Drell-Yan Production of the exotic 1^{--} hadrons $\phi(2170)$, $X(4260)$ and $Y_b(10890)$ at the LHC and the Tevatron

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Contents

- Exotic Quarkonium Spectroscopy - An Overview
- Focus on $J^{PC} = 1^{--}$ tetraquark candidates: $\phi(2170)$, $X(4260)$, $Y_b(10890)$; of these, $Y_b(10890)$ not yet confirmed
- A related issue is the interpretation of the charged Bottomonium-like states $Z_b^{\pm}(10610)$ and $Z_b^{\pm}(10650)$ discovered by Belle in $\Upsilon(5S) \to \pi^+\pi^-[b\bar{b}]$ [Wei Wang; TR2]
- Drell-Yan Production of the exotic $J^{PC} = 1^{--}$ states at the LHC and the Tevatron
- Summary

Exotic Spectroscopy - An Overview

- Experimental evidence exists for "Exotic States" from e^+e^-colliders, Tevatron and the LHC
- Lost tribes of Quarkonia? [Quigg (2004)]
- $Q\bar{Q}g$ Hybrids? [Close & Page (2005); Kou & Pene (2005)]
- $D\bar{D}^{(*)}$ and $B\bar{B}^{(*)}$ Molecules? [Tornquist (2004); Braaten & Kusonoki (2004); Swanson (2004); Voloshin (2004); Liu et al. (2005); Rosner (2007); Bondar et al. (2011), Voloshin (2011); Zhang et al. (2011); Sun et al. (2011); Cleven et al. (2011);...]
- Tetraquarks $[Qq][\bar{Q}\bar{q}]$? [Maiani et al.; Polosa et al. (2004 - 2010); Ali et al. (2009 -2012);...]
- Recent Reviews on Heavy Quarkonia: [Zupanc, axiv:0910.3404; Brambilla et al., EPJ, C71, 1534 (2011); Eidelman et al., arxiv:1205.4189]

Exotic states

Belle observations [A. Zupanc [Belle], arXiv:0910.3404 (2009)] (updated)

State	M (MeV)	Γ (MeV)	J^{PC}	Decay Modes	Production Modes	Also observed by
$\phi(2170)$	2175 ± 15	61 ± 18	1^{--}	$\phi f_0(980)$	e^+e^- (ISR) $J/\psi \to \eta Y_s(2175)$	BaBar, BESII
$X(3872)$	3871.5 ± 0.2	< 2.2	$1^{++}/2^{-+}$	$\pi^+\pi^- J/\psi$, $\gamma J/\psi, D\bar{D}^*$	$B \to K X(3872), p\bar{p}$	BaBar CDF, D0,
$X(3915)$	3914 ± 4	28 ± 10	$0/2^{++}$	$\omega J/\psi$	$\gamma\gamma \to X(3915)$	
$\chi_{c2}(2P)$	3929 ± 5	29 ± 10	2^{++}	$D\bar{D}$	$\gamma\gamma \to Z(3940)$	
$X(3940)$	3942 ± 9	37 ± 17	$0^{?+}$	$D\bar{D}^*$ (not $D\bar{D}$ or $\omega J/\psi$)	$e^+e^- \to J/\psi X(3940)$	
$Y(4008)$	4008^{+121}_{-49}	226 ± 97	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^-(ISR)	
$X(4160)$	4156 ± 29	139^{+113}_{-65}	$0^{?+}$	$D^*\bar{D}^*$ (not $D\bar{D}$)	$e^+e^- \to J/\psi X(4160)$	
$Y(4260)$	4263 ± 5	108 ± 14	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^-(ISR)	BaBar, CLEO
$Y(4360)$	4353 ± 11	96 ± 12	1^{--}	$\pi^+\pi^- \psi'$	e^+e^-(ISR)	BaBar
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$\Lambda_c^+\Lambda_c^-$	e^+e^-(ISR)	
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$\pi^+\pi^- \psi'$	e^+e^-(ISR)	
$Z(4050)$	4051^{+24}_{-23}	82^{+51}_{-29}	?	$\pi^\pm \chi_{c1}$	$B \to K Z^\pm(4050)$	
$Z(4250)$	4248^{+185}_{-45}	177^{+320}_{-72}	?	$\pi^\pm \chi_{c1}$	$B \to K Z^\pm(4250)$	
$Z(4430)$	4433 ± 5	45^{+35}_{-18}	?	$\pi^\pm \psi'$	$B \to K Z^\pm(4430)$	
$Y_b(10890)$	$10,888.4 \pm 3.0$	$30.7^{+8.9}_{-7.7}$	1^{--}	$\pi^+\pi^- \Upsilon(1,2,3S)$	$e^+e^- \to Y_b$	

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$\phi(2170)$, $Y(4260)$, $Y_b(10890)$ are $J^{PC} = 1^{--}$ tetraquark candidates

Tetraquarks vs. hadronic molecules

- Two different 4-quark hadrons, seemingly similar

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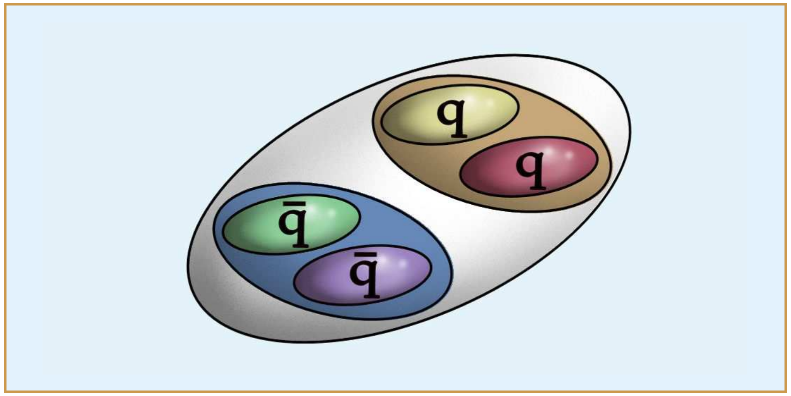
Tetraquarks:

- Diquarks and Antidiquarks are colored

$\Rightarrow$ Strongly bound by QCD forces



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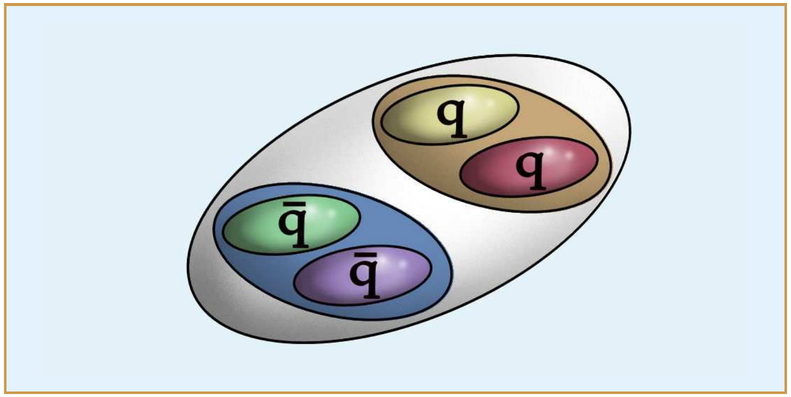
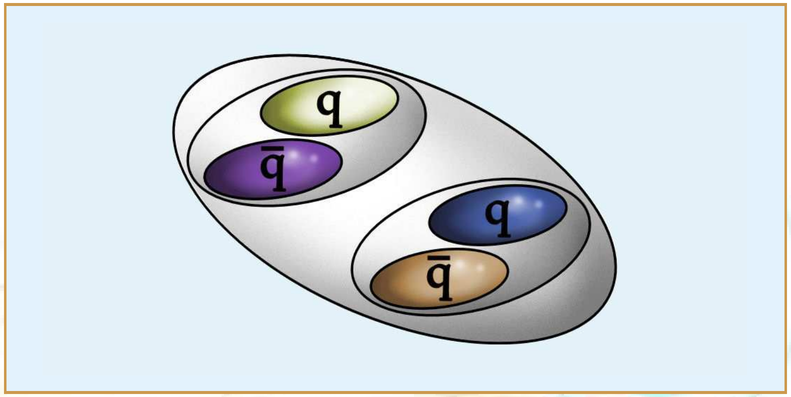


<u>Hadronic molecules</u>:

- Bound states of uncolored mesons

$\Rightarrow$ Bound by pionic exchanges



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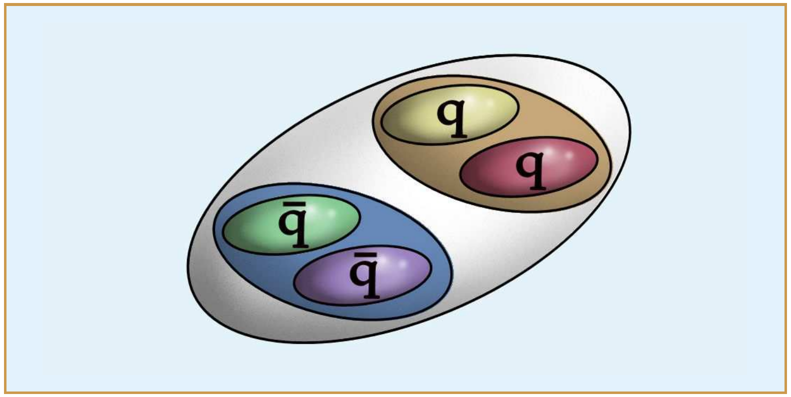

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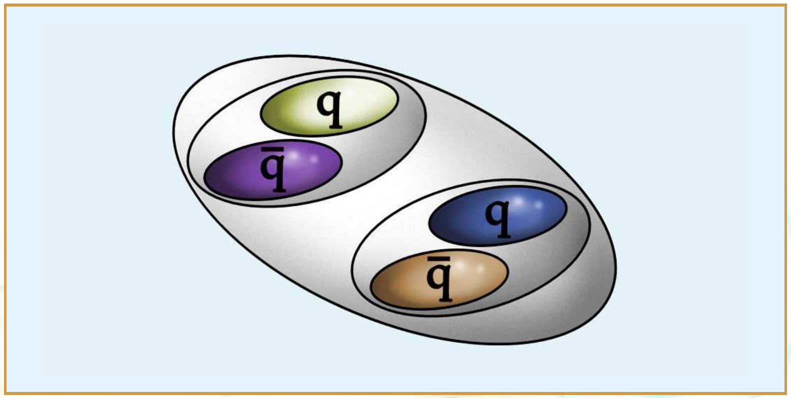


$\Rightarrow$ Very different phenomenology!

Drell-Yan Production of $\phi(2170)$, $X(4260)$, and $Y_b(10890)$

- Drell-Yan production processes are better understood theoretically than the corresponding hadroproduction processes
- However, production of these exotic vector states in the traditional $\ell^+\ell^-$ pair not promising due to the tiny leptonic BRs
- We propose to measure the Drell-Yan processes in the final states in which these hadrons have been discovered:
  $\phi(2170) \to \phi(1020) f_0(980) \to (K^+K^-)(\pi^+\pi^-)$;
  $X(4260) \to J/\psi \pi^+\pi^- \to (\ell^+\ell^-)(\pi^+\pi^-)$;
  $Y_b(10890) \to \Upsilon(nS)\pi^+\pi^- \to (\ell^+\ell^-)(\pi^+\pi^-)$;
- Advantage: Product BRs and $\Gamma_{\ell^+\ell^-}(V)$ provided by e^+e^- expts.
- Disadvantage: Significant combinatoric background from the underlying events

Drell-Yan Production of $\phi(2170)$, $X(4260)$, and $Y_b(10890)$

- Based on factorization formula:

$$\sigma(pp/p\bar{p} \to V+X) = \int dx_1 dx_2 \sum_{a,b} f_a(x_1) f_b(x_2) \otimes \sigma(a+b \to V(p)+X)$$

  - $f_a(x_1)$and $f_b(x_2)$are scale-dependent parton distribution functions (MSTW, CTEQ10); factorization scale: $\mu = \sqrt{p_T^2 + m_V^2}$
  - Include $O(\alpha_s)$corrections (Altarelli et al.; Kubar-Andre-Paige;...)

$$\frac{d^2\sigma}{dy dp_T^2} = \frac{d^2\sigma^{per}}{dy dp_T^2} + f(p_T)\left(\frac{d^2\sigma^{res}}{dy dp_T^2} - \frac{d^2\sigma^{asy}}{dy dp_T^2}\right)$$

  - $d^2\sigma^{res}/dydp_T^2$ resums the large logarithms in the small-p_T region; resummation done in the impact parameter space (Collins-Soper-Sterman)
  - Matching: $f(p_T) = \frac{1}{1+(p_T/Q_{\rm match})^4}$; $\quad Q_{\rm match} = (2 \pm 1) m_V$
  - Non-perturbative matchings and parametrizations obtained by fitting the data on W and Z production (Landsky and Yuan)

Experimental input in DY Processes $pp(\bar{p}) \to V + \ldots$

($V = \phi(2170),\ X(4260),\ Y_b(10890)$) at the LHC and Tevatron

Masses, Total and Partial widths of Vs

	m_V (MeV)	Γ (MeV)	$\Gamma_{ee}\mathcal{B}$ (eV)
$\phi(2170)$	2175 ± 15	61 ± 18	2.5 ± 0.9 [a]
$X(4260)$	4263^{+8}_{-9}	108 ± 21 [Belle]	$6.0^{+4.9}_{-1.3}$ [b] [Belle]
$Y_b(10890)$	$10888.4^{+3.0}_{-2.9}$ [Belle]	$30.7^{+8.9}_{-7.7}$ [Belle]	$0.69^{+0.23}_{-0.20}$ [c] [Belle]
$\mathcal{B}_{\phi\to K^+K^-}$	$(48.9 \pm 0.5)\%$	$\mathcal{B}_{f_0(980)\to\pi^+\pi^-}$	$(50^{+7}_{-9})\%$ [BES]
$\mathcal{B}_{J/\psi\to\mu^+\mu^-}$	$(5.93 \pm 0.06)\%$	$\mathcal{B}_{\Upsilon(1S)\to\mu^+\mu^-}$	$(2.48 \pm 0.05)\%$
$\mathcal{B}_{\Upsilon(2S)\to\mu^+\mu^-}$	$(1.93 \pm 0.17)\%$	$\mathcal{B}_{\Upsilon(3S)\to\mu^+\mu^-}$	$(2.18 \pm 0.21)\%$

[a] $\Gamma_{ee} \times \mathcal{B}(\phi(2170) \to \phi(1020) f_0(980))$.

[b] $\Gamma_{ee} \times \mathcal{B}(X(4260) \to J/\psi\pi^+\pi^-)$, corresponding to Solution I.

[c] $\Gamma_{ee} \times \mathcal{B}(Y_b(10890) \to \Upsilon(1S)\pi^+\pi^-)$ obtained from $\sigma = (2.78^{+0.48}_{-0.41})$ pb. For $Y_b \to \Upsilon(2S)\pi^+\pi^-$, the cross section $(4.82^{+1.01}_{-0.91})$ pb gives $\Gamma_{ee}\mathcal{B} = (1.20^{+0.43}_{-0.37})$ eV, while for $Y_b \to \Upsilon(3S)\pi^+\pi^-$, the cross section $(1.71^{+0.42}_{-0.39})$ pb corresponds to $\Gamma_{ee}\mathcal{B} = (0.42^{+0.16}_{-0.14})$ eV.

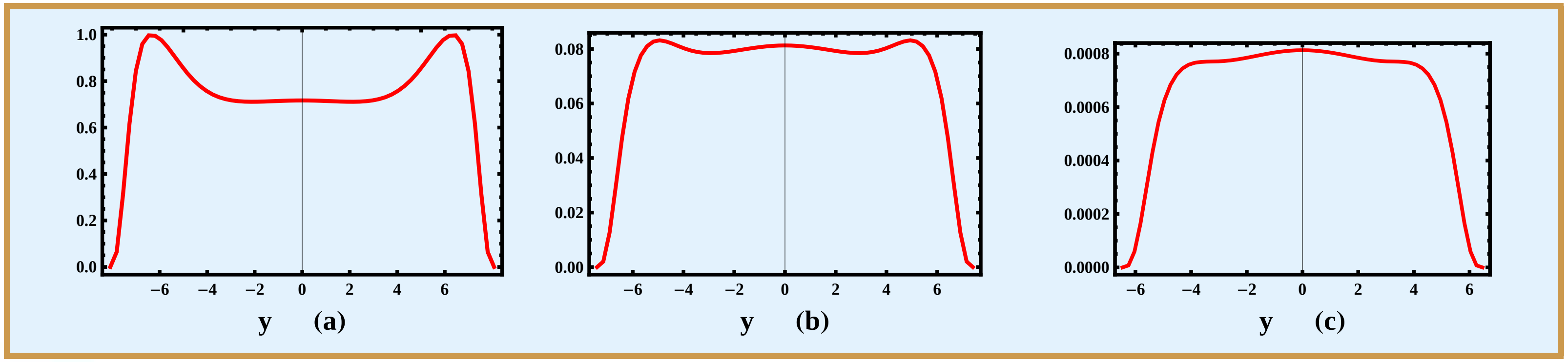
Rapidity and p_T-distributions in DY Production of $\phi(2170)$, $X(4260)$, and $Y_b(10890)$ at the LHC

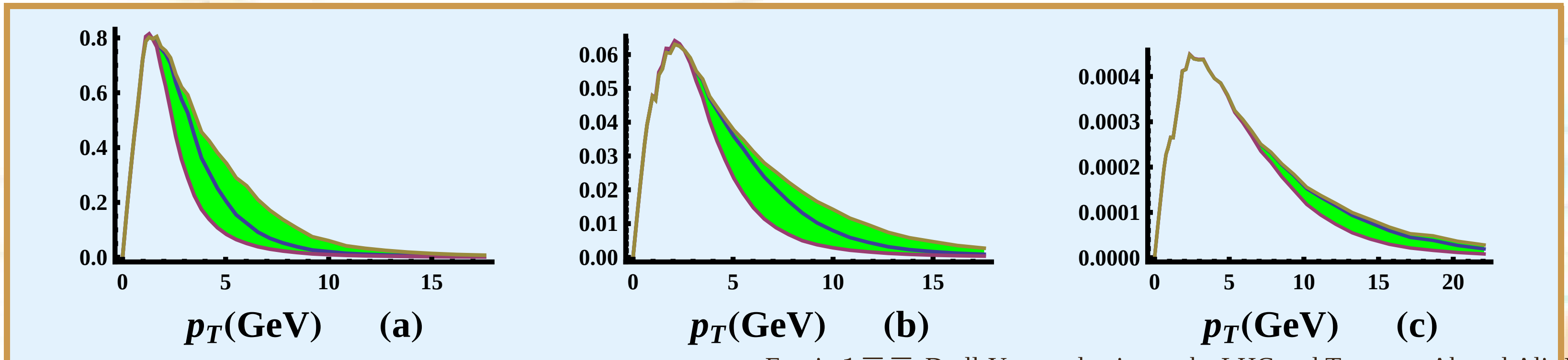
Rapidity (y) (in pb) and p_T-distributions (in pb/GeV) at $\sqrt{s} = 7$ TeV:

(a) $pp \to (\phi(2170) \to \phi(1020) f_0(980) \to K^+K^-\pi^+\pi^-) + \ldots$;

(b) $pp \to (X(4260) \to J/\psi\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-) + \ldots$;

(c) $pp \to (Y_b(10890) \to (\Upsilon(nS)\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-) + \ldots$





DY X-Scetions (in pb) for the processes $pp(\bar{p}) \to V + \ldots$ ($V = \phi(2170),\ X(4260),\ Y_b(10890)$) at the LHC and Tevatron

X-sections including the branching ratios for the processes:

$$pp(\bar{p}) \to (\phi(2170) \to \phi(1020) f_0(980) \to K^+K^-\pi^+\pi^-) + \ldots;$$
$$pp(\bar{p}) \to (X(4260) \to J/\psi\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-) + \ldots;$$
$$pp(\bar{p}) \to (Y_b(10890) \to (\Upsilon(nS)\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-) + \ldots$$

	$\phi(2170)$	$X(4260)$	$Y_b(10890)$
Tevatron($\lvert y\rvert < 2.5$)	$2.3^{+0.9}_{-0.9}$	$0.23^{+0.19}_{-0.05}$	$0.0020^{+0.0006}_{-0.0005}$
LHC 7TeV ($\lvert y\rvert < 2.5$)	$3.6^{+1.4}_{-1.4}$	$0.40^{+0.32}_{-0.09}$	$0.0040^{+0.0013}_{-0.0011}$
LHCb 7TeV ($1.9 < y < 4.9$)	$2.2^{+1.2}_{-1.1}$	$0.24^{+0.20}_{-0.07}$	$0.0023^{+0.0007}_{-0.0006}$
LHC 14TeV ($\lvert y\rvert < 2.5$)	$4.5^{+1.9}_{-1.9}$	$0.54^{+0.44}_{-0.12}$	$0.0060^{+0.0019}_{-0.0016}$
LHCb 14TeV ($1.9 < y < 4.9$)	$2.7^{+1.9}_{-1.6}$	$0.31^{+0.27}_{-0.11}$	$0.0033^{+0.0011}_{-0.0010}$

- $\phi(2170)$ and $X(4260)$ are measurable in Drell-Yan with current luminosities [(2 - 10) (fb)$^{-1}$]; $Y(10890)$ requires higher luminosity

Summary

- Exotic Quarkonia Spectroscopy allows to gain deeper insight in QCD; LHC expected to contribute handsomely in this endeavour
- Newest additions in exotica: Charged $[b\bar{b}]$ states $Z_b^\pm(10610)$ and $Z_b^\pm(10650)$; imperative to understand them, clarify the status of $Y_b(10890)$ and the enigmatic Belle data near $\Upsilon(5S)$
- Hadroproduction X-sections of $Z_b^\pm(10610)$, $Z_b^\pm(10650)$, $Y_b(10890)$, $X(4260)$, $\phi(2170)$ and many more such exotic states are uncertain but expected to be large
- Presented Drell-Yan production of $\phi(2170)$, $X(4260)$ and $Y_b(10890)$ at the LHC and Tevatron in the discovery final states; these measurements are challenging but they will extend the use of Drell-Yan processes to study exotica