2.4%

Same side Kaon tagging
Calibration from $B_s \to D_s\pi$



Opposite side tagging
Calibration from $B_u \to J/\psi K^+$

tagging efficiency ε_{tag} ~ 65%
effective mistag ω_{tag} ~ 39%
effective tagging power $\varepsilon_{tag}(1-2\omega_{tag})^2$ ~ 3.0%

Channel	ϵ_{eff} [%] 2011	Run I	Imprvt	Reference
$B_s^0 \to \phi\phi$	3.29	5.38	+64%	[Phys. Rev. D90 (2014) 052011]
$B_s^0 \to D_s^+ D_s^+$		5.33		[Phys. Rev. Lett. 113 (2014) 211801]
$B_s^0 \to D_s^+ K^-$	5.07			[JHEP 11 (2014) 060]
$B_s^0 \to J/\psi K^+ K^-$	3.13	3.73	+19%	[Phys. Rev. Lett. 114 (2015) 041801]
$B_s^0 \to J/\psi \pi^+\pi^-$	2.43	3.89	+60%	[Phys. Lett. B736 (2014) 186]
$B^0 \to J/\psi K_S^0$	2.38	3.03	+27%	[Phys. Rev. Lett. 115 (2015) 031601]
$B_s^0 \to J/\psi \phi$	1.45	1.49	+3%	Preliminary
$B_s^0 \to J/\psi \phi$	0.97	1.31	+35%	[arXiv:1507.07527]

Impressive improvements in tagging performance in the last 3 years

Results for $B_s \to J/\psi\, h^+ h^-$ at LHCb

CP violating phase [3 fb^{-1}, arXiv:1411.3104]

$$\phi_s = -0.058 \pm 0.049 \pm 0.006$$

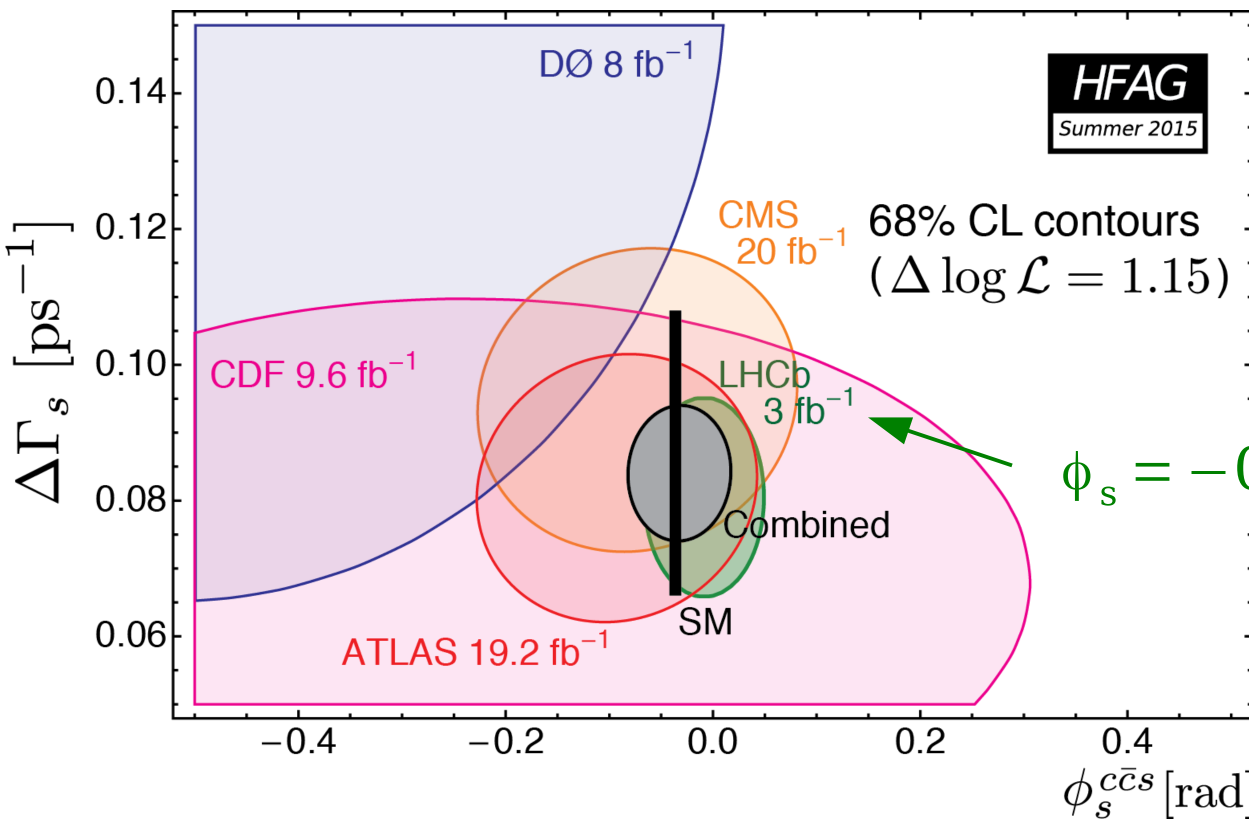
CP violating in mixing or direct decay (no CPV: $|\lambda| = 1$)

$$|\lambda| = 0.964 \pm 0.019 \pm 0.007$$

Decay width difference $\Delta\Gamma_s = (\Gamma_L - \Gamma_H) = 0.0805 \pm 0.0091 \pm 0.0032\ ps^{-1}$

$\Delta\Gamma_s(SM) = 0.087 \pm 0.021\ ps^{-1}$

$\phi_s(SM) = -0.0363\ ^{+0.0012}_{-0.0014}$ rad



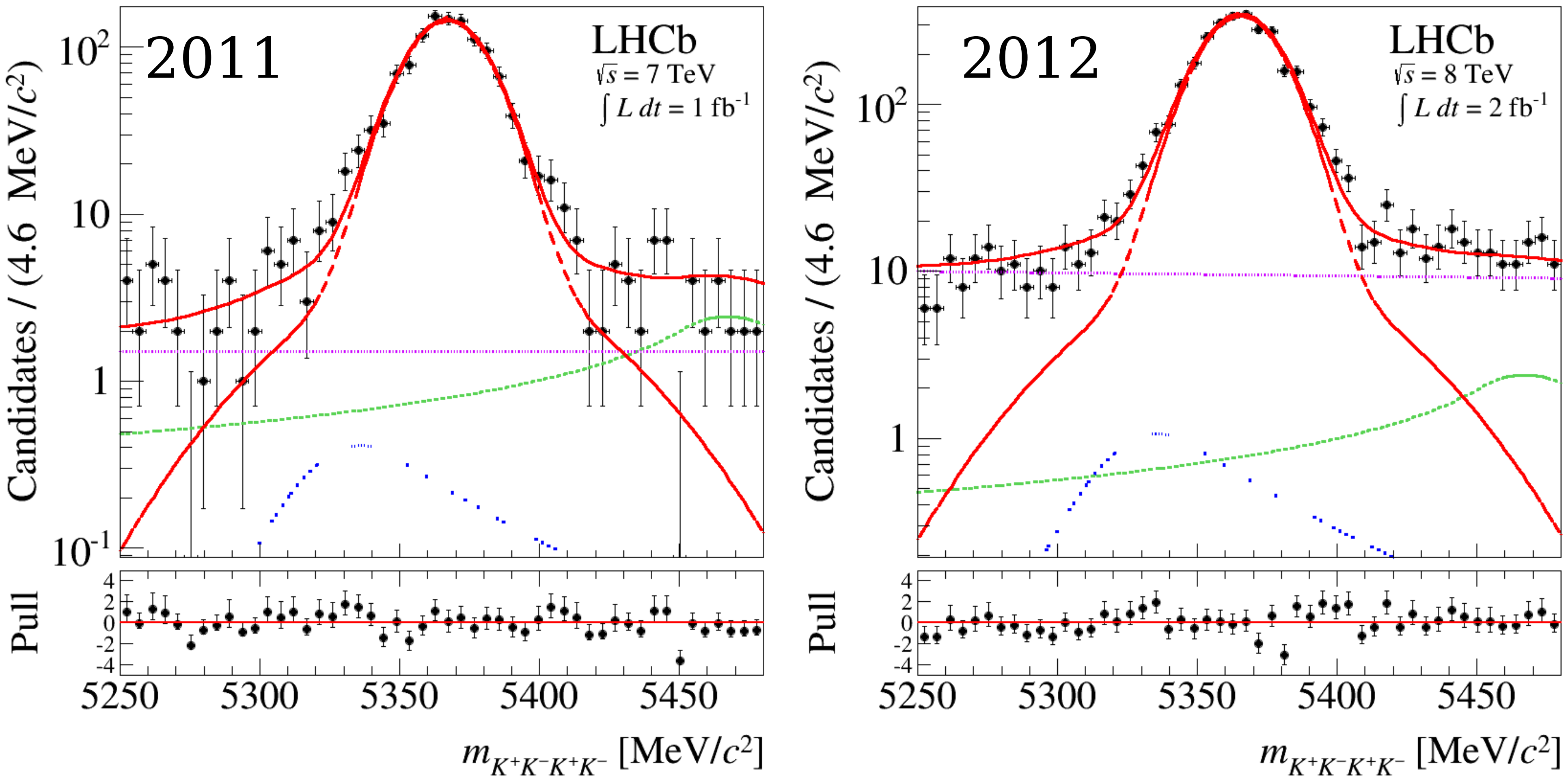
$$\phi_s = -0.010 \pm 0.039 \text{ rad}$$

[combined with $J/\psi\pi\pi$]

$B_s \to \phi\phi$

[arXiv:1407.2222]

$\bar{b} \to \bar{s} s \bar{s}$ loop process



- 4000 signal events
- Combinatorial background is flat and small
- Very small contributions from mis-ID of $B_d \to \phi K^{*0}$ and $\Lambda_b \to \phi p K$
- mixture of CP eigenstates ⇒ angular analysis in helicity basis

$$\phi_s = -0.17 \pm 0.15 \pm 0.03 \text{ rad}$$

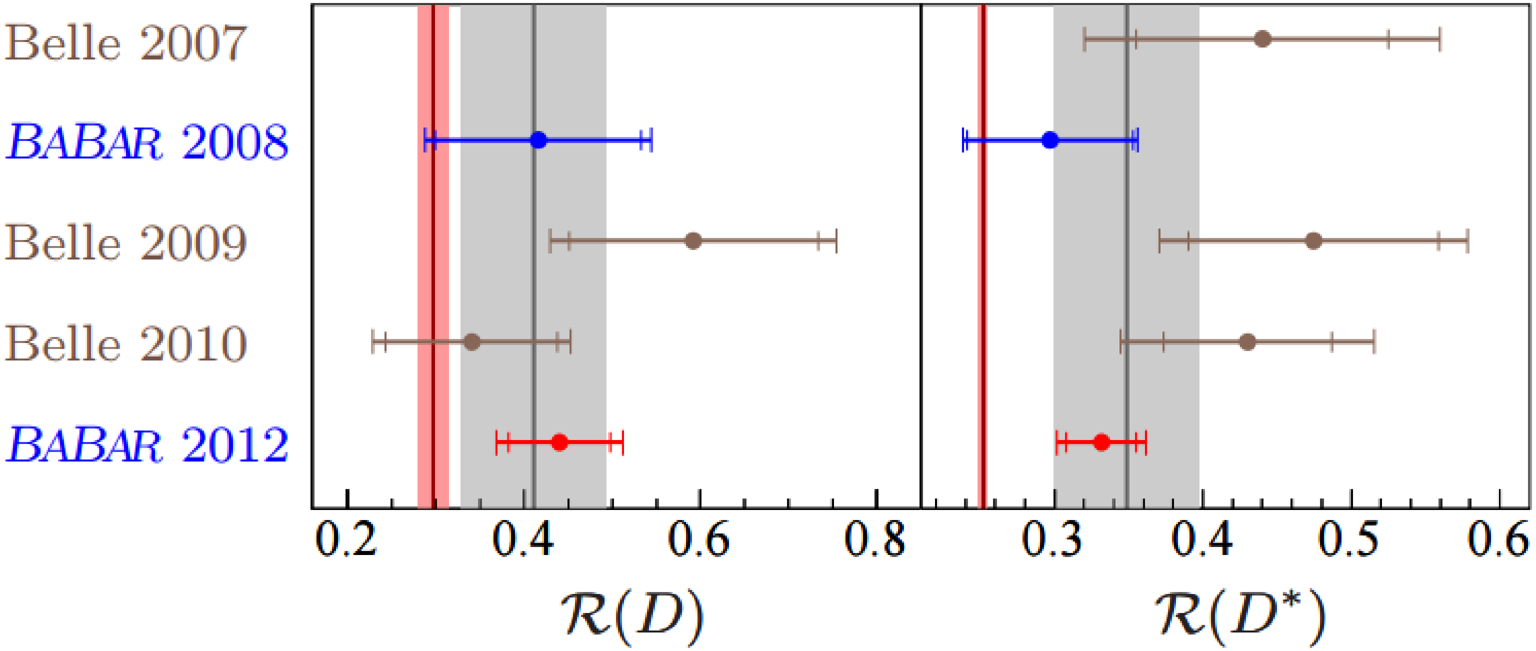
$\phi_s(c\bar{c}s) \sim -0.01 \pm 0.04$ rad

$\phi_s(\mathrm{SM}) = -0.0363^{+0.0012}_{-0.0014}$

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

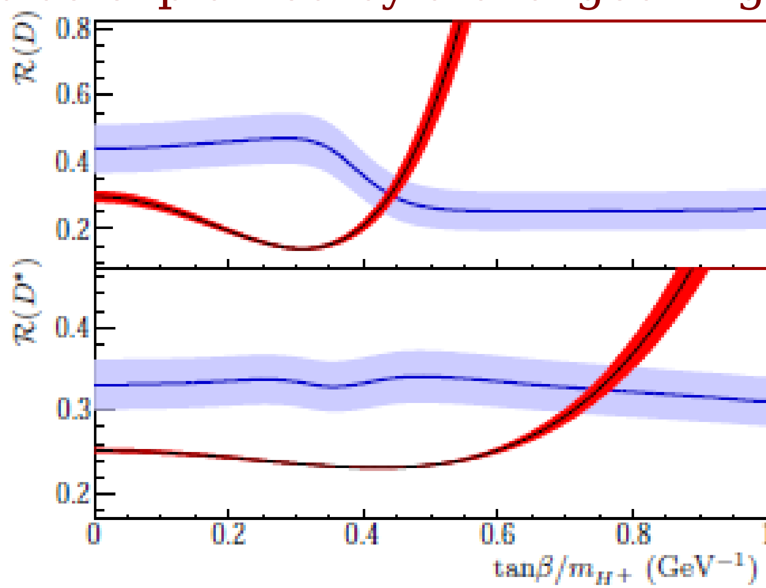
$$R(D^{(*)}) = \frac{B \to D^{(*)} \tau \nu}{B \to D^{(*)} l \nu}$$

Babar and Belle measurements hint to deviation from SM



BaBar (arXiv:1303.0571) observes a 3.4σ excess over SM expectation

''This excess cannot be explained by a charged Higgs boson in the 2HDM type II ''



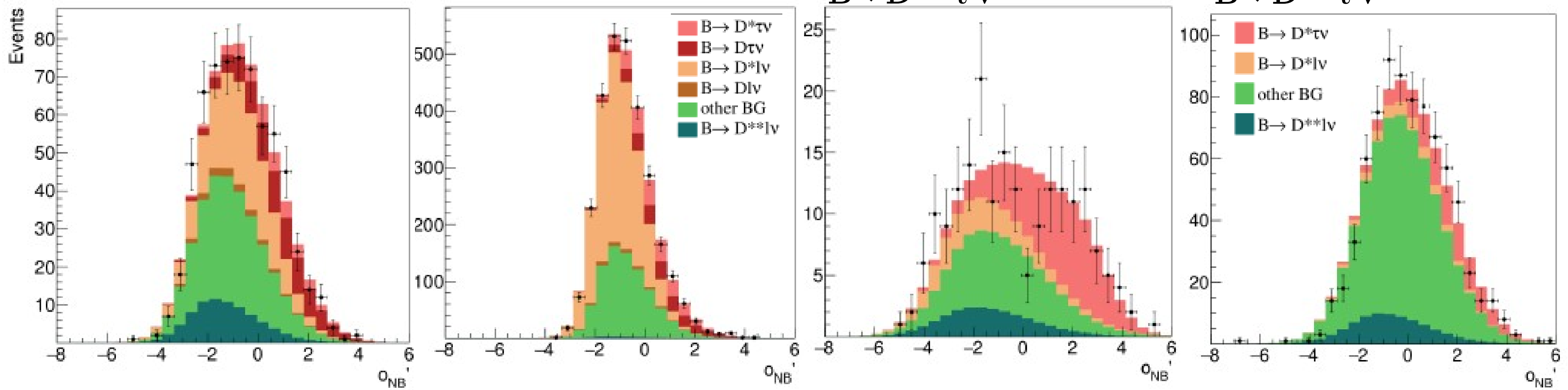
$B \to D^{(*)} \tau \nu$ at Belle

[arXiv:1507.03233]

(with hadronic tagging)

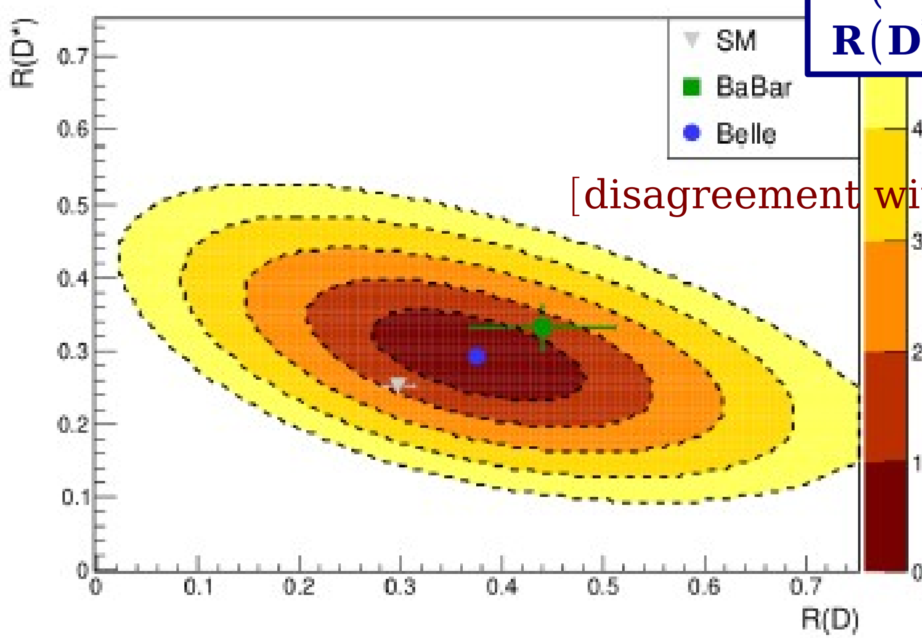
projections for large M^2_{miss} region, $N(D\tau\nu) \sim 300$, $N(D^*\tau\nu) \sim 500$

$B \to D^+ \tau \nu$ $\quad$ $B \to D^0 \tau \nu$ $\quad$ $B \to D^{*+} \tau \nu$ $\quad$ $B \to D^{*0} \tau \nu$



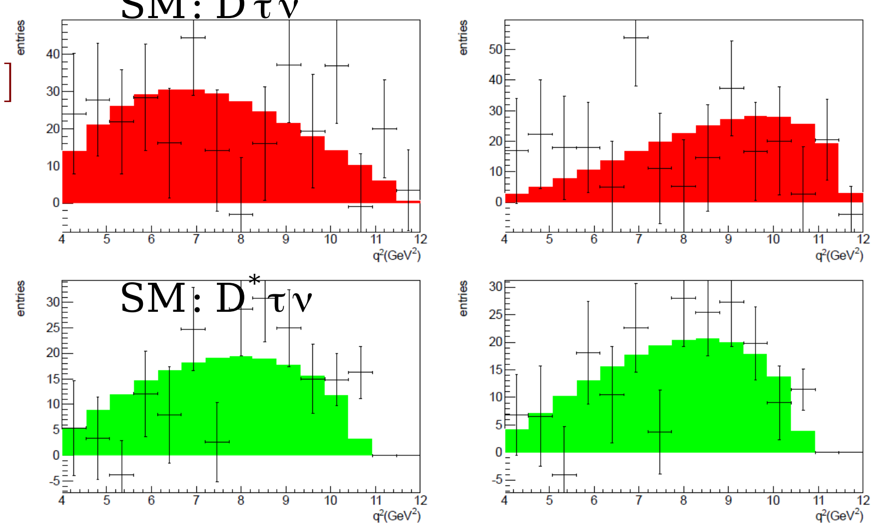
$R(D) = 0.375 \pm 0.064 \pm 0.026$

$R(D^*) = 0.293 \pm 0.038 \pm 0.015$



[disagreement with SM at 1.5σ]

stat error only !



$B \to D^{*+} \tau \nu$ at LHCb

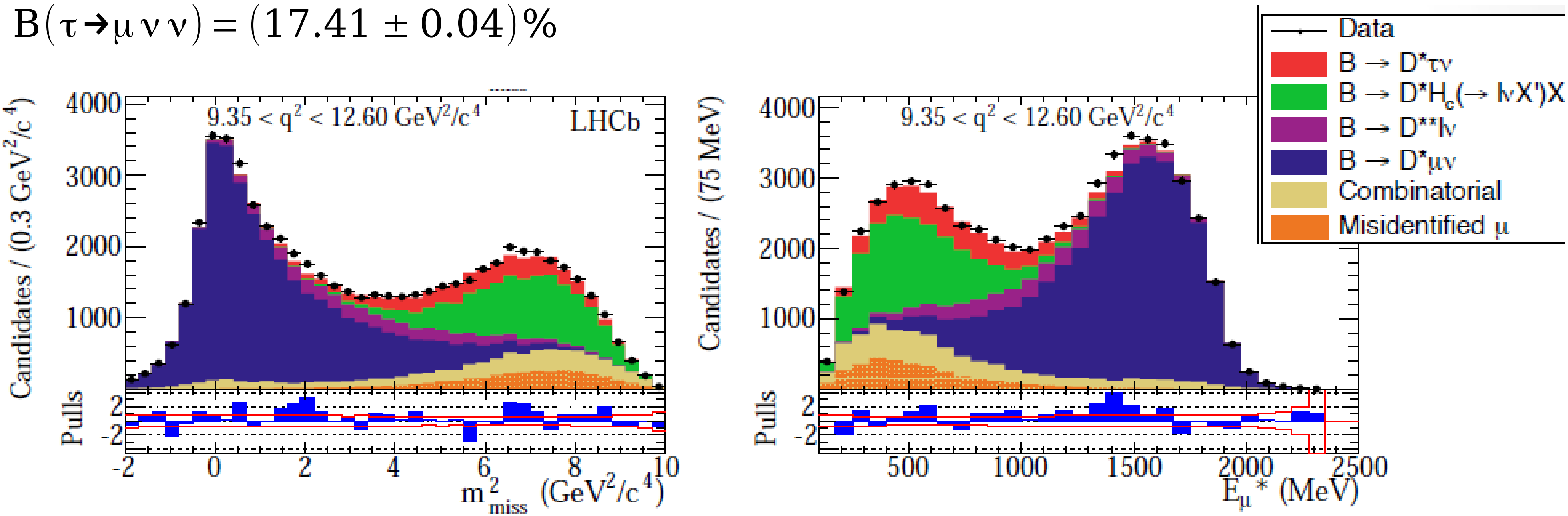
[arXiv:1506.08614]

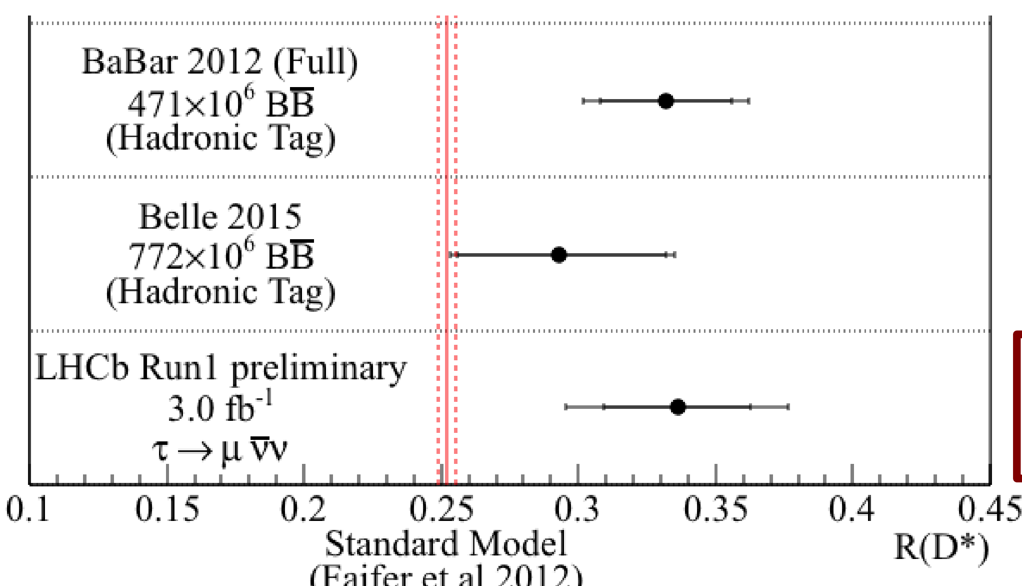
$$R(D^*) \equiv \frac{\mathcal{B}\left(\bar{B}^0 \to D^{*+}\tau^-(\mu^-\bar{\nu}_\mu \nu_\tau)\bar{\nu}_\tau\right)}{\mathcal{B}\left(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu\right)}$$

363,000 ± 1,600 events in $D^*\mu\nu$ sample

$N(D^*\tau\nu)/N(D^*\mu\nu) = (4.54 \pm 0.46)\%$

$B(\tau \to \mu\nu\nu) = (17.41 \pm 0.04)\%$





$R(D^*) = 0.332 \pm 0.024 \pm 0.018$

$R(D^*) = 0.293 \pm 0.038 \pm 0.015$

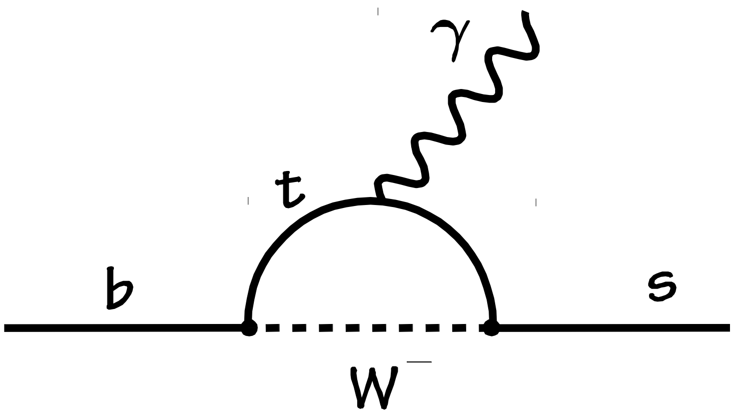
[arXiv:1507.03233]

$R(D^*) = 0.336 \pm 0.027 \pm 0.030$

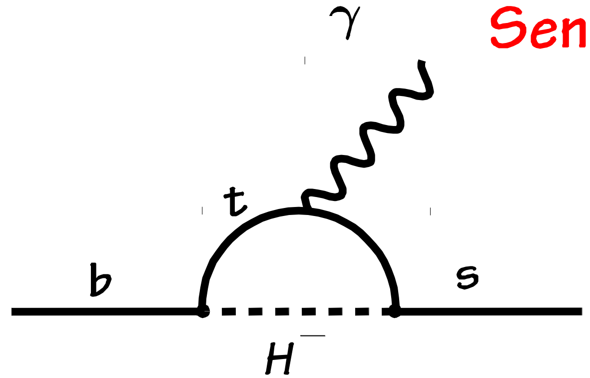
[disagreement with SM at 2.1 σ]

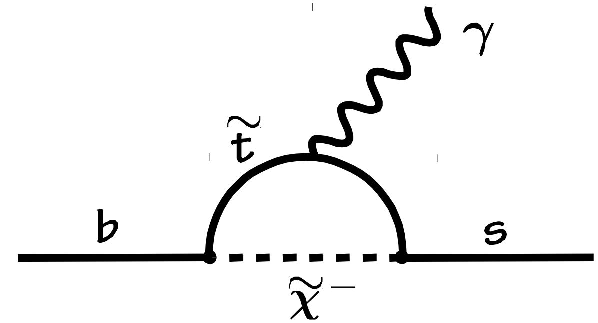
[arXiv:1506.08614]

$B \rightarrow X_s \gamma$



Sensitive to NP





NNLO SM calculation:

$B_{SM}(B \rightarrow X_s \gamma) = (3.36 \pm 0.23) \times 10^{-4}$

(for $E_\gamma > 1.6$ GeV)

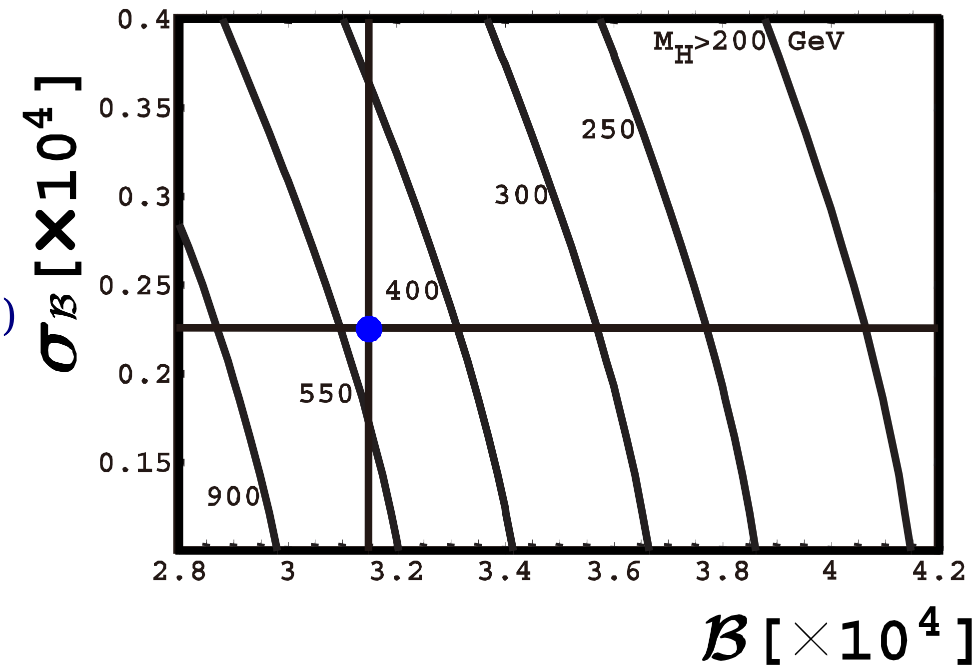
M.Misiak et al.
[arXiv:1503.01789]

(central value increased by 6.4% compared to 2007 value)

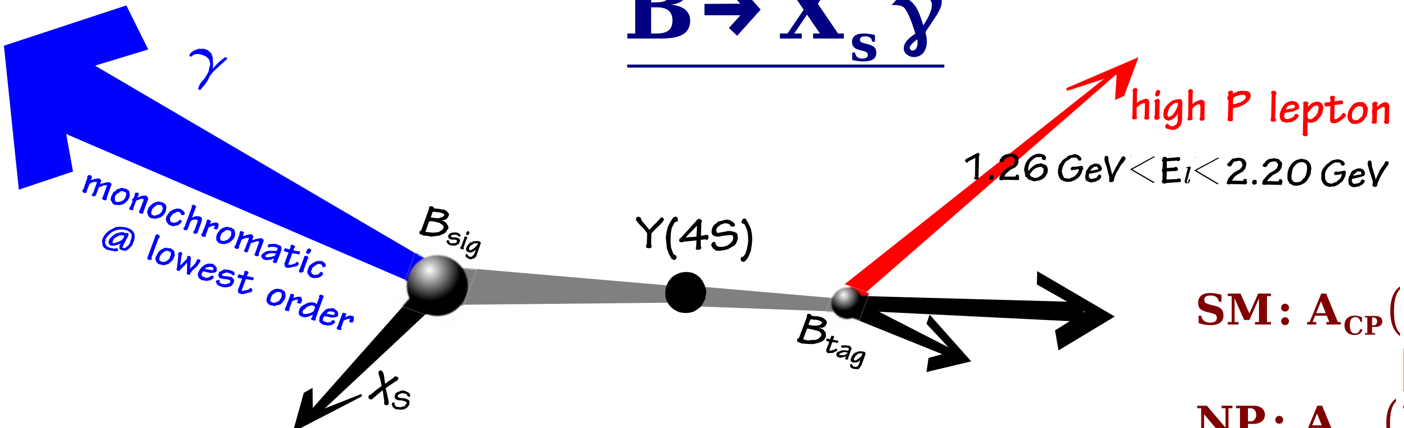
PRL 98, 022002 (2007)

The lower γ energy threshold, the smaller the model uncertainties in SM, but the larger background in measurement

Charged Higgs (2HDM Type II) bound



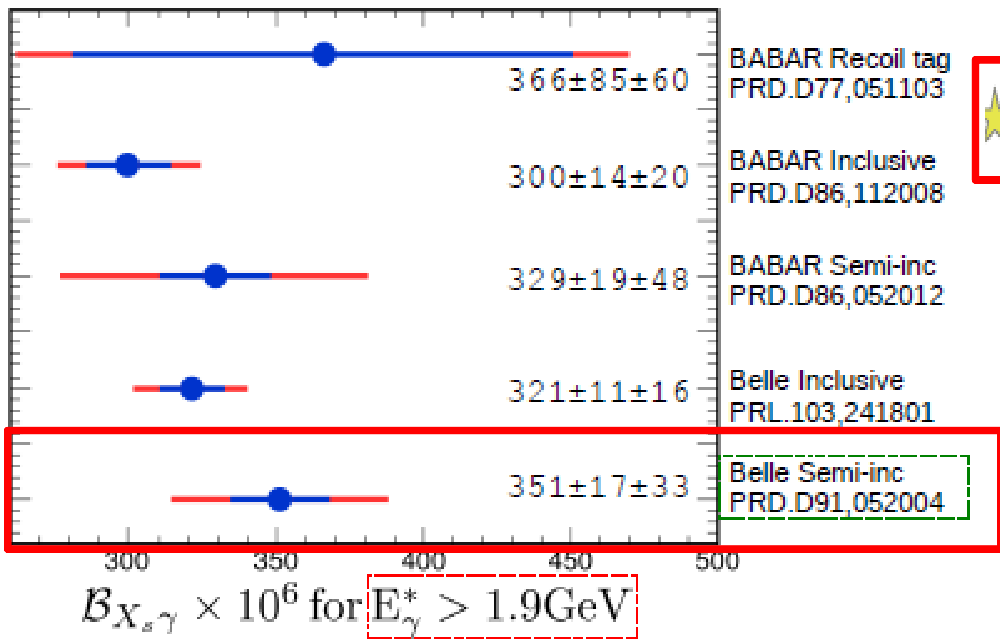
$B \to X_s \gamma$

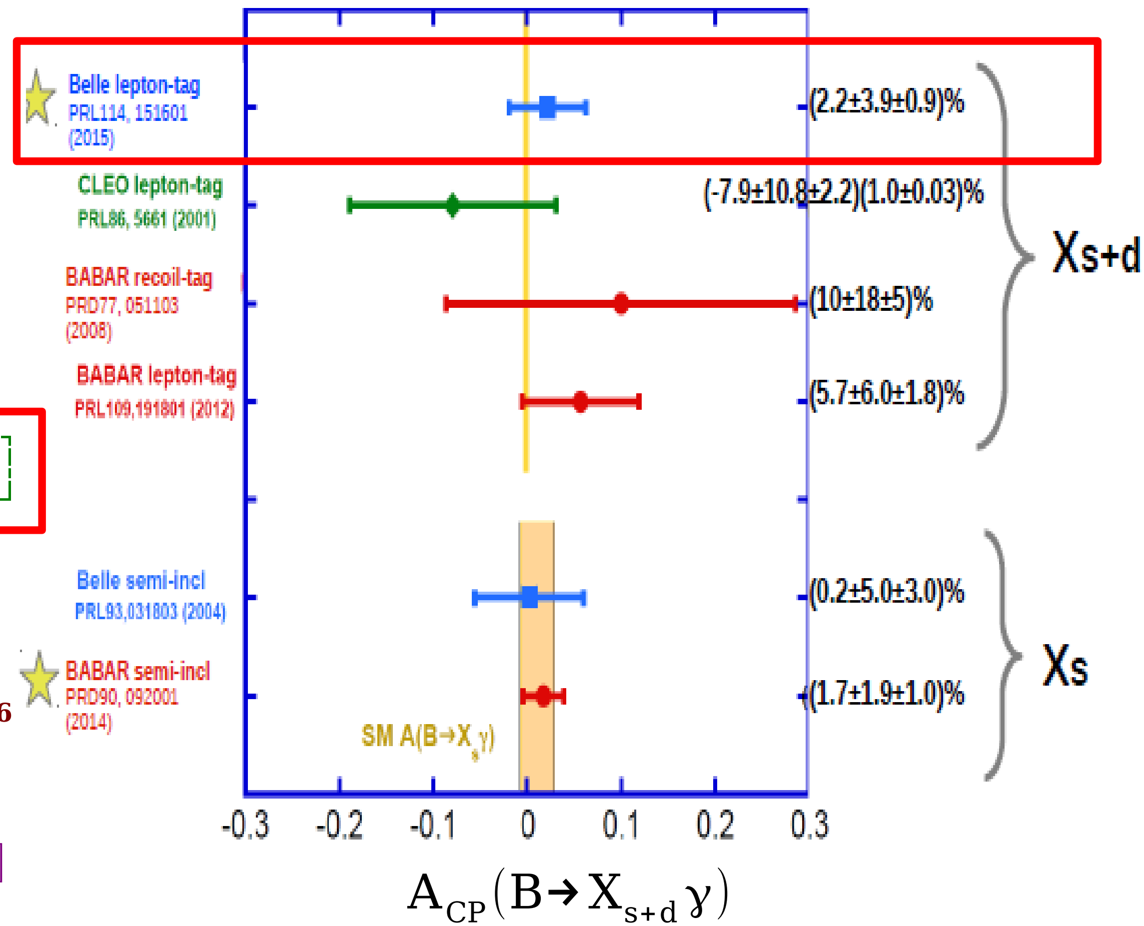


SM: $A_{CP}(B \to X_{s+d}\gamma) = 0$ to order 10^{-6}

[Hurth and Mannel, 2001]

NP: $A_{CP}(B \to X_{s+d}\gamma)$ as large as 10%





at $E_\gamma > 1.6$ GeV:

$\mathcal{B}(B \to X_s\gamma) = (341 \pm 15 \pm 4\ (\text{extrap})) \times 10^{-6}$

$B_{SM}(B \to X_s\gamma) = (336 \pm 23) \times 10^{-6}$

[Misiak et al, arXiv:1503.01789]

For charged Higgs in 2HDM Type II
$M(H^-) > 540$ GeV at 95% CL

$\Rightarrow$ **limited by statistics: Belle II...**