ATLAS highlights: Recent results from ATLAS

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for the ATLAS Collaboration

3 June 2024

introduction

- we use heavy-ion collisions to learn about QGP
- we also use $p+p$ collisions to learn about (lack of) QGP
- large systems: Pb+Pb, Xe+Xe
  - what phenomena are driving jet quenching? is it sub-structure?
  - how do heavy-flavour quark interact with QGP?
  - what can we deduct from anisotropies and fluctuations?
- small systems: p+Pb, $p+p$
  - are jets modified?
  - what is the origin of flow?
  - how are quarkonia formed?
- UPC: $\gamma + \gamma$ or $\gamma +$ Pb
  - are there QGP-like signatures?
  - is there beyond-standard-model physics?

- all ATLAS heavy-ion results

  ➔ **https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults**

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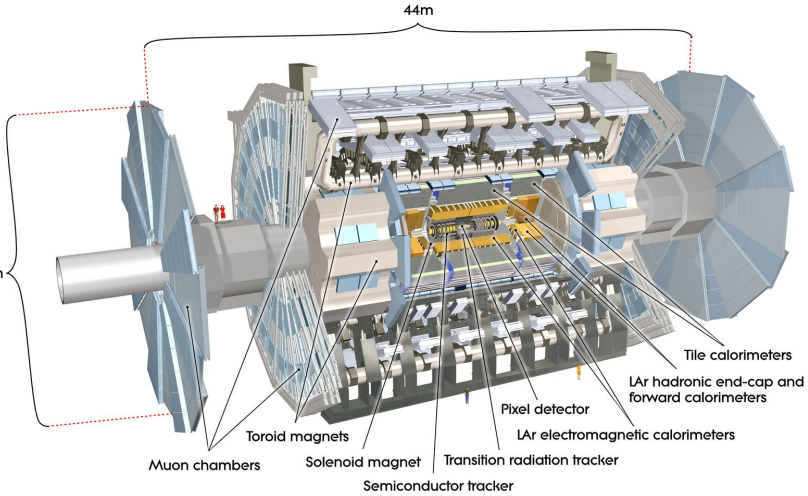
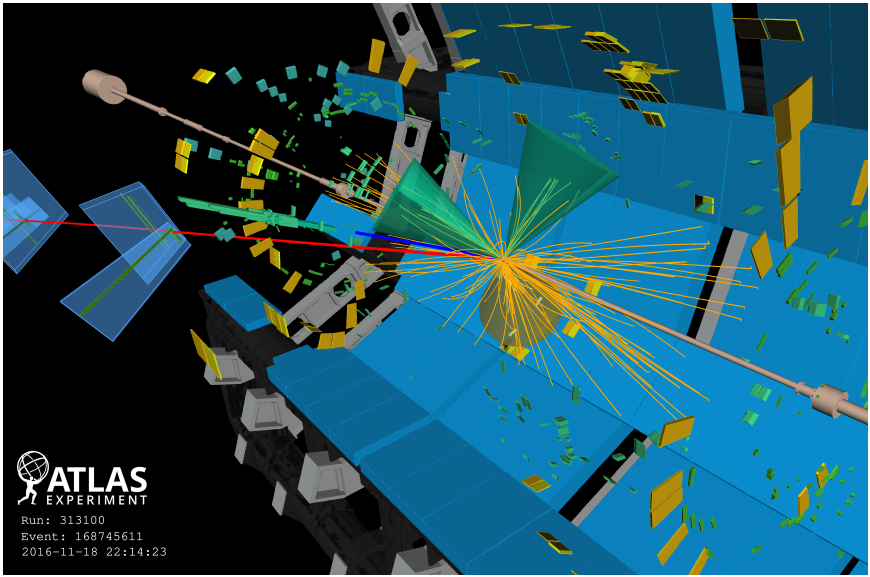
ATLAS detector

- tracker: $|\eta| < 2.5$
- EM and hadronic calorimeters: $|\eta| < 3.2$
- forward calorimeters: $3.1 < |\eta| < 4.9$ used for centrality
- muon spectrometers: $|\eta| < 2.7$
- ZDC: $|\eta| > 8.3$



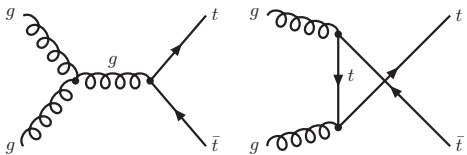
$t\bar{t}$ production in p+Pb

electron
muon
b-tagged jet
non-b-tagged jets

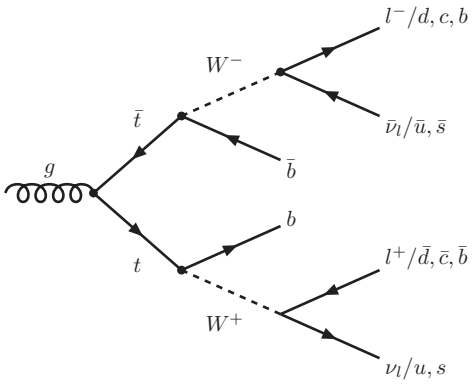


arXiv:2405.05078

$t\bar{t}$ production in p+Pb



$t\bar{t}$ production

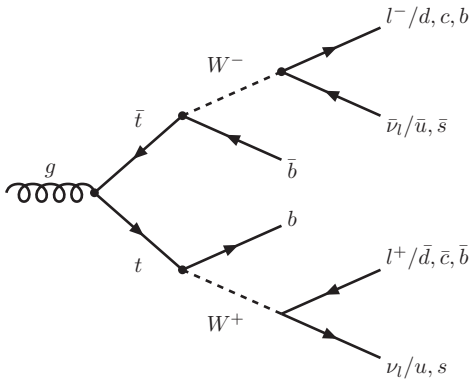


$t\bar{t}$ decay

arXiv:2405.05078

$t\bar{t}$ production in p+Pb

- using 165 nb^{-1} of p+Pb data recorded at $\sqrt{s_{NN}} = 8.16$ TeV in 2016
- in single-lepton channel, we require:
  - 1 lepton
  - at least 4 jets, with at least 1 b-tagged jet
    - ★ b-tagging efficiency = 85%
    - ★ c-quark rejection factor = 2.9
    - ★ light quarks rejection factor = 40
- in di-lepton channel, we require:
  - 2 opposite-sign leptons (Z candidates discarded)
  - at least 2 jets, with at least 1 b-tagged jet



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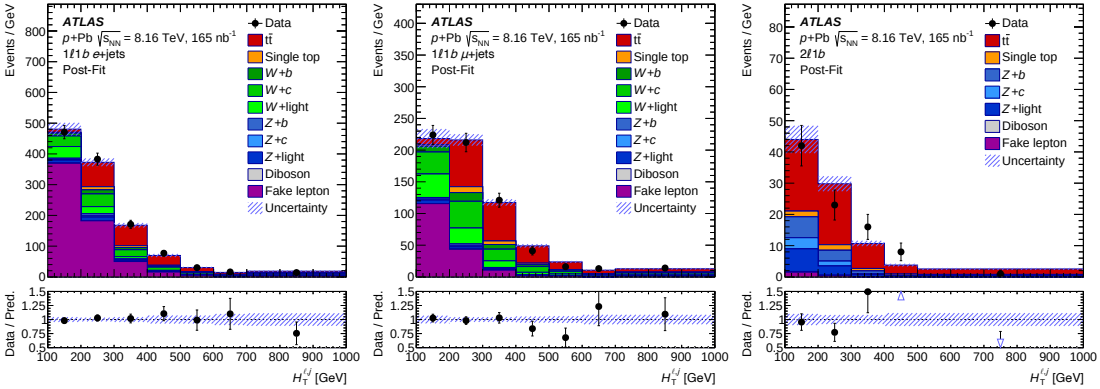
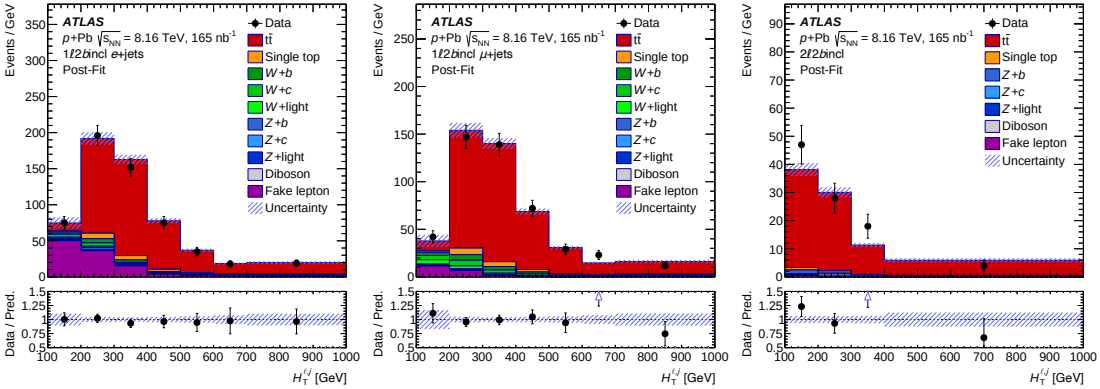
$t\bar{t}$ production in p+Pb



- H_T – scalar sum of leptons' and jets' p_{T}
- events with 2 b-tagged jets have the signal fraction higher than events with 1 b-tagged jet
- extracted signal strength using profile-likelihood fit

arXiv:2405.05078

$t\bar{t}$ production in p+Pb



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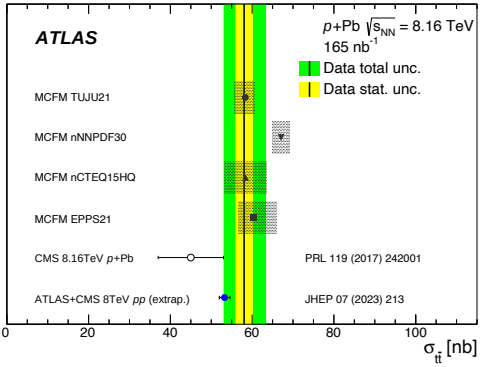
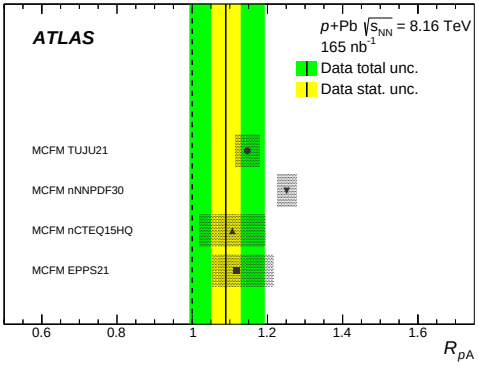




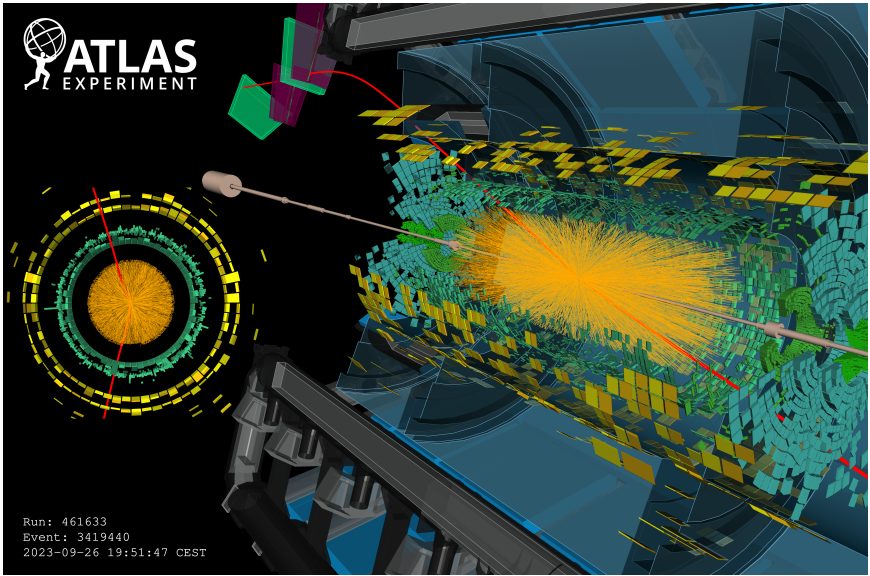
- good agreement with MC predictions and previous CMS measurement
- enhancement of $R_{\mathrm{pPb}} = 1.09 \pm 0.10$ (tot.)
  - relative uncertainty amounts to 9%
  - $t\bar{t}$ cross section in p+p at $\sqrt{s} = 8\,\mathrm{TeV}$ extrapolated to the same $\sqrt{s}$ as p+Pb

arXiv:2405.05078

di-muons produced via heavy-flavour decays

charged particles

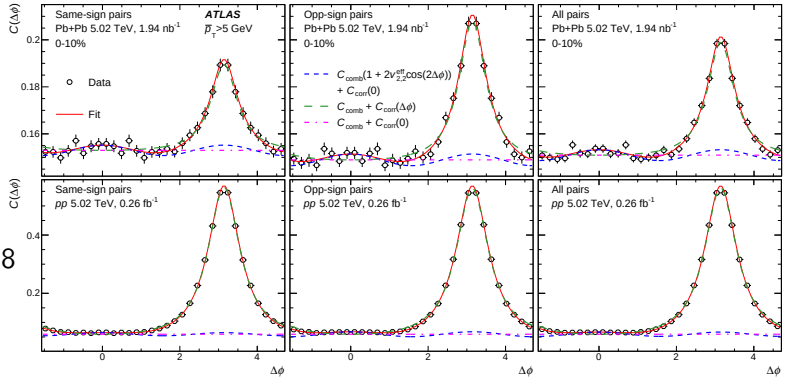
muons



arXiv:2308.16652

di-muons produced via heavy-flavour decays

- $1.94\,\mathrm{nb}^{-1}$ of Pb+Pb
- $0.26\,\mathrm{fb}^{-1}$ of $p+p$ data
- $p_{\mathrm{T}}^{\mu} > 4\,\mathrm{GeV}$, $|\eta^{\mu}| < 2.4$
- $\bar{p_{\mathrm{T}}} > 5\,\mathrm{GeV}$, $|\Delta\eta^{\mu}| > 0.8$
- removed light mesons, J/ψ, Υ, Z
- fit with:



$$C(\Delta\phi) = \underbrace{C_{comb}\left[1 + 2v_{2,2}\cos(2\Delta\phi)\right]}_{\text{combinatorial contrib.}} + \underbrace{C_{corr}(\Delta\phi)}_{\text{correlated contrib. (Breit–Wigner)}}$$

- only pedestal
- pedestal + Breit–Wigner
- pedestal + flow modulation

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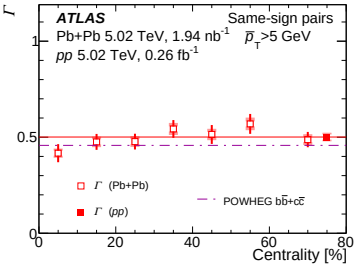
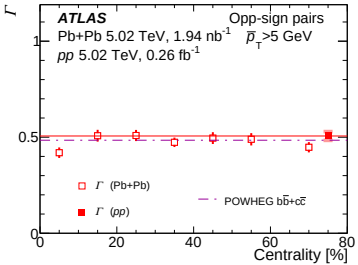
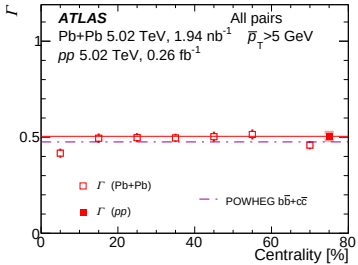
di-muons produced via heavy-flavour decays

- $C_{corr}(\Delta\phi) \sim \frac{\Gamma^2}{(\Delta\phi-\pi)^2+\Gamma^2}$



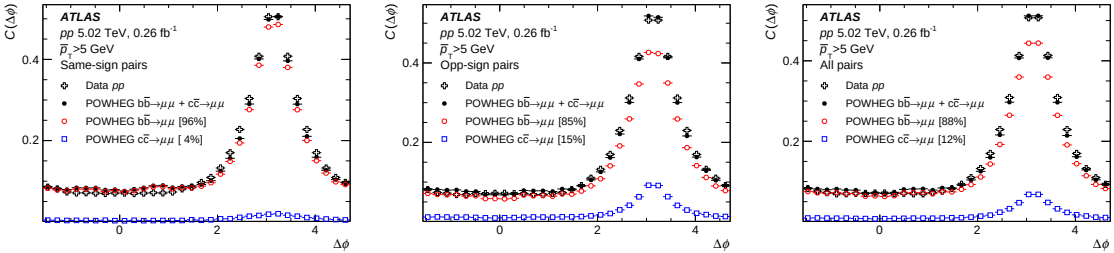




- almost independent on centrality
- similar for p+p and Pb+Pb
- described quite well by Pythia with $b\bar{b}$ and $c\bar{c}$

arXiv:2308.16652

di-muons produced via heavy-flavour decays



- described quite well by Pythia with $b\bar{b}$ and $c\bar{c}$
- both $b\bar{b}$ and $c\bar{c}$ are needed to described data

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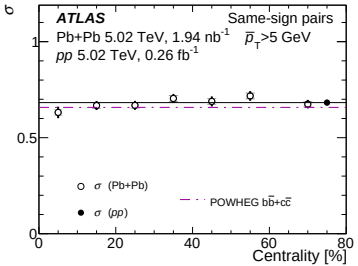
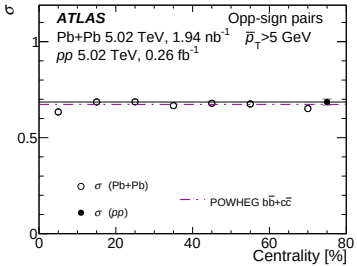
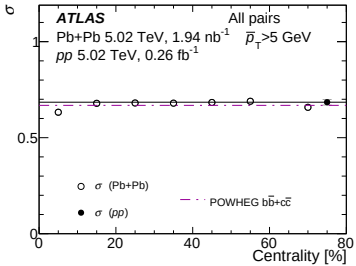
di-muons produced via heavy-flavour decays

- σ: standard deviation of C_{corr} in $0 < \Delta\phi < 2\pi$







- almost independent on centrality, similar for $p+p$

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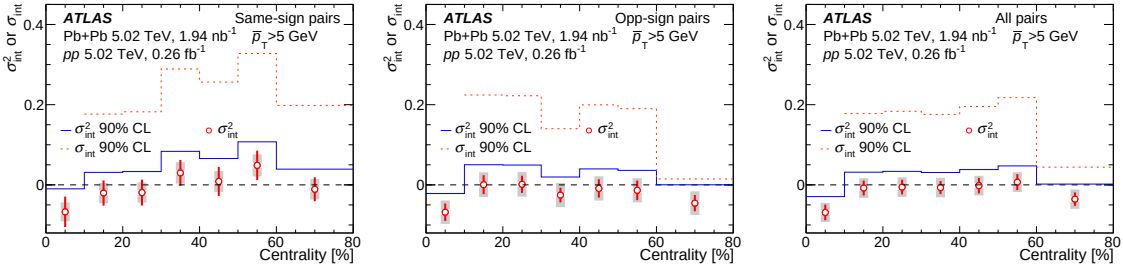
di-muons produced via heavy-flavour decays

- σ: standard deviation of C_{corr} in $0 < \Delta\phi < 2\pi$
- $\sigma^2_{int} = \sigma^2_{\mathrm{Pb+Pb}} - \sigma^2_{p+p}$ ... additional broadening



- model-independent limits on b-quarks deflection

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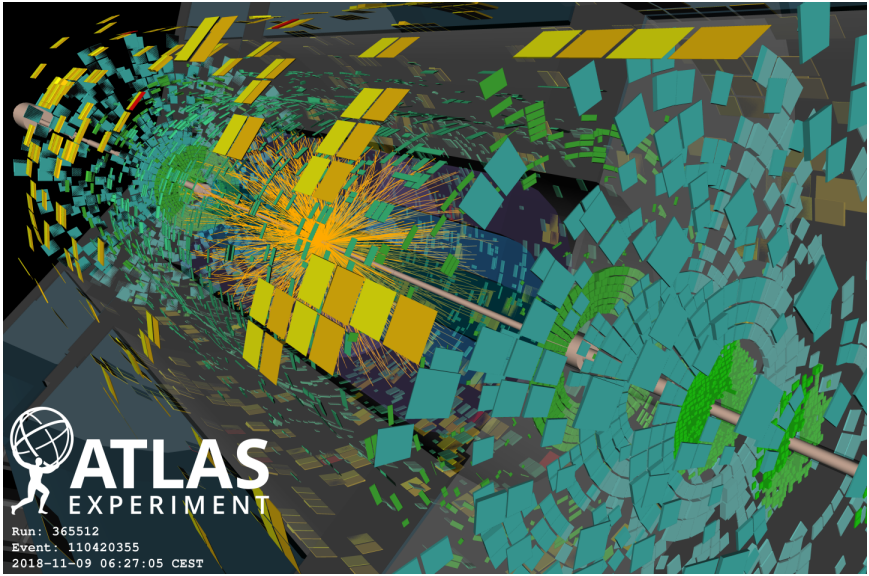
p_{T} fluctuations in Pb+Pb and Xe+Xe



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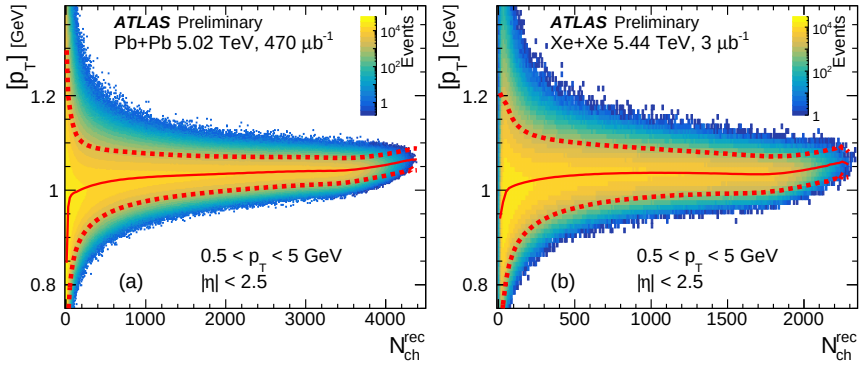

- $[p_{\mathrm{T}}]$: mean p_{T} of tracks within an event
- $\langle[p_{\mathrm{T}}]\rangle$: mean $[p_{\mathrm{T}}]$ within many events of the same multiplicity

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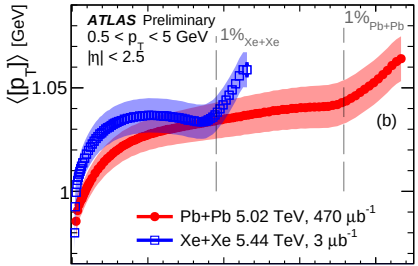
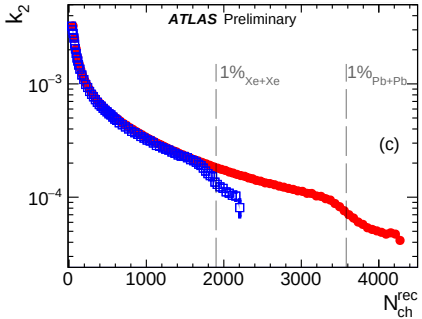
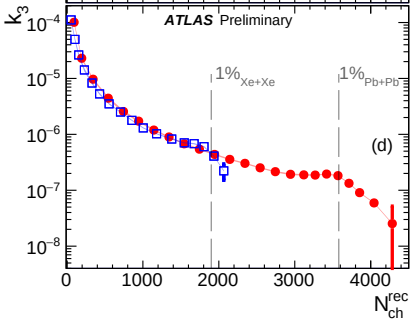
p_{T} fluctuations in Pb+Pb and Xe+Xe

- $c_n = \frac{\sum_{i_1,i_2,\ldots i_n} w_{i_1}(p_{\mathrm{T},i_1} - \langle[p_{\mathrm{T}}]\rangle)\cdots w_{i_n}(p_{\mathrm{T},i_n} - \langle[p_{\mathrm{T}}]\rangle)}{\sum_{i_1,i_2,\ldots i_n} w_{i_1}\cdots w_{i_n}}$
  - unique indices: $i_1 \neq i_2 \cdots \neq i_n$
  - w_{i_x}: a weight to correct i_x-th track for the reconstruction efficiency
- $k_2 = \frac{\langle c_2\rangle}{\langle[p_{\mathrm{T}}]\rangle^2}$
  - variance
- $k_3 = \frac{\langle c_3\rangle}{\langle[p_{\mathrm{T}}]\rangle^3}$
  - skewness







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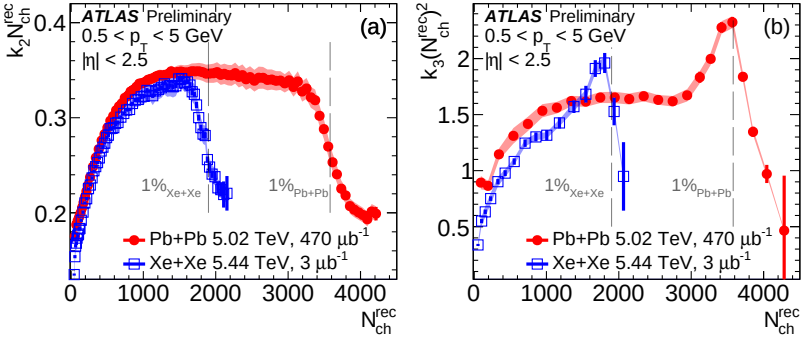
p_{T} fluctuations in Pb+Pb and Xe+Xe



- assuming stochastic sources of the fluctuations:
  - $k_2 \propto N_{part}^{-1} \propto (N_{ch}^{rec})^{-1}$
  - $k_3 \propto N_{part}^{-2} \propto (N_{ch}^{rec})^{-2}$
- true for mid-central to central collisions
- not true for peripheral and very central collisions

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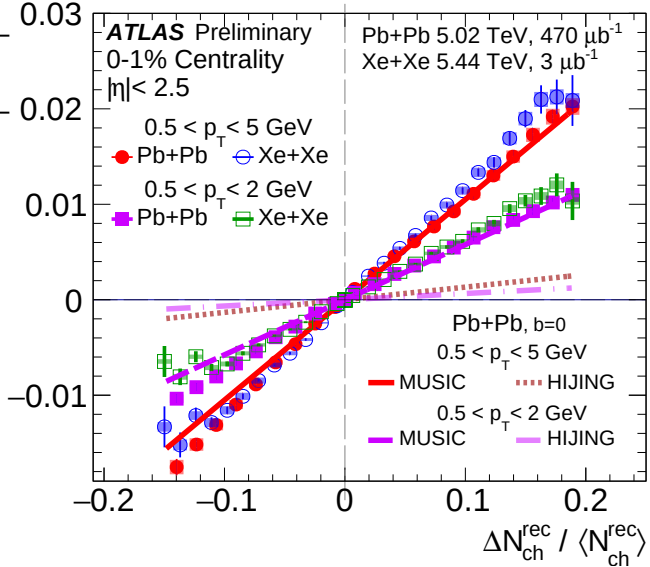
p_{T} fluctuations in Pb+Pb and Xe+Xe

- speed of sound in QGP related to the raise of $\langle [p_{\mathrm{T}}] \rangle$ with increasing centrality:
  - $c_s^2 \propto \frac{\mathrm{d} \ln \langle [p_{\mathrm{T}}] \rangle}{\mathrm{d} \ln N_{ch}^{rec}} \approx \frac{\Delta p_{\mathrm{T}} / \langle [p_{\mathrm{T}}] \rangle}{\mathrm{d} N_{ch}^{rec} / \langle N_{ch}^{rec} \rangle}$
- slope depends on the track selection
- almost independent on the collisions system



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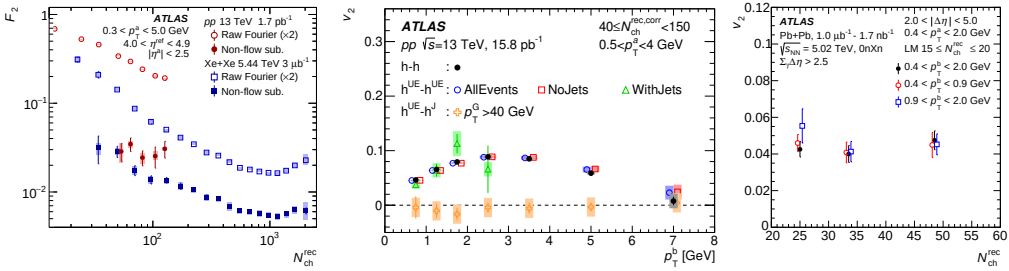
collectivity in small systems



- the decorrelation with η is stronger for Xe+Xe than for $p+p$
  $\Rightarrow$ the mechanism of additional particle production is different
- in $p+p$, no correlations between particles from jet and underlying event, however there are correlations among particles from underlying event
- flow can be observed in photo-nuclear collisions

➔ see talk by Blair Seidlitz, Tuesday, 8:50

summary

- ATLAS offers a whole palette of heavy-ion-related results
- in 2023 Pb+Pb data-taking, we approx. doubled our statistics compared to Run 2
- this year, we expect additional 2-3 nb^{-1}

- all ATLAS heavy-ion results
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