The effect of the spectator charge on the charged pion spectra in peripheral ultrarelativistic heavy-ion collisions

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based on:
A. Rybicki and A. Szczurek
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Introduction/Motivation

- inclusive distributions ==> no clear information on time-space development of the process
- HBT ==> some information on time-space emission

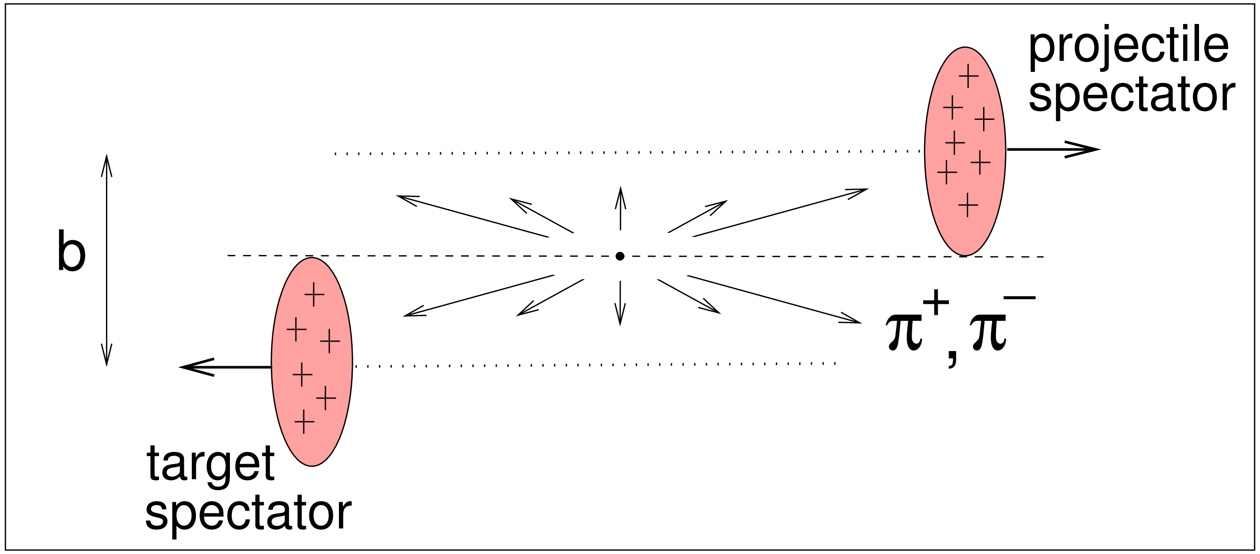
Large charge of remnants in peripheral HI collisions

Questions:

- Can the EM field(s) generated by the remnants of peripheral collisions distort the charged pion spectra ?
- If yes, can this be used to get information on time-space dependence of the pion creation process?

Some work has been done at intermediate energies (CERN, Bevalac).
At higher energies the b-dependence by multiplicity measurements and/or by forward calorimetry.

Modelling a Peripheral Pb+Pb Collision

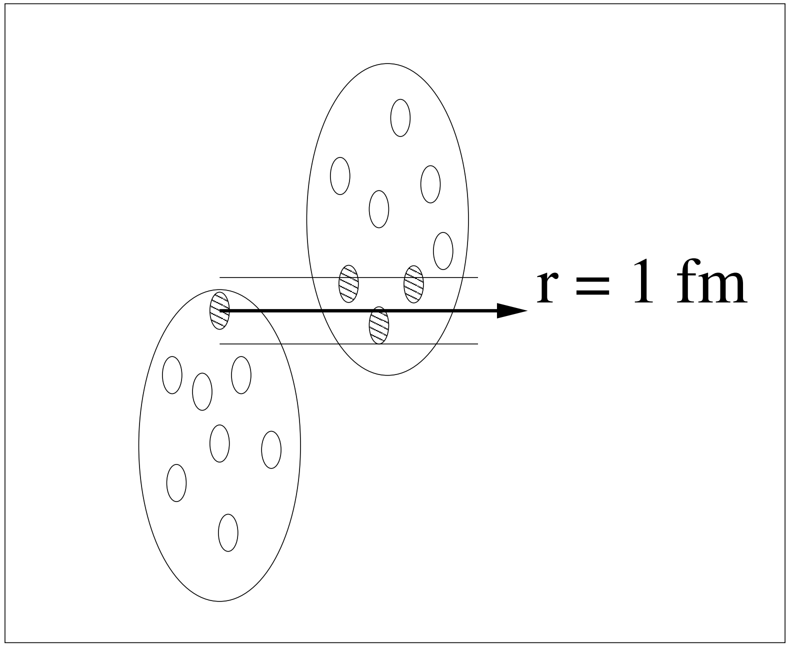


1. the collision takes place at a given impact parameter b.
2. The two charged spectator systems follow their initial path.
3. the participating system evolves until pions are produced.
4. charged pion trajectories are modified by EM interaction.

Modelling a Peripheral Pb+Pb Collision at SPS

1. a peripheral Pb+Pb collision with 60 participating N's (b = 10.61 fm). The spectator systems = uniform spheres in their respective rest frames. $\rho = 0.17/\text{fm}^3$. Q(LS) = Q(RS) = 70. In CM frame the two spheres – disks.
2. the pion emission – single point in space. The emission time t_E is a free parameter. We assume that the initial (x_F, p_T) distribution of the emitted pion is that for underlying N+N collisions (rescaled).
3. charged pions, with their initial momenta traced in the EM field of the spectator charges until they reach a distance of 10,000 fm (from the original interaction point and from each of the two spectator systems).
4. the fragmentation of the spectator systems is neglected, the influence of participant charge, strong FSI are not considered.

Collision Geometry



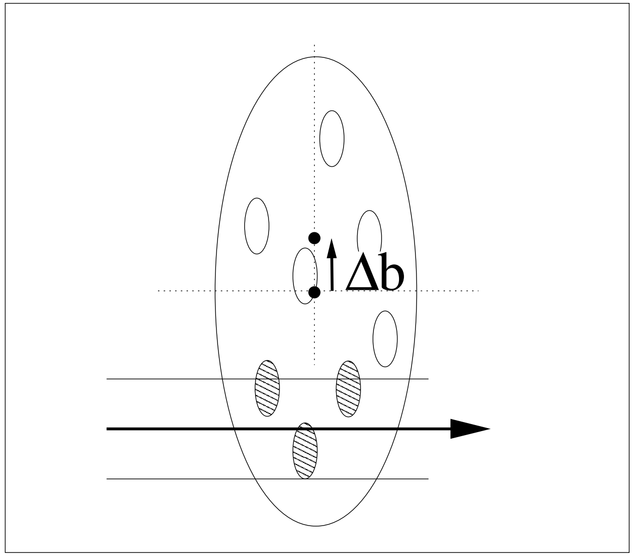
1. We adjust the geometry (centrality) of the Pb+Pb collision to 60 participating nucleons in order to make it comparable to the data sample from SPS.
2. The relation between the impact parameter b, the number of participating nucleons N_{part} and the spectator charge Q is defined by the nuclear density profile and the N+N cross section.

Collision geometry

How we fix initial impact parameter ?

1. We study this by means of a Monte Carlo simulation. Spatial distributions $\rho_p(r)$ and $\rho_n(r)$ for ^{208}Pb from Hartree-Fock-Bogoliubov (HFB) approach Mizutori et al. Our Monte-Carlo takes into account the neutron halo effect.
2. Nucleon is defined as participant if it is crossed by one or more nucleons from the other nucleus within a transverse radius of less than 1 fm.
3. We modify b until we get 60 participating nucleons.

Collision Geometry

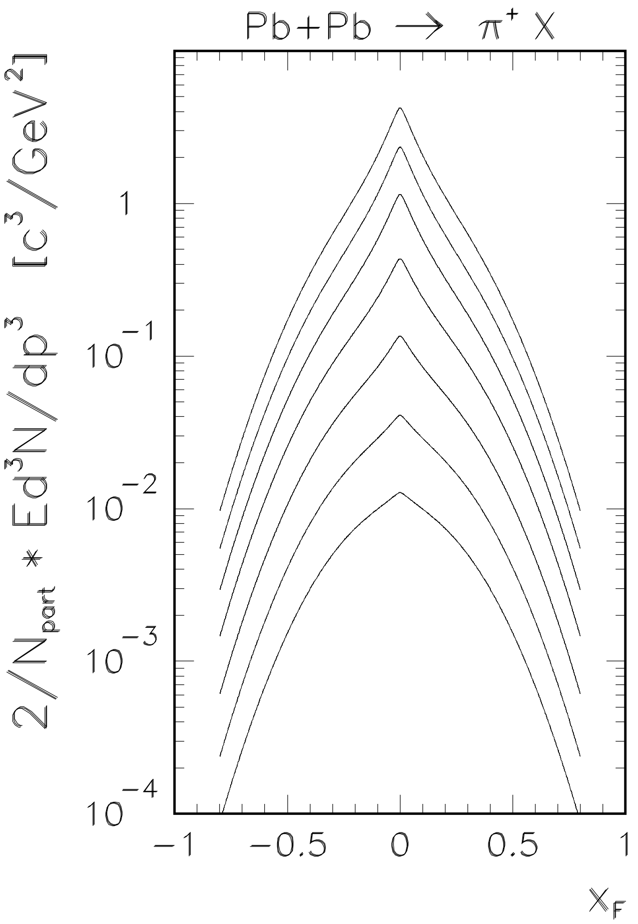


1. Another important parameter – displacement Δb of the spectator protons' centers w.r.t. the center of gravity of the original nucleus. Our MC gives $\Delta b = 0.76$ fm. Thus the effective distance of the closest approach between the spectator centers $b' = b + 2\Delta b = 12.13$ fm.
2. The spectator systems – homogenous spheres with ρ=0.17/fm^3 and with properly shifted centers.

Initial Pion Emission

1. We reduce the unknown initial emission region to a unique point in space – the original interaction point. We assume one emission time t_E (a free parameter).
2. We assume that the initial kinematical spectra of the emitted pions are similar to these in N+N collisions and that they follow wounded nucleon scaling.
3. Full azimuthal symmetry of the emission is assumed.
4. We neglect isospin effects i.e. assume equal initial emission spectra for π^+ and π^-
5. We construct a smooth two-dimensional parametrization that reproduces the most basic features of the pion production in pp coll. (it does not include the more subtle, local shape structures).

Initial Pion Emission



$p_T =$ 50, 100, 200, 400, 600, 800, and 1000 MeV/c
The two top curves multiplied by 2.5 and 1.5. Good description of the NN data

Initial Pion Emission

Assumed form:

$$\frac{2}{N_{part}}\, E\frac{d^3N}{dp^3}_{Pb+Pb\to\pi X} = \sum_{n=1,2} a_n \exp\left(-(x/b_n)^{c_n}\right) \exp\left(-u_T/d_n\right) \;, \tag{1}$$

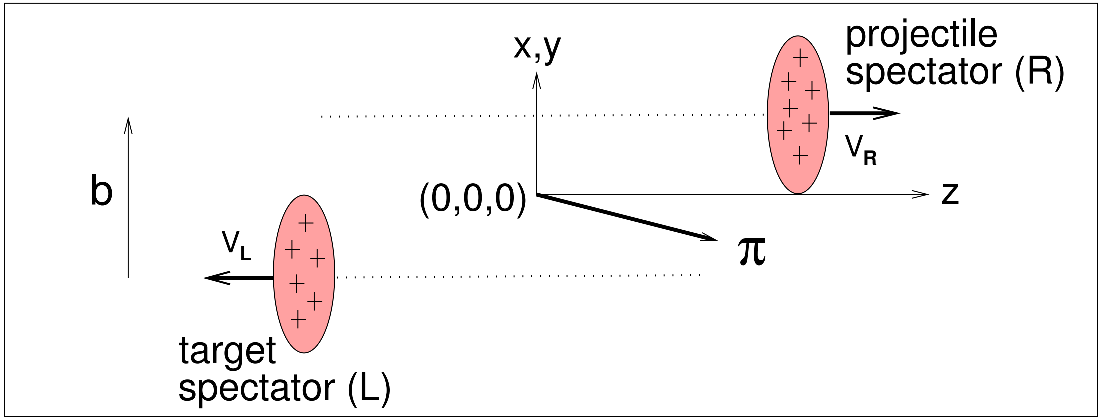
where $\pi = \pi^+$ or π^-, $N_{part} = 60$, $x = \sqrt{x_F^2 + g^2}$,
$u_T = \sqrt{q^2 + p_T^2}$,

Parameters:

n	a_n [c^3/GeV^2]	b_n	c_n	d_n [GeV/c]		
1	2.32229	0.369967	2.	0.191506	$g =$	0.01
2	24.4563	0.0873833	1.001	0.12	$q =$	0.33496

Propagation of Pions in the EM Field

1. The initially produced charged pions are subjected to the EM field of the two spectator systems. The spectator velocity remains constant and identical to the velocity of the parent Pb ion ($v_L = v_R \equiv v_S = 0.994c$).
2. We choose the overall CM system to calculate the evolution of pion trajectories. For symmetric Pb+Pb collisions this is also the N+N CM system.



Propagation of Pions in the EM Field

Time scale: such that at $t = 0$ the center of gravity of each of the spectator systems is found at $z_L = z_R = 0$.

$$\begin{aligned} \vec{R}_L(t) &= -\vec{b}/2 + \vec{v}_L \cdot t \ , \\ \vec{R}_R(t) &= \quad \vec{b}/2 + \vec{v}_R \cdot t \ . \end{aligned} \tag{2}$$

In the rest frames of spectators:

$$\vec{E}'_L(\vec{r'_c}) = \begin{cases} k\,Q\ \ \vec{r'_c}\ /\ {r'_c}^3 & \text{for} \quad r'_c > R_s \\ k\,Q\ \ \vec{r'_c}\ /\ R_s^3 & \text{for} \quad r'_c < R_s \end{cases} \tag{3}$$

$$\vec{E}''_R(\vec{r''_c}) = \begin{cases} k\,Q\ \ \vec{r''_c}/{r''_c}^3 & \text{for} \quad r''_c > R_s \\ k\,Q\ \ \vec{r''_c}/R_s^3 & \text{for} \quad r''_c < R_s \end{cases} \tag{4}$$

$k \approx 1.44$ MeV $\cdot$ fm$/e^2$, $R_s = [N_{spec}/(4/3\pi\rho)]^{1/3}$ is the sphere radius defined by N_{spec} ($R_s = 6.3$ fm).

Propagation of Pions in the EM Field

We transform the fields $\vec{E}'_L$, $\vec{E}''_R$ to the CM system (both electric and magnetic fields). From the general Lorentz transformation we get

$$\begin{aligned} \vec{E}_L(\vec{r},t) &= \gamma_s \vec{E}'_L(\vec{r'_c}) - \frac{\gamma_s^2}{\gamma_s+1}\,\frac{\vec{v}_L}{c}\left(\frac{\vec{v}_L}{c}\cdot\vec{E}'_L(\vec{r'_c})\right) , \\ \vec{B}_L(\vec{r},t) &= \gamma_s\left(\frac{\vec{v}_L}{c}\times\vec{E}'_L(\vec{r'_c})\right) \end{aligned} \tag{5}$$

for the left spectator and

$$\begin{aligned} \vec{E}_R(\vec{r},t) &= \gamma_s \vec{E}''_R(\vec{r''_c}) - \frac{\gamma_s^2}{\gamma_s+1}\,\frac{\vec{v}_R}{c}\left(\frac{\vec{v}_R}{c}\cdot\vec{E}''_R(\vec{r''_c})\right) , \\ \vec{B}_R(\vec{r},t) &= \gamma_s\left(\frac{\vec{v}_R}{c}\times\vec{E}''_R(\vec{r''_c})\right) \end{aligned} \tag{6}$$

for the right spectator.

Propagation of Pions in the EM Field

We now consider a charged pion emitted at time $t = t_E$ from the interaction point $\vec{r} = (0,0,0)$ with its initial momentum $\vec{p}_\pi(t = t_E)$.

$$\frac{d\vec{p}_\pi}{dt} = \vec{F}_\pi(\vec{r},t) = q_\pi \left(\vec{E}(\vec{r},t) + \frac{\vec{v}_\pi(\vec{r},t)}{c} \times \vec{B}(\vec{r},t) \right) . \qquad (7)$$

$\vec{E}(\vec{r},t) = \vec{E}_L(\vec{r},t) + \vec{E}_R(\vec{r},t)$ and $\vec{B}(\vec{r},t) = \vec{B}_L(\vec{r},t) + \vec{B}_R(\vec{r},t)$ are standard superpositions of fields.

The resulting pion trajectory $\vec{r}_\pi(t)$ is defined by its time-dependent velocity $\vec{v}_\pi(\vec{r},t)$:

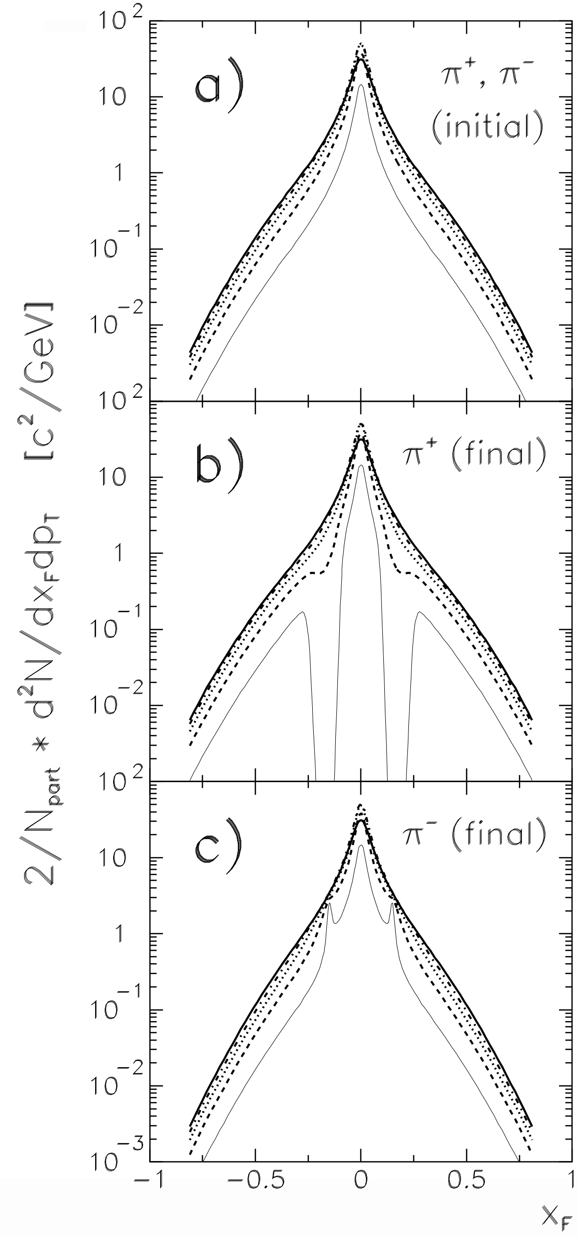
$$\frac{d\vec{r}_\pi}{dt} = \vec{v}_\pi(\vec{r},t) = \frac{\vec{p}_\pi \; c^2}{\sqrt{p_\pi^2 + m_\pi^2}} . \qquad (8)$$

Our calculation implicitly takes account of relativistic retardation effects (Jackson).

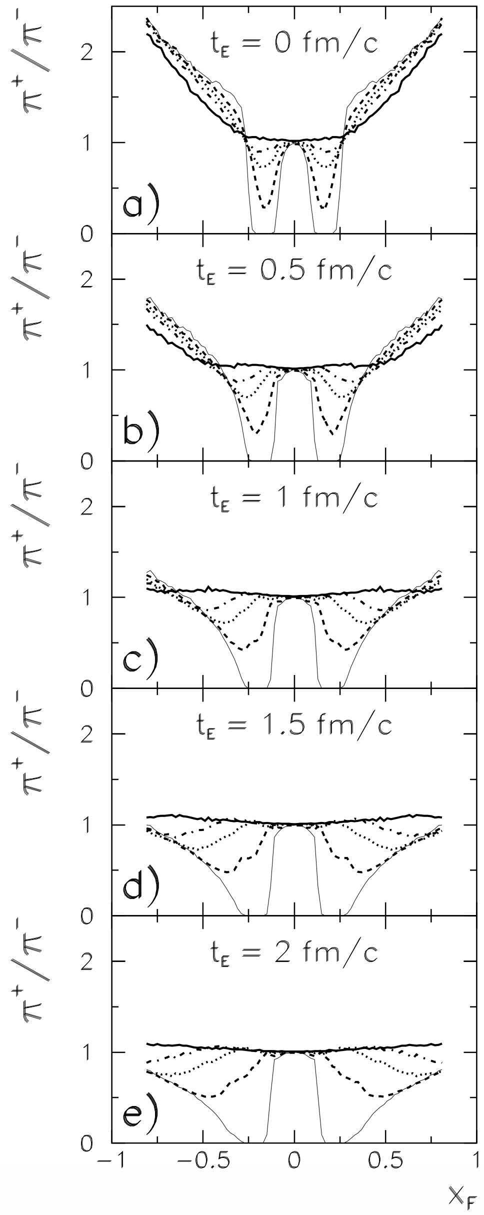
Propagation of Pions in the EM Field

1. The propagation of the pion is made by means of an iterative Monte-Carlo procedure. This procedure starts at $\vec{r} = (0, 0, 0)$ and $t = t_E$ and calculates $\vec{F}_\pi(\vec{r}, t)$, pion momentum and position in small steps in time.
2. The variable step size (!)
3. The procedure is iterated numerically until the distance of the pion from the origin $(0, 0, 0)$ is $r > R_{max}$ and from the spectators (in their respective rest frames) are $r'_c > R_{max}$ and $r''_c > R_{max}$. R_{max} = 10,000 fm is sufficiently large to reproduce asymptotic momenta.
4. The procedure is weighted – each pion is generated with its proper weight $\frac{d^2N}{dx_F dp_T}$ (used to fill the final state pion spectra).
5. Negatively charged pions that do not escape from the spectator potential well are rejected by our procedure.

Charged Pion Spectra

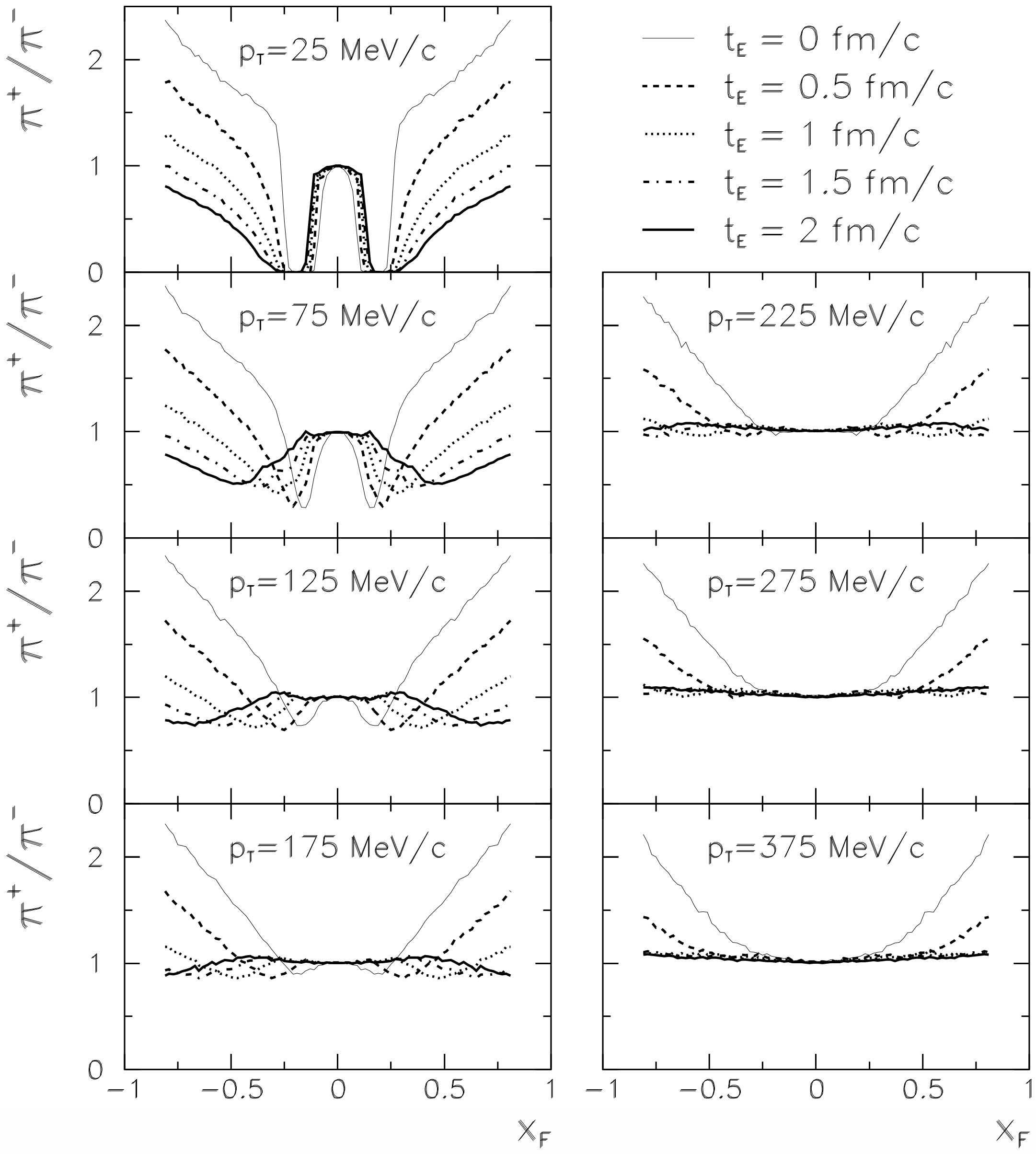


π^+/π^- Ratios



t_E = 0 fm/c
t_E = 0.5 fm/c
t_E = 1 fm/c
t_E = 1.5 fm/c
t_E = 2 fm/c
a)
b)
c)
d)
e)
π^+/π^-
0
1
2
−1
−0.5
0
0.5
1
x_F

π^+/π^- Ratios


t_E = 0 fm/c
t_E = 0.5 fm/c
t_E = 1 fm/c
t_E = 1.5 fm/c
t_E = 2 fm/c
p_T=25 MeV/c
p_T=75 MeV/c
p_T=125 MeV/c
p_T=175 MeV/c
p_T=225 MeV/c
p_T=275 MeV/c
p_T=375 MeV/c
π^+/π^-
0
1
2
−1
−0.5
0
0.5
1
x_F

Summary/Conclusions

1. The EM interaction caused by the moving remnant charge produces visible distorsions in the final state distributions of π^+ and π^-.
2. The main feature of this “Coulomb” effect is a big dip in the π^+ density distribution at low transverse momenta in the vicinity of $x_F \approx \pm 0.15$, accompanied by a substantial increase of π^- density in the same region.
3. The effect is clearly sensitive to initial conditions (carry interesting information on the mechanism of the non-perturbative particle production process).
4. Our study demonstrates the importance of new, double-differential data on the x_F and p_T-dependence of pion production in peripheral nucleus+nucleus collisions.

Outlook

1. Estimate effect for minimum bias collisions
2. Isospin violation: $(\pi^+ + \pi^-)/2 \neq \pi^0$
3. Effect on R_{AA} separately for π^+ and π^- for at large y BRAHMS ?
4. Effect on $d\sigma/d\eta$ for charged particles at large η PHOBOS ?
5. Effect for kaons ?