New physics with heavy quarkonia at

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Lepton Sector :

- *Lepton Universality Violation*
- *Rare leptonic decays*
- *Lepton Flavor Violation*

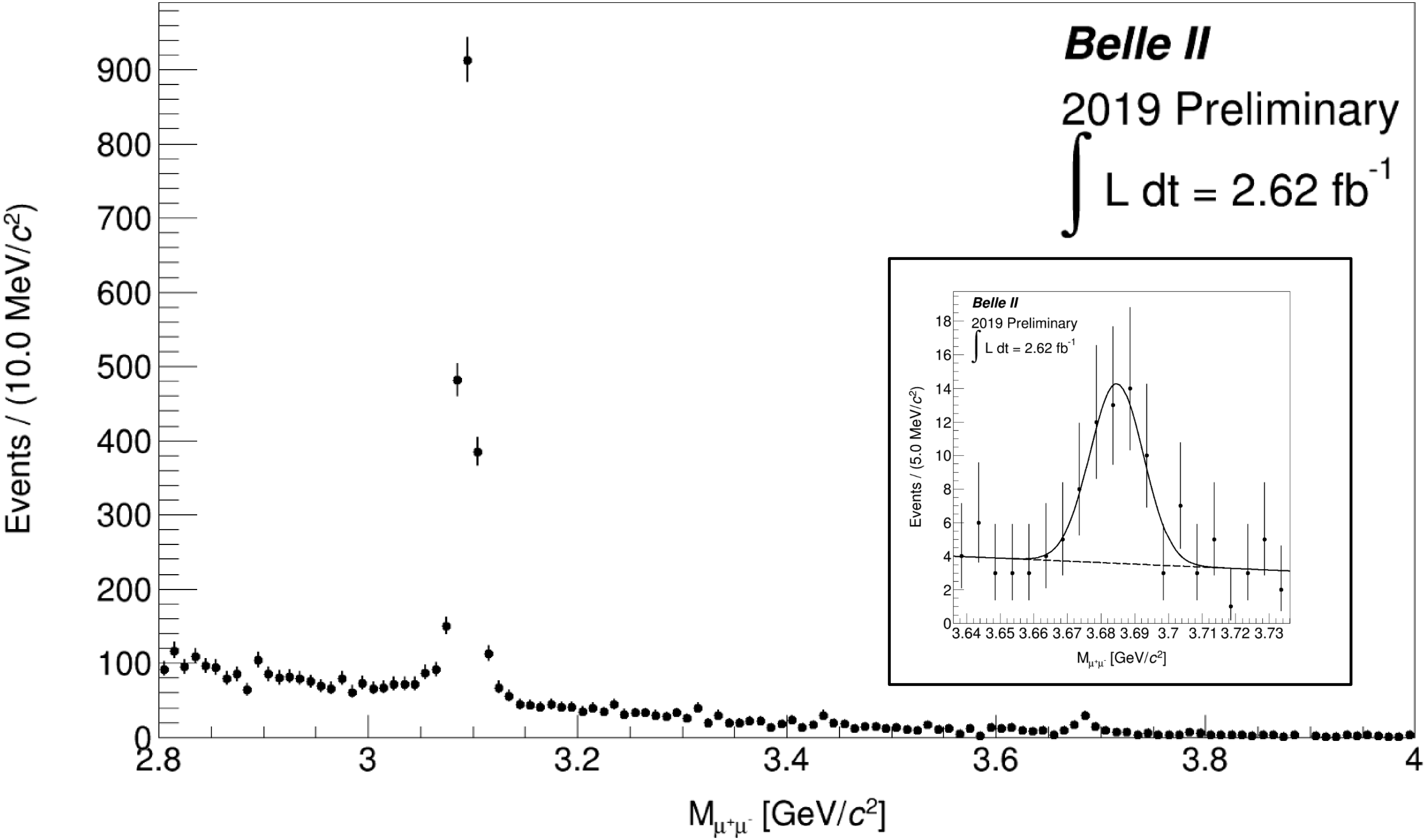
Hadron Sector :

- *Antinuclei inclusive production*
- *Strange dibaryons : cold DM?*

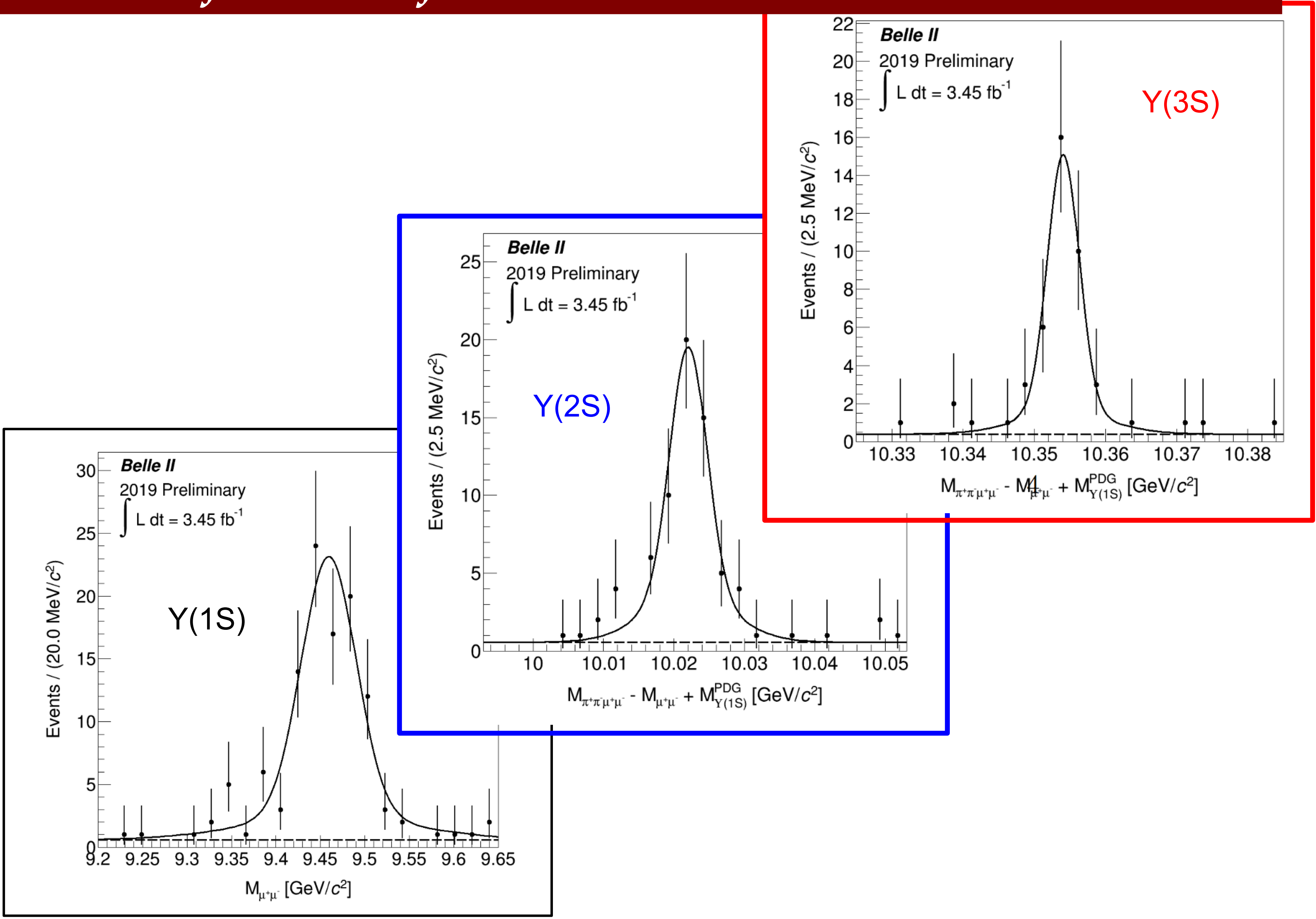
EU grant n.644294

Jennifer2 Kickoff Meeting September 12, 2019, Vienna

Results from the first Phase3 data: charmonia



Results from the first Phase3 data: bottomonia



Lepton Universality in Υ(nS) decays: experiments

Still dominated by old CLEO measurements taken on Υ(nS) peaks

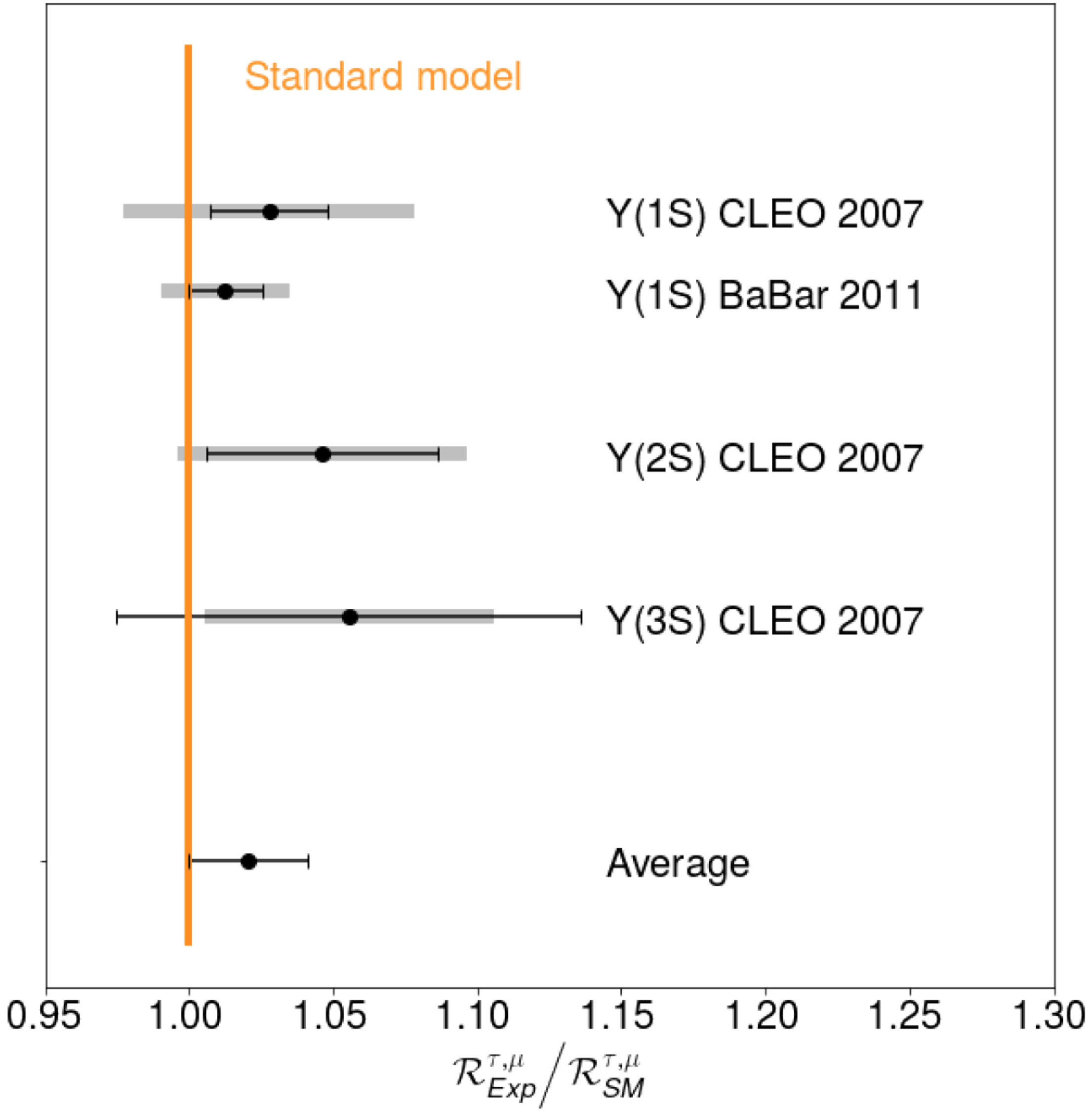
Babar result uses dipion tagging of Υ(1S) from their Υ(3S) sample

Babar systematics:

- tracking efficiency

- event shapes

With O(10^9) decays at 3S peak, Belle-II has opportunities to improve significantly the Babar measurement.

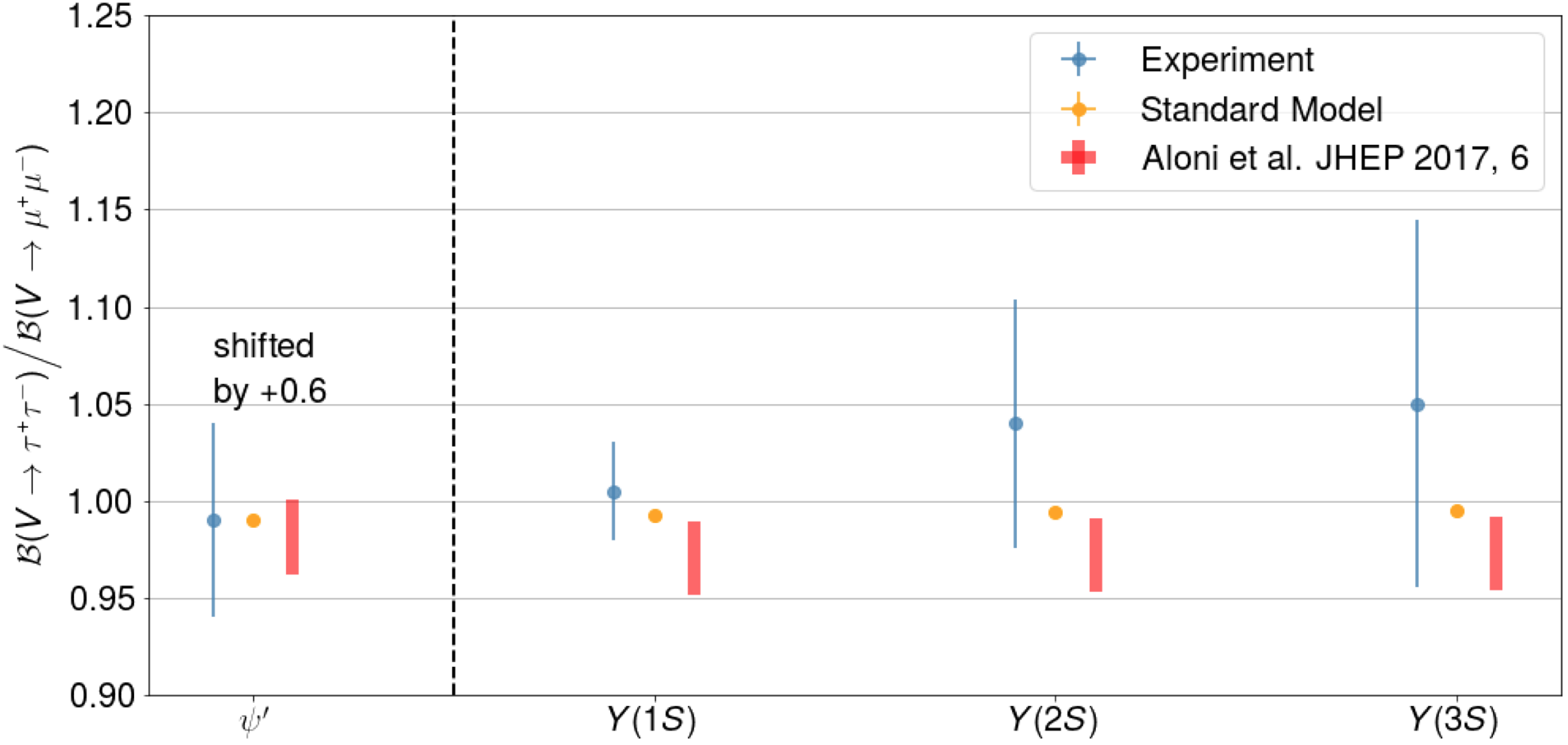


Lepton Universality in Υ(nS) decays

Aloni et al,JHEP 1706 (2017) 019

- NP solutions to R(D(*)) puzzle can be directly checked on Υ(nS) and ψ+leptonic decays
- R(D*) discrepancy with SM is at 30%, in a tree level process.
- Leptonic widths are at tree level (2%), well known.
- Add NP contributions as 4-fermions operators, tuning the Wilson coefficients on R(D*)

$$R^V_{\tau/\ell} \simeq \left[1+\frac{2m_\tau^2}{m_V^2}\right]\left[1-\frac{4m_\tau^2}{m_V^2}\right]^{1/2} = 1-\mathcal{O}\left(\frac{m_\tau^4}{m_V^4}\right)$$



Leptonic χ_{b0} decays

Godfrey, Logan, PRD93 (2016) 055014

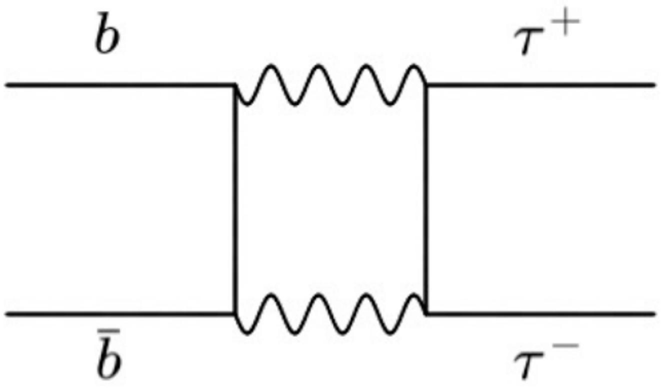
Study of NP effects within a Type II 2HDM, on the rare J=0++ bottomonium decays

QED term (two photon amplitude):

$$\Gamma^{2\gamma}(\chi_0 \to \ell^+\ell^-) \simeq \frac{\alpha^2}{2\beta_\ell}\left[\frac{m_\ell}{M_{\chi_0}} \ln \frac{(1+\beta_\ell)}{(1-\beta_\ell)}\right]^2 \Gamma(\chi_0 \to \gamma\gamma)$$

$$\mathrm{BR}^{2\gamma}(\chi_{b0}(1P) \to \tau^+\tau^-) \simeq 1 \times 10^{-9}$$

$$\mathrm{BR}^{2\gamma}(\chi_{b0}(2P) \to \tau^+\tau^-) \simeq 6 \times 10^{-9}$$

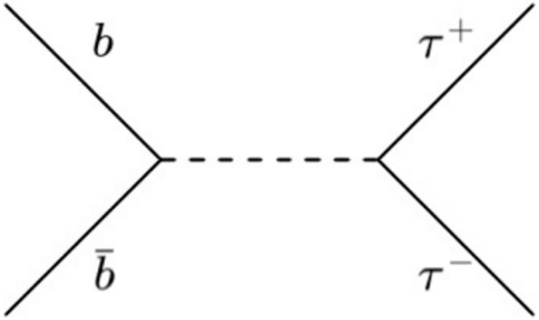


SM Higgs in s-channel contribution:

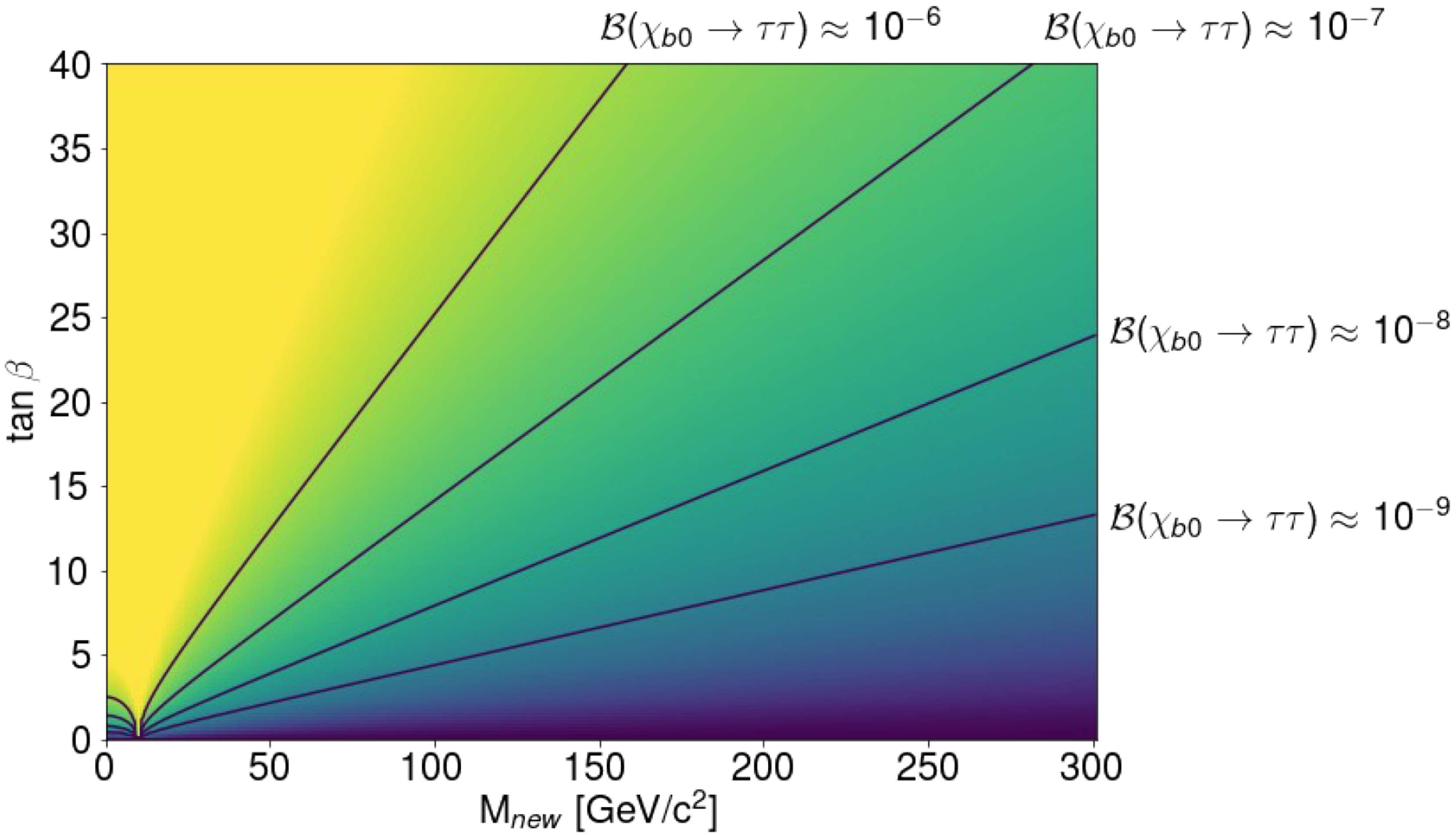
$$\Gamma^{H}(\chi_0 \to \ell^+\ell^-) = \frac{M_{\chi_0}}{8\pi}\left[1 - \frac{4m_\ell^2}{M_{\chi_0}^2}\right]^{3/2} \left(\frac{m_q m_\ell}{v^2 M_H^2}\right)^2 f_{\chi_0}^2.$$

$$\mathrm{BR}^{H}(\chi_{b0}(1P) \to \tau^+\tau^-) = 3.1 \times 10^{-13},$$

$$\mathrm{BR}^{H}(\chi_{b0}(2P) \to \tau^+\tau^-) = (1.9 \pm 0.5) \times 10^{-12}$$



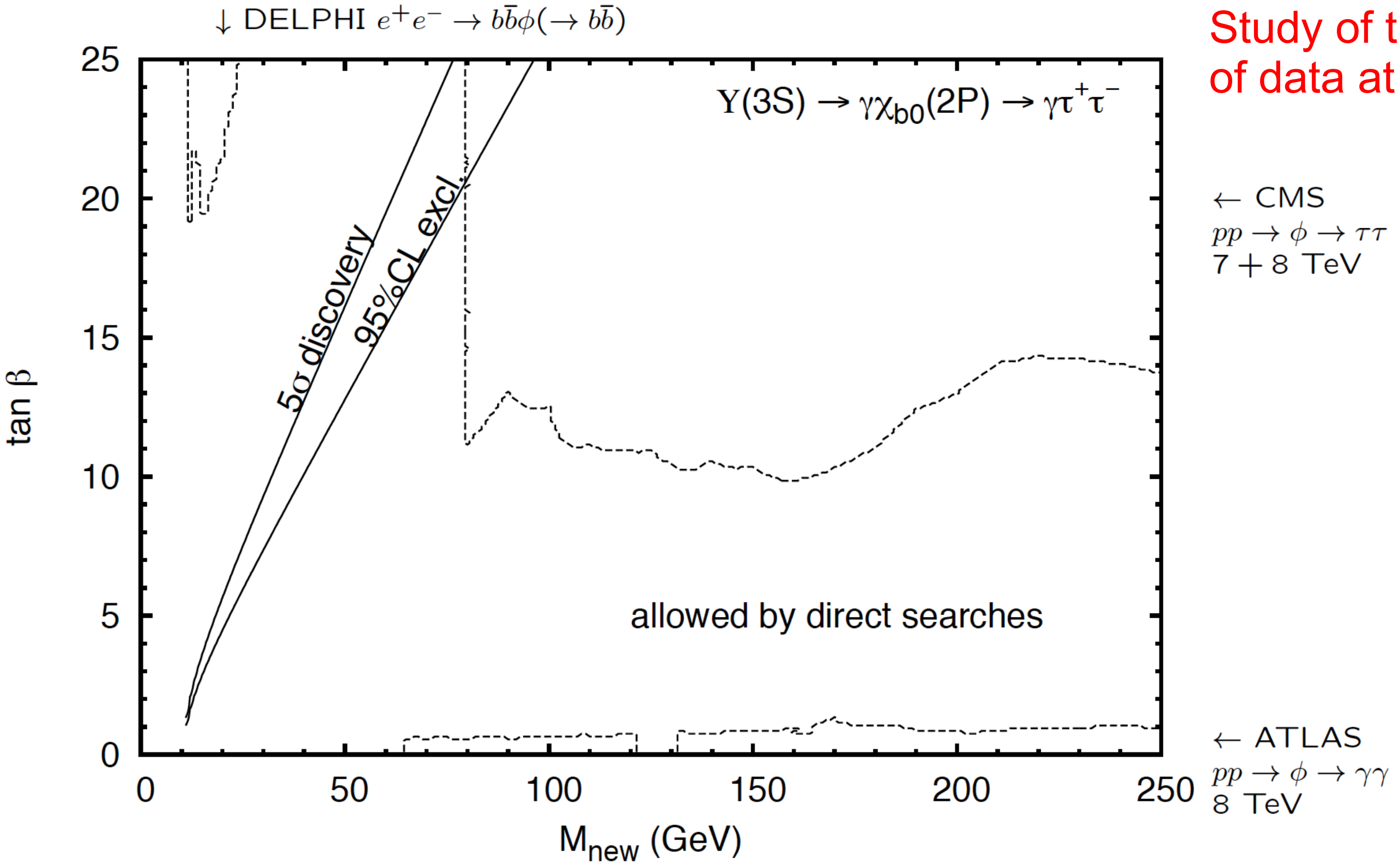
Leptonic χ_{b0} decays



$$\Gamma^H(\chi_0 \to \ell^+\ell^-) = \frac{M_{\chi_0}}{8\pi}\left[1-\frac{4m_\ell^2}{M_{\chi_0}^2}\right]^{3/2}\left(\frac{m_q m_\ell}{v^2 M_H^2}\right)^2 f_{\chi_0}^2 \cdot \quad \times \quad \left[1+\frac{M_H^2}{M_{\rm new}^2 - M_{\chi_{b0}}^2}\tan^2\beta\right]^2$$

Leptonic χ_{b0} decays

Study of the sensitivity using 250 fb^{-1} of data at Y(3S) peak

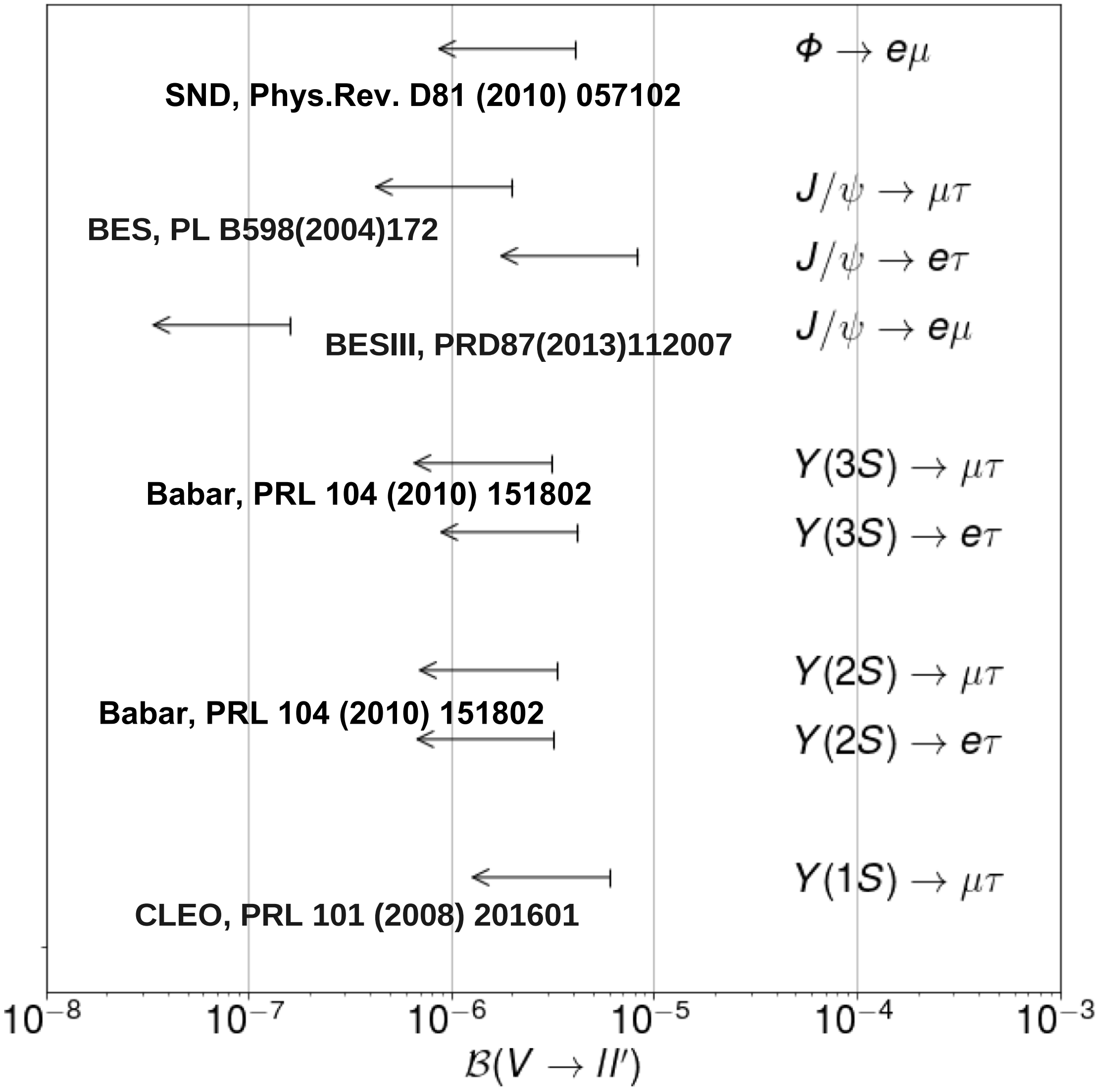


Highest sensitivity on a second CP-even Higgs (ϕ) is at χ_{b0}(2P) (lower background)

Parent	Daughter	E_γ	δE_γ	$d\sigma_B/dE_\gamma$	N_B
$\Upsilon(3S)$	$\chi_{b0}(2P)$	122 MeV	0.24 MeV	36 fb/MeV	4320
$\Upsilon(3S)$	$\chi_{b0}(1P)$	484 MeV	1.3 MeV	8.8 fb/MeV	5720
$\Upsilon(2S)$	$\chi_{b0}(1P)$	163 MeV	1.3 MeV	30 fb/MeV	19500

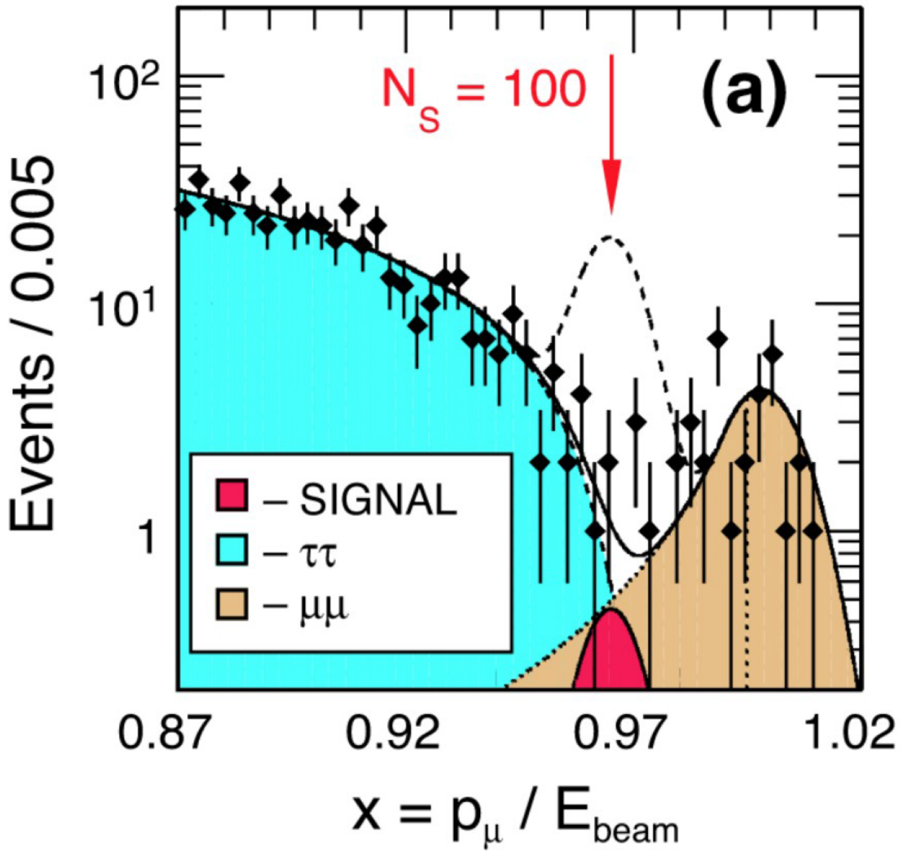
LFV in Y(nS) decays: experiments

On Y(nS), the contribution from Belle is still missing.
One analysis is currently ongoing.



On resonance peak:
measurement of muon momentum

Dipion tagged:
like searches for invisible decays

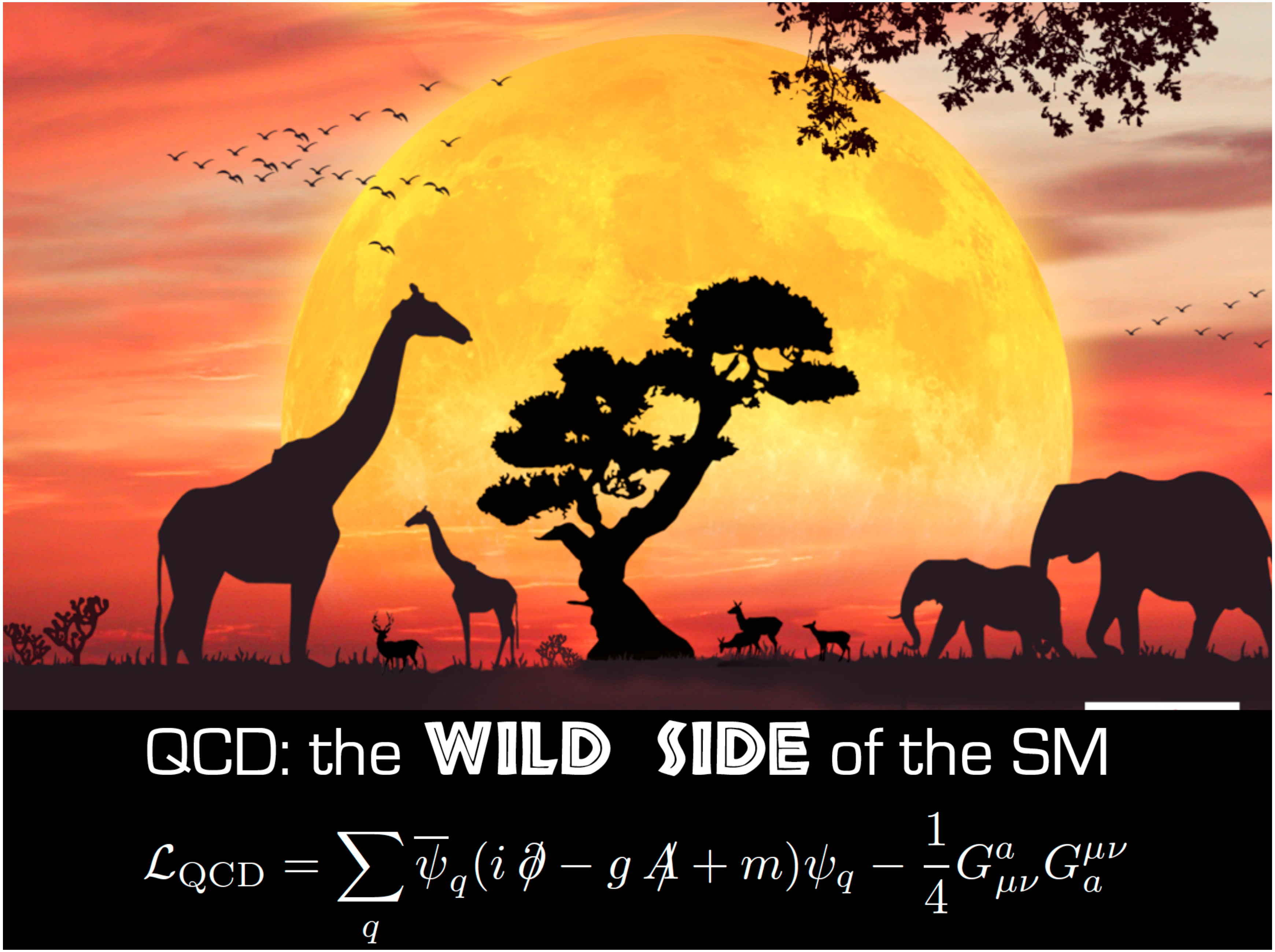


LFV in $\Upsilon(nS)$ decays

Hazard, Petrov, PRD94 (2016) 074023
(see also PRD98 (2018) 015027 for K,D,B decays)

	Leptons	Initial state (quark)				
Wilson coefficient (GeV^{-2})	$\ell_1\ell_2$	$\Upsilon(1S)$ (b)	$\Upsilon(2S)$ (b)	$\Upsilon(3S)$ (b)	J/ψ (c)	ϕ (s)
$\left\|C_{VL}^{q\ell_1\ell_2}/\Lambda^2\right\|$	$\mu\tau$	5.6×10^{-6}	4.1×10^{-6}	3.5×10^{-6}	5.5×10^{-5}	n/a
	$e\tau$	–	4.1×10^{-6}	4.1×10^{-6}	1.1×10^{-4}	n/a
	$e\mu$	–	–	–	1.0×10^{-5}	2×10^{-3}
$\left\|C_{VR}^{q\ell_1\ell_2}/\Lambda^2\right\|$	$\mu\tau$	5.6×10^{-6}	4.1×10^{-6}	3.5×10^{-6}	5.5×10^{-5}	n/a
	$e\tau$	–	4.1×10^{-6}	4.1×10^{-6}	1.1×10^{-4}	n/a
	$e\mu$	–	–	–	1.0×10^{-5}	2×10^{-3}
$\left\|C_{TL}^{q\ell_1\ell_2}/\Lambda^2\right\|$	$\mu\tau$	4.4×10^{-2}	3.2×10^{-2}	2.8×10^{-2}	1.2	n/a
	$e\tau$	–	3.3×10^{-2}	3.2×10^{-2}	2.4	n/a
	$e\mu$	–	–	–	4.8	1×10^{4}
$\left\|C_{TR}^{q\ell_1\ell_2}/\Lambda^2\right\|$	$\mu\tau$	4.4×10^{-2}	3.2×10^{-2}	2.8×10^{-2}	1.2	n/a
	$e\tau$	–	3.3×10^{-2}	3.2×10^{-2}	2.4	n/a
	$e\mu$	–	–	–	4.8	1×10^{4}

New Physics from the QCD jungle....



QCD: the **WILD SIDE** of the SM

$$\mathcal{L}_{\mathrm{QCD}} = \sum_q \overline{\psi}_q (i \not\partial - g \not A + m) \psi_q - \frac{1}{4} G^a_{\mu\nu} G_a^{\mu\nu}$$

Antinuclei in Y(nS) decays

First observed by ARGUS, then CLEO :

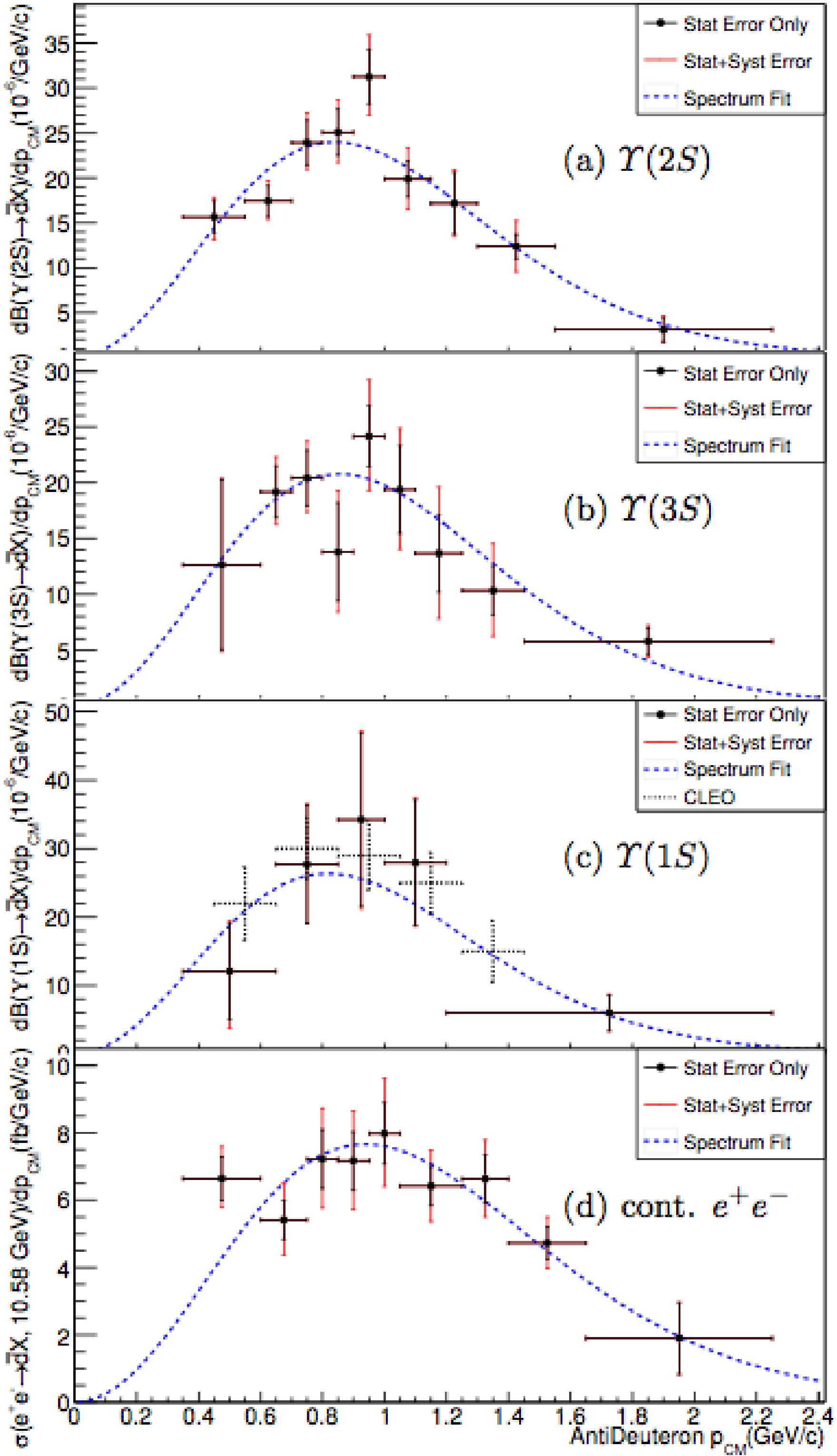
$$\mathcal{B}^{\,\mathrm{dir}}(\Upsilon(1S) \to \bar{d}X) = (3.36 \pm 0.23 \pm 0.25) \times 10^{-5}.$$

$$\mathcal{B}\,(\Upsilon(2S) \to \bar{d} + X) = (3.37 \pm 0.50 \pm 0.25) \times 10^{-5}.$$

More recent result from BABAR :

Resonance	**Onpeak**	**# of Υ Decays**	**Offpeak**
$\Upsilon(4S)$	$429\,\mathrm{fb}^{-1}$	463×10^6	$44.8\,\mathrm{fb}^{-1}$
$\Upsilon(3S)$	$28.5\,\mathrm{fb}^{-1}$	116×10^6	$2.63\,\mathrm{fb}^{-1}$
$\Upsilon(2S)$	$14.4\,\mathrm{fb}^{-1}$	98.3×10^6	$1.50\,\mathrm{fb}^{-1}$

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



Production in bottomonium decays: 10x continuum
Production mechanism still unclear: coalescence?

Associated d$\bar{\text{d}}$ production: not checked by Babar
Good target for future Y(3S) decays samples

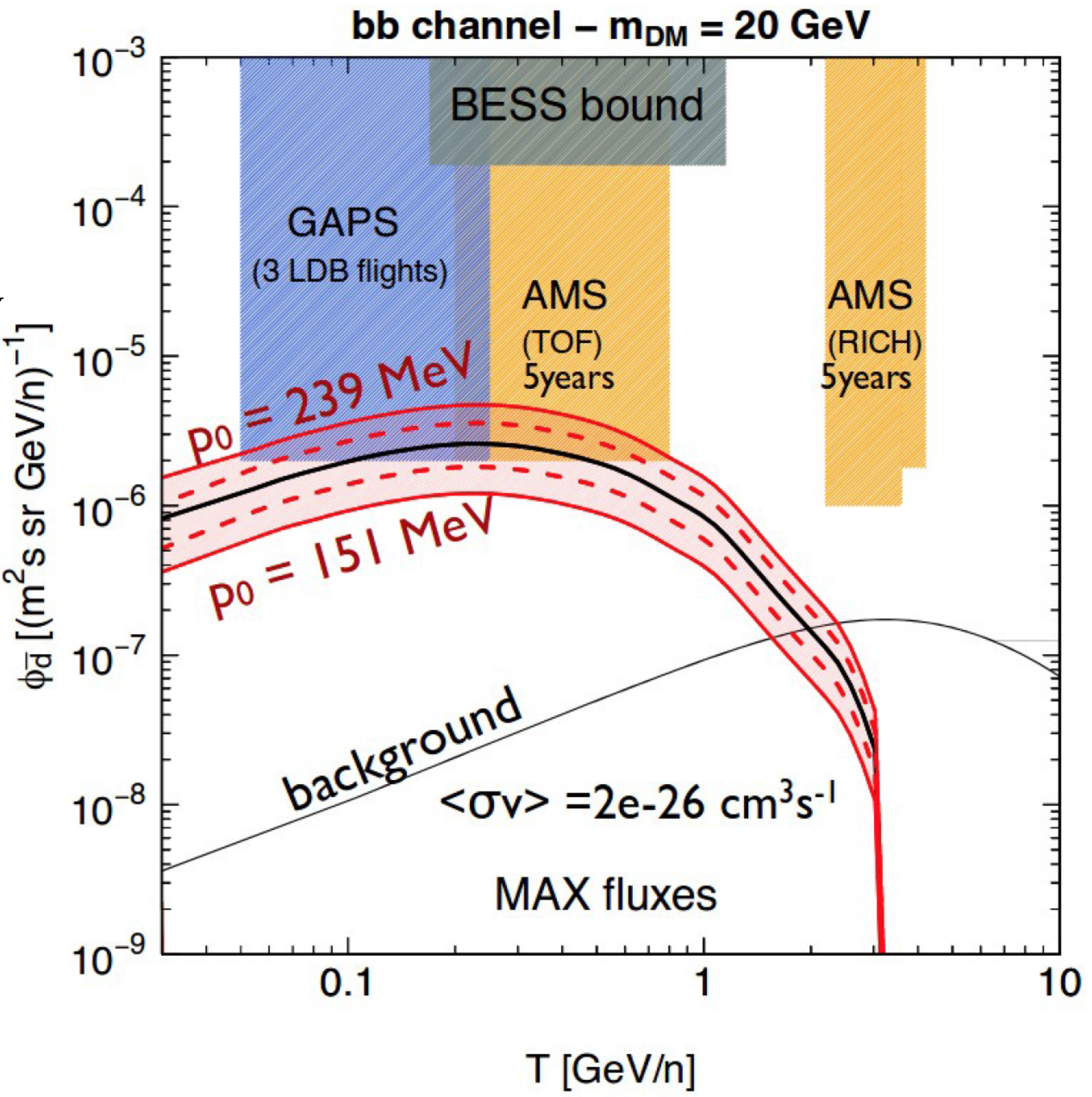
Antideuteron in CR as DM signature

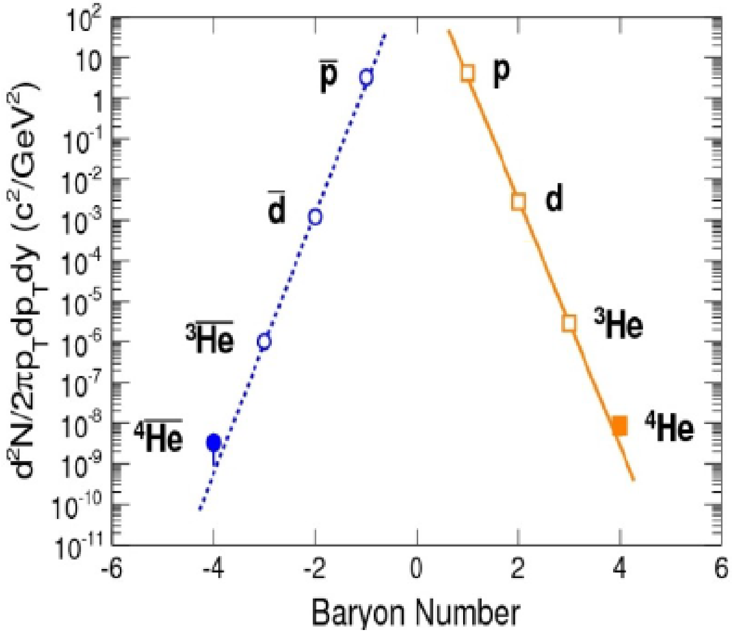
An excess of anti-nuclei in cosmic rays has been suggested as a possible Dark Matter signature
Donato et al, PRD 62 (2000) 043003

AMS2 observation of 8 $^{3}\overline{\text{He}}$ candidates

Inclusive $\overline{\text{d}}$ production cross sections in pA collisions should be measured in a broad energy range (LHCB, Compass)

Production of antinuclei in gluon rich matter is measured by STAR, Phenix, ALICE.





STAR Exp.,Nature 473 (2011) 353, Erratum-ibid. 475 (2011) 412

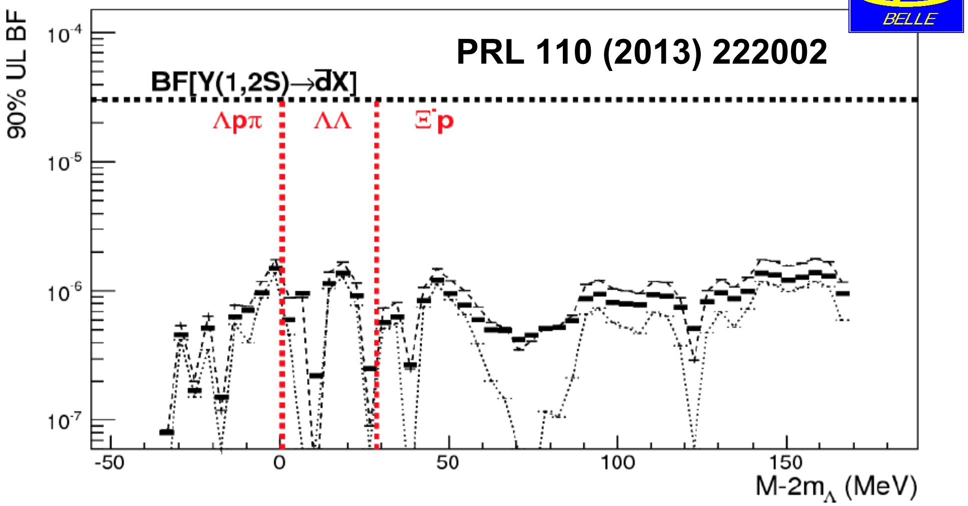
Gluon density in Y annihilations (10 GeV in r~0.04 fm) is higher than in RHIC and ALICE experiments.
Belle-II will reach sensitivity to $^{3}\overline{\text{He}}$ production in Y decays

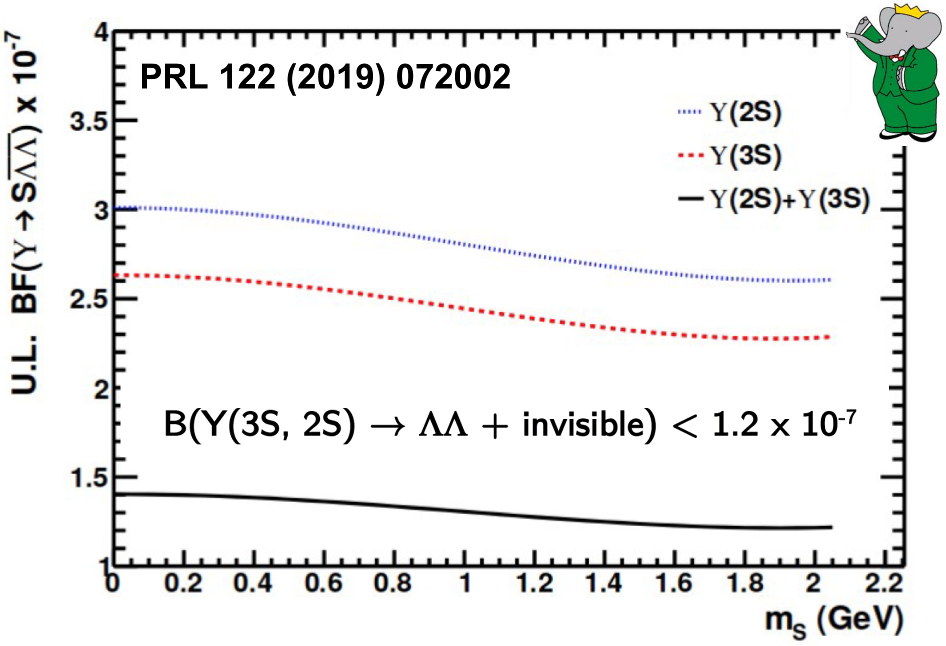
Searching H/S in Y(nS) decays

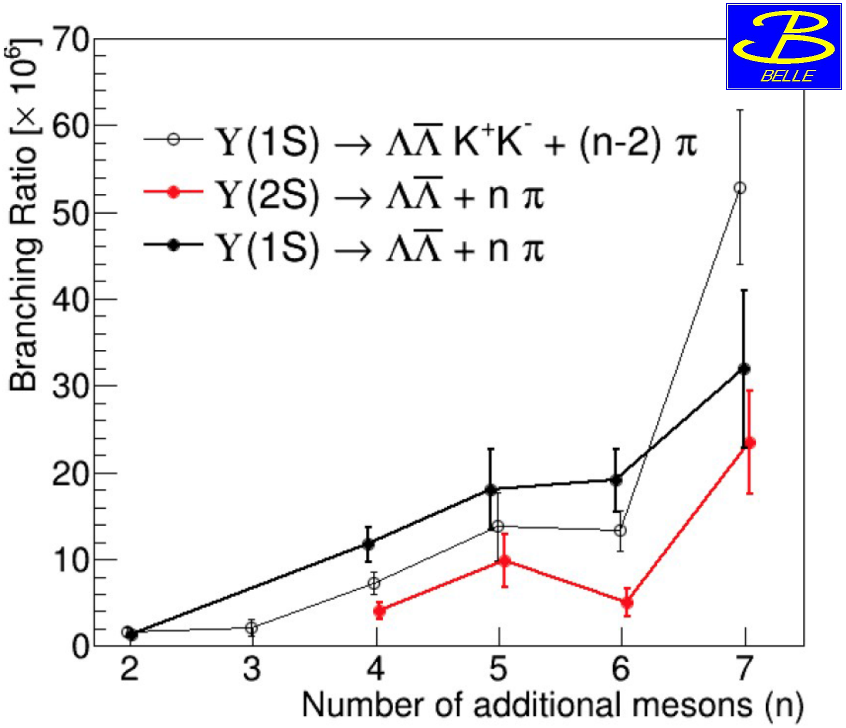
Enhaced production of strange hadrons and of antideuteron inspired the search for Jaffe's H-dibaryon in Y decays.

Belle set limits on inclusive production of a weakly bound H-dibaryon in Y(1,2S) decays in a broad mass range at below O(10^{-1}) of the measured $\bar{d}$ production.

Babar set naïve limits for the 3 body process Y(2,3S) to $S\overline{\Lambda\Lambda}$ + c.c.





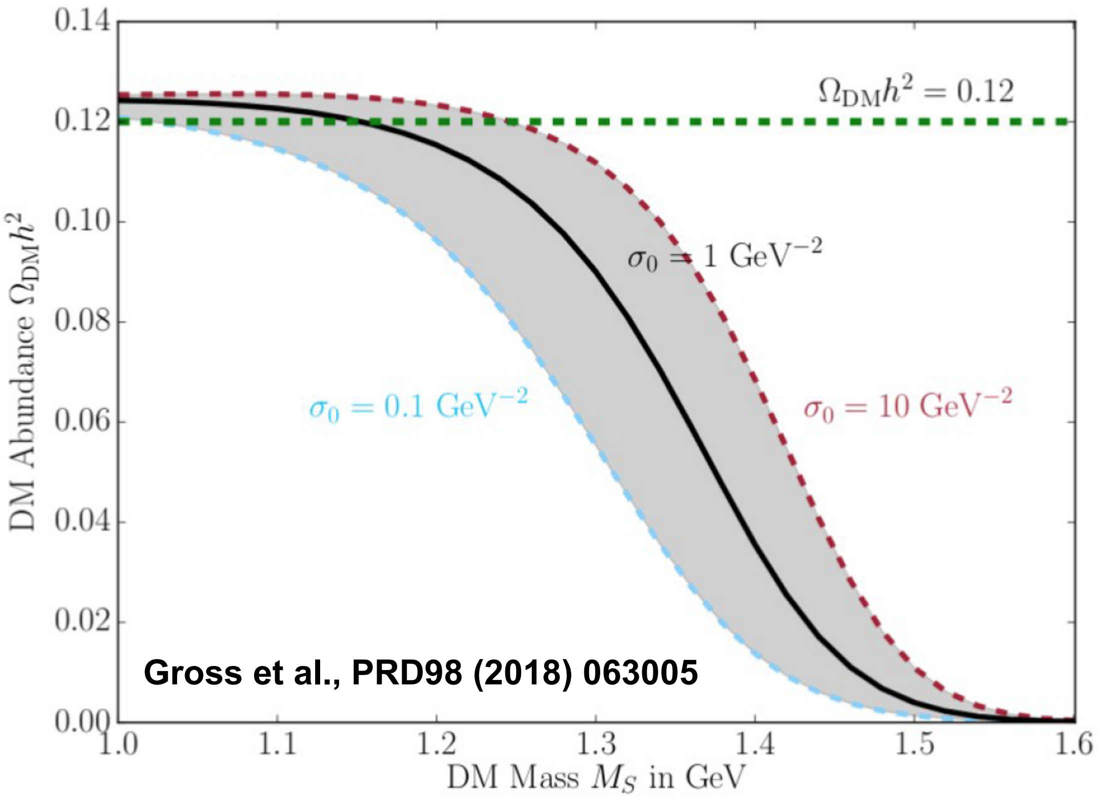


H-Dibaryon/S-exaquark as DM?

Kochelev, **JETP Lett. 70 (1999) 491**
Farrar-Zaharijas, **Int.J.Theor.Phys. 42 (2003) 1211,**
Phys.Rev. D70 (2004) 014008
Shuryak, **J.Phys.Conf.Ser. 9 (2005) 213-217**

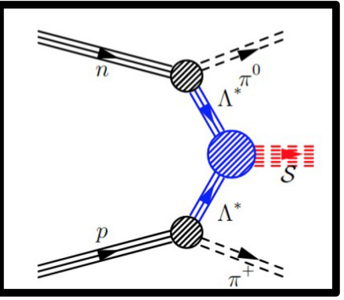
Interests revived recently after:
Farrar, arXiv:1708.08951
H-dibaryon ^ Sexaquark S

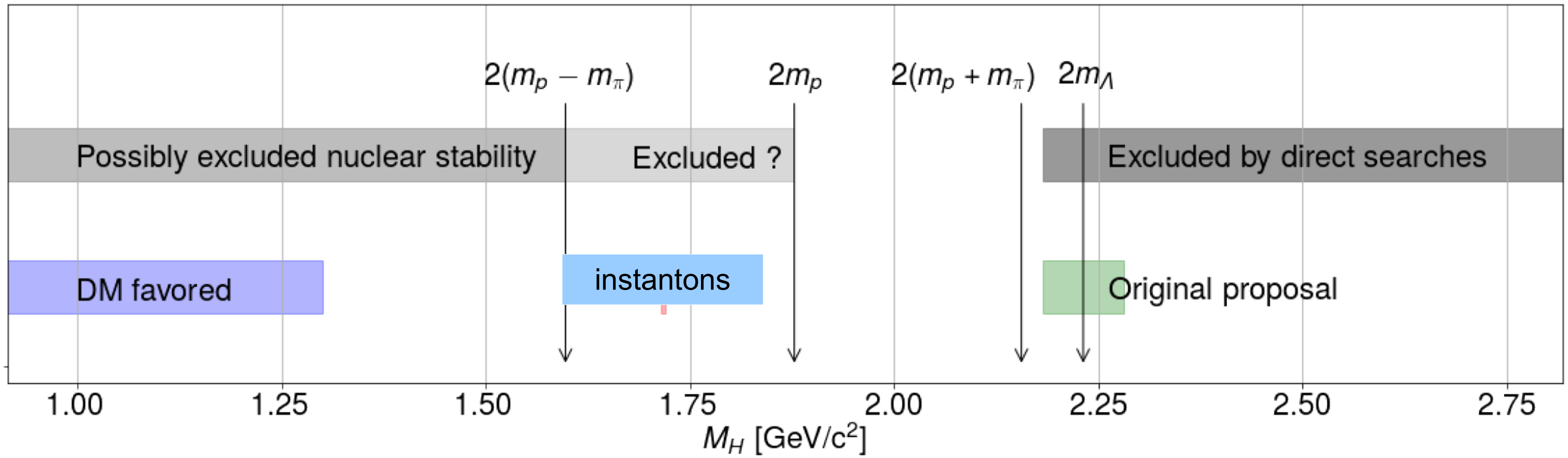
Discussed by :
Gross,Polosa et al., PRD98 (2018) 063005
McDermott et al, PRD99 (2019) 035013
Kolb,Turner, PRD99 (2019) 063519



Gross et al., PRD98 (2018) 063005

If M_s<1.6, Oxigen decays





Take home message

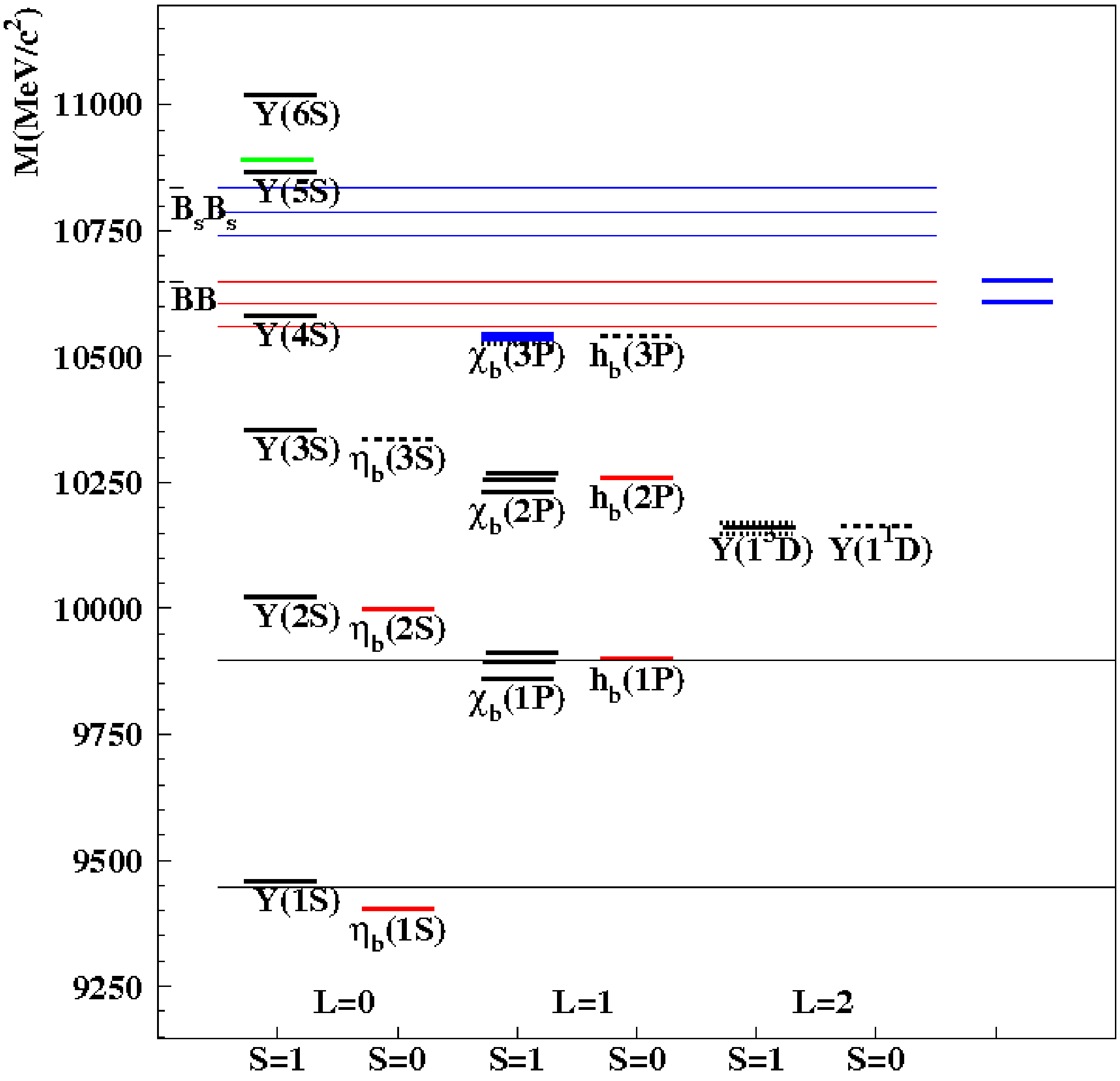
Besides being a unique system for testing QCD in the border between non-perturbative and perturbative regime, the narrow heavy quarkonia provide useful tests to many processes which may test many of the models for physics beyond SM.

Per se, QCD is the weakest sector of SM, at low energy, and this sets serious limits to our capability to find new physics in the quark sector.

In addition, despite unlikely, we cannot disregard the possibility that cold dark matter candidates can arise from QCD, as very compact S=2 exaquarks may have decoupled from ordinary matter in the first instants of the universe. Υ decays provide a unique potential source of these objects.

Thank you

Bottomonium spectra

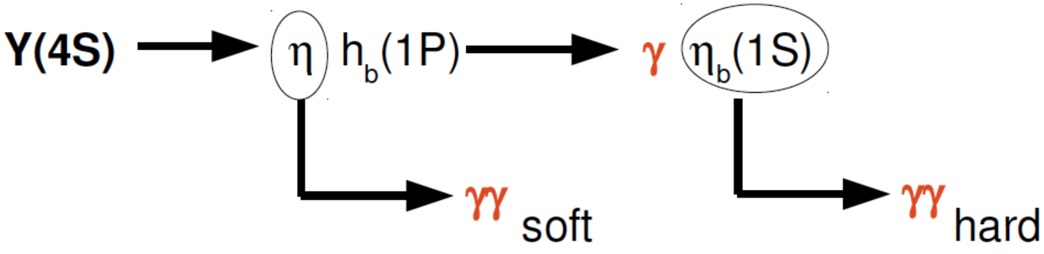


Bottomonium physics from Υ(4,5S): $\eta_b \to \gamma\gamma$

Chung, Lee, Yu (2011)

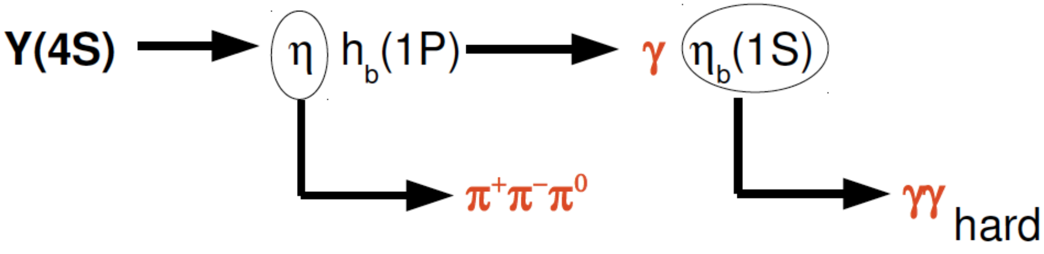
$\Gamma[\eta b(1S) \to \gamma\gamma] = 0.512 \pm 0.095$ keV, → **$B[\eta b(1S) \to \gamma\gamma] \sim 5 \times 10^{-5}$**

$\Gamma[\eta b(2S) \to \gamma\gamma] = 0.235 \pm 0.043$ keV → **$B[\eta b(2S) \to \gamma\gamma] > 1 \times 10^{-5}$**

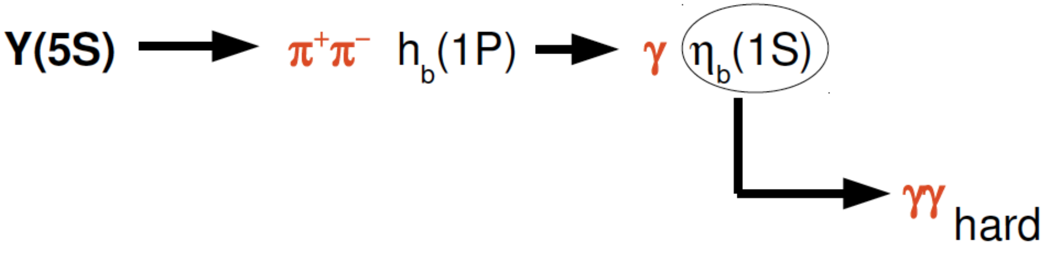


All neutral final state
Trigger on hard γγ pair not possible due to $e^+e^- \to \gamma\gamma$ QED background

Trigger on soft dipion pair + hard γγ is the solution



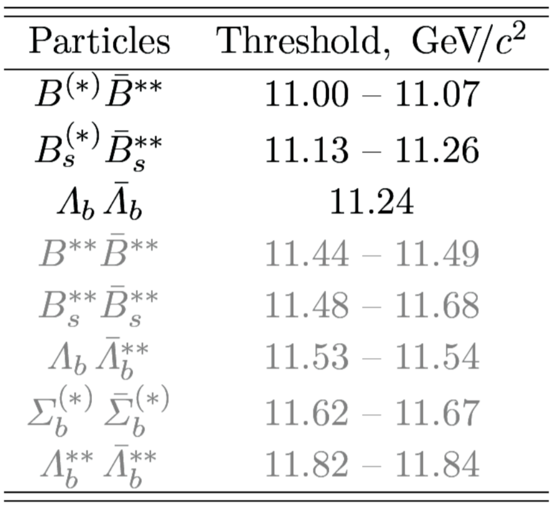
~0.5 Millions $\eta_b(1S)$ ($\eta \to \pi\pi\pi$)
in 50/ab of Υ(4S)
~ 15 full reconstructed $\eta_b(1S) \to \gamma\gamma$



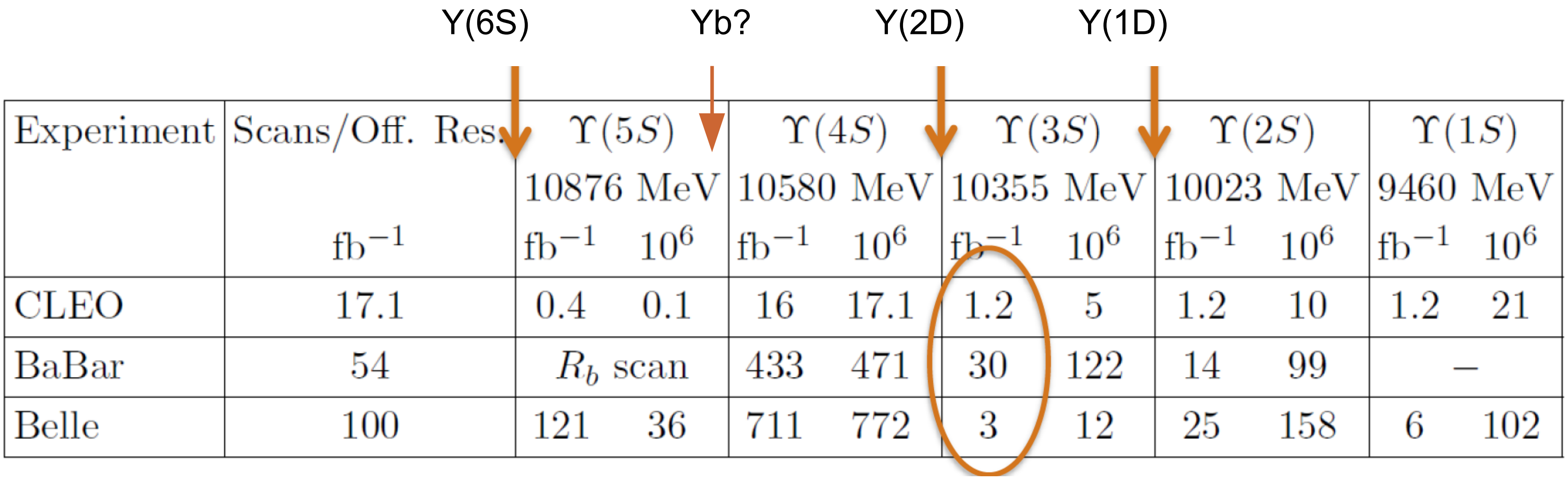
~2.5 Millions $\eta_b(1,2S)$
in 10/ab of Υ(5S)
~ 100 full reconstructed $\eta_b(1,2S) \to \gamma\gamma$

Plans for non-Υ(4S) running

Energy	Outcome	Lumi (fb^{-1})	Comments
Υ(1S) On	N/A	60+	-No interest identified -Low energy
Υ(2S) On	New physics searches	20+	-Requires special trigger
Υ(1D) Scan	Particle discovery	10-20	-Already accessible in B Factories?
Υ(3S) On	Many -onia topics	200+	-Known resonance -Luminosity requirement: Phase 3
Υ(3S) Scan	Precision QED	~10	-Understanding of beam conditions needed
Υ(2D) Scan	Particle discovery	10-20	-Unknown mass
>Υ(4S) On	Particle discovery?	10+?	-Energy to be determined
Υ(6S) On	Particle discovery?	30+?	-Upper limit of machine energy
Single γ	New physics?	30+	-Special triggers required



Particles	Threshold, GeV/c^2
$B^{(*)}\bar{B}^{**}$	11.00 – 11.07
$B_s^{(*)}\bar{B}_s^{**}$	11.13 – 11.26
$\Lambda_b\bar{\Lambda}_b$	11.24
$B^{**}\bar{B}^{**}$	11.44 – 11.49
$B_s^{**}\bar{B}_s^{**}$	11.48 – 11.68
$\Lambda_b\bar{\Lambda}_b^{**}$	11.53 – 11.54
$\Sigma_b^{(*)}\bar{\Sigma}_b^{(*)}$	11.62 – 11.67
$\Lambda_b^{**}\bar{\Lambda}_b^{**}$	11.82 – 11.84



Experiment	Scans/Off. Res.	Υ(5S)		Υ(4S)		Υ(3S)		Υ(2S)		Υ(1S)	
		10876 MeV		10580 MeV		10355 MeV		10023 MeV		9460 MeV	
	fb^{-1}	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6
CLEO	17.1	0.4	0.1	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan		433	471	30	122	14	99	–	
Belle	100	121	36	711	772	3	12	25	158	6	102