Study of baryon-strangeness and charge-strangeness correlations in Pb–Pb collisions at 5.02 TeV with ALICE

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Motivation

Correlations between net-conserved quantities such as net-baryon (*B*), net-charge *(Q),* and net-strangeness (*S*) number can **provide valuable insights into the QCD phase structure**:

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- ➔ can be studied in the thermal model (HRG) and measurements can constrain the thermal properties of the QCD medium formed at LHC

$$\chi^{lmn}_{B,S,Q} = \left[\frac{\partial^{(l+m+n)}(P(\hat{\mu}_B, \hat{\mu}_S, \hat{\mu}_Q)/T^4)}{\partial \hat{\mu}^l_B \partial \hat{\mu}^m_S \partial \hat{\mu}^n_Q} \right]_{\vec{\mu}=0}$$

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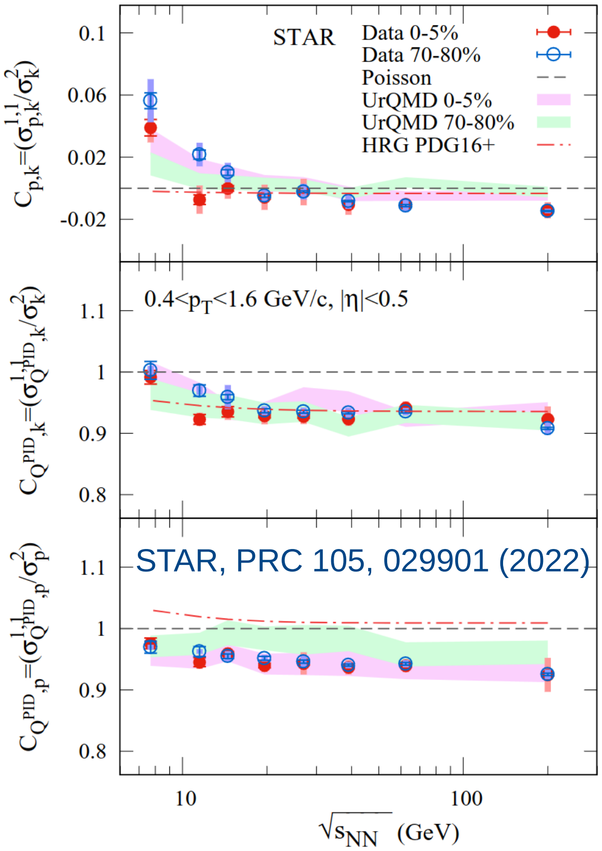
- ➔ Compared to similar measurements at lower energy, STAR experiment at RHIC



STAR, PRC 105, 029901 (2022)

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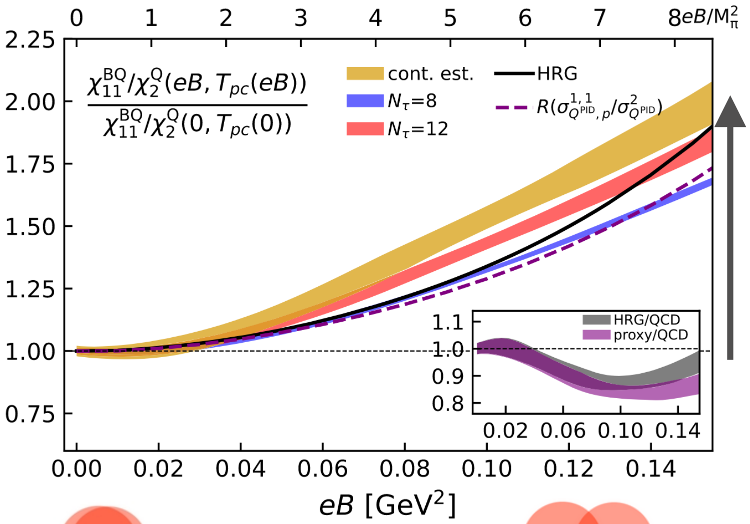
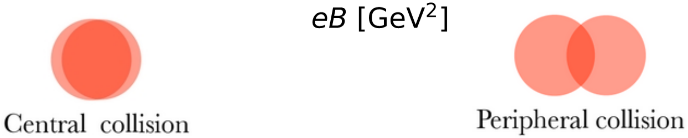
LQCD suggests that correlations of B and Q can be a useful probe to detect the imprints of magnetic fields in the final stages of heavy-ion collisions.

H.-T. Ding et al., Phy.Rev.Lett 132 (2024) 201903





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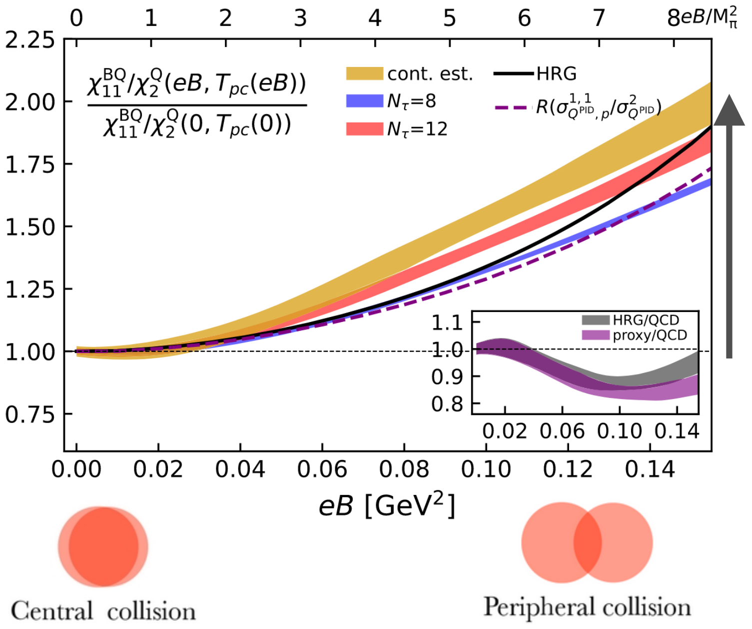
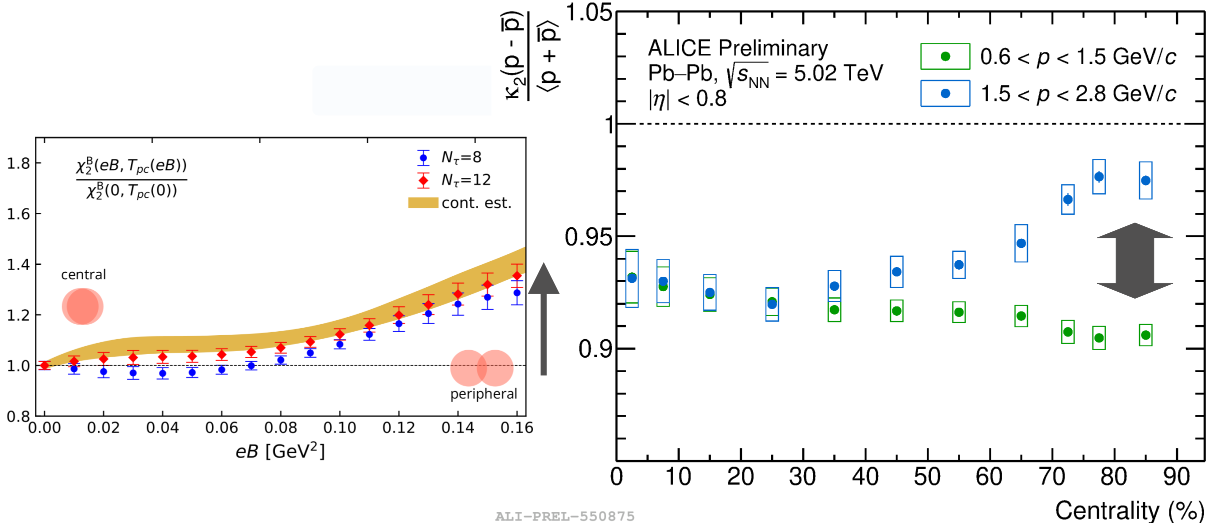


Quark Matter 2023: 2nd order net-proton cumulant



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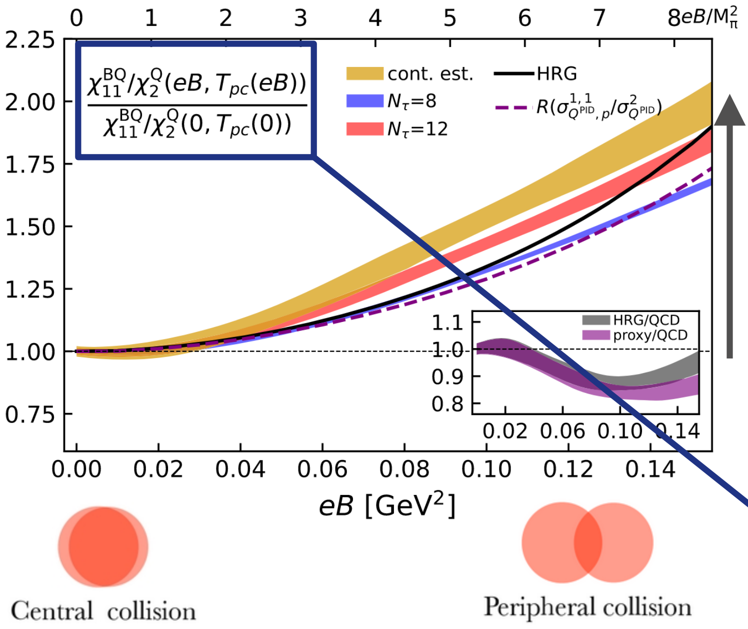

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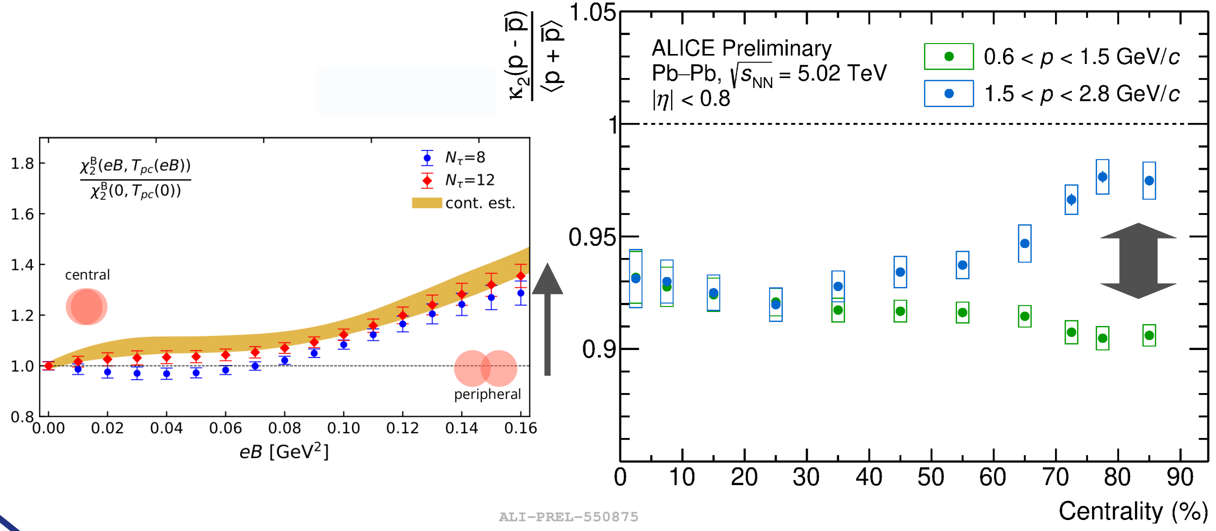

Can **centrality dependence** of this quantity **reveal a magnetic field** in late-stage heavy-ion collisions?

Observables

The susceptibilities of *B*, *S*, *Q* are related to the cumulants (σ) of the event-by-event distribution of the associated conserved charges:

$$\chi^{lmn}_{B,S,Q} = \frac{1}{VT^3}\sigma^{lmn}_{B,S,Q}$$

Definitions: *Q* → net-charge | *B* → net-baryon | *S* → net-strangeness

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Off-diagonal cumulants

$$\sigma^{11}_{B,S} = \langle BS\rangle - \langle B\rangle\langle S\rangle$$
$$\sigma^{11}_{Q,S} = \langle QS\rangle - \langle Q\rangle\langle S\rangle$$
$$\sigma^{11}_{Q,B} = \langle QB\rangle - \langle Q\rangle\langle B\rangle$$

Diagonal cumulants

$$\sigma^{2}_{Q} = \langle Q^2\rangle - \langle Q\rangle^2$$
$$\sigma^{2}_{B} = \langle B^2\rangle - \langle B\rangle^2$$
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→

$$C_{B,S} = \sigma^{11}_{B,S}/\sigma^2_S$$
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$$\sigma^2_\alpha = \langle(\delta N_\alpha)^2\rangle, \quad \sigma^{11}_{\alpha,\beta} = \langle(\delta N_\alpha)(\delta N_\beta)\rangle$$

$$\delta N_\alpha = (N_{\alpha+} - N_{\alpha-}) - \langle(N_{\alpha+} - N_{\alpha-})\rangle$$

α*, *β* → *Q*, *B*, or *S

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Experiments:

Proxies:

- *Q* → net-pion+net-kaon+net-proton
- *B* → net-proton (p)
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→ **this is what we measure**

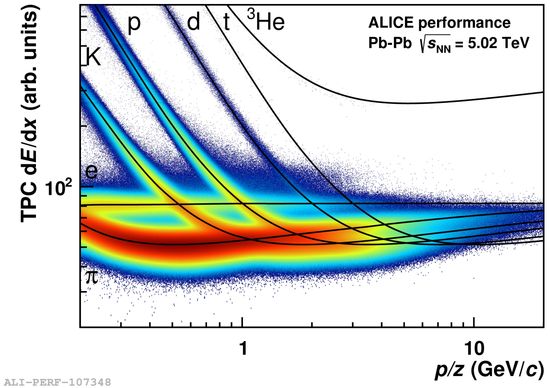
ALICE Detector

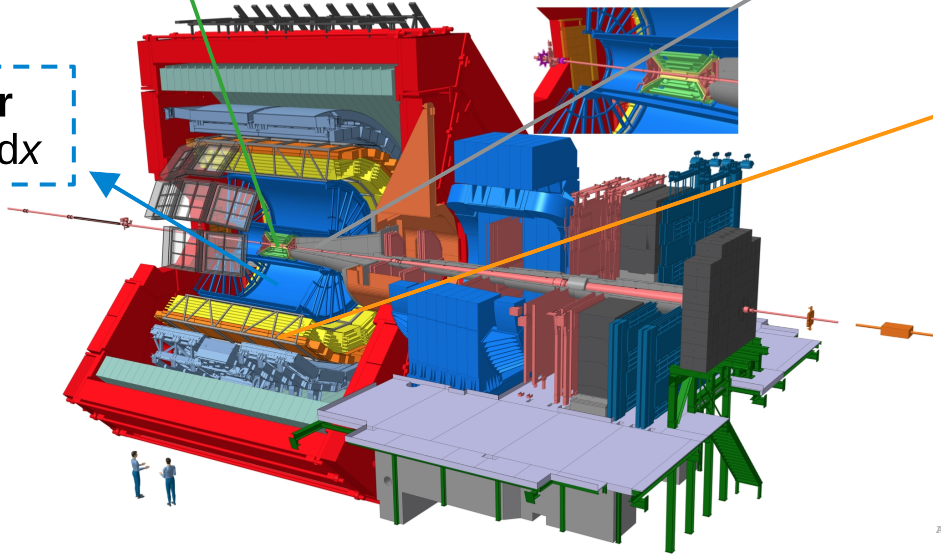
Inner Tracking System (ITS): tracking, vertexing, trigger

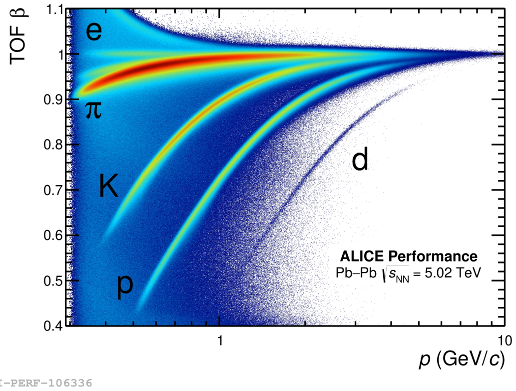
V0: trigger, centrality estimation

Time Projection Chamber (TPC): tracking, PID via dE/dx

Time-Of-Flight (TOF): PID via time of flight







Run 2 data: Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

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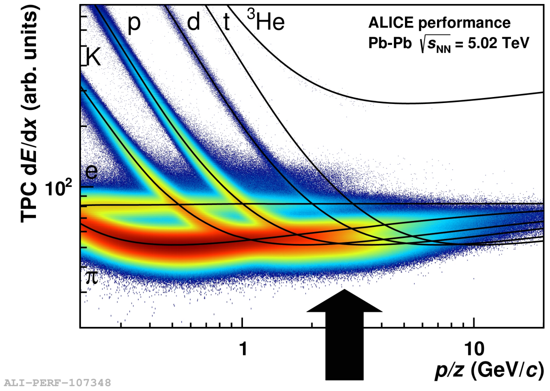

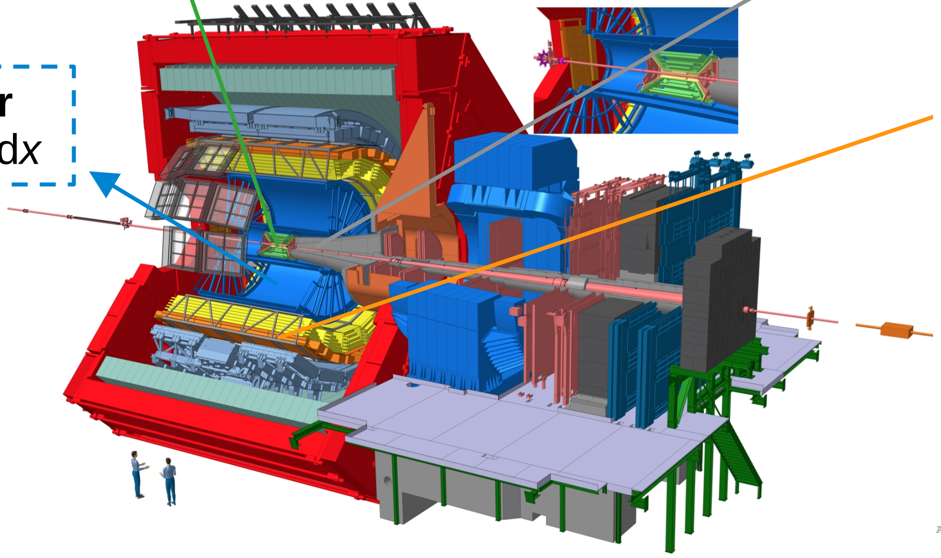

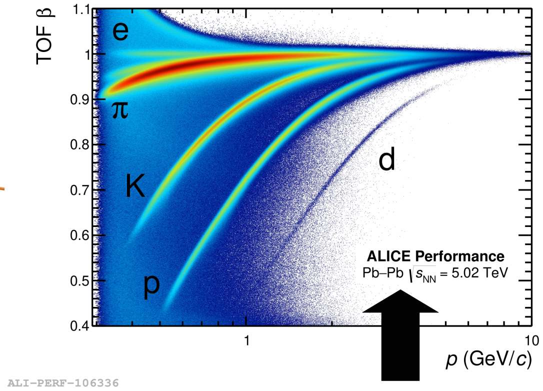

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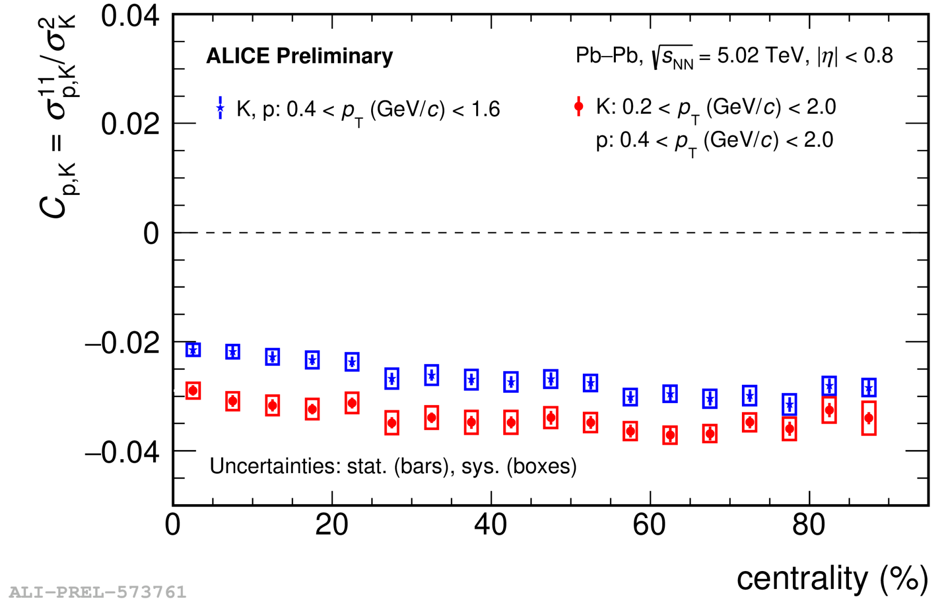
✔ **PID using information from TPC and TOF**

Correlation of net-proton and net-kaon

→ a proxy of ***B* – *S*** correlation



- **Anti-correlation** between fluctuations in *B* and *S*
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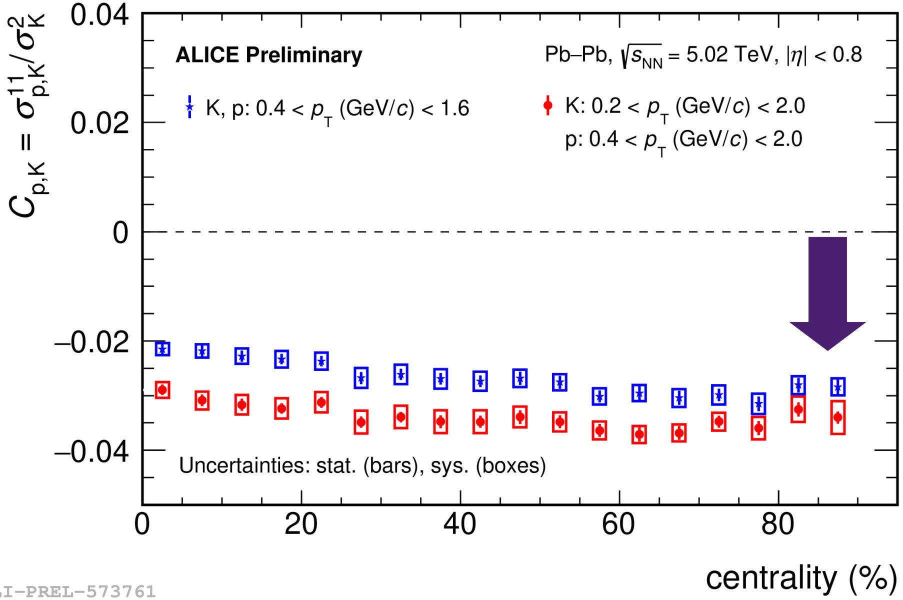

ALI-PREL-573761

- **Anti-correlation** between fluctuations in *B* and *S*
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- **Larger correlations** compared to the Poisson baseline

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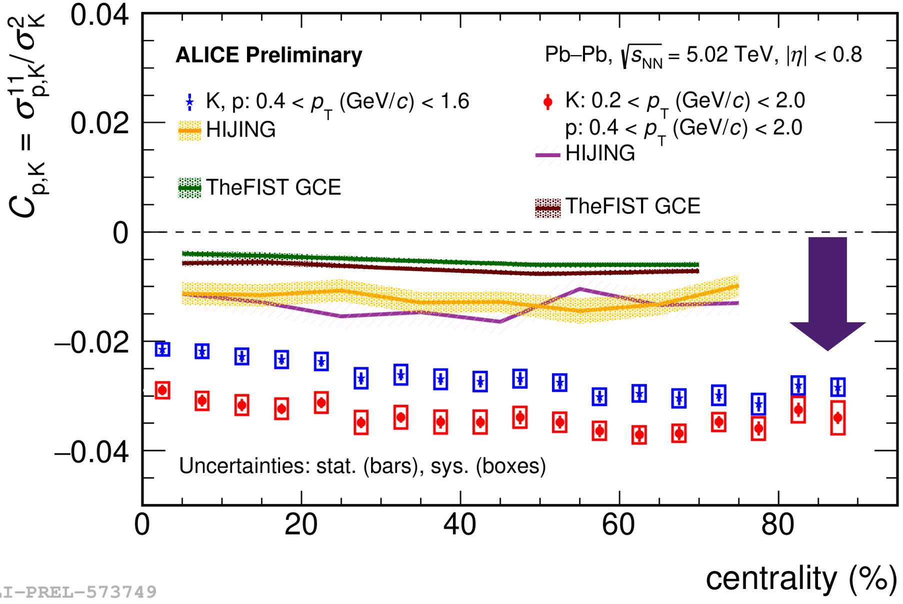

- **Anti-correlation** between fluctuations in *B* and *S*
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ThermalFIST (Statistical Hadronization Model) - Parameters from published fit

- Grand Canonical Ensemble (GCE) → quantum numbers conserved on average

V. Vovchenko et al., Phys.Rev.C 100 (2019) 5, 054906

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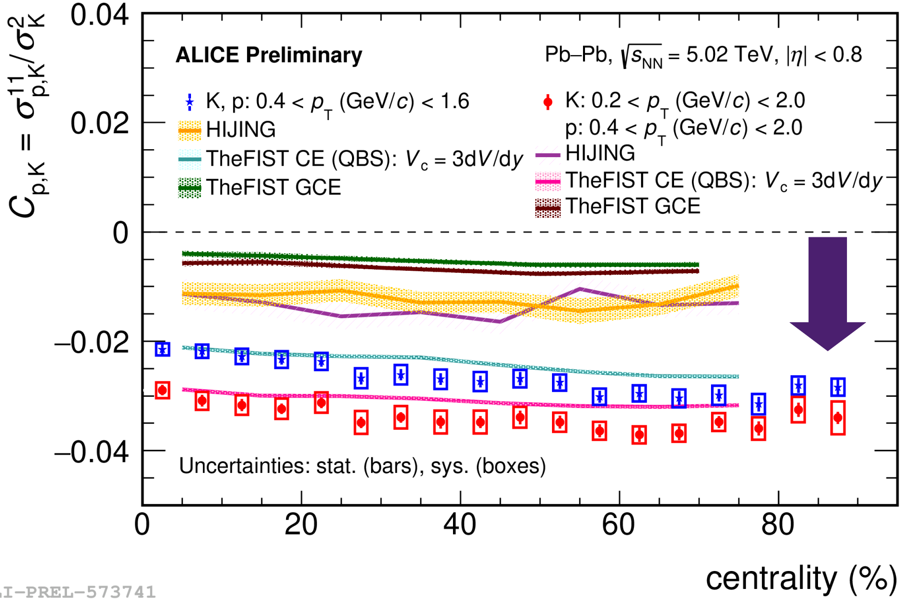

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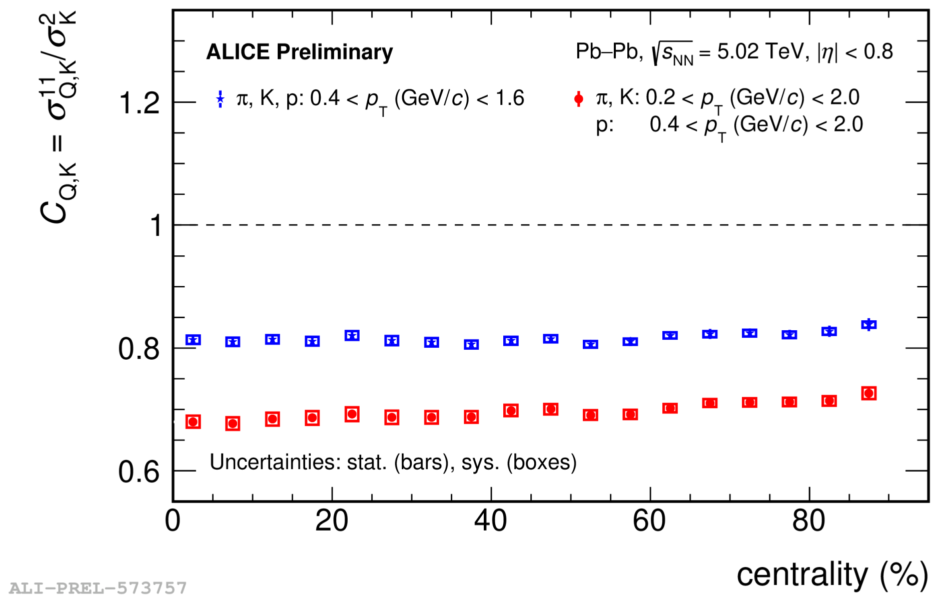
Correlation of net-charge and net-kaon



→ a proxy of ***Q*** **–** ***S*** correlation

- Momentum range dependence

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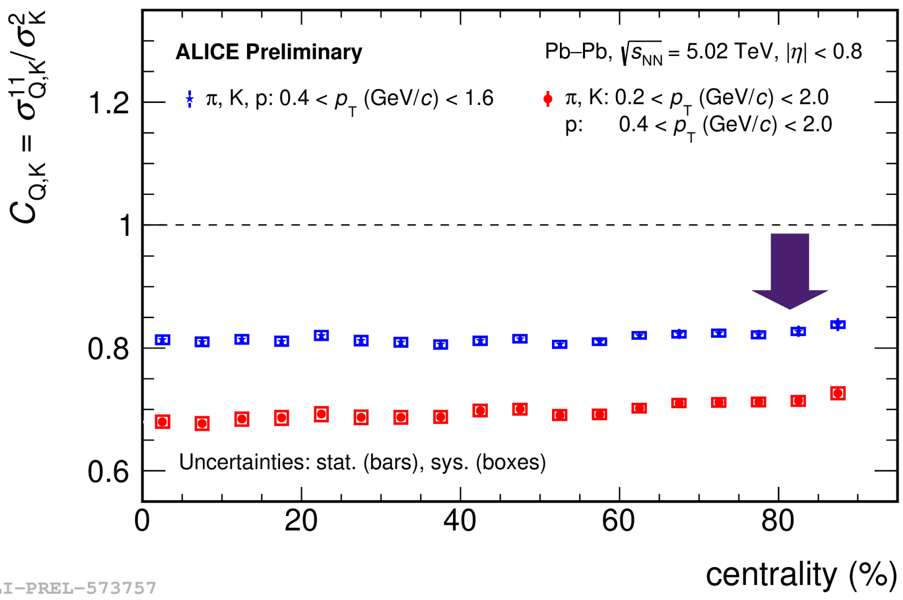

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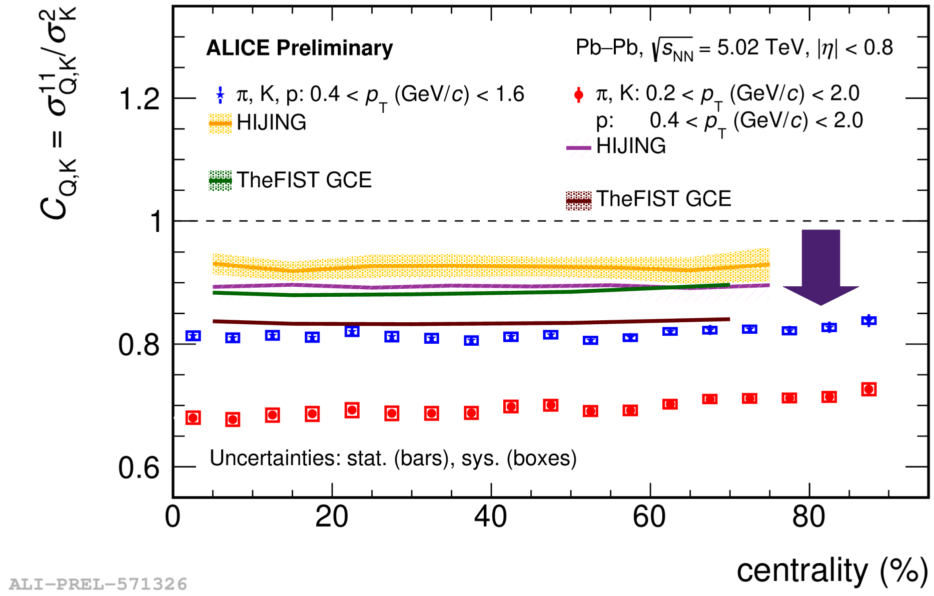

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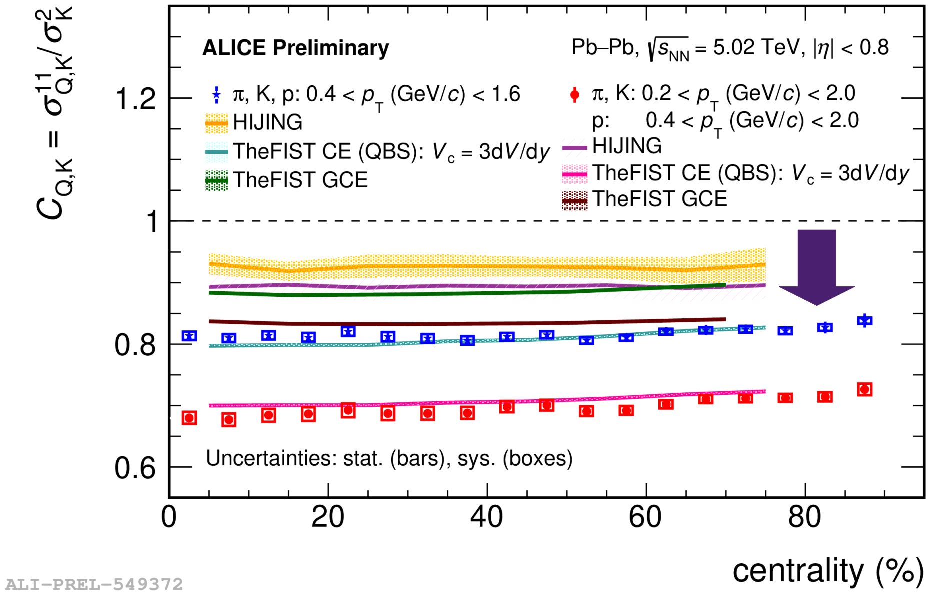

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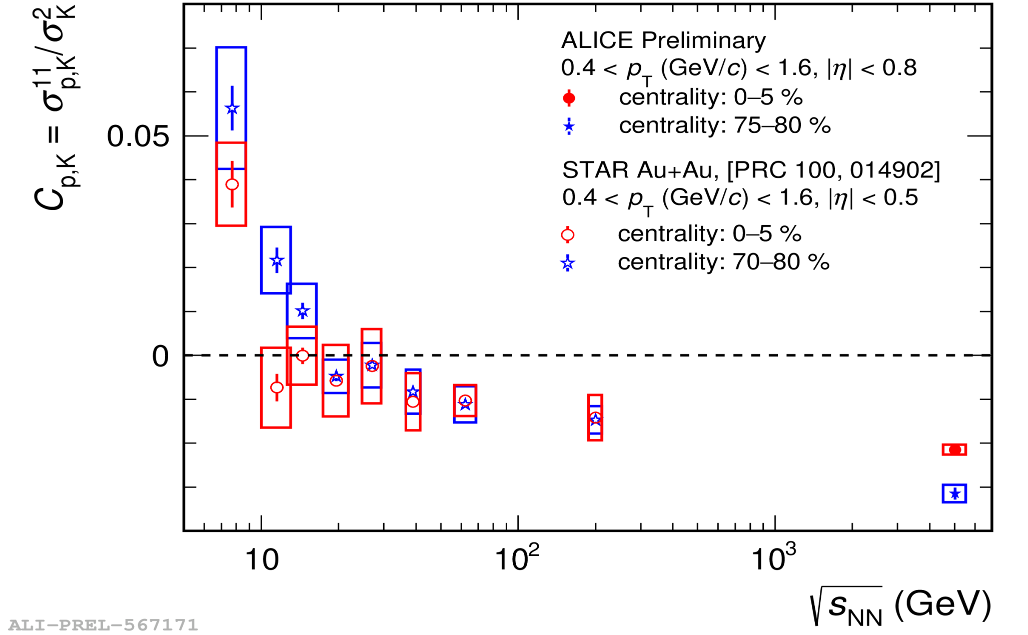
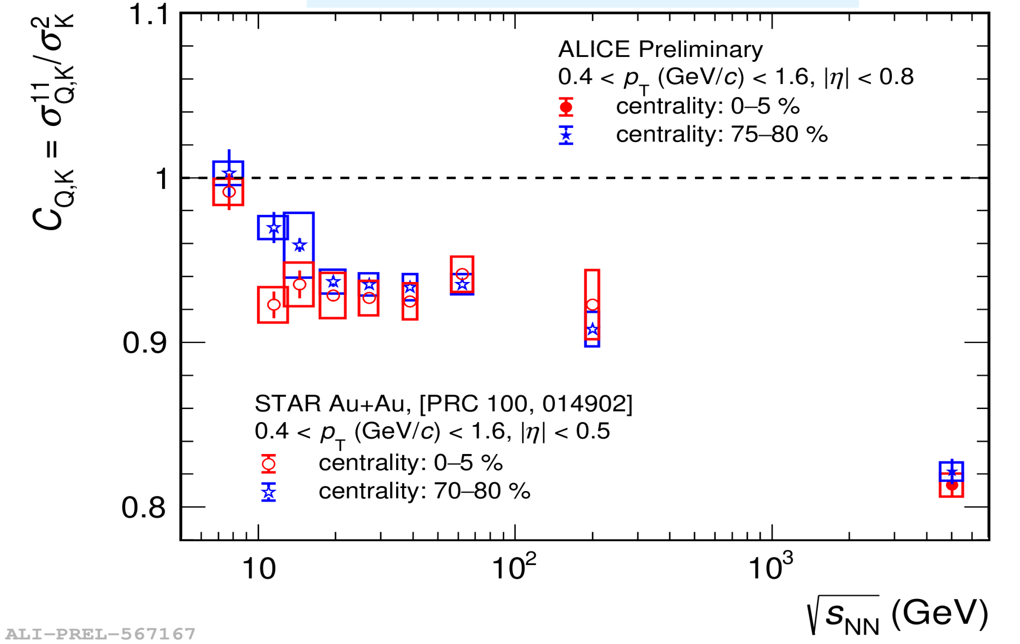
Energy dependence

Correlation between **p – K**



Correlation between ***Q* – K**

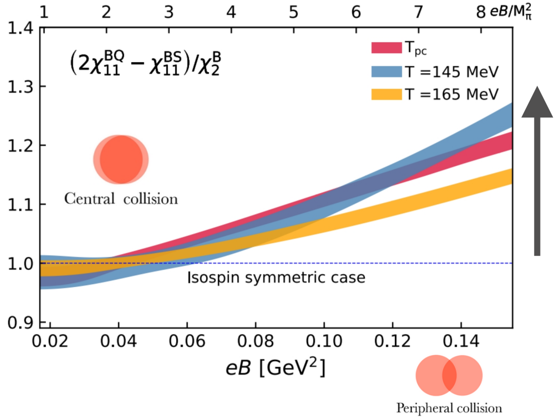


- Decreasing trend of the correlations with increasing energy from RHIC to LHC

Magnetic field effect?

Magnetic field: Absent
Isospin symmetry of u and d quarks

Magnetic field: Present
Isospin symmetry breaks



H.-T. Ding et al., EPJ. A (2021) 57:202, CPOD-2024

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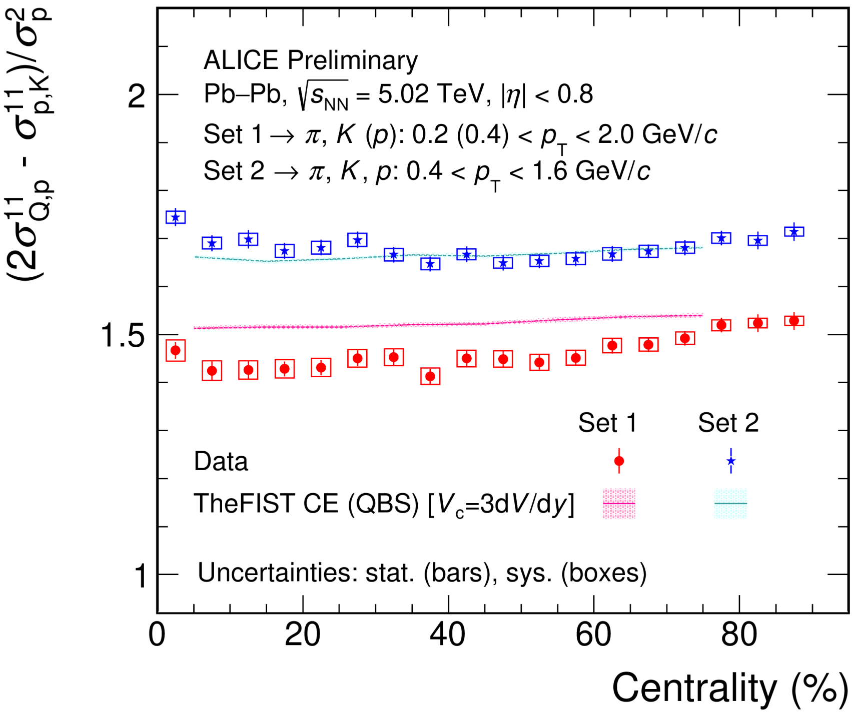

ALI-PREL-574188

Poisson baseline → 2

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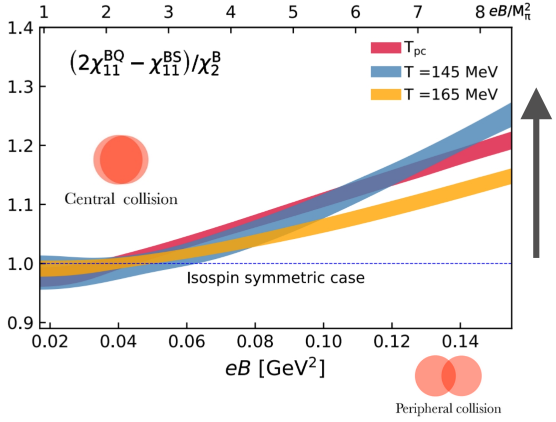

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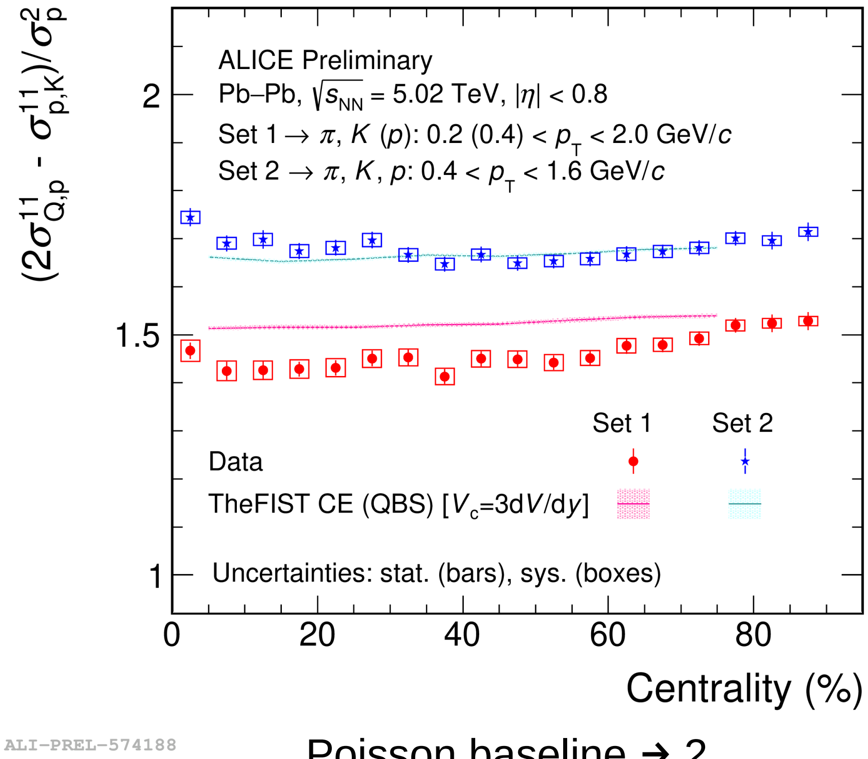

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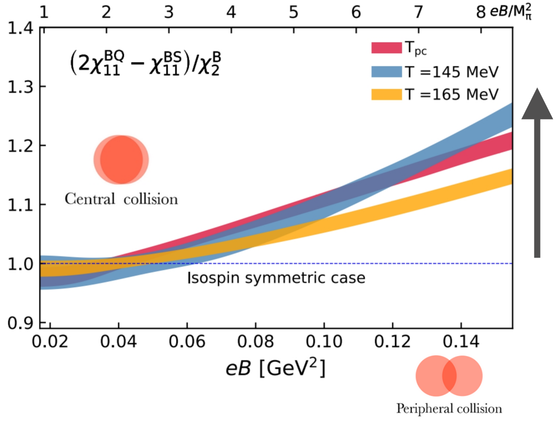

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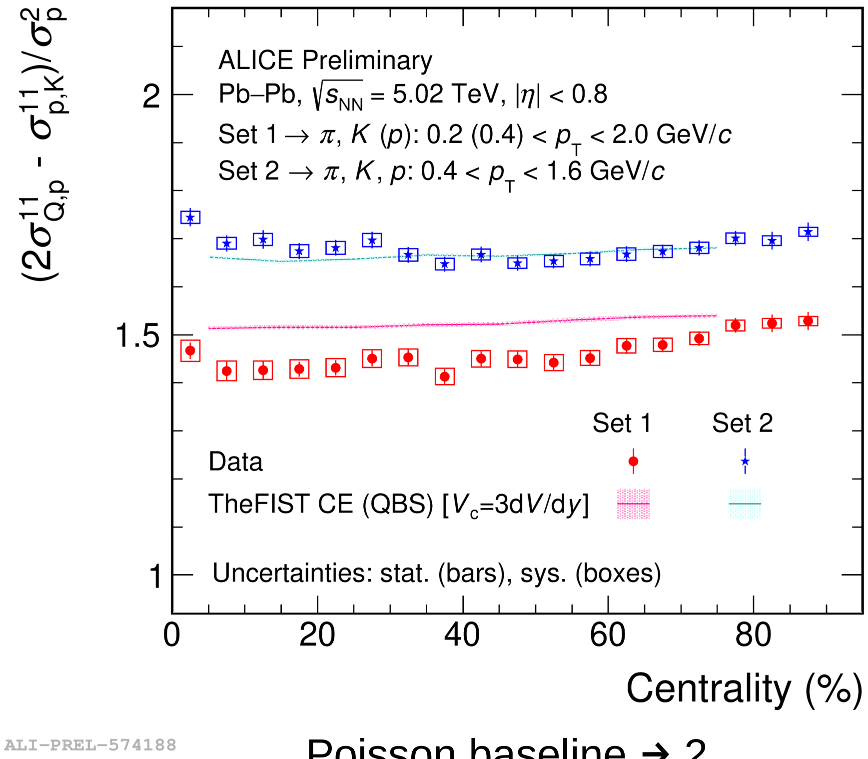

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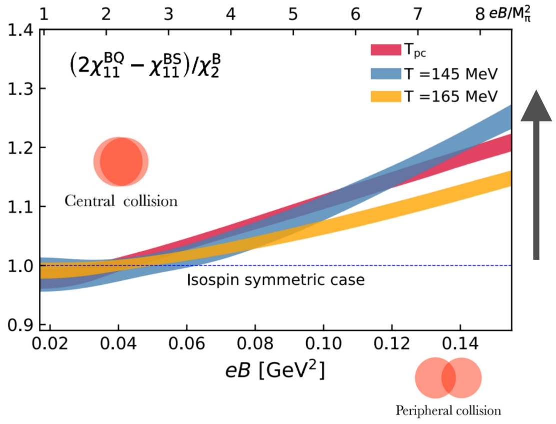

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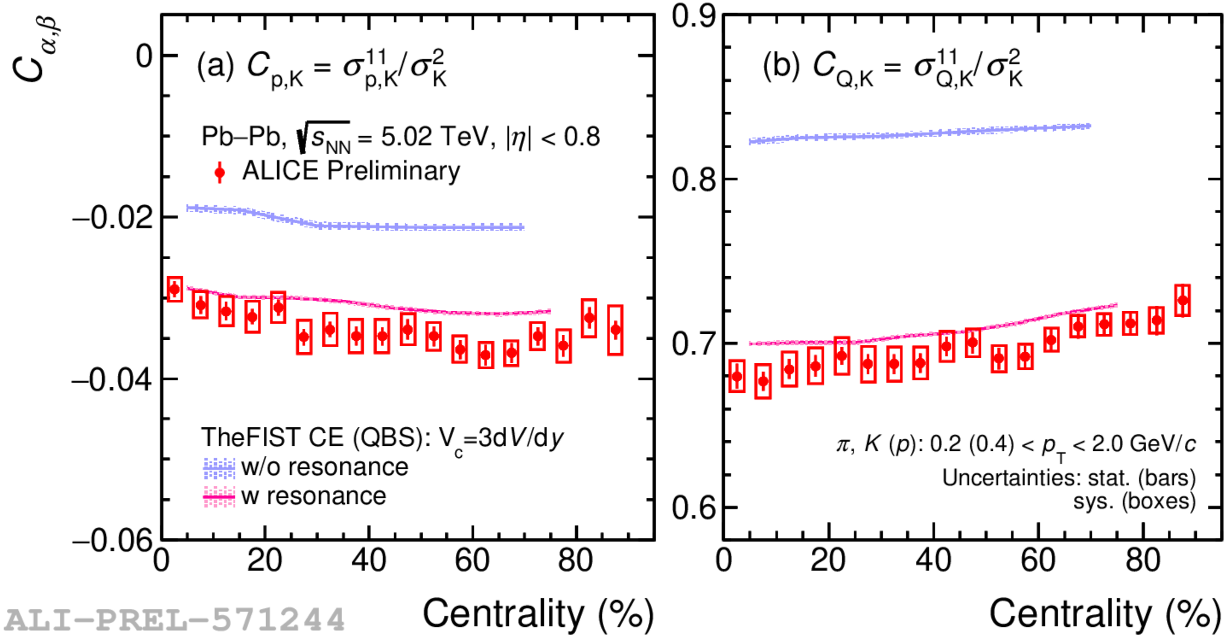

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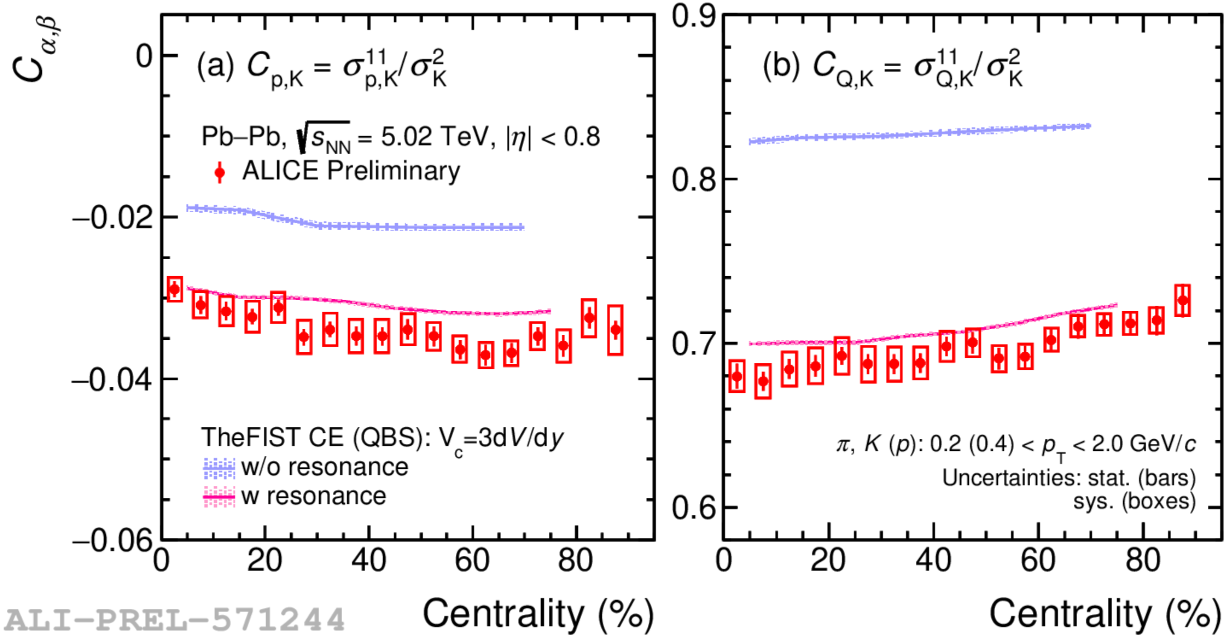
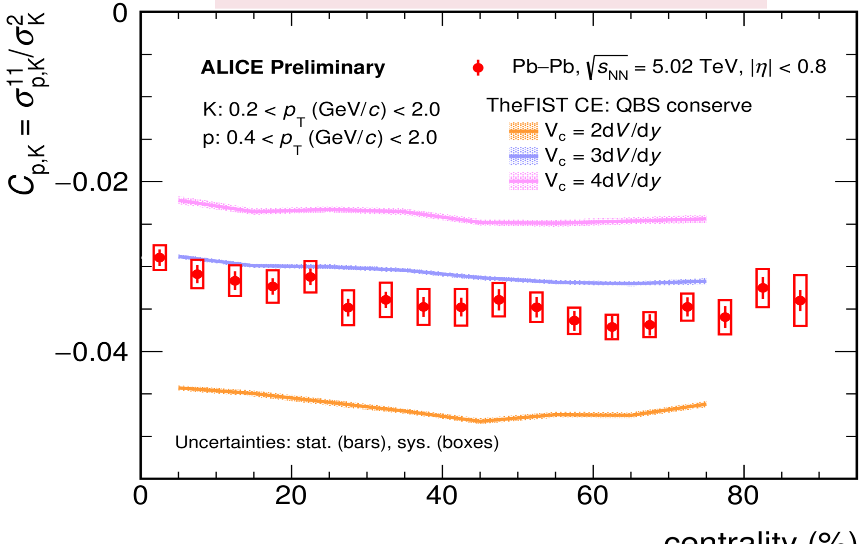


Canonical ensemble (CE)→ exact conservation of Q, B, S in V_c = 3 dV/dy

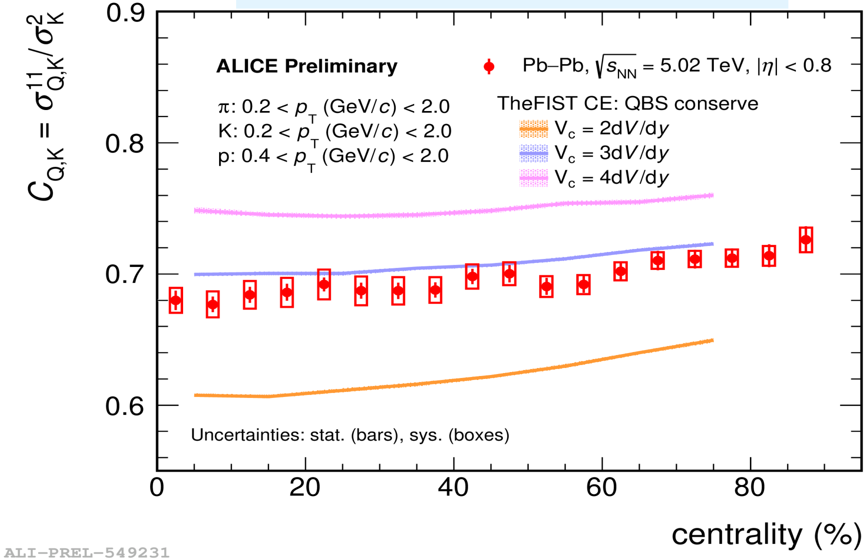
- **Significant impact of resonances**
- **ThermalFIST is comparatively better** in capturing the resonance contributions

Effect of correlation volume

Correlation between **p – K**



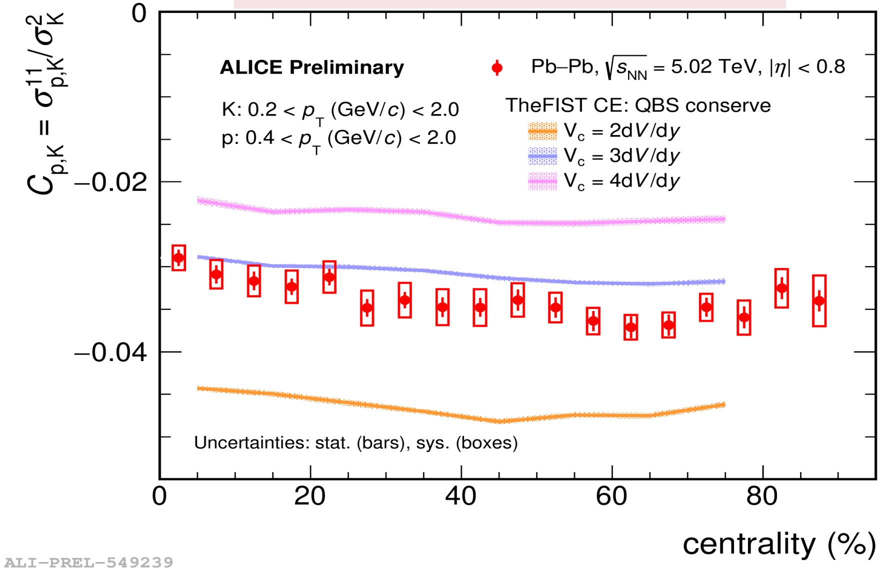
Correlation between ***Q* – K**



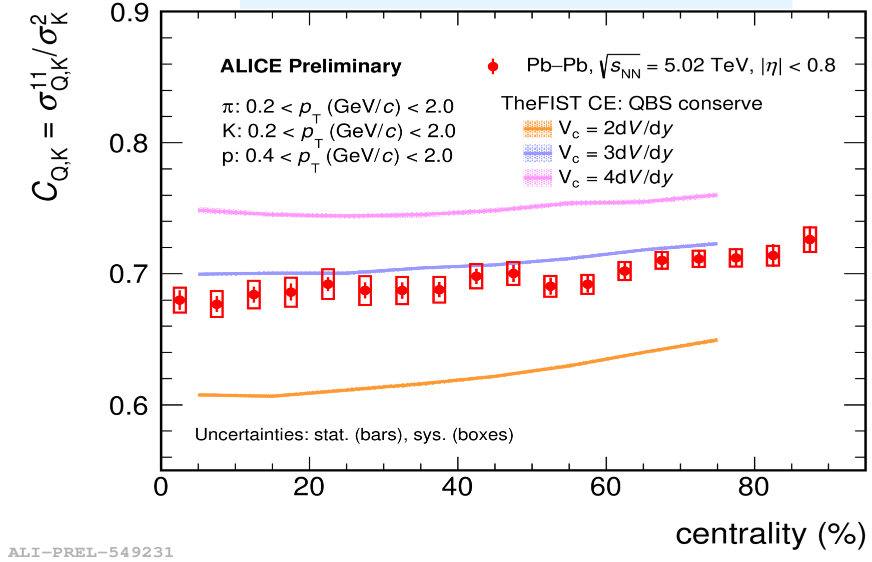
- **Sensitive to the correlation volume** (V_c) in thermal model

Effect of correlation volume

Correlation between **p – K**



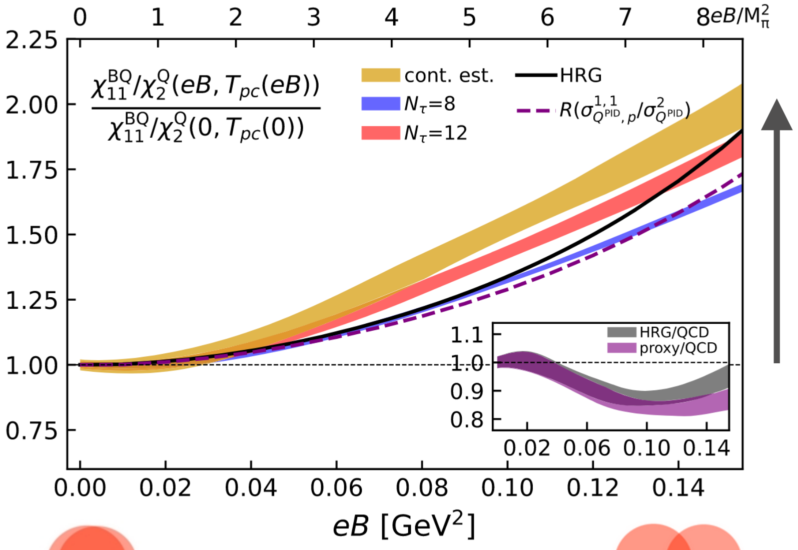
Correlation between ***Q* – K**

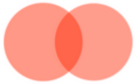


- **Sensitive to the correlation volume** (V_c) in thermal model
- A combined χ^2-minimization of three correlations (p – K, *Q* – K and *Q* – p) gives ***V_c* ~ 2.6d*V*/dy** for *Q*, *B*, and *S* conservation
  – **slightly lower** than that of net-proton fluctuations, net-Λ fluctuations, and net-Ξ–net-K correlations (V_c~3d*V*/dy)

Magnetic field effect?

H.-T. Ding et al., Phy.Rev.Lett 132 (2024) 201903





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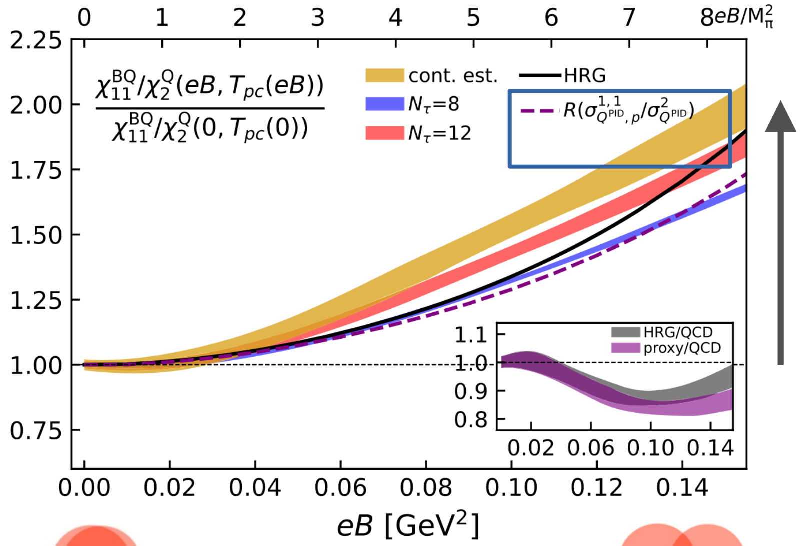
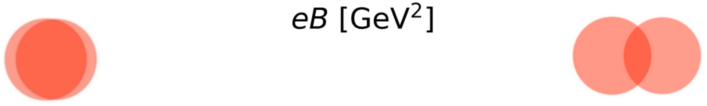
H.-T. Ding et al., Phy.Rev.Lett 132 (2024) 201903





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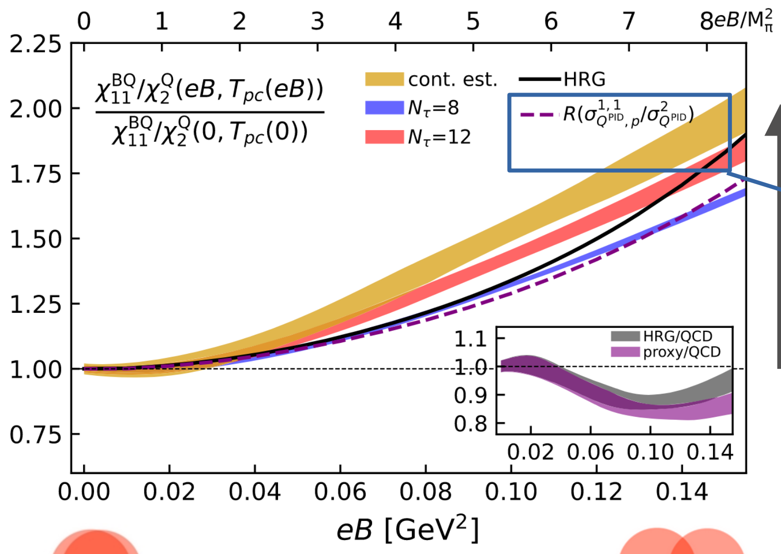
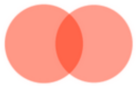
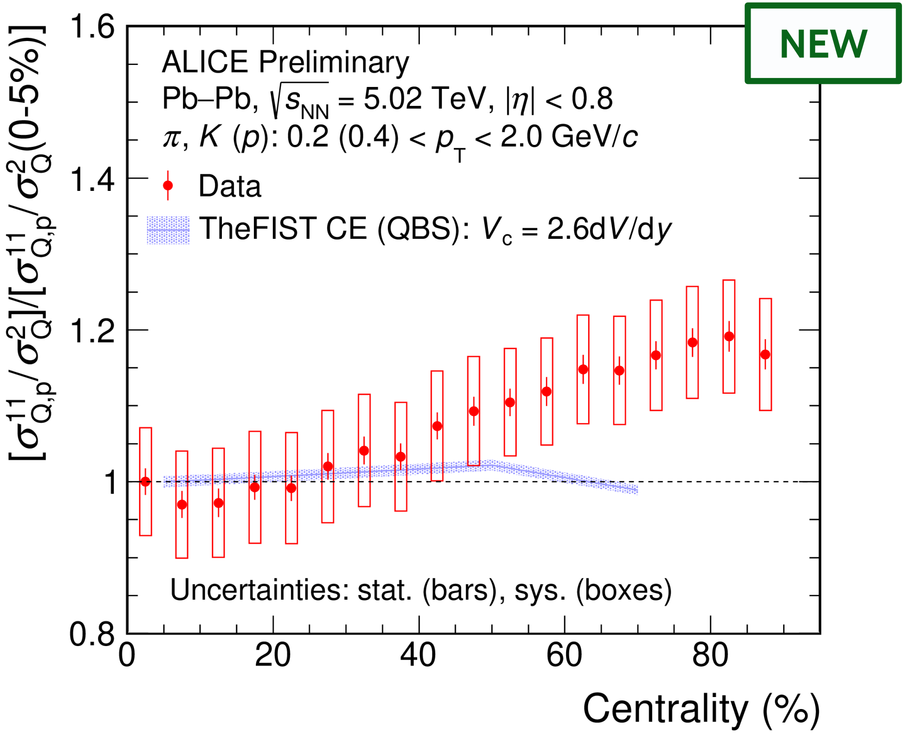
H.-T. Ding et al., Phy.Rev.Lett 132 (2024) 201903



Central collision

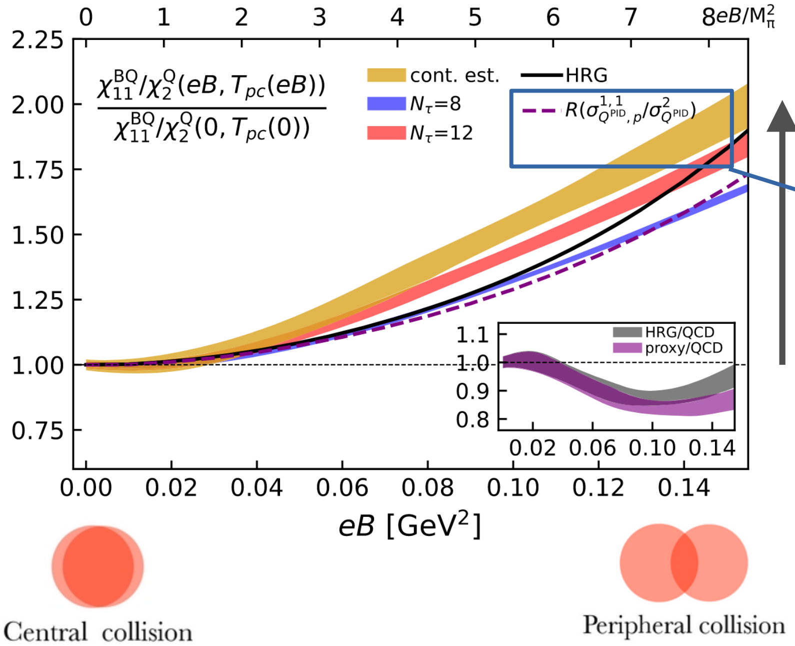


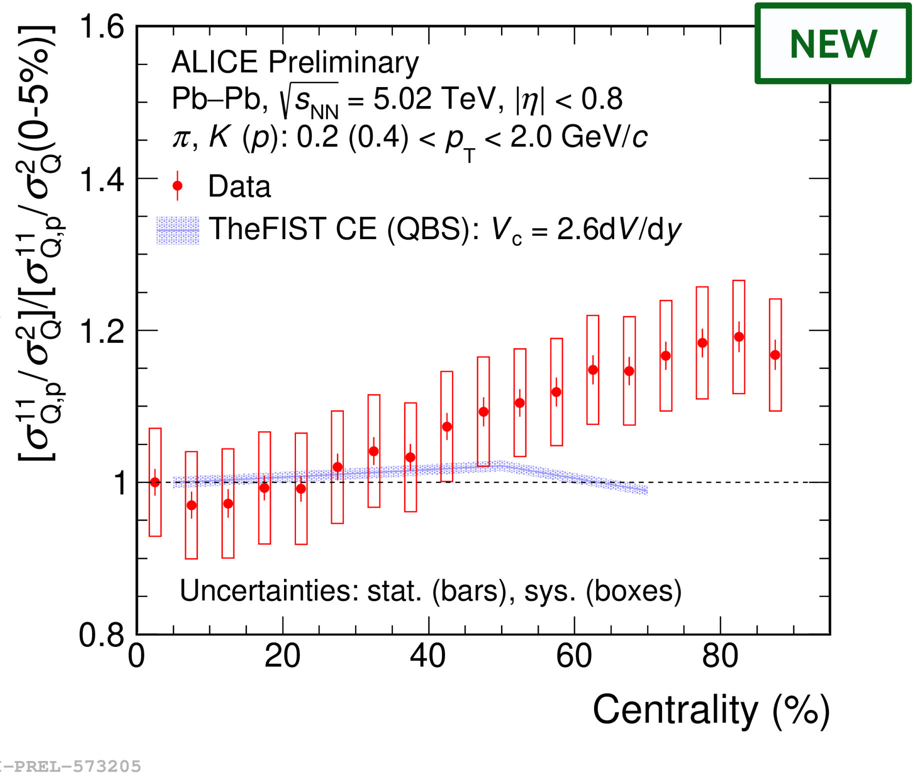
Peripheral collision



Magnetic field effect?

H.-T. Ding et al., Phy.Rev.Lett 132 (2024) 201903





- Observed **an increase of ~20% from central to peripheral collisions**
  – Hint of magnetic field effect?

Summary

- Centrality dependence of correlations among net-charge, net-baryon, and net-strangeness are presented for Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV**.**
- **Resonance decay** leads to deviation from Poisson baseline for all three measured correlations.
- Thermal-FIST model within CE framework and *Q*, *B* and *S* conservation suggests a correlation volume, **$V_c \sim 2.6\mathrm{d}V/\mathrm{d}y$** for explaination of all three correlations simultaneously.
- **Hint of magnetic field** effect in correlation of net-charge and net-proton.

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Stay tuned for more results on event-by-event fluctuations with Run 3 data.

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Stay tuned for more results on event-by-event fluctuations with Run 3 data.

Thank you

Additional slides

Theory predictions

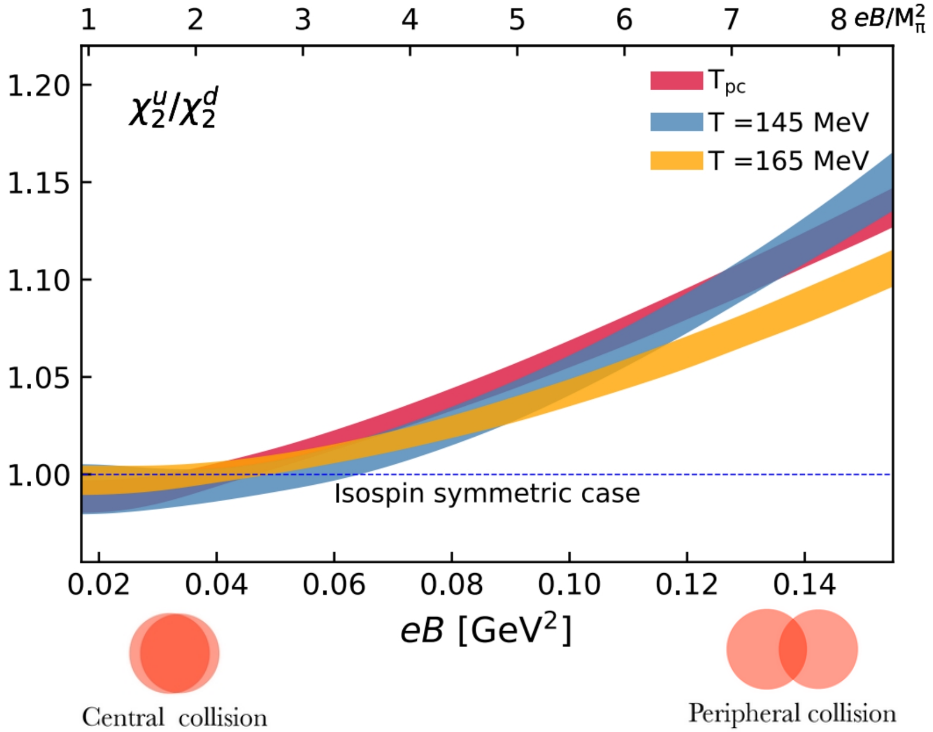
Magnetic field ✗
Isospin symmetry of u and d quarks

Magnetic field ✔
Isospin symmetry breaks

$$\text{At } eB = 0, \chi_u = \chi_d$$

$$2\chi_{11}^{QS} - \chi_{11}^{BS} = \chi_2^S$$

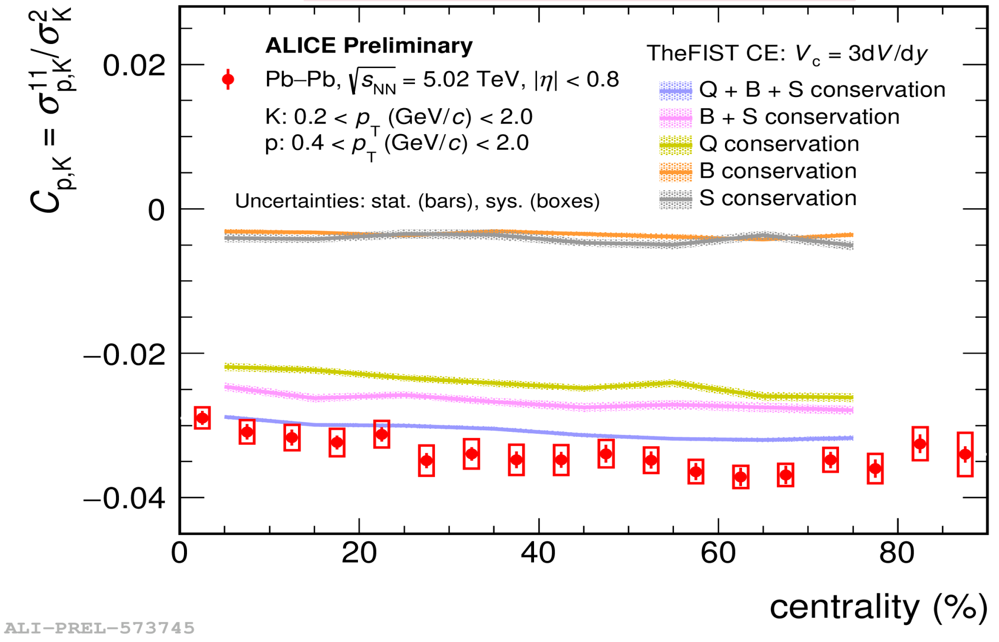
$$2\chi_{11}^{BQ} - \chi_{11}^{BS} = \chi_2^B$$



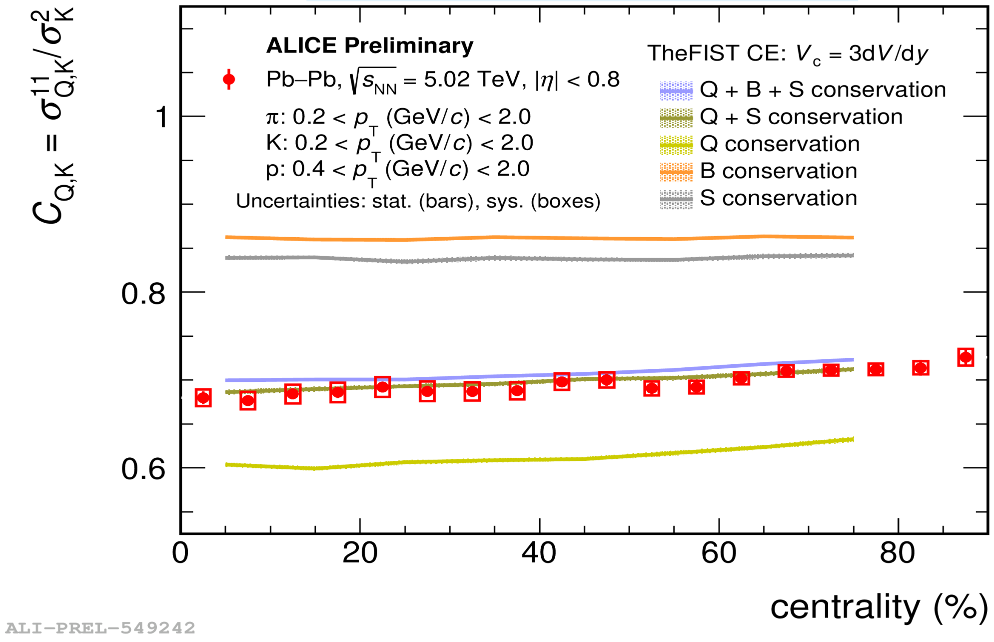
H.-T. Ding et al., EPJ. A (2021) 57:202, **CPOD-2024**

Effect of charge conservations

Correlation between **p – K**



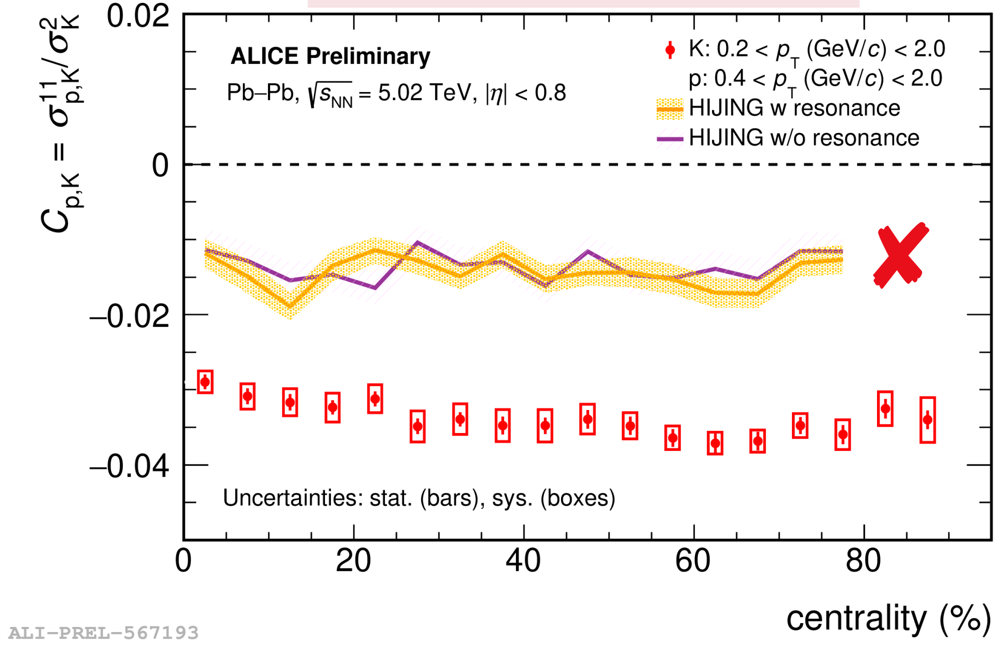
Correlation between ***Q* – K**



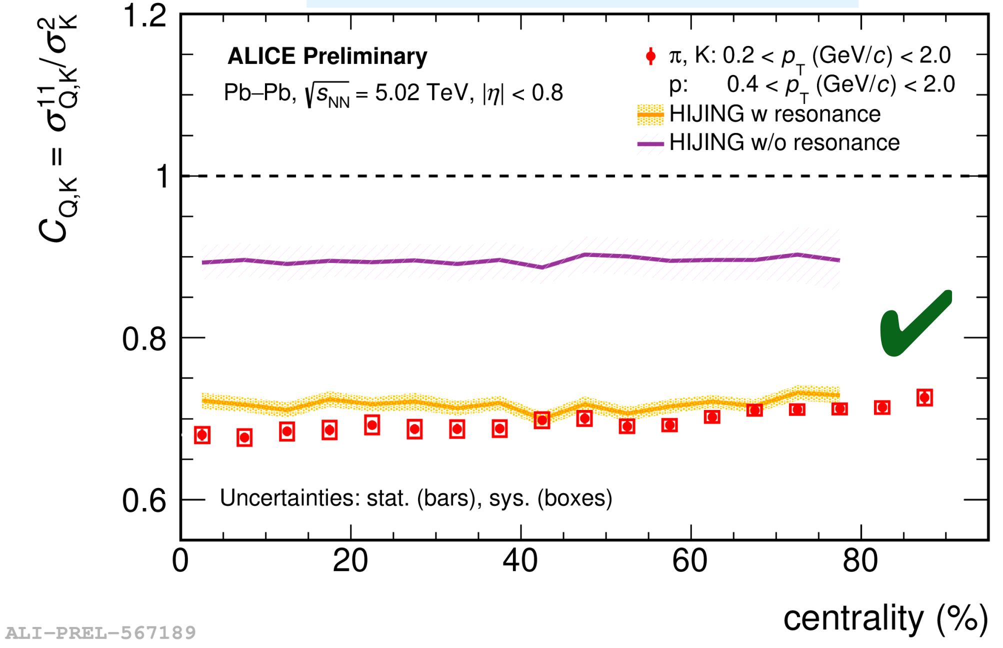
- Contribution to the net-particle correlations from *Q*, *B*, and *S* conservation are shown

Effect of resonances

Correlation between **p – K**

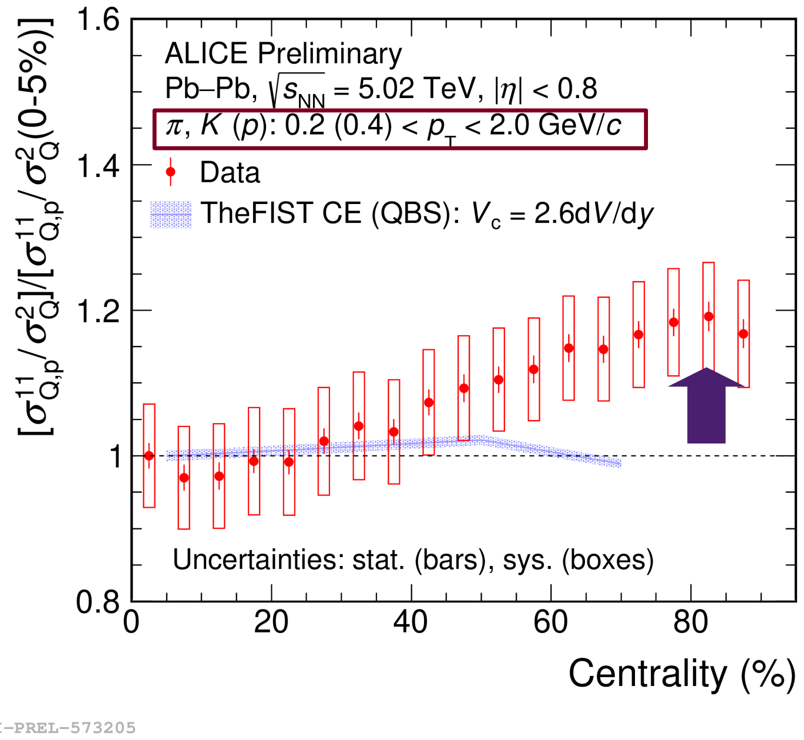


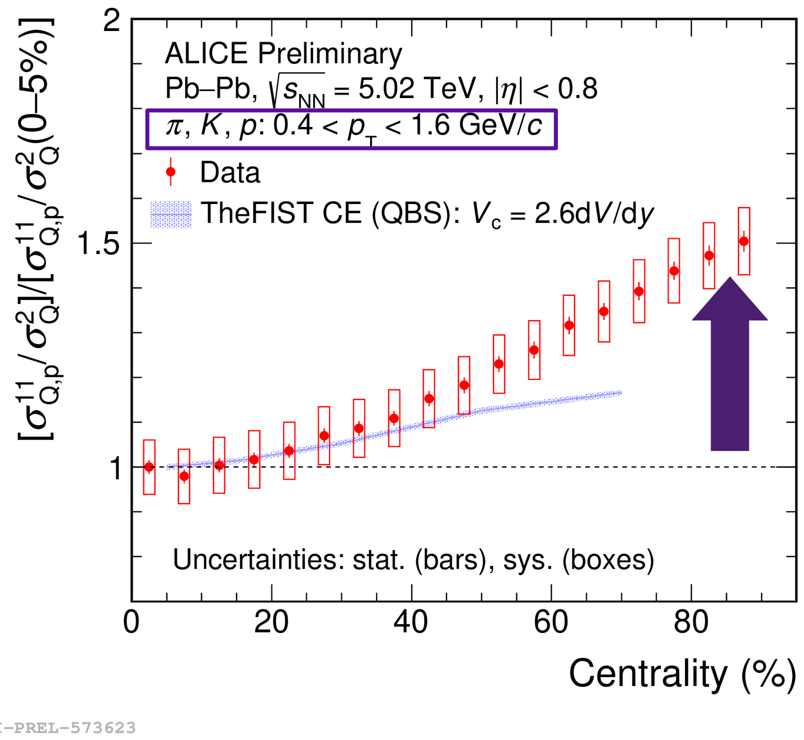
Correlation between ***Q* – K**



- HIJING is not good in capturing the resonances for $C_{p,K}$, but good for $C_{Q,K}$

Magnetic Field?





- Larger deviation with change in the momentum range
  → low p_T pions diminishing the effect of magnetic field on Q – K correlations?