Belle II: Status and prospects

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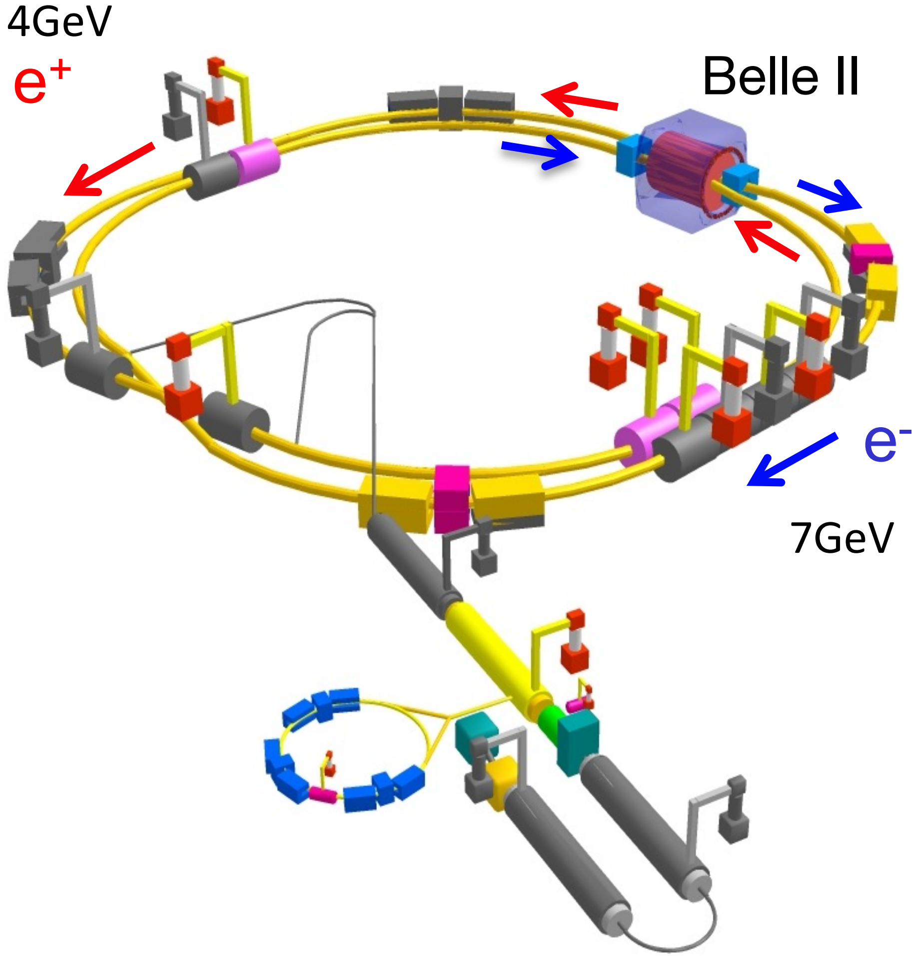
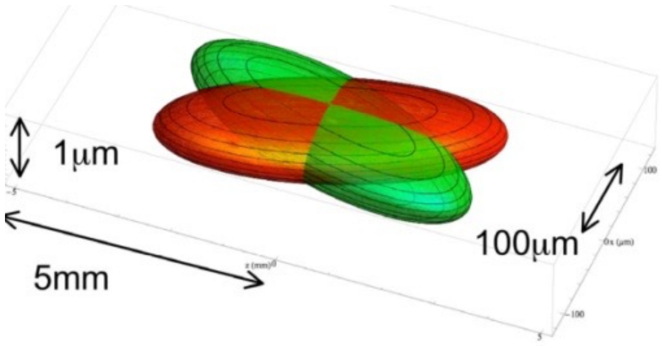
Outline

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

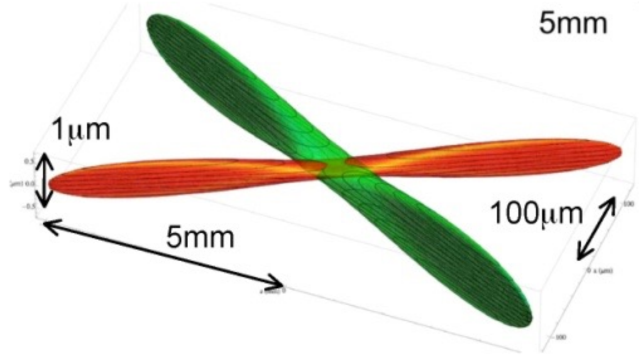
SuperKEKB



KEKB



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		41.5		mrad
Beta functions at IP	β_x^*/β_y^*	1200/5.9		60/0.3		mm
Beam currents	I_b	1.64	1.19	2.5	1.8	A
Luminosity	L	2.1 x 10^{34}		6.5 x 10^{35}		$cm^{-2}s^{-1}$

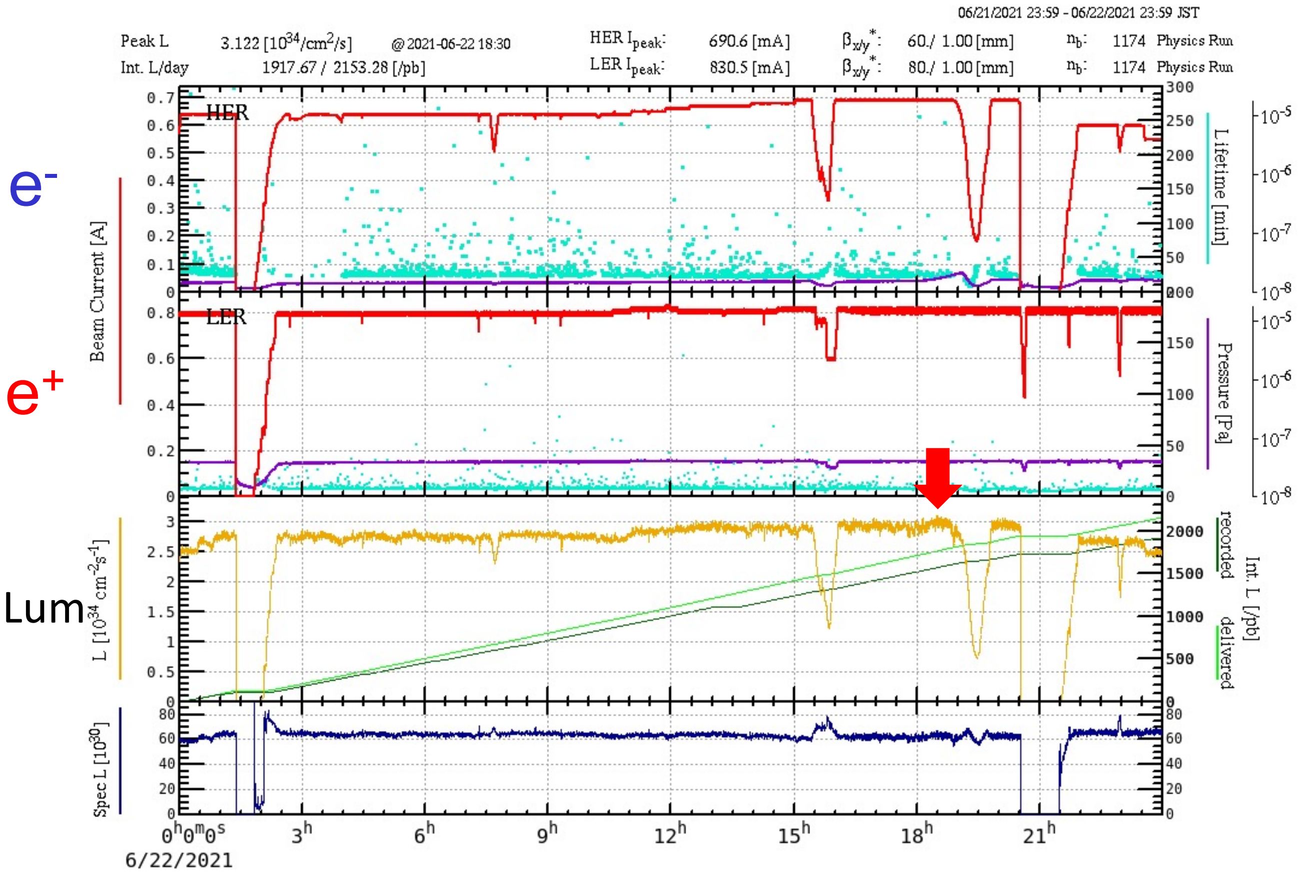
x20 →

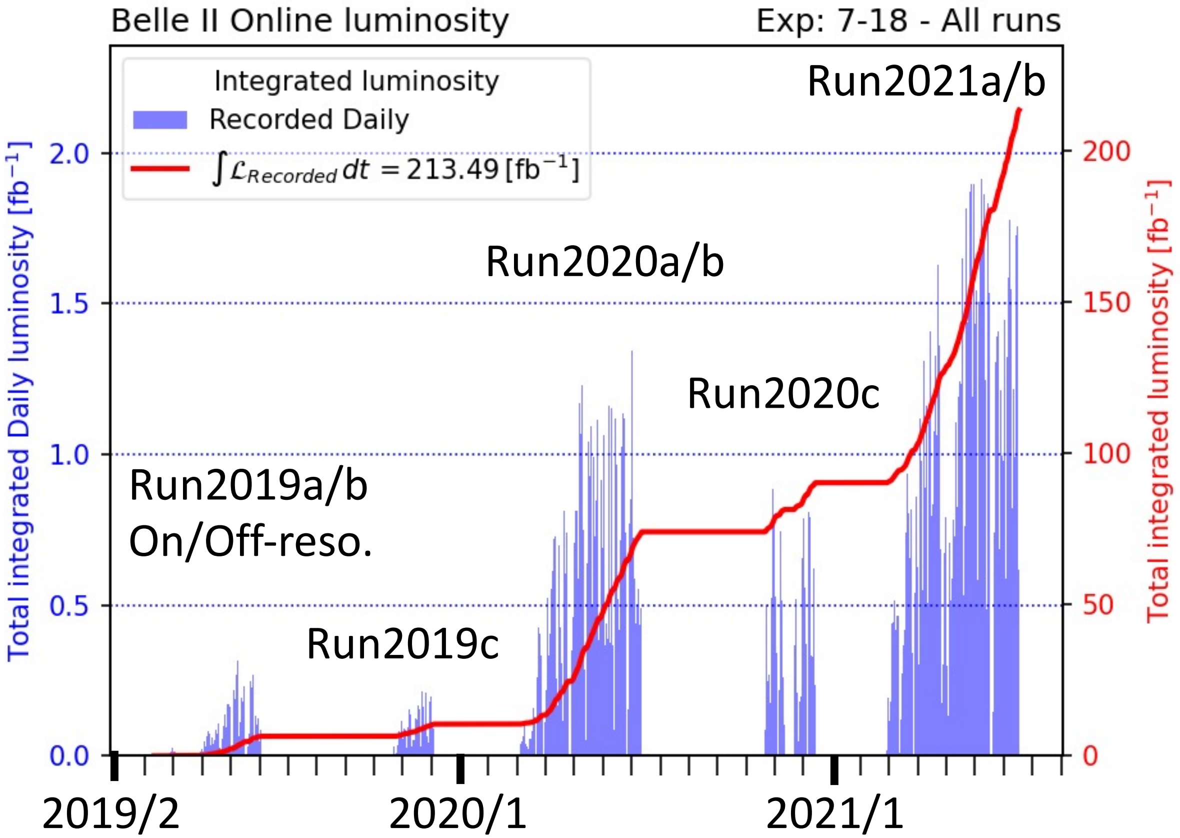
x1.5 →

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

- 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 x $10^{34}/cm^2/sec$ at off-resonance set on 22nd June 2021 (previous KEKB set 2.1 x $10^{34}/cm^2/sec$ on 2010).
- Data taking efficiency is almost achieved ~90% by improved efficient detector operation. The 2021a/b physics run makes statistics double. Now ∫L ~ 213 fb-1.

Beauty, charm and tau-factory,

Υ(1S) Υ(2S) Υ(3S) Υ(4S) Υ(5S) Υ(6S)

√s 9.460GeV 10.023GeV 10.355GeV 10.580GeV 10.876GeV 11.02GeV

Off-resonance
10.520GeV

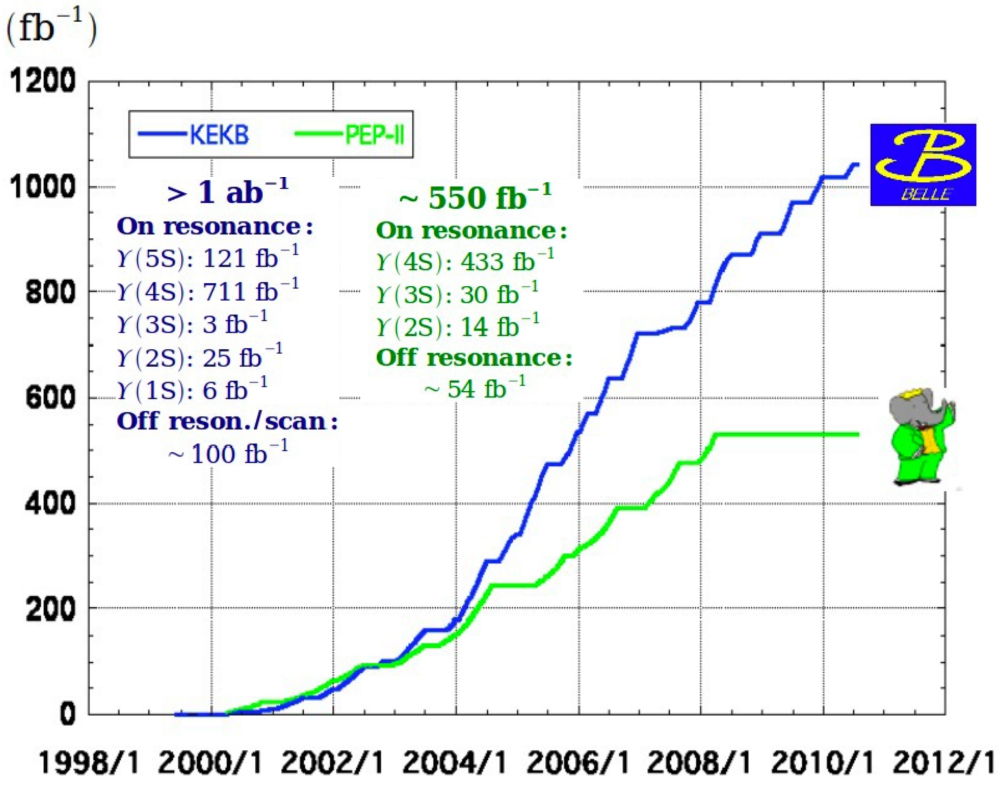
$\sigma(e^+e^- \to \Upsilon(4S)) = 1.11$ nb

$\sigma(e^+e^- \to \Upsilon(5S)) = 0.3$ nb

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

$\sigma(e^+e^- \to \tau^+\tau^-) = 0.92$ nb

10.750GeV
energy scan



ISR
Two-photon
Exotic
Dark sector

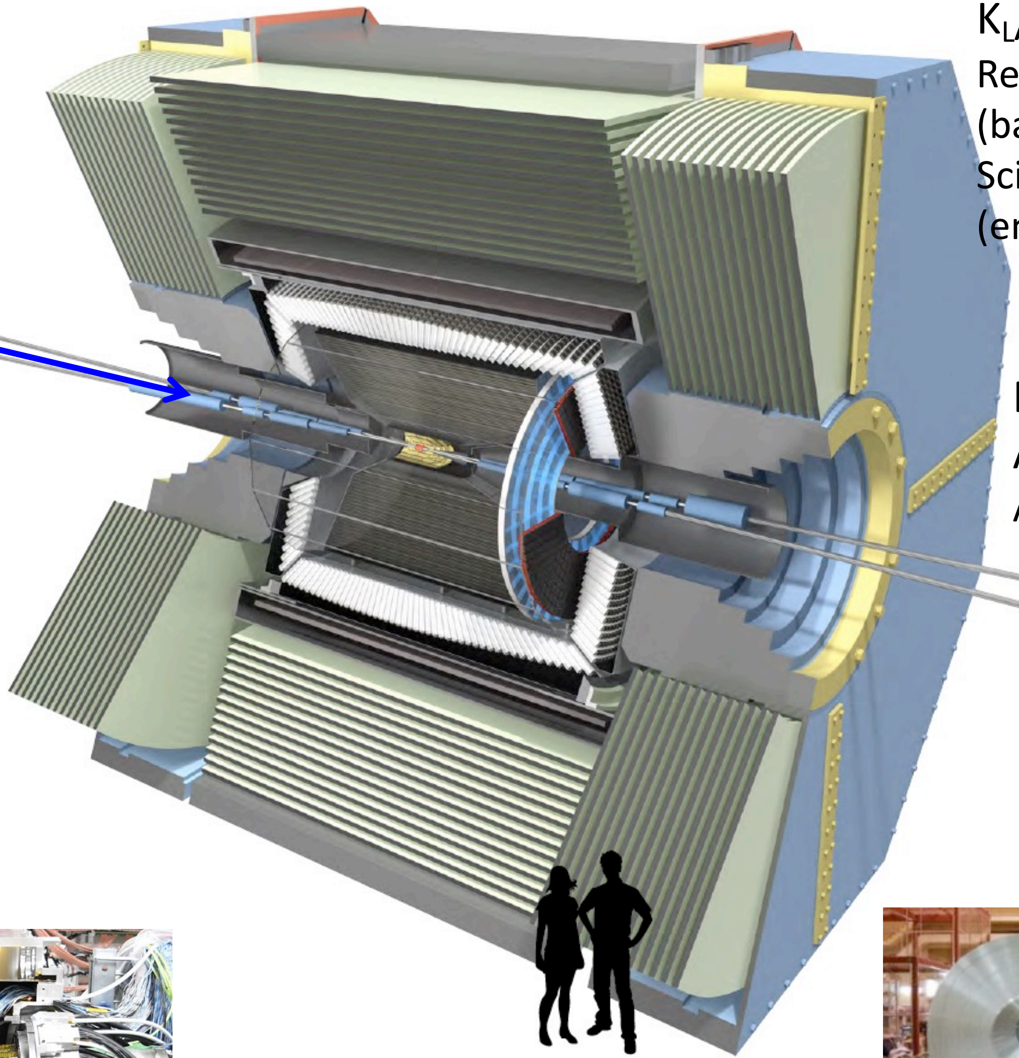
See talk by Junhao Yin
"Quarkonium at Belle II"

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

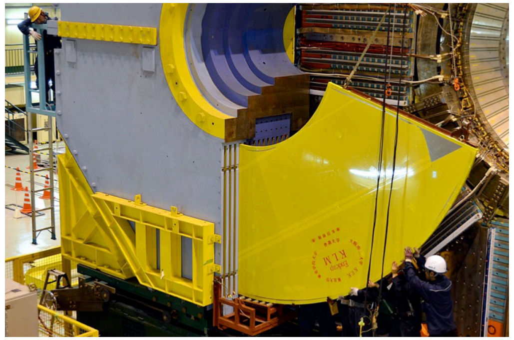
Belle II Detector

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

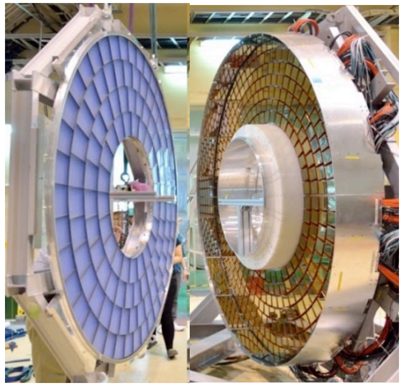
electron
(7GeV)



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



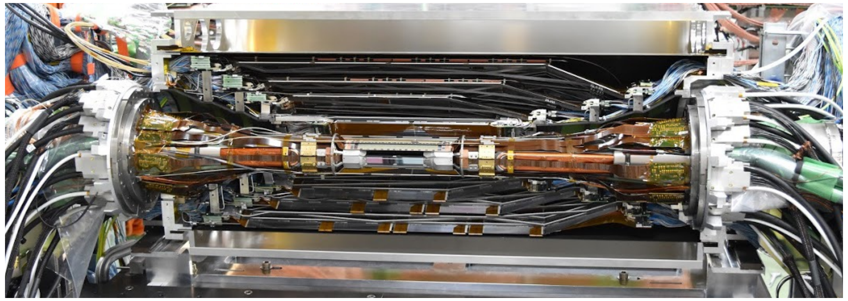
Focusing Aerogel RICH:
ARICH
Aerogel+HAPD for PID



positron (4GeV)

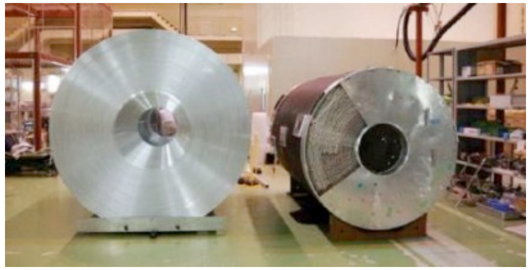
Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers Pixel + 4 layers Strip

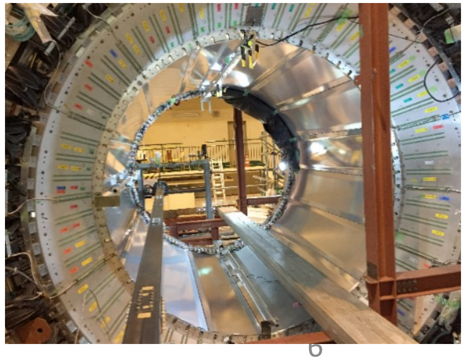


Central Drift Chamber(CDC)
He(50%):C_2H_6(50%), Small cells,
long lever arm, fast electronics

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

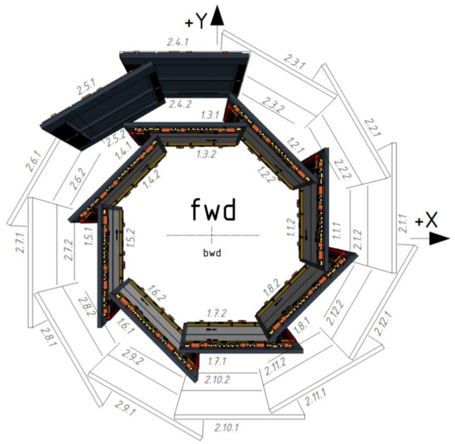


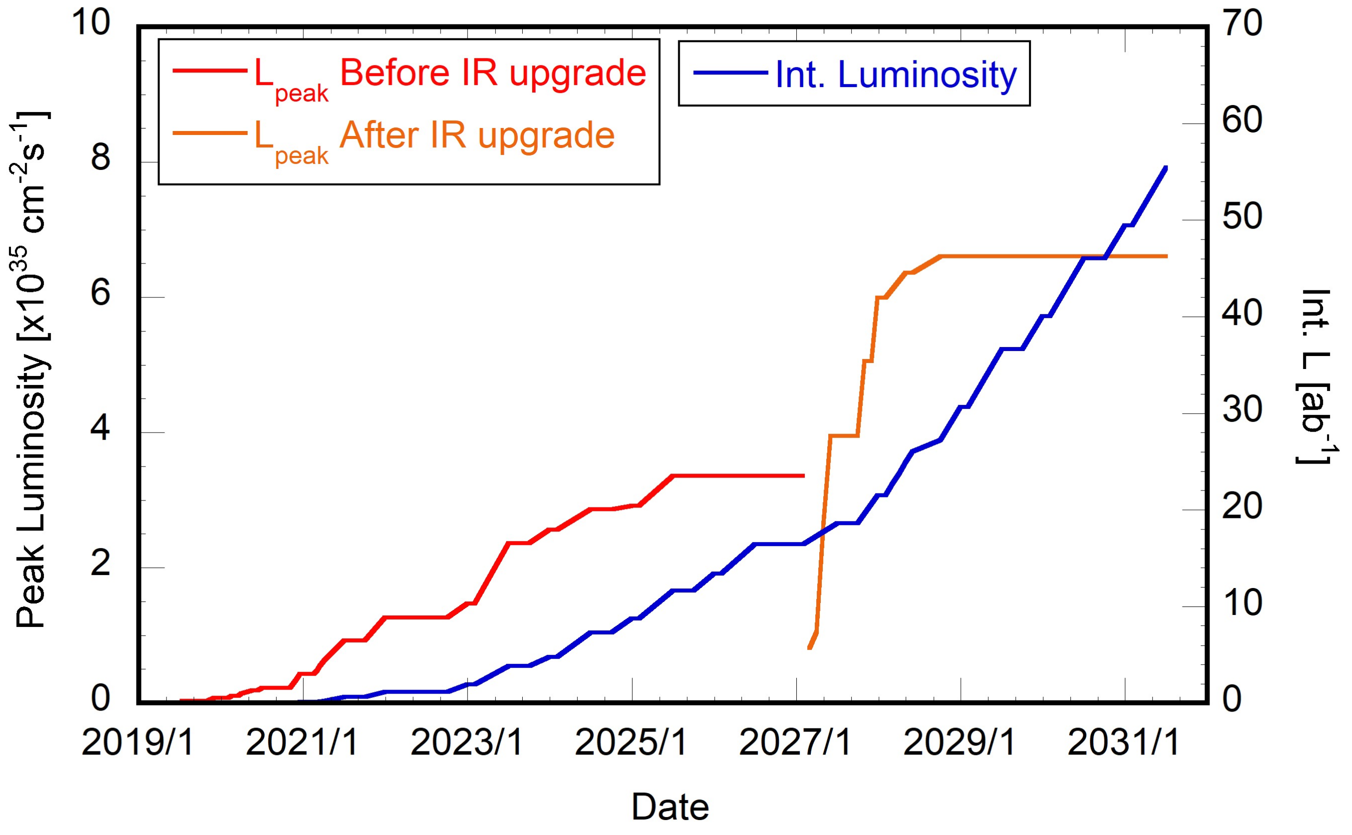
BelleII/CDC Belle/CDC



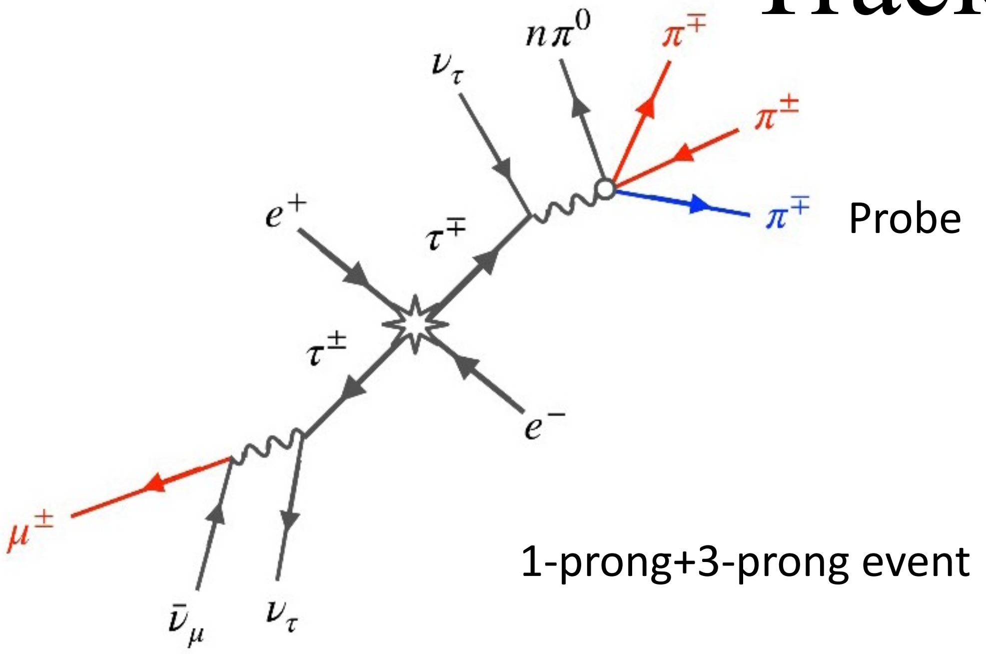
Run plan

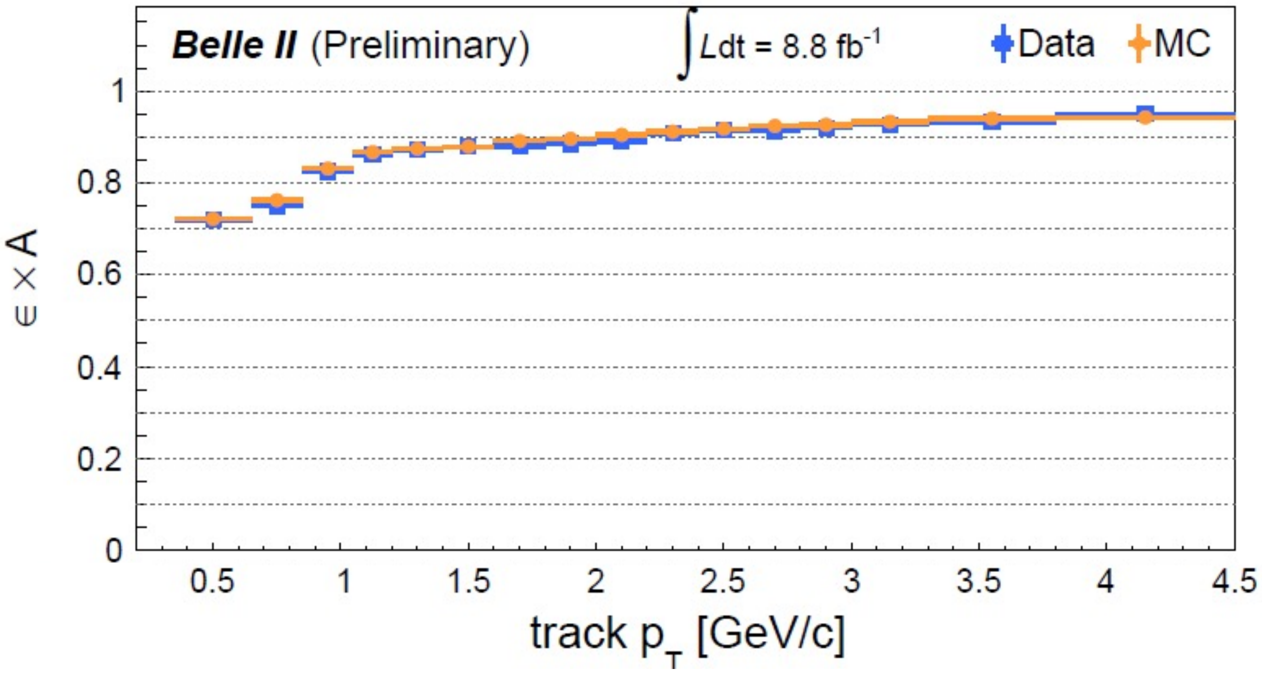
- 2021 July-5. Total >213 fb-1
- 2021 Summer shutdown
- 2021 Autumn run.
  - Y(4S) ~400 fb-1(BaBar)
  - 10.75GeV+scan for 10 fb-1 is planned.
- 2022 Summer ~700 fb-1(Belle)
- 2022 Long shutdown1(LS1)
  - Full pixel in the 2nd inner most layer
  - TOP PMT replacement
- 2026 ~15 ab-1
- 2031 ~50 ab-1





Tracking efficiency





BELLE2-NOTE-PL-2020-014

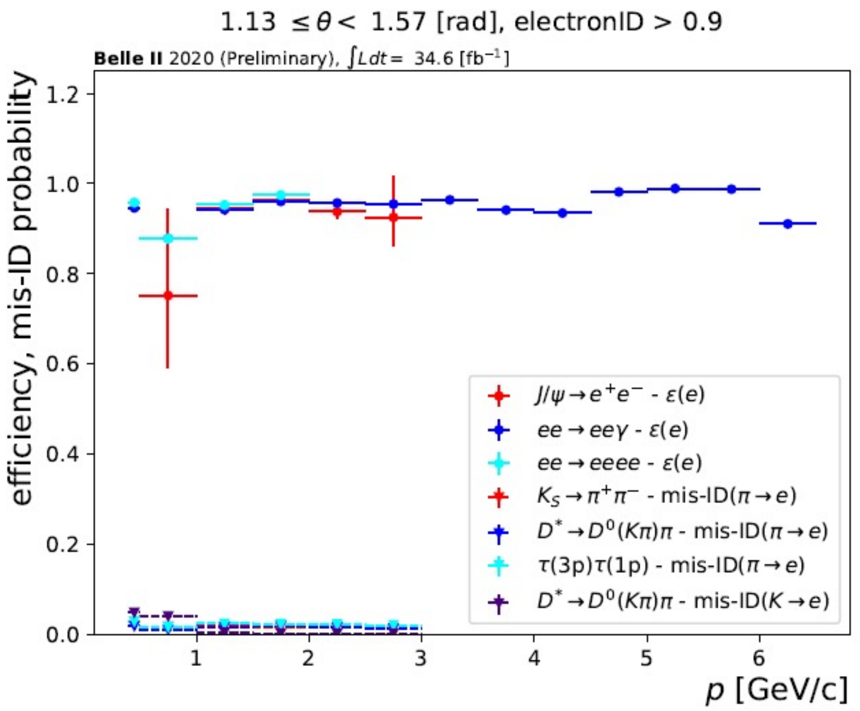
Find a lepton and 2 good tracks with $\Sigma q_i = \pm 1$.
Find 4th track that passes $\Sigma q_i = 0$.
Count the events where the probe track is found(N4) and not found (N3):
$\varepsilon \times A = N4/(N4+N3)$
A: detector acceptance
ε: track reconstruction efficiency

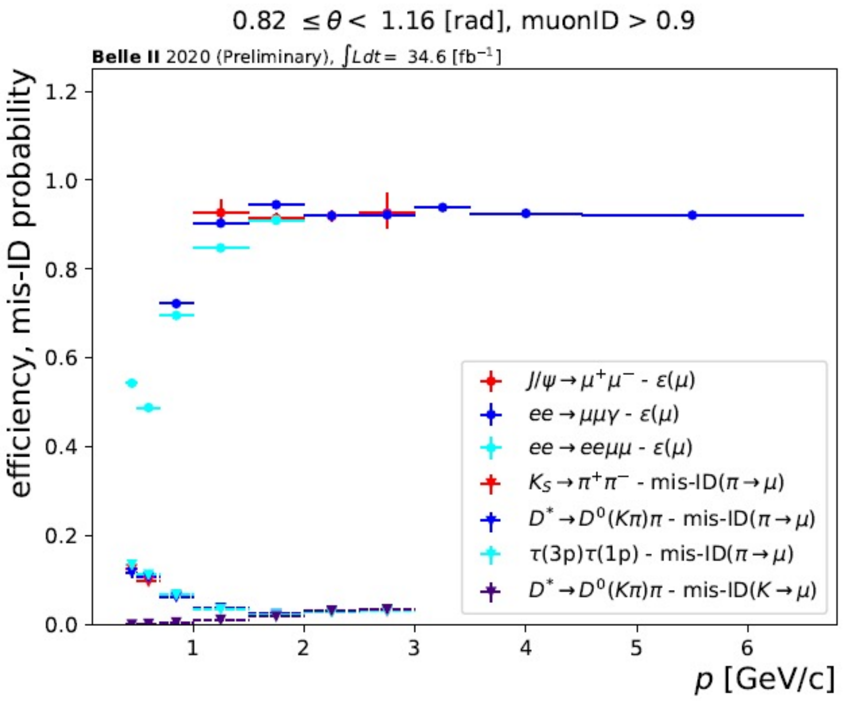
After the calibration factor introduced, DATA/MC agrees in the broad p_T range.

Particle ID

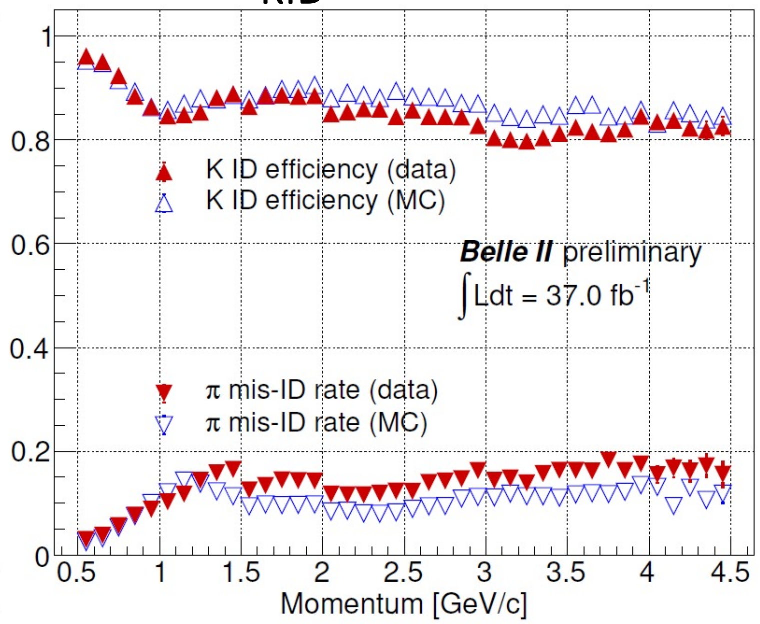
Each PID detector defines likelihood $\mathcal{L}_i$ for each charged particle hypothesis and the global likelihood is defined $\mathcal{L} = \Pi\mathcal{L}_i$.
The global likelihood ratio of the particle l can be defined :

$$\ell ID = \frac{\mathcal{L}_\ell}{\mathcal{L}_e + \mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K + \mathcal{L}_p}$$





KID $D^{*+} \to D^0[K^-\pi^+]\pi^+$

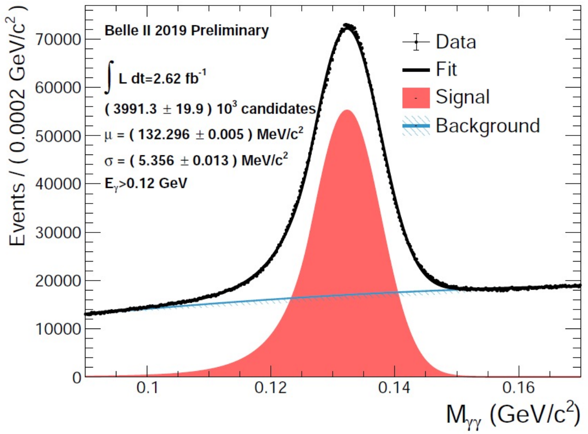


BELLE2-NOTE-PL-2020-020

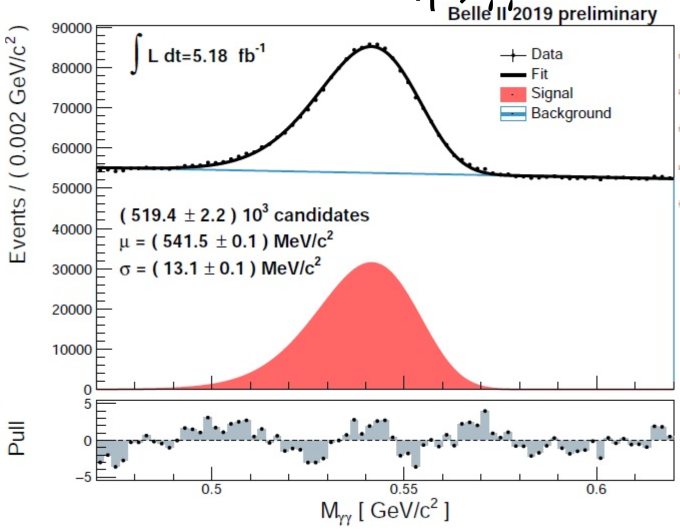
Shows good PID separation.

Neutral reconstruction

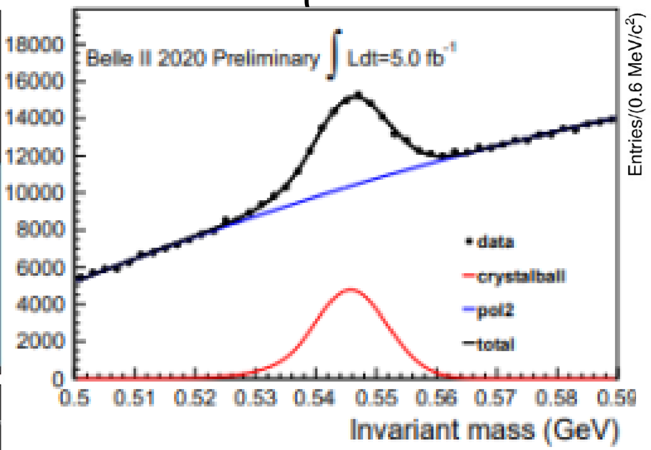
$\pi^0 \rightarrow \gamma\gamma$



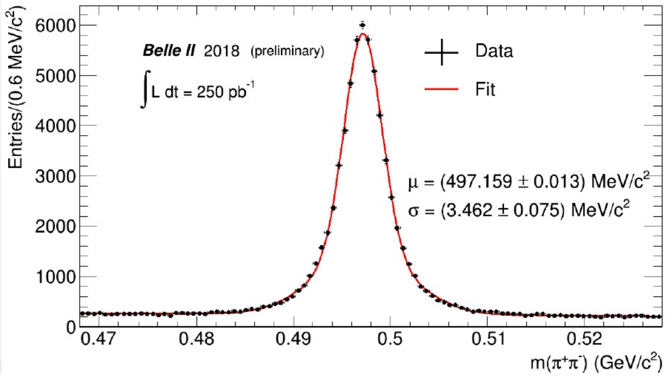
$\eta \rightarrow \gamma\gamma$



$\eta \rightarrow 3\pi^0$

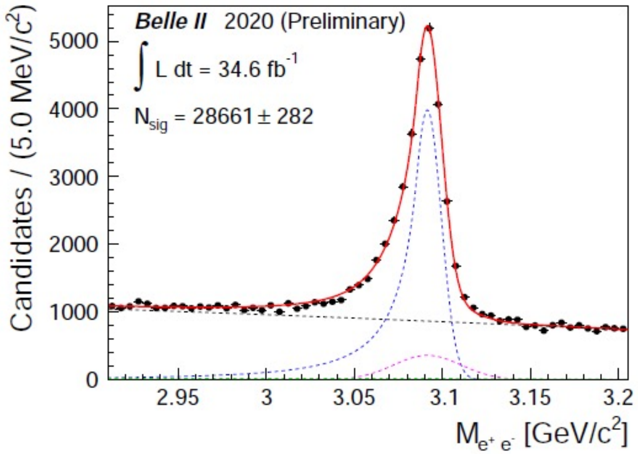


$K_S \rightarrow \pi^+\pi^-$

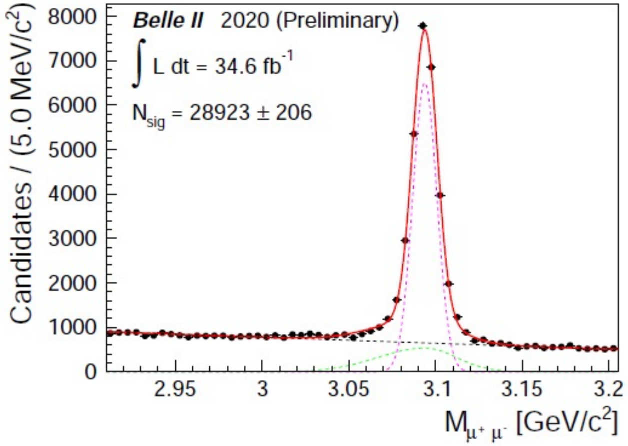


Breams photon recovered

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



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



Large solid angle and good uniformity detector
→ better reconstruction of neutrals.
Also has capabilities

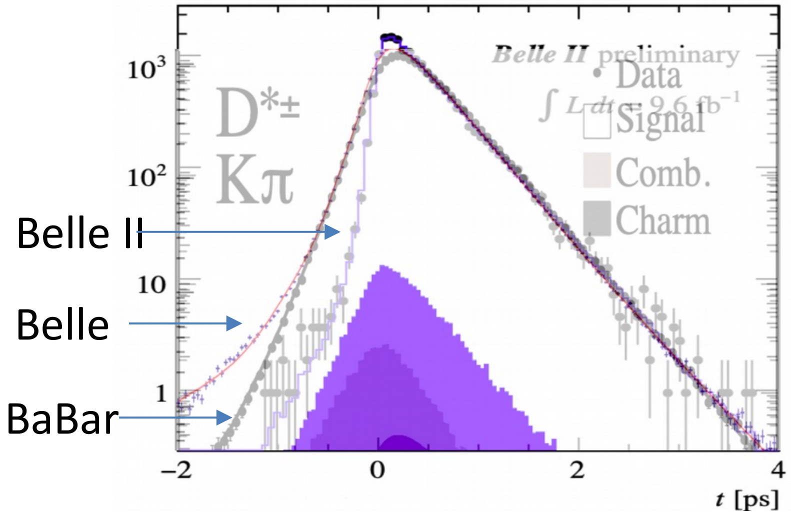
- to recover Bremsstrahlung photon
- to detect isolated ISR/FSR

as well.

Vertexing

D^0 lifetime measurement w/ 9.6fb-1

BELLE2_NOTE_PL_2020_008

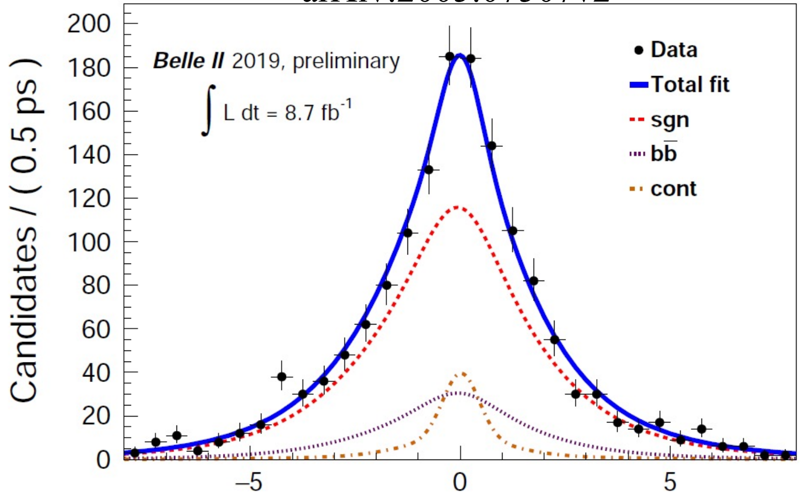


$$\tau_{D^0} = 412.3 \pm 2.0\ fs(stat\ only)$$

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

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

arXiv:2005.07507v2

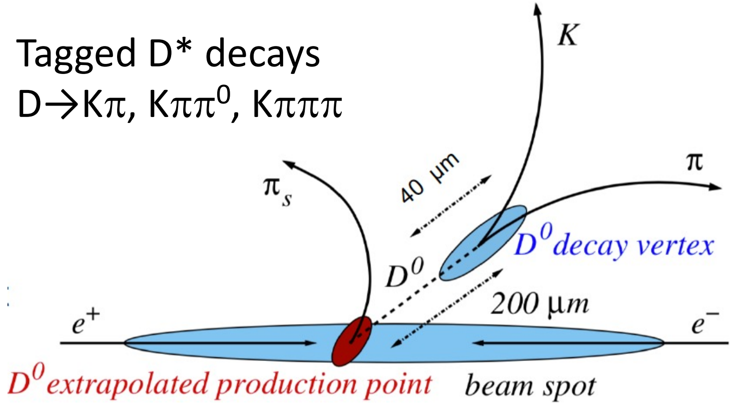


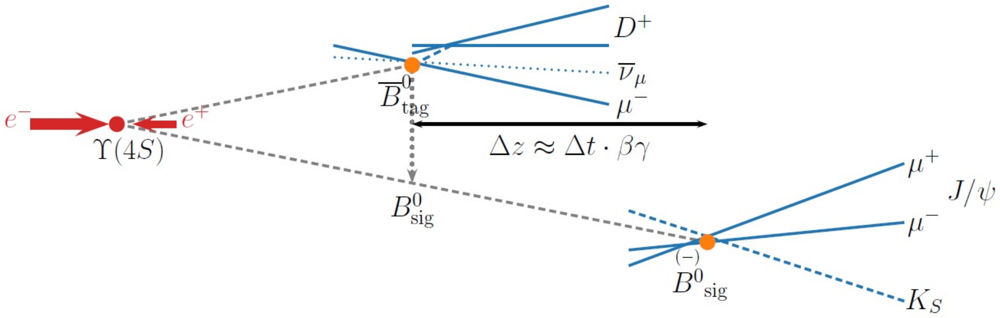
$$\tau_{B^0} = 1.48 \pm 0.28 \pm 0.06\ ps$$

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

Tagged D* decays

$D \rightarrow K\pi$, $K\pi\pi^0$, $K\pi\pi\pi$

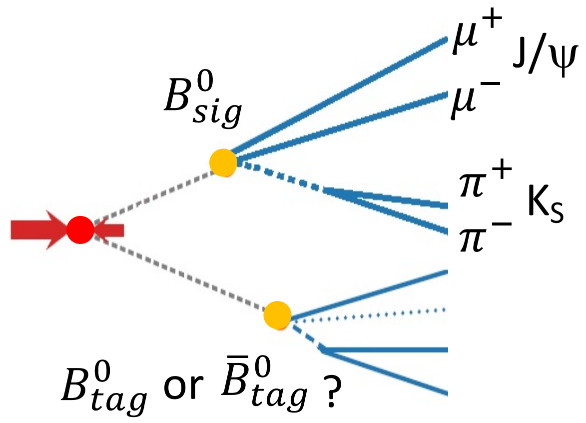




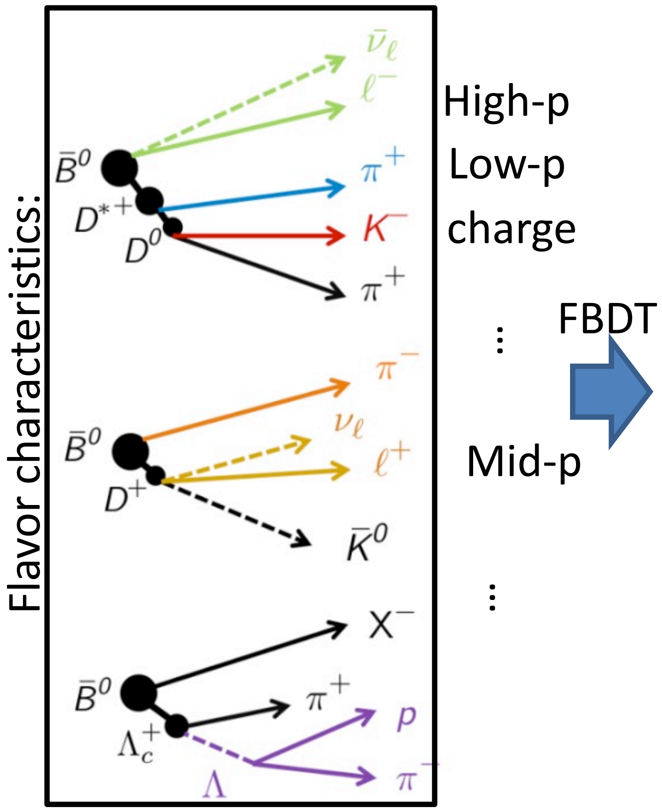
Pixel detector improves the vertex position resolution.

Flavor identification

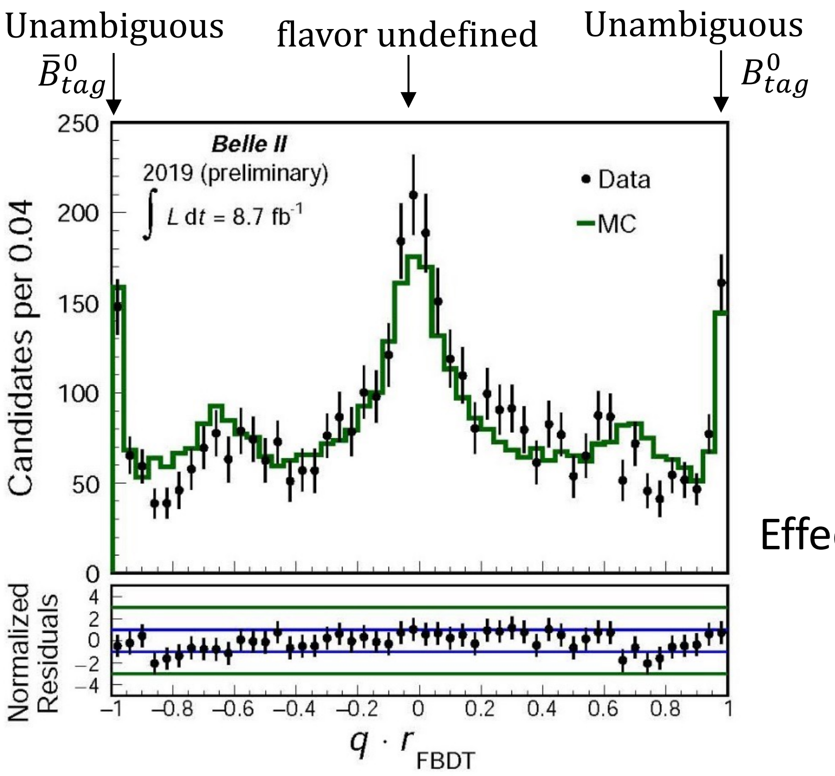
arXiv:2008.02707



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



Flavor tag index : q·r_{FBDT}



The w can be estimated by flavor specific decay B⁰->D^(*)h mode with q·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 $r_{FBDT}^i \approx 1-2w_i$

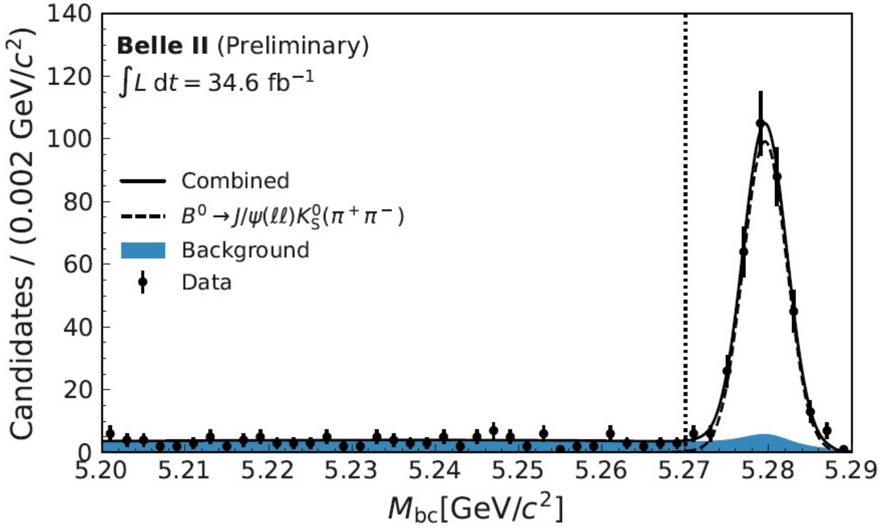
Effective Tag efficiency: $\varepsilon_{eff} = \Sigma\varepsilon^i_{tag}\cdot(1-2w_i)^2$

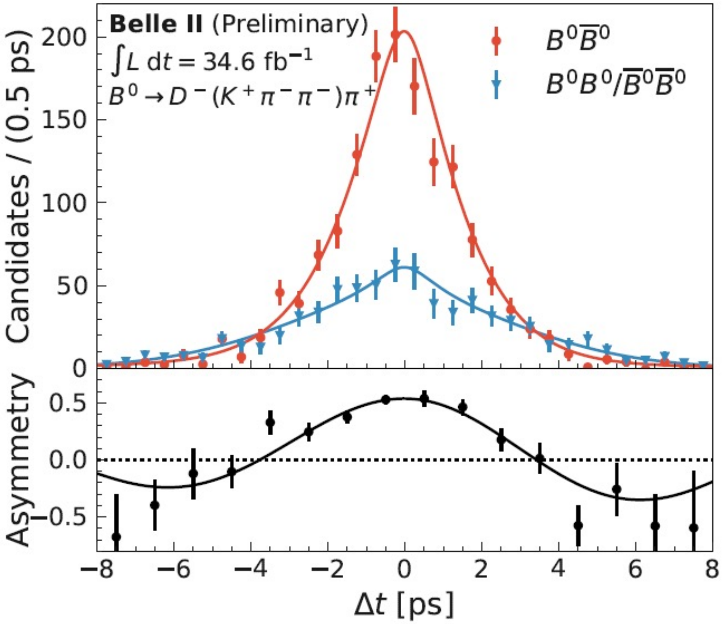
Belle II: $\varepsilon_{eff} = 33.8 \pm 3.6 \pm 1.6\ \%$

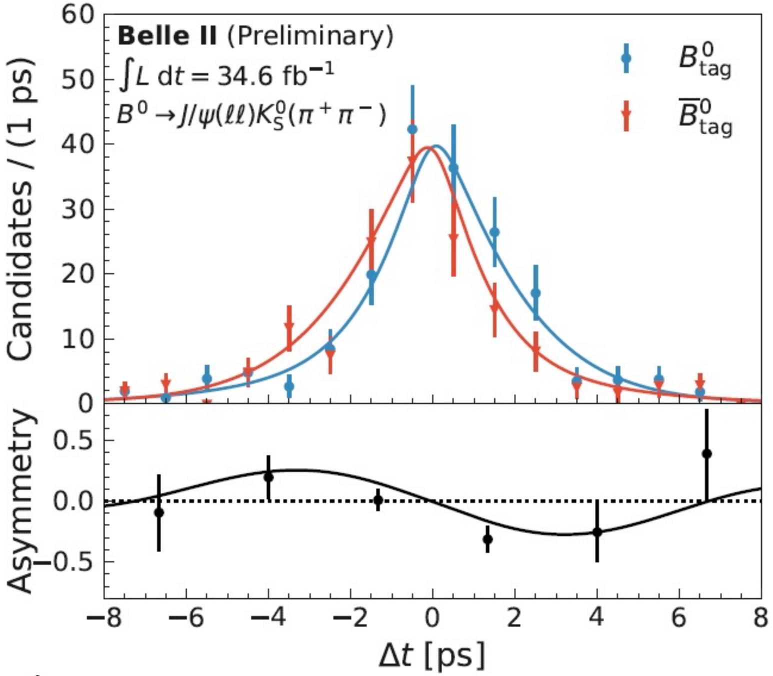
Belle: $\varepsilon_{eff} = 30.1 \pm 0.4\%$

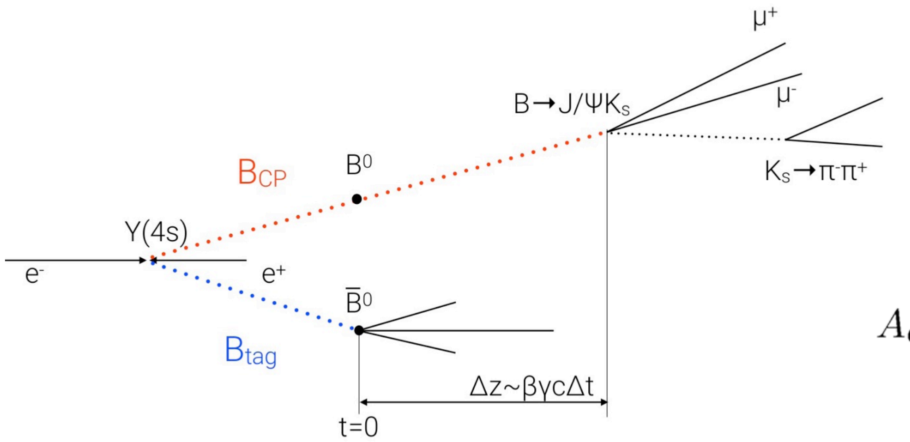
Time-dependent CPV measurement

BELLE2-NOTE-PL-2020-11









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

$$\Delta m_d = \big(0.531 \pm 0.046(stat.) \pm 0.013(syst.)\big)ps$$

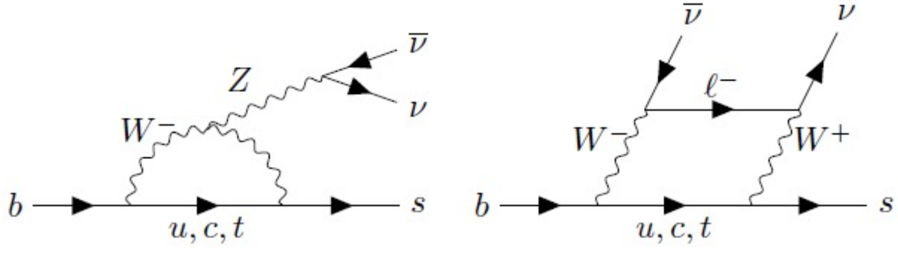
W.A. 0.5065±0.0019

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

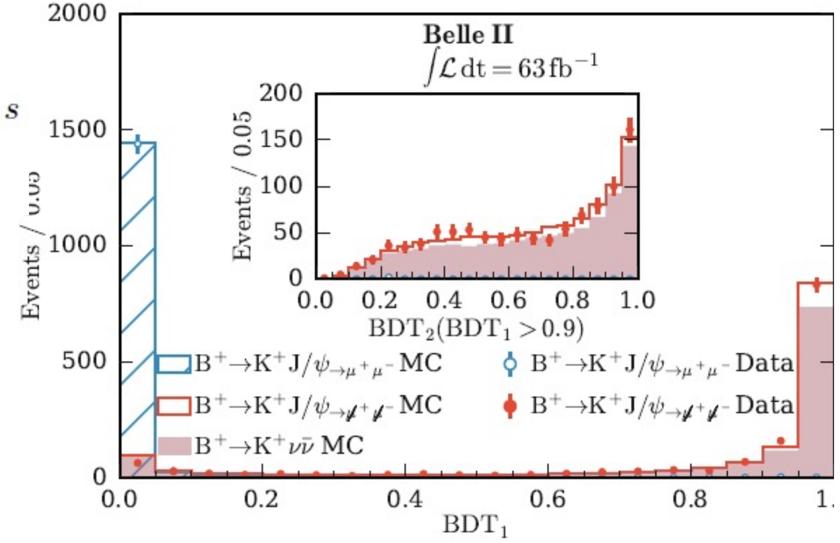
$$S = \sin 2\phi_1 = 0.55 \pm 0.21(stat.) \pm 0.04(syst.)$$

W.A. 0.695±0.019

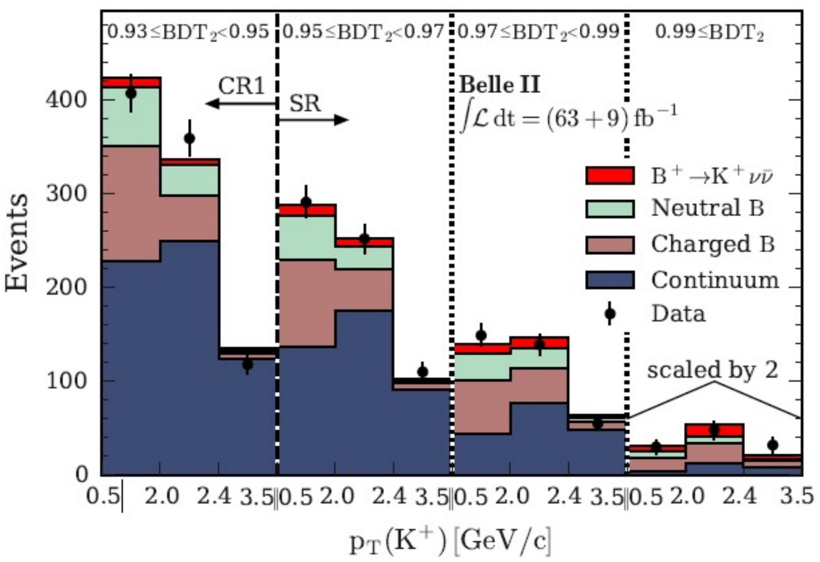
$B^+ \to K^+\nu\nu$ decay w/ inclusive tagging

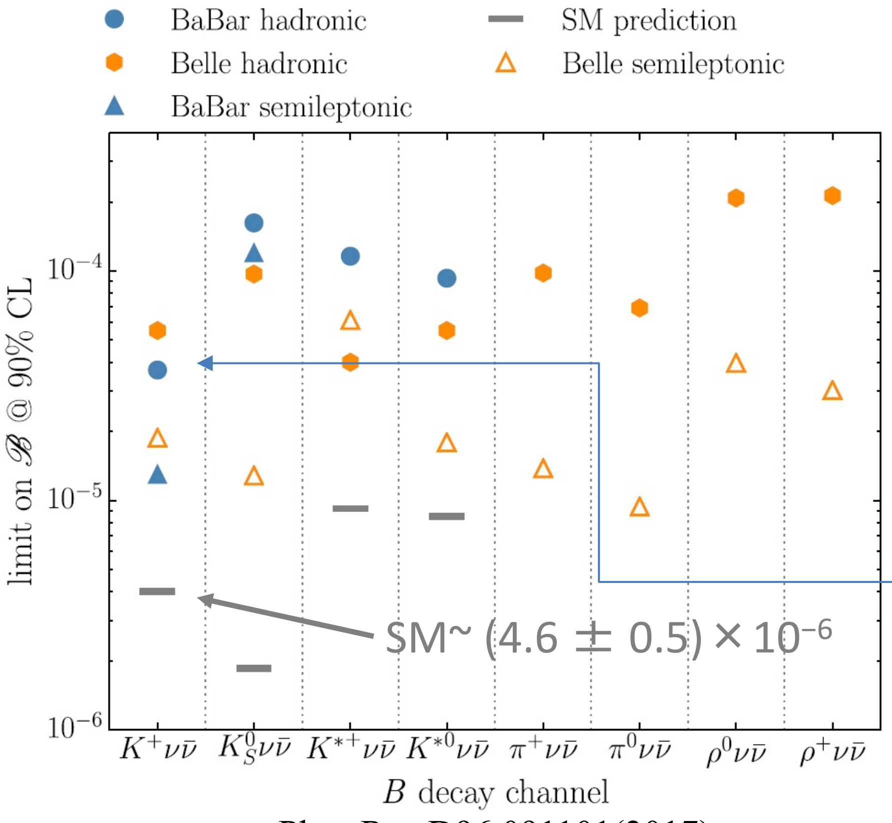


(a) Penguin diagram (b) Box diagram



arXiv:2104.12624 63 fb-1





Phys.Rev.D96,091101(2017)

Unknown flavor of ν.
This mode may enhance from SM expectation.

$Br(B^+ \to K^+\nu\bar{\nu}) < 4.1 \times 10^{-5}$ (90% C.L.) using 63 fb-1 Belle II

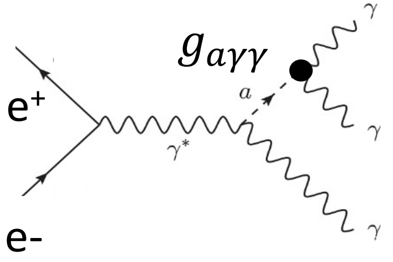
Already comparable result of hadronic tag in

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

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

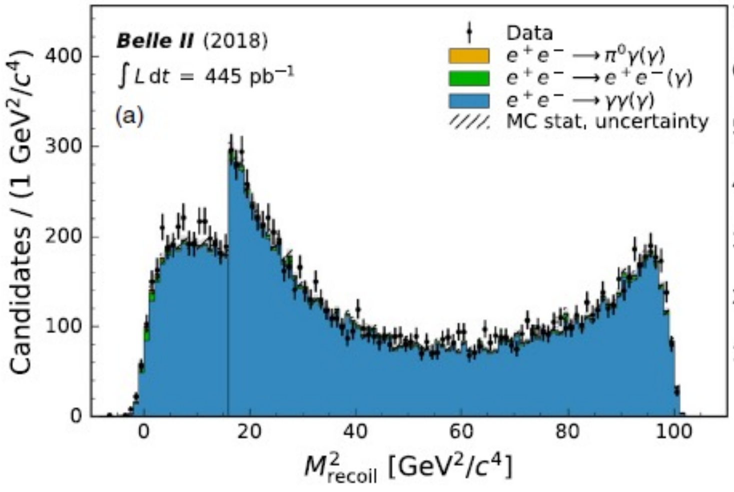
Axion/ALPS and Z' search

$$E^{\mathrm{c.m.}}_{\mathrm{recoil}\gamma} = \frac{s - m_a^2}{2\sqrt{s}},$$

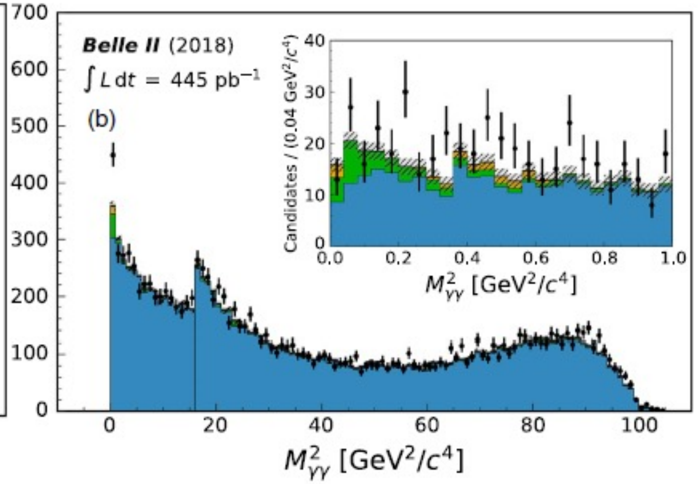


ALPS
JHEP12(2017)094

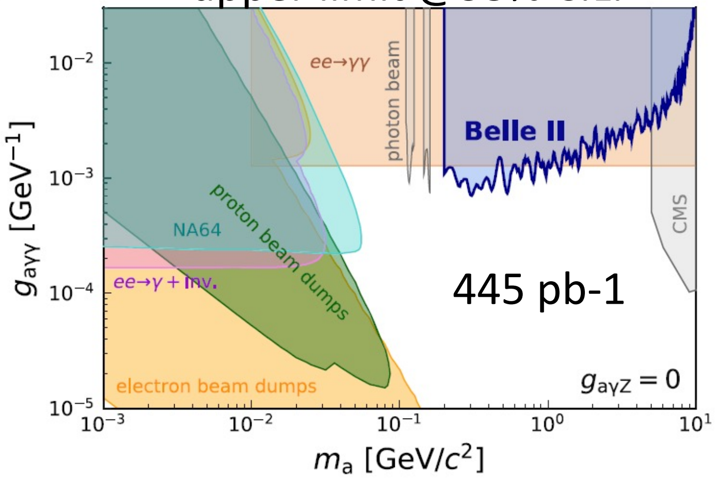
For $m_a > 6.85$ GeV/c^2



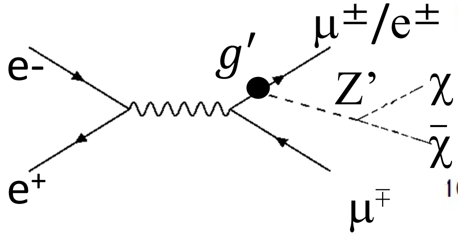
For $m_a < 6.85$ GeV/c^2



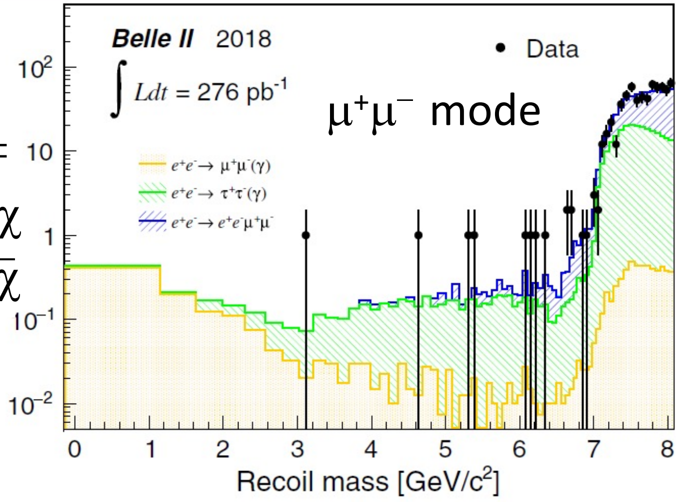
upper limit @95% C.L.

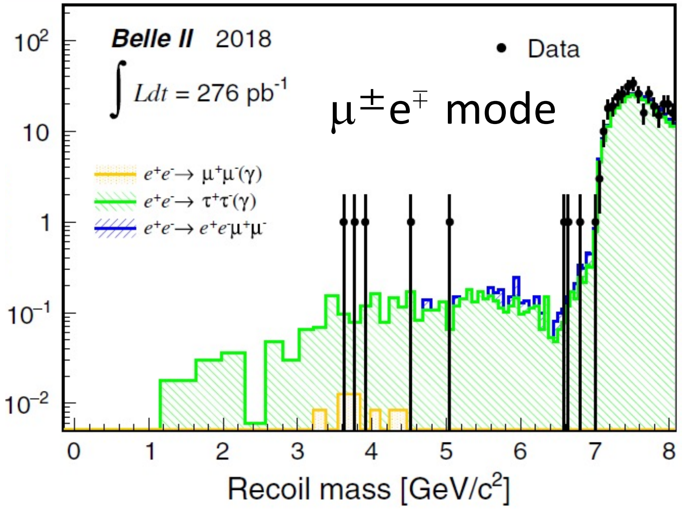


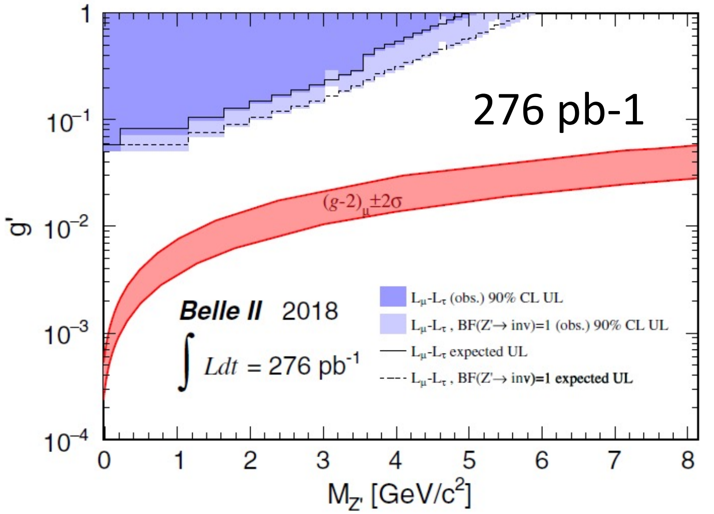
Phys.Rev.Lett. 125,161806(2020)



L_μ-L_τ 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_μ-L_τ model.

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

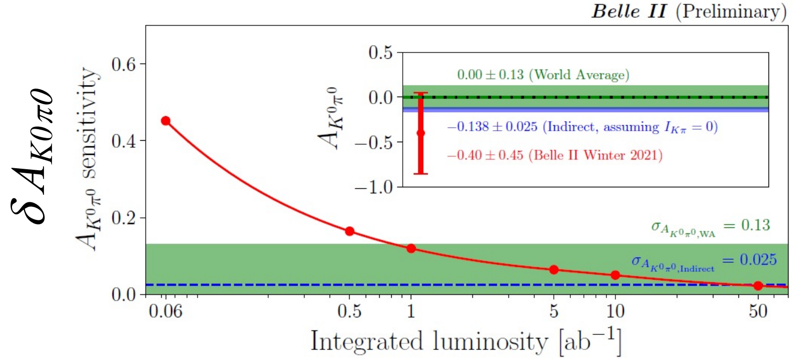
Direct CP asymmetry $A_{CP}(K^-\pi^+) \equiv \frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\overline{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$ b→s$q\overline{q}$ transition

Measurement of $A_{CP}(B^0 \to K^+\pi^-)$ and $A_{CP}(B^+ \to K^+\pi^0)$: $\Delta A_{CP}(K\pi)$=0.0120±0.021

Simple expectation $\Delta A_{CP}(K\pi)$~0
If Tree & Penguin are dominant.
Suffering the hadronic uncertainty

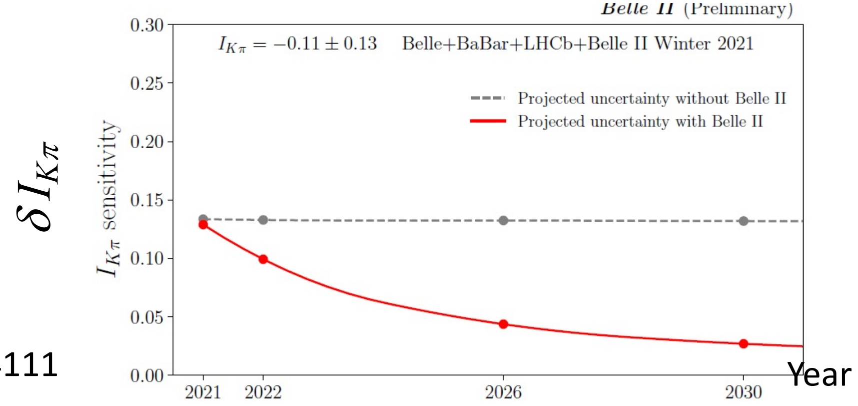
The isospin sum rule test was proposed Phys.Lett.B627(2005)82

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



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

arXiv:2104.14871
63 fb-1



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

$I_{K\pi}$ = -0.11±0.13

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

See also arXiv:2105.04111

Summary

- SuperKEKB/BelleII are running stable.
  - Instantaneous L=3.1 $\times$ 10^{34} /cm/sec recorded.
  - Integrated L_{int}= 213 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.