

Work package 1 Report

“Search for New Physics Signals at Belle II”

Christoph Schwanda (HEPHY-OEAW), Dec 12, 2022



The Belle II experiment



KEK
Tsukuba, Japan

Vertex detector
2 layers of DEPFET pixels (PXD) and
4 layers of silicon strips (SVD)
Vertex resolution $\sim 15\mu\text{m}$

Central drift chamber
Spatial resolution $\sim 100\mu\text{m}$
 dE/dx resolution: 5%
 p_T resolution: 0.4%

KLM
Instrumented flux return

Electromagnetic Calorimeter
Energy resolution: 1.6 - 4%

Forward and barrel Part. Id.
K eff. 90%, fake π rate 5%

$E_{\text{cm}} = 10.58 \text{ GeV}$
($\Upsilon(4S)$ resonance)

7 GeV e^-

4 GeV e^+

Aerial view of KEK Tsukuba campus (Japan)

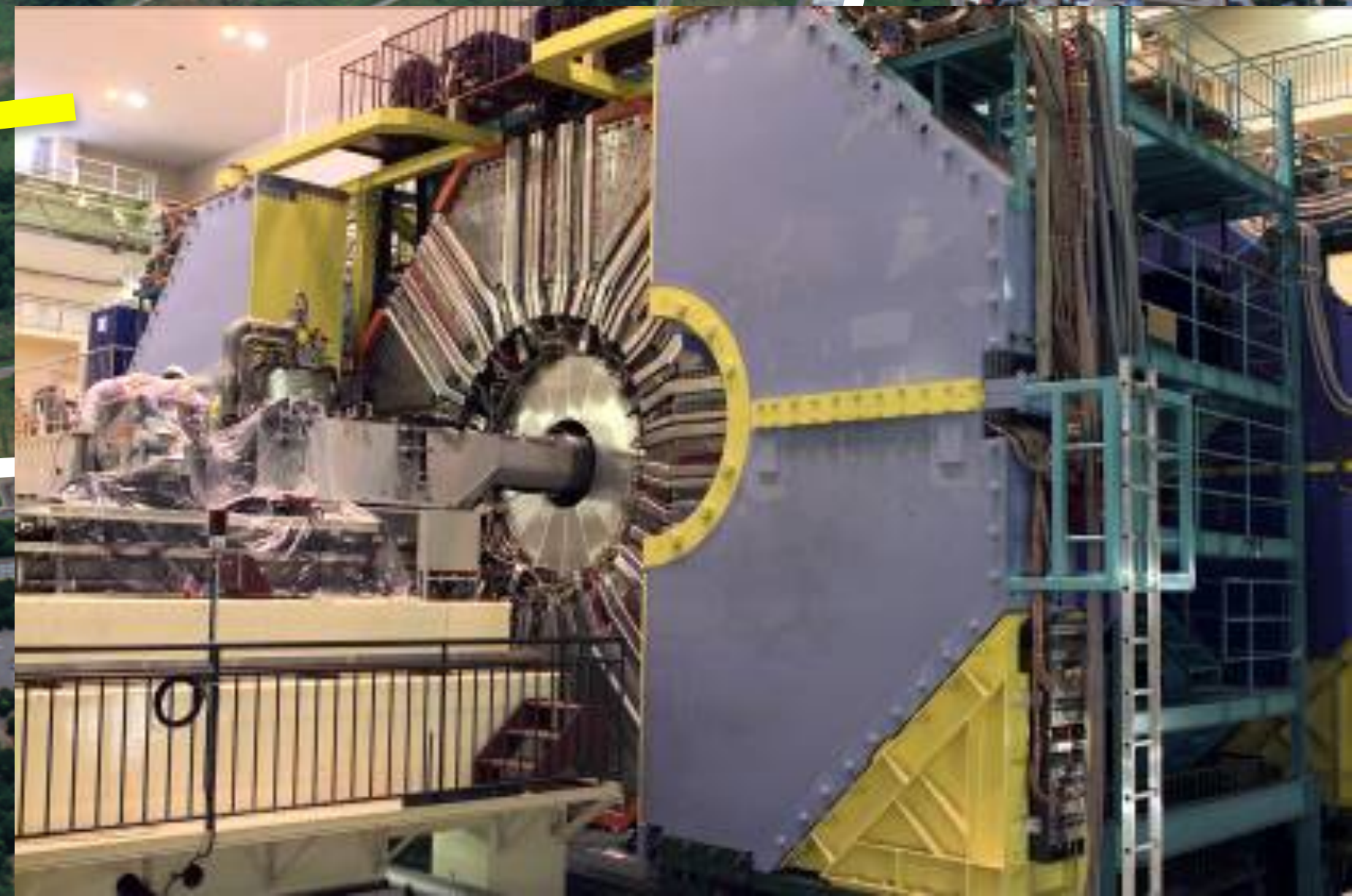
Linac

Damping ring e^+

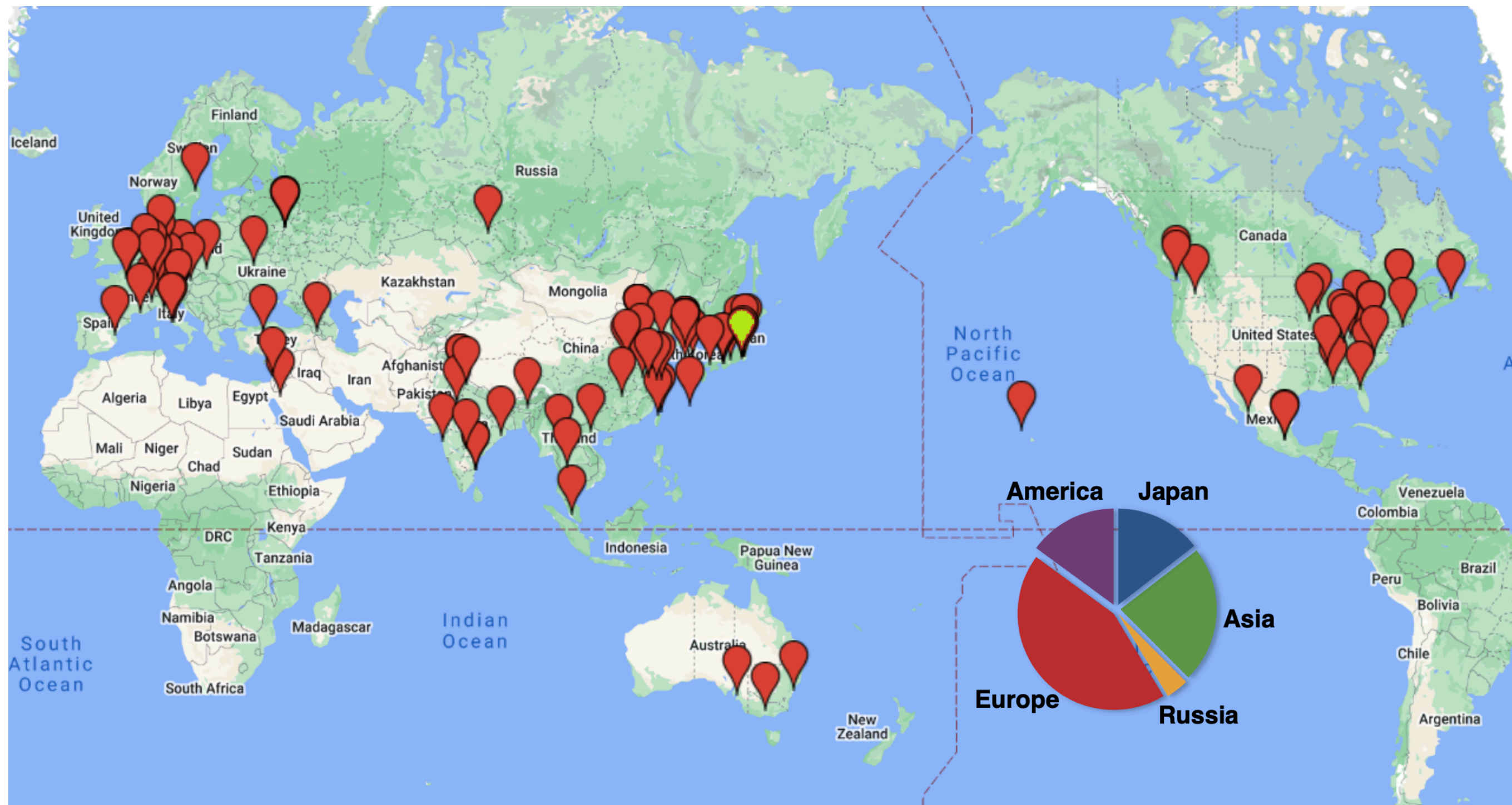
SuperKEKB double ring
 e^+e^- collider

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$$

Belle II detector



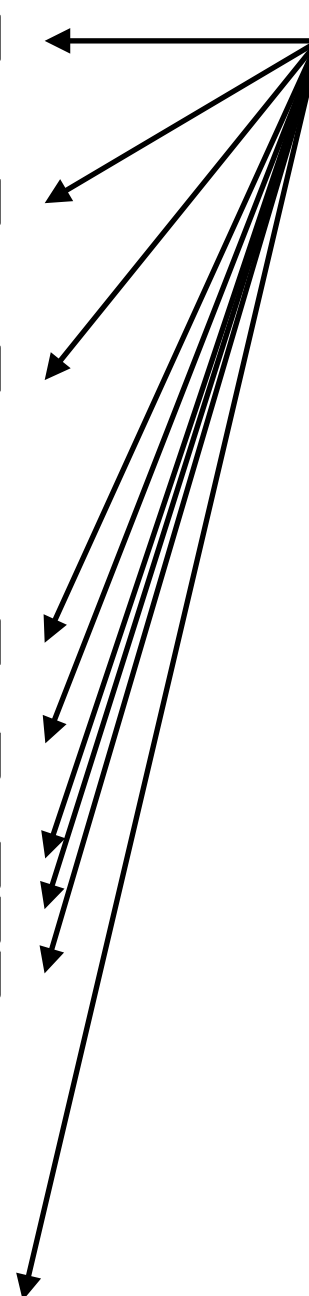
Belle II collaboration



27 countries, 123 institutions, 1155 members

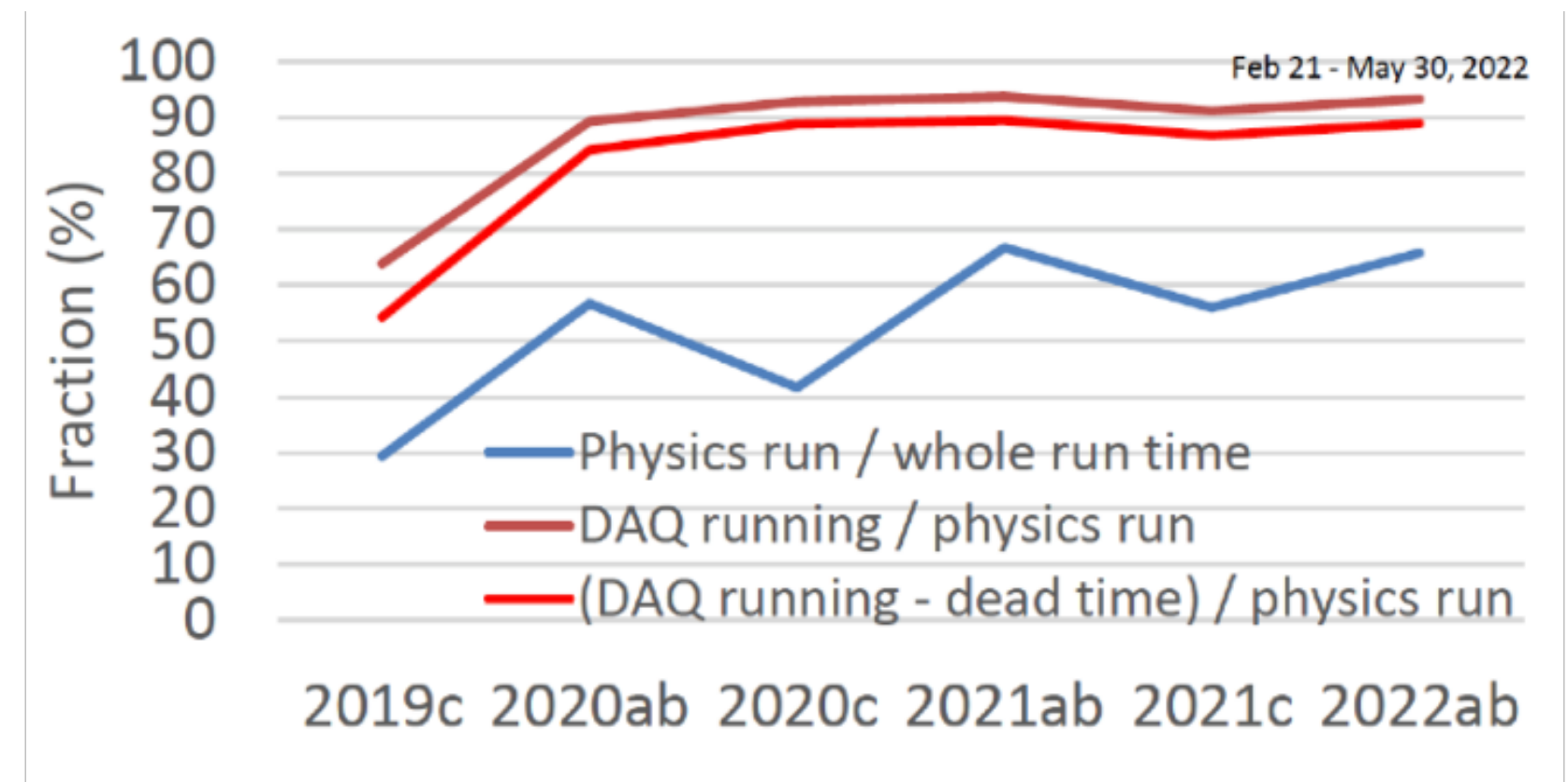
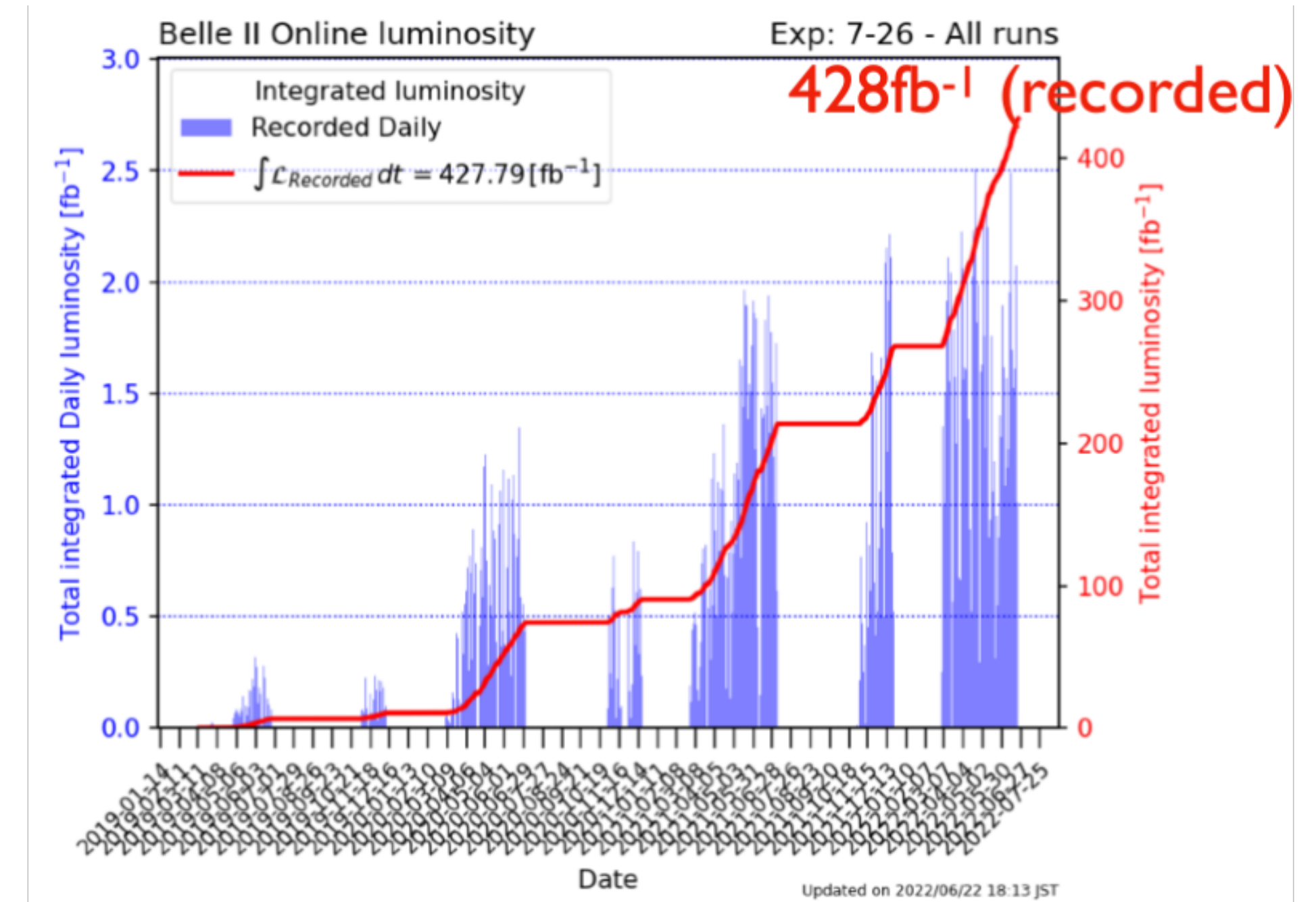
Country	Members
Germany	236
Japan	171
U.S.A.	119
Italy	109
China	73
India	64
France	60
Canada	41
South Korea	41
Taiwan	40
Russia	40
Austria	33
Australia	26
Slovenia	25
Mexico	14
Israel	10
Czechia	8
Poland	7
Armenia	7
Ukraine	6
Spain	5
Thailand	5
Viet Nam	4
Turkey	4
Saudi Arabia	4
Sweden	2
Malaysia	1
Gesamtergebnis	1155

JENNIFER2

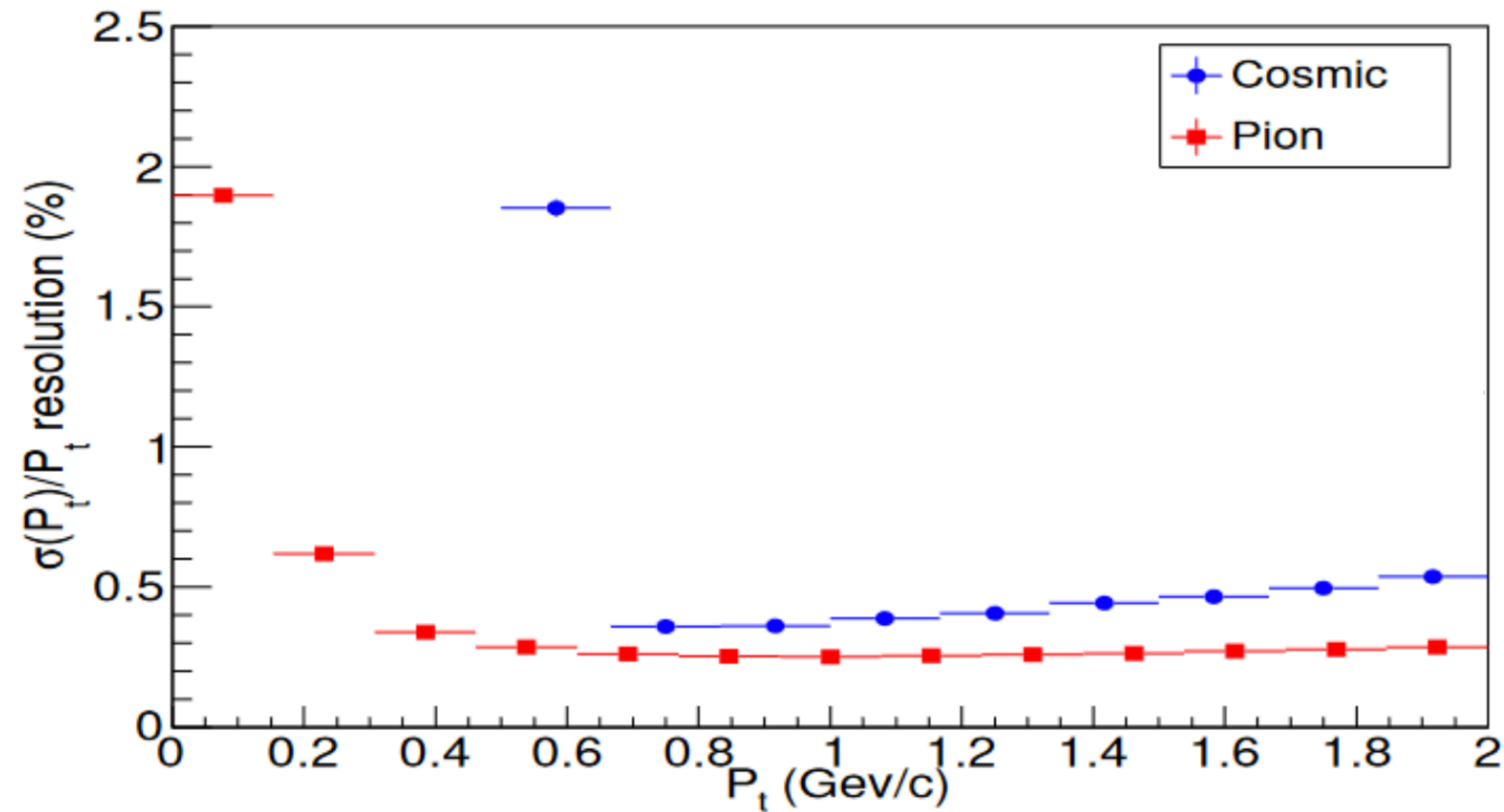


Status of SuperKEKB and Belle II

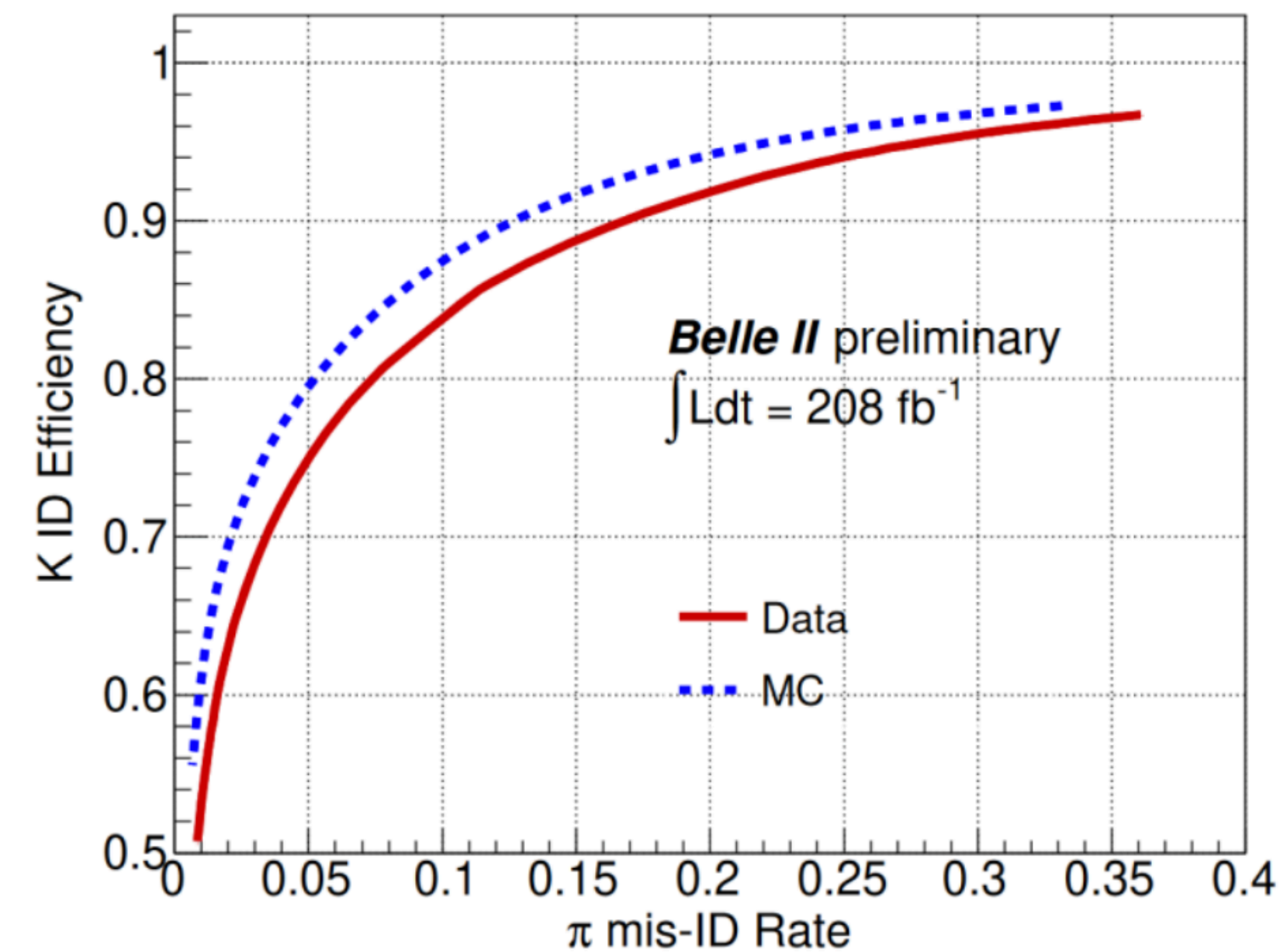
- The Super B factory operated since 2019, throughout the pandemic and entered a shutdown in June 2022 (LS1) for detector and machine upgrades
 - A world record luminosity of $\sim 4.7 \times 10^{34}/\text{cm}^2/\text{s}$ was achieved in the spring run 2022
 - In total, 428/fb of data were recorded by Belle II
 - Operation is expected to resume towards the end of 2023
- Overall the detector performed well and collected high quality data for physics analysis
 - The data taking efficiency at $\sim 90\%$ before LS1



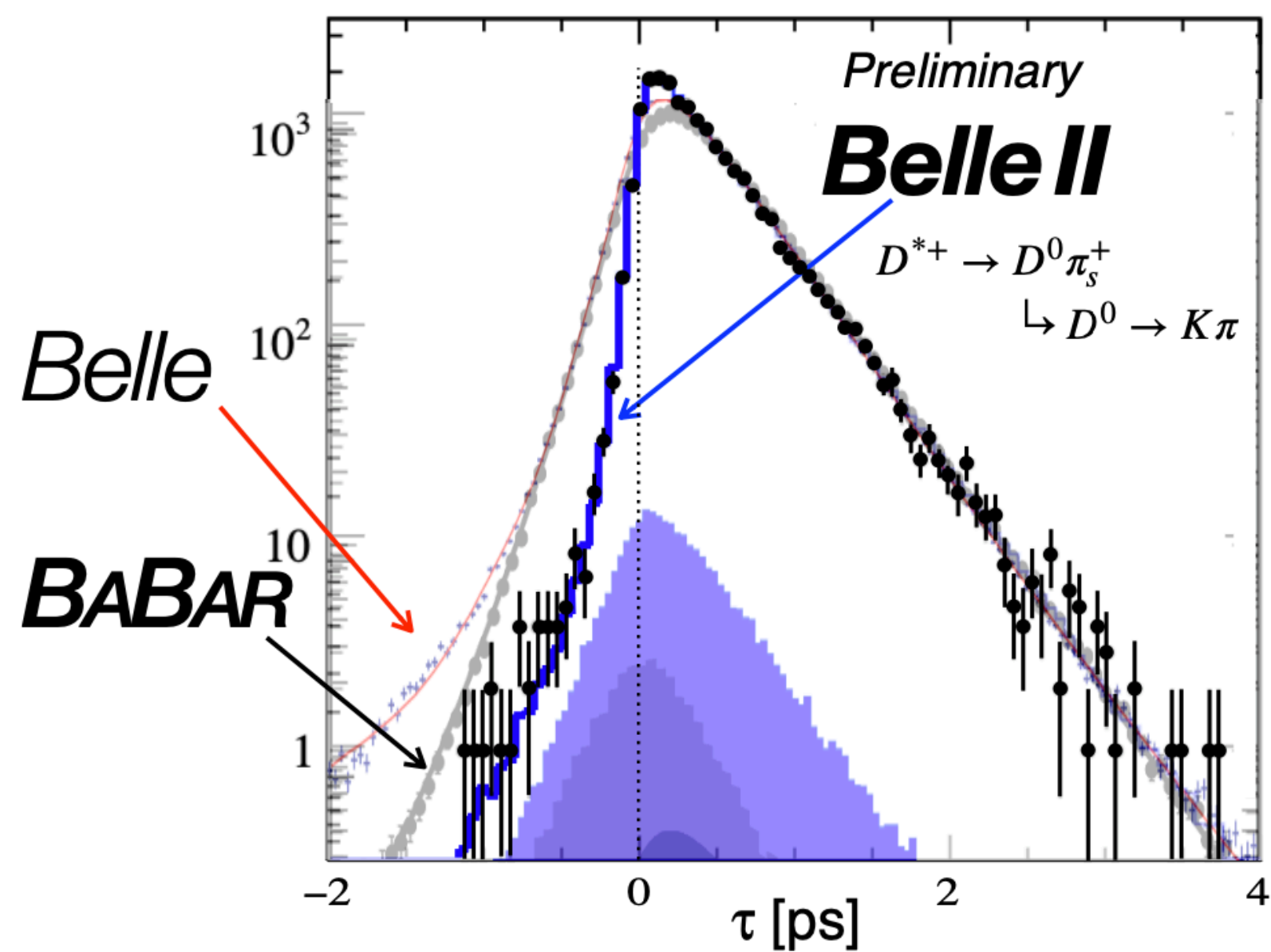
Improved P_t resolution wrt Belle



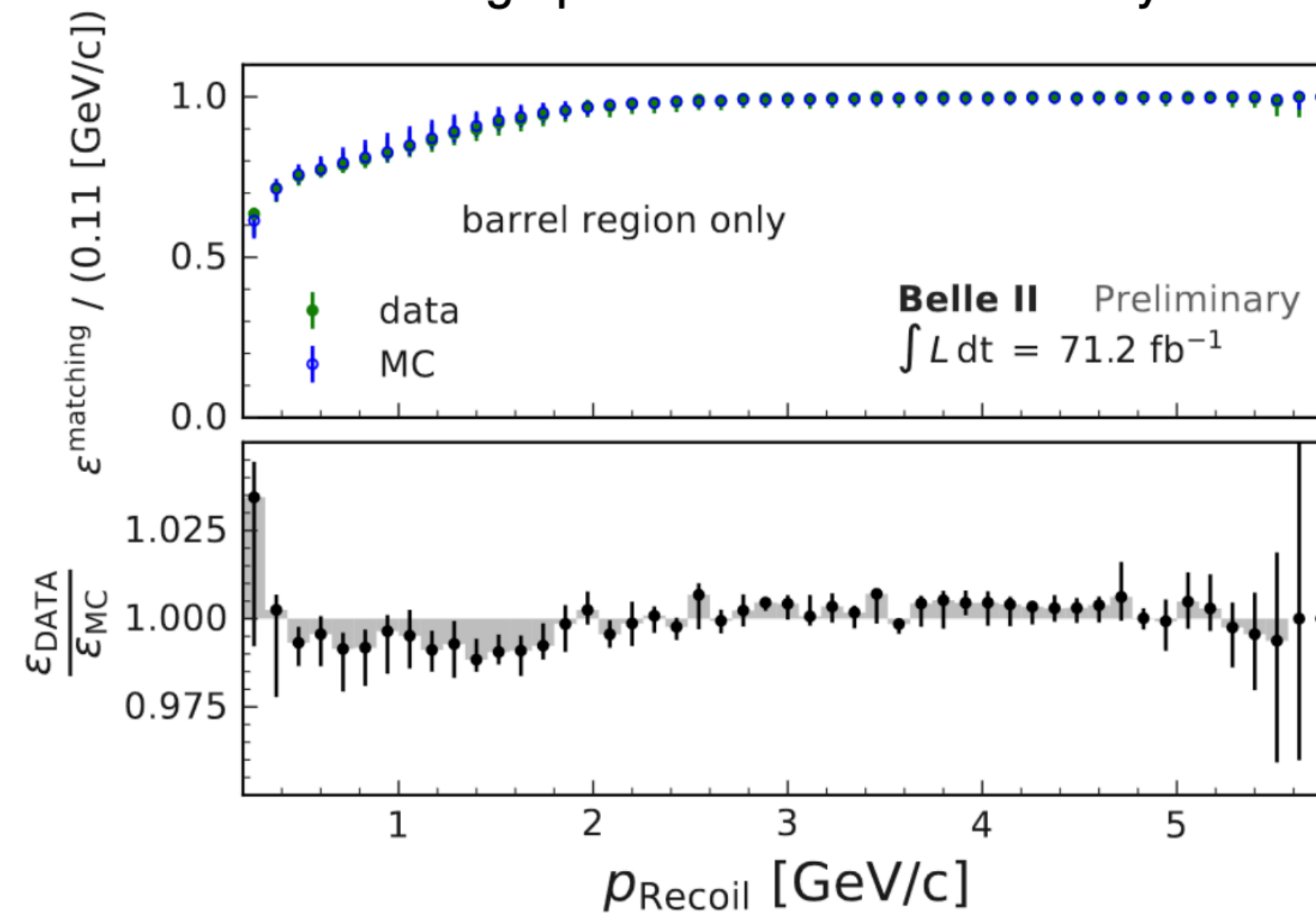
K/ π ID still slightly worse than Belle



Vertex resolution twice as good as Belle



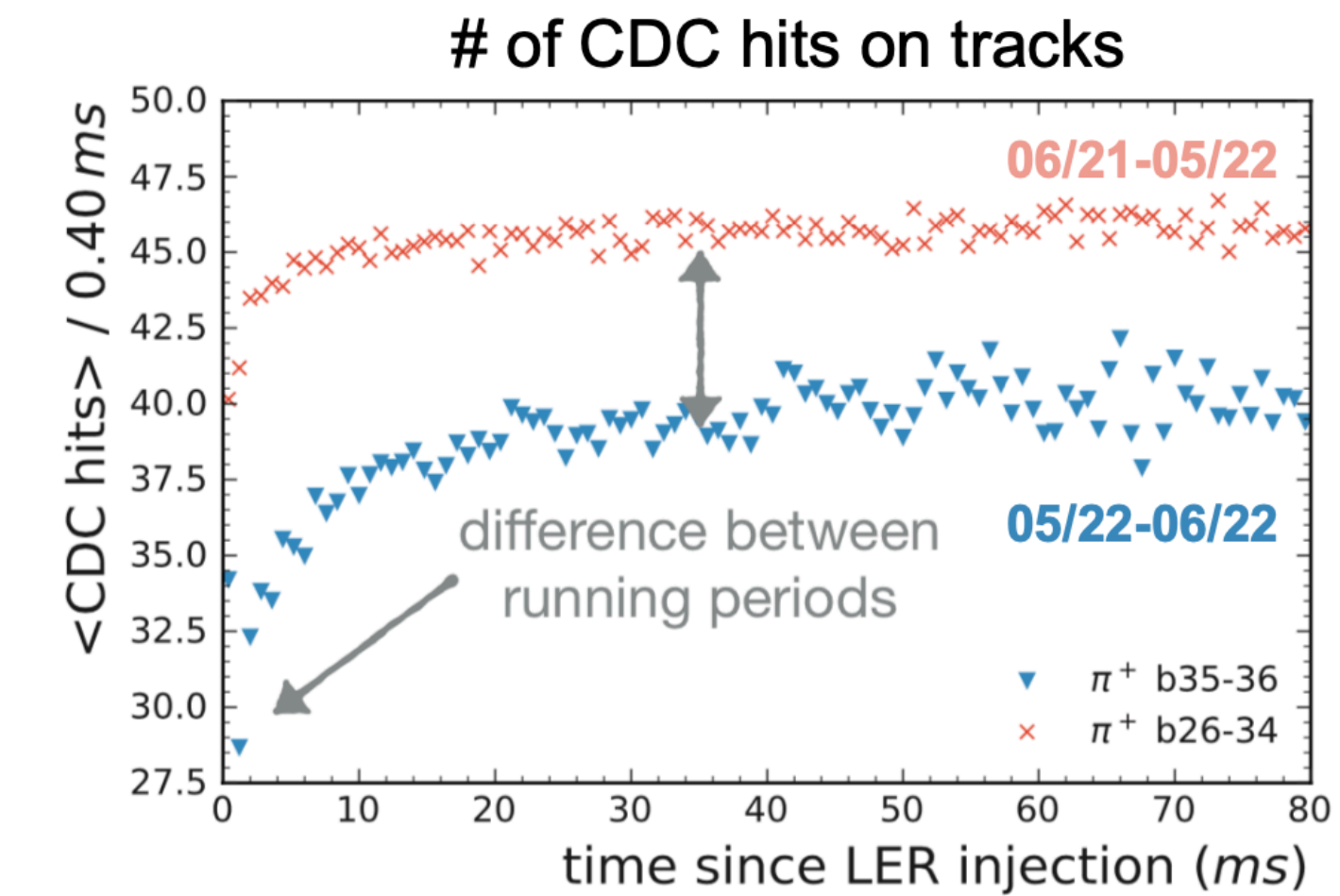
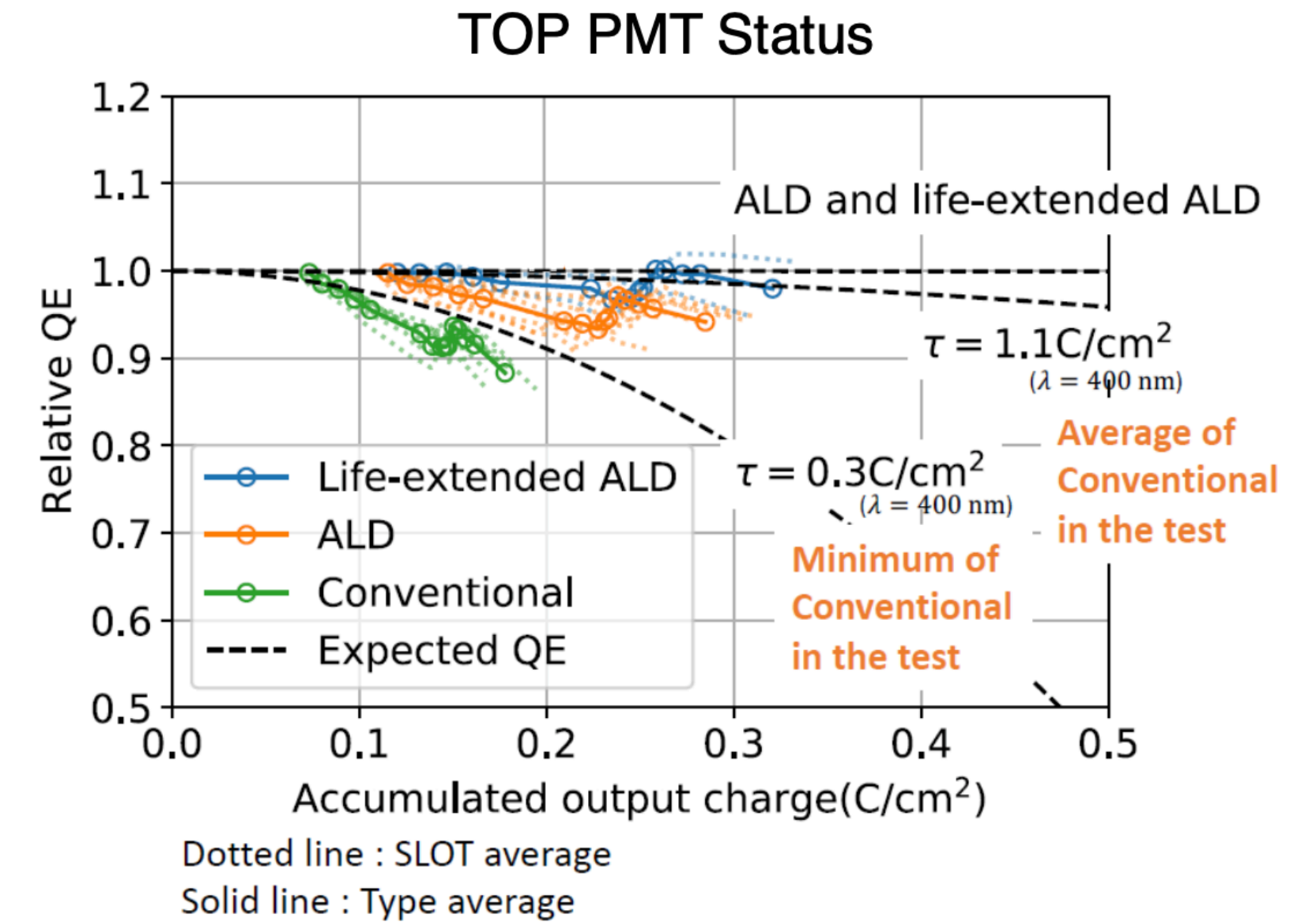
High photon detection efficiency



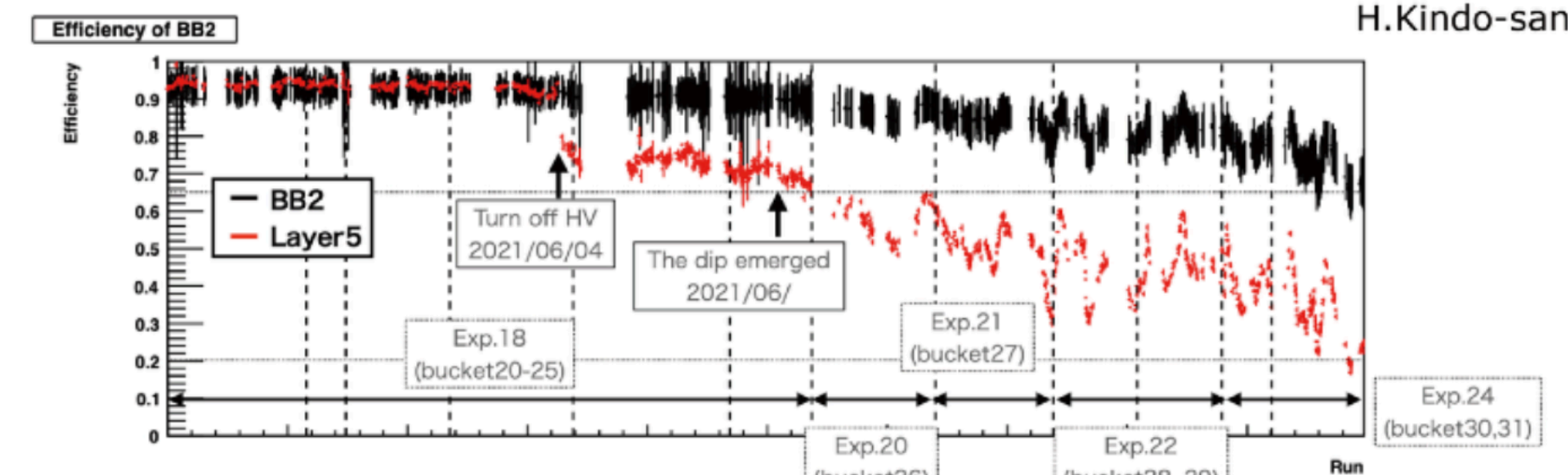
Planned work during LS1

Sep 2022 – End of 2023

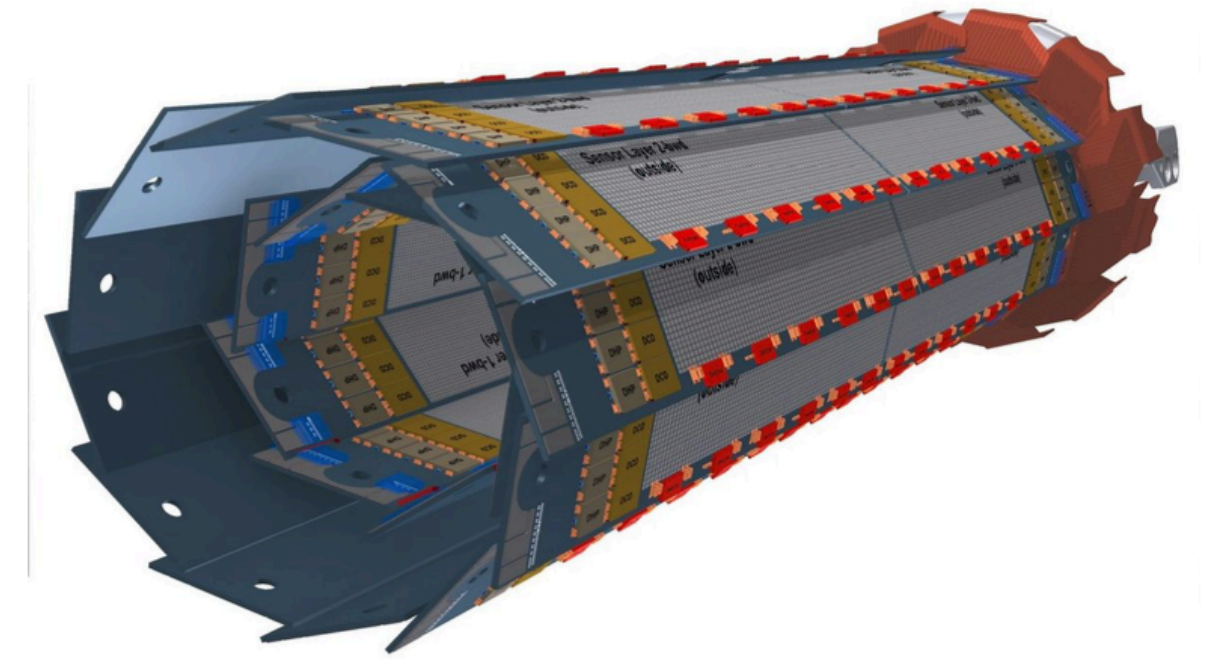
- Belle II
 - Installation of a complete pixel detector (PXD2)
 - Replacement of aged TOP photomultiplier tubes
 - Other maintenance (DAQ/trigger upgrade, CDC, KLM)
- SuperKEKB
 - Several modifications for more stable beam injection, longer beam lifetime, improved beam stability and more stable operation (see backup)



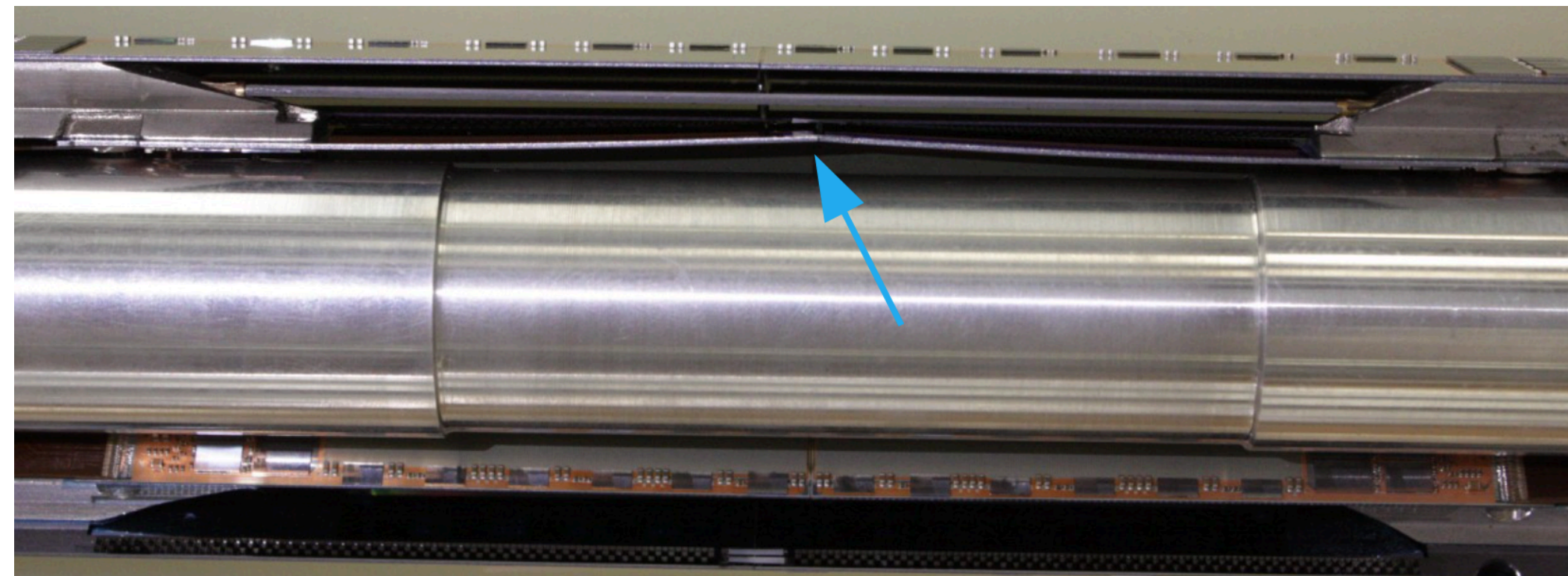
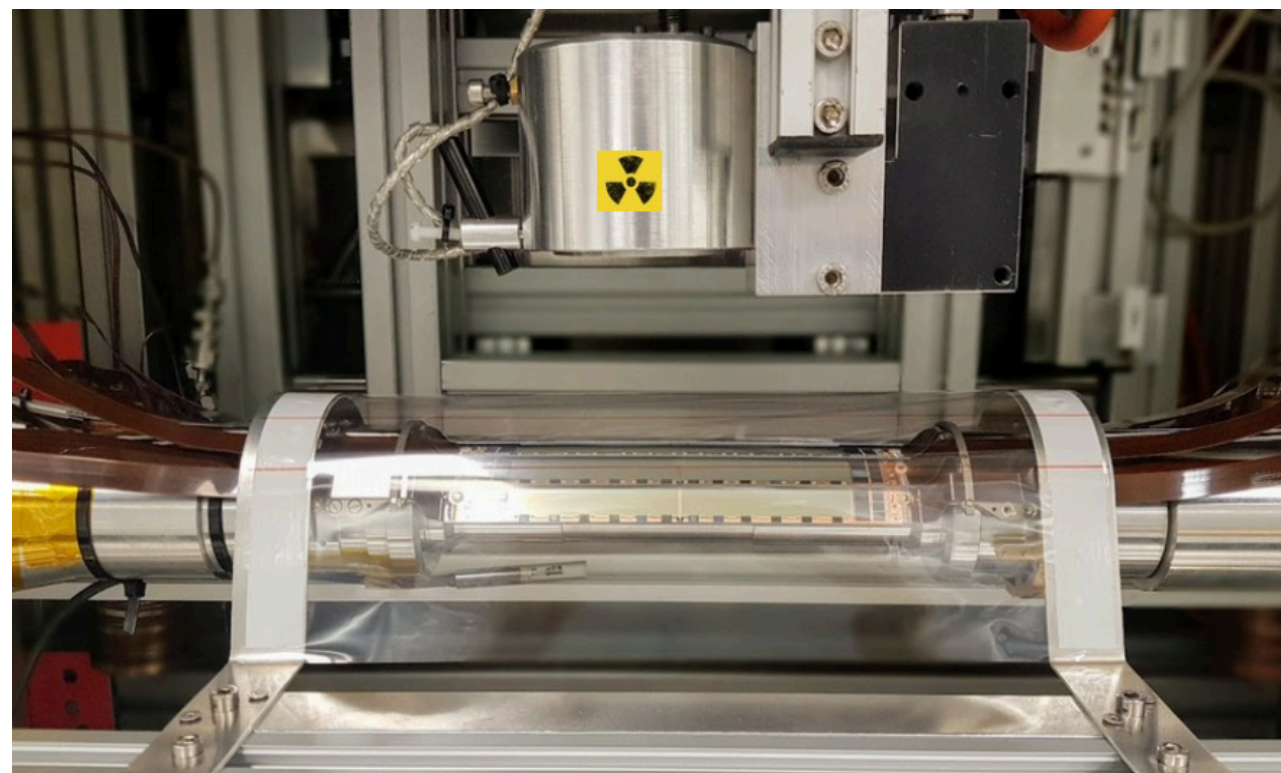
- KLM efficiency drop at BB2 (sector 2 in the backward barrel)



PXD2 installation

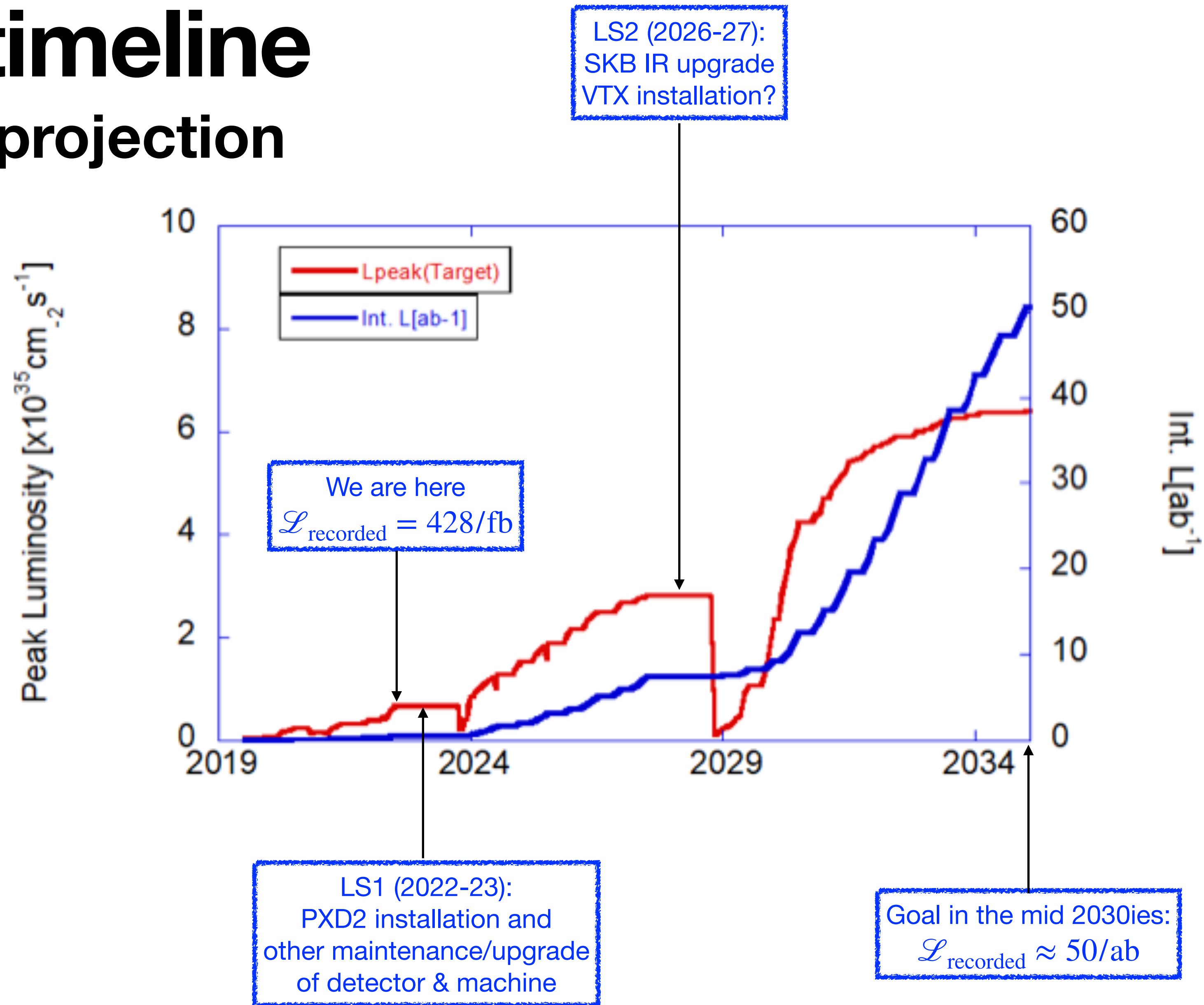


- PXD2 employs the same technology as PXD1 but with improved manufacturing processes and more time
- Module production and half-shell production finished at MPP Munich
- Half shells tests ongoing in DESY Hamburg (electrical tests, ^{90}Sr source measurements)
 - During these tests a glue joint on the first half shell opened
 - Cause and repair strategy under investigation
 - Decision on PXD2 installation to be taken at February 2023 collaboration meeting



Belle II timeline

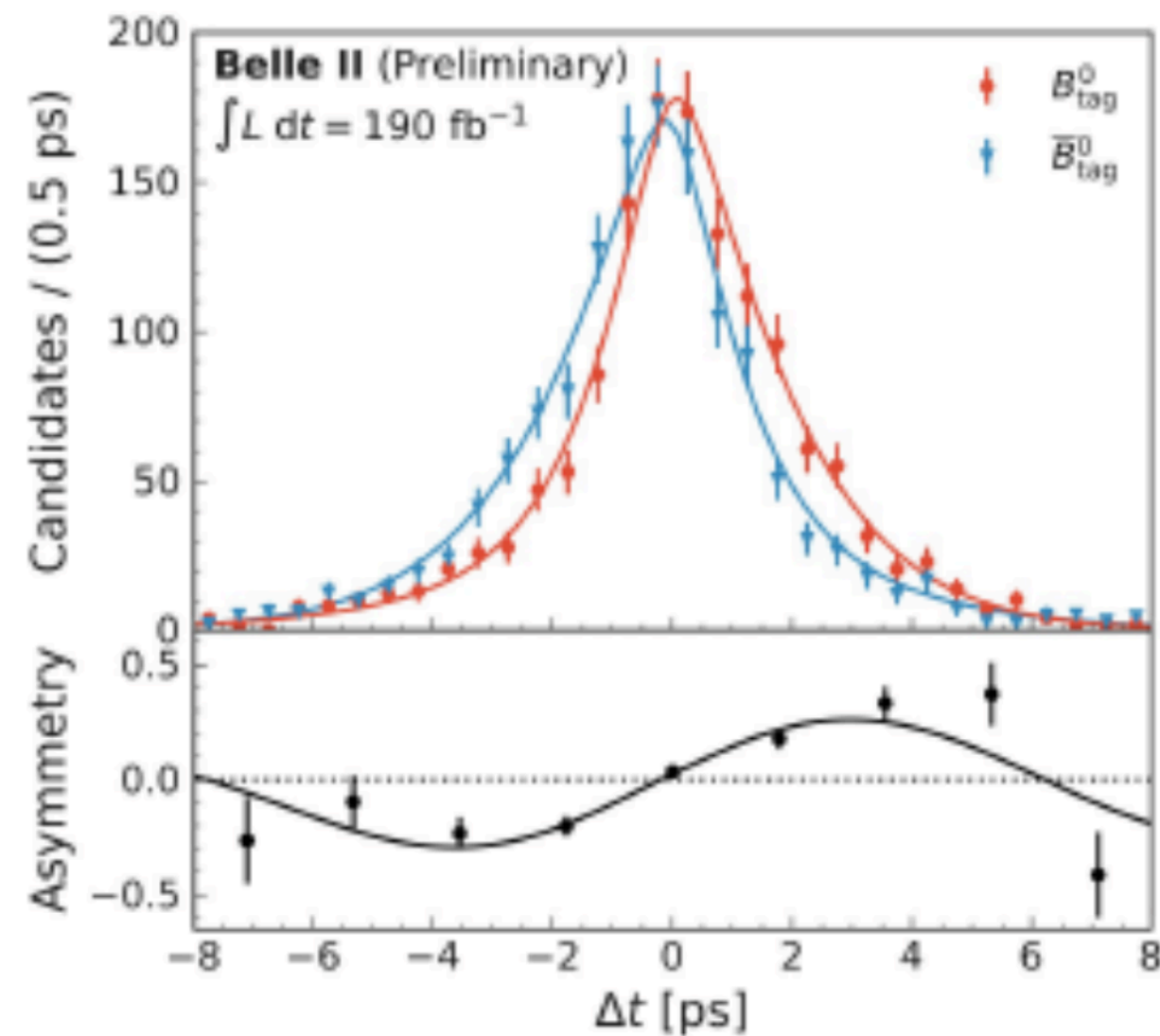
Luminosity projection



Belle II physics results (summer 2022)

Probing the Cabibbo-Kobayashi-Maskawa mechanism

CPV in $B \rightarrow J/\psi K_S^0$ (190fb^{-1})



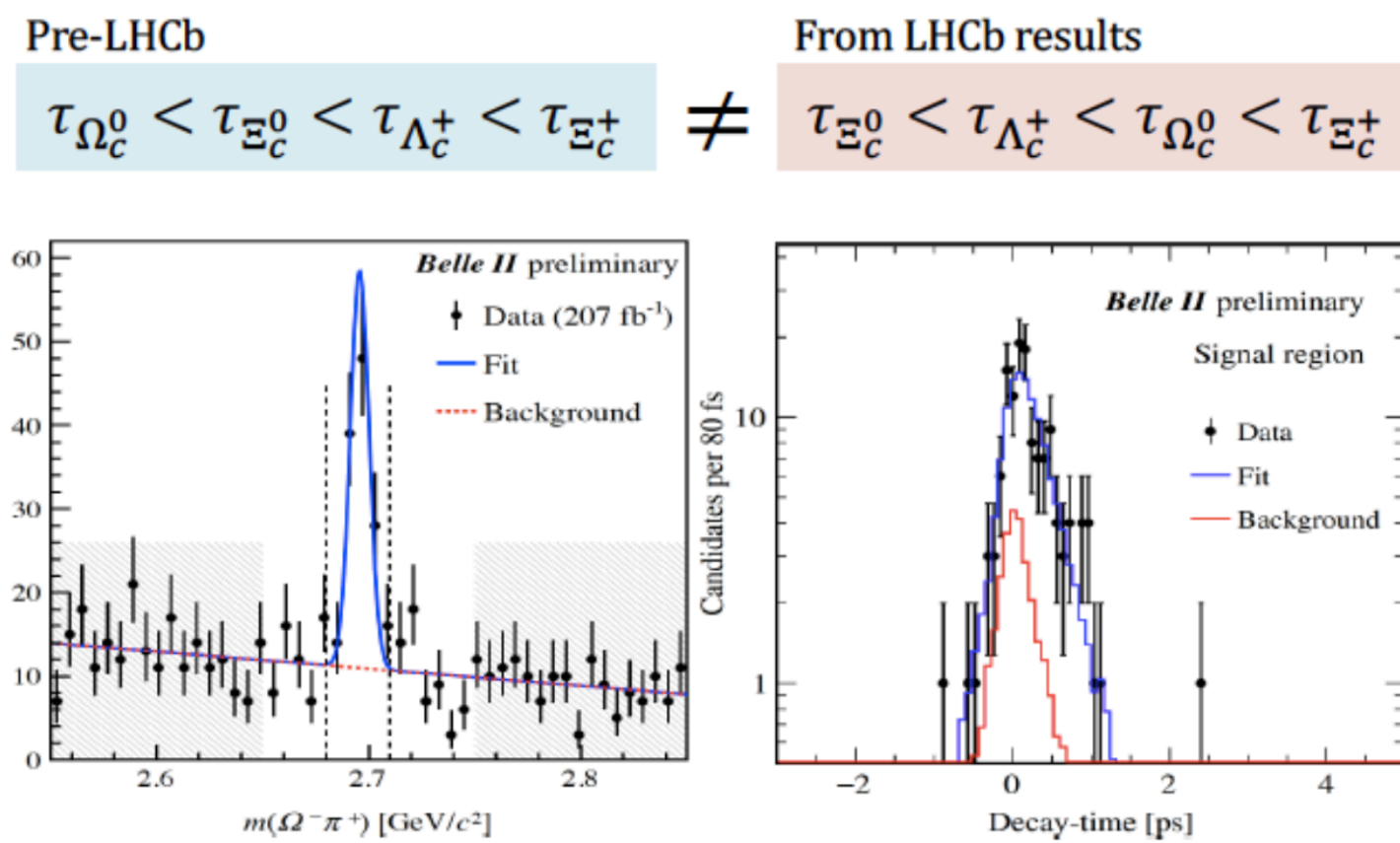
$$S_{CP} = 0.720 \pm 0.062(\text{stat}) \pm 0.016(\text{syst}),$$

$$A_{CP} = 0.094 \pm 0.044(\text{stat}) \begin{matrix} +0.042 \\ -0.017 \end{matrix} (\text{syst})$$

World Average: $S_{CP} = 0.695 \pm 0.019,$
 $A_{CP} = 0.000 \pm 0.020$

La Licata @ ICHEP

Charmed-Baryon Lifetime (207fb^{-1})



$$\tau_{\Omega_c^0} = (243 \pm 48 \pm 11) \text{ fs}$$

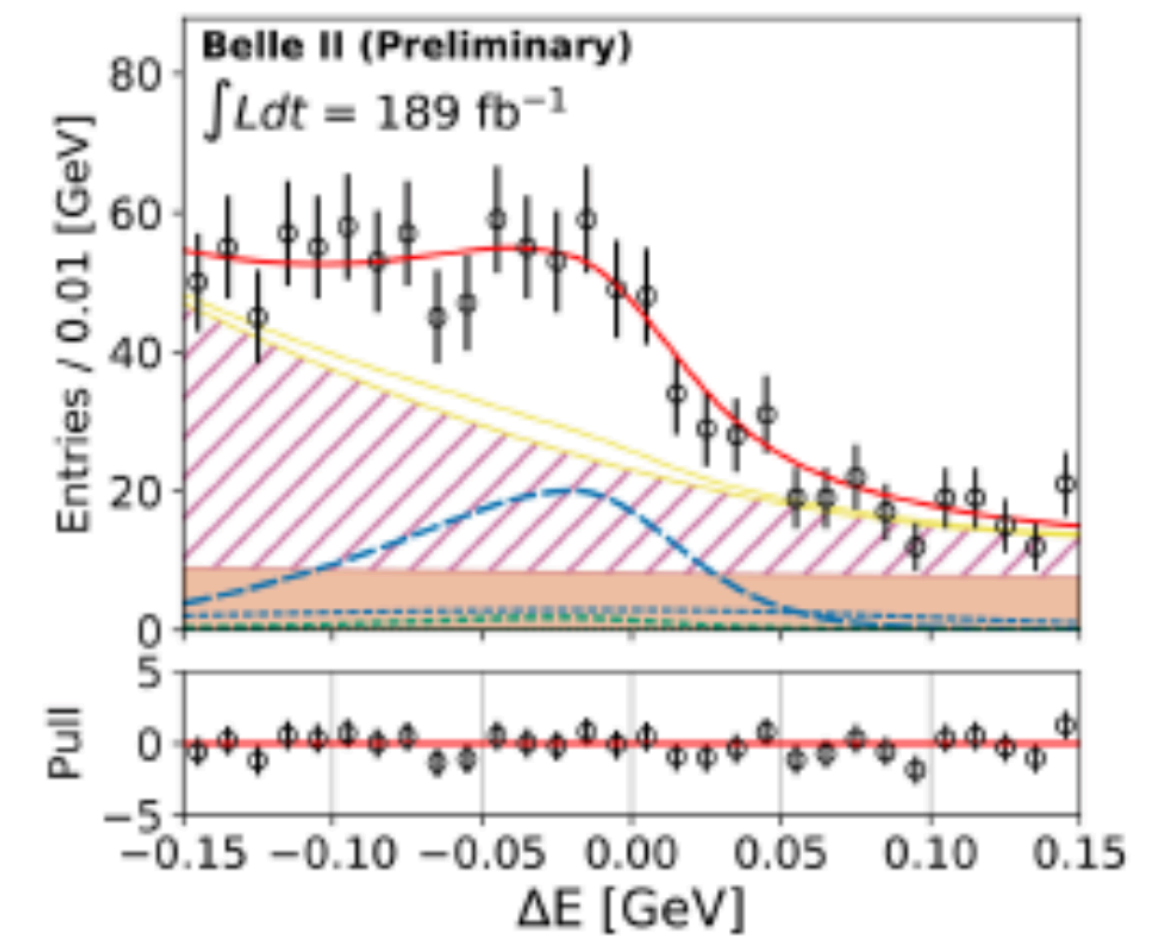
... Belle II confirms the LHCb results

arXiv:2208.08573, to appear in PRD(L)

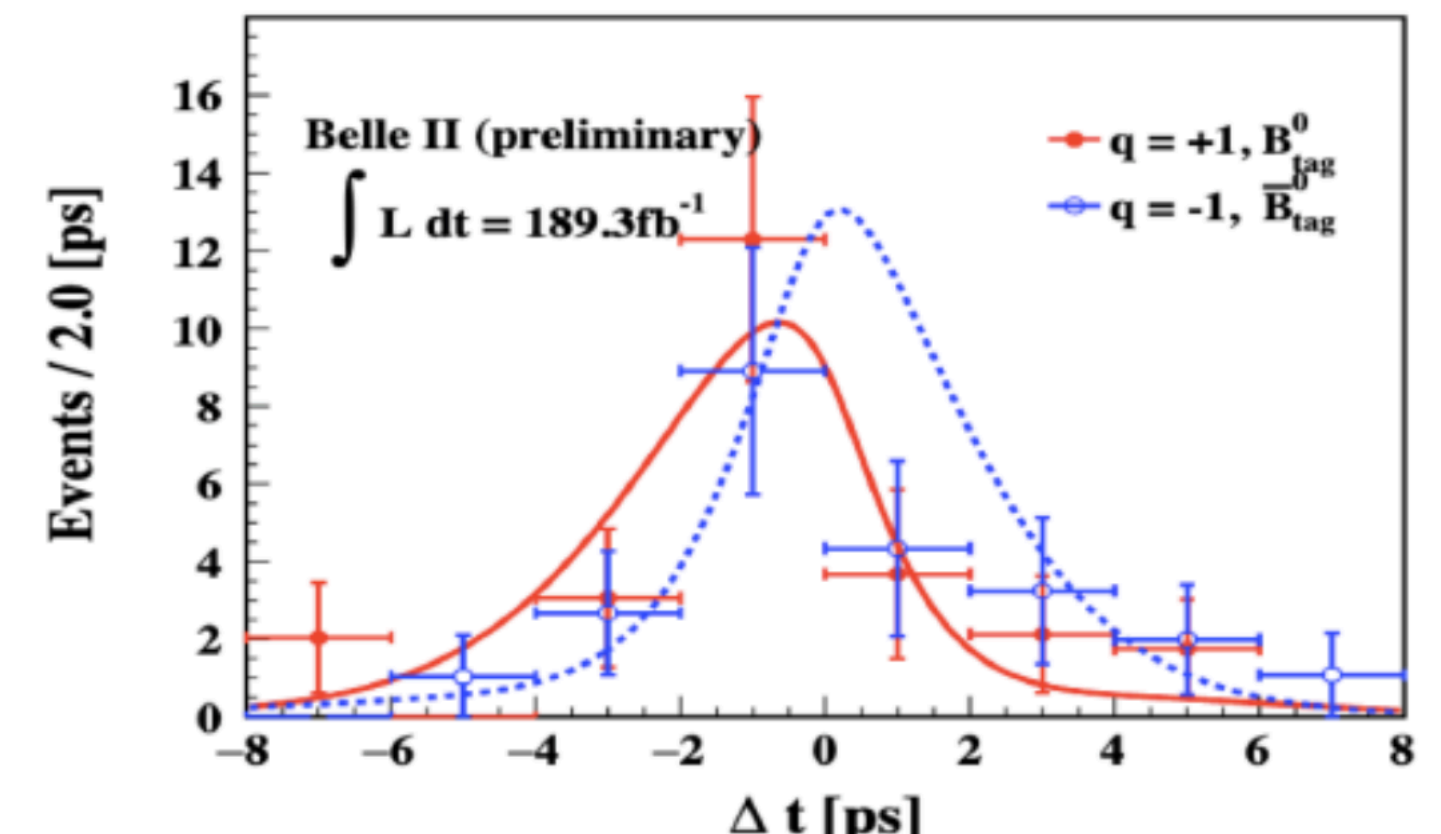
$$S_{CP} = -1.86 \pm 0.83 \pm 0.09$$

$$\mathcal{A}_{CP} = -0.22 \pm 0.29 \pm 0.04$$

$Br(B^0 \rightarrow \rho^+ \rho^-)$



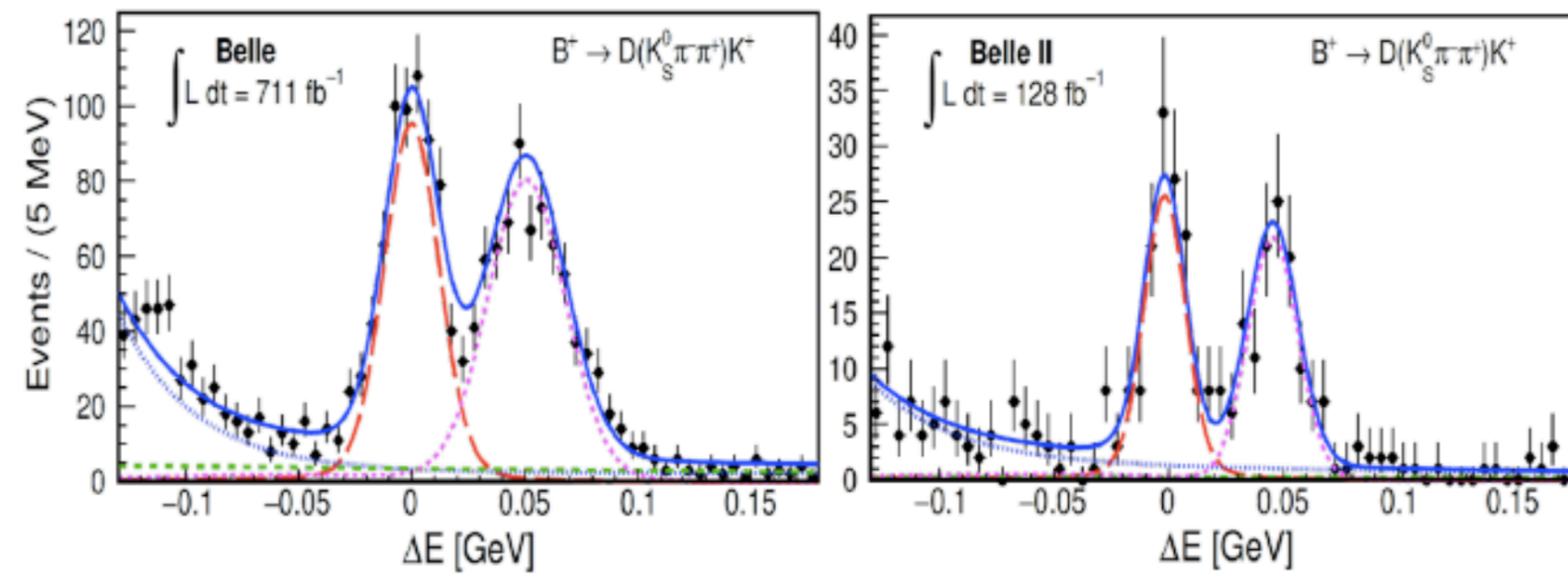
CPV in $B \rightarrow K_S^0 K_S^0 K_S^0$ (190fb^{-1})



Belle II physics results (summer 2022)

Probing the Cabibbo-Koyabashi-Maskawa mechanism

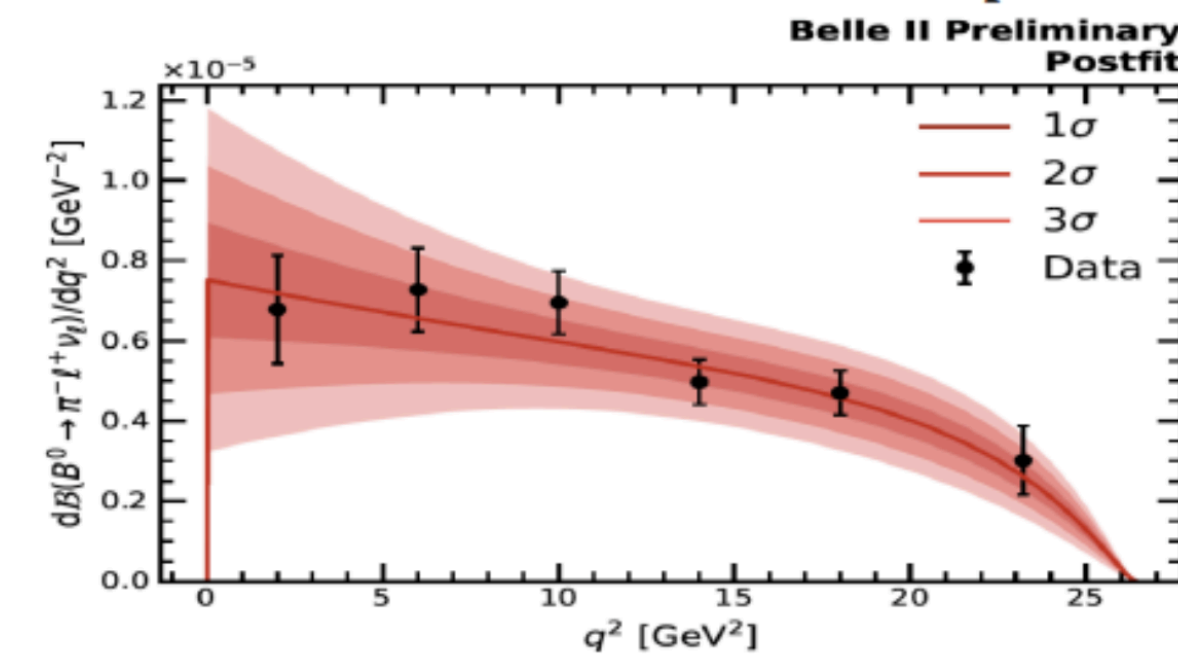
ϕ_3 measurement (Belle 711 fb⁻¹+Belle II 128fb⁻¹)



$$\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ$$

The third error arises from the uncertainty in the input from BESIII.

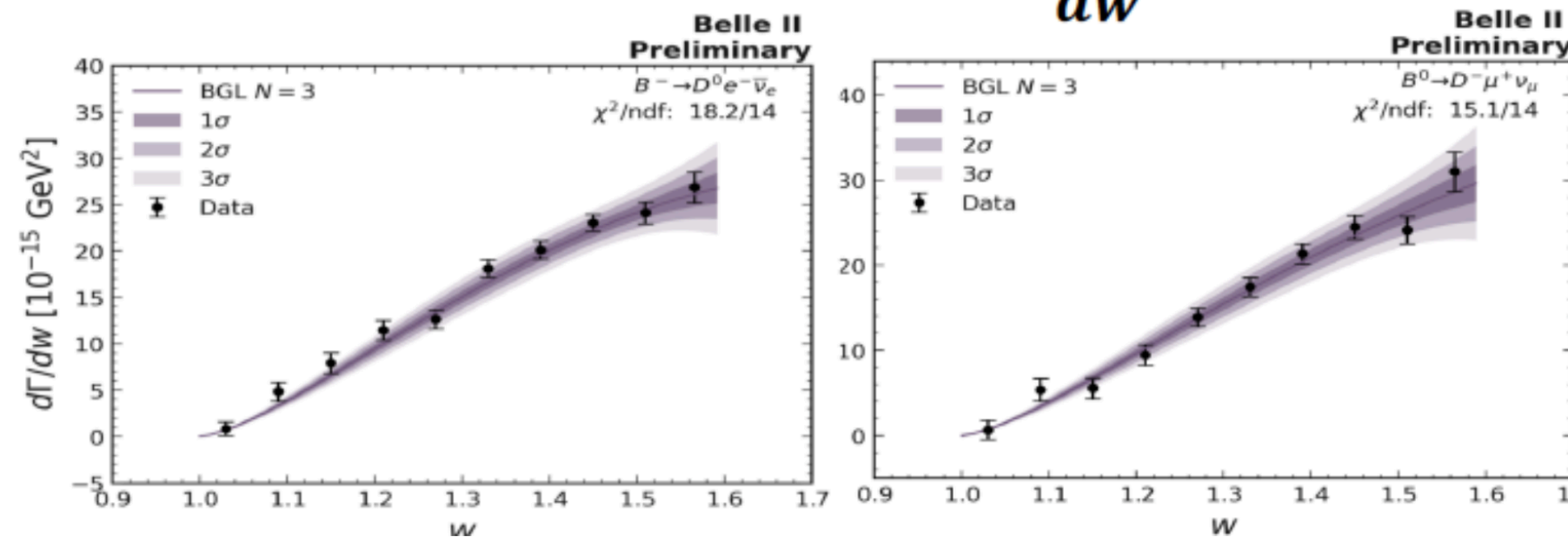
$|V_{ub}|$ exclusive extraction: $\frac{d\Gamma(q^2)}{dq^2} \propto |V_{ub}|^2$



$$|V_{ub}|_{\pi^- \ell^+ \nu_\ell} = (3.54 \pm 0.12 \pm 0.15 \pm 0.16) \times 10^{-3}$$

... consistent with the WAs

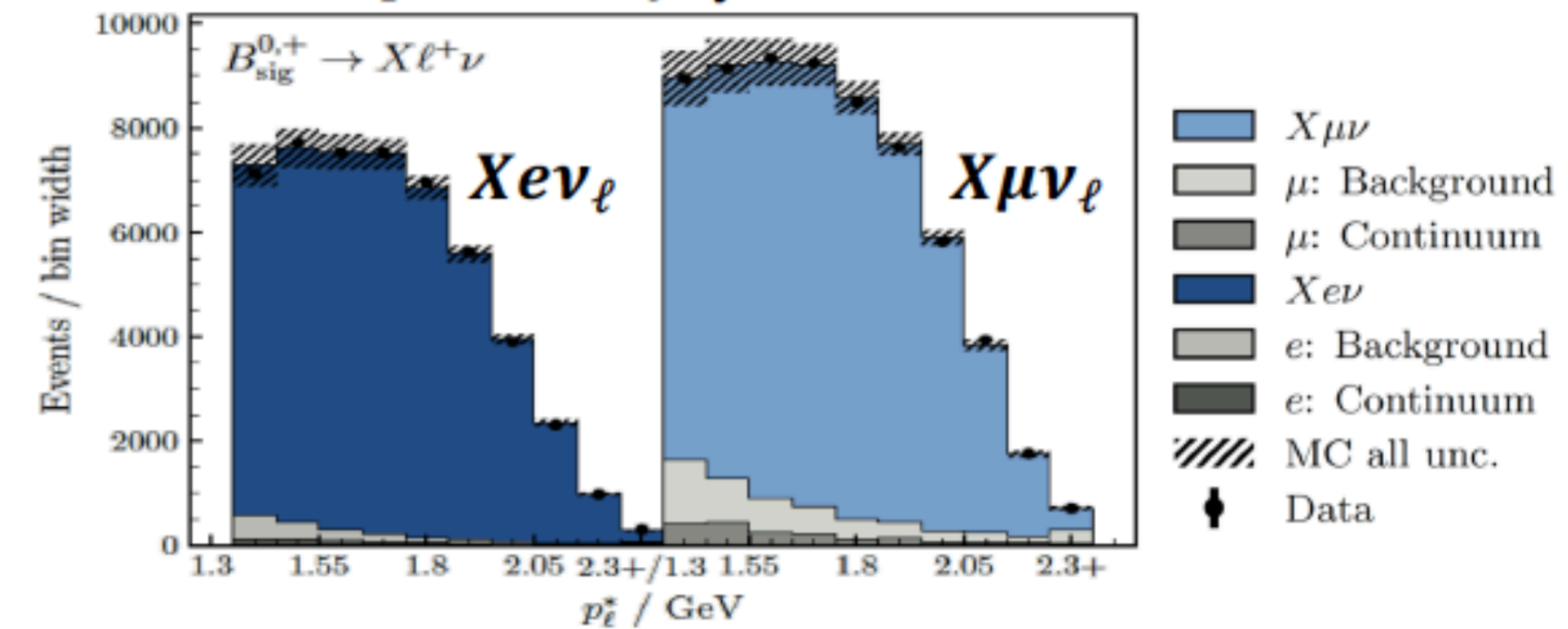
$|V_{cb}|$ exclusive extraction: $\frac{d\Gamma(w)}{dw} \propto \eta_{EW} |V_{cb}|^2$



$$\eta_{EW} |V_{cb}| = (38.53 \pm 1.15) \times 10^{-3}$$

... consistent with the exclusive WA

Belle II preliminary $\int \mathcal{L} dt = 189.9 \text{ fb}^{-1}$



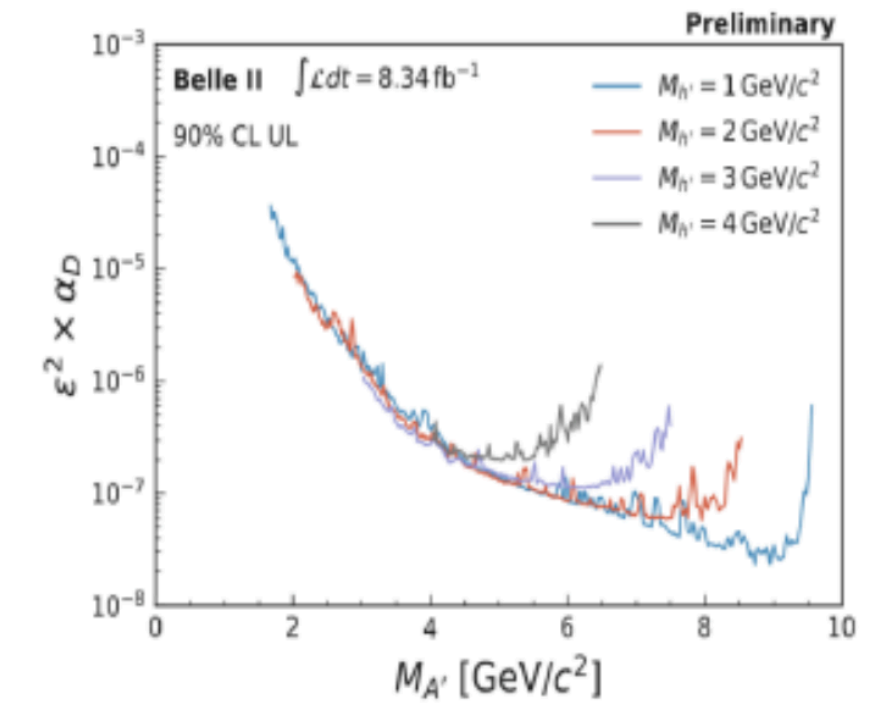
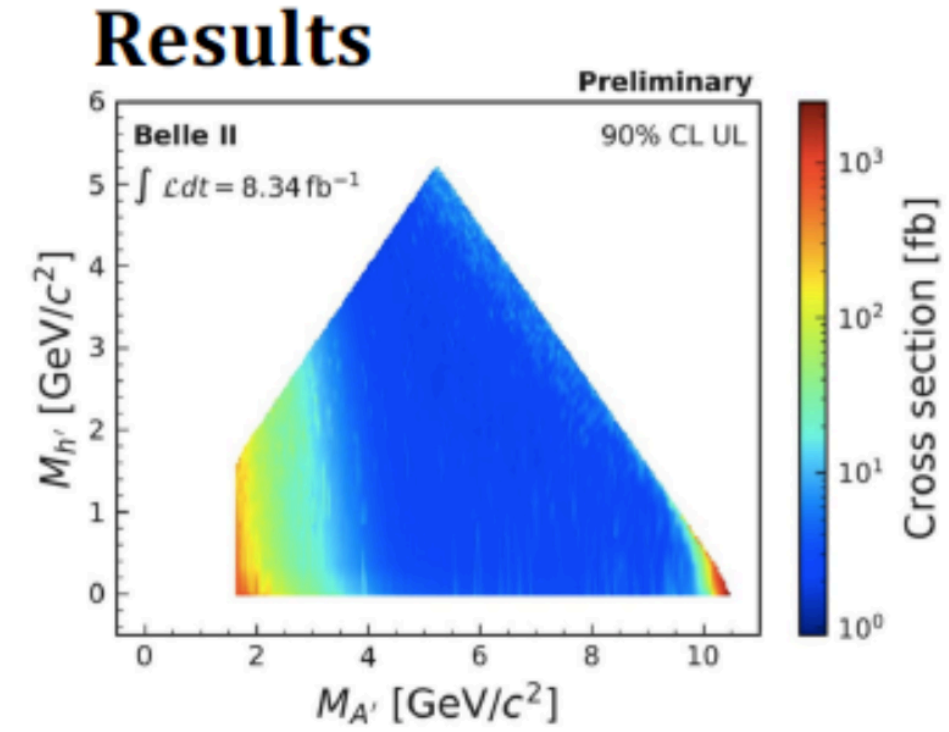
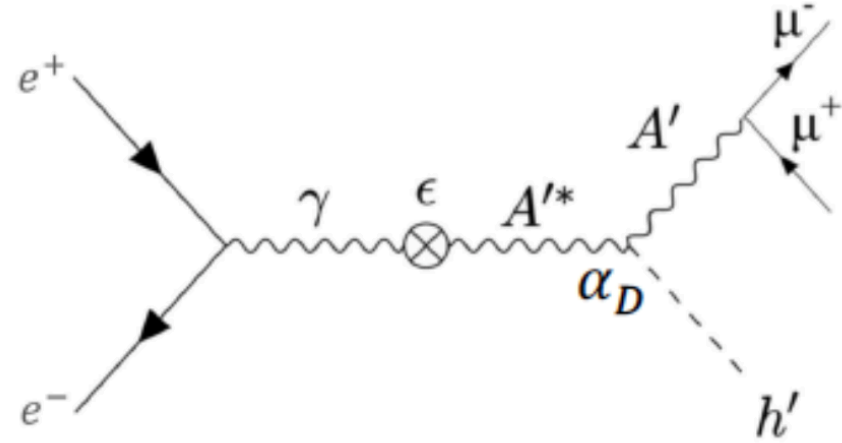
$$R(X_{e/\mu}) = 1.0333 \pm 0.010 \pm 0.020$$

First inclusive test of (e, μ) LFU in $B \rightarrow X \ell \nu_\ell$.

Recent Belle II physics results

Results on production of dark matter

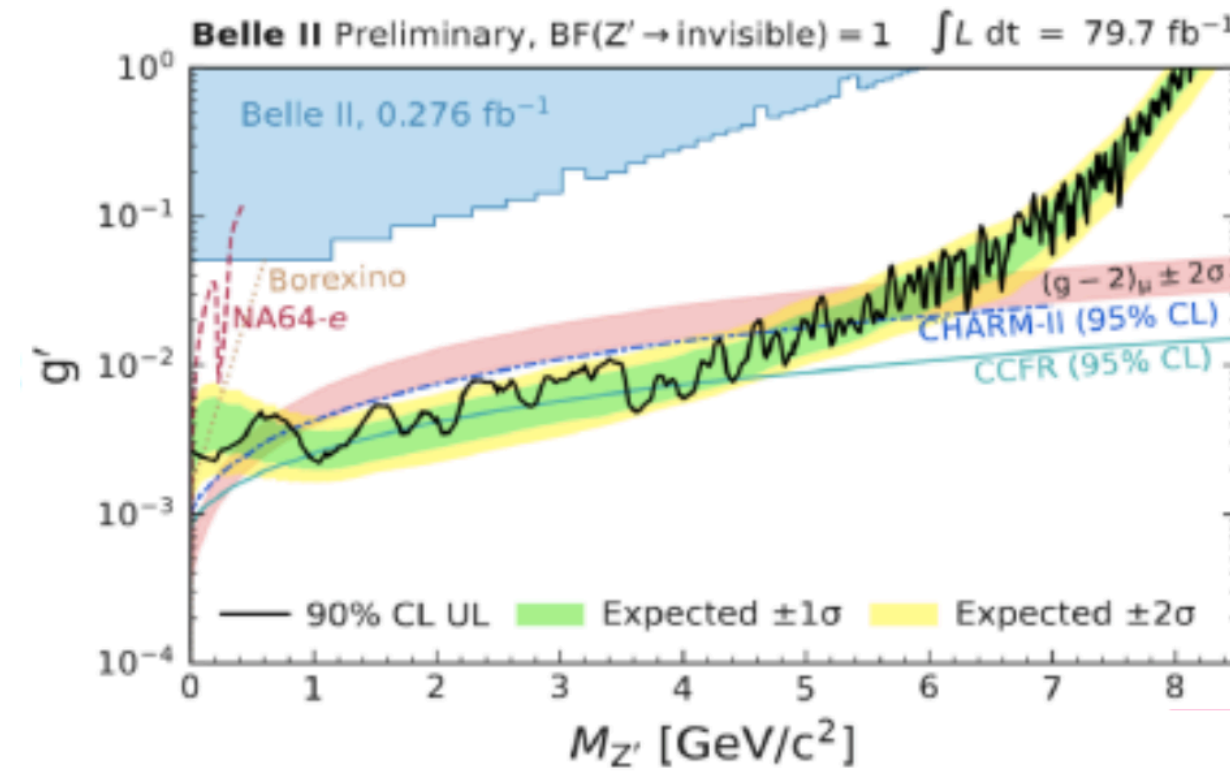
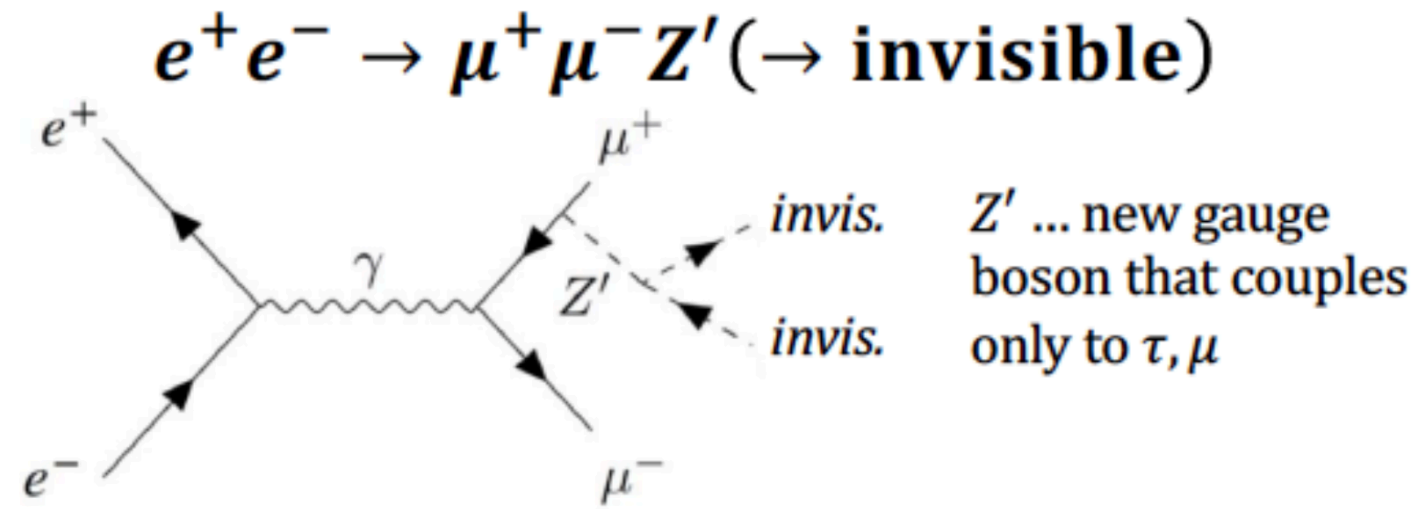
Dark-sector particle search [A', h']



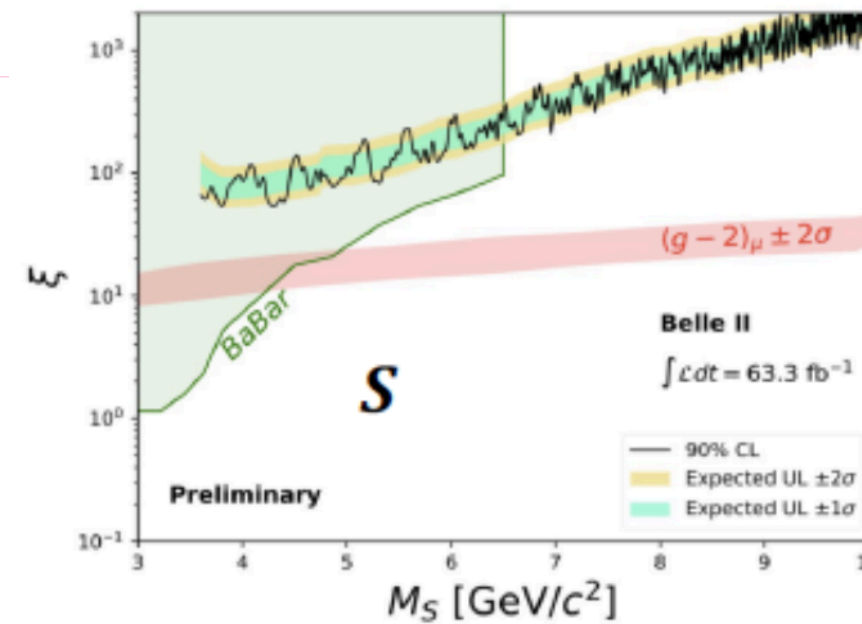
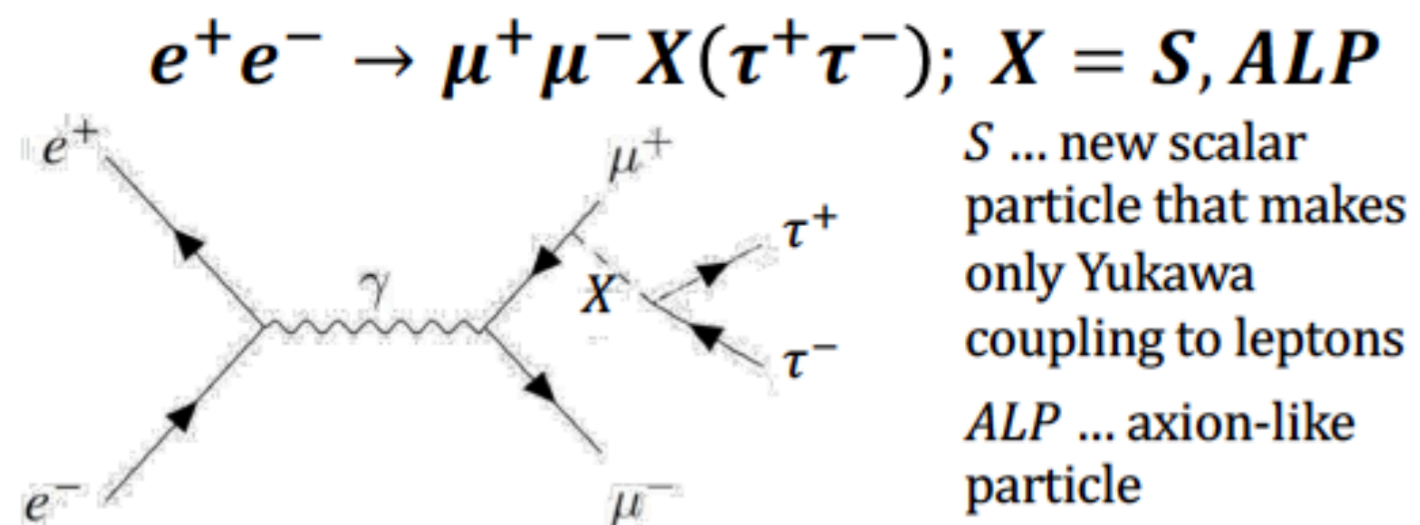
8.34 fb⁻¹

World leading limits for $1.65 < M_{A'} < 10.51 \text{ GeV}/c^2$

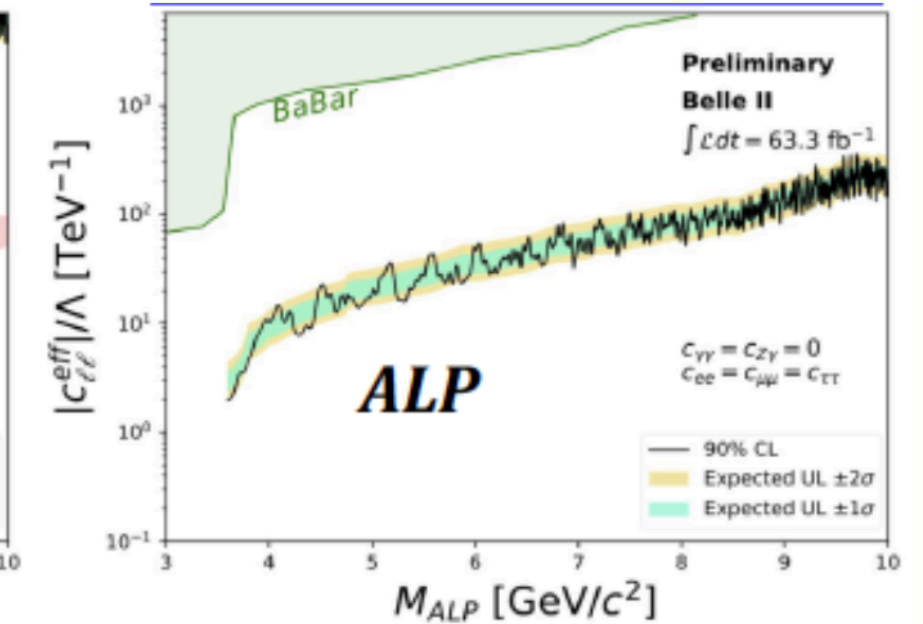
79.7 fb⁻¹



First excluding Z' as an explanation of the $(g - 2)_\mu$ anomaly for $0.8 < M_{Z'} < 5 \text{ GeV}/c^2$.



First constraint on S for $M_S > 6.5 \text{ GeV}/c^2$



First direct constraint on ALP $\rightarrow \tau\tau$

63.3 fb⁻¹

Dissemination strategy

As of today, there are...

- 13 Belle II journal publications
 - Could be more but publication has been suspended as a consequence of the war in Ukraine and resumed only recently (Nov 2022)
- 36 Belle II conference papers
- 146 Belle II conference talks in 2021 (83 or 56% by European speaker)
 - Almost at the pre-COVID level (155 in 2019)
- JENNIFER2 sponsored workshop “Anomalies and Precision in the Belle II era” (Sep 6-8, 2021, Mauerbach, AUSTRIA)
- Outreach work (Belle II masterclasses, ...) → WP6 report

WP1 secondment status

Including planned (future) secondments

Institution	WP1 done (months)	WP1 planned	WP1 % done
INFN	28.6	56.0	51.1%
DESY	35.1	70.0	50.2%
OEAW-HEPHY	9.4	22.0	42.9%
IFJ-PAN	2.1	11.0	18.8%
UKP	1.8	9.0	20.4%
JSI	8.0	15.0	53.1%
METU	0.0	6.0	0.0%
TAU	1.9	6.0	31.7%
LAL-CNRS	11.2	25.0	44.9%
CEA		0.0	
IFAE		0.0	
UNIGE		0.0	
NCBJ		0.0	
KCL (Qmul)		0.0	
UKRI		0.0	
CAEN		0.0	
FBK		0.0	
Total	98.2	220.0	44.6%

- WP1 is running faster than the rest of JENNIFER2
 - LS1 hardware activities shifting into scope
- WP1 milestones are basically already achieved
- This table might include secondments that cannot be completed

Secondment impact

Career development of early stage researchers

- Gianluca Ingluglia (HEPHY-OEAW; JENNIFER secondee)
 - Won ERC-Stg in Nov 2020
- Michel Bertemes (HEPHY-OEAW; JENNIFER2 secondee for 2.2 months, JENNIFER2 co-supervision programme)
 - Won Schrödinger fellowship in Oct 2021 from FWF (Austrian national funding agency) for research at BNL, US
- Giulio Dujany (CNRS; JENNIFER2 secondee for 1.4 months)
 - Laureate of the call for proposal 2021 from the ANR (French Research National Agency) with a project of development of a new FEI based on deep learning and its application to the search for $B \rightarrow K^{(*)} \nu \nu$

Summary

- SuperKEKB/Belle II have completed a first period of data taking and have entered long shutdown 1 (LS1) for completing various hardware activities
 - The installation of the new pixel detector PXD2 is of particular relevance for European groups
- No pause for physics analysis — Belle II has started to deliver first exciting results relevant to the New Physics signal searches with much more to come. Stay tuned
- JENNIFER2 funding is an important pillar for European groups to fully participate in Belle II research
 - WP1 has already completed 44.6% of its planned secondments, WP1 milestones are basically done

Backup

WP1 tasks

Task 1.1: Detector performances assessment. Determine and optimize detector resolutions and efficiencies using real data, in order to provide precise inputs to physics analyses. Each sub-detector has to be studied both by itself and in combination with the others, thus requiring the collaboration of all sub-detector experts from different groups.

Task 1.2: Study of CP violation and search for new phenomena in rare decays. Physics analyses to test CKM matrix unitarity (measurement of $|V_{cb}|$ and $|V_{ub}|$ using leptonic and semileptonic decays; measurement of the angles of the CKM unitarity triangle, in particular the gamma angle), studies of rare B decays ($B \rightarrow X_s \gamma$; charmless hadronic B decays) and of rare charm decays are developed in this task.

Task 1.3: Lepton flavour and lepton universality violations. Hints for lepton flavour non-universality are currently seen in the $B \rightarrow D^* \tau \nu$ and $B \rightarrow X_s l+l-$ channels by the BaBar, Belle and LHCb experiments. These anomalies can be interpreted within various new physics models but require final experimental confirmation, for which Belle II measurements are essential. Lepton flavour violation is best tested in tau decays, where many channels can also be studied. Missing energy due to neutrinos requires in turn full event reconstruction to reject backgrounds.

Task 1.4: Dark sector and exotics. Production of the so called “dark photon” and of other Z-like or Higgs-like particles will be searched for. Limits on exotic processes including axions and WIMPS can also be improved. All such events require hermeticity and excellent control of machine and accidental backgrounds.


Task 1.5: Quarkonium Spectroscopy. This task aims at performing quarkonium spectroscopy in B decays, ISR and two-photon processes.

WP1 partners

Partner number and short name ¹⁰
1 - INFN
2 - DESY
3 - OEAW
4 - JSI
5 - CNRS
9 - UKP
10 - IFJ PAN
12 - TAU
13 - METU
18 - KEK

WP1 milestones

May 2023



Milestone number ¹⁸	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS1	Report on detector performances	1 - INFN	24	Belle II internal reports on detector performances
MS2	Conference presentation on CPV	3 - OEAW	24	Presentation to international conference of the preliminary Belle II results on CPV
MS3	Conference presentation on LFV and LFUV	2 - DESY	24	Presentation to international conference of the preliminary Belle II results on Lepton Flavour Violation and Lepton Flavour Universality Violation
MS4	Conference presentation on dark sector	3 - OEAW	24	Presentation to international conference of the preliminary Belle II results on dark sector searches
MS5	conference presentation on spectroscopy	4 - JSI	24	Presentation to international conference of the preliminary Belle II results on quarkonium spectroscopy

WP1 deliverables

May 2025

Deliverable Number ¹⁴	Deliverable Title	Lead beneficiary	Type ¹⁵	Dissemination level ¹⁶	Due Date (in months) ¹⁷
D1.1	Publication on detector Performance	1 - INFN	Report	Public	48
D1.2	Publication on CPV	3 - OEAW	Report	Public	48
D1.3	Publication on LFV and LFUV	2 - DESY	Report	Public	48
D1.4	Publication on dark sector	3 - OEAW	Report	Public	48
D1.5	Publication on Spectroscopy	4 - JSI	Report	Public	48

D1.1 : Publication on detector Performance [48]

Journal(s) publication(s) on detector performances and calibration

D1.2 : Publication on CPV [48]

Paper on CP violation analysis with Belle II detector

D1.3 : Publication on LFV and LFUV [48]

First publication on searches for Lepton Flavour Violation and Lepton Flavour Universality Violation

D1.4 : Publication on dark sector [48]

First publication on searches for dark sector processes

D1.5 : Publication on Spectroscopy [48]

First publication on quarkonium spectroscopy