Exotic and Conventional Quarkonium Physics Prospects at Belle II

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(on behalf of Belle II Collaboration)

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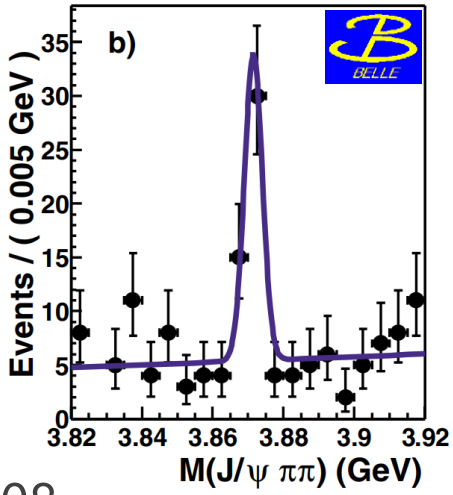
OCTOBER 23–27, 2018
Hilton Waikoloa Village,
Hawaii Island

Hadron Spectroscopy with
Electron, Photon, and Hadron Beams II

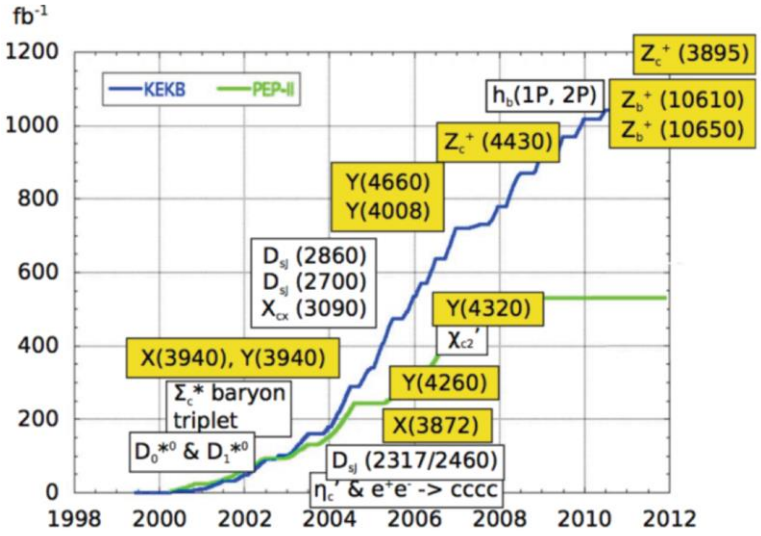
October 25, 2018

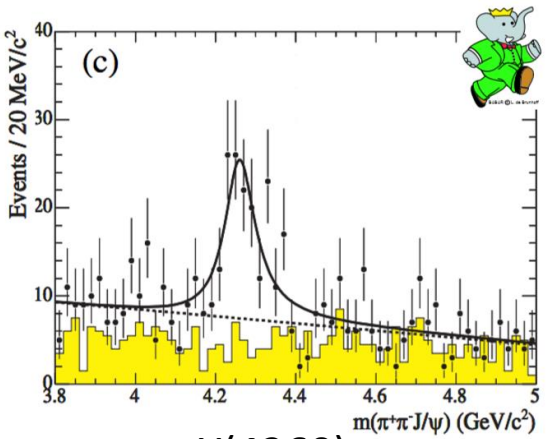
Introduction

- B Factories have played a pivotal role in discovery of exotic quarkonium states…
  - First observation of X(3872) at Belle in 2003.
  - First observation of Y(4260) at BaBar in 2005.
  - Charged exotic $Z_c^{\pm}(4430)$ observed at Belle in 2008.
  - …and many other exotic candidates over years…

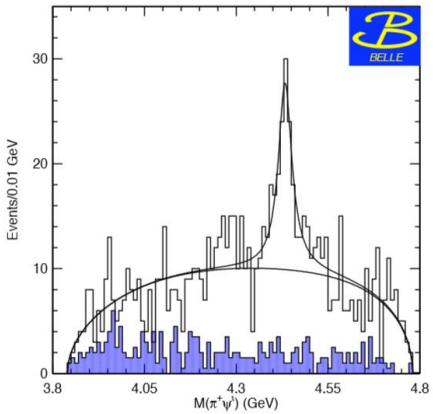


X(3872)
[PRL 91, 262001 (2003)]



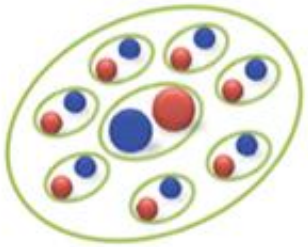


Y(4260)
[PRL 95, 142001 (2005)]



$Z_c(4430)$
[PRL 100, 142001 (2008)]

Many questions remain…



hadroquarkonium

diquark-diantiquark

tetraquark

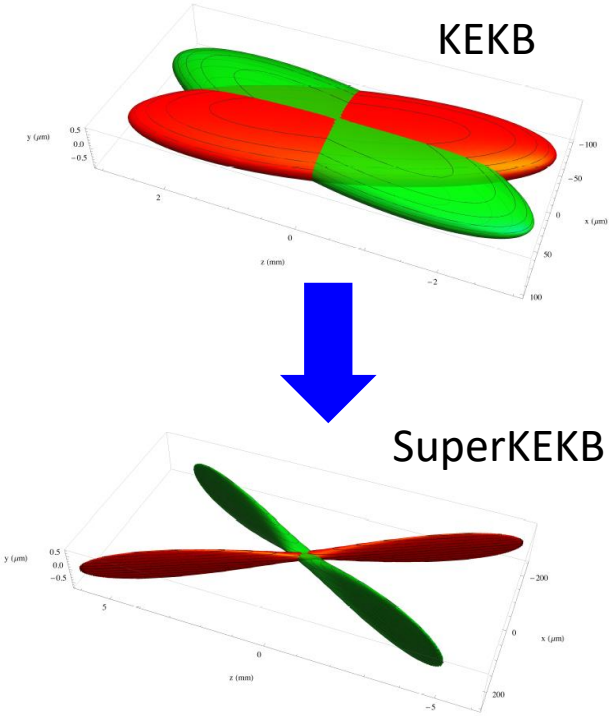
D-$\bar{D}^*$ "molecule"

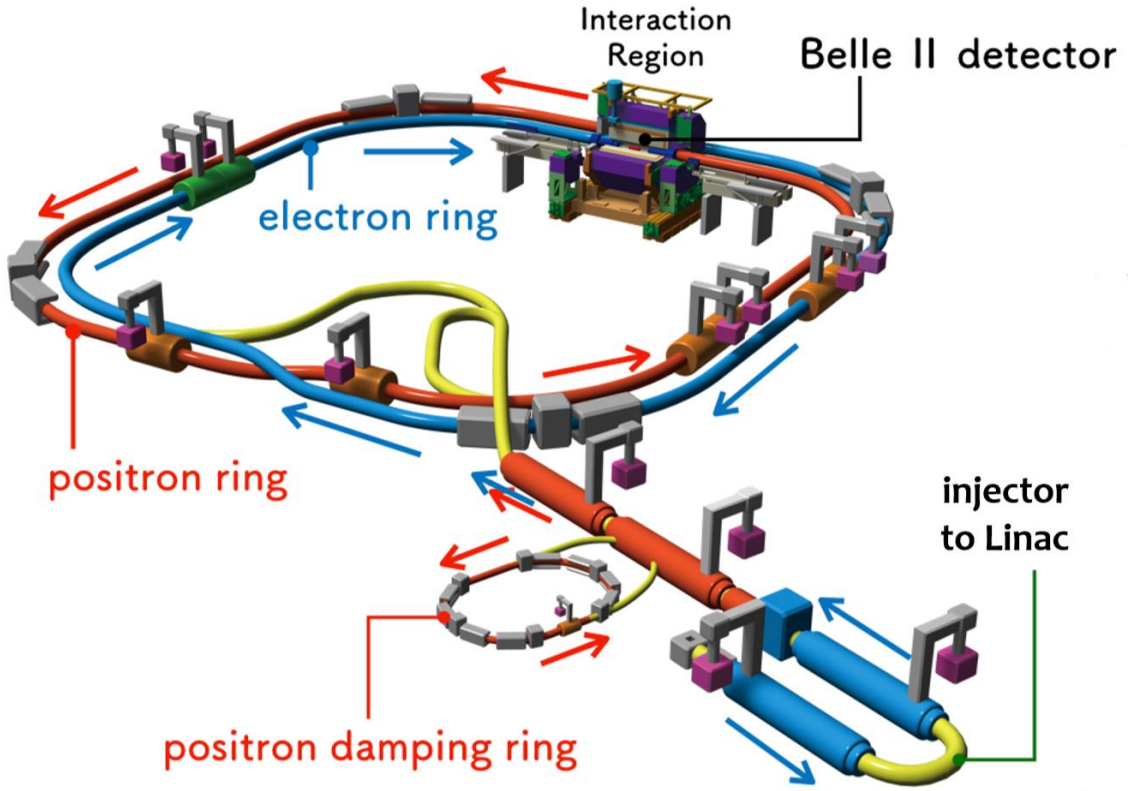
q$\bar{q}$-gluon "hybrid"

- What is the proper interpretation of the exotic states?
- Why are widths of exotics so narrow, despite being above threshold?

➔ LHCb, BESIII, **now Belle II** will explore quarkonium sector over coming years!

Upgrade to SuperKEKB, Belle II





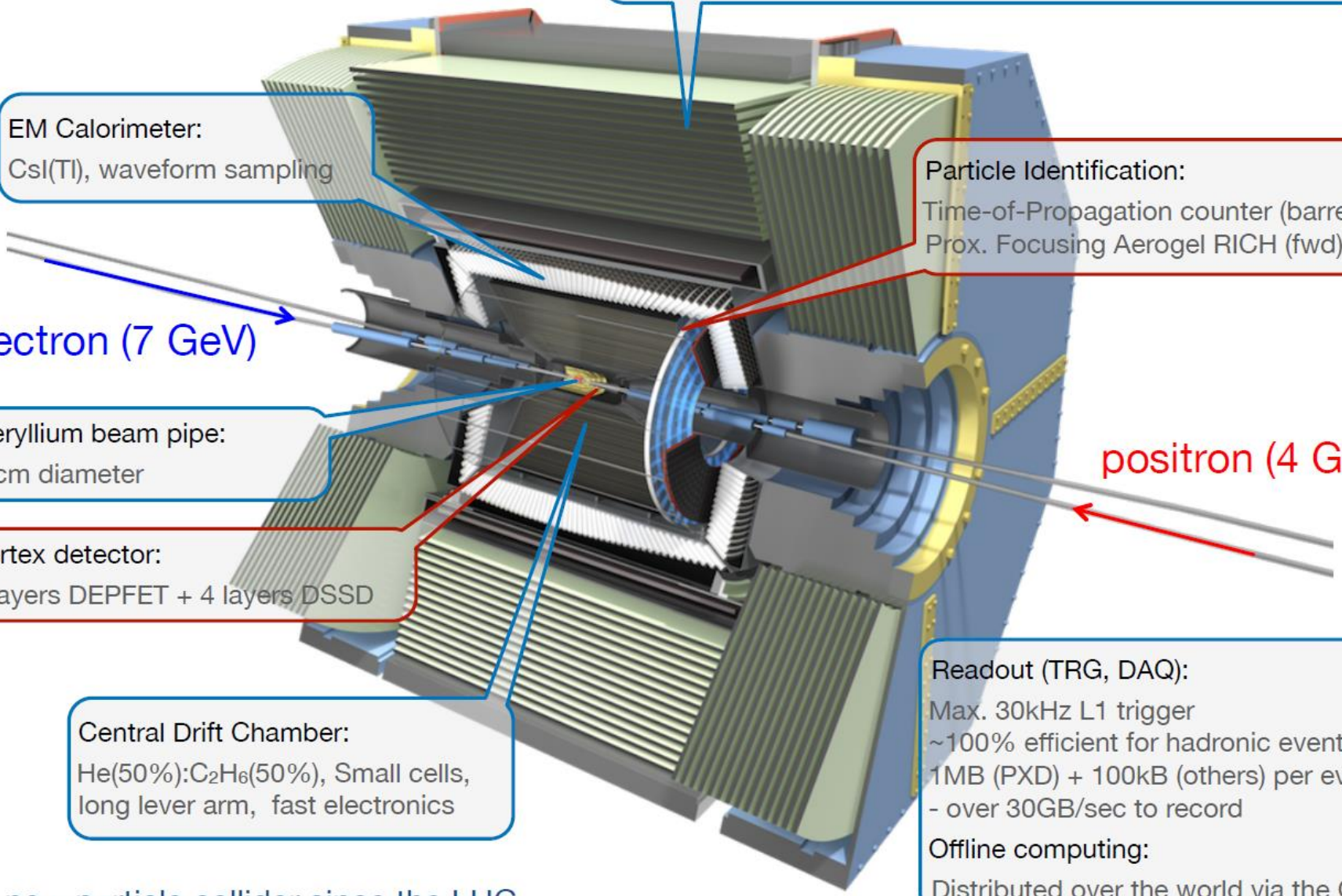
- "Nano-beam" scheme [P. Raimondi]
  - Squeeze beam at IP by ~1/20.
  - Reduce effective bunch length.
- Double beam currents.

➔ 40x increase in peak luminosity!

<u>Operations Phases</u>:

- Phase 1 (2016) – first turns, accelerator commissioning.
  - No QCS or Belle II.
- Phase 2 (2018) – first runs with QCS, Belle II, no vertexing.
- Phase 3 (2019) – first physics runs with full Belle II.

The Belle II detector



K_L and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling

Particle Identification:
Time-of-Propagation counter (barrel)
Prox. Focusing Aerogel RICH (fwd)

electron (7 GeV)

positron (4 GeV)

Beryllium beam pipe:
2 cm diameter

Vertex detector:
2 layers DEPFET + 4 layers DSSD

Central Drift Chamber:
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

Readout (TRG, DAQ):
Max. 30kHz L1 trigger
~100% efficient for hadronic events.
1MB (PXD) + 100kB (others) per event
- over 30GB/sec to record

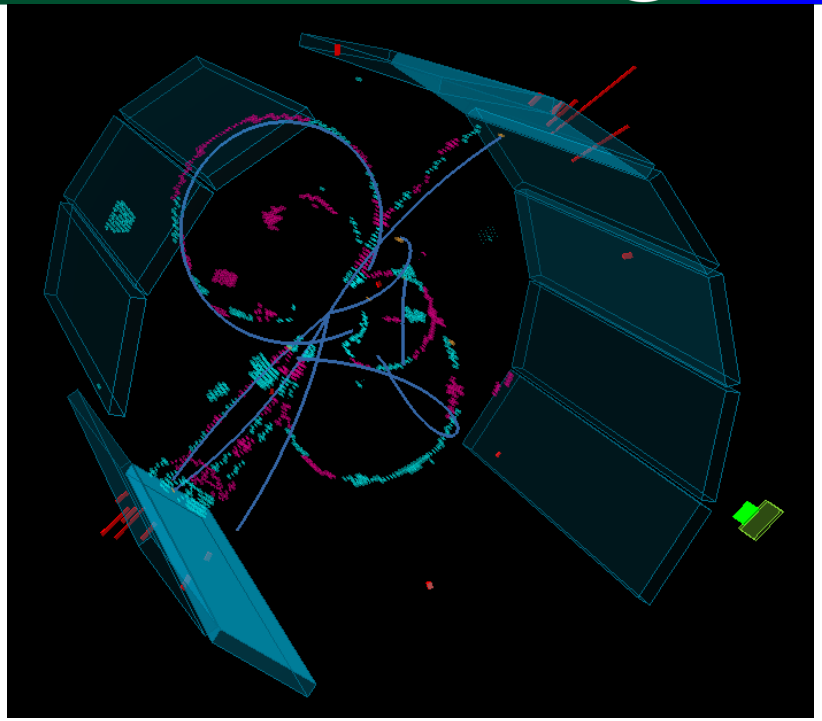
Offline computing:
Distributed over the world via the GRID

First new particle collider since the LHC
(intensity rather than energy frontier; e^+e^- rather than pp)

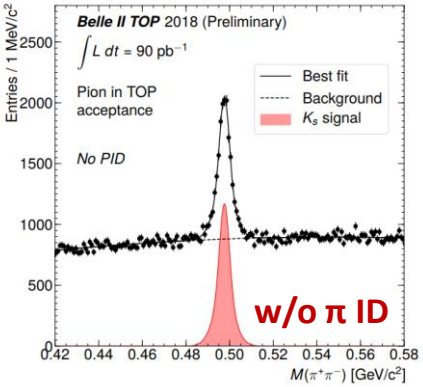
arXiv:1011.0352 [physics.ins-det]

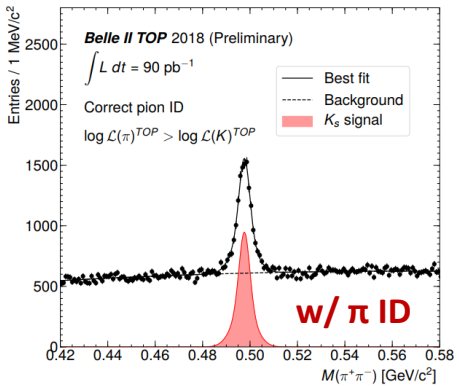
Start of Data Taking @ Belle II

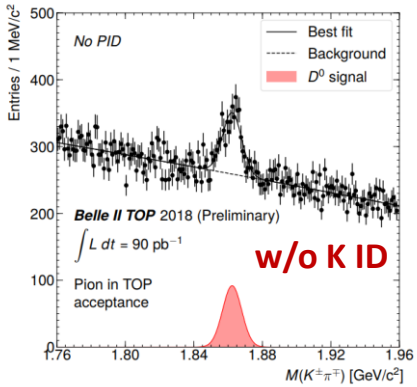
April 26, 2018: First Collisions!

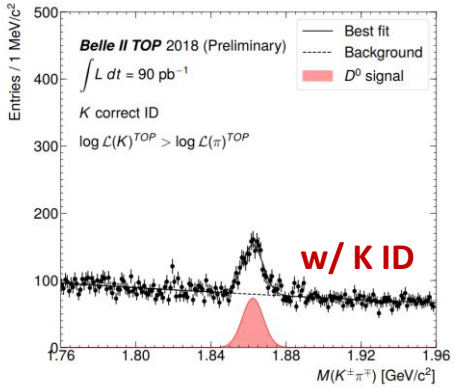


Straight to work checking detector performances! Examples checking pion and kaon ID using the Time of Propagation (TOP) subdetector in $K_S \rightarrow \pi\pi$, $D^0 \rightarrow K\pi$.



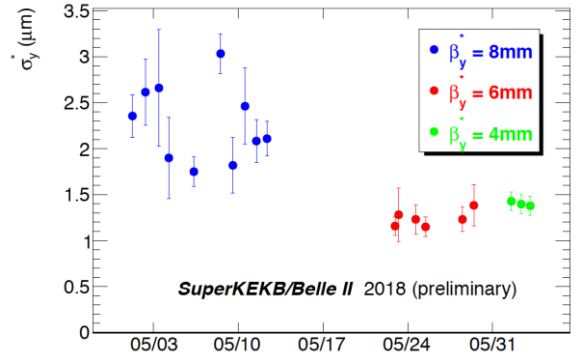


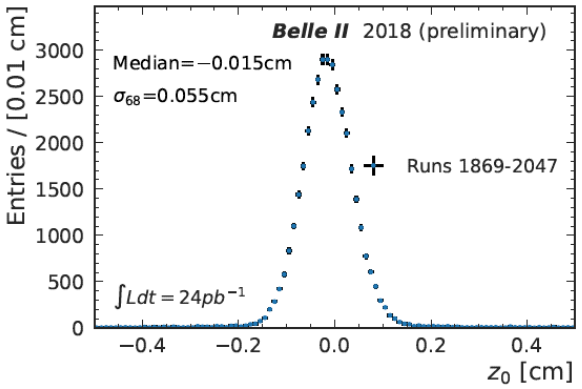


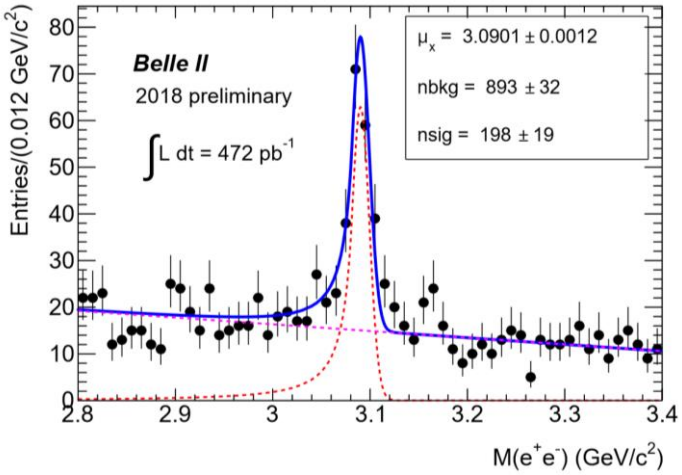


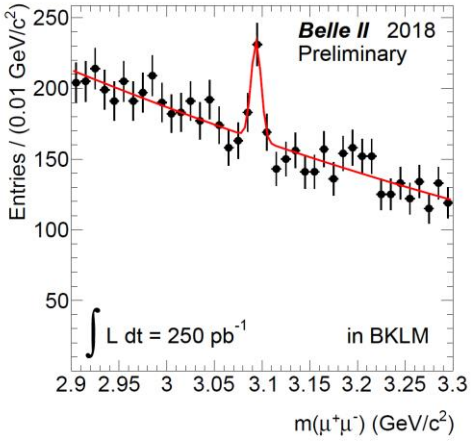
Phase 2 Running

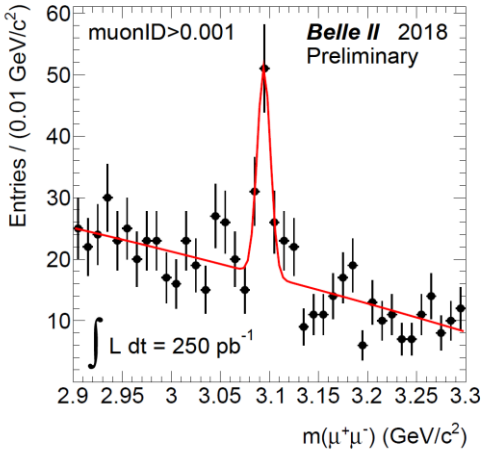
- Phase 2 run concluded in July.
  - Machine tuning, verification of nano-beam scheme!
  - Peak luminosity reached ~5 x 10^{33} $cm^{-2}s^{-1}$, ~25% of peak of Belle.
  - Total integrated luminosity ~0.5 fb^{-1} recorded at Y(4S).
  - Beam background measurements and minimization (without vertex detectors).
  - Detector calibrations.
  - "Rediscovery" of many states, including J/ψ ➔ ee, μμ:



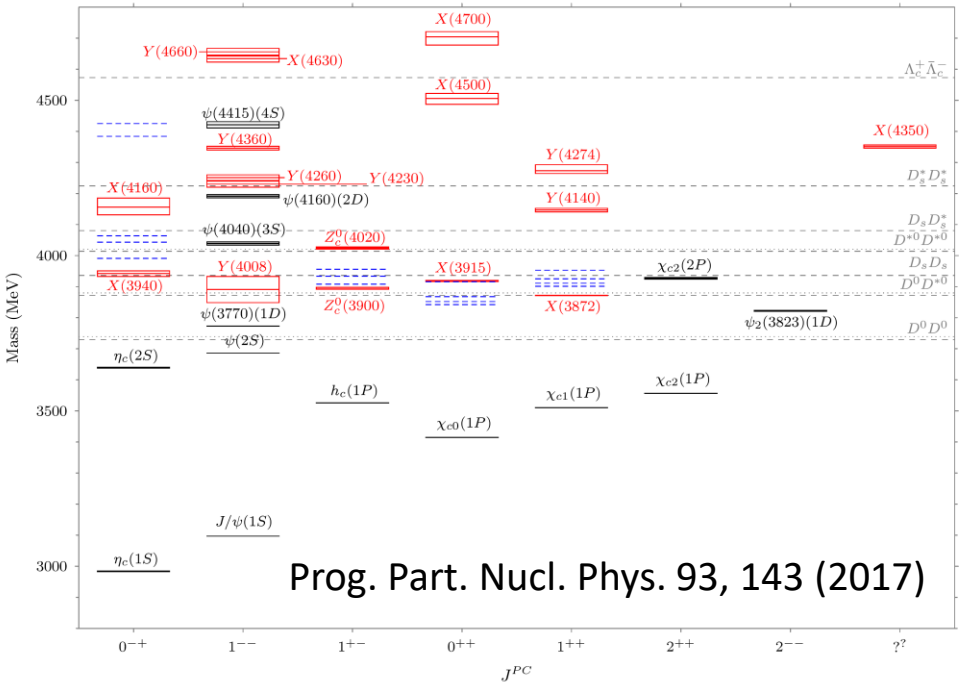






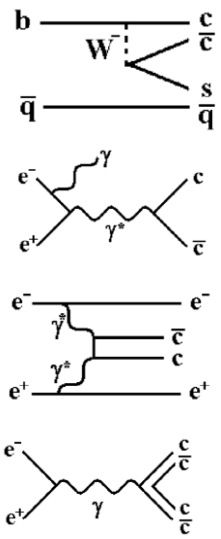


Charmonium Physics at Belle II



Prog. Part. Nucl. Phys. 93, 143 (2017)

- Many charmonium production mechanisms:
- B decays:
  - All quantum numbers.
- Initial state radiation (ISR):
  - $J^{PC} = 1^{--}$
- Two-photon process:
  - $J^{PC} = 0^{-+}, 1^{++}, 2^{++}$
- Double charmonium:



- Many production modes allows multiple pathways to observe same states.
- Belle II charmonium program can be conducted in parallel with B physics!

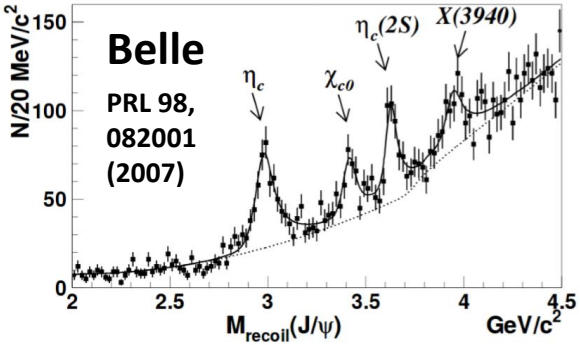
Belle II Charmonium Program

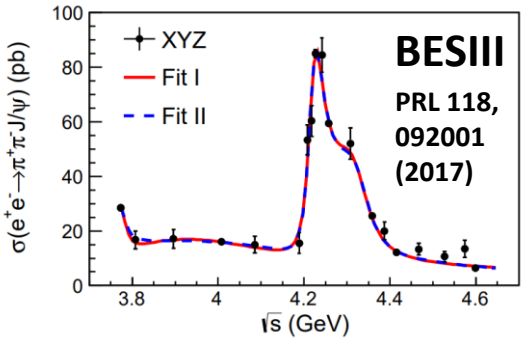
- ISR:
  - Y(4230), Y(4260), Y(4360) could all be explored.
  - Unexpected Y(4260) line-shape measured at BESIII, inconsistent among different modes. Could explore w/ ISR. Cross sections of exclusive ($c\bar{c}$) + hadrons.
  - Search for strange partner of Z(3900) in K^+K^-J/ψ.
- Double charmonium:
  - Uniquely measurable at Belle II!
  - Absolute branching fractions.
  - Cross sections.
  - Spectroscopy.
- Two photon:
  - Also uniquely measurable at Belle II.
  - Could disentangle two of the four states seen by LHCb in Φ J/Ψ.
- In addition, B physics program will provide ~50x more data for expansion of studies in B ➔ charmonium.

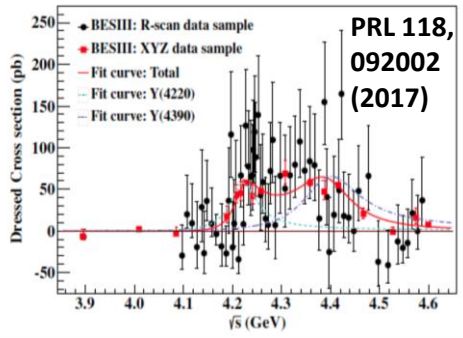
Belle II Physics Book [arXiv:1808.10567]

ISR Channels **@10 ab^{-1} (50 ab^{-1})**

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)	$Y(4220)$

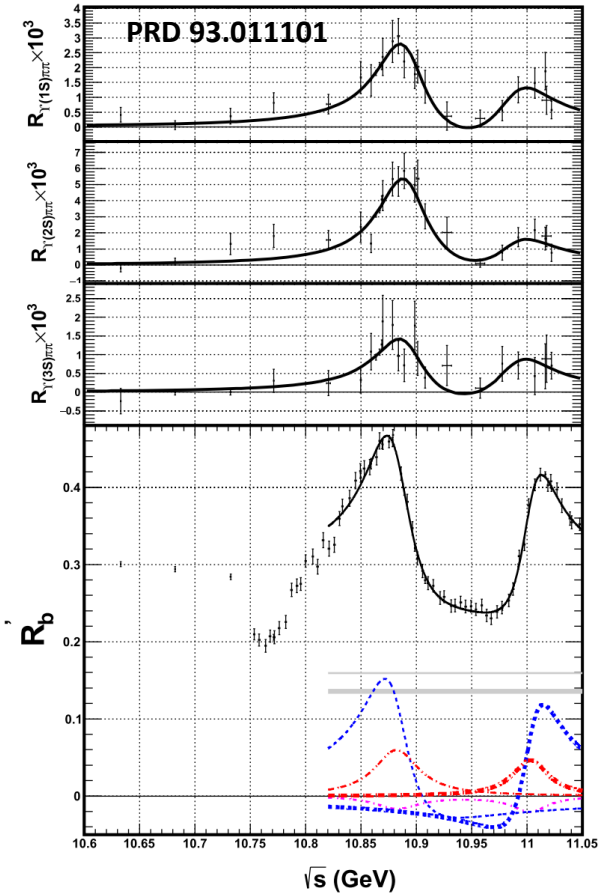


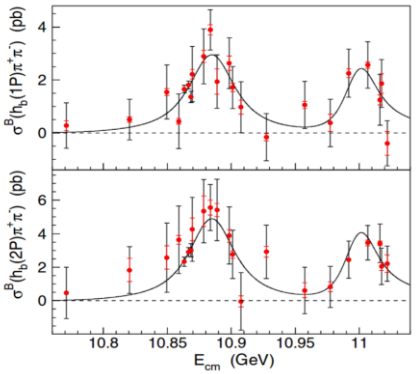




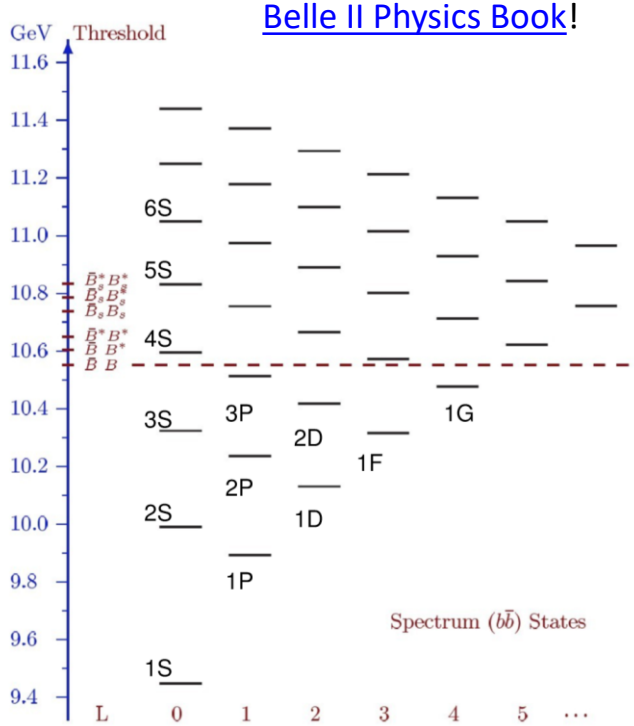
Bottomonium Physics at Belle II

- Examples of open questions in Υ(5S, 6S)…





- Υ(5S) line shapes:
  Apparent discrepancies in shape in ππΥ modes vs. ππh modes.
- Hint of a new resonance around 10.75 GeV?
- Is Z_b above/below $B^{(*)}B^*$ threshold?
- 5S and 6S provide windows to search for missing narrow states in the bottomonium spectrum.



**Many other 1S,2S,3S topics… see Belle II Physics Book!

➔ These runs require dedicated scans and/or samples on specific resonances!

Proposals for Belle II Y(5S, 6S) Program

Current samples in fb^{-1} (millions of events), and the proposal for Belle II

Experiment	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(4S)$	$\Upsilon(5S)$	$\Upsilon(6S)$	$\frac{\Upsilon(nS)}{\Upsilon(4S)}$
CLEO	1.2 (21)	1.2 (10)	1.2 (5)	16 (17.1)	0.1 (0.4)	-	23%
BaBar	-	14 (99)	30 (122)	433 (471)	R_b scan	R_b scan	11%
Belle	6 (102)	25 (158)	3 (12)	711 (772)	121 (36)	5.5	23%
BelleII	-	-	300 (1200)	5×10^4 (5.4×10^4)	1000 (300)	100+400(scan)	3.6%

- Proposed runs at ~1 ab^{-1} at Y(5S).
  - Complementary with B_s physics.
  - Determine if Zb is above/below $B^{(*)}B^*$ threshold.
- Scan Y(5S,6S) line shapes:
  - Proposed scans at ~10 MeV steps, 10 fb^{-1} each.
  - Search in ππY modes vs. ππh modes.
- Settle the nature of the 5S!
- Complementary with the B_s physics program.

- Search for various exotics in hadronic channels of Y(6S) decay.
- SuperKEKB maximum E_{cm}~11.02 GeV, just above Y(6S).
- Would benefit from linac upgrade to get to max E_{cm}~11.24 GeV.
- Staged running at Y(6S):
  - Exploratory runs at low luminosity first, e.g., 10 fb^{-1} … 30 fb^{-1} …100 fb^{-1}.

Conclusion

- SuperKEKB has completed initial commissioning, has moved into first collisions as of April 26, 2018!

- Belle II has just completed Phase 2 running:
  - Calibrations, detector studies, and many rediscoveries!
  - Vertex detectors are being installed for Phase 3 physics run.

- Phase 3 begins early 2019, is the beginning of a new program of charmonium and bottomonium physics.
  - Charmonium program runs in parallel with B physics program.
  - Small samples of special runs at Y(6S, 5S, 3S) can provide a wide variety of new bottomonium results.
  - Much more detail available in Belle II Physics Book [arXiv:1808.10567]!

- Stay tuned for new results!