Onia at Belle II

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New possibilities in Physics of Quarkonia
IHP-Paris, 24-25 September 2015

Introduction: Why Belle II?

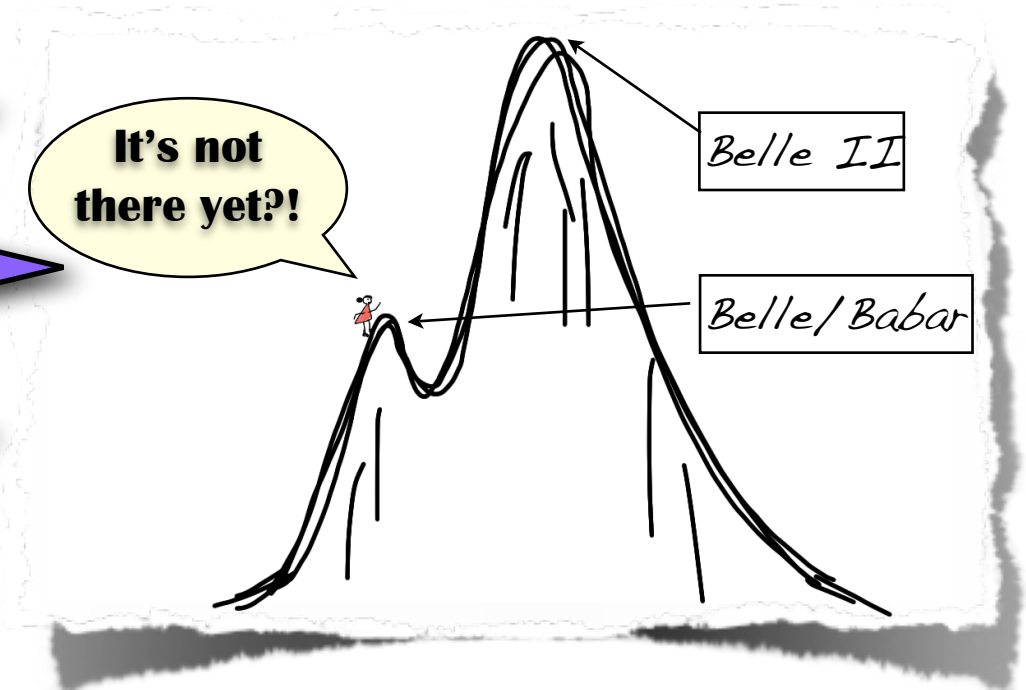
Discovery in Flavour Physics

Well motivated. But we need to improve the sensitivity?

- New physics models predict naturally deviation from SM in flavour and CP violating phenomena.
- But then, what is the indication of the non-appearance of new physics? And where/how to search it now?

Increase the sensitivity to new physics by an order of magnitude!

SuperKEKB/Belle II



Strategy to discovery via precision

Discovery by the intensity frontier experiments.

Increase the sensitivity = reduce the errors

$$\Delta_{NP} = \text{Deviation from SM}$$
$$= (\text{exp.} - \text{SM}) \pm \sqrt{(\sigma_{exp})^2+(\sigma_{SM})^2}$$

Increasing the sensitivity = find new observables (large c and small n)

$$\Delta_{NP} = \text{Allowed NP contribution}$$
$$= c/(M_{NP})^n$$

new physics coupling c, new physics scale M_{NP}

Strategy to discovery via precision

Discovery by the intensity frontier experiments.

Increase the sensitivity = reduce the errors

Δ_{NP} = Deviation from SM

$= (\text{exp.} - \text{SM}) \pm \sqrt{(\sigma_{exp})^2+(\sigma_{SM})^2}$

Increasing the sensitivity = find new observables (lar[illegible] and small n)

Δ_{NP} = Allowed NP co[illegible]

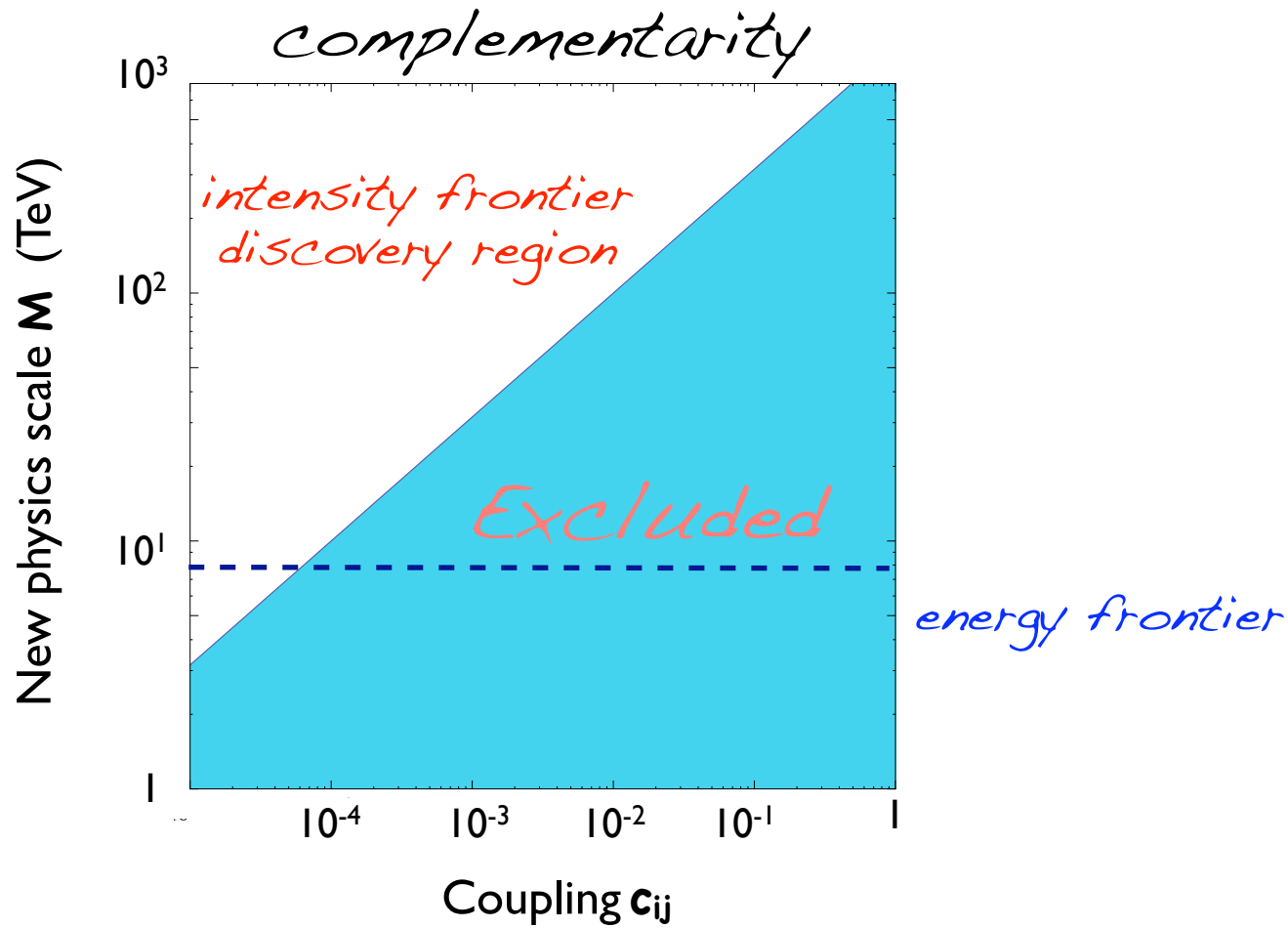
$= c/(M_{NP})^n$

new physics [illegible]

Find benchmark points, benchmark models for Belle II!!!

Discovery through precision

$$\Delta_{NP} = (\text{exp.} - \text{SM}) \pm \sqrt{(\sigma_{exp})^2+(\sigma_{SM})^2}$$
$$= c/(M_{NP})^{n=2}$$



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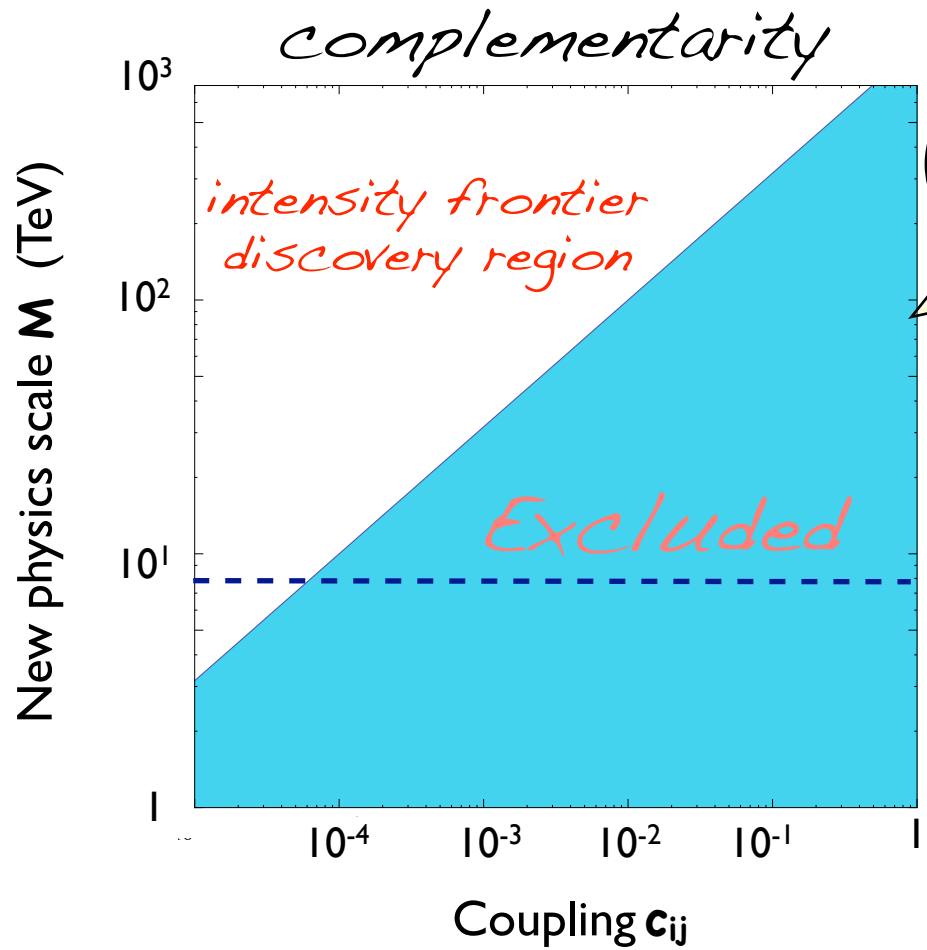

How do we push this bound by an order of magnitude???

If the new physics was at the vicinity of the current bound, we should have seen a tail???

Discovery through precision

$$\Delta_{NP} = (\text{exp.} - \text{SM}) \pm \sqrt{(\sigma_{exp})^2+(\sigma_{SM})^2}$$
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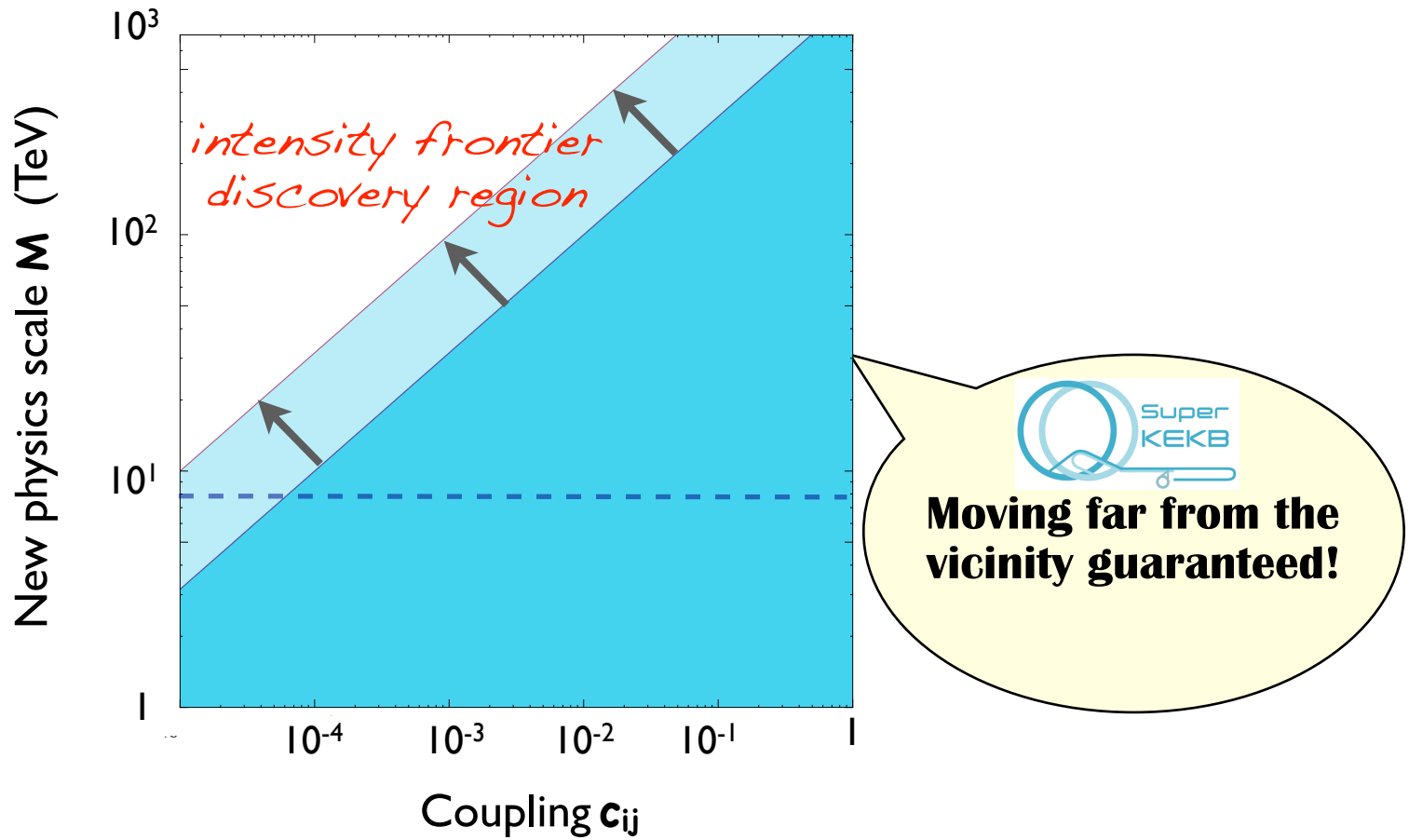
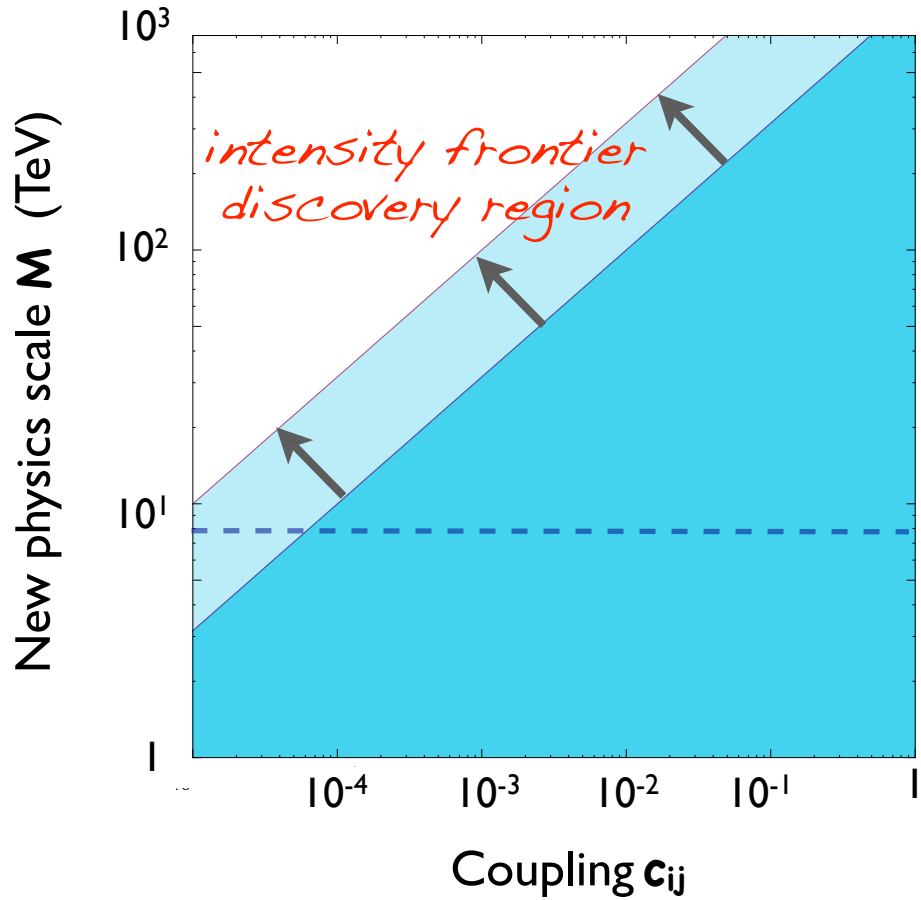


Statistics is not all about Belle II!

$$\Delta_{NP} = (\text{exp.} - \text{SM}) \pm \sqrt{(\sigma_{exp})^2+(\sigma_{SM})^2}$$

Reducing the systematic errors

- New detectors allow to reduce the systematic errors.
- Theoretical development in QCD higher order corrections, Lattice QCD etc allow to reduce the theoretical uncertainties.
- Improved measurements of "theoretical control channels" are very important to reduce the theoretical errors.



Statistics is not all about Belle II!

$$\Delta_{NP} = (\text{exp.} - \text{SM}) \pm \sqrt{(\sigma_{exp})^2 + (\sigma_{SM})^2}$$

The strength of Belle II (by me)!!

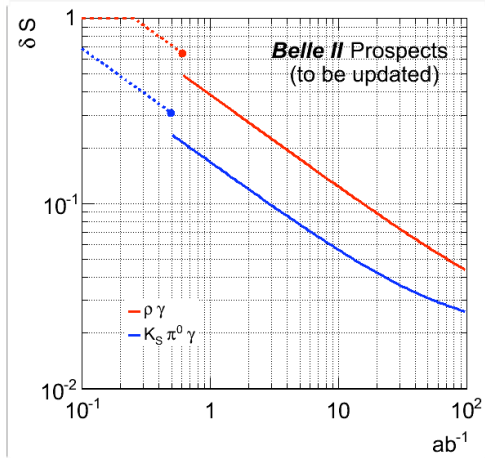
Statistics:

Remove also "reducible systematic errors"

$$\sigma_{Belle\ II} = \sqrt{(\sigma^2_{stat} + \sigma^2_{syst})\frac{\mathcal{L}_{Belle}}{50\text{ab}^{-1}} + \sigma^2_{ired}}$$

Particle ID:

Jump in the δS sensitivity!



Challenges for legendary channels?!

Time dependent CPV in $\pi^0\pi^0$??

- photon conversion makes vertexing possible⟶ time-dependent analysis

  $\mathcal{S}_{CP}^{\pi^0\pi^0}$: important **new** input for isospin analysis

  ⇒ Belle2 opens new possibilities

Missing energy channels!

Full reconstruction of B

- modes w/ multiple ν's
- Improved low p_T tracking - more slow π in tag side D* candidates

What is B2TiP(*)

See details on the slide at the kickoff meeting:

http://kds.kek.jp/getFile.py/access?contribId=14&sessionId=0&resId=0&materialId=slides&confId=15226

KEK where Belle II is hosted is the natural gathering point where flavour physics experts meet to discuss and develop topics of flavour physics for Belle II.

What's new in Belle II compared to Babar/Belle?

- ➡ Efficiencies and precision of the new hardware
- ➡ New analysis softwares and methods

What's new in theory after Babar/ Belle & LHCb result?

- ➡ Progresses in QCD
- ➡ New physics models and their constraints
- ➡ New observables

NEW IDEAS

Deliverable: "KEK green report" by the early 2017

(*)B2TiP: Belle II-Theory interface Platform

9 working groups

Find details on the B2TiP website

https://belle2.cc.kek.jp/~twiki/bin/view/Public/B2TIP

WG1	G. De Nardo, A. Zupanic, M. Tanaka, F. Tackmann, A. Kronfeld
WG2	A. Ishikawa, J. Yamaoka, U. Haisch, T. Feldmann
WG3	T. Higuchi, L. Li Gioi, J. Zupan, S. Mishima
WG4	J. Libby, Y. Grossman, M. Blanke
WG5	P. Goldenzweig, M. Beneke, C.-W. Chiang, S. Sharpe
WG6	G. Casarosa, A. Schwartz, A. Kagan, A. Petrov
WG7	Ch.Hanhart, R.Mizuk, R.Mussa, C.Shen, Y.Kiyo, A.Polosa, S.Prelovsek
WG8	K. Hayasaka, T. Feber, E. Passemar, J. Hisano
WGNP	R.Itoh, F.Bernlochner, Y.Sato, U.Nierste, L.Silvestrini, J.Kamenik, V.Lubicz

I: Leptonic/Semi-leptonic II: Radiative/Electroweak III: phi1(beta)/phi2(alpha) IV: phi3 (gamma)
V: Charmless/hadronic B decays VI: Charm VII: Quarkonium(like) VIII: Tau & low multiplicity NP: New Physics

Workshop schedule

To receive information, subscribe to the mailing list b2tip@... send an e-mail to Ph.Urquijo

02/14 *Approval of B2TiP*

06/14 Kickoff meeting

10/14 *WS-KEK* *KEKFF*

~04/15 WS (nonKEK) Krakow

02/15 *NP-WG* *KIT workshop*

~10/15 *WS-KEK* *KEKFF (Tokyo)* *B2TiP (KEK)*

~05/16 *WS (nonKEK)* *Pittsburgh*

~11/16 *B2TiP* *Report Camp* *@ MIAPP* *(Munich)*

early 17 *Editorial meeting*

REPORT PLANNING

Phase 1(2014)

- Identifying the 'Golden channels'

Phase II (2015)

- Detailed studies (theory uncertainties, experimental simulations)
- New ideas???

Phase III (2016)

- Finalizing the analysis/text
- Editing

Krakow workshop (~100 participants)

B2TiP Krakow 2015 highlights

https://d2comp.kek.jp/record/283

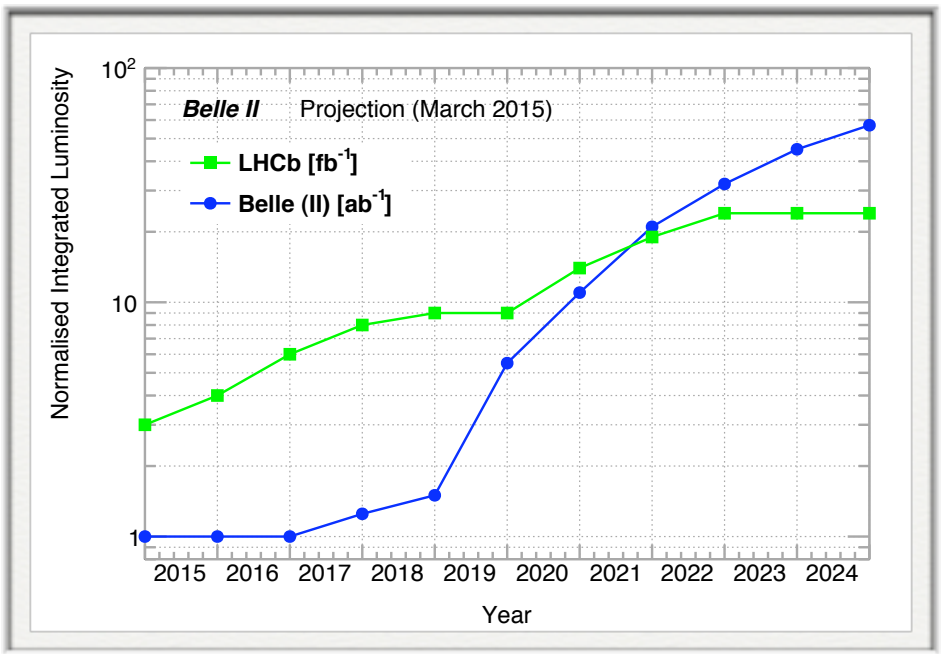
Summary of the 2nd B2TiP workshop (Krakow)*

In this short note, we summarize the report from the working groups on the last day of the 2nd B2TiP Workshop at Krakow (26-29 April, 2015).

The working group conveners are asked to propose five top priority observables, i.e. *Belle II golden modes*, and scrutinize them within the B2TiP working groups, namely by estimating the precision of the theoretical uncertainties and the achievable precision at Belle II with 5, 10, and 50 ab^{-1} of data.

Many new Belle II simulation results presented!

Many LHCb talks: comparison or competition???



Competition!

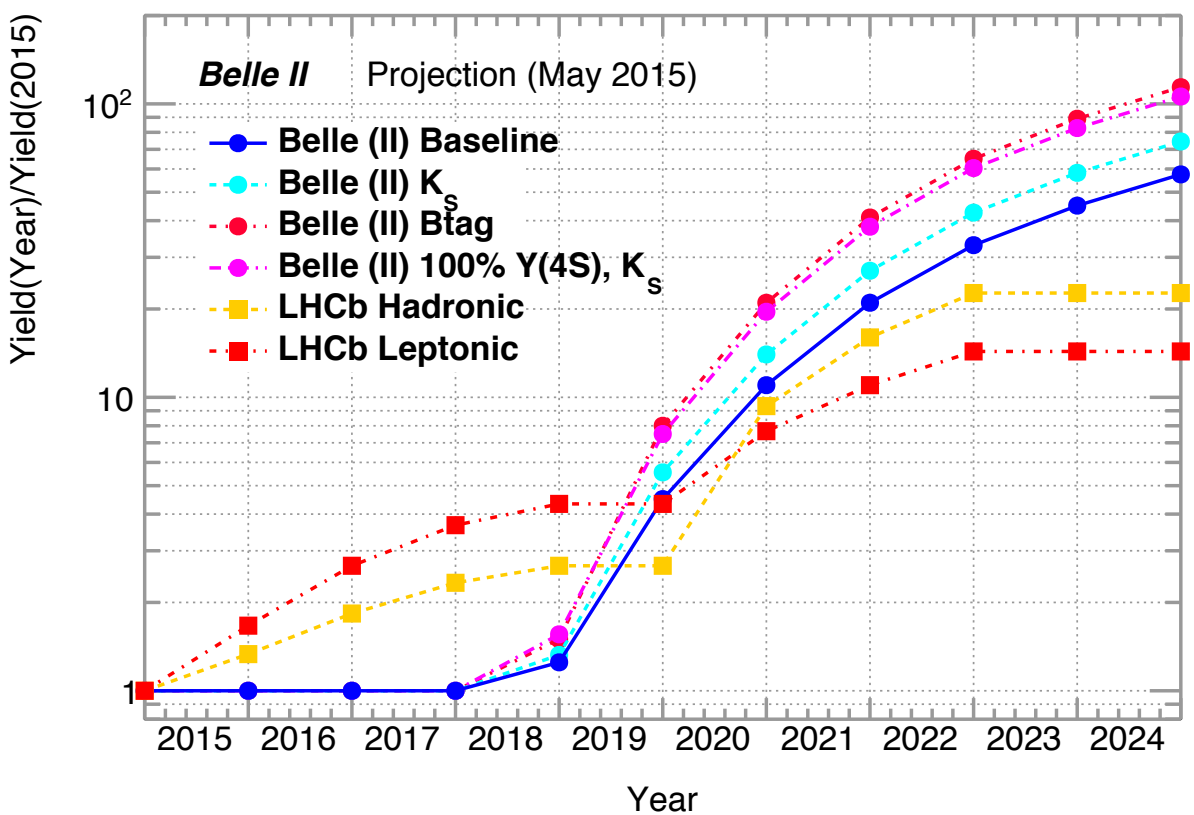
https://d2comp.kek.jp/record/234
BELLE2-NOTE-PH-2015-004

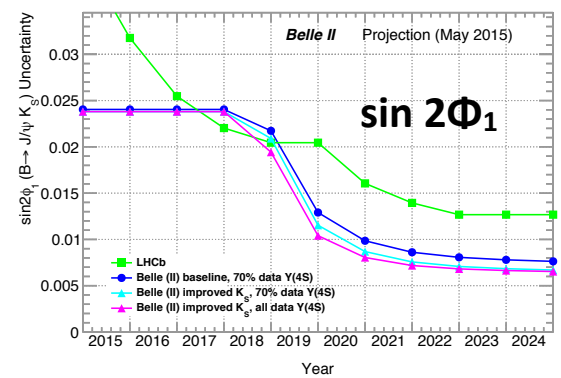
LHC era			HL-LHC era	
Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2020-22)	Run 4 (2025-28)	Run 5+ (2030+)
3 fb^{-1}	8 fb^{-1}	23 fb^{-1}	46 fb^{-1}	100 fb^{-1}

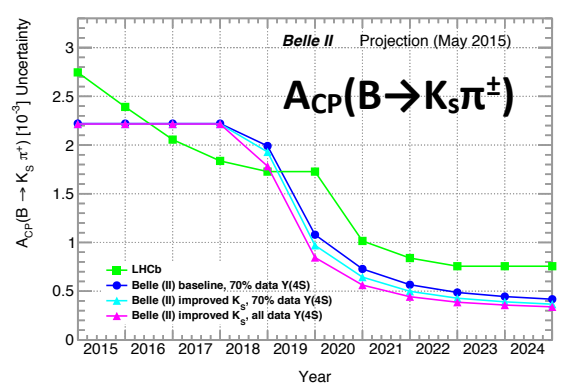
b-, c- quark σ scale linear with √s

Run-2 50% less efficient for hadronic triggered modes

Run-3 will have a new trigger: recovering efficiency loss in hadron trigger, no change for muon triggers.

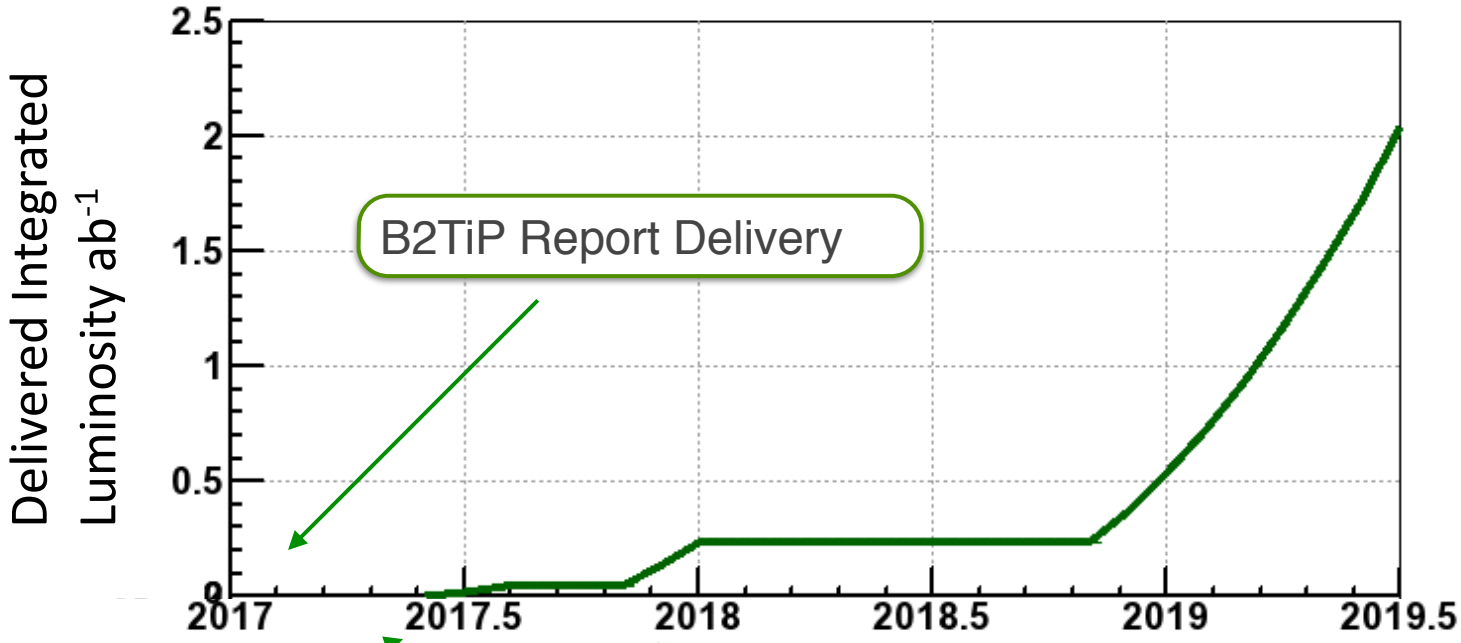






Onia at Belle II

The first data samples: “first-physics”



Phase 1
First collisions.
BEAST commissioning detector
Belle II not rolled in
“Beam analysis”

Phase 2
Belle II rolled in
SVD & PXD not installed
“Commissioning & unique data sets”

Phase 3
Full detector.
All systems go.

We need to maximise “first-physics” scientific/ publication output in phase 2 & early phase 3.

Phase 3 Physics: First O(1 ab^{-1})

Full detector operation. Considering options for balancing unique, non-Y(4S) samples, and Y(4S) samples. Proposals required.

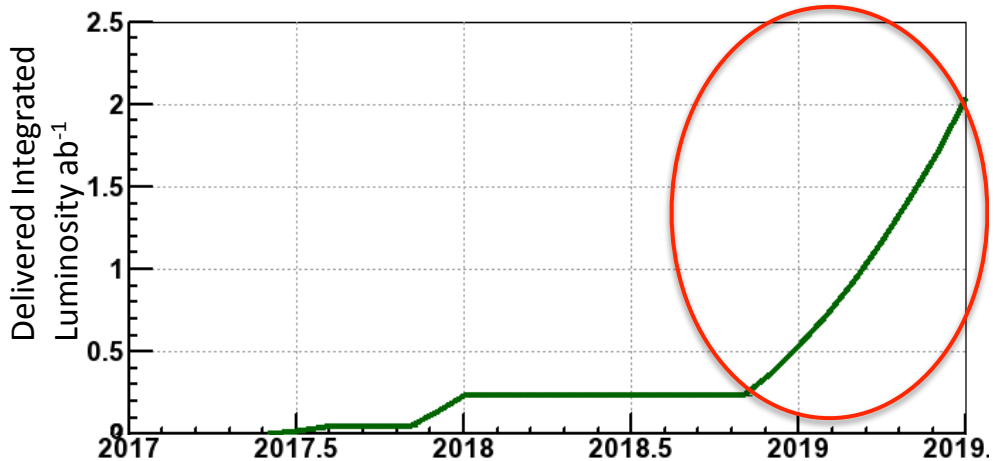
1. Y(4S) is our core. Clear motivations to run mostly at Y(4S) → see Φ_3 projection.

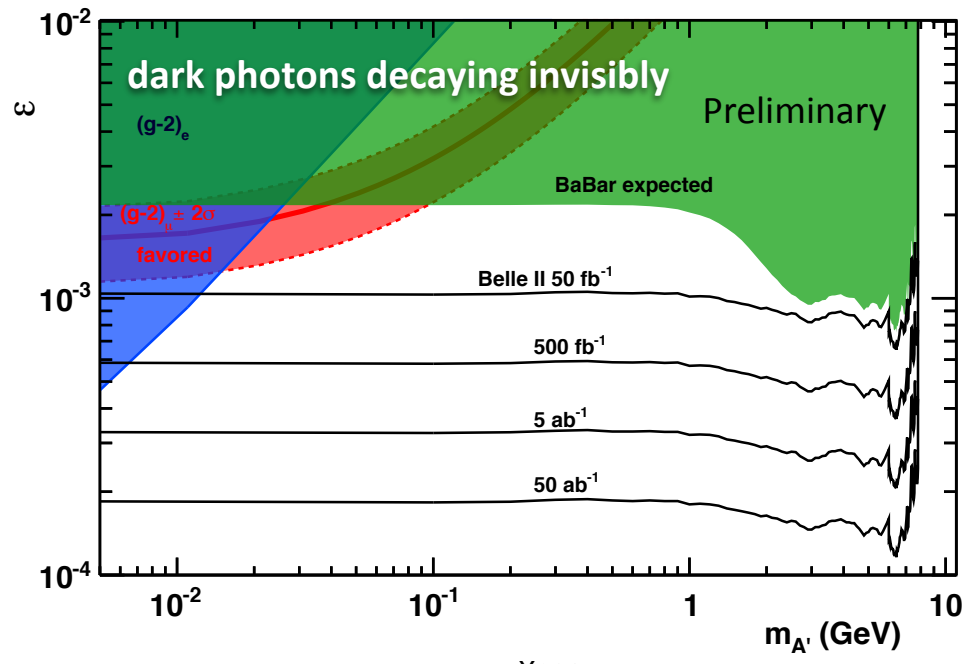
2. *Quantitative* arguments for running non Y(4S) [for a few weeks] will be seriously considered.

   Quarkonia(like) / **Y(3S), Y(6S), Scans**

   We won't decide the program in the report, only to provide physics cases**.**

3. **Dark sectors** and low multiplicity trigger limited at Belle may have good opportunities irrespective of E_{CM}.





First Physics is all about quarkonium!

Golden modes for First Physics at $\Upsilon(6S)$ run and scanning above

- $\Upsilon(6S) \to \Upsilon(1S/2S/3S)\pi^+\pi^-$ to test the influence of the nearby threshold.
- Searching for missing bottomonium such as $h_b(1P, 2P), \eta_b(2S)$ and the $2D - 1F$ multiplet
- Searching for molecular states - partners of Z_b
- Scanning near and above $\Upsilon(6S)$, to clarify the structure of $\Upsilon(6S)$ state (R_b measurement), to search for vector bottomonium-like states and to study the $\Lambda_b\Lambda_b$ threshold region

Golden modes for First Physics at $\Upsilon(3S)$ run, and scanning above

- Search for $\Upsilon(3S) \to \eta\Upsilon(1S)$ (test of the hadron transition puzzle)
- First observation of $\Upsilon(3S) \to \pi^0 h_b$ and $\Upsilon(3S) \to \gamma\eta_b$
- High statistics study of $\Upsilon(3S) \to \pi\pi\Upsilon(1, 2S)$ (charged/neutral)
- Systematic study of $E1 - M1$ discrepancy in $\eta_b(1, 2S)$ mass measurement via photon conversion and $\pi\pi\Upsilon(2S)$ tagging
- Dark matter, light-Higgs search
- Scan of $\Upsilon(1^3D_1)$ and $\Upsilon(2^3D_1)$

WG7: Quarkonium(-like) Golden modes

(1) ISR e+e- -> pi+pi-J/psi(psi'), K+K-J/psi(psi'), pi+pi-hc(1P, 2P), omega/phi chi_cJ, pi+pi-X(3823), gamma X(3872), DD(*)pi, ... to search/study Zc, Zc'. Zcs, ... all possible Y states, new resonances and understand the line shapes

(2) Tow-photon processes: gamma gamma -> phi J/psi to confirm/deny X(4350) and search for Y(4140), study of eta_c(2S), gamma gamma ->omega J/psi, DD*, etac pi0, ... to study X(3915), search for X(3872)-like states, ...

(3)B decays to
a. charmonium (eta_c, J/psi, h_c, chi_cJ, eta_c(2S), psi(2S)), light hadrons and kaon (search for the only missing
b. narrow charmonium state eta_c2(1D), for new charmonium-like states and for new channels of known states);
c. open charm-anti-charm final states (DD, DD*, DD*pi, DsDs,..) and kaon (search for elastic channels of known states,
d. search for new charmonium(-like) states).

state	looking for	experimental channel
$X(3872)$	mass and width	$B \to XK \to J/\psi\pi^+\pi^-K$
	lineshape	$B \to XK$, $X \to (D^0\overline{D}^0\pi,\ D^0\overline{D}^0\gamma)$
	isospin violation	$B \to XK \to J/\psi\omega K$
	charged partners	$B \to X^\pm K \to J/\psi\pi^\pm\pi^0 K$
$Z_c^{(\prime)}$	mass and binding energy	$e^+e^- \to \gamma_{\rm ISR}(J/\psi, h_c)\pi^+\pi^-$
	production mechanism	$e^+e^- \to \gamma_{\rm ISR}(J/\psi, h_c)\pi^+\pi^-$
	discriminating channel	$Z^{(\prime)} \to \eta_c\rho$
$Z_b^{(\prime)}$	mass and binding energy	$\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$
$Z(4430)$	open charm decay modes	$B \to Z(4430)K \to \overline{D}D^*(2600)K$
		$B \to Z(4430)K \to \overline{D}^*D(2550)K$
$Z(4200)/Z(4430)$		$B \to Z(4430)K \to \overline{D}D^*K$
Y states	tetraquark confirmation	$e^+e^- \to \gamma_{\rm ISR}\, J/\psi\pi^+\pi^-$
$Y(4260)$	open charm decay mode	$e^+e^- \to \gamma_{\rm ISR} DD^*\pi$
$Y(4220)$	confirmation	$e^+e^- \to \gamma_{\rm ISR}\, h_c\pi^+\pi^-$
$X(3915)$	tetraquark model prediction	$Y(4220) \to \gamma X_0' = \gamma X(3915)$?
	0^+, 2^+ isosinglet tetraquarks	$\gamma\gamma \to \eta_c\eta$, $\gamma\gamma \to J/\psi\omega$
	0^+, 2^+ isovector tetraquarks	$\gamma\gamma \to \eta_c\pi$, $\gamma\gamma \to J/\psi\pi^+\pi^-$
	tetraquark radiative transitions	$Y(4630) \to \gamma X_2$, $Y(4008) \to \gamma X_0$
$\Upsilon(5S)$	tetraquark prediction	$\Upsilon(5S) \to \gamma X_b \to \gamma\Upsilon(nS)\pi^+\pi^-(\pi^0)$
		$\Upsilon(5S) \to \gamma X_b \to \gamma B^0\bar{B}^{*0}$
$\Upsilon(6S)$	bottom-strange decay modes	$\Upsilon(6S) \to B_s^{(*)}B_s^{(*)}$
X_b	production	$\Upsilon(5S) \to X_b\gamma \to \Upsilon(nS)\pi^+\pi^-\gamma$

Table 4: Summary of decay modes of interest to discuss molecules/tetraquarks.