New results on Coulomb interaction effects in relativistic heavy ion collisions

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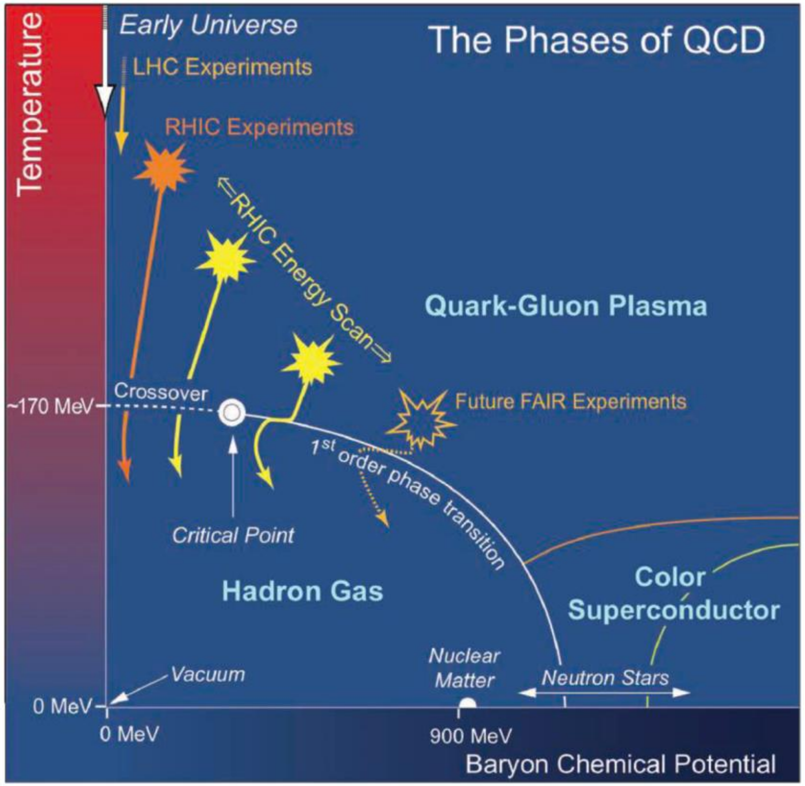
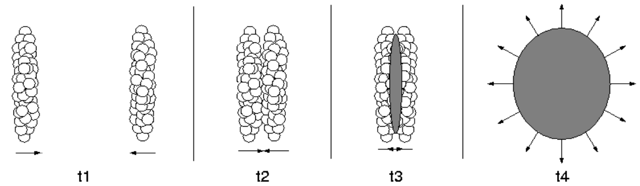
Outline

- Motivation
- Model and data used
- Results
- Conclusions

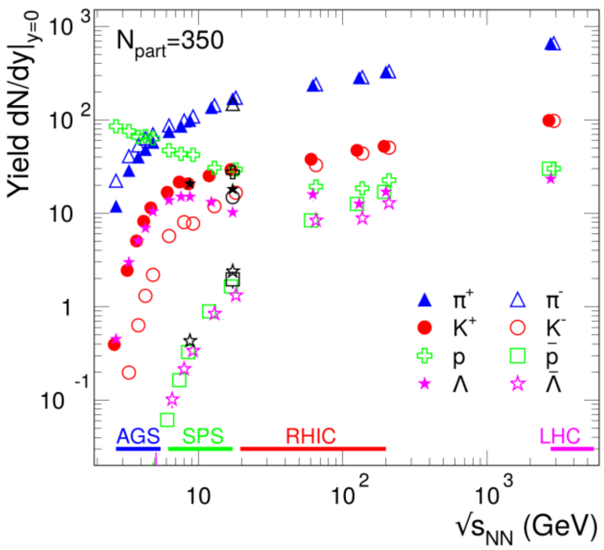
Exploring the phase diagram



By changing the energy available in the collision and the projectile-target combinations, one can obtain systems characterized by various T, μ_B → different regions on the phase diagram can be investigated

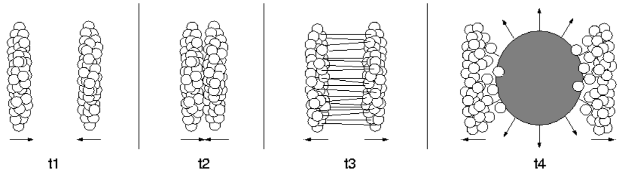


From full stopping:



A. Andronic, Int. J. Mod. Phys. A 29(2014)1430047

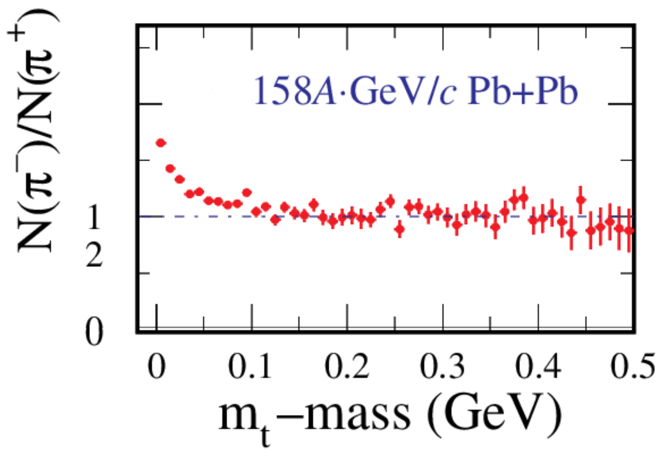
To transparency:

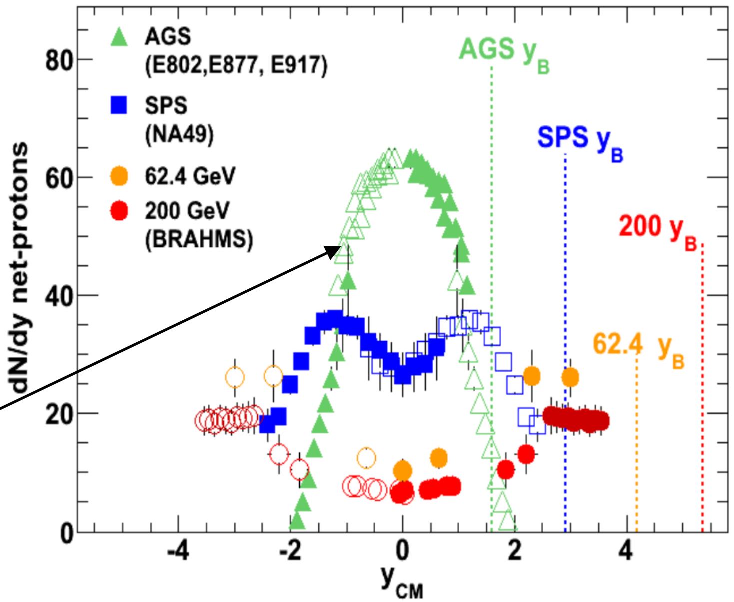


Coulomb effects on charged pions

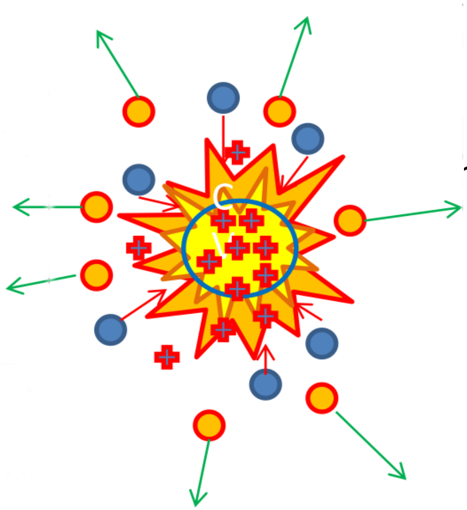
SPS previous results (NA44, Phys. Lett. B 372 (1996)339):

$\sqrt{s_{NN}}$ = 4.7 17.3 200 GeV





At midrapidity, evolution from baryon (AGS) to meson (RHIC) dominated medium

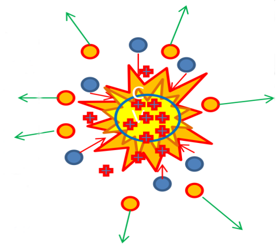


Coulomb interaction between the pions and positive net-charge → π+ (π-) are accelerated (decelerated) by the Coulomb field generated by the positive charge

D. Cebra cartoon

Data and theoretical model used

Data:



STAR-BES Au-Au data at $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27 and 39 GeV
(STAR coll., Phys. Rev. C 96 (2017) 44904)

Model*:

- considers the longitudinal Bjorken expansion of the fireball and assumes that on average, a charged pion will receive a momentum change → "Coulomb kick", p_c

$$p_c \equiv |p_T - p_{T,0}| \cong 2e^2 \frac{dN^{\mathrm{ch}}}{dy} \frac{1}{R_f}$$

The Coulomb effect can be derived from the p_T spectra, assuming an exponential shape:

$$\frac{dN}{d^2p_\perp} = \frac{dN_0}{d^2p_{0,\perp}} \frac{p_{0,\perp}}{p_\perp} , \quad \text{with} \quad dN/d^2p_\perp \propto \exp(-m_\perp/T)$$

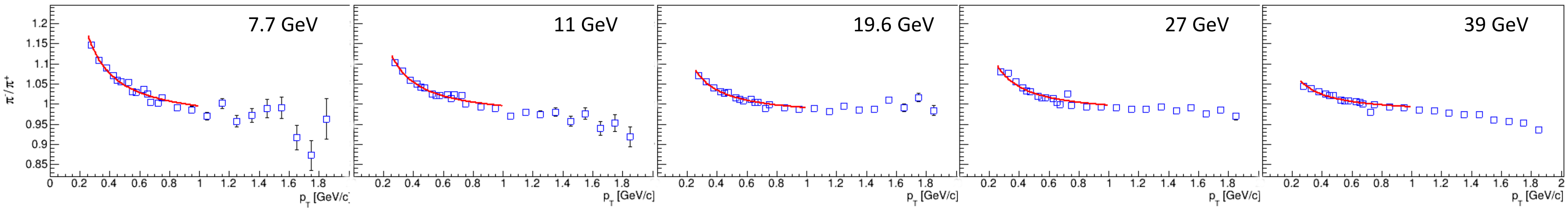
The charged pion ratio is:

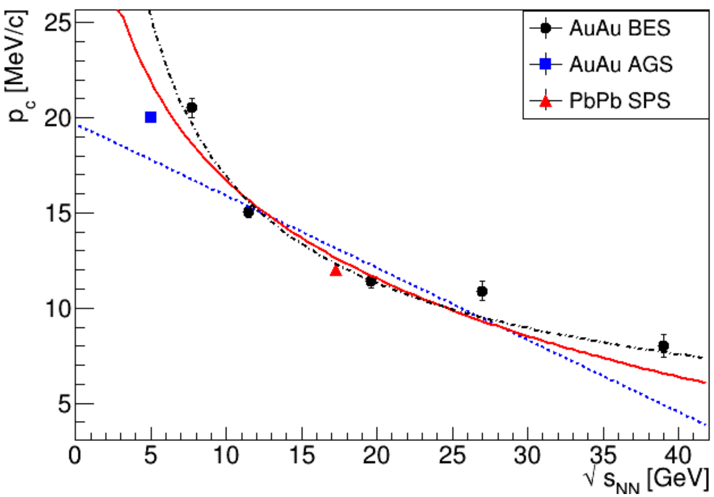
$$\frac{\pi^-}{\pi^+} = \left\langle \frac{\pi^-}{\pi^+} \right\rangle \frac{p_T + p_c}{p_T - p_c} \exp\left(\frac{m_T^- - m_T^+}{T} \right)$$

where T thermal freeze-out temperature, $\langle \pi^-/\pi^+ \rangle$ initial pion ratio and $m_T^\pm = \sqrt{m^2 + (p_T \pm p_c)^2}$

*H. W. Barz, J. P. Bondorf, J. J. Gaardhøje, and H. Heiselberg, Phys. Rev. C 57 (1998)2536–2546; H. Heiselberg, Nuclear Physics A 638 (1998) 479C

Energy dependence of Coulomb interaction





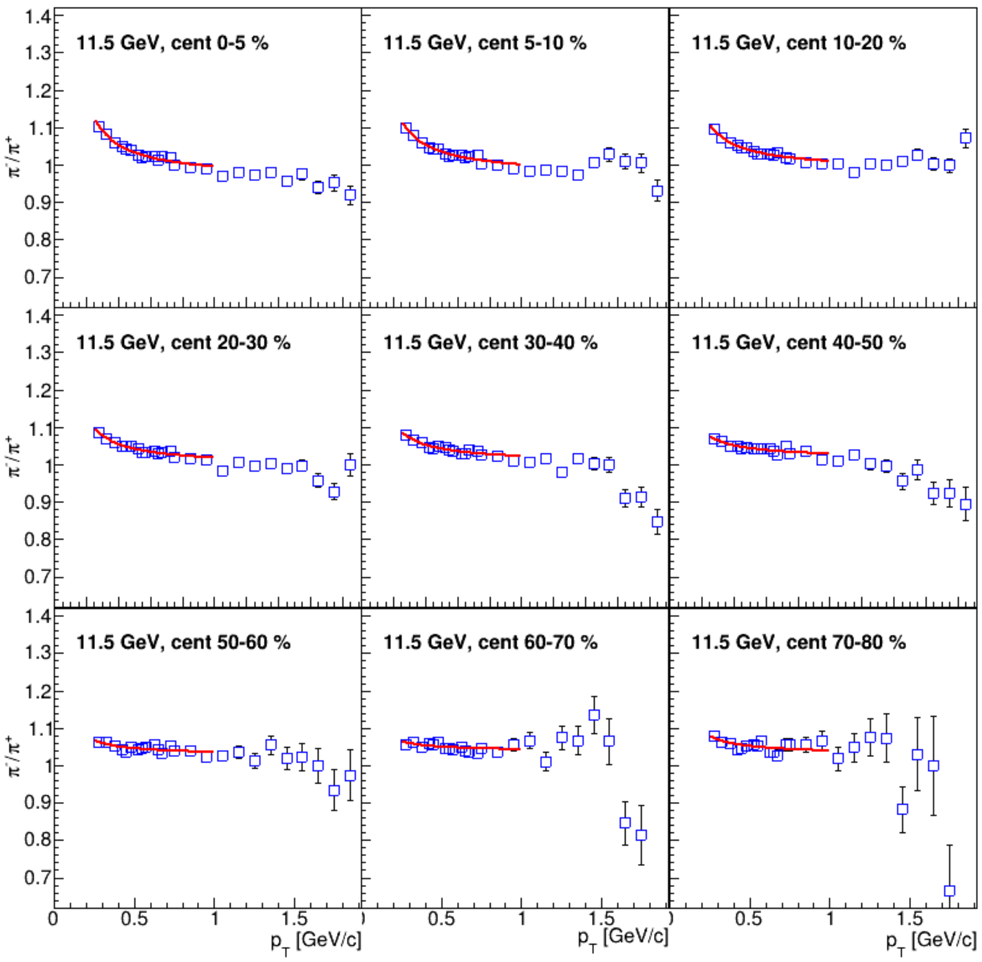
AGS ans SPS results, H. W. Barz, J. P. Bondorf, J. J. Gaardhøje, and H. Heiselberg, Phys. Rev. C 57 (1998)2536–2546

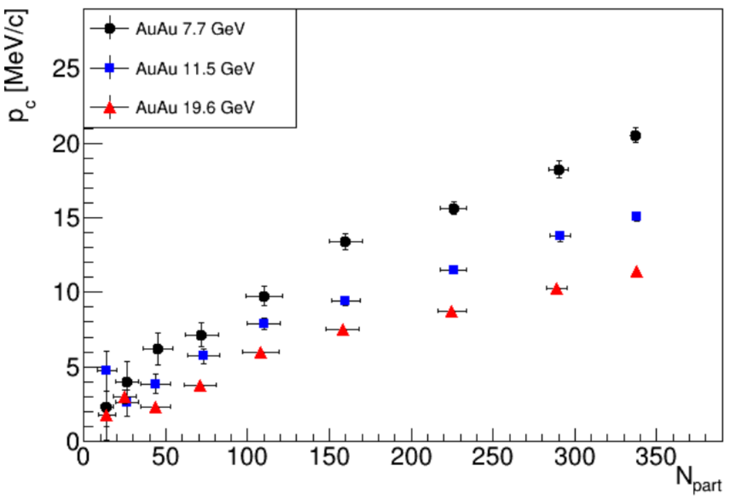
$$\frac{\pi^-}{\pi^+} = \left\langle \frac{\pi^-}{\pi^+} \right\rangle \frac{p_T + p_c}{p_T - p_c} \exp\left(\frac{m_T^- - m_T^+}{T} \right)$$

$$f_1 = a + b \ln \sqrt{s_{\rm NN}} \qquad f_2 = a\left(\sqrt{s_{\rm NN}}\right)^b \qquad f_3 = a + b\sqrt{s_{\rm NN}}$$

	f_1	f_2	f_3
a	32.98±1.08	61.66±5.01	19.62±0.41
b	-7.04±0.38	-0.56±0.03	0.34±0.02
χ2/ndf	10.11	4.25	28.23

Centrality dependence



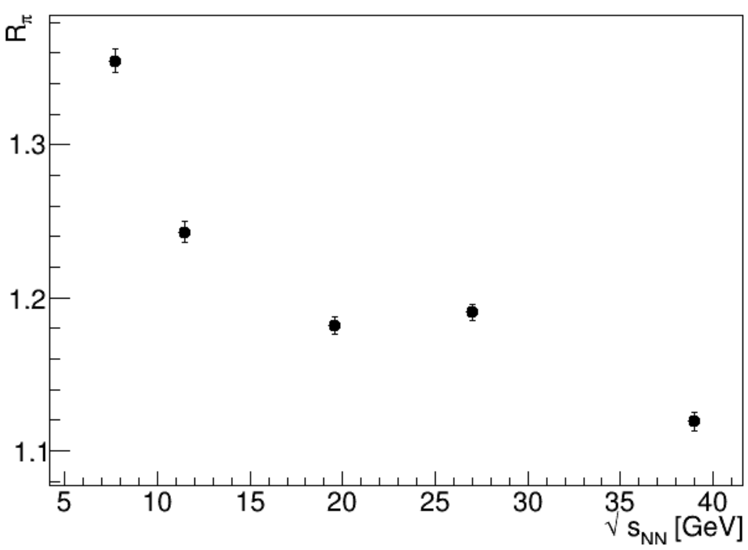


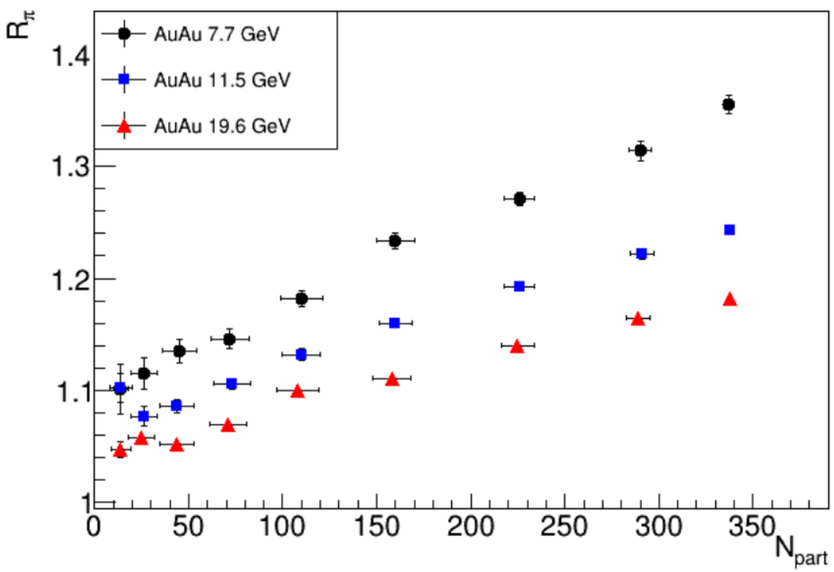
p_c decreases from central to peripheral collisions for all energies → the overlap volume is smaller → less positive charge generates a smaller Coulomb field.

$\sqrt{s_{NN}}$ [GeV]	7.7	11.5	19.6
dN^{ch}/dy (0-5%)	54.5±6.1	42.5±5.3	30.0±4.5

STAR coll., Phys. Rev. C 96 (2017) 44904

Initial pion ratio

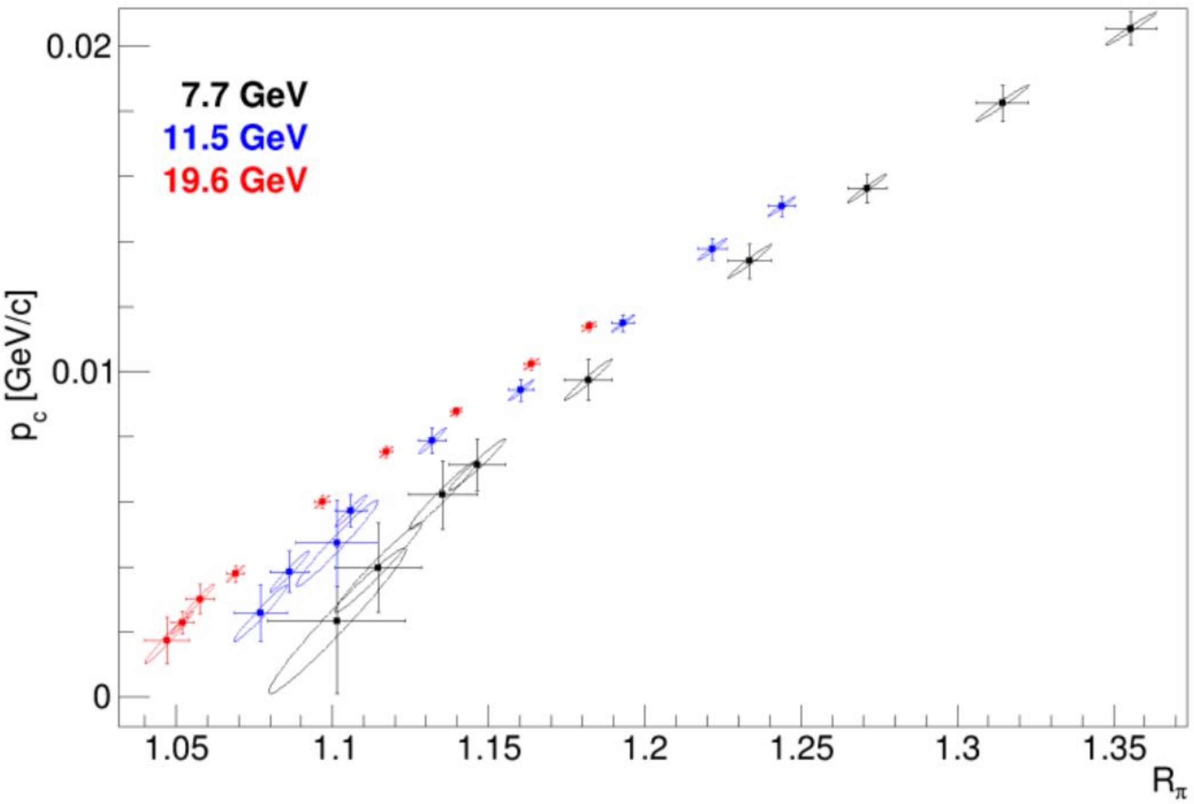




At lower beam energies the ratios are larger than unity → due to isospin conservation and significant contributions from Δ resonance decays.

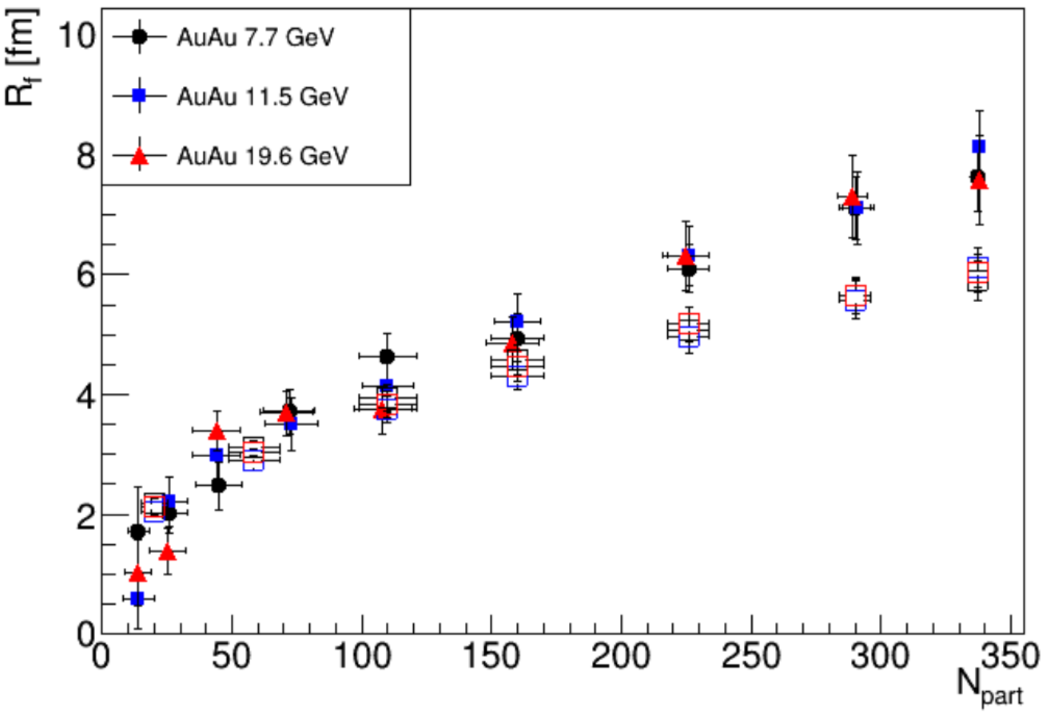
As the energy is increasing → a change in pion production mechanisms and direct pion pair production dominates

p_c – R_π correlation



- the two parameters are positively correlated
- the 1-σ contour lines do not overlap for the studied energies
- in peripheral collisions there is a wider range of possible values compared to more central collisions.

Freeze-out radii



$$p_c \equiv |p_T - p_{T,0}| \cong 2e^2 \frac{dN^{ch}}{dy} \frac{1}{R_f}$$

- The kinetic freeze-out radius decreases from central to peripheral collisions → in a central collision a larger system is formed.

- the open symbols → the chemical freeze-out radius based on a thermal model analysis (STAR coll., Phys. Rev. C 96 (2017) 44904)
- solid symbols → kinetic freeze-out radius based on Coulomb interaction model

Conclusions

- The Coulomb kick decreases with the increase of beam energy, showing that the Coulomb interaction is stronger at lower energies
- For the same energy, the Coulomb interaction is larger in central collisions because there is strong stopping and an important positive net-charge in the central rapidity region.
- The Coulomb interaction decreases in peripheral collisions.
- The kinetic FO radius is not changing with energy for the energy interval considered and shows an increase from peripheral to central collisions → a larger system in more central collisions.

Backup

The time component of the electromagnetic potential from a moving charge, Q with a velocity , v:

$$\phi(r_\perp, t) = A^0 = \frac{Q}{\sqrt{v^2t^2 + (1-v^2)r_\perp^2}},$$

The electric field is:

$$\mathbf{E}(r_\perp, t) = -\nabla\phi(r_\perp, t) = e\int \frac{dN^{ch}}{dy}\frac{\mathbf{r}_\perp dv}{(r_\perp^2 + v^2(t^2 - r_\perp^2))^{3/2}}$$

A charged pion receives a momentum change:

$$p_c \equiv \Delta\mathbf{p}_\perp = \mathbf{p}_\perp - \mathbf{p}_{\perp,0} = \pm e\int_{\tau_f}^{\infty}\mathbf{E}(r_\perp, t)dt \simeq 2e^2\frac{dN^{ch}}{dy}\frac{1}{R_f},$$

The Coulomb effect can be derived from the transverse particle distributions, assuming an exponential shape:

$$\frac{dN}{d^2p_\perp} = \frac{dN_0}{d^2p_{0,\perp}}\frac{p_{0,\perp}}{p_\perp}. \quad \text{with} \quad dN/d^2p_\perp \propto \exp(-m_\perp/T)$$

The pion ratio is:

$$\frac{\pi^-}{\pi^+} = \left\langle\frac{\pi^-}{\pi^+}\right\rangle \frac{p_T + p_c}{p_T - p_c}\exp\left(\frac{m_T^- - m_T^+}{T}\right) \quad \text{with} \quad m_T^\pm = \sqrt{m^2 + (p_T \pm p_c)^2}$$

H. W. Barz, J. P. Bondorf, J. J. Gaardhøje, and H. Heiselberg, Phys. Rev. C 57 (1998)2536–2546; H. Heiselberg, Nuclear Physics A 638 (1998) 479C