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 (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)

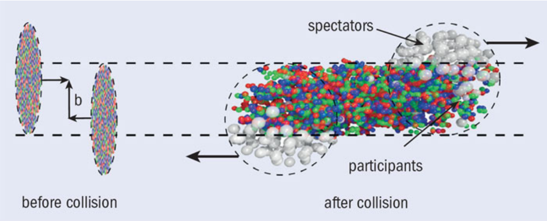


Figure: http://cerncourier.com/cws/article/cern/53089

Centrality definition

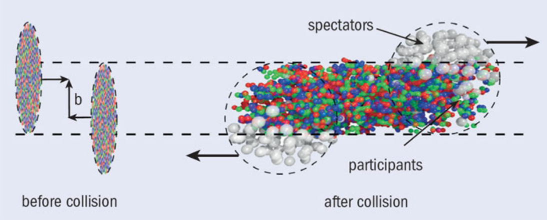


Figure: http://cerncourier.com/cws/article/cern/53089

- 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)

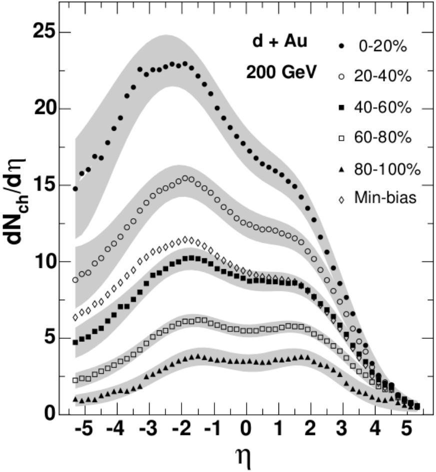


Figure: B. B. Back *et al.* [PHOBOS Collaboration], Phys. Rev. C **72**, 031901 (2005)

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

WQM: MC Glauber

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
  - $d_q \leq \sqrt{\sigma_{qq}/\pi}$
  - $\sigma_{qq} = 7$ mb for $\sqrt{s_{NN}} = 200$ 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

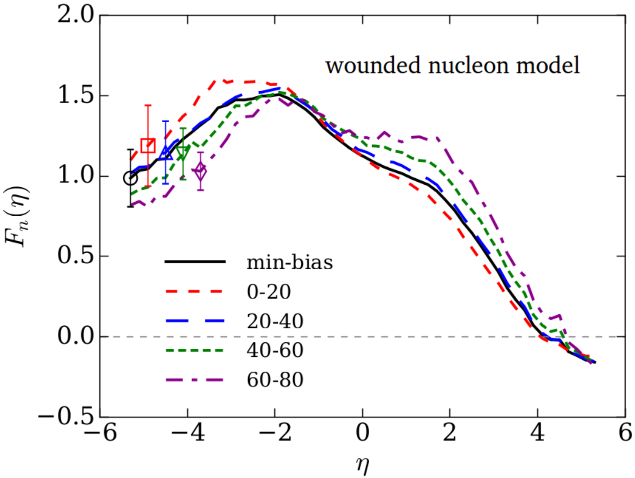


Figure: Phys. Rev. C **97**, no. 3, 034901 (2018)

The wounded quark emission functions

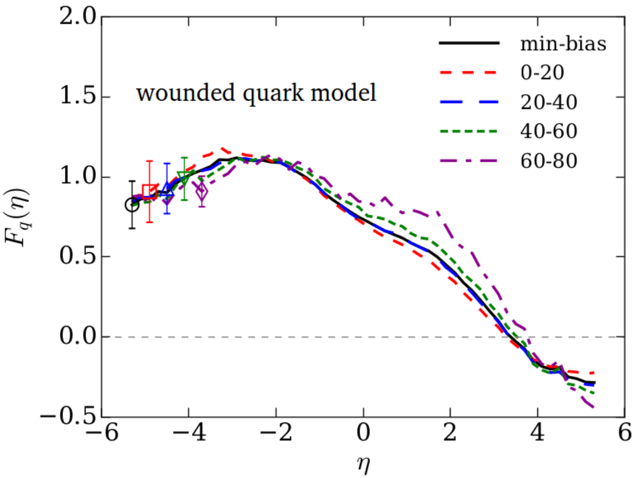


Figure: Phys. Rev. C **97**, no. 3, 034901 (2018)

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

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

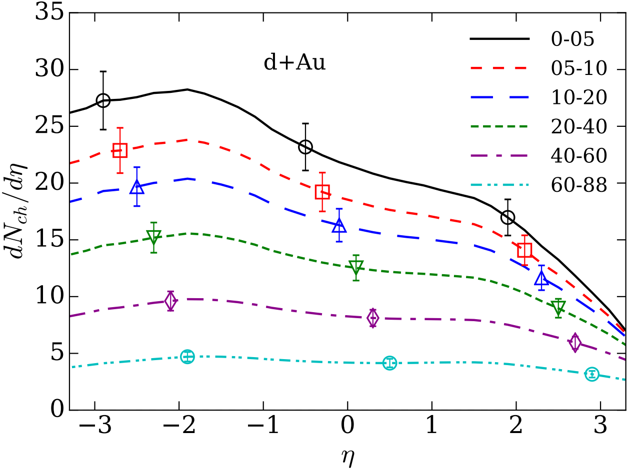


Figure: arXiv:1712.02618v2 [hep-ph]

PHENIX request: p+Au

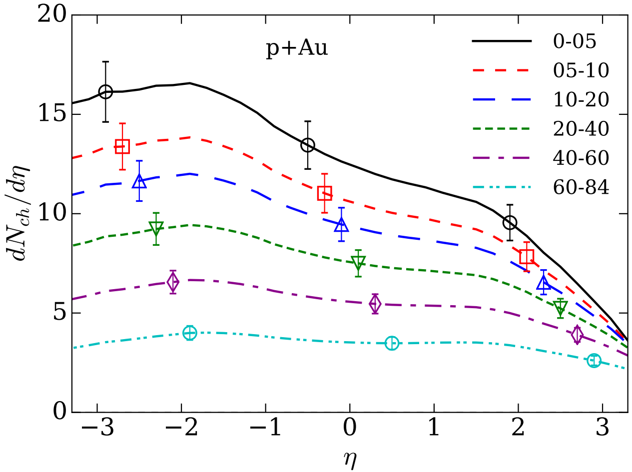


Figure: arXiv:1712.02618v2 [hep-ph]

PHENIX request: ^{3}He+Au

^{3}He nucleons positions from:

J. Carlson, R. Schiavilla, Rev. Mod. Phys. **70**, 743 (1998)

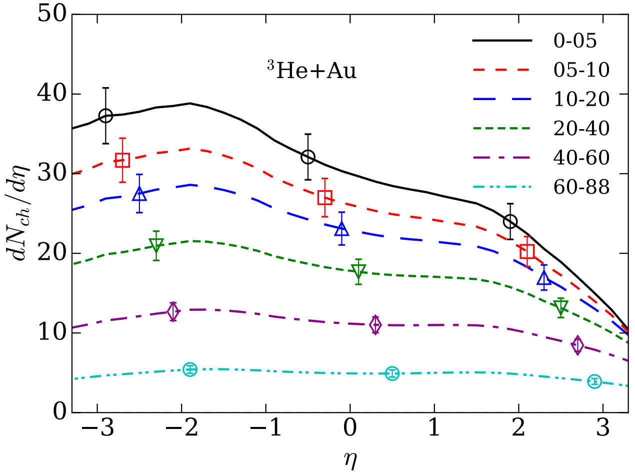


Figure: arXiv:1712.02618v2 [hep-ph]

PHENIX request: p+Al

Al - deformed nucleus:

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

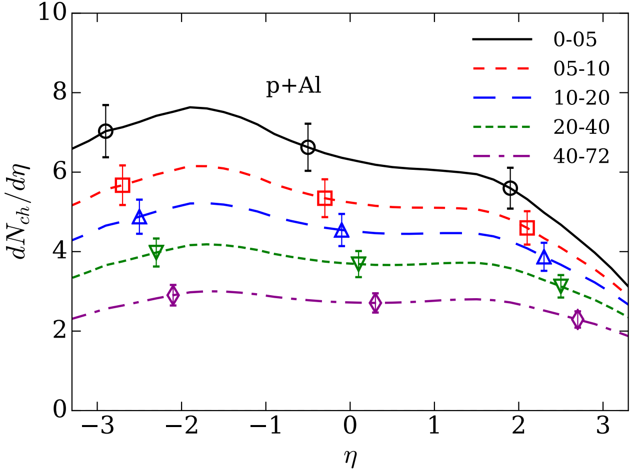


Figure: arXiv:1712.02618v2 [hep-ph]

Comparison with new PHENIX results

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

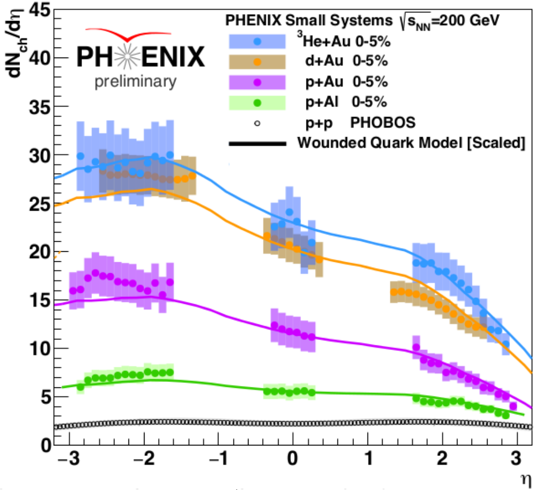


Figure: D. McGlinchey — PHENIX $dN_{ch}/d\eta$ in small systems — Quark Matter 16 May 2018

Comparison with new PHENIX results

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

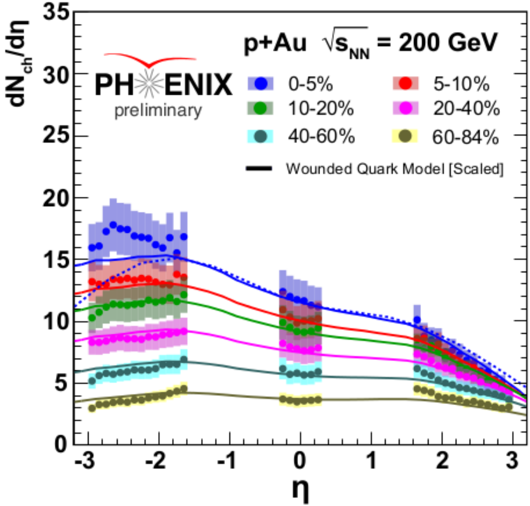


Figure: D. McGlinchey — PHENIX $dN_{ch}/d\eta$ in small systems — Quark Matter 16 May 2018

Comparison with new PHENIX results

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

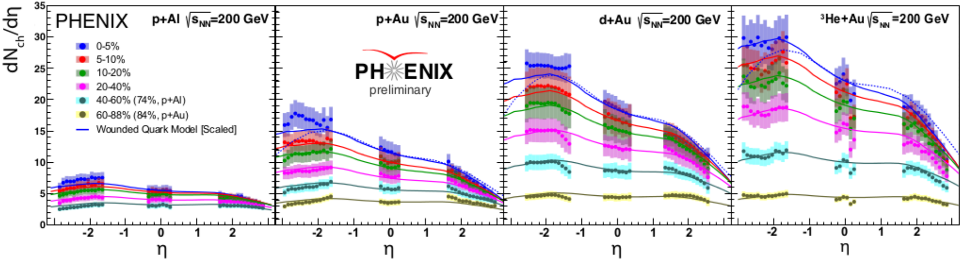


Figure: D. McGlinchey — PHENIX $dN_{ch}/d\eta$ in small systems — Quark Matter 16 May 2018

Limited η range of application

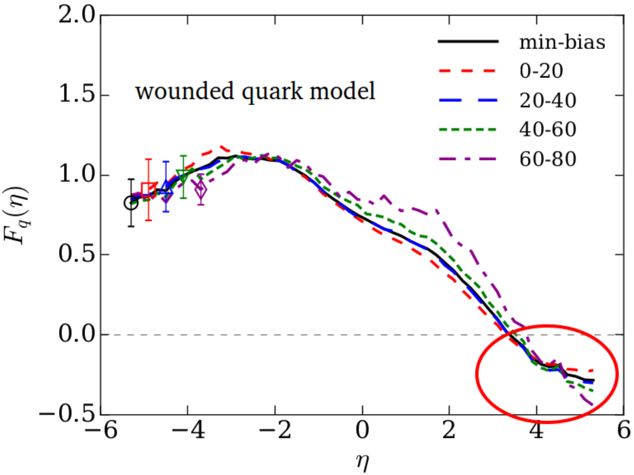
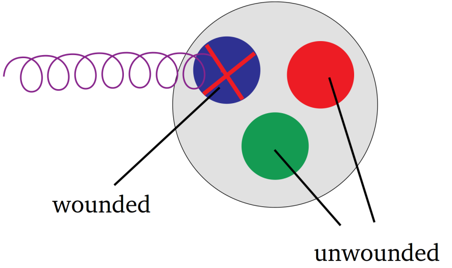


Figure: Phys. Rev. C **97**, no. 3, 034901 (2018)

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!

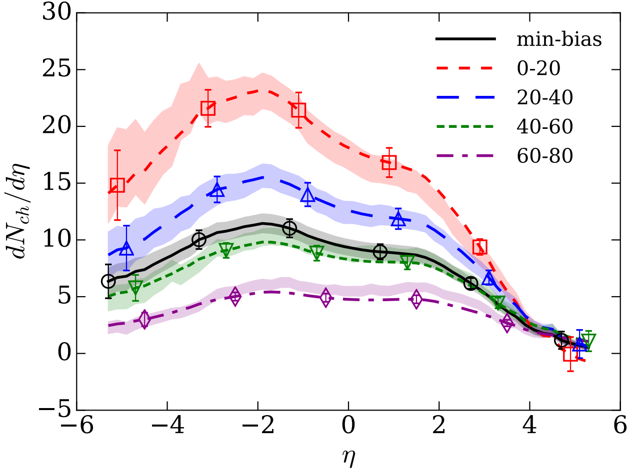


- A. Białas, A. Bzdak, Phys. Lett. B **649**, 263 (2007) Erratum: [Phys. Lett. B **773**, 681 (2017)]

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}He+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: $F_q(\eta) - F_q(-\eta)$

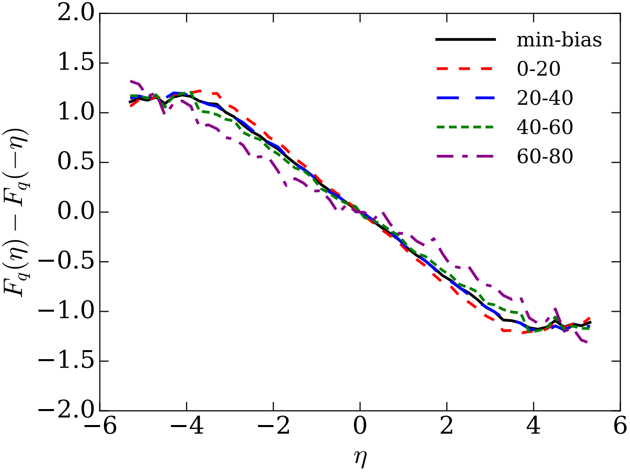


Figure: MB, A. Bzdak and P. Gutowski, Phys. Rev. C **97**, no. 3, 034901 (2018)