Belle II Status and Highlights

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Belle II spokesperson

on behalf of the Belle II collaboration

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Belle II at SuperKEKB

Plan to collect **50 ab^{-1}** of collisions at and near $\Upsilon(4S)$

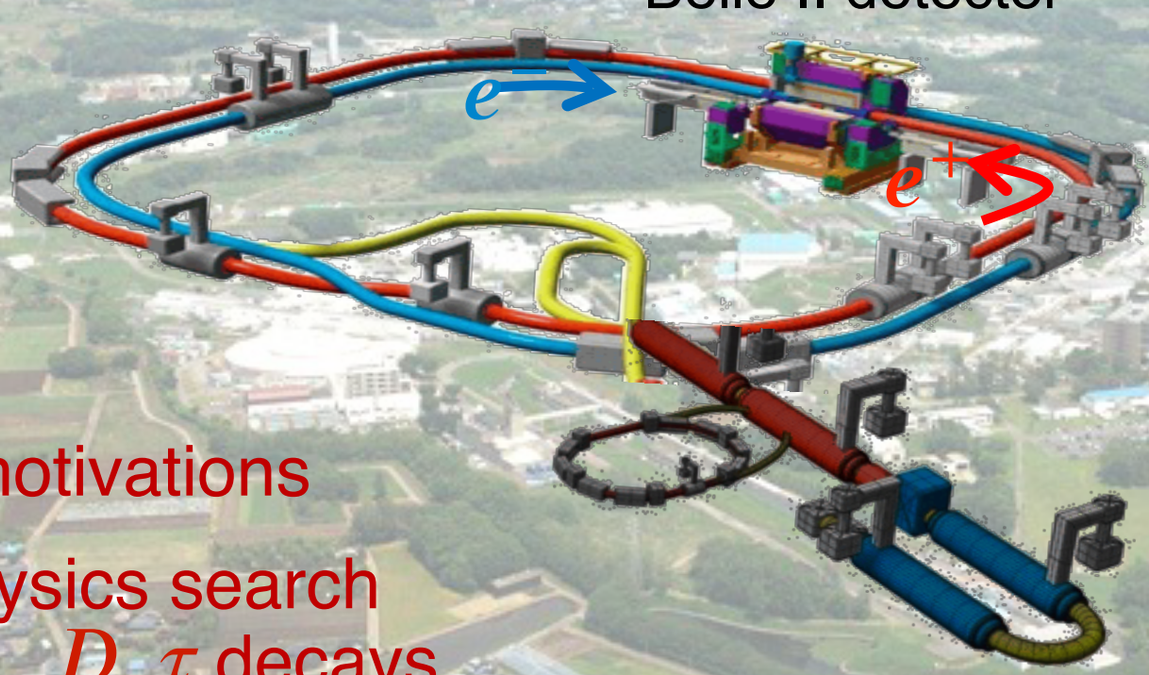
Successor to Belle at KEKB (1.05 ab^{-1})

At $\Upsilon(4S)$, $E_{CM} = 10.58$ GeV

7 GeV e^- (HER; High Energy Ring)

4 GeV e^+ (LER; Low Energy Ring)

Belle II detector

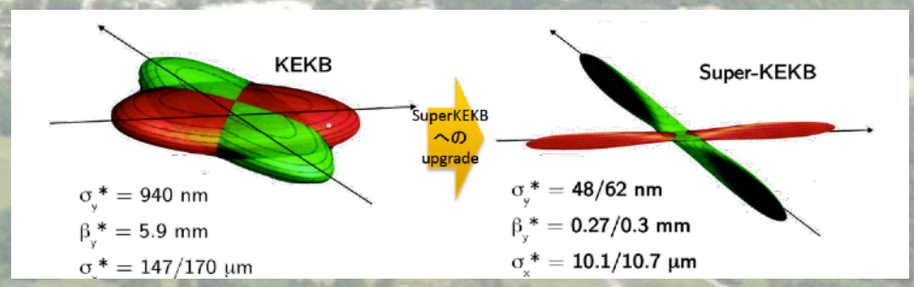


Nano beam scheme

$$\mathscr{L} = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

5.9 → 0.3 mm

KEKB SuperKEKB



Physics motivations

- New physics search in B, B_s, D, τ decays
- Direct search for light new particles
- Precise measurement of Standard Model
- Hadron physics

Belle II detector

Superconducting solenoid (1.5 T)

K_L and μ detector

- Resistive plate chamber (outer barrel)
- Scintillator + MPPC (inner 2 barrel layers, end-caps)

Electromagnetic calorimeter

CsI(Tl), waveform sampling

Particle ID detectors

- TOP (Time-of-Propagation) counter (barrel)
- Aerogel RICH (forward end-cap)

Tracking detector

Drift chamber (He + C_2H_6)
of small cell, longer lever arm
with fast readout electronics

Silicon vertex detector

- 1→2 layers DEPFET (pixel)
- 4 outer layers DSSD

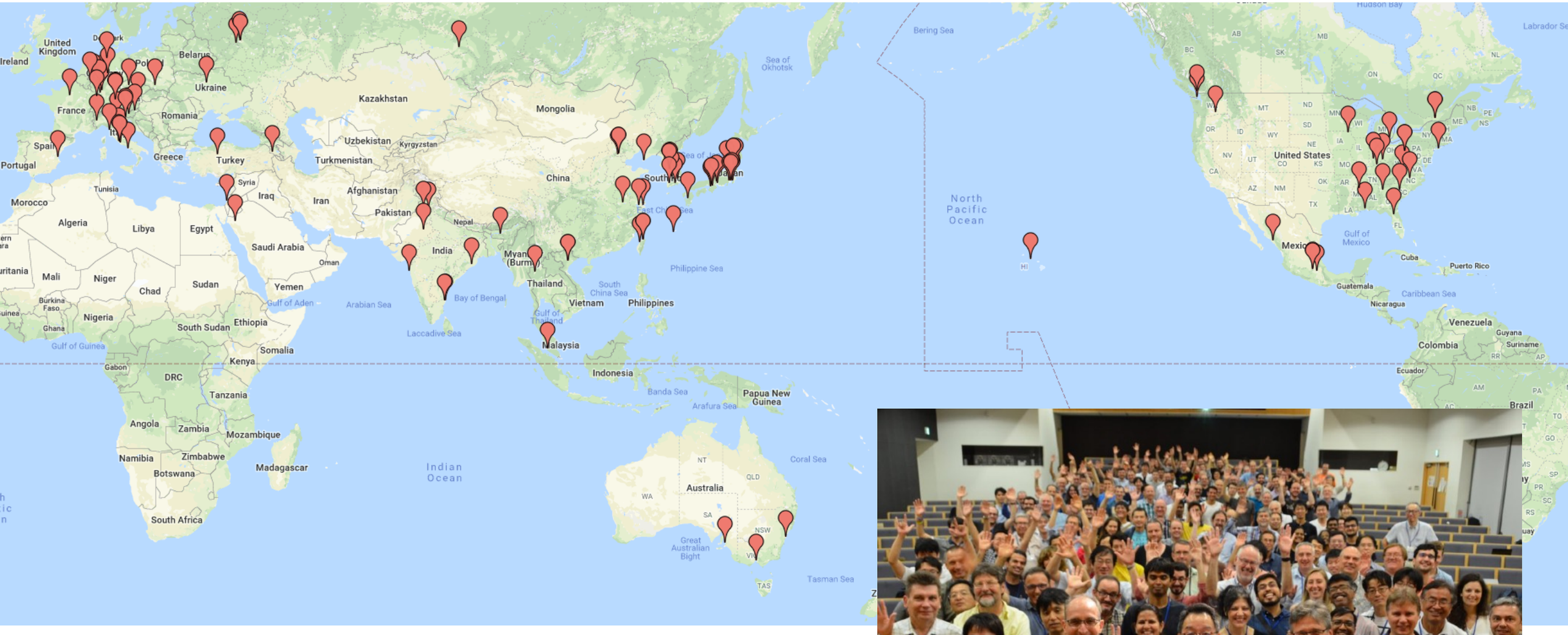
Trigger and DAQ

Max L1 rate: 0.5→30 kHz
Pipeline readout

GRID computing

Better performance even at the higher trigger rate and beam background

Belle II Collaboration



- ~1050 active members
  - ~220/~140/~70 (Ph.D/Msc/Undergrad.) students
- 120 institutes
- 26 countries

T.I.

Belle II Physics Program

- Precision CKM
- CPV in b→s penguin decays
- Tauonic decays
- FCNC
- Charm decays
- LFV τ decays

+

- Hadron spectroscopy
- Dark sector

Observables	Expected the. accuracy	Expected exp. uncertainty	Facility (2025)	
UT angles & sides				
ϕ_1 [°]	***	0.4	Belle II	
ϕ_2 [°]	**	1.0	Belle II	
ϕ_3 [°]	***	1.0	LHCb/Belle II	
$\|V_{cb}\|$ incl.	***	1%	Belle II	
$\|V_{cb}\|$ excl.	***	1.5%	Belle II	*
$\|V_{ub}\|$ incl.	**	3%	Belle II	
$\|V_{ub}\|$ excl.	**	2%	Belle II/LHCb	
CP Violation				
$S(B \to \phi K^0)$	***	0.02	Belle II	
$S(B \to \eta' K^0)$	***	0.01	Belle II	
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II	
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II	
(Semi-)leptonic				
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	3%	Belle II	
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II	
$R(B \to D\tau\nu)$	***	3%	Belle II	
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb	
Radiative & EW Penguins				
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II	
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II	
$S(B \to K^0_S\pi^0\gamma)$	***	0.03	Belle II	
$S(B \to \rho\gamma)$	**	0.07	Belle II	
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II	
$\mathcal{B}(B \to K^*\nu\overline{\nu})$ $[10^{-6}]$	***	15%	Belle II	
$\mathcal{B}(B \to K\nu\overline{\nu})$ $[10^{-6}]$	***	20%	Belle II	
$R(B \to K^*\ell\ell)$	***	0.03	Belle II/LHCb	
Charm				
$\mathcal{B}(D_s \to \mu\nu)$	***	0.9%	Belle II	
$\mathcal{B}(D_s \to \tau\nu)$	***	2%	Belle II	
$A_{CP}(D^0 \to K^0_S\pi^0)$ $[10^{-2}]$	**	0.03	Belle II	
$\|q/p\|(D^0 \to K^0_S\pi^+\pi^-)$	***	0.03	Belle II	*
$\phi(D^0 \to K^0_S\pi^+\pi^-)$ [°]	***	4	Belle II	
Tau				
$\tau \to \mu\gamma$ $[10^{-10}]$	***	< 50	Belle II	
$\tau \to e\gamma$ $[10^{-10}]$	***	< 100	Belle II	
$\tau \to \mu\mu\mu$ $[10^{-10}]$	***	< 3	Belle II/LHCb	

"Belle II Physics Book"
B2TIP (Belle II Theory Interface Platform)
PTEP 2019, no. 12, 123C01 (2019)

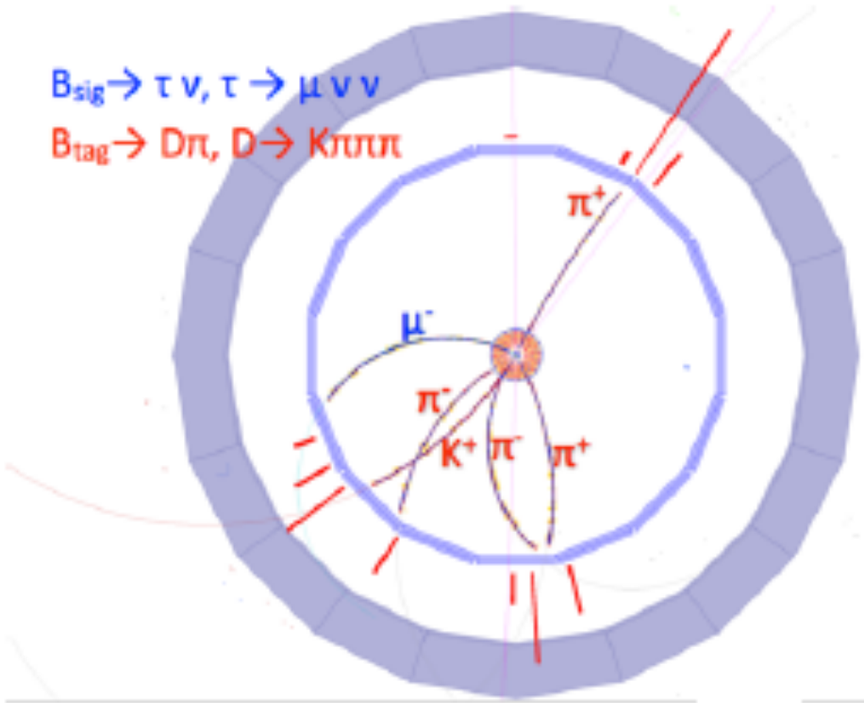
* LHCb is now more competitive

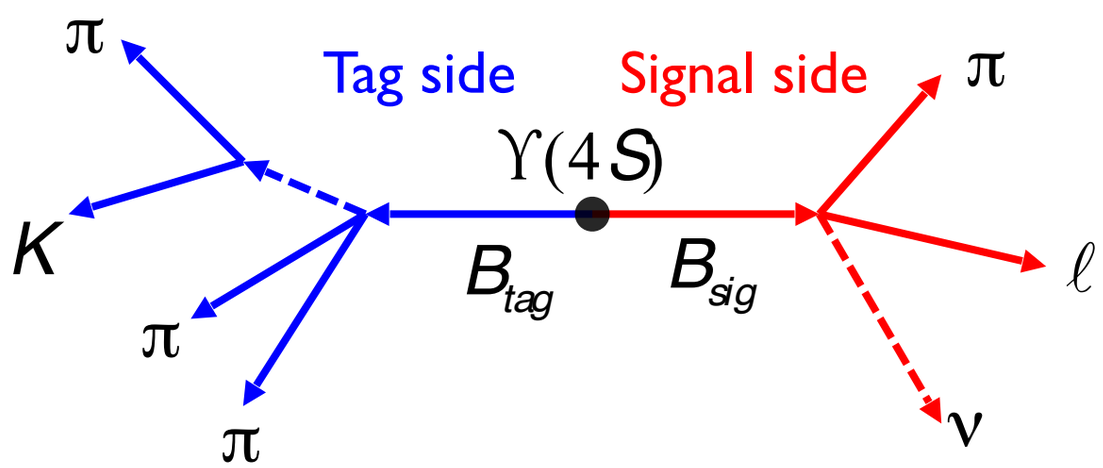
Measurements with ultimate precisions down to theory errors !

Advantage of e^+e^- Flavor Factory

- Clean environment
  - Efficient detection of neutrals (γ, π^0, η, …)
- Quantum correlated $B^0\bar{B}^0$ pairs
  - High effective flavor tagging efficiency :

    ~34%(Belle II) ⟷ ~5% (LHCb)
- Large sample of τ leptons
  - Search for LFV τ decays at $O(10^{-9})$
- Full reconstruction tagging possible
  - A powerful tool to measure;
    - $b \to u$ semileptonic decays (CKM)
    - decays with large missing energy
- Good hermeticity
  - acceptance close to 4π
  - e+/e- beam energies less asymmetric than Belle, BaBar
- Systematics different from LHCb
  - Two experiments are required to establish NP



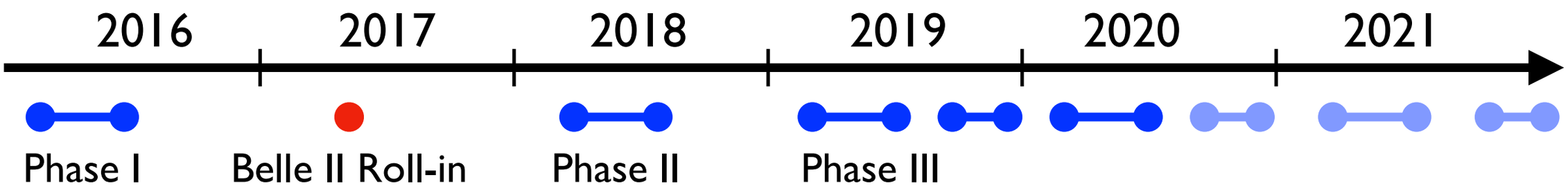


$B \to \pi\, l\, \nu$

$B \to \tau\, \nu, D\, \tau\, \nu$

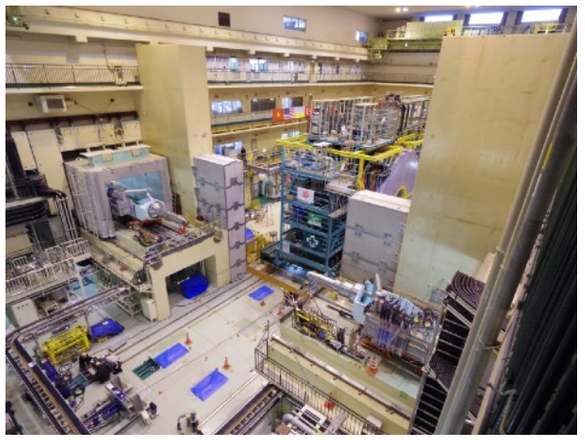
$B \to K\, \nu\, \nu$

SuperKEKB/Belle II Operation History



Phase I (w/o QCS/Belle II)

- Accelerator tuning w/ single beams



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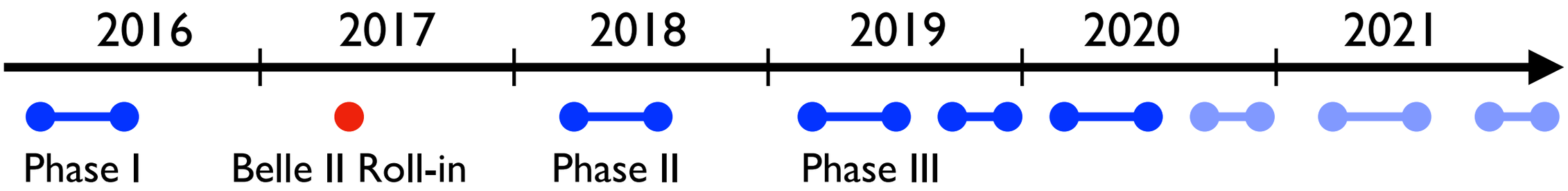

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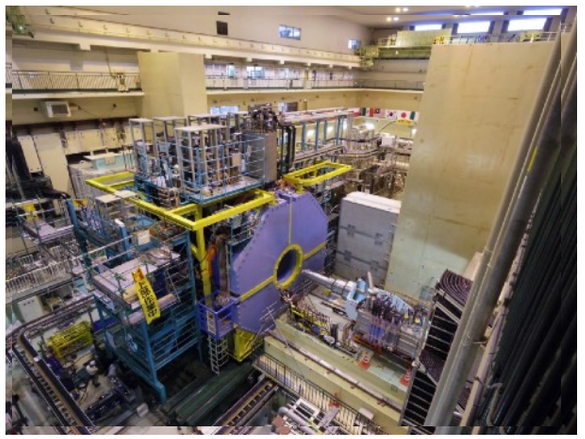
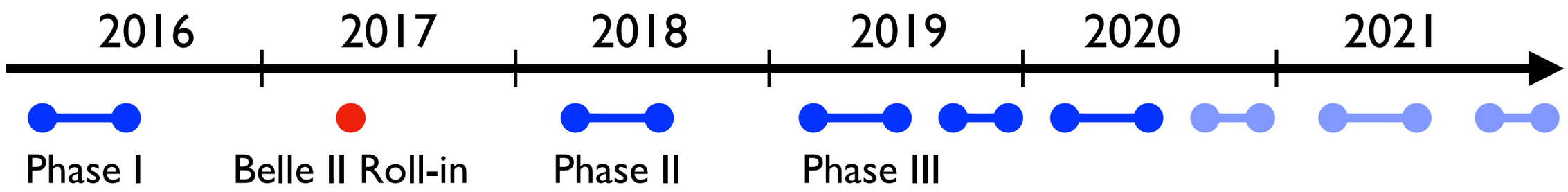


Belle II roll-in (2017.4.17)

SuperKEKB/Belle II Operation History

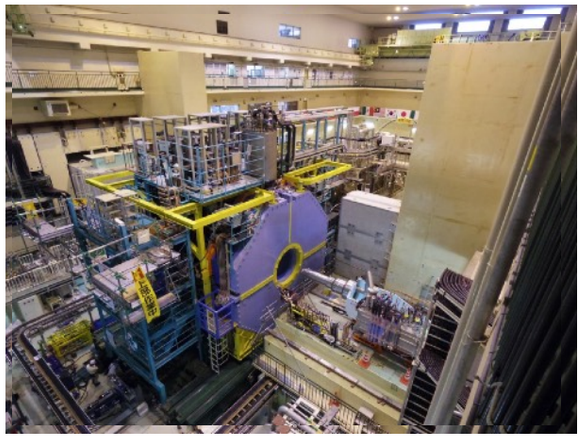


Phase 1 (w/o QCS/Belle II)

- Accelerator tuning w/ single beams

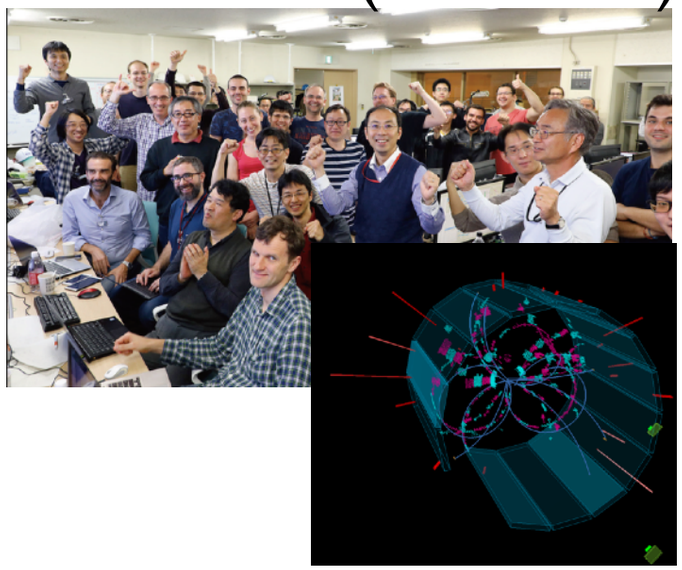
Phase 2 (w/ QCS/Belle II but w/o VXD)

- Verification of nano-beam scheme
- Understand beam background
- Collision data w/o VXD

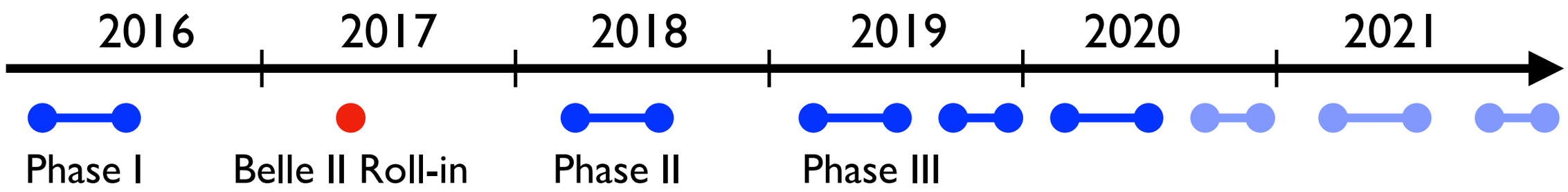


Belle II roll-in (2017.4.17)

1st collision (2018.4.26)



SuperKEKB/Belle II Operation History



Phase 1 (w/o QCS/Belle II)

- Accelerator tuning w/ single beams

Phase 2 (w/ QCS/Belle II but w/o VXD)

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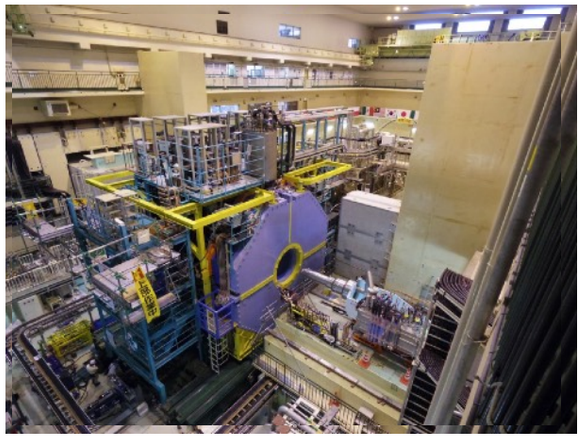
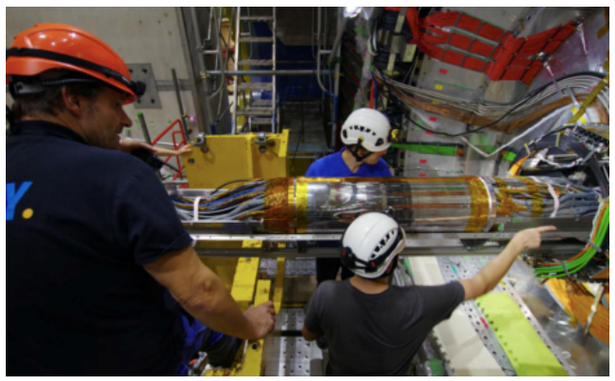


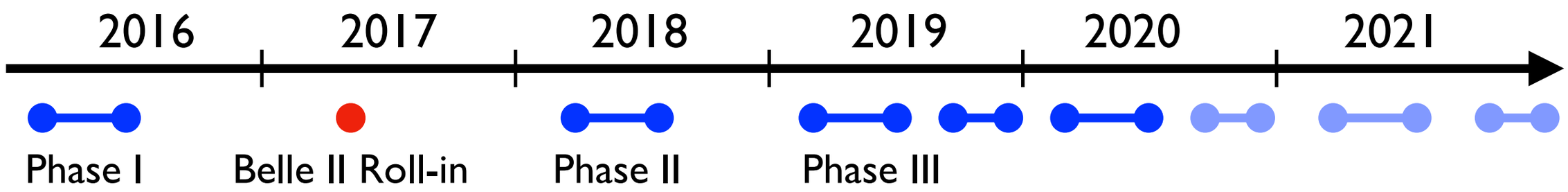
Belle II roll-in (2017.4.17)

1st collision (2018.4.26)

Installation of VXD



SuperKEKB/Belle II Operation History



Phase 1 (w/o QCS/Belle II)

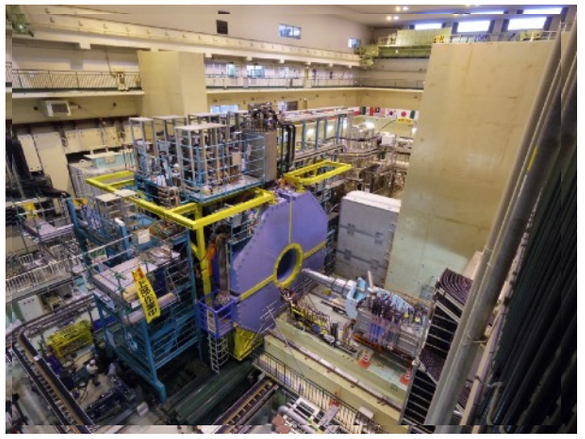
- Accelerator tuning w/ single beams

Phase 2 (w/ QCS/Belle II but w/o VXD)

- Verification of nano-beam scheme
- Understand beam background
- Collision data w/o VXD

Phase 3 (w/ full detector)

- Production of physics data



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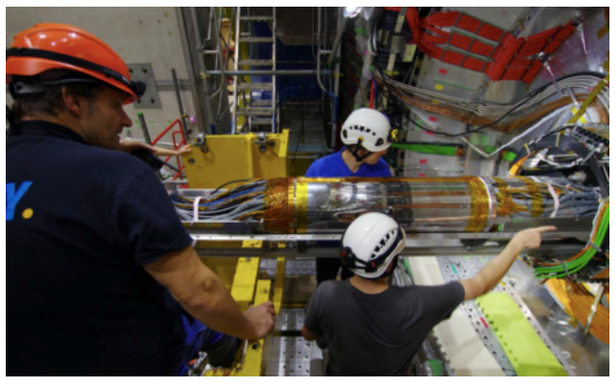


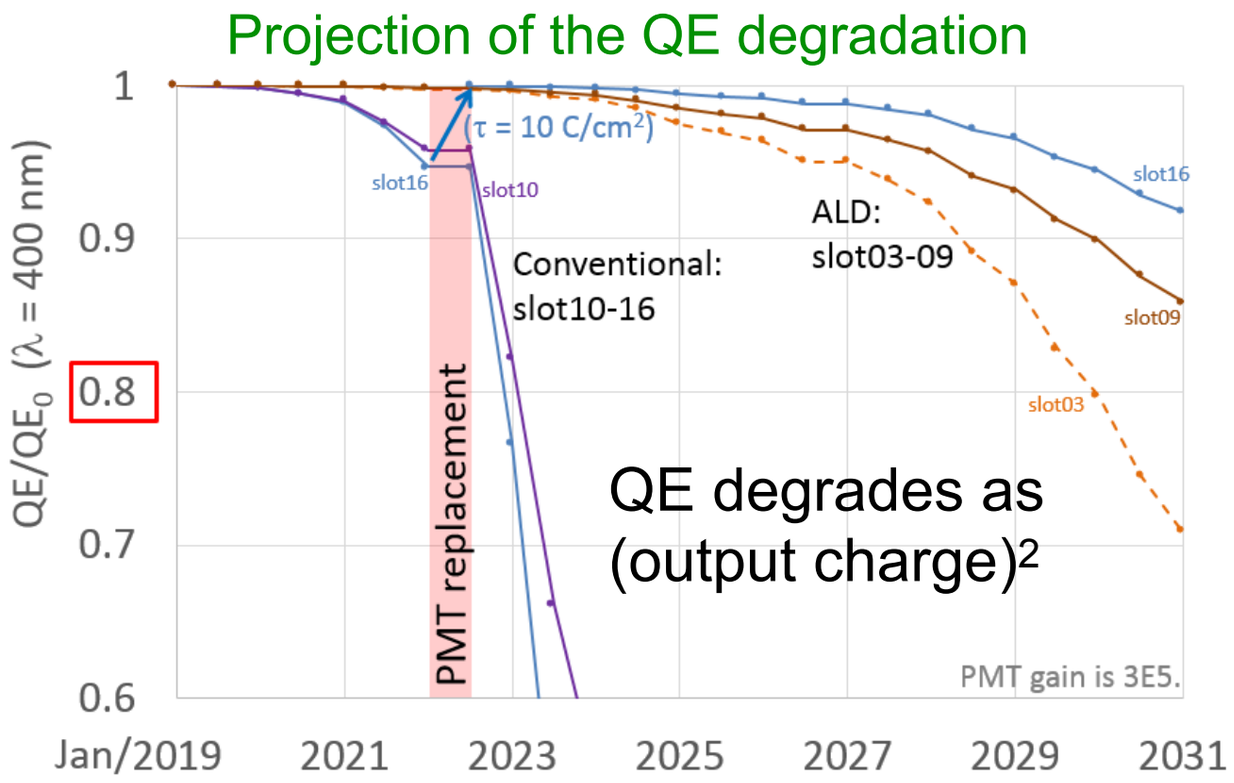
Phase 3 physics run (2019.3.25~)

Major issues in the operation

- Detector lifetime (in particular TOP counter)
  - To keep the MCP-PMT QE within an acceptable level ($QE/QE_0 > 80\%$) until 50 ab^{-1}, the Touschek and beam gas backgrounds, which increase with (beam current)^2, have to be kept constant by collimators, beam tuning, additional shielding, …

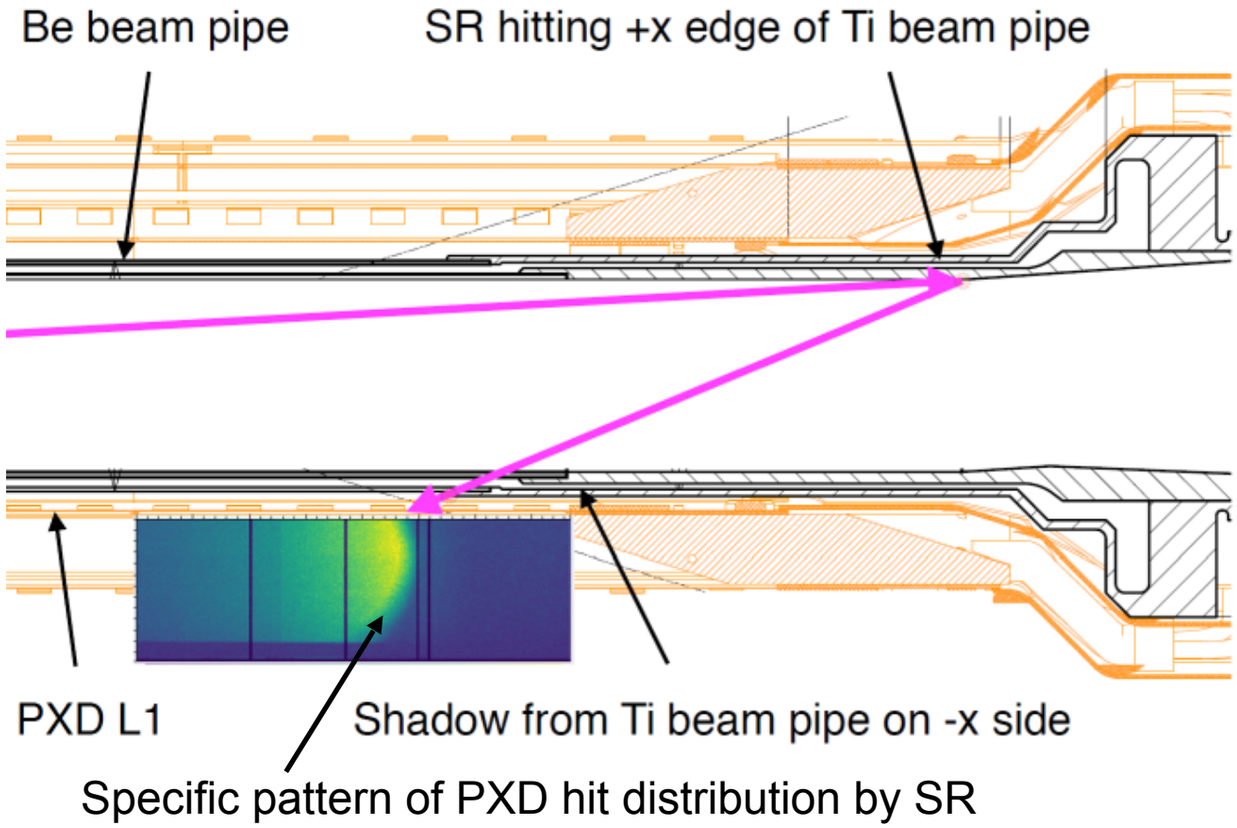
    → TOP PMT hit rate could limit the luminosity.
- Permanent damage on PXD and SVD by accidental huge beam loss.
- Synchrotron radiation from HER beam on PXD

  → Should be carefully monitored not to irradiate PXD unnecessarily.



Assume luminosity background (MC) + 1.2 MHz/PMT

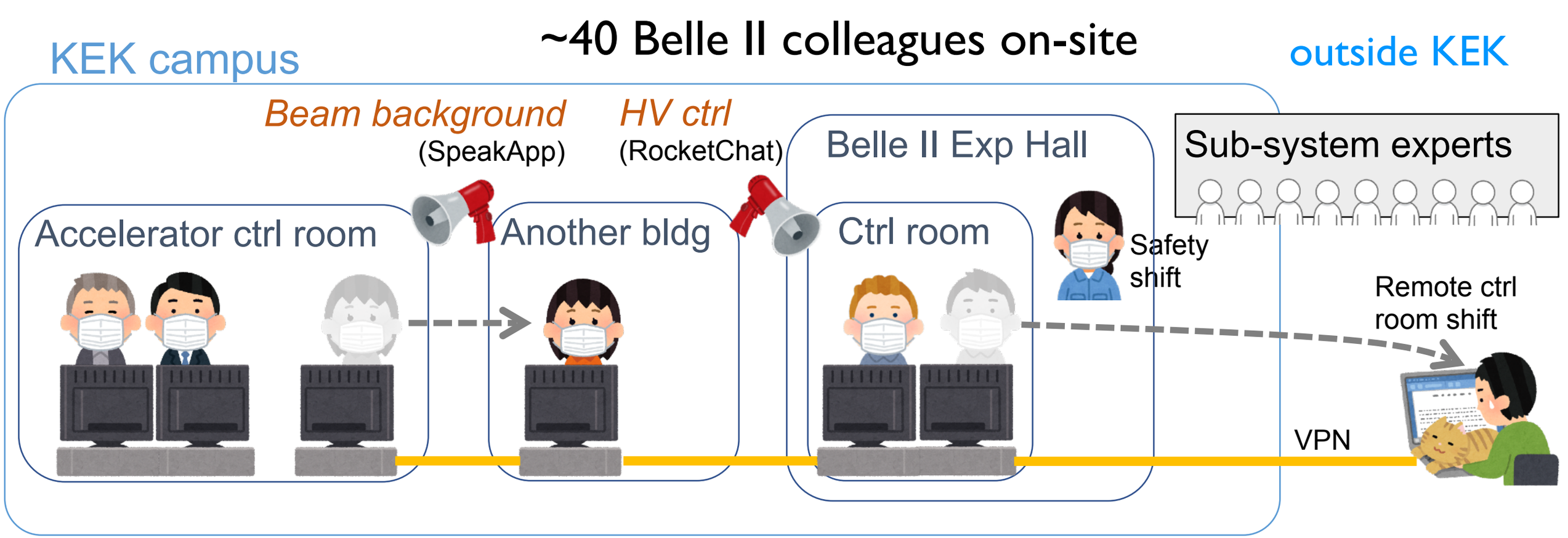
PMT for 7 modules (out of 16) will be replaced.



Belle II under COVID-19

- SuperKEKB/Belle II was operated under Covid-19 pandemic while minimizing risk of infection:
  - Minimize person-to-person contact and avoid 3C
    - Remote control room shifts and expert shifts
    - Online communications in run operation (chat tools), run meetings etc.
    - Hygiene (face mask, alcohol disinfection, ventilation, …)

Closed space
Crowded places
Close-contact settings



"New normal" scheme for sustainable operation under discussion.

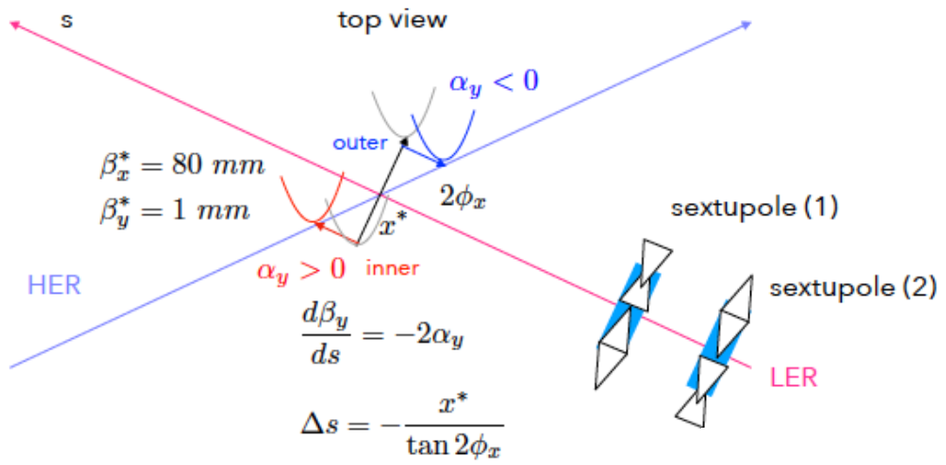
SuperKEKB Luminosity in 2020a,b

- Max current = 770mA(LER) / 660mA(HER)
- L_{peak} = 2.4 x $10^{34}cm^{-2}s^{-1}$ (world highest)
- Int. luminosity/day = 1.346 fb^{-1}/1.498 fb^{-1}
  recorded delivered

KEKB record
- L_{peak} = 2.11 x $10^{34}cm^{-2}s^{-1}$
- $L_{day}^{rec.}$ = 1.48 fb^{-1} (2009.6.14)

- LER: β_x^*/β_y^* = 80mm/1mm → 60mm/0.8mm
- HER: β_x^*/β_y^* = 60mm/1mm → 60mm/0.8mm

"Crab Waist" scheme



Operation history in 2020a,b

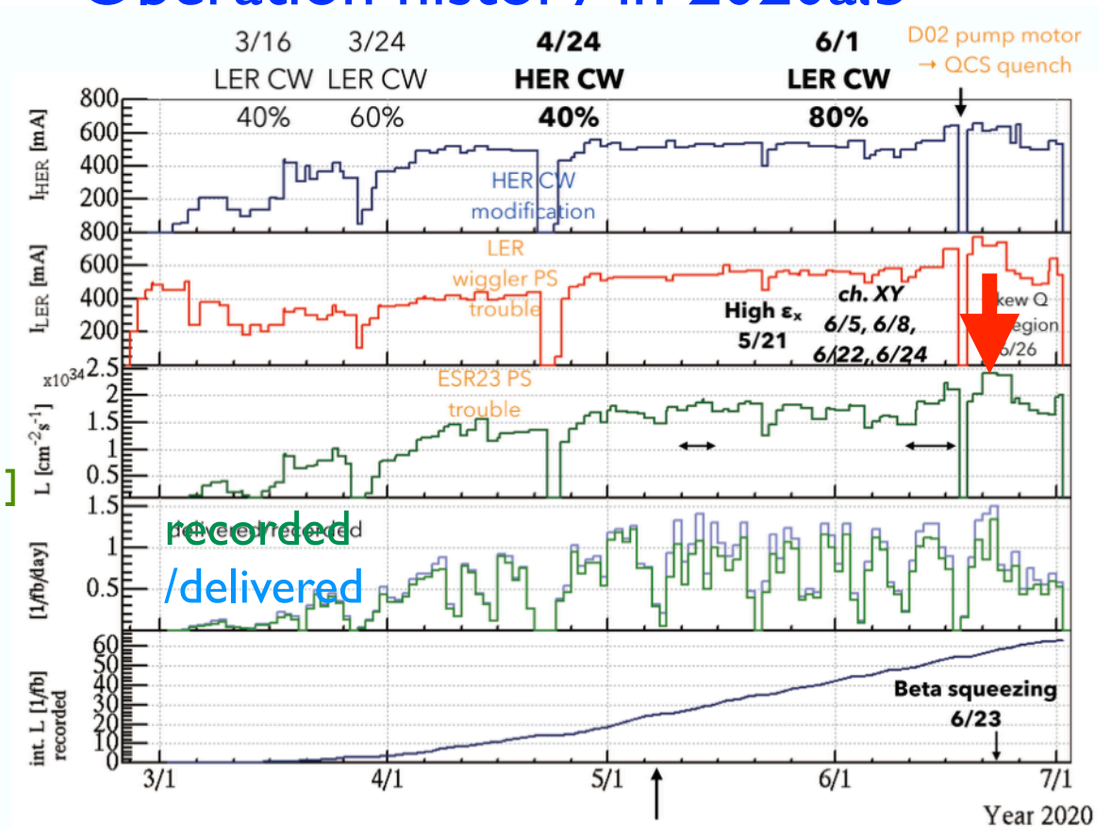
I_{HER}[mA]

I_{LER}[mA]

L_{peak} [x10^{34} $cm^{-2}s^{-1}$]

L_{day}[fb^{-1}]

L_{int}[fb^{-1}]

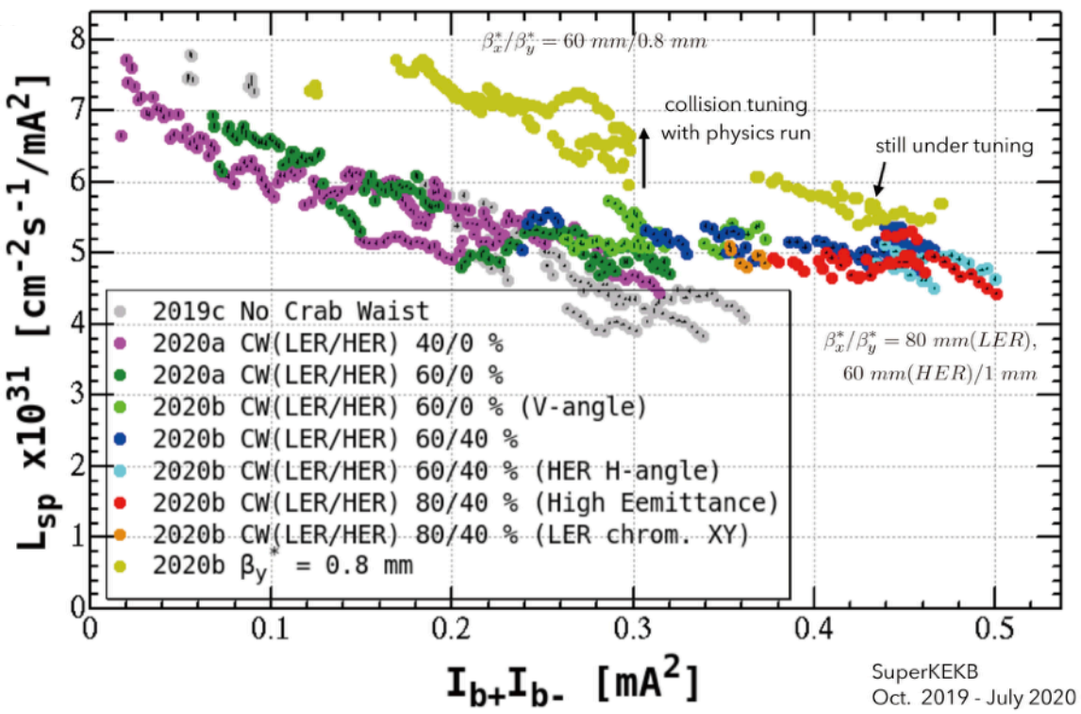


Remarks : Online luminosity does not include trigger-veto dead-time before May 7.

Specific luminosity

$$L_{sp} = \frac{L}{I_{b+} I_{b-} n_b} \propto \frac{1}{\sigma_{x,eff}^* \sigma_y^*}$$

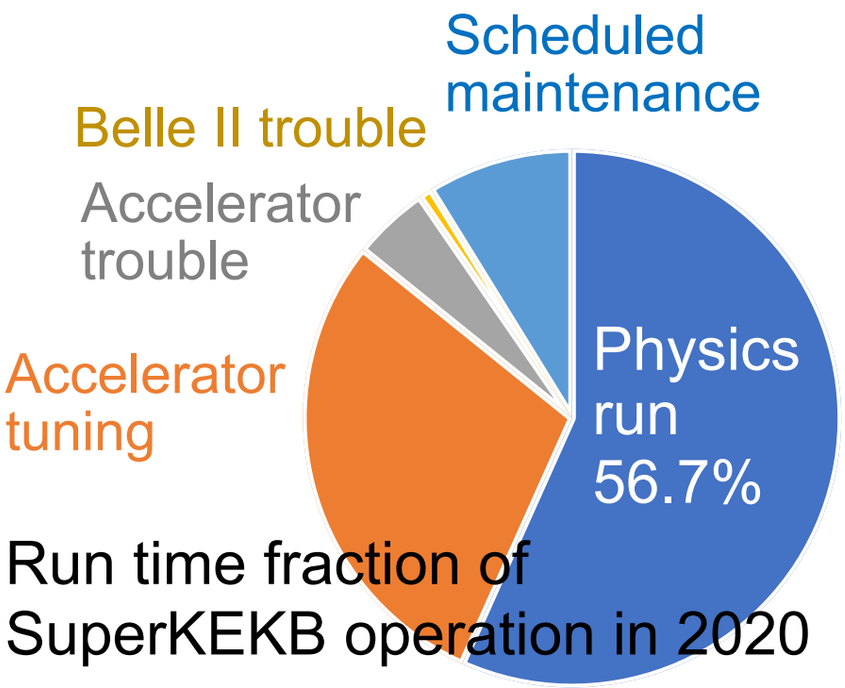
$\beta_y^* = 1\ mm$ and $0.8\ mm$



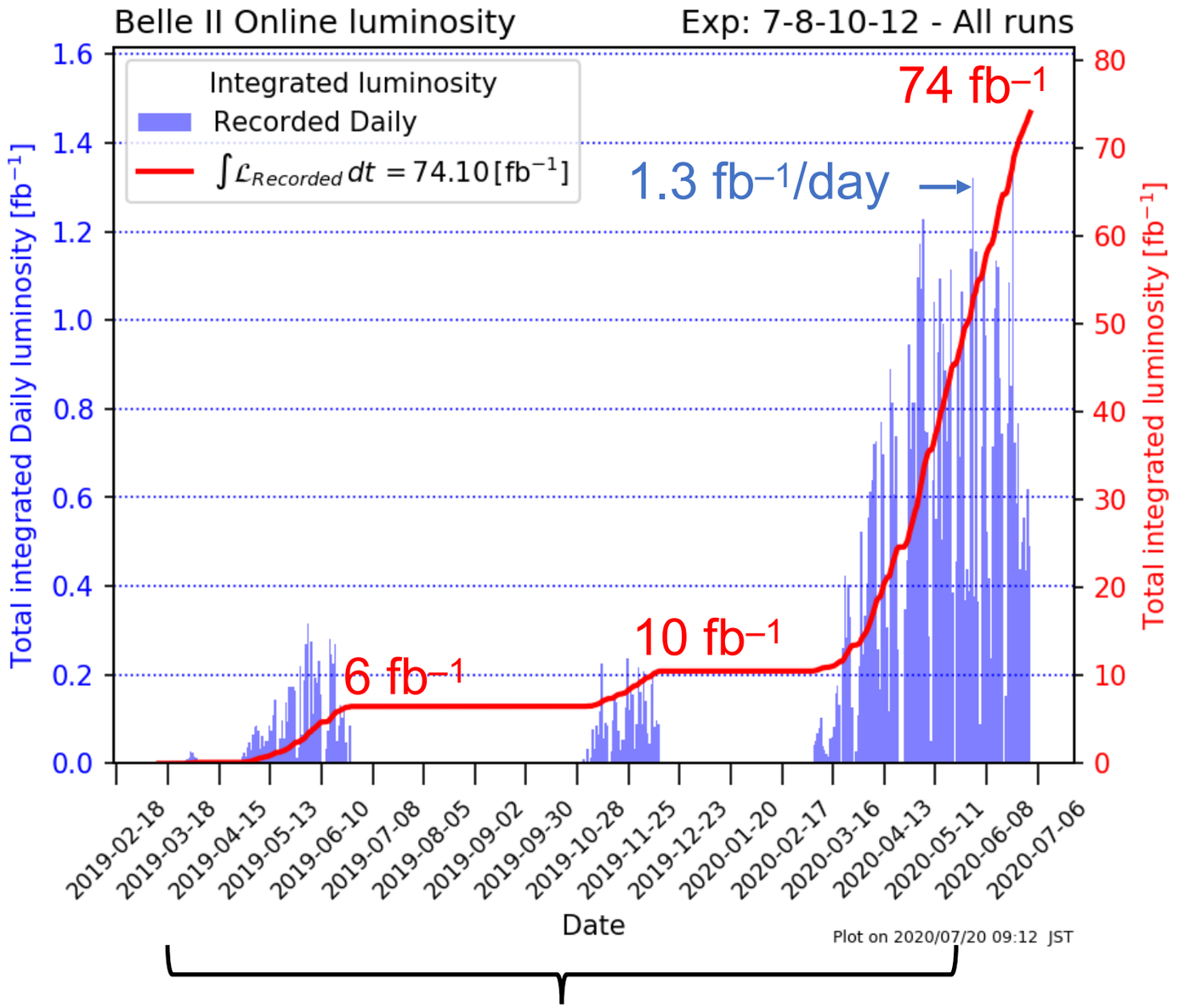
Belle II Operation

Belle II data taking efficiency has been improved to 84%.

- ✓ Less DAQ errors and more prompt recovery from the errors by experts' consistent effort
- ✓ Error analysis and monitor by ELK (**E**lasticsearch **L**ogstash **K**ibana)
- ✓ More experienced shifters
- ✓ Controlled injection veto dead time (avg. 4.9%) as a result of injection background studies



Run time fraction of SuperKEKB operation in 2020



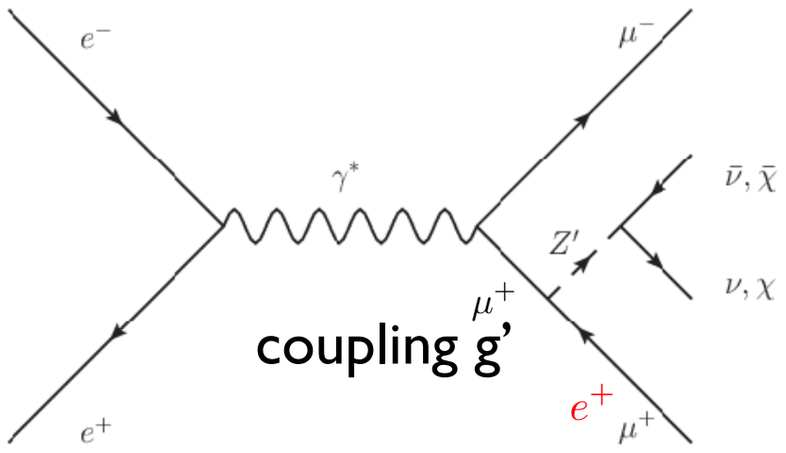
ICHEP2020 dataset
34.6(3.2) fb^{-1} on-(off-)resonance

Search for Dark Sector

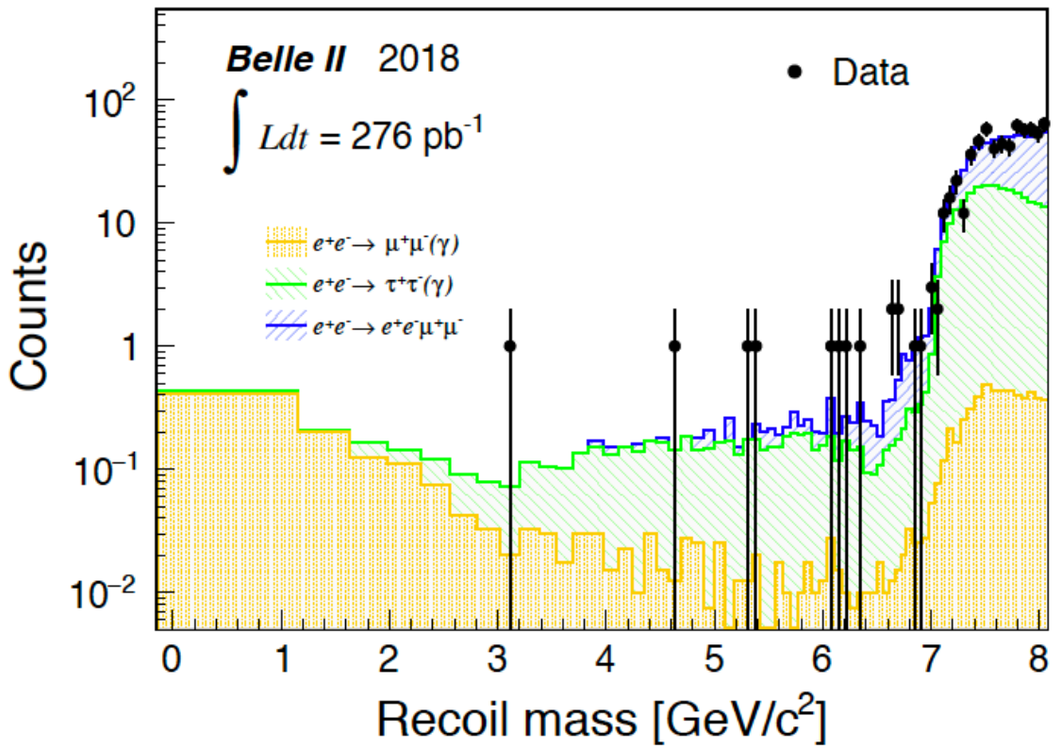
Z' → invisible

Talk by Savino Longo

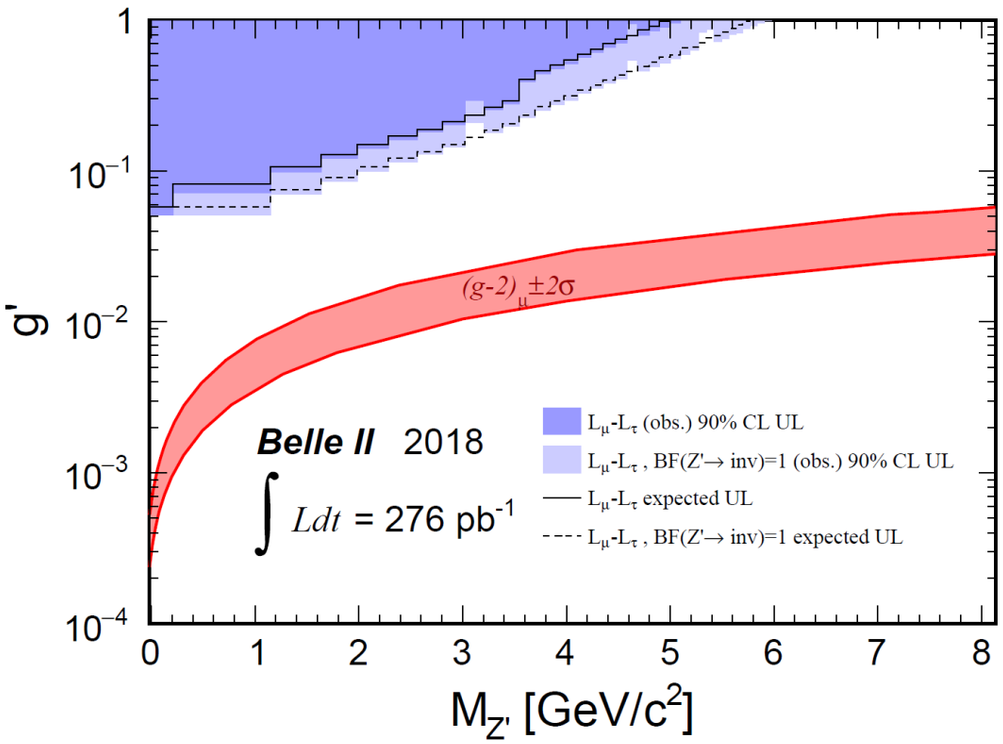
- A novel result on the dark sector (Z' → nothing) recoiling against di-muons or an electron-muon pair.
- Both possibilities are poorly constrained at low Z' mass and in the first case, could explain the muon g-2 anomaly.



Recoil mass against di-muons



Limit on g' (Lμ-Lτ model)



The first physics paper ! (Phys. Rev. Lett. 124, 141801 (2020))

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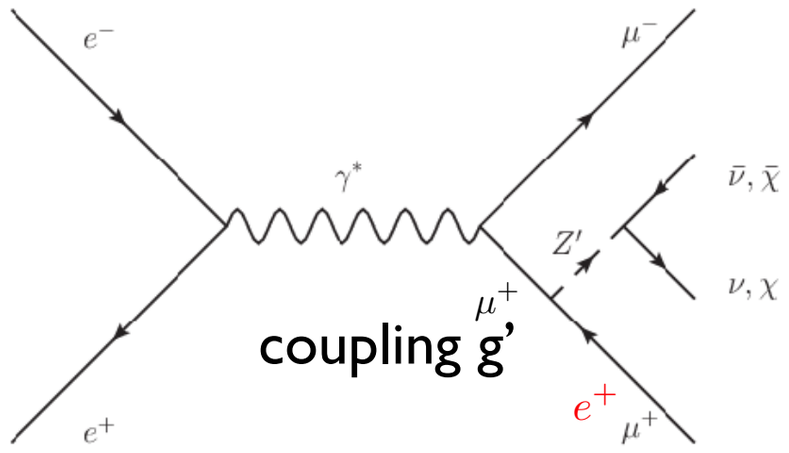
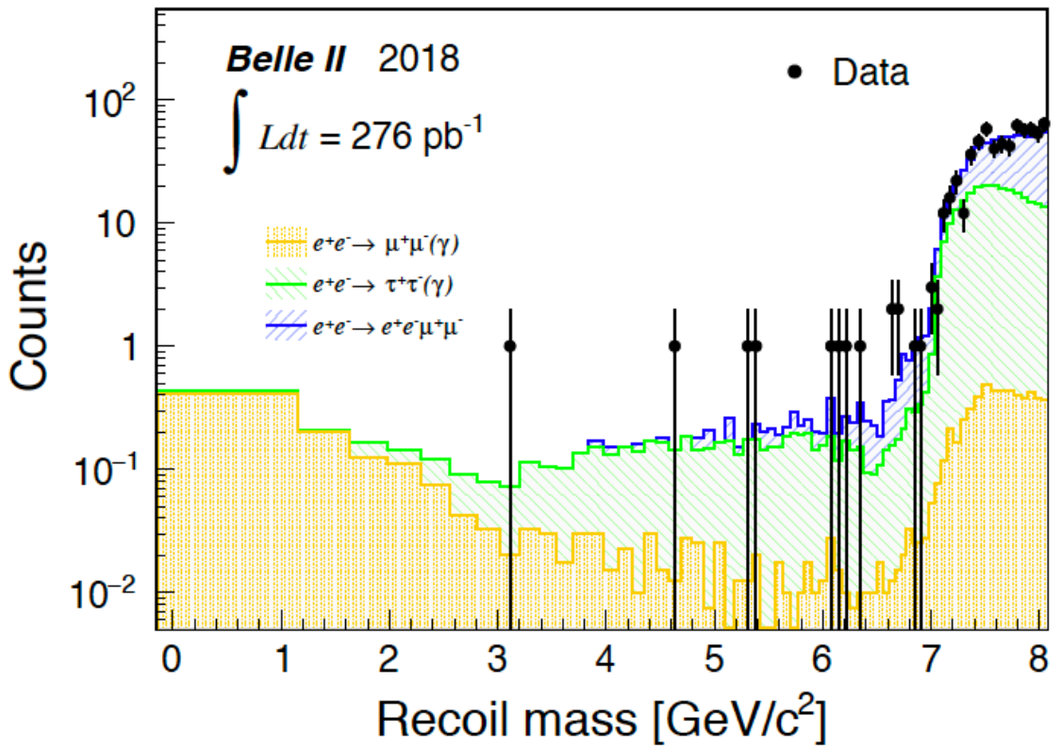
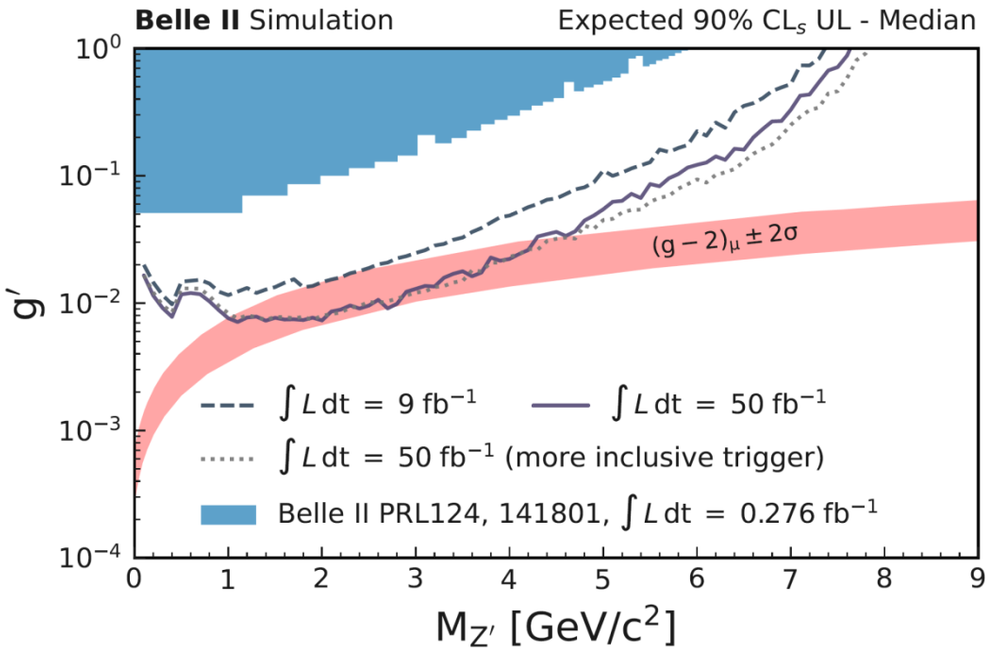


Recoil mass against di-muons



Limit on g' (Lμ-Lτ model)

Near future prospect



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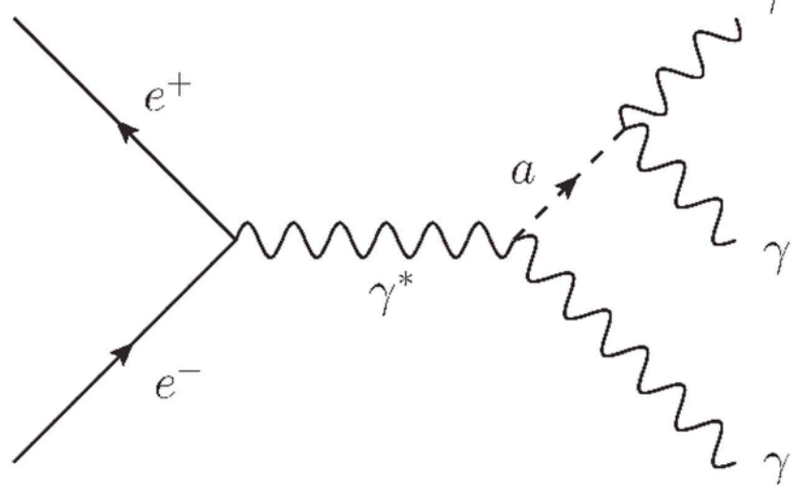
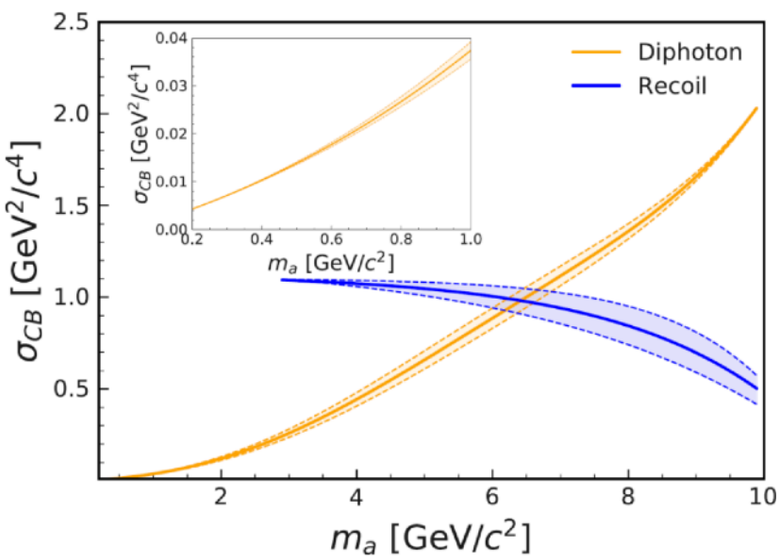
Search for Axion Like Particle (ALP)

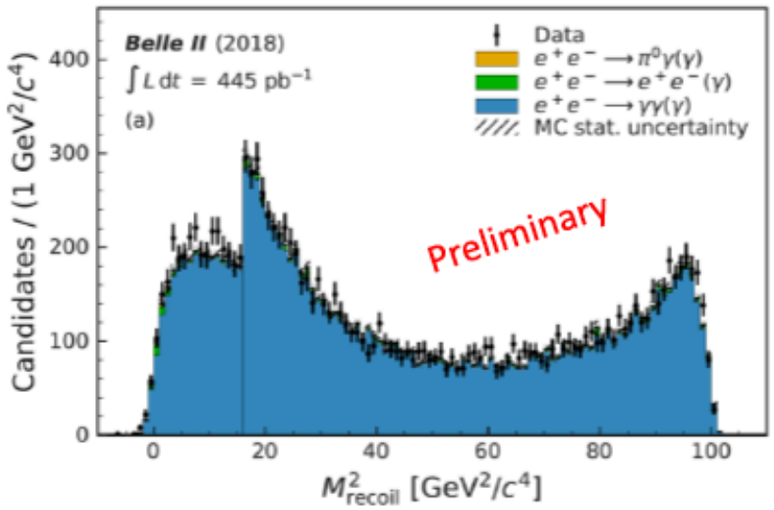
Talk by Savino Longo

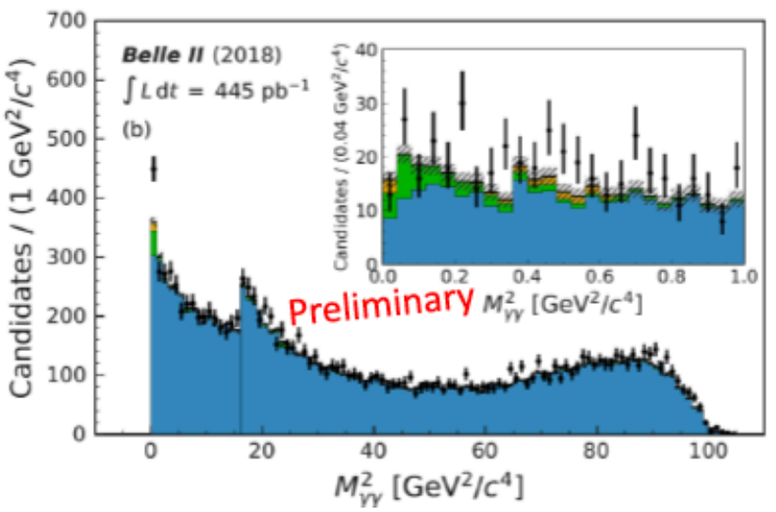
- Appear in SM extensions after some global (i.e. family) symmetry breaking
- Pseudo-Goldstone bosons → Naturally light
- Cold dark matter candidates if m_a is sub MeV
- Couple naturally to photons



- Search for3-photon final states via ALP-strahlung either in
  - recoil invariant mass (high m_a)
  - di-photon mass (low m_a)
- assume Br(a → γγ)=100% → $g_{a\gamma\gamma}$



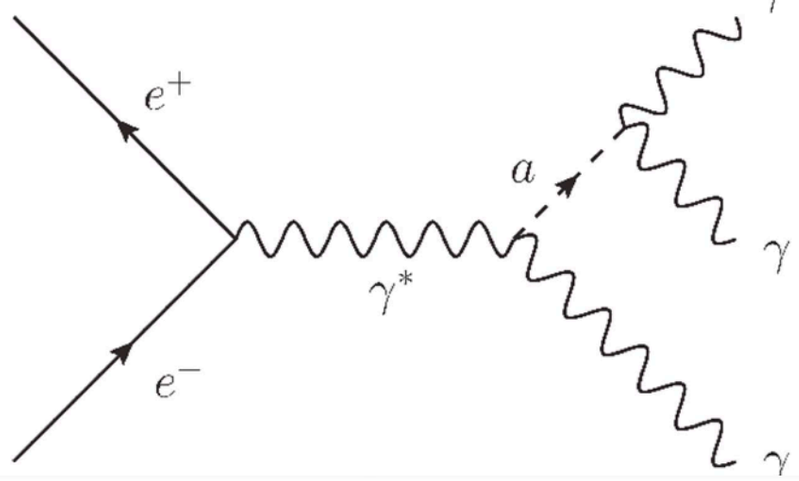




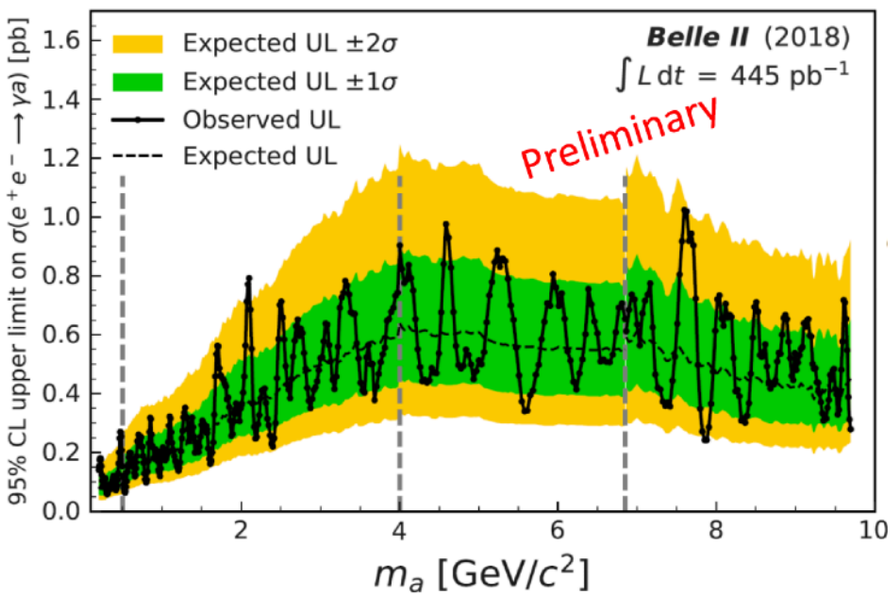
Search for Axion Like Particle (ALP)

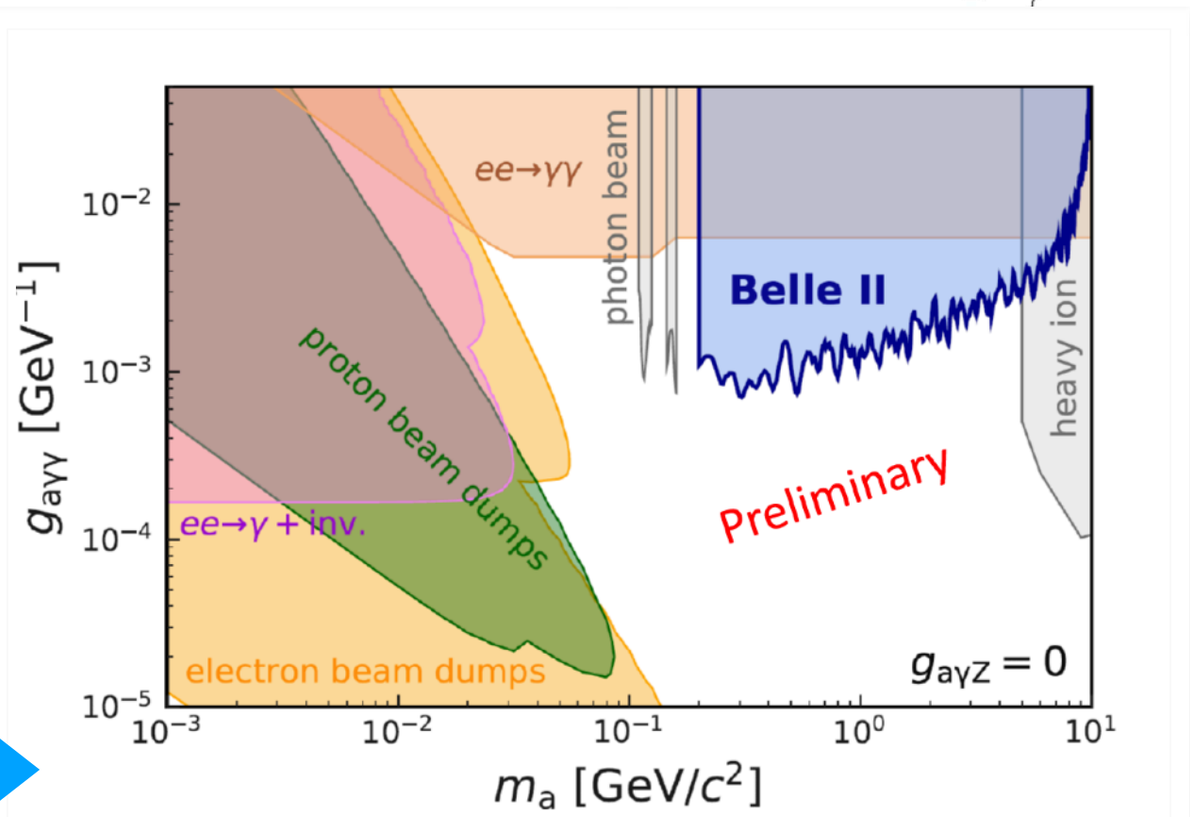
Talk by Savino Longo

- Appear in SM extensions after some global (i.e. family) symmetry breaking
- Pseudo-Goldstone bosons → Naturally light
- Cold dark matter candidates if m_a is sub MeV
- Couple naturally to photons



- Search for3-photon final states via ALP-strahlung either in
  - recoil invariant mass (high m_a)
  - di-photon mass (low m_a)
- assume Br(a → γγ)=100% → $g_{a\gamma\gamma}$

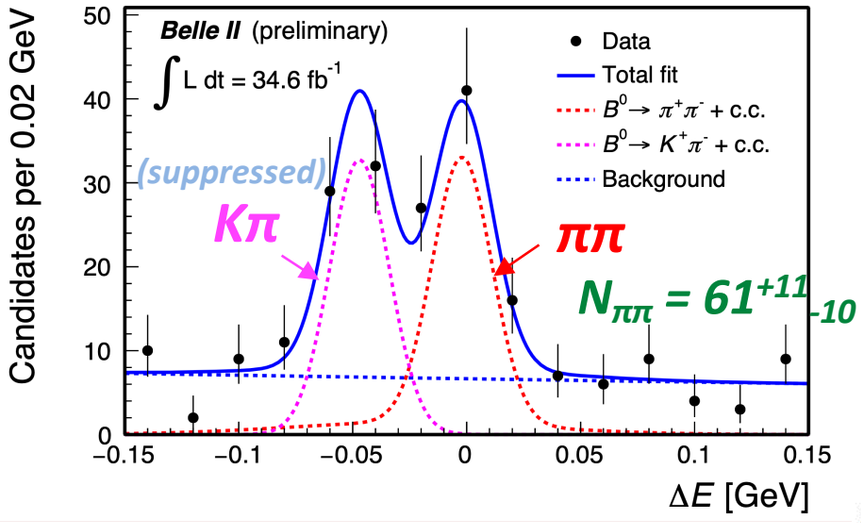




2nd physics paper by Belle II
arXiv: 2007.13071, submitted to PRL

Toward Φ_1, Φ_2, Φ_3 measurements

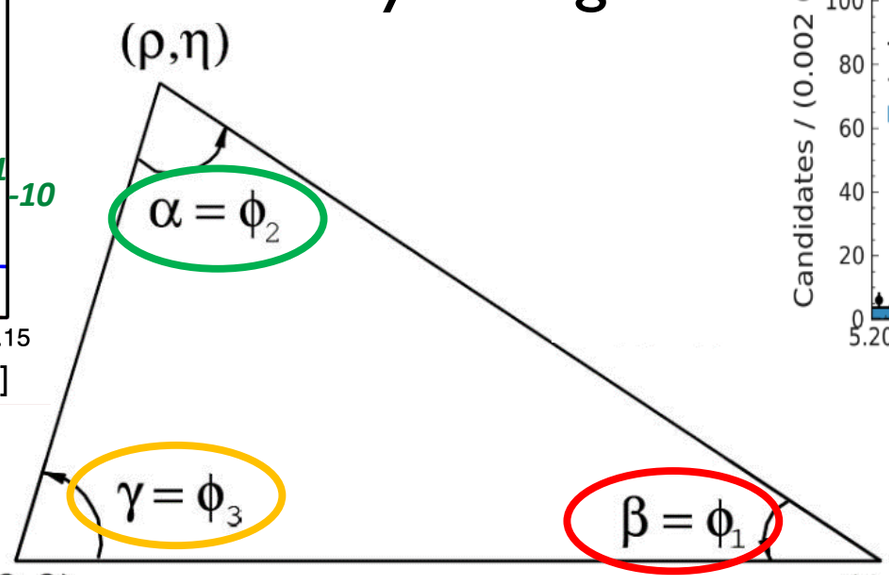
$B^0 \to \pi^\pm\pi^\mp$ $[\varphi_2]$



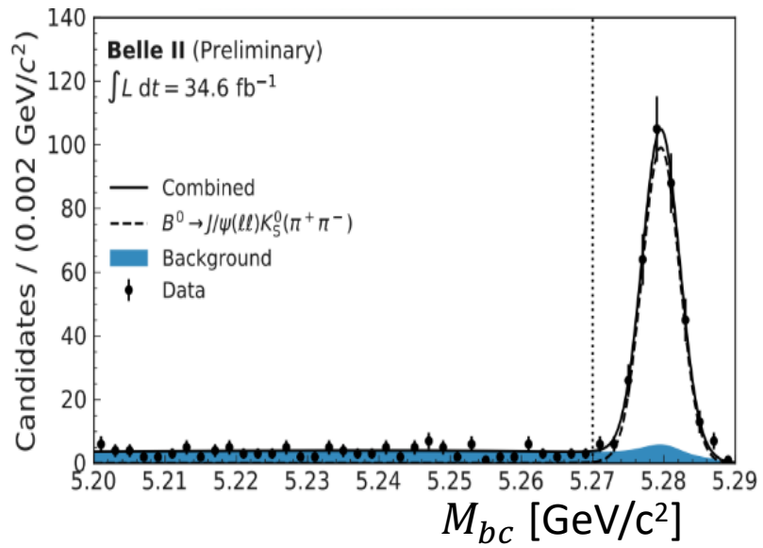
$Br = (5.6^{+1.0}_{-0.9} \pm 0.3) \times 10^{-6}$

CKM

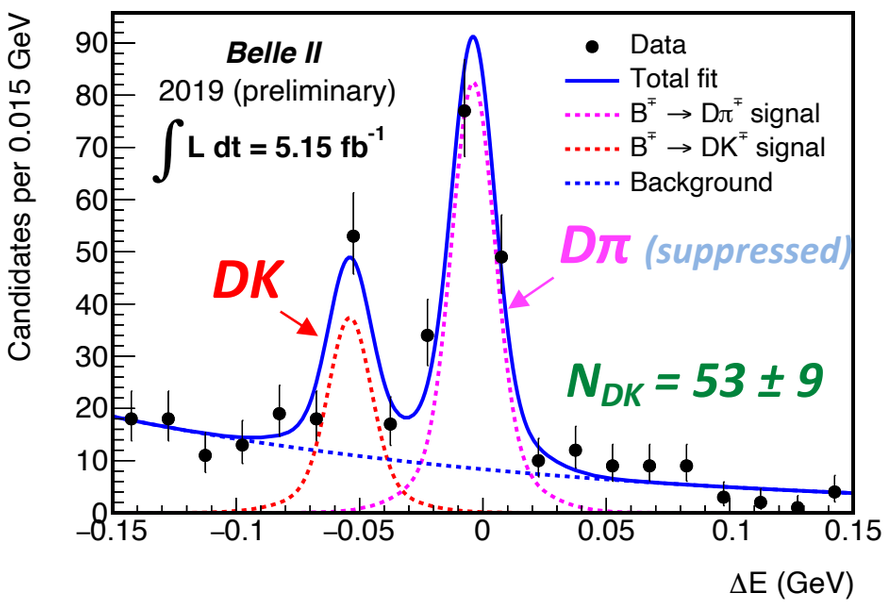
Unitarity triangle



$[\varphi_1]$ $B^0 \to J/\psi\, K_s$



$B^\pm \to D^0 K^\pm$ $[\varphi_3]$

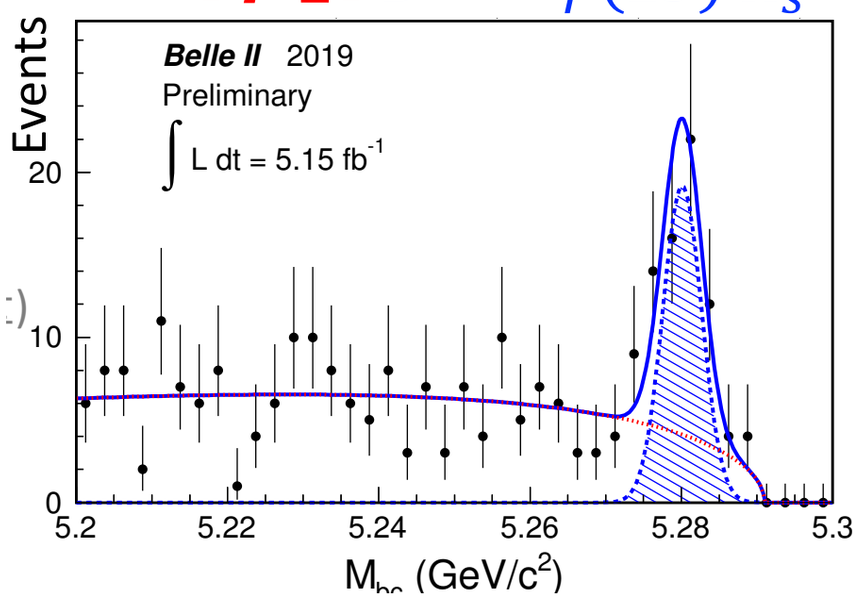


Beam energy constrained mass

$$M_{\rm bc} \equiv \sqrt{E^{*2}_{\rm beam} - p^{*2}_B}$$

$$\Delta E \equiv E^*_B - E^*_{\rm beam}$$

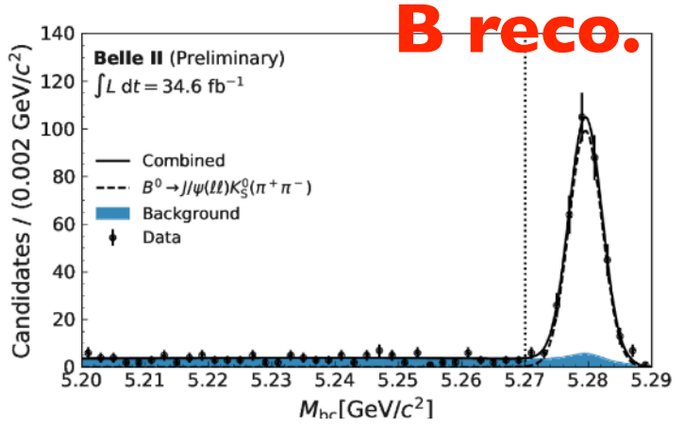
$[\varphi_1]$ $B^0 \to \psi(2S)\, K_s$

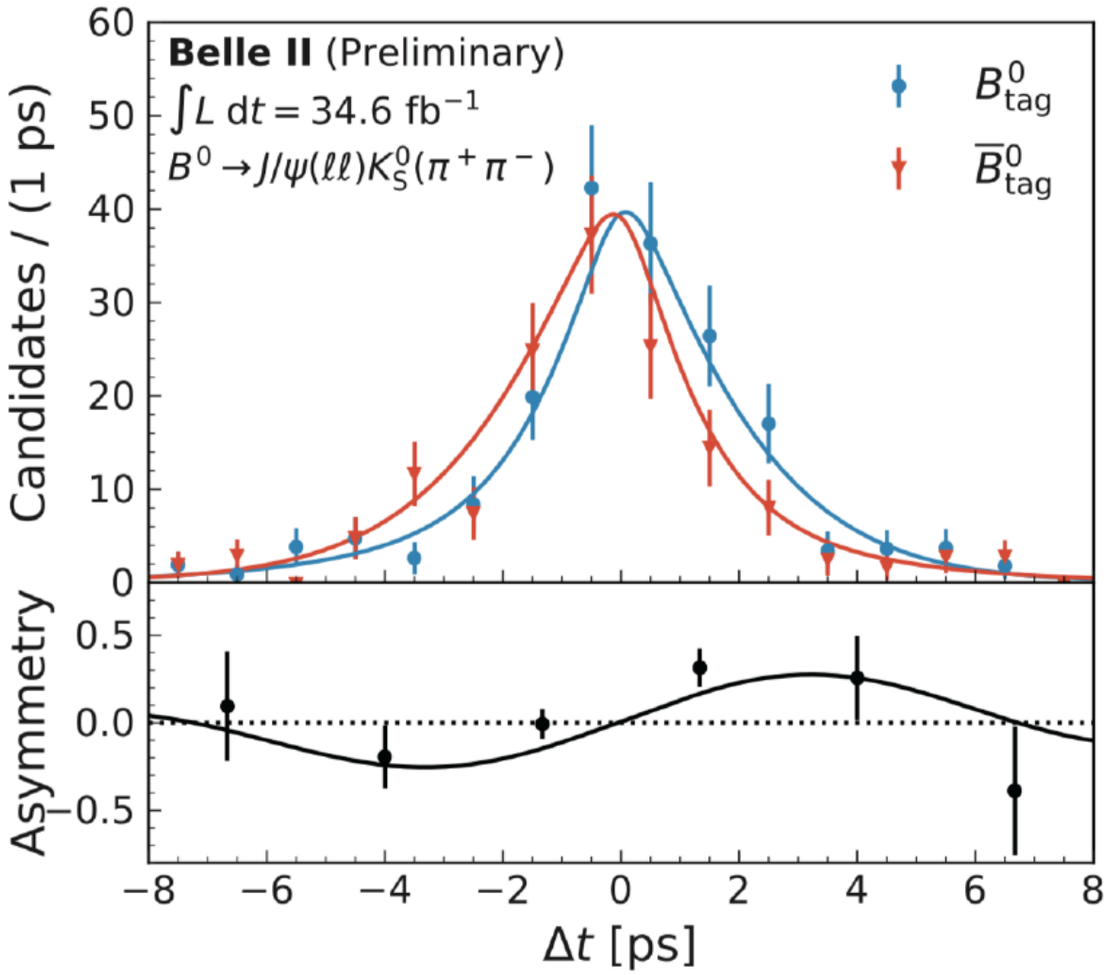


TDCPV ($B \to J/\psi K_S^0$)

- The golden channel $B^0 \to J/\psi(ll)K_S^0(\pi^+\pi^-)$ is studied.
- CPV is assumed only from the B^0 mixing ($A_{CP}=0$)

B reco.

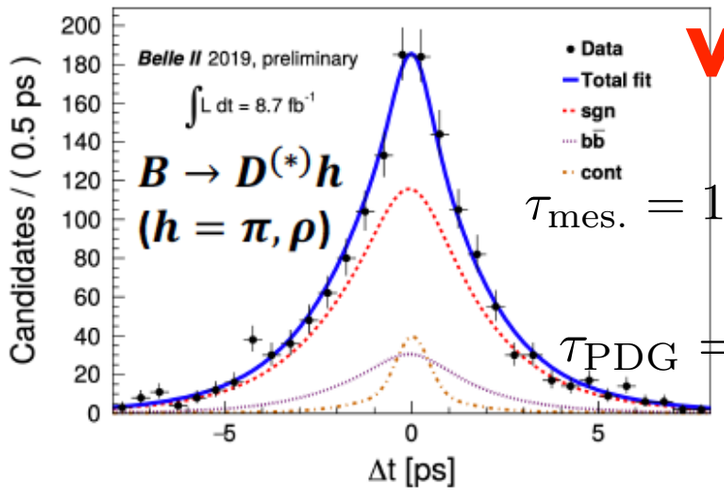




$$S_{CP} = 0.55 \pm 0.21(\text{stat.}) \pm 0.04(\text{system.})$$

$$S_{\text{PDG}} = 0.701 \pm 0.017$$

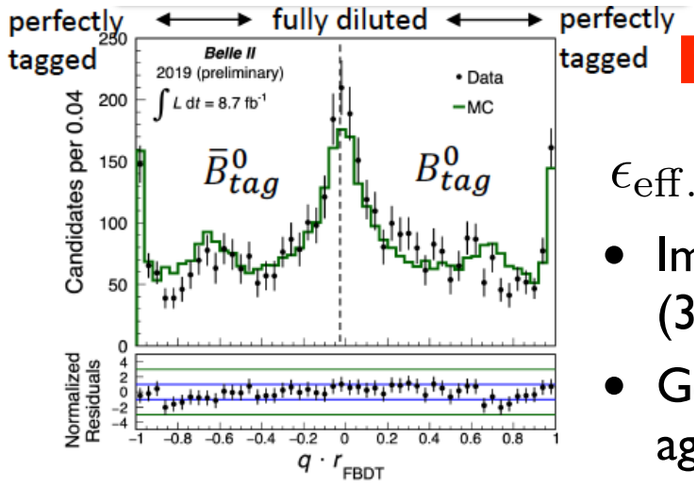
Vertex reso.



$$\tau_{\text{mes.}} = 1.48 \pm 0.28 \pm 0.06[\text{ps}]$$

$$\tau_{\text{PDG}} = 1.519 \pm 0.004[\text{ps}]$$

Flavor tag.



$$\epsilon_{\text{eff.}} = 33.8 \pm 3.9\%$$

- Improved over Belle (30.1±0.4%)
- Good Data/MC agreement

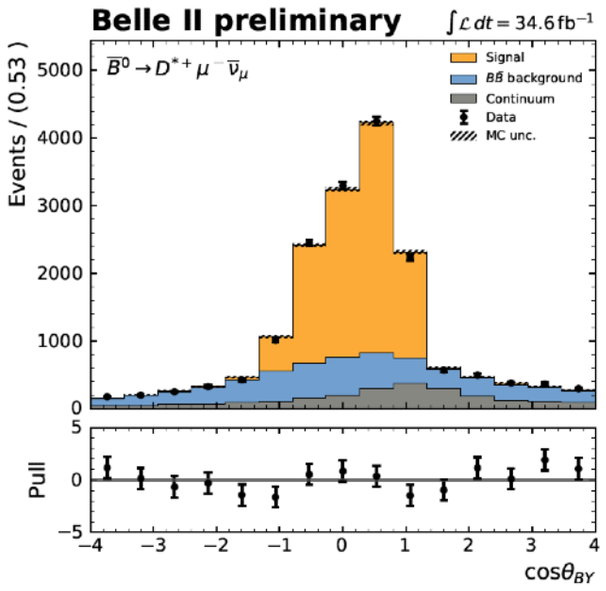
Semileptonic B decays

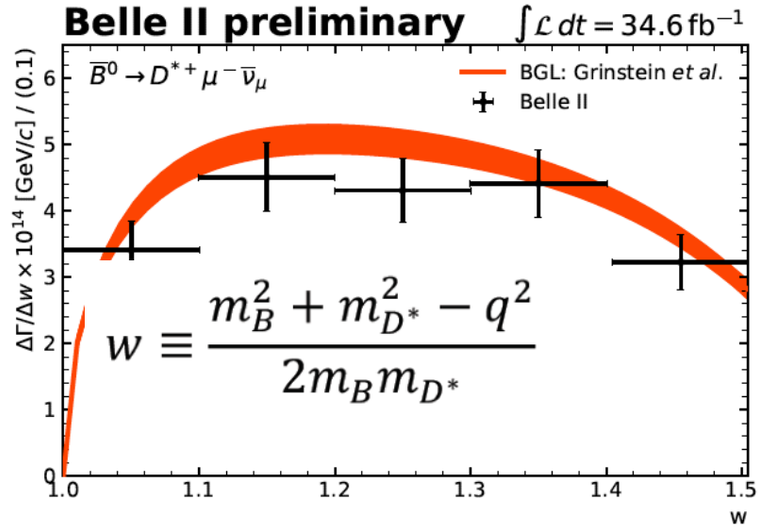
$|V_{cb}|$ from exclusive B→D*lν (untag)

- Extract signal in the $\cos\theta_B$ dist.

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

- Obtain $|V_{cb}|$ from the rate at the zero recoil limit with more statistics



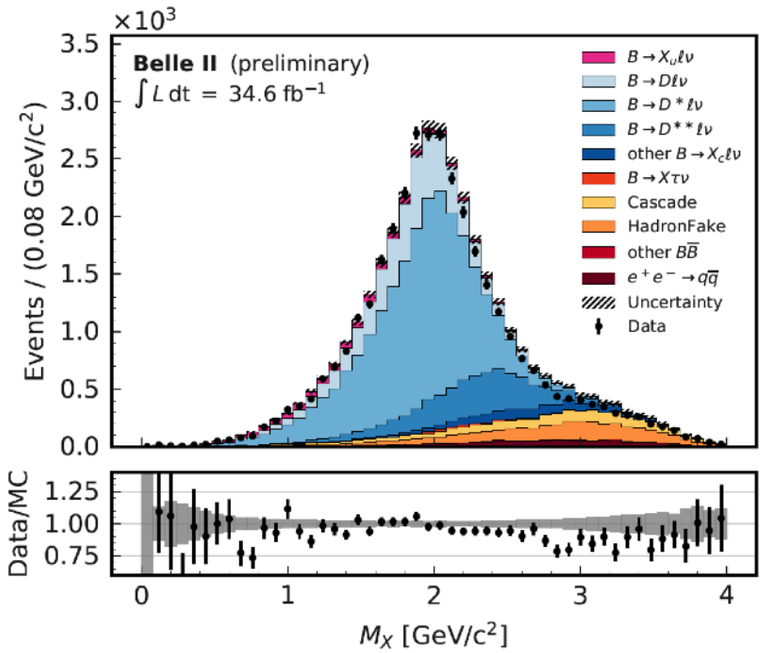


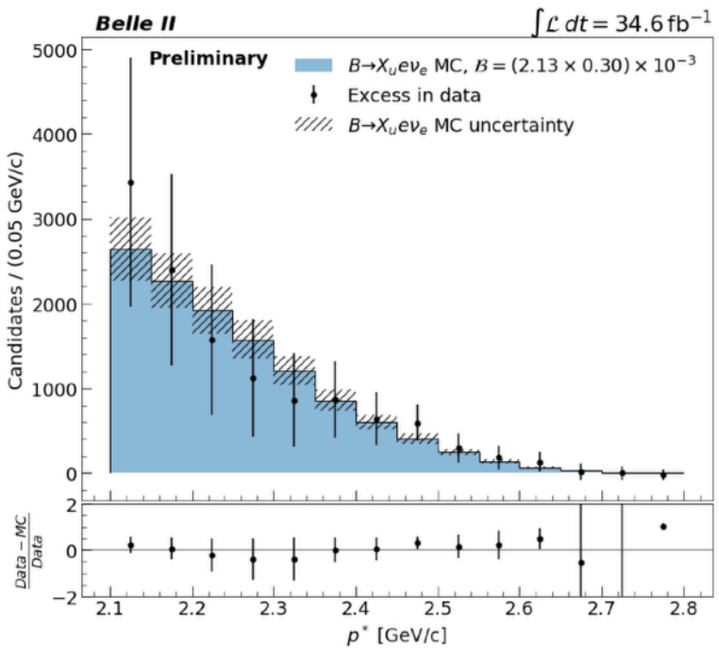
$|V_{cb}|$ from inclusive b→c

- Hadronic FEI tag to measure Mx (hadronic invariant mass)
- Mx moment to constrain non-perturbative parameters

$|V_{cb}|$ from inclusive b→u

- Untag
- Lepton at the end-point (less b→c background)





BELLE2-CONF-PH-2020-011

τ mass measurement

- Select τ→3πν decays in e+e- →τ+τ-
- τ mass estimated by pseudo mass and fit the distribution at the edge.

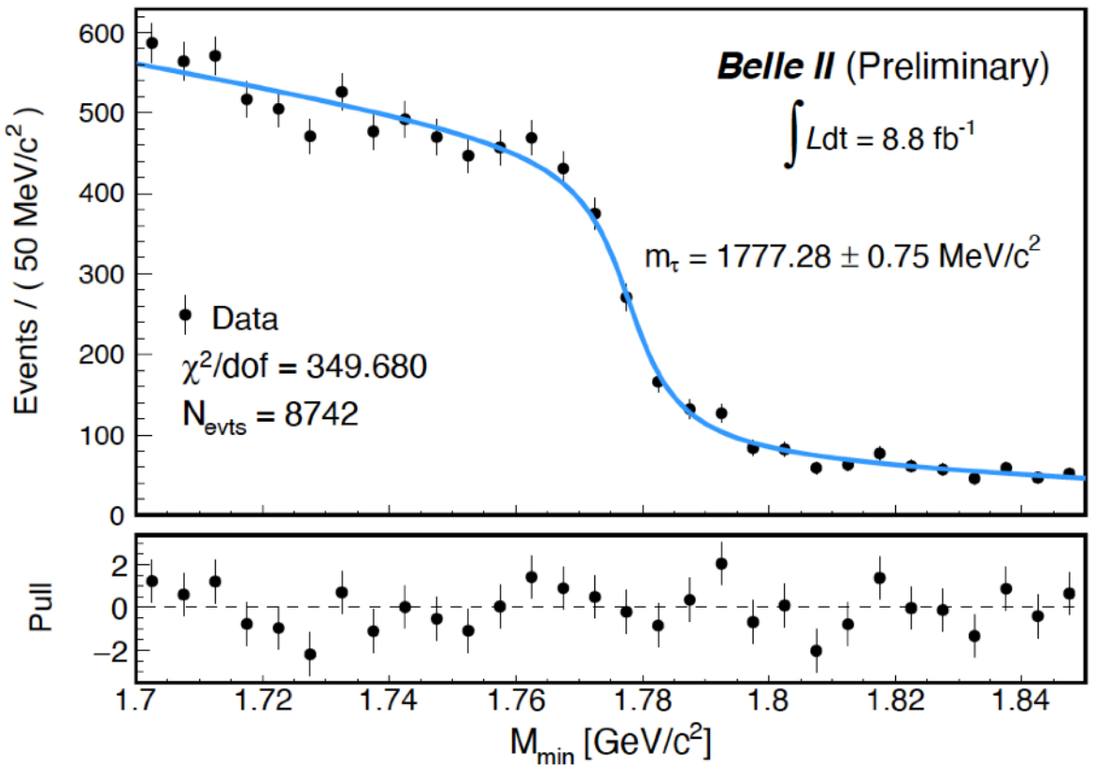
$$M_{min} \equiv \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})} \leq m_\tau$$

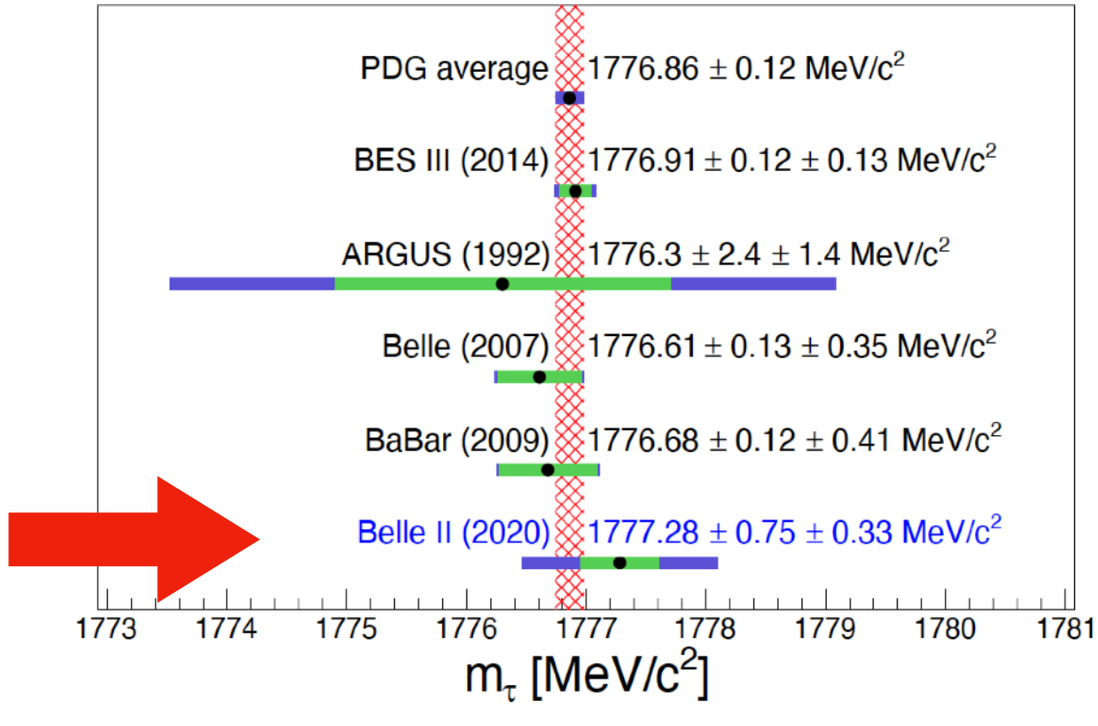
$$m_\tau = 1777.28 \pm 0.75(\text{stat.}) \pm 0.33(\text{syst.})$$

$$m_\tau(\text{PDG}) = 1776.86 \pm 0.12\text{MeV}$$

- Systematic errors are already comparable to Belle, BaBar

Systematic uncertainty	MeV/c^2
Momentum shift due to the B-field map	0.29
Estimator bias	0.12
Choice of p.d.f.	0.08
Fit window	0.04
Beam energy shifts	0.03
Mass dependence of bias	0.02
Trigger efficiency	≤ 0.01
Initial parameters	≤ 0.01
Background processes	≤ 0.01
Decay model	≤ 0.01
Tracking efficiency	≤ 0.01





Belle II talks in BEAUTY2020

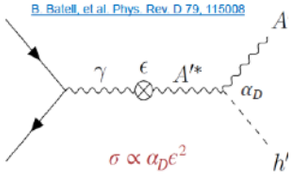
- Thibaud Humair "B-lifetime and time-dependent CP violation measurement at Belle II"
- Keisuke Yoshihara "b→s Penguin Analysis Updates from Belle II”
- Yun-Tsung Lai "Updates in Charmless B-Meson Decays at Belle II"
- Hulya Atamacan"Measurement of R(D) and R(D*) at Belle II"
- Andrea Fodor "Measurement of B→Xu l ν at Belle II"
- Guanda Gong" Charmed-Meson Physics at Belle II"
- Savino Longo "Dark-matter and ALP search at Belle II"
- Kiyoshi Tanida "Spectroscopy Study at Belle II"
- Eiasha Waheed "Measurement of the CKM angle Φ_3 at Belle II"
- Phillip Urquijo "Short and longer-term future of B physics" (plenary)

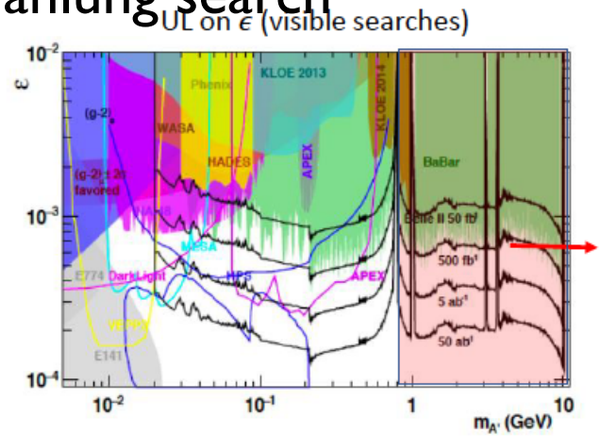
Near Term Prospects

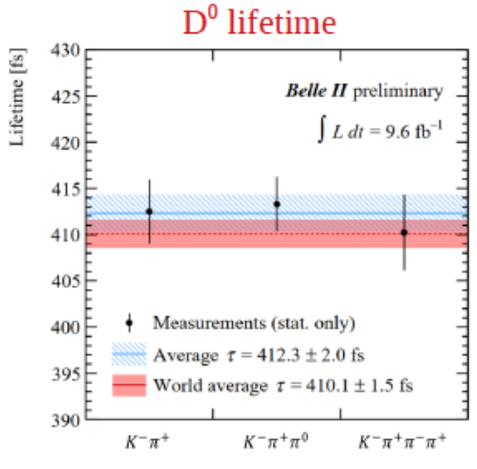
- The data taken by 2020b(+ by this JFY) provides world competitive or leading results;
  - $B \to D^* l \nu$, D lifetime, τ mass etc.
  - Dark sector searches
- Belle II is ready to accumulate more data; comparable to Belle by 2021 summer and >1ab^{-1} target by 2021 X'mas.

Many world-leading results !

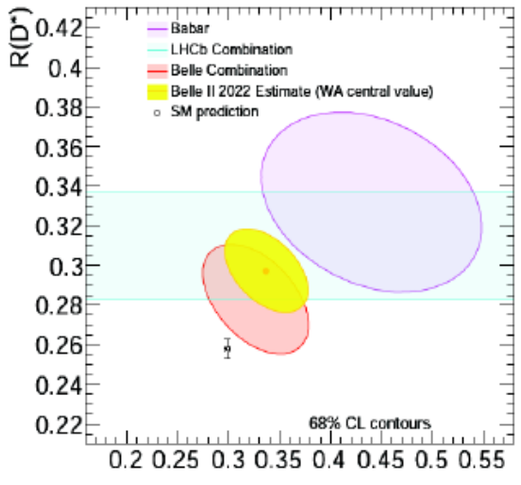
Dark higgstrahlung search

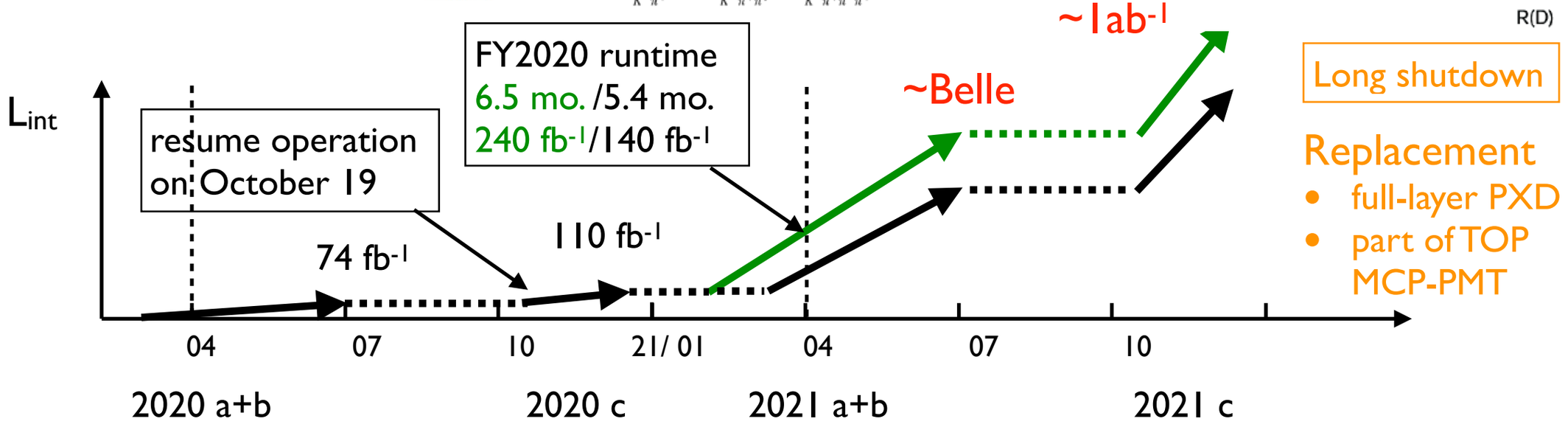






R(D$^{(*)}$) w/ 1.5ab^{-1}



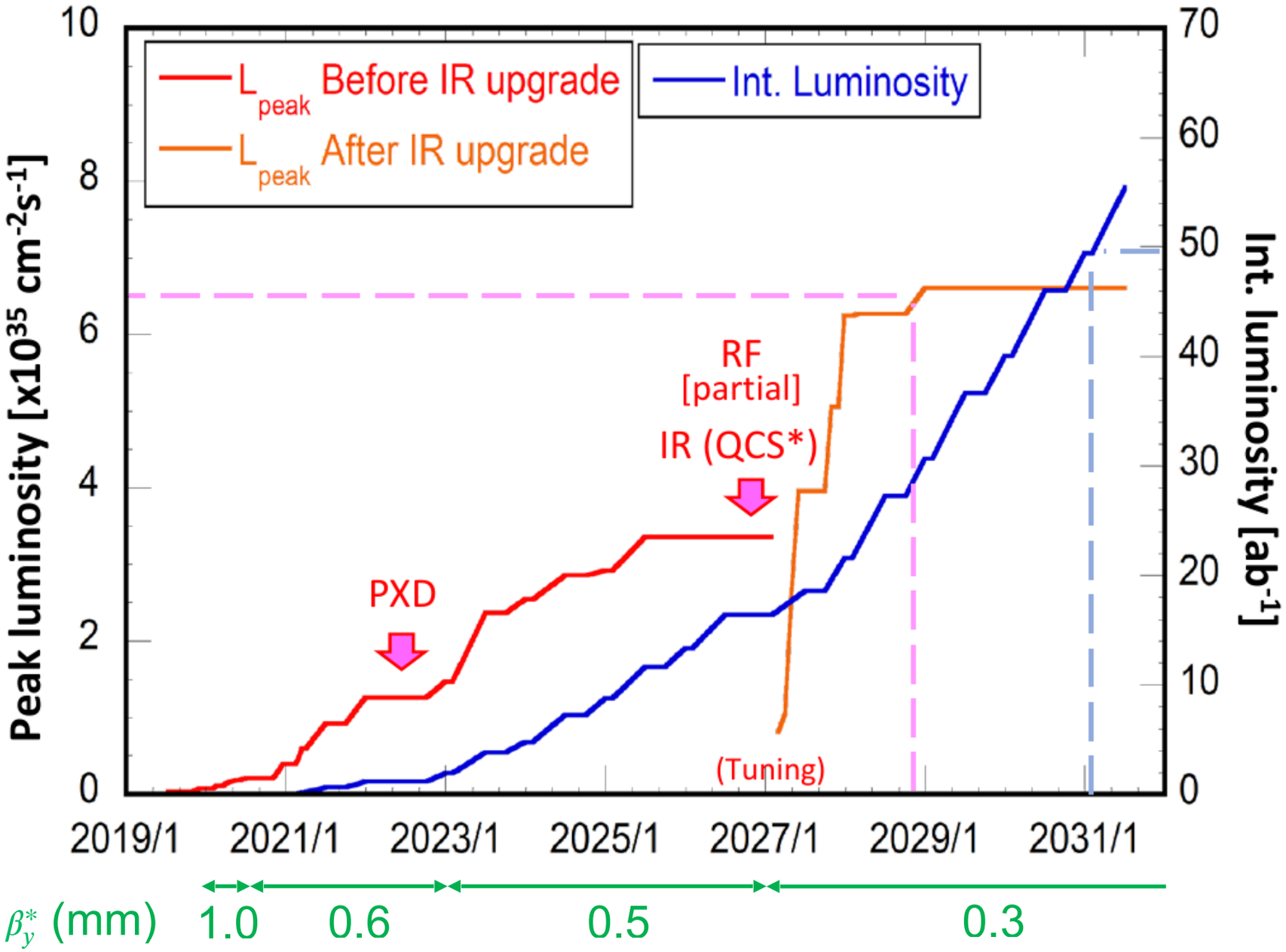


Long shutdown

Replacement
- full-layer PXD
- part of TOP MCP-PMT

Mid-Long Term Plan

- Recently updated based on the past results.
  - $L_{peak} > 6 \times 10^{35} cm^{-2}s^{-1}$ after modification of SuperKEKB (partial RF, IR, …) and Belle II
  - Reach $50 ab^{-1}$ goal around 2030



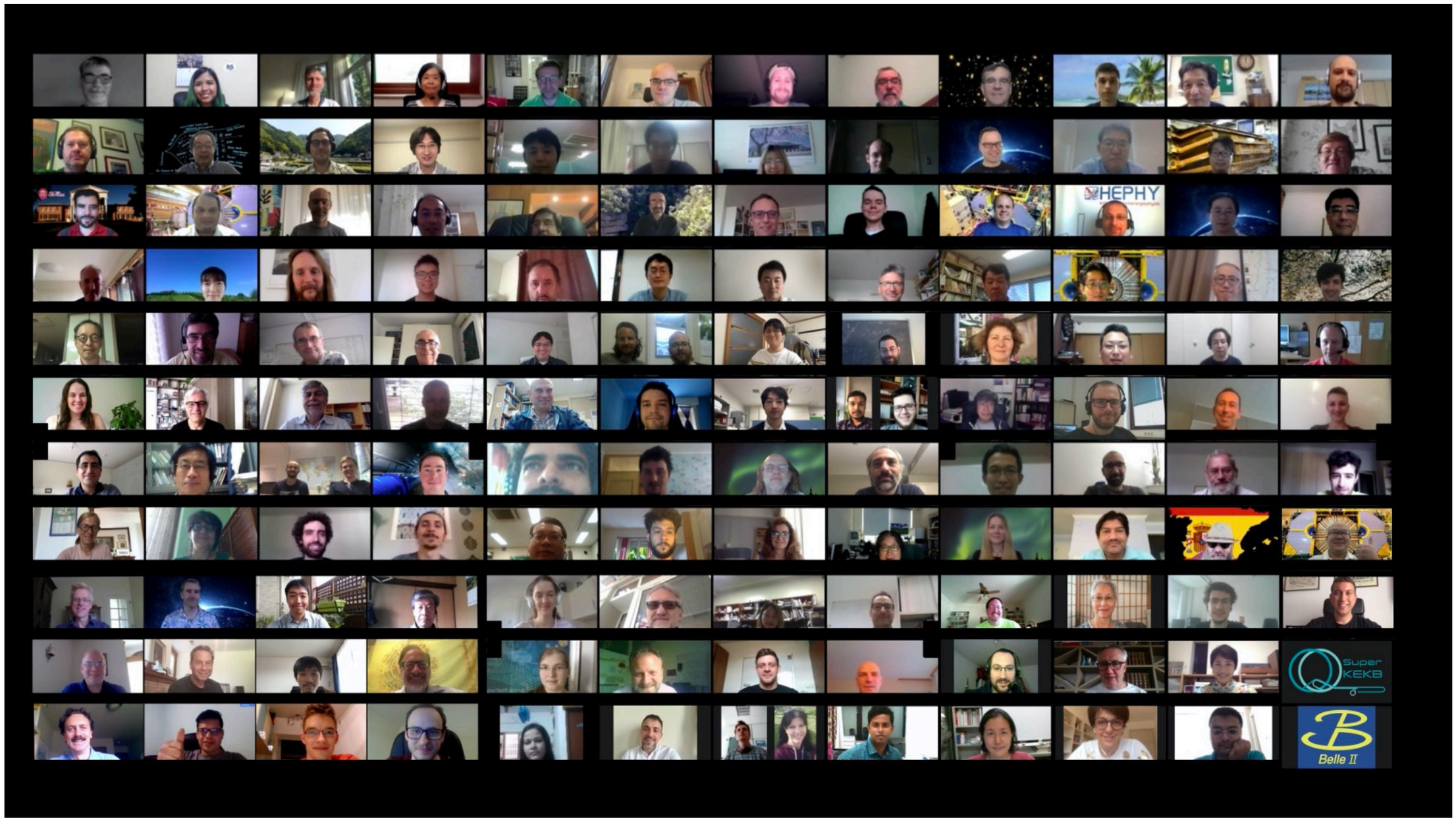
Summary

- The Belle II experiment at SuperKEKB aims to find New Physics beyond the SM with ultimate precision measurement (a few %, typically) of heavy flavor decays.
- SuperKEKB has achieved L_{peak} =2.4 x $10^{34}cm^{-2}s^{-1}$ (world highest luminosity)
- Belle II is performing as expected, and obtained early physics results.
  - Accumulated 74 fb^{-1} by summer 2020.
  - World leading results for dark sector physics
- Belle II is ready to accumulate more luminosity.
  - Belle/BaBar data size and beyond by 2021
- SuperKEKB/Belle II aims at accumulate 50ab^{-1} by ~2030, by further improving the luminosity performance.
- Aggressive plans toward > 50ab^{-1} and w/ pol. e^- beam are also discussed.
  - being document (e.g. : Snowmass 2021)

Stay Tuned !

Thank you !

Belle II Group Photo @ B2GM, June 2020



Backup Slides