Belle II legacy and correlation with HL-LHC

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(for the Belle II collaboration)

Workshop on the physics of HL-LHC, and perspectives at HE-LHC

CERN
Oct. 30 - Nov. 1, 2017

Karlsruhe Institute of Technology

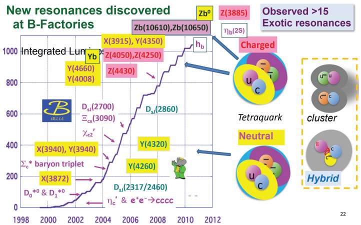
Belle II

Outline

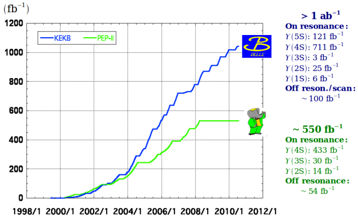
- ***B* factories legacy.**
- **SuperKEKB and Belle II status and timeline.**
- **Selection of tensions with the SM and prospects for Belle II and HL-LHC.**

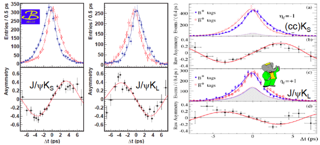
Success of the B factories (1999-2010)

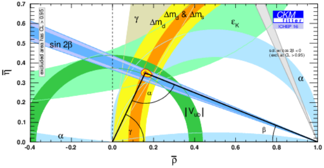
- Spectacular accelerator and detector performance.
- Discovery of CP violation in B decays.
- Confirmation of the CKM picture of flavor physics.
- Discovery of several new particles.
- Probe of rare B decays.
- Limits on New Physics scenarios.



Integrated luminosity of B factories







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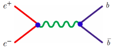
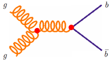
Belle II

Belle II



- Clean experimental environment.
- Holistic interpretation of events with missing energy (ν).
- Decays with multiple photons.
- Inclusive decays ($B \to X_{s,d}\gamma$).
- Long-lived particles (K_S and K_L).

LHCb



- Large cross section.
- Decays to all charged particle final states.
- Fast mixing.

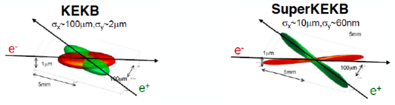
B2TiP Report (in progress)

Observables	Expected th. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	Belle II/LHCb
$S(B_s \to J/\psi\phi)$	***	0.01	LHCb
$\lvert V_{cb}\rvert$ incl.	***	1%	Belle II
$\lvert V_{cb}\rvert$ excl.	***	1.5%	Belle II
$\lvert V_{ub}\rvert$ incl.	**	3%	Belle II
$\lvert V_{ub}\rvert$ excl.	**	2%	Belle II/LHCb
CPV			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\beta_s^{\rm eff}(B_s \to \phi\phi)$ [rad]	**	0.1	LHCb
$\beta_s^{\rm eff}(B_s \to K^{*0}\bar{K}^{*0})$ [rad]	**	0.1	LHCb
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II
(Semi-)leptonic			
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II
$R(B \to D\tau\nu)$	***	3%	Belle II
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb
Radiative & EW Penguins			
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II
$S(B \to K_S^0\pi^0\gamma)$	***	0.03	Belle II
$2\beta_s^{\rm eff}(B_s \to \phi\gamma)$	***	0.05	LHCb
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\bar{\nu})$ $[10^{-6}]$	***	15%	Belle II
$\mathcal{B}(B \to K\nu\bar{\nu})$ $[10^{-6}]$	***	20%	Belle II
$q_0^2 A_{\rm FB}(B \to K^*\mu\mu)$	**	0.05	LHCb/Belle II
$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	***	< 2	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb/Belle II
Charm			
$\mathcal{B}(D_s \to \mu\nu)$	***	0.9%	Belle II
$\mathcal{B}(D_s \to \tau\nu)$	***	2%	Belle II
$\Delta A_{CP}(D^0 \to K^+K^-)$ $[10^{-4}]$	**	0.1	LHCb
$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	**	0.03	Belle II
$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	***	0.03	Belle Ii
$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	***	4	Belle II
Tau			
$\tau \to \mu\gamma$ $[10^{-9}]$	***	< 5	Belle II
$\tau \to e\gamma$ $[10^{-9}]$	***	< 10	Belle II
$\tau \to \mu\mu\mu$ $[10^{-9}]$	***	< 0.3	Belle II/LHCb

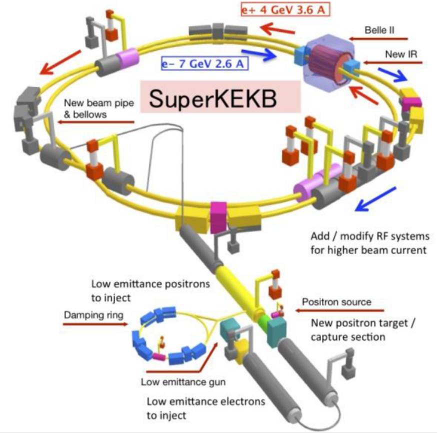
Upgrade for SuperKEKB and Belle II to achieve 40x peak $\mathcal{L}$ under 20x bkgd

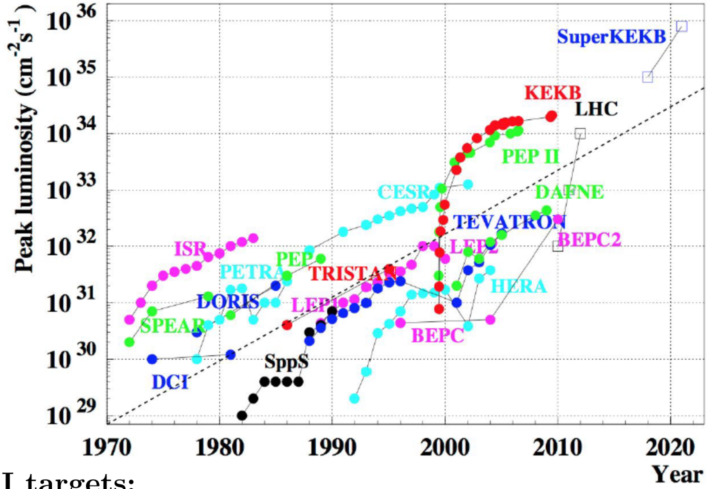
- Reduction in the beam size by 1/20 at the IP.
- Doubling the beam currents.

$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$



- ▶ *First turns achieved Feb. 2016*
- ▶ *Beam-background studies ongoing*



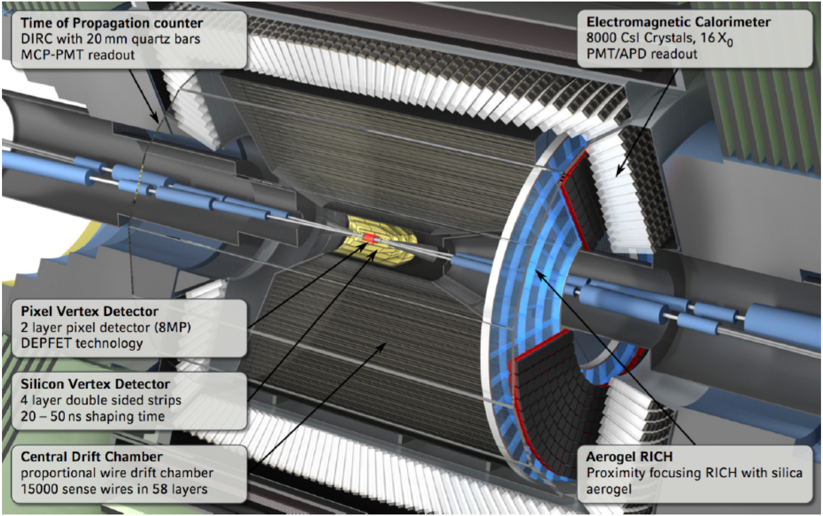


Belle II targets:

Instantaneous luminosity $\mathbf{8 \times 10^{35} cm^{-2} s^{-1}}$

Integrated luminosity $\mathbf{50 ab^{-1}}$ **by 2024**

Belle II detector



Targeted improvements: *Increase K_S^0 efficiency; Improve IP and secondary vertex resolution, K/π separation, and π^0 efficiency; Particle and μ ID in endcaps.*

Si pixel (2 layers) and strip (4 layers):

- 1^{st} pixel layer at $r = 14mm$ to IP

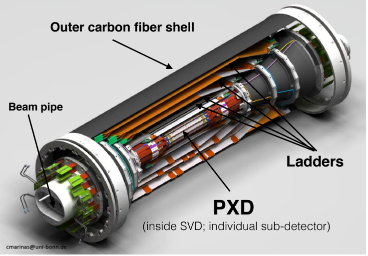
  [Belle at $r = 20mm$]

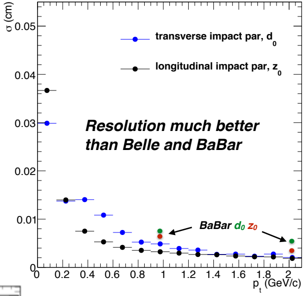
  Improves vertex resolution along z-axis

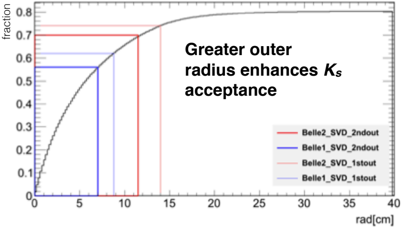
- Larger SVD w/outer layer at $r = 135mm$.

  [Belle at $r = 88mm$]

  Higher fraction of K_S' with vertex hits improves vertex resolution



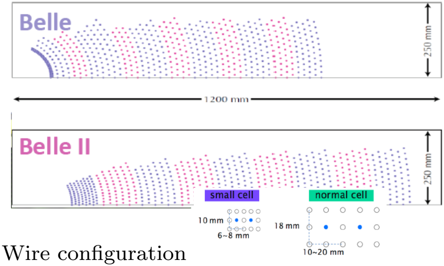




Tracking detector

Central Drift Chamber:

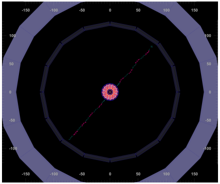
- Larger outer radius of 1111mm (Belle 863mm) allows for improved p resolution.
- Smaller cells with lower occupancy and capacity for higher hit rate.



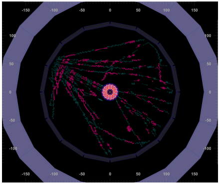
Wire configuration

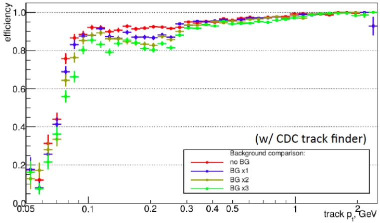
Full readout of the CDC

Single track



Showering event



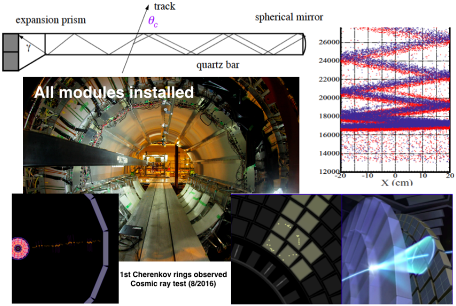


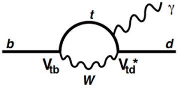
Simulated track reconstruction efficiency

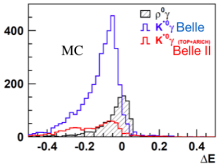
Stable performance for up to 3x predicted beam BG

Two RICH systems covering full momentum range

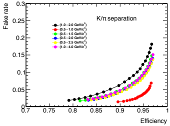
- Barrel: Time of Propagation (TOP) counter (16 modules).
  $\Rightarrow$ *Measure x-y position of Cherenkov γ's and their arrival time.*
- Forward Endcap: Aerogel Ring Imaging Cherenkov detector (ARICH)
  $\Rightarrow$ *Proximity focusing with silica aerogel (4σ separation at $1-3.5$ GeV/c)*

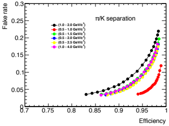






Average ϵ_K vs. π fake rate improved: Fake rate decreases by ≈ 3 for the same ε w.r.t. Belle



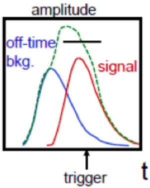


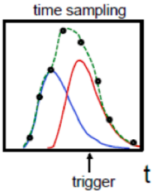
The background $B \to K^*\gamma$ (Belle/Belle II) $\approx 30x$ more abundant than $B \to \rho\gamma$.

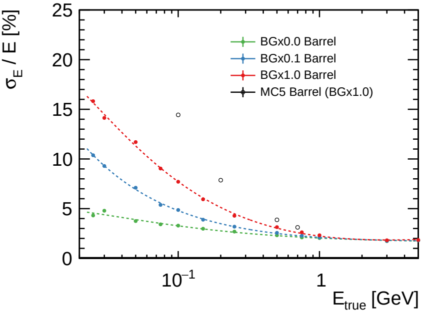
Electromagnetic calorimeter

Re-usage of Belle's CsI(TI) crystal calorimeter, but with new electronics with 2MHz wave form sampling to compensate for the larger beam-related backgrounds and the long decay time of CsI(TI) signals.

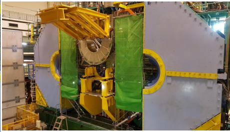
⇒ *Resolution much better at Belle II*

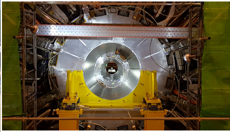






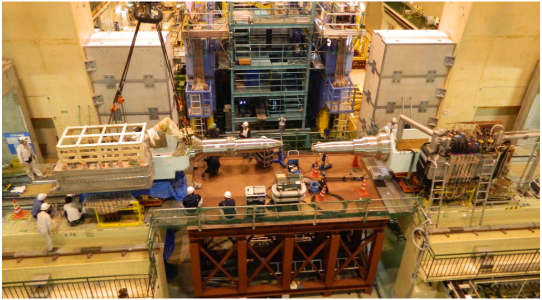
Peak energy resolution in the ECL barrel as a function of true photon energy

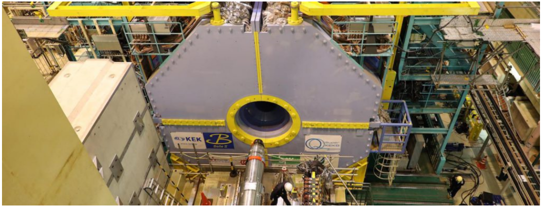




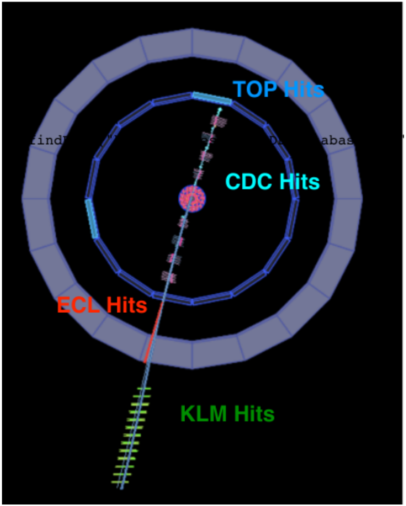
Endcap Installation

Belle II today





Belle II roll-in (April 11)

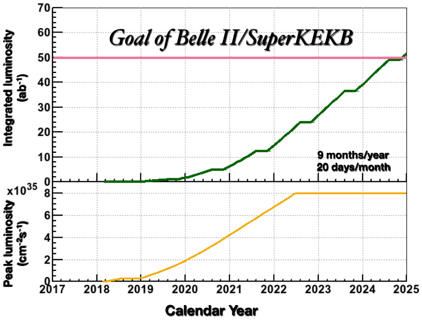


Global cosmic run (August)

Phase 2: Feb.-July 2018

- First collisions.
- Beam commissioning.
- Physics run without VXD on $\Upsilon(4S)$ & $\Upsilon(6S)$. $\mathcal{L} \approx 20\text{fb}^{-1}$.
  - ⇒ *Physics measurements:* $\Upsilon(6S)$ *conventional bottonium and exotic states (e.g.,* Z_b*, QCD hybrids in* BB^**)* (talk by T. Kuhr).
- New triggers for exotic dark signatures in low multiplicity events (talk by T. Ferber).

SuperKEKB luminosity projection



Phase 3:

- Luminosity tuning. ⇒ Physics run with full Belle II: $\mathcal{L} = 5(50)\text{ab}^{-1}$ by 2020(2024).

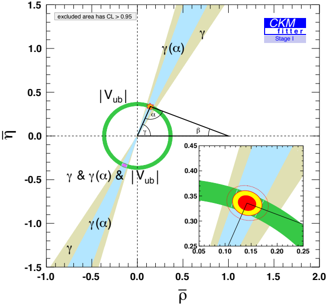
Many open questions and as-yet unobserved processes awaiting Belle II data...

The future of the UT (?)

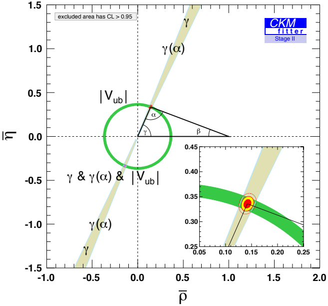
- Belle II expects to improve precision to $\alpha \approx 0.3°$, $\beta \approx 1.0°$, $\gamma \approx 1.5°$.
- Improvement in precision should help to resolve the tension between inclusive and exclusive measurements of $|V_{ub}|$ and $|V_{cb}|$.

Future sensitivities *assuming data consistent with the SM*:

Belle 5ab^{-1}, LHCb 7fb^{-1} (2020)



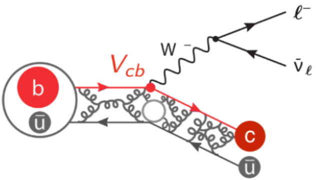
Belle 50ab^{-1}, LHCb 50fb^{-1} (2030)

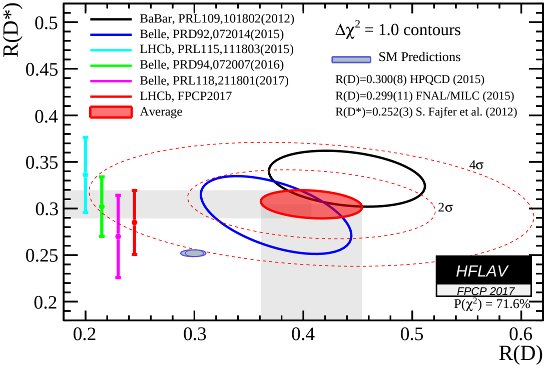


arXiv:1309.2293

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

- Very clean prediction from theory.
- New Physics could change the ratios $\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\overline{B}\to D^{(*)}\tau\nu)}{\mathcal{B}(\overline{B}\to D^{(*)}\ell\nu)}$.
- Effect could be different for D and D^*.
- World average 4σ away from SM.





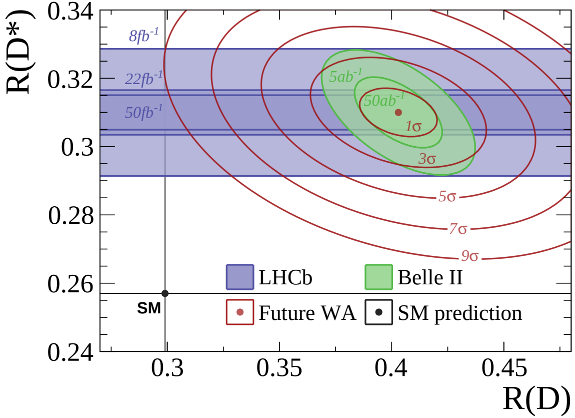
Belle: Hadronic tag, leptonic τ Semileptonic tag, leptonic τ Hadronic tag, hadronic τ

BaBar: Hadronic tag, leptonic τ LHCb: leptonic τ hadronic τ

$\overline{B} \to D^{(*)}\tau\overline{\nu}$ with Belle II & LHCb

arXiv:1709.10308: J. Albrecht, F. U. Bernlochner, M. Kenzie, S. Reichert, D. M. Straub, A. Tully

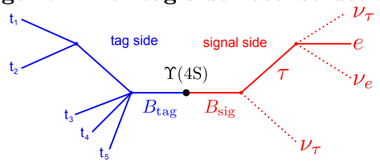
Measurement	SM prediction	Current World Average	Current Uncertainty	Projected Uncertainty[1]				
				Belle II		LHCb		
				5ab^{-1}	50ab^{-1}	8fb^{-1}	22fb^{-1}	50fb^{-1}
				2020	2024	2019	2024	2030
$R(D)$	(0.299 ± 0.003)	$(0.403 \pm 0.040 \pm 0.024)$	11.6%	5.6%	3.2%	-	-	-
$R(D^*)$	(0.257 ± 0.003)	$(0.310 \pm 0.015 \pm 0.008)$	5.5%	3.2%	2.2%	3.6%	2.1%	1.6%

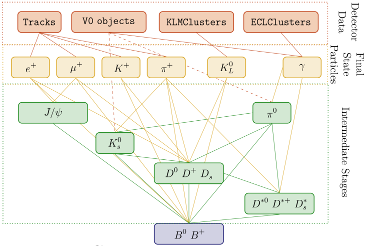


[1] *Projected uncertainties not including improvements in detectors and algorithms*

Improved algorithms @ Belle II

New Full Event Interpretation (FEI) algorithm for tag-side reconstruction



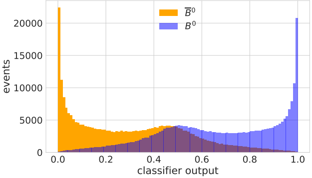


Tagging ε on MC

Tag	FR[1]	FEI Belle	FEI Belle II
Hadronic B^+	0.28%	0.76%	0.66%
SL B^+	0.67%	1.80%	1.45%
Hadronic B^0	0.18%	0.46%	0.38%
SL B^0	0.63%	2.04%	1.94%

[1] Belle Full Reconstruction algorithm.

Deep NN based flavor tagger

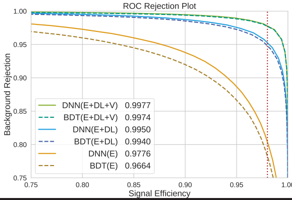


Tagging ε on MC

	Category-based	Deep NN
Belle II MC	$33.29 \pm 0.01\%$	$40.69 \pm 0.03\%$
Belle MC	$29.30 \pm 0.10\%$[2]	$34.42 \pm 0.09\%$

[2] Belle flavor tagger

Deep NN based $e^+e^- \to q\overline{q}$ background suppression



- Within the SM, decays proceed via one loop diagram:

  JHEP0712:040,2007

  $$\mathcal{R}_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ e^+ e^-)} = 1.00030^{+0.00010}_{-0.00007}$$

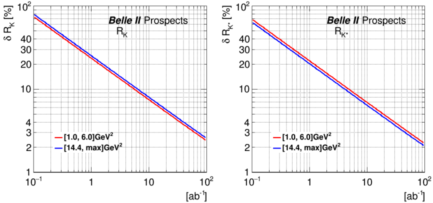
- LHCb reported a 2.6σ deviation for the dilepton invariant mass squared region $1 < q^2 < 6$ GeV$^4/c^2$:

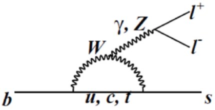
  $$\mathcal{R}_K = 0.745^{+0.090}_{-0.074} \pm 0.036$$

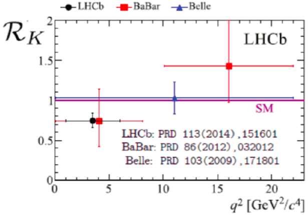
  Phys. Rev. Lett. **113** 151601 (2016)

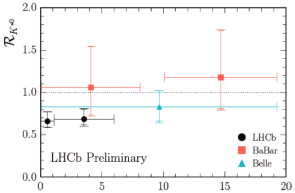
- Electrons and muons have the same ε at Belle II:

  $\Rightarrow$ *Both low and high q^2 regions possible.*









- PRD 86 (2012) 032012
- PRL 103 (2009) 171801

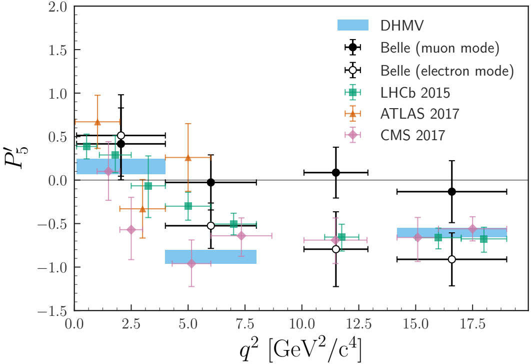
2017 ATLAS & CMS results, and lepton-flavor-dependent angular analysis by Belle

Plot: S. Wehle

Belle: PRL 118, 111801 (2017)

- Largest deviation of 2.6σ from the SM for the muon channel for $4 < q^2 < 8\ \mathrm{GeV}^4/c^2$.
- Electron channel deviation of 1.1σ.

- Belle II and LHCb will be comparable for this process.
- Belle II will be able to perform an isospin comparison of K^{*+} and K^{*0}, or the ground states K.



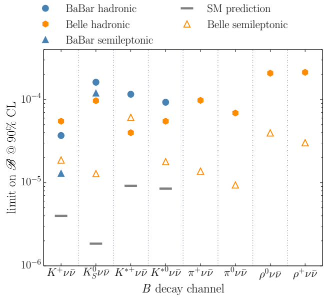
Belle II sensitivity of P_5'

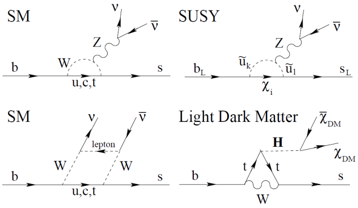
q^2 (GeV^2)	Belle	Belle II $(50\mathrm{ab}^{-1})$
0.10 - 4.00	0.416	0.059
4.00 - 8.00	0.277	0.040
10.09 - 12.00	0.344	0.049
14.18 - 19.00	0.248	0.033

Neutrino EWP decays $b \to s, d\nu\bar{\nu}$

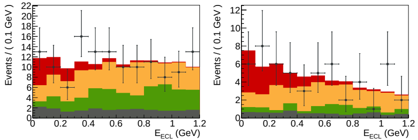
⇒ *The ultimate test of Belle II*

- Theoretically clean due to a maximum of one electromagnetically interacting charged particle in the final state, as opposed to $K^{(*)}l^+l^-$ decays.
- Several new physics models (SUSY, non-standard Z coupling) could enhance these decays.





$K^+\nu\bar{\nu} < 1.9 \times 10^{-5}$ $\quad$ $K^{*+}\nu\bar{\nu} < 6.1 \times 10^{-5}$



Extract the signal yield by fitting the extra energy in the calorimeter:

$$E_{ECL} = \sum E_{\text{Calor.}} - \left(\sum E_{\text{tag}} + \sum E_{\text{sig}}\right)$$

Sum of energies of neutral clusters not associated with reconstructed particles

New Belle semileptonic tag result: arXiv:1702.03224 (to appear in PRD(RC))

$B \to K^{(*)}\nu\bar{\nu}$ and $B \to \nu\bar{\nu}$ @ Belle II

- Observation of $B \to K^*\nu\bar{\nu}$ (combining charged and neutral) with 4ab^{-1} (based on FEI algorithm).
- Expected sensitivities of $\mathcal{B}(B \to K^*\nu\bar{\nu})$ to reach 10% with 50ab^{-1} (comparable with SM predictions).
- Longitudinal polarization (f_L) of K^* reaches 0.08 for charged and neutral B decays. (SM uncertainty is 0.03 arXiv:1409.4557.)

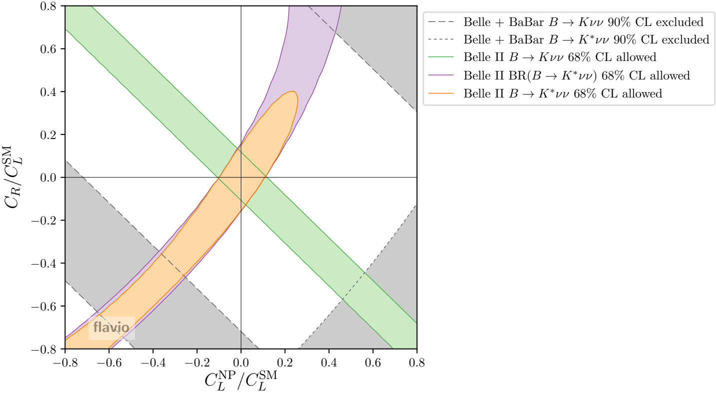
Sensitivities of modes with $\nu\bar{\nu}$ in the final state

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathcal{B}(B^+ \to K^+\nu\bar{\nu})$	$< 450\%$	30%	11%
$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})$	$< 180\%$	26%	9.6%
$\mathcal{B}(B^+ \to K^{*+}\nu\bar{\nu})$	$< 420\%$	25%	9.3%
$f_L(B^0 \to K^{*0}\nu\bar{\nu})$	–	–	0.079
$f_L(B^+ \to K^{*+}\nu\bar{\nu})$	–	–	0.077
$\mathcal{B}(B^0 \to \nu\bar{\nu}) \times 10^6$	< 14	< 5.0	< 1.5

B2TiP Report (in progress)

Constraints on NP contributions to C_L^{NP} & C_R^{NP} (norm. to the SM value of C_L)

- Gray areas show the 90% CL excluded regions from Belle & BaBar.
- Allowed region (@68% CL) of $B \to K^+\nu\bar{\nu}$ with 50ab^{-1} (assuming sensitivities in prev. slide)
- Constraints from $B \to K^*\nu\bar{\nu}$ using $\mathcal{B}$ only.
- Constraints from $B \to K^*\nu\bar{\nu}$ using $\mathcal{B}$ and f_L.

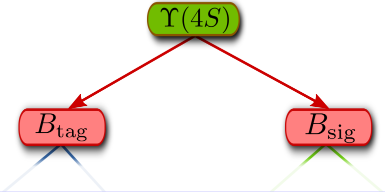


Summary

- The SuperKEKB accelerator is operational and beam background studies are under way.
- The Belle II detector construction is nearing completion.
- Physics with partial detector scheduled for early 2018.
- Full detector to begin taking data in late 2018.
- Broad program to search for NP with flavor observables.
- Significant complementarity with HL-LHC in many interesting channels.

Extra material

Which tag-side reconstruction?



Tagging techniques

Purity

$\longrightarrow$

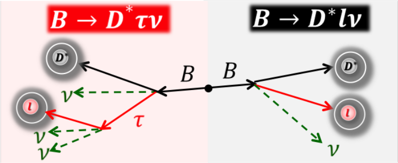
$\longleftarrow$

Efficiency

Inclusive	Semileptonic	Hadronic
$B \to$ anything	$B \to D^{(*)}\ell\nu_\ell$	$B \to$ hadrons
$\epsilon \approx \mathcal{O}(2\%)$	$\epsilon \approx \mathcal{O}(0.2\%)$	$\epsilon \approx \mathcal{O}(0.1\%)$
Very large statistics; Also very large background	Mid-range reconstruction efficiency; Less information about B_{tag} due to neutrino	Cleaner sample Knowledge of $p(B_{\text{sig}})$; Lower tagging efficiency

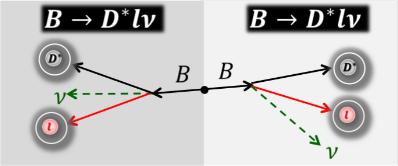
$\mathcal{R}(D^*)$ with SL tag @ Belle

Semitauonic signal-side decay and semileptonic tag-side.



Numerator in $\mathcal{R}(D^*)$

Normalization events are double semileptonic decays.



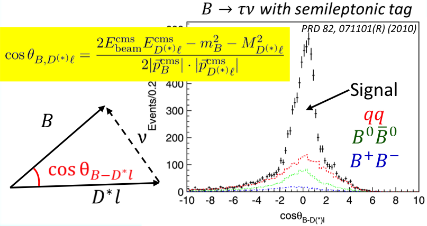
Denominator in $\mathcal{R}(D^*)$

D^* reconstruction:

- $D^{*+} \to D^0\pi^+, D^+\pi^0$ ($\sim 100\%$)
  - D^0: 10 modes ($\sim 37\%$)
  - D^+: 5 modes ($\sim 22\%$)

Tag semileptonic B-decay: Combine D^{*+} and oppositely-charged lepton candi-

$\Rightarrow$



Separate correctly reconstructed signal and normalization events using NeuroBayes NN with the following variables:

- Missing mass squared: $M^2_{\text{miss}} = \sqrt{(2E_{\text{beam}} - \sum_i E_i)^2 - |\sum_i \vec{p}_i|^2}$
- Visible energy: $E_{\text{vis}} = \sum_i E_i$, where $(\vec{p}_i, E_i)$ is the reconstructed four-momentum at the $\Upsilon(4S)$ rest frame of particles used in the reconstruction.
- $\cos\theta_{B\text{-}D^*\ell}$

$\Rightarrow$ *Trained on MC samples of signal and normalization.*

Dominant backgrounds:

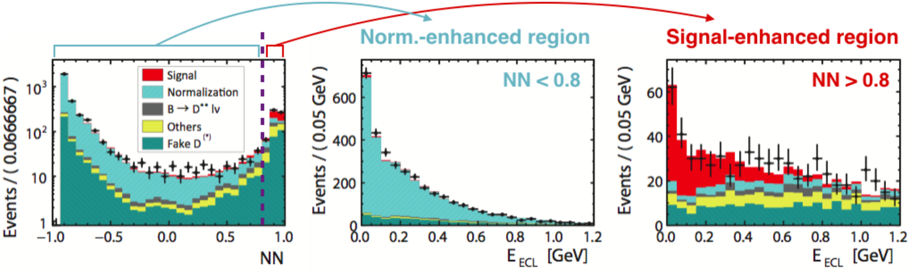
- Fake (falsely reco'd) D^*.
- $B \to D^{**} l \nu_l$, with $D^{**} \to D^{(*)}$
- $B \to X_c D^*$, with $X_c \to$ decaying semileptonically.

Separated from signal and normalization using the ***sum of energies of neutral clusters not associated with reco'd particles:*** E_{ECL}

2D fit to NN and E_{ECL} to extract signal and normalization

Component	**Yield**	**Shape**
Signal	Float	1D X 1D
Normalization	Float	2D
Fake $D^{(*)}$	Fix	2D
$B \to D^{**} l\nu$	Float	2D
Other	Fix	2D

2D fit to NN and E_{ECL}:



$$\mathcal{R}(D^*) = \frac{1}{\mathcal{B}(\tau^- \to l^- \bar{\nu}_l \nu_\tau)} \cdot \frac{\varepsilon_{\text{norm}}}{\varepsilon_{\text{sig}}} \cdot \frac{N_{\text{sig}}}{N_{\text{norm}}}$$

$\varepsilon_{\text{norm}}/\varepsilon_{\text{sig}} = 1.289 \pm 0.015$ (from MC simulation)

$$\mathcal{R}(D^*) = 0.302 \pm 0.030(\text{stat}) \pm 0.011(\text{syst}) \quad (13.8\sigma)$$

$\mathcal{R}(D^*)$ with SL tag @ Belle

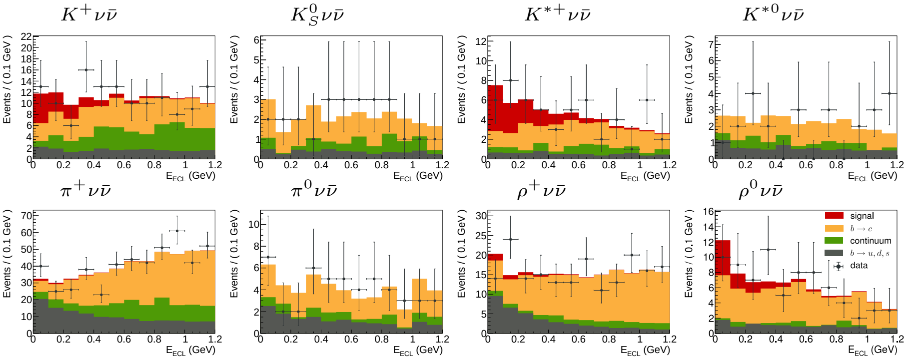
	$\mathcal{R}(D^*)$ [%]		
Sources	$\ell^{\rm sig} = e, \mu$	$\ell^{\rm sig} = e$	$\ell^{\rm sig} = \mu$
MC statistics for PDF shape	2.2%	2.5%	3.9%
PDF shape of the normalization	$^{+1.1}_{-0.0}$%	$^{+2.1}_{-0.0}$%	$^{+2.8}_{-0.0}$%
PDF shape of $B \to D^{**}\ell\nu_\ell$	$^{+1.0}_{-1.7}$%	$^{+0.7}_{-1.3}$%	$^{+2.2}_{-3.3}$%
PDF shape and yields of fake $D^{(*)}$	1.4%	1.6%	1.6%
PDF shape and yields of $B \to X_c D^*$	1.1%	1.2%	1.1%
Reconstruction efficiency ratio $\varepsilon_{\rm norm}/\varepsilon_{\rm sig}$	1.2%	1.5%	1.9%
Modeling of semileptonic decay	0.2%	0.2%	0.3%
$\mathcal{B}(\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau)$	0.2%	0.2%	0.2%
Total systematic uncertainties	$^{+3.4}_{-3.5}$%	$^{+4.1}_{-3.7}$%	$^{+5.9}_{-5.8}$%

- Dominant uncertainty arises from the limited size of the MC samples for the PDF shapes. $\Rightarrow$ *Evaluated with Toy MC studies.*
- Large error due to poorly known $\mathcal{B}(B \to D^{**} l \nu_l)$ and of the D^{**} decay. $\Rightarrow$ *Varied within their uncertainties.*

Consistent results for individual samples (separated @ $B_{\rm sig}$)

$$\mathcal{R}(D^*) = 0.311 \pm 0.038 \pm 0.013 \ \ (\ell^{\rm sig} = e)$$
$$\mathcal{R}(D^*) = 0.304 \pm 0.051 \pm 0.018 \ \ (\ell^{\rm sig} = \mu)$$

Extended binned ML fit to E_{ECL}:



- Histogram templates to model signal and bkgds from charm B decay, charmless B decay, and continuum.
- Relative fractions of the background components fixed to MC expectations.
- Signal and overall background yield allowed to vary.

Channel	Observed $N_{\rm sig}$	Significance
$K^+\nu\bar{\nu}$	$17.7 \pm 9.1 \pm 3.4$	1.9σ
$K^0_S\nu\bar{\nu}$	$0.6 \pm 4.2 \pm 1.4$	0.0σ
$K^{*+}\nu\bar{\nu}$	$16.2 \pm 7.4 \pm 1.8$	2.3σ
$K^{*0}\nu\bar{\nu}$	$-2.0 \pm 3.6 \pm 1.8$	0.0σ
$\pi^+\nu\bar{\nu}$	$5.6 \pm 15.1 \pm 5.9$	0.0σ
$\pi^0\nu\bar{\nu}$	$0.2 \pm 5.6 \pm 1.6$	0.0σ
$\rho^+\nu\bar{\nu}$	$6.2 \pm 12.3 \pm 2.4$	0.3σ
$\rho^0\nu\bar{\nu}$	$11.9 \pm 9.0 \pm 3.6$	1.2σ

- **Expected (exp.) and observed upper limits at the 90% confidence level** (including systematic uncertainties)

Channel	Efficiency	Expected Limit	Measured Limit
$K^+\nu\bar{\nu}$	2.16×10^{-3}	0.8×10^{-5}	1.9×10^{-5}
$K^0_S\,\nu\bar{\nu}$	0.91×10^{-3}	1.2×10^{-5}	1.3×10^{-5}
$K^{*+}\nu\bar{\nu}$	0.57×10^{-3}	2.4×10^{-5}	6.1×10^{-5}
$K^{*0}\nu\bar{\nu}$	0.51×10^{-3}	2.4×10^{-5}	1.8×10^{-5}
$\pi^+\nu\bar{\nu}$	2.92×10^{-3}	1.3×10^{-5}	1.4×10^{-5}
$\pi^0\nu\bar{\nu}$	1.42×10^{-3}	1.0×10^{-5}	0.9×10^{-5}
$\rho^+\nu\bar{\nu}$	1.11×10^{-3}	2.5×10^{-5}	3.0×10^{-5}
$\rho^0\nu\bar{\nu}$	0.82×10^{-3}	2.2×10^{-5}	4.0×10^{-5}

Combine charged and neutral modes:

- The systematic uncertainties are evaluated on independent MC and data control samples for charged and neutral modes.
  $\Rightarrow$ *Can be considered uncorrelated.*
- Add the -$\mathcal{L}$ and scale the $\mathcal{B}$ of the neutral modes by τ_B^+/τ_B^0 and repeat the calculation of the limit:

$$\mathcal{B}(B \to K\nu\bar{\nu}) < 1.6\times10^{-5}$$
$$\mathcal{B}(B \to K^*\nu\bar{\nu}) < 2.7\times10^{-5}$$
$$\mathcal{B}(B \to \pi\nu\bar{\nu}) < 0.8\times10^{-5}$$
$$\mathcal{B}(B \to \rho\nu\bar{\nu}) < 2.8\times10^{-5}$$

	$K^+\nu\bar{\nu}$	$K_S^0\nu\bar{\nu}$	$K^{*+}\nu\bar{\nu}$	$K^{*0}\nu\bar{\nu}$	$\pi^+\nu\bar{\nu}$	$\pi^0\nu\bar{\nu}$	$\rho^+\nu\bar{\nu}$	$\rho^0\nu\bar{\nu}$
K_L^0 veto	0.2	0.2	0.1	0.2	0.6	0.4	0.6	0.0
fixed fraction	0.4	0.3	0.1	0.2	1.3	0.1	0.1	1.0
continuum correction	2.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0
tag correction	0.5	0.2	0.1	0.1	1.9	0.1	0.2	0.5
shape uncertainty	2.6	1.3	1.8	1.7	4.5	1.5	2.3	3.4
fit bias	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.2
total	3.4	1.4	1.8	1.8	5.9	1.6	2.4	3.6

- Uncertainties related to the signal yield (table [absolute]) are estimated by refitting the data with each quantity varied by $\pm 1\sigma$, with the exception of the shape uncertainty which is evaluated from Toy MC studies.
- Remaining uncertainties include: π^0 and charged track veto (4%); raw track requirement (1%); particle ID efficiency (2%) π^0 efficiency (4%), K_S^0 efficiency (2.2%) $N_{B\bar{B}}$ (1.4%).

Belle, PRD 87, 031103(R) (2013)

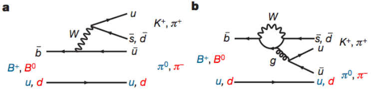
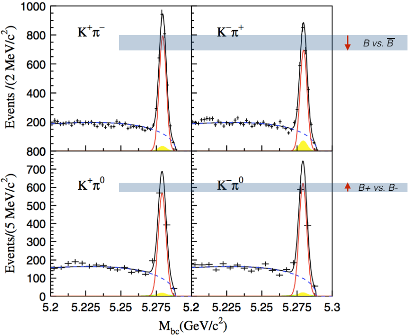


Figure 17.4.4. The dominant Tree-level (a) and Penguin-loop (b) Feynman diagrams in the two-body decays $B \to K\pi$ and $B \to \pi\pi$ (Lin, 2008).



Measurements of $DCPV$ in $B^+ \to K^+\pi^0$ found to be different than in $B^0 \to K^+\pi^-$, *contrary to naive expectation from the presence of electroweak penguin diagrams.*

$$\mathcal{A}_{K^+\pi^0} - \mathcal{A}_{K^+\pi^-} = 0.112 \pm 0.027 \pm 0.007 \quad (4\sigma)$$

The difference could be due to:

- Neglected diagrams contributing to B decays (theoretical uncertainty is still large).
  $K^+\pi^- : T + P + P^C_{EW}$
  $K^+\pi^0 : T + P + C + P_{EW} + P^C_{EW} + A$
- Some unknown NP effect that violates Isospin.

$\Rightarrow$ *In combination with other $K\pi$ measurements and with the larger Belle II dataset, strong interaction effects can be controlled and the validitiy of the SM can be tested in a model-independent way.*

$B \to K\pi$: Test of sum rule

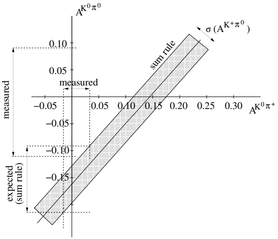
Test-of-sum (isospin) rule for NP nearly free of theoretical uncertainties, where the SM can be tested by measuring all observables: [Proposed by: PLB 627, 82(2005), PRD 58, 036005(1998)]

$$I_{K\pi} = \mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+} \frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0} \frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0} \frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

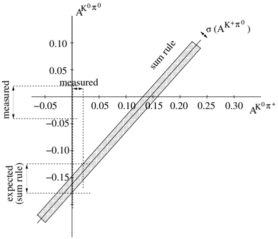
$$I_{K\pi} = -0.270 \pm 0.132 \pm 0.060 \quad (1.9\sigma)$$

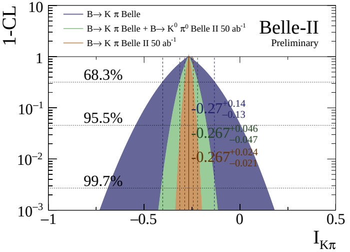
Isospin sum rule can be presented as a band in the $\mathcal{A}_{K^0\pi^0}$ vs. $\mathcal{A}_{K^0\pi^+}$ plane.

Current data



Belle II $\mathcal{L} = 50\text{ab}^{-1}$





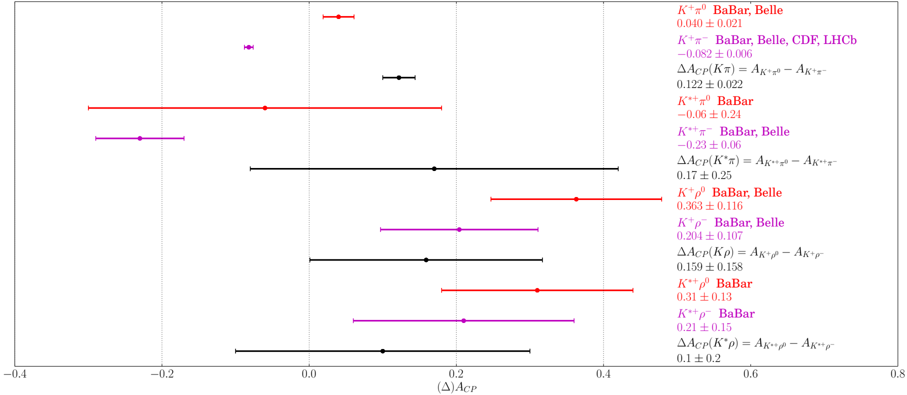
→ Most demanding measurement is $K^0\pi^0$ final state. With Belle II, the uncertainty on $\mathcal{A}(B \to K^0\pi^0)$ from time-dep. analyses is expected to reach $\sim 4\%$

⇒ *Sufficient for NP studies.*

Improvements in flavor tagging key to reducing

Extension to $K^*\pi$ and $K^{(*)}\rho$ systems.

(N)NLO calculations for $(\Delta)A_{CP}$ & isospin breaking parameter:
PLB 750(2015)348-355



Uncertainty much improved in $K\pi$ but still too large in $K^*\pi$ and $K^{(*)}\rho$ systems to be conclusive.

High precision results from LHCb and Belle II necessary.

$DCPV$ in B_s Decays

Karlsruhe Institute of Technology

Belle II

First measurment of A_{CP} in B_s decays by LHCb: Phys. Rev. Lett. **110**, 221601 (2013)

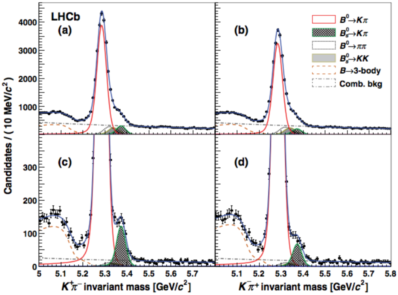
$$A_{CP}(B_s \to K^+\pi^-) = 0.27 \pm 0.04 \pm 0.01 (6.5\sigma).$$

Allows for a stringent test of

$$\Delta = \frac{A_{CP}(B^0 \to K^+\pi^-)}{A_{CP}(B_s \to K^-\pi^+)} + \frac{A_{CP}(B^0 \to K^-\pi^+)\tau_d}{A_{CP}(B_s \to K^+\pi^-)\tau_s}$$

$$= -0.02 \pm 0.05 \pm 0.04$$

No evidence for a deviation from 0 is observed.



At e^+e^-, $\Upsilon(5S)$ decays are well-suited for studying large multiplicity B_s decays due to the lower particle momenta, the almost 100% trigger ε, and the excellent π/K separation.

First observation of $B_s \to K^0\overline{K}^0$ by Belle with 121fb^{-1}: PRL 116, 161801 (2016)