$J/\psi$ pair production in $\pi N$ collisions at COMPASS

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First evidence of double $J/\psi$ production

The NA3 double $J/\psi$ results:

- $\pi^- (150, 280 \text{ GeV})$ and $p (400 \text{ GeV})$ beams;

- N.B. kinematic distributions are not corrected for the acceptance;

- interpreted using single parton scattering mechanism ($q\bar{q} \rightarrow 2J/\psi$ and $gg \rightarrow 2J/\psi$);


- interpreted using intrinsic charm hypothesis ($|d\bar{u}c\bar{c}c\bar{c}\rangle$ Fock component of pion materialization).

Intrinsic charm of hadron


- The existence of non-perturbative (intrinsic) Fock component in a hadron with $c$-quarks is postulated:

$$|p\rangle = a_0 |uud\rangle + a_1 |uudg\rangle + a_2 |uudc\bar{c}\rangle + \ldots$$

- In perturbative QCD the extrinsic charm component in hadrons arises from gluon splitting.

- Intrinsic charm contribution is generated non-perturbatively via $gg \to Q\bar{Q}$;

$T_{4c}$-tetraquarks


- first time $T_{4c}$ states were predicted in 1975;
- many theoretical models ([cc][c̄c] model, Drell-Yan type mechanism, etc) exist;
- $M_{T_{4c}} \approx 6 - 7 \text{ GeV}/c^2$;
- no experimental observations of $T_{4c}$ till 2020;

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Chinese Phys. C 43 013105

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- [cc][c̄c] model
- Drell-Yan type mechanism
The LHCb reported the narrow X(6900) structure in the double $J/\psi$ mass spectrum using proton-proton collision data at $\sqrt{s} = 7, 8$ and 13 TeV.

**Model I - X(6900) resonance (without interference):**

$m[X(6900)] = 6905 \pm 11 \pm 7 \text{ MeV}/c^2$

$\Gamma[X(6900)] = 80 \pm 19 \pm 33 \text{ MeV}$

**Model II - X(6900) + interference between broad structure (6.2-6.8) and SPS:**

$m[X(6900)] = 6886 \pm 11 \pm 11 \text{ MeV}/c^2$

$\Gamma[X(6900)] = 168 \pm 33 \pm 69 \text{ MeV}$
COMPASS experiment at CERN
COmmom Muon Proton Apparatus for Structure and Spectroscopy

Phase 1:
- Nucleon Spin Structure (2002-2011)

Phase 2:
- Primakoff (2012)
- Drell-Yan (2015, 2018)
Unique hadron beam in DY runs:

- hadron beam composition: 96.80% $\pi^-$, 2.40% $\bar{K}$, 0.80% $\bar{p}$;
- beam momentum: $190 \pm 3$ GeV/c;
- intensity: up to $7 \times 10^7$ hadrons / sec;
COMPASS Drell-Yan setup

Polarized target:
- two 55 cm long cells filled with NH$_3$ immersed in LHe used in particular in polarized DY studies.

Nuclear targets (Al and W):
- used to remove hadrons originating from target interactions or beam;
- used as an additional nuclear targets:
  - aluminum (A ~ 27): 7cm length;
  - tungsten (beam plug, 120 cm, A ~ 184): first 10 cm used for the physics analyses.
DY and $J/\psi$ studies at COMPASS

- Large statistics of single $J/\psi$ event collected
- Mass resolution: $\sigma_{J/\psi} = 0.181 \text{ GeV/c}^2$
- A shoulder from $\psi(2S)$ is visible
Double $J/\psi$ data at COMPASS

2015: ~4 months of data taking; 2018: ~5 months of data taking;

NH$_3$ target: 25 events
- used for the analysis

Al target: 4 events

W target: 21 events
- large background contamination
- used only for cross-section estimation.
Differential cross-sections

**COMPASS results:**

![Graphs showing COMPASS preliminary data for\( \psi^3 \) and\( \psi^5 \) distributions.]

**The NA3 results:**

- Results were interpreted using double IC of pion hypothesis.
- N.B. Double \( J/\psi \) kinematic distributions were published without acceptance correction.

R Vogt, S.J. Brodsky
The COMPASS double $J/\psi$ mass spectrum does not contain any evident signal from $T_{4c}$ states.
Double $J/\psi$ production mechanisms

The **SPS + Intrinsic Charm** fit:

- the double parton scattering (DPS) is not considered in the fit;
- the DPS contribution at $\sqrt{s} = 18.9$ GeV is less than 8% (**arXiv:1909.06195 [hep-ph]**);
- the data are consistent with pure SPS hypothesis.

**SPS curve:**
- Color Singlet $J/\psi$ production model.

**IC curve:**
Double $J/\psi$ cross-section measurement

COMPASS preliminary

- $\sigma_{2J/\psi} / \sigma_{J/\psi}$
- $\sigma_{2J/\psi}^{\text{NH3}} / \sigma_{J/\psi}$
- $\sigma_{2J/\psi}^W / \sigma_{J/\psi}$
- $\sigma_{2J/\psi}^{\text{Al}} / \sigma_{J/\psi}$

Main sources of systematics:
- uncertainty of $\sigma_{J/\psi}$
- background estimation
- acceptance of double $J/\psi$
- acceptance of single $J/\psi$
- uncertainty of the number of single $J/\psi$

COMPASS results do not contradict to NA3 values.
No A-dependence of $\sigma_{2J/\psi}$ was found.

The measured by the NA3
$\sigma_{J/\psi} = 4.9 \pm 0.77 \frac{nb}{\text{nucleon}}$ was used for the estimation of $\sigma_{2J/\psi}$.
Summary

1. Double $J/\psi$ hadroproduction is a tool:
   • to study the intrinsic charm component of hadrons
   • to search for bound $T_{4c}$ states.

2. The COMPASS collaboration:
   • has searched for double $J/\psi$ events produced in NH$_3$, Al and W targets
   • has estimated double $J/\psi$ production cross-section.

3. The COMPASS data are consistent with SPS production mechanism.

4. No evidence of presence of $T_{4c}$ states in the double $J/\psi$ mass spectrum.
BACKUP
DPS/SPS ratio and generated SPS MC

J.-P. Lansberg, H.-S. Shao

- The DPS contribution is expected to be low at $\sqrt{s} = 18.9$ GeV.

- The generated distributions for double $J/\psi$ MC (SPS sample, HELAC-Onia generator):