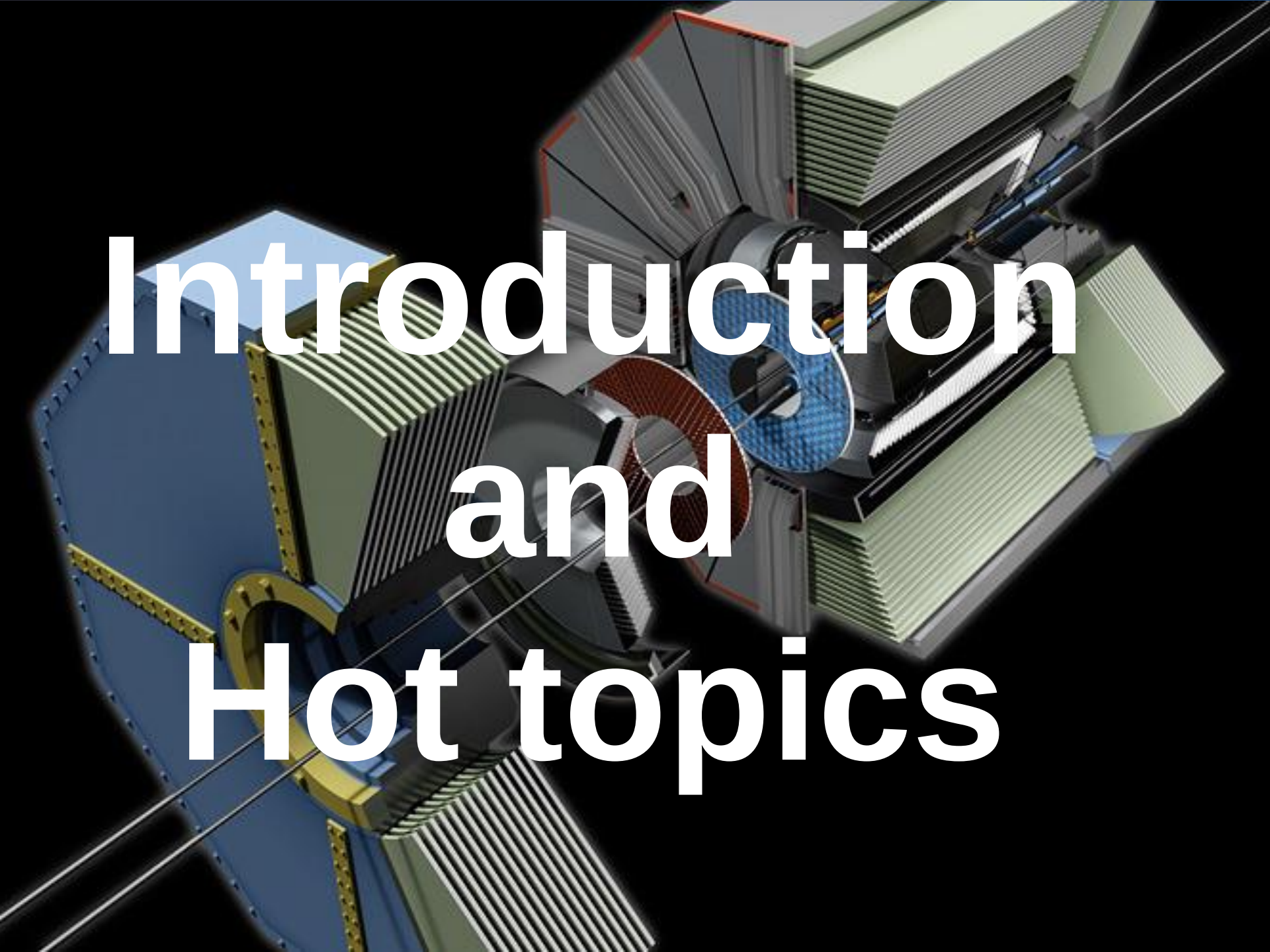
Belle II Experiment: Status and Physics Prospects

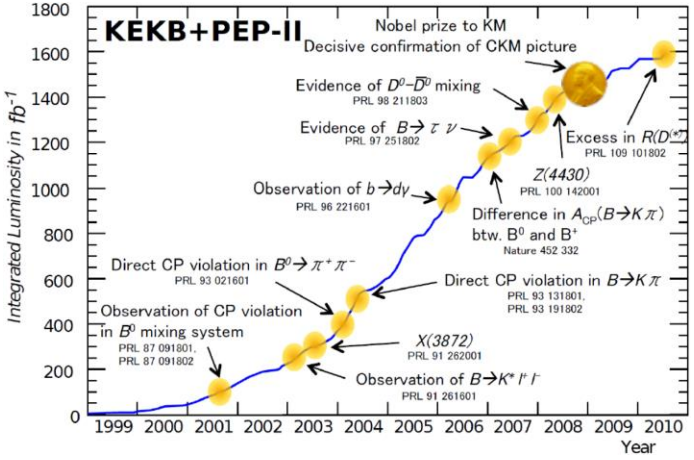
Hideki Miyake (KEK)
On behalf of Belle II collaboration

2018 June 8th, FPCapri 2018, Anacapri, Capri, Italy


Introduction
and
Hot topics

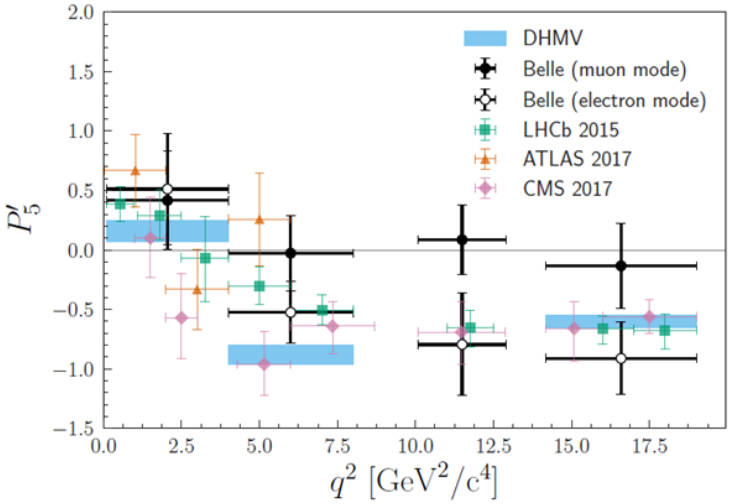
B-factory: Belle to Belle II

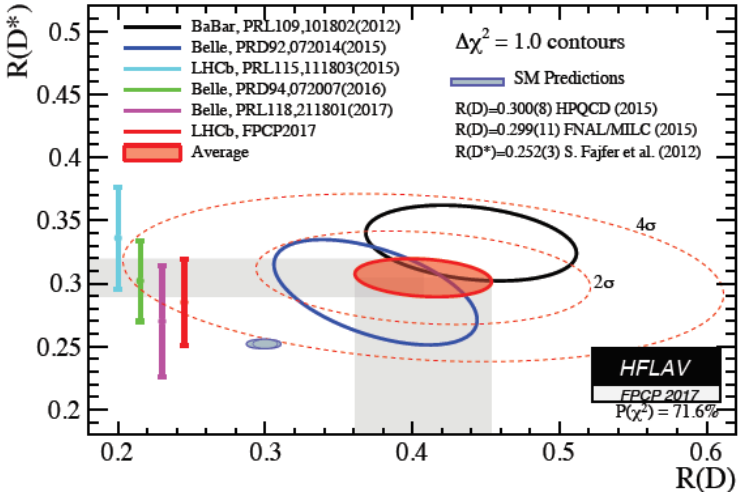
- e^+e^- B-factories have been a driving force to establish the standard model and search for new physics



Observation machines!

- Recently some anomalies measured in B decays… a hint of BSM!

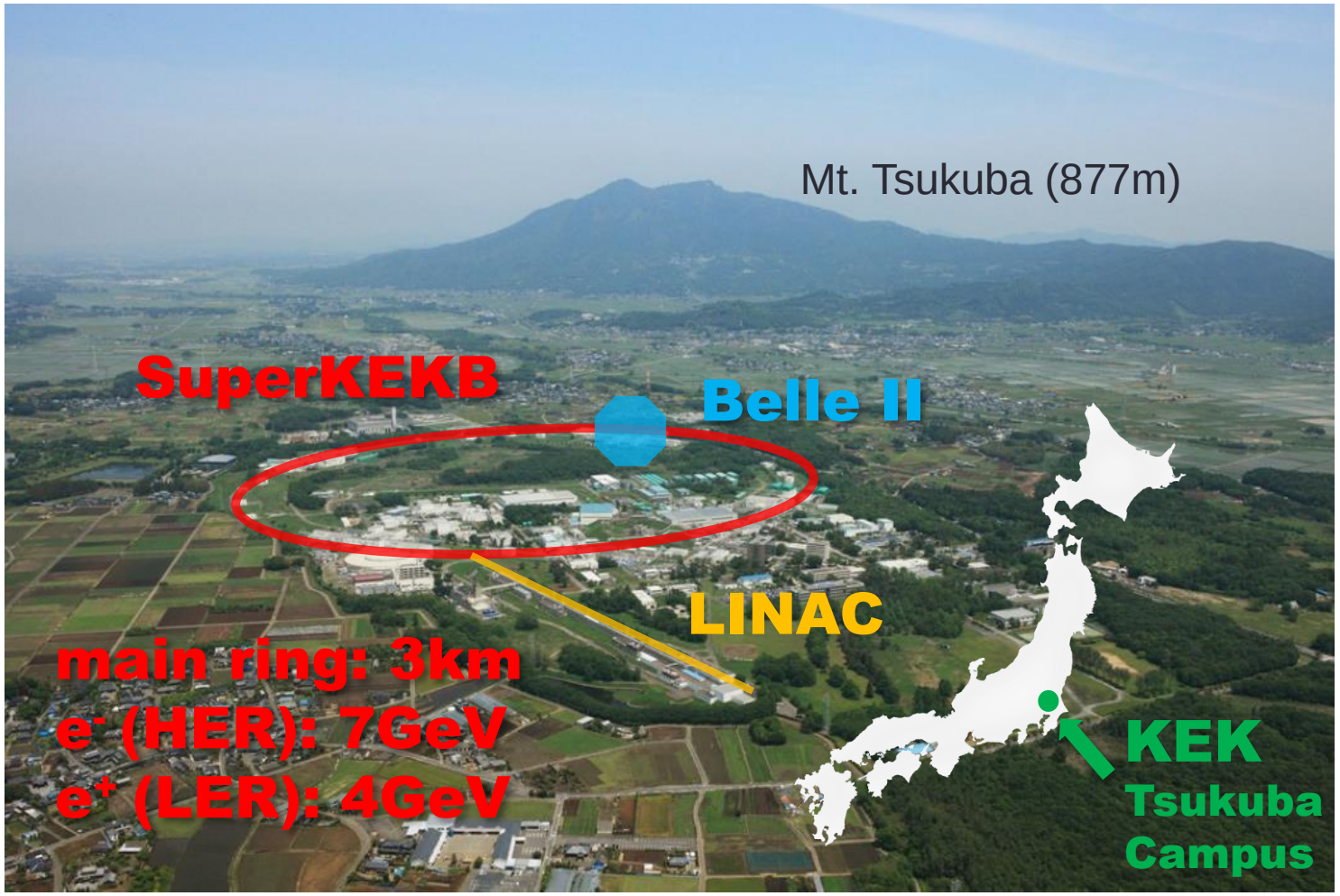




- Belle II provides
  - Complementary measurements to LHC experiments
  - Rich physics program (not only B decays) … x40 luminosity than Belle

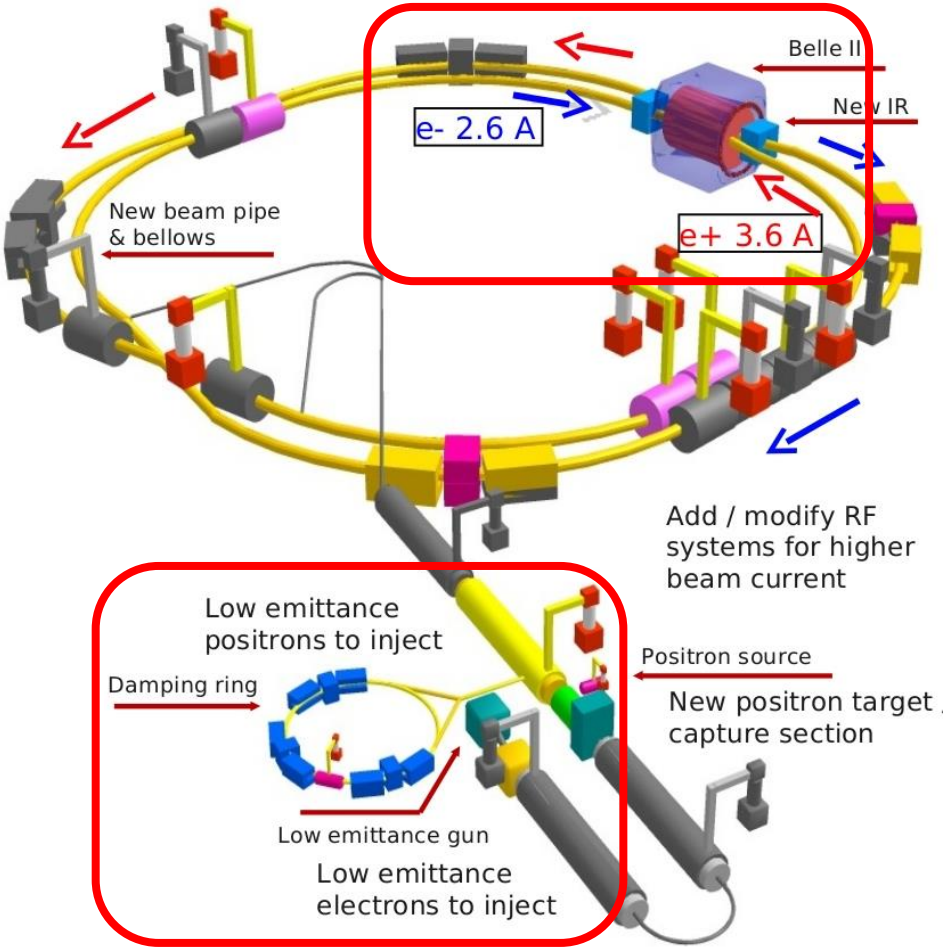
Belle II + SuperKEKB

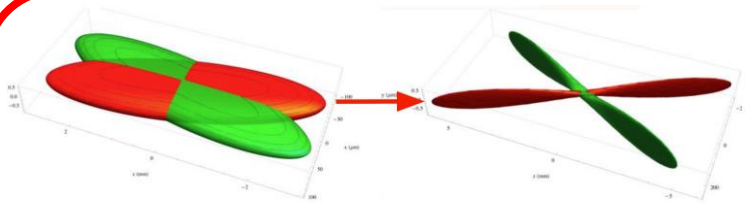
- KEK is located in Tsukuba, Japan (50km away from Tokyo)



SuperKEKB

- SuperKEKB is successor of former KEKB but refurbished with the new design





KEKB SuperKEKB

"nano-beam" scheme
Beam squeezing: x20 smaller at IR

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

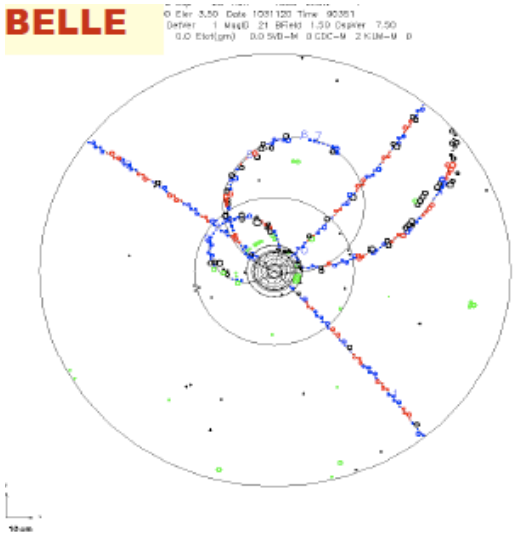
x2

X1/20

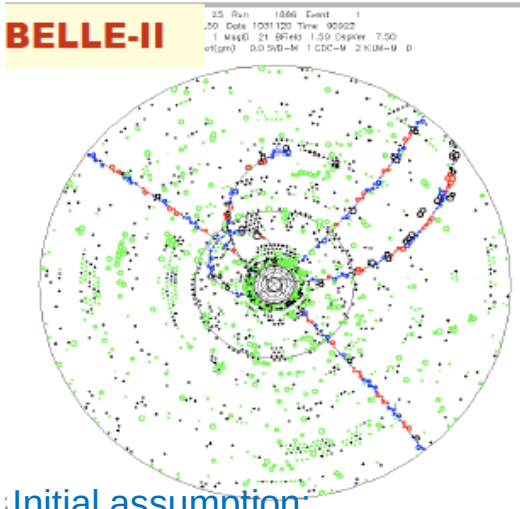
Target luminosity: $8\times10^{35}\text{cm}^{-2}\text{s}^{-1}$
KEKB x 40!

Challenge: high beam background

- x40 times peak luminosity also brings severe beam related backgrounds



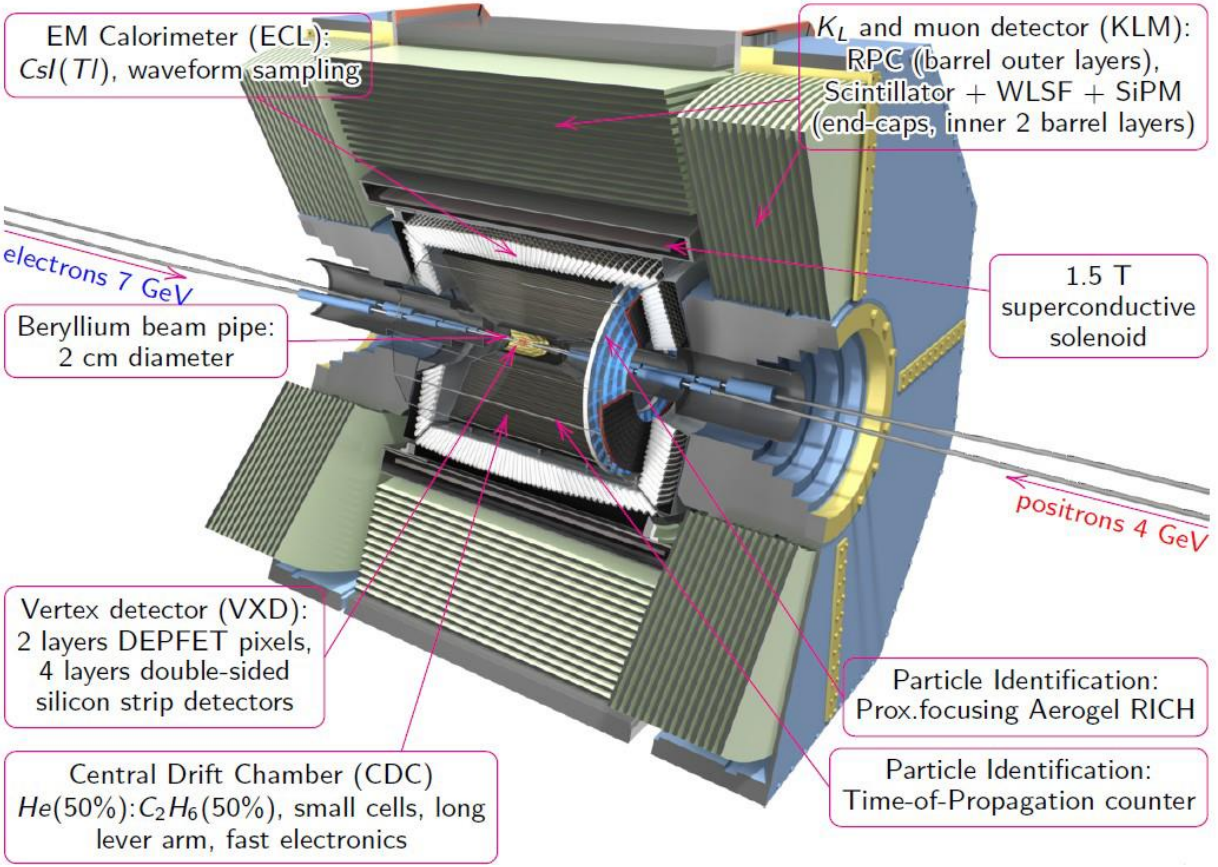
- Belle II detector was designed to overcome the issue
  - Finer granularity
  - Better timing resolution
  - High trigger rate through pipeline readout



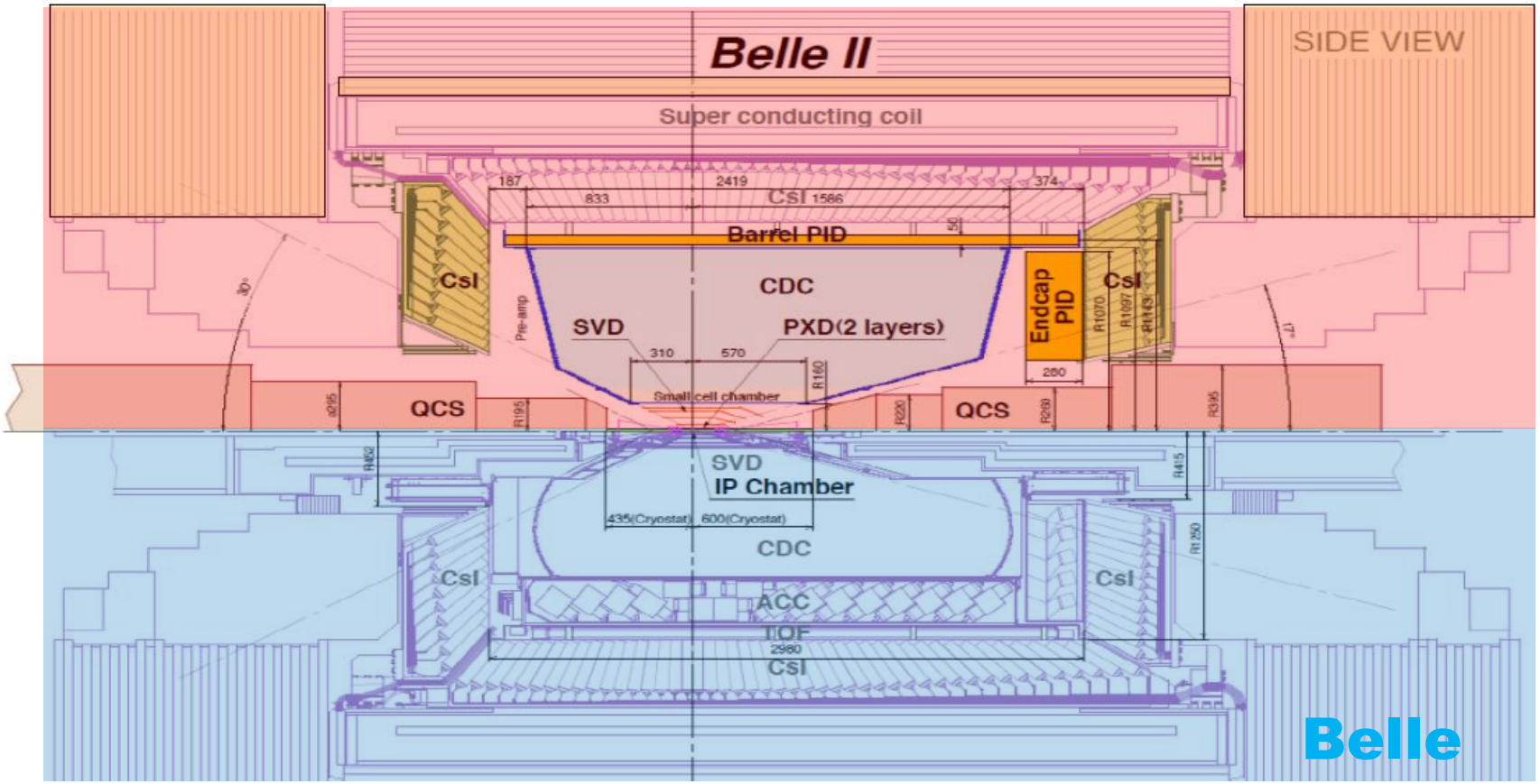
Initial assumption:
Belle detector with KEKB x20 BG

Belle II detector

- Replaced most of Belle detectors (reused only calorimeter crystal and a part of K_L and muon detector)

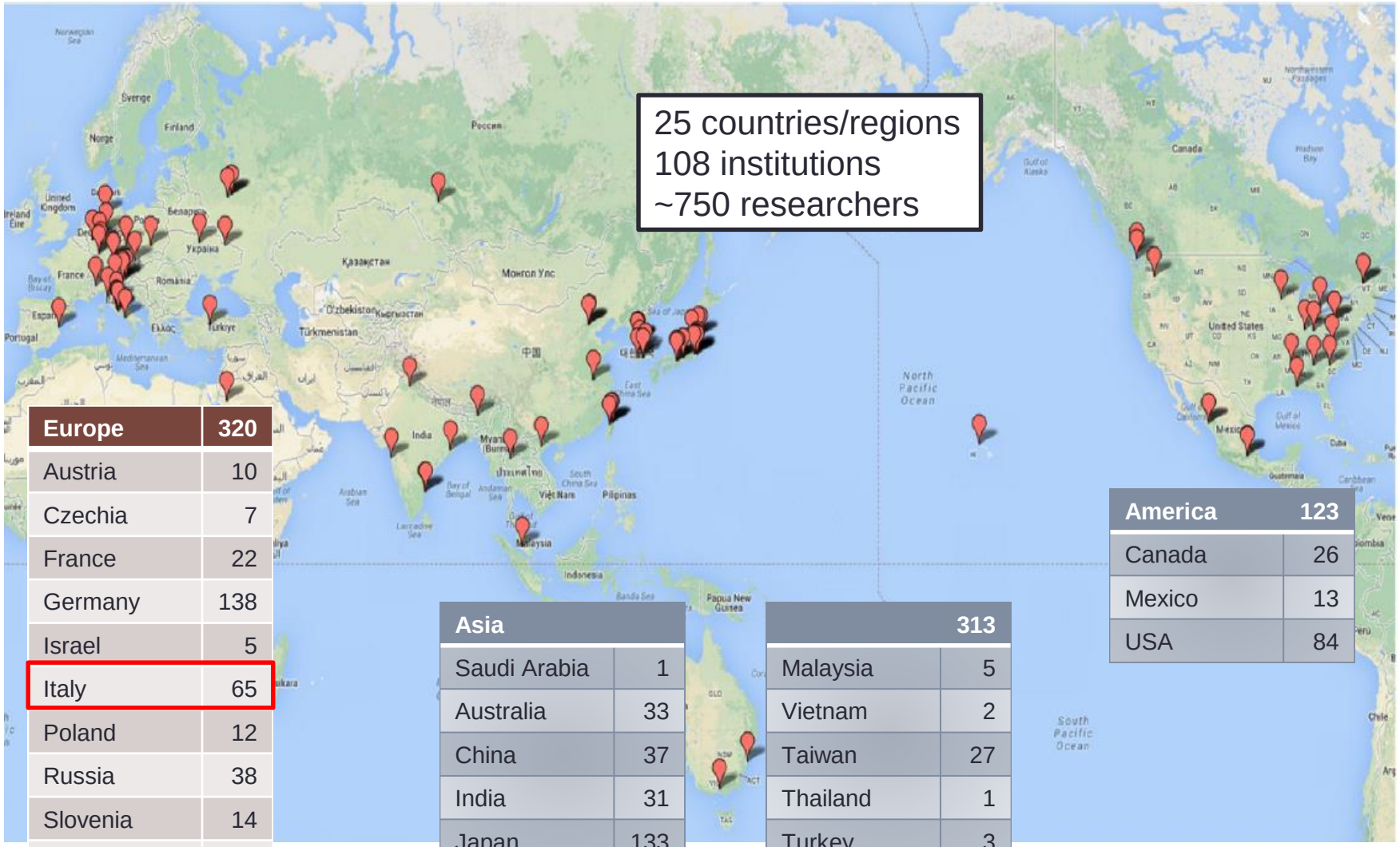


Belle vs Belle II



SVD 4 layers (DSSD) → 2 DEPFET + 4 DSSD
CDC: small cell, long lever arm
ACC+TOF → TOP+ARICH
ECL: waveform sampling
KLM: RPC → Scintillator+SiPM
TDR arXiv:1011.0352

Belle II collaboration



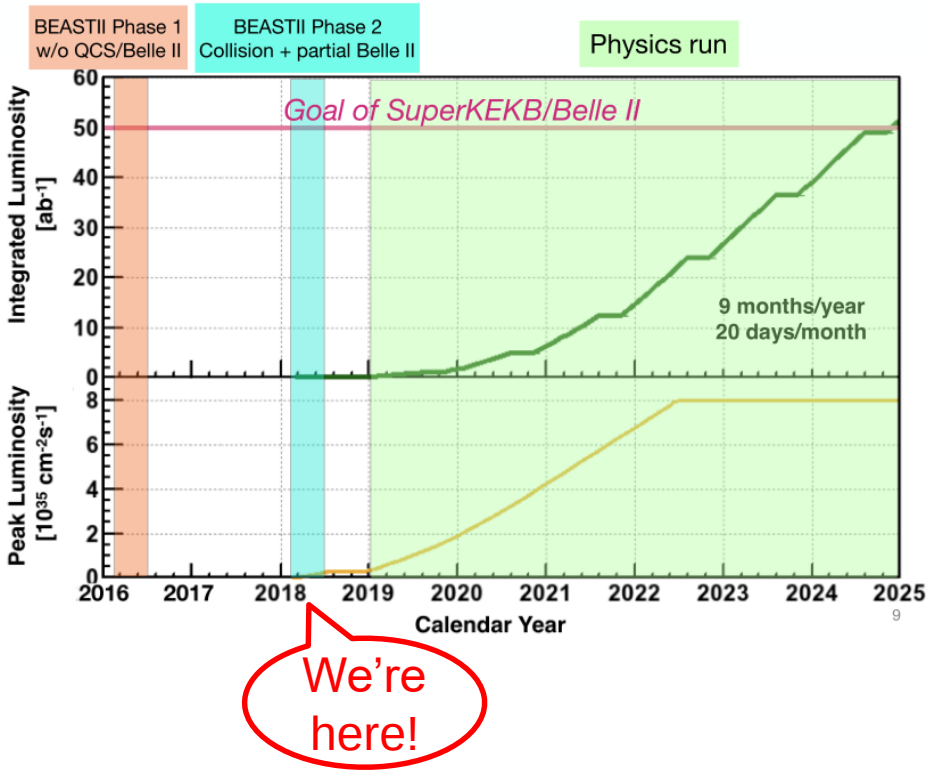
Europe	320
Austria	10
Czechia	7
France	22
Germany	138
Israel	5
Italy	65
Poland	12
Russia	38
Slovenia	14
Spain	5
Ukraine	4

Asia	
Saudi Arabia	1
Australia	33
China	37
India	31
Japan	133
Korea	40

	313
Malaysia	5
Vietnam	2
Taiwan	27
Thailand	1
Turkey	3

America	123
Canada	26
Mexico	13
USA	84

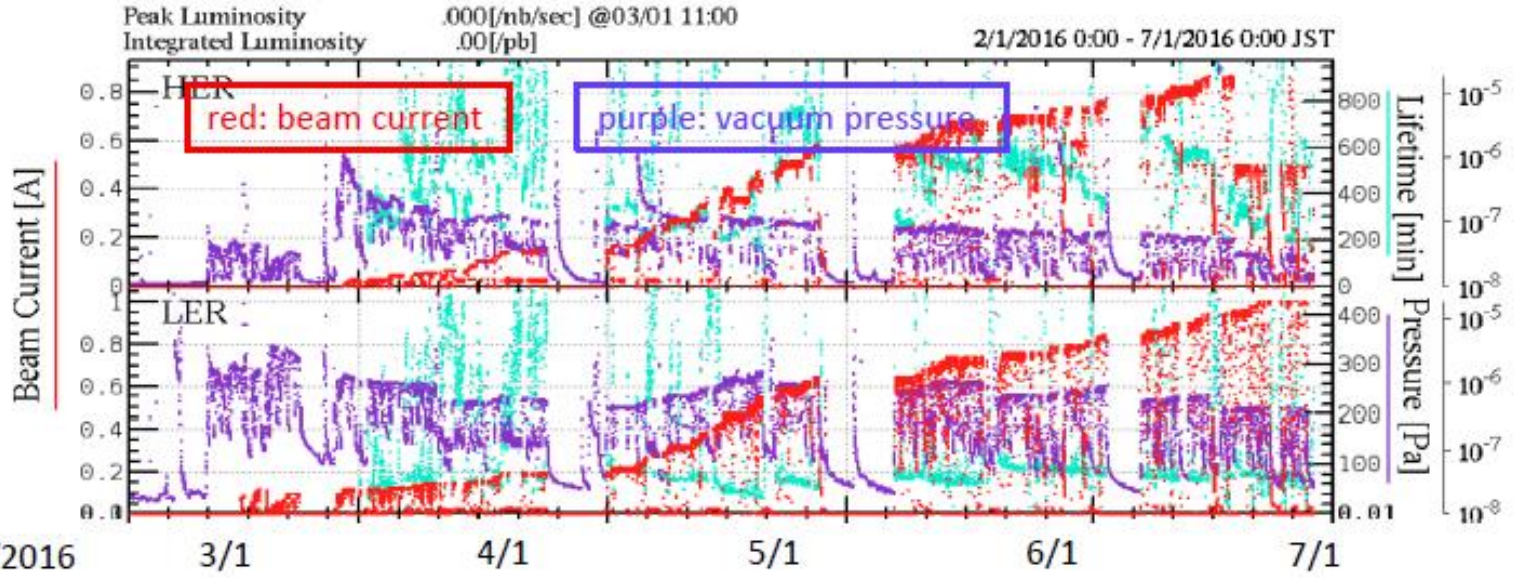
Schedule



- Belle II/SuperKEKB is gradually being launched
  - Phase 1 w/o Belle II (2016…done)
  - Phase 2 partial Belle II (since 2018…ongoing!)
  - Phase 3 full Belle II (plan for early 2019)

Phase 1

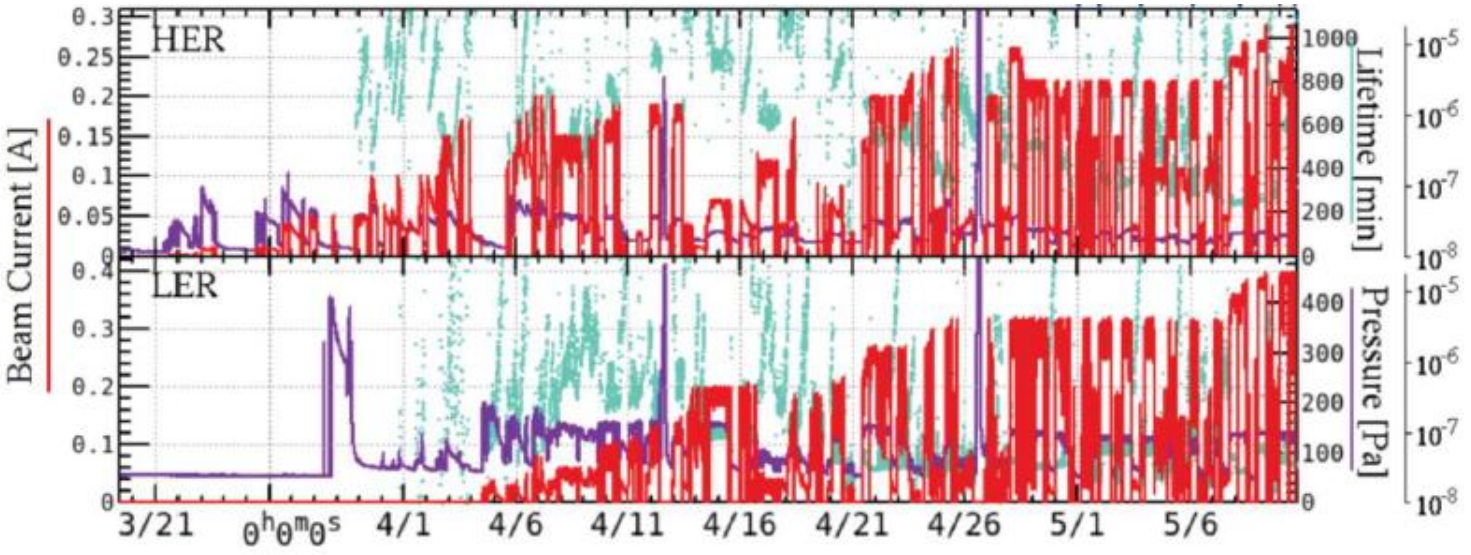
- 2016 Feb – July (no e^+e^- collisions)
- w/o Belle II (installed commissioning detector)
  - Main goal: accelerator test and BG study



- First turns of SuperKEKB beams (2016 Mar)
- Maximum stored beam current
  - 870 mA (HER)
  - 1010 mA (LER)

Phase 2

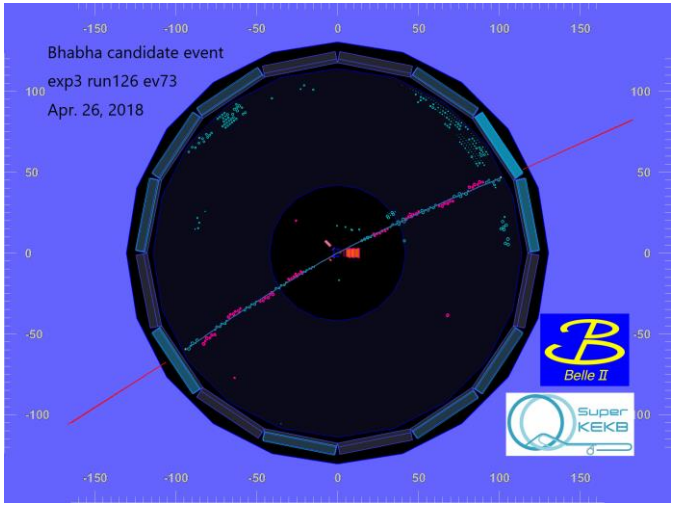
- 2018 March – ongoing
- w/ partial Belle II (no vertex detectors)
  - Verification of nano-beam scheme (target: $L>10^{34}cm^{-2}s^{-1}$)
  - Understand of beam background (especially for vertex detectors)
  - Data taking for physics (up to 20 fb^{-1} of data)



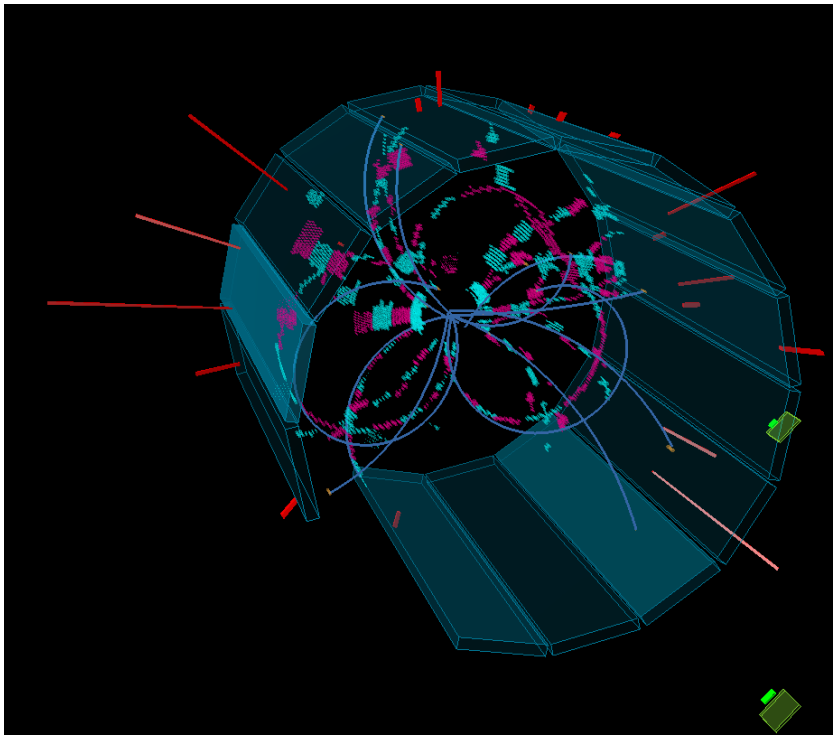
- Gradually increasing the beam current
- Gradually squeezing the beam (smaller beta)


First collisions at Apr 26!
B-factory came back to the game!

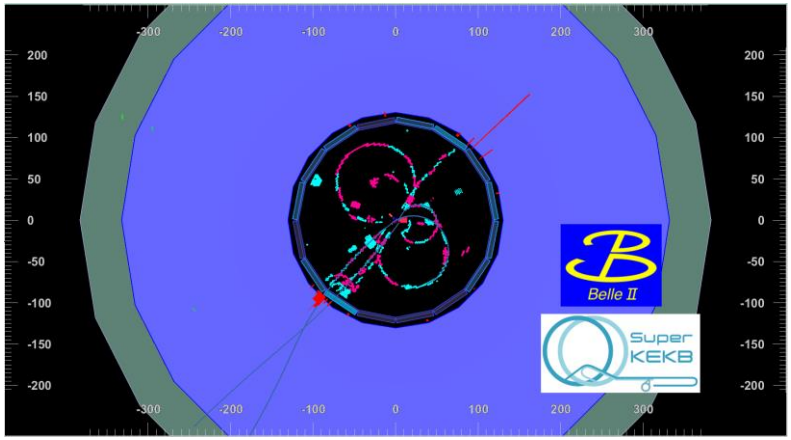
Some “first” events



Bhabha event

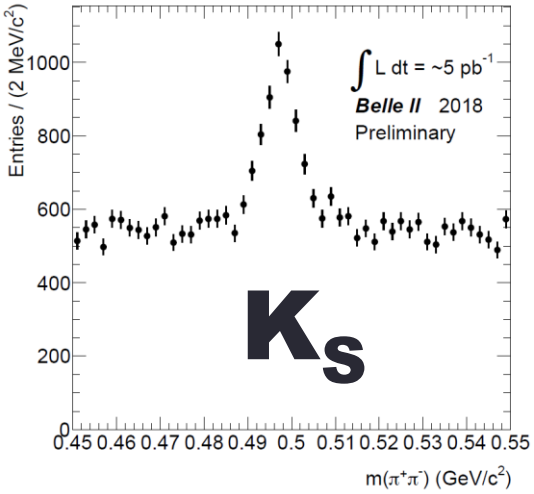


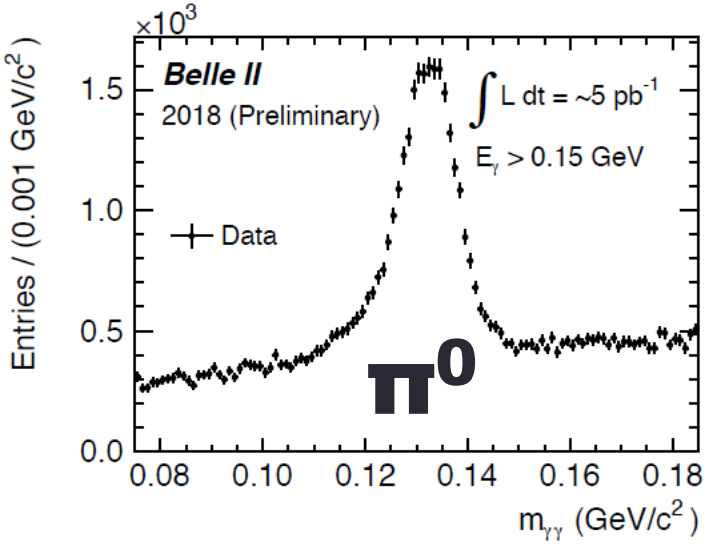
$B\bar{B}$ like event

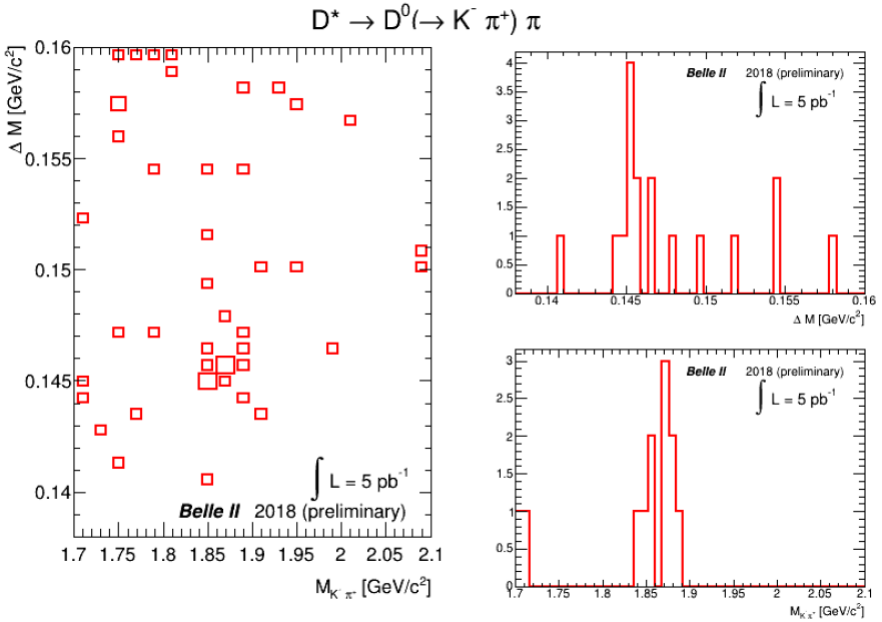


Hadronic event

… and revisit PDG

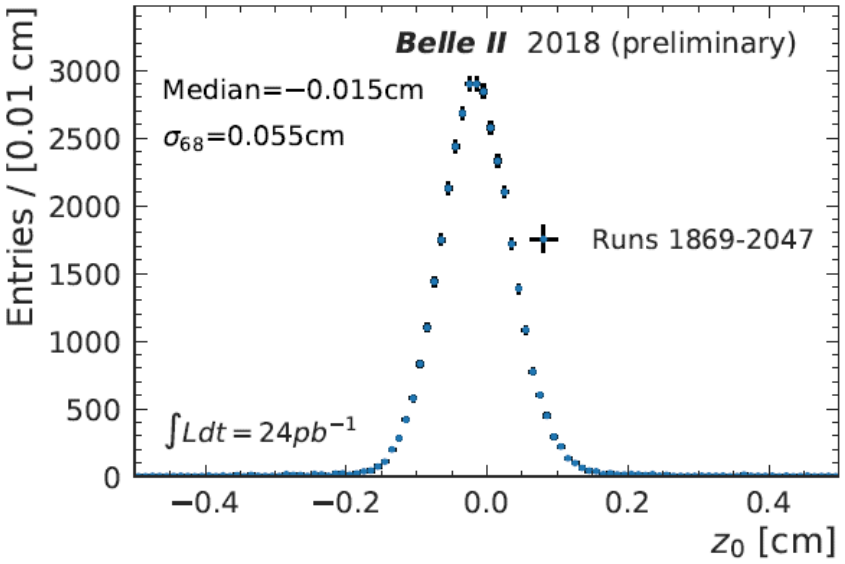


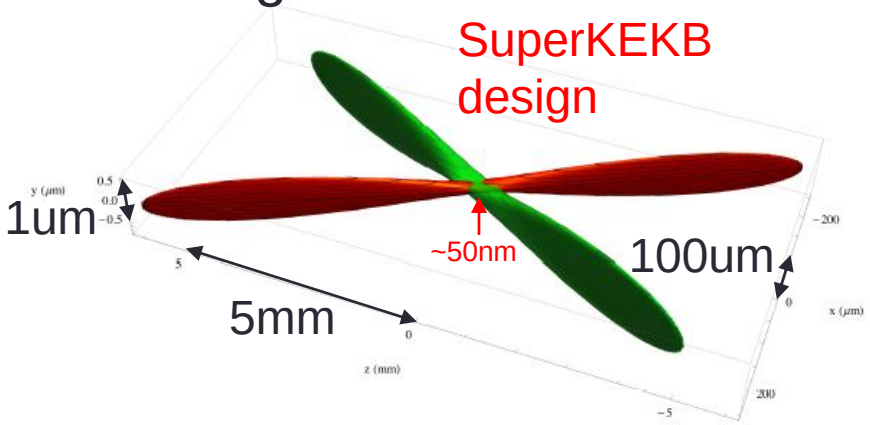


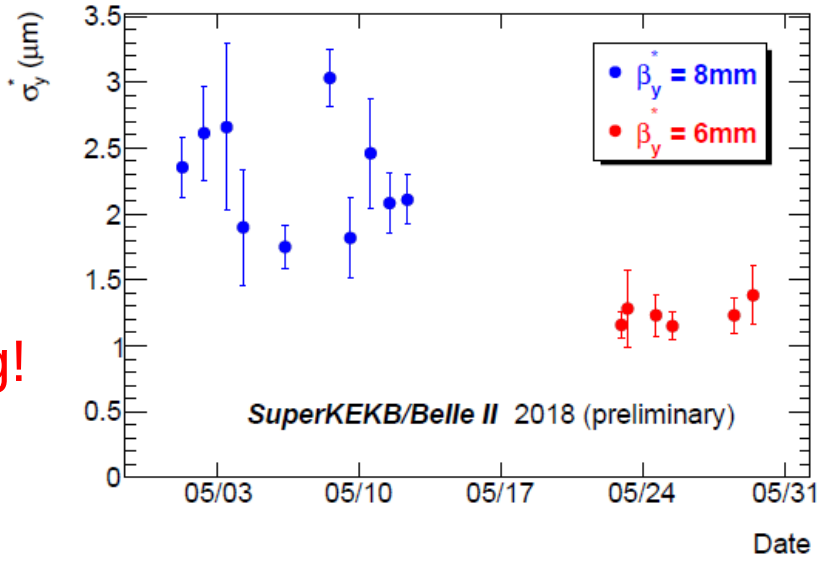


Interaction vertex

- Distribution of the longitudinal component of the interaction vertex is much smaller than the bunch length



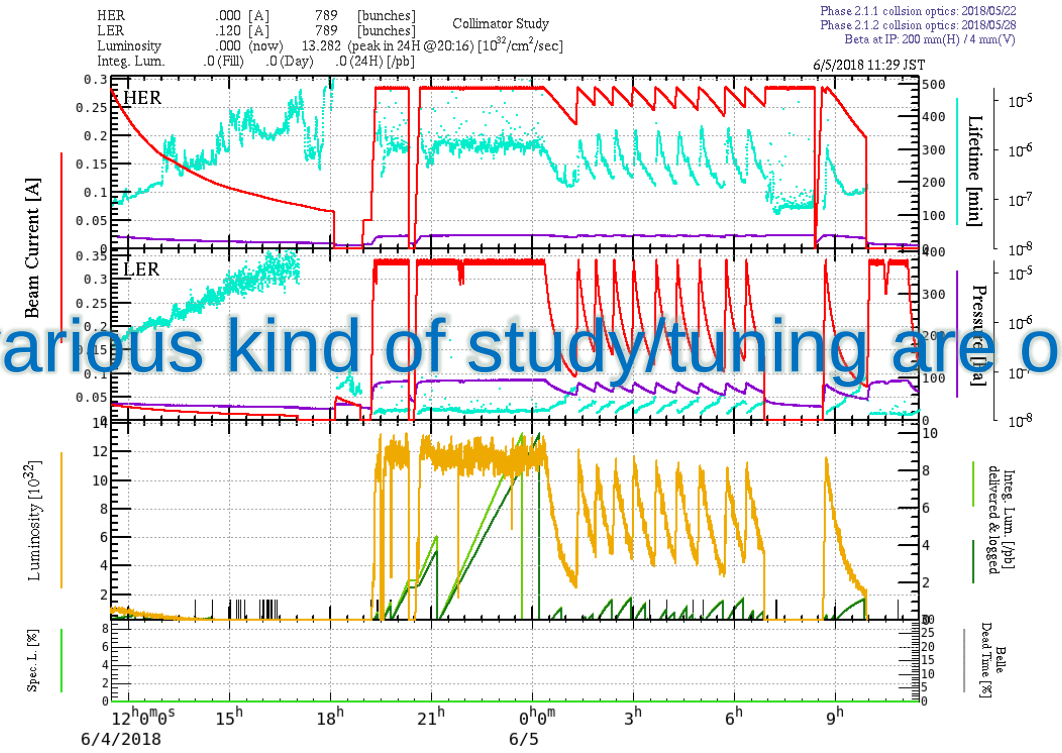




- The nano beam scheme is working!

Phase 2 status

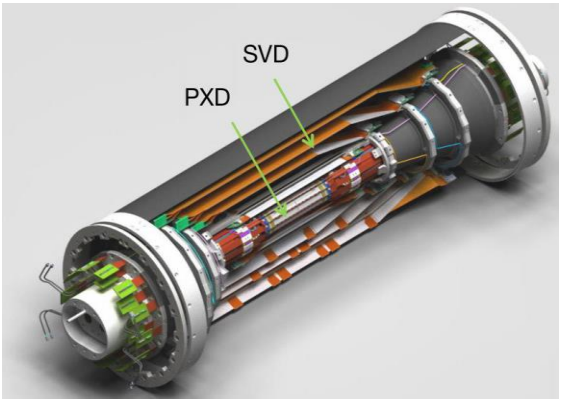
- Phase 2 operation continues until July 17th
- Achievement so far
  - Peak luminosity: ~1.35 x $10^{33}cm^{-2}s^{-1}$ (1/20 of KEKB record)
  - Integrated luminosity: ~180 pb^{-1} as of June 4th

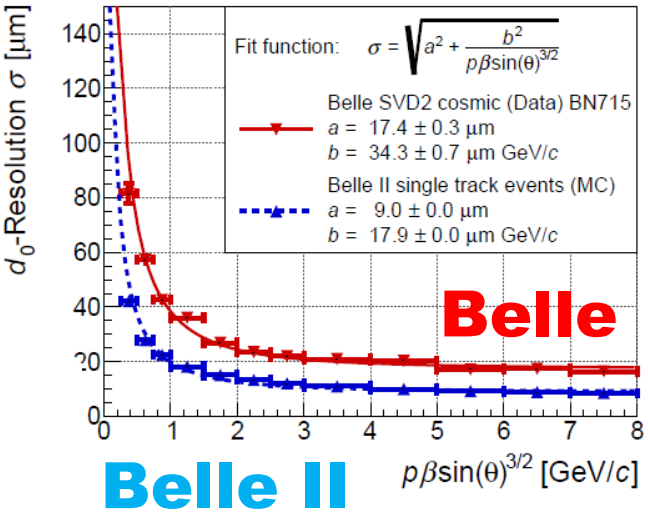


Still various kind of study/tuning are ongoing

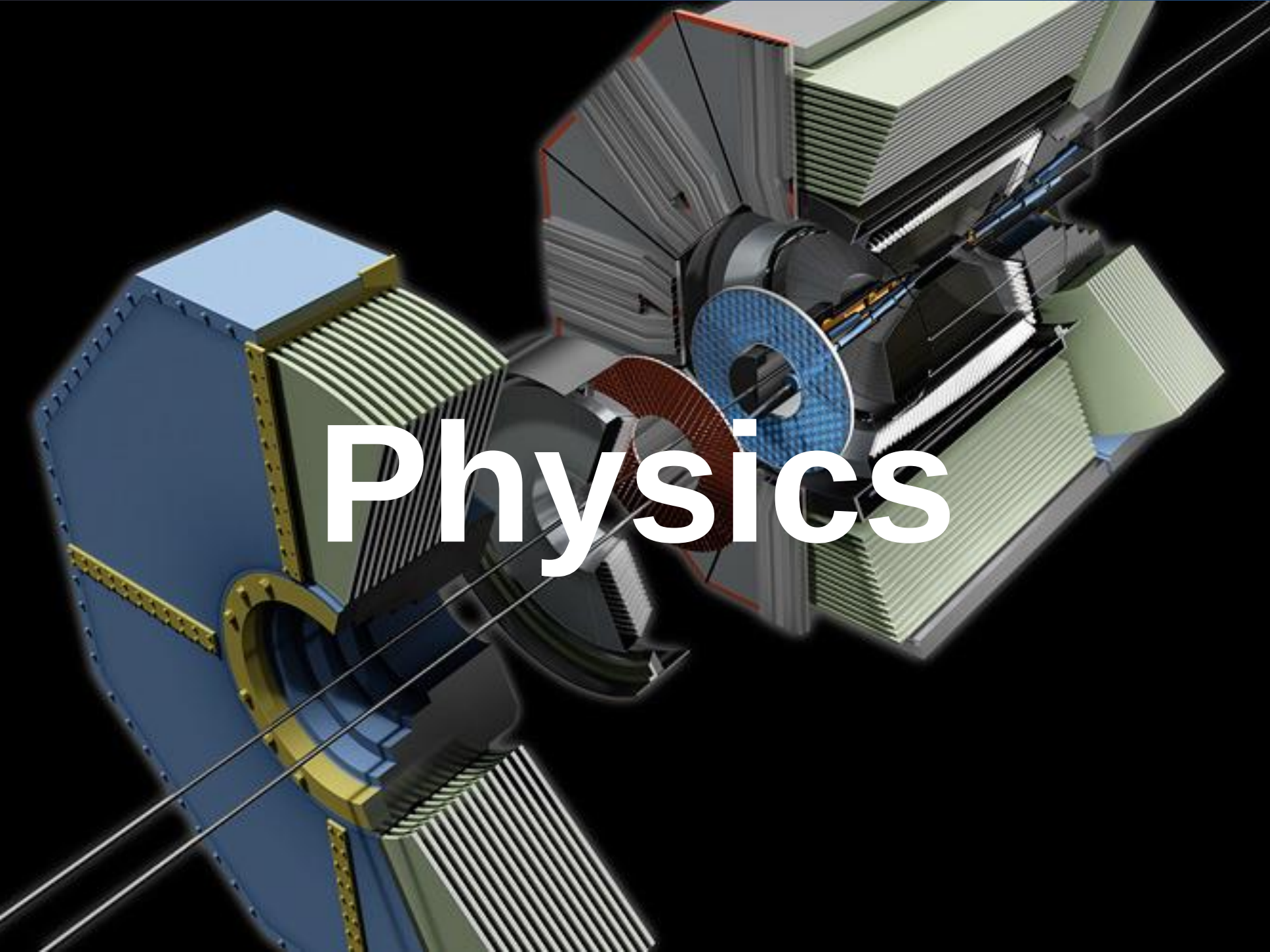
Phase 3 preparation

- After phase 2, vertex detectors will be installed to Belle II
  - 4 layer silicon strip (SVD) + 2 layer pixel (PXD)
- Significantly improve the vertex resolution
  - Compensated for reduced boost





$$\sigma_{\Delta t}^{\text{Belle II}} \sim \frac{3}{4}\sigma_{\Delta t}^{\text{Belle}}$$


Physics

Early physics program

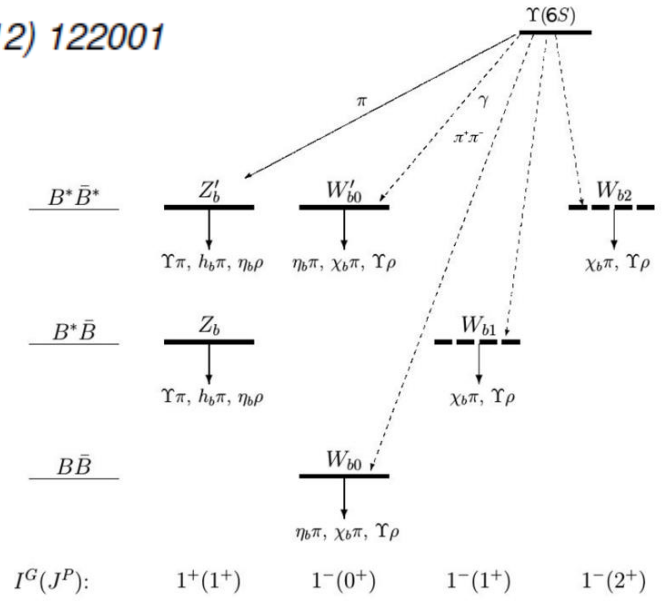
- Phase2: commissioning with partial Belle II (no VXD)
- Data taking time is limited…2018 Apr to July
- We aim to accumulate 20 fb^{-1} of collisions data, but it depends on the machine and detector status
- Even for the limited situation, we plan to study some interesting topics as our early physics program

Y(6S) resonance

- Unique opportunity to focus on Y(6S) resonance
  - Belle: 5.6fb^{-1} and no other experiments (resonance scan by BaBar)
- Bottomonium studies
- Possible exotic resonances in the intermediate states

Z_b observation: *Phys. Rev. Lett. 108 (2012) 122001*

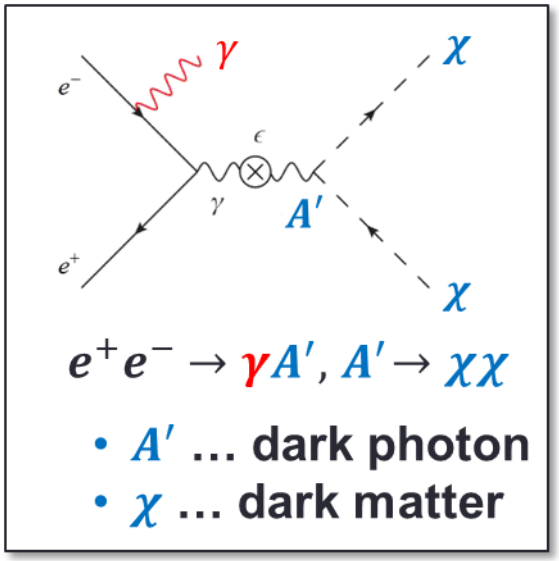
1	$\Upsilon(6S) \to Z_b^+ \pi^- \to h_b(1P, 2P)\, \pi^+ \pi^-$
2	$\Upsilon(6S) \to Z_b^+ \pi^- \to \Upsilon(1S, 2S, 3S)\, \pi^+ \pi^-$
3	$\Upsilon(6S) \to Z_b^+ \pi^- \to \eta_b\, \rho$
4	$\Upsilon(6S) \to W_b^0\, \gamma,\ W_b \to \eta_b\, \pi, \chi_b \pi, \Upsilon \rho$
5	$\Upsilon(6S) \to W_b^0\, \pi^+ \pi^-,\ W_b \to \eta_b\, \pi, \chi_b \pi, \Upsilon \rho$
6	$\Upsilon(6S) \to \gamma\, X_b\ (\to \omega\, \Upsilon(1S))$
7	$\Upsilon(6S) \to \pi\, \pi\, X_b\ (\to \omega\, \Upsilon(1S))$
8	QCD hybrids in BB*

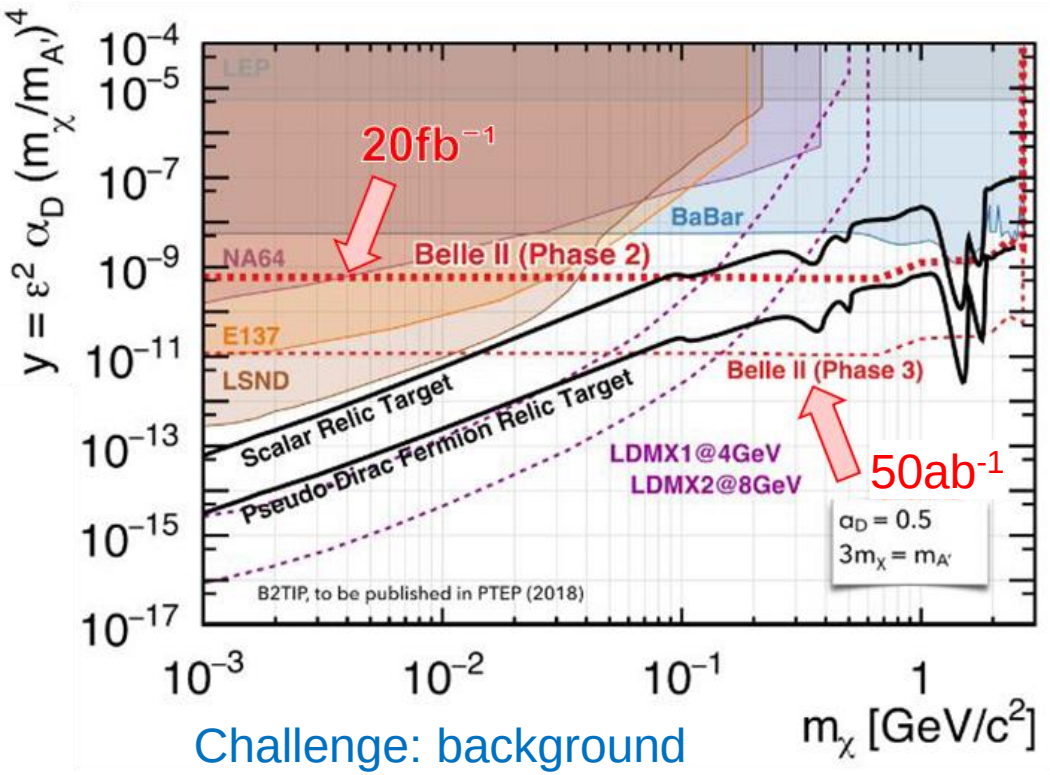


In phase 3 we propose 100 fb^{-1} data taking on Y(6S) resonance

Dark sector

- Newly introduced single photon trigger enables to explore the dark photon (A') decays
  - Energetic γ : E_γ >1GeV
  - Secondary γ : none or E_γ<200MeV





Challenge: background

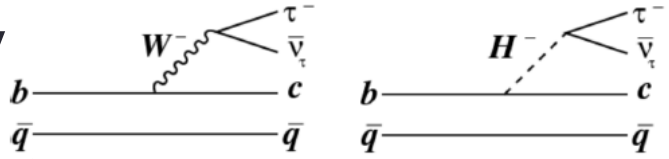
Phase 3 program

- We have a lot of topics in the phase 3!

- Today I focus on a few topics relevant to lepton flavor anomaly
  - $B \to D^{*} \ell \nu$
  - $B \to K \ell \ell$
  - LFV in τ decays

$B \to D^{(*)} \ell \nu$: challenge to lepton universality

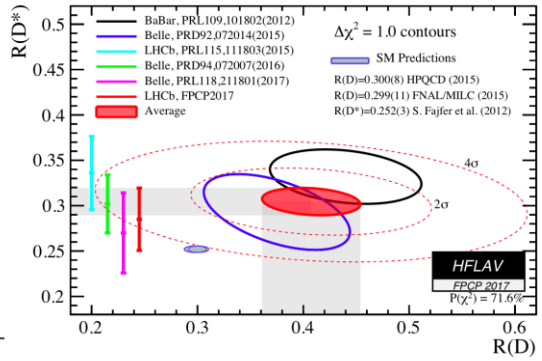
- Theoretically clean channel in SM
- Charged Higgs can contribute the decay
- $R(D^{(*)})$ is sensitive parameter to BSM!

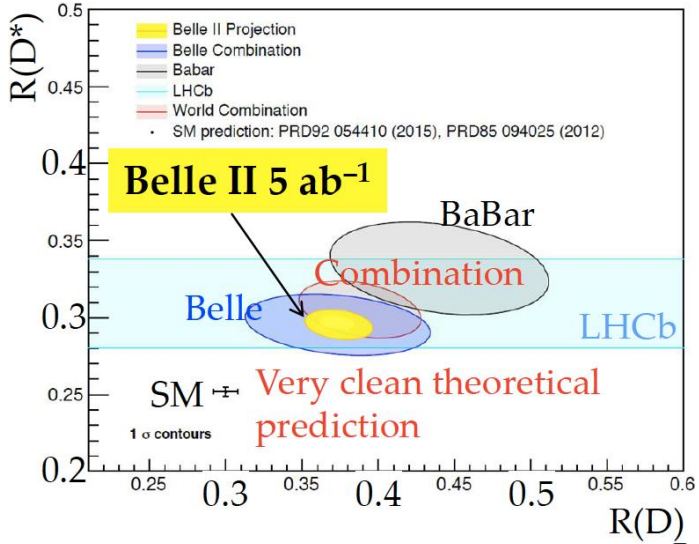


$$R(D^{(*)}) = \frac{\mathrm{Br}(B \to D^{(*)} \tau \nu)}{\mathrm{Br}(B \to D^{(*)} \mu \nu)}$$

	Exp	SM
$R(D^*)$	0.304±0.013±0.007	0.252±0.003
$R(D)$	0.407±0.039±0.024	0.300±0.008

4.1σ away from the SM



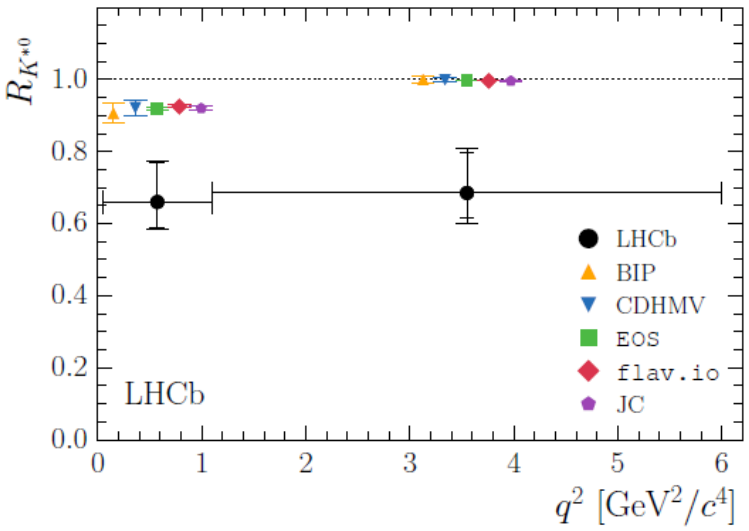


Belle II should be able to confirm the excess with ~5ab^{-1} data

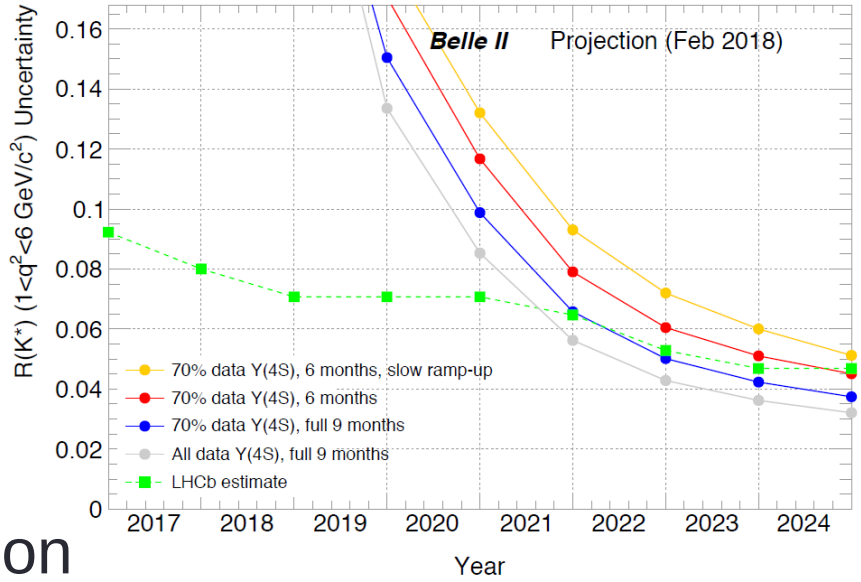
B→K*ℓ ℓ : yet another smoking gun

- Interesting discrepancy as well as measured in P5’

JHEP 08 (2017) 055



$$R(K^*) = \frac{BR(K^* \mu\mu)}{BR(K^* ee)}$$



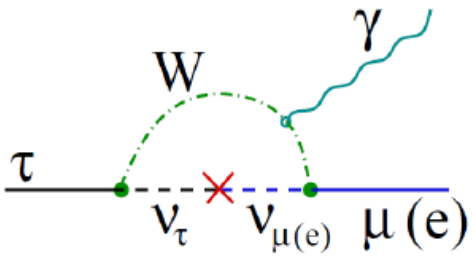
- Belle II: good electron identification

K*ee: ~200 events/ab^{-1}
K*μμ: ~280 events/ab^{-1}

Note: LHCb value is extrapolated from run-1 result

Lepton flavor violation in τ decays

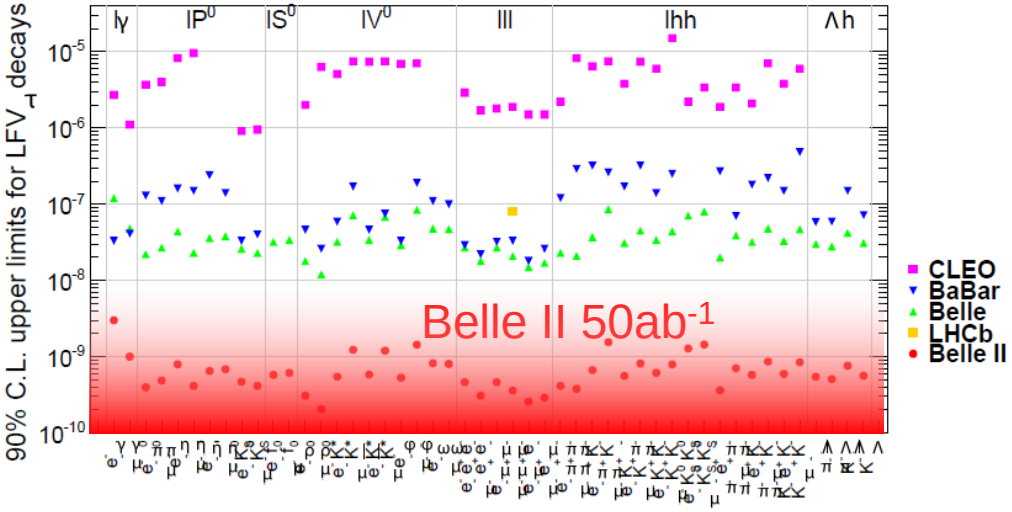
- Extremely suppressed in the SM



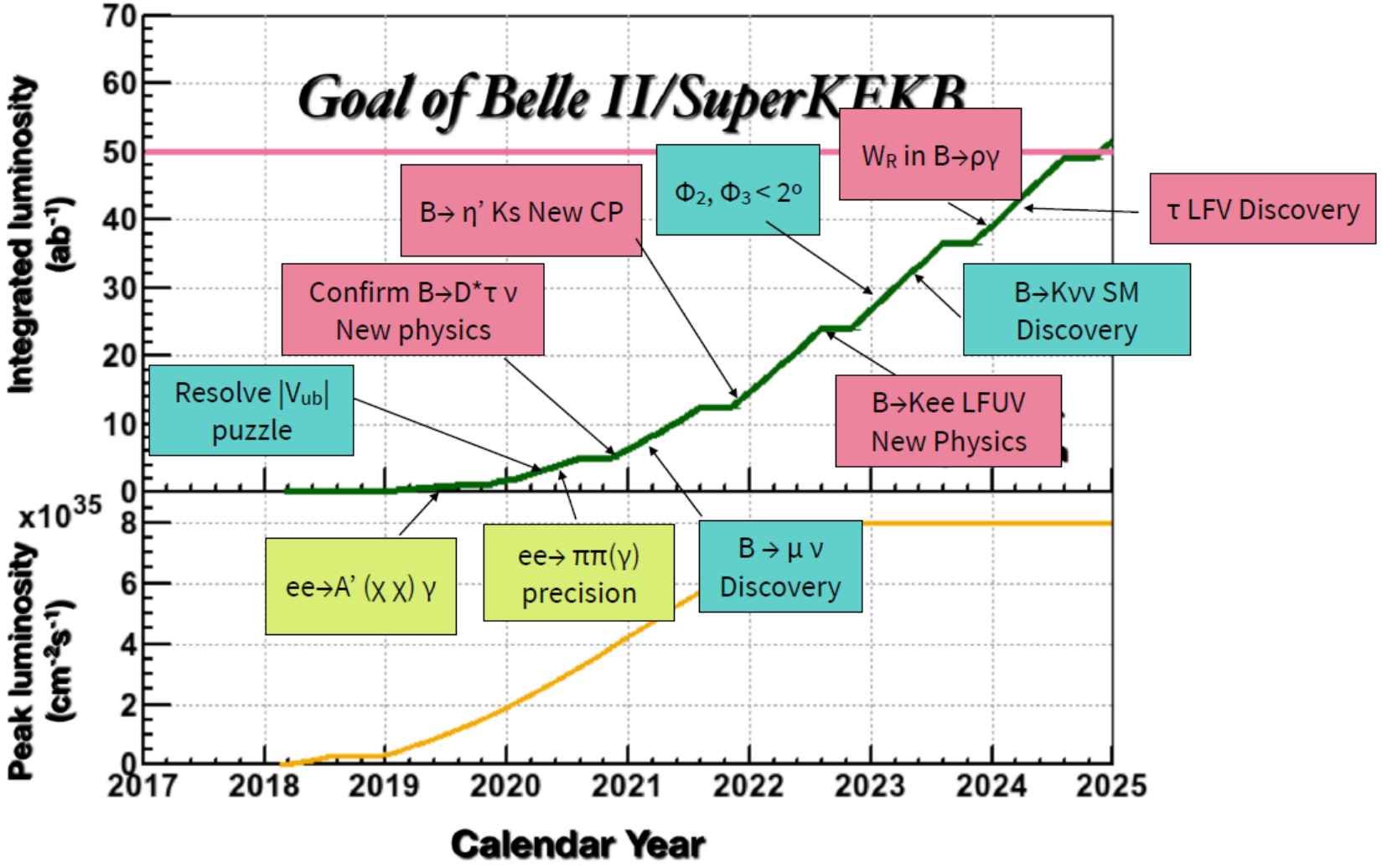
$$\mathcal{B}(\tau \to l\gamma) = \frac{3\alpha}{32\pi}\left|\sum_i U^*_{\tau i} U_{\mu i} \frac{\triangle^2_{3i}}{m^2_W}\right|^2 \leq 10^{-53} \sim 10^{-49}$$

- Many BSM model enhances the LFV decays
- Belle II can access variety of τ LFV decays to test many NP models

Model	Br($\tau \to \mu\gamma$)	Source
SUSY+GUT	10^{-7}	PRD 66(2002)11501
SUSY SO(10)	10^{-8}	PRD 68(2003)033012
SM+ heavy ν_R	10^{-9}	PRD 66(2002)034008
Non-universal Z'	10^{-9}	PLB 547(2002)252
Little Higgs	10^{-10}	JHEP 0705, 013 (2007)
SUSY Higgs	10^{-10}	PLB 566(2003)217
SM	10^{-40}	EPJ C8 (1999) 513



Luminosity and Physics Prospect



Summary

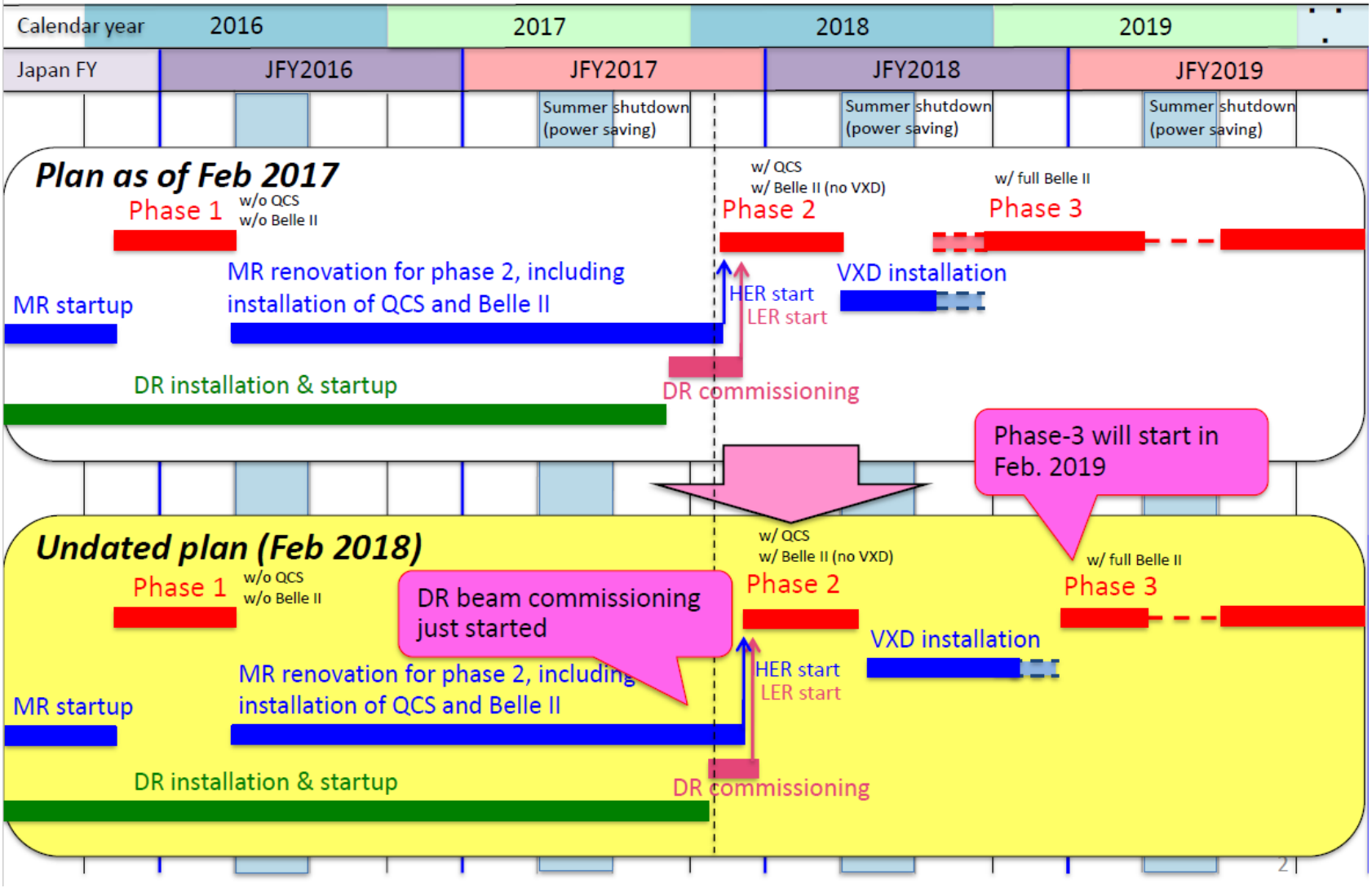
- **Belle II + SuperKEKB is steadily being launched**
- **Phase 2 operation is ongoing**
  - **Commissioning toward phase 3 operation**
  - **First collisions at April 26**
- **Rich early and long term physics programs… a plenty of results coming soon!**

Backup

References

- p1: photos by Mario Penner, available under a Creative Commons Attribution-NonCommercial 3.0 Unported license

Backup


Calendar year
2016
2017
2018
2019
Japan FY
JFY2016
JFY2017
JFY2018
JFY2019
Summer shutdown (power saving)
Summer shutdown (power saving)
Summer shutdown (power saving)
Plan as of Feb 2017
Phase 1
w/o QCS
w/o Belle II
w/ QCS
w/ Belle II (no VXD)
Phase 2
w/ full Belle II
Phase 3
MR renovation for phase 2, including installation of QCS and Belle II
MR startup
HER start
LER start
VXD installation
DR installation & startup
DR commissioning
Phase-3 will start in Feb. 2019
Undated plan (Feb 2018)
Phase 1
w/o QCS
w/o Belle II
w/ QCS
w/ Belle II (no VXD)
Phase 2
w/ full Belle II
Phase 3
DR beam commissioning just started
VXD installation
MR renovation for phase 2, including installation of QCS and Belle II
HER start
LER start
MR startup
DR installation & startup
DR commissioning