Cold matter affects quarkonia production

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Reminder of the two striking behaviors of J/ψ suppression at RHIC energy

1. $R_{AA}(\text{RHIC}) \approx R_{AA}(\text{SPS})$
2. $R_{AA}(y\approx1.7) < R_{AA}(y\approx0)$
$R_{\text{AuAu}} \ (y \approx 0 \ \text{in PHENIX}) \approx R_{\text{PbPb}} \ (@ \ SPS)$

- Midrapidity $R_{AA}$ looks surprisingly similar, while there are obvious differences:
  - At a given $N_{\text{part}}$, different energy densities...
  - Cold nuclear matter effects ($x_{\text{Bjorken}}, \sigma_{\text{abs}}$...)
$R_{\text{AuAu}} (y \approx 1.7) < R_{\text{AuAu}} (y \approx 0)$ in PHENIX

- @ RHIC, more J/$\psi$ suppression at forward rapidity!
- While energy density should be smaller...

![Graph showing $R_{\text{AA}}$ vs. $N_{\text{part}}$.]
How much of this is due to normal nuclear matter?

(what cannot claim anything about quark gluon plasma without first answering this question)
Cold nuclear matter effects?

- Many possible effects:
  - $J/\psi$ (or $c\bar{c}$) absorption/breakup
  - (Anti) shadowing (gluon saturation, CGC...)
  - Energy loss of initial parton
  - $p_T$ broadening (Cronin effect)
  - Complications from feed down
    $\psi'$ & $\chi_c$?
  - Intrinsic charm?
  - Something else?
- Absolute need for data!

Eskola, Kolhinen, Vogt
NPA696 (2001) 729

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Nobody is perfect...

@SPS: many pA! High statistics! But small kinematics
(−0.1 < x_F < +0.1)
  – Nuclear absorption does a splendid job
@FNAL: less pA... High statistics! Large rapidity (x_F)
coverage... No AA...
  – Many cold nuclear effects needed!
@HERAB: similar, negative x_F (−0.35 to +0.15)
@RHIC: only dAu, low statistics, but rapidity (−2.2 to +2.2) and centrality dependence
  – Absorption + (anti)shadowing
A snapshot of SPS

To first order, a simple and elegant description of nuclear matter effects

$$\sigma_{\text{abs}} = 4.2 \pm 0.5 \text{ mb}$$
• **Normal nuclear absorption alone** does a splendid job describing pA, SU and peripheral InIn and PbPb:
  – (including one preliminary pA @ 158 GeV from NA60, final yet to come...)

• \( \exp(-\sigma_{\text{abs}} \rho_0 L) \)
  – \( L \) nuclear thickness
  – (or in Glauber model)
  – \( \sigma_{\text{abs}} = 4.2 \pm 0.5 \text{ mb} \)

\[ \sigma_{\text{abs}} = 4.2 \pm 0.5 \text{ mb} \]
$R_{dAu}$ rapidity dependence

(Capella et al aussi?)
• At RHIC, $J/\psi$ mostly produced by gluon fusion, and thus sensitive to gluon’s pdf
• In PHENIX, three rapidity ranges probe different momentum fraction of Au partons
  – South ($y < -1.2$) : large $x_2$ (in gold) $\approx 0.005$ to $0.140$
  – Central ($y \approx 0$) : intermediate $x_2 \approx 0.011$ to $0.022$
  – North ($y > 1.2$) : small $x_2$ (in gold) $\approx 0.002$ to $0.005$

An example of gluon shadowing prediction

$R_g^A(x,Q^2)$

$Q^2 = 2.25$ GeV$^2$

$A = 208$

LHC

RHIC

SPS

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11/16
$R_{dAu}(y)$ @ RHIC

- New analysis of run 3 RHIC data
  - Same p+p reference as Au+Au and Cu+Cu
  - Better (cancellation of) systematics
- Suppression at forward rapidity
  - Shadowing
- Assuming a shadowing scheme, adjust an absorption cross-section

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R_{dAu}(y)

NDSG shadowing
\[ \sigma_{\text{abs}} = 2.2^{+1.8}_{-1.5} \text{ mb} \]

EKS shadowing
\[ \sigma_{\text{abs}} = 2.8^{+1.7}_{-1.4} \text{ mb} \]
Also tried to fit the centrality dependence
  - (assuming a inhomogeneous shadowing scheme)

Consistent results within (large) uncertainties
• Now extrapolate to AuAu collisions →
  - (Also available for CuCu)
  - Mid and forward are correlated through shadowing scheme
  - If you believe this shadowing, large anomalous suppression, larger at forward rapidity

• (NDSG midrapidity)
Yet another shadowing scheme?

Shadowing from Schwimmer multiple scattering:

+ E-p conservation
+ regeneration

Shadowing effect:
NDSG: (y=0) < (y=1.7)
EKS: (y=0) ≈ (y=1.7)
Schwimmer: (y=0) > (y=1.7)

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Capella et al, arXiv:0712.4331
Something odd @ SPS?

- Do we fully understand CNM @ SPS?
- Not these surprising rapidity distribution asymmetries →
  - Variation of ~30 to ~50% in one unit of rapidity!
  - Seems large to be (anti)shadowing...
  - Not taken into account in CNM extrapolation...
$R_{dAu}$ centrality dependence
• Re-plot PHENIX $R_{dA}$ vs local impact parameter $b$ from Glauber model
• Phenomenological fit to $R_{dA}(b) \rightarrow$
  – (other shapes tried)
From dA to AA

- For a given A+A collision at $b_{AA}$, Glauber provides a set of N+N collisions occurring at $b_{i1}$ and $b_{i2}$

- One minimal assumption is rapidity factorization: $R_{AA}(|y|, b_{AA}) = \Sigma_{\text{collisions}} [R_{dA}(-y, b_{i1}) \times R_{dA}(+y, b_{i2})] / N_{coll}$

- Works (at least) for absorption & shadowing since production

\[ \sim pdf1 \times pdf2 \times \exp(-\rho\sigma(L_1+L_2)) \]

RGdC, QM06, hep-ph/0701222
$R_{AA} (N_{\text{part}})$

- Pros and cons:
  - No shadowing scheme nor absorption scheme
  - Mid and forward are not correlated, less model dependent → larger uncertainties (esp. $y\approx 0$)
- Anomalous suppression at least at forward rapidity!
- Anomalous suppression could be identical at midrapidity
- (No dCu, so no CuCu)
Unaccounted cold effects?

- Could $R_{dA}(-y) \times R_{dA}(+y)$ factorization be wrong?
- Yes, in case of strong saturation...
- $dAu$ computation →
- $AuAu$ computation underway... But:
  - Is saturation at play beyond traditional shadowing at $x_2 \approx 0.003$?
  - How to describe $x_2 \approx 0.1$?
Unaccounted cold effects?

- Saturation could suppress forward $J/\psi$ in AuAu
- First numerical estimate, work in progress...

Experiment

Saturation

"Flat anomalous" suppression here?

Normalisation here?

0-20%  20-40%  40-60%  60-93%

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$R_{dAu}$ transverse momentum

(Mettre un plot de Roberta)
Various $R_{XY}(p_T)$

- Several (hints of) raising $R_{AA}(p_T)$
  1. $R_{CP}$ PbPb (NA50)
  2. $R_{AuAu}$ (PHENIX)
  3. $R_{dAu}$ (PHENIX)

- Several potential reasons:
  - Leakage effect, $J/\psi$ escape
    - High $p_T$ $J/\psi$ forming beyond QGP
  - Cronin effect
  - Raising $x_B$ = less shadowing
    - 0.02 to 0.05 from 0 to 9 GeV/c
    - See discussion in $\rightarrow$

- Think about it...

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PHENIX, arxiv:0711.3917 compared to Ferreiro, Fleuret, Rakotozafindrabe, arxiv: 0801.4949
3. $p_T$ broadening @ SPS?

- Different scaling in pA and AA collisions
- Something else going on in AA?
  - High $p_T$ J/$\psi$ escape?
Various $R_{XY}(p_T)$

- Several (hints of) $R_{AA}(p_T)$
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Three existing cold scenarios could justify the rapidity anomalous dependence

1. The data itself!
2. A given shadowing scheme
3. Color glass condensate
3. $p_T$ broadening @ RHIC? vs $N_{\text{part}}$?

- Widely unknown initial charm production:
  - Recombined $R_{AA}$ are poorly constrained...
- Instead look at $p_T$:
  - Hot: Inherited $p_T$ should be lower than initial
  - Cold: Cronin effect should broaden initial $p_T$
- Cronin goes like:
  \[ \langle p_T^2 \rangle_{AB} = \langle p_T^2 \rangle_{pp} + \alpha \times L \]

- No strong $\langle p_T^2 \rangle$ dependence...
- Modest rise at forward rapidity
- Could be broadening
- No need for recombination here
• Widely unknown initial charm production:
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  – Could be broadening
  – No need for recombination here
Let’s wait for this run analysis before to say more about cold matter (and derive decent survival probabilities)
That’s all folks
2. Cold matter again?

- Fitting an effective break-up cross section (depending on y) and extrapolate to CuCu and AuAu...

- Do you agree that we have poor handle on the cold nuclear matter effect?
Face to face

**EKS (y=0) ≈ (y=1.7)**

**NDSG (y=0) < NDSG (y=1.7)**
6. STAR upsilon’s

- Proof of principle: dozens of \( Y \) in \( p+p \) & \( A+A! \)
- Nuclear modification factor to come soon
- Suffers less from cold matter (\( x=0.02 \) to 0.1=EKS antishadow)
  - (should be checked with run8 \( d+Au \))
- Should measure (unseparated) excited states melting

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Unaccounted CNM?

- Strong initial states effect ala color glass condensate?
  - But they have to violate rapidity symmetrisation $R_{AA}(y) = R_{dA}(-y) \times R_{dA}(+y)$
  - (otherwise taken into account in CNM extrapolation)
- Could this + sequential melting produce $R_{AA}(y \sim 0)$ and $R_{AA}(y \sim 1.7)$?
- Double ratio should drop...
- A possibility...

This calc. is for open charm, but similar for $J/\psi$?

Tuchin, hep-ph/0402298

$syst_{global} = +14\%$

$\sqrt{s} = 200$ GeV

$\eta = 0$

$\eta = 2$

$R_{AA}(y \sim 1.7)$

$R_{AA}(y \sim 0)$
• Hard probes 2004
  – hep-ph/0504133
• Coherent production of charm (open or closed)
  – (y<0 production time to low to make computation)
  – Shadowing from CGC computation...
+ absorption for SPS & fermilab