Recent results on B and D decay from Belle II

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on behalf of the Belle II collaboration

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Contents

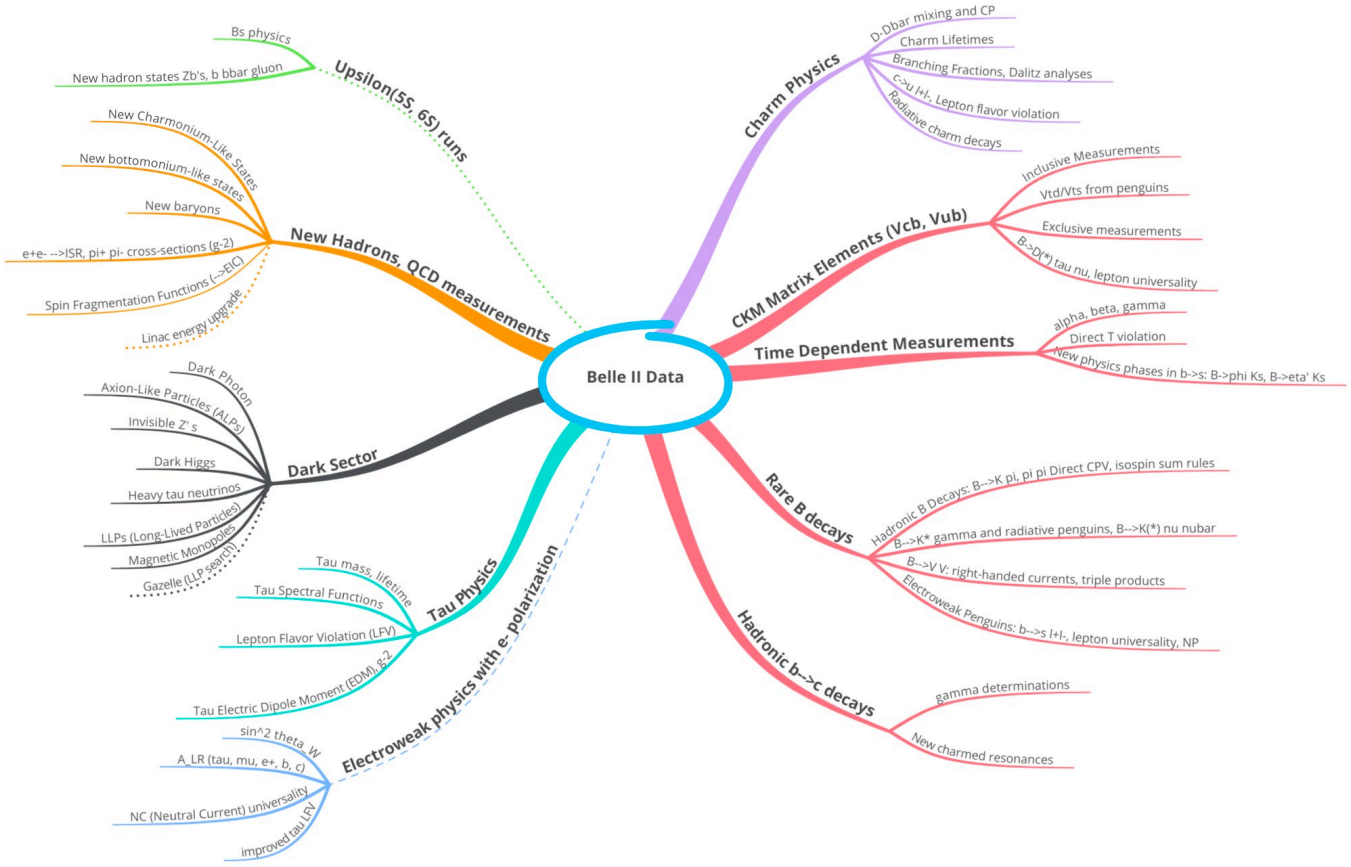
- Introduction
- The charm lifetimes
- CKM and CPV (selected topics)
- Rare B decays
- Summary

Belle II Experiment in a Nutshell

- Belle II Plan: collecting 50 ab^{-1} as $e^+ e^-$ collisions at Upsilon(4S) and nearby
  - About 50 times larger than its predecessor, Belle with 1.05 ab^{-1}
- Upsilon(4S) decays into $B\ \bar{B}$ meson pairs coherently with no additional fragments.
  - High tagging efficiency of B decays (Belle II ~30% vs LHCb ~5%)
  - Full event reconstruction tagging possible
- Direct detection of neutrals such as γ, π^0, K_L.
- A hermetic detector:
  - Detection of neutrinos or invisibles as missing energy/momentum.
- Large τ samples: Search for LFV τ decays at $O(10^{-9})$.
  - Detect both e and μ with similar performance.

Belle II Physics Prospects

- Charm decays
- Next precision CKM matrix
  - Semileptonic B decays (CKM elements)
  - Hadronic B decays (angles and CPV)
  - Time dependent CP violation
- τ physics
- Hadron spectroscopy
- Rare decays, FCNC
- New physics
  - Lepton flavor violation
  - Dark sector, Long lived particles



https://confluence.desy.de/display/BI/Snowmass+2021

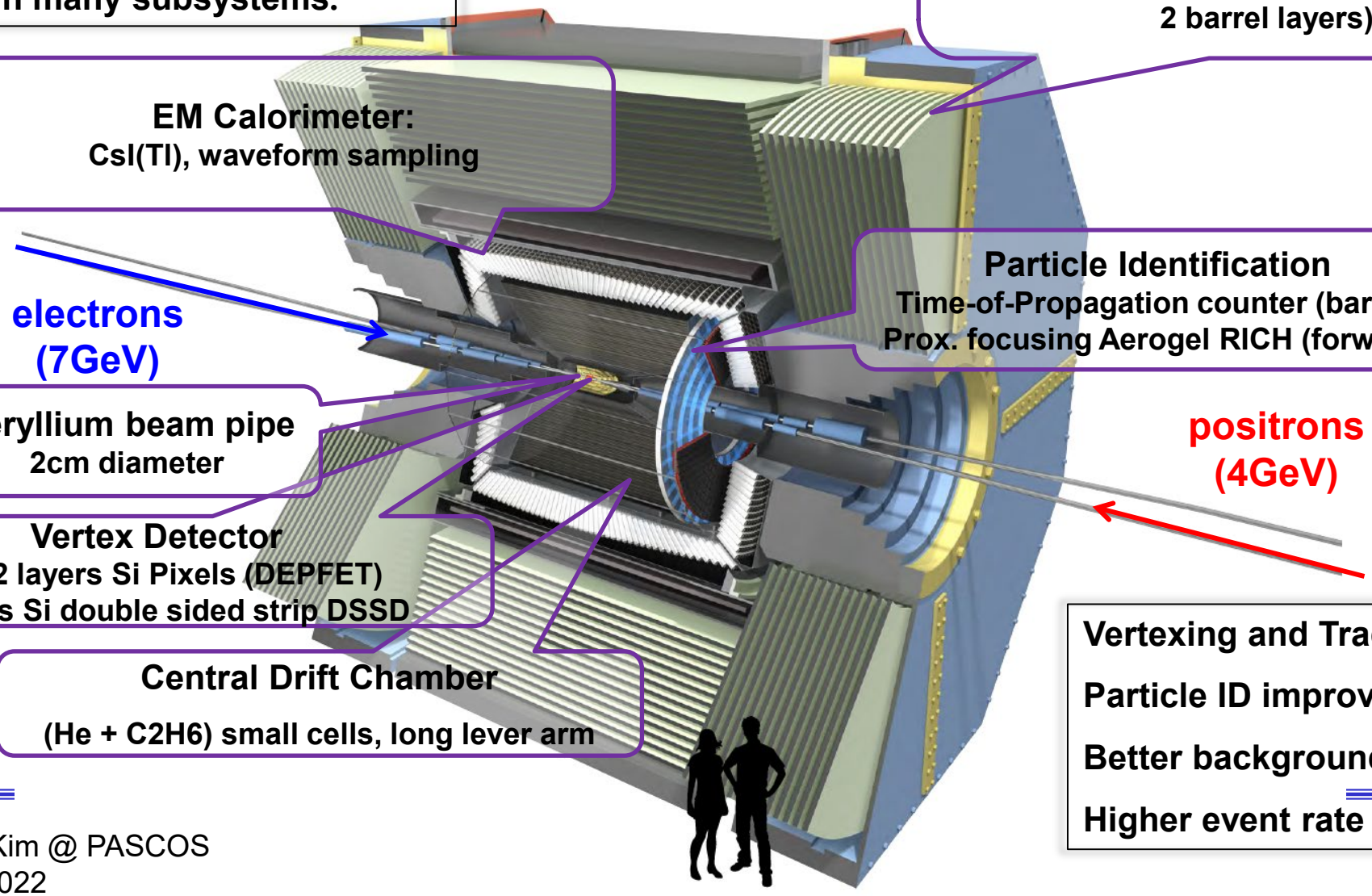
The Belle II Detector

7.4 m

Pixelated photo sensors in TOP/ARICH/KLM
Front-end ASICs in many subsystems.

KL and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling



electrons (7GeV)

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)

Beryllium beam pipe
2cm diameter

positrons (4GeV)

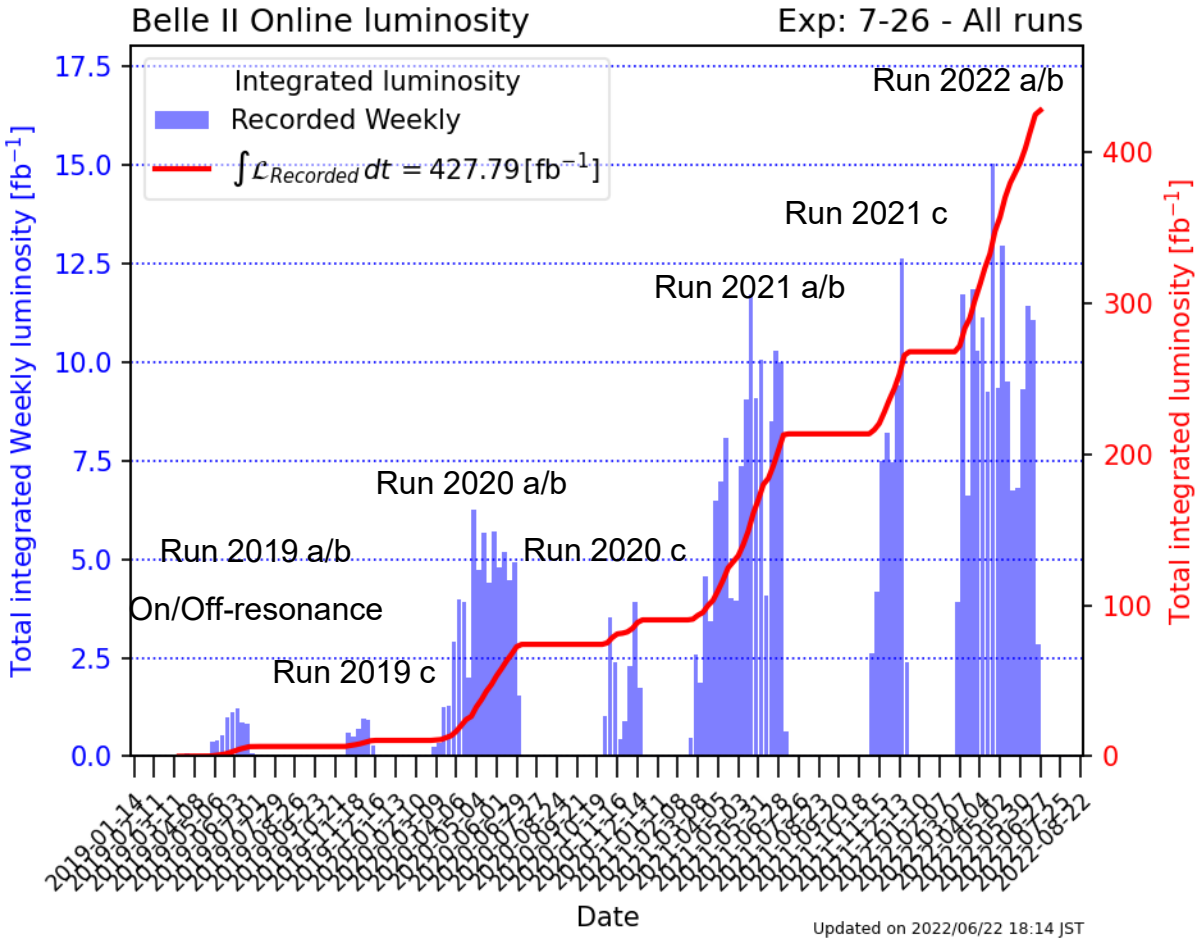
Vertex Detector
1 to 2 layers Si Pixels (DEPFET)
4 layers Si double sided strip DSSD

Central Drift Chamber
(He + C2H6) small cells, long lever arm

Vertexing and Tracking Improved
Particle ID improved
Better background insensitivity
Higher event rate

SuperKEKB Luminosity: Current Status

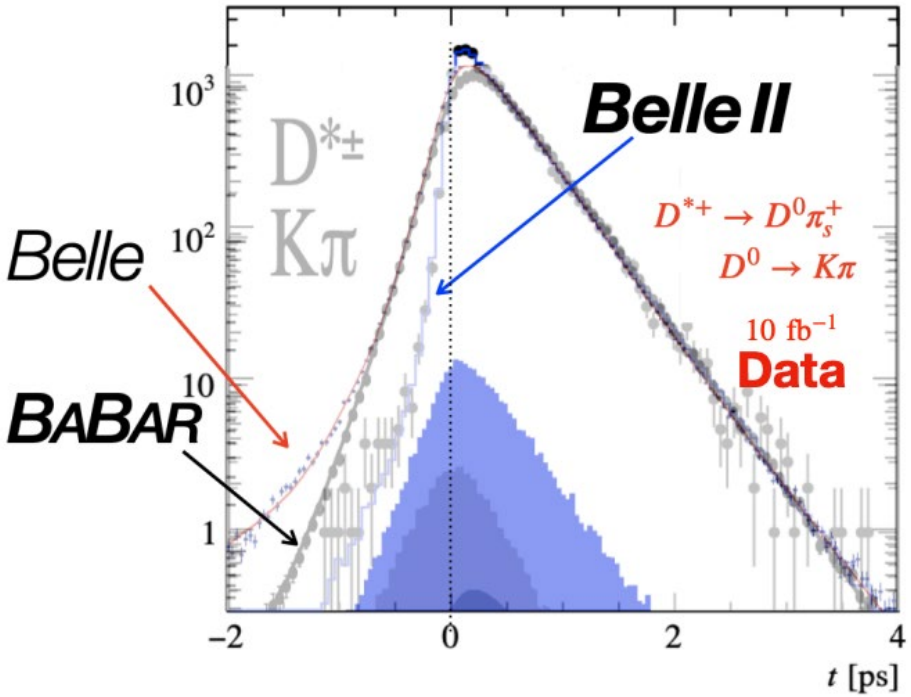
- After the commission phases, Phase III started spring 2019.
- Reclaimed the luminosity record on June 2020! (Previously held by LHC.)
- Spring/summer 2022 run ended June.
  - Current peak luminosity record at $\boldsymbol{L_{peak} = 4.7 \times 10^{34} cm^{-2} s^{-1}}$, the current world record on June 22nd.
  - Current integrated luminosity at $\int L_{recorded} dt = 427.79\ fb^{-1}$. (~ Babar, ~ ½ Belle)
- Long shutdown 1 (LS1) started for upgrades (beam pipe, pixel, TOP PMT).



THE CHARM LIFETIMES

Charm Particle Lifetime

- Charm particles @ low-energy QCD calculation (non-perturbative and high order correction). The effective models do have uncertainties.
- Measurements of charm lifetimes can test the models.

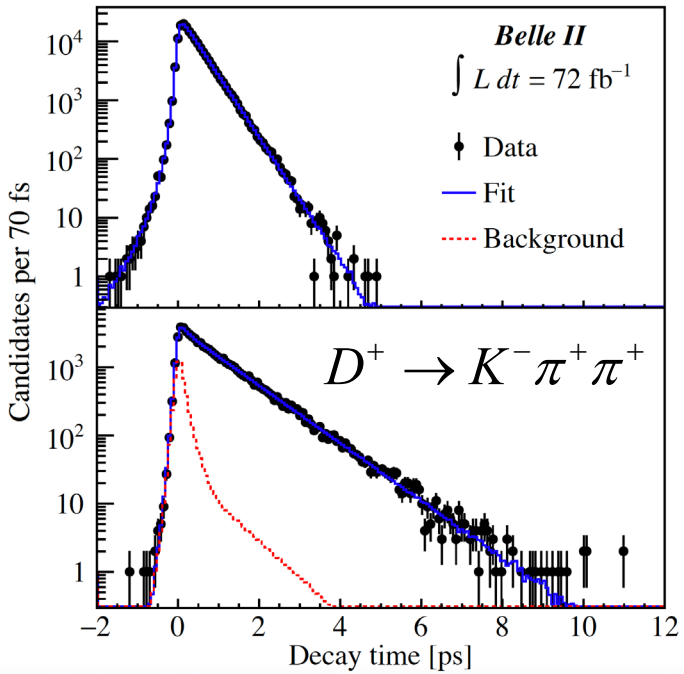


- At SuperKEKB, $\sigma_{c\bar{c}} \sim \sigma_{b\bar{b}}$. Large charm sample.
- $e^+ e^-$ collision gives clean environment. Less bias.
- Small interaction region and the new Belle II vertex detector give strong constraints and better resolutions.
- A great opportunity to measure the world best charm lifetimes.

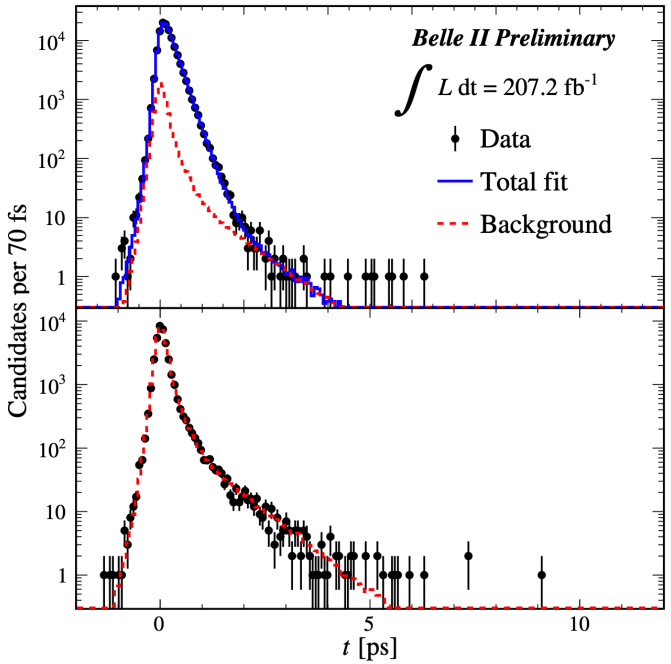
Phys. Rev. Lett. 127 (2021), 211801

D^0, D^+, Λ_c^+, Ω_c^0 Lifetimes

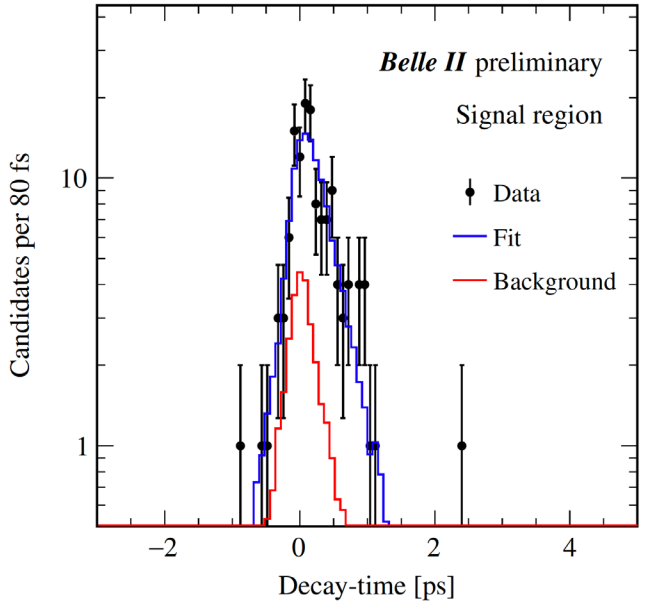
$D^0 \to K^-\pi^+$



$\Lambda_c^+ \to pK^-\pi^+$



$\Omega_c^0 \to \Omega^-\pi^+$, $\Omega^- \to \Lambda^0 K^-$, $\Lambda^0 \to p\pi^-$



Mode	meas. (fs)	stat	syst	Ref.
D^0	410.5	1.1	0.8	Phys. Rev. Lett. 127 (2021), 211801
D^+	1030.4	4.7	3.1	
Λ_c^+	203.2	0.9	0.8	arXiv: 2206.15227v1 preliminary
Ω_c^0	243	48	11	ICHEP 2022 preliminary

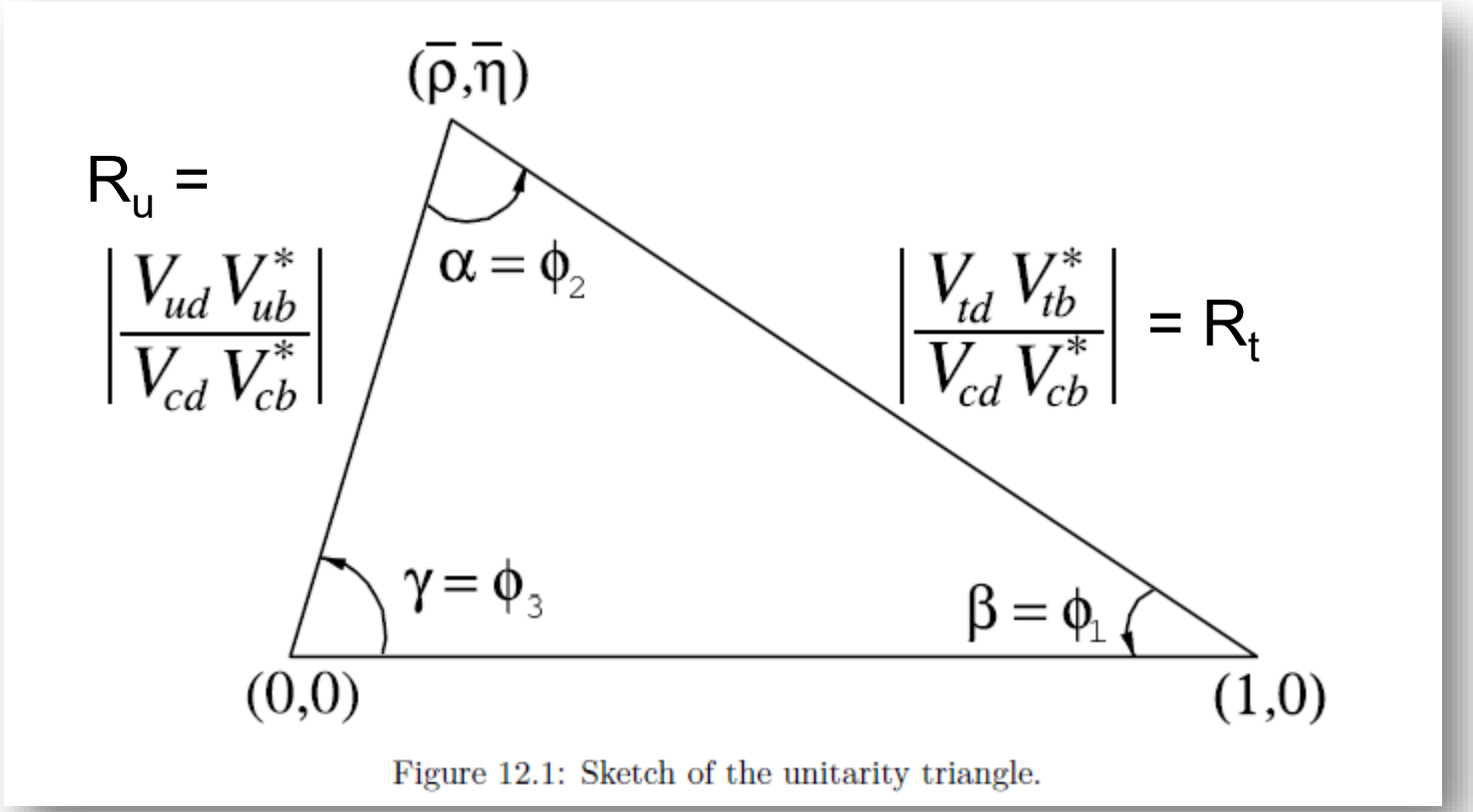


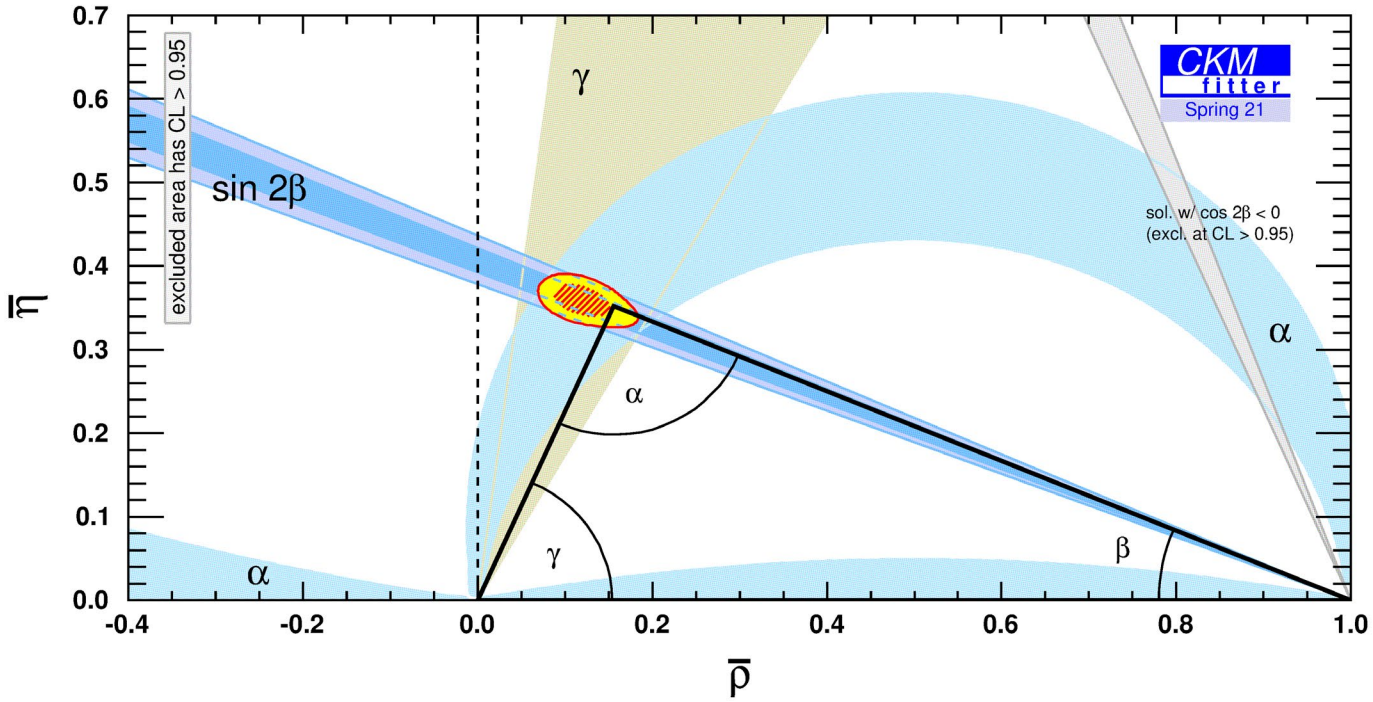
Figure 12.1: Sketch of the unitarity triangle.

Prog. Theor. Exp. Phys. 2020 083C01 (2020)
aka PDG 2020

CKM AND CPV

Why CKM Matrix?

- Unitary triangle constraints are powerful test of the SM.
  - Precision on α and γ angles are much less than β.
- Predicting rare decays involves $V_{qq'}$. Needed for NP searches.
  - Use semi-leptonic, leptonic decays of mesons.



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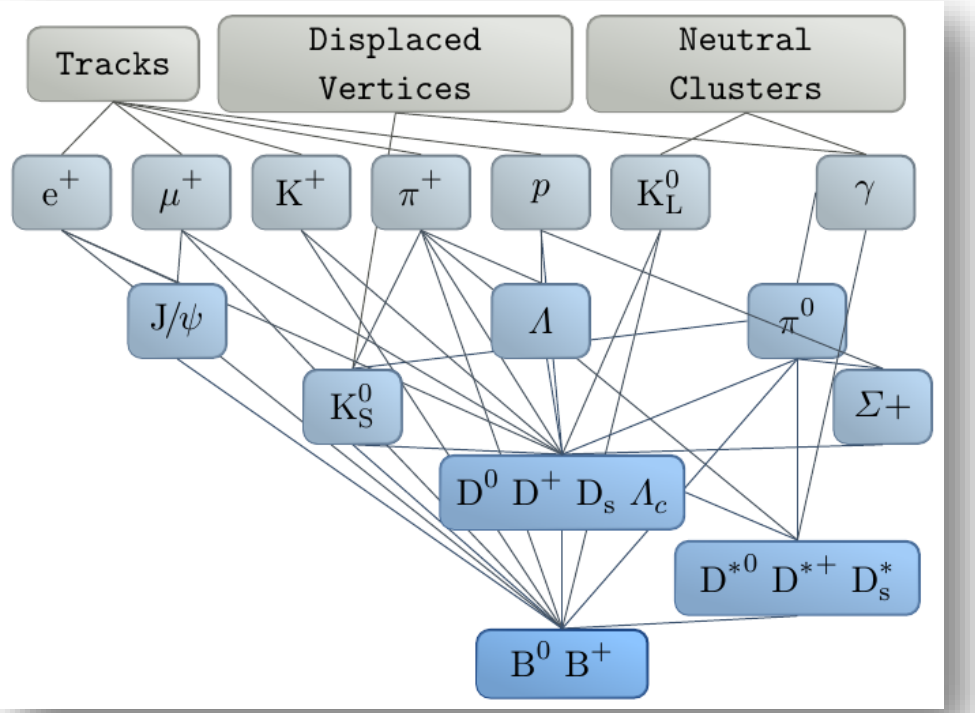
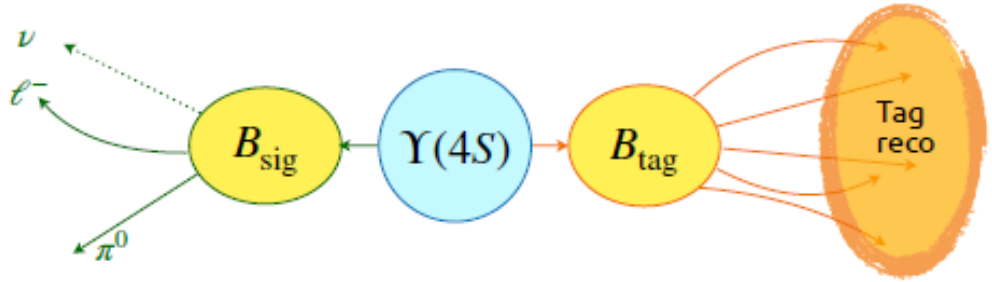
Full Event Interpretation



Hierachial reconstruction is performed to obtain B (tag) meson exclusively. Then use the Upsilon(4S) constraint to get the B (sig) meson.



- Traditionally, at Upsilon(4s), one B (tag) is reconstructed first. The rest of the event is considered as a signal B. https://arxiv.org/abs/2008.02707
- An improved tool (FEI) is developed based on Boosted Decision Tree. T. Keck et al., Comput. Softw. Big Sci. 3, 6 (2019)
- MVA based. O(10^4) decay channels.
- $\varepsilon_{had} \approx 0.5\%$ and $\varepsilon_{SL} \approx 2\%$

The CKM Matrix elements

- The ~ 3σ tension between inclusive and exclusive measurements in $|V_{cb}|, |V_{ub}|$ is still going on.
- Preliminary Belle II results, based on 190/fb samples.

Matrix elem.	Signal B	Other B	Meas.	Ref.
$\|V_{cb}\|$	$B \to Dl\nu, (l = e, \mu)$	Untagged	$(38.53 \pm 1.15\ (stat. + sys. + theo.)) \times 10^{-3}$	ICHEP 2022
	$B^0 \to D^* l\nu, (l = e, \mu)$	Hadronic	$(38.2 \pm 2.8\ (stat. + sys. + theo.)) \times 10^{-3}$	Moriond 2022
$\|V_{ub}\|$	$B^0 \to \pi l\nu, (l = e, \mu)$	Untagged	$(3.54 \pm 0.12 \pm 0.15 \pm 0.16) \times 10^{-3}$	ICHEP 2022
	$B \to \pi e\nu$	hadronic	$(3.88 \pm 0.45(stat. + sys. + theo.)) \times 10^{-3}$	Moriond 2022

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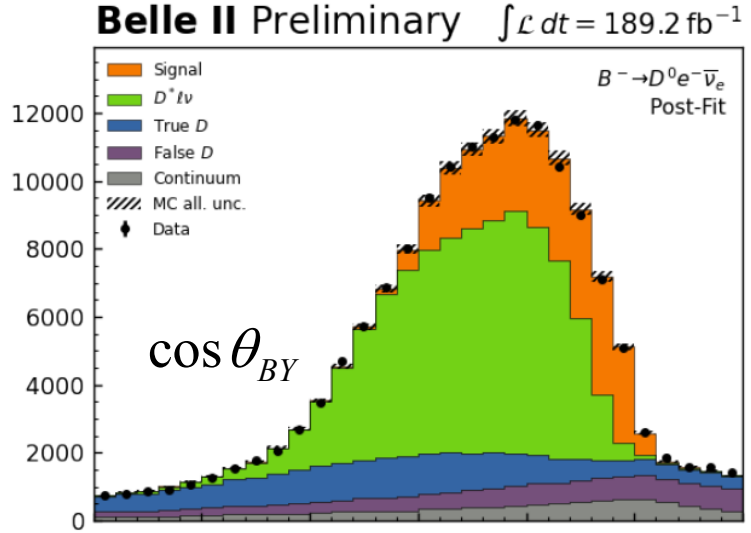
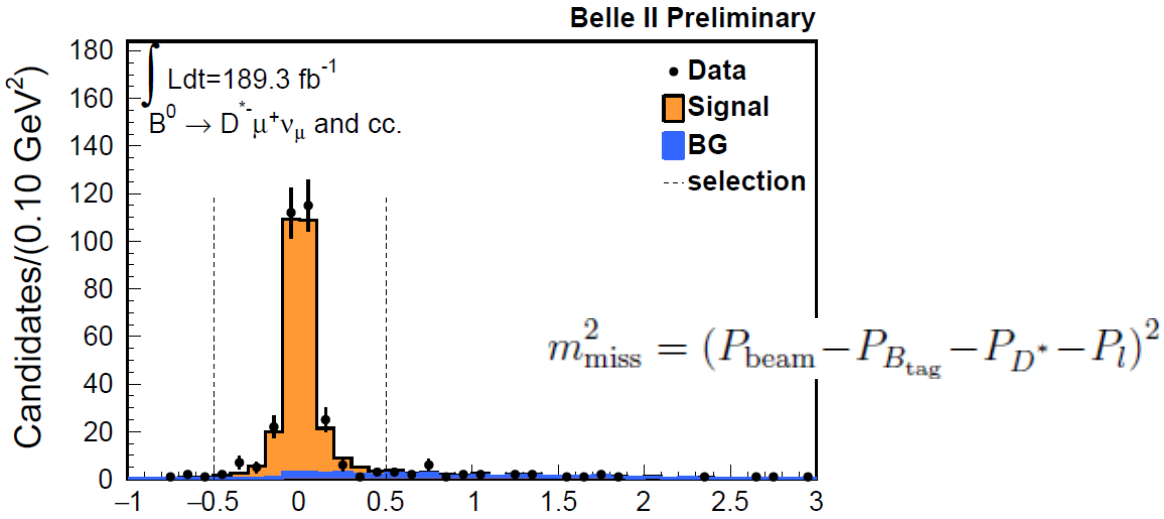
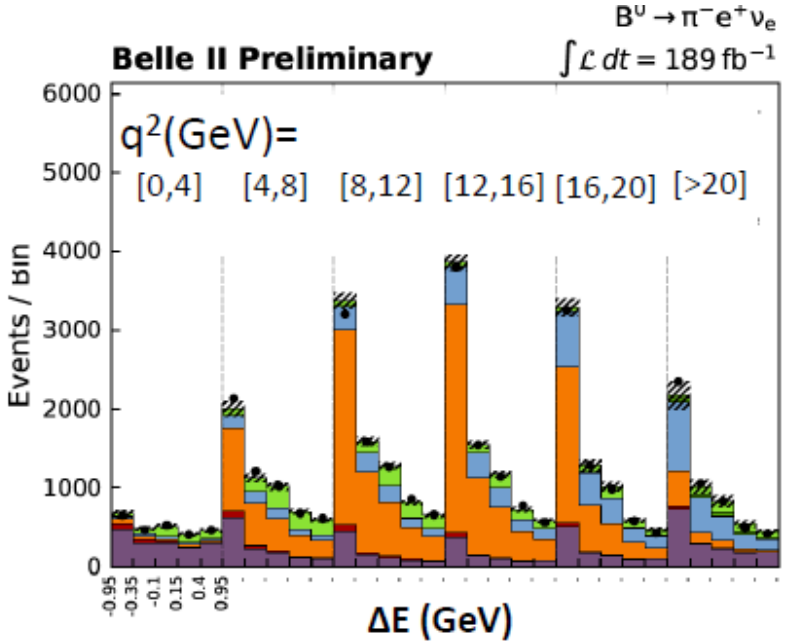
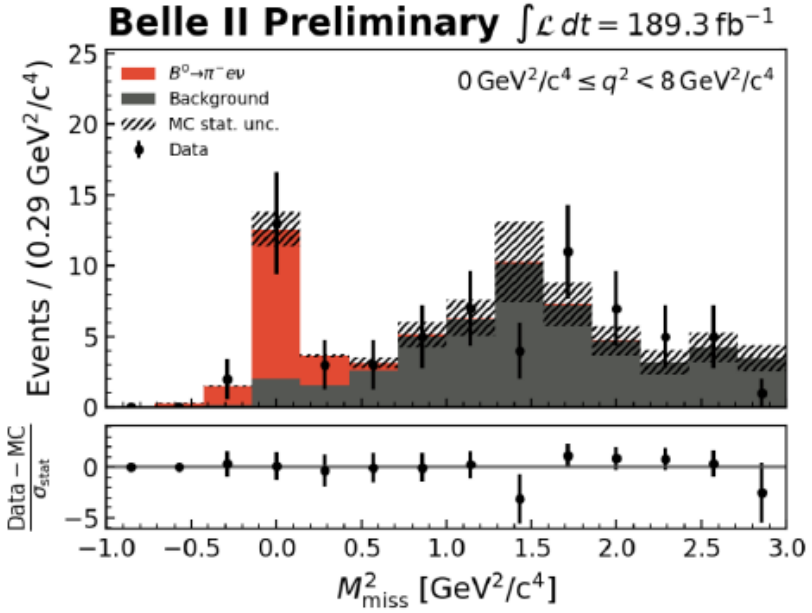
Signal Selection of SL modes.

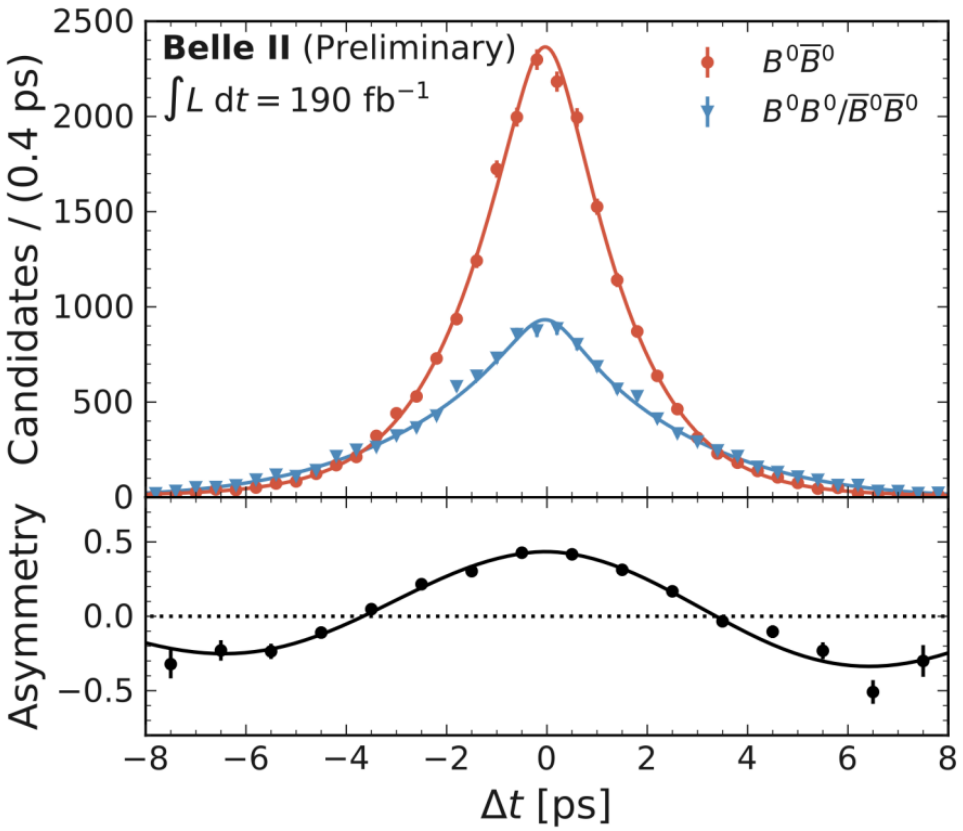




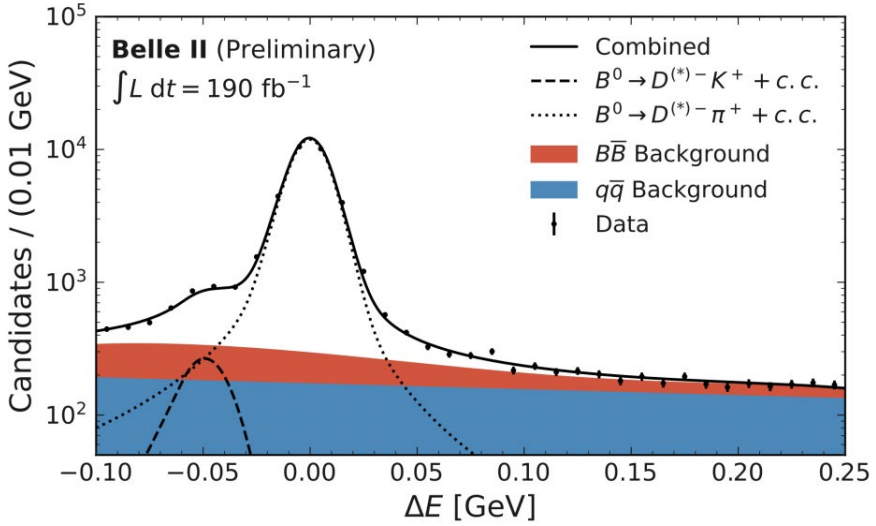




Time Dependent CPV and Mixing



- 190/fb sample was studied to extract B0 lifetime and mixing frequency.
- 30k B0 to D(*)- pi(+) decays are used.
- The current results is not competitive with Belle yet, but the svstematics has been reduced.



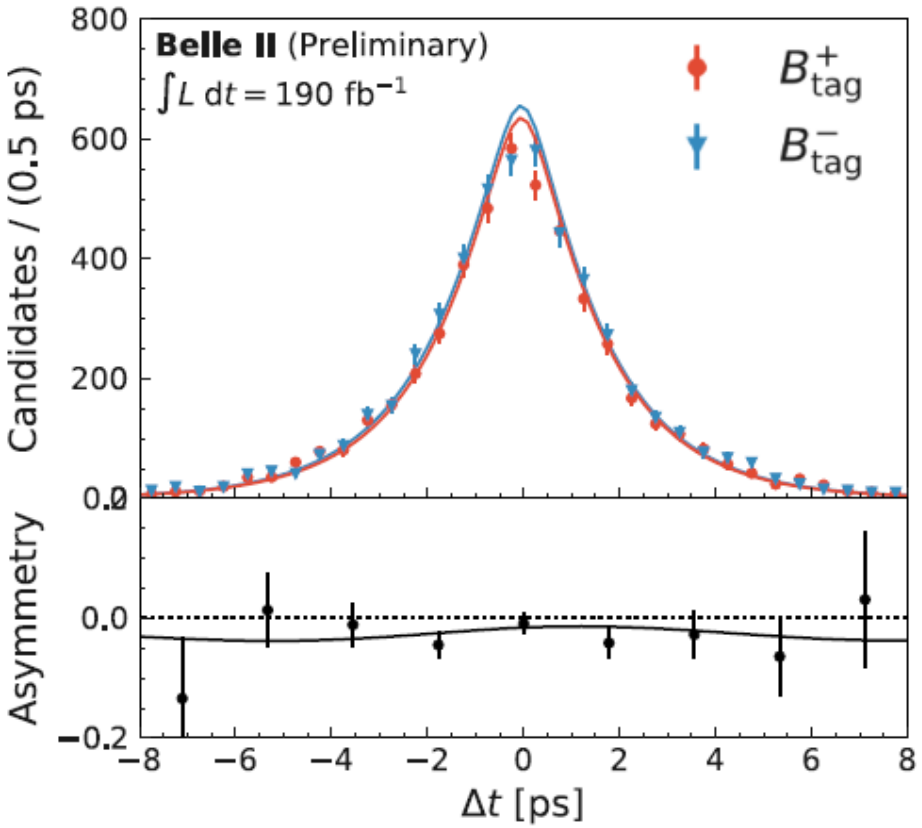
Belle II: $\tau_{B^0} = 1.499 \pm 0.013(stat) \pm 0.008(syst)\,ps$ W. A.: $1.510 \pm 0.004\,ps$

Belle II: $\Delta m_d = 0.516 \pm 0.008(stat) \pm 0.005(syst)\,/\,ps$ W. A.: $0.50665 \pm 0.0019\,/\,ps$

Time Dependent CPV and Mixing

sin2ϕ_1 validation

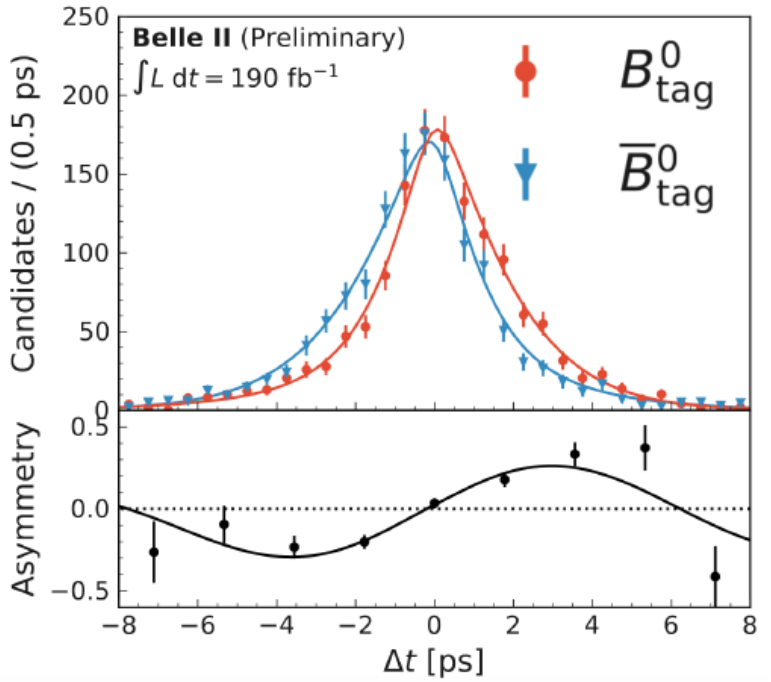
Signal yield: 10028 ± 105 $B^+ \to J/\psi K^+$ decays



sin2ϕ_1 results

Apply analysis to $B^0 \to J/\psi K_s^0$ sample

Signal yield: 2774 ± 55



S_{CP} = 0.720 ± 0.062 (stat.) ± 0.016 (syst.)

A_{CP} = 0.094 ± 0.044 (stat.) $^{+0.042}_{-0.017}$ (syst.)

nt

RARE B DECAYS

Rare B decays: Overview

- FCNC b $\rightarrow$ s transitions are suppressed in the SM. A good are to look for NP.
- The 10 to 30% uncertainty in the SM BR (10^{-5} to 10^{-7}) can be supplemented by ratios, asymmetries, and angular distributions.
- An excellent place to test LFU and LFV.
  - Belle II have similar detector performances between electron and muon.
  - Currently Belle II is statistically limit, but will become competitive with a few /ab.

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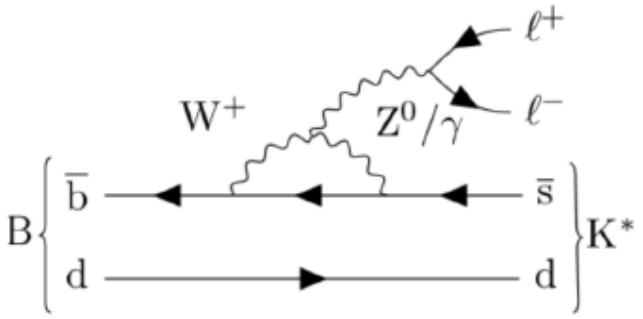
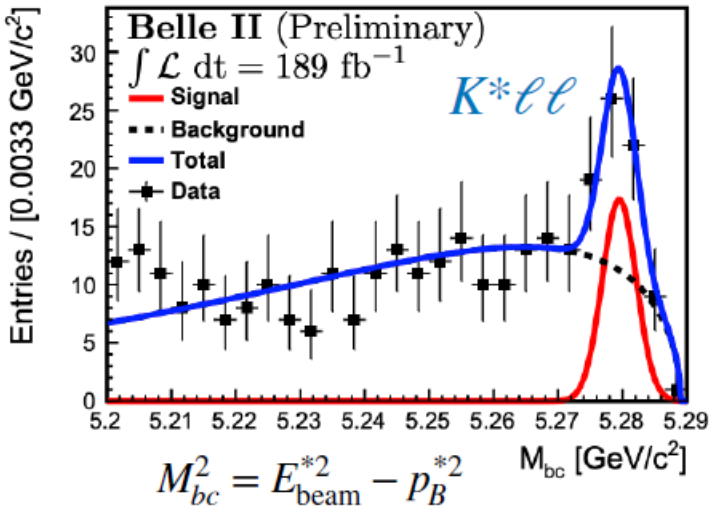
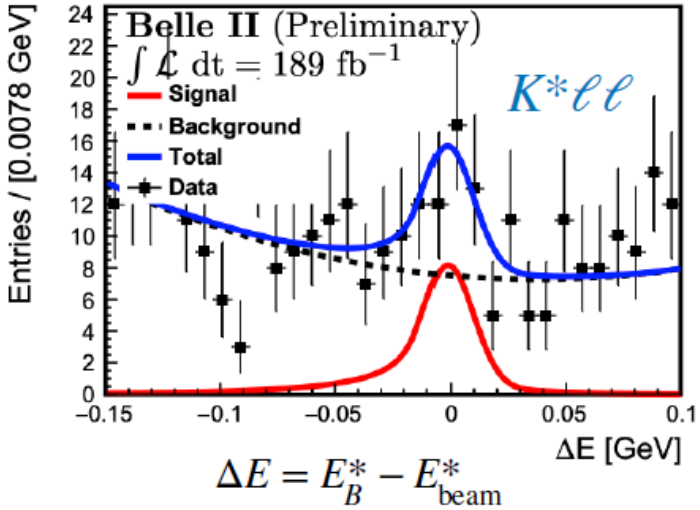
$B^+ \to K^* ll$



- Current R_{K^*} measurements have a 2-3 σ discrepancies.
- The first Belle II report on $190\ fb^{-1}$ sample.
- Background suppressed by BDT, and veto on J/ψ, ψ(2S) mass.
- 2D fit to M_{bc} and delta E
- The current results are statistically limited.

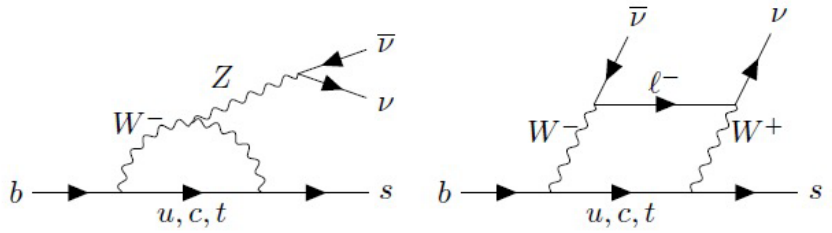
Modes	Belle II	WA
$B \to K^* \mu^+\mu^-$	$(1.19 \pm 0.31^{+008}_{-0.07}) \times 10^{-6}$	$(1.06 \pm 0.09) \times 10^{-6}$
$B \to K^* e^+e^-$	$(1.42 \pm 0.48 \pm 0.09) \times 10^{-6}$	$(1.19 \pm 0.20) \times 10^{-6}$
$B \to K^* l^+l^-$	$(1.25 \pm 0.30^{+008}_{-0.07}) \times 10^{-6}$	$(1.05 \pm 0.10) \times 10^{-6}$





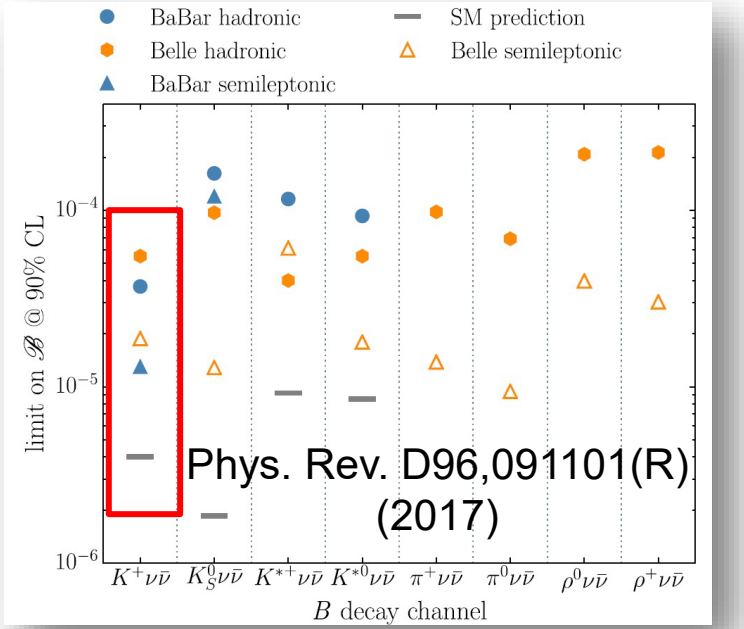
arXiv: 2206.05946

$B^+ \to K^+ \nu\nu$ with Inclusive Tagging

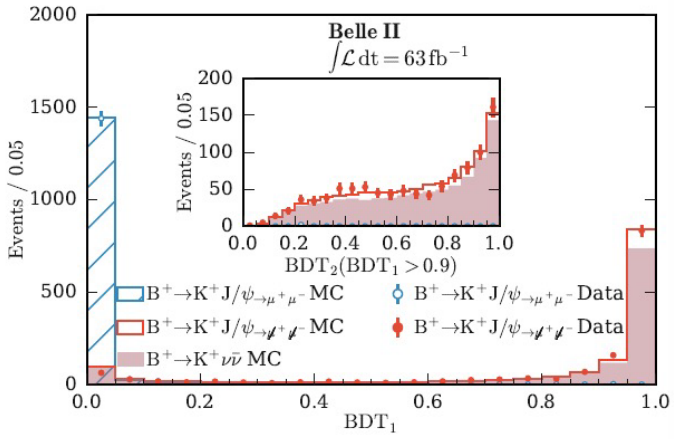


(a) Penguin diagram (b) Box diagram

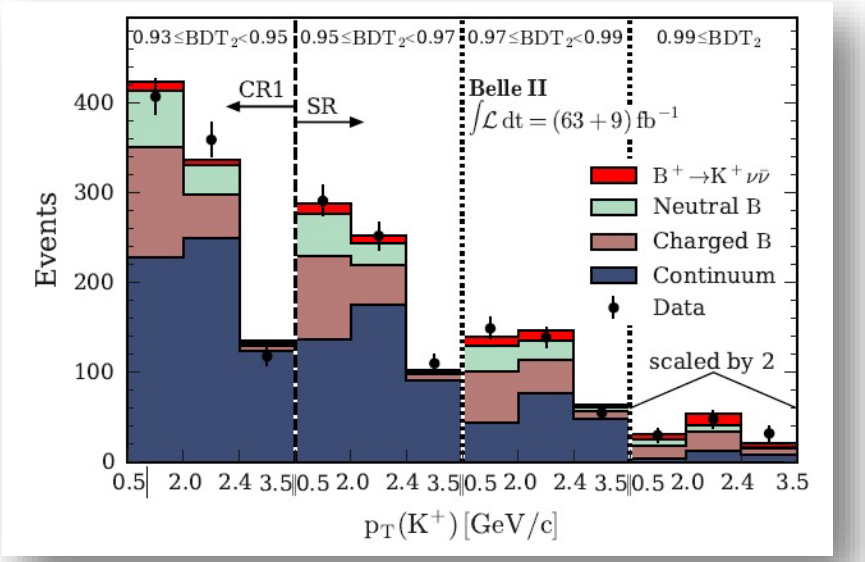
FIG. 1: Lowest-order quark-level diagrams for the $b \to s\nu\bar{\nu}$ transition in the SM.



Phys. Rev. D96,091101(R) (2017)



Boosted Decision Tree Outputs



- The Belle II measurement at $63\ fb^{-1}$ is comparable to the previous Babar/Belle measurements.
- Next step : $190\ fb^{-1}$ sample, and extra channels (K*, K_S)

Babar	$< 1.6 \times 10^{-5}$ (90% C.L.)	Phys. Rev. D87,112005 (2013)
Belle	$< 1.9 \times 10^{-5}$ (90% C.L.)	Phys. Rev. D96,091101(R) (2017)
Belle II	$< 4.1 \times 10^{-5}$ (90% C.L.)	https://arxiv.org/abs/2105.05754

PhysRevLett.127.181802

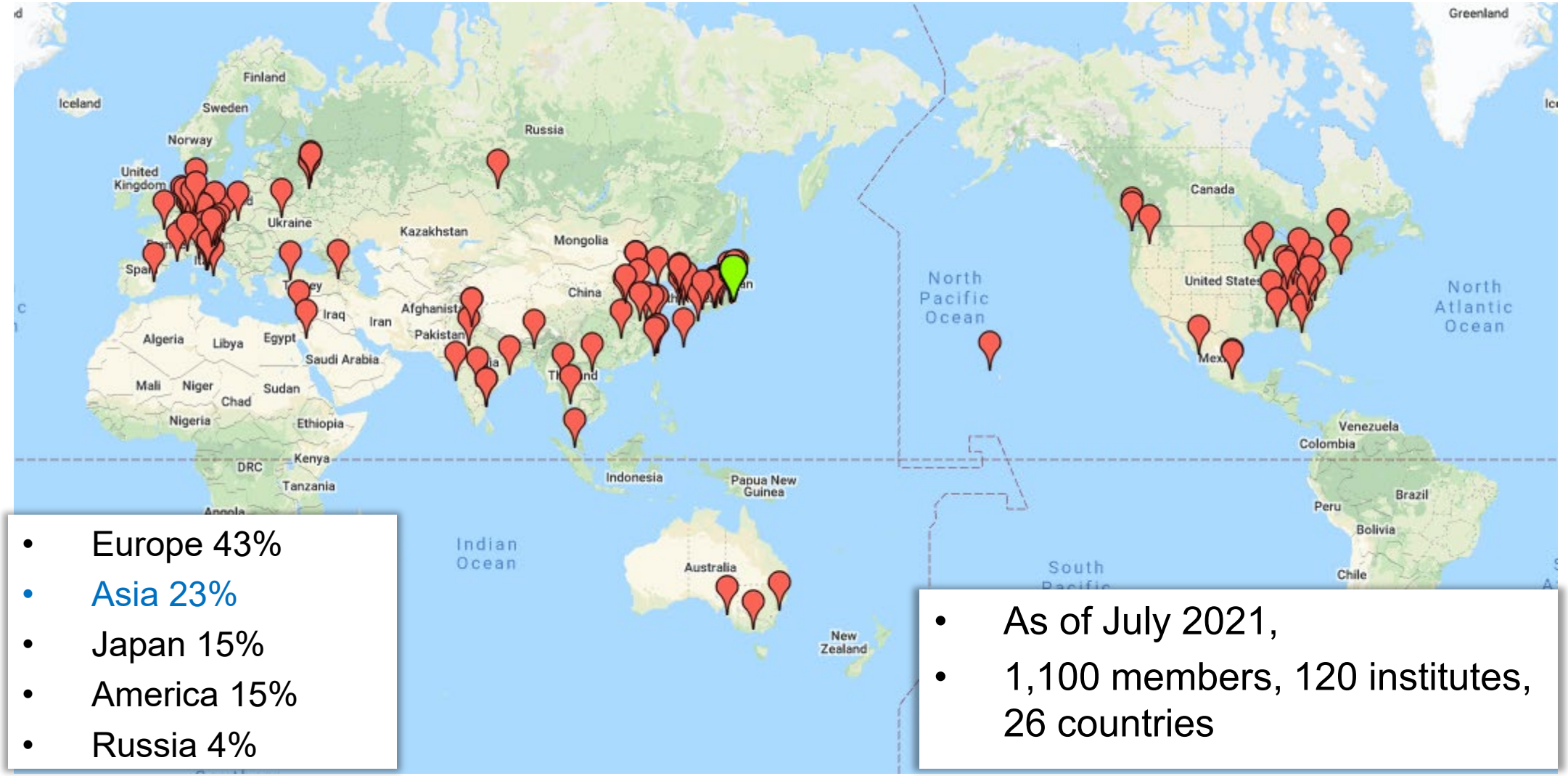
SUMMARY

Summary

- SuperKEKB has achieved $L_{peak} = 4.7 \times 10^{34} cm^{-2} s^{-1}$, the world record on June 22nd.
  - It is a super B factory now.
- Belle II has started producing new results, including a world leading results in charm lifetime.
  - More updates are coming with Phase III data
- Belle II started producing results on many intertesing B physics.
  - Reports at ICHEP 2022, Moriond 2022.
- This is a very exciting time to do flavor physics, looking for physics beyond the Standard Model.

EXTRA

The Belle II Collaboration

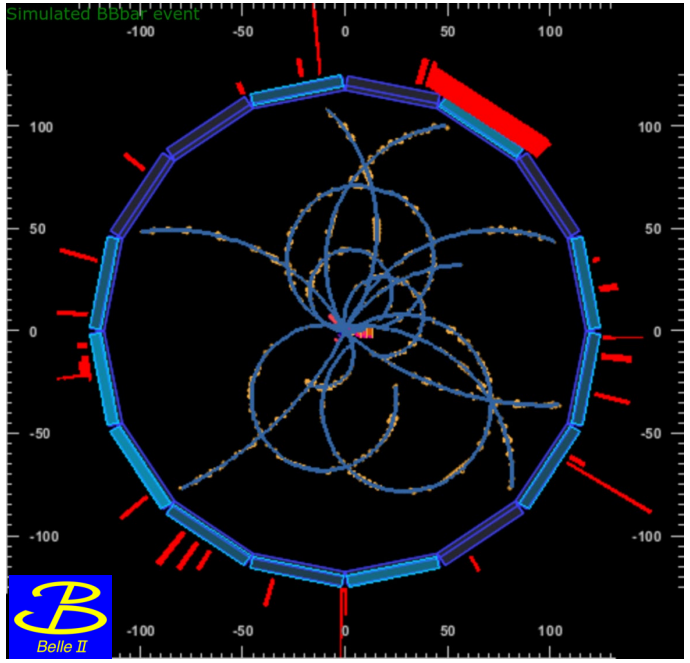


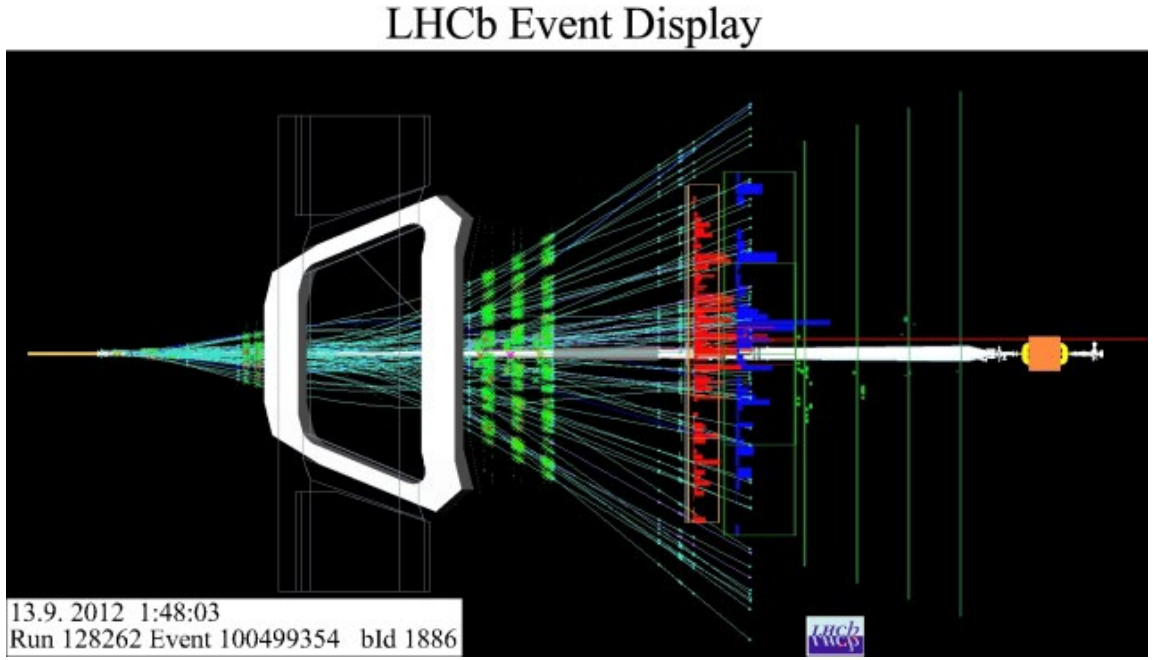
- Europe 43%
- Asia 23%
- Japan 15%
- America 15%
- Russia 4%

- As of July 2021,
- 1,100 members, 120 institutes, 26 countries

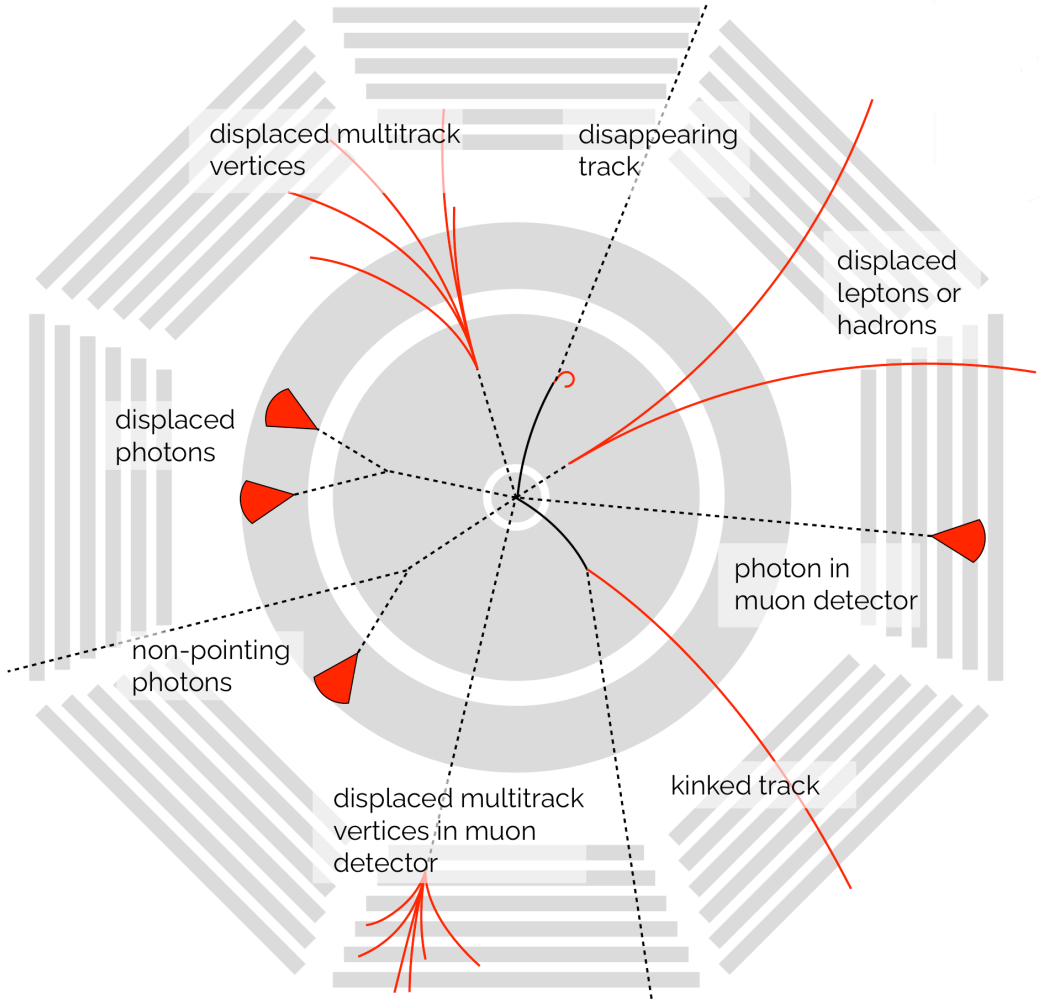
Belle II and LHCb

- Belle II and LHCb have different systematics
  - Two experiments are required to establish NP.
  - LHCb: large $b\bar{b}$ cross-section (LHCb 1 fb^{-1} ~ Belle II 1 ab^{-1}). Good sensitivity and S/N with di-muon modes and charged tracks with a vertex.





Long Lived Particles



- December 2020, FSP Workshop focusing on feasibility studies

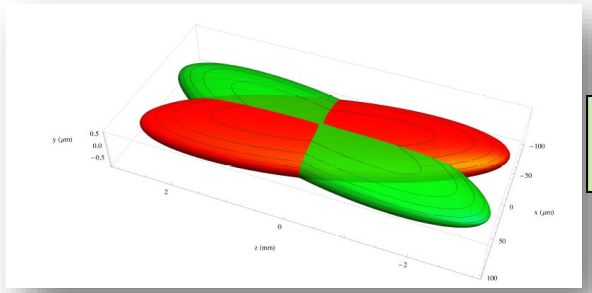
  https://indico.belle2.org/event/2920/
- Additional displacement vertex trigger is needed to enhance the LLP sensitivities.
- A Snowmass White Paper including a proposal of the Gazelle detector

  https://www.snowmass21.org/docs/files/summaries/RF/SNOWMASS21-RF6_RF0_Torben_Ferber-020.pdf

KEKB to SuperKEKB: Accomplished

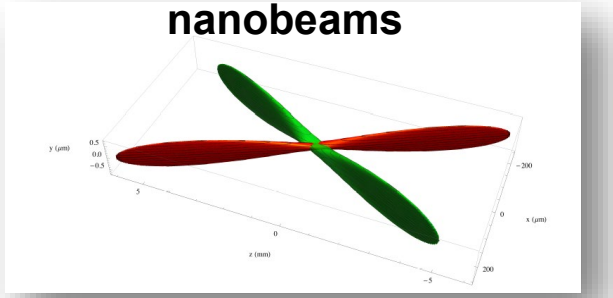
- Nano beam scheme + Crab waist optics
- Target: vertical beta function β_y^* 5.9 mm (KEKB) to 0.3 mm (SuperKEKB)
- Increase beam currents $I_{e\pm}$
- Increase beam-beam interaction ξ_y

KEKB beams



Beam crossing angle 22mrad

SuperKEKB nanobeams



Beam crossing angle 83mrad

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