Charmonia Production in p(d)+A and A+A Collisions

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- p+p - one comment
- p+A and d+A
- CNM in A+A & PHENIX compared to SPS

\[ \lambda_{J/\psi} \]

p+p → J/ψ at \( \sqrt{s} = 200 \) GeV

\[ \alpha \]

E866/NuSea Preliminary

800 GeV p+A

EKS98 CNM baseline

- PHENIX Au+Au y = 0
- PHENIX Au+Au y = 1.7
- NA60 In+In
- NA50 Pb+Pb

Narrow boxes - correlated sys
Wide boxes - CNM baseline sys

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Quarkonia Polarization
p+p Collisions
- One comment -
Quarkonia Production - Polarization

\( \lambda_{J/\psi} \) for (2S+3S), but NOT for (1S)

* Is feed-down washing out polarization? (~40% of 1S from feed-down)

\( \gamma \) maximally polarized for (2S+3S), but NOT for (1S)

(\textit{does not include effect of feeddown from } \chi_c \text{ & } \psi'\text{)}
CNM effects on Quarkonia p+A (FNAL) and d+A (RHIC)
Traditional shadowing from fits to DIS or from coherence models

Absorption (or dissociation) of $c\bar{c}$ into two D mesons by nucleus or co-movers

Gluon saturation from non-linear gluon interactions for the high density at small $x$; amplified in a nucleus.

Energy loss of incident gluon shifts effective $x_F$ and produces nuclear suppression which increases with $x_F$
Transverse Momentum Broadening
Another Cold Nuclear Matter Effect

Initial-state gluon multiple scattering causes $p_T$ broadening (or Cronin effect)

$$\sigma_A = \sigma_N A^\alpha$$

PHENIX 200 GeV dAu shows some $p_T$ broadening, but may be flatter than at lower energy ($\sqrt{s}=39$ GeV in E866/NuSea)
At large $x_F \geq 0.5$ intrinsic $c\bar{c}$ components of the projectile proton can dominate the production of charm pairs

- $A^{2/3}$ dependence via surface stripping of light quarks to free charm pair component

(also includes absorption and shadowing)

But E789 set limit on I.C. contribution via shape of cross section vs $x_F$

- $< 2.3 \times 10^{-3}$ nb/nucleon (1.8 nb/nucleon predicted)
J/ψ suppression in p+A fixed-target

- J/Ψ and Ψ' similar at large $x_F$ where they both correspond to a $c\bar{c}$ traversing the nucleus
- Near $x_F = 0$ -- $D^0$ not suppressed, $J/Ψ$ and $Ψ'$ suppressed due to absorption, $Ψ'$ slightly stronger since both starting to become hadronized states in nucleus
- what about open charm at higher $x_F$?

Many ingredients to explain the $J/ψ$ nuclear dependence - R. Vogt (2000)

800 GeV p+A (FNAL)
PRL 84, 3256 (2000); PRL 72, 2542 (1994)

$\alpha = X_1 - X_2$

Hadronized $J/ψ$?
(Small) J/ψ Nuclear Dependence Even for Deuterium/Hydrogen!

Nuclear dependence in deuterium seems to follow the systematics of larger nuclei, but with $A_{\text{eff}}$, smaller than two.

From fits to E866/NuSea p + Be, Fe, W data: $\sigma_{pA} \sim \sigma_{pp} A^\alpha$

\[ \alpha(x_F) \propto 1 - 0.052x_F - 0.034x_F^2 \]

\[ \alpha(p_T) \propto 0.06p_T + 0.011p_T^2 \]
New Analysis of Run3 d+Au with new 2005 p+p baseline

PRC 77,024912(2008)

Compared to E866/NuSea p+A results & lower-energy NA3 at CERN

Suppression not universal vs $x_2$ as expected for shadowing, but closer to scaling with $x_F$, why?
- initial-state gluon energy loss?
- gluon saturation?

Scaling of E886 vs PHENIX better vs $y_{cm}$
Fermilab E789: $D^0$ & $B \rightarrow J/\psi X$
(charm & beauty using silicon)

Dimuon spectrometer

16-plane, 50\(\mu\)m pitch/8.5k strip silicon vertex detector

$B \rightarrow J/\psi + X$

$D^0 \rightarrow K\pi$
$K^-\pi^+$
$K^+\pi^-$

Mass (GeV/c²)

$\alpha$

$\sigma = \sigma_n A^\alpha$

$E866$/NuSea, $\sigma = \sigma_n A^\alpha$

$800$ GeV $p + A \rightarrow J/\psi$
E866/NuSea Open Charm Measurement

- hadronic cocktail explains ~30% of target & <5% of dump μ’s
  - as expected since dump absorbs light hadrons before they can decay
- charm decays consistent between Cu target and Cu dump
- use same method for Be to get nuclear dependence

E866/NuSea 800 GeV p+A
- S. Klinksiek thesis - hep-ex_0609002
- paper in preparation
Comparing Open & Closed charm Nuclear Dependences

Open-charm p+A nuclear dependence (single-$\mu$ $p_T > 1$ GeV/c) - very similar to that of $J/\Psi$

- dominant effects are in the initial state
  - e.g. shadowing, $dE/dx$, Cronin
- weaker open-charm suppression at $y=0$ attributed to lack of absorption for open charm

E866/NuSea 800 GeV p+A
Difference in Suppression (alpha) between Open & Closed charm

\[ \alpha(x_F) = 0.960 (1 - 0.0519 x_F - 0.338 x_F^2) \]

\[ \alpha_{\text{charm}} - \alpha_{J/\Psi} \]

\[ y_{\text{c.m.}} \]

E866 Preliminary

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SELEX - hep-ex_0902.0355??

SELEX - a zoo of beams & charm particles:
• \((\pi^\pm, p, \Sigma^-) + A \rightarrow (D^0, D^*, D^\pm, D_s, \Lambda_c)\)

Appears to be inconsistent with both E789 \(D^0\) & E866/NuSea open charm single muon msmts

Hint of more similar result for \(p_T^2 > 1.3\) GeV/c in one SELEX channel?
CNM effects (EKS shadowing + dissociation from fits to d+Au data, with R. Vogt calculations) give large fraction of observed Au+Au suppression, especially at mid-rapidity.

Present CNM Constraints on A+A data


EKS Model

$\sigma_{\text{breakup}} = 0.1, 2, 3, 5 \text{ mb (top to bottom)}$

Best Fit $\sigma_{\text{breakup}} = 2.8^{+2.3}_{-2.1} \text{ mb}$

more accurate d+Au constraint from new 2008 data
Quarkonia Production & Suppression – J/ψ in d+Au

Initial d+Au J/ψ update from new 2008 data (~30x 2003)

\[ R_{CP}^{0-20\%} = \frac{N_{inv}^{0-20\%}}{N_{inv}^{60-88\%}} \times \frac{\langle N_{coll}^{0-20\%} \rangle}{\langle N_{coll}^{60-88\%} \rangle} \]

- \( R_{CP} \) pretty flat vs centrality at backward rapidity; but falls at forward rapidity (small-\( x \))

- more soon – precision statistics requires precision systematics & careful analysis
New CNM fits using 2008 PHENIX d+Au Rcp (Tony Frawley, Ramona Vogt, ...)

• similar to before, use models with shadowing & absorption/breakup
  • but allow effective breakup cross section to vary with rapidity
    • to obtain good description of data for projections to A+A

• get \( \sigma_{\text{breakup}}(y) \); compare to E866/NuSea & HERA-B
  • Lourenco, Vogt, Woehri - arXiv:0901.3054

• common trend: large increasing effective breakup cross section at large positive rapidity
  • need additional physics in CNM model - e.g. initial-state dE/dx
Comparision of New Effective Breakup Cross Section fits to published 2003 $d+Au$ $R_{dAu}$ Results
(cross check)

CNM derived from new Rcp is consistent with RdAu from old 2003 data
• *PRC 77, 024912(2008)*
Anomalous Suppression vs Npart
SPS & PHENIX separate at large Npart

![Graph showing R_{AA} / R_{AA} (CNM) vs Npart]

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Npart

0 100 200 300 400
Anomalous Suppression vs Npart
With PHENIX CuCu added
Comparing Anomalous Suppression at RHIC & SPS vs Energy Density

Caution - Many systematic uncertainties on relative (SPS vs RHIC) energy density scales:

- Using WA98 for dE_T/dy at NA50/60 (matches best with dN/dy from Roberta Analdi)
  - substantially different from NA49 values (~25%)?
  - see PRC 71, 034908 (2005)
- use Glauber MC for NA50/60 areas
- Use tau*energy density scale; but is tau same or different between SPS & RHIC energy?
- No Cu+Cu dN/dy or dE_T/dy at RHIC, so using Au+Au values at same N_{part}
Anomalous Suppression vs $dN_{ch}/d\eta$
Anomalous Suppression vs $dE_T/d\eta$
Future
Recent PHENIX $J/\Psi \rightarrow \mu \mu$ data sets

Run9 p+p now ongoing, with longitudinal polarization:
- 28 days of 500 GeV
- ~64 days of 200 GeV
Vertex Detectors (VTX & FVTX)
• better $\Upsilon \rightarrow e^+e^-$ mass resolution & background at mid-rapidity
• separation of $\Psi'$ from $J/\Psi$ & reduction of backgrounds at forward-rapidity ($\mu^+\mu^-$)
• $B \rightarrow J/\Psi X$

Forward Calorimetry (FOCAL)
• $\chi_c \rightarrow J/\Psi + \gamma$ in p+p & d+Au

Removing Hadron Blind Det. (HBD)
• when vertex detectors go in, HBD comes out (smaller photon conversion backgrounds)

And increased machine Luminosity benefits these rare processes
Summary

New CSM good except for forward $J/\Psi$ polarization

Many CNM effects possible:
- similarity of open charm $\rightarrow$ initial state
- lack of $x^2$ scaling $\rightarrow$ not shadowing

Anomalous Suppression @ RHIC & SPS

Scales with Energy Density?