Wounded quark emission function at the top RHIC energy

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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 (WMN)**

- **Wounded quark model (WQM)**

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

Collision centrality defined by multiplicity of produced charged particles $N_{ch}$

Asymmetric collisions

Data $d+Au$ at $\sqrt{s_{NN}} = 200$ GeV

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

- 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 \( N(\eta) := \frac{dN_{ch}}{d\eta} \)
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

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
- $F(\eta) = \frac{1}{2} \left[ \frac{N(\eta) + N(-\eta)}{w_L + w_R} + \frac{N(\eta) - N(-\eta)}{w_L - w_R} \right]$
Similar to the WNM case with some differences:

- **Quarks positions**
  \[ \varrho(\vec{r}) = \varrho_0 \exp \left( -\frac{r}{a} \right) \]

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

- **Charged particles production**
  - For each wounded quark NBD with \( \langle n \rangle = 5/1.3 \) and \( k = 1/1.3 \)
  \[ F(\eta) = \frac{1}{2} \left[ \frac{N(\eta)+N(-\eta)}{w_L+w_R} + \frac{N(\eta)-N(-\eta)}{w_L-w_R} \right] \]
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)
Observations

- 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: $^3$He+Au

$^3$He nucleons positions from:

Figure: arXiv:1712.02618v2 [hep-ph]
PHENIX request: $p+\text{Al}$

Al - deformed nucleus:

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

Figure: arXiv:1712.02618v2 [hep-ph]
Comparison with new PHENIX results

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

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 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

![Graph showing $F_q(\eta)$ as a function of $\eta$ for different centrality intervals. The graph includes a legend indicating the colors for min-bias, 0-20, 20-40, 40-60, and 60-80 centrality classes. The graph highlights the wounded quark model with data points and error bars. The figure is from 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!

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 $p+Al$, $p+Au$, $d+Au$, $^3He+Au$ collisions for different centralities reasonably well
- Plan for near future: take unwounded quarks into consideration - regions $|\eta| > 3$ and study $Au+Au$, $Cu+Cu$ collisions
$dN_{ch}/d\eta$ for d+Au from min-bias $F_q(\eta)$
Another test: \( F_q(\eta) - F_q(-\eta) \)

\[
\begin{align*}
F_q(\eta) - F_q(-\eta) \\
\text{min-bias} \\
0-20 \\
20-40 \\
40-60 \\
60-80
\end{align*}
\]

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