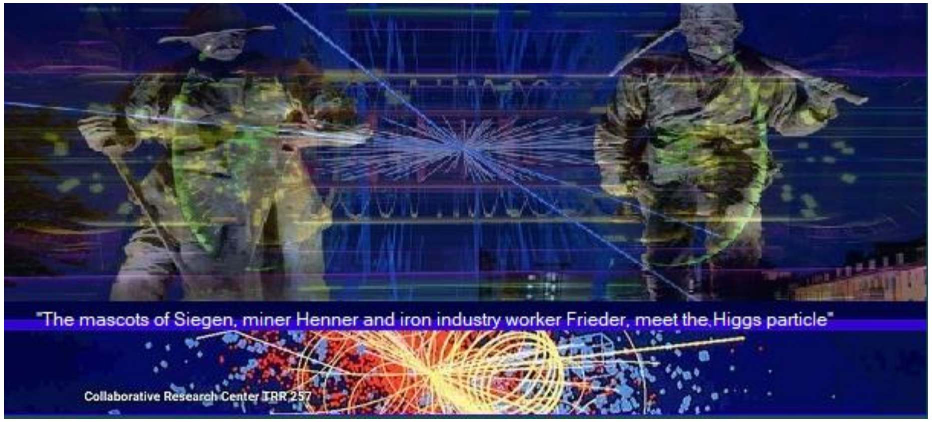
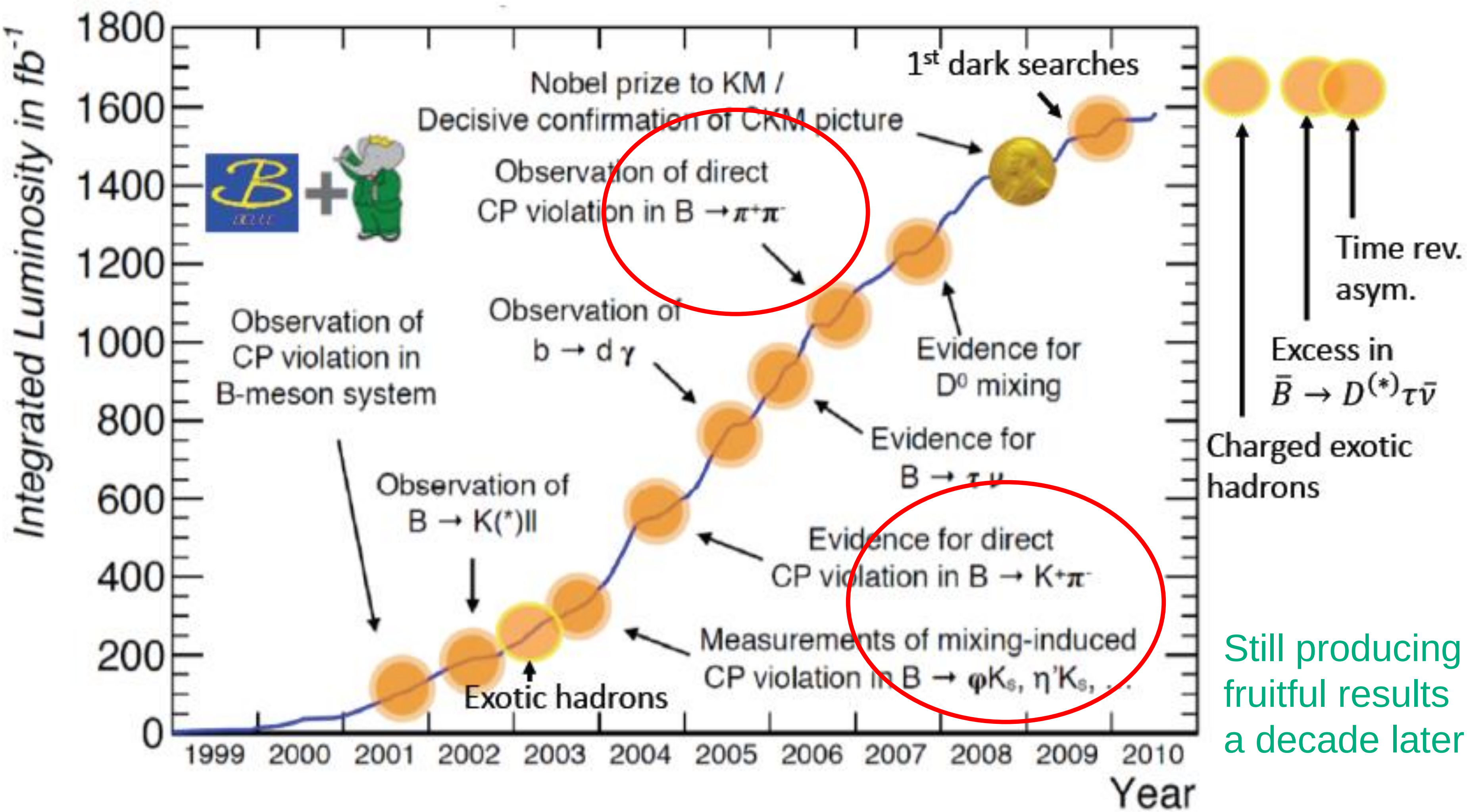
Charmless B decay at Belle II

- Introduction
- SuperKEKB
  & BelleII
- $B \to \eta' K$
- $B^0 \to K^0 \pi^0$
- $B^+ \to \rho^+ \rho^0$
- Summary



M.-Z. Wang
on behalf of Belle II Collaboration
2022/6/2@
Non-leptonic B meson decays workshop

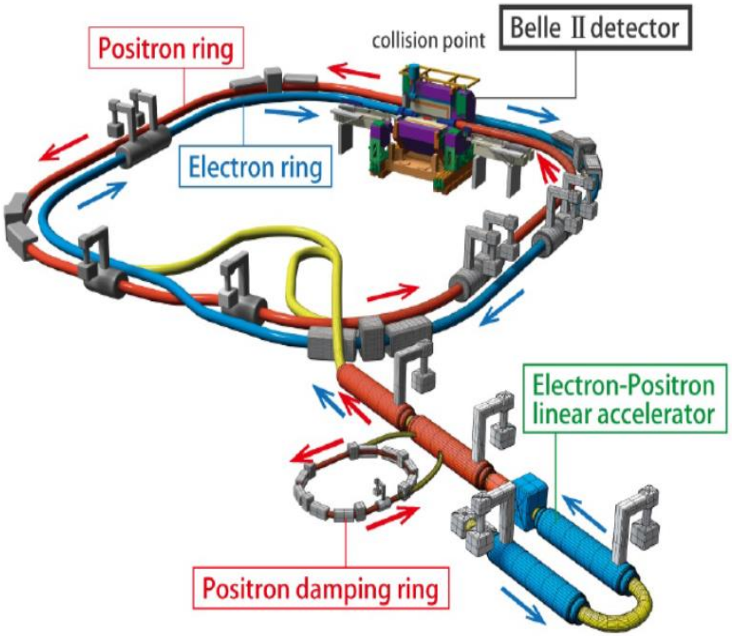
Findings from B-factories



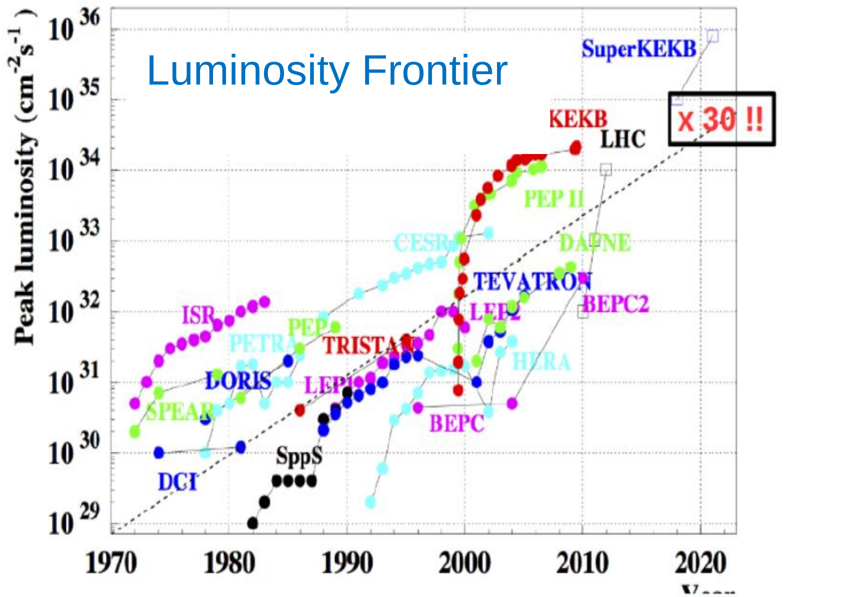
Still producing fruitful results a decade later

SuperKEKB nano-beam technology

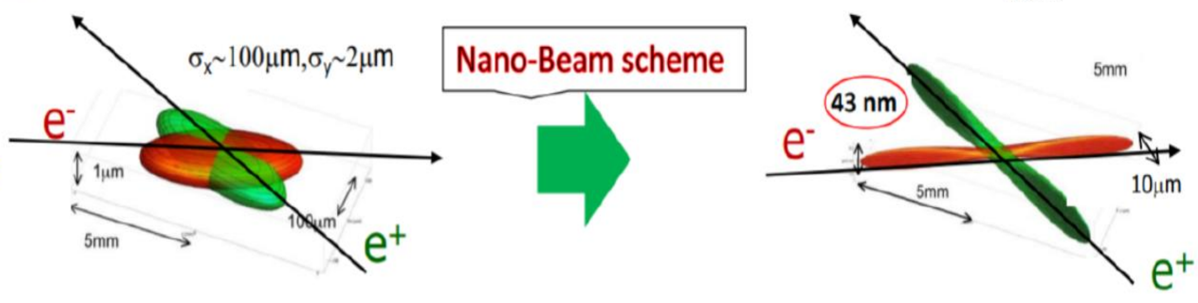
Asymmetric energy e^+e^- collider at KEK: 7 GeV e^- and 4 GeV e^+



A 30 fold increase in instantaneous luminosity over Belle, $\mathscr{L} = 6 \times 10^{35} cm^{-2}s^{-1}$

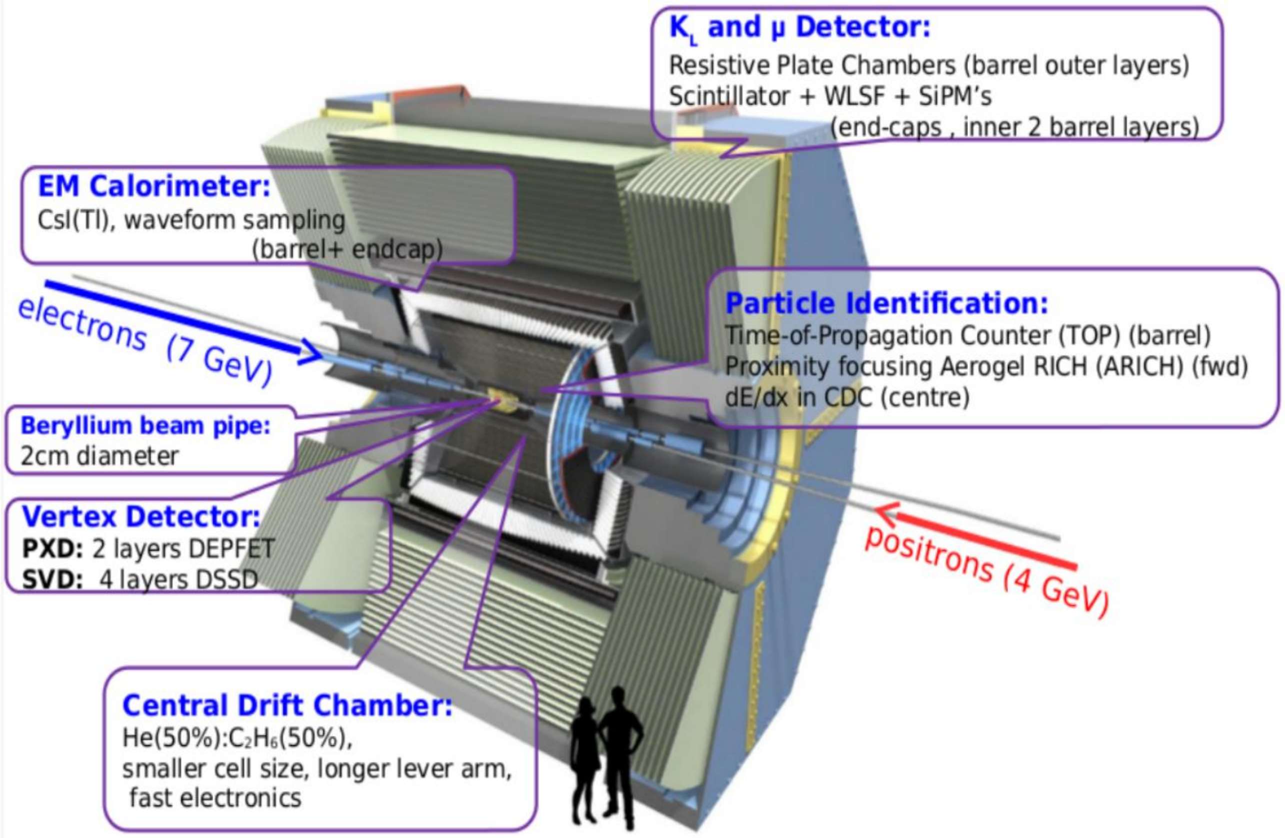


20 times smaller beam spot and 1.5 times increase in beam current ➡ 30 x luminosity



Belle II detector

- High trigger rate
- Higher beam background
- New tracking system and improved vertexing capability
- New particle identification systems
- Better time resolution at calorimeter



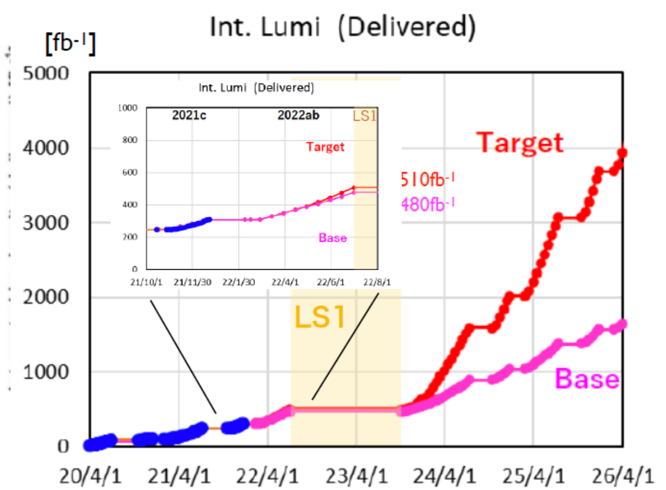
Accumulated data

In this presentation, only a maximum of 190 fb-1 used

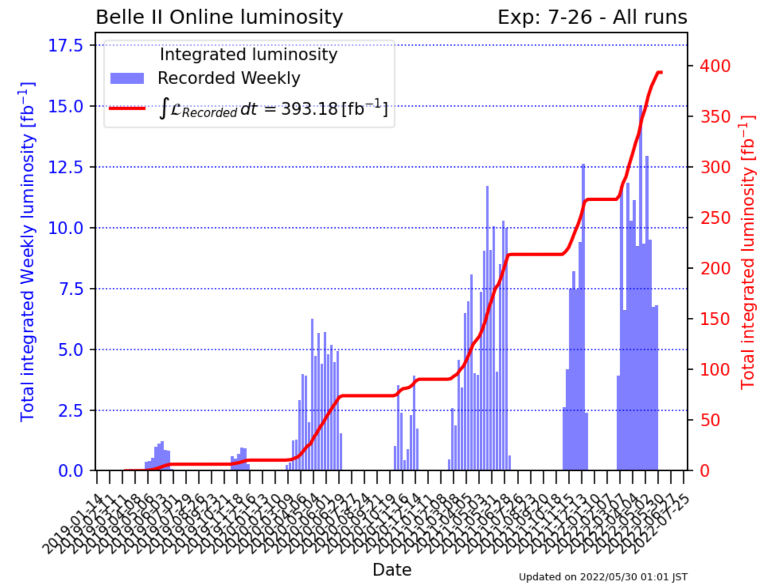
Luminosity

Status:

- Collected $\sim$393fb^{-1} since April 2019
- Slower luminosity accumulation than initially planned, but with $\sim$90% data-taking efficiency
- **Record-breaking instantaneous luminosity:** 4.1 $\times\ 10^{34}$cm^{-2}s^{-1}
- **Highest daily integrated luminosity: 2.2 fb^{-1}**



Comparable to Belle data before 2022 LS

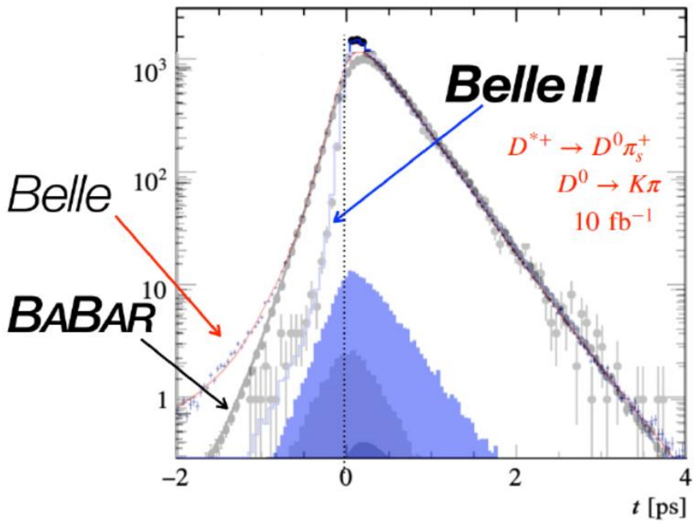


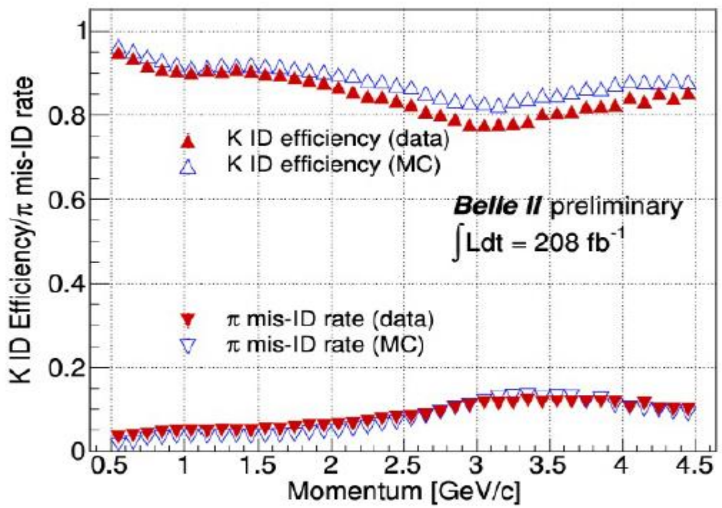
Plans:

- **Short-term plan**: shutdown in 2022:
  - full PXD installation $\rightarrow$ important to maintain good vertex resolution at high luminosity
- **Goal: 50 ab^{-1}**

Detector performance

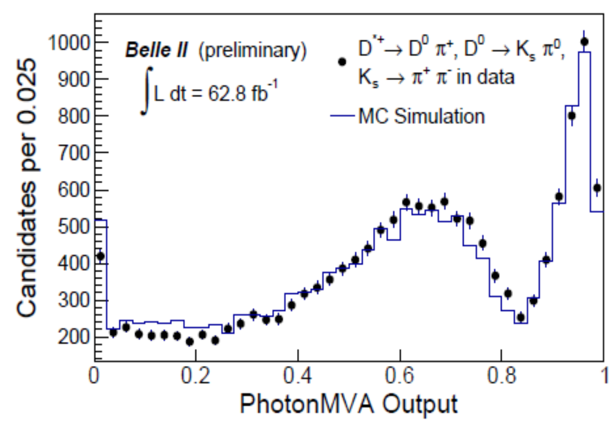
Phys.Rev.Lett. 127: 211801





Mainly using $D^{(*)}$ decays to validate

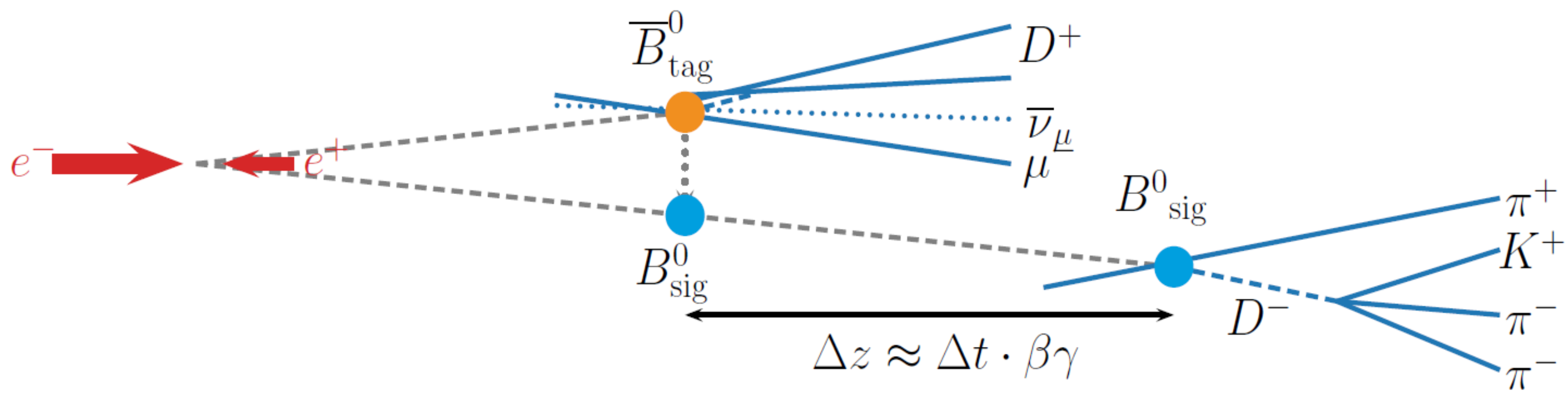
- Excellent vertexing/tracking
- Good K-π separation
- Well simulated photon tagging



. The output of the FBDT classifier for photons in $D^{*+} \to \overline{D}^0\pi^+$, $\overline{D}^0 \to K_S^0\pi^0$, $K_S^0 \to \pi^+\pi^-$

B flavor tagging at Belle II

Time-dependent analyses at the B factories



Critical for good time-dependent measurements:

- Good vertex resolution
- High tagging efficiency $\varepsilon_{\mathrm{tag}}$

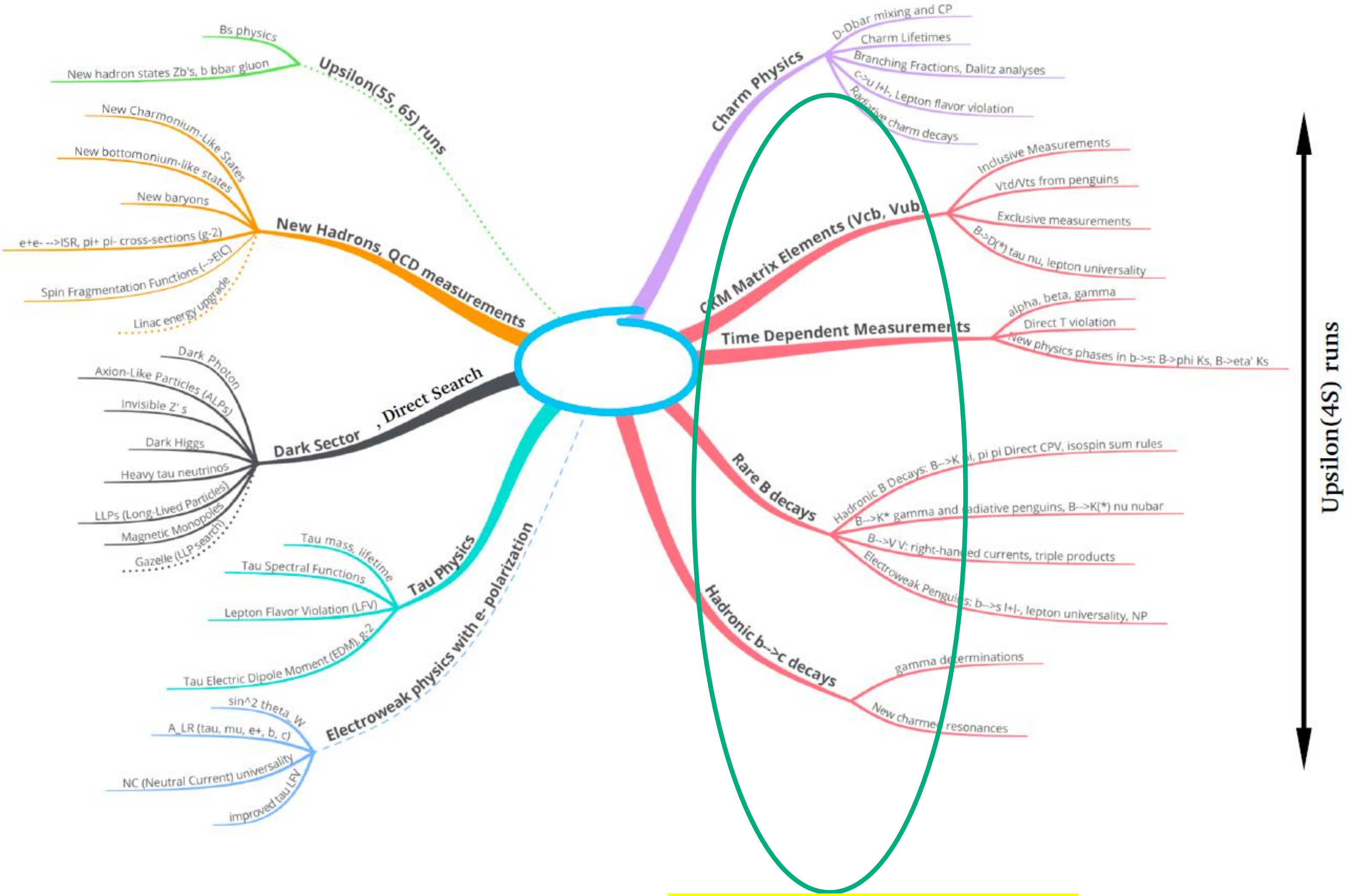
Belle II: $\varepsilon_{\mathrm{tag}} = (30.0 \pm 1.3)\%$
Belle : $\varepsilon_{\mathrm{tag}} = (30.1 \pm 0.4)\%$

arXiv:2110.00790

Eur. Phys. J. C 82, 283 (2022)

B mixing and life time measurements, see M. Sevior's talk

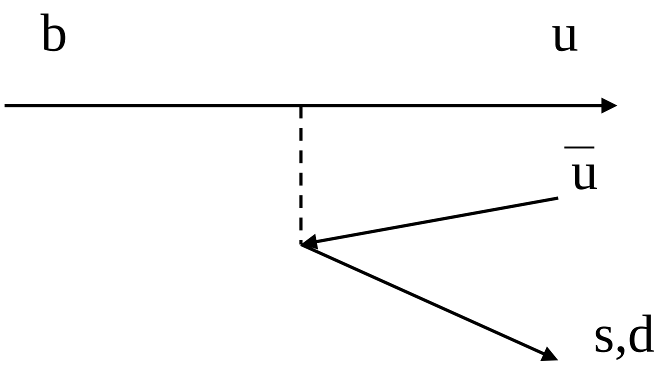
Physics topics at Belle II

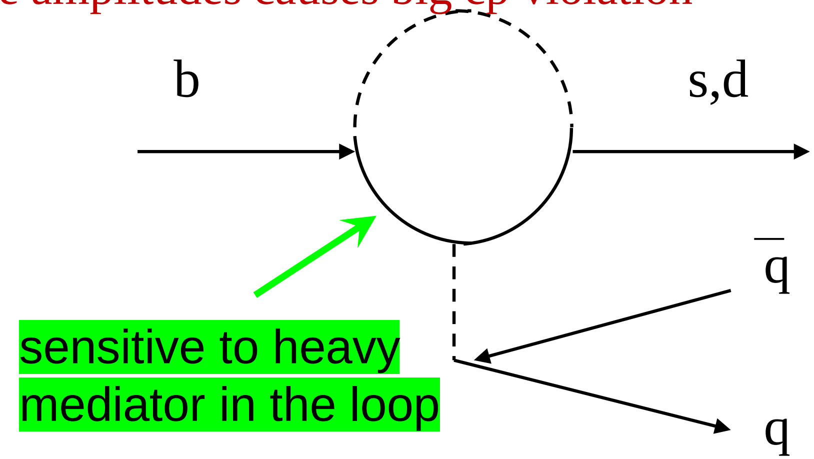


Non-leptonic B decays

Basic quark diagrams for charmless B decays

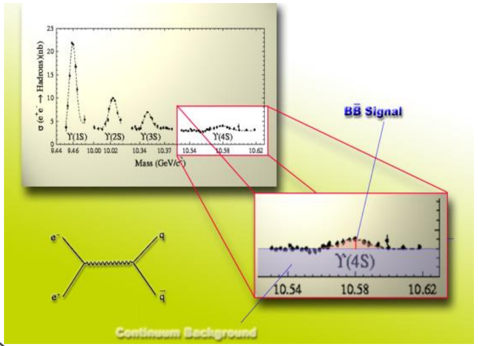
interference between comparable amplitudes causes big cp violation





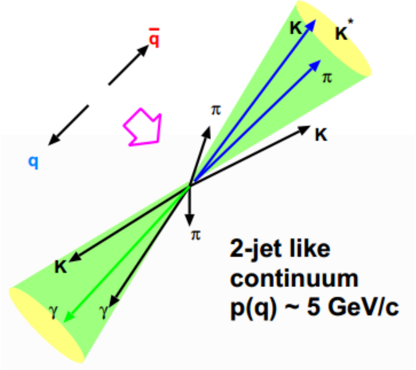
Looking for deviations from the SM predictions of a small BF or Acp

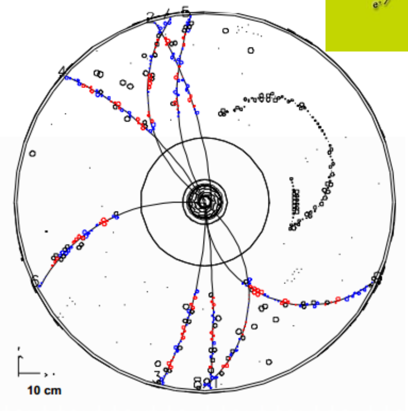
Continuum background suppression



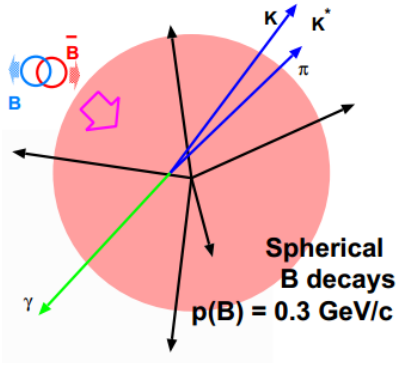
Need to develop good pattern recognition tools (AI) in order to fight against huge continuum background in rare B decays!

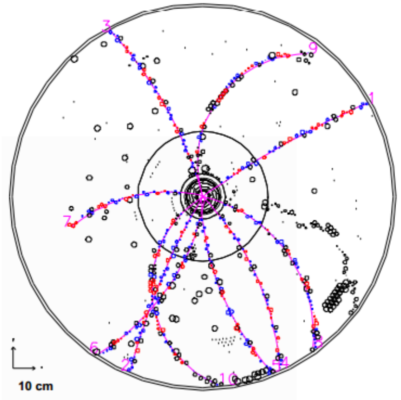
$q\bar{q}$ pair event





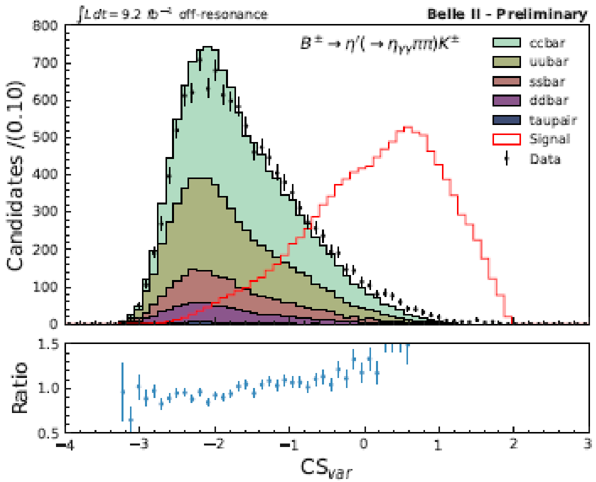
B decay event

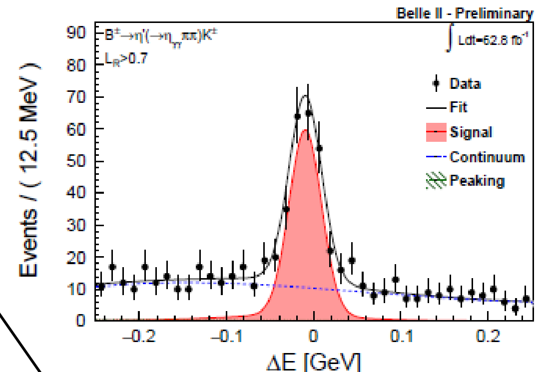


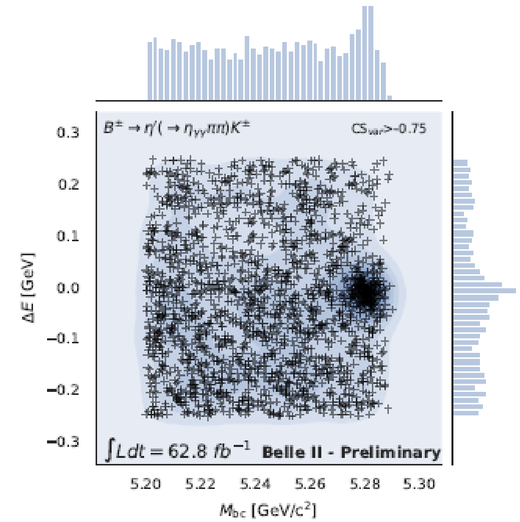


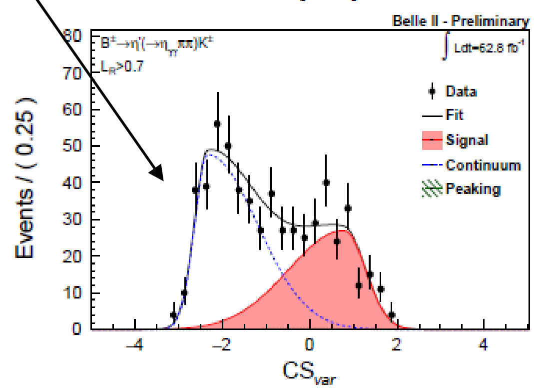
$B \to \eta' K$

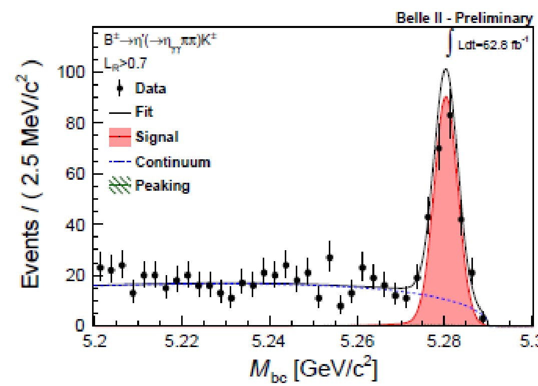
Charged











Summary of systematics uncertainties (in %) by category and channel.

Channel	$B^\pm \to \eta' K^\pm$	$B^0 \to \eta' K^0_S$	$B^\pm \to \eta' K^\pm$	$B^0 \to \eta' K^0_S$
Source	$\eta' \to \eta\pi^+\pi^-$		$\eta' \to \rho\gamma$	
Tracking efficiency	2.1	2.8	2.1	2.8
Photon efficiency	0.5	0.5	0.5	0.5
K^0_S efficiency	-	4.5	-	4.5
$\pi^\pm$ PID	-	-	2.4	2.4
$K^\pm$ PID	2.5	-	2.5	-
Cont. supp. modelling	5.0	1.0	5.5	2.3
SxF fraction	2.6	1.8	5.9	3.2
N($B\overline{B}$)		1.4		
Total	6.6	5.9	9.1	7.2

$$\mathcal{B}(B \to X) = \frac{N_{sig}}{2 \cdot N(B\overline{B}) \cdot f_{00/+-} \cdot \varepsilon\mathcal{B}}$$

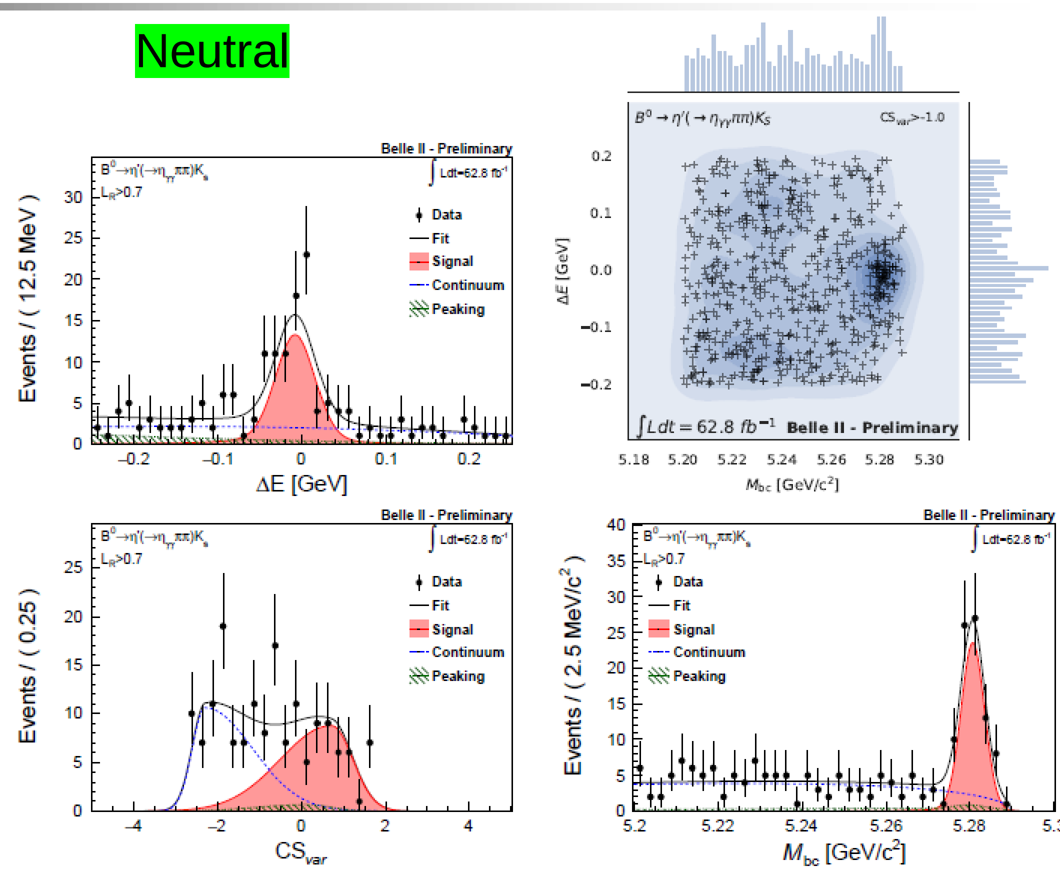
systematic uncertainty will shrink after better understanding of detector performance

$B \to \eta' K$

Neutral

already compatible to the world average

Channel	This analysis $\mathcal{B}$ $(\times 10^6)$	World average
$B^\pm \to \eta' K$	$63.4\ ^{+3.4}_{-3.3}(\text{stat}) \pm 3.4(\text{syst})$	70.4 ± 2.5
$B^0 \to \eta' K^0$	$59.9\ ^{+5.8}_{-5.5}(\text{stat}) \pm 2.7(\text{syst})$	66 ± 4



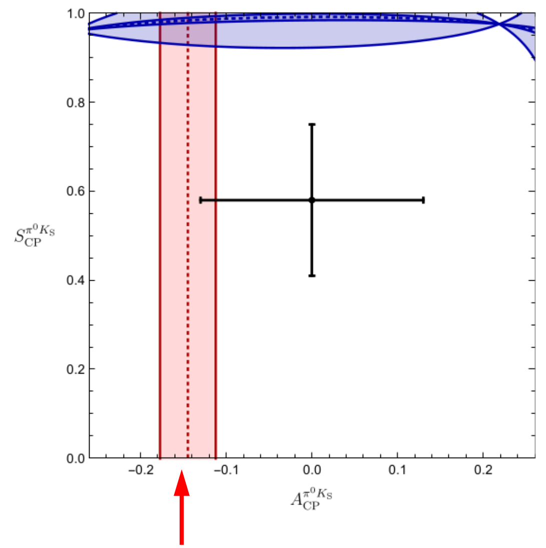
Mode	N_{sig}	$sig.$	$\varepsilon(\%)$	$\varepsilon\mathcal{B}(\%)$	$\mathcal{B}\ (10^{-6})$
$B^\pm \to \eta'(\to \eta(\to \gamma\gamma)\pi^+\pi^-)K^\pm$	$263\ ^{+18}_{-19}$	25.7	31.7 ± 0.03	5.45	$63.9\ ^{+4.6}_{-4.4} \pm 4.0$
$B^\pm \to \eta'(\rho(\to \pi^+\pi^-)\gamma)K^\pm$	$335\ ^{+26}_{-25}$	22.2	24.2 ± 0.04	7.05	$62.9\ ^{+4.8}_{-4.8} \pm 5.5$
$B^0 \to \eta'(\to \eta(\to \gamma\gamma)\pi^+\pi^-)K^0_S$	$80.0\ ^{+11.2}_{-10.4}$	13.8	31.0 ± 0.03	1.80	$61.6\ ^{+8.6}_{-8.0} \pm 3.9$
$B^0 \to \eta'(\rho(\to \pi^+\pi^-)\gamma)K^0_S$	$99.7\ ^{+14.2}_{-12.7}$	14.2	23.6 ± 0.04	2.35	$58.5\ ^{+7.9}_{-7.4} \pm 4.4$

$B^0 \rightarrow K^0 \pi^0$

- Long standing puzzle in A_{CP} for $B^0 \rightarrow K^{\pm}\pi^{\mp}$ vs $B^{\pm} \rightarrow K^{\pm}\pi^0$
- Over 5 σ difference between A_{CP} for the two modes.
- Only change the Spectator quark for the two decays.
- Strong Interaction or New Physics?
- $A_{CP}\ B \rightarrow K_s\pi^0$ can distinguish
- Paper by Fleischer, Jaarmsa, Vos PLB 785 (2018) 525–529
  Shows additional correlation with S_{CP}
  for $B \rightarrow K_s\pi^0$

A golden mode at Belle II since both charged and neutral B⟶ Kπ decays, and related isospin modes can be accessed altogether
arXiv:2106.03766, arXiv:2106.04111

Currently limitation is still dominantly by statistical uncertainty with non-negligible systematic uncertainty



A_{cp} derived from sum-rule

Acp measurement for $B^0 \to K^0 \pi^0$

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

SM: direct $CPV \sim 0$

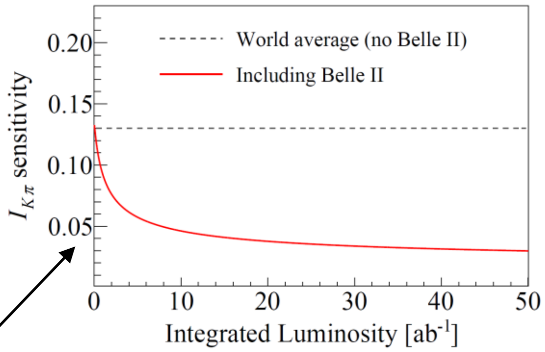
May sensitive to NP if $A_{K_S^0\pi^0} \neq 0$

SM: time-dependent CPV

$S_{K_S^0\pi^0} = sin(2\phi_1)$

$$I_{K\pi} = \mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)} = 0$$

- $B^0 \to K_S^0\pi^0$ is important to test isospin sum-rule
- Uncertainty is dominated by $A_{K_S^0\pi^0}$
- Feasible at Belle-II



Null sensitivity can be down to 0.03 level in the long run
Snowmass 2021 update

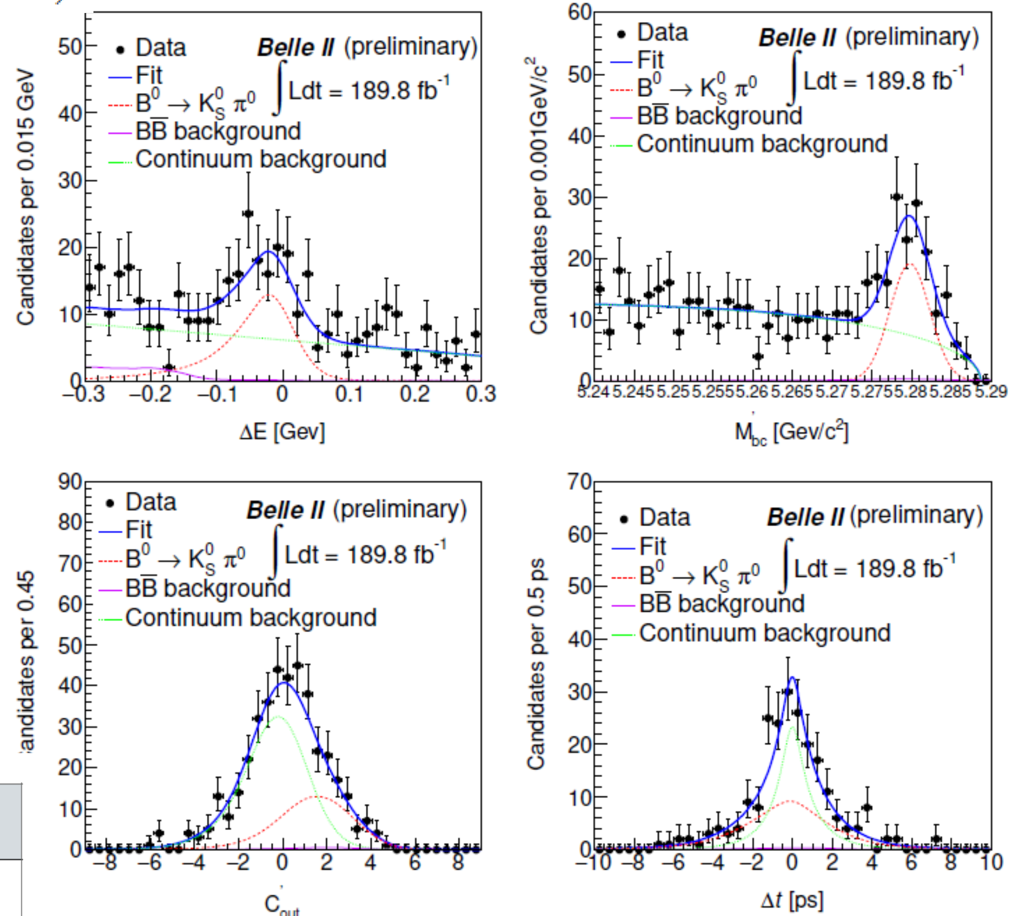
$B^0 \rightarrow K^0 \pi^0$ 189.8 fb^{-1}

$$M'_{bc} = \sqrt{E^2_{beam} - \left(\vec{p}_{K^0_S} + \frac{\vec{p}_{\pi^0}}{|\vec{p}_{\pi^0}|}\sqrt{(E_{beam} - E_{K^0_S})^2 - m^2_{\pi^0}}\right)^2}$$

$$C'_{out} = \ln\left(\frac{C_{out} - C_{out,min}}{C_{out,max} - C_{out}}\right)$$

Source	$\delta\mathcal{B}$ (%)	$\delta\mathcal{A}_{CP}$
Tracking efficiency	0.6	–
K^0_S reconstruction efficiency	4.2	–
π^0 reconstruction efficiency	7.5	–
Continuum suppression efficiency	1.6	–
Number of $B\bar{B}$ pairs	3.2	–
Flavor tagging	–	0.040
Resolution function	–	0.050
Physics parameters	0.4	0.021
$B\bar{B}$ background asymmetry	–	0.002
Signal modelling	1.0	0.015
Background modelling	0.9	0.004
Possible fit bias	2.0	0.010
Tag-side interference	–	0.038
Total	9.6	0.086

Observable	Fitted value	WA
$BF(B^0 \rightarrow K^0_S \pi^0) \times 10^{-6}$	$11.0 \pm 1.2 \pm 1.0$	9.9 ± 0.5
A_{CP}	$-0.41^{+0.30}_{-0.32} \pm 0.09$	-0.01 ± 0.10



$B^+ \to \rho^+ \rho^0$

$B^+ \to \rho^+(\pi^+\pi^0)\rho^0(\pi^+\pi^-)$

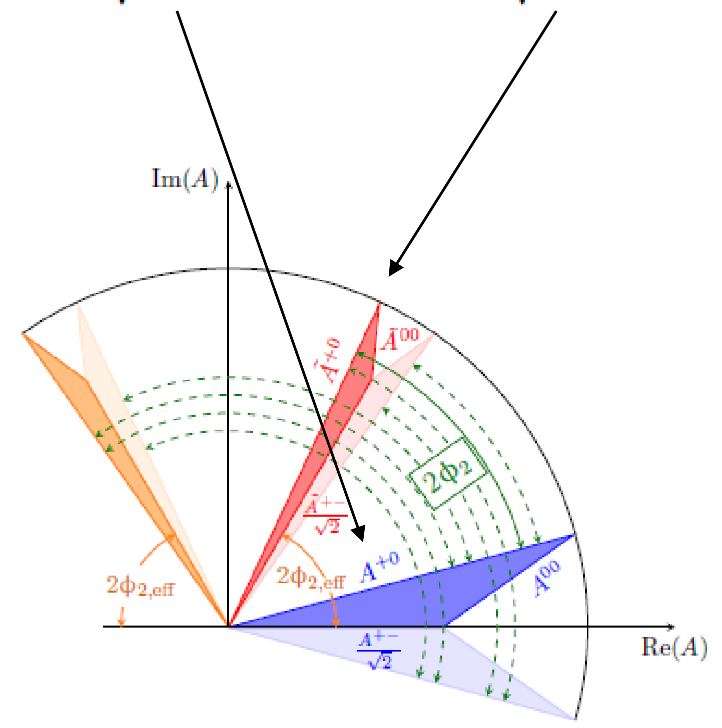
Using combined **B → ρ ρ** measurements and isospin symmetries to have better constrain on the hadronic uncertainties

The CKM unitary angle φ_2 can be determined by the measurements of BF and A_{CP} of **B → ρ ρ**

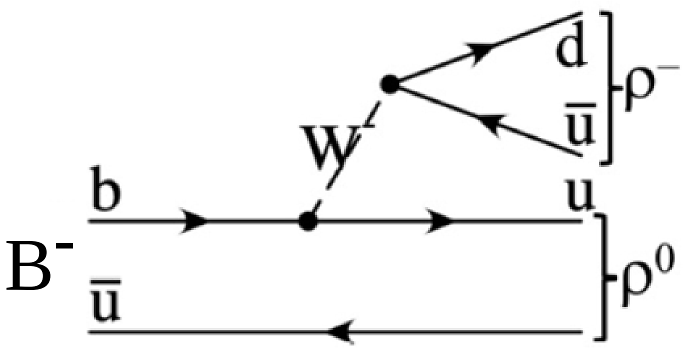
A 6D un-binned fit has been applied to 63 fb^{-1} data for signal extraction
arXiv:2109.11456

The same method can be applied to **B → ππ** in order to extract φ_2
arXiv:2105.04111
arXiv:2107.02373

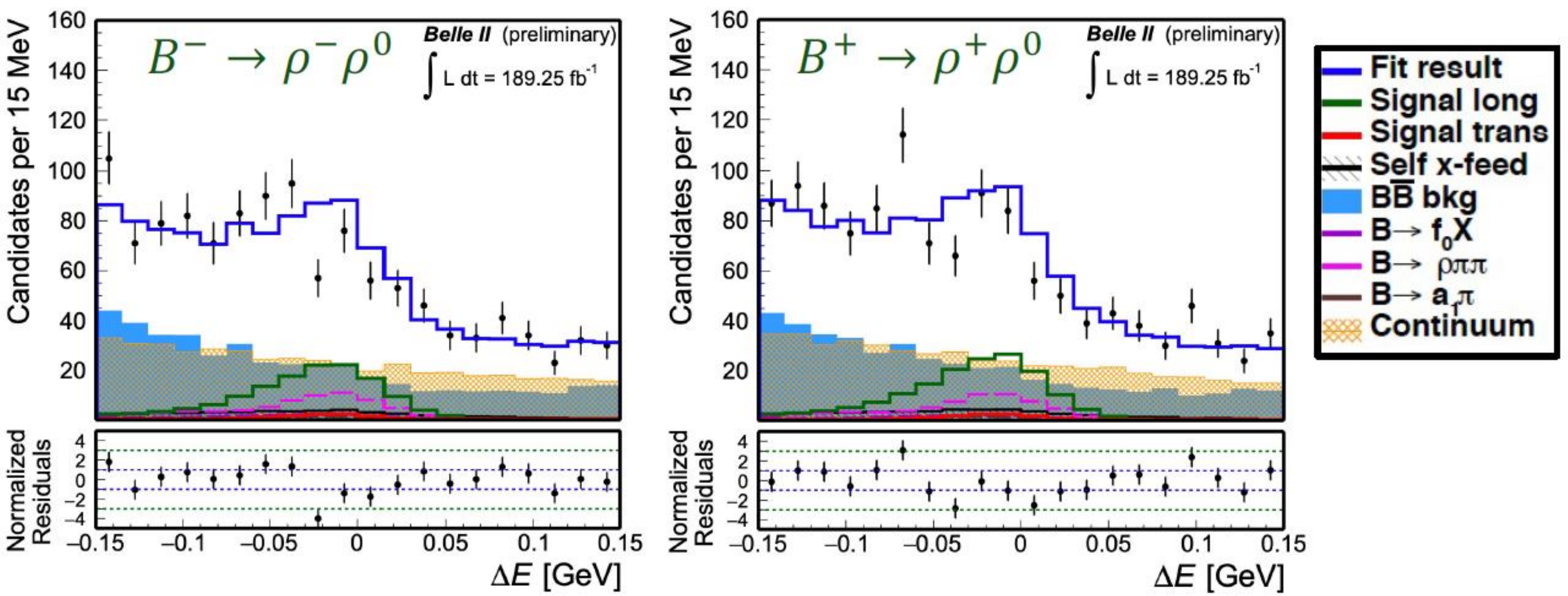
$$A^{+0} = \frac{1}{\sqrt{2}}A^{+-} + A^{00}, \quad \bar{A}^{-0} = \frac{1}{\sqrt{2}}\bar{A}^{+-} + \bar{A}^{00}$$



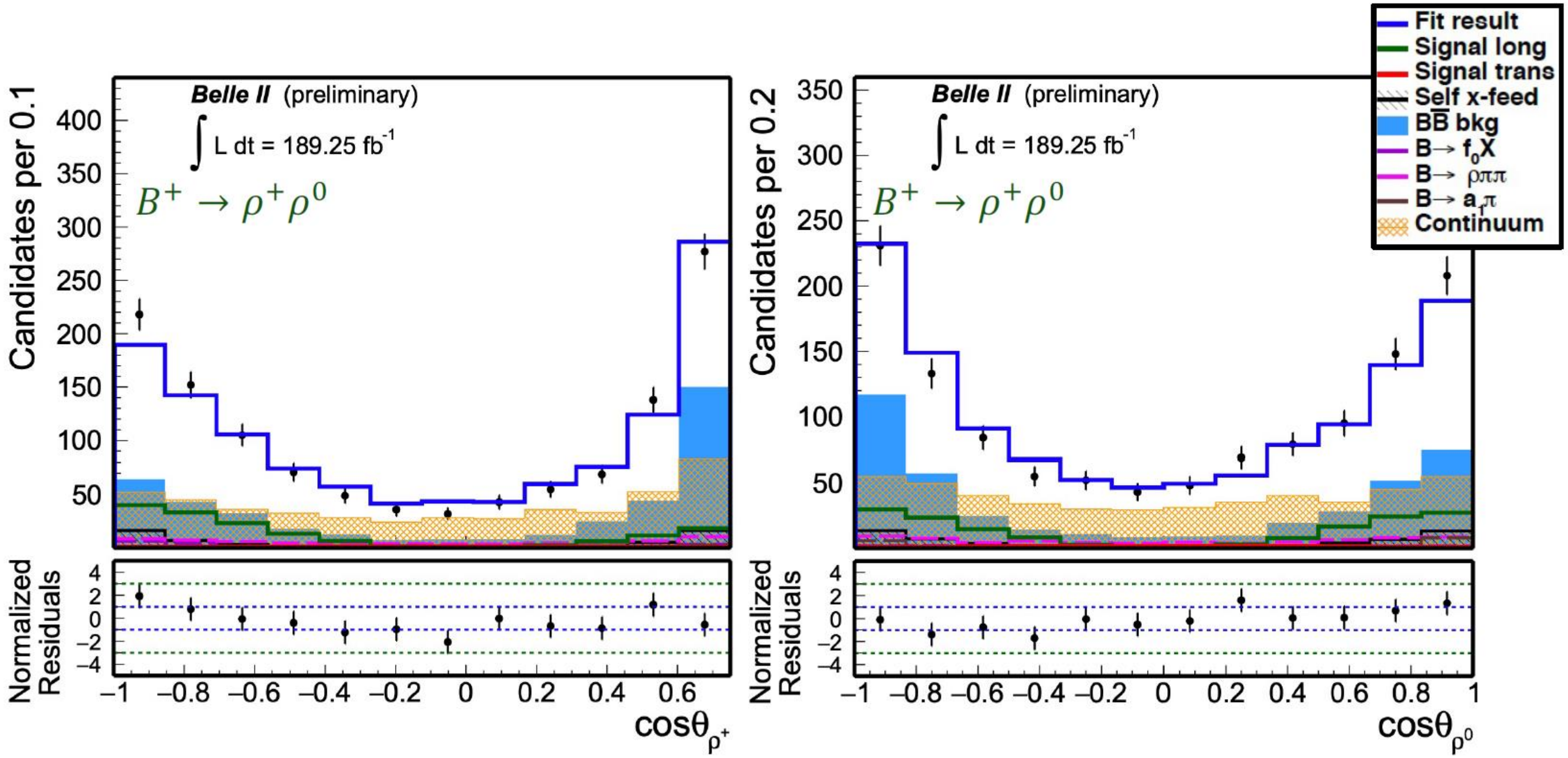
Update of $B^+ \rightarrow \rho^+ \rho^0$ 189.8 fb^{-1}



- Can extract φ_2 using info from three isospin-related decays $B^+ \rightarrow \rho^+\rho^0$, $B^0 \rightarrow \rho^+\rho^-$, and $B^0 \rightarrow \rho^0\rho^0$ PRL 65 (1990) 3381
- Belle II is unique having access to all of them



Update of $B^+ \to \rho^+ \rho^0$ 189.8 fb^{-1}



	Results	PDG
A_{CP}	$-0.069 \pm 0.068 \pm 0.060$	(-0.05 ± 0.05)
$BF\ (10^{-6})$	$23.2^{+2.2}_{-2.1} \pm 2.7$	(24.0 ± 1.9)
f_L	$0.943^{+0.035}_{-0.033} \pm 0.027$	(0.950 ± 0.016)

Expected physics results

The Belle II Physics Book Prog Theor Exp Phys (2019)
arXiv:1808.10567

Snowmass2021 Belle II Physics
Upgrade&update arXiv:2203.11349

Observable	2022 Belle(II), BaBar	Belle-II 5 ab^{-1}	Belle-II 50 ab^{-1}
$\sin 2\beta/\phi_1$	0.03	0.012	0.005
γ/ϕ_3 (Belle+BelleII)	11°	4.7°	1.5°
α/ϕ_2 (WA)	4°	2°	0.6°
$\lvert V_{ub}\rvert$ (Exclusive)	4.5%	2%	1%
$S_{CP}(B \to \eta' K^0_S)$	0.08	0.03	0.015
$A_{CP}(B \to \pi^0 K^0_S)$	0.15	0.07	0.025
$S_{CP}(B \to K^{*0}\gamma)$	0.32	0.11	0.035
$R(B \to K^* \ell^+ \ell^-)^\dagger$	0.26	0.09	0.03
$R(B \to D^* \tau \nu)$	0.018	0.009	0.0045
$R(B \to D \tau \nu)$	0.034	0.016	0.008
$\mathcal{B}(B \to \tau \nu)$	24%	9%	4%
$B(B \to K^* \nu \bar{\nu})$	–	25%	9%
$\mathcal{B}(\tau \to \mu\gamma)$ UL	42×10^{-9}	22×10^{-9}	6.9×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$ UL	21×10^{-9}	3.6×10^{-9}	0.36×10^{-9}

Summary

- BelleII will collect ~500 fb^{-1} data before long shutdown in 2022
- Some new results were obtained with ≤190fb^{-1} data
- We have prepared analysis tools to better tag neutral final state particles and to suppress continuum background
- LHCb and Belle II are complementary in new physics search