Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

Exotic and conventional bottomonium studies at Belle II

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INFN - Sezione di Torino

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The big picture

Quarkonium physics is complex and extensive

$\rightarrow$ Decays in annihilation

$\rightarrow$ Decays in open flavor

$\rightarrow$ Spectroscopic levels

$\rightarrow$ Transition rates

$\rightarrow$ Prompt production modes

$\rightarrow$ Cross section line-shapes

$\rightarrow$ Rare and invisible decays

$\rightarrow$ Leptonic decays

Open questions: future research lines

1) **The $q\bar{q}$ description of spectroscopy is way too naive**

$\rightarrow$ Flourishing of effective models (molecule, tetraquark, cusp...)

$\rightarrow$ Light quarks are a dominant effect

$\rightarrow$ Hadronic transitions pattern is much more complicated

$\rightarrow$ No real solution in sight...

2) **We can make precision conventional spectroscopy**

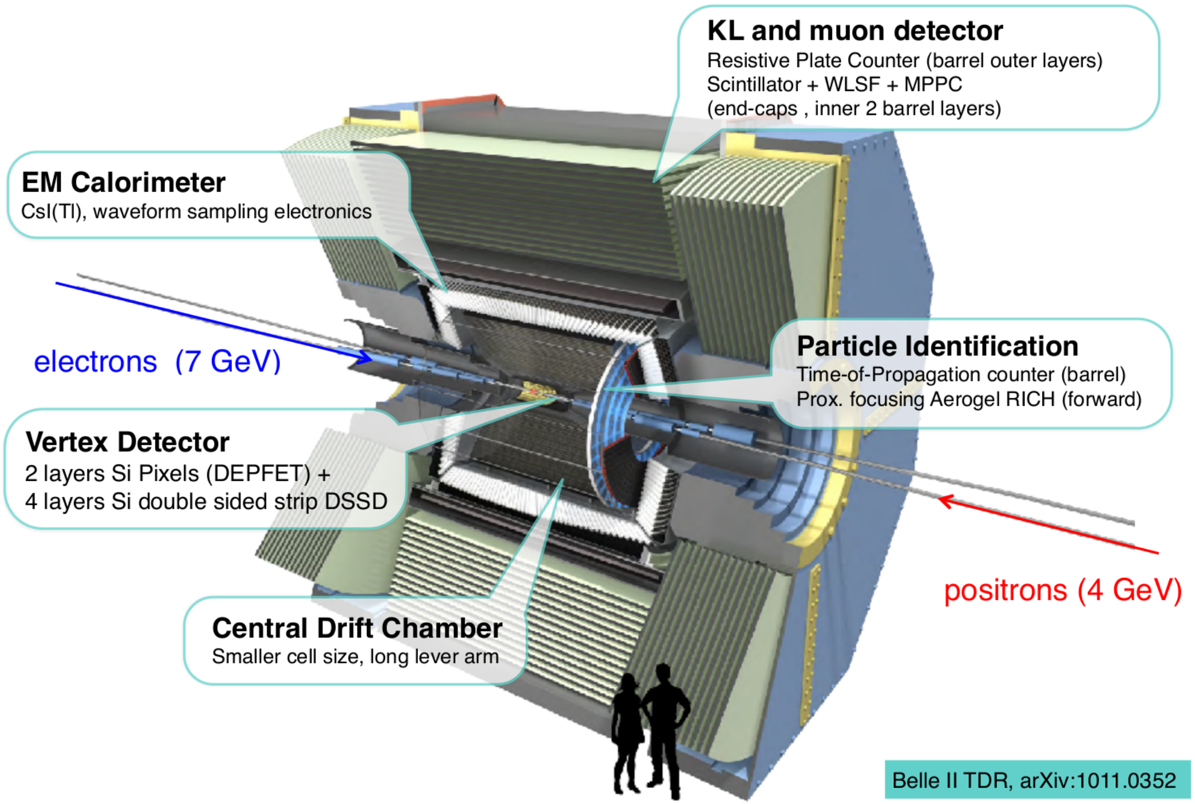
$\rightarrow$ NNLO NRQCD predictions on widths and splittings are available

3) **The bottomonium hadronic annihilations are surprising, unexplored and sensitive to the gluon fragmentation**

$\rightarrow$ Strangeness enhancement

$\rightarrow$ Large nuclei production

The Belle II detector

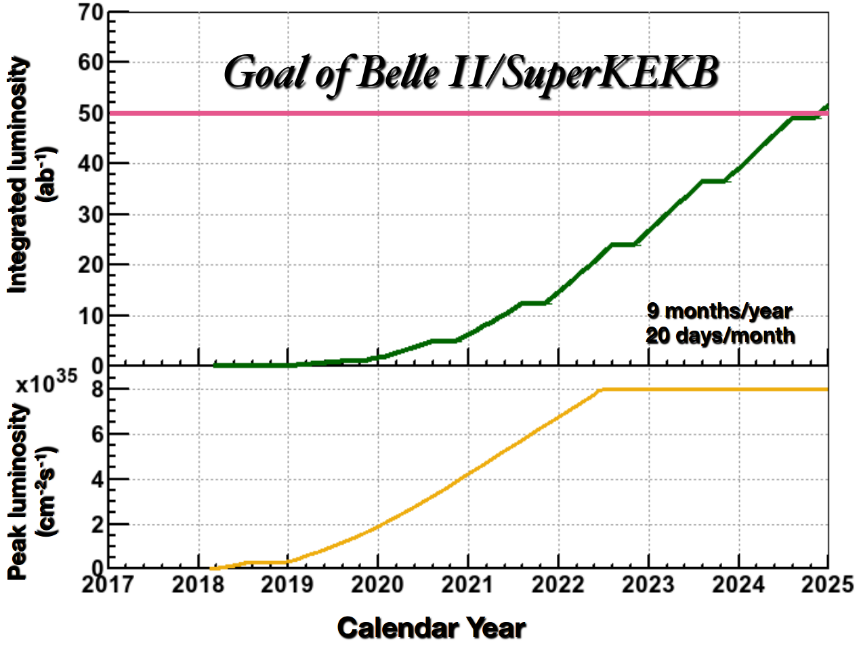


→ **See Higuchi-san's talk tomorrow**

The Belle II physics program

Current samples in fb^{-1} (millions of events)

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				5×10^4 (5.4×10^4)			



50x the Belle's $B\bar{B}$ sample by 2025

- → Rare B decays, NP
- → CP violation
- → τ physics
- → Bottomonium (Only Belle II can do it!)
- → Charmonium and Charmed baryons
- → Hyperons
- → Fragmentation functions
- → QED / low mult cross section
- → ...

The Belle II bottomonium program

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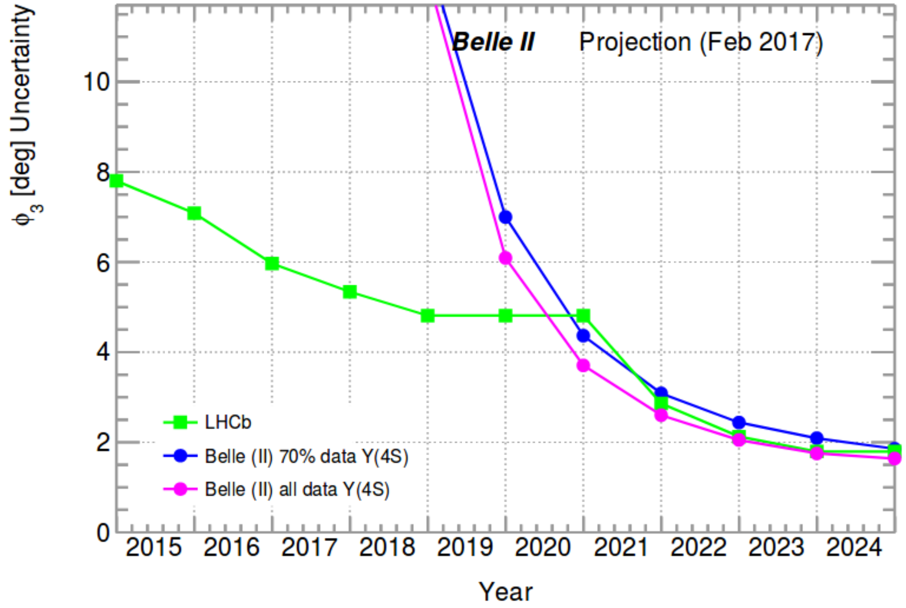

Head-to-head competition with LHCb on B physics

→ Unrealistic to spend 20% of our luminosity at non-Y(4S) energies

→ Bottomonium physics do not need 50x samples

The Belle II bottomonium program

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BelleII	-	-	300 (1200)	5×10^4 (5.4×10^4)	1000 (300)	100+400(scan)	3.6%

1.6% for bottomonium only

- Narrow states spectroscopy (Y(1D), χ_b(nP)...)
- Exotica as virtual contributions to transitions
- Precision NRQCD test
- New Physics (DM / light higgs)
- Missing hadronic and radiative transitions
- Baryon physics (inc. correlations)
- Anti-nuclei production (with DM applications)
- Gluon fragmentation
- Inclusive charmonium production and $D\bar{D}$ correlations
- LFV and LUV in Y(nS) decays

- Bs physics
- Exotica discovery
- Precision Zb mass measurement
- Missing hadronic and radiative transitions
- Light meson spectroscopy in transitions

- Exotica discovery
- Y(5S-6S) lineshape

The Belle II bottomonium program

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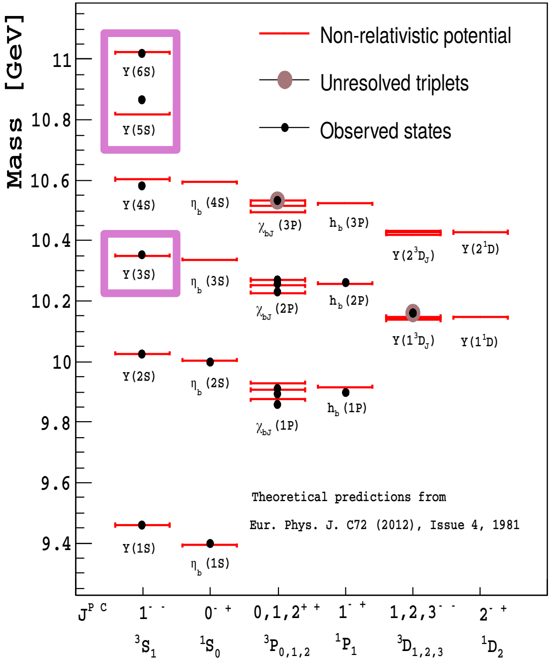


tl;dr:

Y(5S, 6S) $\rightarrow$ Exotica and conventional bottomonia

Y(3S) $\rightarrow$ Annihilations, fragmentation, light hadrons and conventional bottomonia

Selected topics: Spectroscopy

→ Search for exotica

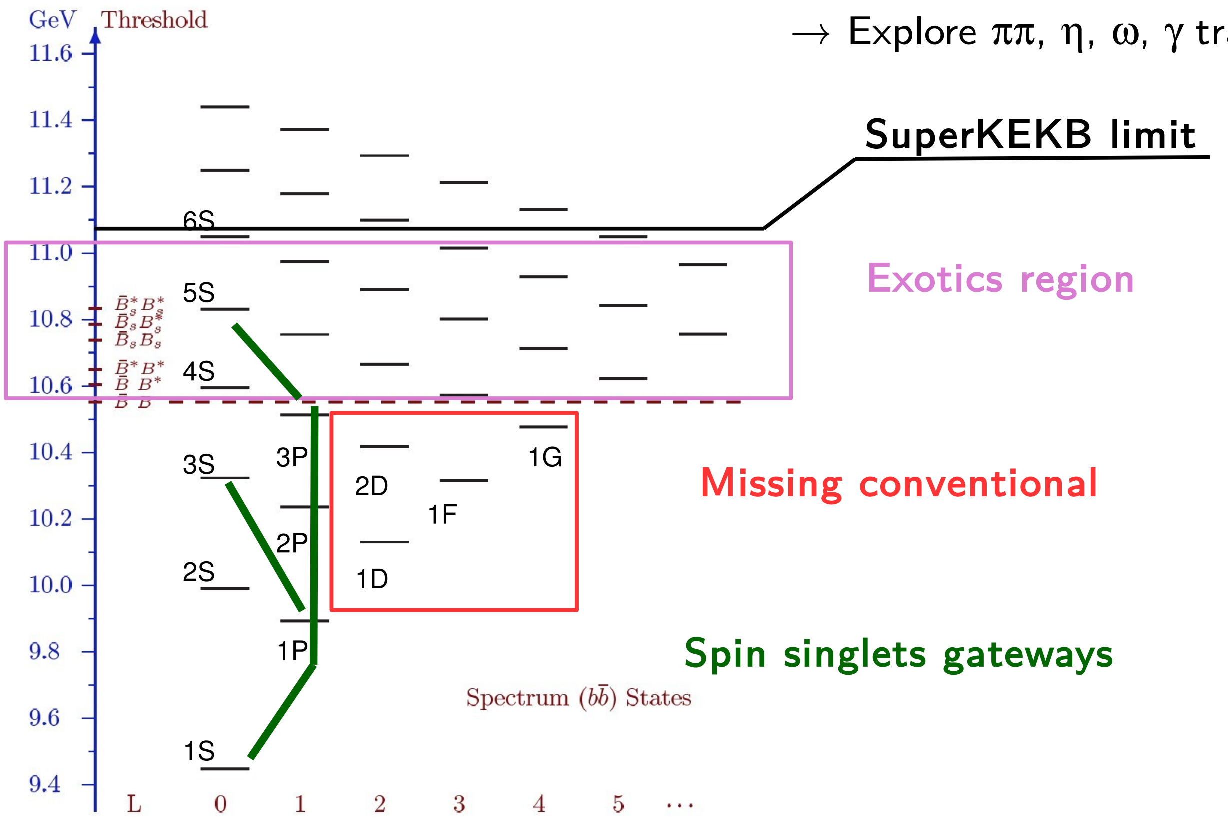
→ Precision tests of NRQCD

Exotica: General strategy

How to maximize the discoveries?

→ Take data as high in energy as possible (but on a resonance)

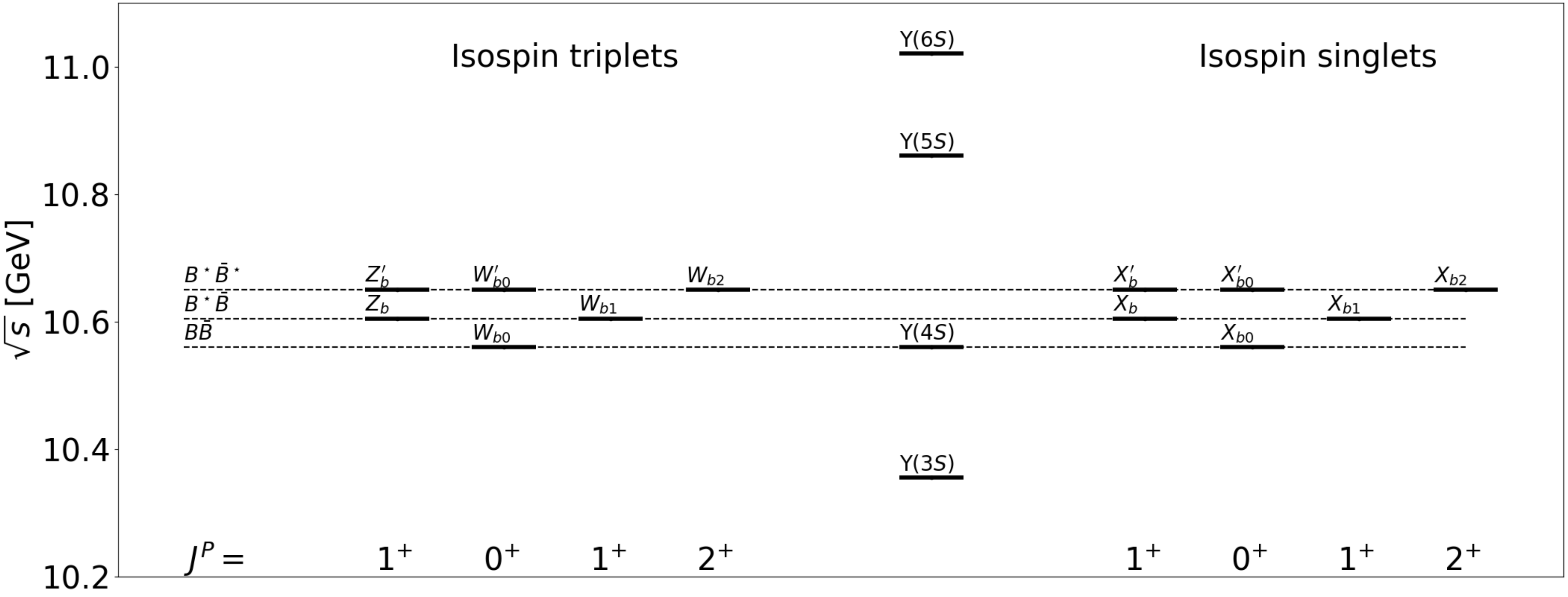
→ Explore ππ, η, ω, γ transitions (exclusive, inclusive, multiple...)



Exotic states: direct search

If the Z_b is a loosely bound state, then several other molecules must appear at the thresholds

Re-elaborated from Mod. Phys. Lett. A 32, 1750025 (2017)



→ These new states are accessible via η, ρ or γ transitions form Υ(nS) (tables in the backup)

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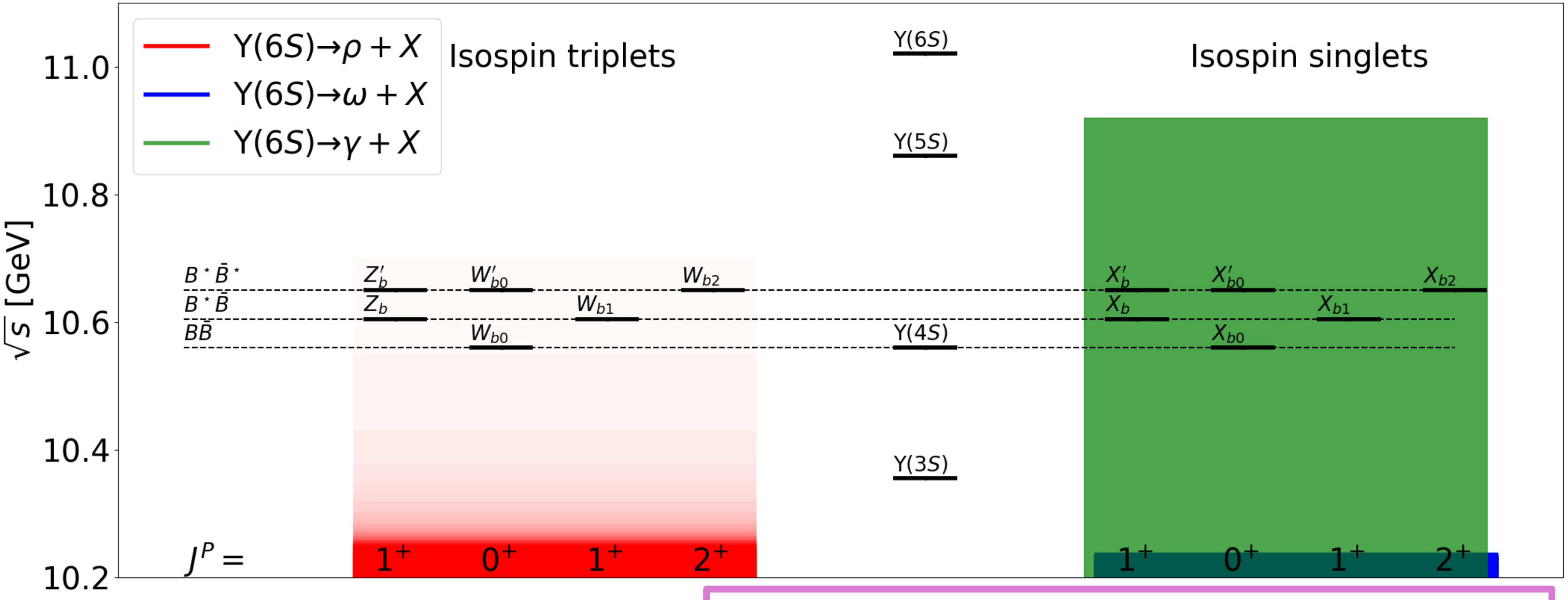


→ ρ PHSP suppression: 0.5%

→ g transitions are probably more appealing

Belle II goals:

→ Υ(6S): 100 fb^{-1} exploratory run

→ Υ(5S): 1 ab^{-1} “high statistics” run

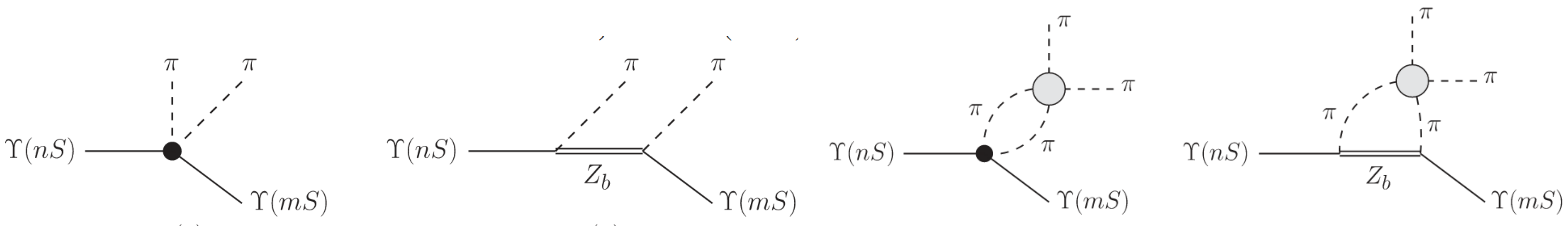
Exotic states: ***in***direct search

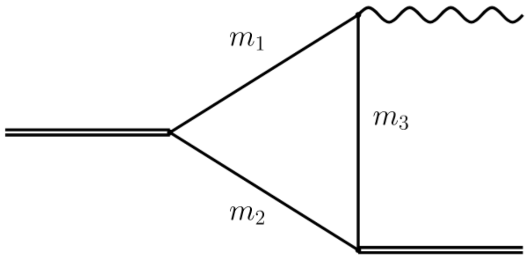
Exotic stats contribute to the <u>hadronic and radiative</u> transitions from narrow quarkonia

→ Complementary approach to the direct search from the Υ(5S) and Υ(6S)

Y.H. Chen et al, PRD93 (2016) 034030

Physics Letters B 760 (2016) 417–421





Belle II Goals:

→ Perform full amplitude analysis of Υ(3S) → ππ Υ(1S), Υ(2S)

→ Branching ratio of hindered radiative transitions

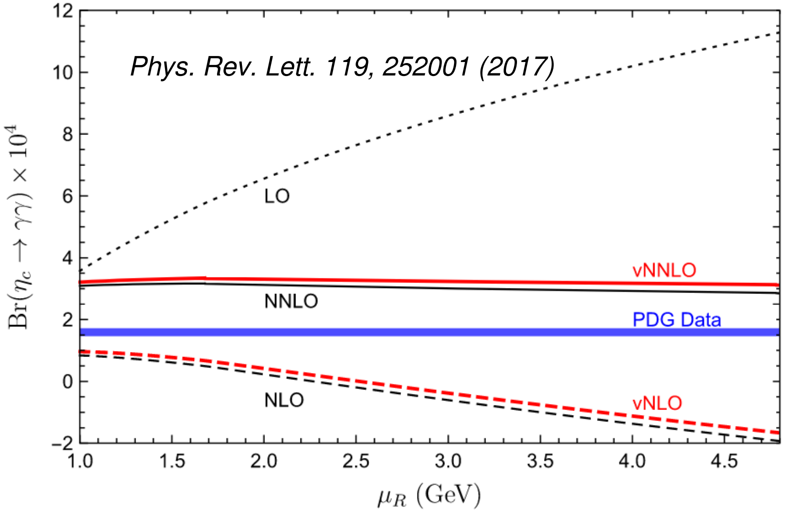
NRQCD crisis in charmonia

Theoretical progresses are producing more and more precise predictions, but we start seeing large discrepancies with the data

→ Quarkonia is a privileged ground to approach the NPQCD problem and test new theories.

→ NNLO predictions on $\eta_c \to \gamma\gamma$: 1700+ diagrams computed 10^5 CPU hrs, and still a large discrepancy with the measurement (and slow convergence?)

→ Are we about to witness the crisis of the NRQCD?

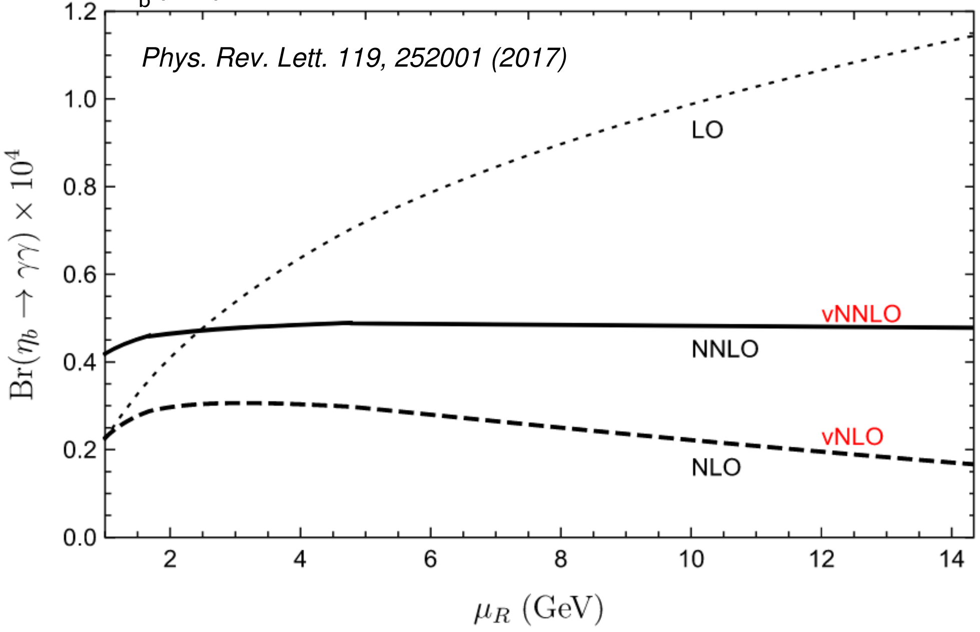


Bottomonium is even less relativistic!

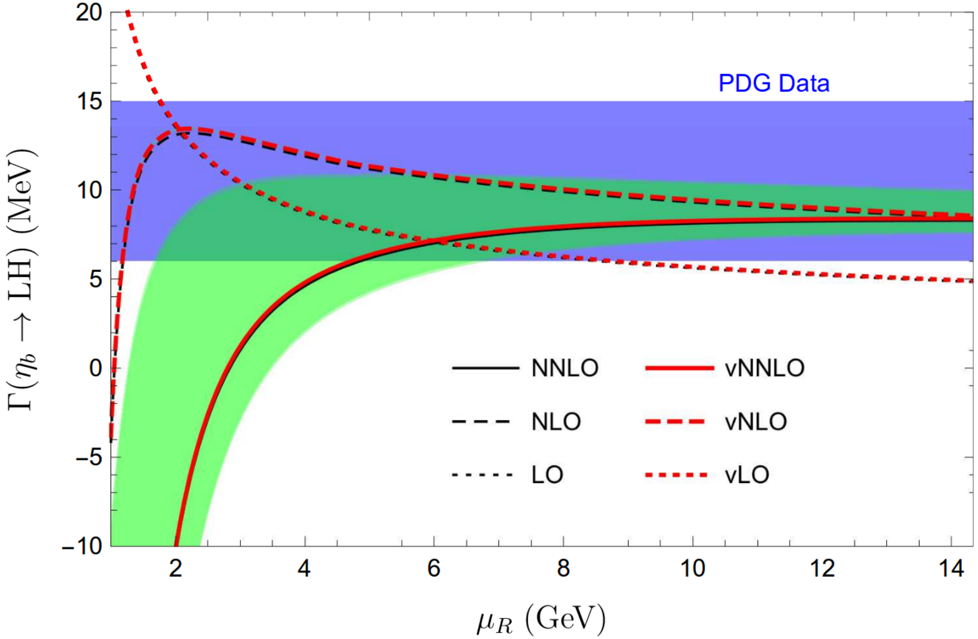
Precision NRQCD: the $\eta_b(1S)$

The $\eta_b(1S)$ is very well known theoretically, but the experimental measurements poor or absent

$\eta_b(1S) \to \gamma\gamma$, No measurements



$\eta_b(1S)$ total width, Poor measurements

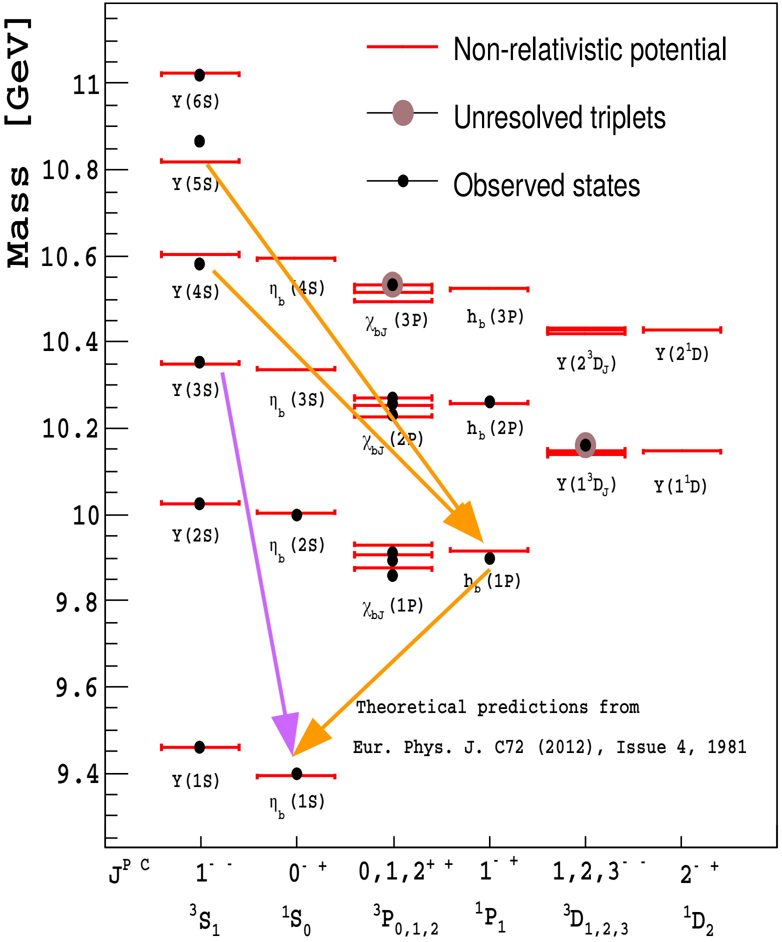


Precision NRQCD: The Belle II prospects

Belle II $\eta_b(1S)$ samples:

5 Millions with η,ππ+γ tag from Υ(4S, 5S) [50x Belle]

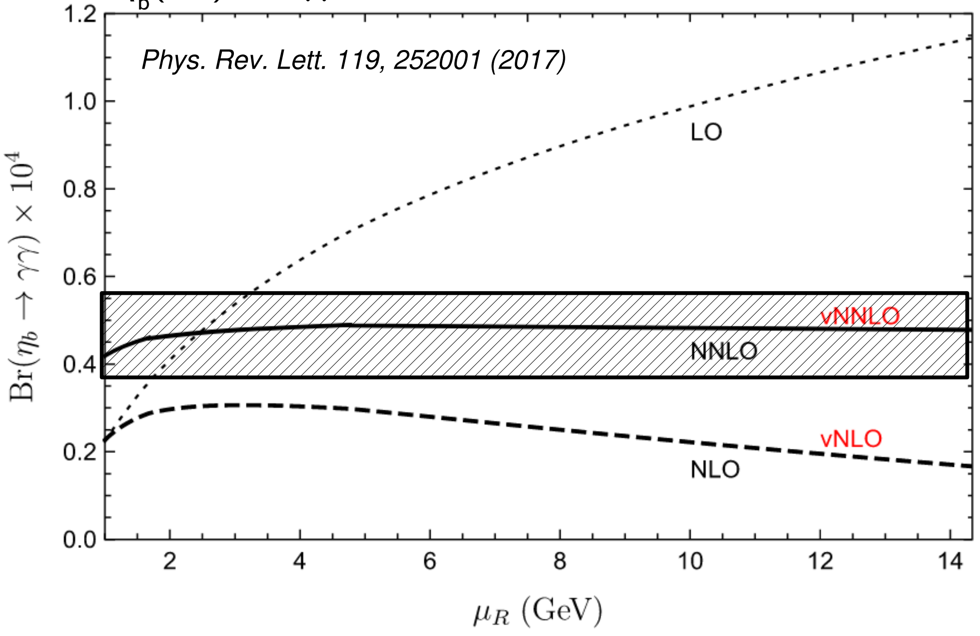
0.5 Millions with γ tag from Υ(3S) [10x BaBar]



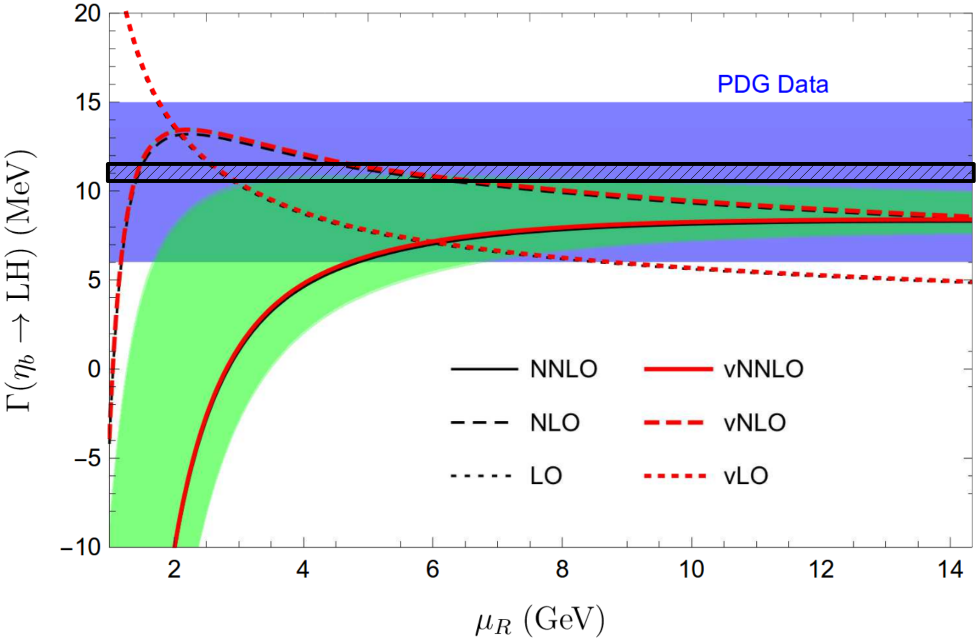
Precision NRQCD: The Belle II prospects

Belle II projection (approximate)

$\eta_b(1S) \to \gamma\gamma$



$\eta_b(1S)$ total width



Selected topics: Two ideas to exploit the annihilations

→ Inclusive production of exotic charmonia

→ Deuteron production

Annihilations overview

Y(nS) $\rightarrow$ ggg is a small hadronic event

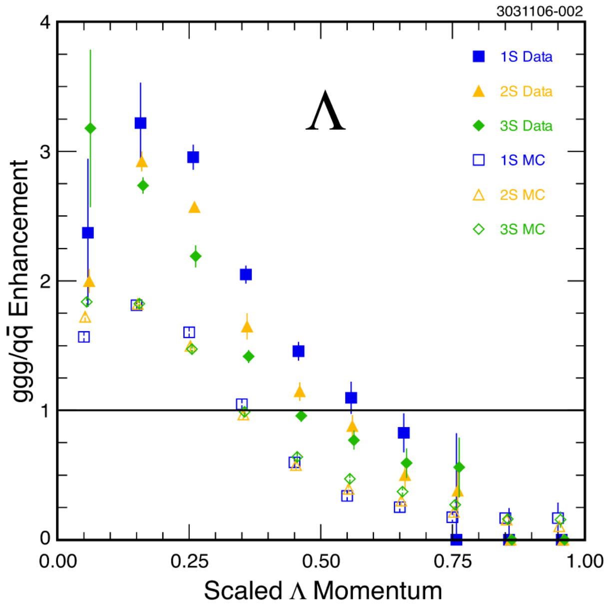
- $\rightarrow$ 10-15 particles, but very high energy density (~10 GeV / fm^3)
- $\rightarrow$ Common features with heavy ion / pp collisions

Production of charmonia

Phys. Rev. D 93, 112013

Baryon and strangeness enhancement

PRD76 012005 (2007)



Production of nuclei

Phys.Rev. D89 (2014) no.11, 111102

Process	Rate
$\mathcal{B}(\Upsilon(3S) \rightarrow \bar{d}X)$	$(2.33 \pm 0.15^{+0.31}_{-0.28}) \times 10^{-5}$
$\mathcal{B}(\Upsilon(2S) \rightarrow \bar{d}X)$	$(2.64 \pm 0.11^{+0.26}_{-0.21}) \times 10^{-5}$
$\mathcal{B}(\Upsilon(1S) \rightarrow \bar{d}X)$	$(2.81 \pm 0.49^{+0.20}_{-0.24}) \times 10^{-5}$
$\sigma(e^+e^- \rightarrow \bar{d}X)$ $[\sqrt{s} \approx 10.58\,\text{GeV}]$	$(9.63 \pm 0.41^{+1.17}_{-1.01})$ fb
$\frac{\sigma(e^+e^- \rightarrow \bar{d}X)}{\sigma(e^+e^- \rightarrow \text{Hadrons})}$	$(3.01 \pm 0.13^{+0.37}_{-0.31}) \times 10^{-6}$

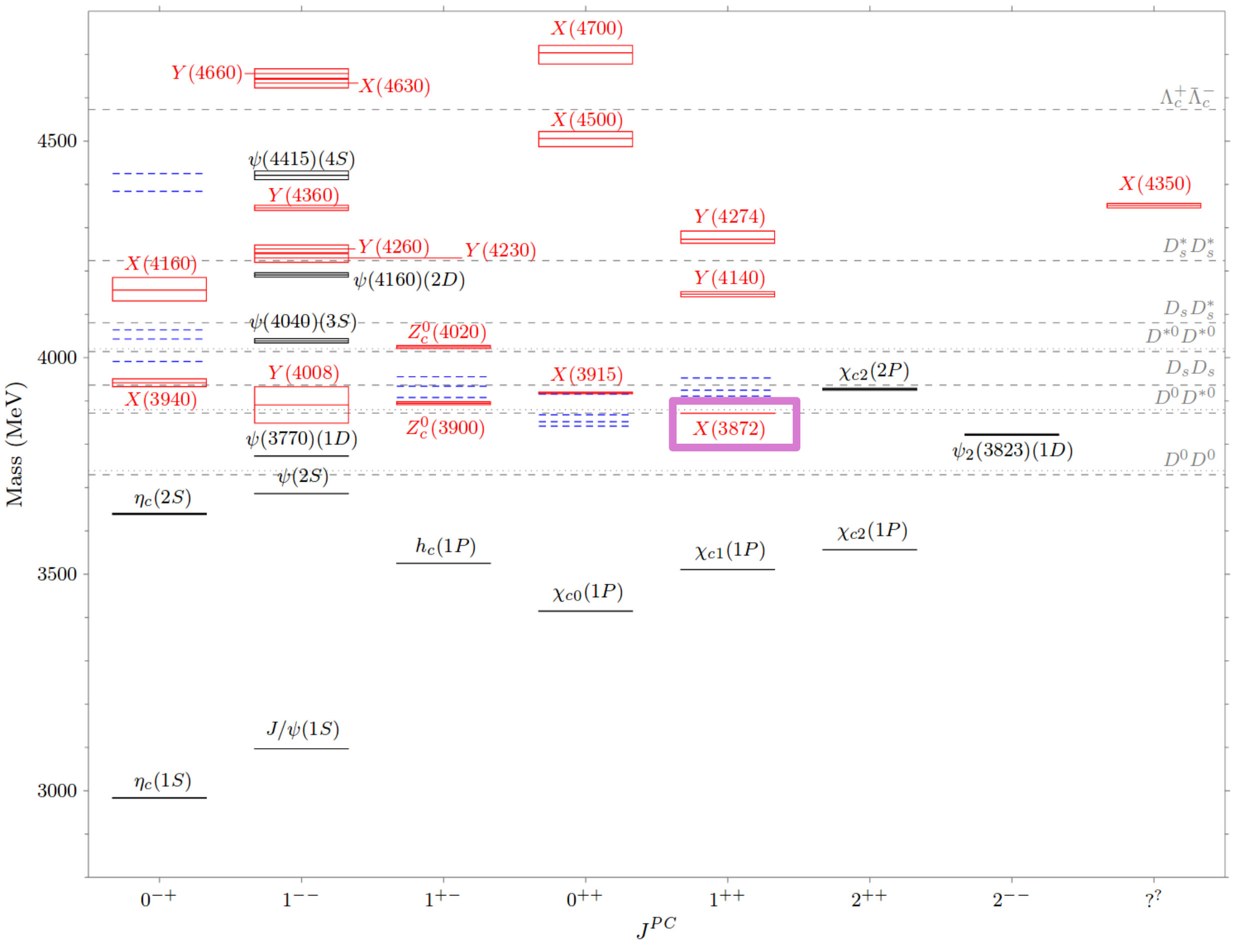
Anti-deuteron is 10 times more abundant in Y(nS) $\rightarrow$ ggg than in $e^+e^- \rightarrow q\bar{q}$ at the same energy

Idea nr. 1: Charmonia production

We have observed ~20 exotic charmonia in different channels

→ Usually each one appears in one channel only

→ Only the X(3872) has been seen in inclusive prompt production ($\sigma \times$ BF ~ 7% of ψ')



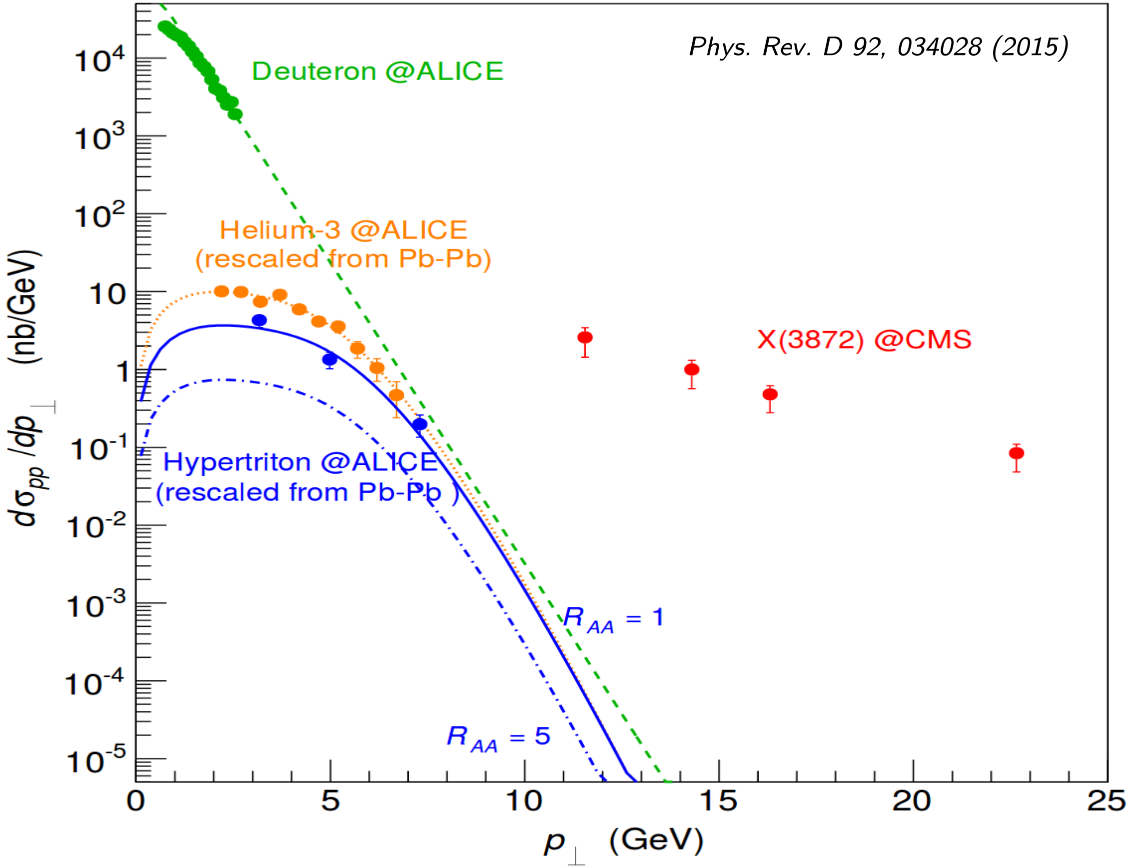
Idea nr. 1: Charmonia production

We have observed ~20 exotic charmonia in different channels

→ Usually each one appears in one channel only

→ Only the X(3872) has been seen in inclusive prompt production ($\sigma \times BF \sim 7\%$ of ψ')

→ Evidence of non-molecular nature?

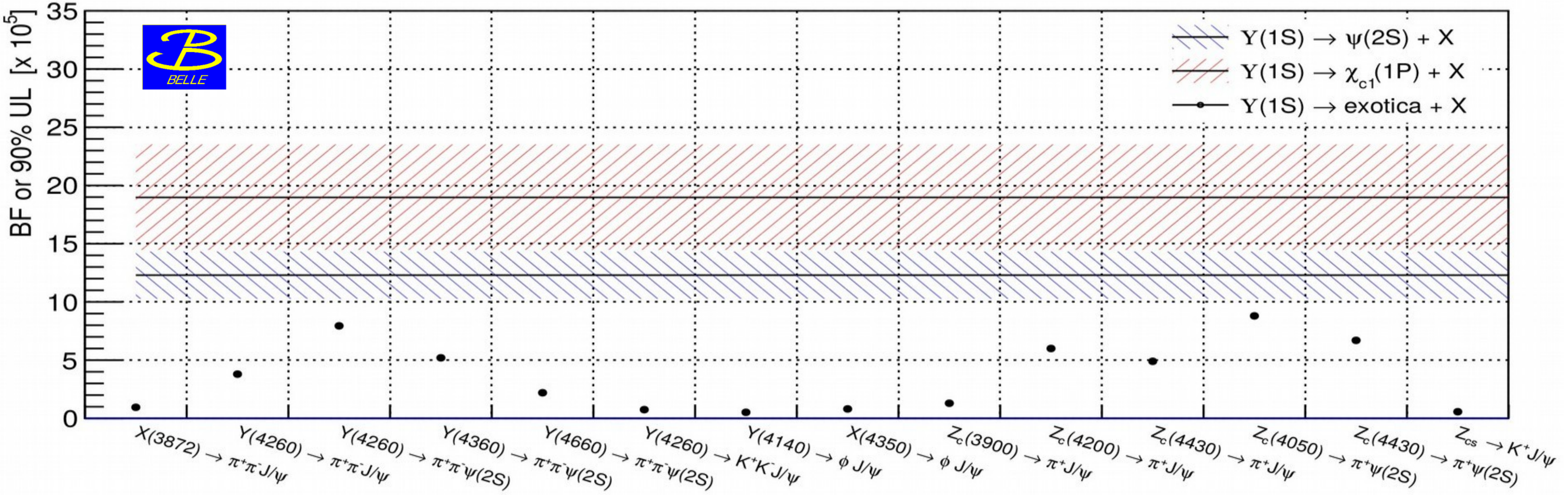


Idea nr. 1: The Belle experience

Belle searched for exotica in $\Upsilon(nS)$ annihilations

$\rightarrow$ No signal, strongly statistically limited analysis!

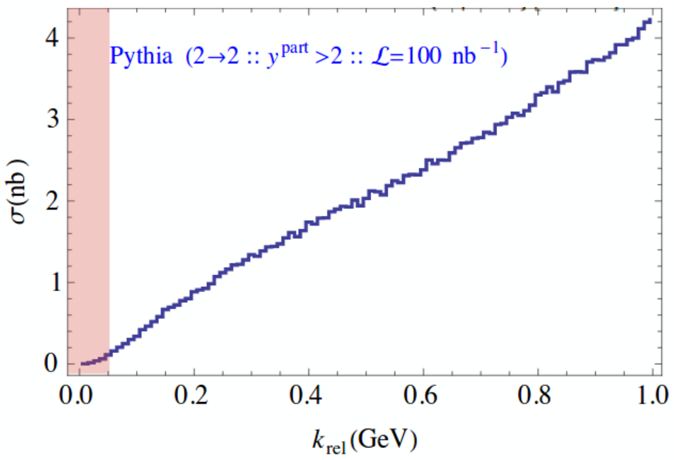
Based on Phys. Rev. D 93, 112013 [Belle]



$\rightarrow$ **Can we get anything more than just statistics from Belle II?**

Idea nr. 1: DD* correlations

- Production at Colliders speaks against extended objects;
- using Pythia to estimate the probability to find a D-Dbar pair in the relevant phase space, factors of 10^{-2} with respect to the X(3872) cross section measured by CDF (~ 30 nb) are found.



L. Maiani's talk at "Bound states in strongly coupled systems"

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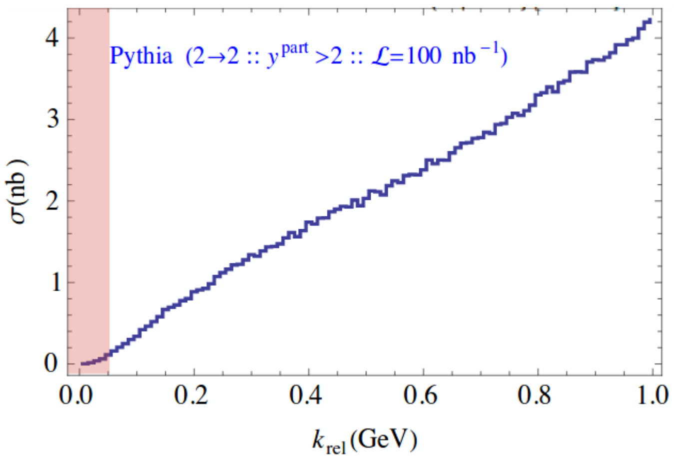


L. Maiani's talk at "Bound states in strongly coupled systems"

BaBar measured a reasonably high production of D* from Y(1S) annihilations $B[Y(nS) \to D^* + X] = 2.5\%$

Belle II will have:

→ ~10x the data

→ Better efficiency at low momenta

We can aim for associated DD* and (maybe) DD* correlations, and if we actually observe also the X(3872)…

Idea nr. 2: Bottomonium for astrophysics

Donato, Fornengo, Salati, PRD 62, 043003 (2000)
Aramaki et al. Phys. Rept. 618 (2016) 1-37

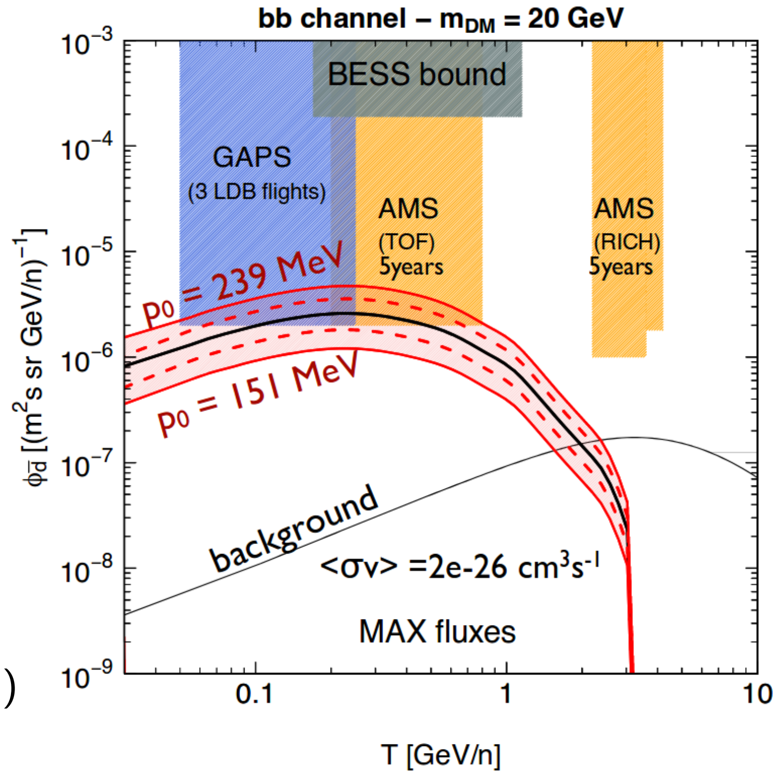
$\bar{d}$ detection in cosmic rays is considered since long a probe for low or intermediate mass WIMPs

→ Anti-deuteron production is described by **p-n coalescence models tuned on the HEP data**

$$\frac{dN_{\bar{d}}}{dT_{\bar{d}}} = \frac{p_0^3}{6} \frac{m_{\bar{d}}}{m_{\bar{n}} m_{\bar{p}}} \frac{1}{\sqrt{T_{\bar{d}}^2 + 2m_{\bar{d}} T_{\bar{d}}}} \frac{dN_{\bar{n}}}{dT_{\bar{n}}} \frac{dN_{\bar{p}}}{dT_{\bar{p}}}$$

→ Most recent data are from Alice (large final state, MC-driven correction)

→ Strong need to further constrain the $\bar{d}$ production model (new AMS-02 data are coming, **few $\overline{He3}$ could have been observed**)



Idea nr. 2: Deuteron production at Belle II

Dedicated PID software is being developed to minimize systematics

→ Neither Belle nor BaBar had specific deuteron ID form the very beginning

Belle II goals

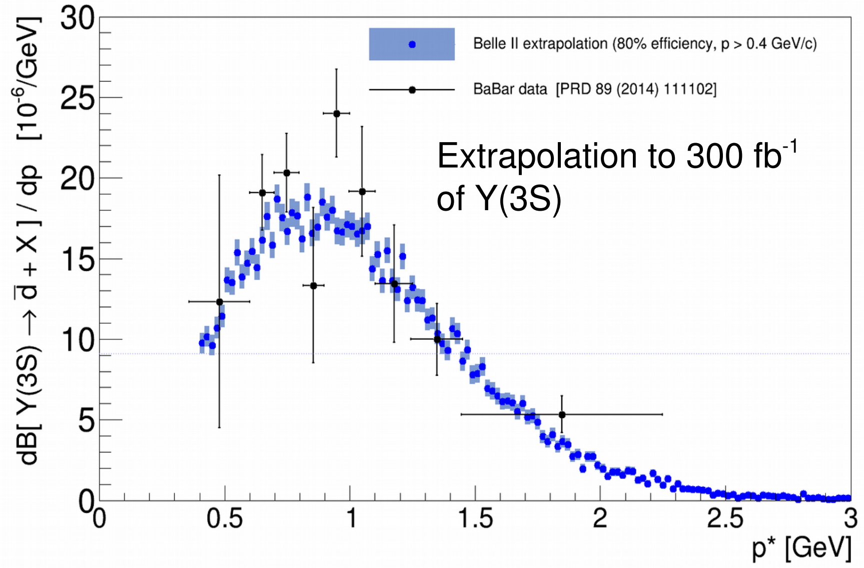
→ BF[Y(3S) → $\bar{d}$+ X] = 3 x 10^{-5}

→ Collect ~30000 $\bar{d}$, with dedicated tracking and PID

→ Get the world best estimate of the coalescence parameter

→ Simultaneous fit of the proton spectrum to reduce the model systematics

→ $d\bar{d}$ associated production



Wrapping it up

Belle II offers:

→ Improved tracking (efficiency and resolution)

→ Improved hermeticity (smaller boost)

→ 8-10x Belle statistics

→ 10 MeV-wide cross section scans

Belle II could take

→ O(ab^{-1}) at Υ(5S)

→ Fine-grained scan around Υ(5S) and Υ(6S)

→ O(1 Billion) Υ(3S)

Unfortunately, nothing comes for free

→ BelleII is mainly focused on BSM physics in the weak sector

→ Most of the data taking will take place at Υ(4S) for B physics: max 30% of data off-Υ(4S), including continuum

→ Competition with LHCb is pressing

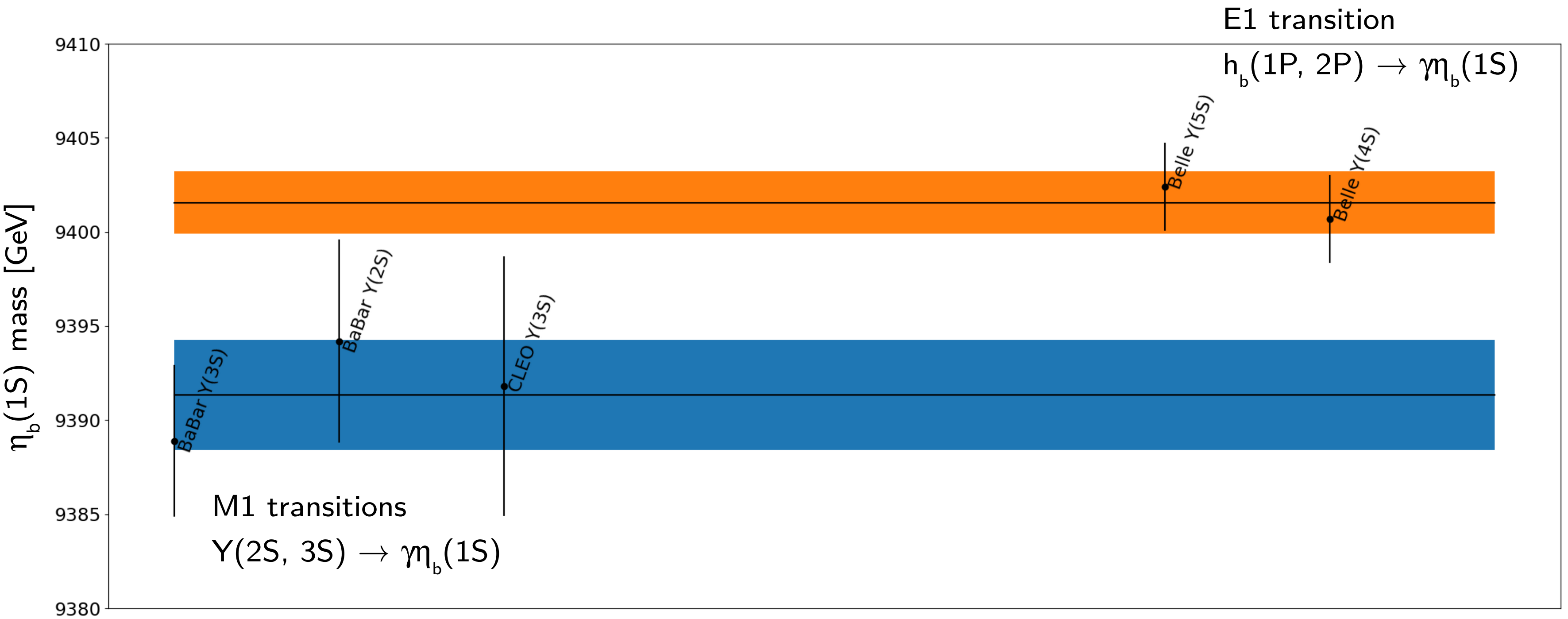
Support and inputs from **all** the QCD theoretical physics communities are welcome!

Backup

Precision NRQCD: the $\eta_b(1S)$ status

The $\eta_b(1S)$ is very well known theoretically, **but the experimental measurements are poor and inconsistent**

$\rightarrow$ Precision test of NRQCD (Precision soft QCD?)

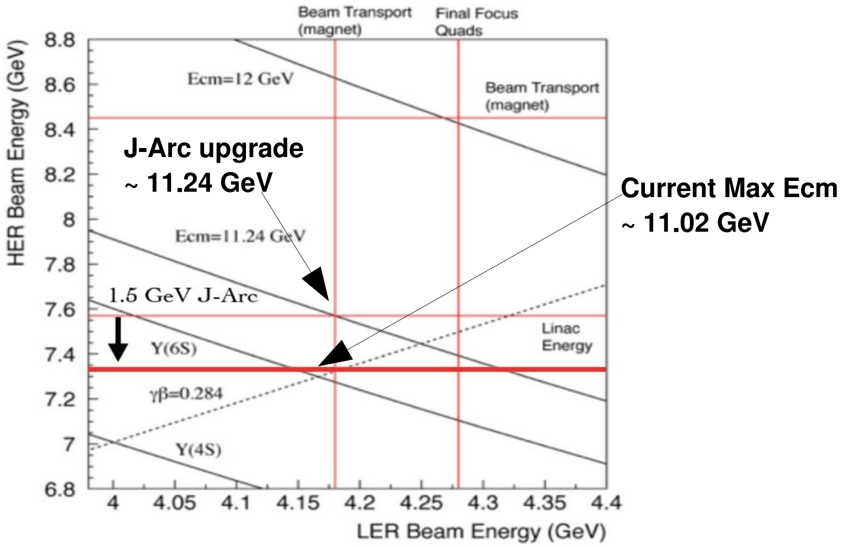


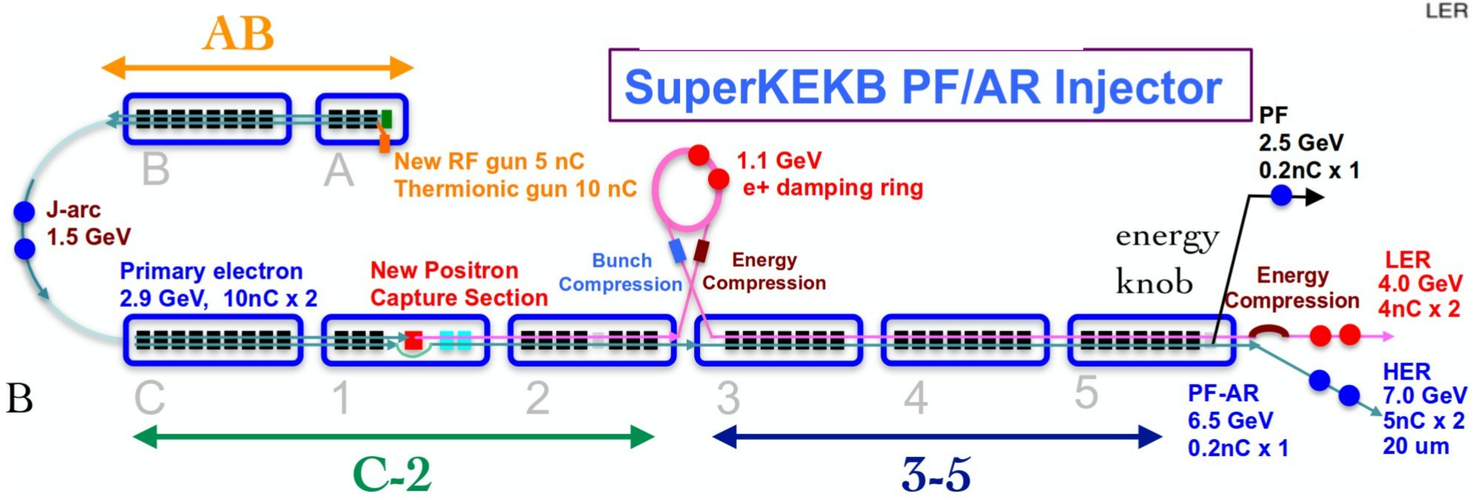
Accelerator requirements for bottomonium

→ Present max E_{cm} = ~ 11.02 GeV, a bit above Υ(6S)

→ Need to run safely at this energy

→ Would greatly profit from a linac upgrade to reach 11.24 GeV (see next slide)





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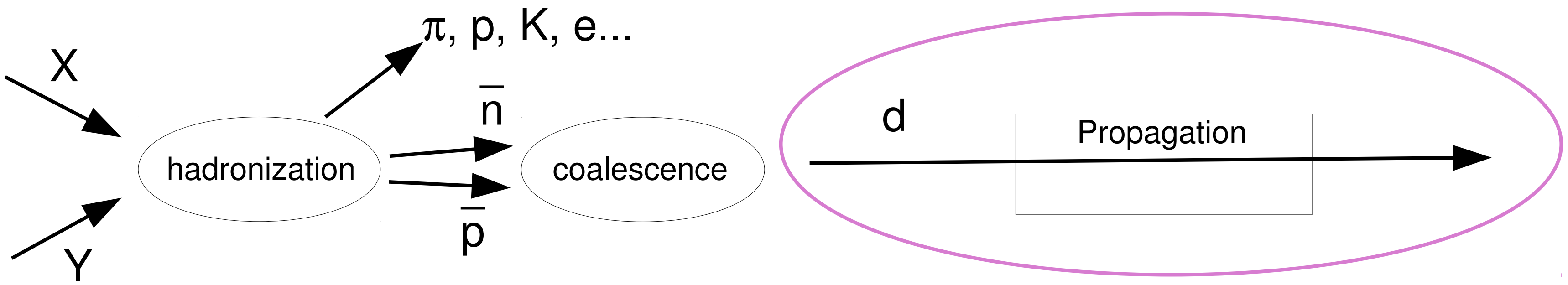
$\bar{d}$ detection in cosmic rays is considered since long a probe for low or intermediate mass WIMPs

$\rightarrow$ it's kinematically easier to produce a d from $\chi\chi$ annihilation than from SM processes



Nuclear uncertainties

$\rightarrow$ $\bar{p}$ and $\bar{n}$ production rates

rel. uncertainty $\sim$ 10

$\rightarrow$ $\bar{d}$ production model

rel. uncertainty $\sim$ $\sim$ 50 - 200

Astrophysical uncertainties

$\rightarrow$ Galactic density profile

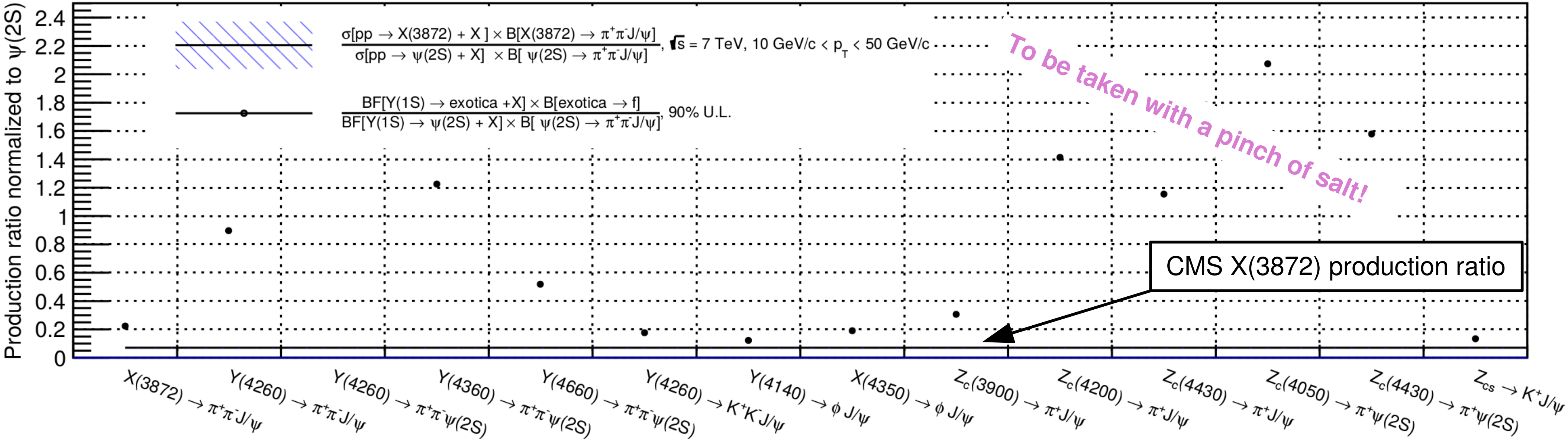
rel. uncertainty $\sim$ 20

$\rightarrow$ Transport models

rel. uncertainty $\sim$ 500

Idea nr. 1: Y(nS) for exotic charmonia

A tentative comparison between Belle and CMS.



Belle II prospects with 300 fb^{-1}:

→ 3-5 x sensitivity in inclusive production from Y(3S)

B[Y(nS) → X(3872)+had] / B[Y(nS) → ψ'+had] > 7%

→ 10-15 x sensitivity in double charmonium

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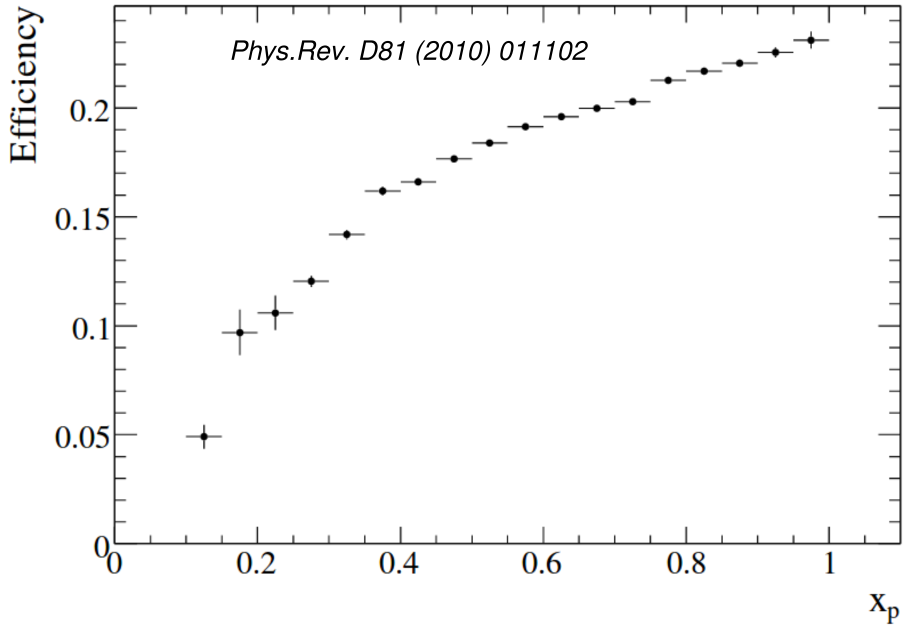
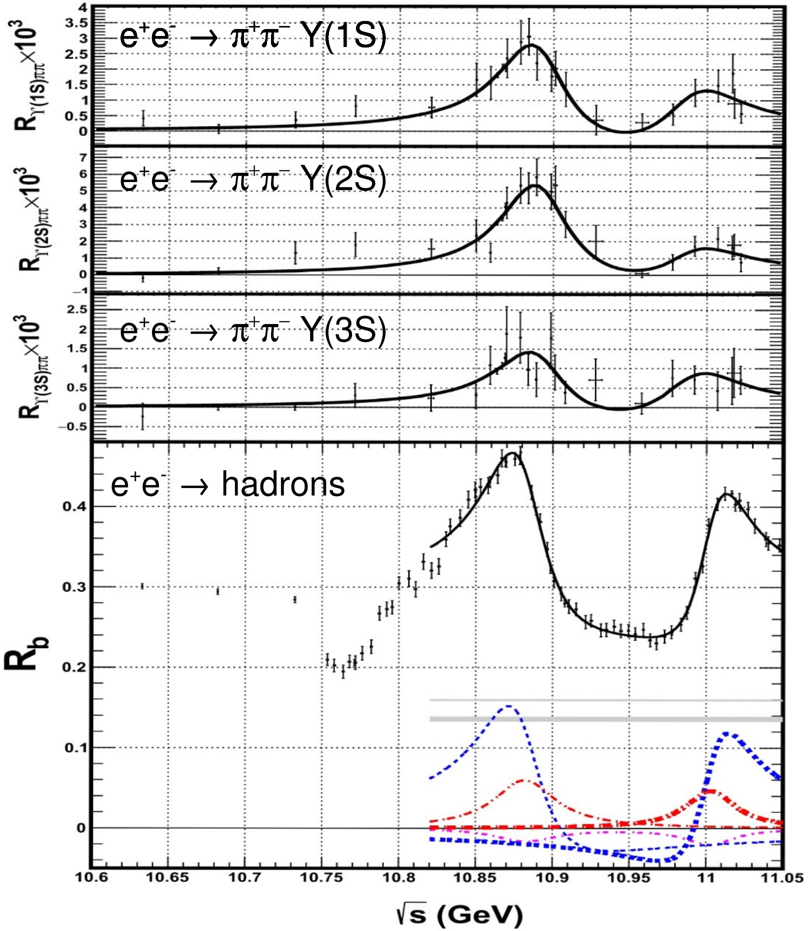
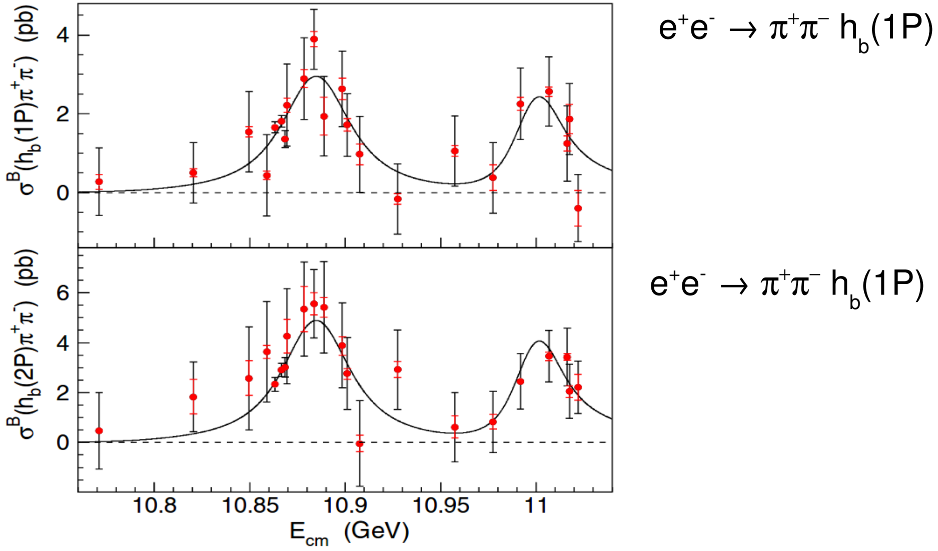


FIG. 3: Reconstruction efficiency for the decay chain $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$, $\Upsilon(1S) \to D^{*\pm}X$ as a function of the scaled $D^{*\pm}$ momentum x_p.

Exotica in direct production

Phys. Rev. D 93, 011101 (2016)





Belle II scan goal:

→ Investigate the presence of a broad resonance at 10.750 GeV

→ 10 MeV wide steps, 10 fb^{-1} each (10x Belle scan)

→ Y(5S) and Y(6S) line-shapes in R, $R_{Y\pi\pi}$ and $R_{h\pi\pi}$

→ Rb decomposition (BB, BB*, B*B*, BB*π, B*B*π, BsBs ...)

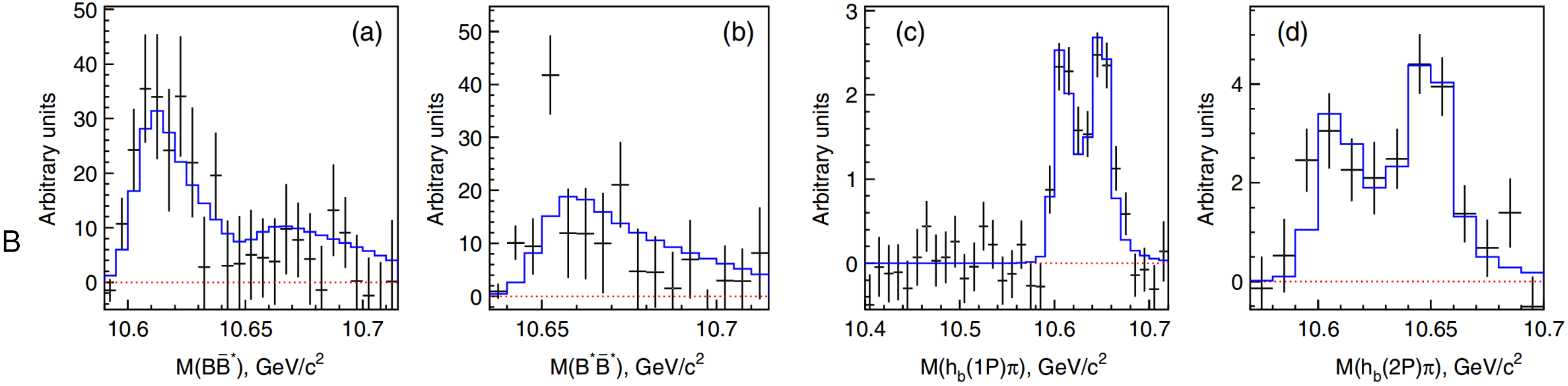
→ Overall goal: settle the nature of the Y(5S)

Precision measurements: the Z_b masses

The measurement of the Zb masses is foundamental to determine their nature: are they above or below the $B^{(*)}B^*$ thresholds?

→ Equivalent to the X(3872) mass problem: above or below the open threshold?

Phys. Rev. D 93, 074031 (2016)



Current best estimate of the Zb location with respect to the thresholds:

$$\varepsilon_B(Z_b) = (0.60^{+1.40}_{-0.49} \pm i0.02^{+0.02}_{-0.01})\ \mathrm{MeV},$$

$$\varepsilon_B(Z_b') = (0.97^{+1.42}_{-0.68} \pm i0.84^{+0.22}_{-0.34})\ \mathrm{MeV},$$

Belle II Goals:

→ Determine if the Zb are located above or below the open flavour threshold using 1 ab^{-1} of Y(5S)

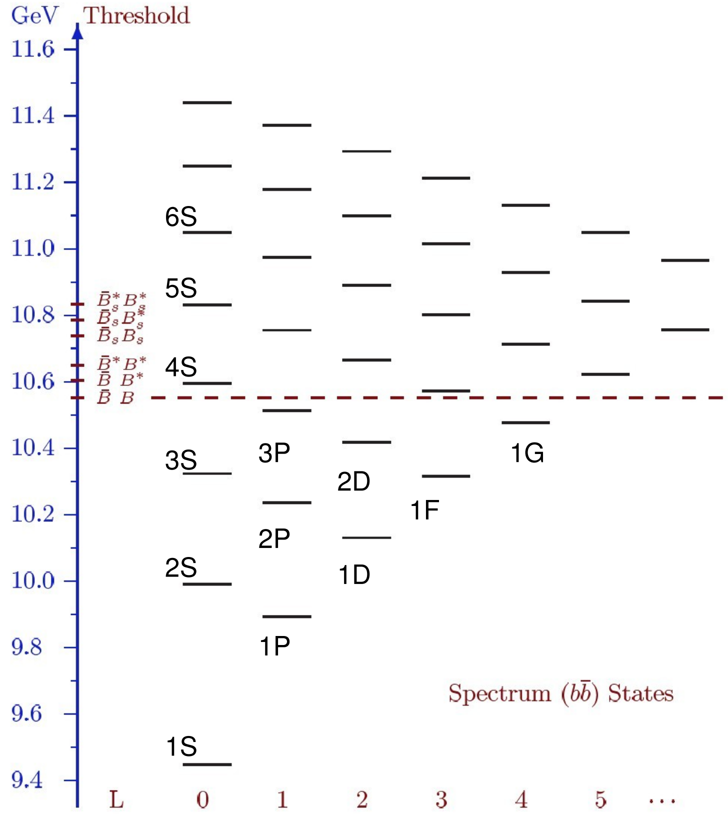
→ **Stat. Uncertainty from 1. to 0.3 MeV**

Conventional states: direct search

→ Υ(5S)-Υ(6S) are portals to the missing narrow states

→ Υ(5S) → η Υ(1D) is the largest Υ(5S), single-meson transition

→ The conventional spectrum gets contributions from the couple channel effect (again, light quarks...)



Mod. Phys. Lett. A 32, 1750025 (2017)

Name	L	S	J^{PC}	Emitted hadrons [Threshold, GeV/c^2]
$\eta_b(3S)$	0	0	0^{-+}	ω [11.12], ϕ [11.36]
$h_b(3P)$	1	0	1^{+-}	$\pi^+\pi^-$ [10.82], η [11.09], η' [11.50]
$\eta_{b2}(1D)$	2	0	2^{-+}	ω [10.93], ϕ [11.17]
$\eta_{b2}(2D)$	2	0	2^{-+}	ω [11.23], ϕ [11.47]
$\Upsilon_J(2D)$	2	1	$(1,2,3)^{--}$	$\pi^+\pi^-$ [10.73], η [11.00], η' [11.41]
$h_{b3}(1F)$	3	0	3^{+-}	$\pi^+\pi^-$ [10.63], η [10.90], η' [11.31]
$\chi_{bJ}(1F)$	3	1	$(2,3,4)^{++}$	ω [11.14], ϕ [11.38]
$\eta_{b4}(1G)$	4	0	4^{-+}	ω [11.31], ϕ [11.55]
$\Upsilon_J(1G)$	4	1	$(3,4,5)^{--}$	$\pi^+\pi^-$ [10.81], η [11.08], η' [11.49]

Belle II goals:

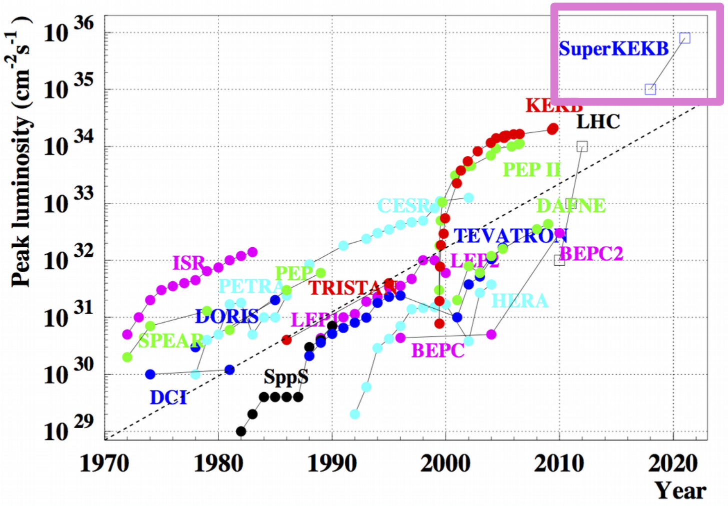
→ Search for new, predicted, resonances

→ Use both single transitions and double cascades

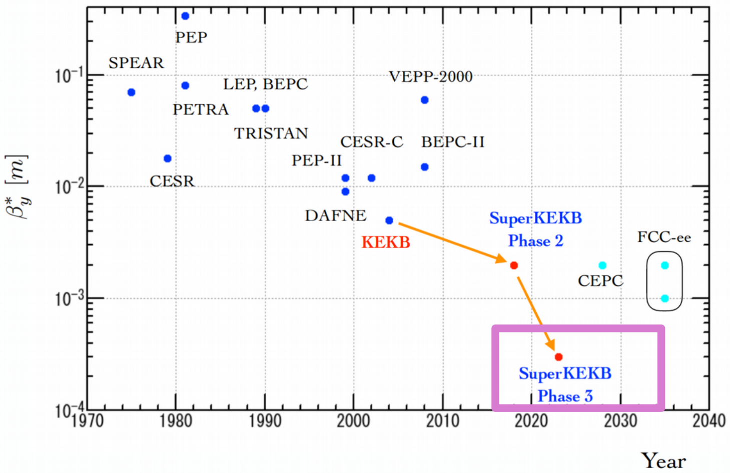
→ Fill the remaining spectrum to measure the effects of the coupled channels contributions

Super-KEKB

Super-KEKB aims for **8 x 10^{35} cm^{-2} s^{-1}**

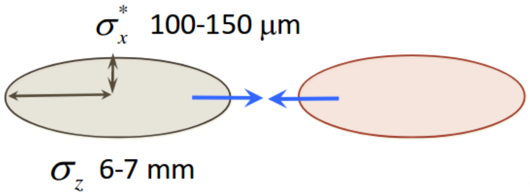


SuperKEKB will try to make the smallest β_y* in the world !



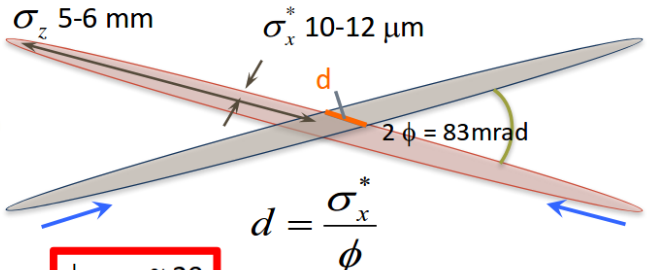
P. Raimondi

KEKB head-on (crab crossing)



interaction region = bunch length

Nano-Beam Scheme SuperKEKB



$$d = \frac{\sigma_x^*}{\phi}$$

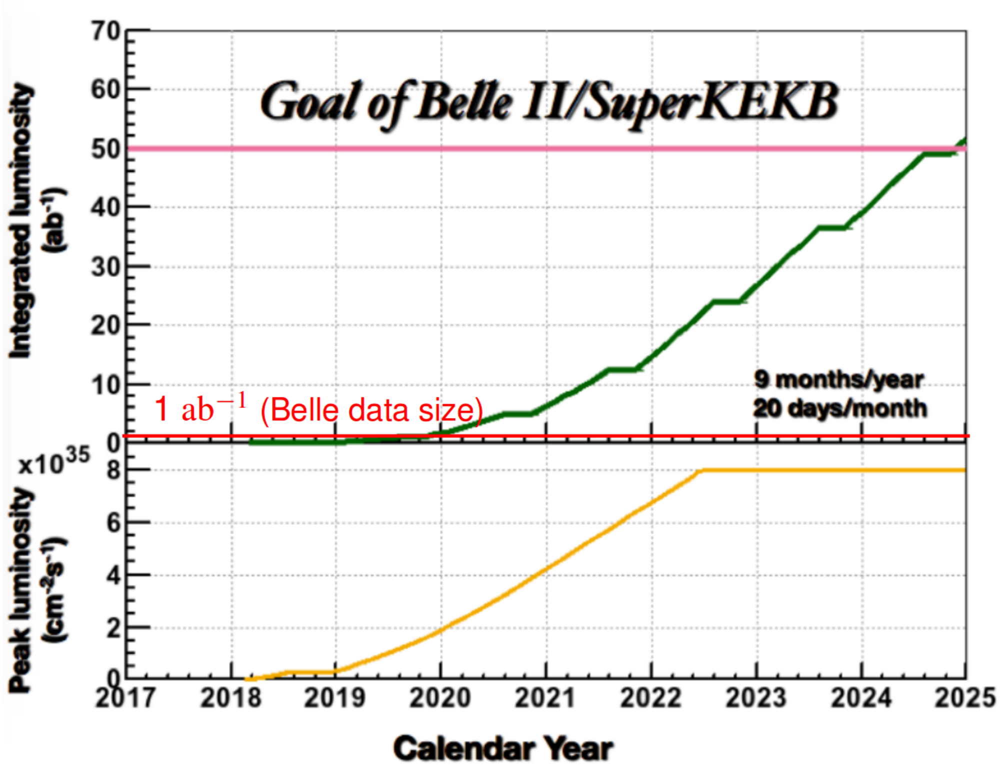
$\phi_{pwinski}$ ~ 20

Half crossing angle: ϕ

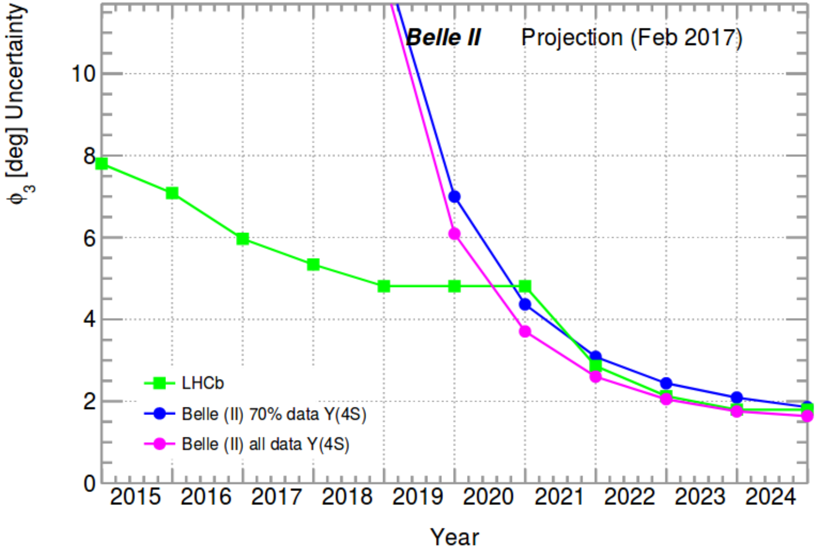
interaction region << bunch length

Super-KEKB

Super-KEKB aims for **8 x 10^{35} cm^{-2} s^{-1}**



Competition with LHCb is quite pressing!



A reasonable non-Y(4S) request:

1 ab^{-1} @ Y(5S)

100 fb^{-1} @ Y(6S)

300 fb^{-1} @ Y(3S) (1.2 Billions)

400 fb^{-1} scan (?)

Rare decays as BSM probes

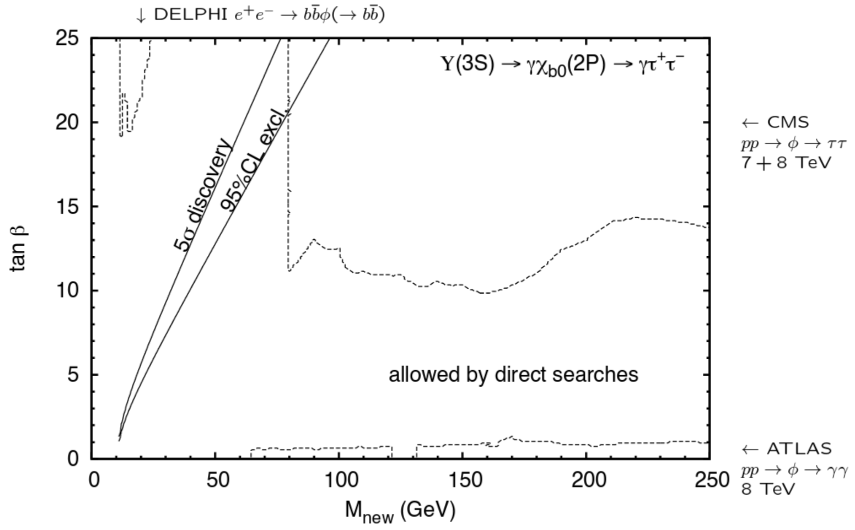
Godfrey and Logan, Phys. Rev. D 93, 055014 (2016)

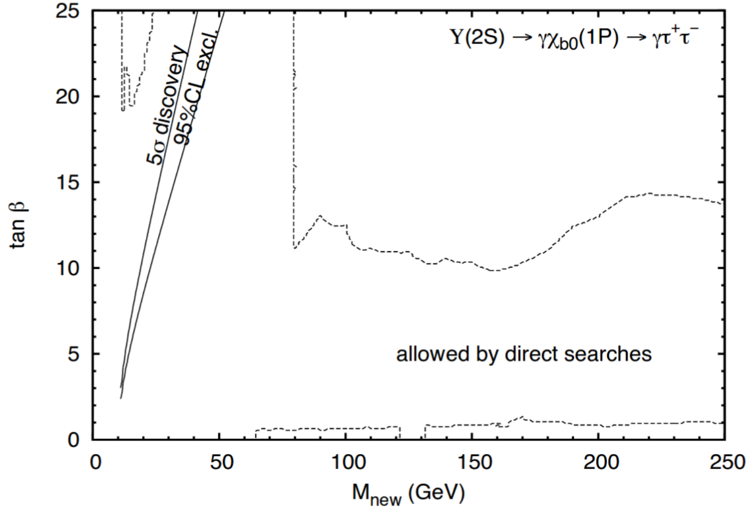
$\chi_b(2P) \to \tau\tau$ is sensitive to the presence of a CP-even light Higgs (as $B \to \tau\tau$, $B \to \tau\nu$...)

$$\left.\begin{array}{l} \mathrm{BR}^H(\chi_{b0}(1P) \to \tau\tau) = 3.1 \times 10^{-13} \\ \mathrm{BR}^H(\chi_{b0}(2P) \to \tau\tau) = (1.9 \pm 0.5) \times 10^{-12} \end{array}\right\} \times \left[1 + \frac{M_{H_{125}}^2 \tan^2\beta}{M_{\rm new}^2 - M_{\chi_{b0}}^2}\right]^2$$

Will only need $(M_{H_{125}}/M_{H_{\rm new}})\tan\beta \sim 30$ for $\mathcal{O}(100)$ signal events in $\Upsilon(3S) \to \gamma\chi_{b0}(2P) \to \gamma\tau\tau$

Results: $\Upsilon(3S)$





BelleII prospects:

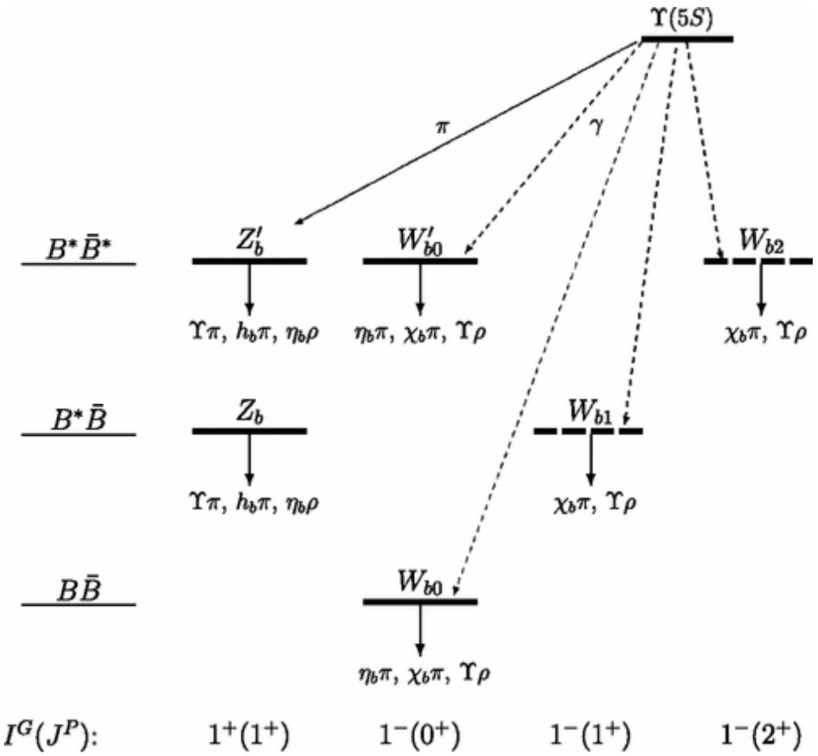
→ Collect 300fb^{-1} at Υ(3S) only, and run both fully inclusive and fully exclusive analysis

→ Challenging background from QED ee → γττ

Exotic states: direct search

→ If the Z_b is a loosely bound state, then several other molecules must appear

→ Exploratory run, no predictions on the production rates



Mod. Phys. Lett. A 32, 1750025 (2017)

$I^G(J^P)$	Name	Composition	Co-produced particles [Threshold, GeV/c^2]	Decay channels
$1^+(1^+)$	Z_b	$B\bar{B}^*$	π [10.75]	$\Upsilon(nS)\pi$, $h_b(nP)\pi$, $\eta_b(nS)\rho$
$1^+(1^+)$	Z'_b	$B^*\bar{B}^*$	π [10.79]	$\Upsilon(nS)\pi$, $h_b(nP)\pi$, $\eta_b(nS)\rho$
$1^-(0^+)$	W_{b0}	$B\bar{B}$	ρ [11.34], γ [10.56]	$\Upsilon(nS)\rho$, $\eta_b(nS)\pi$
$1^-(0^+)$	W'_{b0}	$B^*\bar{B}^*$	ρ [11.43], γ [10.65]	$\Upsilon(nS)\rho$, $\eta_b(nS)\pi$
$1^-(1^+)$	W_{b1}	$B\bar{B}^*$	ρ [11.38], γ [10.61]	$\Upsilon(nS)\rho$
$1^-(2^+)$	W_{b2}	$B^*\bar{B}^*$	ρ [11.43], γ [10.65]	$\Upsilon(nS)\rho$
$0^-(1^+)$	X_{b1}	$B\bar{B}^*$	η [11.15]	$\Upsilon(nS)\eta$, $\eta_b(nS)\omega$
$0^-(1^+)$	X'_{b1}	$B^*\bar{B}^*$	η [11.20]	$\Upsilon(nS)\eta$, $\eta_b(nS)\omega$
$0^+(0^+)$	X_{b0}	$B\bar{B}$	ω [11.34] γ [10.56]	$\Upsilon(nS)\omega$, $\eta_b(nS)\eta$
$0^+(0^+)$	X'_{b0}	$B^*\bar{B}^*$	ω [11.43] γ [10.65]	$\Upsilon(nS)\omega$, $\eta_b(nS)\eta$
$0^+(1^+)$	X_b	$B\bar{B}^*$	ω [11.39] γ [10.61]	$\Upsilon(nS)\omega$
$0^+(2^+)$	X_{b2}	$B^*\bar{B}^*$	ω [11.43] γ [10.65]	$\Upsilon(nS)\omega$

Belle II goals:

→ Y(6S): 100 fb^{-1} exploratory run

→ Y(5S): 1 ab^{-1} "high statistics" run

→ full-fledge search in all the possible channels:

- → hadronic (mostly from 6S)
- → radiative (very low BF, mostly from 5S)

$\Upsilon(1S) \rightarrow$ invisible

$\Upsilon(1S) \rightarrow$ invisible is well calculable in the SM

$$\frac{BR(\Upsilon(1S)\rightarrow\nu\bar{\nu})}{BR(\Upsilon(1S)\rightarrow e^+e^-)} = \frac{27G^2 M^4_{\Upsilon(1S)}}{64\pi^2\alpha^2}\left(-1+\frac{4}{3}\sin^2\theta_W\right)^2 = 4.14\times10^{-4}$$

$$BR(\Upsilon(1S)\rightarrow\nu\bar{\nu}) \sim 9.9\times10^{-6}$$

Non-SM contributions from $\Upsilon(1S) \rightarrow \chi\chi$

Belle: Phys.Rev.Lett. 98 (2007) 132001

Source	(%)	
Track selection	5.6	
π^0 veto	2.4	
Fisher discriminant	6.1	
Other selection requirements	1.1	
$\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S)$	7.6	4% in BaBar
Trigger efficiency	8.7	
Fit bias	0.2	
Statistics of control sample	1.4	
$\mathcal{B}(\Upsilon \rightarrow \mu^+\mu^-)$	2.0	
Total	14.7	

Belle II prospects

→ 10x dataset w/ respect to BaBar

→ Sensitivity ~1 x 10^{-4} on the BF

→ Reduce the systematic with precision measurement of the pp and gg transitions

→ Trigger is crucial: capability to trigger on 2p + missing energy depends on the BG levels and luminosity

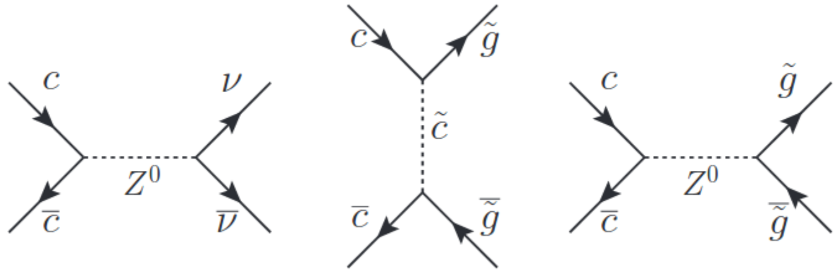
Υ(1S) → invisible

Υ(1S) → invisible is well calculable in the SM

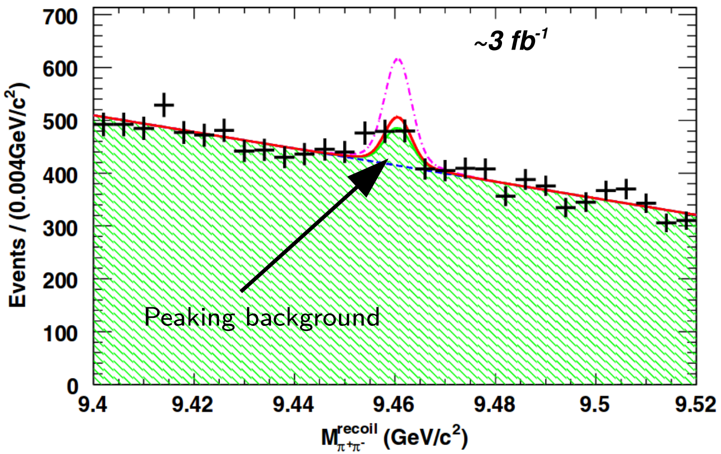
$$\frac{BR(Y(1S)\rightarrow\nu\bar{\nu})}{BR(Y(1S)\rightarrow e^+e^-)}=\frac{27G^2M^4_{Y(1S)}}{64\pi^2\alpha^2}\left(-1+\frac{4}{3}\sin^2\theta_W\right)^2=4.14\times10^{-4}$$

$$BR(Y(1S)\rightarrow\nu\bar{\nu})\sim9.9\times10^{-6}$$

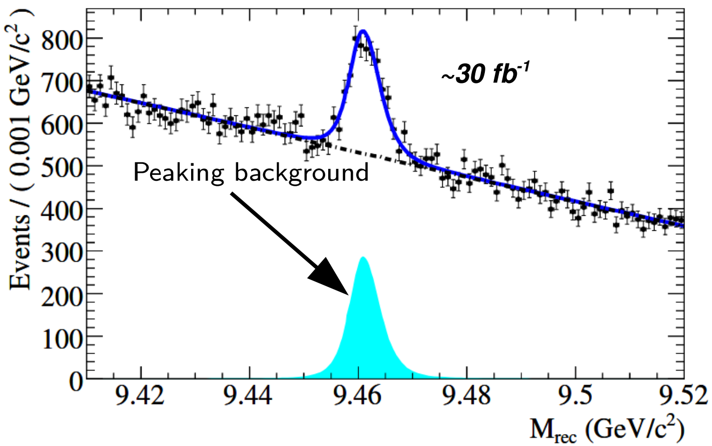
Non-SM contributions from Υ(1S) → χχ



Belle: Phys. Rev. Lett. 98 (2007) 132001

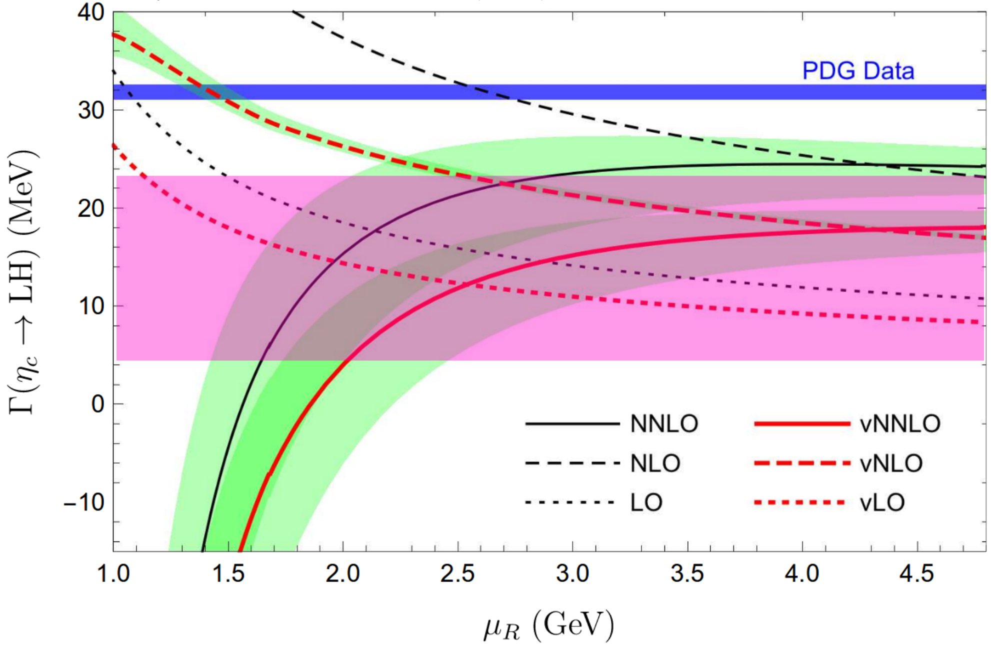


BaBar, Phys. Rev. Lett. 103, 251801 (2009)



The η_c width conundrum

Phys. Rev. Lett. 119, 252001 (2017)



What do I understand from this?

→ NNLO is still not enough

→ Is NRQCD converging fast enough?

→ The problem is not in the experimental resolution

A funny coincidence: what happens if we take the measurements done with M1 naive fit?

11.5 ± 4.5	GAISER	1986	CBAL	$J/\psi \to \gamma$ X, $\psi(2S) \to \gamma$ X
$11.0 \pm 8.1 \pm 4.1$	12 BAI	2000F	BES	$J/\psi \to \gamma\eta_c$ and $\psi(2S) \to \gamma\eta_c$
$17.0 \pm 3.7 \pm 7.4$	10 BAI	2003	BES	$J/\psi \to \gamma\eta_c$