Presence of Non-dynamical Fluctuations in the Higher Moments of Net-proton Measurements

Prakhar Garg

Department of Physics and Astronomy

Stony Brook University

Stony Brook University

OUTLINE

- ⌘ **Brief Introduction**
- ⌘ **Sources of Non-dynamical Fluctuations**
- ⌘ **MC studies for stopped protons and pile-up contributions**
- ⌘ **Conclusion**

BES Motivation: CEP

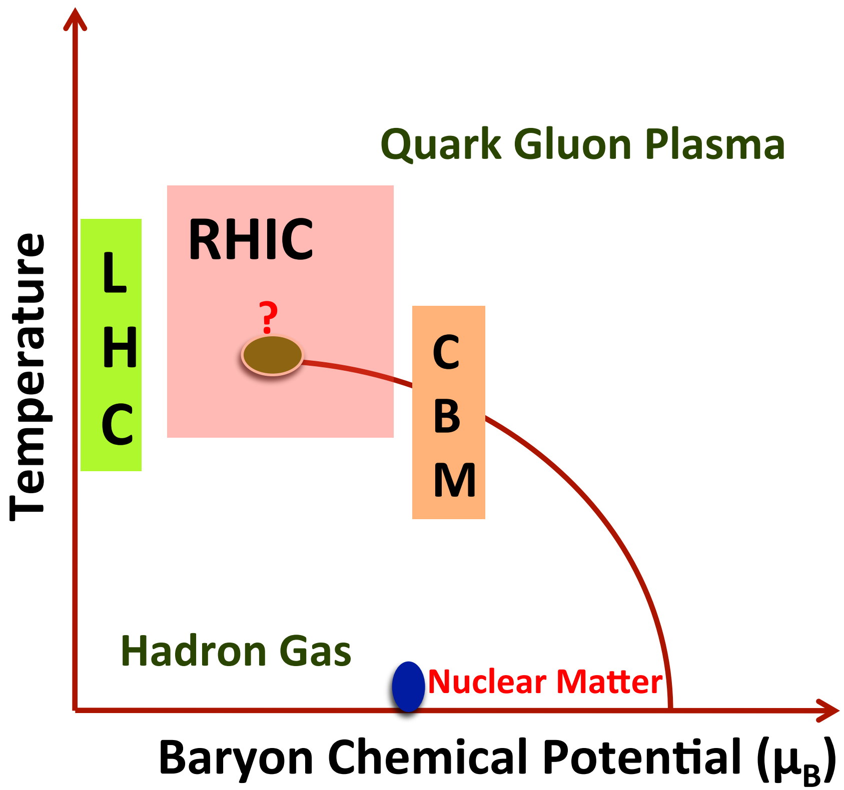
- The temperature driven transition at zero μ_B indicate a rapid crossover from the hadronic phase to the QGP phase.

- The μ_B driven transition at finite T is a first order phase transition.

- A first order line originating at zero T must end somewhere in the midst of the phase diagram where the phase transition is a crossover

This end point of a first order phase transition line is a critical end point (CEP)

Limited theoretical guidance, need data!!



Fluctuations: Theory to Experimental observables are performed using cumulants

- **Cumulants of fluctuations of conserved quantities are related to thermodynamic susceptibilities *(Lattice QCD and Hadron Resonance Gas (HRG) model)***

- **1st moment:**
  mean $\mu = \langle x \rangle$
- **2nd cumulant:**
  variance $\kappa_2 = \sigma^2 = \langle (x-\mu)^2 \rangle$
- **3rd cumulant: $\kappa_3 = \mu_3 = \langle (x-\mu)^3 \rangle$**
- **3rd standardized cumulant:**
  skewness = $S = \kappa_3/\kappa_2^{3/2} = \langle (x-\mu)^3 \rangle / \sigma^3$
- **4th cumulant:** $\kappa_4 = \langle (x-\mu)^4 \rangle - 3\kappa_2^2$
- **4th standardized cumulant:**
  kurtosis = $\kappa = \kappa_4/\kappa_2^2 = \{\langle (x-\mu)^4 \rangle / \sigma^4\} - 3$

Calculate moments from the event-by-event net-multiplicity distribution $\Delta N = N^+ - N^-$

$$\frac{\kappa_2}{\kappa_1} = \frac{\sigma^2}{\mu} = \frac{\chi_2}{\chi_1}$$

$$\frac{\kappa_4}{\kappa_2} = \kappa\sigma^2 = \frac{\chi_4}{\chi_2}$$

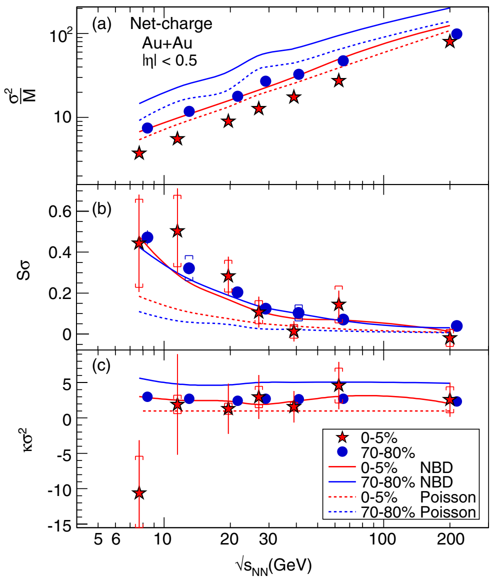
$$\frac{\kappa_3}{\kappa_2} = S\sigma = \frac{\chi_3}{\chi_2}$$

Cumulant ratios are Independent of Volume

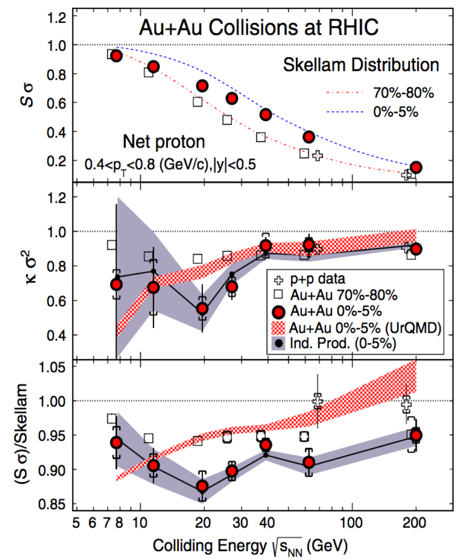
M.Cheng et al, Phys. Rev. D 79, 074505 (2009)
F. Karsch and K. Redlich, Phys. Lett. B 695, 136 (2011)

Several Measurements

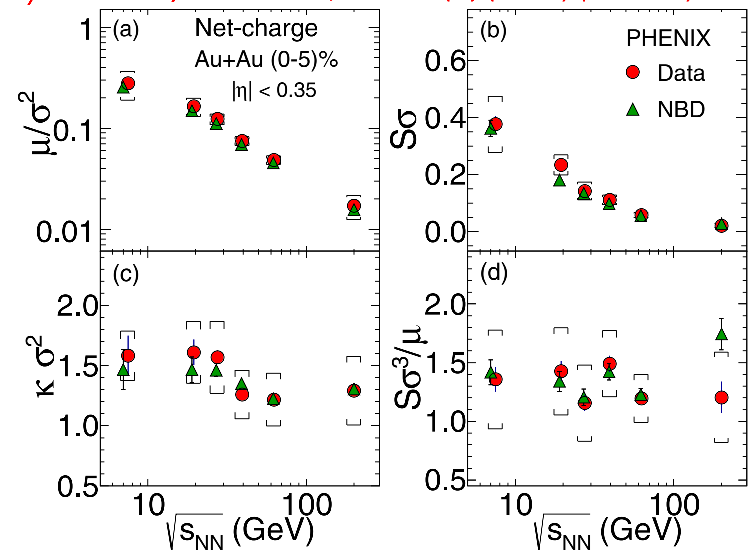
Phys.Rev.Lett.113,092301(2014) (STAR)



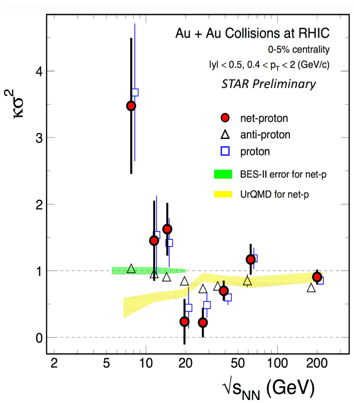
Phys.Rev.Lett.112,032302(2014) (STAR)



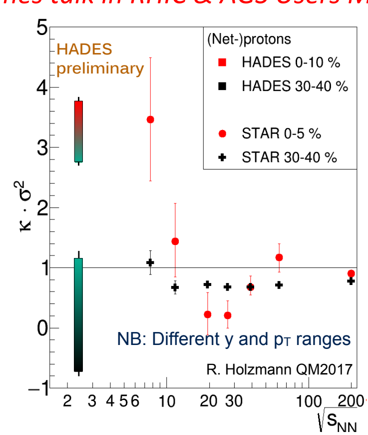
*Phys. Rev. C **93**, 011901(R) (2016) (PHENIX)*



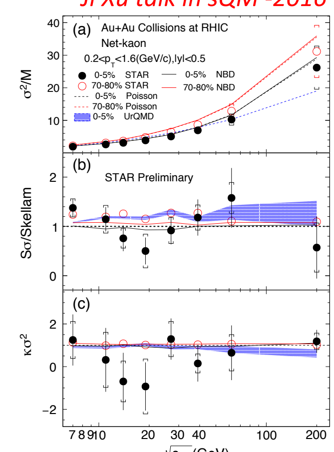
Roli Esha talk in CPOD 2017 (STAR)



Helen Caines talk in RHIC & AGS Users Meeting-2017



Ji Xu talk in sQM -2016



Sources of Non-dynamical Fluctuations

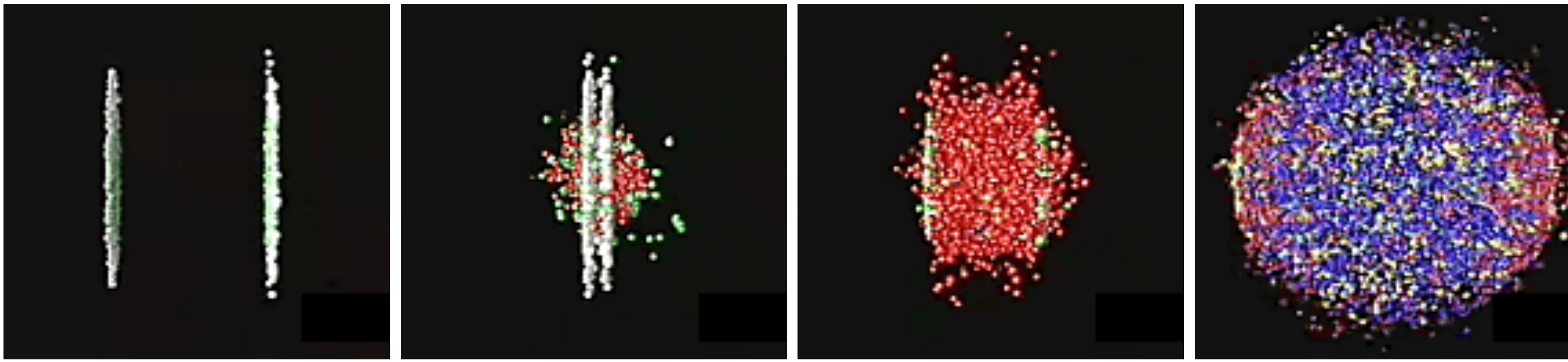
- **Effect of phase-space acceptance:** *P. Garg, D. K. Mishra et al. (Phys. Lett. B 726 (2013) 691-696)*
  Frithjof Karsch el al. Phys. Rev. C 93(2016), 034907
- **Effect of e-by-e eficiency corrections:** *P. Garg, D. K. Mishra et al. (J. Phys. G 40 (2013) 055103)*
  A. Bzdak and V. Koch, Phys. Rev. C 86 (2012), 044904
  A. Bzdak and V. Koch, Phys. Rev. C 91 (2015) 027901
- **Effect of non-extensive statistics:** *D. K. Mishra, P. Garg et al. (J. Phys. G 42 (2015), 105105)*
- **Ensemble dependence:** *P. Garg, D. K. Mishra et al. (Eur. Phys. J. A52 (2016), 27)*
- **Effect of correlations on cumulants:** *P. Garg, D. K. Mishra et al. (Phys. Rev. C 93 (2016), 024918)*
- **Effect of Resonance Decay:** *D. K. Mishra, P. Garg et al. (Phys. Rev. C 94 (2016), 014905)*
  Marlene Nahrganget al. Eur. Phys. J. C (2015) 75:573
- **Effect of Participant Fluctuations:** *P. Braun-Munzinger et al. (NPA 960 (2017) 114)*
- **Global baryon number conservation:** *P. Braun-Munzinger et al. (PLB 747 (2015) 292)*
- ***........ AND SO ON***

In this talk (for net-proton fluctuation measurements)

⌘ Effect of stopped proton Fluctuations -> *D. K. Mishra & P. Garg* arXiv:1706.04012
and
D. Thakur, S. Jakhar, P. Garg et al. (Phys.Rev. C95 (2017), 044903)

⌘ Effect of event Pile-up -> *P. Garg & D. K. Mishra* *arXiv:1705.01256*

Part I: Baryon Stopping



Ions about to collide *Ion collision* *Quarks, gluons freed* *Plasma created*

- Large amount of energy is deposited in a small region of space in a short duration of time.

- Occurrence of high energy density regions:
  -> Baryon rich Quark Gluon Plasma (@ low $\sqrt{s_{NN}}$)
  -> Baryon free Quark Gluon Plasma (@ high $\sqrt{s_{NN}}$)

At RHIC BES-I Energies: Inclusive protons contain produced protons and stopped protons

Number of stopped protons fluctuate e-by-e leading to additional fluctuations

Need **to disentangle the contribution of stopped protons and produced protons**

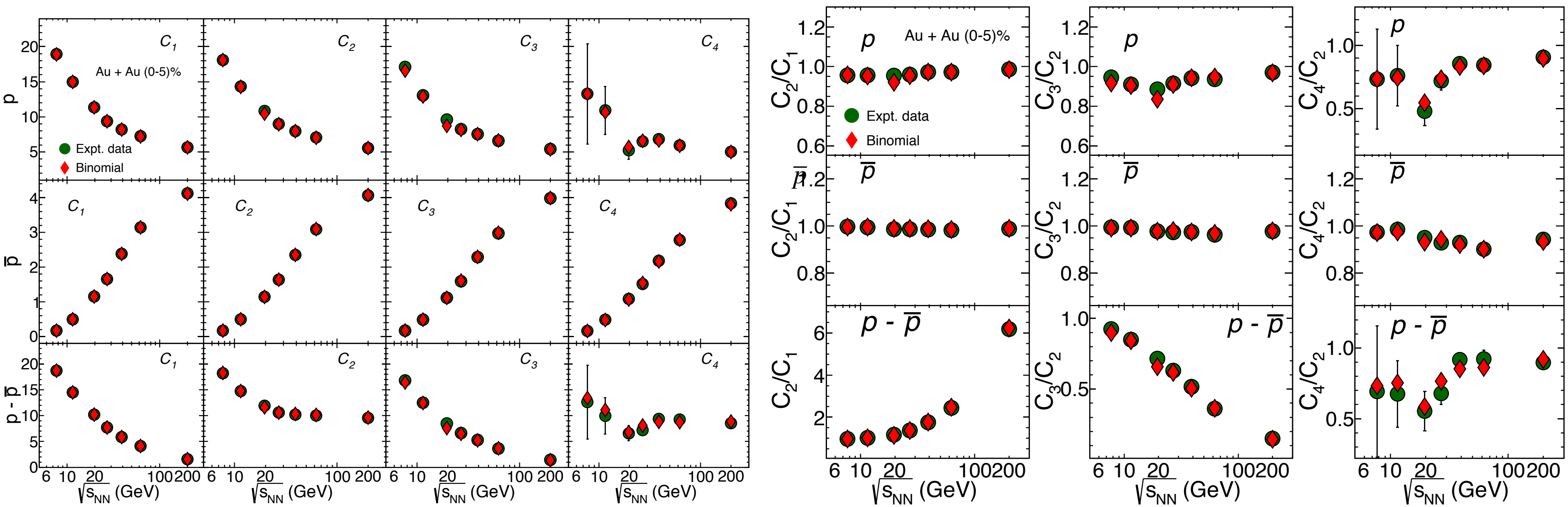
Experimentally difficult to tag stopped proton and produced proton

Get proton and anti-proton distributions by tuning with STAR cumulants data for Au+Au collisions

STAR net-proton DATA https://drupal.star.bnl.gov/STAR/files/starpublications/205/data.html

MC Points

arXiv:1706.04012



The Binomial expectations are tuned for proton and anti-proton cumulants data at each $\sqrt{s_{NN}}$

The cumulants in data are already corrected for efficiency and finite bin width effects

Comparison of Stopped Protons with STAR results

Phys.Rev. C95 (2017), 044903

Phys. Lett. B 690,358(2010)

$$N^{\text{protons}}_{\text{stopped}}(\text{STAR}) = 158 \times N^{\text{protons}}_{\text{stopped}}\% \times N^{\text{protons}}_{p_T}\%$$

(a) $\sqrt{s_{NN}}$	(b) $N^{\text{protons}}_{\text{stopped}}(\text{STAR})$	(c) $N^{\text{protons}}_{\text{STAR}}$	(d) Diff.	(e) $N^{\text{antiprotons}}_{\text{STAR}}$
7.7	17.21 ± 0.86	18.92 ± 0.01	1.71 ± 0.86	0.165
11.5	12.89 ± 0.86	15.00 ± 0.01	2.10 ± 0.86	0.49
19.6	9.73 ± 0.80	11.37 ± 0.00	1.63 ± 0.80	1.15
27.0	7.61 ± 0.73	9.39 ± 0.00	1.78 ± 0.73	1.65
39.0	5.78 ± 0.65	8.22 ± 0.00	2.44 ± 0.65	2.38
62.4	3.78 ± 0.54	7.25 ± 0.00	3.47 ± 0.54	3.14
200	1.54 ± 0.33	5.664 ± 0.00	4.12 ± 0.33	4.11

STAR DATA: https://drupal.star.bnl.gov/STAR/files/starpublications/205/data.html

- A large contribution of stopped protons at BES energies.
- After subtracting the stopped protons from the mean of STAR protons distribution, remaining produced protons are consistent with mean of anti-proton distribution measured by STAR.

Method: Extract the weight factors

Phys.Rev. C95 (2017), 044903

$\sqrt{s_{NN}}$ (GeV)	7.7	11.5	19.6	27	39	62.4	200
Incl. proton	18.918 ± 0.009	15.005 ± 0.006	11.375 ± 0.003	9.390 ± 0.002	8.221 ± 0.001	7.254 ± 0.002	5.664 ± 0.001
anti-proton	0.165 ± 0.001	0.490 ± 0.001	1.150 ± 0.001	1.652 ± 0.001	2.379 ± 0.001	3.135 ± 0.001	4.116 ± 0.001
stopped proton	17.21 ± 0.86	12.89 ± 0.86	9.73 ± 0.80	7.61 ± 0.73	5.78 ± 0.65	3.78 ± 0.54	1.54 ± 0.33

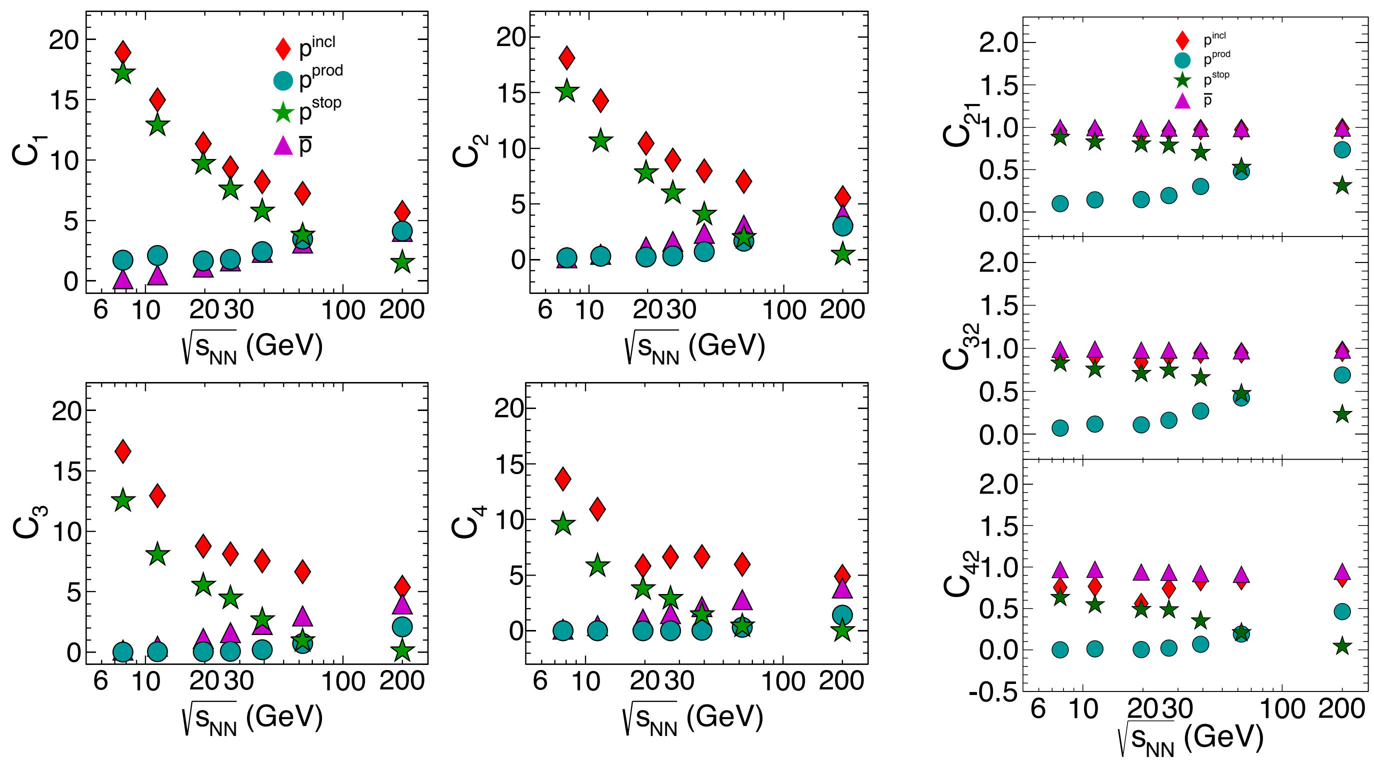
$$\frac{C_1 \text{ of } p^{stop}}{C_1 \text{ of } p^{inclu}} = \text{Fraction of Stopped Protons}$$

Now, "assuming" that this fraction is also distributed according to the Binomial distribution

We get a corrected distribution for produced protons

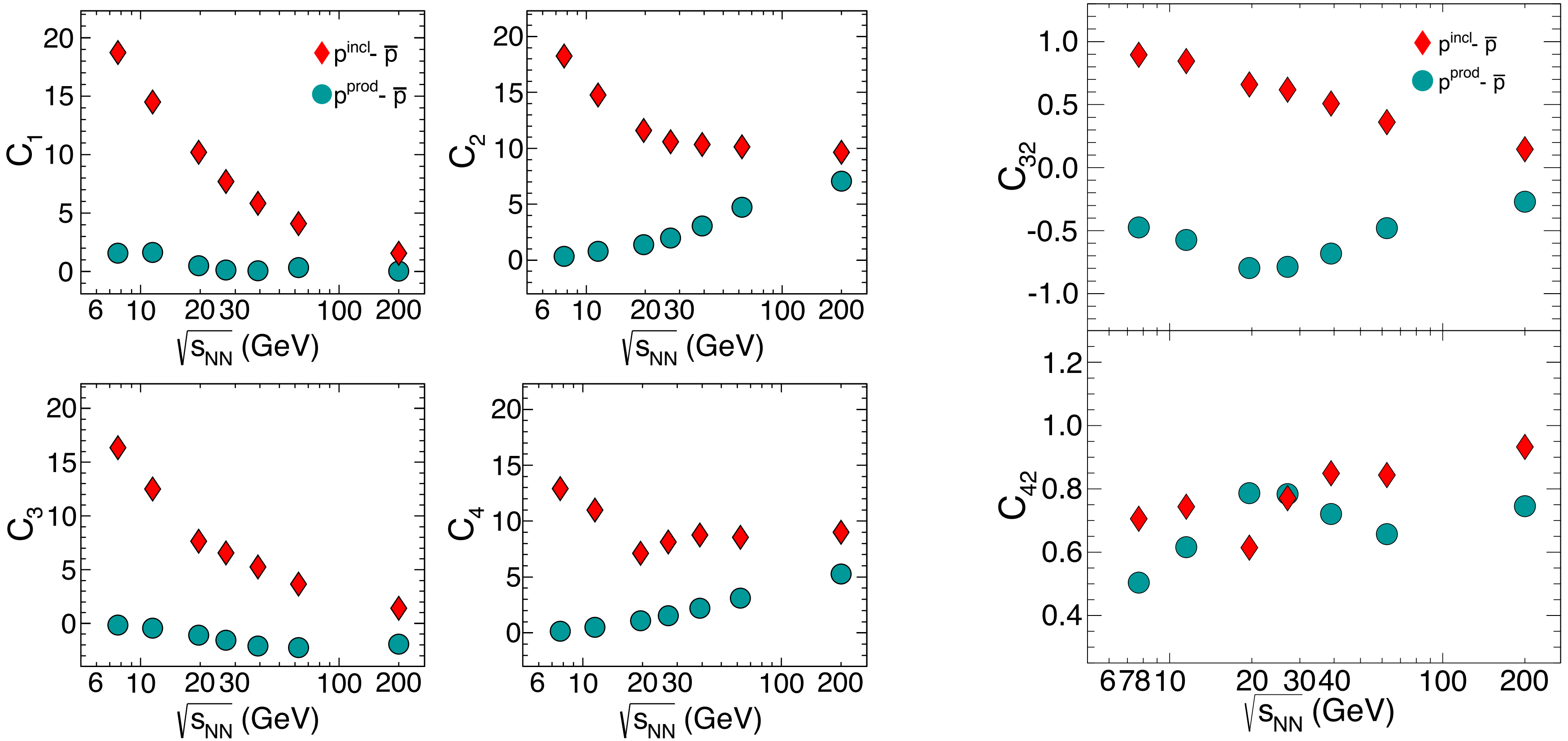
Cumulants and their ratios for individuals

arXiv:1706.04012



At lower collision energies, the p^{incl} fluctuations are dominated by p^{stop} and at higher energies they are dominated by produced proton fluctuations.

Cumulants and their ratios for net-protons



➢ **Corrections for stopped proton fluctuation may enhance the signal as can be seen for C_{32}**

arXiv:1706.04012

Part II: Event Pile-up Effects

In high luminosity heavy-ion collisions, there may be following sources of the background events during a collision

- In-time pile-up: If more than one collisions are occurring in the same bunch-crossing in a collision of interest;
- Out-of-time pile-up: If additional collisions are occurring in a bunch-crossing before and after the collision.
- Cavern background: Mainly low energy neutrons and photons
- Beam halo events: The dispersion in the beam
- Beam gas events: Collisions between the bunch and the residual gas inside the beam-pipe.

Ref: ***Harnarine Ian, "A Study of Pile-up in 200 GeV Au+Au Collisions at RHIC", Doctoral dissertation, University of Illinois at Chicago, 2005. and references therein.***

Simple MC for event pile-up study

arXiv:1705.01256

Generate the Poisson or NBD Distribution for protons and anti-protons using the Mean values from STAR data

↓

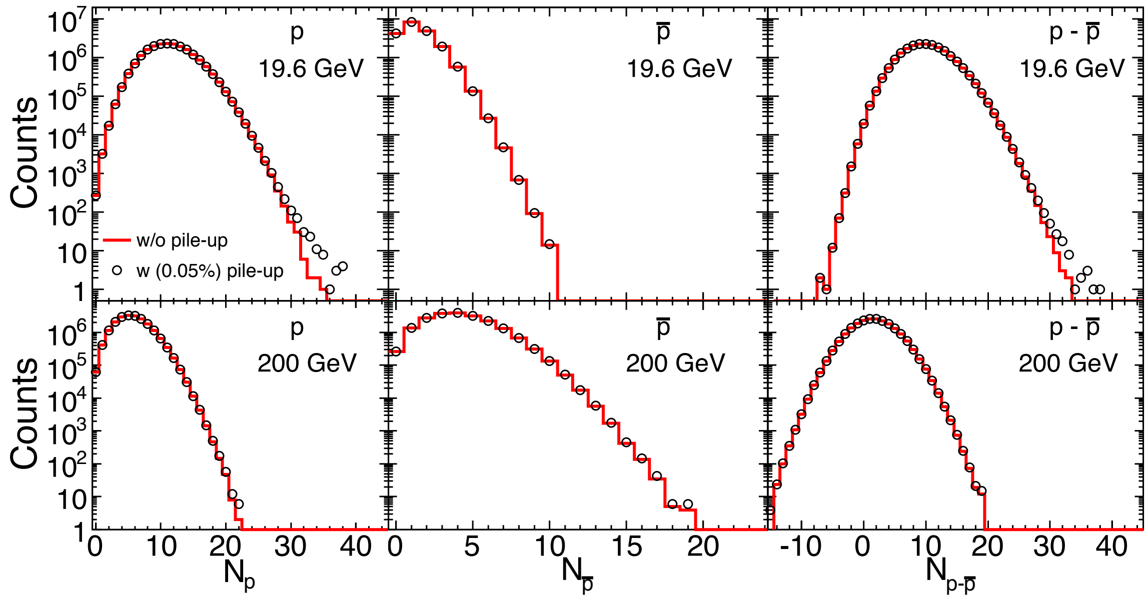
Add extra protons and anti-protons coming from pile-up event

↓

Randomly select the proton multiplicity from MB proton sample and add it to the original distribution

↓

Study the effect on cumulants with different fraction of mixed events

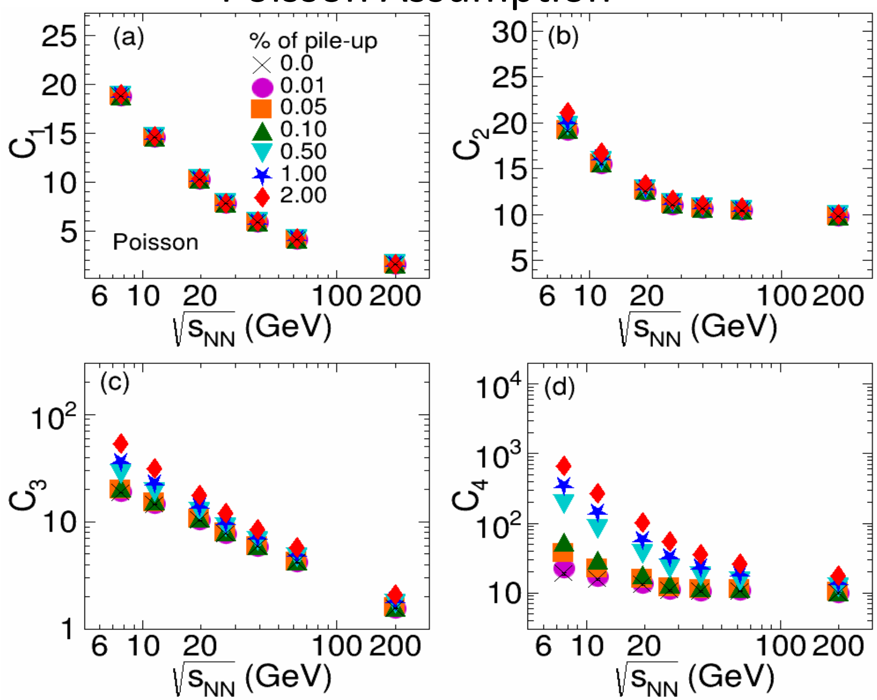


- The proton and anti-proton multiplicities from minimum bias events as pile-up are added with the individual p and $\bar{p}$ distributions assuming each of the distribution as NBD.

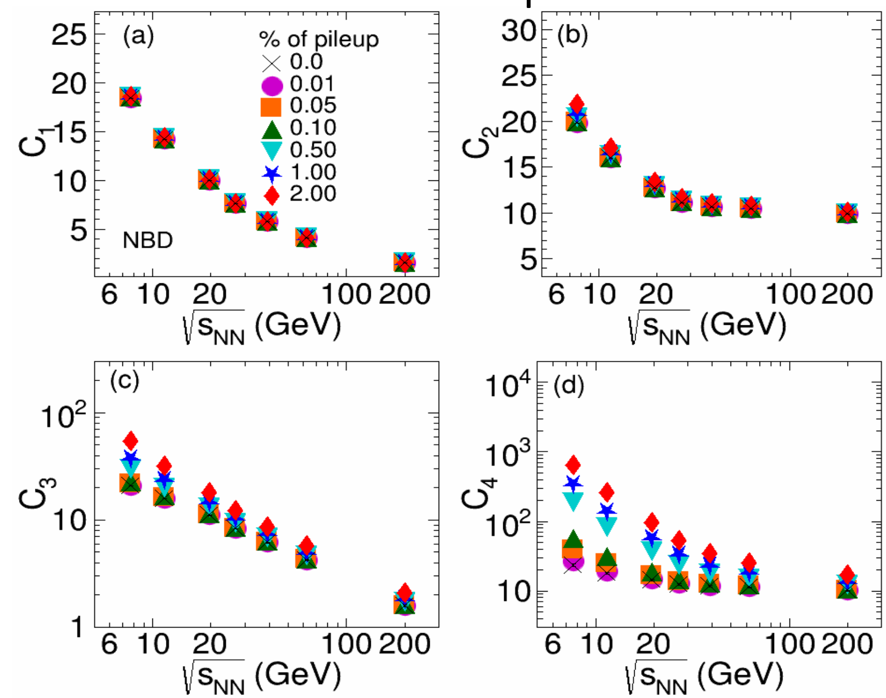
Central + Minimum Bias event as pile-up

arXiv:1705.01256

Poisson Assumption



NBD Assumption

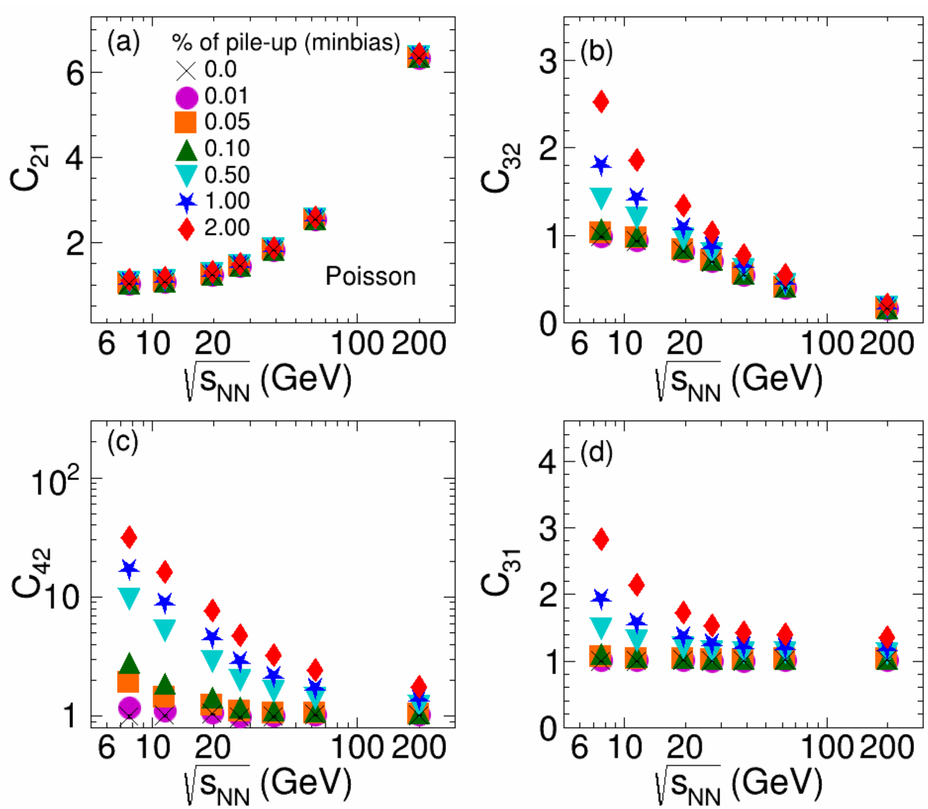


- **More important for higher cumulants!!**

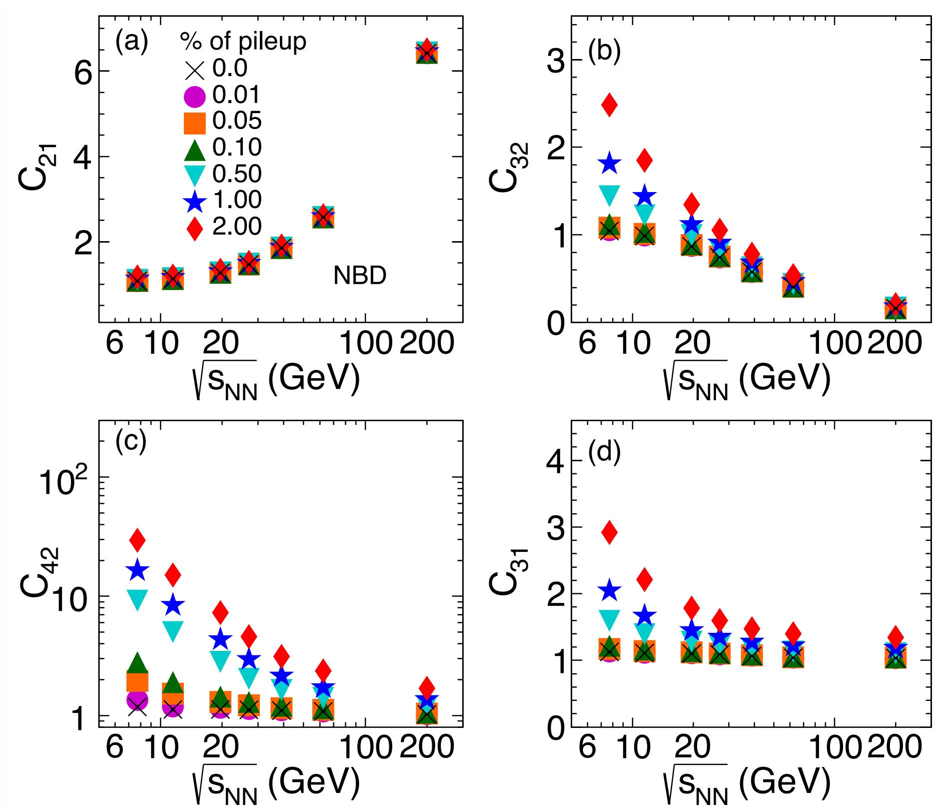
Central + Minimum Bias event as pile-up

arXiv:1705.01256

Poisson Assumption



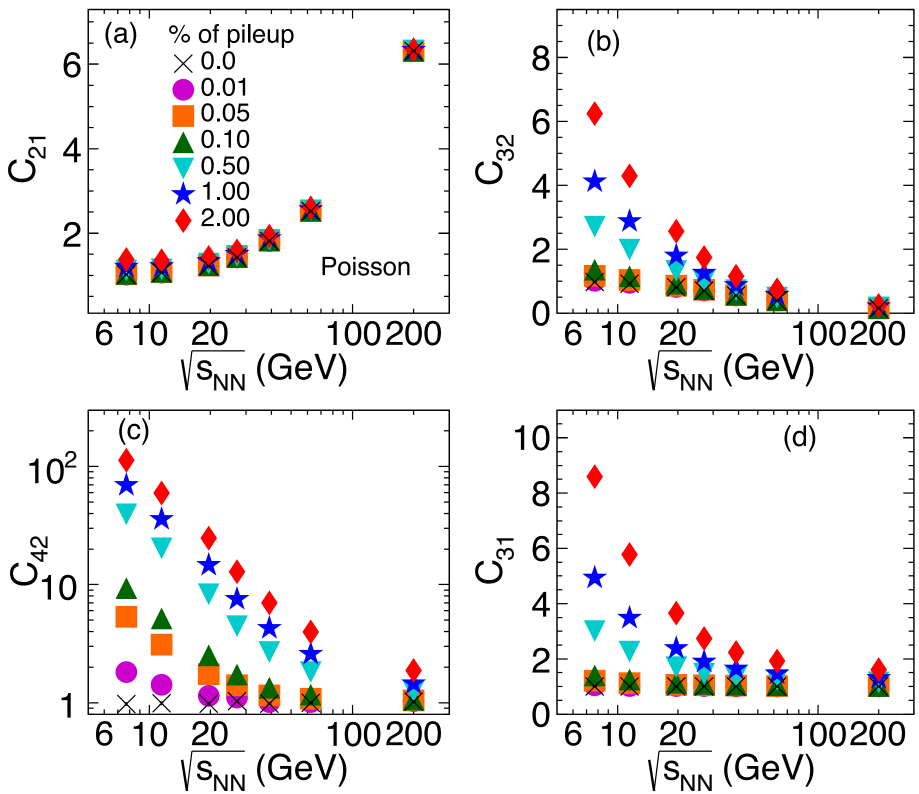
NBD Assumption



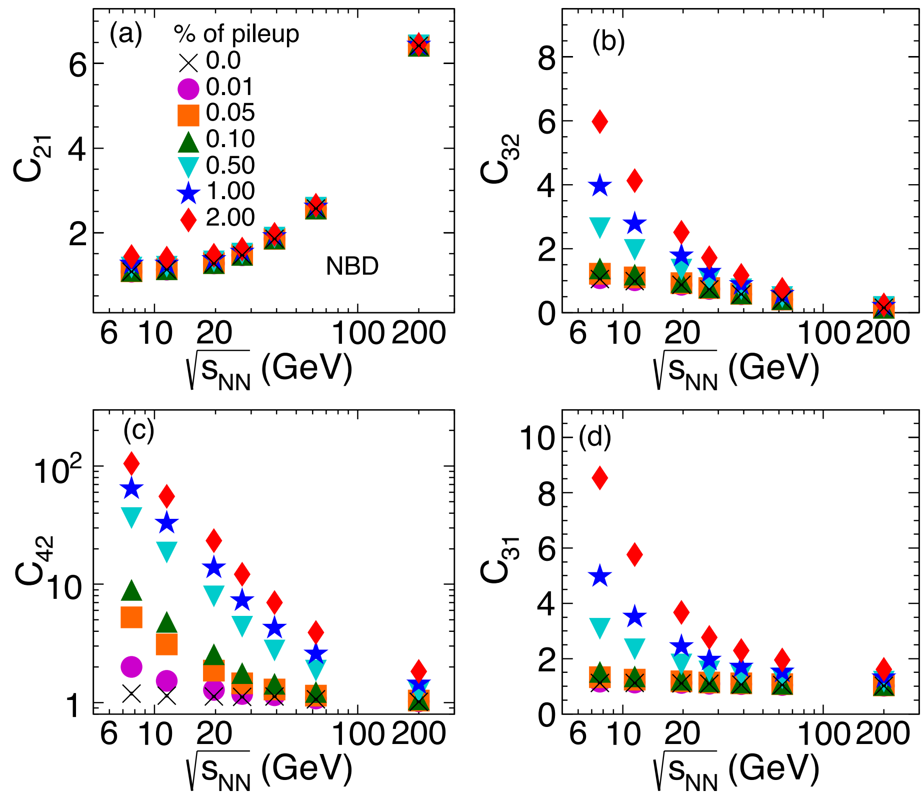
Most Extreme Situation
(Central + Central event as a pile-up)

arXiv:1705.01256

Poisson Assumption



NBD Assumption



Conclusion

- Stopped Proton Fluctuations may have significant effect on the net-proton measurements which needs to be addressed carefully.

- Event-pile up can also influence the Fluctuation Measurements and should be studied in each experimental set-up for cumulants observable.