PROSPECT OF RAPIDITY ASYMMETRY AND NUCLEAR MODIFICATIONS

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24th Winter Workshop on Nuclear Dynamics ’08
5-12 April 2008 – South Padre Island, Texas, USA

US DOE: DE-FG02-86ER40251
0. Motivation – nuclear effects at high $p_T$

- $R_{dAu}(p_T)$ gives information about nuclear effects
- $Y_{asym}$ reflects the geometrical properties of nuclear effects

I. Rapidity asymmetry and distribution

- Geometrical properties in the $\eta$ distribution
- Effect of shadowing and multiple scattering

II. Nuclear modification and rapidity asymmetries

- Results at FERMILAB, RHIC and LHC energies
- Results with different shadowing parameterizations
Rapidity Asymmetry vs. Nuclear Modification

Rapidity asymmetry, \( Y_{asym}(p_T) \)

- In non-symmetric systems, like e.g. \( pA(dAu) \) collisions, the small geometrical differences of the backward/forward yields can be enlarged via rapidity-asymmetry ratio:

\[
Y_{asym} = \frac{\text{Yield(”backward”)}}{\text{Yield(”forward”)}} = \frac{\text{Yield(”Au-side”)}}{\text{Yield(”d-side”)}}
\]

Nuclear modification, \( R^{h}_{AA'}(p_T) \)

- In both, symmetric and non-symmetric systems, the relative difference in yields from \( pA(dA) \) or \( AA' \) collisions are relative to \( pp \)

\[
R^{\pi}_{AA'} = \frac{1}{\langle N_{bin} \rangle} \frac{d\sigma/d^3p_T(AA'\rightarrow\pi)}{d\sigma/d^3p_T(pp\rightarrow\pi)} = \frac{d\sigma/d^3p_T(AA'\rightarrow\pi)(”with nuclear effects”)}{d\sigma/d^3p_T(AA'\rightarrow\pi)(”without nuclear effects”)}
\]
STAR $h^\pm$ data in $dAu$

- However, theoretical models described well the $R_{dAu}$, BUT gives opposite results for the $\eta_{asym}$ values?
STAR $h^\pm$ data in $dAu$

- However, theoretical models described well the $R_{dAu}$, BUT gives opposite results for the $\eta_{asy}$ values?
- Maybe FF effects: $h^\pm$ vs. $\pi^0$?

The BIG QUESTION: Where is the devil?
Latest STAR PID data in \(dAu\)

- More detailed data on \(Y_{\text{asym}}\) for \(p\) and \(\pi^\pm\) in \(dAu\) collisions

- PRC 76 54903 (2007)

- The geometrical effect is still there, but at high-\(p_T\) difference start to disappear.

- Similar for the \(p\) and \(\pi\) (not FF)
BRAHMS and PHOBOS $dN/d\eta$ data in $dAu$

- Rapidity distribution, $dN/d\eta$ is "integrated over" the $p_T$ range
- PRL 98 032301 (2005)
- PRC 72 031901(R) (2005)
- Centrality dependence is also measured as in STAR data
- The "extracted" $Y_{asym}$ in $\eta$ ranges are similar, but not same

The devil is always in the details!
Pseudorapidity distributions – 1.

Inclusive $\pi^0$ spectra in $dAu$ vs. $\eta$ at fixed $p_T = 2.25$ GeV/c

- Simple pQCD calculation
- NO nuclear effects, only pure geometry (scaled $pp$)
- HIJING shadowing as an asymmetric nuclear effect
  $\implies$ asymmetry appears:
  more $\pi^0$ at backward

The rapidity asymmetry becomes greater than 1. – OK?!
Pseudorapidity distributions – 2.

Inclusive $\pi^0$ spectra in $dAu$ vs. $\eta$ at fixed $p_T = 2.25$ GeV/c

- pQCD calculation with $k_T$
- NO nuclear effects, only pure geometry (scaled $pp$)

⇒ this enhances the yields up to intermediate $p_T$s and this $\langle k_T^2 \rangle$ requires to describe hadron spectra.
⇒ Symmetry preserved

Still symmetric: rapidity asymmetry equal to 1. – OK?!
Intrinsic \( k_T \) is needed to get a precise description at \( \eta = 0 \)
... and it seems still need at higher (pseudo)rapidity values
Pseudorapidity distributions – 2.

Inclusive $\pi^0$ spectra in $dAu$ vs. $\eta$ at fixed $p_T = 2.25$ GeV/c

- pQCD calculation with $k_T$
- NO nuclear effects, only pure geometry (scaled $pp$)

$\Rightarrow$ this enhances the yields up to intermediate $p_T$s and this $\langle k_T^2 \rangle$ requires to describe hadron spectra.

$\Rightarrow$ Symmetry preserved

Still symmetric: rapidity asymmetry equal to 1. – OK?!
Pseudorapidity distributions – 3.

Inclusive $\pi^0$ spectra in $dAu$ vs. $\eta$ at fixed $p_T = 2.25$ GeV/c

- pQCD calculation with $k_T$
- need for nuclear multiple scattering to describe $pA$
  $dA$ or $AA'$ yields and the Cronin effect

$\Rightarrow$ Multiple scattering cause more enhancement in the forward, even with shadowing.

Multiscattering changes the rapidity asymmetry below 1.
Pseudorapidity distributions – 4.

Inclusive $\pi^0$ spectra in $dAu$ vs. $\eta$ at fixed $p_T = 2.25$ GeV/c

- pQCD calculation with $k_T$
- and with multiscattering, but NO shadowing

$\Rightarrow$ Is multiple scattering the $\pi^0$, what turns the $Y_{asym} < 1.$ to the opposite?
Meanwhile this needed to describe hadron spectra.

Let’s eliminate the multiple scattering (😈) from the model!
What we can do with the strength nuclear effects?

- No reason why multiscattering should be constant vs. $\eta$.
- Find the different scaling for the Cronin (Int.J.Mod.Phys.E16:1923,2007)
- or just make a stronger shadowing, like EPS08 (arXiv:0802.0139v1)
It is definitely better at low $p_T$ values

- Multiple scattering is in the parameterization, scales with $x$
- Nicely describe the froward data in $dAu$ at RHIC
- BUT we lose more on the high-$x$ effect like e.g. EMC
2. INTERMEZZO for SPS

Why are we want to keep nuclear multiscattering?
- At SPS energies the main contribution comes from higher-$x$
- the nuclear modification caused by shadowing is $\lesssim 5$

$\implies$ thus, NO chance to describe OLD data by Cronin et al.
Pseudorapidity distributions – beyond high-$p_T$s

Inclusive $\pi^0$ spectra in $dAu$ vs. $\eta$ at fixed $p_T = 2.25$ GeV/c

$\Rightarrow$ The observed effect is stronger at low $p_T$ ranges

![Graph showing inclusive $\pi^0$ spectra in $dAu$ vs. $\eta$ at fixed $p_T = 2.25$ GeV/c. The graph illustrates the distribution of $\pi^0$ particles as a function of pseudorapidity $\eta$. The observed effect is stronger at low $p_T$ ranges.]
Pseudorapidity distributions – beyond high-$p_T$s

Inclusive $\pi^0$ spectra in $dAu$ vs. $\eta$ at fixed $p_T = 6.25$ GeV/c

- The observed effect is stronger at low $p_T$ ranges
- It is weakening as going beyond higher $x$ values due to shadowing functions
Pseudorapidity distributions – beyond high-$p_T$s

Inclusive $\pi^0$ spectra in $dAu$ vs. $\eta$ at fixed $p_T = 13.0$ GeV/c

- The observed effect is stronger at low $p_T$ ranges
- It is weakening as going beyond higher $x$ values due to shadowing functions
  $\Rightarrow$ Parallel we are leaving from the Cronin region

...at much larger $x$ values EMC effect may be seen?
Rapidity Asymmetry Ratio – in \( pBe \) at FNAL

\[
\begin{align*}
Y_{\text{Asym}} & = \frac{N_{\text{forward}} - N_{\text{backward}}}{N_{\text{forward}} + N_{\text{backward}}} \\
\text{where } N_{\text{forward}} & = \text{number of particles in forward direction} \\
\text{and } N_{\text{backward}} & = \text{number of particles in backward direction}
\end{align*}
\]

\[
\langle k_T^2 \rangle = 1.36, \quad 1.0 < |\eta| < 1.5
\]
Rapidity Asymmetry Ratio – in $dAu$ at RHIC

\[ Y_{\text{Asym}} \]

\[ p_T \ [\text{GeV/c}] \]

- $|\eta| < 0.5$
- $0.5 < |\eta| < 1.0$
- $1.0 < |\eta| < 1.2$
- $1.2 < |\eta| < 1.9$
- $1.9 < |\eta| < 2.35$
- $2.35 < |\eta| < 2.9$
- $2.9 < |\eta| < 3.5$
- $3.5 < |\eta| < 3.7$
- $3.7 < |\eta| < 4.3$

STAR data
EKS + $k_T$
HIJING + $k_T$
HIJING + $k_T + m_s$

$<k_T^2> = 2.5$
Rapidity Asymmetry Ratio – in $dPb$ at LHC

$10^0$ $10^1$ $10^2$ $10^3$

$p_T$ [GeV/c]

$Y_{Asym}$

$0.0 < |\eta| < 0.9$

$2.4 < |\eta| < 4.0$

<em><k_T^2> = 10.1</em>
SUMMARY

We have better and better experimental data – Thank You!

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Note: don’t bury the multiple scattering it is still living!