Experimental Status for QCD Critical Point Search at STAR experiment

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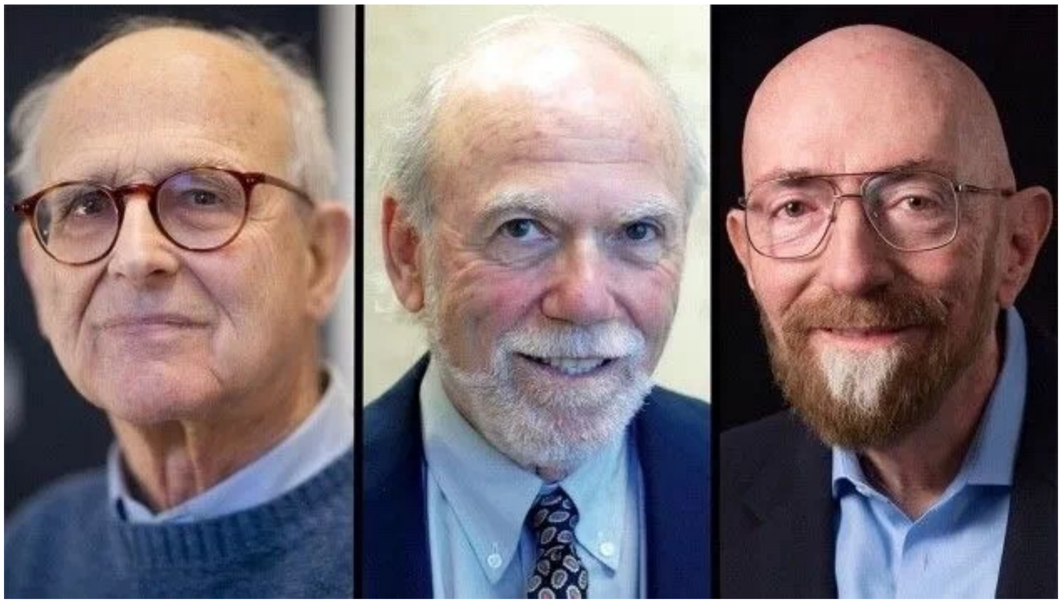
Many thanks to ShinIchi Esumi, Shu He, Masakiyo Kitazawa, Feng Liu, Bedanga Mohanty, Toshihiro Nonaka, Yasushi Nara, Tetsuro Sugiura, Nu Xu.

The Nobel Prize in Physics 2017

For decisive contributions to the LIGO detector and the observation of gravitation wave

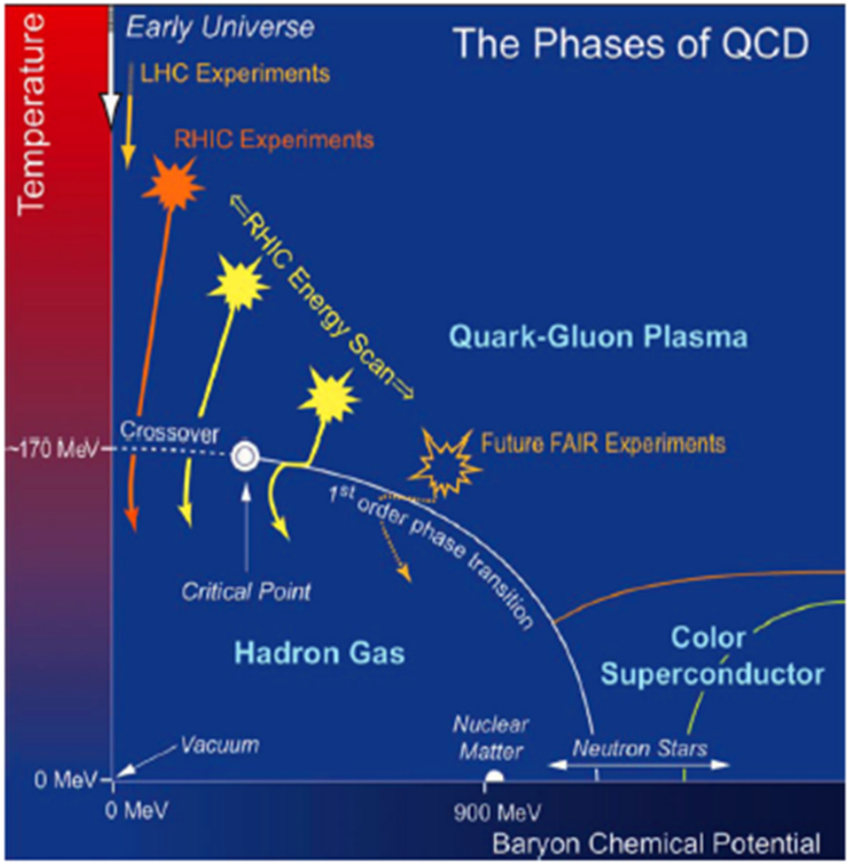


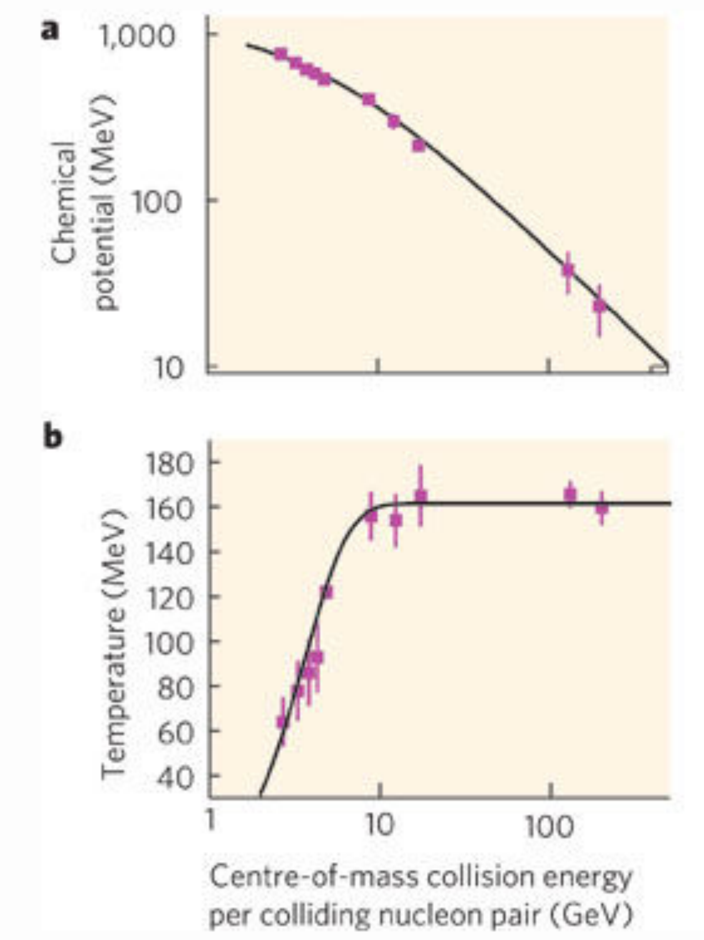
Rainer Weiss (MIT) | Barry C. Barish (Caltech) | Kip S. Thorne (Caltech)

The initial LIGO collected data from 2002 to 2010 but no gravitational waves were detected.

1. 100 years prediction from Einstein's General Relativity.
2. 40 years experimental search : Collaboration (>1000 members) + High precision detector. (Hardware New technique)
3. Novel data analysis techniques: machine learning. (Software New technique)

Physics Motivation





Exploring the QCD phase structure

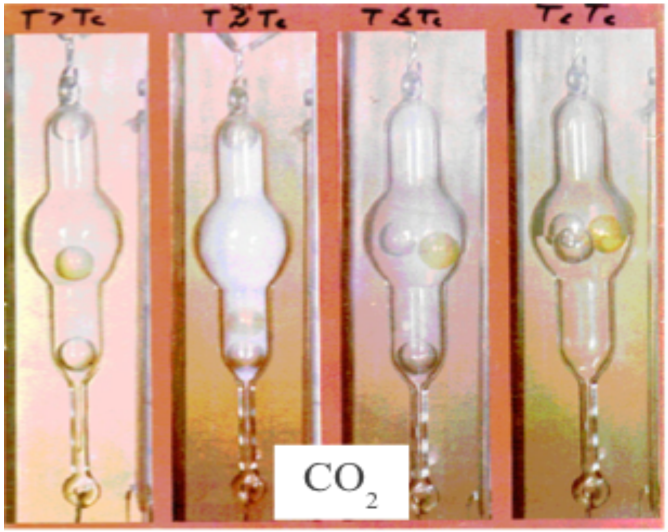
1. Onset of the sQGP signal.
2. Search for the QCD Critical Point
3. 1st order phase boundary

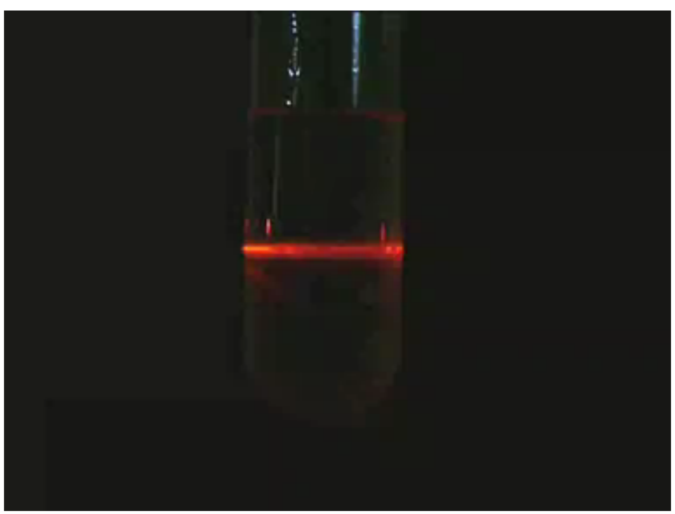
Scan the QCD phase diagram by tuning the colliding energies in heavy-ion collisions !

PBM&Johanna, Nature **448**, 302-309 (2007)

Critical Point and Critical Phenomena

T. Andrews.Phil. Trans. Royal Soc., 159:575, 1869.





Critical Phenomena :

- Density fluctuations and cluster formations.
- Divergence of Correlation length (ξ).

  Susceptibilities (χ), heat capacity (C_V) , Compressibility (κ) etc.

  Critical opalescence.
- Universality and critical exponents determined by the symmetry and dimensions of underlying system.
- Finite Size and Finite time effects.

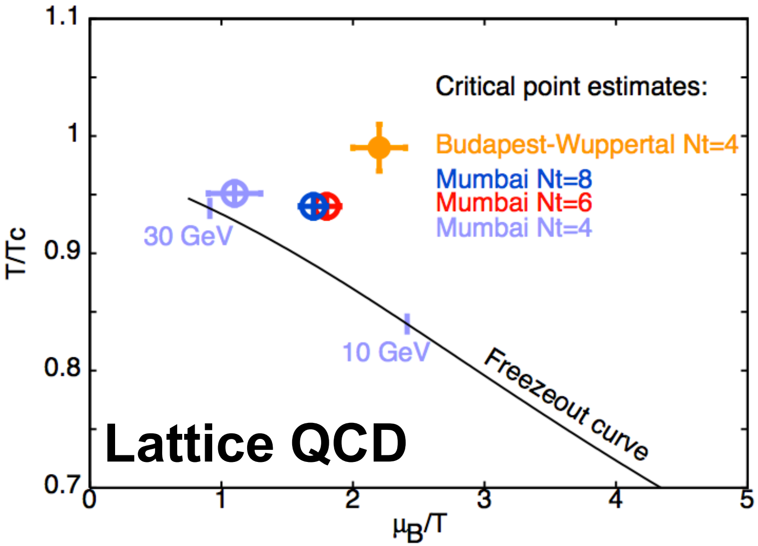
First CP is discovered in 1869 for CO_2 by Andrews.

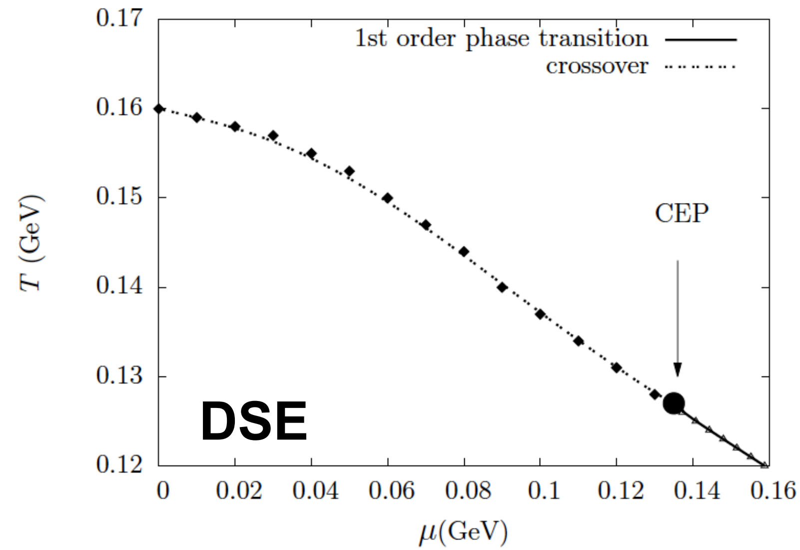
T_c = 31°C

Can we discovery the Critical Point of Quark Matter ? (Put a permanent mark in the QCD phase diagram in text book.)

T_c ~ Trillion (10^{12}) °C

Location of CEP: Theoretical Prediction





Lattice QCD:

1): Fodor&Katz, JHEP 0404,050 (2004):
$(\mu^E_B, T_E) = (360, 162)$ MeV (Reweighting)

2): Gavai&Gupta, NPA 904, 883c (2013)
$(\mu^E_B, T_E) = (279, 155)$ MeV (Taylor Expansion)

3): F. Karsch ($\mu^E_B / T_E > 2$, CPOD2016)

DSE:

1): Y. X. Liu, et al., PRD90, 076006 (2014); 94, 076009 (2016).
$(\mu^E_B, T^E) = (372, 129)$; $(262.3, 126.3)$ MeV

2): Hong-shi Zong et al., JHEP 07, 014 (2014).
$(\mu^E_B, T_E) = (405, 127)$ MeV

3): C. S. Fischer et al., PRD90, 034022 (2014).
$(\mu^E_B, T^E) = (504, 115)$ MeV

$\mu^E_B = 262 \sim 504$ MeV, $T_E = 115 \sim 162$, $\mu^E_B / T_E = 1.74 \sim 4.38$

Fluctuations and Correlations

Two-point correlation functions of magnetic moment:

$$G(\vec{r}) = \langle S(\vec{r})S(0)\rangle - \langle S(\vec{r})\rangle\langle S(0)\rangle$$

$S(\vec{r})$: Spatial Magnetic moment

In 3D case: $$G(\vec{r}) \propto \frac{1}{r} e^{-r/\xi(t)}$$

Correlation length

$$\xi(t) = \xi_0 |t|^{-1/2}$$

Susceptibility (fluctuations) ⟷ **Correlation length**

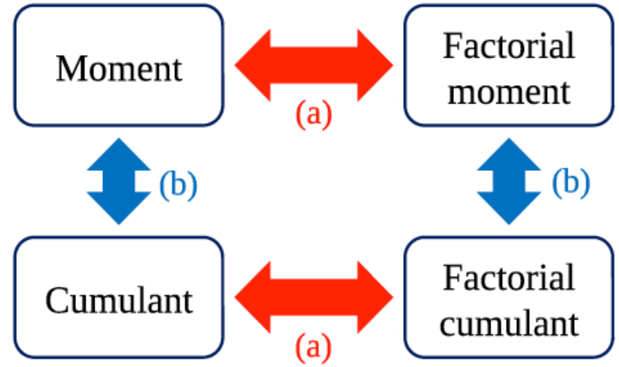
$$\chi \propto \int G(\vec{r})d\vec{r} \propto \xi^2(t)$$

Quantify the Fluctuations

Cumulants generating fun.:

$$G(\theta)=\sum_{n} e^{\theta n}P(n)=\left\langle e^{\theta n}\right\rangle \qquad \left\langle n^{m}\right\rangle_{c}=\left.\frac{\partial^{m}K(\theta)}{\partial\theta^{m}}\right|_{\theta=0}$$

- For Poisson distributions: $C_n = C_1$
- For Gaussian distributions: $C_n=0$, $(n>=3)$



M. Kitazawa, X. Luo, PRC96, 024910 (2017)

- Describe the shape of the distribution
- "Factorial": Remove self-correlations, easy efficiency correction.

Cumulants and Central Moments:

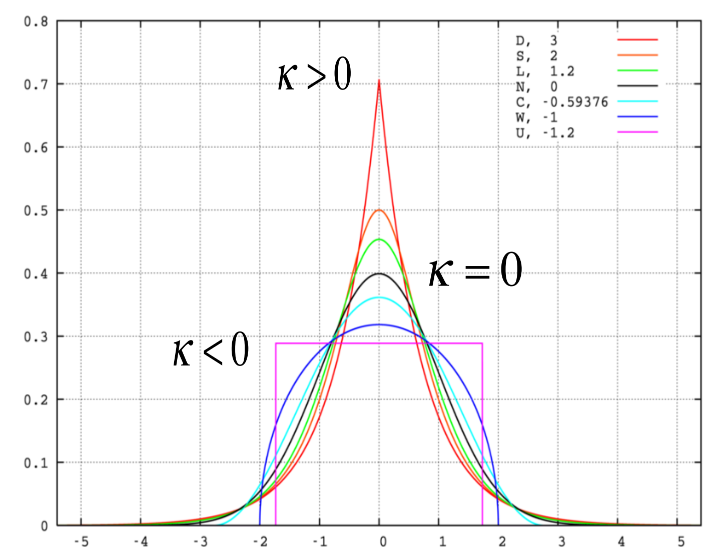
$$C_{1,N}=\langle N\rangle, \quad C_{2,N}=\left\langle(\delta N)^{2}\right\rangle$$

$$C_{3,N}=\left\langle(\delta N)^{3}\right\rangle, \quad C_{4,N}=\left\langle(\delta N)^{4}\right\rangle-3\left\langle(\delta N)^{2}\right\rangle^{2}$$

$$\delta N=N-\langle N\rangle$$

Variance, Skewness and Kurtosis:

$$\sigma^{2}=C_{2,N}, S=\frac{C_{3,N}}{(C_{2,N})^{3/2}}, \kappa=\frac{C_{4,N}}{(C_{2,N})^{2}}$$



Cumulants of Conserved Charges Distributions

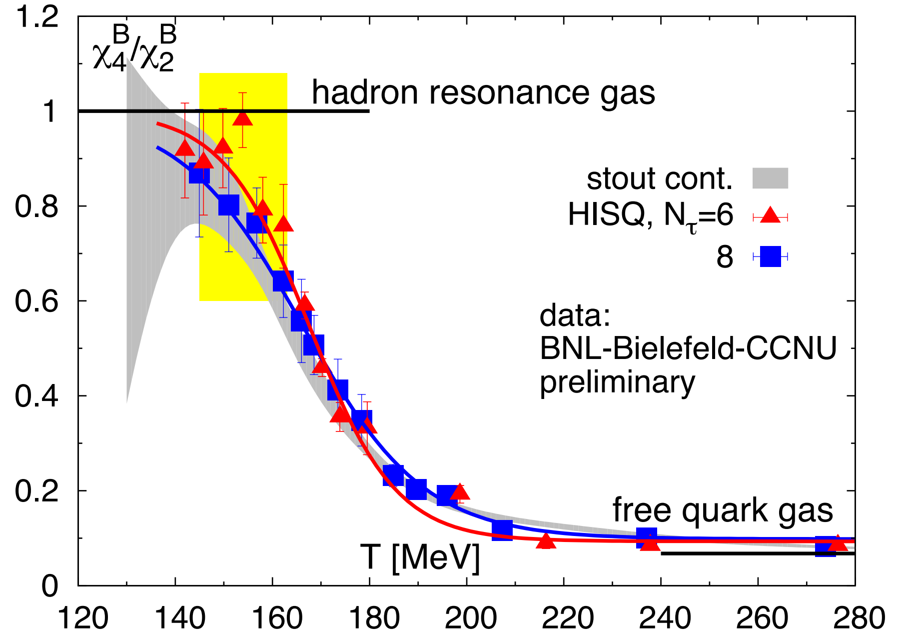
The cumulants of conserved charges (B, Q, S) in grand canonical ensemble are extensive variables, and are directly connected to the susceptibility of the system.

$$C_{n,q} = VT^3 \chi_q^{(n)} = \frac{\partial^n (p/T^4)}{\partial(\mu_q/T)^n}, \qquad q = B,Q,S$$

Cancel out the volume dependence by taking ratios of cumulants:

$$\frac{C_{4,q}}{C_{2,q}} = \kappa\sigma^2 = \frac{\chi_q^{(4)}}{\chi_q^{(2)}}$$

$$\frac{C_{3,q}}{C_{2,q}} = S\sigma = \frac{\chi_q^{(3)}}{\chi_q^{(2)}}$$

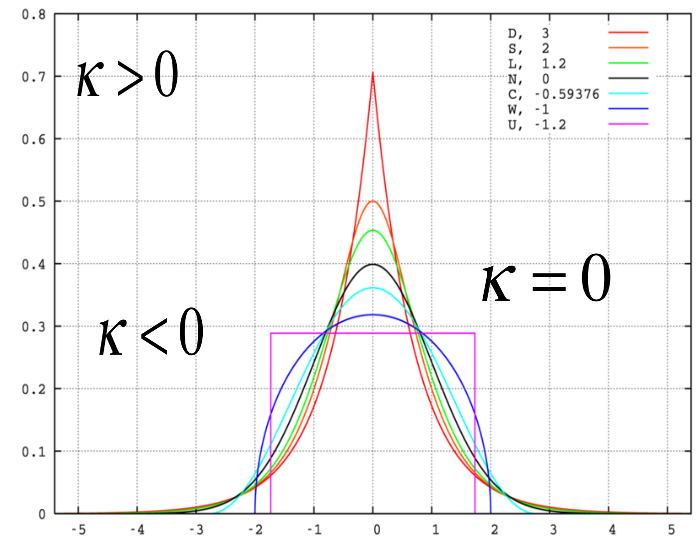


S. Ejiri et al,Phys.Lett. B 633 (2006) 275. B. Friman et al., EPJC 71 (2011) 1694. F. Karsch and K. Redlich , PLB 695, 136 (2011). S. Gupta, et al., Science, 332, 1525(2012).

Observables measured at STAR

Cumulants of the event-by-event net-proton, net-charge and net-kaon distributions.

- **Net-Proton:** $N_p - N_{\bar{p}}$
  (Net-Baryon, *B*)
- **Net-Charge:** $N_{Q^+} - N_{Q^-}$
- **Net-Kaon:** $N_{K^+} - N_{K^-}$
  (Net-Strangeness, *S*)



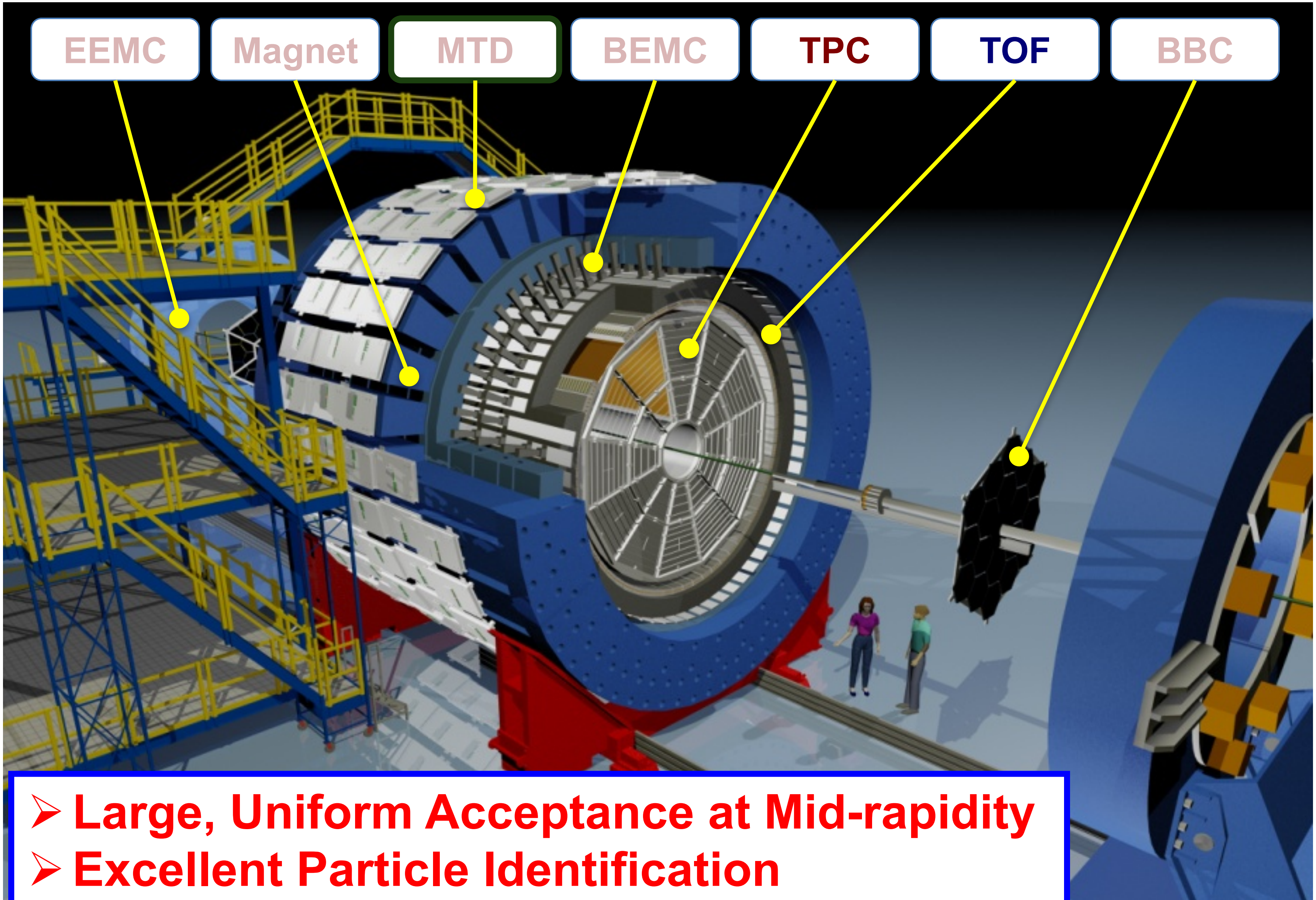
$$C_{2,q} \propto \xi^2, C_{3,q} \propto \xi^{4.5}, C_{4,q} \propto \xi^7$$

$$\frac{C_{4,q}}{C_{2,q}} = \kappa\sigma^2 \propto \xi^5$$

$$\frac{C_{3,q}}{C_{2,q}} = S\sigma \propto \xi^{9/4}$$

M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).
M.Asakawa, S. Ejiri and M. Kitazawa, Phys. Rev. Lett. 103, 262301 (2009).

STAR Detector

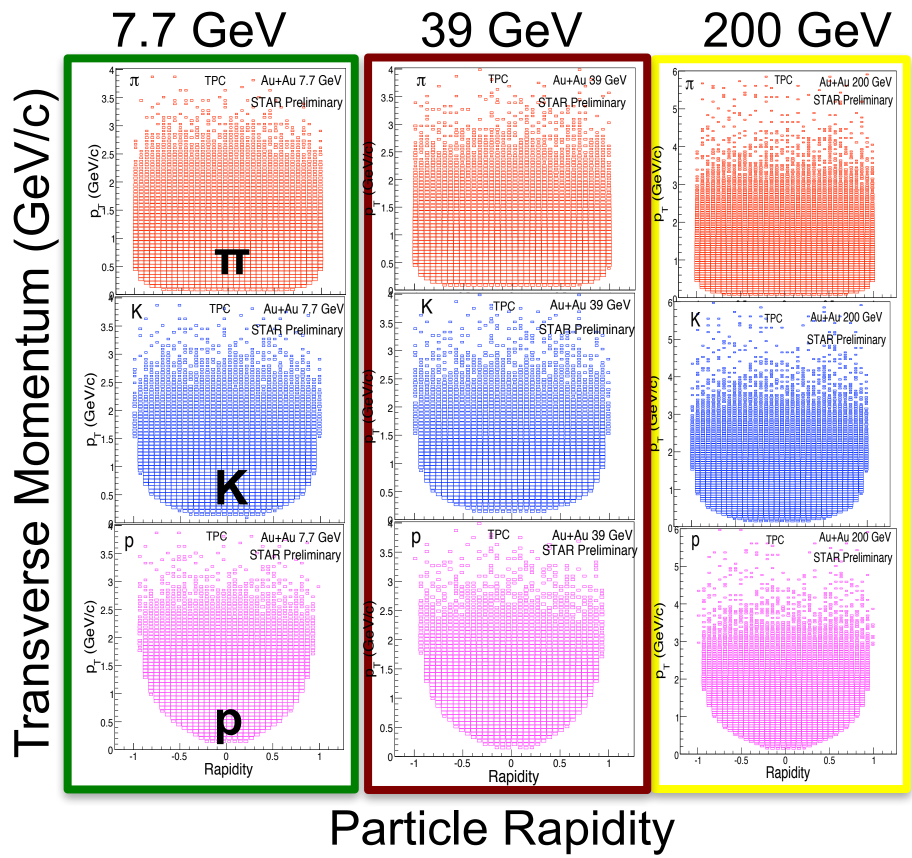


- Large, Uniform Acceptance at Mid-rapidity
- Excellent Particle Identification

Beam Energy Scan - I (2010-2017)

$\sqrt{s_{NN}}$ (GeV)	Events ($X10^6$)	Year	*μ_B (MeV)	*T_{CH} (MeV)
200	350	2010	25	166
62.4	67	2010	73	165
54.4	~500	2017	83	165
39	39	2010	112	164
27	70	2011	156	162
19.6	36	2011	206	160
14.5	20	2014	264	156
11.5	12	2010	316	152
7.7	4	2010	422	140

*(μ_B, T_{CH}) : J. Cleymans et al., PR**C73**, 034905 (2006)

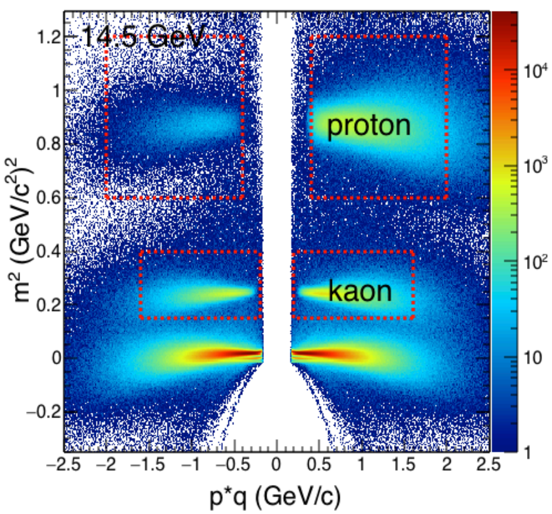


- ➢ Large and homogeneous acceptance at mid-rapidity.
- ➢ STAR has good opportunity to explore the QCD phase structure by accessing broad region of phase diagram.

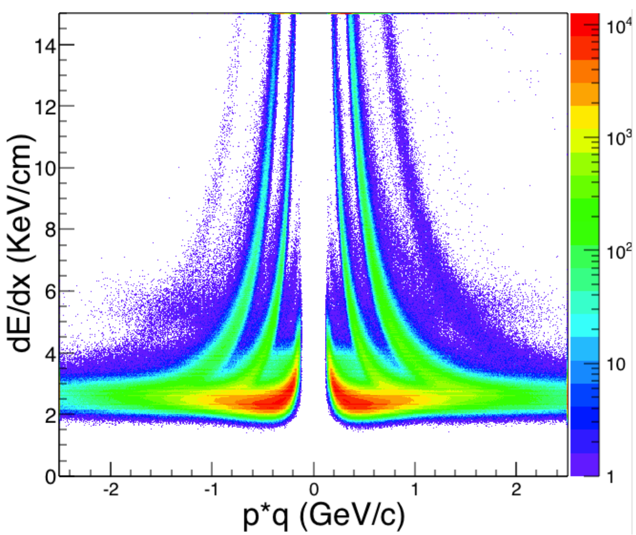
Analysis Details

	Net-Charge	Net-Proton	Net-Kaon
Kinematic cuts	$0.2 < p_T$ (GeV/c) < 2.0 $\|\eta\| < 0.5$	$0.4 < p_T$ (GeV/c) < 2.0 $\|y\| < 0.5$	$0.2 < p_T$ (GeV/c) < 1.6 $\|y\| < 0.5$
Particle Identification	Reject protons form spallation for $p_T < 0.4$ GeV/c	$0.4 < p_T$ (GeV/c) < 0.8 → TPC $0.8 < p_T$ (GeV/c) < 2.0 → TPC+TOF	$0.2 < p_T$ (GeV/c) < 0.4 → TPC $0.4 < p_T$ (GeV/c) < 1.6 → TPC+TOF
Centrality definition, → *to avoid auto-correlations*	Uncorrected charged primary particles multiplicity distribution	Uncorrected charged primary particles multiplicity distribution, without (anti-)protons	Uncorrected charged primary particles multiplicity distribution, without (anti-)kaons
	$0.5 < \|\eta\| < 1.0$	$\|\eta\| < 1.0$	$\|\eta\| < 1.0$

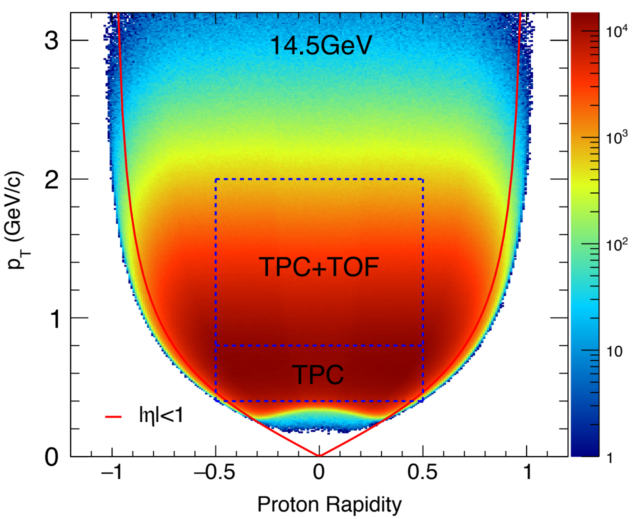
TOF PID



TPC PID

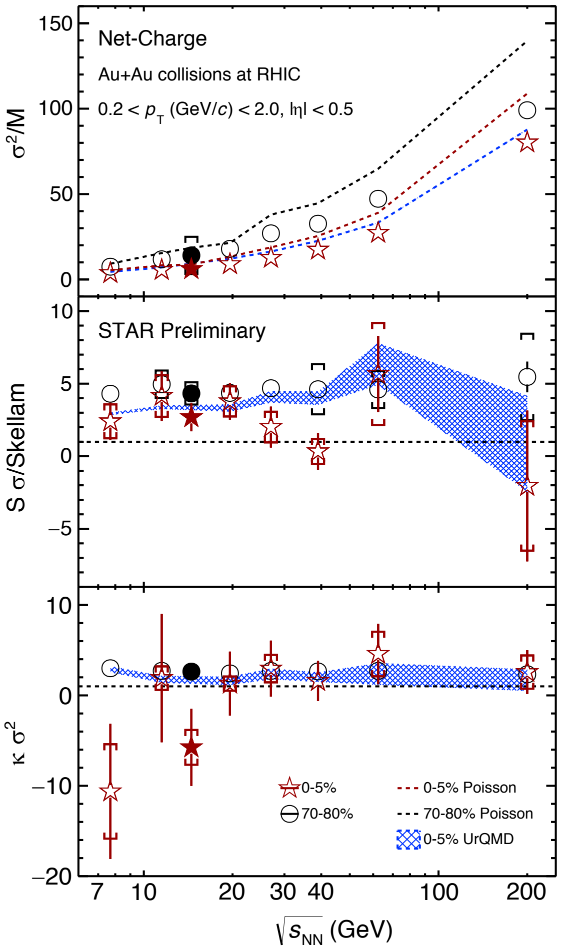


Phase Space



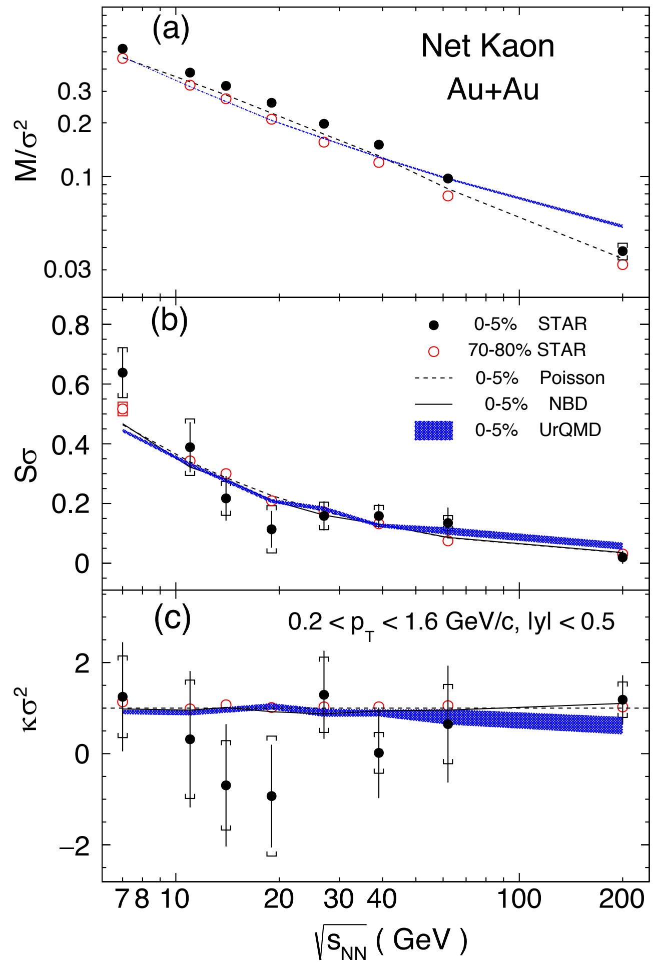
Experimental Results : Energy dependence

Net-Charge (Q)



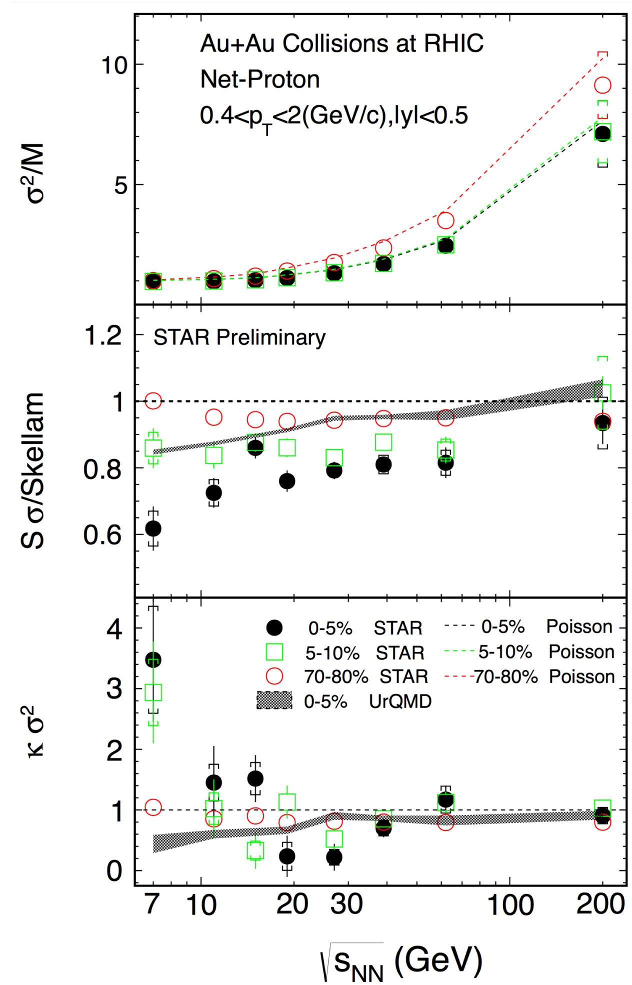
STAR, PRL113,092301 (2014)
STAR, QM 2015

Net-Kaon (S)



STAR, submitted to PLB [arXiv: 1709.00773]

Net-Proton (B)



STAR, PRL105,022302 (2010);
STAR, PRL112,032302 (2014).
STAR, CPOD 2014, QM 2015

1. Large errors are observed in Q and S fluctautions, Statistical Errors: Q > S > B.
2. Non-monotonic energy dependence observed in 4th order net-proton fluctuations.

What those data can be used for ?

1. Search for QCD Critical Point (CP).

See Misha's talk

2. Extract chemical freeze-out conditions in heavy-ion collisions.

See Frithjof, Rene and Claudia's talk

3. Other applications.

Three questions need to be addressed for CP search

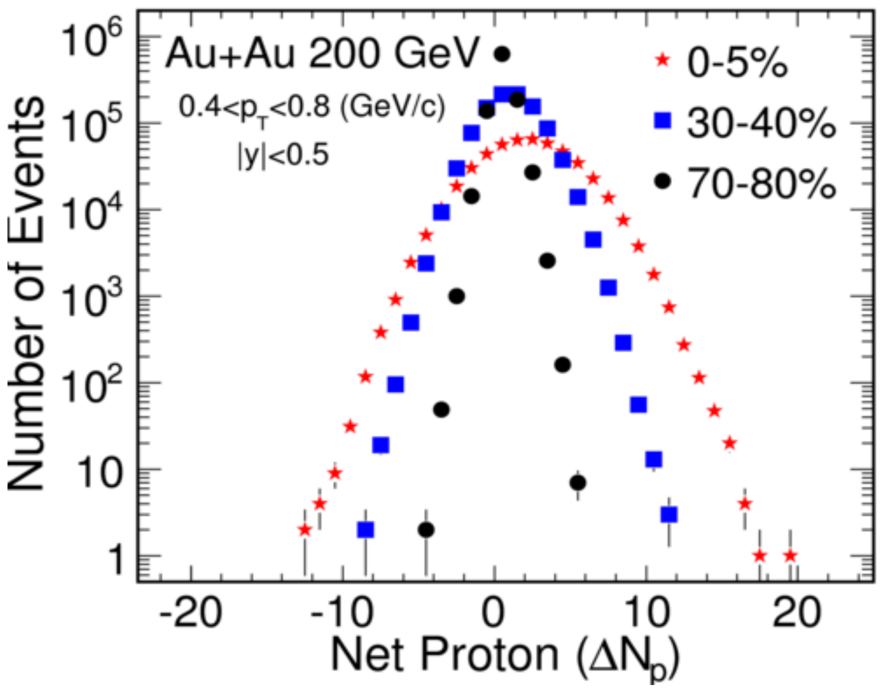
1. Do we precisely measure the fluctuations in heavy-ion collisions (value and uncertainties) ? (experimental analysis methods)

2. What's the characteristic signature (model independent) of the QCD critical point for the fluctaution observable in heavy-in collisions ?

3. What's the background (non-CP) contributions to the experimental observables ?

Data Analysis Methods

Raw net-p prob. distribution



STAR, **PRL**105,022302 (2010);

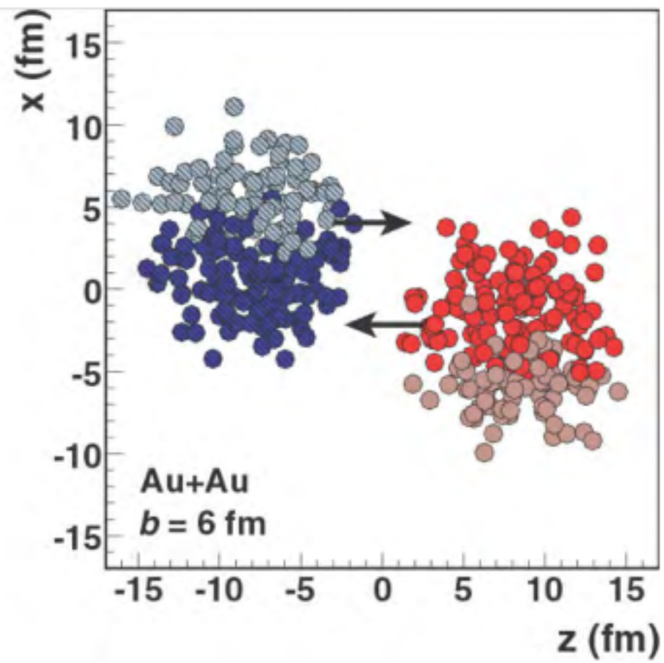
1. **Initial Volume Fluctuations.**
   centrality bin width correction.
2. **Remove auto-correlation.**
   New centrality definition.
3. **Efficiency Correction.**
   Binomial efficiency response
4. **Statistical Error Estimation.**
   Delta theorem and Bootstrap

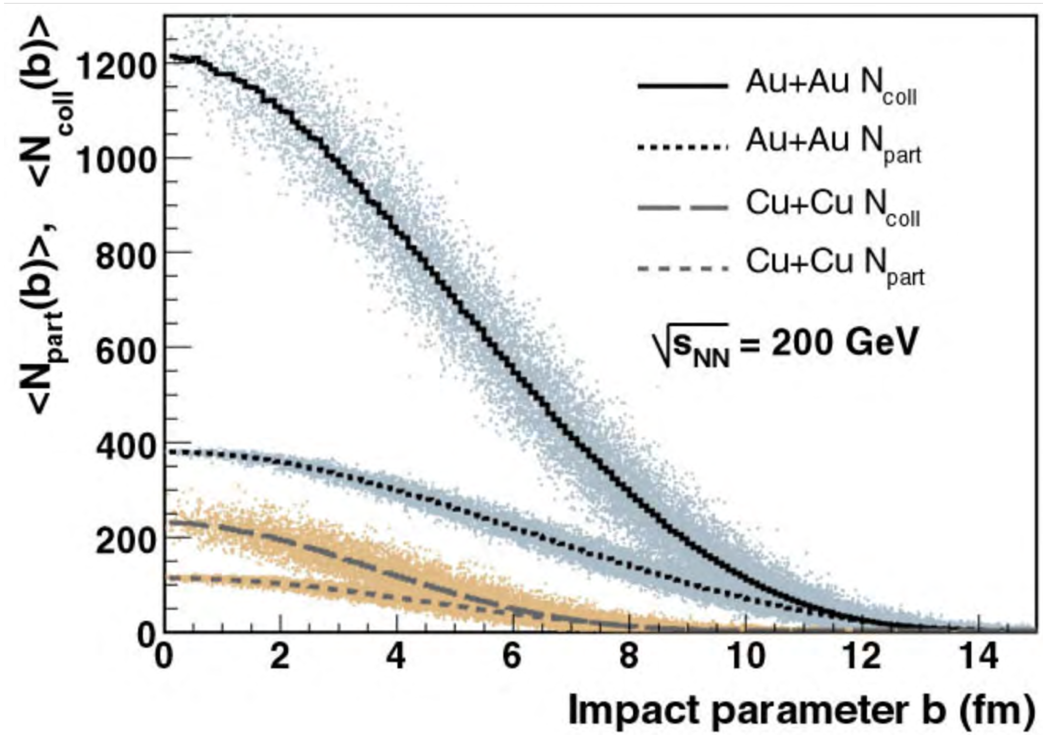
$$error \propto O\left(\sigma^n / \varepsilon^\alpha\right)$$

X.Luo, et al. J. Phys. G39, 025008 (2012); *A. Bzdak and V. Koch, PRC86, 044904 (2012); X.Luo, et al. J. Phys. G40,105104(2013); X.Luo, Phys. Rev. C 91, 034907 (2015); A . Bzdak and V. Koch, PRC91, 027901 (2015). T. Nonaka et al., PRC95, 064912 (2017). M. Kitazawa and X. Luo, PRC*96, 024910 (2017).

Review article : X. Luo and N. Xu, Nucl. Sci. Tech. 28, 112 (2017). [arXiv: 1701.02105]

Collision Volume (Geometry) Fluctuations



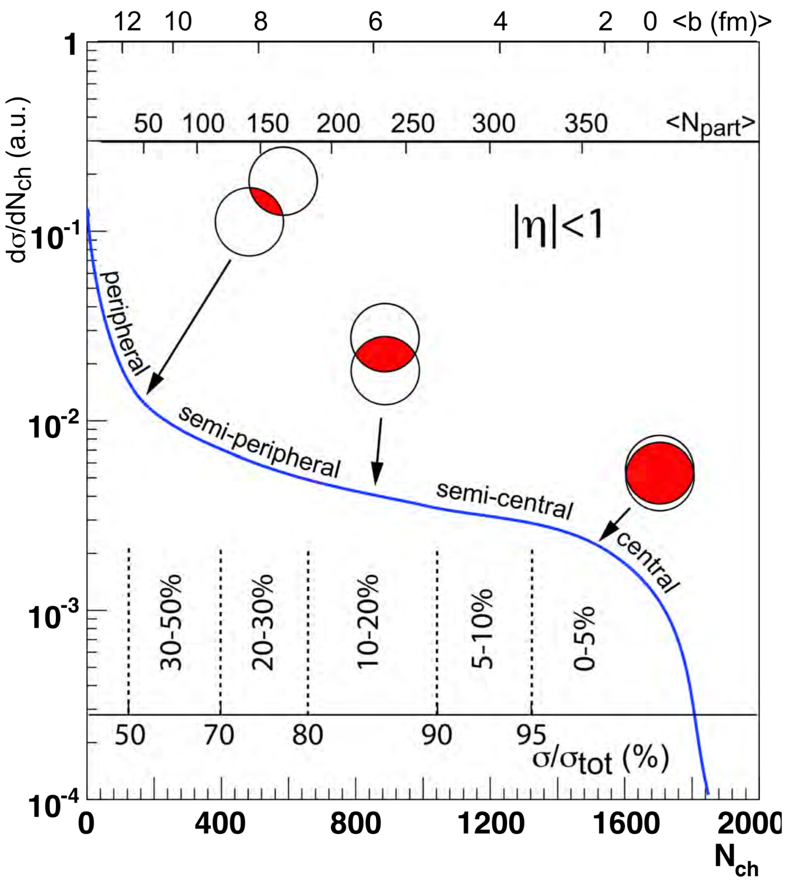


- Even at fix impact parameters, the number of participant and binary collisions still show large fluctuations.
- The quantities (b, Npart, Ncoll) cannot be directly measured experimentally.

Grand Canonical Ensemble, but the system volume fluctuate event-by-event
How to control the volume fluctuations ?

Centrality Determination Matters

Experimental results are usually reported within one wide centrality



N_{ch}: Charged particle multiplicity

Generally, collision centralities are determined by N_{ch} in heavy-ion collisions.

- Multiplicity Fluctuations by assuming superposition of independent nucleon-nucleon collisions:

PHYSICAL REVIEW D VOLUME 42, NUMBER 3 1 AUGUST 1990

Multiplicity moments and nuclear geometry in relativistic heavy-ion collisions

Zhuang Pengfei and Liu Lianshou
Institute of Particle Physics, Hua-Zhong Normal University, Wuhan 430070, China
(Received 3 October 1989; revised manuscript received 19 April 1990)

The energy, target-mass, and rapidity-window independence or approximate independence of the multiplicity moments in high-energy nucleus-nucleus collisions are analyzed. It is pointed out that all of these properties are due to nuclear geometry. It is proved under general conditons that, when the target mass is not extremely light and the rapidity window not very narrow, the normalized moments of multiplicity are approximately equal to that of the number of participating nucleons. The calculated results for both minimum-bias and central events agree with recent experimental data.

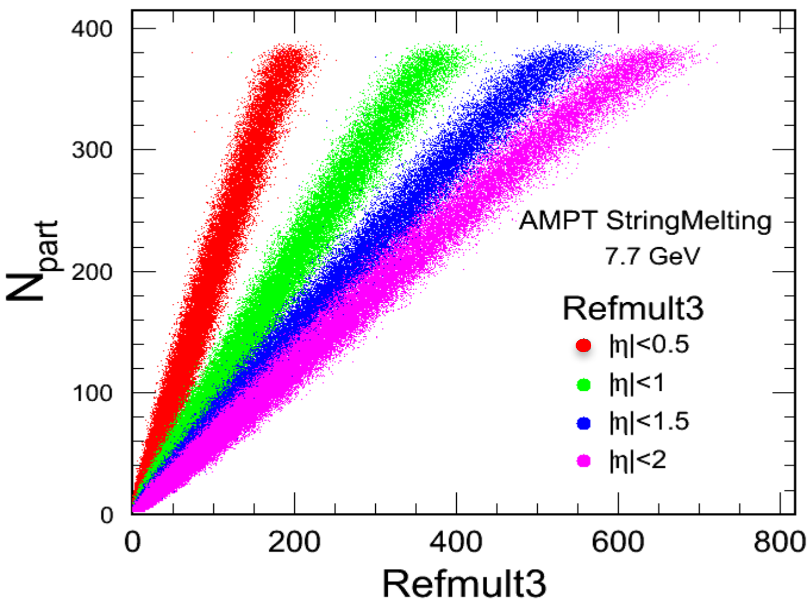
$$\frac{\sigma_N^2}{M_N} = \frac{\sigma_n^2}{M_n} + < n > \frac{\sigma_{N_p}^2}{M_{N_p}}$$

N_{part} fluctuations.

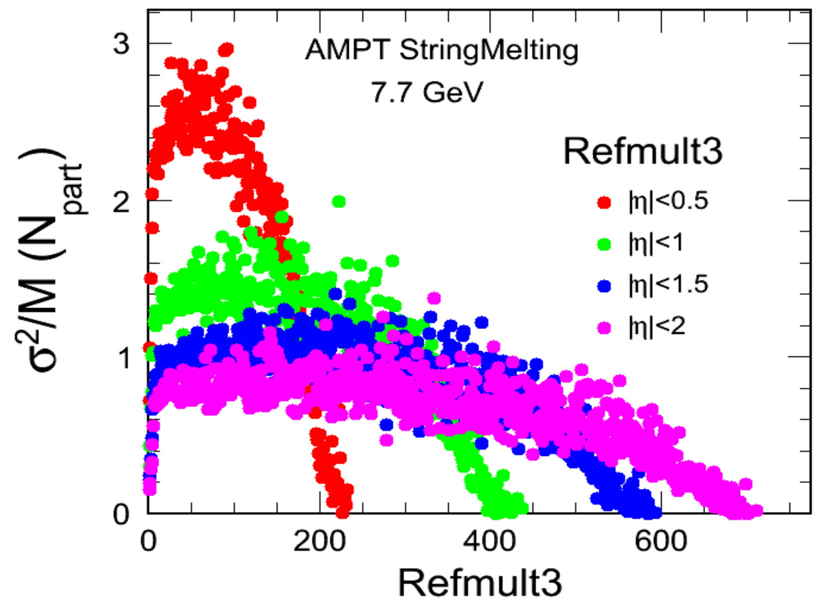
Even for fixed N_{part} or impact parameter, N_{ch} will show event-by-event fluctuations.

Demonstrate Volume Fluctuations in Centrality Definition

2D histogram



Fluctuations of N_{part} (Number of Participant)

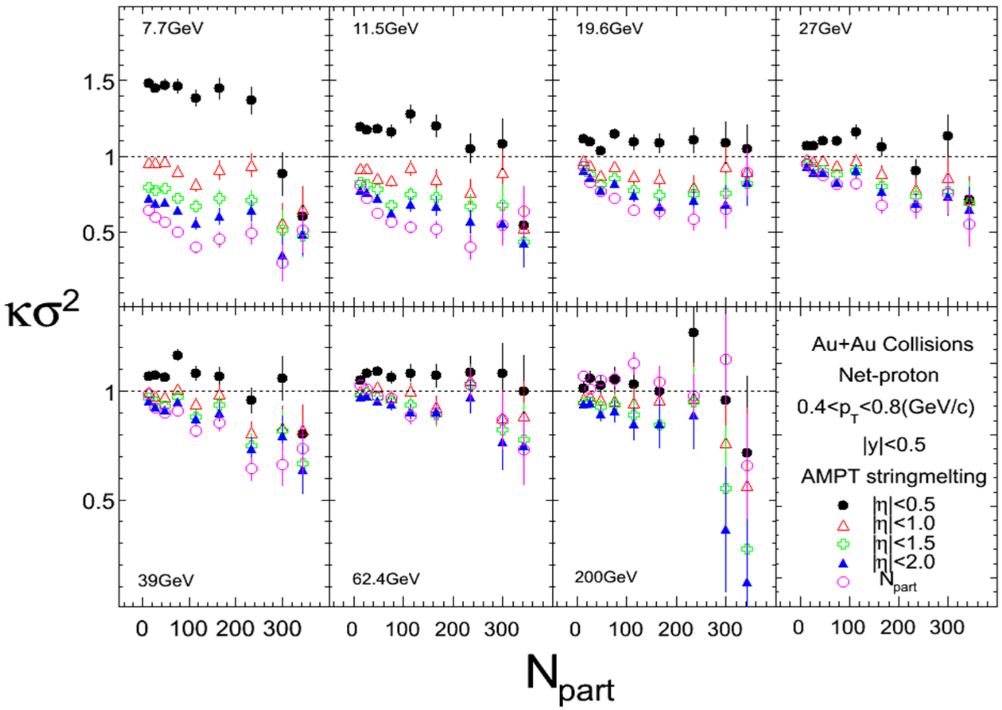


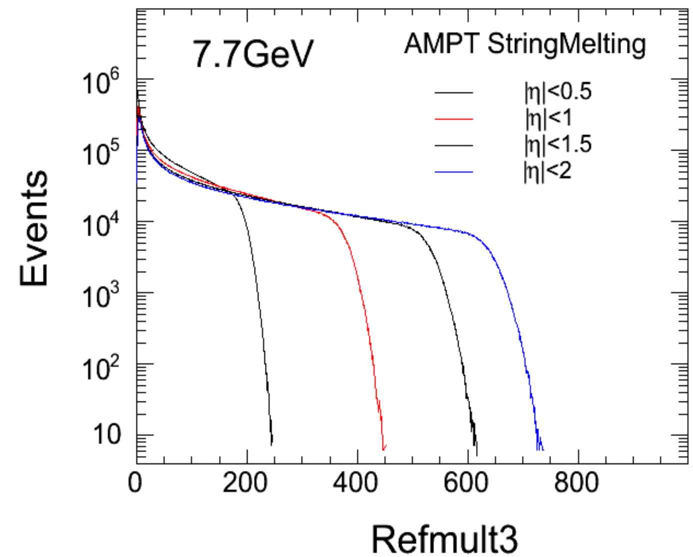
Refmult3: To avoid auto-corr., the charged Kaon + Pion Multiplicities are used to determine the centrality.

- Volume fluctuations are much smaller for central collisions than mid-central and peripheral collisions.
- Volume fluctuations will be largely suppressed at mid-central and peripheral collisions by increasing the particle multiplicities in the centrality definition.

Suppress Volume Fluctuations in Moment Analysis

X.Luo, J. Xu, B. Mohanty and N. Xu. J. Phys. G40,105104(2013);





- Volume fluctuations can be largely suppressed by including more particles in centrality det. and by applying centrality bin with correction.

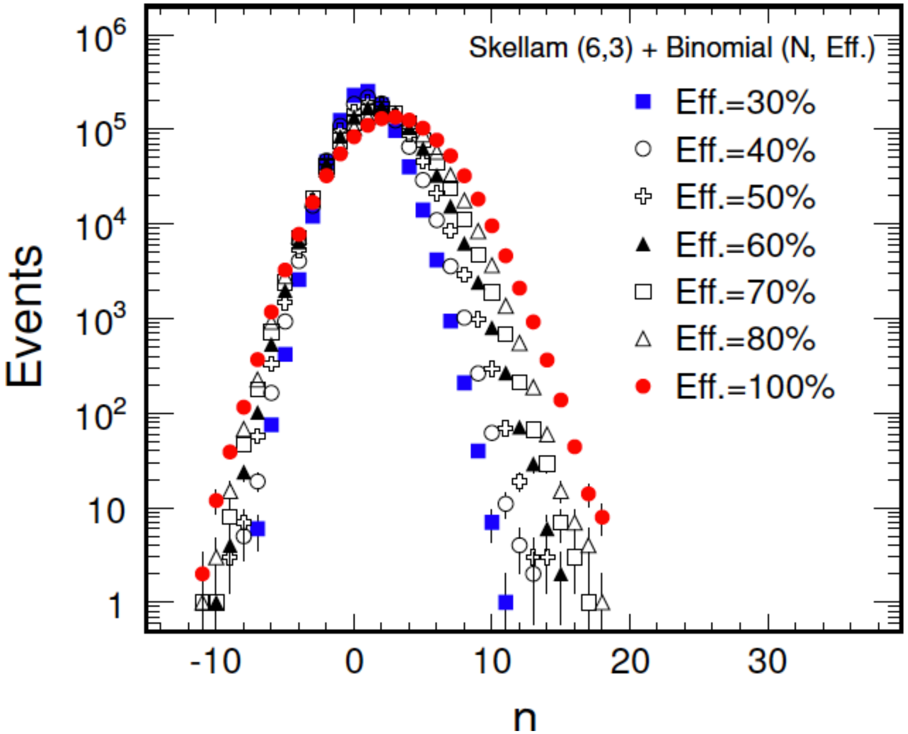
Can we find model independent methods to completely isolate the volume fluctuations ?
See Anar and Viktor's talk

Centrality Bin Width Correction (CBWC): Cumulants calculated in a wide centrality bin (for eg., 0-5%):

$$C_n = \frac{\sum_{r=N_1}^{N_2} n_r C_n^r}{\sum_{r=N_1}^{N_2} n_r} = \sum_{r=N_1}^{N_2} \omega_r C_n^r$$

where the n_r is the number of events for multiplicity bin r and the corresponding weight for the multiplicity r,

Effects of Finite Detection Efficiency



Efficiency Response Function :

$$B(n;N,\varepsilon)=\frac{N!}{n!(N-n)!}\varepsilon^{n}(1-\varepsilon)^{N-n}$$

With the total produced multiplicity N and the detector efficiency ε, the probability of detected number of particles can be treated as a binomial process.

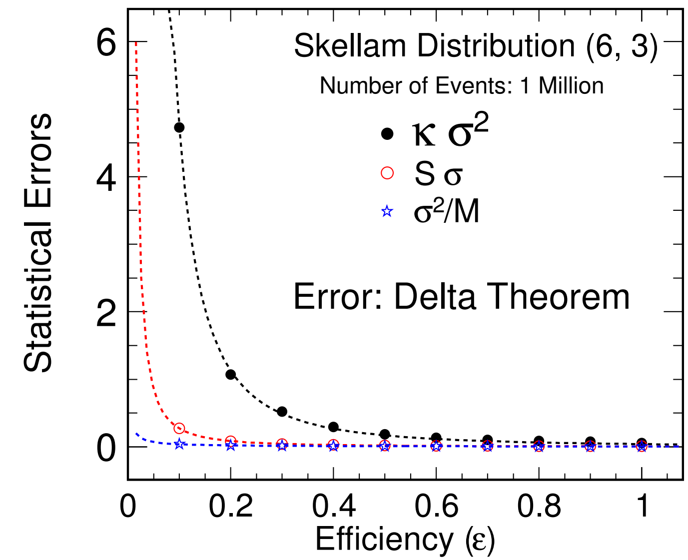
$$p(n_p,n_{\bar{p}})=\sum_{N_p=n_p}^{\infty}\sum_{N_{\bar{p}}=n_{\bar{p}}}^{\infty}P(N_p,N_{\bar{p}})\times\frac{N_p!}{n_p!\,(N_p-n_p)!}(\varepsilon_p)^{n_p}(1-\varepsilon_p)^{N_p-n_p}$$
$$\times\frac{N_{\bar{p}}!}{n_{\bar{p}}!\,(N_{\bar{p}}-n_{\bar{p}})!}(\varepsilon_{\bar{p}})^{n_{\bar{p}}}(1-\varepsilon_{\bar{p}})^{N_{\bar{p}}-n_{\bar{p}}}$$

Effects of possible non-binomial efficiency are under studied via unfolding technique See ShinIchi and Toshihiro's talk

Efficiency Correction and Error Estimation

We provide a unified description of efficiency correction and error estimation for moments analysis in heavy-ion collisions.

$$
\begin{aligned}
&F_{r_1,r_2}(N_p, N_{\bar{p}}) = F_{r_1,r_2}(N_{p_1}+N_{p_2}, N_{\bar{p}_1}+N_{\bar{p}_2}) \\
&= \sum_{i_1=0}^{r_1}\sum_{i_2=0}^{r_2} s_1(r_1,i_1)s_1(r_2,i_2) < (N_{p_1}+N_{p_2})^{i_1}(N_{\bar{p}_1}+N_{\bar{p}_2})^{i_2} > \\
&= \sum_{i_1=0}^{r_1}\sum_{i_2=0}^{r_2} s_1(r_1,i_1)s_1(r_2,i_2) < \sum_{s=0}^{i_1}\binom{i_1}{s} N_{p_1}^{i_1-s}N_{p_2}^{s} \sum_{t=0}^{i_2}\binom{i_2}{t} N_{\bar{p}_1}^{i_2-t}N_{\bar{p}_2}^{t} > \\
&= \sum_{i_1=0}^{r_1}\sum_{i_2=0}^{r_2}\sum_{s=0}^{i_1}\sum_{t=0}^{i_2} s_1(r_1,i_1)s_1(r_2,i_2)\binom{i_1}{s}\binom{i_2}{t} < N_{p_1}^{i_1-s}N_{p_2}^{s}N_{\bar{p}_1}^{i_2-t}N_{\bar{p}_2}^{t} > \\
&= \sum_{i_1=0}^{r_1}\sum_{i_2=0}^{r_2}\sum_{s=0}^{i_1}\sum_{t=0}^{i_2}\sum_{u=0}^{i_1-s}\sum_{v=0}^{s}\sum_{j=0}^{i_2-t}\sum_{k=0}^{t} s_1(r_1,i_1)s_1(r_2,i_2)\binom{i_1}{s}\binom{i_2}{t} \\
&\times s_2(i_1-s,u)s_2(s,v)s_2(i_2-t,j)s_2(t,k) \times F_{u,v,j,k}(N_{p_1},N_{p_2},N_{\bar{p}_1},N_{\bar{p}_2})
\end{aligned}
$$



Fitting formula: $f(\varepsilon) = \frac{1}{\sqrt{n}}\frac{a}{\varepsilon^b}$

We can express the moments and cumulants in terms of the factorial moments and factorial cumulants, which can be easily efficiency corrected.

$$error(S\sigma) \propto \frac{\sigma}{\varepsilon^{3/2}}$$

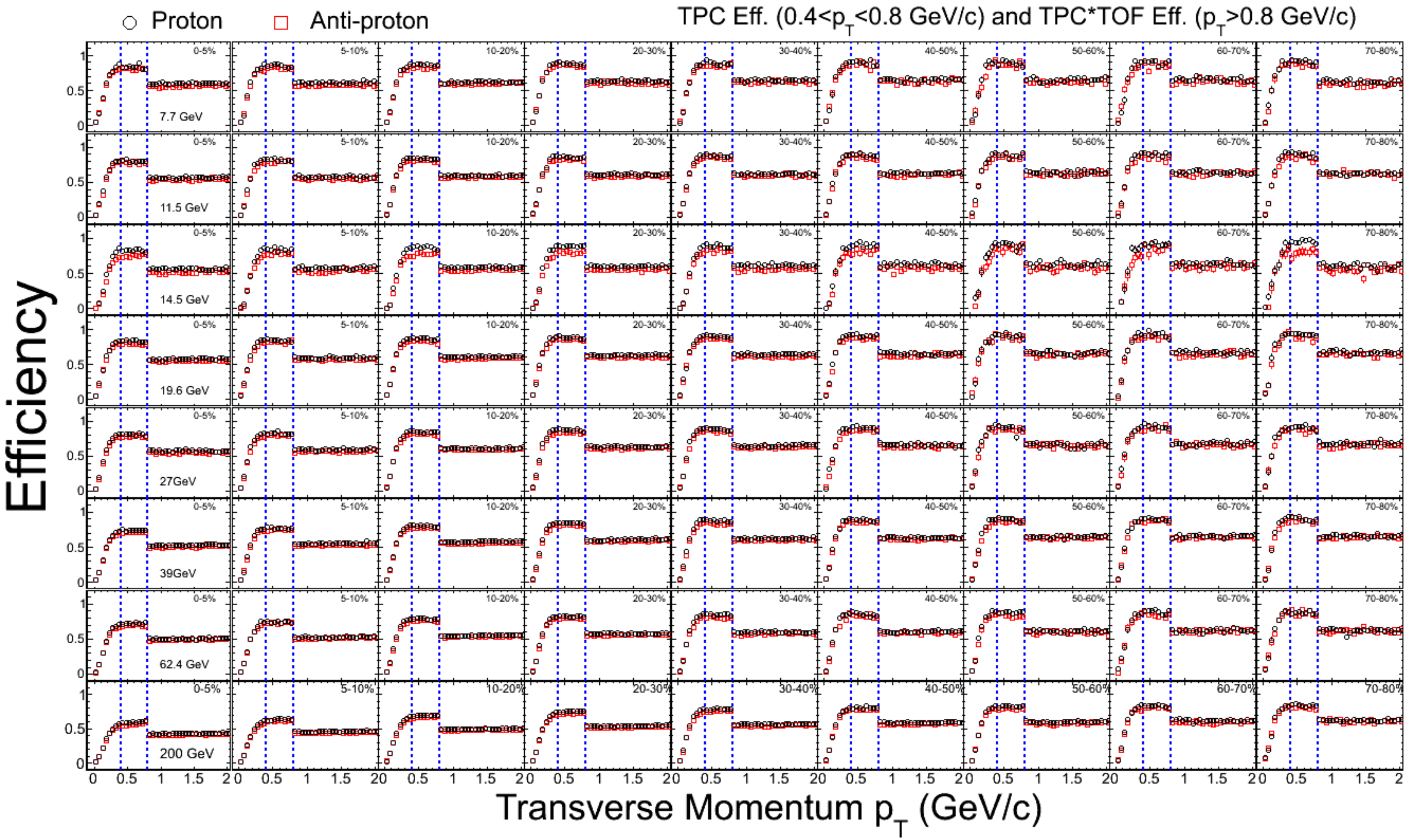
$$error(\kappa\sigma^2) \propto \frac{\sigma^2}{\varepsilon^2}$$

Binomial response for efficiency:

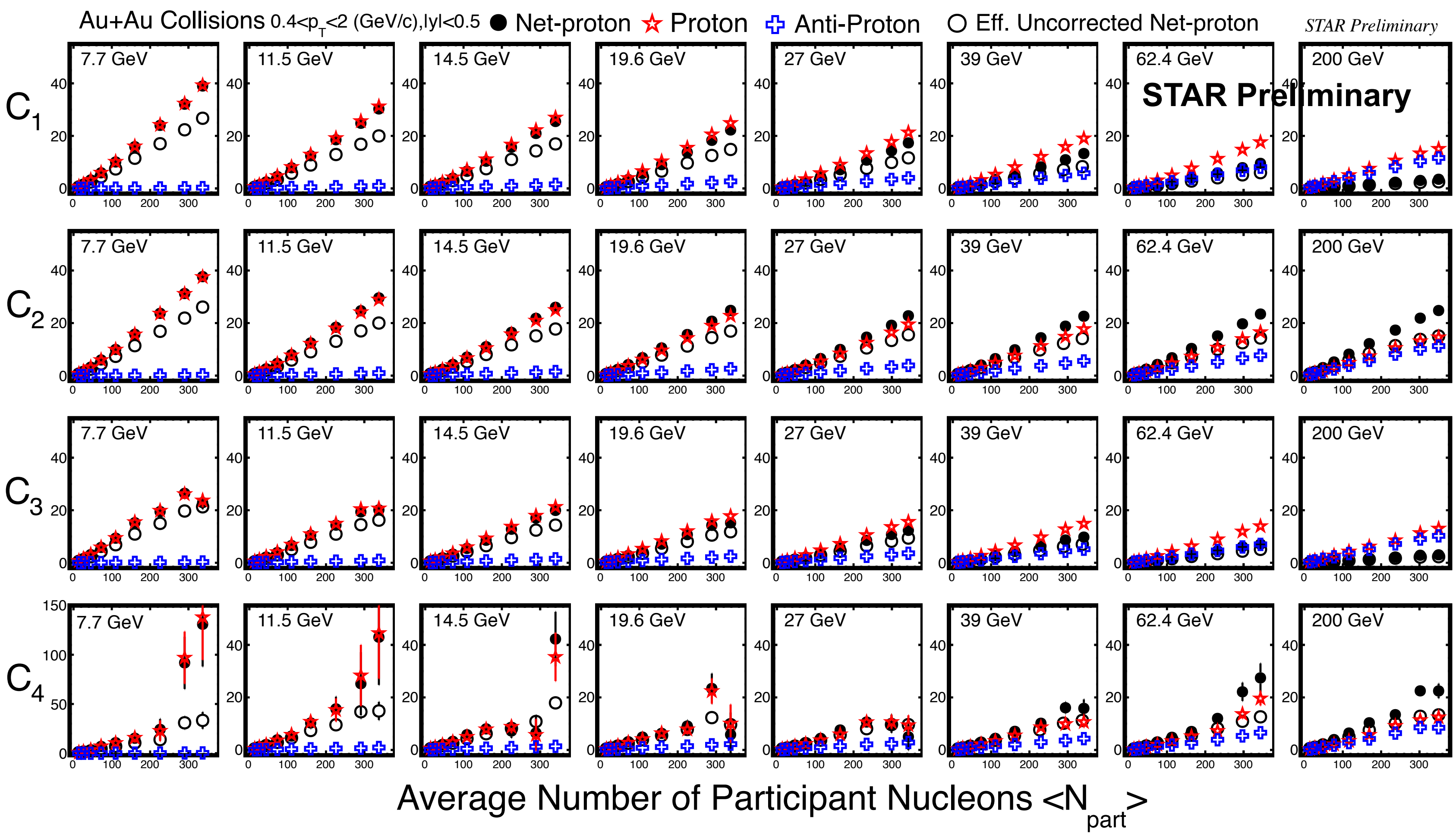
$$F_{u,v,j,k}(N_{p_1},N_{p_2},N_{\bar{p}_1},N_{\bar{p}_2}) = \frac{f_{u,v,j,k}(n_{p_1},n_{p_2},n_{\bar{p}_1},n_{\bar{p}_2})}{(\varepsilon_{p_1})^u(\varepsilon_{p_2})^v(\varepsilon_{\bar{p}_1})^j(\varepsilon_{\bar{p}_2})^k}$$

X. Luo, PRC91, 034907 (2015).
A. Bzdak and V. Koch, PRC91,027901(2015), PRC86，044904(2012).
T. Nonaka, et al., PRC95, 064912 (2017).

Efficiency for Proton and Anti-proton



Net-Proton, Proton and Anti-Proton Cumulants (C_1~C_4)

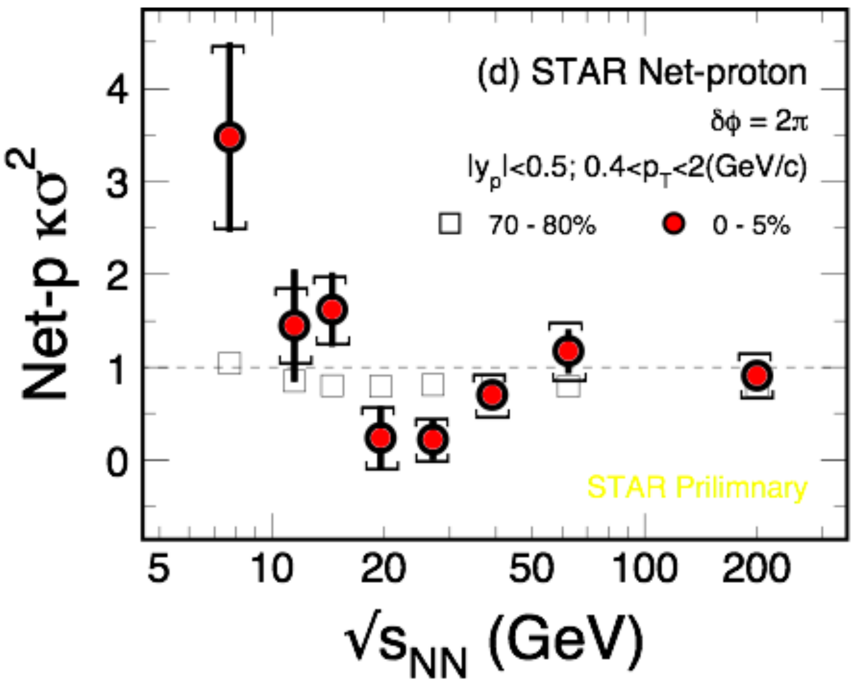


1. Efficiency corrections are important for both value and statistical errors.
2. Generally, cumulants are linearly increasing with $\langle N_{part} \rangle$.
3. At low energies, the proton cumulants are close to net-proton.

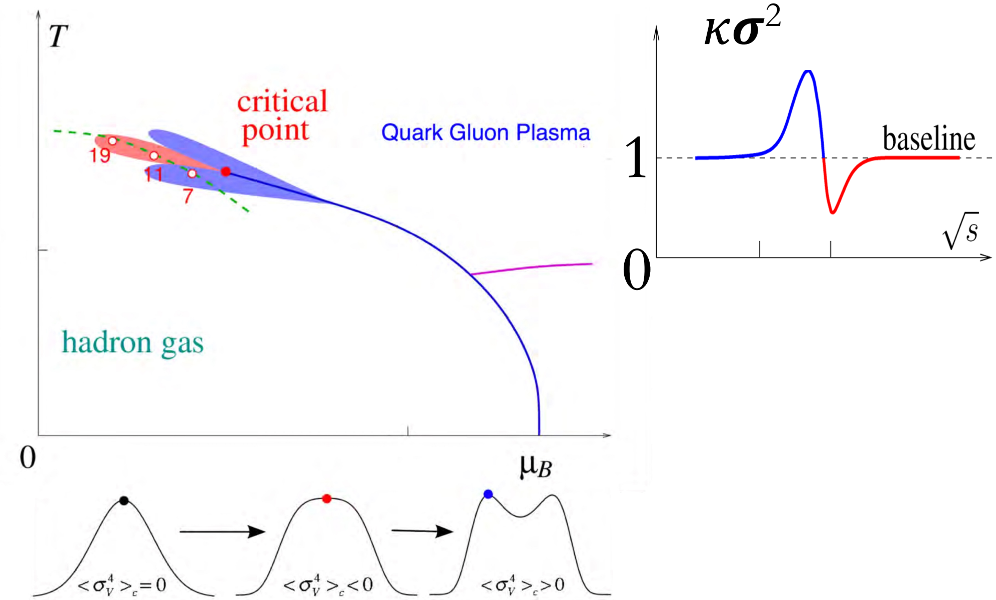
4^{th} order Net-Proton Fluctuations $\kappa\sigma^2 = C_4/C_2$

➢ First observation of the non-monotonic energy dependence of fourth order net-proton fluctuations. Hint of entering Critical Region ??

STAR Data



σ field Model



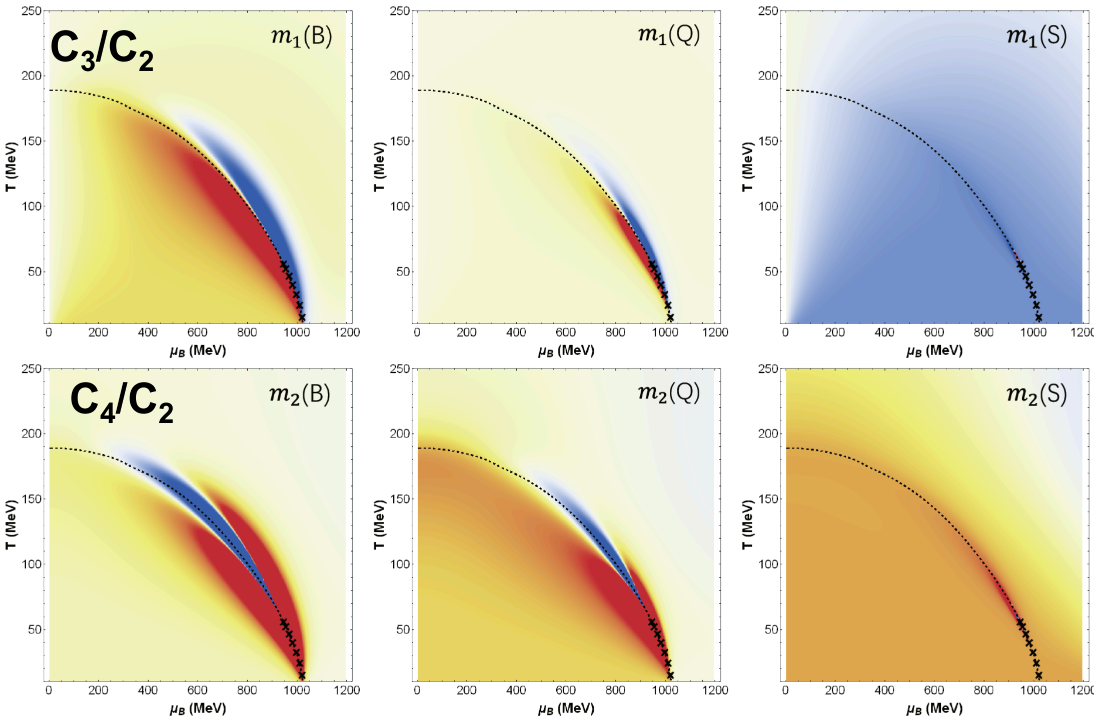
Critical signal: Oscillation Structure

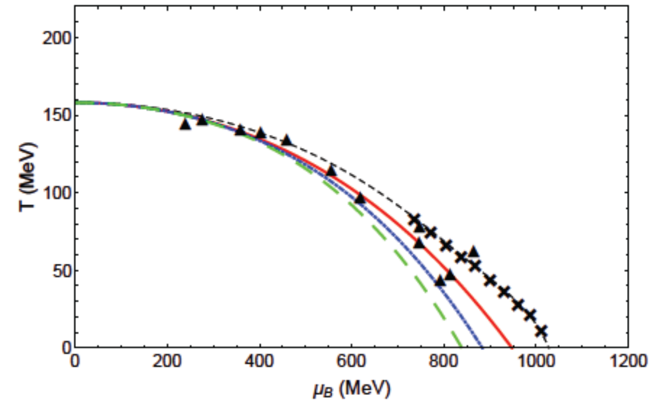
STAR, PRL105,022302 (2010); PRL112,032302 (2014).
STAR, CPOD2014, QM2015

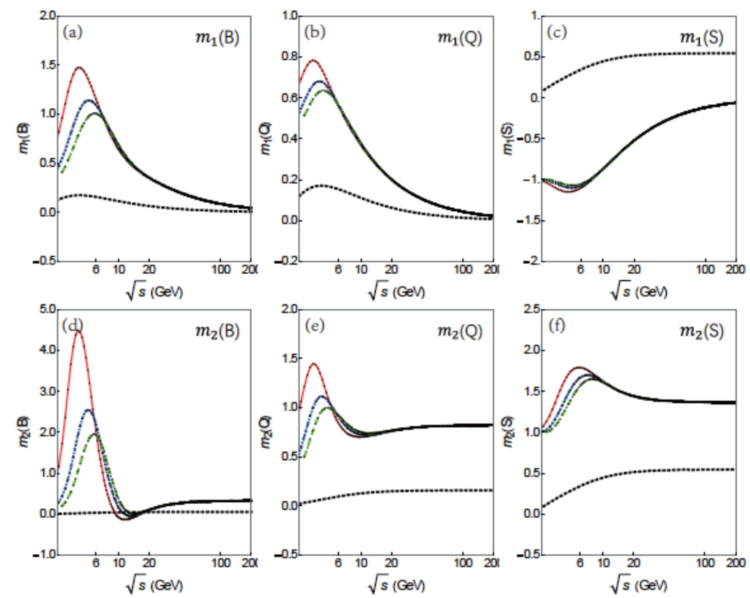
M. A. Stephanov, PRL102, 032301 (2009).
M. A. Stephanov, PRL107, 052301 (2011).

NJL Model Calculations

Baryon (B) **Charge (Q)** **Strangeness (S)**



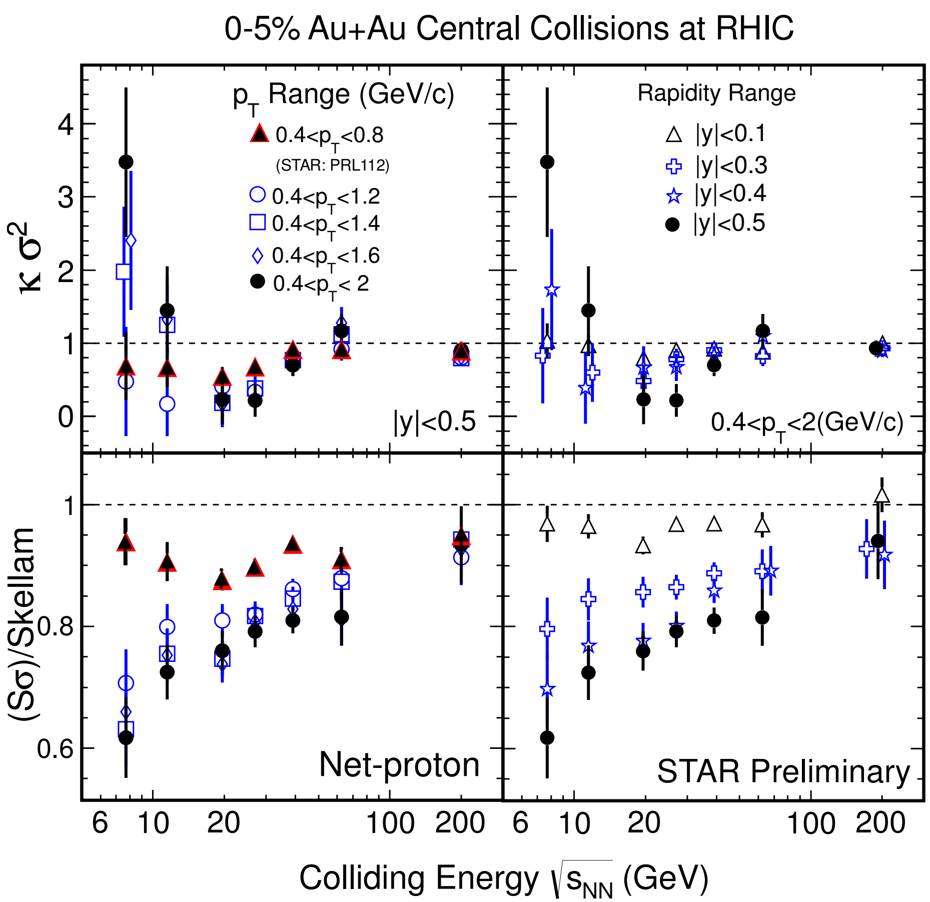


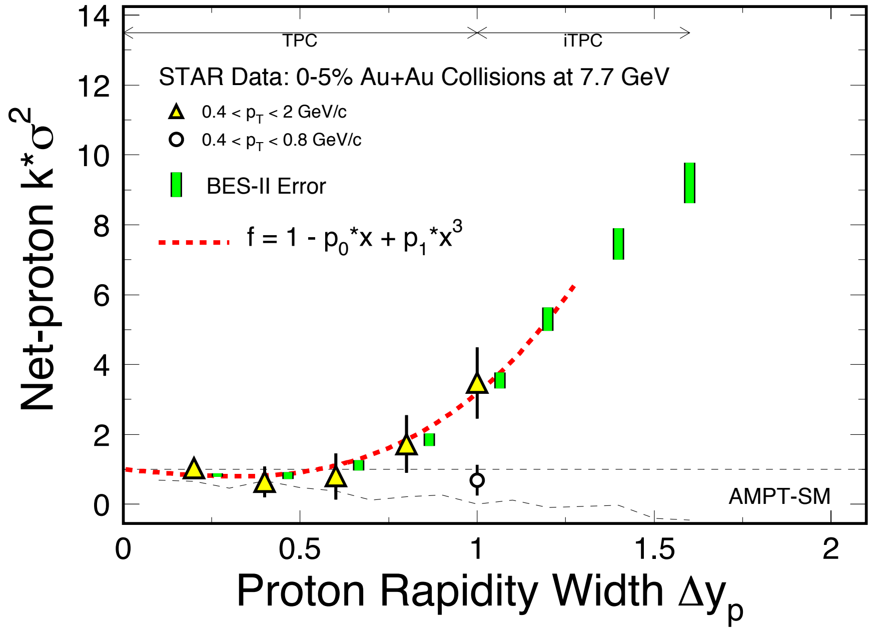


1) Due to large mass of s quark, CP Signals in Q and S are much smaller than B.
2) Forth and third order fluctuations have very different behavior.

W. K. Fan, X. Luo, H.S. Zong, IJMPA 32, 1750061 (2017).
JW Chen, JDeng et al., PRD93, 034037 (2016), PRD95, 014038 (2017)

Acceptance Dependence: STAR Data



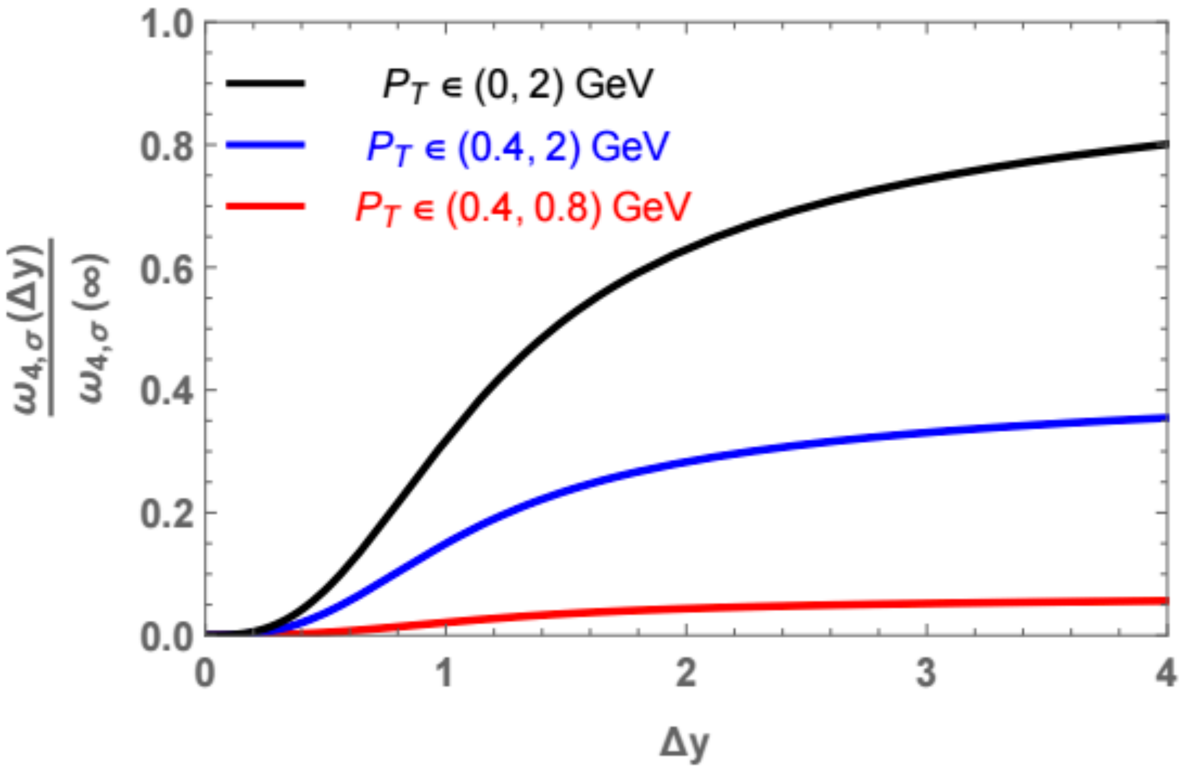


Enhance the fluctuation signals
by enlarge the acceptance.

- The smaller the acceptance window the closer to the Poisson values.
- The acceptance needs to be large enough to capture the critical fluctuations.

Acceptance Dependence: Theoretical Calculations

Acceptance dep. near CP



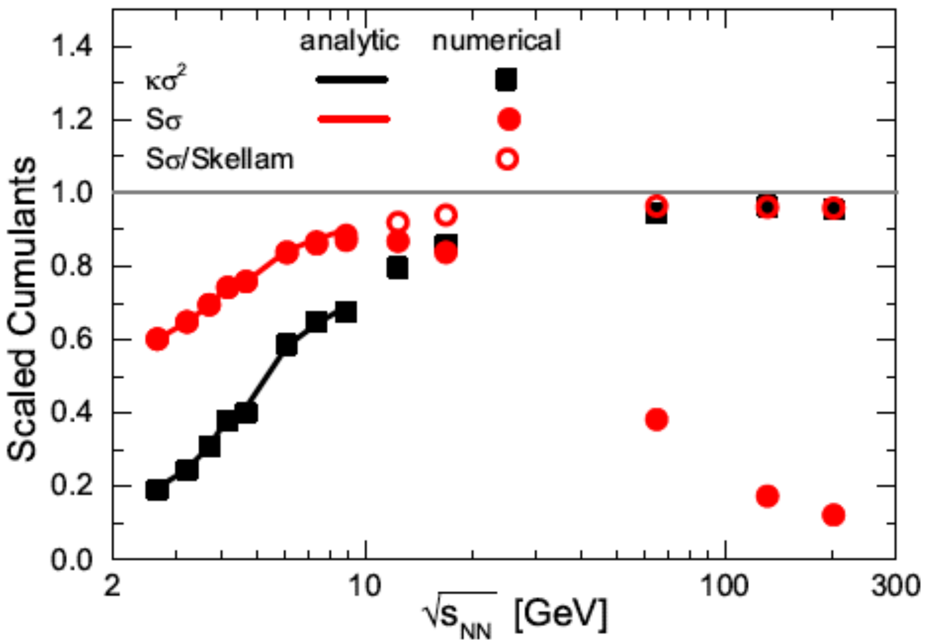
B. Ling, M. Stephanov, Phys. Rev. C 93, 034915 (2016).
A. Bzdak, V. Koch, Phys.Rev. C95, 054906 (2017)
H. Song et al., PRC94, 024918 (2016)
M. Kitazawa, X. Luo, PRC96, 024910 (2017).

See Masakiyo and Huichao's talk

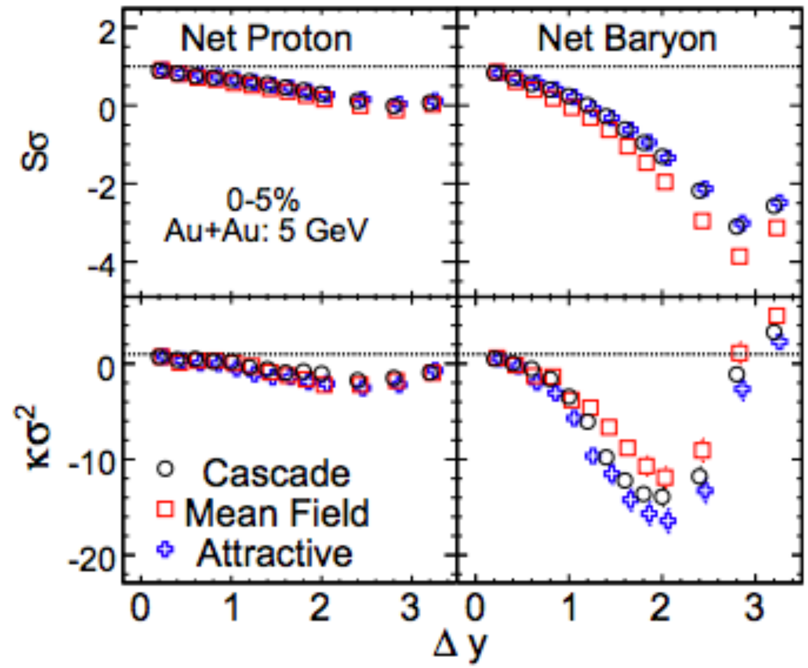
Signals can be enhanced by enlarging the acceptance.

Transport Model Results : Net-Proton $\kappa\sigma^2$

UrQMD (with Deuteron Formation)



Au+Au 5 GeV @JAM Model

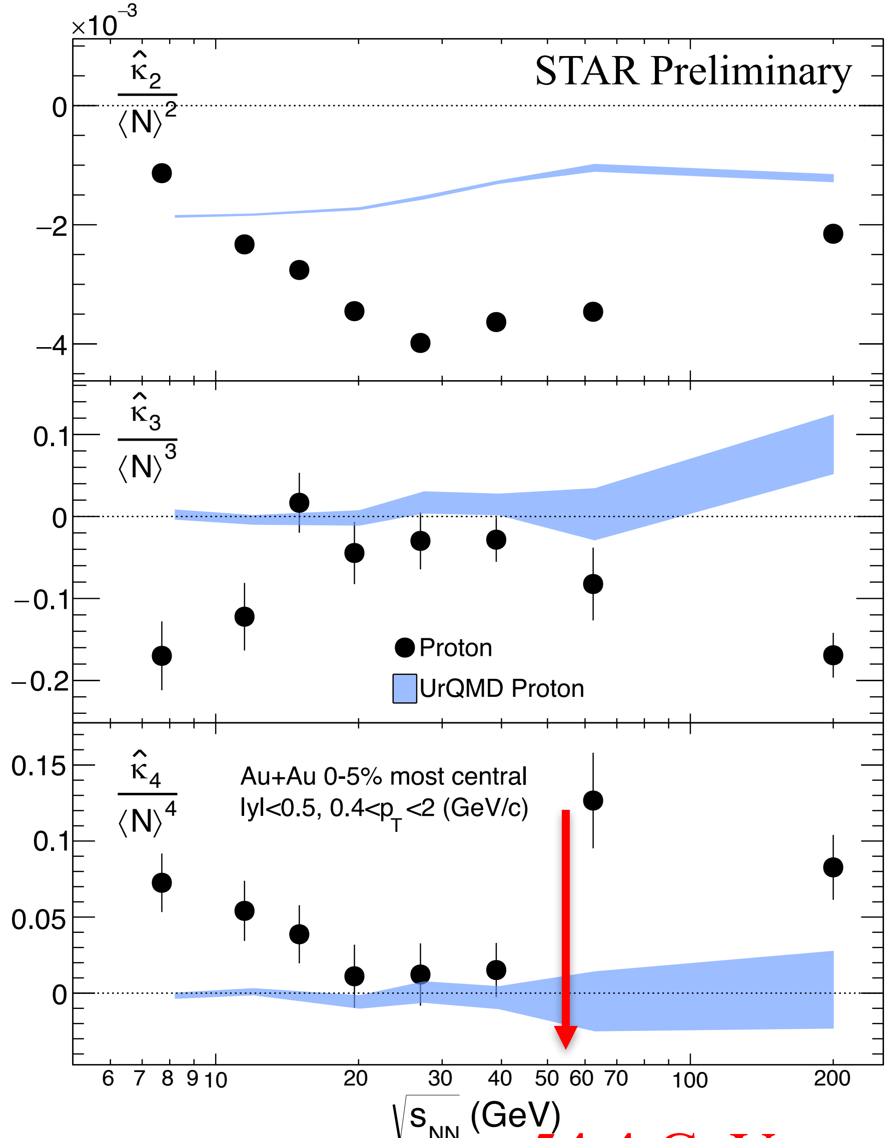


At $\sqrt{s_{NN}} \leq 10$ GeV: Data: **$\kappa\sigma^2 > 1$** Model: **$\kappa\sigma^2 < 1$**

- ➢ Model simulation indicates: *Baryon number conservations, Mean-field potential, Deuteron formation, Softening of EOS.*
  All suppress the net-proton fluctuations.

1) Z. Feckova, J. Steonheimer, B. Tomasik, M. Bleicher, PR**C92**, 064908(2015). J. Xu, S. Yu, F. Liu, X. Luo, PR**C94**, 024901(2016). X. Luo *et al*, NP**A931**, 808(14), P.K. Netrakanti *et al.* 1405.4617, NP**A947**, 248(2016), P. Garg *et al.* Phys. Lett. **B726**, 691(2013).
2) S. He, X. Luo, Y. Nara, S. Esuimi, N. Xu, Phys.Lett. **B762** (2016) 296-300.

Reduced Proton Correlation Functions



Single variable formula:

Cumulants:

$$C_1 = < N >$$
$$C_2 = < N > + \hat{\kappa}_2$$
$$C_3 = < N > + 3\hat{\kappa}_2 + \hat{\kappa}_3$$
$$C_4 = < N > + 7\hat{\kappa}_2 + 6\hat{\kappa}_3 + \hat{\kappa}_4$$

Corr. Func.

Reduced proton correlation function :

$$\hat{c}_n = \frac{\hat{\kappa}_n}{\langle N \rangle^n}$$

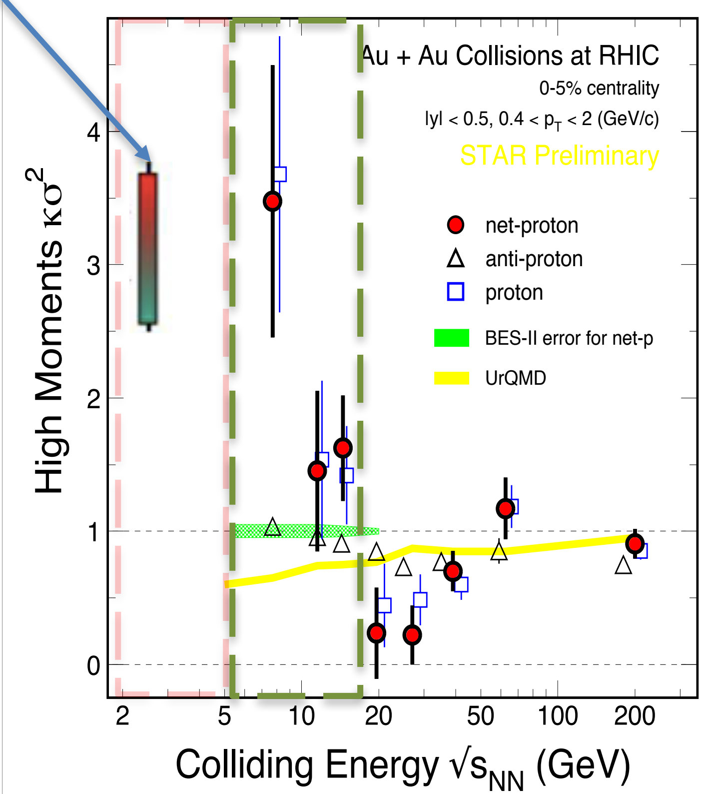
1. Insensitive to baryon number conservation effects with n>=3.
2. Cancel binomial efficiency effects.
3. Proton cluster formation can explain the large enhance at low energies for C_4.

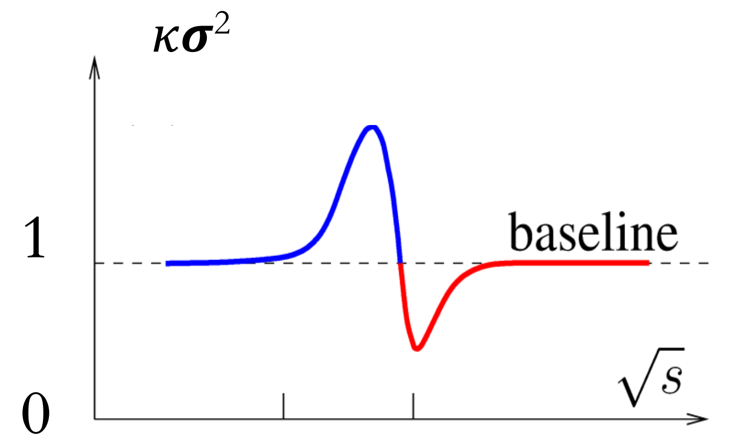
See Adam's talk

S. He, X. Luo, arXiv: 1704.00423
M. Kitazawa, X. Luo, PRC96, 024910 (2017)
Adam&Volker, arXiv: 1707.02640

Future Plan for Critical Point Search

Preliminary HADES Results (QM2017)





Need precision measurement between 7.7 to 20 GeV

CBM/STAR FXT/HADES/NICA Experiments (**2.5 < $\sqrt{s_{NN}}$ < 8** GeV) :

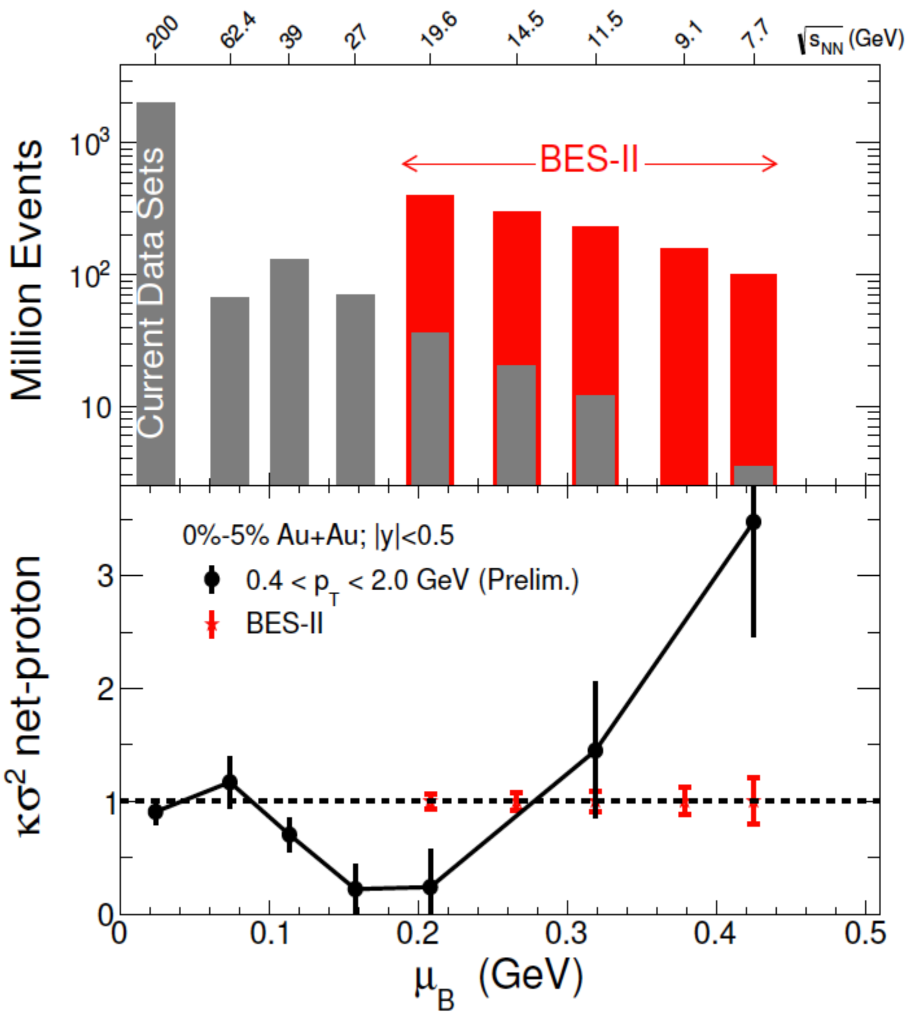
Key region for Critical Point search

STAR Data: X.F. Luo *et al*, CPOD2014, QM2015; PRL**112** (2014) 32302

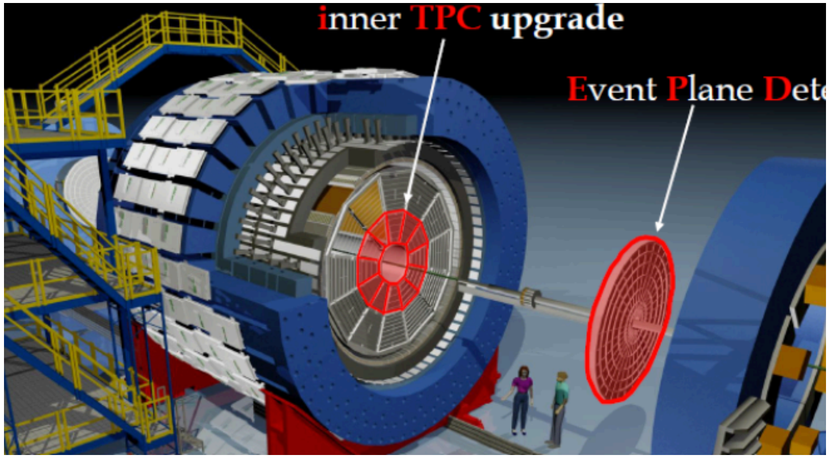
BES-II at RHIC (2019-2020)

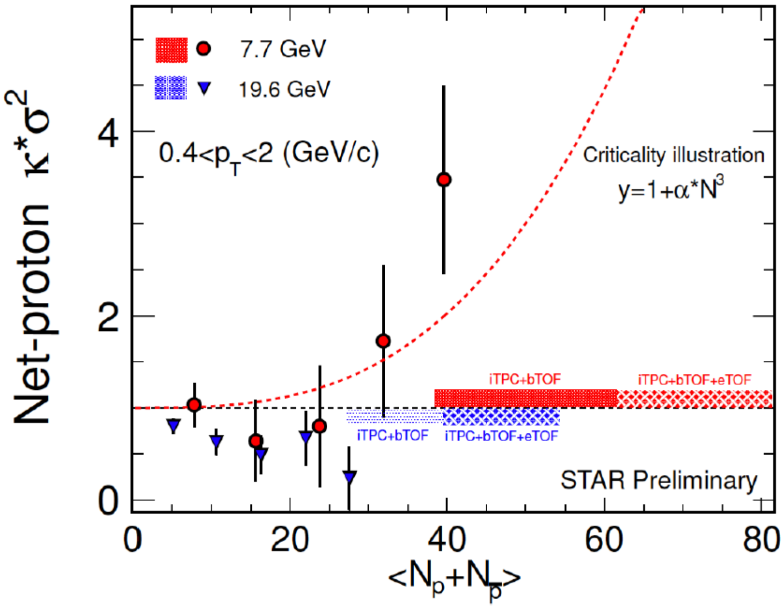
More Data

RHIC Luminosity Upgrade for Low Energies



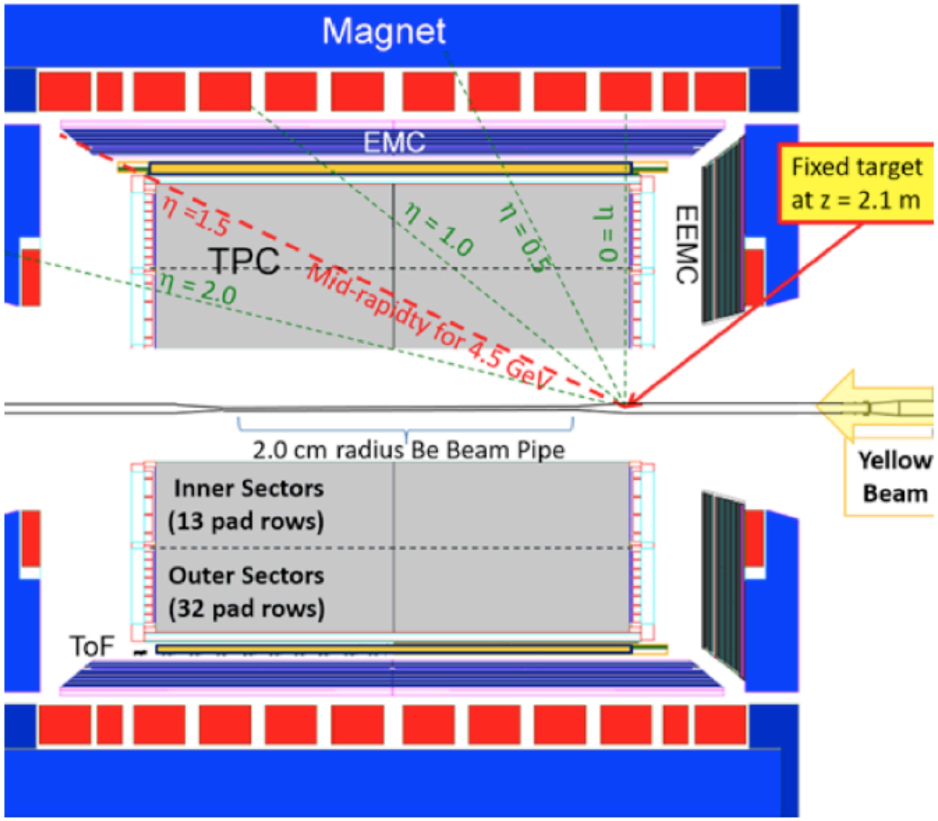
iTPC upgrade extends the rapidity coverage to Δy = 1.6

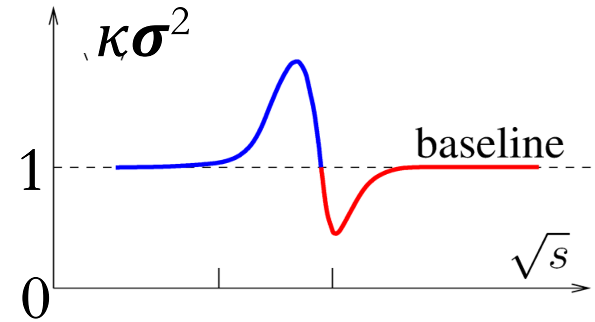


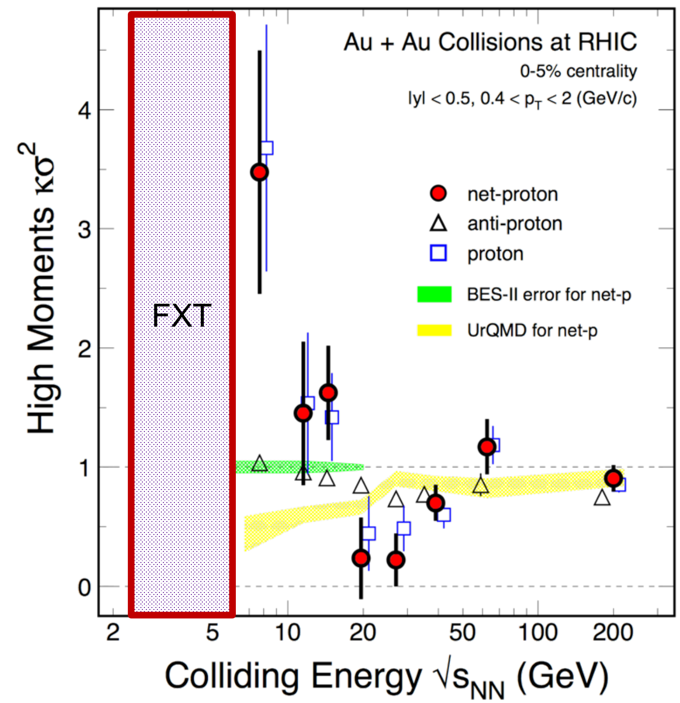


FXT Experiments at STAR (2018-2019)

- Key step to confirm the signature of QCD critical point







FXT Data Taking Plan：
2015: Au+Au: 4.5 GeV (test Run)
2018: Au+Au :3 GeV (100 million events)
2019-2020: Au+Au: 6.2, 5, 4.5, 4, 3.5 GeV

Summary

- Clear non-monotonic energy dependence is observed in the net-proton kurtosis at most central Au+Au collision.
  A hint of entering critical region.
  Need to confirm with more statistics and lower energies data.

- Model simulation (No CP) indicates: *Baryon conservations, Mean-field potential, hadronic scattering, Deuteron formation.*
  All suppress the net-proton fluctuations.

- Within current uncertainties, net-charge and net-kaon fluctuations show flat energy dependent. Need more statistics.

- Study the QCD phase structure at high baryon density with high precision:
  (1) BES-II at RHIC (2019-2020, both collider and fix target mode).
  (2) Future Fix-target at low energies: FAIR/CBM, CSR/HIAF etc.

Thank you !