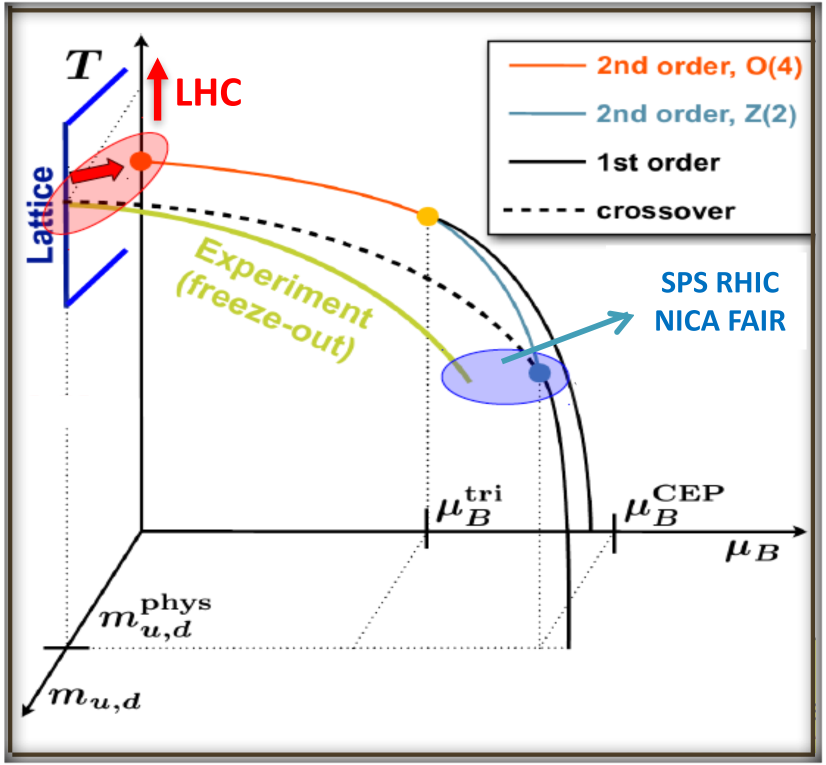
Recent results on event-by-event fluctuations in ALICE

Mesut Arslandok
Physikalisches Institut, Heidelberg University
on behalf of the ALICE Collaboration

Quark Matter 2019
The 28th International Conference on Ultra-relativistic Nucleus-Nucleus Collisions
3-9 November 2019, Wuhan, China

Nature of chiral phase transition



F. Karsch, Schleching 2016

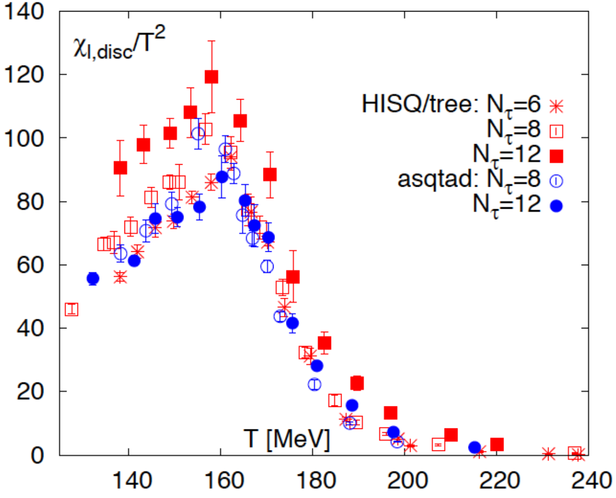
small u, d quark masses

↔

vicinity to 2nd order O(4) criticality

pseudocritical features possible

HotQCD Collaboration
Phys.Rev. D85 (2012) 054503, Phys.Lett. B795 (2019) 15



$$T_{pc} = 156.5 \pm 1.5 \text{ MeV}$$

Criticality at Crossover

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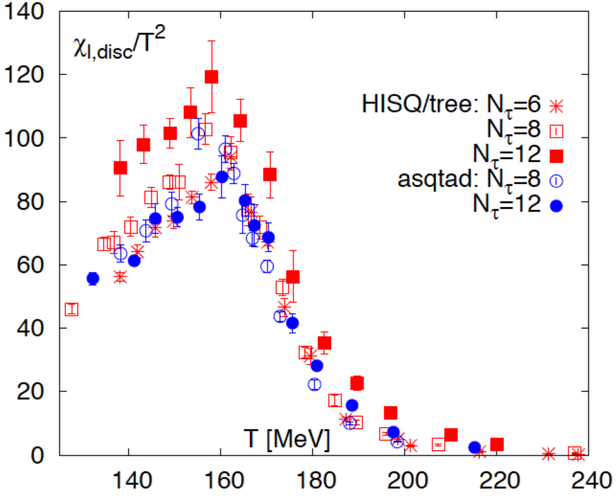

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A. Andronic, P. Braun-Munzinger, J. Stachel and K. Redlich
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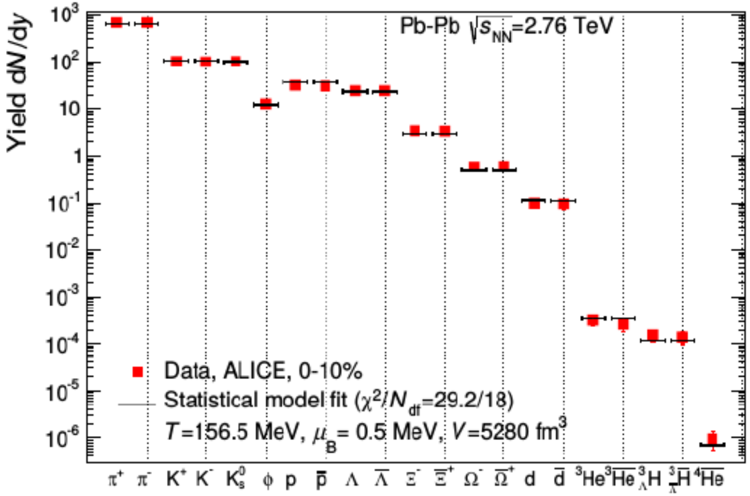

$$T_{\mathrm{fo}}^{\mathrm{ALICE}} = 156.5 \pm 3\ \mathrm{MeV}$$

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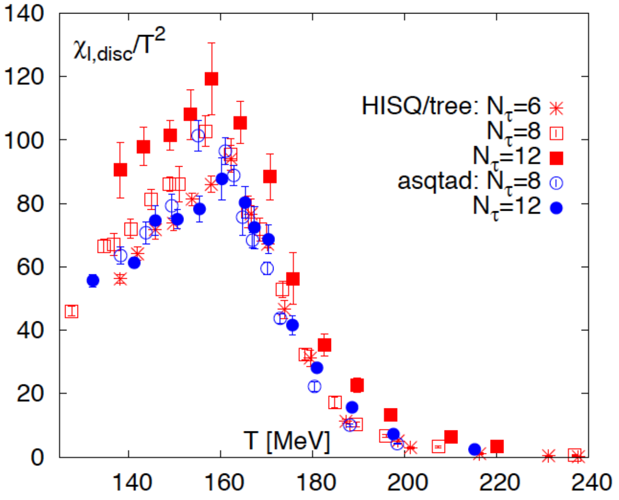

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Chemical freeze-out at the phase boundary!

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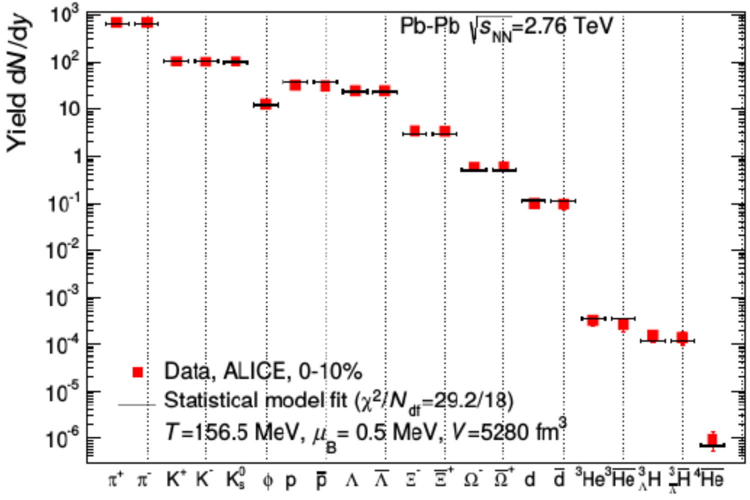

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Chemical freeze-out near T_{pc} → motivation to look for higher order moments

Link to LQCD: Fluctuations of conserved charges

For a thermal system within the **Grand Canonical Ensemble**

$$\frac{P}{T^4} = \frac{1}{VT^3}\ln Z\left(V,T,\mu_{B,Q,S}\right) \Rightarrow \hat{\chi}_n^{N=B,S,Q} = \frac{\partial^n P/T^4}{\partial\left(\mu_N/T\right)^n} \Rightarrow \hat{\chi}_2^B = \frac{\kappa_2\left(\Delta N_B\right)}{VT^3}$$

Susceptibilities **Cumulants**

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Higher orders

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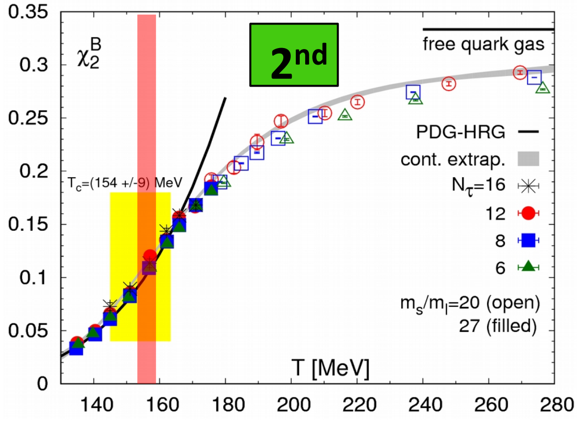
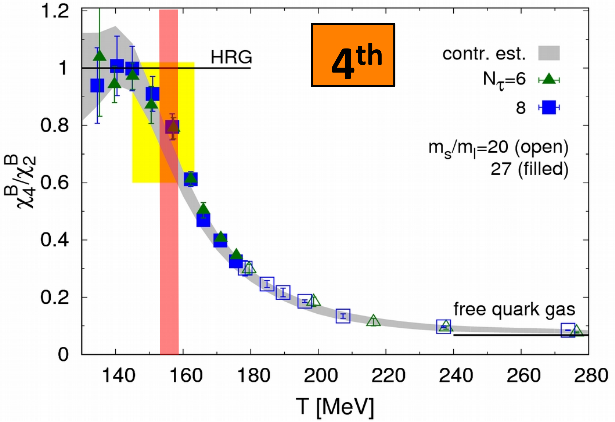
Phys. Rev. D 95 (2017), 054504





- **At 4th order** LQCD shows a **deviation (~30% from unity)** from Hadron Resonance Gas (HRG)

Baseline: Skellam distribution

$$\boxed{X = N_B - N_{\overline{B}}}$$

- **rth central moment:**

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

- **First four cumulants**

$$\boxed{\begin{array}{ll} \kappa_1 = \langle X \rangle, & \kappa_2 = \mu_2, \\ \kappa_3 = \mu_3, & \kappa_4 = \mu_4 - 3\mu_2^2 \end{array}}$$

- **Uncorrelated Poisson limit:**

$$\langle N_B N_{\overline{B}} \rangle = \langle N_B \rangle \langle N_{\overline{B}} \rangle$$

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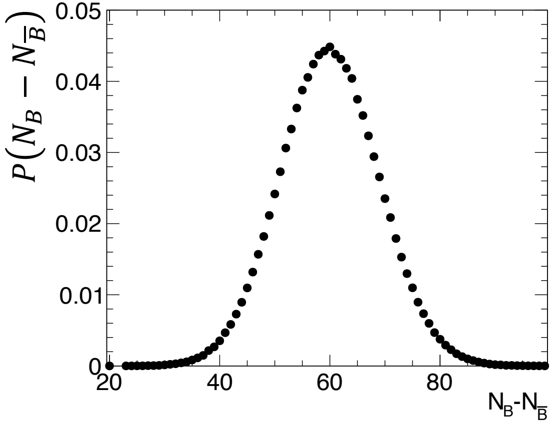


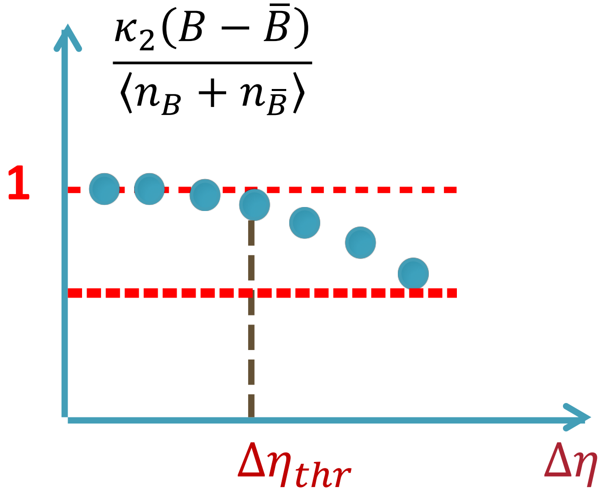
Difference between two independent Poissonian distributions

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

$$\frac{\kappa_{2n+1}}{\kappa_{2k}} = \frac{\langle n_B \rangle - \langle n_{\bar{B}} \rangle}{\langle n_B \rangle + \langle n_{\bar{B}} \rangle}$$

Importance of acceptance and baryon number conservation

- Fluctuations of conserved charges appear **only inside finite acceptance**
- **In the limit of very small acceptance** → only Poissonian fluctuations



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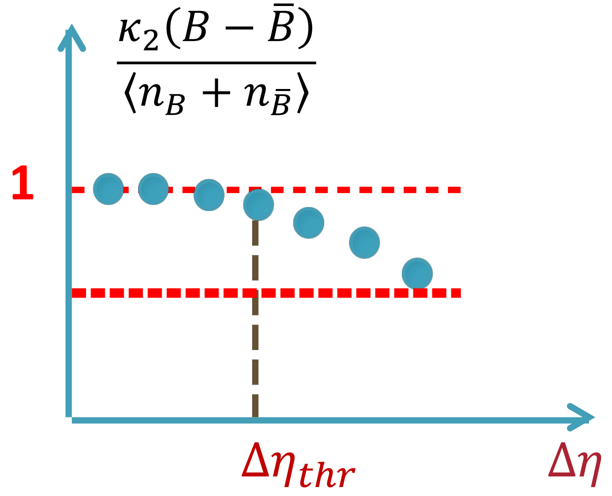
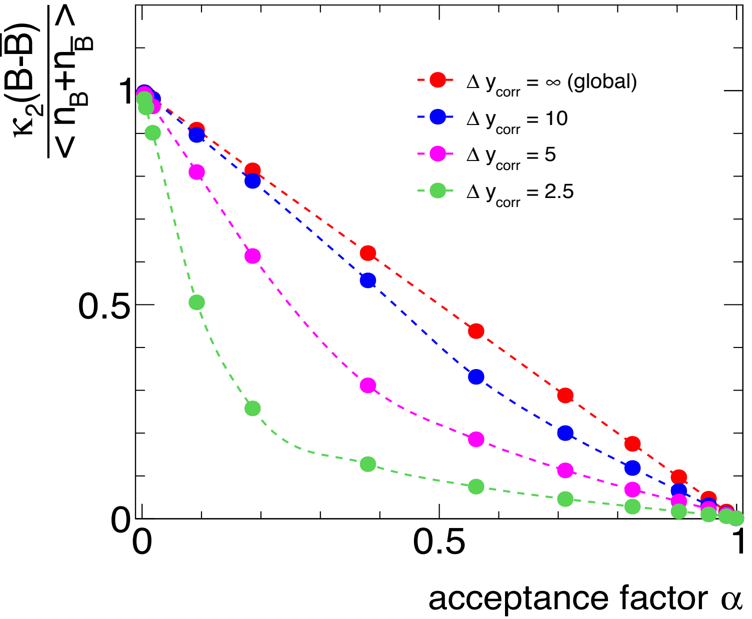


- **Baryon number conservation** imposes subtle correlations

$$\alpha = \frac{\langle N_B^{acc} \rangle}{\langle N_B^{4\pi} \rangle} \qquad |y_{\bar{B}} - y_B| < \frac{\Delta y_{corr}}{2}$$



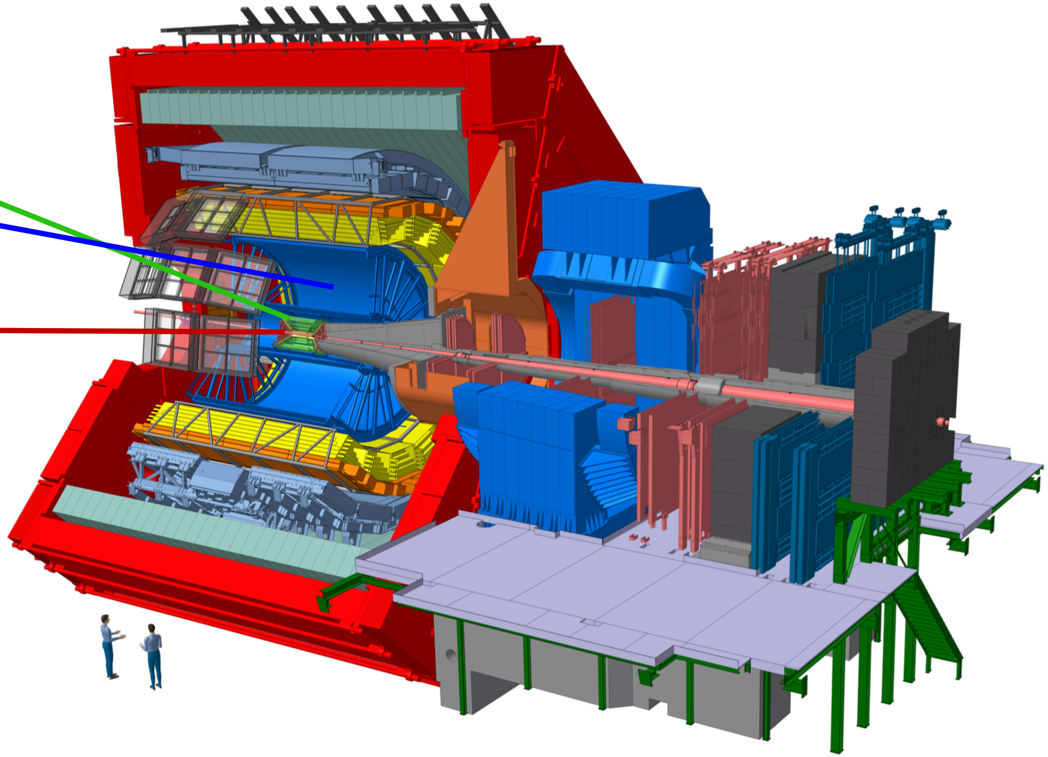
P. Braun-Munzinger, A. Rustamov, J. Stachel, arXiv:1907.03032

RESULTS

A Large Ion Collider Experiment

Main detectors used:

- Inner Tracking System (ITS)
  → Tracking and vertexing
- Time Projection Chamber (TPC)
  → Tracking and
  Particle Identification (PID)
- Vertex 0 (V0)
  → Centrality determination



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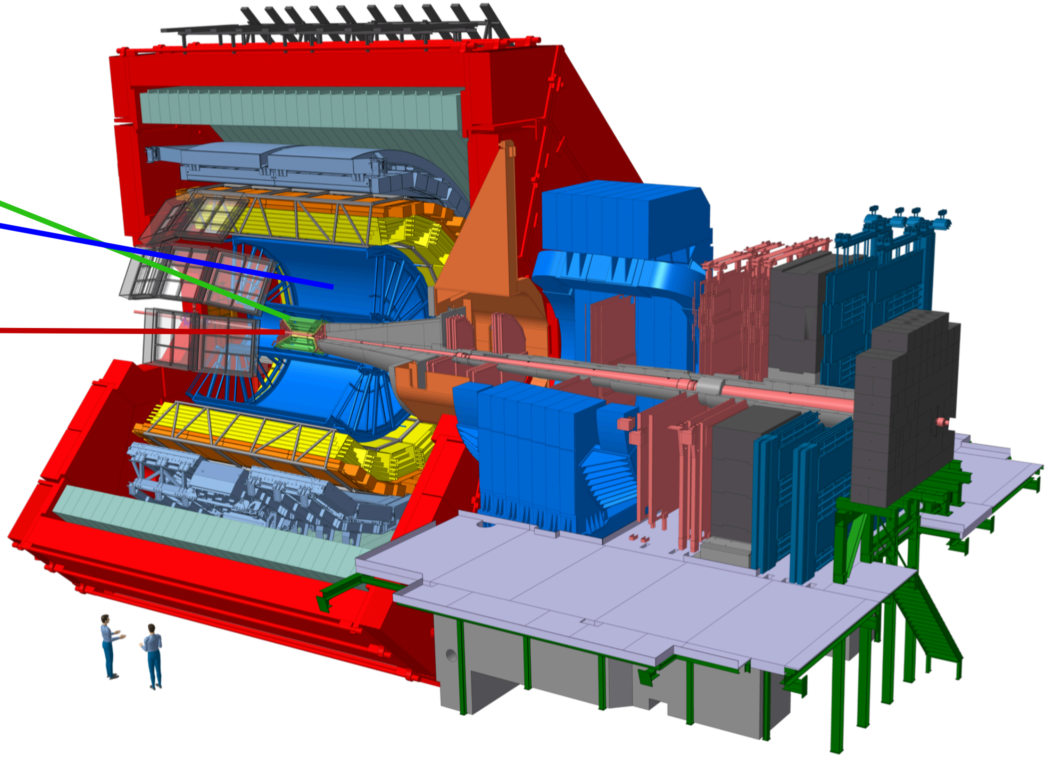


Data Set:

- $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, ~78 M events
- $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, ~12 M events

Kinematic acceptance:

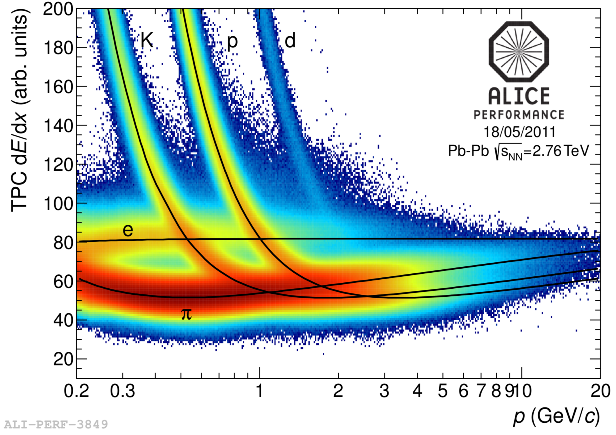
- $0.6 < p < [1.5, 2]$ GeV/c
- $|\eta|<0.2, 0.4, \ldots, 0.8$

Cut-based approach:

- count tracks of a given particle type

Identity method:

- count probabilities to be of a given particle type



A. Rustamov, M. Gazdzicki, M. I. Gorenstein, PRC 86, 044906 (2012),
M. Arslandok, A. Rustamov, NIM A 946 (2019) 162622

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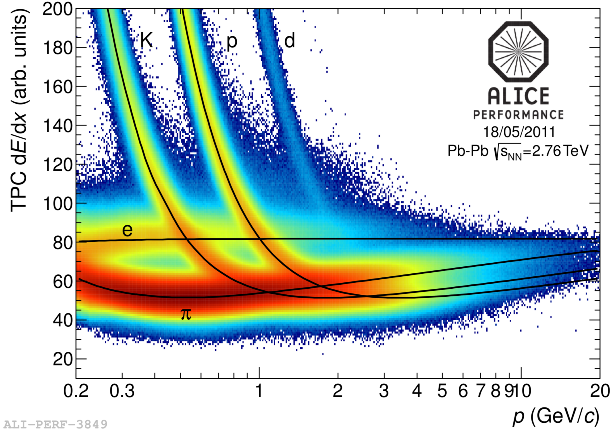

Advantages:

- Gives folded multiplicity distribution
- Allows for **larger efficiencies** → smaller correction

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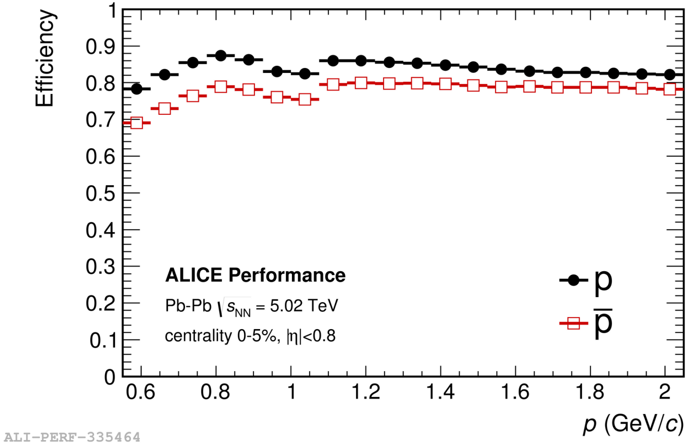
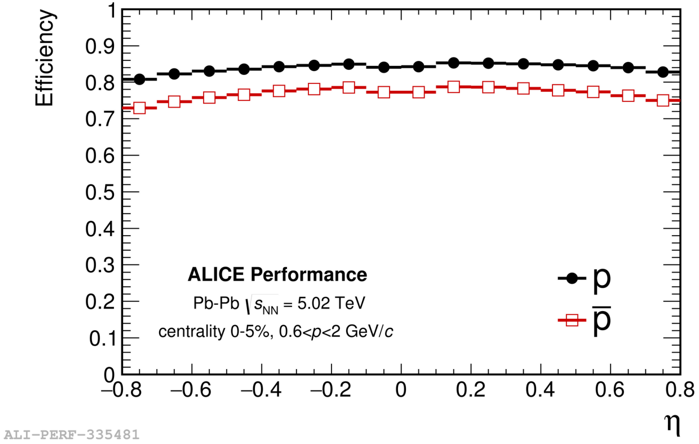
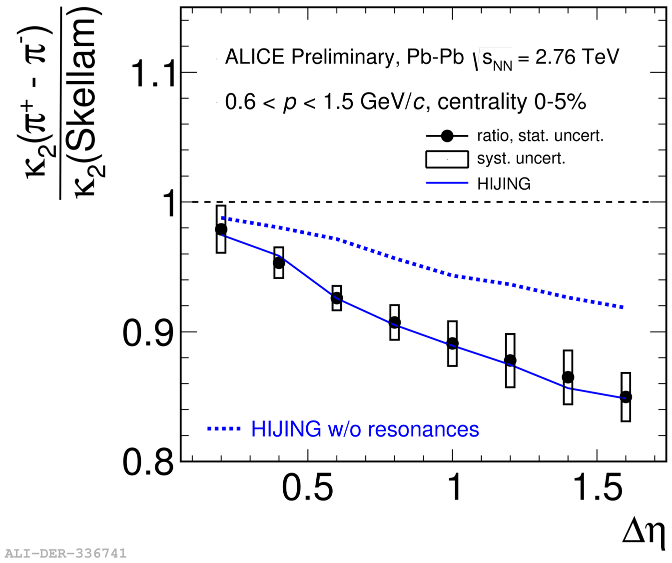




Net-(global)charge fluctuations



➢ **Net-electric-charge:** → Strongly dominated by **resonance contributions** <u>(Poster: Shaista Khan)</u>

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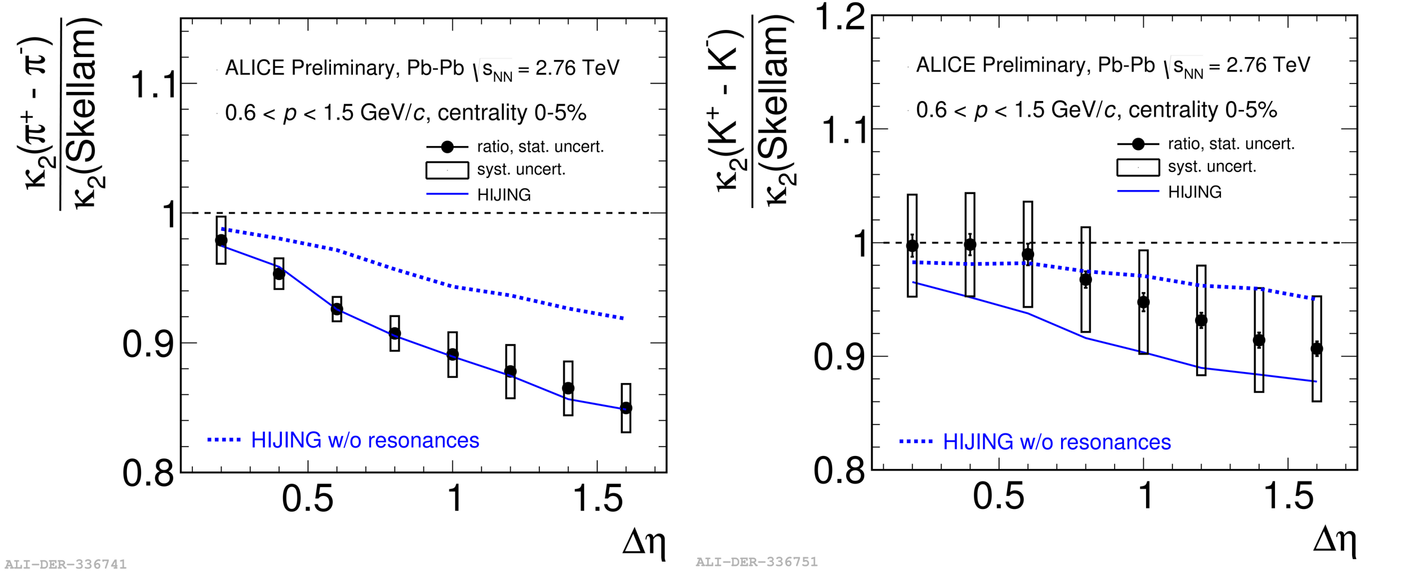

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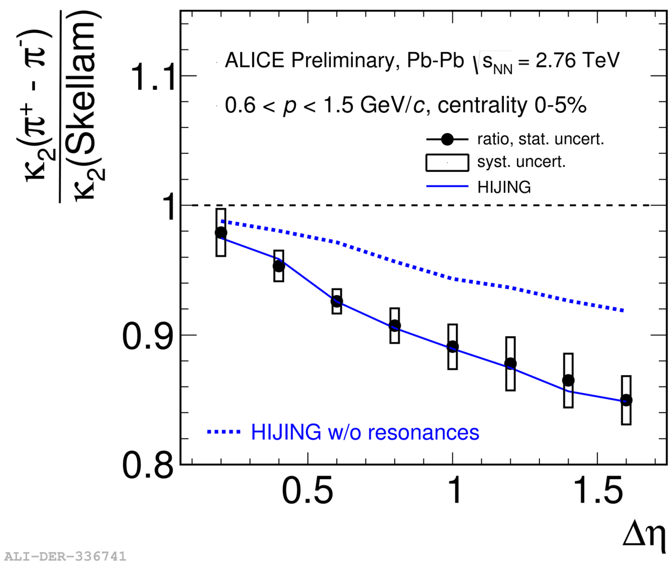
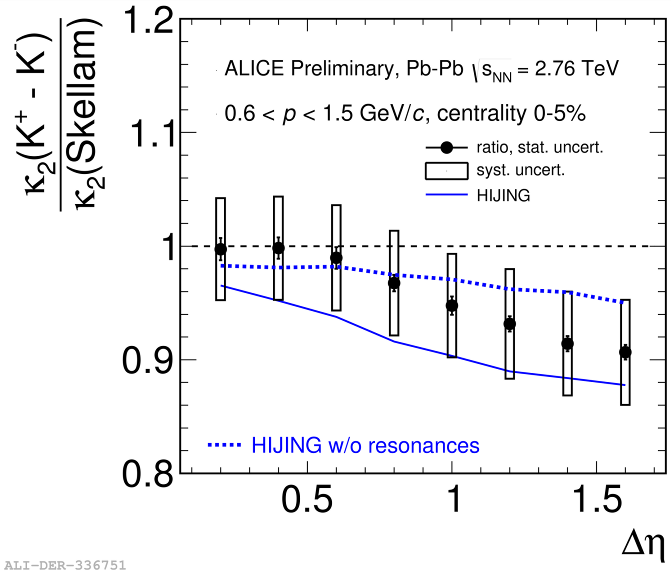
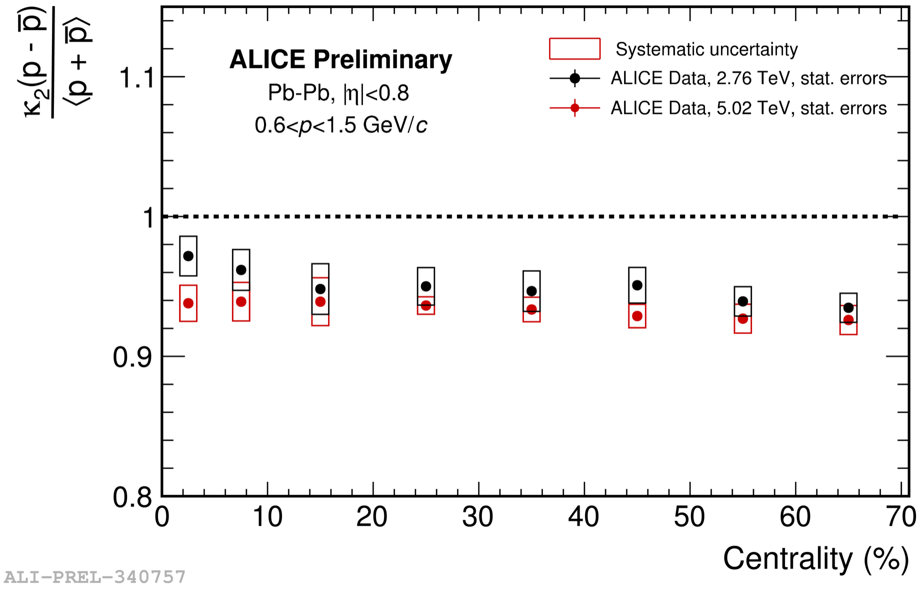
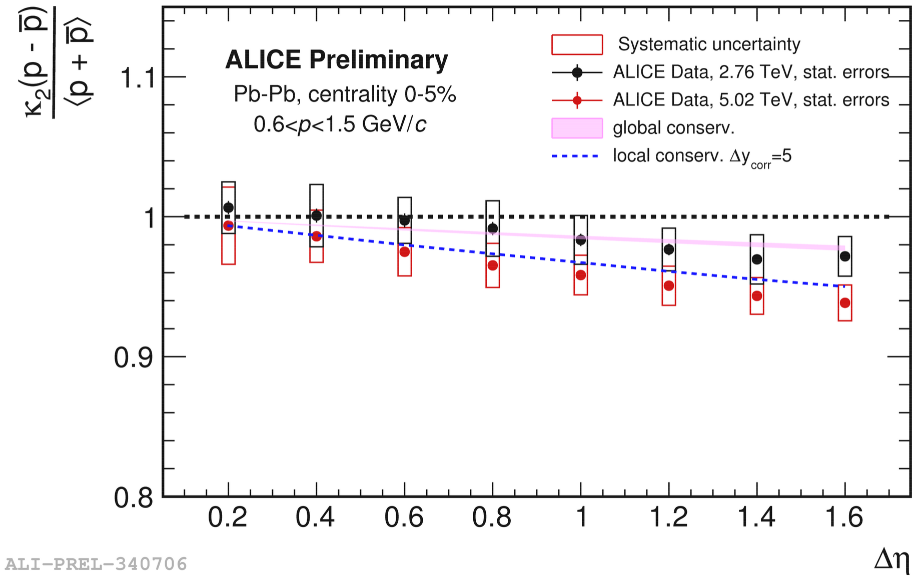




- **Net-electric-charge:** → Strongly dominated by **resonance contributions** (Poster: Shaista Khan)
- **Net-strangeness:** → Kaons are dominated by **ϕ-decay**
- **Net-baryon:**
  - → Due to **isospin randomization,** at $\sqrt{s_{\mathrm{NN}}}$ > 10 GeV **net-baryon** fluctuations can be obtained from corresponding **net-proton** measurements (M. Kitazawa, and M. Asakawa, Phys. Rev. C 86, 024904 (2012))
  - → No resonance feeding $\mathrm{p} + \bar{\mathrm{p}}$
  - → **Best candidate for measuring charge susceptibilities**

2^{nd} order cumulants of net-p: Energy dependence





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- ALICE data suggest **long range correlations,** $\Delta y = \pm 2.5$ unit **or longer**

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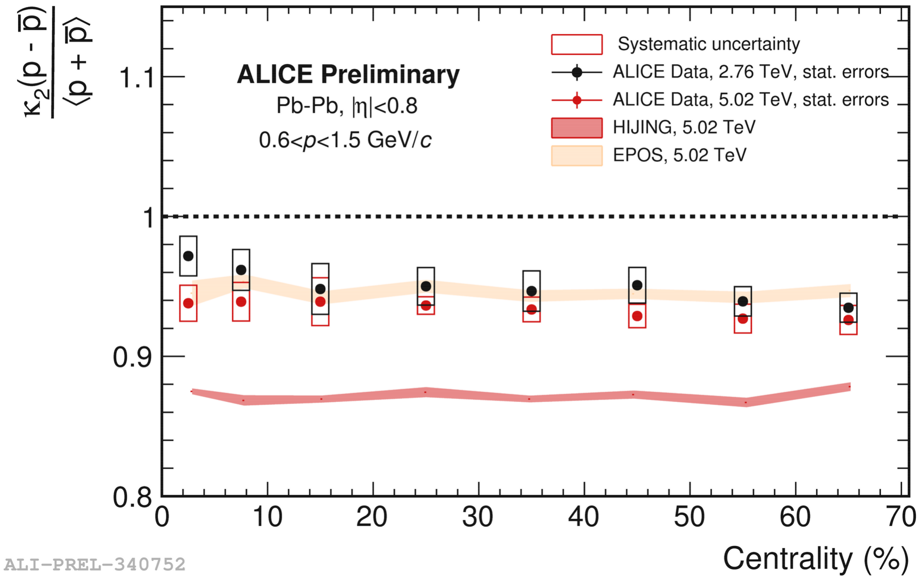
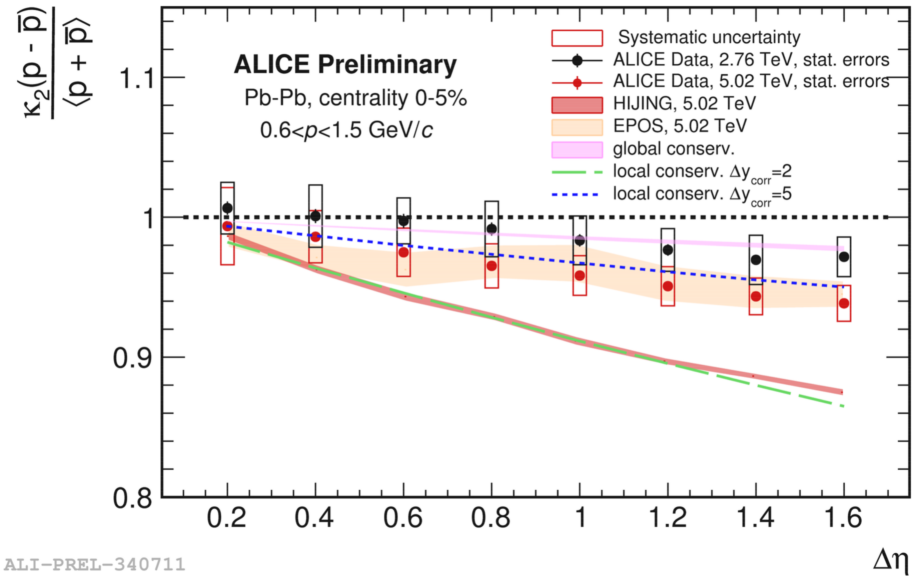
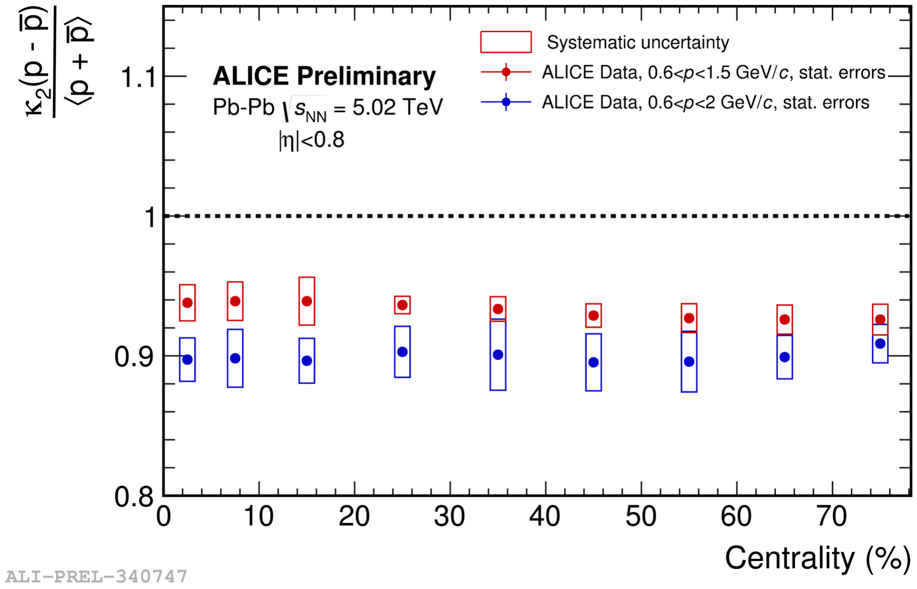
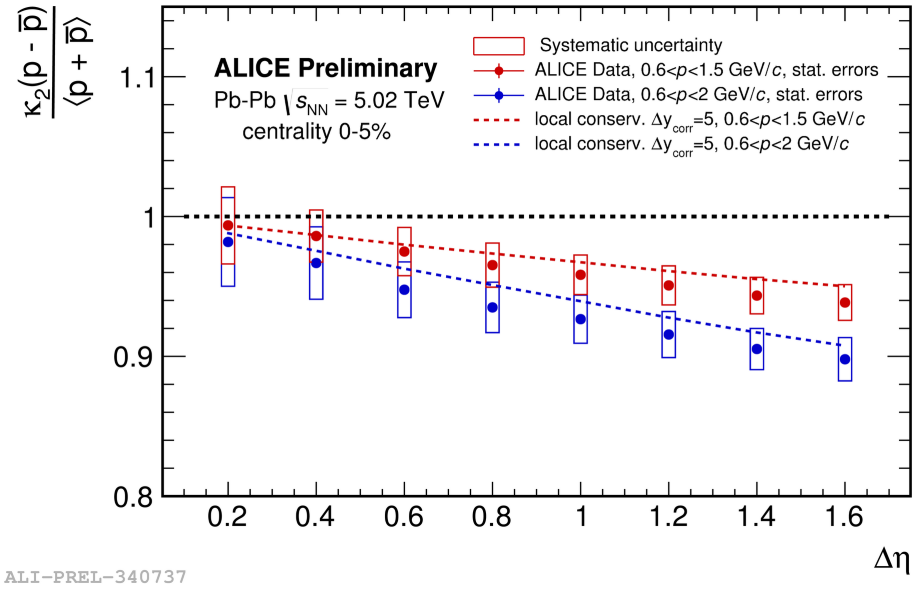




- Deviation from Skellam baseline is due to **baryon number conservation**
- ALICE data suggest **long range correlations,** $\Delta y = \pm 2.5$ unit **or longer**
- EPOS agrees with ALICE data but HIJING deviates significantly
  - Event generators based on string fragmentation (HIJING) conserve baryon number over $\Delta y = \pm 1$ unit

2^{nd} order cumulants of net-p: Acceptance dependence





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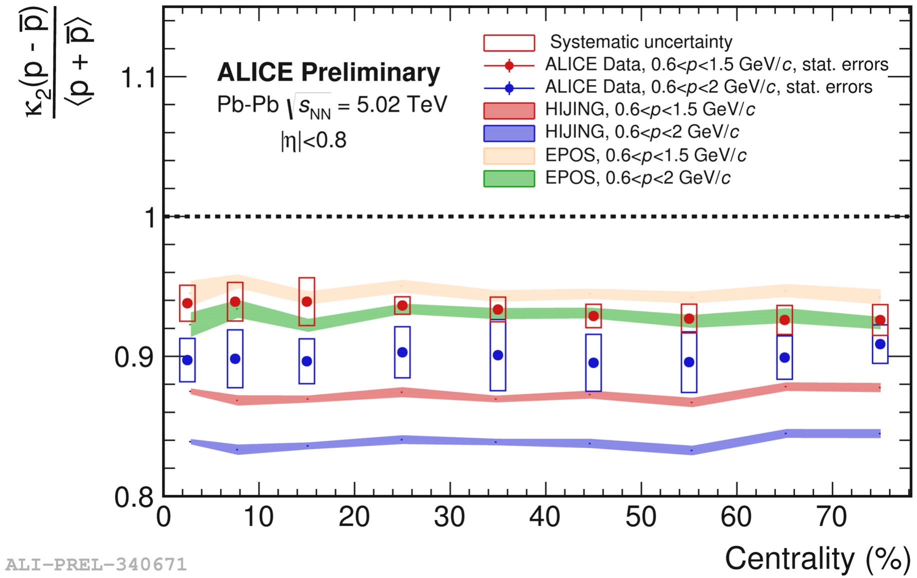

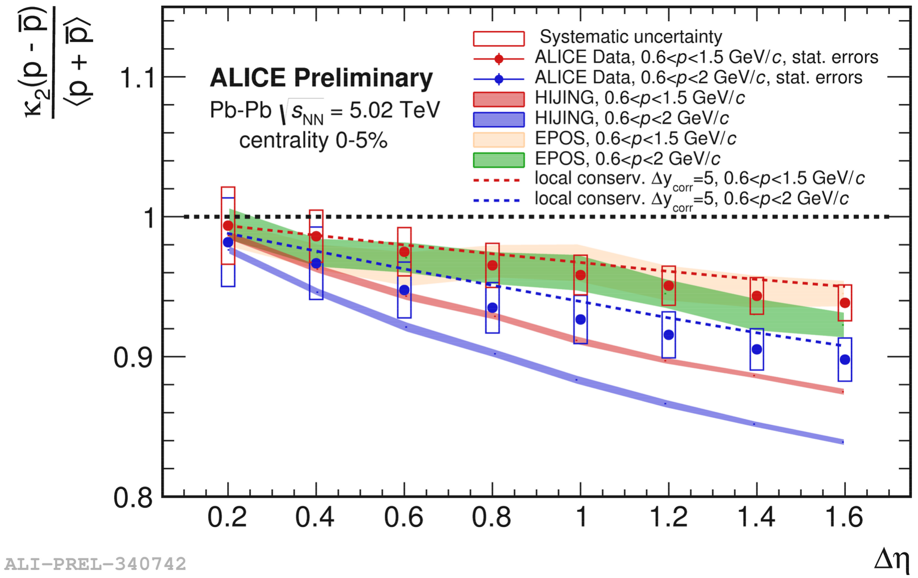

- Consistent with the baryon number conservation picture
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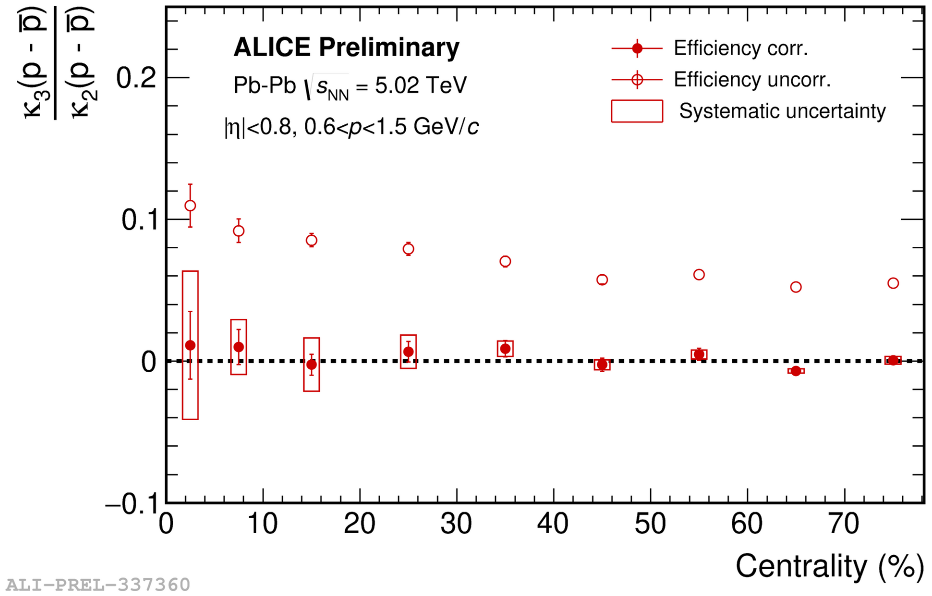
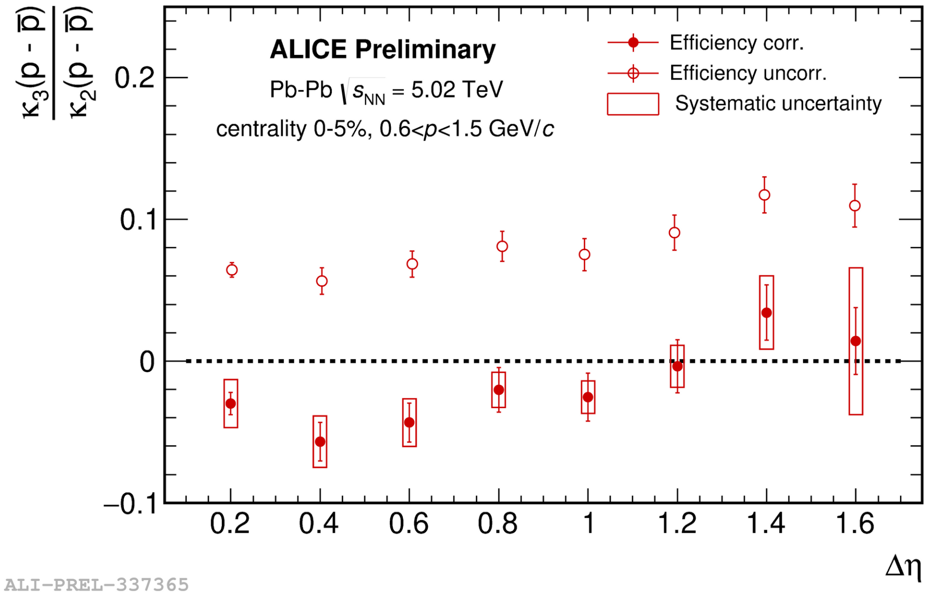
- EPOS & HIJING show this drop qualitatively

3^{rd} order cumulants of net-p: Centrality and pseudorapidity dependence





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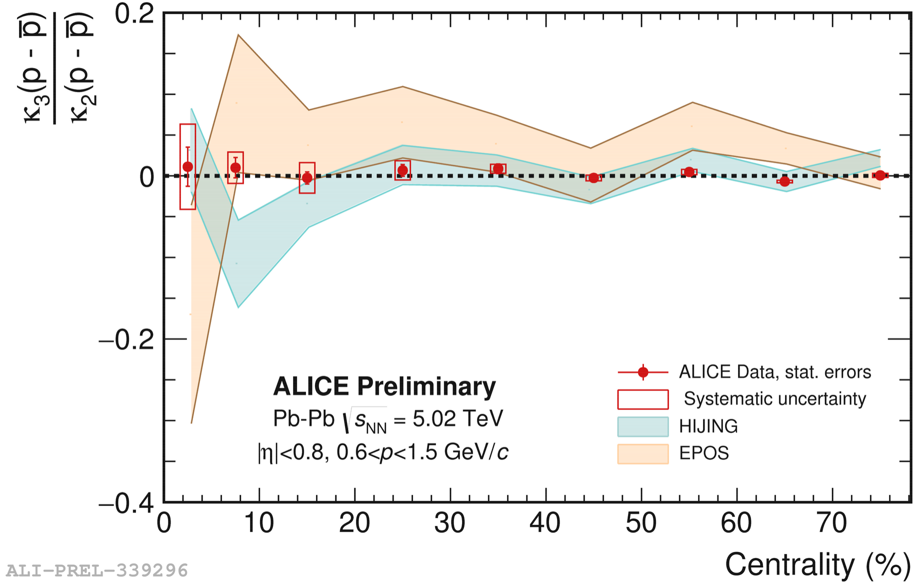

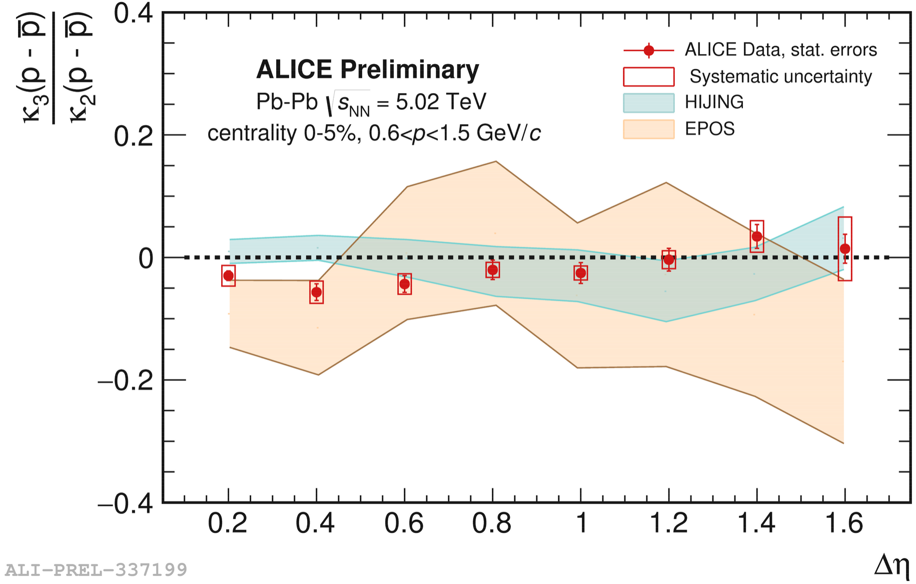

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- **EPOS and HIJING in agreement with data**
  - Both models conserve global charge → net-p within acceptance is ~0

Summary & Outlook

- **Net-electric-charge fluctuations:** Challenge are the dominant **resonance contributions**
- **Net-proton fluctuations:**
  - ✓ **1st order:** $T_{fo}^{ALICE} \sim T_{pc}^{LQCD}$
  - ✓ **2nd order:** Deviation from Skellam baseline is due to baryon number conservation
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  - ✓ **3rd order:** Agrees with Skellam baseline **"0"** as a function of centrality and pseudorapidity
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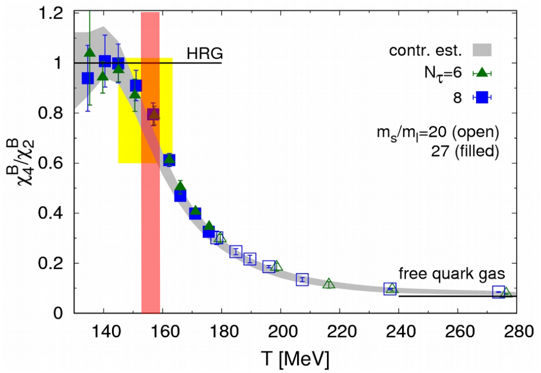
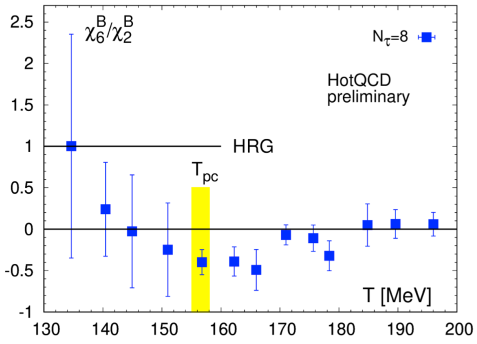
- **Holy grail: see critical behavior in 6th and higher order cumulants**

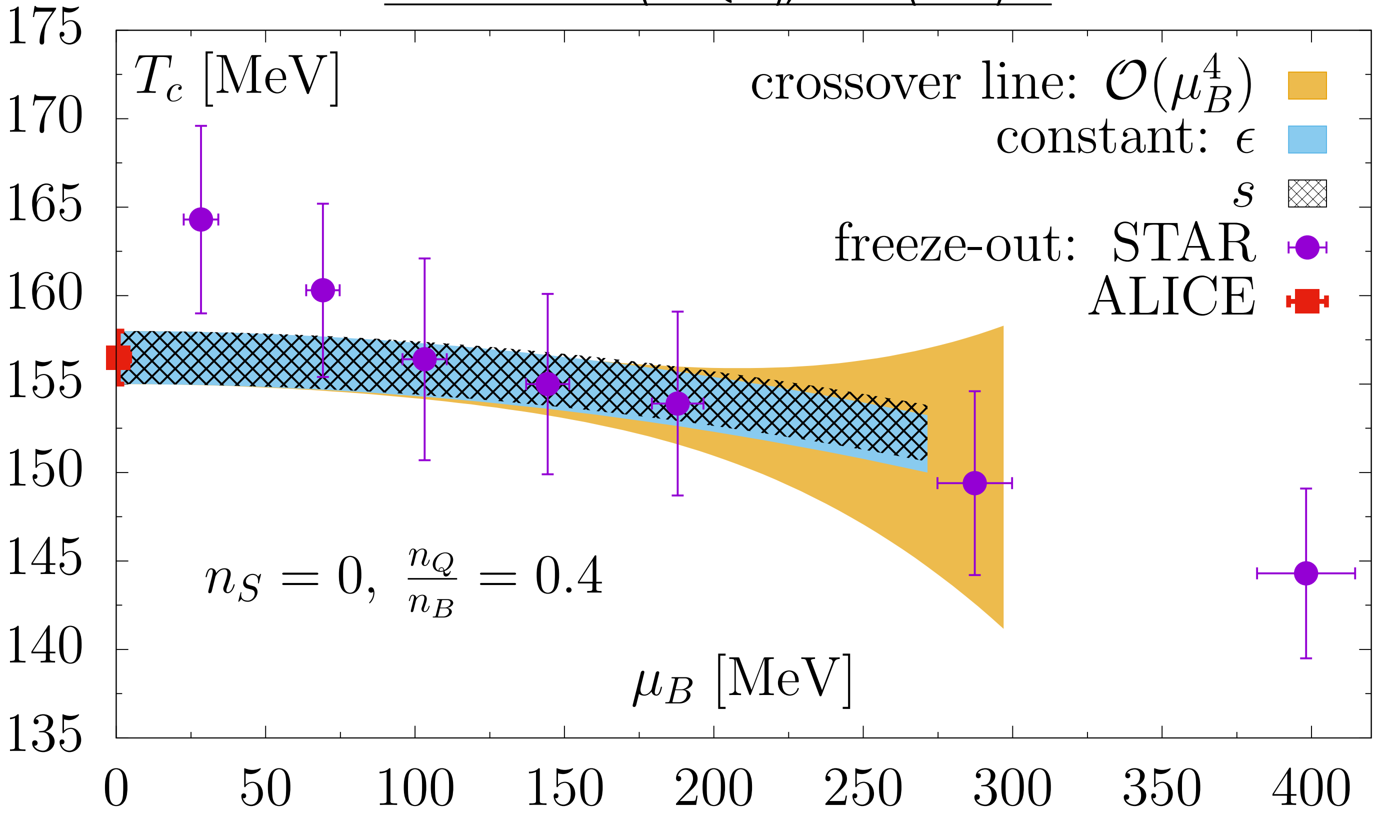


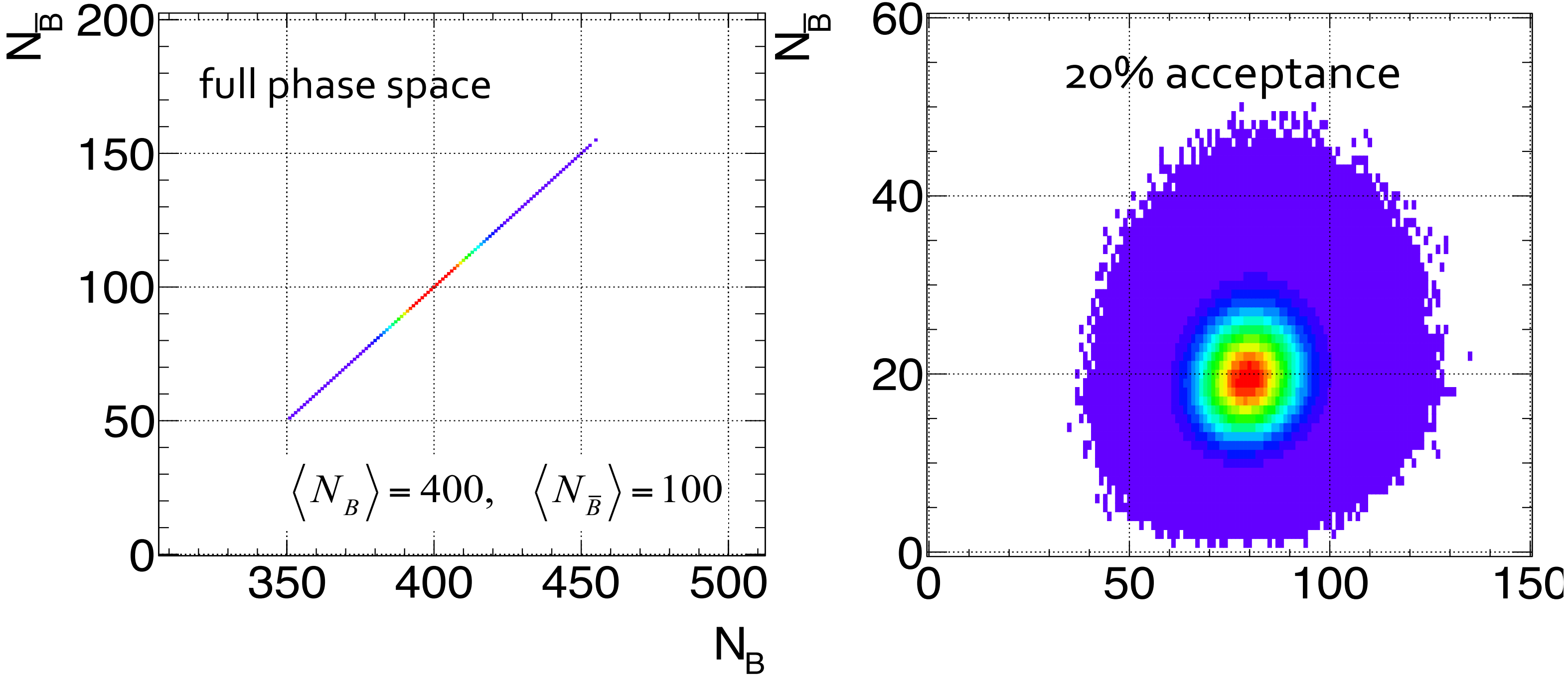


RUN1: 2nd order (~13M min. bias events)
RUN2: 4th order (~150M central events)
RUN3: **6th …** (>1000M central events)

BACKUP

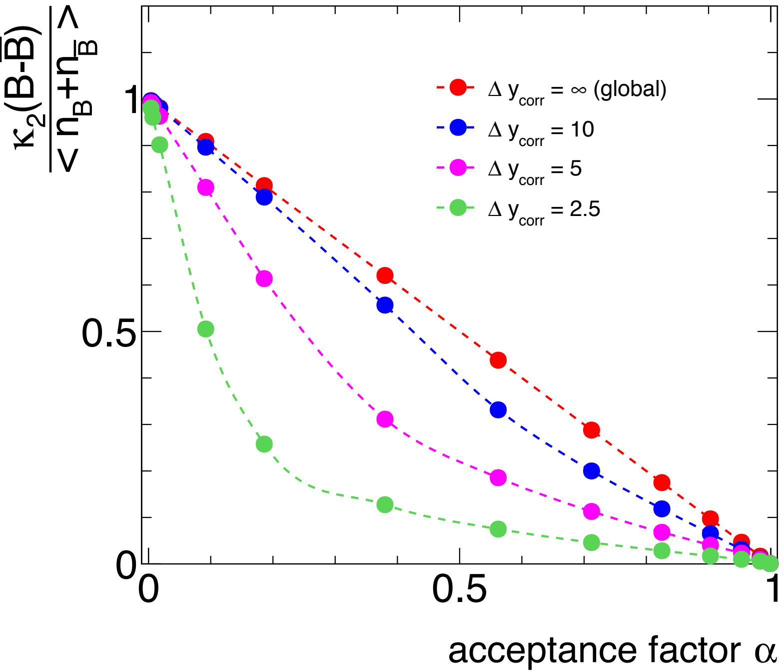
A. Bazavov et al. (HotQCD),PLB795(2019)15

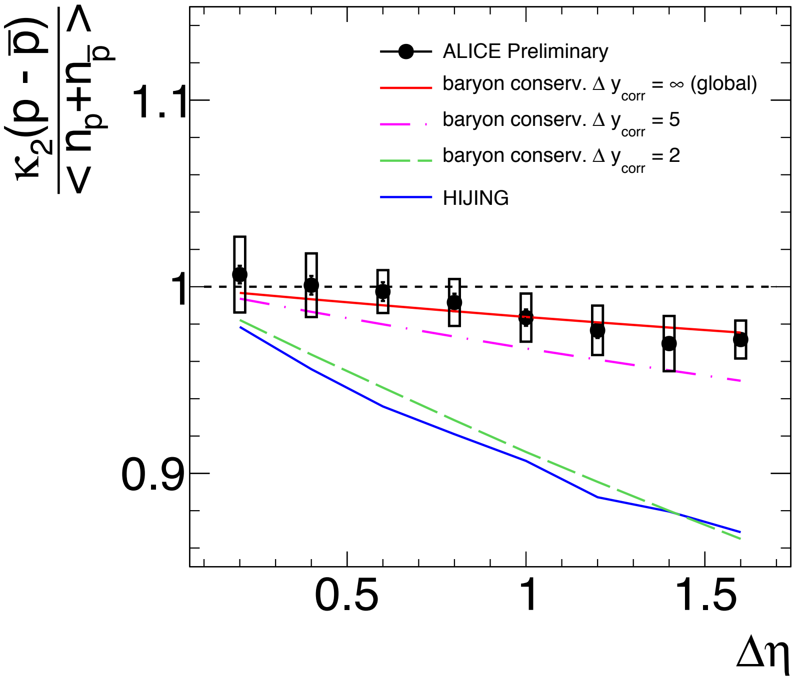


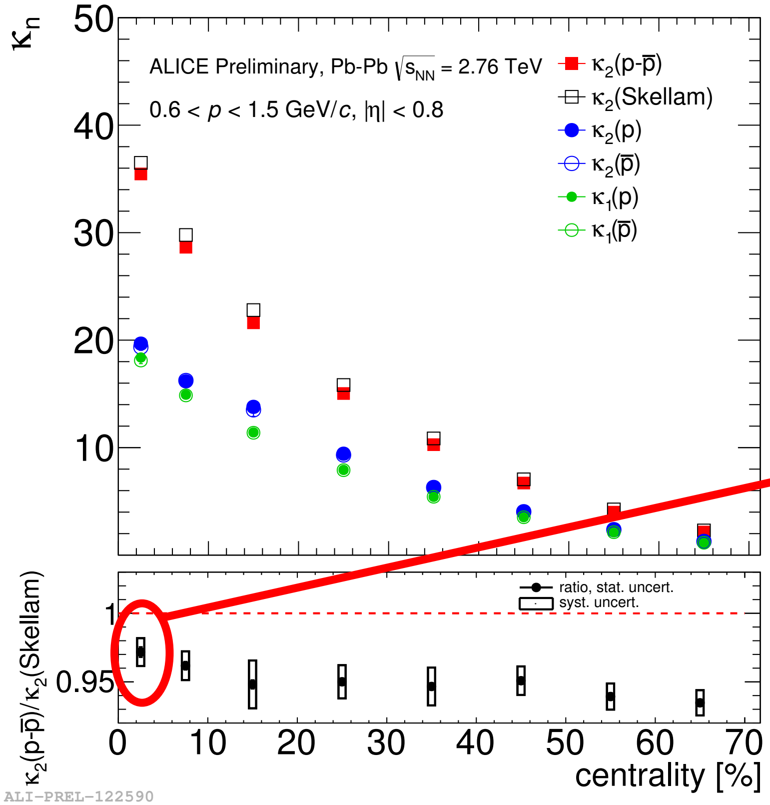


P. Braun-Munzinger, A. Rustamov, J. Stachel, QM18, NPA 982 (2019) 307-310

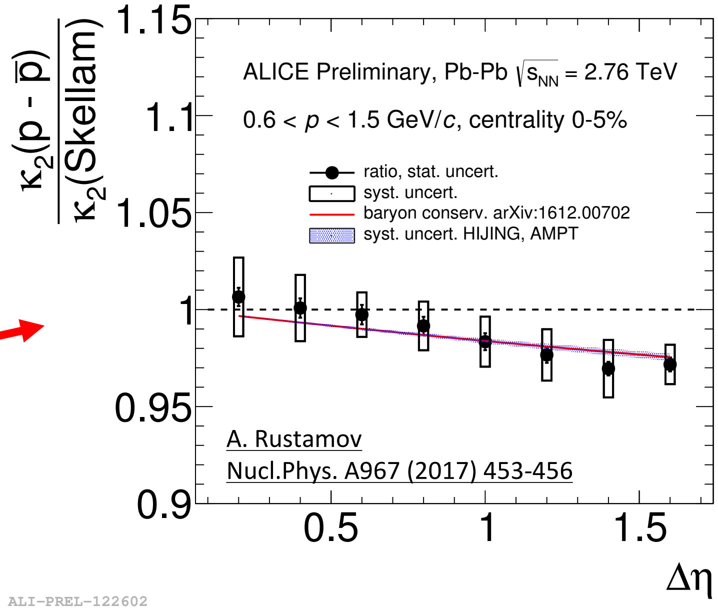
P. Braun-Munzinger, A. Rustamov, J. Stachel, arXiv:1907.03032





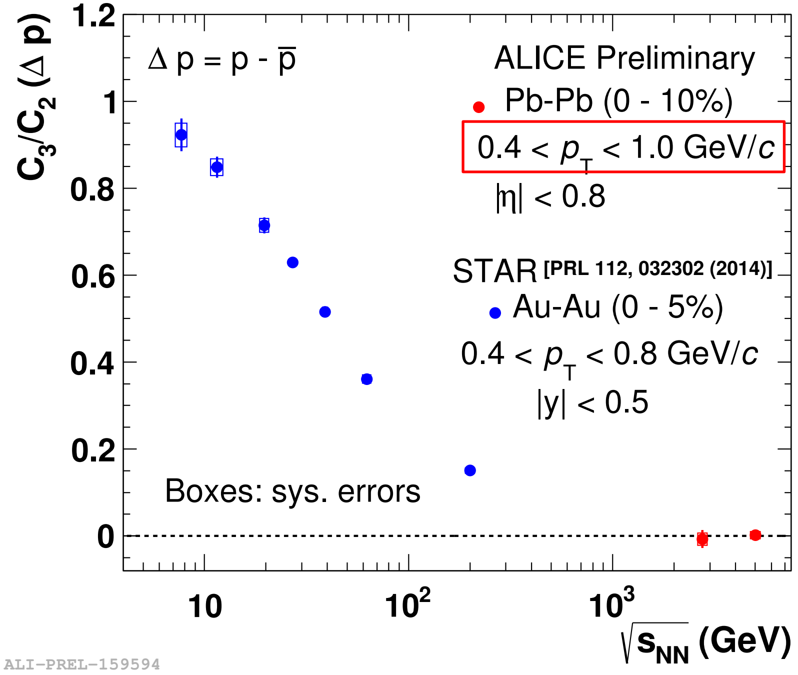


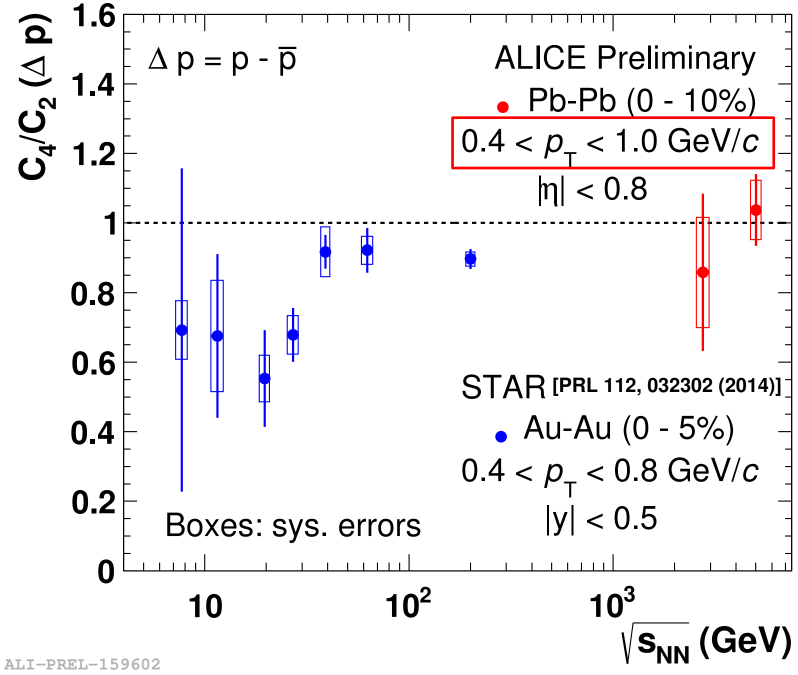
ALICE Preliminary, Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
0.6 < p < 1.5 GeV/c, $|\eta|$ < 0.8
$\kappa_2(\text{p-}\bar{\text{p}})$
κ_2(Skellam)
κ_2(p)
$\kappa_2(\bar{\text{p}})$
κ_1(p)
$\kappa_1(\bar{\text{p}})$
κ_n
ratio, stat. uncert.
syst. uncert.
$\kappa_2(\text{p-}\bar{\text{p}})/\kappa_2$(Skellam)
centrality [%]
ALI-PREL-122590



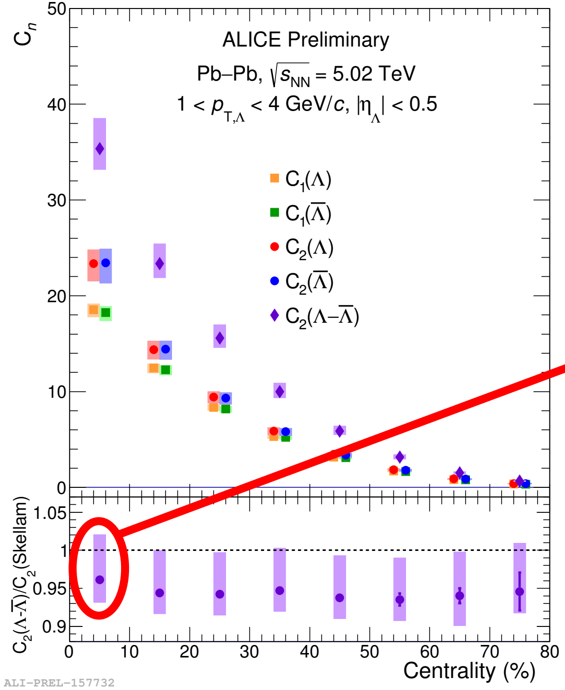
ALICE Preliminary, Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
0.6 < p < 1.5 GeV/c, centrality 0-5%
ratio, stat. uncert.
syst. uncert.
baryon conserv. arXiv:1612.00702
syst. uncert. HIJING, AMPT
A. Rustamov
Nucl.Phys. A967 (2017) 453-456
$\frac{\kappa_2(\text{p - }\bar{\text{p}})}{\kappa_2(\text{Skellam})}$
$\Delta\eta$
ALI-PREL-122602

Nirbhay Kubera, QM18, NPA 982 (2019) 851

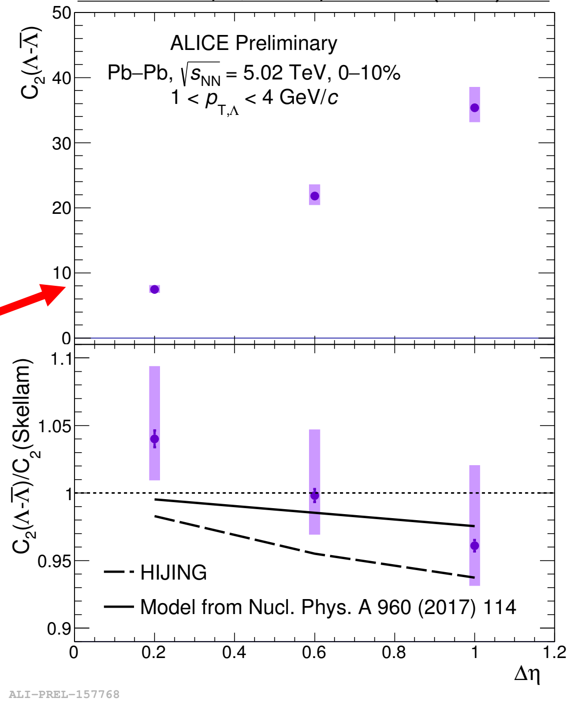




$$\kappa_2(n-\overline{n}) \equiv C_2(n-\overline{n})$$



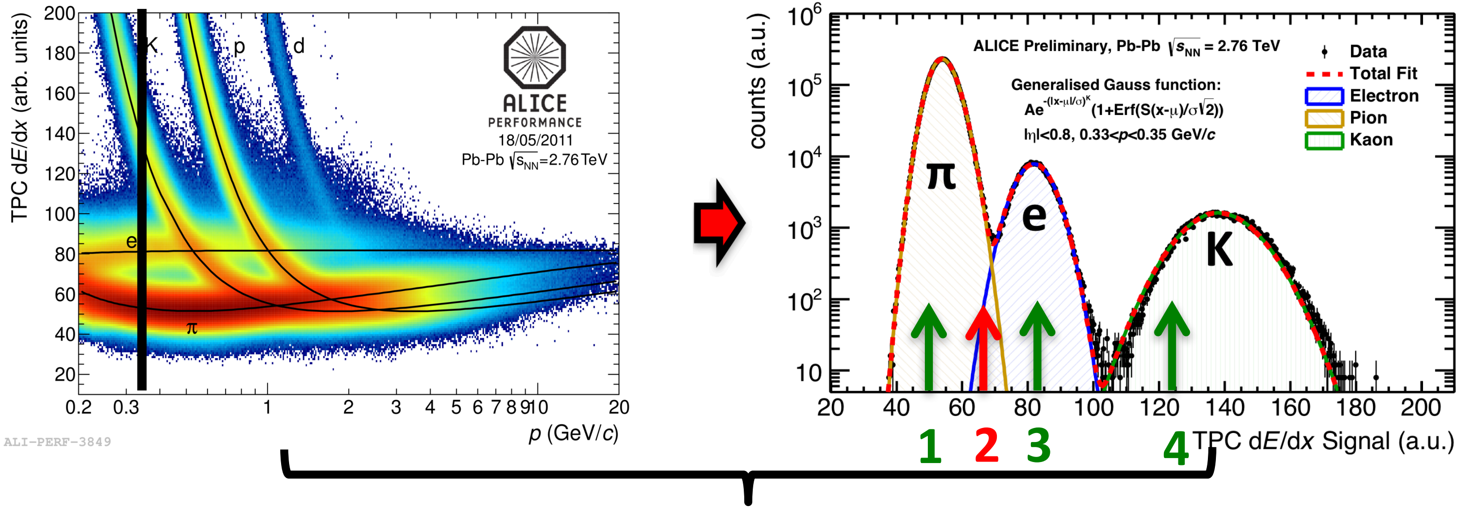
Alice Ohlson, QM2018, NPA 982 (2019) 299



- Similar trend as for **net-p**
- Better precision is needed to disentangle global vs local conservation laws

Cut-based approach: count tracks of a given particle type

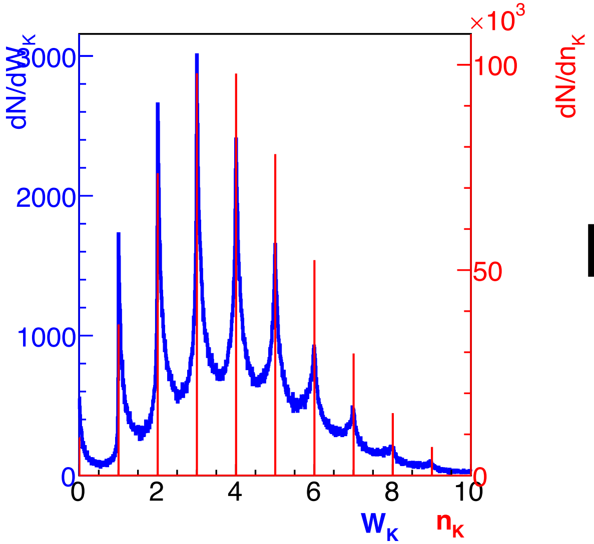
Identity method: count probabilities to be of a given particle type



$$\omega_\pi^{(1)} = 1,\quad \omega_\pi^{(2)} \cong 0.6,\quad \omega_\pi^{(3)} = 0,\quad \omega_\pi^{(4)} = 0 \quad \Rightarrow \quad \boxed{W_\pi = 1.6 \neq N_\pi}$$

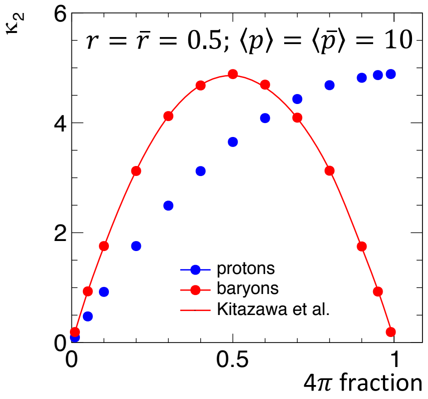
A. Rustamov, M. Gazdzicki, M. I. Gorenstein, PRC 86, 044906 (2012), PRC 84, 024902 (2011)

A. Rustamov, M. Arslandok, arXiv:1807.06370, NIM in print

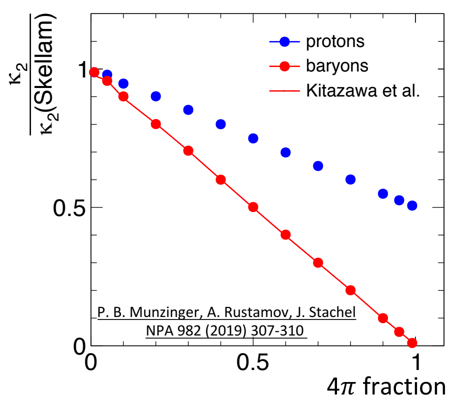


$$\langle N_j^n \rangle = A^{-1} \langle W_j^n \rangle$$

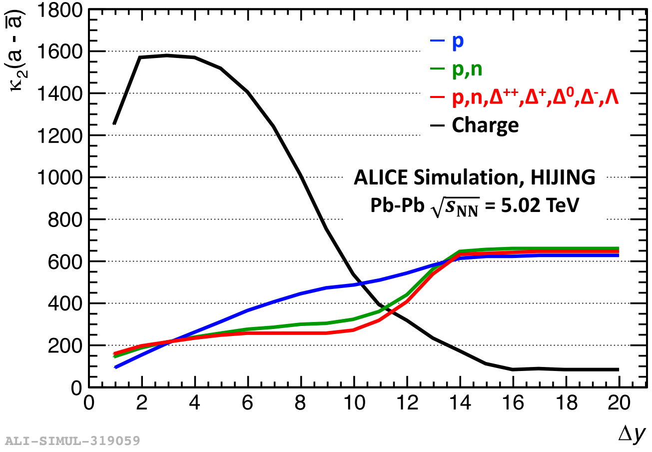
- **Cut-based approach**
  - Uses additional detector information or reject a given phase space bin
  - Challenge: efficiency correction and contamination
- **Identity Method**
  - Gives folded multiplicity distribution
  - Allows for larger efficiencies → smaller correction needed
  - Ideal approach for low momentum (p<2 GeV/c)



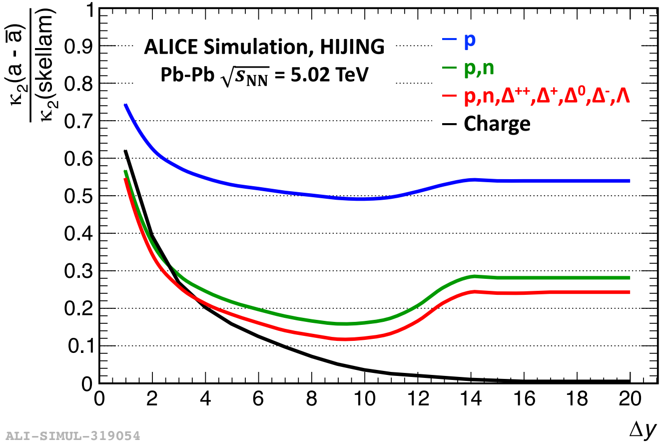
$r = \bar{r} = 0.5; \langle p \rangle = \langle \bar{p} \rangle = 10$
protons
baryons
Kitazawa et al.
κ_2
4π fraction



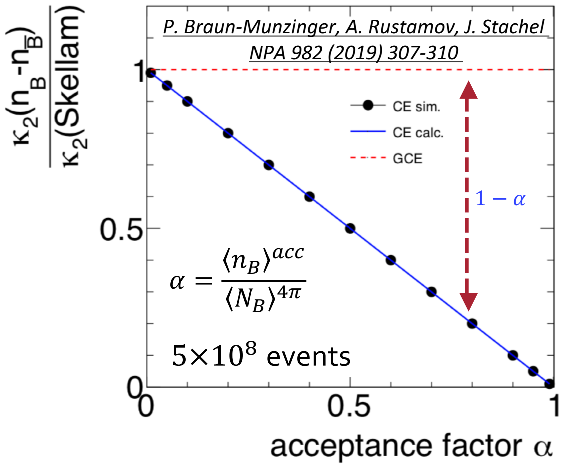
protons
baryons
Kitazawa et al.
P. B. Munzinger, A. Rustamov, J. Stachel
NPA 982 (2019) 307-310
$\frac{\kappa_2}{\kappa_2(\text{Skellam})}$
4π fraction

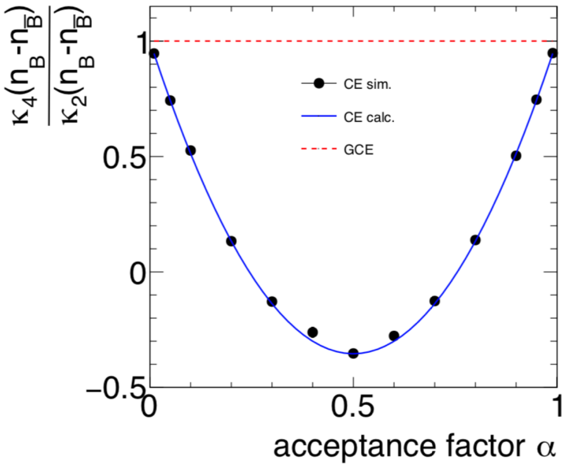


p
p,n
$p,n,\Delta^{++},\Delta^{+},\Delta^{0},\Delta^{-},\Lambda$
Charge
ALICE Simulation, HIJING
Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
$\kappa_2(a - \bar{a})$
Δy
ALI-SIMUL-319059

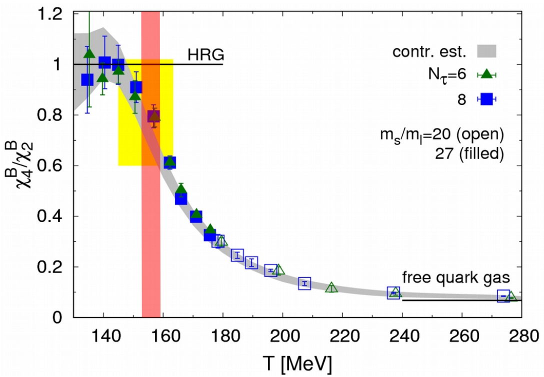


ALICE Simulation, HIJING
Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
p
p,n
$p,n,\Delta^{++},\Delta^{+},\Delta^{0},\Delta^{-},\Lambda$
Charge
$\frac{\kappa_2(a - \bar{a})}{\kappa_2(\text{skellam})}$
Δy
ALI-SIMUL-319054



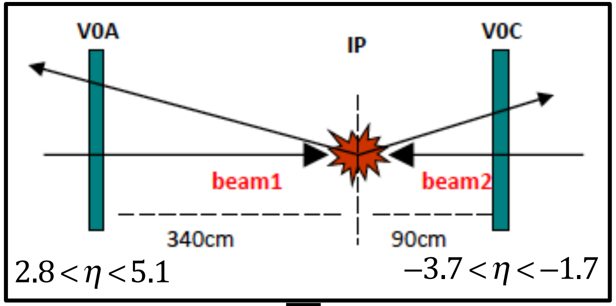


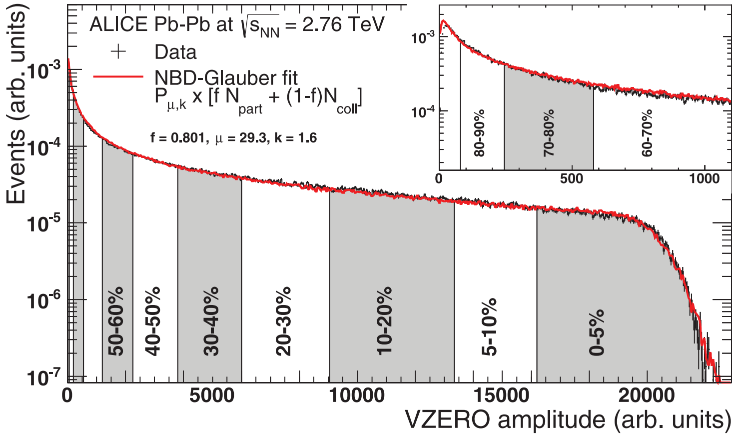
Deviations from unity are driven by different mechanisms

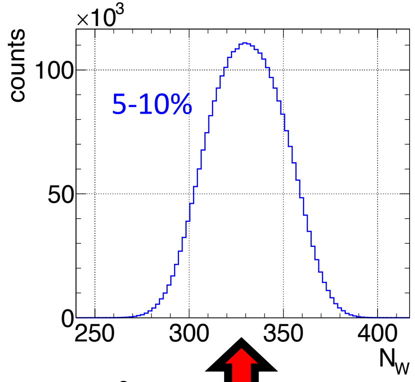


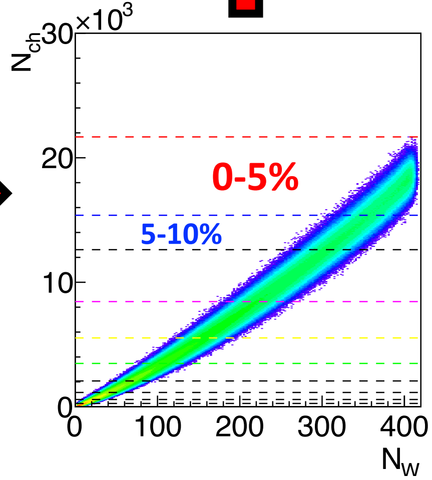
A. Bzdak, V. Koch, V. Skokov, PRC87 (2013) 014901
K. Redlich and L. Turko, Z. Phys. C5 (1980) 201

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

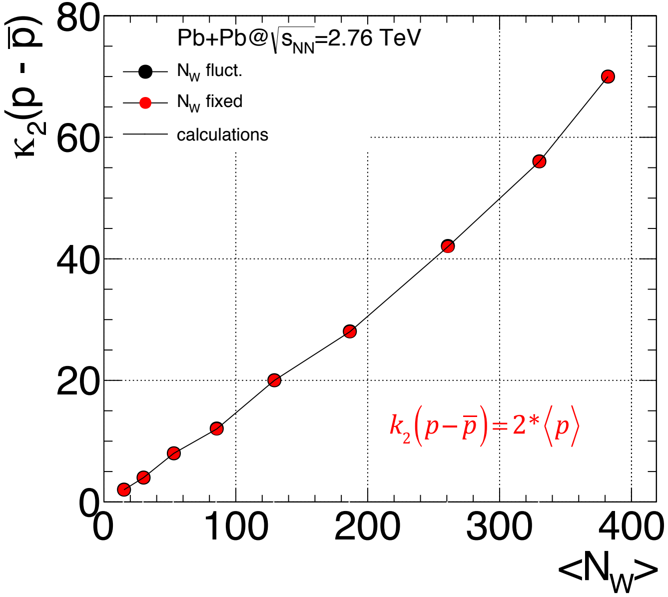




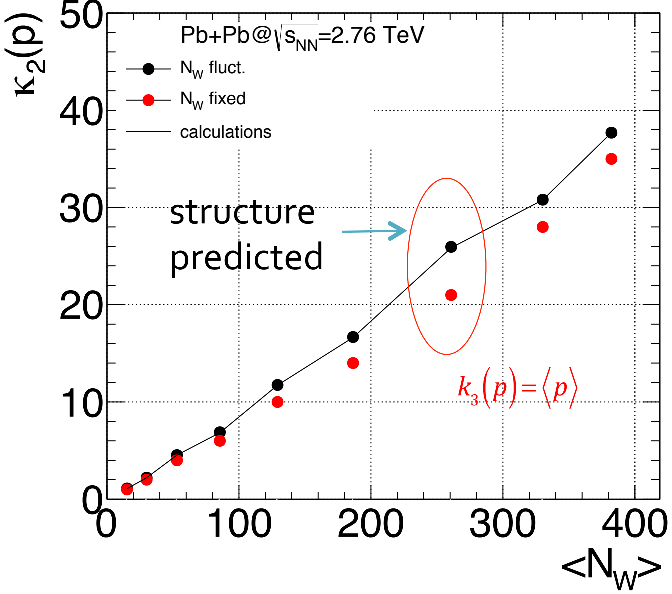




150*10^6 Events



P. Braun-Munzinger, A. Rustamov, J. Stachel
Nuclear Physics A 960 (2017) 114–130



$$k_2(p-\bar{p})=\langle N_w\rangle k_2(n-\bar{n})+\langle n-\bar{n}\rangle^2 k_2(N_w)$$

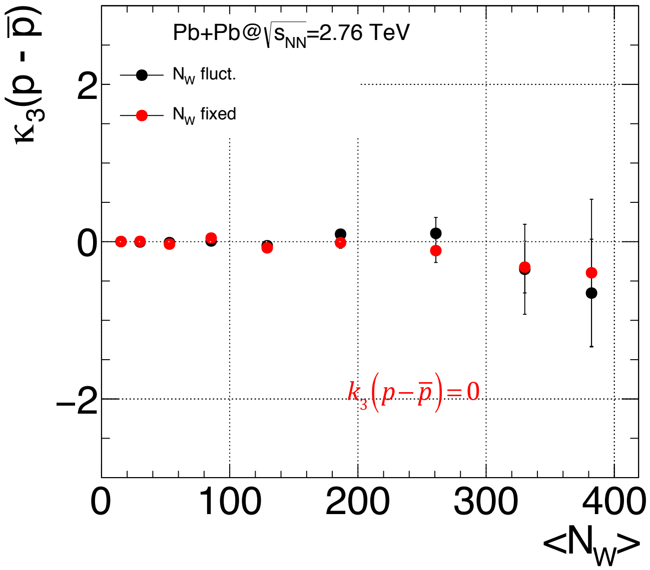
vanishes for ALICE

$$k_2(p)=\langle N_w\rangle k_2(n)+\langle n\rangle^2 k_2(N_w)$$

does not vanish

$n,\bar{n}$ from single wounded nucleon

$150*10^6$ Events



P. Braun-Munzinger, A. Rustamov, J. Stachel
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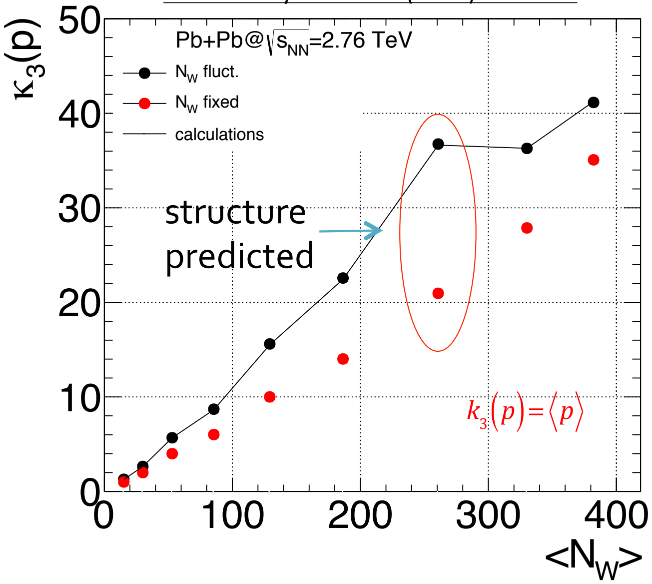


$$k_3(p-\bar{p})=\langle N_w \rangle k_3(n-\bar{n})+\langle n-\bar{n} \rangle(\ldots)$$

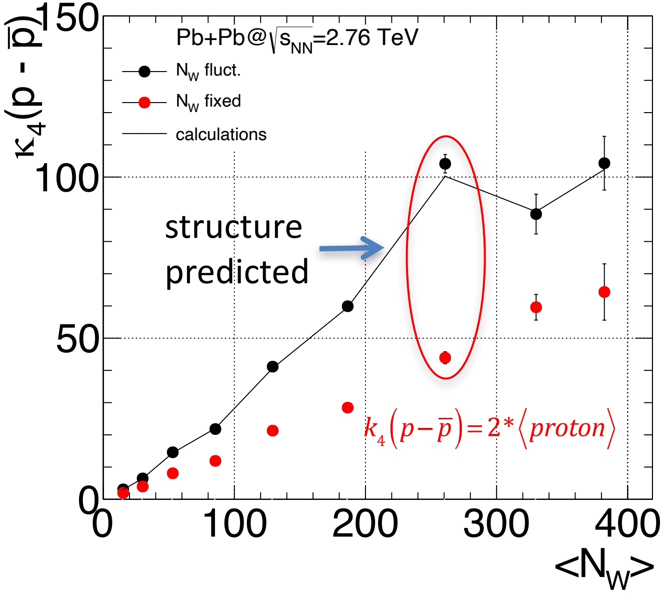
vanishes for ALICE

$$k_3(p)=\langle N_w \rangle k_3(n)+\langle n \rangle(\ldots)$$

does not vanish

$n,\bar{n}$ from single wounded nucleon

150*10^6 Events



P. Braun-Munzinger, A. Rustamov, J. Stachel
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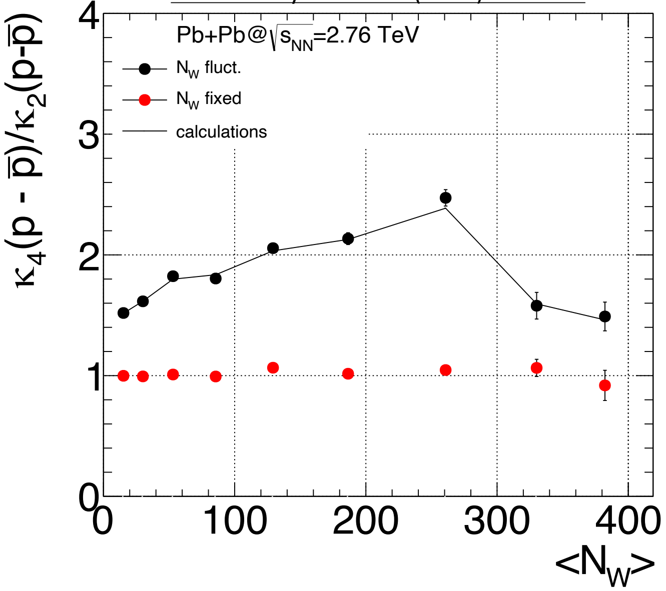
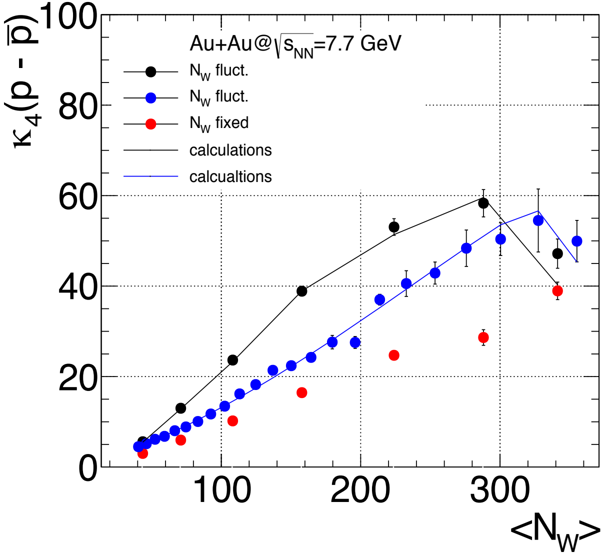


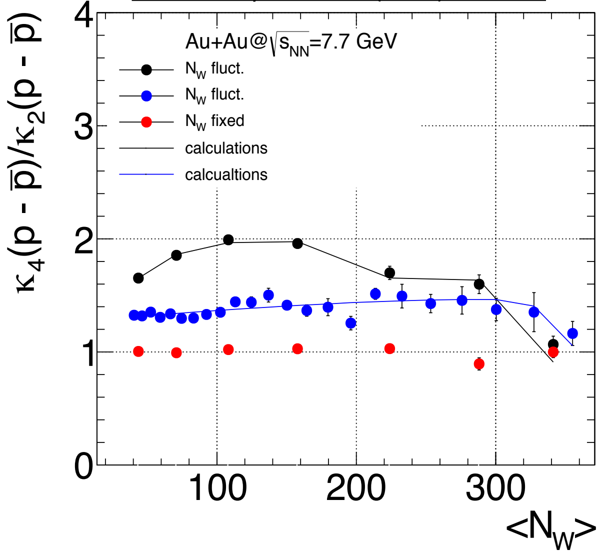
$$k_4(p-\bar{p}) = \langle N_w \rangle k_4(n-\bar{n}) + 3k_2(n-\bar{n})^2 k_2(N_w) + \langle n-\bar{n} \rangle (\ldots)$$

vanishes for ALICE

$n, \bar{n} \rightarrow$ from single wounded nucleon

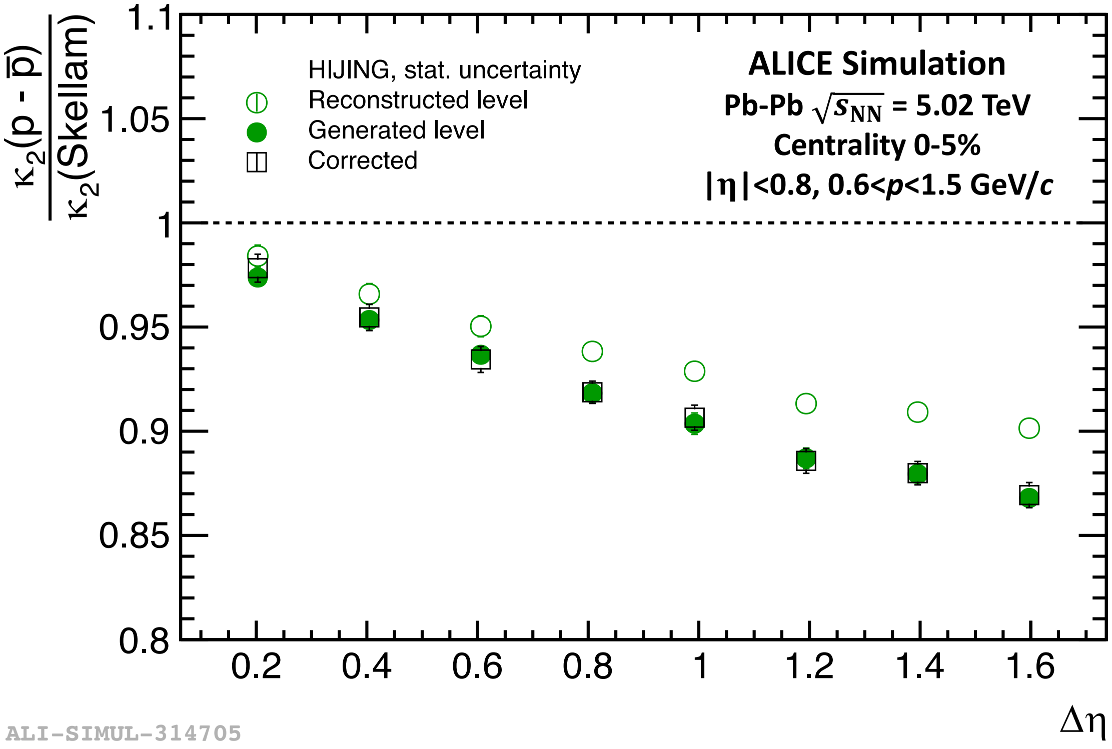
P. Braun-Munzinger, A. Rustamov, J. Stachel, Nuclear Physics A 960 (2017) 114–130





- Subdividing a given centrality bin into smaller ones and then merging them together incoherently.
- Incoherent addition of data from intervals with very small centrality bin width will eliminate true dynamical fluctuations.

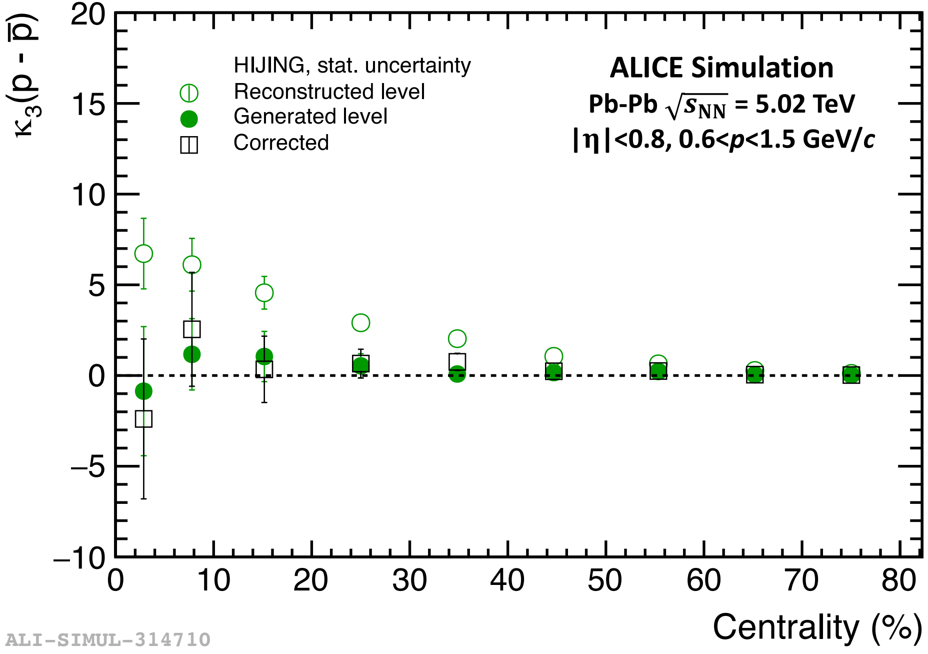
Better publish uncorrected results

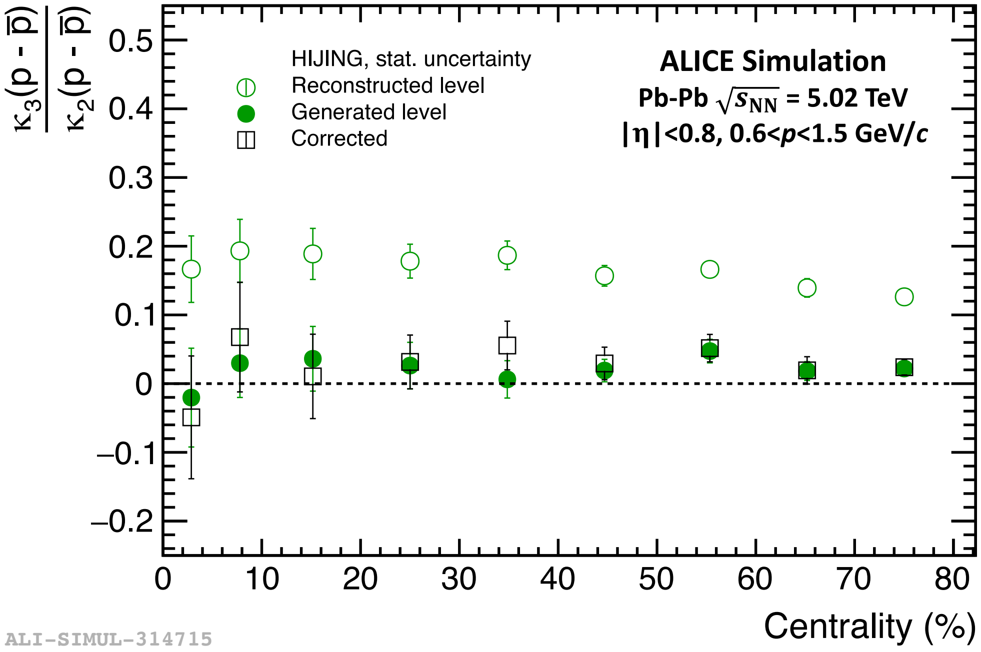


Efficiency correction with binomial assumption:

T. Nonaka, M. Kitazawa, S. Esumi, Phys. Rev. C 95, 064912 (2017)

Adam Bzdak, Volker Koch, Phys. Rev. C86, 044904 (2012)





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