



Belle II: Status and prospects

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On behalf of Belle II collaboration

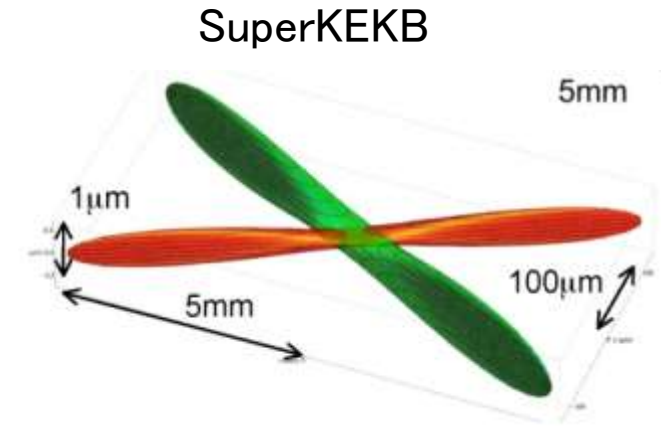
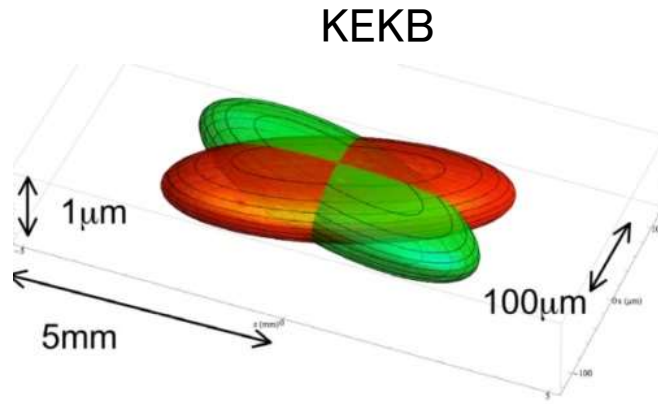
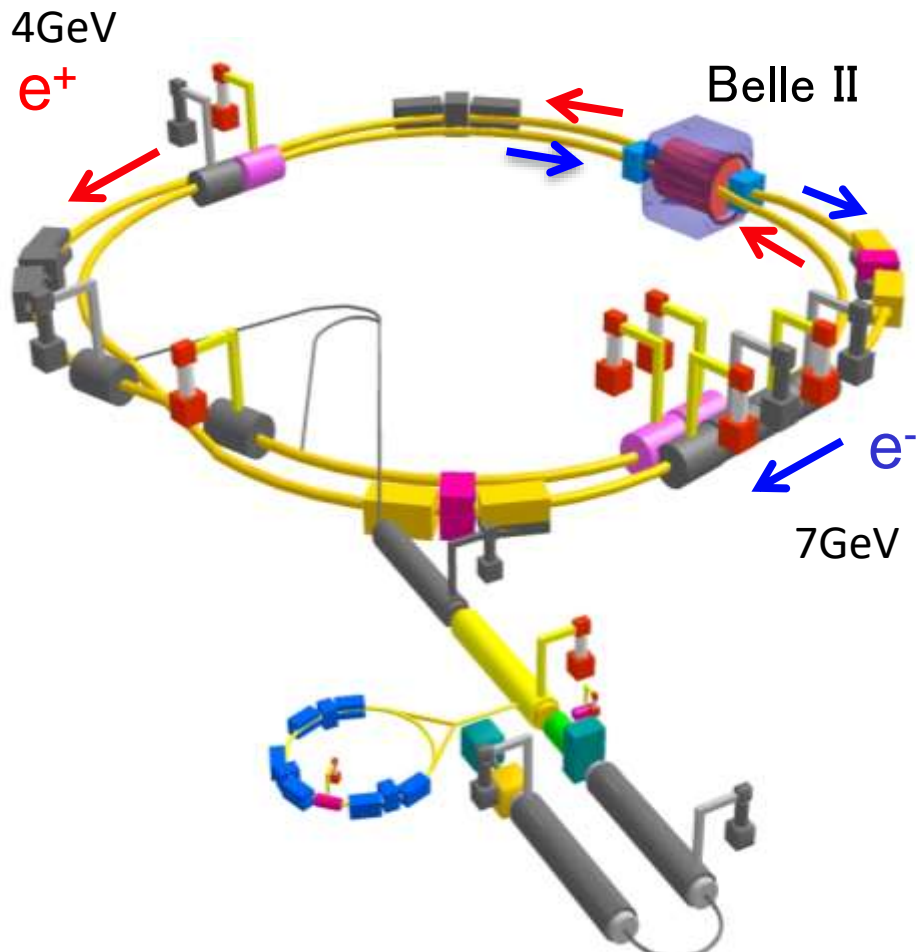
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University of Tokyo, Japan

Outline

- SuperKEKB and BelleII detector
- Run plan
- Detector performance
- Selected topics
- Summary

SuperKEKB

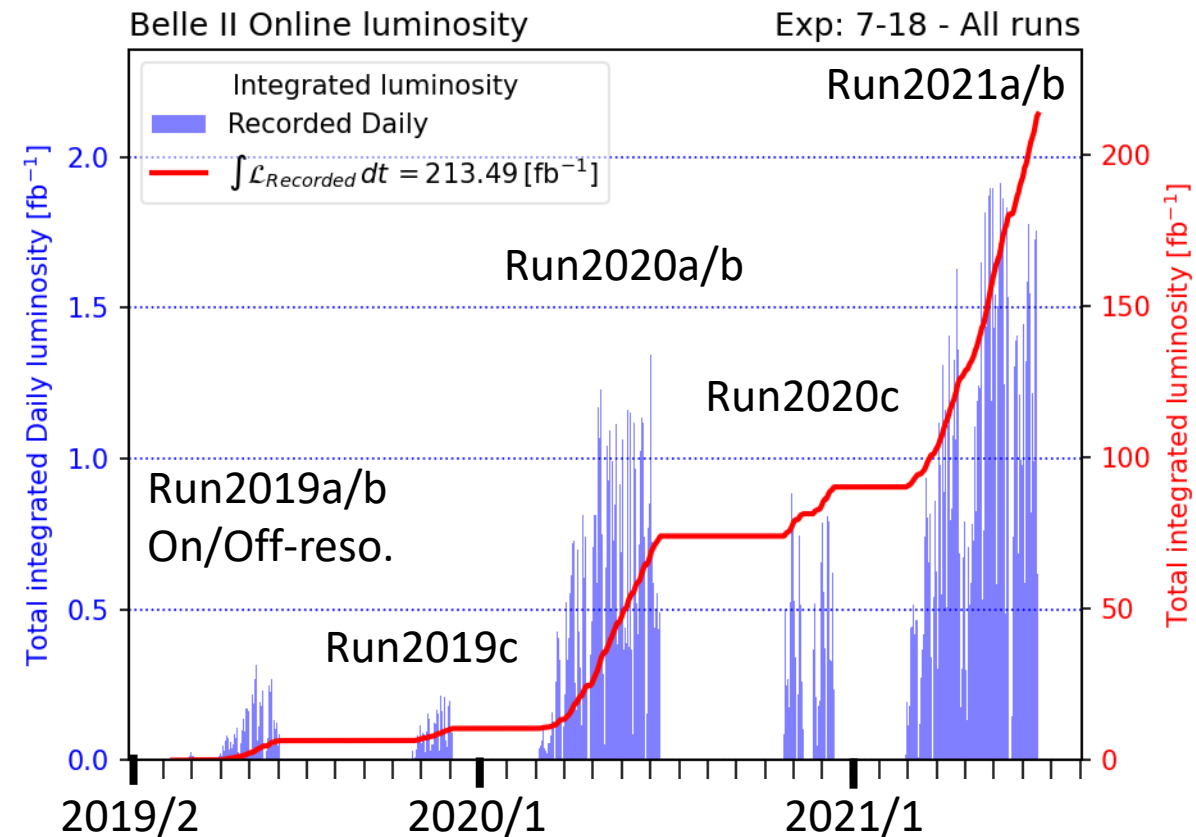
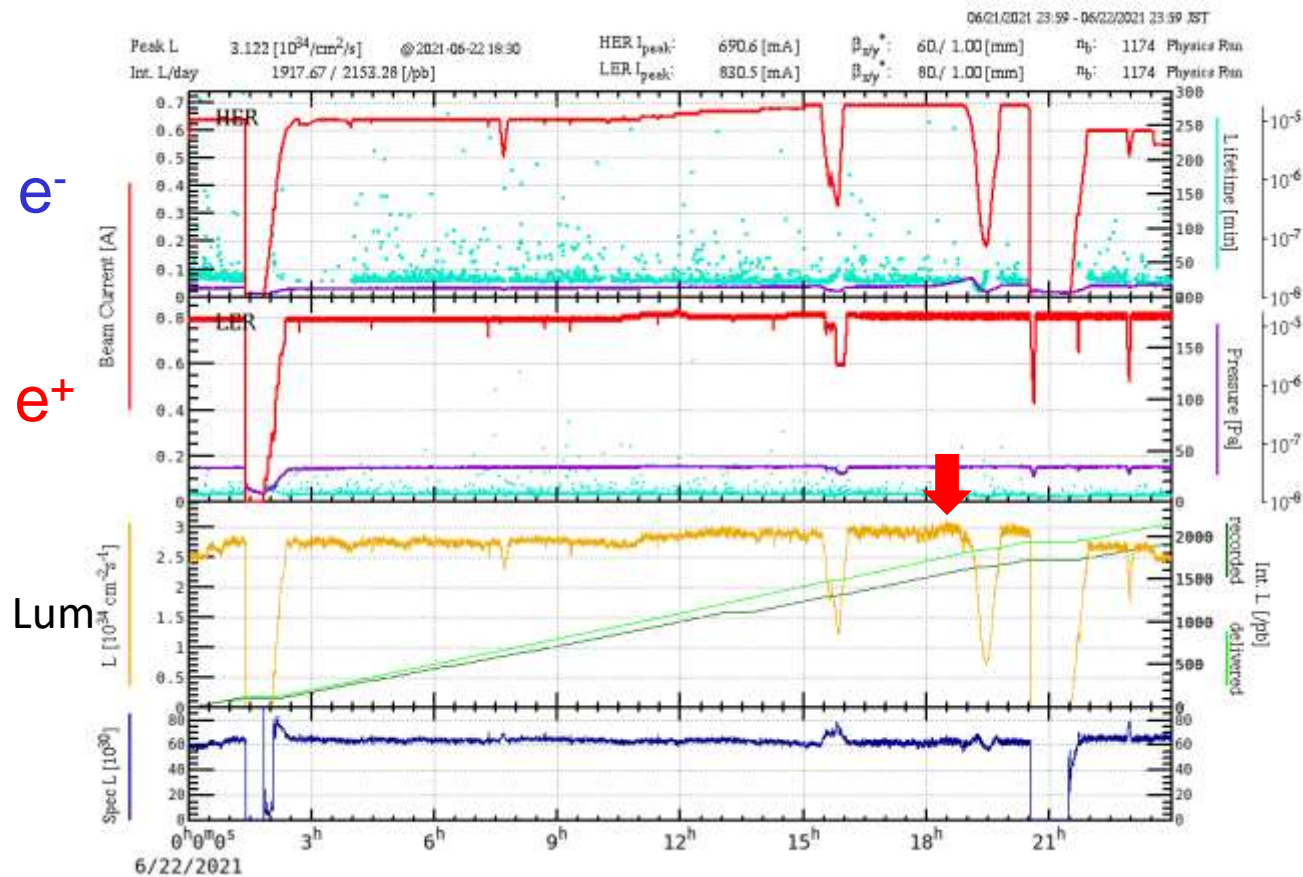


parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
bg		0.425		0.28		
Half crossing angle	ϕ	11	x20	41.5		mrاد
Beta functions at IP	β_x^*/β_y^*	1200/5.9		60/0.3		mm
Beam currents	I_b	1.64	x1.5	2.5	1.8	A
Luminosity	L	2.1×10^{34}		6.5×10^{35}		$\text{cm}^{-2}\text{s}^{-1}$

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

- Very strong vertical focusing at the interaction point (IP)
- Increase beam current

Current luminosity



- 2021b run ended July-5.
- New luminosity world record $3.1 \times 10^{34}/\text{cm}^2/\text{sec}$ at off-resonance set on 22nd June 2021 (previous KEKB set $2.1 \times 10^{34}/\text{cm}^2/\text{sec}$ on 2010).
- Data taking efficiency is almost achieved $\sim 90\%$ by improved efficient detector operation. The 2021a/b physics run makes statistics double. Now $\int \mathcal{L} \sim 213 \text{ fb}^{-1}$.

Beauty, charm and tau-factory,



Off-resonance
10.520GeV

$$\sigma(e^+e^- \rightarrow \Upsilon(4S)) = 1.11 \text{ nb}$$

$$\sigma(e^+e^- \rightarrow c\bar{c}) = 1.3 \text{ nb}$$

$$\sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.92 \text{ nb}$$

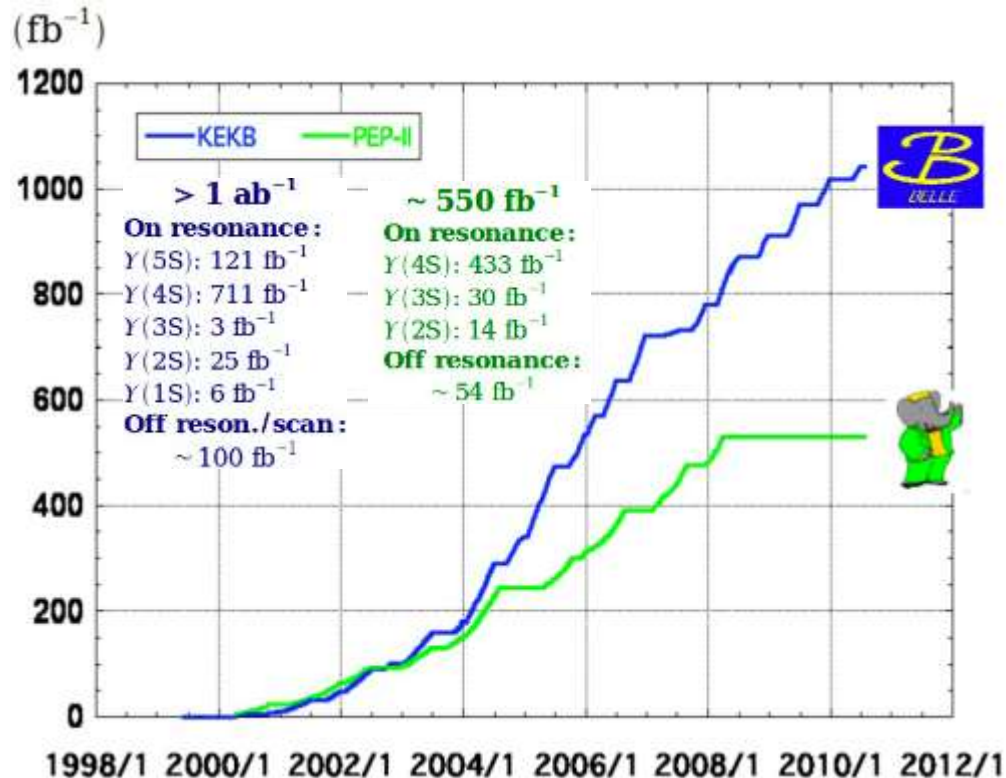
$$\sigma(e^+e^- \rightarrow \Upsilon(5S)) = 0.3 \text{ nb}$$

10.750GeV
energy scan

- ISR
- Two-photon
- Exotic
- Dark sector

See talk by Junhao Yin
"Quarkonium at Belle II"

SuperKEKB/BelleII has a capability to cover the just below Y(1S) and just above Y(6S).

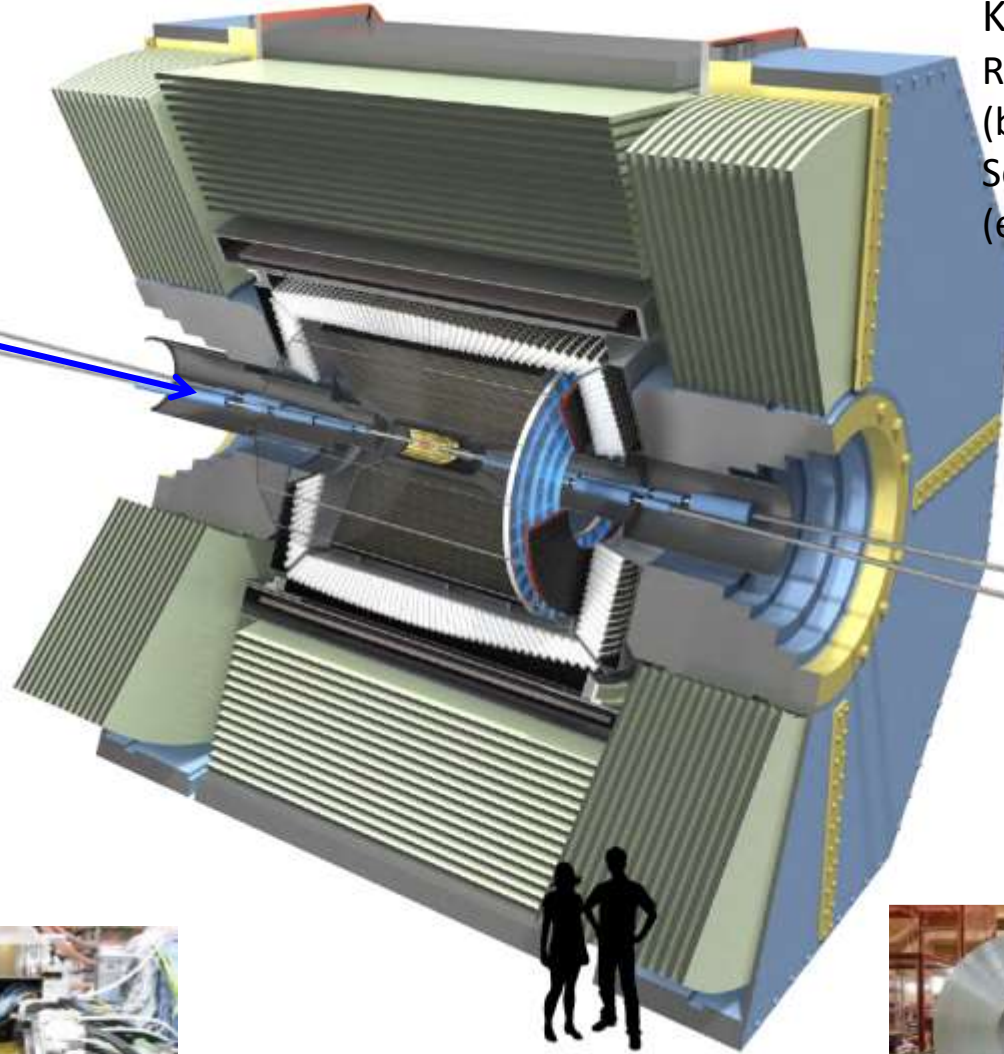


Belle II Detector

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)



electron
(7GeV)

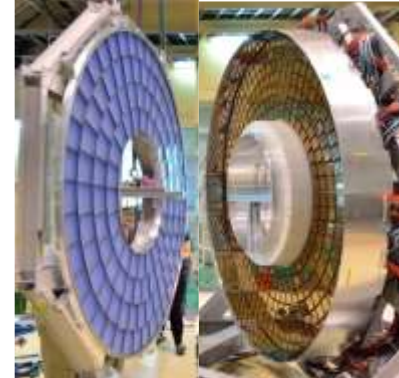


K_L/μ detector:KLM
Resistive Plate
(barrel)
Scint.+WLSF+MPPC
(end-caps)

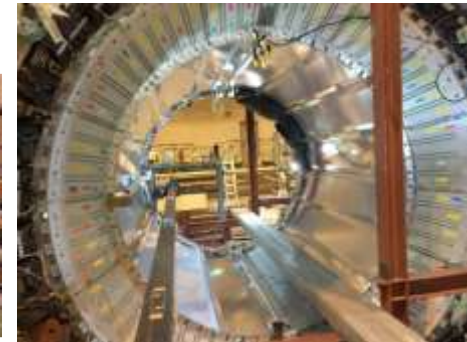


Focusing Aerogel RICH:
ARICH
Aerogel+HAPD for PID

positron (4GeV)

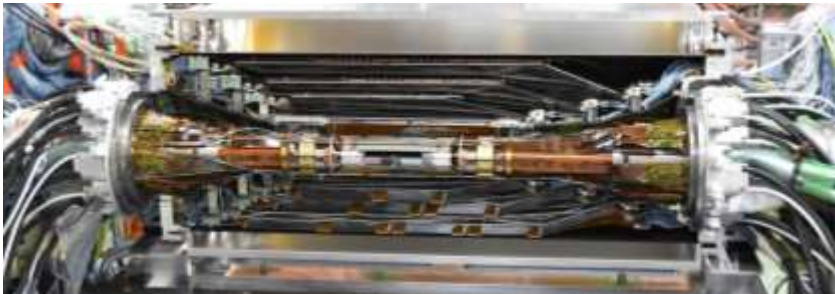


Time-of-Propagation counter: TOP
Quarz+MCP PMT



Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers Pixel + 4 layers Strip



Central Drift Chamber(CDC)
He(50%):C₂H₆(50%), Small cells,
long lever arm, fast electronics

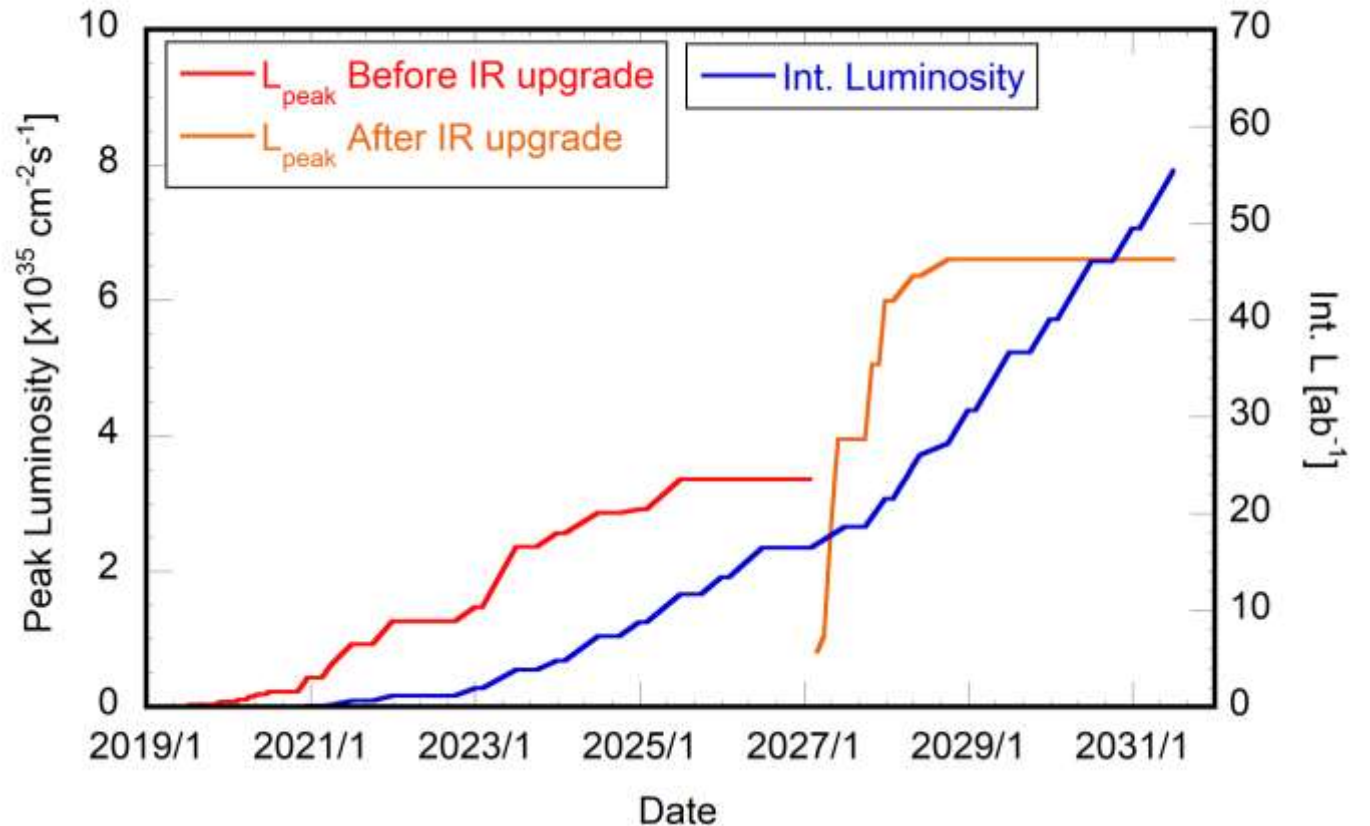
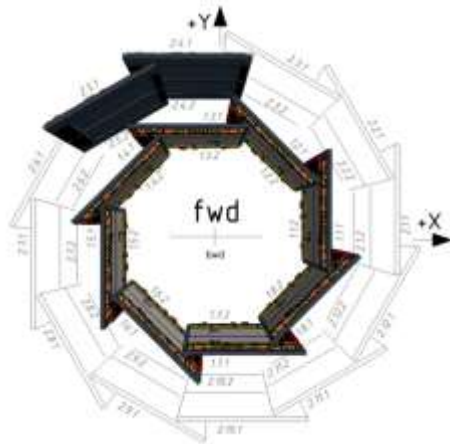


BelleII/CDC

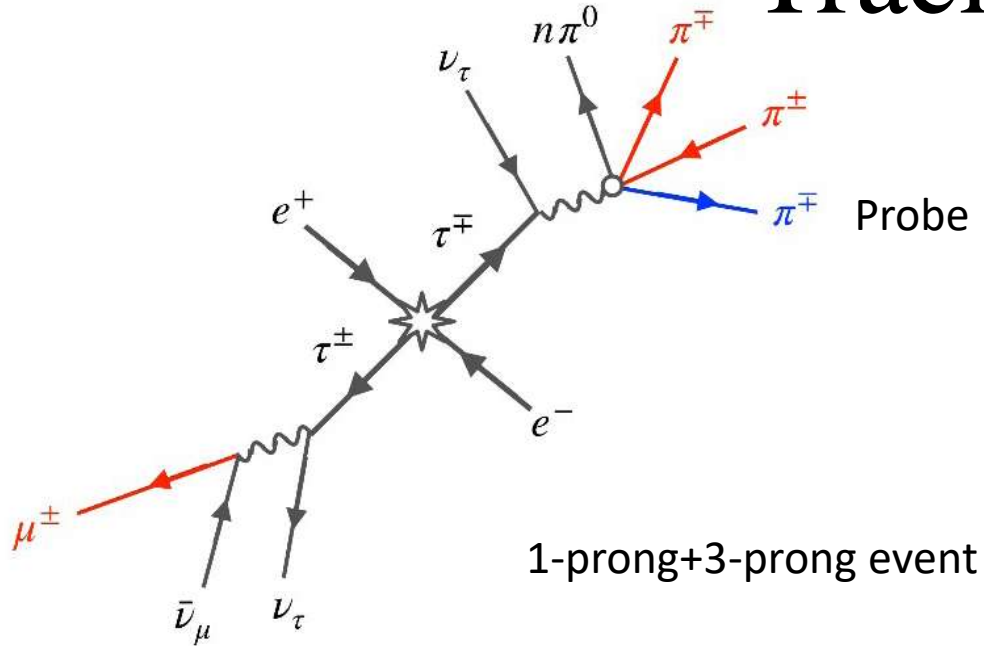
Belle/CDC

Run plan

- 2021 July-5. Total >213 fb-1
- 2021 Summer shutdown
- 2021 Autumn run.
 - Y(4S) ~400 fb-1(BaBar)
 - 10.75GeV+scan for 10 fb-1 is planned.
- 2022 Summer ~700 fb-1(Belle)
- 2022 Long shutdown1(LS1)
 - Full pixel in the 2nd inner most layer
 - TOP PMT replacement
- 2026 ~15 ab-1
- 2031 ~50 ab-1



Tracking efficiency



Find a lepton and 2 good tracks with $\sum q_i = \pm 1$.

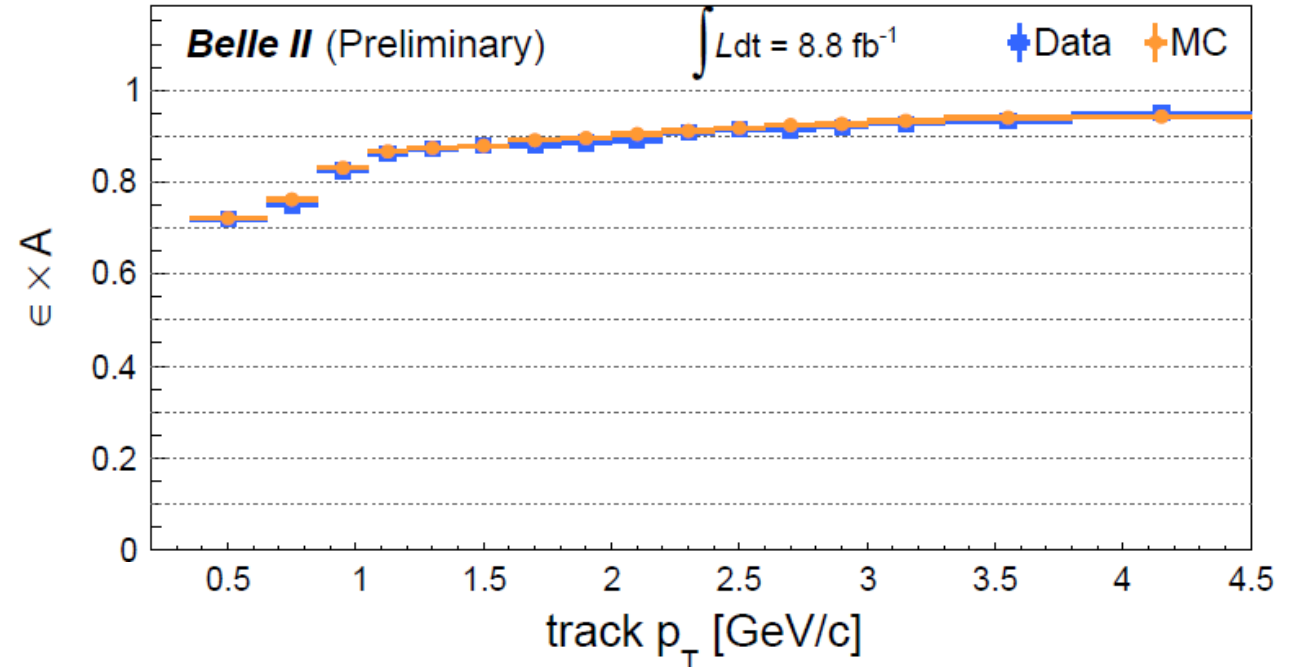
Find 4th track that passes $\sum q_i = 0$.

Count the events where the probe track is found (**N4**) and not found (**N3**):

$$\varepsilon \times A = \frac{\mathbf{N4}}{(\mathbf{N4} + \mathbf{N3})}$$

A: detector acceptance

ε : track reconstruction efficiency



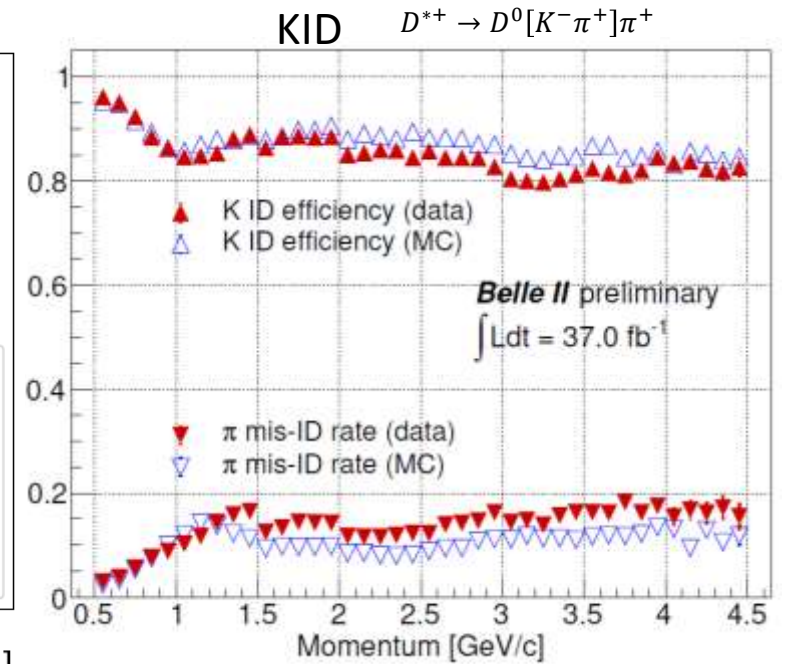
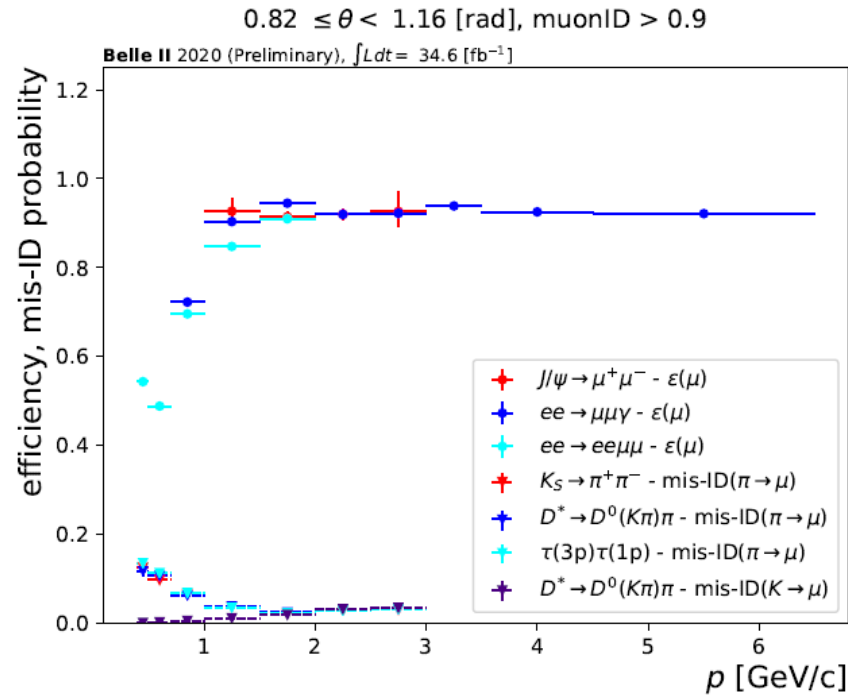
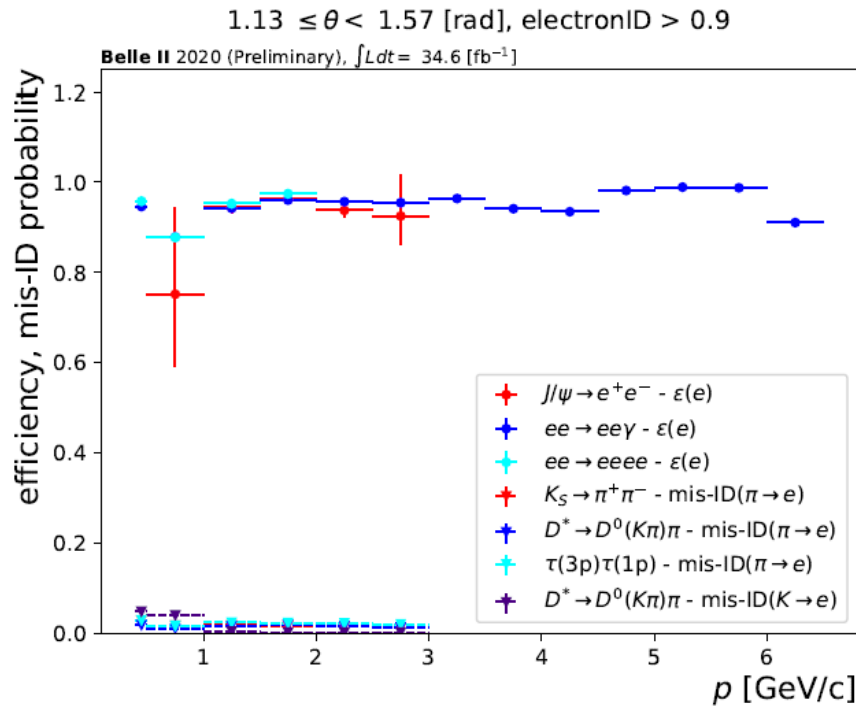
BELLE2-NOTE-PL-2020-014

After the calibration factor introduced,
DATA/MC agrees in the broad p_T range.

Particle ID

Each PID detector defines likelihood \mathcal{L}_i for each charged particle hypothesis and the global likelihood is defined $\mathcal{L} = \prod \mathcal{L}_i$.

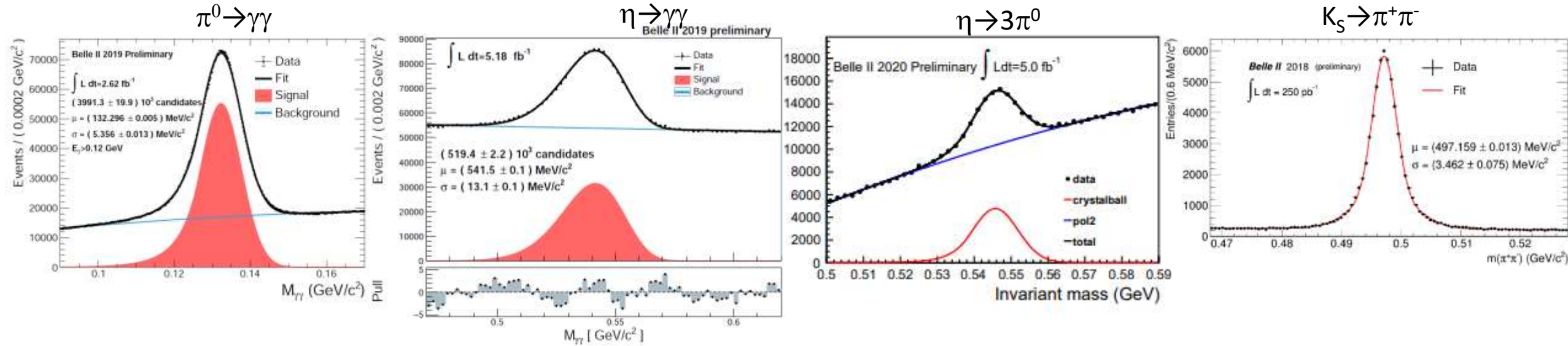
The global likelihood ratio of the particle ℓ can be defined :
$$\ell^{ID} = \frac{\mathcal{L}_\ell}{\mathcal{L}_e + \mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K + \mathcal{L}_p}$$



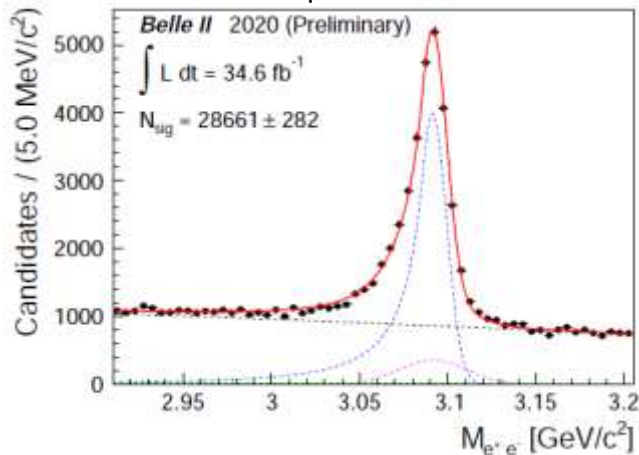
BELLE2-NOTE-PL-2020-020

Shows good PID separation.

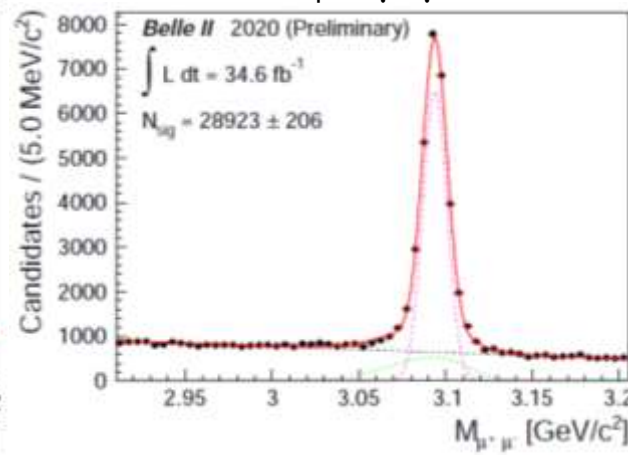
Neutral reconstruction



Brems photon recovered
 $J/\psi \rightarrow e^+e^-$



$J/\psi \rightarrow \mu^+\mu^-$



Large solid angle and good uniformity detector
 \rightarrow better reconstruction of neutrals.

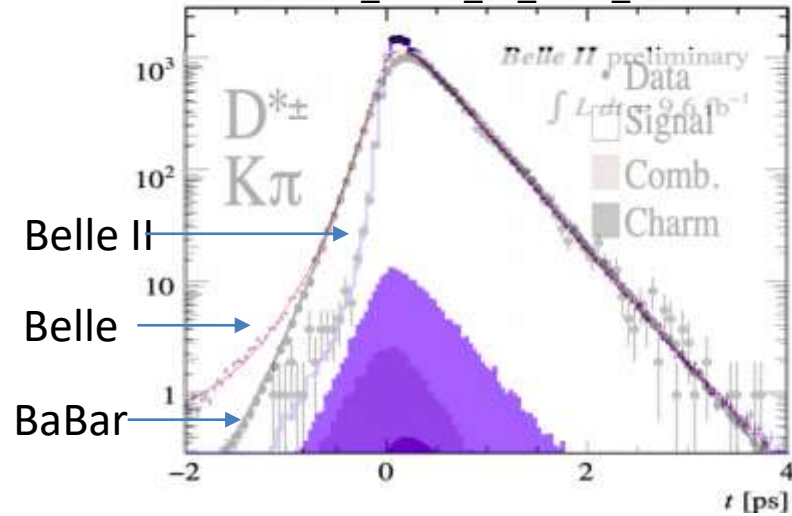
Also has capabilities

- to recover Bremsstrahlung photon
- to detect isolated ISR/FSR as well.

Vertexing

D^0 lifetime measurement w/ 9.6fb⁻¹

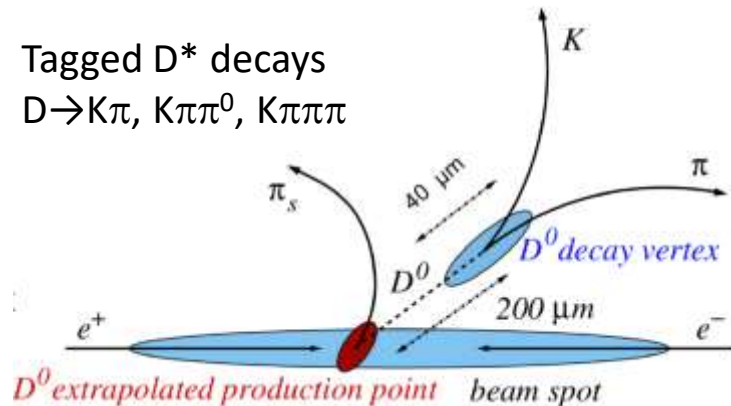
BELLE2_NOTE_PL_2020_008



$$\tau_{D^0} = 412.3 \pm 2.0 \text{ fs (stat only)}$$

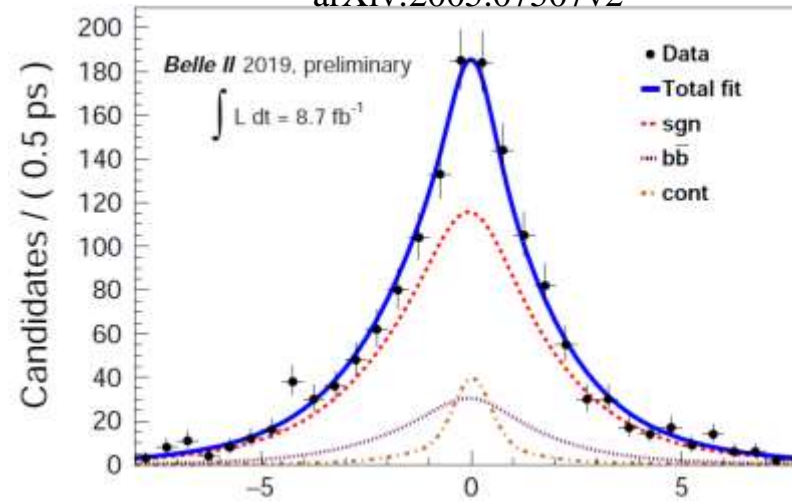
W.A. $\tau_{D^0} = 410.1 \pm 1.5 \text{ fs}$

Tagged D^* decays
 $D \rightarrow K\pi, K\pi\pi^0, K\pi\pi\pi$



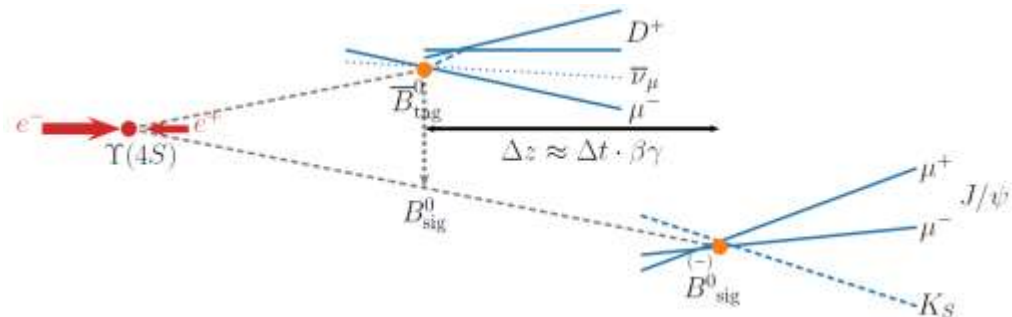
$B^0 \rightarrow D^{(*)}h$ lifetime measurement w/ 8.7fb⁻¹

arXiv:2005.07507v2



$$\tau_{B^0} = 1.48 \pm 0.28 \pm 0.06 \text{ ps}$$

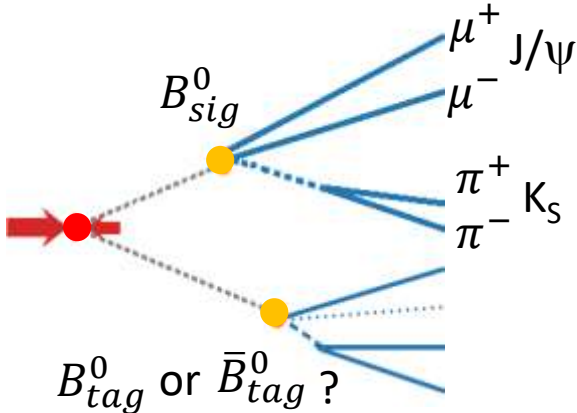
W.A. $\tau_{B^0} = 1.519 \pm 0.004 \text{ ps}$



Pixel detector improves the vertex position resolution.

Flavor identification

Flavor id of tag-side B-meson : B_{tag}^0 or \bar{B}_{tag}^0 ? Wrong flavor tag fraction w can dilute observed CP asymmetry : $A_{CP}^{Obs} = A_{CP}^{Raw}(1 - 2w)$



The w can be estimated by flavor specific decay $B^0 \rightarrow D^{(*)}h$ mode with $q \cdot r_{FBDT}$

Flavor tag index : $q \cdot r_{FBDT}$

$$\frac{N_{OF} - N_{SF}}{N_{OF} + N_{SF}} = (1 - 2w) \cdot (1 - \chi_d)$$

N_{OF} : opposite flavor in B_{sig} and B_{tag}
 N_{SF} : same flavor in B_{sig} and B_{tag}
 χ_d : mixing prob.(W.A. 0.1858 ± 0.0011).

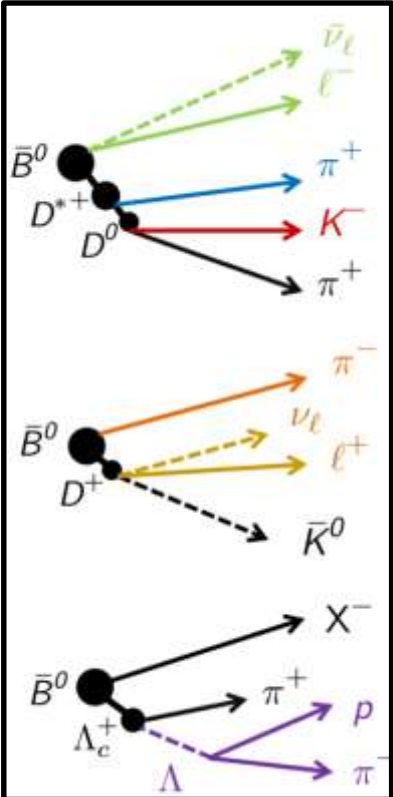
r_{FBDT} used binning the flavor tag in 7bins to avoid possible MC bias $r_{FBDT}^i \approx 1 - 2w_i$

Effective Tag efficiency: $\epsilon_{eff} = \sum \epsilon_{tag}^i \cdot (1 - 2w_i)^2$

Belle II: $\epsilon_{eff} = 33.8 \pm 3.6 \pm 1.6 \%$

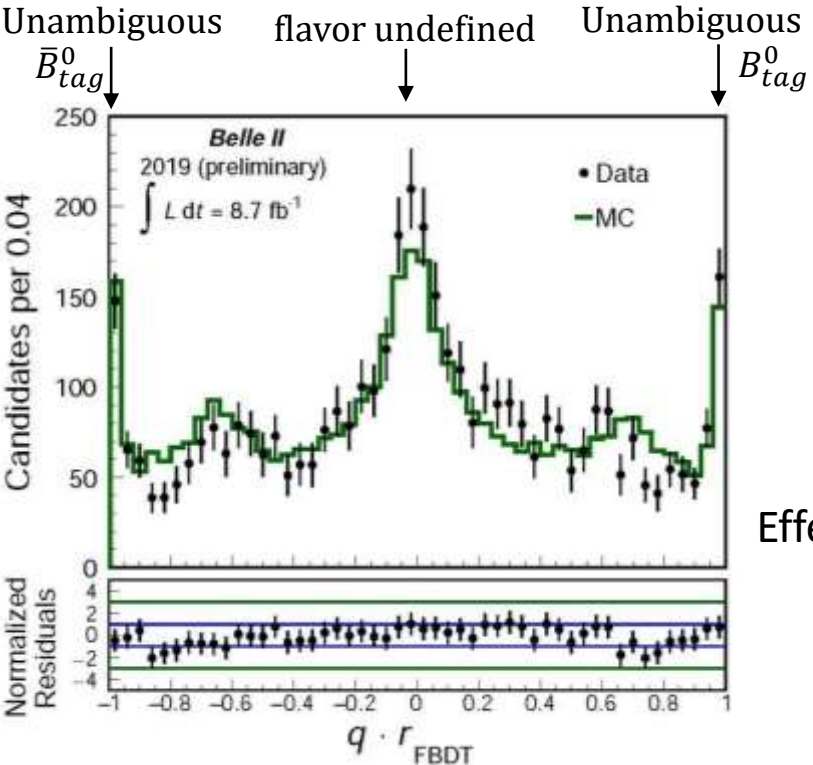
Belle: $\epsilon_{eff} = 30.1 \pm 0.4\%$

Flavor characteristics:



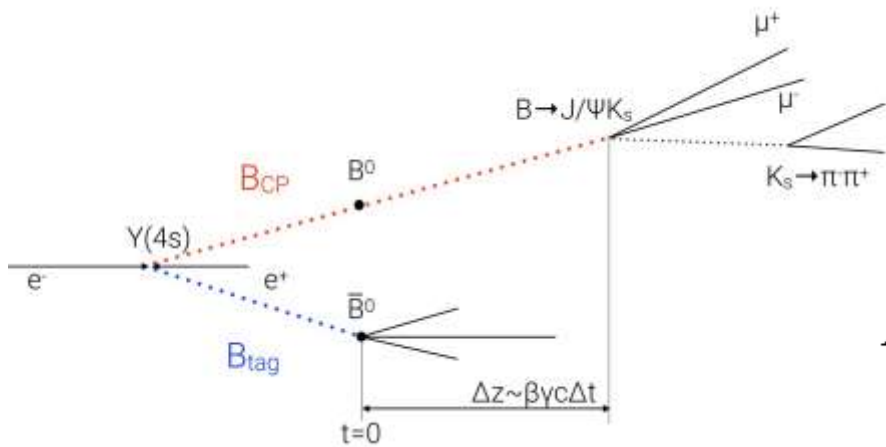
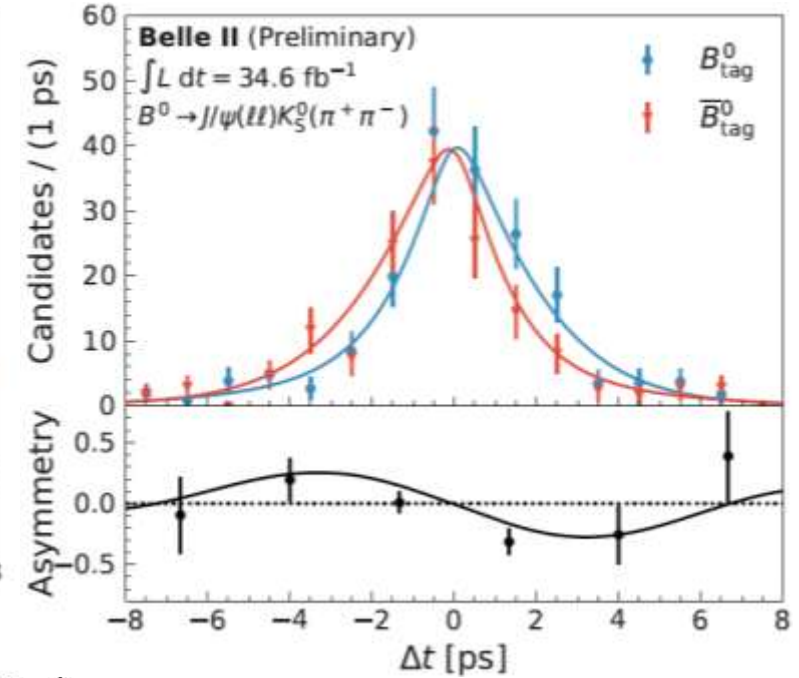
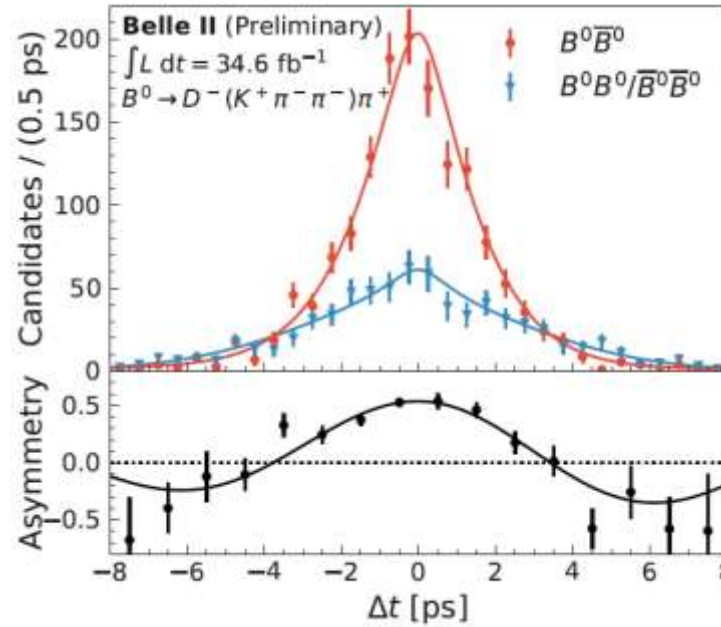
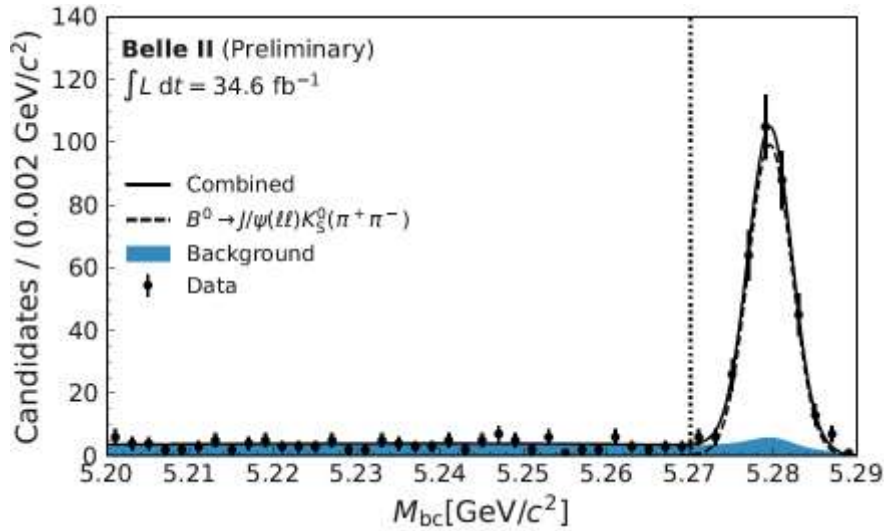
High-p
Low-p
charge

∴ FBDT
Mid-p



Time-dependent CPV measurement

BELLE2-NOTE-PL-2020-11



$$A(\Delta t) = \frac{N_{OF} - N_{SF}}{N_{OF} + N_{SF}} = \cos(\Delta m_d \Delta t)(1 - 2w)$$

$$\Delta m_d = (0.531 \pm 0.046(\text{stat.}) \pm 0.013(\text{syst.}))ps$$

$$\text{W.A. } 0.5065 \pm 0.0019$$

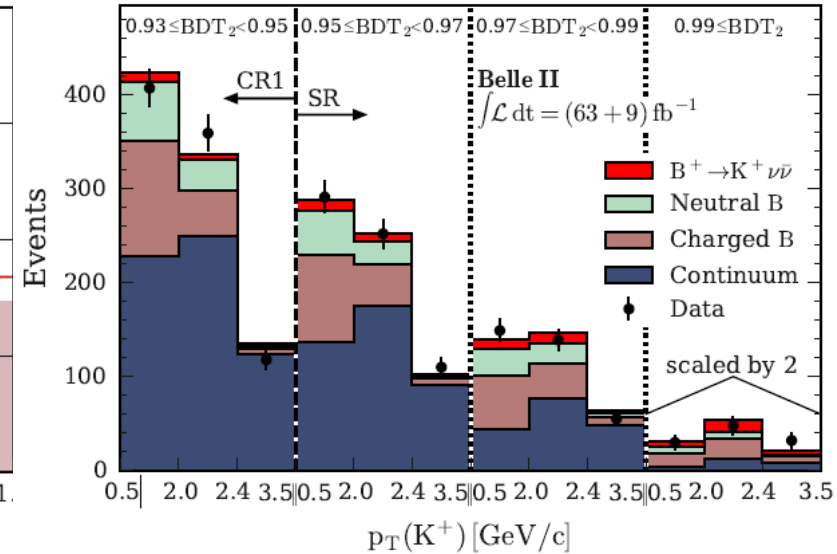
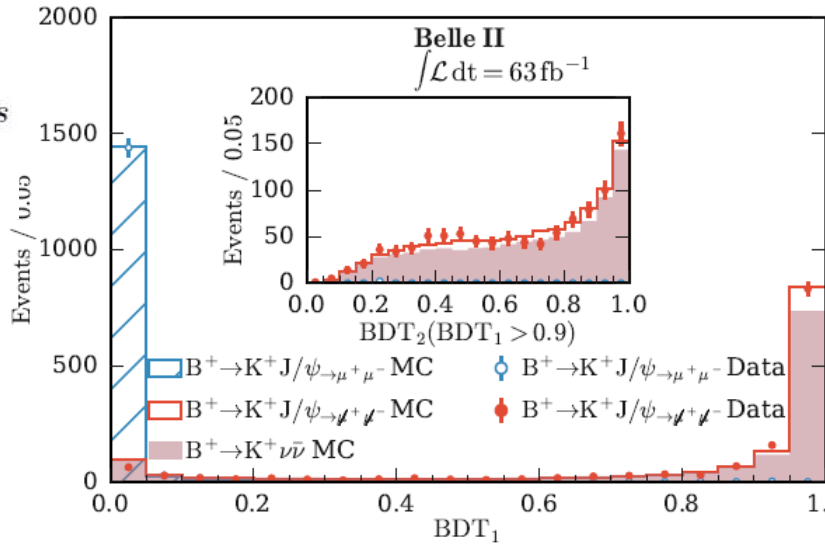
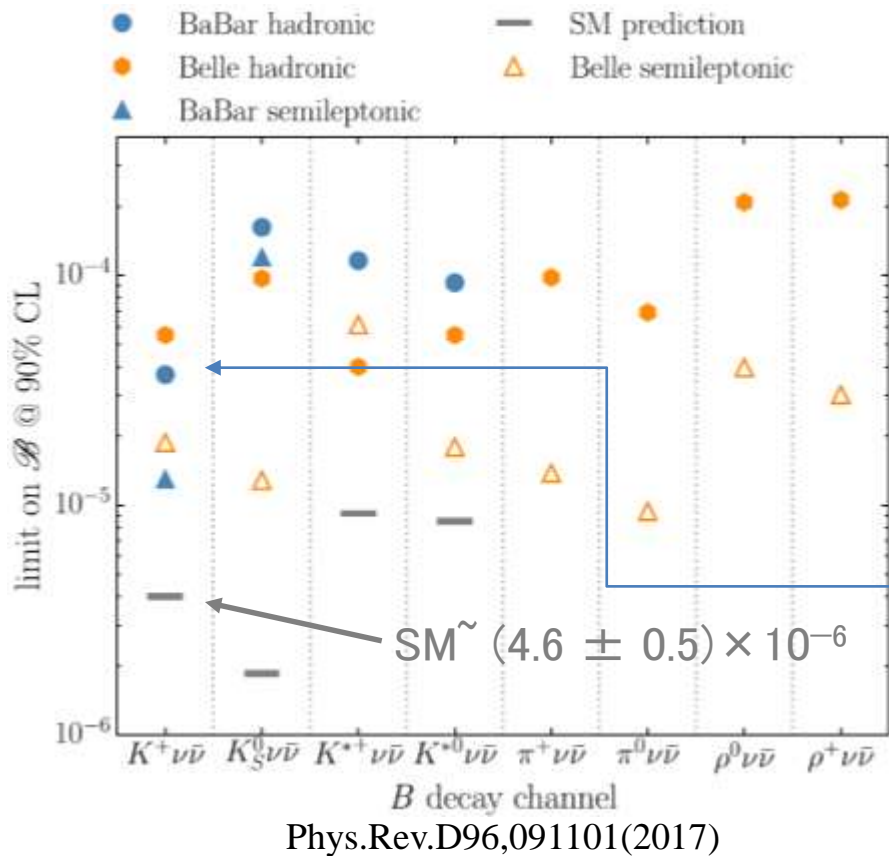
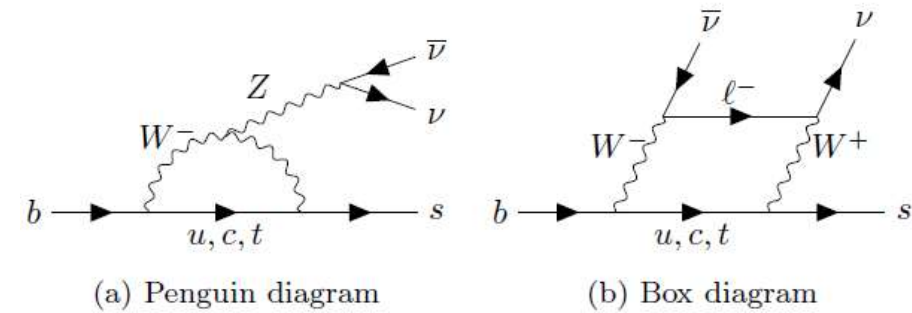
$$A_{CP}(\Delta t) \equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)} = S \sin \Delta m \Delta t + A \cos \Delta m \Delta t$$

$$S = \sin 2\phi_1 = 0.55 \pm 0.21(\text{stat.}) \pm 0.04(\text{syst.})$$

$$\text{W.A. } 0.695 \pm 0.019$$

$B^+ \rightarrow K^+ \nu \bar{\nu}$ decay w/ inclusive tagging

arXiv:2104.12624 63 fb⁻¹



Unknown flavor of ν .

This mode may enhance from SM expectation.

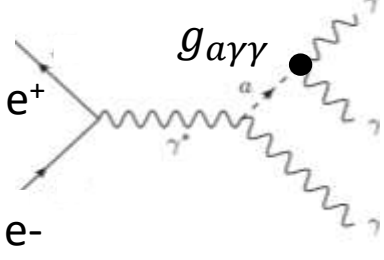
Already comparable result of hadronic tag in

$< 3.7 \times 10^{-5}$ (90% C.L.) BaBar Phys.Rev.D87,112005(2013)

$< 5.5 \times 10^{-5}$ (90% C.L.) Belle Phys.Rev.D87,1110103(2013)¹⁴

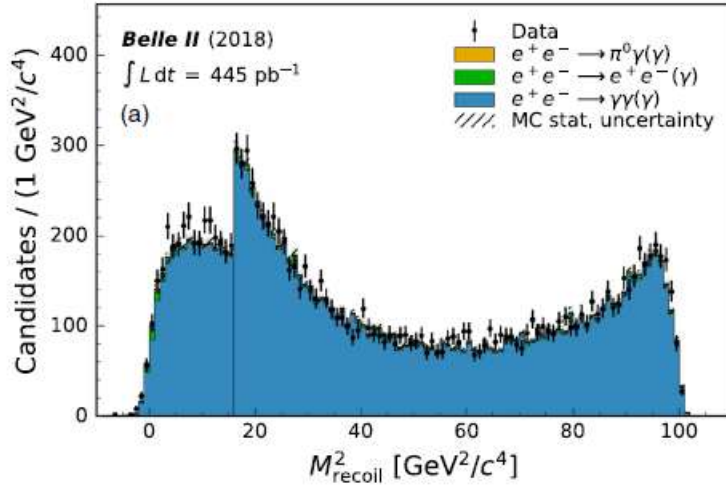
Axion/ALPS and Z' search

$$E_{\text{recoil}}^{\text{c.m.}} = \frac{s - m_a^2}{2\sqrt{s}}$$

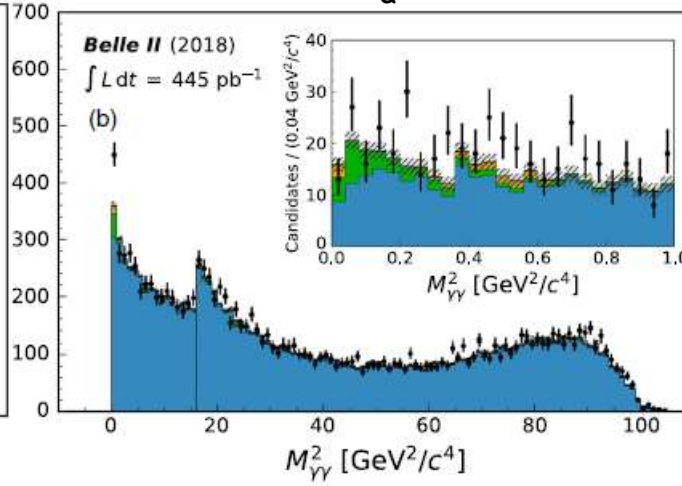


ALPS
JHEP12(2017)094

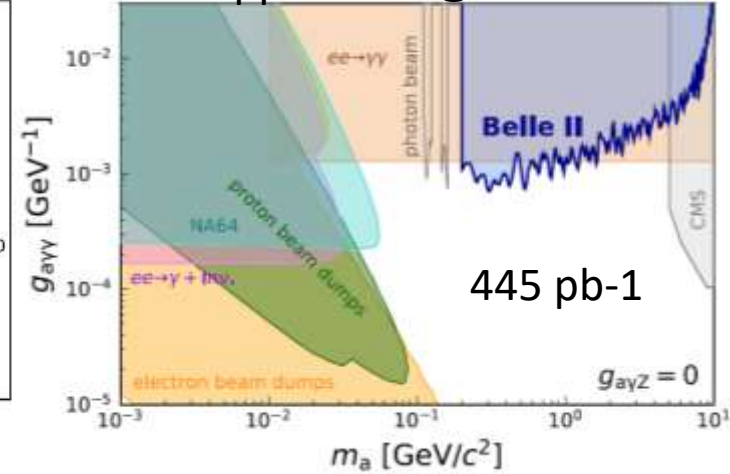
For $m_a > 6.85 \text{ GeV}/c^2$



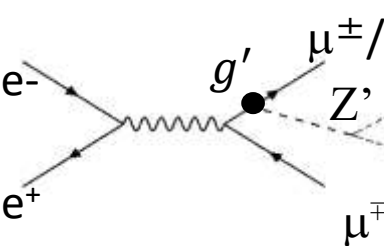
For $m_a < 6.85 \text{ GeV}/c^2$



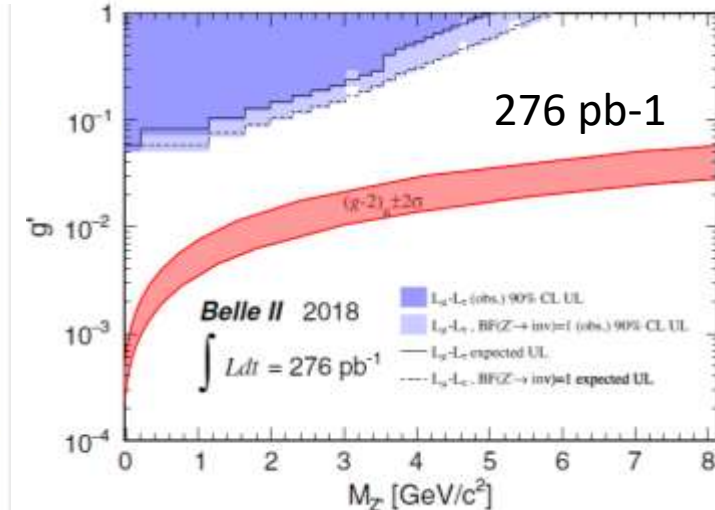
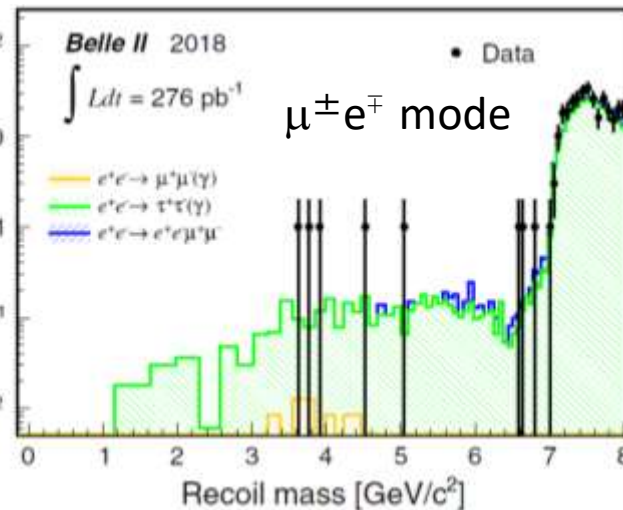
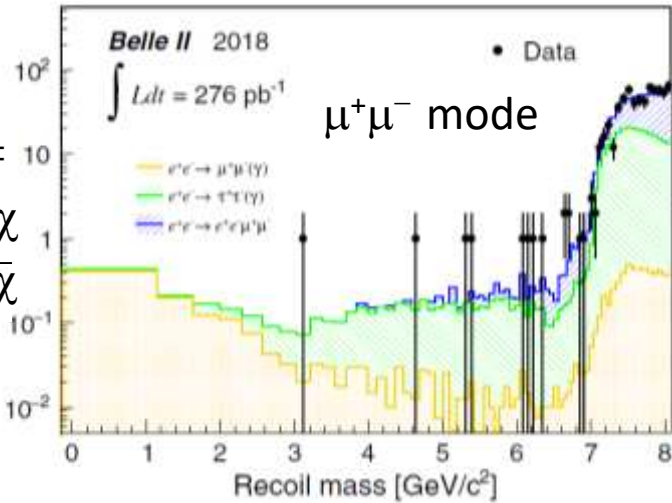
upper limit @95% C.L.



Phys.Rev.Lett. 125,161806(2020)



$L_\mu - L_\tau$ model
Phy.Rev D89,113004 (2014)
JHEP12(2016)106



Phys.Rev.Lett. 124,141801(2020)

BelleII can explore large parameter space in ALPS and to exploit the favored g-2 band in $L_\mu - L_\tau$ model.

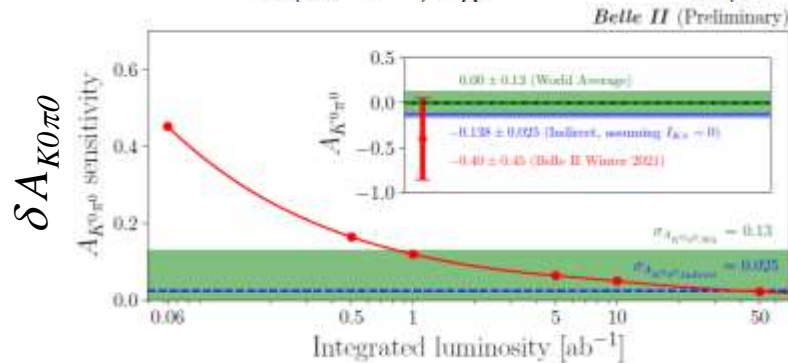
Direct CPV $A_{CP}(K\pi)$

Direct CP asymmetry $A_{CP}(K^-\pi^+) \equiv \frac{\Gamma(\bar{B}^0 \rightarrow K^-\pi^+) - \Gamma(B^0 \rightarrow K^+\pi^-)}{\Gamma(\bar{B}^0 \rightarrow K^-\pi^+) + \Gamma(B^0 \rightarrow K^+\pi^-)}$ $b \rightarrow sq\bar{q}$ transition

Measurement of $A_{CP}(B^0 \rightarrow K^+\pi^-)$ and $A_{CP}(B^+ \rightarrow K^+\pi^0)$: $\Delta A_{CP}(K\pi) = 0.0120 \pm 0.021$ Simple expectation $\Delta A_{CP}(K\pi) \sim 0$
 If Tree & Penguin are dominant.
 Suffering the hadronic uncertainty

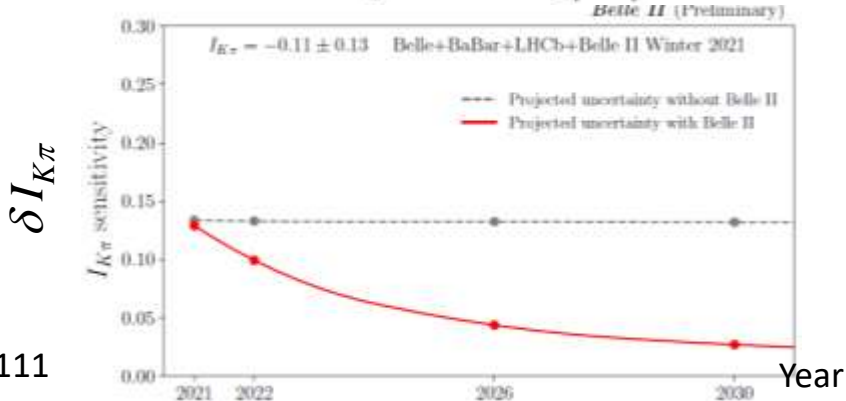
The isospin sum rule test was proposed Phys.Lett.B627(2005)82

$$I_{K\pi} = \mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+} \frac{\mathcal{B}(K^0\pi^+) \tau_{B^0}}{\mathcal{B}(K^+\pi^-) \tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0} \frac{\mathcal{B}(K^+\pi^0) \tau_{B^0}}{\mathcal{B}(K^+\pi^-) \tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0} \frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)} = 0 \text{ in SM. If non-zero, evidence of NP.}$$



$$\mathcal{A}_{K^0\pi^0} = -0.40_{-0.44}^{+0.46}(\text{stat}) \pm 0.04(\text{syst}), \text{ and } \mathcal{B}(B^0 \rightarrow K^0\pi^0) = [8.5_{-1.6}^{+1.7}(\text{stat}) \pm 1.2(\text{syst})] \times 10^{-6}$$

} arXiv:2104.14871
63 fb-1



Current W.A. (Belle+BaBar+LHCb+BelleII winter2021)

$$I_{K\pi} = -0.11 \pm 0.13$$

BelleII can contribute the determination the $I_{K\pi}$

Summary

- SuperKEKB/BelleII are running stable.
 - Instantaneous $L=3.1 \times 10^{34}$ /cm/sec recorded.
 - Integrated $L_{\text{int}}= 213 \text{ fb}^{-1}$ accumulated now.
 - 400 fb-1 @Y(4S) and energy scan are planned in this year.
 - Deepen understanding of our detector
- Various analyses on going
 - Results with better precision than Belle/BaBar will be appeared soon.