Results from the B-factories in charmless (Quasi-)2-body B decays and Belle II prospects for DCPV in charmless B decays

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on behalf of Belle Collaboration
29 Nov 2016, CKM2016

<u>Outline</u>
Results on Bs decays
Results on B decays
Belle II prospects

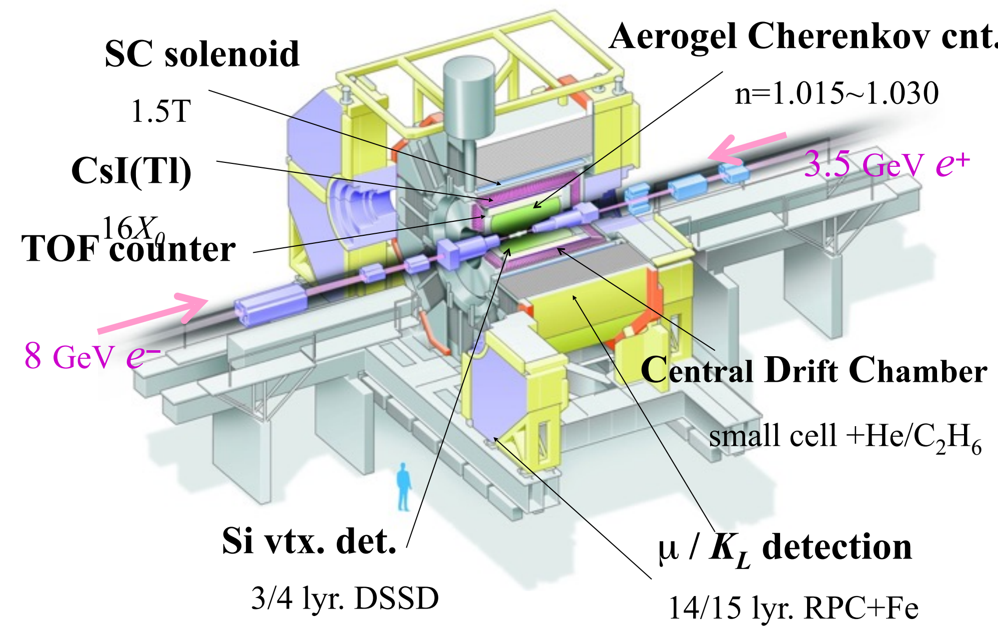
Two-body charmless B decay

- $b \to c$ decays ~ O(99%) of all B decays
  The others ($b \to u, d, s$, or NP) are charmless and rare.
- Charmless B decays provide a rich probe to search for new physics and understand B decay mechanisms
  - Interference between weak and strong phases can lead to direct CP violation.
  - Relative weak phase of tree and penguin gives Unitarity Triangle angles.
- Allows searches for New Physics from new particles by looking for enhanced $\mathcal{B}$, A_{CP}, …

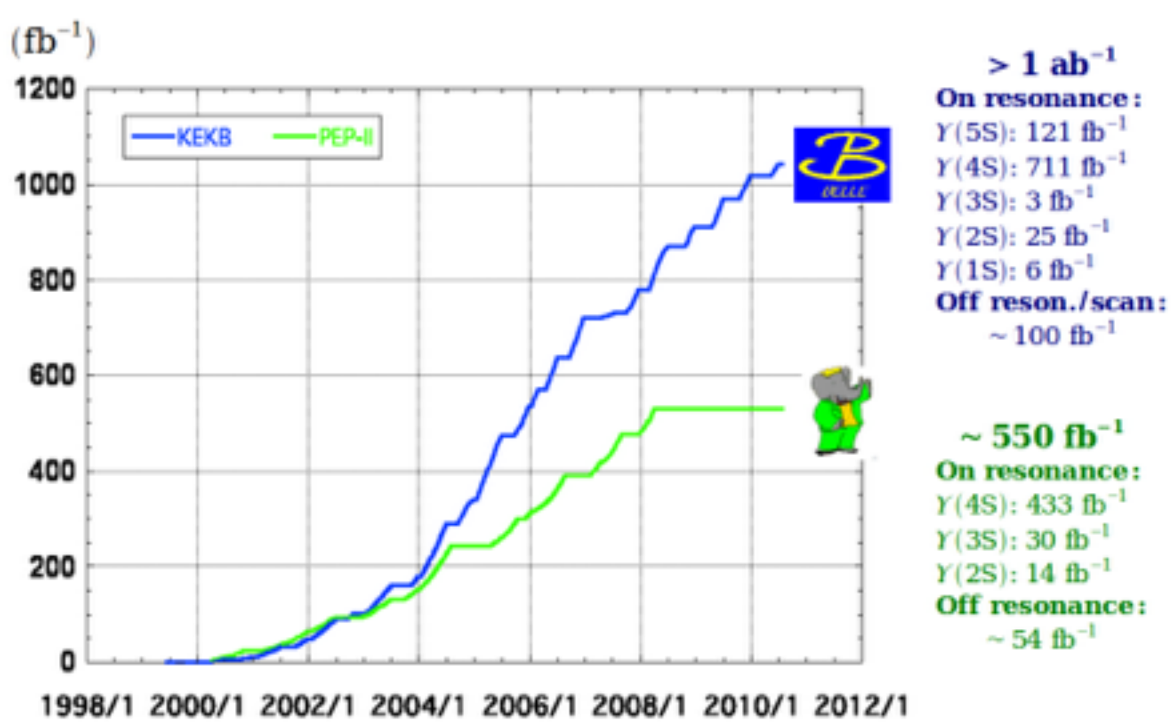
Experimental Overview

- Dataset:
  Belle: 711 fb^{-1} $\Upsilon(4S)$
  121 fb^{-1} $\Upsilon(5S)$
  BaBar: 433 fb^{-1} $\Upsilon(4S)$
- Particle identification
  High purity/efficiency of neutral particles
  γ, π^0, K_s…
  Clean background reduction

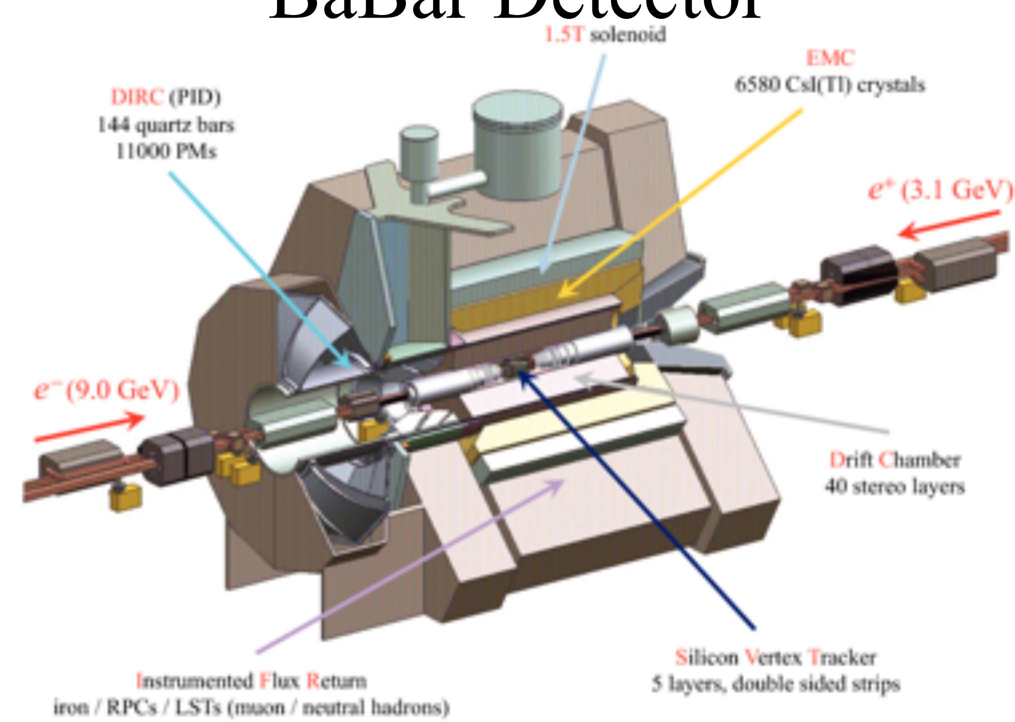
Belle Detector



Integrated luminosity of B factories



BaBar Detector

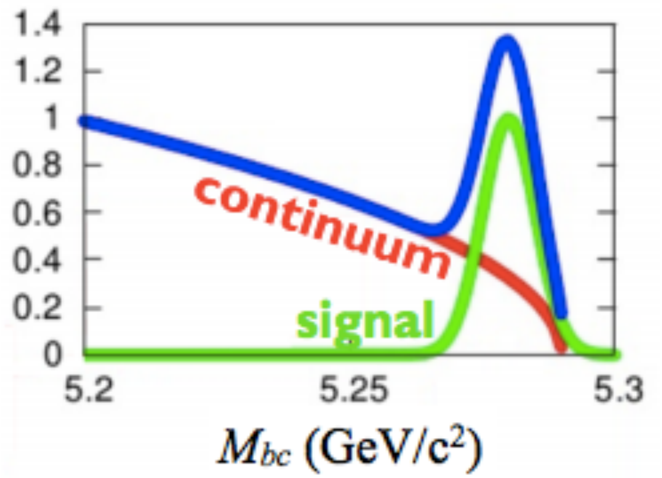


Analysis technique

- Kinematic variables are used to identify B decays:

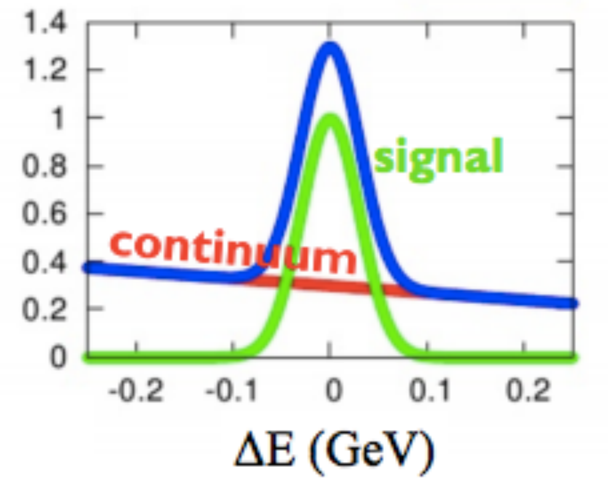
Beam-constrained mass

$$M_{\rm bc} = \sqrt{E^{*2}_{beam} - p^{*2}_B}$$



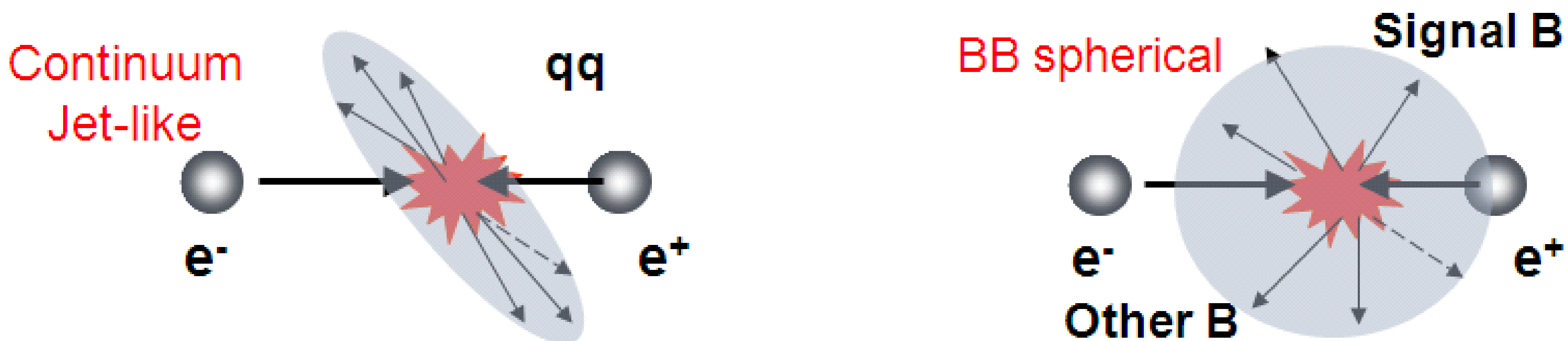
Energy difference

$$\Delta E = E^*_B - E^*_{beam}$$

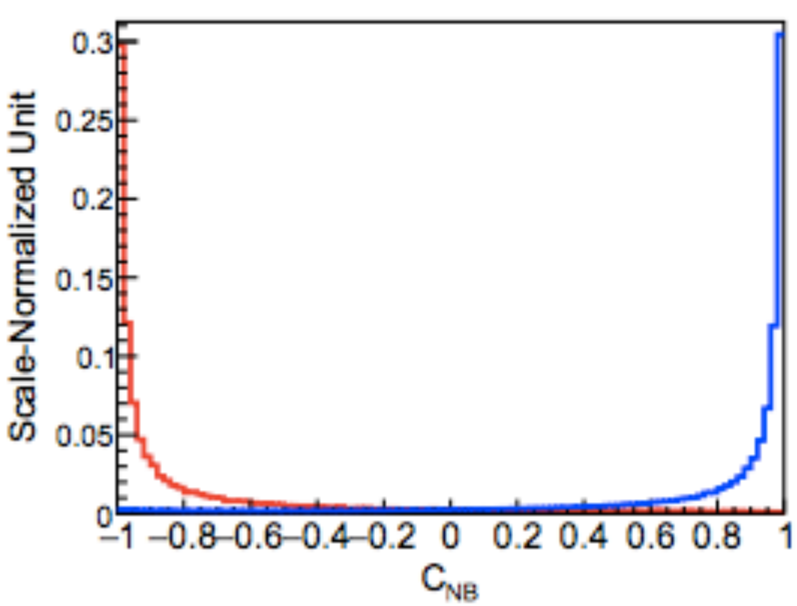


Analysis technique - cont'

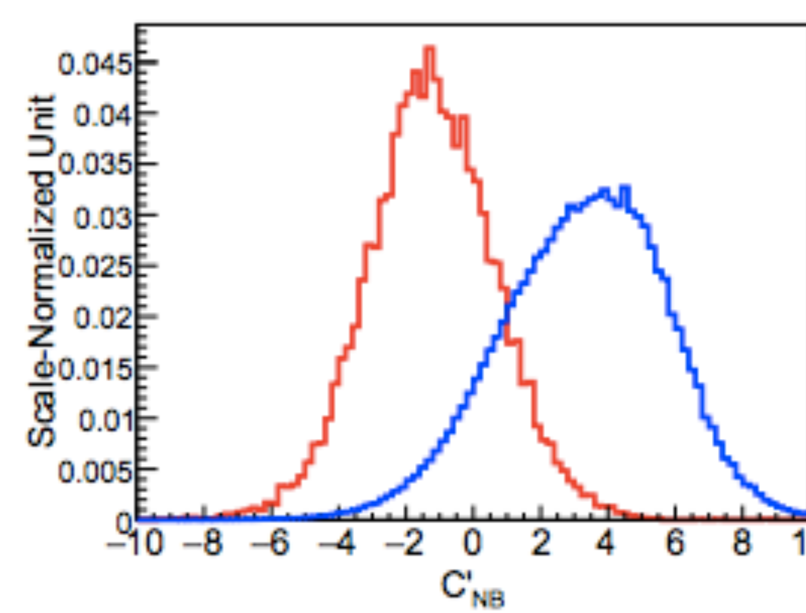
- Continuum suppression:
  - Variables describing the event topology
    - Combined in a multivariate analysis (Fisher Discriminant or Neural Network)



    - Optimize selection to reduce background, or make loose selection and use the information in the fit

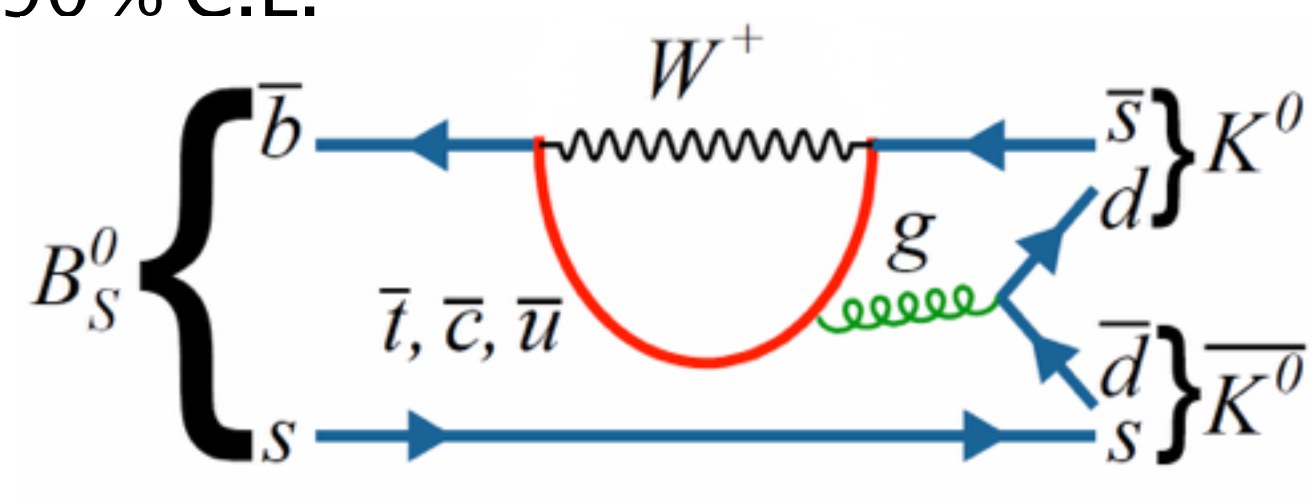


$$C'_{NN} = \ln \frac{C_{NN} - C_{NN}^{min}}{C_{NN}^{max} - C_{NN}}$$

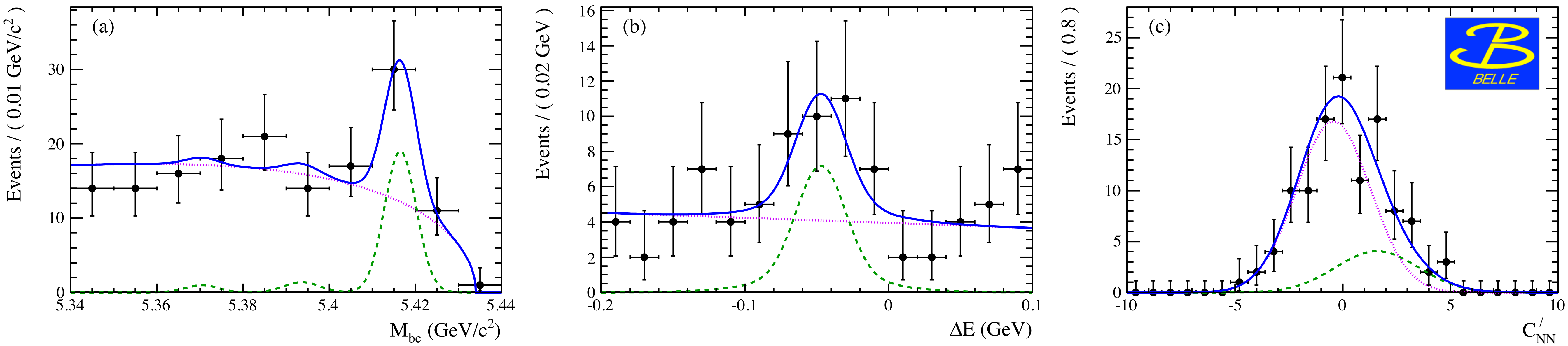


$B_s \to K^0 \bar{K}^0$ Analysis

- Mainly through $b \to s$ penguin decay, highly sensitive to NP
- SM prediction on branching fraction is $(1.6 - 2.7) \times 10^{-5}$
  JHEP 0612, 027 (2006)
- Contribution from non SM particles (e.g. Z') may enhance the branching fraction to 3×10^{-5}. J. Phys. G 41, 105002(2014)
- Direct CP asymmetry in this mode is a very promising observable to search for the new physics.
  A_{CP} is not more than 1% in SM, but can be 10 times large in the presence of SUSY, while the branching ratio remain unaffected. JHEP 0612, 019(2006)
- Previously this decay mode was searched by Belle with 23.6 fb^{-1} of data and set an upper limit of $\mathcal{B}(B_s \to K^0 \bar{K}^0) < 6.6 \times 10^{-5}$ at 90 % C.L.
  PRD 82,072007 (2010)



$B_s \to K^0 \bar{K}^0$ Results



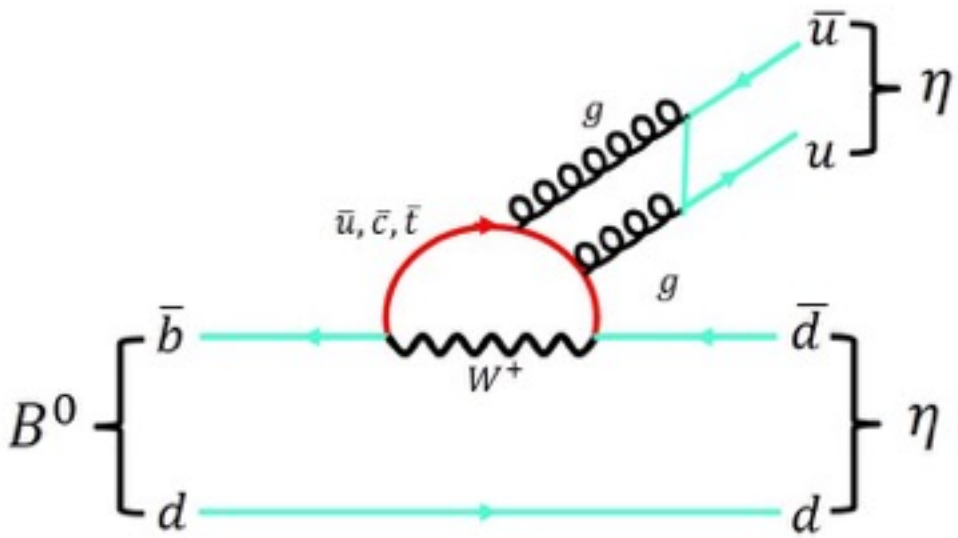
Three peaks in M_{bc}:

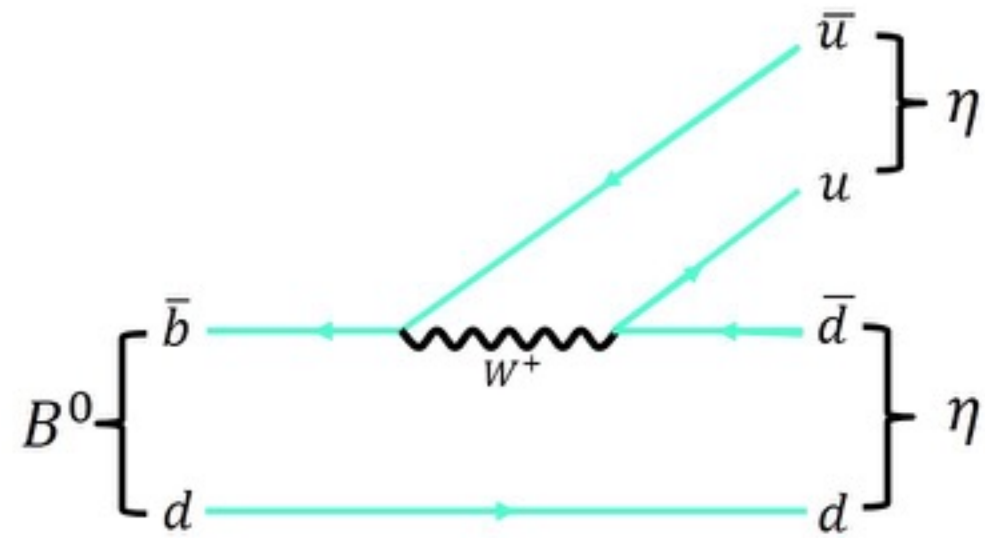
$$\Upsilon(5S) \to B_s^0 \bar{B}_s^0, (B_s \bar{B}_s^* + \bar{B}_s B_s^*), B_s^* \bar{B}_s^*$$

- This analysis is based on 121 fb^{-1} Y(5S) data.
- 3D fit is performed for signal extraction [$M_{\mathrm{bc}}, \Delta E, C'_{NN}$]
- $N_{\mathrm{sig}} = 29.0^{+8.5}_{-7.6}$ with 5.1σ including systematic uncertainty.
  $\mathcal{B}(B_s^0 \to K^0 \bar{K}^0) = [19.6^{+5.8}_{-5.1}(stat.) \pm 1.0(syst) \pm 2.0(N_{B_s^0 \bar{B}_s^0})] \times 10^{-6}$
- First observation of a charmless two-body B_s decays involving only neutral hadrons, and with a good agreement of SM.

PRL 116, 161801 (2016)

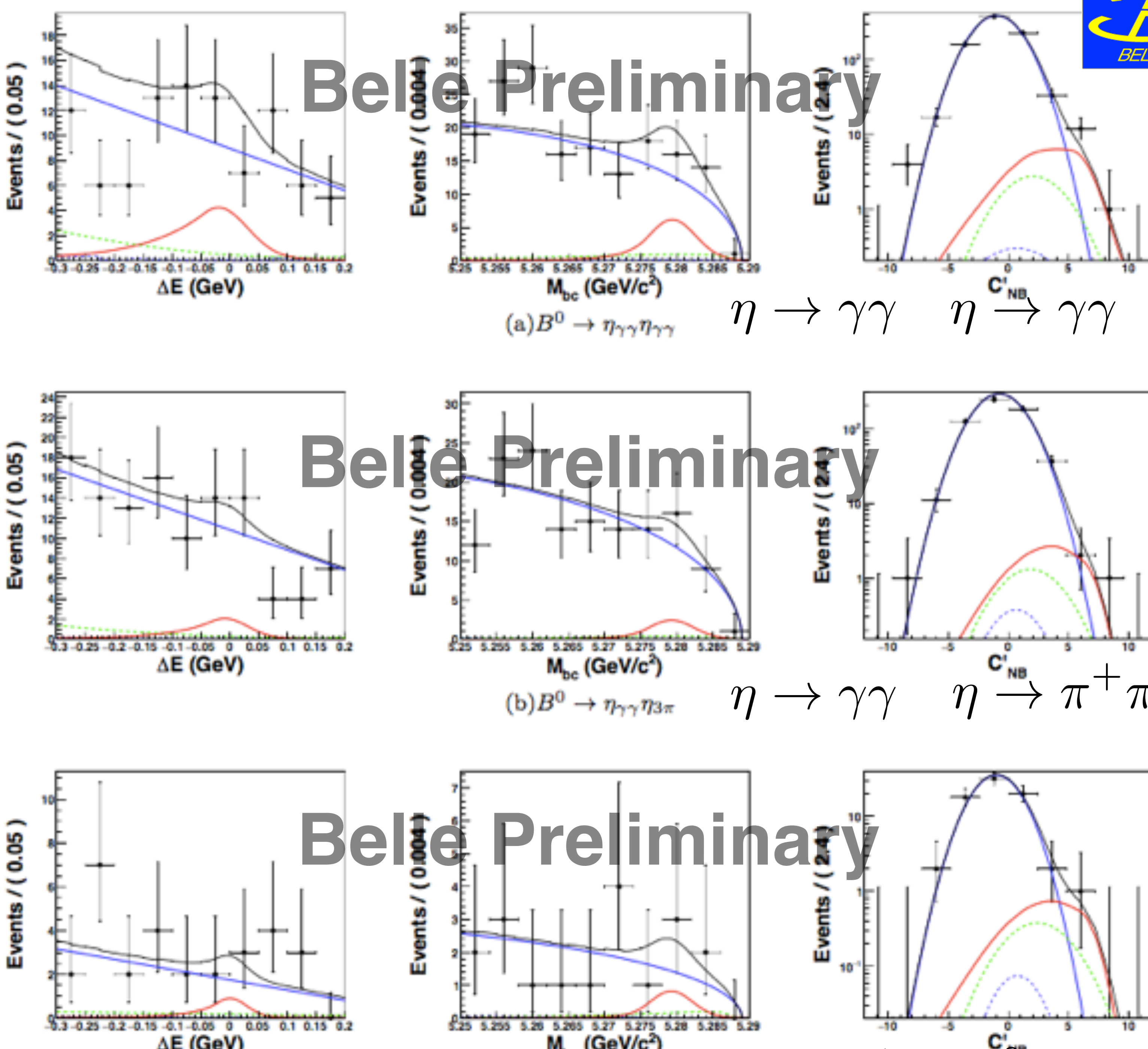
$B^0 \to \eta\eta$ **Analysis**





- Mainly proceeds: $b \to u$ color suppressed tree
  $b \to d$ penguin
- Can be used in flavor SU(3) based calculations of $|S_{ccs} - S_f|$ where f = ηK, φK. This $\sin 2\phi_1$ deviation bound may be improved by more precise measurements of the branching fraction of this mode.
  Expected $\mathcal{B}$: $0.32^{+0.15}_{-0.07} \times 10^{-6}$ **PRD 80,114008 (2009)**
- Previous results:
  Belle: $\mathcal{B}(B \to \eta\eta) < 2.0 \times 10^{-6}$ (152M BB) **PRD 71, 091106(R) (2005)**
  BaBar: $\mathcal{B}(B \to \eta\eta) < 1.0 \times 10^{-6}$ (476M BB) **PRD 80, 112002(R) (2009)**

$B^0 \to \eta\eta$ Results



(a) $B^0 \to \eta_{\gamma\gamma}\eta_{\gamma\gamma}$ $\quad \eta \to \gamma\gamma \quad \eta \to \gamma\gamma$

(b) $B^0 \to \eta_{\gamma\gamma}\eta_{3\pi}$ $\quad \eta \to \gamma\gamma \quad \eta \to \pi^+\pi^-\pi^0$

(c) $B^0 \to \eta_{3\pi}\eta_{3\pi}$ $\quad \eta \to \pi^+\pi^-\pi^0 \quad \eta \to \pi^+\pi^-\pi^0$

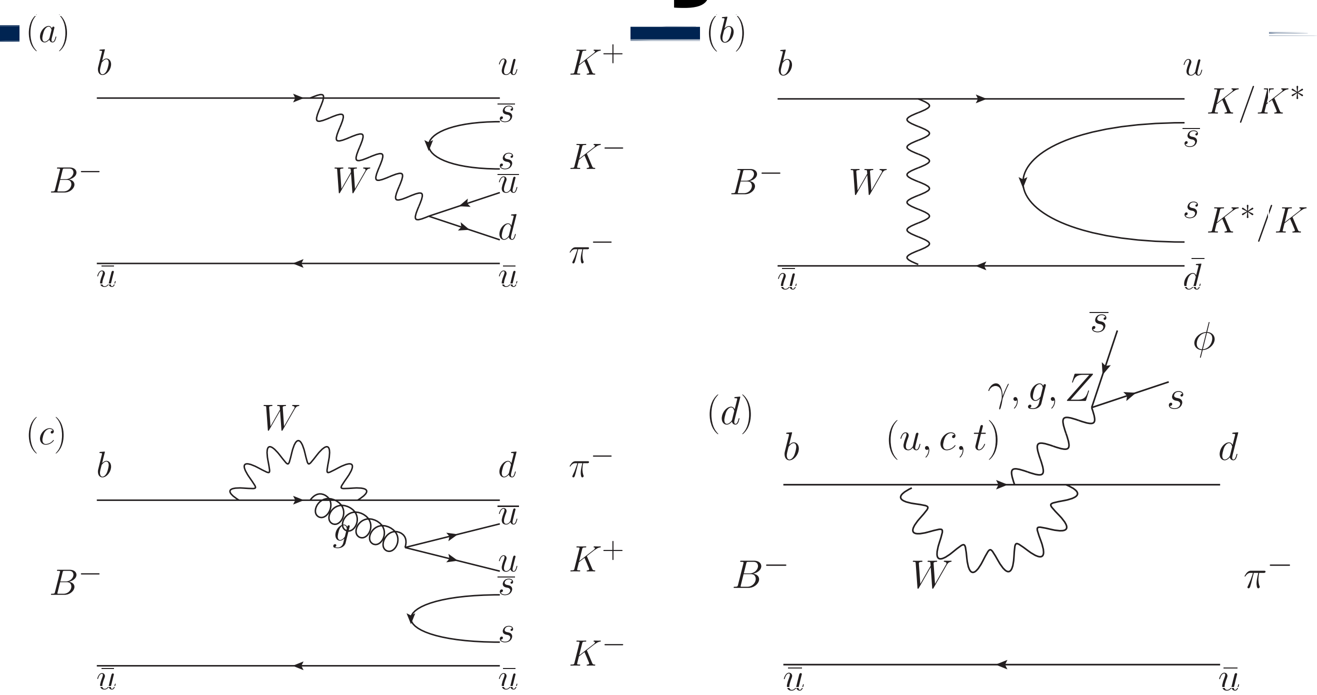
- This result is based on 698 fb−1 Y(4S) data.

Sub-decay model	Yield
$\eta_{\gamma\gamma}\eta_{\gamma\gamma}$	$23.6^{+8.1}_{-6.9}$
$\eta_{\gamma\gamma}\eta_{3\pi}$	$9.2^{+3.2}_{-2.7}$
$\eta_{3\pi}\eta_{3\pi}$	$2.7^{+0.9}_{-0.8}$

- $\mathcal{B}(B^0 \to \eta\eta) = (7.6^{+2.7+1.4}_{-2.3-1.5}) \times 10^{-7}$ at 3.3σ
  - First evidence for this channel

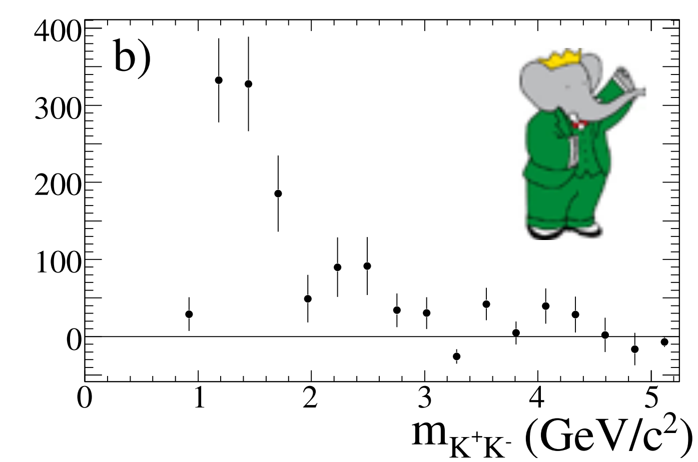
arXiv:1609.03267

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



- Mainly proceeds:
  color suppressed tree
  strong penguin
- No intermediate state observed yet.

- Unidentified mass spectrum in low M_{KK} region, and a large local A_{CP} in the same region.
  These results suggested that final-state interaction may be a contributing factor to CP violation.
  PLB 726, 337 (2013) **PRD 89, 094013 (2014)**

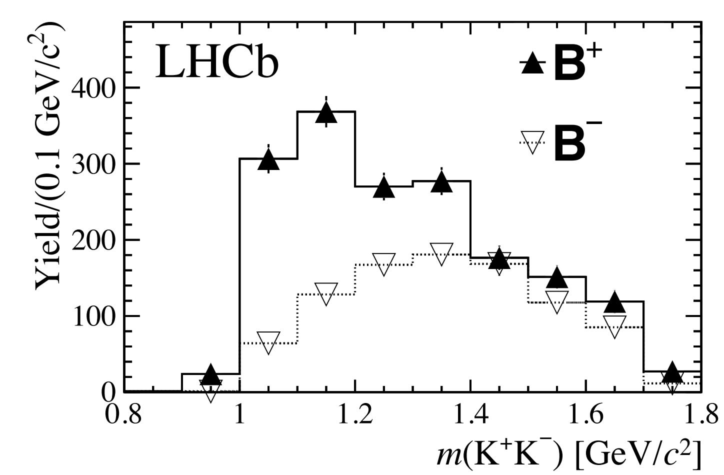


- Experimental results:

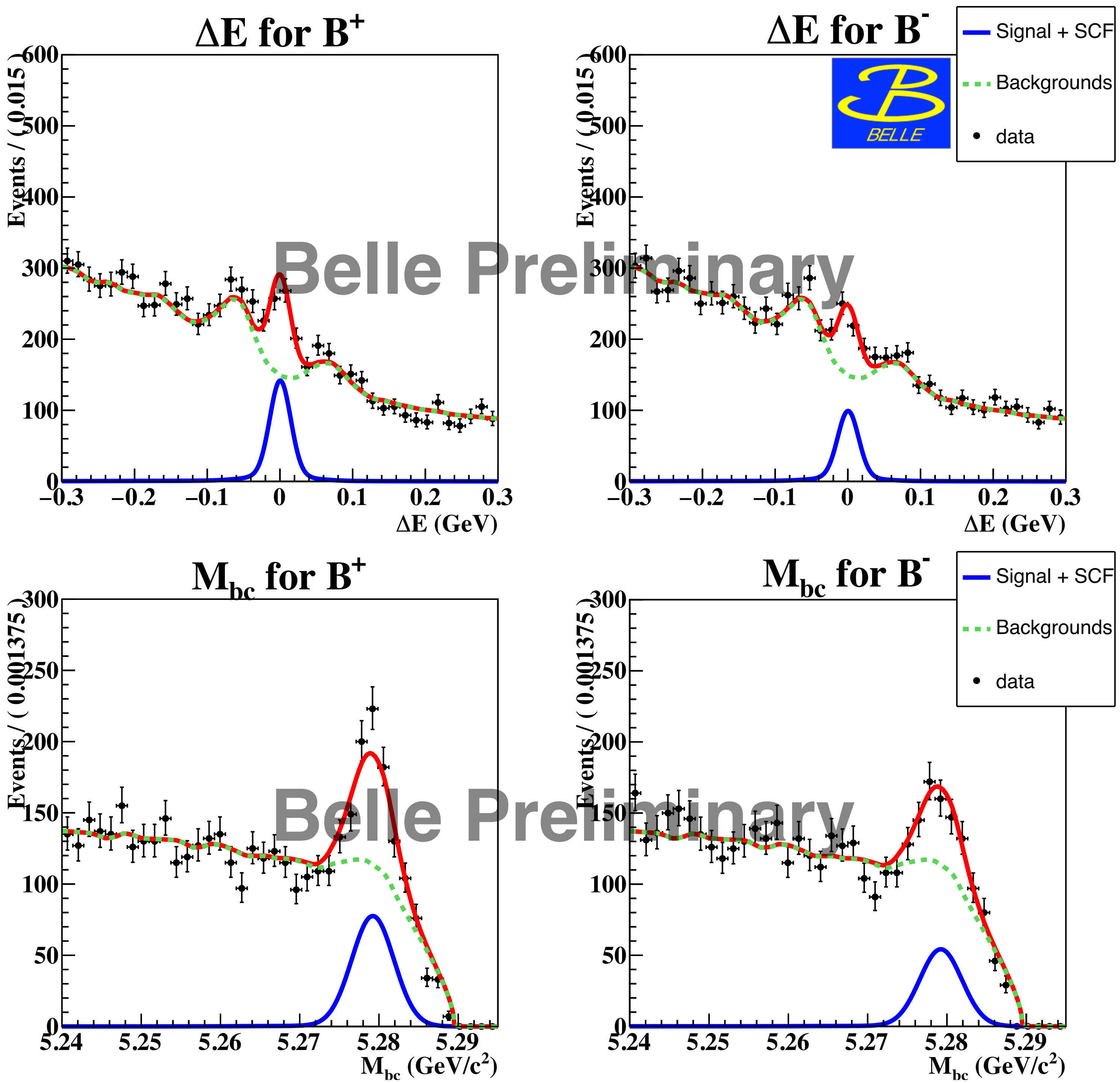
$$\mathcal{B}(K^+K^-\pi^\pm) = (5.0 \pm 0.5 \pm 0.5) \times 10^{-6}$$

$$\mathcal{A}_{CP} = -0.123 \pm 0.017 \pm 0.012 \pm 0.007$$

BaBar, PRL 99, 221801 (2007)
LHCb, PRD 90, 112004 (2014)



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



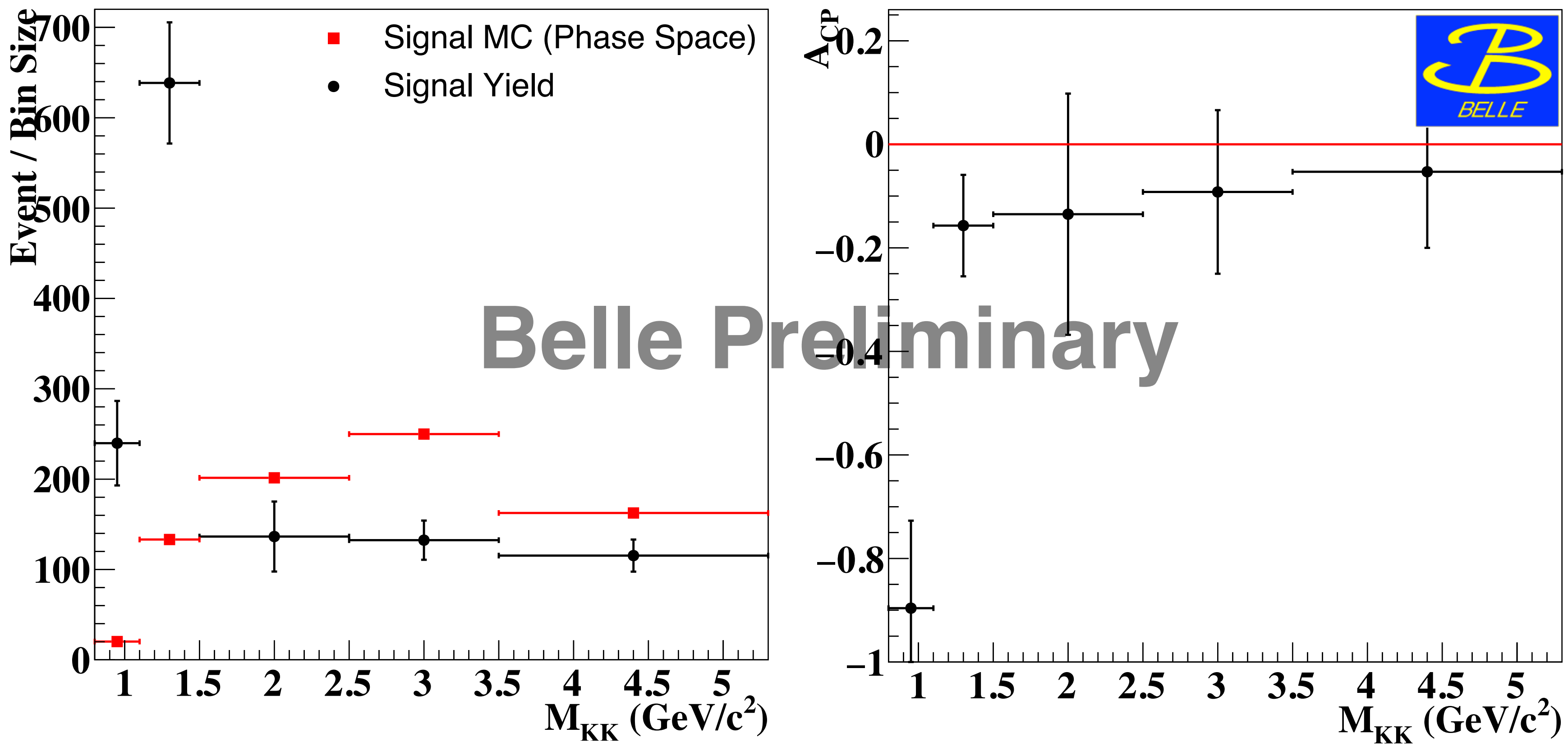
- Tight requirement on C_{NN} to reduce 99% of continuum events.
- This analysis is based on 711 fb^{-1} Y(4S) dataset, we obtain

$$N_{\rm sig} = 714.6 \pm 47.8$$

$$\mathcal{B}(K^+K^-\pi^\pm) = (5.68 \pm 0.38 \pm 0.25) \times 10^{-6}$$

$$\mathcal{A}_{CP} = -0.177 \pm 0.067 \pm 0.006$$

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



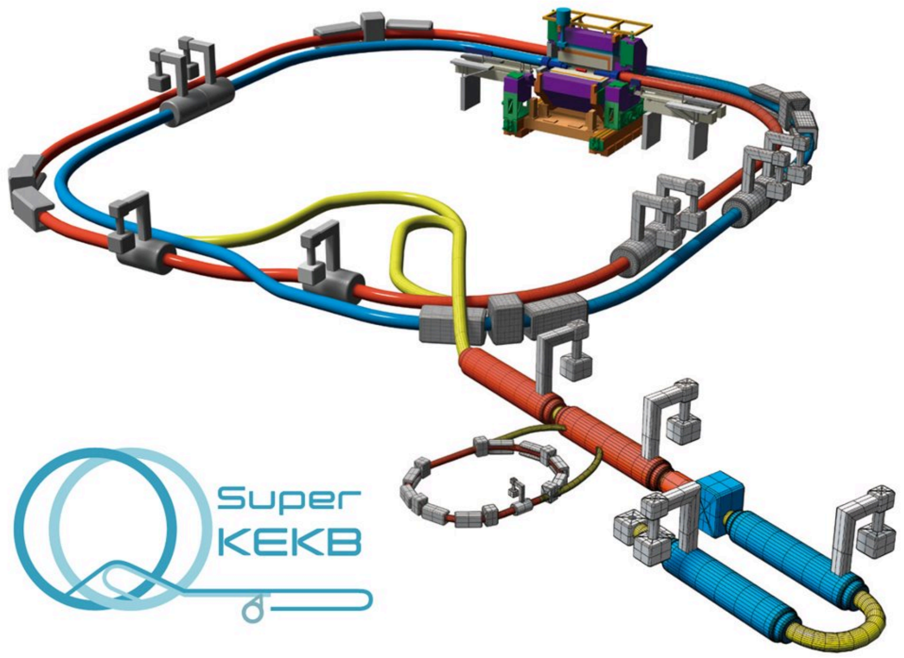
Bin index	Size (GeV/c^2)
0	0.3
1	0.4
2	1.0
3	1.0
4	1.8

- Signal and A_{CP} are fitted in M_{KK} bins.
- Observed an excess similar to LHCb and BaBar in $M_{KK} < 1.5\ \mathrm{GeV/c^2}$
- Strong evidence of a large A_{CP} in $M_{KK} < 1.1\ \mathrm{GeV/c^2}$

$$\mathcal{A}_{CP} = -0.896 \pm 0.166 \pm 0.030 \quad \text{with } 4.8\sigma$$

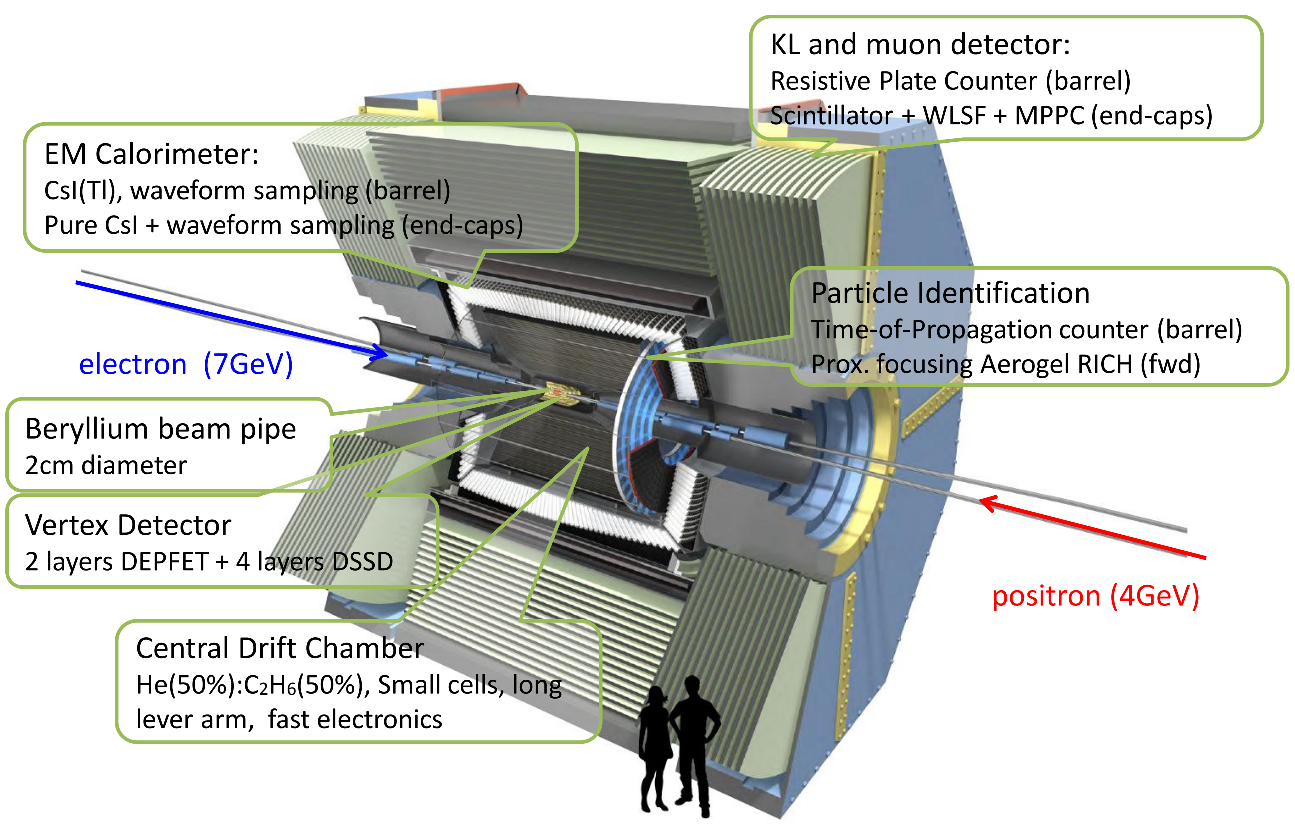
to be submitted soon

Prospects at Belle II



- Asymmetric beam energy at Υ(4S) resonance (7 GeV e− on 4 GeV e+).
- L_{peak}: 40 times
  L_{int}: 50 ab^{-1}, 50xBelle data

Belle II Detector



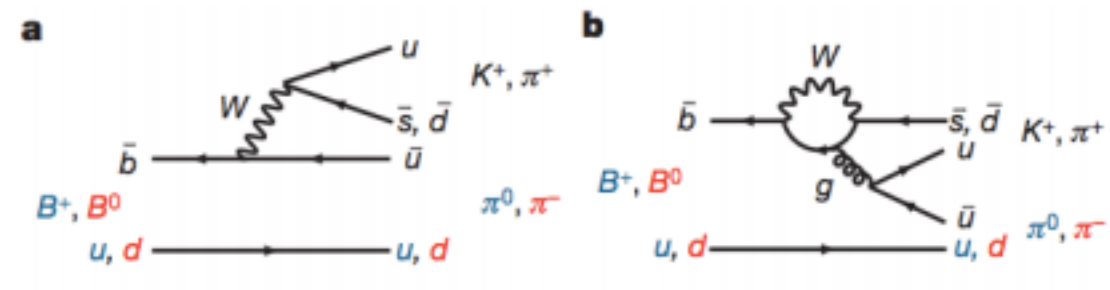
- Detector Improvements:
  - Improve IP and secondary vertex resolution
  - Improve K/π separation
  - Increase K_S efficiency
  - Improve π^0 efficiency
  - Add PID in endcaps.

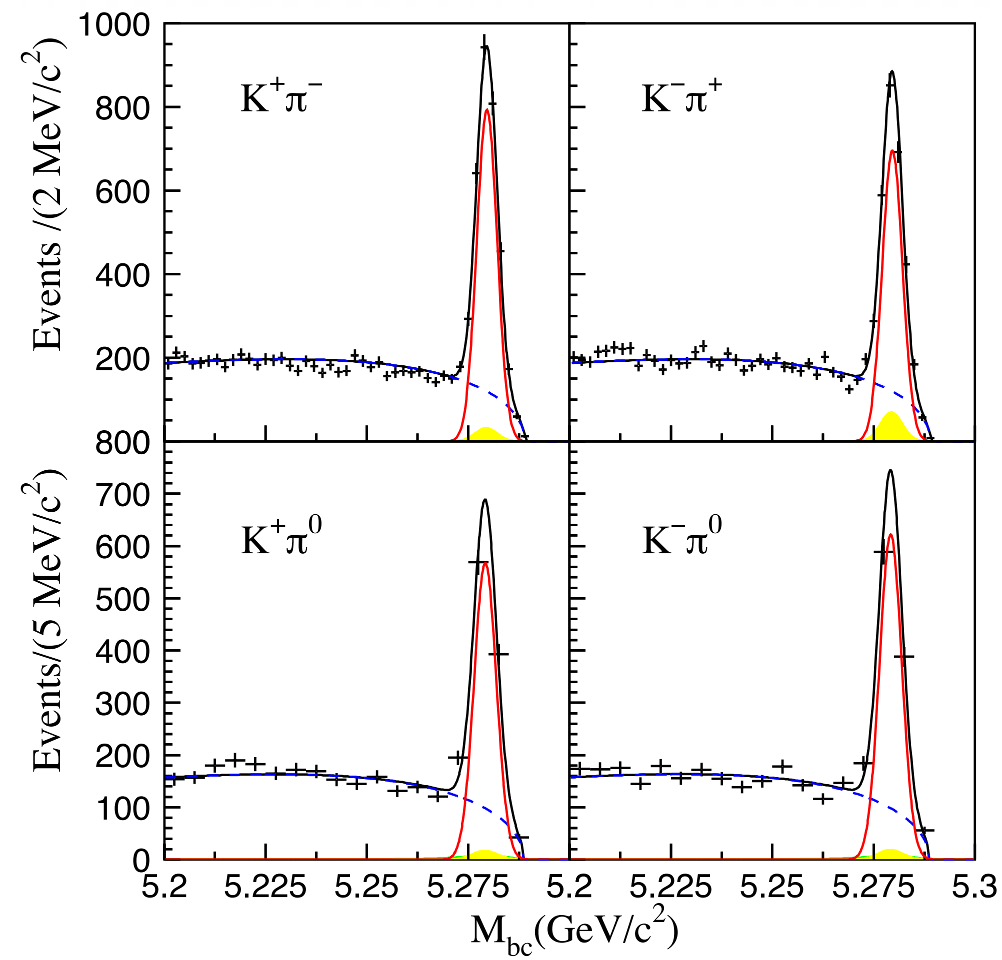
$B \to K\pi$

- Measurements of DCPV in $B^+ \to K^+\pi^0$ found to be different than the same quantity in $B^0 \to K^+\pi^-$

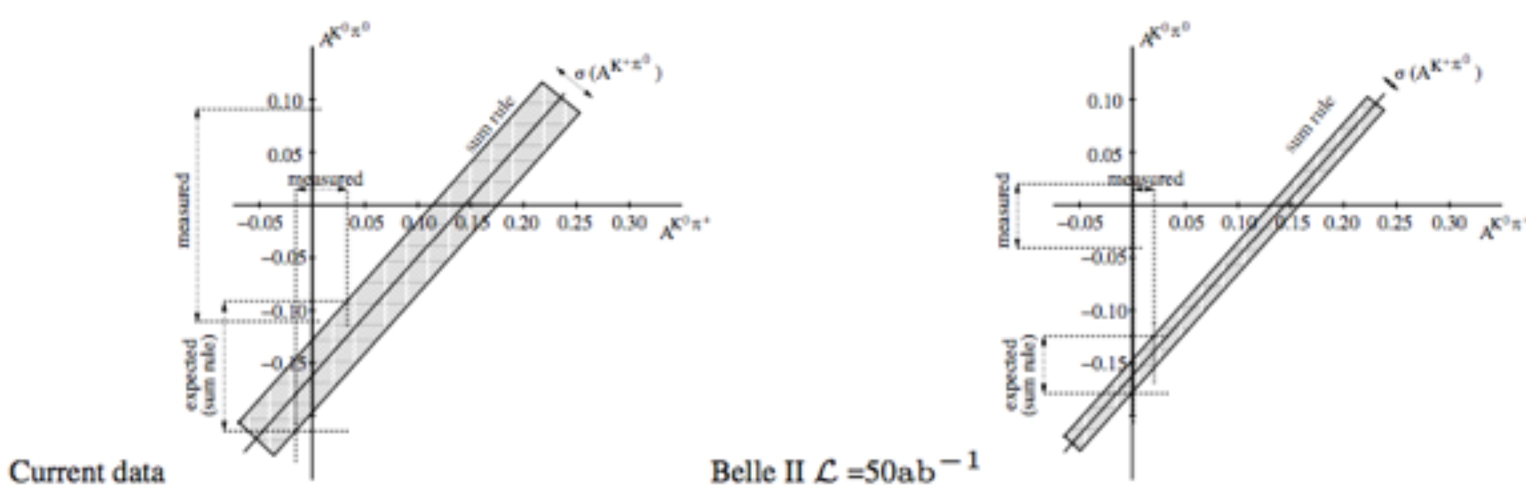
$$\mathcal{A}_{K^+\pi^0} - \mathcal{A}_{K^+\pi^-} = 0.112 \pm 0.027 \pm 0.007 \;\; (4\sigma)$$

- Combine with other measurements and with the larger Belle II dataset, strong interaction effects can be controlled and the validity of the SM can be tested in a model-independent way.
- Isospin sum rule can be presented as a band in the $\mathcal{A}_{K^0\pi^0}$ vs. $\mathcal{A}_{K^+\pi^0}$ plane.





PRD 87, 031103(R) (2013)

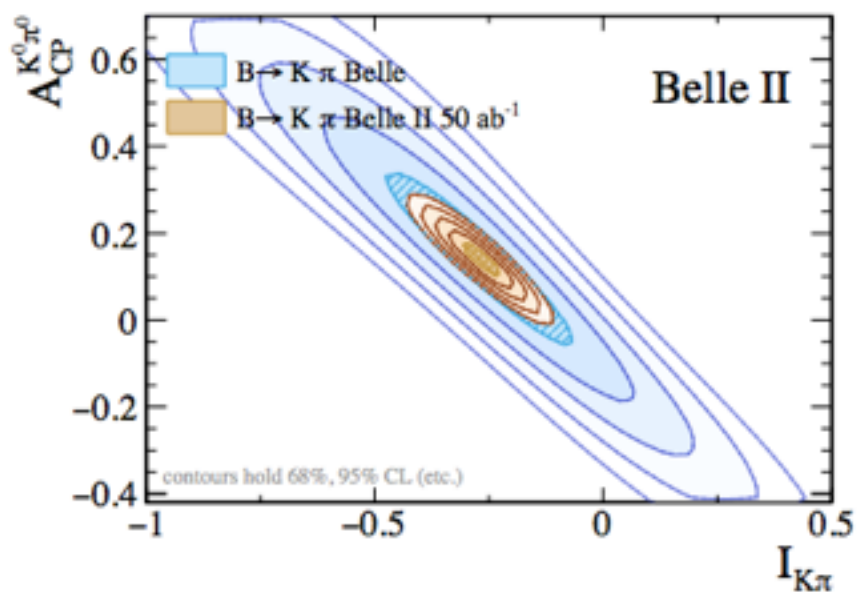


Most demanding measurement is $K^0\pi^0$ final state. With Belle II, the uncertainty on A_{CP} from time-dep. analyses is expected to reach ~ 4% ⇒ sufficient for NP studies

$B \to K\pi$ for Belle II

- A 2D[$A_{K\pi}$, $I_{K\pi}$] scan for different Belle II scenarios.
  - Asymmetry of $K^0/\bar{K}^0$ interactions in material ($\sigma_{ired} \approx 0.2\%$) **PRD 84, 111501 (2011)**
    - Assume that the errors are not correlated.
  - Additionally the systematic uncertainties are conservatively provided and they are still smaller than the statistical errors.

P. Urquijo, BELLE2-NOTE-0021



Projections for the $B \to K\pi$ isospin sum rule parameter, $I_{K\pi}$, at the Belle measured central value.

Scenario	$\mathcal{A}_{K^0\pi^0}$ Value	Stat.	(Red., Irred.)	$I_{K\pi}$
Belle	0.14	0.13	(0.06, 0.02)	-0.27 ± 0.14
Belle + $B \to K^0\pi^0$ at Belle II 5 ab^{-1}		0.05	(0.02, 0.02)	-0.27 ± 0.07
Belle II 50 ab^{-1}		0.01	(0.01, 0.02)	-0.27 ± 0.03

Summary

- We have presented results for $B_s^0 \to K^0\bar{K}^0$, $B^0 \to \eta\eta$, $B^+ \to K^+K^-\pi^+$
- First observation of $B_s^0 \to K^0\bar{K}^0$ at 5.1σ at Belle
  $\mathcal{B}(B_s^0 \to K^0\bar{K}^0) = [19.6^{+5.8}_{-5.1}(stat.) \pm 1.0(syst) \pm 2.0(N_{B_s^0\bar{B}_s^0})] \times 10^{-6}$
- First evidence of $B^0 \to \eta\eta$ at 3.3σ
  The measured branching fraction is
  $\mathcal{B}(B^0 \to \eta\eta) = (7.6^{+2.7+1.4}_{-2.3-1.5}) \times 10^{-7}$
- Branching fraction and A_{CP} in inclusive $B^+ \to K^+K^-\pi^+$
  $\mathcal{B}(B^+ \to K^+K^-\pi^+) = (5.68 \pm 0.38 \pm 0.25) \times 10^{-6}$

  $\mathcal{A}_{CP} = -0.177 \pm 0.067 \pm 0.006$

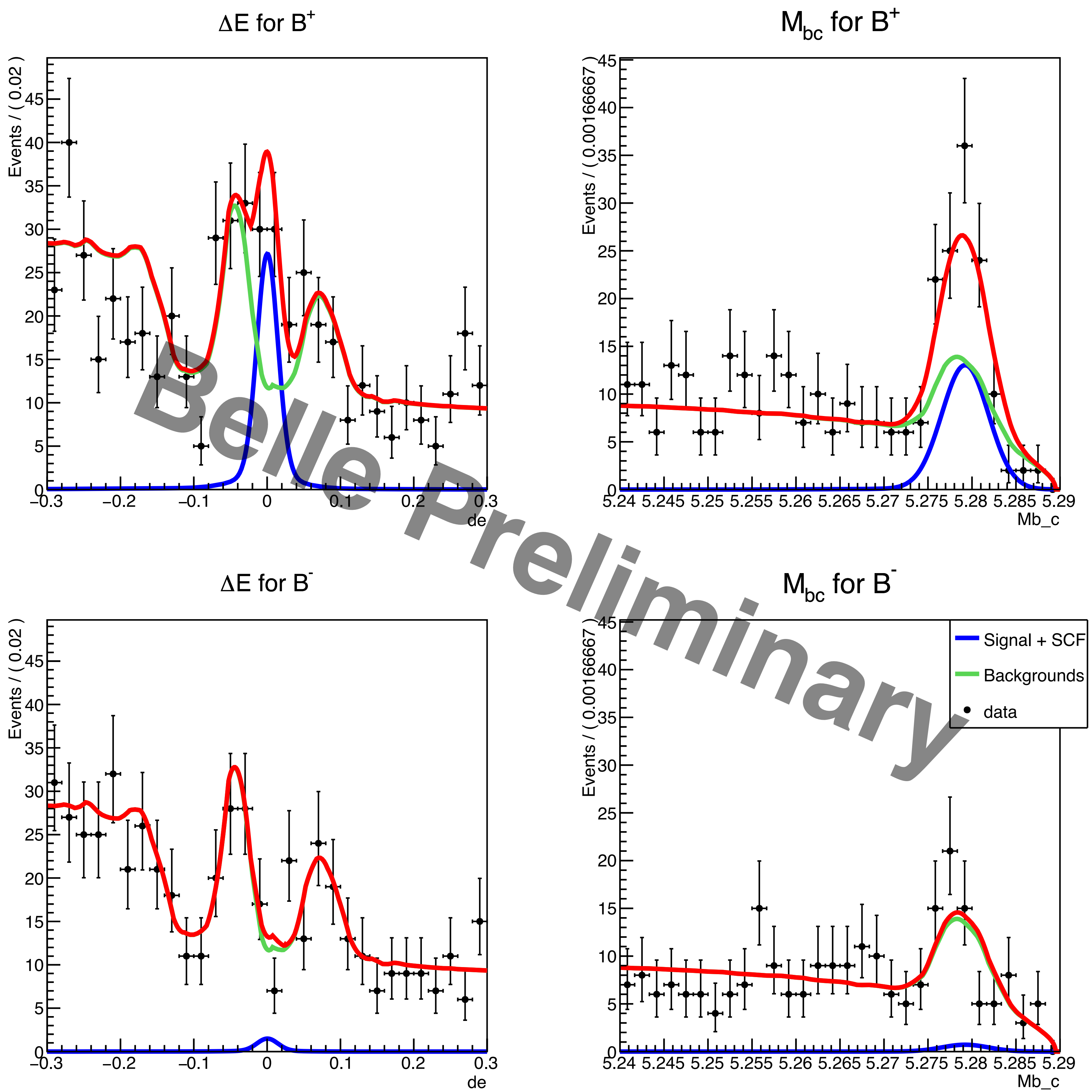
  Strong evidence of A_{CP} in low M_{KK} region at 4.8σ
  $\mathcal{A}_{CP} = -0.896 \pm 0.166 \pm 0.030$ in $M_{KK} < 1.1\ \mathrm{GeV/c^2}$

- Higher statistics + Improvements in reconstruction efficiency, PID, tracking and more at Belle II
  Precise measurement for DCPV, angular analyses, and amplitude analyses in charmless B decays.

Thank you!

Backup

Fitted results in low M_{KK}



Prospects at Belle II

- Test-of-sum (isospin) rule for NP nearly free of theoretical uncertainties, where the SM can be tested by measuring all observables:

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

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

- Extrapolate Belle measurements to 5 and 50 ab^{-1}
  - Systematic uncertainties scale primarily with integrated luminosity.
  - Ideally separate the reducible and irreducible systematic errors (unchanged throughout data accumulation) Apply scaling to all statistical and systematic errors to Belle results via:

$$\sigma_{Belle\ II} = \sqrt{(\sigma^2_{stat} + \sigma^2_{syst})\frac{\mathcal{L}_{Belle}}{\mathcal{L}_{BelleII}} + \sigma^2_{ired}}$$