Belle II Experiment: Status and Prospects

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Stony Brook, NY

Outline

- SuperKEKB
- Belle II Detector
- Detector Performance
- Belle II Physics Program
- Summary & Conclusion

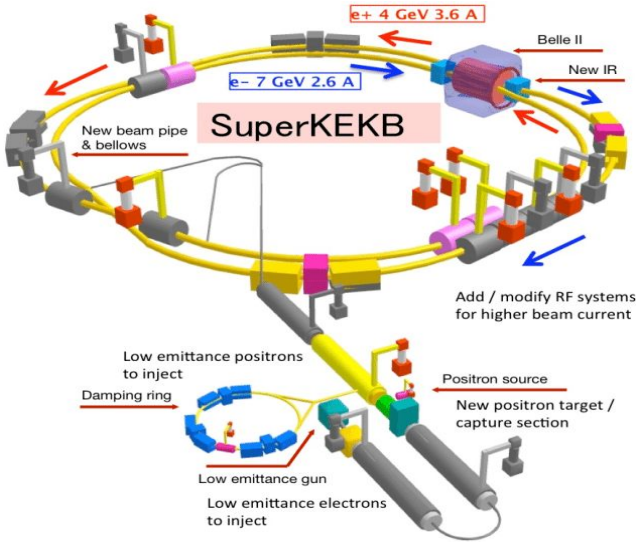
SuperKEKB

- SuperKEKB is an asymmetric e^+ (4 GeV) and e^- (7 GeV) collider located at KEK, Japan.
- It uses "Nano beam" scheme to achieve the higher luminosity.

►Squeeze the vertical beta function β_y^* at the IP and increase the beam current.

$e^+ + e^- \rightarrow \Upsilon$ (4S) at $\sqrt{s}$ = 10.58 GeV

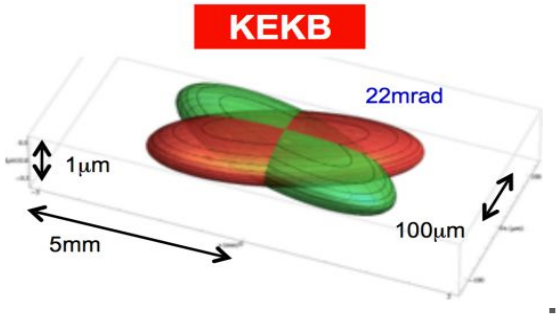
Instantaneous luminosity: $6 \times 10^{35} cm^{-2} s^{-1}$

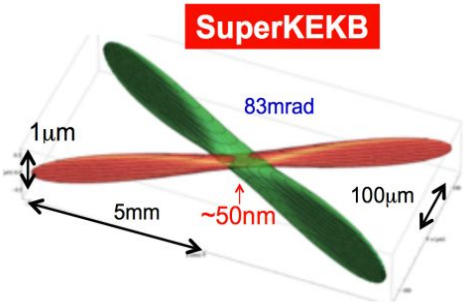


Luminosity

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

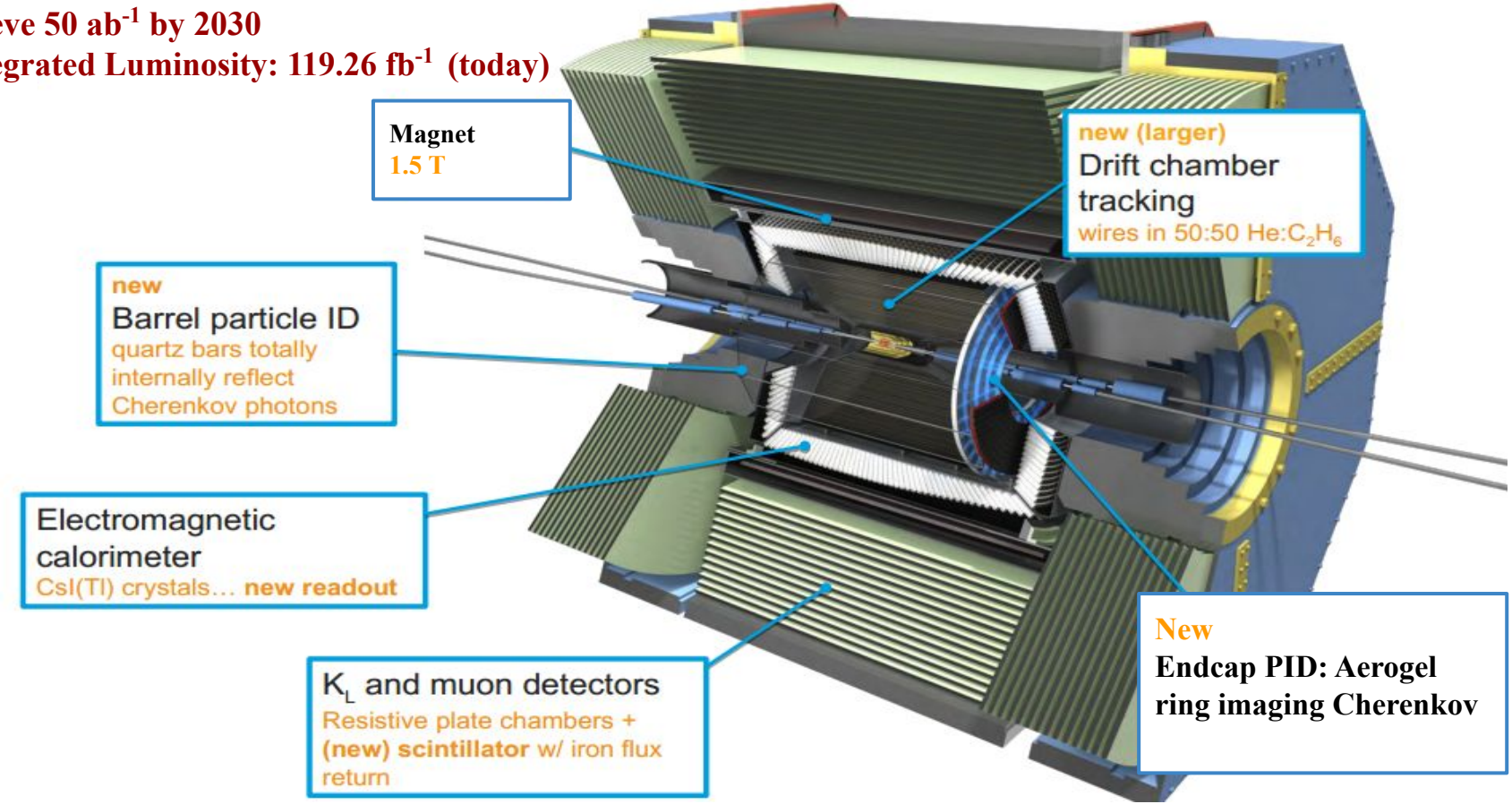
beam size: σ^*
beam-beam par.: $\xi_{y\pm}$
beam current $I_\pm$
beta function: β^*





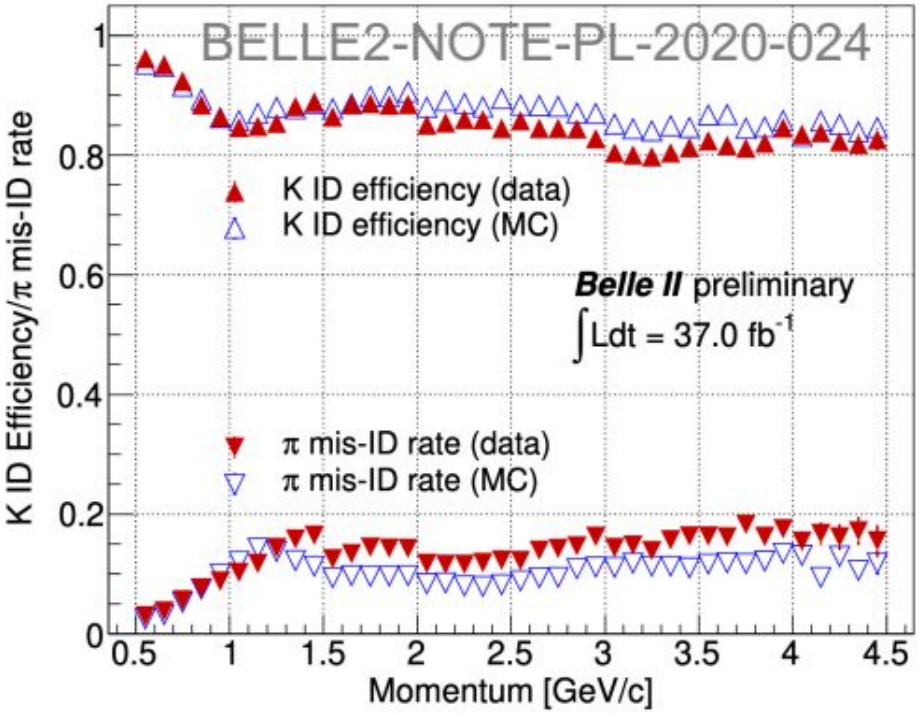
Belle II Detector

Aim to achieve 50 ab^{-1} by 2030
Current Integrated Luminosity: 119.26 fb^{-1} (today)

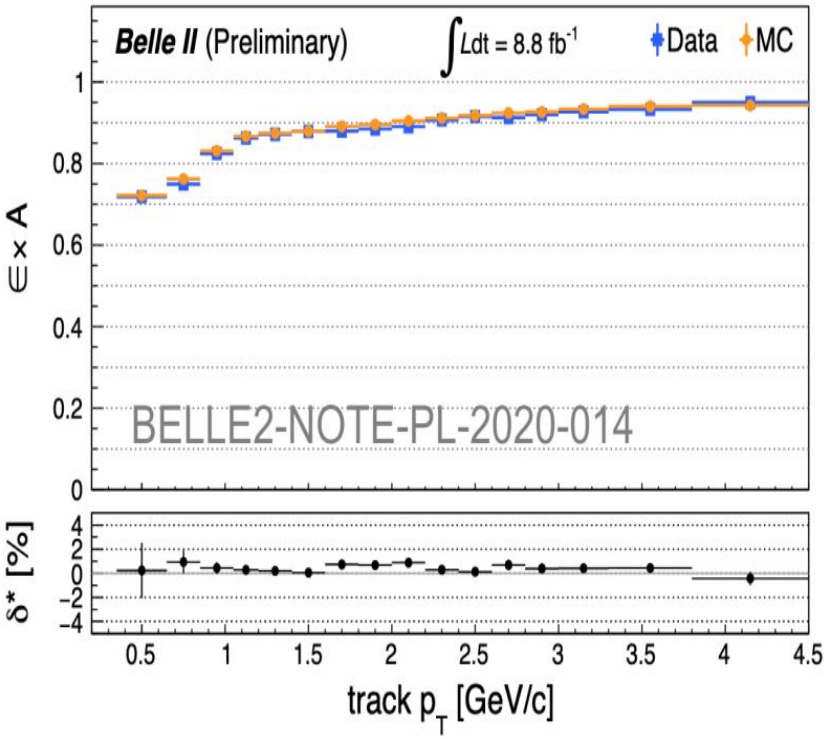


Performance of Belle II Detector

Particle Identification (K/π Separation)

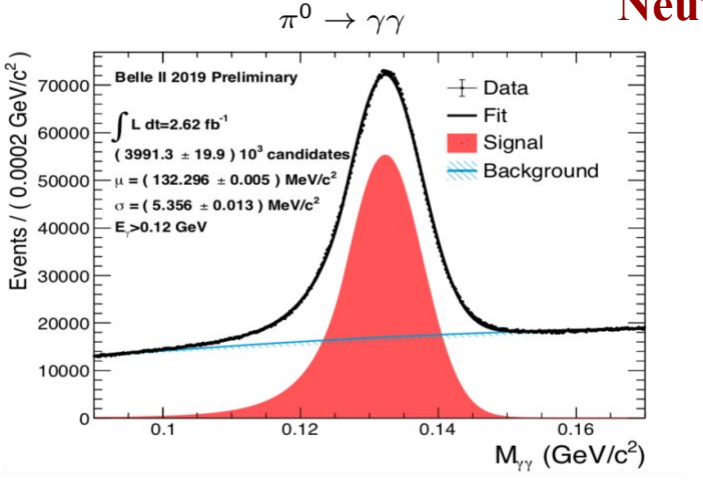


Tracking Efficiency (τ)



Performance of Belle II Detector (continue..)

Neutral reconstruction



Clear signal is observed for $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$.

It demonstrates the reconstruction performance for neutral particles.

Flavor tagging

B flavor tagger

$\varepsilon_{effective} = \sum_i \varepsilon_i \cdot (1-2w_i)^2$

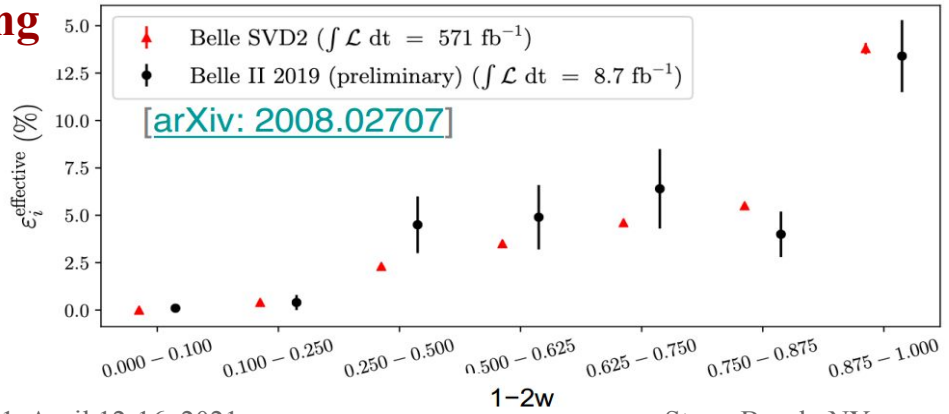
w_i = wrong-tag fractions

ε_i = tag efficiency

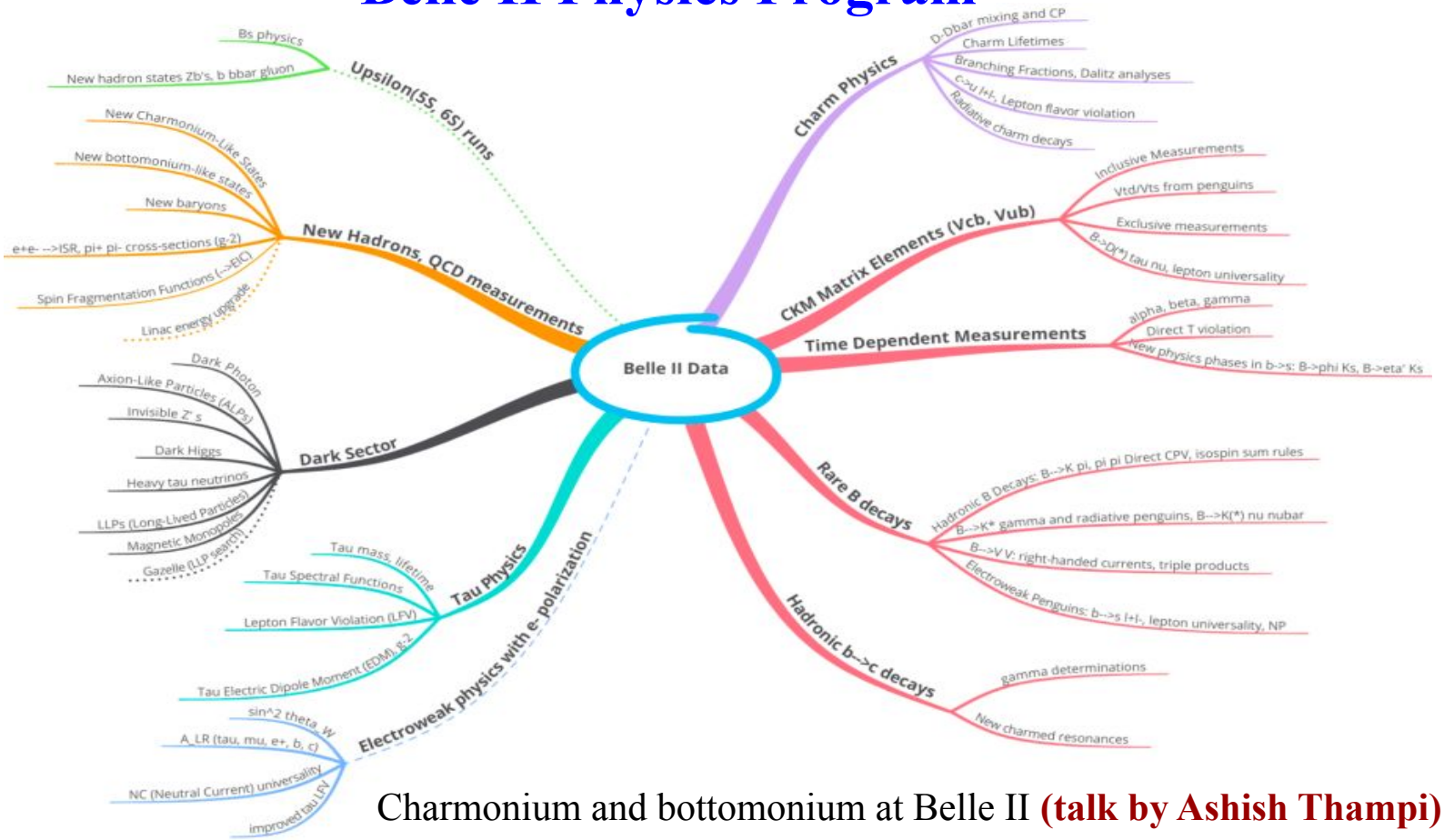
$\varepsilon_{effective}$ (Belle II MC) = ~37%

$\varepsilon_{effective}$ (Belle II) = (33.8±3.9)%

$\varepsilon_{effective}$ (Belle) = (30.1±0.4)%



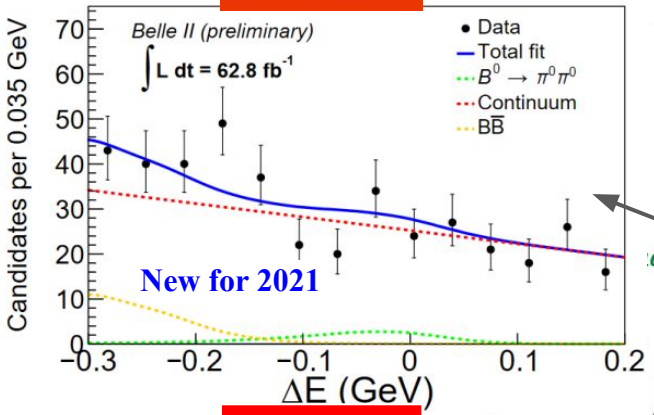
Belle II Physics Program



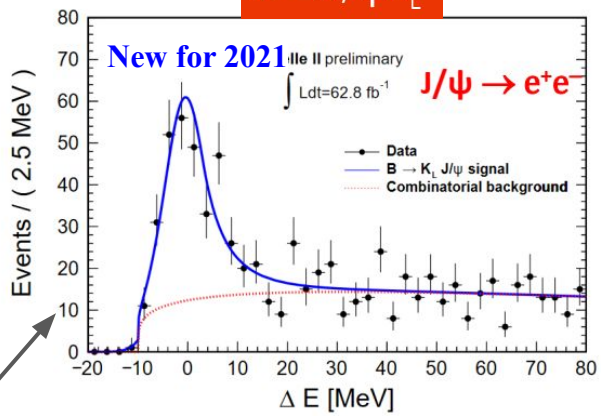
Charmonium and bottomonium at Belle II **(talk by Ashish Thampi)**

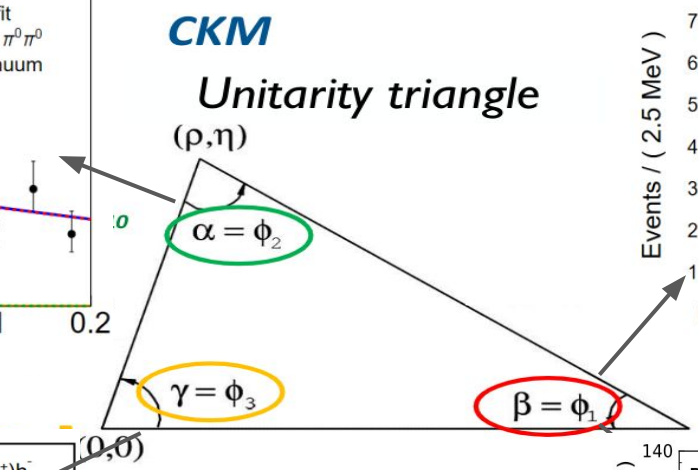
Measurement of the CKM Angles

$B^0 \to \pi^0\pi^0$

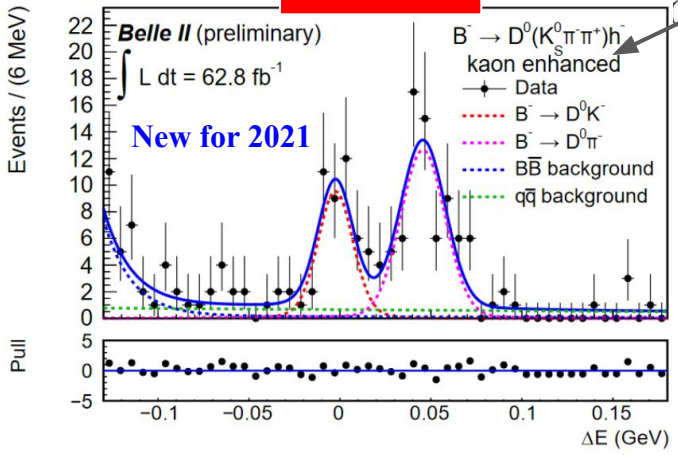


$B^0 \to J/\psi K_L^0$





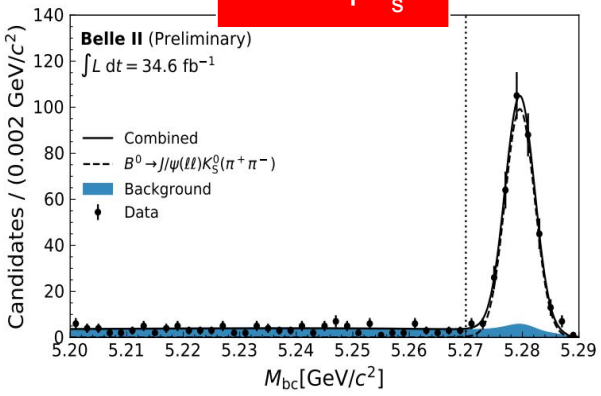
$B^0 \to D^0 h^-$



$$\Delta E = E_B^* - E_{\text{beam}}^*$$

$$M_{\text{bc}} = \sqrt{E_{\text{beam}}^{*\,2} - p_B^{*2}}$$

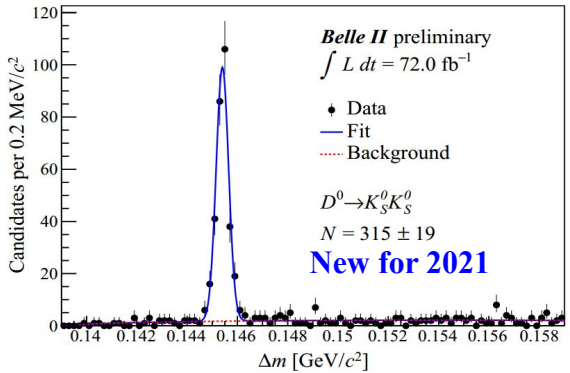
$B^0 \to J/\psi K_S^0$



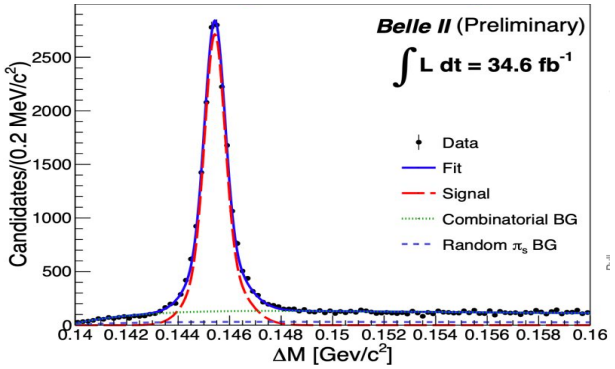
Charm Physics

Time-integrated CP Asymmetry

$D^{*+} \to D^0 \pi^+,\ D^0 \to K_s K_s$

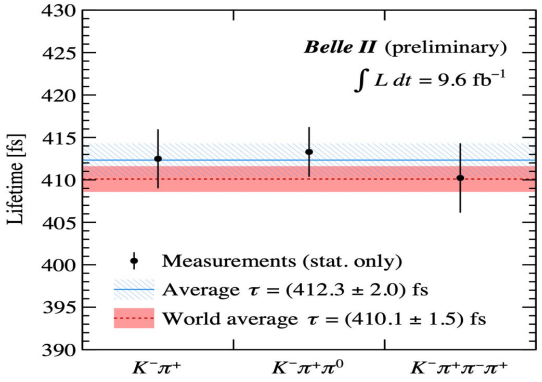


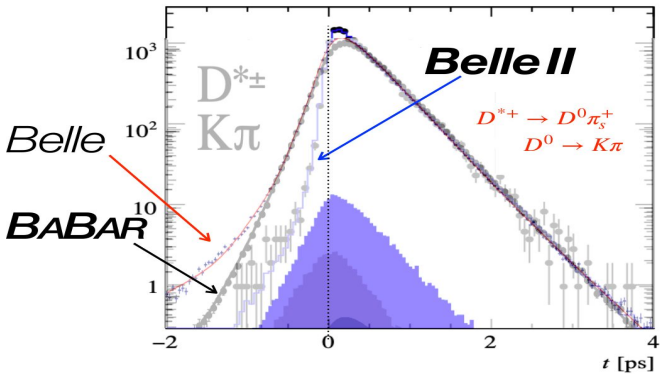
$D^{*+} \to D^0 \pi^+,\ D^0 \to K_s \pi^0$



The resolution and background level is comparable with Belle, with only 1.5 years of data taking.

D^0 lifetime measurement





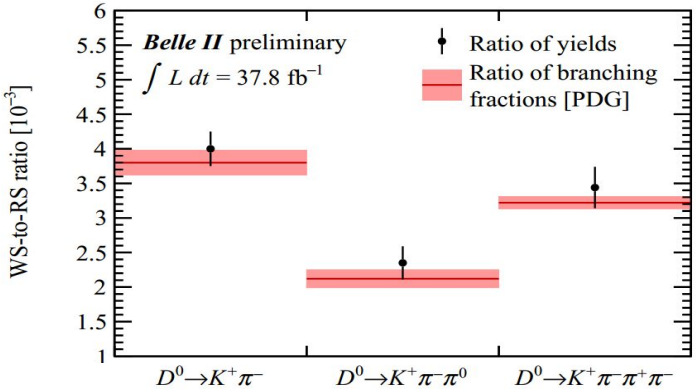
- 2x better time resolution over Belle/Babar (thanks to the improved vertex detector and the"nano-beams" technique in Belle II)
- Resolution improvement visible at $t < 0$

Charm Physics :D^0 - $\bar{D}^0$ Mixing

$$R_{WS}(t) = N_{WS}(t)/N_{RS}(t)$$

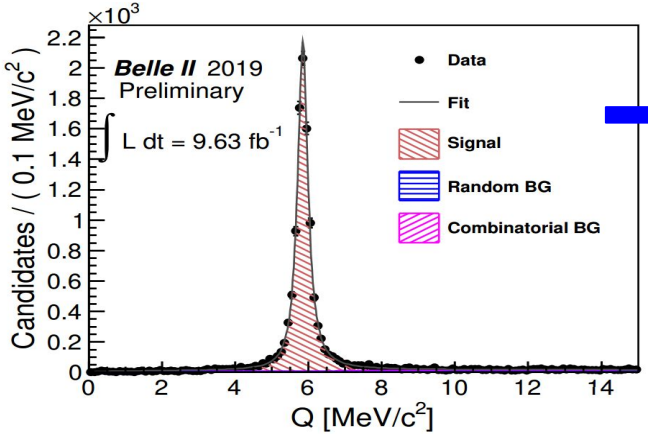
D^0 wrong-sign decays

- Used to measure CPV and mixing parameters.
- Reconstruct RS & WS decays, extract PDF from RS and use it to fit the WS distributions.
- Compute the WS-to-RS ratio of yields, expected to be equivalent to the ratio of branching ratios (WA).



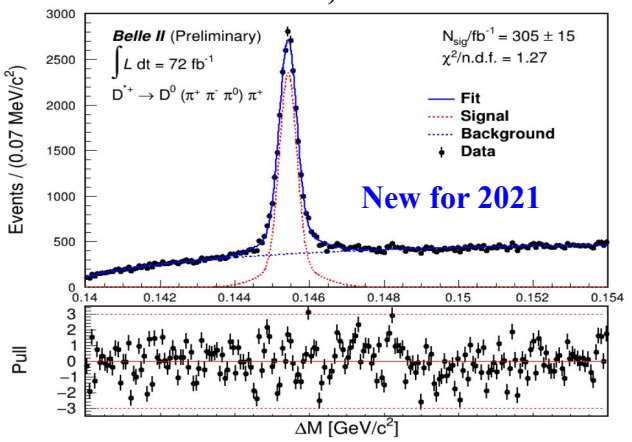
Time-dependent Dalitz analysis

$D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow K_s \pi^+ \pi^-$



The resolution of release energy Q, is a factor of 2 better than Belle.

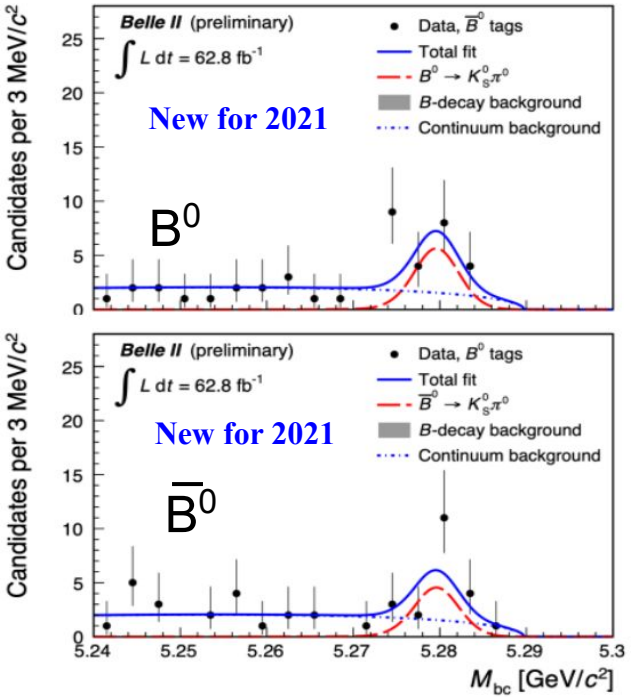
$D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow \pi^0 \pi^+ \pi^-$



Charmless B decays

Stringent SM test: B→Kπ isospin sum rule (hep-ph/0508047).

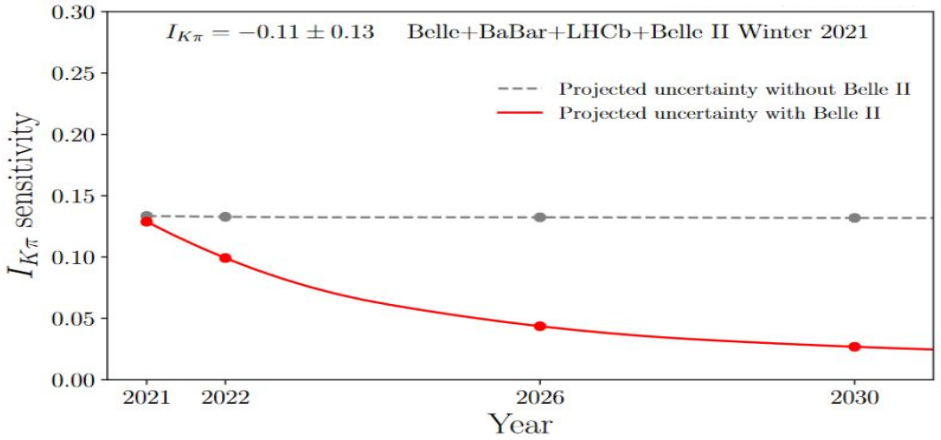
$$I_{K\pi} = A_{K^+\pi^-} + A_{K^0\pi^+}\frac{B(K^0\pi^+)\tau_B^0}{B(K^+\pi^-)\tau_B^+} - 2A_{K^+\pi^0}\frac{B(K^+\pi^0)\tau_B^0}{B(K^+\pi^-)\tau_B^+} - 2A_{K^0\pi^0}\frac{B(K^0\pi^0)}{B(K^+\pi^-)}$$



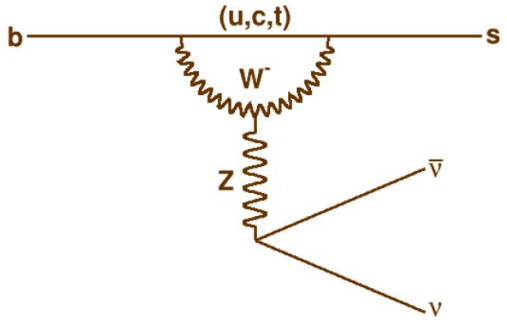
$$N(B^0 \longrightarrow K^0\pi^0) = 45^{+9}_{-8} \quad \text{---(1)}$$

$$\mathcal{B} = [8.5^{+1.7}_{-1.6}(stat) \pm 1.2(syst)] \times 10^{-6} \quad \text{---(2)}$$

$$A_{K^0\pi^0} = -40^{+0.46}_{-0.44}(stat) \pm 0.04(syst) \quad \text{---(3)}$$

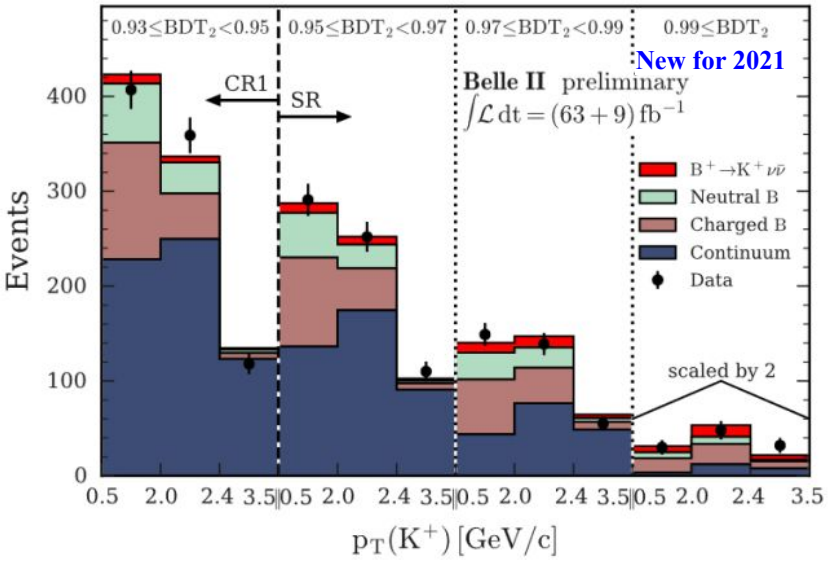


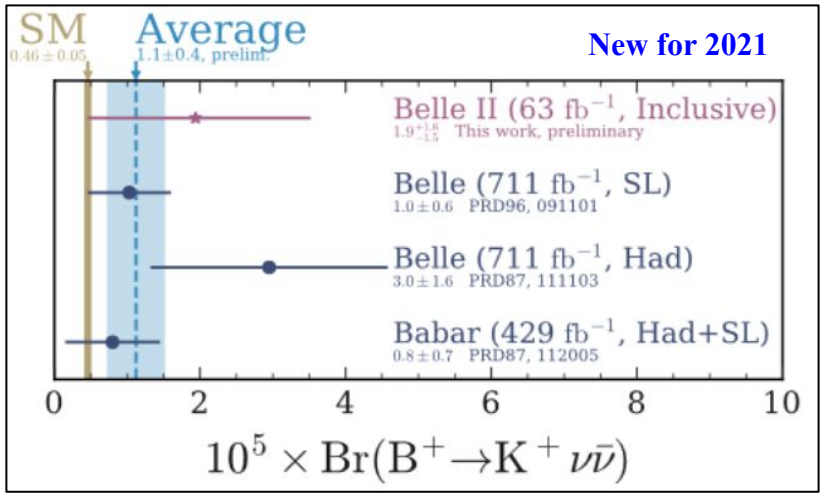
$B^+ \to K^+ \nu\,\nu$ decays



- Transition mediated by a virtual Z-boson.
- SM prediction for the BF $[B^+ \to K^+ \nu\,\nu]_{SM}$ is $(4.6 \pm 0.5) \times 10^{-6}$ [B2TIP, PTEP 2019, 123C01].

$$\mathcal{B}[B \to K^+ \nu\nu] = 1.9^{+1.3+0.8}_{-1.3-0.7} \times 10^{-5}$$





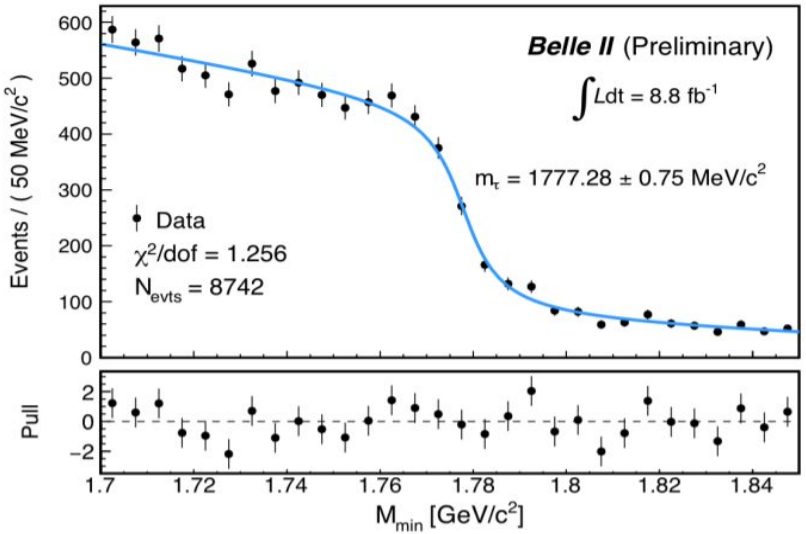
Sensitivity with just 63 fb^{-1} data is already close to previous searches with significantly larger data-set.

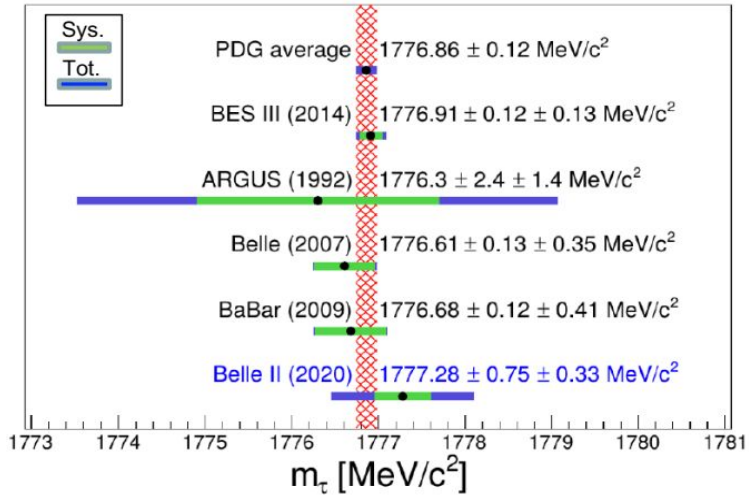
τ Mass Measurement

BELLE2-CONF-PH-2020-010

Mass of τ lepton is measured from the threshold in "pseudomass" variable.

$$M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})}$$





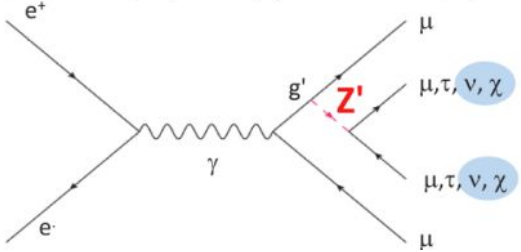
This measurement is in good agreement with the current world average.

Search for Dark Sector (Z'→ invisible)

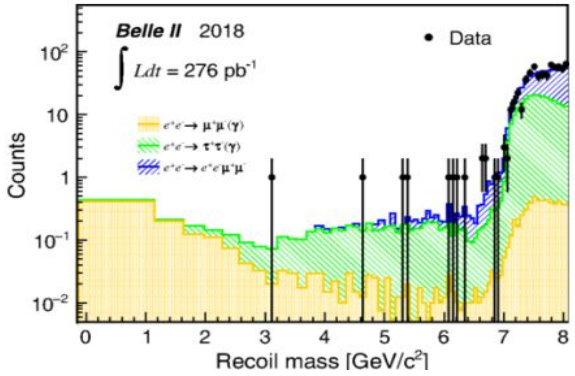
PRL 124(2020)141801

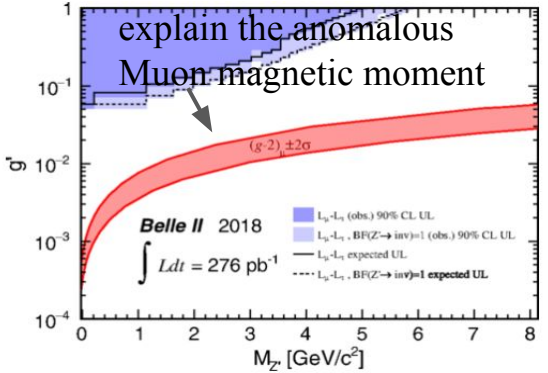
$L_\mu - L_\tau$ model

$e^+e^- \rightarrow \mu^+\mu^- Z'$, $(Z' \rightarrow \text{invis.})$



The signature is a bump in the recoil mass distribution of the ℓ+ℓ- system

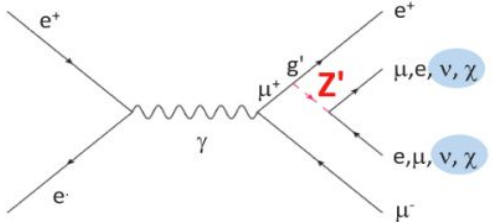


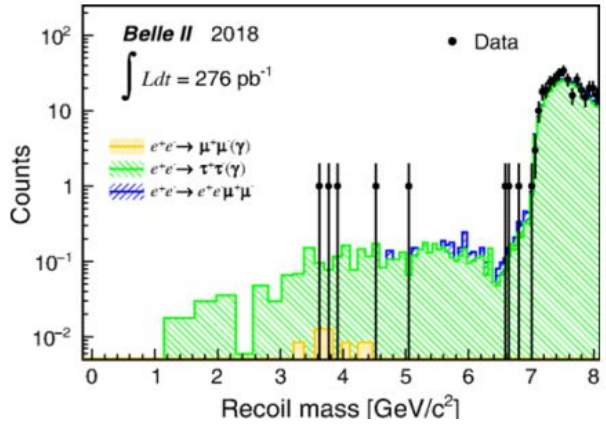


90% C.L. upper limits on coupling constant g.

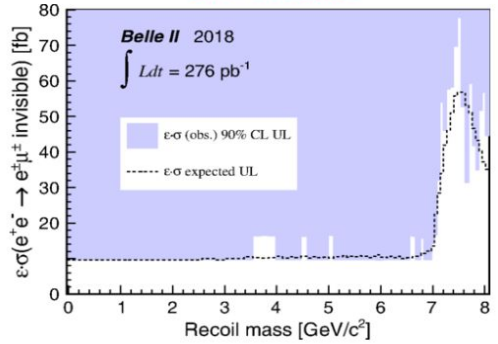
LFV scenario (e - μ coupling)

$e+e- \rightarrow e^\pm\mu^\mp Z'$, $(Z' \rightarrow \text{invis.})$





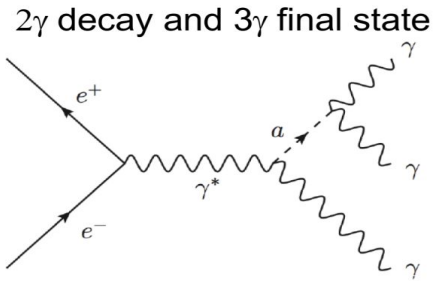
LFV scenario



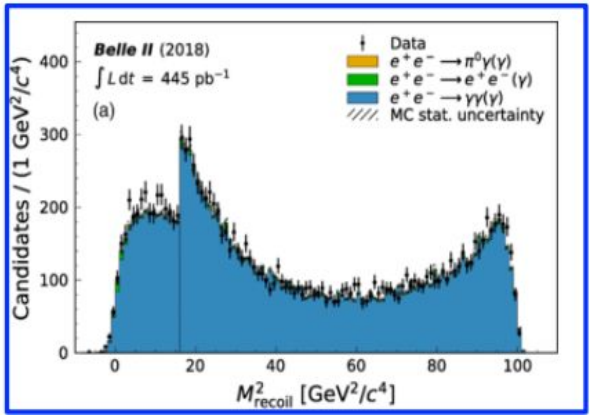
90% C.L. upper limits on signal efficiency times cross section.

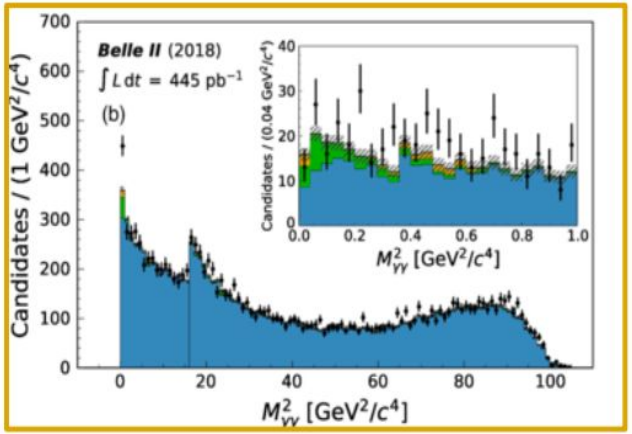
Dark sector: Axion-like particles

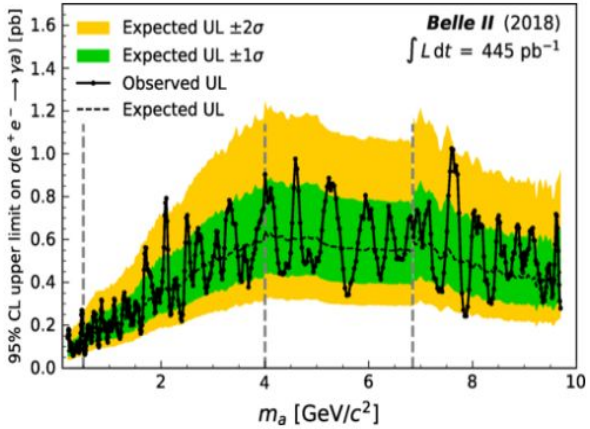
Signal can be identified by a peak in the recoil invariant mass and 2g invariant mass.

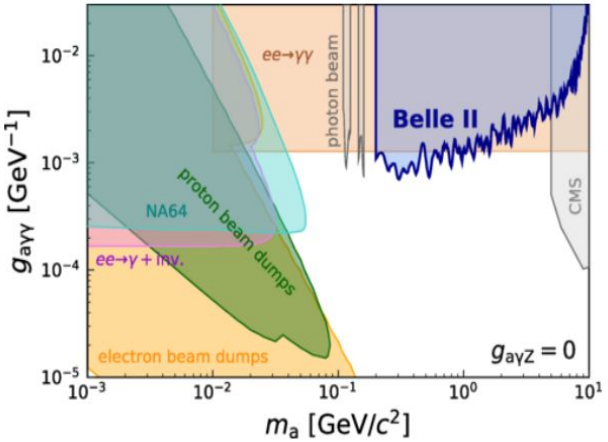


No significant excess seen.
The highest local significance is 2.8σ.









Extension of the exclusion region in the ($g_{a\gamma\gamma}$,m_a) parameter space already with ~0.5 fb^{-1}

PRL 125(2020)161806

Belle II Physics Results

2 published PRL dark-sector searches:

- Search for an invisibly decaying Z' boson [PRL 124(2020)141801] (published 6 April 2020)
- Search for axion-like particles [PRL 125 (2020)161806] (published 14 October 2020)

12 conference papers posted to arXiv:

- Calibration of the hadronic full-event interpretation. [arXiv:2008.06096] (17 Aug. 2020)
- B0 → D*+ ℓν (1) first result (2) untagged (3) using FEI). (12 June, 18 Aug., 16 Sep. 2020)
- Hadronic mass moments of B → X_cℓν decays. [arXiv:2009.04493] (9 Sep. 2020)
- Rediscovery of B → πℓν. [arXiv:2008.08819] (20 Aug. 2020)
- B lifetime in hadronic decays. [arXiv:2005.07507] (15 May 2020)
- Calibration of the flavour tagger [arXiv:2008.02707] (6 Aug 2020)
  used to make "rediscovery" of CPV in B → J/ψ K_S. [BELLE2-NOTE-PL-2020-11-1]
- Rediscovery of B → φK*. [arXiv:2008.03873] (10 Aug 2020)
- B → charmless (1) first result (2) CP asymmetries). (27 May, 20 Sep. 2020)
- Tau lepton mass measurement [arxiv:2008.04665] (10 Aug 2020)

Summary and Conclusion

- The maximal luminosity 2.4×10^{34} cm^{-2} s^{-1} (now) will be increased and will reach 6×10^{35} cm^{-2} s^{-1} in 2029.

- Published two PRL papers with adding new exclusion limits in the Dark Sector from the data collected in the 2018 commissioning run.

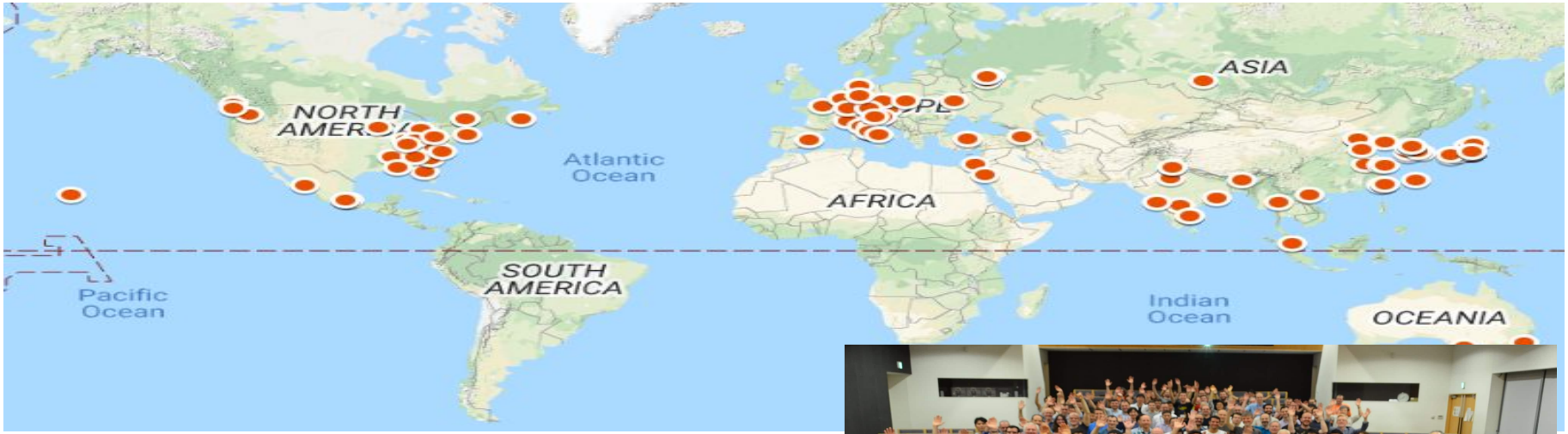
- Belle II started Phase 3 operations in March 2019, up to now a total of 119.26 fb^{-1} integrated luminosity have been recorded.

- Several analysis are ongoing, we are already competitive with BaBar and Belle in the Dark Sector.

- Upcoming large and clean samples of B, D mesons will allow Belle II to search for NP and will improve the measurements of SM parameters.

Stay tuned for more results

Thank you for your kind attention



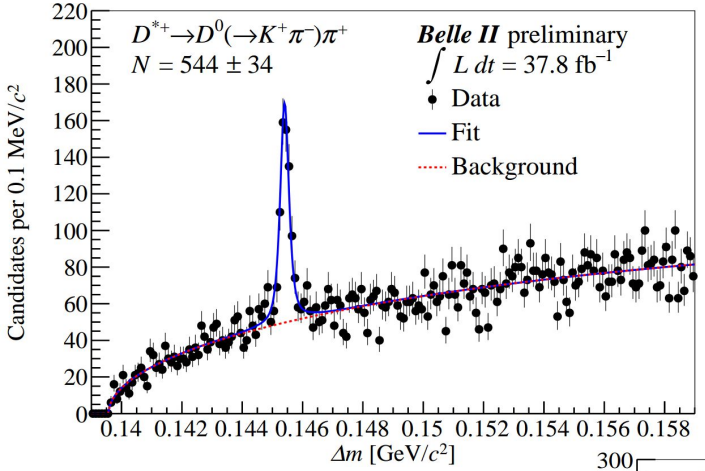
Picture taken at 33rd B2GM

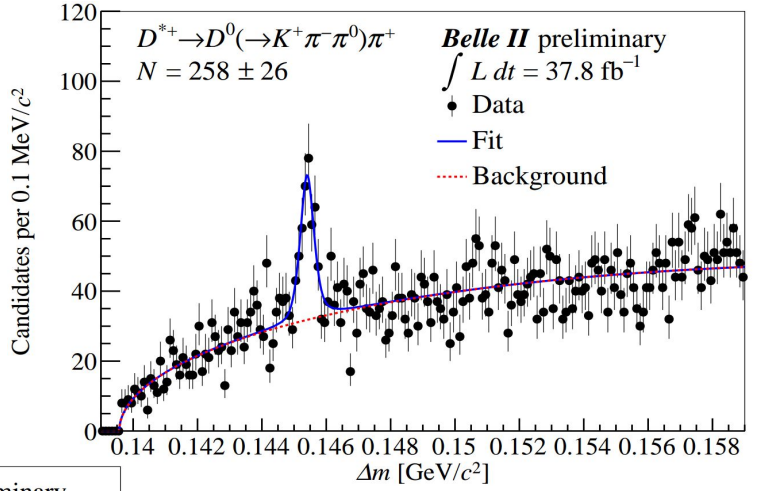
Belle II Collaboration:
Members: 1050
Institutions: 120
Countries/Regions: 26

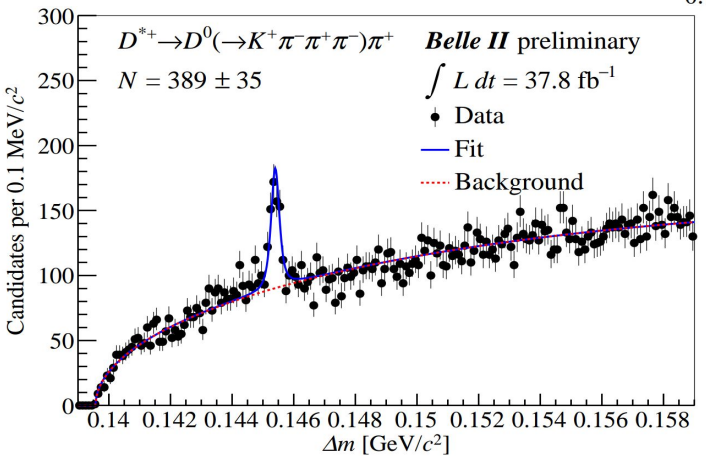
Backup Slides

Charm Physics

D^0 wrong sign decays

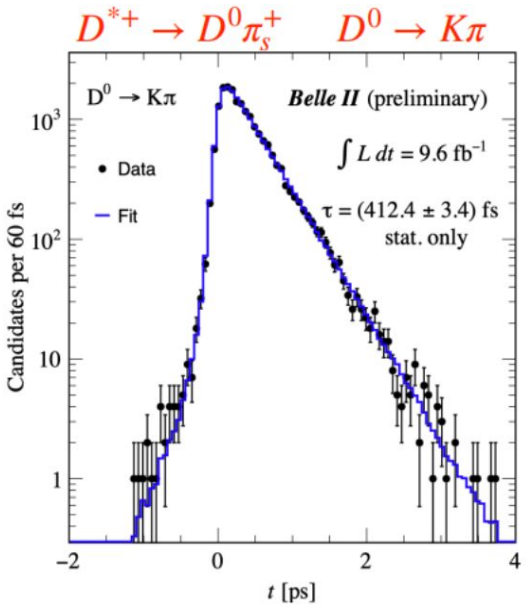


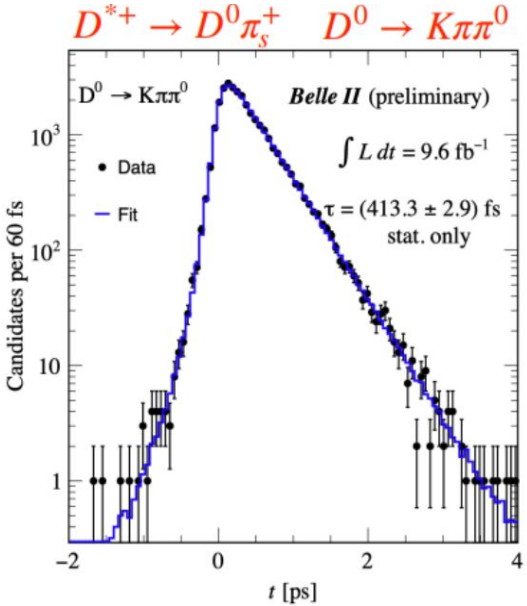


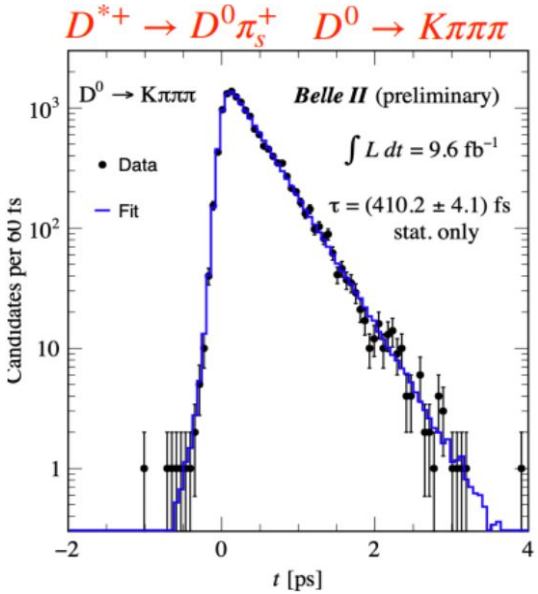


Charm Physics

D^0 lifetime measurement

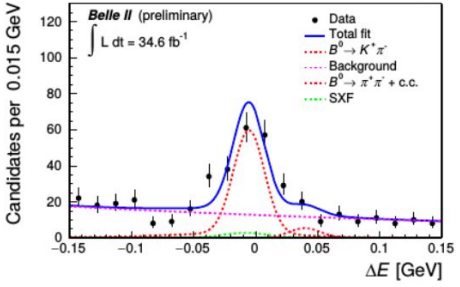




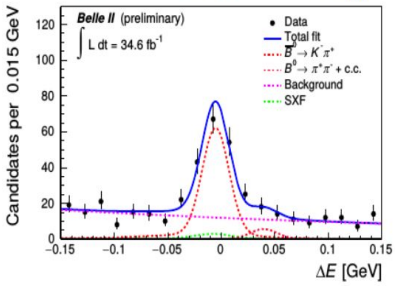


CP Asymmetry in Charmless two body decays

$B^0 \to K^+\pi^-$ 142^{+13}_{-13}

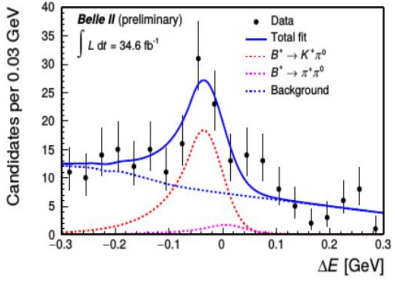


$\bar{B}^0 \to K^-\pi^+$ 147^{+13}_{-13}

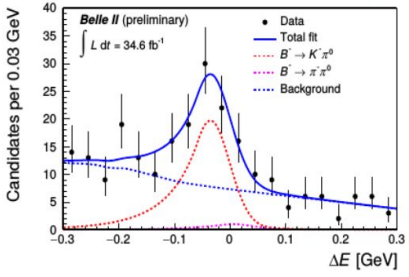


Measured $\mathcal{A}_{CP}$	$0.030 \pm 0.064(stat.) \pm 0.008(syst.)$
PDG	-0.083 ± 0.004

$B^+ \to K^+\pi^0$ 69^{+14}_{-14}

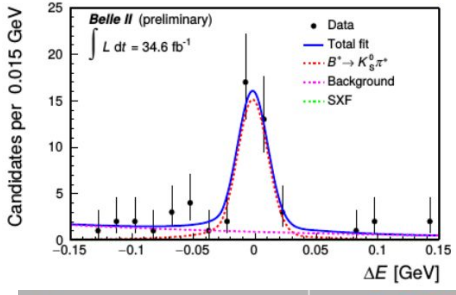


$B^- \to K^-\pi^0$ 75^{+15}_{-15}

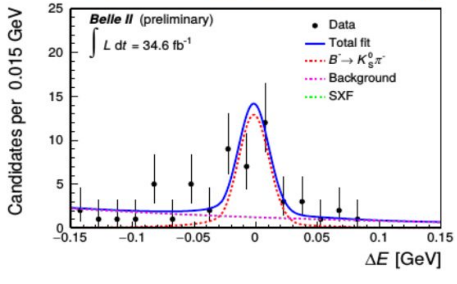


Measured $\mathcal{A}_{CP}$	$0.052^{+0.121}_{-0.119}(stat.) \pm 0.022(syst.)$
PDG	0.037 ± 0.021

$B^+ \to K^0\pi^+$ 35^{+5}_{-5}

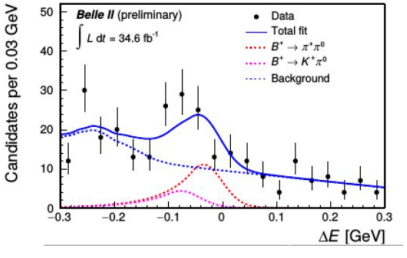


$B^- \to K^0\pi^-$ 30^{+4}_{-5}

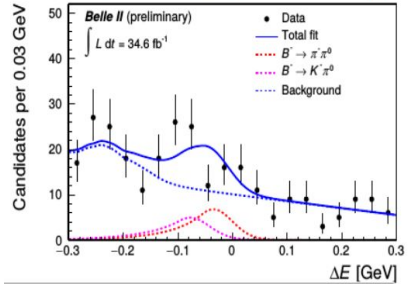


Measured $\mathcal{A}_{CP}$	$-0.072^{+0.109}_{-0.114}(stat.) \pm 0.024(syst.)$
PDG	-0.017 ± 0.016

$B^+ \to \pi^+\pi^0$ 43^{+19}_{-20}

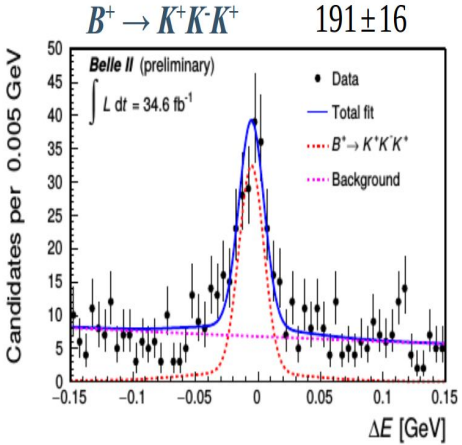


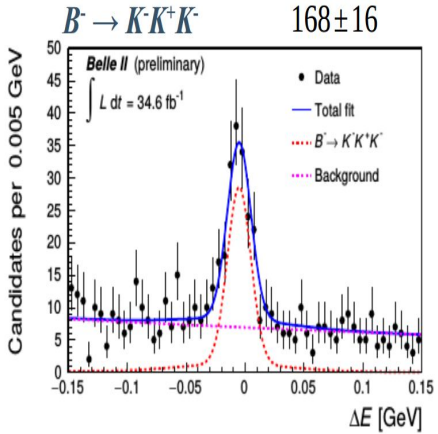
$B^- \to \pi^-\pi^0$ 24^{+13}_{-14}



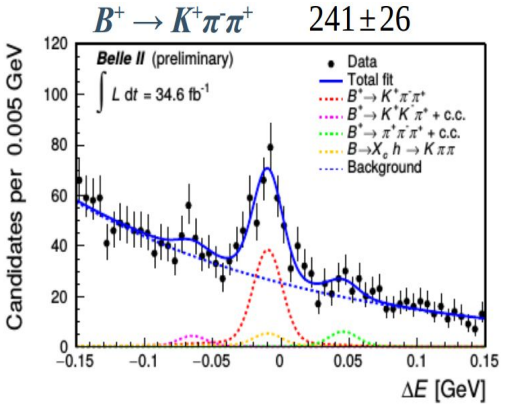
Measured $\mathcal{A}_{CP}$	$-0.268^{+0.249}_{-0.322}(stat.) \pm 0.123(syst.)$
PDG	0.03 ± 0.04

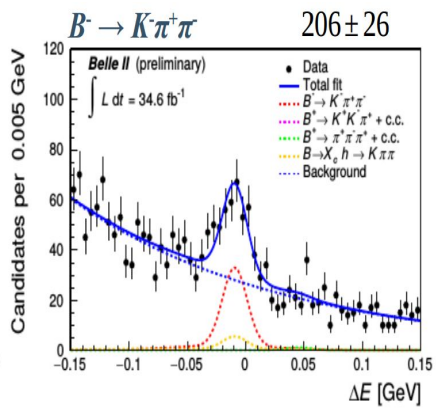
CP Asymmetry in Charmless 3 body decays





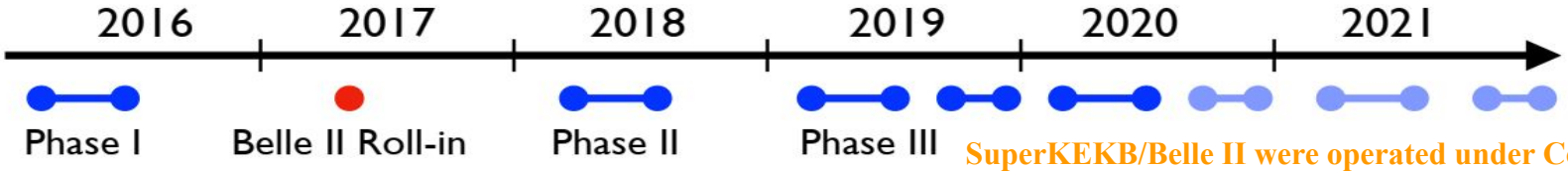
Measured $\mathcal{A}_{CP}$	$-0.049 \pm 0.063(stat.) \pm 0.022(syst.)$
PDG	-0.033 ± 0.008





Measured $\mathcal{A}_{CP}$	$-0.063 \pm 0.081(stat.) \pm 0.023(syst.)$
PDG	0.027 ± 0.008

Belle II Operation History



SuperKEKB/Belle II were operated under Covid-19 pandemic

Phase I

(w/o QCS/Belle II)

- Accelerator tuning w/ single beams

Belle II roll-in (2017.4.17)

Phase II

(w/ QCS/Belle II but w/o VXD)

- Verification of nano-beam scheme
- Understand beam background
- Collision data w/o VXD

1st collision (2018.4.26)

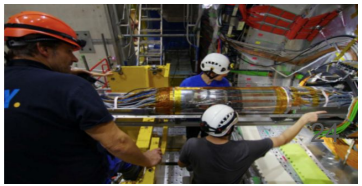
Phase III

(w/ full detector)

- Production of physics data

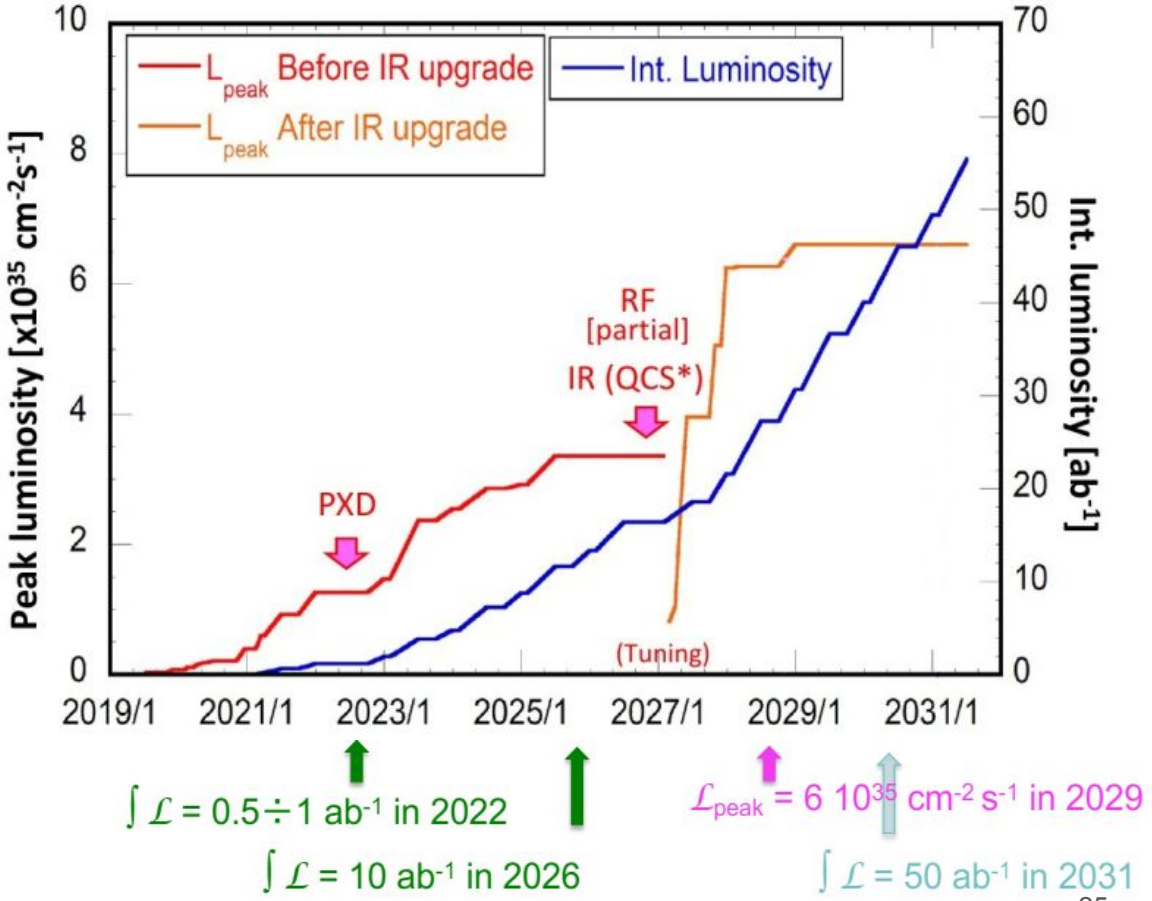
Phase 3 physics run (2019.3.25~)

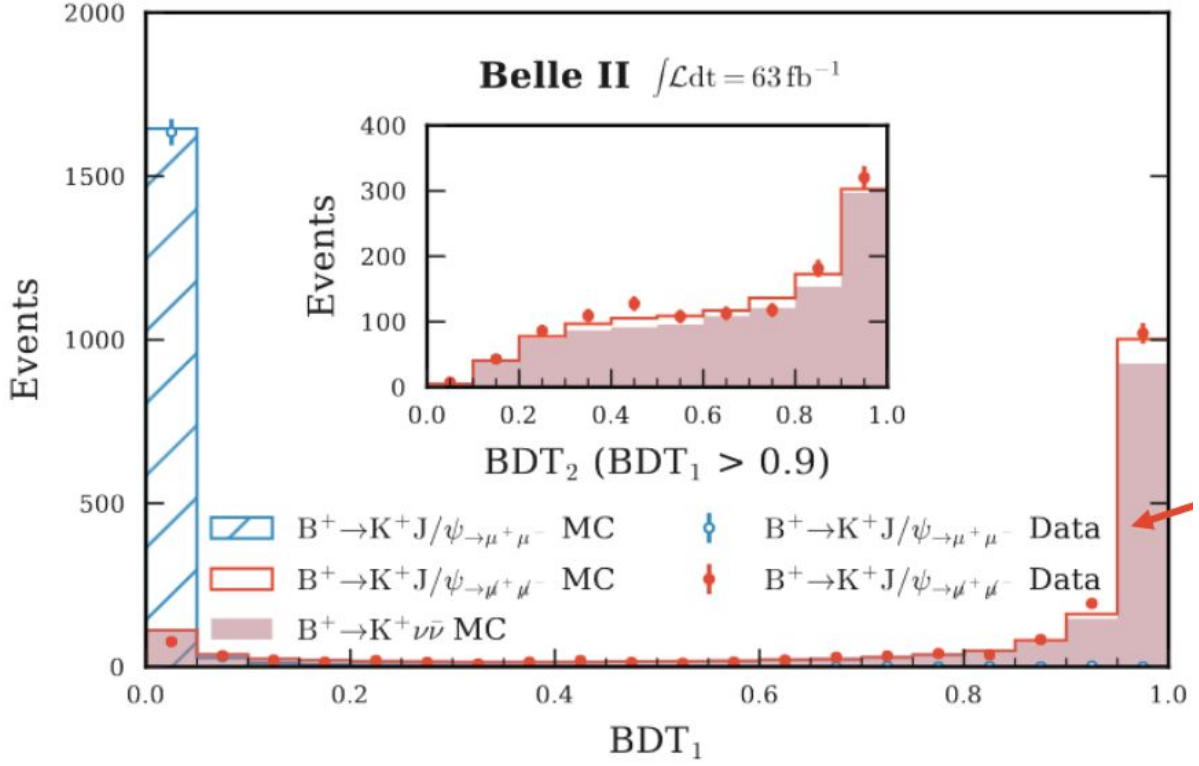
Installation of VXD



Long-term Plans

- Design luminosity: 6 x 10^{35}cm^{-2}s^{-1} after modification of SuperKEKB (partial RF, IR,…) and Belle II.
- Aim to accumulate 50 ab^{-1} around 2030.




Belle II $\int \mathcal{L} dt = 63\,\mathrm{fb}^{-1}$
Events
BDT_1
BDT_2 ($BDT_1 > 0.9$)
$B^+ \to K^+ J/\psi_{\to \mu^+\mu^-}$ MC
$B^+ \to K^+ J/\psi_{\to \mu^+\mu^-}$ MC
$B^+ \to K^+ \nu\bar{\nu}$ MC
$B^+ \to K^+ J/\psi_{\to \mu^+\mu^-}$ Data
$B^+ \to K^+ J/\psi_{\to \mu^+\mu^-}$ Data