



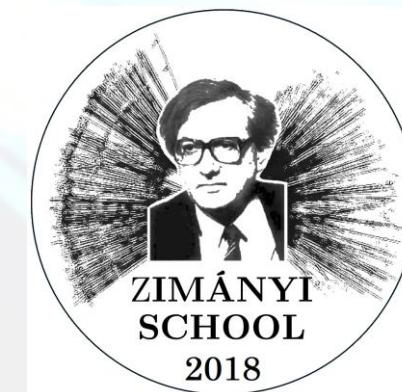
PHENIX results on collision energy dependent Lévy HBT correlations from $\sqrt{s_{NN}} = 15$ to 200 GeV

ZIMÁNYI WINTER SCHOOL ON HEAVY ION PHYSICS,

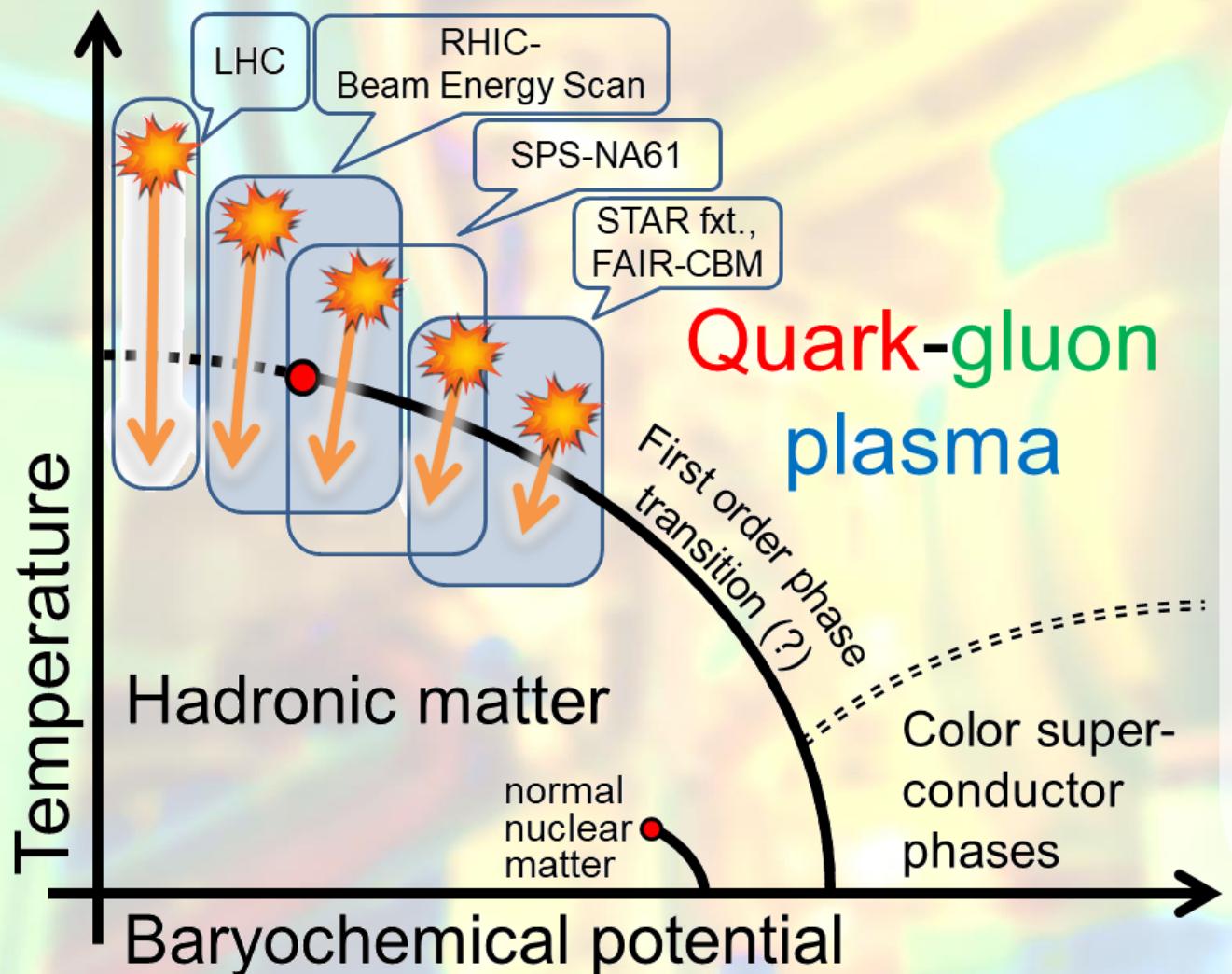
3-7 DECEMBER 2018, BUDAPEST, HUNGARY

DÁNIEL KINCSES FOR THE PHENIX COLL.

EÖTVÖS UNIVERSITY, BUDAPEST



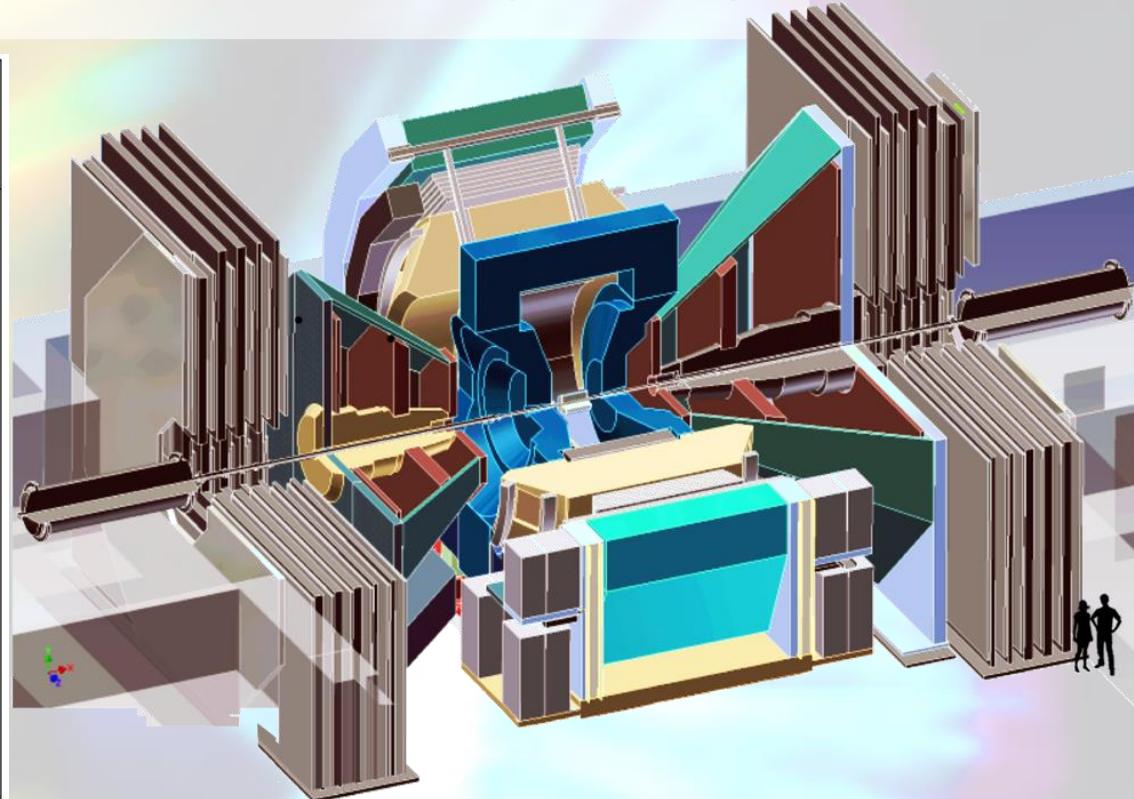
The phase diagram of QCD



- One of the most important still open questions:
Is there a critical point, and if there is, where?
- How can we look for a critical point?
- Beam Energy Scan!

The PHENIX experiment and the RHIC-BES

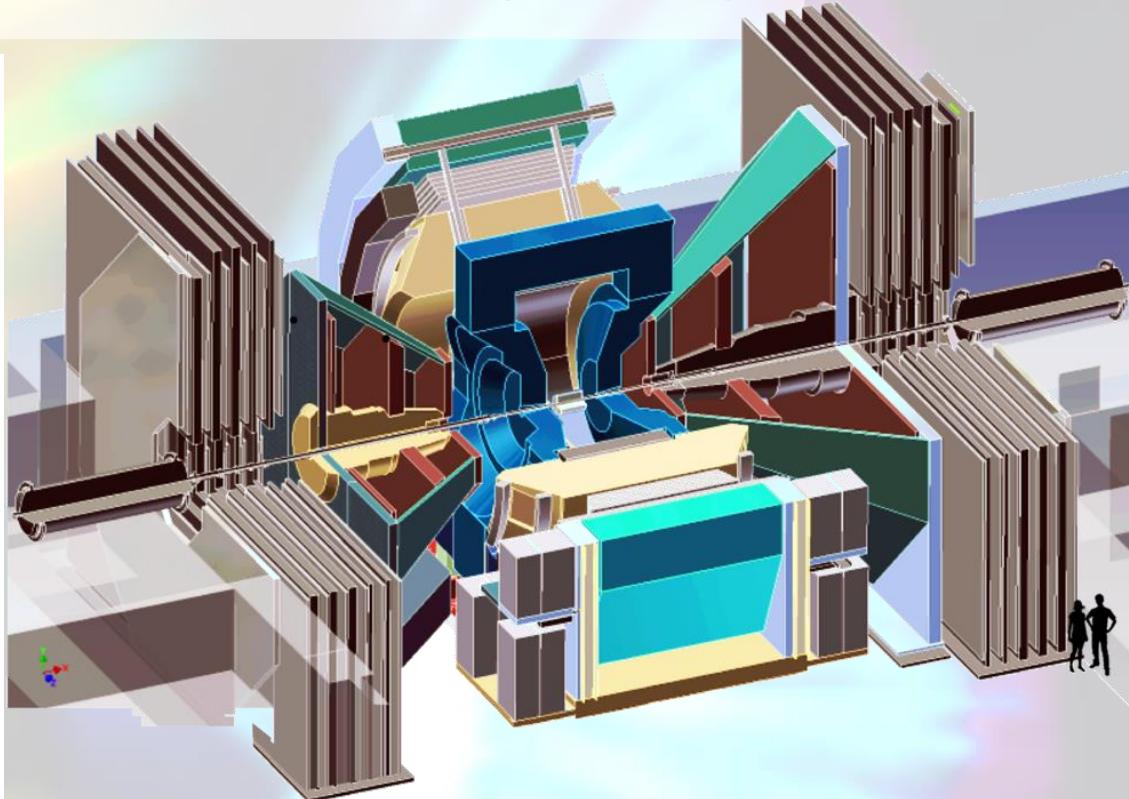
\sqrt{s} [GeV]	p+p	p+Al	p+Au	d+Au	$^3\text{He}+\text{Au}$	Cu+Cu	Cu+Au	Au+Au	U+U
510	✓								
200	✓	✓	✓	✓	✓	✓	✓	✓	✓
130								✓	✓
62.4	✓				✓	✓		✓	✓
39					✓			✓	✓
27							✓	✓	✓
20				✓		✓		✓	✓
14.5							✓	✓	✓
7.7								✓	✓



- Au+Au collision energies: 200 GeV – 7.7 GeV
- $\mu_B = 23.5 \text{ MeV} - 422 \text{ MeV}$, $T_{ch} = 166 \text{ MeV} - 139 \text{ MeV}$

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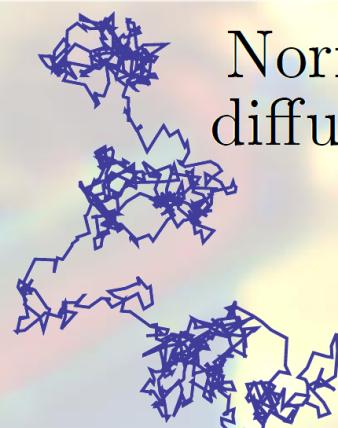


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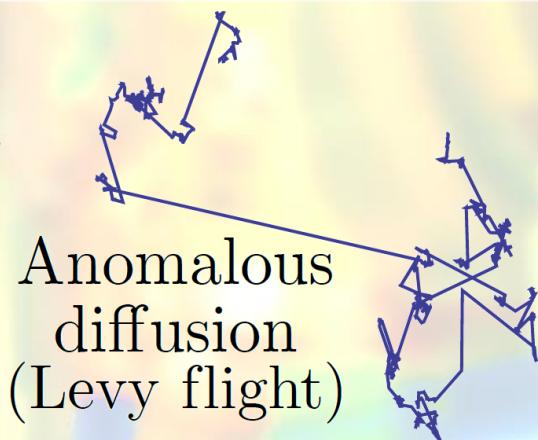
The HBT effect and Lévy femtoscopy

- Mom. corr. of identical pions
- We can map out the source on the femtometer scale
- Usually assumed source shape: Gaussian
- Generalization: Lévy distribution
- Lévy-type corr. func.:

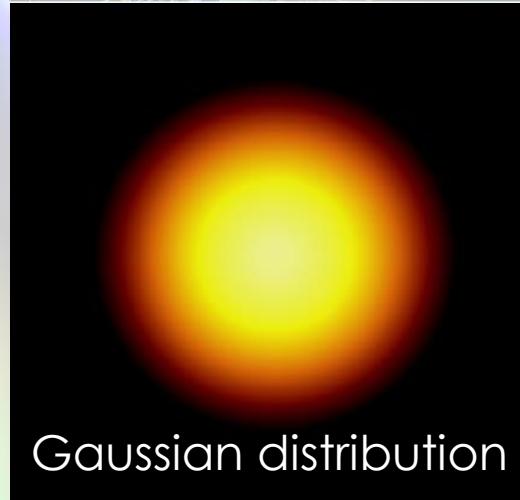
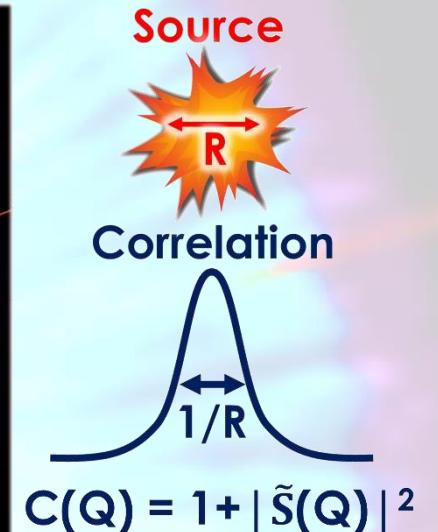
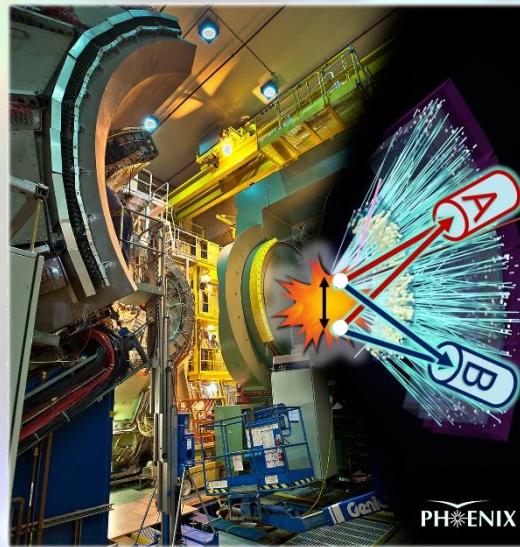
$$C(Q) = 1 + \lambda \cdot e^{-(RQ)^\alpha}$$



Normal diffusion

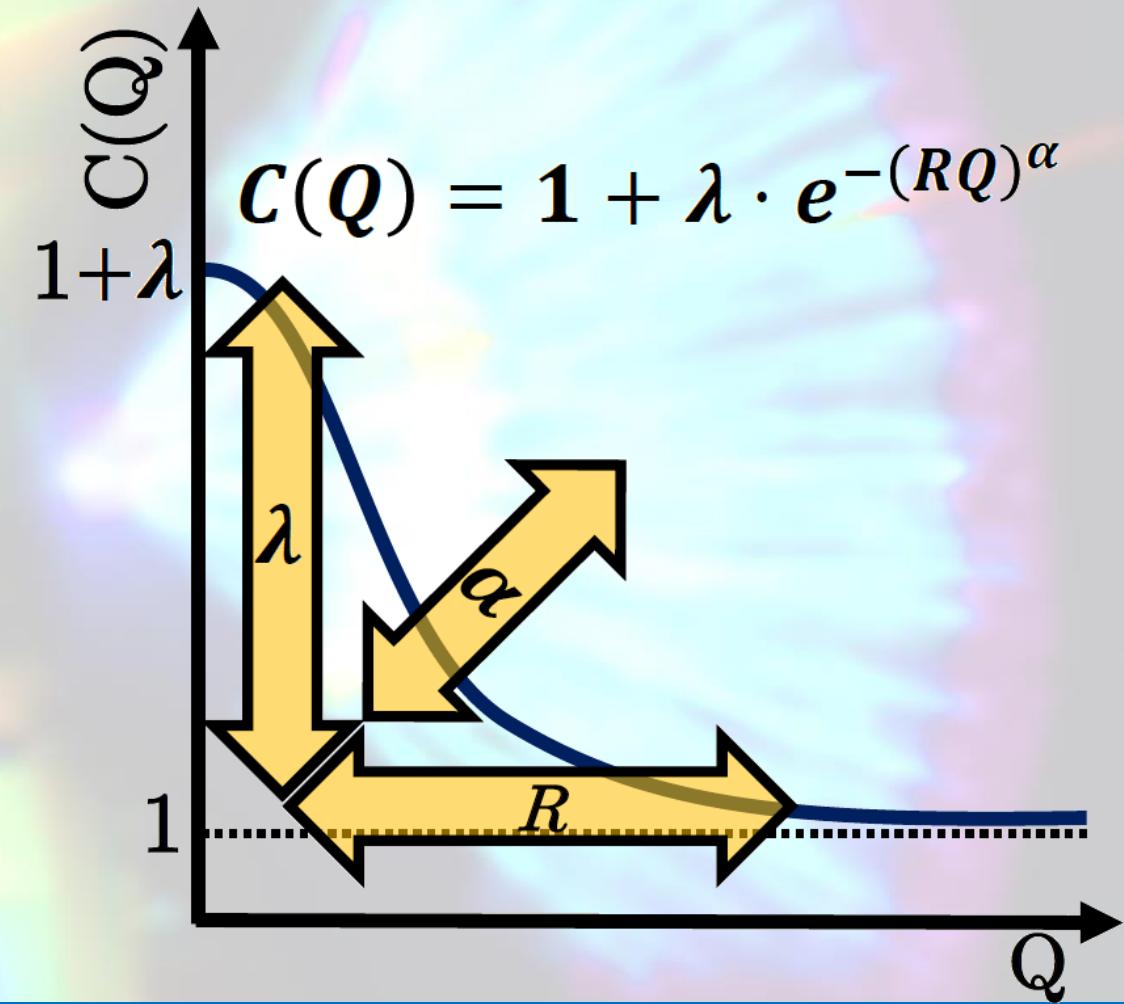


Anomalous diffusion
(Lévy flight)



Parameters of a Lévy-type correlation function

- **Correlation strength λ**
 - Intercept of the corr. func.
 - Core-Halo model:
 $\sqrt{\lambda} = N_C/(N_C + N_H)$
- **Lévy-scale R**
 - Physical size of the source
 - Usually decreases with m_T
- **Lévy-exponent α**
 - Connected to critical exponent η
 - Could be a good signal of CEP
- **$\hat{R} = R/(\lambda(1 + \alpha))$**
 - Can be determined more precisely
 - Less correlated with other params.



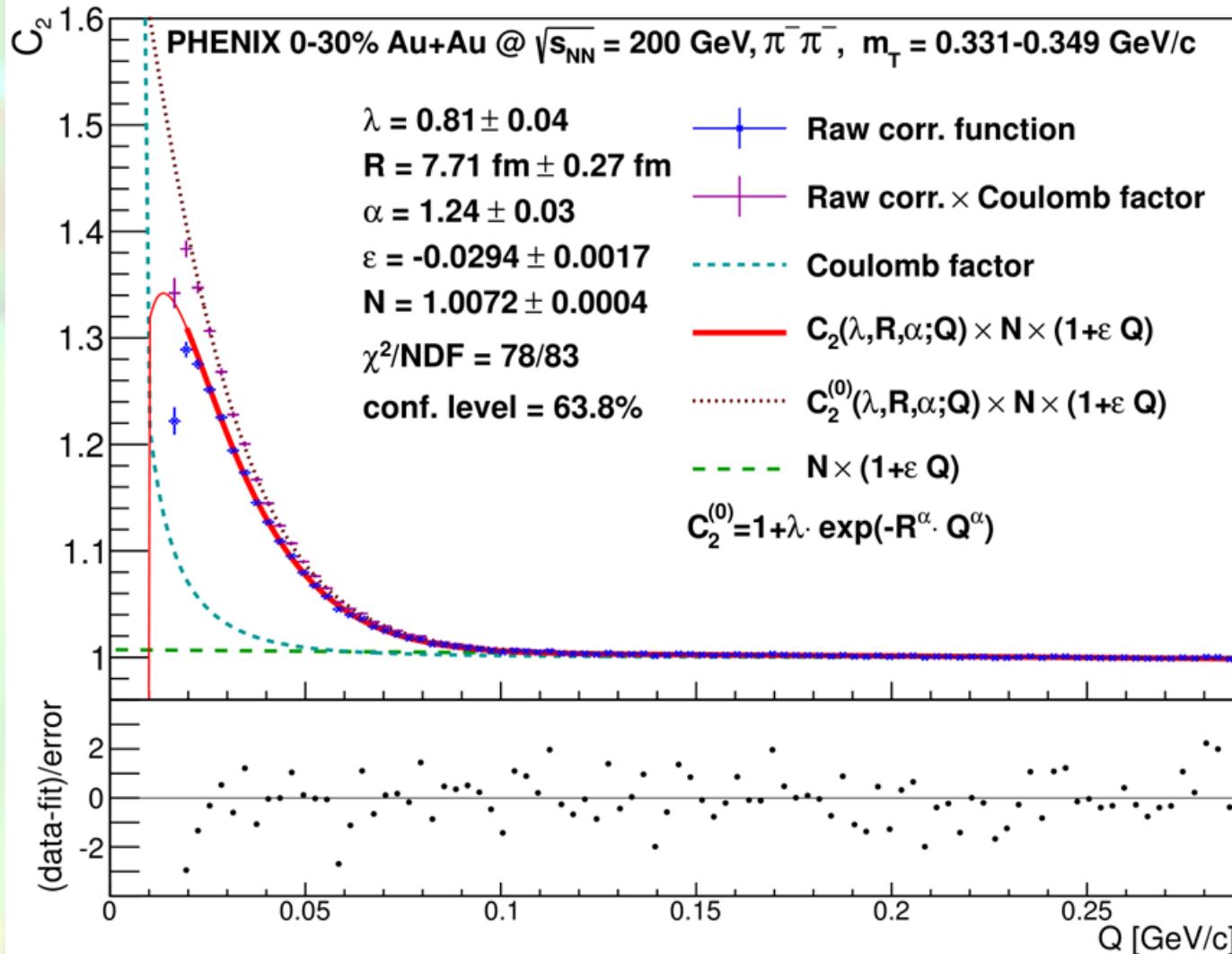
PHENIX Lévy-HBT analysis overview

- Data set: $\sqrt{s_{NN}} = 200, 62, 39, 27, 20, 15 \text{ GeV Au+Au, identified pions}$
- Some details of the analysis:
 - 1D $\pi^\pm\pi^\pm$ corr. func. as a function of m_T and centrality
 - investigation of systematic uncertainties:
 - One- and two-particle criteria (PID, matching, paircuts)
 - Other sources of syst. uncertainties
(e. g. fit stability, Coulomb-effect)
 - Fitting the measured corr. func. with Lévy-shape
 - Investigation of the source parameters (λ, R, α)

Handling the Coulomb-effect

- Identical charged particles → **Coulomb repulsion**
- Pair wave function with Coulomb interaction incorporated: $\Psi_q^{(2)}(\mathbf{r})$
- HBT Correlation function: $C_2(Q, K) = 1 - \lambda + \lambda \int d^3 r S(r, K) |\Psi_q^{(2)}(\mathbf{r})|^2$
- Fitting of the data:
 - Using a numerically pre-calculated lookup table
 - Iterative, self-consistent fit method with Coulomb corrected function
- Other option:
 - parametrized Coulomb correction → **see the poster of S. Lököš!**

Example correlation function

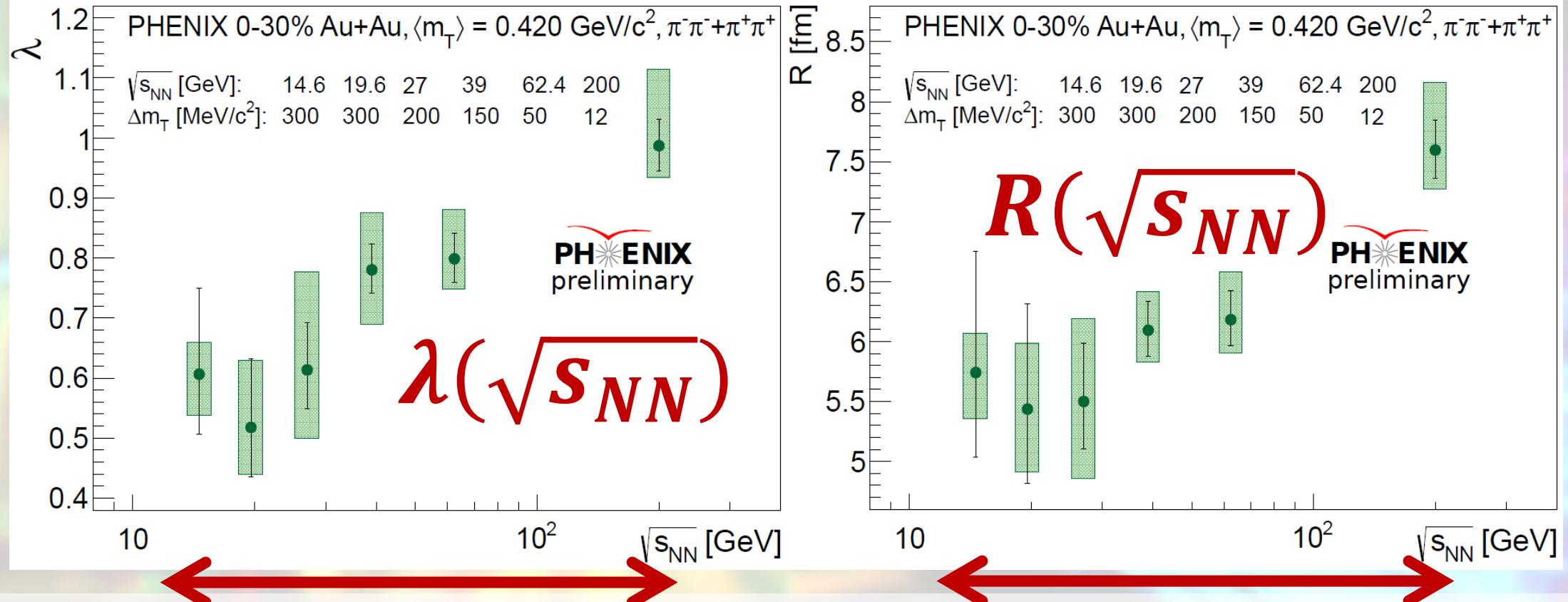


- $\pi^-\pi^-$ corr. func.
- $m_T = 0.33-0.35$ GeV/c
- 0-30% centrality Au+Au
- Fitted function:
 - HBT-correlation+
 - Coulomb interaction+
 - linear background

Excitation functions of the Lévy parameters

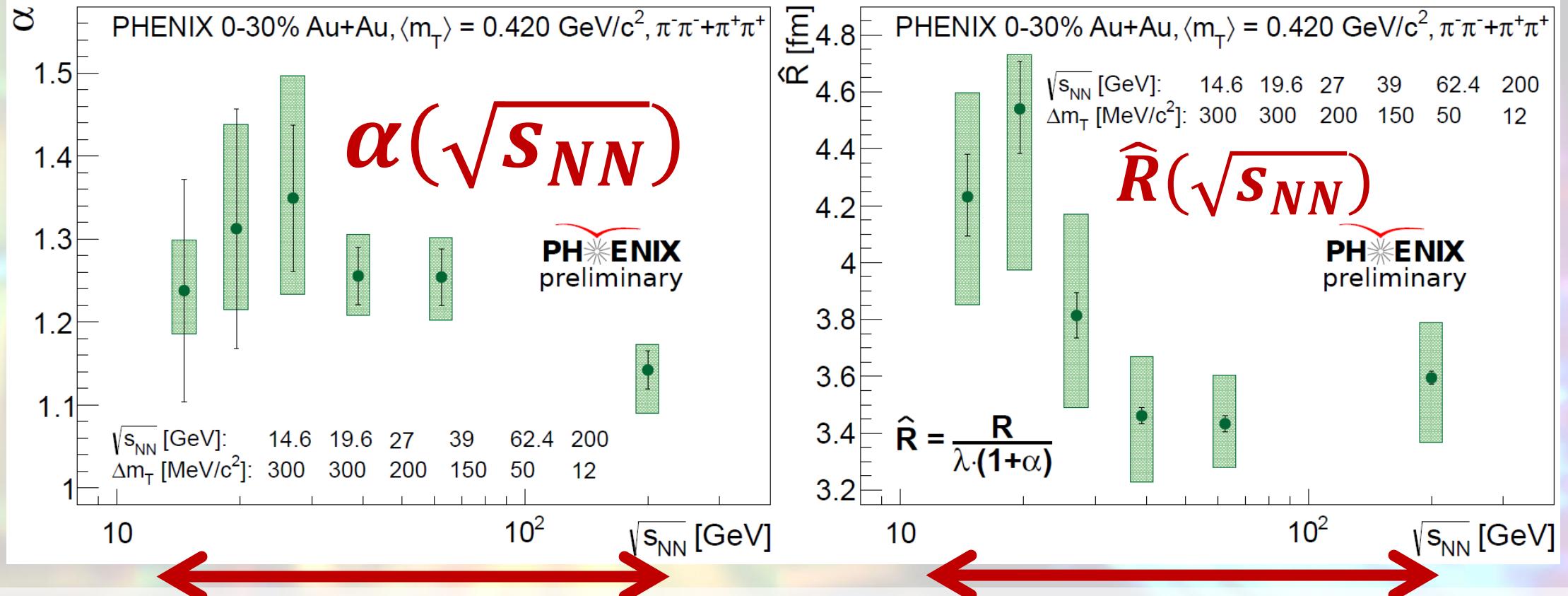
- Going down in $\sqrt{s_{NN}}$ is challenging due to low statistics
- Solution: only one centrality range (0-30%) and one m_T bin
- At lower energies: wider m_T bins while keeping $\langle m_T \rangle$ the same
- **New results down to 15 GeV!**

Excitation functions of the Lévy parameters



- Weak non-monotonicity is seen
 - Effect of m_T bin width is an important syst. uncert.
- 15-200 GeV**

Excitation functions of the Lévy parameters



- α is still far from Gaussian (2) & CEP (0.5) limits
- \hat{R} has a statistically very significant change **15-200 GeV**

Summary

- **Lévy fits work well at all energy, centrality and m_T ranges**
- Excitation functions show weak non-monotonicity
- Lévy exponent α is far from the conjectured CEP value (0.5)
 - More detailed investigation needed, may have to change the interpretation (?)
- More details about the related analyses:
 - PHENIX Coll., A. Adare et al., **Phys. Rev. C97 (2018) no.6, 064911**
 - D. Kincses for the PHENIX Collaboration, Universe 2018, 4(1), 11
 - S. Lököс for the PHENIX Collaboration, Universe 2018, 4(2), 31

Thank you for your attention!



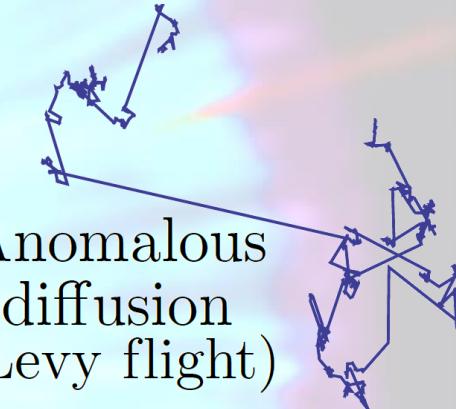
Lévy femtoscopy and the critical point

- Lévy distribution: $\mathcal{L}(\alpha, R, r) = \frac{1}{(2\pi)^3} \int d^3q e^{iqr} e^{-\frac{1}{2}|qR|^\alpha}$
- Critical behavior → **critical exponents**
- Spatial corr. at the CEP $\propto r^{-(d-2+\eta)}$
- In case of Lévy source, spatial corr. $\propto r^{-1-\alpha}$
- QCD universality cl. → (rdf.) 3D Ising → **$\eta \leq 0.5$**
- Lévy-type corr. func.:

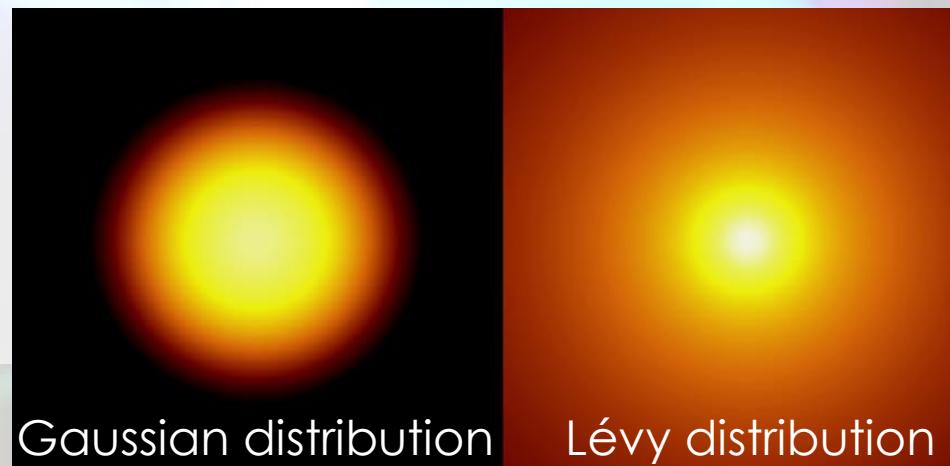
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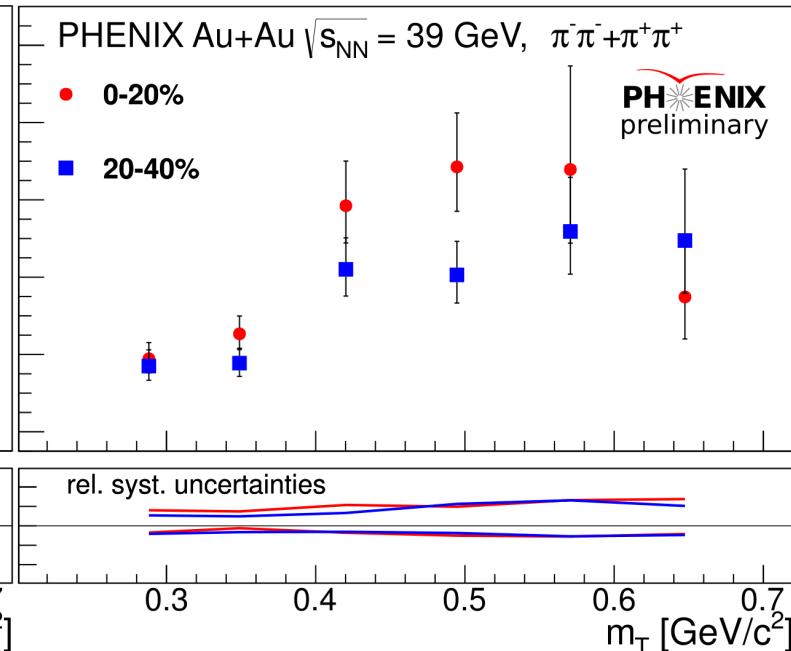
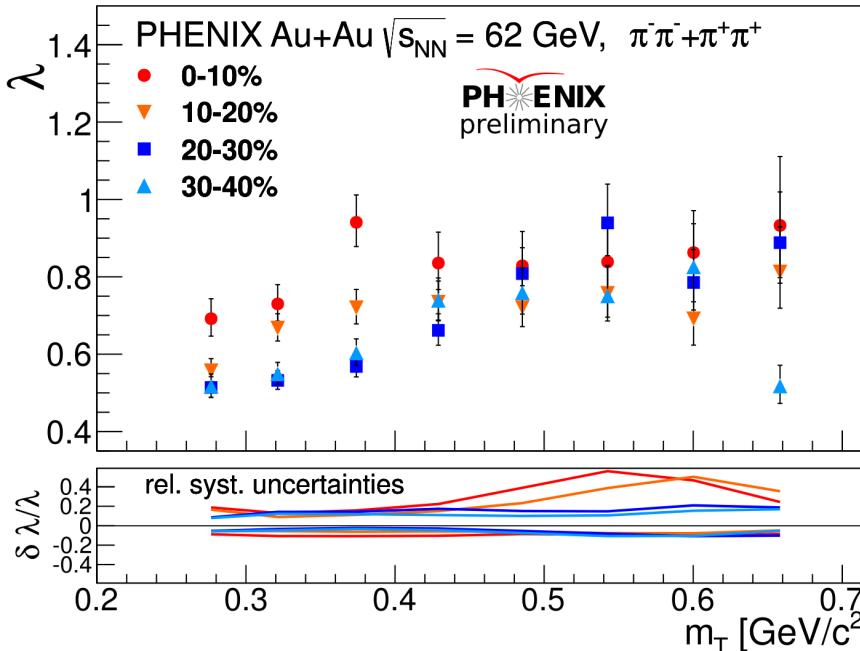
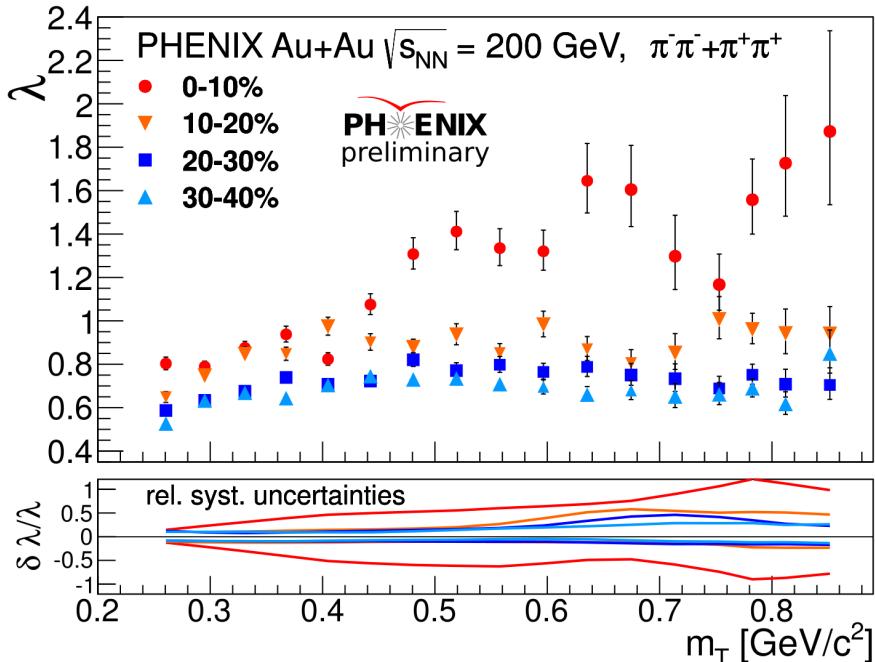


λ - Centrality and m_T dependence

$\sqrt{s_{NN}} = 200 \text{ GeV}$

$\sqrt{s_{NN}} = 62 \text{ GeV}$

$\sqrt{s_{NN}} = 39 \text{ GeV}$



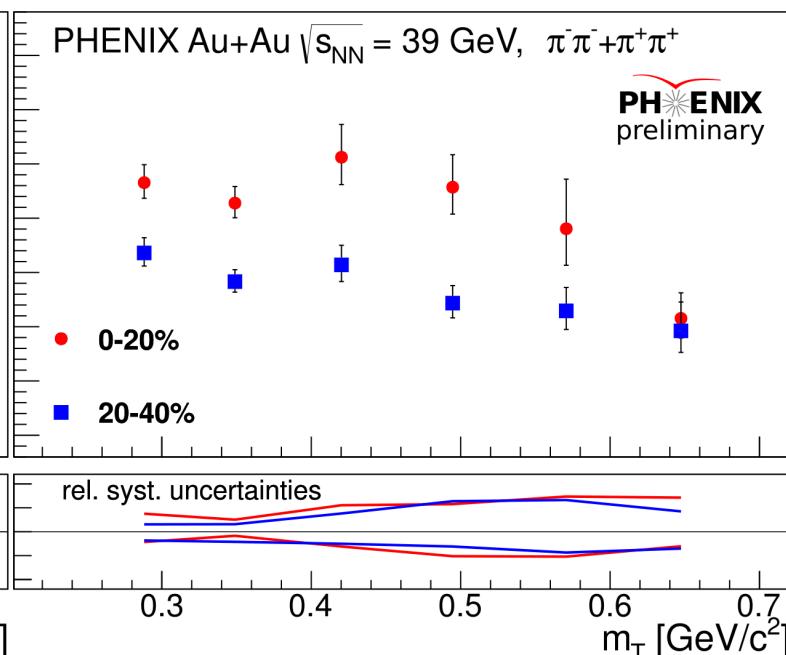
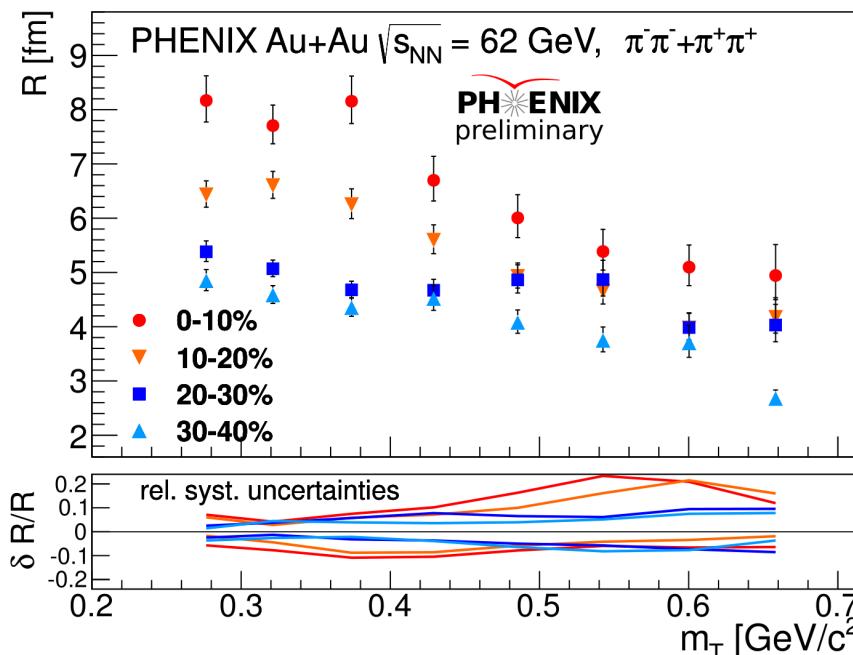
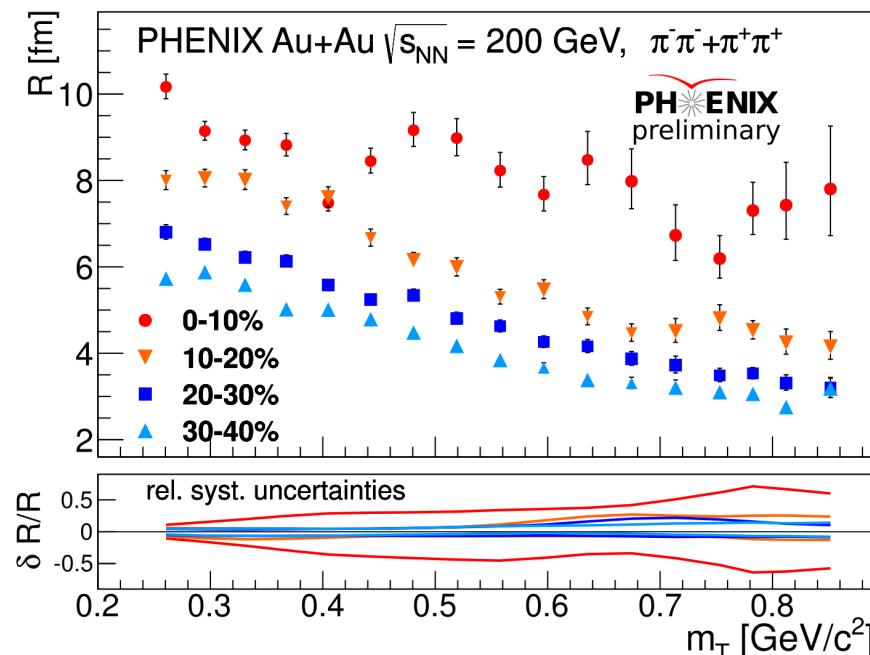
- Decrease at small m_T is present at all centralities and energies
- Sign of in-medium mass modification?

R - Centrality and m_T dependence

$\sqrt{s_{NN}} = 200 \text{ GeV}$

$\sqrt{s_{NN}} = 62 \text{ GeV}$

$\sqrt{s_{NN}} = 39 \text{ GeV}$



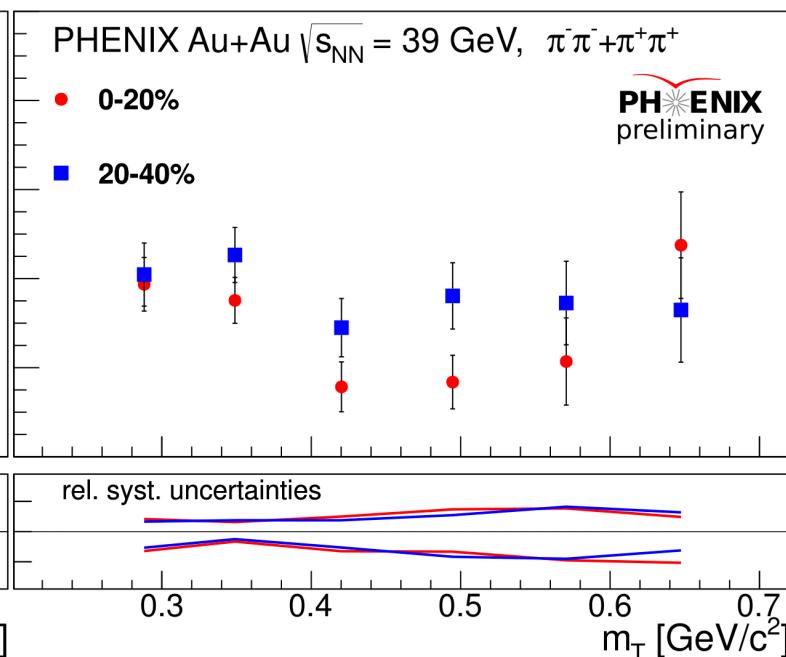
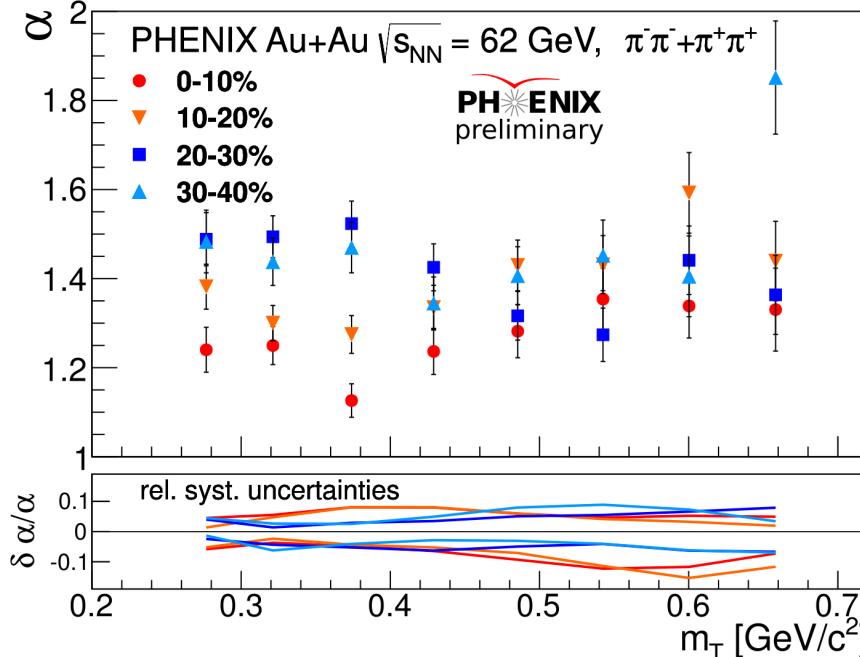
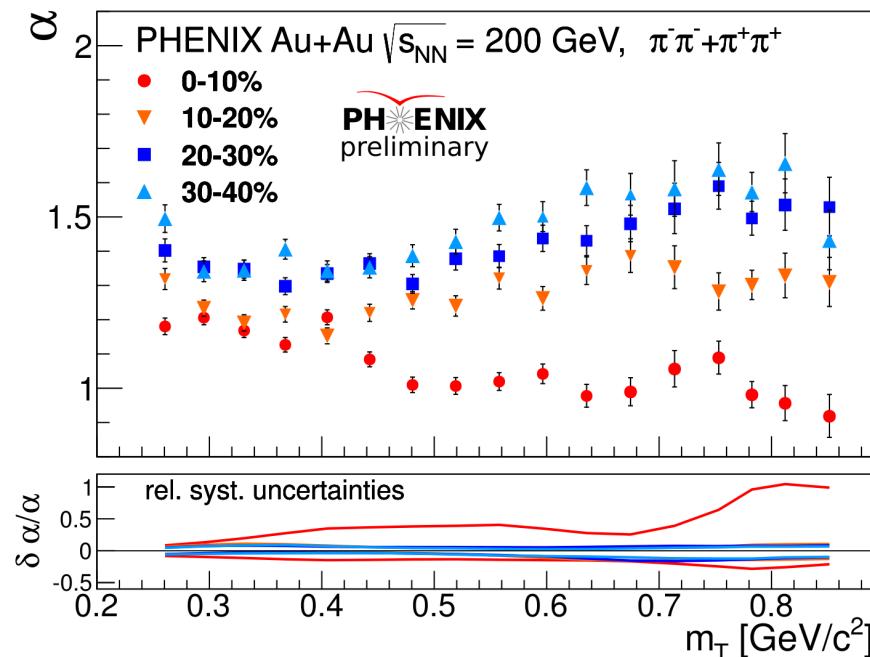
- Geometrical centrality dependence
- Usual decrease with m_T is present

α - Centrality and m_T dependence

$\sqrt{s_{NN}} = 200 \text{ GeV}$

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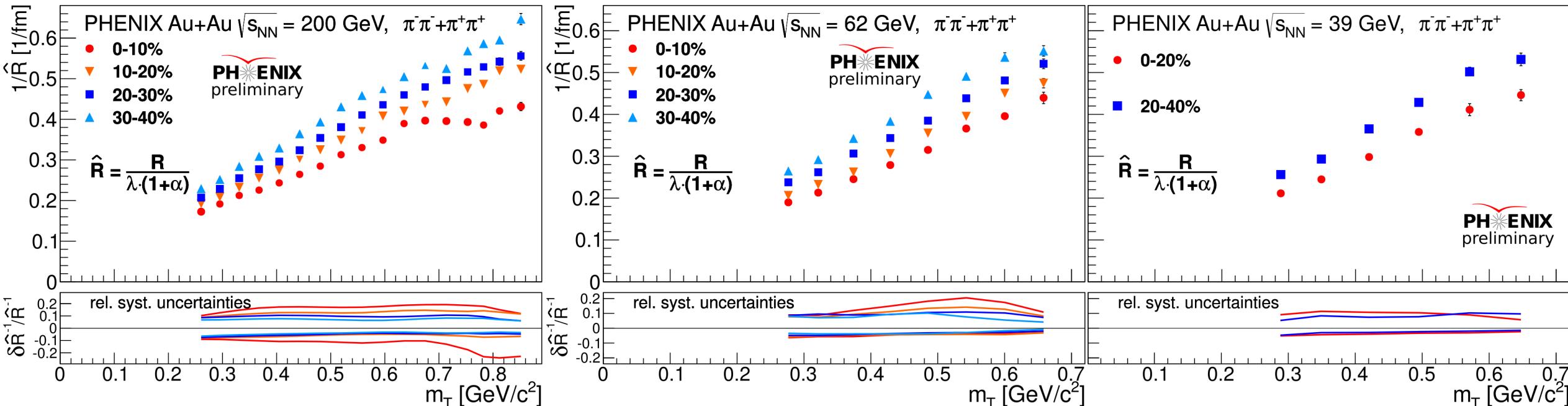
- Values are far from Gaussian (2) and rfd.3D Ising at CEP (0.5)
- Weak m_T dependence is present

$1/\hat{R}$ - Centrality and m_T dependence

$\sqrt{s_{NN}} = 200 \text{ GeV}$

$\sqrt{s_{NN}} = 62 \text{ GeV}$

$\sqrt{s_{NN}} = 39 \text{ GeV}$



- Empirically found scaling parameter
- Geometrical centrality dependence, linear in m_T