Prospects for Heavy Quarkonium at SuperB

- The SuperB project
- Exotic Charmonium
- Bottomonium
- Light Higgs searches

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for the SuperB collaboration

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SuperB: an overview

Ways to New Physics

Power of intensity:

- Precision measurements in the flavor sector sensitive to NP: interference effects in known processes, SM rare or forbidden decays
- NP effects are controlled by NP scale Λ and effective couplings: measuring the coupling ↔ disentangle different NP patterns

Flavour Physics: shake the Box, listen

virtual particles

LHC: Open the box

real particles

Ways to New Physics

Power of intensity:

- Precision measurements in the flavor sector sensitive to NP: interference effects in known processes, SM rare or forbidden decays
- NP effects are controlled by NP scale Λ and effective couplings: measuring the coupling ↔ disentangle different NP patterns
- With 5 to 10 x 10^{10} $b\bar{b}$, $c\bar{c}$, $\tau\tau$ pairs (50-100 ab^{-1}):

LHC finds NP (Λ)

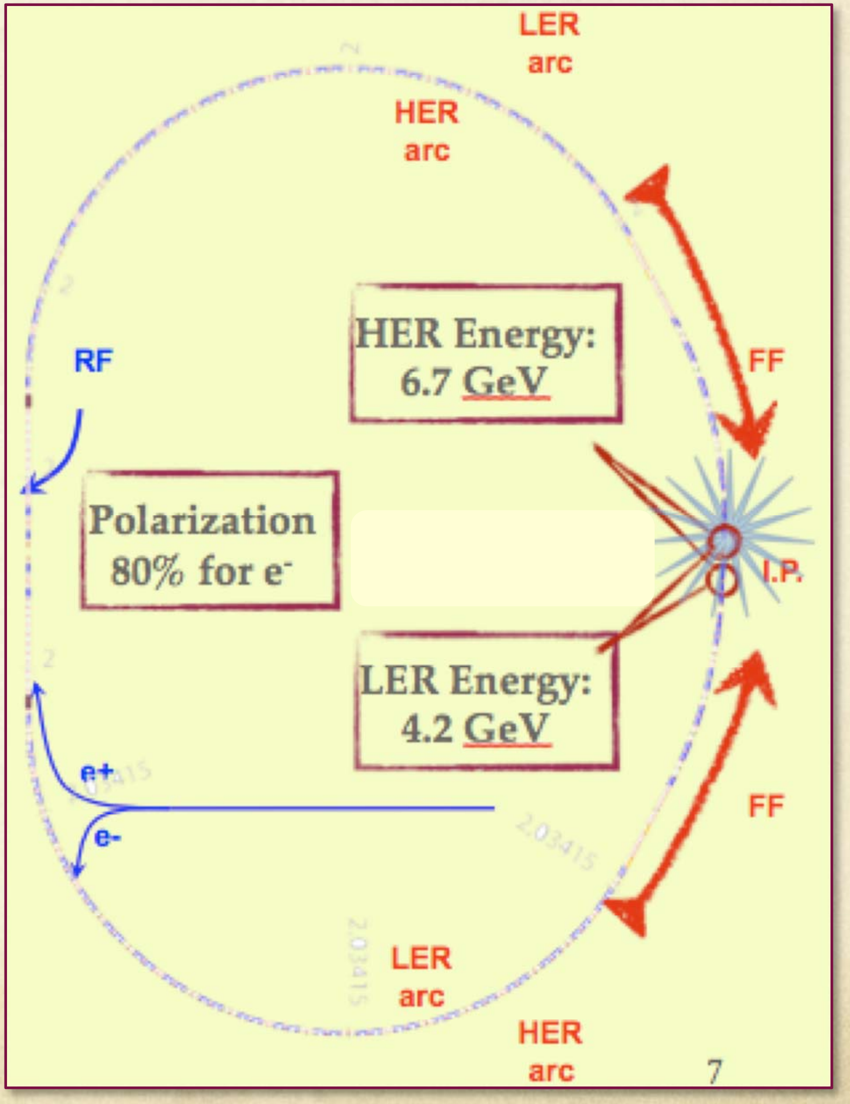
- Determine detailed structure of couplings of NP
- Look for heavier states
- Study NP flavor structure

LHC does not find NP (Λ)

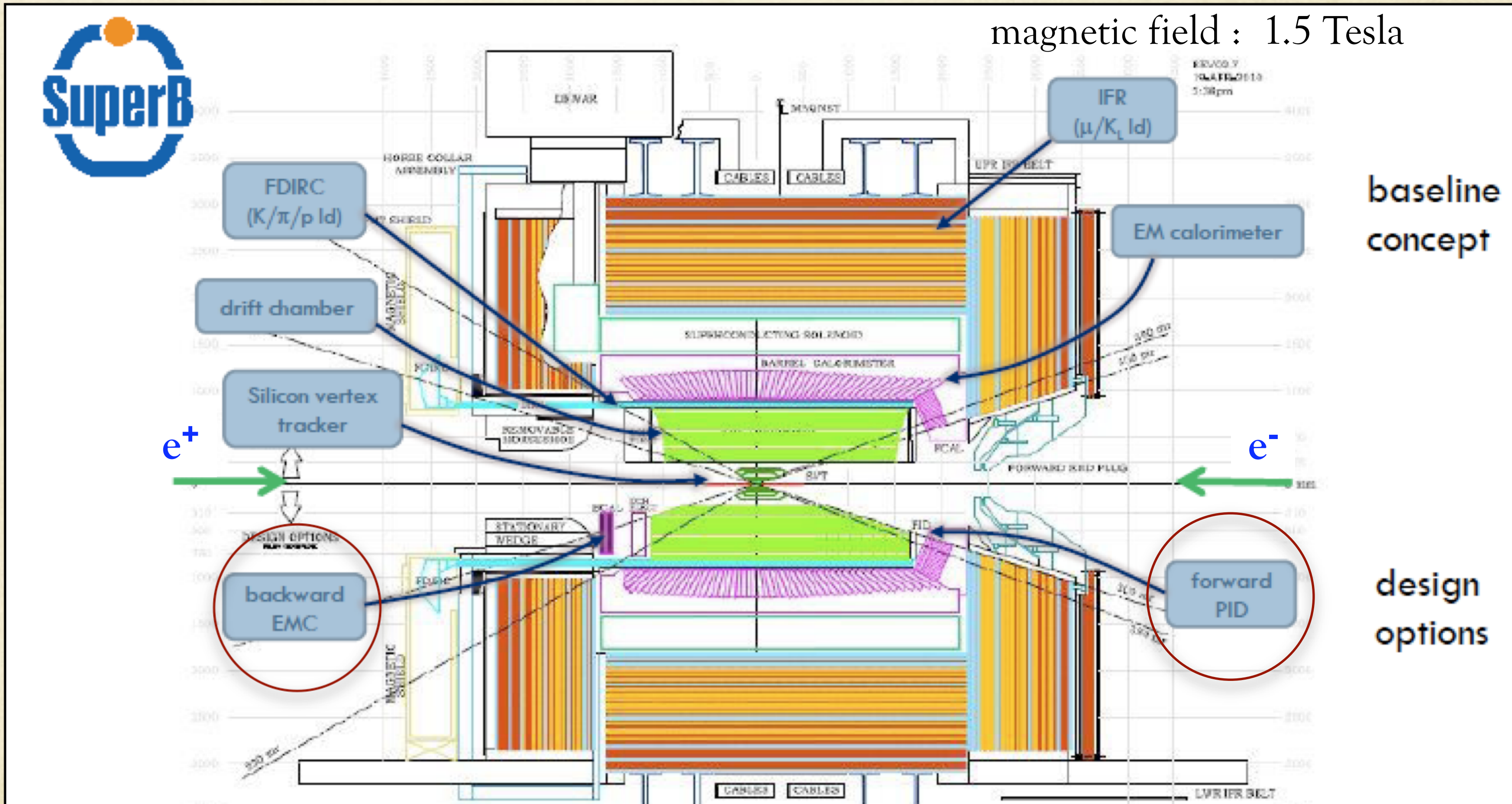
- Look for indirect NP signals
- Connect them to models
- Exclude regions in parameters space

The SuperB project

- asymmetric e^+e^- machine [1]
- CM energies:
  - mainly Υ(4S) mass
  - also runs at Ψ(3770), and scan between Υ(1S) and Υ(6S)
- Design luminosity: 10^{36} cm^{-2} s^{-1} @ 4S
- Project status:
  - approved in December 2010
  - Site chosen in May 2011: Tor Vergata Campus close to Rome
  - First data in mid-2016
  - 75 ab^{-1} @ Υ(4S) in 5 years



The SuperB detector[2]



The SuperB physics opportunity (other than HQ)[3]

B physics

Observable	B factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi \pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (*)
$S(\eta' K^0)$	0.05	0.01 (*)
$S(K_S^0 K_S^0 K_S^0)$	0.15	0.02 (*)
$S(K_S^0 \pi^0)$	0.15	0.02 (*)
$S(\omega K_S^0)$	0.17	0.03 (*)
$S(f_0 K_S^0)$	0.12	0.02 (*)
γ $(B \to DK, D \to CP$ eigenstates)	$\sim 15^\circ$	2.5°
γ $(B \to DK, D \to$ suppressed states)	$\sim 12^\circ$	2.0°
γ $(B \to DK, D \to$ multibody states)	$\sim 9^\circ$	1.5°
γ $(B \to DK$, combined)	$\sim 6^\circ$	1–2°
α $(B \to \pi\pi)$	$\sim 16^\circ$	3°
α $(B \to \rho\rho)$	$\sim 7^\circ$	1–2° (*)
α $(B \to \rho\pi)$	$\sim 12^\circ$	2°
α (combined)	$\sim 6^\circ$	1–2° (*)
$2\beta + \gamma$ $(D^{(*)\pm}\pi^\mp, D^\pm K_S^0 \pi^\mp)$	20°	5°
$\lvert V_{cb}\rvert$ (exclusive)	4% (*)	1.0% (*)
$\lvert V_{cb}\rvert$ (inclusive)	1% (*)	0.5% (*)
$\lvert V_{ub}\rvert$ (exclusive)	8% (*)	3.0% (*)
$\lvert V_{ub}\rvert$ (inclusive)	8% (*)	2.0% (*)
$BR(B \to \tau\nu)$	20%	4% (†)
$BR(B \to \mu\nu)$	visible	5%
$BR(B \to D\tau\nu)$	10%	2%
$BR(B \to \rho\gamma)$	15%	3% (†)
$BR(B \to \omega\gamma)$	30%	5%
$A_{CP}(B \to K^*\gamma)$	0.007 (†)	0.004 († *)
$A_{CP}(B \to \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \to s\gamma)$	0.012 (†)	0.004 (†)
$A_{CP}(b \to (s+d)\gamma)$	0.03	0.006 (†)
$S(K_S^0 \pi^0 \gamma)$	0.15	0.02 (*)
$S(\rho^0\gamma)$	possible	0.10
$A_{CP}(B \to$ [illegible]	[illegible]	1%
$A^{FB}(B \to$ [illegible]	[illegible]	9%
$A^{FB}(B \to$ [illegible]	[illegible]	5%
$BR(B \to K\nu\bar{\nu})$	visible	20%
$BR(B \to \pi\nu\bar{\nu})$	–	possible

D physics

Mode	Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$D^0 \to K^+K^-$	y_{CP}	$2\text{–}3 \times 10^{-3}$	5×10^{-4}
$D^0 \to K^+\pi^-$	y'_D	$2\text{–}3 \times 10^{-3}$	7×10^{-4}
	x'^2_D	$1\text{–}2 \times 10^{-4}$	3×10^{-5}
$D^0 \to K_s^0\pi^+\pi^-$	[illegible]	[illegible]	[illegible] $\times 10^{-4}$
	[illegible]	[illegible]	[illegible] $\times 10^{-4}$
Average	y_D	[illegible]	[illegible] $\times 10^{-4}$
	x_D	$2\text{–}3 \times 10^{-3}$	5×10^{-4}

	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0 e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K_s^0 e^+e^-$, $D^0 \to K_s^0\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+ e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^\pm\mu^\mp$	1×10^{-8}
$D^+ \to \pi^+ e^\pm\mu^\mp$	1×10^{-8}
$D^0 \to \pi^0 e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K_s^0 e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^- e^+e^+$, $D^+ \to K^- e^+e^+$	1×10^{-8}
$D^+ \to \pi^-\mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^- e^\pm\mu^\mp$, $D^+ \to K^- e^\pm\mu^\mp$	1×10^{-8}

τ physics

Process	Sensitivity
$\mathcal{B}(\tau \to \mu\,\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\,\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\,\mu\,\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K_S^0)$	2×10^{-10}

+ τ FC physics (CPV, ...)

Super Flavour Factory

a "treasure chest" of new physics-sensitive observables

B_s physics

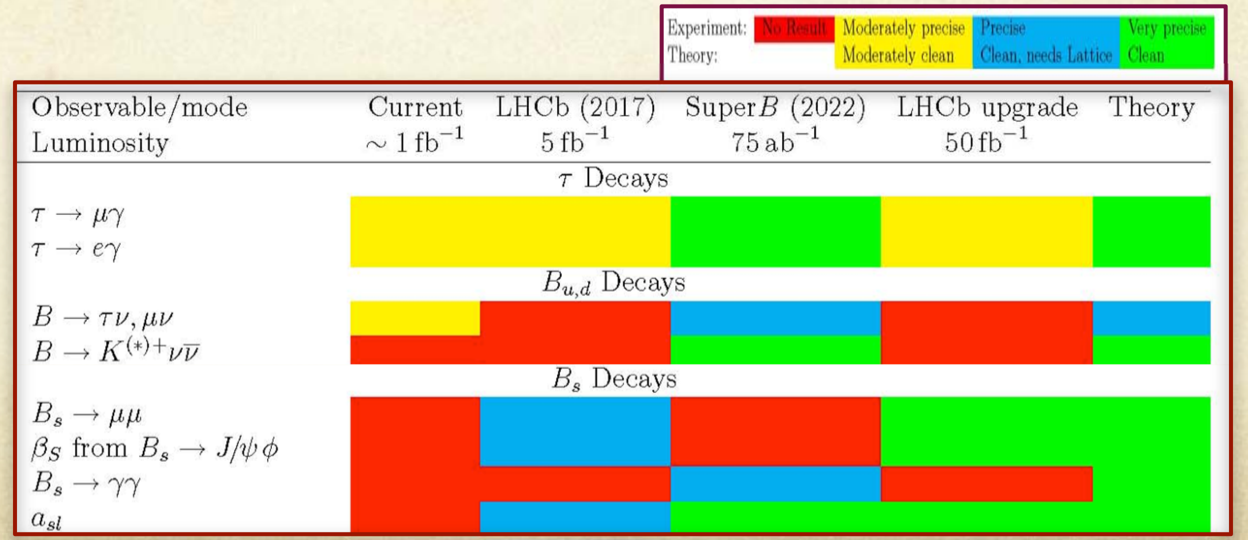
Observable	Error with 1 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}
Γ	0.07 ps^{-1}
[illegible]	[illegible]
A_{CH}	[illegible]
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-
$\lvert V_{td}/V_{ts}\rvert$	0.08
$\mathcal{B}(B_s \to \gamma\gamma)$	38%
β_s from $J/\psi\phi$	10°

Interplay with other experiments

- High luminosity @ Y(4S), asymmetric beams, good vertex resolution:
  - Belle II : 2/3 lumi, starting earlier

    LHCb : high statistics, dirty environment, some final states hardly or not accessible
- Energy scan:
  - BES III : up to 4 GeV

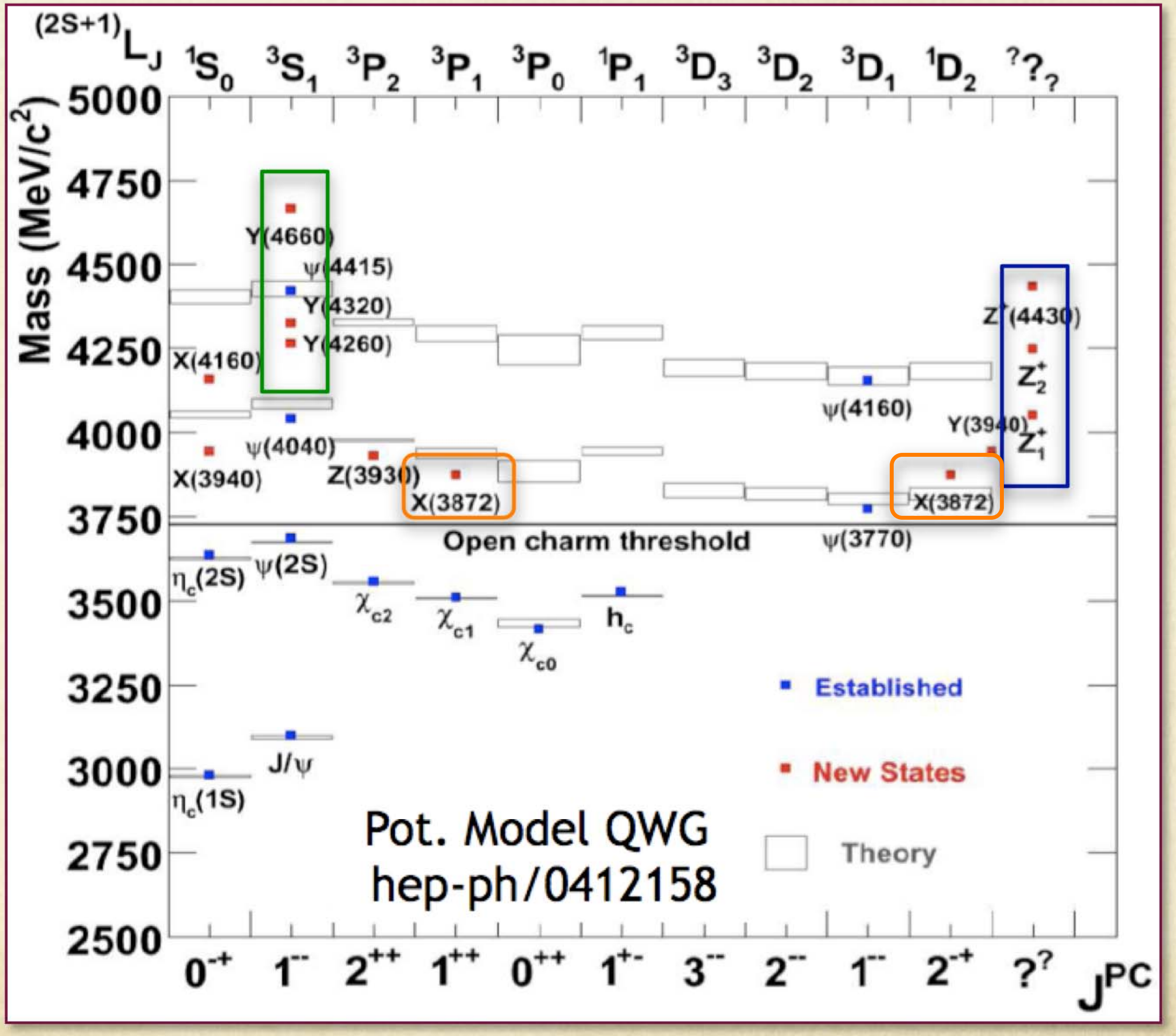
    Panda : more suitable for narrow states, lower statistics, no bottomonium spettroscopy
- Beam polarization (exploited in τ physics): feature of SuperB only
- Some examples:



Heavy Quarkonium @ SuperB

Exotic charmonium: state of the art

- States below threshold well in agreement with theory
- Unexpected narrow states above DD̲ threshold not predicted by theory
- A few examples of SuperB reaches for
  - X (3872)
  - 1^{--} Y family
  - charged Z family



Exotic charmonium: X(3872) states

- X(3872), where it all began:
  - first observed in $B \to (J/\psi\pi\pi)K$ by Belle and confirmed by BaBar et al.

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment (#σ)	Year	Status
$X(3872)$	3871.52±0.20	1.3±0.6	$1^{++}/2^{-+}$	$B \to K(\pi^+\pi^- J/\psi)$	Belle [85, 86] (12.8), BABAR [87] (8.6)	2003	OK
		(<2.2)		$p\bar{p} \to (\pi^+\pi^- J/\psi) + ...$	CDF [88–90] (np), DØ [91] (5.2)		
				$B \to K(\omega J/\psi)$	Belle [92] (4.3), BABAR [93] (4.0)		
				$B \to K(D^{*0}\bar{D}^0)$	Belle [94, 95] (6.4), BABAR [96] (4.9)		
				$B \to K(\gamma J/\psi)$	Belle [92] (4.0), BABAR [97, 98] (3.6)		
				$B \to K(\gamma\psi(2S))$	BABAR [98] (3.5), Belle [99] (0.4)		

[4]

  - tetraquark? $\underline{D}^{*0}D^0$ molecule?

- SuperB with 50 ab^{-1}:
  - 3-11 K of fully reconstructed $B \to X(3872)K$ events
  - detailed study on decay dynamics and line-shape to give possible evidence of non $q\underline{q}$-composition

Exotic charmonium: 1^{--} Y family

- Found @ B factories in Initial State Radiation events ($J^{PC} = 1^{--}$)
  - $Y(4260) \to J/\psi\pi\pi$; $Y(4320)$, $Y(4660) \to \psi(2S)\pi\pi$
    - known and understood $J^{PC} = 1^{--}$ charmonium states already in the game
    - $B(Y(4260) \to D\underline{D})/B(Y(4260) \to J/\psi\pi\pi) < 1$ @90%CL
    - $\Gamma(J/\psi\pi\pi)/\Gamma(\psi(2S)\pi\pi)$ small for Y(4320), Y(4660) and large for Y(4260)
  - hybrids? tetraquarks? hadrocharmonium?

- SuperB with 50 ab^{-1}:
  - 30K events for $Y(4260) \to J/\psi\pi\pi$ and 3K events for $Y(4320)$, $Y(4660) \to \psi(2S)\pi\pi$
  - detailed studies of line-shape, partial width ratio, $\pi\pi$ invariant mass spectra
  - possible inclusion of other exclusive decays to charmonium: $J/\psi\ \eta/\pi^0$, $\psi(2S)\ \eta/\pi^0$, $\chi_{cJ}\pi\pi$, $\gamma J/\psi$, $\gamma\psi(2S)$

Exotic charmonium: Z^+ states

- The most debated states: seen by Belle, not confirmed by BaBar

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment (#σ)	Year	Status
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008	NC!
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008	NC!
$Z(4430)^+$	4443^{+24}_{-18}	107^{+113}_{-71}	?	$B \to K(\pi^+\psi(2S))$	Belle [115, 116] (6.4)	2007	NC!

[4]

  - tetraquark? Z(4430): molecule? threshold effects?
  - neutral partners exist?

- SuperB with 50 ab^{-1}:
  - 100 K – 1.5 M events for $B \to J/\psi\pi K$, $\psi(2S)\pi K$, $\chi_{cJ}\pi K$
  - unanbigusly establish Z^+ existence and study properties

Exotic charmonium: outlooks

- An example: exotic charmonia from B decays
  - similar tables for ISR, J/ψ, γγ and recoil analysis
- Just look at colors!

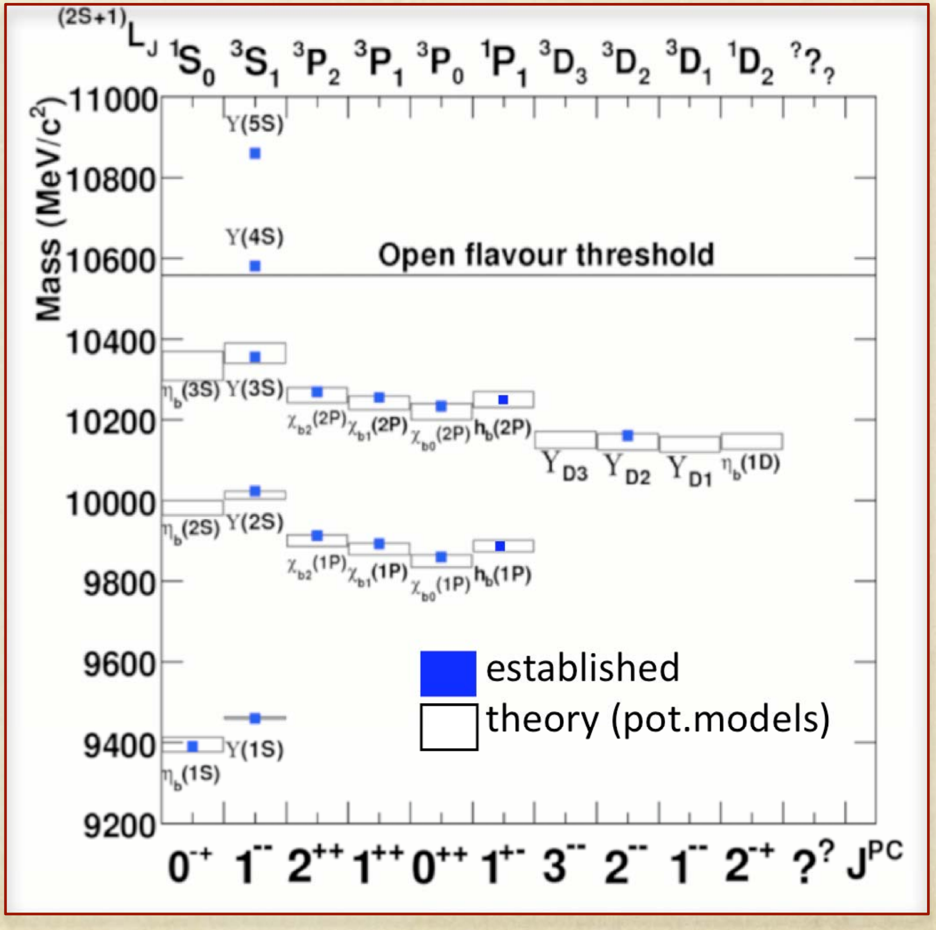
legenda
- S: seen
- M/F: missing fit
- N/S: not seen
- N: not searched
- N/A: not applicable

B decays	J/ψππ	J/ψω	J/ψγ	J/ψφ	J/ψη	ψ(2S)ππ	ψ(2S)ω	ψ(2S)γ	χcγ	pp	ΛΛ	ΛcΛc	DD	DD*	D*D*	Ds(*)Ds(*)	γγ
X(3872)	S	S	S	N/A	N/S	N/A	N/A	S	N/S	M/F	M/F	N/A	N/A	S	N/A	N/A	N/S
X,Y (3940)	M/F	S	N/S	N/A	N/A	N/A	N/A	M/F	N/A	M/F	M/F	N/A	M/F	N/S	N/A	N	N
Z(3940)	M/F	M/F	N/S	N/A	N/A	N/A	N/A	M/F	N/A	M/F	M/F	N/A	M/F	M/F	N/A	N	N
Y(4140)	M/F	M/F	N	S	N/A	N	N/A	N	N/A	M/F	M/F	N/A	M/F	N	N	N	N
X(4160)	M/F	M/F	N	M/F	N/A	N	N/A	N	N/A	M/F	M/F	N/A	M/F	N	N	N	N
Y(4260)	S	N/A	N/A	N/A	M/F	N	N/A	N/A	N	M/F	M/F	N/A	N	N	N	N	N/A
X(4350)	M/F	M/F	N	M/F	N/A	N	N	N	N/A	M/F	M/F	N/A	N	N	N	N	N
Y(4350)	M/F	N/A	N/A	N/A	M/F	N	N/A	N/A	N	M/F	M/F	N/A	N	N	N	N	N/A
Y(4660)	N	N/A	N/A	N/A	M/F	N	N/A	N/A	N	M/F	M/F	M/F	N	N	N	N	N/A

n.b. : not updated to the latest measurements

Bottomonium: regular states

- incomplete knowledge of below-threshold states
- η_b(2S,3S) and 3 D-states not observed yet
- η_b(1S) discovered but poorly known
- need higher statistics from Super Flavor Factories to
  - complete the spectrum
  - make a detailed study of already establish states (exclusive decay modes, partial widths,...)
  - precisely measure hyperfine splitting

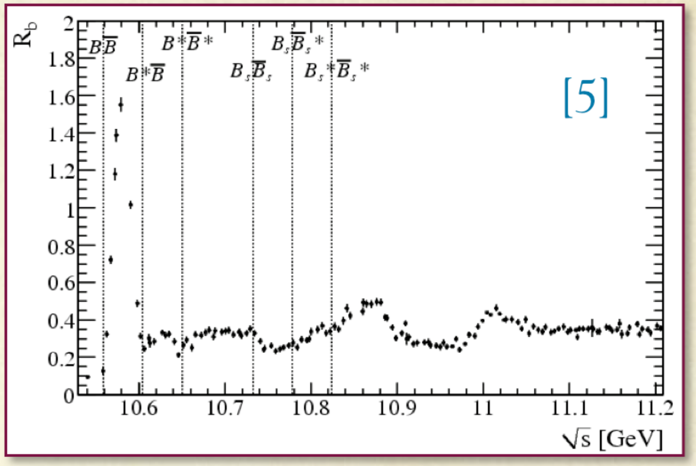


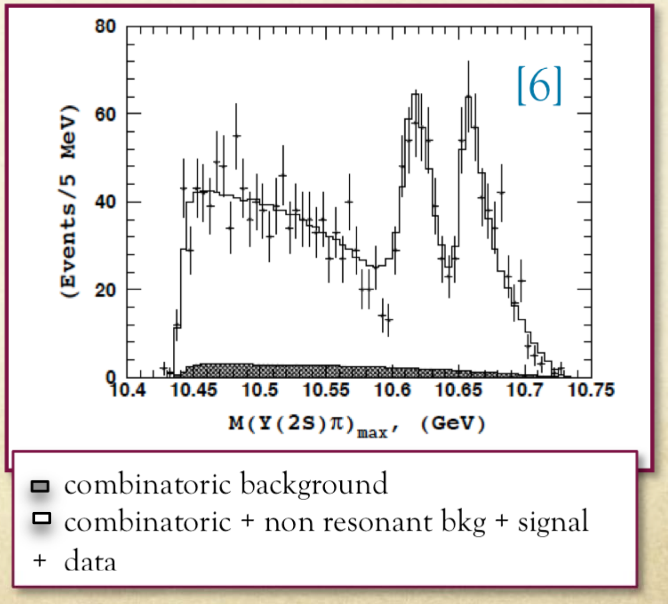
Bottomonium: exotics states from above-Y(4S) scan

- Exclusive scan performed by BaBar:
  - no effects shown
- Exclusive analysis performed by Belle
  - evidence for Z_b^+ (10610) and Z_b^+(10650)

  in Y(5S) $\rightarrow Z_b^+\pi^- \rightarrow$ Y(1S,2S,3S)$\pi^+\pi^-$

  h_b(1P,2P) $\pi^+\pi^-$
- @ SuperB :
  - larger statistics to perform inclusive analysis
  - Y(5S) nature is not yet understood and require more data

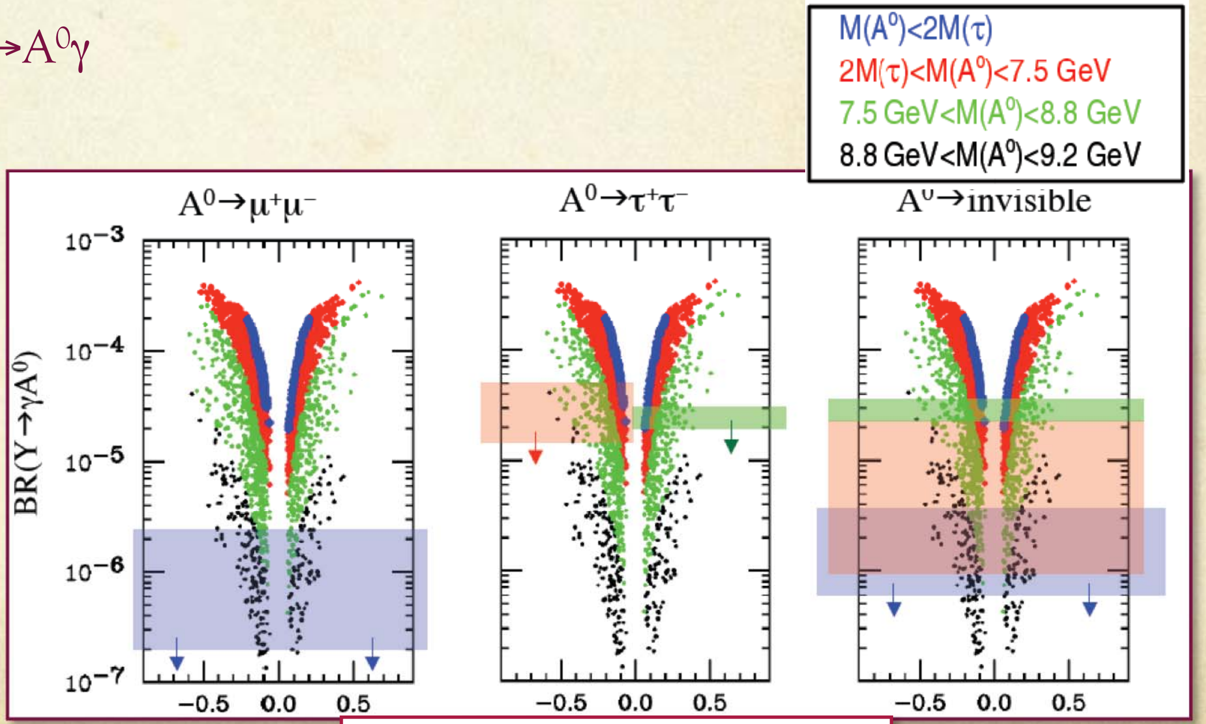




Light Higgs searches: overview

- Next-to-MSSM: light CP-odd Higgs (A^0)[7] → mass is not constrained by LEP ($m_{A0}<2m_b$)
  - not accessible to LHC experiments (high p_μ cut at trigger level)
- A^0 = mixing of a singlet with MSSM-like Higgs = A−MSSM cos θ_A + A-singlet sin θ_A
- A^0 detectable in $\Upsilon(2S,3S)\to A^0\gamma$
- Dominant decay mode

  depend on A^0 mass
  - $A^0 \to$ invisible, $\mu\mu$, $\tau\tau$, hadrons
- BaBar measurements on $\Upsilon(2S,3S) \to A^0\gamma$[8]:



non-singlet fraction ($\cos\theta_A$)

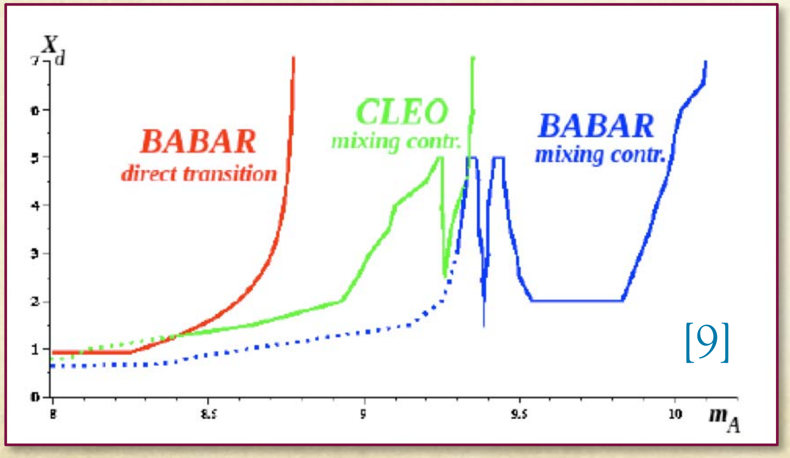
Light Higgs searches: SuperB sensitivity

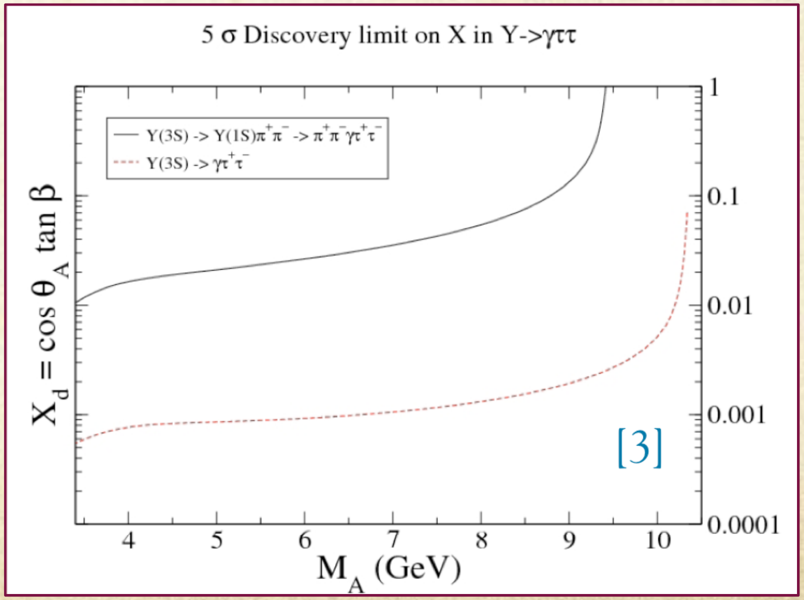
- Assuming $M_{A0} > 2M_{\tau}$, search for a monochromatic photon in
  - Y(2S,3S) → Y(1S)ππ, Y(1S) → ττγ

    4.5% BF, low background contamination
  - Y(2S,3S) → ττγ:

    higher BF, larger background from ee→ ττγ

- SuperB : 5σ discovery with 1 ab^{-1}





Conclusions

- SuperB will be one of the next generation Super Flavor Factory
  - first data on 2016, 75 ab^{-1} @ Υ(4S) in 5 years
  - precision measurements and indirect searches for NP in the flavor sector complementary to LHC
- What SuperB will say on Heavy Quarkonia with high statistics and energy scans:
  - investigate exotic charmonium state properties
  - complete observation of regular bottomomium states and investigate higher mass states using data from energy scan data
  - search for light Higgs in Υ decays
  - + items not discussed in this talk, i.e. Υ decays in invisible final states, lepton universality in Υ decays,...
- Study on SuperB reaches with simulation under way

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7 October 2011 http://www.interactions.org
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Content: Press Release
Date Issued: 7 October 2011
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Dedicated to Nicola Cabibbo the international laboratory for SuperB

Signed today the official startup of the Laboratory Nicola Cabibbo. The international centre for physics, promoted by INFN and University of Rome Tor Vergata, will lead - within six years - to the construction of SuperB accelerator on the campus of Rome Tor Vergata.

The birth of the Laboratory Nicola Cabibbo was signed today. The new international centre for fundamental and applied physics has been promoted by the National Institute for Nuclear Physics and the University of Rome Tor Vergata that made official today the establishment of a consortium for the realization of the SuperB. The SuperB project is one of the most significant of the 14 flagship

It is then the starting event for the SuperB project, which aims to complete within 6 years the construction of the accelerator and will become a large infrastructure for basic and applied research and for the development of technological innovations.

http://www.interactions.org/cms/?pid=1031120

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Extra - Slides

Unconventional $b\bar{b}$ and $c\bar{c}$ states

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment (#σ)	Year	Status
$X(3872)$	3871.52±0.20	1.3±0.6 (<2.2)	$1^{++}/2^{-+}$	$B \to K(\pi^+\pi^- J/\psi)$	Belle [85, 86] (12.8), BaBar [87] (8.6)	2003	OK
				$p\bar{p} \to (\pi^+\pi^- J/\psi) + ...$	CDF [88–90] (np), DØ [91] (5.2)		
				$B \to K(\omega J/\psi)$	Belle [92] (4.3), BaBar [93] (4.0)		
				$B \to K(D^{*0}\bar{D}^0)$	Belle [94, 95] (6.4), BaBar [96] (4.9)		
				$B \to K(\gamma J/\psi)$	Belle [92] (4.0), BaBar [97, 98] (3.6)		
				$B \to K(\gamma \psi(2S))$	BaBar [98] (3.5), Belle [99] (0.4)		
$X(3915)$	3915.6 ± 3.1	28±10	$0/2^{?+}$	$B \to K(\omega J/\psi)$	Belle [100] (8.1), BaBar [101] (19)	2004	OK
				$e^+e^- \to e^+e^-(\omega J/\psi)$	Belle [102] (7.7)		
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^- \to J/\psi(D\bar{D}^*)$	Belle [103] (6.0)	2007	NC!
				$e^+e^- \to J/\psi\ (...)$	Belle [54] (5.0)		
$G(3900)$	3943 ± 21	52±11	1^{--}	$e^+e^- \to \gamma(D\bar{D})$	BaBar [27] (np), Belle [21] (np)	2007	OK
$Y(4008)$	4008^{+121}_{-49}	226±97	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	Belle [104] (7.4)	2007	NC!
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008	NC!
$Y(4140)$	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	$B \to K(\phi J/\psi)$	CDF [106, 107] (5.0)	2009	NC!
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^- \to J/\psi(D\bar{D}^*)$	Belle [103] (5.5)	2007	NC!
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008	NC!
$Y(4260)$	4263 ± 5	108±14	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	BaBar [108, 109] (8.0)	2005	OK
					CLEO [110] (5.4)		
					Belle [104] (15)		
				$e^+e^- \to (\pi^+\pi^- J/\psi)$	CLEO [111] (11)		
				$e^+e^- \to (\pi^0\pi^0 J/\psi)$	CLEO [111] (5.1)		
$Y(4274)$	$4274.4^{+8.4}_{-6.7}$	32^{+22}_{-15}	$?^{?+}$	$B \to K(\phi J/\psi)$	CDF [107] (3.1)	2010	NC!
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0,2^{++}$	$e^+e^- \to e^+e^-(\phi J/\psi)$	Belle [112] (3.2)	2009	NC!
$Y(4360)$	4353 ± 11	96±42	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- \psi(2S))$	BaBar [113] (np), Belle [114] (8.0)	2007	OK
$Z(4430)^+$	4443^{+24}_{-18}	107^{+113}_{-71}	?	$B \to K(\pi^+\psi(2S))$	Belle [115, 116] (6.4)	2007	NC!
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^- \to \gamma(\Lambda_c^+\Lambda_c^-)$	Belle [25] (8.2)	2007	NC!
$Y(4660)$	4664±12	48±15	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- \psi(2S))$	Belle [114] (5.8)	2007	NC!
$Y_b(10888)$	10888.4±3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^- \to (\pi^+\pi^- \Upsilon(nS))$	Belle [37, 117] (3.2)	2010	NC!

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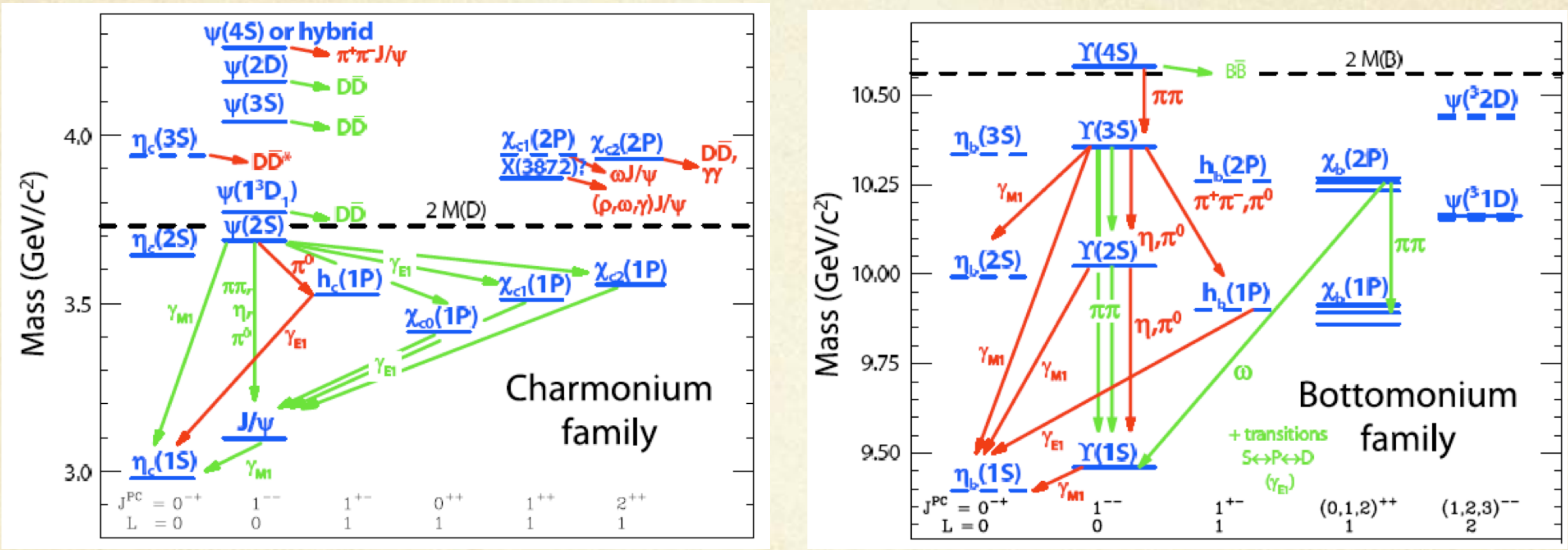

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