Dijets in heavy ion collisions and the rapidity dependence of the nuclear medium

Michal Deák

Institute of Nuclear Physics PAN, Kraków

In collaboration with Krzysztof Kutak, IFJ PAN and Konrad Tywoniuk, CERN

arXiv:1706.08434

Contents

- Motivation
  - High Energy Factorization (HEF)
- Multiple soft scattering
- HEF in heavy ion collisions
- Numerical results
- Conclusions and Outlook

High Energy Factorization (HEF)

- Hybrid HEF formula for Pb-Pb collision:

$$\frac{d\sigma_{acd}}{dy_1 dy_2 dp_{t1} dp_{t2} d\Delta\phi} = \frac{p_{t1} p_{t2}}{8\pi^2 (x_1 x_2 S)^2} \overline{|\mathcal{M}_{ag^* \to cd}|}^2 x_1 f_{a/A}^{Pb}(x_1, \mu^2)\, \mathcal{F}_{g/B}^{Pb}(x_2, k_t^2, \mu^2) \frac{1}{1 + \delta_{cd}}$$

- ! integrate over momentum fractions, initial state transversal momentum !
- Exact kinematics at leading order in α_s
  - Jets not necessarily back to back
- Transversal momentum dependent (TMD) nuclear parton density function (nPDF)

$$\mathcal{F}_{g/B}^{Pb}(x_2, k_t^2, \mu^2)$$

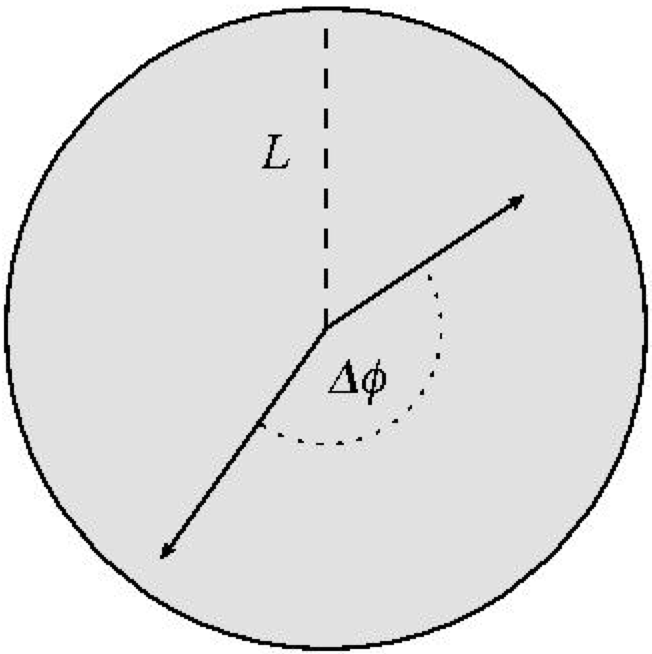
- Collinear nPDF

$$x_1 f_{a/A}^{Pb}(x_1, \mu^2)$$

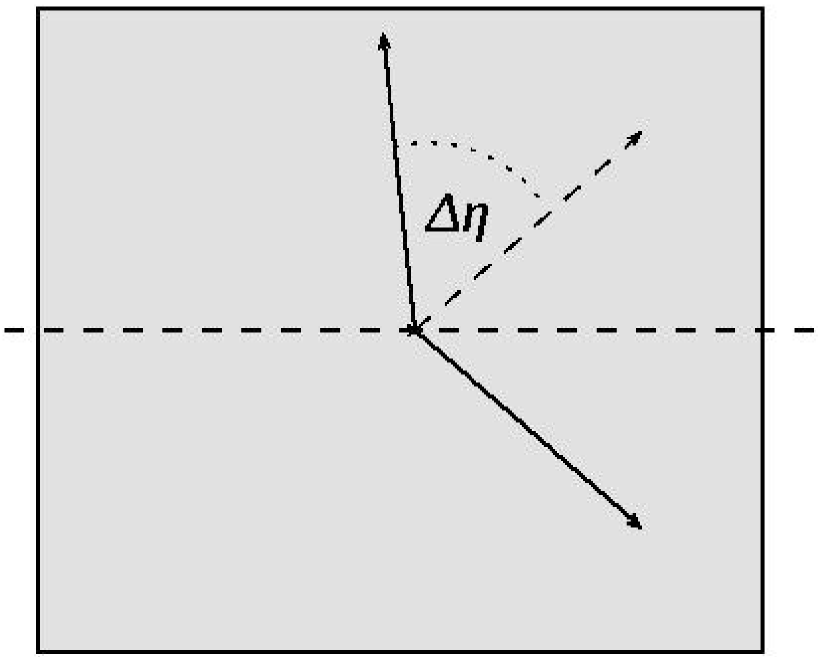
- Implemented in the Monte Carlo program **`KaTie`** (used in this analysis)

A. van Hameren, arXiv:1611.00680

Jets passing through the medium



Azimuthal cross section of the medium



Longitudinal cross section of the medium

- Kinematics:

$$k_t^2 = p_{t1}^2 + p_{t2}^2 + 2 p_{t1} p_{t2} \cos\Delta\phi, \text{ and}$$

$$x_1 = \frac{1}{\sqrt{S}} \left(p_{t1} e^{y_1} + p_{t2} e^{y_2} \right) , \qquad x_2 = \frac{1}{\sqrt{S}} \left(p_{t1} e^{-y_1} + p_{t2} e^{-y_2} \right)$$

Multiple Soft Scattering (MSS)

- Emission spectrum of medium induced bremsstrahlung in MSS:

$$\omega \frac{dI_R(\chi)}{d\omega} = \frac{\alpha_s C_R}{\omega^2} 2\mathrm{Re} \int^{\chi\omega} \frac{d^2\boldsymbol{q}}{(2\pi)^2} \int_0^\infty dt' \int_0^{t'} dt \int d^2\boldsymbol{z} \exp\left[-i\boldsymbol{q}\cdot\boldsymbol{z} - \frac{1}{2}\int_{t'}^\infty \mathrm{d}s\, n(s)\sigma(\boldsymbol{z})\right]$$
$$\times\, \partial_{\boldsymbol{z}} \cdot \partial_{\mathbf{y}} \left[\mathcal{K}(\boldsymbol{z}, t'; \mathbf{y}, t|\omega) - \mathcal{K}_0(\boldsymbol{z}, t'; \mathbf{y}, t|\omega)\right]_{\mathbf{y}=0},$$

with

$$\mathcal{K}(\boldsymbol{z}, t'; \mathbf{y}, t|\omega) = \int_{\boldsymbol{r}(t)=\mathbf{y}}^{\boldsymbol{r}(t')=\boldsymbol{z}} \mathcal{D}\boldsymbol{r}\, \exp\left\{\int_t^{t'} \mathrm{d}s \left[i\frac{\omega}{2}\dot{\boldsymbol{r}}^2 - \frac{1}{2}n(s)\sigma(\boldsymbol{r})\right]\right\}$$

- Describes propagation of a quark through nuclear medium
- Gluon emission spectrum in MSS:

$$P_R(\epsilon) = \Delta(L) \sum_{n=0}^{\infty} \frac{1}{n!} \prod_{i=1}^{n} \int_0^L \mathrm{d}t \int \mathrm{d}\omega_i \frac{\mathrm{d}I_R(\chi)}{\mathrm{d}\omega_i \mathrm{d}t}\, \delta\left(\epsilon - \sum_{i=1}^{n}\omega_i\right)$$

- Probability resulting from resummation of in medium emissions
- "Drag" in the longitudinal direction – transversal momentum "kicks" neglected

$$n(s)\sigma(\boldsymbol{r}) \approx \hat{q}(s)\boldsymbol{r}^2/2$$

harmonic oscillator approximation

$$\hat{q} \sim g^4 T^3$$

transport coefficient

C. Salgado, U. Wiedemann, Phys.Rev. D68 (2003) 014008

HEF in Heavy Ion Collisions

- Cross section formula with medium effects included:

$$\frac{\mathrm{d}\sigma}{dy_1 dy_2 dp_{t1} dp_{t2} d\Delta\phi} = \sum_{a,c,d} \int_0^\infty d\epsilon_1 \int_0^\infty d\epsilon_2 \, P_a(\epsilon_1) P_g(\epsilon_2) \; \frac{d\sigma_{acd}}{dy_1 \mathrm{d}y_2 dp'_{t1} dp'_{t2} d\Delta\phi}\Bigg|_{\substack{p'_{1t}=p_{1t}+\epsilon_1 \\ p'_{2t}=p_{2t}+\epsilon_2}}$$

$$P\left(\xi, r\right) = C_1 \, \delta\left(\xi\right) + C_2 \, D\left(\xi, r\right)$$

$$\xi = \epsilon/\omega_c \text{ with } \omega_c = \hat{q}L^2/2$$

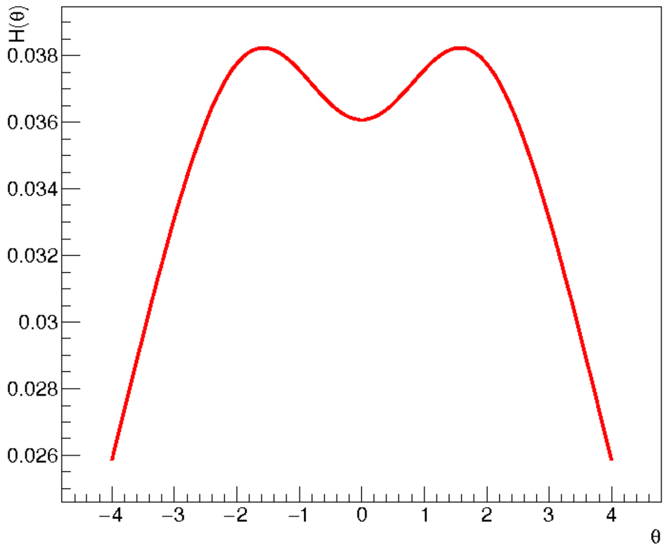
$$r = \hat{q}L^3/2$$

- Probability density has 2 components:
  - discrete – no-suppression ↔ coefficient C_1
  - continuous ↔ coefficient C_2

- Algorithm:
  1. generate random $0 < r < 1$
     if $r < C_1$ no suppression occurs $\xi = 0$; go to next event
     else
  2. generate ξ according to $D(\xi,r)$; go to next event

Model of rapidity dependence and other parameters

- A model of the rapidity dependence of the nuclear medium:



T. Renk, J. Ruppert, C. Nonaka, S. A. Bass, Phys. Rev. C75 (2007) 031902

$$\hat{q} = 2\,K\,\varepsilon^{3/4}$$

$$\varepsilon = \varepsilon_{\mathrm{tot}} W\left(\mathbf{x},\mathbf{y};\mathbf{b}\right)\ H\left(\eta\right)$$

- We neglect the dependence on in impact parameter → $W(\mathbf{x},\mathbf{y};\mathbf{b})=1$
- K=1 (not fitted)
- $\epsilon_{\mathrm{tot}} = 143\ \mathrm{GeV/fm^3}$ total energy density corresponding to $\hat{q}$ = 1 GeV/fm at mid rapidities (not fitted)
- $L = 5\ \mathrm{fm}$ constant

- A fit to ALICE (0 - 5% centrality) data:

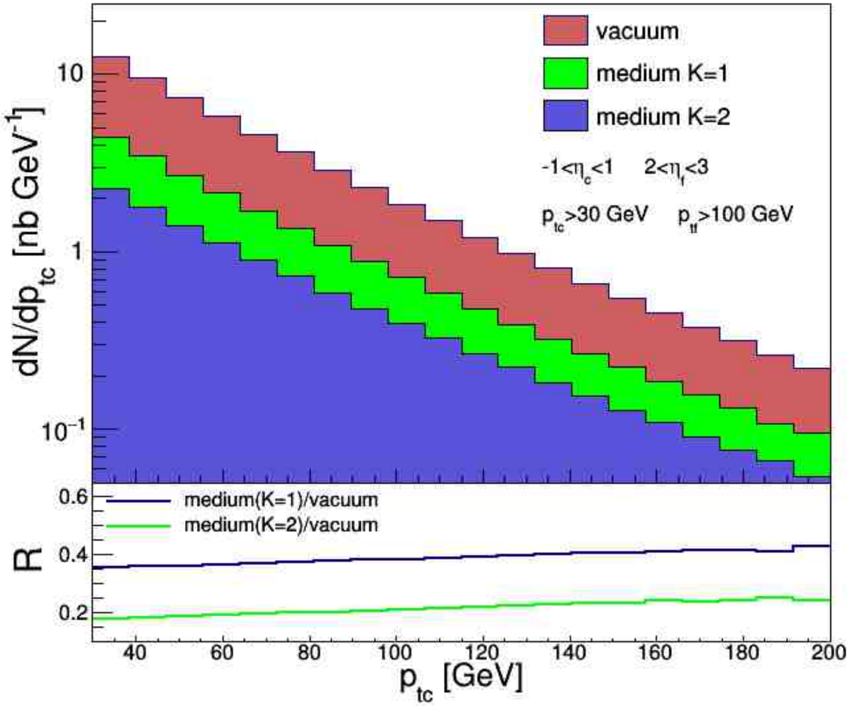
$$H\left(\eta\right) = \frac{1}{\sqrt{2\pi}\left(a_1\,b_1 - a_2\,b_2\right)}\left[a_1\,e^{-|\eta|^2/\left(2\,b_1^2\right)} - a_2\,e^{-|\eta|^2/\left(2\,b_2^2\right)}\right]$$

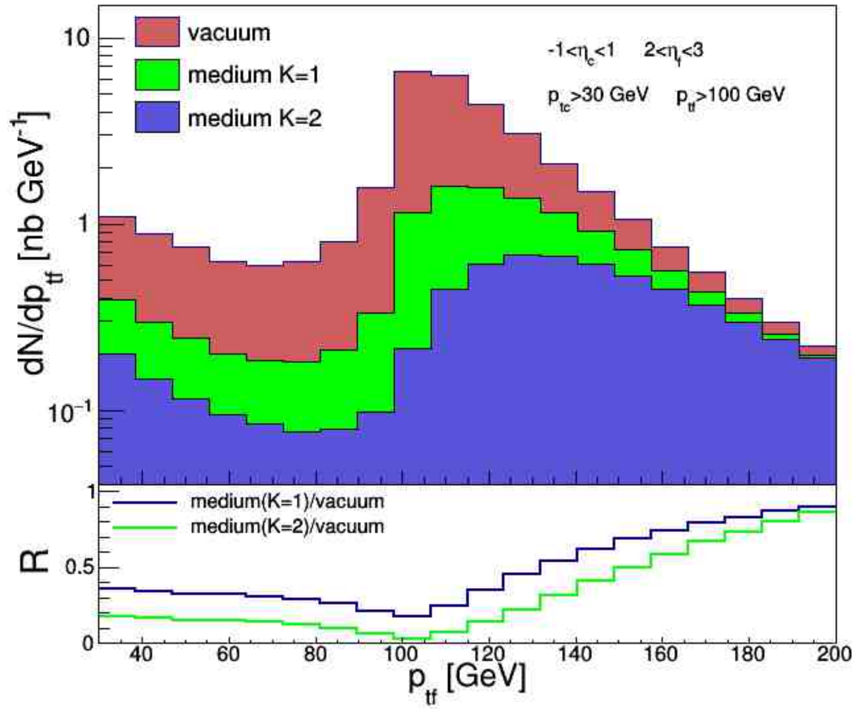
$$a_1 = 2108.05,\ b_1 = 3.66935,\ a_2 = 486.368,\ b_2 = 1.19377$$

Transversal momenta of jets

$p_{tc} > 100 \text{ GeV}$ $\quad$ $p_{tf} > 30 \text{ GeV}$

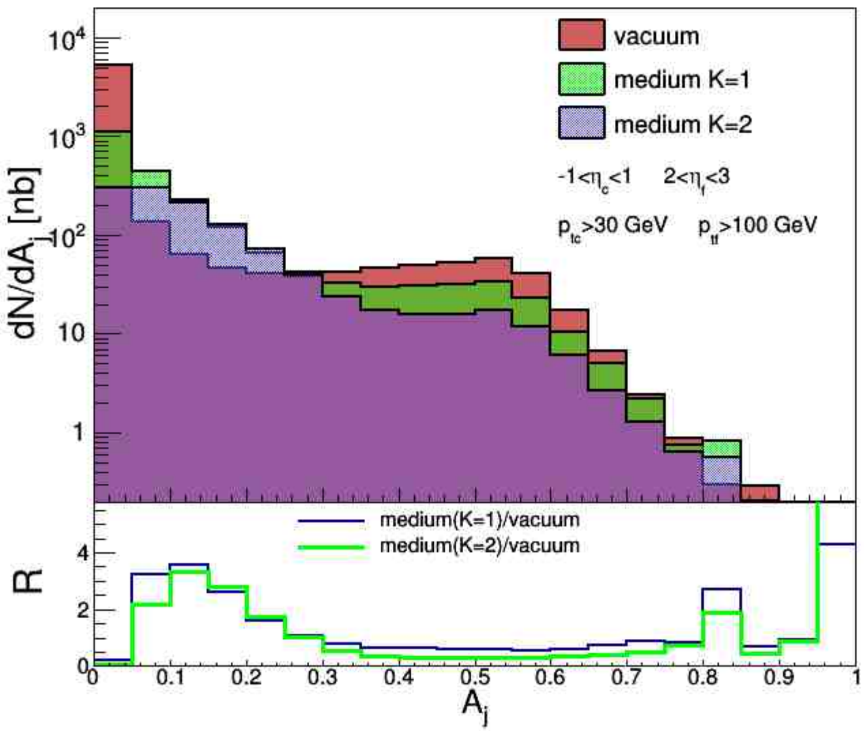
$-1 < \eta_c < 1$ $\quad$ $2 < \eta_f < 3$





- back-to-back peak in the plot on the right

Relative transversal momentum difference



$$A_j = \left(p_{t\,c} - p_{t\,f}\right) / \left(p_{t\,c} + p_{t\,f}\right)$$

$$p_{t\,c} > 100 \ \text{GeV} \qquad p_{t\,f} > 30 \ \text{GeV}$$

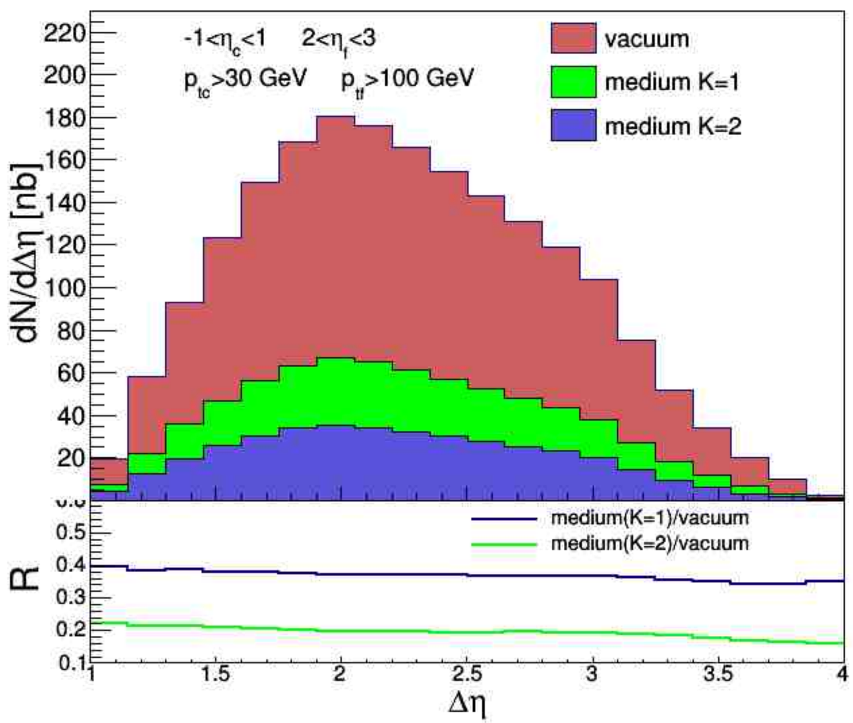
$$-1 < \eta_c < 1 \qquad 2\, p_{t\,c} > 100 \ \text{GeV}$$

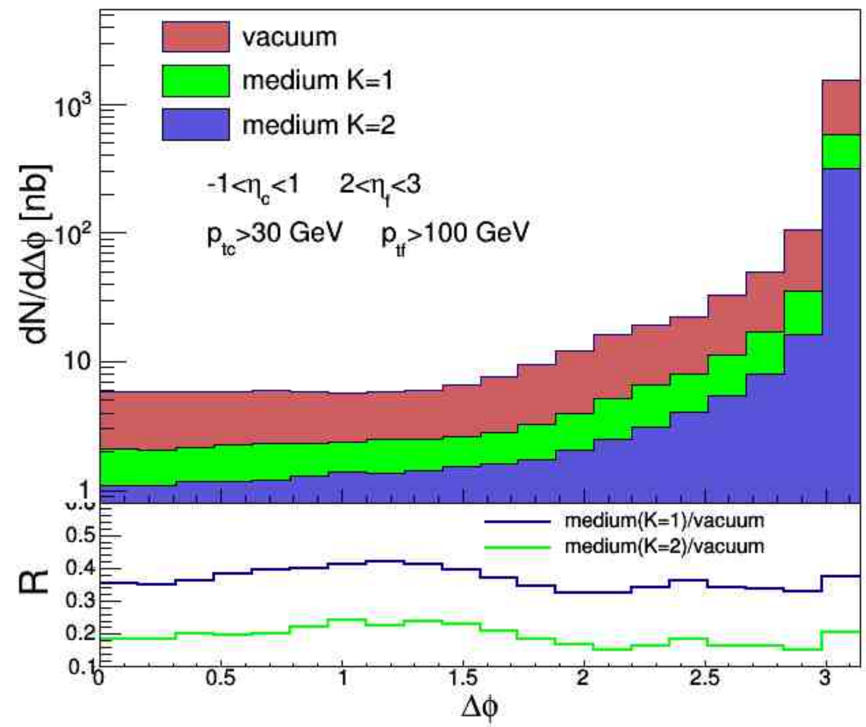
- Nuclear medium is shuffling dijets from back-to-back configuration to less balanced configuration – effect increases with bigger constant K (bigger $\hat{q}$)

Rapidity and azimuthal angle distance

$p_{tc} > 100$ GeV $\qquad p_{tf} > 30$ GeV

$-1 < \eta_c < 1 \qquad 2 < \eta_f < 3$





- Slow increase of medium suppression with $\Delta\eta$
- “re”-emergence of $\Delta\varphi$ dependence for low $\Delta\varphi$

Summary and Outlook

- Implementation of nuclear medium effects into a HEF Monte Carlo program

Planned:

- More precise description for nucleus-nucleus collision (impact parameter dependence, event by event treatment, variable medium length)
- Inclusion of saturation effects
- More precise treatment of the medium jet interactions