Pion interferometry with Lévy-stable sources in $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions at STAR

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Introduction to femtoscopy and the appearance of Lévy-type sources

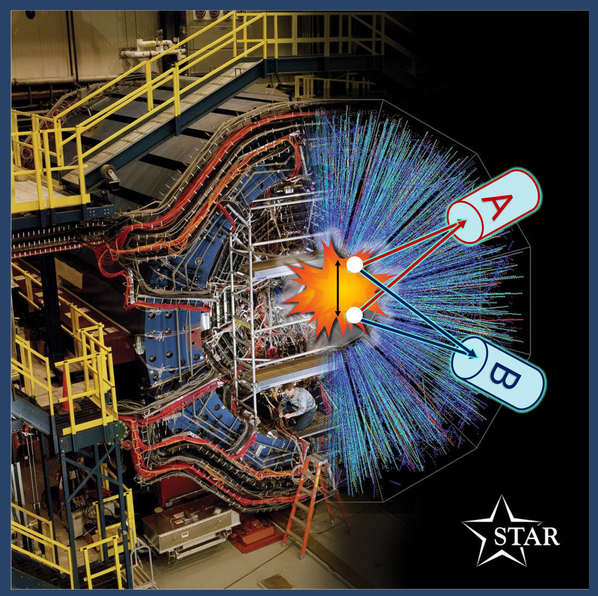
1) Femtoscopy for identical particles

- Pair momentum correlation (relative momentum Q):

$$C_2(Q) = \int D(r)\left|\psi_Q(r)\right|^2 dr$$

- Pair source function (pair separation r, avgerage mom. K):

$$D(r,K) = \int d^4\rho S\left(\rho + \frac{r}{2}, K\right) S\left(\rho - \frac{r}{2}, K\right)$$



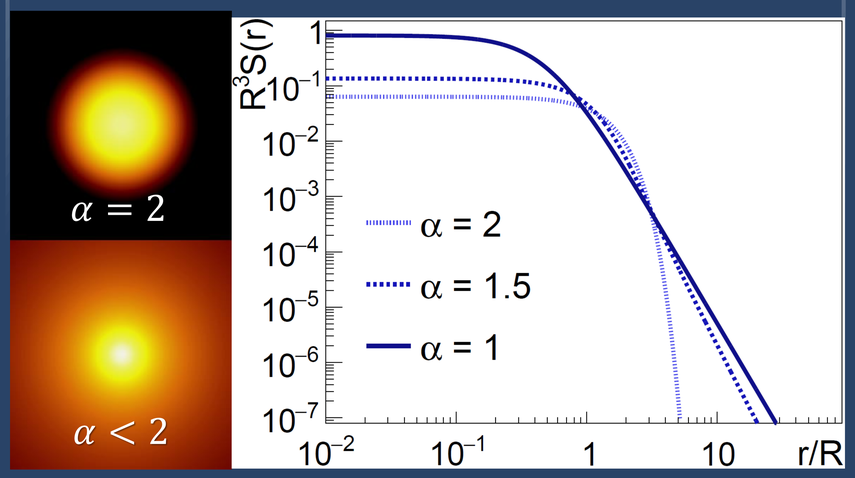
2) Lévy-type source functions

- Appearance of such sources [1-6]: anom. diff., crit. behavior, jets, decays

$$\mathcal{L}(\alpha, R; \boldsymbol{r}) = \frac{1}{(2\pi)^3}\int d^3\boldsymbol{q} e^{i\boldsymbol{q}\boldsymbol{r}} e^{-\frac{1}{2}|\boldsymbol{q}\boldsymbol{R}\boldsymbol{q}|^{\alpha/2}}$$

$$S(r) = \mathcal{L}(\alpha, R; r)$$
$$\Downarrow$$
$$D(r) = \mathcal{L}\left(\alpha, 2^{1/\alpha}R; r\right)$$

- Lévy exponent: $\alpha = 2$ Gaussian, $\alpha < 2$ power-law
- Lévy-scale parameter R: connection to geometry



3) Final-State Interactions (FSI)

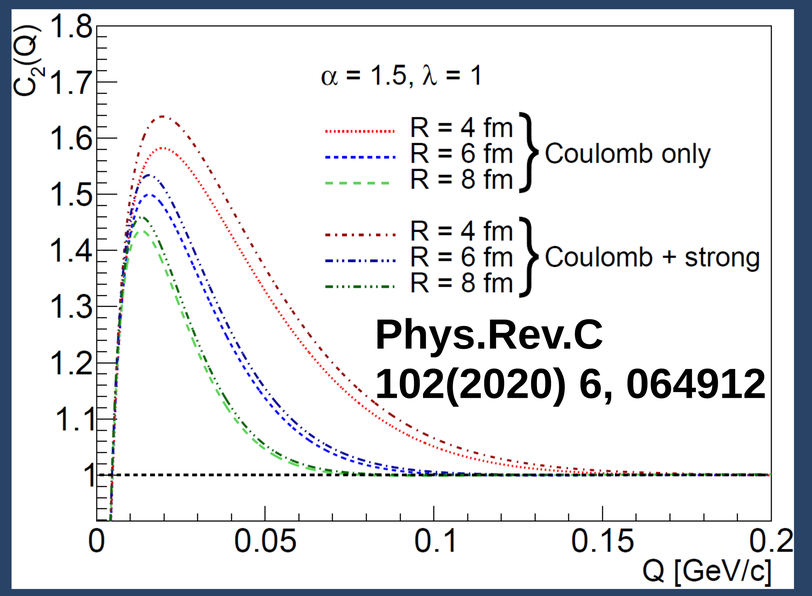
- Correlation function (w/o FSI, w strength param. λ):

$$C_0(Q) = 1 + \lambda \cdot e^{-(RQ)^\alpha}$$

- Correlation function with Coulomb correction $\mathcal{K}$ [6]:

$$C_2(Q) = 1 - \lambda + \lambda \cdot \mathcal{K} \cdot \left(1 + e^{-(RQ)^\alpha}\right)$$

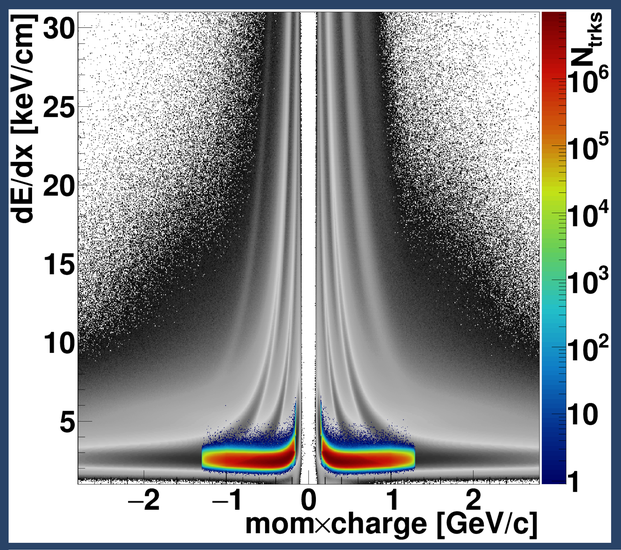
- $\mathcal{K} = \left(\int D(r)\left|\psi_Q(r)\right|^2 dr\right) / \left(1 + e^{-(RQ)^\alpha}\right)$
- Strong interaction - small effect [7]

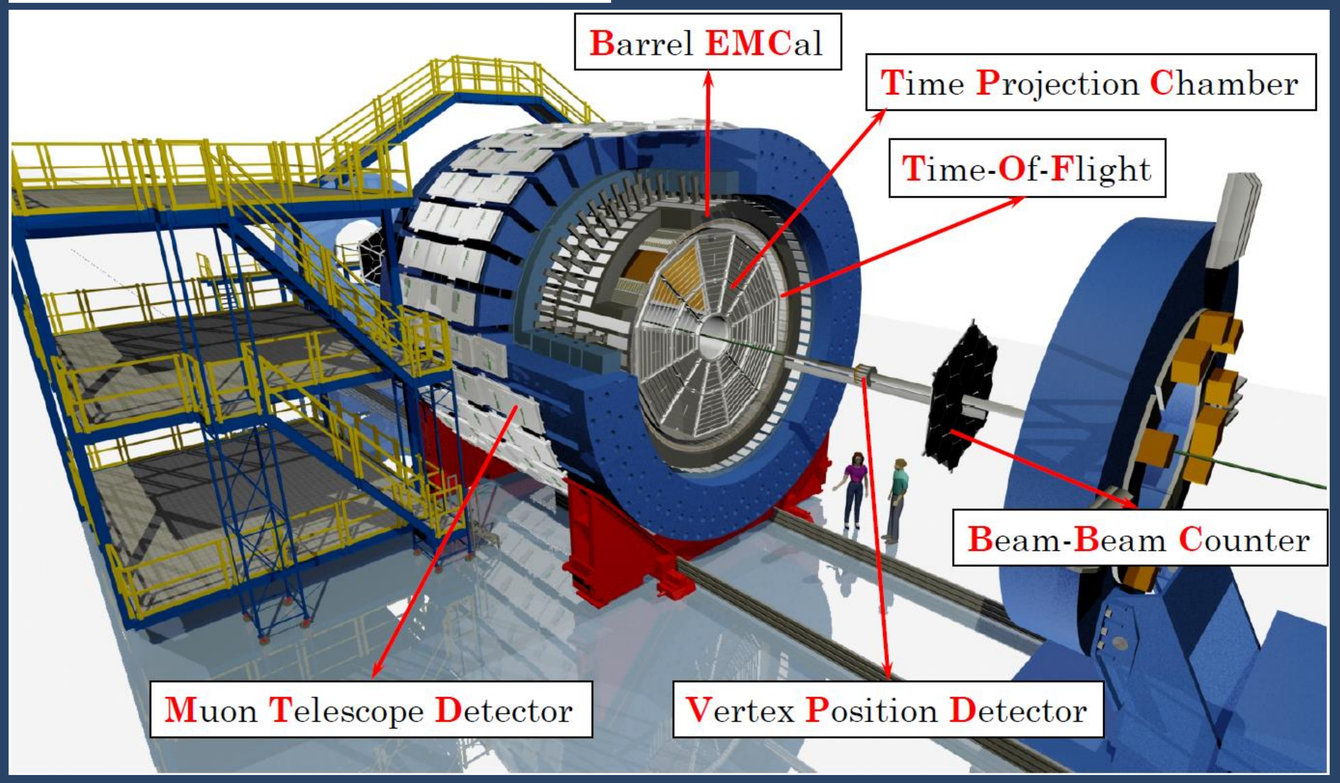


Measurement and fitting of two-pion correlation functions

4) The STAR experimental setup

- Vertex position, centrality: **BBC, VPD, TPC**
- Tracking and momentum reconstruction: **TPC**
- Particle ID: **TPC (dE/dx), TOF**



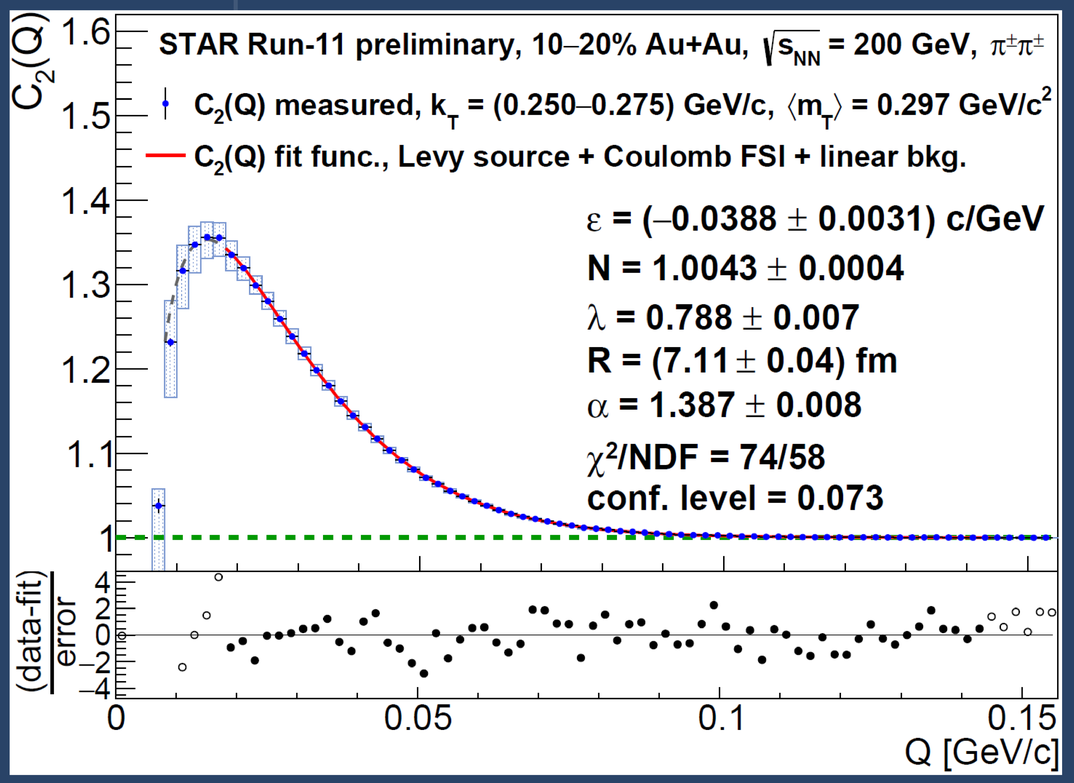


5) Measurement of the corr. func.

- Run-11 Au+Au, $\sqrt{s_{NN}} = 200\ \mathrm{GeV}$, ~550 M evts.
- Event-mixing: C(Q) = A(Q)/B(Q)
  - A(Q): pairs w members from same evt.
  - B(Q): pairs w members from diff. evt.
- C(Q) measurements:
  - Avg. tr. mom.: $k_T = 0.5\sqrt{K_x^2 + K_y^2}$ 21 bins, (0.175-0.750) GeV/c
  - Centrality: 0-10%,10-20%, 20-30%, 30-40%

6) Example fit to a measured C(Q)

- Iterative fitting method, Coulomb FSI & Lévy source
- Track and pair systematic uncert. illustrated with boxes
- Fit range study included in total systematic uncertainty
- Fits converged with conf.level > 0.001 in all cases



m_T and centrality dependence of the source parameters

7) Correlation strength λ

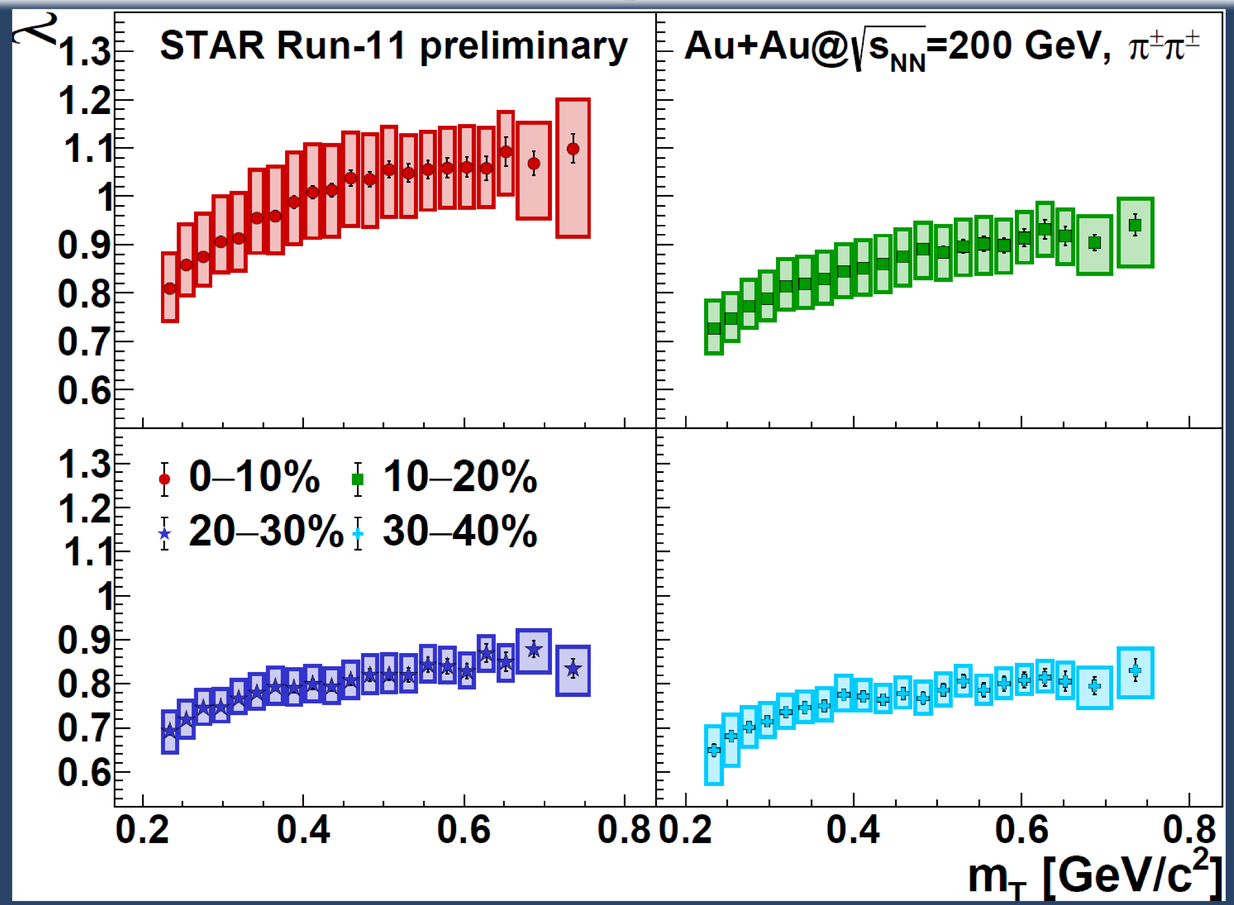
- Increase from low to high $m_T = \sqrt{m_\pi^2 + k_T^2}$
- Decrease from central to peripheral

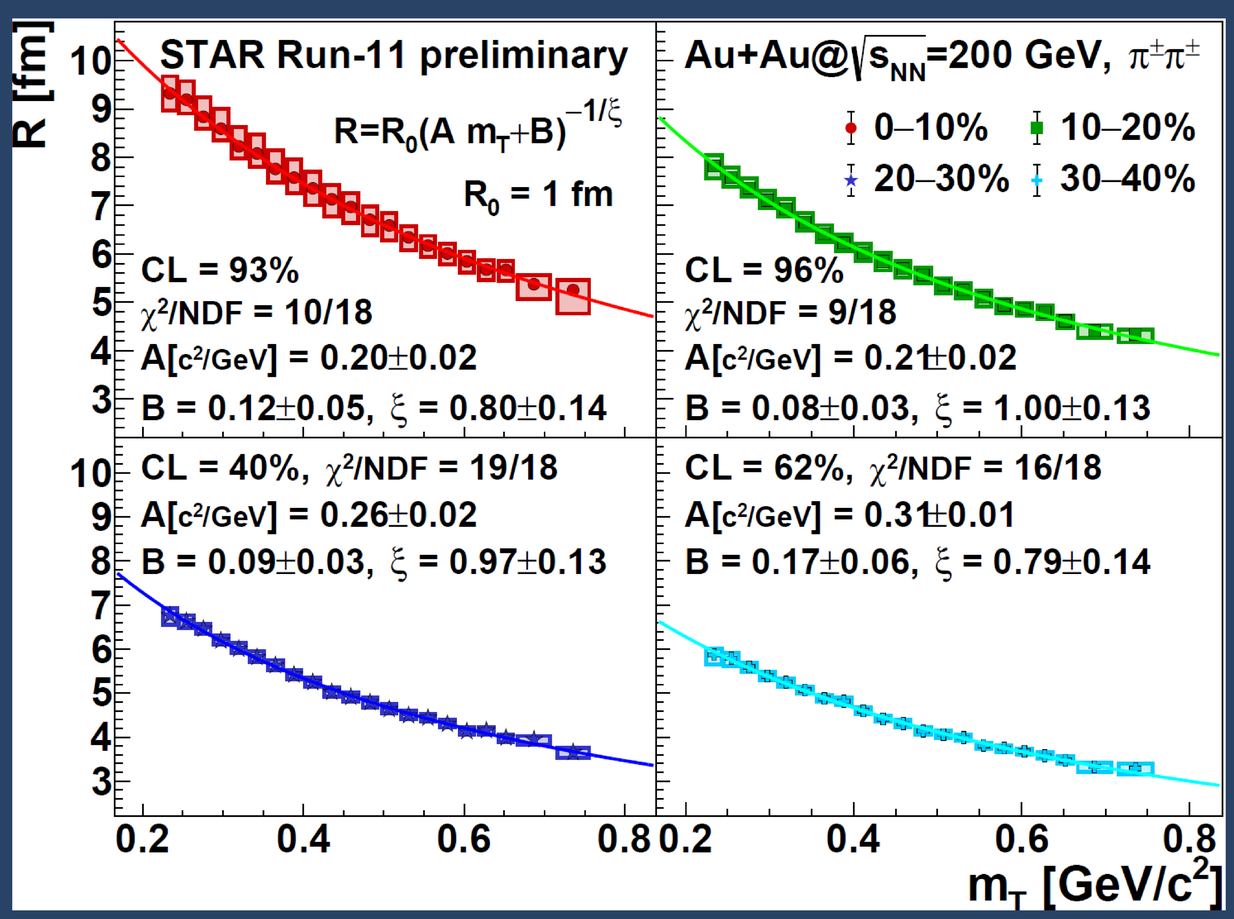
8) Lévy scale R

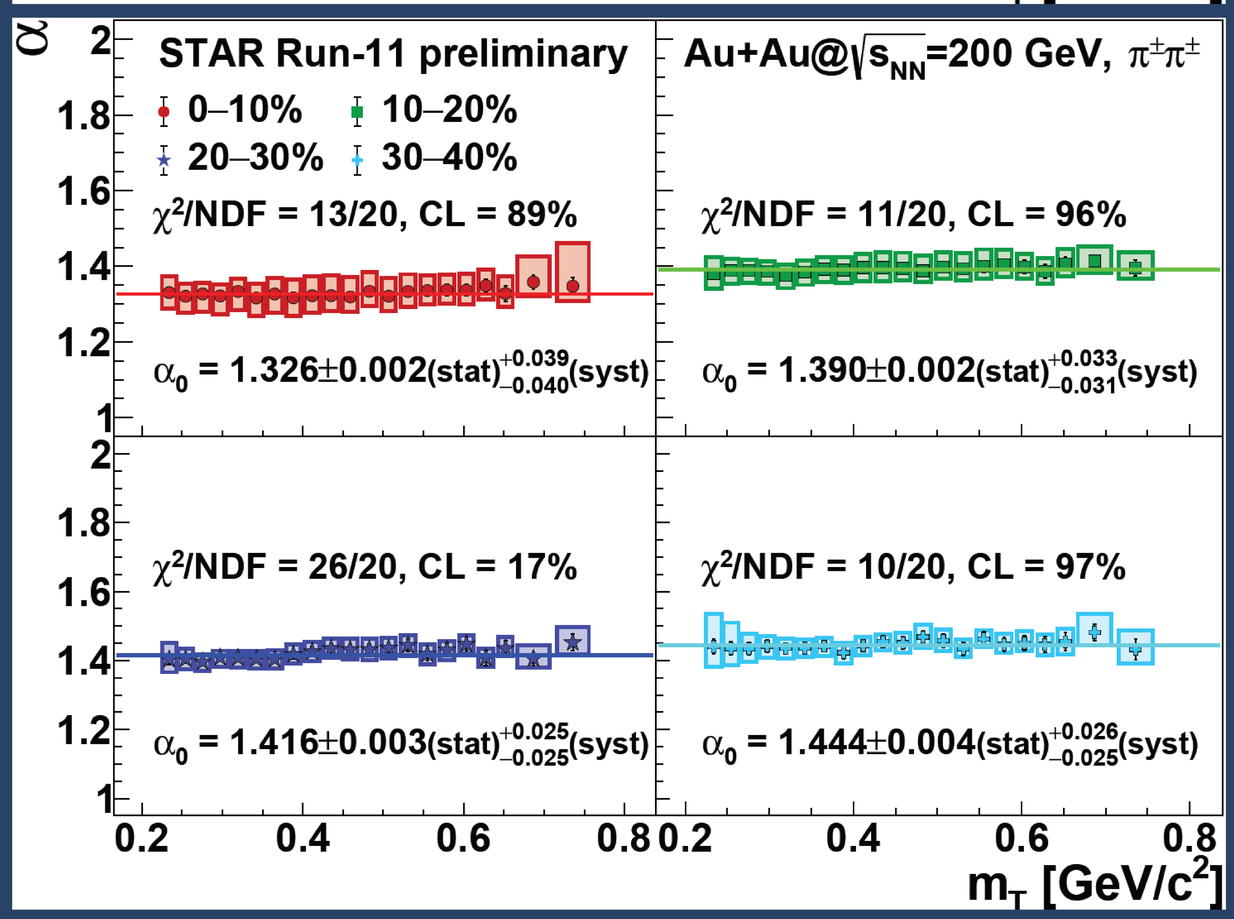
- $R = R_0(Am_T + B)^{-1/\xi}$
  good description for m_T dep.
- Decreases with centrality (connection to geometry)

9) Lévy exponent α

- $\alpha = \alpha_0$ constant fit,
  good description for m_T dep.
- Slight increase from central to peripheral



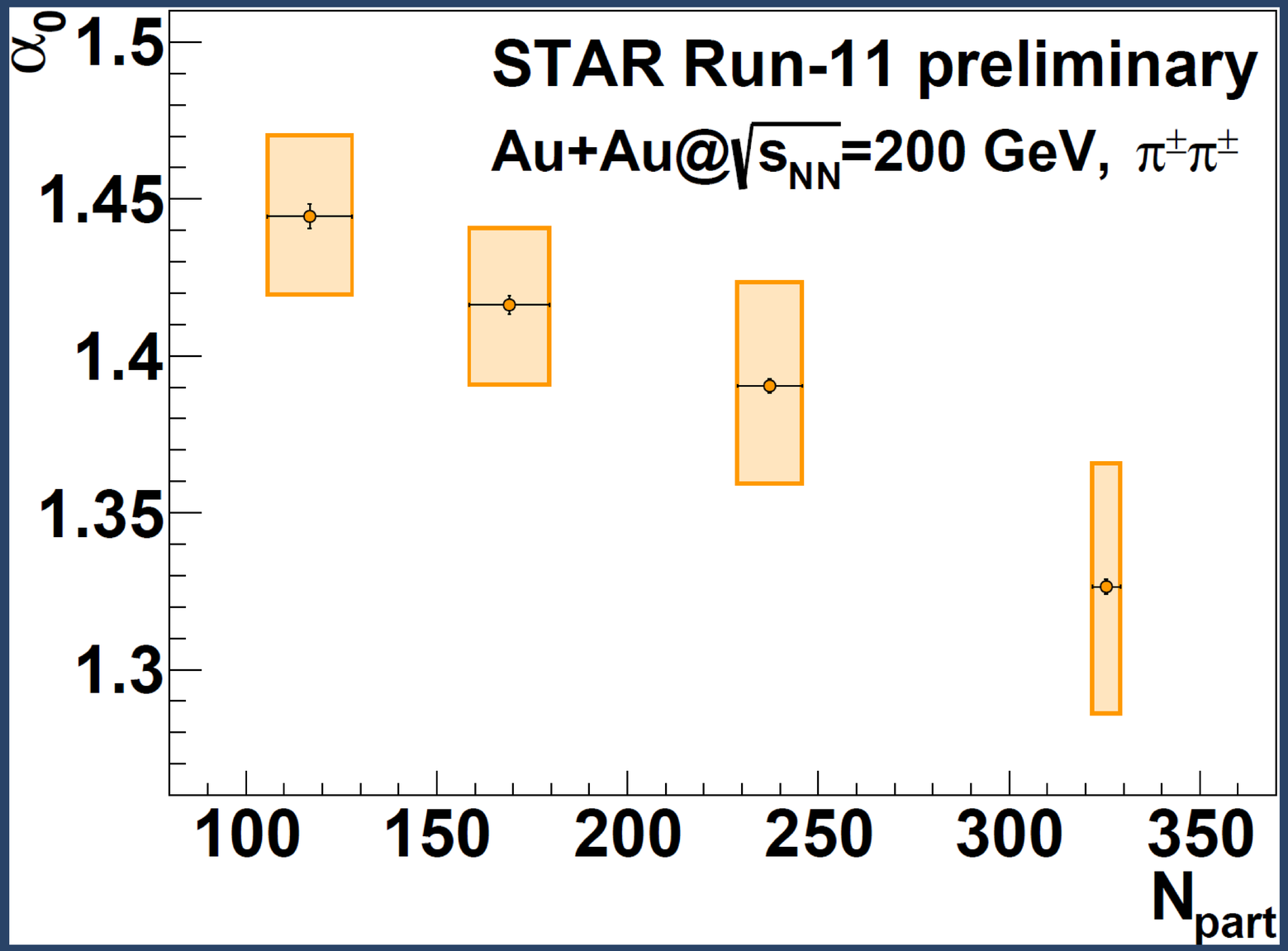




Conclusions

10) Summary, outlook

- Pion pair source described by Lévy distribution
- m_T and centrality dependence investigated
- Lévy-exponent $\alpha \approx 1.3 - 1.5$, not Gaussian ($\alpha \neq 2$)
- α independent of m_T, slightly decreasing with N_{part}
- Next steps:
  similar analysis in 3D,
  similar analysis for kaons,
  similar analysis at lower energies
- **For more discussion, come and check out the poster!**



11) References

[1] PHENIX Coll., Phys.Rev.C 97 (2018) 6, 064911
[2] Metzler, Klafter, Physics Reports 339(2000) 1-77;
[3] Csörgő, Hegyi, Zajc , Eur.Phys.J.C36(2004) 67;
[4] Csörgő, Hegyi, Novák, Zajc, AIP Conf.Proc. 828;
[5] Kincses, Stefaniak, Csanád, Entropy 2022, 24(3), 308
[6] Kurgyis, Kincses, Nagy, Csanád, Universe 9(2023) 328
[7] Kincses, Nagy, Csanád, Phys.Rev.C102(2020)6,064912