Femtoscopic results in pp and Pb-Pb collisions from ALICE

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Femtoscopy

The study of particle correlations on the scale of femto-meters.

We study 3 sources of femtoscopic correlations:

Quantum Statistics

<u>100% Chaotic Sources</u>

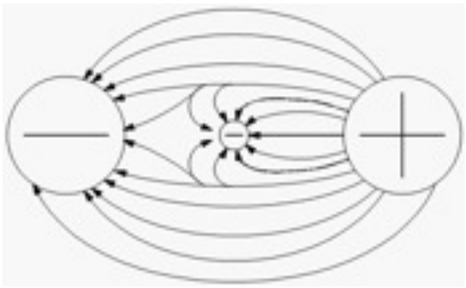
- Bunching of bosons in momentum space (“HBT”).
- Anti-bunching of fermions.

<u>100% Coherent Sources</u>

- Minimized ΔxΔp uncertainty.
- No HBT effect.

Coulomb Interactions

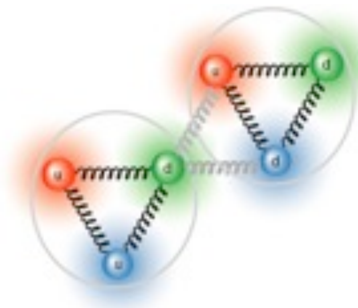
Electrostatic Attraction/Repulsion



Strong Interactions

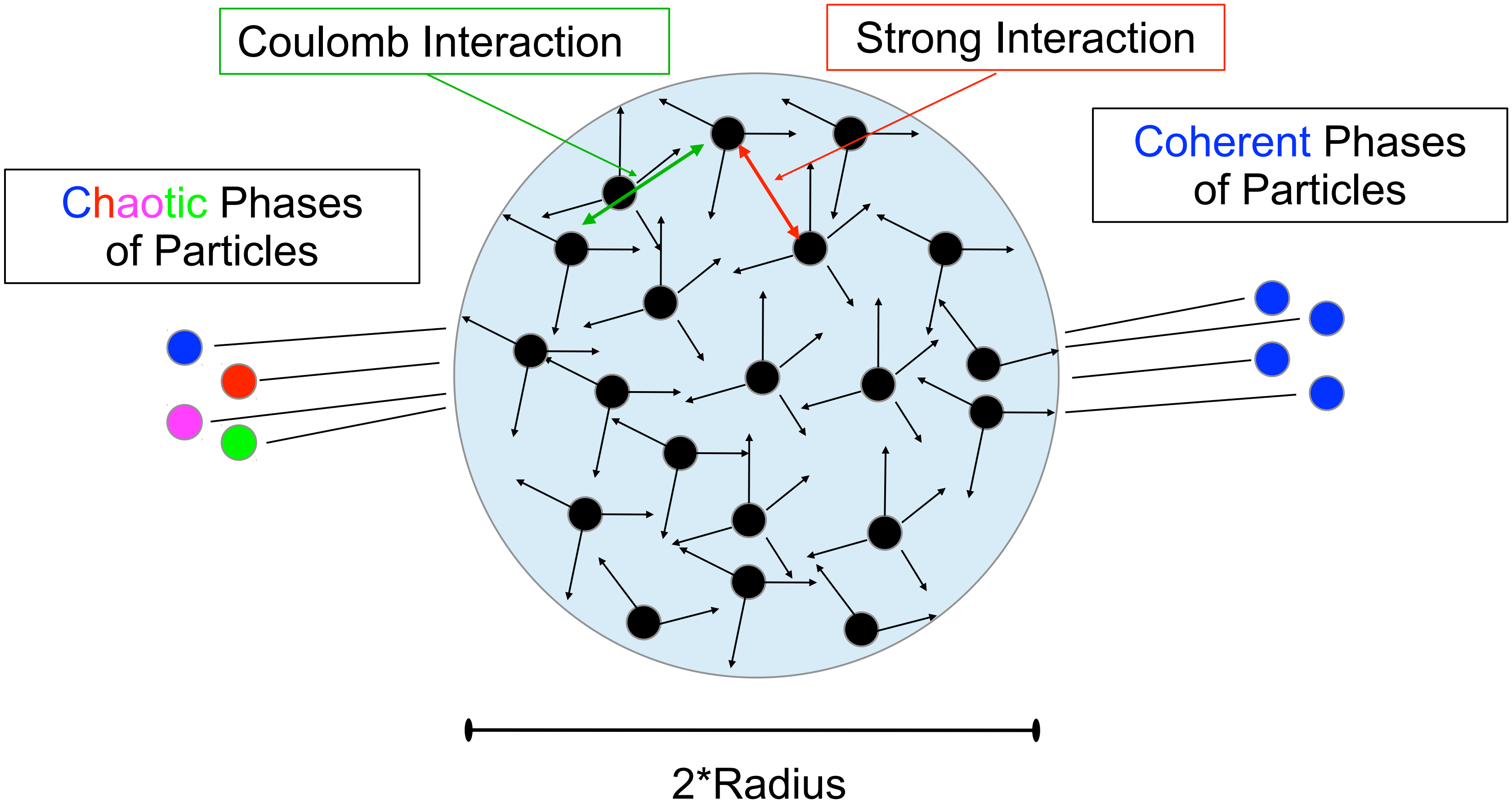
Color Attraction/Repulsion

- Least well-understood



All three can be used to learn about the particle emitting sources in the collisions.

A Superposition of Particle Emitting Sources



<u>We study the properties of the particle emitting sources:</u>

- Size and shape of regions of homogeneity?
- Chaotic or coherent particle emission?
- Strength of source-source dynamics?

2-particle Correlations

p_i = 4-momentum of particle i

Relative Momentum

$$q^{\mu} = (p_1 - p_2)^{\mu}$$

Average Momentum

$$K^{\mu} = \frac{(p_1 + p_2)^{\mu}}{2}$$

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

Same-Event pairs (numerator)

Mixed-Event pairs (denominator)

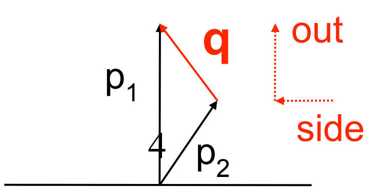
Projections

1-D
Invariant Relative Momentum

$$q_{inv} = \sqrt{-q^{\mu} q_{\mu}}$$

3-D
Longitudinally Co-Moving System (LCMS)

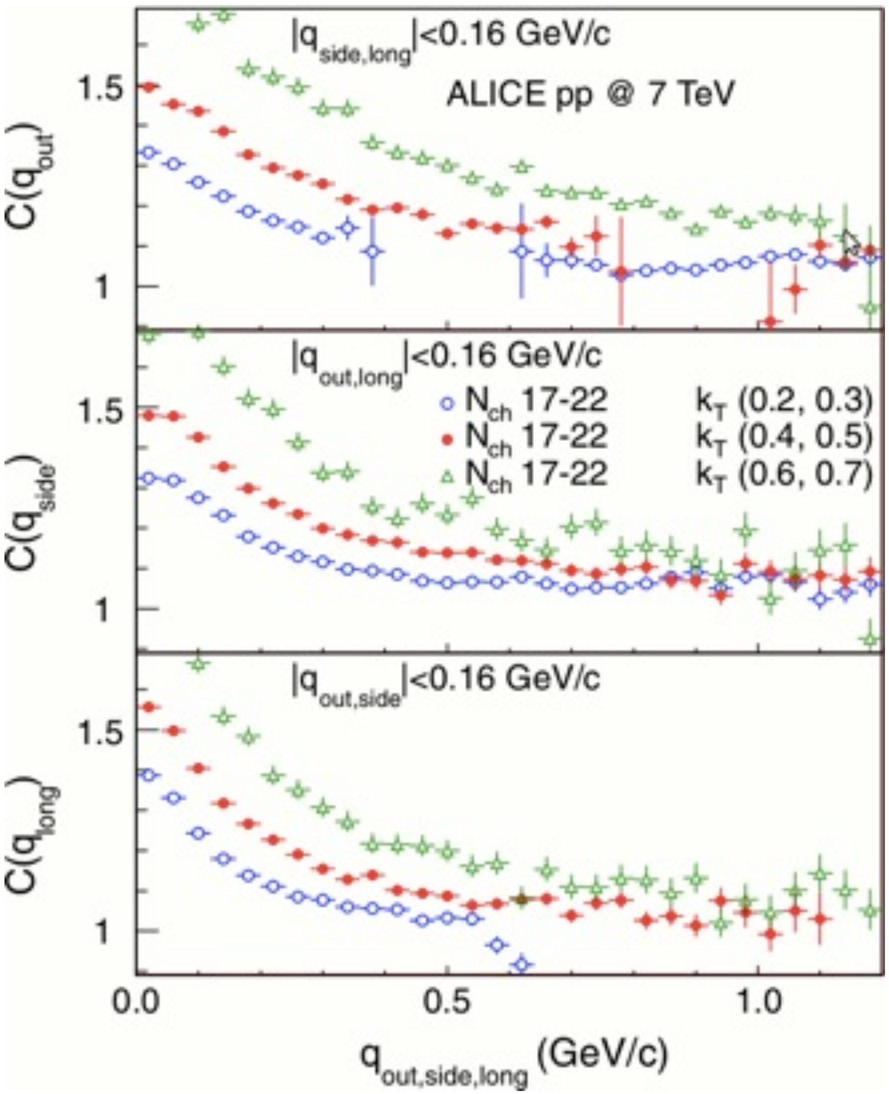
$$q_{out}, q_{side}, q_{long}$$



transverse plane

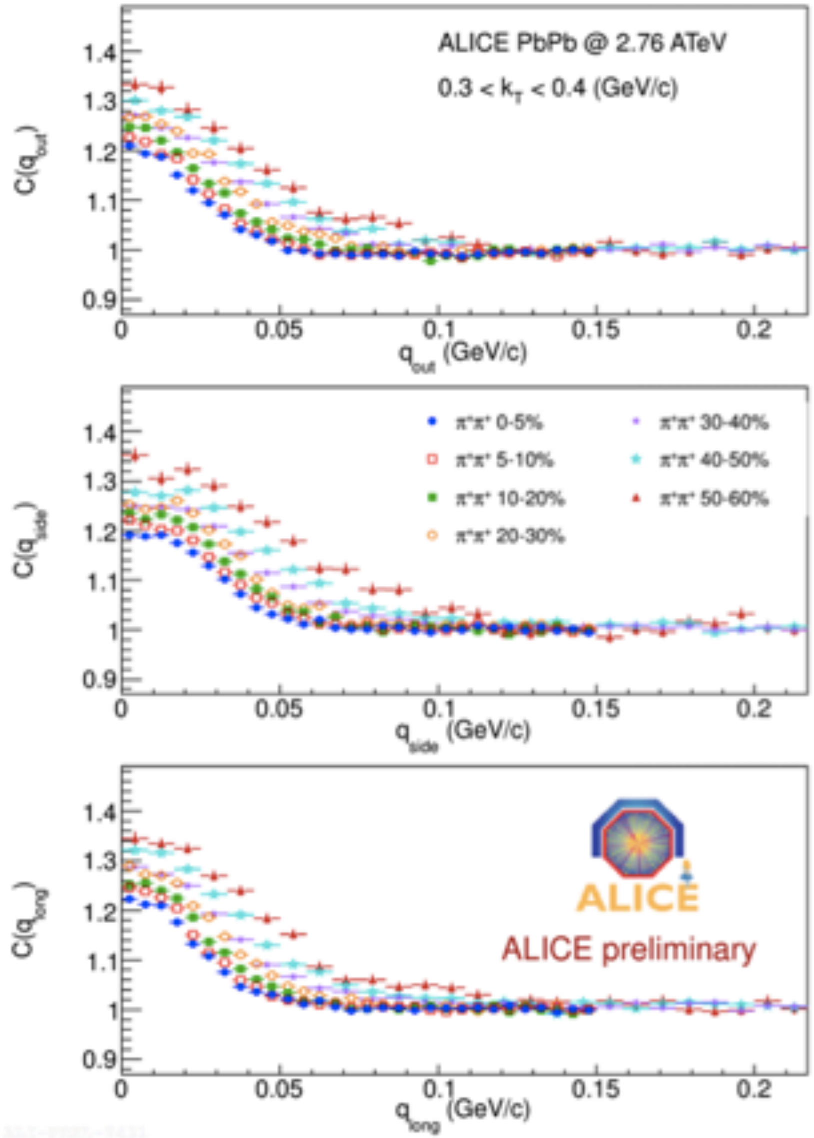
Early ALICE Results

2-pion same-charge correlations
pp $\sqrt{s}$ = 7 TeV



ALICE, Phys. Rev. D **84**: 112004

2-pion same-charge correlations
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV



Geometry of the Source

$$C_2(\boldsymbol{q},\boldsymbol{K})=\frac{\int d^4x_a d^4x_b s(p_a,x_a)s(p_b,x_b)|\phi(\boldsymbol{q}',\boldsymbol{r}')|^2}{\int d^4x_a d^4x_b s(p_a,x_a)s(p_b,x_b)}$$

Quantum Statistics Correlations

Space-time emission function

<u>Parameterize s with a Gaussian</u>

C_2 is then also a Gaussian

Evaluate in longitudinally co-moving system (LCMS)

$$C_2(\boldsymbol{q},\boldsymbol{K})=1+\lambda e^{-(R_{out}q_{out})^2-(R_{side}q_{side})^2-(R_{long}q_{long})^2}$$

- No FSI

$$C_2(\boldsymbol{q},\boldsymbol{K})=(1-\lambda)+\lambda K(1+e^{-(R_{out}q_{out})^2-(R_{side}q_{side})^2-(R_{long}q_{long})^2})$$

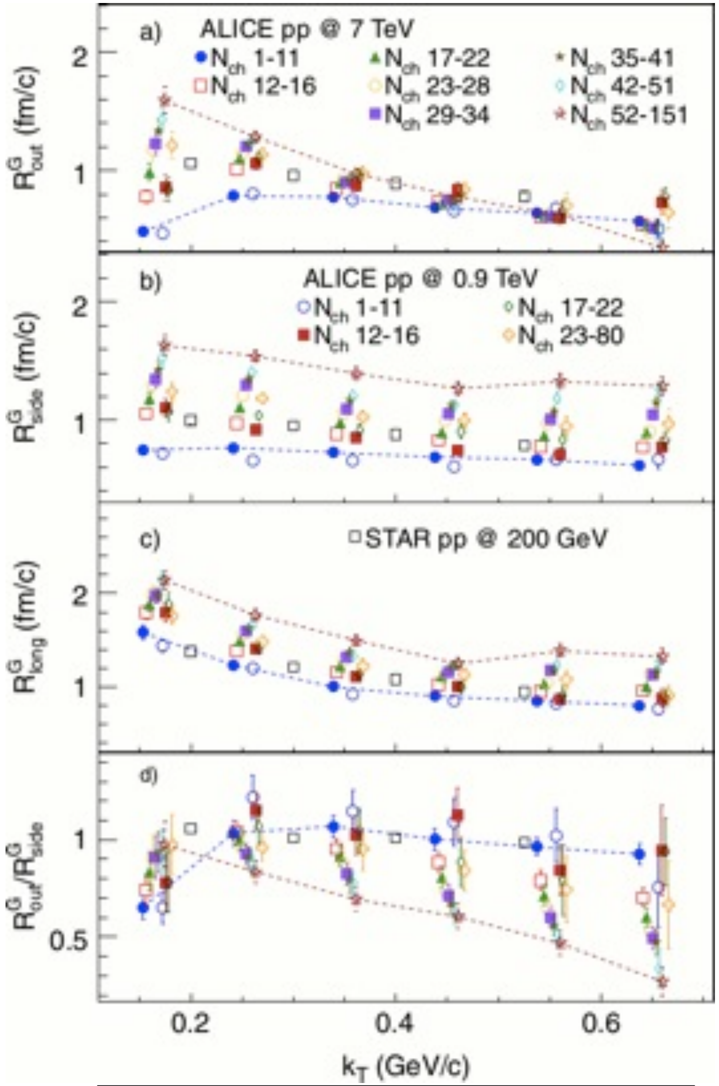
- With Coulomb Repulsion

Pair dilution factor

Coulomb factor

Early ALICE Results: k_t dependence

pp $\sqrt{s}$ = 7 TeV



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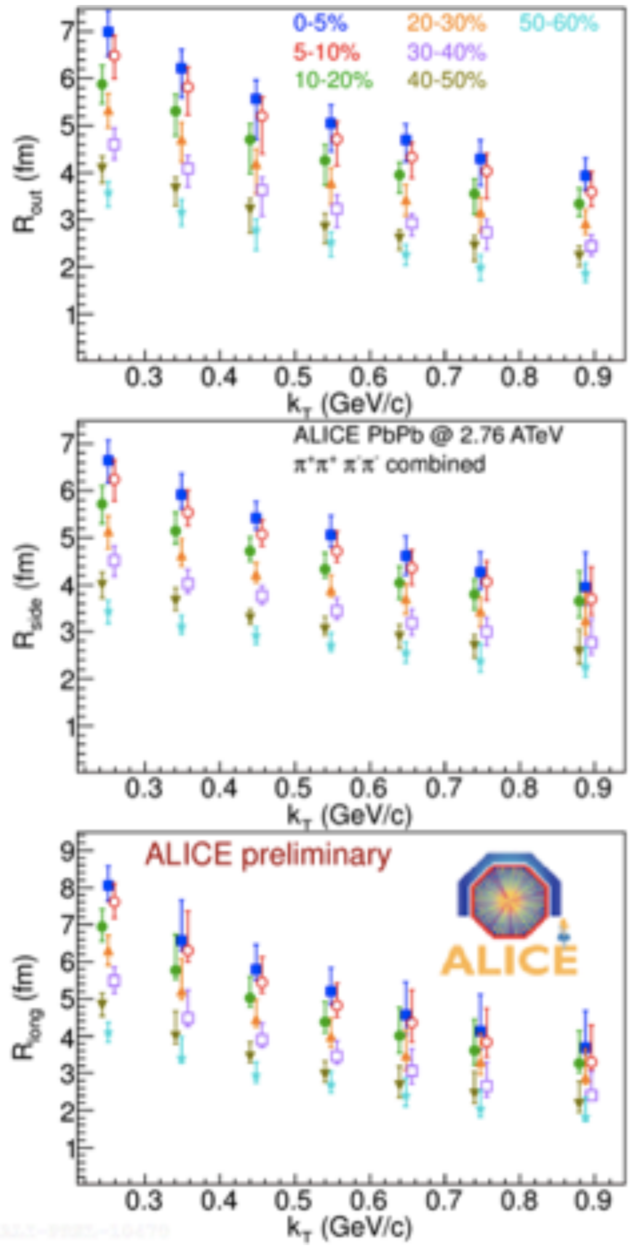
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV

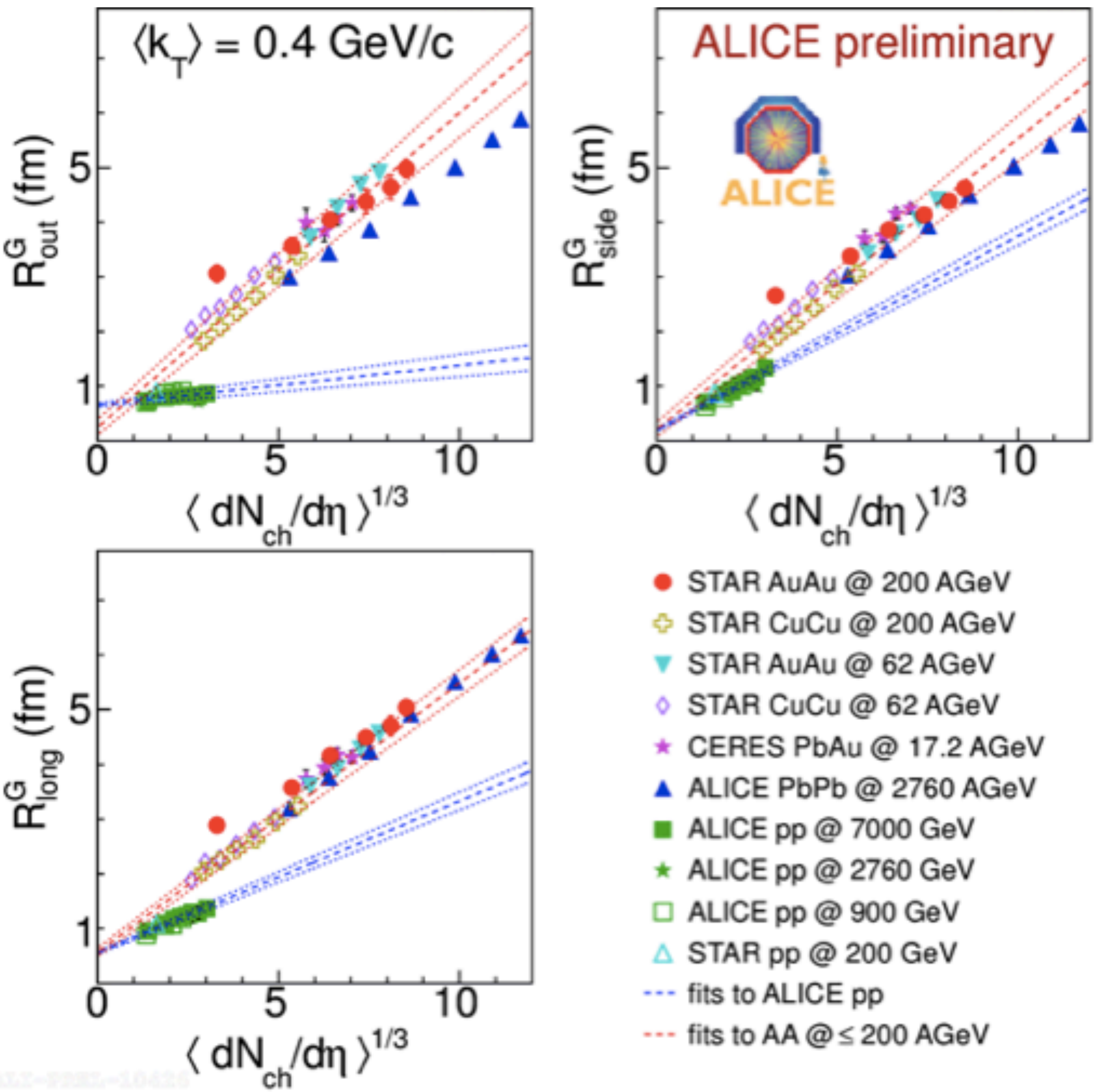


$$k_t = \left|\frac{p_1 + p_2}{2}\right|$$

- Radii decrease with increasing pion momentum in both systems
- Possible interpretation is radial flow

Different colors = Different multiplicity classes

ALICE Compared to the World

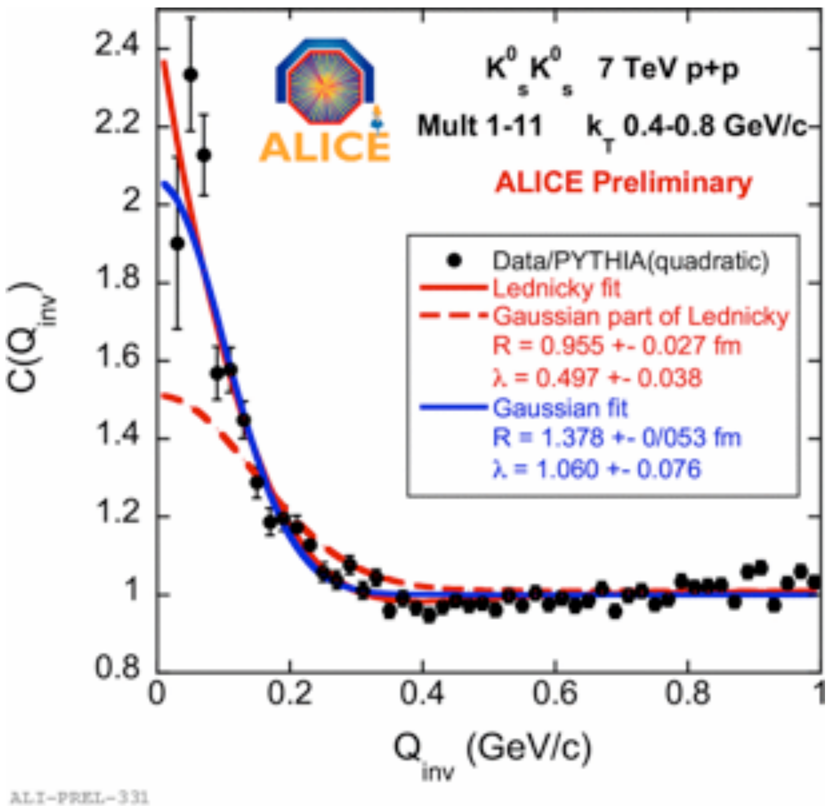


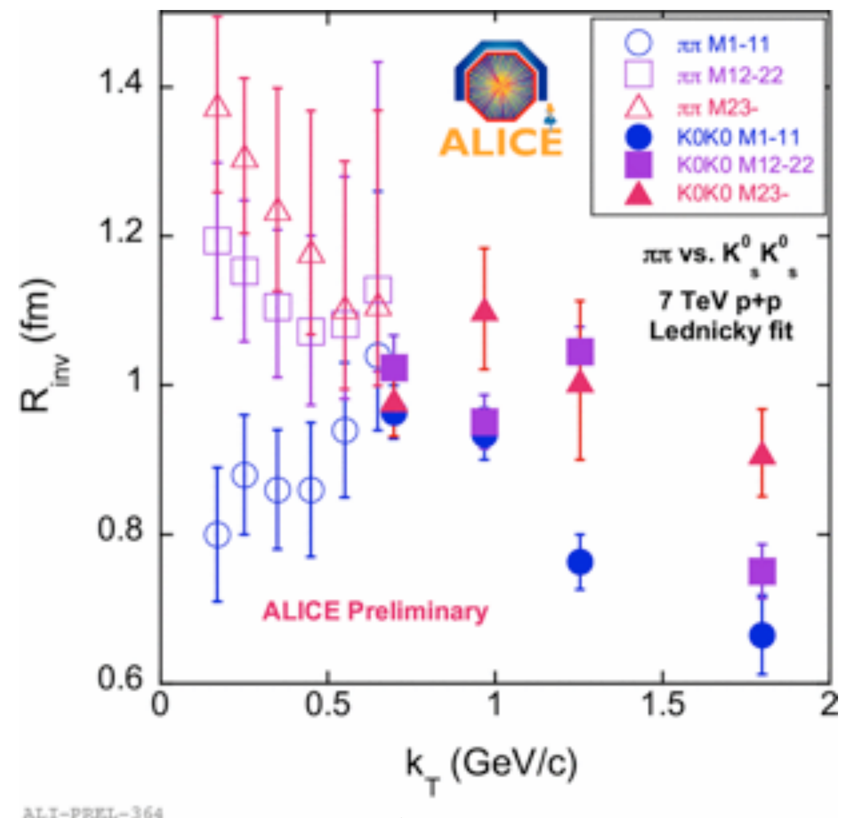
- Both systems scale linearly.
- No universal pp/AA scaling.
- R_{long} in great agreement with world data.
- R_{side} in good agreement with world data.
- R_{out} in fair agreement with world data.

K^0_S Femtoscopy

pp $\sqrt{s}$ = 7 TeV

Multiplicity Classes: M1-11, M12-22, M23-up



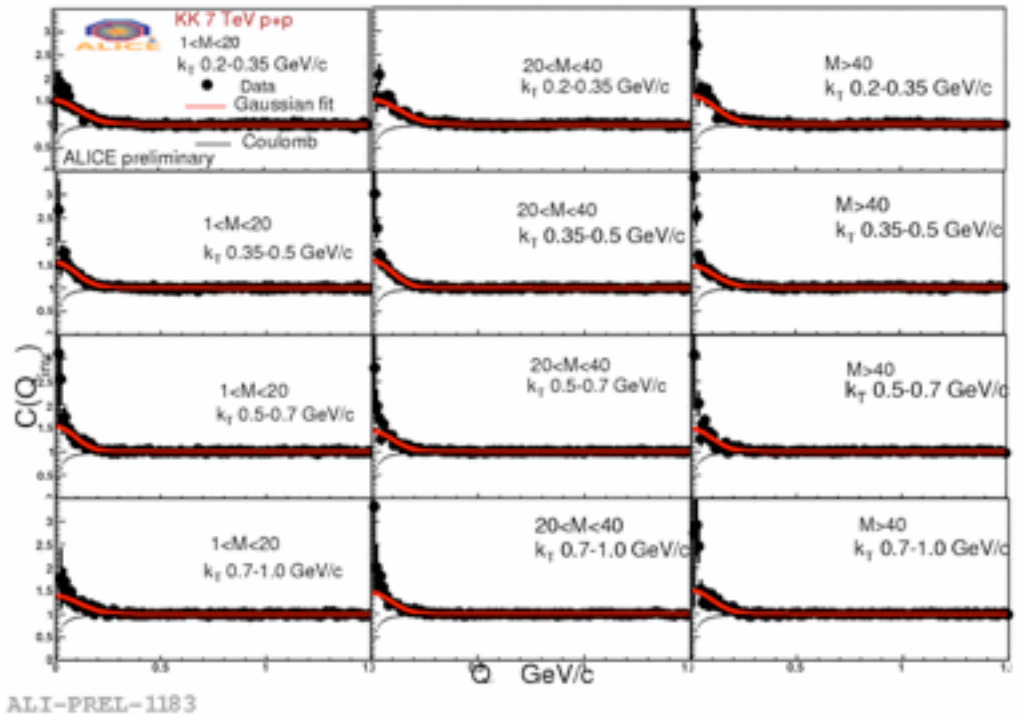


Extended k_t coverage

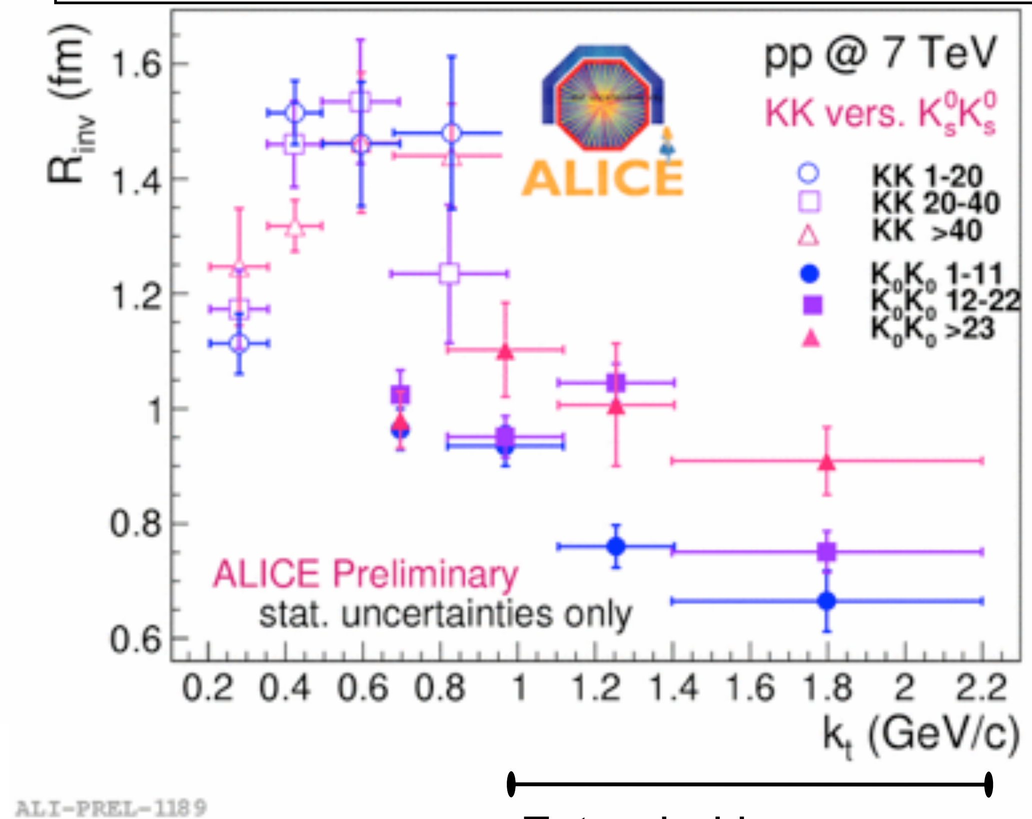
- Baseline estimated with PYTHIA.
- Strong interactions significant.
- Radii consistent with that from pion-pion channel.
- Low M Radii rise with kt for pions but not for K^0_S.
- Also being done in Pb-Pb 2.76 TeV!

K^{+-} Femtoscopy

pp $\sqrt{s}$ = 7 TeV



Different colors = Different multiplicity classes



Extended k_t coverage

- Low M Radii rise for charged kaons but not for $K^0{}_S$
- Also being done in Pb-Pb 2.76 TeV!

Ongoing Measurement in Pb-Pb: Chaoticity

<u>Why should we bother looking again?</u>

- NA44, WA98, and STAR have previously searched for coherent pion radiation. **However, Coulomb corrections were greatly over-estimated.**

Or

Quantum coherence affects all charge types and all orders of correlation functions

Akkelin, Lednicky, Sinyukov PRC 65:064904 (2002)

G(p) = Coherent fraction of pions with momentum p

$C_{QS}^{++}(p,q=0) = 2 - 4/5*G^2(p)$

$C_{QS}^{+-}(p,q=0) = 1 + 1/5*G^2(p)$

$C_{QS}^{00}(p,q=0) = 2 - 1/5*G^2(p)$

$C_{QS}^{+0}(p,q=0) = 1 - 2/5*G^2(p)$

Also, C_{QS}^{+++} and C_{QS}^{++-} provide additional sensitivity to coherent pion radiation.

- Global fit to 2-particle and 3-particle (same and mixed-charge) correlations to better determine the coherent fraction.

Conclusions

- Femtoscopic radii much larger at the LHC than RHIC (~x2).
- Radii in pp and AA show linear scaling with $(dN/d\eta)^{1/3}$.
  - They are very different however.
- Decreasing of radii with increasing k_t observed in Pb-Pb as well as pp.
  - Pions and kaons have consistent trends.
  - Possibly caused by flow in both collision systems.
- Lowest multiplicity bin in pp show an increase of the radii with k_t.
  - Possibly signals a transition from longitudinal flow to hydrodynamic flow.

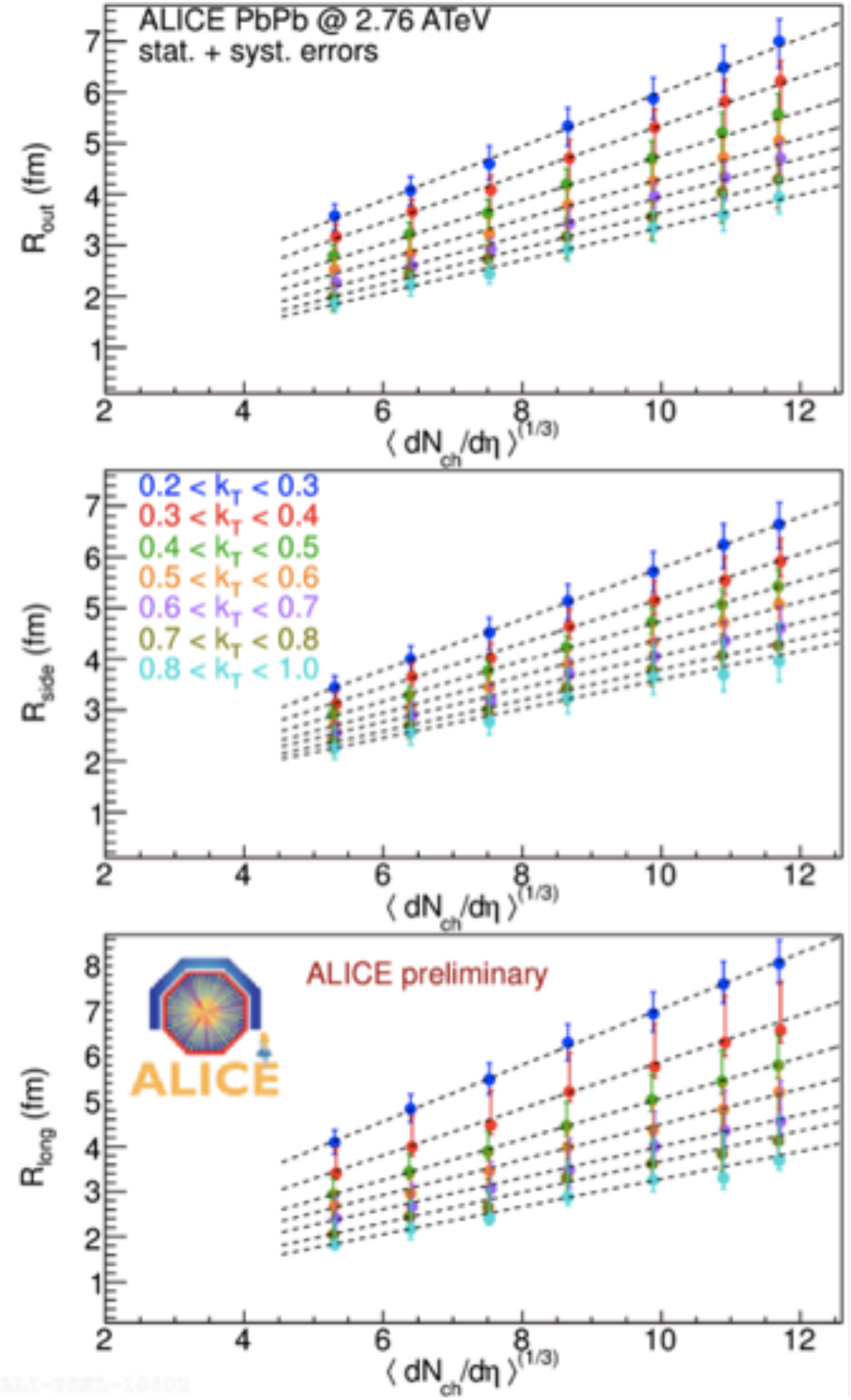
Much more to come.....

p-p, p-p, Λ-Λ, Λ-Λ, p-Λ, p-Λ...

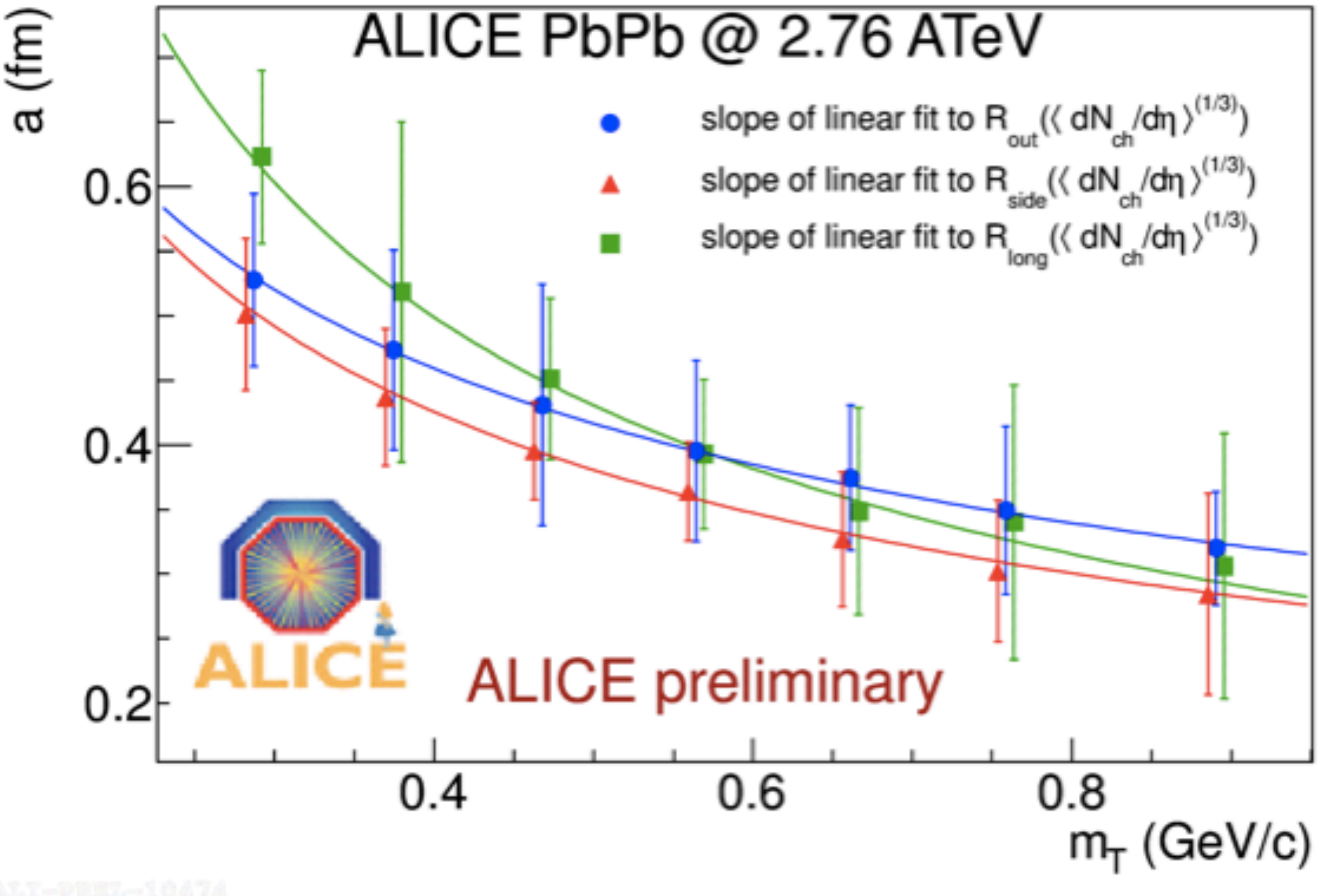
Backup Slides

Scaling

Radii scale linearly for each kt bin. This possibly means that there freeze-out occurs at a constant particle density.

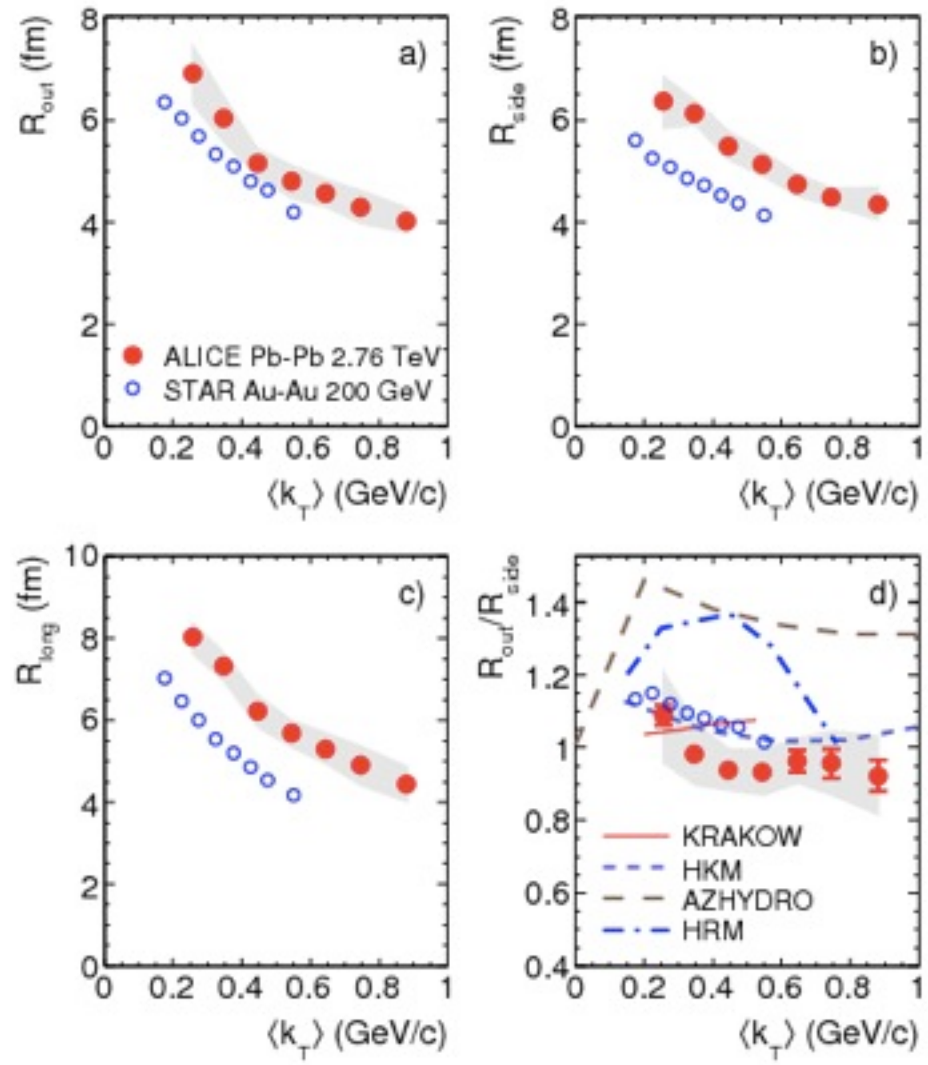


Scaling Slopes



slope parameters (R vs. kt fit) versus mt.

Hydro-Kinetic Model Comparison



Results from the first heavy-ion ALICE paper on femtoscopy