Belle II Prospects for EW Penguin Decay b→sll

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on behalf of the Belle II collaboration

Precision theory for precise measurements at the LHC and future colliders
Quy-Nhon, Vietnam
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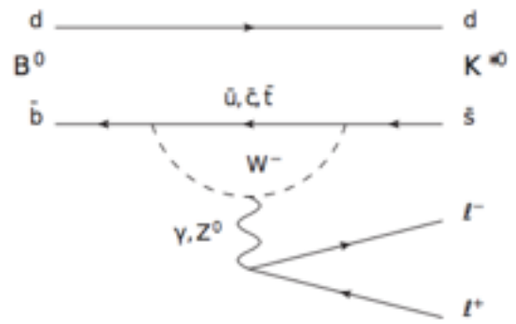
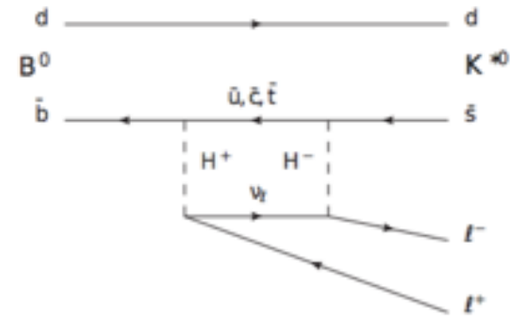
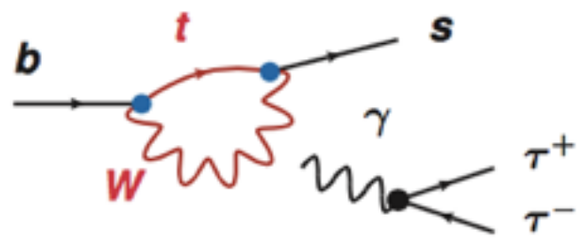
Electroweak Penguin Decays

- Electroweak Penguin Decays with Flavour Changing Neutral Currents (FCNC)
- Occur in the SM only at the loop level



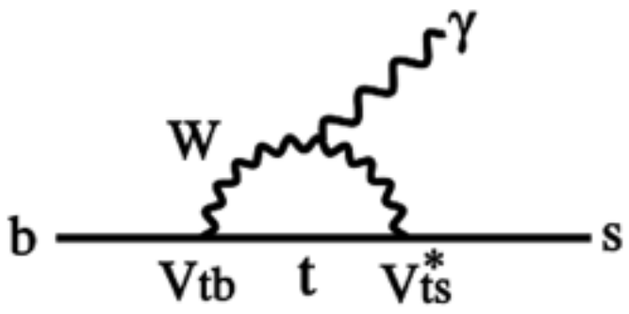


B→K(*)l+l-, l=e,μ
B→K(*)νν
B→XSll

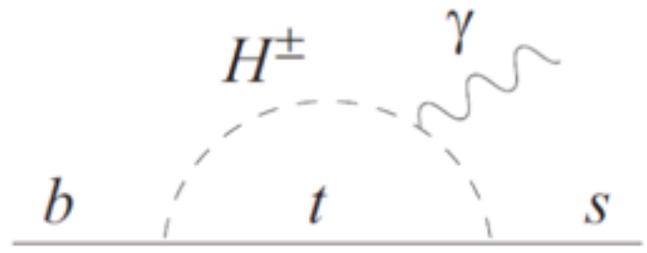


B→K(*)τ+τ-
B→XSτ+τ-

- All heavy particles of SM (t, W, Z) appear in the process.
- NP maybe enter into the loop, Sensitive to NP via interference.

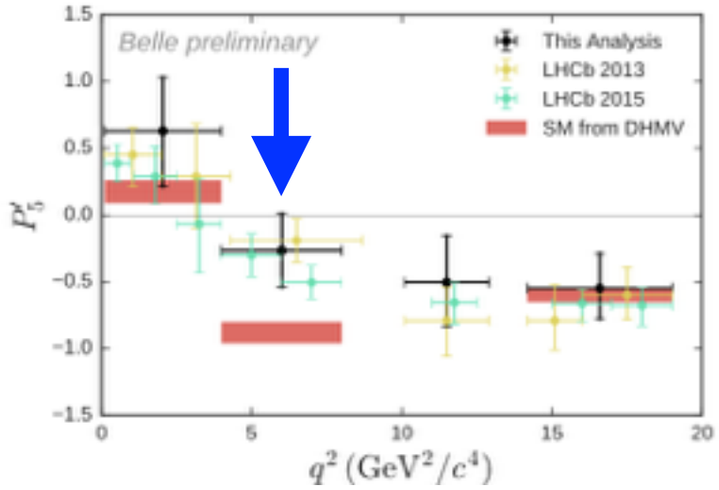


B→XSγ

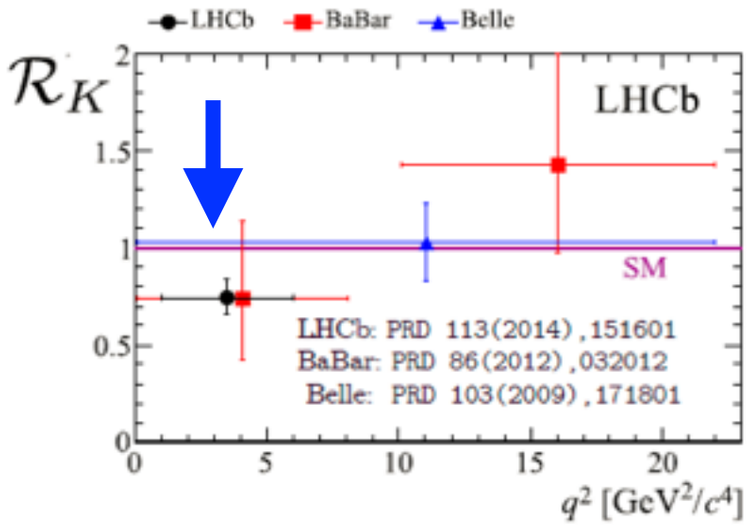


Electroweak Penguin Decays

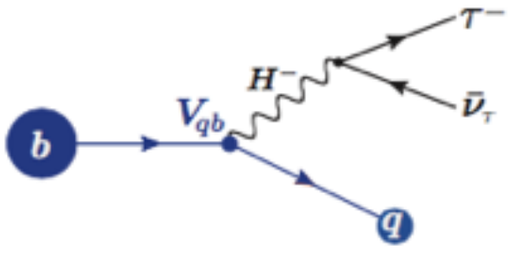
- 3.4σ (LHCb), 2.1σ (Belle) deviation from SM prediction in P_5' for $4<q^2<8$ GeV^2

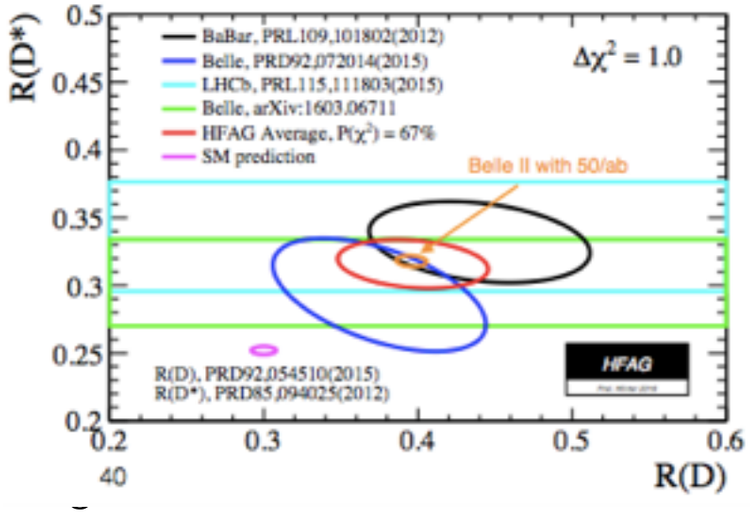


- $R=B(B\to K\mu\mu)/B(B\to Kee)$, 2.6σ deviation from SM (PRL 113, 151601 (2014))



- $R=B(B\to D^{(*)}\tau\nu)/B(B\to D^{(*)}l\nu)$, $\sim 4.0\sigma$ deviation from SM



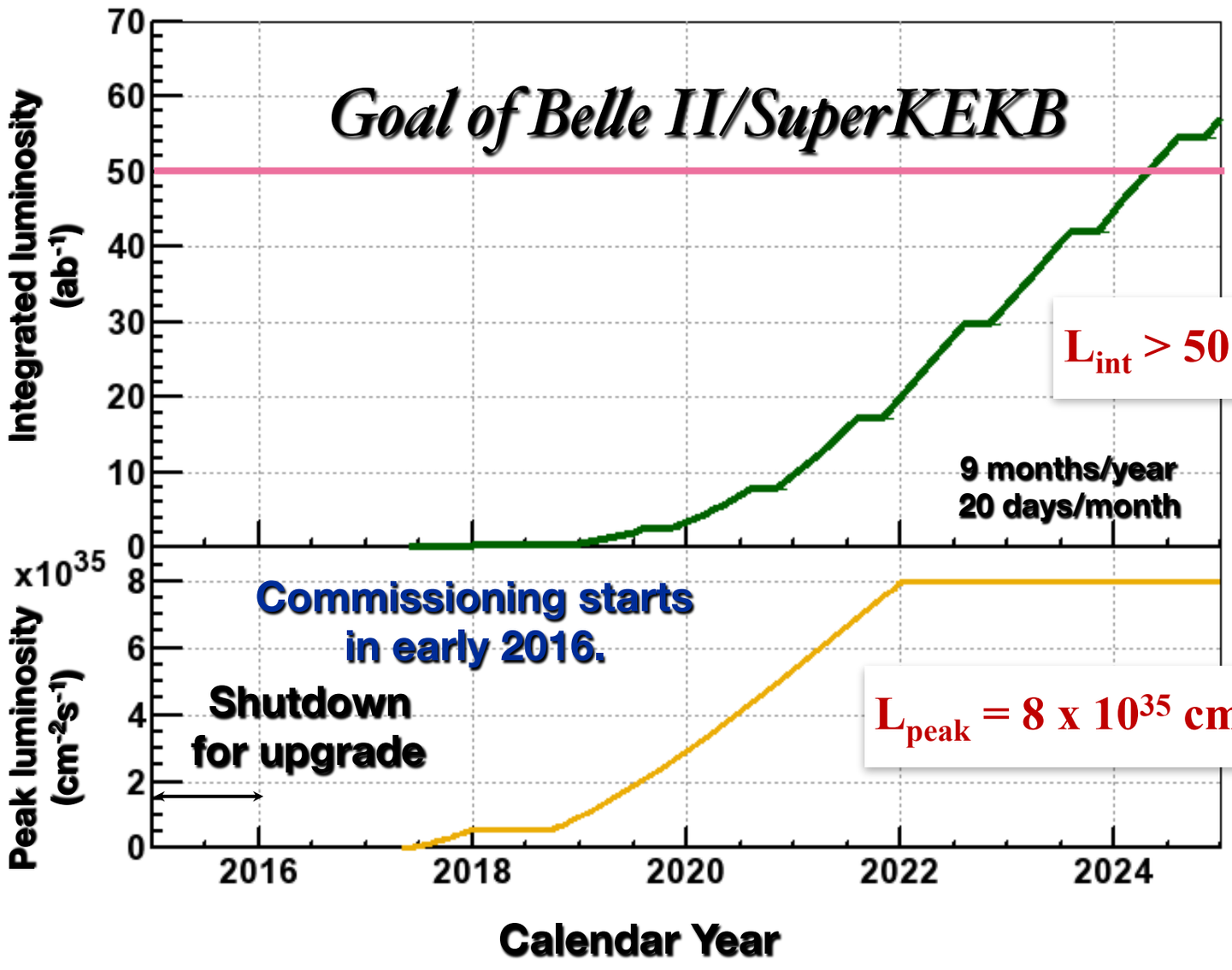


SuperKEKB

An asymmetric electron-positron collider at KEK, Japan

e^+~ 4GeV e^-~ 7GeV

SuperKEKB Luminosity Project



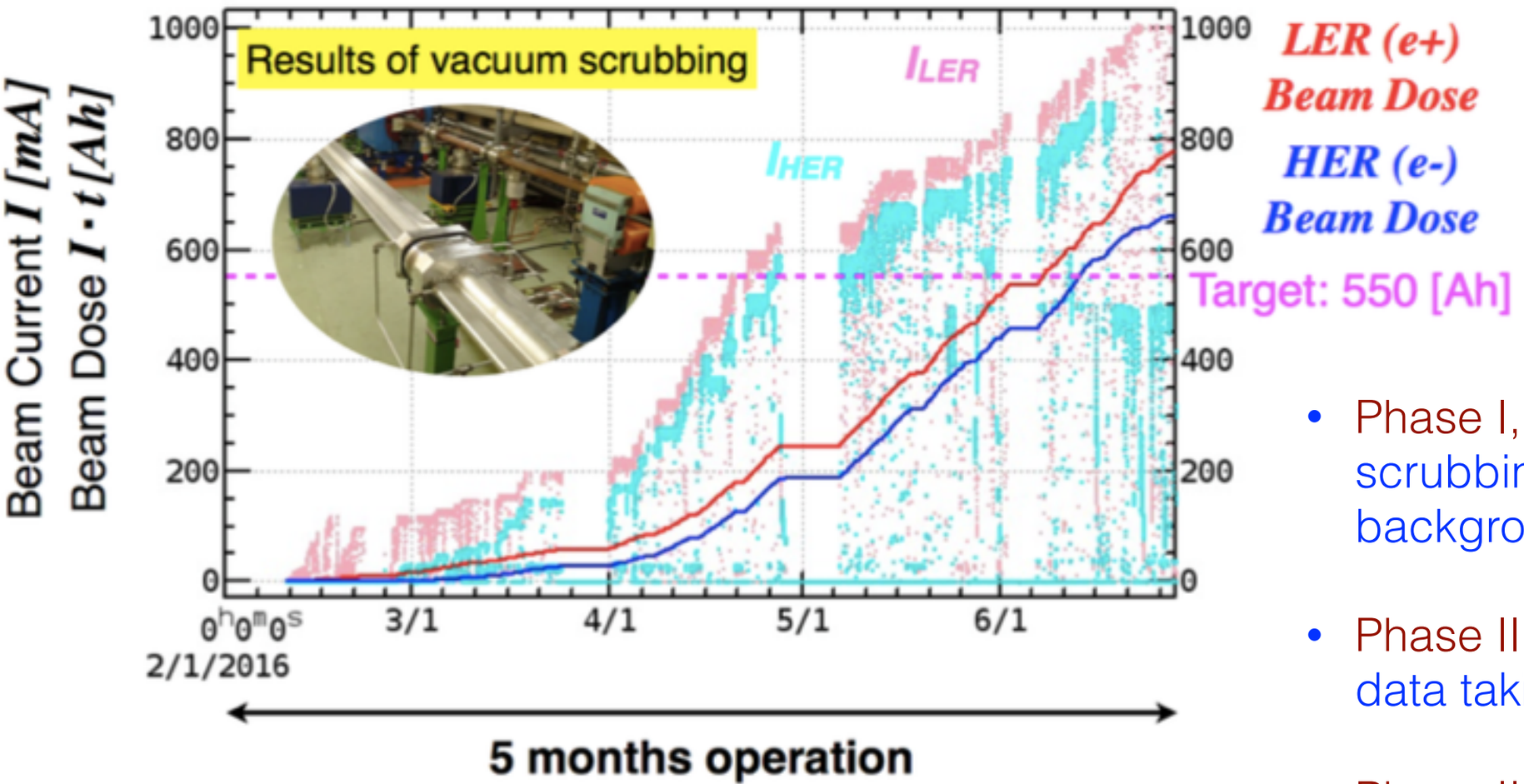
L_{int} > 50 ab^{-1} by 2024 (50 x Belle)

L_{peak} = 8 x 10^{35} $cm^{-2}s^{-1}$ (40 x KEKB)

The Status of SuperKEKB

Beam current of 1 [A] and **Beam dose of 780 [Ah]** were achieved in LER.
Ave. pressure: ~10^{-6} [Pa]

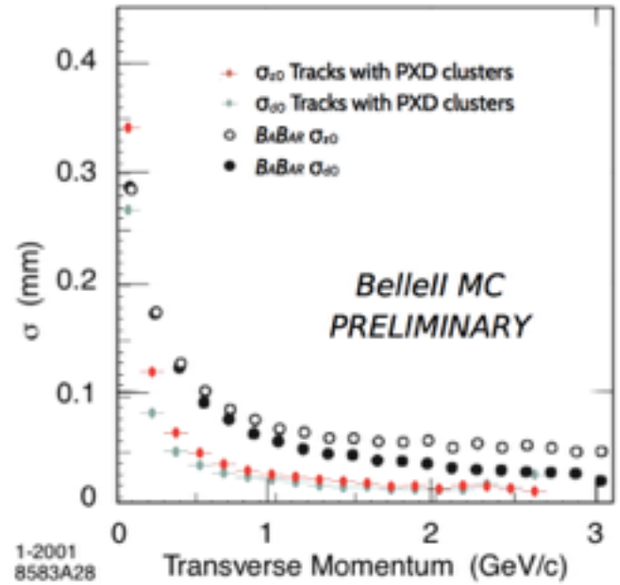
Beam current of 0.87 [A] and **Beam dose of 660 [Ah]** were achieved in HER.
Ave. pressure: ~10^{-7} [Pa]

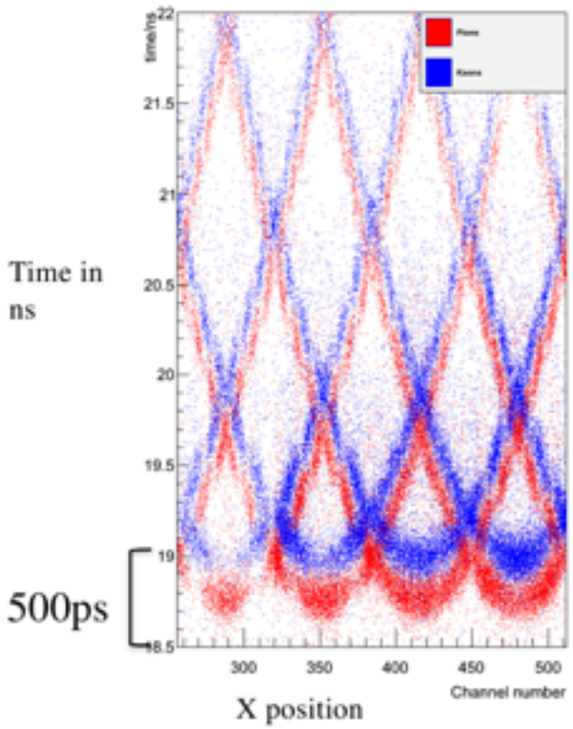


- Phase I, 2016, vacuum scrubbing, beam background study.
- Phase II, 2017-2018, data taking w/o PXD
- Phase III, start on 2018, data taking with all detectors.

Belle II Detector Upgrades

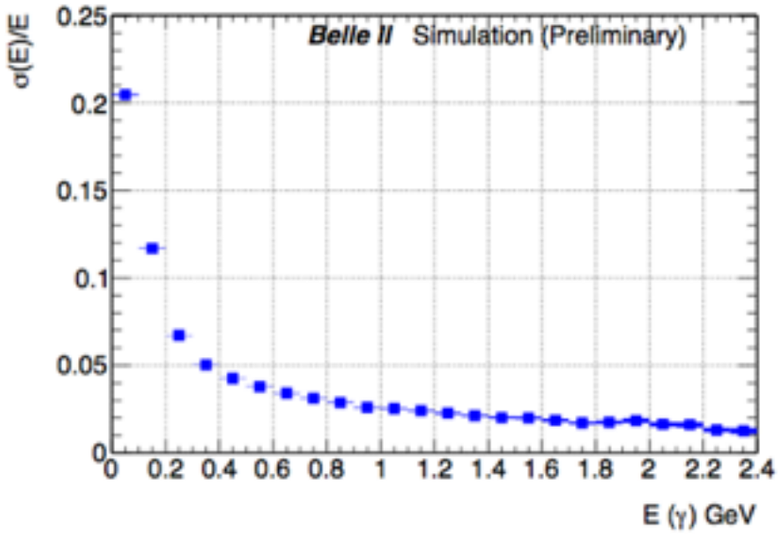
- Vertex detectors
  - 2 layers pixel + 4 layers strip
  - improve vertex resolution





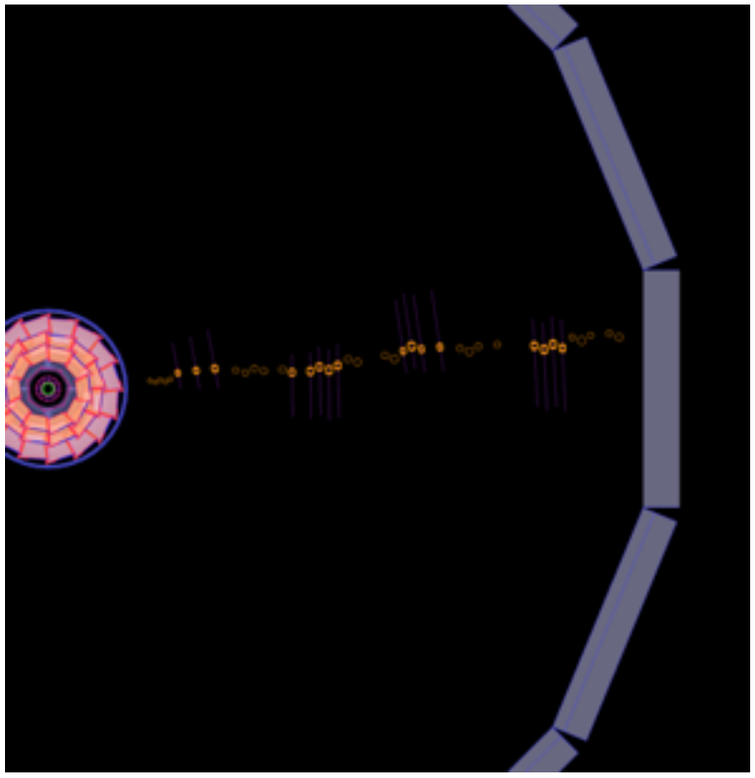
- Particle ID
  - Barrel: Time of Propagation(TOF) + Forward endcap: Aerogel Ring-Imaging Čerenkov (ARICH)
  - 4σ K/π separation at 1-3.5 GeV/c

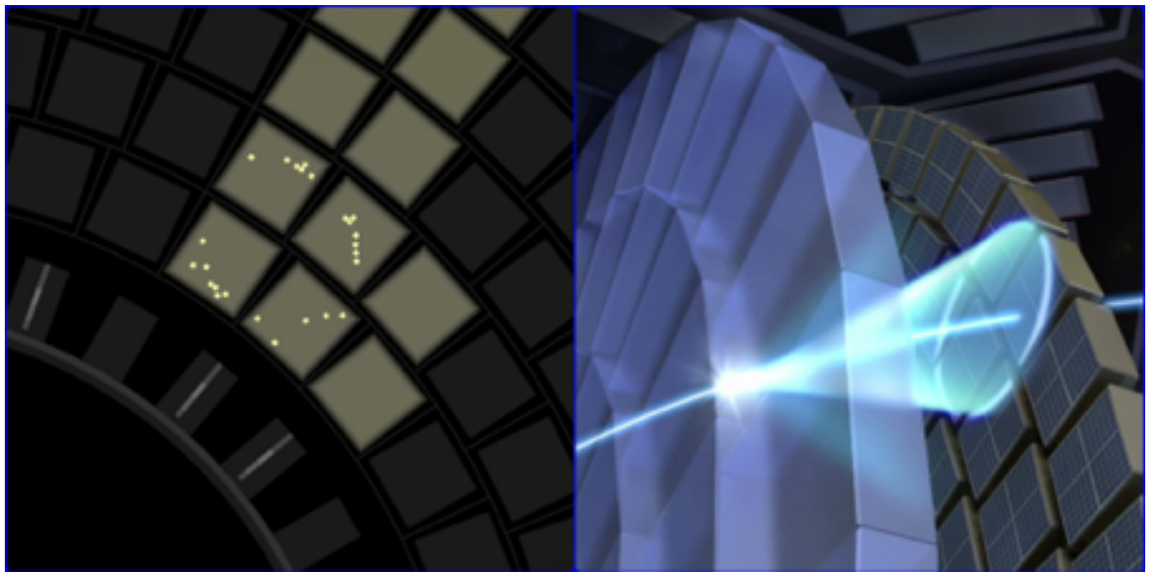
- EM Calorimeter
  - waveform sampling and fitting
  - Low pileup noise, better resolution



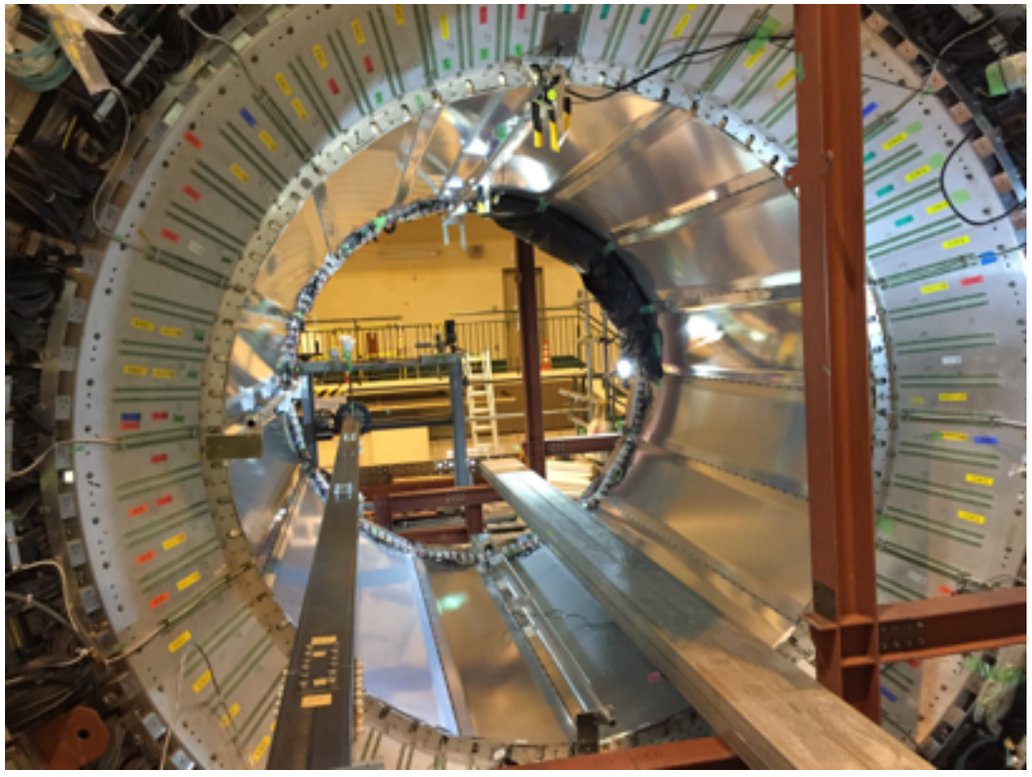
The Status of Belle II Detectors

CDC cosmic ray test





TOP installation completed on May, 2016



ARICH: first cherenkov rings were observed on August, 2016.

Angular analysis of $B \to K^* ll$ at Belle

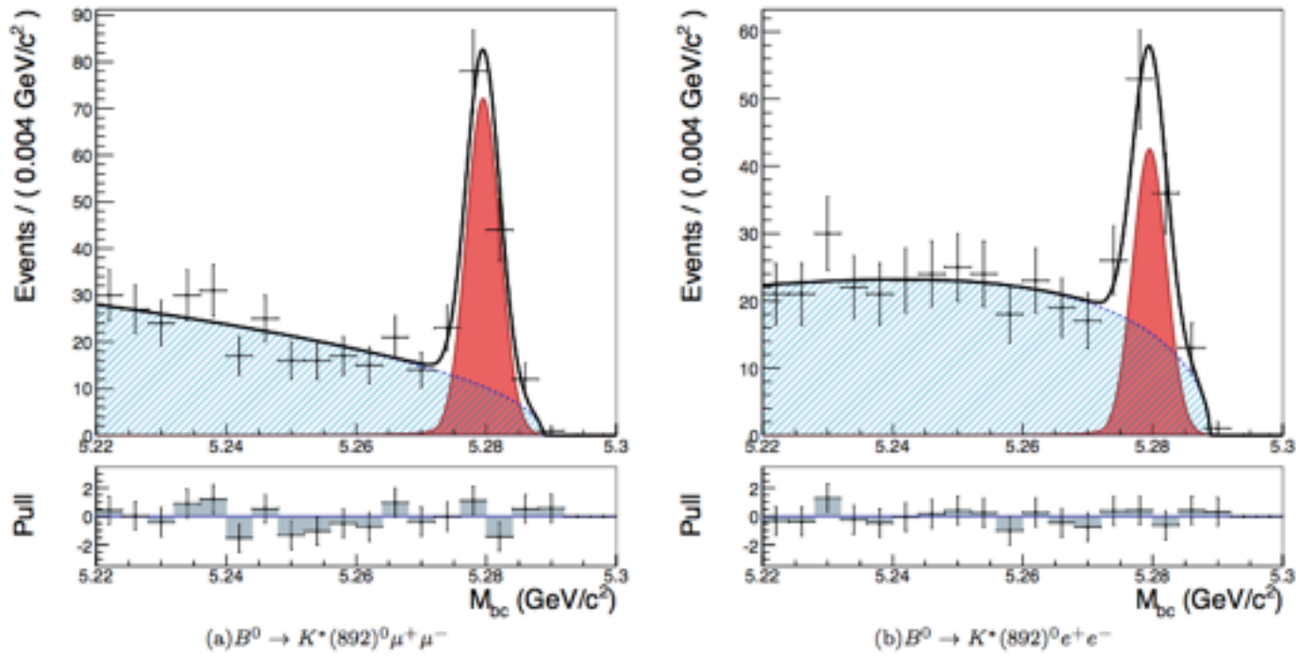
- 711 fb^{-1} Y(4s)
- K^{*0} is formed in $K^{*0} \to K\pi$
- veto $K^{(*)}J/\psi$, $K^{(*)}\psi(2S)$
- Signals are extracted by an unbinned extended maximum likelihood fit to M_{bc}

$$M_{\rm bc} \equiv \sqrt{E^2_{\rm Beam}/c^4 - |\vec{p}_B|^2/c^2}$$

$$\Delta E \equiv E_B - E_{\rm Beam},$$

$$5.22 \ < M_{\rm bc} < \ 5.3 \ {\rm GeV}/c^2$$

$$-0.10 \ (-0.05) \ < \Delta E < \ 0.05 \ {\rm GeV \ for} \ \ell = e \ (\ell = \mu)$$



Belle arXiv:1604.04042

- Signal yields in five q^2 bins

Bin	q^2 range in ${\rm GeV}^2/c^4$	$n_{\rm sig}$	$n_{\rm bkg}$
0	$1.00 - 6.00$	49.5 ± 8.4	30.3 ± 5.5
1	$0.10 - 4.00$	30.9 ± 7.4	26.4 ± 5.1
2	$4.00 - 8.00$	49.8 ± 9.3	35.6 ± 6.0
3	$10.09 - 12.90$	39.6 ± 8.0	19.3 ± 4.4
4	$14.18 - 19.00$	56.5 ± 8.7	16.0 ± 4.0

Angular analysis of B→K*ll at Belle

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

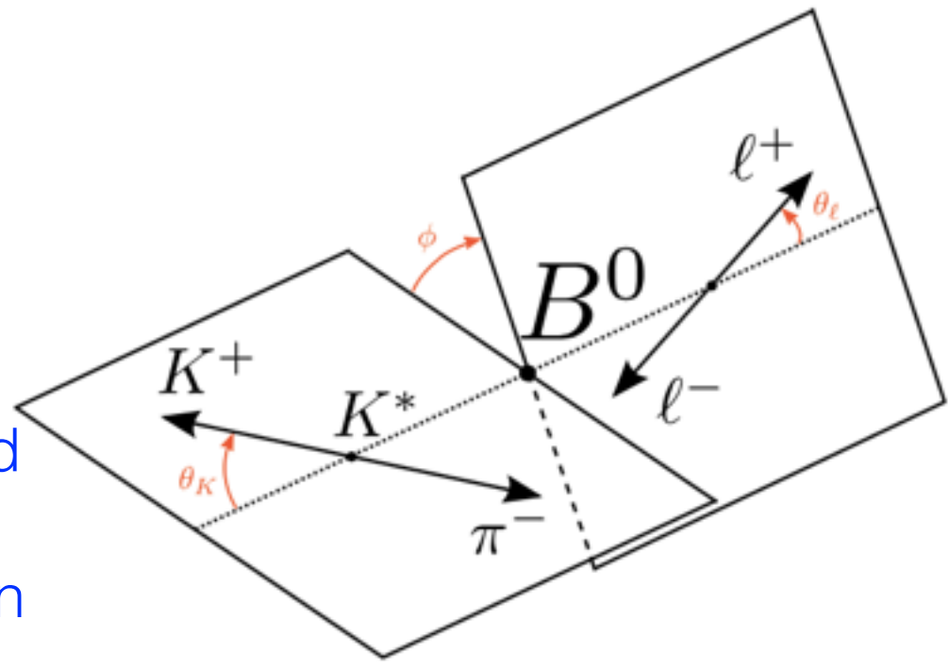
8 free parameters

$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}},$$

Transformation→

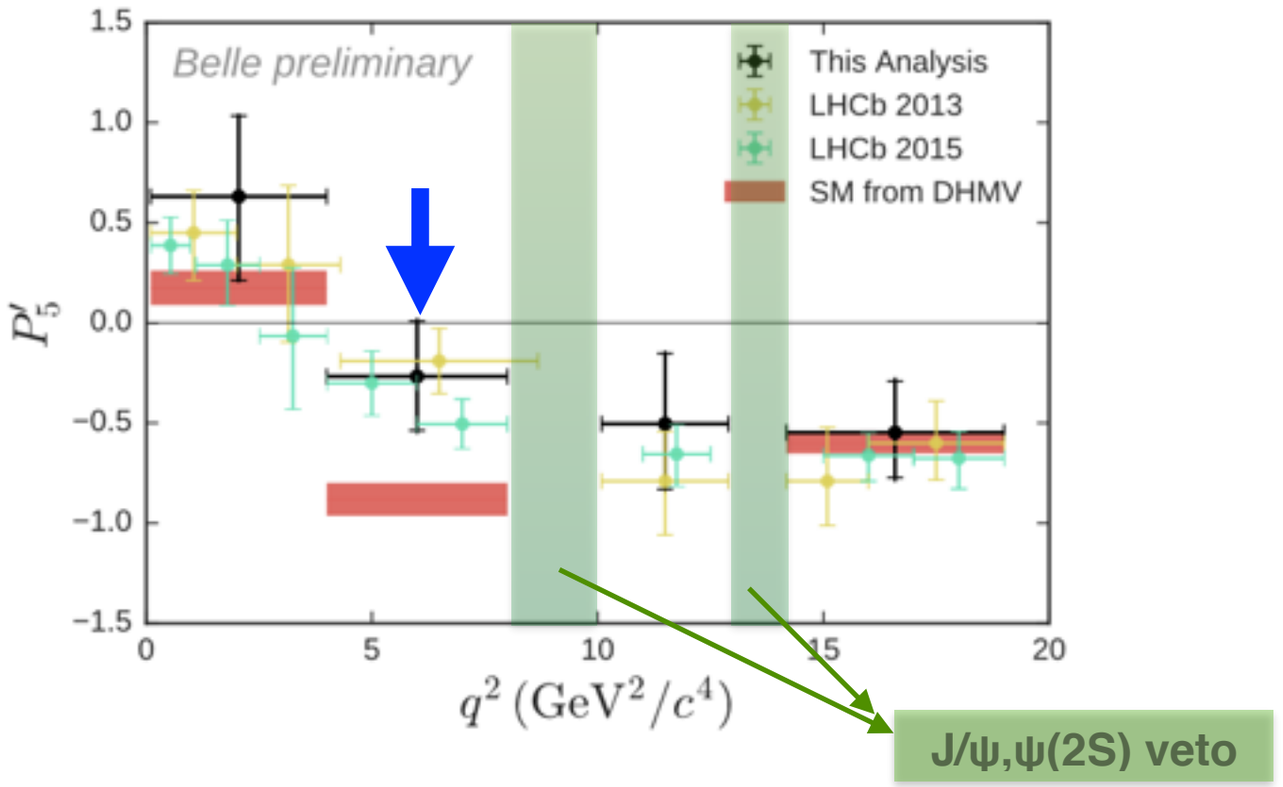
$$P'_5, S_5 : \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases}$$

- Free parameters reduce to three: F_L, S_3, and the observable S_5 or P_5'
- $S_{4,7,8}$ or $P_{4,6,8}$' have the similar transformation



Angular analysis of $B \to K^* ll$ at Belle

- For $P_{4,6,8}'$, overall agreement with SM predications.
- For P_5', 2.1σ deviation is observed from Standard Model prediction in the range $4.0<q^2<8.0\ GeV^2$



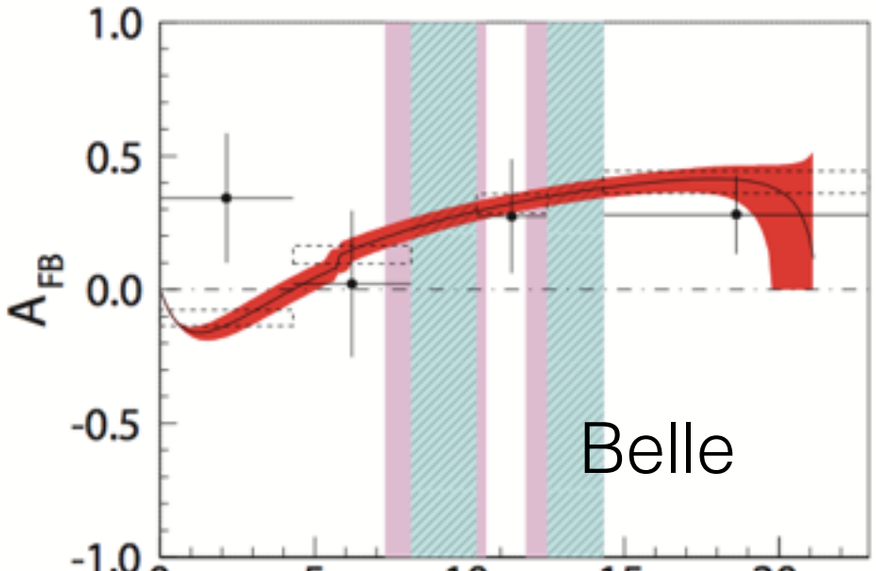
- Belle II and LHCb will be comparable for this process
- Belle II will be able to do a lot more, e.g. isospin comparison of K^{*+} and K^{*0}, the ground states K.

Absolute error on P_5'

q^2 GeV2/	Belle	LHCb 3 fb^{-1}	Belle II 50	LHCb 23 fb^{-1}
0.1-4	0.416	0.109	0.059	0.040
4.00-8.00	0.277	0.099	0.040	0.037
10.09-12.0	0.344	0.155	0.049	0.056
14.18-19.0	0.248	0.092	0.033	0.033

Inclusive $B \to X_s ll$ at Belle II

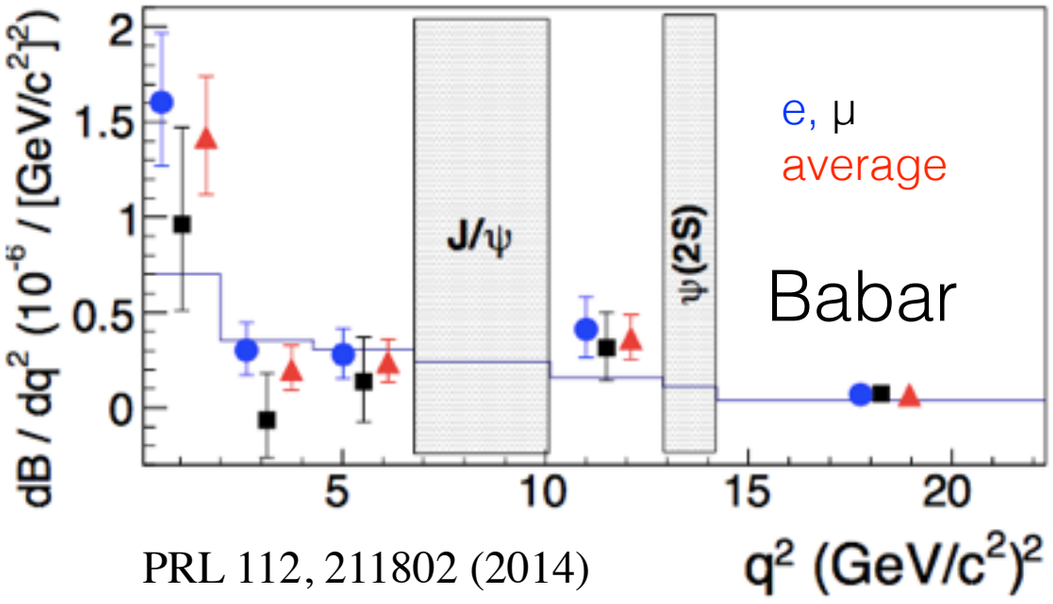
- Decay amplitude can be expressed in terms of the effective Wilson coefficients for the electromagnetic penguin, C_7, and the vector and axial-vector electroweak contributions C_9 and C_{10}
- Inclusive decay, sum of exclusive hadronic final states
- Precise theoretical prediction
- The current measurements are statistical dominant



Belle, PRD 93, 032008 (2016)

Uncertainty of C_7/C_9 at Belle II study as a toy MC study

Observable	0.7 ab^{-1}	5 ab^{-1}	50 ab^{-1}
q_0^2	80%	30%	10%
$d\Gamma/dq^2$	20%	10%	9%
Combined	19%	9%	6%



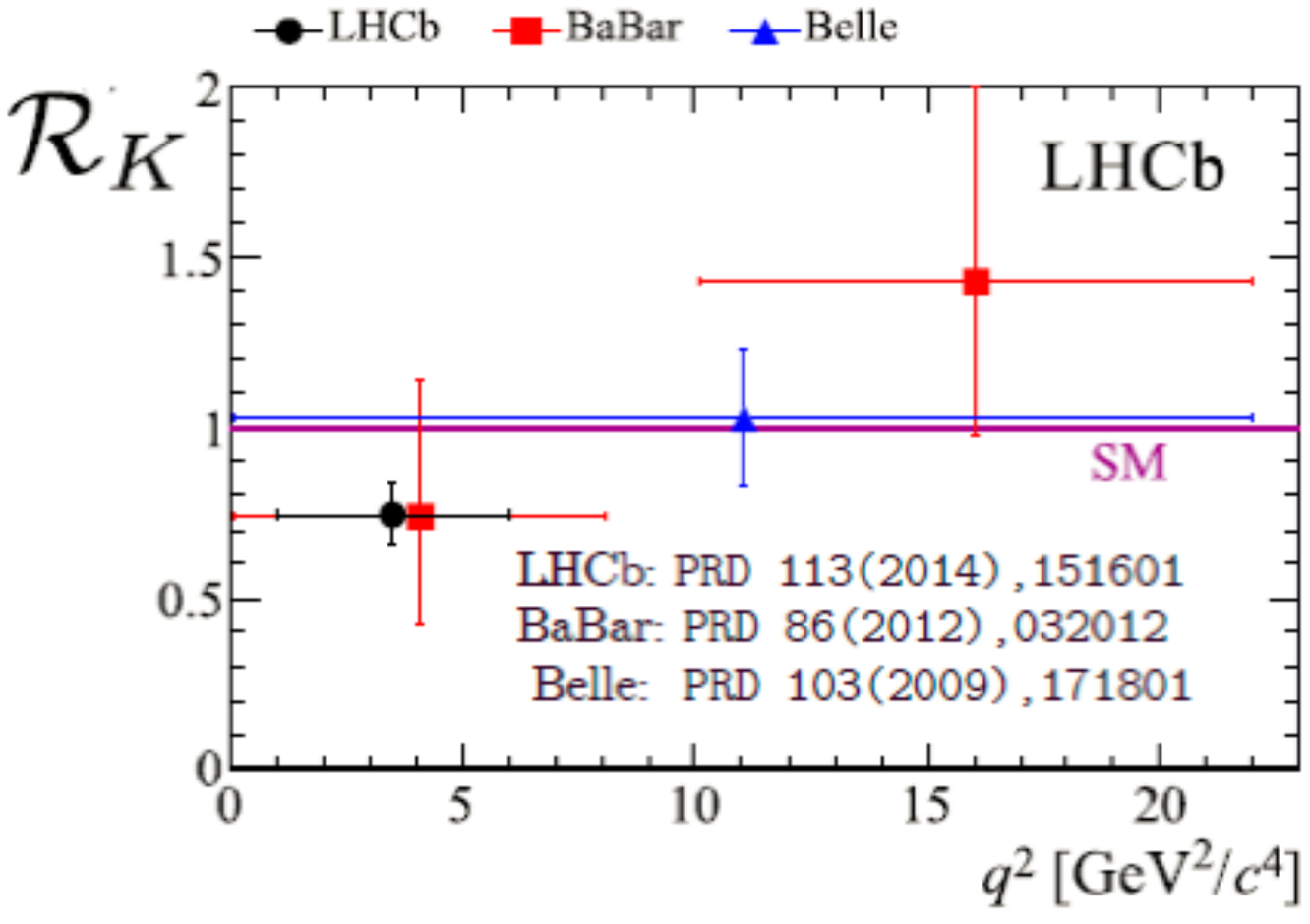
PRL 112, 211802 (2014)

R(K), R(K*), R(Xs)

- B→Kll proceeds via one loop diagram
- LHCb reported 2.6σ deviation of ratio of BFs

$$R_K = \frac{\mathcal{B}(B \to K\mu\mu)}{\mathcal{B}(B \to Kee)}$$

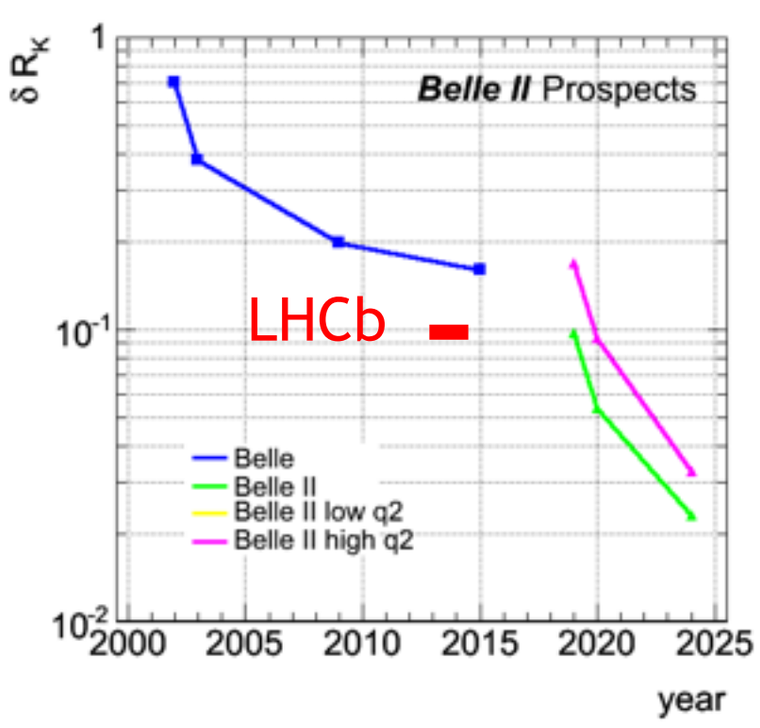
$$\mathcal{R}_K = 0.745^{+0.090}_{-0.074} \pm 0.036$$

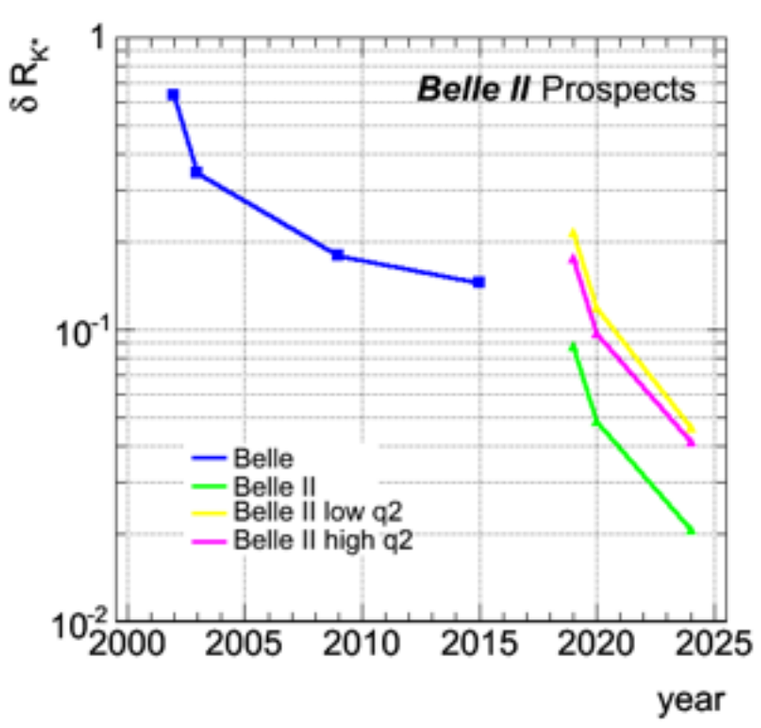


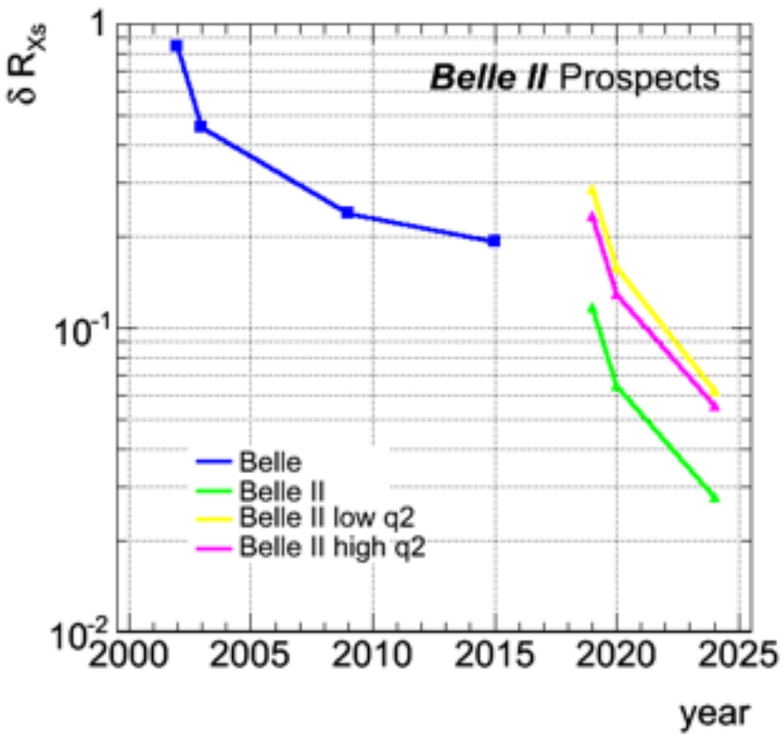
Phys. Rev. Lett. 113, 151601 (2014)

R(K), R(K*), R(Xs) at Belle II

- Belle II
  - All K, K* and Xs modes possible
  - The errors reach to 0.02 for all K, K* and Xs modes
  - Electron and muon modes have same efficiency
  - Sensitive to both low and high q^2





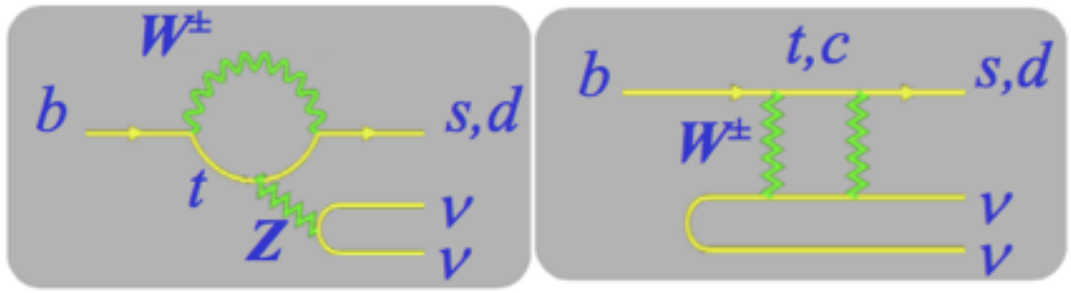


$B \to K^{(*)} \nu\nu$

- SM: penguin + box digram

$B_{SM}(B^+ \to K^+\nu\nu) = (4.68\pm0.64)\times10^{-6}$

$B_{SM}(B^0 \to K^{*0}\nu\nu) = (9.48\pm1.10)\times10^{-6}$

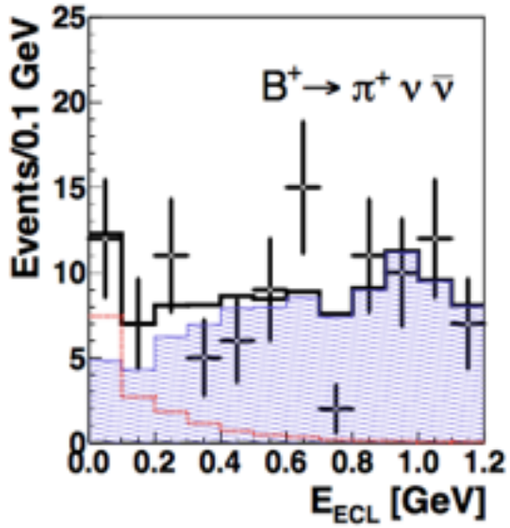


- Belle:

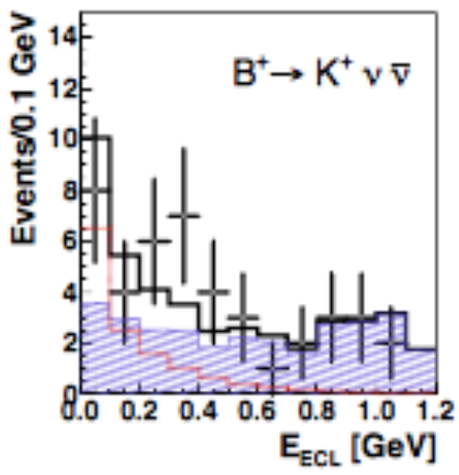
$B(B^+ \to K^+\nu\nu) < 5.5\times10^{-5}$,
Nsig=13.3+7.4-6.6, 2.0σ

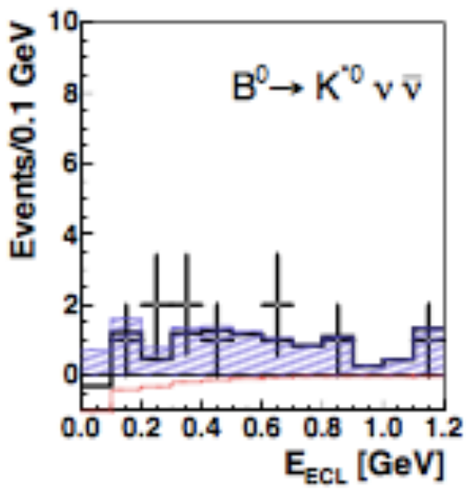
$B(B^0 \to K^{*0}\nu\nu) < 5.5\times10^{-5}$

$B(B^+ \to \pi^+\nu\nu) < 9.8\times10^{-5}$,
Nsig=15.2+7.1-6.2, 2.6σ



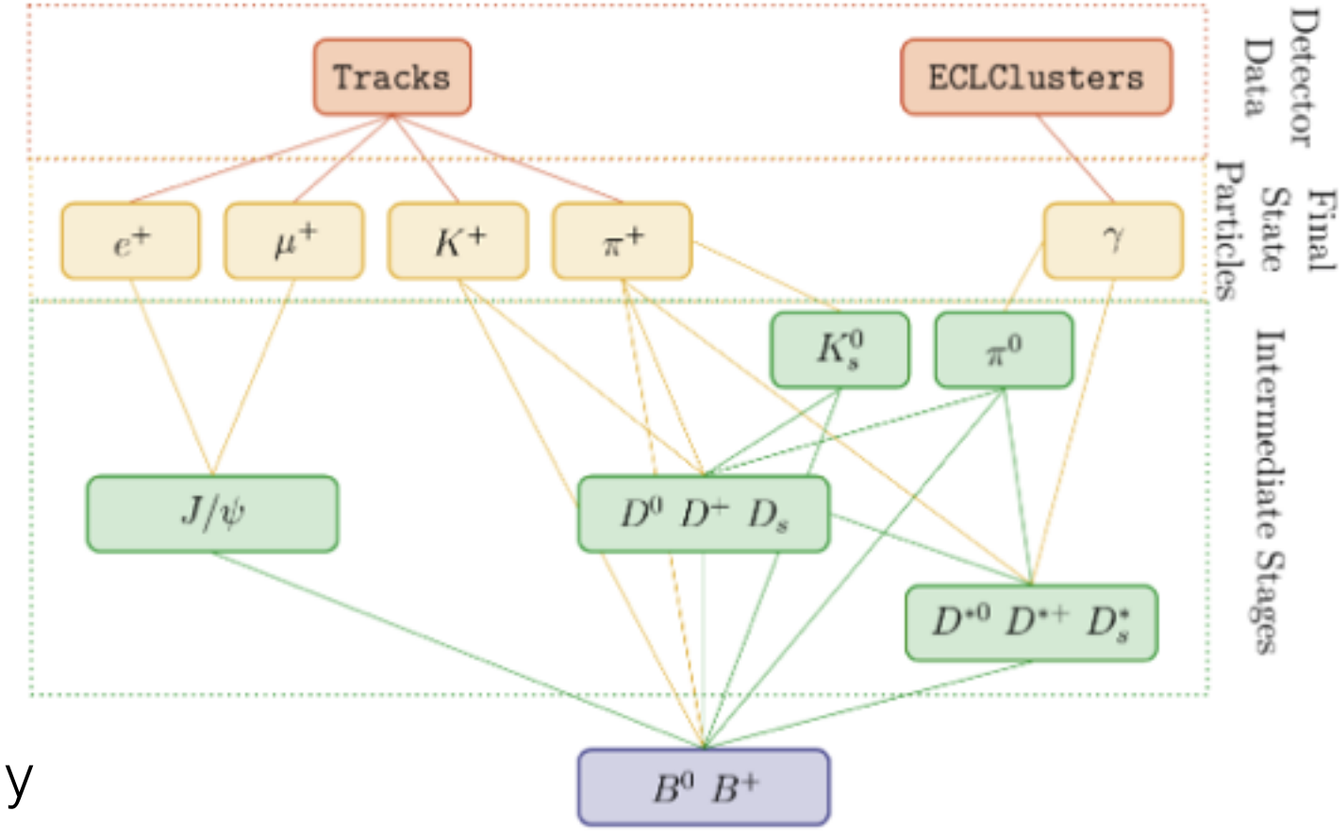
Belle, PRD 87, 111103(R) (2013)





Full Event Interpretation (FEI)— Missing Energy Decays

- Tag B: full reconstruction with hadronic and semileptonic decays
  - Hierarchical Approach
  - Different training are employed for the final-state and intermediate particles reconstruction
  - Training is physics decay oriented
  - The Signal-probability is the only output value.



- Signal B: all remaining tracks/neutrals belong to signal B

Tag with hadronic decays

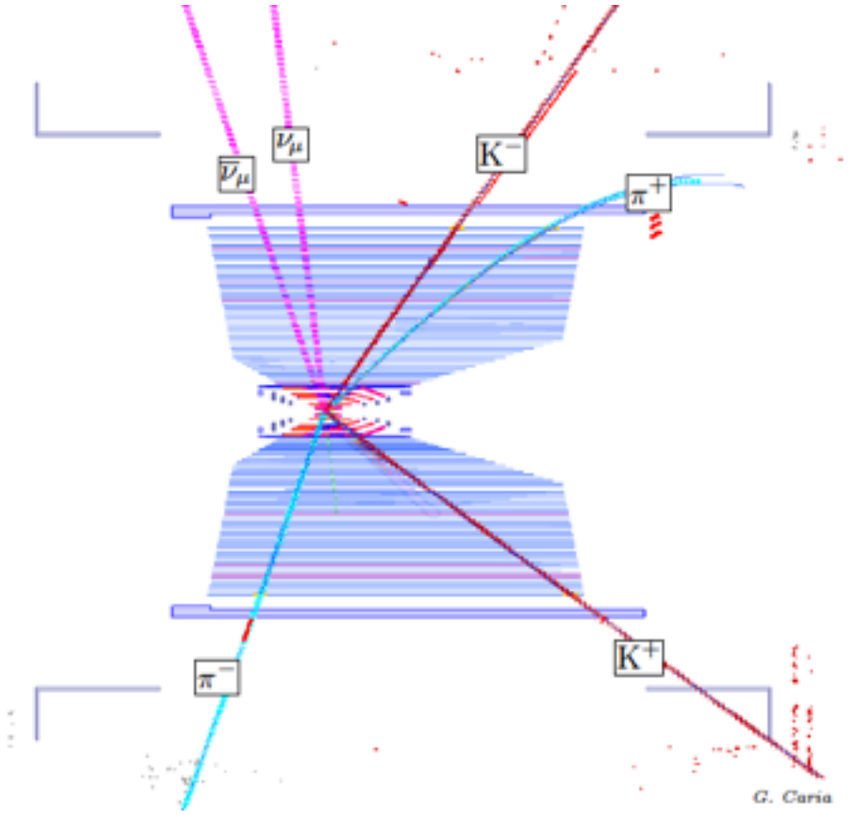
$\varepsilon(B^0_{\rm tag}) = 0.33\%$ **Belle II** $\varepsilon(B^+_{\rm tag}) = 0.36\%$

$\varepsilon(B^0_{\rm tag}) = 0.19\%$ **Belle** $\varepsilon(B^+_{\rm tag}) = 0.28\%$

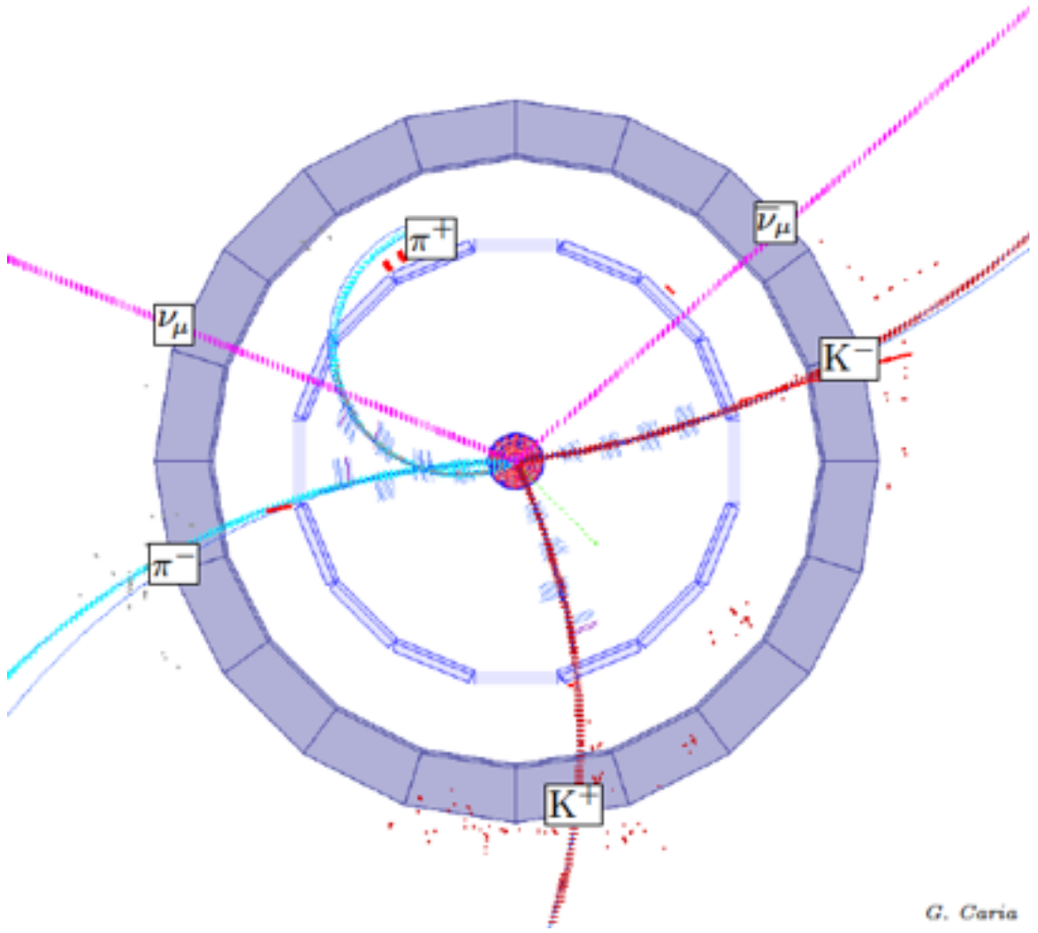
B→K$^{(*)}$νν at Belle II

"Missing Energy Decay" in a Belle II GEANT4 MC simulation

Signal B→K ν ν tag B→Dπ; D→Kπ



View in r-z



Zoomed view of the vertex region in r-ϕ

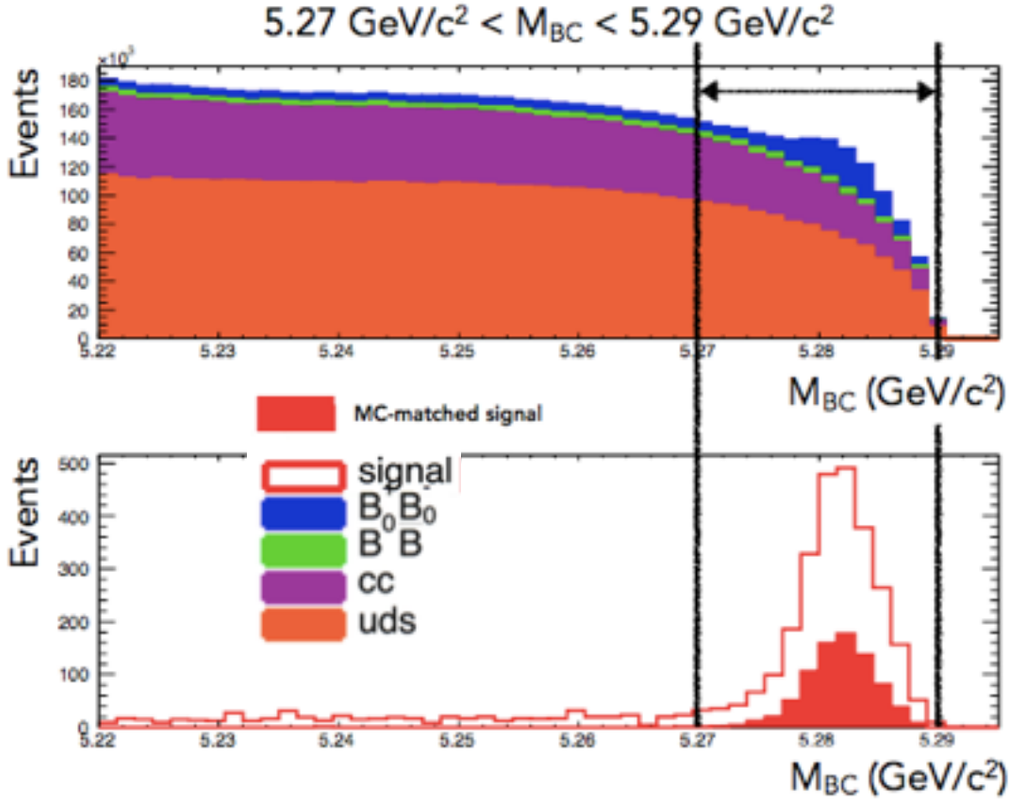
B→K$^{(*)}$νν at Belle II

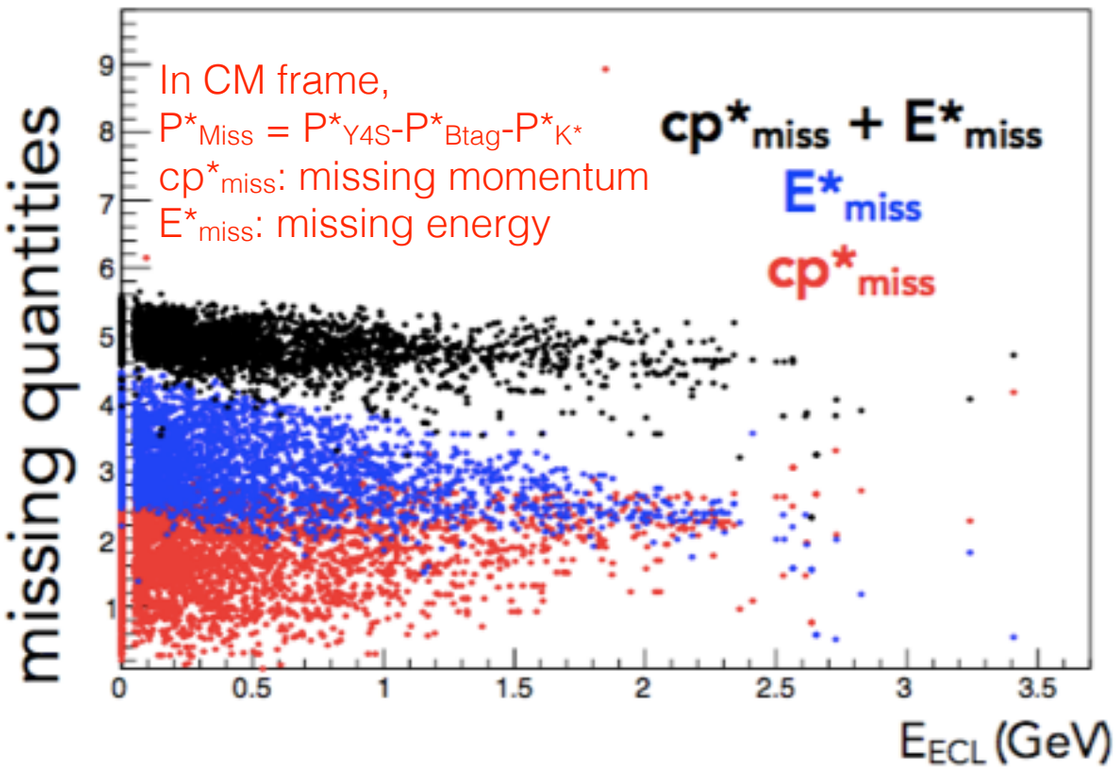
- Belle II sensitivity projection based on Belle measurement
  - Hadronic tag has 100% higher efficiency
  - Ks reconstruction has 30% higher efficiency
  - 50 ab^{-1} Y(4S)

mode	$\mathcal{B}_{SM}[10^{-6}]$	$N_{Sig-exp.}(50ab^{-1})$	Statistical error	Total Error
$B^+ \to K^+\nu\bar{\nu}$	4.68	245	20%	22%
$B^0 \to K^0_S\nu\bar{\nu}$	2.17	22	94%	94%
$B^+ \to K^{*+}\nu\bar{\nu}$	10.22	158	21%	22%
$B^0 \to K^{*0}\nu\bar{\nu}$	9.48	143	20%	22%
$B \to K^*\nu\bar{\nu}$ combined			15%	17%

$B \to K^{(*)} \nu\nu$ at Belle II

- **MC study at Belle II**
  - 500 fb^{-1} Y(4S) MC simulation samples with beam background mixing
  - FEI to reconstruct tag side B
  - Signal and bkg extraction by a 2-D fit to extra neutral energy & missing quantities
  - $B(B^+ \to K^{+(*)} \nu\nu) < 4.4 \times 10^{-4}$ with 500 fb^{-1}
  - Compatible to Babar's result with 413 fb^{-1} data
  - Selection criteria will be optimised.





Summary

- EW penguin B decays are sensitive to NP, and an important motivation of Belle II.
- Upgrades of detectors and software make more physics analysis possible at Belle II
- Belle II shed light on these anomalies.
  - Better understand the deviations from SM in $B \to K^{(*)}ll$
  - Inclusive $B \to X_s ll$ could be measured with high precision
  - $B \to K^{(*)}\nu\nu$ could be probed at 5σ