Cold Nuclear Matter Effects in 200 GeV d+Au Collisions at PHENIX
PHENIX Au+Au Measurements

- PHENIX observed strong suppression of light mesons such as $\pi^0$ in central Au+Au collisions.
- At high $p_T$, single electrons from heavy quarks are also suppressed strongly.
- The interpretation of these results requires - among others - an understanding of the initial state.
- d+Au collisions are a tool to study this initial state.

Submitted to PRC (arXiv:1208.2254)
Cold nuclear matter effects

- Cronin enhancement
  - multiple scattering of partons in incoming nuclei
- PID dependence at RHIC, higher enhancement for protons than pions
- Parton distributions modified in nuclei compared to protons
  - can lead to enhancement (anti-shadowing) or suppression (shadowing, EMC effect), depending on the x of the partons and the Q^2
- Nuclear PDFs with uncertainties, such as EPS09
- Color glass condensate - mostly at forward rapidities, at very low x
Centrality dependence of nuclear PDFs

- Helenius, Eskola, et. al. published centrality dependent nuclear PDFs (arXiv:1205.5359)
- Compared to (2003) PHENIX $\pi^0 R_{dA}$
  - Looks as if the curves agree with data (note that the data is scaled up/down within systematics, i.e. up to 9.8%)
  - Limited significance of data at high $p_T$
  - New data can help constraining these nPDFs

arXiv:1205.5359
The PHENIX Experiment

• Versatile detector to measure rare probes
• Tracking detectors for charged particles, such as electrons and charged pions
• RICH allows electron ID
• Photon and electron energy measured with electromagnetic calorimeters
• Data taken in 2008 d+Au run are 30-fold increase compared to 2003
New results

I will discuss the following
• direct photons (briefly)
• light mesons ($\pi^0$, $\eta$) and reconstructed jets
• single electrons from heavy flavor
The lightest: direct photons

- Direct photons appear unmodified in d+Au
- Possibly slight enhancement at low $p_T$
- Theoretical models agree with data
- Data cannot (yet) distinguish between models
- Two different methods cover large $p_T$ range
- Strong enhancement at low $p_T$ in Au+Au final state effect
Measuring jets in PHENIX
Measuring jets in PHENIX

- Gaussian filter algorithm
  - seedless, infrared and collinear safe, cone-like algorithm with Gaussian angular weighting (w.r.t. jet axis)

- Developed for heavy-ion collisions, previously used in Cu+Cu and p+p at PHENIX

- Focus on energetic core of jet, optimized S/B

- Small underlying event in d+Au, evaluated with embedding analysis

- Fake rate determined to be < 5% for jets with \( p_T > 9 \) GeV/c

**Poster by Dennis Perepelitsa**
Light quarks and gluons: $\pi^0$, $\eta$, jets

- New results on $\pi^0$, $\eta$, and jets
  - $\pi^0$ now up to $p_T=20$ GeV/c
  - $\eta$ up to $p_T=22$ GeV/c
  - jets up to $p_T=45$ GeV/c
Modification?

- Looking at d+Au collisions without centrality selection: $R_{dA}$ appears consistent with unity over the whole $p_T$ range
  - Maybe slight enhancement for $p_T > 2$ GeV/c
- $\pi^0$ and $\eta$ show the same behavior
  - Both $\pi^0$ and $\eta$ have same system (and energy) dependence
- Suppression in Au+Au is final state effect (we knew that before)
**η/π⁰ production ratio**

- There is no centrality dependence of the η/π⁰ ratio.
- At high pT, the ratio flattens out, at low pT, there is turn-on.
  - Consistent with m_T scaling.
  - m_T scaling factor between η and π⁰ is ~0.48, which is consistent with measurement in p+p.
Centrality dependence

- In all three channels, there is quite strong centrality dependence.
- $R_{dA}$ enhanced in peripheral, for $\pi^0$, $\eta$, and jets.
- In central events, jets show some suppression ($R_{dA} \approx 0.85$) at high $p_T$, $\pi^0$ and $\eta$ show consistent behavior.
- Though hints existed in old data, this is a surprise (comparison shown later).
**R_{CP}: another perspective of centrality dependence**

- **R_{CP},** the ratio of the scaled yield in central divided by peripheral

- Suppression of yield in central compared to peripheral collisions

- Present in all three measurements

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**NEW RESULTS**

- [Graph showing data for R_{CP} in different centrality ranges**](#)
$R_{CP}$: another perspective of centrality dependence

- $R_{CP}$, the ratio of the scaled yield in central divided by peripheral
  - Suppression of yield in central compared to peripheral collisions
  - Present in all three measurements
- Stretching the $\pi^0$ $p_T$ with an empirical factor of $1/0.7$
  - data align very well! Shape is the same after stretching
  - remember: high $p_T$ hadrons are considered proxy for jets

![Graphs showing $R_{CP}$ ratios for different centralities.](image)
EPS09s - does it describe the data?

- Does EPS09s explain the centrality dependence?
- n.b.: in their publication, PHENIX data were scaled up/down

Curves from arXiv:1205.5359
EPS09s - does it describe the data?

- Does EPS09s explain the centrality dependence?
- n.b.: in their publication, PHENIX data were scaled up/down
- Adding new data: EPS09s does not explain the centrality dependence!
  - reasonable agreement in central
  - however, does neither describe enhancement nor shape in peripheral
  - insufficient constraint on high $p_T$ from old data

2003 and 2008 data

curves from arXiv:1205.5359
EPS09 with real PHENIX centrality

- Mapping centrality dependence as integrated longitudinal density through the nucleus, using EPS09 + Glauber MC + PYTHIA (x,Q^2)
- Using real PHENIX centrality distributions
- Leads also to only a weak centrality dependence
- Again, data is not matched in peripheral collisions
- It seems that T_A scaling does not work => different physics, beyond modified nPDFs
Heavy quarks

- Single electrons from heavy flavor decays
- Enhancement in central d+Au at intermediate $p_T$
  - Can this be Cronin enhancement?
  - Anti-shadowing is expected around $<x>\sim0.1$
- No suppression visible

Submitted to PRL (arXiv:1208.1293)

Poster by Matt Durham
EPS09

- Comparison with EPS09, centrality dependence via integrated longitudinal density

- Works well in peripheral collisions

- Disagreement in enhancement region in central collisions

- Calculation does not include Cronin enhancement!
Summary and outlook

• PHENIX measured centrality dependence of $\pi^0$, $\eta$, reconstructed jets, and electrons from heavy flavor, and minimum bias direct photons in d+Au

• Photons not modified, low $p_T$ enhancement in Au+Au final state effect

• Quite strong centrality dependence of high $p_T$ $\pi^0$, $\eta$, and jets with slight suppression in central and enhancement in peripheral collisions
  • EPS09 nuclear PDF does not describe this centrality dependence, are there additional mechanisms in peripheral d+Au?

• HF electrons enhanced at intermediate $p_T$ in central collisions, not in peripheral

• Future: high statistics direct photon measurement with 2008 data

• Future detector upgrade (MPC-EX) will allow more precise measurements at forward rapidity
Related talks and posters

• Talks:
  • M. Wysocki (Monday plenary session, 15:05)
  • D. McGlinchey (Tuesday parallel 4 session, 15:15)

• Posters:
  • D. Perepelitsa
  • M. Durham
Backup
$R_{CP}$ compared with the 2003 data

- They are the same

- Centrality dependence in $d+Au$ is nothing new, but measured much more precise now
EPS09 - another look at the centrality dependence

• Calculating $R_{CP}$ for EPS09s: does not predict a strong centrality dependence

• largest deviation from 1 for $R_{CP}$ (from arXiv:1205.5359) at $p_T \sim 6$ GeV/c when comparing central to peripheral

• No modification at high $p_T$ in EPS09s, significant modification in PHENIX data