Number of XYZ States per day at Panda

Charmonium-Exotics Meeting, 31.08.2015
Internal note rn-qcd-2015-004
Planned to be presented at hadron2015, 13.-18.09.2015
Alexander Blinov, Sören Lange, Elisabetta Prencipe

What is the issue?

Issue is <u>not</u> showing results about the search for the Z(3730), yet.

Instead:

We would like to show

Number of X(3872) per day at PANDA
Number of Y(4260) per day at PANDA
Number of Z(3900) per day at PANDA

at the hadron2015 conference
(in other words: the internal note contains some numbers to be released)

These numbers are part of an internal note:
https://panda.gsi.de/publication/rn-qcd-2015-004

(In the future, there will also be PandaRoot results about the Z(3730),
But this is not relevant for today)

Summary of the review (so far)

Internal note was posted ~2 months ago
why internal ?
→ Email 03.07.15 by F. Nerling to PANDA-LightCharmoniumExotics@gsi.de
→ Nothing to be released here.

Since then, review by the convenor (F. Nerling) and one member of the PubCom (K. Goetzen) invited by the convenor.
During that time, only exchange of (many) private emails.

The review was not concluded yet, but we applied to make the note public to the collaboration, for 2 reasons:
- questions were asked repeatedly (although already answered)
  → better to use the forum for keeping track,
- to discuss some of the questions raised in a wider auditory.

Questions by F. Nerling were answered in the review.

Some questions by K. Goetzen are open
(→ topic of today).

Issue #1:

Detailed Balance

Detailed Balance

Eq. (1) in the internal note:

$$\sigma[p\bar{p} \to R] \cdot \mathcal{B}(R \to f) = \frac{(2J+1)\cdot 4\pi}{s - 4m_p^2} \cdot \frac{\mathcal{B}(R \to p\bar{p}) \cdot \mathcal{B}(R \to f) \cdot \Gamma_R^2}{4(\sqrt{s} - m_R)^2 + \Gamma_R^2}$$

Formula follows from Breit-Wigner formula (inserting k and E_0).

$$\sigma(E) = \frac{2J+1}{(2S_1+1)(2S_2+1)} \frac{4\pi}{k^2} \left[\frac{\Gamma^2/4}{(E-E_0)^2 + \Gamma^2/4} \right] B_{in} B_{out},$$

K.A. Olive *et al.* (Particle Data Group), Chin. Phys. C, 38 (2014) 090001.

We cite PDG as reference, but reference was not accepted as appropriate and more fundamental reference for time-reversal invariance was required

→ L. Onsager, Phys. Rev. 37 (1931) 405.

PHYSICAL REVIEW D VOLUME 47, NUMBER 3 1 FEBRUARY 1993

ARTICLES

Measurement of the J/ψ and ψ' resonance parameters in $\bar{p}p$ annihilation

T. A. Armstrong,[f] D. Bettoni,[b] V. Bharadwaj,[a] C. Biino,[g] G. Borreani,[b]

...

E760/E835 Experiment

excitation curve. The Breit-Wigner cross section for the formation and subsequent decay of a $c\bar{c}$ resonance R of spin J, mass M_R, and total width Γ_R formed in the reaction $p\overline{p} \to R$ is

$$\sigma_{\mathrm{BW}}(E_{\mathrm{c.m.}}) = \frac{(2J+1)}{(2S+1)(2S+1)} \frac{4\pi(\hbar c)^2}{[E_{\mathrm{c.m.}}^2 - 4(m_p c^2)^2]} \times \frac{\Gamma_R^2 B_{\mathrm{in}} B_{\mathrm{out}}}{[E_{\mathrm{c.m.}} - M_R c^2]^2 + \Gamma_R^2/4} . \quad (1)$$

Here S is the spin of the proton, B_{in} and B_{out} are the branching ratios ($B = \Gamma_{\mathrm{partial}}/\Gamma_R$) in the resonance formation channel ($\bar{p}p \to R$) and in the decay channel respectively. For the present study we select the decay

A.Lundborg, T. Barnes, U. Wiedner

Phys.Rev. D73 (2006) 096003

hep-ph/0507166

C. Connecting charmonium decay and production

The partial width $\Gamma_{\Psi\to mp\bar{p}}$ and the production cross section $\sigma_{p\bar{p}\to m\Psi}$ given above are simply related in the constant amplitude approximation, since both are given by simple kinematic and spin factors times the same spin-summed squared amplitude. Eliminating the common squared amplitude, we find the following relation between the cross section and decay width:

$$\sigma_{p\bar{p}\to m\Psi} = 4\pi^2(2S_\Psi + 1)\,\frac{M_\Psi^3}{A_D}\,\Gamma_{\Psi\to mp\bar{p}}\left[\frac{p_{m\,cm}}{p_{p\,cm}}\,s^{-1}\right]. \quad (7)$$

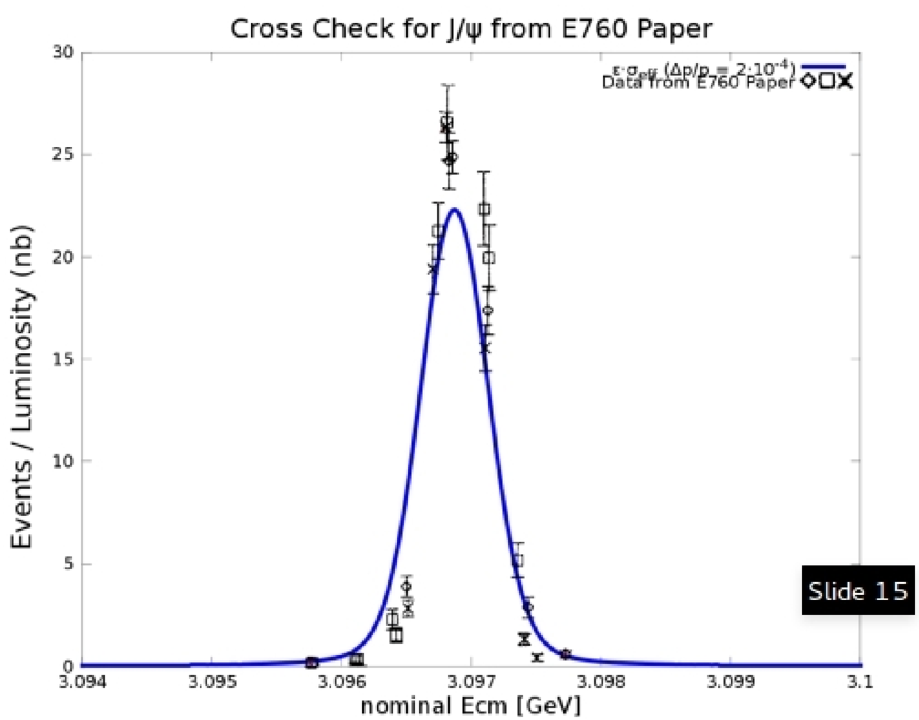
How do we know that detailed balance works for Panda ?

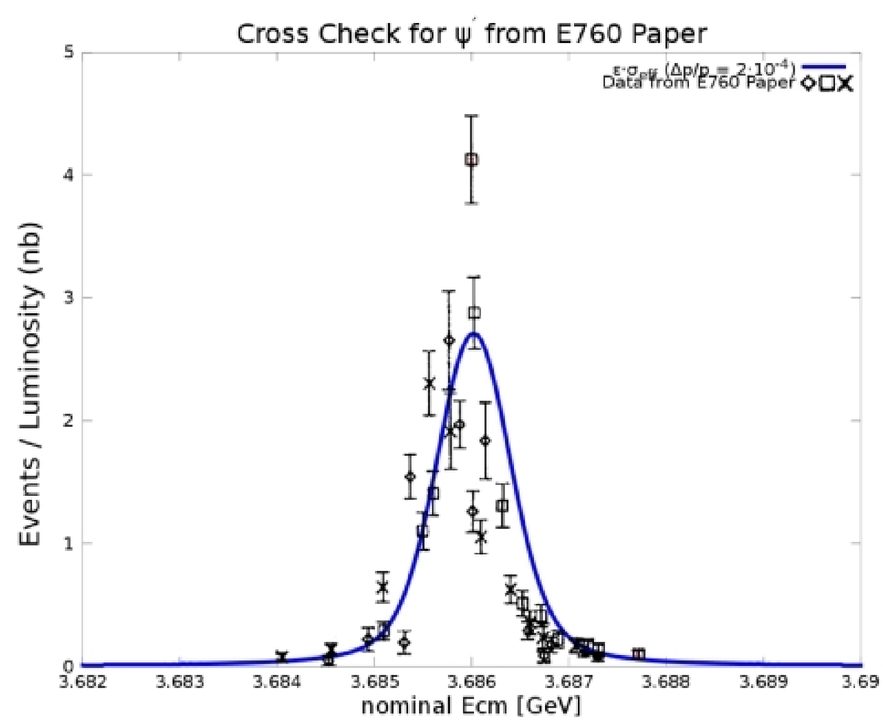
See talk by Martin Galuska, Panda Meeting, June 2013

Blue curves are from detailed balance (using branching fractions from PDG or LHCb).

Data points from E760.

Method Cross Check With Data from E760 Paper [E7693]





$$\sigma[p\bar{p} \to R] \cdot \mathcal{B}(R \to f) = \frac{(2J+1) \cdot 4\pi}{s - 4m_p^2} \cdot \frac{\mathcal{B}(R \to p\bar{p}) \cdot \mathcal{B}(R \to f) \cdot \Gamma_R^2}{4(\sqrt{s} - m_R)^2 + \Gamma_R^2}$$

This is used in the internal note for R=Y(4260).

We use B(Y(4260) → $J/\psi\pi^+\pi^-$) =100%

Question in the review:
what happens, if it is less than 100% ?
("it does not cancel")

(Let's call it "invisible decays", but the particular concern was maybe for Y(4260) → $J/\psi\pi^0\pi^0$)

We think that it applies to both sides of the equation:

$$\sigma[p\bar{p} \rightarrow R \rightarrow f] + \boxed{\sigma[p\bar{p} \rightarrow R \rightarrow invisible]} =$$

$$\frac{(2J+1)\cdot 4\pi}{s-4m_p^2} \cdot \frac{\mathcal{B}(R \rightarrow p\bar{p}) \cdot (\mathcal{B}(R \rightarrow f) + \boxed{\mathcal{B}(R \rightarrow invisible)}) \cdot \Gamma_R^2}{4(\sqrt{s}-m_R)^2 + \Gamma_R^2}$$

Issue #2:

Partial Widths

How do we calculate cross sections for Panda?

Ansatz:

If branching fraction B(R → pp) is known:

→ apply detailed balance

If branching fraction B(R → pp) is unknown:

→ apply assumption that partial width is identical

Partial widths

$\Gamma(R \rightarrow p\bar{p})$ assumed identical

for all charmonium(-like) states

Eq. (4) in the internal note

$$BR(Y(4260) \rightarrow \bar{p}p) = BR(J/\psi \rightarrow \bar{p}p) \cdot \frac{\Gamma(J/\psi)}{\Gamma(Y(4260))}$$

Is required to estimate the (unknown) coupling of Y(4260) to $p\bar{p}$

→ without this estimate: no numbers for the Y(4260)

Significant issue in the review of the note

Scaling is used in
Panda physics performance report, p. 78,Sec. 4.2.2.5.
for scaling from J/Psi to psi(3770).

Comment from our referee: “This method unfortunately is unreferenced, since the it is simply claimed in TPR without any further supporting paper”.

The charm production cross sections close to threshold in $\overline{\mathrm{p}}\mathrm{p}$ annihilations are unknown. To estimate the $D\overline{D}$ production cross section a Breit-Wigner approach can be used to calculate the resonant cross section, where the unknown branching ratios to $\overline{\mathrm{p}}\mathrm{p}$ are estimated by scaling the known ratio $J/\psi \rightarrow \overline{\mathrm{p}}\mathrm{p}$ [31]. This method estimates only the strength of the resonance contribution to the cross section. The strength of the $D\overline{D}$ continuum production is unknown and to account for its contribution, the known decay branchings $c\overline{c} \rightarrow D\overline{D}$ have been set to 100 %, which leads to assumptions for the cross sections of:

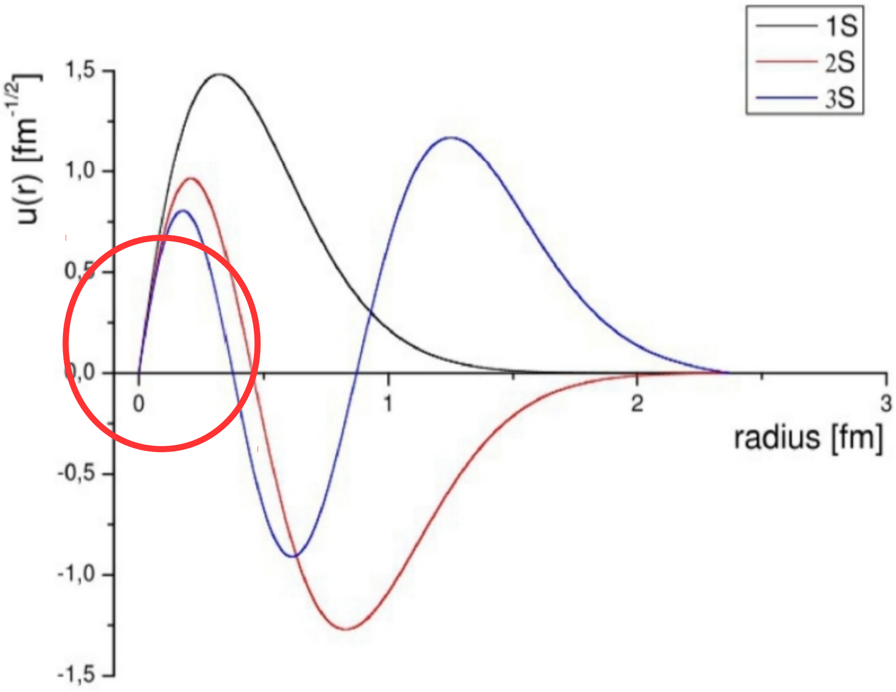
$$\sigma(\overline{\mathrm{p}}\mathrm{p} \rightarrow \Psi(3770) \rightarrow D^+D^-) = 2.8\,nb$$

for the first channel, and

$$\sigma(\overline{\mathrm{p}}\mathrm{p} \rightarrow \Psi(4040) \rightarrow D^{*+}D^{*-}) = 0.9\,nb$$

Physics reason for scaling:

- wave function
- partial width for annihilation scales with | psi(r=0) |2
- short range wave function dominated by spin-spin interaction
  → similar for all radial excitations



$$\Gamma(^3S_1 \to \gamma) = \frac{65\pi}{9} \frac{\alpha_{em}}{m_c^2} |\psi(r=0)|^2$$

$$\Gamma(^3S_1 \to ggg) = \frac{40}{81\pi} (\pi^2 - 9) \frac{\alpha_S^3}{M_0^2} |\psi(r=0)|^2$$

Maybe first historical case of
scaling for the Y(4260) to standard charmonium

BaBar Collaboration, arXiv:0808.1543[hep-ex]

(here it is partial width to e+e-,
at Panda this would be partial width to $p\bar{p}$).

$$\frac{\Gamma_{ee}(Y)\mathcal{B}(Y \to \pi^+\pi^- J/\psi)}{\Gamma_{ee}(\psi(2S))\mathcal{B}(\psi(2S) \to \pi^+\pi^- J/\psi)} = \left(\frac{N(\gamma\, Y)}{N(\gamma\, \psi(2S))}\right) \cdot \left(\frac{m(Y)}{m(\psi(2S))}\right) \cdot \left(\frac{\varepsilon(\psi(2S))}{\varepsilon(Y)}\right) \cdot \left(\frac{W(\psi(2S))}{W(Y)}\right)$$

BESIII

Analysis of $\psi(3770) \to p\bar{p}$, by Yutie Liang (Giessen)

arXiv:1403.6011, Phys. Lett. B735 (2014) 101

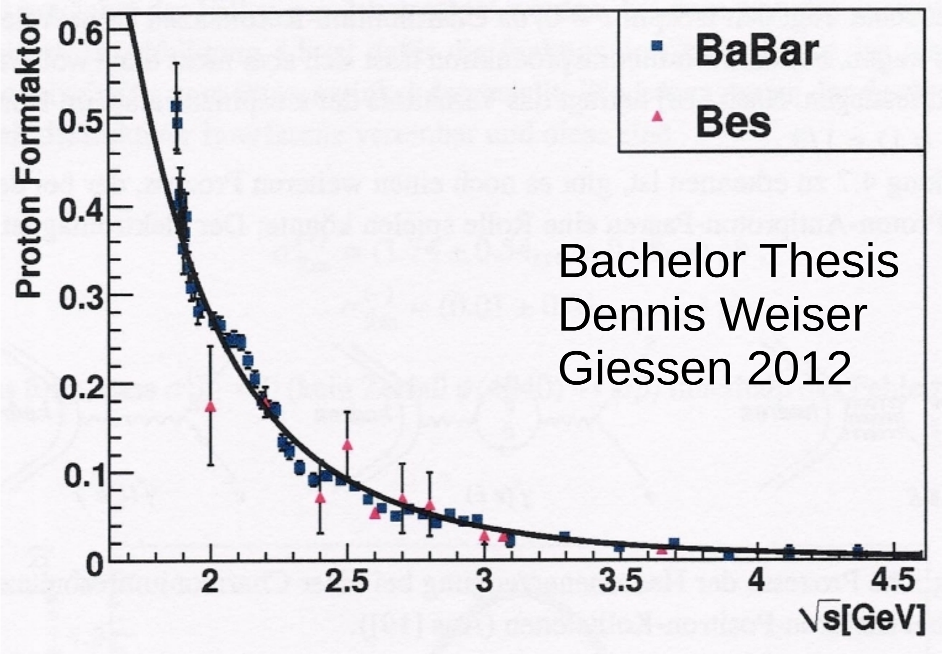
detector. Theoretical estimations vary with several orders of magnitude [33, 34, 35, 36, 37, 38, 39, 40, 41]. In the physics performance report for $\bar{\text{P}}$ANDA [42], the $D\bar{D}$ production cross section is estimated to be 6.35 nb, with the unknown branching ratio of $\psi(3770) \to p\bar{p}$ scaled from the known ratio of $J/\psi \to p\bar{p}$. In this paper, the cross section of $\sigma(p\bar{p} \to \psi(3770))$ has been determined. As the first charmonium state above the $D\bar{D}$ threshold, $\psi(3770)$ could be used as a source of open charm production.

(1) This is a <u>published</u> Phys. Lett. B

(2) Co-Authors: many Panda people
incl. authors and reviewers of internal note

(3) for BESIII scaling for $p\bar{p}$ is accepted,
for Panda (in the review of the internal note) not accepted
→ appears contradiction

Why scaling for $p\bar{p}$ may not work perfectly → proton formfactor



e+e– → pointlike

$p\bar{p}$ → formfactor
energy dependence in implicitly included in branching fraction (quadratically)

Issue #3:

Branching Fractions
of Y(4260)

In the note, we use $B(J/\psi\pi+\pi-)=100\%$ (and mention it explicitely in the text).

The reviewers ask us to apply Clebsch-Gordan coefficients for isospin, and subtract the estimated $B(J/\psi\pi^0\pi^0)$.

BR (from PDG)
(1) no numbers are given, only "seen" (incl. $J/\psi\pi^0\pi^0$)
(2) all values are normalized to $J/\psi\pi^+\pi^-$

$\Gamma(J/\psi\pi\pi)$ is even called here Γ_{total}

$X(4260)\to J/\psi\pi^+\pi^-$ = seen

$\Gamma(X(4260)\to J/\psi\pi^0\pi^0)$ = seen No number, no reference

$\Gamma(X(4260)\to J/\psi K^+K^-)$ = seen <1.2 eV

$\Gamma(X(4260)\to X(3872)\gamma)\ /\ \Gamma(J/\psi\pi^+\pi^-)$= seen No number

$\Gamma(X(4260)\to Z_c(3900)^-\pi^+)\ /\ \Gamma(J/\psi\pi^+\pi^-)$= seen 0.215 ±0.033 ±0.075

$\Gamma(X(4260)\to J/\psi\ f0)\ /\ \Gamma(J/\psi\pi^+\pi^-)$= seen 0.17 ±0.13

$\Gamma(X(4260)\to \bar{p}p)\ /\ \Gamma(J/\psi\pi^+\pi^-)$= seen <0.13 No evidence

$\Gamma(X(4260)\to D\bar{D})\ /\ \Gamma(J/\psi\pi^+\pi^-)$= seen <1.0 No evidence

$\Gamma(X(4260)\to D_s^{*+}D_s^{*-})\ /\ \Gamma(J/\psi\pi^+\pi^-)$= seen <0.8 No evidence

$\Gamma(X(4260)\to D_s^{+}D_s^{-})\ /\ \Gamma(J/\psi\pi^+\pi^-)$= seen <0.7 No evidence

$\Gamma(X(4260)\to D^*\bar{D}^*\pi)\ /\ \Gamma(J/\psi\pi^+\pi^-)$= seen <8.2 No evidence

$\Gamma(X(4260)\to \bar{D}D^*)\ /\ \Gamma(J/\psi\pi^+\pi^-)$= seen <34 No evidence

$\Gamma(X(4260)\to D^0D^{+*}\pi^-)\ /\ \Gamma(J/\psi\pi^+\pi^-)$= seen <9 No evidence

Referenes for Upper Limits (same sequence as previous page, but some papers have multiple references)

Phys. Rev. D77 (2008) 011105

Phys. Rev. Lett. 112 (2014) 092001

Phys. Rev. Lett. 110 (2013) 252001

Phys. Rev. D86 (2012) 051102

Phys. Rev. D73 (2006) 012005

Phys. Rev. D76 (2007) 111105

Phys. Rev. D80 (2009) 072001

Phys. Rev. D79 (2009) 092001

Phys. Rev. D80 (2009) 091101

- All BR normalized to $J/\psi\pi^+\pi^-$, dominant decay
- No reference for $J/\psi\pi^0\pi^0$

Reminder: upper limits have huge systematic errors, but not quoted (many of them are consitent with zero).

Normalization of Y(4260)

arXiv:1406.6311 [pdf], Eur. Phys. J. C74 (2014) 3026

BaBar & Belle Collaboration, The Physics of the B Factories

$$\begin{aligned}
\mathcal{B}(Y(4260) \to D\overline{D})/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) &< 1.0, \\
\mathcal{B}(Y(4260) \to D^*\overline{D})/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) &< 34, \\
\mathcal{B}(Y(4260) \to D^*\overline{D}^*)/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) &< 40.
\end{aligned} \tag{18.3.9}$$

BABAR also set 90% C.L. limits for the $Y \to D_s^{(*)+}D_s^{(*)-}$ decay channels (del Amo Sanchez, 2010d):

$$\begin{aligned}
\mathcal{B}(Y(4260) \to D_s^+D_s^-)/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) &< 0.7, \\
\mathcal{B}(Y(4260) \to D_s^-D_s^{*-})/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) &< 44, \\
\mathcal{B}(Y(4260) \to D_s^{*+}D_s^{*-})/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) &< 30.
\end{aligned} \tag{18.3.10}$$

See also BaBar, hep-ex/0607083

We see no reason to apply another normalization.

Proposal for new approach

(1) we use the ψ(3770) as reference (nice proposal by Alexander)

$$\mathcal{B}(\psi(3770) \to p\bar{p}) = (7.1^{+8.6}_{-2.9}) \cdot 10^{-6}$$
$$\sigma(p\bar{p} \to \psi(3770)) = (9.8 \pm 5.7)\ nb\ (< 17.2\ nb\ at\ 90\%\ C.L.))$$

BESIII, arXiv:1403.6011, Phys. Lett. B 735 (2014) 101

(2) for scaling from one mass to another mass
we use the formfactor

exception: if we start from <u>measured</u> BR's,
as in that case formfactor is already included

(3) any other assumptions are following PDG

Assumptions (if they are explicitely mentioned) are also normal procedure
Example BESIII
arXiv:1310.4101, **Phys. Rev. Lett. 112, 092001 (2014)**

Combining with the $e^+e^- \to \pi^+\pi^- J/\psi$ cross section measurement at $\sqrt{s} = 4.260$ GeV from BESIII [14], we obtain $\sigma^B[e^+e^- \to \gamma X(3872)] \cdot \mathcal{B}[X(3872) \to \pi^+\pi^- J/\psi]/\sigma^B(e^+e^- \to \pi^+\pi^- J/\psi) = (5.2 \pm 1.9) \times 10^{-3}$, under the assumption that the $X(3872)$ is produced only from the $Y(4260)$ radiative decays and the $\pi^+\pi^- J/\psi$ is only from the $Y(4260)$ hadronic decays. If we take $\mathcal{B}[X(3872) \to \pi^+\pi^- J/\psi] = 5\%$ [25], then $\mathcal{R} = \frac{\sigma^B[e^+e^- \to \gamma X(3872)]}{\sigma^B(e^+e^- \to \pi^+\pi^- J/\psi)} = 0.1$, or equivalently, $\frac{\mathcal{B}[Y(4260) \to \gamma X(3872)]}{\mathcal{B}(Y(4260) \to \pi^+\pi^- J/\psi)} = 0.1$.

Lower limit | Upper limit

X(3872)

Lower limit: —

Upper limit:

50 nb

estimate by Eric Braaten

(compare 402 nb for ψ(2S), and consistent with detailed balance

<68 nb

(see talk M. Galuska, Panda Meeting June 2013)

Y(4260)

Lower limit:

77 pb

assuming (based upon annihilation)

$\Gamma(Y \to p\bar{p})$ / $\Gamma(Y \to e^+e^-)$ =
$\Gamma(\psi(3770) \to p\bar{p})$ / $\Gamma(\psi(3770) \to e^+e^-)$

compare σ(e+e–)=69 pb (BESIII)

Upper limit:

2.2 nb

Using Eq. (4)

(assume identical partial width)

and using (3770) as reference

(similar total width,

27.2 Mev vs. 120 MeV)

Z(3900)

$$R = \frac{\sigma(e^+e^- \to Z_c(3900)^+\pi^- \to J/\psi\pi^+\pi^-)}{\sigma(e^+e^- \to J/\psi\pi^+\pi^-)} = 21.5\%$$ BESIII

~ 17 pb | ~ 473 pb

assume 100% resonant Y(4260) and normalize to B(Y → J/ψπ+π–)=100%
(and mention it explicitely)

And: assume no numbers which are only given as “seen” in PDG

Upper limit for X(3872)

We use

$$\sigma(p\bar{p} \to X(3872)) \quad = \quad 50\ nb$$

which is based upon

E. Braaten, arXiv:0711.1854 [hep-ph], Phys. Rev. D77(2008)034019

and private communication with E. Braaten in 2010.

Lower limit for X(3872)

We use the cross section from [1] of 9.8 nb for the $\psi(3770)$ and correct for the mass difference between the $\psi(3770)$ and the X(3872) by using an energy dependence of the proton formfactor in the charmonium mass range of

$$|G(s)| = \frac{C}{s^2 ln^2(s/\Lambda^2)} \tag{4}$$

with scale parameter Λ=0.3 GeV and C=64.0±7.6 from a fit to BESIII and BaBar data in D. Weiser, Bachelor Thesis, Giessen, 2012.

This give

Not applicable
X(3872) is too narrow

$$\begin{aligned} \sigma(p\bar{p} \to X(3872)) &= 9.8\ nb \cdot \frac{|G(3872)|^2}{|G(3770)|^2} \\ &= 9.8\ nb \cdot \frac{0.01185^2}{0.01225^2} \\ &= 9.2\ nb \end{aligned} \tag{5}$$

Upper limit for Y(4260)

We start from Eq. (4), using $\psi(3770)$ as a reference

$$\mathcal{B}(Y(4260) \to p\overline{p}) = \mathcal{B}(\psi(3770) \to p\overline{p}) \cdot \frac{\Gamma_{total}(\psi(3770))}{\Gamma_{total}(Y(4260))} \tag{6}$$

which we can rewrite using the detailed balance principle as

$$\sigma(p\overline{p} \to Y(4260)) = \sigma(p\overline{p} \to \psi(3770)) \cdot \frac{\Gamma_{total}(\psi(3770))}{\Gamma_{total}(Y(4260))} \tag{7}$$

using the numbers from [1]

$$\begin{aligned} \sigma(p\overline{p} \to Y(4260)) &= 9.8\ nb \cdot \frac{27.2\ MeV}{102\ MeV} && (8) \\ &= 2.2\ nb && (9) \end{aligned}$$

Lower limit for Y(4260)

We use the assumption that the annihilation part, which manifest in the decay into e^+e^- and the decay into $p\overline{p}$, are identical:

$$\begin{aligned}
\sigma(p\overline{p} \to Y(4260)) &= 2.2\ nb \cdot \frac{\Gamma_{ee}(Y(4269)}{\Gamma_{ee}(\psi(3770))} && (10)\\
&= 2.2\ nb \cdot \frac{\Gamma_{ee}(Y(4269)}{\mathcal{B}(\psi(3770) \to e^+e^-) \cdot \Gamma_{total}(\psi(3770))} && (11)\\
&= 2.2\ nb \cdot \frac{9.2\ eV}{9.6 \cdot 10^{-6} \cdot 27.2\ MeV}\\
&= 0.077\ nb
\end{aligned}$$

using the partial width Γ_{ee}(Y(4260))and Γ_{total} from PDG and $\mathcal{B}(\psi(3770) \to p\overline{p})$ from [1].

Upper limit of Z(3900)

We use the fraction of Z(3900) production in Y(4260) decays

$$\frac{\sigma(e^+e^- \to Z(3900)^+\pi^- \to J/\psi\pi^+\pi^-}{\sigma(e^+e^- \to J/\psi\pi^+\pi^-} = (21.5 \pm 3.3 \pm 7.5)\% \tag{12}$$

from BESIII, arXiv:1303.5949, Phys. Rev. Lett. 110 (2013) 252001.

We assume 100% resonant Y(4260) production and assume a branching fraction $\mathcal{B}(J/\psi\pi^+\pi^-)$=100%, which was used as normalization for all upper limits of Y(4260) decays in the book "The physics of the B factories", arXiv:1406.6311, Eur. Phys. J. C74 (2014) 3026 Under these particular assumptions, this leads to

$$\sigma(p\bar{p} \to Z(3900)) = 2.2\ nb \cdot 21.5\% = 0.473\ nb \tag{13}$$

Lower limit of Z(3900)

We use the same procedure as for the upper limit of Z(3900), but using the lower limit of Y(4260)

$$\sigma(p\bar{p} \to Z(3900)) = 0.077\ nb \cdot 21.5\% = 0.017\ nb \tag{14}$$

Summary and Conclusion:

We kindly ask for approval of page 26 for hadron2015.

If cross sections on page 26 are approved,
we would calculate numbers of XYZ per day
based upon these cross sections.