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Two identical pions correlations at small relative momenta in collisions of Al+Al and Ni+Ni at 1.9A GeV

Volha Charviakova

National Center for Nuclear Reaserch
Faculty of Physics University of Warsaw

for the FOPI collaboration

FOPI experiment GSI (Darmstadt)

- *FOPI spectrometer @SIS18*
- *Al+Al and Ni+Ni experiments*

Two-particle correlation function

- *Introduction*
- *One dimensional parameterization*
- *Three dimensional parameterization*

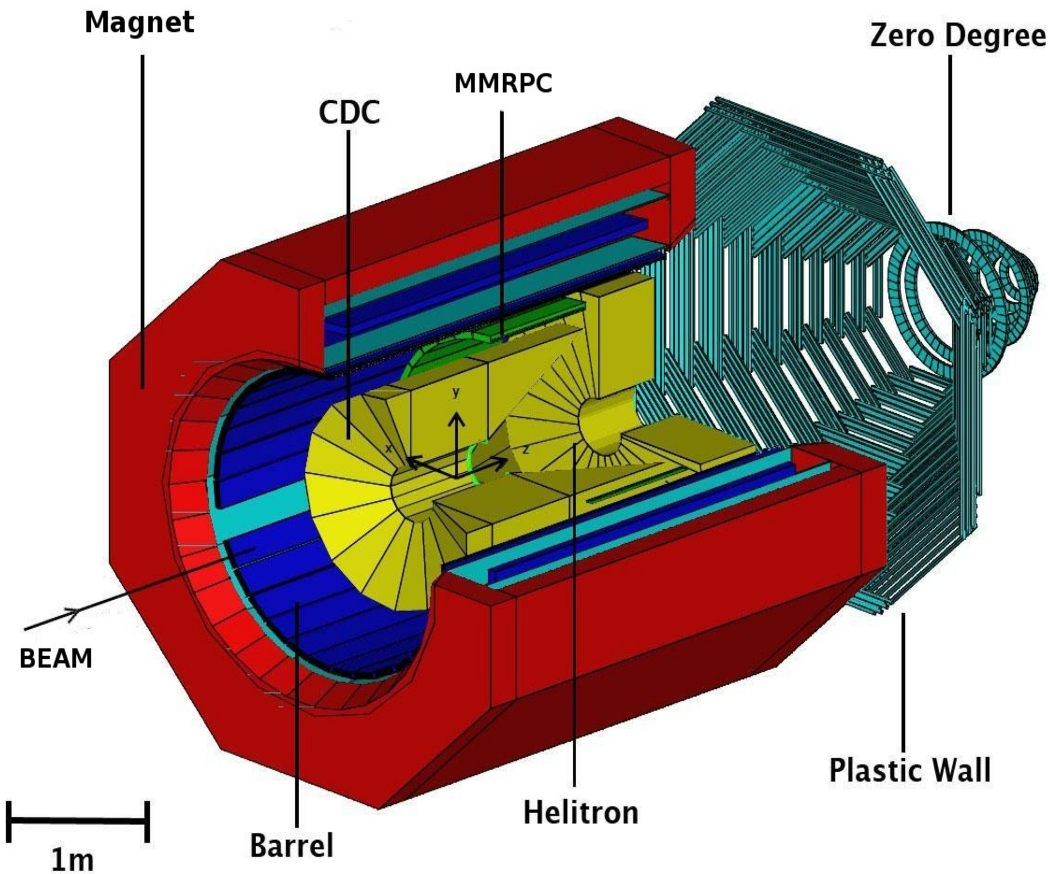
Two identical $\pi^+\pi^+$ correlation function

- *System size dependence*
- *Centrality dependence*
- *Total kinetic energy dependence*
- *Total transverse momentum dependence*

Conclusions and outlook

FOPI experiment GSI (Darmstadt)

FOPI spectrometer @SIS18



Experimental set-up:

- Fixed target experiment
- Charged particles registered
- Nearly 4π coverage
- T_{beam} (0.1 ÷ 2)A GeV
- Magnetic field B=0.6 T

Detectors:

Drift chambers

- CDC (22°<θ<105°)
- Helitron (7°<θ<30°)

ToF detectors

- Barrel (56°<θ<100°)
- MMRPC (28°<θ<52°)
- Plastic Wall (8°<θ<30°)
- Zero Degree (1°<θ<7°)

Physics topics:

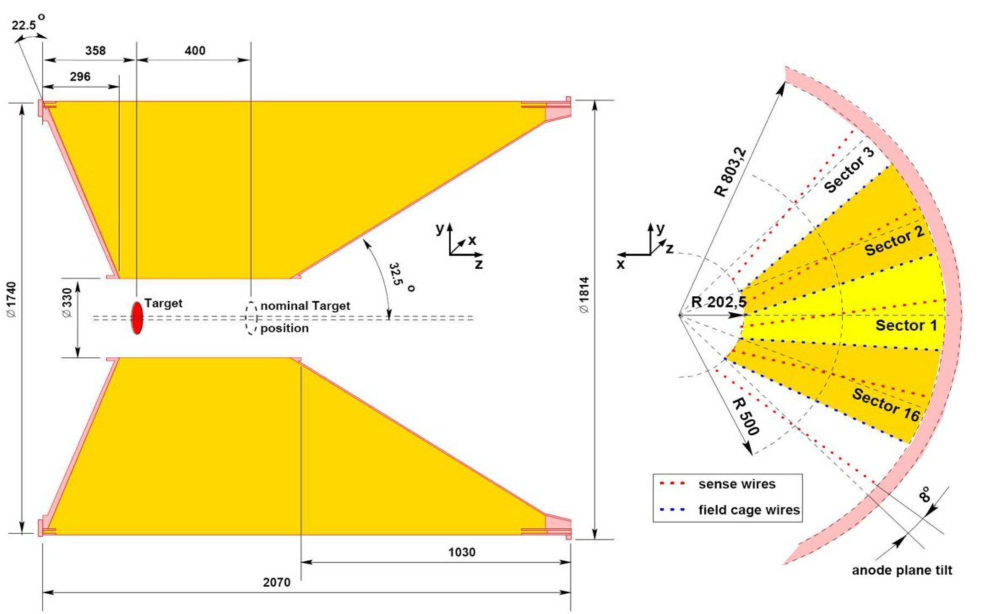
- Nuclear fragmentation
- Pion production
- Production of strange particle (K,Λ)
- Investigation of flow

FOPI experiment GSI (Darmstadt)

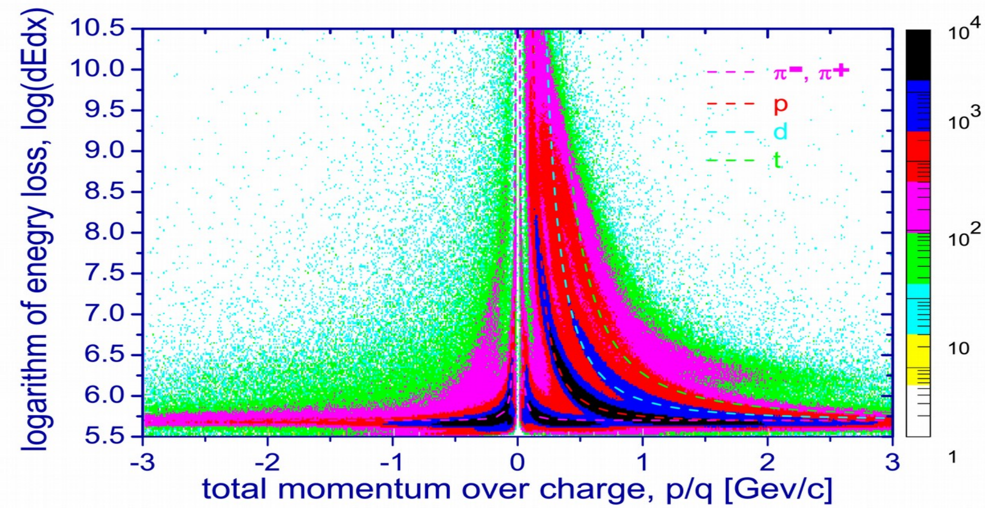
FOPI spectrometer @SIS18

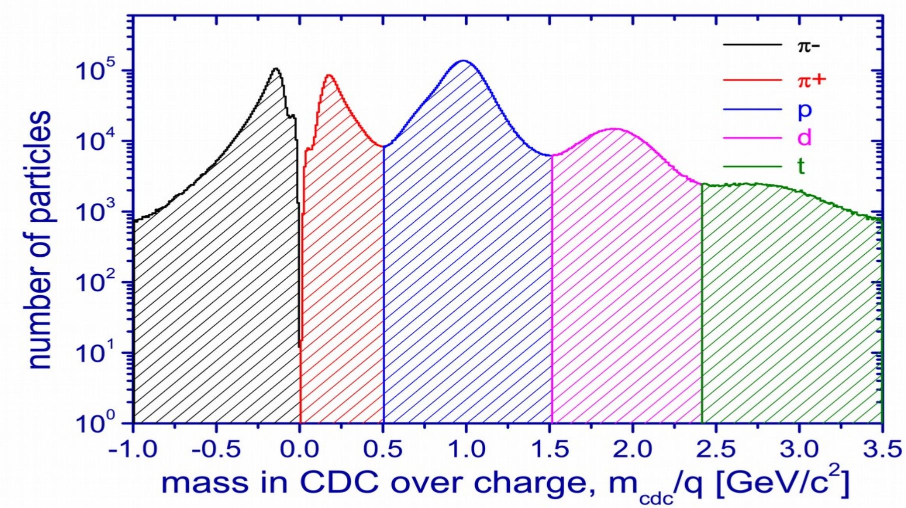
Central Drift Chamber (CDC)

- Gas mixture Ar - 88 %
  iso-C_4H_{10} - 10 %
  CH_4 - 2 %
- Position resolution 300 µm – xy plane
  15 cm – z direction
- Angle resolution $\sigma_\Theta \approx 6°$ polar
  $\sigma_\varphi \approx 0.6°$ azimuthal
- Momentum resolution (5÷15) %



Particle identification in CDC





p p = (0.1÷1.5) GeV/c **π^+** p = (0.1÷0.75) GeV/c

t p = (0.3÷1.5) GeV/c **π^-** p = (0.1÷3) GeV/c

d p = (0.25÷1.5) GeV/c

FOPI experiment GSI (Darmstadt)
Al+Al and Ni+Ni experiments

Experiment Al+Al

Beam $^{27}Al^{+13}$

- T_{beam} 1.9A GeV
- I_{beam} ~10^5 ions per spill

Target ^{27}Al

- size 4.5×4.5 mm^2
- thickness 260 μm

Interaction probability ~2.5%

Centrality 15% most central

- σ_{trig} ≈ 220 mb
- b_{max} ≈ 2.4 fm

Number of events $400 \cdot 10^6$

Experiment Ni+Ni

Beam $^{58}Ni^{+28}$

- T_{beam} 1.9A GeV
- I_{beam} ~10^7 ions per spill

Target ^{58}Ni (95%)

- size 4.5×4.5 mm^2
- thickness 405 μm

Interaction probability ~1%

Centrality 50% most central

- σ_{trig} ≈ 1530 mb
- b_{max} ≈ 7 fm

Number of events $53 \cdot 10^6$

Two-particle correlation function

Introduction

Theoretical two-particle correlation function is defined as the ratio of the probability to measure simultaneously two particle with momenta p_1 and p_2 and the product of the corresponding single-particle probabilities

$$C(\vec{p}_{1,}\vec{p}_2) = \frac{P(\vec{p}_{1,}\vec{p}_2)}{P(\vec{p}_1)P(\vec{p}_2)}$$

$$C(\vec{p}_{1,}\vec{p}_2) = \frac{\int |\Psi|^2 S(x_{1,}p_1)S(x_{2,}p_2)d^4x_1d^4x_2}{\int S(x_{1,}p_1)d^2x_1\int S(x_{2,}p_2)d^2x_2}$$

$|\Psi|^2$ is the squared relative two-particle wave function
$S(x,p)$ is emission source function definded as the probability that a particle with momentum p is emitted from the space-point x in the collision region.

Experimental two-particle correlation function is calculated from the ratio of true and background yields

$$C(\vec{p}_1,\vec{p}_2)=N\frac{\sum Y_{true}(\vec{p}_1,\vec{p}_2)}{\sum Y_{mix}(\vec{p}_1,\vec{p}_2)}$$

$Y_{true}(p_1,p_2)$ true yield, where particle 1 and 2 taken from the same event

$Y_{mix}(p_1,p_2)$ the uncorrelated background, where particle 1 and 2 were taken from the different events

N normalization factor

Two-particle correlation function

One dimensional parameterization

Chaotic source + Bose-Einstein statistics

$$C(q_{inv},\vec{P}) = 1+\exp\left[-q_{inv}^2 R_{inv}(\vec{P})^2/4\right]$$

where $q_{inv} = \sqrt{(\vec{p}_1-\vec{p}_2)^2-(E_1-E_2)^2}$, for equal mass particles q_{inv} is equal to the half of relative momentum calculated in the pair c.m. frame. The experimental correlation function is then projected onto the relative momentum q, calculated in c.m. $|\vec{q}| = |\vec{p}_1-\vec{p}_2|/2$
Constructed in this way function usually named an angle-integrated correlation function.

Real source (Coulomb correction + coherence emission, Bowler-Synyukov procedure)

$$C(q_{inv},\vec{P}) = (1-\lambda(\vec{P}))+\lambda(\vec{P})K_c(\vec{P})\exp\left[-q_{inv}^2 R_{inv}(\vec{P})^2/4\right]$$

$\lambda(P)$ incoherence parameter, depends on module of the average pair momentum.

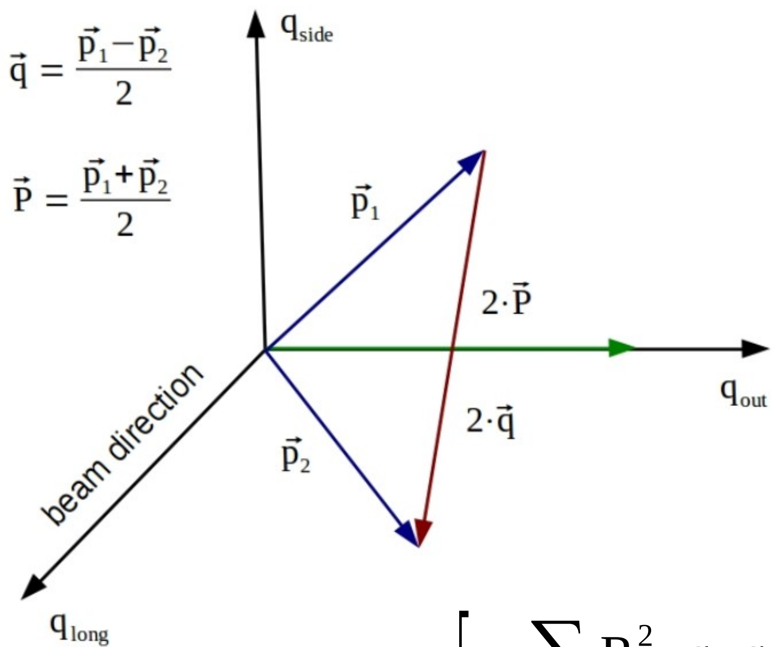
$K_c = 2\pi\eta/(\exp[-2\pi\eta]-1)$ two-pion Coulomb wave function

$\eta = m_\pi \alpha / 2 q_{inv}$ squared over a spherical Gaussian source of fixed radius

$\exp(-q_{inv}^2 R_{inv}^2/4)$ quantum-statistical part

Two-particle correlation function - Three dimensional parameterization

Bertsch- Pratt parametrization (the longitudinally co-moving system LCMS)



a rest frame moving along the longitudinal direction such that P_z=0

q_{long} is parallel to the beam direction.

q_{out} points in the direction of P, is perpendicular to the beam axis

q_{side} is perpendicular to the other two

$$C(\vec{q},\vec{P}) = 1+\exp\left[-\frac{\sum_{\alpha,\beta} R^2_{\alpha\beta} q_\alpha q_\beta}{4}\right] = 1+\exp\left[-\frac{R^2_{out} q^2_{out} + R^2_{side} q^2_{side} + R^2_{long} q^2_{long}}{4}\right]$$

The three Gaussian parameters R_{out} , R_{side} and R_{long} dimensions of the souce a long out side and long axis. Others six cros-terms can be set to zero using the reflection symmetries for the mid-rapidity central source.

$$R_{long} \approx \frac{V_{therm}}{dv/dz} = V_{therm}\langle t\rangle$$

V_{therm} is the thermal velocity

<t> is mean emission time

$$(V_\perp + V_S)^2 (\Delta\tau)^2 \approx R^2_{out} + R^2_{side}$$

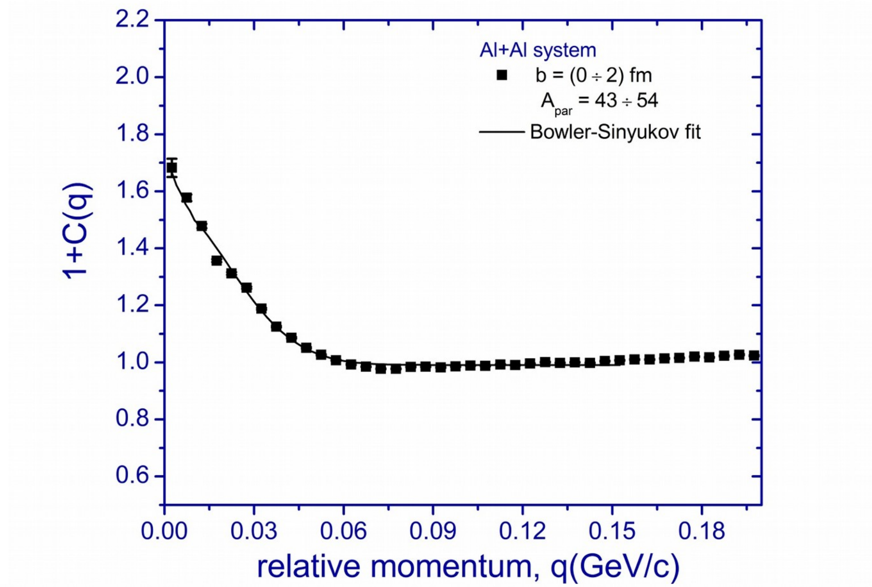
$V_\perp$ is the velocity of the pair in the LCMS frame

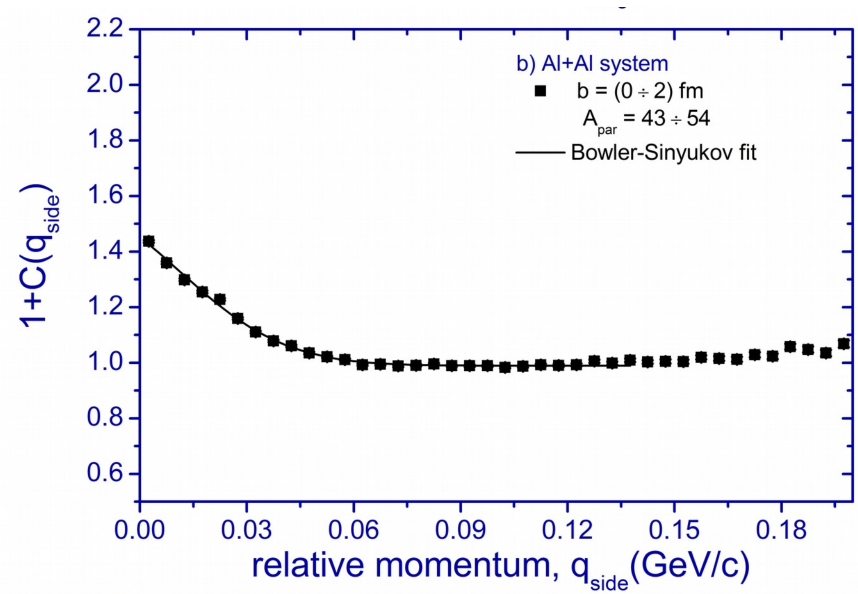
V_s is the pair velocity in the side direction

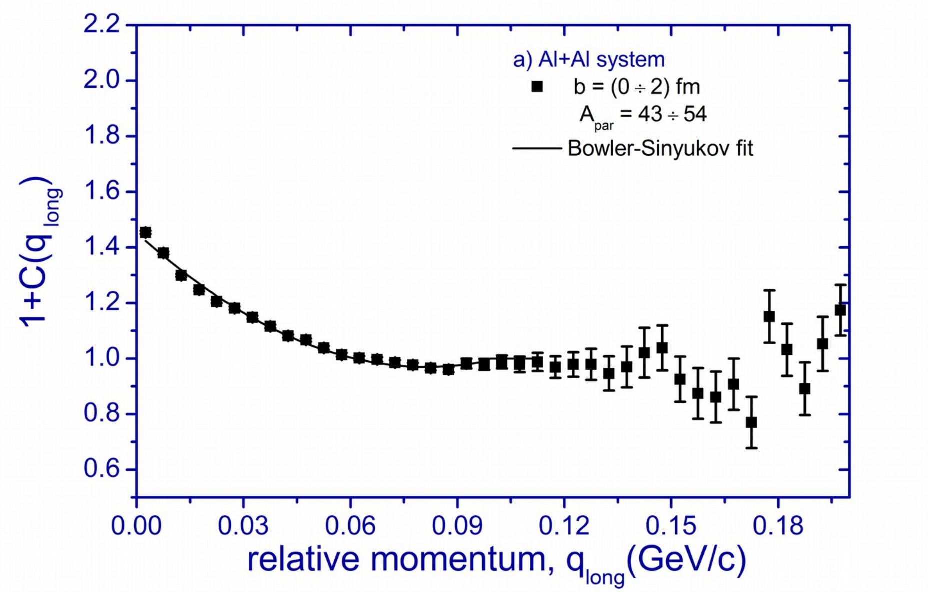
$\Delta\tau$ is the liftime

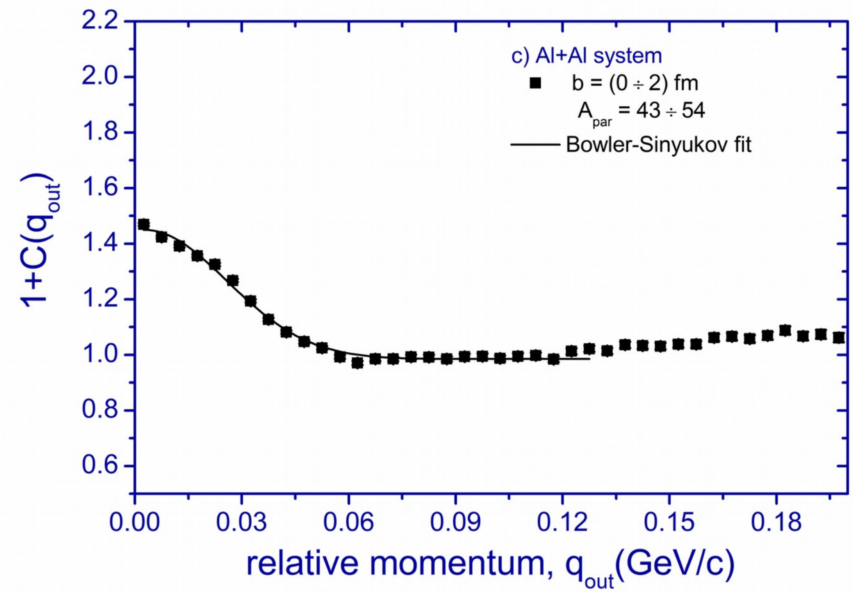
Two $\pi^+\pi^+$ correlation function

System size and Centrality dependence - Al+Al system



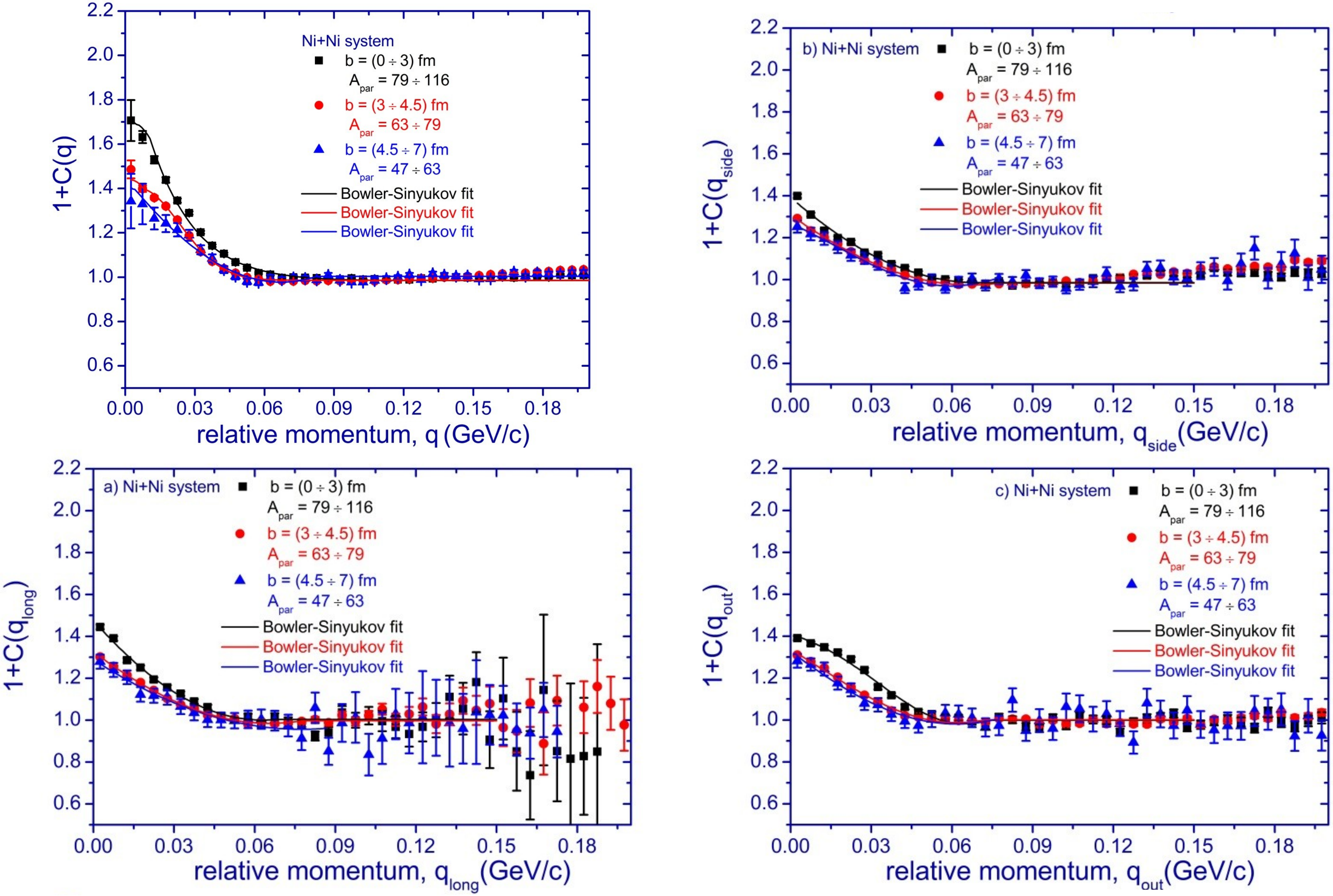




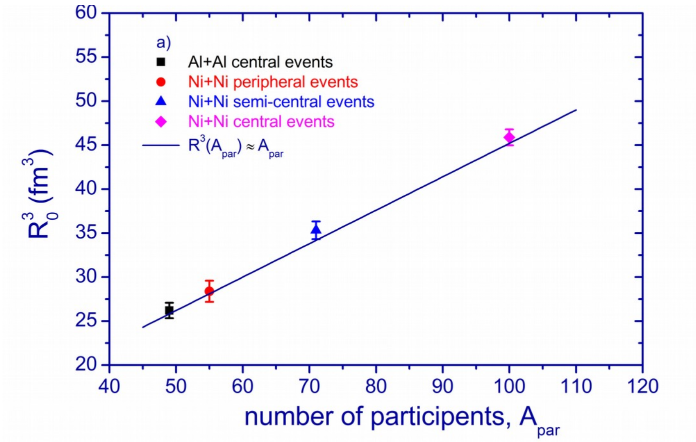


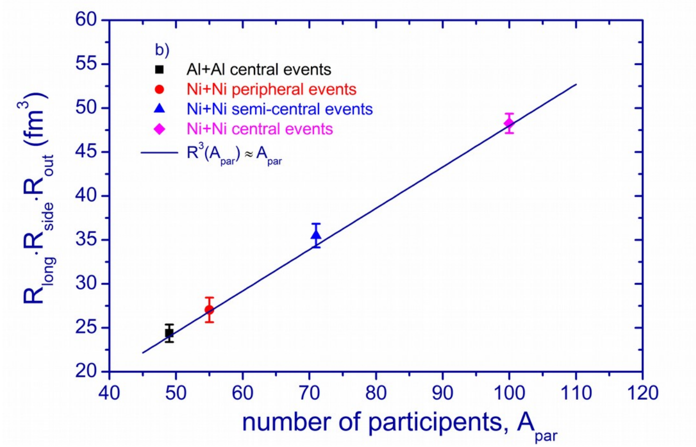
Two $\pi^+\pi^+$ correlation function

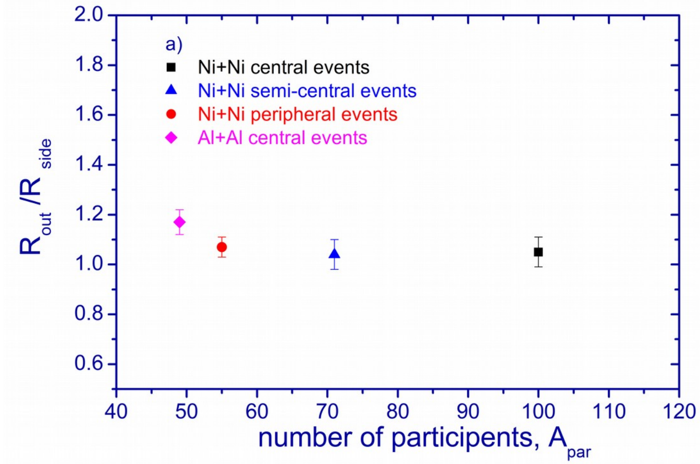
System size and Centrality dependence - Ni+Ni system

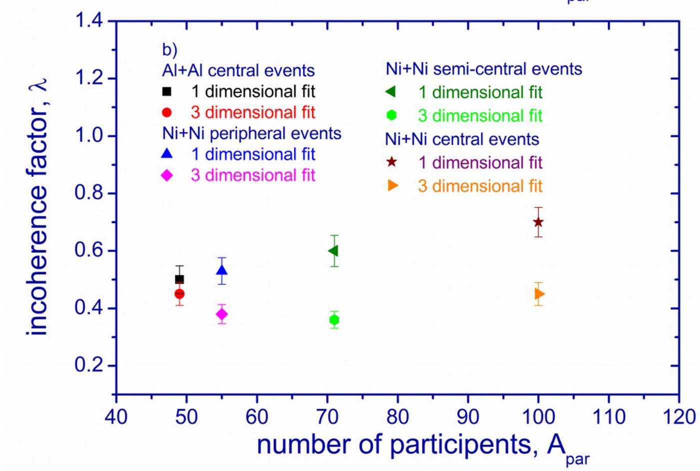


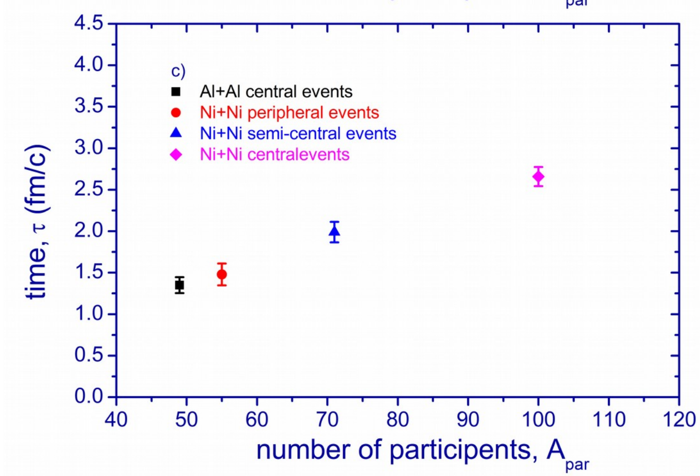
Two $\pi^+\pi^+$ correlation function - System size and Centrality dependence





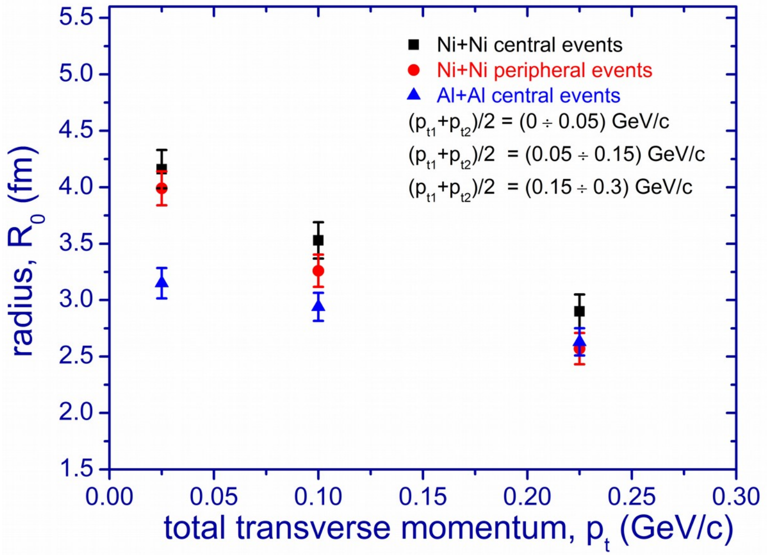






- With increasing size of the colliding system and centrality of the events the source radius for the pions are increased.
- Source radius for Ni+Ni system is large than for the Al+Al.
- Incoherence factor increased with number of participants.
- Ratio of for the Ni+Ni system doesn't depends on A_{par} and is smaller the for the Al+Al system.
- Lifetime of the pion source increases with the A_{par}.

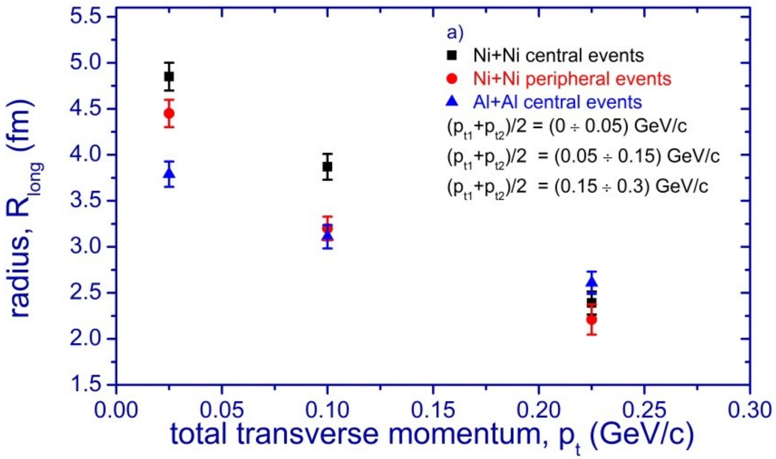
Two $\pi^+\pi^+$ correlation function - Total transverse momentum dependence

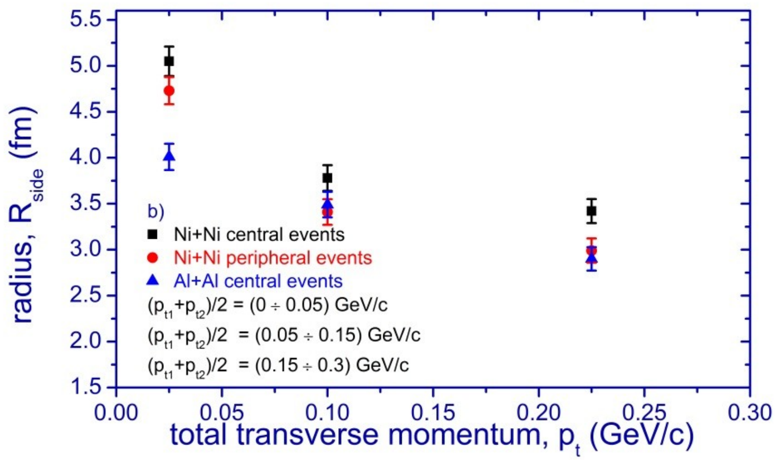


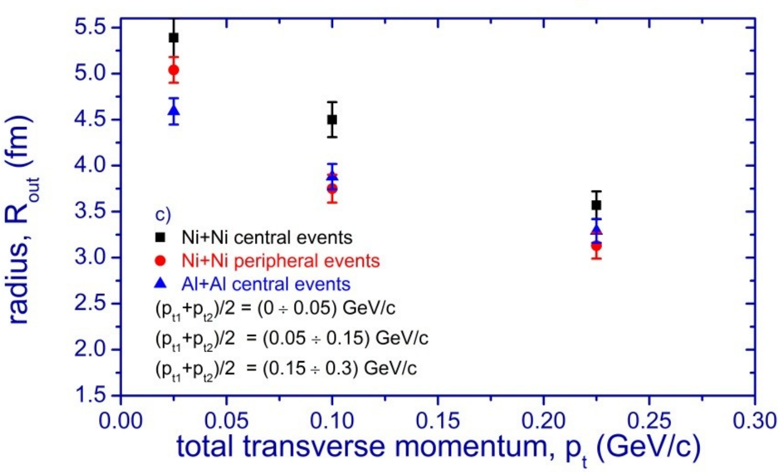
Tree ranges of the half of the total transverse momentum :
(0 ÷ 0.05) GeV/c, (0.05 ÷ 0.15) GeV/c, (0.15 ÷ 0.3) GeV/c

Al+Al system: b = (0÷2) fm, A_{par} = 43÷54
Ni+Ni system: b = (0÷3.4) fm, A_{par} = 84÷116
b = (3.4÷7) fm, A_{par} = 47÷84

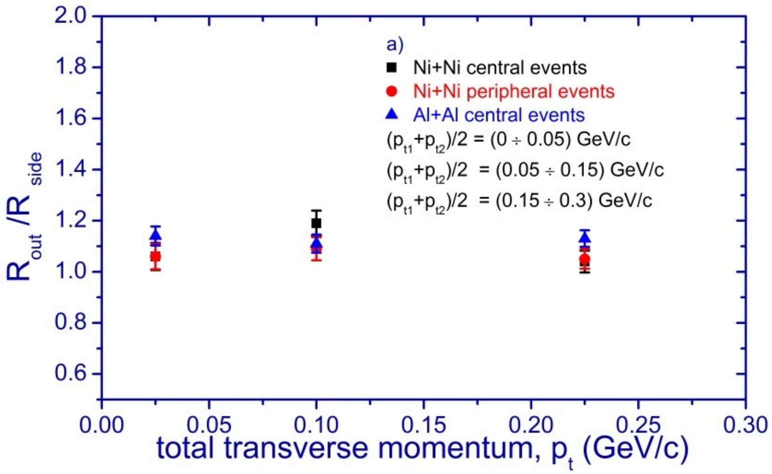
- With increasing total transverse momentum of the two pions the source radii R_0, R_{out}, R_{side}, R_{long} are decreased for the Al+Al and Ni+Ni systems.
- Difference between the source size R_0 for Ni+Ni system and for Al+Al system decreases with increasing total transverse momentum. The same is correct for the values of R_{out}, R_{side}, R_{long}.

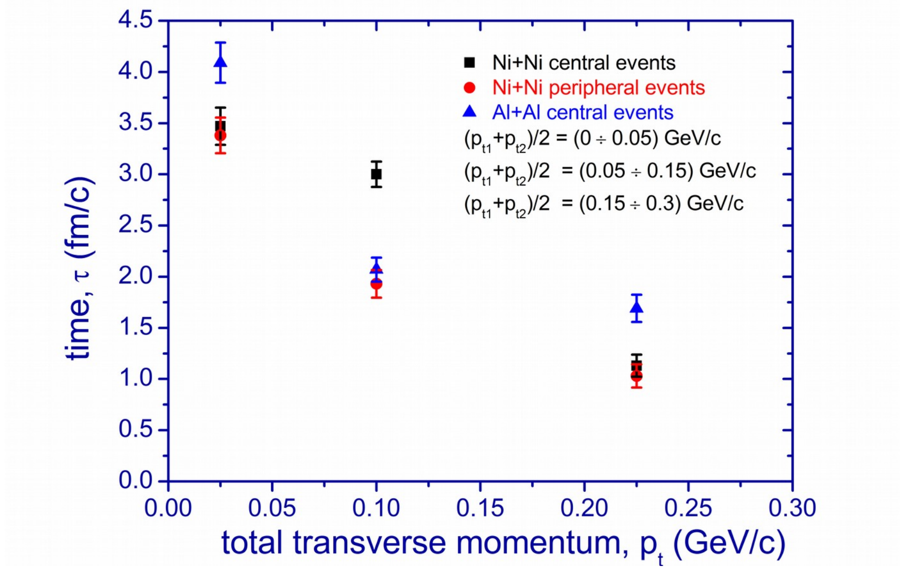


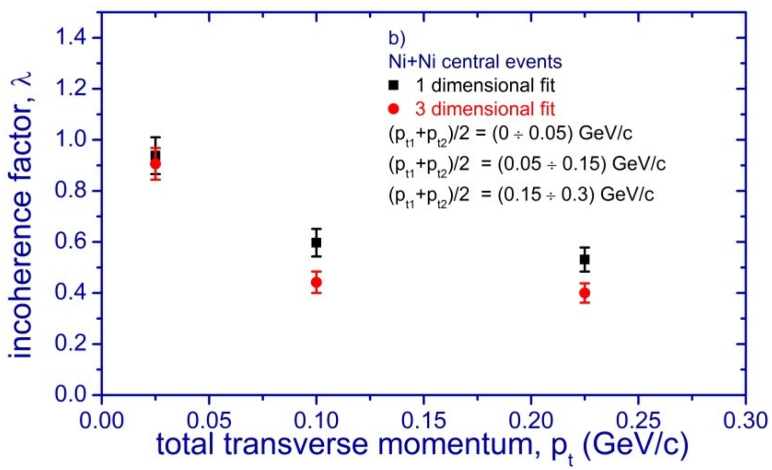


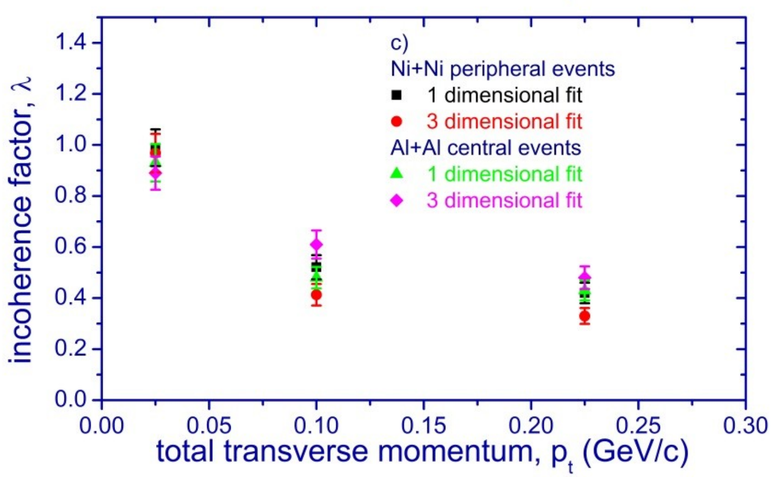


Two $\pi^+\pi^+$ correlation function - Total transverse momentum dependence



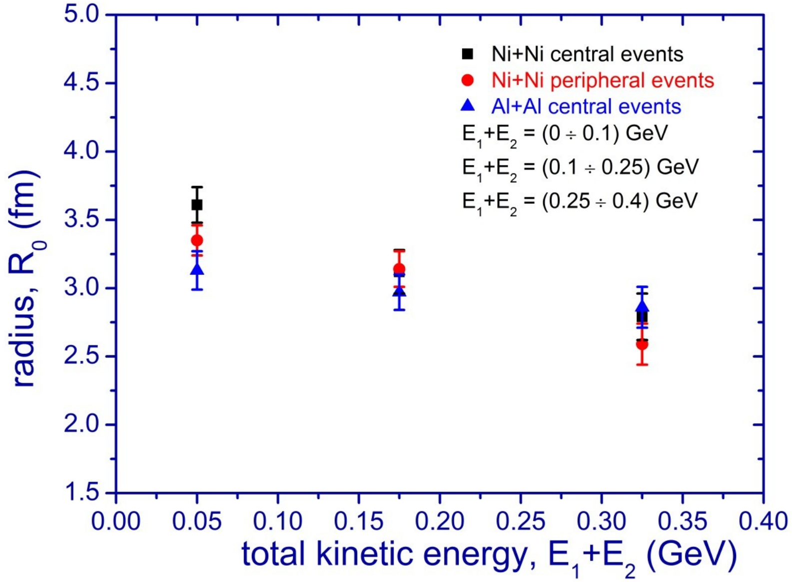


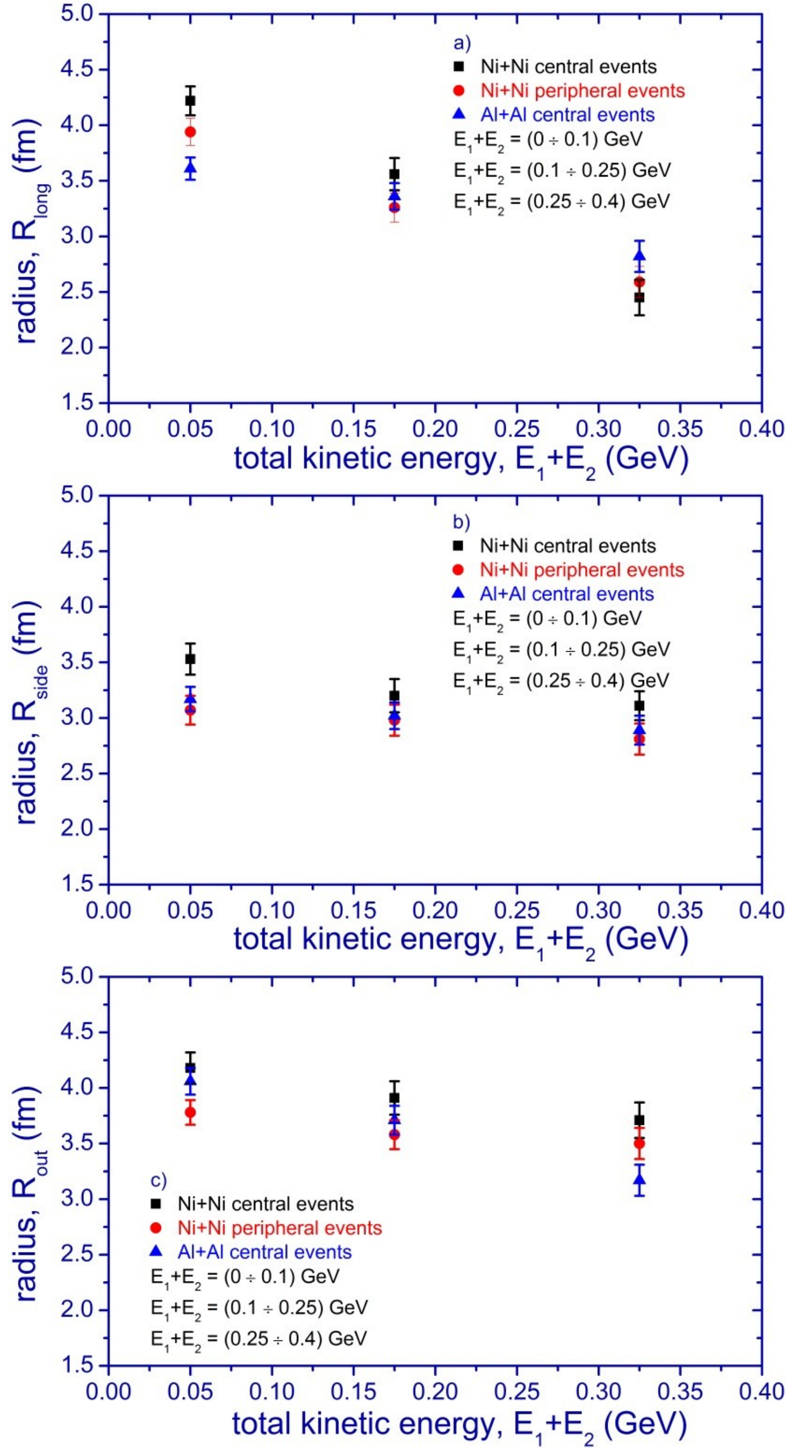




- ➢ Calculated values of R_{out} is large then values of R_{side}.
- ➢ Ratio of R_{out}/R_{side} for the Ni+Ni system and Al+Al system doesn't changes significantly with increasing total transverse momentum.
- ➢ Values of λ extracted from one-dimensional Bowler-Sinyukov fits is similar to those from tree-dimensional fits.
- ➢ Lifetime of the pion source decreases with the increasing total transverse momentum of two coincident pions.

Two $\pi^+\pi^+$ correlation function - Total kinetic energy dependence



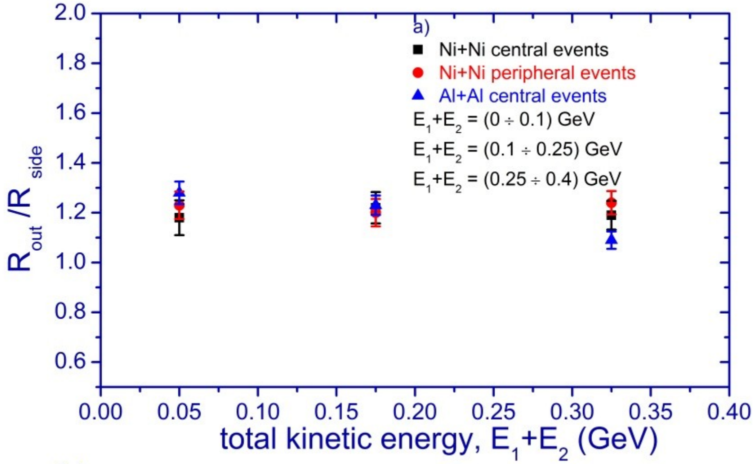


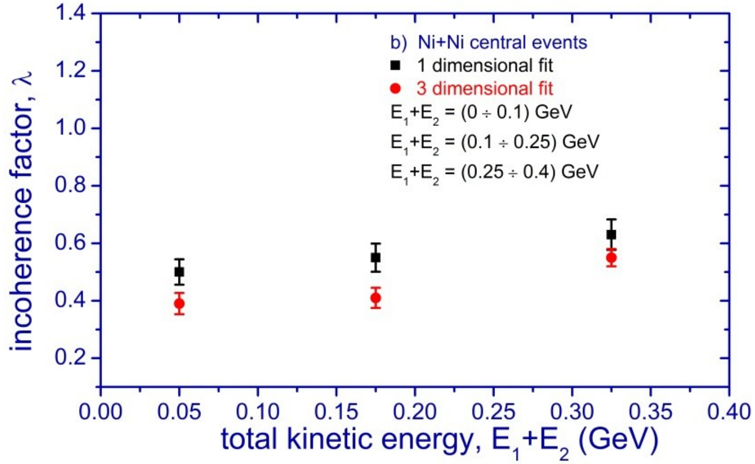
Tree ranges of the total kinetic energy of two pions :
(0 ÷ 0.1) GeV, (0.1 ÷ 0.25) GeV and (0.25 ÷ 0.4) GeV

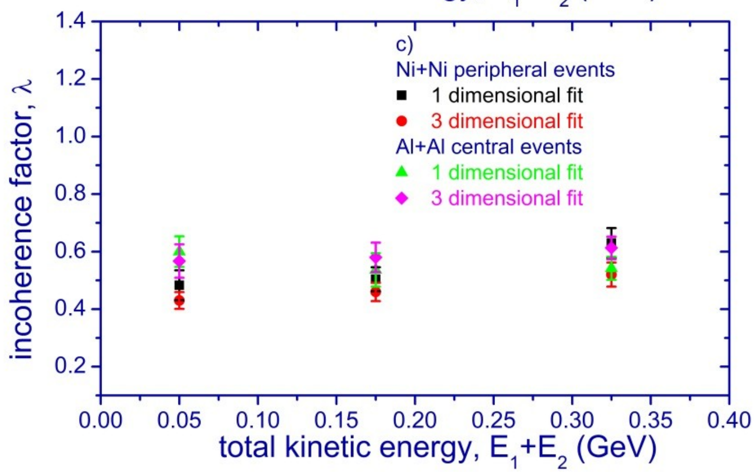
Al+Al system: b = (0÷2) fm, A_{par} = 43÷54
Ni+Ni system: b = (0÷3.4) fm, A_{par} = 84÷116
b = (3.4÷7) fm, A_{par} = 47÷84

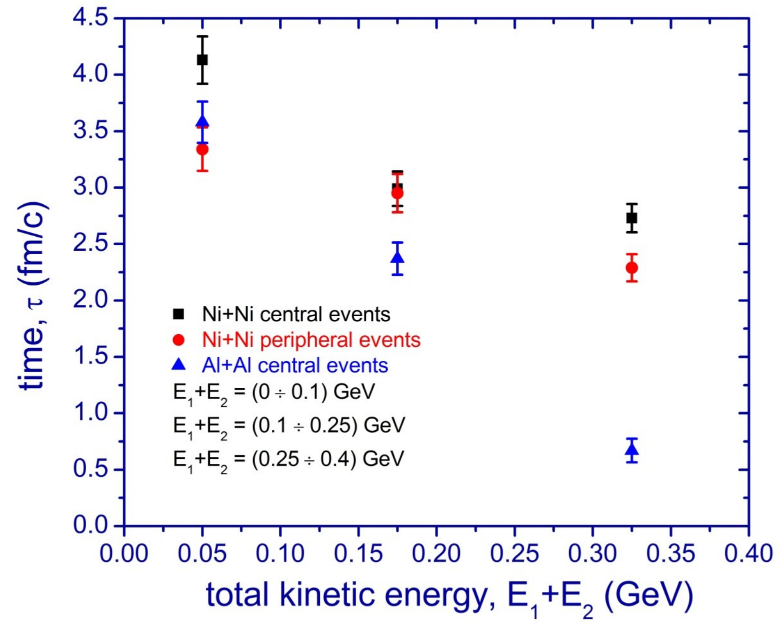
- With increasing total kinetic energy of two pions for the Al+Al and Ni+Ni system central and peripheral events effective source radius R_0 decreases.
- Radii R_{long} and R_{out} for both system decreases with increasing kinetic energy.
- Radius R_{side} for Al+Al and Ni+Ni system doesn't changes with the total kinetics energy of two pions.

Two $\pi^+\pi^+$ correlation function - Total kinetic energy dependence









- Calculated values of R_{out} is large then values of R_{side}.
- Ratio of R_{out}/R_{side} for both systems doesn't changes significantly with increasing total kinetic energy.
- For the Ni+Ni system central events values of incoherence factors extracted from one-dimensional Bowler-Sinyukov fits is larger then those from tree-dimensional fits.
- Values of λ extracted from one-dimensional Bowler-Sinyukov fits for the Ni+Ni peripheral events and Al+Al system central events is similar to those from tree-dimensional fits.
- Lifetime of the pion source decreases with the increasing total kinetic energy of two coincident pions.

Conclusions and outlook

- Large sample of $\pi+\pi+$ and $\pi-\pi-$ pairs for Al+Al and Ni+Ni collisions at 1.9A GeV obtained by FOPI collaboration

- Two pion source radius shown system-size dependence ($R_{Ni} > R_{Al}$, $R \approx A^{1/3}$)
  With increasing size of the colliding system the source radius are found to increase.
  This dependence is due to a larger number of participants in the collision zone.

- Source radius decrease with energy. The high-energy first generation source smaller to source of secondary pions.

- With increasing total transverse momentum of two coinciding particles the source radii become smaller. This dependence is consistent with the concept of the collective expansion of nuclear matter after the compression phase.

- 3-dimensional radii of effective source extracted from two positive pion correlations is similar to the results of two negative pion correlations.

Thank you for attention !!!!