Charged Particle Nuclear Modification Factors in pPb, PbPb, and XeXe Collisions with CMS

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Introduction

- Charged particle $R_{AA}$ is a well-studied observable
- Sensitive to many effects:
  - nPDF effects
  - Cronin effect
  - Hydrodynamic flow
  - Parton energy loss
- Strong suppression indicates presence of hot medium
- Detailed understanding of particle spectra helps constrain models of the QGP
- Also useful as reference for flavor-dependent studies

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_Td\eta}{T_{AA}d^2\sigma^{NN}/dp_Td\eta}$$
5.02 TeV PbPb $R_{AA}$ and $R_{pPb}$

- Measured $R_{AA}$ up to 300 GeV with 5.02 TeV PbPb data
- Strong suppression similar to 2.76 TeV PbPb
  - Rising trend between 10 to 100 GeV

- $R_{pPb}$ updated with measured pp reference
- Shadowing effects significant at $p_T<2$ GeV
- Slight enhancement seen at higher-$p_T$
  - Radial flow ($\sim$3 GeV)
  - Cronin effect ($\sim$3 GeV)
  - Anti-shadowing ($>30$ GeV)
- Initial-state effects not responsible for suppression seen in $R_{AA}$ above $\sim$3 GeV
XeXe Collisions at 5.44 TeV

- CMS gathered 19M (3.42 μb⁻¹) of \(^{129}\)Xe collisions in fall 2017
- Unique opportunity to study a mid-sized collision system at LHC
- Tests strength of suppression signal vs system size
- Probes path-length dependence of parton energy loss
5.44 TeV pp reference

- No pp data at 5.44 TeV exists
- MC-based extrapolation of 5.02 TeV spectrum

- Extrapolation factor from 3-18%

- Cross-checked with:
  - EPOS LHC
  - Herwig++
  - Extrapolation from 7 TeV pp
  - 'relative placement' procedures
  - $x_T$ scaling procedures

- All methods found to be consistent within a few %
XeXe spectra

- XeXe spectra in 6 centrality bins
  - $p_T=0.5$ to 100 GeV

- Similar power-law behavior as pp reference ($p_T>10$ GeV)

- Largest uncertainties at low-$p_T$ in central events from tracking

- Peripheral XeXe has large normalization uncertainty

- Event selection efficiency

- pp reference uncertainty dominated by 5 TeV measurement
$R^*_{AA}$ – central events

- $R^*_{AA}$ – asterisk denotes use of extrapolated reference
- $\text{XeXe } R^*_{AA}$ compared with $\text{PbPb } R_{AA}$
- Strong suppression in $\text{XeXe}$
- Similar oscillatory shape as $\text{PbPb}$
- $\text{XeXe}$ and $\text{PbPb}$ agree well for $p_T < 3$ GeV
- Indication of less suppression at higher $p_T$
$R^{*}_{AA}$ – peripheral events

- XeXe $R^{*}_{AA}$ increases in more peripheral events until last centrality bin
- Flat trend in 70-80% XeXe
  - Larger suppression than 70-90% PbPb events
  - 30% normalization uncertainty ($T_{AA}$ + event selection efficiency)
- Strong quenching not expected in peripheral events
  - Could also be affected by $p_T$-dependent event selection biases

CMS-PAS-HIN-18-004

27.4 pb$^{-1}$ (5.02 TeV pp) + 3.42 µb$^{-1}$ (5.44 TeV XeXe)
Event Selection Bias

- Charged particle yields compared using $N_{\text{coll}}$ vs forward $E_T$ selection
- Depletion of particles for low $N_{\text{coll}}$ events
Event Selection Bias

- Charged particle yields compared using $N_{\text{coll}}$ vs forward $E_T$ selection
- Depletion of particles for low $N_{\text{coll}}$ events
- Leads to $p_T$-dependent event selection bias
  - Magnitude is highly model dependent
  - HYDJET predicts up to 50% suppression
  - AMPT with string melting: only 20%
• Linear Boltzmann Transport Model
  • $\mathrm{CLV_{isc}}$ hydro medium expansion
  • Quadratic energy loss in static QGP
• Djordjevic Model
  • Bjorken expansion of medium
• CUJET3.1
  • CIBJET modeling of flow harmonics
• Andrés et al.
  • 'quenching weights' formalism
• SCET$_G$
  • Medium evolution with IEBE hydro
  • Energy loss scales as roughly $N_{\text{part}}^{2/3}$

• Models predict $R_{AA}$ reasonably
• Similar agreement in 30-50%
$R_{\text{Pb}}^{\text{Xe}}$ – Ratio without reference

- $R_{\text{Pb}}^{\text{Xe}}$: XeXe and PbPb spectra ratio without pp reference
- No correlated pp reference uncertainty
- Compare to expectation from difference in center of mass energies
- 5.44/5.02 TeV PYTHIA (same as reference extrapolation factor)
- Rising structure around 6-10 GeV – interplay between flow and energy loss
- 50-70% compatible with center of mass energy difference

**CMS-PAS-HIN-18-004**

404 µb⁻¹ (5.02 TeV PbPb) + 3.42 µb⁻¹ (5.44 TeV XeXe)
$R_{AA}$ vs $N_{\text{part}}$

CMS-PAS-HIN-18-004

- XeXe and PbPb $R_{AA}$ follow similar trends when comparing vs. $<N_{\text{part}}>$
\( R_{AA} \) vs \( N_{\text{part}} \)

- XeXe and PbPb \( R_{AA} \) follow similar trends when comparing vs. \( \langle N_{\text{part}} \rangle \)
\( R_{AA} \) vs \( N_{\text{part}} \)

- XeXe and PbPb \( R_{AA} \) follow similar trends when comparing vs. \( <N_{\text{part}} > \)
- \( R^{Xe}_{Pb} \): comparison of XeXe and PbPb spectra for similar \( <N_{\text{part}} > \)
- XeXe more suppressed around 6 GeV than expected from energy difference

CMS-PAS-HIN-18-004
Summary

- Observe strong suppression of $R_{AA}$ in central PbPb and XeXe collisions.
- Peripheral $R_{AA}$ suppression could be from event selection biases.
- See high-$p_T$ differences comparing XeXe and PbPb events at same centrality.
- Behavior is different when comparing similar $<N_{part}>$ instead of centrality.
- Constrains path-length dependence of energy loss models.

CMS-PAS-HIN-18-004

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CMS 5.44 TeV XeXe
LBT
Djordjevic
CUJET3.1/CIBJET
Andrés et al.
SCET$_G$

Preliminary

Normalization uncertainty $|\eta| < 1$

$0$-$10\%$

Theory/Data

Total data uncertainty

NEW RESULT
QM18

The MIT group's work was supported by US DoE-NP.
Backup
$R^{Xe}_{Pb}$ – Ratio without reference

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- Compare to expectation from difference in center of mass energies
- 5.44/5.02 TeV PYTHIA (same as reference extrapolation factor)
- Rising structure around 6-10 GeV – interplay between flow and energy loss
Theory Comparisons - 30-50%

- **Linear Boltzmann Transport Model**
  - CLV\textsubscript{isc} hydro medium expansion
  - Quadratic energy loss in static QGP
- **Djordjevic Model**
  - Bjorken expansion of medium
  - CUJET3.1
  - CIBJET modeling of flow harmonics
- Models predict $R_{AA}$ reasonably
Event Selection Bias - AMPT

- Similar study performed in AMPT with string melting
- Smaller bias observed than in HYDJET
- Depends on modeling of forward energies and high-$p_T$ yields in barrel
Comparisons at similar $N_{\text{part}}$

- 5-10% XeXe: $N_{\text{part}} = 207$
- 10-30% PbPb: $N_{\text{part}} = 227$
- Peripheral events: $N_{\text{part}}$ compatible within uncertainties

$$R_{\text{Pb}}^{\text{Xe}}(p_T) = \frac{dN_{\text{XeXe}}^{\text{Xe}}/dp_T}{dN_{\text{PbPb}}^{\text{Pb}}/dp_T} \frac{T_{\text{PbPb}}}{T_{\text{XeXe}}}.$$
- Two systems agree at low-$p_T$
- XeXe slightly higher starting around $\sim 6$ GeV
$R_{AA}$ vs $N_{\text{part}}$ – Higher $p_T$

- Agreement between PbPb and XeXe $R_{AA}$ also observed at higher $p_T$
XeXe Tracking Efficiency

CMS

Simulation Preliminary

|\eta| < 1
PYTHIA 8 + HYDJET

CMS-PAS-HIN-18-004
Input 5.02 TeV Spectra

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