Recent Belle II results on decay-time-dependent CP violation

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On behalf of Belle II Collaboration,
Fu Jen Catholic University(FJCU)

Outline

- Introduction
- Time-dependent study of radiative $b \to s\gamma$ decays
  - $B^0 \to K^*(K_S^0 \pi^0)\gamma$
- Time-dependent study of penguin dominate $b \to sq\bar{q}$ decay
  - $B^0 \to K_S^0 K_S^0 K_S^0$
- Summary

Introduction

- $B^0 - \overline{B}^0$ mixing
  - B meson flavor changes via a box diagram and flavor oscillates with time evolution

- In Belle II, B meson pairs are produced from $\Upsilon(4S)$ decay and mixing occurs simultaneously in two B mesons due to quantum entanglement.

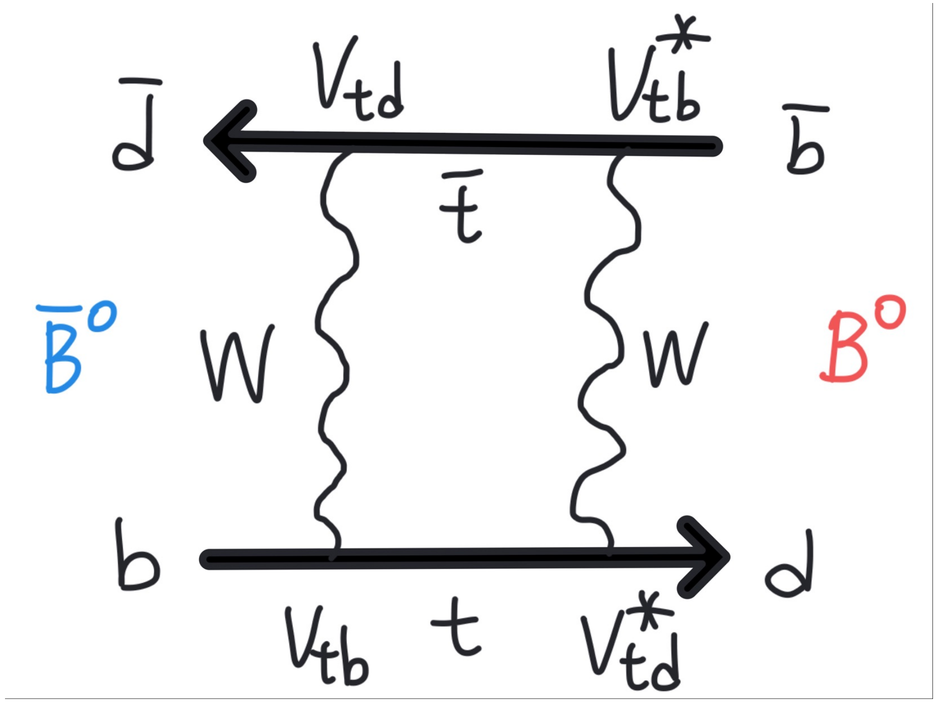


Fig1. box diagram

Introduction

- **Time-dependent analyses are performed by measuring a decay time difference of B mesons Δt.**
- **Number of Mixed ($B^0 - B^0$ or $\bar{B}^0 - \bar{B}^0$) and Un-mixed ($B^0 - \bar{B}^0$) events:**
  - $N_M \propto e^{-\frac{|\Delta t|}{\tau_{B^0}}[1-\cos(\Delta m \Delta t)]}$
  - $N_U \propto e^{-\frac{|\Delta t|}{\tau_{B^0}}[1+cos(\Delta m \Delta t)]}$

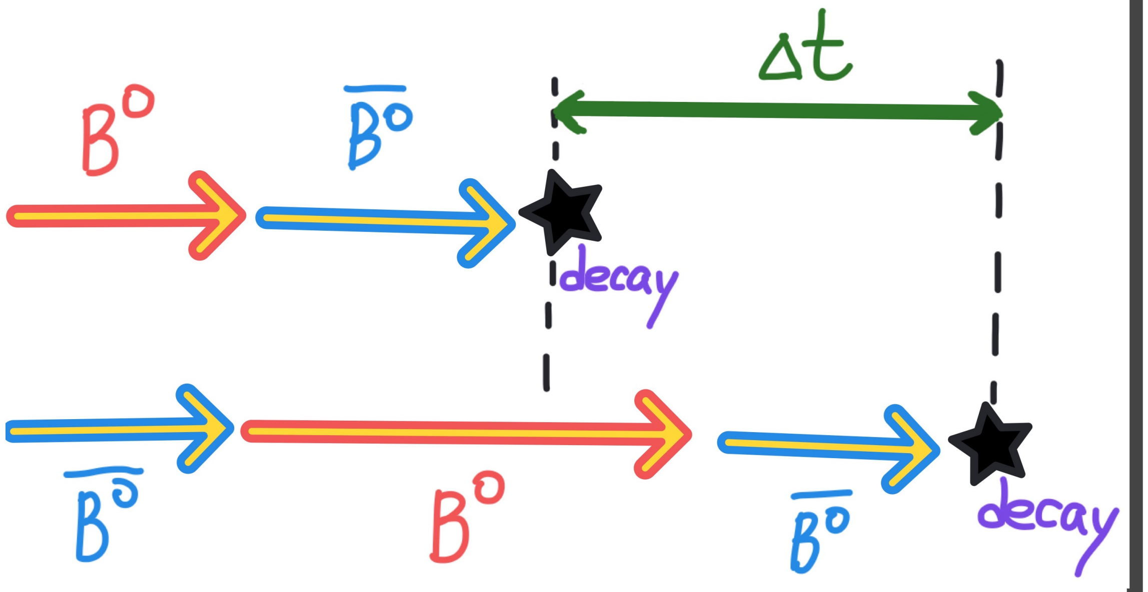


Fig2. Decay time difference of B mesons Δt

Time-dependent CP violation (TDCPV)

- **Time-dependent CP asymmetry**
  - $A_{CP}(\Delta t) = \frac{P(\bar{B}^0(\Delta t)\to f_{CP}) - P(B^0(\Delta t)\to f_{CP})}{P(\bar{B}^0(\Delta t)\to f_{CP}) + P(B^0(\Delta t)\to f_{CP})} = S\sin\Delta m\Delta t + A\cos\Delta m\Delta t$
    - SM: S, A are very small
    - S: Time-dependent CPV parameter
    - A(=-C): Direct CPV parameter
    - Δm: B-B mass difference
    - Δt: B-B decay time difference

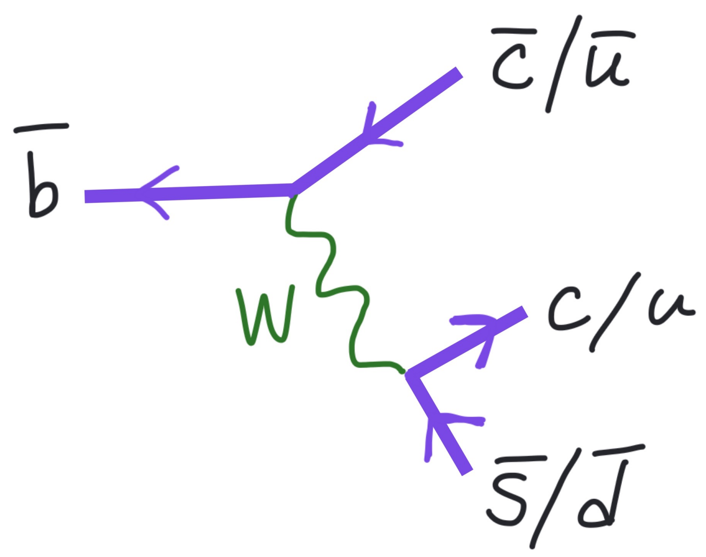


Fig3. Tree with box diagram.

Vertexing

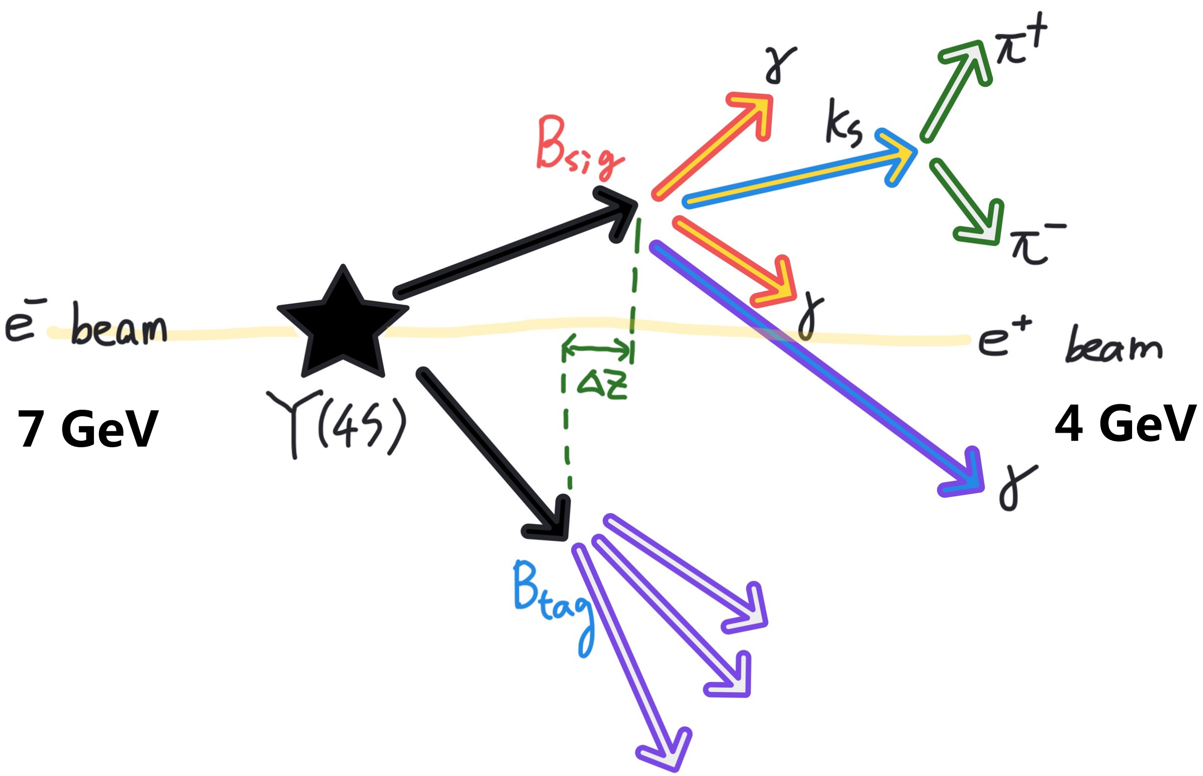


Fig4. An example of reconstruction of decay vertices of B mesons, $B^0 \rightarrow K_S\pi^0\gamma$.

- **B mesons are produced through asymmetric energy collision of e^+e^- beams, displacement of decay vertices is measured**
- **$\Delta z \sim \beta\gamma\Delta t$ relies on vertexing of both B mesons (B_{sig} and B_{tag}), it converts to Δt as known as boost effect**

Vertexing

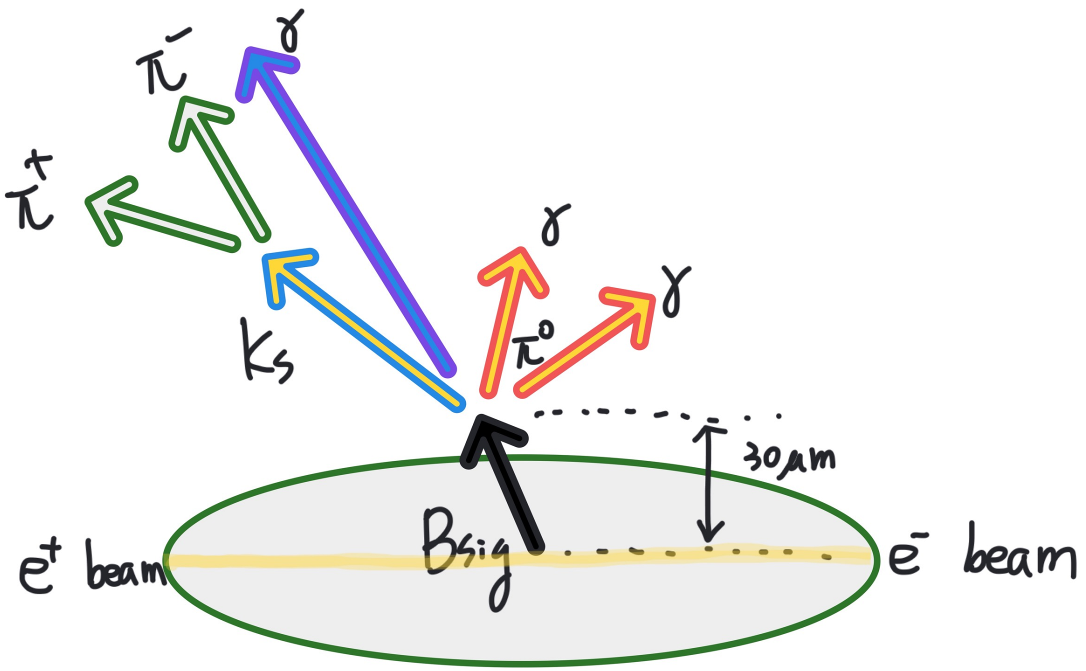


Fig5. An example of reconstruction of decay vertices of B mesons if no charge track **originates at B_{sig} vertex**, $B^0 \rightarrow K_S\pi^0\gamma$.

- **Beam spot constraining technique if no charge track originates at B_{sig} vertex**
- **Extrapolate K_s flight to the beam spot**
- **Fit $\Upsilon(4S) \rightarrow B^0\overline{B}^0$ with kinematical constraint**
- **Validate using $B^0 \rightarrow J/\psi K_s$ control sample**
- **The vertex precision is related to vertex detector resolution**

$B^0 \to K^*(K_s\pi^0)\gamma$ results

Fig6. $\mathrm{B}^0 \to \mathrm{K_S}\pi^0\gamma$.

- **Variation of CP asymmetries along $m(K_S\pi^0)$ expected small**
- **Check the $K^*(892)$ range**

didn’t find released results in Belle II web page. Who should I talk to?

Summary of the $b \to s\gamma$ mode

- **Time-dependent analyses of the $b \to s\gamma$ mode have been performed by Belle II**
  - $B^0 \to K^*(K_s^0\pi^0)\gamma$
- **Measurements compatible with CP conservation**
- **All measurements limited by statistics**

Penguin dominate: $\mathrm{B}^0 \to \mathrm{K_s K_s K_s}$

$$P(\Delta t) = \frac{e^{-\frac{|\Delta t|}{\tau_{B^0}}}}{4\tau_{B^0}}(1 + q[S sin(\Delta m_d \Delta t) + A cos(\Delta m_d \Delta t)])$$

The SM predicts that $\mathcal{S} = -\sin 2\phi_1$ and $\mathcal{A} = 0$

- **The deviation of $\sin 2\phi_1$ from $\mathrm{B}^0 \to \mathrm{J}/\psi\mathrm{K}_S^0$ is predicted to be 0.06 ± 0.00**

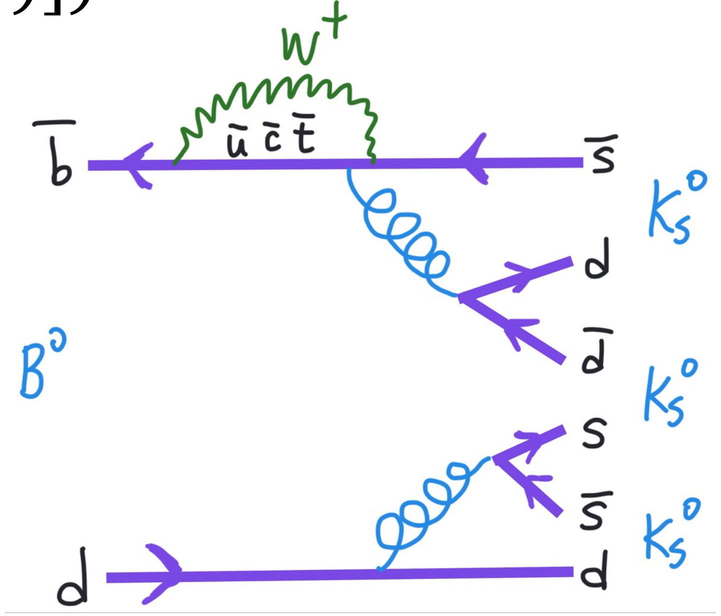


Fig8. Penguin amplitude for the $\mathrm{B}^0 \to \mathrm{K_S K_S K_S}$ decays

Penguin dominate: $\mathbf{B^0 \to K_s K_s K_s}$

- **Belle experiment using 772 M $B\bar{B}$ pairs**
  - $S = -0.71 \pm 0.23\ (stat) \pm 0.05\ (syst)$
  - $A = 0.12 \pm 0.16\ (stat) \pm 0.05\ (syst)$
- **BaBar experiment using 468 M $B\bar{B}$ pairs**
  - $S = -0.94^{+0.24}_{-0.21}\ (stat) \pm 0.06\ (syst)$
  - $A = 0.17 \pm 0.18\ (stat) \pm 0.04\ (syst)$

Belle II data in this analysis using 200 M $B\bar{B}$ pairs

- $S = -1.86 \pm 0.83\ (stat) \pm 0.09\ (syst)$
- $A = -0.22 \pm 0.29\ (stat) \pm 0.04\ (syst)$

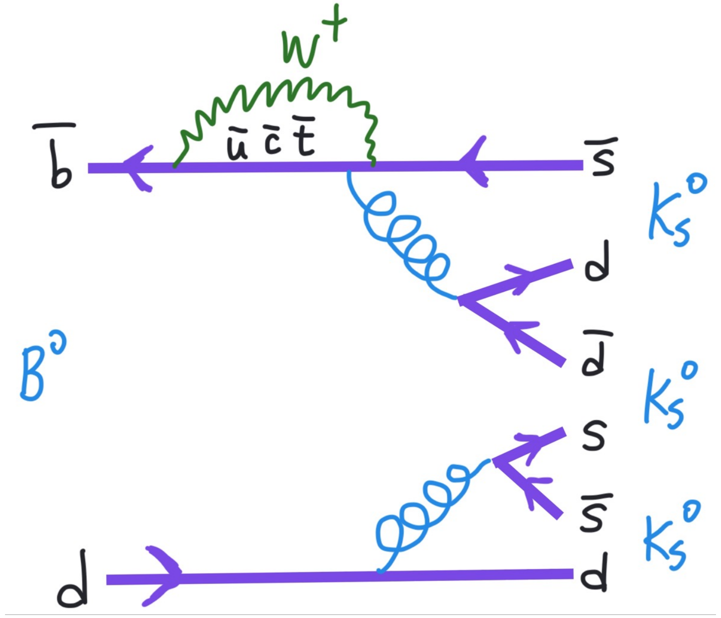
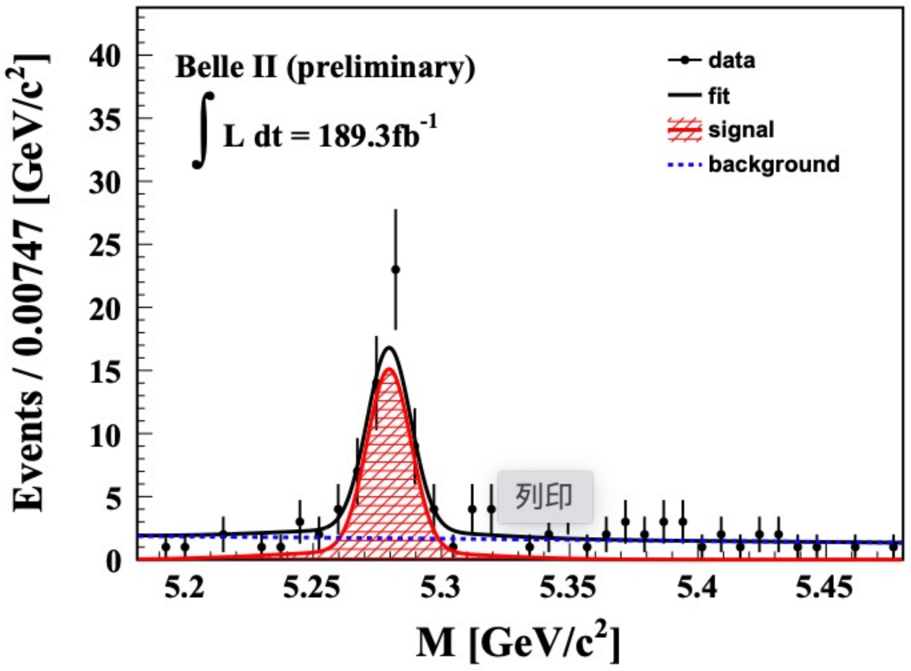
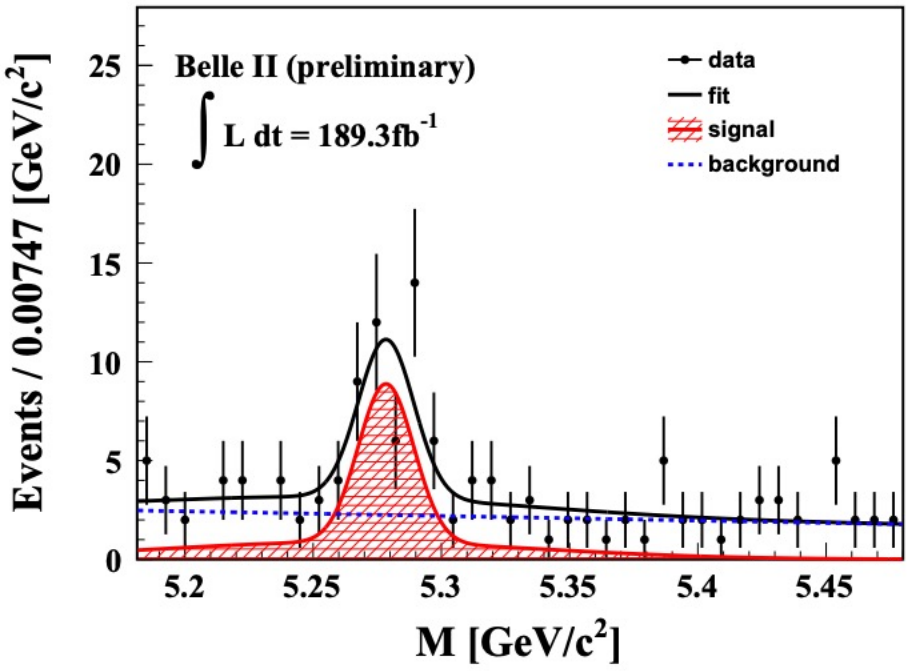


Fig8. Penguin amplitude for the $\mathbf{B^0 \to K_S K_S K_S}$ decays

The M_{bc} distributions: $B^0 \to K_S K_S K_S$





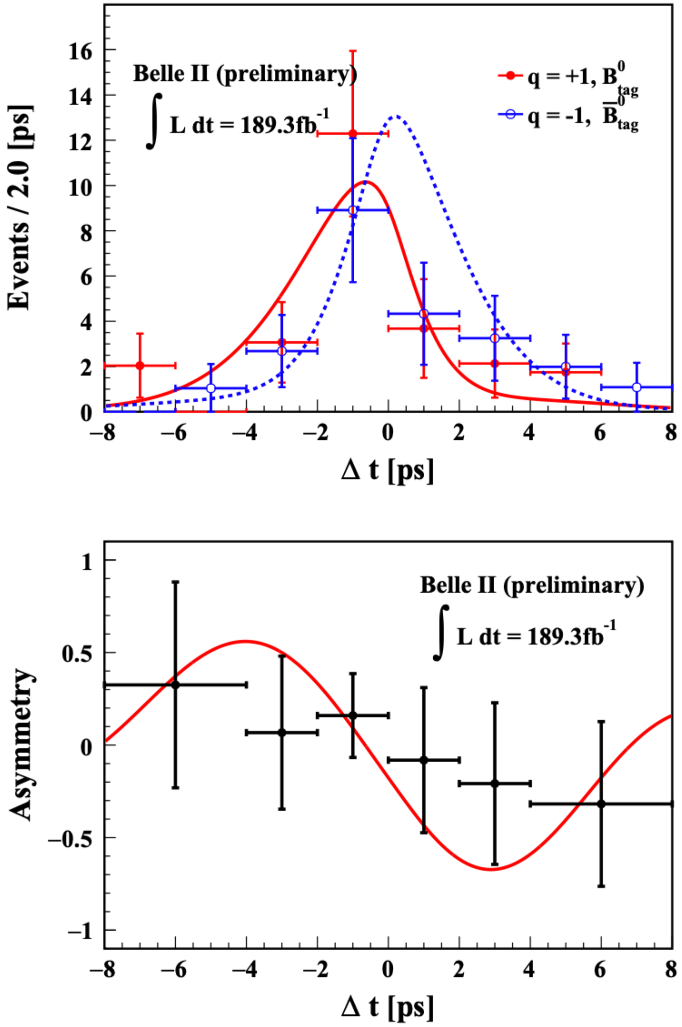
Systematic uncertainties: $B^0 \to K_S K_S K_S$

Table 1: Systematic uncertainties

Source	$\delta\mathcal{S}$	$\delta\mathcal{A}$
Vertex reconstruction	0.025	0.022
Flavor tagging	0.079	0.030
Resolution function	0.012	0.006
Physics parameters	0.008	0.000
Fit bias	0.003	0.002
Signal fraction	0.011	0.007
Background Δt shape	0.011	0.001
Detector misalignment	0.002	0.004
Resolution model	0.001	0.003
Tag-side interference	0.014	0.015
Total	0.087	0.042

Dominate systematic uncertainties is Flavor tagging

Δt Results: $B^0 \to K_s K_s K_s$



measurements limited by statistics

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    - $B^0 \to K_s K_s \ K_s$
    - Measurements compatible with CP conservation

  Belle II data in this analysis using 200 M $B\bar{B}$ pairs
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backup

Introduction

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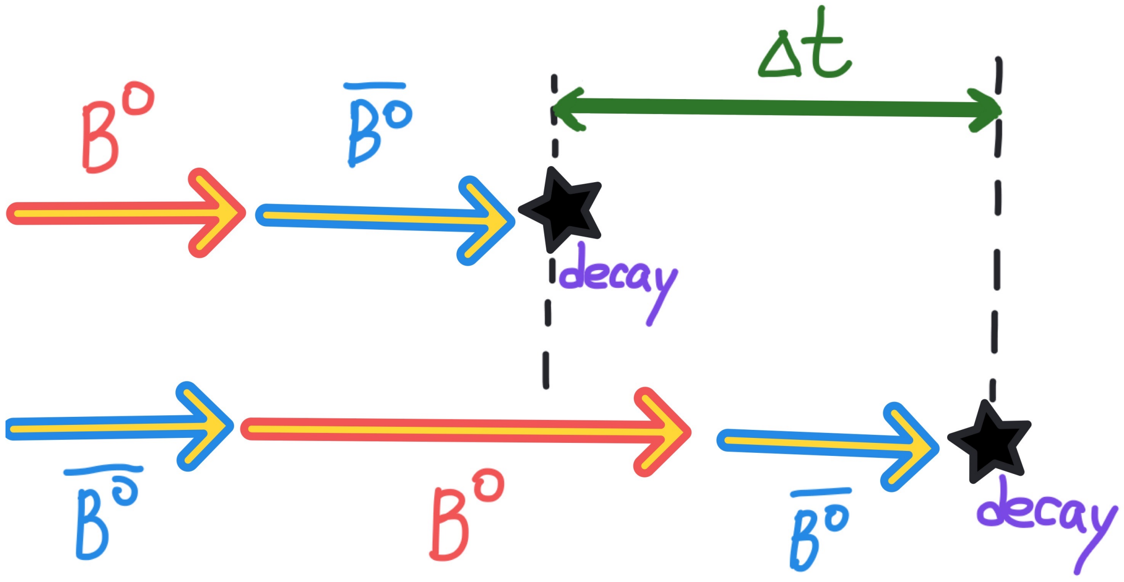

Fig2. Decay time difference of B mesons Δt

Time-dependent CP violation (TDCPV)

- Induced by quantum interference with decay to the CP-eigenstates
- Time-dependent CP asymmetry
  - $A_{CP}(\Delta t) = \frac{P(\overline{B}^0(\Delta t)\rightarrow f_{CP}) - P(B^0(\Delta t)\rightarrow f_{CP})}{P(\overline{B}^0(\Delta t)\rightarrow f_{CP}) + P(B^0(\Delta t)\rightarrow f_{CP})} = S sin\Delta m\Delta t + A cos\Delta m\Delta t$
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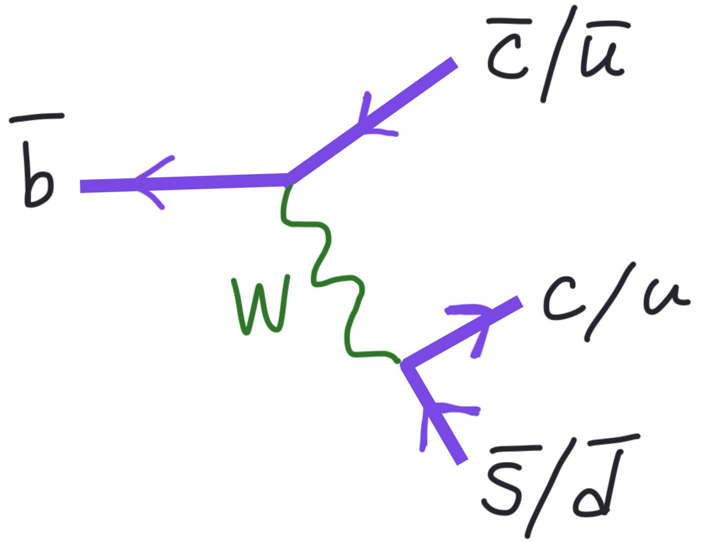

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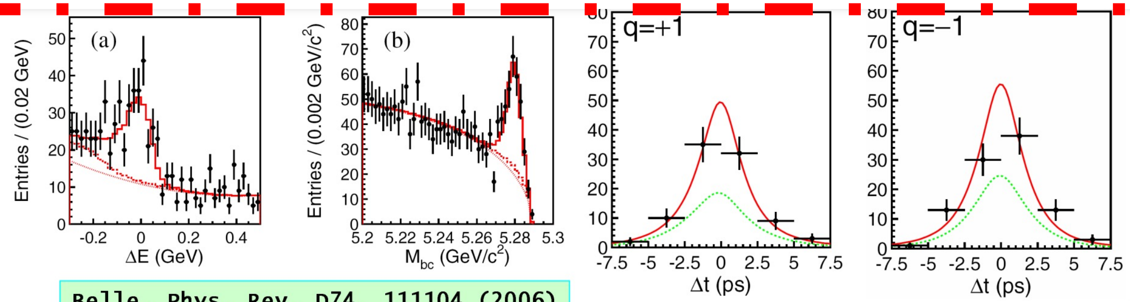
$B^0 \to K^*(K_s\pi^0)\gamma$ results



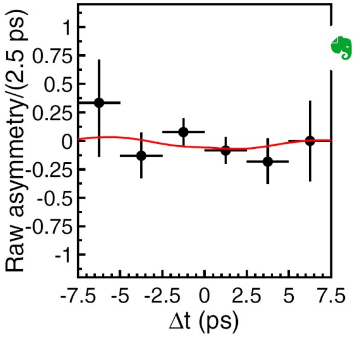
Belle, Phys. Rev. D74, 111104 (2006)
N(BB) = 535M

$S = -0.10 \pm 0.31 \pm 0.07$
$A = -0.20 \pm 0.20 \pm 0.06$

"Inclusive" analysis, m($K_s\pi^0$) < 1.8 GeV/c^2

$S = -0.32^{+0.36}_{-0.33} \pm 0.05$
$A = -0.20 \pm 0.24 \pm 0.05$

"K*(892)-only" analysis, 0.8 < m($K_s\pi^0$) < 1.0 GeV/c^2



can't find the new results in Belle II web page. Who should I talk to?

- **Variation of CP asymmetries along $m(K_S\pi^0)$ expected small**
- **Check inside/outside the $K^*(892)$ range**

BELLE2-CONF-PH-2021-014

Penguin dominate: $B^0 \rightarrow K_s K_s K_s$

$$P(\Delta t) = \frac{e^{-\frac{|\Delta t|}{\tau_{B^0}}}}{4\tau_{B^0}}(1 + q[S sin(\Delta m_d \Delta t) + A cos(\Delta m_d \Delta t)])$$

$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}(1 + q[\mathcal{S}\sin(\Delta m_d \Delta t) + \mathcal{A}\cos(\Delta m_d \Delta t)])$$

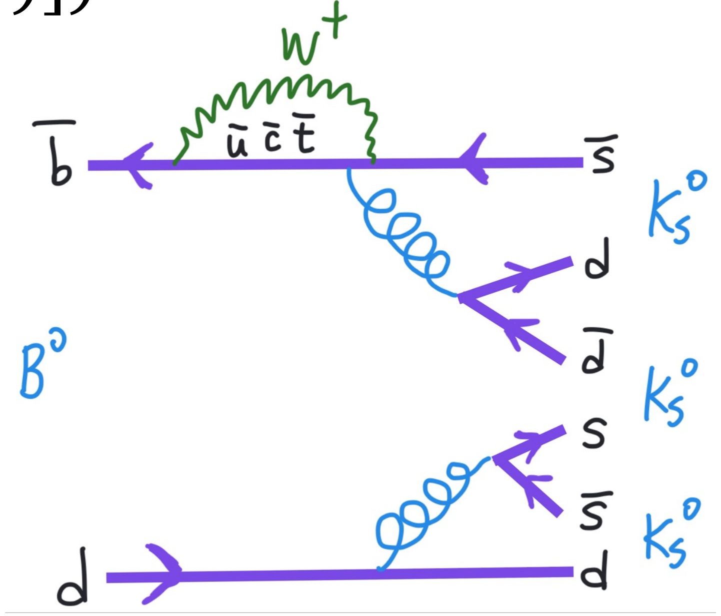
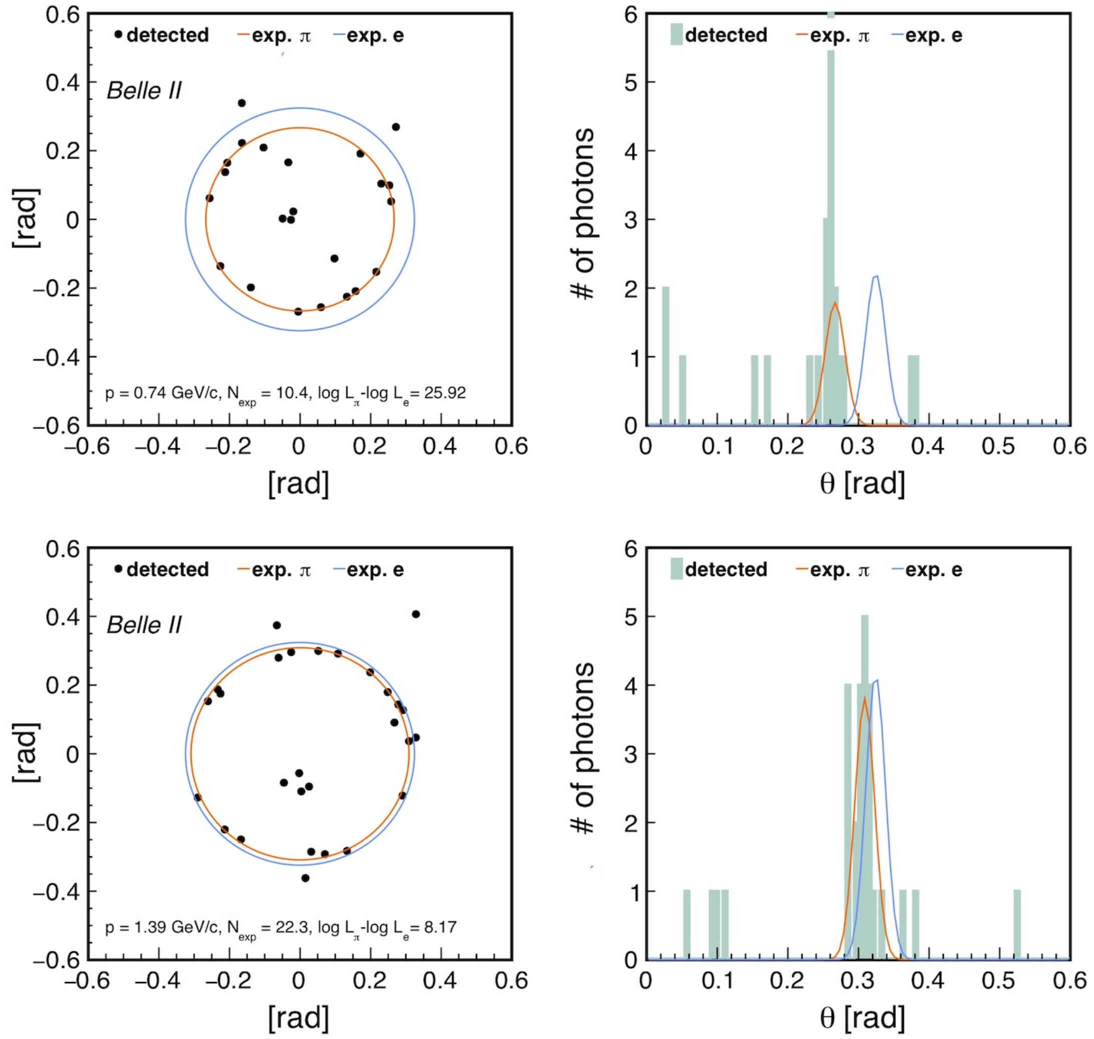


Fig8. Penguin amplitude for the $B^0 \rightarrow K_S K_S K_S$ decays

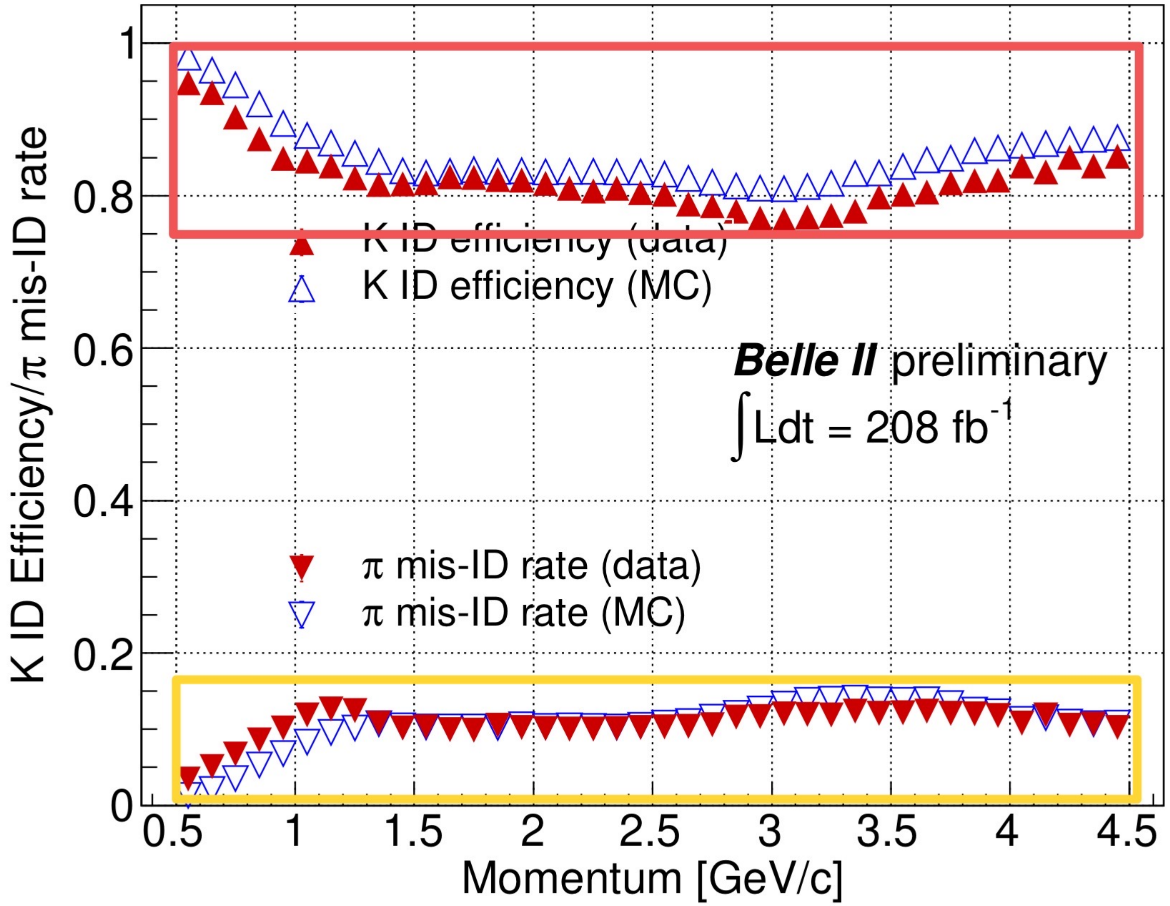
Performance highlights from Belle II



The observed Cherenkov rings for pion tracks in data from $K_s^0 \to \pi^+\pi^-$ decays with track momentum of p = 0.74 GeV/c (top) and p = 1.39 GeV/c (below). The red and blue rings show the expected rings for the pion and electron hypotheses respectively.

#2022 Belle II ICHEP note

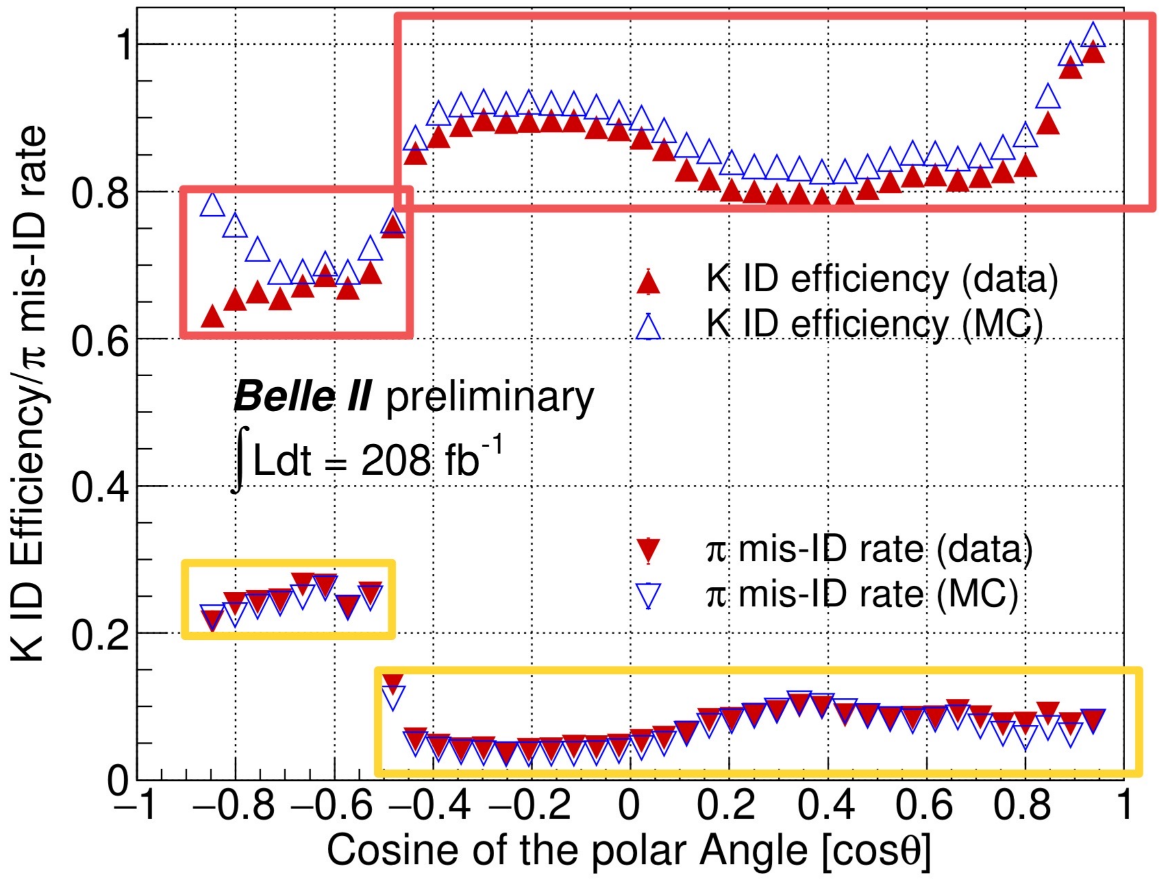
Performance highlights from Belle II



Binary ($R_{K\pi} > 0.5$) K/π separation performance as a function of the laboratory frame momentum measured with the $D^{*+} \to D^0\pi_s^+, D^0 \to K^-\pi^+$ sample. Upward pointing triangles: K identification efficiency for the dependent MC (empty blue triangles) and data (filled red). Downward pointing triangles: π mis-identification probability for MC (empty blue) and data (filled red).

#2022 Belle II ICHEP note

Performance highlights from Belle II



Binary ($R_{K\pi} > 0.5$) K/π separation performance as a function of the $cos\theta_{lab}$ measured with the $D^{*+} \to D^0\pi_s^+, D^0 \to K^-\pi^+$ sample. Upward pointing triangles: K identification efficiency for the dependent MC (empty blue triangles) and data (filled red). Downward pointing triangles: π mis-identification probability for MC (empty blue) and data (filled red).

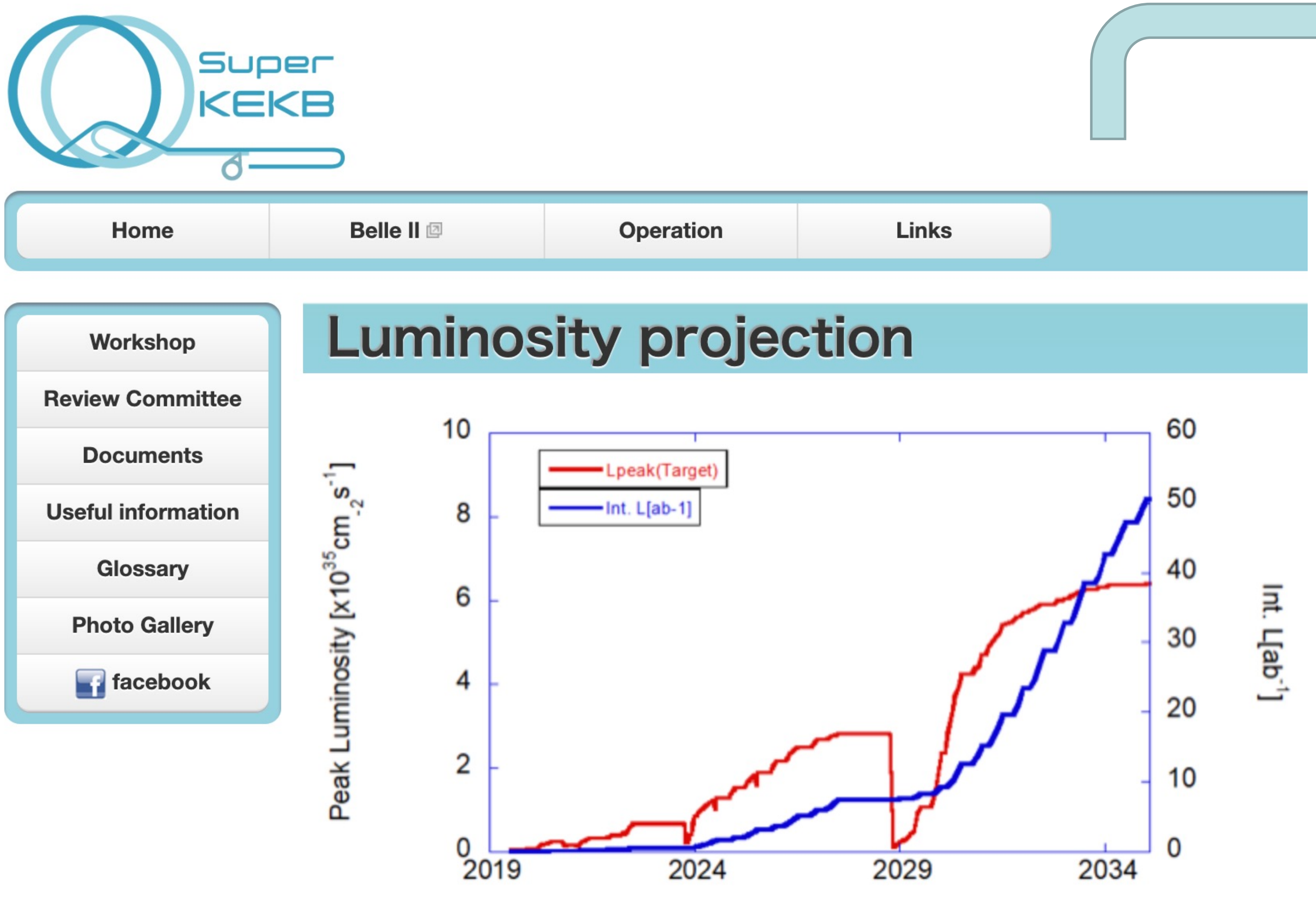
#2022 Belle II ICHEP note

Belle II, international collaboration

Member Institutes: (based on B2MMS data as on Aug 17th, 2019)

KEK, Japan

Accelerator: SuperKEKB

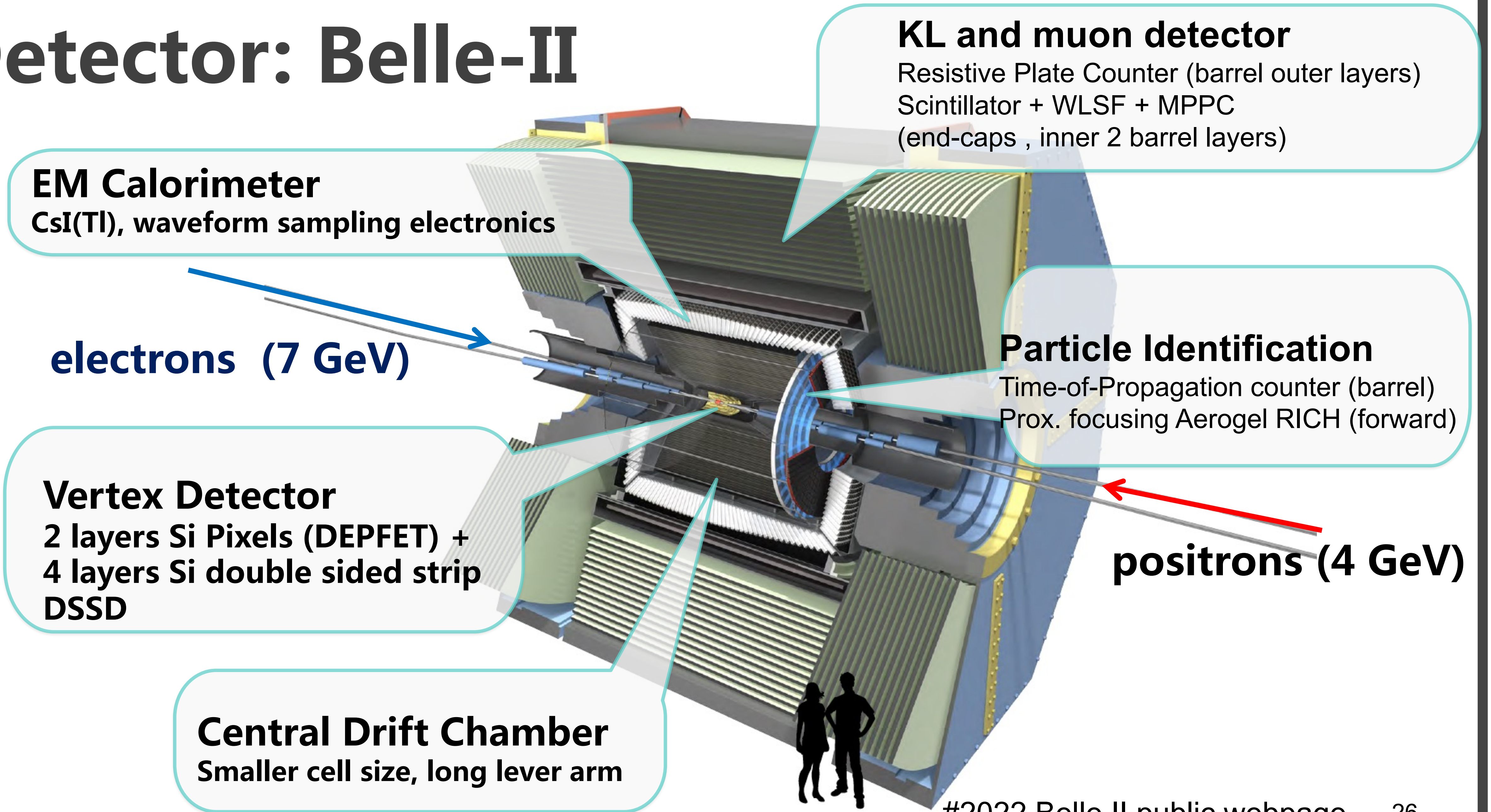


Goal

Year	Peak luminosity $\times 10^{35}\ cm^{-2}s^{-1}$	Integral Luminosity ab^{-1}
2024	1	1
2029	3	10
2034	6	40

#2022 Belle II public webpage

Detector: Belle-II



#2022 Belle II public webpage