Workshop on status and perspectives of physics at high intensity

Status and prospects for hadron spectroscopy at Belle II

Bianca SCAVINO on behalf of the Belle II Collaboration

Johannes Gutenberg University of Mainz

bscavino@uni-mainz.de

Spectroscopy

Spectroscopy: non-perturbative QCD regime

- Interplay of experimental observations and semi-phenomenological effective models needed

Theory

- No direct calculations
- Rely on models approximating QCD
- Huge number of theoretical predictions

Experiment

- Perfect ground to test different theoretical models
- Often reveals expected features,
  new knowledge feed back to theory

Spectroscopy

QCD bound states (up to 11 GeV)

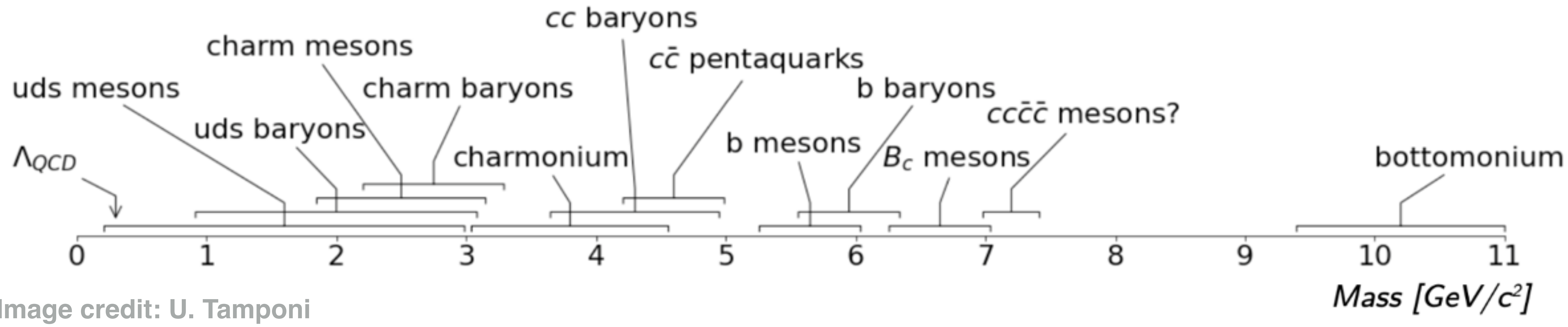
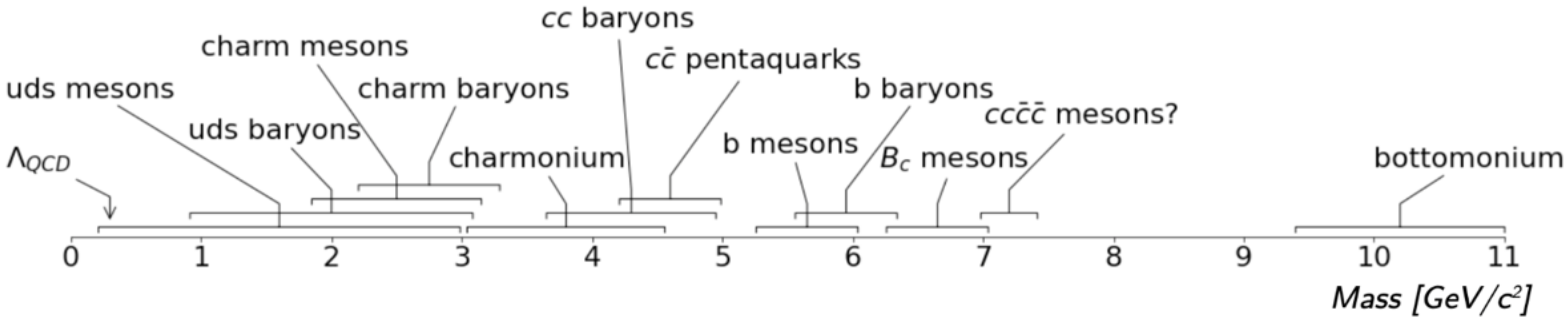


Image credit: U. Tamponi

“Multiplayer game”, where each of the players has its own strengths and weaknesses

Spectroscopy

QCD bound states (up to 11 GeV)



"Multiplayer game", where each of the players

has its own strengths and weaknesses

Quarkonium(-like) spectroscopy, experienced players

BELLE

Observation of a narrow charmonium-like state in exclusive $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ decays #1

Belle Collaboration • S.K. Choi (Gyeongsang Natl. U.) et al. (Sep, 2003)

Published in: Phys.Rev.Lett. 91 (2003) 262001 • e-Print: hep-ex/0309032 [hep-ex]

pdf | links | DOI | cite | claim | reference search | 2,215 citations

Study of $e^{+}e^{-} \to \pi^{+}\pi^{-}J/\psi$ and Observation of a Charged Charmoniumlike State at Belle #7

Belle Collaboration • Z.Q. Liu (Beijing, Inst. High Energy Phys.) et al. (Mar 30, 2013)

Published in: Phys.Rev.Lett. 110 (2013) 252002, Phys.Rev.Lett. 111 (2013) 019901 (erratum) • e-Print: 1304.0121 [hep-ex]

pdf | links | DOI | cite | datasets | claim | reference search | 813 citations

Observation of a resonance-like structure in the $pi^{\pm}\psi'$ mass distribution in exclusive $B \to K\pi^{\pm}\psi'$ decays #8

Belle Collaboration • S.K. Choi (Gyeongsang Natl. U.) et al. (Aug, 2007)

Published in: Phys.Rev.Lett. 100 (2008) 142001 • Proceedings of: 23rd International Symposium on Lepton-Photon Interactions at High Energy (LP07) • e-Print: 0708.1790 [hep-ex]

pdf | DOI | cite | claim | reference search | 749 citations

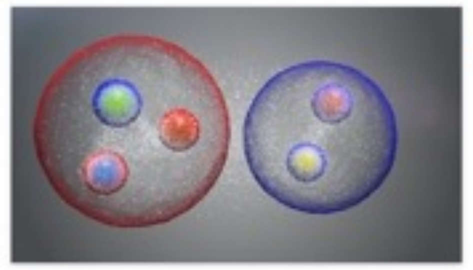
Observation of two charged bottomonium-like resonances in Y(5S) decays #9

Belle Collaboration • A. Bondar (Novosibirsk, IYF) et al. (Oct, 2011)

Published in: Phys.Rev.Lett. 108 (2012) 122001 • e-Print: 1110.2251 [hep-ex]

pdf | links | DOI | cite | claim | reference search | 636 citations

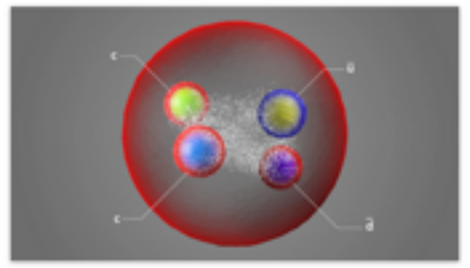
LHCb



LHCb discovers three new exotic particles

The collaboration has observed a new kind of "pentaquark" and the first-ever pair of "tetraquarks"

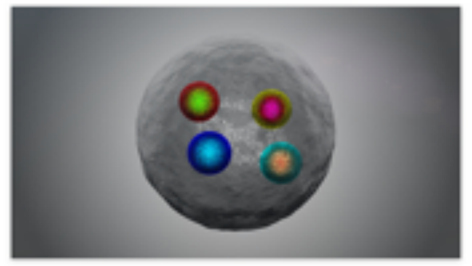
News | Physics | 05 July, 2022



Long-lived exotic particle discovered

Discovery of a new exotic hadron containing two charm quarks and an up and a down antiquark

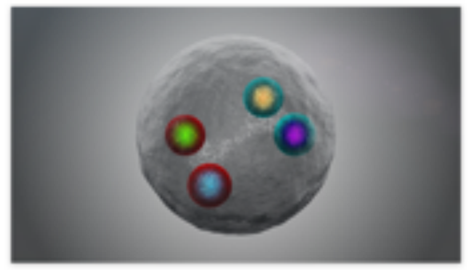
News | Physics | 29 July, 2021



LHCb discovers first "open-charm" tetraquark

The particle, which has been called X(2900), was detected by analysing all the data LHCb has recorded so far from collisions at CERN's Large Hadron Collider

News | Physics | 21 August, 2020

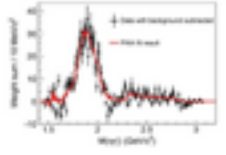


LHCb discovers a new type of tetraquark at CERN

The LHCb collaboration has observed an exotic particle made up of four charm quarks for the first time

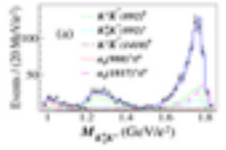
News | Physics | 01 July, 2020

BESIII



Observation of an Isoscalar Resonance with Exotic J^PC=1^(-+) Quantum Numbers in J/ψ→γηη'

The BESIII collaboration reported the observation of an isoscalar resonance with exotic JPC=1-+ quantum numbers. This research is published in Physical Review Letters [Phys. Rev. Lett. 129, 192002 (2022)], accompanied by a detailed companion paper in Physical Review D [Phys. Rev. D 106, 072012 (2022)]. This is an observation of a new category of hadronic matter, which is an important step forward in low energy QCD.

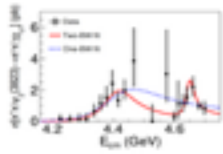


Observation of a charged scalar a0(1817)* in Charmed-strange meson Ds decay

The BESIII Collaboration recently reported the observation of an a0-like state with mass of 1.817 GeV/c2 in DS decays with the data sets collected at the center-of-mass energy region between 4.178 GeV and 4.226 GeV. The paper has been published online in Physical Review Letter. [Phys. Rev. Lett. 129, 182001 (2022)].

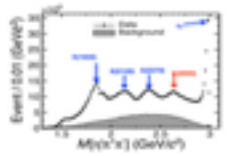
First evidence for the first neutral open-strange hidden-charm tetraquark state

The BESIII Collaboration recently reported the evidence of a new exotic multi-quark state, namely Zcs(3985)0. It is the neutral partner of the charged tetraquark Zcs(3985)+ observed in 2021 at BESIII. This is the first candidate of the neutral hidden-charm tetraquark with non-zero strangeness, which marks a new milestone in exploration of the genuine properties of the family of the exotic multi-quark hadrons. The paper has been published in Physical Review Letters [Phy. Rev. Lett. 129 (2022) 112003].



Observation of resonance structures in e+ e- → π+ π- ψ2(3823)

The BESIII experiment recently reported an observation of resonance structures in the e+ e-→π+ π- ψ2(3823) process, and also achieved the most precise mass measurement of theψ2(3823) state. These results have been published in Physical Review Letters [Phys. Rev. Lett. 129, 102003 (2022)].



Observation of the X(2600) state

The BESIII Collaboration recently reported the observation of a new state, X(2600), using 10 billion Jpsi decay events. It was published online in the Journal of Physical Review Letter on July 19, 2022 [Phys. Rev. Lett. 129 (2022) 042001].

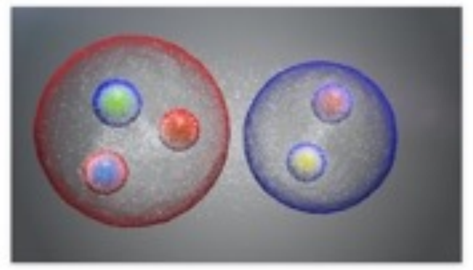
Quarkonium(-like) spectroscopy, experienced players

Observation of a narrow charmonium-like state in exclusive $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ decays #1
Belle Collaboration • S.K. Choi (Gyeongsang Natl. U.) et al. (Sep, 2003)
Published in: Phys.Rev.Lett. 91 (2003) 262001 • e-Print: hep-ex/0309032 [hep-ex]
pdf | links | DOI | cite | claim | reference search | 2,215 citations

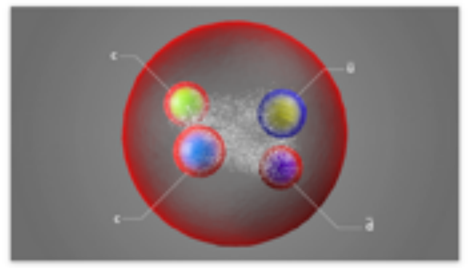
Study of $e^{+}e^{-} \to \pi^{+}\pi^{-}J/\psi$ and Observation of a Charged Charmoniumlike State at Belle #7
Belle Collaboration • Z.Q. Liu (Beijing, Inst. High Energy Phys.) et al. (Mar 30, 2013)
Published in: Phys.Rev.Lett. 110 (2013) 252002, Phys.Rev.Lett. 111 (2013) 019901 (erratum) • e-Print: 1304.0121 [hep-ex]
pdf | links | DOI | cite | datasets | claim | reference search | 813 citations

Observation of a resonance-like structure in the $pi^{\pm}\psi'$ mass distribution in exclusive $B \to K\pi^{\pm}\psi'$ decays #8
Belle Collaboration • S.K. Choi (Gyeongsang Natl. U.) et al. (Aug, 2007)
Published in: Phys.Rev.Lett. 100 (2008) 142001 • Proceedings of: 23rd International Symposium on Lepton-Photon Interactions at High Energy (LP07) • e-Print: 0708.1790 [hep-ex]
pdf | DOI | cite | claim | reference search | 749 citations

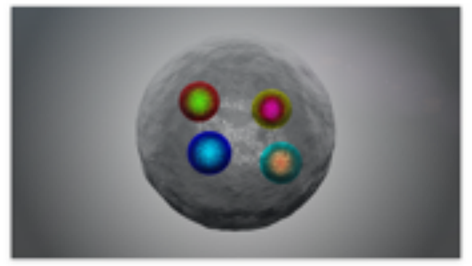
Observation of two charged bottomonium-like resonances in Y(5S) decays #9
Belle Collaboration • A. Bondar (Novosibirsk, IYF) et al. (Oct, 2011)
Published in: Phys.Rev.Lett. 108 (2012) 122001 • e-Print: 1110.2251 [hep-ex]
pdf | links | DOI | cite | claim | reference search | 636 citations



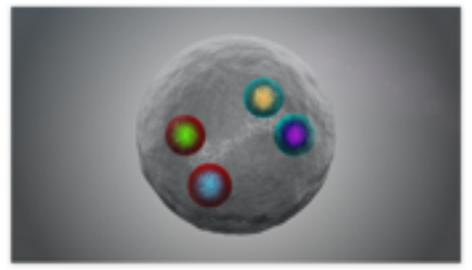
LHCb discovers three new exotic particles
The collaboration has observed a new kind of "pentaquark" and the first-ever pair of "tetraquarks"
News | Physics | 05 July, 2022



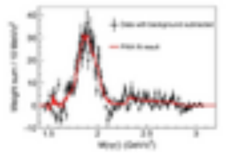
Long-lived exotic particle discovered
Discovery of a new exotic hadron containing two charm quarks and an up and a down antiquark
News | Physics | 29 July, 2021



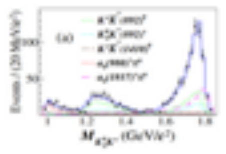
LHCb discovers first "open-charm" tetraquark
The particle, which has been called X(2900), was detected by analysing all the data LHCb has recorded so far from collis at CERN's Large Hadron Collider
News | Physics | 21 August, 2020



LHCb discovers a new type of tetraquark at CERN
The LHCb collaboration has observed an exotic particle made up of four charm quarks for the first time
News | Physics | 01 July, 2020



Observation of an Isoscalar Resonance with Exotic J^PC=1^(-+) Quantum Numbers in J/ψ→γηη'
The BESIII collaboration reported the observation of an isoscalar resonance with exotic JPC=1-+ quantum numbers. This research is published in Physical Review Letters [Phys. Rev. Lett. 129, 192002 (2022)], accompanied by a detailed companion paper in Physical Review D [Phys. Rev. D 106, 072012 (2022)]. This is an observation of a new category of hadronic matter, which is an important step forward in low energy QCD.



Observation of a charged scalar a0(1817)* in Charmed-strange meson Ds decay
The BESIII Collaboration recently reported the observation of an a0-like state with mass of 1.817 GeV/c2 in DS decays with the data sets collected at the center-of-mass energy region between 4.178 GeV and 4.226 GeV. The paper has been published online in Physical Review Letter. [Phys. Rev. Lett. 129, 182001 (2022)].

First evidence for the first neutral open-strange hidden-charm tetraquark state
The BESIII Collaboration recently reported the evidence of a new exotic multi-quark state, namely Zcs(3985)0. It is the neutral partner of the charged tetraquark Zcs(3985)+ observed in 2021 at BESIII. This is the first candidate of the neutral hidden-charm tetraquark with non-zero strangeness, which marks a new milestone in

Quarkonium(-like) spectroscopy, characterization of our player

The game levels within our reach:

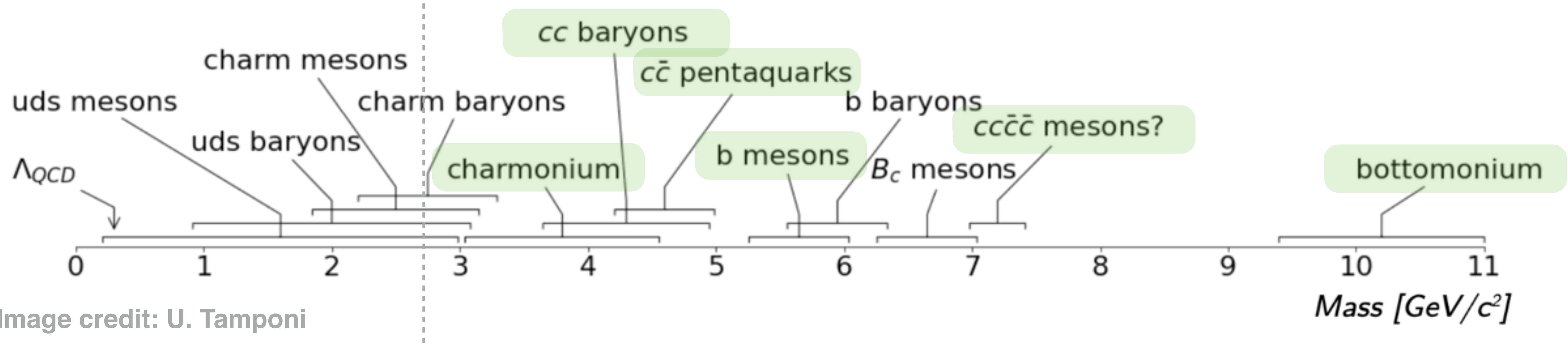


Image credit: U. Tamponi

Quarkonium(-like) spectroscopy, characterization of our player

The game levels within our reach:

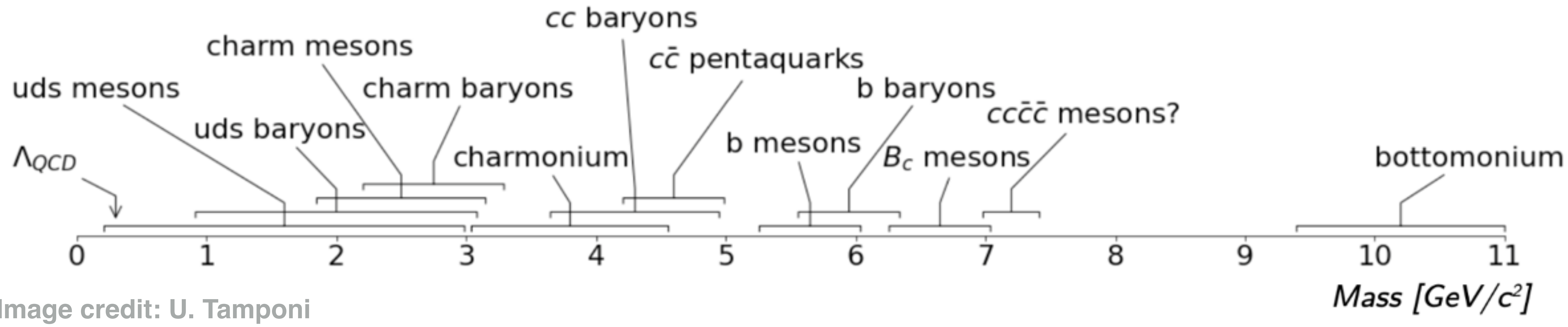
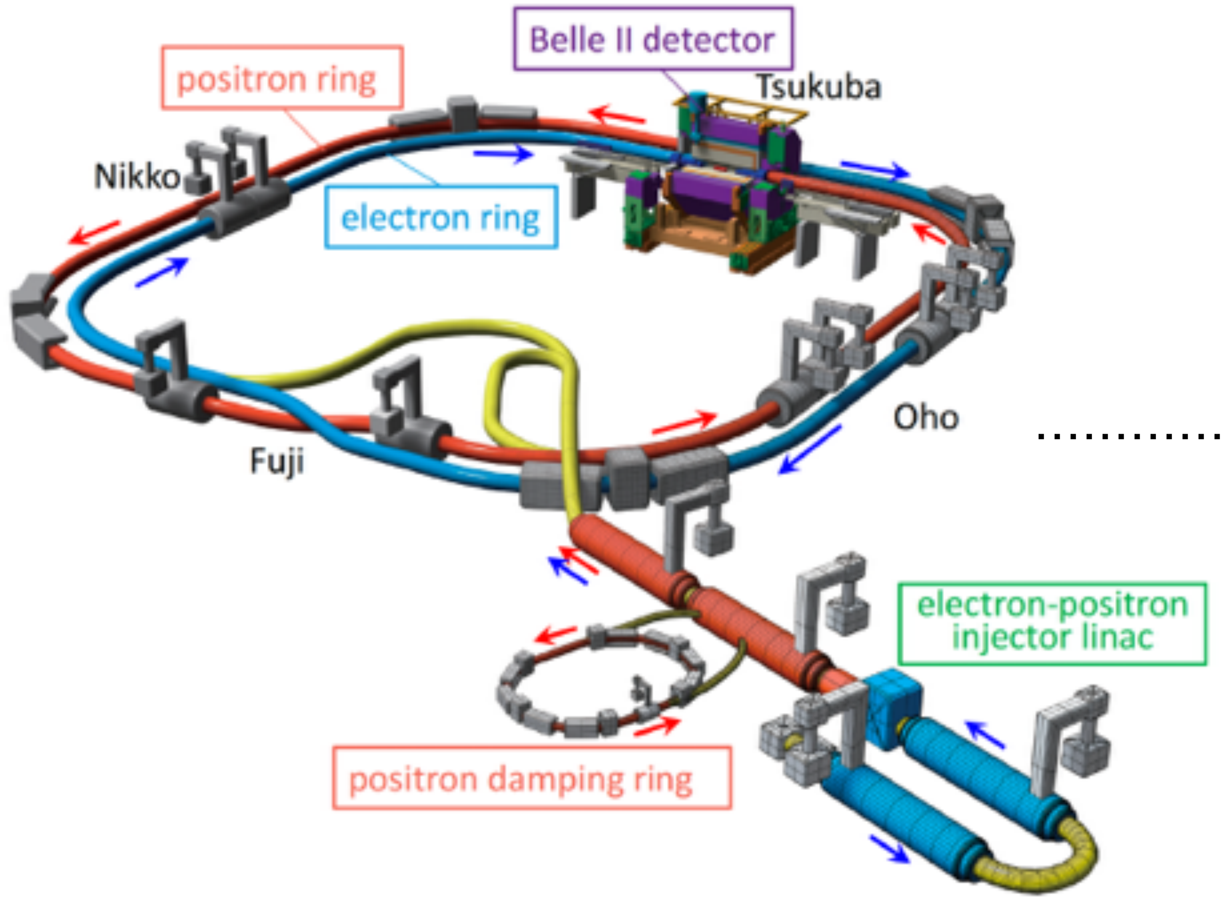
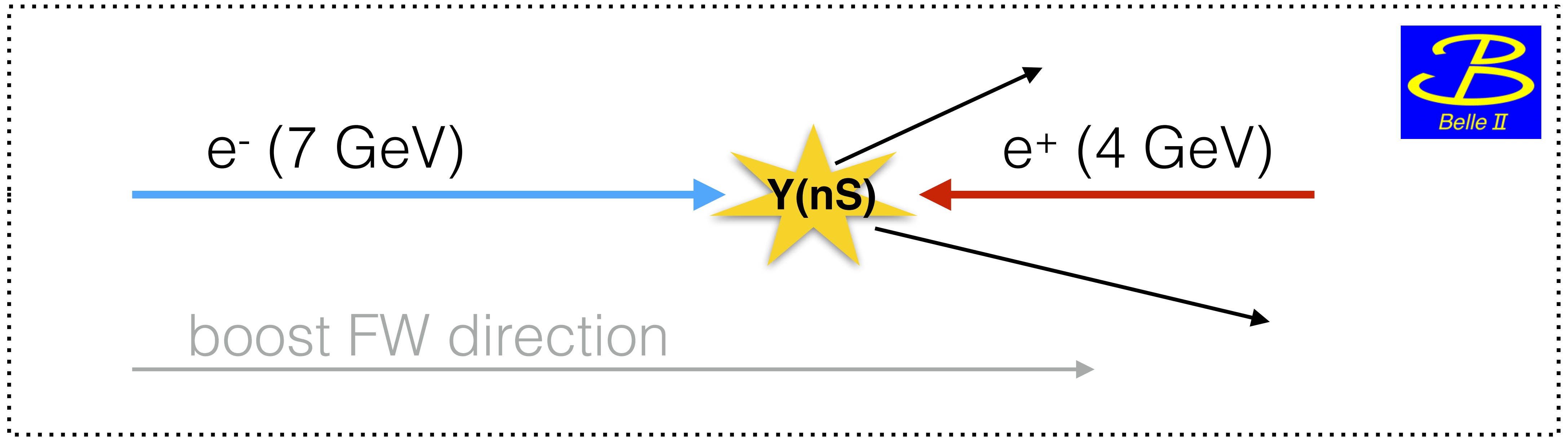


Image credit: U. Tamponi

Equipment:



E_{cm} ~ 10.58 GeV = M(Υ(4S))



Quarkonium(-like) spectroscopy, characterization of our player

The game levels within our reach:

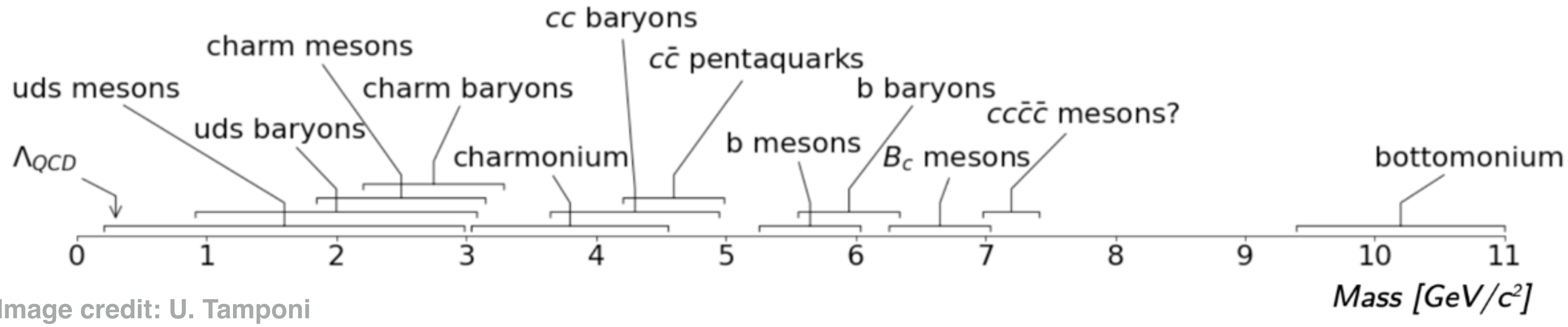
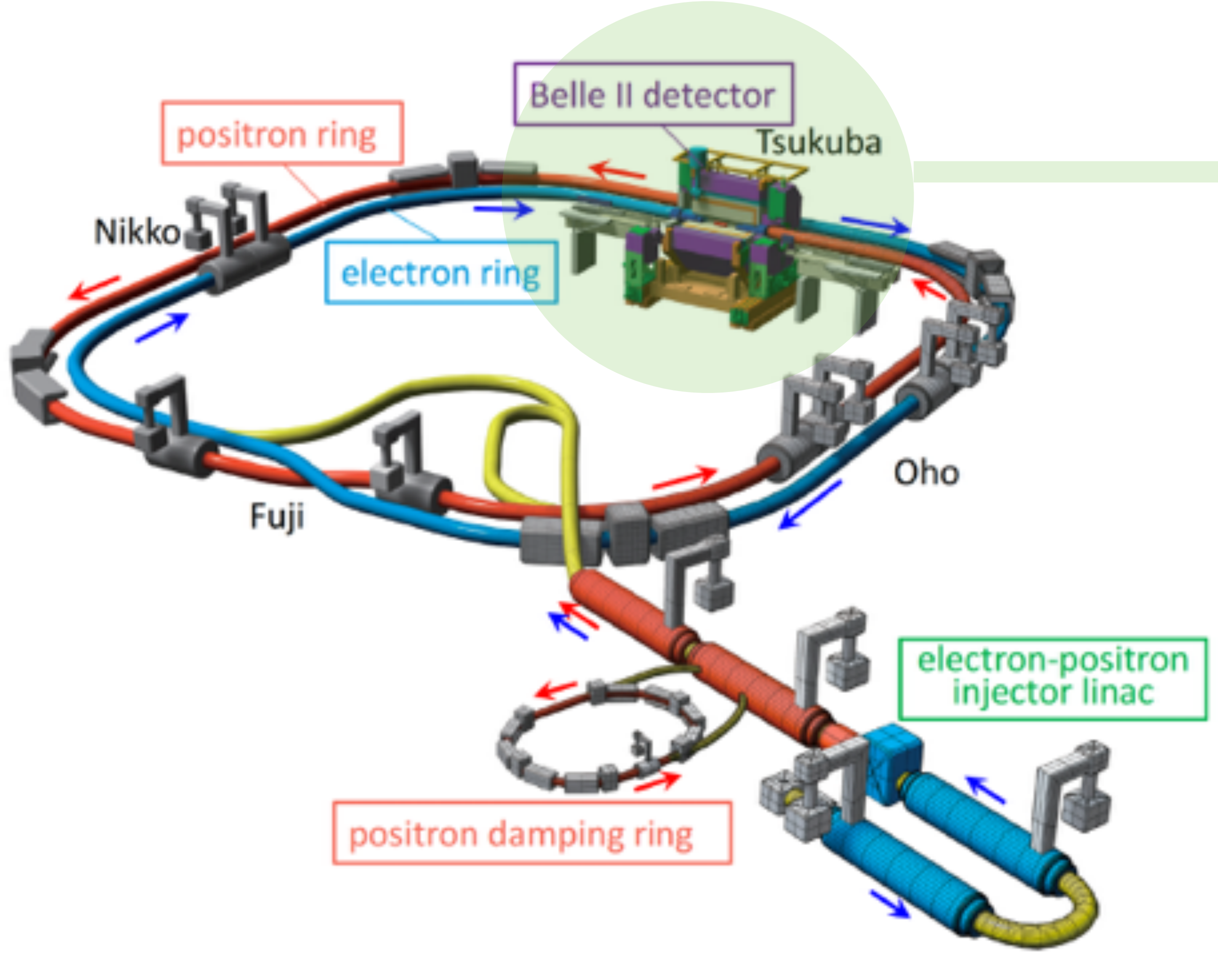
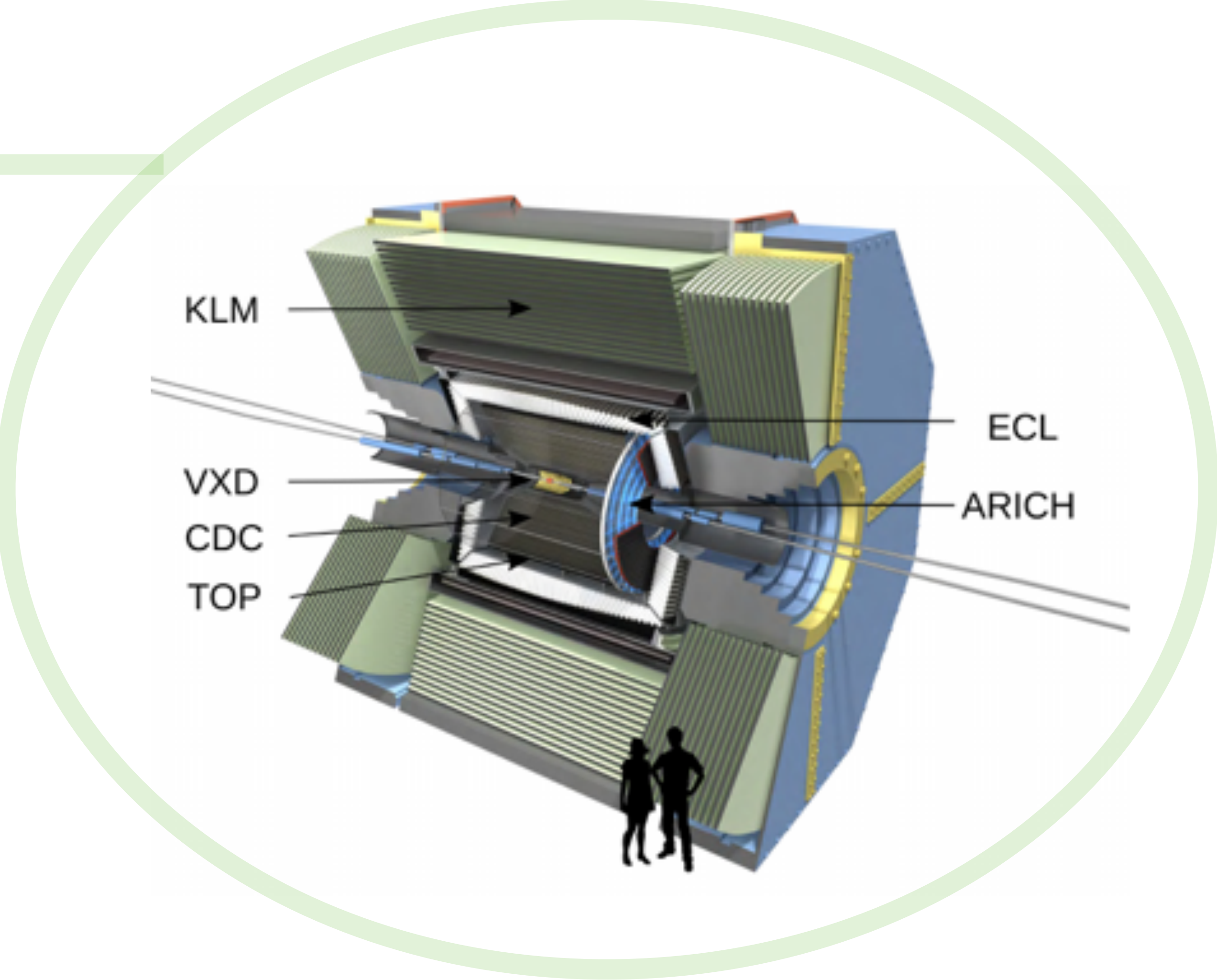


Image credit: U. Tamponi

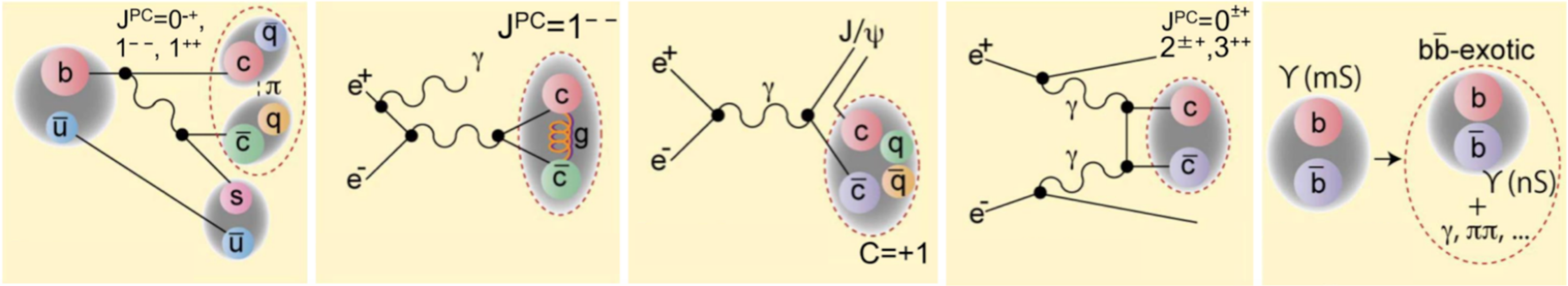
Equipment:





Quarkonium(-like) spectroscopy, characterization of our player

Best skill: variety of production mechanisms accessible



B decays

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

Initial State Radiation

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

Double charmonium

- Seen: J=0, $J^{PC} = 1^{--}$

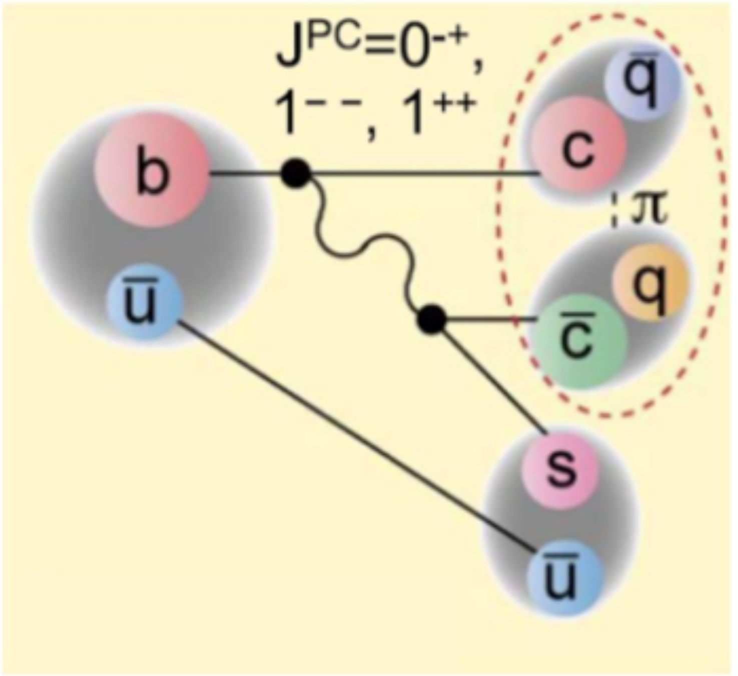
Two γ production

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

Change CM energy

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

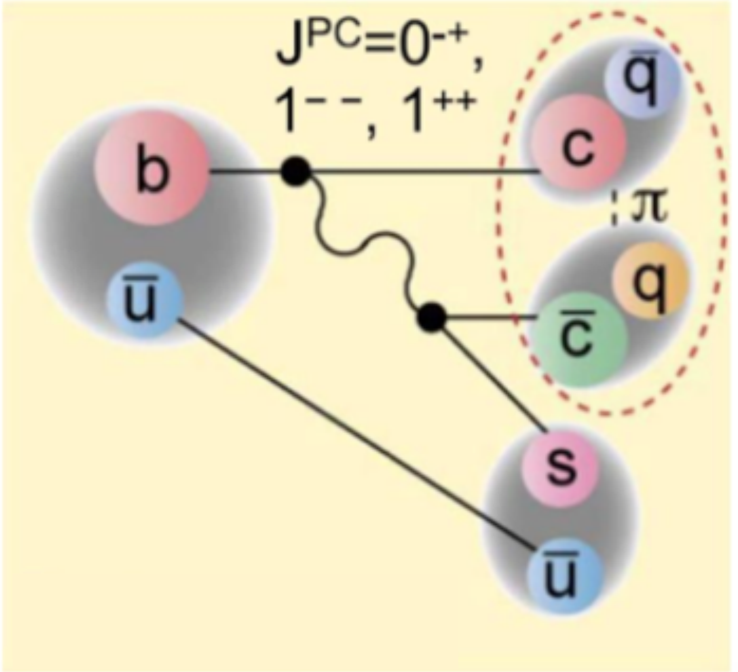
B decays



Rewards to be earned

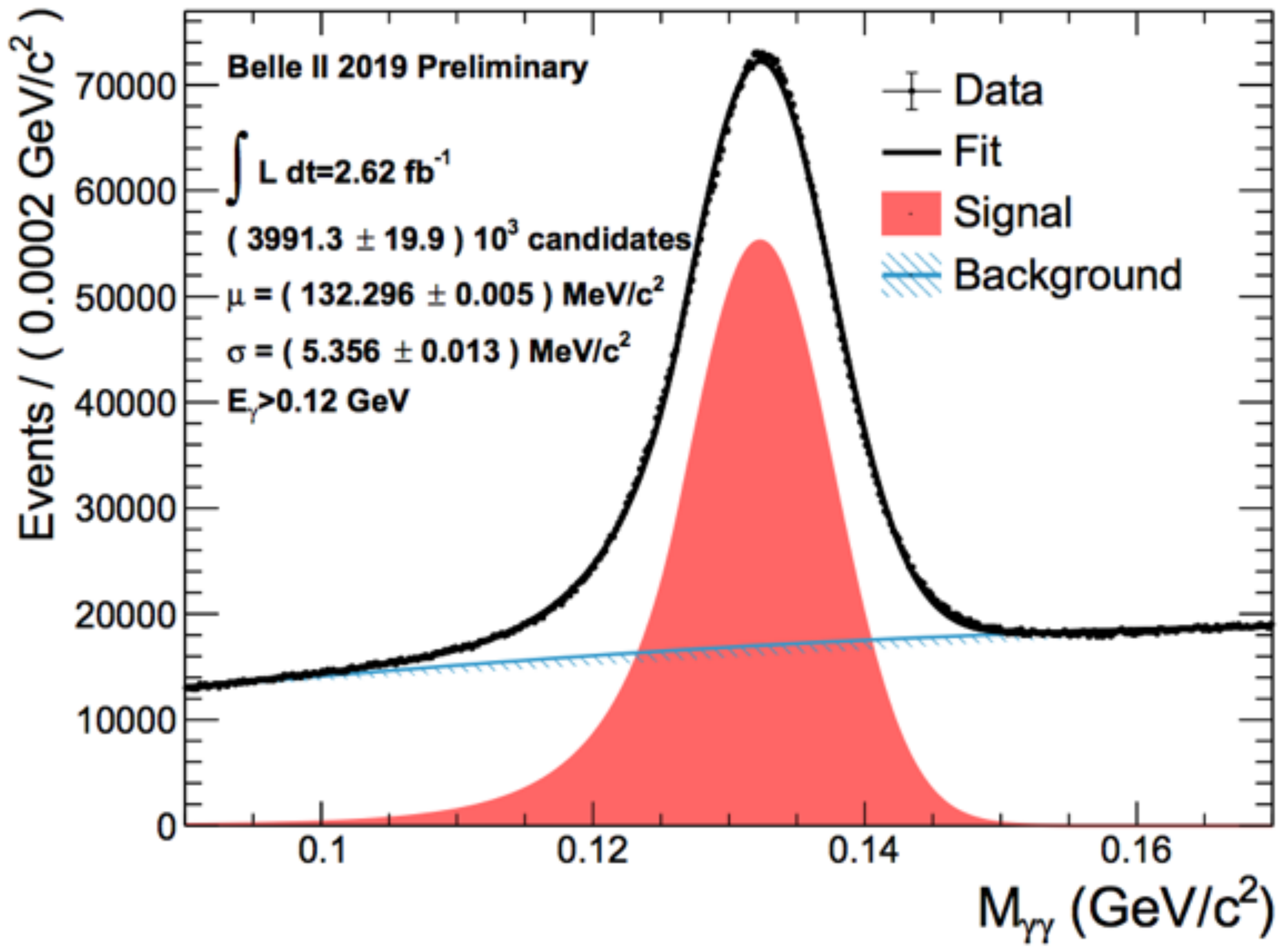
- All quantum numbers accessible
- Possibility of investigating the charged isospin partners (not many isospin triplets are complete)
- Of great interest for X states in particular

B decays



Rewards to be earned

- All quantum numbers accessible
- Possibility of investigating the charged isospin partners (not many isospin triplets are complete)
- Of great interest for X states in particular



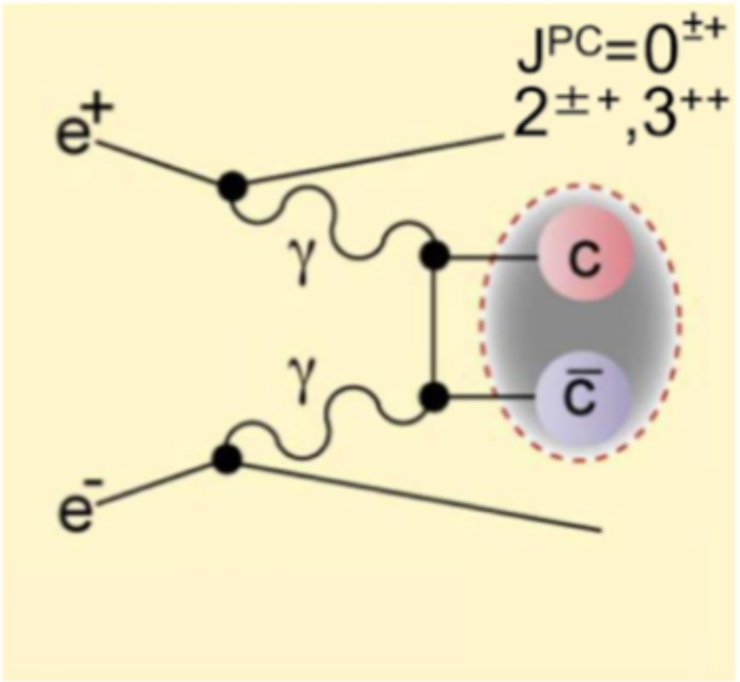
Main challenges / competitors

- Statistics

Belle II strengths

- Reconstruction of neutrals
- Possibility of inclusive studies via recoil exploiting the knowledge of the initial state

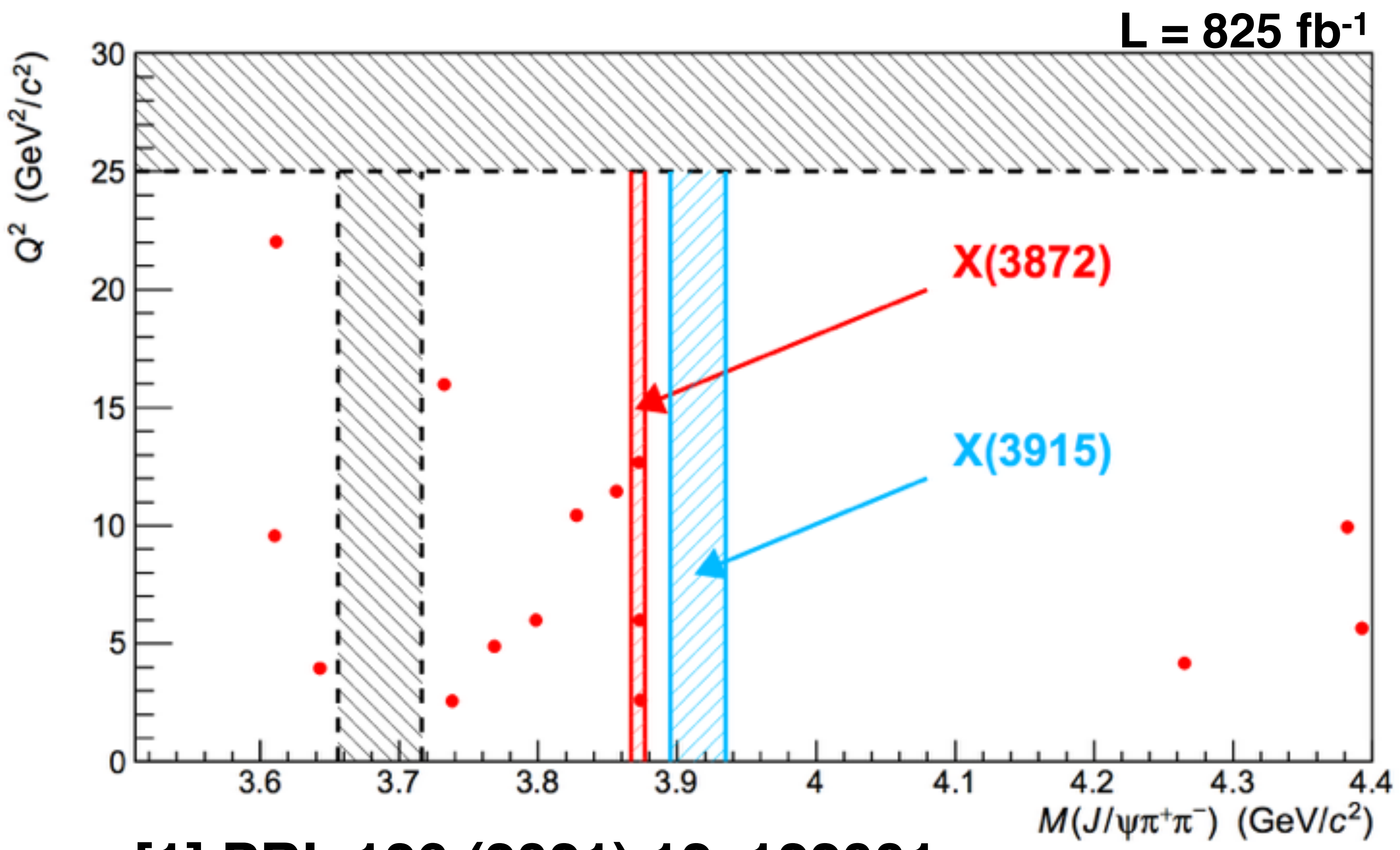
Two photon process



Rewards to be earned

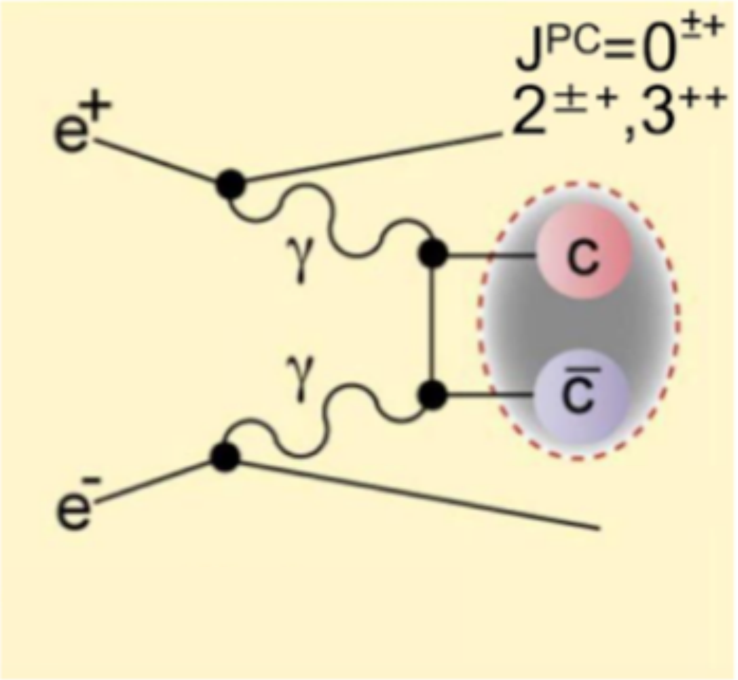
- J = 0, 2 accessible
- Possibilities in the exotic baryons sector (Θ^+, ..)
- Study the production of X(3872) in

  2-photon γ* γ processes (seen by Belle [1])



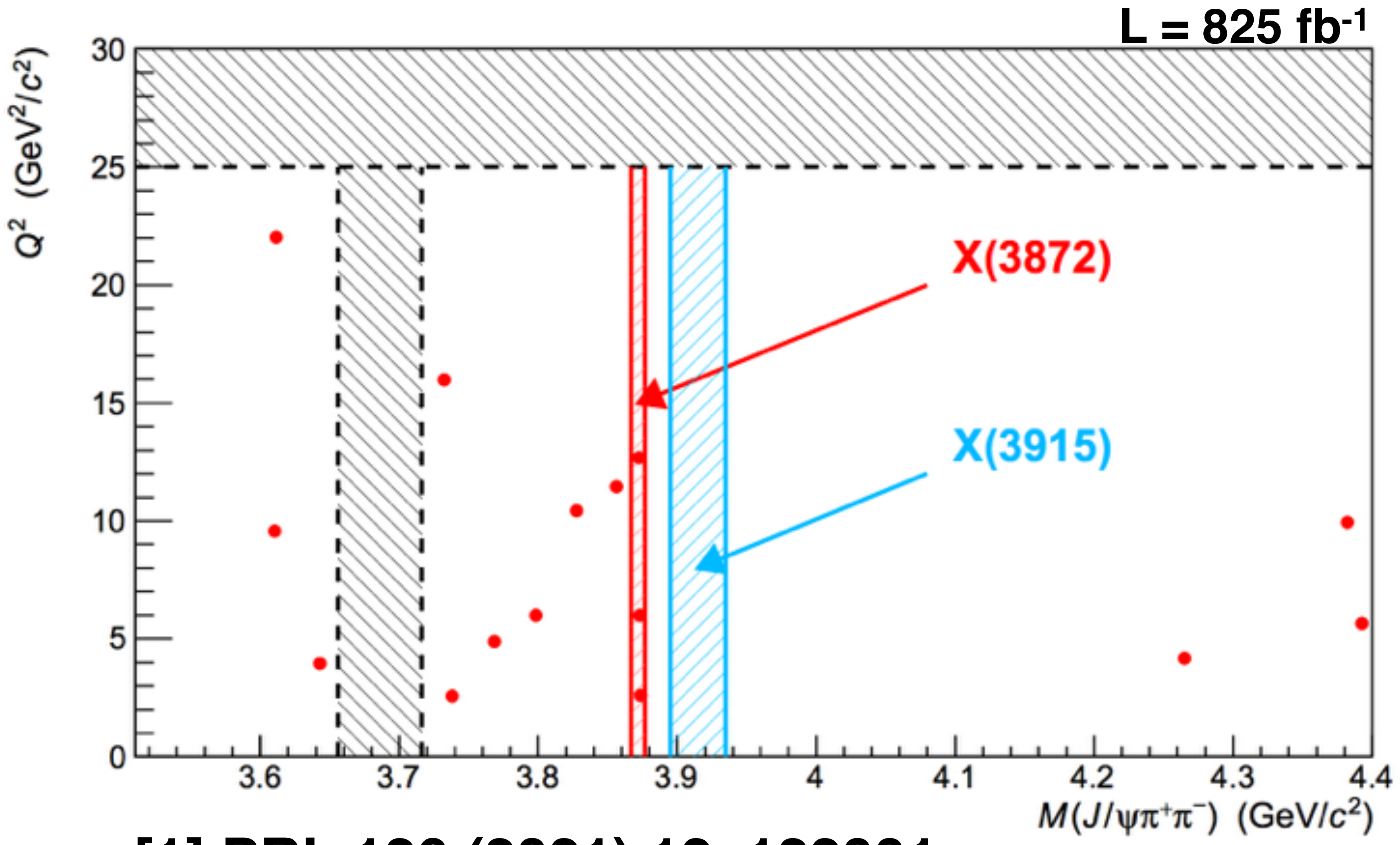
[1] PRL 126 (2021) 12, 122001

Two photon process



Rewards to be earned

- J = 0, 2 accessible
- Possibilities in the exotic baryons sector (Θ^+, ..)
- Study the production of X(3872) in 2-photon γ* γ processes (seen by Belle [1])



[1] PRL 126 (2021) 12, 122001

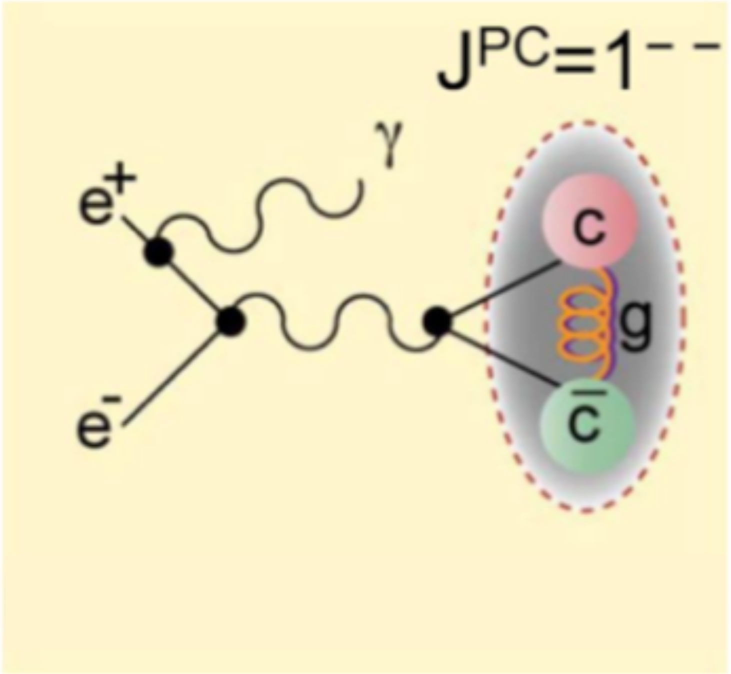
Main challenges / competitors

- BESIII

Belle II strengths

- Statistics (w/ full data sample)

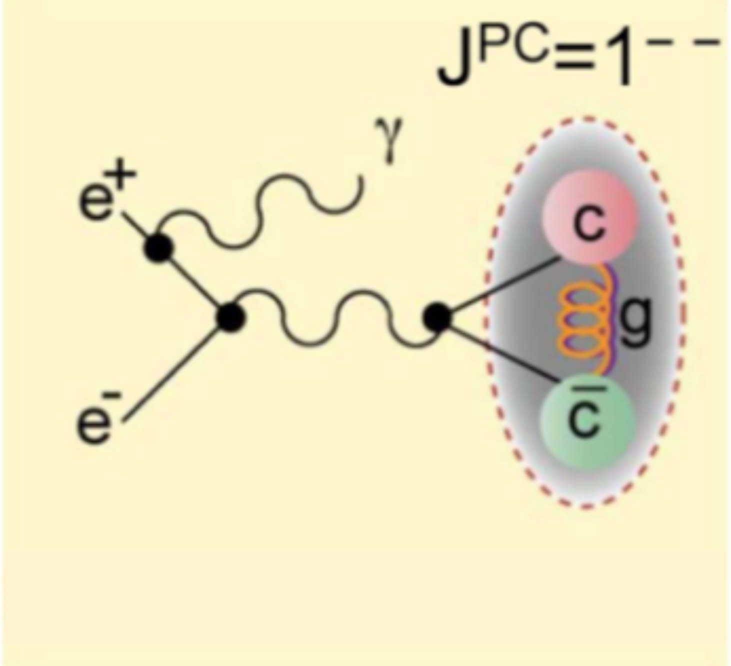
Initial State Radiation



Rewards to be earned

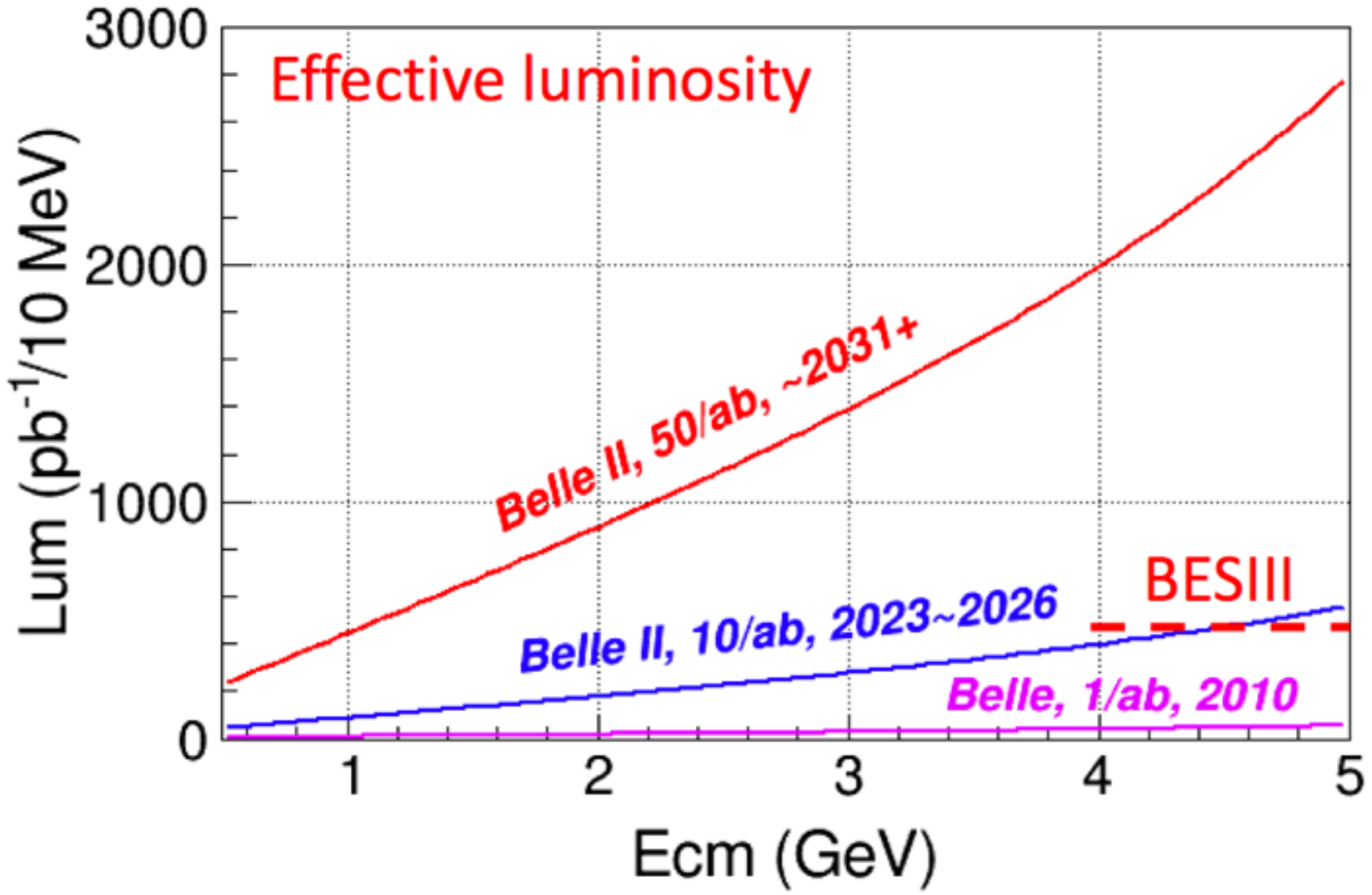
- Vectorial states 1^{--} accessible
- Fully exploit charmonium region “for free”
- Measurements of hadronic cross sections
- Opportunity to confirm BESIII results

Initial State Radiation



Rewards to be earned

- Vectorial states 1^{--} accessible
- Fully exploit charmonium region “for free”
- Measurements of hadronic cross sections
- Opportunity to confirm BESIII results



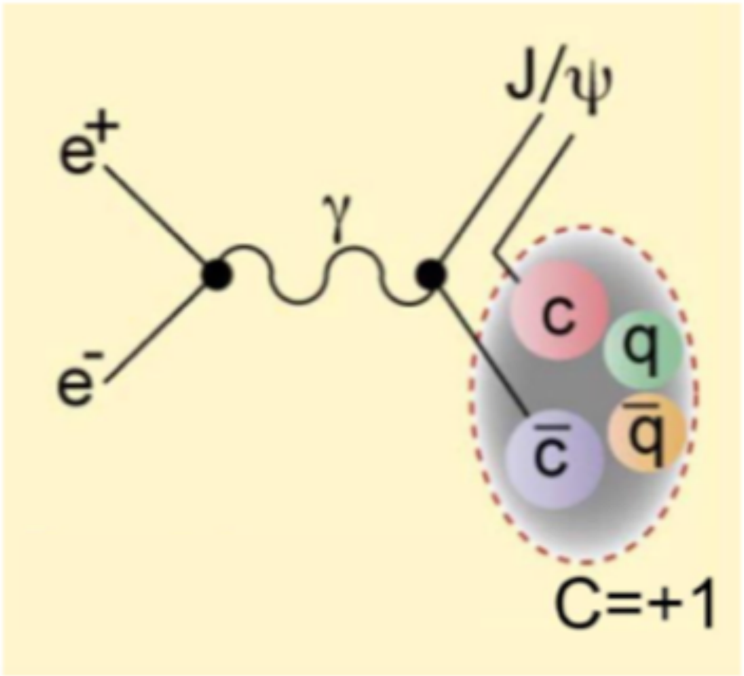
Main challenges / competitors

- BESIII

Belle II strengths

- Two strategies to exploit: (non-)tagged ISR γ
- The region above ~5 GeV is not accessible to BESIII
- Good capabilities of reconstructing γ (especially hard γ)

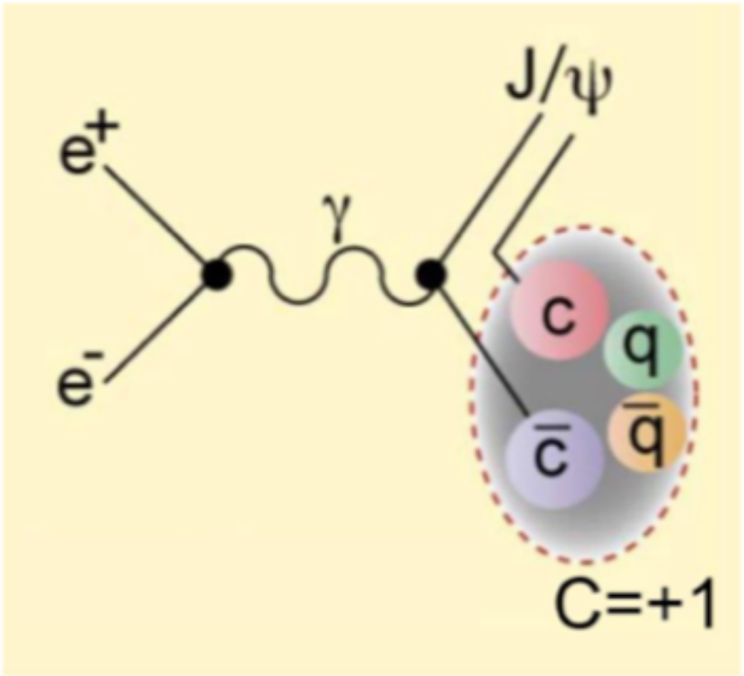
Double charmonium production



Rewards to be earned

- Production of 4 quark c ➞ linked to one of the hot topics of the moment: T_{cccc}
- Search for vector T_{cccc} , double charm baryon production
- Compare cross sections of double charmonium VS charmonium+$D\bar{D}$ VS double $D\bar{D}$

Double charmonium production



Rewards to be earned

- Production of 4 quark c → linked to one of the hot topics of the moment: T_{cccc}
- Search for vector T_{cccc} , double charm baryon production
- Compare cross sections of double charmonium VS charmonium+$D\bar{D}$ VS double $D\bar{D}$

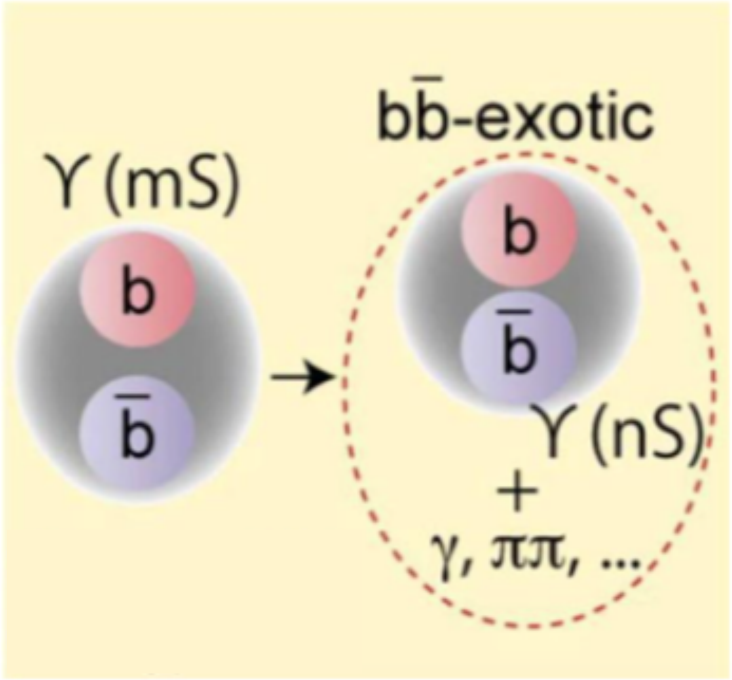
Main challenges / competitors

- Unique position!

Belle II strengths

- Statistics

Change CM energy

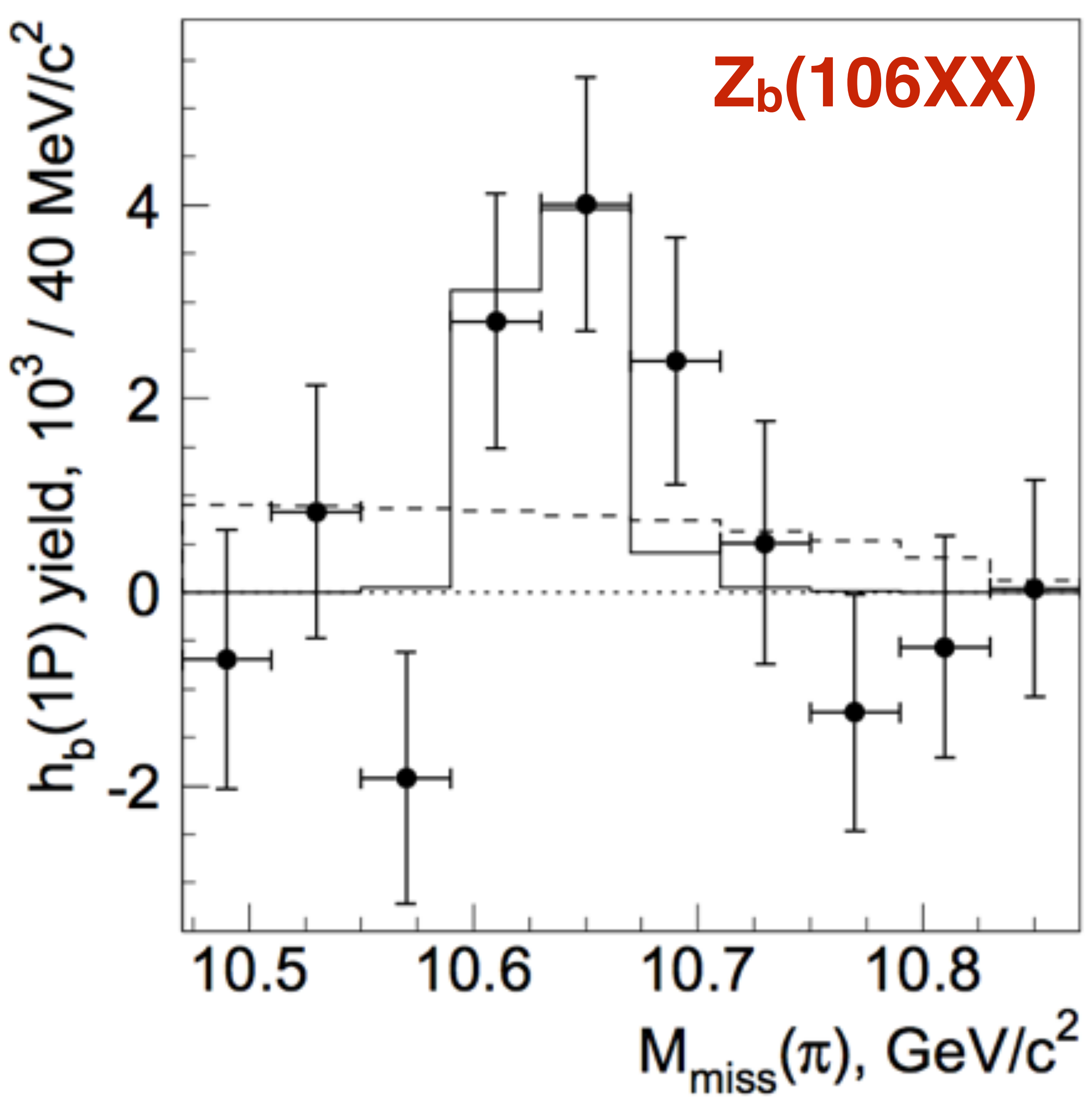


Rewards to be earned

- Investigate $Z_b(10610)$ and $Z_b(10650)$
- Investigate Υ(10750)
- (BSM) LFV, LFU searches
- (BSM) Υ(1S) → invisible w/ dipion tag

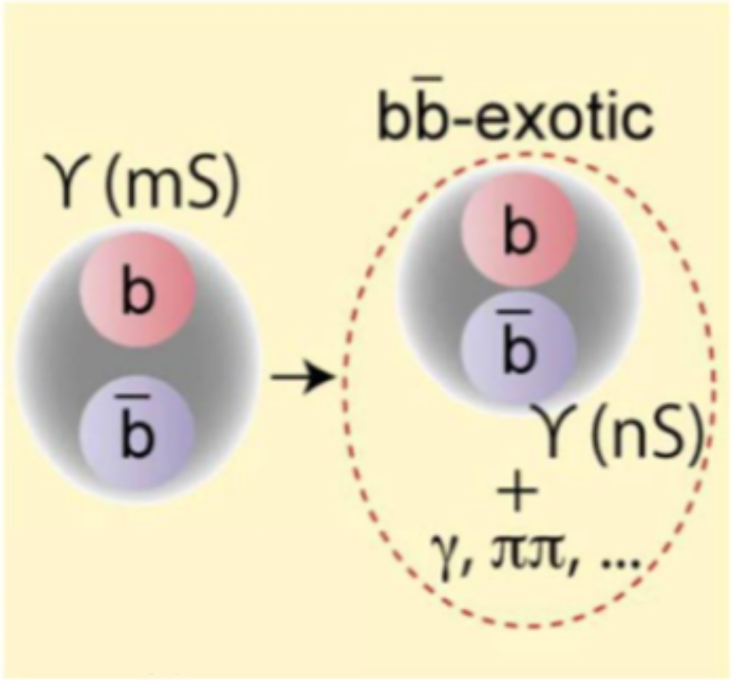
Above Υ(4S)

Below Υ(4S)



PRL 117, 142001 (2016)

Change CM energy

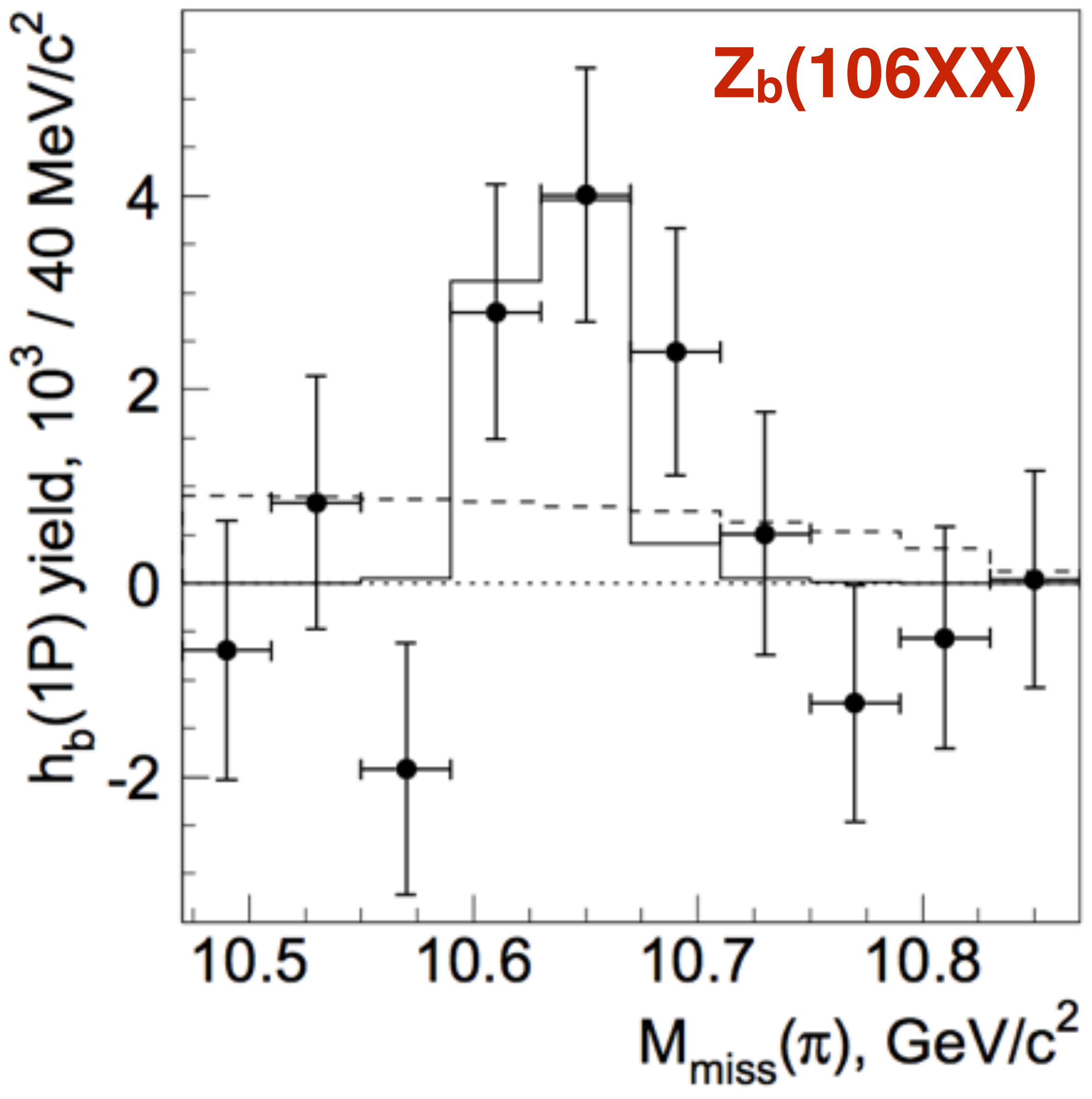


Rewards to be earned

- Investigate Z_b(10610) and Z_b(10650)
- Investigate Υ(10750)
- (BSM) LFV, LFU searches
- (BSM) Υ(1S) → invisible w/ dipion tag

Above Υ(4S)

Below Υ(4S)



PRL 117, 142001 (2016)

Main challenges / competitors

- Unique position!

Belle II strengths

- we can “sit” directly on interesting energies and collect data there
- η_b and h_b in recoil

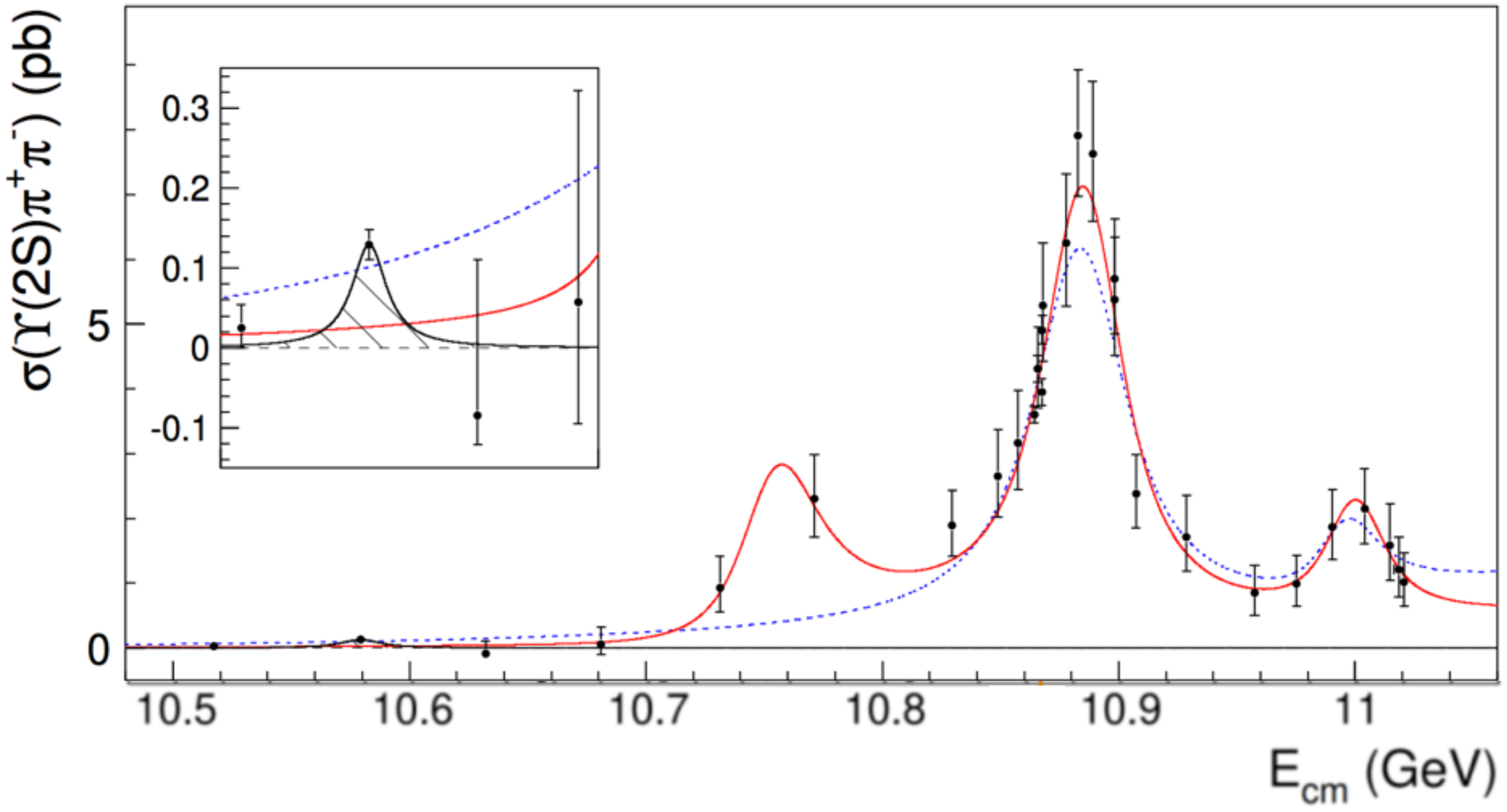
First experience points!

Unique dataset at 10.75 GeV!

Data collected at 4 energy points around 10.75 GeV (nov 2021)

- Key to understand the nature of Υ(10750) [1]

[1] JHEP 10, 220 (2019)



- Its nature generated considerable theoretical debate (conventional bottomonium, hybrid, tetra quark state)

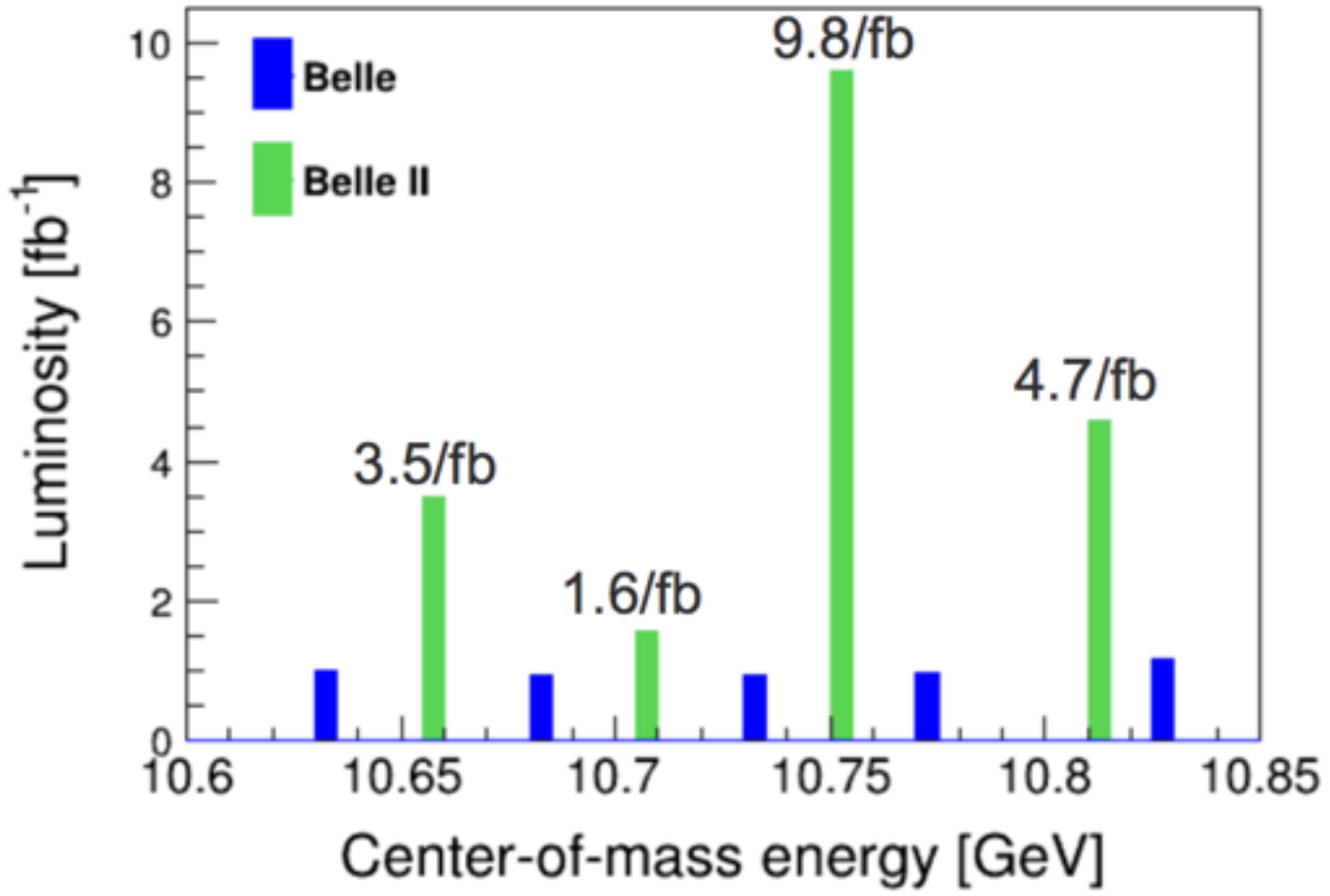
- Predicted to decay into $\omega\,\chi_{bJ}$ with BF of 10^{-3} based on an interpretation ad admixture of the conventional 4S and 3D states

First experience points!

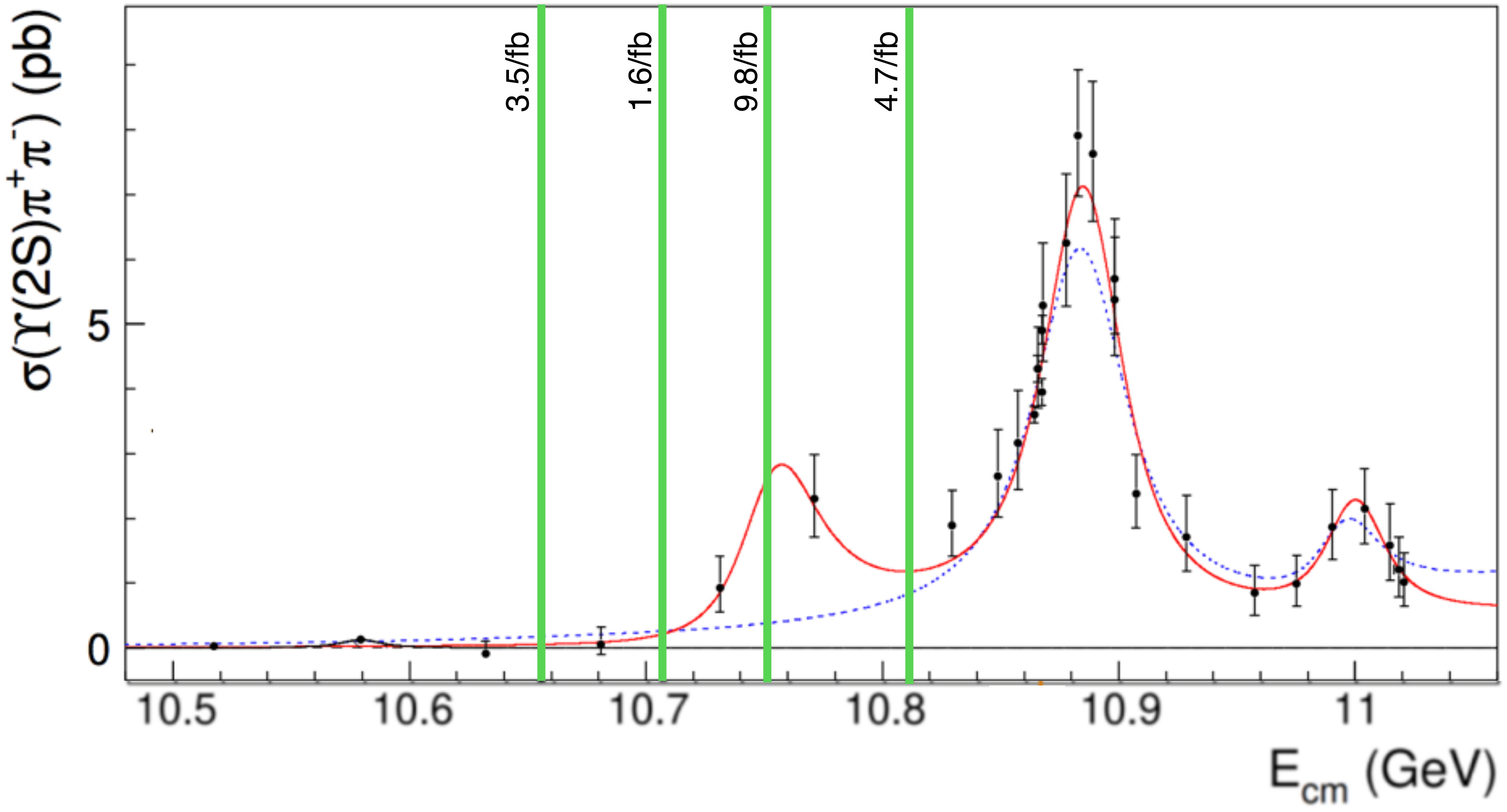
Unique dataset at 10.75 GeV!

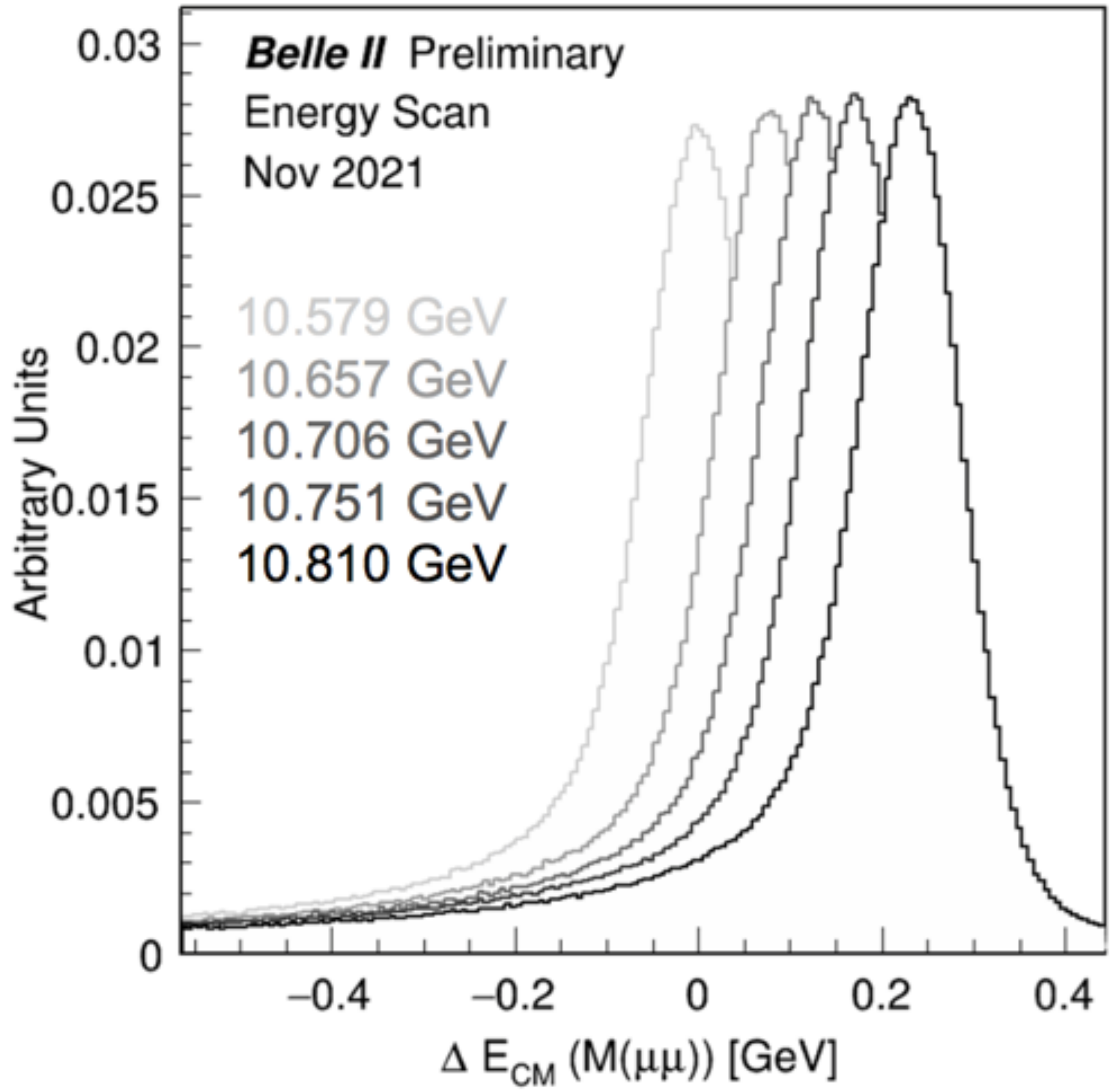
Data collected at 4 energy points around 10.75 GeV (nov 2021)

- Key to understand the nature of Υ(10750) [1]



[1] JHEP 10, 220 (2019)





First experience points!

arXiv:2208.13189

Unique dataset at 10.75 GeV!

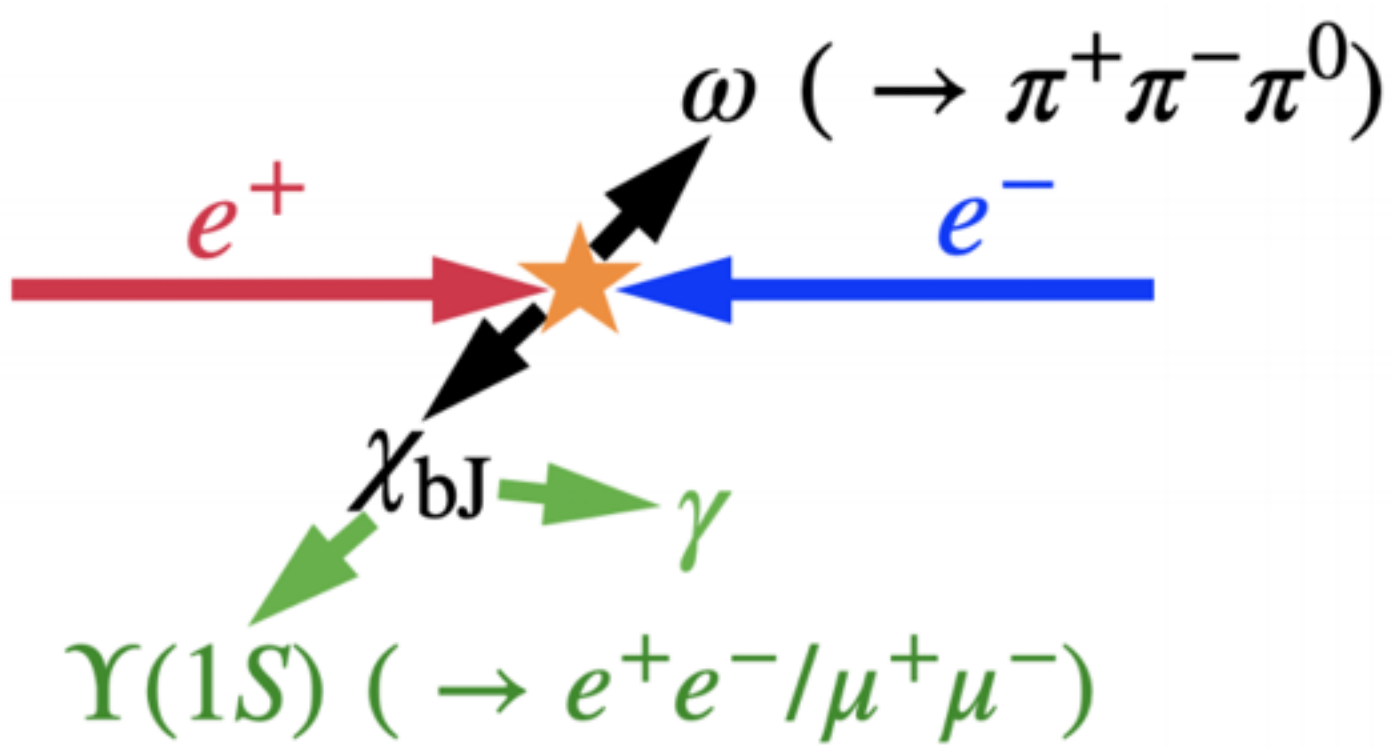
$e^+e^- \rightarrow \omega\, \chi_{bJ}$

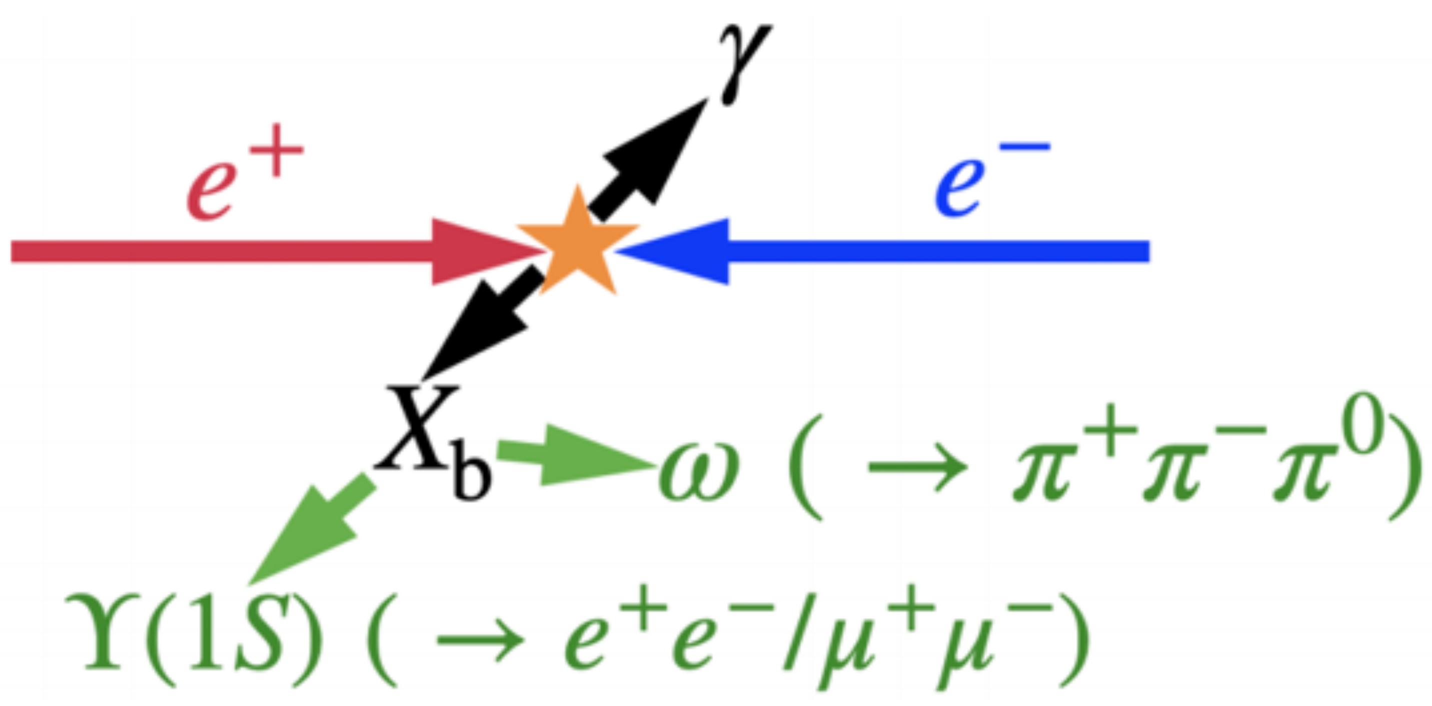
- Determine the Born cross section for $e^+e^- \rightarrow \omega\, \chi_{bJ}$ using unique scan data samples at $\sqrt{s}$ = 10.701, 10.745 and 10.805 GeV
- Study the energy dependence cross section of $e^+e^- \rightarrow \omega\, \chi_{bJ}$ by combining with Belle data at $\sqrt{s}$ = 10.867

$e^+e^- \rightarrow \gamma\, X_b$

- Search for the X_b using the unique data scan samples at 10.701, 10.745 and 10.805 GeV

X_b: posited bottomonium counterpart of X(3872)

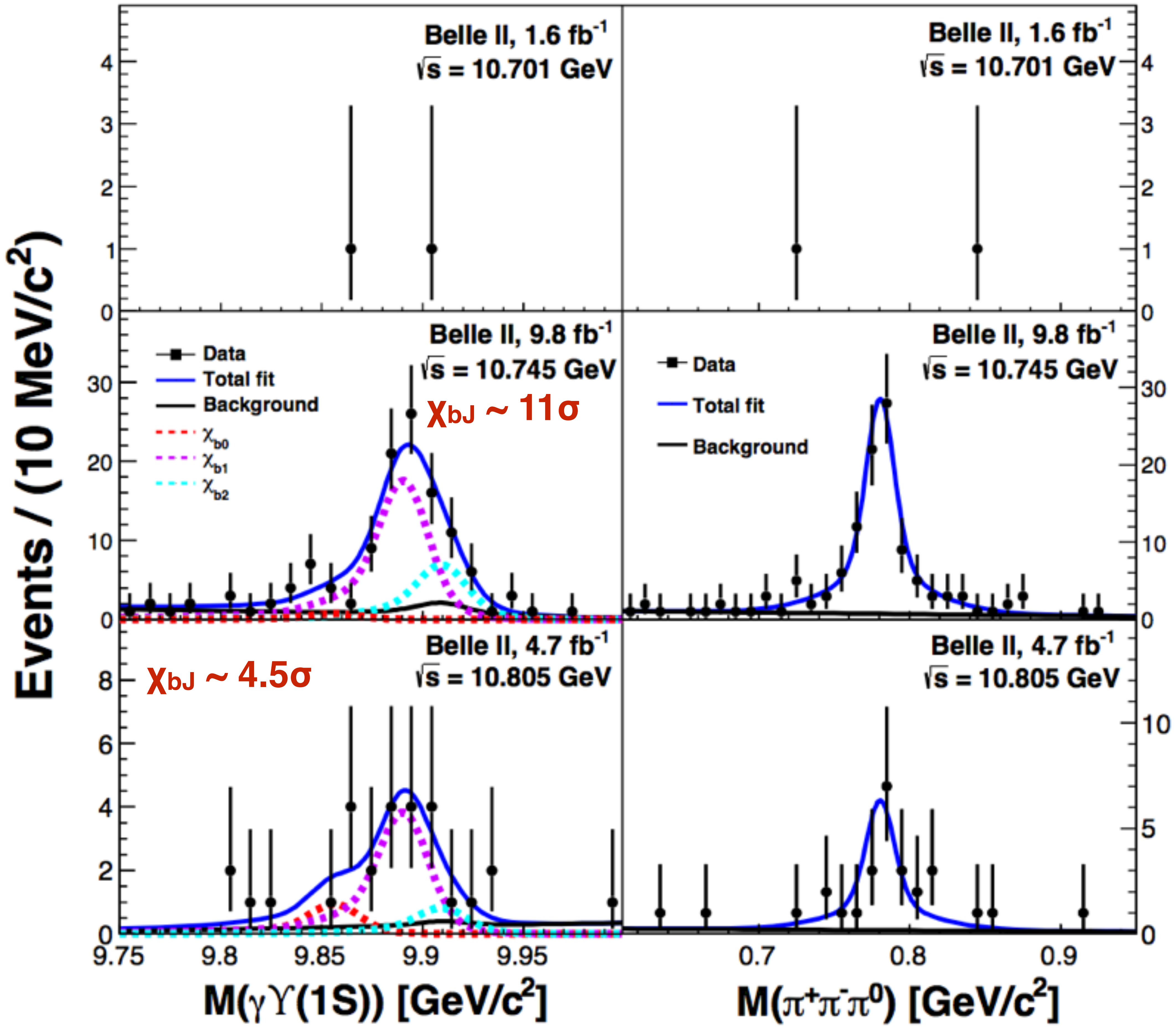




First experience points!

arXiv:2208.13189

Observation of $e^+e^- \to \omega\, \chi_{bJ}$



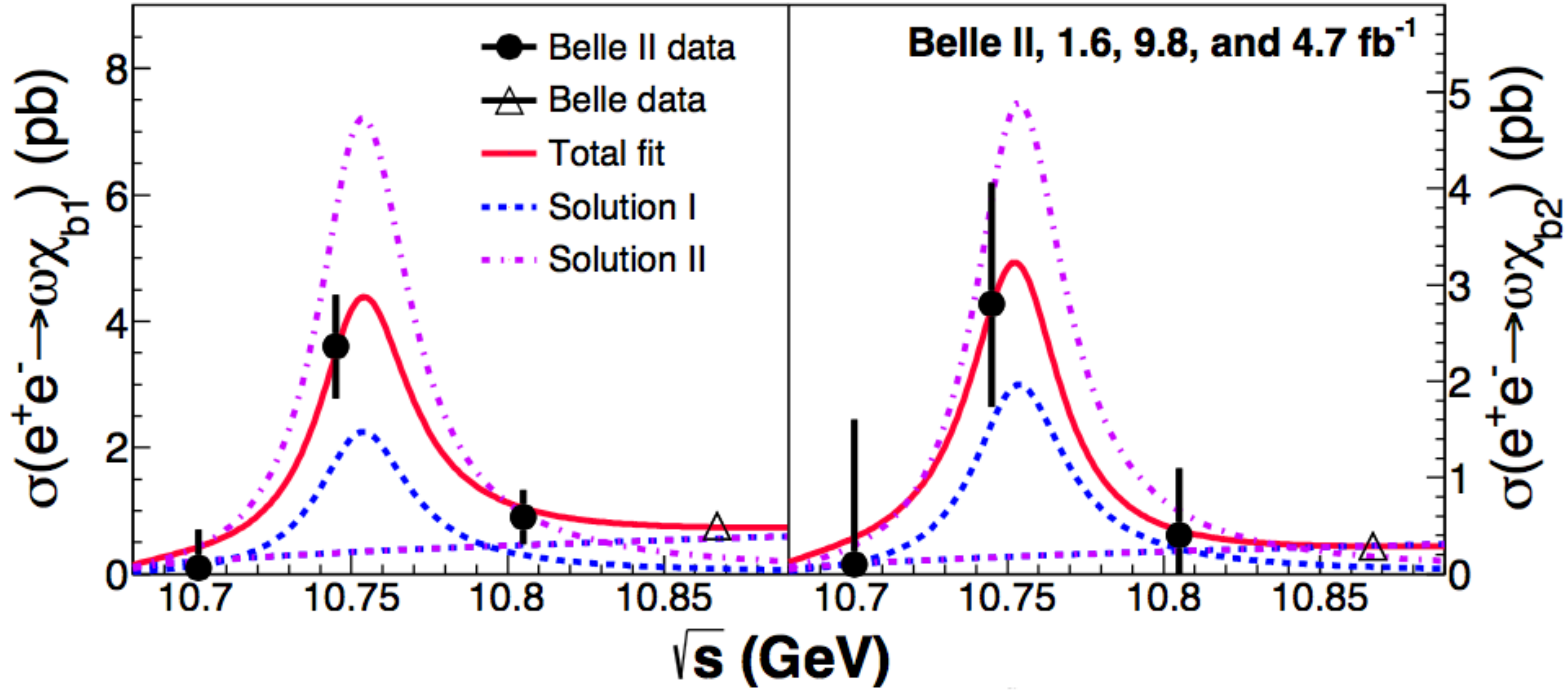
Two dimensional unbinned maximum likelihood fit to M(γ Υ(1S)) versus M ($\pi^+ \pi^- \pi^0$)

Channel	√s [GeV]	N_{sig}	$\sigma_B^{(up)}$ [pb]
$e^+e^- \to \omega\chi_{b1}$	10.745	$68.9^{+13.7}_{-13.5}$	$3.6^{+0.7}_{-0.7}$ (stat)±0.4(sys)
$e^+e^- \to \omega\chi_{b2}$		$27.6^{+11.6}_{-10.0}$	$2.8^{+1.2}_{-1.0}$ (stat)±0.5(sys)
$e^+e^- \to \omega\chi_{b1}$	10.805	$15.0^{+6.8}_{-6.2}$	1.6 @ 90% C.L.
$e^+e^- \to \omega\chi_{b2}$		$3.3^{+5.3}_{-3.8}$	1.5 @ 90% C.L.

First experience points!

arXiv:2208.13189

Observation of Υ(10753) → $\omega\ \chi_{bJ}$



$\Gamma_{ee}\ B_f$	Solution I	Solution II
Υ(10753) → $\omega\chi_{b1}$	$(0.63 \pm 0.39_{stat} \pm 0.20_{sys})$ eV	$(2.01 \pm 0.38_{stat} \pm 0.76_{sys})$ eV
Υ(10753) → $\omega\chi_{b2}$	$(0.53 \pm 0.46_{stat} \pm 0.15_{sys})$ eV	$(1.32 \pm 0.44_{stat} \pm 0.55_{sys})$ eV

$\sigma(e^+e^- \to \omega\ \chi_{b1,2})$ peak at Υ(10753)

No obvious peak at Υ(10860)

- Combined with Belle measurement at $\sqrt{s}$ = 10.867 [1]
- Fit with a coherent sum of two-body phase space and a BW function

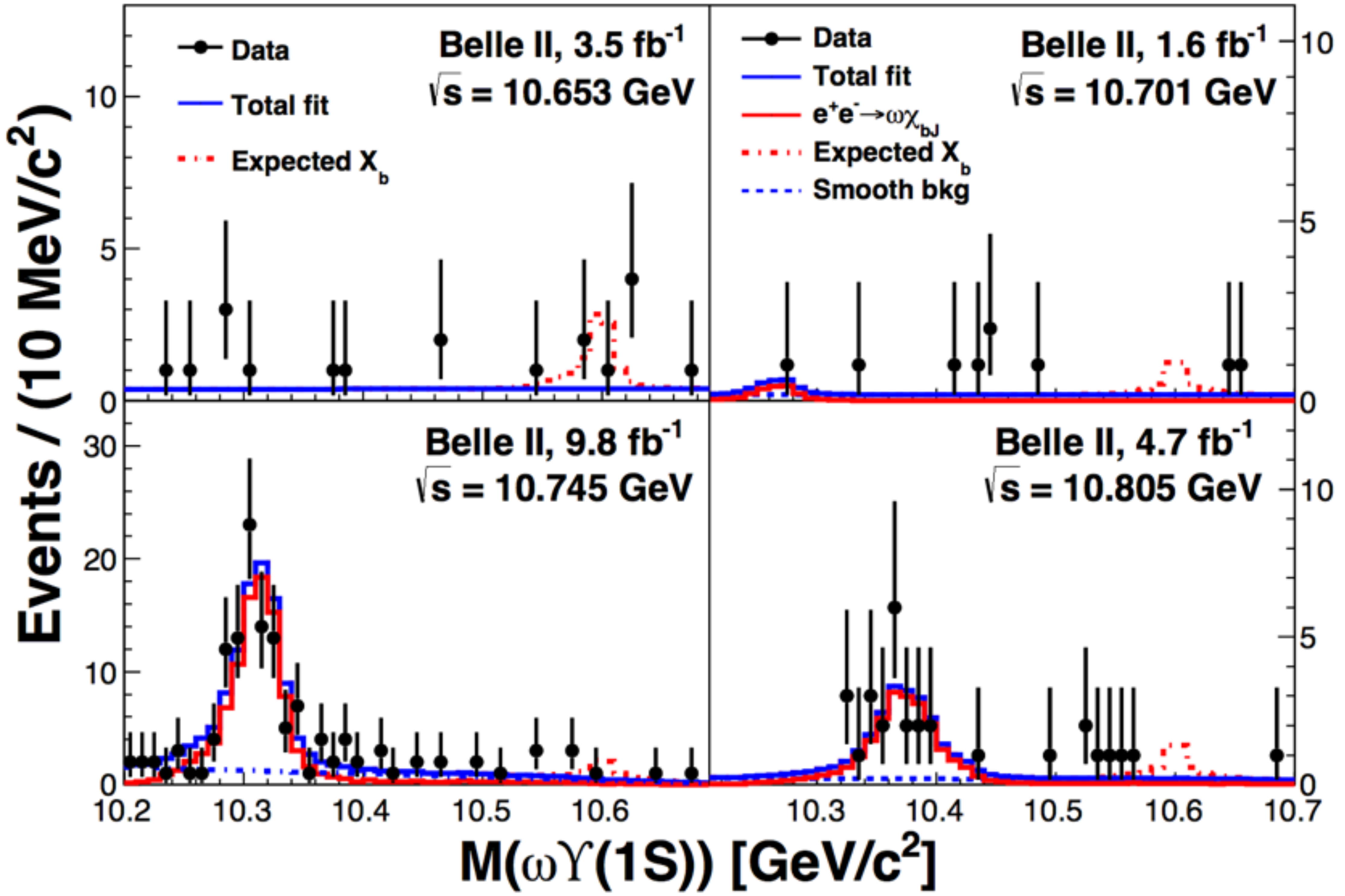
$$\mathrm{BW}(\sqrt{s}) = \frac{\sqrt{12\pi\Gamma_{ee}\mathcal{B}_f\Gamma}}{s - M^2 - iM\Gamma}\sqrt{\frac{\Phi_2(\sqrt{s})}{\Phi_2(M)}},$$

[1] PRL 113, 142001 (2014)

First experience points!

arXiv:2208.13189

Search for X_b



No significant X_b observed

Peaks: reflections of $e^+e^- \to \omega\, \chi_{bJ}$

Expected X_b

- Simulated events with $M(X_b)$=10.45 to 10.65 GeV

Upper limits at 90% C.L. on the production cross-section times BF, $\sigma_{X_b}^{UL}$

$\sqrt{s}$ (GeV)	M_{X_b} (GeV/c^2)	N^{UL}	ε	$\lvert 1-\Pi \rvert^2$	$1+\delta_{ISR}$	Syst (%)	$\sigma^{UL}_{X_b}$ (pb)
10.653	10.59	10.0	0.154	0.931	0.72	8.7	0.55
10.701	10.45	8.1	0.166	0.931	0.76	8.7	0.84
10.745	10.45	8.1	0.164	0.931	0.78	8.7	0.14
10.805	10.53	10.7	0.165	0.932	0.81	8.8	0.37

(Only least stringent bound reported)

Summary

Multiplayer game of spectroscopy is a thriving environment that is constantly developing and is a perfect ground for new discoveries

More data (and more players) are important to pass the various levels of the game

Player “B2” just joined the game **arXiv:2208.13189**

It can make a significant impact in spectroscopy

Summary

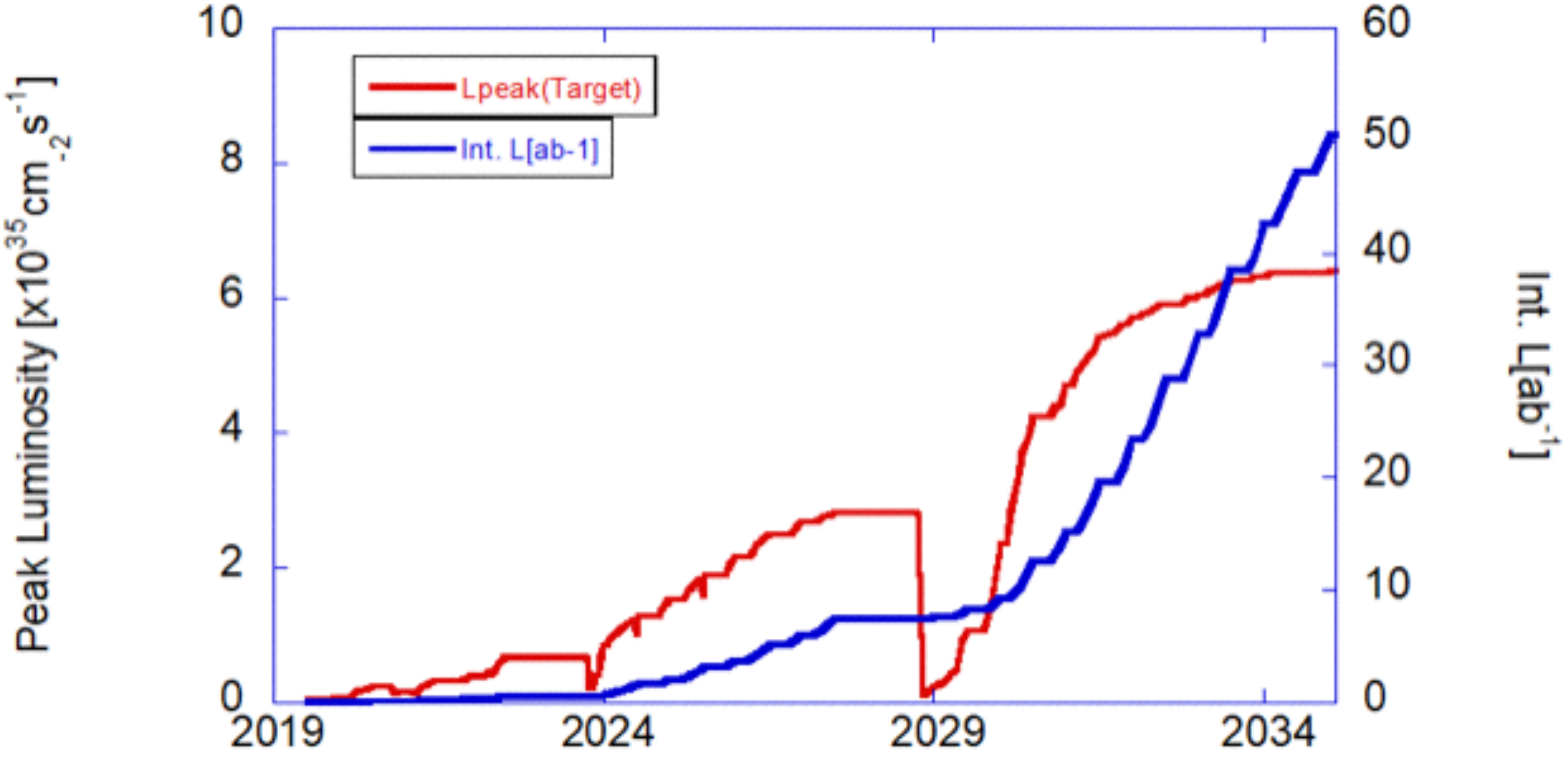
- Multiplayer game of spectroscopy is a thriving environment that is constantly developing and is a perfect ground for new discoveries
- More data (and more players) are important to pass the various levels of the game
- Player "B2" just joined the game **arXiv:2208.13189**
- It can make a significant impact in spectroscopy

Thank you for the attention
and stay tuned!

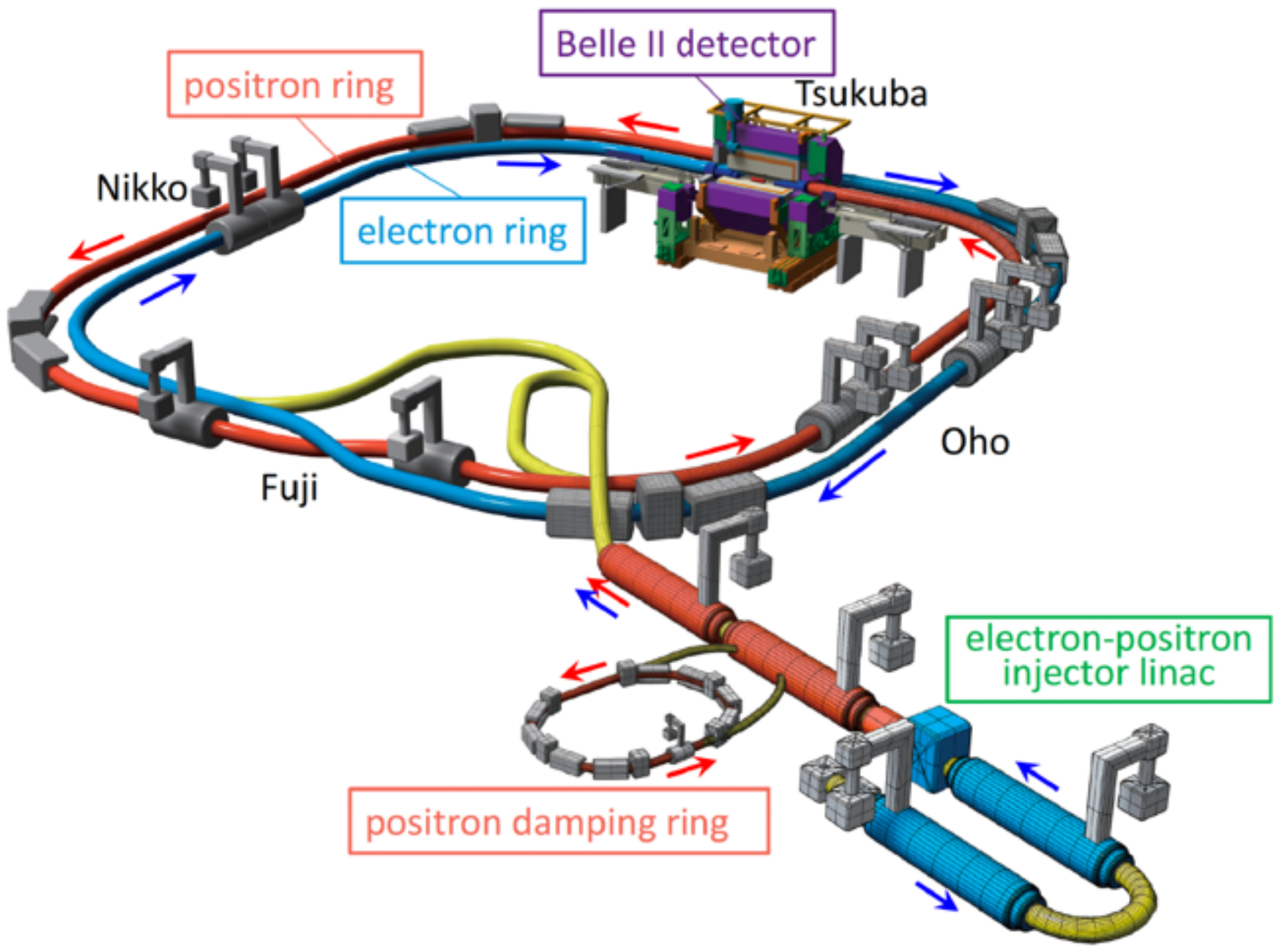
PRESS
START

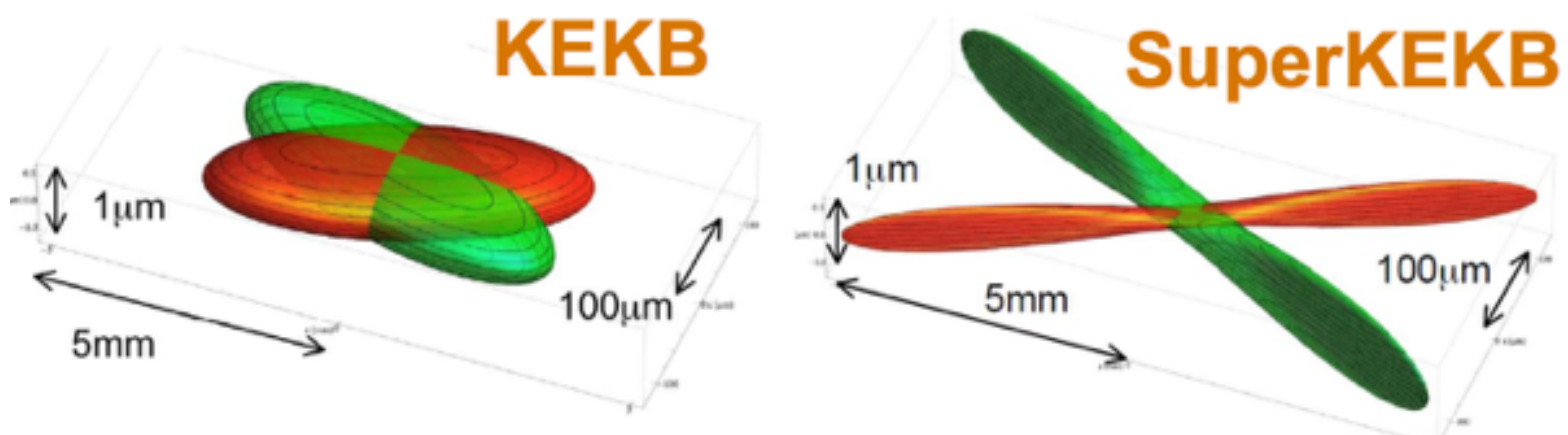
Additional material

Belle II, luminosity projection



SuperKEKB





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

Nucl. Instrum. Meth. A, vol 499, pp. 1-7, 2018

	KEKB LER (e^+) / HER (e^-)	SuperKEKB LER (e^+) / HER (e^-)
E [GeV]	3.5 / 8.0	4.0 / 7.0
2ϕ [mrad]	22	83
ξ_x	0.127 / 0.102	0.0028 / 0.0012
ξ_y	0.129 / 0.090	0.088 / 0.081
β_y^*	5.9 / 5.9	0.27 / 0.30
I [A]	1.64 / 1.19	3.60 / 2.60
σ_x^* [μm]	147 / 170	10.1 / 10.7
σ_y^* [nm]	940 / 940	48 / 62
$\mathcal{L}$ [10^{35} cm^{-2} s^{-1}]	0.211	8
$\int \mathcal{L}$ dt[ab$^-1$]	1	50

Belle II

Tracking detectors

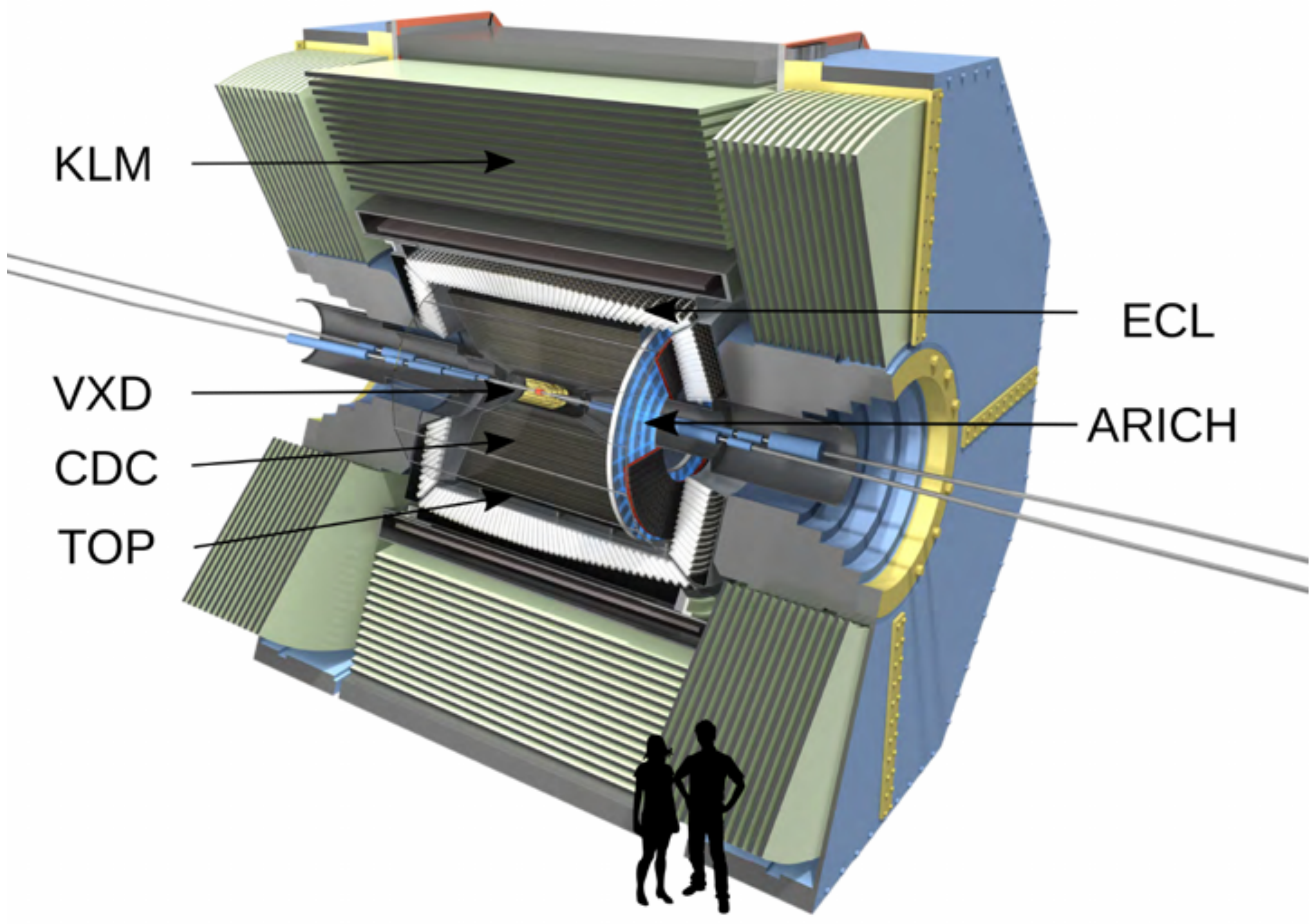
- VerteX Detector (VXD)
  - PiXel Detector (PXD, 2 layers)
  - Silicon Vertex Detector (SVD, 4 layers)
- Central Drift Chamber (CDC)

Particle identification subsystems

- Time Of Propagation (TOP) counter (central region)
- Aerogel Ring-Imaging CHerenkov (ARICH, forward region)

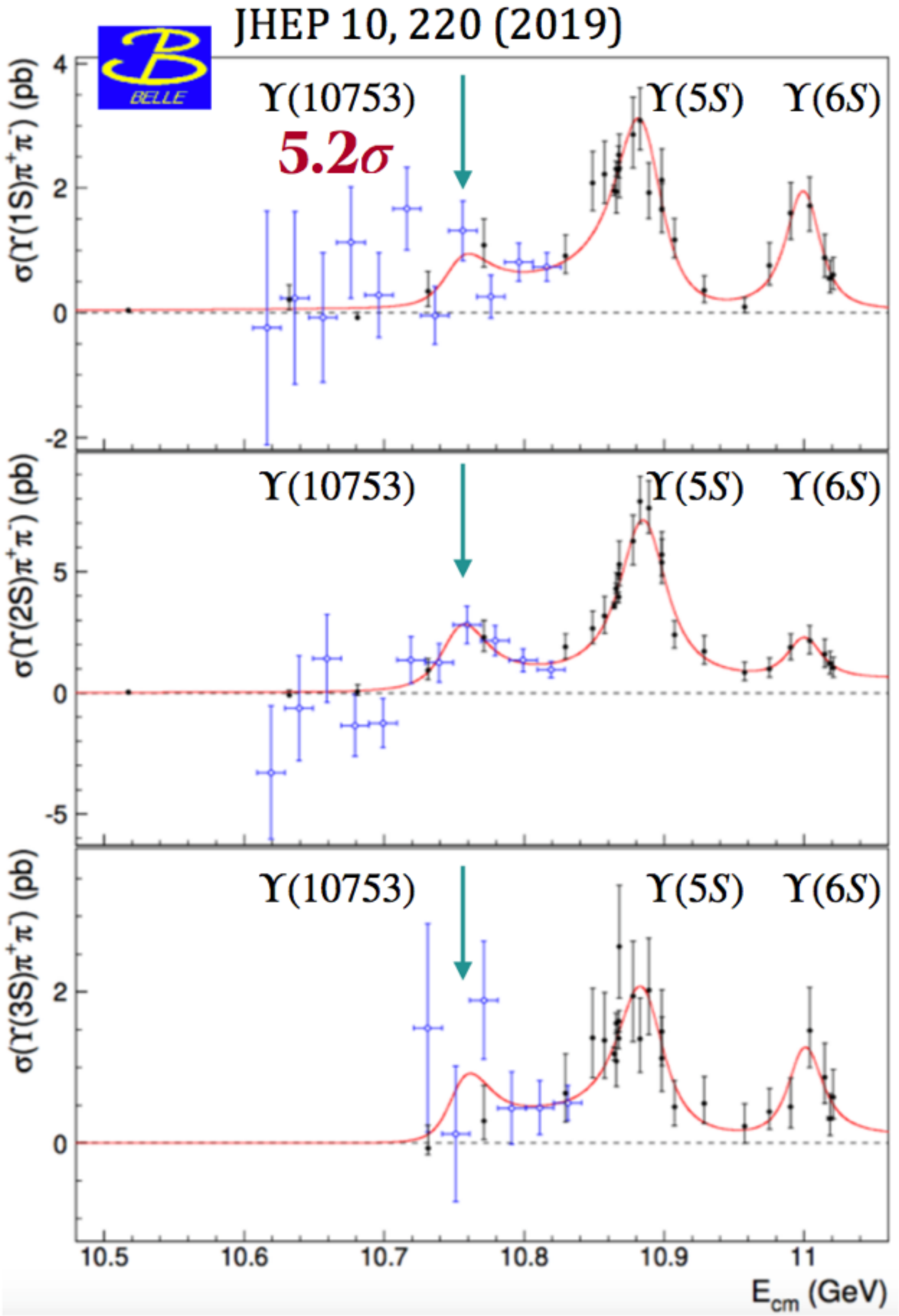
Outermost structures

- Electromagnetic CaLorimeter (ECL)
- Superconductive solenoid (1.5 T)
- K_L and Muon detector (KLM)



arXiv:1011.0352, 2010

Y(10753)



- Belle: several $\sim 1\text{fb}^{-1}$ scan points below $\Upsilon(5S)$
- New structure $\Upsilon(10753)$ observed in the $\pi^+\pi^-\Upsilon(nS)$ transition[1]

	$\Upsilon(10860)$	$\Upsilon(11020)$	New structure
M (MeV/c^2)	$10885.3 \pm 1.5\,^{+2.2}_{-0.9}$	$11000.0^{+4.0}_{-4.5}\,^{+1.0}_{-1.3}$	$10752.7 \pm 5.9\,^{+0.7}_{-1.1}$
Γ (MeV)	$36.6^{+4.5}_{-3.9}\,^{+0.5}_{-1.1}$	$23.8^{+8.0}_{-6.8}\,^{+0.7}_{-1.8}$	$35.5^{+17.6}_{-11.3}\,^{+3.9}_{-3.3}$

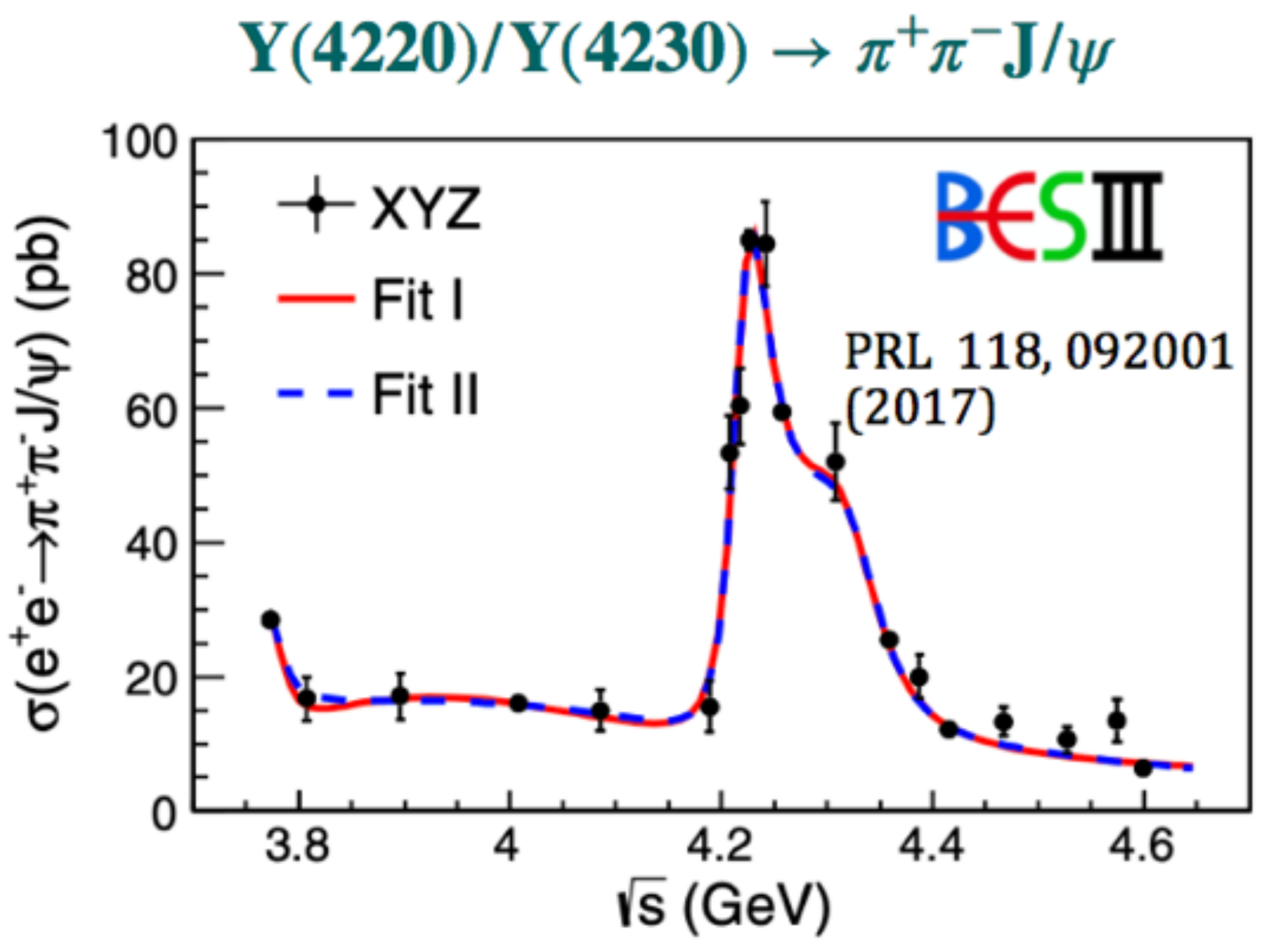
- Interpreted as conventional bottomonium[2] or exotics state[3] .
- Predicted to decay into $\omega\chi_{bJ}$ with a BF of 10^{-3} based on the mixing of conventional states 4S and 3D[4].

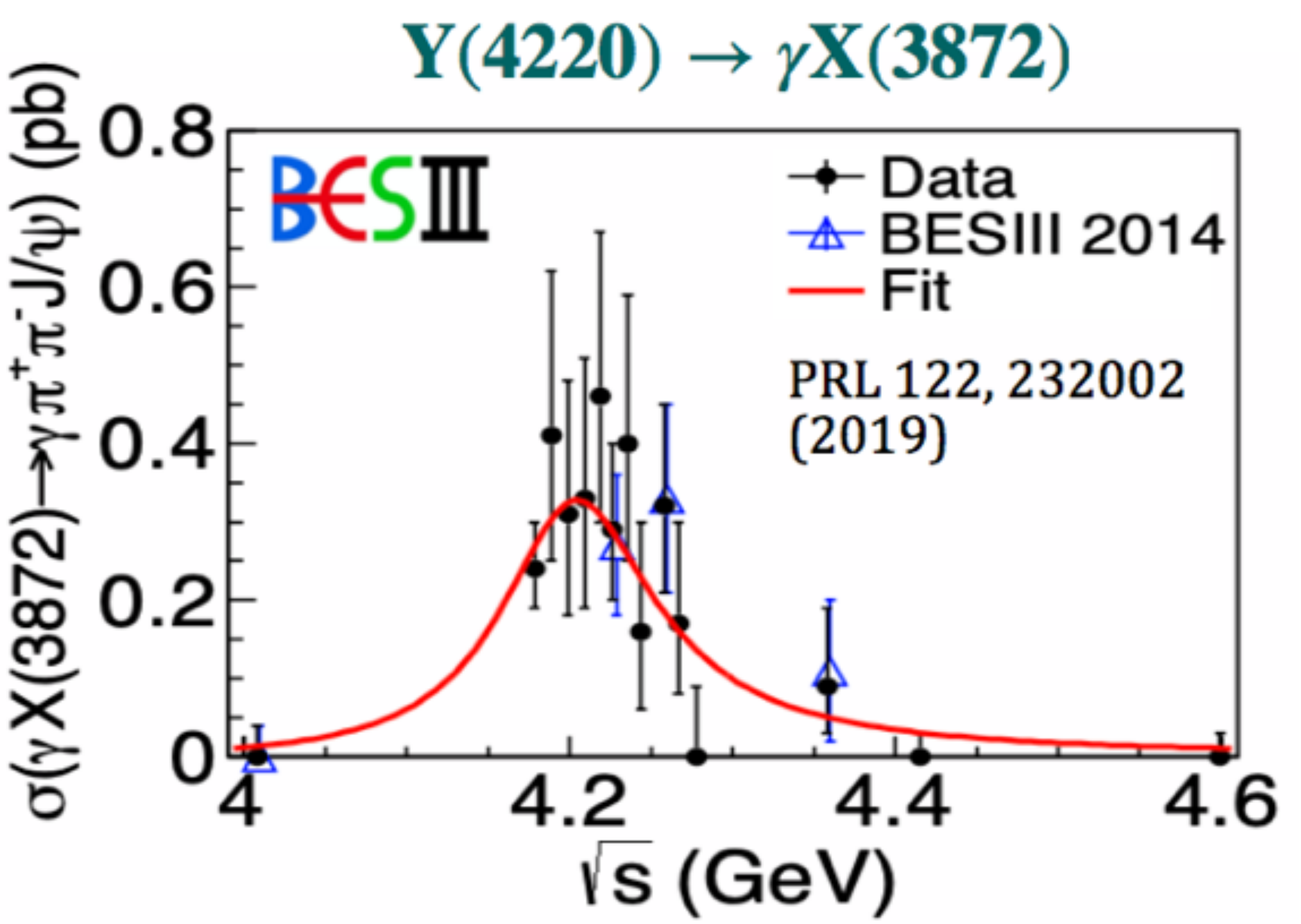
[1]. JHEP 10, 220 (2019); [2]. PRD 105, 074007(2022); PRD 104,034036 (2021); EPJC 80,59 (2020)

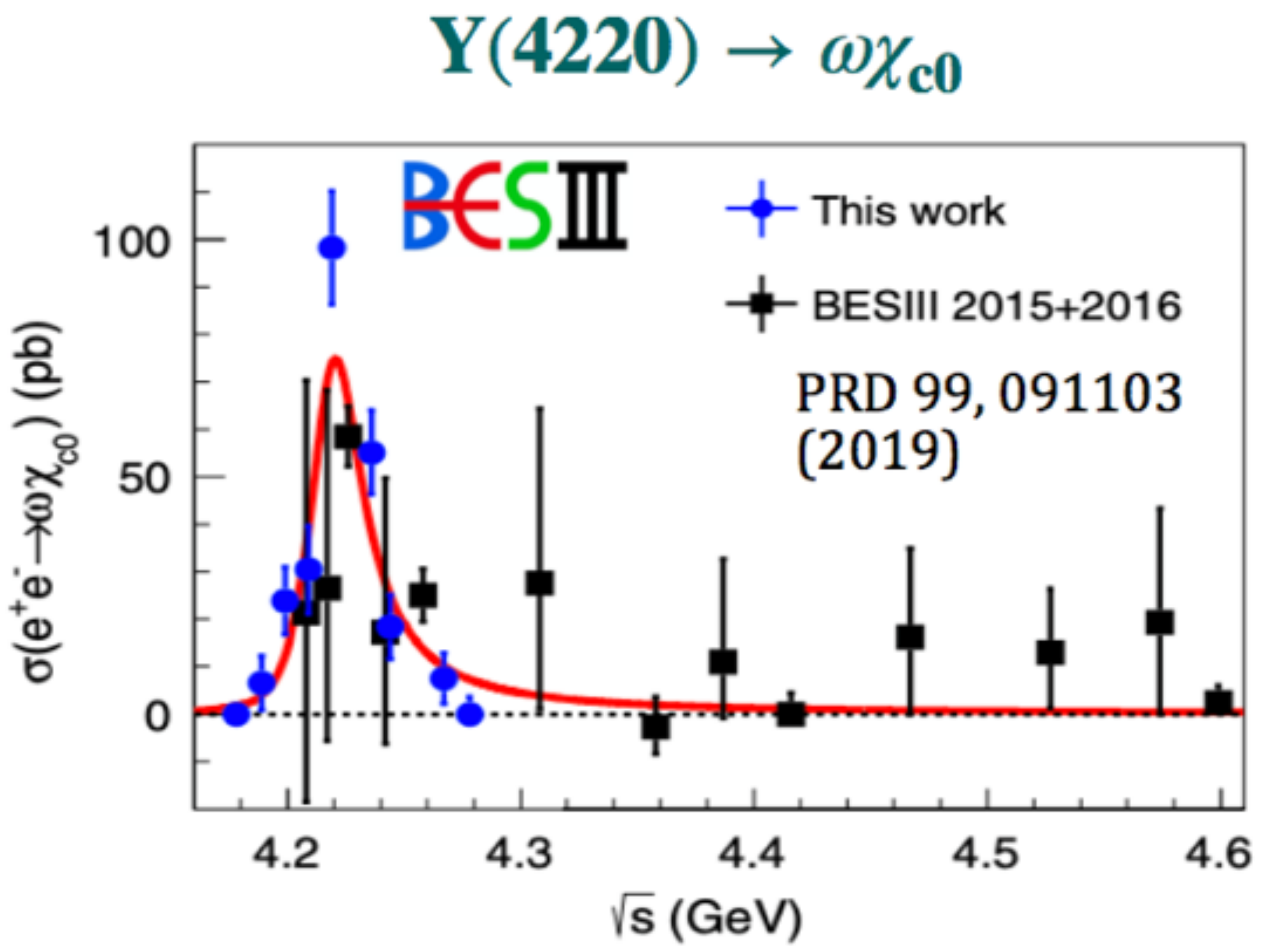
[3]. PRD 104,034019(2021); PRD 103,074507(2021); Chin. Phys. C 43, 123102 (2019); [4]. PRD 104,034036)2021.

X_b: bottomonium counterpart of X(3872)?

- Two close peaks observed in the cross sections for $e^+e^- \to \pi^+\pi^- J/\psi$ by BESIII[1] and $e^+e^- \to \pi^+\pi^-\Upsilon(nS)$ by Belle[2], respectively. These peaks may indicate similar nature.
- $Y(4220) \to \gamma X(3872)$[3] and $\omega\chi_{c0}$[4], observed by BESIII.
- Evidence of $\Upsilon(5S) \to \omega\chi_{b1,2}$ observed by Belle[5], BESIII observed higher charmonium decays to $\omega\chi_{c1,2}$[6].
- So expect the $\Upsilon(10753)$ state to decay into γX_b with $X_b \to \omega\Upsilon(1S)$, as well as a potential resonance in the line shape of $\sigma(e^+e^- \to \omega\chi_{b1,2})$.

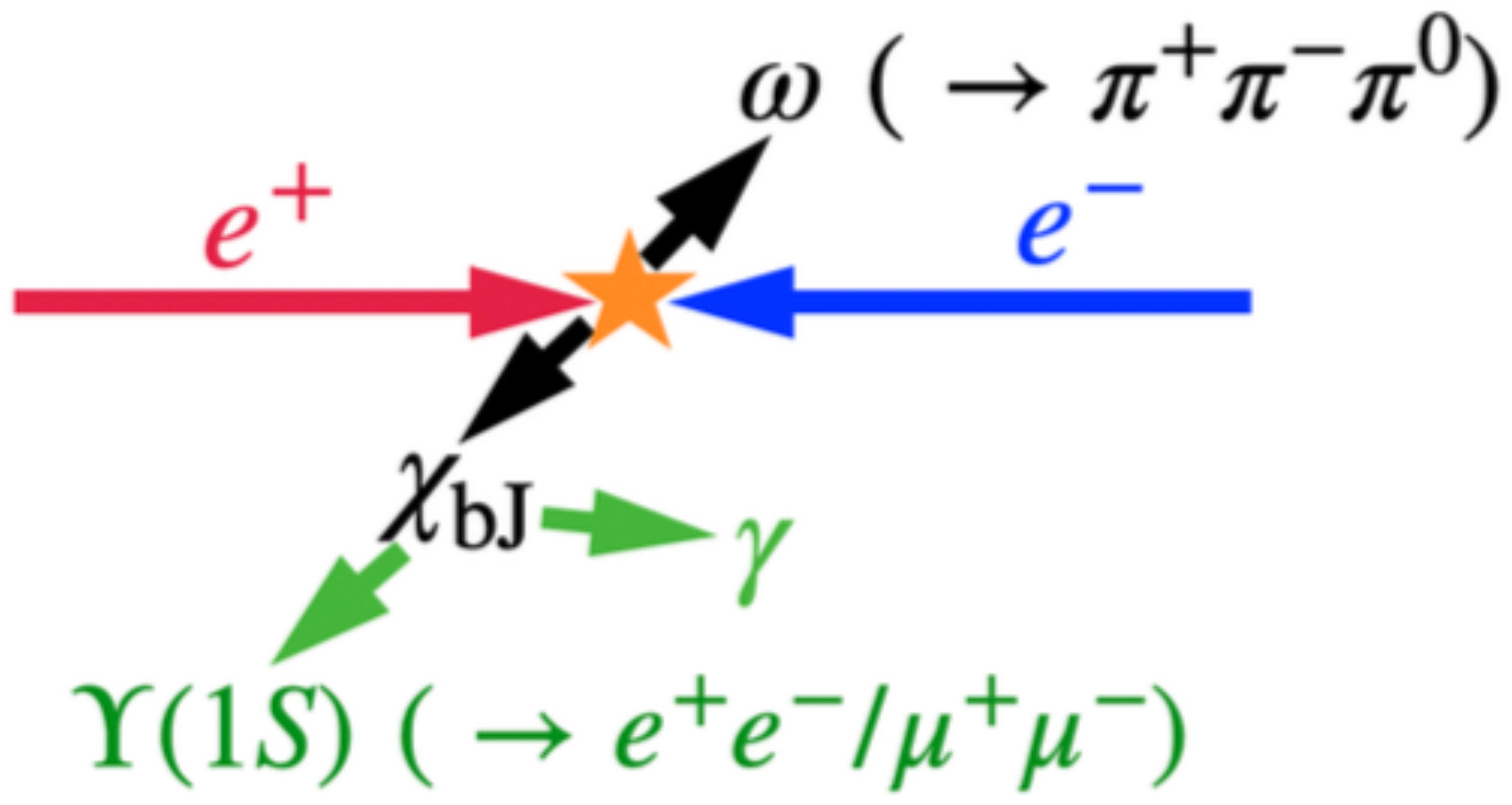


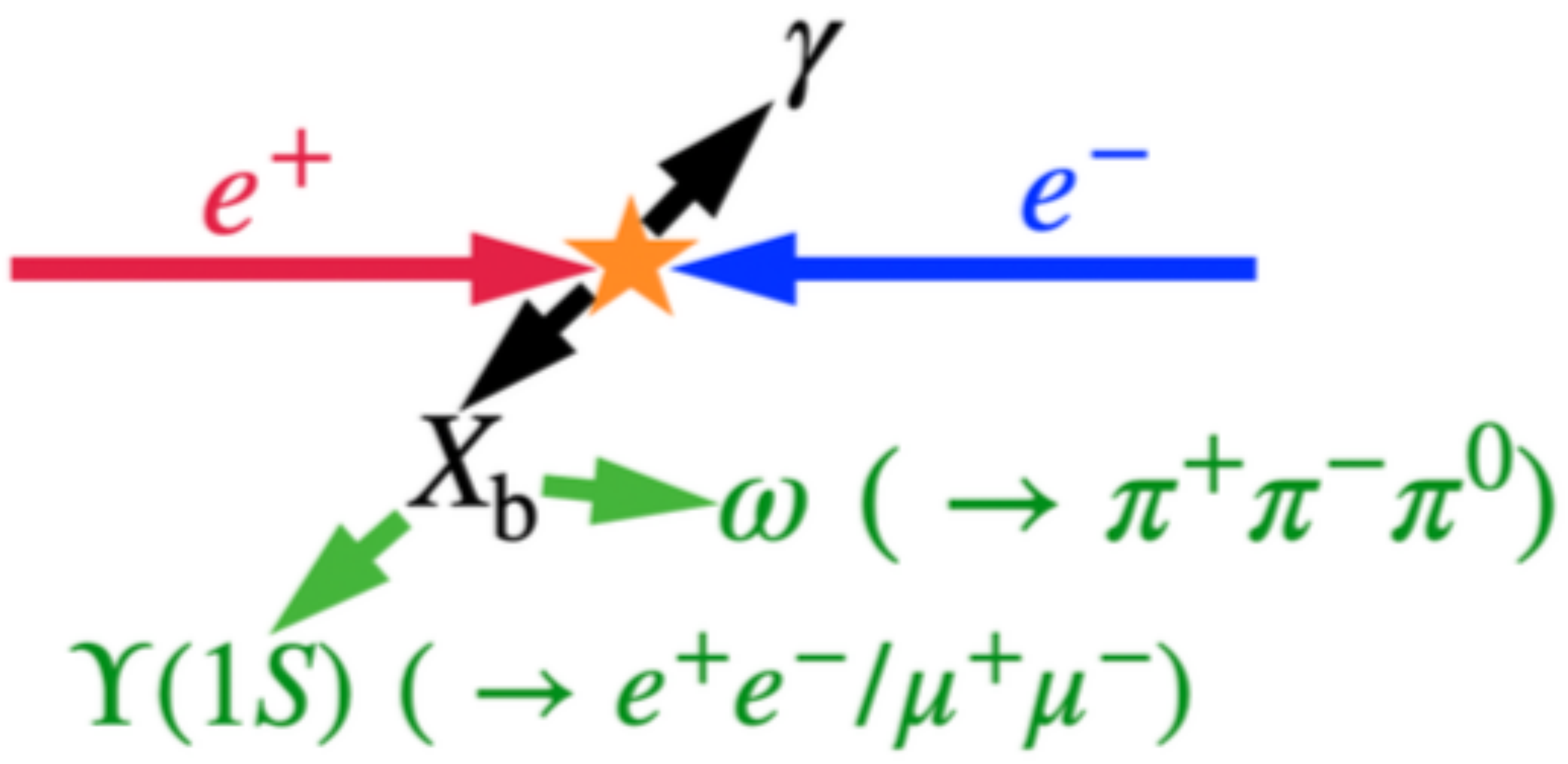




[1]. PRL 91, 262001(2003); [2]. JHEP 10, 220 (2019); [3]. PRL 122, 232002 (2019); [4]. PRD 99, 091103 (2019); [5]. PRD 98, 091102 (2018); [6]. PRD 93,011102(R) (2016)

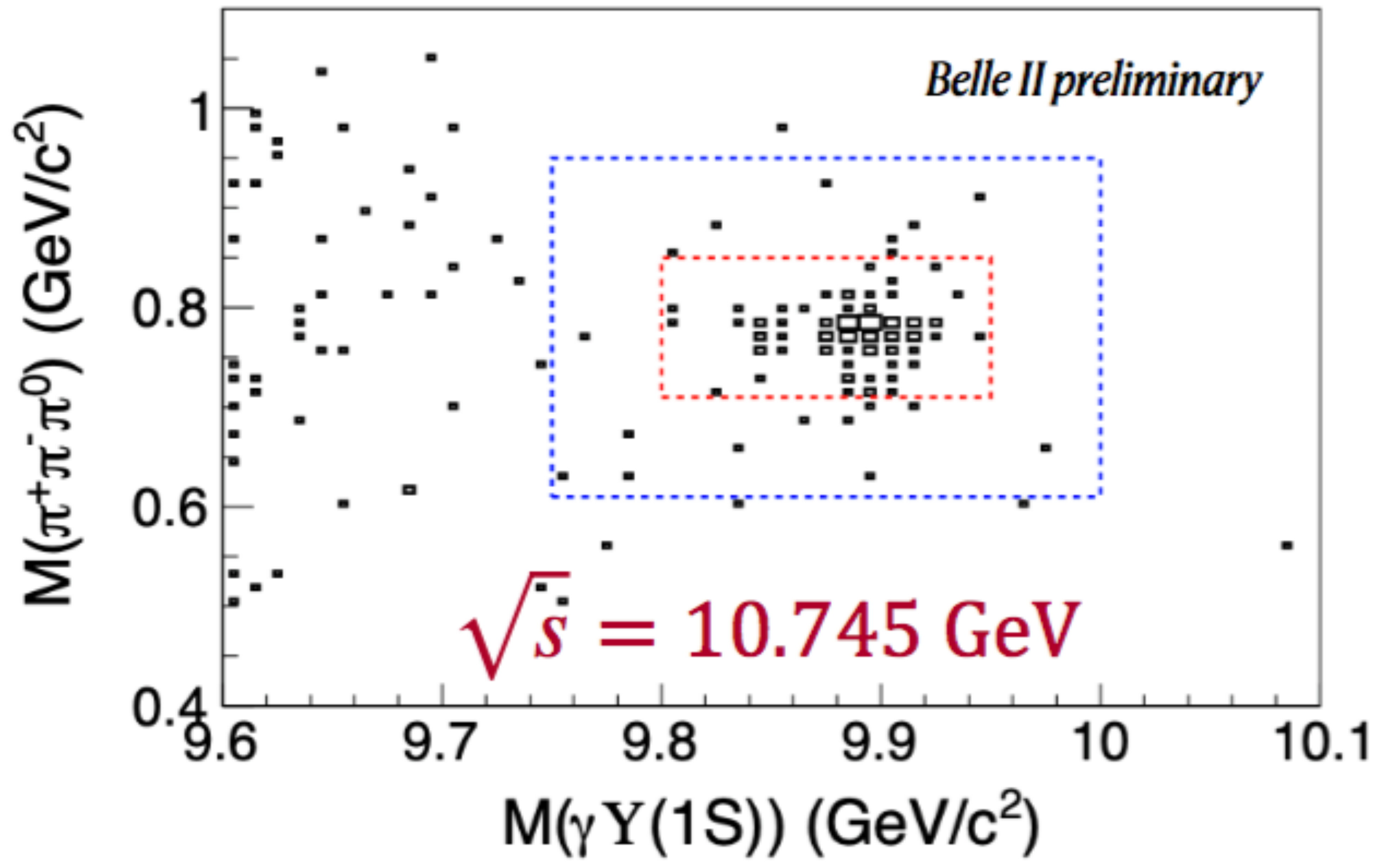
Events selection

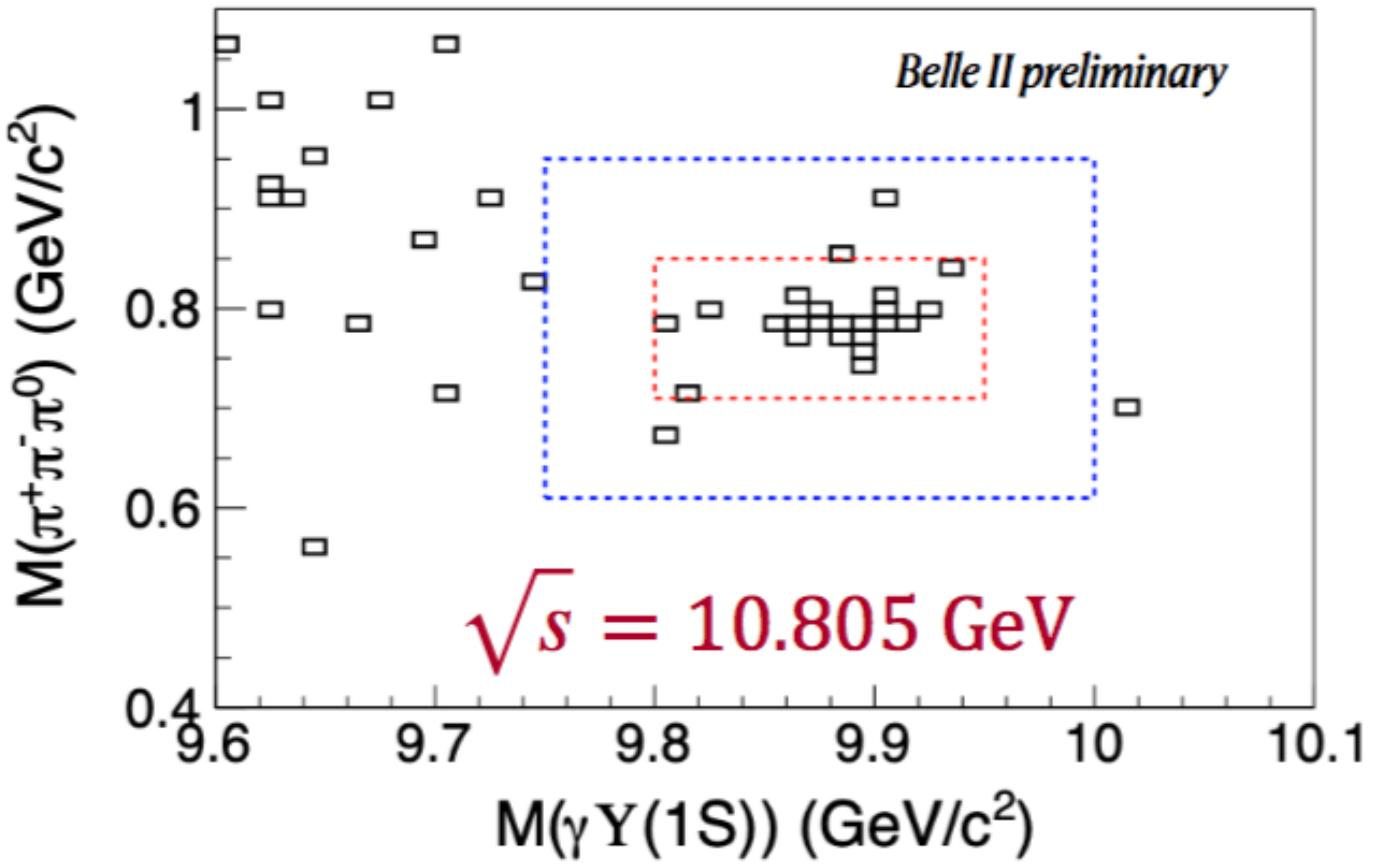




- Event selection
  - 4 or 5 charged tracks.
  - standard Belle II PID: 90%-95% efficiency with 1–5% misID.
  - photons from χ_{bJ} decays: $E_\gamma > 50$ MeV
  - π^0 candidates: $M(\gamma\gamma) \in (0.105, 0.150)$ GeV$/c^2$ with 90% efficiency.
  - Constrained kinematic fit to $\pi^+\pi^-\pi^0\gamma e^+e^-/\mu^+\mu^-$ final.
  - Best candidate based on best fit quality.
- Data driven corrections and systematics from control samples

Mass distribution





- Red box contains 95% of signals
- Blue box defines one-dimensional projection ranges

slide credit: Qingping Ji

Other active ongoing analyses based on unique scan data:

Channel
$B\bar{B}$ decomposition
$e^+e^- \to \omega\eta_b(1S)$
$e^+e^- \to \phi\eta_b(1S)$
$e^+e^- \to \eta h_b(1P)$
$e^+e^- \to \Upsilon(1S) + X$
$e^+e^- \to \pi^+\pi^- Y_2(1D)$
$e^+e^- \to \pi^+\pi^- \Upsilon(nS)$
$e^+e^- \to \pi^+\pi^- h_b(nP)$

- Precise measurements of the mass and width of $\Upsilon(10753)$
- Search for more decays of $\Upsilon(10753)$
- Search for the the X_b state (the bottomonium counterpart of $X(3872)$)
- Study the $\pi^+\pi^-/\omega/\eta/\phi$ transitions in the e^+e^- annihilations to test NRQCD