Upgrades of Belle II (beyond Int(L dt) = 50 ab^{-1} up to 250 ab^{-1})

Tom Browder (University of Hawai'i)
Mike Roney (University of Victoria)

Some of the relevant Snowmass White Papers, describing future physics opportunities at *Belle II*

Executive Summary of Belle II/SuperKEKB White Papers: https://arxiv.org/abs/2203.10203

Belle II Detector Upgrades White Paper https://arxiv.org/abs/2203.11349
SuperKEKB Electron Polarization Upgrade White Paper
https://drive.google.com/file/d/14vnE4U0spOJBJwPhQA7pVybHlq-MvobQ/view
Belle II Physics Program White Paper
https://www.slac.stanford.edu/~mpeskin/Snowmass2021/BelleIIPhysicsforSnowmass.pdf

Opportunities for Precision QCD at Belle II https://arxiv.org/abs/2204.02280
Charged Lepton Flavor Violation in the Tau Sector
(joint paper of Belle II and other future experiments) https://arxiv.org/abs/2203.14919

See talks by Anselm Vossen and Swagato Banerjee.

New Hadrons by Bryan Fulsom

https://arxiv.org/abs/2203.06827, MC simulation of NP and Delta Observables for $B \rightarrow K^* l^+ l^-$

https://arxiv.org/abs/2203.07189, MC simulation of NP and Delta Observables for $B \rightarrow D^* l \nu$

See talks by Rusa Mandal and Lopa Mukherjee

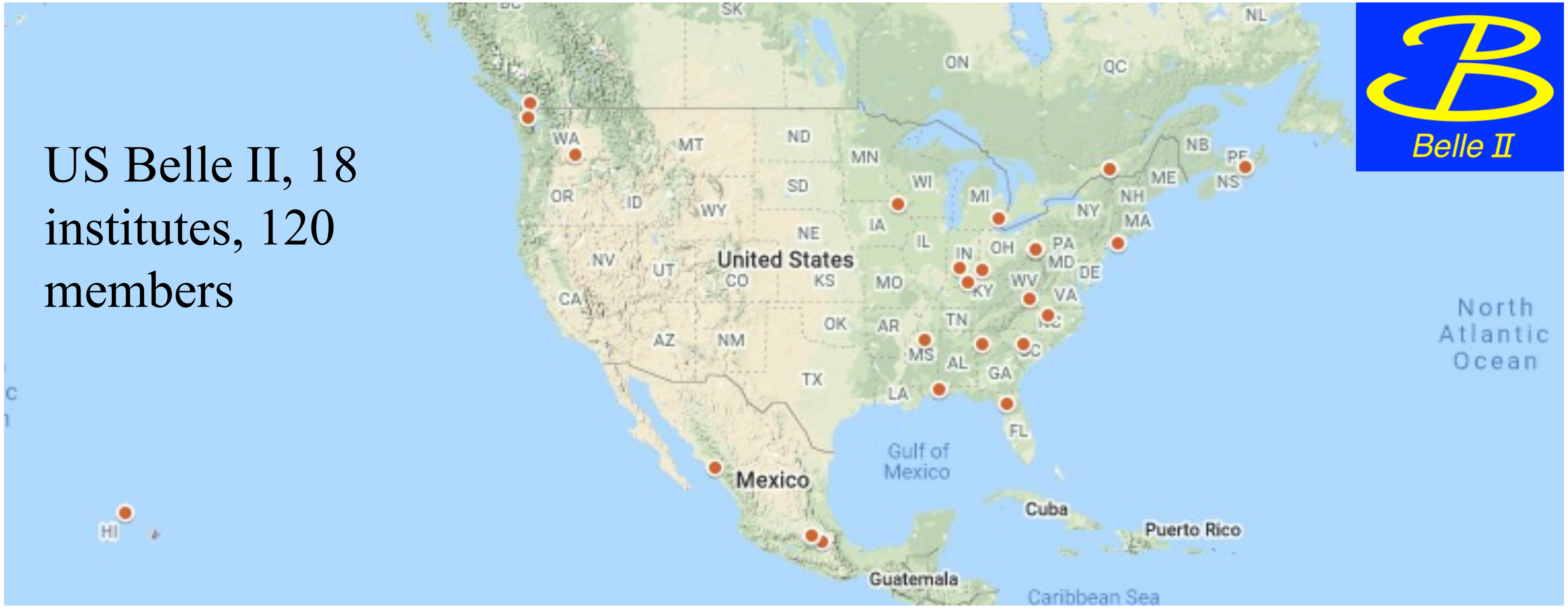
The Geography of the International Belle II collaboration

Belle II now has grown to ~1000 researchers from 26 countries

This is rather unique in Japan. The only comparable example is the T2K experiment at JPARC, which is also an international collaboration

Youth and potential: There are ~330 graduate students in the collaboration

US Belle II, 18 institutes, 120 members



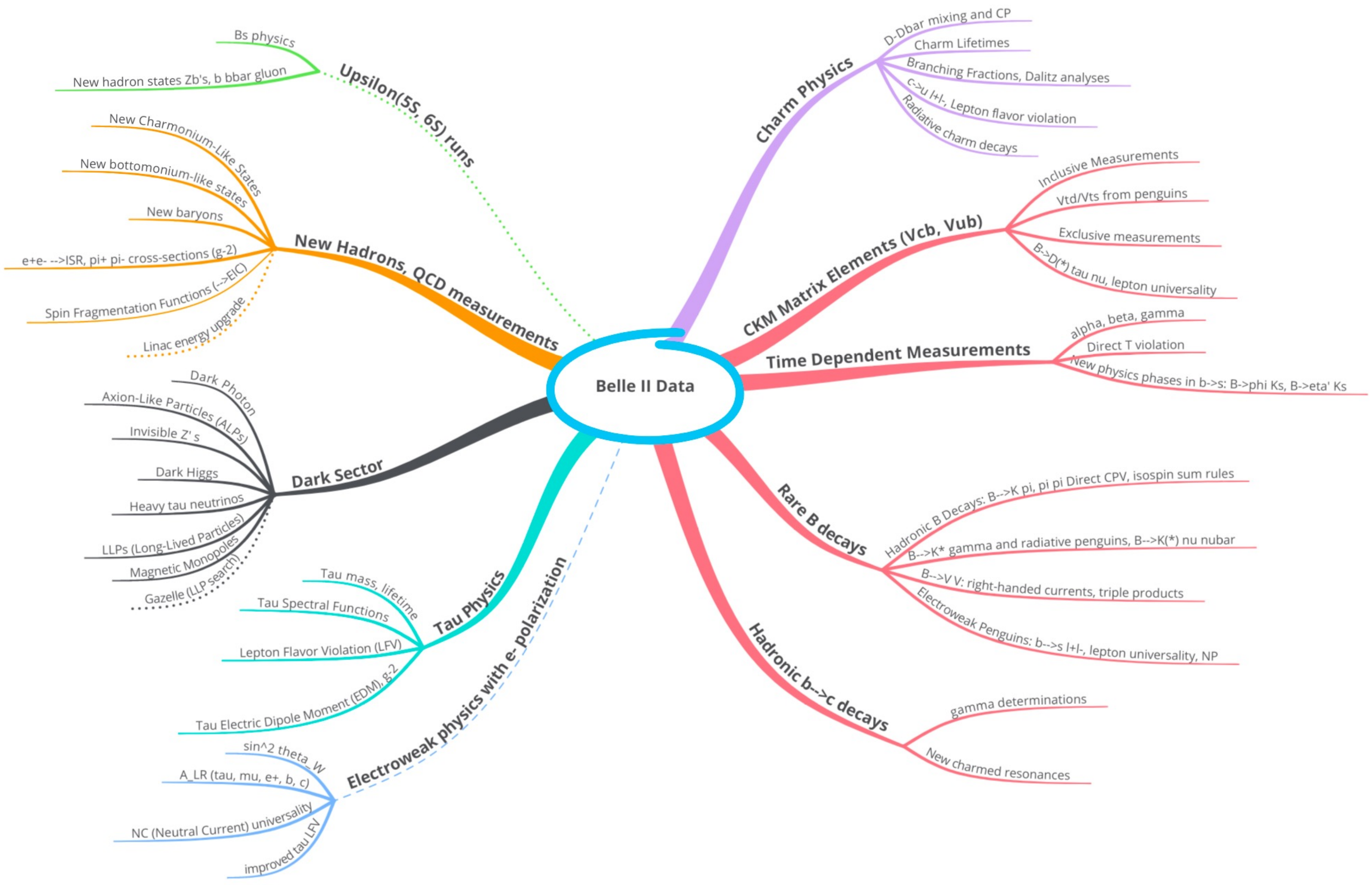
Brookhaven National Laboratory (BNL)
Carnegie Mellon University
Duke University
Iowa State University
Indiana University
Kennesaw State University
Luther College
Pacific Northwest National Laboratory (PNNL)
Virginia Tech

University of Cincinnati
University of Florida
University of Hawai'i
University of Louisville
University of Mississippi
University of Pittsburgh
University of South Alabama
University of South Carolina
Wayne State University

Belle II Physics "Mind Map" for Snowmass 2022

Wealth of new physics possibilities in different domains of HEP (weak, strong, electroweak interactions). Many opportunities for *initiatives* by young scientists.

Belle II



Today, we focus on the B physics neurons and briefly touch the ElectroWeak polarization neuron and new physics opportunities at 250 ab^{-1}

FAQ: Is there really enough physics for 330 graduate students ?

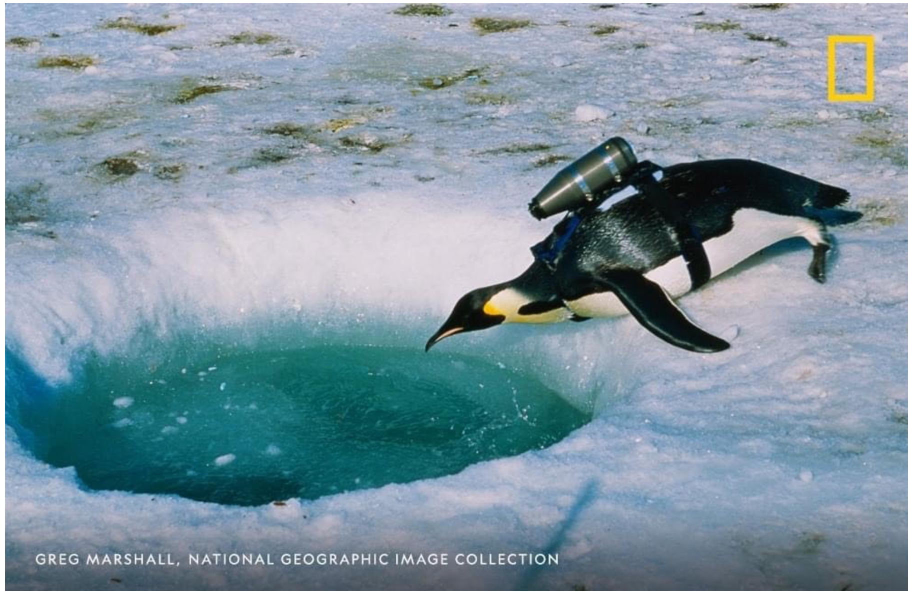
Ans: Absolutely, c.f. B factory experiments, >500 papers. Most by Phd student/advisor, postdoc or small group.

Dashed lines indicate extensions to SuperKEKB/Belle II that can enhance the physics reach of the facility. Details in https://confluence.desy.de/display/BI/Snowmass+2021

Now will describe some speculations about how Belle II might discover new physics and discuss whether significantly more data is needed.

Photo Credit: National Geographic

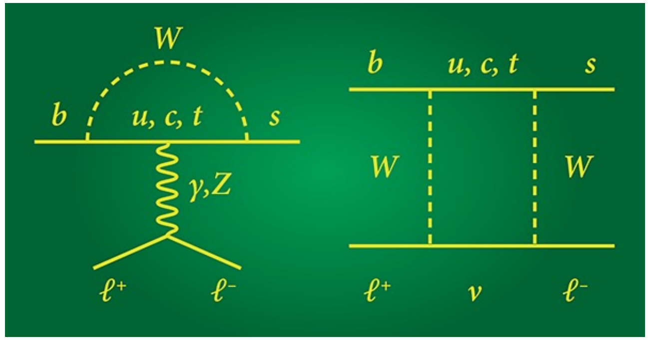
Research penguin

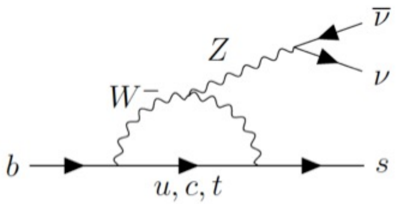


Exploring the unknown with b→s "electroweak penguins": (neutral current)

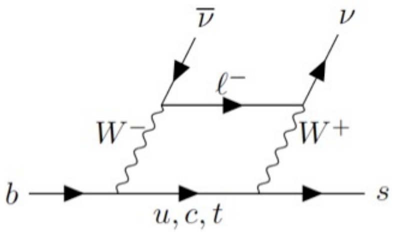
Sequoia National Forest

Discovering NP with $b \to c\, l\, \nu$ "trees": (charged current)



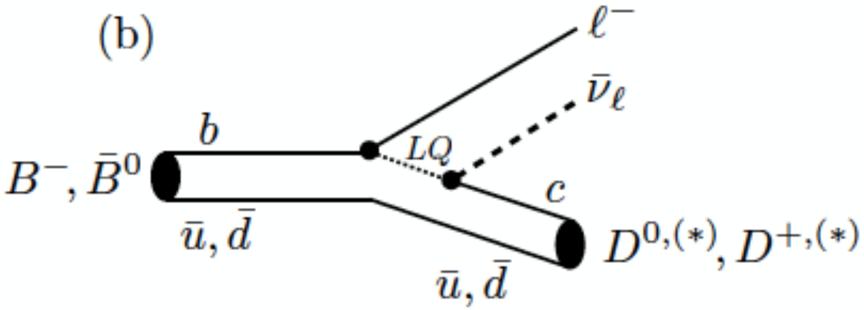


(a) Penguin diagram



(b) Box diagram

(b)



What happens beyond 50 ab^{-1} ?

Belle II
Higher sensitivity to decays with photons and neutrinos (e.g. $B \to K\nu\nu$, $\mu\nu$), inclusive decays, time dependent CPV in B_d, τ physics.

LHCb
Higher production rates for ultra rare B, D, & K decays, access to all b-hadron flavours (e.g. Λ_b), high boost for fast B_s oscillations.

Overlap in various key areas to verify discoveries.

Upgrades
Most key channels will be stats. limited (not theory or syst.).

Observable	2022 Belle(II), BaBar	2022 LHCb	Belle-II 5 ab^{-1}	Belle-II 50 ab^{-1}	LHCb 50 fb^{-1}	Belle-II 250 ab^{-1}	LHCb 300 fb^{-1}
$\sin 2\beta/\phi_1$	0.03	0.04	0.012	0.005	0.011	0.002	0.003
γ/ϕ_3	11°	4°	4.7°	1.5°	1°	0.8°	0.35°
α/ϕ_2	4°	–	2°	0.6°	–	0.3°	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	4.5%	6%	2%	1%	2%	< 1%	1%
$S_{CP}(B \to \eta' K^0_S)$	0.08	–	0.03	0.015	–	0.007	–
$A_{CP}(B \to \pi^0 K^0_S)$	0.15	–	0.07	0.04	–	0.018	–
$S_{CP}(B \to K^{*0}\gamma)$	0.32	–	0.11	0.035	–	0.015	–
$R(B \to K^*\ell^+\ell^-)^\dagger$	0.26	0.12	0.09	0.03	0.022	0.01	0.009
$R(B \to D^*\tau\nu)$	0.018	0.026	0.009	0.0045	0.0072	<0.003	<0.003
$R(B \to D\tau\nu)$	0.034	–	0.016	0.008	–	<0.003	–
$\mathcal{B}(B \to \tau\nu)$	24%	–	9%	4%	–	2%	–
$\mathcal{B}(B \to K^*\nu\bar{\nu})$	–	–	25%	9%	–	4%	–
$\mathcal{B}(\tau \to e\gamma)$ UL	42×10^{-9}	–	22×10^{-9}	6.9×10^{-9}	–	3.1×10^{-9}	–
$\mathcal{B}(\tau \to \mu\mu\mu)$ UL	21×10^{-9}	46×10^{-9}	3.6×10^{-9}	0.36×10^{-9}	1.1×10^{-9}	0.07×10^{-9}	5×10^{-9}

The dagger refers to a measurement in the range $1 < q^2 < 6$ GeV^2/c^2

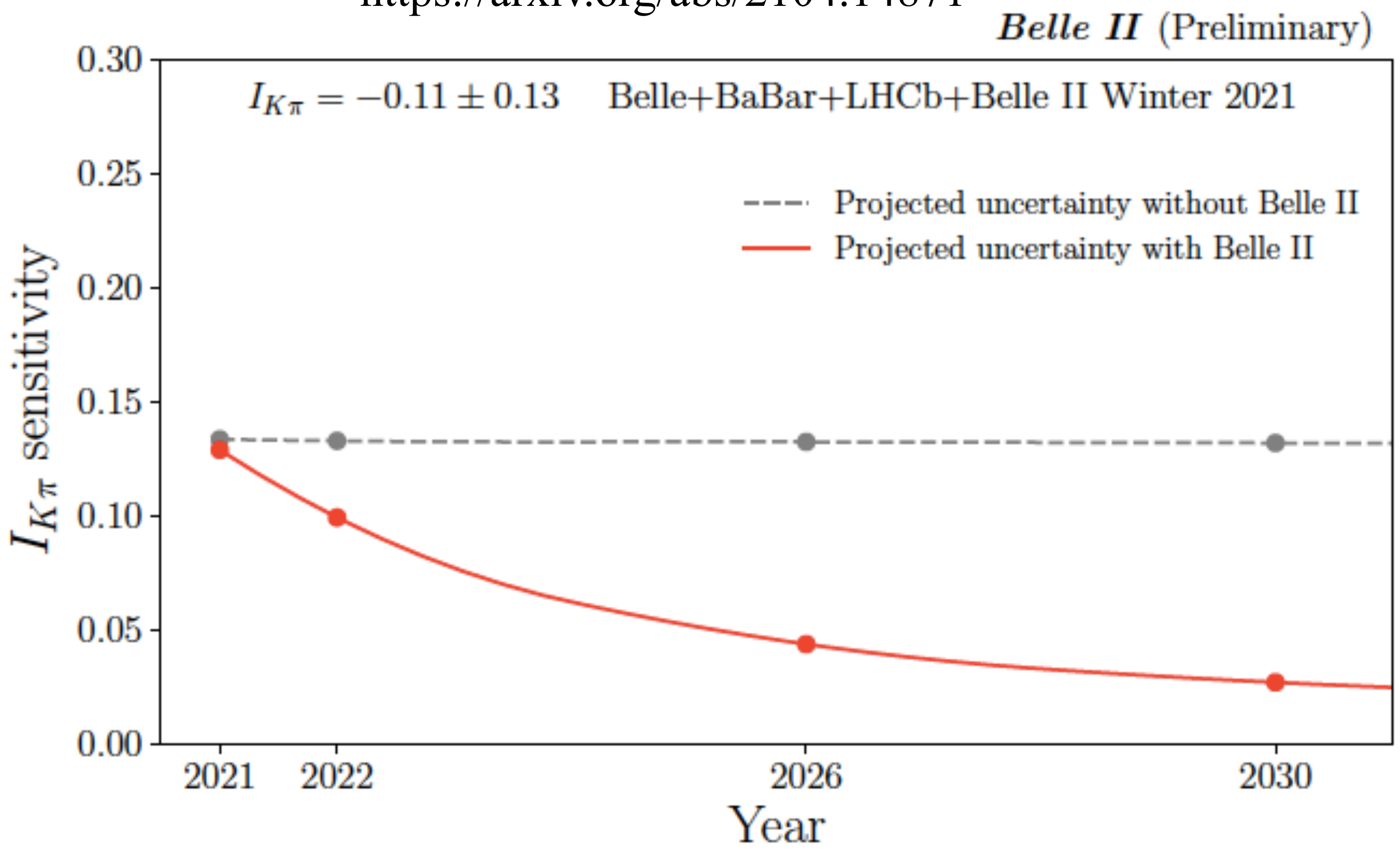
JAHEP report to Snowmass: Arxiv 2203:13979

Consideration of further luminosity upgrade and electron polarization capability of SuperKEKB are started for ultimate new physics searches with heavy flavor quarks and leptons including τ lepton $g-2$ in the light of muon $g-2$ anomaly [28].

https://arxiv.org/abs/2104.14871

Michael Gronau

The isospin sum rule detects enhanced NP electroweak penguins in B→K π



With Belle II@250 ab^{-1} , expect a sensitivity of ~0.018

Requires neutrals *and* flavor tagging.

Without Belle II measurements of $A_{CP}(B^0 \to K^0 \pi^0)$, we are stuck.

FIG. 4. The projected uncertainty on $I_{K\pi}$ with and without Belle II inputs. The inputs for $I_{K\pi}$ are averages of the estimated updates from ongoing LHCb and Belle II experiments with current world averages [10]. The red curve shows a projection when updates on the complete set of $K\pi$ measurements are considered, and the grey curve is the case if only $A_{K^+\pi^-}, A_{K^+\pi^0}, A_{K^0\pi^+}$ are updated by LHCb. The projection corresponds to the luminosity plans from LHCb and Belle II.

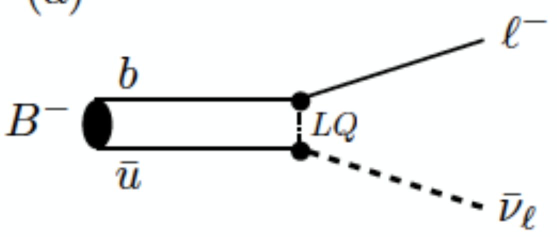
B→D$^{(*)}$ τ υ, there is a possible breakdown of lepton universality

Use ratios to reduce dependence of SM predictions on FF's.

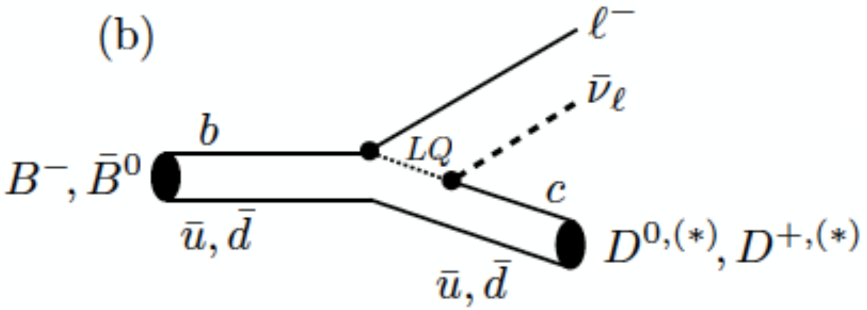
$$R_D^{(*)} = \frac{\mathscr{B}(B \to D^{(*)}\tau\nu_\tau)}{\mathscr{B}(B \to D^{(*)}\ell\nu_\ell)}$$

Some new physics possibilities (leptoquarks (LQ), charged Higgs type 3 etc..):

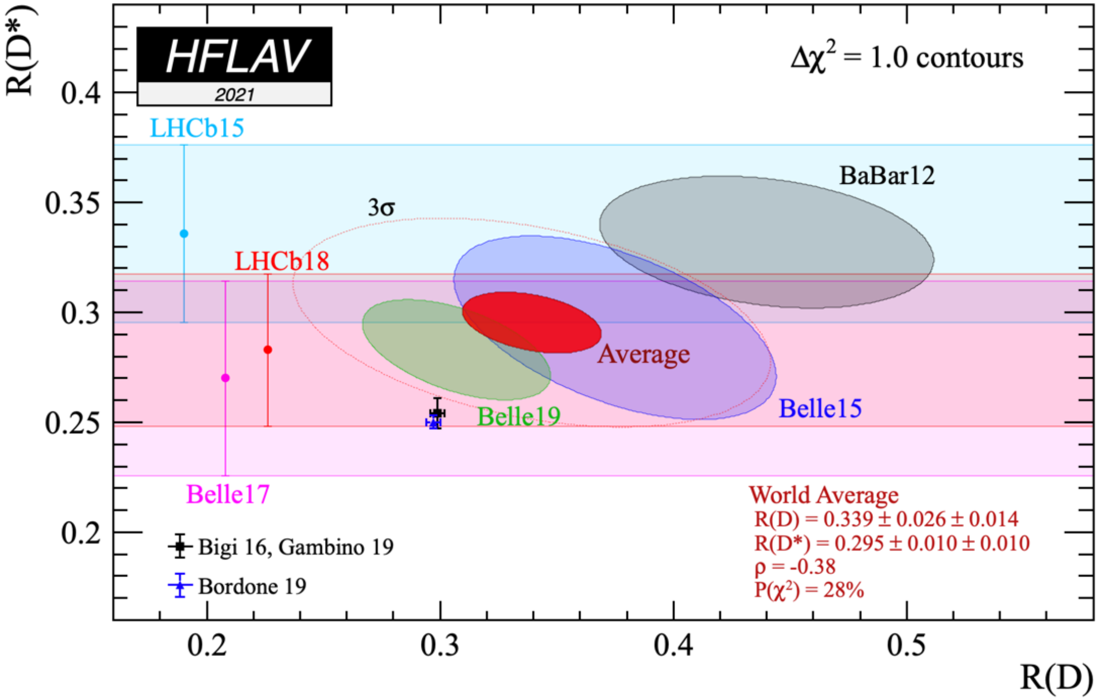
(a)



(b)



This could be NP in the weak b→c charged current



N.B. Systematics are included.

	$5\,\text{ab}^{-1}$	$50\,\text{ab}^{-1}$
R_D	$(\pm 6.0 \pm 3.9)\%$	$(\pm 2.0 \pm 2.5)\%$
R_{D^*}	$(\pm 3.0 \pm 2.5)\%$	$(\pm 1.0 \pm 2.0)\%$
$P_\tau(D^*)$	$\pm 0.18 \pm 0.08$	$\pm 0.06 \pm 0.04$

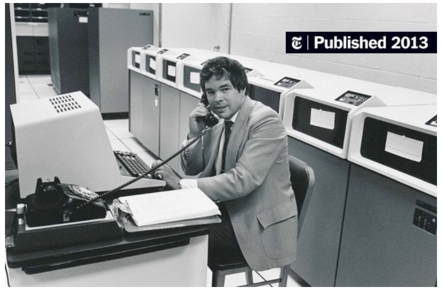
With current data from Belle, LHCb and BaBar: Evidence of lepton universality breakdown in semileptonic B decays with τ leptons. Last Belle measurement with semileptonic tags brings down the WA discrepancy from 4→3.4σ. With Belle II@250 ab^{-1}, expect R sensitivities below 0.3% and *can do NP angular distributions using* $\tau \to \pi\nu$

New Physics Couplings in b→s

Feynman family and diagrams

The effective Hamiltonian for $b \to s$ transitions can be written as

$$\mathcal{H}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{e^2}{16\pi^2} \sum_i (C_i O_i + C_i' O_i') + \text{h.c.}$$



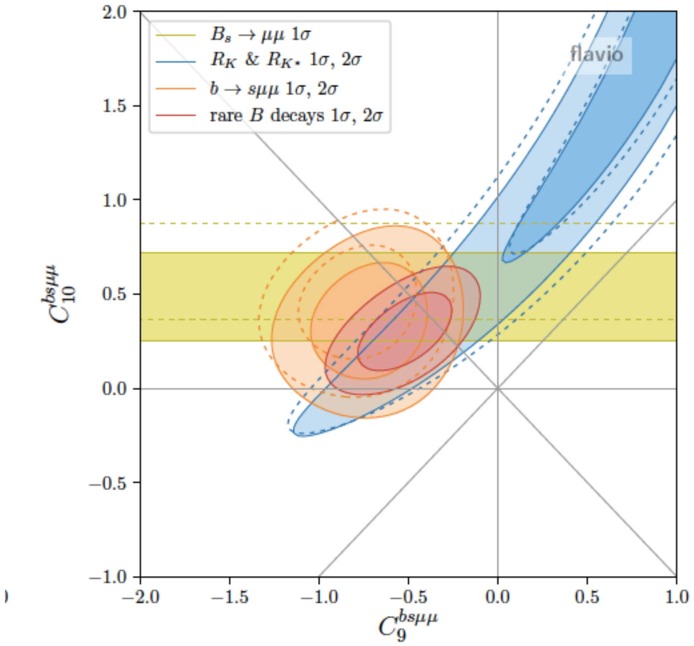
Ken Wilson

and we consider NP effects in the following set of dimension-6 operators,

$$O_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, \qquad O_9' = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)\,,$$

$$O_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, \qquad O_{10}' = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,.$$

The primes are right-handed couplings.



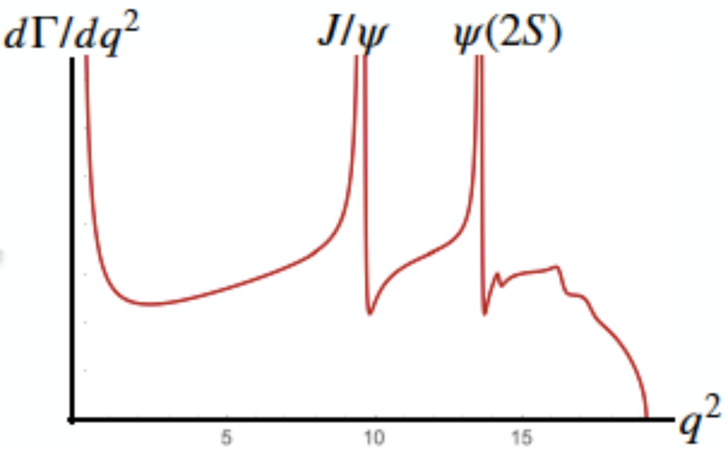
Altmanshofer, Stangel fit to all data (mostly LHCb)
https://arxiv.org/pdf/2103.13370.pdf

	Wilson coefficient	$b \to s\mu\mu$ best fit	pull	LFU, $B_s \to \mu\mu$ best fit	pull	all rare B decays best fit	pull
NP errors	$C_9^{bs\mu\mu}$	$-0.75^{+0.22}_{-0.23}$	3.4σ	$-0.74^{+0.20}_{-0.21}$	4.1σ	$-0.73^{+0.15}_{-0.15}$	5.2σ
	$C_{10}^{bs\mu\mu}$	$+0.42^{+0.23}_{-0.24}$	1.7σ	$+0.60^{+0.14}_{-0.14}$	4.7σ	$+0.54^{+0.12}_{-0.12}$	4.7σ
	$C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$	$-0.53^{+0.13}_{-0.13}$	3.7σ	$-0.35^{+0.08}_{-0.08}$	4.6σ	$-0.39^{+0.07}_{-0.07}$	5.6σ
SM errors	$C_9^{bs\mu\mu}$	$-0.88^{+0.22}_{-0.21}$	3.7σ	$-0.74^{+0.20}_{-0.21}$	4.1σ	$-0.78^{+0.15}_{-0.15}$	5.3σ
	$C_{10}^{bs\mu\mu}$	$+0.44^{+0.21}_{-0.21}$	2.1σ	$+0.60^{+0.14}_{-0.14}$	4.7σ	$+0.54^{+0.12}_{-0.12}$	4.8σ
	$C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$	$-0.58^{+0.17}_{-0.18}$	3.6σ	$-0.35^{+0.08}_{-0.08}$	4.6σ	$-0.39^{+0.07}_{-0.07}$	5.5σ

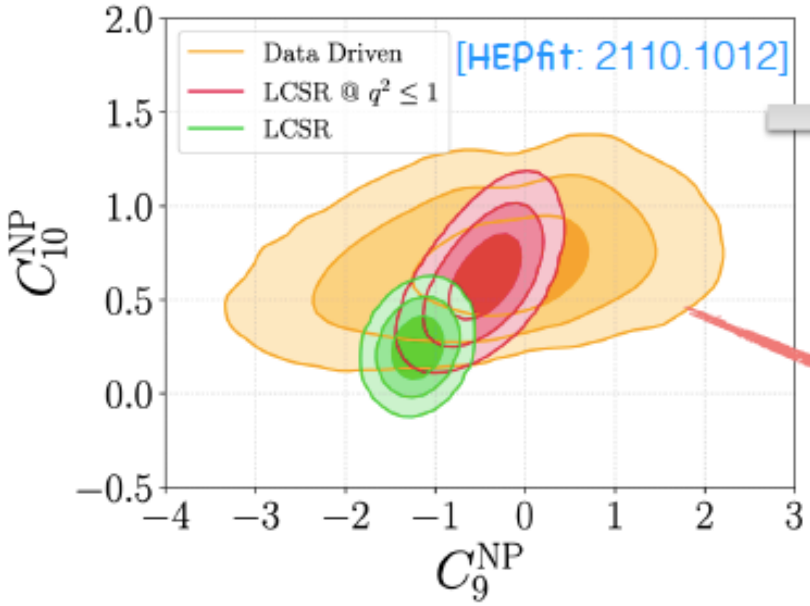
C_9 : $>5\sigma$ from the SM

Be very careful about 5σ NP claims, leftmost column assumes minimal *QCD, resonance effects in angular asymmetries and q^2 distribution.*

Angular analysis



Resonant b→c cbar s contributions



Global fits to current $b \to s\ell\ell$ data with three different treatments to parametrize charm-loop effects

Hadronic uncertainties due to long distance physics can overshadow new physics

Further cancellation required for angular observables

☑ use different lepton flavors: $\frac{S_i^{b\to s\mu\mu}(q^2)}{\Gamma_f^{b\to s\mu\mu}(q^2)} - \frac{S_i^{b\to see}(q^2)}{\Gamma_f^{b\to see}(q^2)}$

Q-observables [Capdevila *et. al*, '16] [Belle: '16]

☑ Directly extract $\Delta C_9 = \delta C_9^{b\to s\mu\mu} - \delta C_9^{b\to see}$

The solution is the Delta (Δ) Observables.

https://arxiv.org/abs/2203.06827

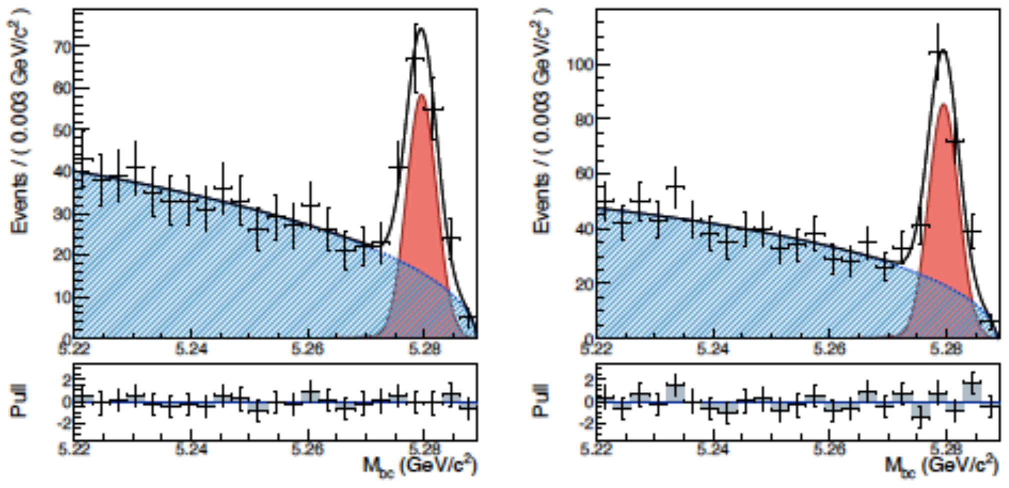
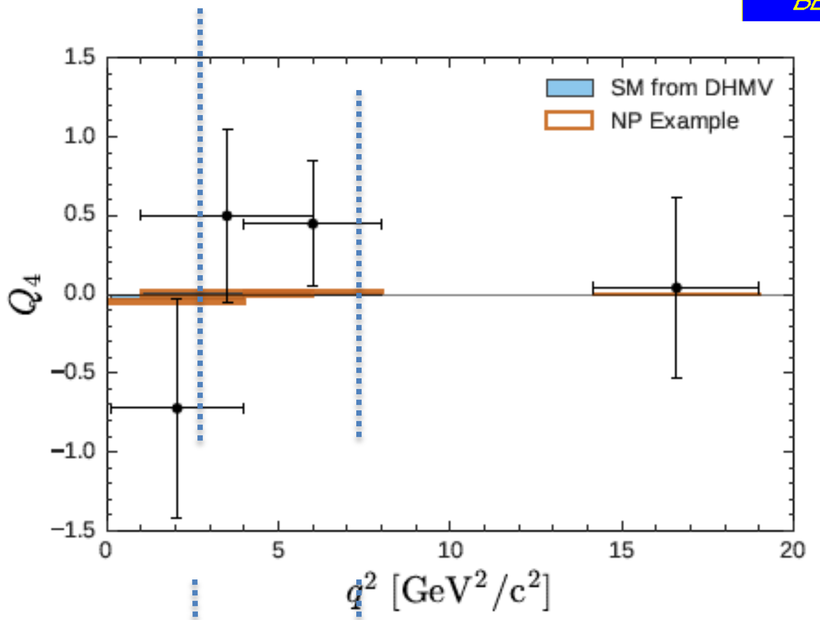
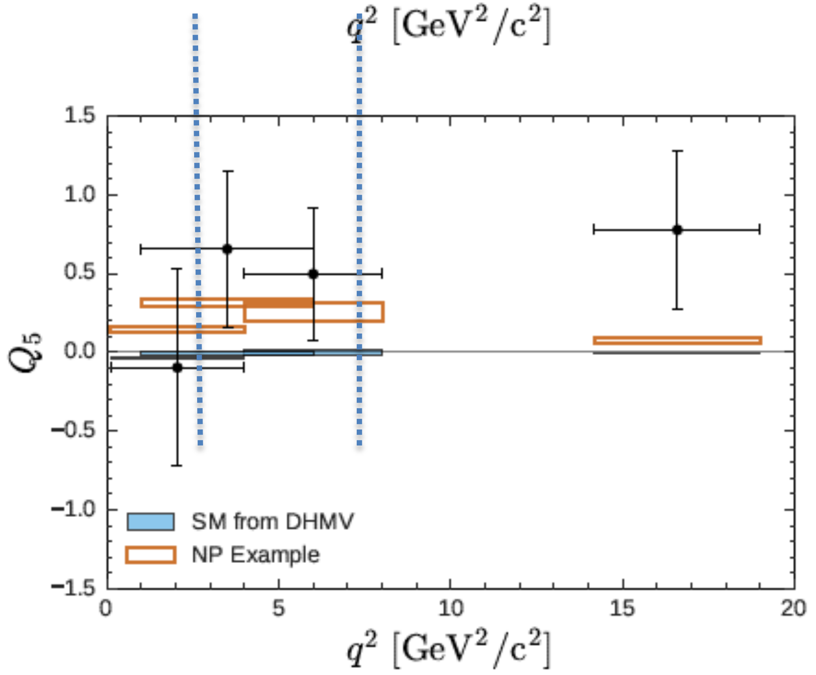


FIG. 1. Distribution of the beam-energy constrained mass for selected $B \to K^{*}e^{+}e^{-}$ (left) and $B \to K^{*}\mu^{+}\mu^{-}$ (right). Combinatorial background (shaded blue), signal (red filled) and total (solid) fit functions are superimposed on the data points

$$\Delta P_4' = P_4'(B \to K^*\mu^+\mu^-) - P_4'(B \to K^*e^+e^-)$$ a.k.a. Q_4

$$\Delta P_5' = P_5'(B \to K^*\mu^+\mu^-) - P_5'(B \to K^*e^+e^-)$$ a.k.a. Q_5





Belle has tried out some of the Δ Observables with 0.7 ab^{-1}

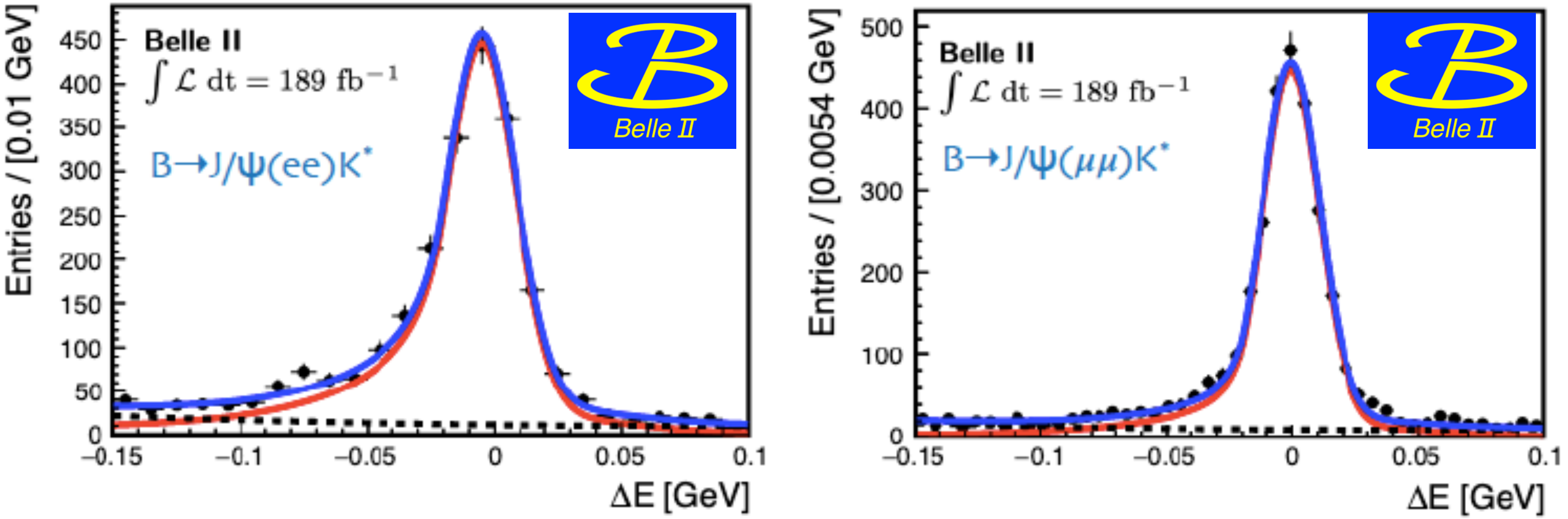
S. Wehle, C. Niebuhr, S. Yashchenko, et al. (Belle Collaboration), [PRL118, 111801 (2017)]

Belle II is gearing up for lepton universality tests (a few examples from data).

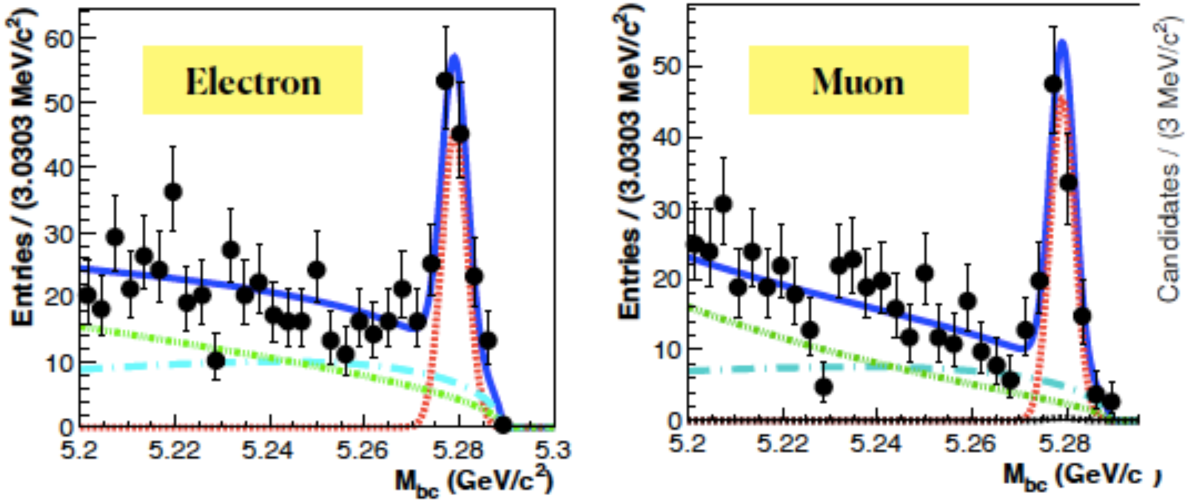
- $B \to K^* J/\psi(\ell^+\ell^-)$ used as a control mode - also a background. Bremsstrahlung recovered in electron channels.
- Belle (II) has similar sensitivity both for electron and muon modes. Also seen in $B \to K\ell\ell$ at Belle.

$M_{bc} \equiv \sqrt{E_{\text{beam}}^{2} - \overrightarrow{p}_B^{*2}}$, $\Delta E \equiv E^*_{\text{beam}} - E^*_B$

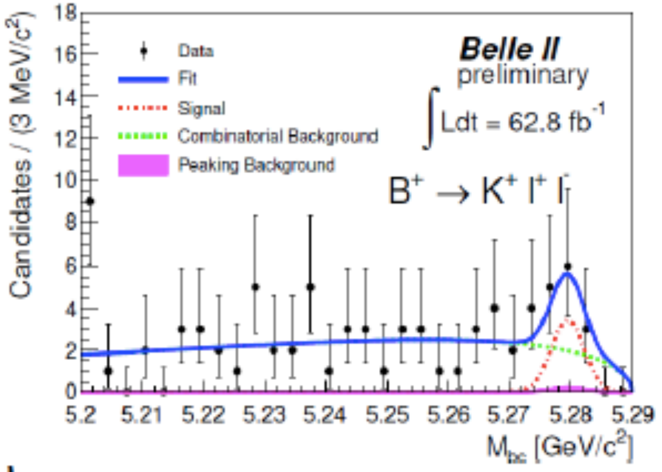
Belle II Preliminary



Belle JHEP 2103, 105 (2021) $B \to K\ell\ell$
Belle Phys. Rev. Lett. 126, 161801 (2021)



Belle II Preliminary $B \to K\ell\ell$

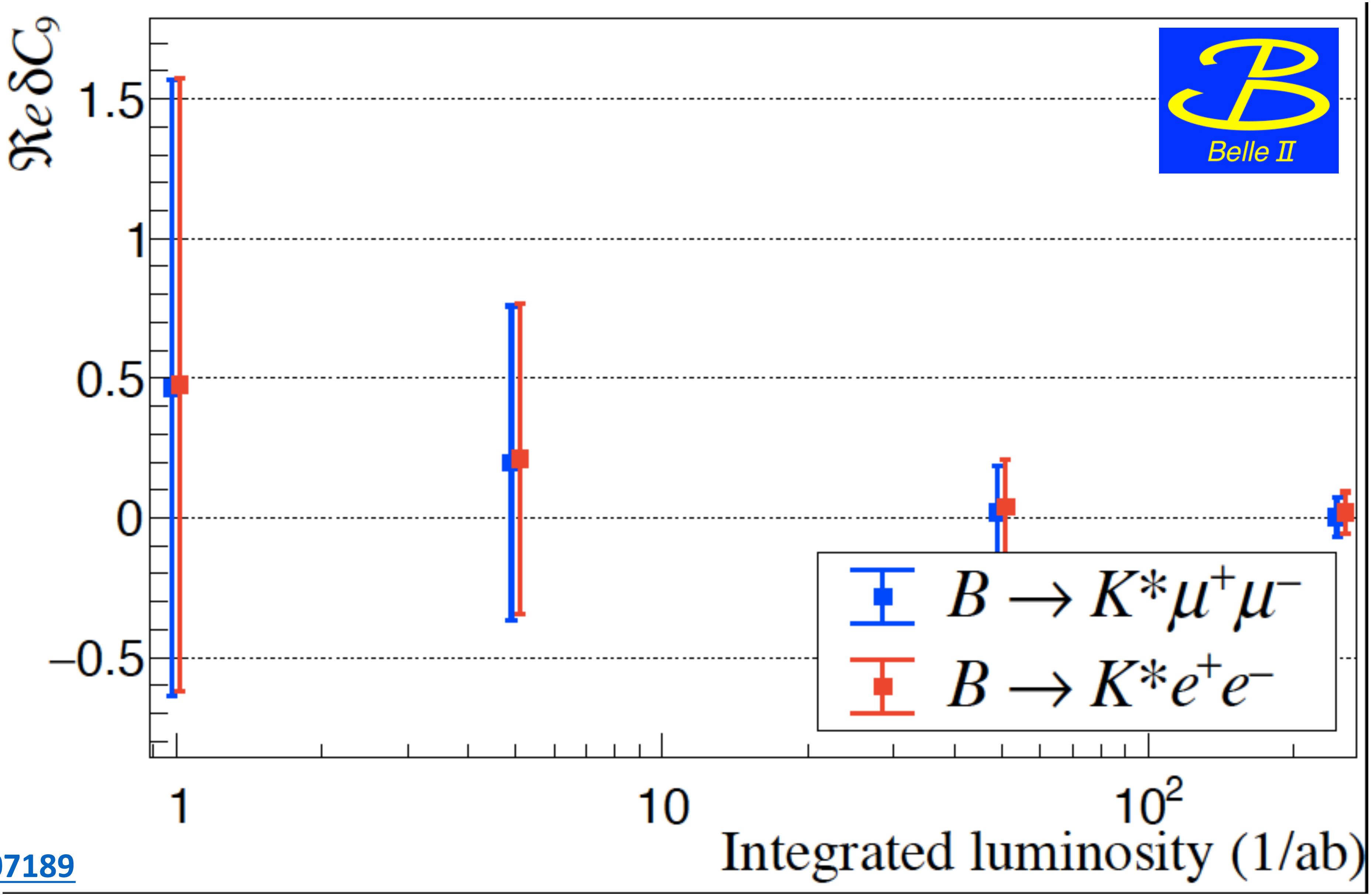


Reminder and Motivation:

C_9 : Global fit to world b→s data gives a >5σ deviation from the SM

Estimates use pseudo-experiments with 4-D unbinned maximum likelihood fits to 4 variables in $B \to K^* l^+ l^-$ to extract Wilson coefficients C_i directly from data.

Use q^2 >1 GeV^2 and $|q^2 - M^2|$<0.25 GeV^2 and assume 25% Belle efficiency

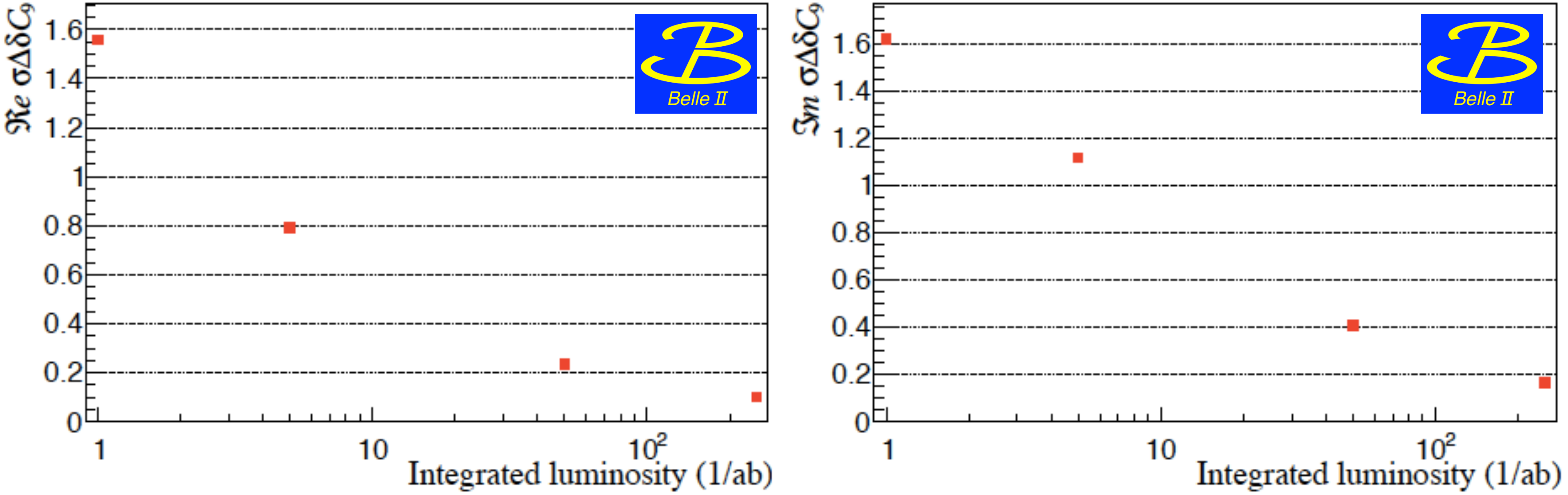


A. Sibidanov et al.

https://arxiv.org/abs/2203.07189

Snowmass Bullet Point:

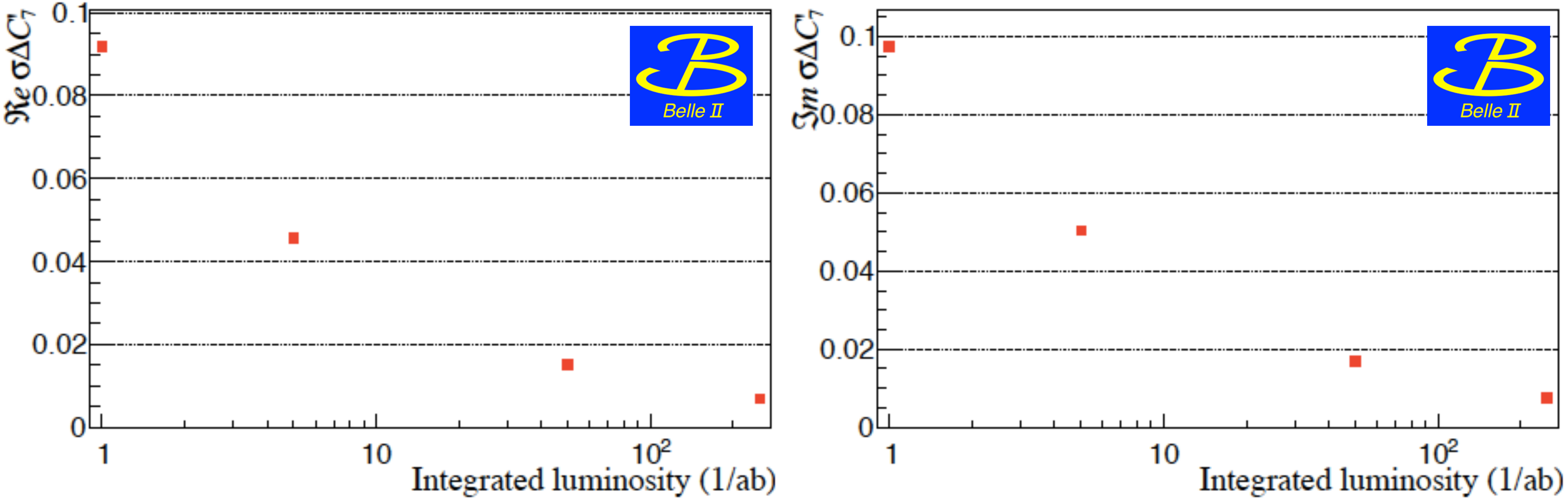
Use the Δ Observables in $B \to K^* \; l^+ l^-$ to discover New Physics at Belle II without QCD and hadronic uncertainties.



A. Sibidanov et al., https://arxiv.org/abs/2203.07189

Belle II Sensitivity to NP Right-Handed Currents, (C_7')

A. Sibidanov et al., https://arxiv.org/abs/2203.07189

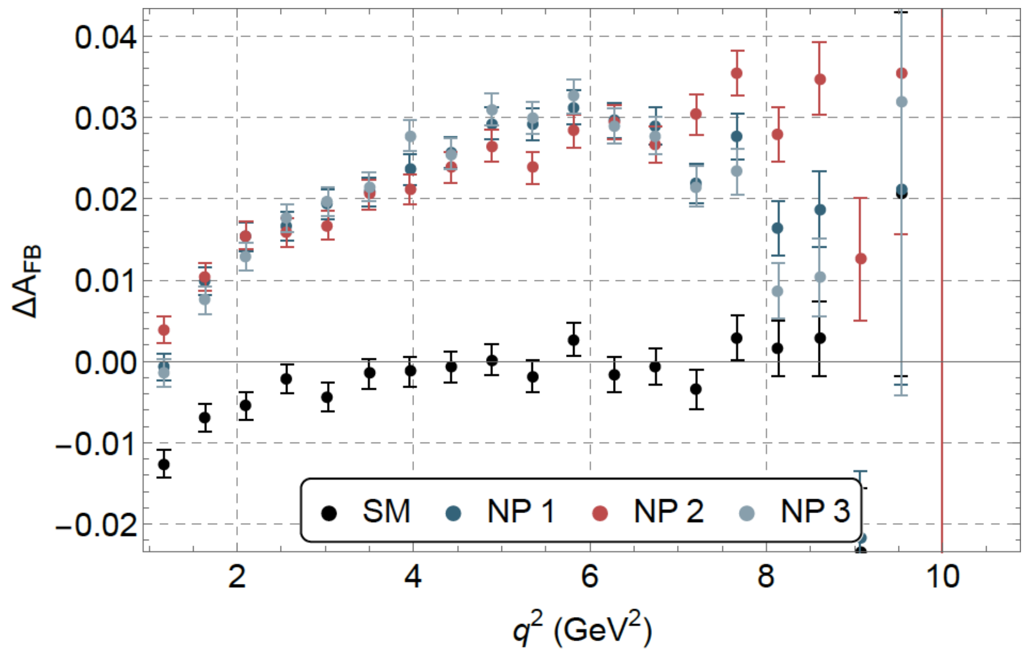


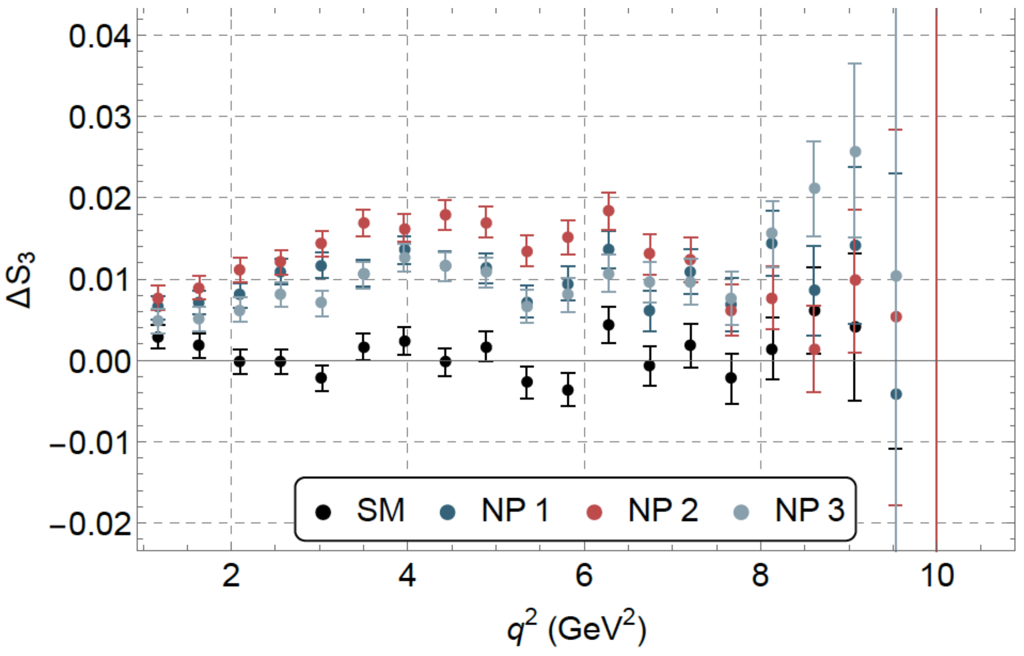
Snowmass Bullet Point:

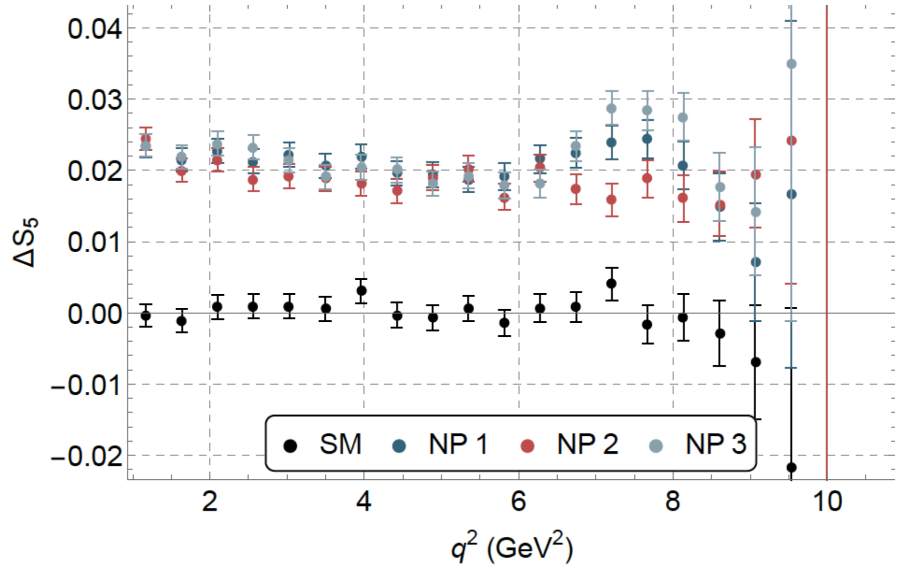
Use the Δ Observables in $B \rightarrow K^* \; l^+ l^-$ to discover New Physics at Belle II without QCD and hadronic uncertainties.

$$\Delta A_{FB}(B \to D^{*+}\ell\nu) = A_{FB}(B \to D^{*+}\mu^-\nu) - A_{FB}(B \to D^{*+}e^-\nu)$$

+ correlated angular asymmetries@250 ab^{-1}







The Δ *variables eliminate dependence on hadronic FFs*.

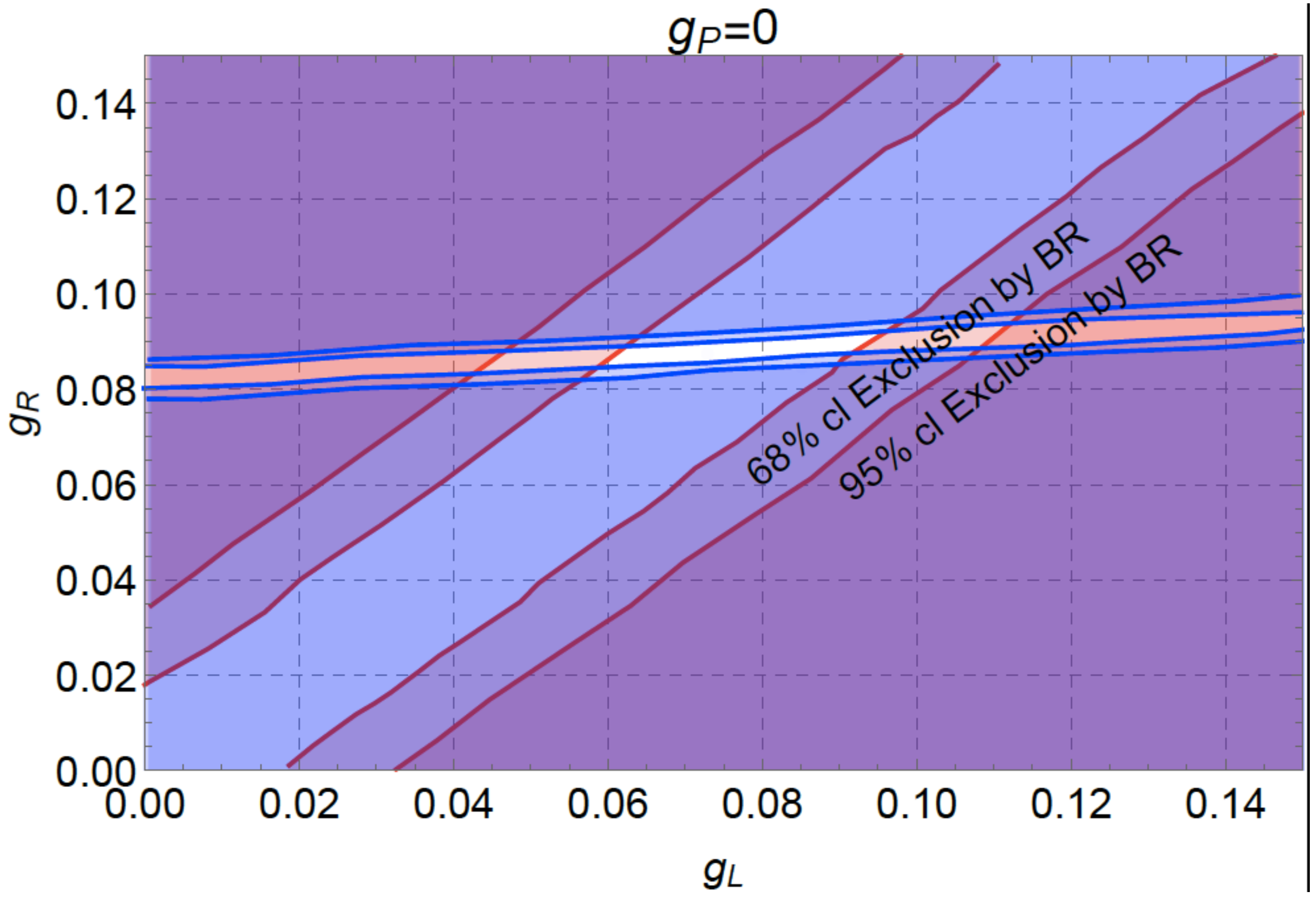
Zero in the SM;
Triple-product T violating asymmetry,
S_7, may reach 0.3% in some NP scenarios and be visible @250 ab^{-1}

Plots: Quinn Campagna (Ole Miss) https://arxiv.org/abs/2203.07189

$$\Delta A_{FB}(B \to D^{*+}\ell\nu) = A_{FB}(B \to D^{*+}\mu^-\nu) - A_{FB}(B \to D^{*+}e^-\nu)$$

+ constraints on NP coupling parameters@250 ab^{-1}

N.B. Form Factor uncertainties cancel out in Δ variables



Angular asymmetries provide a tighter constraint on NP LFUV couplings (right-handed V+A, extra left-handed V-A and pseudo-scalar couplings).

Plots: Quinn Campagna (Ole Miss)

https://arxiv.org/abs/2203.07189

B→K ν vbar: NP *without* hadronic uncertainties !

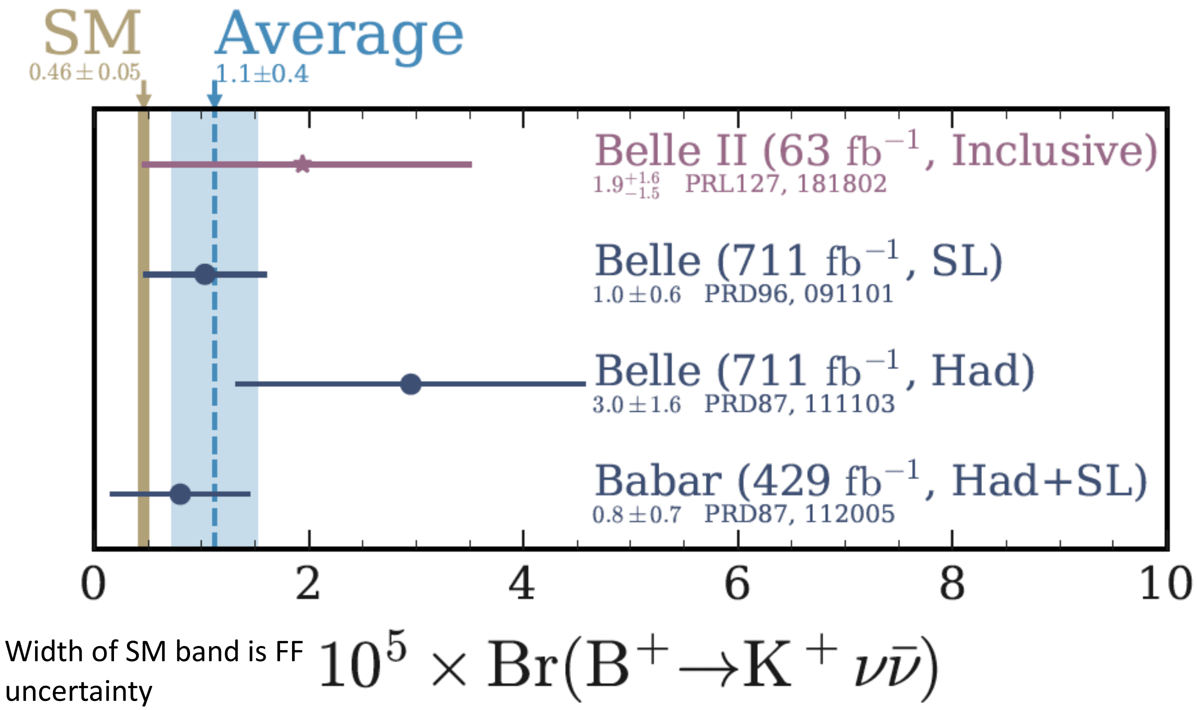
4% experimental error on B→K* ν *vbar with Belle II@250 ab*$^{-1}$

$$B \to K\nu\bar{\nu}$$

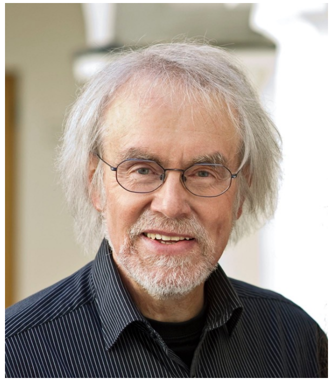
New Technique from Belle II with inclusive ROE (Rest of the Event) tagging.

Phys. Rev. Lett. 127, 181802, (2021)

An emerging anomaly ???



Width of SM band is FF uncertainty



Andrezj Buras

"Note there are no charm loops here"- Wolfgang A.

But it is also possible that NP shows up only in b→s l+ l- but not in b→s nu nubar or vice-versa. The two classes of EWPs are related but distinct.

This is one way that Belle II could discover New Physics soon. For example: https://arxiv.org/abs/2107.01080, Phys. Rev. D. 104, 053007 (2021)

Upgrading SuperKEB with Polarized Electron Beams: "Chiral Belle" uses Belle II with L-R polarized SuperKEKB

- Goal is ~70% polarization with 80% polarized source (SLC had 75% polarization at the experiment)
- Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode (similar to SLC source)
- Inject vertically polarized electrons into the High Energy Ring (HER) - needs low enough emittance source to be able to inject.
- Rotate spin to longitudinal before IP, and then back to vertical after IP using solenoidal and dipole fields – recent studies have demonstrated feasibility
- Use Compton polarimeter to monitor longitudinal polarization with <1% absolute precision, higher for relative measurements (arXiv:1009.6178) - needed for real time polarimetry – similar to HERA and EIC technologies.
- Use tau decays to obtain absolute average polarization at IP – *BABAR* analysis demonstrates 0.5% precision (see C. Miller, Lake Louise Winter Institute 2022)

"Chiral Belle II" -> Left-Right Asymmetries

- Measure *difference* between cross-sections with left-handed beam electrons and right-handed beam electrons
- Same technique as SLD A_{LR} measurement at the Z-pole giving single most precise measurement of :

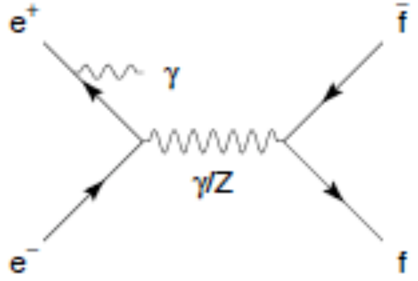
$$\sin^2\theta_{eff}^{lepton} = 0.23098 \pm 0.00026$$

- At 10.58 GeV, polarized e^- beam yields product of the neutral axial-vector coupling of the electron and vector coupling of the final-state fermion via Z-γ interference:

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_F s}{4\pi\alpha Q_f}\right) g_A^e g_V^f \langle Pol \rangle$$

$$\propto T_3^f - 2Q_f \sin^2\theta_W$$

(for s-channel Born)

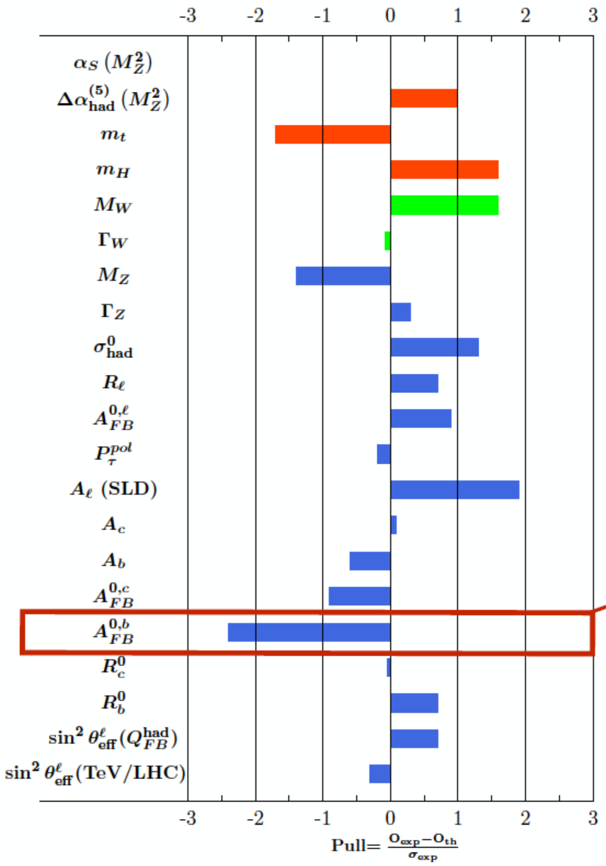


Belle II/SuperKEKB with a polarized e^- beam can address this long-standing electroweak discrepancy and hint of NP

Warning: Does not include CDF 2022 W mass update.

SM fit results: Predictions for EWPO

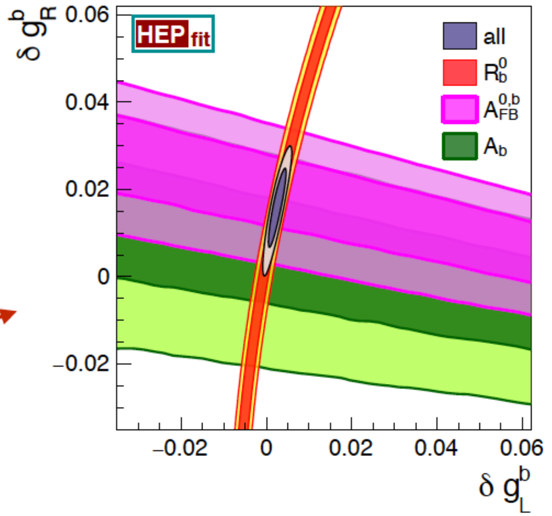
Also good agreement between indirect determination of EWPO and experimental measurements, with one notable exception



~2.5 σ discrepancy in forward-fackward asymmetry of the b quark

Requires modifications of (right-handed) *Zbb* couplings

$$g^b_{L,R} = g^{b\,\mathrm{SM}}_{L,R} + \delta g^b_{L,R}$$

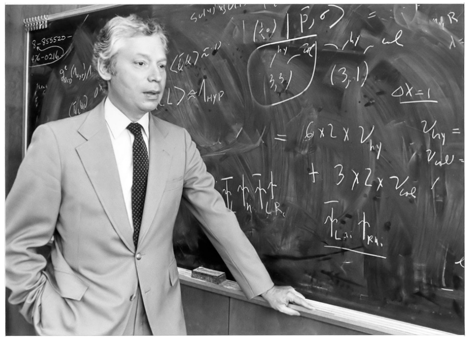


	Fit result	Correlations	
δg^b_R	0.017±0.007	1.00	
δg^b_L	0.003±0.001	0.89	1.00

29th International Symposium on Lepton Photon Interactions at High Energies
Toronto, August 6, 2019 19 Jorge de Blas
INFN - University of Padova

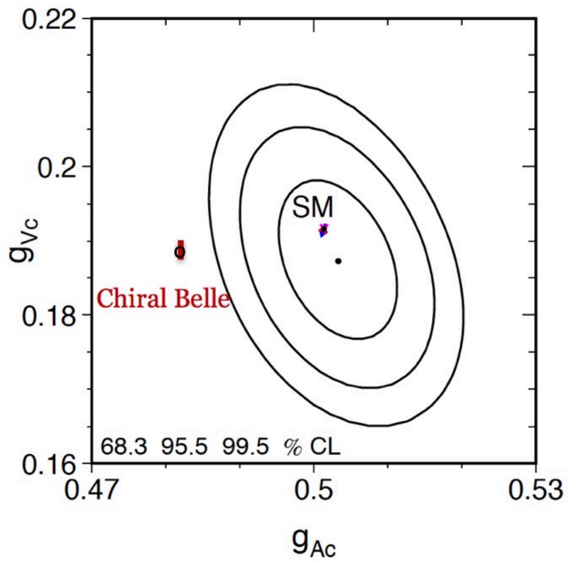
A New Path for Belle II Discovery in a *Precision Neutral Current Electroweak Program* with Heavy Quarks

- Left-Right Asymmetries (A_{LR}) yield high precision measurements of the *neutral current vector couplings* (g_V) to each of accessible fermion flavor, *f* :
  - beauty (D-type)
  - charm (U-type) (as well as for 3 charged leptons and light quarks)

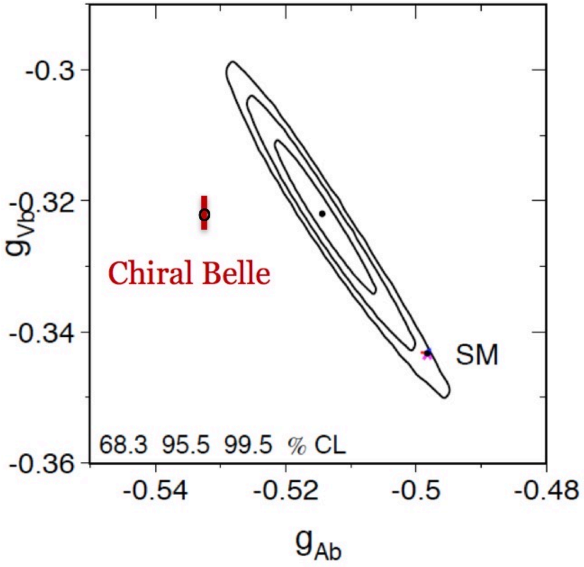


Steve Weinberg

c-quark:
Chiral Belle ~7 times more precise



b-quark:
Chiral Belle ~4 times more precise
with 20 ab^{-1}



$$\text{Recall: } g_V^f \text{ gives } \theta_W \text{ in SM} \begin{cases} g_A^f = T_3^f \\ g_V^f = T_3^f - 2Q_f \sin^2\theta_W \end{cases}$$

T_3 = -0.5 for charged leptons and D-type quarks
+0.5 for neutrinos and U-type quarks

Unique Access to New Physics in bottom-to-charm Neutral Current Vector Coupling Universality Ratio via A_{LR} (b-bbar)/ A_{LR} (c-cbar)

Belle II

Projections of b-quark and c-quark Neutral Current Vector Coupling Sensitivities with 70% polarized e^- beam

UNPRECEDENTED PRECISION

Final State Fermion	SM	World Average[1]	Chiral Belle 20 ab^{-1}	Chiral Belle 50 ab^{-1}	Chiral Belle 250 ab^{-1}
	g_V^f (M_Z)	g_V^f (M_Z)	σ (g_V^f) or σ(g_V^b/ g_V^c)	σ (g_V^f) or σ(g_V^b/ g_V^c)	σ (g_V^f) or σ(g_V^b/ g_V^c)
b-quark	-0.3437	-0.322	±0.0003(stat) ±0.0017(sys)	±0.0002(stat) ±0.0017(sys)	±0.00009(stat) ±0.0017(sys)
(eff.=0.3)	± .00049	±0.0077	±0.0017(total)	±0.0017(total)	±0.0017(total)
		2.8σ tension	**Improves x 4**	Improves x 4	Improves x 4
c-quark	0.192	0.1873	±0.0006(stat) ±0.0009(sys)	±0.00035(stat) ±0.0009(sys)	±0.00016(stat) ±0.0009(sys)
(eff.=0.3)	± .0002	±0.0070	±0.0011(total)	±0.0010(total)	±0.0009(total)
			Improves x 7	Improves x 7	Improves x 8
g_V^b /g_V^c	**-1.7901**	**-1.719**	**±0.0058 (stat ~ total)**	**±0.0034 (stat ~ total)**	**±0.00015 (stat ~ total)**
Ratio	± .0005	± .082	**Improve x 14**	**Improve x 24**	**Improve x 53**
Relative error:	0.18%	4.8%	**0.32%**	**0.19%**	**0.09%**

Get stuck at ~20 ab^{-1}

Use the ratio

bottom-to-charm UNIVERSALITY RATIO Beam Polarization (dominant systematic) cancels in the ratio

1 - Physics Report Vol 427, Nos 5-6 (2006), ALEPH, OPAL, L3, DELPHI, SLD

$\sin^2\Theta_W$ - all LEP+SLD measurements combined WA = 0.23153 ± 0.00016

$\sin^2\Theta_W$ - Chiral Belle combined leptons with 40 ab^{-1} have error ~current WA

Conclusions on the Belle II/SuperKEKB upgrade physics program @250 ab^{-1}

- Leverage Belle II's photon, electron, π^0, missing energy sensitivities for rare B decays, to measure CKM parameters and find NP.
- *Use Δ Observables to find NP in angular asymmetries in b →s and b →c (ideally suited for Belle II at ultra- high luminosity, which has strong capabilities for both electrons and muons).*
- *Use the Belle II/SuperKEKB's e- polarization upgrade and A_{LR} (b bbar)/ A_{LR} (c cbar) to resolve a precision electroweak anomaly and discover NP (and bypass the systematic limits).*
- *Belle II has Strong and Unique Capabilities for New Physics and resolution of the major high energy physics anomalies (not just those in B physics).*

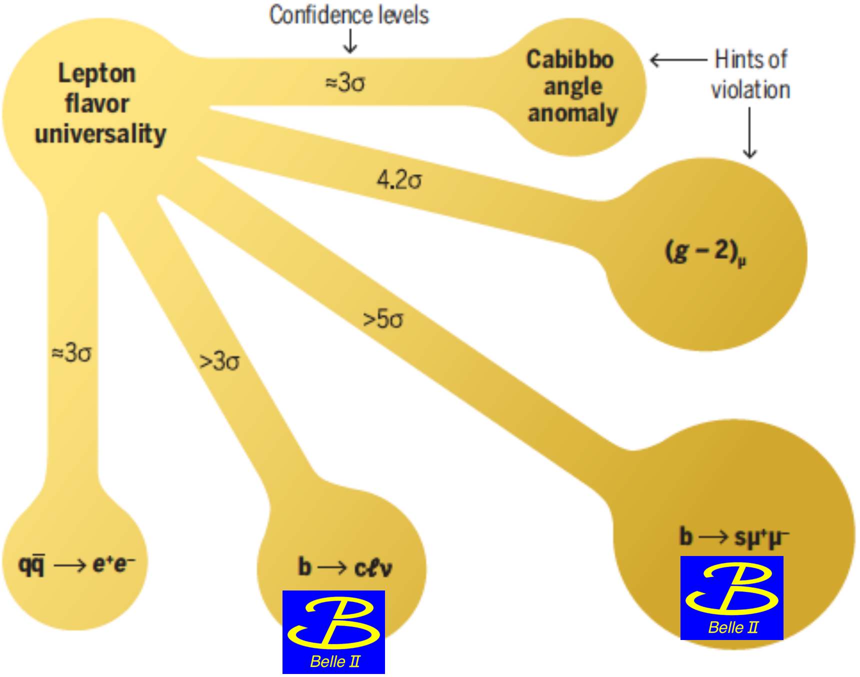
New members in the Belle II UWG (Upgrade Working Group, chair: Francesco Forti) are welcome to join. R&D on Belle II detector upgrades is the current focus.

Belle II Snowmass White Papers: https://confluence.desy.de/display/BI/Snowmass+2021

Examples of how Belle II might find New Physics in the coming years.

Possible violations of lepton flavor universality are getting harder to ignore

Shown are five hints for the violation of lepton flavor universality from existing experimental data, with the size of each circle and length of each arm reflecting the level of confidence for the experimental data to break away from standard model predictions.

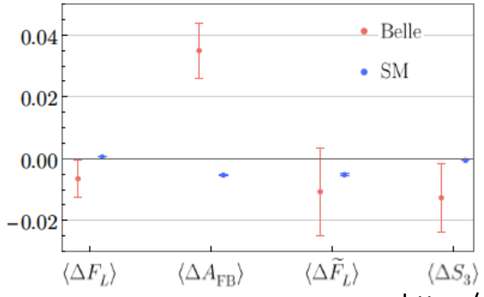


From December 2021 SCIENCE magazine article by A. Crivellin and M. Hoferichter.

Belle II's Strong and Unique Capabilities for New Physics and resolution of HEP Anomalies:

$$\Delta A_{FB}(B \to D^{*+}\ell\nu) = A_{FB}(B \to D^{*+}\mu^-\nu) - A_{FB}(B \to D^{*+}e^-\nu)$$

ΔA_{FB} A 4σ deviation from the SM is found in a meta-analysis of Belle data (0.71 ab^{-1})

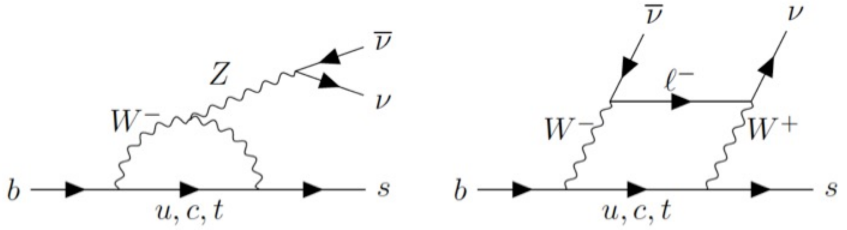


Eur. Phys. J.C. 81 (2021).

https://arxiv.org/abs/2104.02094

Belle II's unique inclusive and missing energy capabilities.

The current WA for B→K nu nubar (2.4 +-1.1) SM.



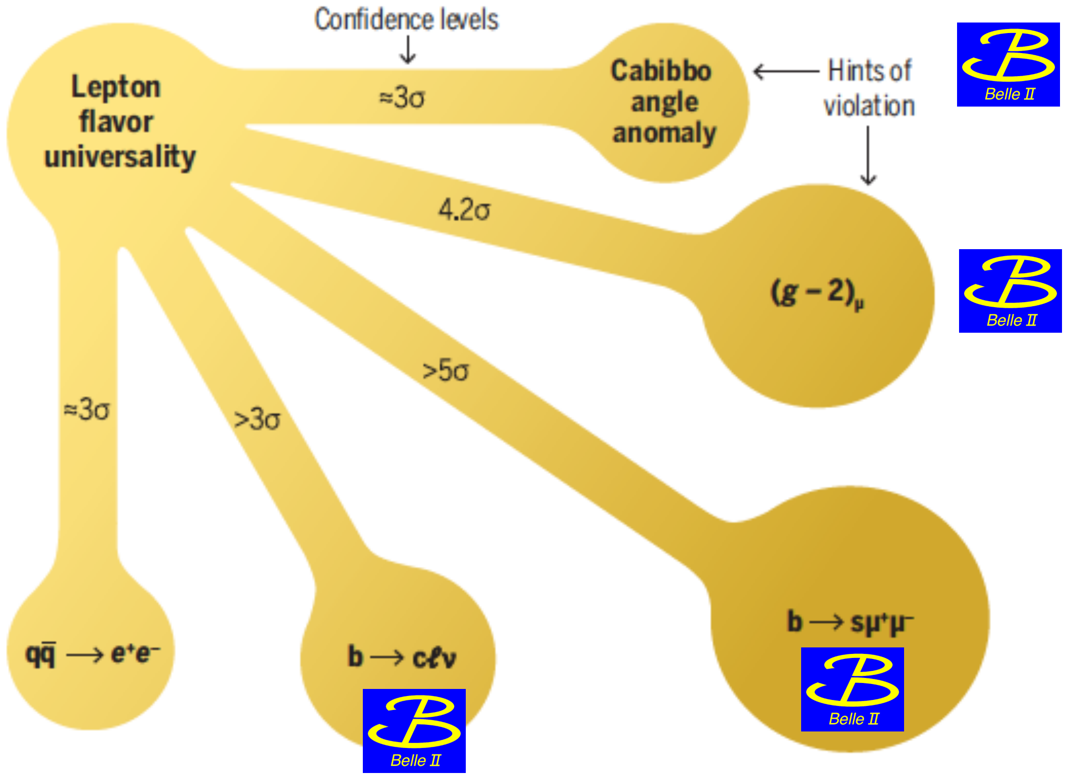
(a) Penguin diagram (b) Box diagram

Belle II; Phys. Rev. Lett. 127, 181802 (2021)

But these modes require lots of data…."There is no royal road to new physics" (to paraphrase Euclid). *Diagnosis of NP may require Int(L dt)=250 ab^{-1}*

Possible violations of lepton flavor universality are getting harder to ignore

Shown are five hints for the violation of lepton flavor universality from existing experimental data, with the size of each circle and length of each arm reflecting the level of confidence for the experimental data to break away from standard model predictions.



From December 2021 SCIENCE magazine article by A. Crivellin and M. Hoferichter.

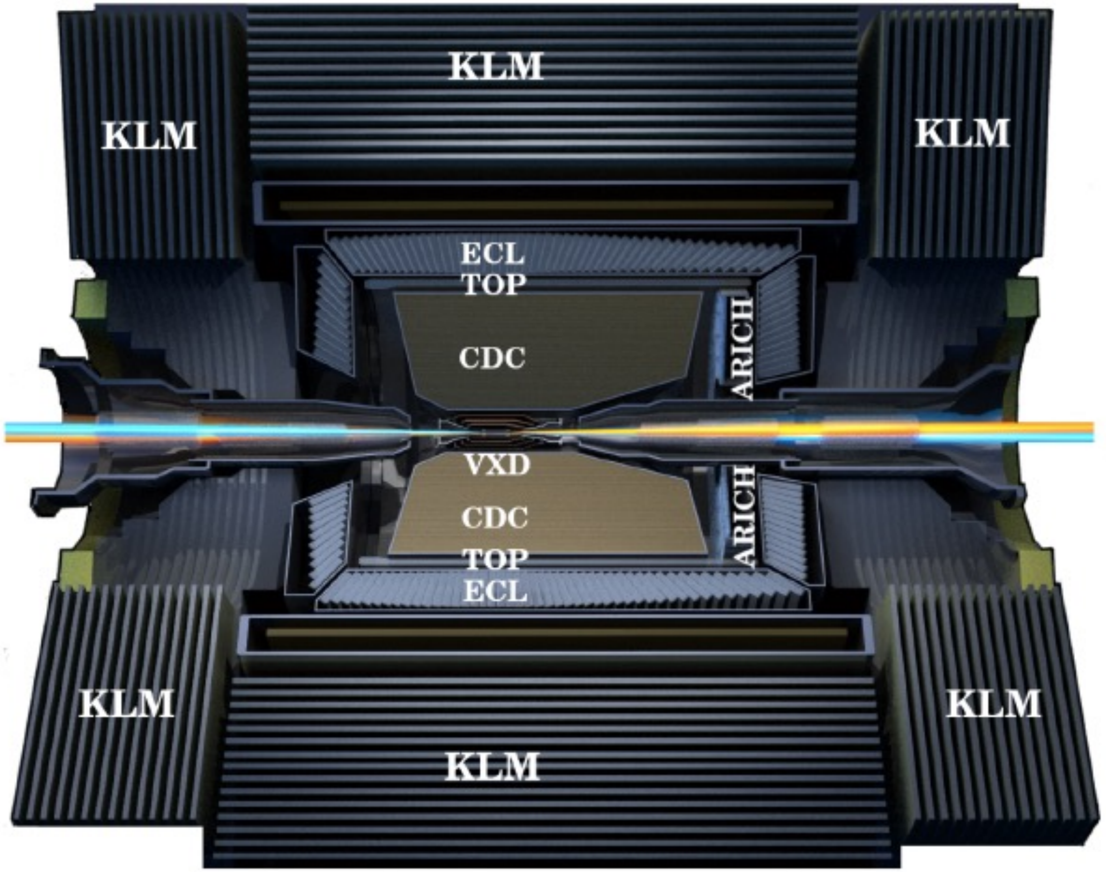
Snowmass bullet points for NP:

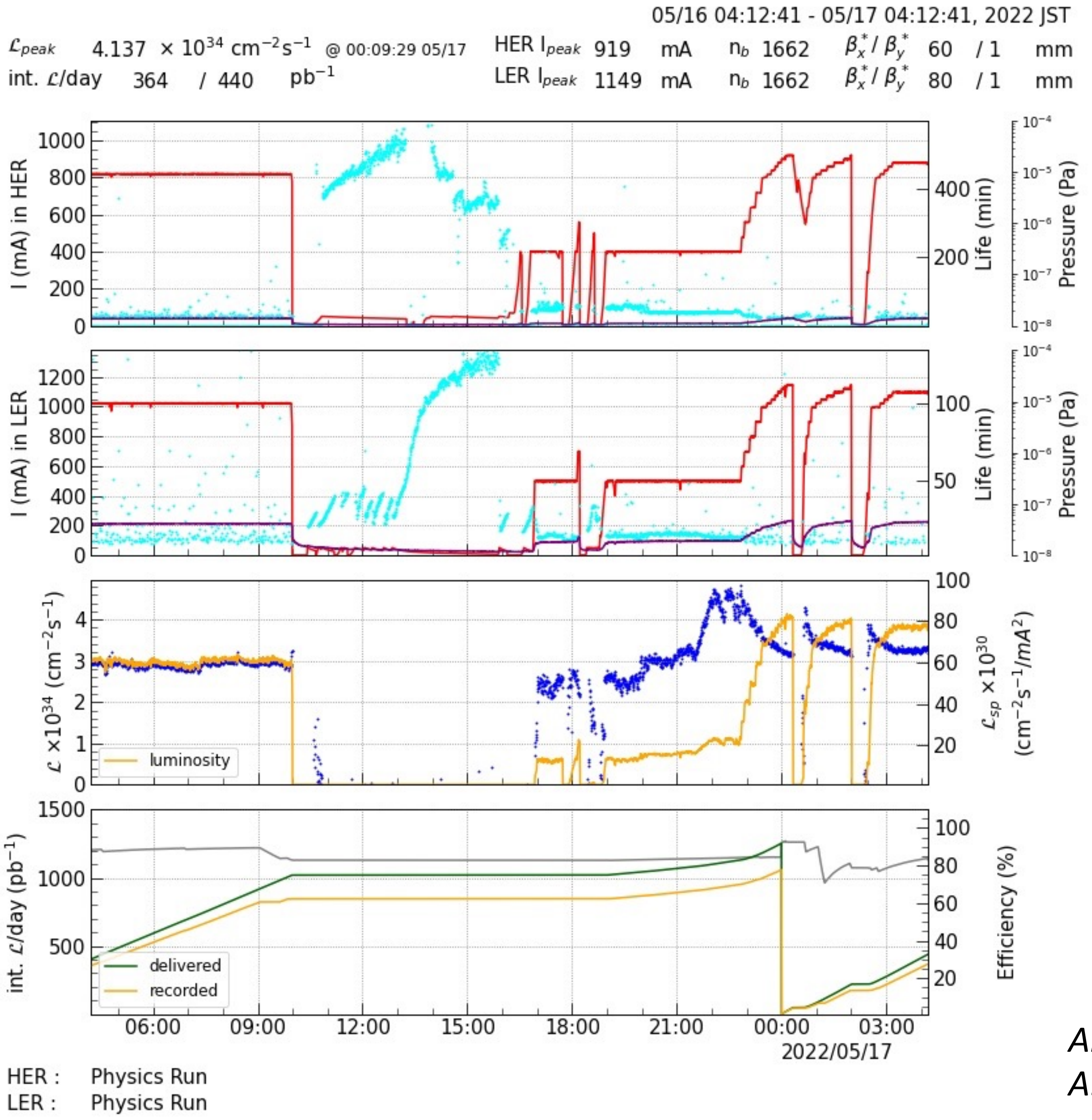
Critical role of Belle II for the resolution of B physics anomalies.

A major supporting role of Belle II in the resolution of two more of the other major HEP anomalies (g-2) and the Cabibbo Angle Angle Anomaly. See Belle II White Papers and talks by Anselm Vossen and Swagato Bannerjee.

In many cases, Int(L dt) =250 ab^{-1} >> 50 ab^{-1} may be needed at Belle II to diagnose the nature of the new physics (e.g. Wilson coefficients in $b \to s\, l^+ l^-$ or NP couplings in $B \to D^* l \nu$)

Snowmass Backup Materials





May 16, 2022: SuperKEKB passed L=4 x $10^{34}/cm^2/sec$. A new world record for accelerators.

This about 3.5 times higher than L_max(PEP-II/BaBar) with a factor of 5 lower product of beam currents. *A factor of two better than KEKB.* Nanobeams work !

KEK has convened an International Task Force (ITF) for SuperKEKB to map out a path to the target luminosity 6 x $10^{35}/cm^2/sec$.

ITF Participation from accelerator teams at CERN (FCC-ee), IHEP, ESRF, BNL, SLAC….

Also see Snowmass paper on beam bkgs A. Natochii et al . http://arxiv.org/abs/2203.05731

https://arxiv.org/abs/1808.10567

Outcome of the B2TIP (Belle II Theory Interface) Workshops (2014-2018)

Emphasis is on New Physics (NP) reach.

Strong participation from theory community, *lattice QCD community* and Belle II experimenters. 689 pages, published by Oxford University Press

Some updates in Belle II Physics Program White Paper https://www.slac.stanford.edu/~mpeskin/Snowmass2021/BelleIIPhysicsforSnowmass.pdf

The Belle II Physics Book

E. Kou[74,¶,†], P. Urquijo[143,§,†], W. Altmannshofer[133,¶], F. Beaujean[78,¶], G. Bell[120,¶], M. Beneke[112,¶], I. I. Bigi[146,¶], F. Bishara[148,16,¶], M. Blanke[49,50,¶], C. Bobeth[111,112,¶], M. Bona[150,¶], N. Brambilla[112,¶], V. M. Braun[43,¶], J. Brod[110,133,¶], A. J. Buras[113,¶], H. Y. Cheng[44,¶], C. W. Chiang[91,¶], M. Ciuchini[58,¶], G. Colangelo[126,¶], H. Czyz[154,29,¶], A. Datta[144,¶], F. De Fazio[52,¶], T. Deppisch[50,¶], M. J. Dolan[143,¶], J. Evans[133,¶], S. Fajfer[107,139,¶], T. Feldmann[120,¶], S. Godfrey[7,¶], M. Gronau[61,¶], Y. Grossman[15,¶], F. K. Guo[41,132,¶], U. Haisch[148,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[88,¶], J. Hisano[88,89,¶], L. Hofer[125,¶], M. Hoferichter[166,¶], W. S. Hou[91,¶], T. Huber[120,¶], S. Jaeger[157,¶], S. Jahn[82,¶], M. Jamin[124,¶], J. Jones[102,¶], M. Jung[111,¶], A. L. Kagan[133,¶], F. Kahlhoefer[1,¶], J. F. Kamenik[107,139,¶], T. Kaneko[30,26,¶], Y. Kiyo[63,¶], A. Kokulu[112,138,¶], N. Kosnik[107,139,¶], A. S. Kronfeld[20,¶], Z. Ligeti[19,¶], H. Logan[7,¶], C. D. Lu[41,¶], V. Lubicz[151,¶], F. Mahmoudi[140,¶], K. Maltman[171,¶], S. Mishima[30,¶], M. Misiak[164,¶],

- Fit to left- and right-handed Wilson coefficients with $B \to K^* \mu^+ \mu^-$ and $B \to K^* e^+ e^-$ decays.
- 1, 5, 50, and 250 ab^{-1} with 25 % selection efficiency which correspond 142, 711, 7110, and 35560 events in a pseudo-experiment.
- For the C_7 extraction the number of decays increases by 9 and 36 % for the di-muon and di-electron mode respectively.
- Default hadronic form factors, pseudo-data with no resonances.
- 0.25 GeV^2/c^4 veto windows around J/ψ and $\psi(2S)$ regions.
- $q^2 > 1\mathrm{GeV}^2/c^4$ for C_9 and C_{10} only – the pole data is kept for the C_7 extraction.
- In the fit only one complex Wilson coefficient is released.
- For reference $C_7 = -0.304$, $C_9 = 4.211$, and $C_{10} = -4.103$.
- Linearity test – fit to pseudo-data generated with the biased Wilson coefficients.

Assume Belle efficiency

MC for NP in $b \to c\ell\bar{\nu}$ decays

To answer this question we now have a new Monte-Carlo based on Evtgen:
https://github.com/qdcampagna/BTODSTARLNUNP_EVTGEN_Model

$$\mathcal{H}_{\rm eff} = \frac{G_F V_{cb}}{\sqrt{2}} \Big\{ (1+g_L)\,[\bar{c}\gamma_\mu(1-\gamma_5)b]\,[\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell]$$
$$+g_R\,[\bar{c}\gamma_\mu(1+\gamma_5)b]\,[\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell]$$
$$+g_S\,[\bar{c}b]\,[\bar{\ell}(1-\gamma_5)\nu_\ell]$$
$$+g_P\,[\bar{c}\gamma_5 b]\,[\bar{\ell}(1-\gamma_5)\nu_\ell]$$
$$+g_T\,[\bar{c}\sigma^{\mu\nu}(1-\gamma_5)b]\,[\bar{\ell}\sigma_{\mu\nu}(1-\gamma_5)\nu_\ell] \Big\} + h.c.$$

Caveats :

1. Neutrinos are always left-handed.
2. The scalar matrix element $\langle D^*|\bar{c}b|\bar{B}\rangle = 0$
3. SM case : $g_L = g_R = g_P = g_T = 0$
4. Hadronic matrix elements are expressed in terms of form factors which are non-perturbative objects (cannot be calculated form first principles of QCD).

- We pick out a few NP scenarios as listed below.
- The choice is motivated such that :
  - the ratio of semi-leptonic branching fractions is constrained to be within 3% of unity.
  - they are able to explain the experimental $\langle \Delta A_{FB} \rangle$ i.e within 0.0349 ± 0.0089.
  - they also satisfy constraints on other angular observables such as $\langle \Delta F_L \rangle^{exp} = -0.0065 \pm 0.0059$ and $\langle \Delta \tilde{F}_L \rangle^{exp} = -0.0107 \pm 0.0142$.

	g_L	g_R	g_P
Scenario 1:	0.06	0.075	0.2 i
Scenario 2:	0.08	0.090	0.6 i
Scenario 3:	0.07	0.075	0