Fate of the Weakly-Bound $\psi(2s)$ in Nuclear Matter

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Collisions of nuclei are *inherently different* from collisions of bare nucleons

- Nuclear PDF is modified: S, AS, EMC, saturation?
- RHIC probes a unique crossover region in $x$, both shadowing and anti-shadowing regions easily accessible
- Heavy quarks especially sensitive to gluon nPDF
Effects in Nuclear Collisions-Cronin

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  - Energy loss in CNM
  - kT kicks (“traditional” explanation of Cronin, but mass dependence?)
- Baryon enhancement, recombination?
- Possible hydrodynamic phenomena in d+A?

PRC 88 024906 (2013)
Effects in Nuclear Collisions-QGP

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- In A+A collisions, all of the above effects plus:
  - Strong charm flow and energy loss
  - Color screening in deconfined medium
  - Recombination (likely at LHC, maybe at RHIC)

PRC 84 044905 (2011)
Quarkonia at PHENIX

Designed to measure quarkonia down to $p_T = 0$ through dilepton decays at mid and forward rapidity:

Muons: $1.2 < |y| < 2.2$,
- Tracked with wire chambers
- Further muon ID with layers of steel and streamer tubes

NEW: Precision silicon tracking

Electrons: $|y| < 0.35$,
- Tracked with DC, PC
- ID with RICH, EmCal

$$x \approx 5 \times 10^{-3}$$
Shadowing region

$$x \approx 3 \times 10^{-2}$$
Near anti-shadowing/shadowing crossover

$$x \approx 8 \times 10^{-2}$$
Anti-shadowing region

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Open HF versus J/ψ

Sensitive to same initial state effects: gluon shadowing, kT broadening, partonic energy loss in nucleus (details on open HF in S. Lim’s talk)
BIG difference: nuclear breakup of charmonia bound states

*Keep in mind different kinematics for decay leptons from single charm quark versus fully reconstructed cc state
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Forward: similar behavior
- Short time in nucleus
- Low co-mover density
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enhanced open HF versus suppressed $J/\psi$

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Compelling evidence for significant cc breakup effects
Excited charmonia: $\psi(2s)$

Very weakly bound: $E_b \sim 50$ MeV

PHENIX $ee$ measurements at midrapidity in $p+p$:
$\psi(2s)/\psi(1s) = 2.1 \pm 0.5 \%$

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Finalized measurement in d+Au:
PRL 111, 202301 (2013)

By eye, clear difference in peaks between peripheral and central d+Au

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ψ(2s) more suppressed by a factor of ~3 in central collisions
Very different trend than ψ(1s)
Confirmation at LHC

Similar effect observed by ALICE in Min Bias p+Pb
arXiv:1405.3796
Relative Modification of $\psi(2s)/\psi(1s)$ – time in nucleus

After $cc$ formation, the pair expands as it crosses nucleus

$\psi(1s)$ formation time $\sim 0.15$ fm
Relative Modification of $\psi(2s)/\psi(1s)$ – time in nucleus

After $cc$ formation, the pair expands as it crosses nucleus

$\psi(1s)$ formation time ~0.15 fm

At RHIC, $\tau \sim 0.05$ fm

Precursor state crosses nucleus before final state meson forms

Increased suppression NOT due to same breakup mechanism while inside nucleus.

Breakup outside nucleus (co-mover interactions)?
Or is there an altogether different mechanism at RHIC energies?
Relative Modification of $\psi(2s)/\psi(1s)$ – particle density

Relative modification in all systems follows common trend with increasing produced particle density.

Co-mover (or medium?) density seems to be the relevant quantity.
Mini-summary

- Charmonia production in the nucleus suppressed beyond open charm – breakup effects are significant
- The magnitude and trend of $\psi(2s)$ suppression in nuclear collisions is quite different from $J/\psi$
- Very short crossing time: effect likely to occur outside the nucleus
- Approximate scaling with produced particle density

- Measurements at different rapidities at same CM energy would:
  - Effectively vary produced particle density, proper time in nucleus
  - Increased discrimination between models
Precision Tracking at Forward Rapidity: the FVTX

Forward Silicon Vertex Tracker

- Four layers of silicon sensors in each end of central rapidity silicon
- 75um pitch in r, 3.75 deg in phi
- Full azimuthal coverage at forward and backward rapidity

Details just published:
NIM A 755 (2014) 44

- Position resolution better than 30 um in each station
- Single hit efficiency >95%
FVTX in PHENIX

Run-13 p+p $\sqrt{s} = 510$ GeV

-2.2 < y <-1.2

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Opening angle in front of absorber: Greatly improved mass resolution and background rejection

Run-13 p+p $\sqrt{s} = 510$ GeV

-2.2 < y < -1.2
Extracting the $\psi(2s)$ peak

Signal peaks: Crystal Ball + gaussian

Bg: mixed event combinatorial + exponential continuum
First measurement at 510 GeV. First measurement at forward rapidity at RHIC. Consistent with world data. ➔ p+p baseline well understood experimentally.
Near Future Plans

Run-14: 200 GeV Au+Au:

PHENIX luminosity goals reached, still 7 weeks to go in run.

Our BEST Au+Au dataset ever. First Au+Au with FVTX.

Run-15: 200 GeV p+Au
First p+Au at RHIC

Reconstructed FVTX tracks in a typical Au+Au event
Summary

• The difference between suppression of charmonia states in d+Au collisions at RHIC indicates late stage breakup that occurs outside the nucleus
• PHENIX is actively exploring this topic with greatly enhanced capabilities at forward rapidity
• Looking forward to Run-15: p+A at RHIC
Centrality in dA

![Graph showing centrality in dA](image-url)