Belle II measurement of $B^+ \to K^+\pi^0$ and $B^+ \to \pi^+\pi^0$ decays

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Iso-spin sum-rule

Iso-spin sum-rule provides null test of standard model:

$$I_{K\pi} = \mathcal{A}^{\mathrm{CP}}_{K^+\pi^-} + \mathcal{A}^{\mathrm{CP}}_{K^0\pi^+}\frac{\mathcal{B}_{K^0\pi^+}}{\mathcal{B}_{K^+\pi^-}}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}^{\mathrm{CP}}_{K^+\pi^0}\frac{\mathcal{B}_{K^+\pi^0}}{\mathcal{B}_{K^+\pi^-}}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}^{\mathrm{CP}}_{K^0\pi^0}\frac{\mathcal{B}_{K^0\pi^0}}{\mathcal{B}_{K^+\pi^-}} \approx 0$$

Theoretical precision: $\mathcal{O}(1\%)$, Experimental precision: $\mathcal{O}(10\%)$

Belle II is a unique place to measure all involved decays!

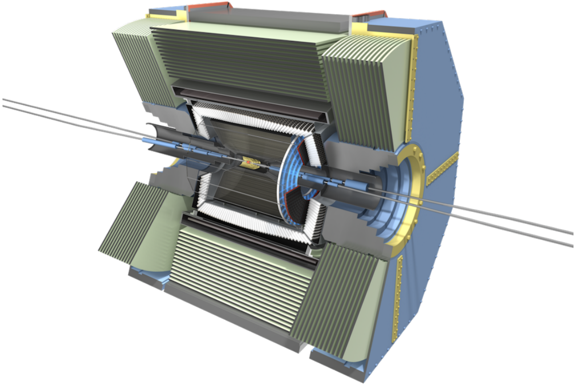
Today: Measurement of all involved decays and full test of iso-spin sum-rule

SuperKEKB and Belle II

Belle II: general purpose detector situated at the interaction point of SuperKEKB

SuperKEKB: asymmetric $e^+ - e^-$ collider operating at $\Upsilon(4S)$ resonance

$\Rightarrow$ Clean environment
$\Rightarrow$ Constrained beam kinematics
$\Rightarrow$ Good neutral reconstruction



Operation:

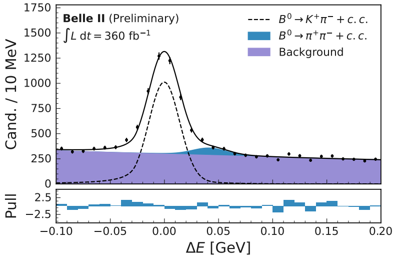
- Recorded 362 fb^{-1} on-res
- Achieved world record: $\mathcal{L} = 4.7 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (more than twice of KEKB/Belle)

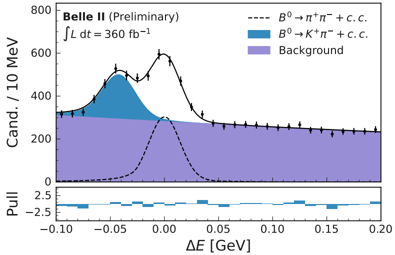
$B^0 \to K^+\pi^-$ Measurement

Experimental challenges:

- Large background from $e^+e^- \to q\bar{q}$
  $\Rightarrow$ Reduced using multivariate algorithm
- Peaking $B^0 \to \pi^+\pi^-$ background
  $\Rightarrow$ Divide into pion- and kaon-enhanced sample
  $\Rightarrow$ Fit both simultaneously
- 2D fit in $\Delta E = E_B^* - E_{\text{beam}}^*$ and MVA output

$$\mathcal{A}^{CP}_{K^+\pi^-} = (-7.2 \pm 1.9 \text{ (stat)} \pm 0.7 \text{ (syst)})\%$$
$$\mathcal{B}_{K^+\pi^-} = (20.67 \pm 0.37 \text{ (stat)} \pm 0.62 \text{ (syst)}) \times 10^{-6}$$
$$\mathcal{B}_{\pi^+\pi^-} = (5.83 \pm 0.22 \text{ (stat)} \pm 0.17 \text{ (syst)}) \times 10^{-6}$$



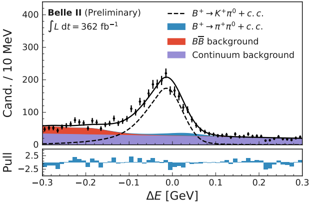


$B^+ \to K^+\pi^0$ and $B^+ \to K_S^0\pi^+$ Measurements

Key: Understanding neutral particles

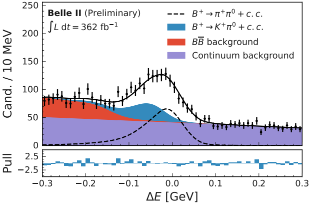
- π^0 energy leakage in calorimeter, broadens signal ΔE peaks
- K_S^0 flies 10 cm on average, decays after first detector layers

$\boldsymbol{B^+ \to K^+\pi^0}$: measure peaking $B^+ \to \pi^+\pi^0$ background (same as $B^0 \to K^+\pi^-$)



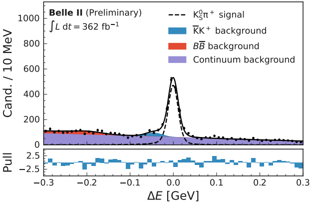
$\mathcal{A} = (1.3 \pm 2.7 \text{ (stat)} \pm 0.5 \text{ (syst)})\%$

$\mathcal{B} = (14.21 \pm 0.38 \text{ (stat)} \pm 0.85 \text{(syst)}) \times 10^{-6}$



$\mathcal{A} = (-8.2 \pm 5.4 \text{ (stat)} \pm 0.8 \text{ (syst)})\%$

$\mathcal{B} = (5.02 \pm 0.28 \text{ (stat)} \pm 0.31 \text{(syst)}) \times 10^{-6}$



$\mathcal{A} = (4.6 \pm 2.9 \text{ (stat)} \pm 0.7 \text{ (syst)})\%$

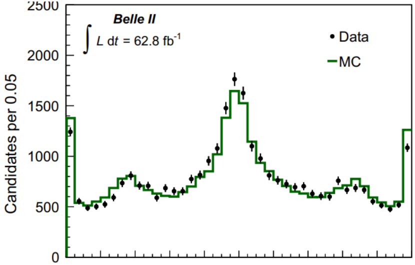
$\mathcal{B} = (24.40 \pm 0.71 \text{ (stat)} \pm 0.86 \text{(syst)}) \times 10^{-6}$

$K_S^0\pi^0$ Time-dependent CP violation

Measure time-dependent CP asymmetry of $K_S^0\pi^0$:

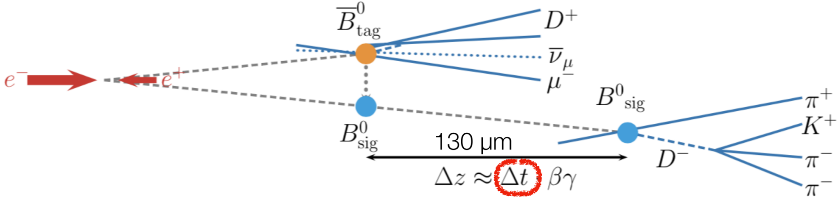
$$\mathcal{A}_{CP}(\Delta t) = A_{CP}\cos(\Delta m_d \Delta t) + S_{CP}\sin(\Delta m_d \Delta t)$$

A_{CP} direct CP asymmetry
S_{CP} mixing induced CP asymmetry



Flavor tagger determines B_{tag} flavor

Asymmetric beam energy translates decay time difference into spacial diff.

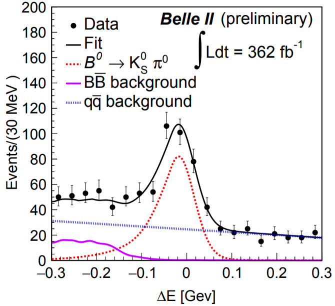


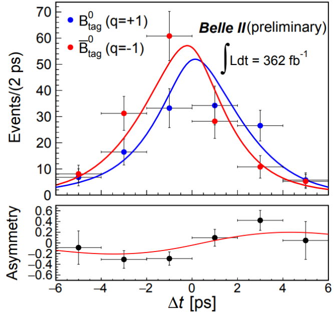
$K_S^0\pi^0$ Result

Analysis strategy:

- Perform 4D fit including ΔE, Δt
- Simultaneous fit in 7 bins of flavor tagger output
- Combine result of $\mathcal{A}^{\text{CP}}$ and $\mathcal{B}$ with time-integrated analysis

$$\mathcal{S}^{\text{CP}} = (0.74\ {}^{+0.20}_{-0.23}\ (\text{stat}) \pm 0.04(\text{syst}))\times 10^{-6}$$
$$\mathcal{A}^{\text{CP}} = (-1 \pm 12\ (\text{stat}) \pm 5\ (\text{syst}))\%$$
$$\mathcal{B} = (10.50 \pm 0.62\ (\text{stat}) \pm 0.67(\text{syst}))\times 10^{-6}$$





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Putting all together:

$$I_{K\pi} = -0.03 \pm 0.13 \pm 0.05$$

Competitive with world average -0.13 ± 0.11

Conclusion

Test of the iso-spin sum-rule is still statistically limited

Belle 2 is providing competitive results with its current data set
(half of Belle, equivalent to BaBar)