Belle II

천병구 (한양대)

On behalf of the Belle II Collaboration

Korean-DPF Workshop, DEC/17-18/2021

Why SuperKEKB/Belle II ?

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, …

Leptons spin =1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0–0.13)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009–0.13)\times10^{-9}$	0
μ muon	0.106	–1
ν_H heaviest neutrino*	$(0.04–0.14)\times10^{-9}$	0
τ tau	1.777	–1

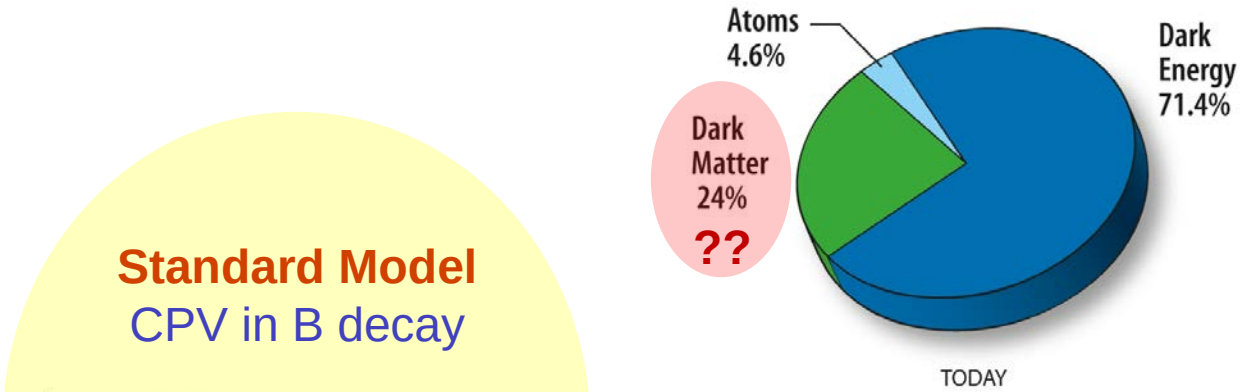
Quarks spin =1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

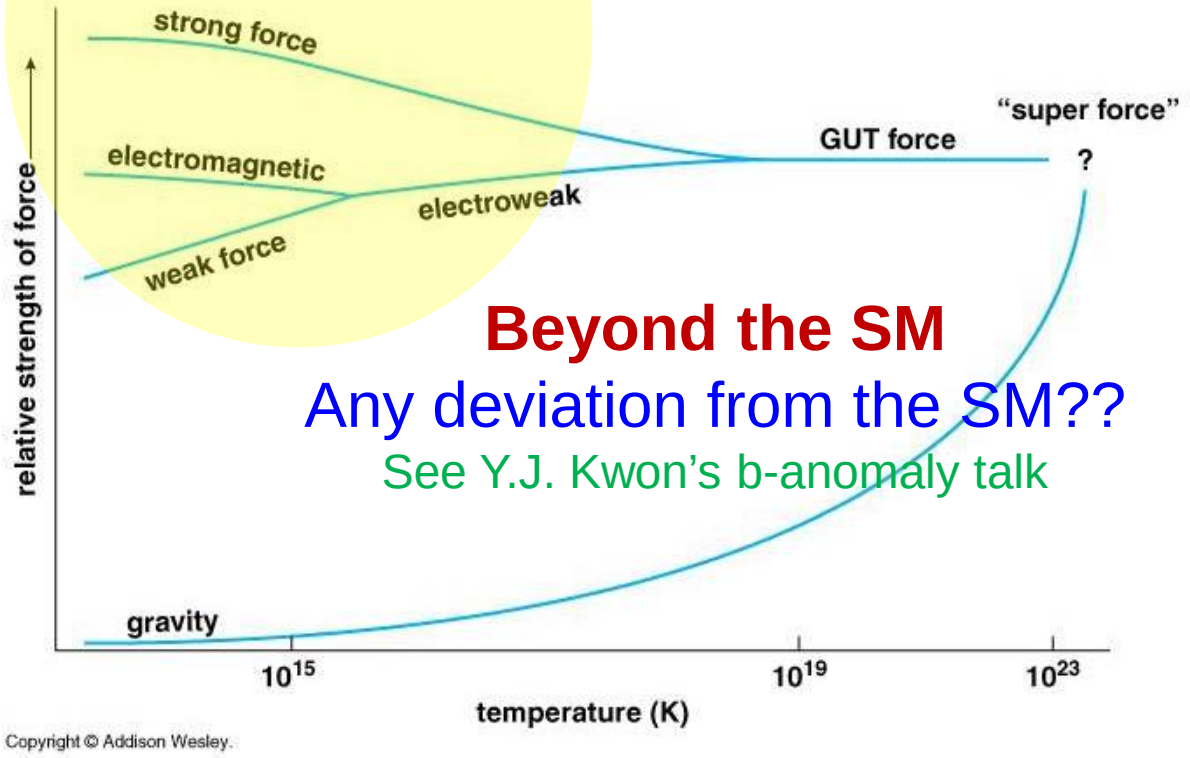
Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60



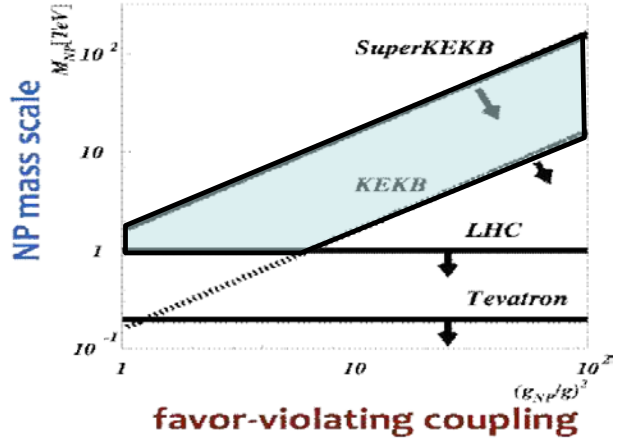
Standard Model
CPV in B decay



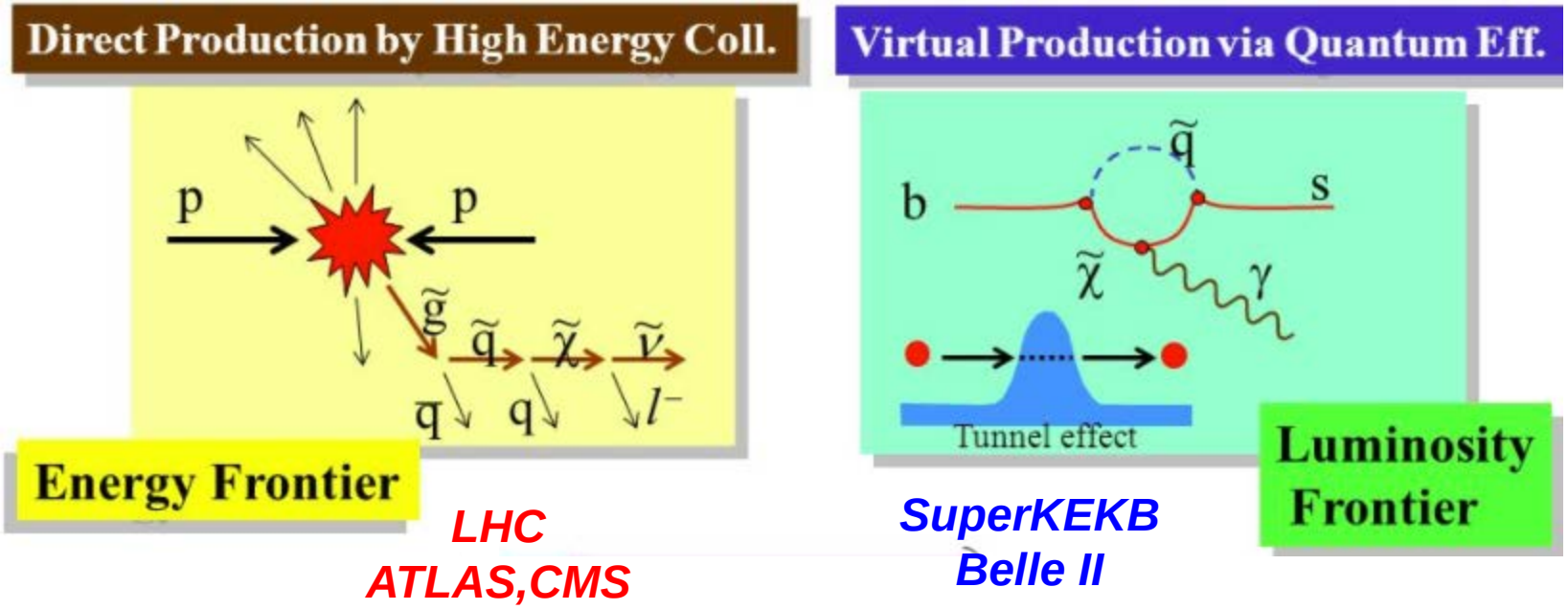
Beyond the SM
Any deviation from the SM??
See Y.J. Kwon's b-anomaly talk

Why SuperKEKB/Belle II ?

- Search for the New Physics beyond the SM
- Direct new particle production : ATLAS/CMS @LHC
  - So far, no evidence of the New Physics from LHC
- Indirect new particle contribution : Belle II @SuperKEKB



LHC 실험과 Belle II 실험의 상보성



Belle II @ SuperKEKB

Belle II @ Super-KEKB

Intensity frontier B-factory experiment, Successor to Belle @KEKB (1999-2010)

7 GeV e^-, 4 GeV e^+

E_{CM} Y(4S) = 10.58 GeV + scans

Y(4S) → B anti-B

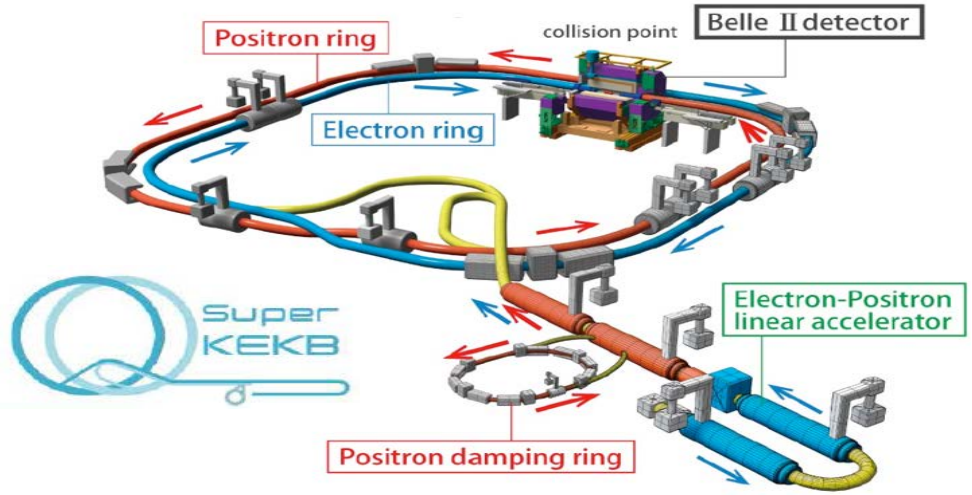
B + Charm + τ factory

~1120 active members
from 123 institutes in 26 countries

Belle II @ SuperKEKB

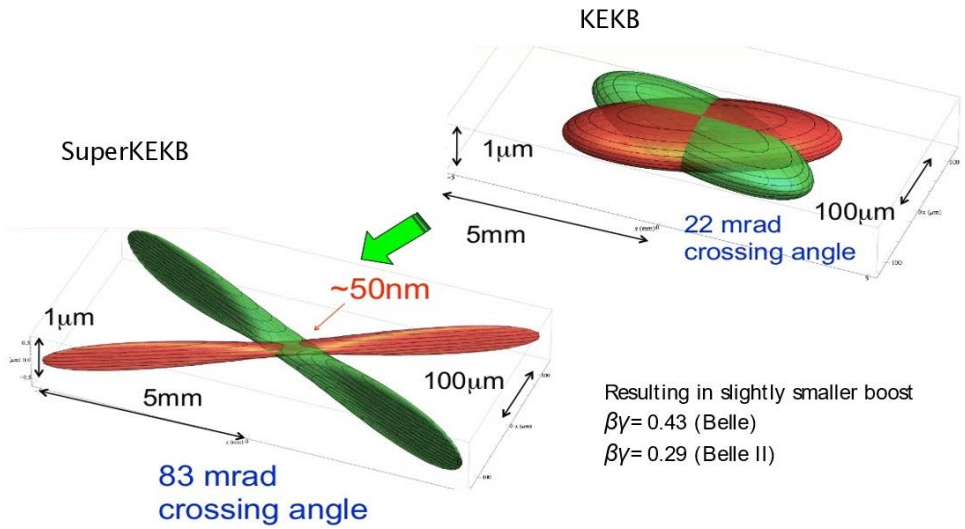
- Successor to Belle @ KEKB (~1 ab^{-1})
- No enough Belle data for the New Physics beyond the SM
- Plan to collect 50 ab^{-1} of collisions mostly at Y(4S)
- SuperKEKB peak luminosity design goal is 8 x $10^{34}/cm^2/sec$

	E(GeV) e+ / e-	β^*_y e+ / e-	I(A) e+ / e-	Peak $\mathcal{L}$ ($cm^{-2}s^{-1}$)
KEKB	3.5 / 8.0	5.9 / 5.9	1.6 / 1.2	2.1 × 10^{34}
SuperKEKB	4.0 / 7.0	0.27 / 0.30	3.6 / 2.6	80 × 10^{34}



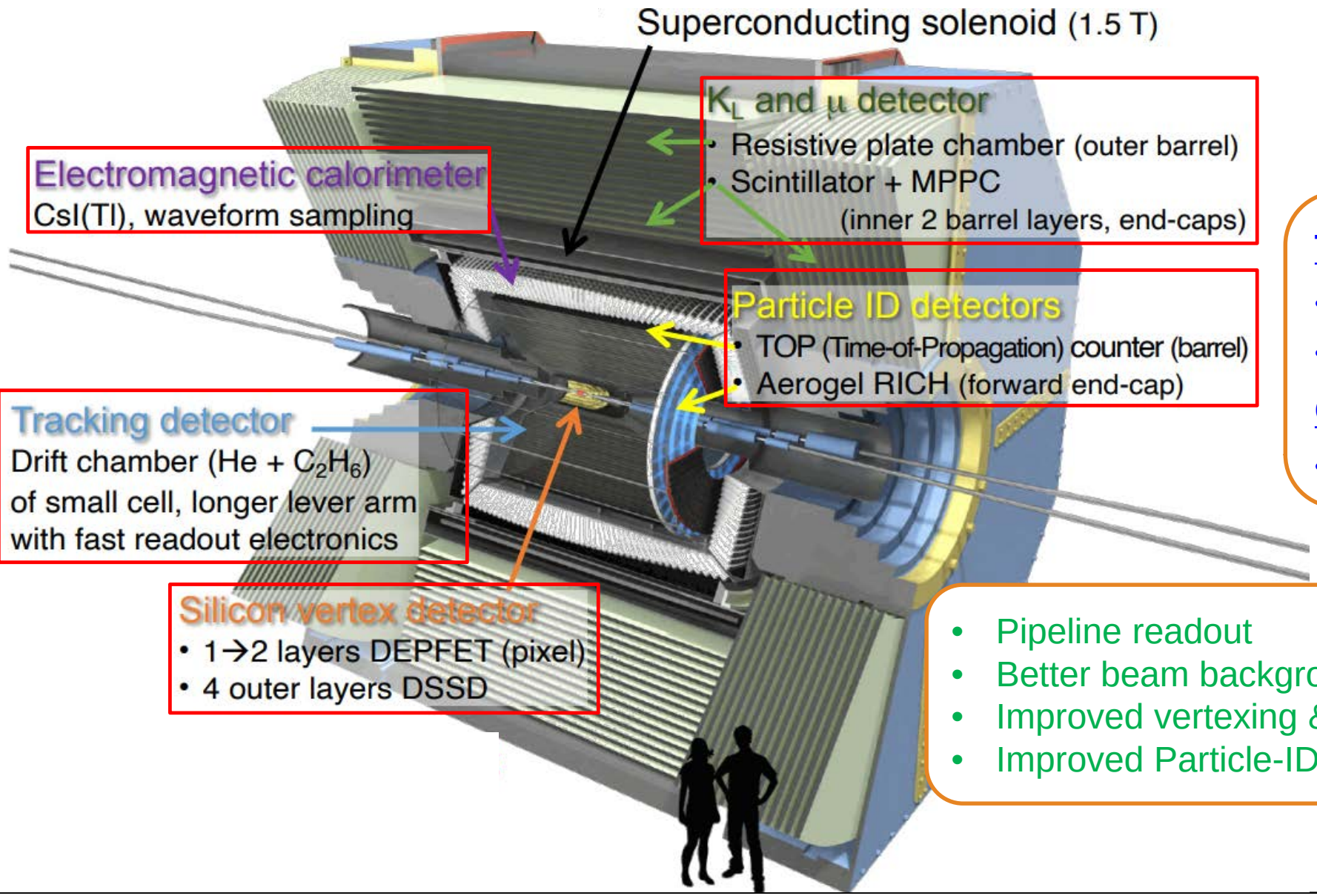
- Beam current: ×2 (High RF power)
- Beam size: x 1/20 (Nano-beam; low emittance, compact and strong focusing quads; QCS)

Super KEKB Nano-Beam Scheme



The Belle II detector

Belle II TDR arXiv:1011.0352



Trigger & DAQ readout :

- Max. 30kHz Hardware trigger rate
- High Level Trigger 1/3 rate reduction

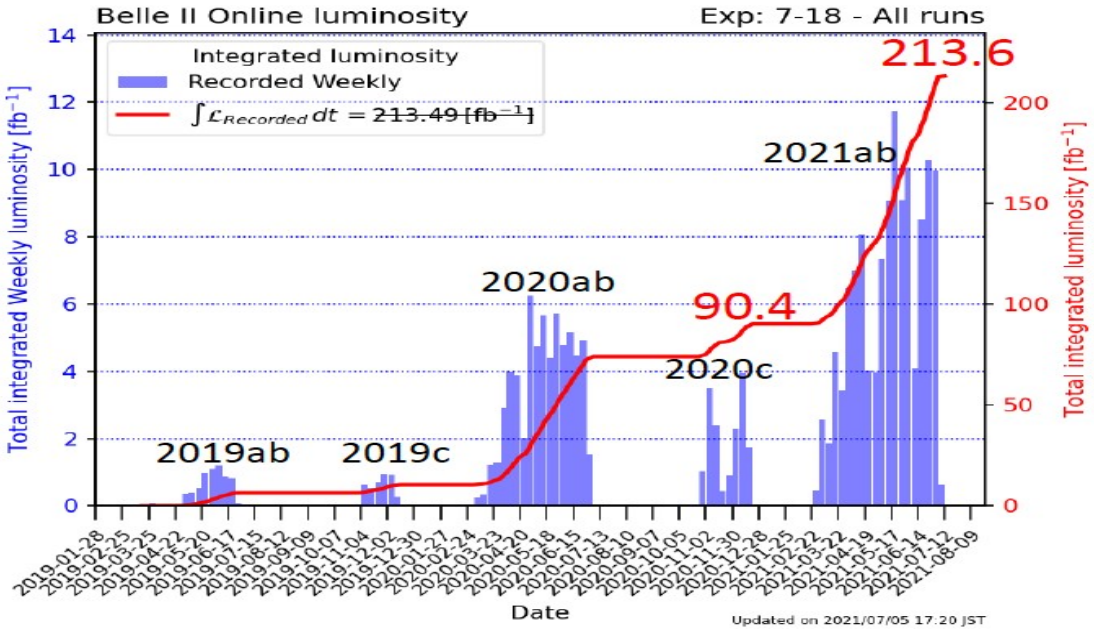
Offline computing:

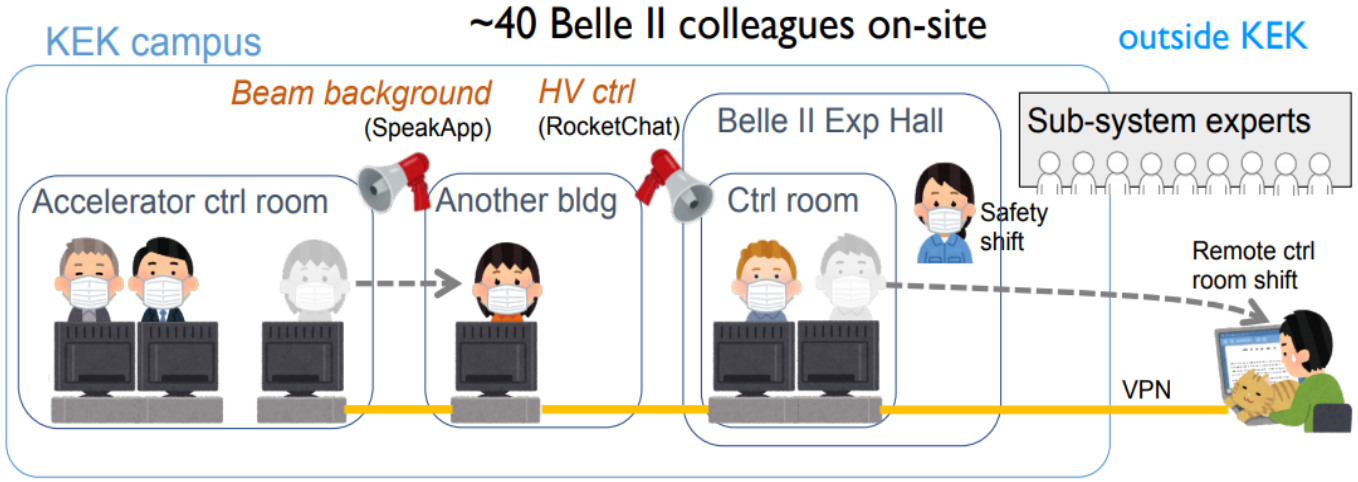
- Distributed over the world via GRID

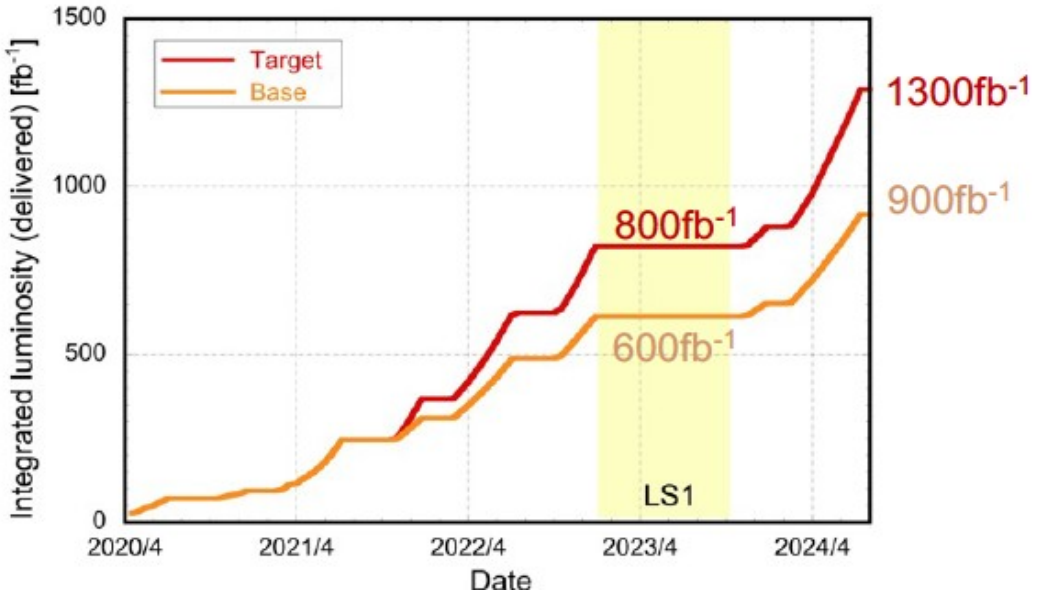
- Pipeline readout
- Better beam background insensitivity
- Improved vertexing & tracking
- Improved Particle-ID (K/π/p)

Belle II operation status

- Collected 213.6 fb^{-1} by 2021ab run
- World highest peak luminosity: 3.12 x 10^{34} $cm^{-2}s^{-}$
- Resumed Belle II operation (2021c run)
- LS1 planned for PXD/TOP system upgrade after collecting Belle II data comparable to Belle
- Data taking continued even in the covid-19 situation with caution.

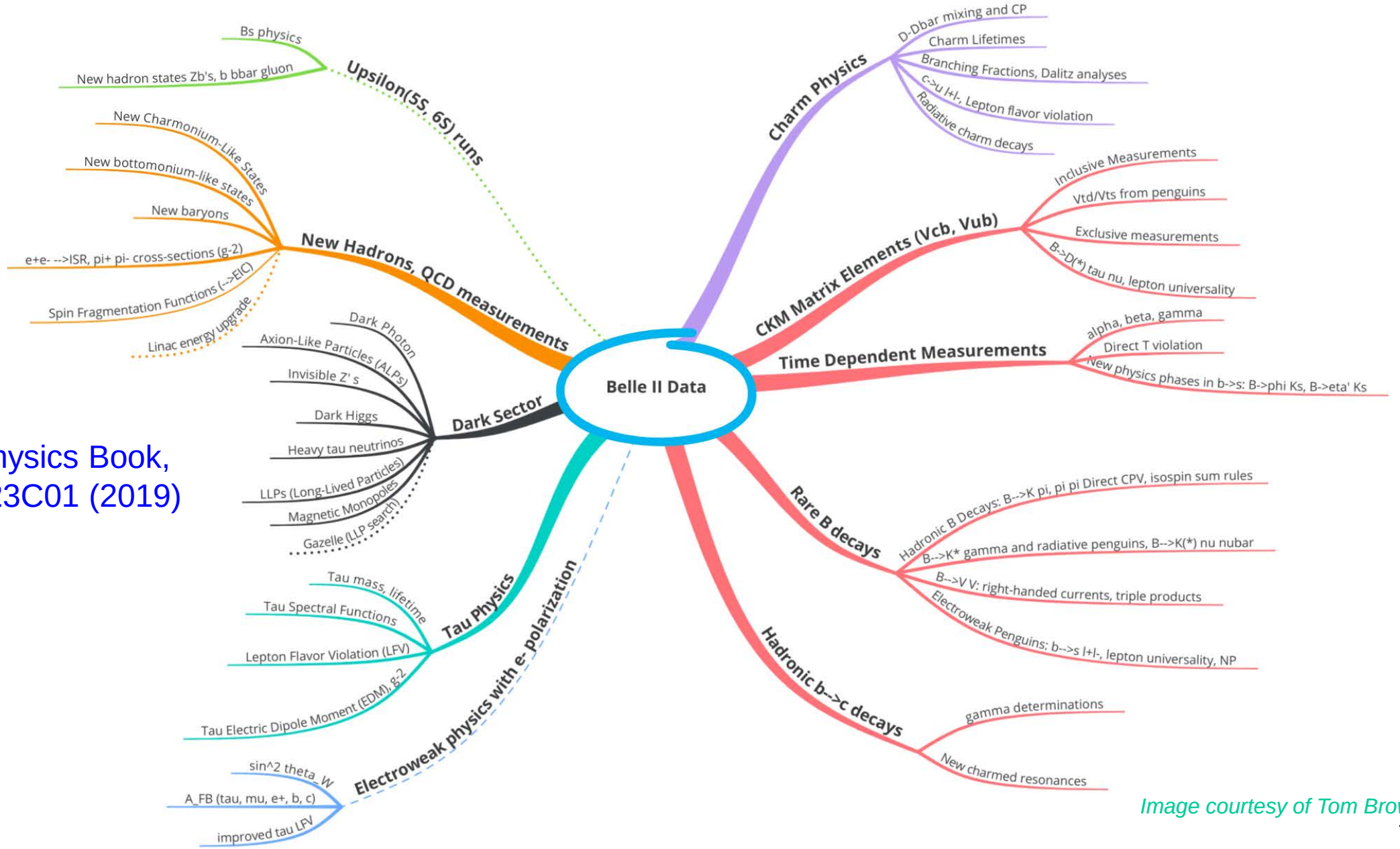






Belle II Physics

Belle II Physics Program



The Belle II Physics Book,
PTEP 2019, 123C01 (2019)

Image courtesy of Tom Browder

Belle II vs LHCb

Observable	SM prediction	Theory error	Present result	Future error	Future Facility
$\|V_{us}\|$ $[K \to \pi\ell\nu]$	input	$0.5\% \to 0.1\%_{\text{Latt}}$	0.2246 ± 0.0012	0.1%	K factory
$\|V_{cb}\|$ $[B \to X_c\ell\nu]$	input	1%	$(41.54 \pm 0.73) \times 10^{-3}$	1%	Super-B
$\|V_{ub}\|$ $[B \to \pi\ell\nu]$	input	$10\% \to 5\%_{\text{Latt}}$	$(3.38 \pm 0.36) \times 10^{-3}$	4%	Super-B
γ $[B \to DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	3°	LHCb
$S_{B_d \to \psi K}$	$\sin(2\beta)$	$\lesssim 0.01$	0.671 ± 0.023	0.01	LHCb
$S_{B_s \to \psi\phi}$	0.036	$\lesssim 0.01$	$0.81^{+0.12}_{-0.32}$	0.01	LHCb
$S_{B_d \to \phi K}$	$\sin(2\beta)$	$\lesssim 0.05$	0.44 ± 0.18	0.1	LHCb
$S_{B_s \to \phi\phi}$	0.036	$\lesssim 0.05$	—	0.05	LHCb
$S_{B_d \to K^*\gamma}$	few $\times$ 0.01	0.01	-0.16 ± 0.22	0.03	Super-B
$S_{B_s \to \phi\gamma}$	few $\times$ 0.01	0.01	—	0.05	LHCb
A_{SL}^d	-5×10^{-4}	10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	LHCb
A_{SL}^s	2×10^{-5}	$< 10^{-5}$	$(1.6 \pm 8.5) \times 10^{-3}$	10^{-3}	LHCb
$A_{CP}(b \to s\gamma)$	< 0.01	< 0.01	-0.012 ± 0.028	0.005	Super-B
$\mathcal{B}(B \to \tau\nu)$	1×10^{-4}	$20\% \to 5\%_{\text{Latt}}$	$(1.73 \pm 0.35) \times 10^{-4}$	5%	Super-B
$\mathcal{B}(B \to \mu\nu)$	4×10^{-7}	$20\% \to 5\%_{\text{Latt}}$	$< 1.3 \times 10^{-6}$	6%	Super-B
$\mathcal{B}(B_s \to \mu^+\mu^-)$	3×10^{-9}	$20\% \to 5\%_{\text{Latt}}$	$< 5 \times 10^{-8}$	10%	LHCb
$\mathcal{B}(B_d \to \mu^+\mu^-)$	1×10^{-10}	$20\% \to 5\%_{\text{Latt}}$	$< 1.5 \times 10^{-8}$	[?]	LHCb
$A_{\text{FB}}(B \to K^*\mu^+\mu^-)_{q_0^2}$	0	0.05	(0.2 ± 0.2)	0.05	LHCb
$B \to K\nu\bar{\nu}$	4×10^{-6}	$20\% \to 10\%_{\text{Latt}}$	$< 1.4 \times 10^{-5}$	20%	Super-B
$\|q/p\|_{D-\text{mixing}}$	1	$< 10^{-3}$	$(0.86^{+0.18}_{-0.15})$	0.03	Super-B
ϕ_D	0	$< 10^{-3}$	$(9.6^{+8.3}_{-9.5})^\circ$	2°	Super-B
$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})$	8.5×10^{-11}	8%	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	10%	K factory
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})$	2.6×10^{-11}	10%	$< 2.6 \times 10^{-8}$	[?]	K factory
$R^{(e/\mu)}(K \to \pi\ell\nu)$	2.477×10^{-5}	0.04%	$(2.498 \pm 0.014) \times 10^{-5}$	0.1%	K factory
$\mathcal{B}(t \to cZ, \gamma)$	$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-13})$	$< 0.6 \times 10^{-2}$	$\mathcal{O}(10^{-5})$	LHC (100 fb^{-1})

Complementary to each other

Property	LHCb	Belle II
$\sigma_{b\bar{b}}$ (nb)	~150,000 ☺	~1
$\int L\,dt$ (fb^{-1})	~25	☺ ~50,000
Background level	High	☺ Low
Typical efficiency	Low	☺ High
π^0, K_S efficiency	Low	☺ High
Initial state	Not well known	☺ Well known
Decay-time resolution	Excellent ☺	Good
Collision spot size	Large	☺ Tiny
Heavy bottom hadrons	B_s, B_c, b-baryons ☺	Partly B_s
τ physics capability	Limited	☺ Excellent
B-flavor tagging efficiency	3.5 - 6%	☺ 36%

adapted from

1. **Flavor Physics Constraints for Physics Beyond the Standard Model**
Gino Isidori (Frascati & TUM-IAS, Munich), Yosef Nir, Gilad Perez (Weizmann Inst.). Feb 2010. 33 pp.
Published in **Ann.Rev.Nucl.Part.Sci. 60 (2010) 355**

Belle II Physics Results

Belle II Physics Results

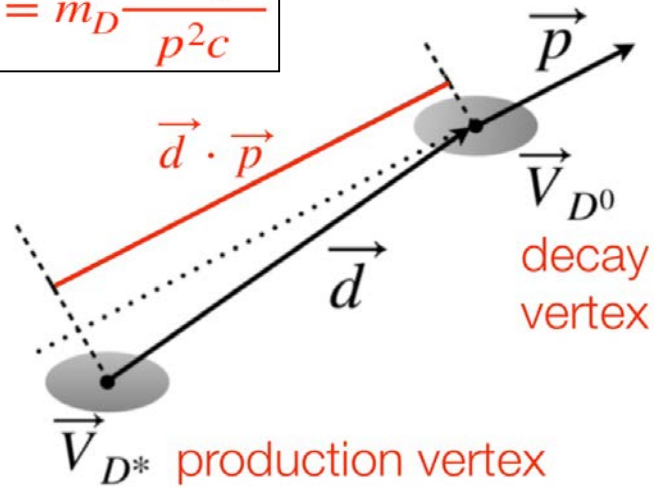
- Many data analyses of various physics sectors have been performed.
  - 20 conference papers are available.
- 4 physics journal papers published.

Precise measurement of the D^0 and D^+ lifetimes at Belle II	Phys. Rev. Lett. 127, 211801 (2021) DOI: 10.1103/PhysRevLett.127.211801
Search for $B^+ \to K^+ \nu\bar{\nu}$ decays using an inclusive tagging method at Belle II	Phys. Rev. Lett. 127, 181802 (2021) DOI: 10.1103/PhysRevLett.127.181802
Search for Axionlike Particles Produced in e^+e^- Collisions at Belle II	Phys. Rev. Lett. 125, 161806 (2020) DOI: 10.1103/PhysRevLett.125.161806
Search for an Invisibly Decaying Z' Boson at Belle II in $e^+e^- \to \mu^+\mu^-(e^\pm\mu^\mp)$ Plus Missing Energy Final States	Phys. Rev. Lett. 124, 141801 (2020) DOI: 10.1103/PhysRevLett.124.141801

D^0/D^+ lifetime measurements @ Belle II

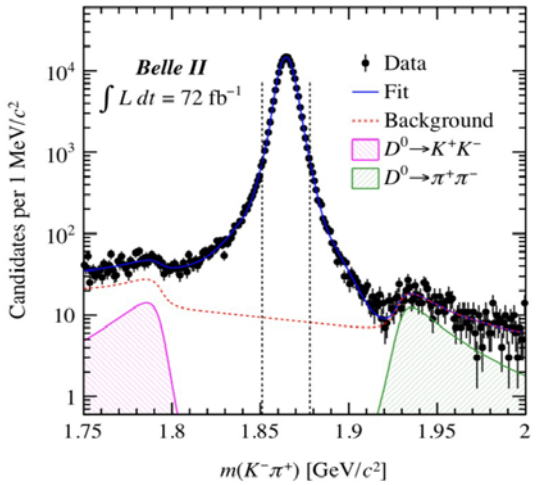
- Lifetime measurements test effective QCD models and provide guidance to describe strong interactions

$$t = m_D \frac{\vec{d} \cdot \vec{p}}{p^2 c}$$

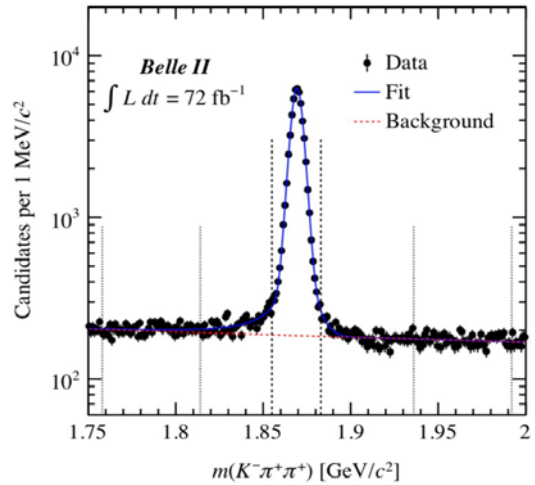


- High precision measurement
  - Excellent vertex detector alignment
  - Precise calibration of final state particle momenta

- Data sample
  - 72 fb^{-1} Belle II dataset
  - High-purity golden decay modes
  - Reconstruct $D^{*+} \to D^0(\to K^- \pi^+)\ \pi_s^+$
    $D^{*+} \to D^+(\to K^- \pi^+ \pi^+)\ \pi_s^0$
    from mostly $e^+e^- \to c\bar{c}$



0.2% bkg



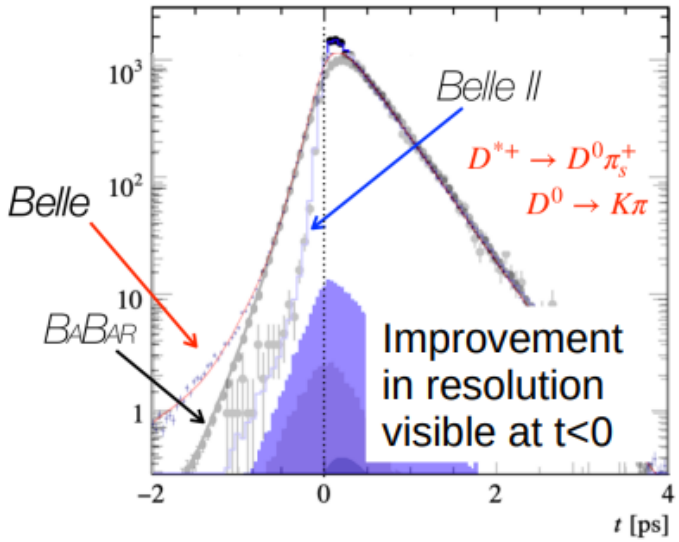
8.8% bkg

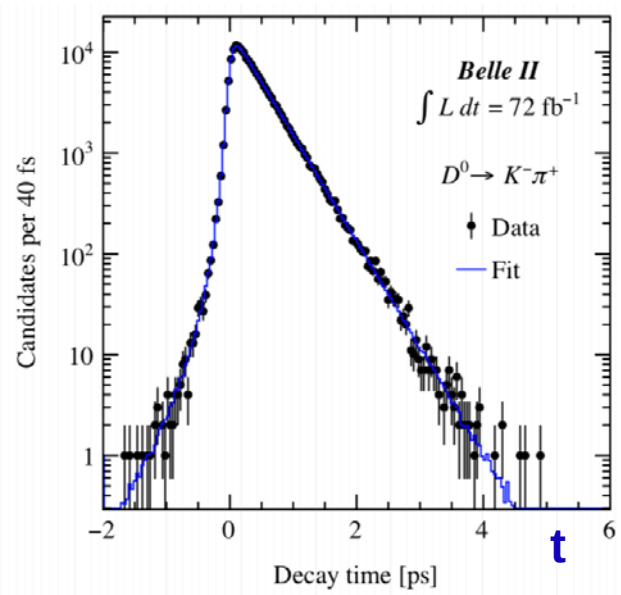
D^0/D^+ lifetime measurements @ Belle II

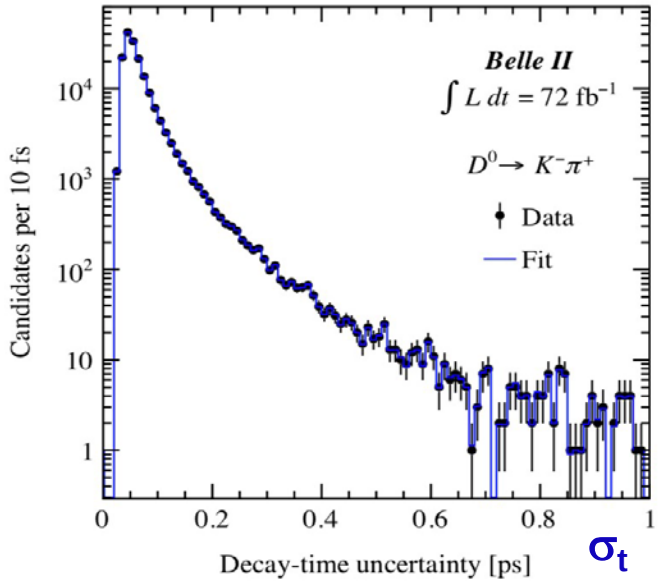
- Unbinned ML fit to (t, σ_t)
- Resolution ~ 60-70 fs

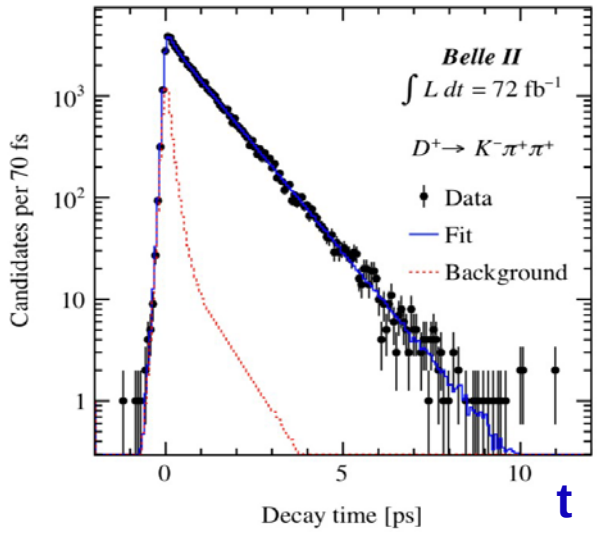
TABLE I. Systematic uncertainties.

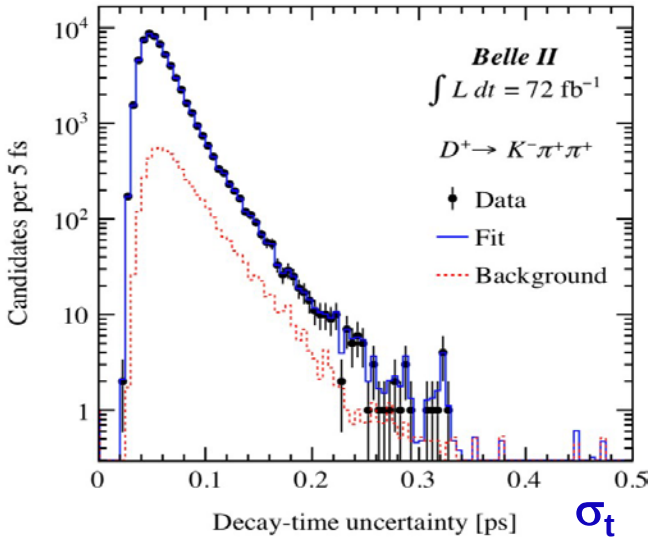
Source	$\tau(D^0)$ [fs]	$\tau(D^+)$ [fs]
Resolution model	0.16	0.39
Backgrounds	0.24	2.52
Detector alignment	0.72	1.70
Momentum scale	0.19	0.48
Total	0.80	3.10











D^0/D^+ lifetime measurements @ Belle II

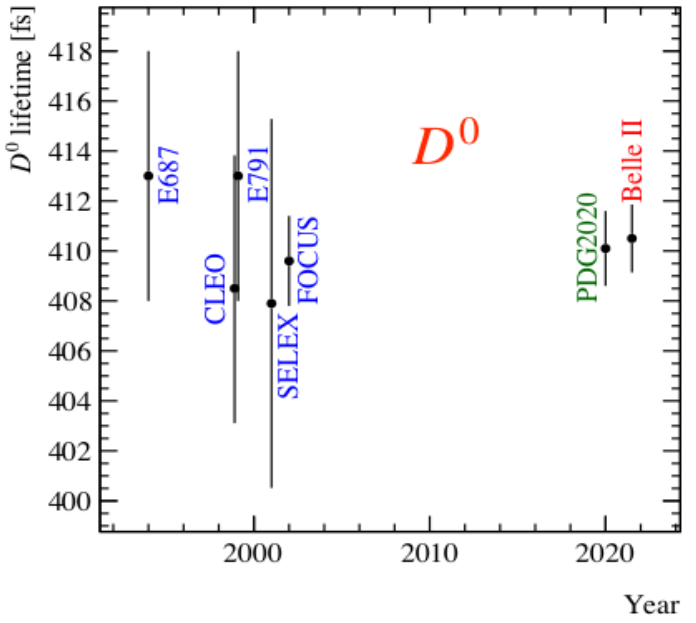
Phys. Rev. Lett. 127, 211801 (2021)

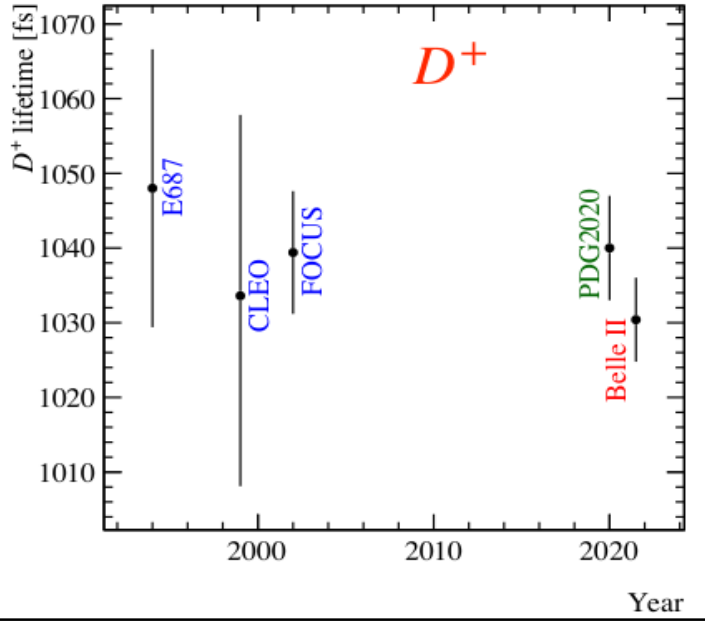
$$\tau(D^0) = 410 \pm 1.1(\text{stat}) \pm 0.8(\text{syst})\ \text{fs}$$

$$\tau(D^+) = 1030.4 \pm 4.7(\text{stat}) \pm 3.1(\text{syst})\ \text{fs}$$

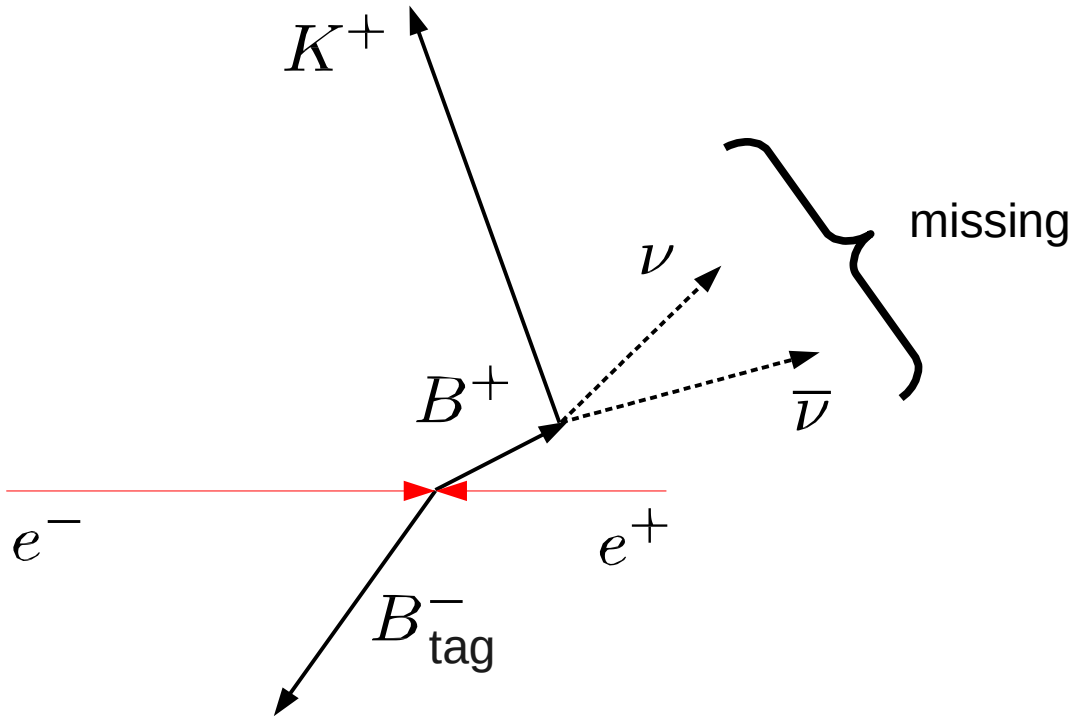
$$\frac{\tau(D^+)}{\tau(D^0)} = 2.510 \pm 0.013(\text{stat}) \pm 0.007(\text{syst})$$

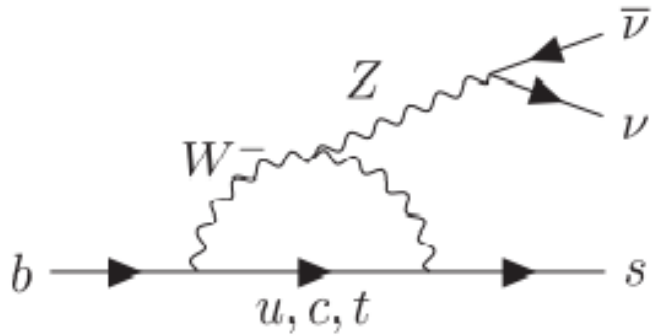
- Most precise to date
- Consistent with other experiments
- Demonstrated excellent vertexing capabilities
- Confirmed understanding of systematic effect
- Impact future decay-time-dependent analyses



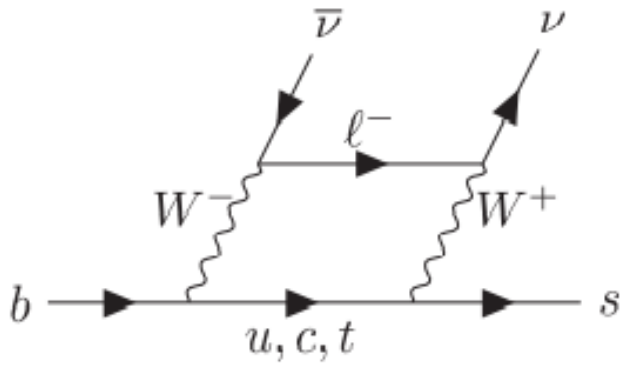


$B^+ \to K^+ \nu \bar{\nu}$ decay @ Belle II





(a) Penguin diagram

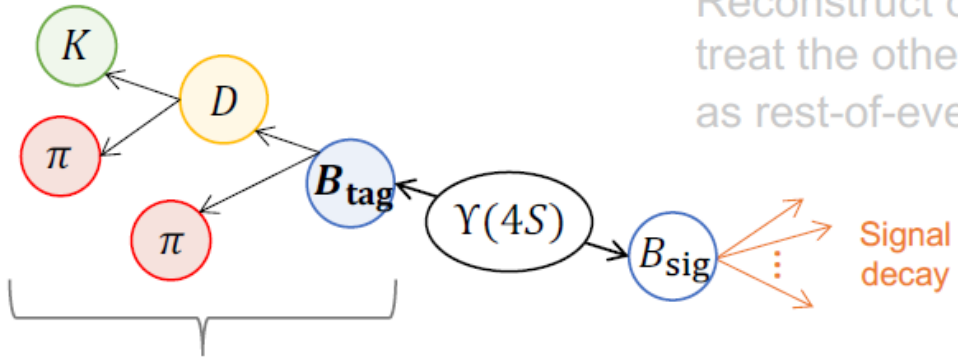


(b) Box diagram

B signal reconstruction @ Belle II : Tagged Analysis

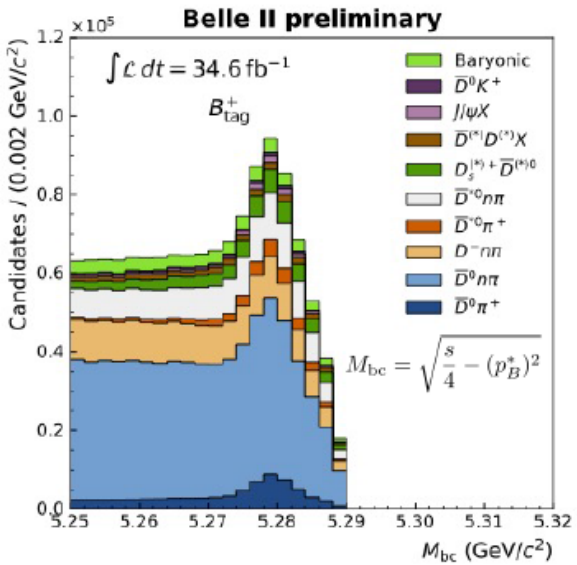
1. Tagged Analysis

One B meson from $\Upsilon(4S)$ decay is exclusively reconstructed to tag $B\bar{B}$ events.



2. Untagged Analysis
(Inclusive Tagged Analysis)

Reconstruct only signal B decay and treat the other particles not in B_{sig} as rest-of-event information.



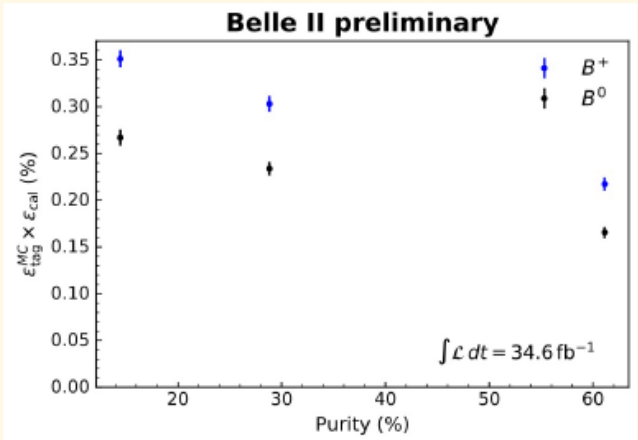
Full Event Interpretation (FEI): Comp. and Soft. For Big Sci. **3**, 6 (2019)

Multivariate algorithm for exclusive tagging of one B meson in a $\Upsilon(4S)$ decay using hierarchal approach.

Over 100 B meson decay channels and over 10,000 decay cascades

Improved effiiciency up to 50% relatively with respect to conventional approaches!

arXiv:2008.06096



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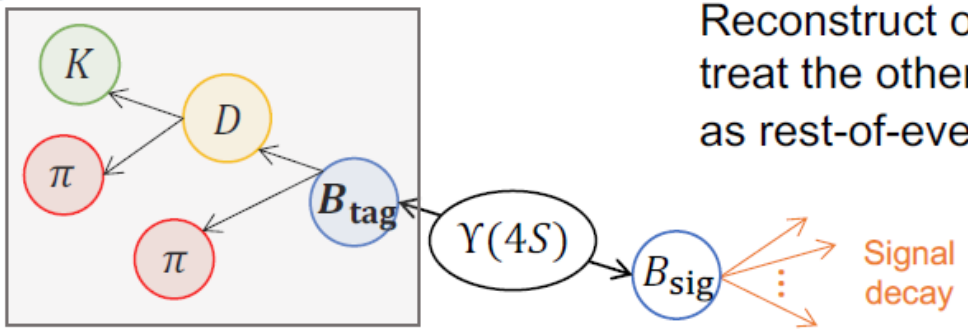
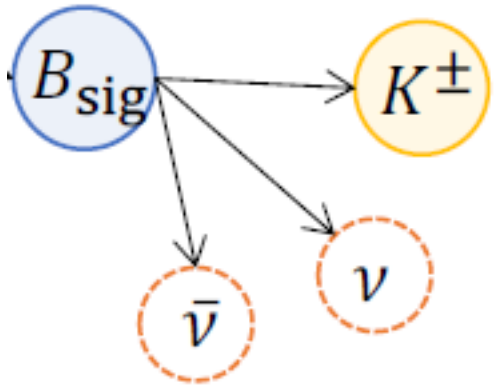


highest p_T track



$$B \to K^* \nu\bar{\nu}/K_S^0 \nu\bar{\nu},\ B^+ \to \tau^+ \nu$$

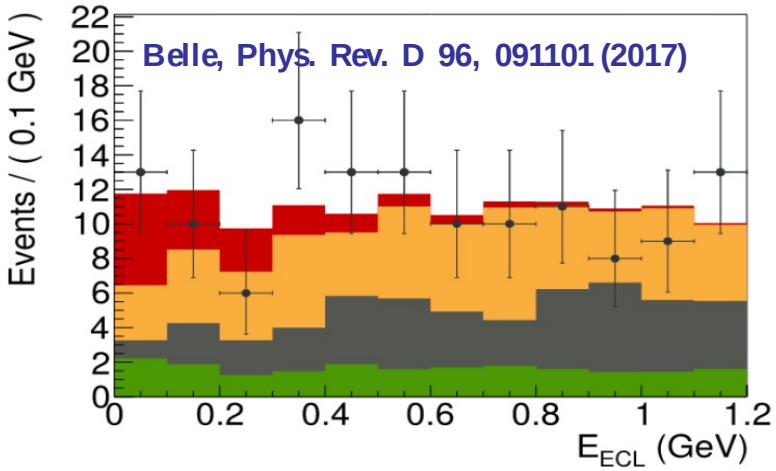
$B^+ \to K^+ \nu \bar{\nu}$ decay @ Belle II

- Complementary probe of BSM physics scenarios with $b \to s\ell\ell$ transitions.
- Not observed yet..
- SM prediction:

$$\mathcal{B}(B \to K\nu\bar{\nu})_{SM} = (4.6 \pm 0.5) \times 10^{-6}$$

T. Blake et al., Prog. Part. Nucl. Phys. 92 (2017) 50

- Previous Belle analyses
  - Advantage for e^+e^- collisions : E_{cm} is fixed
    Signature : missing energy (peaking at zero)
  - B meson tagging (**Full Recon.** on opposite side)
    Hadronic tagging $\varepsilon_{sig} \times \varepsilon_{tag}$ ~ 0.04%
    Semileptonic tagging $\varepsilon_{sig} \times \varepsilon_{tag}$ ~ 0.20%



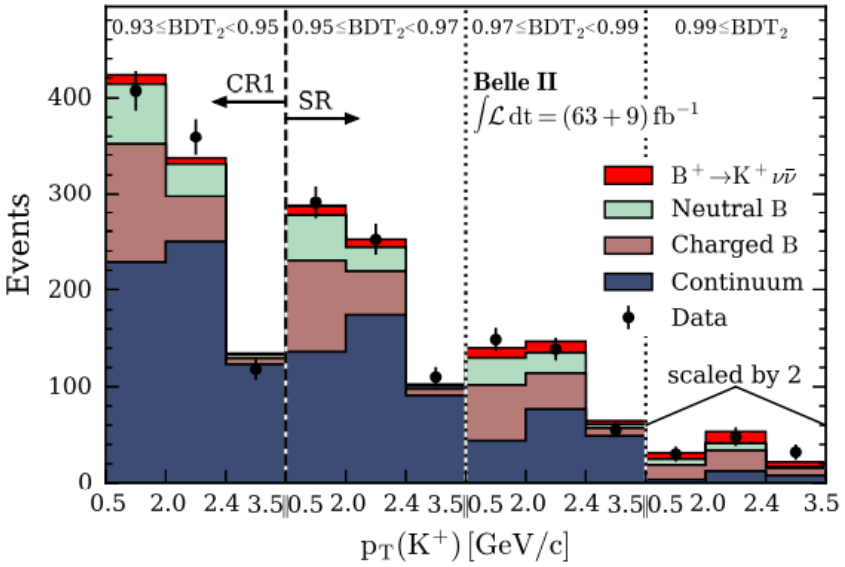
- New approach at Belle II :
  - "Inclusive tagging" for the first time!
  - Belle II data (only), 63 fb^{-1}

Experiment	Year	Observed limit on $BR(B^+ \to K^+\nu\bar{\nu})$	Approach	Data [fb^{-1}]
BABAR	**2013**	$< 1.6 \times 10^{-5}$ [Phys.Rev.D87,112005]	SL + Had tagging	429
Belle	**2013**	$< 5.5 \times 10^{-5}$ [Phys.Rev.D87,111103(R)]	Had tagging	711
Belle	**2017**	$< 1.9 \times 10^{-5}$ [Phys.Rev.D96,091101(R)]	SL tagging	711

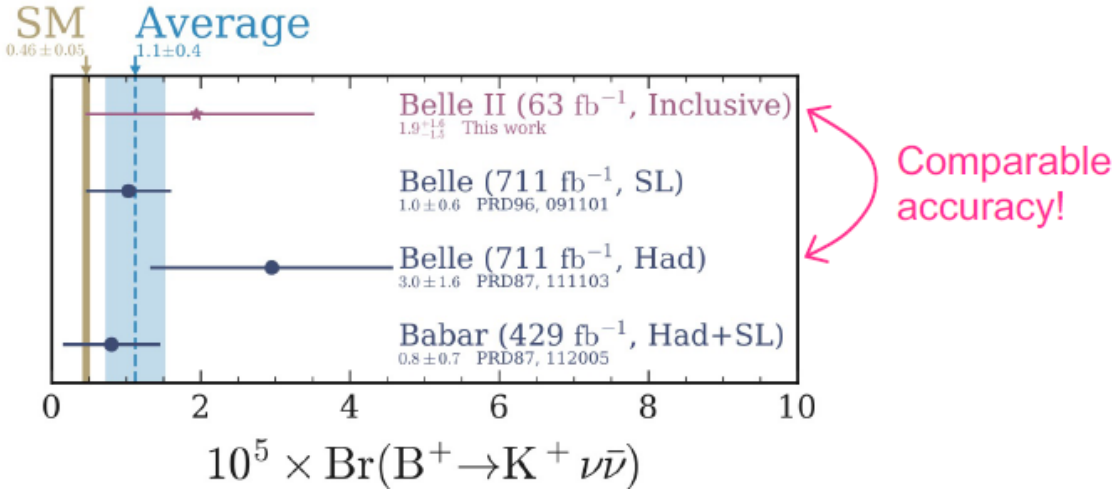
$B^+ \to K^+ \nu \bar{\nu}$ decay @ Belle II

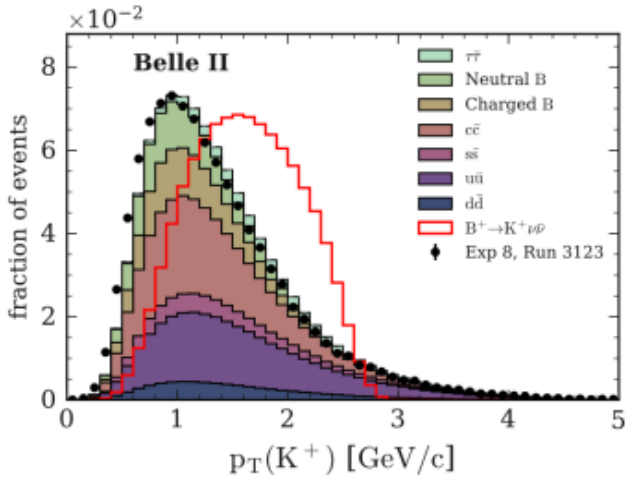
- Signal reconstructed as the highest p_T track
- Inclusive reconstruction of the rest-of-event (ROE)
- Inclusive tagging: Train two Boosted Decision Trees (BDTs) in cascade to suppress backgrounds using 51 input parameters such as event shape and ROE…
  - -- BDT_1 : Discriminate signals mainly by topological features
  - -- BDT_2 : Improve purity of signals in events with BDT_1 >0.9

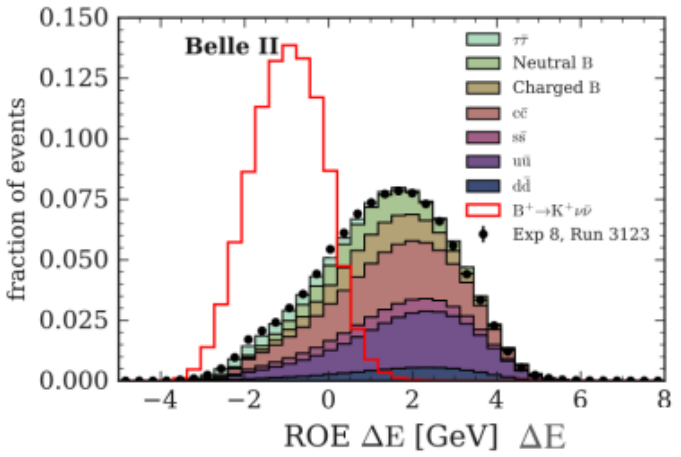
Phys. Rev. Lett. 127, 181802 (2021)



$$\mathcal{B}(B \to K\nu\bar{\nu}) \leq 4.1 \times 10^{-5}\ (90\%\ CL)$$



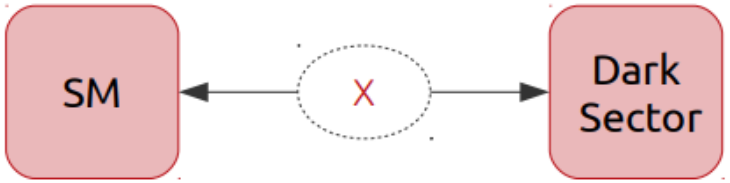


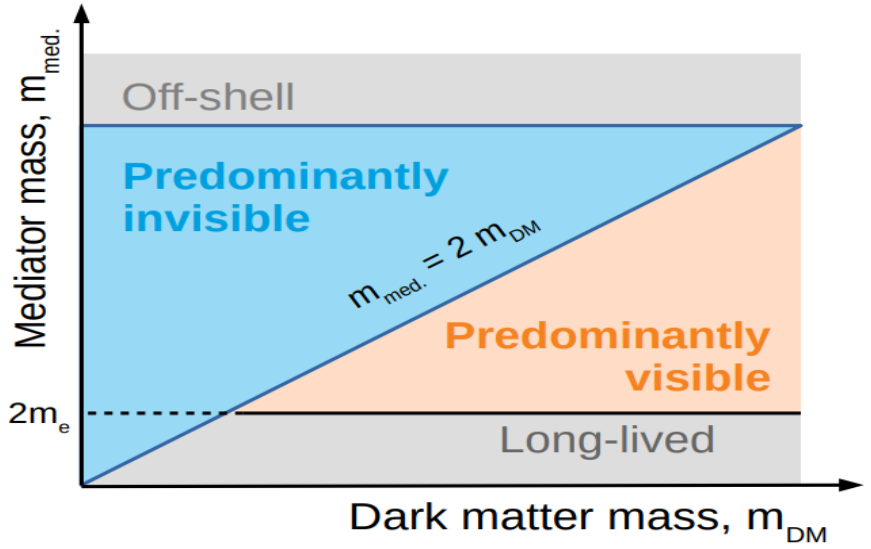


$$\Delta E = \sum_i E_i^{CMS} - E_{beam}$$

Dark sector search @ Belle II

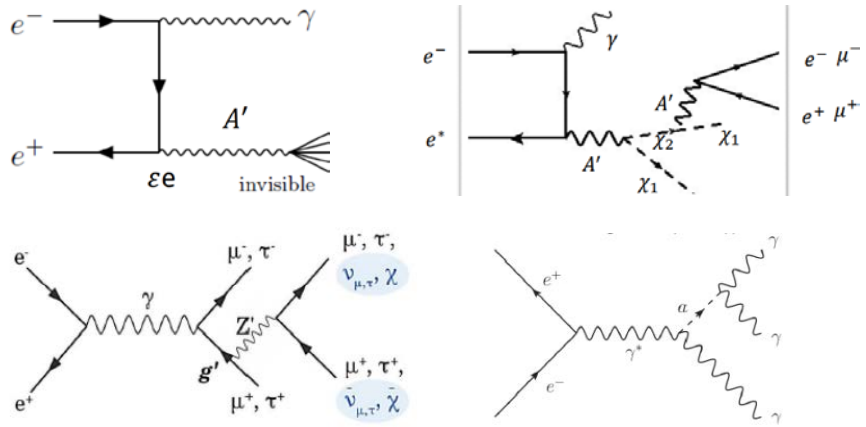
In recent years, the possibility that both the DM and the particles mediating its interactions to the Standard Model (SM) have a mass of MeV to GeV–scale has gained much attraction.





- There is a small number of possible portals between dark sector and standard model:

1) VECTOR PORTAL (dark photon A', dark Z', iDM);
2) PSEUDO-SCALAR PORTAL (Axion-Like particle);
3) SCALAR PORTAL (dark scalars, extended Higgs model);
4) NEUTRINO PORTAL (sterile neutrino)



Belle II has a perfect environment where to search for dark matter or mediators :

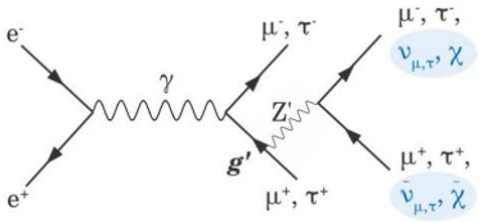
- ✓ Hermetic 4π-detector
- ✓ well-known initial conditions
- ✓ Minimal background from collision pile-up
- ✓ Excellent Particle-ID
- ✓ Dedicated triggers for low multiplicity events

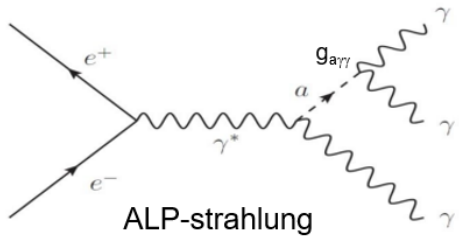
Dark sector search @ Belle II

We have a lot of analyses planned

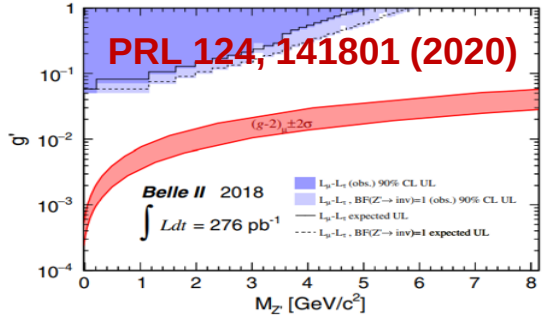
Just to give you an idea

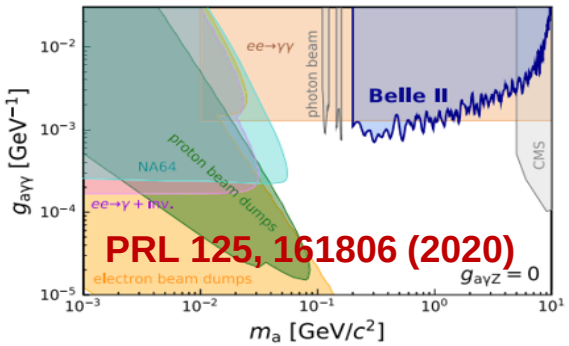
- ee → μμ Z'; { Z' → inv. | Z' → ℓℓ | Z' → 4μ }
- ee → μe Z'; { Z' → inv. | Z' → ℓℓ }
- ee → γ A'; { A' → inv. | A' → ℓℓ }
- ee → { γ a | ee a }; a → γγ
- ee → h' A'; A' → ℓℓ
- b → s { h' | a }
- ee → γ + DM; DM → A + inv.; A' → { ee | μμ | ππ }; "Inelastic dark matter".
- Dark QCD final states.
- Long lived (& very) long lived particles: generic displaced vertices.
- ee → eeπ^0; light hadronic form factor
- ee → π$^+$π$^-$(γ); for $(g-2)_\mu$
- ee → e$^\pm$e$^\pm$μ$^\mp$μ$^\mp$
- ee → τℓ
- ee → { μe | μτ } + missing





ALP-strahlung





- b → s inv. (interpretation of b-physics golden channel B → K$^{(*)}$νν).
- B → Λ + inv.
- Υ(1S) → { inv. | γ + inv. }

Belle II Conference papers in 2020

2020

CONF paper #	Title	Preprints
BELLE2-CONF-PH-2020-012	Measurements of branching fractions and CP-violating charge asymmetries in charmless B decays reconstructed in 2019-2020 Belle II data	arXiv:2009.09452 (PDF), inspirehep
BELLE2-CONF-PH-2020-011	Measurement of Hadronic Mass Moments in $B \to X_c \ell \nu$ Decays at Belle II	arXiv:2009.04493 (PDF), inspirehep
BELLE2-CONF-PH-2020-010	τ lepton mass measurement at Belle II	arXiv:2008.04665 (PDF), inspirehep
BELLE2-CONF-PH-2020-009	Measurement of the semileptonic $\bar{B}^0 \to D^{*+} \ell^- \nu_\ell$ branching fraction with fully reconstructed B meson decays and 34.6 fb^{-1} of Belle II data	arXiv:2008.10299 (PDF), inspirehep
BELLE2-CONF-PH-2020-008	Studies of the semileptonic $\bar{B}^0 \to D^{*+} \ell^- \bar{\nu}_\ell$ and $B^- \to D^0 \ell^- \bar{\nu}_\ell$ decay processes with 34.6 fb^{-1} of Belle II data	arXiv:2008.07198 (PDF), inspirehep
BELLE2-CONF-PH-2020-007	Exclusive $B^0 \to \pi^- \ell^+ \nu_l$ Decays with Hadronic Full Event Interpretation Tagging in 34.6 fb^{-1} of Belle II Data	arXiv:2008.08819 (PDF), inspirehep
BELLE2-CONF-PH-2020-006	Rediscovery of $B \to \phi K^{(*)}$ decays and measurement of the longitudinal polarization fraction f_L in $B \to \phi K^*$ decays using the Summer 2020 Belle II dataset	arXiv:2005.07507 (PDF), inspirehep
BELLE2-CONF-PH-2020-005	A calibration of the Belle II hadronic tag-side reconstruction algorithm with $B \to X \ell \nu$ decays	arXiv:2008.06096 (PDF), inspirehep
BELLE2-CONF-PH-2020-004	First flavor tagging calibration using 2019 Belle II data	arXiv:2008.02707 (PDF), inspirehep
BELLE2-CONF-PH-2020-003	Measurement of the B^0 lifetime using fully reconstructed hadronic decays in the 2019 Belle II dataset	arXiv:2005.07507 (PDF), inspirehep
BELLE2-CONF-PH-2020-002	Measurement of the branching fraction of $B^0 \to D^{*-} l^+ \nu_l$ with early Belle II data	arXiv:2004.09066 (PDF), inspirehep
BELLE2-CONF-PH-2020-001	Charmless B decay reconstruction in 2019 data	arXiv:2005.13559 (PDF), inspirehep

Belle II Conference papers in 2021

2021

CONF paper #	Title	Preprints
BELLE2-CONF-PH-2021-013	Exclusive Decays with Hadronic Full-event-interpretation Tagging in 62.8 of Belle II Data	arxiv:2111.00710 (PDF) inspirehep
BELLE2-CONF-PH-2021-012	Measurement of the inclusive semileptonic B meson branching fraction in 62.8 fb^{-1} of Belle II data	arxiv:2111.09405 (PDF) inspirehep
BELLE2-CONF-PH-2021-011	Measurement of the $B^- \to D^0 \ell^- \nu$ branching fraction in 62.8 fb^{-1} of Belle II data	arxiv:2110.02648 (PDF) inspirehep
BELLE2-CONF-PH-2021-010	Measurement of the branching fraction for $B^0 \to \pi^0\pi^0$ decays reconstructed in 2019-2020 Belle II data	arxiv:2107.02373 (PDF) inspirehep
BELLE2-CONF-PH-2021-008	Study of $B \to D^{(*)}h$ decays using 62.8 fb^{-1} of Belle II data	arxiv:2104.03628 (PDF), inspirehep
BELLE2-CONF-PH-2021-006	Measurements of branching fractions and direct CP-violating asymmetries in $B^+ \to K^+\pi^0$ and $B^+ \to \pi^+\pi^0$ decays using 2019 and 2020 Belle II data	arxiv:2105.04111 (PDF), inspirehep
BELLE2-CONF-PH-2021-005	Measurement of the branching fractions of of $B \to \eta' K$ decays using 2019/2020 Belle II data	arxiv:2104.06224 (PDF), inspirehep
BELLE2-CONF-PH-2021-001	First search for direct CP-violating asymmetry in $B^0 \to K^0\pi^0$ decays at Belle II	arxiv:2104.14871 (PDF), inspirehep

Belle II Korean Group

Belle II Korean Group

- 참여: 9개 기관 46명
  고려대,경북대,서울대,숭실대,
  연세대,중앙대,전남대,한양대,KISTI

- 한국그룹 전체 미팅 : 2~3회/년

- Belle II HW/SW contribution :
- ECL Calorimeter Trigger Construction
- CDC Track Trigger Firmware
- SVD Vertex Detector Assembly
- DAQ Slow Control
- Data Production and Geant4 validation
- Data Handling System using AMGA

K-B2GM
Nov/5-6/2021
전남대 주관

Nuclear Inst. and Methods in Physics Research, A 1014 (2021) 165748

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journal homepage: www.elsevier.com/locate/nima

Trigger slow control system of the Belle II experiment

C.-H. Kim [a,*], Y. Unno [a], H.E. Cho [a], B.G. Cheon [a,*], S.H. Kim [b,a], I.S. Lee [b,a], E.-J. Jang [c], S.-K. Choi [c], Y.J. Kim [d], J.K. Ahn [d], M. Remnev [e,f], A. Kuzmin [e,f], T. Koga [g], Y.-T. Lai [g], Y. Iwasaki [g], H. Nakazawa [h], D. Liventsev [i,g], M. Nakao [g,j], S. Yamada [g], R. Itoh [g], T. Konno [k], S.-H. Park [g,l], Y.-J. Kwon [l], O. Hartbrich [m], M. Ritzert [n]

[a] Department of Physics and Institute of Natural Sciences, Hanyang University, Seoul 04763, South Korea
[b] Institute for Basic Science, Daejeon 34126, South Korea
[c] Gyeongsang National University, Jinju 52828, South Korea
[d] Korea University, Seoul 02841, South Korea

Belle II Korean Group

2021 Korean Belle II General Meeting

5 Nov 2021, 13:20 → 6 Nov 2021, 13:00 Asia/Seoul

FRIDAY, 5 NOVEM

13:20 → 18:20 **Session: Friday Session**

Conveners: Prof. Jung Keun Ahn (Korea Univeristy) , Prof. Kyungkwang Joo (Cl

- 13:20 **Welcoming remarks**
  Speaker: Prof. Kyungkwang Joo (Chonnam National University)
- 13:25 **Opening remarks**
  Speaker: Prof. Doris Yangsoo Kim (Soongsil University)
  email - MC14ri_d re...
- 13:30 **Systematics corrections for hadron identification at Bel**
  Speaker: Dr Andres Ramirez Morales (KNU)
  kbelle_2021_andres...
- 13:50 **Identification of low-lying \Lambda_c^+ baryons**
  Speaker: Dr Hugo Garcia Tecocoatzi (KNU)
  Belle_Meeting_2021...
- 14:10 **Lambda(1670) study with \Lambda_{c}^{+} decay**
  Speaker: Dr Seongbae Yang (Korea university)
  20211105_kbelle_y...
- 14:30 **Lambda_c^+ -> Ks p pi0 decay**
  Speaker: Young Jun Kim (Korea University)
  211105yjkim.pdf
- 14:50 **Analysis of dark photon including e+e- -> mu+mu-A' wit**
  Speaker: Kihong Park (UST-KISTI)
  2021_kb2gm_dm_k...

- 15:10 **Coffee Break**
- 15:30 **Multivariable Analysis for charmed particle**
  Speaker: Dr Li Jin (KNU)
  KBelle-202111.pdf
- 15:50 **Search for CP violation using T-odd asymmetry in the decays D(s)+ -> KsK+pi+p for Cabibbo suppressed decay Ds+ -> KsK+K-pi+**
  Speaker: Hyunki Moon (Korea Univ.)
  KBGM_2111_hkmo...
- 16:10 **Charmonium prospects in the Belle-II experiment**
  Speaker: Dr Yin Junhao (Korea Univ.)
  charmonium prospe...
- 16:30 **MC study for BF(D+ —> K+ pi0)**
  Speaker: Hae-Yeon Hwang (Soongsil Univ.)
  KBGM 발표.pdf
- 16:50 **Stretching Break**
- 17:00 **Construction and operation of remote control room for Belle II**
  Speaker: Kihyeon Cho (KISTI)
  kbelle_rcr_cho_110...
- 17:20 **Status on ECLTRG & local run calibration**
  Speaker: Eunji Jang (Gyeongsang National University)
  Eunji Jang_Status o...
- 17:40 **TRGECL DQM Status**
  Speaker: HanEol Cho (Hanyang Univ.)
  KB2GM_CHO_2111...

20:00 → 21:00 **Korean Belle II Institutional Board Meeting**
Speaker: Prof. Byunggu Cheon (Hanyang University)

09:00 → 13:00 **Session: Saturday Session**

Conveners: Prof. Doris Y. Kim (Soongsil Univ.) , Prof. Sookyung Choi (Chung Ang University)

- 09:00 **Preliminary measurement of A_{CP} in D^0 \rightarrow K^+K^- and D^0 \rightarrow \pi^+\p**
  Speaker: Ijeong Na (Soongsil Univ.)
  kbgm_Ijeong_Na.pdf
- 09:20 **Radiative and electroweak penguin B decays**
  Speaker: Dr Shun Watanuki (Yonsei University)
  KB2GM2021_wata-...
- 09:50 **B -> K A' A' (A' -> l+ l-)**
  Speaker: Yongkyu Kim (Yonsei Univ.)
  KBGM_2021-11-06_...
- 10:10 **B -> K a (a -> gamma gamma)**
  Speaker: Sungjin Cho (Yonsei Univ.)
  2021KB2GM.pdf
- 10:30 **Study of B+ -> X_{ccbar} K+ -> ppbar K+ Decays**
  Speaker: Jaekeum Lee (SNU)
  20211106_kbelle_jk...
- 10:50 **Everybody knows that Morning Coffee is Indispensable**
- 11:00 **Inclusive B -> Xs nu nu**
  Speaker: Junewoo Park (Yonsei University)
  KB2GM_Junewoo_P...
- 11:20 **Search for B0->Ks0Ks0gamma and B+->K+Ks0gamma Decays at the Belle II Experiment**
  Speaker: Seungcheol Lee (Kyungpook National University, Korea)
  211106_KB2GM_scl...
- 11:40 **Search for B -> l tau decay with b2bii and semileptonic FEI**
  Speaker: Dr Kyungho Kim (KISTI)
  khkim_21kbgm_fall....
- 12:00 **B --> Tau Tau** **Cheolhun Kim (Hanyang)**

18 Data analysis talks +
3 Belle II operation talks

- **Belle II 분담금** : ~1억원/년 ; 연구재단 해외대형시설활용과제 수행

한국 SuperKEKB & Belle II 실험연구단

[세부 1] Belle II 실험의 전자기열량계 트리거 운용 연구 및 총괄지원 관리

[세부 2] Belle II 실험의 궤적트리거 운용 및 매혹입자 붕괴 연구

[세부 3] Belle II 실험의 실리콘검출기 운용 및 실험 데이터분석 연구

[세부 4] Belle II 실험의 시뮬레이션 소프트웨어 최적화 및 매혹입자 희귀붕괴 연구

[세부 5] SuperKEKB 충돌형 가속기의 빔 궤도 안정화 연구

[세부 6] Belle II 실험의 B 중간자 희귀붕괴 탐색과 암흑섹터 연구

[세부 7] Belle II 실험을 통한 XYZ 미지입자 연구

[세부 8] Belle II 실험을 통한 경입자 맛깔 구조 및 새로운 물리 탐색 연구

Summary

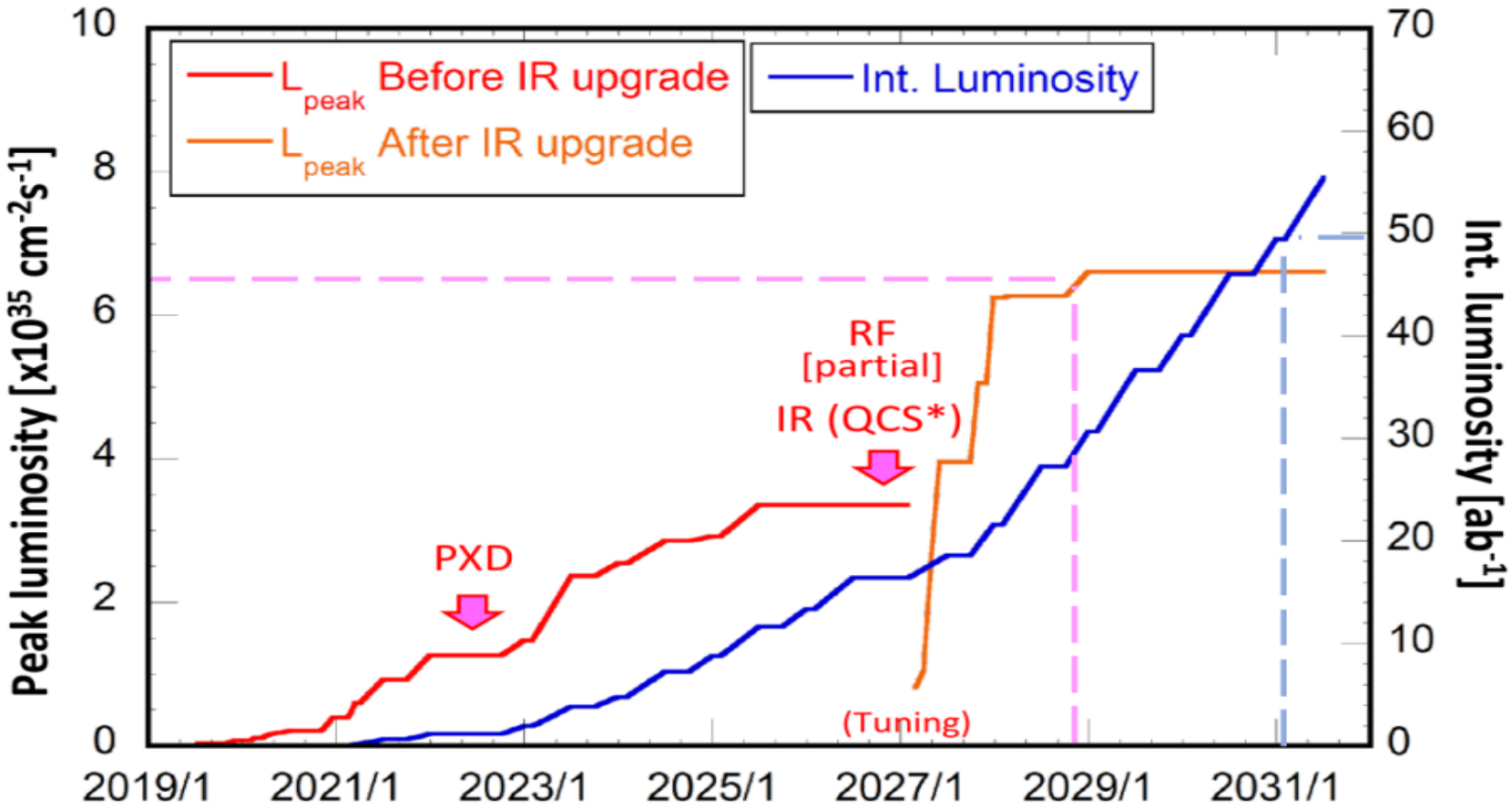
- Belle II to probe the New Physics with ultimate precision of heavy flavor decays, and to search light dark matters in GeV range as well.

- ~1 ab^{-1} Belle II data (comparable to Belle) to be ready in 2023 and many world-leading physics results available.

- 50 ab^{-1} design goal to be accomplished by ~2031 after modification of SuperKEKB/Belle II components in LS2 (around 2026).

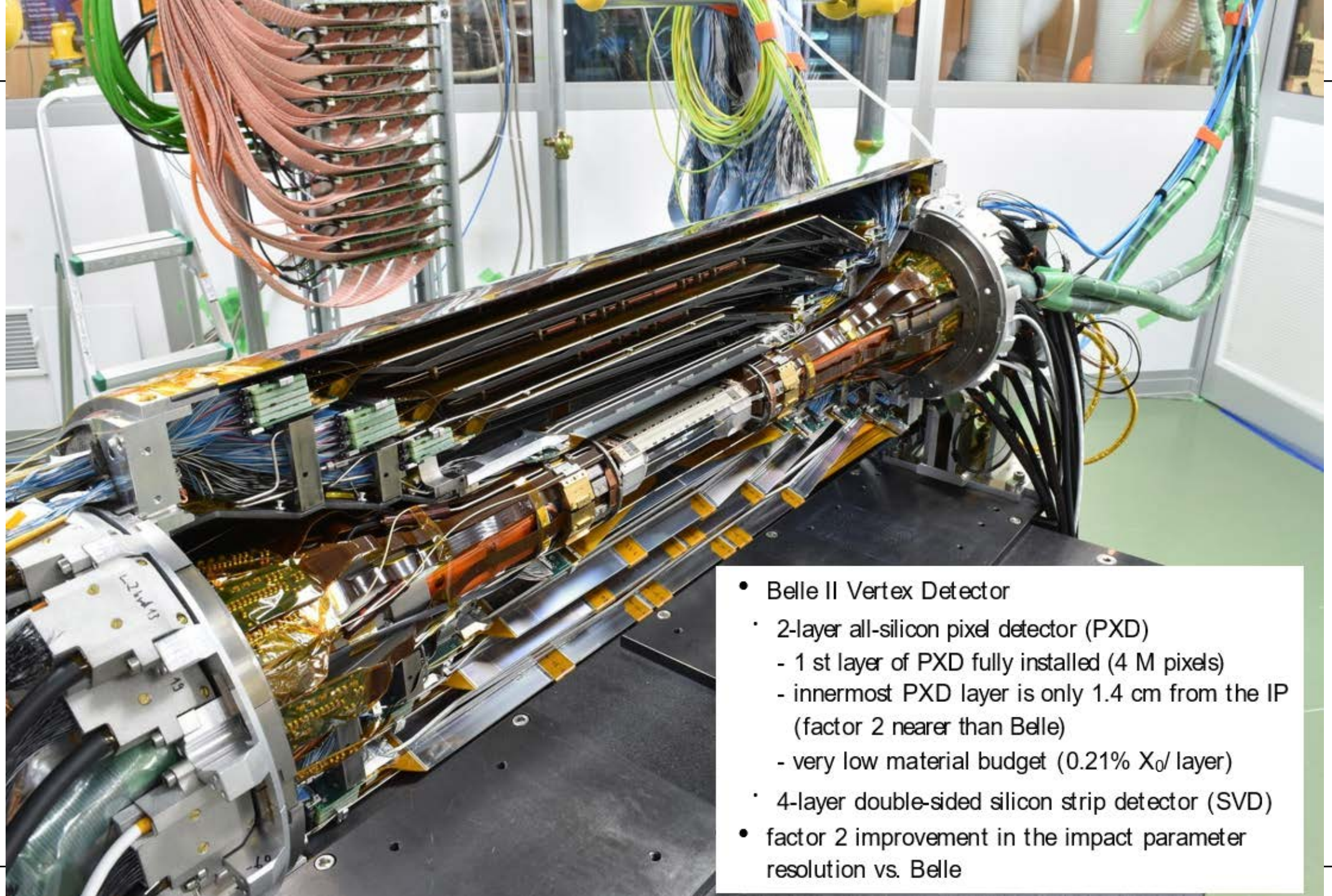
감사합니다.

SuperKEKB Long-term Plan



2 steps
+
2 steps

- Intermediate peak luminosity : (1-2 x10^{35}/cm^2/sec, 5 ab^{-1})
- High peak luminosity : (6.5 x 10^{35}/cm^2/sec, 50 ab^{-1}) with detector upgrade
- Beam polarization upgrade, advanced R&D
- Ultra high luminosity : (4 x 10^{36}/cm^2/sec, 250 ab^{-1}), R&D project



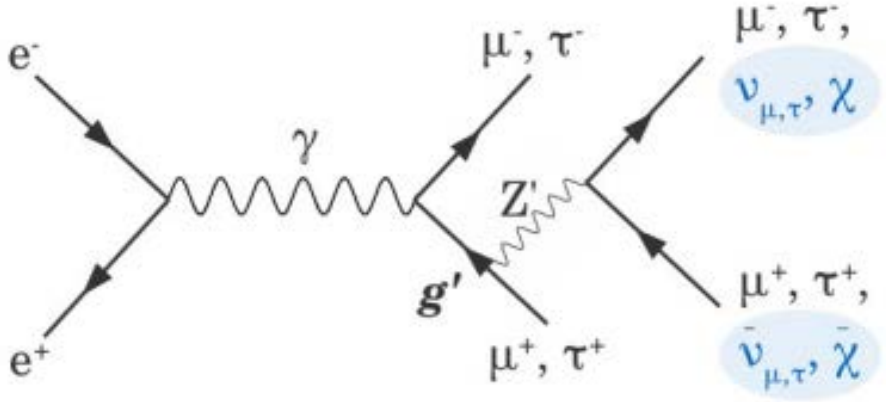
- Belle II Vertex Detector
  - 2-layer all-silicon pixel detector (PXD)
    - 1 st layer of PXD fully installed (4 M pixels)
    - innermost PXD layer is only 1.4 cm from the IP (factor 2 nearer than Belle)
    - very low material budget (0.21% X_0/ layer)
  - 4-layer double-sided silicon strip detector (SVD)
- factor 2 improvement in the impact parameter resolution vs. Belle

Search for Z' → Invisible

L_μ - L_τ model* :

- suggest new light gauge boson Z' only interacting with the second and the third generation of leptons;
- would explain $(g\text{-}2)_\mu$ anomaly, $b \to s\mu\mu$ anomalies

* Shuve et al. (2014), arXiv:1403.2727; Altmannshofer et al. (2016), arXiv: 1609.04026



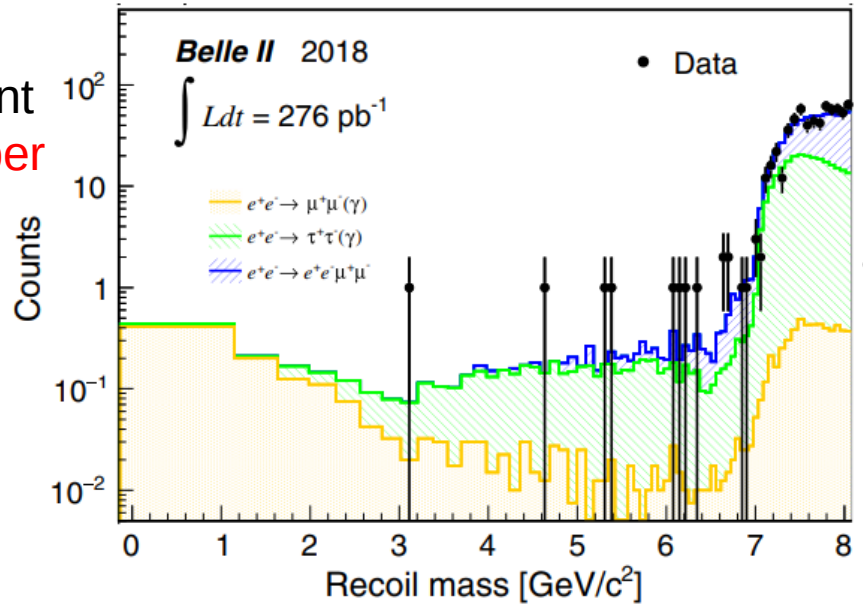
e+e- → μ+μ- Z' ; Z' → invisible

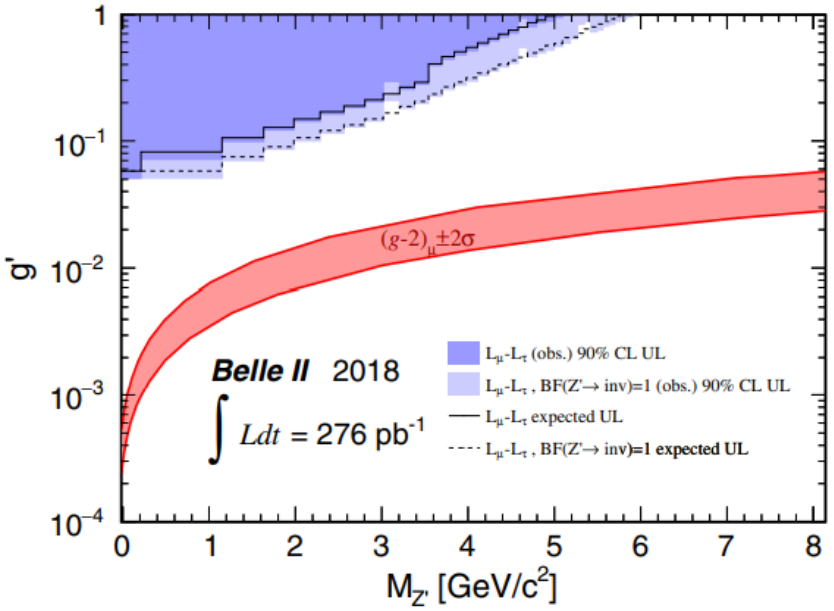
Experimental procedure :

- Used only 0.276 fb^{-1} of Phase 2 data
- Looking for a peak in the recoil mass distribution against $\mu\mu$ lepton pair
- Nothing else in the rest of the event
- No excess observed; 90% CL upper limit on coupling constant g': first result ever

PRL124, 141801 (2020)

Belle II 1st physics paper

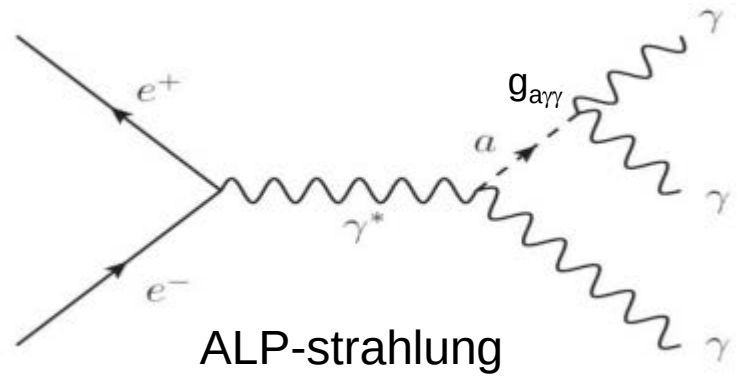




Search for Axion-Like Particle (ALP)

- ALPs are pseudo-scalars particles coupled with SM photons.
- Possible dark sector mediator and impact on $(g-2)_\mu$ if MeV-GeV range

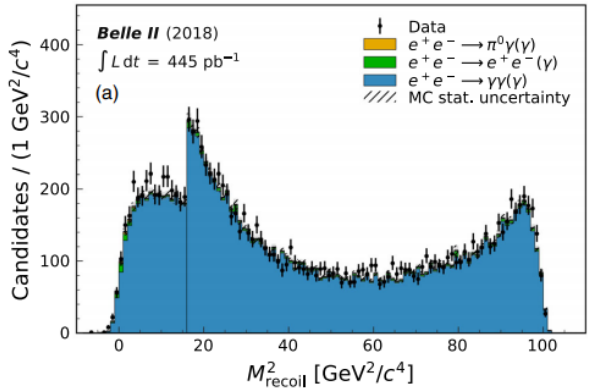
- Used 0.445 fb^{-1} of Phase 2 data
- Looking for 3-photon final state via ALP-strahlung
- Search for a bump in recoil and di-photon mass distribution

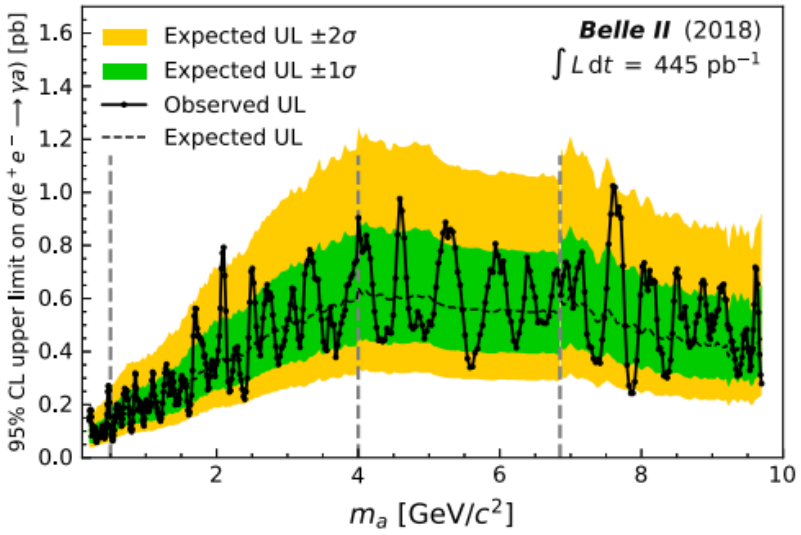


ALP-strahlung

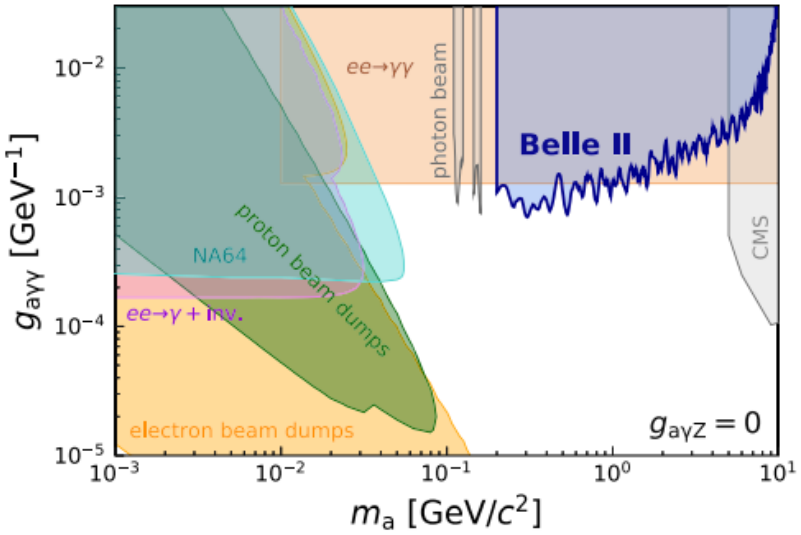
PRL 125, 161806 (2020)

- No excess observed, set 95% CL upper limit on the ALP-photon coupling
- Limit on $g_{a\gamma\gamma}$ assuming BF(a→γγ) = 100%





$$\sigma_a = \frac{g^2_{a\gamma\gamma}\alpha_{\rm QED}}{24}\left(1-\frac{m_a^2}{s}\right)^3$$



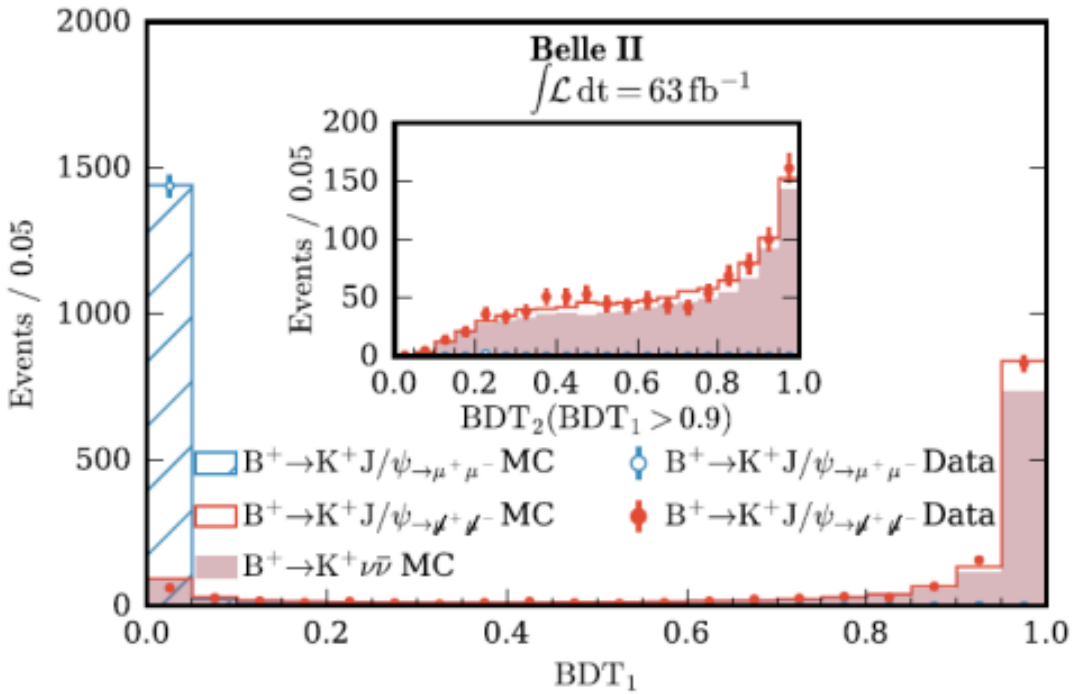


FIG. 2. Distribution of the classifier output BDT_1 (main figure) and BDT_2 for $BDT_1 > 0.9$ (inset). The distributions are shown before ($J/\psi_{\to\mu^+\mu^-}$) and after ($J/\psi_{\to\not{\mu}^+\not{\mu}^-}$) the muon removal and update of the kaon-candidate momentum of selected $B^+ \to K^+ J/\psi$ events in simulation (MC) and data. As a reference, the classifier outputs directly obtained from simulated $B^+ \to K^+ \nu\bar{\nu}$ signal events are overlaid. The simulation histograms are scaled to the total number of $B^+ \to K^+ J/\psi$ events selected in data.

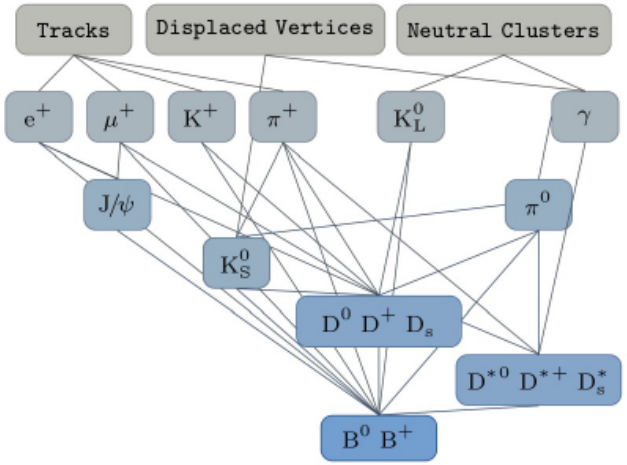
- Purpose of the figure
  - To show performance of classifiers
- Distribution of classifier output
  - (Main figure) BDT_1
  - (Inset) BDT_2
    - for $BDT_1 > 0.9$
- Validation
  - validation with $B^+ \to K^+ J/\psi$ ($J/\psi \to \mu^+\mu^-$)
    - An independent validation channel)
    - sim / data 에서 mu mu 있는 경우
    - mu mu 무시(ignoring)하고 모멘텀을 K+에
      - generator-level
      - mimic $B^+ \to K^+ \nu\bar{\nu}$

Full Event Interpretation

Multivariate algorithm for exclusive tagging of one B meson in a $\Upsilon(4S)$ decay using hierarchal approach with six stages of objects.

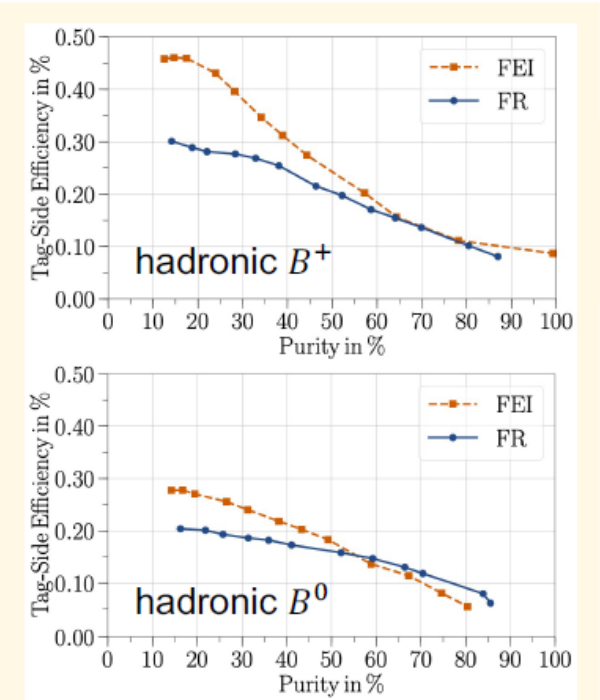
Over 100 B meson decay channels and over 10,000 decay cascades

Comp. and Soft. For Big Sci. 3, 6 (2019)



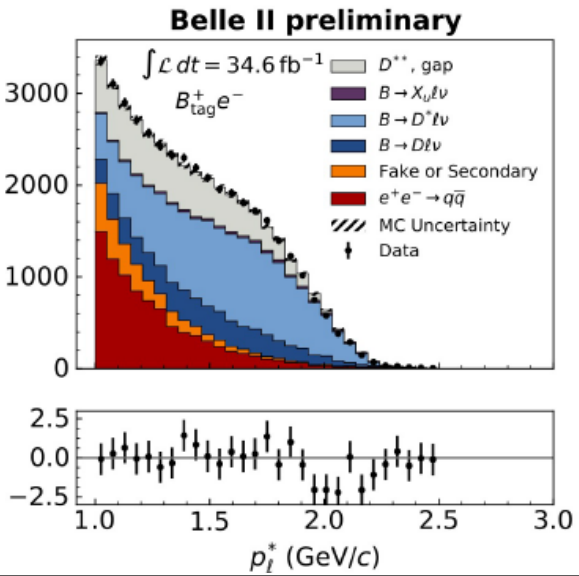
Tagging efficiency of B^+/B^0 at 10% purity in Belle MC

Tagging Algorithm	Hadronic	Semileptonic
Full Reconstruction	0.28%/0.18%	0.67%/0.63%
FEI	0.78%/0.46%	1.80%/2.04%



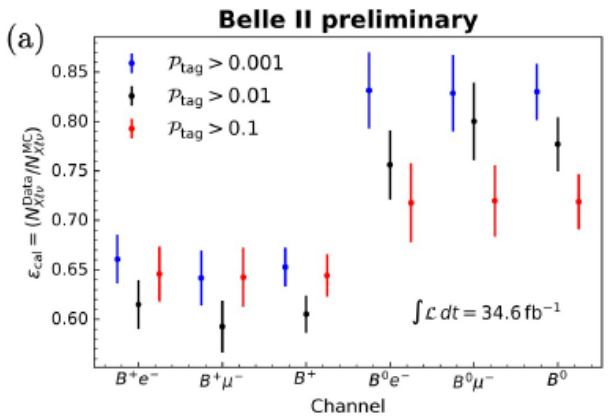
The performance calibration is made with $B \to X\ell\nu$

arXiv:2008.06096

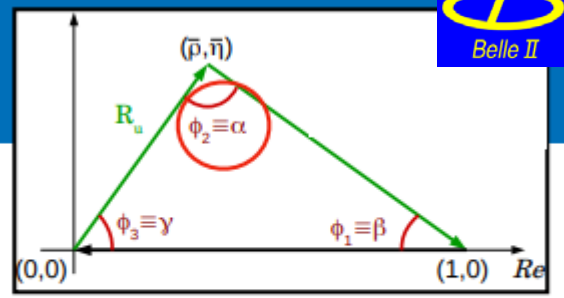


$N_{X\ell\nu}$ is determined by the fit on p_ℓ^* distribution both in data and in MC.

→ The calibration factor $\epsilon_{\mathrm{cal}} = N^{\mathrm{data}}_{X\ell\nu}/N^{\mathrm{MC}}_{X\ell\nu}$



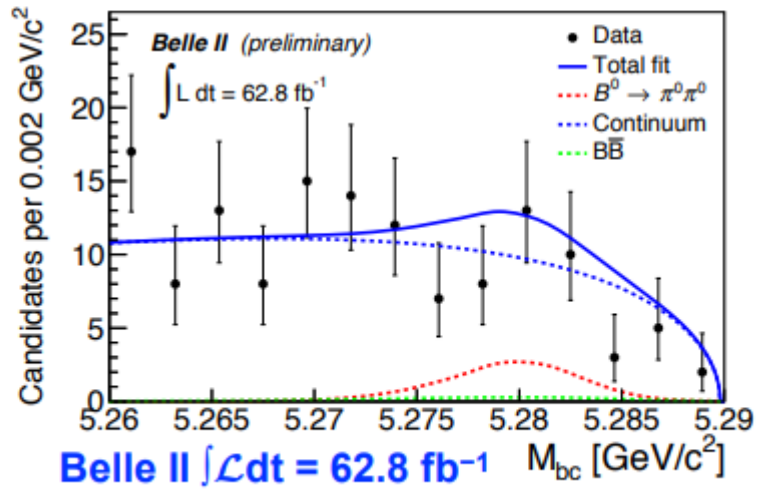
Towards ϕ_2/α



- Accessible via $b \to u$ transitions with large contribution from penguin ($b \to d$) diagrams
- Unique Belle II capability to determine ϕ_2/α by $B^0 \to \pi^0\pi^0$, $B^+ \to \rho^+\rho^0$
- $B^0 \to \pi^0\pi^0$ is very challenging due to four photons in final state
  - Main background is from continuum π^0
  - Dedicated MVA for photon selection

arXiv:2107.02373

- $\mathcal{B}(B^0 \to \pi^0\pi^0) = [0.98^{+0.48}_{-0.39}(\text{stat}) \pm 0.27(\text{syst})] \times 10^{-6}$

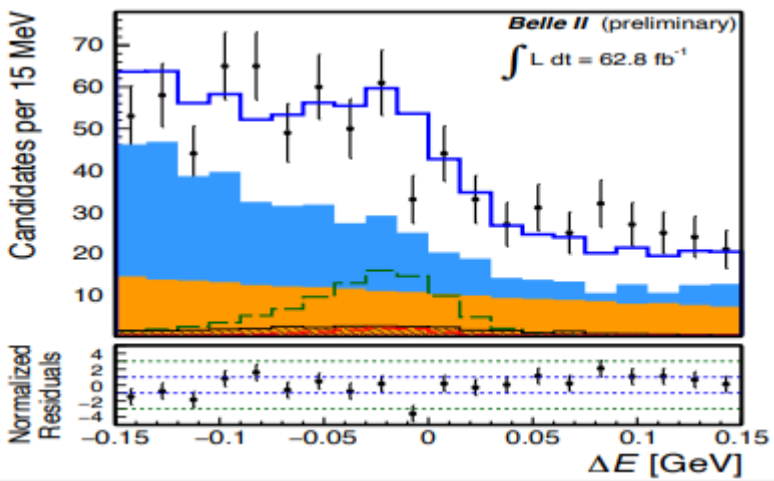


- $B^+ \to \rho^+\rho^0$ is pion only final state
  - Main background due to ρ mass width
  - Branching ratio is compatible with WA

$$\Delta E = E_B^* - E_{beam}$$
$$M_{bc} = \sqrt{E_{beam}^2 - \vec{p}_B^{\,2}}$$

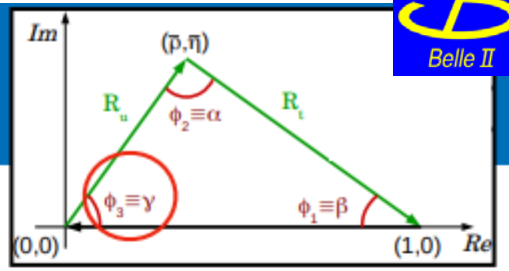
arXiv:2109.11456v2

- $\mathcal{B}(B^+ \to \rho^+\rho^0) = [20.6 \pm 3.2(\text{stat}) \pm 4.0(\text{syst})] \times 10^{-6}$



First reconstruction in Belle II data→preparing for measurement of α/ϕ_2

ϕ_3/γ Measurement with Combined Belle + Belle II Data

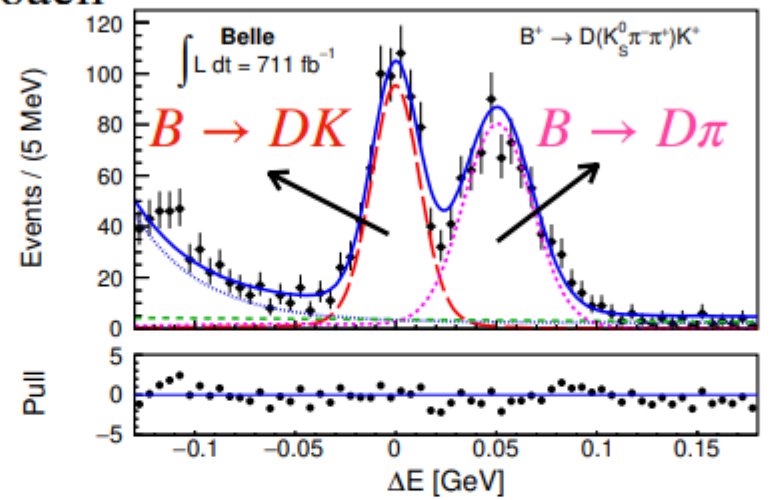


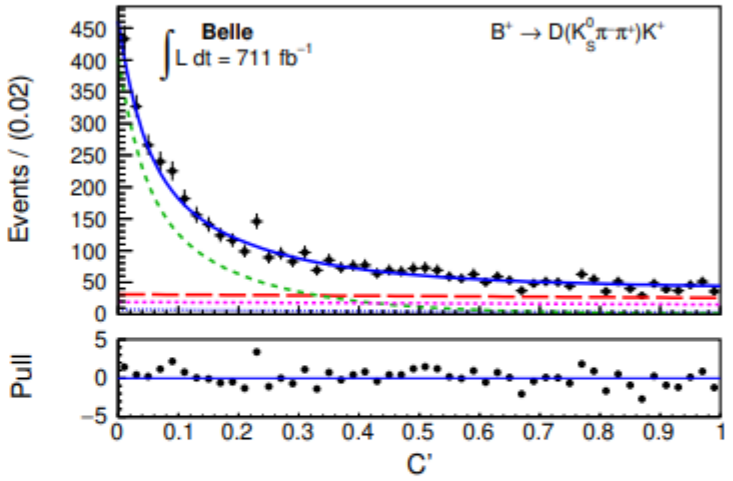
- $B^- \to D^0(K^0_S\pi^+\pi^-)K^-$ is the golden mode for γ/ϕ_3 measurement for Belle/Belle II.
- Using BPGGSZ model independent approach

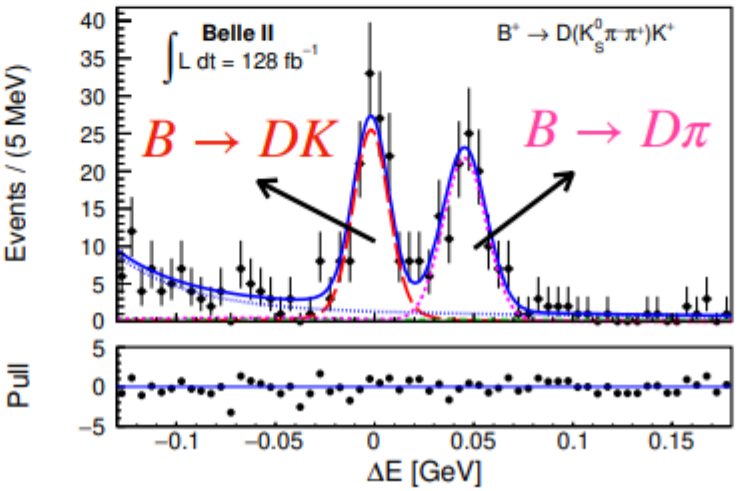
$$\frac{\mathcal{A}^{suppr.}(B^- \to \overline{D^0}K^-)}{\mathcal{A}^{favor.}(B^- \to D^0K^-)} = r_B e^{i(\delta_B+\phi_3)}$$

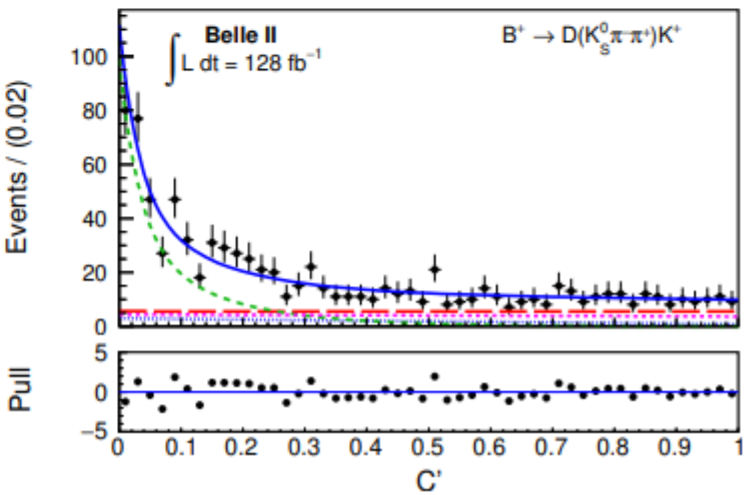
- r_B: magnitude of the ratio of amplitudes
- δ_B: strong phase difference

- Dominant and clean decay $B^- \to D^{(*)0}\pi^-$ and $B^0 \to D^{(*)+}\pi^-$ provide good control sample.
  Signal enhanced with $M_{bc} > 5.27$ GeV/c^2 and PID to K/π from signal B
- Unbinned ML fit in ΔE and MVA output (with event shape variables).









ϕ_3/γ Measurement with Combined Belle + Belle II Data

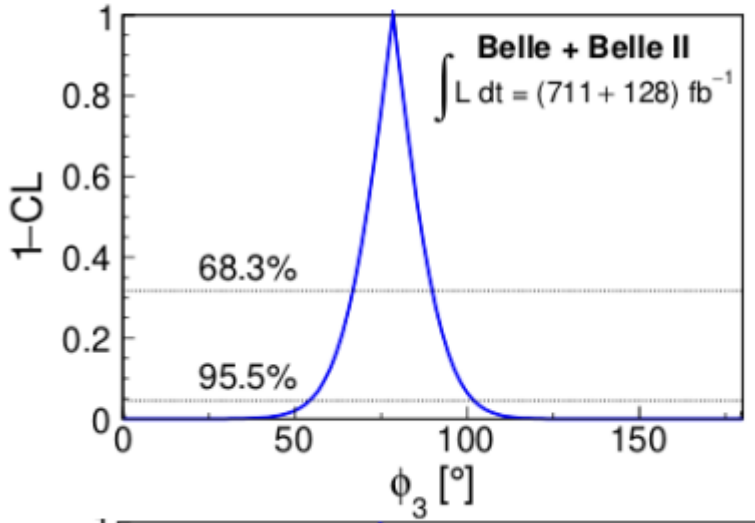
- First Belle and Belle II combined measurement

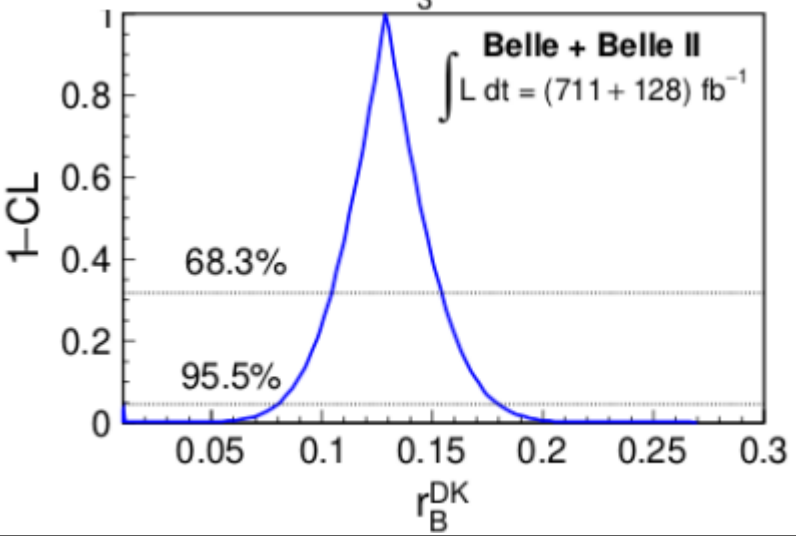
Belle+Belle II $\int\mathcal{L}dt$ = (711 + 128) fb^{-1}

$$\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ ,$$
$$r_B^{DK} = 0.129 \pm 0.024 \pm 0.001 \pm 0.002,$$
$$\delta_B^{DK} = (124.8 \pm 12.9 \pm 0.5 \pm 1.7)^\circ .$$

- Statistical uncertainty improved by 30 % with just 20 % more data
- Experimental systematics reduced from 4° to 0.5°
- Systematics associated with inputs reduced from 4° to 1° due to recent updates from by BESIII

arXiv:2110.12125
Submitted to JHEP



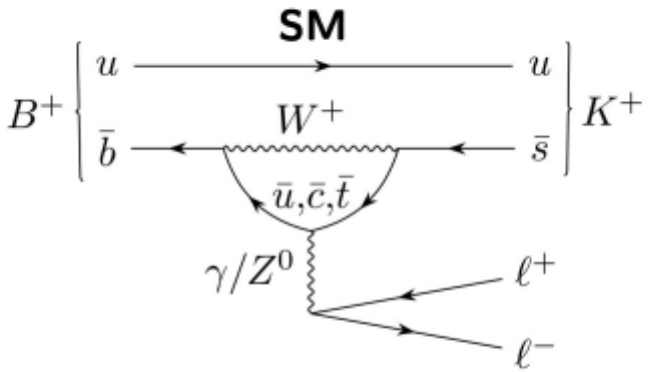


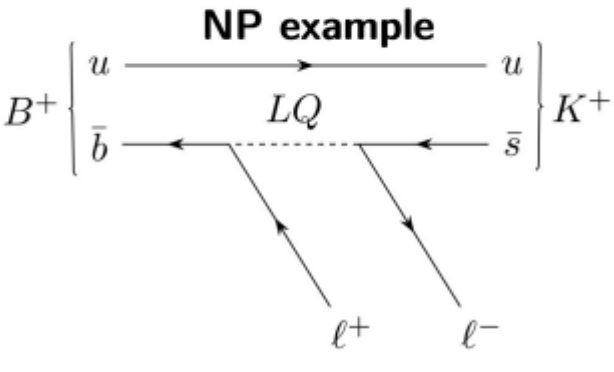
$B^+ \to K^+\ell^+\ell^-$

B . F ~ 10^{-7}

- Important FCNC decay measurement $B^+ \to K^+\ell^+\ell^-$ (l = e, μ) sensitive to many SM extensions.
- BDT (event shape, vertex related and missing energy variables) to suppress background from **light quark** and **inclusive *B* decays**.
- First look with 63 fb^{-1} data
- 2D fit to $\Delta E = E_B^* - E_{beam}$ and $M_{\rm bc} = \sqrt{E_{\rm beam}^2 - \vec{p}_B^{\,2}}$ distribution
- Signal Yield : $8.6^{+4.3}_{-3.9} \pm 0.4$ events

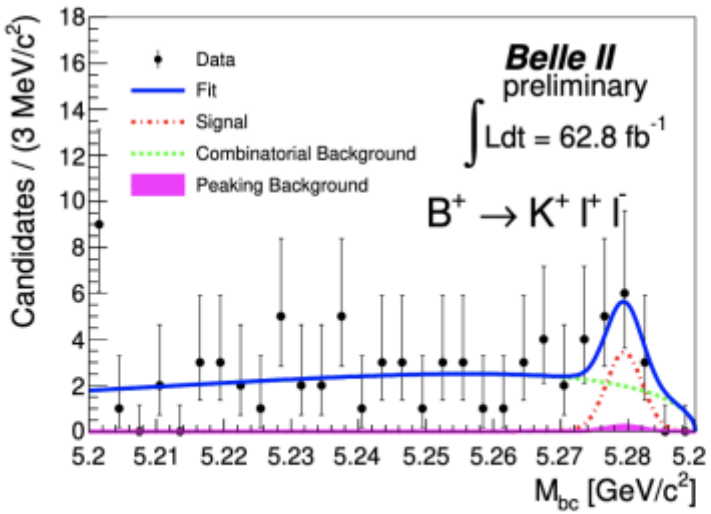
More data needed for $\mathcal{B}$ and R_K measurement

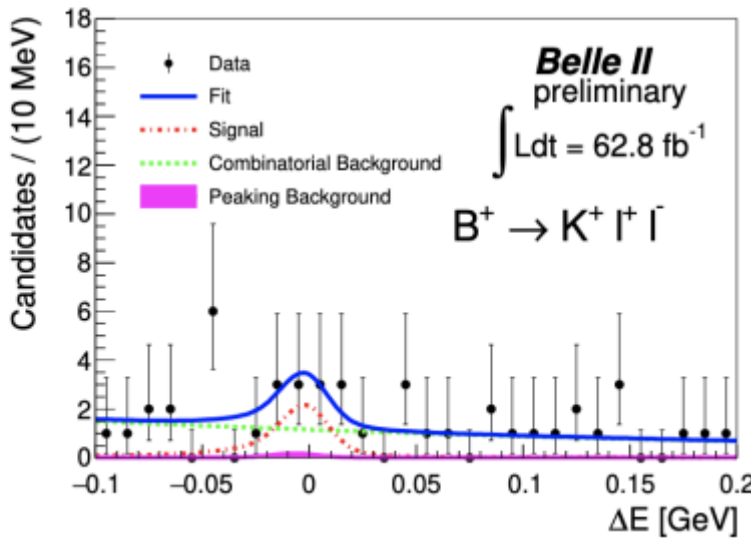




$$R_{K^{(*)}} := \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} \overset{\rm SM}{\cong} 1$$

Any significant deviation is hint for non-SM Physics!!





Inclusive $B \to X_c \ell \nu$

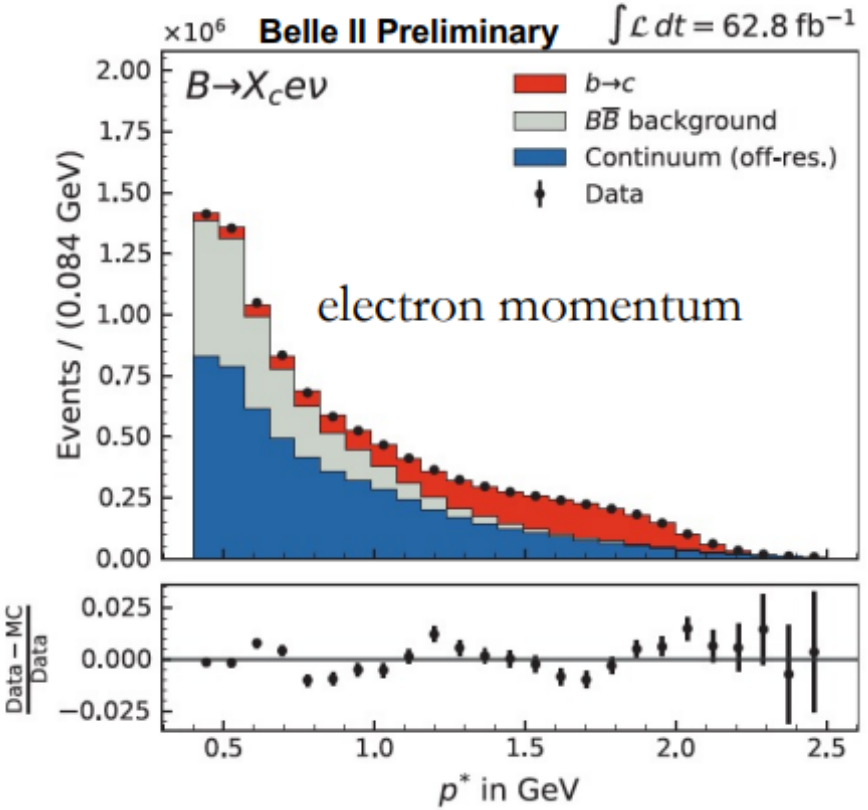
- Different strategies may help resolve the inclusive/exclusive discrepancy in $b \to c\ell\nu$ and $b \to u\ell\nu$
- Measure q^2-moments (moments of lepton energy or hadronic mass) to simultaneously determine non perturbative elements and $|V_{cb}|$

arXiv: 2109.01685

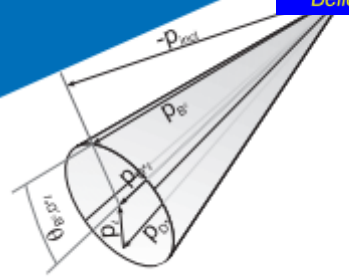
- Belle II performed both the untagged and the hadronic tagged analyses.
- **Untagged analysis**
- Require one well identified lepton
- Exploit missing mass and momentum to reject backgrounds
- Measure the branching fraction with a fit to p_l^*

$$\mathcal{B}(B \to X_c \ell \nu) = (9.75 \pm 0.03(\text{stat}) \pm 0.47(\text{syst}))\,\%$$

Next: $|V_{cb}|$ from q^2 moments



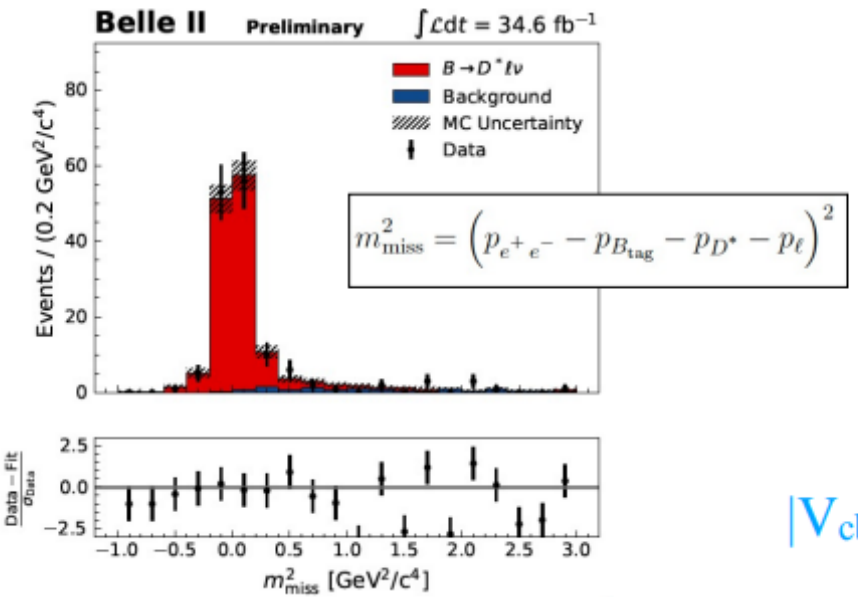
Exclusive $B \to D^{(*)}\ell\nu$



- $B \to D^{(*)}\ell\nu$ has been explored with both tagged and untagged approaches
- Tagged analysis
  - Almost zero background after tag
  - Signal selection from D^* and D^0 invariant masses, and lepton momentum
- Untagged analysis
  - Signal selection from $\cos\theta_{B,Y}$ where $\theta_{B,Y}$ is angle b/w B and direction of $D^*\ell$/ $D^0\ell$ system

$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_l) = (4.51 \pm 0.41_{\text{stat}} \pm 0.27_{\text{syst}} \pm 0.45_{\pi_s})\,\%$$

$$\mathcal{B}(B^- \to D^0\ell^-\overline{\nu}_l) = (2.29 \pm 0.05_{\text{stat}} \pm 0.08_{\text{syst}})\%$$



arXiv:2008.10299v4

$$\cos\theta_{BY} = \frac{2E_B^* E_Y^* - M_B^2 - m_Y^2}{2p_B^* p_Y^*}$$

$|V_{cb}|$ measurement in progress …