Measurement of initial stages via color neutral probes in pPb and PbPb

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Drell-Yan in 8.16 TeV pPb
HIN-18-003

Z in 5 TeV PbPb
HIN-19-003
$Z/\gamma^*$ in Heavy Ions

- $Z/\gamma^*$ lifetime is $\sim$ the QGP formation time in HI collisions
- Should not be modified by QGP - cleanly probe initial state
- Previous yield and $v_2$ measurements support this
- Limited precision in peripheral events
- Sensitive to valence and sea quark distributions - tests nPDFs
- pPb data used in nPDF fits currently limited to $Z$ mass region

![Graphs and data from JHEP 03 (2015) 022 and PRL 110, 022301 (2013)]
Search for onset of jet quenching

- Studies of high $p_T$ charged hadrons have indicated a suppression in peripheral events
- Problem for jet quenching interpretation in peripheral events
- Recently HG-PYTHIA proposes a mechanism for non-medium suppression in charged hadrons
- Geometric biases on initial nucleon-nucleon impact parameter
- Centrality selection biases - hard/soft correlations
- ATLAS data seems to indicate opposite trend for $Z$, $W$ bosons
- Precise peripheral yield measurements needed
Testing nPDFs with Drell-Yan in 8.16 TeV pPb
HIN-18-003
- 2016 8.16 TeV pPb (173 nb⁻¹)
- $Z \rightarrow \mu^+\mu^-$ Channel
- $10 < m_{\mu\mu} < 600$ GeV
- Able to probe to lower x region!
- $t\bar{t}$, Electroweak, QCD backgrounds subtracted
- Large signal/background ratio
- Data overshoots Powheg at low $m_{\mu\mu}$
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Rapidity Distributions

- Rapidity differential cross section measured for low and Z mass
- Compared to CT14 pdf and CT14+EPPS16 nPDF
- Favors nPDF around Z mass ($\chi^2/\text{ndof} = 1.45$ vs 2.13); low mass inconclusive
Rapidity Distributions

- Uncertainties are comparable to nPDF uncertainties
- Full correlation matrix available
- Allows correct treatment of correlated uncertainties in global fits
p_T Distributions

- Differential cross sections
- Difficult to distinguish between different (n)PDFs
- Powheg undershoots data at low p_T, m_{\mu\mu} - better modeling needed in this region
Forward-Backward Ratios

15 < $m_{\mu\mu}$ < 60 GeV

60 < $m_{\mu\mu}$ < 120 GeV

• Ratio of forward-backward yields cancels systematic uncertainties
• Clear preference for CT14+EPPS16 around Z mass
• Uncertainties significantly smaller than existing nPDF uncertainties
Probing the initial state with Z bosons in 5 TeV PbPb
HIN-19-003
Mass Peaks

- 2018 5 TeV PbPb (1.7 nb⁻¹)
- $|\eta_\mu| < 2.4$, $|\eta_e| < 2.1$, $p_T^l > 20$ GeV

- Large signal/background ratio
  
  ![Graph showing mass peaks for muons and electrons](image)

  - Data (0-100%)
  - MC
  - Same sign (QCD)
  - EM background
  - $Z/\gamma^*\rightarrow\tau^+\tau^-$
  - $W^\pm + X$
  - $t\bar{t}$
• $v_2$ measured with 3-subevent method (forward calorimeters and tracker)

• $\eta$-gap of >3 units (suppresses non-flow)

• Both channels combined into 1 measurement

• Consistent with Z bosons being created early and not being modified by medium

\[ v_2 = \frac{\langle Q_Z Q_A^* \rangle}{\sqrt{\langle Q_A Q_B^* \rangle \langle Q_A Q_C^* \rangle}}. \]
Rapidity compared to models

- Differential cross section compared to MadGraph5_aMC@NLO + 3 (n)PDF sets
- Models scaled by $T_{AA} \sigma_{PbPb}^{MB}$
- Data slightly favors steeper decrease in forward region
- Can’t conclusively distinguish between (n)PDF sets with current precision
• Similar comparison made for $p_T$ differential cross section
• Deviation between models observed at $p_T > 40$ GeV
• $p_T$ modeling of aMC@NLO is not perfect - difficult to extract nPDF information
• Potentially a useful probe in the future?
Centrality Dependence

- \( \frac{N_Z}{N_{MBT_{AA}}} \) plotted versus centrality

- Numerator of \( R_{AA} \)
  - Consistent with \( \sigma_{NN}^{\text{Z}} \) from MC

- Data is flat in 0-40%
- Consistent with previous measurements of \( N_{\text{col}} \) scaling
Peripheral events

- 40-90% deviates from flat scaling at $\sigma_{Z}^{NN}$
- 2.8\(\sigma\) effect in 70-90%
- Effects considered in HG-PYTHIA
  - Initial geometry biases in NN impact parameter
  - Centrality selection biases
  - Hard process correlated with more soft production
- Uncertainties similar to Glauber uncertainties
- Advantageous to replace $T_{AA}$ with $\frac{N_{Z}}{\sigma_{Z}^{NN}N_{MB}}$: possible cancellation of biases
Conclusions

- New pPb Drell-Yan measurement extended to lower mass region to offer new nPDF constraints
- Shadowing in EPPS16 favored over free nucleon pdf
- PbPb Z boson $v_2$ consistent with zero and yields support $N_{\text{coll}}$ scaling in central events
- Downward trend seen in peripheral Z boson yields - seems to be described by HG-PYTHIA
- Z provides data-driven method to study bias effects when searching for onset of jet quenching

Drell-Yan in pPb
HIN-18-003

Z in PbPb
HIN-19-003
pPb $\phi^*$ Distributions

CMS Preliminary  

$pPb$ (173 nb$^{-1}$, 8.16 TeV)

\[ \frac{d\sigma}{d\phi} [\text{nb}] \]

- $2.87 < |y_{CM}| < 1.93$
- $15 < m_{\mu\mu} < 60$ GeV

\[ 15 < m_{\mu\mu} < 60 \text{ GeV} \]

\[ 60 < m_{\mu\mu} < 120 \text{ GeV} \]

\[ \phi^* \approx p_T / m_{\mu\mu} \]

\[ \phi^* \equiv \tan \left( \frac{\pi - \Delta\phi}{2} \right) \sin(\theta^*_\eta), \quad \cos(\theta^*_\eta) = \tanh(\Delta\eta/2), \]

- Only depends on angular variables - better resolution than $p_T$ measurement
3-subevent v$_2$ method

\[ Q_n = \sum_{k=0}^{M} \omega_k e^{i n \phi_k} \]

\[ v_2 = \frac{\langle Q_Z Q_A^* \rangle}{\sqrt{\langle Q_A Q_B \rangle \langle Q_A Q_C^* \rangle}} \]

HF
-5<\eta<-3

Tracker
|\eta|<0.75

HF
3<\eta<5

Subevt A

Subevt C

Subevt B

Z Candidate
Previous pPb result

34.6 nb$^{-1}$ (pPb 5.02 TeV)

CMS

pPb → Z → ll

$p_T > 20$ GeV/c, $|y_{lab}| < 2.4$

- Data
  - Yellow: MCFM + CT10
  - Green: MCFM + CT10 + EPS09
  - Red: MCFM + CT10 + DSSZ
  - Luminosity uncertainty: 3.5%

Ratio to CT10

$y_{cm}$

$R_{FB}(Y_{cm})$

34.6 nb$^{-1}$ (pPb 5.02 TeV)

CMS

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- Data
  - Yellow: MCFM + CT10
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Ratio to CT10

$|y_{cm}|$

$R_{FB}(|y_{cm}|)$
• Run HIJING to calculate $N_{\text{coll}}$ and $N_{\text{MPI}}$

• Superimpose $N_{\text{coll}}$ Pythia MB events that have the same number of MPIs
  • These events have no QGP physics

• Perform a centrality calibration

• Plot $R_{AA}$ by comparing to cross section from pp collisions

• Geometry biases - $<b_{NN}>$ can be biased for different $b_{PbPb}$

• Centrality selection bias - correlations in hard/soft production can cause migration of event with hard processes to higher centrality
  • Leads to depletion in peripheral events
• Choice of TGlauberMC version can affect peripheral results a bit
• CMS uses v3.2
  • Orange points should be used for a fair comparison with ATLAS
Comparison to ATLAS

- Scaled ATLAS RAA by \( \sigma_{NN}^Z \) to try to make a comparison
  - Note: could still be some difference in normalization

- Roughly estimated compatibility
  - CMS T_{AA} uncertainty ignored

- Central bins roughly consistent

- 40-50% centrality: \( \sim 1.8\sigma \) deviation

- ATLAS 50-60% vs. CMS 50-70%: <1\sigma

- ATLAS 60-80% vs.
  - CMS 50-70%: \( \sim 2\sigma \)
  - CMS 70-90%: \( \sim 2.7\sigma \)

- Correlations between centrality bins (and W/Z channels for ATLAS) are important when interpreting these data
  - For example: the leading syst. uncertainty in the CMS 70-90% bin is quite correlated w/ 50-70%