Report on Samara group activity

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Talk at the SPD Collaboration meeting, 2023

Outline

1. Samara University group
2. JINR grant reports
3. Publications
4. Future plans

Samara University group

The activity of six students (*) are supported by JINR grants

- Saleev V. - group leader
- Shipilova A. - scientist
- Karpishkov A. - scientist
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- Alimov L.* - master's student, diploma
- Anufriev A.* - master's student, diploma
- Shilyaev K.* - master's student, diploma
- Morozova S.* - master's student
- Ospennikov N.* - master's student
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- Chernyshev A.* - undergraduate student, diploma
- Omelyanchuk S - undergraduate student, diploma

Samara University group

Samara University group

Theory

- Hard processes at the SPD NICA energies (production of charmonium states, D-mesons and prompt photons) in the Parton Model
- Perturbative QCD calculations
- Factorization approaches: CPM, GPM, TMD PM, PRA
- Heavy quark hadronization mechanisms
- Production of polarized J/ψ
- TMD PDFs in polarized and unpolarized $pp-$collisions

Modeling

- Signal/Background ratio using PYTHIA
- Time slice simulation and event reconstruction using GEANT4
- Modeling in the TMD PM using KaTie

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Talks at the current SPD Meeting

- Anufriev A.:**On η_c production at the SPD NICA**
- Alimov L. and Ospennikov N.: **Associated $J/\psi+\gamma$ production at the SPD NICA**
- Shipilova A. and Morozova S.: **Time slice simulation and event reconstruction**

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In my talk

- Pair J/ψ production in the ICEM using KaTie (*Chernyshev A.*)
- Polarized J/ψ production in the NRQCD (*Shilyaev K.*)

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Pair production of J/ψ in pp and $\pi^- p$ collisions at the energy $\sqrt{s} = 20 - 30$ GeV

Data for pair J/ψ production from $\sqrt{s} = 17$ GeV up to 13 TeV:

Collaboration	Initial state	Energy
NA3, 1982	$\pi^- A$	$\sqrt{s} = 17$ GeV
NA3, 1985	pA	$\sqrt{s} = 27$ GeV
CDF, 2014	pp	$\sqrt{s} = 1.96$ TeV
LHCb, 2011, 2017, 2023	pp	$\sqrt{s} = 7, 13, 13$ TeV
CMS, 2014	pp	$\sqrt{s} = 7$ TeV
ATLAS, 2017, 2023	pp	$\sqrt{s} = 8, 13$ TeV
COMPASS, 2022	$\pi^- A$	$\sqrt{s} = 19$ GeV

- NA3, 1985: $N_{\rm ev} = 15 \pm 4$
  No data on differential cross sections.
- COMPASS, 2022:
  $N_{\rm ev}^{\rm NH_3} = 25 \pm 1$
  $N_{\rm ev}^{\rm Al} = 1$
  $N_{\rm ev}^{\rm W} = 5$

In all cases: $x_F^{\psi} > 0$.

Processes of pair J/ψ production is a good tool to study hadronization of heavy quarkonia.

Model for pair J/ψ production

Color Evaporation Model (CEM) [Fritzsch and Halzen '77] $\hookrightarrow$ **Improved CEM (ICEM)** [Ma and Vogt '16]
Cross section for single J/ψ production (using Parton Reggeization Approach [Nefedov, Saleev, and Shipilova '13]):

$$d\sigma_{J/\psi} = \mathscr{F}^{\psi} \times \sum_{a,\bar{b}} \int_{M_\psi}^{2M_D} dM \; [\theta(M - M_{\mathscr{Q}}) - \theta(M - 2M_H)] \; (\Phi_1 \; \Phi_2) \otimes d\hat{\sigma}_{ab\to c\bar{c}},$$

where $\Phi_i = \Phi_{a/h_i}(x_i, t_i, \mu)$. Previously we find that $\mathscr{F}^{\psi}$ is strongly depend on energy $\sqrt{s}$ [Chernyshev and V.S. '22].

In case of pair J/ψ production: $\boxed{d\sigma_{2J/\psi} = d\sigma^{\mathrm{SPS}}_{2J/\psi} + d\sigma^{\mathrm{DPS}}_{2J/\psi}}$.

- SPS master formula:

$$d\sigma^{\mathrm{SPS}}_{2J/\psi} = \mathscr{F}^{\psi\psi} \times \sum_{a,\bar{b}} \prod_{i=1,2} \int_{M_\psi}^{2M_D} dM_i \; [\theta(M_i - M_{\mathscr{Q}}) - \theta(M_i - 2M_H)] \; (\Phi_1 \; \Phi_2) \otimes d\hat{\sigma}_{ab\to c\bar{c}c\bar{c}}$$

  with $\mathscr{F}^{\psi} \simeq \mathscr{F}^{\psi}$ [Chernyshev and V.S. '22].
- DPS pocket formula:

$$d\sigma^{\mathrm{DPS}}_{2J/\psi} = (\mathscr{F}^{\psi})^2 \times \frac{1}{2\;\sigma_{\mathrm{eff}}} \times \sum_{a,\bar{b}} \prod_{i=1,2} \int_{M_\psi}^{2M_D} dM_i \; [\theta(M_i - M_{\mathscr{Q}}) - \theta(M_i - 2M_H)] \; (\Phi_1 \; \Phi_2) \otimes d\hat{\sigma}_{ab\to c\bar{c}},$$

here σ_{eff} is a free parameter which controls the contribution of the DPS fixed early [Chernyshev and V.S. '22,23].

Pair J/ψ production in the ICEM

A	$\sigma^{\text{exp}} \pm (\text{stat.}) \pm (\text{syst.})$ [pb]	σ^{theor} [pb]	σ^{SPS} [pb]	σ^{DPS} [pb]
NA3, 1985, pA, $\sqrt{s} = 27$ GeV				
Pt	27.0 ± 10.0	$5.0^{+38.1}_{-4.4}$	$3.1^{+20.0}_{-2.6}$	$1.9^{+18.1}_{-1.8}$
COMPASS[1] , 2022, $\pi^- A$, $\sqrt{s} = 23$ GeV				
NH_3	$10.7 \pm 2.3 \pm 3.2$	$1.260^{+3.811}_{-0.975}$	$0.925^{+2.300}_{-0.640}$	$0.335^{+1.511}_{-0.235}$
Al	$3.6 \pm 8.2 \pm 1.4$	$1.202^{+3.664}_{-0.833}$	$0.882^{+2.224}_{-0.610}$	$0.320^{+1.440}_{-0.223}$
W	$3.3 \pm 3.0 \pm 1.8$	$1.173^{+3.545}_{-0.814}$	$0.861^{+2.140}_{-0.595}$	$0.312^{+1.405}_{-0.219}$

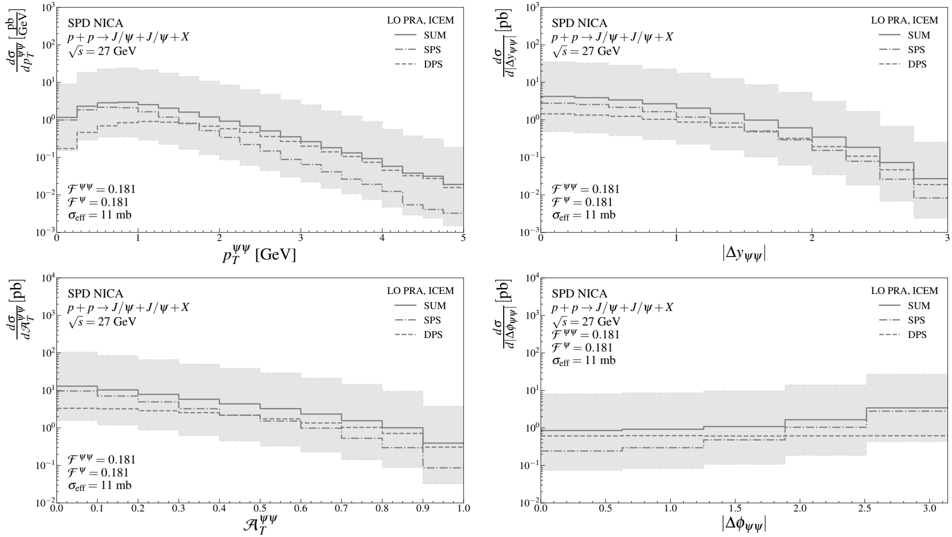
Table 1: Comparison of theoretical and experimental total cross sections for pair J/ψ production in pA and π^- collisions.

Conclusions:

- The big theoretical uncertainty from choice of the hard scale μ in case pair J/ψ production is founded;
- Our predictions with $\mathscr{F}^{\psi\psi} = \mathscr{F}^{\psi} = 0.327$ for pair J/ψ production cross section approximately agree with COMPASS data for Al and W targets and underestimate data for NH3 data by one order;
- *More data should be analyzed, it is necessary to evaluate the possibility of extracting data on pair J/ψ production at future SPD experiment.*

[1]For details see Talk at the 3rd COMPASS «Analysis Phase» mini–workshop, 19 April 2023 by V. Saleev.

Pair J/ψ production in the ICEM



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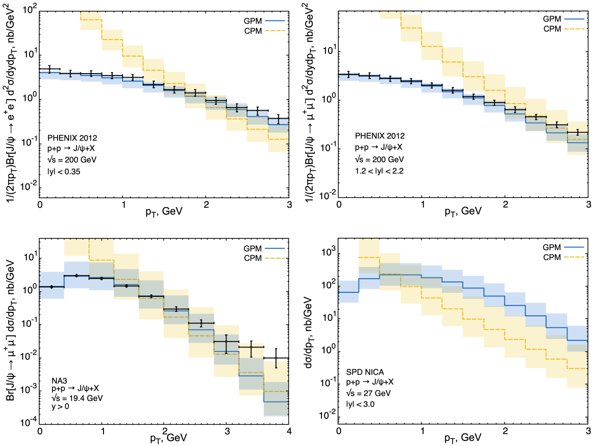
Polarized J/ψ production in the NRQCD



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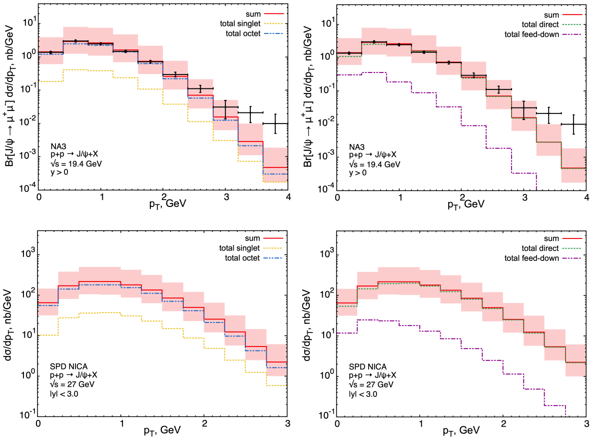
Polarized J/ψ production in the NRQCD



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Polarized J/ψ production in the NRQCD

$$\frac{d\sigma}{d\Omega} \sim 1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \, \cos 2\varphi + \lambda_{\theta\varphi} \cos\varphi,$$

$$\lambda_\theta = \frac{\sigma_\mathrm{T} - 2\,\sigma_\mathrm{L}}{\sigma_\mathrm{T} + 2\,\sigma_\mathrm{L}} = \frac{\sigma - 3\,\sigma_\mathrm{L}}{\sigma + \sigma_\mathrm{L}}$$

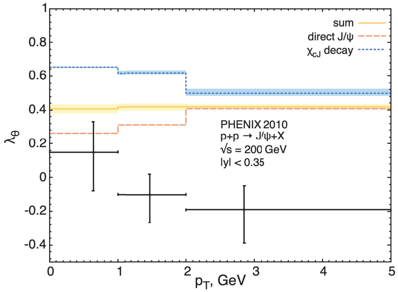

Figure 4: Polarized prompt J/ψ production at $\sqrt{s} = 200$ GeV.

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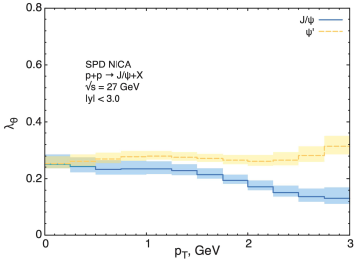
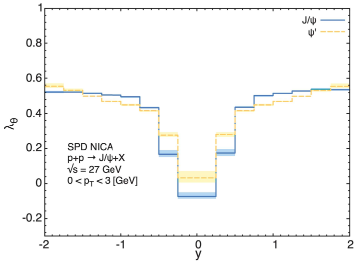
Polarized J/ψ production in the NRQCD





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Polarized J/ψ production in the NRQCD

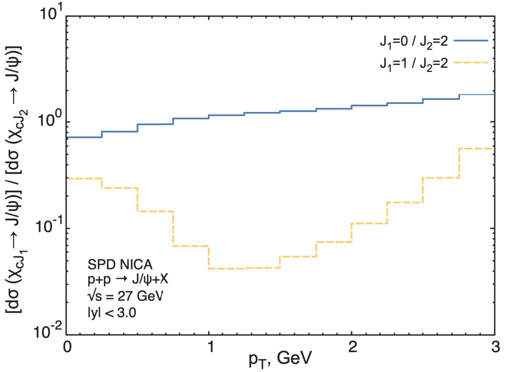

Figure 6: Polarized prompt J/ψ production at $\sqrt{s} = 27$ GeV.

Publications, 2022-2023

1. V. A. Saleev and A. V. Shipilova, "Double Longitudinal-Spin Asymmetries in Direct Photon Production at NICA," Phys. Part. Nucl. Lett. **20** (2023) no.3, 400-403
2. V. A. Saleev and A. A. Chernyshev, "Pair Production of J/ψ in the Color Evaporation Model and the Parton Reggeization Approach," Phys. Part. Nucl. Lett. **20** (2023) no.3, 389-394
3. A. Guskov, A. Datta, A. Karpishkov, I. Denisenko and V. Saleev, "Probing Gluons at the Spin Physics Detector,"[arXiv:2304.04604 [hep-ex]].
4. A. Karpishkov and V. Saleev, "On Transverse Single-Spin Asymmetries in D-Meson Production at the SPD NICA Experiment," Phys. Part. Nucl. Lett. **20** (2023) no.3, 360-363
5. V. A. Saleev and A. V. Shipilova, "Gluon Sivers Function in Transverse Single-Spin Asymmetries of Direct Photons at NICA," Phys. Atom. Nucl. **85** (2022) no.6, 737-747

- A. Anufriev, V. Saleev, Production of η_c mesons at high energy in proton-proton collisions, submitted to PEPAN
- L. Alimov, V. Saleev, Associated $J/\psi + \gamma$ production in high-energy limit of QCD, submitted to PEPAN
- V. Saleev and K. Shilyaev, Prompt polarized J/ψ production at the SPD NICA in NRQCD, submitted to Vestnik Samara University
- A. Karpishkov, V. Saleev and K. Shilyaev, Production of prompt polarized J/ψ in the NRQCD and Generalized Parton Model, submitted to Phys. Atom. Nucl.

Future plans, 2024

- Polarized J/ψ production in the ICEM
- Double Longitudinal-Spin Asymmetries in J/ψ and $D-$meson production
- Hard processes in the "exact" TMD PM
- Gluon Boer-Mulders TMD PDF in different hard processes
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- Signal/Backgruond ratio: prompt photon, $J/\psi+\gamma$, η_c
- Time slice simulation
- Implementation of TMD PDF in KaTie

Thank you for your attention!