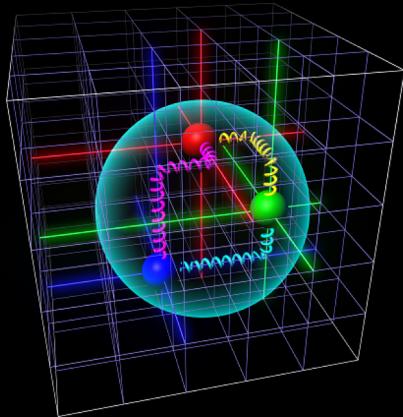
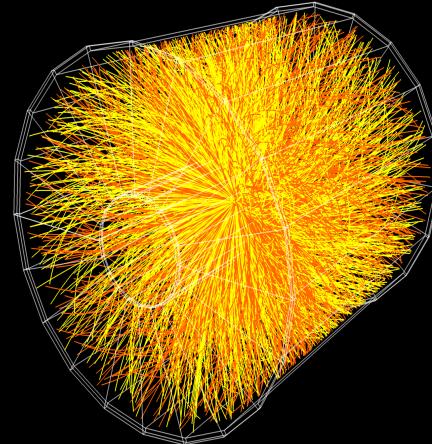


FLUCTUATIONS AND CORRELATIONS (EXPERIMENT)

Anar Rustamov
GSI/EMMI, NNRC



$$\hat{\chi}_2^B = \frac{\langle \Delta N_B^2 \rangle - \langle \Delta N_B \rangle^2}{V T^3}$$





Outline

📌 Why fluctuations

Fluctuations of conserved quantities

Baselines from LQCD

📌 From data to Susceptibilities on the lattice

Centrality selection and participant fluctuations

Acceptance selection and conservation laws

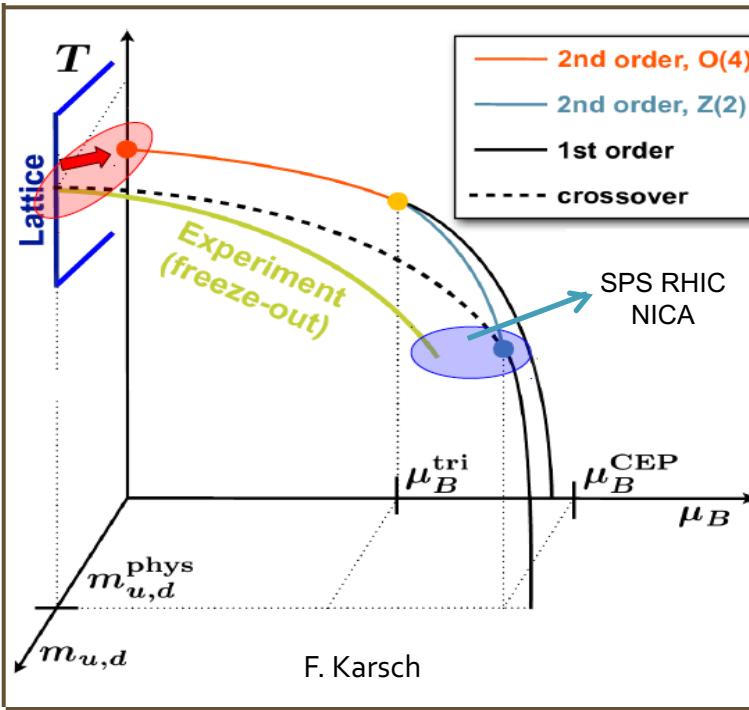
📌 Experimental results

Artefact of conservation laws on fluctuation measurement

Cumulants vs. correlation functions

📌 Summary

Why Fluctuations?



To probe the structure of strongly interacting matter
 Locate phase boundaries
 Search for critical phenomena
 ...

E-by-E fluctuations are predicted within Grand Canonical Ensemble

$$\frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle^2} = \frac{T \chi_T}{V} \quad \chi_T = - \frac{1}{V} \left(\frac{\partial V}{\partial P} \right)_T$$



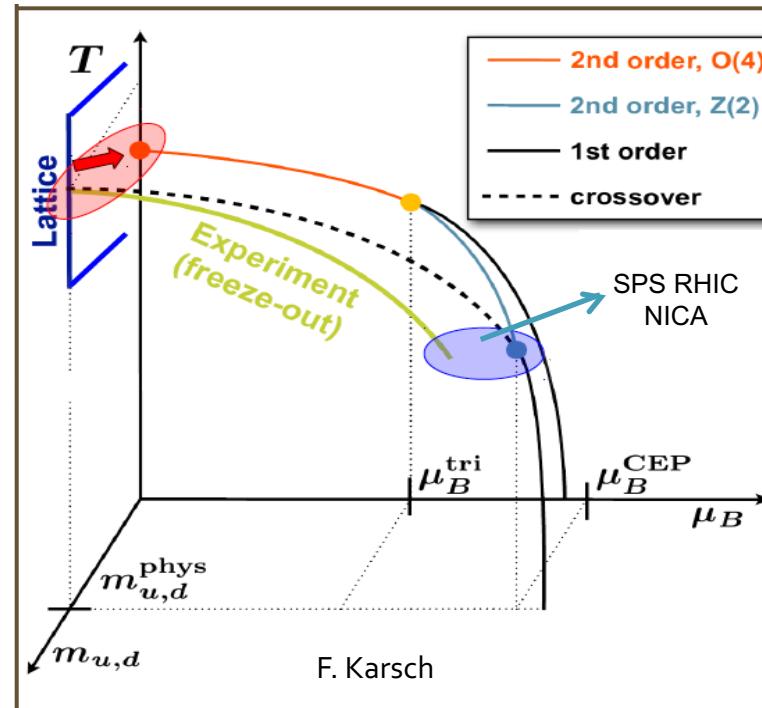
direct link to the EoS

$$\langle N^2 \rangle - \langle N \rangle^2 = \kappa_2(N) = T^2 \frac{\partial^2 \ln Z}{\partial \mu^2}$$

probing the response of the system to external perturbations

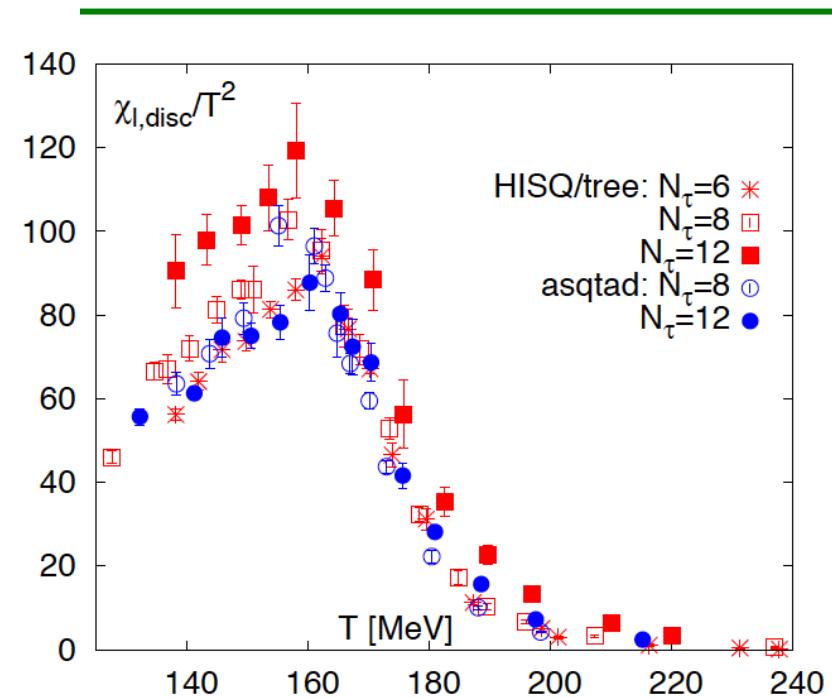
A. Bazavov et al., Phys.Rev. D85 (2012) 054503

Why Fluctuations?



fingerprints of criticality for $m_{u,d} = 0$
survive at crossover with $m_{u,d} \neq 0$

A. Bazavov et al., Phys.Rev. D85 (2012) 054503



$$T_c^{LQCD} = 156.5 \pm 1.5 \text{ MeV}$$

$$\langle \bar{\psi} \psi \rangle_l = \frac{T}{V} \frac{\partial \ln Z}{\partial m}$$

$$\chi_l = \frac{\partial}{\partial m} \langle \bar{\psi} \psi \rangle_l$$

A. Bazavov et al., Phys.Rev. D85 (2012) 054503

Understanding the QCD phase transition

Freeze-out at the phase boundary

$$T_{fo}^{ALICE} = 156.5 \pm 1.5 \text{ MeV} \pm 3 \text{ MeV(sys)}$$

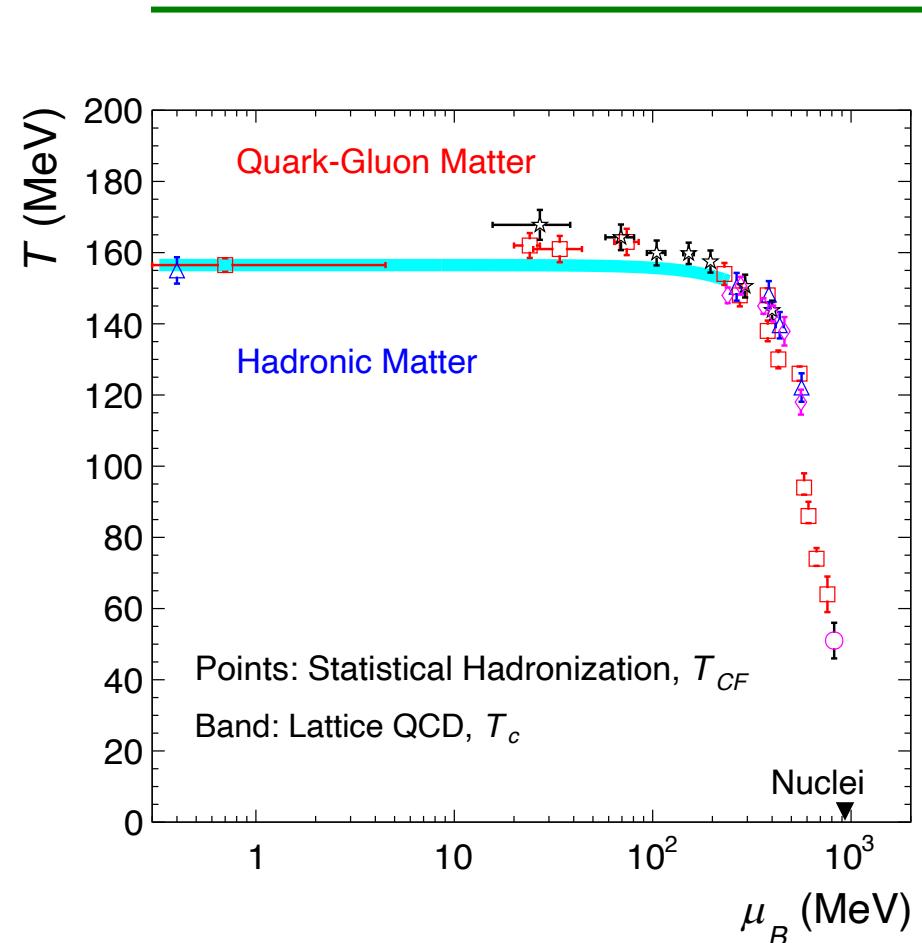
$$T_c^{LQCD} = 156.5 \pm 1.5 \text{ MeV}$$

Experimental plan:

- 📌 measuring fluctuations of net-baryons along the QCD phase boundary

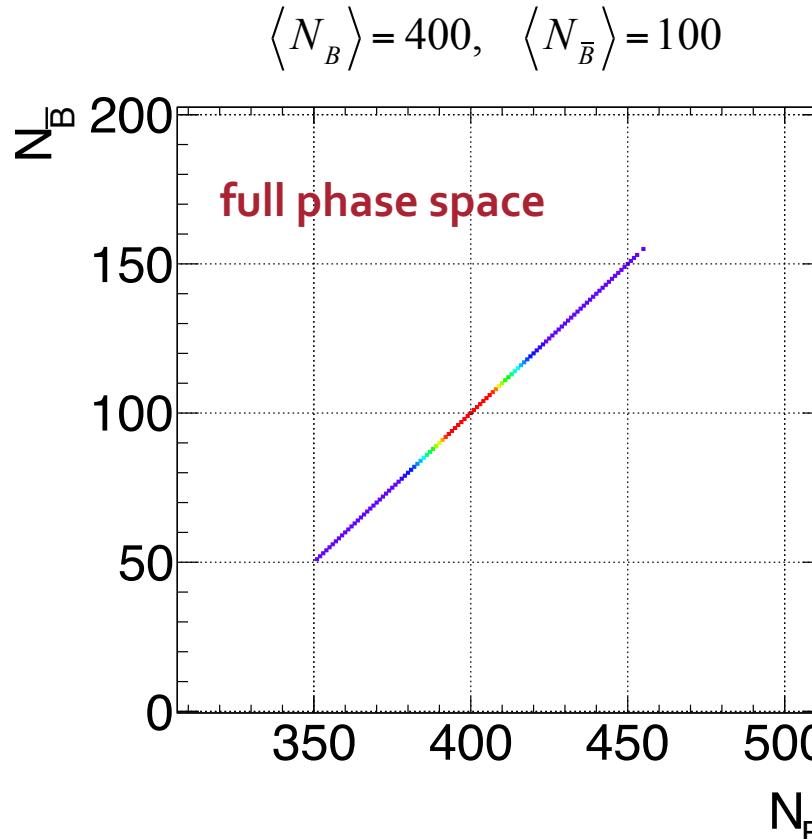
Open questions:

- 📌 the order of the phase transition
- 📌 existence of the critical endpoint
- 📌 ...



A. Andronic, P. Braun-Munzinger, K. Redlich and J. Stachel,
Nature 561, 321–330 (2018)
A. Bazavov et al., Phys.Rev. D85 (2012) 054503

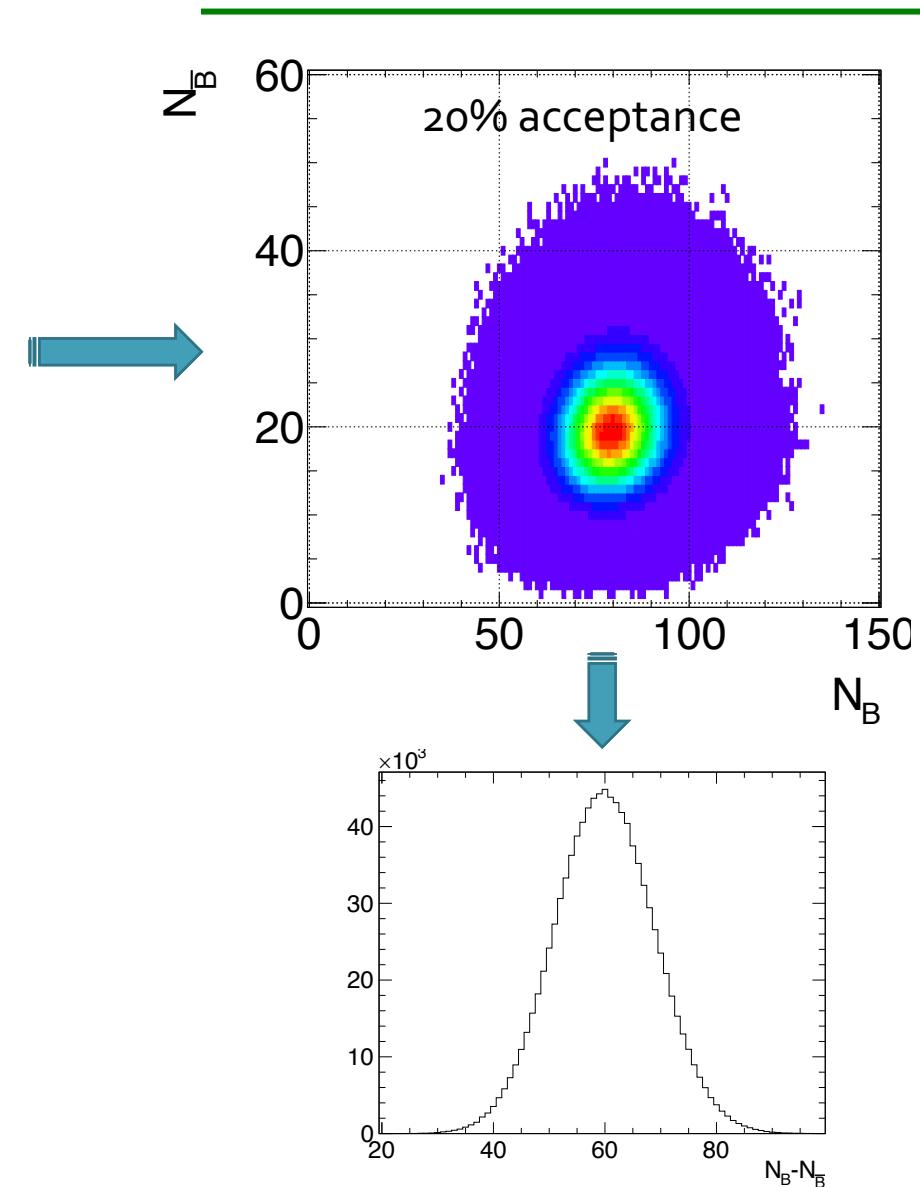
Fluctuations of conserved charges



fluctuations of net-baryons appear only
inside finite acceptance

event generator used from:

P. Braun-Munzinger, A. Rustamov, J. Stachel,
QM18, NPA 982 (2019) 307-310



Basic definitions

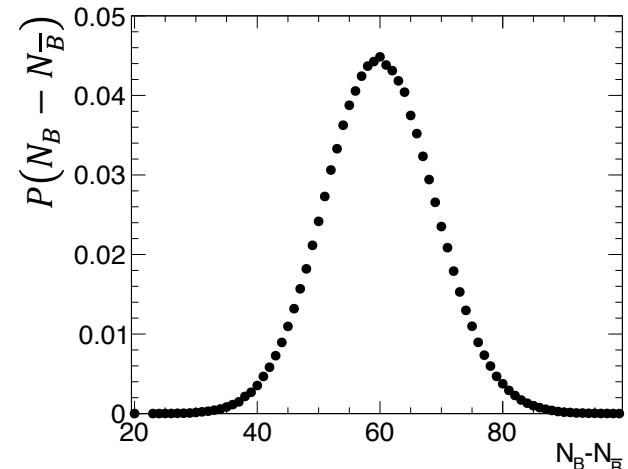
$$X = N_B - N_{\bar{B}}$$

r^{th} central moment:

$$\mu_r \equiv \langle (X - \langle X \rangle)^r \rangle = \sum_X (X - \langle X \rangle)^r P(X)$$

first four cumulants

$$\kappa_1 = \langle X \rangle, \quad \kappa_2 = \mu_2, \quad \kappa_3 = \mu_3, \quad \kappa_4 = \mu_4 - 3\mu_2^2$$



Uncorrelated Poisson limit: $\langle N_B N_{\bar{B}} \rangle = \langle N_B \rangle \langle N_{\bar{B}} \rangle$

Net-Baryons \rightarrow Skellam

$$\kappa_n = \langle N_B \rangle + (-1)^n \langle N_{\bar{B}} \rangle$$

$$\frac{\kappa_{2n+1}}{\kappa_{2k}} = \tanh\left(\frac{\mu}{T}\right) = \frac{\langle N_B \rangle - \langle N_{\bar{B}} \rangle}{\langle N_B \rangle + \langle N_{\bar{B}} \rangle}$$

Baselines from LQCD

for a thermal system in a fixed volume V
within the Grand Canonical Ensemble

$$\hat{\chi}_2^B = \frac{\langle \Delta N_B^2 \rangle - \langle \Delta N_B \rangle^2}{VT^3} \equiv \frac{\kappa_2(\Delta N_B)}{VT^3}$$

$$\hat{\chi}_n^{N=B,S,Q} = \frac{1}{VT^3} \frac{\partial^n \ln Z(V, T, \mu_{B,Q,S})}{\partial (\mu_N/T)^n}$$

Assumptions:

- 📌 Volume is fixed in each event
- 📌 Conservations are imposed on the averages

Reality:

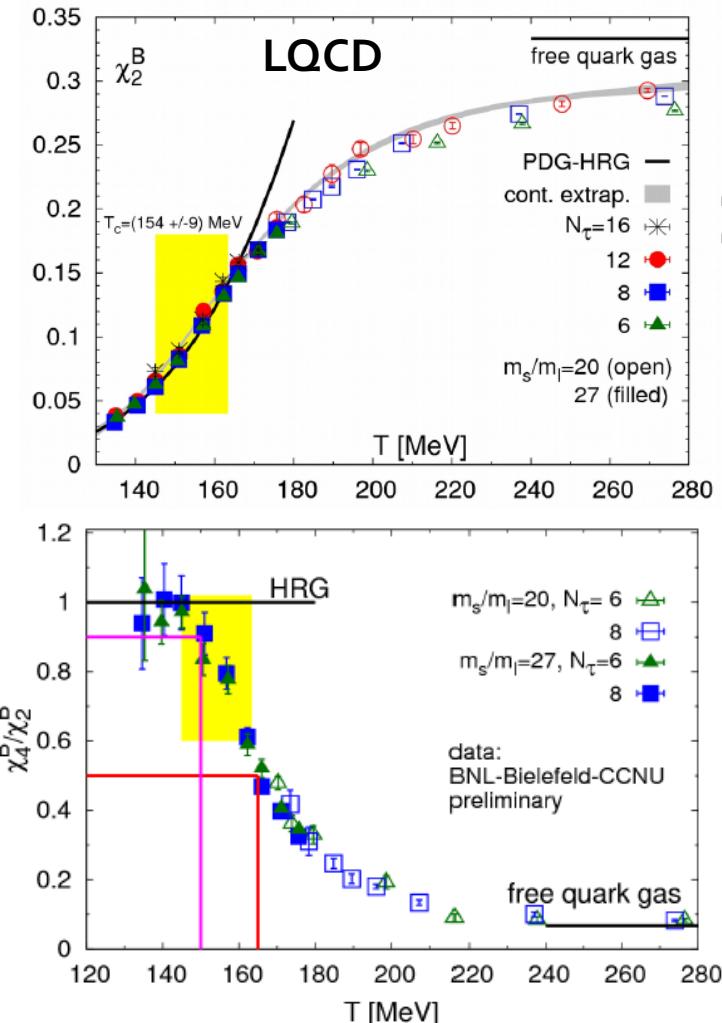
- 📌 Volume fluctuates from E -to- E
- 📌 Conservations depend on the acceptance

$$\frac{\kappa_4^{\exp}(\Delta N_B)}{\kappa_2^{\exp}(\Delta N_B)} \neq \frac{\hat{\chi}_4^B}{\hat{\chi}_2^B}$$

$$\frac{\kappa_3^{\exp}(\Delta N_B)}{\kappa_2^{\exp}(\Delta N_B)} \neq \frac{\hat{\chi}_3^B}{\hat{\chi}_2^B}$$

P. Braun-Munzinger, A. Rustamov, J. Stachel, NPA 960 (2017) 114

V. Skokov, B. Friman, and K. Redlich, Phys.Rev. C88 (2013) 034911



smaller than in HRG for $T > 150$ MeV

F. Karsch; QM17, arXiv:1706.01620

O. Kaczmarek; QM17, arXiv:1705.10682

Cross-correlators

$$\chi_1^{X=B,Q,S} = \frac{1}{VT^3} \frac{\partial \ln Z(V, T, \mu_{B,Q,S})}{\partial (\mu_X/T)}$$

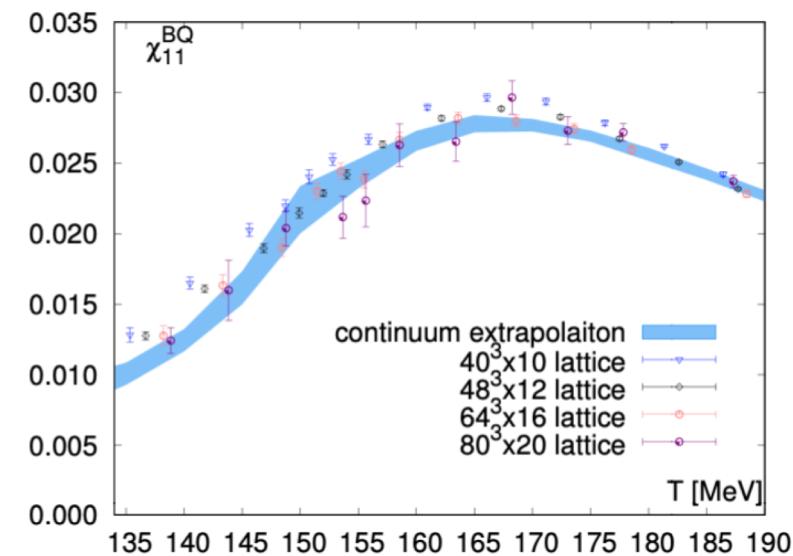
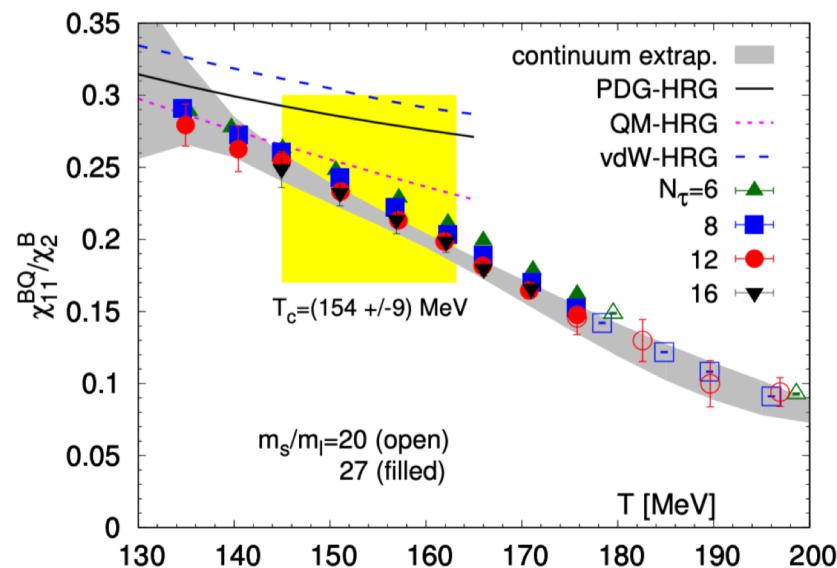
$$\langle N_X - N_{\bar{X}} \rangle$$

$$\chi_2^X = \frac{1}{VT^3} \frac{\partial^2 \ln Z(V, T, \mu_{B,Q,S})}{\partial (\mu_X/T)^2}$$

$$\langle (N_X - N_{\bar{X}})^2 \rangle$$

$$\chi_{11}^{XY} = \frac{1}{VT^3} \frac{\partial^2 \ln Z(V, T, \mu_{B,Q,S})}{\partial (\mu_X/T) \partial (\mu_Y/T)}$$

$$\langle (N_X - N_{\bar{X}})(N_Y - N_{\bar{Y}}) \rangle$$



significant deviations from HRG already for the second mixed cumulants

F. Karsch, Nucl. Phys. A967 (2017) 461, arXiv:1706.01620

O. Kaczmarek, Nucl. Phys. A967 (2017) 137, arXiv:1705.10682

R. Bellwied et al., arXiv:1910.14592



bridging the gap between measurements and theory predictions



Measurement details

Non-dynamical contributions

- ✖ e-by-e fluctuations of wounded nucleons (volume fluctuations)
- ✖ depends on centrality selection methods
- ✖ *has to be estimated for each experiment*

P. Braun-Munzinger, A. Rustamov, J. Stachel, NPA 960 (2017) 114

V. Skokov, B. Friman, and K. Redlich, Phys. Rev. C88 (2013) 034911

M. I. Gorenstein and M. Gazdzicki, Phys. Rev. C 84 (2011) 014904

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

Efficiency correction methods of cumulants

- ✖ depend on the response functions of detectors
- ✖ has to be studied for each experiment

A. Bzdak and V. Koch, Phys. Rev. C 86, 044904 (2012)

A. Bzdak and V. Koch, Phys. Rev. C 91, 027901 (2015)

X. Luo, Phys. Rev. C 91, 034907 (2015)

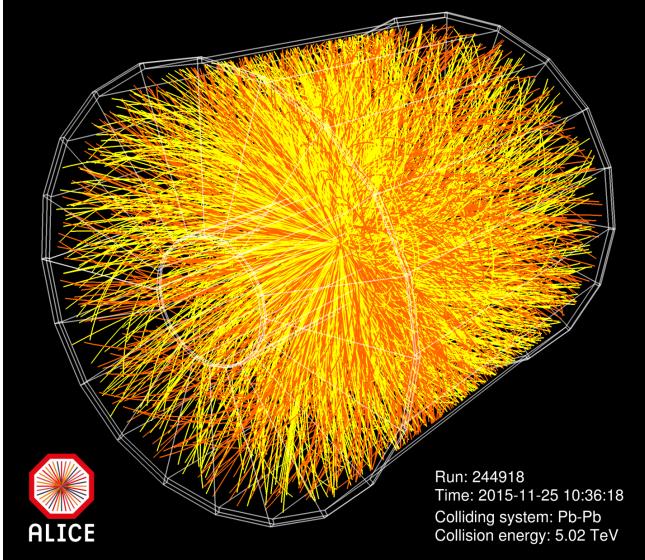
M. Kitazawa, Phys. Rev. C 93, 044911 (2016)

T. Nonaka, M. Kitazawa, and S. Esumi, Phys. Rev. C95, 064912 (2017).

keep efficiency as high as possible!

what should be the optimum acceptance to confront with theory calculations?

Acceptance selection



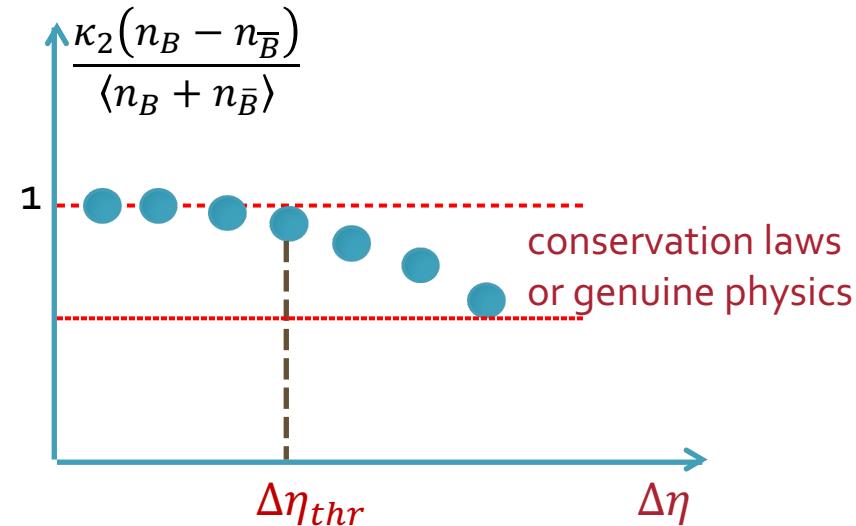
To achieve requirements of GCE
cuts in p_T , Δy or $\Delta\eta$ are imposed

$$\Delta\eta > \Delta\eta_{thr}$$

✓ conservations dominate

$$\Delta\eta < \Delta\eta_{thr}$$

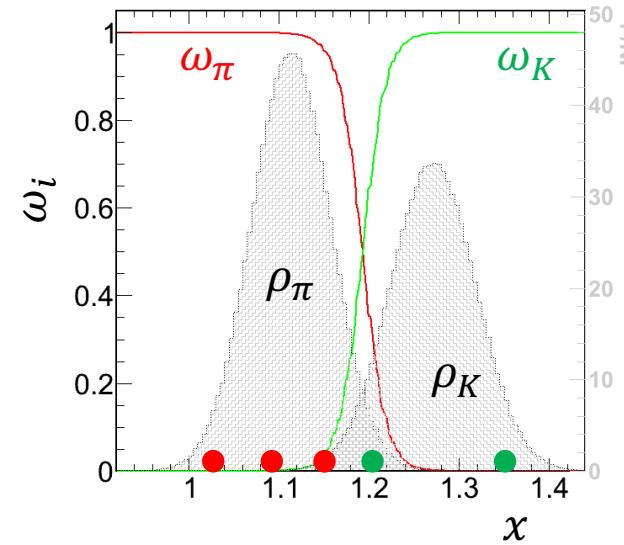
✗ dynamical fluctuations may disappear
(Poisson limit)





experimental results

Measurement techniques



Cut based approach

use additional detector information
or reject a given phase space bin

(challenge: decrease in efficiency)

Identity method (ALICE, NA49, NA61/SHINE)

$$\omega_\pi(x_i) = \frac{\rho_\pi(x_i)}{\rho_\pi(x_i) + \rho_K(x_i)}$$

$$\omega_K(x_i) = \frac{\rho_K(x_i)}{\rho_\pi(x_i) + \rho_K(x_i)}$$

$$W_\pi = \sum_{i=1}^5 \omega_\pi(x_i)$$

$$W_K = \sum_{i=1}^5 \omega_K(x_i)$$

W_π , W_K - proxies for particle multiplicities

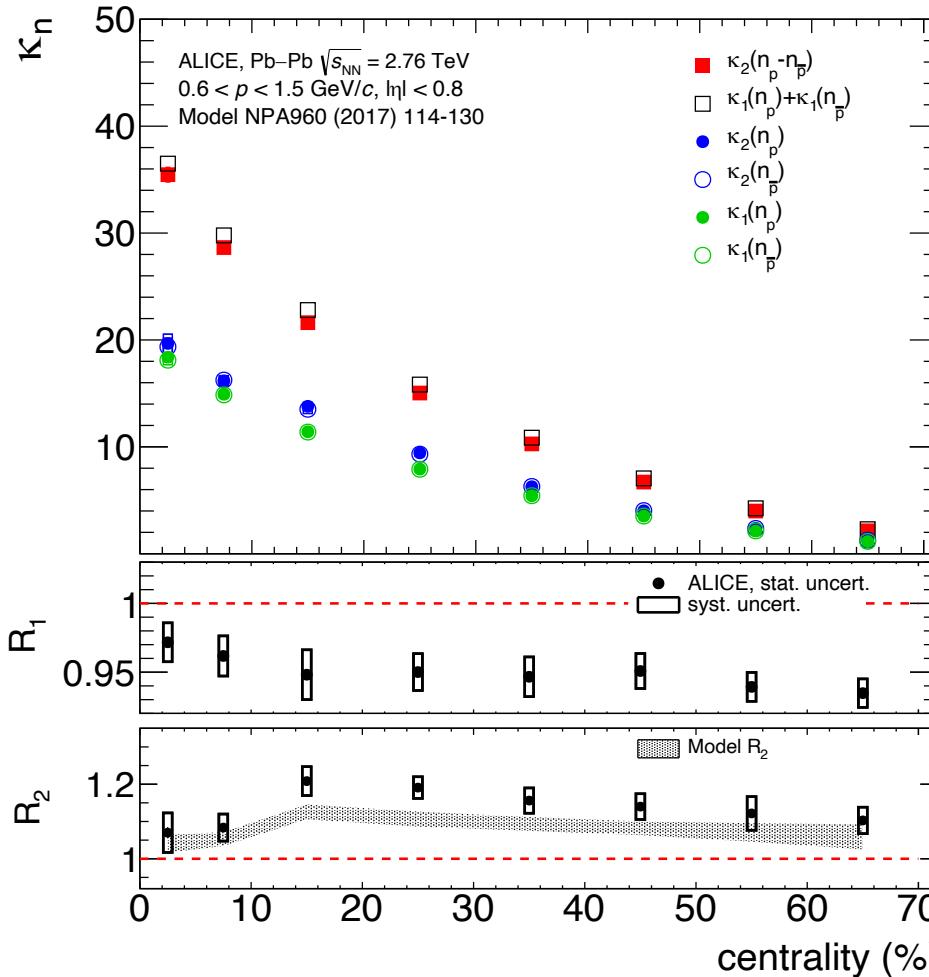
M. Gazdzicki et al., PRC 83, 054907 (2011)

M. I. Gorenstein, PRC 84, 024902 (2011)

A. Rustamov, M. I. Gorenstein, PRC 86, 044906 (2012)

M. Arslanbek, A. Rustamov, NIM A946, 162622 (2019)

Results from ALICE (Identity method)



ALICE Collaboration : S. Acharya et al. arXiv:1910.14396

$$R_1 = \frac{\kappa_2(n_p - n_{\bar{p}})}{\langle n_p + n_{\bar{p}} \rangle}$$

$$R_2 = \frac{\kappa_2(n_p)}{\langle n_p \rangle}$$

Note: $\langle n_p + n_{\bar{p}} \rangle = \kappa_2(\text{Skellam})$

At LHC R_1 is protected against volume fluct.
 R_2 can be described by volume fluctuations

P. Braun-Munzinger, A. Rustamov, J. Stachel, NPA 960 (2017) 114

$$R_1 = \boxed{\frac{\kappa_2(n_p) + \kappa_2(n_{\bar{p}})}{\langle n_p + n_{\bar{p}} \rangle}} - \underbrace{2 \frac{\text{cov}(n_p, n_{\bar{p}})}{\langle n_p + n_{\bar{p}} \rangle}}_{\text{correlation term}}$$

unity in ideal
HRG

$$\text{cov}(n_p, n_{\bar{p}}) = \langle n_p n_{\bar{p}} \rangle - \langle n_p \rangle \langle n_{\bar{p}} \rangle$$

Conservations laws

$$\kappa_2(n_B - n_{\bar{B}}) = \kappa_2(n_B) + \kappa_2(n_{\bar{B}}) - 2\text{cov}(n_B n_{\bar{B}})$$

$$\text{cov}(n_B n_{\bar{B}}) = \langle n_B n_{\bar{B}} \rangle - \langle n_B \rangle \langle n_{\bar{B}} \rangle$$

- 📌 Global baryon number conservation:
📌 y_b and $y_{\bar{b}}$ are produced independently

$$R_1 = 1 - \alpha$$

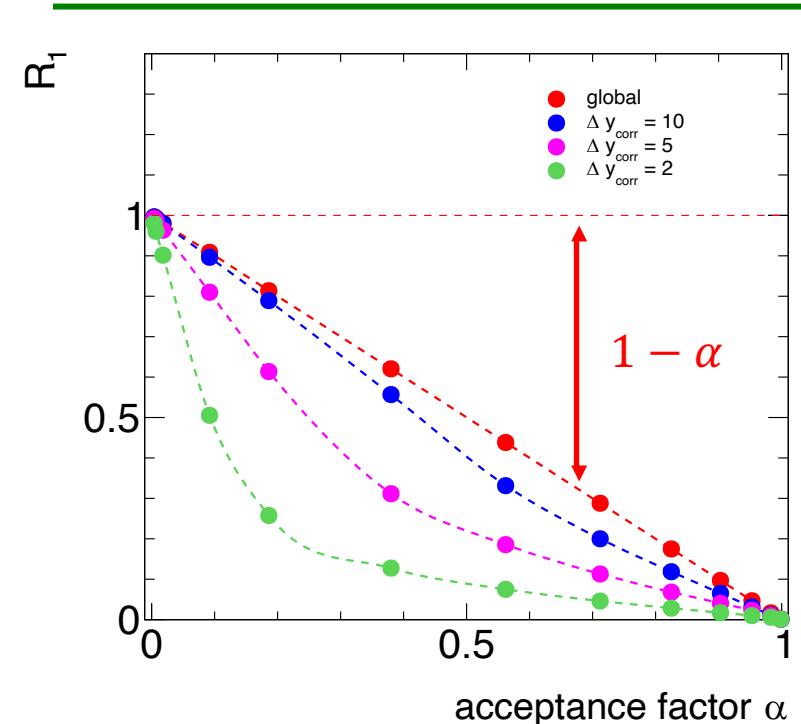
P. Braun-Munzinger, A. R., J. Stachel, QM18, NPA 982 (2019) 307-310

A. Bzdak, V. Koch, V. Skokov, PRC87 (2013) 014901

- 📌 Local baryon number conservation:

$$|y_B - y_{\bar{B}}| < \Delta y_{corr}/2$$

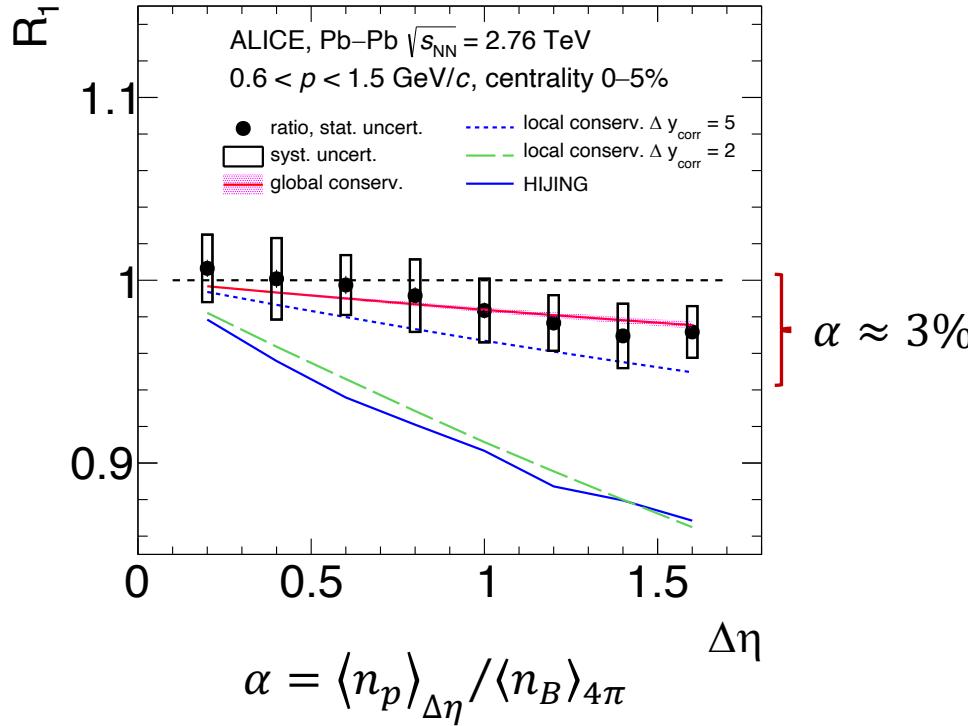
P. Braun-Munzinger, A. Rustamov, J. Stachel, arXiv:1907.03032



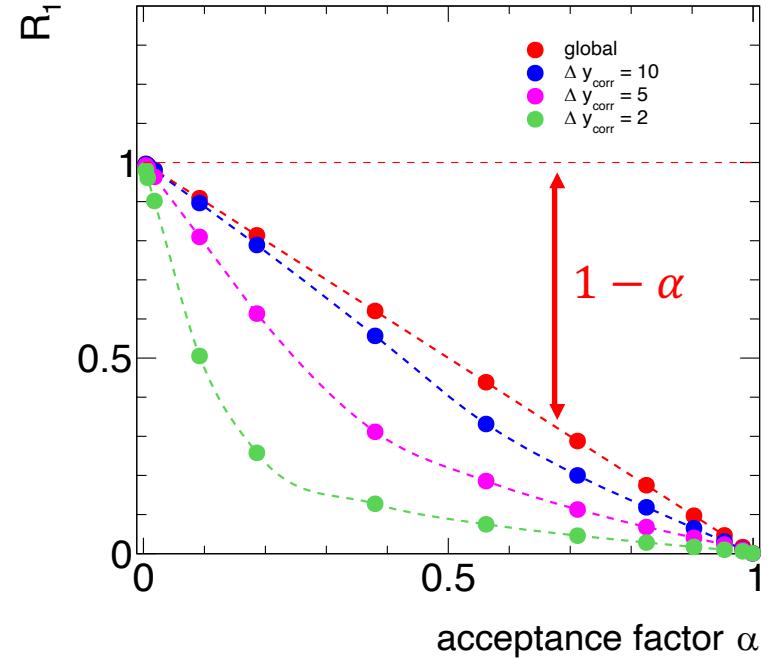
$$R_1 = \frac{k_2(n_B - n_{\bar{B}})}{\langle n_B + n_{\bar{B}} \rangle} \quad \alpha = \frac{n_B^{acc}}{n_B^{4\pi}}$$

conservation laws introduce subtle correlations between baryons and antibaryons

Results from ALICE (Identity method)



ALICE Collaboration : S. Acharya et al. arXiv:1910.14396

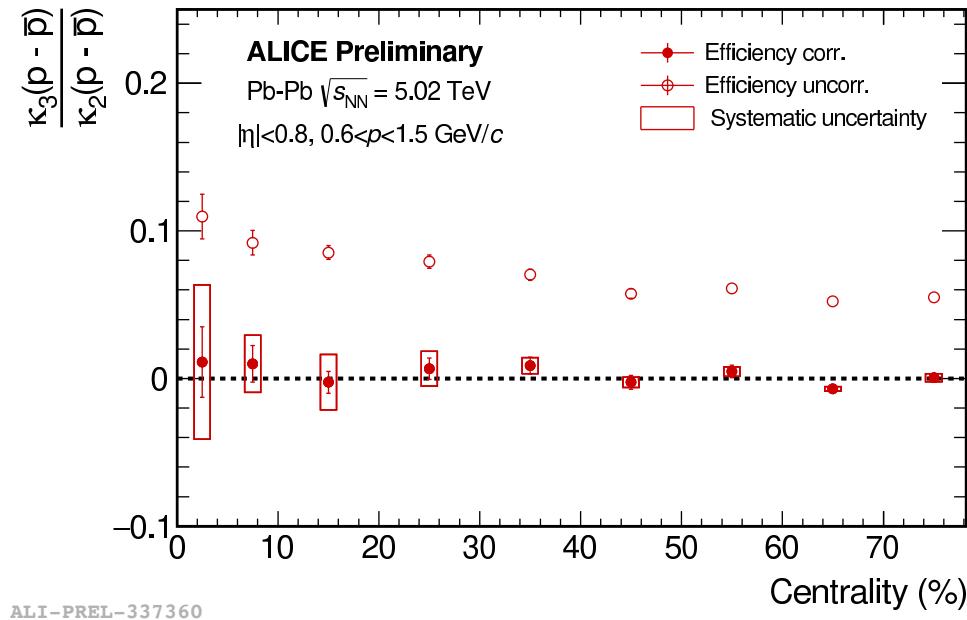


P. Braun-Munzinger, A. Rustamov, J. Stachel, arXiv:1907.03032

- 📌 The data are best described by global baryon number conservation: $R_1 = 1 - \alpha$
- 📌 However, the results are also consistent with $\Delta y_{\text{corr}} = 5$
- 📌 HIJING corresponds to $\Delta y_{\text{corr}} = 2$, not consistent with the data

the ALICE data suggest long range correlations

Results from ALICE (Identity method)

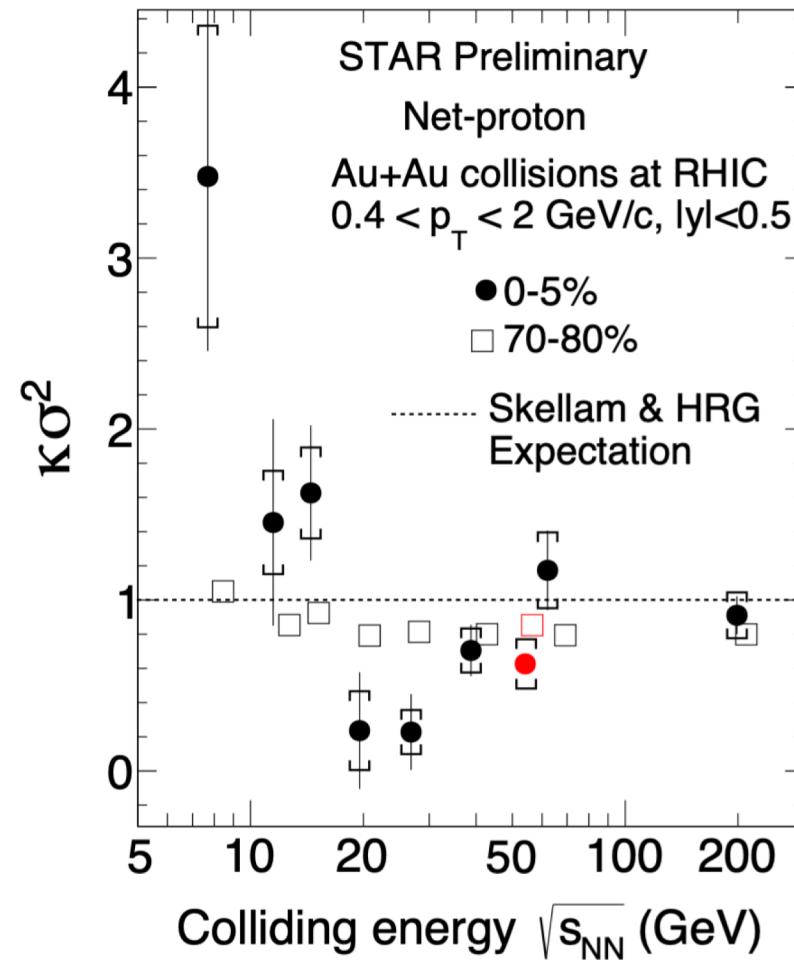


- 📌 vanishing 3rd cumulants at LHC energies.
- 📌 consistent with expectations

essential crosscheck before proceeding to higher moments (κ_4, κ_6)

Mesut Arslanok, Tue, Search for the CP I

Results from STAR

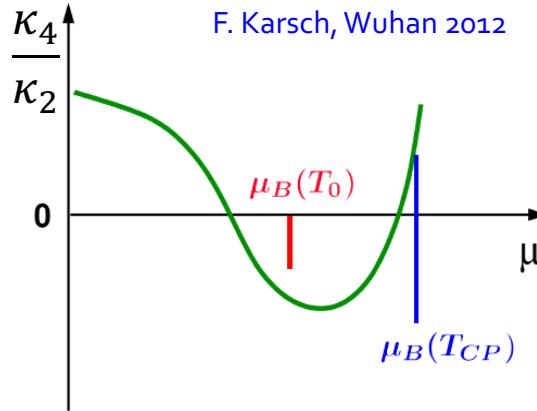


note different notation: $k\sigma^2 \equiv \kappa_4/\kappa_2$

- 📌 non-monotonic energy dependence
- 📌 κ_4/κ_2 measurement at 54.4 GeV follows the trend established by the BES-I results

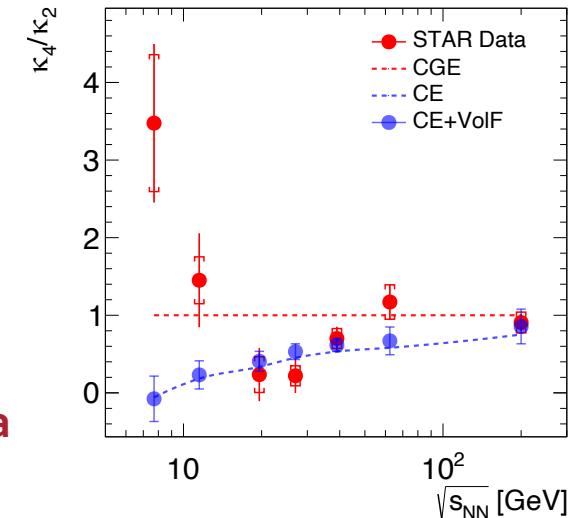
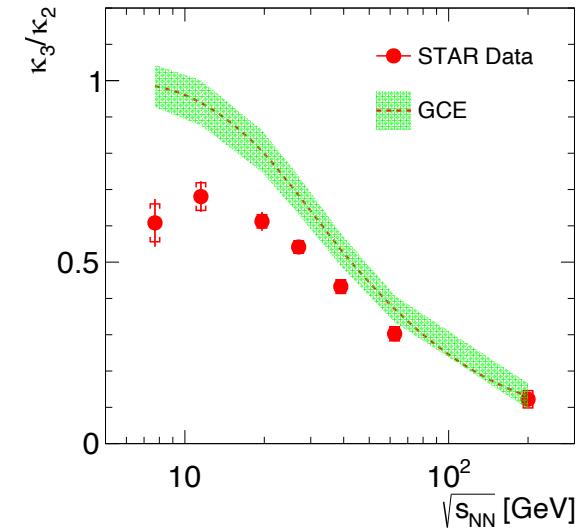
Ashish Pandav, Tue, Search for the CP I

Baryon number conservation



a dip in the excitation function
seems to be generic

STAR DATA: X. Luo, PoS CPOD2014, 019 (2015)



Assumption:

📌 κ_3/κ_2 is entirely driven by baryon number conservation

Prediction:

📌 excitation function for κ_4/κ_2

above 11.5 GeV CE suppression describes the κ_4/κ_2 data

Cumulants vs. correlation functions

$$\rho(x_1, x_2) = \rho(x_1)\rho(x_2) + C_2(x_1, x_2)$$

$$\rho(x_1, x_2, x_3) = \rho(x_1)\rho(x_2)\rho(x_3) + \rho(x_1)C_2(x_2, x_3) + \dots + C_3(x_1, x_2, x_3)$$

ρ - distribution functions

C_n - integrated correlation functions

$$\kappa_2 = \kappa_1 + C_2$$

$$\kappa_3 = \kappa_1 + 3C_2 + C_3$$

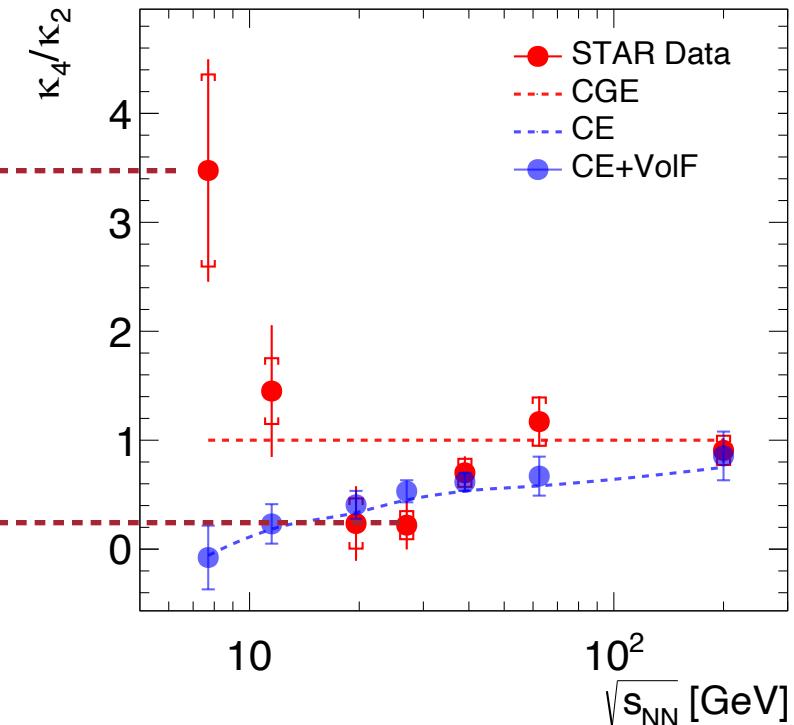
$$\kappa_4 = \kappa_1 + 7C_2 + 6C_3 + C_4$$

STAR DATA: X. Luo, PoS CPOD2014, 019 (2015)

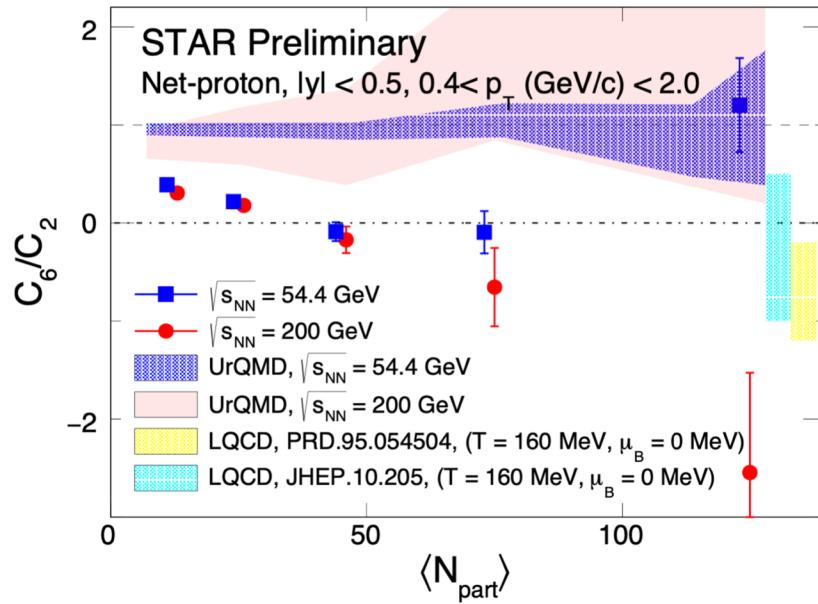
driven by 4-proton
correlation function, C_4

A. Bzdak, V. Koch, V. Skokov and N. Strodthoff, NPA 967, 465 (2017)

dominated by 2-proton
correlation function, C_2
(consistent with baryon number conservation)

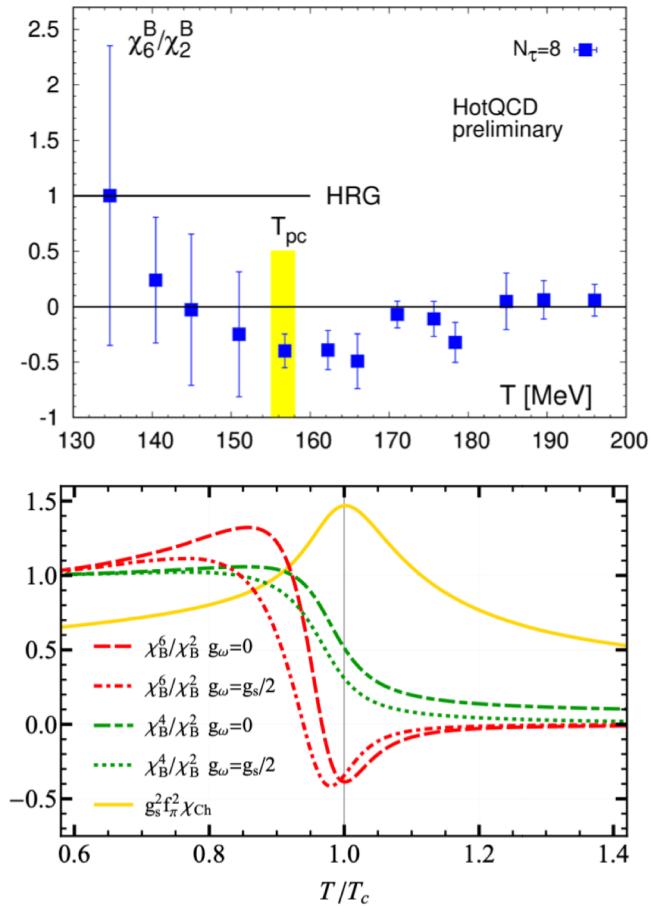


Results from STAR



C_6/C_2 for most central collisions

- negative for $\sqrt{s_{NN}} = 200 \text{ GeV}$
- positive for $\sqrt{s_{NN}} = 54.4 \text{ GeV}$



negative value of six-order cumulant
due to O(4) chiral criticality

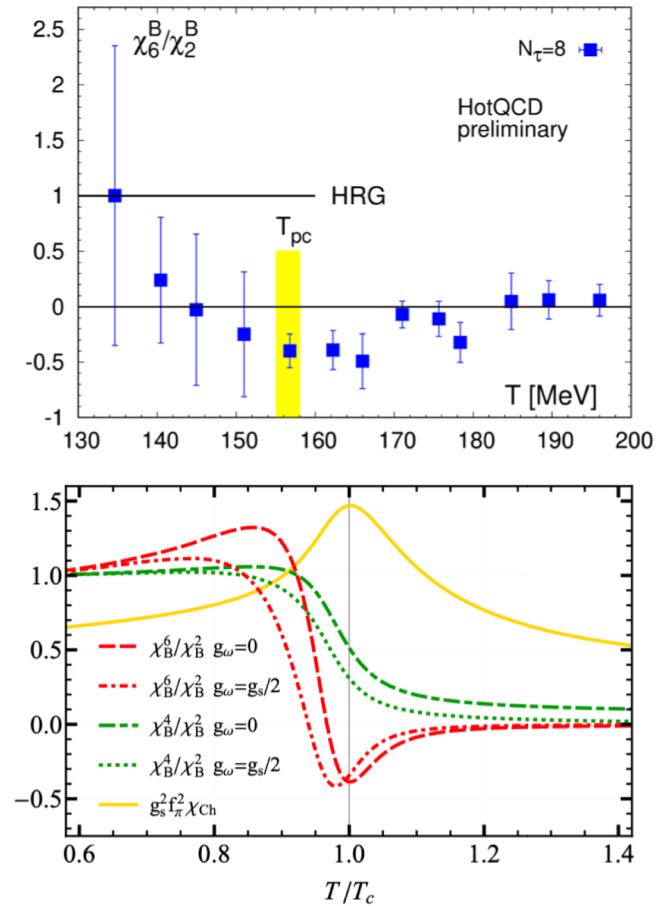
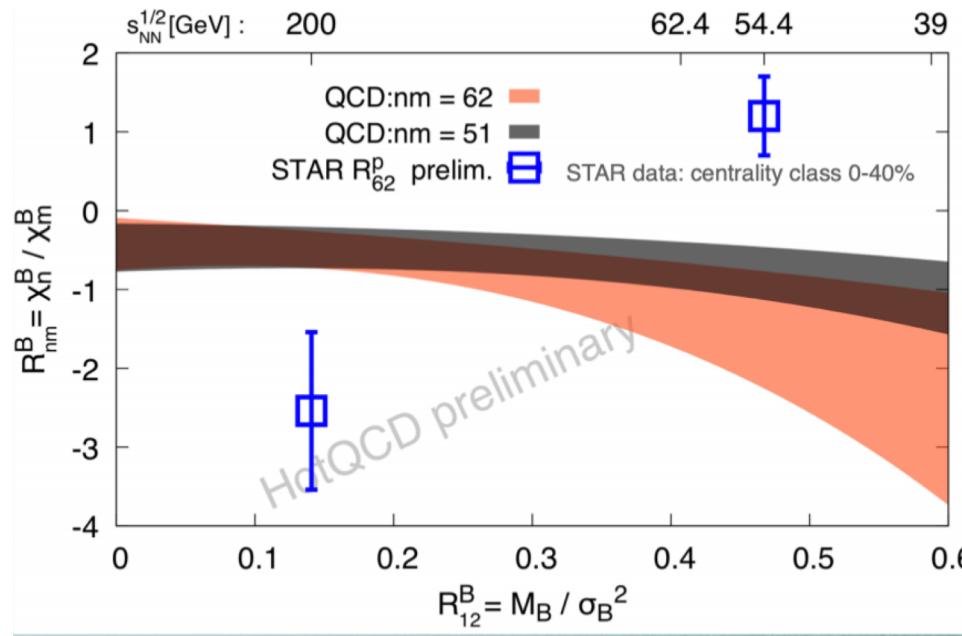
A. Bazavov et al., Phys. Rev. D95 (2017) 054504

S. Borsanyi et al., arXiv:1805.04445

G.A. Almasi, B. Friman and K. Redlich,
PRD 96, no. 1, 014027 (2017)

Ashish Pandav, Tue, Search for the CP I

Results from STAR and LQCD



- ✖ STAR data are not consistent with LQCD
- ✖ would be interesting to see also κ_5 from STAR

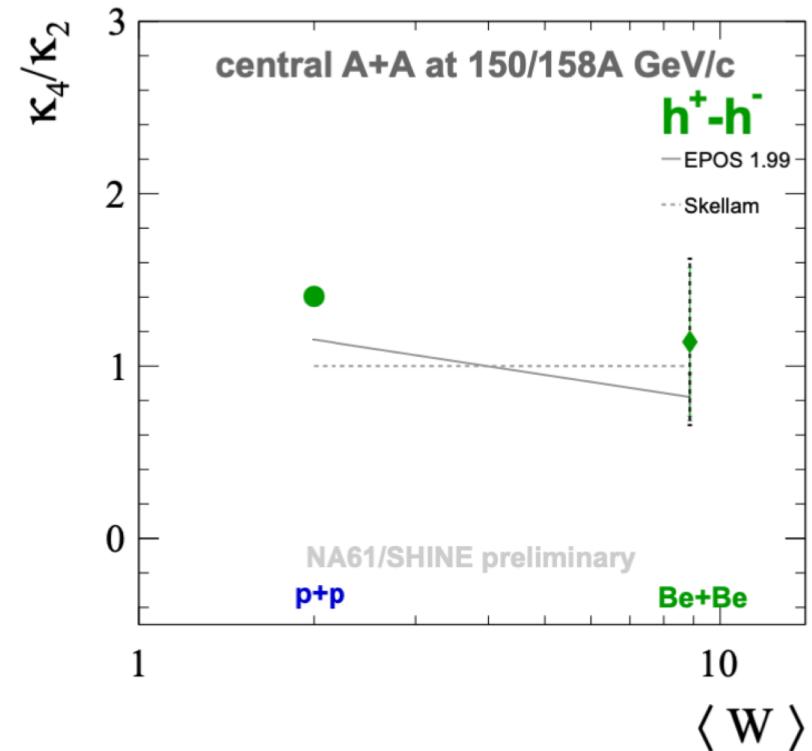
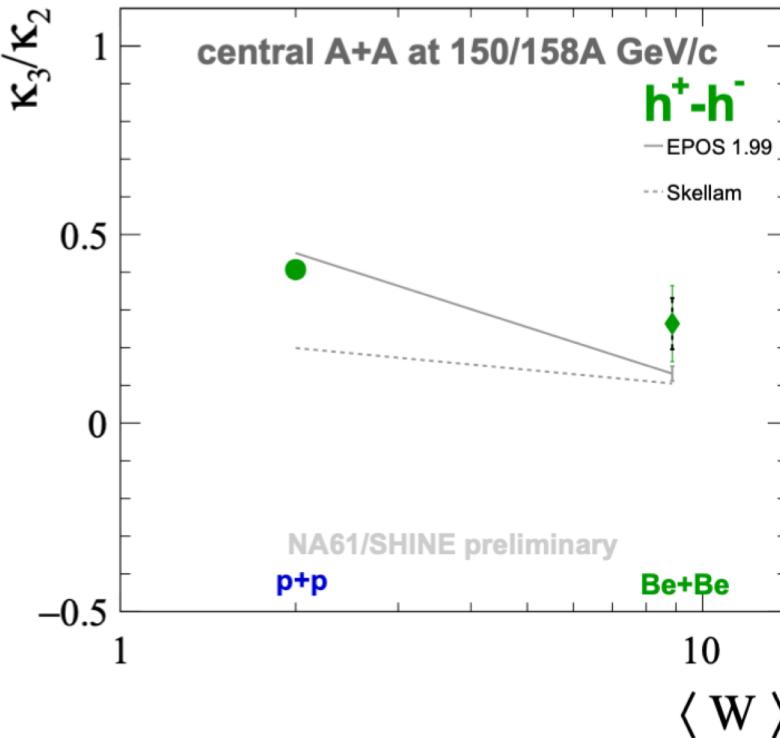
Heng-Tong Ding, Mon, Plenary
 Dennis Bollweg, Wed, QCD at finite temperature III
 Ashish Pandav, Tue, Search for the CP I

negative value of six-order cumulant
 due to O(4) chiral criticality

A. Bazavov et al., Phys. Rev. D95 (2017) 054504
 S. Borsanyi et al., arXiv:1805.04445
 G.A. Almasi, B. Friman and K. Redlich,
 PRD 96, no. 1, 014027 (2017)

Results from NA61/SHINE

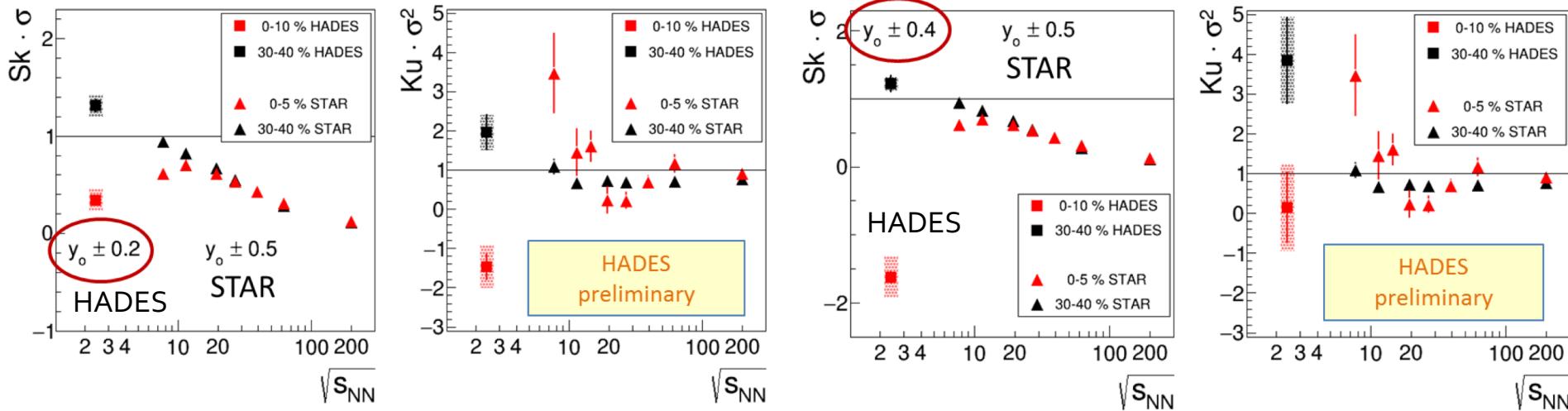
$$\sqrt{s_{NN}} \approx 17 \text{ GeV}$$



- 📌 $p + p \approx Be + Be$ both in κ_3/κ_2 and κ_4/κ_2
- 📌 EPOS predictions agree with the measured data
- 📌 No critical behavior in Be+Be collisions

Maja Mackowiak, Tue, Search for the CP I

Results from HADES



GSI/FAIR covers important energy regime to understand the excitation function of cumulants

For the smaller acceptance ($y_0 \pm 0.2$)

- ✖ κ_3/κ_2 - is below unity
- ✖ κ_4/κ_2 - is negative

For the larger acceptance ($y_0 \pm 0.4$)

- ✖ κ_3/κ_2 - becomes negative
- ✖ κ_4/κ_2 - approaches unity, still consistent with negative

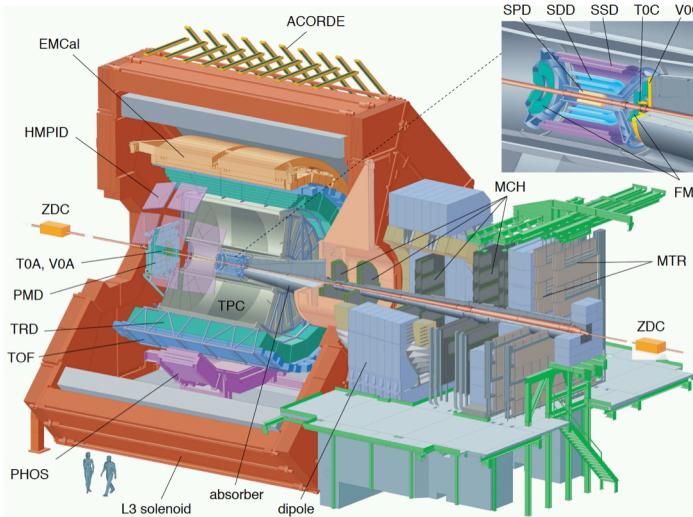
the results are obtained with NLO volume corrections, based on:

P. Braun-Munzinger, A. Rustamov, J. Stachel, NPA 960 (2017) 114
V. Skokov, B. Friman, and K. Redlich, Phys.Rev. C88 (2013) 034911

Near Future Experiments

ALICE upgrade

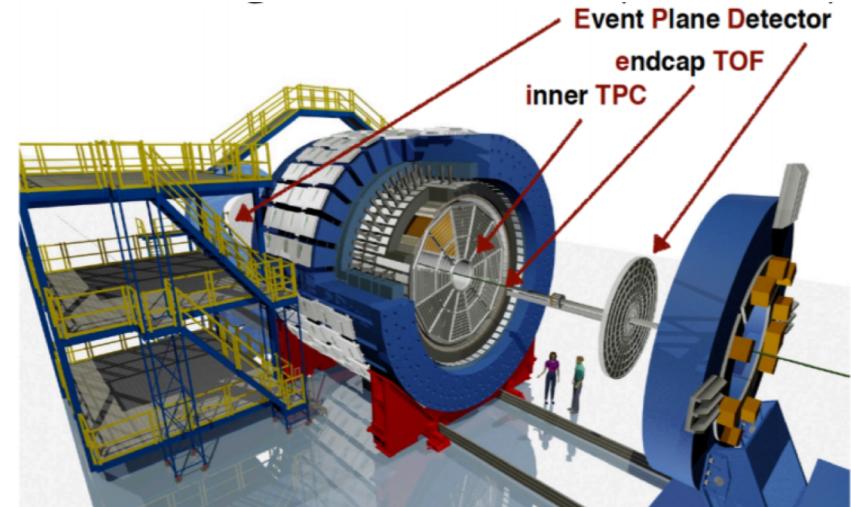
- 📌 new ITS: better vertexing
- 📌 faster TPC: MWPC → GEMs
- 📌 record minimum-bias Pb-Pb data at 50 kHz (currently < 1 kHz)
 - 📌 order of magnitude more events
 - 📌 measuring κ_6 , may be beyond



Michael Weber: ALICE plenary

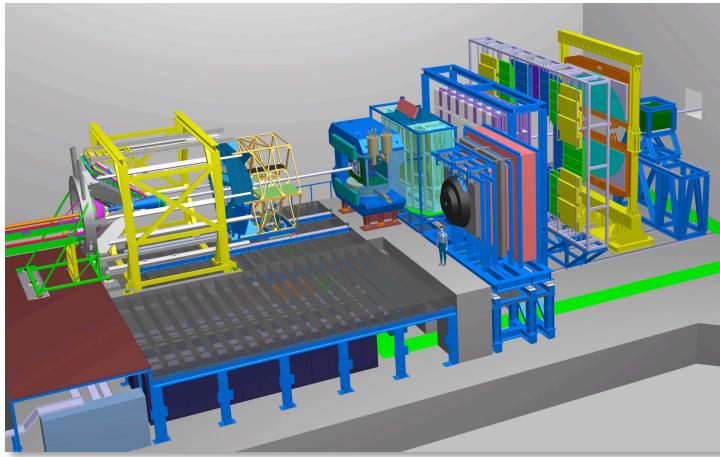
STAR upgrade, BES - II

- 📌 iTPC: $|\eta| < 1.5$
- 📌 better dE/dx resolution
- 📌 lower momentum acceptance
- 📌 EPD: $2.1 < |\eta| < 5.1$
 - 📌 centrality determination
 - 📌 ~ factor 20 more statistics

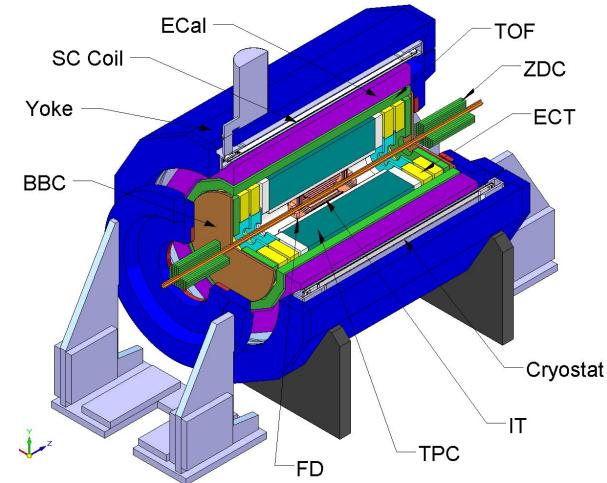


Zhangbu Xu: STAR plenary

Near Future Experiments



CBM at FAIR (fixed target)



MPD at NICA (collider)

both experiments plan to explore fluctuations and correlations of conserved charges

**Subhasis Samanta, Tue, Search for the CP I
MPD: Adam Kisiel, Tue, Future facilities
CBM: Viktor Klochkov, Tue, Future facilities**



Summary

- 📌 Event-by-event fluctuation signals are promising tools to explore the phase structure of a matter under the study
- 📌 To confront experiment with theory, a number of non-dynamical contributions are to be accounted for
 - 📌 Fluctuations of participant nucleons
 - 📌 Conservation of baryon and/or strangeness number
- 📌 The measured second cumulants of net-protons at ALICE are, after accounting for global baryon number conservation, in agreement with the corresponding second cumulants of the Skellam distribution
- 📌 LQCD predicts a Skellam behavior for the second cumulants of net-baryons at $T_{pc} = 156 \text{ MeV}$
- 📌 Contributions due to local baryon number conservation at LHC energies are small
 - 📌 The ALICE data suggest long range correlations
- 📌 Measured third cumulants are consistent with zero
 - 📌 Essential crosscheck before proceeding to higher moments (κ_4, κ_6)



Summary

- 📌 The STAR data show non-monotonic energy dependence in κ_3/κ_2 and κ_4/κ_2
- 📌 The new results at 54.4 GeV on κ_4/κ_2 are consistent with the BES-I results
- 📌 For the most central collisions at 200 GeV, the value of κ_6 is negative while at 54 GeV it stays positive
 - 📌 Not consistent with the LQCD predictions for crossover
 - 📌 Would be interesting to see κ_5 results
- 📌 NA61/SHINE results on net-charge fluctuations are similar for p-p and Be-Be collisions
 - 📌 Evidences for critical behavior are not observed so far
- 📌 HADES results strongly depend on rapidity interval, but are always below the corresponding cumulant ratios as measured by STAR at 7.7 GeV

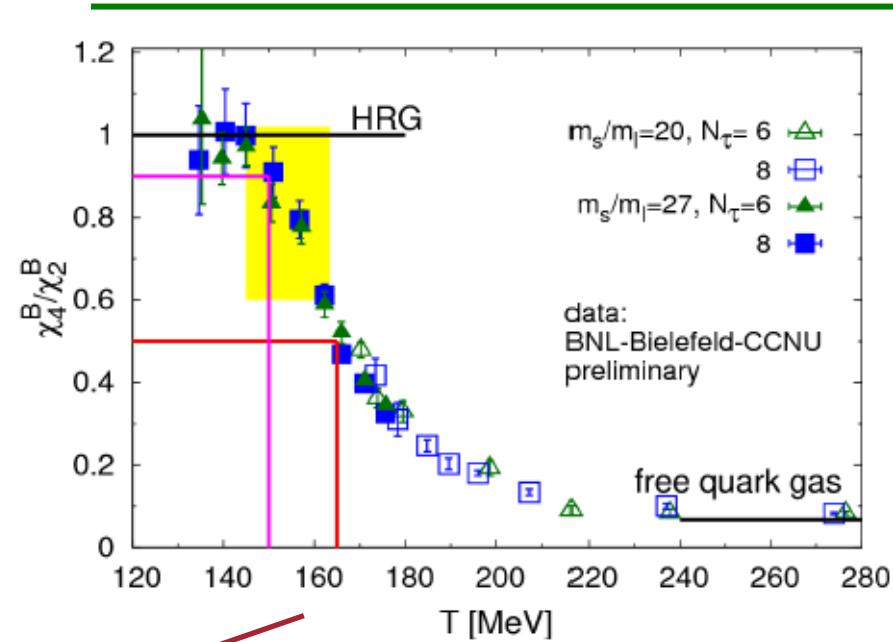
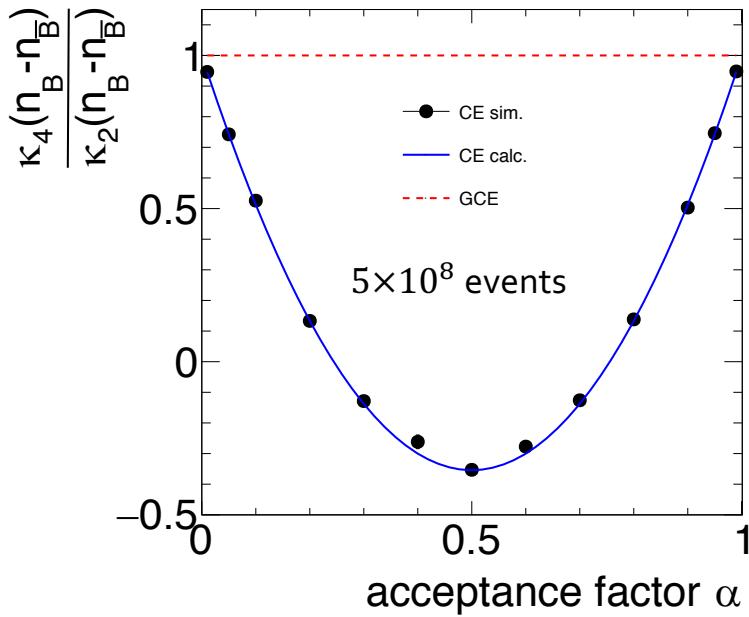


Thank you for your attention



Bonus slides

Acceptance selection



📌 deviations from unity are driven by different mechanisms

$$\alpha = \frac{\langle n_B \rangle^{acc}}{\langle N_B \rangle^{4\pi}}, \quad \frac{\kappa_4(n_B - \bar{n}_B)}{\kappa_2(n_B - \bar{n}_B)} = 1 - 6\alpha(1 - \alpha) \left[1 - \frac{2}{\langle N_B + \bar{N}_B \rangle_{CE}} \left(\langle N_B \rangle_{GCE} \langle \bar{N}_B \rangle_{GCE} - \langle N_B \rangle_{CE} \langle \bar{N}_B \rangle_{CE} \right) \right]$$

P. Braun-Munzinger, A. R., J. Stachel, QM18, NPA 982 (2019) 307-310

A. Bzdak, V. Koch, V. Skokov, PRC87 (2013) 014901

Modeling net-baryon fluctuations

Phenomenological approach

due to isospin randomization at $\sqrt{s_{NN}} > 10\text{GeV}$

$$\wp(n_p, n_{\bar{p}}; n_B, n_{\bar{B}}) = \wp(n_B, n_{\bar{B}}) B(n_p; n_B, r) B(n_{\bar{p}}; n_{\bar{B}}, \bar{r})$$

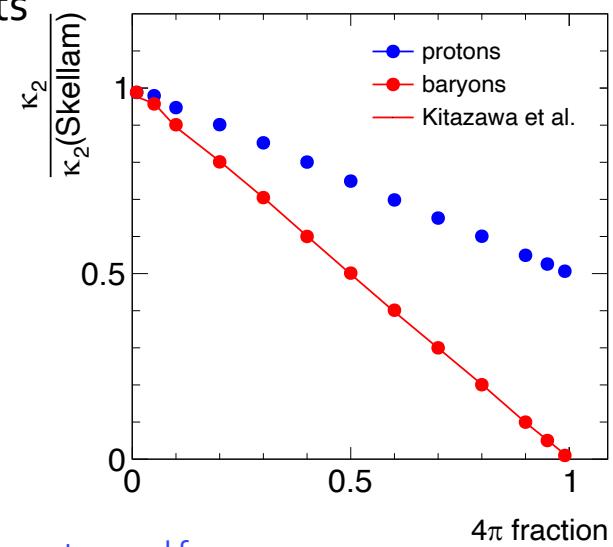
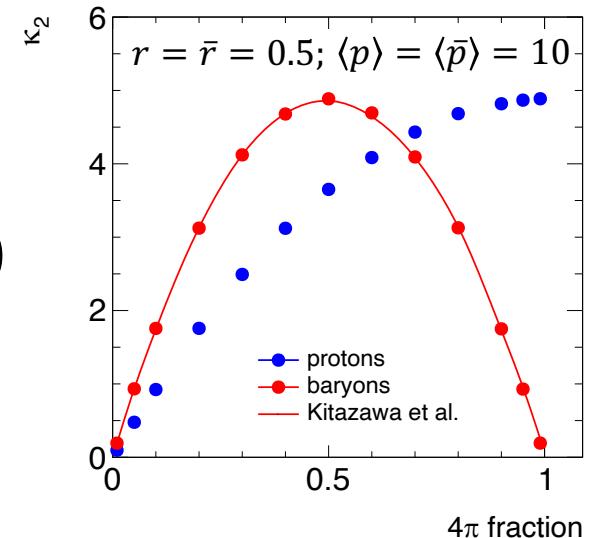
$$r = \langle n_p \rangle / \langle n_B \rangle \quad \bar{r} = \langle n_{\bar{p}} \rangle / \langle n_{\bar{B}} \rangle$$

in this case net-baryon fluctuations can be easily obtained from corresponding net-proton measurements

M. Kitazawa, and M. Asakawa, Phys. Rev. C86 (2012)

Experimental approach

measurement of fluctuations of other baryons
to improve understanding of net-baryon baseline
to study correlated baryon-strangeness fluctuations

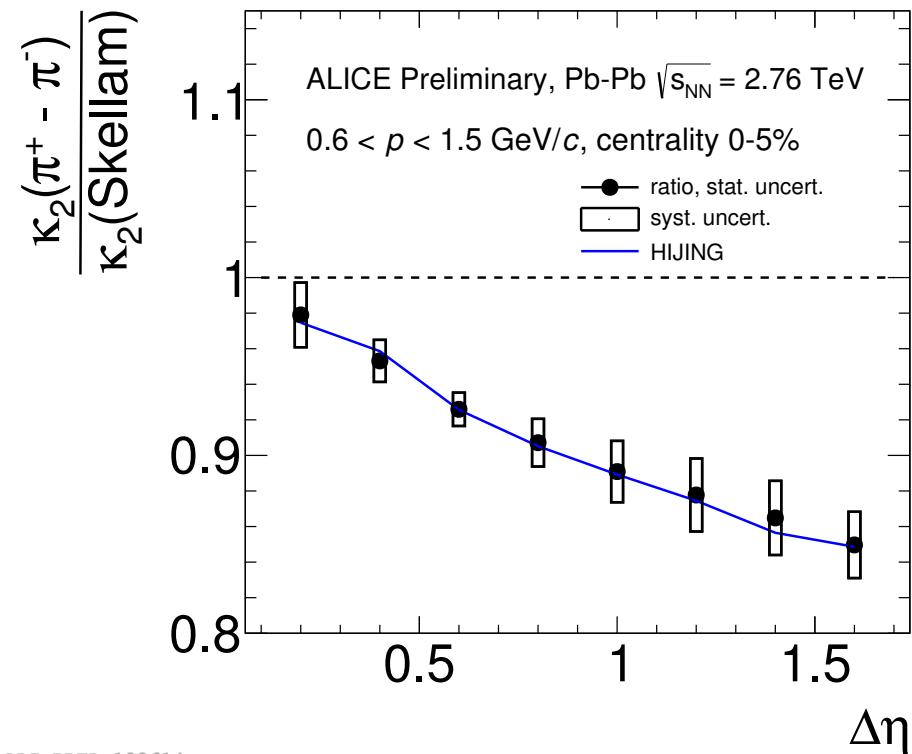


event generator used from:

P. Braun-Munzinger, A. R., J. Stachel, NPA 982 (2019) 307-310

Net-pions and Net-kaons

net-pions

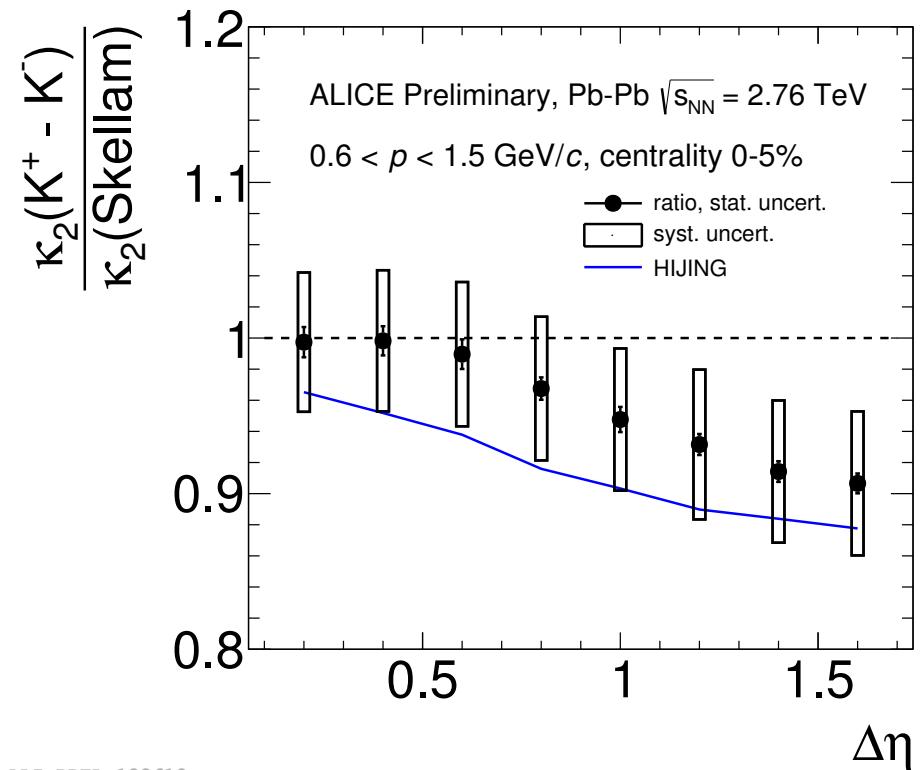


perfect agreement with HIJING

resonance pion and kaon production is likely to explain the measured trend

Warning: Skellam is not a proper baseline for net-pions and net-kaons

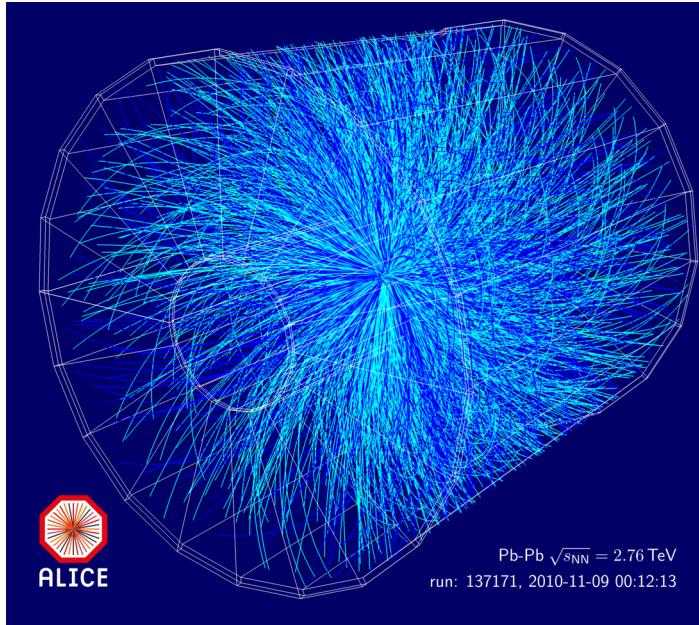
net-kaons



reasonable agreement with HIJING

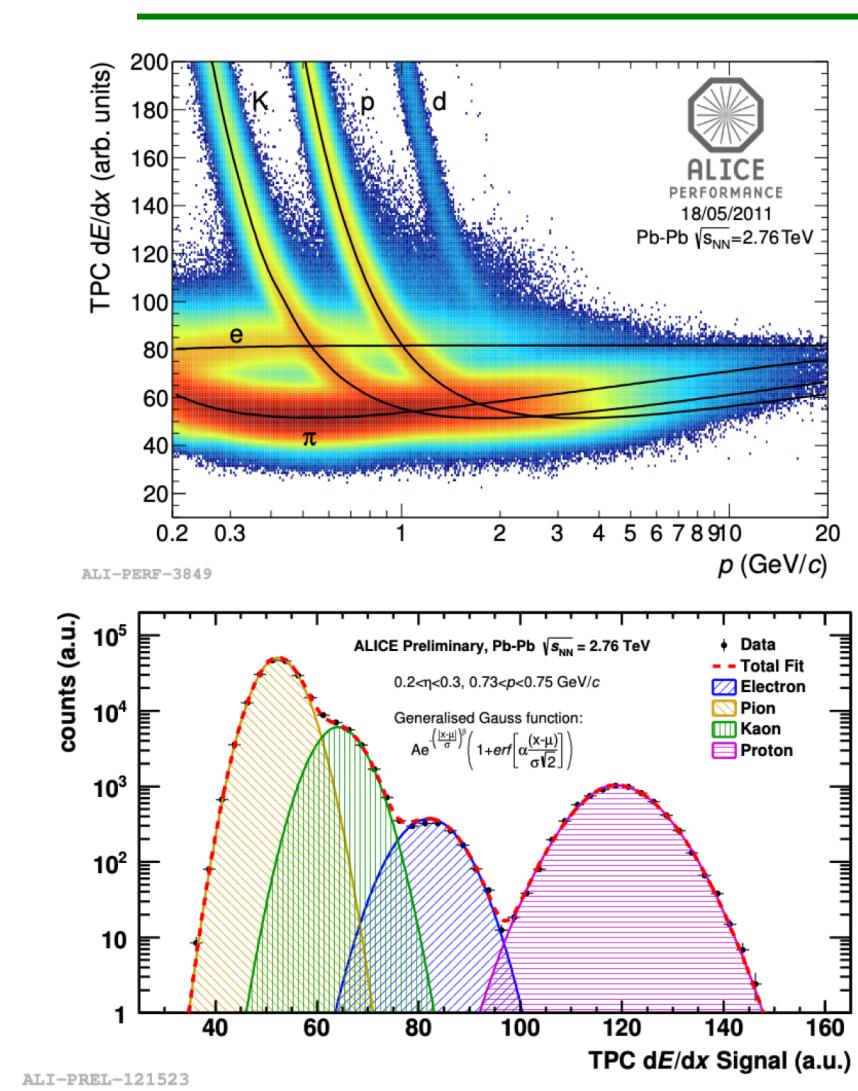


Analysis technique (PID)

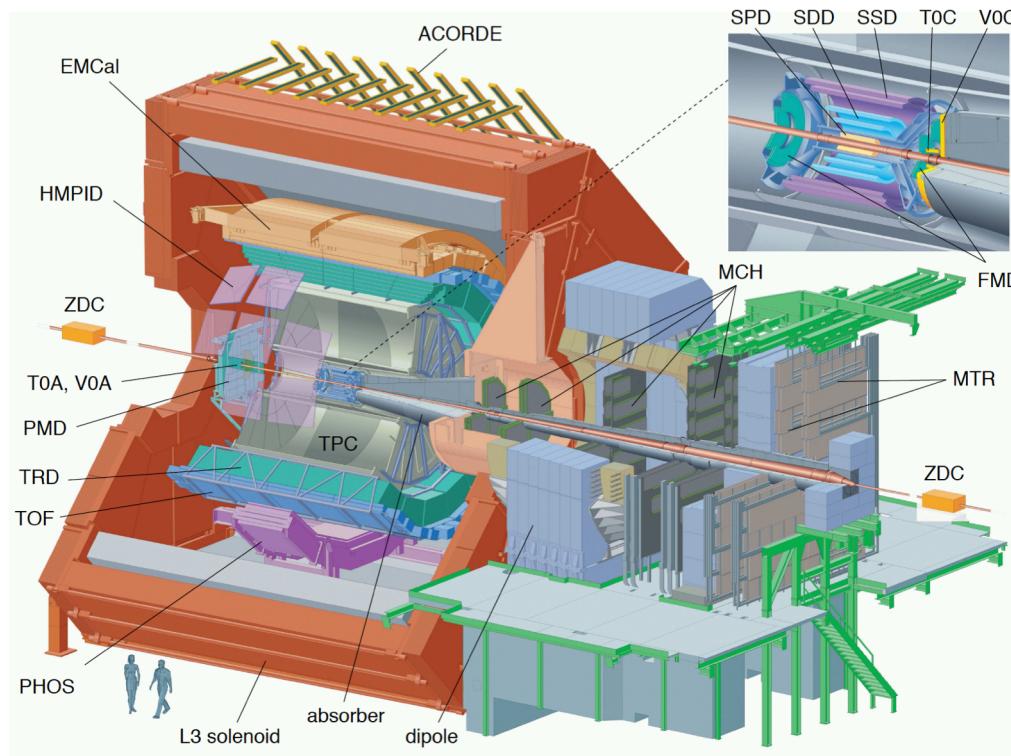


😱 in experiments we use net-protons
as a proxy for net-baryons

😱 moreover, protons contain feed-down
contributions from weak decays



The ALICE apparatus and data sets



main detectors used in the analysis

Inner Tracking System (ITS): tracking, vertexing

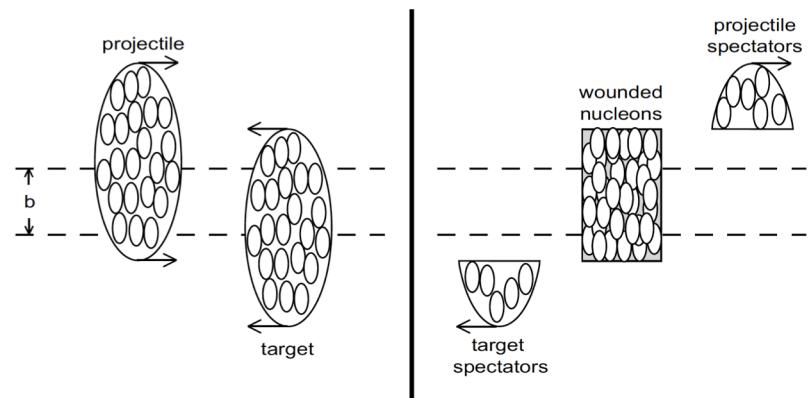
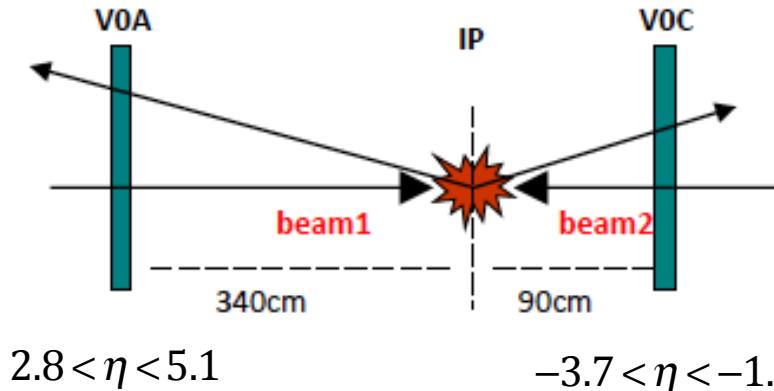
Time Projection Chamber (TPC): tracking, PID

V0 detector (V0A, V0C): centrality selection

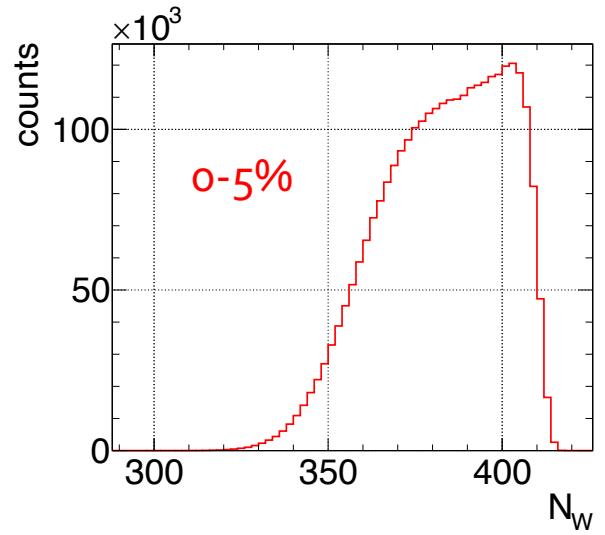
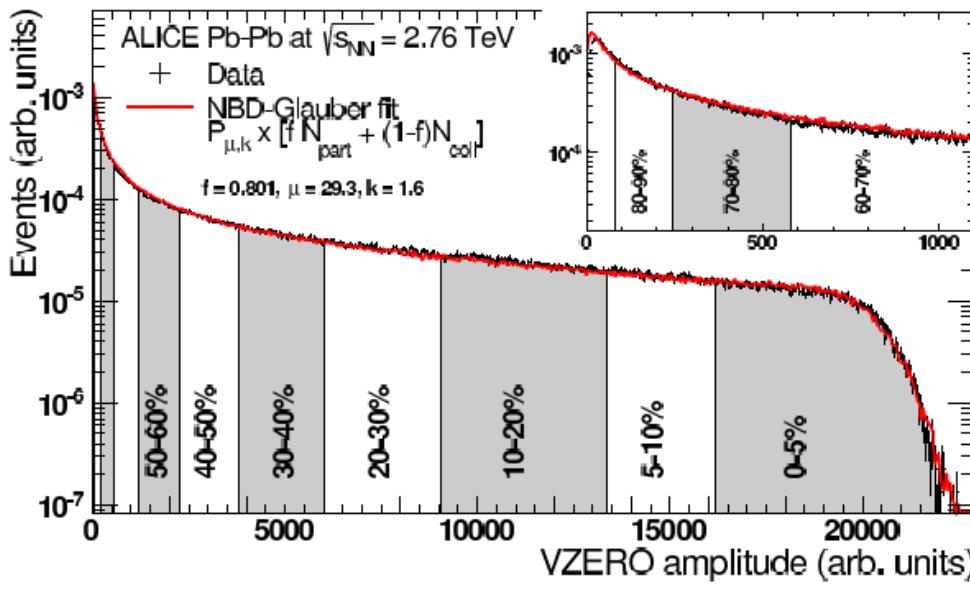
minimum bias $Pb-Pb$ data sets

$\sqrt{s_{NN}}$ [TeV]	events
2.76	13×10^6
5.02	59×10^6

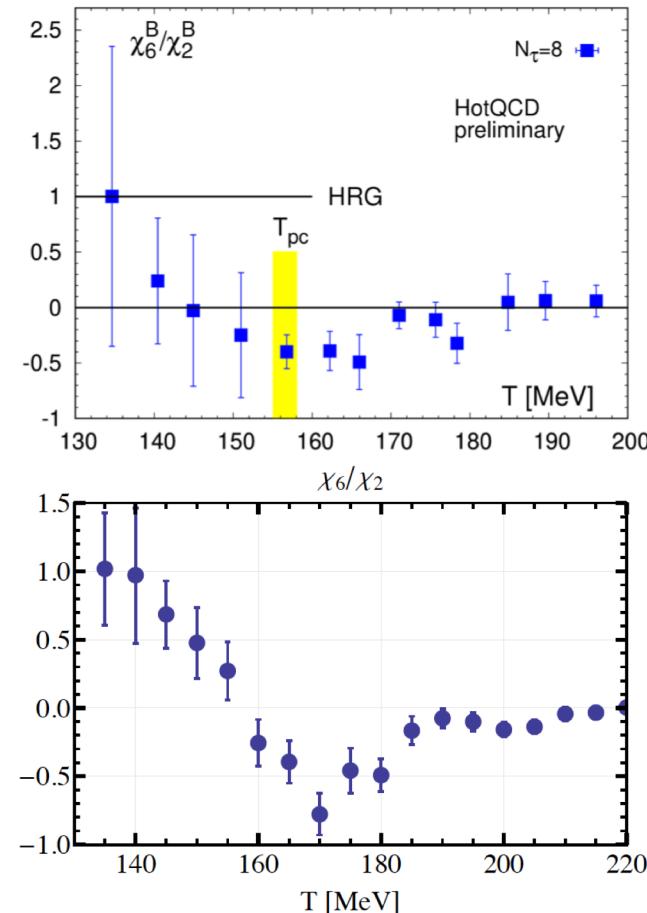
Participant (volume) fluctuations



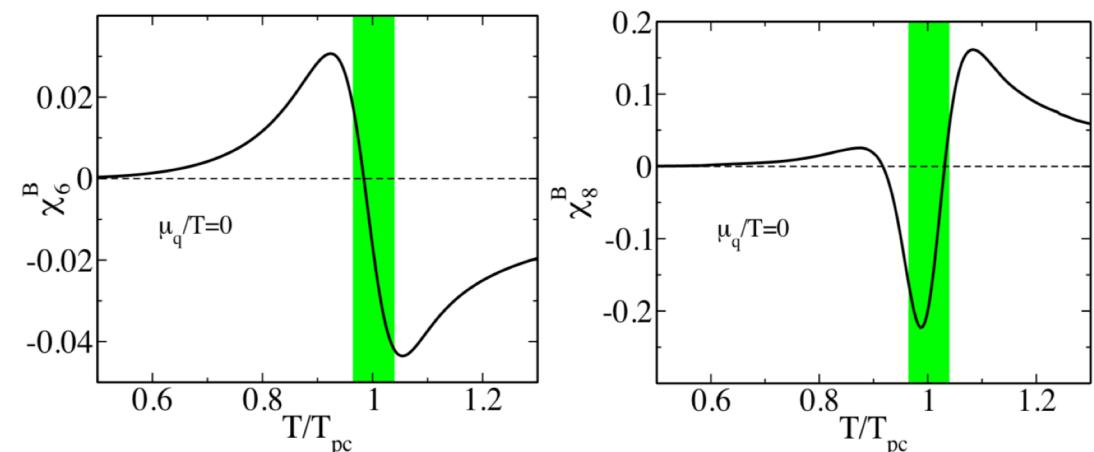
ALICE: Phys.Rev.C88 (2013) no.4, 044909



Outlook



A. Bazavov et al., Phys. Rev. D95 (2017) 054504
 S. Borsanyi et al., arXiv:1805.04445



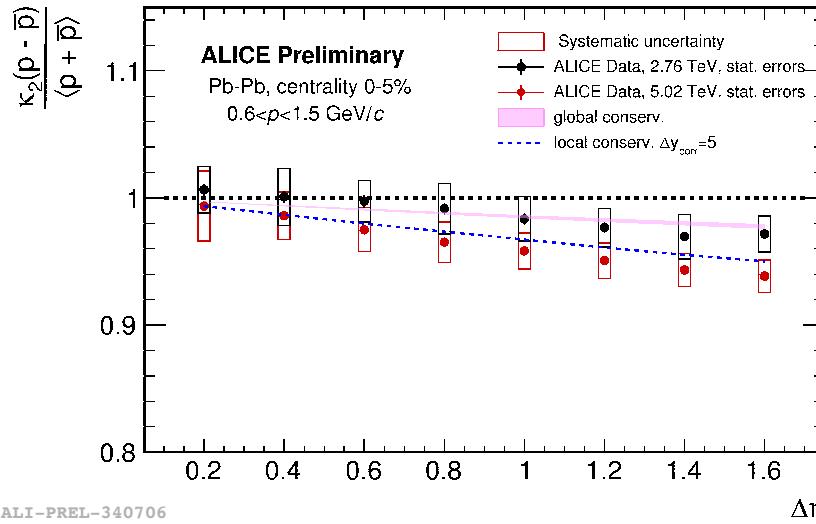
B. Friman, F. Karsch, K. Redlich, V. Skokov Eur. Phys. J. C (2011) 71: 1694

search for the critical behavior in 6th and higher cumulants for vanishing net baryon densities
is achievable with the upcoming ALICE data
Increased statistics x100 in RUN3 and RUN4

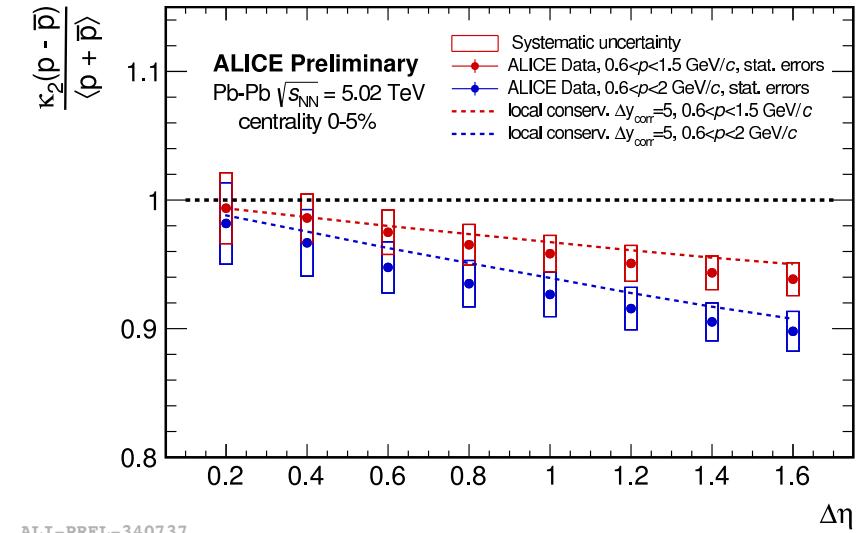
Yellow Report: arXiv:1812.06772

Results from ALICE (Identity method)

comparison between two energies



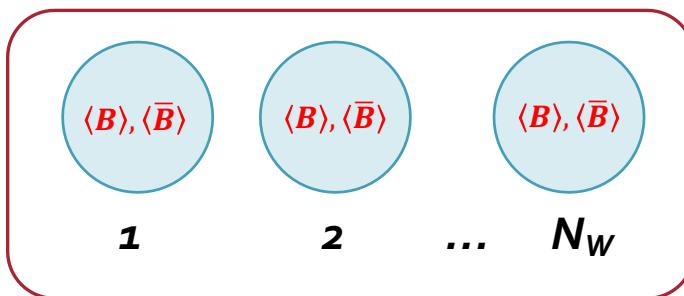
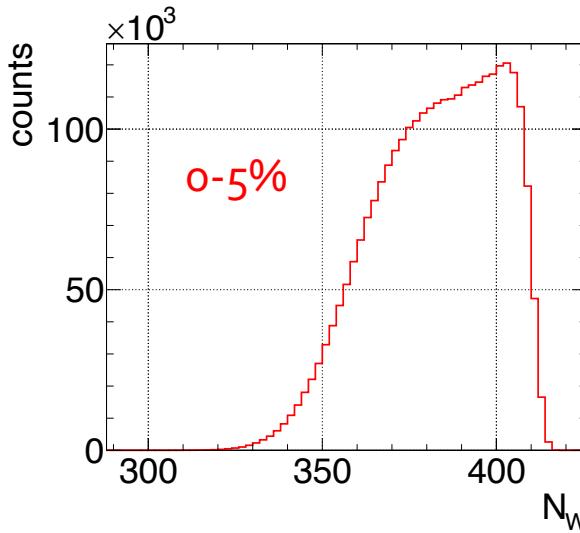
different momentum ranges



- 📌 deviation from unity due to baryon number conservation
- 📌 both data sets are consistent with $\Delta y_{\text{corr}} = 5$
- 📌 more deviation from unity for larger momentum range
- 📌 consistent with baryon number conservation

More details in: M. Arslandok,

Participant (volume) fluctuations



$$\hat{\chi}_2^B = \frac{\langle \Delta N_B^2 \rangle - \langle \Delta N_B \rangle^2}{VT^3} \equiv \frac{\kappa_2(\Delta N_B)}{VT^3}$$

$$k_2^{exp}(\Delta N_B) = \kappa_2(\Delta N_B) + \frac{\langle N_B - N_{\bar{B}} \rangle}{\langle N_W \rangle} k_2(N_W)$$

$$k_n^{exp}(\Delta N_B) = \kappa_n(\Delta N_B) + F(\kappa_1, \kappa_2, \dots, \kappa_n(N_W))$$

$$\frac{\kappa_4^{exp}(\Delta N_B)}{\kappa_2^{exp}(\Delta N_B)} \neq \frac{\hat{\chi}_4^B}{\hat{\chi}_2^B}$$

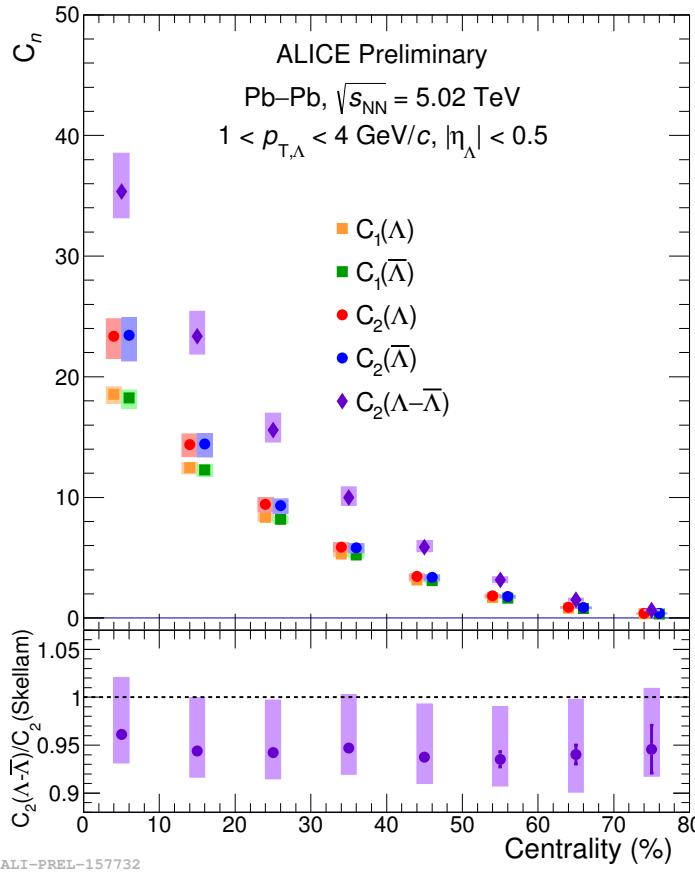
$$\frac{\kappa_3^{exp}(\Delta N_B)}{\kappa_2^{exp}(\Delta N_B)} \neq \frac{\hat{\chi}_3^B}{\hat{\chi}_2^B}$$

😱 $\kappa_n(N_W)$ are experiment dependent
 contributions from volume fluctuations
 have to be subtracted **for each experiment**

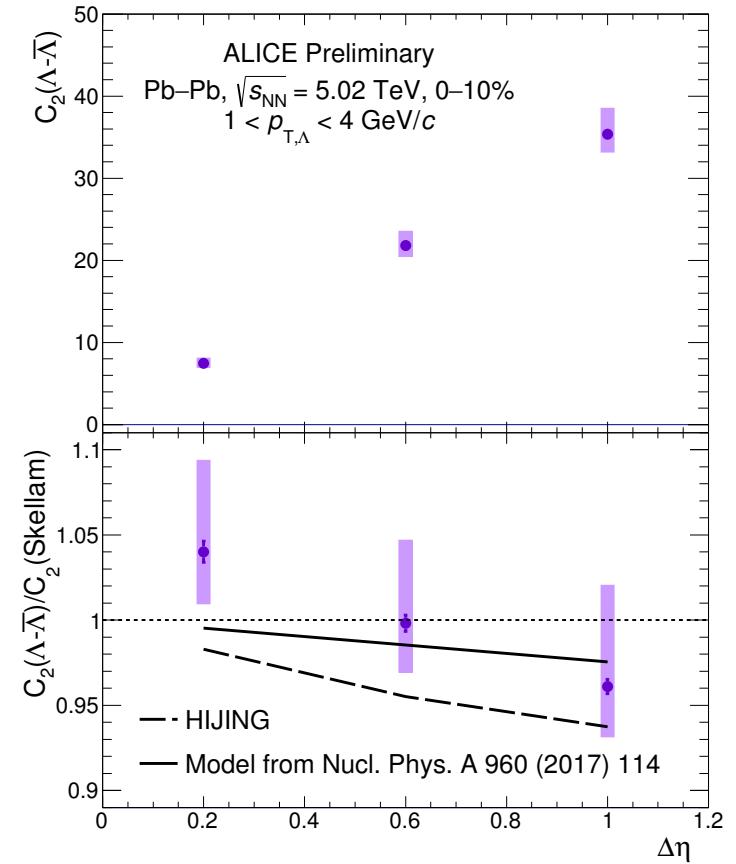
- P. Braun-Munzinger, A. R., J. Stachel, arXiv:1612.00702, NPA 960 (2017) 114
 V. Skokov, B. Friman, and K. Redlich, Phys. Rev. C88 (2013) 034911
 A. Bialas, and M. Bleszynski, W. Czyz, NPB 111 (1976) 461.

Net-Lambda cumulants (Identity Method)

$$\kappa_2(n - \bar{n}) \equiv C_2(n - \bar{n})$$

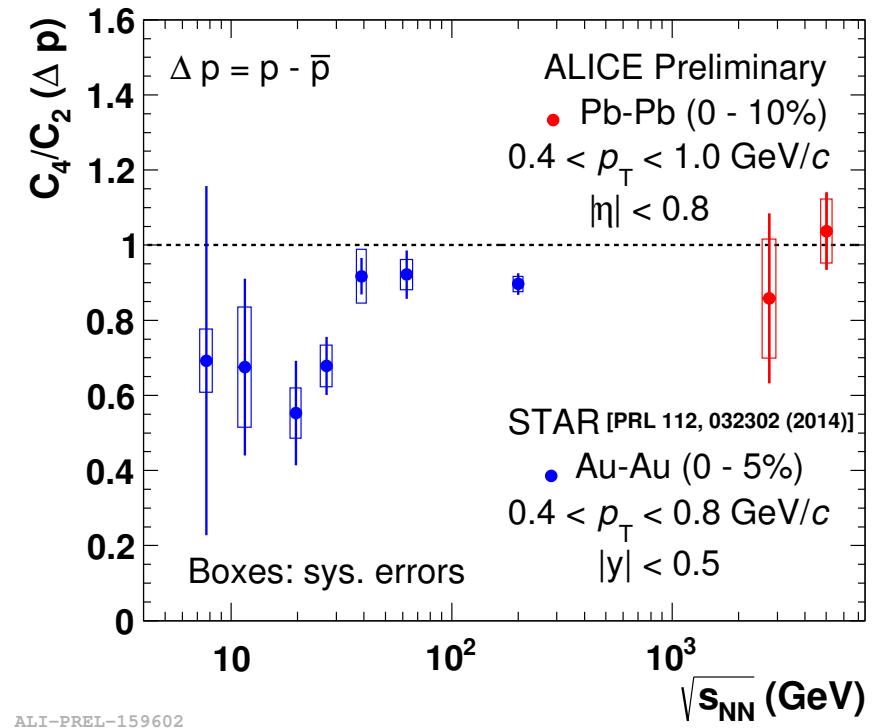
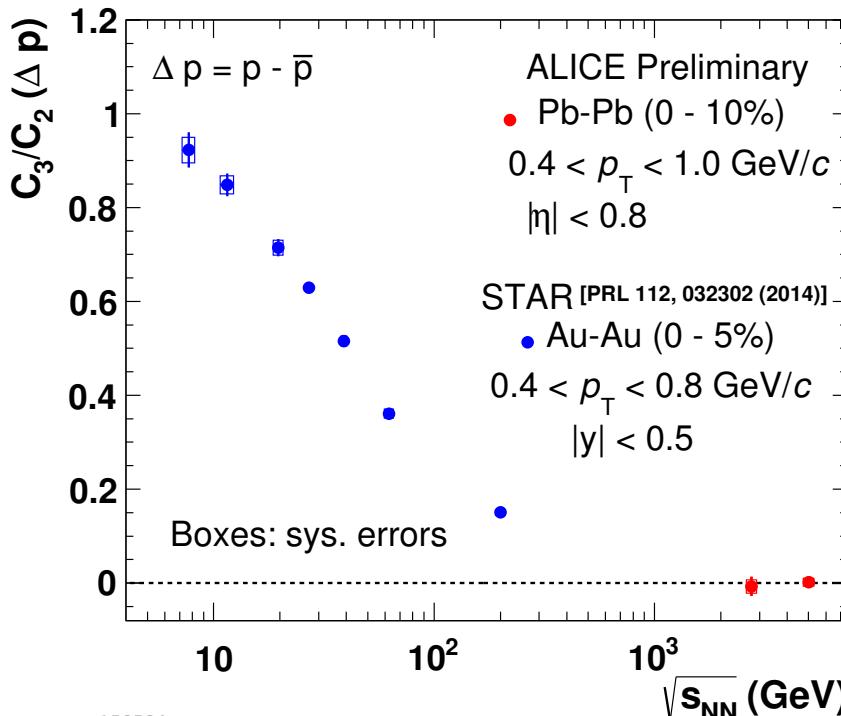


A. Ohlson, QM18, NPA982 (2019) 299-302



Similar trend as for net-protons

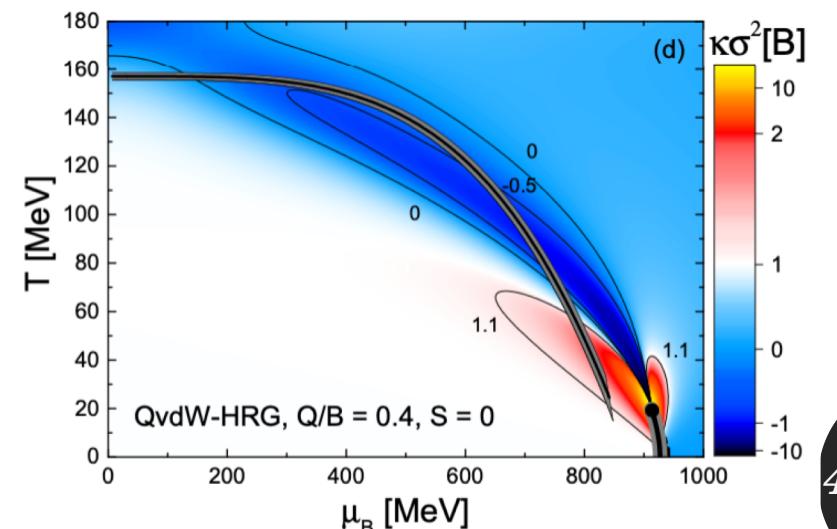
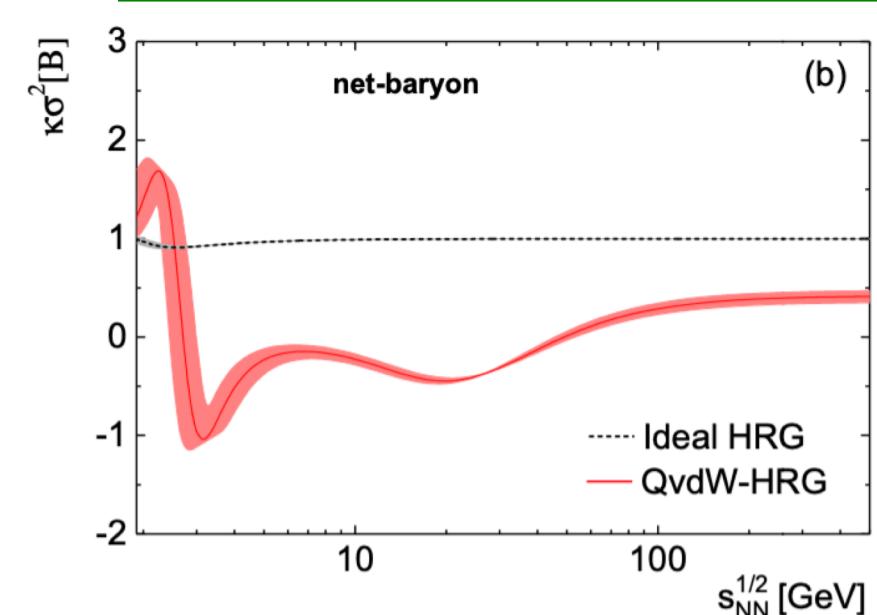
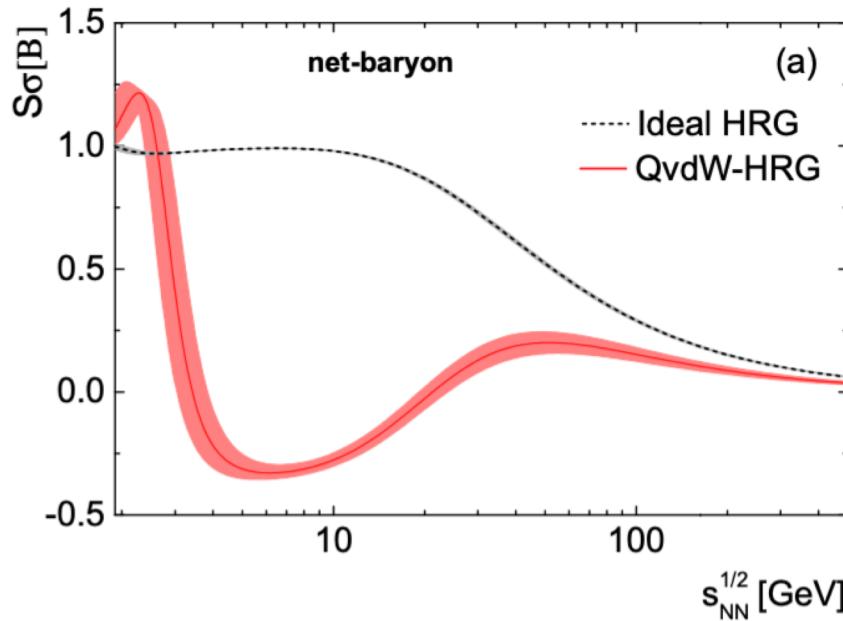
Higher cumulants (cut-based)



N. Behera, QM18, NP A982 (2019) 851-854

measured with the cut-based approach in a rather small p_T acceptance

Both ALICE and STAR attempting to improve p_T acceptance



R. Poberezhnyuk, V. Vovchenko, A. Motornenko,
M. I. Gorenstein and H. Stoecker, arXiv:1906.01954 [hep-ph]