Spectroscopy, Production and Exotica in Heavy Flavour in ATLAS

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On behalf of the ATLAS Collaboration

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Outline

- ATLAS detector, (multi-,) muon triggers

Focus on recent results

- $b\bar{b}$ correlation with $J/\psi+\mu$, JHEP 11 (2017) 62
- $X(3872)$ production measurement, prompt and non-prompt, JHEP 01 (2017) 117
- $B_s\pi$ states, PRL 120 (2018) 202007

- Summary and perspectives
The ATLAS detector at LHC

Inner Detector

\(|\eta|<2.5\), Solenoid B=2T

\(\sigma/pT \sim 3.4\times10^{-4} \text{ pT} + 0.015 \) for \(|\eta|<1.5\)

Used for Tracking and Vertexing:

Precise momentum and lifetime measurements

Muon Spectrometer

\(|\eta|<2.7\)

Toroid B-Field, average \(\sim 0.5\text{T}\)

Muon Momentum resolution

\(\sigma/p< 10\% \) up to \(\sim 1\text{ TeV}\)
bb production at the LHC

**Needed for H→bb and new physics searches**

**Flavour creation**
- Production of a $b\bar{b}$ pair by gluon fusion or annihilation of light quarks

**Gluon splitting**
- $b\bar{b}$ pair produced from gluon but not part of the initial hard process
- In MC from parton shower / fragmentation

**Flavour Excitation**
- Scattering of a $b$-quark out of the initial state into the final state by a light quark or a gluon
  - Sensitive to heavy flavor PDFs

Large $\Delta\phi$, back-2-back $p_T$ balance
Small $\Delta\phi$, colinear
Large $\Delta\eta$, broad $\Delta\phi$

**Need to tag both $b$’s without losses when colinear**

Unlike methods using $b$-jets, $J/\psi+\mu$ works for large and small separations
J/ψ muons:
- $|\eta| < 2.3$
- $2.6 < m(\mu\mu) < 3.5$ GeV

1.9 M J/ψ candidates

Additional muons
- $|\eta| < 2.5$
- ‘Fakes’ mainly J/ψ+K, control with BDT trained on Monte Carlo

$\tau_{\text{eff}} = \frac{L_{xy} m(\mu\mu)}{c p_T(\mu\mu)}$

$L_{xy} = \frac{L}{p_T(\mu\mu)} p_T(\mu\mu)$

Use pseudo proper lifetime of J/ψ to separate prompt/non prompt J/ψ & background, in mass/lifetime fit

Use 3rd muon impact parameter and BDT to templates from MC to extract signal/prompt/fake contributions
Choose $\Delta R$ as an example – many more observables studied

- Pythia 8 poorly reproduces shape of the angular distributions
- The $p_T$-based scale splitting kernels give better description at low $\Delta R$ – Opt 4 best overall
- Herwig++ is better than Pythia 8 for the $\Delta R$
- 4- and 5-flavour MadGraph5 predictions sit either side of the data; 4-flavour is closer
- 5-flavour SHERPA & MadGraph similar
- Good understanding of systematics

Fiducial cross section is also measured

17.7$\pm$ 0.1 (stat) $\pm$ 2.0 (syst) nb
What is X(3872)?

‘Exotic’ resonance first observed by Belle in 2003 in J/ψπ⁺π⁻ final state
Subsequently confirmed by BaBar, CDF, D0 and now LHC experiments
Current world average X(3872) mass very close to the D₀ D₀* threshold
What is it? No clear picture yet!

Loosely bound $D^0 - D^{0*}$ molecule?  Unlikely: NRQCD with this premise over-predicts production compared to CMS 2011 measurement

New excited charmonium state? Unlikely: LHCb measured $J^{PC} = 1^{++}$, no such state expected around that mass

A mix of these two, $\chi_{c1}(2P) - (D^0 D^{0*})$, with hadronic decays dominated by the $\chi_{c1}(2P)$ component? Maybe, if the mixture is determined through fit to CMS results (PRD 96, 074014 (2017))

Tetraquark (diquark – diantiquark)? Possible, but hard to make any solid predictions

Measuring X(3872) and the well-studied $\Psi(2S)$ in the same analysis and in the same final state J/ψπ⁺π⁻ helps reduce systematics for various ratios and comparisons
Outline of the $X(3872)$ Analysis

Analysis performed for $|y| < 0.75$ for the $J/\psi \pi^+ \pi^-$ system, for optimal tracking resolution.

Each $J/\psi \pi^+ \pi^-$ candidate weighted to correct for trigger/reconstruction/acceptance losses.

For each $p_T$ and lifetime bin, binned minimum $\chi^2$ fit in the $J/\psi \pi^+ \pi^-$ invariant mass to determine $\psi(2S)$ and $X(3872)$ signal yields.

For each $p_T$ bin, the yields in individual lifetime windows are subsequently fitted:
- to determine lifetime dependence and hence separate the signal into prompt and non-prompt components.

The lifetime fits are performed separately for $\psi(2S)$ and $X(3872)$.

Mass narrow/wide Gaussian ratio common for the two states.
Event selection

11.4 fb\(^{-1}\) at 8 TeV

Muon cuts:
- Opposite sign ‘combined’ muons
- \(p_T > 4\) GeV, \(|\eta| < 2.3\)

J/ψ cuts:
- \(\chi^2_{\text{dimu}} < 200\), \(p_T > 8\) GeV & \(|y| < 2.3\)

Pion cuts:
- Opposite sign, \(p_T > 600\) MeV, \(|\eta| < 2.4\)

Use kinematic and vertex fits combined with mass and opening angle cuts to select signal and reject background

Constrained vertex fit on each \(\mu^+\mu^-\pi^+\pi^-\) candidate:
- di-muon \((2.8 < m_{\mu\mu} < 3.4)\) GeV fit to a single vertex
- di-muon mass constrained to the J/ψ mass
- pion mass hypothesis used for the other two tracks

J/ψπ^+π^− background suppression cuts
- \(P(\chi^2_{J/\psi\pi\pi}) > 4\%\)
- Opening angle \(\Delta R(J/\psi, \pi^\pm) < 0.5\)
- \(Q = m(J/\psi\pi^+\pi^-) - m(J/\psi)_{\text{PDG}} - m(\pi^+\pi^-) < 300\) MeV

3.6 M J/ψ candidates

370 k \(\psi(2S)\) 30 k \(\chi(3872)\)
**Single**: Assumes non-prompt $\psi(2S)$ and $X(3872)$ are produced from the same mix of parent $b$-hadrons:

- same lifetimes for $\psi(2S)$ and $X(3872)$ in each $p_T$ bin
- $p_T$ spectra of $\psi(2S)$ and $X(3872)$ linked through kinematics

$\Rightarrow$ Effective lifetimes for $\psi(2S)$ consistent with single component independent of $p_T$;

$X(3872)$ possibly slightly shorter in low $p_T$ bins (from $B_c$?)

$\Rightarrow$ **Double lifetime fit:**

- $\tau_{LL} = 1.45 \pm 0.05$ ps determined from fits to $\psi(2S)$, allowing for some SL contribution
- $\tau_{SL} = 0.40 \pm 0.05$ ps obtained from simulation, varying $B_c$ decay mode

In either case, $X(3872) : \psi(2S)$ ratio vs $p_T$ extracted

*Fit to kinematic ($p_T$) templates* obtained from simulations of various $b$-hadron decays into $\psi(2S)$ and $X(3872)$

$\Rightarrow$ **Extract overall non-prompt $X(3872) : \psi(2S)$ ratio**

*Two-lifetime fit results quoted from now on, unless stated otherwise*
**Prompt:** Described well by NLO NRQCD assumes X(3872) is a mix $\chi_{c1}(2P) - (D^0 D^{0*})$ with $\chi_{c1}(2P)$ dominant (production parameters fitted to CMS data) not surprising, CMS and ATLAS consistent

**Non prompt:**
use the fitted kinematic template to recalculate from FONLL $\psi(2S)$ prediction

PBR not measured – estimate from Artoisenet, Braaten based on Tevatron data [hep-ph:0911.2016] $R_B = \frac{Br(B \rightarrow X(3872)) Br(X(3872) \rightarrow J/\psi \pi^+ \pi^-)}{Br(B \rightarrow \psi(2S)) Br(\psi(2S) \rightarrow J/\psi \pi^+ \pi^-)} = 18\pm8\%$

Clearly overshoots the data: factor of 4 to 8, increasing with pT
Non-prompt fraction of $X(3872)$:
- no visible $p_T$ dependence
- consistent with CMS result within errors
- Very unlike $J/\psi$’s strong $p_T$ dependence

Ratio of non-prompt $X(3872)$ : $\psi(2S)$
- long-lived part fitted to kinematic template
  \[
  R_{B}^{2L} = \frac{\mathcal{B}(B \rightarrow X(3872) + \text{any})\mathcal{B}(X(3872) \rightarrow J/\psi \pi^+ \pi^-)}{\mathcal{B}(B \rightarrow \psi(2S) + \text{any})\mathcal{B}(\psi(2S) \rightarrow J/\psi \pi^+ \pi^-)} = (3.57 \pm 0.33 \text{(stat)} \pm 0.11 \text{(sys)}) \times 10^{-2}
  \]
  - short-lived part: assuming non-fragmentation $B_c$
  - fit with $a \cdot p_T^{-2}$ relative to fragmentation production
  - integrate the fits to determine the fraction of non-prompt $X(3872)$ that is short-lived,
  for $p_T>10$ GeV:
  \[
  \frac{\sigma(pp \rightarrow B_c) Br(B_c \rightarrow X(3872))}{\sigma(pp \rightarrow \text{non-prompt } X(3872))} = (25 \pm 13 \text{(stat)} \pm 2 \text{(sys)} \pm 5 \text{(spin)}) \%
  \]

$B_c$ small fraction of $b$-hadrons at LHC => Indication $X(3872)$ production enhanced in $B_c$ decays
Di-pion mass distributions: results

In $\psi(2S)$ to $J/\psi\pi^+\pi^-$ decays
- dipion mass distribution peaks at high masses
- fit to Voloshin-Zakharov function

$$\frac{1}{\Gamma} \frac{d\Gamma}{dm_{\pi\pi}} \propto (m_{\pi\pi}^2 - \lambda m_{\pi}^2)^2 \times PS$$

- found $\lambda = 4.16 \pm 0.06\text{ (stat)} \pm 0.03\text{ (syst)}$
- in agreement with previous measurements

In $X(3872)$ to $J/\psi\pi^+\pi^-$ decays
- dipion mass distribution has an even sharper peak at high masses
- in agreement with simulation where the di-pion system is produced via $\rho^0$ meson decay
• D-Zero published evidence for $X(5568)$ in $B_s^0\pi^\pm$ spectrum
  - $B_s^0 \to J/\psi\phi$, $B_s^0 \to \mu^+D_s^{-}(\phi\pi^\pm)X$
  - $m=5566.9^{+3.2}_{-3.1}\text{(stat)}^{+0.6}_{-1.2}\text{(syst)}$ MeV
  - Significance $6.7\sigma$, bsud state?

PRL 117 (2016) 022003; PRD 97 (2018) 092004

• ATLAS $B_s^0 \to J/\Psi(\mu\mu)\phi$ (KK)
  - $4.9\text{ fb}^{-1}$ at 7 TeV
  - $19.5\text{ fb}^{-1}$ at 8 TeV

PRL 120 (2018) 202007

$M_{\text{fit}}(B_{s}^0)=5366.6\pm0.1$ MeV
$N(B_{s}^0)=52750\pm280$ (stat)
Study of $B_s^0\pi^\pm$ Candidates

- Combine $B_s$ candidates with tracks from same primary vertex
  - Pion hypothesis, $p_T > 500\text{MeV}$
  - Extended unbinned fit:
    \[
    m(B_s\pi) = m(J/\psi KK\pi) - m(J/\psi KK) + m_{\text{fit}}(B_s)
    \]
- Consider
  - $p_T(B) > 10\text{GeV}$
  - $p_T(B) > 15\text{GeV}$
Setting Limits

No significant X(5568) signal

Fitted X(5568) yields & Limits:

\[ p_T(B) > 10 \text{ GeV}: \]
- \[ N(X) = 60 \pm 140 \text{ (stat)} \]
- \[ N(X) < 382 \text{ @95\% CL} \]

\[ p_T(B) > 15 \text{ GeV}: \]
- \[ N(X) = -30 \pm 150 \text{ (stat)} \]
- \[ N(X) < 356 \text{ (@95\% CL)} \]
Extract 95% CL upper limit on production
Measure relative to $B_s >$ given $p_T(B_s)$

$$\rho_X \equiv \frac{\sigma(pp \to X + \text{anything}) \times B(X \to B_s^0\pi^\pm)}{\sigma(pp \to B_s^0 + \text{anything})} = \frac{N(X)}{N(B_s^0)} \times \frac{1}{\epsilon^{\text{rel}}(X)}$$

Signal: Breit-Wigner from D0 observation
Scan range 5550 – 5700 MeV

Systematic uncertainties includes
Event by event resolutions and relative efficiencies needed

$\rho_X < 0.015$ @95% CL

$\rho_X < 0.016$ @95% CL
Candidates per 5 MeV/

$\pi^0$ mass for $p_T(B_s^0) > 10$ GeV, for candidates in the $B_s^0$ mass range and for the mass sidebands, as indicated. The fit to the data with a freely floating (null) signal is overlaid in a solid (dashed) line.

$\rho_X (p_T > 10$ GeV$)$

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Zero</td>
<td>$(8.6\pm1.9\pm1.4)%$</td>
</tr>
<tr>
<td>ATLAS</td>
<td>&lt;1.5%</td>
</tr>
<tr>
<td>CMS</td>
<td>&lt;1.1%</td>
</tr>
<tr>
<td>LHCb</td>
<td>&lt;2.4%</td>
</tr>
<tr>
<td>CDF</td>
<td>&lt;6.7%</td>
</tr>
</tbody>
</table>

No significant $X(5568)$ signal observed
Perspectives

- ATLAS is a “general purpose” experiment, and, due to the universality of the detector and ingenuity of analysers, a number of important contributions to heavy quark physics can be made.
- Studies of $b\bar{b}$ production important for model building.
- $X(3872)$ production have been studied in some detail, with potentially interesting results.
- No evidence for the $X(5568)$ in the $B_s(J/\psi\phi)\pi$ channel, upper limit set.

- A large amount of data collected at 13 TeV are still being studied, with new challenges related to increasing trigger thresholds and increased high pileup.
LHC luminosity over the years

- ATLAS as a detector is optimised for “high pT” physics – Higgs and BSM searches

- In early years of LHC luminosity was not as high, could afford dimuon triggers with low thresholds

- Many quarkonium-related measurements made, including some rather unexpected “first observations

- In Run 2 many successful low-pT dimuon triggers are heavily prescaled, and muon trigger thresholds creep higher and higher

- Need to be more and more creative and inventive to maintain interest in the area of heavy flavour physics
Comparisons with Pythia

Pythia 8 does not reproduce well the shape of the angular distributions

The pT-based scale splitting kernels (Opt 1 and 4) give a better description at low ΔR

Overall the kernel of Opt 4 does best
Comparisons with Other Models

Herwig++ is better than Pythia 8 for the $\Delta R$

4- and 5-flavour MadGraph5 predictions sit either side of the data; the 4-flavour prediction is closer

The 5-flavour Sherpa prediction is similar (but worse) than madGraph5

Difference between 4-flavour and 5-flavour predictions are larger in the high-pT $\Delta R$ distribution; the 4-flavour version is still closer to data
Other results

Similar picture for rapidities, pT, mass etc

Fiducial cross section is also measured
17.7± 0.1 (stat) ± 2.0 (syst) nb

Good understanding of systematics
Mass fits in lifetime windows

Mass fits: double-Gaussian signal peaks on a smooth background:

\[
f(m) = f_{12} \left( Y_\psi G_{1}^{\psi}(m) + Y_X G_{1}^{X}(m) \right) + \left( 1 - f_{12} \right) \left( Y_\psi G_{2}^{\psi}(m) + Y_X G_{2}^{X}(m) \right) + N_{\text{bkg}} (m - m_0)^{p_2} e^{p_1(m-m_0)} P(m - m_0)
\]

Fraction of narrow Gaussian \(f_{12}\) shared between \(\psi(2S)\) and \(X(3872)\)

Resolution parameters linked by

\[\sigma_X = \kappa \sigma_\psi\]

Values of parameters \(f_{12}\) and \(\kappa\) determined from global fits

Verified with MC and varied during systematic studies

- Data: \(-0.3 < \tau < 0.025\) ps (\(w_0\))
- Fit
- Data: \(0.025 < \tau < 0.3\) ps (\(w_1\))
- Fit
- Data: \(0.3 < \tau < 1.5\) ps (\(w_2\))
- Fit
- Data: \(1.5 < \tau < 15\) ps (\(w_3\))
- Fit

\(p_T: 12-16\) GeV

Pull distributions
**Single lifetime fit - results**

**Assumption:** non-prompt $\psi(2S)$ and $X(3872)$ are produced from the same mix of parent $b$-hadrons:
- same lifetimes for $\psi(2S)$ and $X(3872)$ in each $p_T$ bin
- $p_T$ spectra of $\psi(2S)$ and $X(3872)$ linked through kinematics

**Effective lifetimes**
- for $\psi(2S)$ independent of $p_T$
- for $X(3872)$ possibly slightly shorter in low $p_T$ bins

**Kinematic template** obtained from simulations of various $b$-hadron decays into $\psi(2S)$ and $X(3872)$
- takes into account mass difference and
- possible variation in mass of hadronic association

**Non-prompt $X(3872) : \psi(2S)$ ratio**
- fit to kinematic template

$$R_{B}^{\text{LL}} = \frac{\mathcal{B}(B \to X(3872) + \text{any}) \mathcal{B}(X(3872) \to J/\psi \pi^+\pi^-)}{\mathcal{B}(B \to \psi(2S) + \text{any}) \mathcal{B}(\psi(2S) \to J/\psi \pi^+\pi^-)} = (3.95 \pm 0.32(\text{stat}) \pm 0.08(\text{sys})) \times 10^{-2}$$
Alternative lifetime model: two-lifetime fit

\[ F_{NP}^i(\tau) = (1 - f_{SL}^i)F_{LL}(\tau) + f_{SL}^i F_{SL}(\tau) \]

- non-prompt component presented as a sum of short-lived and long-lived
- two single-sided exponentials smeared with the same resolution function
- \( f_{SL} \) is a fraction of short-lived within non-prompt – supposedly from \( B_c \) decays
- statistical power of data does not allow determination of two free lifetimes
- the two lifetimes fixed, the fraction of short-lived contribution left free in the fit

Fixing the two lifetimes

- effective pseudo-proper lifetime depends on parent’s lifetime and decay kinematics
- \( \tau_{LL} \) determined from fits to \( \psi(2S) \), allowing for some SL contribution
- \( \tau_{SL} \) obtained from simulation, varying \( B_c \) decay mode
  (low mass association gives shorter effective lifetime)
- both varied within limits shown during systematic studies

Two-lifetime fit results quoted from now on, unless stated otherwise

\[ \tau(B^\pm) = 1.638 \pm 0.004 \text{ ps} \]
\[ \tau(B^0) = 1.525 \pm 0.009 \text{ ps} \]
\[ \tau(B_s^0) = 1.465 \pm 0.031 \text{ ps} \]
\[ \tau(\Lambda_b) = 1.451 \pm 0.013 \text{ ps} \]
\[ \tau_{LL} = 1.45 \pm 0.05 \text{ ps} \]
\[ \tau(B_c) 0.507 +/-0.009 \text{ ps} \]
\[ \tau_{SL} = 0.40 \pm 0.05 \text{ ps} \]
### Backup: Table of results for $\psi(2S)$ and $X(3872)$

<table>
<thead>
<tr>
<th>pT range [GeV]</th>
<th>10–12</th>
<th>12–16</th>
<th>16–22</th>
<th>22–40</th>
<th>40–70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross sections times branching fractions [pb / GeV]</td>
<td></td>
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</tr>
<tr>
<td>$\psi(2S)_{P}$</td>
<td>92.4 ± 1.9 ± 4.8</td>
<td>27.97 ± 0.27 ± 1.02</td>
<td>5.61 ± 0.06 ± 0.19</td>
<td>0.57 ± 0.01 ± 0.02</td>
<td>0.021 ± 0.001 ± 0.001</td>
</tr>
<tr>
<td>$\psi(2S)_{NP}$</td>
<td>61.9 ± 1.9 ± 3.4</td>
<td>23.66 ± 0.27 ± 0.85</td>
<td>6.63 ± 0.06 ± 0.22</td>
<td>0.97 ± 0.01 ± 0.03</td>
<td>0.048 ± 0.001 ± 0.003</td>
</tr>
<tr>
<td>$\psi(2S)_{LL}^{NP}$</td>
<td>60.8 ± 1.6 ± 4.0</td>
<td>23.09 ± 0.27 ± 1.46</td>
<td>6.53 ± 0.06 ± 0.41</td>
<td>0.93 ± 0.01 ± 0.06</td>
<td>0.047 ± 0.002 ± 0.003</td>
</tr>
<tr>
<td>$\psi(2S)_{SL}^{NP}$</td>
<td>1.1 ± 2.4 ± 3.9</td>
<td>0.56 ± 0.37 ± 1.14</td>
<td>0.11 ± 0.08 ± 0.29</td>
<td>0.04 ± 0.01 ± 0.04</td>
<td>0.001 ± 0.002 ± 0.002</td>
</tr>
<tr>
<td>$X(3872)_{P}$</td>
<td>6.05 ± 1.30 ± 0.38</td>
<td>2.75 ± 0.20 ± 0.13</td>
<td>0.60 ± 0.04 ± 0.02</td>
<td>0.06 ± 0.01 ± 0.00</td>
<td>0.003 ± 0.001 ± 0.000</td>
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<tr>
<td>$X(3872)_{NP}$</td>
<td>2.90 ± 1.20 ± 0.21</td>
<td>1.28 ± 0.20 ± 0.07</td>
<td>0.29 ± 0.04 ± 0.01</td>
<td>0.03 ± 0.01 ± 0.00</td>
<td>0.001 ± 0.001 ± 0.000</td>
</tr>
<tr>
<td>$X(3872)_{LL}^{NP}$</td>
<td>1.87 ± 0.82 ± 0.14</td>
<td>0.92 ± 0.16 ± 0.06</td>
<td>0.29 ± 0.04 ± 0.02</td>
<td>0.03 ± 0.01 ± 0.00</td>
<td>0.001 ± 0.001 ± 0.000</td>
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<tr>
<td>$X(3872)_{SL}^{NP}$</td>
<td>1.02 ± 1.49 ± 0.20</td>
<td>0.35 ± 0.25 ± 0.06</td>
<td>0.01 ± 0.06 ± 0.02</td>
<td>0.00 ± 0.01 ± 0.00</td>
<td>0.000 ± 0.001 ± 0.000</td>
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<table>
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<tbody>
<tr>
<td>$F_{\psi(2S)}^{NP}$</td>
<td>0.40 ± 0.01 ± 0.02</td>
<td>0.46 ± 0.00 ± 0.01</td>
<td>0.54 ± 0.00 ± 0.01</td>
<td>0.63 ± 0.00 ± 0.01</td>
<td>0.69 ± 0.01 ± 0.02</td>
</tr>
<tr>
<td>$F_{\psi(2S)}^{SL}$</td>
<td>0.02 ± 0.04 ± 0.06</td>
<td>0.02 ± 0.02 ± 0.05</td>
<td>0.02 ± 0.01 ± 0.04</td>
<td>0.04 ± 0.01 ± 0.04</td>
<td>0.03 ± 0.03 ± 0.05</td>
</tr>
<tr>
<td>$F_{X(3872)}^{NP}$</td>
<td>0.32 ± 0.12 ± 0.02</td>
<td>0.32 ± 0.04 ± 0.01</td>
<td>0.33 ± 0.04 ± 0.01</td>
<td>0.34 ± 0.06 ± 0.01</td>
<td>0.34 ± 0.18 ± 0.03</td>
</tr>
<tr>
<td>$F_{X(3872)}^{SL}$</td>
<td>0.35 ± 0.39 ± 0.05</td>
<td>0.28 ± 0.16 ± 0.04</td>
<td>0.03 ± 0.19 ± 0.05</td>
<td>0.03 ± 0.26 ± 0.05</td>
<td>0.03 ± 0.63 ± 0.13</td>
</tr>
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<table>
<thead>
<tr>
<th>Ratios</th>
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<tbody>
<tr>
<td>$X(3872)<em>{P}/\psi(2S)</em>{P}$</td>
<td>0.065 ± 0.014 ± 0.004</td>
<td>0.098 ± 0.007 ± 0.004</td>
<td>0.106 ± 0.008 ± 0.004</td>
<td>0.107 ± 0.011 ± 0.004</td>
<td>0.128 ± 0.044 ± 0.012</td>
</tr>
<tr>
<td>$X(3872)<em>{NP}/\psi(2S)</em>{NP}$</td>
<td>0.047 ± 0.019 ± 0.004</td>
<td>0.054 ± 0.008 ± 0.003</td>
<td>0.044 ± 0.006 ± 0.002</td>
<td>0.033 ± 0.007 ± 0.001</td>
<td>0.030 ± 0.019 ± 0.003</td>
</tr>
<tr>
<td>$X(3872)<em>{LL}^{NP}/\psi(2S)</em>{LL}^{NP}$</td>
<td>0.031 ± 0.014 ± 0.002</td>
<td>0.040 ± 0.007 ± 0.003</td>
<td>0.044 ± 0.006 ± 0.003</td>
<td>0.033 ± 0.006 ± 0.002</td>
<td>0.030 ± 0.019 ± 0.003</td>
</tr>
<tr>
<td>$X(3872)<em>{SL}^{NP}/\psi(2S)</em>{SL}^{NP}$</td>
<td>0.016 ± 0.024 ± 0.003</td>
<td>0.015 ± 0.011 ± 0.003</td>
<td>0.001 ± 0.008 ± 0.002</td>
<td>0.001 ± 0.009 ± 0.004</td>
<td>0.001 ± 0.024 ± 0.005</td>
</tr>
</tbody>
</table>