Rare decays studies using early Belle II data

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(Tokyo Metropolitan University)
on behalf of the Belle II collaboration

BEAUTY 2019
18th INTERNATIONAL CONFERENCE ON B-PHYSICS AT FRONTIER MACHINES
Ljubljana, Slovenia
September 30 - October 4, 2019

Outline

- **Introduction**
  - Belle II experiment
  - Rare decays
- **Rare decays at early Belle II**
  - $B \to K^{*}\gamma$
  - $B \to K\pi$
  - Prospects
- **Summary**

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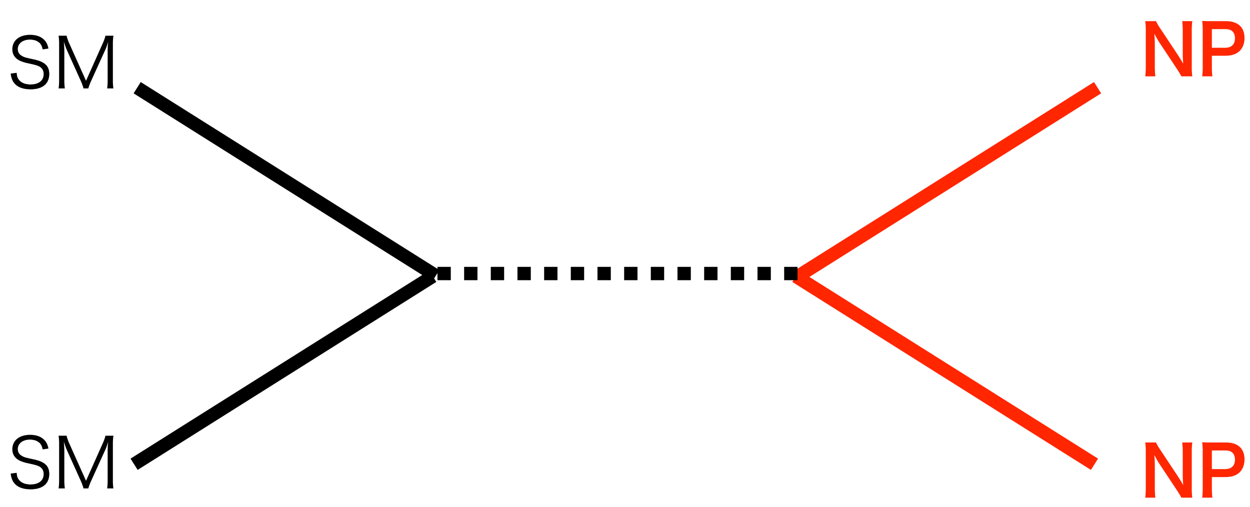
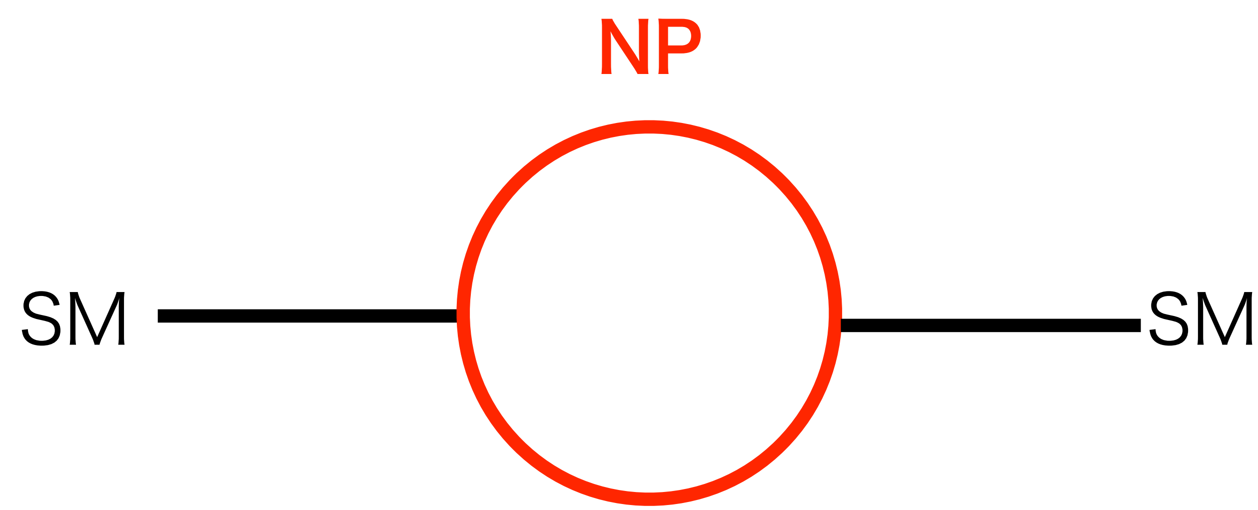
New physics search

Energy frontier
~direct approach~



Directly produce new particles
using high energy collision.
↓
Sensitive to the energy scale of NP.

Luminosity frontier
~indirect approach~



Find signatures of new particles
in the intermediate state.
↓
Sensitive to the flavor structure of NP.

The Belle II experiment is a luminosity frontier experiment.

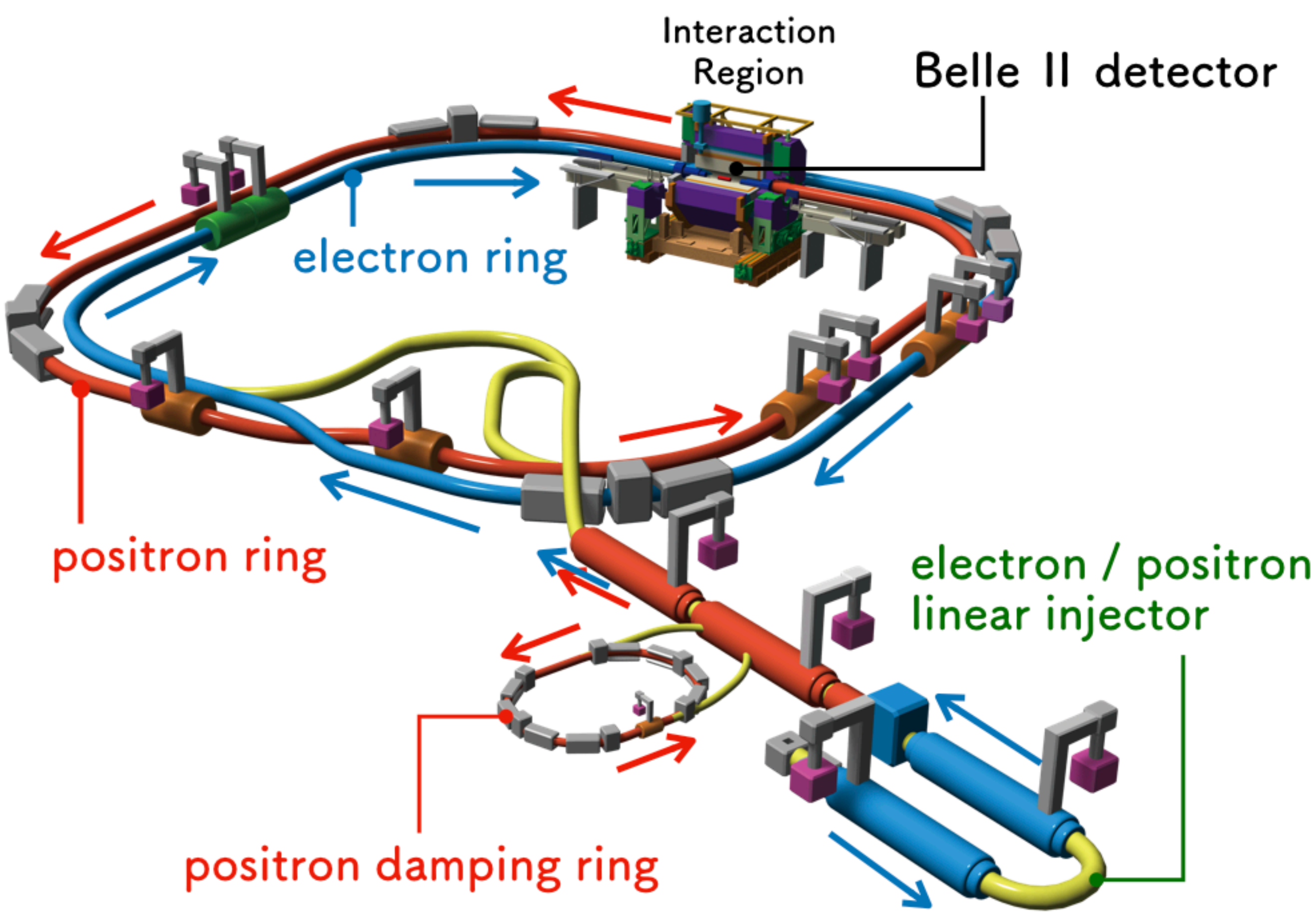
The Belle II experiment

The Belle experiment
- KEKB accelerator
- Belle detector

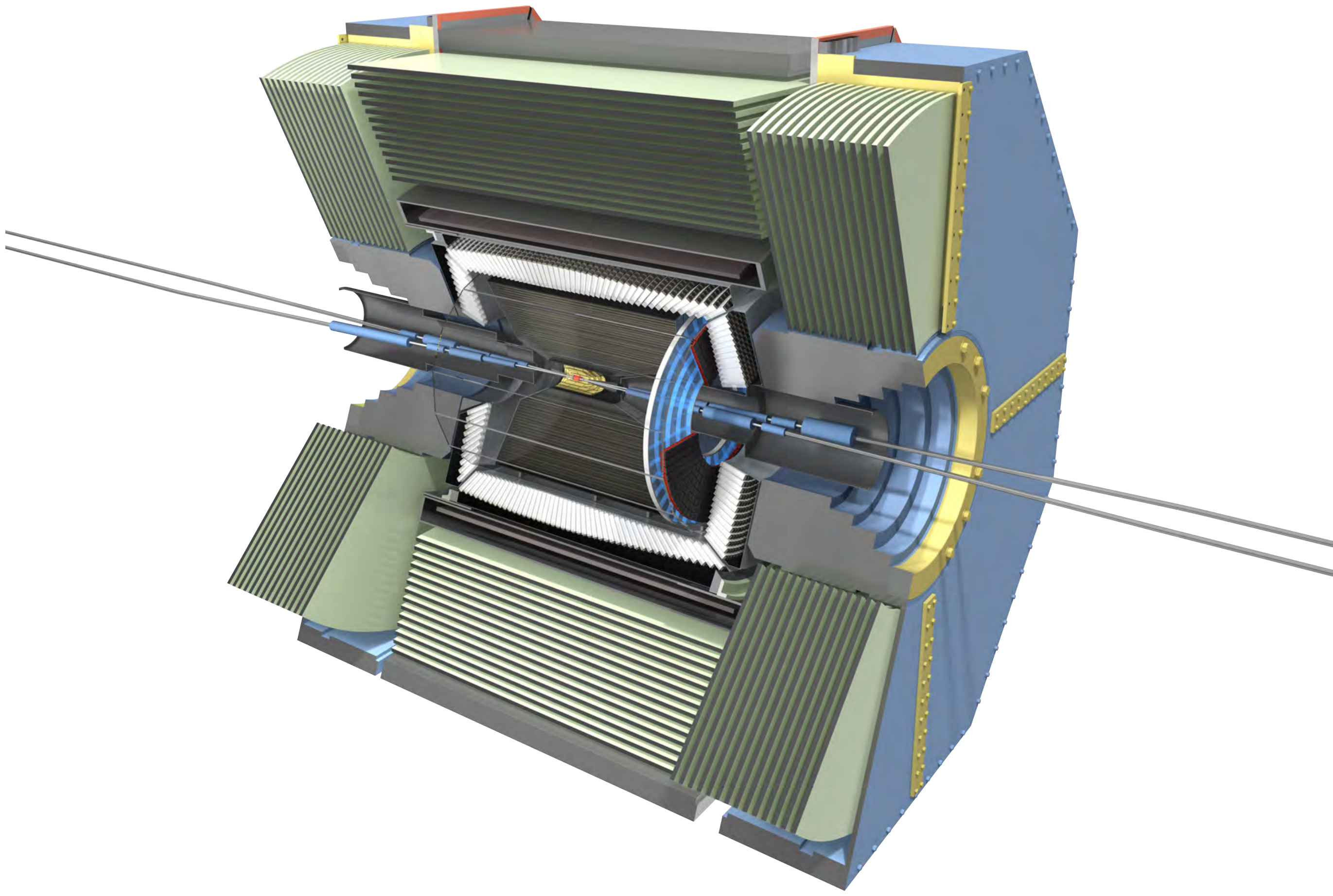
upgrade →

The Belle II experiment
- SuperKEKB accelerator
- Belle II detector

Search for new physics beyond the Standard Model with high statistics data up to 50 ab^{-1} integrated luminosity.

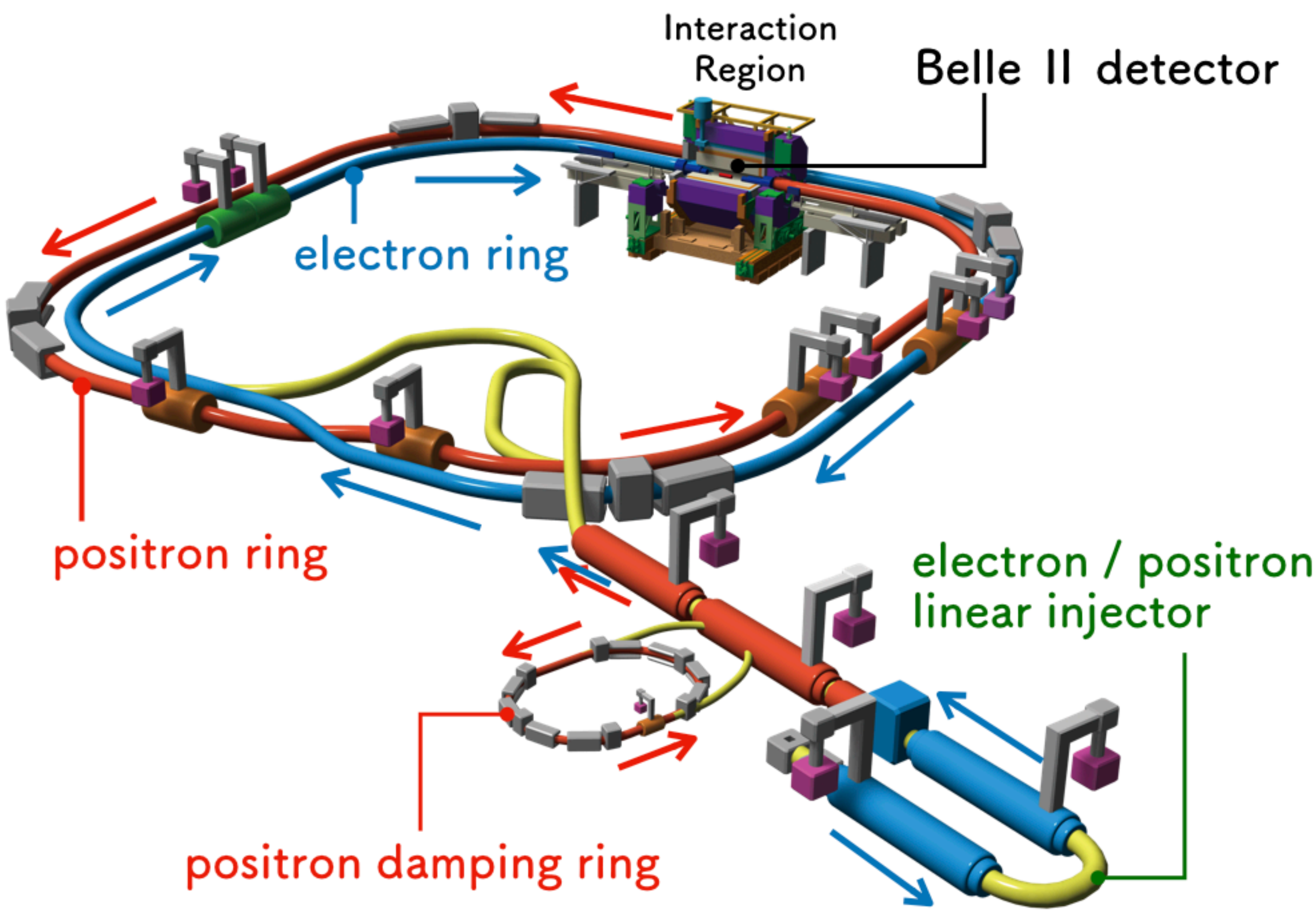


The SuperKEKB accelerator



The Belle II detector

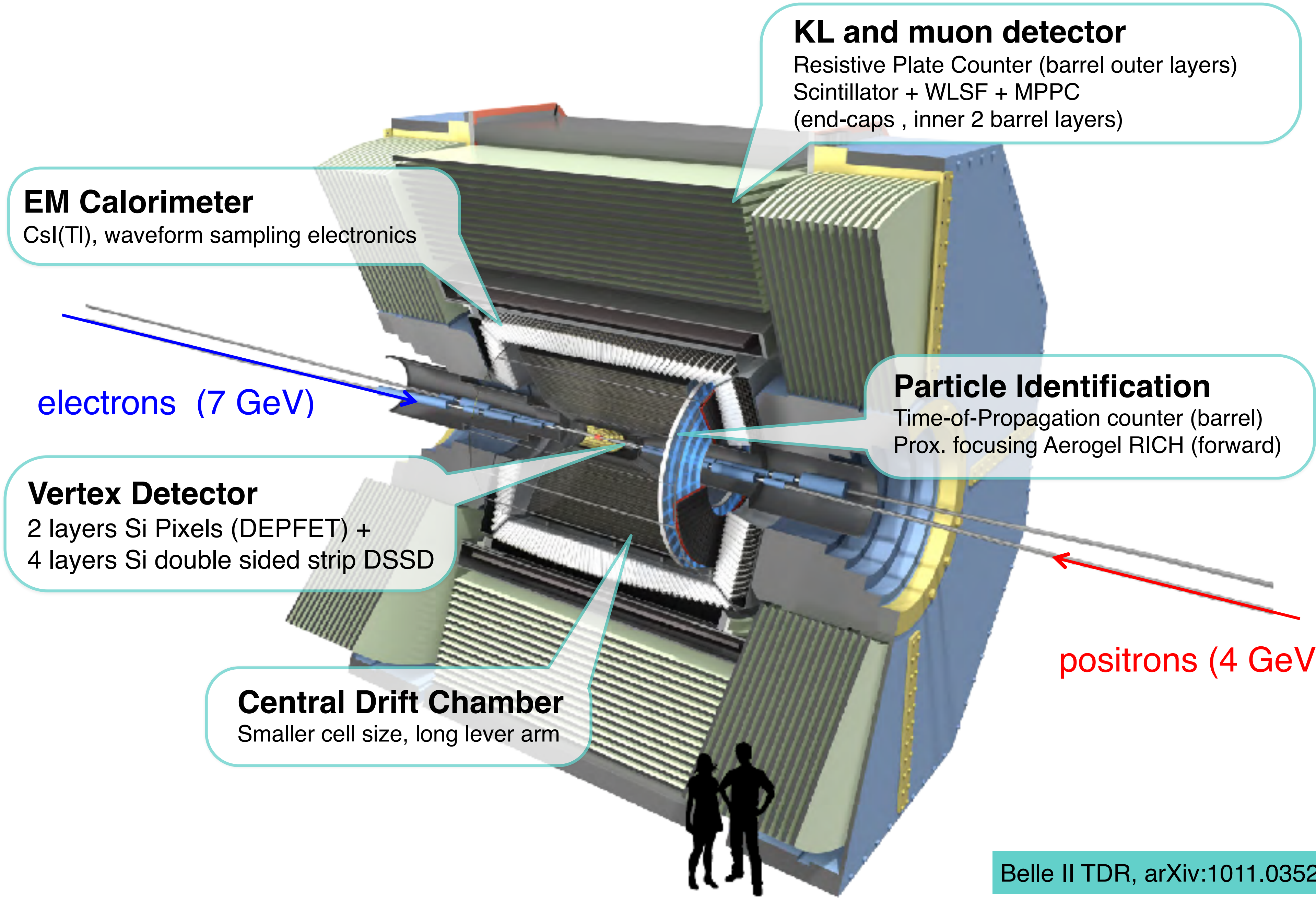
The SuperKEKB accelerator



- Asymmetric beam energy
  - e^-(7 [GeV]) and e^+(4 [GeV])

    $e^- \longrightarrow \leftarrow e^+ \Rightarrow \Upsilon(4S) \Rightarrow B\bar{B}$
- Boosted $B\bar{B}$ pairs
  - Lorentz factor : $\beta\gamma$=0.28
- Target luminosity : 8×10^{35} [$cm^{-2}s^{-1}$]
  - Luminosity at KEKB ×40

The Belle II detector



Belle II TDR, arXiv:1011.0352

- General purpose spectrometer
- Seven sub-detectors
- ~4π acceptance
- 30 kHz readout
- High background resistance
- Good particle identification

History

[Feb. ~ June 2016] Phase 1 : beam background study w/o Belle II detector

[March ~ July 2018] Phase 2 : Belle II detector w/o VXD

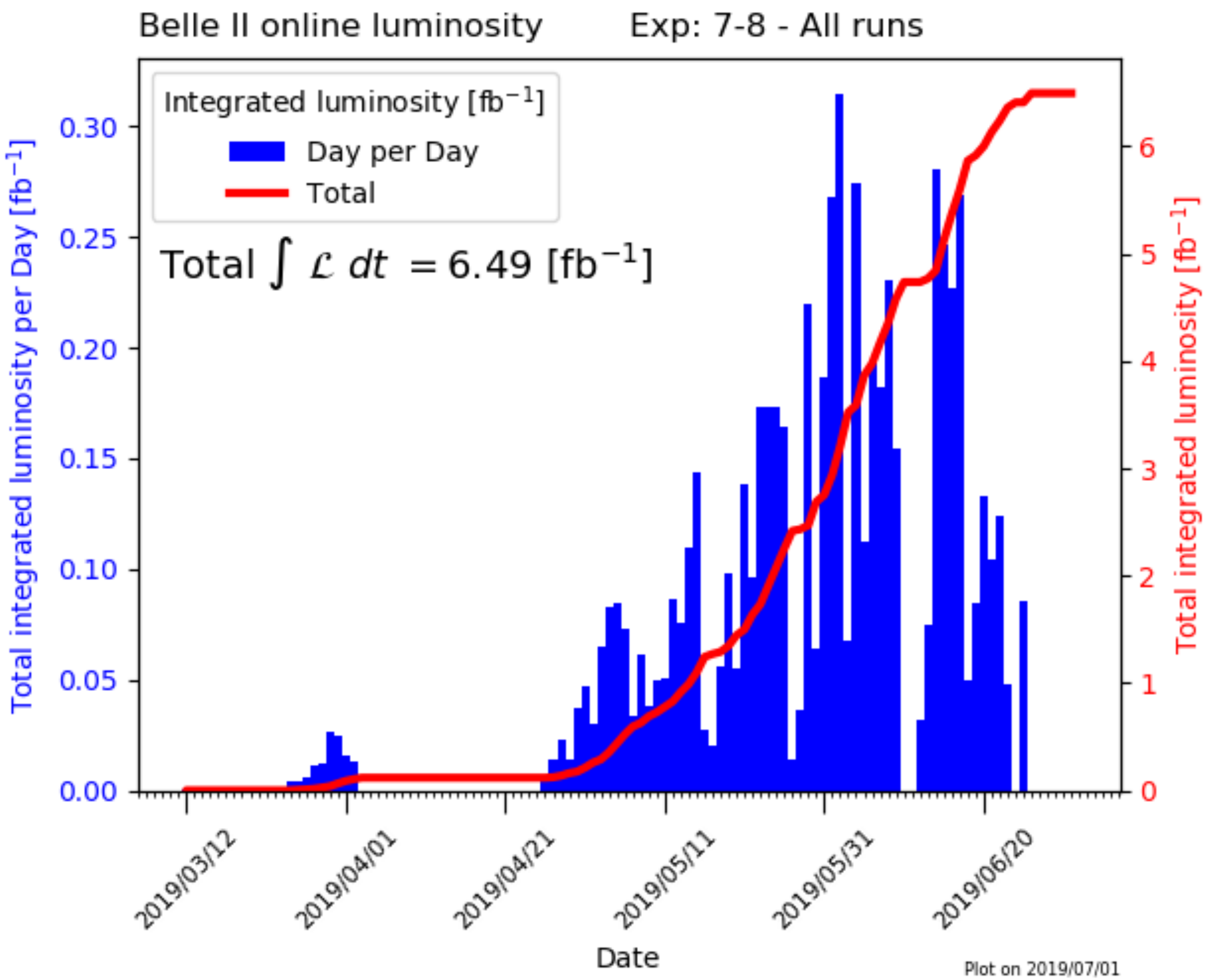
First collision!

[March ~ June 2019] Phase 3 : Full Belle II detector

First physics run with full Belle II detector

Phase 3 run summary

- Collected 6.5 fb^{-1} with full Belle II detector
- Peak Lumi. at data taking
  - $L_{peak} = 5.5 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$
- Lumi. challenge (SuperKEKB peak)
  - $L_{peak} = 1.2 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$



We have started to look into various physics processes.

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Rare decays

- Rare decays have high sensitivity to search new physics.
  - New physics contributes in loops or new tree diagrams.
- Some new physics models contribute some of rare decays.
  - New physics model can be identified by patterns of deviation from SM.

Observables	Experimental Sensitivity	Multi-Higgs Models (§17.2)	generic SUSY	MFV (§17.3)	Z' models (§17.6.1)	gauged flavour (§17.6.2)	3-3-1 (§17.6.3)	left-right (§17.6.4)	leptoquarks (§17.6.5)	compositeness (§17.7)	dark sector (§16.1)
$b \to s$ EW penguins:											
$\Delta A_{CP}(B \to K^{(*)}\pi)$	★★★	×	★	×	★★★	★	★★★	□	×	□	×
Radiative Penguins:											
$\mathcal{B}(B \to X_s \gamma)$	★★★	★★★	★★★	★★★	★	★★	★	★	★	★★★	×
$A_{CP}(B \to X_{s+d}\gamma)$	★★★	★★★	★★★	×	★	★	★	★★	★	★	×
$S_{CP}(B_d^0 \to K_S^0 \pi^0 \gamma)$	★★★	★★★	★★★	★★★	★	★	★	★★	★	★★★	×
$S_{CP}(B_d^0 \to \rho\gamma)$	★★★	★★★	★★★	★★★	★	★	★	★★	★	□	×
$B_s^0 \to \eta^{(\prime)}\gamma$ lifetime	★★★	★★★	★★★	★★★	★	★	★	★★	★	□	×

Belle II Physics book : arXiv:1808.10567

★★★ : Sensitive
★★ : Moderate effect
★ : Small effect
□ : No specific study
× : No significant contribution

Measurement of rare decays are important to search new physics.

Rare decays

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Semileptonic $b \to s$ Penguin Decays:											
$B \to K^{(*)}\ell\ell$ angular	★★	×	×	★★	★★	×	★★	×	★★★	★★	×
$R(K^*)$, $R(K)$	★★	×	×	×	★★	×	★★	×	★★★	★★	×
$\mathcal{B}(B \to X_s\ell\ell)$	★★★	×	×	★★★	★★	×	★★	×	★★★	★★	×
$R(X_s)$	★★★	×	×	×	★★	×	★★	×	★★★	★★	×
$\mathcal{B}(B \to K^{(*)}\tau\tau)$	★★★	★★★	×	★	★	×	★	×	★★★	★	×
$\mathcal{B}(B \to X_s\tau\tau)$	□	★★★	×	★	★	×	★	×	★★★	★	×
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	★★★	×	×	★	★	×	★	×	★★★	★	×
$\mathcal{B}(B \to X_s\nu\nu)$	□	×	×	★	★	×	★	×	★★★	★	×

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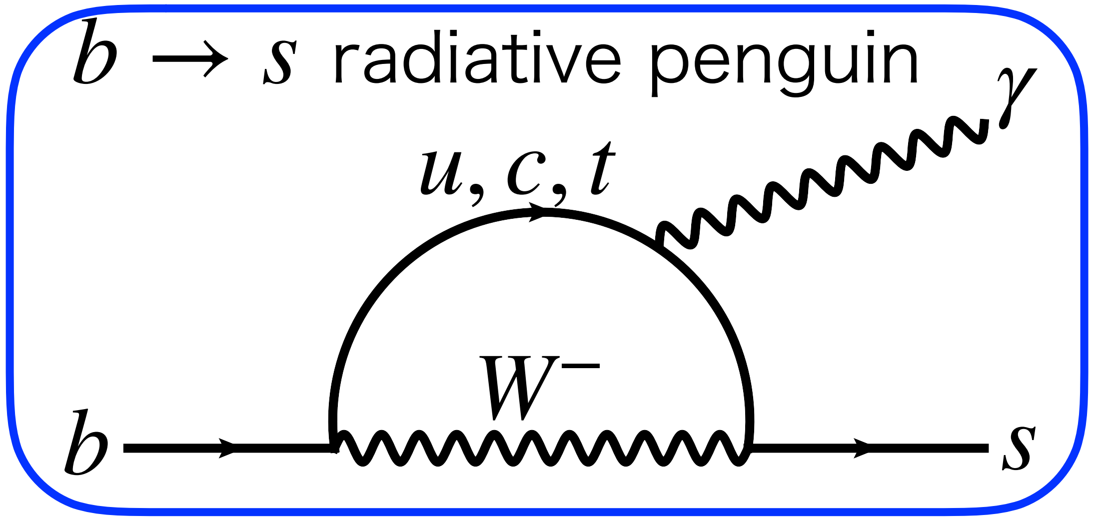
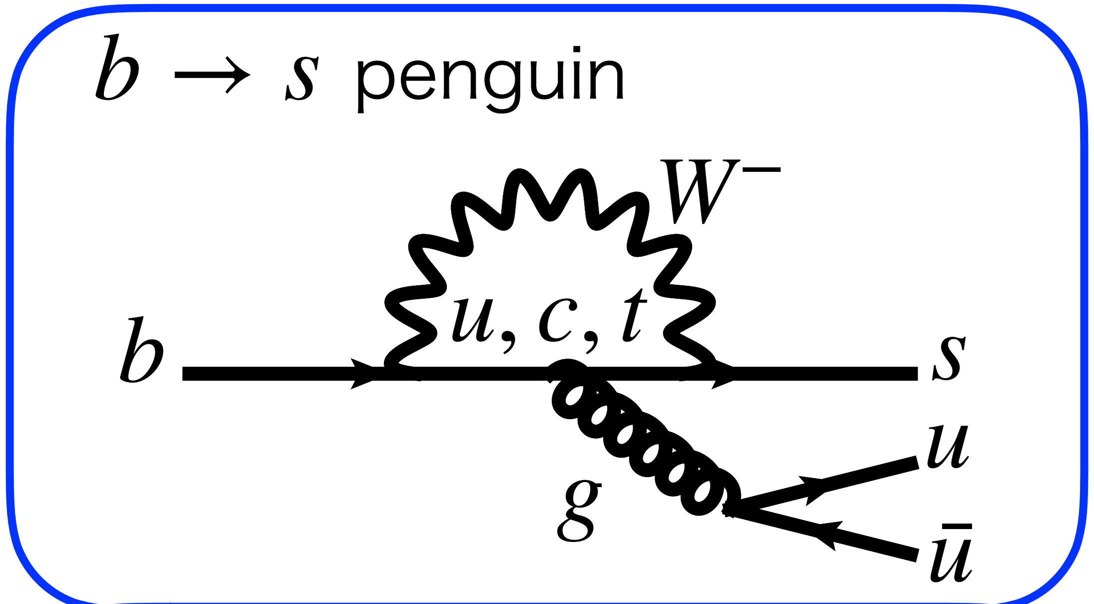
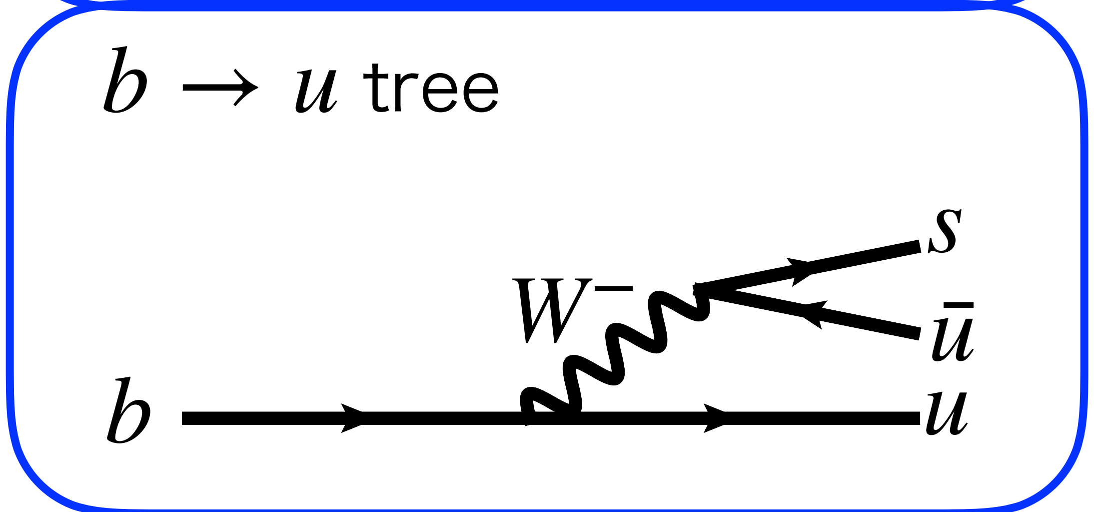
Measurement of rare decays are important to search new physics.

Rare decays at early Belle II

- There are many rare decays
  - Radiative and electroweak penguin
  - Charmless hadronic
  - etc.
- Today, two decay studies will be shown.
  - $B \to K^*\gamma$
    - $b \to s$ radiative penguin
    - Most major mode in radiative B decay.
  - $B \to K\pi$
    - $b \to s$ penguin + $b \to u$ tree
    - Direct CP
    - Most major mode in charmless hadronic B decay.







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$B \to K^*\gamma$ status

Phys. Rev. Lett. 119 (2017), 191802

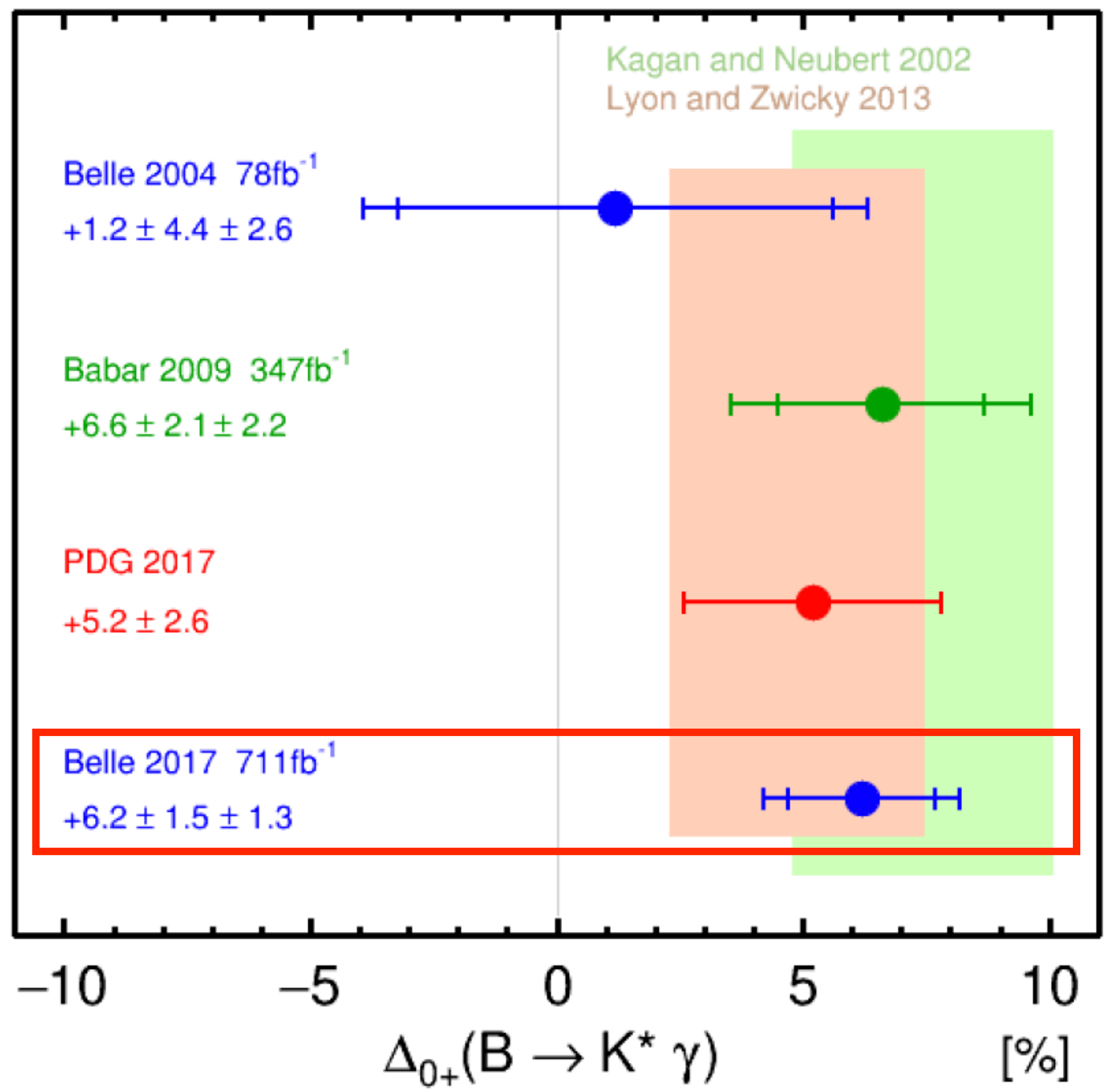
- Flavor changing neutral current (FCNC)
  - $b \to s\gamma$ process

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (3.96 \pm 0.07 \pm 0.14) \times 10^{-5}$$

$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (3.76 \pm 0.10 \pm 0.12) \times 10^{-5}$$

$$\Delta_{0+} = (+6.2 \pm 1.5 \pm 0.6 \pm 1.2)\,\%$$

Uncertainties
first : statistical
second : systematic
third : f_{+-}/f_{00}

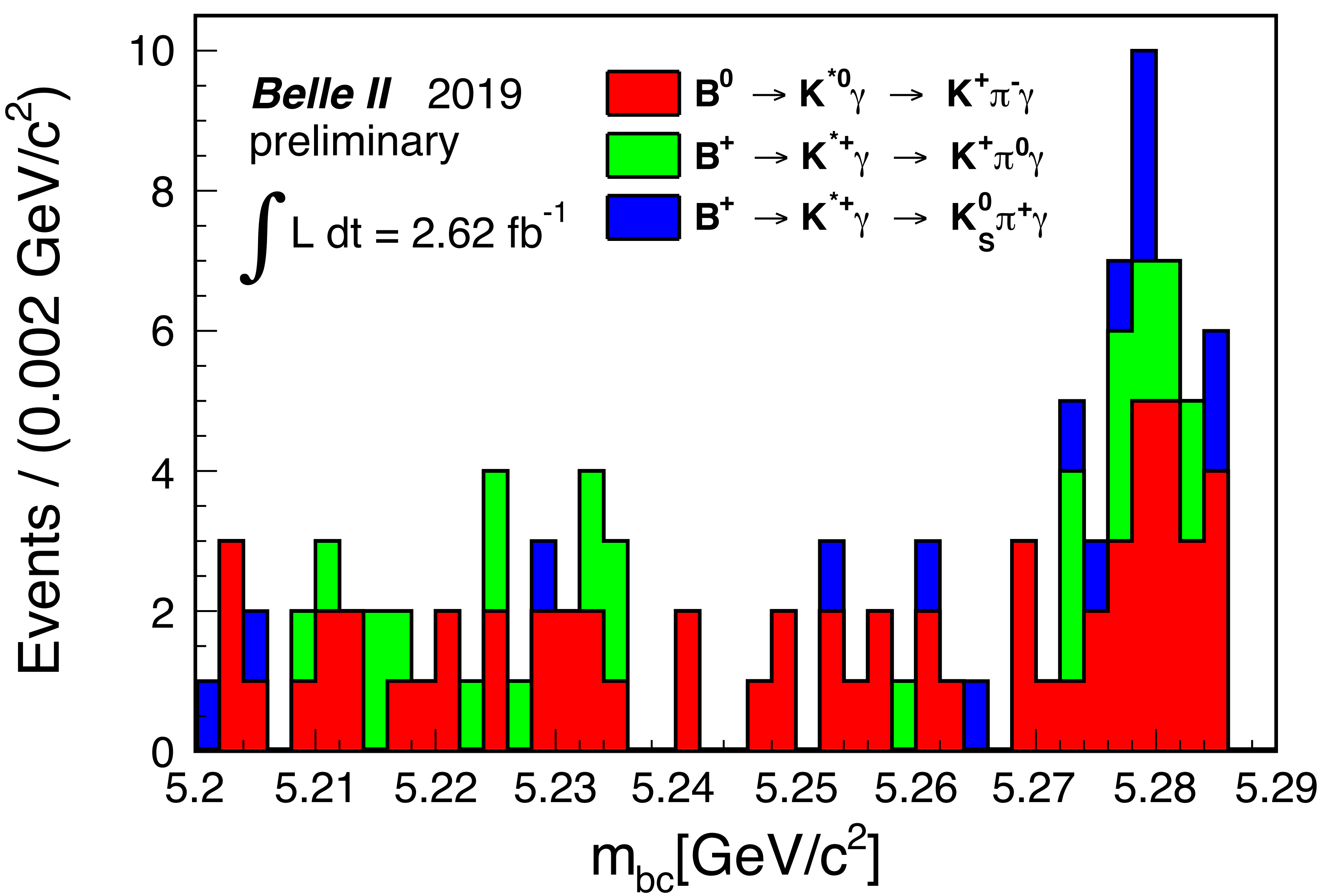


- Isospin violation.
  - Evidence : 3.1 σ
  - Constrain mSUGRA parameter space.

Isospin violation can be found with >5σ precision at Belle II.

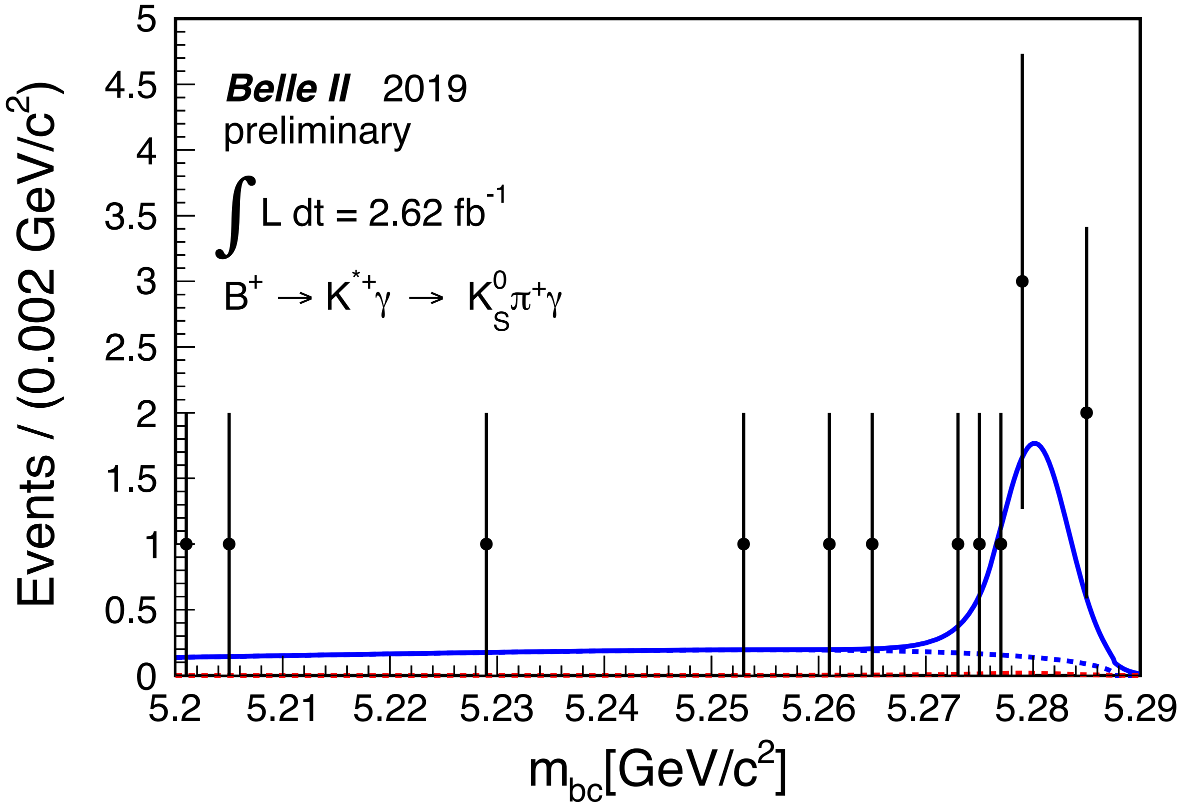
$B \to K^*\gamma$ results at Belle II

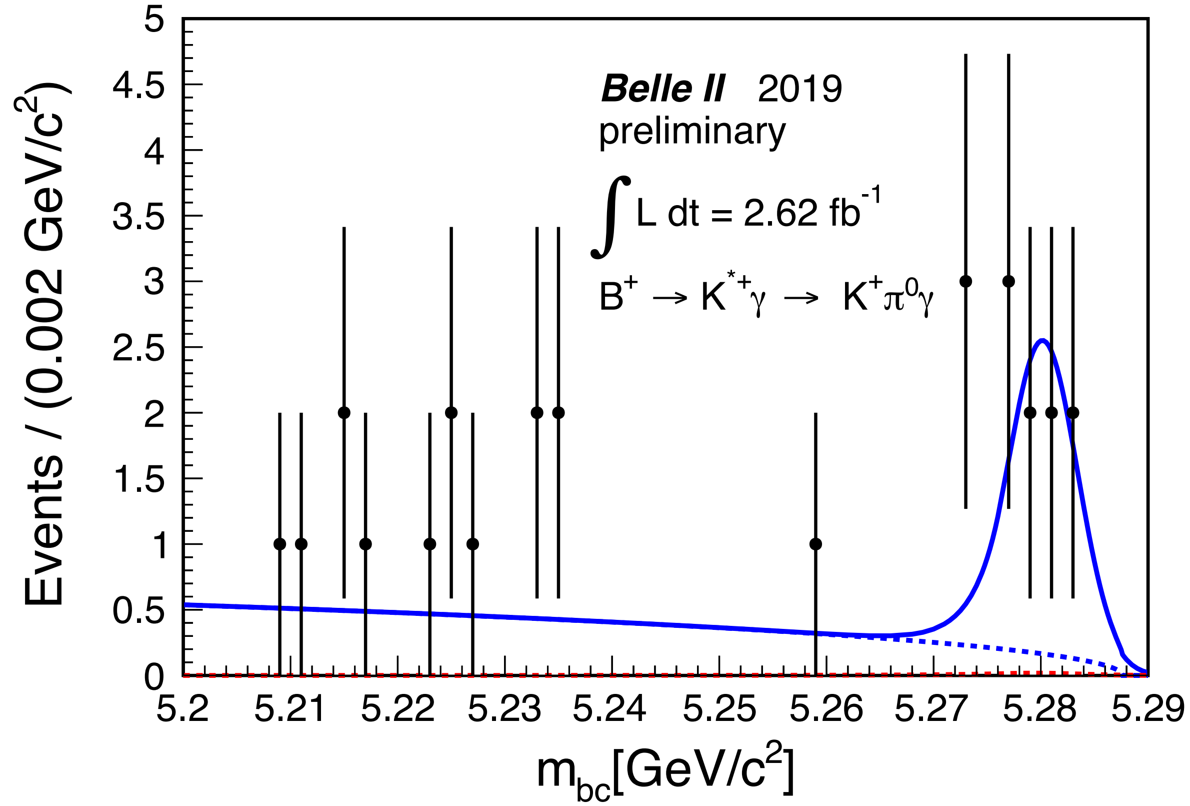
- Search $B \to K^*\gamma$ decay using three decay modes
  - $B^0 \to K^{*0}(\to K^+\pi^-)\gamma$
  - $B^+ \to K^{*+}(\to K^+\pi^0)\gamma$
  - $B^+ \to K^{*+}(\to K_S^0\pi^+)\gamma$

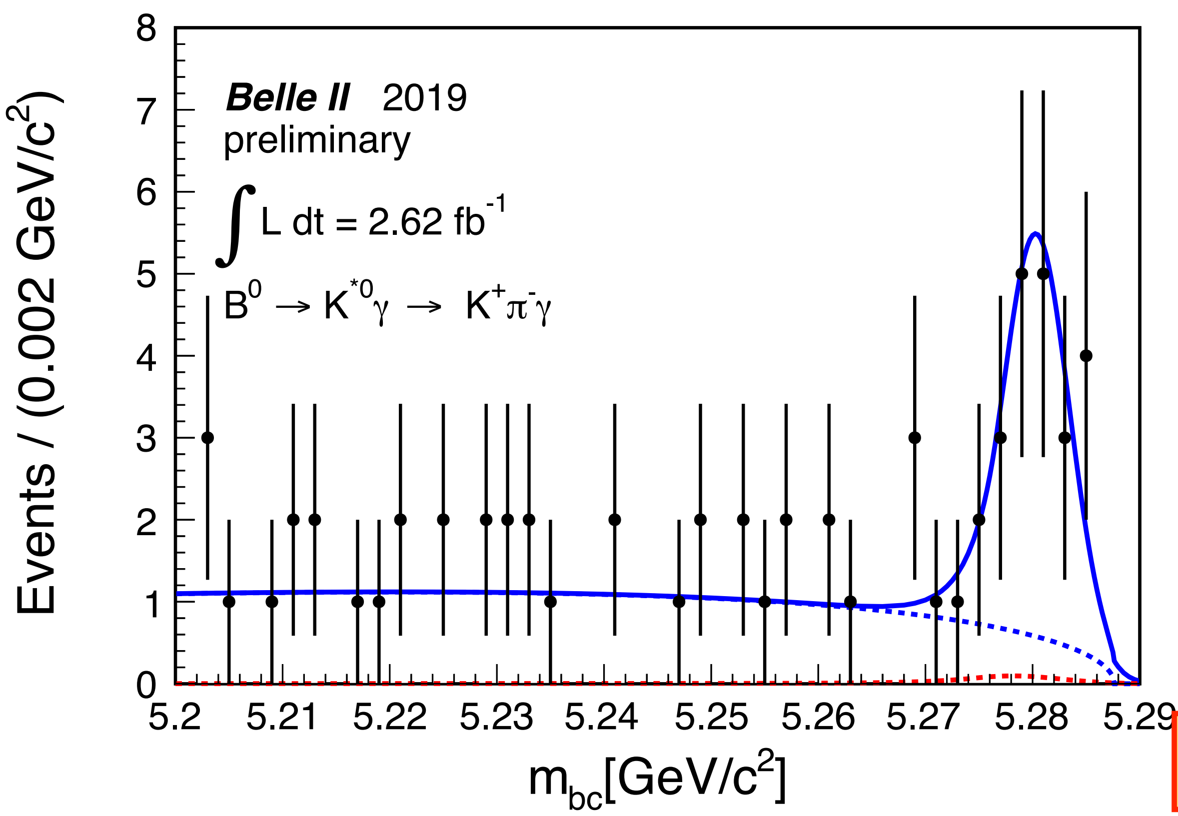


- Distribution of beam energy constrained mass $m_{bc} = \sqrt{E_{beam}^2 - p_B^{*2}}$
  clear peak is seen at $m_B = 5.28\,\mathrm{GeV}/c^2$
- Signal yield and significance is obtained by fitting. → next page

$B \to K^*\gamma$ signal yield extraction







	signal yield (statistics only)	significance
$B^0 \to K^{*0}(\to K^+\pi^-)\gamma$	19.1 ± 5.2	4.4 σ
$B^+ \to K^{*+}(\to K^+\pi^0)\gamma$	9.8 ± 3.4	3.7 σ
$B^+ \to K^{*+}(\to K^0_S\pi^+)\gamma$	6.6 ± 3.1	2.1 σ

- Yields agree with WA branching fractions.
- Combined significance exceeds 5 σ.

Rediscovery of penguin decay at Belle II

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$B \to K\pi$ status

- Charmless hadronic B decay
- ΔA_{CP} puzzle : 5.6 σ discrepancy

  of the difference of CP asymmetry.
  - $A_{CP}(K^+\pi^-) = -0.082 \pm 0.006$
  - $A_{CP}(K^+\pi^0) = +0.040 \pm 0.021$
- Isospin sum rule can identify NP or not

$$I_{K\pi} = A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}K^+\pi^-}\cdot\frac{\tau_0}{\tau_+}$$
$$-A_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}K^+\pi^-}\cdot\frac{\tau_0}{\tau_+} - A_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}K^+\pi^-}$$

  - If $I_{K\pi} \neq 0$, effect of NP in EW penguin.
  - $I_{K\pi} = -14 \pm 11\,\%$ (WA)

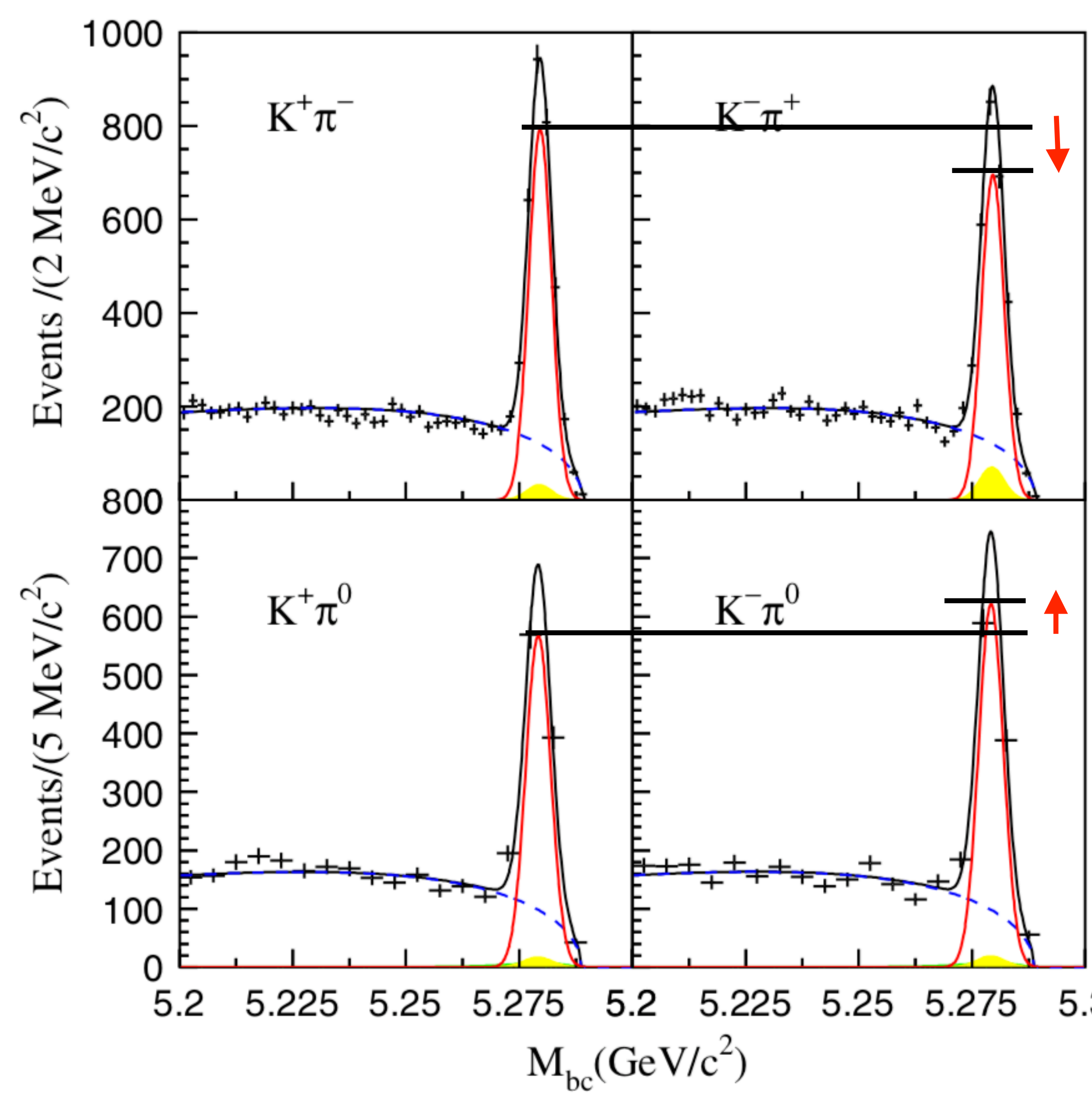
Need more statistics for precise measurement.

arXiv:1612.07233v2[hep-ex]

Phys. Rev. D 87, 031103(R) (2013)

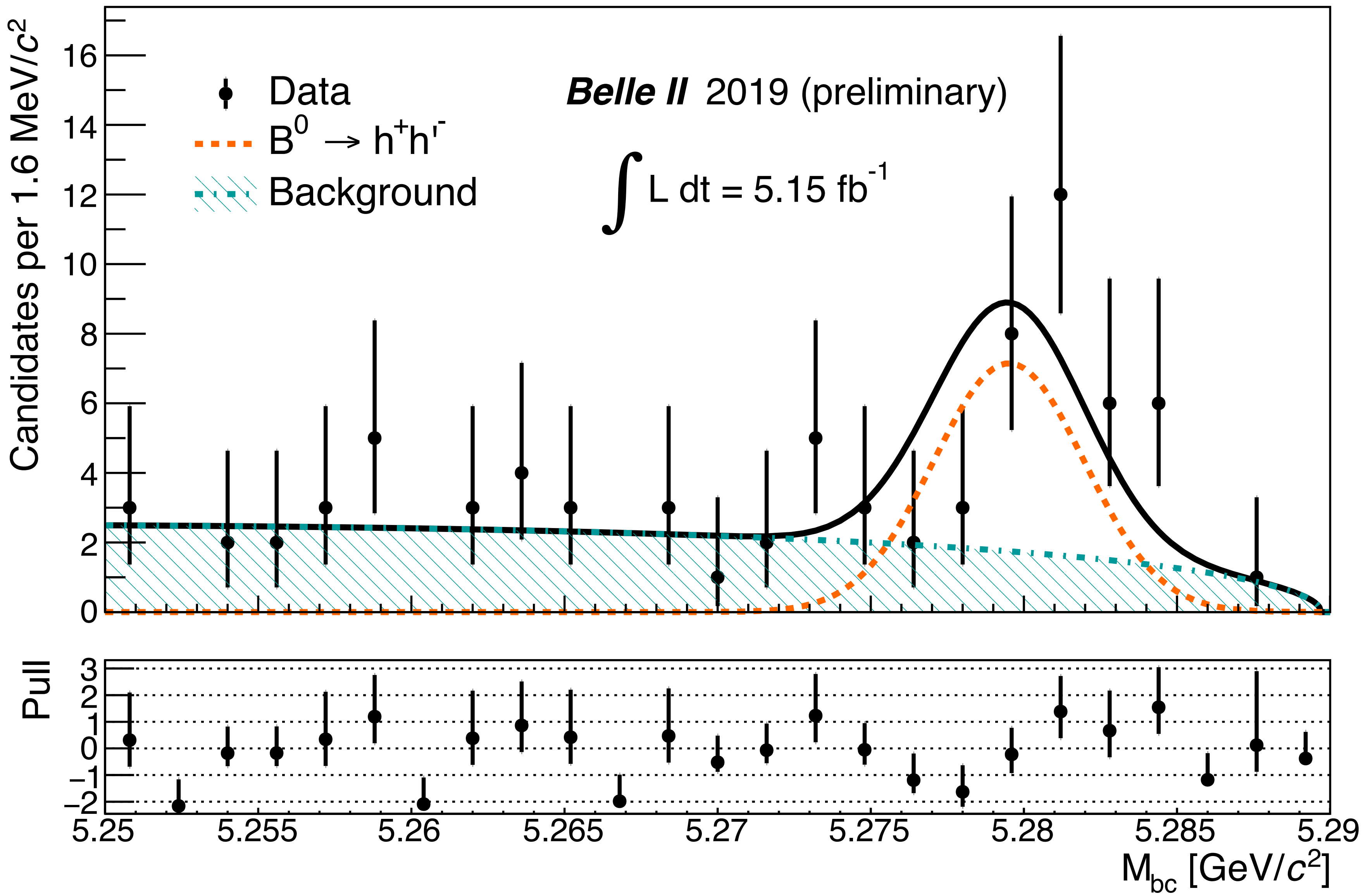
Phys. Lett. B 627, 82 (2005)

Phys. Rev. D 58, 036005(1998)



$B \to K\pi$ results at Belle II

- Search $B \to K\pi$ decay using following decay mode.
  - $B^0 \to K^{\pm}\pi^{\mp}$



yield : 26.3±6.2, significance : 5.46 σ

First signal of charmless hadronic B decay at Belle II.

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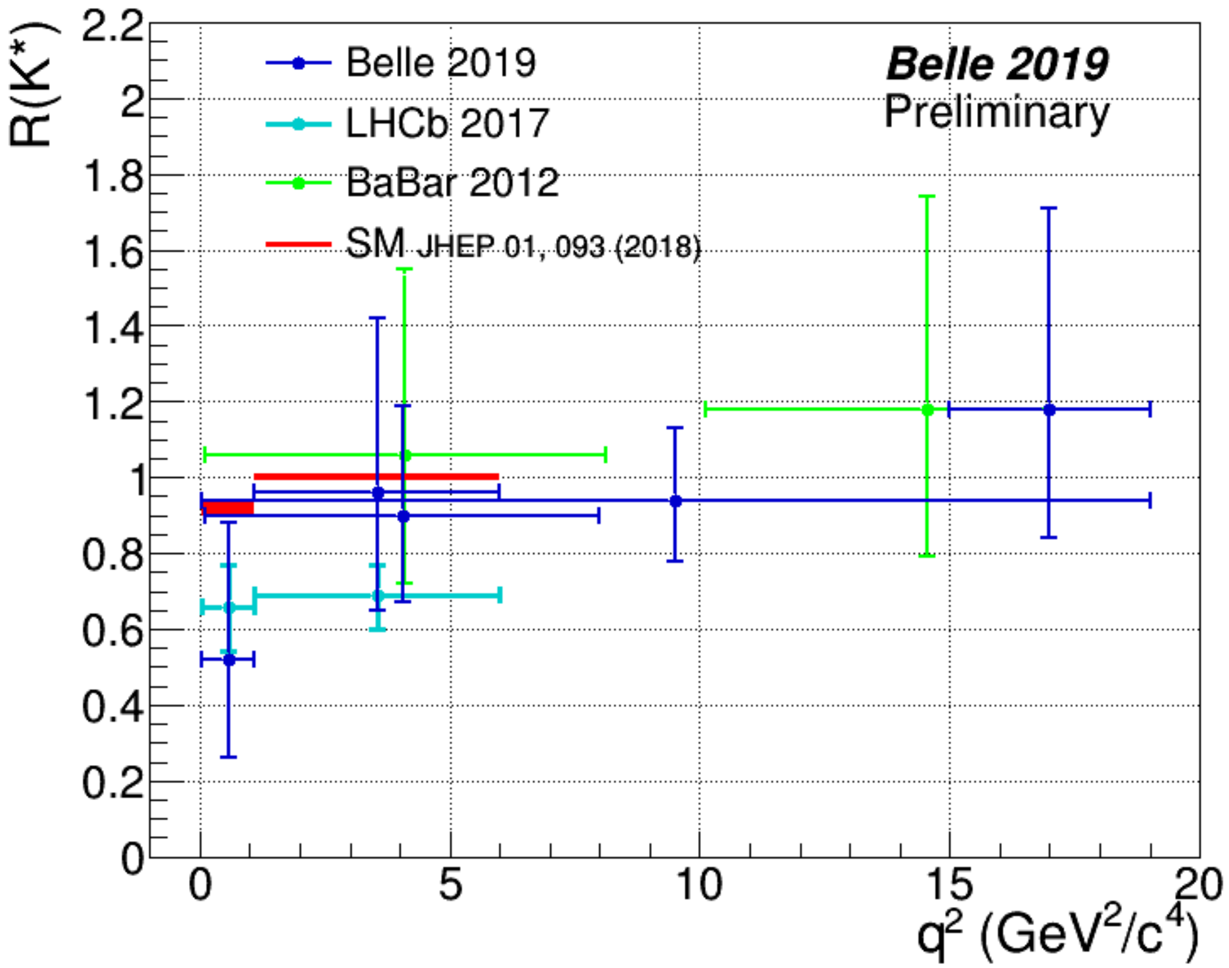
Prospects for $B \to K^* ll$

JHEP 08 (2017), 055

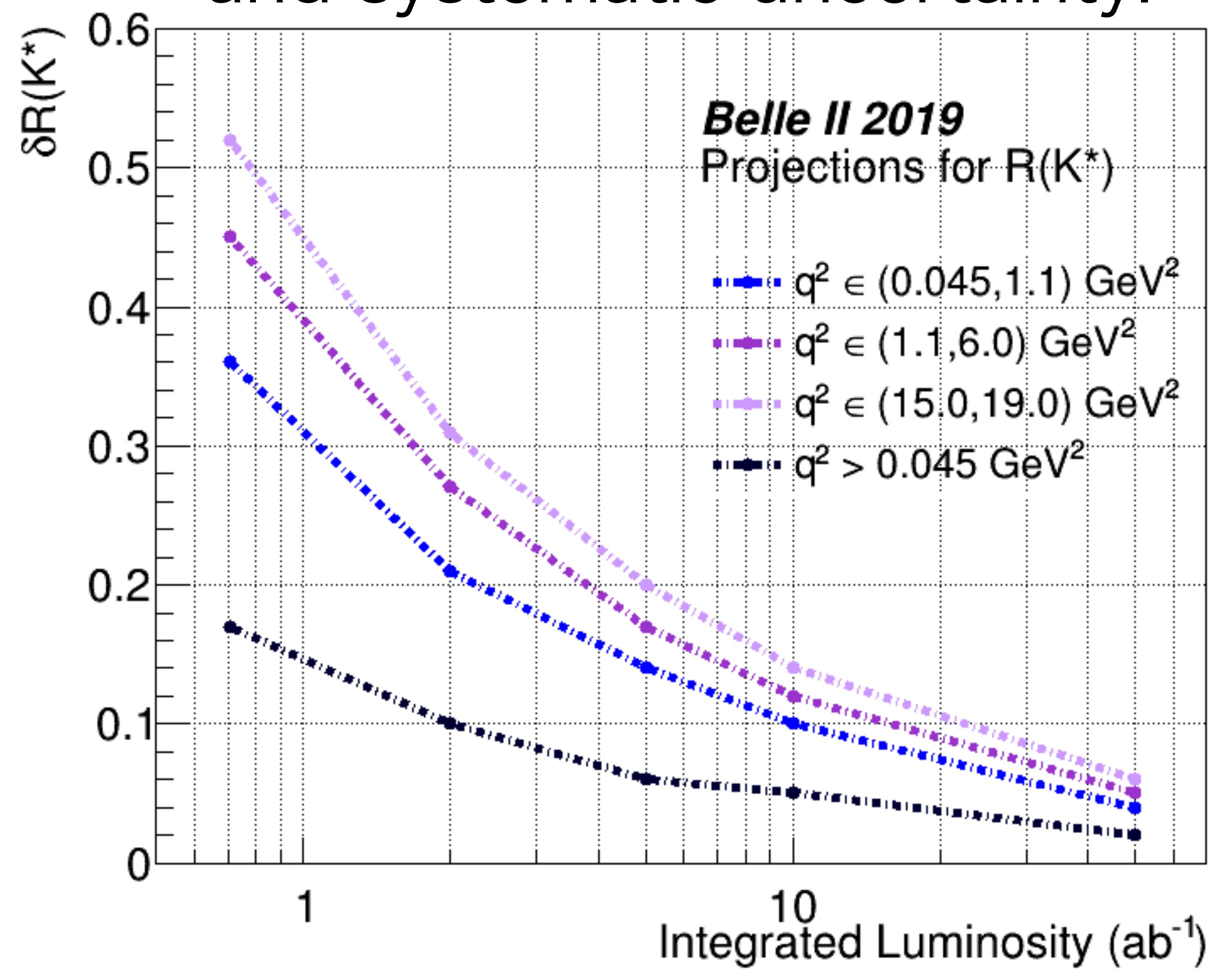
arXiv:1904.02440v2 [hep-ex]

- $b \to sll$ process
  - loop or box diagram
- Anomaly of lepton universality : 2.4-2.5σ from SM
  - Latest Belle result is compatible with previous measurement.

$$R(K^*) = \frac{\mathcal{B}(B \to K^* \mu^+\mu^-)}{\mathcal{B}(B \to K^* e^+e^-)}$$



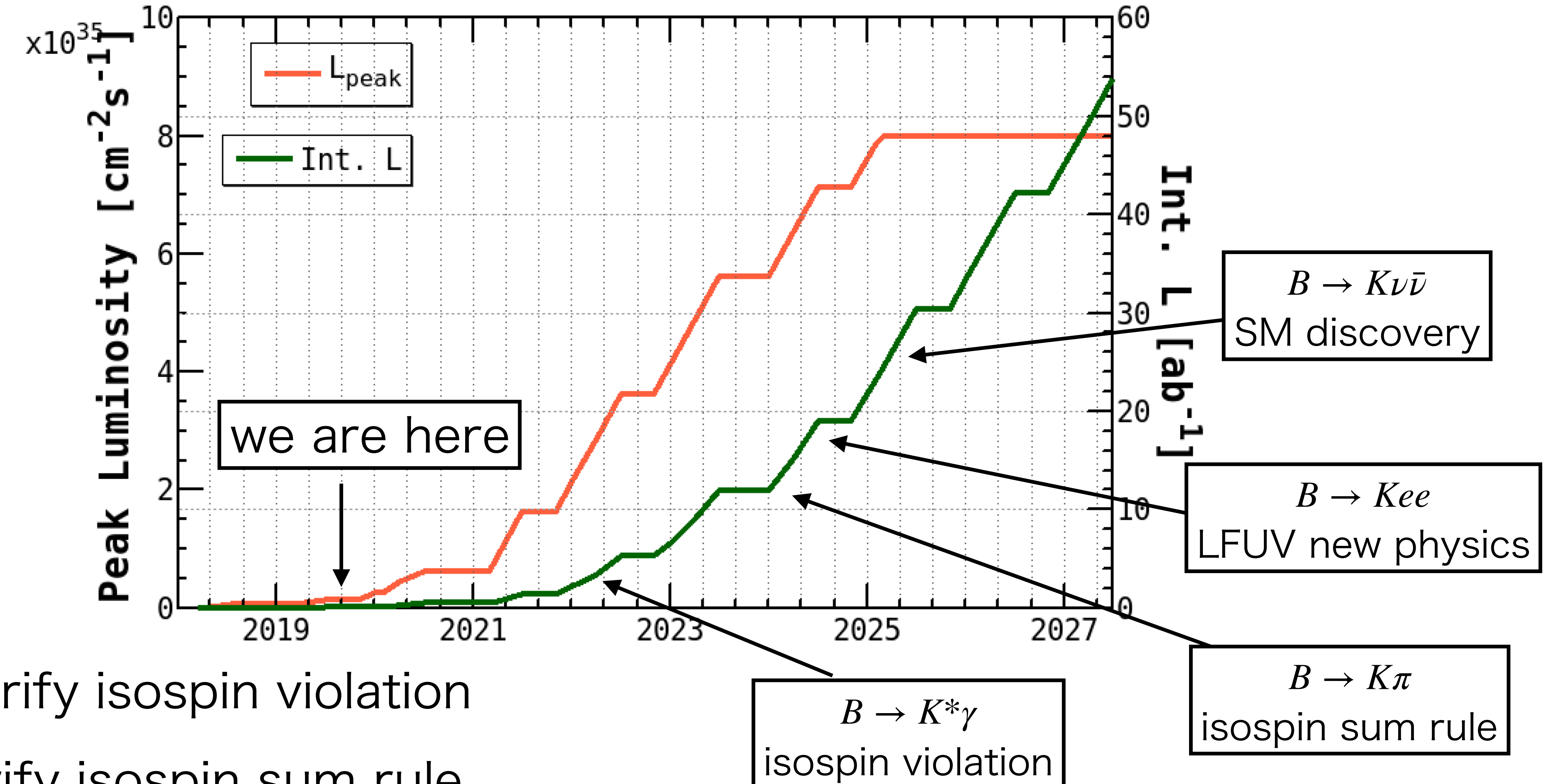
$\delta R(K^*)$ includes both statistics and systematic uncertainty.



Expect to verify the lepton universality violation.

Prospects

- Primary goal : collect $L_{int} = 50\,\mathrm{ab}^{-1}$
- Current status : very early stage with $L_{int} = 6.5\,\mathrm{fb}^{-1}$



$B \to K^*\gamma$: verify isospin violation

$B \to K\pi$: verify isospin sum rule

$B \to K^*ll$: verify lepton universality violation

$B \to h\nu\bar{\nu}$: can be observed etc.

We will provide many results.

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Summary

- Belle II have started collecting beam collision data.
  - Collected 6.5 fb^{-1} integrated luminosity.
- Rare decays are important to search new physics.
- Studies of various processes have been started.
  - Rediscovered $B \to K^{*}\gamma$ decay.
  - Signal for first charmless hadronic B decay.
- We are searching new physics with rare decays.
  - We will show many results.

stay tuned!

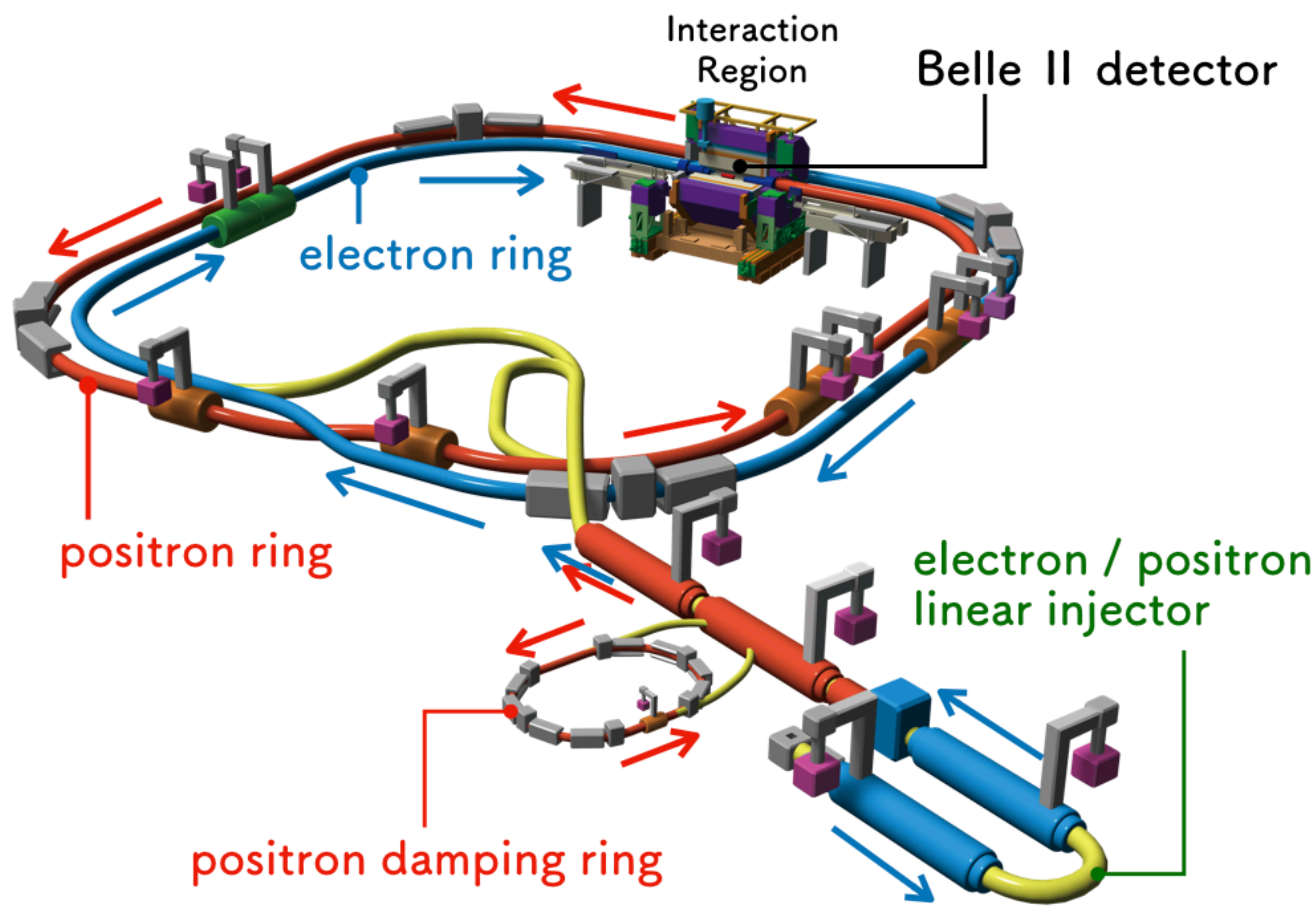
Thank you for your attention!

Back up

SuperKEKB

KEKB→SuperKEKB

- LER (3.5 GeV → 4.0 GeV)
  - longer Touschek lifetime
- HER (8.0 GeV → 7.0 GeV)
  - Lower emittance beam
  - Lower Synchrotron radiation loss
- Luminosity ×40
  - smaller beams ×20
  - large currents ×2



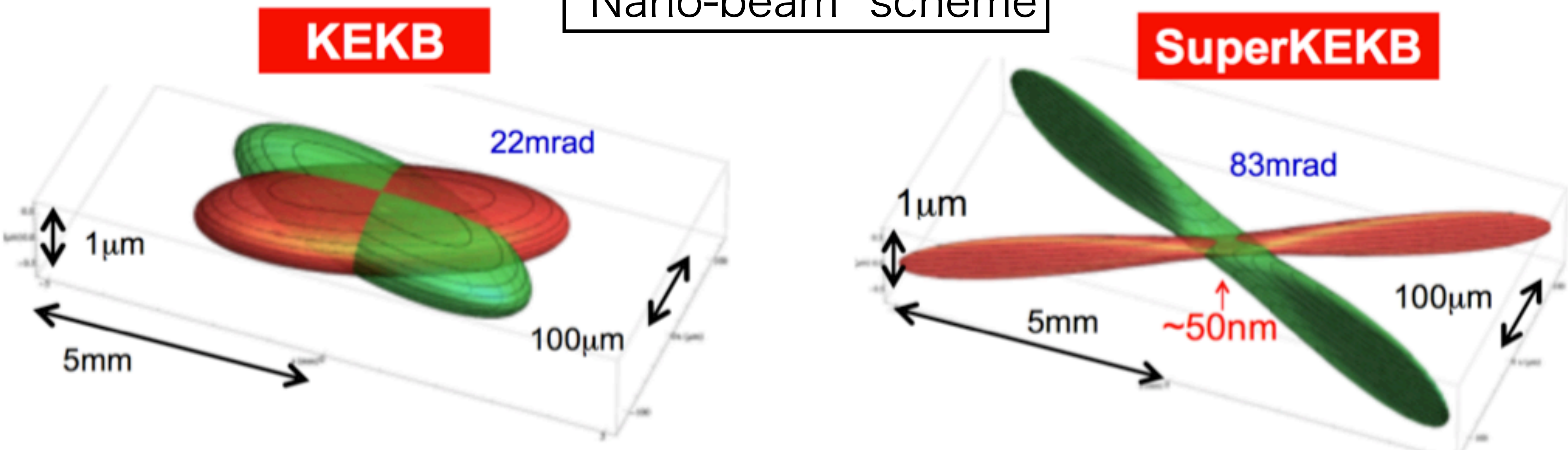
	KEKB LER/HER	SuperKEKB LER/HER	
E [GeV]	3.5/8.0	4.0/7.0	
β_y at IP [mm]	5.9/5.9	0.27/0.30	×20
I [A]	1.6/1.2	3.6/2.6	×2
Lifetime [min]	130/200	~10	
crossing angle [mrad]	22	83	
L [$cm^{-2}s^{-1}$]	2.1×10^{34}	80×10^{34}	×40

Major upgrades

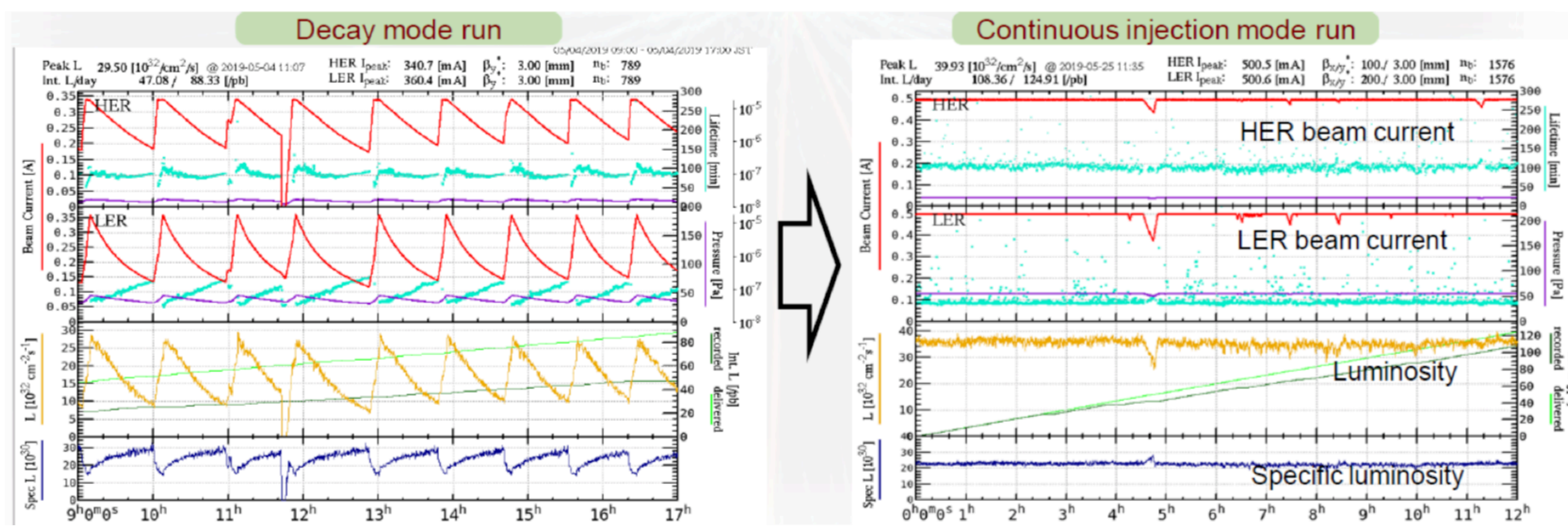
- beam pipe
- e^+ source
- positron damping ring
- QCS for nano-beam scheme
- IR design etc.

SuperKEKB

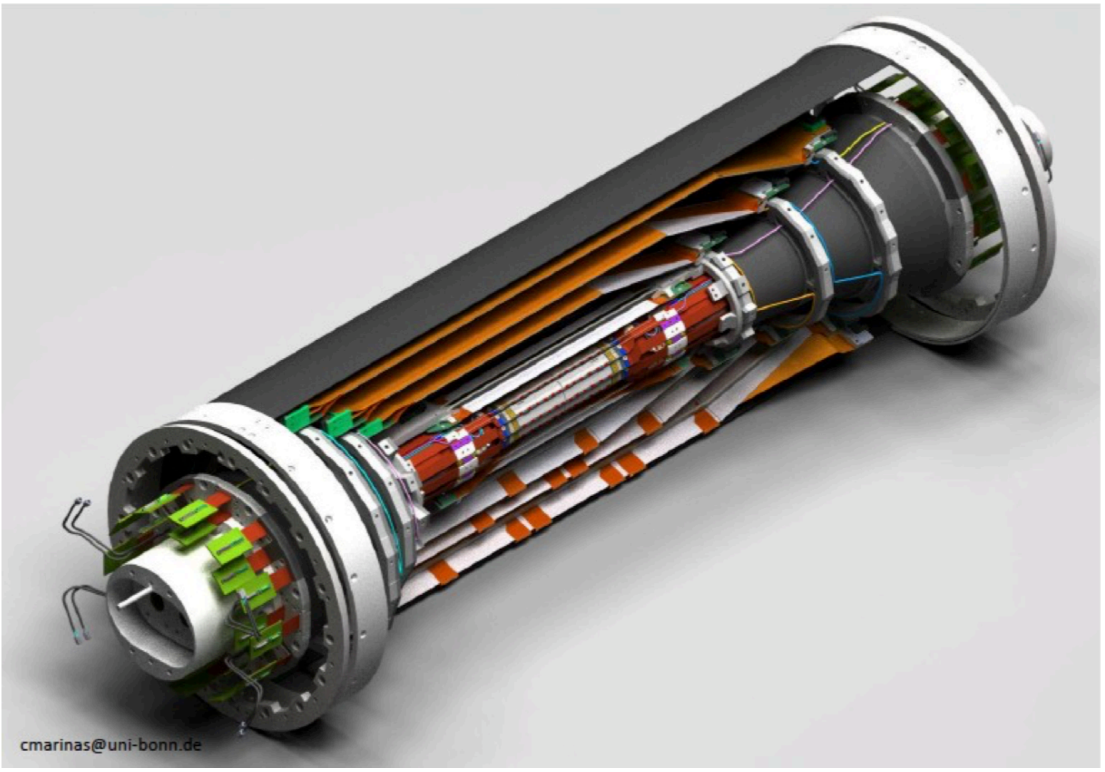
“Nano-beam" scheme



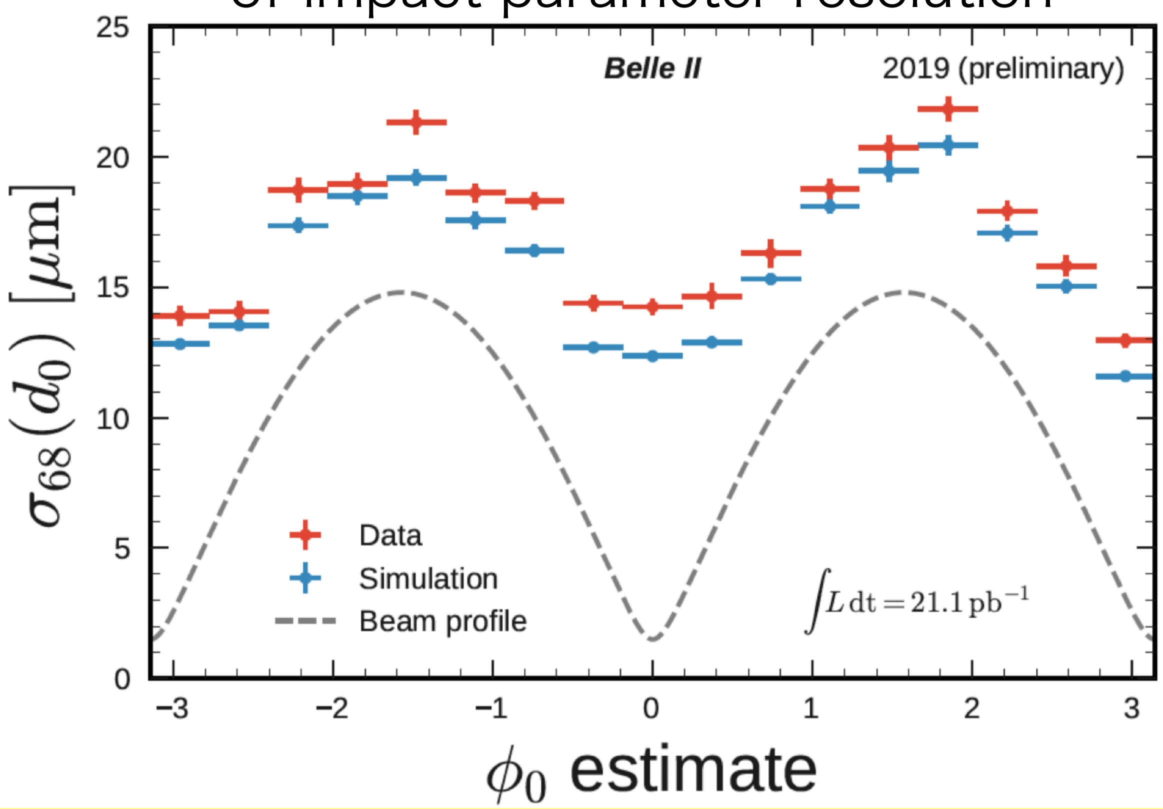
Continuous beam injection (started from 14th, May)



Vertexing



Distribution of width
of impact parameter resolution



Beampipe : r = 10 mm

DEPFET pixels

- Layer 1 : r = 14 mm
- Layer 2 : r = 22 mm

Double sided silicon detectors

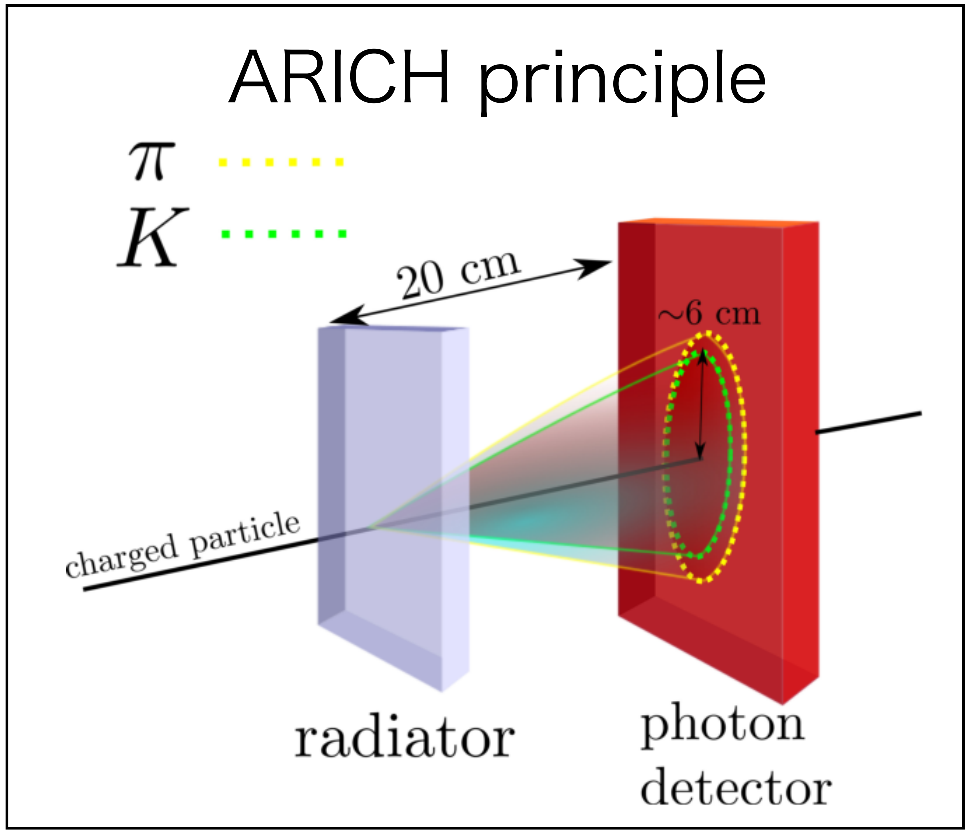
- Layer 3 : r = 38 mm
- Layer 4 : r = 80 mm
- Layer 5 : r = 115 mm
- Layer 6 : r = 140 mm

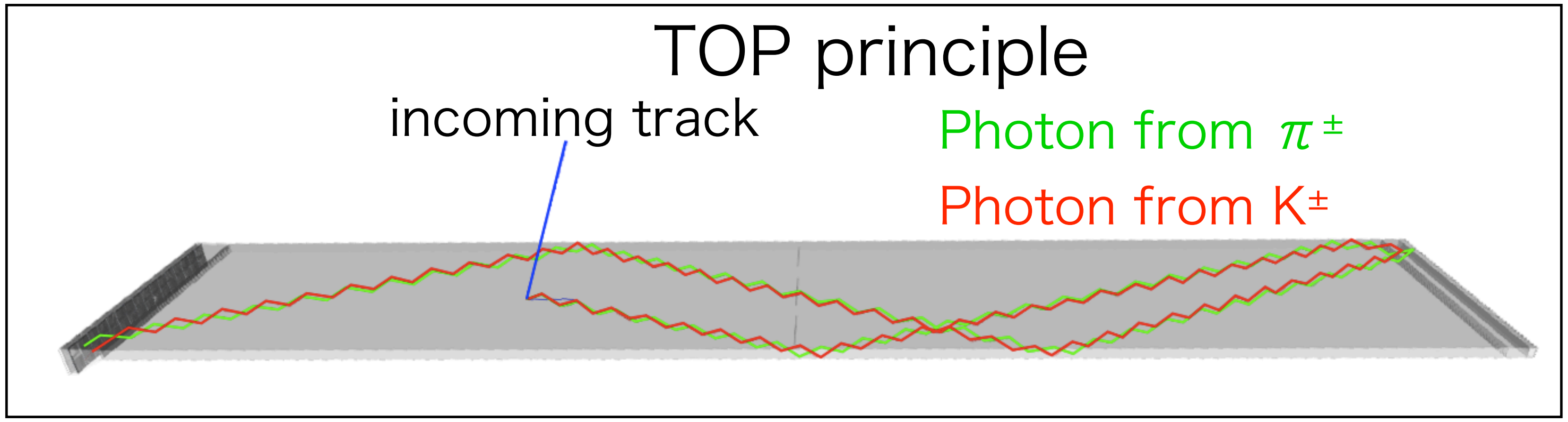
VXD resolution in
impact parameter ~ 14 μm.

Particle identification

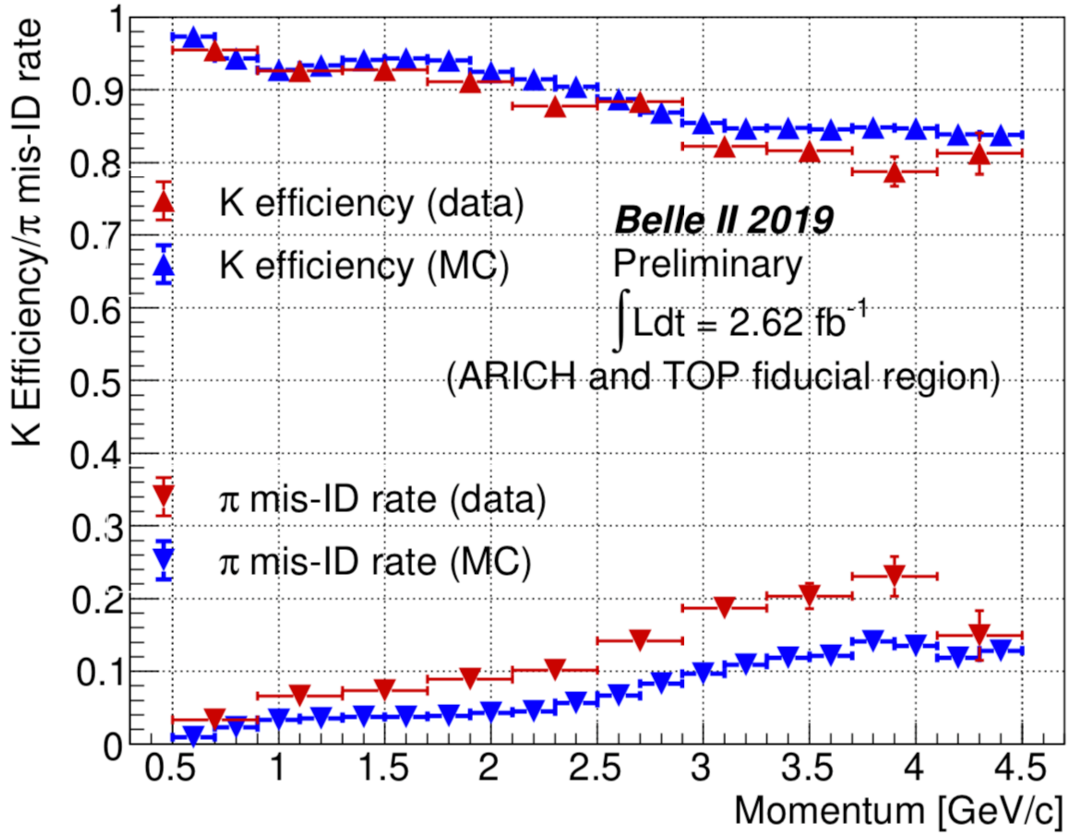
Barrel : Time of Propagation (TOP)

forward endcap : Aerogel RICH (ARICH)





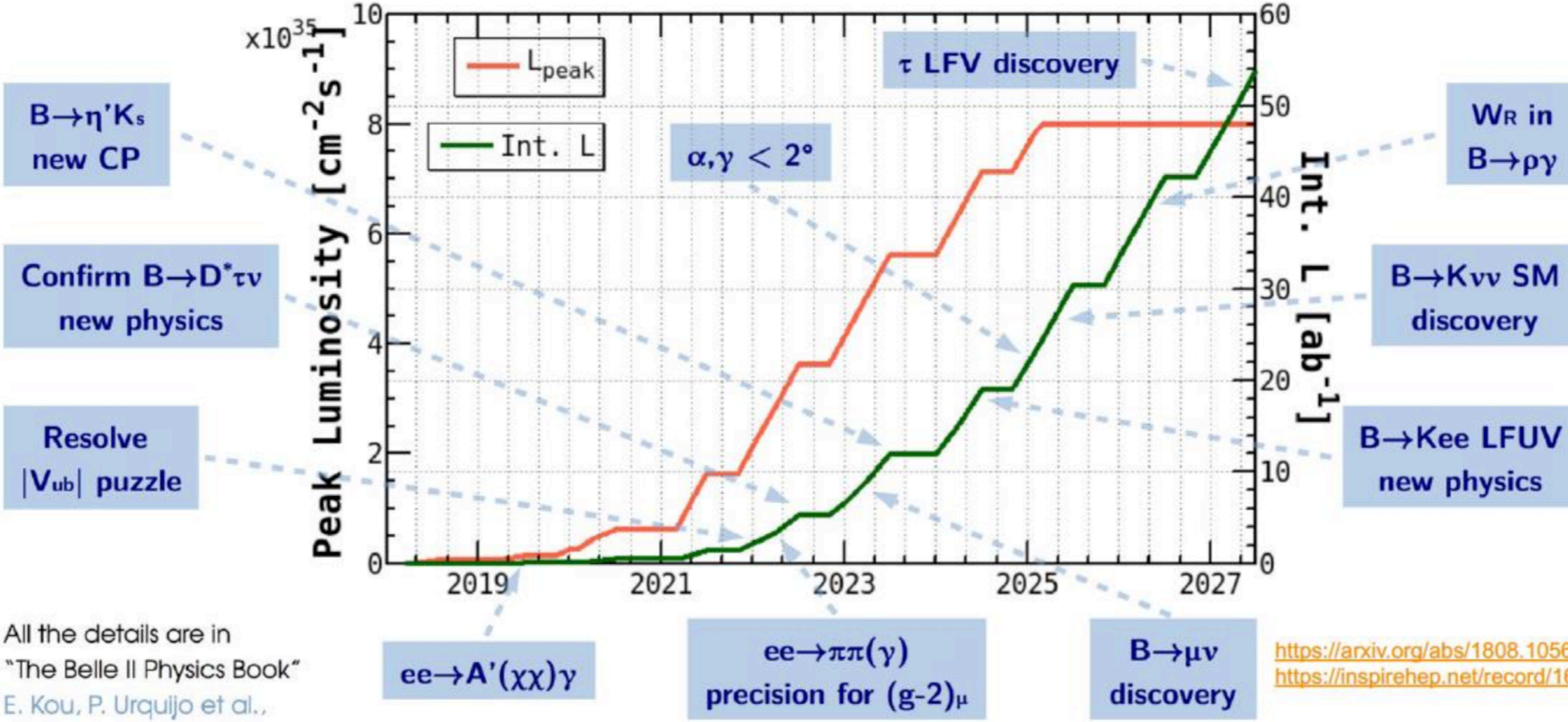
K ID and π mis-ID from CDC, TOP, ARICH



K efficiency and π mis-ID by combining CDC dE/dx, TOP and ARICH.

$D^{*+} \to D^0\pi^+; D^0 \to K^-\pi^+$

Long term prospects



All the details are in
"The Belle II Physics Book"
E. Kou, P. Urquijo et al.,

https://arxiv.org/abs/1808.10567
https://inspirehep.net/record/1692393/

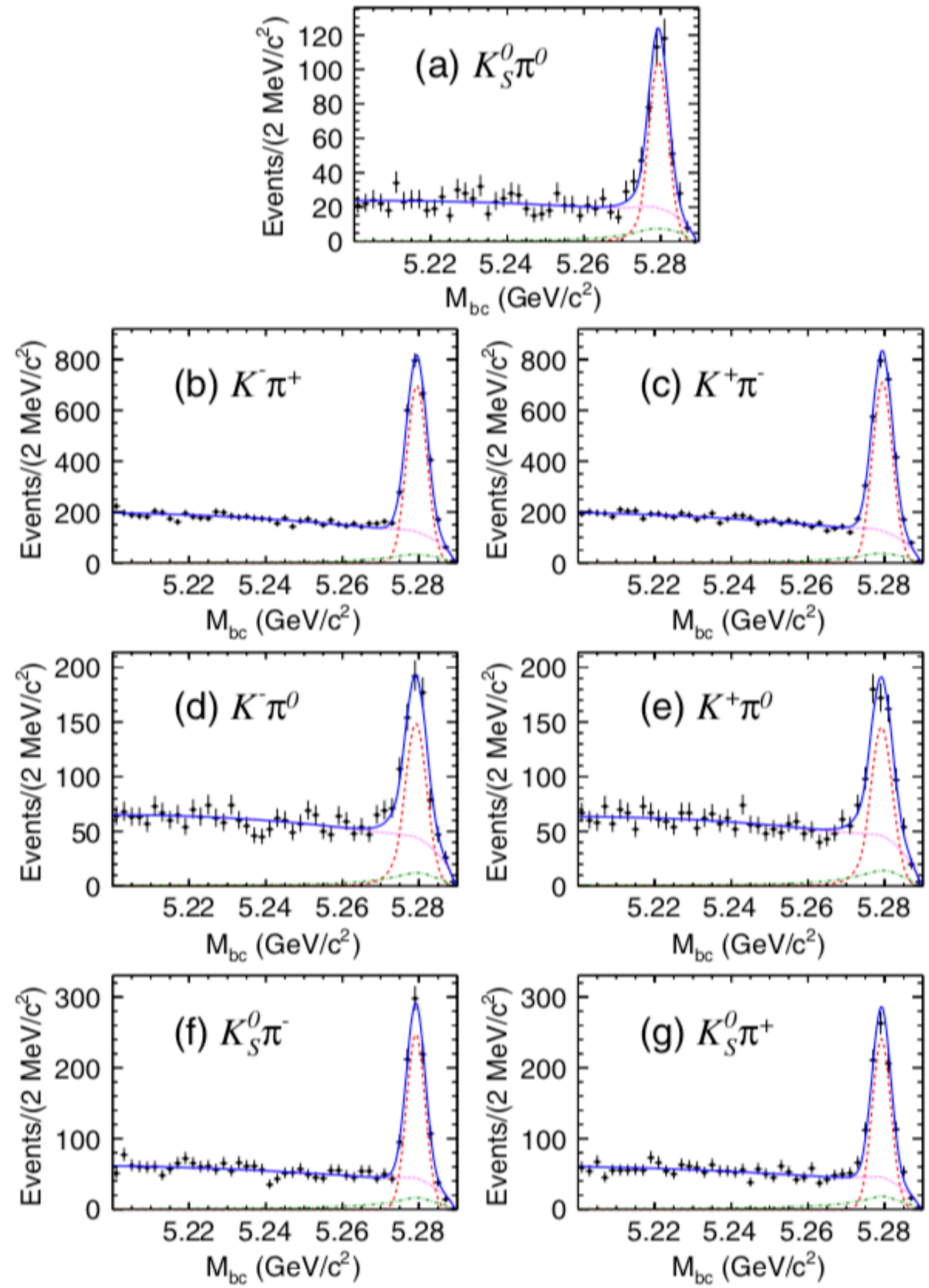
$B \to K^*\gamma$ measurement at Belle

Phys. Rev. Lett. 119 (2017), 191802

Simultaneous fit to m_{bc} distribution in 7 categories to extract branching fraction and asymmetries

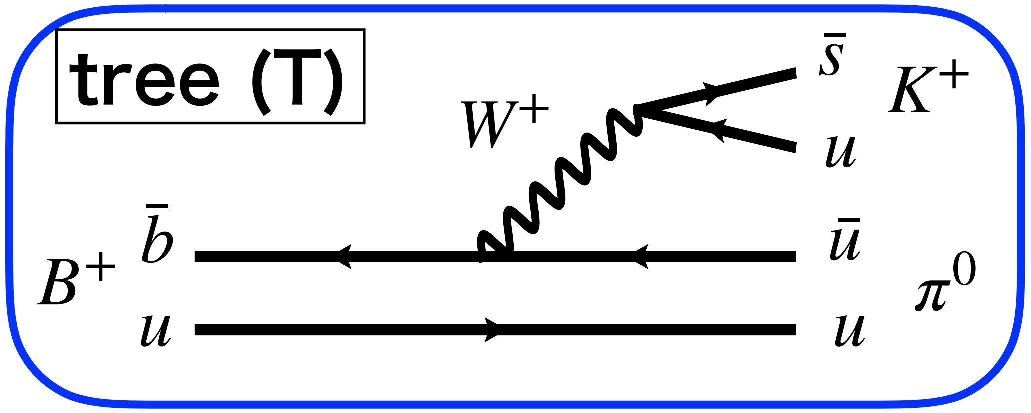
Fit results

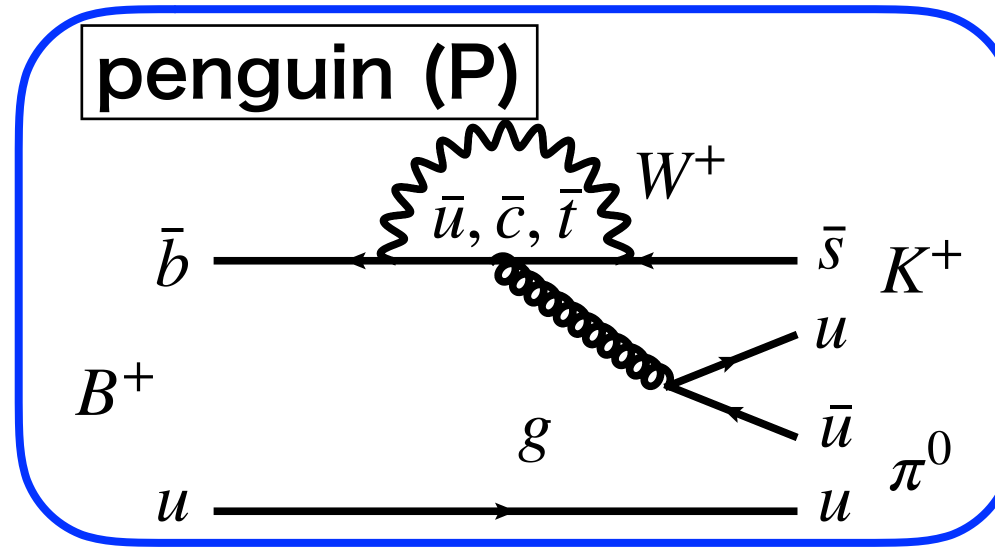
$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (3.96 \pm 0.07 \pm 0.14) \times 10^{-5}$$
$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (3.76 \pm 0.10 \pm 0.12) \times 10^{-5}$$
$$A_{CP}(B^0 \to K^{*0}\gamma) = (-1.3 \pm 1.7 \pm 0.4)\,\%$$
$$A_{CP}(B^+ \to K^{*+}\gamma) = (+1.1 \pm 2.3 \pm 0.3)\,\%$$
$$\Delta_{0+} = (+6.2 \pm 1.5 \pm 0.6 \pm 1.2)\,\%$$
$$\Delta A_{CP} = (+2.4 \pm 2.8 \pm 0.5)\,\%$$
$$\bar{A}_{CP} = (-0.1 \pm 1.4 \pm 0.3)\,\%$$

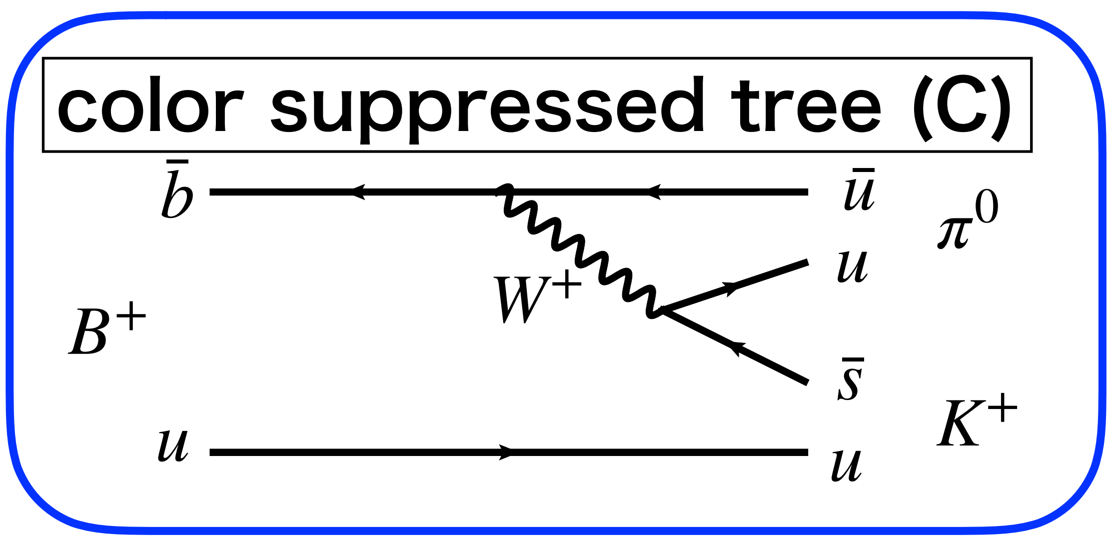


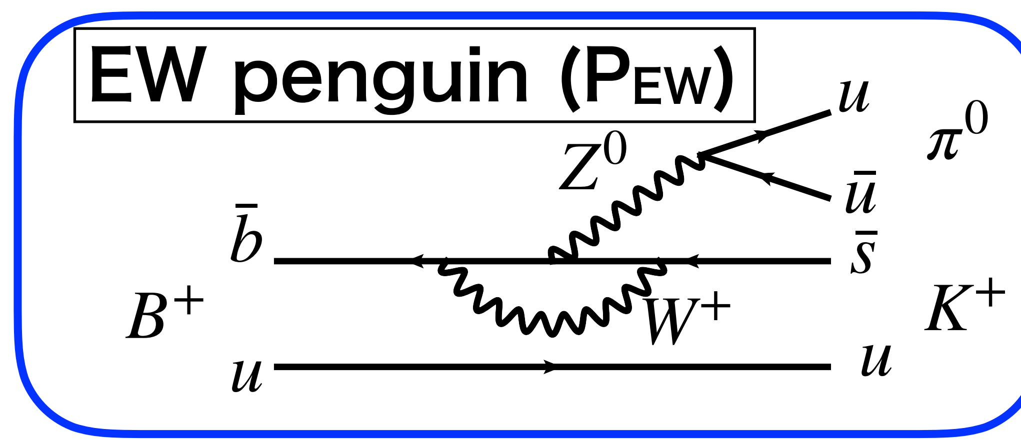
$B \to K\pi$

diagrams for $B^+ \to K^+\pi^0$ decay









- C and PEW are expected to be negligible in SM.
  - Enhancement of C? → breakdown of theoretical understanding
  - Enhancement of PEW? → would include new physics

$B \to h\nu\bar{\nu}$

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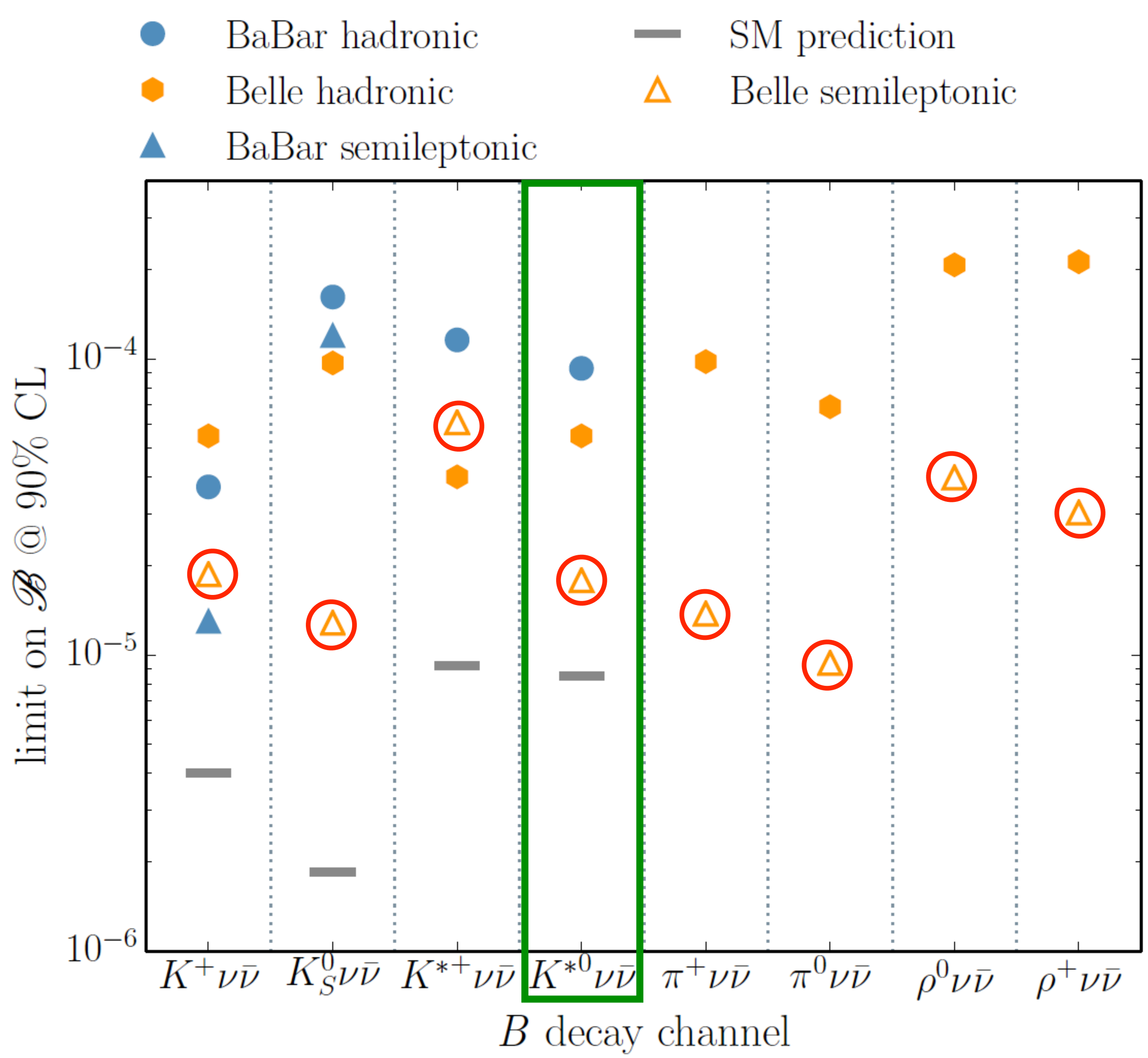

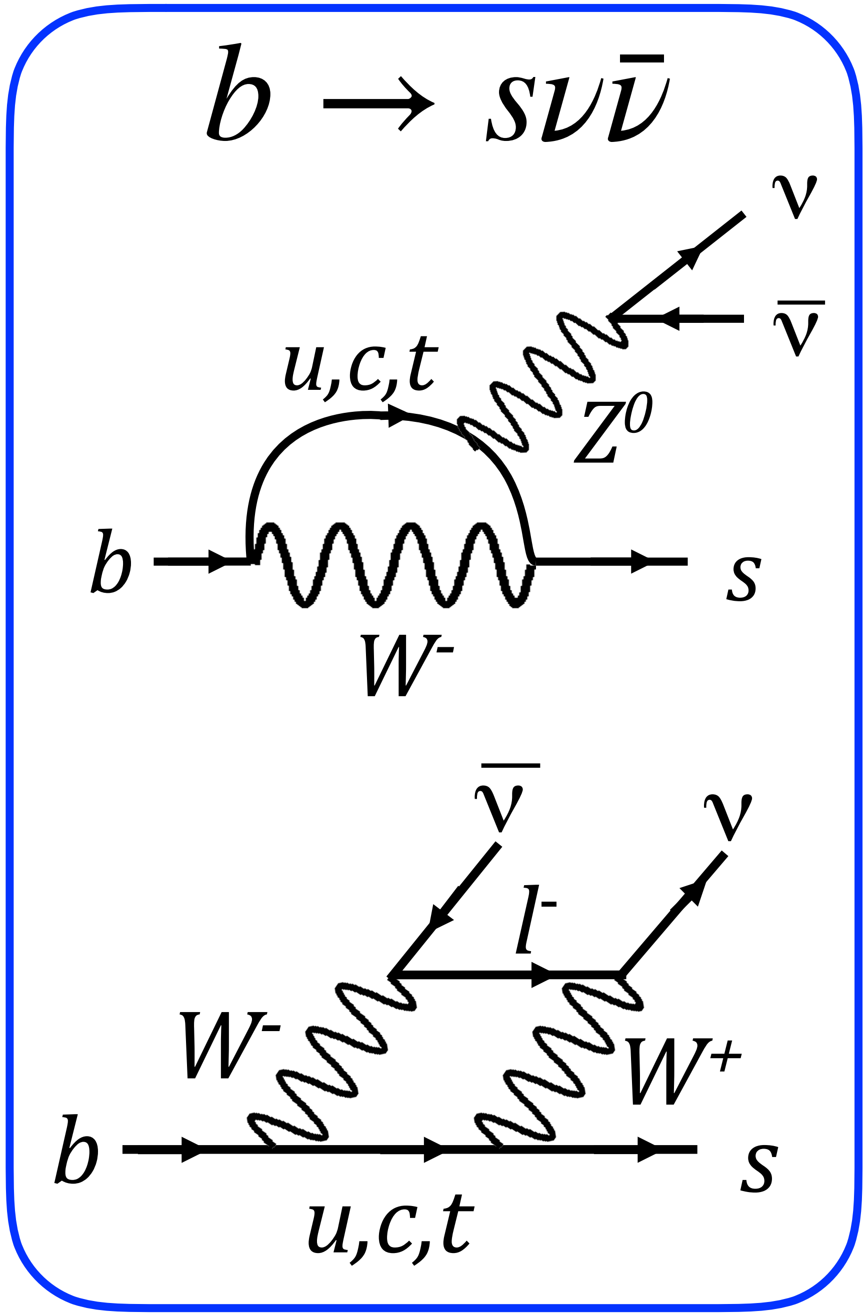

Not observed yet : factor 2 above SM expectation

→ can be observed at Belle II