Femtoscopy of neutral kaons

Diana Pawłowska
for the STAR Collaboration

Warsaw University of Technology

Faculty of Physics
WARSAW UNIVERSITY OF TECHNOLOGY

Zimanyi School 2020
Budapest (Hungary), December 7 - 11, 2020

Outline

- Main goals
- Motivation
- The STAR experiment at RHIC
- Femtoscopy
- Results
  - Therminator
  - Energy dependence
  - Centrality dependence
- Conclusions

Outline

- Main goals
- Motivation
- The STAR experiment at RHIC
- Femtoscopy
- Results
  - Therminator
  - Energy dependence
  - Centrality dependence
- Conclusions

- study the theoretical size of the neutral kaon emitting source
- compare with the experimental results

Outline

- Main goals
- Motivation
- The STAR experiment at RHIC
- Femtoscopy
- Results
  - Therminator
  - Energy dependence
  - Centrality dependence
- Conclusions

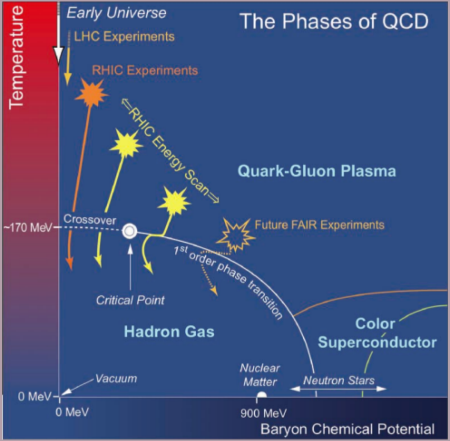
- study the theoretical size of the neutral kaon emitting source
- compare with the experimental results

Why do we analyse kaons?

Kaons can provide complementary information to pions:

- contain strange quarks
- less affected by the feed-down from resonance decays
- smaller cross section with the hadronic matter

The STAR experiment at RHIC



- RHIC was built to find QGP (new and complicated phase of matter)
- The main goals of the BES program include:
  - turn-off QGP signature
  - find critical point between cross-over and the first-order phase transition
  - examine the area between the hadronic and quark-gluon matter (first order phase transition)

$$\sqrt{s_{NN}} = 7.7 \text{ - } 200 \text{ GeV}$$
$$20 \text{ MeV} < \mu_B < 420 \text{ MeV}$$

Femtoscopy

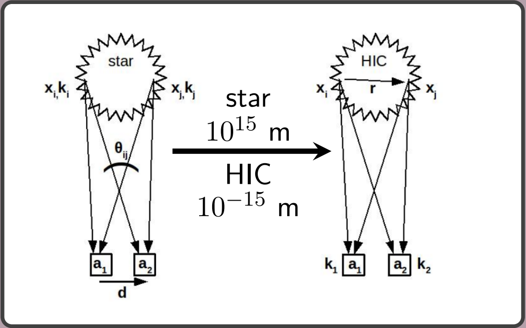
Hanbury Brown and Twiss interferometry

HBT

measure the angular size of astronomical objects through the use of Michelson interferometry

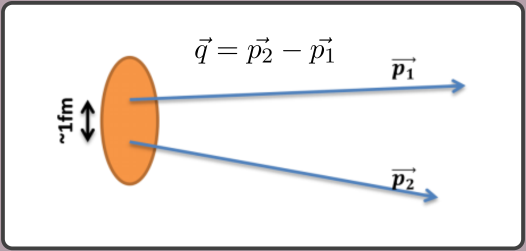
Femtoscopy

examine the particle-emitting source by measuring a momentum distribution



R.Lednicky, Nucl.Phys. A774 (2006) 189-198

Correlation function



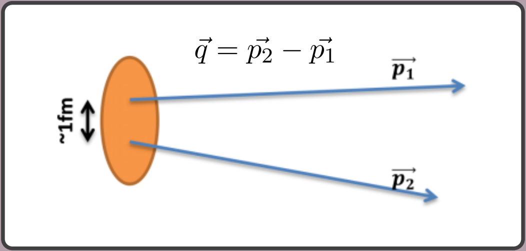
Theory

$$C_2(\vec{p_1}, \vec{p_2}) = \frac{P_2(\vec{p_1}, \vec{p_2})}{P_1(\vec{p_1})P_1(\vec{p_2})}$$

P_2 - the probability of finding two particles at the same place and time

P_1 - the probability of finding these particles separately

Correlation function



Theory

$$C_2(\vec{p_1}, \vec{p_2}) = \frac{P_2(\vec{p_1}, \vec{p_2})}{P_1(\vec{p_1})P_1(\vec{p_2})}$$

P_2 - the probability of finding two particles at the same place and time

P_1 - the probability of finding these particles separately

Experiment

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

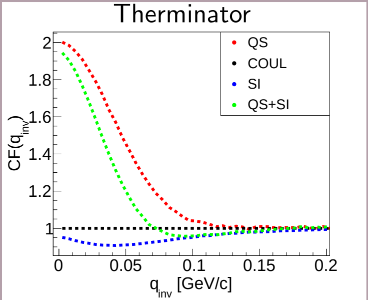
$A(\vec{q})$ - the measured distribution of pairs from the same event

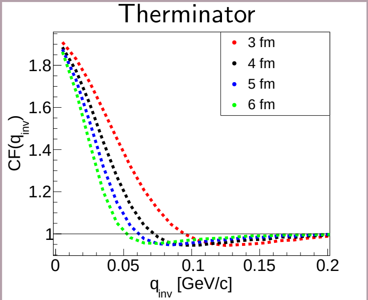
$B(\vec{q})$ - the reference distribution of pairs from mixed events

Correlation function

The shape of the kaon correlation function depends on:

- Quantum Statistical effects (QS)
- Final State Interactions (FSI)
  - ~~Coulomb Interaction (COUL)~~
  - Strong Interaction (SI)





Fitting procedure

Lednicky & Lyuboshitz model

R.Lednicky and V.L. Lyuboshitz, Sov.J.Nucl.Phys. 35, 770 (1982)

$$C(q_{inv}) = 1 + \lambda \left[\exp[-R_{inv}^2 q_{inv}^2] + \frac{1}{2} \left(\left| \frac{f(k^*)}{R_{inv}} \right|^2 + \frac{4\Re f(k^*)}{\sqrt{\pi} R_{inv}} F_1(q_{inv} R_{inv}) - \frac{2\Im f(k^*)}{R_{inv}} F_2(q_{inv} R_{inv}) \right) \right]$$

λ - the correlation strength; R_{inv} - the size of the particle-emitting source

$$F_1(z) = \int_0^z dx \frac{\exp[x^2 - z^2]}{z}, F_2(z) = \frac{1 - \exp[-z^2]}{z}$$

$f(k^*)$ is the s-wave scattering amplitude for a given system

$$f(k^*) = \frac{1}{2}[f_0(k^*) + f_1(k^*)]$$

$$f_I(k^*) = \frac{\gamma_r}{m_r - s - i\gamma_r k^* - i\gamma_r' k_r'}$$

$$s = 4(m_K^2 + k^{*2})$$

$\gamma_r(\gamma_r')$ - refers to the coupling of the resonanses to the f_0 and a_0 channels,; m_r - the resonance mass; k_r' - refers to the momentum in the PRF for the second decay channel.

Results

Therminator

THERMal heavy **I**o**N** gener**ATOR 2**

"is a Monte Carlo generator written in C++ and using the standard CERN ROOT environment. That way, apart from model applications, the code can be easily adapted for purposes directly linked to experimental data analysis, detector modeling, or estimates for the heavy-ion experiments at RHIC, LHC, SPS, FAIR, or NICA."

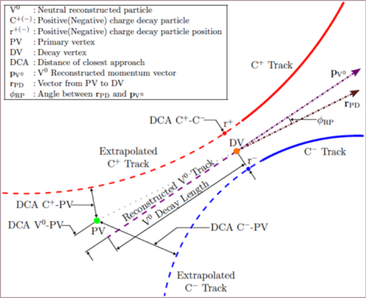
Comput.Phys.Commun. 183 (2012) 746-773
Proc.SPIE Int.Soc.Opt.Eng. 11581 (2020) 1158104

Analysis details

Therminator data

- **1D Femtoscopy of $K^0_S K^0_S$ pairs**
- **Au+Au** collisions at BES energies

Energy [GeV]	no. of events
200 (0-5%)	50k
200 (0-10%)	100k
200(10-70%)	300k
62.4 (0-5%)	50k
39 (0-5%)	50k
27 (0-5%)	50k
19.6 (0-5%)	50k
11.5 (0-5%)	50k
7.7 (0-5%)	50k

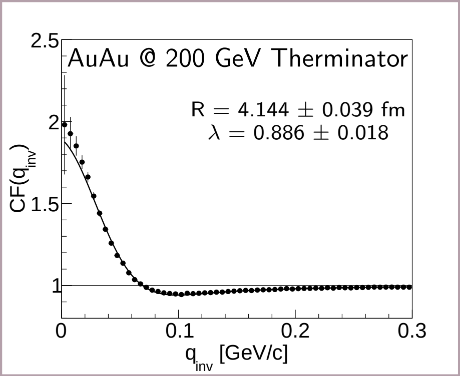


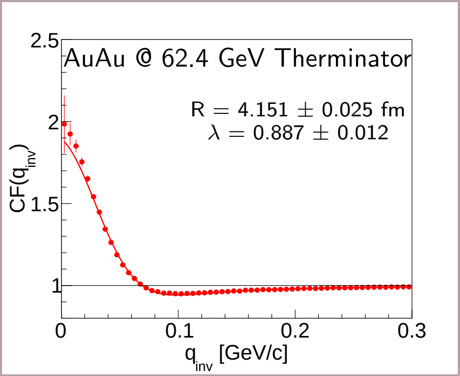
- $K^0_S \rightarrow \pi^+ + \pi^-$ (69.20±0.05) %
- **200 GeV** (included hydrodynamic evolution): 0-5%, 0-10% and 10-70%
- **other energies** (Blast-Wave model): 0-5%

- p_T: 0.4-2.0 GeV/c
- $|\eta|$: < 0.5

Energy dependence

the most central collisions (0-5%)

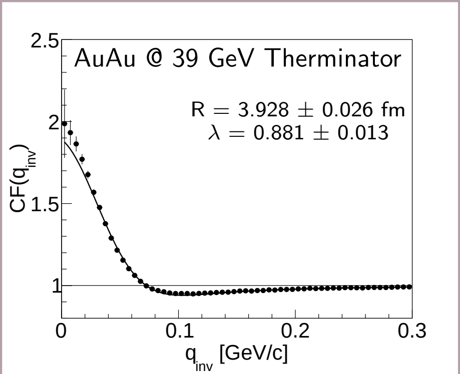


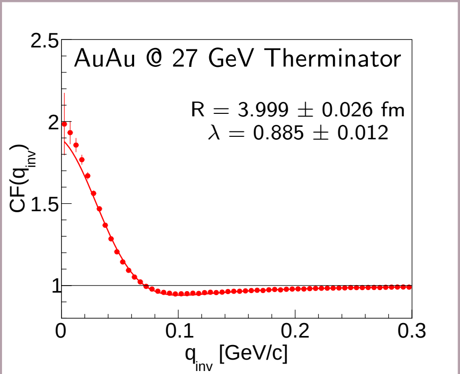


Similar values of the source size for these energies

Energy dependence

the most central collisions (0-5%)

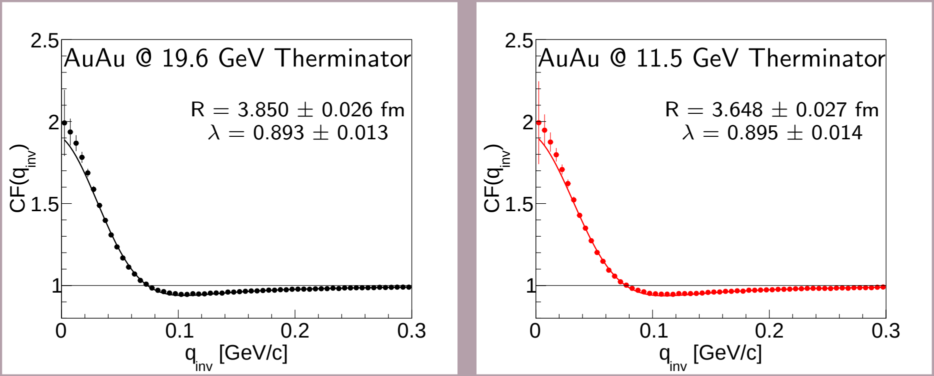




Strange behavior for 39 GeV or 27 GeV

Energy dependence

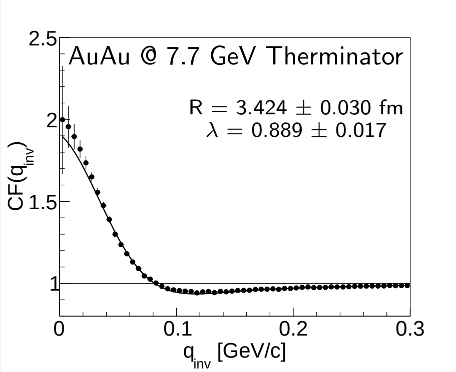
the most central collisions (0-5%)



Larger source size for higher energy

Energy dependence

the most central collisions (0-5%)



200 GeV

4.144 ± 0.039 fm	0.886 ± 0.018

62.4 GeV

4.151 ± 0.025 fm	0.887 ± 0.012

39 GeV

3.928 ± 0.026 fm	0.881 ± 0.013

27 GeV

3.999 ± 0.026 fm	0.885 ± 0.012

19.6 GeV

3.850 ± 0.026 fm	0.893 ± 0.013

11.5 GeV

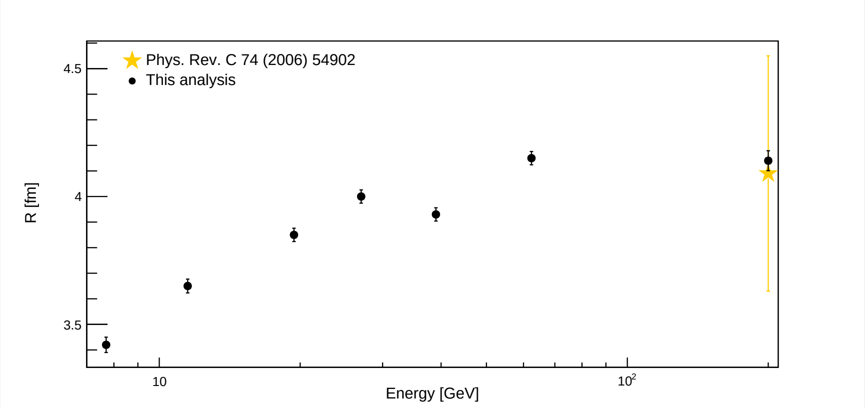
3.648 ± 0.027 fm	0.895 ± 0.014

7.7 GeV

3.424 ± 0.030 fm	0.889 ± 0.017

Energy dependence

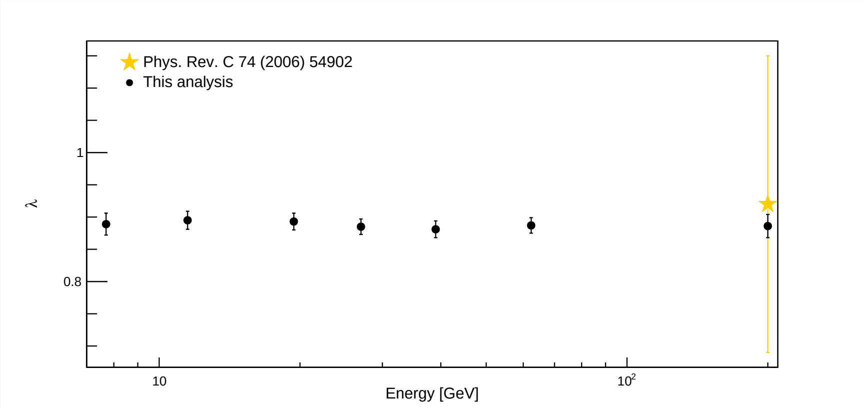
Radii vs. energy
the most central collisions (0-5%)



Clear energy dependence
Only 39 GeV deviates from this trend

Energy dependence

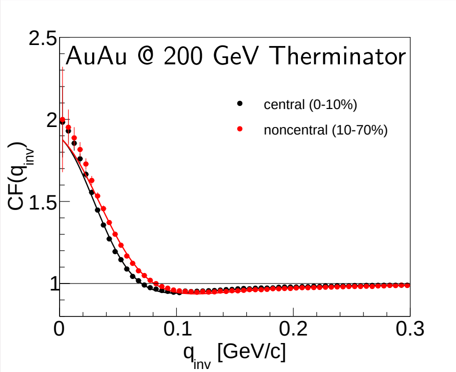
Lambda vs. energy
the most central collisions (0-5%)



Similar values of lambda parameter for all energies

Centrality dependence

collisions from $\sqrt{s_{NN}} = 200$ GeV



central (0-10%)

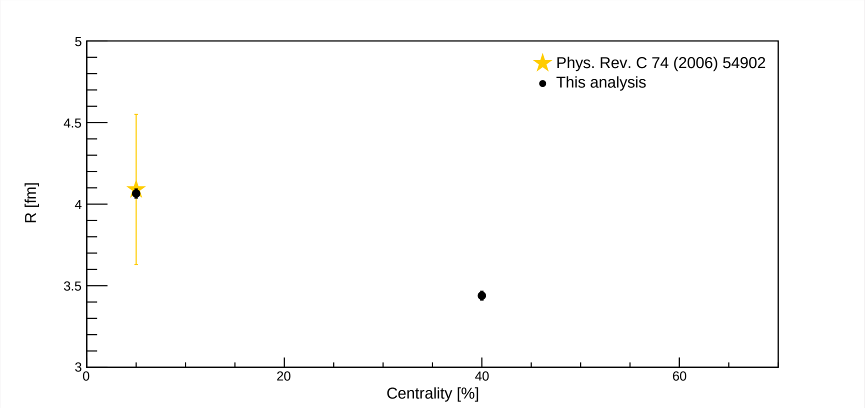
4.065 ± 0.028 fm	0.884 ± 0.013

noncentral (10-70%)

3.439 ± 0.027 fm	0.869 ± 0.015

Centrality dependence

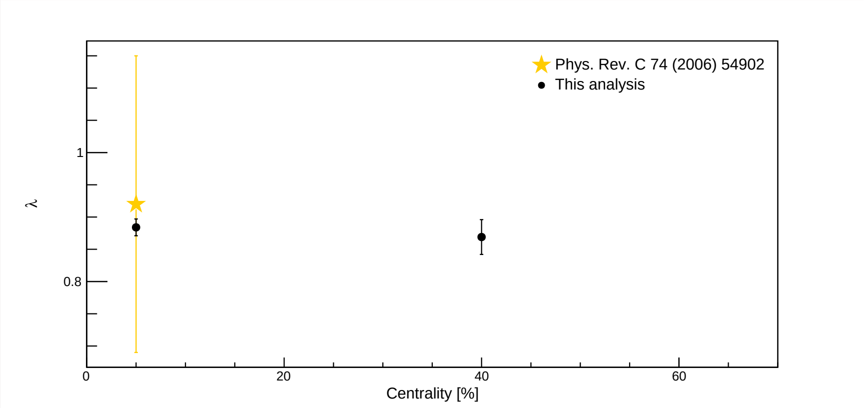
Radii vs. centrality
collisions from $\sqrt{s_{NN}} = 200$ GeV



Clear centrality dependence

Centrality dependence

Lambda vs. centrality
collisions from $\sqrt{s_{NN}} = 200$ GeV



Similar values of lambda parameter

Conclusions

Neutral kaon femtoscopy based on Therminator data

- **Clear energy dependence for energies $\sqrt{s_{NN}}$ =7.7 - 200 GeV**
  - λ parameters are similar for all energies
  - R_{inv} increases with energy

$$R_{200GeV} > ... > R_{7.7GeV}$$

  - visible difference for $\sqrt{s_{NN}} = 39$ GeV
- **Clear centrality dependence for $\sqrt{s_{NN}} = 200$ GeV**
  - λ parameters are similar for all centralities
  - R_{inv} increases with centrality

$$R_{0-10\%} > R_{10-70\%}$$

- **Comparison with the experimental results shows compliance for $\sqrt{s_{NN}} = 200$ GeV**

Plan for experimental data analysis: checking the same dependencies for the data collected by the STAR experiment.

Thank you for your attention!