Dynamics of particle production in Au+Au collisions at 39 GeV

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STAR

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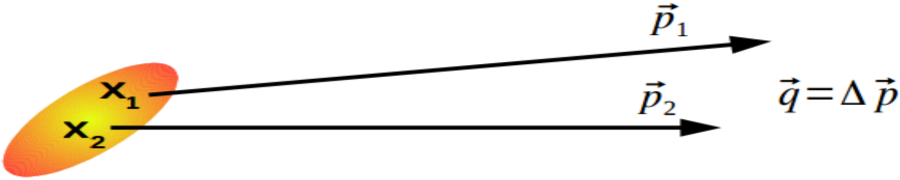
ZIMÁNYI SCHOOL'18
Budapest, 3-7.12.2018

HBT interferometry (Hanbury-Brown, Twiss)

Intensity interferometry $\rightarrow$ allows to study size of the emitting source by measuring a momentum distribution of emitted particles.
Originally this effect was used to study properties of stars

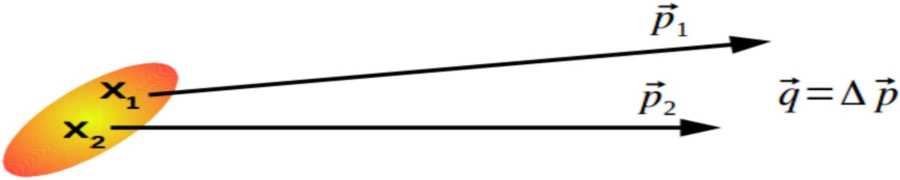
We can use a two-particle correlation to measure one of the smallest sizes in the nature ($\sim 10^{-15} m$)

Correlation Function



- analyze many pairs of particles $(\vec{p_1}, \vec{x_1})$ and $(\vec{p_2}, \vec{x_2})$ with relative momentum $\vec{q} = \vec{p_1} - \vec{p_2}$

Correlation Function



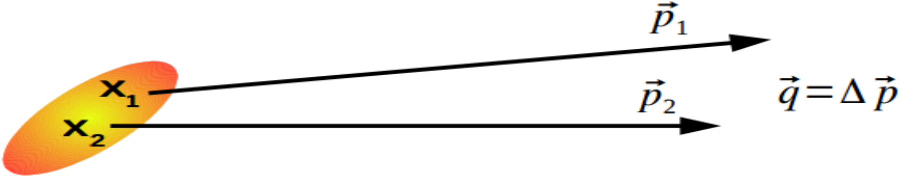
- analyze many pairs of particles $(\vec{p_1}, \vec{x_1})$ and $(\vec{p_2}, \vec{x_2})$ with relative momentum $\vec{q} = \vec{p_1} - \vec{p_2}$
- calculate correlation function (CF) of pairs:

$$CF(\vec{p_1}, \vec{p_2}) = \frac{P_2(\vec{p_1}, \vec{p_2})}{P_1(\vec{p_1})P'_1(\vec{p_2})}$$

$P_2(\vec{p_1}, \vec{p_2})$ — probability of observing two particles with momentum $\vec{p_1}$ and $\vec{p_2}$ at the same time and the same place

$P_1(\vec{p_1})$, $P'_1(\vec{p_2})$ — probability of observing two particles with momentum $\vec{p_1}$ and $\vec{p_2}$ separately

Correlation Function



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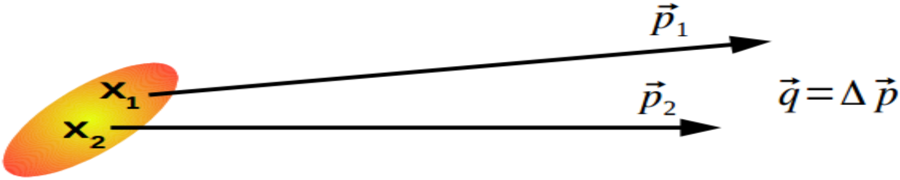
experimental correlation function:

$$CF(\vec{q}) = \frac{A(\vec{q})}{B(\vec{q})}$$

Correlation Function



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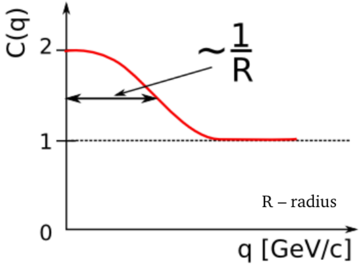


- calculate size of the source

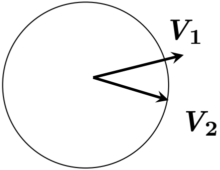
$P_2(\vec{p_1}, \vec{p_2})$ — probability of observing two particles with momentum $\vec{p_1}$ and $\vec{p_2}$ at the same time and the same place

$P_1(\vec{p_1}), P_1'(\vec{p_2})$ — probability of observing two particles with momentum $\vec{p_1}$ and $\vec{p_2}$ separately

Non-identical particle combinations

Time asymmetry

$t_1 \neq t_2$
$\Delta r = 0$

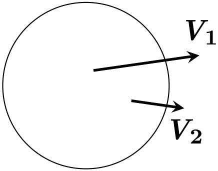


$t_1 > t_2$ - Catching up

$t_1 < t_2$ - Run away

Space asymmetry

$t_1 = t_2$
$\Delta r \neq 0$



Catching up

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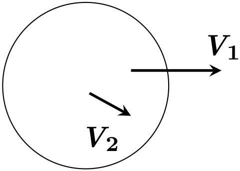


Run away

t — emission time

r — emission point distance from the center

R. Lednicky, et al.,
Phys. Lett. B373,
30-34 (1996)

Catching up
longer interaction,
strong correlation
Running away
shorter interaction,
weaker correlation

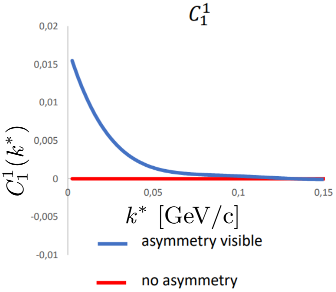
Spherical Harmonics

$$C(\mathbf{q}) = \sum_{l,m} C_l^m(q)\, Y_l^m(\theta, \phi) \qquad C_l^m(q) = \int_\Omega C(q, \theta, \phi)\, Y_l^m(\theta, \phi)\, d\Omega$$

Ω - full solid angle
$Y_l^m(\theta, \phi)$ - spherical harmonic function
$q = |\mathbf{q}|$, θ and ϕ - spherical coordinates

$C_0^0 \rightarrow$ sensitive to the size of the emitting source (shapes same as correlation function)

$C_1^1 \rightarrow$ sensitive to the spacetime emission asymmetry



P. Danielewicz and S. Pratt.
Phys. Lett B618: 60 2005

A. Kisiel and D.A. Brown
Phys. Rev. C80:064911 2009

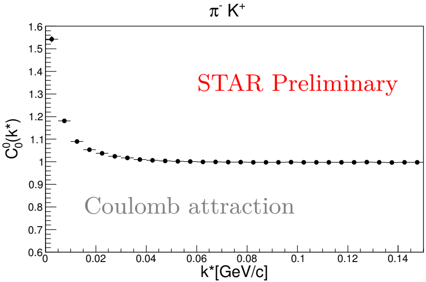
P. Danielewicz and S. Pratt.
Phys. Rev. C75:034907 2007

A. Kisiel
Phys. Rev. C81:064906 2010

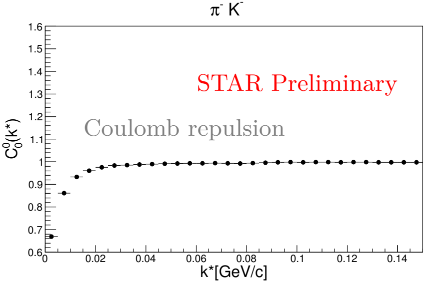
The shape of non-identical particle CF depends on FSI:

- Strong Interaction
- ***Coulomb force***
- ~~Quantum Statistics effect~~

Correlation between unlike-sign pairs



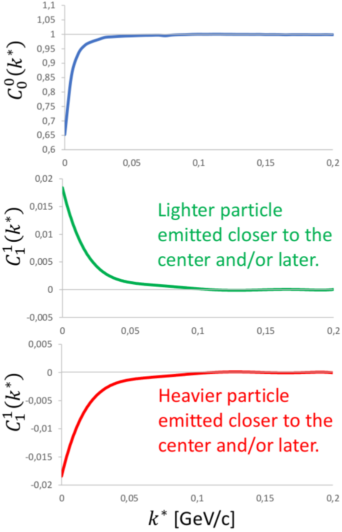
Correlation between like-sign pairs



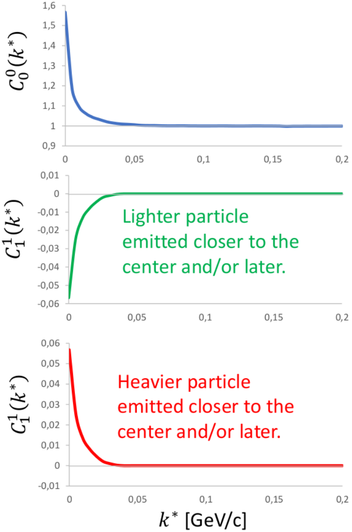
Au+Au @ 39 GeV, 0-10%

Which particle...?

Like-sign particle combinations



Unlike-sign particle combinations

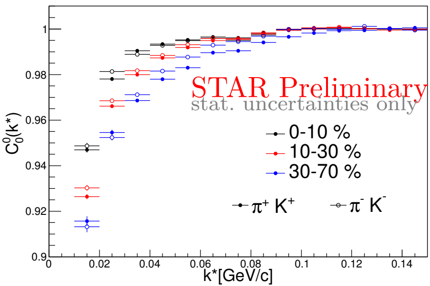


Results

Centrality dependence

$C_0^0 \rightarrow$ sensitive to the size of the emitting source

like-sign $\pi - K$ @ Au+Au 39 GeV



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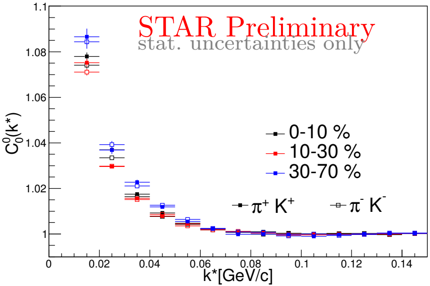


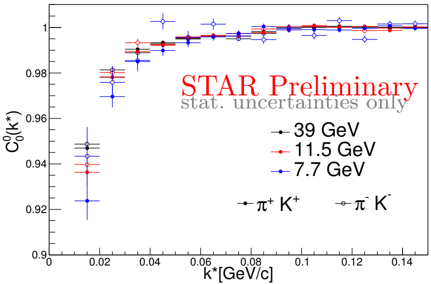
Clear centrality dependence

R(0-10%) > R(10-30%) > R(30-70%)

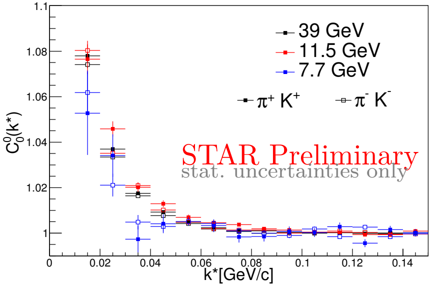
Energy dependence

$C_0^0 \rightarrow$ sensitive to the size of the emitting source

like-sign $\pi - K$: 0-10%



unlike-sign $\pi - K$: 0-10%



No significant dependence on energy.

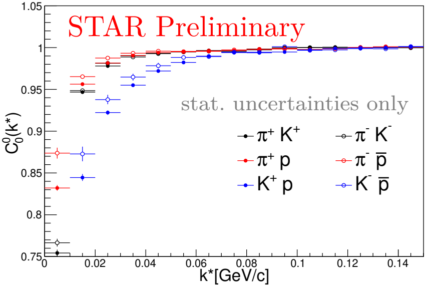
Required source parameters

(extracted fit parameters) to compare.

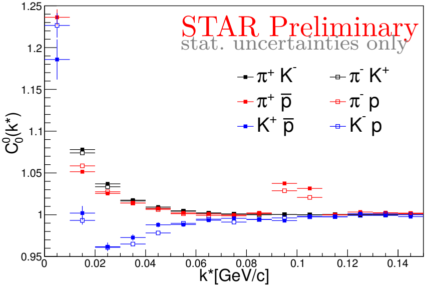
System dependence

Clear system dependence

like-sign @ Au+Au 39 GeV 0-10%



unlike-sign @ Au+Au 39 GeV 0-10%



Like sign: correlations are dominated by Coulomb interaction

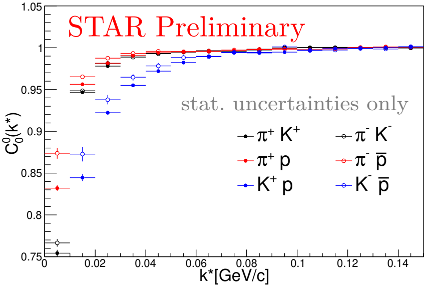
Coulomb strength depends on Bohr radius of the pair

K-p — lowest Bohr radius → strongest correlation

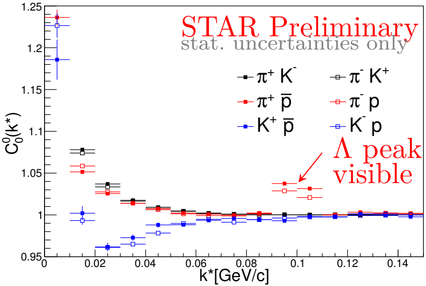
System dependence

Clear system dependence

like-sign @ Au+Au 39 GeV 0-10%



unlike-sign @ Au+Au 39 GeV 0-10%



Unlike sign: interactions are more complicated

Λ peak visible in pion-proton

System dependence

Clear system dependence

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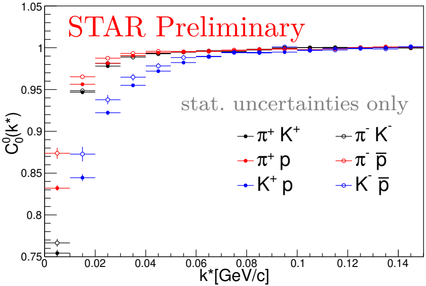

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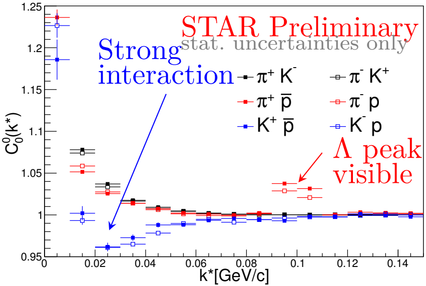


Unlike sign: interactions are more complicated

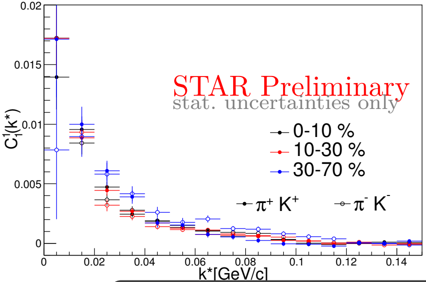
Λ peak visible in pion-proton

strong interaction is not negligible in kaon-proton

Emission asymmetry — centrality dependence

$C_1^1 \rightarrow$ sensitive to the space-time emission asymmetry

like-sign $\pi - K$ @ Au+Au 39 GeV



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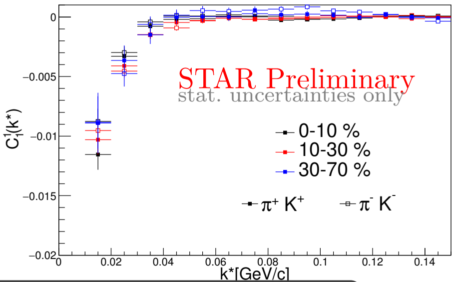


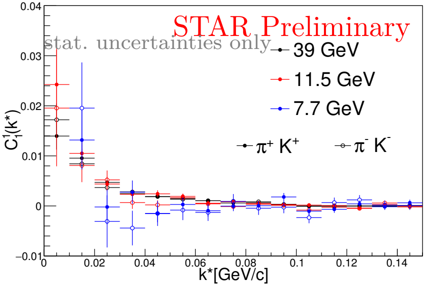
Clear signal of emission asymmetry

pions are emitted closer to center and/or later than kaons

Emission asymmetry — energy dependence

$C_1^1 \rightarrow$ sensitive to the space-time emission asymmetry

like-sign $\pi - K$: 0-10%



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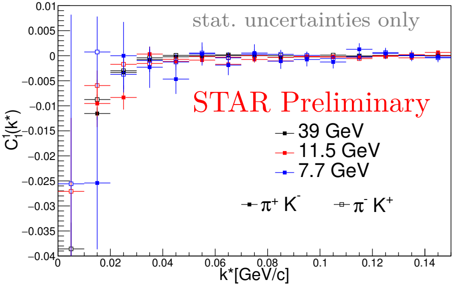

Clear signal of emission asymmetry

asymmetry does not disappear for low energies

Emission asymmetry — system dependence

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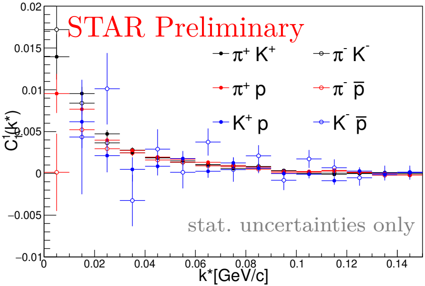
like-sign @ Au+Au 39 GeV 0-10%



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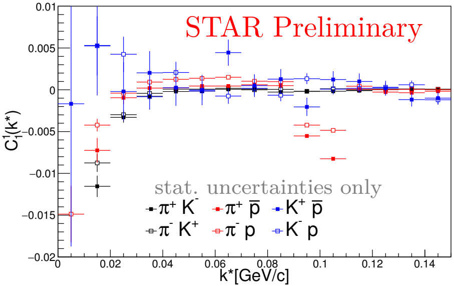

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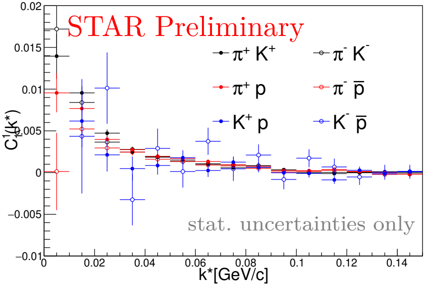

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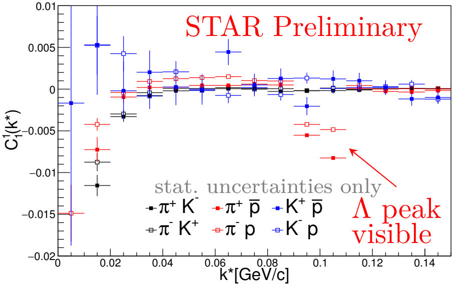

Expected ordering of particles:
Lighter particle is emitted closer to the center and/or later.

R. Lednicky, et al., Phys. Lett. B373, 30-34 (1996)

Emission asymmetry — system dependence

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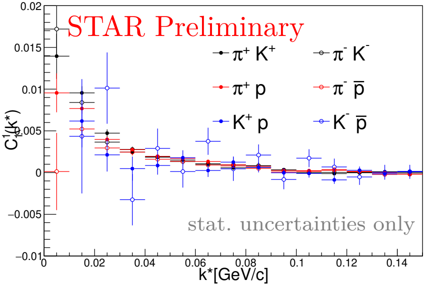

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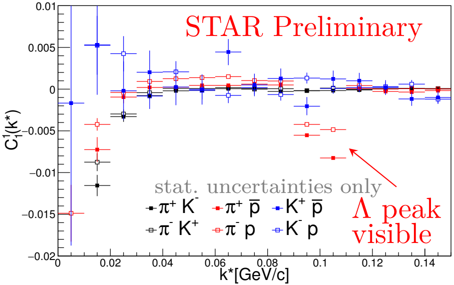

Heavier particles pushed by flow towards the edge of the source more strongly than lighter particles.
Heavier particles freeze-out earlier.

A. Kisiel Phys. Rev. C81:064906 2010

Summary

Geometry:

- Significant centrality and system dependence of the source size at BES energies
- **Strong interaction is not negligible in kaon-proton systems**

Dynamics:

- Clear signal of emission asymmetry for particles with different masses at BES energies
- Asymmetry does not disappear for low energies
- **Lighter particles are emitted closer to the center of the source and/or later than heavier particles — flow pushes heavier particles harder to the edge**

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Thank you for your attention!