Chaoticity Measurements in Pb-Pb Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV in ALICE

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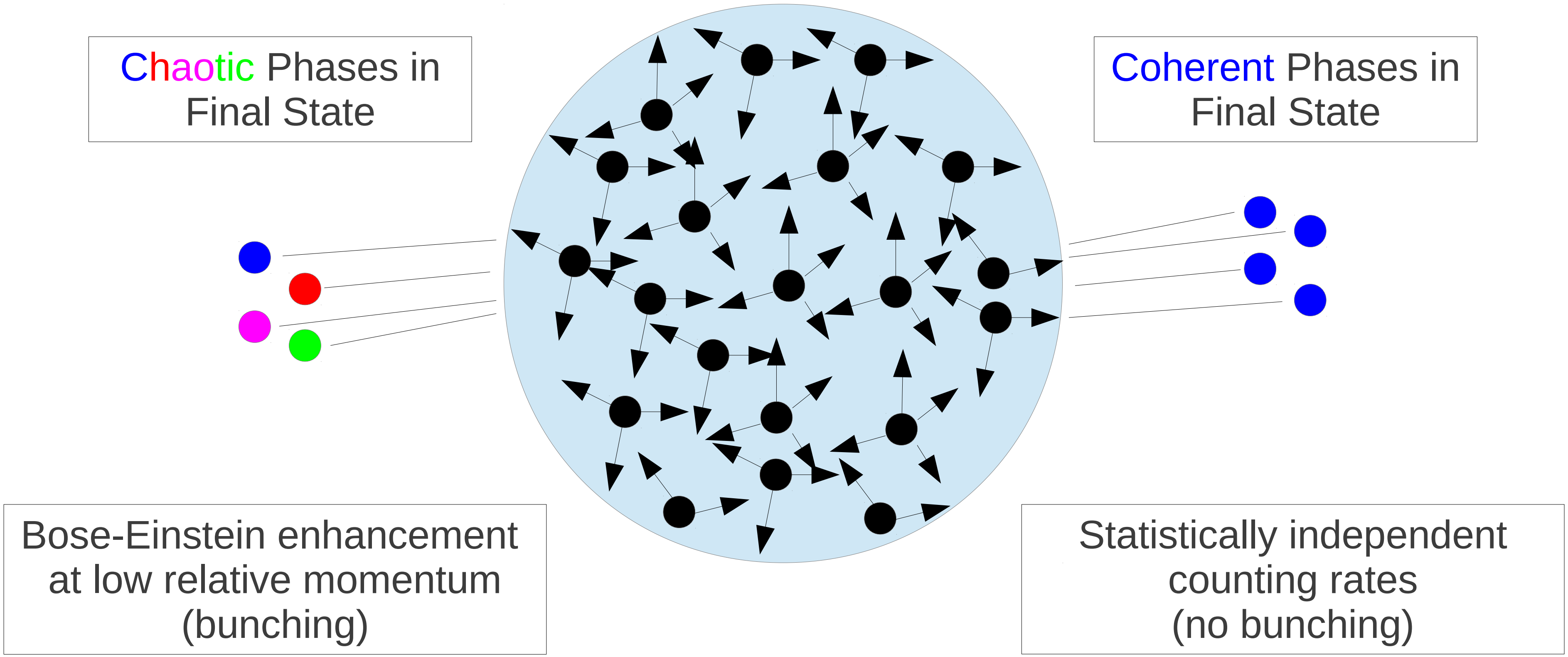
Motivation

Question: What are the Quantum Statistical (QS) properties of charged pions in heavy-ion collisions? Chaotic or Coherent emission?



Chaotic Phases in Final State

Coherent Phases in Final State

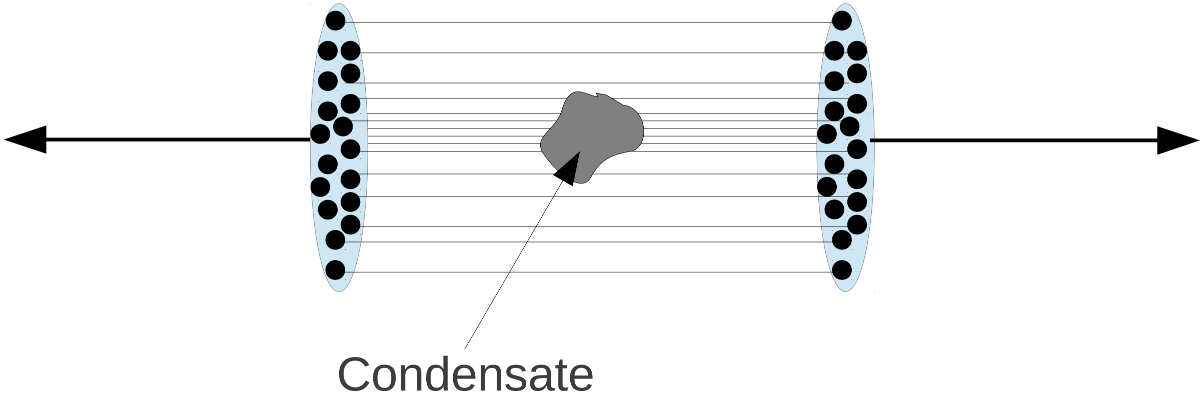
Bose-Einstein enhancement at low relative momentum (bunching)

Statistically independent counting rates (no bunching)

Two Possible Sources of Coherence

Bjorken's "Baked Alaska" (SLAC-PUB-6109, 1993):
The interior of the "fireball" from high-energy collisions can be relatively cold. In the cold region, a Disoriented-Chiral-Condensate (DCC) can form and live for quite some time after the hot shell dissipates.

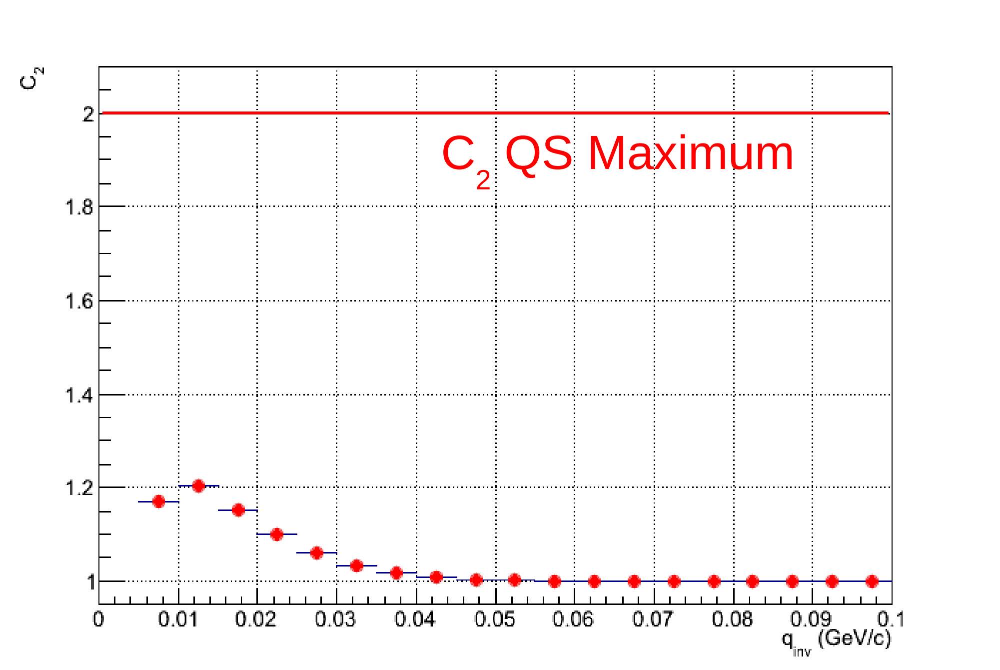
Color-Glass-Condensate initial conditions (arXiv:1107.5296v2 (2011)):
The Glasma produced at very early times will have an "overpopulation" of gluons. If the evolution of the Glasma proceeds mainly through elastic scattering then a gluon-condensate can form (McLerran et al.).



How We Will Search For It

2-pion correlations

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



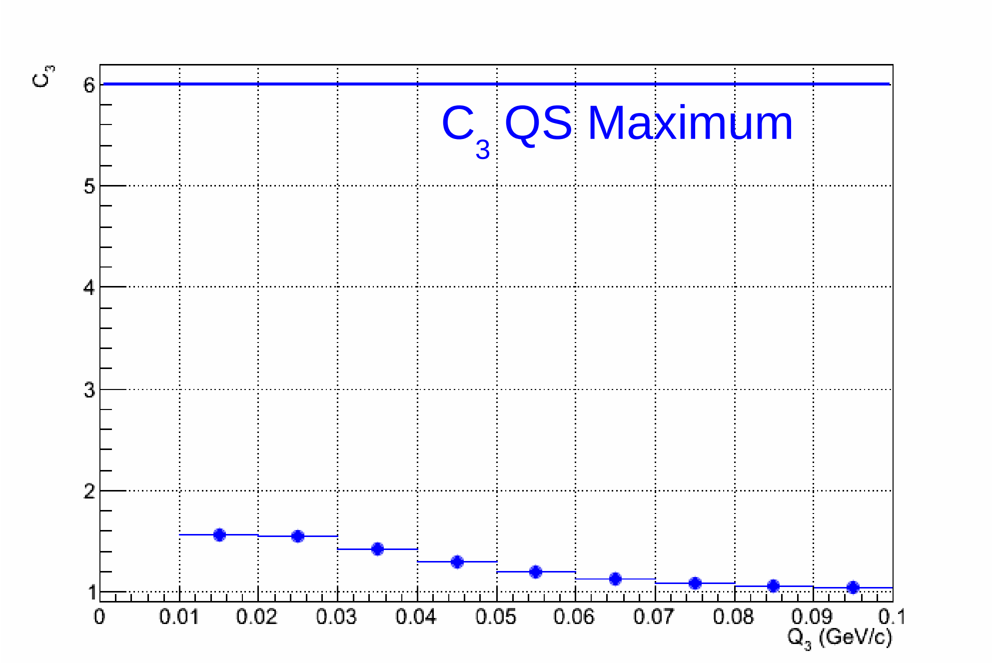
$$C_2(q) = (1-\lambda) + \lambda K_2\left(1 + A(q)\,e^{-R^2 q^2} - \frac{4}{5}G^2\right)$$

G = coherent fraction

Akkelin, Lednicky, Sinyukov, PRC 65: 064904

3-pion correlations

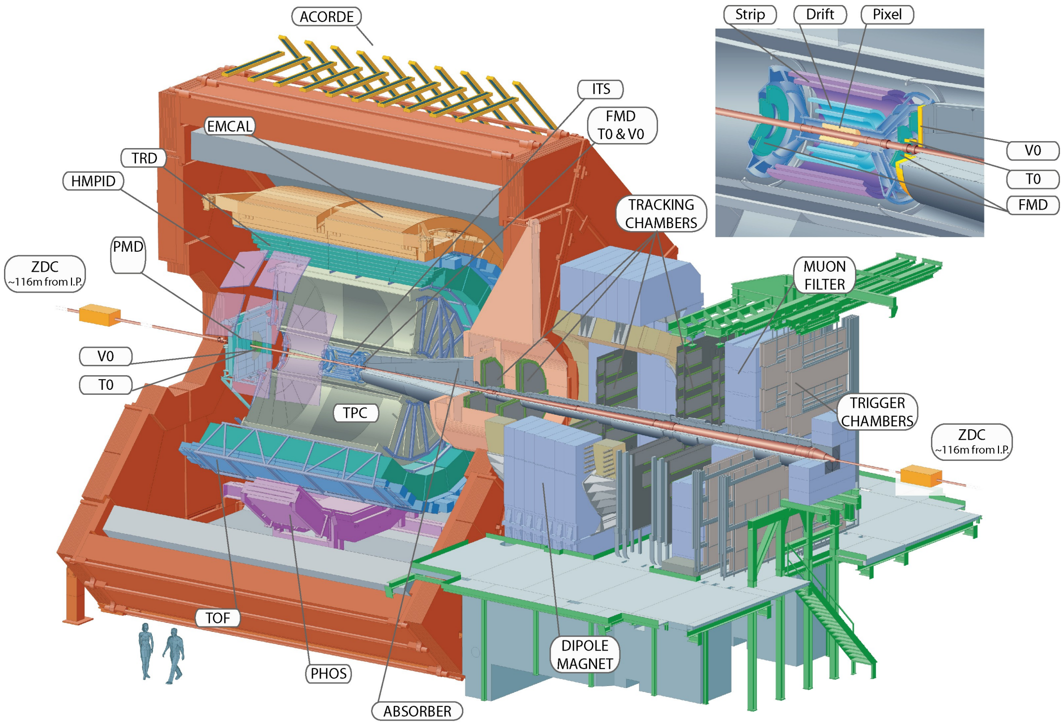
$$C_3 = \frac{N_3(p_1, p_2, p_3)}{N_1(p_1)\,N_1(p_2)\,N_1(p_3)}$$



$$C_3(q_{12}, q_{13}, q_{23}) = (1-\lambda^{1/2})^3 + 3\lambda^{1/2}(1-\lambda^{1/2})^2$$
$$+\lambda(1-\lambda^{1/2})[C_2(q_{12}) + C_2(q_{13}) + C_2(q_{23}) - 3(1-\lambda)]$$
$$+K_3\lambda^{3/2} C_3^{QS}(q_{12}, q_{13}, q_{23})$$

$$Q_3 = \sqrt{q_{12}^2 + q_{13}^2 + q_{23}^2}$$

ALICE



Inner-Tracking-System (ITS):

- 6 layers of silicon proving precise tracking close to the collision vertex.

Time-Projection-Chamber (TPC):

- 90 m^3 of ionizing gas providing ½ M tracking points every 1/100 sec.
- Provides accurate particle identification for momenta <~ 0.9 GeV/c.

Time-Of-Flight Detector (TOF):

- Provides accurate particle identification for momenta >~ 0.6 GeV/c.

Data Used Here:

- Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV Minimum Bias
- 0-5% centrality only here

Track Cuts:

- $0.16 < p_t < 1.0$ GeV/c
- $|\eta| < 0.8$
- Charged pions selected (nSigma TPC/TOF < 2.0)

Pair Cuts:

- Very strict pair spatial separation cuts to remove track merging/splitting.

Final-State-Interactions (FSI)

It is absolutely crucial to accurately take into account FSI
- Same-charge pions: Coulomb repulsion
- Mixed-charge pions: Coulomb + Strong attraction

2-pions

$$\Psi_2^{FSI} = e^{i(p_1 x_1 + p_2 x_2)} \Phi_{p_1, p_2}(x_1, x_2) + e^{i(p_1 x_2 + p_2 x_1)} \Phi_{p_1, p_2}(x_2, x_1)$$

Coulomb + Strong Wave-functions can be found here: Lednicky. Phys. Part. Nucl. 40, 307 (2009)

$$\Phi_{p_i, p_j}(x_i, x_j) = e^{i\delta_c} A_c(p_i, p_j)^{1/2} F(-i\eta, 1, iz)$$

$$K_2 = \frac{\int dx_1\, dx_2\, \rho(x_1)\, \rho(x_2) \left| (\Psi_2^{FSI})^2 \right|}{\int dx_1\, dx_2\, \rho(x_1)\, \rho(x_2) \left| (\Psi_2^{PW})^2 \right|}$$

Source functions (ρ) are taken from Therminator which includes all of the known resonance decays.

My calculations are in excellent agreement with those of Mate Csanad (Coulomb only) as well as Richard Lednicky (Coulomb+Strong).

3-pions

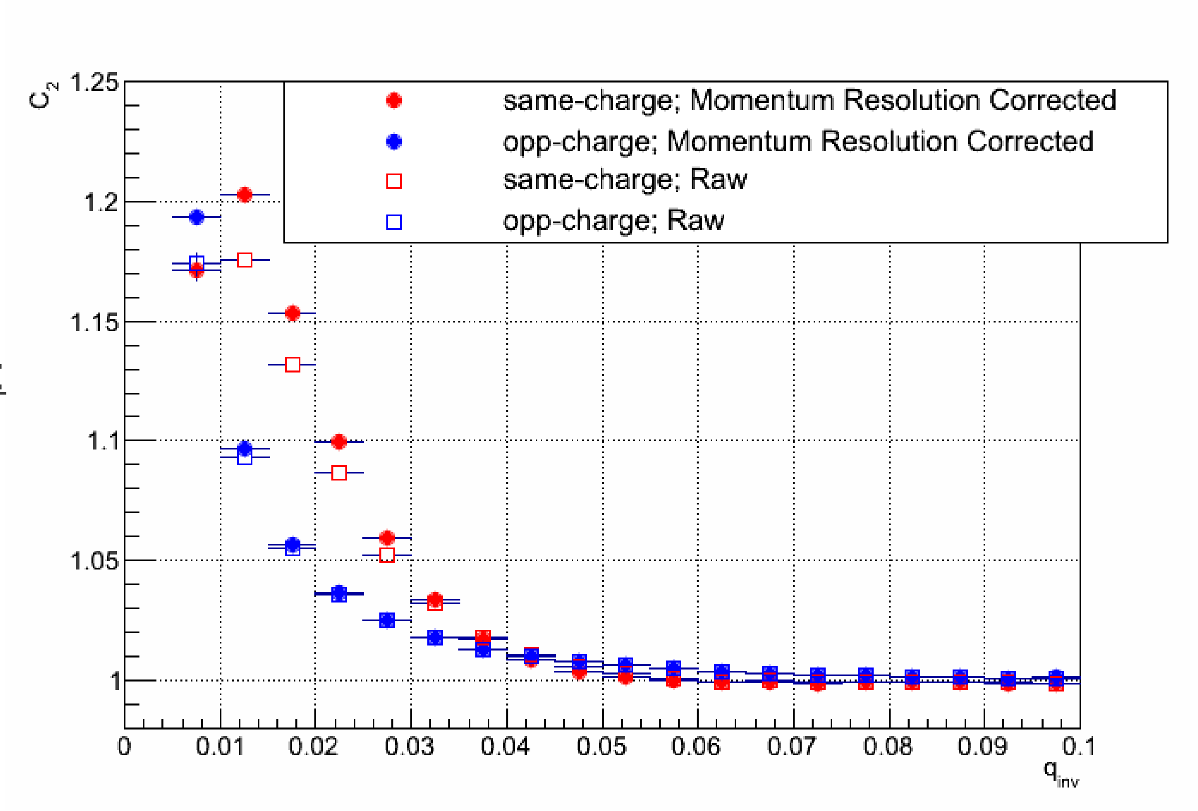
3-body wave-functions can be found here: T. Csorgo et al. Phys. Lett. B 458: 407 (1999).

Asymptotic solutions are used (product of two-body wave-functions). Should be OK for large triplet energies (Q_3 > 10 MeV).

Momentum Resolution Corrections

The smearing of a tracks momentum due to finite detector resolution was not generally taken into account in past coherence correlation searches. It is important!!

Detector Resolution:
δq_{inv} ~ 4 MeV



It is performed using the “ideal” momentum values from HIJING to form a QS+FSI weight (W) attached to the pair and binned according to the reconstructed momentum values. Reconstructed momenta incorporate the smearing from the ALICE detector.

Charge-Constraint for Charged Pion Coherence

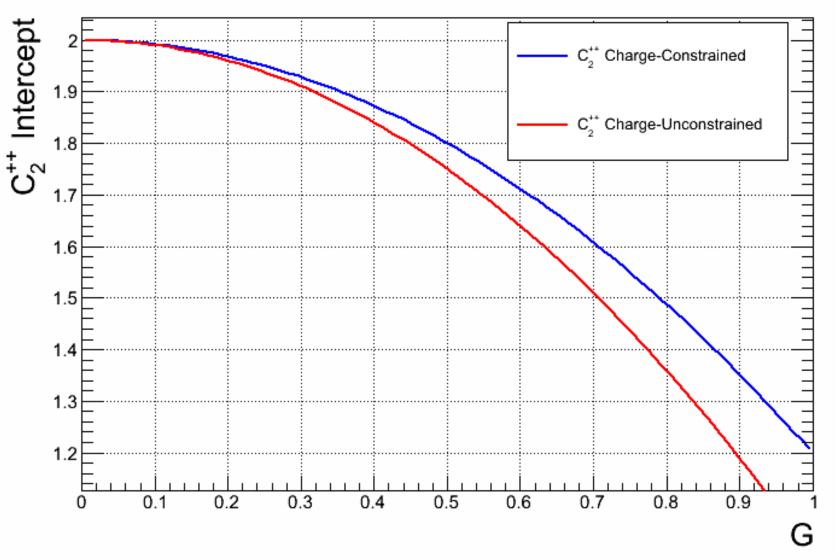
Charged bosons cannot form the usual coherent states first proposed by Glauber. Coherent charged pions must effectively occur in +- pairs.

Akkelin, Lednicky, Sinyukov, PRC 65: 064904

Same-charge pion correlation function intercepts (q=0):

No charge-constraint: $C_2 = 2 - G^2$

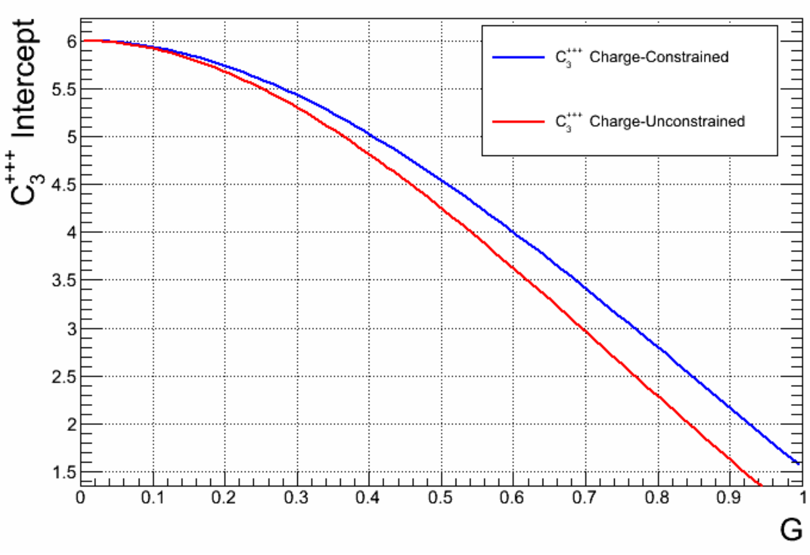
With charge-constraint: $C_2 = 2 - \frac{4}{5} G^2$



No charge-constraint: $C_3 = 6 - 9G^2 + 4G^3$

With charge-constraint: $C_3 = 6 - \frac{36}{5} G^2 + \frac{96}{35} G^3$

This expression recently derived.



Therminator - λ_{++} versus λ_{+-}

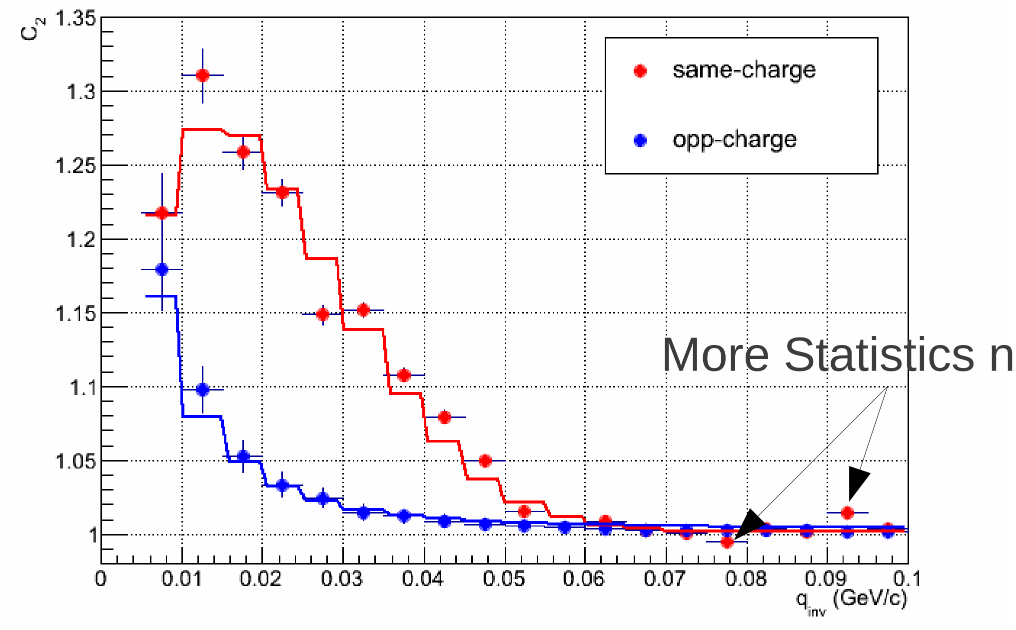
$$C_2^{same-charge} = (1-\lambda) + \lambda\, K_{same-charge}\left(1+e^{-R^2 q^2}\right)$$

$$C_2^{opp-charge} = (1-\lambda) + \lambda\, K_{opp-charge}$$

K = Final State Interaction correlation

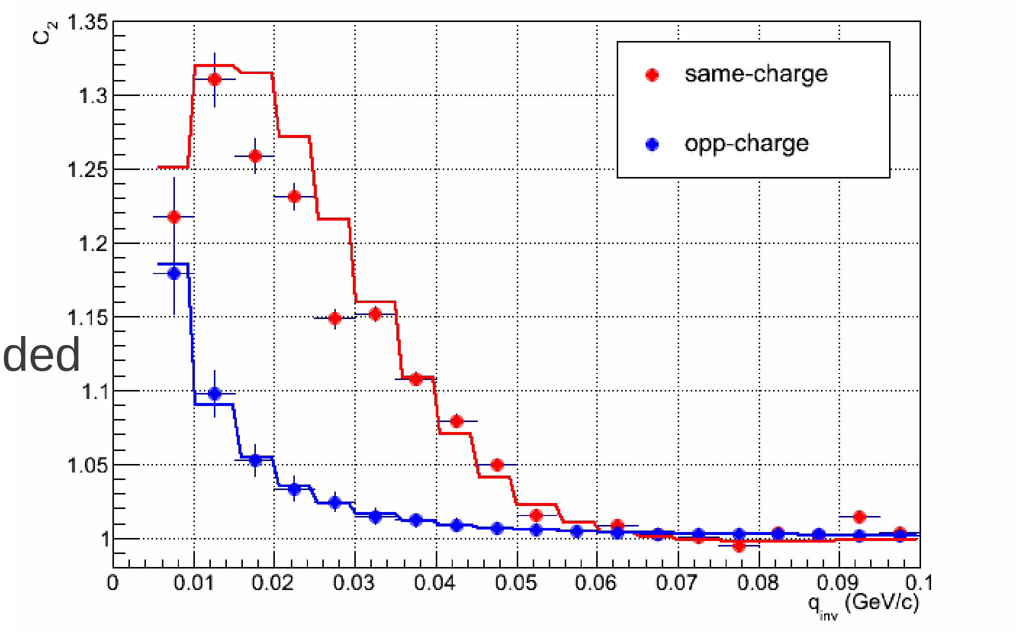
0.2 < kt < 0.3 GeV/c

Same-charge fit:
Use fit λ to predict Opp-charge



More Statistics needed

Opp-charge fit:
Use fit λ to predict Same-charge



λ = 0.466
R = 6.54 fm

Lambda's are compatible in Therminator.

λ = 0.551
R = 6.54 (fixed)

Therminator - Edgeworth expansion

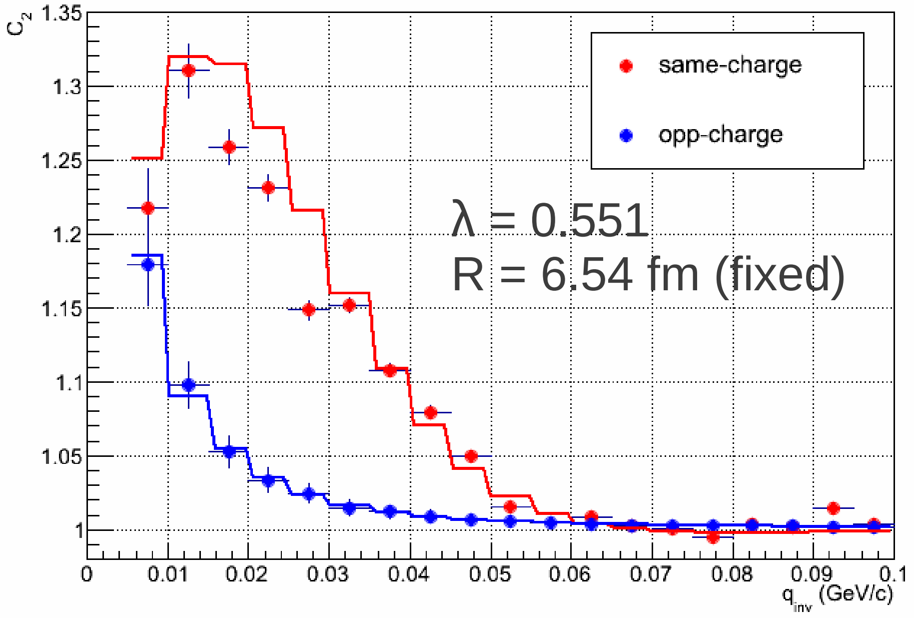
$$C_2^{same-charge} = (1-\lambda) + \lambda K_{same-charge} \left(1 + e^{-R^2 q^2} \left(1 + \frac{\kappa_4}{(2)^{4/2} 4!} H_4(Rq) + \frac{\kappa_6}{(2)^{6/2} 6!} H_6(Rq)\right)^2\right)$$

$$C_2^{opp-charge} = (1-\lambda) + \lambda K_{opp-charge}$$

H = Hermite Polynomials

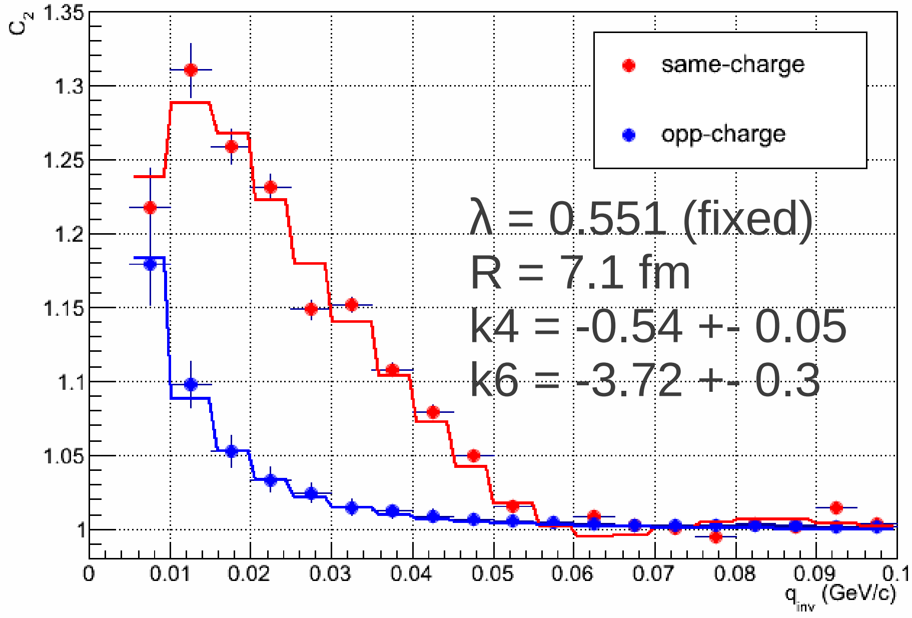
0.2 < kt < 0.3 GeV/c

Opp-charge fit: Use fit λ to predict Same-charge



λ = 0.551
R = 6.54 fm (fixed)

Same-charge fit: Fix λ from Opp-charge



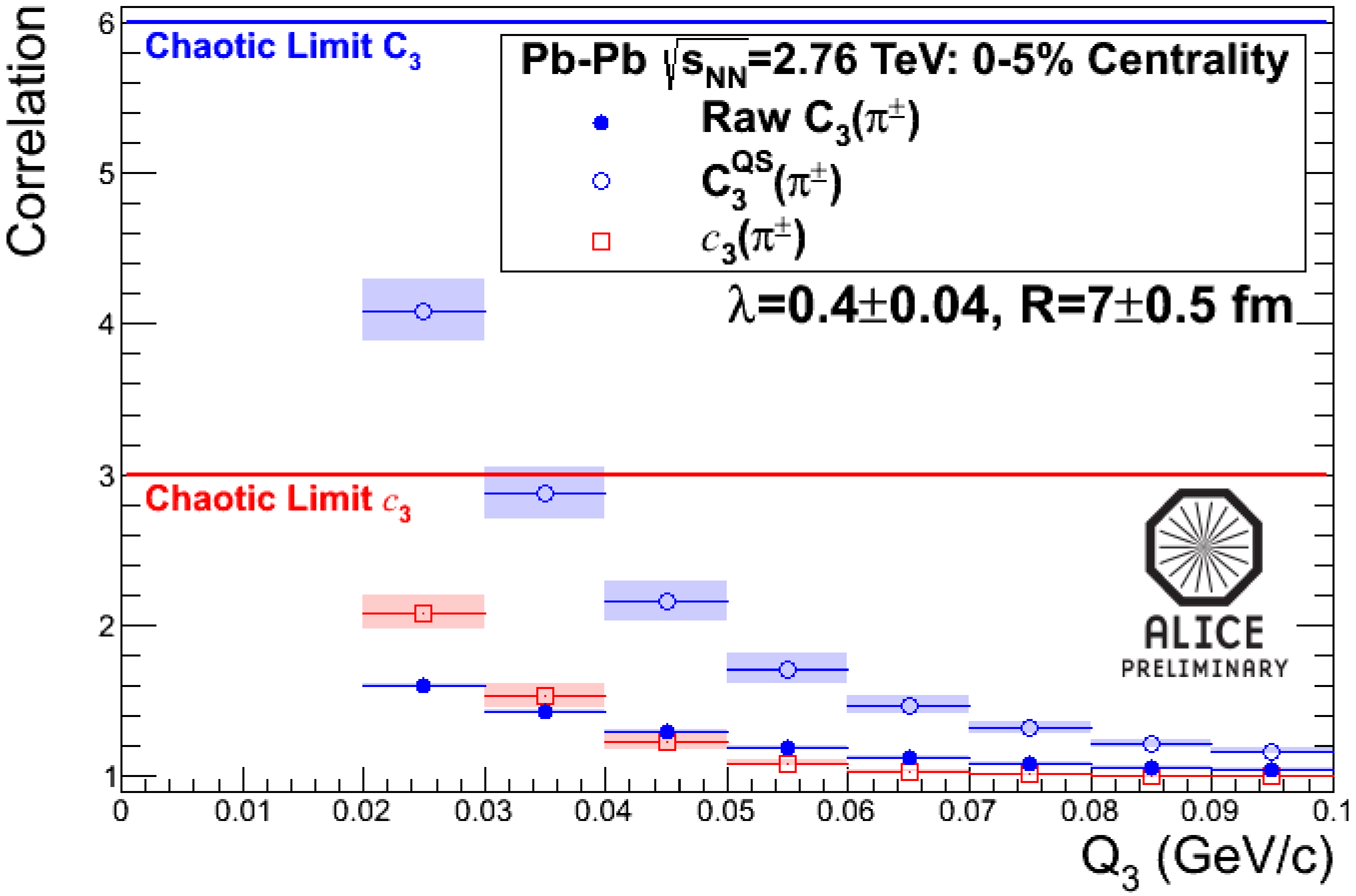
λ = 0.551 (fixed)
R = 7.1 fm
k4 = -0.54 +- 0.05
k6 = -3.72 +- 0.3

λ_{+-} can be used for C2(++)

3-pion Correlations (+++)

$$C_3(q_{12},q_{13},q_{23})=(1-\lambda^{1/2})^3+3\lambda^{1/2}(1-\lambda^{1/2})^2$$
$$+\lambda(1-\lambda^{1/2})[C_2(q_{12})+C_2(q_{13})+C_2(q_{23})-3(1-\lambda)]$$
$$+K_3\lambda^{3/2}C_3^{QS}(q_{12},q_{13},q_{23})$$

$$c_3(q_{12},q_{13},q_{23})=C_3^{QS}(q_{12},q_{13},q_{23})-C_2^{QS}(q_{12})-C_2^{QS}(q_{13})-C_2^{QS}(q_{23})+3$$



$$Q_3=\sqrt{q_{12}^2+q_{13}^2+q_{23}^2}$$

Very large suppression fo the cumulant.

Remarks

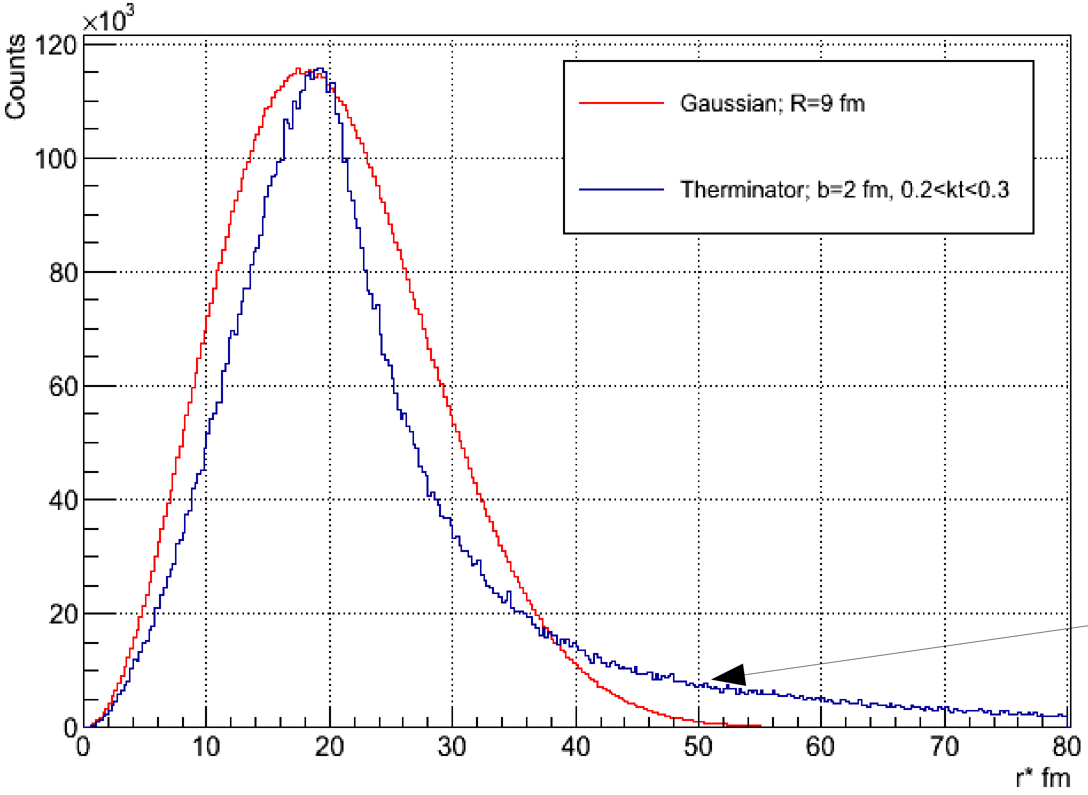
- Large λ discrepancy between C2(++) and C2(+-).
  - Therminator shows smaller discrepancy. The discrepancy can be caused by non-Gaussian features of C2(++).
  - When these are taken into account λ_{+-} can be used for C2(++).
- c3(+++) shows substantial suppression possibly caused by finite coherence.

BackUp

Distribution from Therminator

What about other sources of non-Gaussian features?
Other “chaotic” non-Gaussian features may bias determination of R_{coherent}.

Resonance decays will cause non-Gaussian features in the correlation function.
Therminator contains all of the known resonances.



Resonance “tails”

<u>Very clear difference.</u>
How does this effect the Gaussian assumption at the correlation function level?

C2, C3 HIJING after merging/splitting cuts