Pion-kaon femtoscopy in Therminator 2 model

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Phenomenological models

Phenomenological models

Microscopic | Macroscopic

Phenomenological models

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- Dynamic simulation of the collision process inspired by QCD
- Tracking of individual objects
- Propagation of individual particles through a cascade of collisions and decays

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- No consideration of the dynamics of individual objects in detail
- Statistical description of multiparticulate system

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What about generators?

THERMINATOR generator

THERMal heavy-**I**o**N** Gener**ATOR** 2

- Generates collisions of relativistic ions
- Uses Monte Carlo methods
- Implements thermal models of particle production with single freeze-out

THERMINATOR: THERMal heavy-IoN generATOR
A. Kisiel, T. Tałuć, W. Broniowski, W. Florkowski.
Comput.Phys.Commun. 174 (2006) 669-687

THERMINATOR 2: THERMal heavy-IoN generATOR 2
M. Chojnacki, A. Kisiel, W. Broniowski, W. Florkowski.
Comput.Phys.Commun. 183 (2012) 746-773

THERMINATOR is a Monte Carlo event generator designed for studying of particle production in relativistic heavy-ion collisions performed at such experimental facilities as the SPS, RHIC, or LHC. The program implements thermal models of particle production with single freeze-out.

Input file

```
[Ranges]
# Rapidity range
RapPRange = 4.0

# Spatial rapidity range
RapSRange = 8.0

[Model_parameters]
# Proper time at freeze-out [fm]
Tau = 9.91

# Maximum transverse radius [fm]
RhoMax = 7.43

# Transverse velocity [c]
VelT = 0.407

# Parameter A
ParA = 0.5

# Delay of the particle emition [fm]
Delay = 0.0

# Freeze-Out Temperature [MeV]
Temperature = 165.6

# Chemical potentials for Barion, Isospin (I_3), Strangeness and Charm [MeV]
MuB = 28.5
MuI = -0.9
MuS =  6.9
MuC =  0.0

[Subdirectory]
# subdirectory to store events of this model
EventSubDir = bwap/
```

Input file

Input file takes following information:

- The number of events
- Parameters:
  - Temperature [MeV]
  - MuB, MuI, MuS [MeV]
  - VelT
  - Tau, RhoMax [fm]

Input parameters

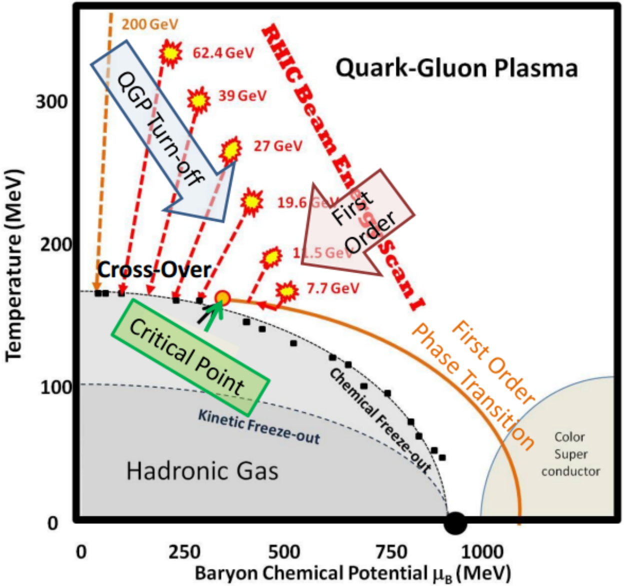
- Temperature (T) and chemical potentials: baryon (μ_B), strangeness (μ_S), third component of isospin (μ_I) — thermodynamical parameters
- VelT (Vt) — a parameter specific to the Blast-Wave model, denoting velocity
- Tau, RhoMax — geometrical parameters

Vt, Tau and RhoMax affect the produced particles
The relation between RhoMax and Tau is:

$$\rho_{max}^2 \cdot \tau \simeq V$$

V is the volume of the source

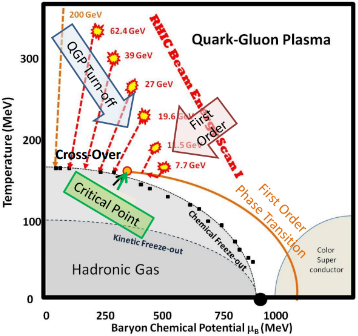
Beam Energy Scan at STAR



BES goals

Developed to find answers for several questions:

- Search for turn-off of QGP signatures
- Search for the QCD critical point
- Search for the signals of phase transition/phase boundary



Thermninator for BES program

$\sqrt{s_{NN}}[GeV]$	T [MeV]	μ_B [MeV]	μ_S [MeV]	μ_{I_3} [MeV]
7.7	139.0	406.4	93.4685	-10.5677
11.5	150.1	303.2	69.9562	-7.9697
19.6	156.2	196.8	45.6875	-5.2882
27	157.6	149.0	34.7938	-4.0845
39	158.4	106.9	25.1974	-3.0241
62.4	158.8	68.9	16.5409	-2.0676

"Therminator generator adaptation to the conditions of RHIC and FAIR experimantal complexes",
Engineer's Thesis, Monika Seniut

Therminator for BES program

$\sqrt{s_{NN}}[GeV]$	τ [fm]	ρ_{max} [fm]	V_T
7.7	8.3	8	0.65
11.5	8.35	8	0.8
19.6	8.75	8.2	0.85
27	8.75	8.85	0.8
39	8.6	8.7	0.75
62.4	9.4	9	0.75

"Adaptation of the THERMINATOR model for BES program",
Quark Matter 2018, H. Zbroszczyk & P. Szymański

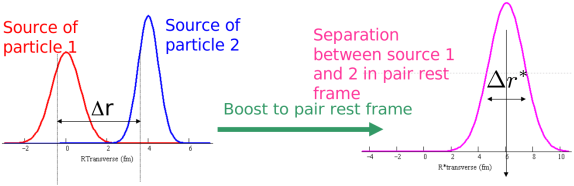
$$C(\vec{q}) = \int |\Psi(\vec{q},\vec{r})|^2 S(\vec{r}) d^3r$$

known ($C(\vec{q})$, Ψ) — unknown ($S(\vec{r})$, μ_{out})

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

$$S(\vec{r}) = exp\left(-\frac{(r_{out}-\mu_{out})^2}{\sigma_{out}^2} - \frac{r_{side}^2}{\sigma_{side}^2} - \frac{r_{long}^2}{\sigma_{long}^2}\right)$$

μ_{out} — asymmetry in the *outward* direction
assumption: $\sigma_{side} = \sigma_{out}$, $\sigma_{long} = 1.3\sigma_{out}$



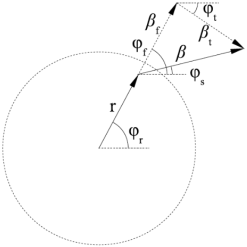
Pion-kaon femtoscopy — asymmetry

$$C(\vec{q}) = \int |\Psi(\vec{q}, \vec{r})|^2 S(\vec{r}) d^3 r$$

known unknown

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

$$S(\vec{r}) = exp(-\frac{(r_{out}-\mu_{out})^2}{\sigma_{out}^2} - \frac{r_{side}^2}{\sigma_{side}^2} - \frac{r_{long}^2}{\sigma_{long}^2})$$



A. Kisiel
Phys. Rev. C81, 064906 (2010)

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$$\beta_{particle} = \beta_f + \beta_t$$

β_f — collective (flow) velocity

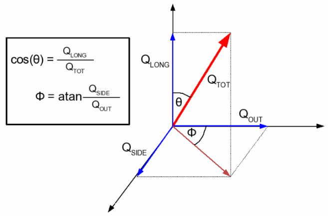
β_t — thermal (random) velocity

Emission asymmetry arises in a system where both thermal and collective velocities exist and are comparable in magnitude

SH representation of 3D correlation function as a set of 1D plots

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

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



P. Danielewicz and S. Pratt.
Phys. Lett B618, 60 (2005)
Phys. Rev. C75, 034907 (2007)

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Ω - full solid angle
$Y_l^m(\theta,\phi)$ - spherical harmonic function
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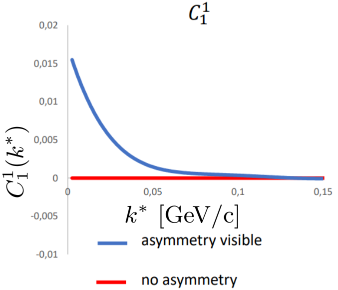
$C_0^0 \rightarrow$ sensitive to the size of the emitting source (shapes same as correlation function)

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



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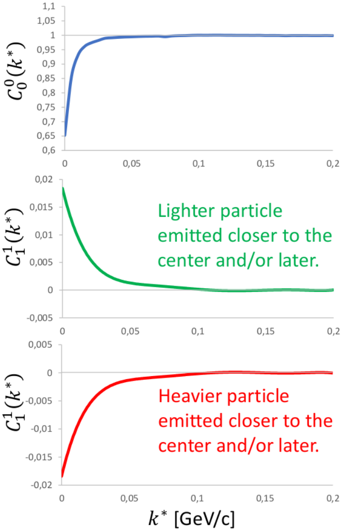
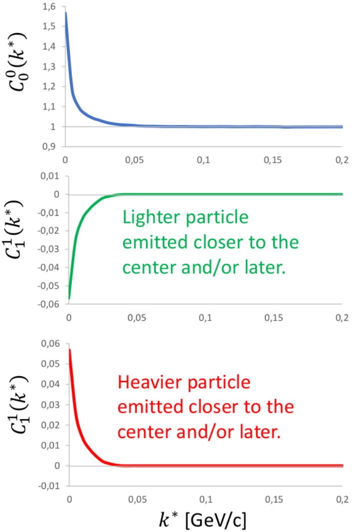
Which particle...?

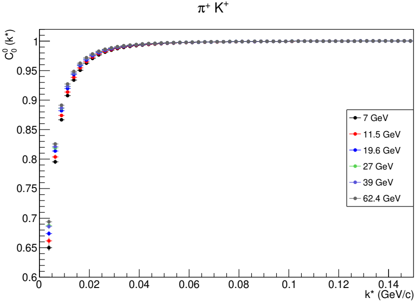
Like-sign particle combinations

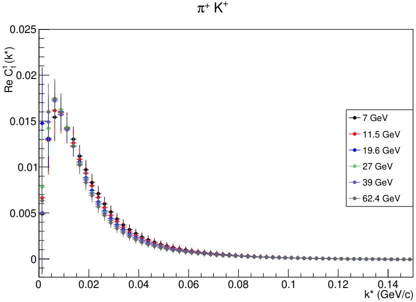


Unlike-sign particle combinations



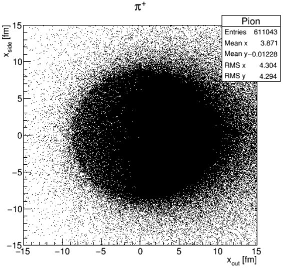
Pion-kaon femtoscopy



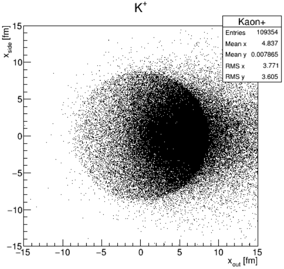


- visible emission asymmetry
- most of the pions are emitted closer to the center and/or later than most of the kaons

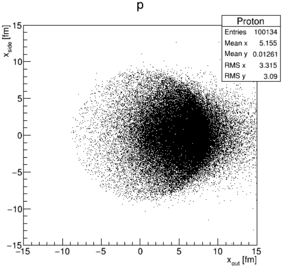
Average emission points



$\langle x_{out} \rangle = 3.87$ fm



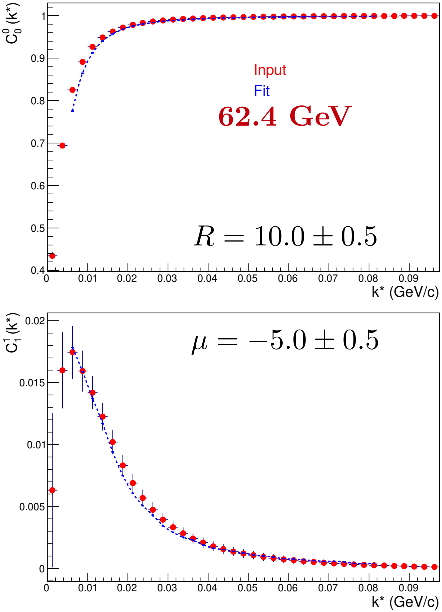
$\langle x_{out} \rangle = 4.84$ fm



$\langle x_{out} \rangle = 5.16$ fm

- visible emission asymmetry
- most of the pions are emitted closer to the center and/or later than most of the kaons

Pion-kaon femtoscopy



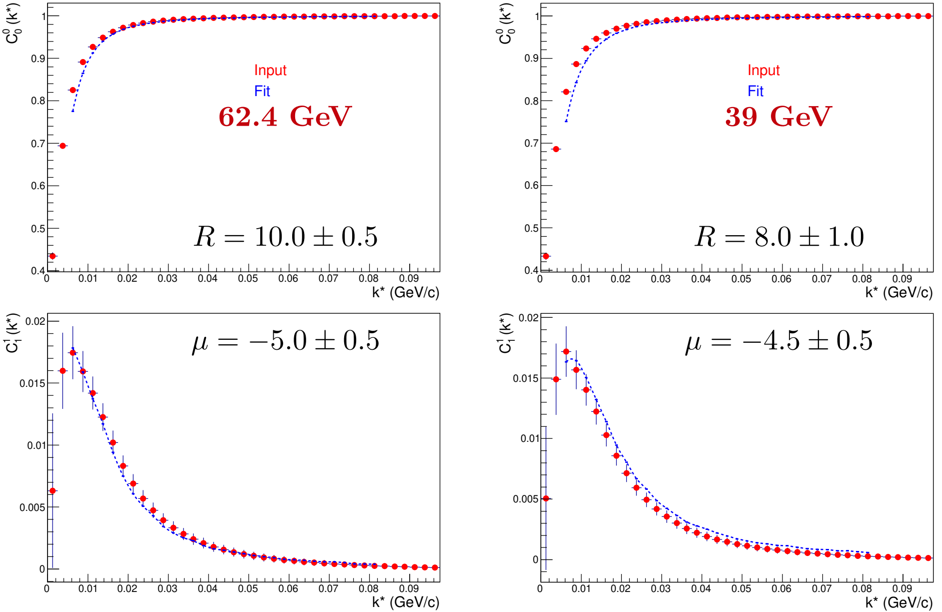
Fitting procedure using CorrFit tool. Gausian source distribution assumed.

CorrFit use the full information of the interaction potential (both coulomb and strong interaction)

The "best-fit" correlation function is found through the minimum χ^2 method

CorrFit - a program to fit arbitrary two-particle correlation functions
A. Kisiel, Nukleonika (2004)

Pion-kaon femtoscopy



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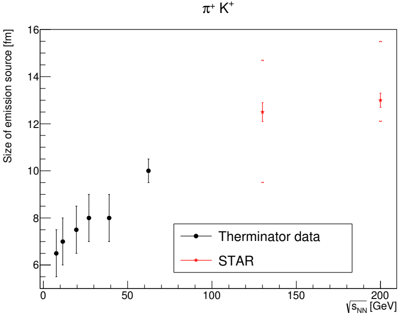

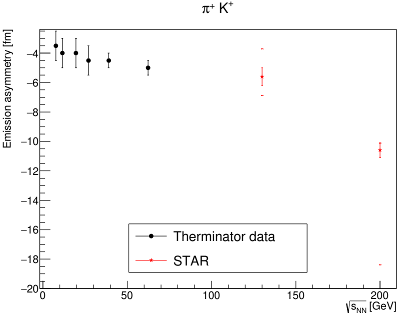

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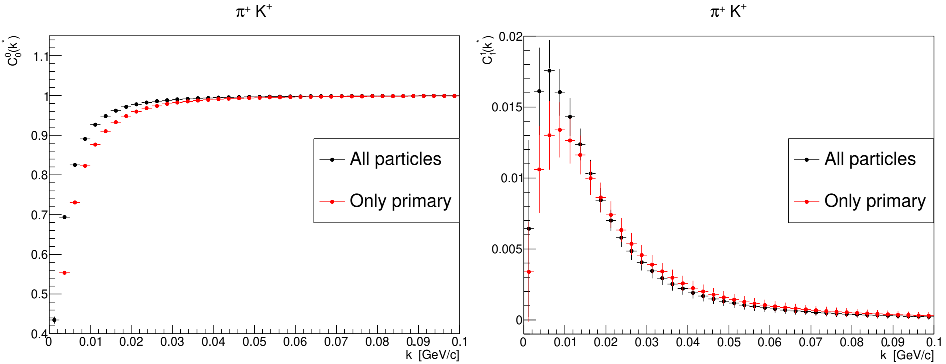
CorrFit - a program to fit arbitrary two-particle correlation functions

A. Kisiel, Nukleonika (2004)

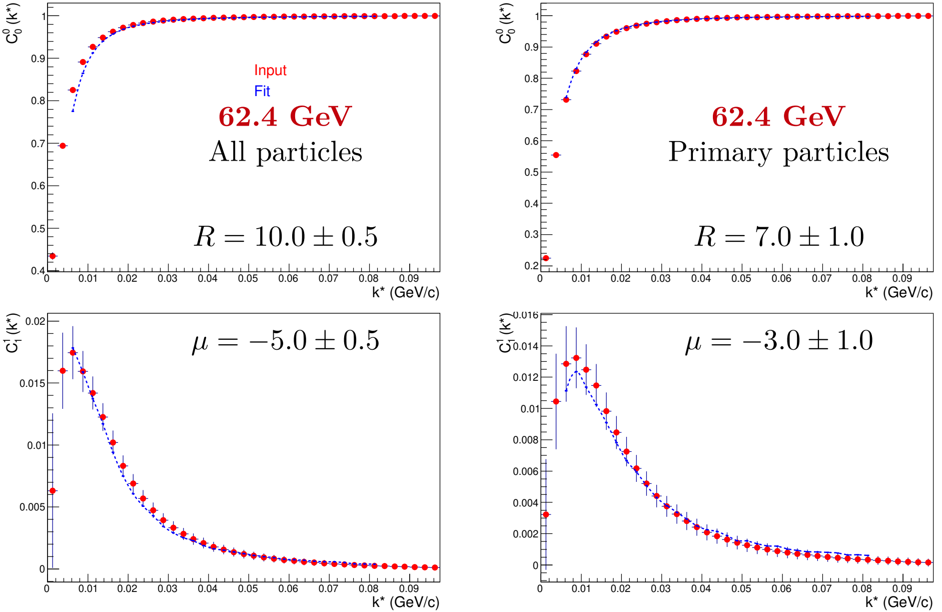
- smaller sizes than size measured in the STAR
- visible size dependence on collision energy
- smaller emission asymmetry than measured in the STAR
- visible asymmetry dependence on collision energy

All and primary particles SH components

$$\sqrt{s_{NN}} = 62.4 \text{ GeV}$$



All and primary particles — 62.4 GeV



Summary

- Obtained size of the source and emission asymmetry from THERMINATOR 2 for BES energies
- Observed clear signal of asymmetry in emission process:
  - pions emitted closer to the center and/or later than kaons
- Size and emission asymmetry show dependence on collision energy
- Source sizes smaller than in the STAR
- Emission asymmetry smaller than in the STAR

- Size and emission asymmetry are smaller for only primary particles

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Thank you for your attention!