CHARMONIUM AND BOTTOMONIUM SPECTROSCOPY AT BELLE II

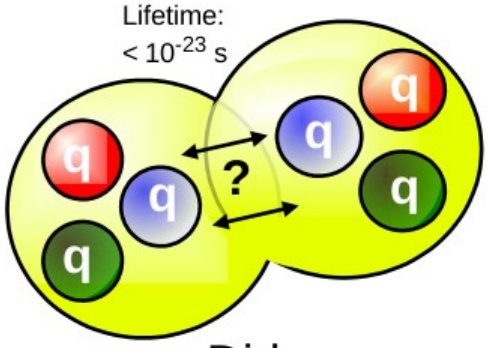
13 APRIL 2021 I ASHISH THAMPI ON BEHALF OF THE BELLE II COLLABORATION

XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, Stony Brook University

QUARK BOUND STATES

Meson

Baryon

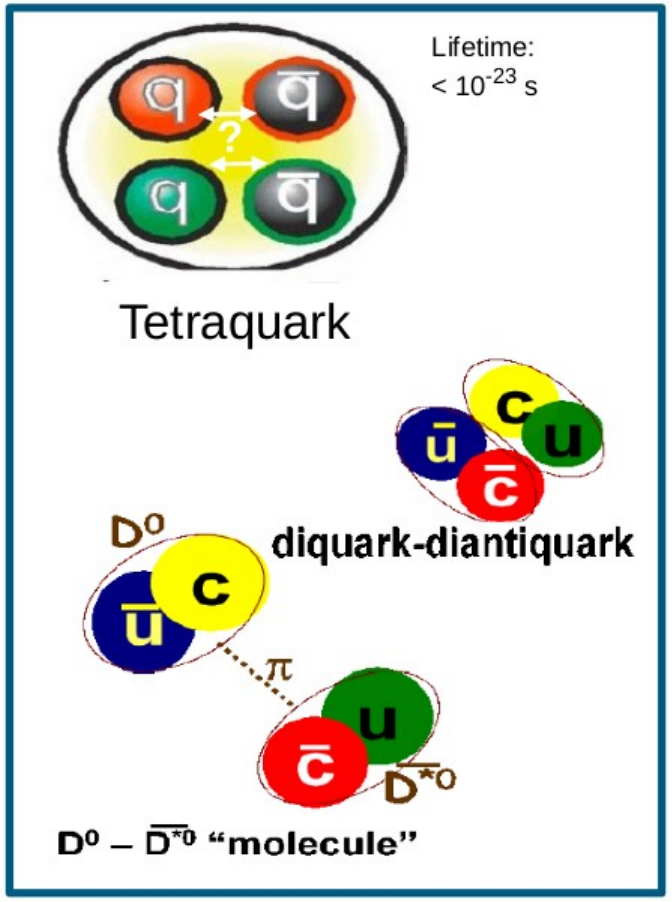


Di-baryon

Pentaquark

Hybrid meson

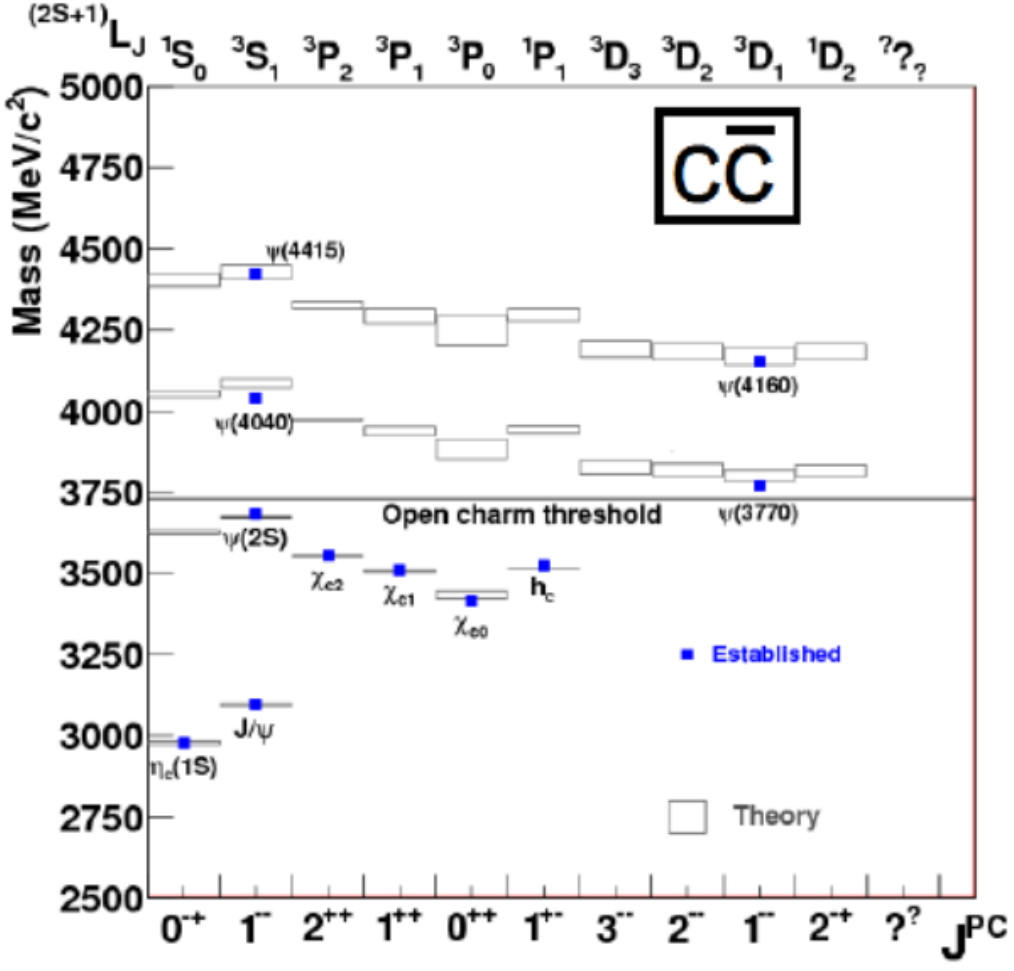
Glueball

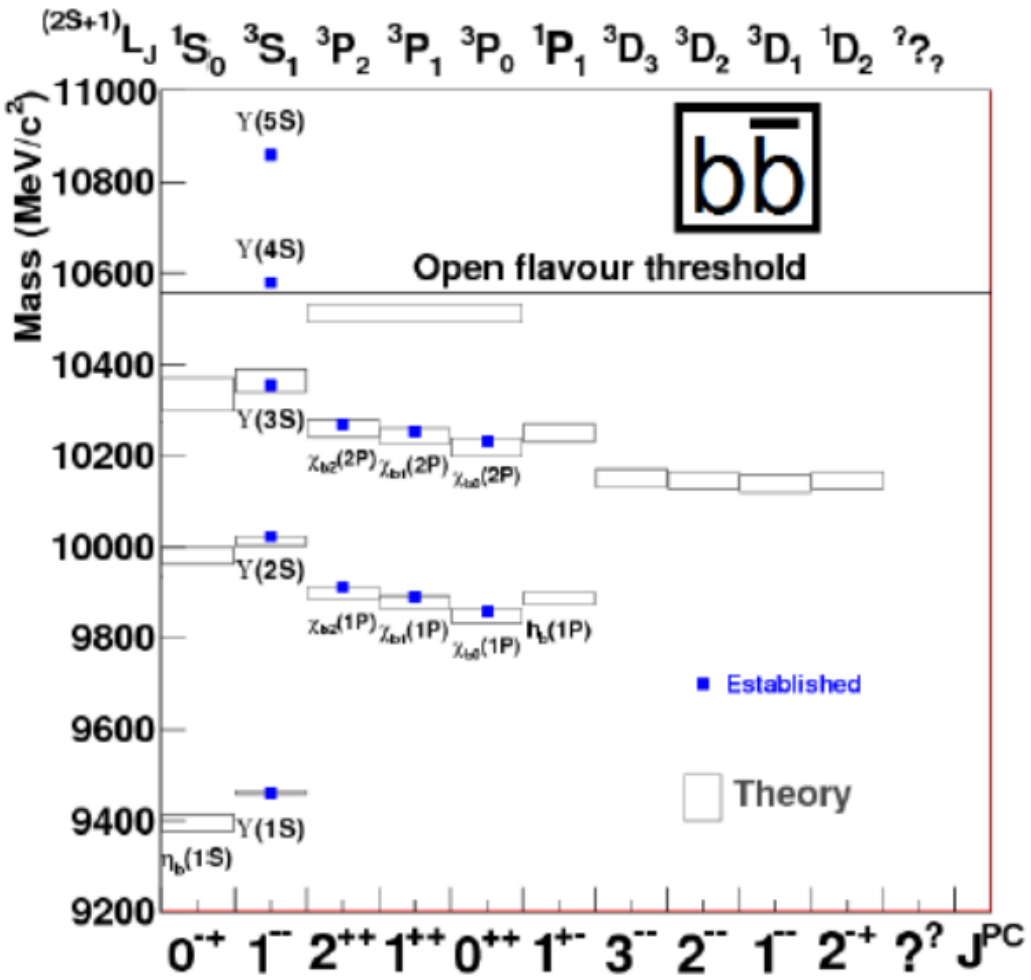


...and superposition of different states: $c_1|q\bar{q}> + c_2|q\bar{q}q\bar{q}> + ...$

QUARKONIA

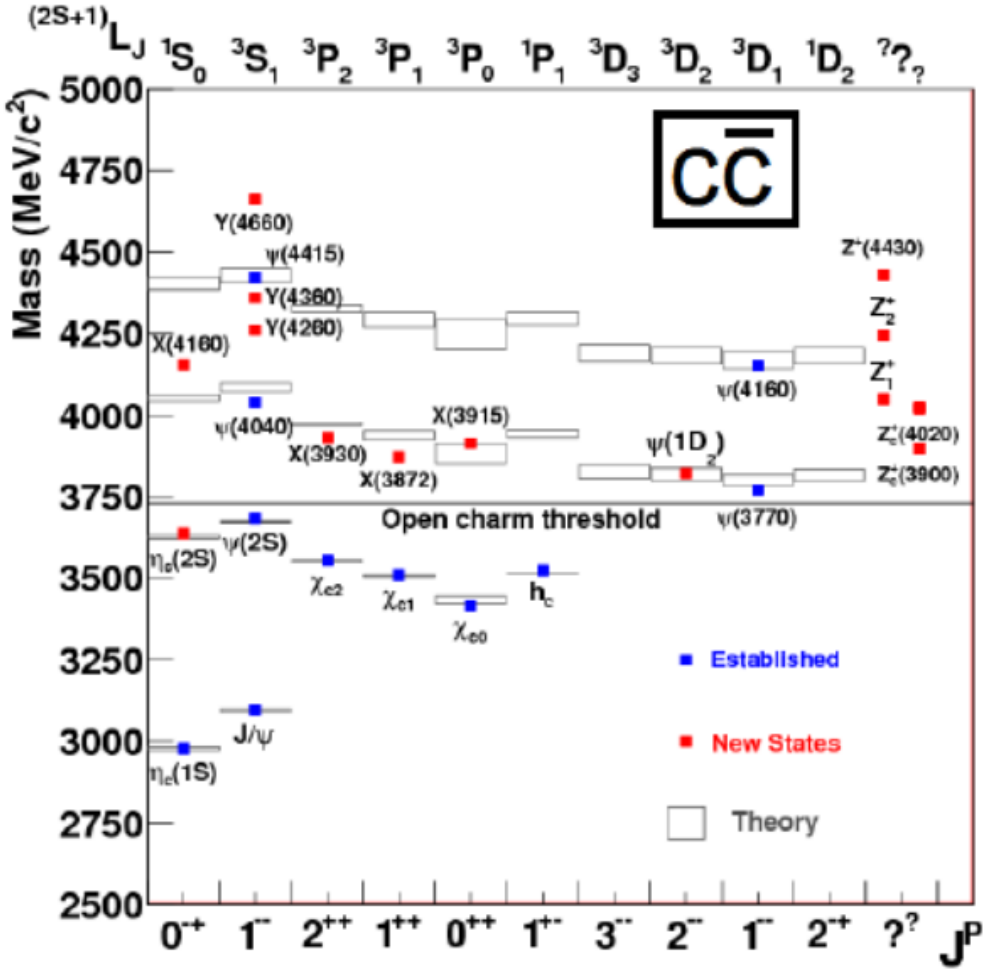
States described by potential model, before the discovery of the X(3872)

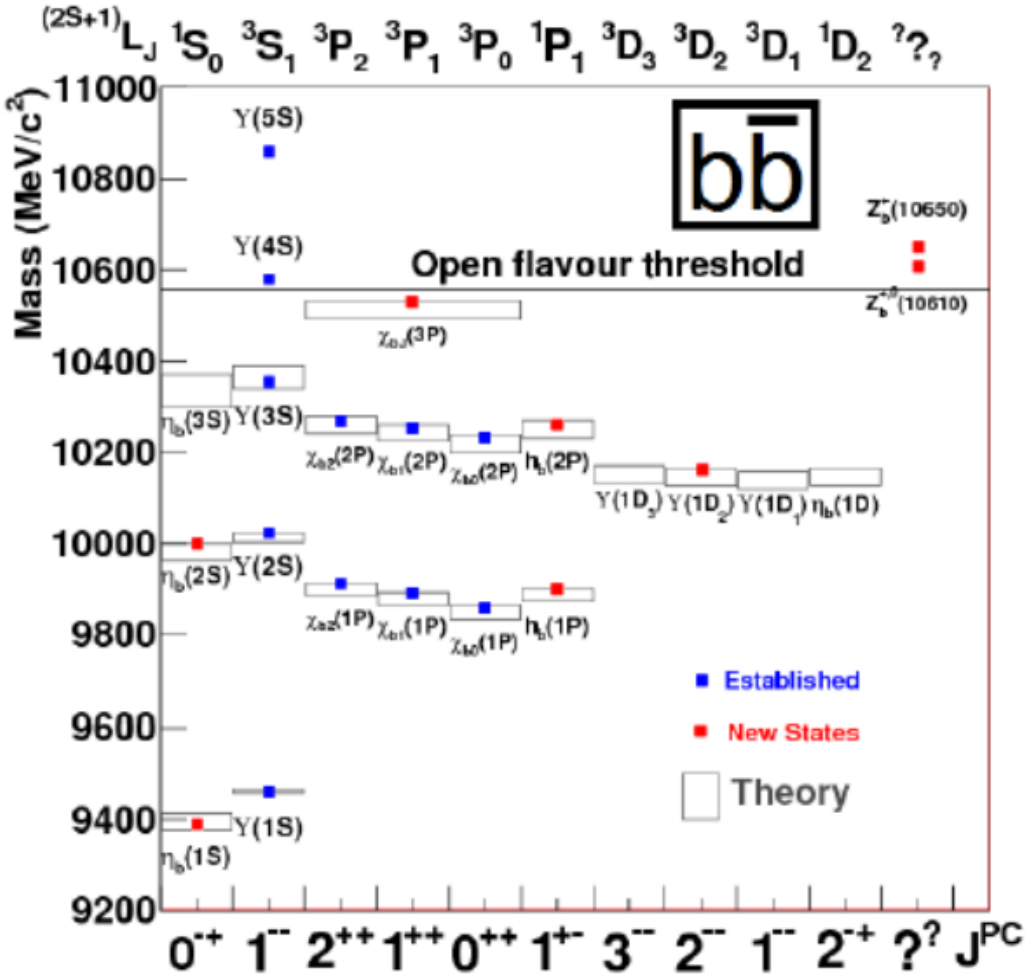




QUARKONIA

States described by potential model, after 2003….

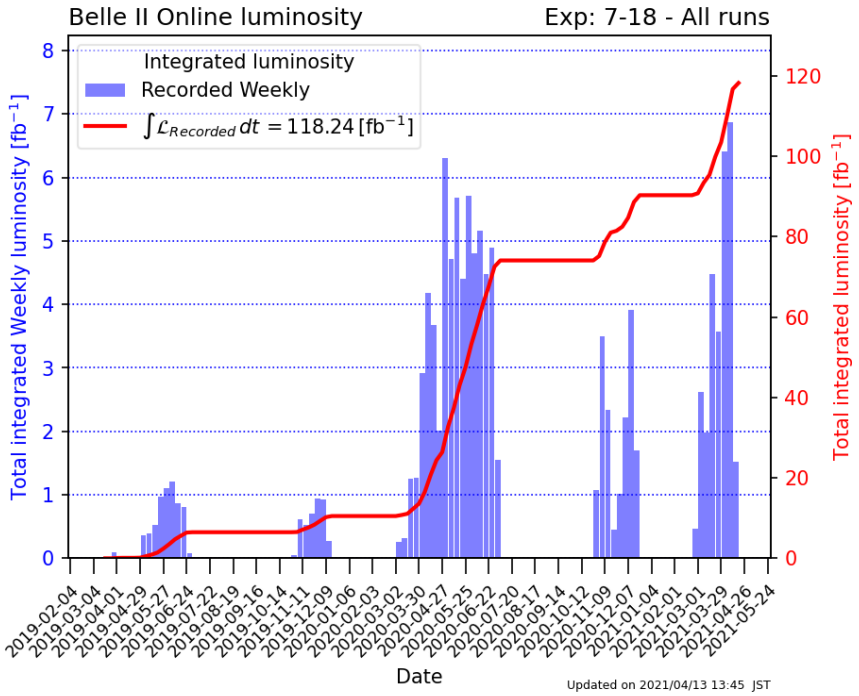


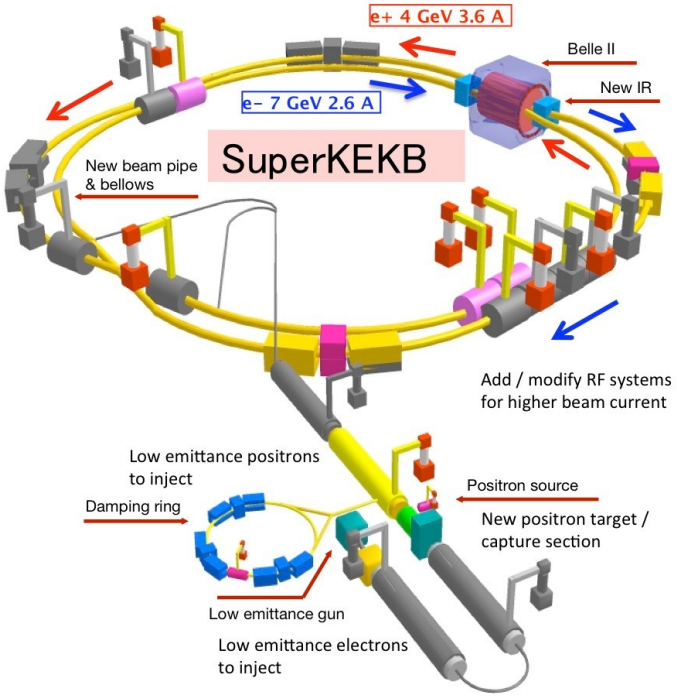


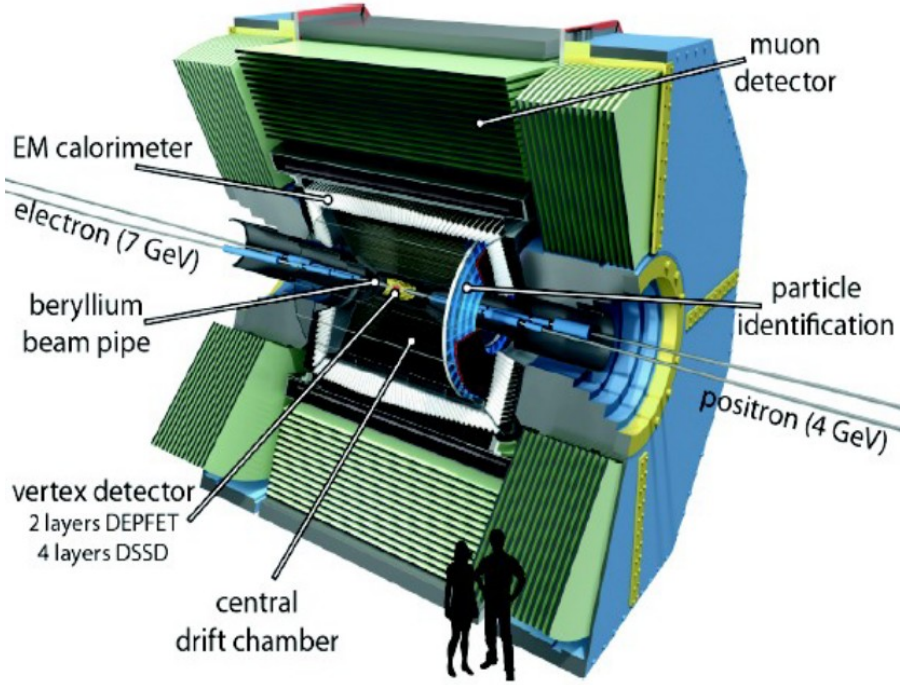
SUPERKEKB AND BELLE II

Overview

- SuperKEKB is an asymmetric e^+ (4 GeV) e^- (7 GeV) collider at Tsukuba, Japan.
  $\sqrt{s}$ = 10.58 GeV = m(Υ(4S)).
- Belle II detector is placed around the IP of SuperKEKB.



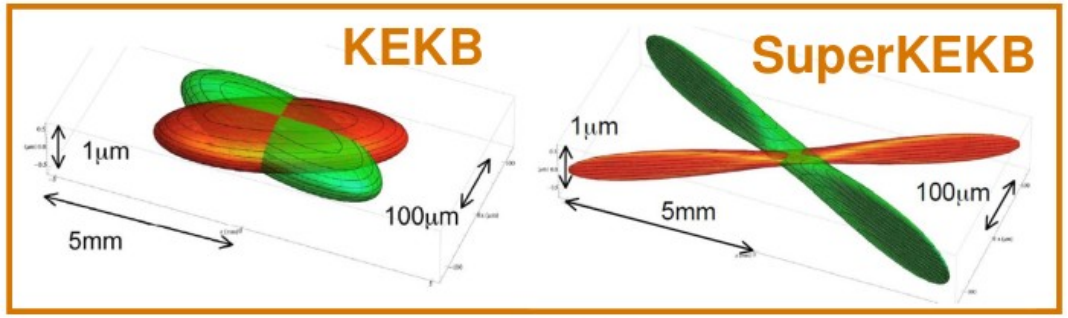




BELLE II

Upgrade from Belle

- Pixel Detector: improved vertex resolution in beam direction 50μm (Belle)→25μm (Belle II).
- Time Of Propogation: TOP measures the timing of the Cherenkov light. Time resolution ~50ps. TOP detector surface is polished to nanometer precision for total reflection of Cherenkov light.
- K_L - Muon Detector: two inner layers of barrel + all layers in the end cap replaced by scintillators, because of large background.
- Electromagnetic Calorimeter: readout electronics replaced, fast FADC sampling for identify pile-up of pulses.
- Luminosity: ~30x instantaneous and integrated luminosity. Beam current, 1.64/1.19 A (Belle) →3.60/2.60 A (Belle II) for e^+/e^- beam. Beta function at IP (β^*_y), 5.9/5.9 mm (Belle)→0.27/0.31 mm (Belle II).



BELLE II POTENTIAL

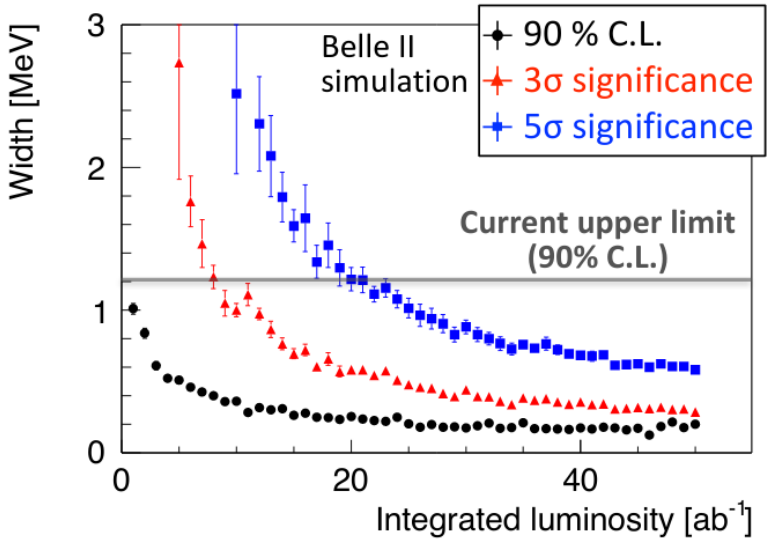
XYZ

- Best BW width from LHCb: $0.96\,^{+0.19}_{-0.18} \pm 0.21\,MeV$ JHEP 08 (2020) 123

- Upper limit from Belle: Γ < 1.2 MeV.
  (estimated from X(3872) → J/Ψπ+π-)

- Expectation with 50 ab^{-1} data at Belle II:

State	Production and Decay	N
X(3872)	B → KX(3872), X(3872) → J/Ψπ+π-	~14400
Y(4230)	ISR, Y(4230) → J/Ψπ+π-	~29600
Z(4430)	B → K±Z(4430),Z(4430) → J/Ψπ±	~10200



X(3872) → $D^0\bar{D}^0\pi^0$

mode	Q value [MeV]
$J/\psi\pi^+\pi^-$	495.65±0.17
$D^0\bar{D}^0\pi^0$	7.05±0.18
$D^0\bar{D}^{0*}$	0.01±0.18

- Search for exotics at DD* threshold (better slow pion detection at Belle II).
  Slow pion reconstruction efficiency >60%.

BELLE II POTENTIAL

Charmonium in ISR

- Line shape of the Y(4230).
- Strange partner of Z(3900) in KKJ/Ψ.
- Cross sections of exclusive ($c\bar{c}$) + hadrons.

Golden Channels	$E_{c.m.}$ (GeV)	Statistical error (%)	Related XYZ states
$\pi^+\pi^- J/\psi$	4.23	7.5 (3.0)	$Y(4008)$, $Y(4260)$, $Z_c(3900)$
$\pi^+\pi^- \psi(2S)$	4.36	12 (5.0)	$Y(4260)$, $Y(4360)$, $Y(4660)$, $Z_c(4050)$
$K^+K^- J/\psi$	4.53	15 (6.5)	Z_{cs}
$\pi^+\pi^- h_c$	4.23	15 (6.5)	$Y(4220)$, $Y(4390)$, $Z_c(4020)$, $Z_c(4025)$
$\omega\chi_{c0}$	4.23	35 (15)	$Y(4220)$

50 ab^{-1}

10 ab^{-1}

- ISR analysis process – unique case at e^+e^- machines, in competition with LHCb

BELLE II POTENTIAL

Bottomonium

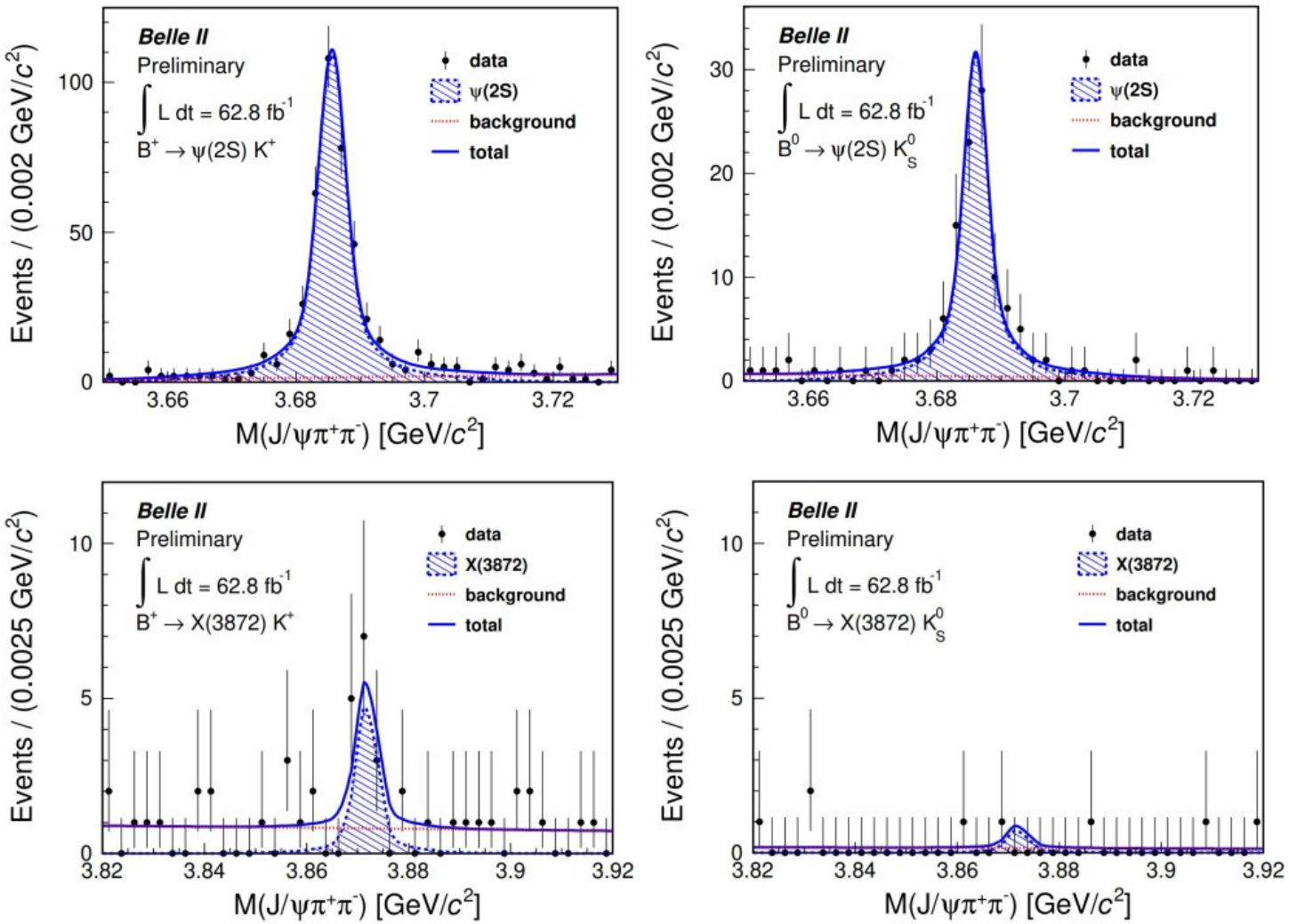
- Z_b states were only found so far in $\Upsilon(5S)$ decays.
- SuperKEKB can reach $E_{c.m.} \cong 11$ GeV.
  $\Upsilon(6S)$ run is possible.
- With the high luminosity, for the first time study of radiative transitions between bottomonium states possible.
- $\Upsilon(6S)$ and $\Upsilon(5S)$: conventional state search
  search for new, predicted, resonances, use both single transitions and double cascade, fill the remaining spectrum to measure the effect of the coupled channel contribution.
- $\Upsilon(3S)$: exotics in transitions
  search for missing $\pi\pi/\eta$ transitions to constrain further theoretical models.
- $\Upsilon(3S)$: charmonia in production, Belle II goals with 300 fb^{-1}:
  up to 5x sensitivity in inclusive production from $\Upsilon(3S)$
  up to 15x in double charmonium

BELLE II PROGRESS

X(3872)

- Reconstruction of final states
  - $B^{\pm} \rightarrow \pi^{+}\pi^{-}J/\Psi(\ell^{+}\ell^{-})\ K^{\pm}$
  - $B^{0} \rightarrow \pi^{+}\pi^{-}J/\Psi(\ell^{+}\ell^{-})\ K_{S}$
- Selection criteria (standard)
  - Particle identification
  - Continuum: nTracks, R2
  - Kinematics: $M_{\pi+\pi-}$, M_{bc}, $|\Delta E|$
- First X(3872) at Belle II
  - 14.4±4.6 events (4.6σ)
  - Belle: ~170 events in 772 Mi. $B\bar{B}$ pairs

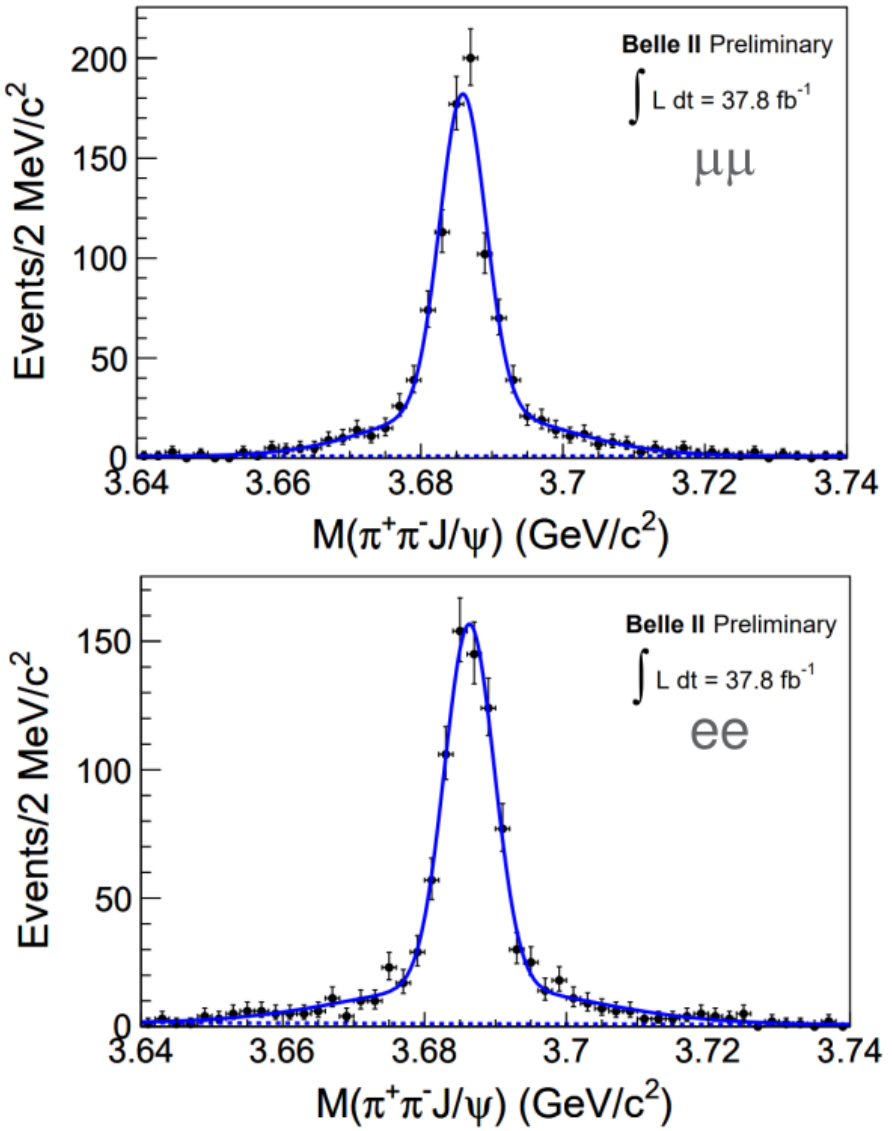
Phys. Rev. D 84, 052004, 2011



BELLE II PROGRESS

ISR $c\bar{c}$ processes

- $e^+e^-\gamma_{ISR} \rightarrow \pi^+\pi^- J/\Psi(\ell^+\ell^-)$ reconstruction
  - Nominal PID requirements
  - $|M(J/\Psi) - M(PDG)| < 75$ MeV
  - ISR photon not required (high efficiency)
  - $|MM^2(\pi^+\pi^- J/\Psi)| < 2$ GeV/c²
- Clear observation of ISR Ψ(2S) signals
- Next step: Y(4230) rediscovery
  - Expect ~60 total events per 100 fb^{-1}



BELLE II PROGRESS

Bottomonium

- $e^+e^-\gamma_{ISR} \rightarrow \pi^+\pi^-$ Initial State Radiation (ISR) production:

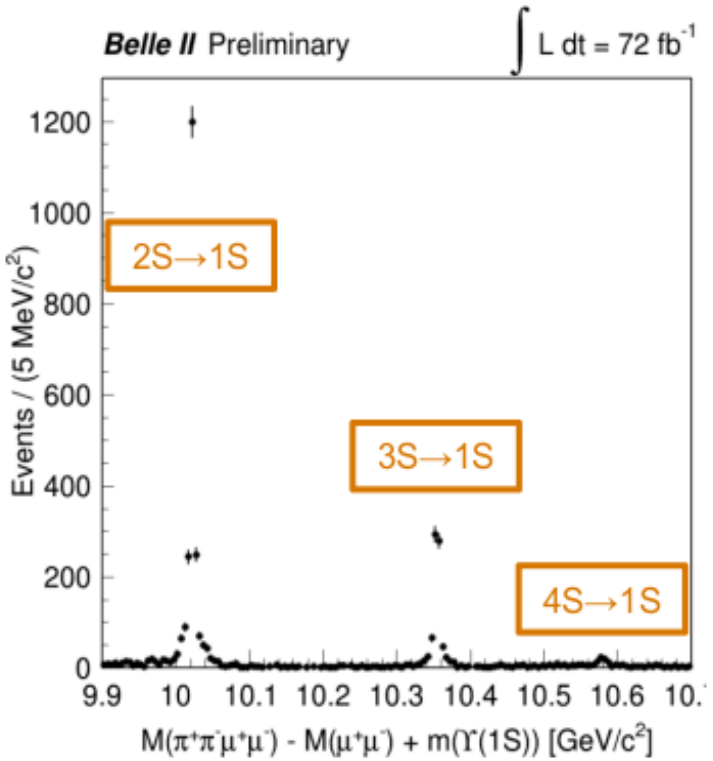
  $\gamma_{ISR}\,\Upsilon(2S) \rightarrow \pi^+\pi^-\Upsilon(1S)(\ell^+\ell^-)$

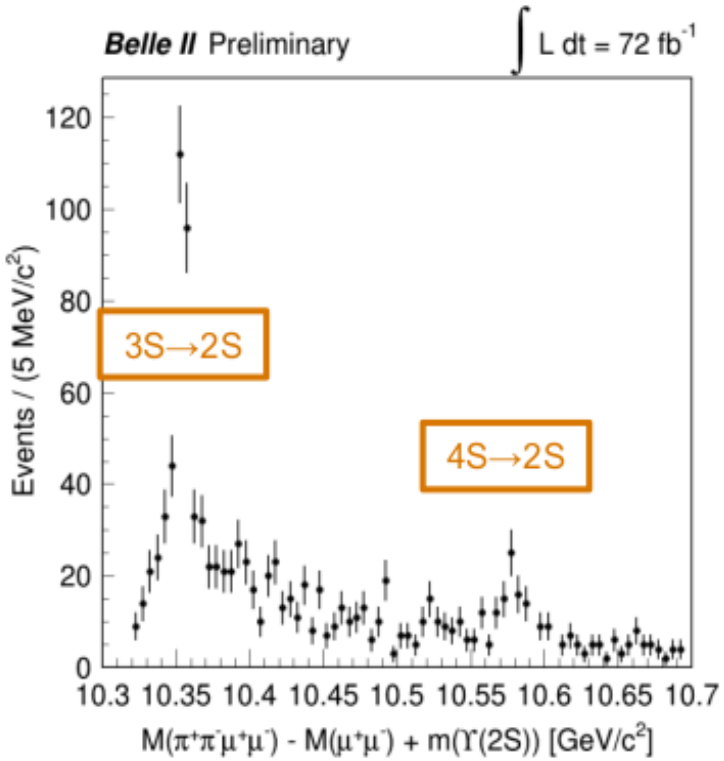
  $\gamma_{ISR}\,\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S,2S)(\ell^+\ell^-)$

- Direct transitions: $\Upsilon(4S) \rightarrow \pi^+\pi^-\Upsilon(1S,2S)$
- All signals observed in early Belle II data

- Future studies:

  $M(\pi^+\pi^-)$ in $\Upsilon(4S)$ transitions

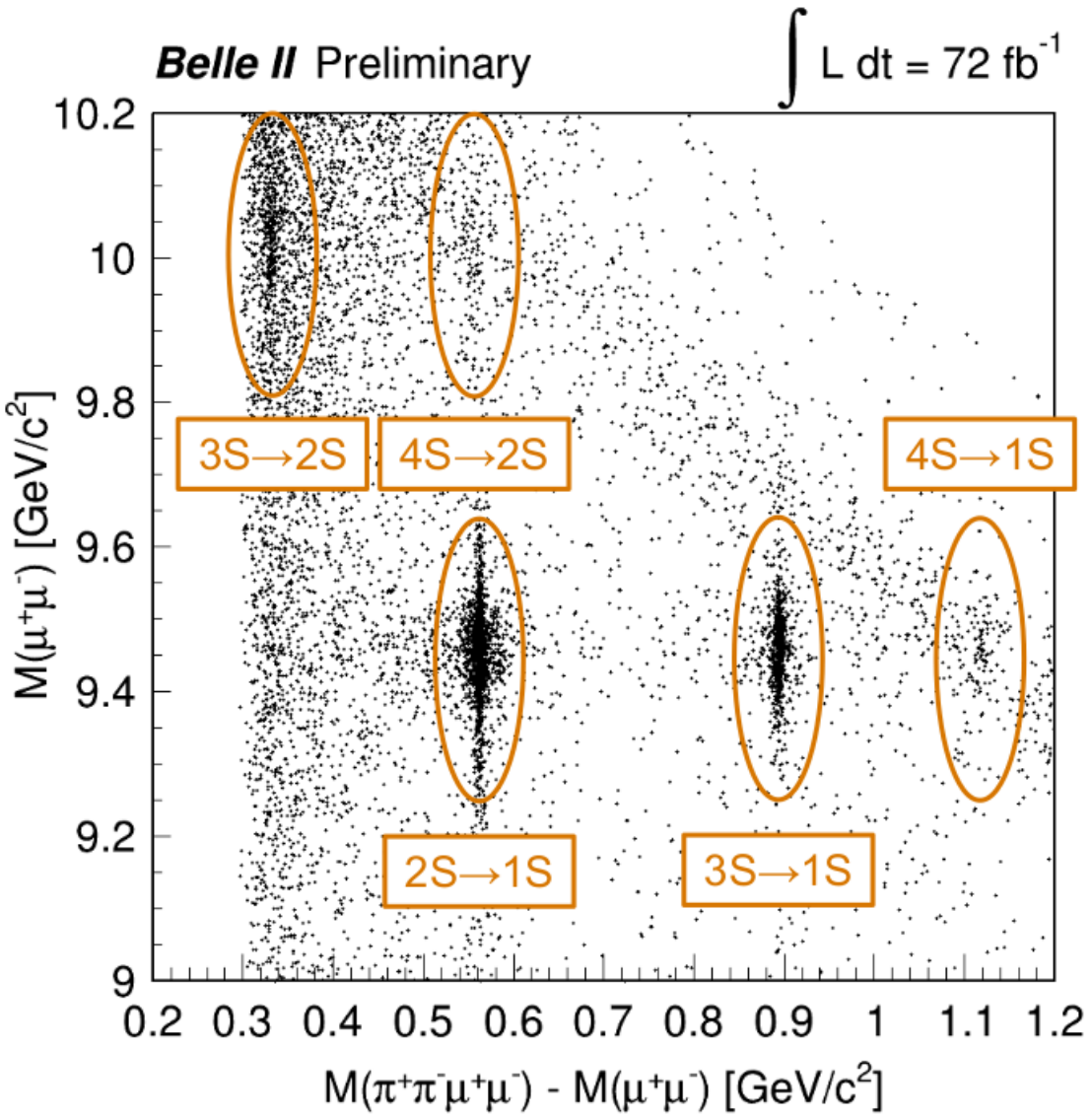




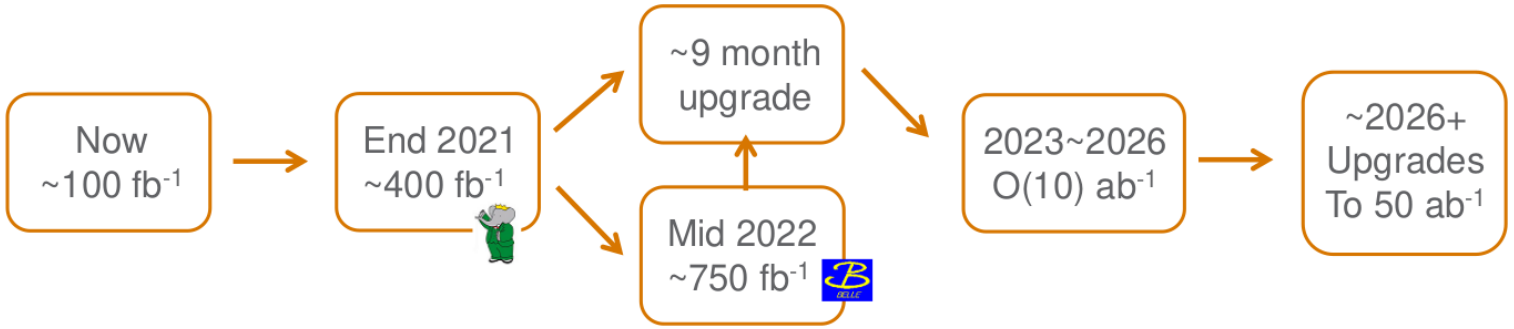
BELLE II PROGRESS

Bottomonium

- Υ-dipion transition in early Phase 3 Data
- Clear evidence of signal with 72 fb^{-1}
- Clusters represent signal transitions



SUMMARY



- Main focus to collect $\Upsilon(4S)$ on-peak data.
- Near-term non-$\Upsilon(4S)$ proposals:
  - 10.751 GeV (10 fb^{-1}): to study $Y_b(10753)$ on-peak
  - 10.657, 10.706, 10.810 GeV (1+2+3 fb^{-1}): additional points for $B\bar{B}$ decomposition
  - 11 GeV (30+ fb^{-1}): post-upgrade to study $\Upsilon(6S)$ on-peak
- Quarkonium / XYZ is one of the main components of the physics program.
- Analysis of early data
  - Rediscoveries of 1^{--} $c\bar{c}$ / $b\bar{b}$ states and X(3872)
  - Statistics soon comparable to BaBar/Belle

THANKS

The Belle II Collaboration

26 countries/regions, 120 institutes, 1050 members