Introduction

The ALICE collaboration has studied the inclusive $\psi(2S)$ production in pp, p-Pb, and Pb-Pb collisions. In this poster, we show the procedures used to extract the $\psi(2S)$ signal in the three collision systems: since the statistics is low (especially in differential analyses), the robustness of the $\psi(2S)$ signal extraction is crucial to extract final physics results.

The ALICE Forward Muon Spectrometer

The $\psi(2S)$ is detected in the dimuon decay channel, using the Forward Muon Spectrometer, which covers the pseudorapidity range $-4 < \eta_{\text{lab}} < -2.5$, and is composed by:
- a dipole magnet (3 T magnetic field);
- an absorber complex;
- 10 planes of tracking chambers;
- 4 planes of trigger chambers.

Signal extraction in p-Pb collisions

Data sample and kinematic cuts:
- 2011 data sample, $\sqrt{s} = 7$ TeV, $L_{\text{int}} = 1.35 \pm 0.07$ pb$^{-1}$;
- dimuon trigger: detection of two opposite sign muon candidates;
- muon trigger-tracking matching;
- tracks are in the range: $-4 < \eta_{\text{lab}} < -2.5$;
- track radial position at the absorber end is in the range: $17.6 \leq R_{\text{abs}} \leq 69.5$ cm;
- dimuon rapidity is in the range: $2.5 \leq y_{\text{abs}} \leq 4$ (* for symmetric systems we consider the rapidity range as positive, even if the muon spectrometer would cover a negative range in the reference system of the experiment).

Signal extraction:
- Charmonium yields are extracted through a fit to the opposite-sign invariant mass spectra, using a combination of signal and background shapes:
  - signal: extended Crystal Ball (CB2) and pseudo-Gaussian functions for J/ψ and $\psi(2S)$;
  - background: variable width Gaussian and 4th-degree polynomial times exponential functions;
- $\psi(2S)$ position and width are tied to J/ψ, using the following formulas:
  \[ \psi(2S) = \left( \psi(2S) - \psi(2S)_{\text{J/ψ}} \right) \frac{1}{\sqrt{2} \sqrt{1 + \left( \frac{m_{\psi(2S)}}{m_{\psi(2S)}^0} \right)^2}} \]
  \[ \sigma_{\psi(2S)} = \sigma_{\psi(2S)}^0 \left( 1 + \frac{m_{\psi(2S)}^2}{m_{\psi(2S)}^0^2} \right) \]
- tail parameters are obtained by fitting the simulated $\psi(2S)$ signals.

Signal extraction in Pb-Pb collisions

Data sample and kinematic cuts:
- 2012 data sample, $\sqrt{s_{NN}} = 5.02$ TeV, two rapidity regions studied (inverting the beam direction in the LHC);
- $L_{\text{int}} = 5.01 \pm 0.17$ nb$^{-1}$;
- same cuts as in p-Pb collisions;
- cut on the transverse distance from the primary vertex of each of the reconstructed muon tracks to reduce the background (pDCA cut).

Signal extraction:
- Same technique used as in the pp analysis.
- A large number of fits to the invariant mass spectra is performed using the techniques described in the previous sections and using various combinations of:
  - signal shapes;
  - background shapes;
  - event mixing and event counting.

Example method, based on event counting:
- The fitted background is subtracted (Fig. 6a and 6b);
- the $\psi(2S)$ number is obtained integrating the background-subtracted invariant mass spectrum in the region $3.5 < m_{\psi(2S)} < 3.8$ GeV/c$^2$;
- the $\psi(2S)$ number is corrected for the fraction of the $\psi(2S)$ signal outside the integration range; (~15%) and for the J/ψ falling in the $\psi(2S)$ mass range (~4%).

Final raw yields and systematics uncertainties

A large number of fits to the invariant mass spectra is performed using the techniques described in the previous sections and using various combinations of:
- signal shapes;
- background shapes;
- start/end point of the fit range;
- the final $\psi(2S)$ yield is obtained as the average of the results of the fits (Fig. 7);
- the systematics uncertainty is obtained as the root-mean-square (RMS) of the distribution.

Summary and conclusions

The $\psi(2S)$ signal extraction is challenging because of S/B. Signal extraction techniques have been finalized depending on the system under study (fitting procedure, event mixing and event counting).

References to related ALICE papers

- $p$-Pb: Measurement of quarkonium production at forward rapidity in pp collisions at $\sqrt{s} = 7$ TeV [arXiv:1403.3648]
- Pb-Pb: Suppression of $\psi(2S)$ production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [arXiv:1506.02474]
- Pb-Pb (2): Suppression of $\psi(2S)$ production in Pb-Pb collisions with the ALICE Forward Muon Spectrometer at the LHC [arXiv:1211.2974]