Moments of net proton distribution in high energy pp collisions and relevance to the QCD critical point

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Outline

- Motivation
- Brief introduction to PACIAE (PYTHIA) models
- PACIAE (PYTHIA) description for charged particle productions
- Preliminary result of moments
- Conclusions

Motivation

One of the goals of the HIC is to locate the CP in the QCD phase diagram. Signature of the CP is related to the fluctuation of event-by-event observable.

- The relation between LQCD calculated NBN susceptibility and HIC experimental data of NBN moments allows one to find critical T of QCD phase transition [S. Gupta et al., Science 332, 1525 (2011)]
- Third moments of conserved charges as probes of QCD phase structure [M. Asakawa et al., PRL 103, 262301 (2009)

- Higher moments as well as moment products are sensitive to the correlation length and directly connected to the thermodynamic susceptibilities computed in LQCD and HRG [X. Luo, J. Phys. Conf. Ser. 316, 012003 (2011)]
- Kurtosis is negative when the CP is approached [M. A. Stephanov, PRL 107, 052301 (2011)]
- Photon production in a scenario of QGP formation in pp at 7 TeV [F.M. Liu and K. Werner, PRL 106, 242301 (2011)]
- At pp and ppbar collisions, there are evidences of crossover from HG to QGP [R. Campanini and G. Ferri, Phys. Lett. B 703 (2011) 237]

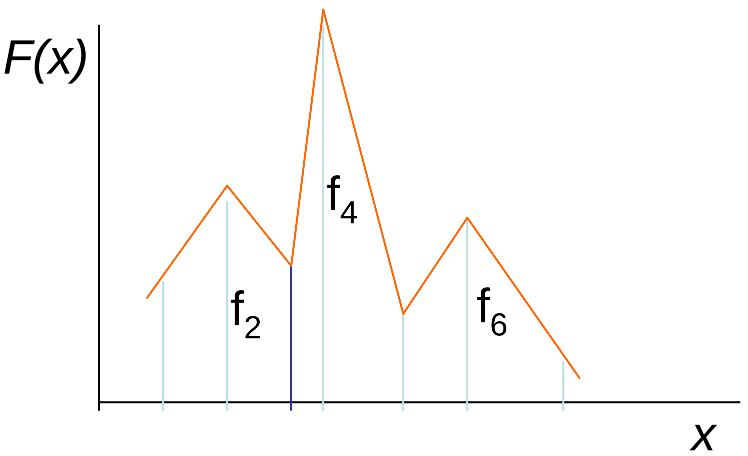
The moments of net proton is expected to be one of the tools to reveal the mystery of critical point.

The net proton is worthy to be studied in pp collision.

Definition

F(x): NBN distribution (NBN fluctuation) in an ensemble composed of N events

$$F(x) = \begin{cases} \sum_{i=1}^{I} f_i \delta(x - x_i), \textit{ discrete dis.} \\ \textit{profile of discrete dis.} \end{cases}$$



f_i : events # in i-th x point

I: total # of discrete x points

moment about mean (x=<x>) of the NBND

$$M^{(n)} = <(x - <x>)^n> = \int (x - <x>)^n F(x) dx$$

moment about zero: $$<x^n> = \int x^n F(X) dx$$

An idea for subtracting the statistical fluctuation

As the study of phase transition and approaching CP is a matter of dynamics in order to eliminate the finite size effect and limit statistic effect etc.,

one should study $M_D^{(n)} = M_R^{(n)} - M_M^{(n)}$ instead of $M_R^{(n)}$ only

where

$M_R^{(n)}$: calculated by real events constructed or generated

$M_M^{(n)}$: calculated by mixed events constructed randomly according to real events event-by-event, with event multiplicity un-change and without any conservation law at all

key moments should be calculated:

- Standard deviation σ

$$\sigma^2 = C^{(2)}$$

- Skewness

$$S = C^{(3)} / (C^{(2)})^{3/2}, \quad S\sigma = C^{(3)} / C^{(2)}$$

- Kurtosis

$$\kappa = C^{(4)}/(C^{(2)})^2, \quad \kappa\sigma^2 = C^{(4)} / C^{(2)}$$

- $C^{(n)}$: n-th cumulant, a linear combination of moments about mean (x=<x>)

$$C^{(n)} = VT^3 T^{n-1} \chi_B^{(n)} \left(\frac{T}{T_c}, \frac{\mu_B}{T} \right)$$

- the (2-4)-th cumulants can expand to a combination of moments about zero:

$$C^{(2)}=M^{(2)}=\langle(x-\langle x\rangle)^2\rangle$$

$$=\langle x^2\rangle-\langle x\rangle^2$$

$$C^{(3)}=M^{(3)}=\langle(x-\langle x\rangle)^3\rangle$$

$$=\langle x^3\rangle-3\langle x^2\rangle\langle x\rangle+2\langle x\rangle^3$$

$$C^{(4)}=M^{(4)}-3\langle(x-\langle x\rangle)^2\rangle^2$$

$$=\langle(x-\langle x\rangle)^4\rangle-3\langle(x-\langle x\rangle)^2\rangle^2$$

$$=\langle x^4\rangle-4\langle x^3\rangle\langle x\rangle+12\langle x^2\rangle\langle x\rangle^2-6\langle x\rangle^4$$

$$-3\langle x^2\rangle^2$$

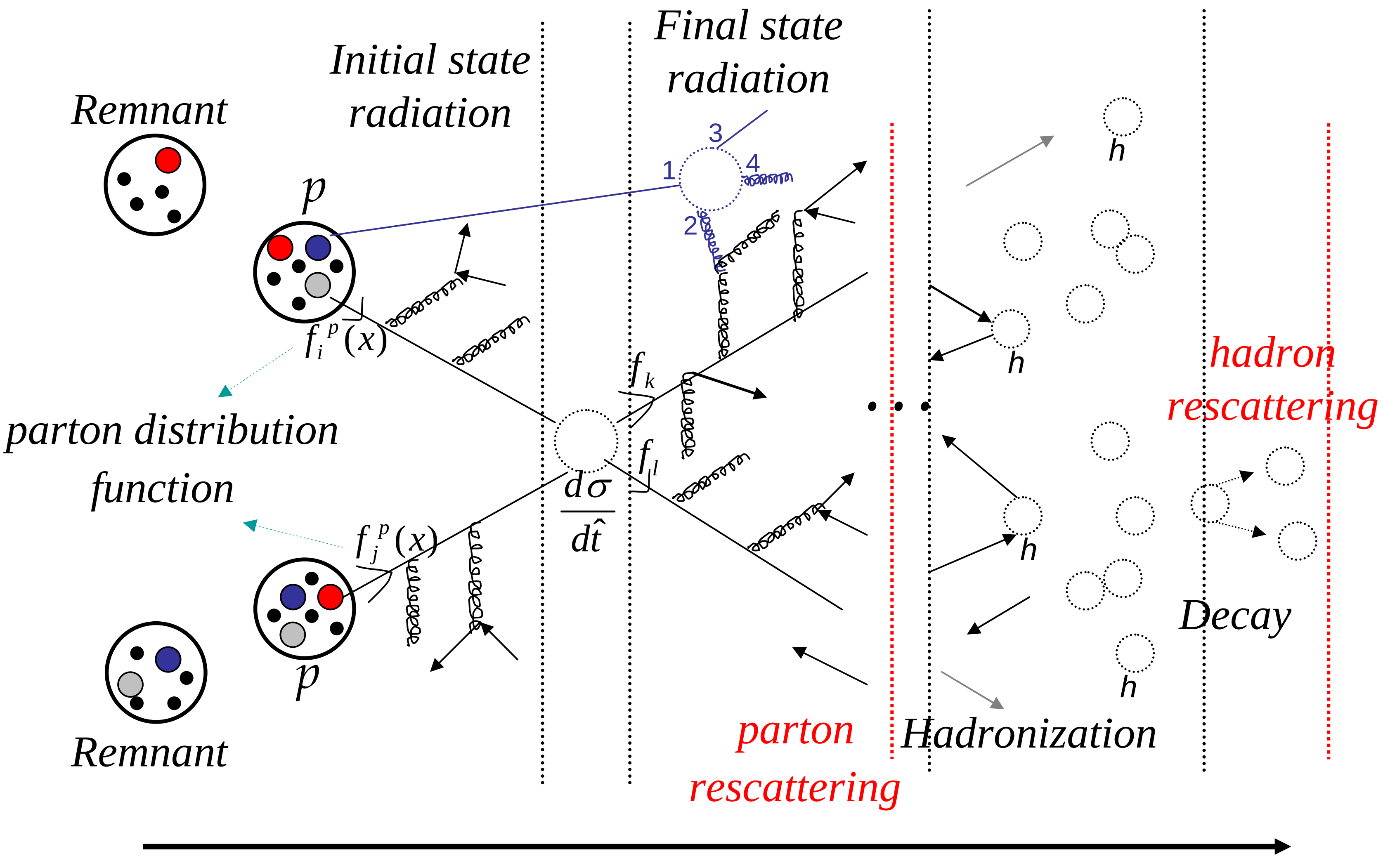
Brief introduction for PACIAE model

PACIAE, parton and hadron cascade model, is based on PYTHIA model for both p+p and A+A collisions. The model is updated to PACIAE 2.0 based on PYTHIA 6.4.

[B. H. Sa et al., Computer Physics Communications 183, 333 (2012)]

DYNAMIC SIMULATION (PYTHIA,PACIAE)

Sketch for pp dynamic simulation



PACIAE (PYTHIA) description for charged particle production

The ALICE, CMS and ATLAS measurement for p+p at LHC energies are analyzed systemically using the PACIAE and PYTHIA model

Charged particle multiplicity

Energy TeV	ATLAS	PYTHIA	PACIAE
0.9	$1.333 \pm 0.003 \pm 0.040$[a]	1.240	1.309
2.36		1.659	1.790
7		2.371	2.768

Energy TeV	CMS	PYTHIA	PACIAE
0.9	$3.48 \pm 0.02 \pm 0.13$[b]	3.07	3.25
2.36	$4.47 \pm 0.04 \pm 0.16$[b]	3.80	4.12
7	$5.78 \pm 0.01 \pm 0.23$[d]	4.91	5.76

Energy TeV	ALICE	PYTHIA	PACIAE
0.9	$3.81 \pm 0.01 \pm 0.07$[c]	3.41	3.64
2.36	$4.70 \pm 0.01 \pm 0.10$[c]	4.15	4.52
7	$6.01 \pm 0.01 \pm 0.16$[c]	5.30	6.11

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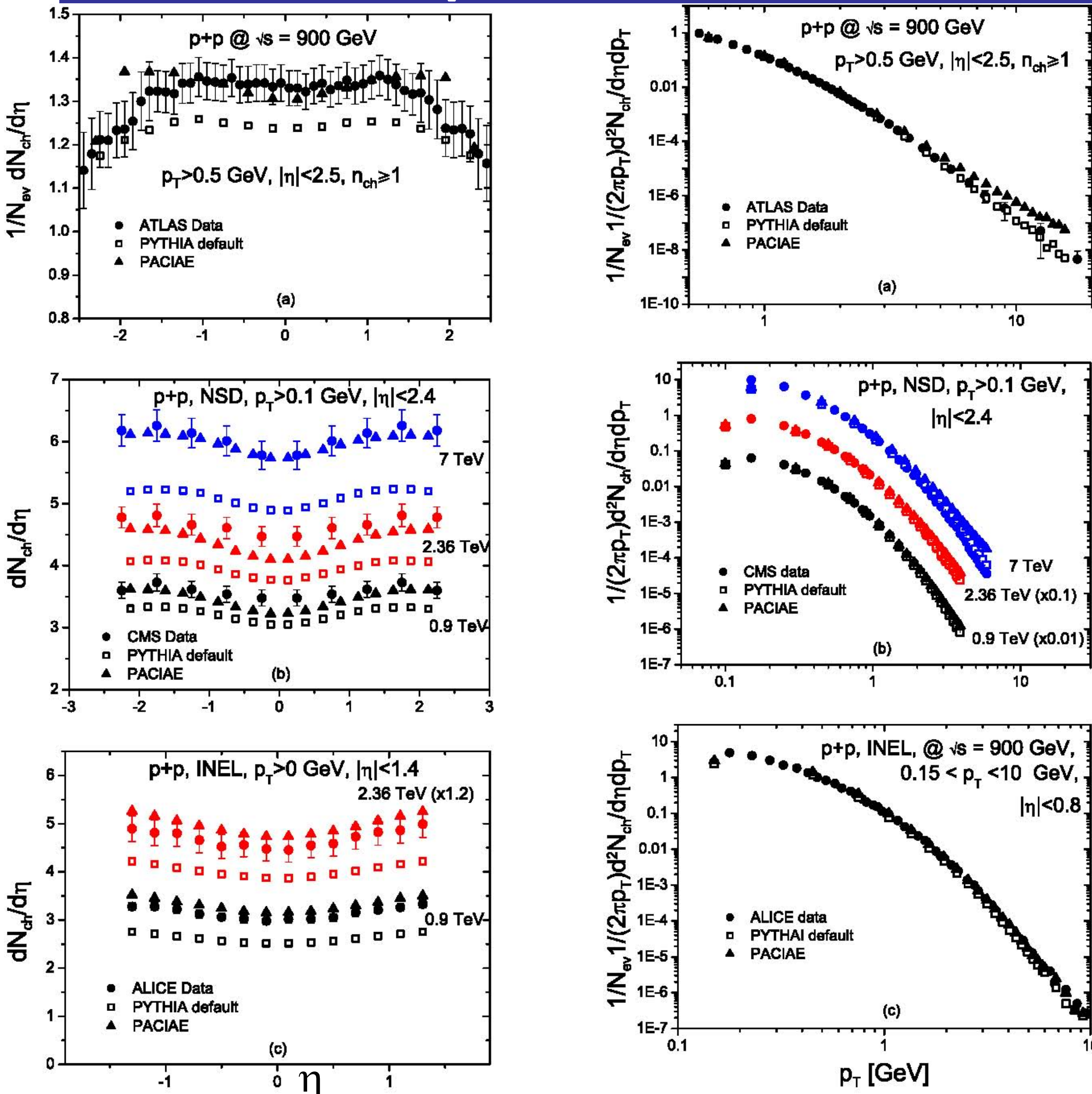
η and pt distributions



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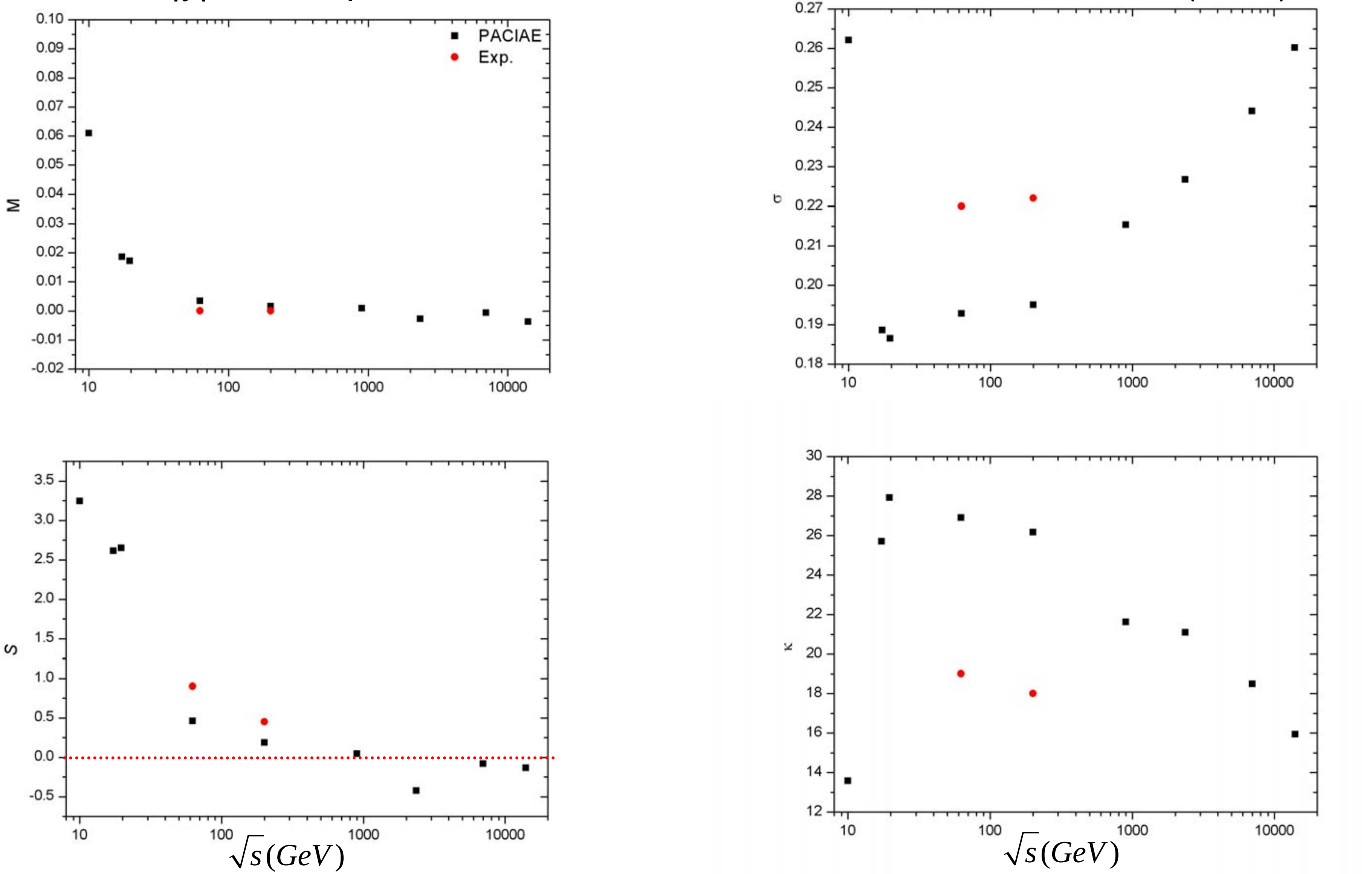
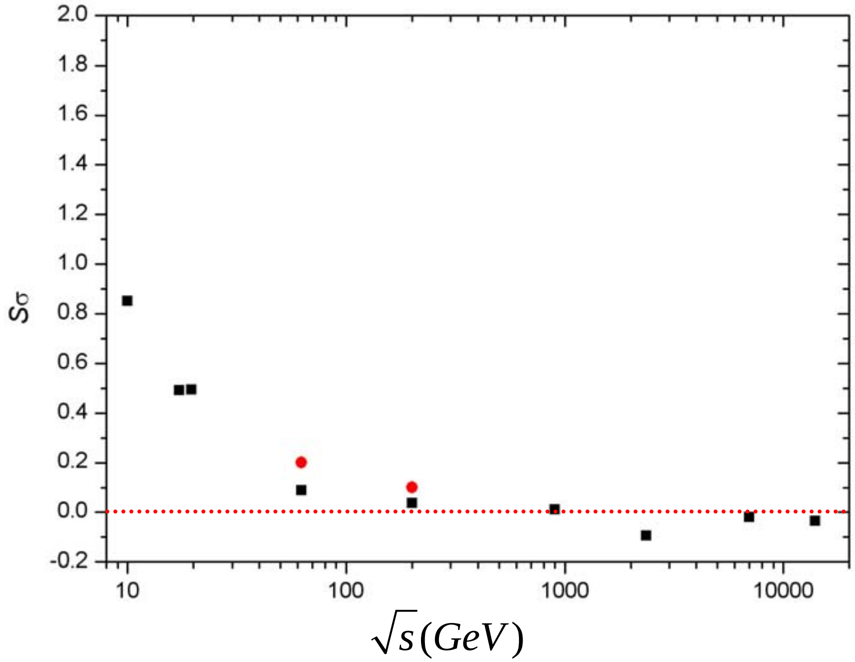
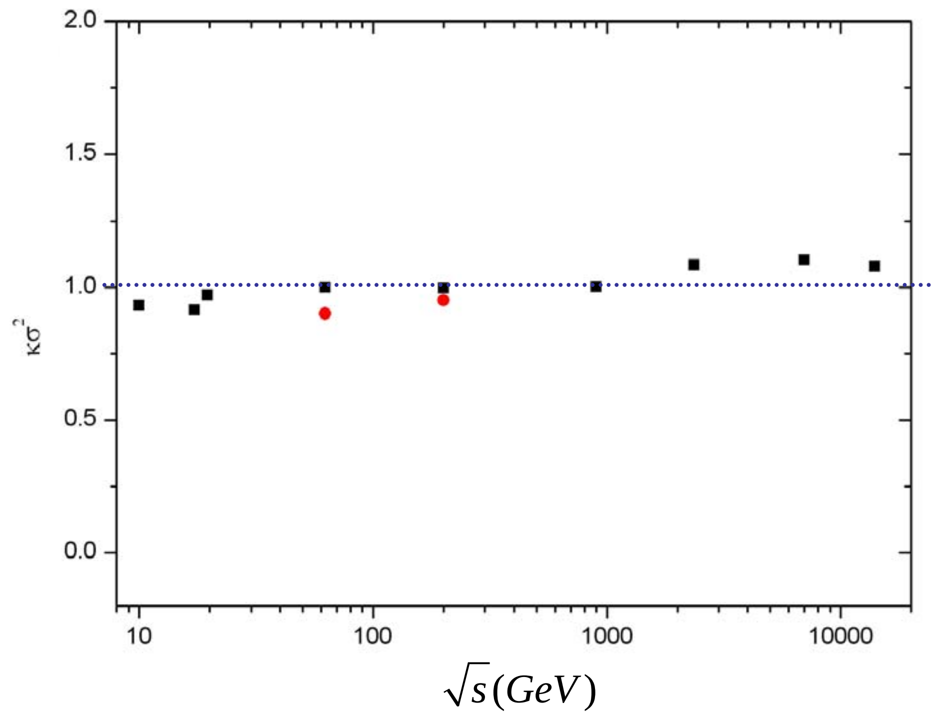
PACIAE preliminary result of moments

p+p@$\sqrt{s}$ = 10, 17.2, 19.6, 62.4, 200, 900 GeV, 2.36, 7 and 14 TeV at 0.4 < pt < 0.8 GeV/c and |y|<0.5; Exp. data are taken from X. Luo, JPCS 316, 012003 (2011)





2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
Sσ
10
100
1000
10000
$\sqrt{s}(GeV)$



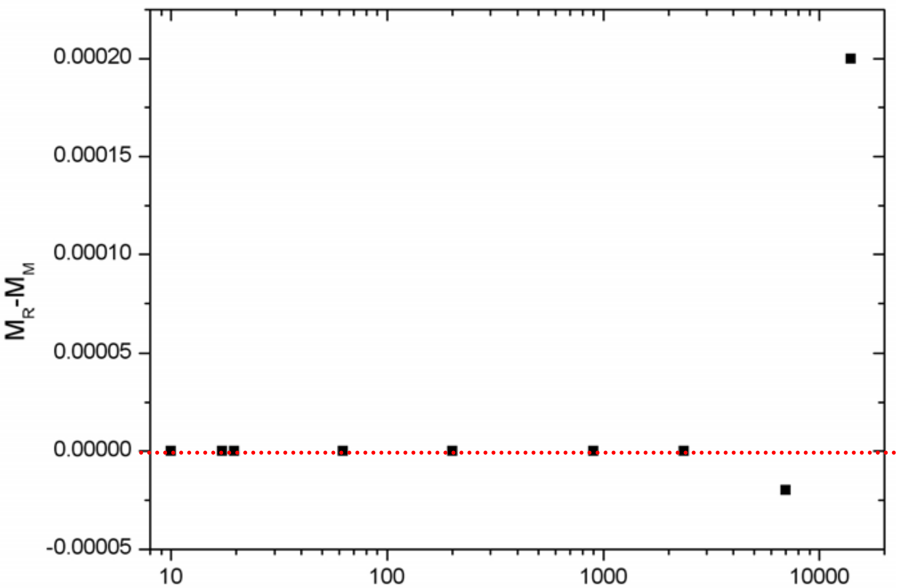
2.0
1.5
1.0
0.5
0.0
$\kappa\sigma^2$
10
100
1000
10000
$\sqrt{s}(GeV)$

PACIAE preliminary result of moments

p+p@$\sqrt{s}$ = 10, 17.2, 19.6, 62.4, 200, 900 GeV, 2.36, 7 and 14 TeV

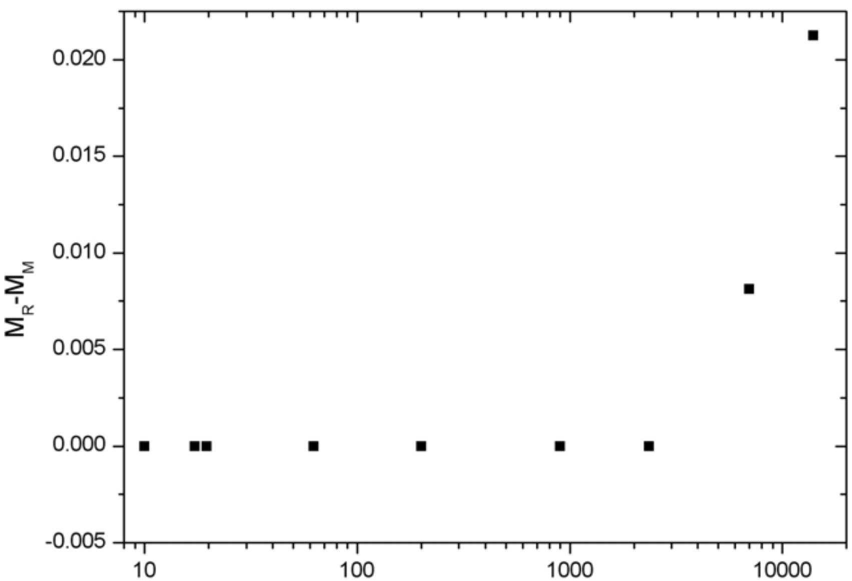
Partial phase space

(0.4 < p_t < 0.8 GeV/c and |y|<0.5)



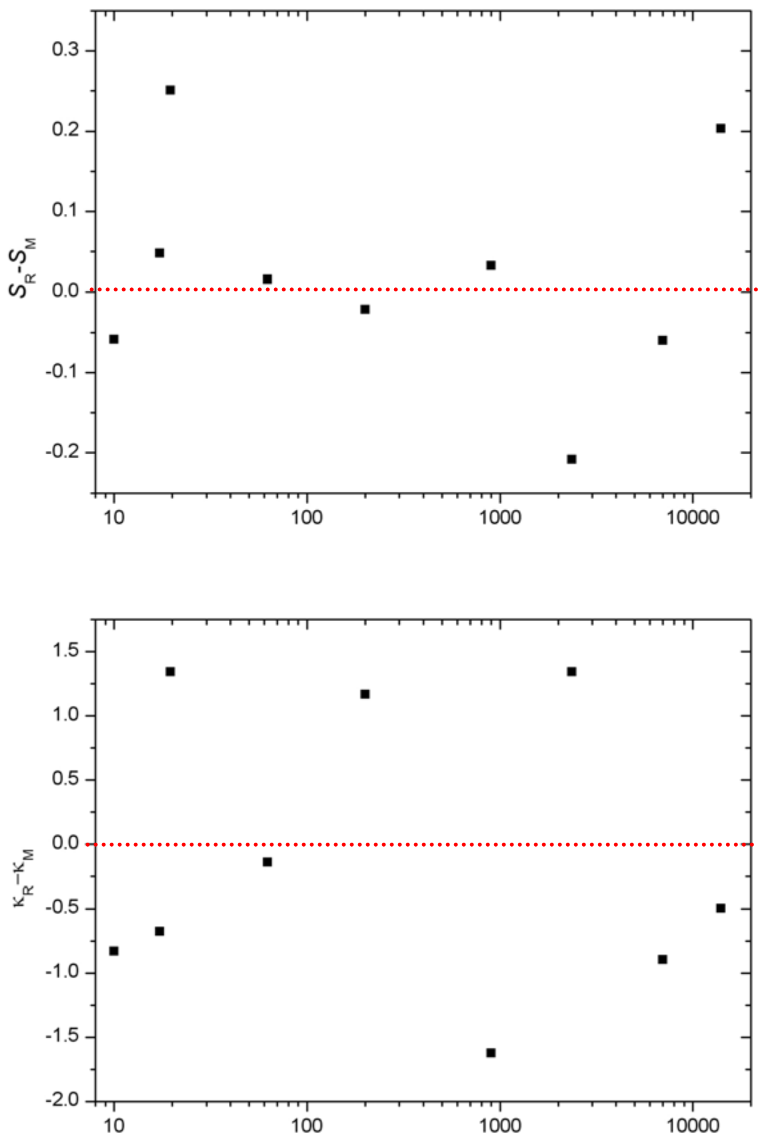
$\sqrt{s}(GeV)$

Full phase space

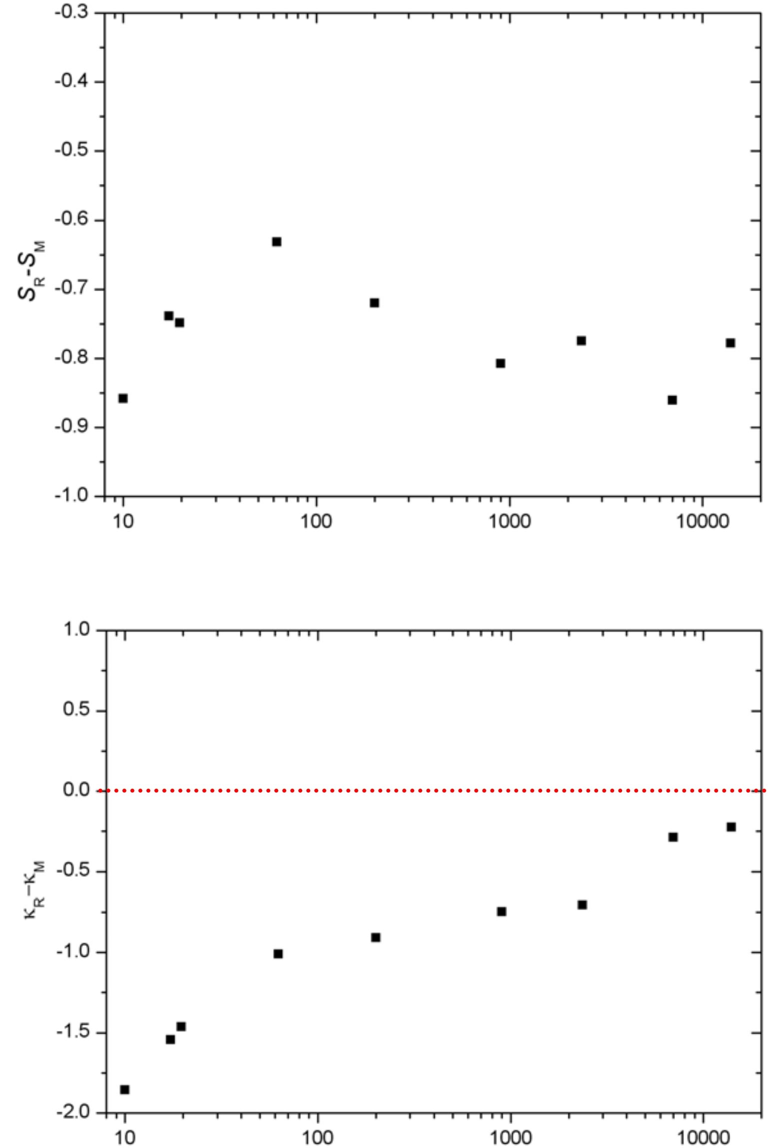


$\sqrt{s}(GeV)$

Partial phase space



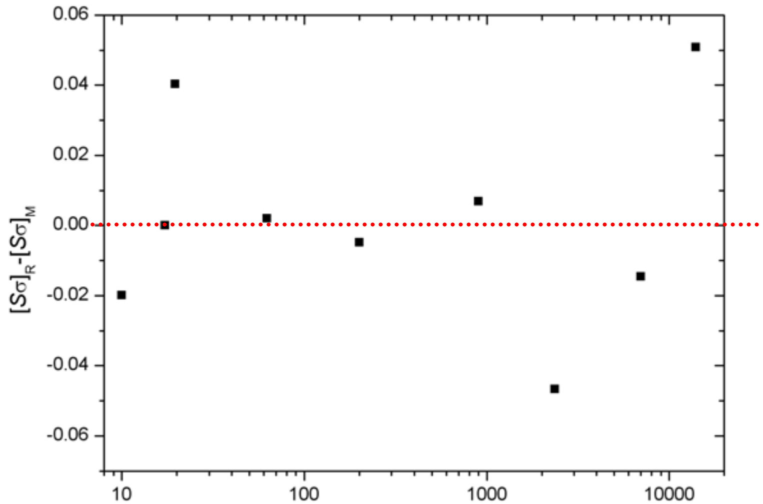
Full phase space

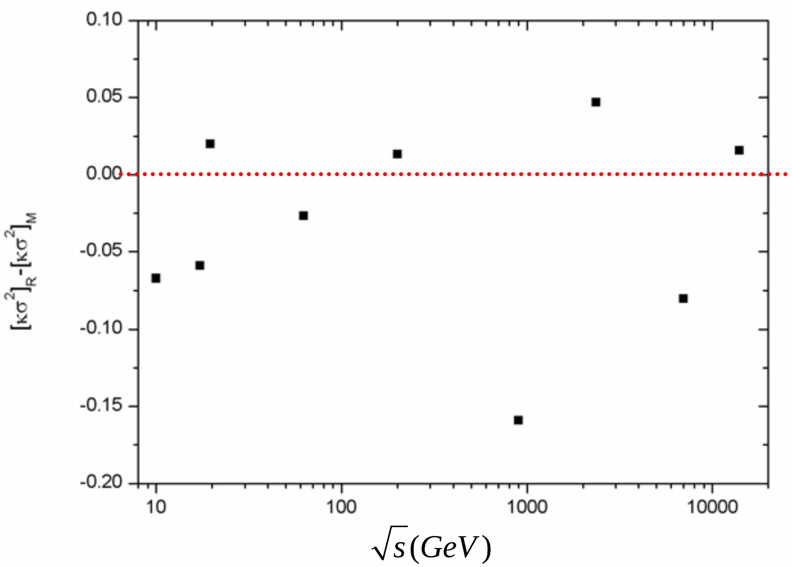


In FS, the dynamical S and κ are negative for the whole energy region

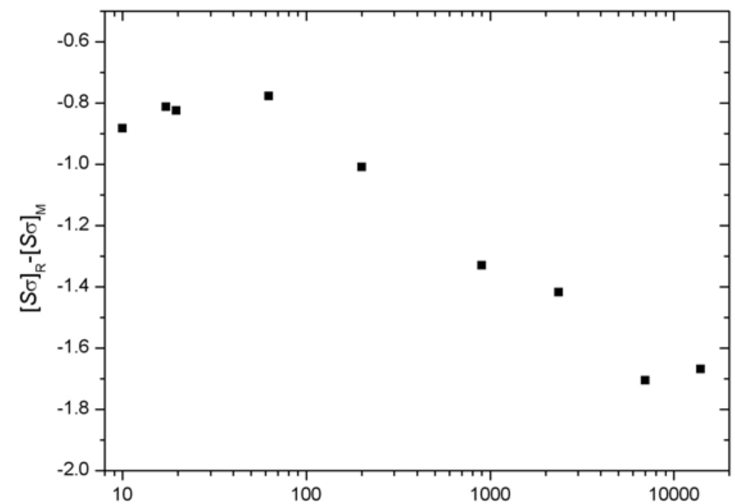
Partial phase space

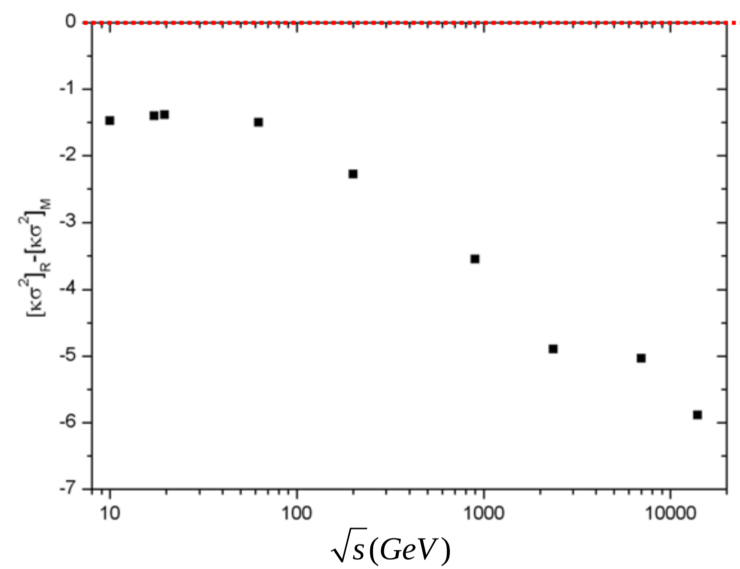
(0.4 < p_t < 0.8 GeV/c and |y|<0.5)





Full phase space





In FS, the moments product are negative for the whole energy region

Conclusion

- PACIAE is able to describe multiplicity, p_t, and η distributions and moments
- For the study of approaching CT, one should study $M_D^{(n)} = M_R^{(n)} - M_M^{(n)}$ instead of $M_R^{(n)}$ itself
- Behavior of moments in partial phase space are different from full phase space
- In partial and full phase space, Kurtosis and Skewness changing sign at difference energy
- Evidences of Kurtosis and Skewness changing sign → approaching critical point?

Note that the results still need to be improved of the statistics

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