

MULTIPLICITY DEPENDENCE IN THE NON-EXTENSIVE HADRONIZATION MODEL CALCULATED BY THE HIJING++ FRAMEWORK

GÁBOR **BIRÓ**

17-21. June 2019

BALATON
WORKSHOP
TIHANY



COLLABORATORS



Gergely Gábor Barnaföldi

Gábor Papp

Péter Lévai

Miklós Gyulassy

Tamás Sándor Biró

(Szilveszter Harangozó)

(Dániel Nagy)

Bálint Horváth-Csurgai

Xin-Nian Wang

Ben-Wei Zhang

(Guoyang Ma)

The research is supported by the

- Hungarian-Chinese cooperation grant No Tét 12 CN-1-2012-0016, No. MOST 2014DFG02050 and Wigner HAS-OBOR-CCNU grant
- OTKA grants K120660, K123815, THOR COST action CA15213
- Wigner Data Center, Wigner GPU Laboratory

CONTENTS

Part I

- Motivation

CONTENTS

Part I

- Motivation
 - (Very) brief summary of SQM19

CONTENTS

Part I

- Motivation
 - (Very) brief summary of SQM19

Part II

- HIJING++
- Tsallis statistics
- Multiplicity classes of identified light hadrons

BÍRÓ, G.; BARNAFÖLDI, G.G.; PAPP, G.; BIRÓ, T.S. UNIVERSE 2019, 5, 134.

Bari, June 10-15

84 experimental talk

- 57 parallel

- 27 plenary

42 theory talk

- 27 parallel

- 15 plenary

63 posters

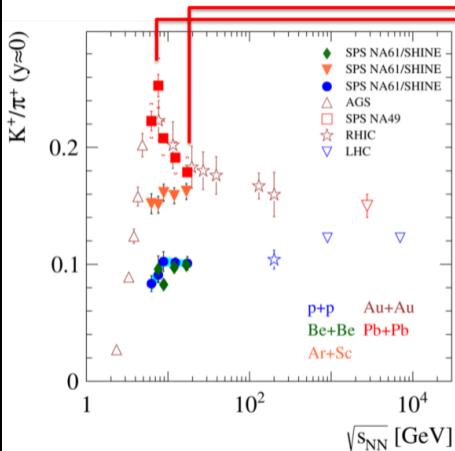


All talks are available at:

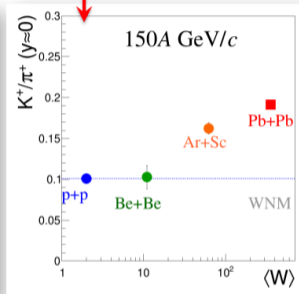
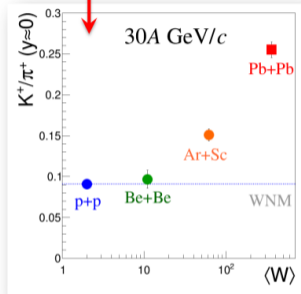
<https://indico.cern.ch/event/755366/>

I. STRANGENESS ENHANCEMENT

SQM '19: STRANGENESS ENHANCEMENT



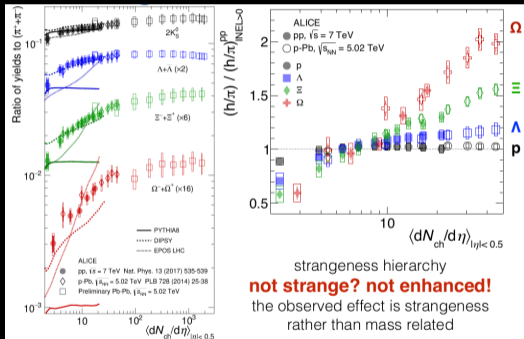
Podlaski, Tuesday | 4:00



- Plateau-like in pp, Be+Be
- Intermediate in Ar+Sc but no horn
- Suggestive of change in production mechanisms?
 - Is there a phase transition involved?



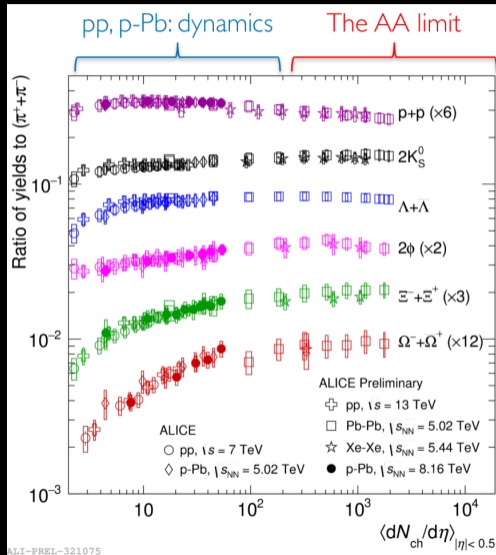
SQM '19: STRANGENESS ENHANCEMENT (AND SYSTEM SIZE)



Roberto Preghenella

ALICE, *Nature Phys.* 13 (2017) 535

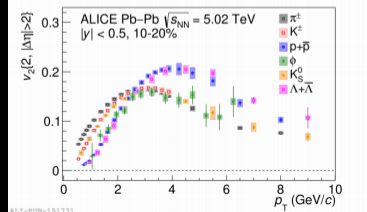
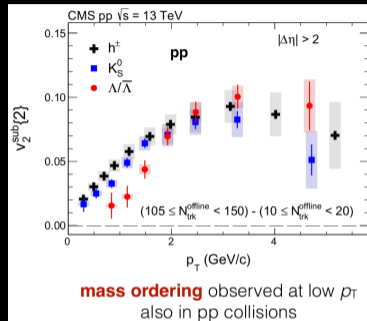
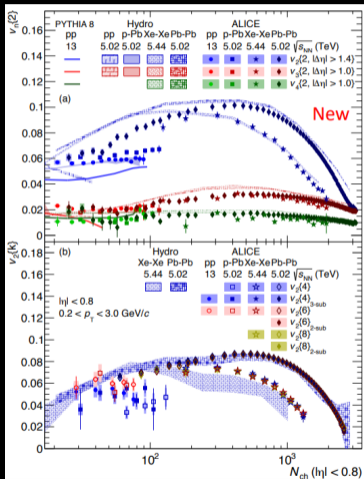
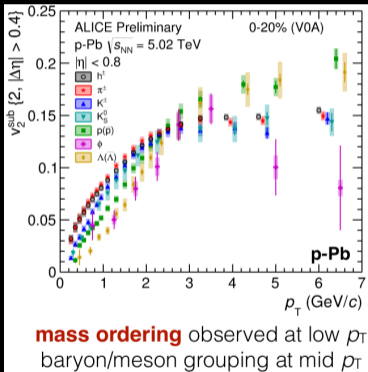
36



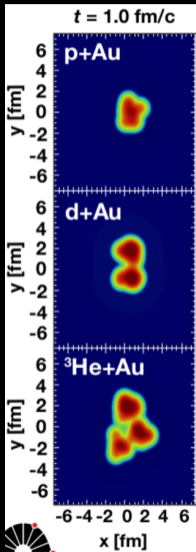
ALI-PREL-321075

II. „EVERYTHING FLOWS...”

SQM '19: „EVERYTHING FLOWS...”

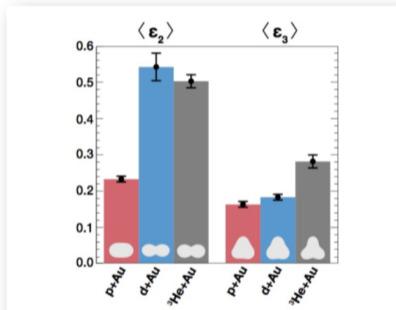


III. QGP DROPLETS

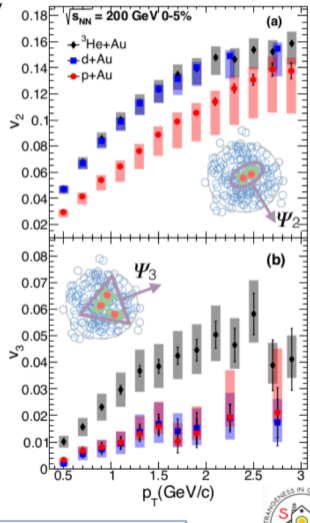


PHENIX: controlling geometry

Nature Physics **15**, 214–220 (2019)

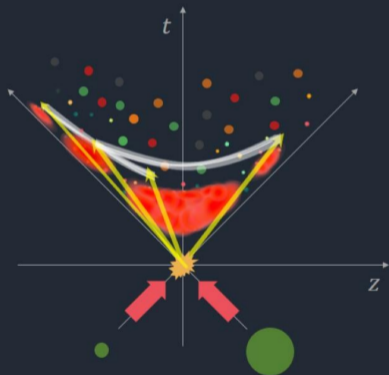


- Changing projectile: change in expected hydro response \rightarrow observed experimentally!
- Hydro simulations reproduce data
- “Creation of quark–gluon plasma droplets with three distinct geometries”



Model

Y. Kanakubo, M. Okai, Y. Tachibana, T. Hirano, PTEP 2018 (2018) no.12, 121D01



Hadronisation (particlisation)

Core → Freezeout at $T_{fo} = 160$ MeV
via Cooper-Frye formula

F. Cooper and G. Frye, Phys. Rev. D **10**, 186 (1974).

+ Resonance correction

A. Andronic *et al.*, Nature 561 (2018) no.7723, 321-330 (2017).

Corona → String fragmentation (PYTHIA)

Evolution of QGP fluids

New

Dynamical core-corona initialisation

(3+1)-D ideal hydro, Lattice EoS (3 flavour)

Y. Tachibana and T. Hirano, Nucl.Phys. A **904-905** (2013)

S. Borsanyi *et al.*,
Phys. Lett. **B730**, 155 (2014).

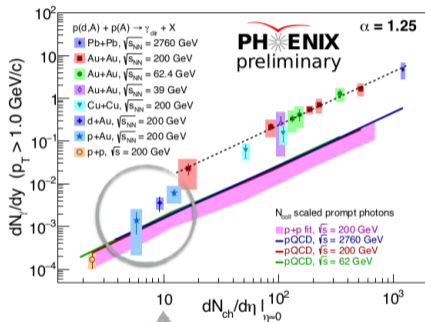
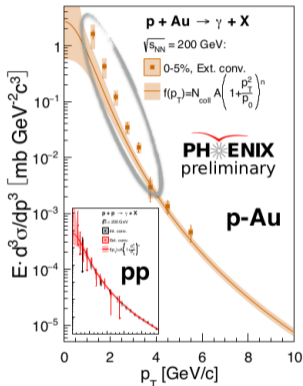
Parton generation

PYTHIA ver 8.230 (hadronization = off)

T. Sjöstrand *et al.*, Comput. Phys. Commun. **191**, 159 (2015).

C. Bierlich *et al.*, JHEP **1610** (2016) 139.

RHIC versatility: different collision systems and energies
 excess of direct photons over scaled pp **also in small systems**



p-Au and d-Au data: bridge between pp and A-A

suggests transition from pp to A-A scaling: radiation from QGP droplets?

IV. MANY OTHER TOPICS...

A small selection:



- System size scan: hydro-like behavior is established everywhere? What does that mean? What about „fluctuations“?
- Unified description from small to large systems is needed
- Indication that something starts happening around $dN_{ch}/d\eta \sim 10-20$
- Indication of partial QGP formation even in NSD p+p
- No clear sign of QGP in small systems up to now
- Strangeness enhancement and direct photon excess – evolves from low- N_{ch} pp to high- N_{ch} p-A towards A-A
- Formation of Quark-Gluon droplets in small systems...
- ...or manifestation of new physics?

HIJING++

HIJING++...

- (...**is** a Heavy Ion Jet INteraction Generator, C++ version.)

HIJING++...

- (...**is** a Heavy Ion Jet INteraction Generator, C++ version.)
- ...**is** a framework, **not** a black box.
- ...**is not** a direct port of the old FORTRAN code.
- ...**is** a direct port of the old FORTRAN code after all (regarding the physics).
- ...**is not** wrapper for Pythia8.
- ...**is still not** published (**yet**).

HIJING++ SUMMARY

	FORTRAN HIJING	HIJING++
Precision	single	double
Pythia version	5.3*	8.2+**
PDF	GRV98lo	LHAPDF6.2+
Colour reconnection	✗	✓
Jet quenching⁺	(✓)	(✓)
Multithreading	✗	✓
Analysis interface	✗	✓***
Module management	✗	✓

*Was modified and hardwired into HIJING

**Default tune for HIJING++ is Monash, for that re-tuning of the parameters is needed

*** Includes: simple ascii, ROOT, Yoda and HepMC2 (Rivet)

HIJING++ SUMMARY

	FORTRAN HIJING	HIJING++
Precision	single	double
Pythia version	5.3*	8.2+**
PDF	GRV98lo	LHAPDF6.2+
Colour reconnection	✗	✓
Jet quenching⁺	(✓)	(✓)
Multithreading	✗	✓
Analysis interface	✗	✓***
Module management	✗	✓


+ See the talk from GÁBOR PAPP

*Was modified and hardwired into HIJING

**Default tune for HIJING++ is Monash, for that re-tuning of the parameters is needed


***Includes: simple ascii, ROOT, Yoda and HepMC2 (Rivet)

Before the release, a set of comparisons with experimental data (and fine-tuning) is needed:

- Chosen (n)PDF set(s): nCTEQ15 (arXiv:1509.00792)
- Raw tuning: ✓
- Fine:  (using Professor*)
- Main observables:
 - Pseudorapidity distributions and multiplicity
 - Charged and PID spectra
 - (Nuclear modification factor)
 - (PID ratios)
 - ...

*Tool for systematic tuning of MC event generators, see arXiv:0907.2973

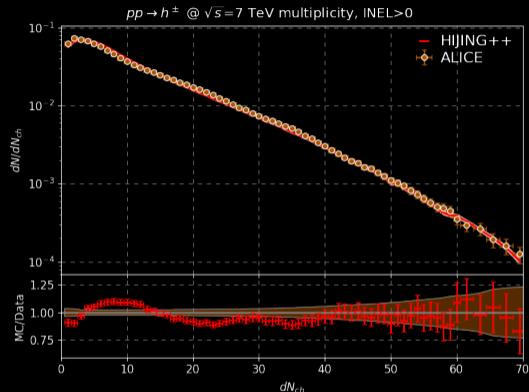
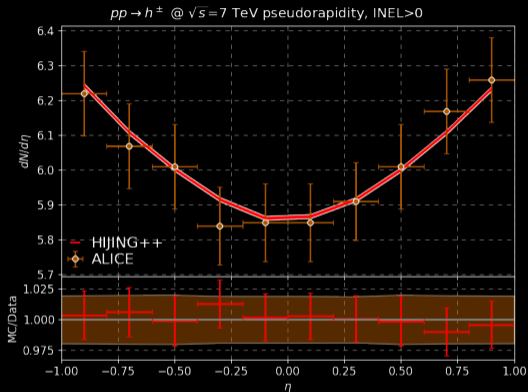
Before the release, a set of comparisons with experimental data (and fine-tuning) is needed:

- Chosen (n)PDF set(s): nCTEQ15 (arXiv:1509.00792)
- Raw tuning: ✓
- Fine:  (using Professor*)
- Main observables:
 - Pseudorapidity distributions and multiplicity
 - Charged and PID spectra
 - (Nuclear modification factor)
 - (PID ratios)
 - ...

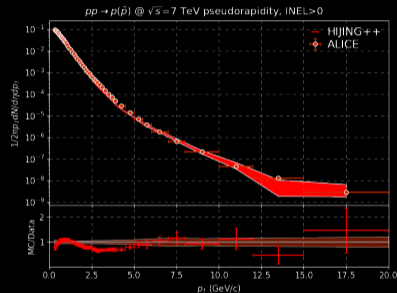
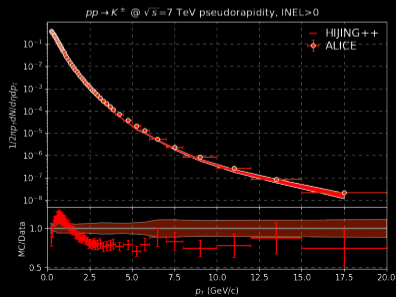
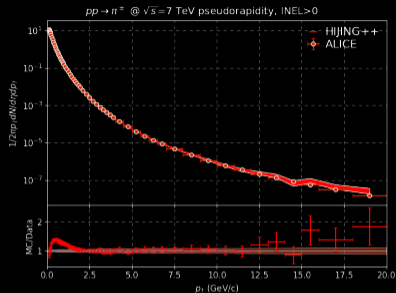
See the talk from BÁLINT HORVÁTH-CSURGAI

*Tool for systematic tuning of MC event generators, see arXiv:0907.2973

HIJING++ TUNING RESULTS: pp AT
 $\sqrt{s} = 7$ TeV



Charged particle pseudorapidity and multiplicity with $INEL > 0$ normalization (at least one charged particle in $|\eta| < 1.0$): 1-10%



Identified $\pi^\pm, K^\pm, p(\bar{p})$ at mid-rapidity with $INEL > 0$ normalization: $\sim 15\%$

TSALLIS STATISTICS AND IDENTIFIED HADRON SPECTRA

The invariant yield:

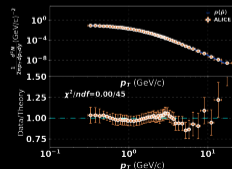
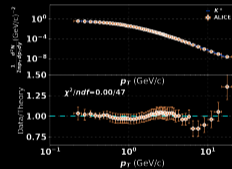
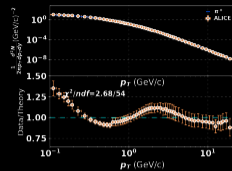
$$\frac{d^2N}{p_T dp_T dy} \Big|_{INEL > 0} = A \cdot m_T \cdot \left(1 + \frac{E}{nT}\right)^{-n}$$

where

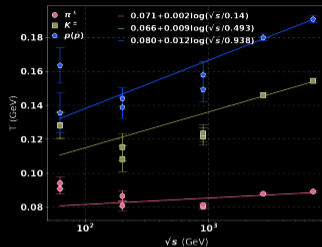
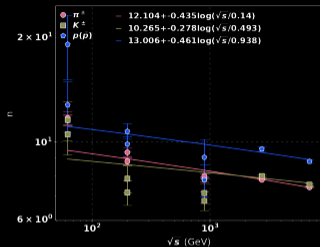
$$n = 1/(q - 1) \quad ,$$

$$E = \gamma(m_T - vp_T) - m$$

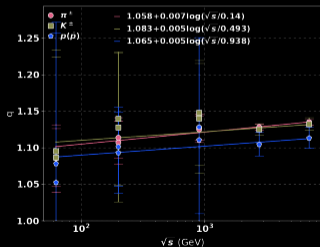
	n	q	T (GeV)	A	v
π^\pm	7.415 ± 0.033	1.135 ± 0.005	0.089 ± 0.010	73.188 ± 9.700	0.000 ± 0.119
K^\pm	7.539 ± 0.086	1.133 ± 0.013	0.155 ± 0.010	0.915 ± 0.095	0.000 ± 0.066
$p(\bar{p})$	8.805 ± 0.184	1.114 ± 0.023	0.191 ± 0.012	0.124 ± 0.013	0.000 ± 0.054



TSALLIS STATISTICS: MASS AND \sqrt{s} TRENDS

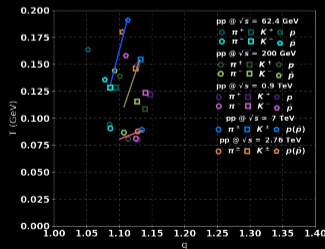


T and q (n) are increasing (decreasing) with energy

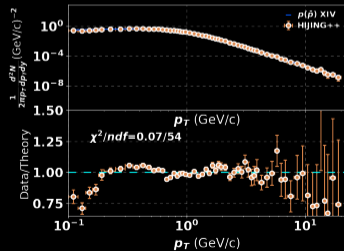
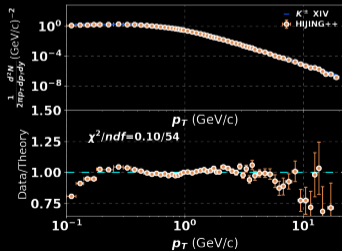
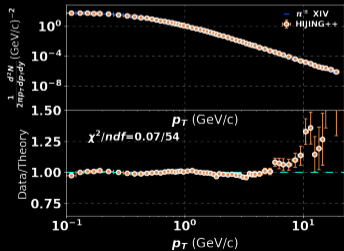
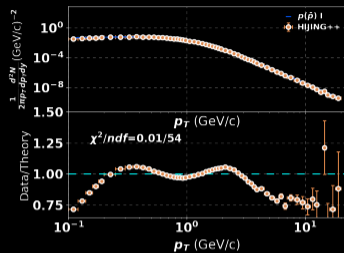
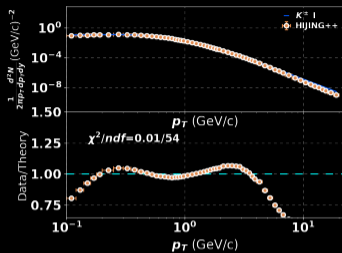
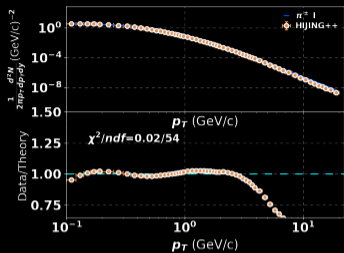


Mass hierarchy

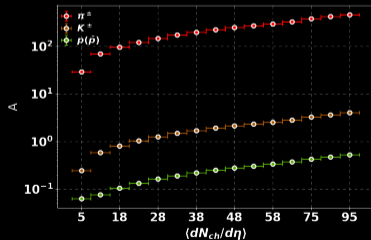
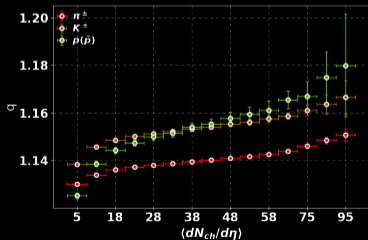
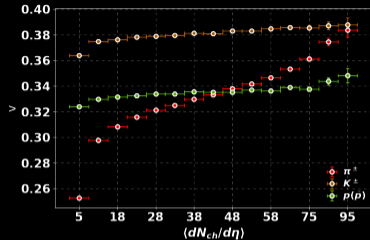
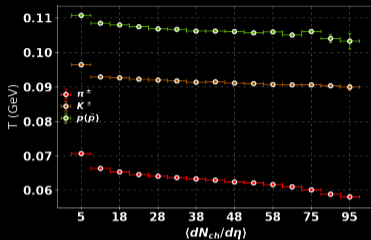
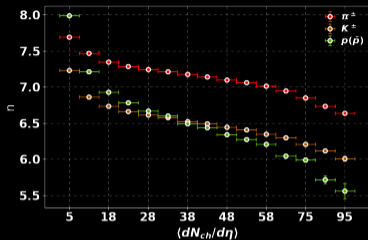
System size...? \rightarrow HIJING++!



TSALLIS STATISTICS: HIJING++ DATA

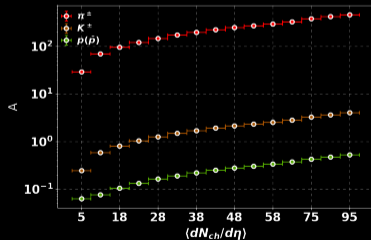
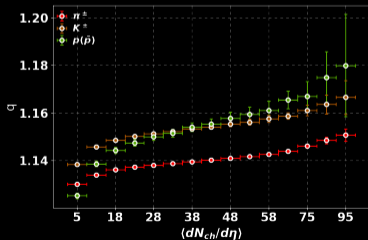
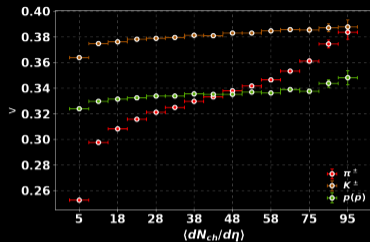
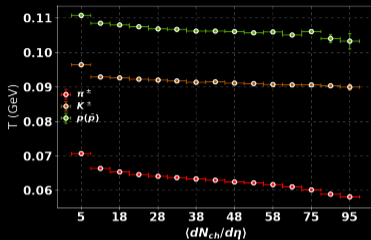
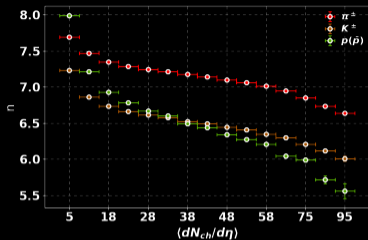


TSALLIS STATISTICS: HIJING++ RESULTS



- Mass hierarchy appears again
- Large $v \neq 0$ values
- System size dependency is strong

TSALLIS STATISTICS: HIJING++ RESULTS



- Mass hierarchy appears again
- Large $v \neq 0$ values
- System size dependency is strong

THANK YOU!