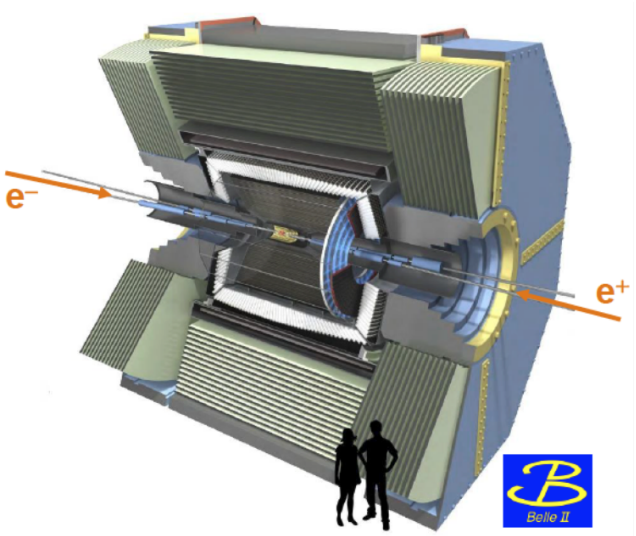
First Results from Belle II on exotic and conventional Quarkonium

Roberto Mussa *(on behalf of Belle-II collaboration)*

INFN TORINO

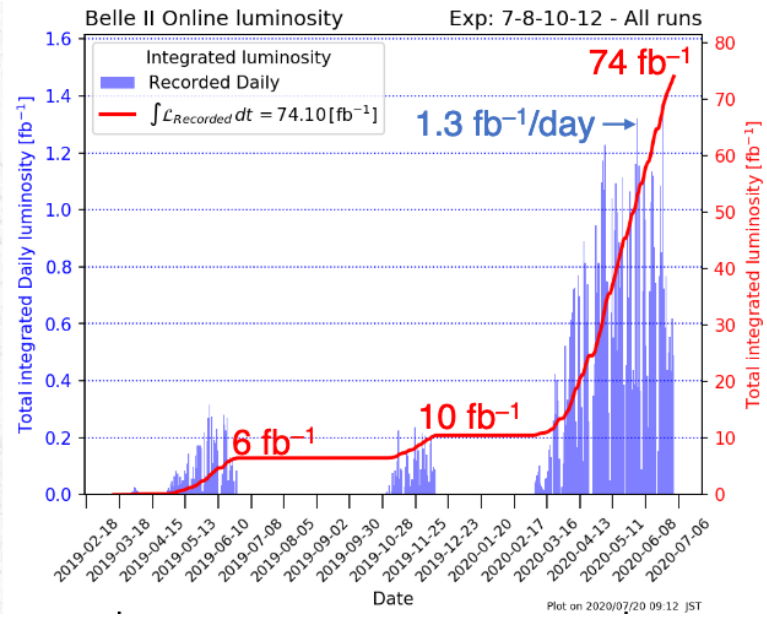


Outline

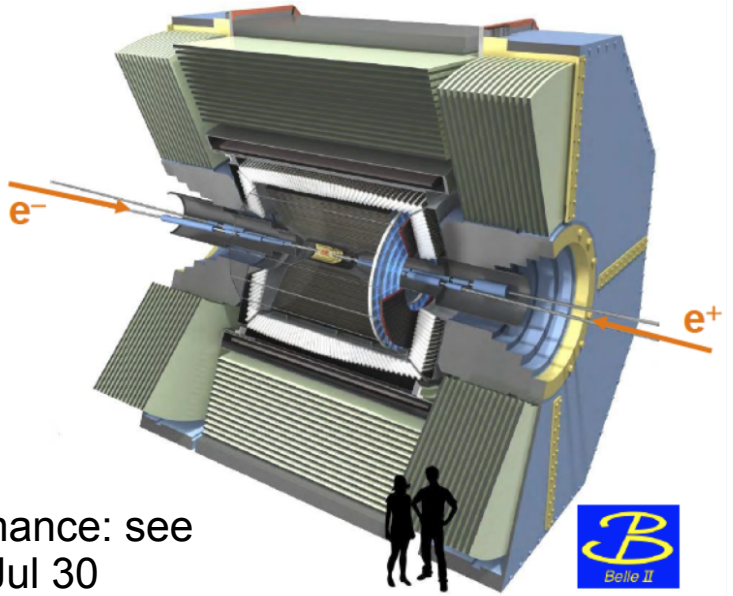
The XYZ states

Reconstruction of
- vector charmonia
- vector bottomonia
- η,η'

First results from the ICHEP dataset :
34.6(3.2)fb^{-1} on-(off-) Υ(4S) peak



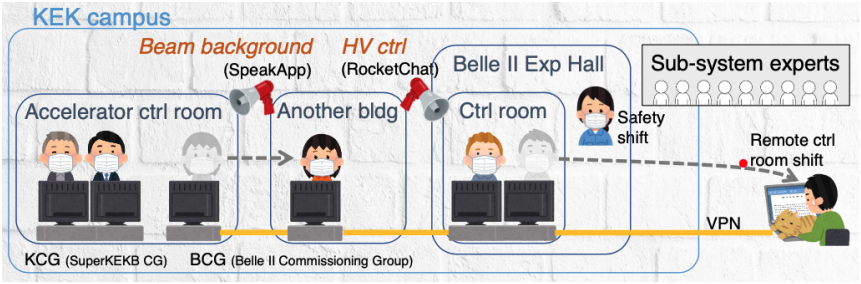
1047 active members
119 institutes
29 countries
(as of June 2020)

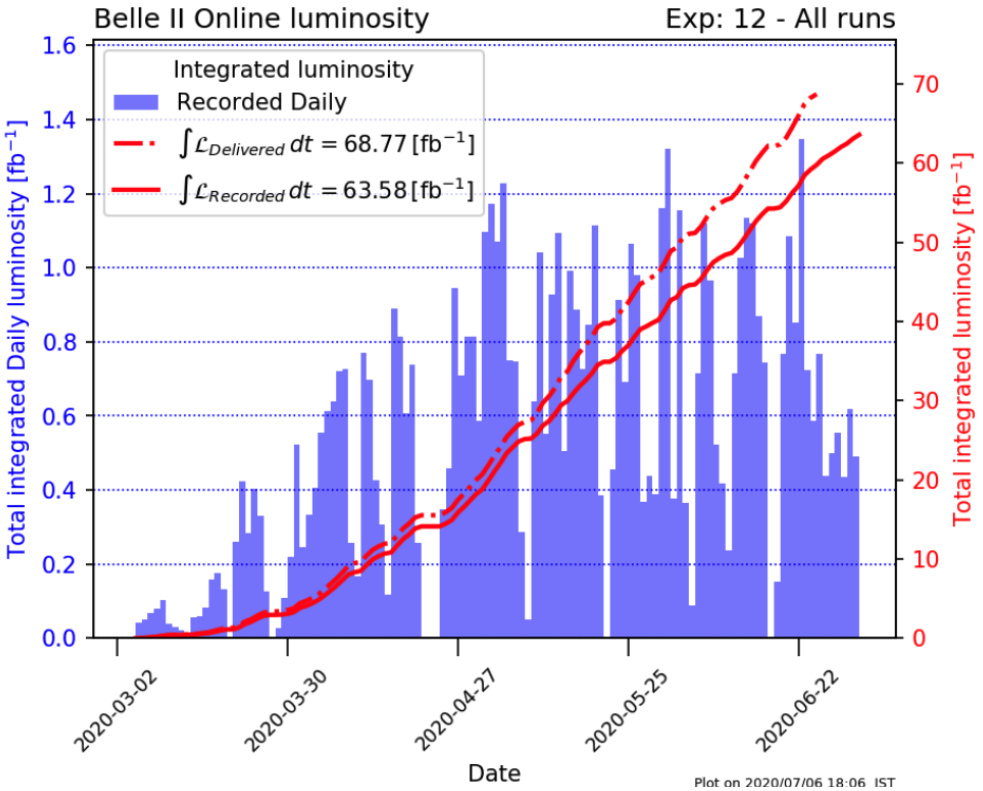


Detector performance: see
K.Matsuoka on Jul 30

Belle-II running during CoViD-19 crisis

Runs 2020a and 2020b operated with heroic efforts of staff physicists trapped in Japan, and reorganization of detector and control room remote control room shifts

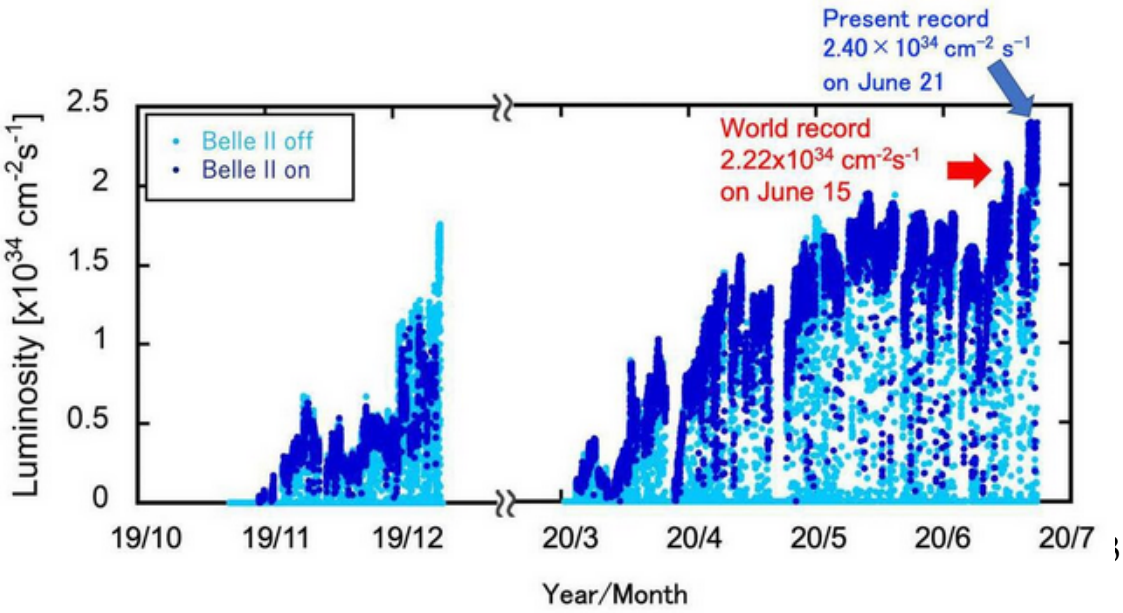




Crab waist sextupoles turned on and operated successfully allowed to reduce beam-beam effects and injection backgrounds.

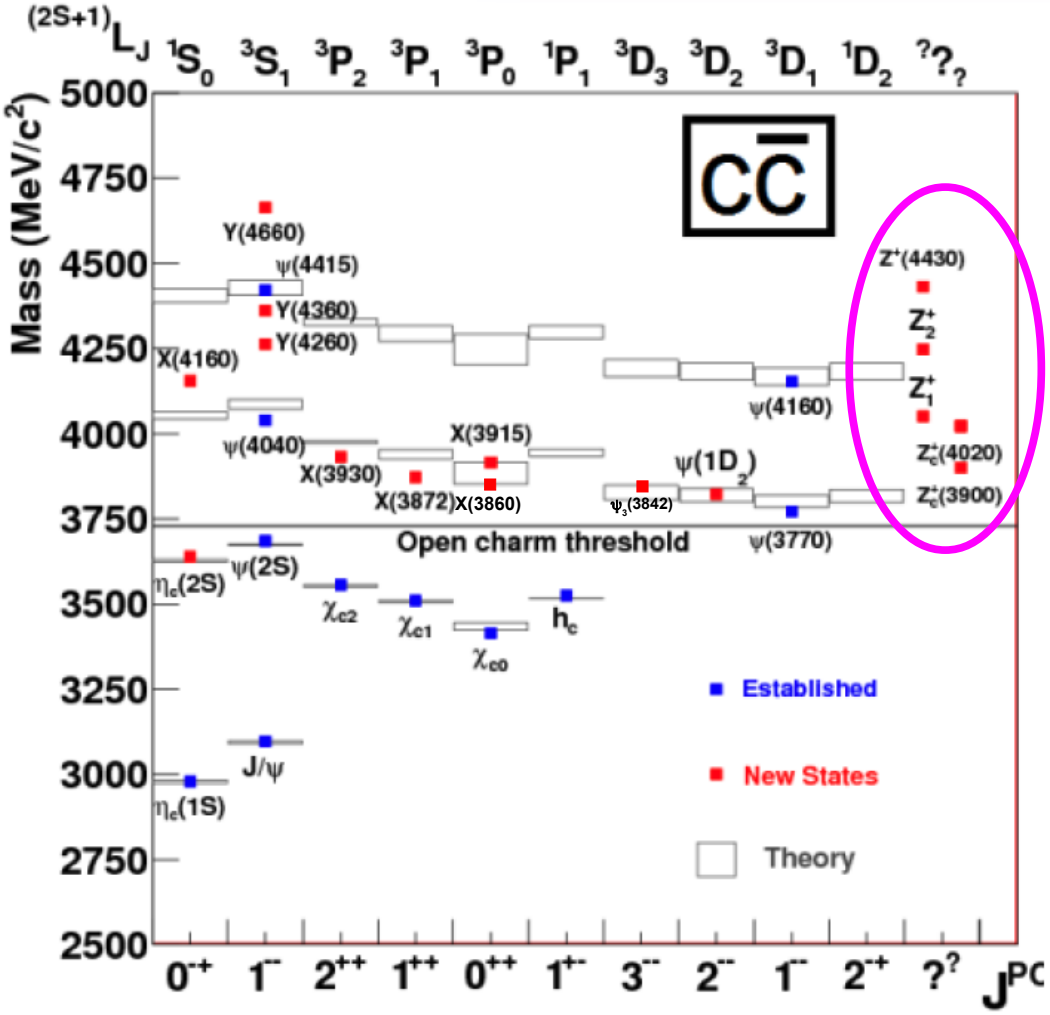
Luminosity world record set:
2.4 10^{34} cm^{-2} sec^{-1}

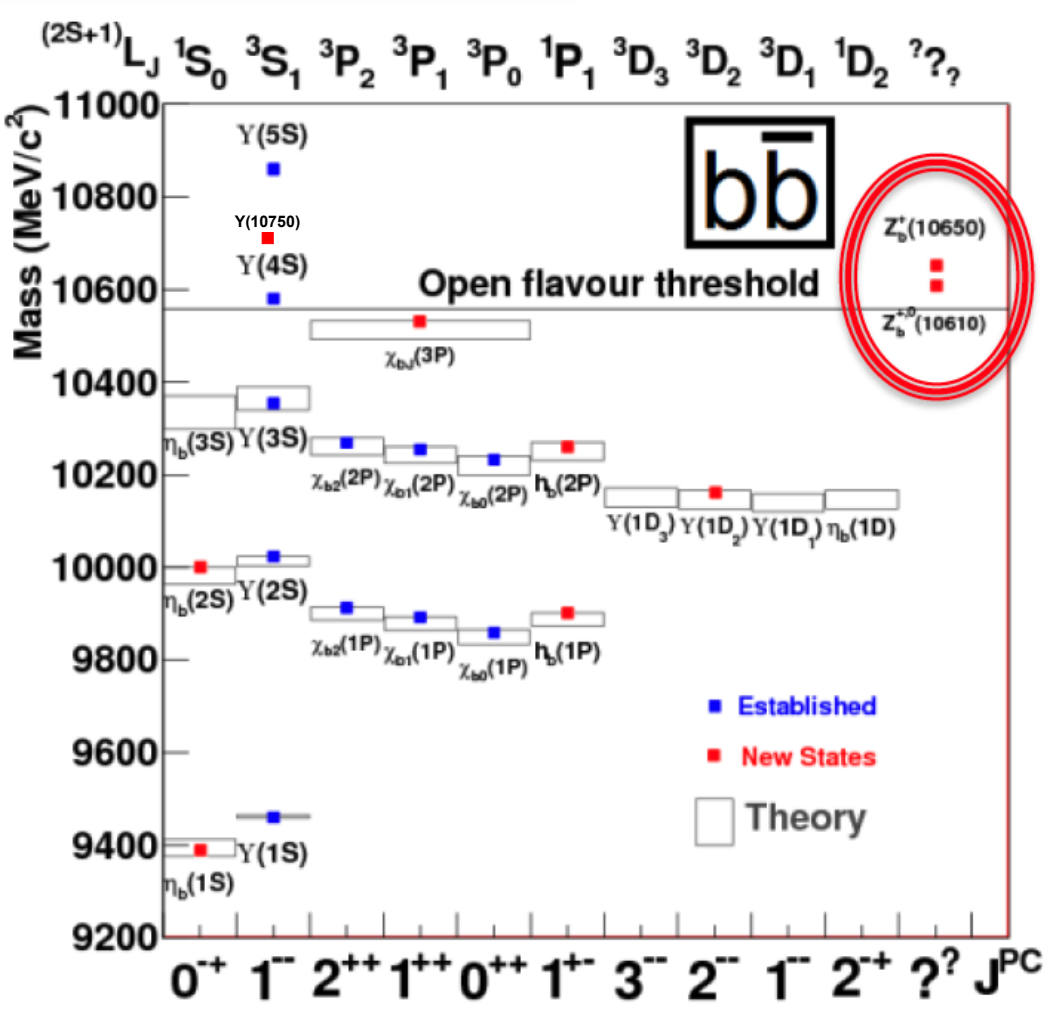
(Previous KEKB record in 2010)



What are the XYZ states?

Besides discovering many missing conventional quarkonium states, the B-factories found many meson states not fitting the models, dubbed the XYZ states.

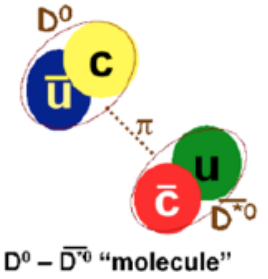




The need to introduce light quark degrees of freedom to describe the XYZ states was finally confirmed with observation of charged charmonium-like (Z_c) and bottomonium-like(Z_b) states.

What are the XYZ states?

The plethora of new charmonium-like and bottomonium-like states found by B-factories and LHC experiments in the last 20 years has been stimulating very lively debates in the QCD theory community. A short compilation of the various models here:



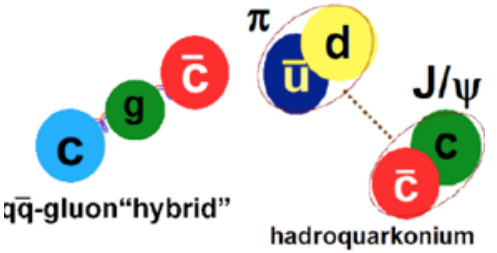
D⁰ – $\bar{D}^{*0}$ "molecule"

Meson Molecules (Guo et al, Rev.Mod.Phys.90,015004 (2018))
weakly bound states of two mesons

diquark-diantiquark

Tetraquarks (Polosa et al, PRD89, 114010 (2014))
Diquark-antidiquark states bound by the color force

Hybrids (Barnes, PRD 52,5242 (1995)
Meyer and Swanson, Prog.Part.Nucl.Phys. 82, 21 (2015))
colored $Q\bar{Q}$ states with a bound excited gluon



qq̄-gluon"hybrid" hadroquarkonium

Hadroquarkonium (Dubinskij et al, PLB 666, 344 (2008))
$Q\bar{Q}$ bound state surrounded by a cloud of light quarks

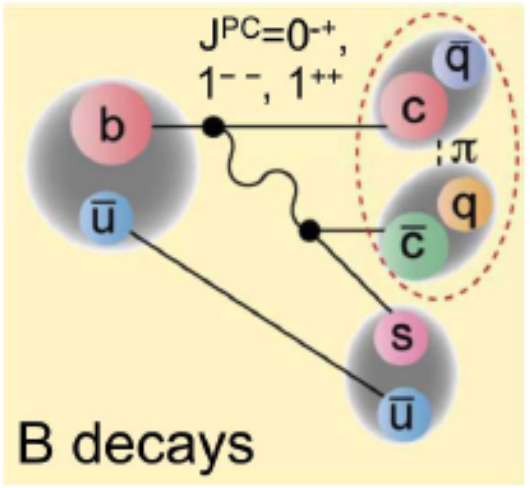
Standard quarkonia (Swanson, PRD 91, 034009 (2015))

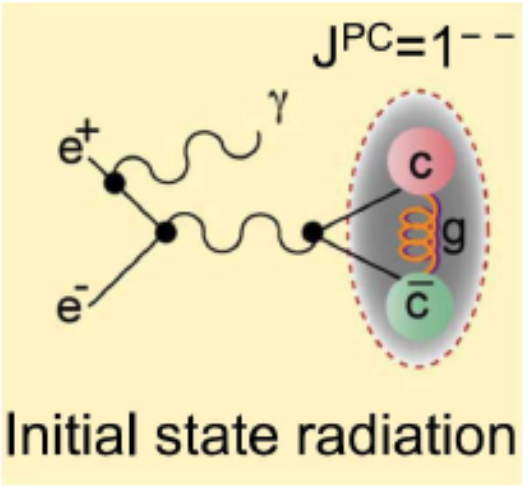
conventional quarkonium

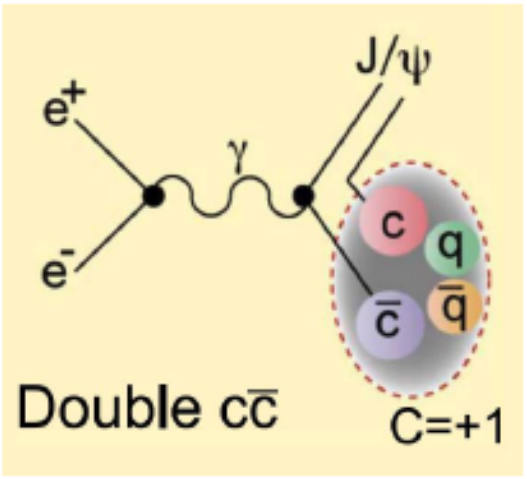
Full comprehensive reviews in:
- Brambilla *et al,* Eur.Phys J C(2011)1534
- Olsen *et al,* Rev.Mod.Phys. 90 (2018) 015003
- Brambilla *et al,* ArXiV:1907.07583

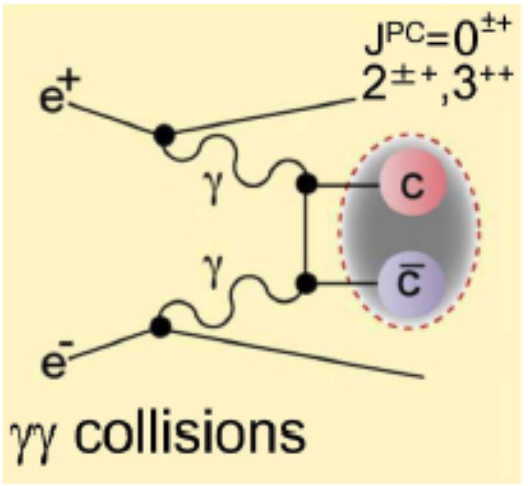
See also: www.qwg.to.infn.it

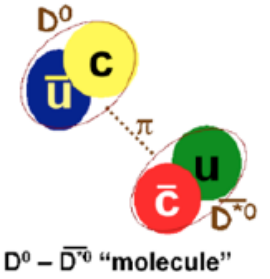
How can we study the XYZ states?

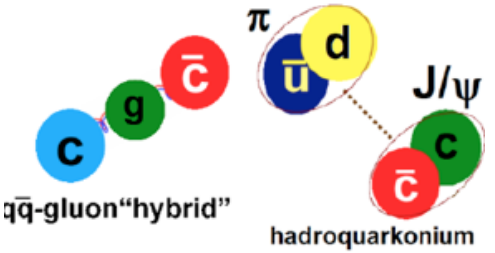












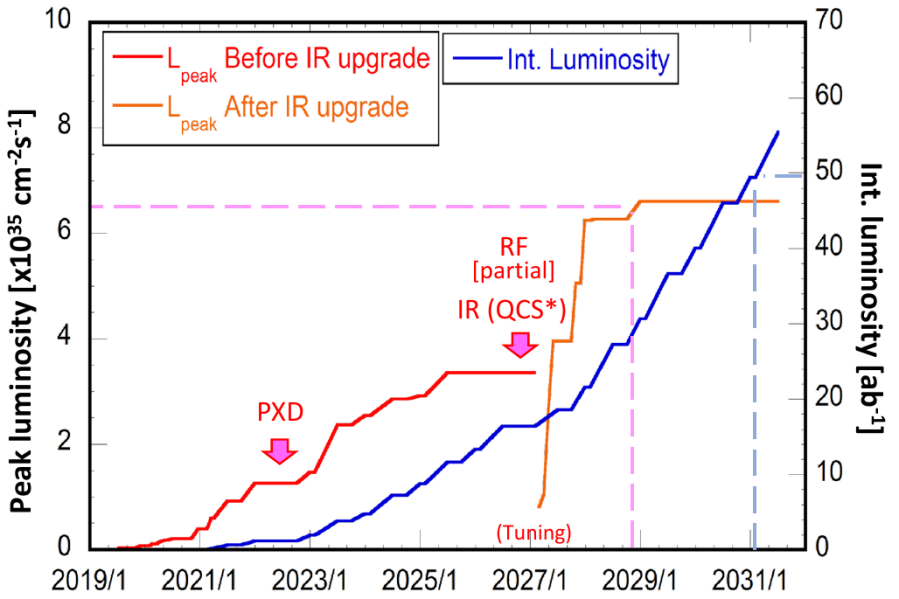
Just warming up the engines

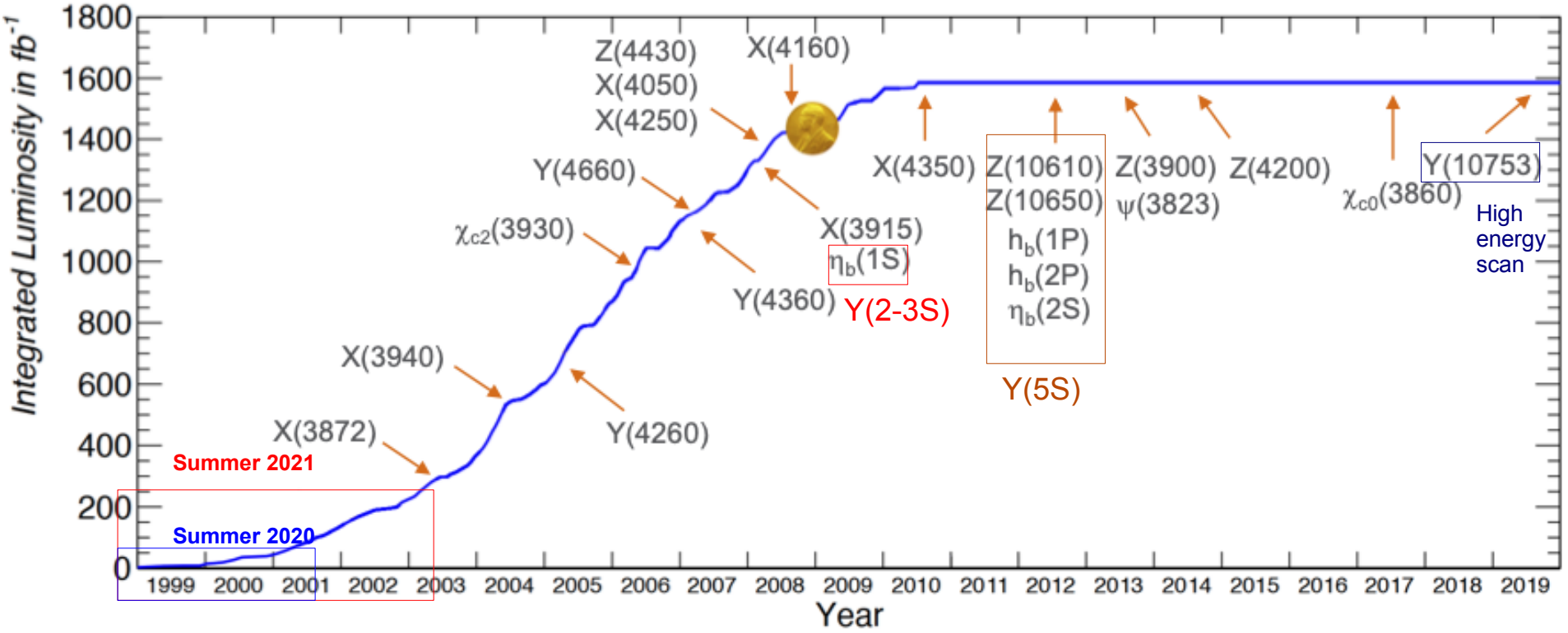
Rediscovery of most surprises from B factories expected after 250 fb^{-1}

- Stay tuned for Summer 2021 conferences

- First ab^{-1} before 2022 shutdown

- Data taking at E_{cm}=10.75 GeV under discussion



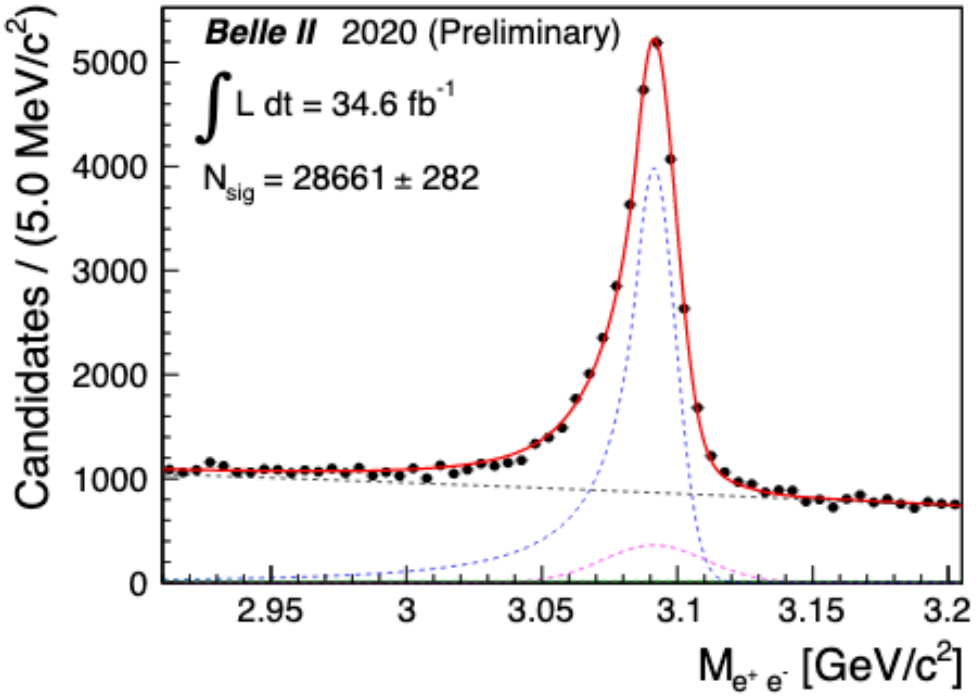


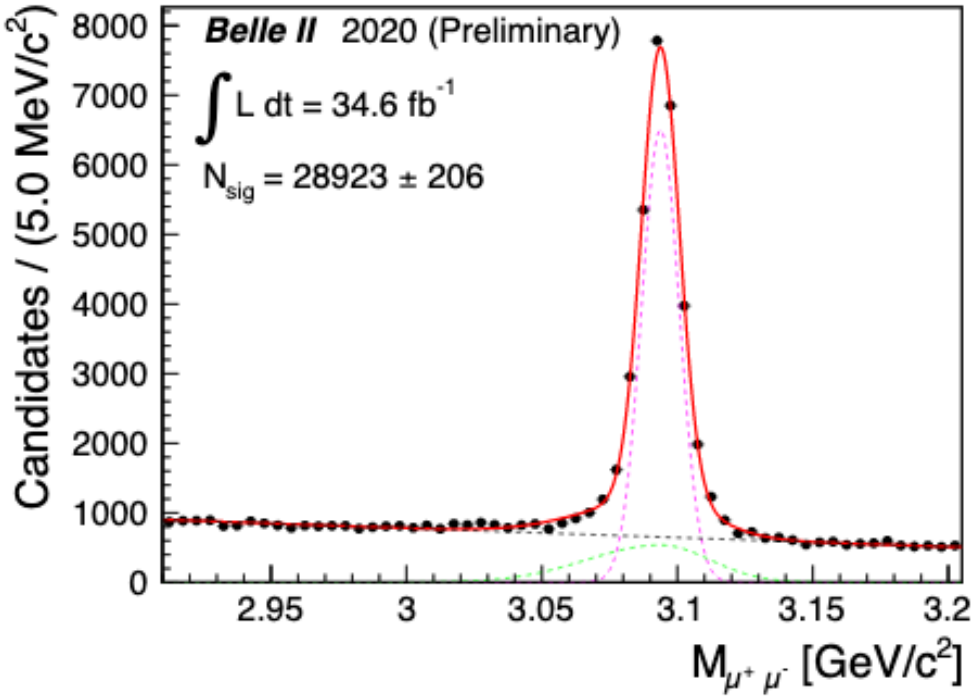
Charmonium production in B decays: J/ψ

Hadronic selection to enhance B decays to charmonium
- Ntracks >= 3 && Bhabha veto

Clear signals in both ee and μμ modes
- used for validation of lepton ID and tracking performance

PDF: CrystalBall+Gaussian for ee , double gaussian for μμ

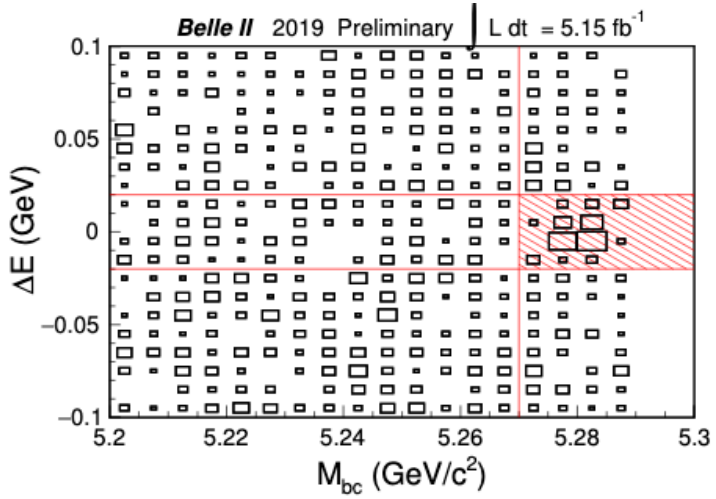


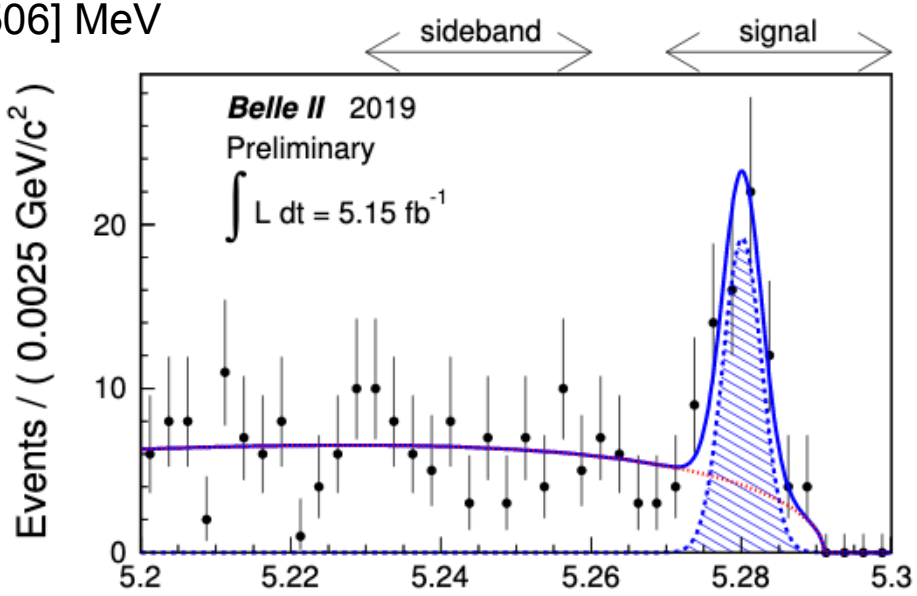


Charmonium production in B decays: ψ′

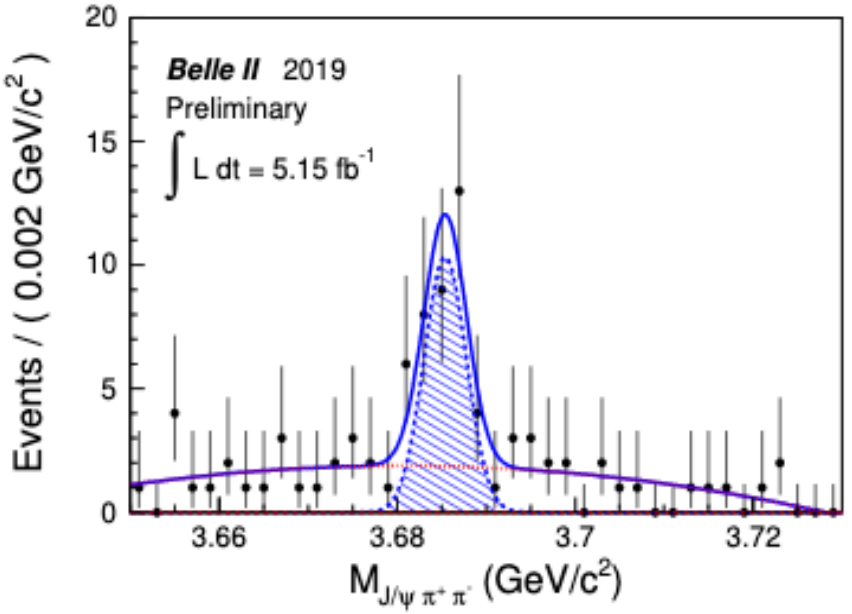
Hadronic selection to enhance B decays to charmonium
- Ntracks >= 3 with pT<0.2 GeV/c && r0 <2 cm && z0<4 cm
- Ks from two opposite charge pion tracks in the range [490,506] MeV

Clear signals in both ee and μμ modes



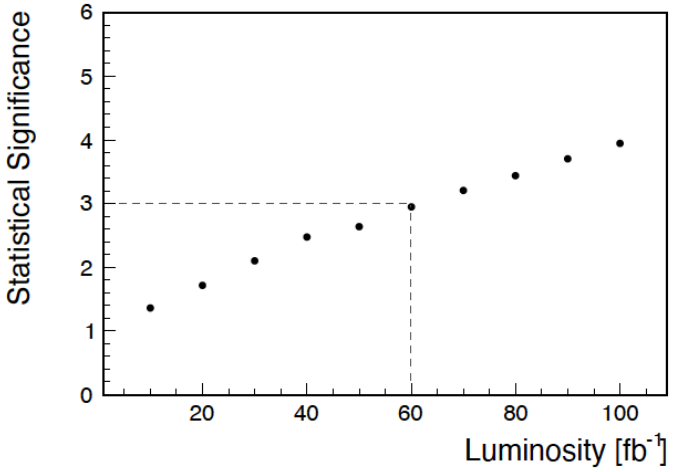


In perspective: rediscovery of X3872
... and new measurements

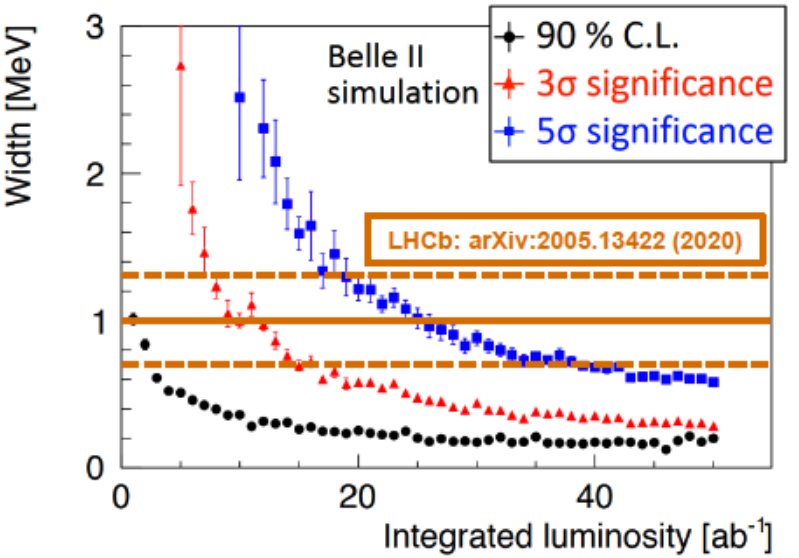


Charmonium production in B decays: X(3872)

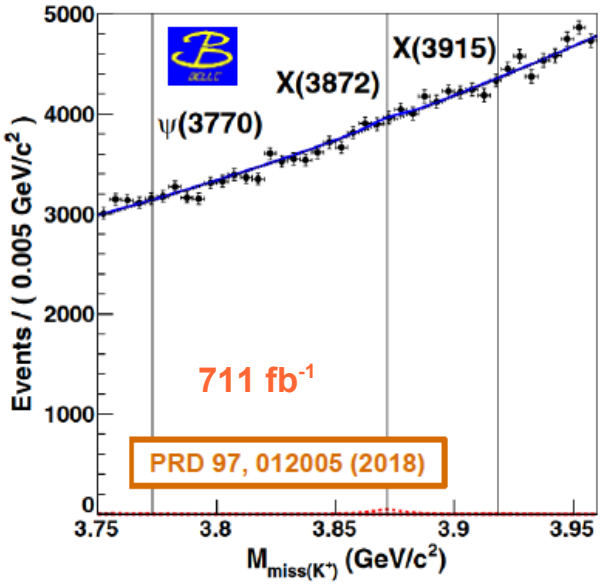
Rediscovery of X3872: >250 fb^{-1} needed

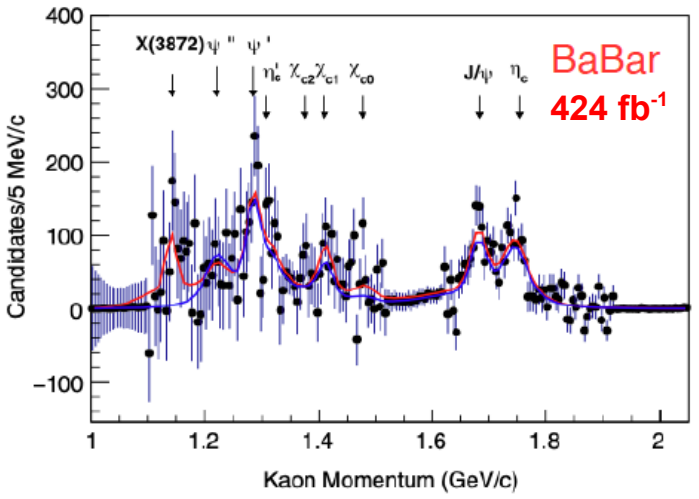


Total width (in DD* mode)



Measurement of BR(B→ K X(3872)) using the Kaon recoil momentum (1-5 ab^{-1}) :





F.Wilson on Jul 29

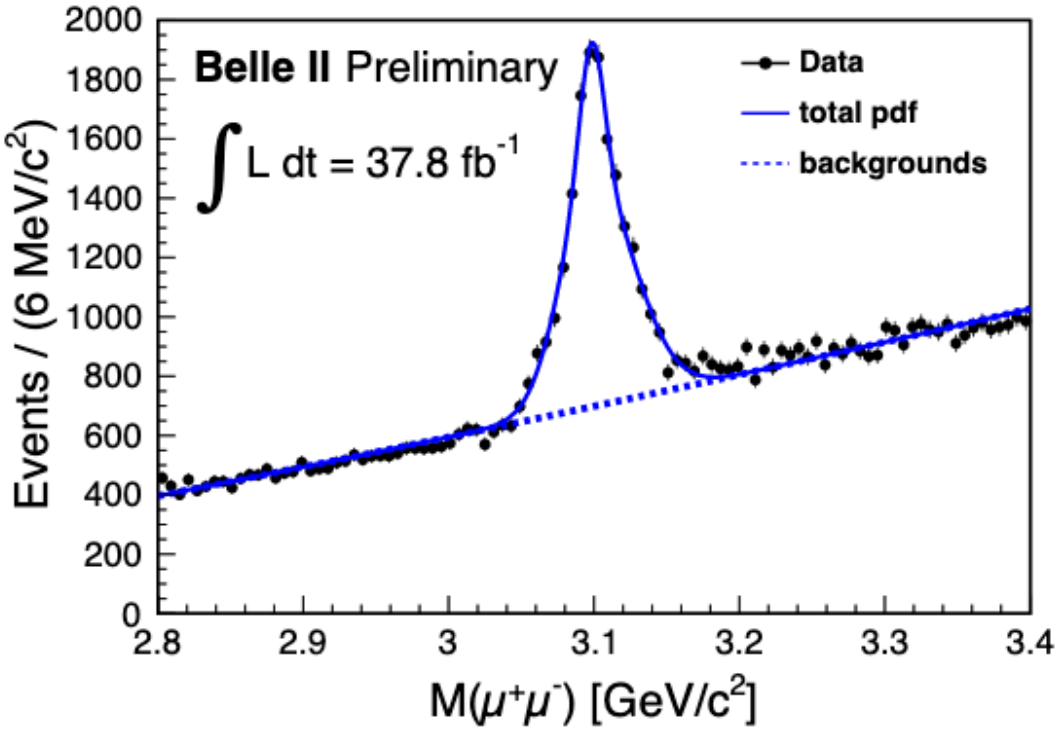
Charmonium ISR production: J/ψ

Distance from IP:
-| R_0 |< 1cm
-| Z_0 |< 3cm

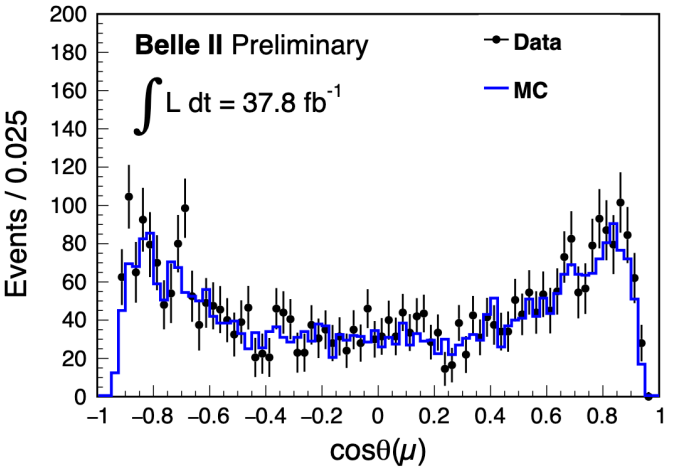
Recoil mass cut:
- -2< MM^2 (J/ψ)< 2(GeV^2/c^4)

Efficiency = (19.1± 0.8)%

PDF: Double Gaussian



Trigger efficiency studies using muon angular distributions

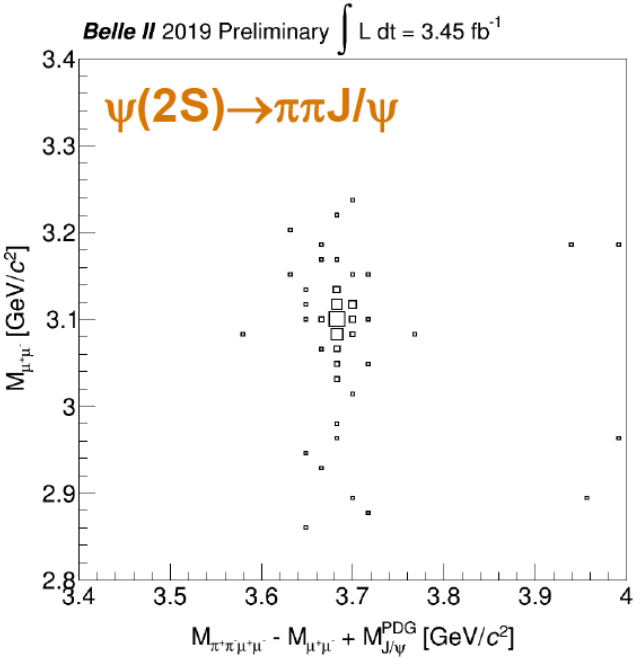


Charmonium ISR production: ψ′

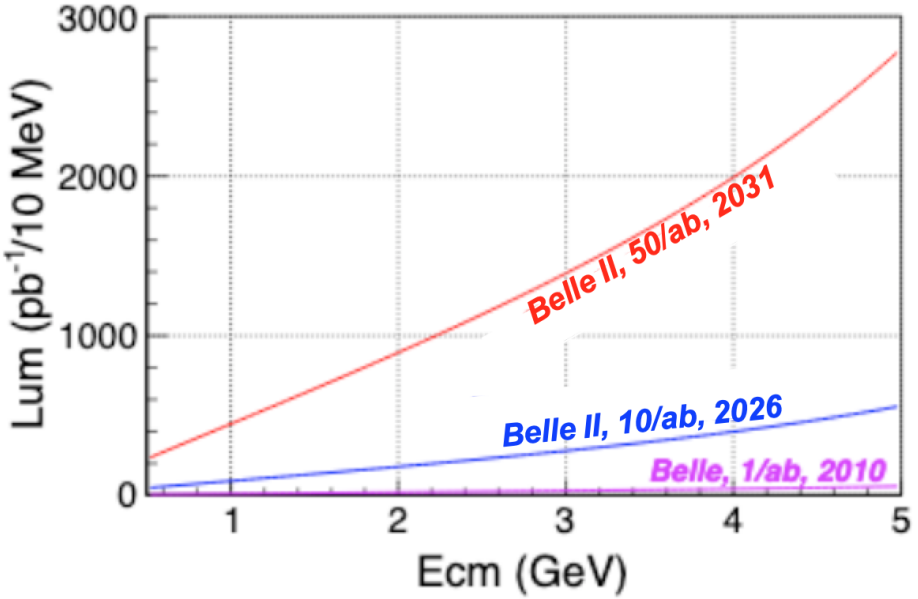
Ldt = 3.45 fb^{-1}

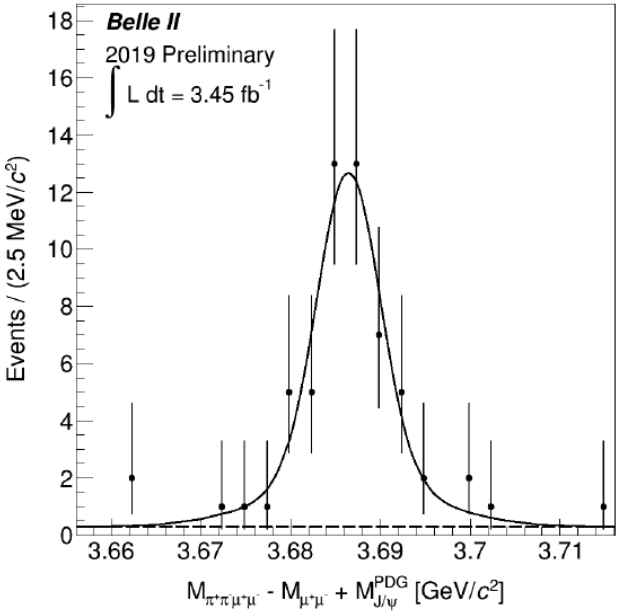
Searched in μμππ mode, asking for Ntracks=4,5.
Recoil mass cuts to isolate ISR production
|Mμμ – M(J/ψ)| <30 MeV

Preliminary to future analyses:
- rediscovery of Y(4260), Y(4360), etc...



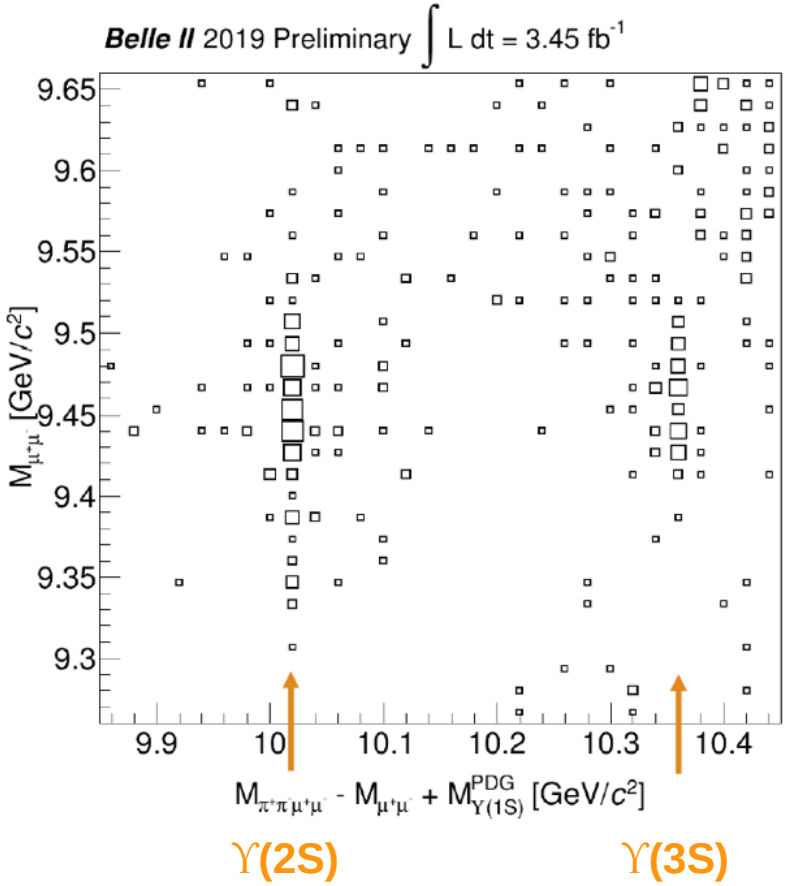
Complementary to BES-III scans, can reach higher energies. The ISR effective luminosity is shown below:

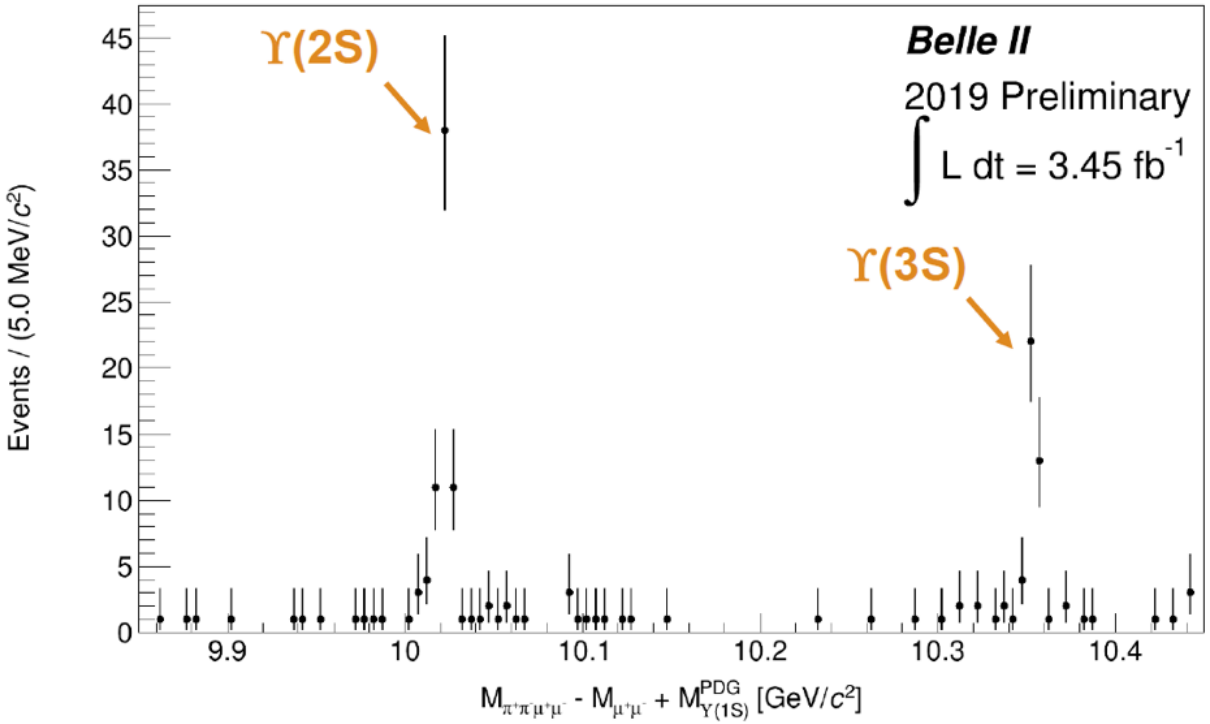




Bottomonium ISR production

Searched in $\mu\mu\pi\pi$ mode, asking for Ntracks=4,5.
Recoil mass cuts to isolate ISR production
$|M_{\mu\mu} - M(\Upsilon(1S))| < 50$ MeV/c^2





In perspective: search for hadron and radiative transitions from $\Upsilon(4S)$ to lower bottomonia with $\Upsilon(1,2S)$ reconstructed in the final dilepton state

$\eta(')$ vs dipion transitions from $\Upsilon(4S)$

Hadronic transitions are the only known pathways to lower bottomonia observed so far. Dipion transitions from Υ(4S) are suppressed if compared with the same ones from Υ(5S), which allowed Belle to discover charged bottomonium-like states $Z_b(10.61,10.65)$.

$B(\Upsilon(4S) \to \eta h_b(1P))$ $(21.8 \pm 2.1) \times 10^{-4}$

Tamponi et al, Belle, PRL115,142001(2015)

By far the largest transition to lower bottomonia, despite the heavy quark spin symmetry (HQSS) violation ***(b quark flips its spin with respect to antiquark)***

ONLY KNOWN portal to the η_b from the Y(4S), via inclusive recoil of $\eta+\gamma$

$B(\Upsilon(4S) \to \eta \Upsilon(1S))$ $(1.81 \pm 0.18) \times 10^{-4}$

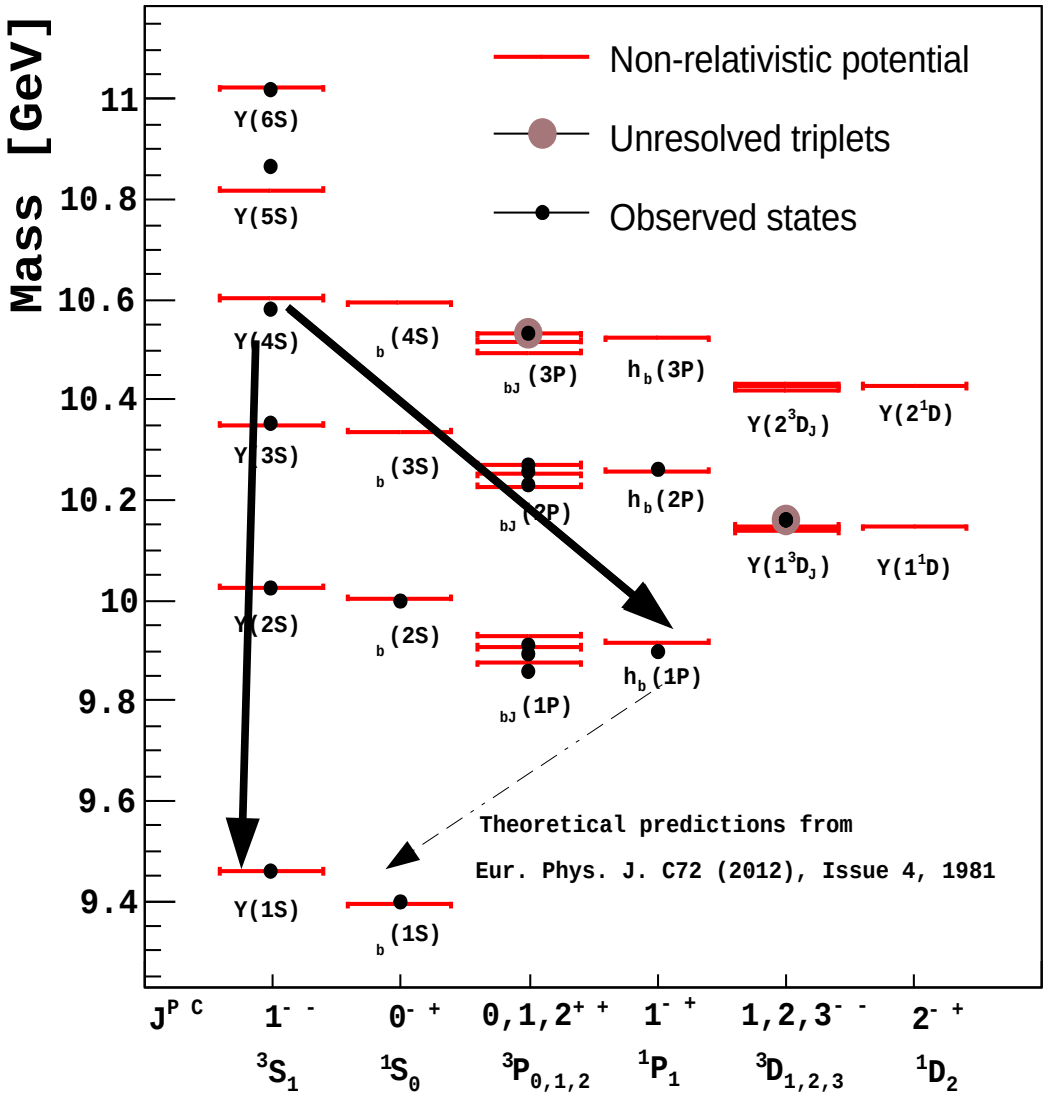
$B(\Upsilon(4S) \to \pi^+\pi^- \Upsilon(1S))$ $(0.82 \pm 0.04) \times 10^{-4}$

$B(\Upsilon(4S) \to \pi^+\pi^- \Upsilon(2S))$ $(0.82 \pm 0.08) \times 10^{-4}$

Aubert et al, Babar, PRD78,112002(2008)
Guido et al, Belle, PRD96,052005(2017)

$B(\Upsilon(4S) \to \eta' \Upsilon(1S))$ $(0.34 \pm 0.09) \times 10^{-4}$

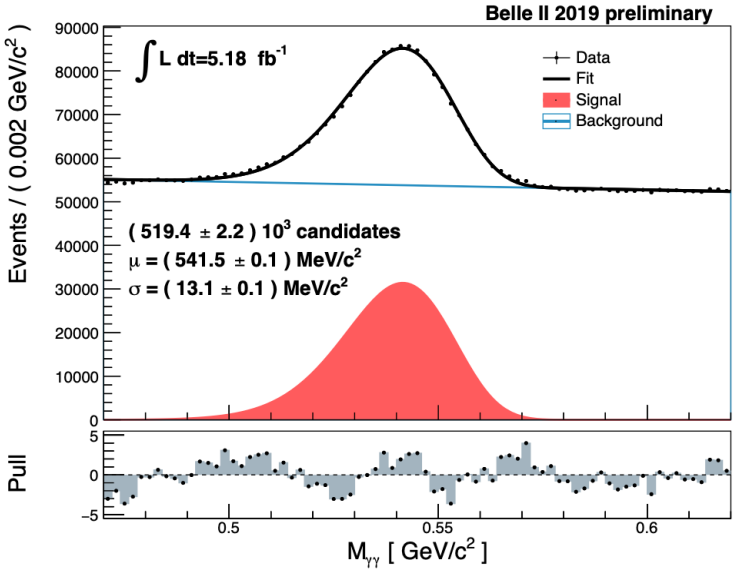
Guido et al, Belle, PRL121,062001(2018)



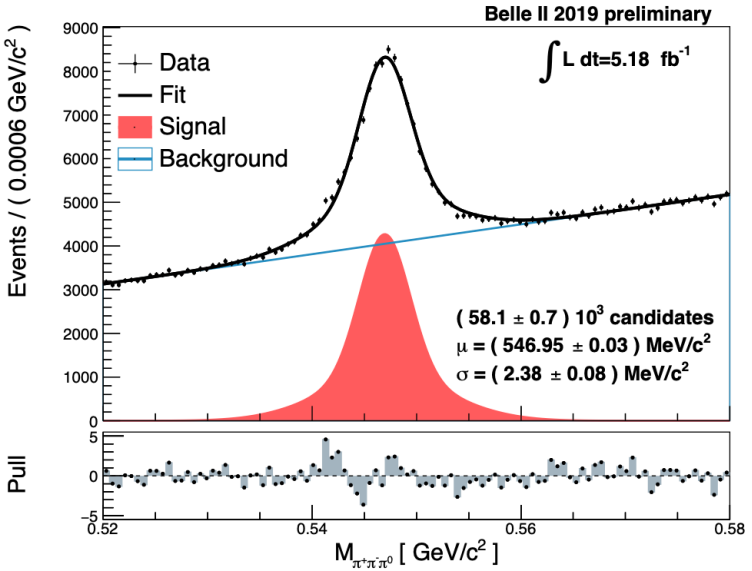
Inclusive η and η' production

Key for the rediscovery of $h_b(1P)$ and $\eta_b(1S)$ from Y(4S) data

$\eta \to \gamma\gamma$



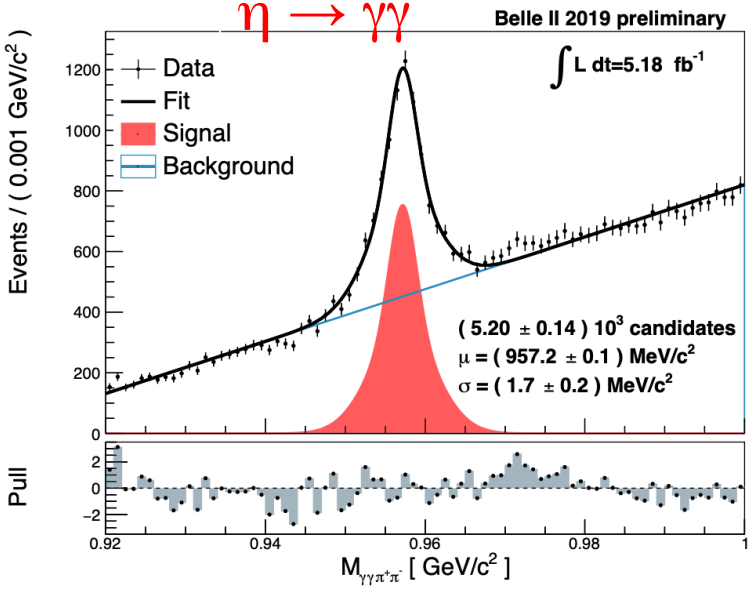
$\eta \to \pi^+ \pi^- \pi^0$



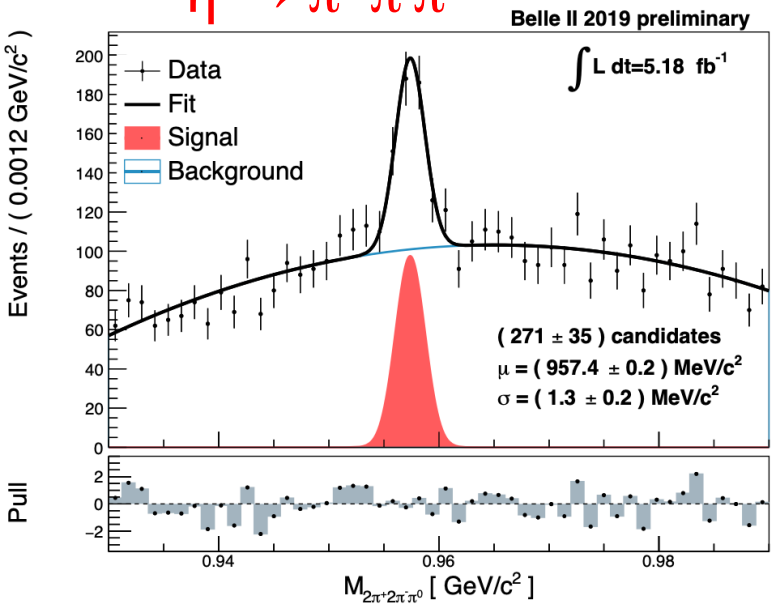
Targeting confirmation of $Y(4S) \to \eta' Y(1S)$ observation

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

$\eta \to \gamma\gamma$



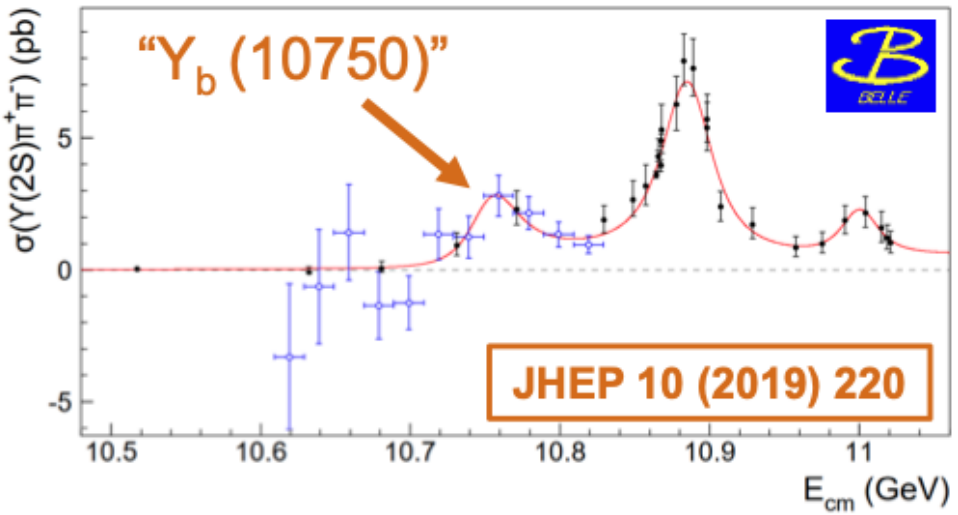
$\eta \to \pi^+ \pi^- \pi^0$

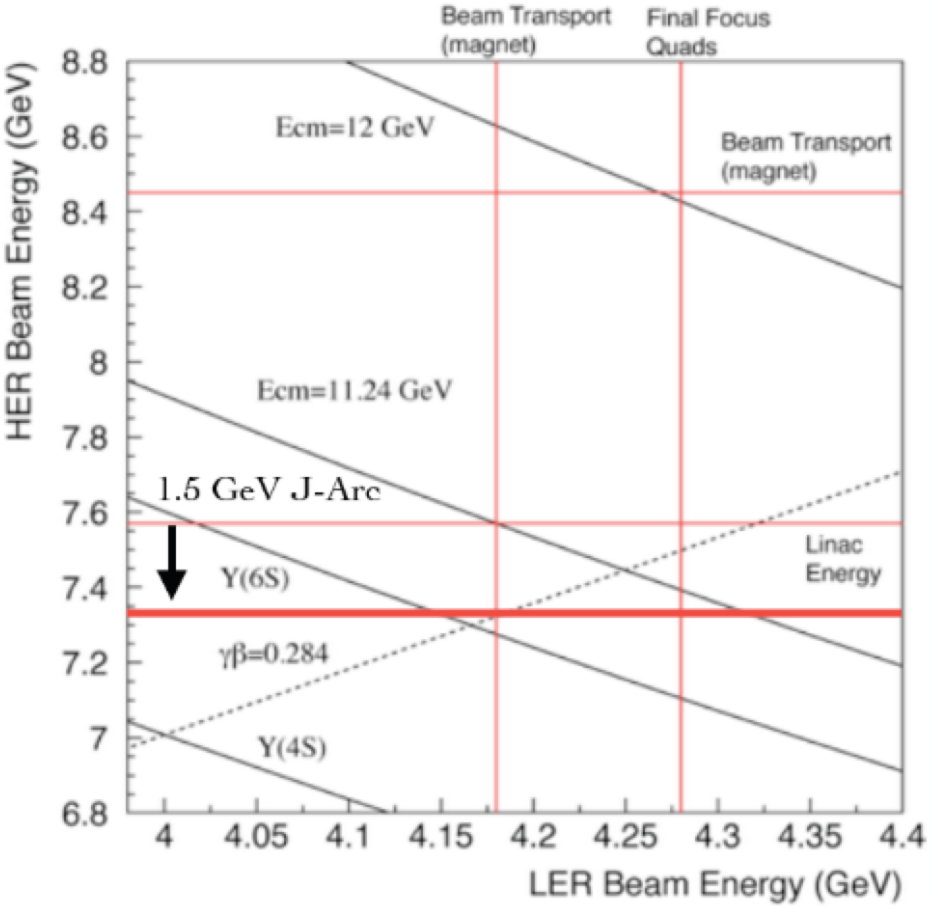


Near term running outside 4S peak

Lack of backup cavities prevents from running safely at Υ(6S) peak, at present. A pilot run of few fb^{-1} may be feasible, in any case.

Before 2022 shutdown, we may envisage running on a few points around 10.75 GeV, where Belle observed a bump hinting to the Y(4260) analogue in bottomonium.





Variety of Interpretations of the Y(10750):

- 3D wave vector state Chen et al, PRD101 (2020)014020
- 4D-5S mixture Li et al EPJC80(2020)59
- hybrid $b\bar{b}$ J.Tarrus Castella, ArXiV:1908.05179
- tetraquark Ali et al, PLB802 (2020) 135217

(see Parkhormenko on Jul.29)

Data taking below Υ(4S) requires Ldt budgets of the order of > 100 fb^{-1}.

Wrapping it up ....

Belle-II , despite the CoViD-19 crisis, is catching momentum

Inst.Luminosity world record in June: $2.4 \times 10^{34} cm^{-2} s^{-1}$

Total Ldt = 74 fb^{-1}, so far. Results with 37.8 fb^{-1} shown here

Observation of vector charmonia and bottomonia are becoming a standard tool for trigger and performance checks, during Belle-II starting phases.

Most rediscoveries of the XYZ states are expected after having harvested more than 250 fb^{-1}, i.e. after summer 2022 shutdown.

A high efficiency of inclusive reconstruction of η mesons will be very important for the re-discovery and further analysis of parabottomonia in the next years.

Some non-$\Upsilon(4S)$ running expected before the 2022 shutdown, possibly:
- around Ecm=10.75 GeV, to clarify the bump observed by Belle
- a pilot run at $\Upsilon(6S)$ peak, to search for more bottomonium-like states

Thanks for your attention !