PHENIX results on Bose-Einstein correlation functions

XI Workshop on Particle Correlations and Femtoscopy

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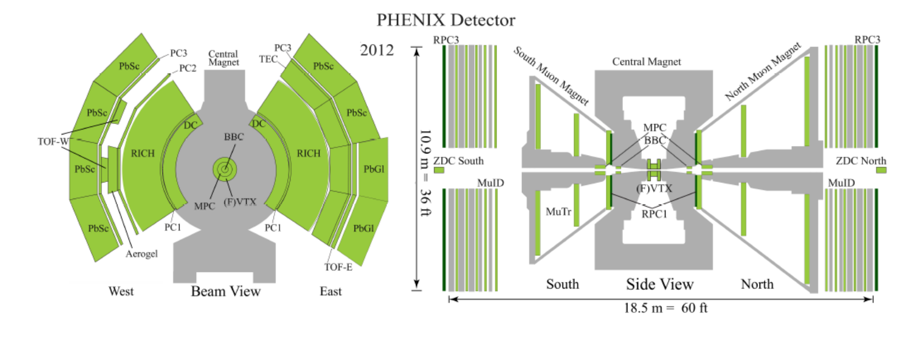
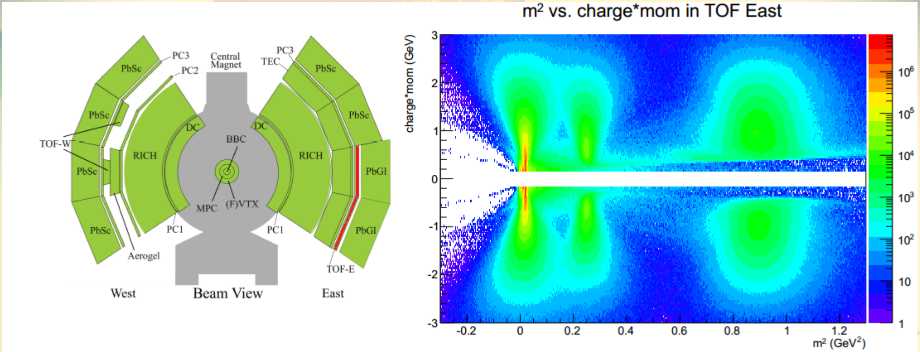
The PHENIX Experiment



The PHENIX detector system

- Observing collisions of p,d,Cu,Au,U
- Charged pion ID for ∼0.2 to 2 GeV/c^2
- Beam energy scan is important

The PHENIX Experiment



The PHENIX detector system

- Observing collisions of p,d,Cu,Au,U
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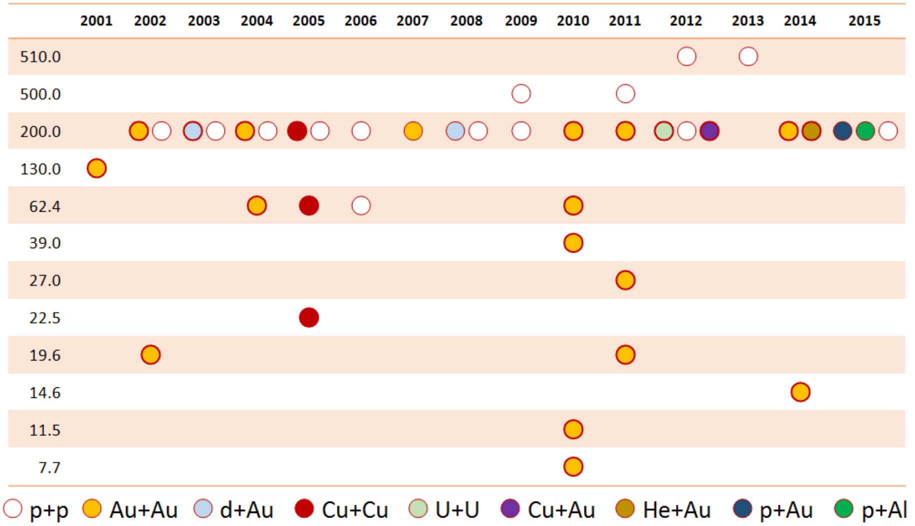
The RHIC Beam Energy Scan



See details at http://www.rhichome.bnl.gov/RHIC/Runs/

Bose-Einstein correlations - a short summary

$N_1(p), N_2(p)$ - invariant momentum distributions, the definition of the correlation function:

$$C_2(p_1, p_2) = \frac{N_2(p_1, p_2)}{N_1(p_1)N_1(p_2)} \quad (1)$$

The invariant momentum distributions

$$N_1(p) - \text{norm.}, N_2(p_1, p_2) = \int S(x_1, p_1)S(x_2, p_2)|\Psi_2(x_1, x_2)|^2 d^4x_2 d^4x_1 \quad (2)$$

- $S(x, p)$ source function (usually Gauss shaped - Lévy is more general)
- Ψ_2 - interaction free case - $|\Psi_2|^2 = 1 + \cos(qx)$

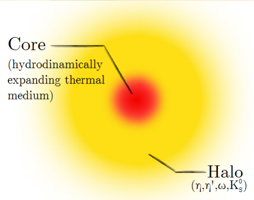
$$x = x_1 - x_2$$
$$q = k_1 - k_2$$
$$K = (k_1 + k_2)/2$$

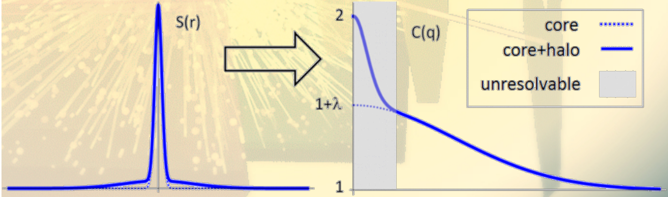
If $k_1 \simeq k_2$: $C_2 \to$ inverse Fourier-trf. $\to S$

$$C_2(q, K) \simeq 1 + \left|\frac{\widetilde{S}(q, K)}{\widetilde{S}(0, K)}\right|^2, \ \widetilde{S}(q, k) = \int S(x, k)e^{iqx}d^4x$$

Final state interactions, resonances

- Final state interactions distort the simple Bose-Einstein picture
  - identical charged pions - Coulomb interaction
    - different methods of handling, an usual practice: Coulomb-correction
    - $C_{B-E}(q) = K(q) \cdot C_{measured}(q)$
    - An other possibility to fit with the effect incorporated in the fitted func.
- Resonance pions reduce the correlation function
- $S = S_C + S_H$
- Primordial pions - Core $<$ 10 fm
- Resonance pions - from very far regions - Halo





The out-side-long system, HBT radii

- Corr. func. (with Gaussian source): $C_2(q) = 1 + \lambda \cdot e^{-R^2_{\mu\nu} q^\mu q^\nu}$
- Bertsch-Pratt pair coordinate-system
  - out direction: direction of the average transverse momentum (K_t)
  - long direction: beam direction (z axis)
  - side direction: orthogonal to the latter two
- LCMS system (Lorentz boost in the long direction)
- From the $R^2_{\mu\nu}$ matrix, R_{out}, R_{side}, R_{long} nonzero - HBT radii
- Out-side difference - $\Delta\tau$ emission duration
- From a simple hydro calculation:

$$R^2_{out} = \frac{R^2}{1 + \frac{m_T}{T_0}\beta_T^2} + \beta_T^2 \Delta\tau^2 \qquad R^2_{side} = \frac{R^2}{1 + \frac{m_T}{T_0}\beta_T^2}$$

- RHIC: ratio is near one $\rightarrow$ no strong 1st order phase trans.

Comparison of charged pion and kaon femtoscopy

PHENIX Collaboration, PhysRevC.92.034914

- Dataset used for the analysis:
  - Run-7, Au+Au, $\sqrt{s_{NN}}$ = 200 GeV, $4.2 \cdot 10^9$ events
  - Min. bias trigger, at least two hits in each BBC required
  - Additional offline requirements:
    - One ZDC hit on each side
    - Collision vertex position less than $\pm$30 cm
  - Single track cuts:
    - 2σ matching cuts in PC3 & PbSc for pions
    - 2.5σ matching cuts in PC3 & PbSc for kaons
  - Particle identification:
    - time-of-flight data from PbSc west, momentum, flight length
    - 2 σ cuts on m^2 distribution
    - π/K separation up to $\sim$ 1 GeV/c
  - Pair-cuts:
    - Pairs associated with hits on the same tower were removed
    - $(\Delta\phi^\pi > 0.07)$ or $(\Delta z^\pi >$ 5 cm & $\Delta\phi^\pi > 0.02)$ or $(\Delta z^\pi >$ 70 cm$)$
    - $(\Delta\phi^K > 0.04)$ or $(\Delta z^K >$ 4 cm & $\Delta\phi^K > 0.01)$ or $(\Delta z^K >$ 65 cm$)$

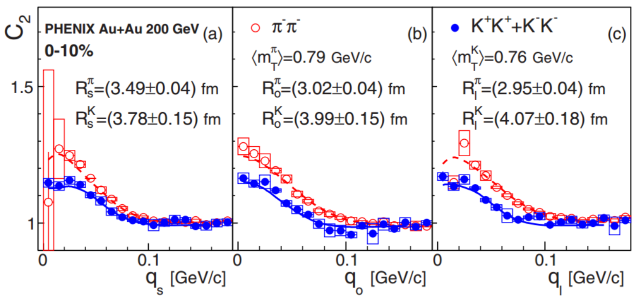
Comparison of charged pion and kaon femtoscopy

PHENIX Collaboration, PhysRevC.92.034914

- Both azimuthal-dependent and azimuthally integrated analysis (We only have time for the latter one)
- Fitted function:

$$C_2(q) = N[\lambda(1 + G(q))F_C + (1 - \lambda)]$$

$$G(q) = e^{-R_s^2 q_s^2 - R_o^2 q_o^2 - R_l^2 q_l^2} \left(\cdot e^{-2R_{os}^2 q_s q_o} \right)$$



Comparison of charged pion and kaon femtoscopy

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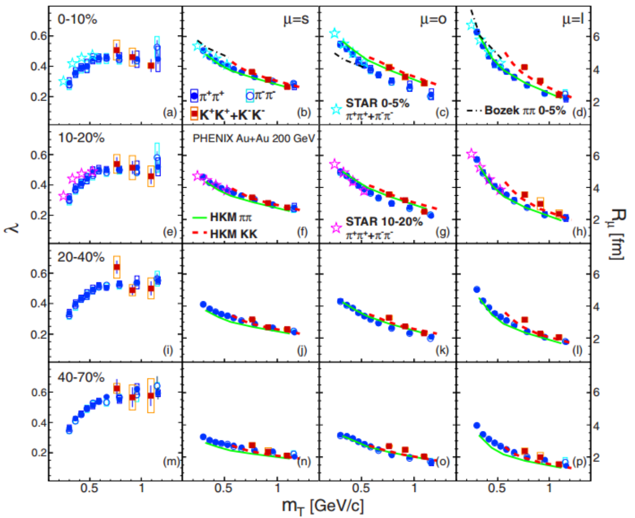
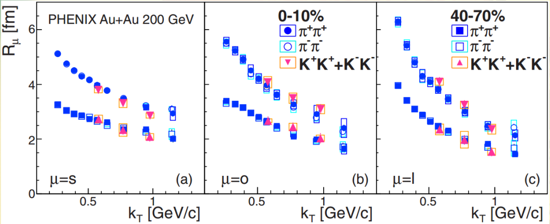


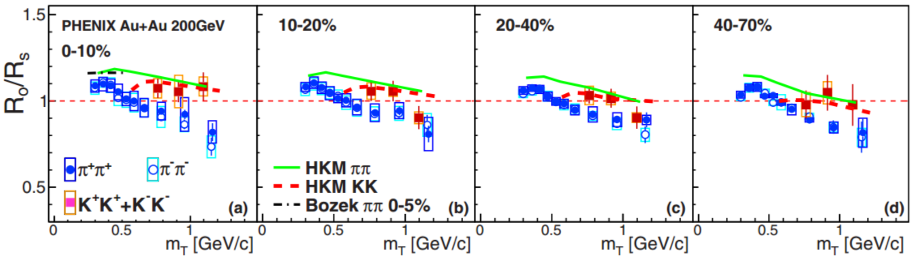
- R_s comparable
- R_o, R_l different
- $\pi^+\pi^+, \pi^-\pi^-$ consistent
- radii from PHENIX and STAR in agreement
- greater difference in λ
- Comparison with HKM

Comparison of charged pion and kaon femtoscopy

PHENIX Collaboration, PhysRevC.92.034914



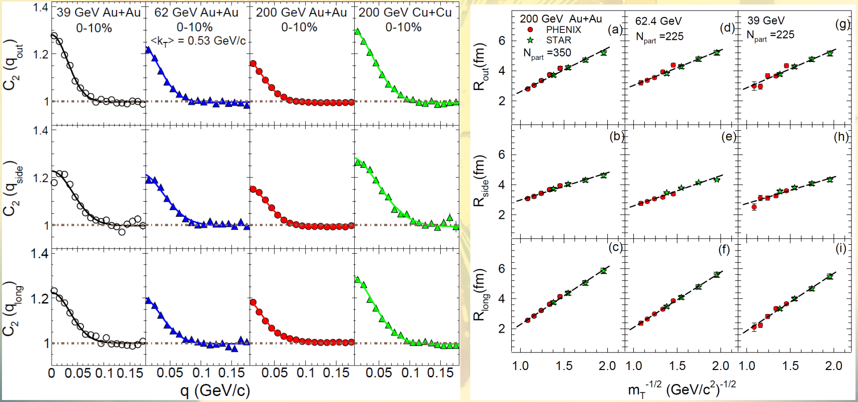
- Radii scale better for k_T
- Longer emission duration for kaons?



Beam energy & system size dependence of HBT radii

PHENIX Collaboration, arXiv:1410.2559

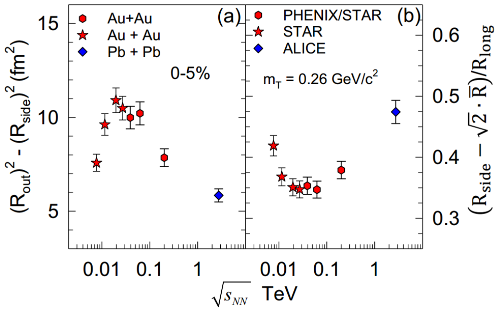
- Corr. func. in 3D, Gaussian fit (details: arXiv:1410.2559)
- $\pi^+\pi^+$, $\pi^-\pi^-$ data combined
- $1/\sqrt{m_T}$ transverse mass scaling of HBT radii
- Linear dependence for all systems and directions
- Interpolation to common m_T, PHENIX and STAR consistent



Beam energy & system size dependence of HBT radii

PHENIX Collaboration, arXiv:1410.2559

- quantities related to emission duration and expansion velocity
- non-monotonic patterns
- indication of CEP?



- More precise mapping and further detailed studies required
- Is there any other way to find the critical point?
- Maybe Levy exponent α!

The most recent PHENIX HBT analysis & future plans

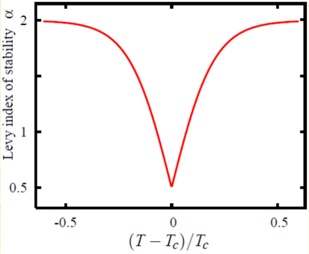
A brief overview

- Dataset:
  - $\sqrt{s_{NN}}$=200 GeV Au+Au, min. bias, more than 7 billion events
  - Huge statistics, fine p_T binning possible
- Goal:
  - Detailed shape analysis of 1D two-pion corr. func.
    - Levy source instead of Gauss $\rightarrow$ better agreement with data
    - $\mathcal{L}(\alpha, R, \mathbf{r}) = \frac{1}{(2\pi)^3} \int d^3q e^{i\mathbf{q}\mathbf{r}} e^{-\frac{1}{2}|\mathbf{q}R|^\alpha}$
  - Extraction and analysis of the source parameters
    - Precision measurement of $\lambda(m_T), \alpha_{Levy}(m_T), R_{Levy}(m_T)$

Ongoing work: PHENIX Levy HBT analysis & future plans

The physics case behind the results

- Measurement of $\alpha_{Levy}(m_T)$
  - $\alpha = 2$ Gaussian, $\alpha = 1$ Cauchy
  - Results indicate strong deviation from Gaussian ($\alpha \simeq 1.15$)
  - α_{Levy} actually identical to critical exponent η
  - At the critical point: $\eta = 0.5$
  - Change in α_{Levy} related to the proximity of CEP
  - Plan: repeating the measurements at lower energies
  - A possible way of finding the Critical End Point?



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Ongoing work: PHENIX Levy HBT analysis & future plans

The physics case behind the results

- Precision $\lambda(m_T)$ measurement
  - Observed decrease at small $p_T \rightarrow$ increase of halo fraction
  - May be connected to mass modifications (c.f. chiral restoration)
  - Core fraction: $f_C = N_{core}/N_{total}$
  - $\lambda_{2pion} = f_C^2, \lambda_{3pion} = 3f_C^2 + 2f_C^3$
  - Three-pion analysis $\rightarrow$ extract λ_{3pion}
  - λ_{2pion} vs λ_{3pion} may reveal deviations from core-halo picture
  - Possible partially coherent pion production?

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Summary I

- Recent PHENIX HBT results:
  - Comparison of charged pion and kaon femtoscopy - PhysRevC.92.034914
    - 200 GeV Au+Au, Gaussian fits, azimuthally dep./int. analysis
    - m_T scaling holds well for R_s
    - visible differences for R_o, R_l between pions & kaons
    - differences larger in more central collisions
    - k_T scaling works well for all radii
    - R_o/R_s is larger for kaons $\rightarrow$ different $\Delta\tau$?
  - Beam energy & system size dependence of HBT radii
    - $1/\sqrt{m_T}$ transverse mass scaling of HBT radii
    - Linear dependence for all systems and directions, PHENIX & STAR consistent
    - Specific combinations of radii vs. $\sqrt{s_{NN}}$ show non-monotonic behaviour
    - Indication of CEP? - further detailed studies required

Summary II

- Ongoing work: Levy HBT analysis
  - Dataset: Run-10 200 GeV Au+Au, $\sim$7 billion evts.
  - Goal: precise measurement of Levy source parameters
  - Future plans: 3 pion correlations, lower energies
  - Expected physics info: mass modifications, partial coherence, CEP

Thank you for your attention!