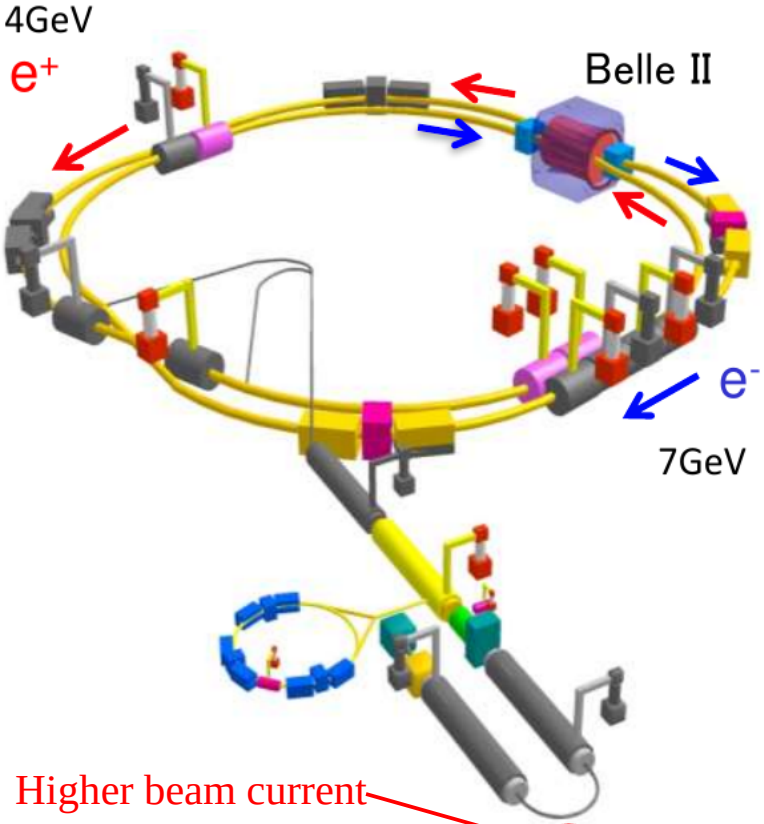
The Belle II prospects for charmonium and bottomonium studies

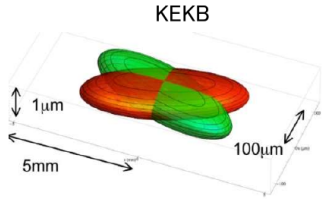
Pavel Krokovny
Budker INP

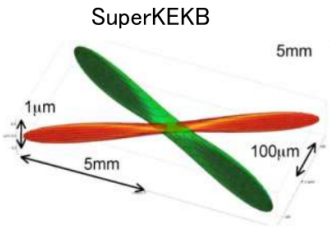
- Experiment status
- Charmonia results
- Bottomonia results
- Summary

SuperKEKB collider



- Asymmetric e^+e^- collider
- Energy limit 11.02 GeV (up to 11.24)
- Luminosity goal: 6×10^{35} $cm^{-2}s^{-1}$
- Belle II goal: collect 50 ab^{-1}





Higher beam current

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

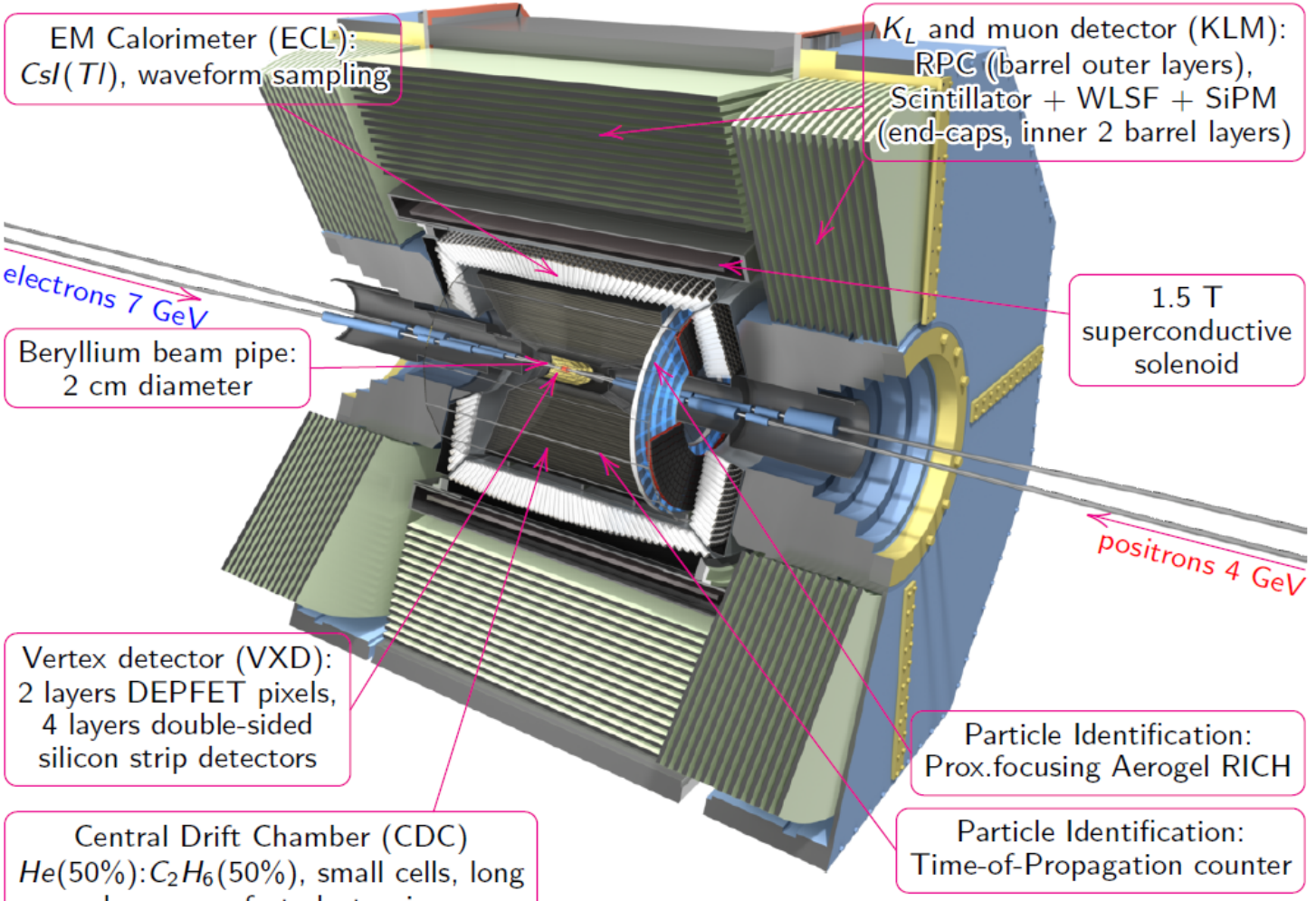
Very strong vertical focusing at the interaction point

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
bg		0.425		0.28		
Half crossing angle	ϕ	11		41.5		mrad
Beta functions at IP	β_x^*/β_y^*	1200/5.9		60/0.3		mm
Beam currents	I_b	1.64	1.19	2.5	1.8	A
Luminosity	L	2.1×10^{34}		6.5×10^{35}		$cm^{-2}s^{-1}$

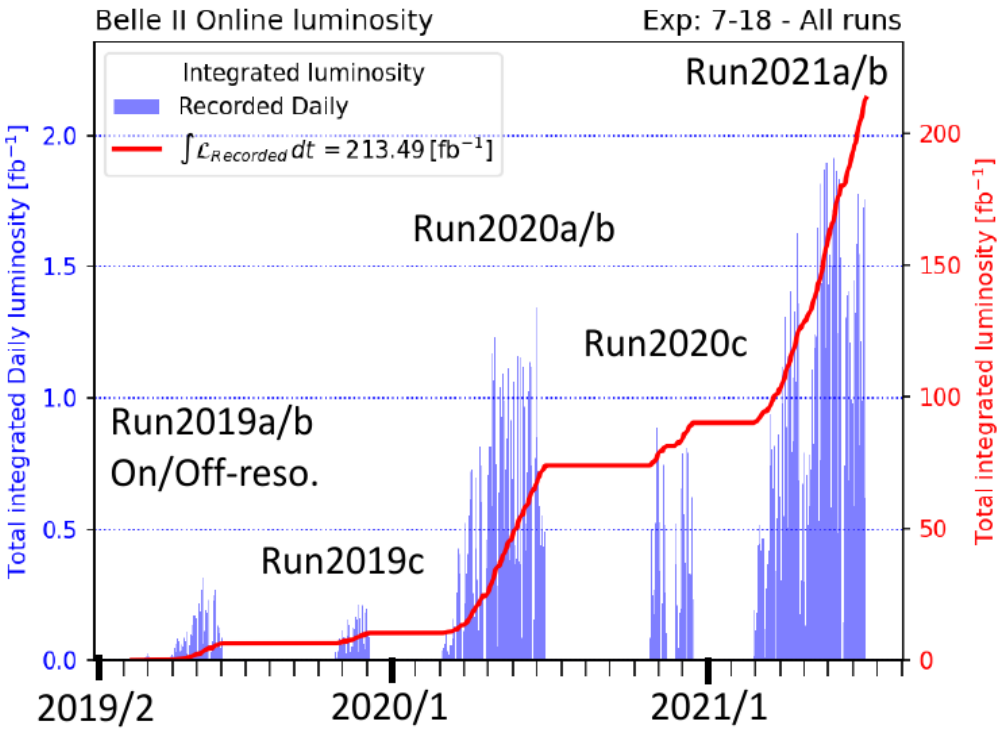
x20

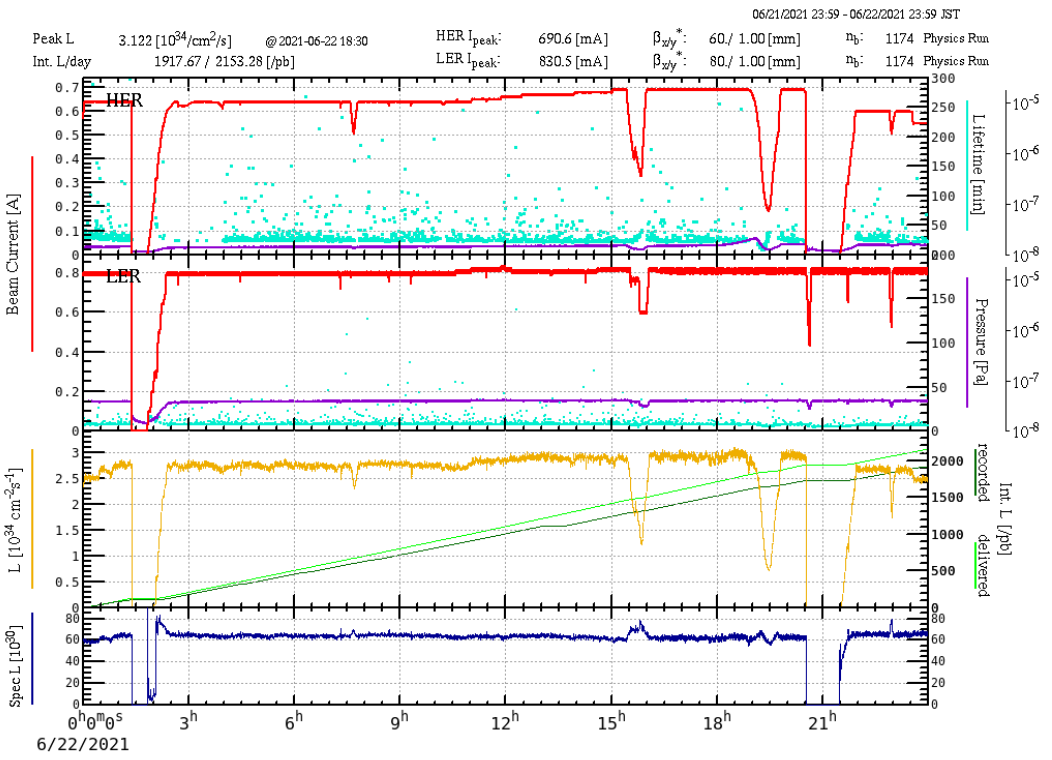
x1.5

Belle II detector



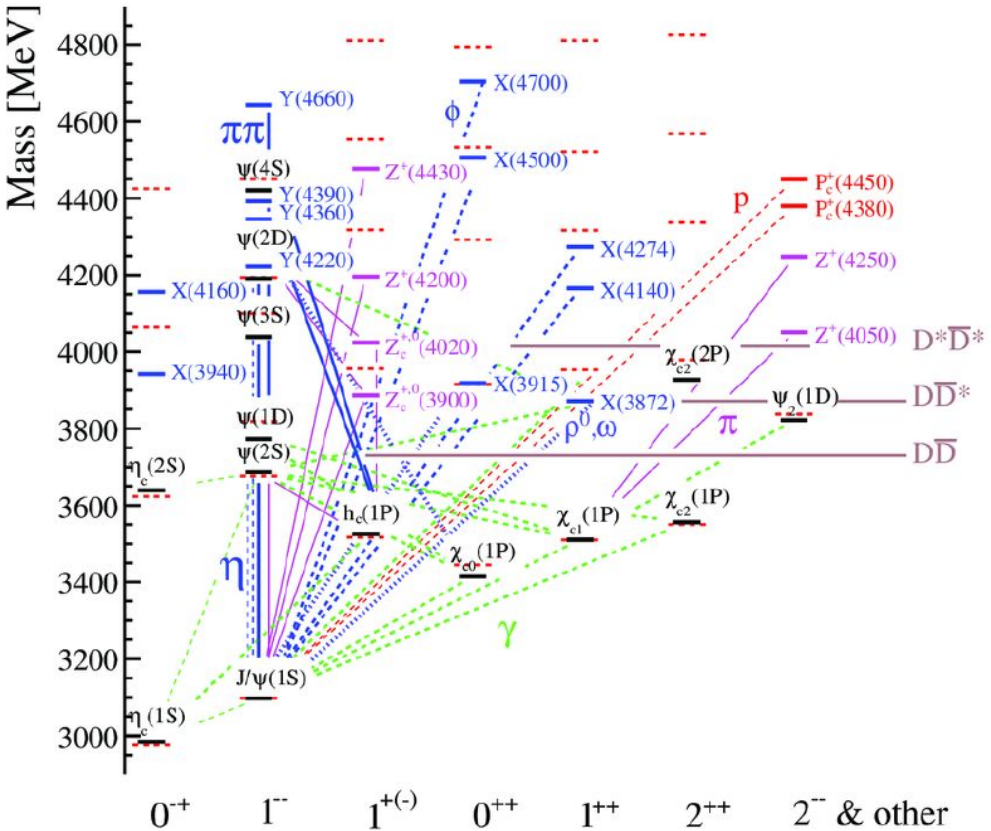
Data taking status





- New luminosity world record 3.1 x 10^{34} $cm^{-2}s^{-1}$ (KEKB: 2.1 x $10^{34}$$cm^{-2}s^{-1}$).
- Data taking efficiency is achieved almost 90%.
- Double available statistics up to 213 fb^{-1} by 2021a/b physics run.

Charmonia



[Rev. Mod. Phys. 90 (2018) 15003]

Observed States:

- Conventional Charmonium
- Unconventional neutral states
- Unconventional charged states
- Pentaquark candidates

Below kinematic threshold:

mostly bound states of mesons/baryons.

Above threshold:

zoo of complex XYZ states.

Charmonia production at B factory

B decay: $B \rightarrow K X_{c\bar{c}}$

$J^{PC} = 0^{-+}, 1^{--}, 1^{++}$

Initial-state Radiation (ISR)

$J^{PC} = 1^{--}$

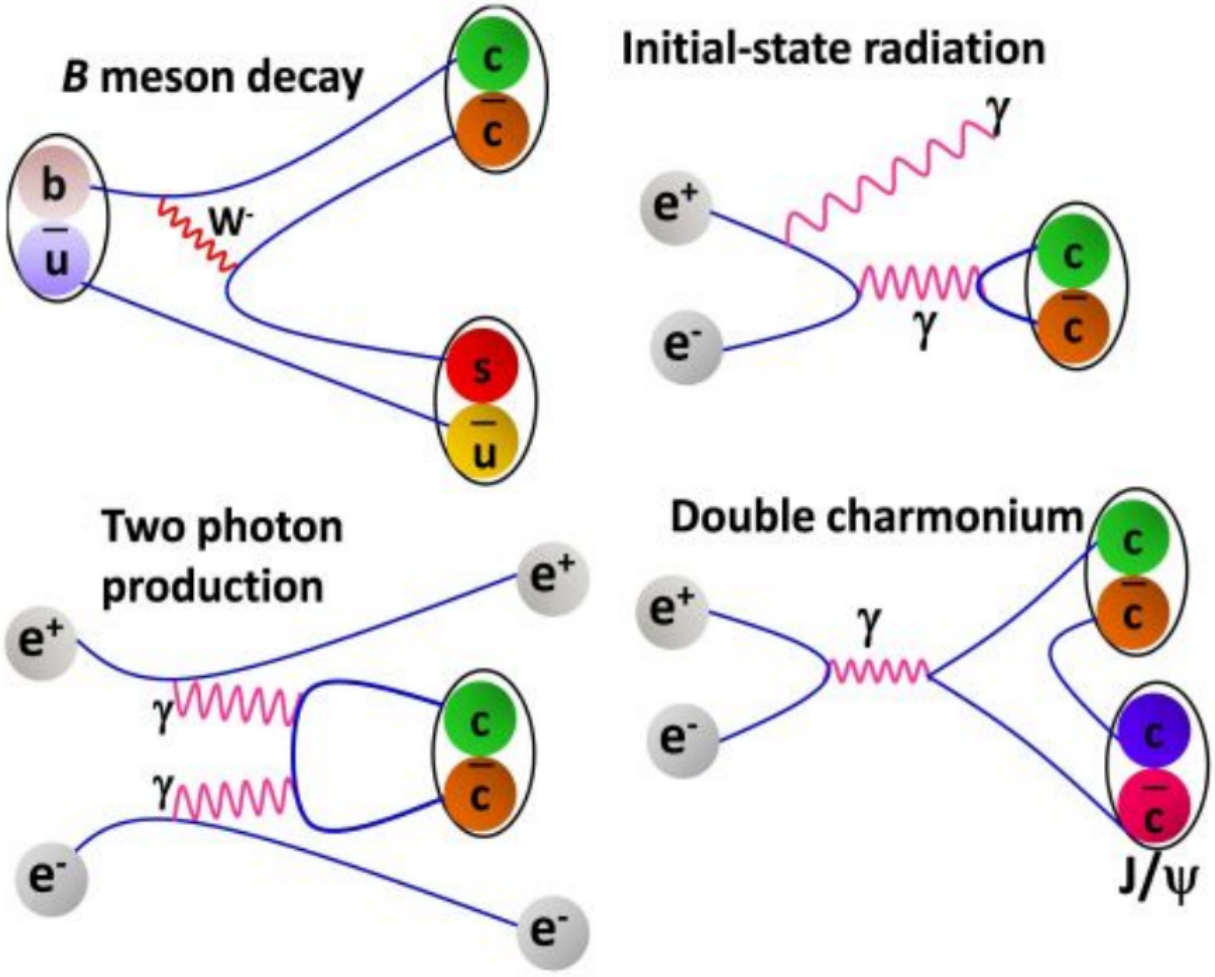
Two-photon Process

$J^{PC} = 0^{-+}, 0^{++}, 2^{++}, 2^{-+}$

Double charmonium

e.g. $e^+e^- \rightarrow J/\psi X$

[PRL 98, 082001 (2007)]



X(3872)

Most interesting particle in charm sector

Observed by Belle

Phys.Rev.Lett. 91 (2003) 262001

Studied by B-Factories, LHCb

Still many puzzles:

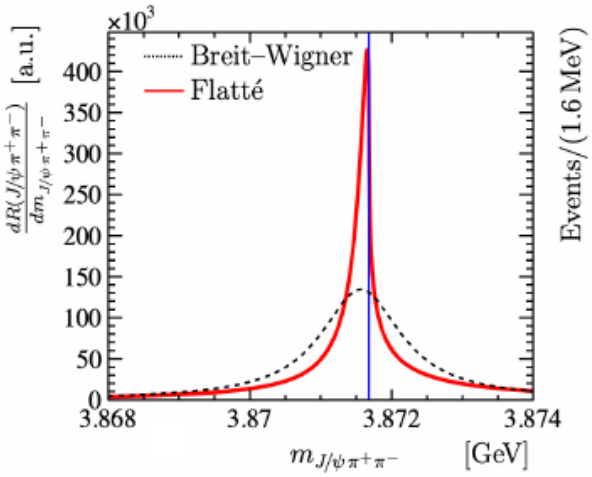
decays ratios?

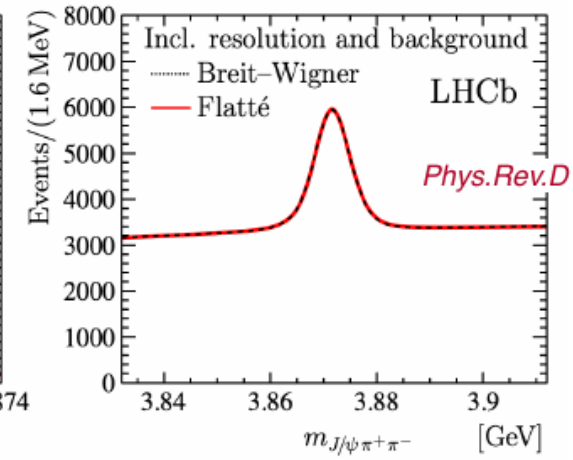
lineshape?

real nature?

Parameter index	Decay mode	Branching fraction
1	$X(3872) \to \pi^+\pi^- J/\psi$	$(4.1^{+1.9}_{-1.1})\%$
2	$X(3872) \to D^{*0}\bar{D}^0 + c.c.$	$(52.4^{+25.3}_{-14.3})\%$
3	$X(3872) \to \gamma J/\psi$	$(1.1^{+0.6}_{-0.3})\%$
4	$X(3872) \to \gamma\psi(3686)$	$(2.4^{+1.3}_{-0.8})\%$
5	$X(3872) \to \pi^0\chi_{c1}$	$(3.6^{+2.2}_{-1.6})\%$
6	$X(3872) \to \omega J/\psi$	$(4.4^{+2.3}_{-1.3})\%$
7	$B^+ \to X(3872)K^+$	$(1.9 \pm 0.6) \times 10^{-4}$
8	$B^0 \to X(3872)K^0$	$(1.1^{+0.5}_{-0.4}) \times 10^{-4}$
	$X(3872) \to$ unknown	$(31.9^{+18.1}_{-31.5})\%$

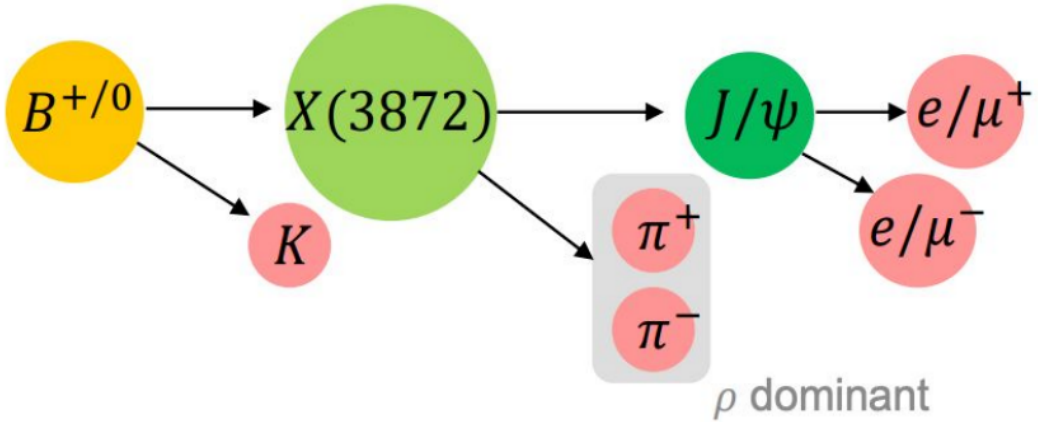
Phys.Rev.D 100 (2019) 9, 094003

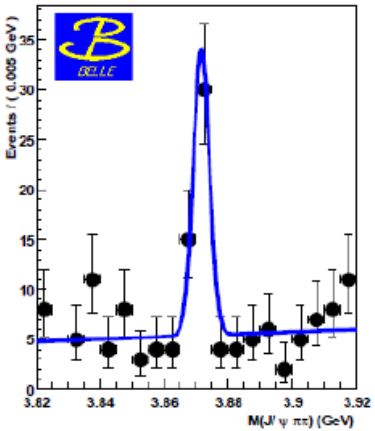




Phys.Rev.D 102 (2020) 9, 092005

X(3872)





X(3872): Most cited Belle paper (~1900)

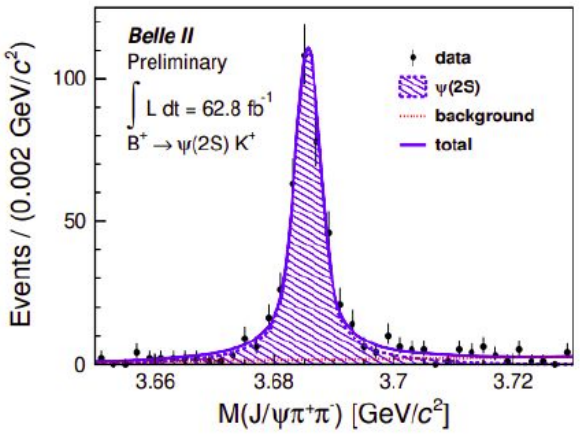
PRL 91, 262001 (2003)

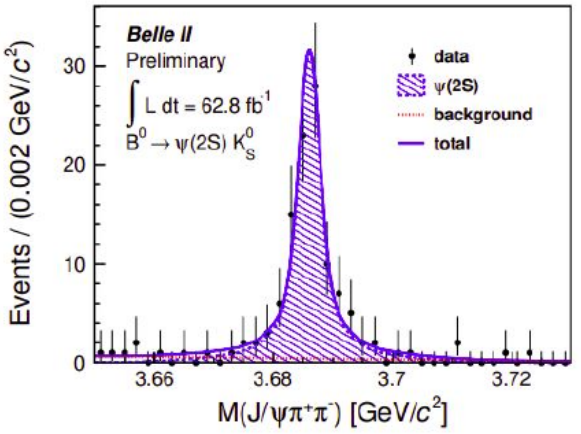
Data Sample: 62.8 fb^{-1}

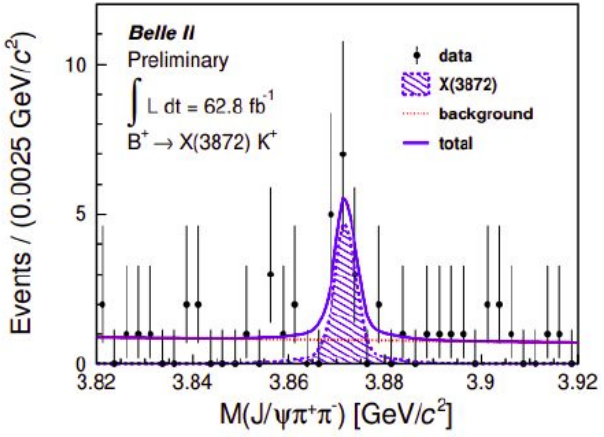
Reconstruction of final states: $B^{\pm} \to \pi^+\pi^- J/\psi(l^+l^-) K^{\pm}$ and $B^0 \to \pi^+\pi^- J/\psi(l^+l^-) K_S$

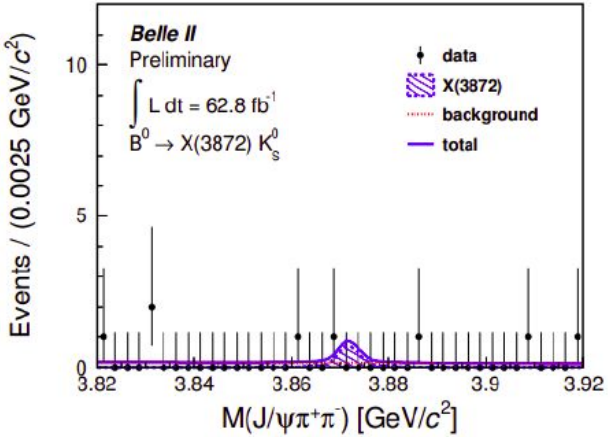
Selection: Continuum suppression,
Particle Identification,
Kinematics criteria: $M_{\pi\pi}$, $M_{bc} = \sqrt{(E^2_{beam} - p_B^2)}$, $|\Delta E| = E_B - E_{beam}$

X(3872) rediscovery at Belle II









Calibration: B → ψ(2S) K.

First X(3872) at Belle II:

14.4±4.6 events (4.6σ)

Consistent with Belle

[BELLE2-NOTE-PL-2021-002]

Charmonium production by ISR

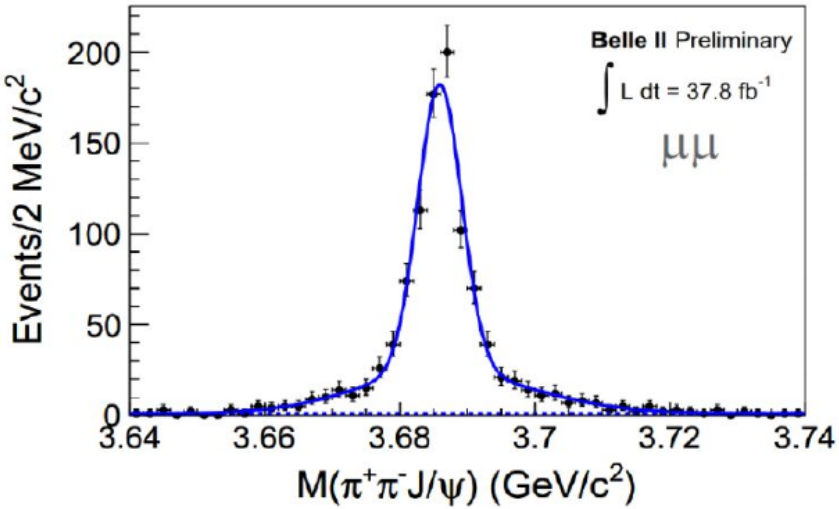
Reconstruction: $e^+e^- \Upsilon_{ISR} \rightarrow \pi^+\pi^- J/\psi(l^+l^-)$

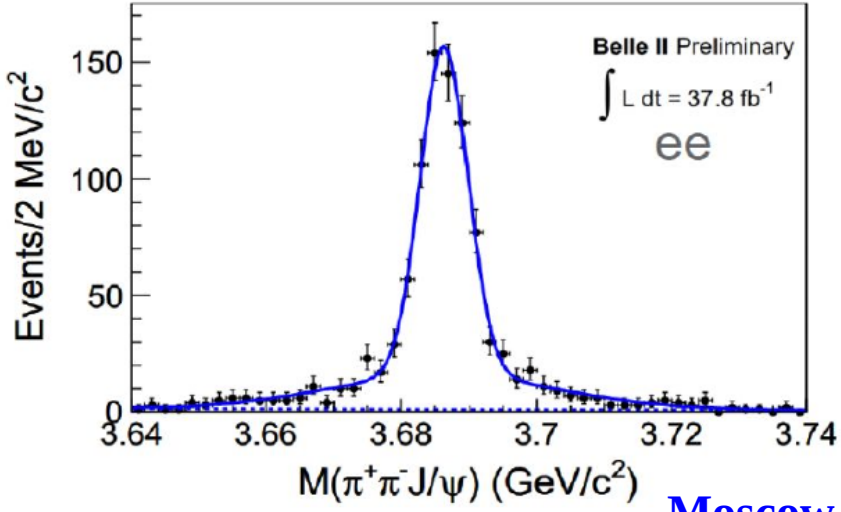
- Nominal PID requirements,
- $|M(l^+l^-) - m_{J/\psi}| < 75$ MeV/c^2,
- $|M^2_{recoil}(\pi^+\pi^- J/\psi)| < 2$ GeV/c^2.

Clear observation of ISR ψ(2S) signals.

Next step is Y(4260) rediscovery.

Expecting ~60 total events per 100 fb^{-1}.



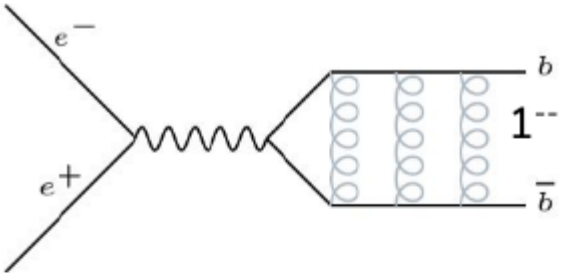


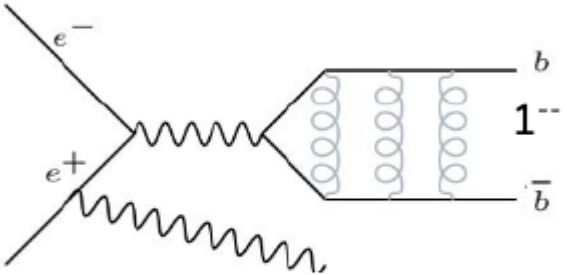
Bottomonia

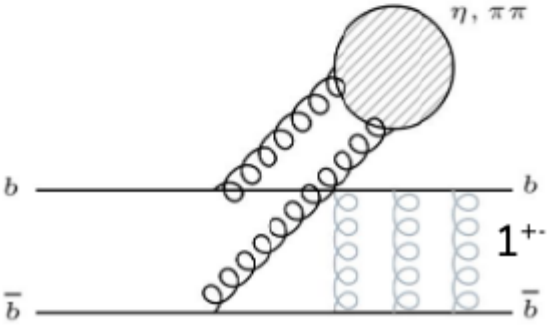
How to produce $b\bar{b}$ at e^+e^- collider:

- Directly from e^+e^- : $J^{PC}=1^{--}$: Y(nS),
- ISR production : $J^{PC}=1^{--}$: Y(nS),
- Hadronic transitions from Y(nS) through $\eta,\pi\pi$

  $J^{PC}=1^{--}, 0^{-+}, 1^{+-}$ ... : Y(nS), h_b(nS), η_b(nS), ...
- Radiative transitions from Y(nS) $J^{PC} = 0^{++},1^{++},2^{++}$: $\chi_{b,}$
- Electric dipole transition (E1) $J^{PC} = 0^{--}$: $\eta_{b,}$
- Hindered magnetic dipole (M1) transitions.

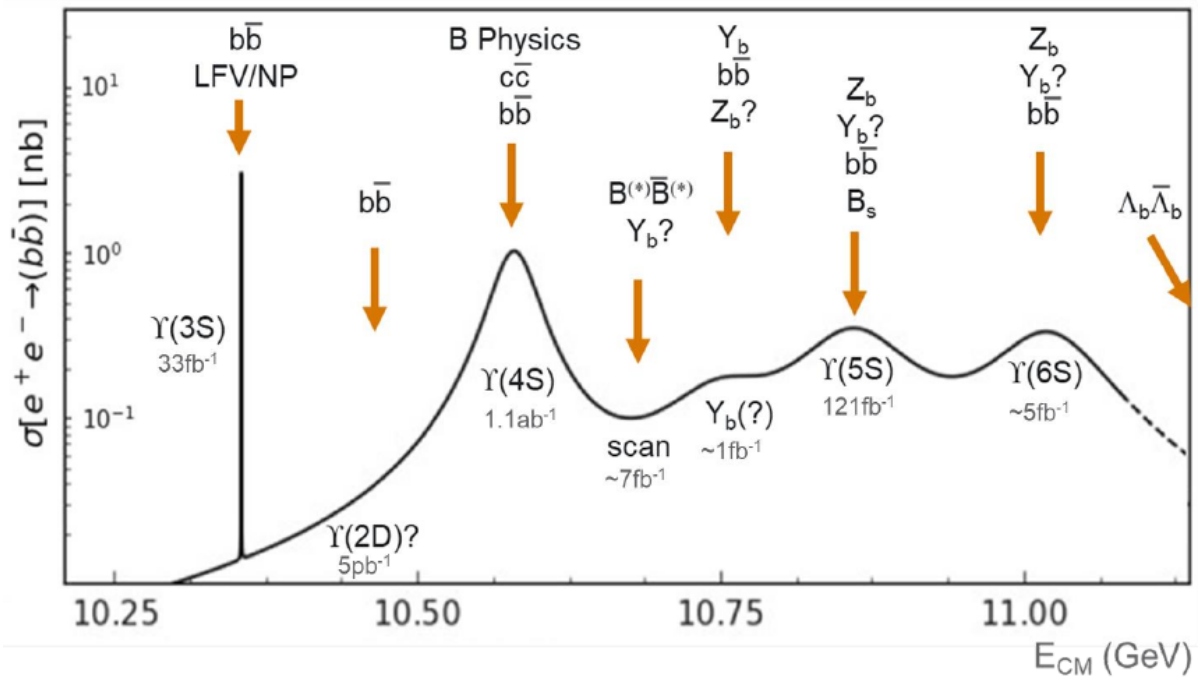


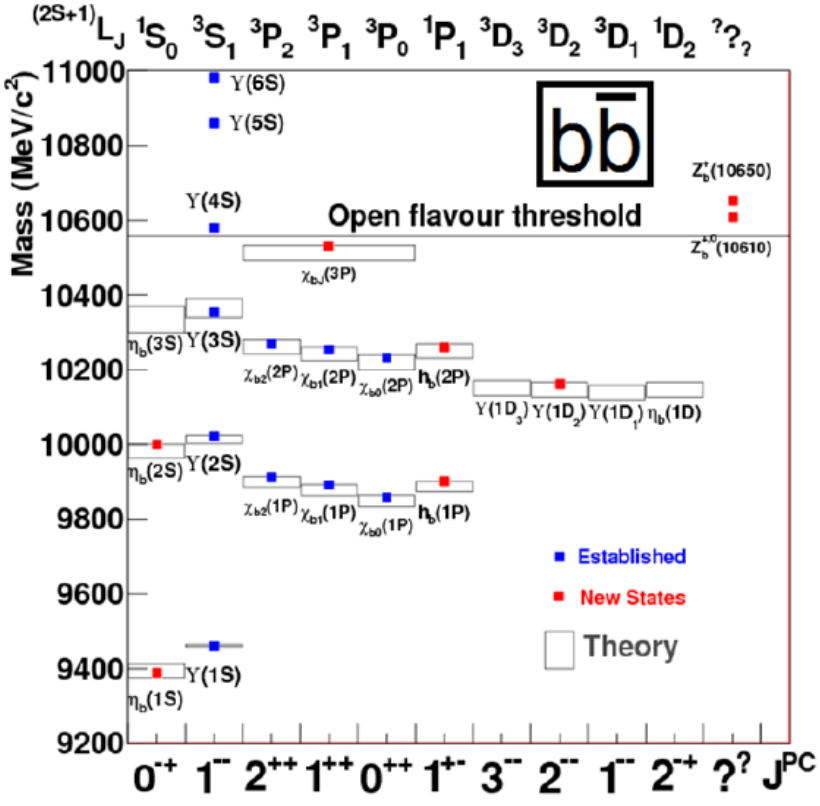




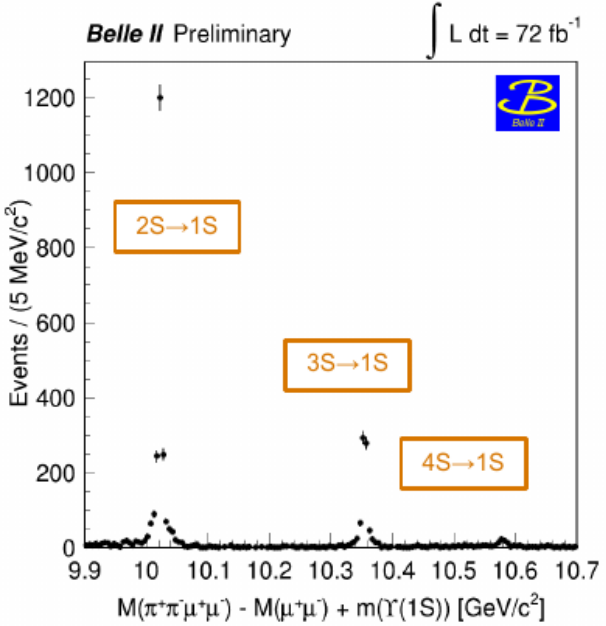
Bottomonia

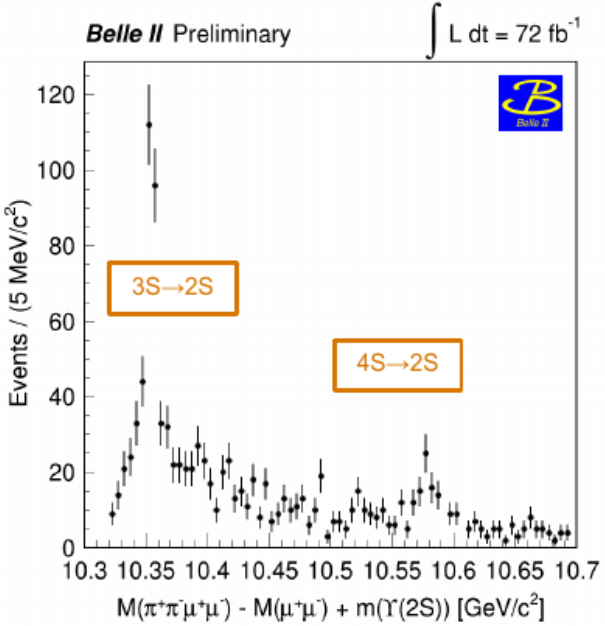
Search exotics by ππ, γ, η transitions

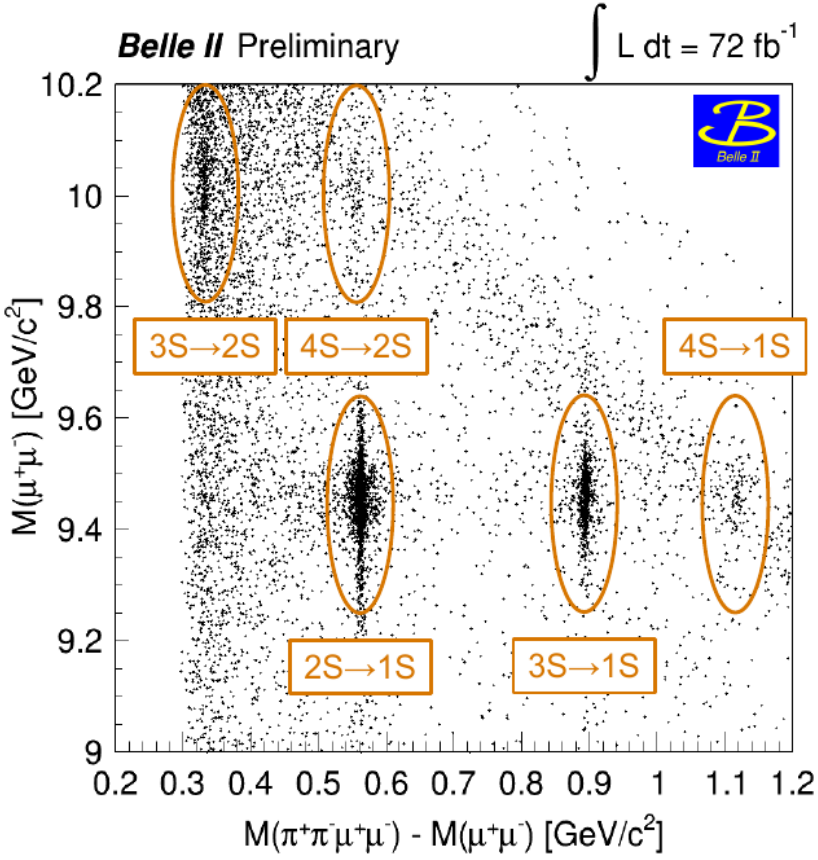




Belle II progress in dipion transitions







- Early Belle II data, 72 fb^{-1}
- Verification of analysis chain for $\pi^+\pi^- l^+ l^-$
- Future studies: $M(\pi^+\pi^-)$ in Y(4S) transitions

Belle II potential

- Run at Y(6S) and Y(5S) and high energy scan:
  - Search for new, predicted, resonances such missing bottomonia, exotic states,
  - Improve precision of already known process and states: e.g. Zb's,
  - Measure the effect of the coupled channel contribution,
  - Study $B^{(*)}\overline{B}^{(**)}$ and $Bs^{(*)}\overline{Bs}^{(**)}$ threshold regions (challenging for Super-KEKb).

- Run at Y(3S) and Y(2S):
  - Search for missing $\pi\pi/\eta$ transitions to constrain further theoretical models,
  - Search for new physics: LFV, LFU, new scalars...

Future Plans

- Main focus to collect Y(4S) on-peak data.
- Upcoming non-Y(4S) plans (Nov 2021):
  - 10.751 GeV (10 fb^{-1}): to study $Y_b(10753)$ on-peak,
  - 10.657, 10.706, 10.810 (1+2+3 fb^{-1}): additional points for $B\overline{B}$ decomposition.
- Expected data: ~400 fb^{-1} by end of 2021, ~750 fb^{-1} by summer 2022.
- 9 month upgrade, then data taking till 2026, expected O(10 ab^{-1}).
- After upgrade: 11 GeV (30 fb^{-1}): to study Y(6S) on-peak.
- Future proposals: options for larger Y(6S), Y(3S), Y(5S) datasets.

Summary

- Belle II: next generation B-Factory.
- Charmonia / bottomonia / XYZ is a significant component of the physics program.
- Advantages with unique production, decay modes related to neutrals.
- Planning for non-Y(4S) energies.

- Analysis of early data.
- Rediscoveries of 1^{--} $b\bar{b}$ states.
- Statistics soon comparable to BaBar/Belle.
- Input welcome from community on 10.75 GeV and other $b\bar{b}$ studies.