Jet-quenching in HIJING++ Monte Carlo Generator

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Introduction

The original HIJING [1] (Heavy Ion Jet INteraction Generator) Monte Carlo model was developed by M. Gyulassy and X.-N. Wang for the "high-energy" at that time, and does not include some relevant medium effect, discovered since. With the recent upgrade of the HIJING code to HIJING++ [2] it already contains the most recent PYTHIA8 [3] code to handle the hard processes and LHAPDF6 [4] PDF libraries; furthermore, due to the modular structure it is easy to implement new features to the code.

Here we report on the inclusion of the jet quenching to the HIJING++ version 3.1.1, namely a module based on the Gyulassy-Lévai-Vitev [5] model. We present comparison of the gluon and quark spectra before and after jet quenching, and the change of the charged particle spectra due to jet quenching in LHC Pb-Pb collisions.

Jet-quenching @ HIJING++

Currently, jet quenching is implemented in HIJING++ through the Gyulassy-Lévai-Vitev [5] formalism. The outgoing jet passes through a high density medium, and during the interaction with it loses energy radiating gluons along its path.

The detailed process is depicted on Figure 1, where the outgoing jet a travels distance L till the closest approach with another parton b, and at that point radiates a gluon with probability

$$p(L) = 1 - e^{-\frac{L}{\lambda_g}}\,, \qquad (1)$$

where L is the distance between subsequent gluon emissions of the jet, while λ_g is the mean free path. The energy loss is described by the GLV [4] formula

$$\Delta E = \frac{C_R \alpha_s}{N(E)} \frac{(L\mu)^2}{\lambda_g} \log\left(\frac{E}{\mu}\right)\,, \qquad (2)$$

where α_s is the strong coupling constant, C_R is the Casimir and μ is a scale parameter, while

$$N(E) = \frac{1}{4 + \frac{22}{\log E}}\,.$$

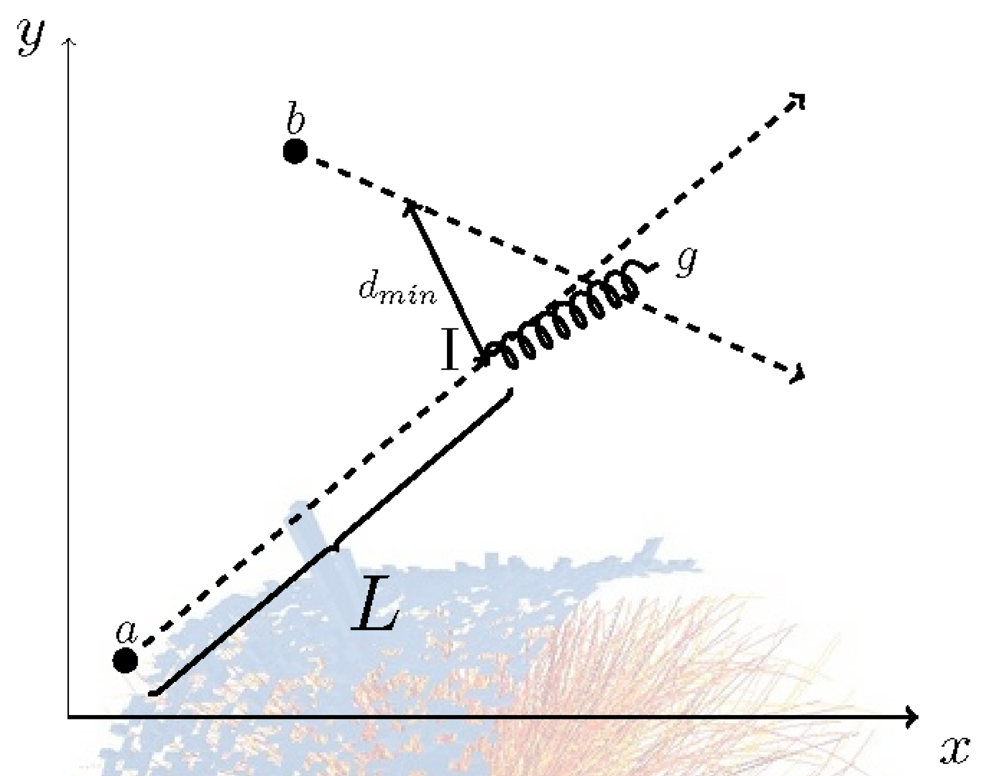

Figure 1. Schematic view of jet quenching: The jet *a* propagates through the medium, and approaching parton *b* at the closest distance (*l*) induces a collinear gluon emission.

After all collisions took place, we check for each parton whether it is on "colliding course" with an another one. Such pairs are ordered according to their distance L, and then with probability (1) a gluon emission is performed. As a result, the energy of the jet is decreasing in proportion with the number of „medium" particles.

Preliminary results

Calculation were performed for Pb-Pb collisions at $\sqrt{s_{NN}}$= 5020 GeV energy, where the separation scale p_0 between hard and soft processes was chosen to be 3 GeV, and the PYTHIA8 parameter for primordial k_T is 1.8 GeV (from Monash tune). The simulation took a day run for 2 million collisions on 200 cores.

We have calculated the effect of jet quenching on the gluons and quarks, separately. Both type of partons loose energy according to the GLV formula Eq. (2). Due to the Casimir, the effect is three times larger for gluons as for quarks. For the parameters chosen, the loss is still moderate, indicating a strong rearrangement at the mid transverse momentum range, pushing the jets towards lower p_T values. At small transverse momenta the gluons from radiative loss are appearing, causing a strong increase in the number of gluons. This effect is missing for the quarks. At high transverse momenta the relative loss is becoming smaller and smaller, and the jet quenching effects less and less the high p_T tail (see Figure 4.).

It is interesting to follow the effect after hadronization. The gluonic pattern shown up also in the charged particle spectrum, with the maximal loss around 5 GeV transverse momentum, and a relative increase at low transverse momentum. The effect is larger in the midrapidity and getting weaker for larger (pseudo)rapidities.

In Figure 5. we show the distribution of the transverse length of the medium, felt by the travelling jet, i.e. the distance till the last possible collision point to another parton. It has an average value approximately 7 fm. The number of possible interaction varies largely during the path, between a couple to 50 partons approaching the jet closely. So far, we are not using this information to extract the typical mean free path λ_g along the jet trajectory allowing fluctuating energy loss, rather fix it a constant value, keeping the ratio L/λ_g to be fixed.

Since the jet quenching module is still in development phase, we are planning to implement a more rigorous GLV model to HIJING++, allowing for fluctuating energy loss. For that purpose we have to be able to translate the number of partons close enough on the jet trajectory into the mean free path, in a self-consistent way. This work is currently in progress.

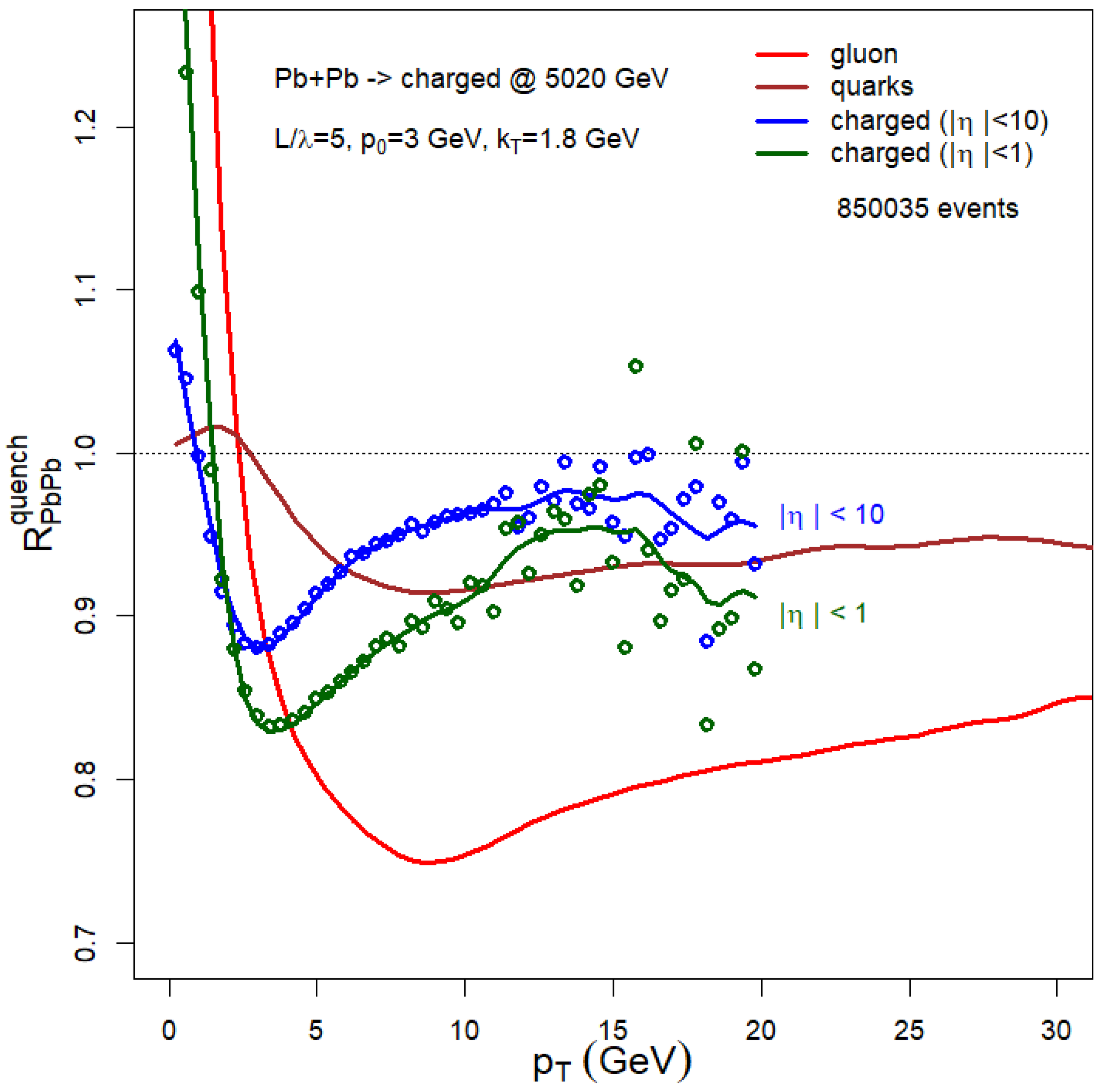

Figure 4. Pb-Pb @ 5020 GeV → charged particle min. bias jet quenching with HIJING++: red line indicates the drop of number of gluons at given transverse scale p_T, the brown line is the same for quarks. The blue and green lines represent the drop in the number of charged (hadronized) particles in two pseudorapidy windows.

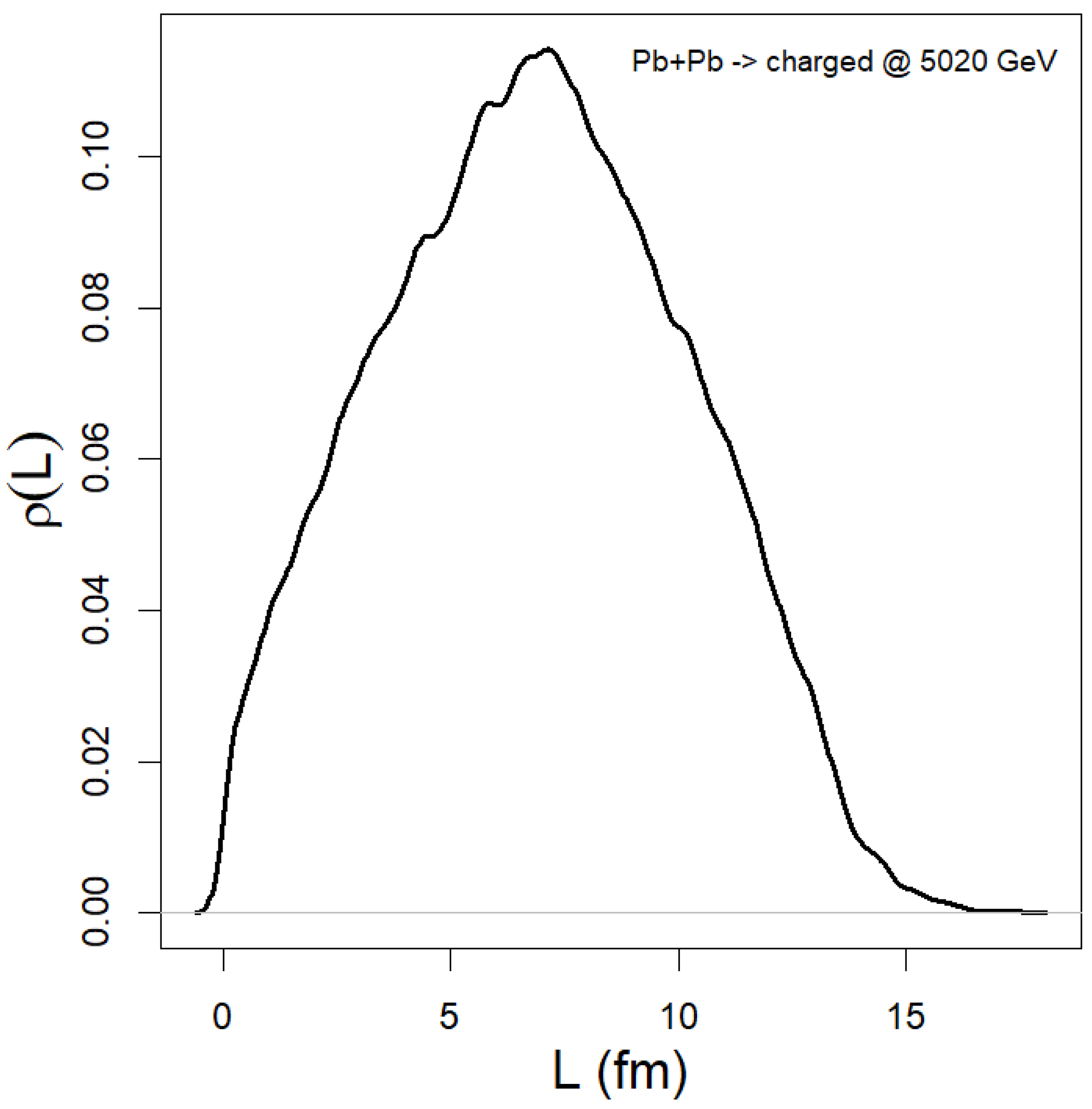

Figure 5. Pb-Pb @ 5020 GeV → charged particle min. bias run with HIJING++, indicating the distribution of maximal transverse direction passed by a jet in medium.

Another extension of the work here is the inclusion of other type of jet-quenching model. An easily implementable family is the one, which is linear in the length parameter L. Such models easily allow for several gluon emissions along the path, making possible to study the effect of multiple emission.

Baseline

First, we tune PYTHIA8 parameters to reproduce synthetic pp data at 5020 GeV energy. Since the soft physics and fragmentation are different in HIJING++ compared to PYTHIA8, we start from the default PYTHIA8 parameters, which are not performing well. Hence, we change the hard cut scale to p_0=3 GeV, and switched on the primordial k_T with width 1.8 GeV.

In Figure 2. we show the fit of the HIJING++ run for 10^8 events to the extrapolated experimental data [6]. The model still underperform in the low p_T region similarly to PYTHIA8, despite the different underlying physical picture.

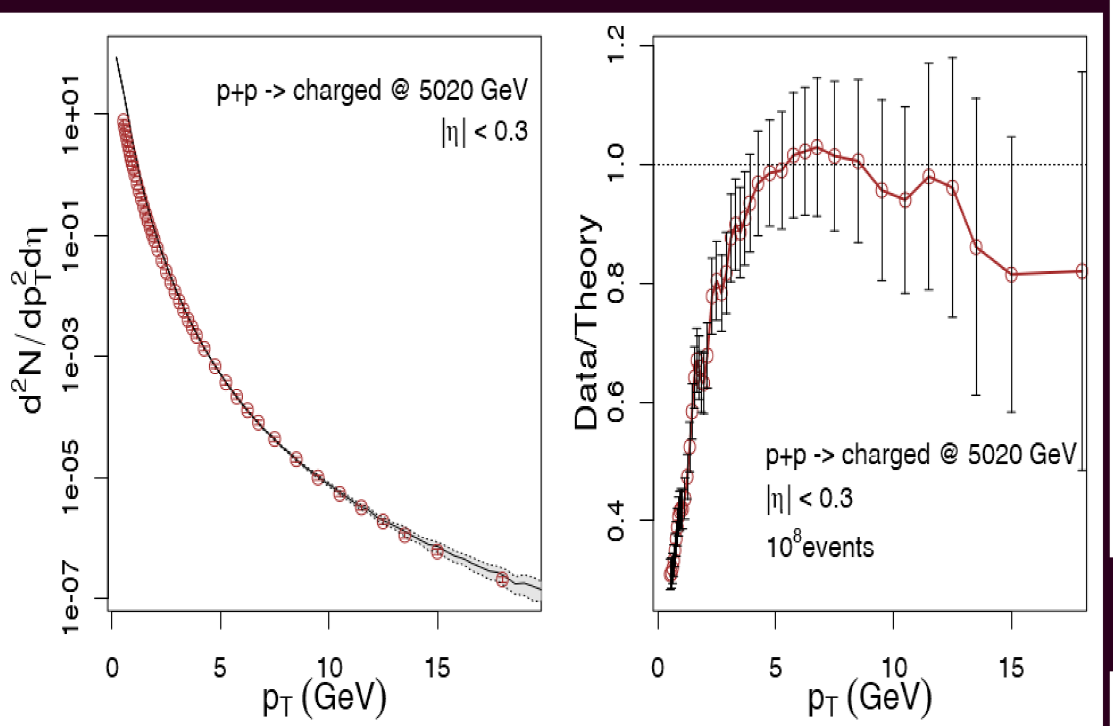

Figure 2. pp @ 5020 GeV → charged particle fit with HIJING++. Hard cut scale p_0=3 GeV was used with primordial k_T = 1.8 GeV. Experimental data is taken from[6].

Next, we tested nuclear effects, like shadowing, Cronin peak and collective fragmentation, keeping the setting as fixed for the *pp* case. There was a correction to the Cronin effect in the HIJING++ version, however, it is still not in the correct position, while performing much better than the original FORTRAN version.

In Figure 3. we show the HIJING++ fit for the experimental data [6], for 10^8 p-Pb events compared to 10^8 pp events. The agreement at p_T > 4 GeV is acceptable.

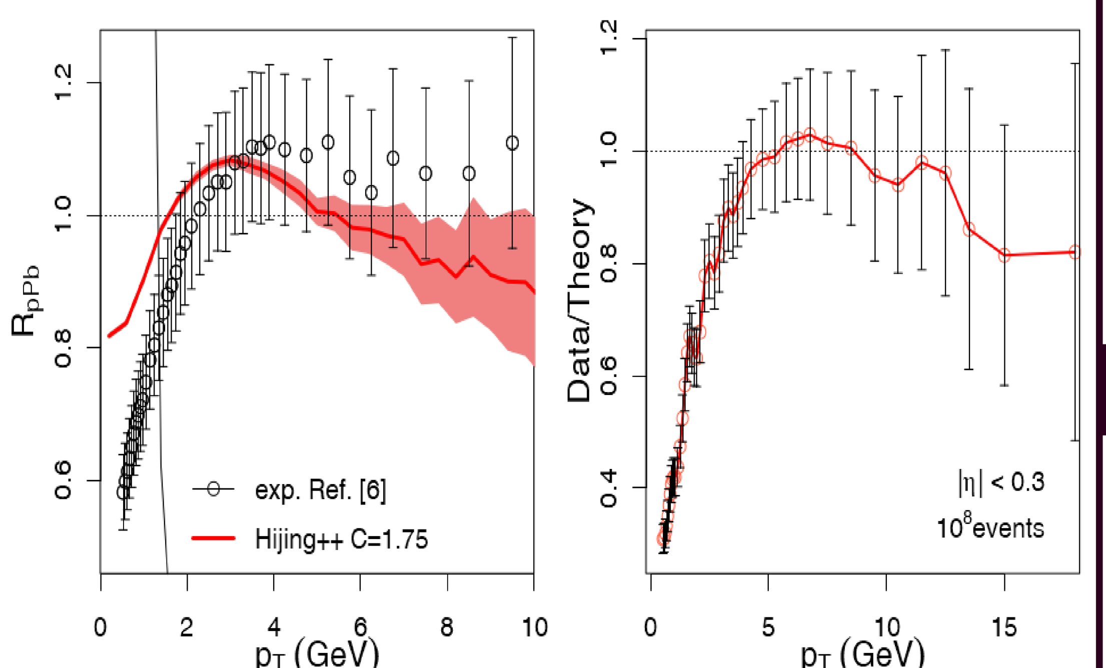

Figure 3. *p-Pb* @ 5020 GeV → charged particle min. bias nuclear modification factor fit with HIJING++. The best fit was obtained with Cronin width parameter *C=1.75* GeV.

Summary

We report on the first implementation of jet quenching to HIJING++ event generator. At the time the GLV [5] quenching was adopted within the HIJING++ structure and first result on gluon and quark quenching was presented with the effect of the quenching on the charged particles. Due to the modular structure of the HIJING++ it is easy to implement other quenching models.

For more info and updates about the project, preliminary datasets, requests and contact details check our webpage on https://gitlab.kfki.hu/hijing/QuarkMatter2018:

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Emberi Erőforrások Minisztériuma

References

[1] X.N. Wang, M. Gyulassy, Phys. Rev. D44, 3501 (1991).
[2] G. Bíró et al, QM2018, poster #NTH-03.
[3] T. Sjöstrand, et al., Comput. Phys.Commun. 191 (2015) 159.
[4] A. Buckey, et al., Eur.Phys.J. C75 (2015) 3, 132
[5] M. Gyulassy, P. Lévai, I. Vitev, Phys.Lett. B538 (2002) 282-288 and Nucl.Phys. B594 (2001) 371-419
[6] ALICE collaboration, Phys.Rev.Lett. 110 (2013) 082302.
[7] G. Papp, G.G. Barnaföldi, G. Bíró, M. Gyulassy, Sz.M. Harangozó, P. Lévai, G. Ma, X.-N. Wang, B.-W. Zhang, arXiv:1805.02635