Belle II physics and early measurements

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on behalf of Belle II collaboration

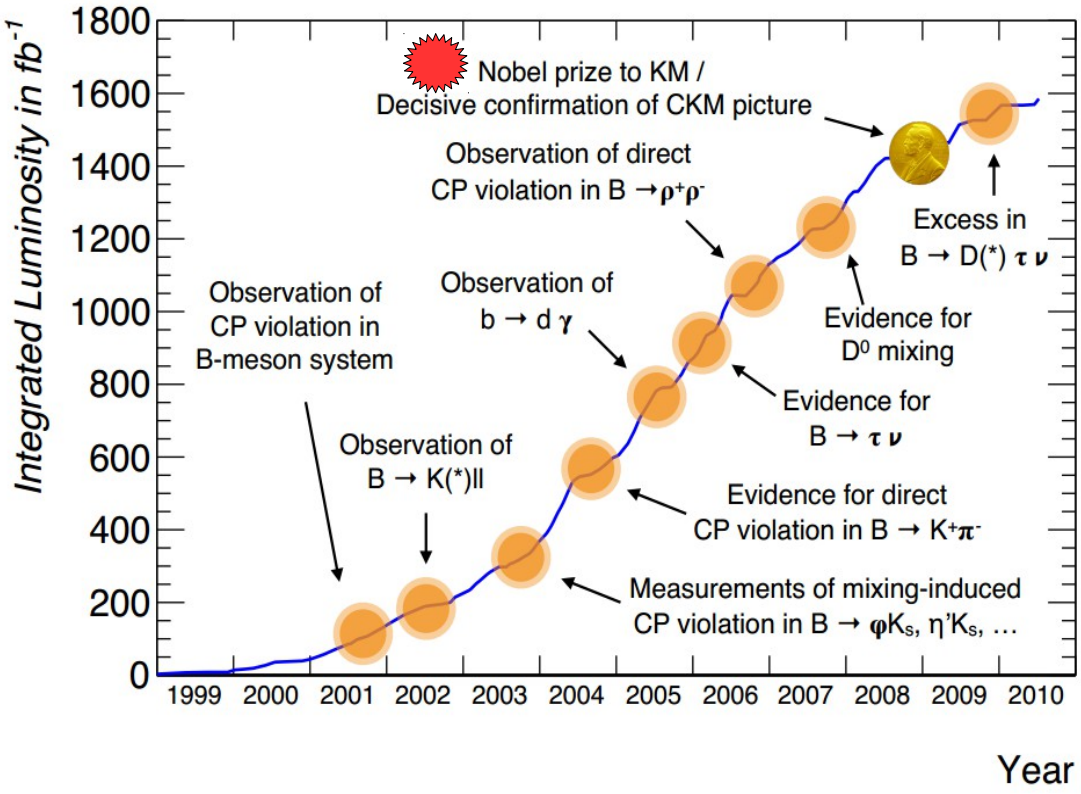
Outline

Belle II
Belle II physics
early measurement
Summary

Why Belle II

After 10 years operation, Belle and BaBar achieved a great success in B (charm, τ) physics studies and explored possible new physics

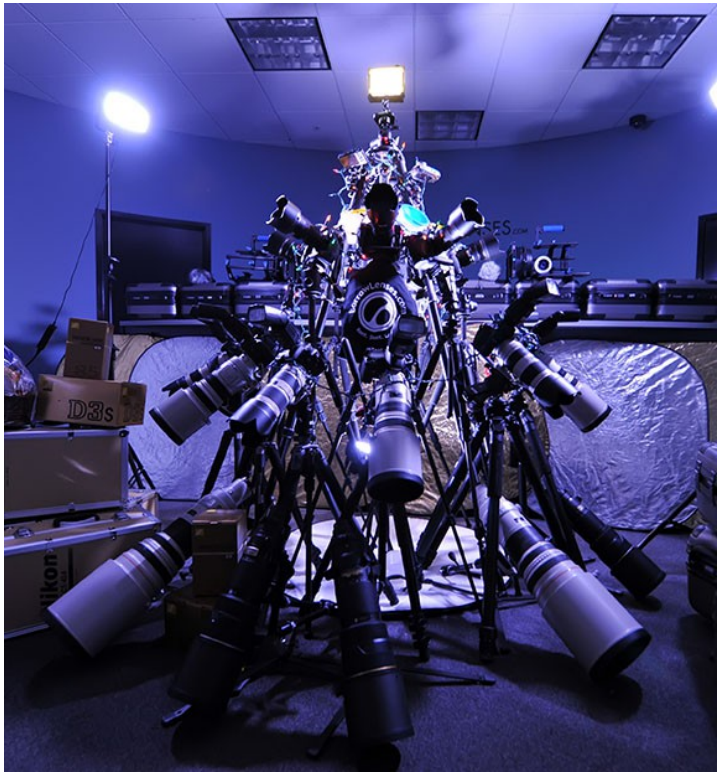
- CKM matrix elements and angles of the unitary triangle
- CP violation in B sector
- Rare B decay modes (B →τν, Dτν)
- Observation of D mixing
- Rare τ decays
- Exotic hadrons
- ….



However, there are still remaining puzzles and open questions

large CPV in the universe
Higgs search, non-SM Higgs?
3 generations or more?
how "standard" is the SM?
…..
Which lead the HEP into two directions.

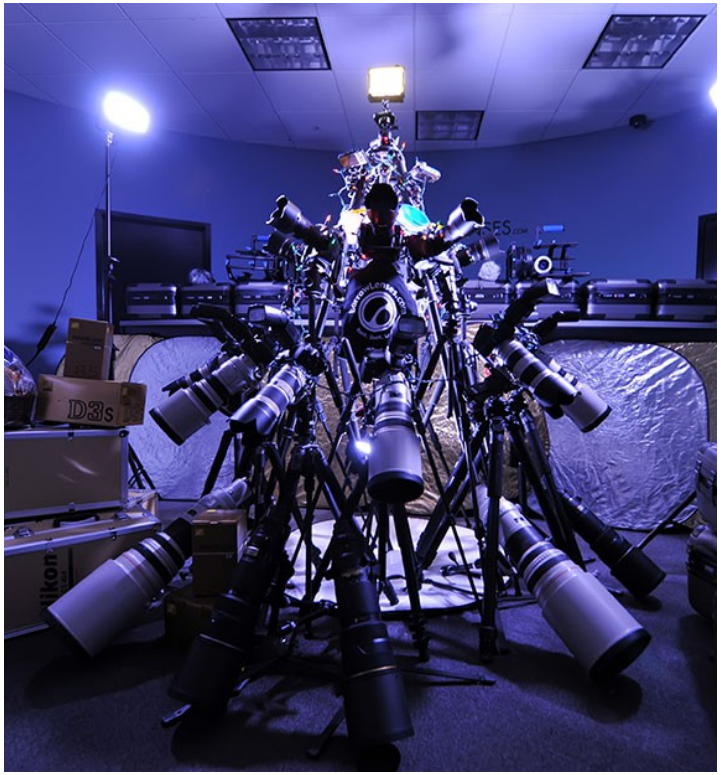
Energy frontier
→ powerful in energy scale to search for new particles and physics. (LHC)

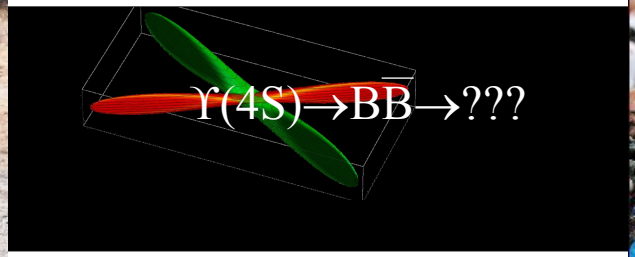


Energy frontier
→ powerful in energy scale to search for new particles and physics. (LHC)

complementary with each other

Precision/intensity frontier
→ focus on a certain energy range for precision measurements to search for anomalies from the SM and new physics from rare decays (SuperKEKB + Belle II)

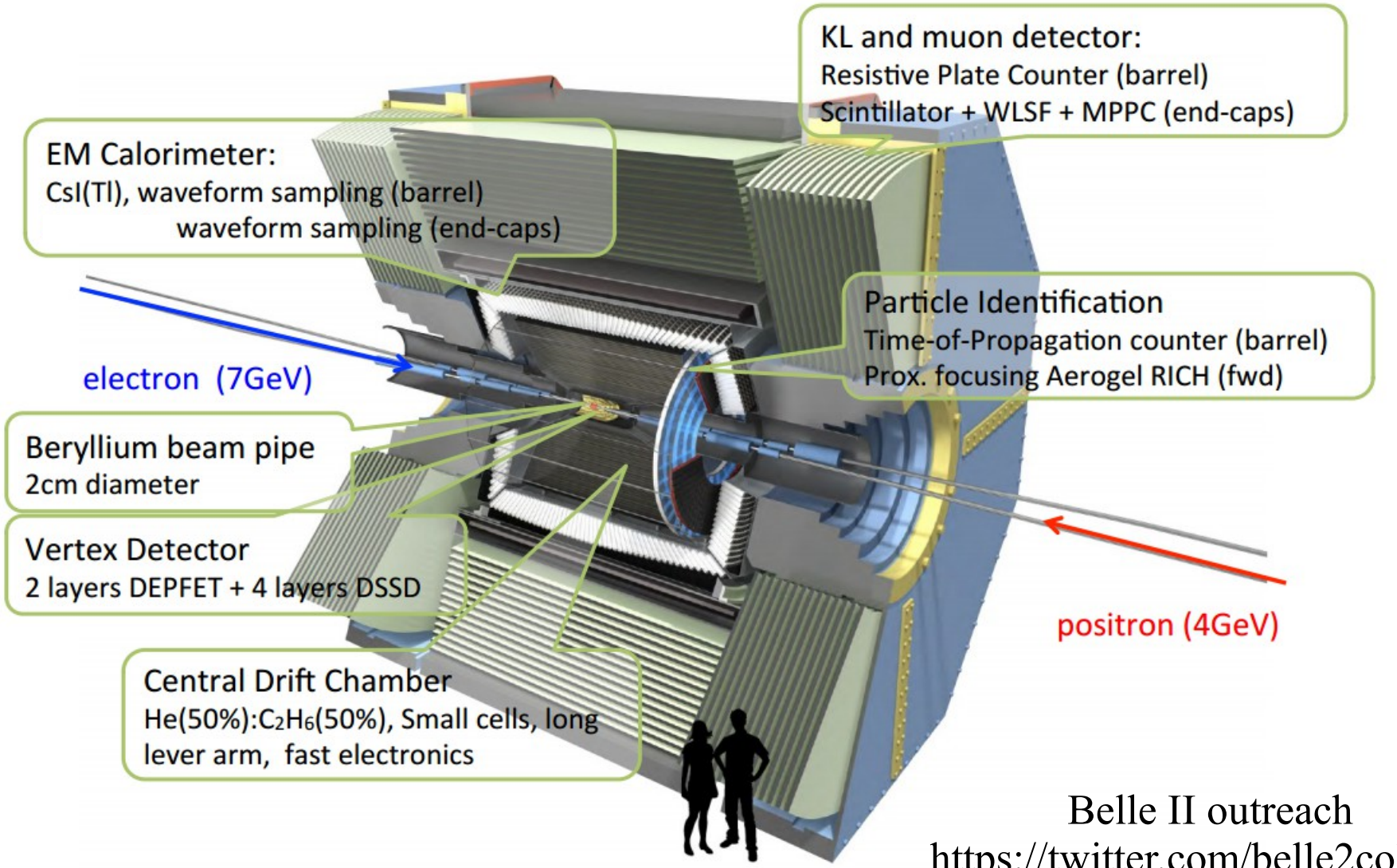




Belle II

Belle II detector

[Belle II TDR, KEK Report 2010-1]



Belle II outreach
https://twitter.com/belle2collab/
https://www.facebook.com/belle2collab/

Detail about SuperKEKB and Belle II status and prospects:
May 5, 09:00~09:20 Minakshi Nayak

Phase 1, Beast2

will pave the road for the beauty.

2016 Feb. ~ Jun.
SuperKEKB
beam commissioning
(no collision)

KEK press conference for 1st SuperKEKB LER/HER beam circulation (Mar. 02, 2016)

First turns and successful storage of beams in the SuperKEKB electron and positron rings

March 2nd, 2016

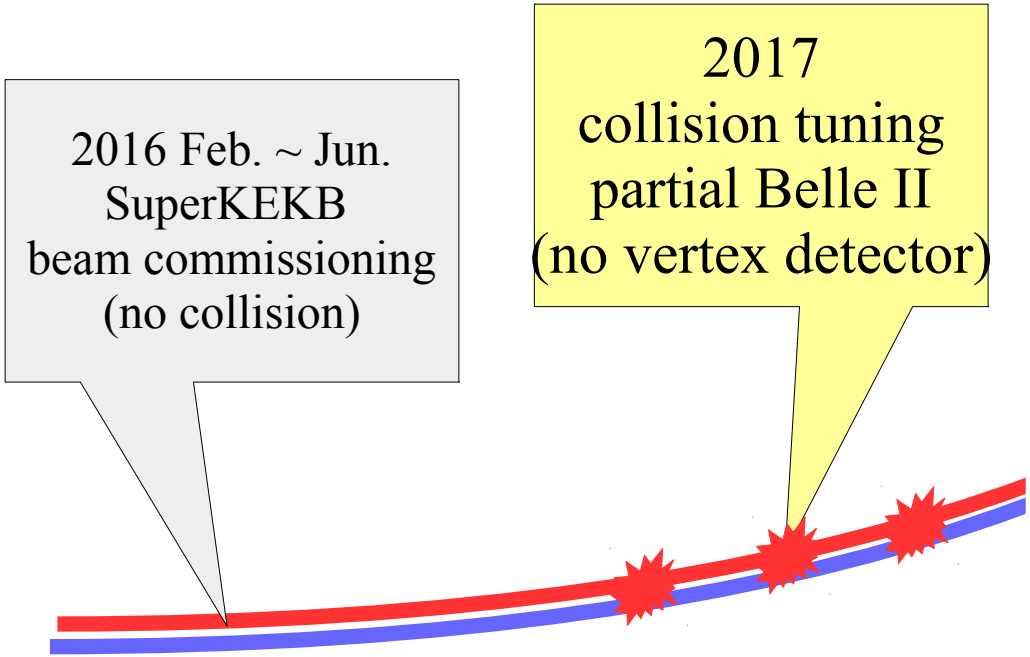
High Energy Accelerator Research Organization (KEK)

Yes, this is what is happening at KEK right now.
We are really not in the future!!

beam bg/machine study

Phase 2, ring a Belle for a new era to come.

Beast 2 with partial Belle II, some measurements possible.



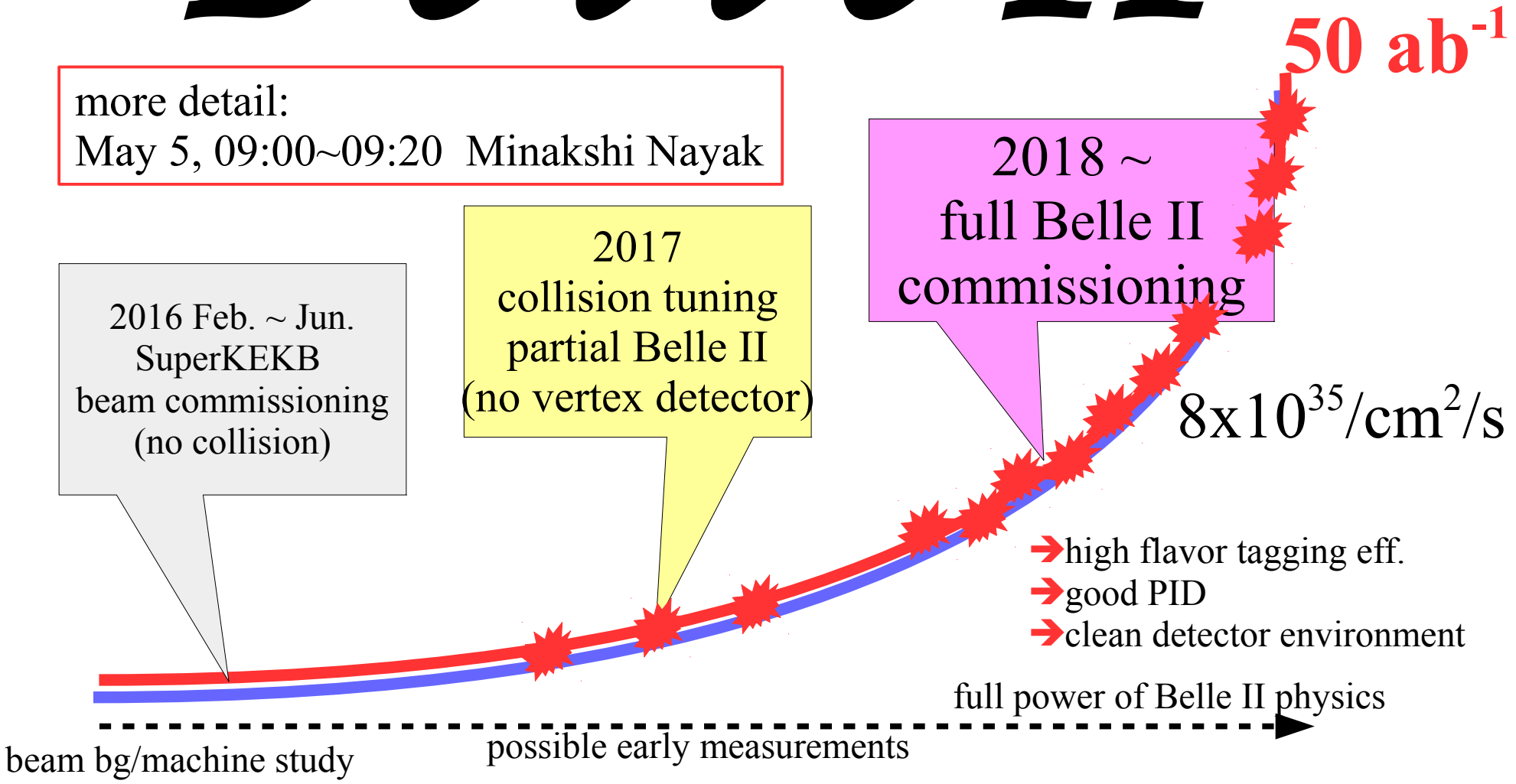
- achieve 10^{34} /cm^2/s (KEKB/Belle peak)
- stable run close to $\Upsilon(4S)$ preferred
- PID not fully reliable
- Integrated luminosity ~(20±20 fb^{-1})

beam bg/machine study

possible early measurements

Phase 3

Belle II



Belle II physics prospect

- precision measurements of CKM elements
- rare B decays
- other B decay physics, ...

- charm physics (Mixing, CPV in charm, rare charm decays,...)

- tau physics (LFV, CPV, ...)

- hadron spectroscopy (4-quark states, bottomonium spectrum)
  → possible early measurements(!)

- exotics state (tetraquark, ...)
- searching for new physics (Higgs BSM, dark sector, leptoquark, ...)

P. Urquijo, "Physics prospects at the Belle II experiment", Nucl. Part. Phys. Proc. 263-264 (2015) 15-23
P. Krizan, "Flavour physics at B factories", Phys. Sci. T158 (2013) 014024
more about Beyond the standard Model @Belle II and B2TiP, Y. Okada, May 3.

Belle II physics prospect – CKM

- does the unitary triangle really a triangle?

current $\alpha+\beta+\gamma = (175\pm9)^\circ$ (PDG)

→ Belle II expects to improve the precision

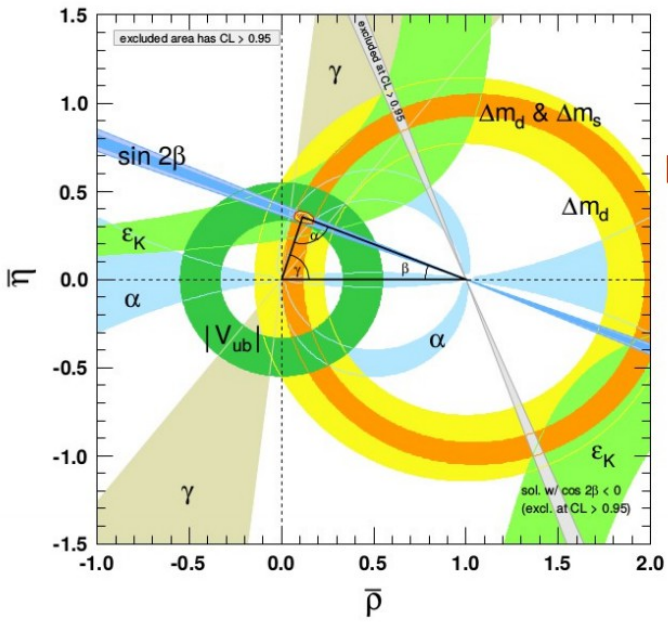
$\beta \sim 0.3^\circ$, $\alpha \sim 1.0^\circ$, $\gamma \sim 1.5^\circ$

- precision measurements of $\sin(2\beta)=\sin(2\phi_1)$

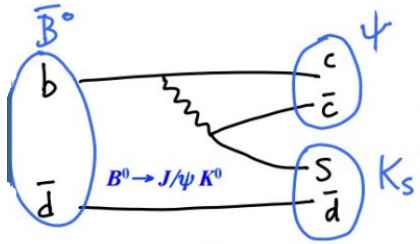
remains an important topic to check the consistency of the Unitary triangle and to search for new source of CPV

→ with 50ab^{-1} data, Belle II can reach 5σ even with a small deviation $\Delta S \sim 0.02$

- improvement in precision should help to resolve the tension between inclusive and exclusive measurements of $|V_{ub}|$ and $|V_{cb}|$



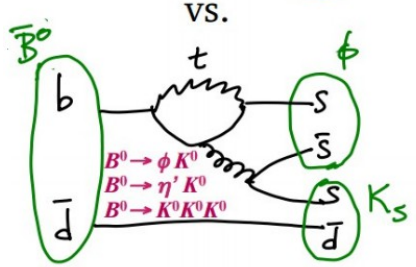
[PDG]



SM:

$$|S_{b\to c} - S_{b\to s}| \simeq 0$$

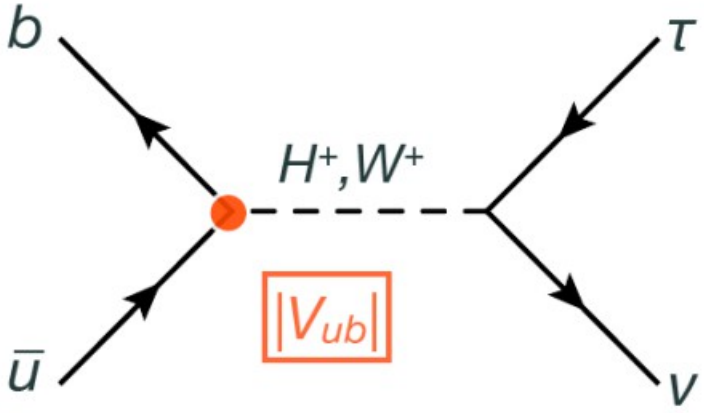
vs.



NP in loop:

$$|S_{b\to c} - S_{b\to s}| > 0$$

Belle II physics prospect $B \to \tau\nu$



sensitive to existence of
a charged Higgs (H-b-u)

$$BR(B \to \tau\nu) = BR_{SM} \times \left[1 - \left(\frac{m_B^2}{m_H^2}\right)\lambda_H\right]^2$$

$\lambda_H = \tan^2(\beta)$ for type II 2HDM

$BR_{SM} = 0.75 \times 10^{-4}$

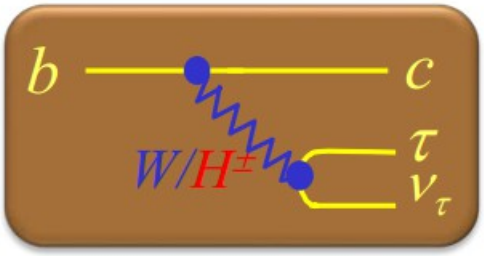
current measurement $(1.14 \pm 0.22) \times 10^{-4}$

This mode is suppressed in the SM, but could be enhanced by NP process.

Belle II could reduce the uncertainty to 5% with full data, useful to test NP models (e.g. charged Higgs, leptoqurak, or other models)

For other related modes, e.g $B \to \mu\nu$, expected precision 10% achievable at Belle II

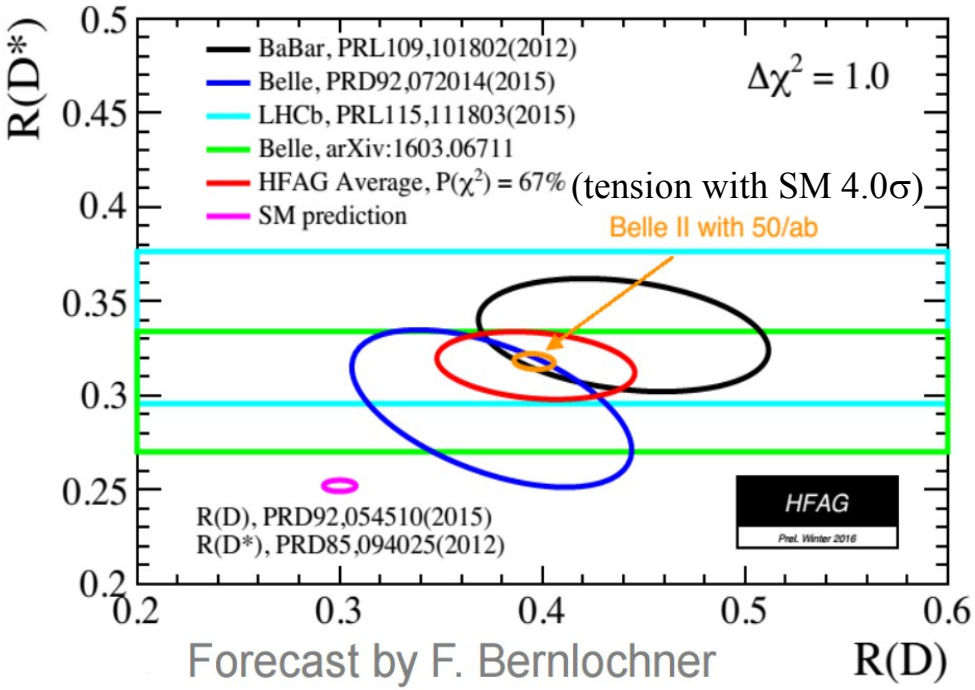
Belle II physics prospect B →D(*) τν

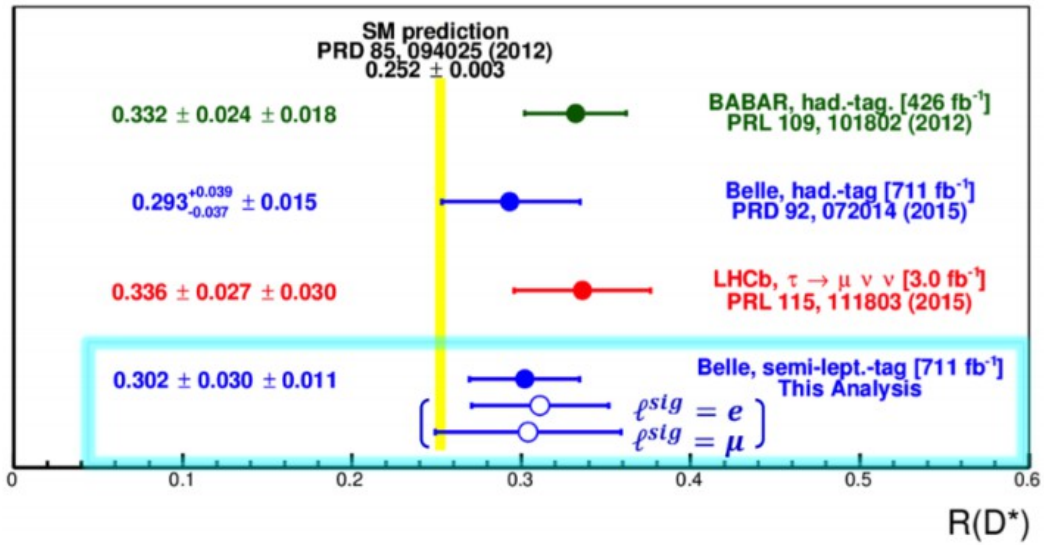


sensitive to H-b-c coupling

$$R(D^{(*)}) = \frac{\Gamma(B^0 \to D^{(*)} \tau \nu)}{\Gamma(B^0 \to D^{(*)} l \nu)_{l=\mu,e}}$$

larger BF in the SM (~1%)
smaller theoretical uncertainty of R(D)
discrimination of W and H by differential distribution





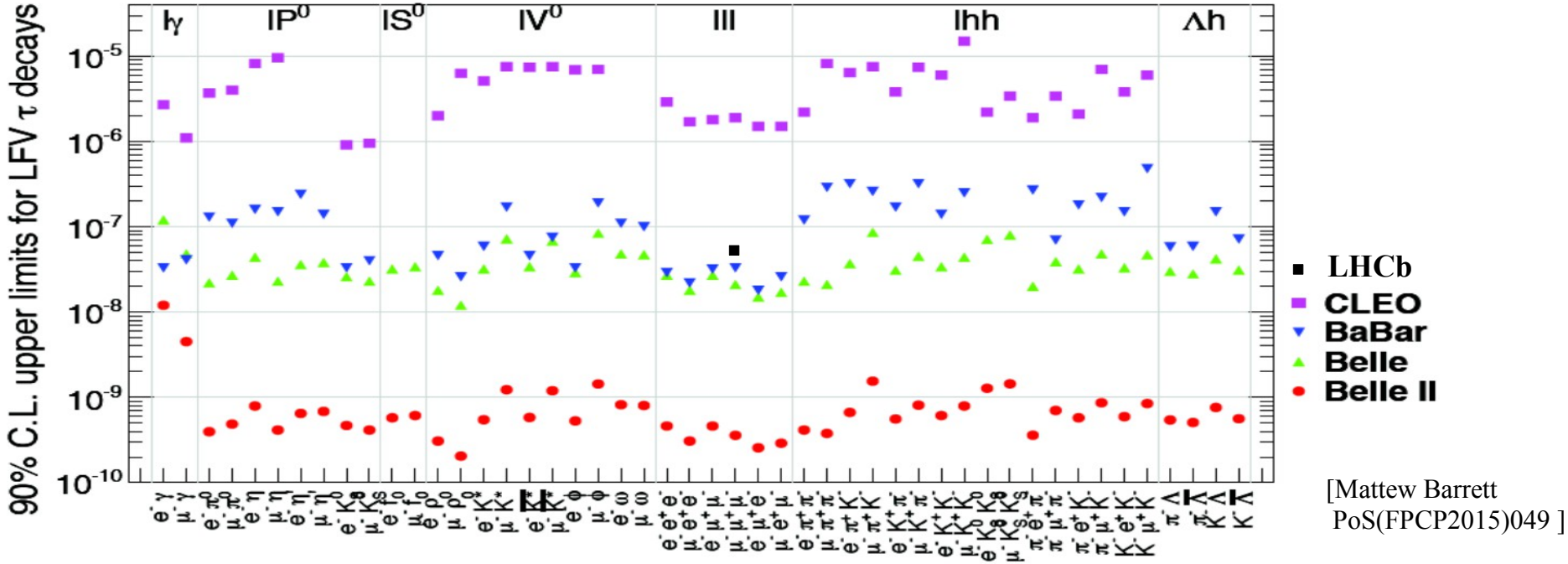
new Belle measurement [hep-ex 1603.06711]
R(D*) = 0.302 ± 0.030(stat) ± 0.011(syst) (13.8 σ)

detail about this study: May 03, Jan Hasenbusch

Belle II physics prospect – tau physics

The low collision bg makes Belle II ideal for several τ physics studies.

Many LFV τ decays have been studied. The sensitivity has currently reached the level of a few times 10^{-8}. It is possible to reach 1 to 2 orders of magnitude lower with full Belle II data. This make it possible to test numerous theoretical predictions.



[Mattew Barrett PoS(FPCP2015)049]

Measure CPV at a level that bounds many models of NP complementary to the LFV searches, e.g. CPV in $\tau \to K_s^0 \pi \nu$, precisely predicted in the SM, to 10^{-4} precision, an order of magnitude better than Belle.

Belle II physics prospect – tau physics

$\tau \to \mu\gamma$

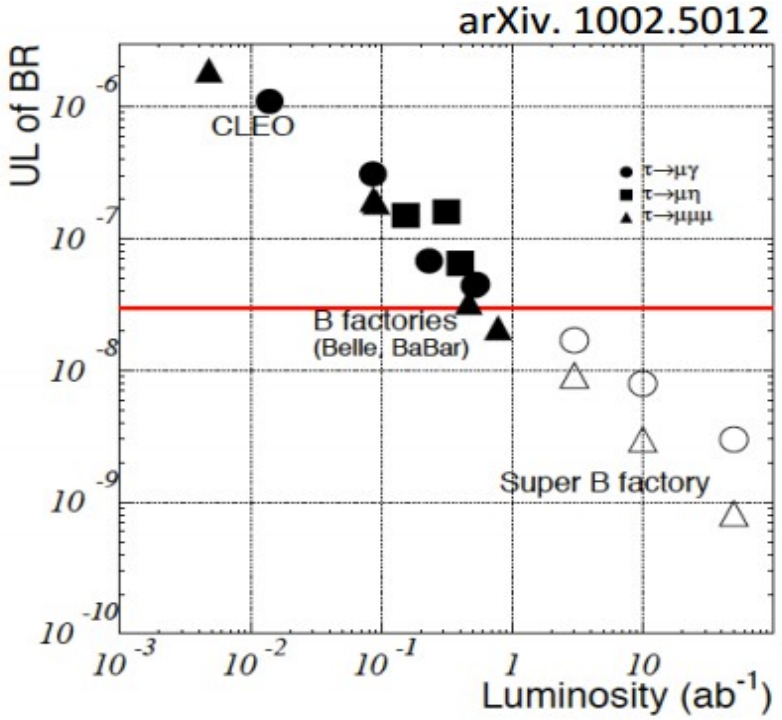
main background from $ee \to \mu\mu\gamma_{ISR}$

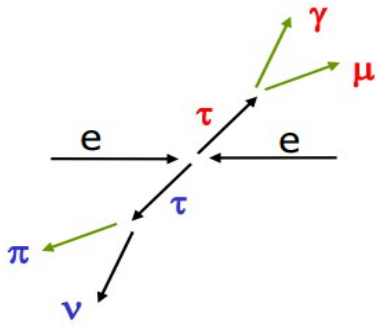
possible to reduce sensitivity by a factor ~7

$\tau \to \mu\mu\mu$

very clean mode

possible to reduce sensitivity by a factor of 50



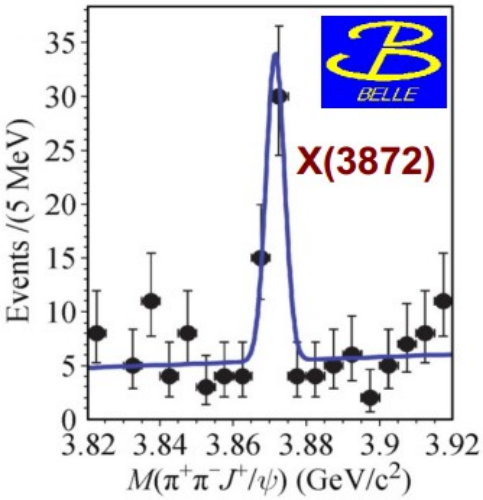


	$\mathcal{B}(\tau \to \mu\gamma)$	$\mathcal{B}(\tau \to \mu\mu\mu)$	
mSUGRA+seesaw	10^{-7}	10^{-9}	PRD 66(2002) 115013
SUSY+SO(10)	10^{-8}	10^{-10}	PRD 68(2003) 033012
SM+seesaw	10^{-9}	10^{-10}	PRD 66(2002) 034008
Non-Universal Z'	10^{-9}	10^{-8}	PLB 547(2002) 252
SUSY+Higgs	10^{-10}	10^{-7}	PLB 566(2003) 217

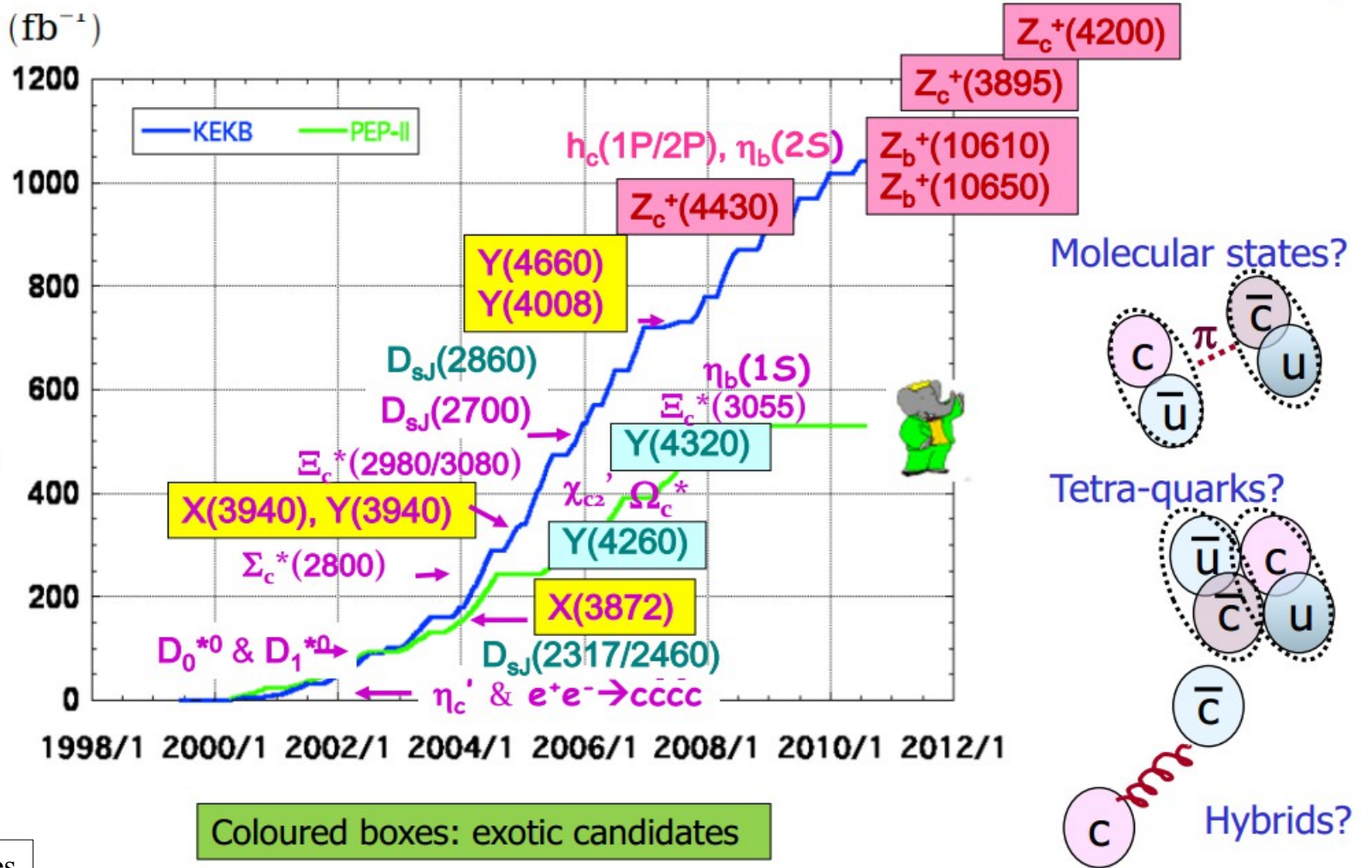
possible reach by Belle II (50 ab^{-1}) $<10^{-9}$ $< 10^{-10}$ → good to test NP models

Belle II physics prospect – hadron spectroscopy

Many new states are observed, which do not fit in the traditional quark model.
More are expected in Belle II, opening a door for exotic state studies.



First exotic state observed.
[PRL 91, 262001 (2003)]



Coloured boxes: exotic candidates

Nice review the exotic states
May 02, Richard Lebed

54th International Winter Meeting on Nuclear Physics, Peter Križan

Belle II physics prospect --- early measurements

Phase 2 (2017)

SuperKEKB:

nominal at 7GeV + 4 GeV ($\Upsilon(4S)$)
possible highest E_{cm} > $\Upsilon(6S)$
reach 1×10^{34} /cm^2/s
a few months physics operation possible
integrated luminosity 20±20 fb^{-1}

Belle II:

no vertex detector
(affecting tracking, vertexing)
no impact on photon efficiency
PID might not be very reliable
DAQ/trigger/software ready

Phase 3 (2018~)

higher luminosity with full Belle II detector for physics commissioning

Possible physics study

bottomonium below $\Upsilon(4S)$,
search for more 4-quark states above $\Upsilon(4S)$,
searching for dark photon (single γ),
precision m_b, fragmentation of light quarks and charm
dark Higgs, light dark matter, light Higgs

The early measurement studies will not stop. They could also set guidelines for future off-$\Upsilon(4S)$ studies.

Belle II physics prospect --- early measurements

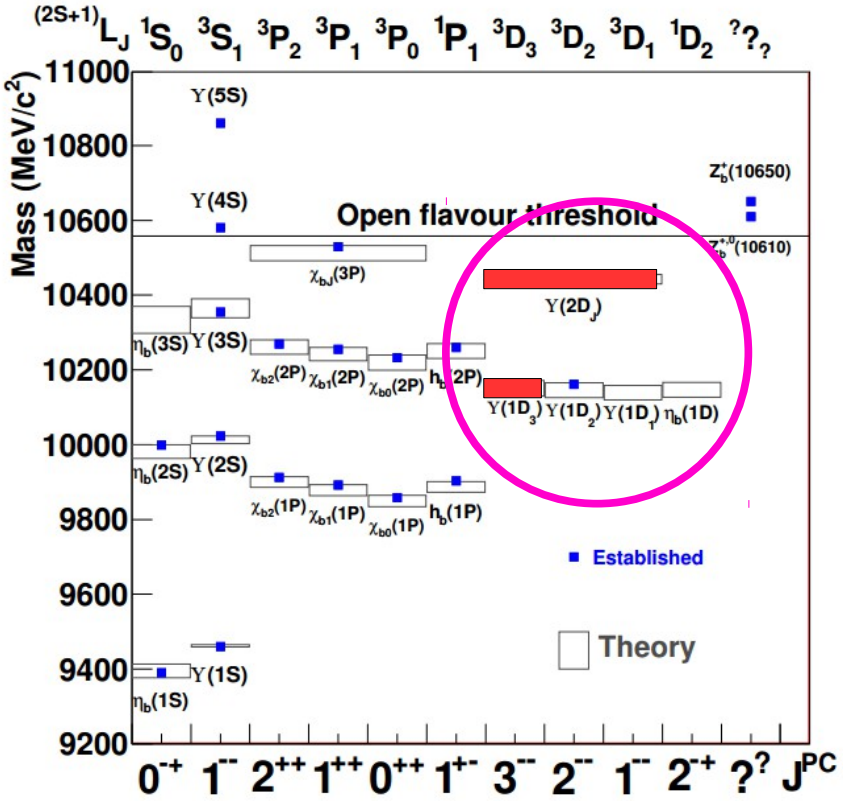
(preliminary ideas)

Energy	motivation	Lumi. (fb^{-1})	Run	comment
Υ(1D) scan	new state	10~20	Phase 2+3	better study for $\Upsilon(1D_2)$ search for $\Upsilon(1D_1)$
Υ(3S) on	many topics	>200	Phase 3	precision measurements for known resonances
Υ(3S) scan	precision QED	~10	Phase 2	need to study beam condition
Υ(2D) scan	new state	10~20	Phase 2+3	search for Υ(2D)
Υ(5S) on + scan	new state	>10	Phase 2	
Υ(6S) on	new state	20	Phase 2	Zb from Υ(6S)? beam energy limit
Single γ	new physics	>20	Phase 2	special trigger

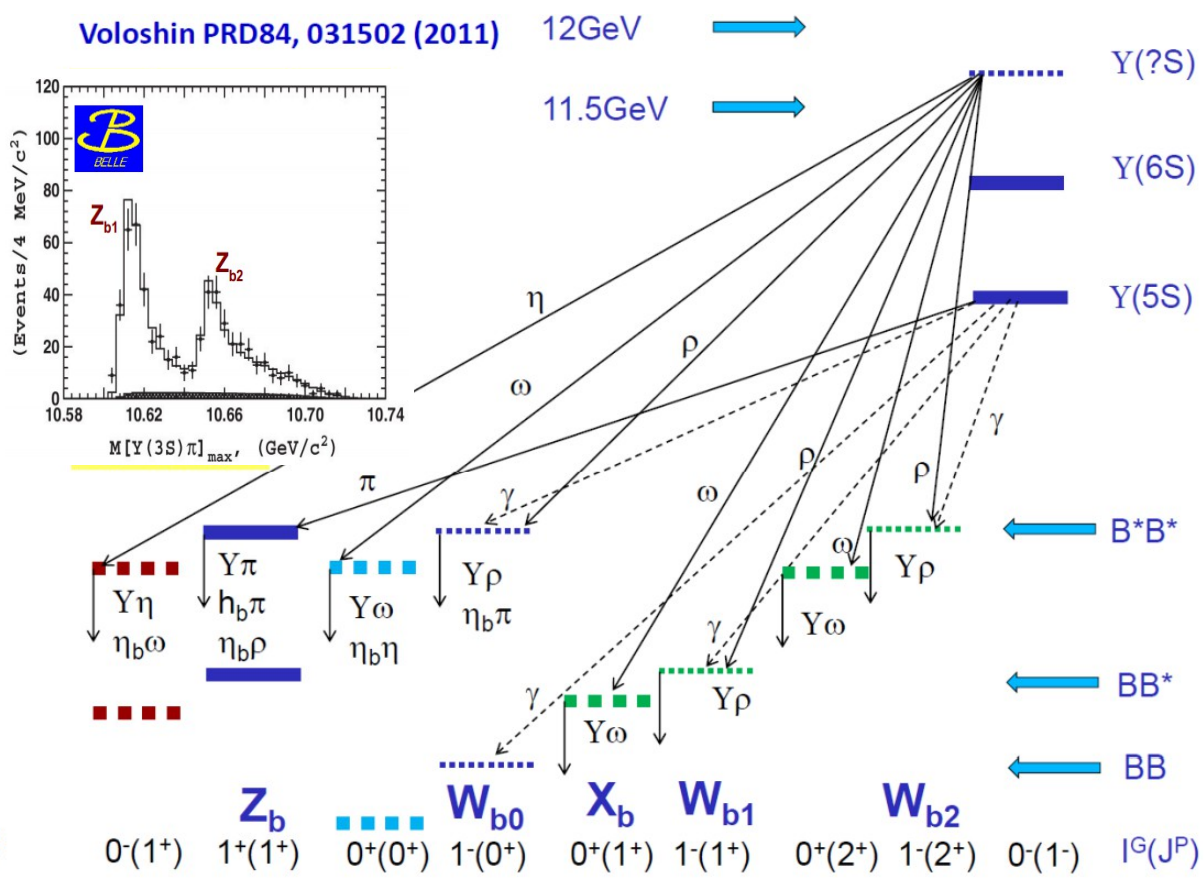
Belle II physics prospect --- early measurements

ϒ(3S)

bottomonium spectrum



Above ϒ(4S)



ϒ(1D$_2$) has been measured by CLEO/BaBar.

ϒ(1D$_1$)ϒ(1D$_3$)ϒ(2D) are not seen yet.

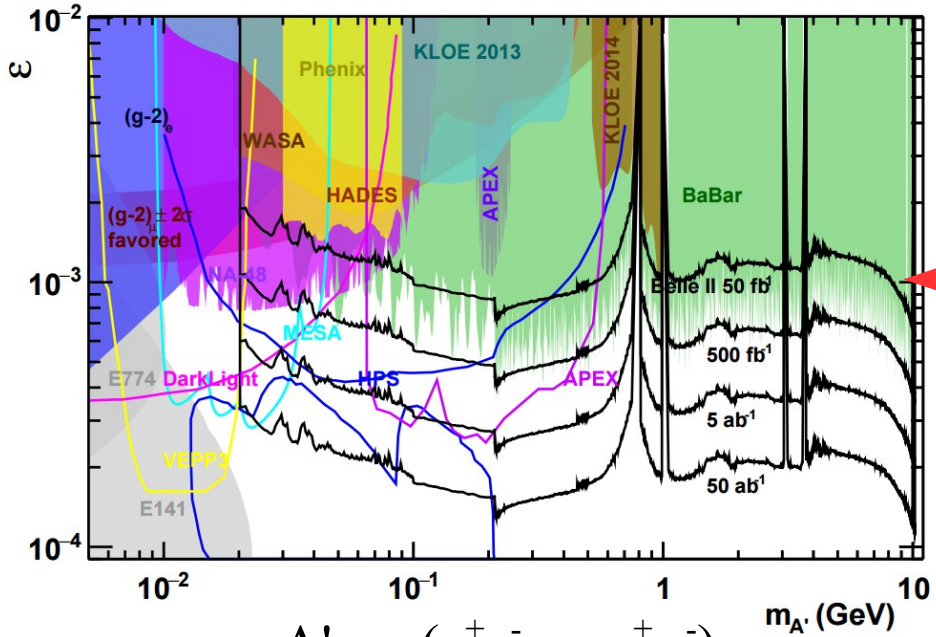
4-quark state Zb(10610/10650) found by Belle in anomalous ϒ(5S) → ππϒ(nS) transitions,
Similar anomaly in ϒ(6S) decay not confirmed

Belle II physics prospect --- early measurements

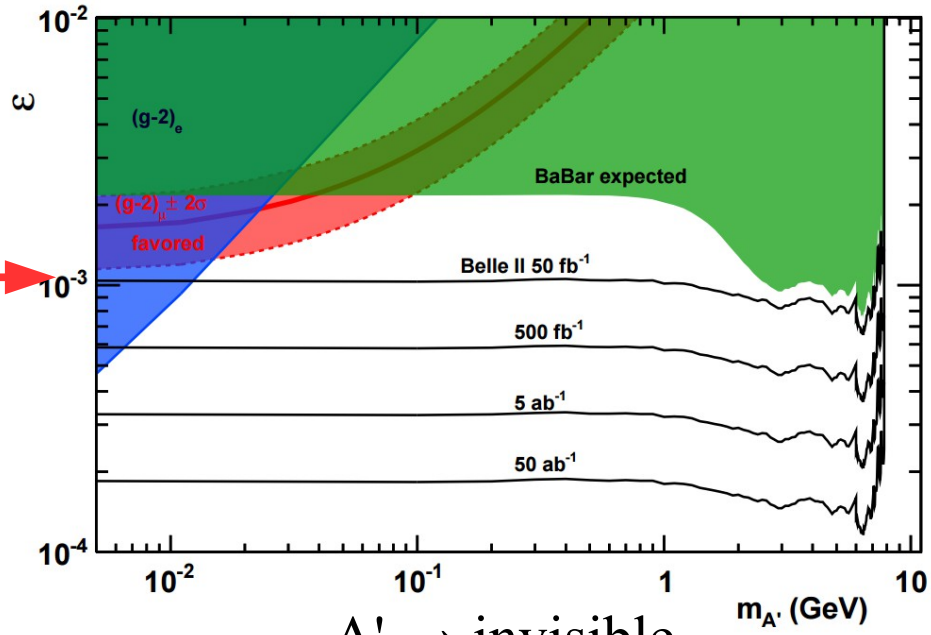
Single photon events, special trigger configuration is considered in the trigger menu.

$e^+e^- \rightarrow \gamma A', \quad A' \rightarrow$ invisible or (e^+e^- or $\mu^+\mu^-$) (dark photon)

$cross\ section \propto \varepsilon^2 \alpha^2 / E_{CM}^2$



$A' \rightarrow (e^+e^-$ or $\mu^+\mu^-)$



$A' \rightarrow$ invisible

exclusion regions (colored) for ε as a function of A' mass, for various experiments and projections of Belle II.

$\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow$ invisible [BaBar hep-ex 0808.0017] (light Higgs)

The talk covers only a small part of the Belle II physics topics. There are many other interesting ones to study.

$B \to X_s\gamma$

$B \to X_{s+d}\gamma$

B_s decays ($\gamma\gamma$, $\tau\tau$, $\mu\mu$, ...)

……

D mixing

CPV in charm

$D \to \gamma\gamma$, $\mu\mu$

$D \to \tau\upsilon$, $\mu\upsilon$

…….

h_b, η_b, and more in spectrum

converted photon

b-mass

QCD (fragmentation)

μ-pair asymmetry

……..

Beauty	
CKM matrix	
$\lvert V_{cb}\rvert$ $[B \to X_c l\nu]$	
$\lvert V_{ub}\rvert$ $[B \to \pi l\nu]$	
$\sin 2\phi_1$	
ϕ_2	
ϕ_3 [B$\to DK$]	
CPV	
$\mathcal{S}(B_s \to J/\psi\phi)$	
$\mathcal{S}(B_s \to \phi\phi)$	
$\mathcal{S}(B_d \to \phi K)$	
$\mathcal{S}(B_d \to \eta' K)$	
$\mathcal{S}(B_d \to K^*\gamma)$	
$\mathcal{S}(B_s \to \phi\gamma)$	
$\mathcal{S}(B_d \to \rho\gamma)$	
$\mathcal{A}_{SL}^{d,s}$	
$\mathcal{A}_{CP}(B_d \to s\gamma)$	
rare decays	
$\mathcal{B}(B \to \tau\nu)$	
$\mathcal{B}(B \to \mu\nu)$	
$\mathcal{B}(B \to D\tau\nu)$	
$\mathcal{B}(B_s \to \mu\mu)$	
$A_{FB}(B \to K^*\mu\mu)_{q_0^2}$	
$\mathcal{B}(B \to K^*\nu\nu)$	
$\mathcal{B}(B \to s\gamma)$	

Charm		
mode		
$D^0 \to K^+K^-$		$D^0 \to K^{(*)-}\ell^+\nu$
$D^0 \to \pi^+\pi^-$		R_M
$D^0 \to \pi^0\pi^0$		$D^0 \to K^+K^-, \pi^+\pi^-$
$D^0 \to K_s^0\pi^0$		y_{CP}
$D^0 \to K_s^0\eta$		A_Γ
$D^0 \to K_s^0\eta'$		$D^0 \to K^+\pi^-$
$D^0 \to \pi^+\pi^-\pi^0$		x'^2
$D^0 \to K^+\pi^-\pi^0$		y'
$D^0 \to K^+\pi^-\pi^+\pi^-$		A_M
$D^+ \to \phi\pi^+$		$\lvert\phi\rvert$
$D^+ \to \eta\pi^+$		$D^0 \to K_s^0\pi^+\pi^-$
$D^+ \to \eta'\pi^+$		x
$D^+ \to K_s^0\pi^+$		y
$D^+ \to K_s^0K^+$		$\lvert q/p\rvert$
$D_s^+ \to K_s^0\pi^+$		ϕ
$D_s^+ \to K_s^0K^+$		

and more ••••••

Summary

- The B-factories have achieved a tremendous success in the last decade
  - CPV in B-decays, confirmation of the SM
  - D meson mixing
  - Explore exotic states
- The next generation B factory (SuperKEKB+BelleII) is now becoming this generation one, aiming at intensity frontier experiment.
  - Complementary with the LHC in energy frontier
  - 50 ab^{-1} integrated luminosity.
- Serve as a clean environment for physics studies
  - B physics
  - Charm and τ physics
  - Exotics states, dark sector, light Higgs, and other NP, ….
- Full power physics commissioning starts in 2018, possible early measurements since 2017.
  - A friendly competition and complementarity with other experiments (LHCb, BESIII), a new and exciting era to explore the physics frontier.