ψ(2S) signal extraction in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC

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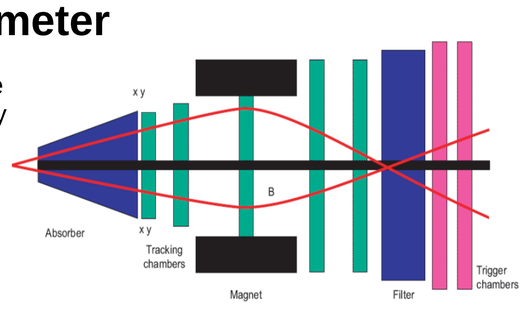
Introduction

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

The ALICE Forward Muon Spectrometer

The ψ(2S) is detected in the dimuon decay channel, using the Forward Muon Spectrometer, which covers the pseudorapidity range $-4 \le \eta_{lab} \le -2.5$, and is composed by:

- a dipole magnet (3 T·m magnetic field);
- an absorber complex;
- 10 planes of tracking chambers;
- 4 planes of trigger chambers.



Signal extraction in pp collisions

Data sample and kinematic cuts:

- 2011 data sample, $\sqrt{s}$ = 7 TeV, L_{int}^{pp} = 1.35 ± 0.07 pb^{-1};
- dimuon trigger: detection of two opposite sign muon candidates;
- muon trigger-tracking matching;
- tracks are in the range: $-4 \le \eta_{lab} \le -2.5$;
- track radial position at the absorber end is in the range: $17.6 \le R_{abs} \le 89.5$ cm;
- dimuon rapidity is in the range*: $2.5 \le y_{lab} \le 4$ (* 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).

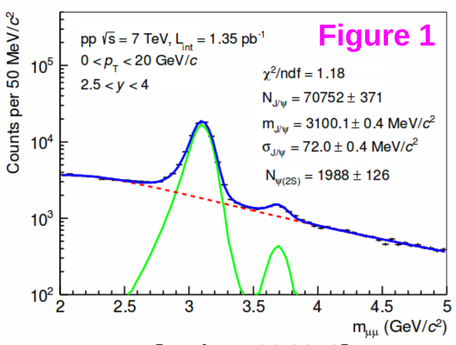


Figure 1

[arXiv:1403.3648]

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 ψ(2S);
- background: variable width Gaussian and 4th-degree polynomial times exponential functions;
- ψ(2S) position and width are tied to the J/ψ, using the following formulas:

$$m_{\psi(2S)} = m_{J/\psi} + (m^{MC}_{\psi(2S)} - m^{MC}_{J/\psi})$$
$$\sigma_{\psi(2S)} = \sigma_{J/\psi} \cdot (\sigma^{MC}_{\psi(2S)} / \sigma^{MC}_{J/\psi})$$

- tail parameters are obtained by fitting the simulated ψ(2S) signals.

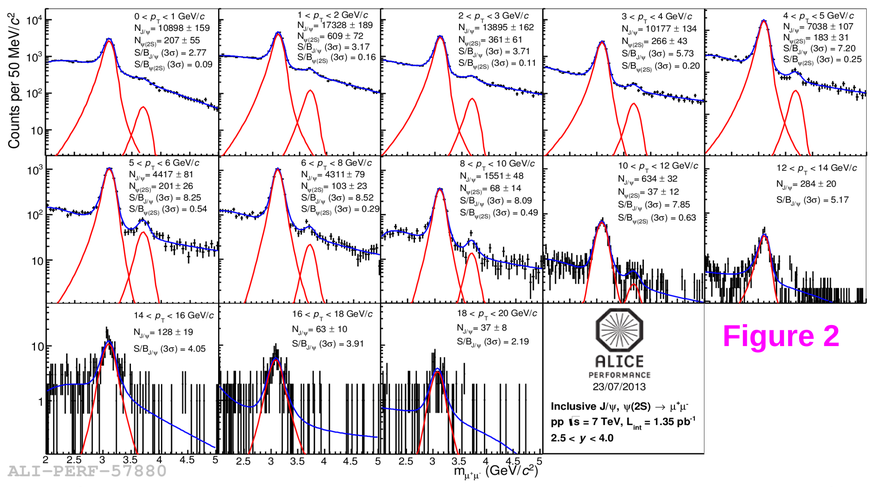


Figure 2

ψ(2S) S/B (3σ) (integrated over p_T and y, Fig. 1): ~ 0.2
ψ(2S) S/B (3σ) (signal visible up to p_T= 12 GeV/c, Fig. 2): 0.1 - 0.6

Signal extraction in Pb-Pb collisions

Data sample and kinematic cuts:

- 2011 data sample: $\sqrt{s_{NN}}$ = 2.76 TeV, L_{int}^{PbPb} = 68.8 μb^{-1};
- same cuts as in pp collisions.

Signal extraction:

Method 1 (Fig. 3, top row): fit to the opposite-sign dimuon invariant mass spectra:

- Signal: extended Crystal Ball (CB2) function ;
- background: variable width Gaussian;
- ψ(2S) position and the width are tied to J/ψ.

Method 2 (Fig. 3, bottom row): event mixing technique for background determination:

- Opposite-sign dimuon mixed background is obtained combining single muons from a sample of events obtained with a low-p_T trigger threshold (0.5 GeV/c);
- the normalization of the mixed spectra is calculated using the measured like-sign pairs by imposing:

$$\int N^{mixed}_{+-} = \int 2R\sqrt{N_{++}N_{--}} \qquad \text{where:} \qquad R = N_{+-}{}^{mixed} / 2\sqrt{N_{++}{}^{mixed} N_{--}{}^{mixed}}$$

- fit the background subtracted spectra with extended Crystal Ball function (signal) and exponential (residual background).

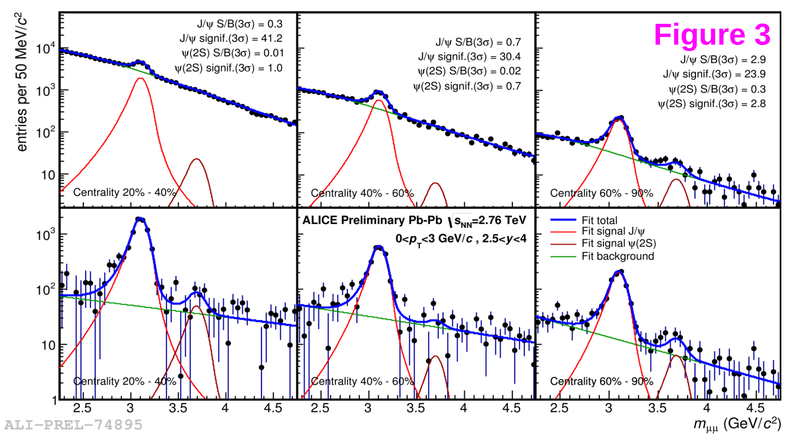
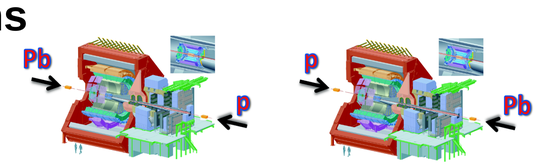


Figure 3

ψ(2S) S/B (3σ) (in 3 centrality bins, method 1, Fig. 3, top row): 0.01 - 0.30

Signal extraction in p-Pb collisions

Data sample and kinematic cuts:



- 2013 data sample, $\sqrt{s_{NN}}$ = 5.02 TeV, two rapidity regions studied (inverting the beam direction in the LHC);
- $L_{int}^{Pb\text{-}p\ (backward)}$ = 5.81 ± 0.18 nb^{-1} ;
- $L_{int}^{p\text{-}Pb\ (forward)}$ = 5.01 ± 0.17 nb^{-1};
- same cuts as in pp 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.

[arXiv:1405.3796]

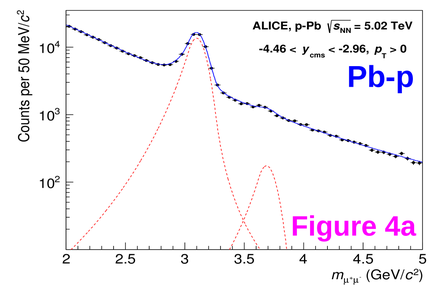


Figure 4a

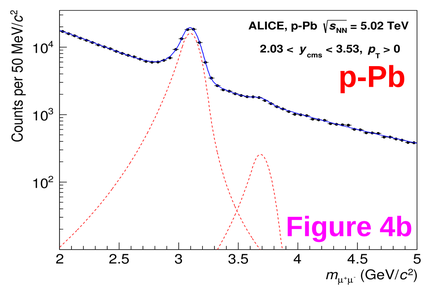


Figure 4b

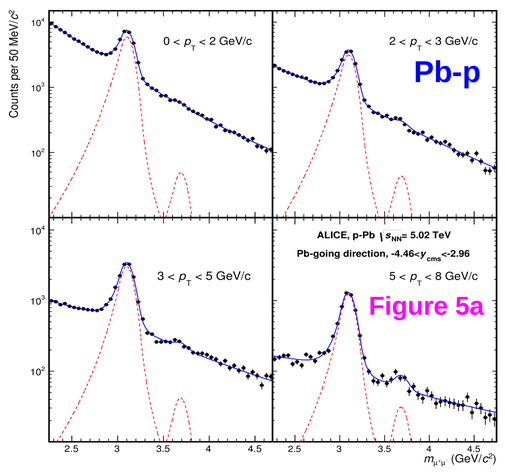


Figure 5a

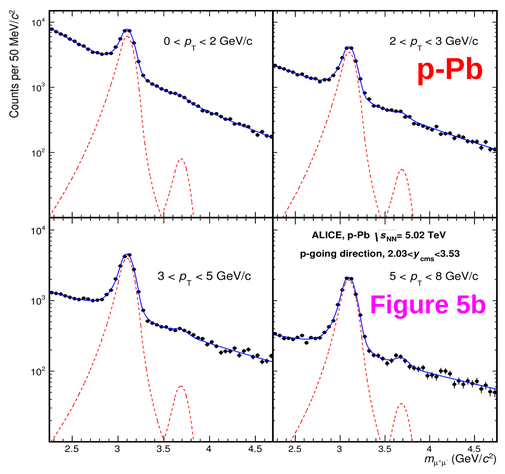


Figure 5b

ψ(2S) S/B (3σ), (integrated over p_T and y, Fig. 4a and 4b) Pb-p - p-Pb ~ 0.07
ψ(2S) S/B (3σ) (in 4 p_T bins, Fig. 5a) Pb-p: ~ 0.05 - 0.25
ψ(2S) S/B (3σ) (in 4 p_T bins, Fig. 5b) p-Pb: ~ 0.05 - 0.15

Alternative method, based on event counting:

- The fitted background is subtracted (Fig. 6a and 6b);
- the ψ(2S) number is obtained integrating the background-subtracted invariant mass spectrum in the region $3.5 < m_{\mu\mu} < 3.8$ GeV/c^2;
- the ψ(2S) number is corrected for the fraction of the ψ(2S) signal outside the integration range; (~15%) and for the J/ψ falling in the ψ(2S) mass range (~8%).

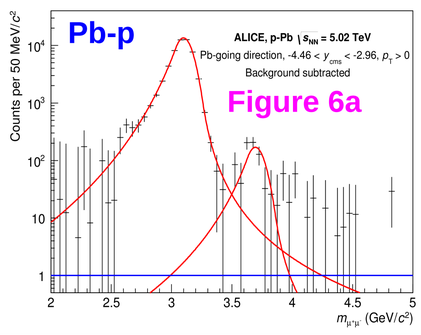


Figure 6a

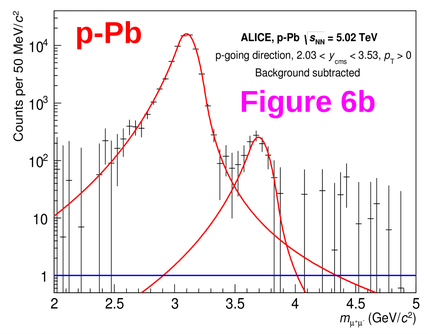


Figure 6b

The ψ(2S) number obtained in this way are in a good agreement (i.e. inside the systematic uncertainties) with the default approach

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:
  1) signal shapes;
  2) background shapes;
  3) start/end point of the fit range;
- the final ψ(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.

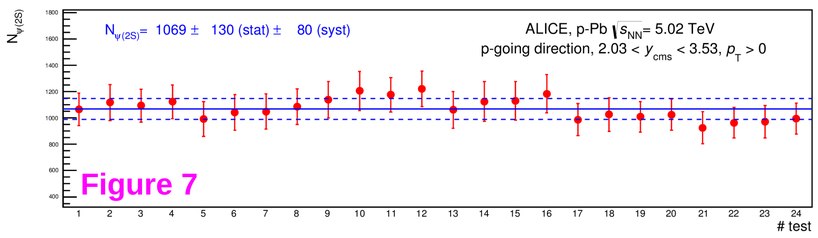


Figure 7

(This example plot is related to forward p-Pb collisions)

Summary and conclusions

The ψ(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). Systematic uncertainty on the signal extraction is summarized in the following table * :

Collision System	Signal extraction systematic (in percent)
p-p	8 (7.5 - 11)
p-Pb	9.5 (8 - 11.9)
Pb-p	9.3 (8.6 - 12.7)
Pb-Pb	(14 - 45)

(* for p_T differential analyses, maximum and minimum values are quoted in parenthesis).

References to related ALICE papers

p-p: *Measurement of quarkonium production at forward rapidity in pp collisions at* $\sqrt{s}$ *= 7 TeV* [arXiv:1403.3648]
p-Pb: *Suppression of ψ(2S) production in p-Pb collisions at* $\sqrt{s_{NN}}$ *= 5.02 TeV* [arXiv:1405.3796]
Pb-Pb (1): *Centrality, rapidity and transverse momentum dependence of J/ψ suppression in Pb-Pb collisions at* $\sqrt{s_{NN}}$ *= 2.76 TeV* [arXiv:1311.0214]
Pb-Pb (2): *J/ψ and ψ(2S) production in Pb-Pb collisions with the ALICE Muon Spectrometer at the LHC* [arXiv:1211.2578]