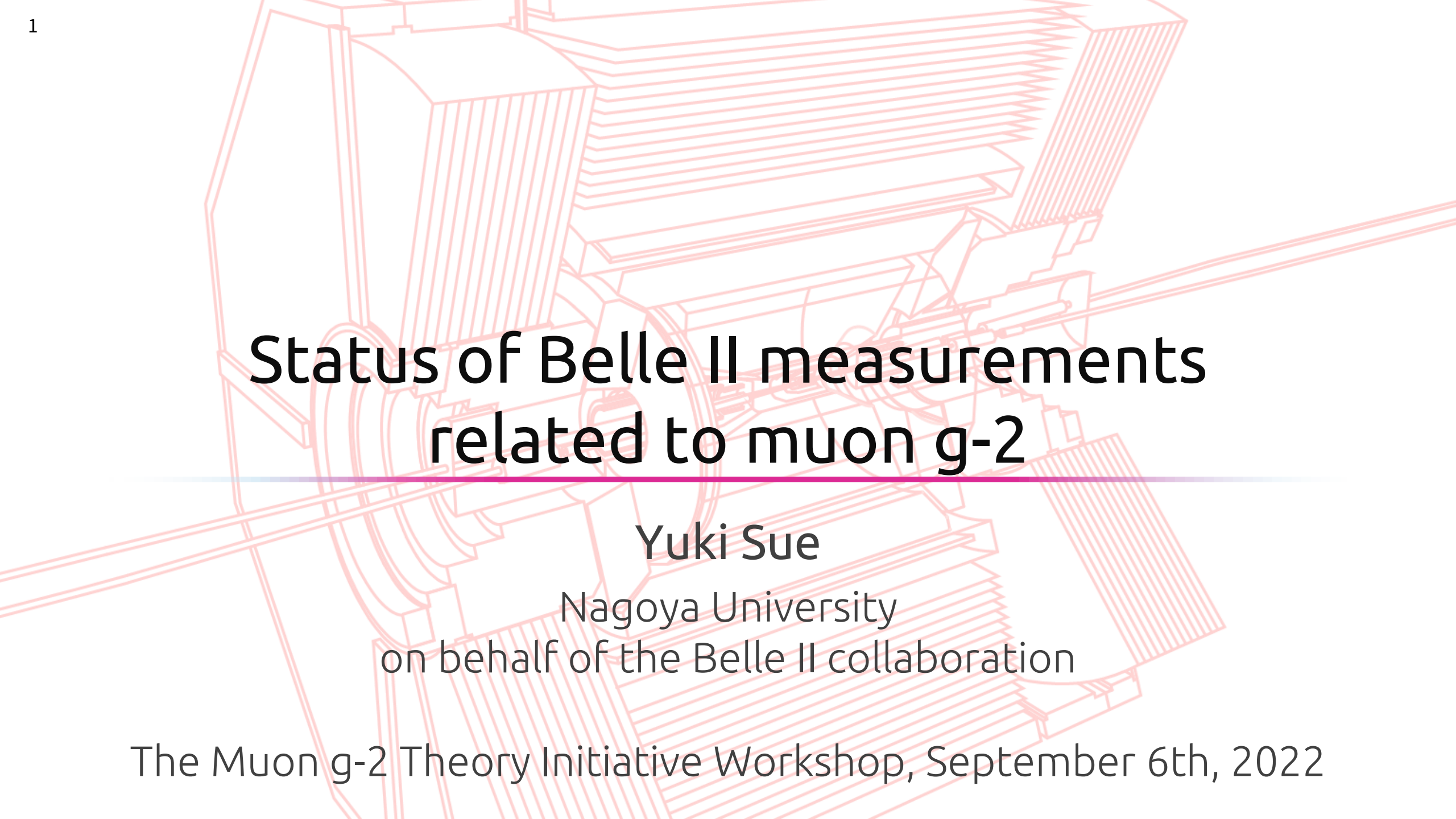


Status of Belle II measurements related to muon g-2

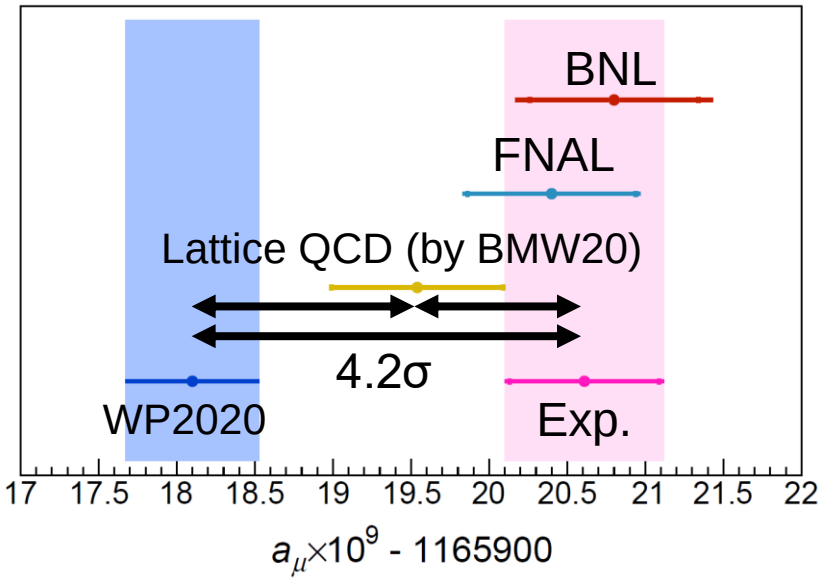
Yuki Sue

Nagoya University
on behalf of the Belle II collaboration

The Muon g-2 Theory Initiative Workshop, September 6th, 2022

Muon g-2

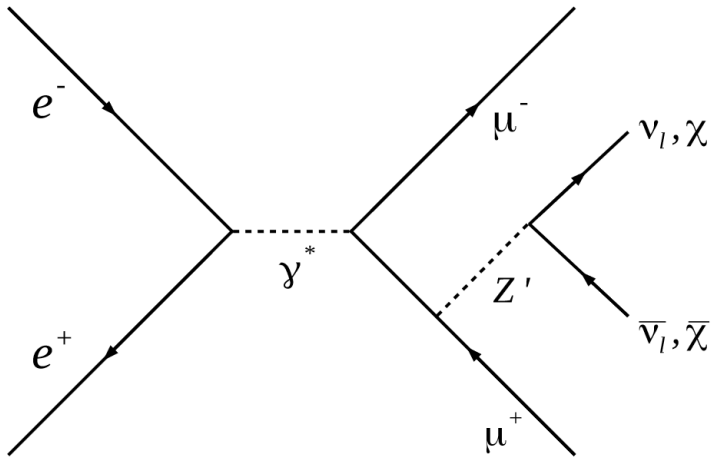
- Two approaches for HVP contribution of SM predictions
  - Dispersion relations (w/ inputs from ee -> hadrons data)
  - Lattice QCD
- >4σ discrepancy btw experimental results and SM prediction based on dispersion relations.
- The disagreement can be due to
  i. An issue with the measurements
  ii. An issue with predictions
  iii. Non-SM dynamics
- Belle II contributes to
  ii) with a program of updated measurements of hadronic cross sections
  iii) by probing with independent measurements some of the most favored models to generate non-SM dynamics that would explain muon g-2.

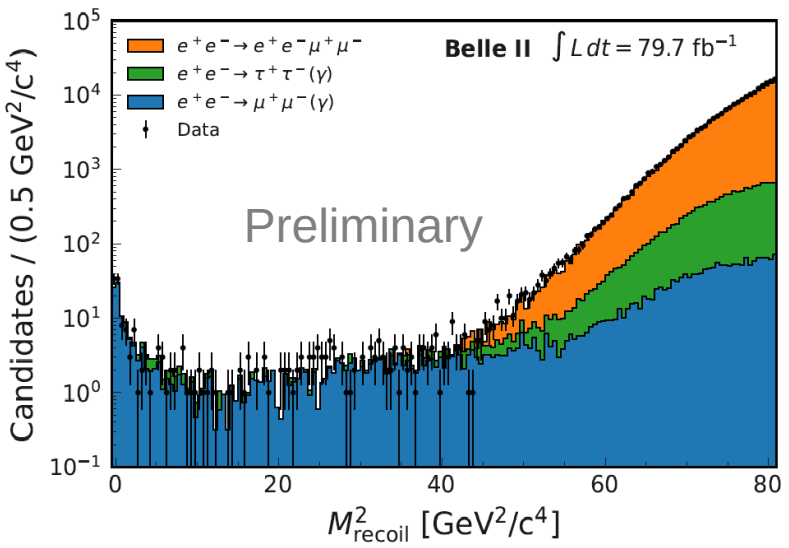


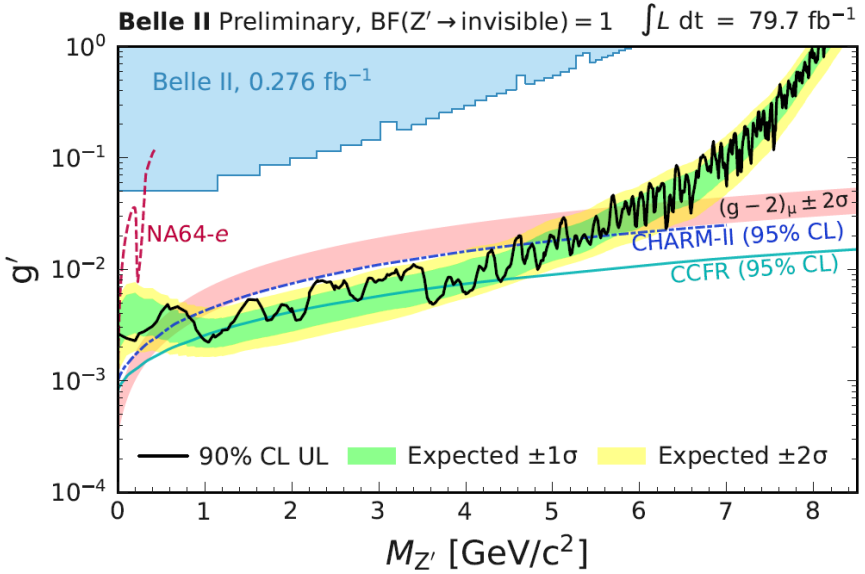
Nature 593 (2021) 7857, 51-55
Phys.Rev.Lett. 126 (2021) 141801
Phys.Rept. 887 (2020), 1-166

Search for Z’ to invisible at Belle II

- $L_\mu - L_\tau$ model : Z’ couples only to μ and τ
- Could provide solution for R(K(*)) and g-2
- Analyze using 79.7 fb^{-1} of data (2019+2020)
- Signature : μμ/ττ final state with missing energy (Z’ => invisible)]
- No excess found : Excluded invisible Z’ as explanation for g-2 in range $0.8 < M_{Z'} < 5.0$ GeV/c^2



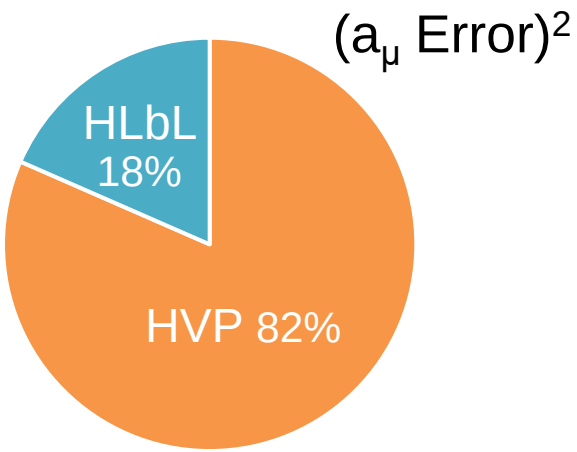


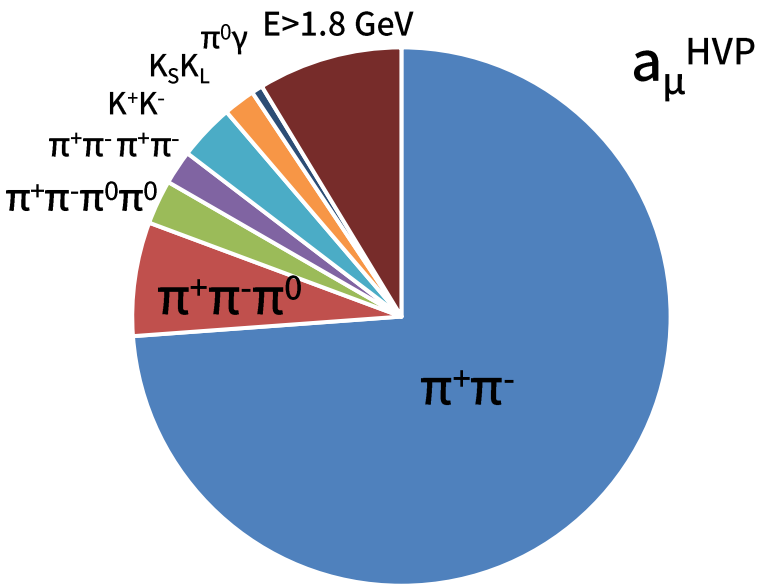


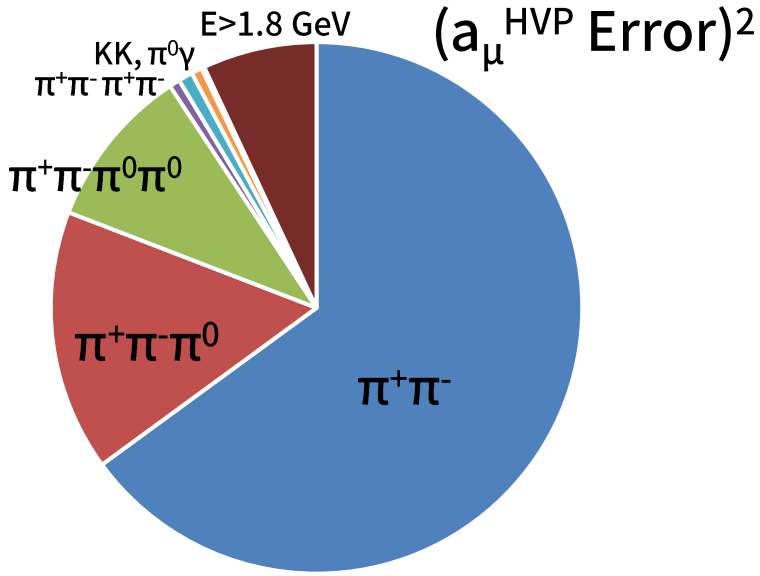
R-ratio measurements

- For dispersion relation, HVP has the largest uncertainty to the prediction.
- Belle II can provide the theoretical inputs by cross section measurements for exclusive hadron production.

$$a_\mu^{\text{HVP, LO}} = \frac{\alpha^2}{3\pi^2}\int_{M_\pi^2}^{\infty}\frac{K(s)}{s}R(s)\,ds$$



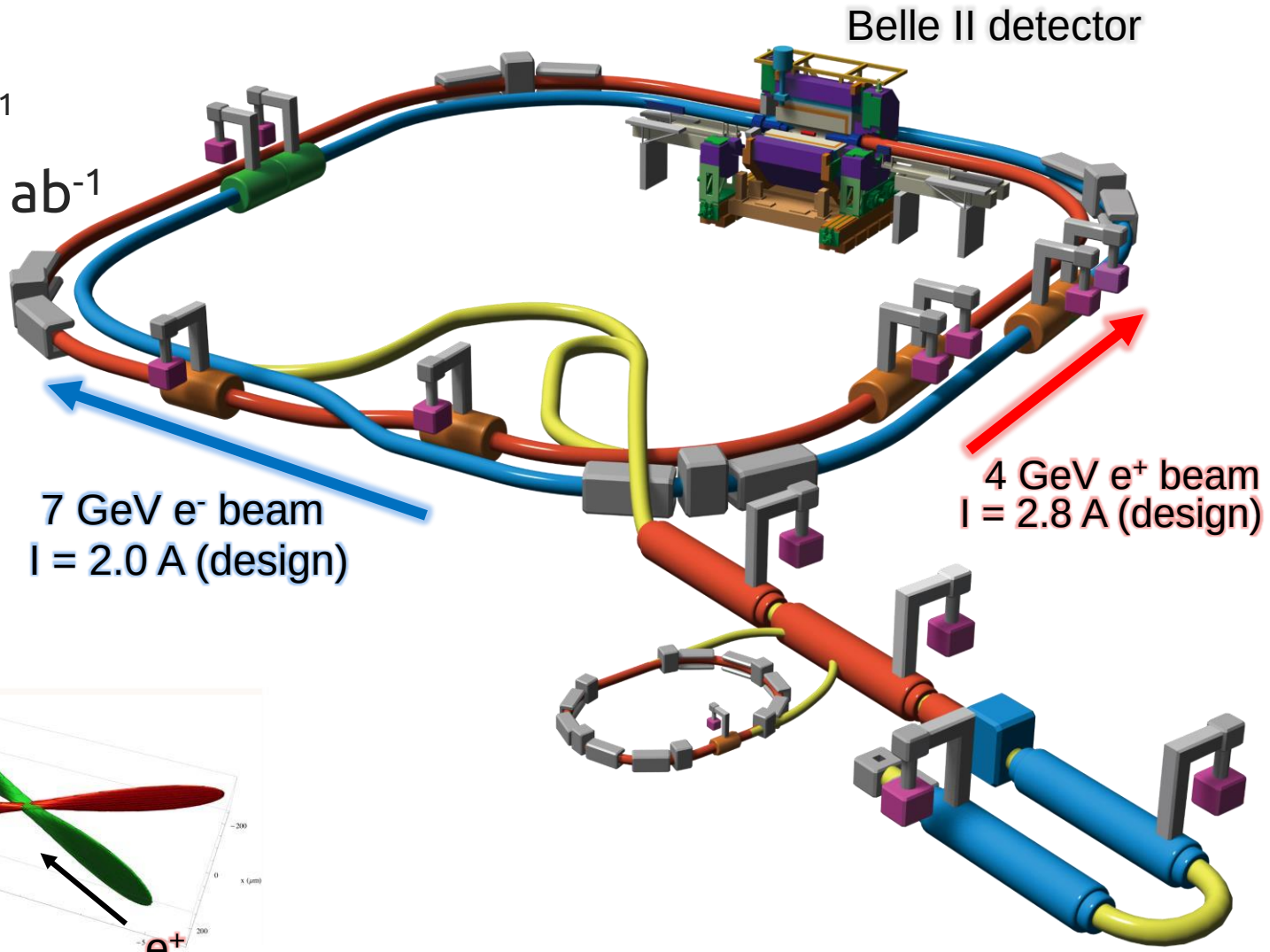




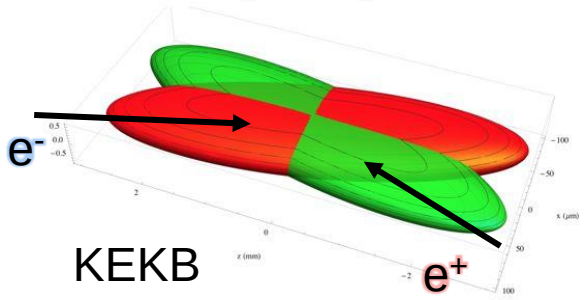

Mt. Tsukuba
KEK

SuperKEKB Collider

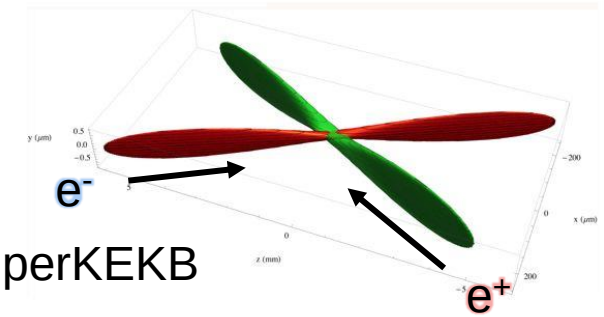
- Asymmetric e^+e^- collider
  - $\sqrt{s}$ = M(Y(4S)) = 10.58 GeV
  - Design luminosity : 6×10^{35} $cm^{-2}s^{-1}$
- Integrated luminosity goal : 50 ab^{-1}
- Improvements
  - Nano beam scheme
  - Higher beam currents



Nano-beam collision



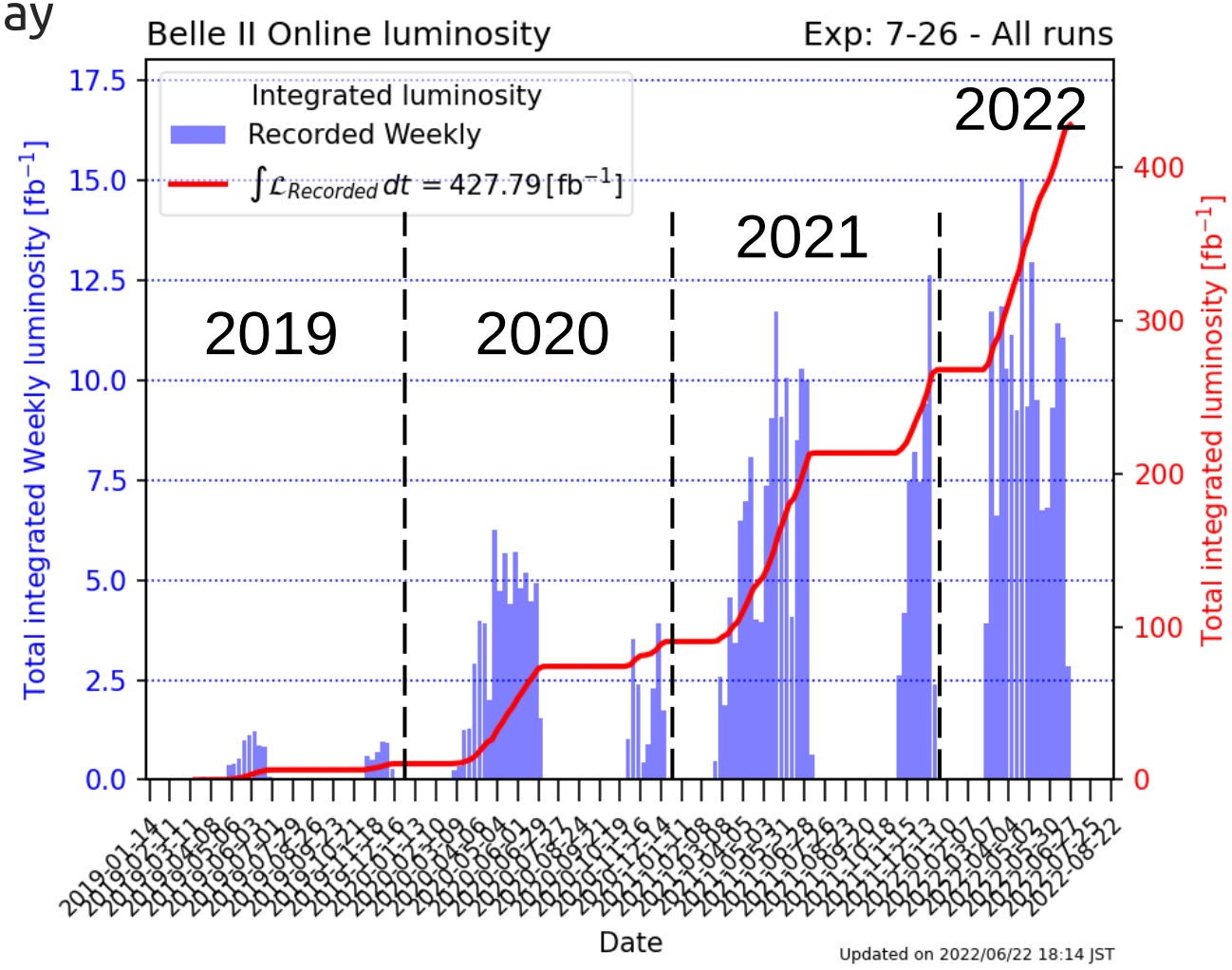
KEKB



SuperKEKB

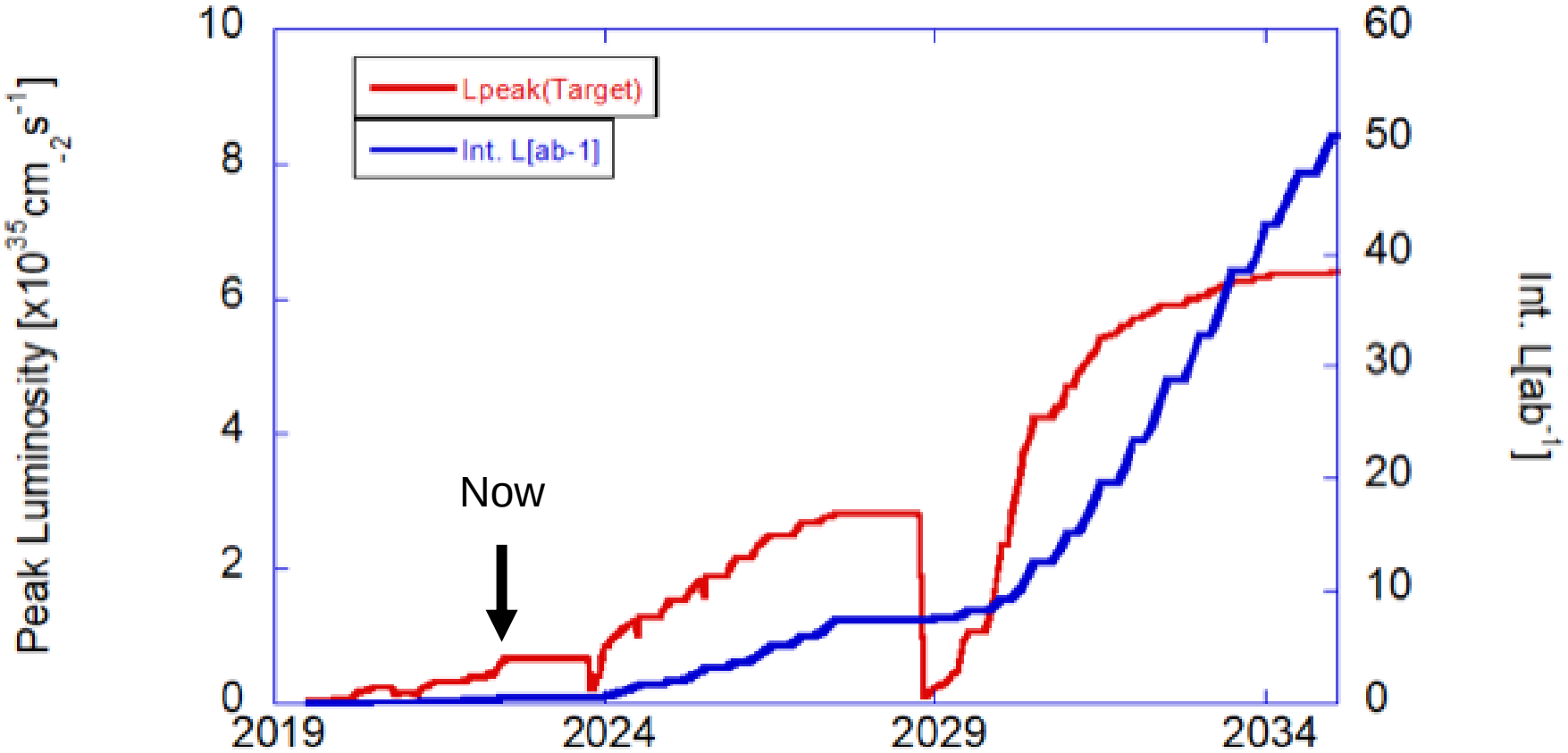
Operation Status

- Keep operation under COVID-19
- Record instantaneous luminosity : 4.7×10^{34} /cm^2/s
  - ~90% data taking efficiency : 1-2/fb/day
- Recorded data : 424 /fb
  - 363 fb^{-1} at √s = 10.58 GeV
  - 42 fb^{-1} at 60 MeV below 10.58 GeV
  - 19 fb^{-1} at 10.75 GeV



Operation Plans

- Long Shutdown 1 started last June.
  - 2022 summer – 2023 autumn
  - Completion of vertex detector
- Another long shutdown may happen around 2027 for upgrades.

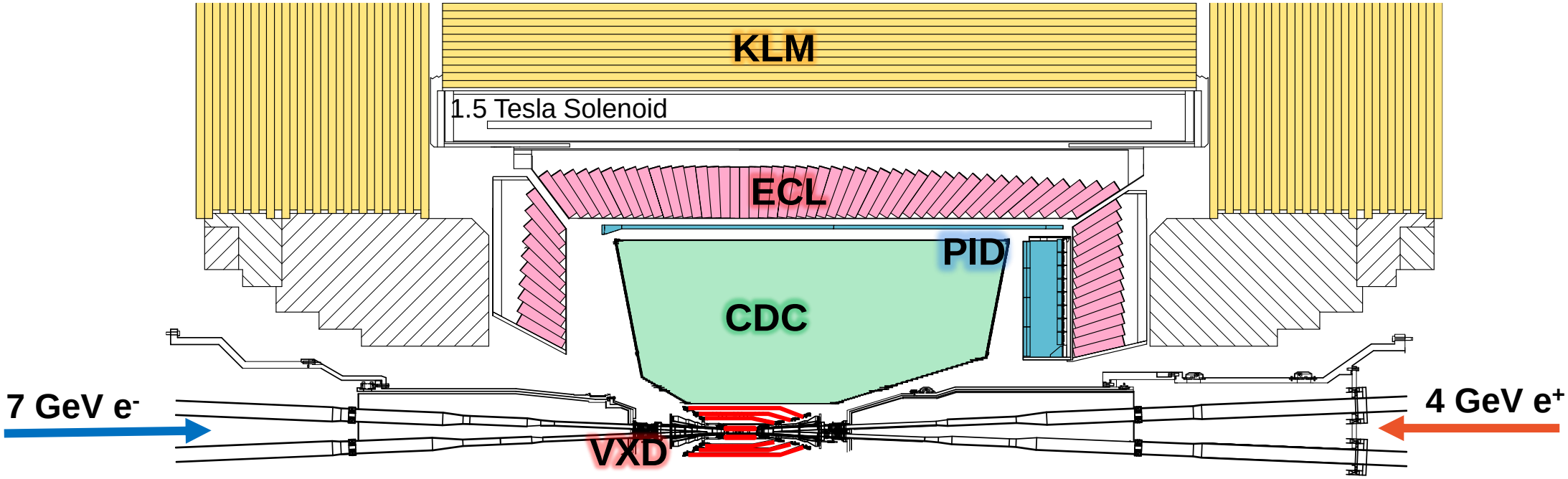


Belle II Detector

Particle Identification
- Aerogel RICH in the forward endcap
- Time-of-Propagation counter in the barrel
- **K/π ID : K efficiency 90% at 1.8% π fake**

Electromagnetic Calorimeter (ECL)
- CsI(Tl) crystals + Waveform sampling
- **Electron ID eff. 90% at <0.1% fake**
- **Energy resolution 1.6-4%**
- **94% of solid angle coverage**

K-long and Muon Detector (KLM)
- Alternating iron and detector plates
- Scintillator / Resistive Plate Chamber
- **Muon ID efficiency 90% at 2% fake**



Vertex Detector (VXD)
- Inner 2 layer : Pixel
- Outer 4 layer : Double side strip
- vertex resolution 20-30 μm

Central Drift Chamber (CDC)
- **91% of solid angle coverage**
- **p_T resolution ~ 0.4%/p_T**
- dE/dx resolution 5% (low-p PID)

Trigger and DAQ
- L1 Trigger rate 30 kHz (design)
- **New trigger line for low-multiplicity events**
- Constant improvements of trigger algorithm

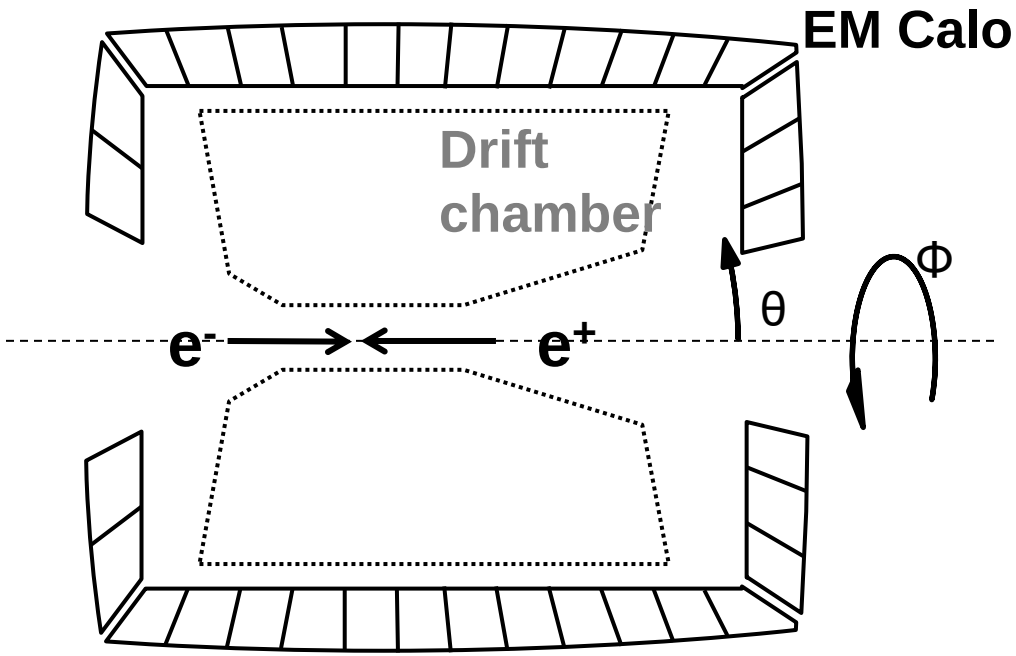
Performance

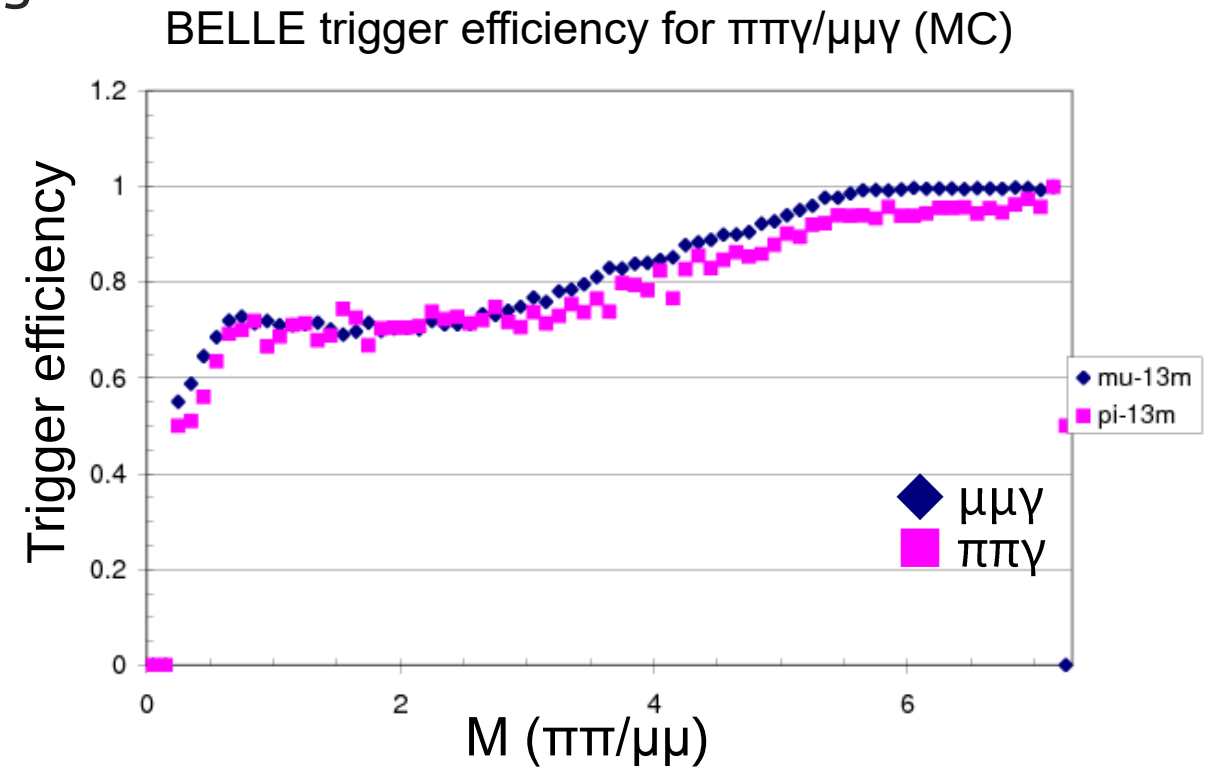
Physics performance for cross section measurements at Belle II

- It is expected that there will be no significant differences from the BABAR measurement, both in analysis methods and in major sources of systematic uncertainty.
- Large statistics of Belle II provides not only signal events but for control samples to estimate systematic uncertainty.
  - 232 fb-1 (BABAR previous result for ππ) → ~450 fb-1 (BABAR full dataset)
  - ~1000 fb-1 (Belle II near future)
- Key performance drives
  - Trigger efficiency
  - Tracking efficiency
  - Photon detection efficiency
  - Luminosity
  - Particle identification (π/μ/K)

Performance : Trigger Efficiency

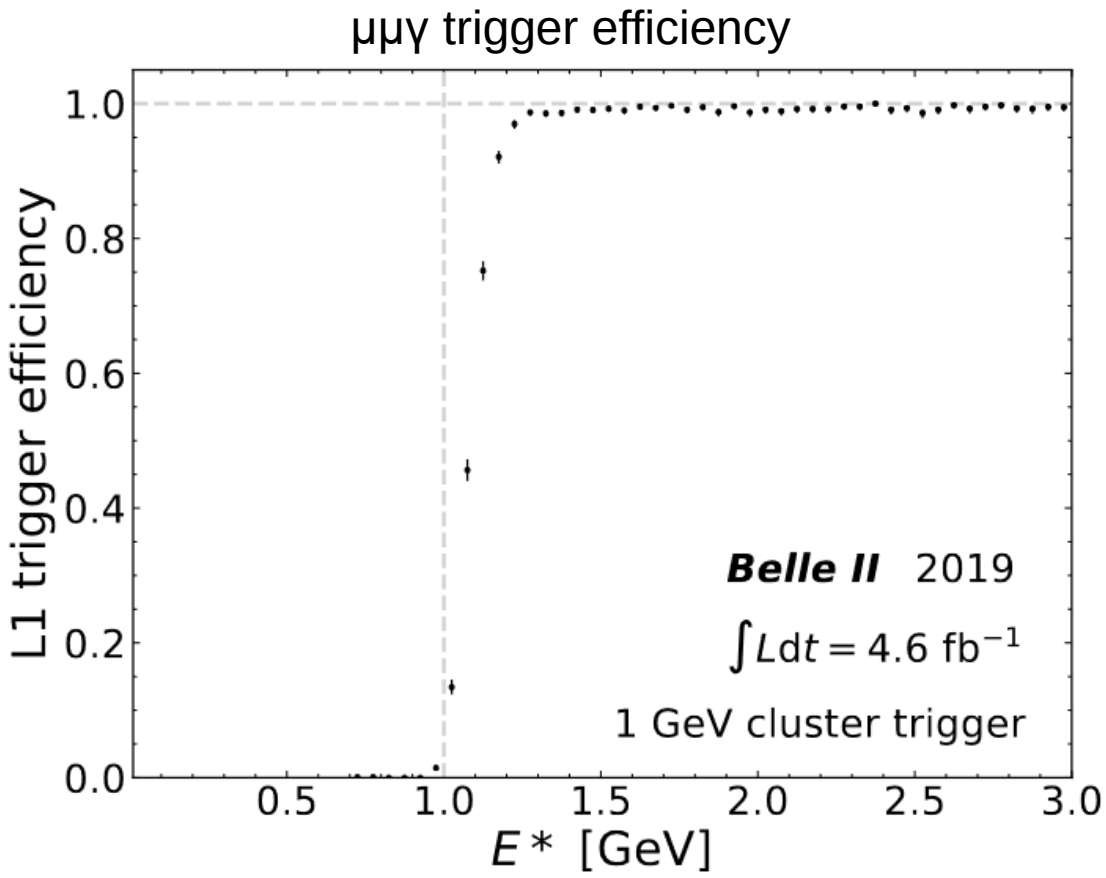
- Most of ee->hadron cross section has not been measured at BELLE.
- Event loss due to bhabha veto was a serious issue.
- Bhabha veto has been upgraded to avoid the inefficiency and uncertainty.
  - BELLE bhabha veto was based on only θ angle.
  - Belle II 3D bhabha veto uses θ and Φ angle.





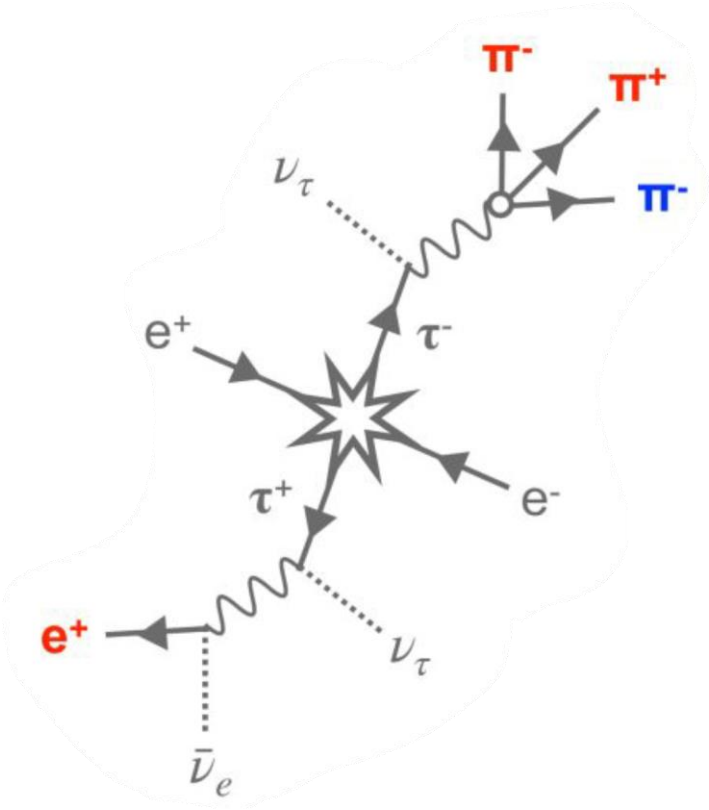
Performance : Trigger Efficiency

- Most of energetic ISR events can be triggered by ECL energy trigger.
  - Total energy deposit on EM calorimeter > 1 GeV
  - ISR photon satisfies this criterion.
  - Efficiency > 99%
  - Event loss due to 3D bhabha veto is suppressed.

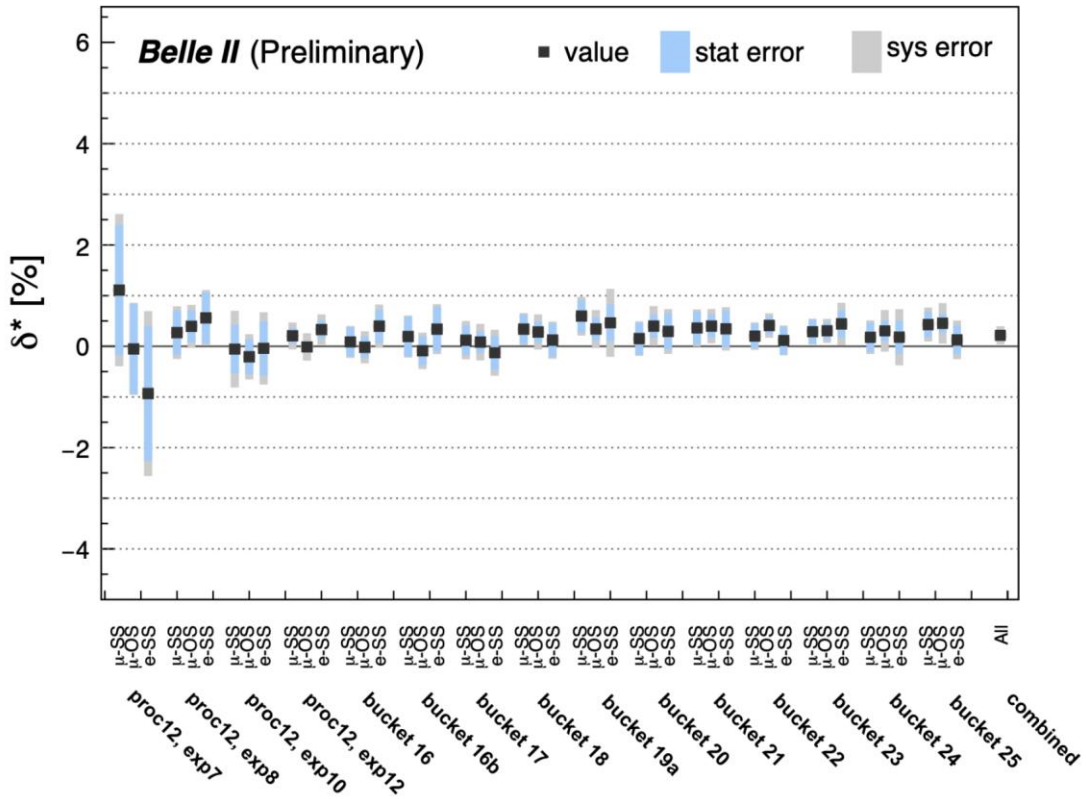


Performance : Tracking Efficiency

- Tracking efficiency is measured by tag-and-probe method on $ee \to \tau\tau \to 1 \times 3$ prong.
  - 3 good quality tracks for tag
  - Look for 4th track for probe
- Uncertainty for tracking efficiency is 0.30% per track.

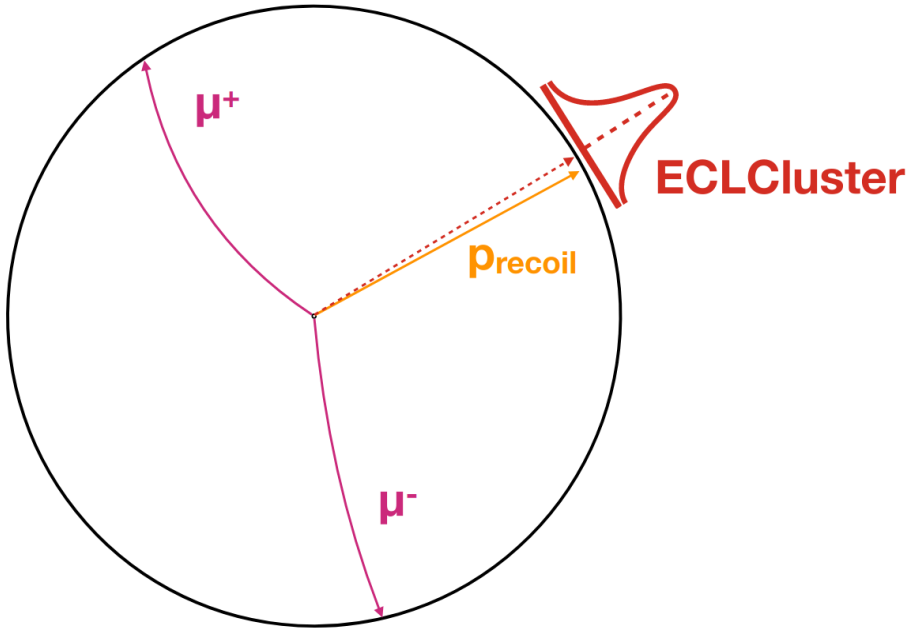


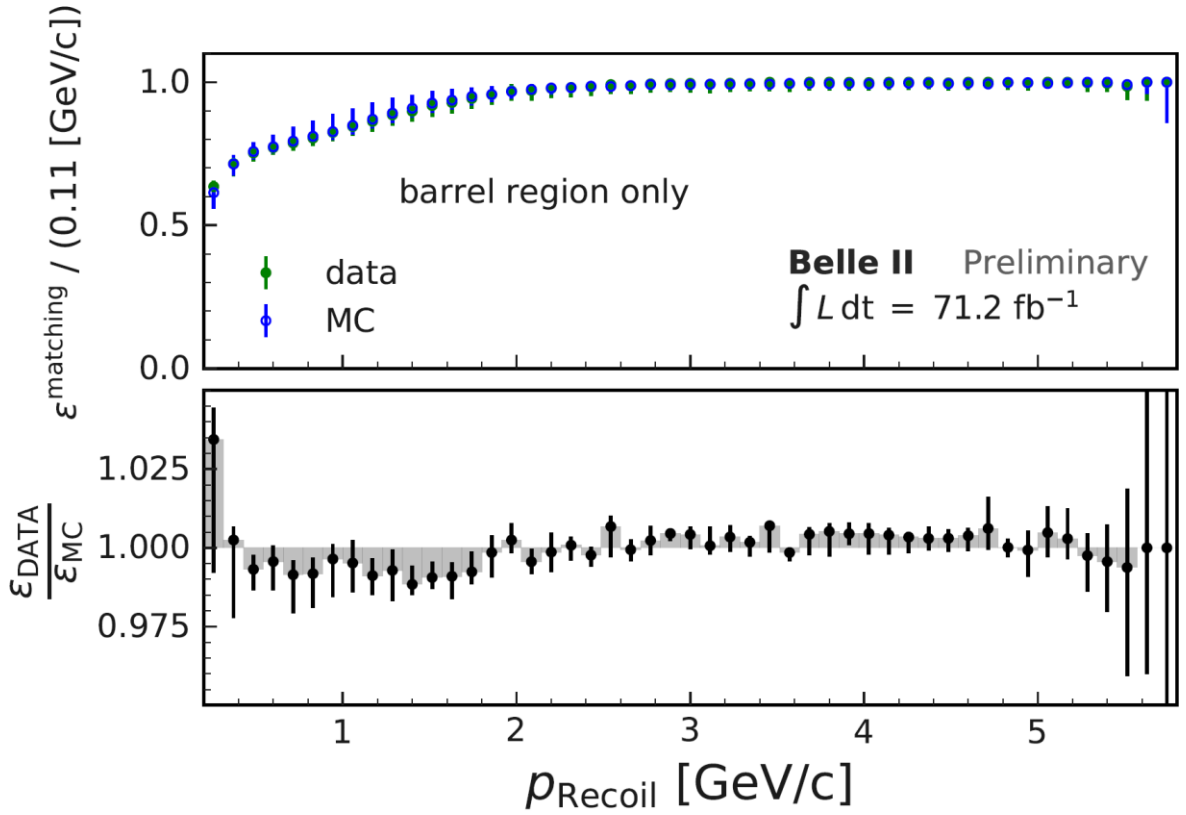
Data/MC discrepancy of tracking efficiency



Performance : Photon Detection Efficiency

- Photon detection efficiency is measured using ee→μμγ events.
  - Detection efficiency is estimated by taking match between a ECL cluster and the missing momentum of dimuon system.
- Data/MC agreement is good. Uncertainty for photon detection efficiency is 0.30%.





Progress of ongoing analysis

- $e^+e^- \to \pi^+\pi^-$
- $e^+e^- \to \pi^+\pi^-\pi^0$
- $e^+e^- \to KK\pi$
- $\gamma^*\gamma \to \pi^0$

$e^+e^- \to \pi^+\pi^-$

- Precision target : 0.5% of $a_\mu(2\pi)$
- Sanity check with < 2 fb^{-1} data
  - Generator (PHOKHARA 10.0)
  - Kinematic fitting tools
  - Trigger efficiency
  - (Beam) Background
- Performance study is ongoing
  - Tracking efficiency
  - PID study
- Plan for intermediate result is under discussion.

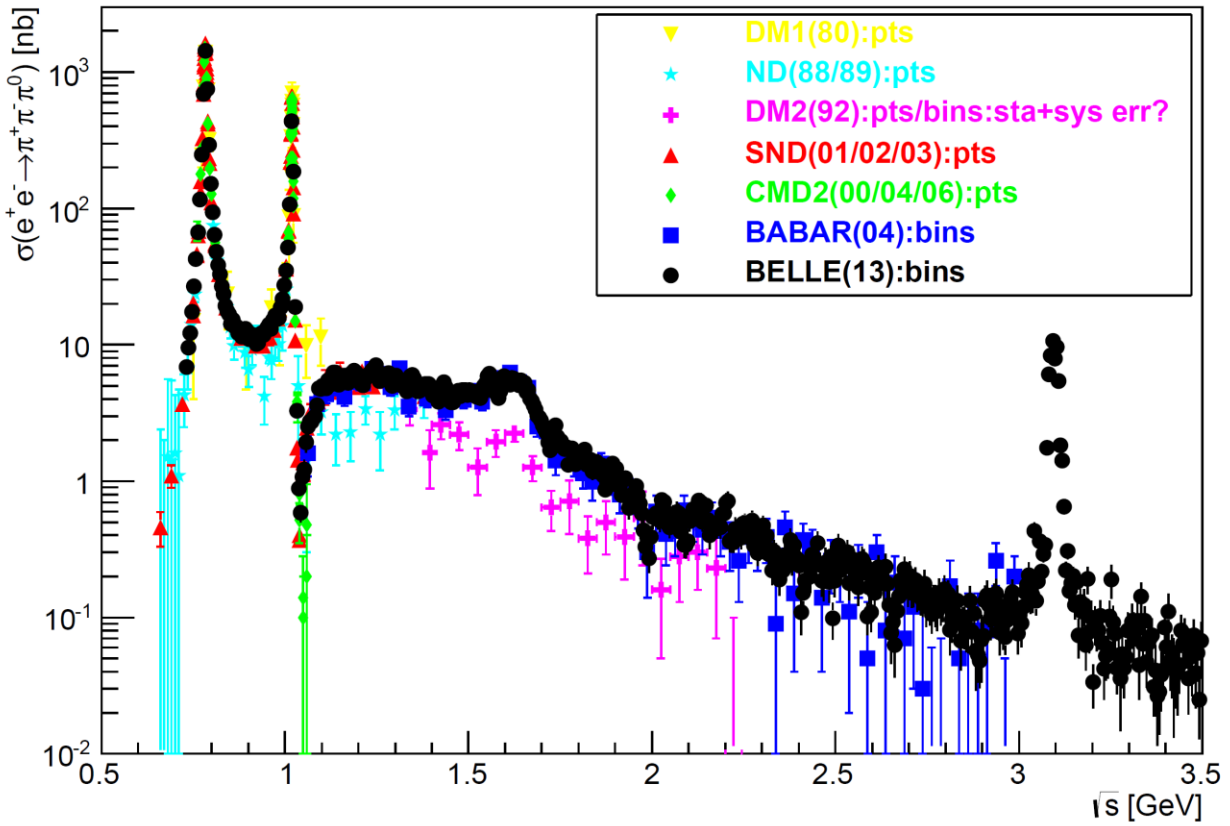
ee→ππ uncertainty at BABAR [Phys.Rev.D 86 (2012), 032013]

Sources	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.9	0.9–1.2
Trigger/filter	5.3	2.7	1.9	1.0	0.7
Tracking	3.8	2.1	2.1	1.1	1.7
π-ID	10.1	2.5	6.2	2.4	4.2
Background	3.5	4.3	5.2	1.0	3.0
Acceptance	1.6	1.6	1.0	1.0	1.6
Kinematic fit (χ^2)	0.9	0.9	0.3	0.3	0.9
Correl. $\mu\mu$ ID loss	3.0	2.0	3.0	1.3	2.0
$\pi\pi/\mu\mu$ non-cancel.	2.7	1.4	1.6	1.1	1.3
Unfolding	1.0	2.7	2.7	1.0	1.3
ISR luminosity	3.4	3.4	3.4	3.4	3.4
Sum (cross section)	13.8	8.1	10.2	5.0	6.5

$e^+e^-\to\pi^+\pi^-\pi^0$: at BELLE

- $e^+e^-\to\pi^+\pi^-\pi^0$ is the 2nd largest contribution to HVP term.
- The measurement in the mass range of $0.73 < \sqrt{s'} < 3.5$ GeV was attempted using 526.6 /fb data.
- Large uncertainty of level-1 trigger efficiency prevents publication, and the result is recorded in a PhD thesis.

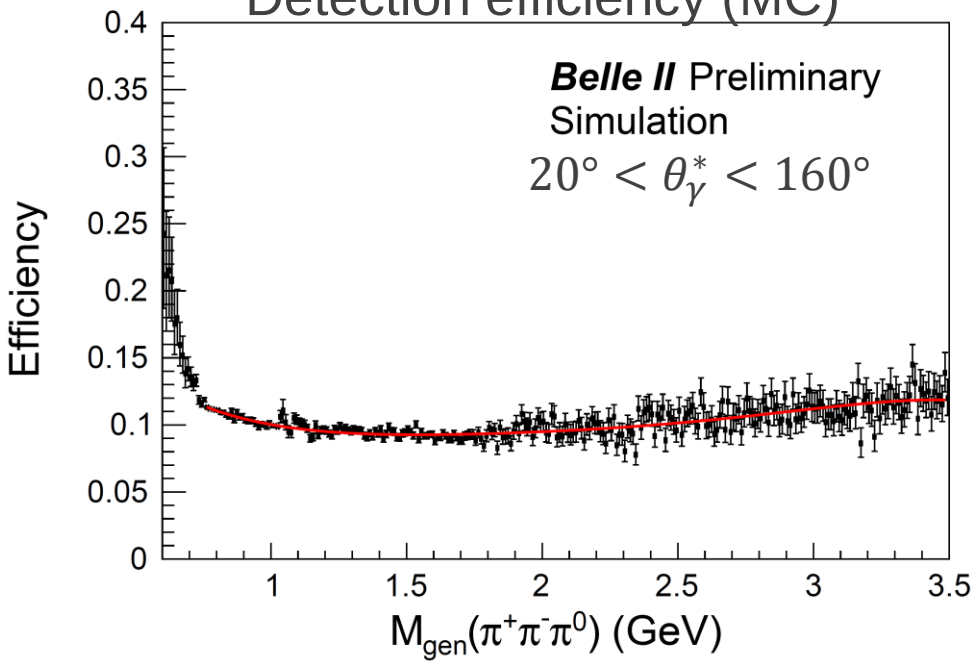
[J. Crnkovic, PhD thesis, Illinois U. (2013)]



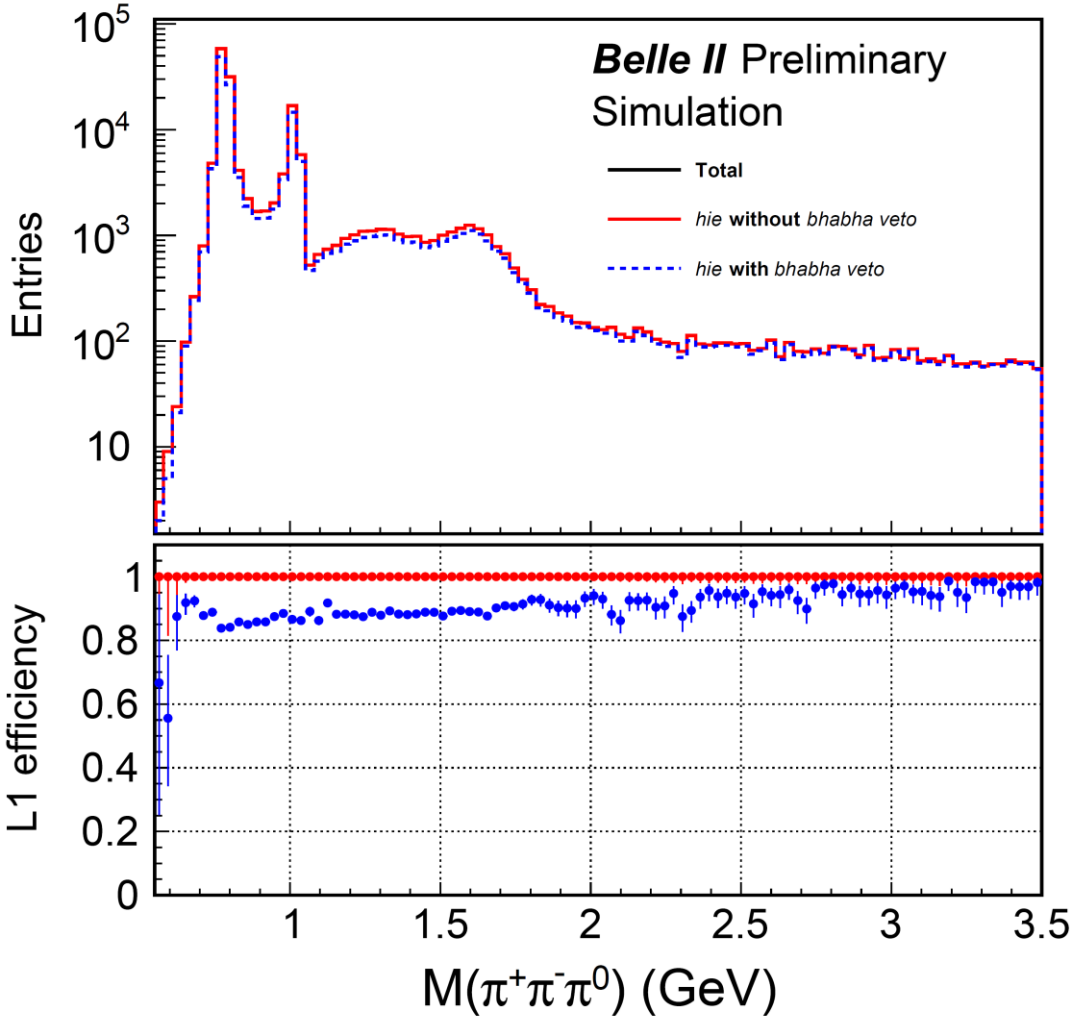
$e^+e^- \to \pi^+\pi^-\pi^0$: at Belle II

- Aim ~2% precision measurement using 189 fb^{-1} data
- Most analysis procedures are established
  - Signal efficiency of 10% is expected.
- Trigger uncertainty can be well suppressed.
  - 3D bhabha veto introduced from 2021 causes signal loss by ~15%.
  - Collected data of 100 /fb without 3D bhabha veto.

Detection efficiency (MC)

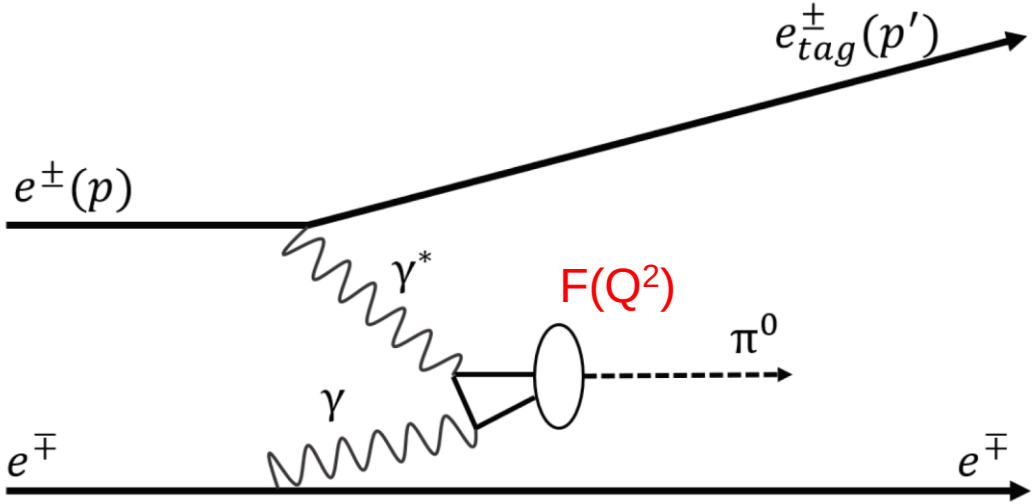


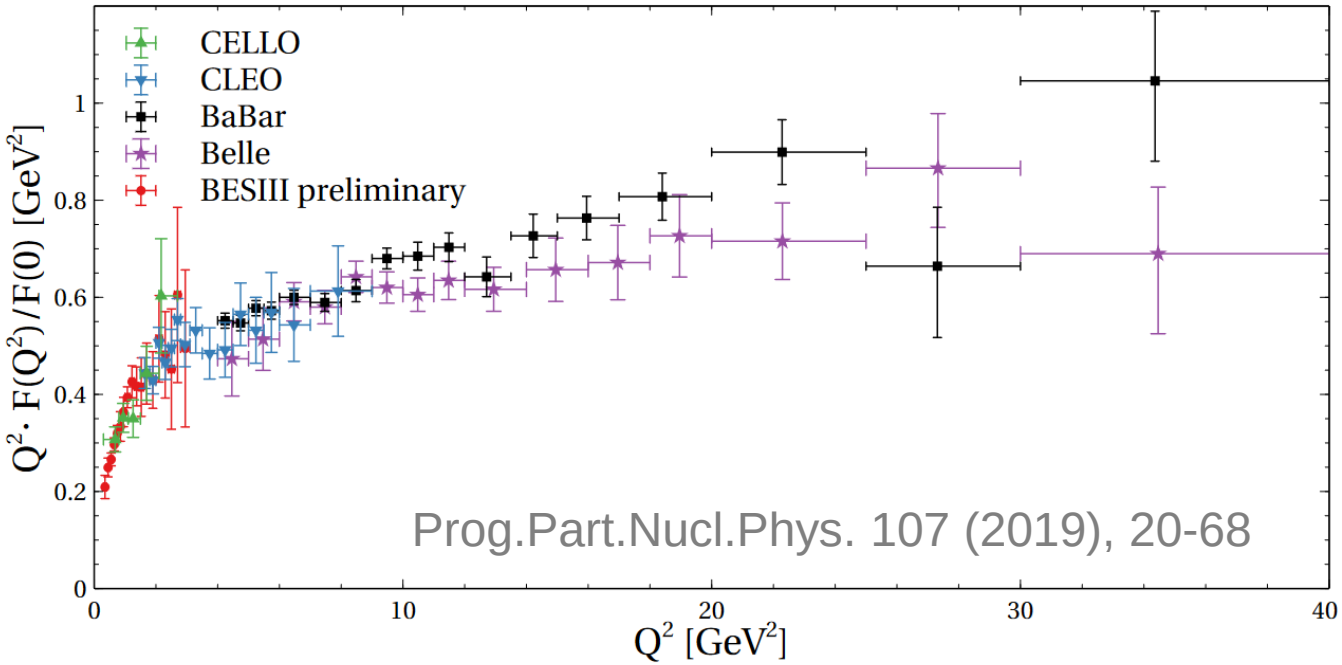
Trigger efficiency (MC)



$\gamma\gamma^* \to \pi^0$: Spacelike π^0 Transit Form Factors

- Exchange of two photons in ee collisions
- $d\sigma/dQ^2 \propto |F(Q^2)|^2/Q^2$
- Contribution to $a_\mu^{HLbL}(\pi^0)$ at low-Q2 region

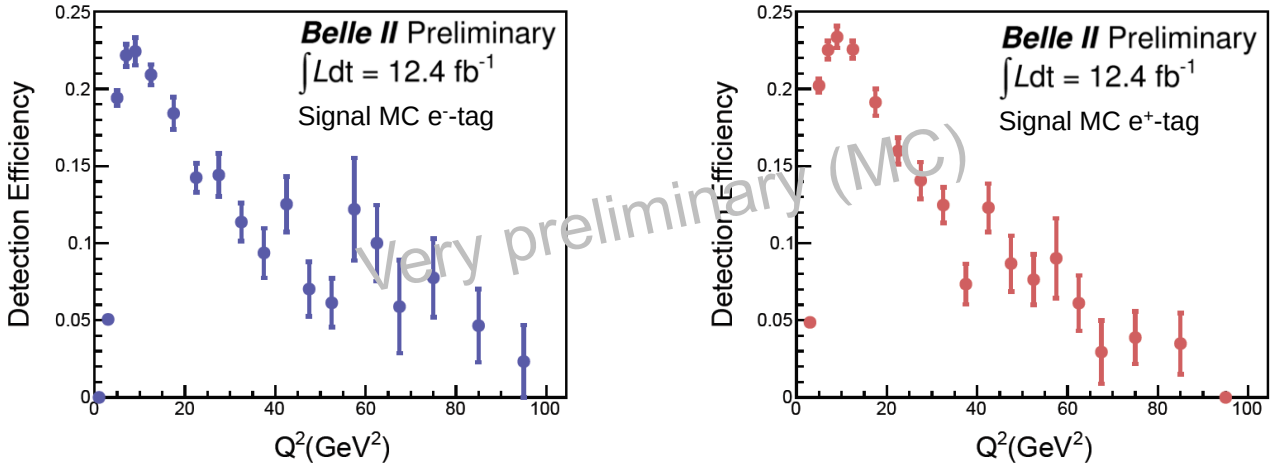


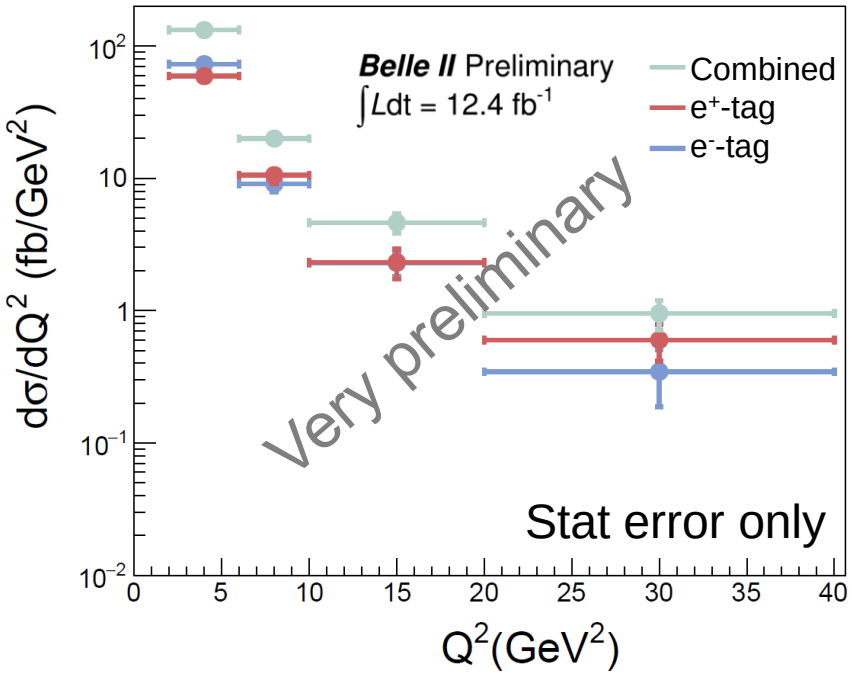


$\gamma\gamma^* \to \pi^0$: Preliminary test

- Single-tagged measurements using 12.4 fb^{-1} data taken on 2019.
- Good agreement with previous measurements in Q^2 = 10 GeV^2 region.
  - Efficiency at low Q^2 improved due to new trigger.
- For measurement with higher statistics
  - Implementation of signal generator
  - Precise simulation of virtual compton scattering
  - Optimization of BDT

Signal efficiency





Summary

- Belle II has collected 424 fb^{-1} data, and data taking keeps going for the goal of 50 ab^{-1}.
  - The SuperKEKB/Belle II is under long shutdown until autumn of 2023.
  - New trigger for ISR-related events is working well.
  - Basic detector performance is now at a compatible level for many analyses.
- Four data analysis relating to muon g-2 are active and in progress.
  - $\pi^+\pi^-$
    - Aim high precision measurement of 0.5%.
    - Focusing on data/MC sanity checks using tiny data of less than 2 /fb.
  - $\pi^+\pi^-\pi^0$
    - Aim to release result with ~2% precision using 189 /fb data in a year.
  - $KK\pi$
    - The analysis is ongoing with ~400 /fb data.
  - $\gamma\gamma^* \to \pi^0$
    - Preliminary check using 12 /fb data is consistent with previous measurements.
    - Further analysis is underway for results using larger dataset.