Status of
New Resonance Search

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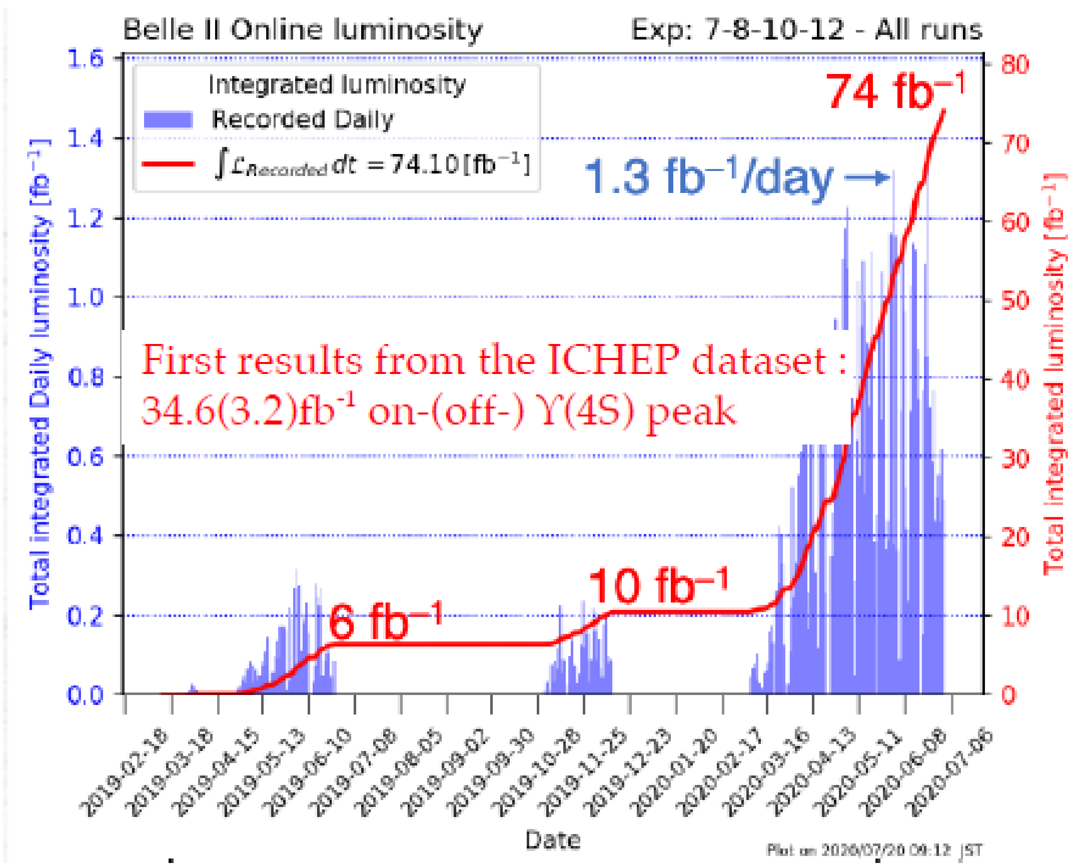
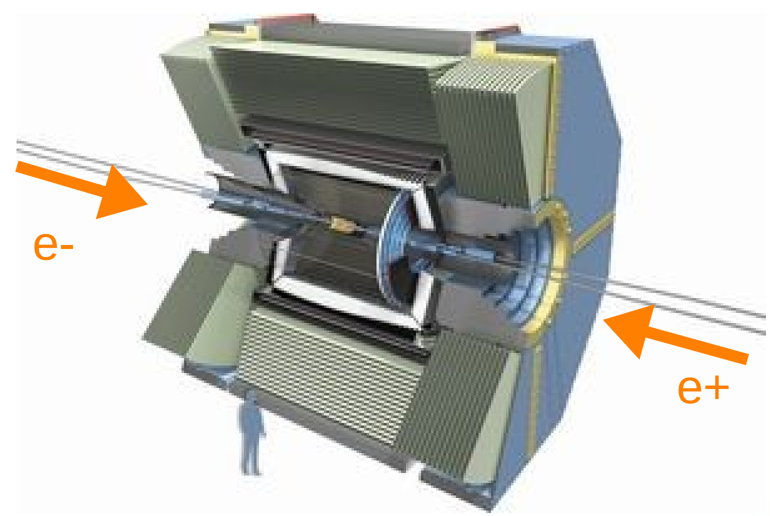
Status of New Resonance Search

This talk is focused on the Belle II opportunities



1047 active members
119 institutes
29 countries (ICHEP2020)



Outline

- Recent results in spectroscopy
- What have we understood from recent observations?
- Recent publications in spectroscopy from Belle and Belle II
- Possibilities and improvements at Belle II
  - the X(3872)
  - radiative decays
  - ISR analyses
- Outlook
- Summary

Introduction

- Gell-Mann Zweig idea: Constituent Quark Model (*CQM*).
  Still valid for half century → it classifies all known hadrons

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" [1-3], we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone [4]. Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means

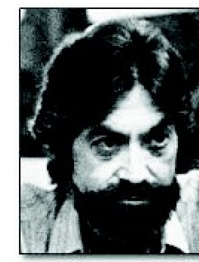
ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^-, s^-, u^0 and b^0 exhibit a parallel with the leptons.

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" [6] q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest baryon configuration $(q\,q\,q)$ gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\,\bar{q})$ similarly gives just **1** and **8**.

AN SU_3 MODEL FOR STRONG INTERACTION SYMMETRY AND ITS BREAKING

G. Zweig *)
CERN - Geneva

8182/TH.401
17 January 1964



ABSTRACT

...

In general, we would expect that baryons are built not only from the product of three aces, AAA, but also from $\bar{A}AAAA$, $\bar{A}\bar{A}AAAAA$, etc., where $\bar{A}$ denotes an anti-ace. Similarly, mesons could be formed from $\bar{A}A$, $\bar{A}\bar{A}AA$ etc. For the low mass mesons and baryons we will assume the simplest possibilities, $\bar{A}A$ and AAA, that is, "deuces and treys".

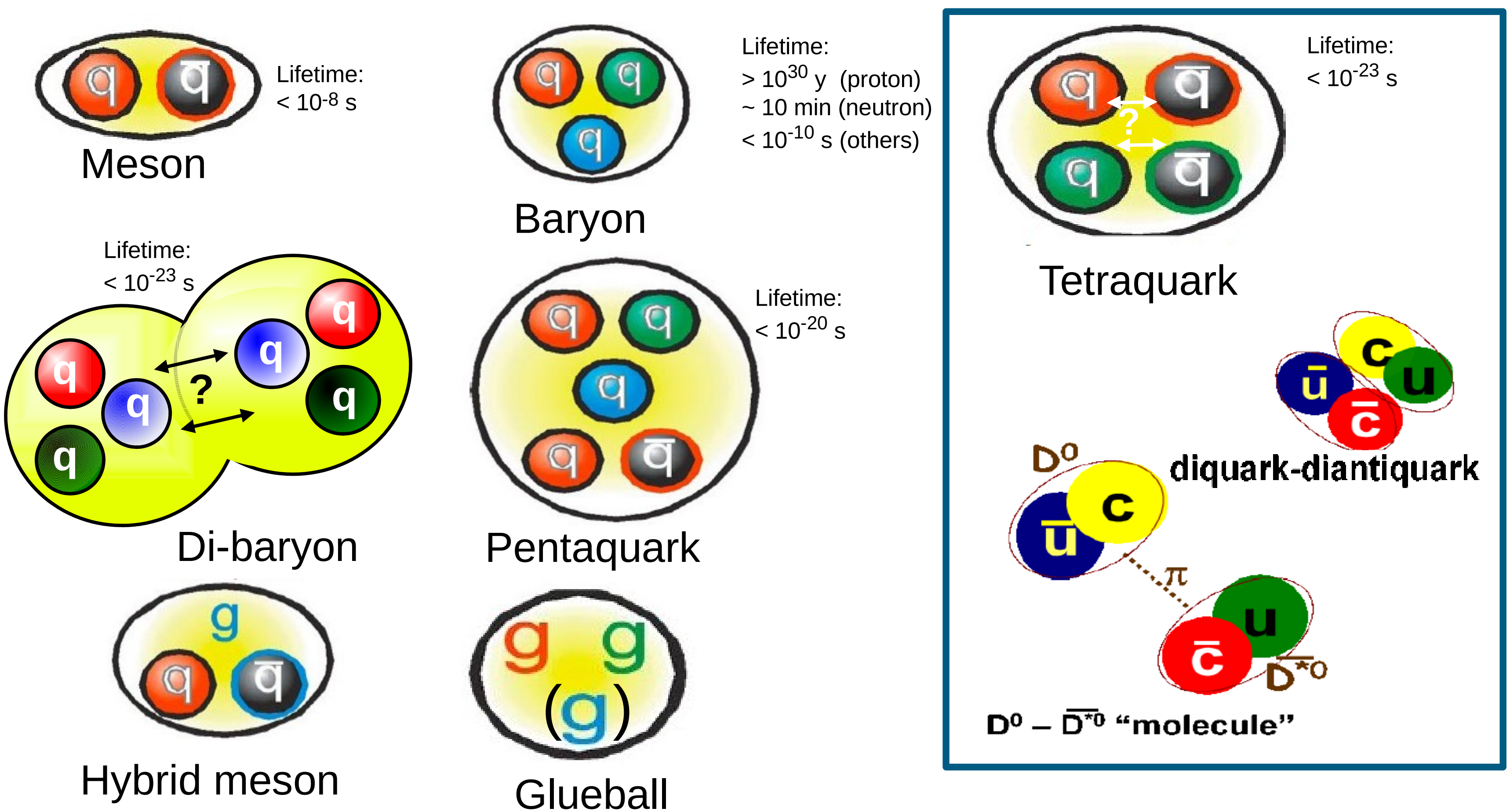
Introduction

- Gell-Mann Zweig idea: Constituent Quark Model (*CQM*).

  Still valid for half century → it classifies all known hadrons
- QCD-motivated models predict the existence of hadrons with more complex structures than simple *qq* (mesons) or *qqq* (baryons) → the so-called XYZ *"charmonium"-like* states
- **Lot of experimental effort to prove the existence of XYZ!**
- Many evidences, few observations, some time confusion….
- Different interpretations, started with the observation of the X(3872)
- Evidence that there is more than *mesons* and *baryons*!

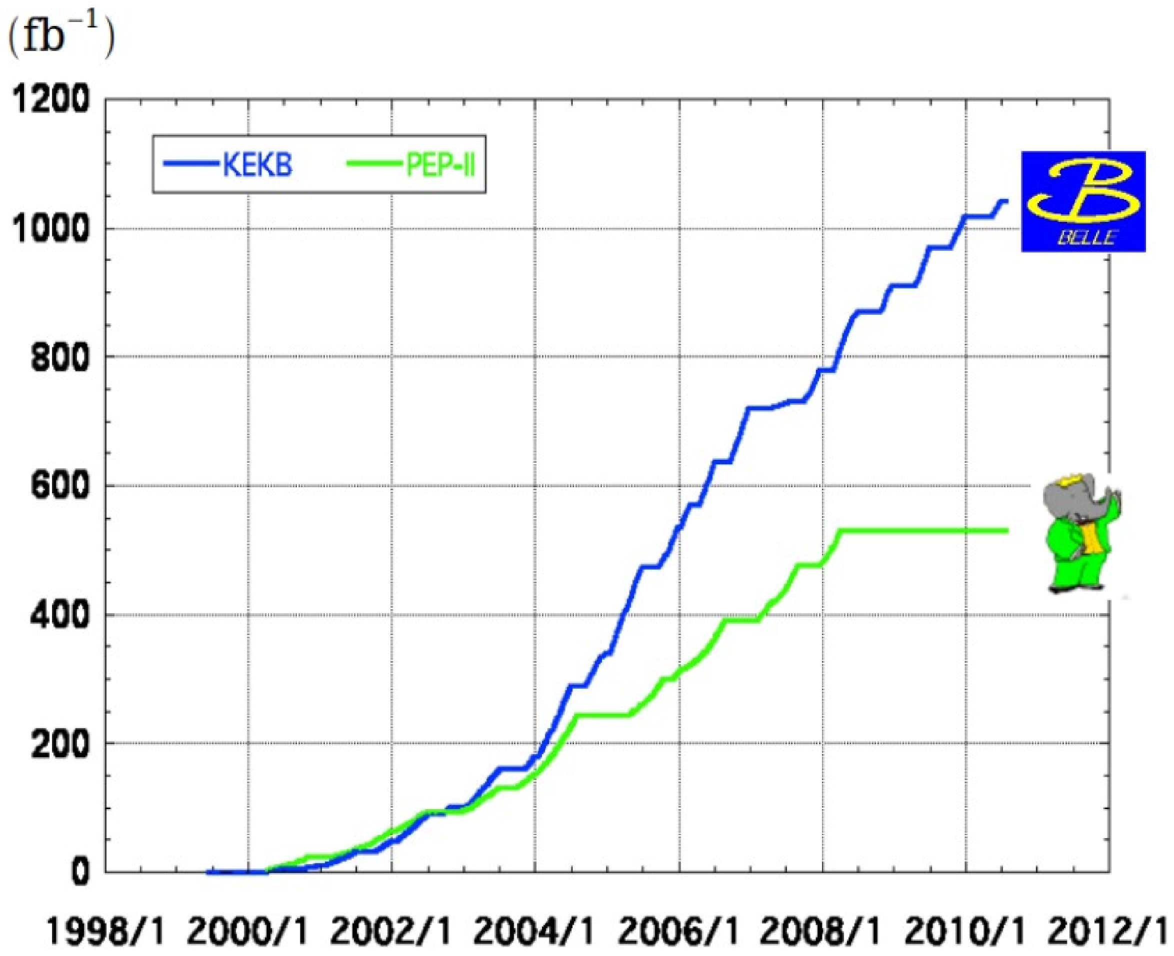
Substantial contribution from B factories (1999-2010) into the field

Quark bound states



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

B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1} 772M $B\overline{B}$

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1} 470M $B\overline{B}$

$\Upsilon(3S)$: 30 fb^{-1}

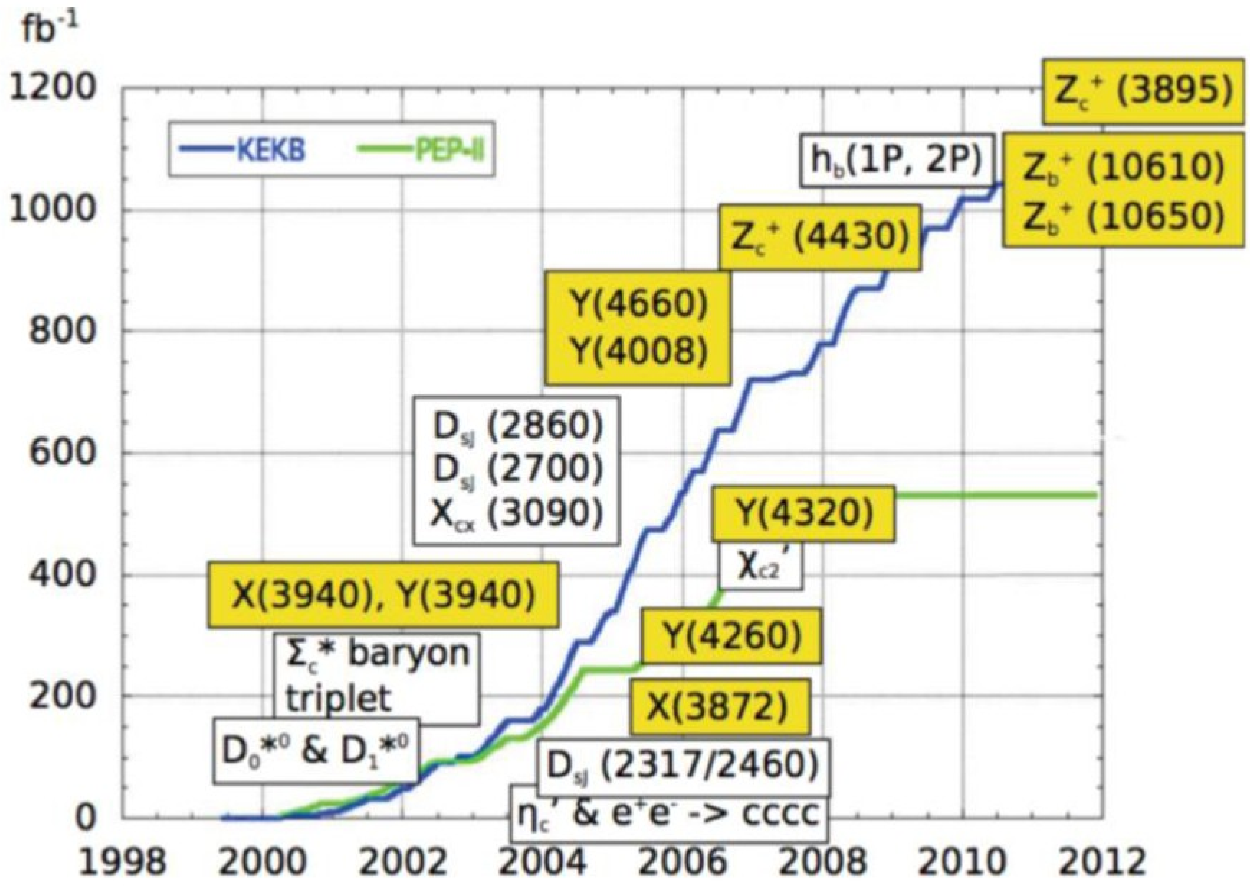
$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

~ 54 fb^{-1}

- Proposal for combined BaBar+Belle analysis in spectroscopy: DFG Pr-1722

XYZ at B factories



- Not only B-factory, but $c\bar{c}$-factory with so high luminosity
- Still statistics limitation in spectroscopy for rare processes (BR<10^{-5})
- Upgrade needed!

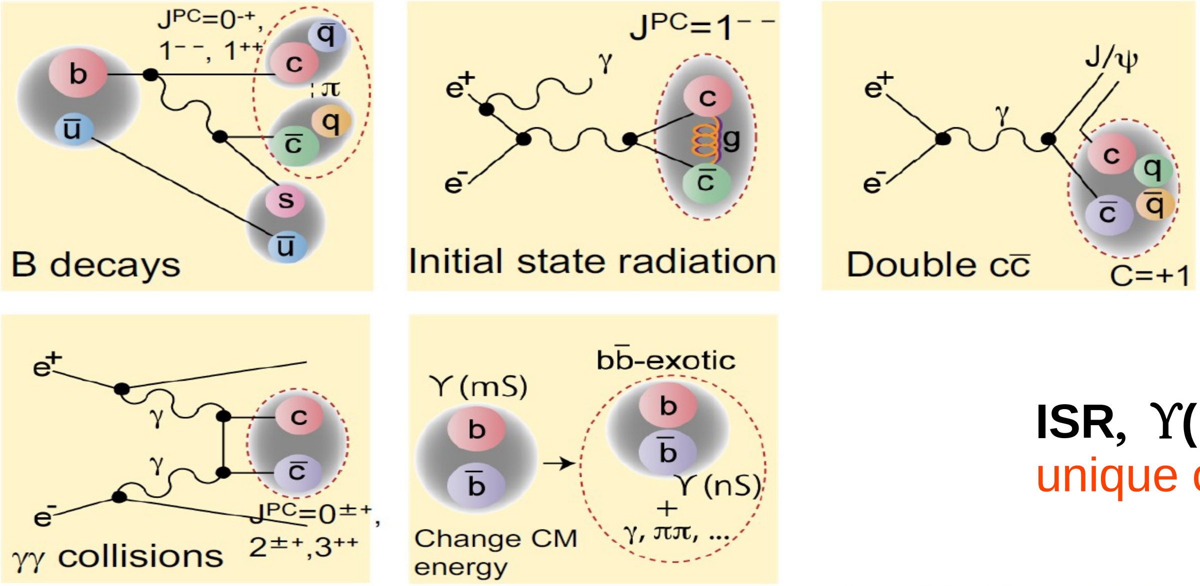
Benefits of the B factories

Example from BELLE II

- 4π general purpose spectrometer with:
  - High momentum resolution, σ_p/p = 0.3%@1GeV/c
  - Ability to detect photons down 30 MeV (reconstruction of η, D*,...)
  - Good photon energy resolution, σ_M = 5 MeV for $\pi^0 \rightarrow \gamma\gamma$
  - Lepton identification capability, ε>0.9
  - K/π/p separation capability, ε~0.9
  - Excellent B decay vertex resolution, $\sigma_{\Delta z}$ = 80 μm
  - World highest luminosity
  - Spectroscopy:
    unique processes to search for new resonances (ISR, Υ(nS) transitions)

Advantages at B factories

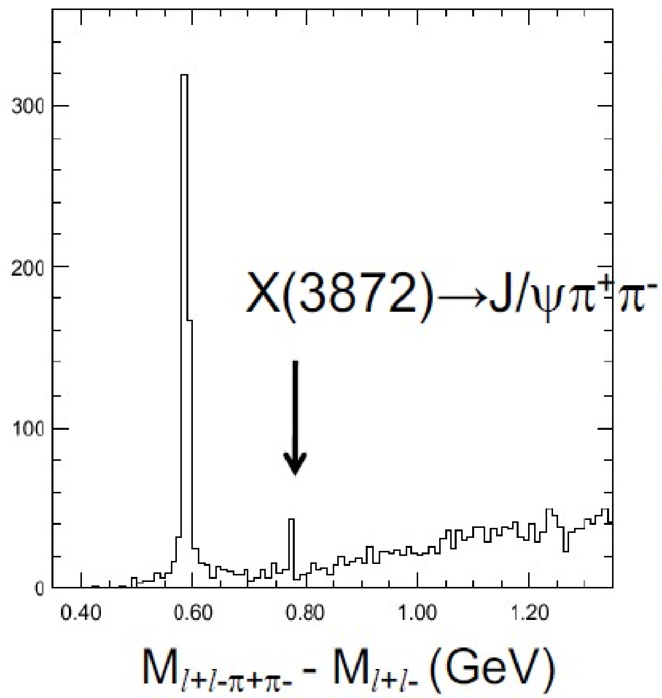
- Studying physics of strong interactions, among other topics, with:
  - Access to different production mechanisms
  - Access to a variety of final states
  - A variety of recorded reactions
  - Make predictions based on observations, using reactions which allow to access specific quantum numbers for exotic states
- Interplay among several approaches is effective



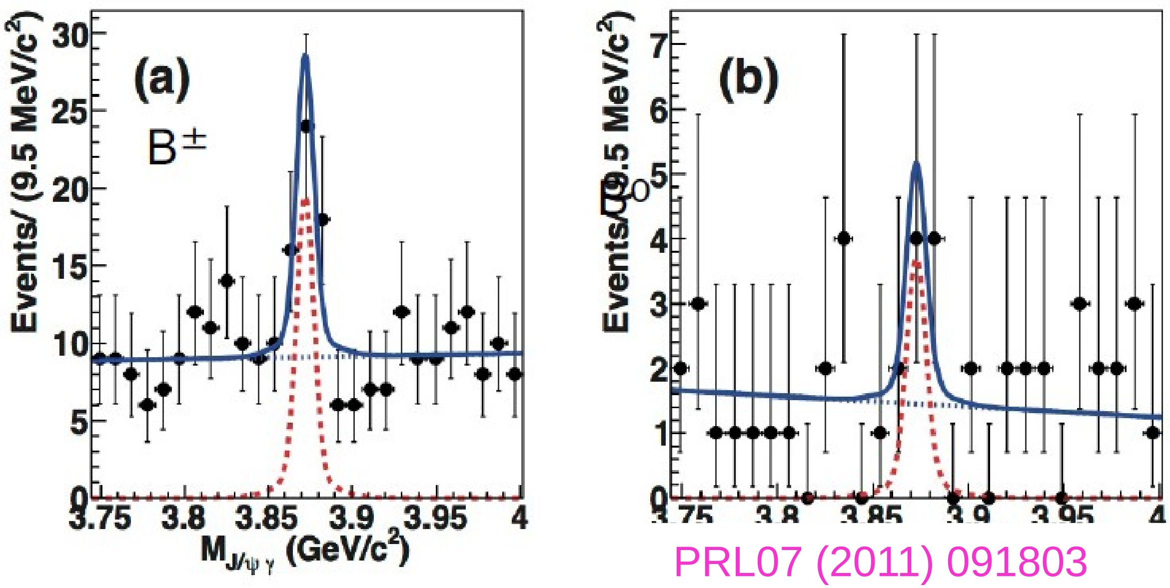
ISR, ϒ(nS):
unique cases @ Belle II

The ‘exotic’ saga: how it started

PRL91 (2003) 261801



X(3872)→J/ψ γ; C=+1



PRL07 (2011) 091803

Belle PRL07,091803(2011)

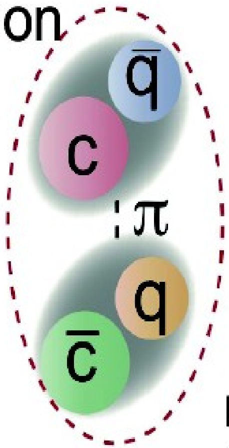
- Highest Belle cited paper ever: >1630 citations up to now, since 2003 (inspires)
- Lots of progresses on this topic since 2003:

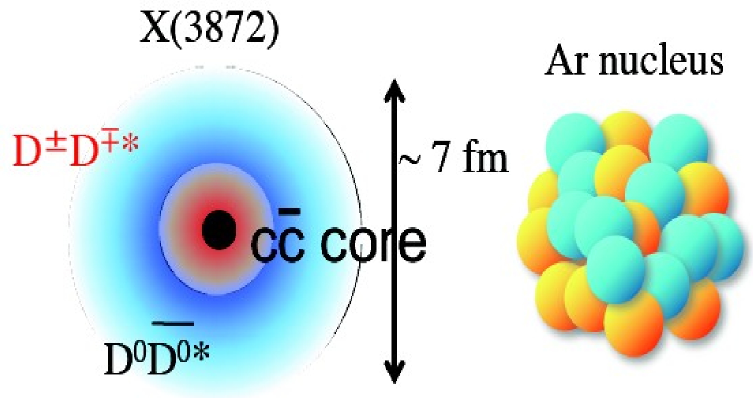
LHCb: $J^{PC}=1^{++}$ (PRL110 (2013) 222001),

Γ_{BW}(X3872)=$0.96^{+0.19}_{-0.18}\pm0.21$MeV (arXiV: 2005.13422, 2020)

Interpretation of X(3872)

Meson-meson molecule





E. J. Eichiten et al. Phys. Rev. D 73, 014014 (2006);
A. M. Badalin et al. Phys. Rev.D 85, 031103 (2012);
S. Takeuchi, K. Shimizu and M.Takizawa PTEP2014, 123D01(2014).

- BR(X(3872)$\rightarrow D^0\bar{D}^{*0}$) is x10 BR(X(3872)$\rightarrow J/\psi\pi^+\pi^-$)
- $D^0\bar{D}^{*0}$ component coupled with the same as J^{PC} $c\bar{c}$ χ_{c1}(2P) (unseen)
- D^+D^{*-} can explain why $J/\psi\pi^+\pi^-$ and $J/\psi\pi^+\pi^-\pi^0$ coexist
- $c\bar{c}$ component in prompt production at LHC seen (pure molecule interpretation is then too weak...)
- Most probable interpretation: admixture
- Investigating the X(3872) to DD* crucial: only 50 yield at Belle on full statistics

X(3872):
a look to the future

NEW

- Known upper limit: Γ < 1.2 MeV (estimated from $X(3872) \to J/\psi\pi^+\pi^-$), on full Belle data sample
- LHCb estimated Γ^{BW} = 0.96 MeV (5.5σ, estimated from $X(3872) \to J/\psi\pi^+\pi^-$), on 9 fb^{-1} arXiV:2005.13422

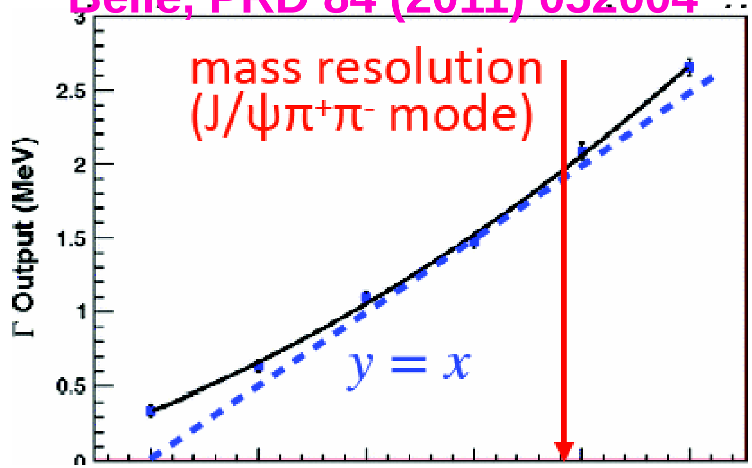
- Very promising: $X(3872) \to D^0\overline{D}^{0*}$

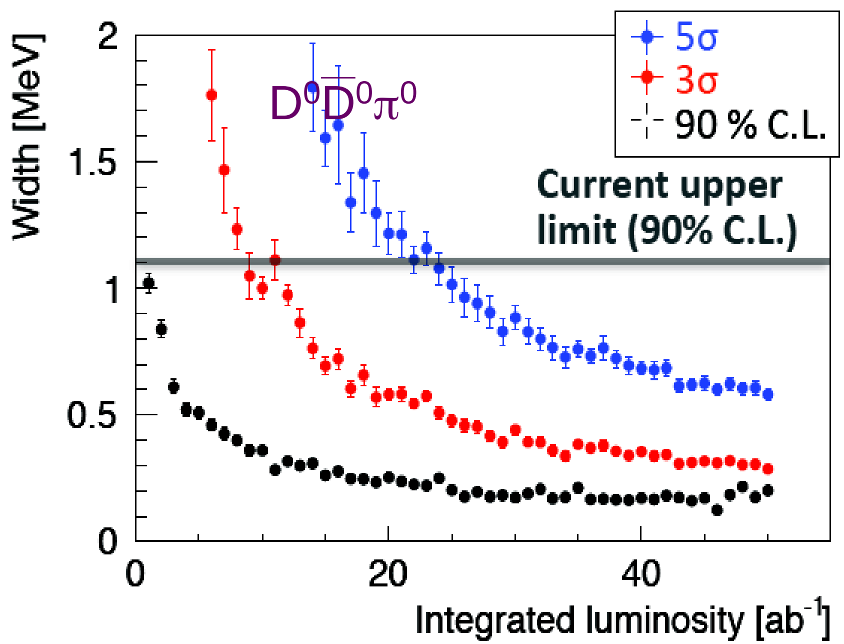
mode	Q value [MeV]
$J/\psi\pi^+\pi^-$	495.65±0.17
$D^0\overline{D}^0\pi^0$	7.05±0.18
$D^0\overline{D}^{0*}$	0.01±0.18

- Due to very low Q value, the mass resolution is extremely good → expected great improvement on the width measurement with 50 ab^{-1}

- D^0, D^{0*} reconstruction: see K. Lautenbach talk, tomorrow

Belle, PRD 84 (2011) 052004





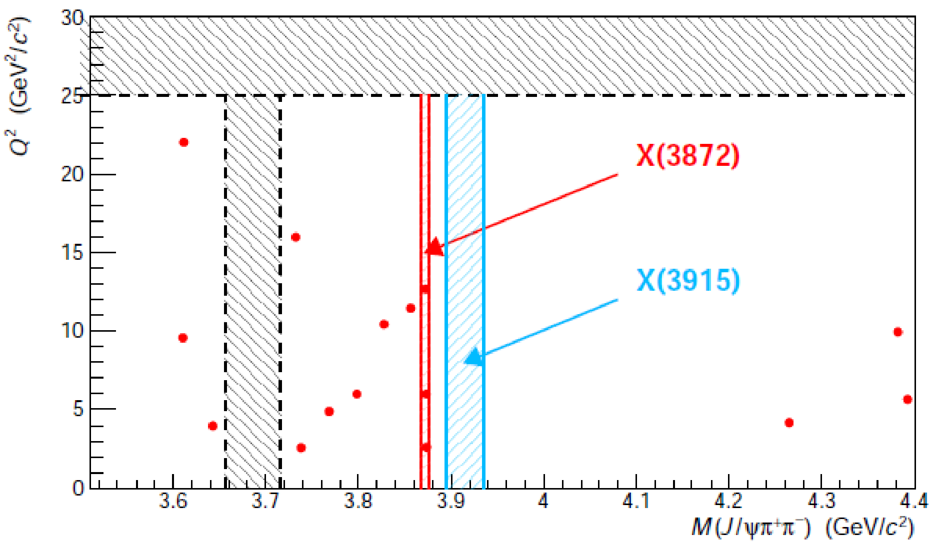
H. Hirata, Master thesis 2019

X(3872) in single-tag two photon interactions

NEW

- First evidence for the X(3872)→$J/\psi\pi^+\pi^-$ production in two-photon interactions (arXiV:2007:05696, 2020)

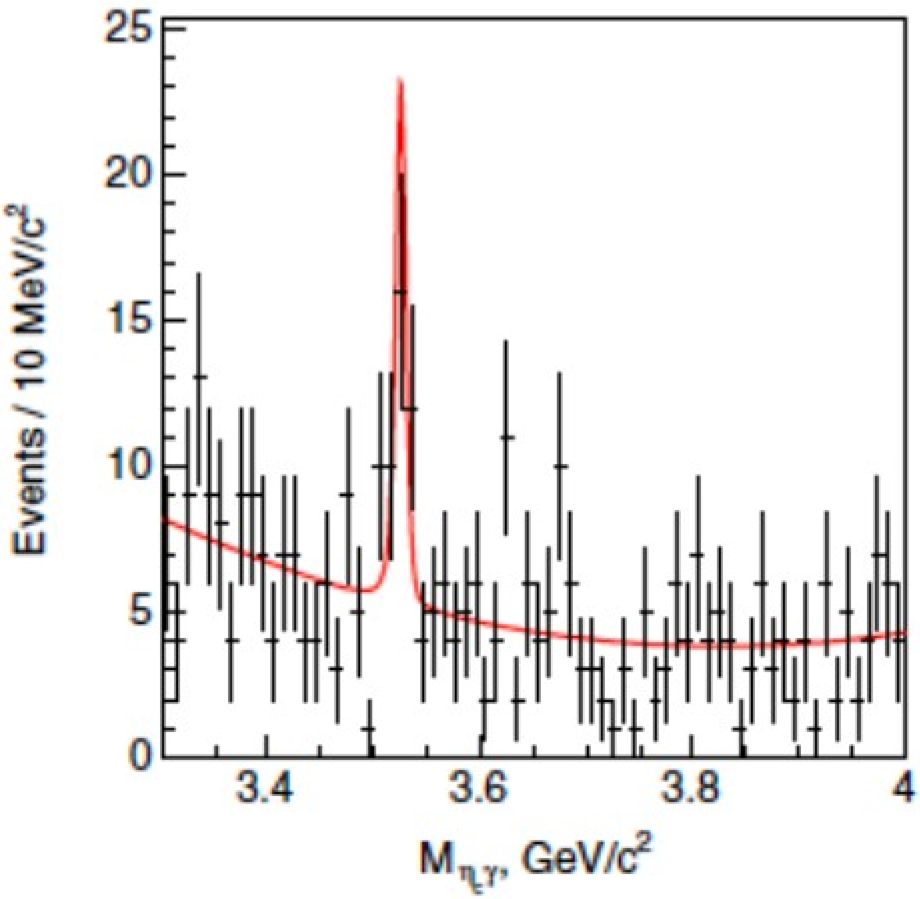
  - tagging either the electron or the positron in the final state
  - exploring the highly virtual photon region
  - 825 fb^{-1} data at Belle
  - 3 events observed with expected bkg 0.11±0.10 (3.2σ)



$$\Gamma_{\gamma\gamma}B(X(3872)\rightarrow J/\psi\pi^+\pi^-) = 5.5^{+4.1}_{-3.8}(\text{stat.})\pm0.7(\text{syst.})\ \text{eV}$$

New observation for charmonium at Belle

NEW



$B^+ \to h_c K^+,\ h_c \to \gamma\ \eta_c$

PRD100 (2019) 012001

- η_c reconstructed in 11 modes
- Multivariate analysis technique used to overcome factorization suppression
- First evidence of h_c in B decays
- Radiative decays into $\gamma\eta_c$ or $\gamma\eta_c(2S)$ are important to look for X(3872) C-odd partners.
  Great Belle contribution from this analysis!

To study η decays will be an advantage at Belle II

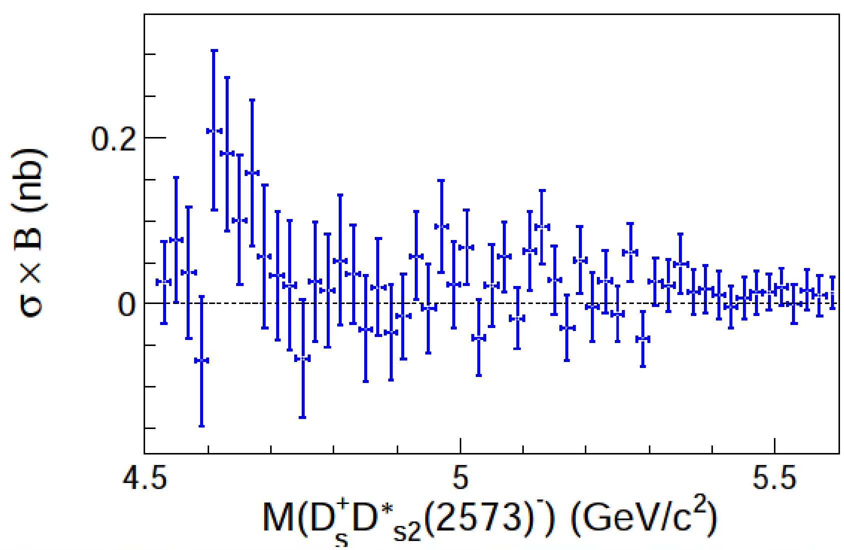
New exotic state in $e^+e^- \to \gamma_{ISR} D^+_s D^*_{s2}(2573)^-$

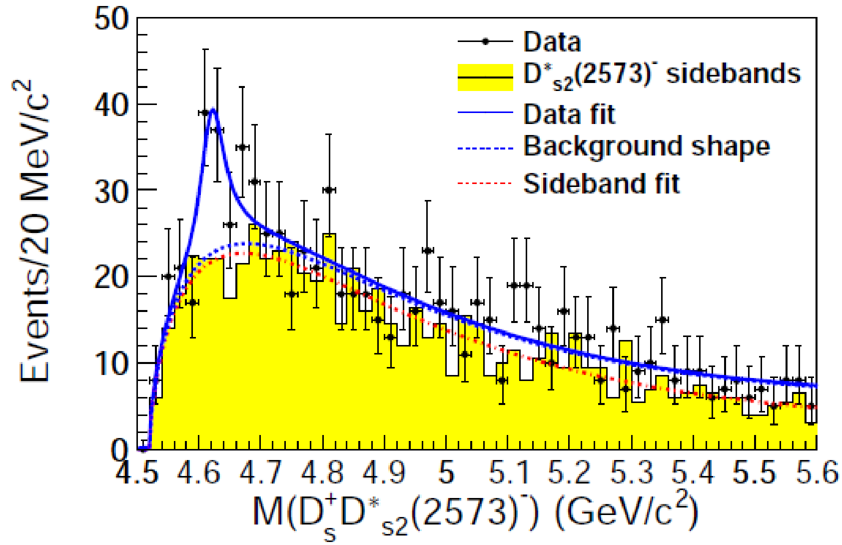
NEW

PRD 101, 091101 (2020)

- 3.4σ evidence for a new $c\bar{c}s\bar{s}$ state, 66 events
- 921.9 fb^{-1} at Belle
- $M = (4619.8^{+8.9}_{-8.0} \pm 2.3)$ MeV/c^2
- $\Gamma = (47^{+31.3}_{-14.8} \pm 4.6)$ MeV
- Consistency with Y(4626) observed in $D_s^+ D_s(2536)^-$ in ISR and the Y(4660)

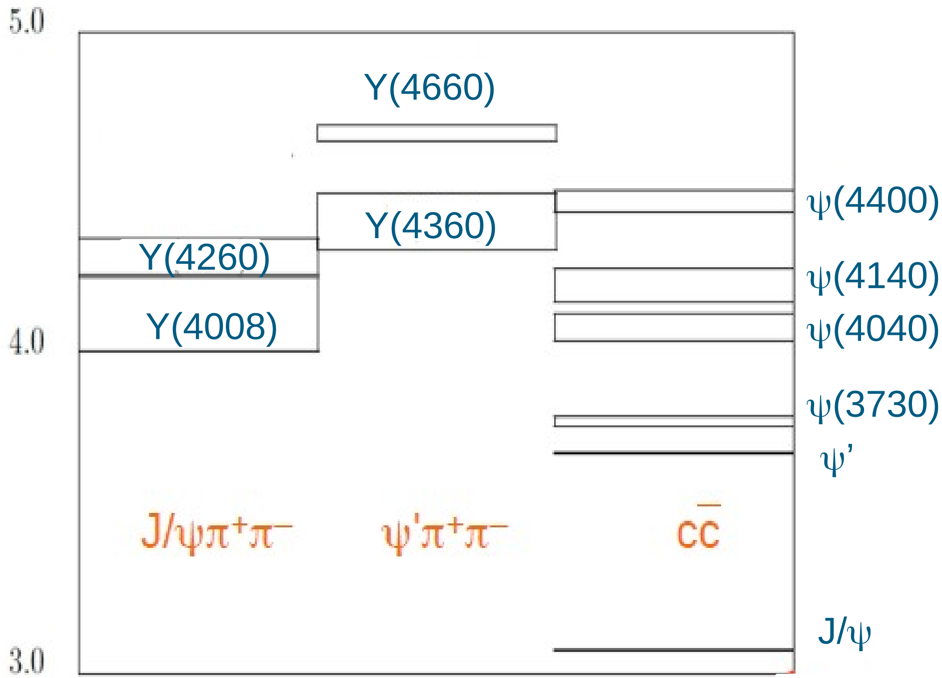
PRD 100 (2019) 111103(R)



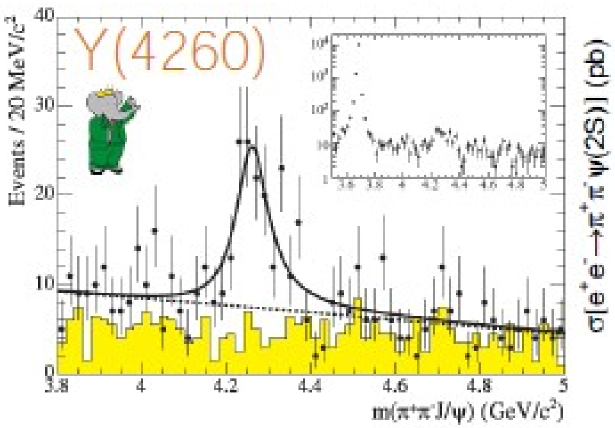


Y family: summary

Contribution from Belle

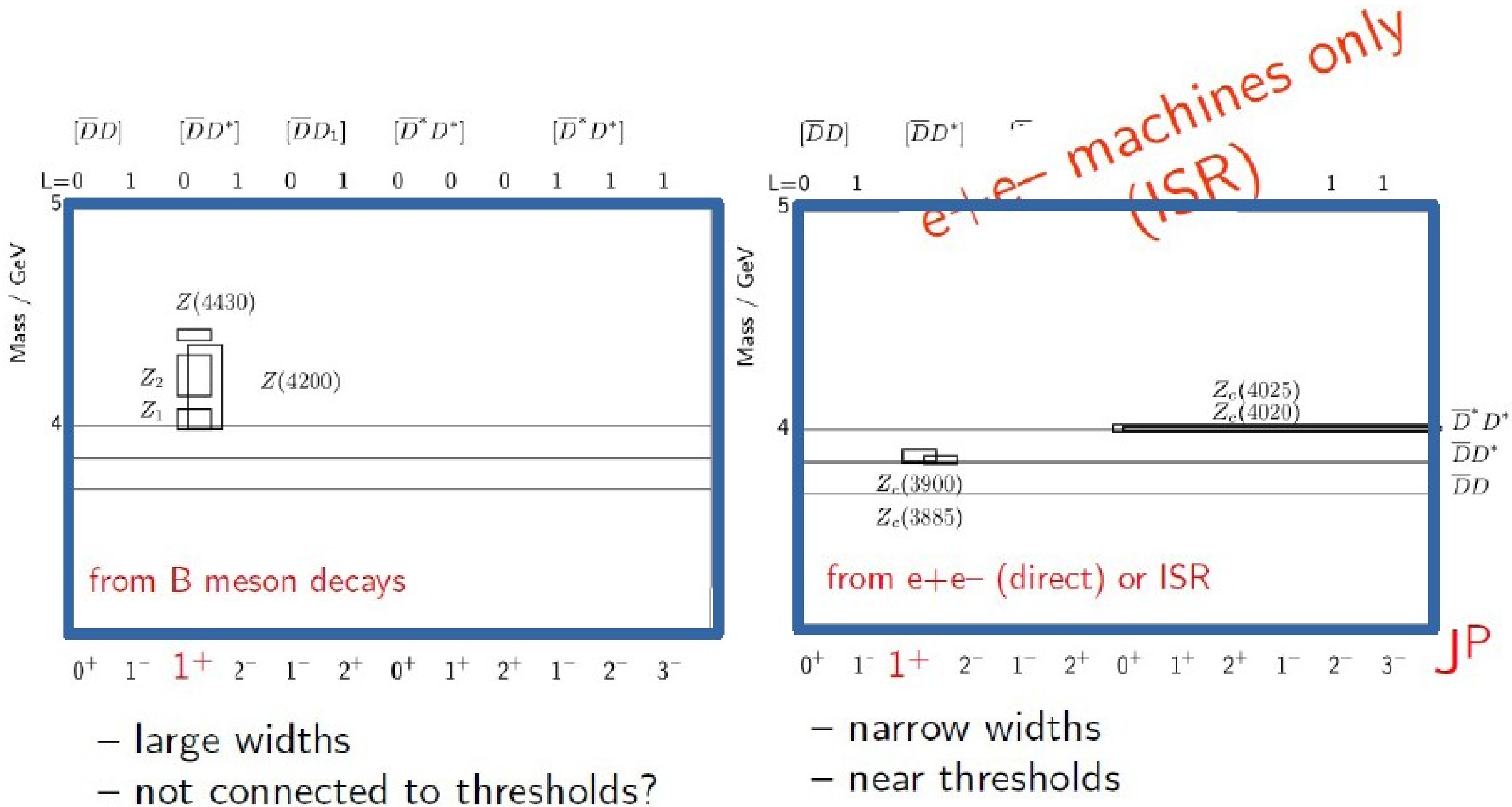


	Mass (MeV/c²)	Width (MeV)
Y(4008)	$4008 \pm 40^{+114}_{-28}$	226±44±87
Y(4260)	4258.6±8.3±12.1	134.1±16.4±5.5
Y(4360)	4361±9±9	74±15±10
Y(4660)	4664±11±5	48±15±3



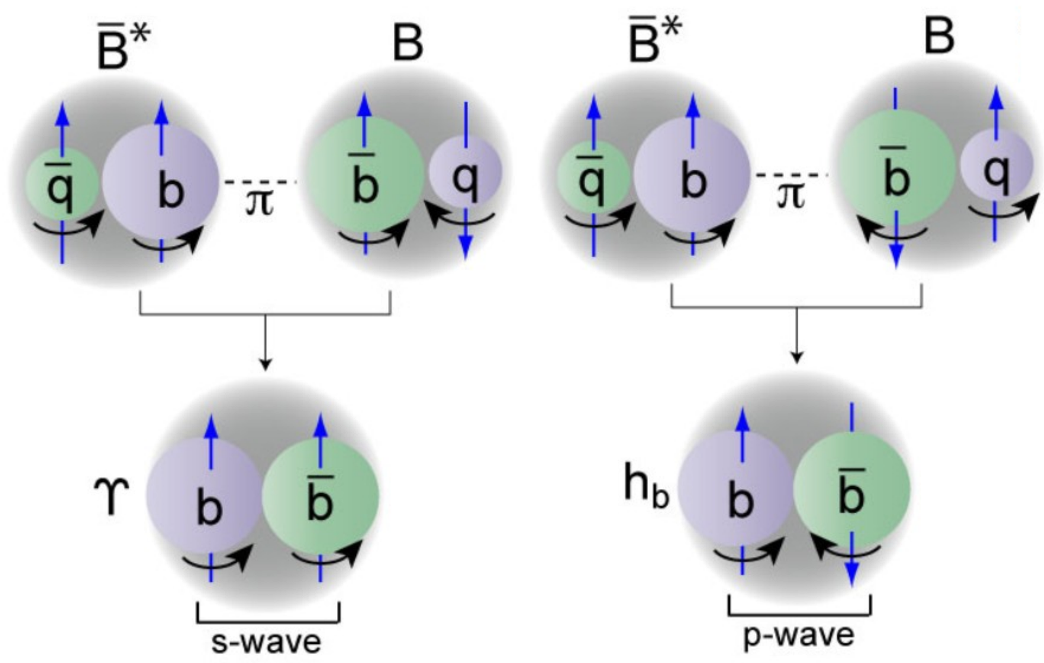
- ISR studies: unique at B factories
- Clear signature: $J^{PC} = 1^{--}$
- No mixing ⇨ surprising!
- Limited statistics at B-factories for such rare events: need more data!

Two different classes of Z states?



- Belle II is in a unique position to look for both Z types:
  - through B decays (LHCb, no BES III)
  - threshold state (BES III, no LHCb up to now)

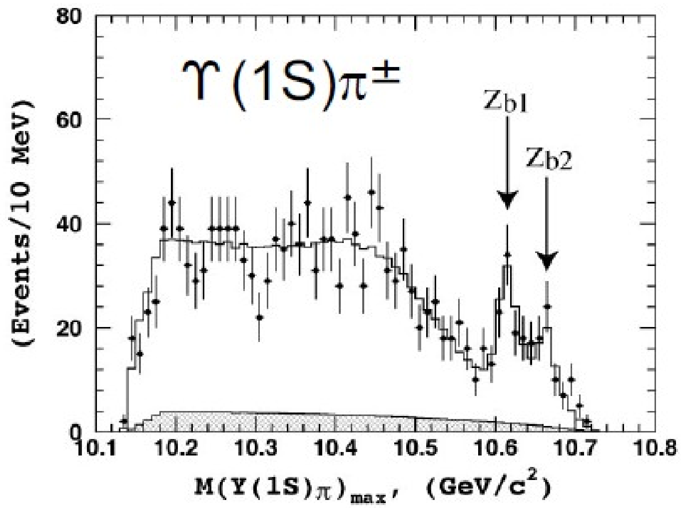
Molecular picture of Υ(nS) transitions

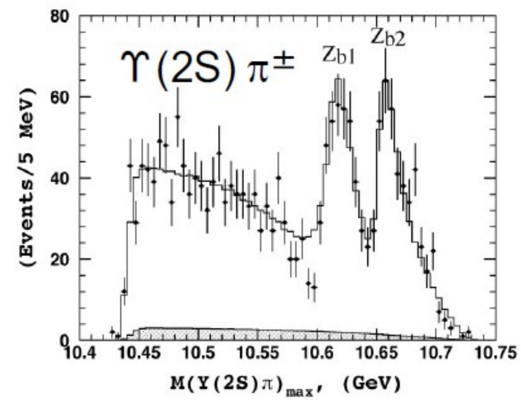


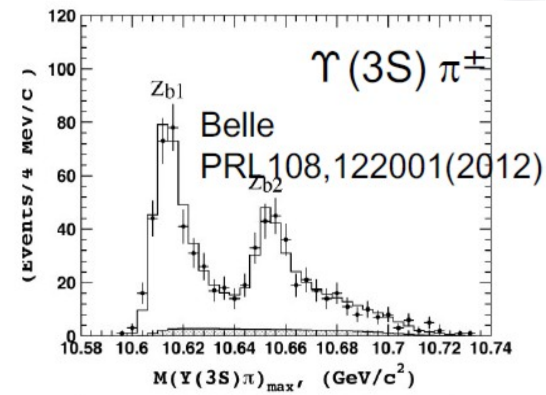
A. Bondar et al, PRD84 (2011) 054010

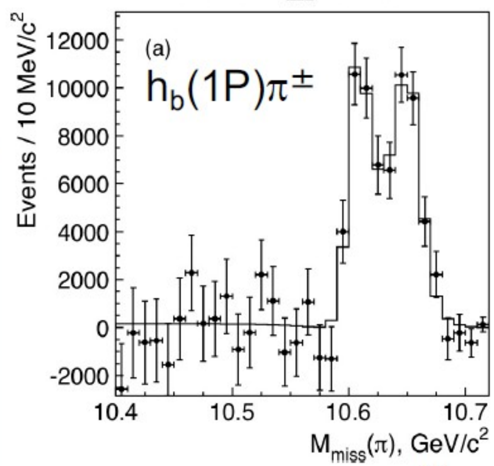
- Decays of Υ(nS) and h_c can coexist
- Decay to $B^*B^{(*)}$ found to be dominant
- $J^P = 1^+$ supported by Dalitz analysis, PRD91 (2015) 072003
- Limited statistics!
- Belle II is suitable for this search, however under debate due to the cost of cavities

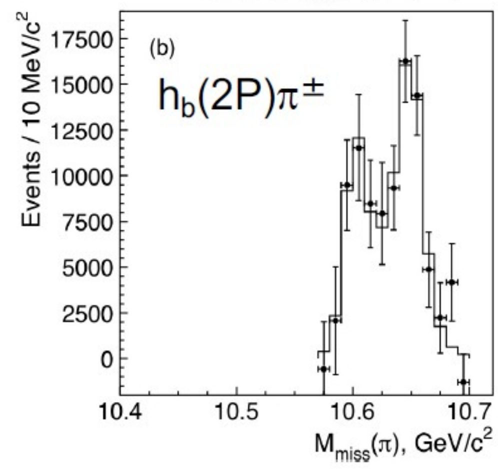
Υ(nS) transitions at Belle

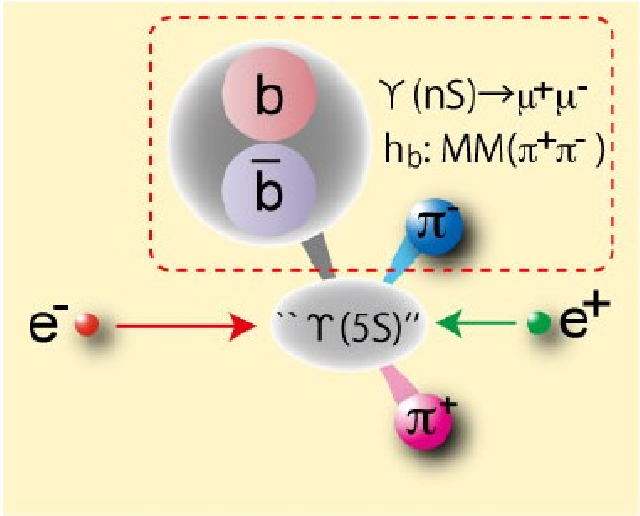












- Υ(5S): yield ~1000 more than Υ(4S) transitions: unsolved puzzle
- Υ(5S) not observed at LHCb so far

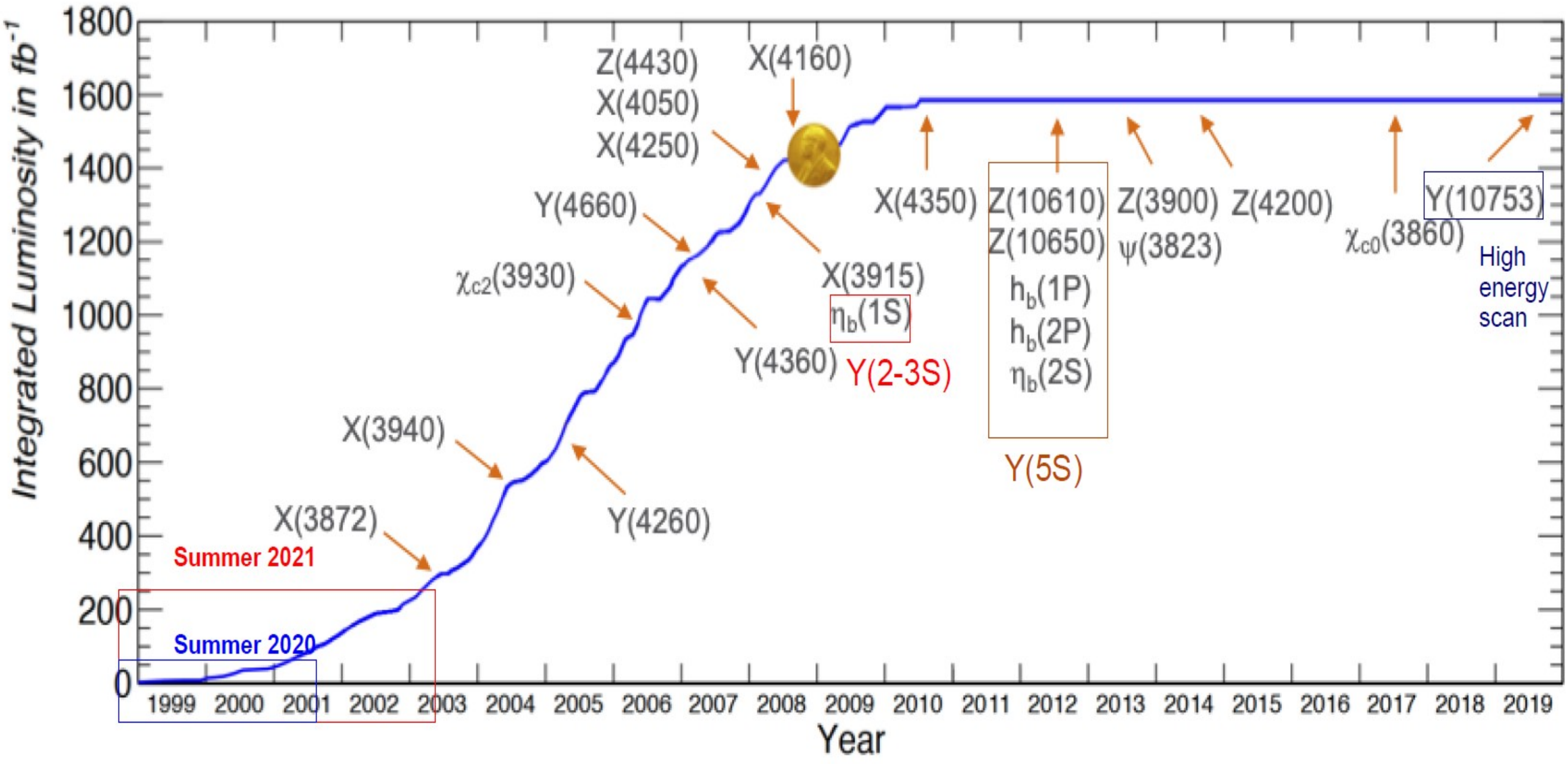
Not only the X(3872)…

- The program in hadron spectroscopy at Belle II is wide and various.

  - Re-discovery channels in B (with more statistics, expected surprises)
  - Charmonium(-like) in ISR: extended search. Unique case!
  - Search for new resonances in the continuum
  - Bottomonium: $\Upsilon(6S)$ unique and feasible!
  - Z_b state search
  - $\Upsilon(5S)$ and $\Upsilon(6S)$ conventional state search, and exotics
  - $\Upsilon(5S)$ and $\Upsilon(6S)$ scan
  - $\Upsilon(3S)$ transitions and charmonia in production
  - Possibility to look for more '*exotic beasts*': hexaquarks, ….

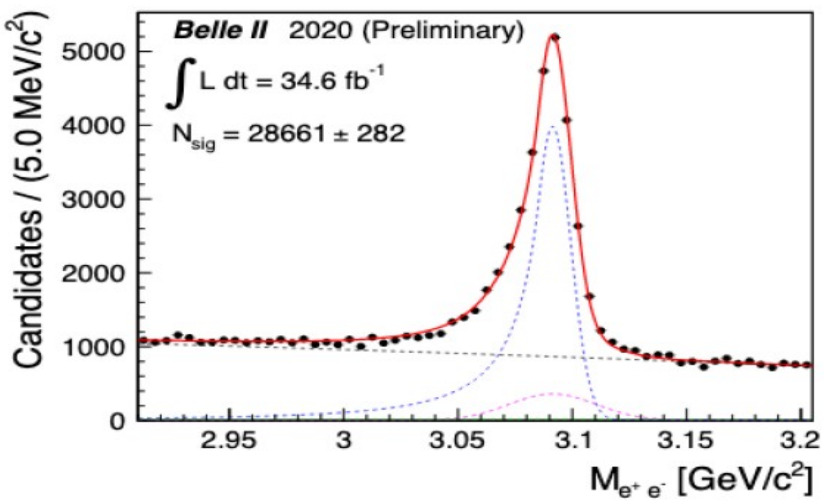
- Possibility to combine Belle and Belle II data in the early future

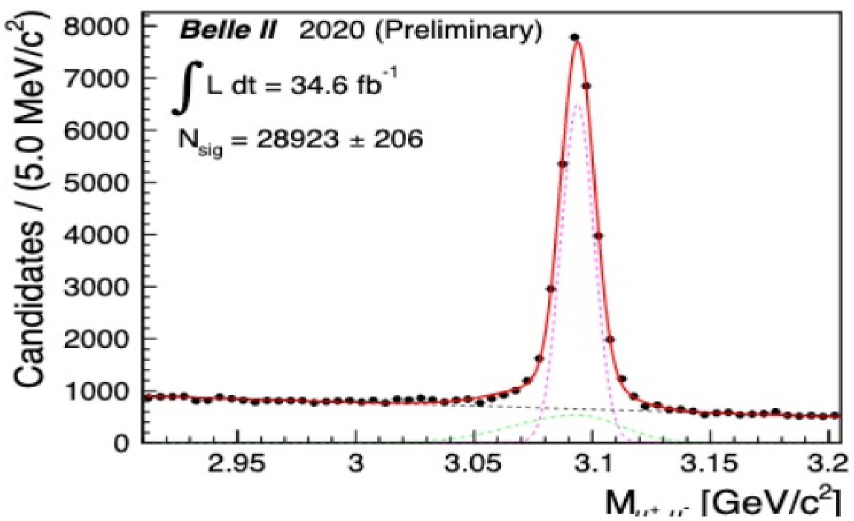
Run perspectives at Belle II in Spectroscopy

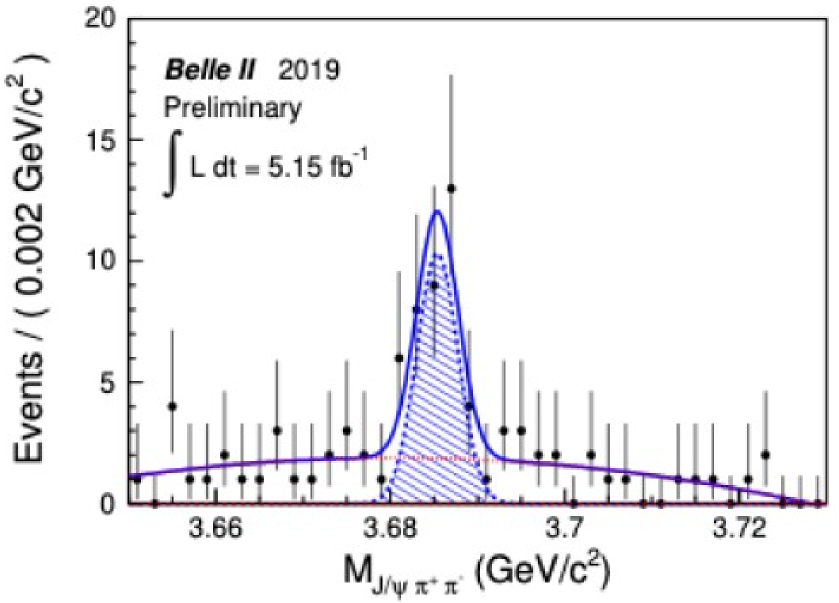


J/ψ and ψ’ from B decays at Belle II

NEW

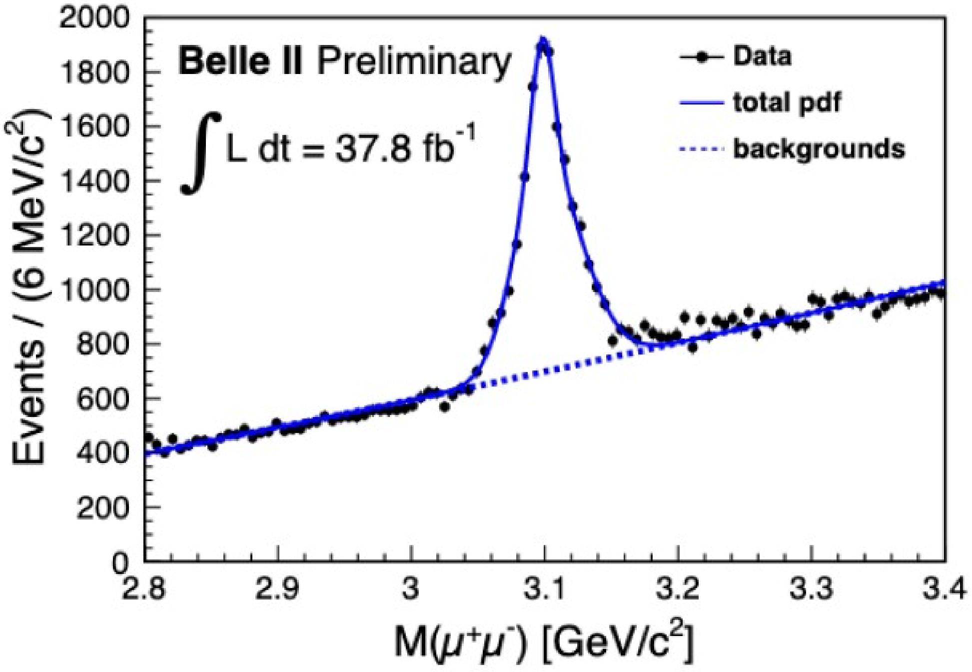


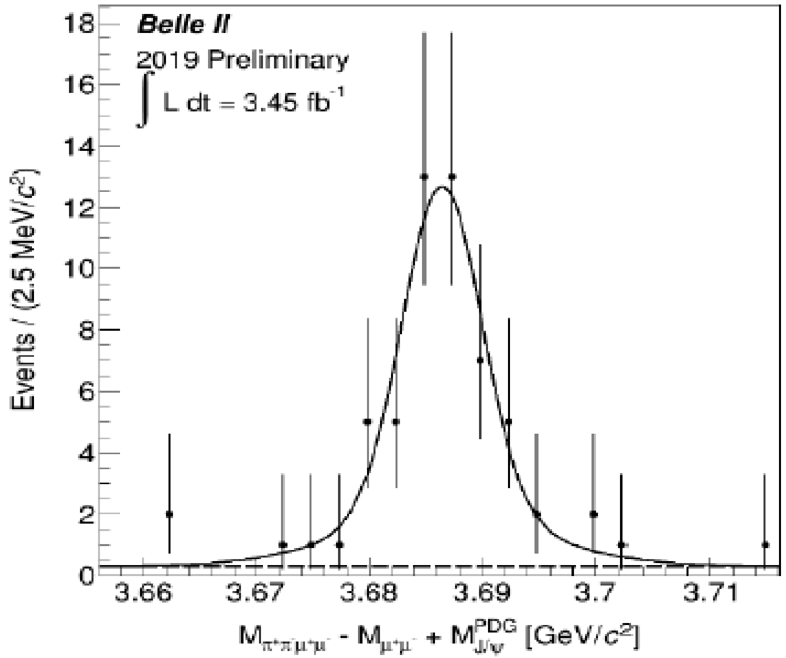




J/ψ and ψ' from ISR at Belle II

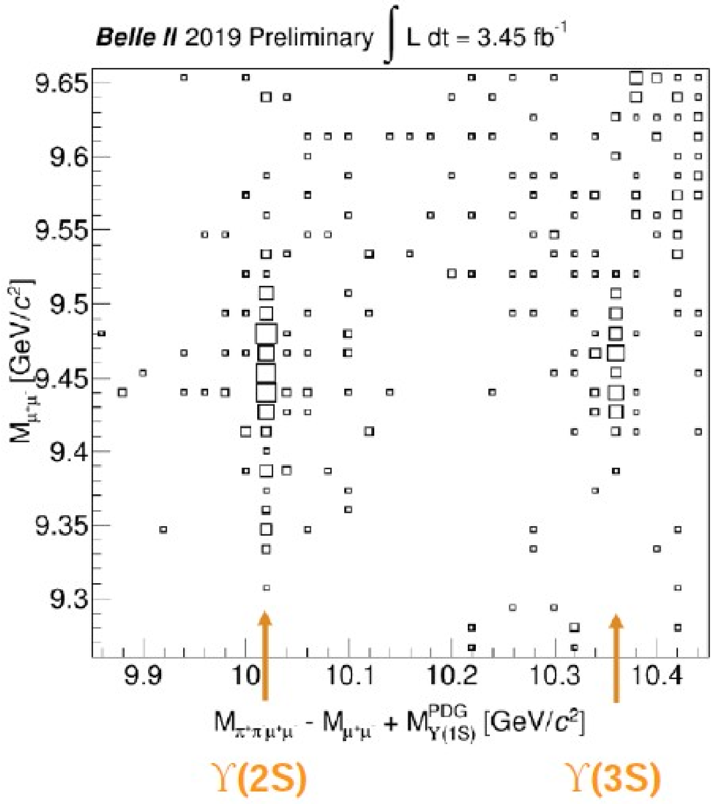
NEW

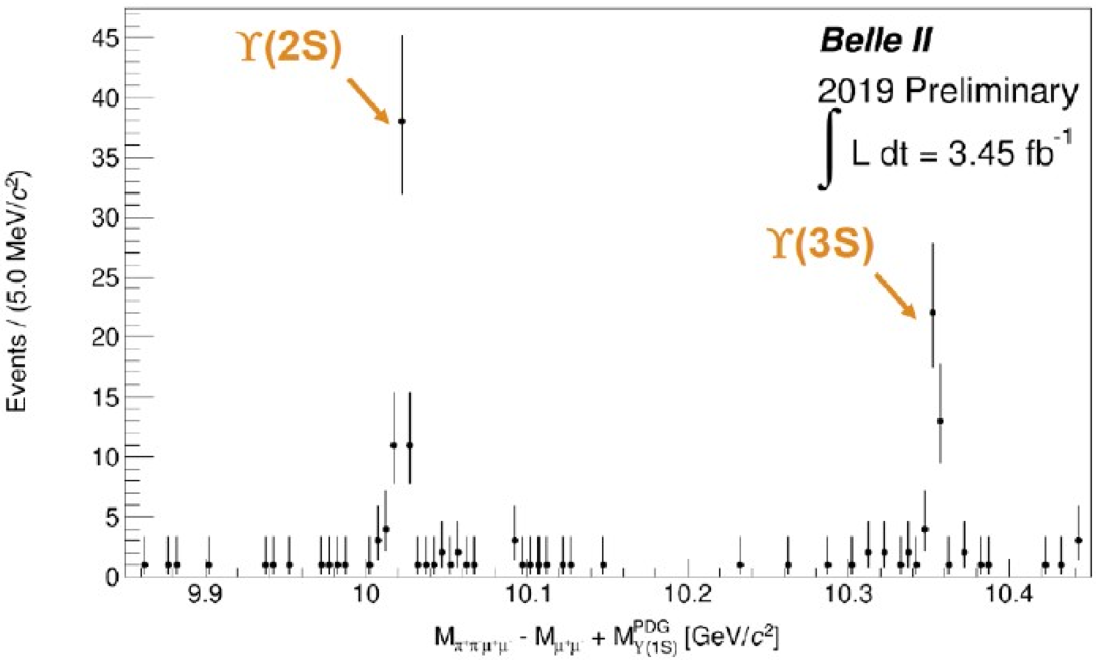




Reminder: ISR not possible at hadron machines!

Bottomonium ISR production at Belle II

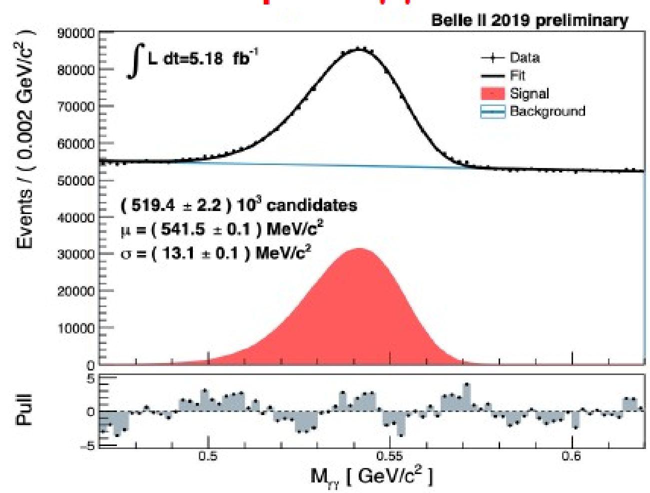




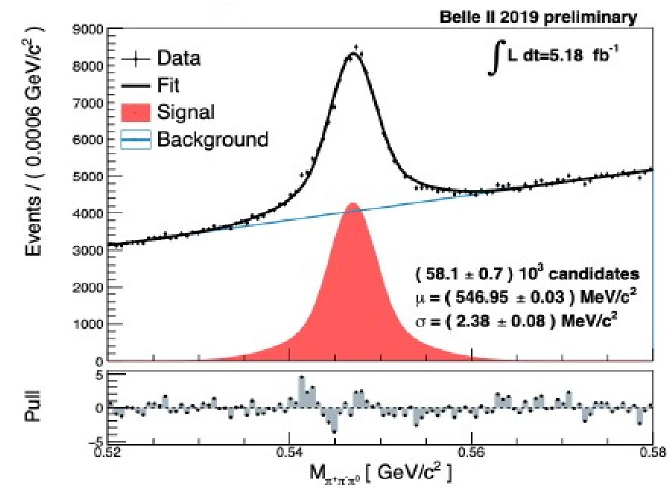
Inclusive η and η’ production at Belle II

NEW

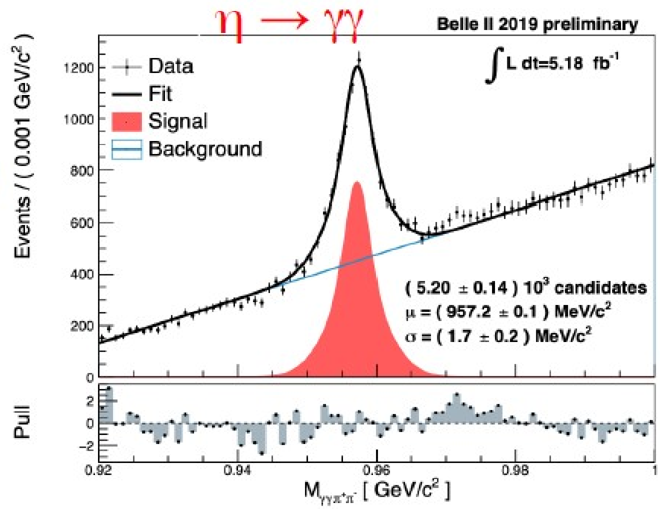
$\eta \rightarrow \gamma\gamma$



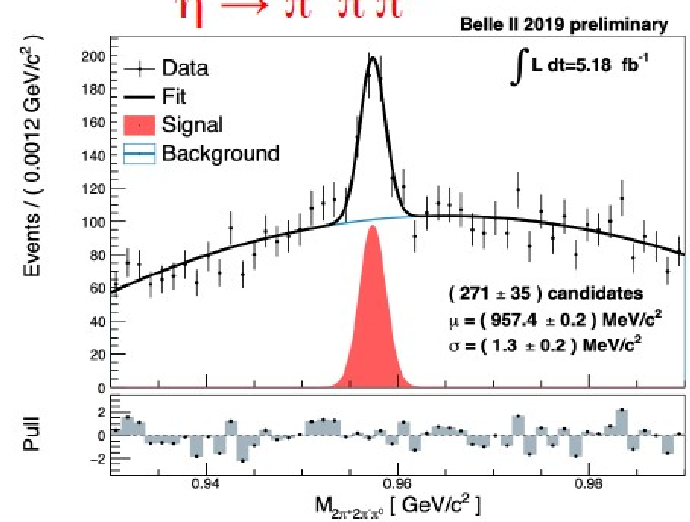
$\eta \rightarrow \pi^+\pi^-\pi^0$



$\eta \rightarrow \gamma\gamma$



$\eta \rightarrow \pi^+\pi^-\pi^0$



$\Upsilon(4S) \rightarrow \eta' \, \Upsilon(1S)$

$\eta' \rightarrow \eta\pi^+\pi^-$

Conclusions

- Many exciting results with full Belle data set:
  - ongoing analyses after 10 years the detector was shut down
- Belle II is progressing well: *re-discovery channels* up to now
- Instantaneous world luminosity record in June: $2.4\times10^{34}cm^{-2}s^{-1}$
- Total integrated luminosity up to now: 74 fb^{-1}
- Observation of charmonia and bottomonia are becoming a standard tool for trigger and performance checks during Belle II starting phase
- Covid-19 affected our activity, but the work is ongoing
- Recent exciting news from LHCb:
  - width (BW) of the X(3872)
  - observation of a structure in J/ψ-pair mass spectrum
  - X(2900); ….
- Belle II will be competitive with BES III and LHCb:
  - interesting physics in spectroscopy will come after 2022 Shut down (>250 fb^{-1} needed)
  - ISR, radiative decays, $\Upsilon(nS)$ transitions: unique!
- Interesting physics in spectroscopy comes soon

Stay tuned!