Measurements of negatively charged hadron intermittency in central Xe+La at 150A GeV/c by NA61/SHINE at CERN SPS

Valeria Reyna

Jan Kochanowski University

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Outline

In our previous talk, Tobiasz introduced:

- Intermittency of protons in central Ar+Sc collisions, the results were presented using cumulative transverse momentum.
- He reported that there is no increase in the dependence of F_2 on M^2
- From previous publications, we know that there is no increase in ΔF_2 in proton intermittency. [1]

In this talk I will present:

- Results on intermittency of negatively charged hadrons in Xe+La interaction with 0-20% centrality at $150A$ GeV/c $(\sqrt{s_{NN}} \approx 17$ GeV)
- Report a strong increase of ΔF_2 with M^2 at p_T binning. But we find that ΔF_2 is approximately independent in cumulative p_T binning.
- The results are attributed to the presence of short-range correlations of the HBT type (around 90% of negatively charged hadrons are π^- mesons subject to Bose-Einstein statistics).

[1] NA61/SHINE. In: *Eur. Phys. J. C* 83.9 (2023), p. 881

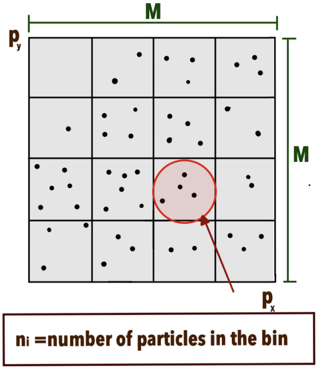
Intermittency: Scaled factorial moments (SFMs)

Upon approaching a critical point, correlation length diverges ⇒ system becomes scale-invariant or self-similar ⇒ enhanced multiplicity fluctuations that can be revealed by scaled factorial moments.

$$F_2(M) = \frac{\left\langle \frac{1}{M^2} \sum_{i=1}^{M^2} n_i(n_i - 1) \right\rangle}{\left\langle \frac{1}{M^2} \sum_{i=1}^{M^2} n_i \right\rangle^2}$$

M – number of sub-division intervals
n_i – number of particles in i-th cell

When the system is a simple fractal, $F_q(M)$ follows a power law dependence: $F_q(M) = F_q(\Delta)(M^2)^{\phi_q}$ where the critical exponent or intermittency indices ϕ_q obey the relation: $\phi_q = (q-1)d_q$ where the anomalous fractal dimension d_q is independent of q.



$F_2(M)$ depends on the shape of inclusive single particle distribution. In order to eliminate this dependence we have two approaches

p_T binning

Instead of studying $F_2(M)$ we study ΔF_2. The quantity defined as:[1]

$$\Delta F_2(M) = F_2^{data}(M) - F_2^{mixed}(M)$$

Cumulative p_T binning

Instead of using p_x and p_y, one uses cumulative quantities Q_x, Q_y:

$$Q_x = \int_{x_{min}}^{x} \rho(x)dx / \int_{x_{min}}^{x_{max}} \rho(x)dx$$

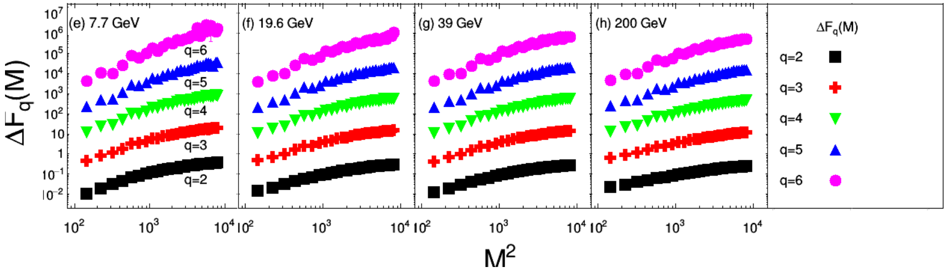
$$Q_y = \int_{y_{min}}^{y} P(x,y)dy / P(x)$$

- Transform any distribution into uniform in dQ and normalized (0,1)) [2]
- Remove the dependence of F_r on the shape of single particle distribution
- Intermittency index of an ideal power law correlation function remain invariant [3]
- Results are displayed in: $\Delta F_2\ (M)_c = F_2{}^{data}(M) - F_2{}^{mix}(M)$ where $F_2{}^{mix} = F(1)$

[1] NA49 collaboration. In: *Eur. Phys. J. C* 75.2 (2015), p. 587
[2] Bialas; Gazdzicki. In: *Physics Letters B* 252.3 (1990), pp. 483–486
[3] Antoniou; Diakonos. URL: https://indico.cern.ch/event/818624

$h^{\pm}$ intermittency results from STAR

In March 2023, the STAR collaboration[4] published intermittency results of ΔF_2 of charged hadrons in central 0-5% Au+Au collisions at four energies:

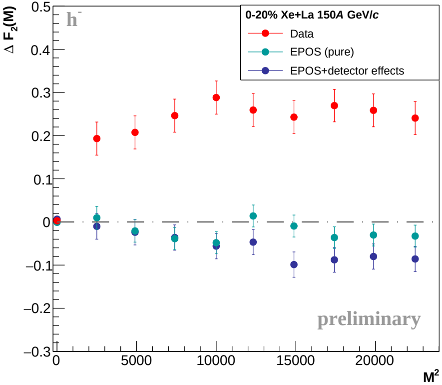


- Plots: $[\Delta F_q(M) = F_q^{data}(M) - F_q^{mixed}(M)\ (q = 2 - 6)]$ in double-logarithmic scale.
- STAR reported[4] that $\Delta F_q(M)$ increases with M^2 and saturates when M^2 is larger than $M^2 > 4000$. Interpretation of the source of this increase needs explanation.

[4] STAR collaboration, Phys.Lett.B 845 (2023)

NA61/SHINE results on ΔF_2 for p_T binning

Negatively charged hadrons

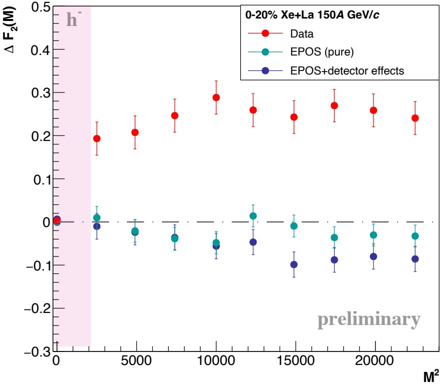


SFMs are calculated for independent sub-sample for each bin in M, only statistical uncertainties are shown.All results showed in this slides are presented this way

- Similarly to STAR, we observe strong increase on ΔF_2 in experimental data and saturation at high M^2.
- We repeat the analysis for EPOS Monte Carlo simulations:
  - in its *pure* form
  - and considering *detector effects*.
- Unlike the ΔF_2 of experimental data, these results do not show any increase.

NA61/SHINE results on ΔF_2 for p_T binning

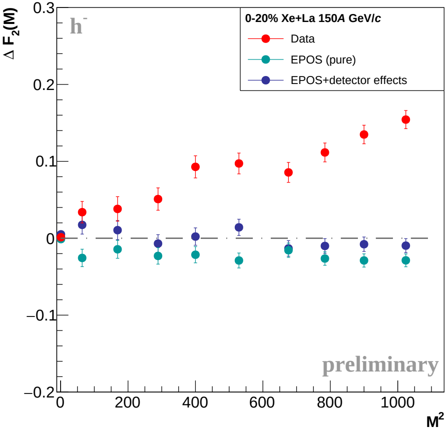
Negatively charged hadrons



SFMs are calculated for independent sub-sample for each bin in M, only statistical uncertainties are shown. All results showed in this slides are presented this way

- In the following slide, I will magnify this region where we see the strong increase.

NA61/SHINE results on ΔF_2 for p_T binning



- Here we focus on M^2 region between 1-1000.
- Within this interval, we also observe a **strong increase** of ΔF_2 for the experimental data.
- But this increase lacks of the characteristic CP power law shape.
- And, once again, EPOS results don't show this increase.

Short range correlations

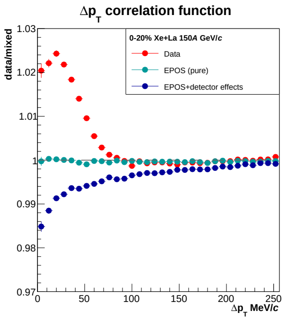
- A strong increase of ΔF_2 with M is observed for results in p_T binning.
- EPOS model does not show this increase
- We remind that in the case of protons we didn't observed any increase of ΔF_2 results, neither in data or EPOS.

Is there a physics correlation which is present for data h^-, and absent in protons and EPOS h^-, that can explain this behaviour?

Yes, short range correlations, of Bose-Einstein type

So we studied the h^--h^- correlation.

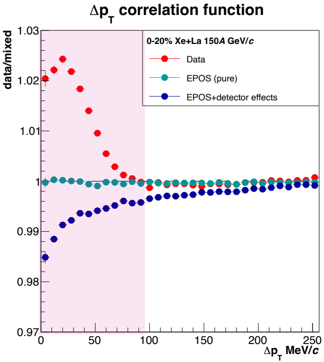
$$\Delta p_T = \sqrt{(p_{2,x} - p_{1,x})^2 + (p_{y,2} - p_{y,1})^2}$$

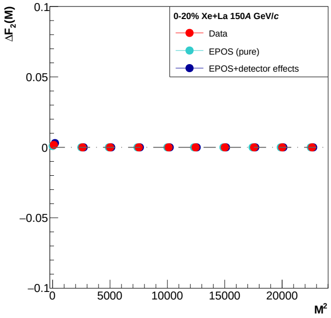


For experimental data we observe the typical expected behavior indicating the presence of short range correlations. For pure EPOS there are no correlations, and for EPOS+detector effects there are anti-correlations due to the limited two track resolution.

Short range correlations

If we remove the region with $\Delta p_T < 100$ MeV/c, the ΔF_2 is independent of M^2 for both experimental data and EPOS.

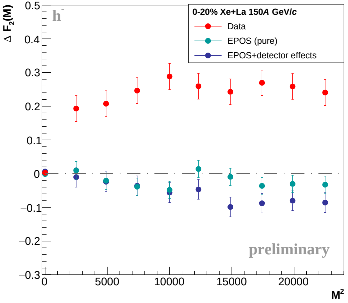




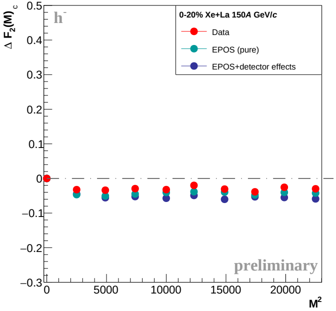
This suggests that the increase of ΔF_2 of the data was cause by this short range correlations
However, this removal of Δp_T region may also affect possible correlations due to CP.

NA61/SHINE ΔF_2 results p_T vs cumulative p_T binning

Cumulative transformation preserves the scale invariant power law correlations (like CP) but destroys other type correlations.



p_T binning

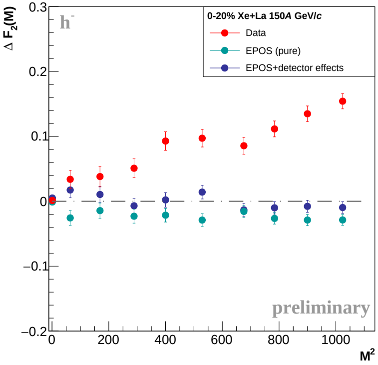


cumulative p_T binning

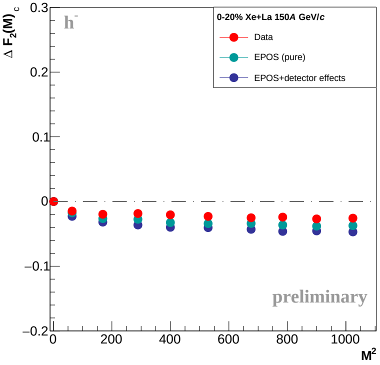
In fact, we found the that **there is not any increase** in the results after cumulative transformation.

NA61/SHINE ΔF_2 results p_T vs cumulative p_T binning

When we optimize the outcomes to focus on the interval where the initial rise was observed, we observe same situation.



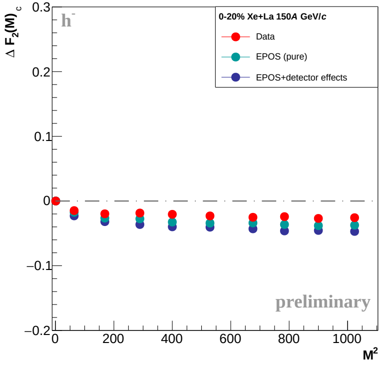
p_T binning

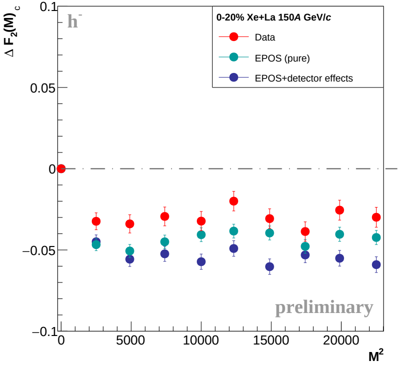


cumulative p_T binning

Results on cumulative p_T binning

*Results in cumulative p_T binning are shown in a different scale





Results after cumulative transformation don't show any increase. This is because cumulative transformation preserves the scale invariant power law correlations, but destroys other types non-scale invariant correlations.

Summary

- We present first preliminary results on intermittency of negatively charged hadrons in Xe+La interactions with 0-20% centrality at $150A$ GeV/c ($\sqrt{s_{NN}} \approx 17$ GeV)
- The experimental data on $\Delta \mathrm{F}_2$ for $\mathrm{p_T}$ binning exhibits an increase, but it does not follow a power law, The increase can be explained by short range correlations (HBT).
- No increase is observed in cumulative $\mathrm{p_T}$ distribution. Cumulative transformation preserves the scale-invariant power-law correlations, but destroys other types non-scale invariant correlations.

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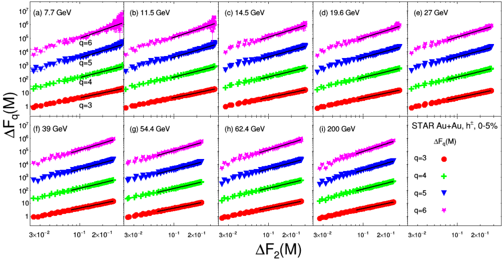
- We present first preliminary results on intermittency of negatively charged hadrons in Xe+La interactions with 0-20% centrality at 150A GeV/c ($\sqrt{s_{NN}} \approx 17$ GeV)
- The experimental data on ΔF_2 for p_T binning exhibits an increase, but it does not follow a power law, The increase can be explained by short range correlations (HBT).
- No increase is observed in cumulative p_T distribution. Cumulative transformation preserves the scale-invariant power-law correlations, but destroys other types non-scale invariant correlations.
- Can the increase of ΔF_2 with M, reported by STAR, be interpreted as due to short-range correlations??

Thanks

Appendix

Intermittency results from STAR



- Distinct power-law scaling of $\Delta F_q(M) \propto \Delta F_2(M)^{\beta_q}$ with a fitting of ΔF_2 from $M \in [30{,}100]$ at all energies after background subtraction. [2]
- Value of β_q is the slope of the fitting line.

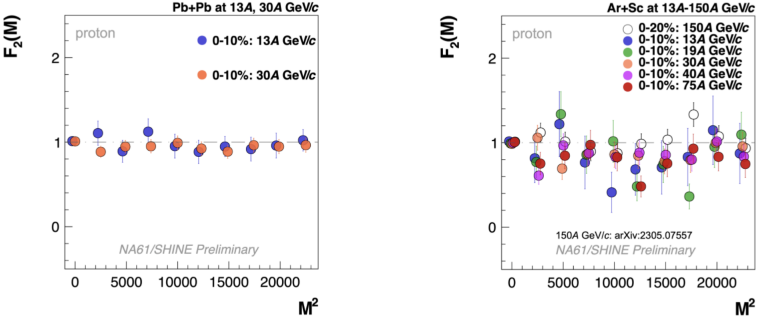
Comments triggered by this publication

- The connection between the minimum observed at $\sqrt{s_{NN}}$ =27 GeV and QCD CP in the context of STAR intermittency remains unclear, as the STAR intermittency group has not provided a convincing answer
- Physical interpretations of the intermittency results published by STAR are not well-understood from a physics perspective.

[2] Phys.Lett.B 845 (2023)

SHINE results: proton intermittency

Results in Cumulative transformation.



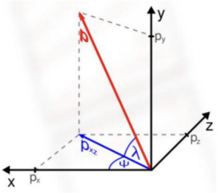
H. Adhikary et.al (NA61/SHINE Collaboration), Eur.Phys.J.C 83 (2023) 9, 881
H. Adhiakry (for NA61/SHINE Collaboration), EPJ Web Conf. 274 (2022) 06008

- - - No indication for power-law increase with bin size - - -

* M points are slightly shifted horizontally for different energies to increase readability *

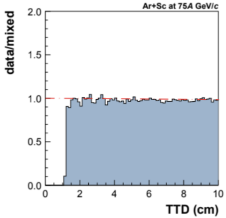
Two particle acceptance map (form NA61/SHINE)

- TPCs are not capable of distinguishing tracks that are too close to each other in space and at a small distance, clusters overlap, and signals are merged
- Two-particle acceptance map provides the precise definition of the biased region in which NA61/SHINE doesn't have good efficiency for measuring two-tracks
- Momentum of each positive particle in both recorded and mixed data sets in the new momentum co-ordinate $s_x(\frac{p_x}{p_{xz}})$, $s_y(\frac{p_y}{p_{xz}})$, and $\rho(\frac{1}{p_{xz}})$
- Proton pairs with momenta inside all following ellipses are rejected



(**see back-up slides for more details**)

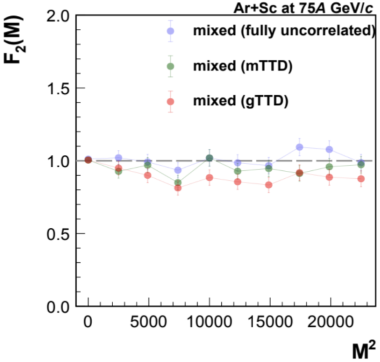
$$\left(\frac{\Delta\rho}{r_\rho}\right)^2 + \left(\frac{\Delta s_y}{r_{s_y}}\right)^2 \leq 1$$
$$\left(\frac{\Delta s_x}{r_{s_x}}\right)^2 + \left(\frac{\Delta s_y}{r_{s_y}}\right)^2 \leq 1$$
$$\left(\frac{\Delta\rho\cos\theta - \Delta s_x\sin\theta}{r_{\rho s_x}}\right)^2 + \left(\frac{\Delta\rho\sin\theta + \Delta s_x\cos\theta}{r_{s_x\rho}}\right)^2 \leq 1$$



These two-particle acceptance maps should be used for comparison of experimental results with a model

Effect of two particle acceptance map

After introducing the two particle acceptance map, small anti-correlation appears in Cumulative p_T binning

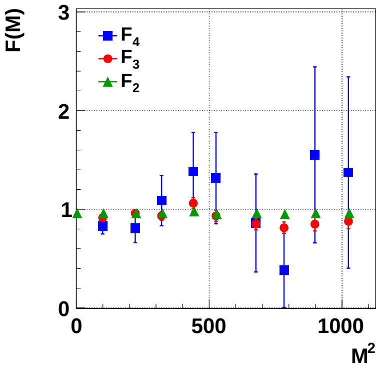


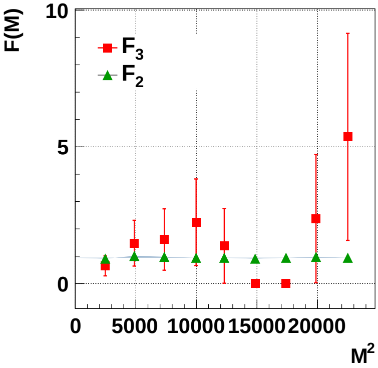
Methodology comparison summary

	NA49	NA61/SHINE	STAR	
goal	QCD CP search	QCD CP search	QCD CP search	
reaction	C+C,Si+Si, Pb+Pb	Pb+Pb, Ar+Sc	Au+Au	
$\sqrt{s_{NN}}$	$\approx 17.3 GeV$	5.1-17 GeV	7.7-200 GeV	
centrality	0-10% and 0-12%	$0 - 10\%$ and 0-20%	0-5% and 10-40%	
particle of interests	$\pi^+\pi^-$, p	p, h^- (except e^-)	p, $\bar{p}$, $\pi^\pm$, $k^\pm$	
phase space	p_x, p_y at mid-rapidity	p_x, p_y at mid-rapidity	p_x, p_y within $\lvert\eta\rvert < 0.5$	$\lvert\eta\rvert$
efficiency correction	not corrected ($\approx$ 90%)	not corrected ($\approx$ 90%)	corrected (low efficiency)	
background subtraction	mixed event method	cumulative variable method	mixed event method	
data points	correlated	independent	correlated	
statistical uncertainties	Bootstrap method	Error propagation	Bootstrap method	
single-particle acceptance maps	—	3D maps (y,p_T, ϕ)	—	
two-particle acceptance maps	geometric	momentum based	—	
final results	$\Delta F_q(M)$	$F_q(M)$	$\Delta F_q(M)$ and $\nu(\sqrt{(s_{NN})})$	

Previous SHINE results in Pb+Pb 30A GeV/c

Results intermittency h$^-$ Cumulative transformation, *note that here is not $\Delta F_2(M)_C$ just $F_2(M)$*





SHINE results in Xe+La 150A GeV/c

Results intermittency h$^-$ in Cumulative transformation,*note that here is not $\Delta F_2(M)_C$ just F_2(M)*