Wounded quark emission function at the top RHIC energy

Michał Barej

AGH University of Science and Technology, Kraków, Poland

in collaboration with Adam Bzdak and Paweł Gutowski

Phys. Rev. C 97, no. 3, 034901 (2018)
Outline

1. Wounded nucleon and wounded quark models
2. Wounded nucleon/quark emission functions
3. Predictions for $dN_{ch}/d\eta$ and comparison with PHENIX results
4. Future plans
5. Conclusions
Heavy ion collisions

- Wounded nucleon model (WNM)
  A. Białas, M. Bleszyński, W. Czyż, Nucl. Phys. B 111, 461 (1976)

- Wounded quark model (WQM)
  A. Białas, W. Czyż, W. Furmanski, Acta Phys. Polon. B 8, 585 (1977)

Figure: [http://cerncourier.com/cws/article/cern/53089](http://cerncourier.com/cws/article/cern/53089)
Centralit y definition

- Collision centrality defined by multiplicity of produced charged particles $N_{ch}$
- Asymmetric collisions
- Data d+Au at $\sqrt{s_{NN}} = 200$ GeV
  B. B. Back et al. [PHOBOS Collaboration], Phys. Rev. C 72, 031901 (2005)
PHOBOS data

- d+Au at $\sqrt{s_{NN}} = 200$ GeV (RHIC)

Figure: B. B. Back et al. [PHOBOS Collaboration], Phys. Rev. C 72, 031901 (2005)
Wounded nucleon/quark emission function

- In WNM, WQM:

\[
\frac{dN_{ch}}{d\eta} = w_L F(\eta) + w_R F(-\eta)
\]

- \( F(\eta) \) - **wounded source emission function**
  - \( w_L \) - mean number of wounded sources in left-going nucleus
  - \( w_R \) - same in right-going
  - A. Bialas and W. Czyz, Acta Phys. Polon. B 36, 905 (2005)

- If \( w_L \neq w_R \):

\[
F(\eta) = \frac{1}{2} \left[ \frac{N(\eta) + N(-\eta)}{w_L + w_R} + \frac{N(\eta) - N(-\eta)}{w_L - w_R} \right]
\]

- where \( N(\eta) := dN_{ch}/d\eta \)
Our approach

\[ F(\eta) = \frac{1}{2} \left[ \frac{N(\eta) + N(-\eta)}{w_L + w_R} + \frac{N(\eta) - N(-\eta)}{w_L - w_R} \right] \]

- \( N(\eta) = dN_{ch}/d\eta \) taken from PHOBOS data
- \( w_L, w_R \) (wounded nucleons or quarks) - obtained in MC Glauber simulation
- Extract \( F(\eta) \) for different centralities
- Compare WNM and WQM

For details see: MB, A. Bzdak and P. Gutowski, Phys. Rev. C 97, no. 3, 034901 (2018) [arXiv:1712.02618v2 [hep-ph]]
WNM: MC Glauber

- Draw impact parameter $b$
- Nucleons positions
  - Au: Woods-Saxon
  - $d$: Hulthen
- Check whether a pair of nucleons collided
  - $d \leq \sqrt{\sigma_{nn}/\pi}$
  - $\sigma_{nn} = 41$ mb for $\sqrt{s_{NN}} = 200$ GeV
- Charged particles production
  - For each wounded nucleon NBD with $\langle n \rangle = 5$ and $k = 1$
- Divide into centrality classes:
  - 0-20%, 20-40%, 40-60%, 60-80%, 80-100%
- Obtain mean $w_L$, $w_R$ for each centrality class
- $F(\eta) = \frac{1}{2} \left[ \frac{N(\eta) + N(-\eta)}{w_L + w_R} + \frac{N(\eta) - N(-\eta)}{w_L - w_R} \right]_I$
Similar to the WNM case with some differences:

- **Quarks positions**
  \[ \varrho(\vec{r}) = \varrho_0 \exp \left( - \frac{r}{a} \right) \]
  S. S. Adler et al. [PHENIX Collaboration], Phys. Rev. C 89, no. 4, 044905 (2014)

- **Check whether a pair of quarks collided**
  \[ d_q \leq \sqrt{\sigma_{qq}/\pi} \]
  \[ \sigma_{qq} = 7 \text{ mb for } \sqrt{s_{NN}} = 200 \text{ GeV} \]

- **Charged particles production**
  For each wounded quark NBD with \( \langle n \rangle = 5/1.3 \) and \( k = 1/1.3 \)

- **Wounded quark emission function**

\[ F(\eta) = \frac{1}{2} \left[ \frac{N(\eta) + N(-\eta)}{w_L + w_R} + \frac{N(\eta) - N(-\eta)}{w_L - w_R} \right] \]
The wounded nucleon emission functions

Figure: Phys. Rev. C 97, no. 3, 034901 (2018)
The wounded quark emission functions

Figure: Phys. Rev. C 97, no. 3, 034901 (2018)
In WNM shape of $F(\eta)$ differs for various centrality bins.
In WQM functions have universal shape

There are limits of this approach:

- $|\eta| \leq 3$
- $w_L \neq w_R$

Assuming $F_q(\eta)$ has an universal shape also for various colliding nuclei, we can predict measurable $dN_{ch}/d\eta$ for different collisions...

\[
\frac{dN_{ch}}{d\eta} = w_L F_q(\eta) + w_R F_q(-\eta)
\]
PHENIX request: d+Au

\[
\frac{dN_{ch}}{d\eta} = w_L F_q(\eta) + w_R F_q(-\eta)
\]

Figure: arXiv:1712.02618v2 [hep-ph]
PHENIX request: p+Au

Figure: arXiv:1712.02618v2 [hep-ph]
PHENIX request: $^3\text{He}+\text{Au}$

$^3\text{He}$ nucleons positions from:
J. Carlson, R. Schiavilla, Rev. Mod. Phys. 70, 743 (1998)

Figure: arXiv:1712.02618v2 [hep-ph]
PHENIX request: p+Al

Al - deformed nucleus:

$$\varrho(r, \theta, \varphi) = \varrho_0 \left[ 1 + \exp \left( \frac{(r - R(1 + \beta_2 Y_{20}(\theta) + \beta_4 Y_{40}(\theta)))}{a} \right) \right]^{-1}$$
Comparison with new PHENIX results

Good agreement with PHENIX data for central collisions for different systems!

Figure: D. McGlinchey — PHENIX $dN_{\text{ch}}/d\eta$ in small systems — Quark Matter 16 May 2018
Comparison with new PHENIX results

Good agreement with PHENIX data for all collision centralities for $p+Au!$

Figure: D. McGlinchey — PHENIX $dN_{ch}/d\eta$ in small systems — Quark Matter 16 May 2018
Comparison with new PHENIX results

Good agreement with PHENIX data for all centralities and for all small systems!

Figure: D. McGlinchey — PHENIX $dN_{ch}/d\eta$ in small systems — Quark Matter 16 May 2018
Limited $\eta$ range of application

Figure: Phys. Rev. C 97, no. 3, 034901 (2018)
Unwounded quarks in wounded nucleons

- Nucleon is wounded if at least one of its quarks is wounded
- If 1 quark is wounded, there are 2 more unwounded quarks remaining!

A. Białas, A. Bzdak, Phys. Lett. B 649, 263 (2007) Erratum: [Phys. Lett. B 773, 681 (2017)]
Conclusions

- Wounded quark emission function has an universal shape (within uncertainties)
- Wounded nucleon emission function looks worse
- Latest PHENIX results show that one common wounded quark emission function describes p+Al, p+Au, d+Au, \(^3\text{He}+\text{Au}\) collisions for different centralities reasonably well
- Plan for near future: take unwounded quarks into consideration - regions \(|\eta| > 3\) and study \(\text{Au}+\text{Au}, \text{Cu}+\text{Cu}\) collisions
$dN_{ch}/d\eta$ for d+Au from min-bias $F_q(\eta)$
Another test: $F_q(\eta) - F_q(-\eta)$

Figure: MB, A. Bzdak and P. Gutowski, Phys. Rev. C 97, no. 3, 034901 (2018)