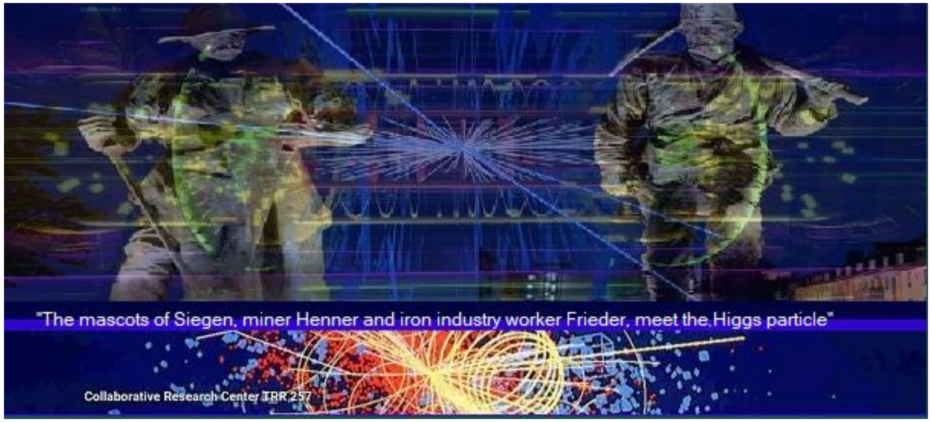
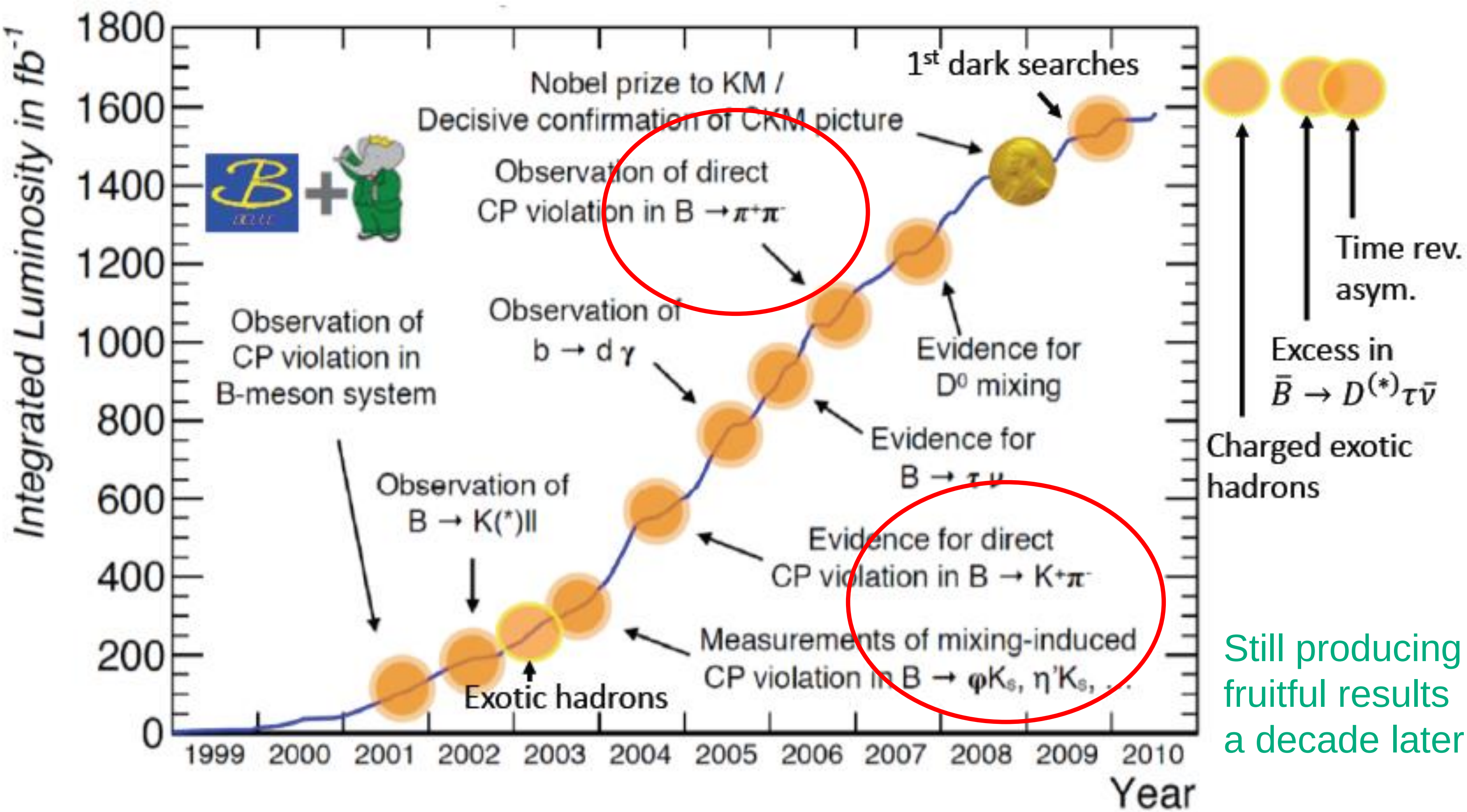
Charmless B decay at Belle II

- **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 BelleII Collaboration
2022/6/2@
Non-leptonic B meson decays workshop

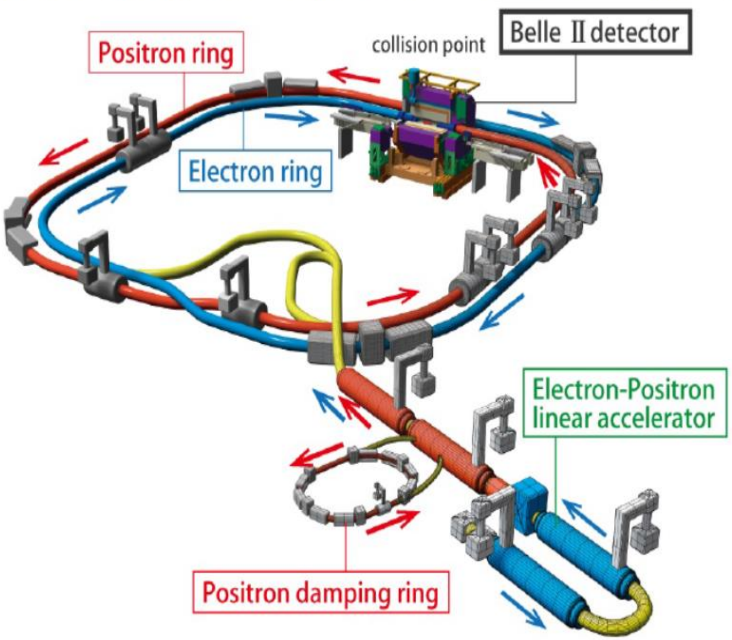
Findings from B-factories



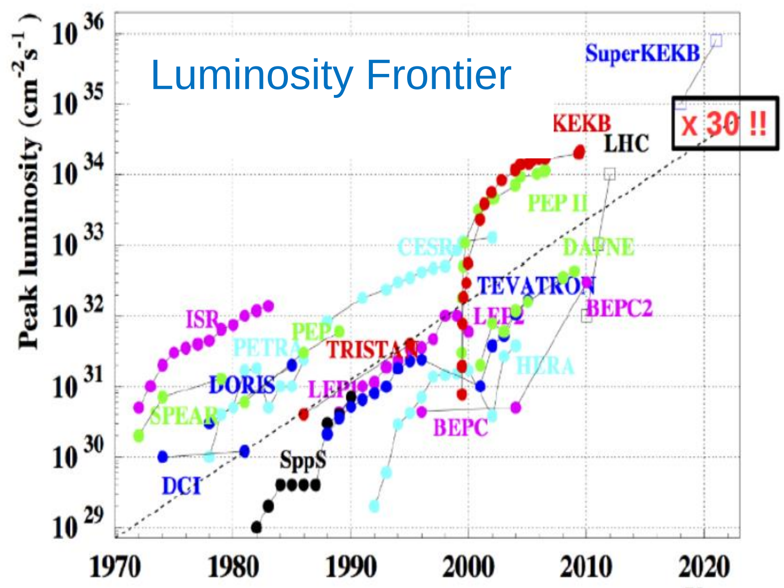
Still producing fruitful results a decade later

SuperKEKB nano-beam technology

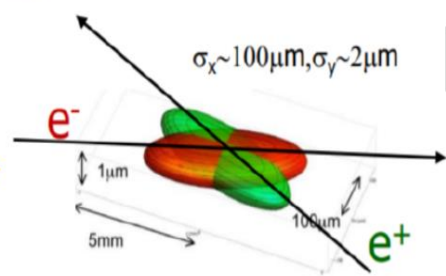
Asymmetric energy e^+e^- collider at KEK: 7 GeV e^- and 4 GeV e^+



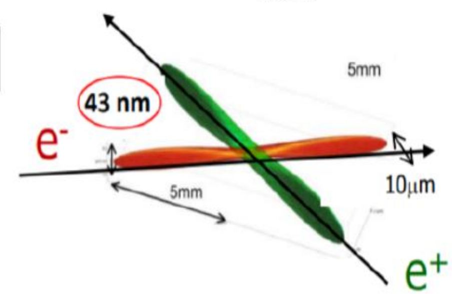
A 30 fold increase in instantaneous luminosity over Belle, $\mathscr{L} = 6 \times 10^{35} cm^{-2}s^{-1}$



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

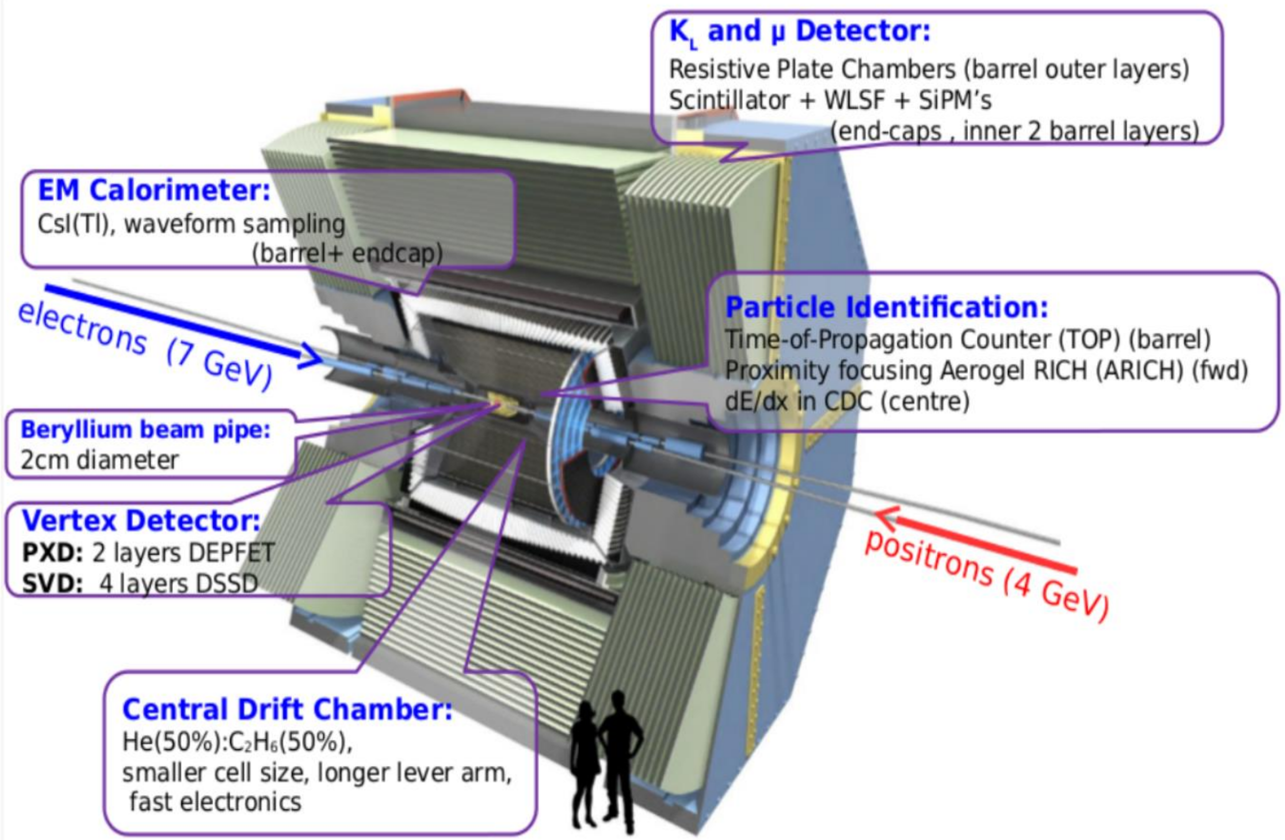


Nano-Beam scheme



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



Belle II international collaboration

- 26 countries
- 123 institutions
- ~1160 working members

Countries (institutions):
Armenia (1), Australia (3), Austria (1), Canada (5), China (12), Czechia (1), France (3), Germany (12), India (9), Israel (1), Italy (9), Japan (16), Malaysia (1), Mexico (3), Poland (1), Russia (6), Saudi Arabia (1), Slovenia (2), South Korea (9), Spain (1), Taiwan (3), Thailand (2), Turkey (1), USA (18), Ukraine (1), Viet Nam (1).

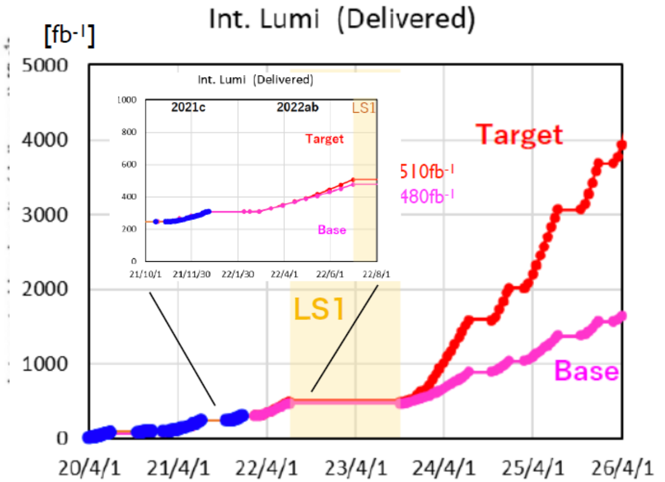
Accumulated data

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

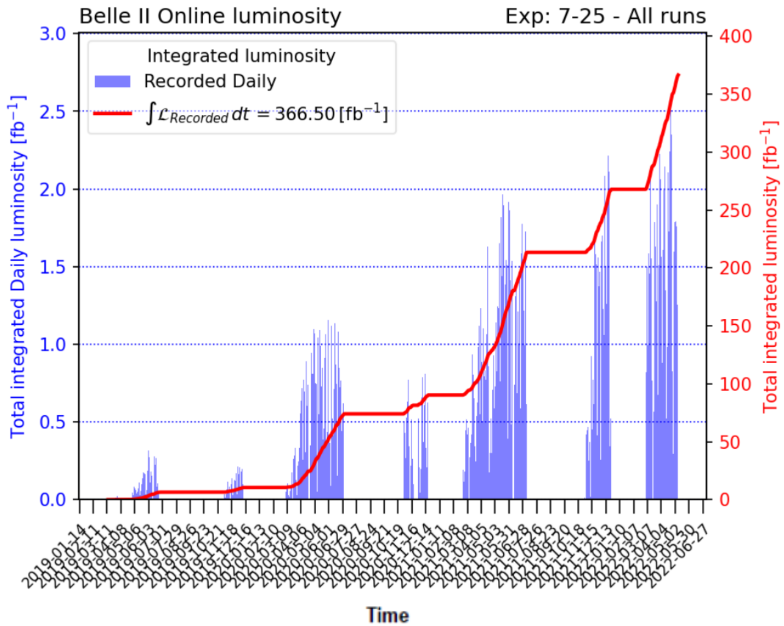
Luminosity

Status:

- Collected $\sim$336$\mathbf{fb}^{-1}$ since April 2019
- Slower luminosity accumulation than initially planned, but with $\sim$90% data-taking efficiency
- **Record-breaking instantaneous luminosity:** $\mathbf{3.8 \times 10^{34} cm^{-2} s^{-1}}$
- **Highest daily integrated luminosity: 2.2 fb^{-1}**



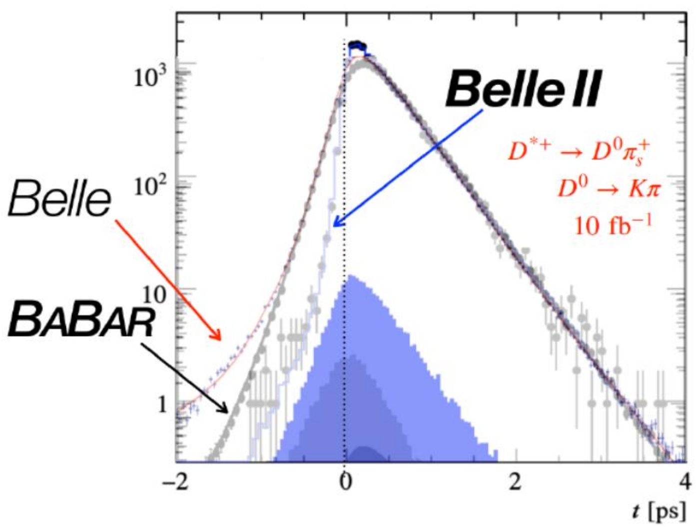
Comparable to Belle data before 2023 LS

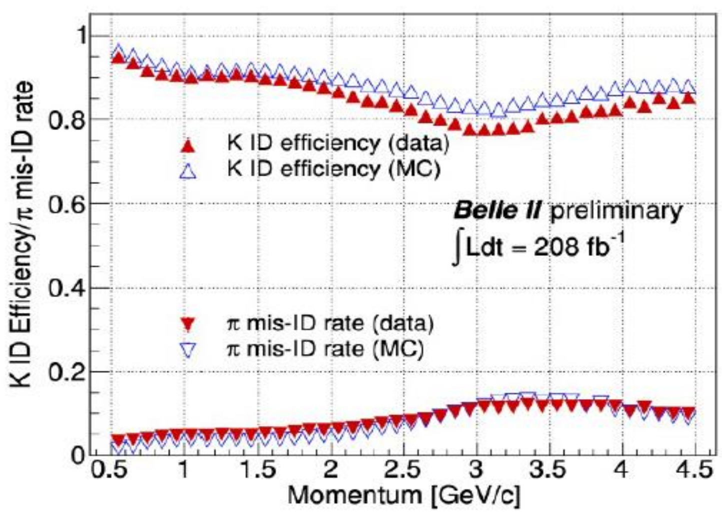


Plans:

- **Short-term plan**: shutdown in 2023:
  - full PXD installation → important to maintain good vertex resolution at high luminosity
  - Replacement of 50% of barrel TOP PMTs
- **Goal: 50 ab^{-1}**

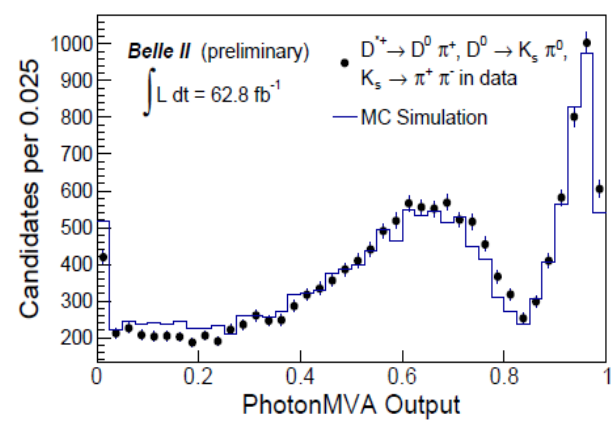
Detector performance





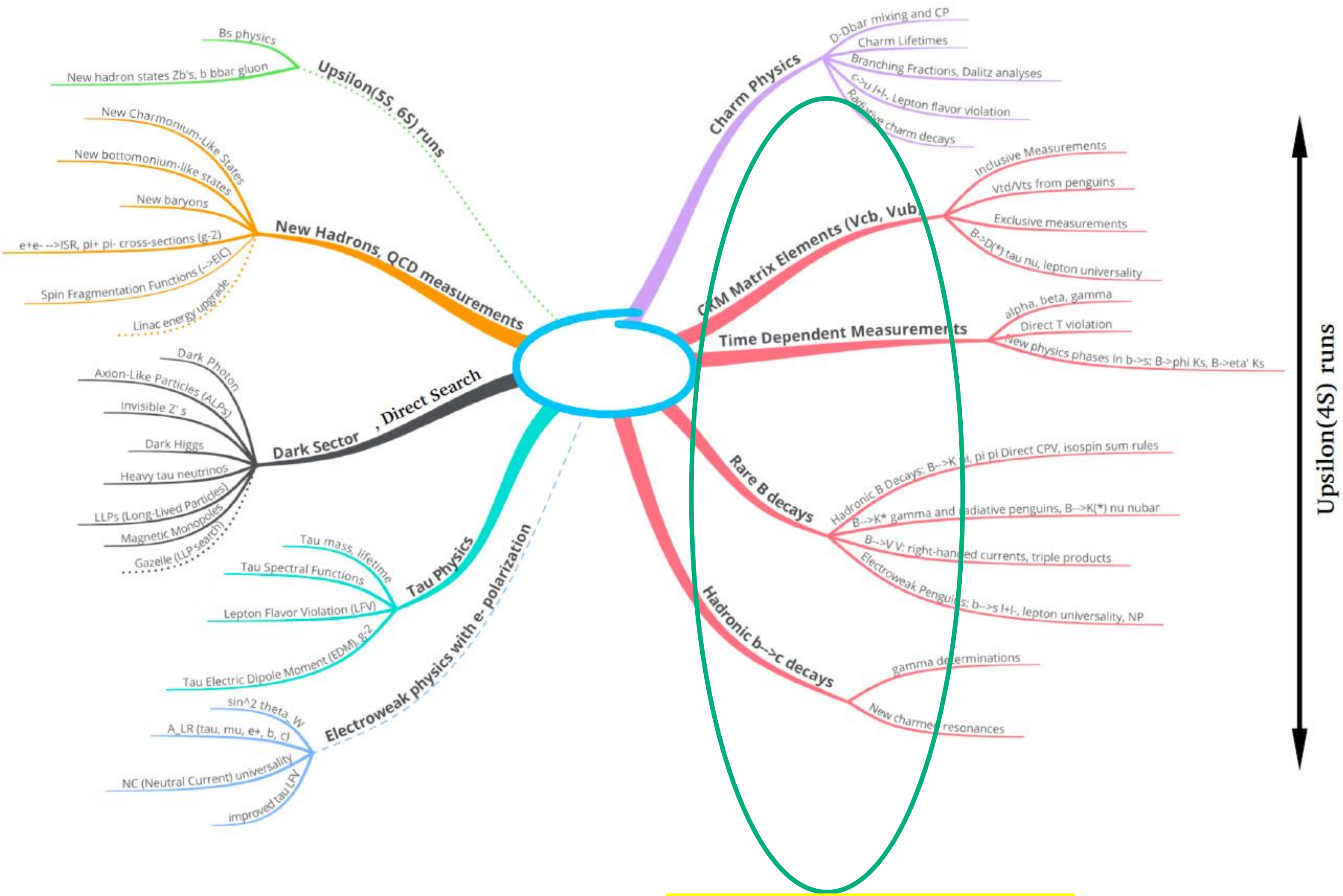
Mainly using D$^{(*)}$ decays to validate

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



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

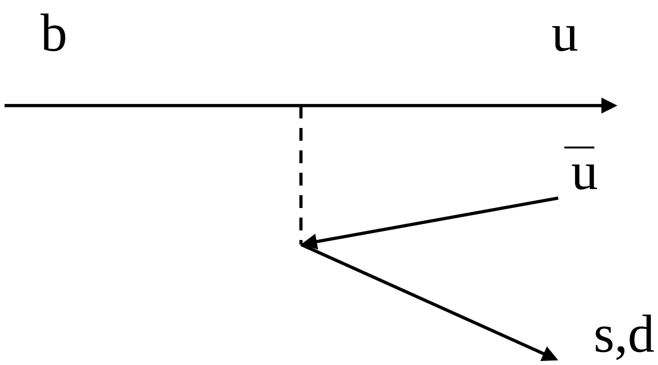
Physics topics at Belle II

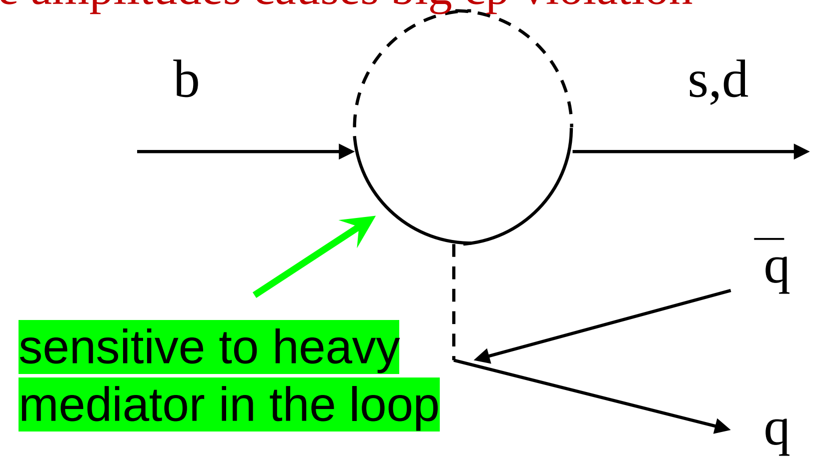


Non-leptonic B decays

Basic quark diagrams for charmless B decays

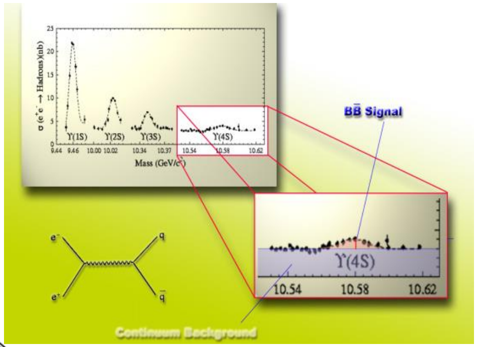
interference between comparable amplitudes causes big cp violation





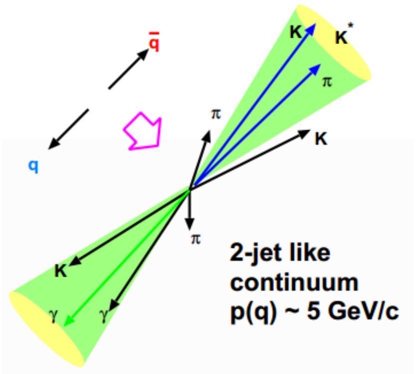
Looking for deviations from the SM predictions of a small BF or Acp

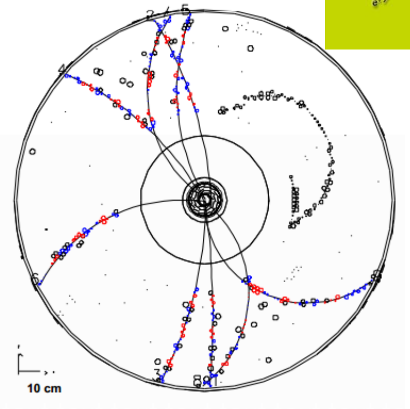
Continuum background suppression



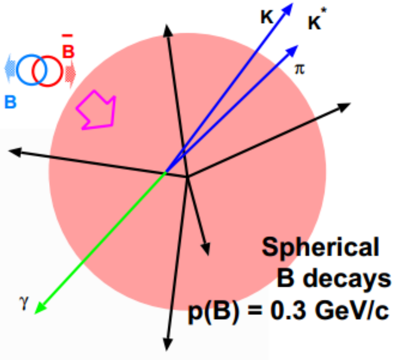
Need to develop good pattern recognition tools (AI) in order to fight against huge continuum background in rare B decays!

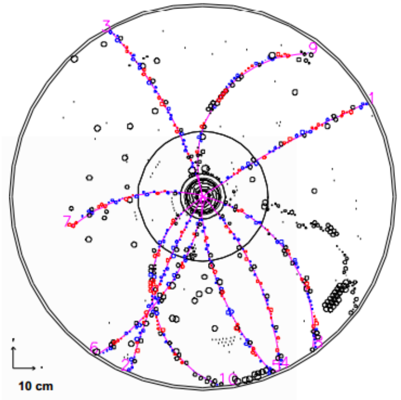
$q\bar{q}$ pair event





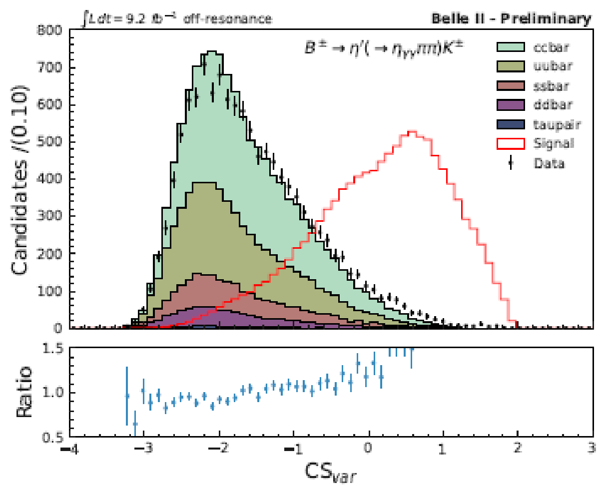
B decay event

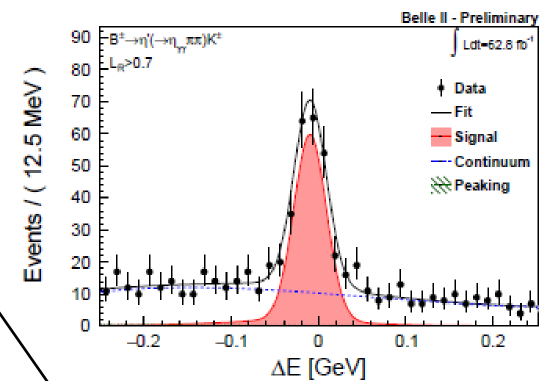


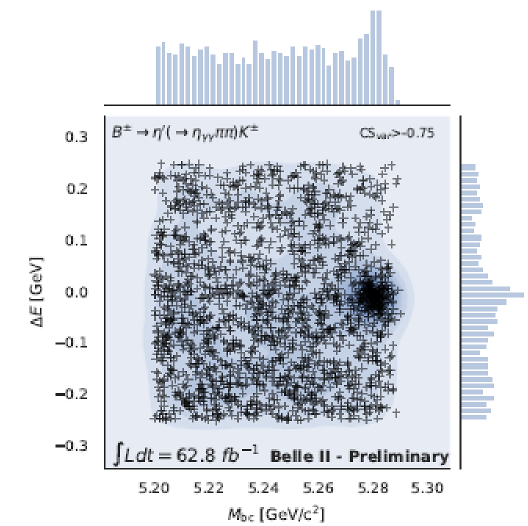


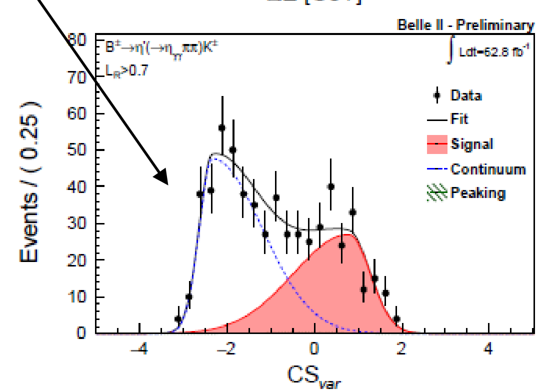
$B \to \eta' K$

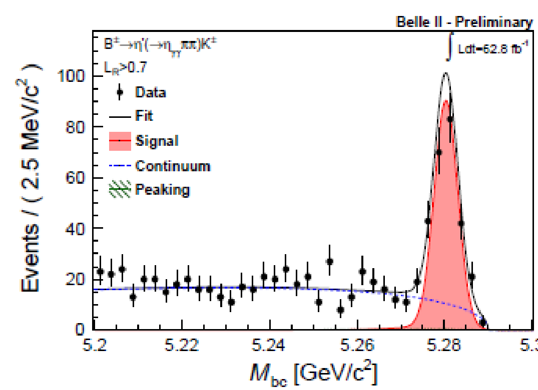
rediscovery











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	$\eta' \to \pi^+\pi^-$		$\eta' \to \rho\gamma$	
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

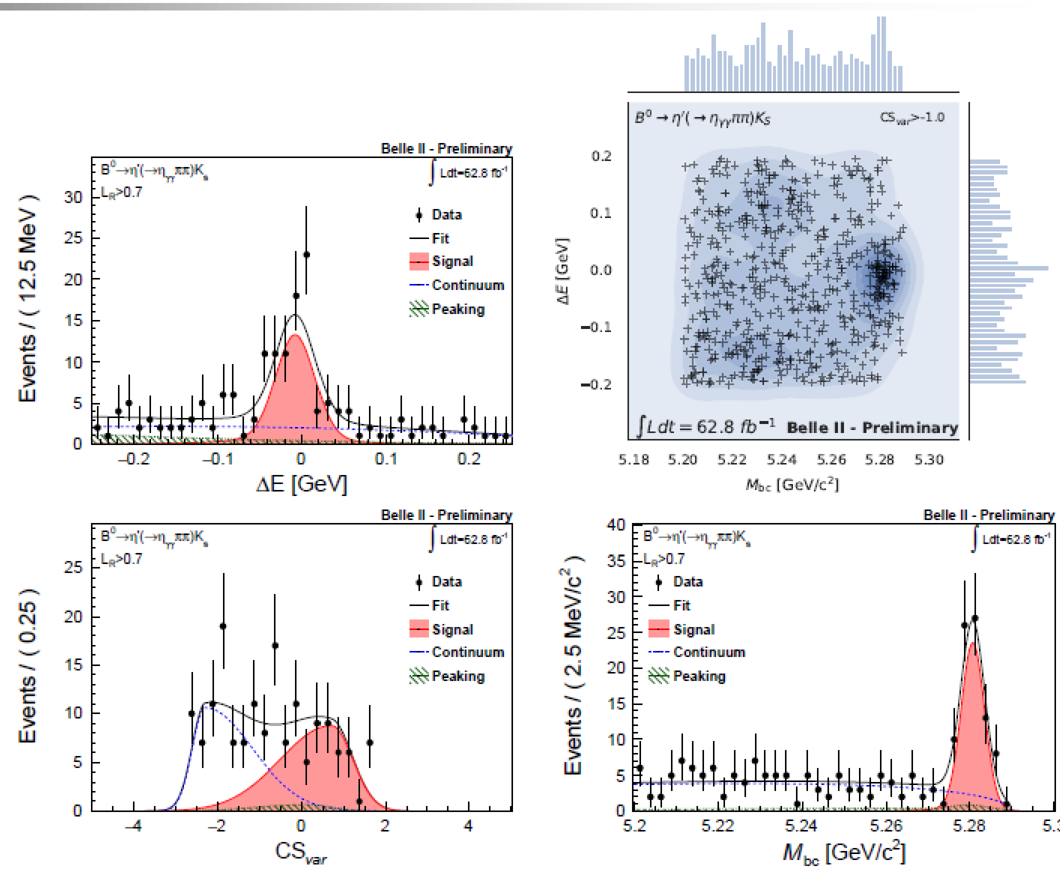
$$\mathcal{B}(B \to X) = \frac{N_{sig}}{2 \cdot N(B\overline{B}) \cdot f_{00/+-} \cdot \varepsilon\mathcal{B}}$$

systematic uncertainty will shrink after better understanding of detector performance

$B \to \eta' K$

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	$58.5\,^{+7.9}_{-7.4} \pm 4.4$

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 $CPV \sim 0$

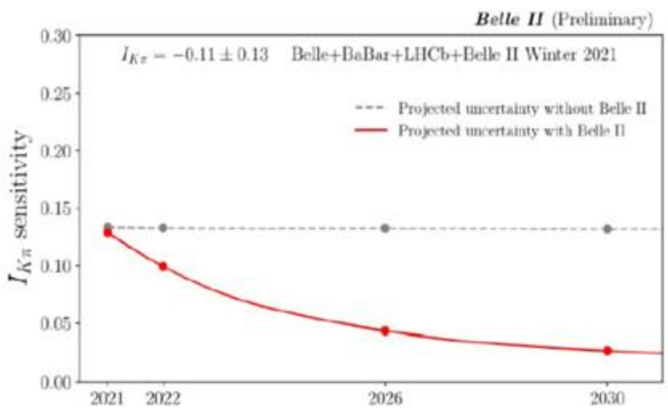
May sensitive to NP if $A_{K^0_S\pi^0} \neq 0$

SM: time-dependent CPV

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

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

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



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

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

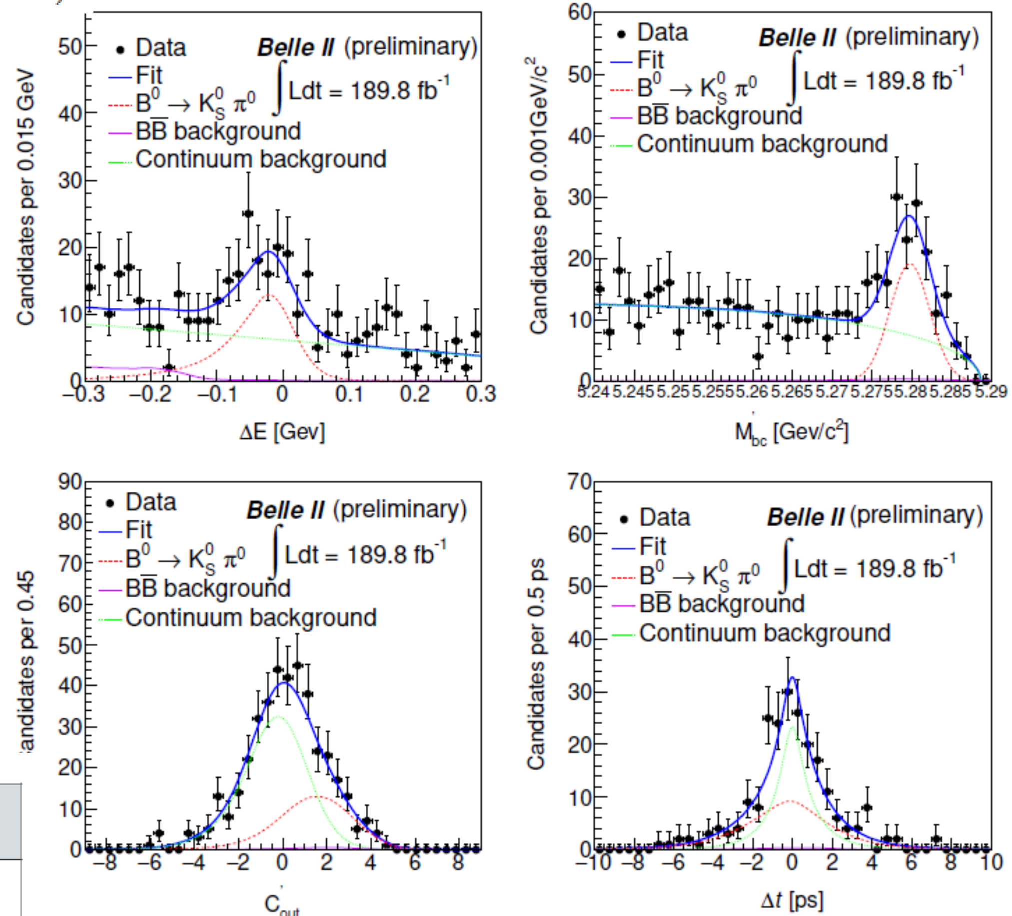
rediscovery

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

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

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



$B^+ \rightarrow \rho^+ \rho^0$

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

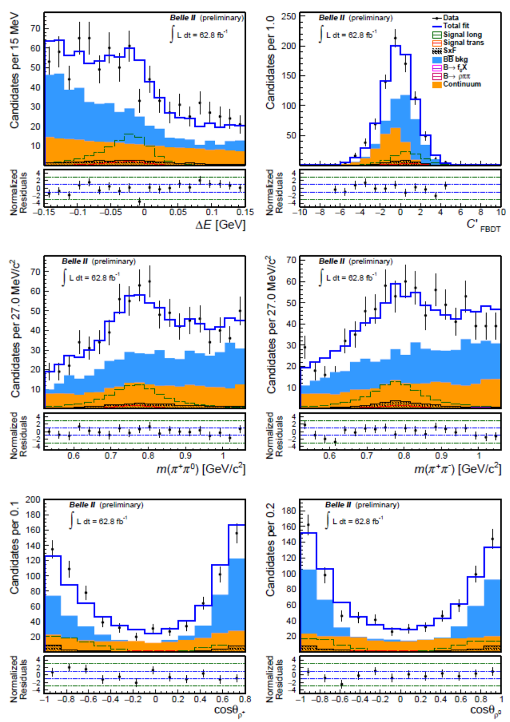
rediscovery

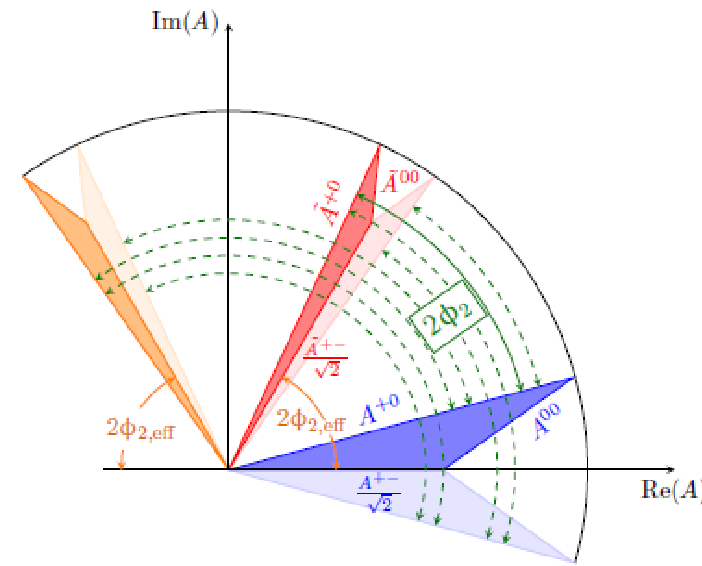
Using combined $B \rightarrow \rho\,\rho$ measurements and isospin symmetries to have better constrain on the hadronic uncertainties

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

The CKM unitary angle φ_2 can be determined by the measurements of BF and A_{CP} of $B \rightarrow \rho\,\rho$

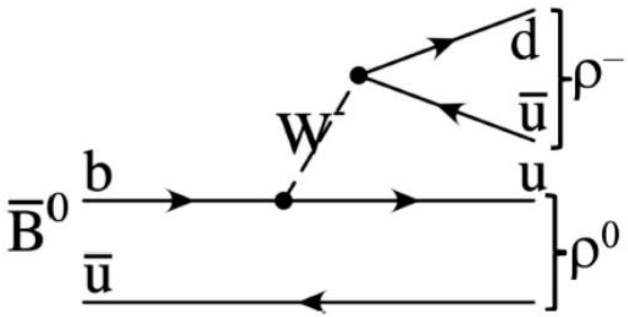
A 6D un-binned fit has been applied to 63 fb^{-1} data for signal extraction



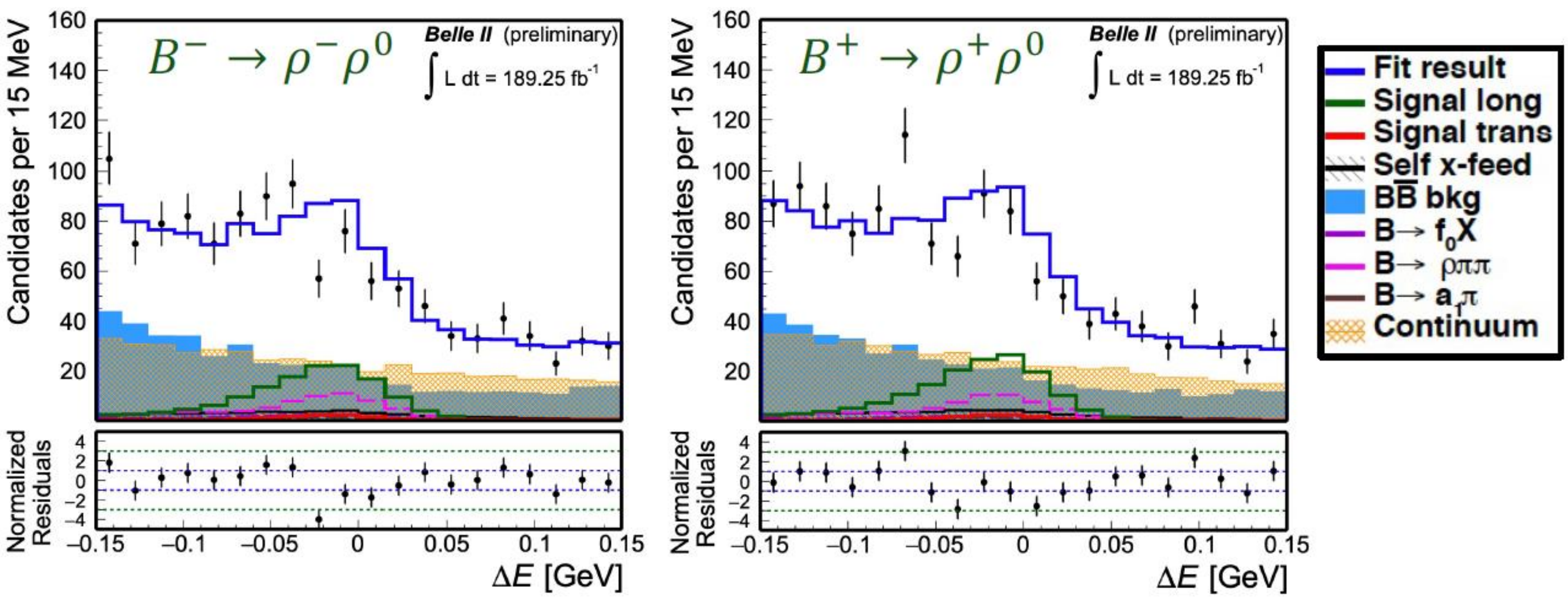


arXiv:2109.11456

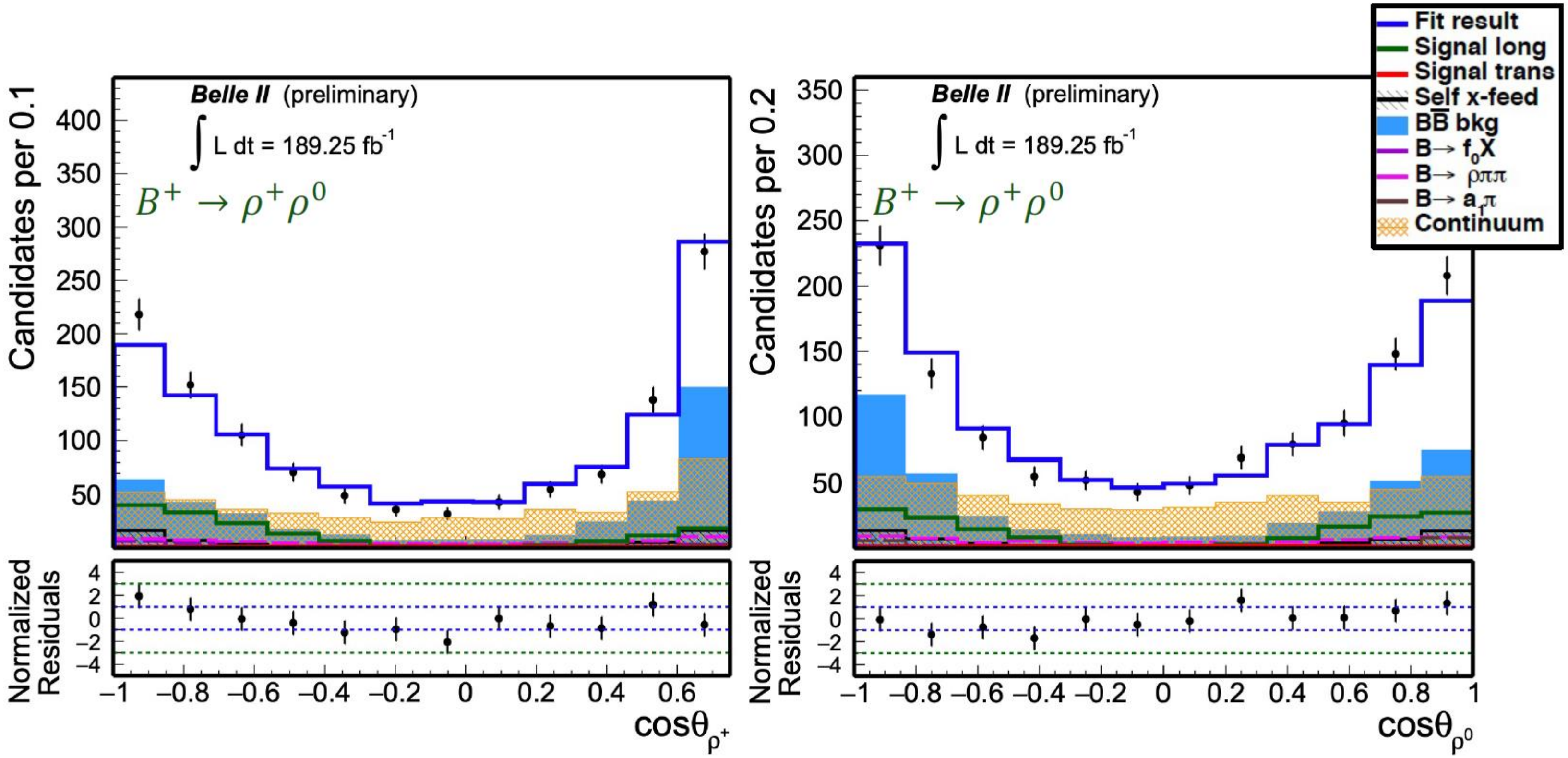
Update of $B^+ \to \rho^+ \rho^0$ 189.8 fb^{-1}



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



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

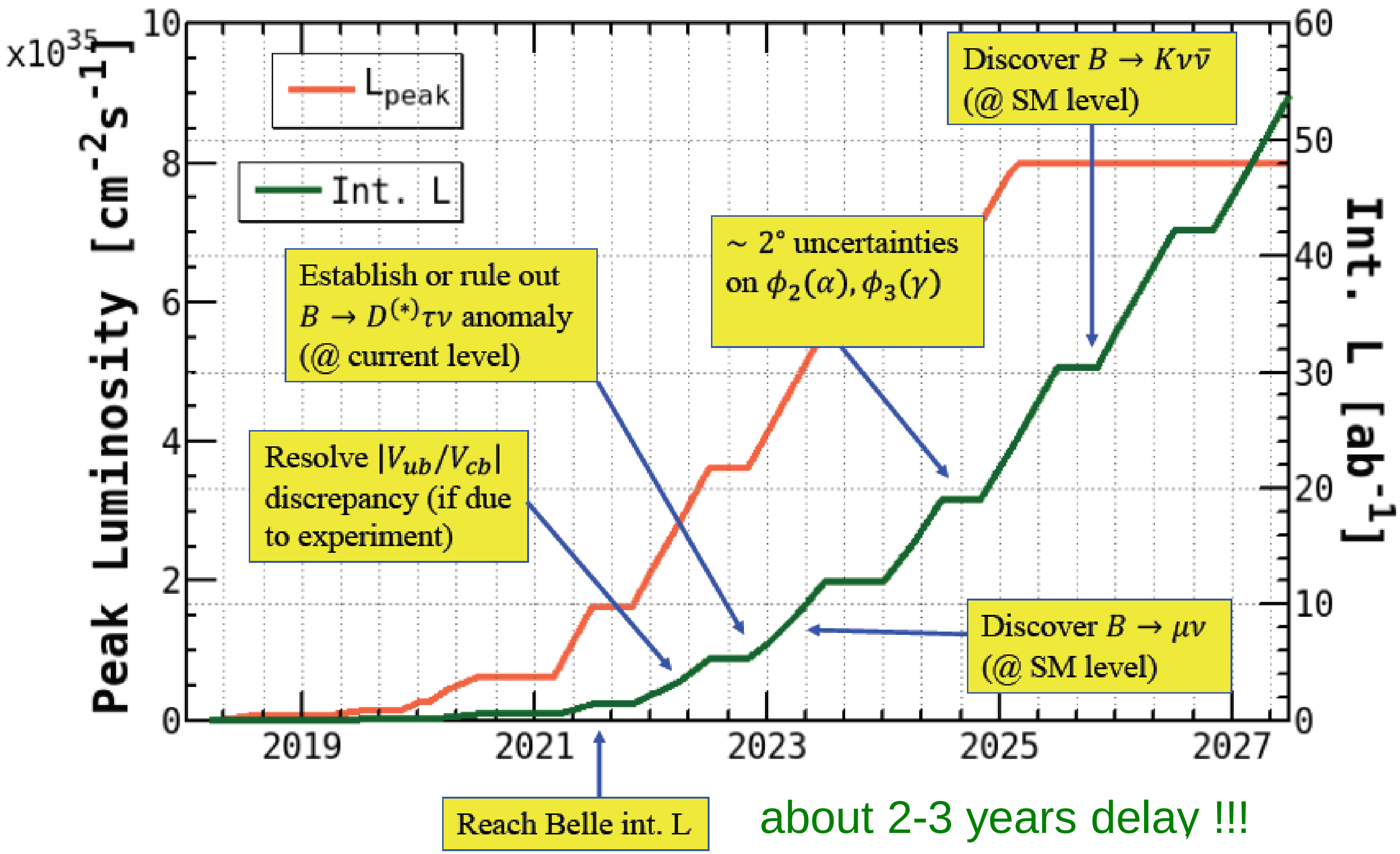


	Results	PDG
A_{CP}	$-0.069 \pm 0.068 \pm 0.060$	(-0.05 ± 0.05)
$BF\ (10^{-6})$	$23.2^{+2.2}_{-2.1} \pm 2.7$	(24.0 ± 1.9)
f_L	$0.943^{+0.035}_{-0.033} \pm 0.027$	(0.950 ± 0.016)

Expected physics results

The Belle II Physics Book

Prog Theor Exp Phys (2019)
arXiv:1808.10567 **[hep-ex]**



about 2-3 years delay !!!

Summary

- BelleII will collect ~500 fb^{-1} data before long shutdown in 2023
- Some rediscovery results were obtained with $\leq$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