High-$p_T$ probes of the partonic structure of heavy nuclei

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New Talent Session
52nd International School of Subnuclear Physics
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Parton densities in nuclei

\[ R = f_{i/A}(x, Q^2) / A \times f_{i/p}(x, Q^2) \]

- Naively, \( f_{i/A}(x, Q^2) = A \times f_{i/p}(x, Q^2) \)
  - but the history of nuclear DIS experiments have shown that parton distributions functions are modified in nuclei
  - nPDFs are far less constrained that proton PDFs
- **Goal:** broad measurement of nPDFs as a function of \( x_A \) and \( Q^2 \)
null hypothesis: $p+A$ collisions behave like an incoherent superposition of a geometrically equivalent number of $pp$ collisions

$$R = \frac{(1/N_{\text{evt}}) \frac{d^2N}{d\rho_Tdy}}{<T_{pA}> \frac{d^2\sigma}{d\rho_Tdy}}$$

Major experimental challenge: dealing with the presence of the correlated nuclear background

double differential jet yield

$pp$ jet cross-section

$nuclear thickness function$

Nucleonic luminosity seen by the proton,

$$<T_{pA}> = \# \text{ colliding nucleons} / \text{NN cross-section}$$

In the absence of nuclear effects, $R = 1$
Experimental selection of geometry

Geometry is inferred through measurements of soft particle production in the downstream A direction

"central" \( p+A \) collisions
- small \( b \)
- many struck nucleons
- large multiplicity

"peripheral" \( p+A \) collisions
- large \( b \)
- few struck nucleons
- small multiplicity

Glauber MC + models of particle production allow us to estimate \( \langle T_{pA} \rangle \) (and thus measure \( R \)) separately for central and peripheral events
Recent $p(d)+A$ data

$d+Au$ collisions, 2008
$\sqrt{s_{NN}} = 200$ GeV

$\sqrt{s_{NN}} = 5.02$ TeV

$p+Pb$ collisions, 2013

PHENIX Experiment @ Relativistic Heavy Ion Collider

ATLAS Experiment @ Large Hadron Collider
Dijet event in $p$+Pb collision at 5.02 TeV, January 2013 @ the LHC
\( d+Au \) collisions @ RHIC

- \( R \) for geometry-selected \( d+Au \) collisions
- \( \approx 1 \), as expected, in early 2003 measurements
$d+Au$ collisions @ RHIC

- $R$ for geometry-selected $d+Au$ collisions
  - $\approx 1$, as expected, in early 2003 measurements
- Surprising effects at higher $p_T$ ($x_{Au} > 0.1$)
  - $R < 1$ for central, $> 1$ for peripheral collisions
- large changes in the density of partons available for hard-scattering?
$p+$Pb collisions

@ LHC

- $b$-averaged $p+$Pb collisions
- over 5 units of rapidity
- $R \approx 1$
- (or only slightly higher from expected nPDF effects, which are small at high $Q^2$)
$p$+$Pb$ collisions
@ LHC

- geometry-selected $p$+$Pb$ collisions

- large deviations from the geometric expectation!

- $R \gg 1$ in **peripheral** events

- $R \ll 1$ in **central** events

- detailed pattern of modification vs. $p_T$, $y^*$, geometry selection, etc.

Large, $b$-dependent changes in nuclear pdf?
Patterns in the kinematic dependence

- Ratio between central and peripheral events

Simple kinematic dependence on the total jet energy \( p \) over many units of rapidity
- in the downstream proton direction, \( p \) mostly reflects \( \approx x_p (\sqrt{s}/2) \)
- The modifications are related to the proton initial state(!?)

\[ \int L dt = 27.8 \text{ nb}^{-1} \]
\[ p + \text{Pb} \sqrt{s}_{\text{NN}} = 5.02 \text{ TeV} \]
\[ \text{anti-}k_t, R=0.4 \]
Proton interaction strength fluctuations

One idea: interaction strength of the proton changes event to event

• in a way that depends on $x_p$ (hep-ph/1402.2868)
• within Glauber, this is like changing the (effective) transverse size of the proton wavefunction
  • nucleus is a filter on the proton size, “mimicking” a geometric signal

Irony: we make these measurements to learn something about the nuclear wavefunction

⇒ we may be learning something about the proton instead…
Conclusion

• Measurements of high-$p_T$ jet production in $p/d+A$ collisions
  • widest kinematic range yet for ($b$-averaged) nPDF’s
  • may be giving us unexpected insight into the nature of the proton wavefunction at high $x$

• More information:
  • $p+$Pb jet production: ATLAS-CONF-2014-024
  • $p+$Pb geometry categorization: ATLAS-CONF-2013-096
  • $d+$Au jet production: Nucl. Phys. A904-905 (2013) 1003c-1006c
    • ☆ RHIC/AGS Thesis Award, 2014
  • Thank you to the organizers and Professor M.J. Tannenbaum
Geometric models of $p+A$ collisions

- MC simulations of the Glauber model
- non-relativistic, semi-classical model
- nuclei are built out of nucleons by sampling the underlying charge distribution
- all nucleons proceed on a straight-line path
- a proton and nucleon collide if $r_{pN} < (\sqrt{\sigma_{NN}})/\pi$