# Search for coherent hadron emission with PHENIX

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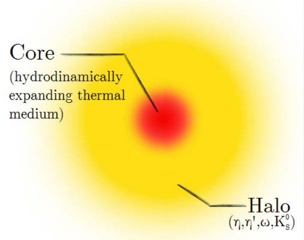
# Introduction to Bose-Einstein correlations

- QGP created at RHIC and LHC
- Exploring space-time structure: Bose-Einstein correlations
  $\longrightarrow$ correlation between bosons due to Bose-Einstein statistics
- Two-particle BEC: connected to the source distribution $\mathcal{S}(r)$
- What about three-particle correlations?
- Core-Halo model: $\mathcal{S} = \mathcal{S}_{\text{core}} + \mathcal{S}_{\text{halo}}$ (primordial + resonance pions)




$$C_2(p_1, p_2) = 1 + \lambda_2 |\tilde{\mathcal{S}}(p_1 - p_2)|^2$$

$$\tilde{\mathcal{S}}(q) = \int \mathcal{S}(x) e^{iqx} d^4x$$

$$\sqrt{\lambda_2} = f_C \equiv \frac{N^c}{N^c + N^h}$$

# Coherence

- If the core partially emits particles in coherent manner:

$$\mathcal{S}_{\mathrm{core}} = \mathcal{S}^{\mathrm{pc}}_{\mathrm{core}} + \mathcal{S}^{i}_{\mathrm{core}}$$

  where pc refers to partially coherent, i to incoherent

- Two particle correlation: $C_2(p_1, p_2) = 1 + \lambda_2 |\tilde{\mathcal{S}}(p_1 - p_2)|^2$, but $\lambda_2 \neq f_C^2$

- Fraction of coherently produced pions:

$$p_C \equiv \frac{N^{\mathrm{coherent}}}{N^{\mathrm{coherent}} + N^{\mathrm{incoherent}}} \to \lambda_2(f_C, p_C)$$

# Three-particle Bose-Einstein correlation function

- Invariant momentum distributions: $N_1(p_i), N_2(p_1, p_2), N_3(p_1, p_2, p_3)$
- The definition of the correlation function:

$$C_n(p_1, \ldots, p_n) = \frac{N_n(p_1, \ldots, p_n)}{N_1(p_1) \cdots N_1(p_n)}$$

for chaotic emission:

$$N_n(p_1, \ldots, p_n) = \int \prod_{i=1}^{n} \mathcal{S}(x_i, p_i) |\Psi_n(\{x_i\})|^2 d^4x_1 \ldots d^4x_n$$

- $\mathcal{S}(x, p)$ source function (usually assumed to be Gaussian - Levy is more general)

$$\mathcal{S}(\boldsymbol{r}) = \frac{1}{(2\pi)^3} \int e^{i\boldsymbol{qr}} e^{-\frac{1}{2}|\boldsymbol{r}R|^\alpha} d^3q \tag{1}$$

# Motivation behind three particle HBT analysis

- *n*-particle correlation strength: $\lambda_n \equiv C_n(0) - 1$
- Core-Halo:
$$\lambda_2 = f_C^2, \quad \lambda_3 = 2f_C^3 + 3f_C^2$$
$$\kappa_3 = (\lambda_3 - 3\lambda_2)/(2\sqrt{\lambda_2^3}) = 1$$
- Partial coherence ($p_C$ fraction of coherently produced $\pi$):
$$\lambda_2 = f_C^2\left[(1-p_C)^2 + 2p_C(1-p_C)\right]$$
$$\lambda_3 = 2f_C^3\left[(1-p_C)^3 + 3p_C(1-p_C)^2\right] + 3f_C^2\left[(1-p_C)^2 + 2p_C(1-p_C)\right]$$
$$\kappa_3 = \kappa_3(p_C)$$

- From $\lambda_2$, $\lambda_3$ we can investigate the deviation from simple Core-Halo
- Search for partial coherence! pion-laser?

# Shape of the correlation function

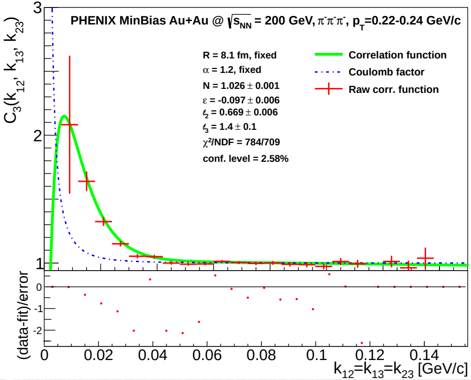
- Model to fit to data?
- Correlation function ($\ell_3 = 2f_C^3$):

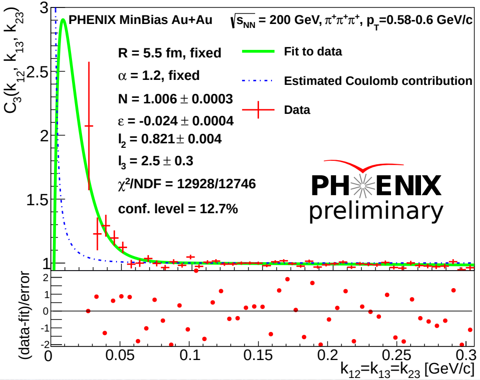
$$C_3^{(0)}(k_{12}, k_{13}, k_{23}) = 1 + \ell_3 e^{-0.5(|2k_{12}R_C|^\alpha + |2k_{13}R_C|^\alpha + |2k_{23}R_C|^\alpha)} + \ell_2 \left( e^{|2k_{12}R_C|^\alpha} + e^{|2k_{13}R_C|^\alpha} + e^{|2k_{23}R_C|^\alpha} \right)$$

- Background: $N(1+\epsilon k_{12})(1+\epsilon k_{13})(1+\epsilon k_{23})$
- Fit parameters: $\ell_3$, $\ell_2$, $R_C$, $\alpha$, $N$, $\epsilon$
- We are looking for: $\lambda_3 \equiv C_3(k_{12} = k_{13} = k_{23} = 0) - 1 = \ell_3 + 3\ell_2$

# Diagonal visualization of fits

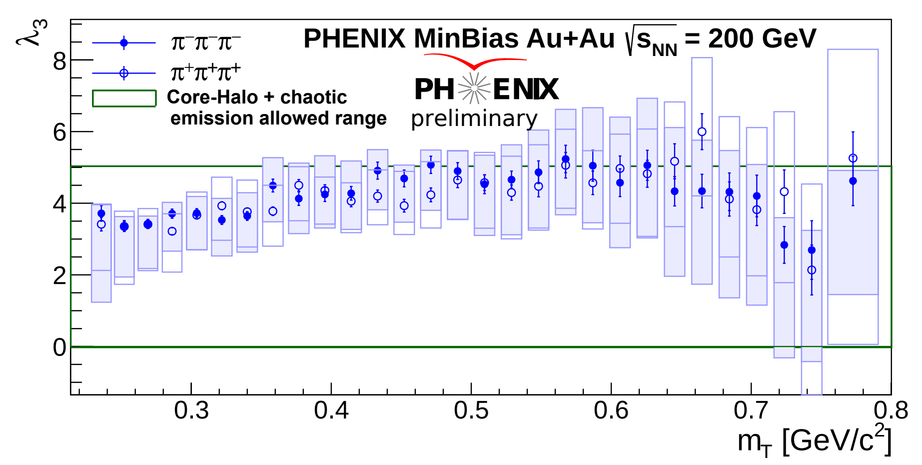
- Visualization in $k_{12} = k_{23} = k_{13}$ subspace: shows good fits



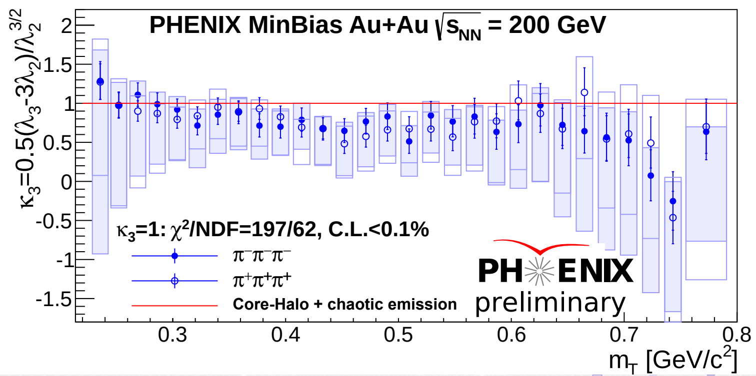
# Three particle correlation strength: $\lambda_3$

- Core-halo model: $0 < \lambda_3 < 5$



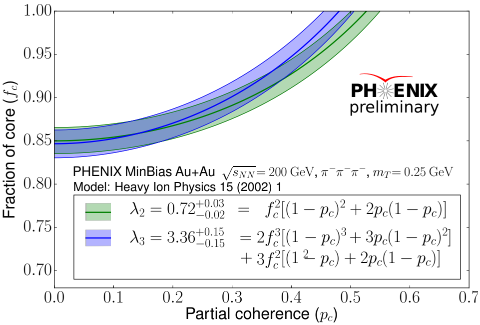
# Core-Halo independent parameter

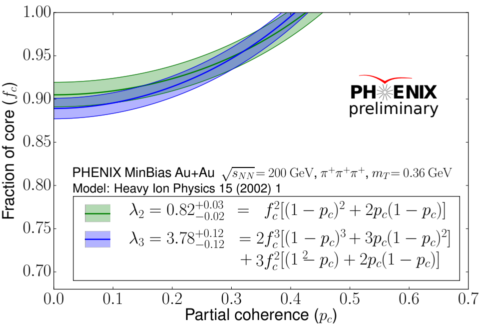
- $\kappa_3 \equiv \frac{\lambda_3 - 3\lambda_2}{2\sqrt{\lambda_2^3}}$ not depend on $f_C$ ($f_C = \text{core}/(\text{core} + \text{halo})$)
- Core-Halo + chaotic emission: $\kappa_3 = 1$
- additional effect (eg. not fully thermal): $\kappa_3 \neq 1$
- Statistically significant deviation from $\kappa_3 = 1$



# Partial coherence ($p_C$) vs fractional core ($f_C$)

- Simple theoretical model: $\lambda_2(f_c, p_c)$, $\lambda_3(f_c, p_c)$
- Measured $\lambda_2^{\text{meas.}} \to \lambda_2^{\text{meas.}} = \lambda_2(f_c, p_c) \Longrightarrow f_c(p_c)$ (green lines)
- Measured $\lambda_3^{\text{meas.}} \to \lambda_3^{\text{meas.}} = \lambda_3(f_c, p_c) \Longrightarrow f_c(p_c)$ (blue lines)
- $f_c < 0.82$ and $p_c > 0.5$ can be excluded, $p_C < 0.5$ can't be excluded



# Summary

- Three-pion BE correlation functions from 200 GeV Au+Au data
- Lévy-distribution for describing the source
- Measured $\lambda_3$ correlation strength within Core-Halo + chaotic emission limit
- PHENIX preliminary $\kappa_3$ data shows a significant effect
- $\lambda_2$ and $\lambda_3$ analysis: possibility for partial coherence
- We need to:
  - finalize this analysis for $0 - 30\%$
  - study detailed centrality and $\sqrt{s_{NN}}$ dependence

# Coulomb correction

- Corrected model:

$$C_3(k_{12}, k_{13}, k_{23}) = C_3^{(0)}(k_{12}, k_{13}, k_{23}) \cdot K_3(k_{12}, k_{13}, k_{23})$$

- "Generalized Riverside" method for 3 particle Coulomb problem

$$K_3(k_{12}, k_{13}, k_{23}) \approx K_1(k_{12})K_1(k_{13})K_1(k_{23})$$