Measurements of J/ψ production in ion-ion collisions

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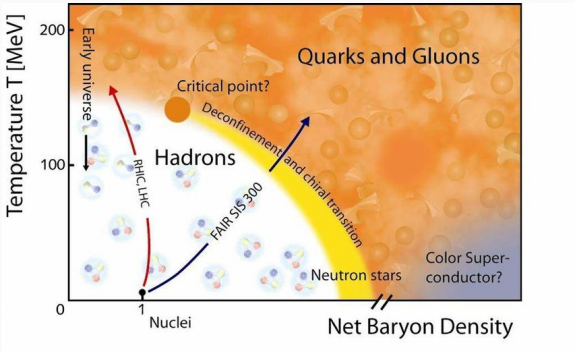
Motivation

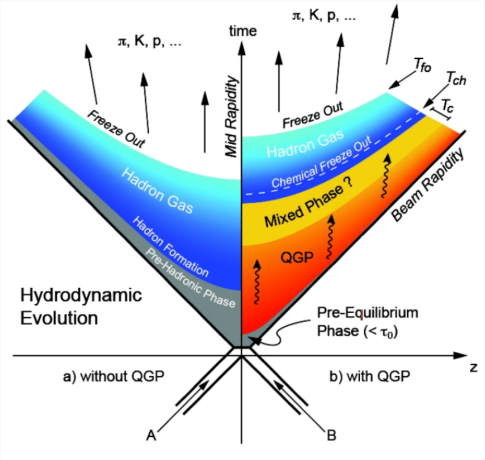
1. Studying of nuclear modified PDFs.
2. Measurements of J/ψ production in the SPD nuclear program can complement the MPD program on studying QCD phase diagram due to the superior performance of the SPD range system compared to that of MPD.



J/ψ production as probe of temperature achieved in the collision

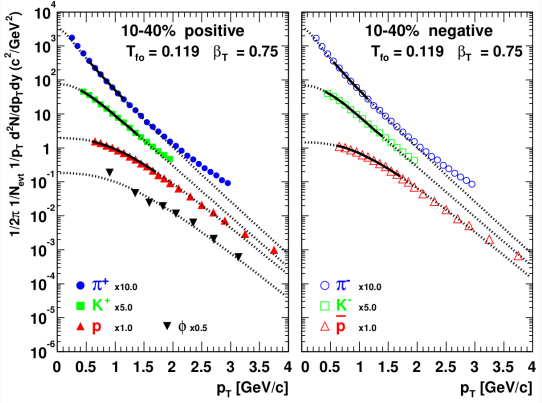
Kinetic freeze-out: Charged hadrons
($\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$)
fragmentation, recombination

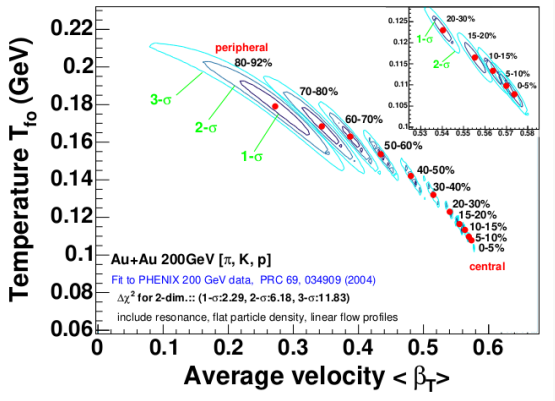
Parton phase: J/ψ-meson production
hard processes



Determination of kinetic freeze-out temperature from particle spectra

Example: Previous PHENIX results on kinetic freeze-out temperature estimation from charged hadron spectra using the Blast-Wave model (relativistic hydrodynamics)





Phase transition temperatue

J/ψ production in hard processes can be used to study temperature of partonic phase of the collision, which can be compared to temperatures of phase transition and kinetic freeze-out.

First-order phase transition between QGP and the hadronic phase:

$$T(\mu) = \frac{1}{\pi}\sqrt{\frac{3}{34}}\sqrt{\sqrt{340\pi^2(220)^4 + 55\mu^4} - 15\mu^2}$$

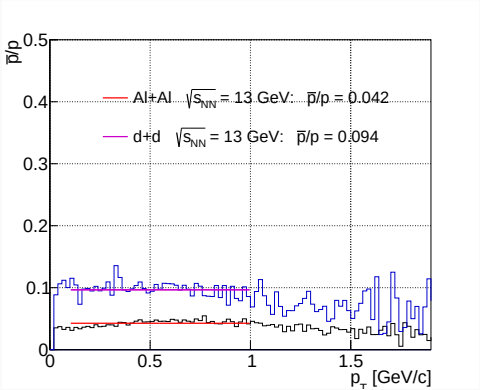
According to the statistical model the $\bar{p}/p$ can be expressed as follows:

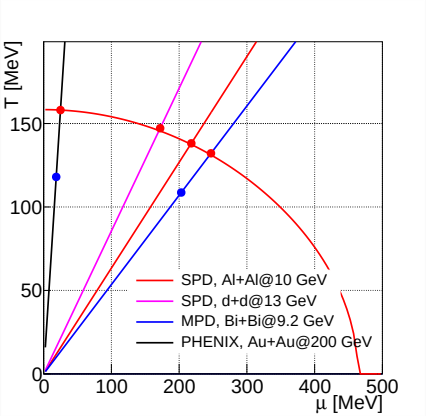
$$\frac{\bar{p}}{p} = \exp\left(\frac{-2\mu_B}{T}\right) \Rightarrow T = \frac{-2\mu_B}{\ln\left(\frac{\bar{p}}{p}\right)}$$

Temperature of phase transition

Phase transition at SPD (d+d): $T \approx 138$ MeV, $\mu_B \approx 218$ MeV

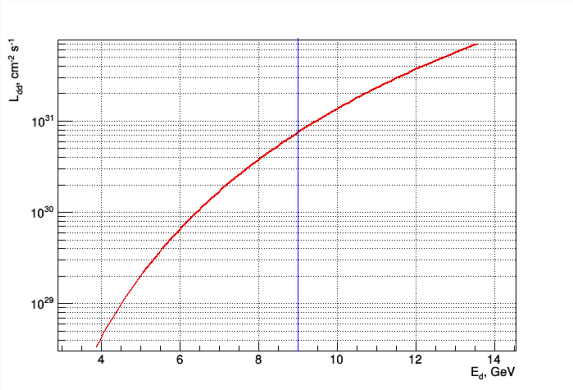
Phase transition at SPD (Al+Al): $T \approx 147$ MeV, $\mu_B \approx 172$ MeV





Experimental requirements

- **Beam species**:
  dd, pp, ion-ion collisions (Al+Al, C+C, Ca+Ca)
- **Collision energy**: 5 -13 GeV
- **Luminosity**:
  $10^{31} cm^{-2} s{-}1$ (d+d, 13 GeV);
  $10^{27} cm^{-2} s{-}1$ (ion-ion)
- **Polarization**: no
- **Involved SPD subsystems**:
  Range system, Straw tracker



Duration of data taking. d+d collisions

$$t = N/(\sigma_{J/\psi} \cdot BR \cdot L \cdot \varepsilon_{rec})$$

d+d, $\sqrt{s_{NN}} = 13$ GeV

$\varepsilon_{rec} \sim 0.8$ - estimations in process

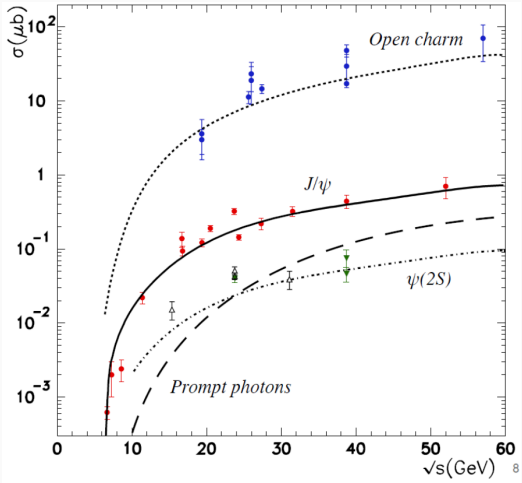
$L = 10^{31} cm^{-2} s^{-1}$

$\sigma_{J/\psi} \approx 3 \cdot 10^{-2} \mu b$

$BR(J/\psi \to \mu\mu) = (5.961 \pm 0.033)$ %

Minimal: $N_{J/\psi} = 1000 \implies t \approx 16$ hours

Optimal: $N_{J/\psi} = 10^5 \implies t \approx 64$ days



Duration of data taking. Al+Al collisions

$$t = N/(\sigma_{J/\psi} \cdot BR \cdot L \cdot \varepsilon_{rec})$$

Al+Al, $\sqrt{s_{NN}} \sim 10$ GeV

$$L = 10^{27} cm^{-2} s^{-1}$$

$\varepsilon_{rec} \sim 0.8$ - estimations in process

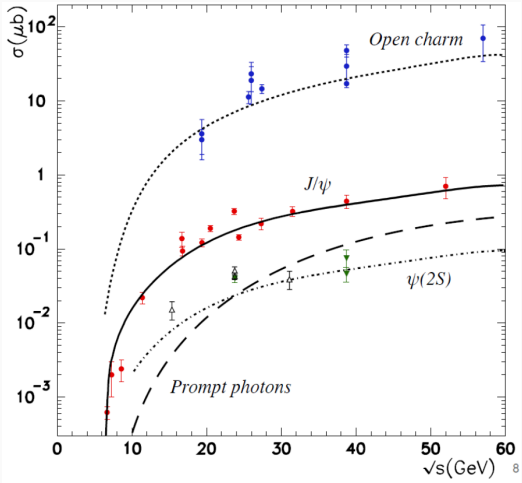
$$R_{AA} = 1/N_{part} \cdot \sigma_{AA}/\sigma_{pp} \overset{R_{AB} \sim 1}{\Longrightarrow}$$

$$\sigma_{AA} \sim N_{part} \cdot \sigma_{pp} \sim 10 \cdot \sigma_{pp}$$

$$\sigma_{J/\psi} = 10 \cdot 10^{-2} = 10^{-1} \mu b$$

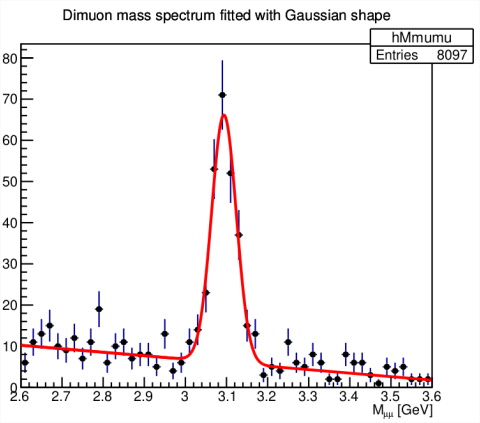
Minimal:

$$N_{J/\psi} = 1000 \implies t \approx 2426 \text{ days}$$

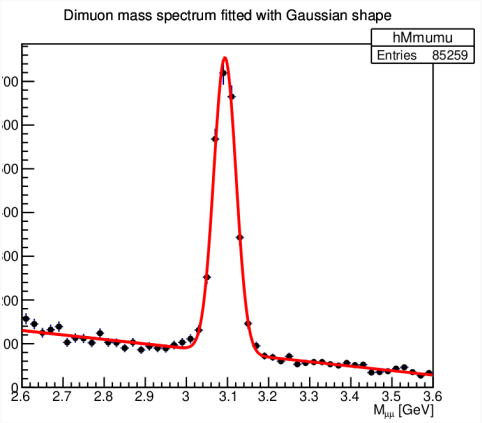


Expected performance (d+d collisions)

$N_{J/\psi} \sim 300$



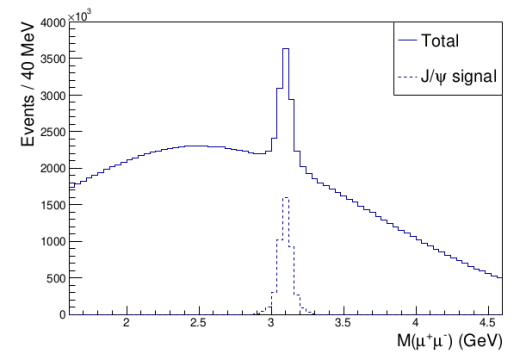
$N_{J/\psi} \sim 2700$

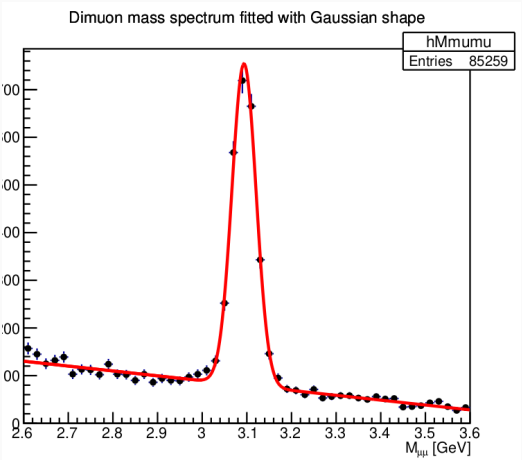


Expected performance (d+d collisions)

From CDR

(after 1 year of data taking, p+p)





Conclusion

- It is unrealistic to measure J/ψ production in ion-ion collisions with $\sim 10^{27} cm^{-2} s^{-1}$ lumitosity at SPD.
- It is possible to measure J/ψ production in d+d collisions
- Measurements of J/ψ production in d+d collisions can serve as tool for studying nuclear modifications of parton distribution functions (PDFs).

We thank Igor Denisenko for the help with simulation of d+d collisions in spdroot.

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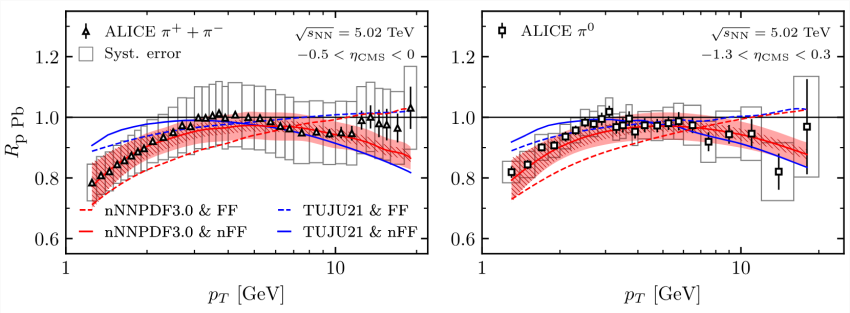
Thank you for your attention!

Backup

Nuclear modified PDFs (nPDFs)

To calculate nuclear-nucleus (nucleon-nucleus) collisions, nuclear-modified parton distribution functions (nuclear PDF) are needed:

$$f^A = \frac{Z}{A} f^{p/A}(x, Q^2) + \frac{A-Z}{A} f^{n/A}(x^2, Q^2)$$



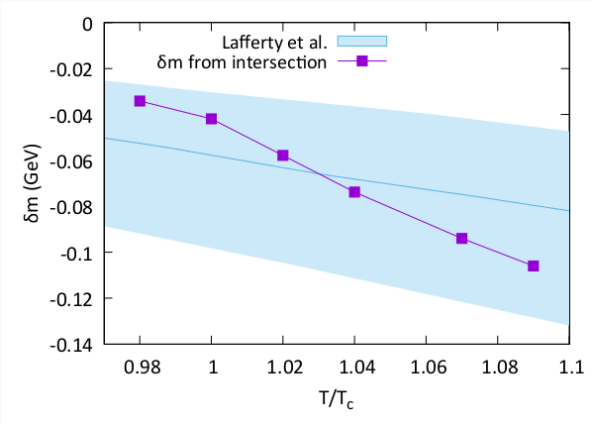
Measurements of J/ψ production in d+d collisions

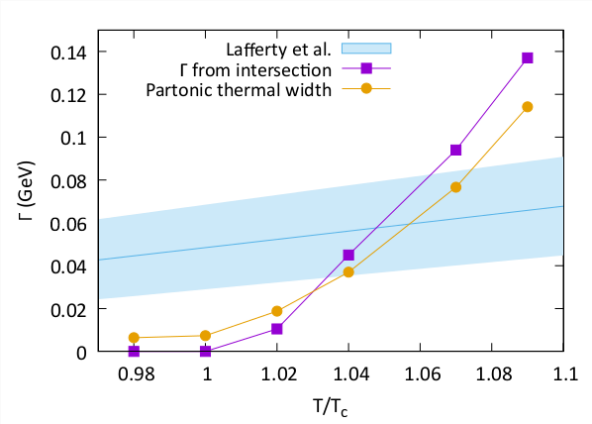
Measurements of J/ψ production in d+d collisions can serve as tool for studying nuclear modifications of parton distribution functions (PDFs). Particularly, measurements of J/ψ production in d+d collisions can be used to study PDFs in neutron.

Despite deuteron being the lightest nucleus, nuclear modification effects are still present and must be taken into account.

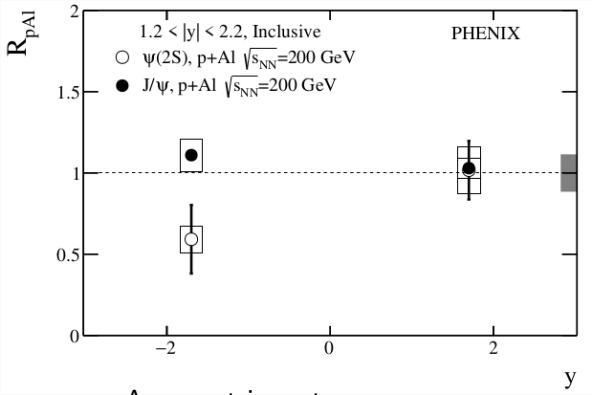
A comparison of experimental data with theoretical LO and NLO predictions will can provide insights into the underlying mechanisms of J/ψ production and help refine theoretical models.

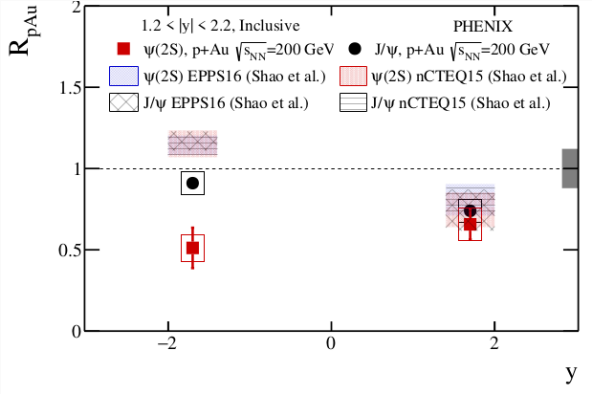
J/ψ production as a signature of phase transition





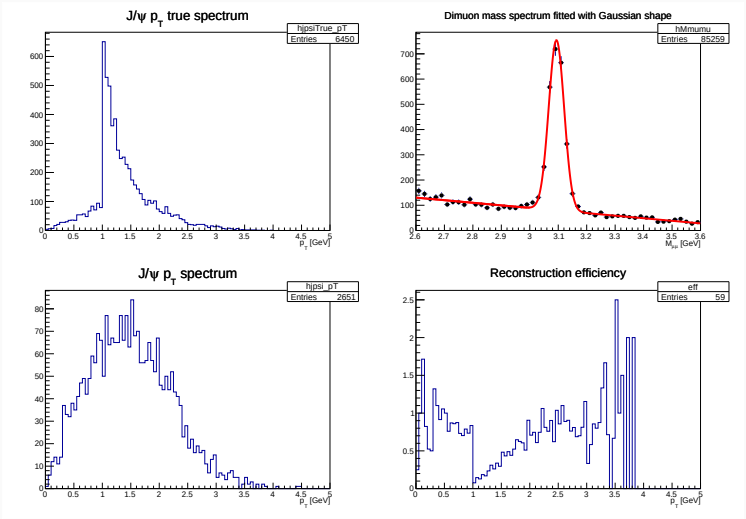
Previous close results: J/ψ production in small systems at PHENIX





- Asymmetric systems
- Backward and forward rapidities

Expected performance (d+d collisions)



Expected performance (d+d collisions)