The study on the early system just after Heavy Ion Collision

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J.Phys G. 29, 2485/JKPS 43, 473

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2004. 10. 8

1. INTRODUCTION

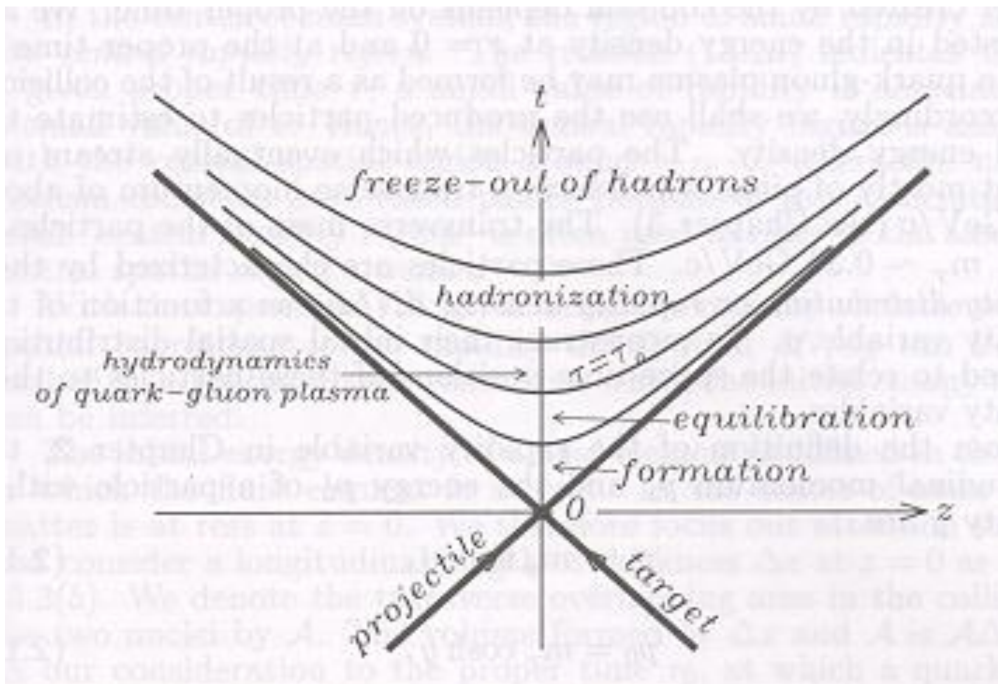
Important questions in Relativistic Heavy Ion Physics:

1) Do we have a QGP after an UrRHIC?
2) If yes, what is the equation of state and what are the measurable signatures?

→ To answer, may need to know from the colliding nuclei way up to hadron detection.

→ In Bjorken picture, we are interested in the early stage from nuclei collision to thermalization.

<Bjorken View>



• Overview of the talk:

1) Find the parton distributions of nuclei.

2) Get the primary parton phase space distribution by combining the parton distribution of nuclei with parton-parton scattering cross section.

3) Solve the Boltzmann Equations of motion by the Monte-Carlo method for a given phase space.

4) Get the information of the system, for example, energy density, number density, isotropicity, rapidity distribution, etc.

2. INITIAL PHASE-SPACE DISTRIBUTION:

(MINIJET PRODUCTION)

- The PARTON DISTRIBUTION of HIGH ENERGY Au:

$$f_{i/A}(x, Q^2) = f_{i/N}(x, Q^2) R_A(x, Q^2),$$

x : Bjorken Variable

Q : Transverse momentum,

N : Nucleon

i : Parton

$f_{i/N}$: The distribution of i-parton, GRV98 Function

R_A : Nucleon distribution of Nucleus A,

EKS98 Ratio Function

➢See other methods, for examples, Kharzeev and Nardi, Parton Saturation Model, HIJING !

- Combine the distribution functions with (elastic) parton - parton cross section to get the primary partons:

$$\frac{dN^{jet}(\vec{b})}{dp_T dy} = K T(\vec{b}) \int dy_2 \frac{2\pi p_T}{\hat{s}} \sum_{ij,kl} x_1 f_{i/A}(x_1, Q^2) x_2 f_{j/A}(x_2, Q^2) \frac{1}{2} \sigma_{ij \to kl}(\hat{s}, \hat{t}, \hat{u})$$

b : impact parameter,
K : K-factor to include higher order,
T(b) : Overlap function,

$$T(\vec{b}) = \int d\vec{s}\, T_A(\vec{s}) T_B(\vec{b} - \vec{s})$$

T_A : Thickness function of the nucleus A.

➢ Note that the space-time are missing here!!

- Primary Collision channels:

$$
\begin{aligned}
gg &\rightarrow gg,\ q\bar{q} \\
g\bar{q} &\rightarrow g\bar{q} \\
g\,q &\rightarrow g\,q \\
\bar{q}\bar{q} &\rightarrow \bar{q}\bar{q} \\
q\,\bar{q} &\rightarrow q\,\bar{q} \\
q\,q &\rightarrow q\,q,\ gg
\end{aligned}
$$

- Numbers of Produced Partons After Relativistic Heavy Ion Collisions(200 AGeV Au, Q_0 = 1.2 GeV)

b(fm)	Gluons	Quarks	Antiquarks	Total
0	3731	585	134	4450
1	3583	561	128	4272
2	3269	512	117	3898
3	2865	449	102	3416
4	2415	378	86	2879
5	1952	306	70	2328
6	1503	235	53	1791
7	1088	170	39	1297
8	727	114	26	867
9	433	67	15	515
10	215	33	7	255
11	75	11	2	88
12	10	1	0	11

3. Test Particle Sampling

- Sampling Method:

1. Sample the MOMENTUM according to the parton production distribution by Monte Carlo.

2. Sample the SPACE-TIME POINT where relativistic elastic scatterings occur: That is where the parton is born.

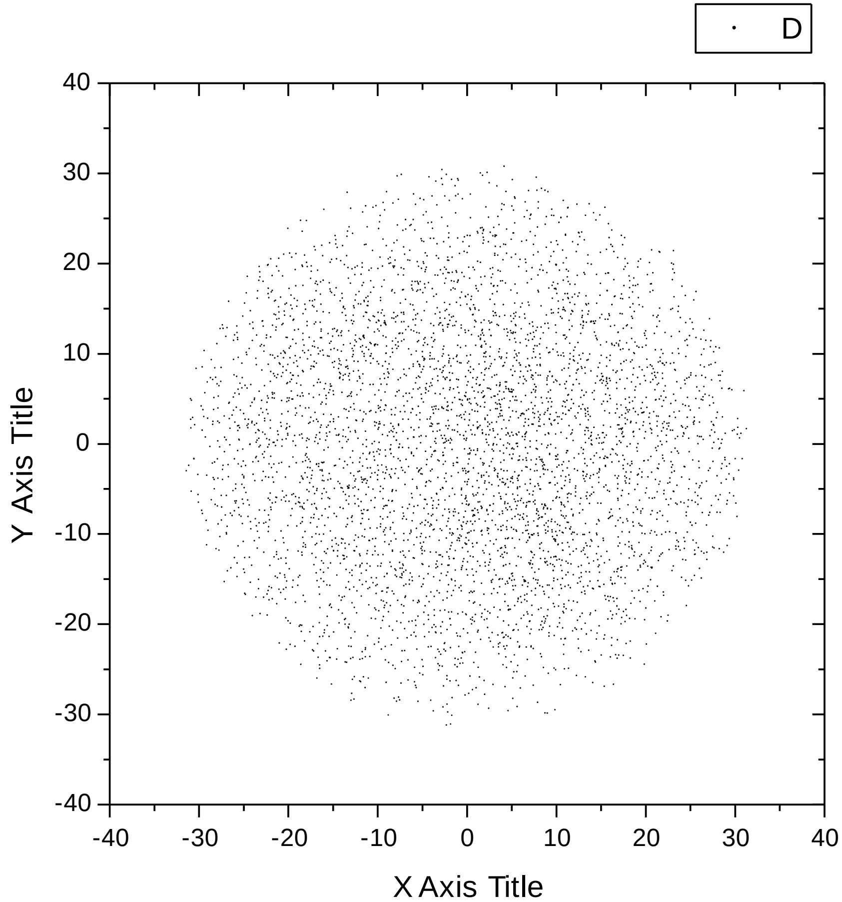
- Space-Time Sampling:

1. **LONGTUDINAL AND TIME**: Assuming the probability density which an elastic collision can be occurred is proportional to the overlap volume, we can obtain the probability density of collision as a function of time, choose the collision time. Then we can calculate the overlap volume and its longitudinal range. We can choose the longitudinal collision position z in this range.

2. **TRANSVERSE**: On the other hand, we can choose the transverse position according to the density profile 'WOODS-SAXON MODEL' or 'SHARP EDGE MODEL'.

NOTE: x-axis is the impact parameter direction, z-axis is the collision axis.

We use 'SHARP EDGE MODEL':



4. Monte Carlo Simulation

SOLVE the BOLTZMANN EQUATIONS of MOTION of PARTON using PCC(Parton Cascade Code):

$$ DIFFERENCE between PCC and Columbia Group:

1) Include the retardation effects exactly up to the Abelian part(EM-like), so that there is NO SUPERLUMINAR.

2) We include gg->ggg processes, so that we include the secondary particle productions:

$$\frac{d\sigma^{gg\to ggg}}{dq_T^2\ dy\ dk_T^2} = \frac{9C_A\alpha_s^3}{2}\frac{q_T^2}{(q_T^2+\mu_D^2)^2}\frac{\Theta(k_T\lambda_f-\cosh y)\Theta(\sqrt{s}-k_T\cosh y)}{k_T^2\sqrt{(k_T^2+q_T^2+\mu_D^2)^2-4k_T^2q_T^2}}$$

- Is the Boltzmann equation valid? **Maybe YES**. A. Mueller and DT Son showed that the dense classical field theory is equivalent to the Boltzmann equation(hep-th/0212198)

<Boltzmann Equations of Motion>

$$
\begin{aligned}
p^{\mu}\partial_{\mu} f_{g}(x,\vec{p}) &= \int_2\int_3\int_4 \frac{1}{2}\, W_{gg\to gg}[f_g(3)f_g(4)-f_g(1)f_g(2)] \\
&+ \int_2\int_3\int_4 W_{gq\to gq}[f_g(3)f_q(4)-f_g(1)f_q(2)] \\
&+ \int_2\int_3\int_4\int_5 \frac{1}{6}\, W_{gg\to ggg}[f_g(4)f_g(5)-f_g(1)f_g(2)] \\
&+ \int_2\int_3\int_4 W_{g\bar{q}\to g\bar{q}}[f_g(3)f_{\bar{q}}(4)-f_g(1)f_{\bar{q}}(2)] \\
&+ \int_2\int_3\int_4 \frac{1}{2}\, [\, W_{q\bar{q}\to gg} f_q(3)f_{\bar{q}}(4) - W_{gg\to q\bar{q}} f_g(1)f_g(2)]
\end{aligned}
$$

$$
\begin{aligned}
p^{\mu}\partial_{\mu} f_{q}(x,\vec{p}) &= \int_2\int_3\int_4 C W_{qq'\to qq'}[f_q(3)f_{q'}(4)-f_q(1)f_{q'}(2)] \\
&+ \int_2\int_3\int_4 W_{gq\to gq}[f_q(3)f_g(4)-f_q(1)f_g(2)] \\
&+ \int_2\int_3\int_4 \frac{1}{2}\, [\, W_{gg\to q\bar{q}} f_g(3)f_g(4) - W_{q\bar{q}\to gg} f_q(1)f_{\bar{q}}(2)]
\end{aligned}
$$

$$
\begin{aligned}
p^{\mu}\partial_{\mu} f_{\bar{q}}(x,\vec{p}) &= \int_2\int_3\int_4 C W_{\bar{q}\bar{q}'\to \bar{q}\bar{q}'}[f_{\bar{q}}(3)f_{\bar{q}'}(4)-f_{\bar{q}}(1)f_{\bar{q}'}(2)] \\
&+ \int_2\int_3\int_4 W_{g\bar{q}\to g\bar{q}}[f_{\bar{q}}(3)f_g(4)-f_{\bar{q}}(1)f_g(2)] \\
&+ \int_2\int_3\int_4 \frac{1}{2}\, [\, W_{gg\to q\bar{q}} f_g(3)f_g(4) - W_{q\bar{q}\to gg} f_{\bar{q}}(1)f_q(2)]
\end{aligned}
$$

<Basic Algorithm(PCC)>

1) Initialize the Parton Phase-Space Database(PPSD).

2) Take one of partons and calculate the nearest distance and time with the rest of partons and so on. Make possible collision cue(Collision Database: CD) as a function of Lab. time.

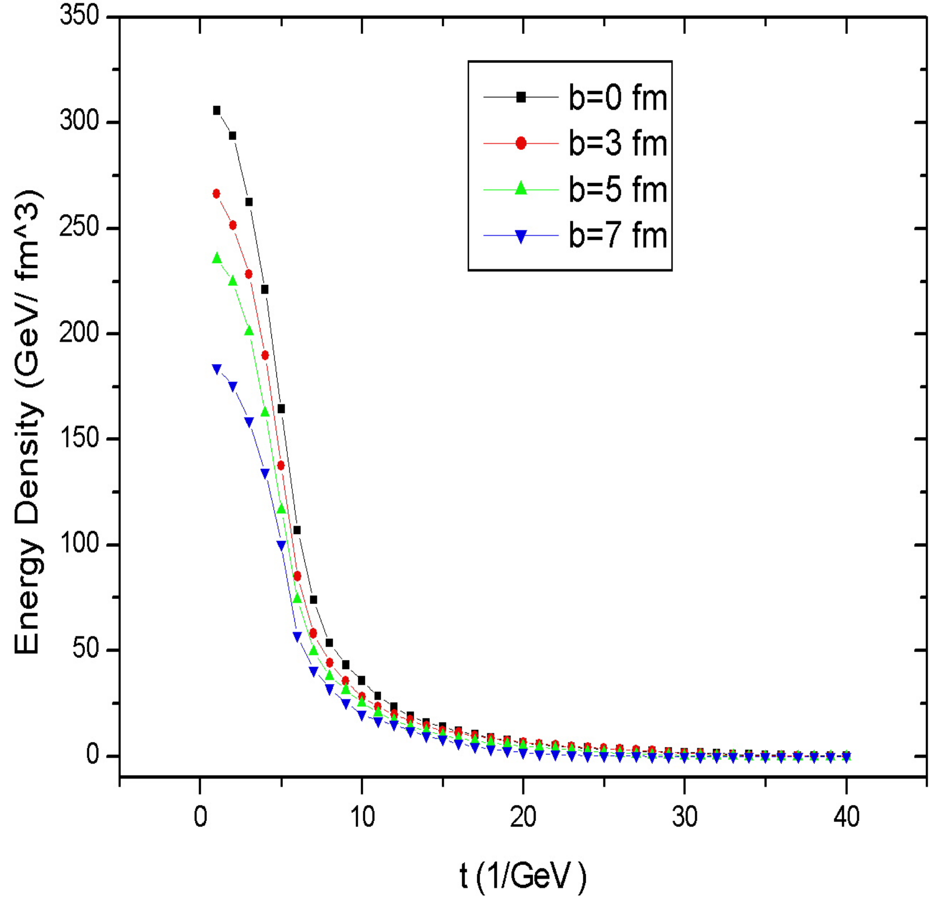
3) Take the first collision: choose the collision channel and find the momenta of newly produced partons using differential cross section. Save them in PPSD and update the CD.

4) Check if time is up. If not, take next collision and do step 3.

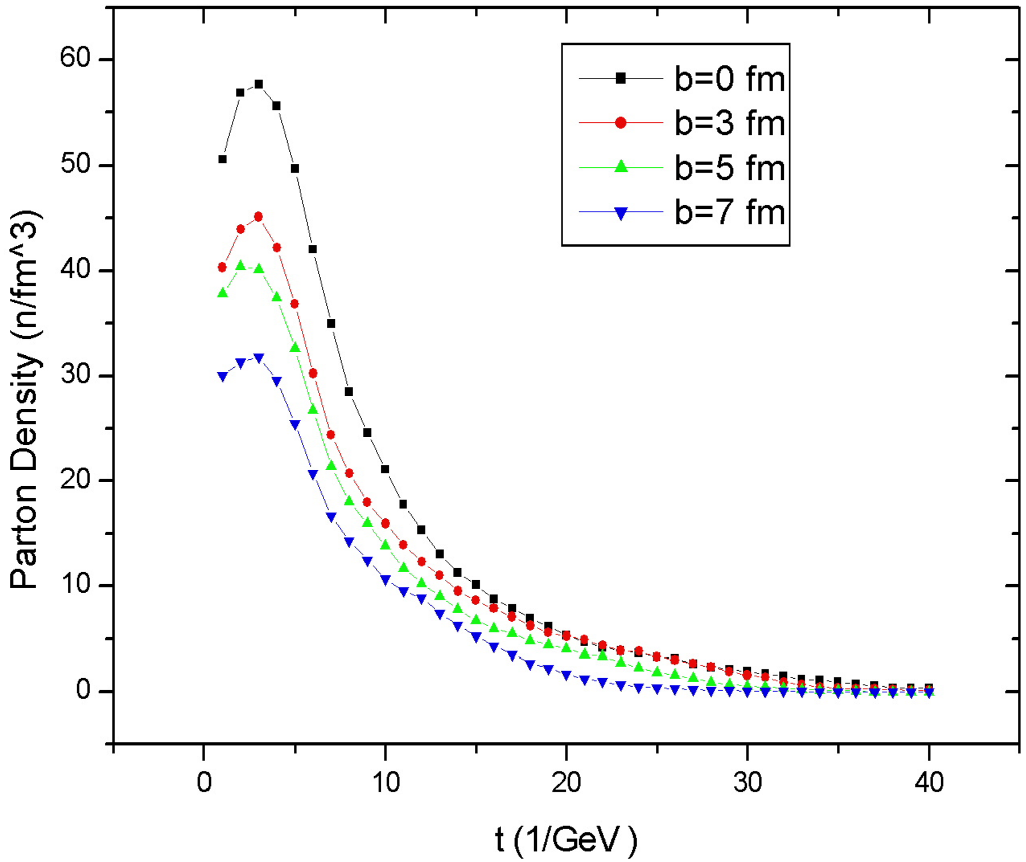
5) Calculate the physical variables for a given time.

Note: need to work in Lab. Frame but we have to use CM frame of two colliding partons so that we transform Lab to CM before collision and transform back to Lab. Energy and momentum conservation are good to judge the procedures.

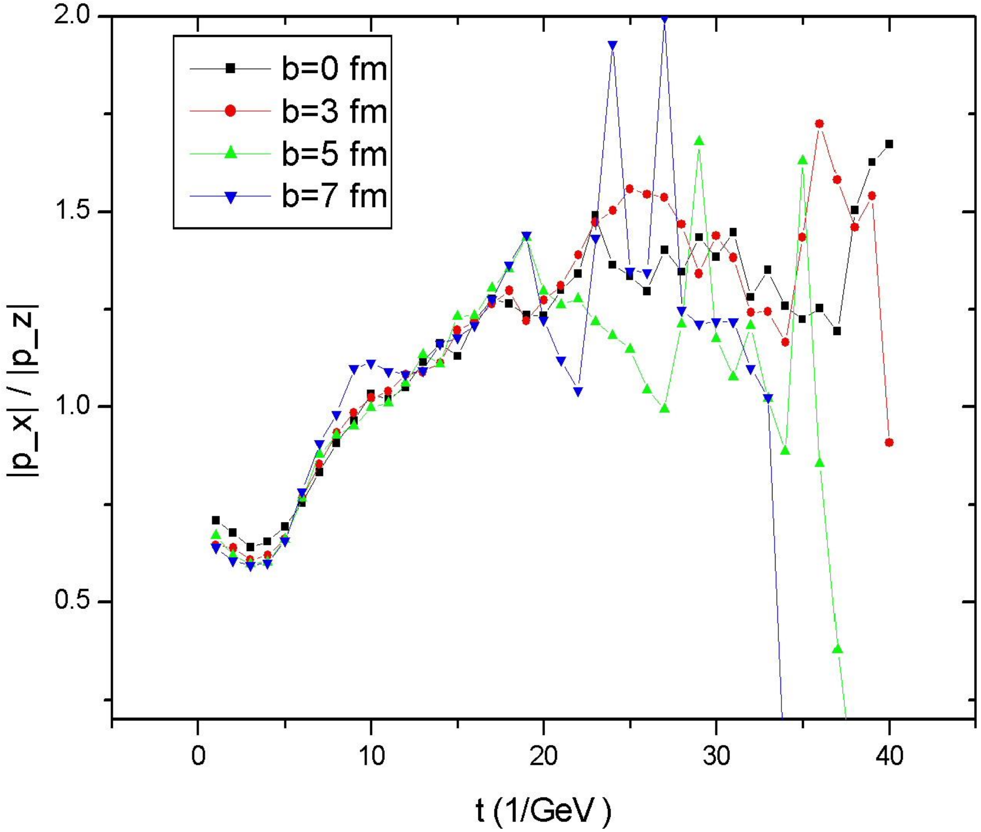
5. RESULTS and DISCUSSIONS



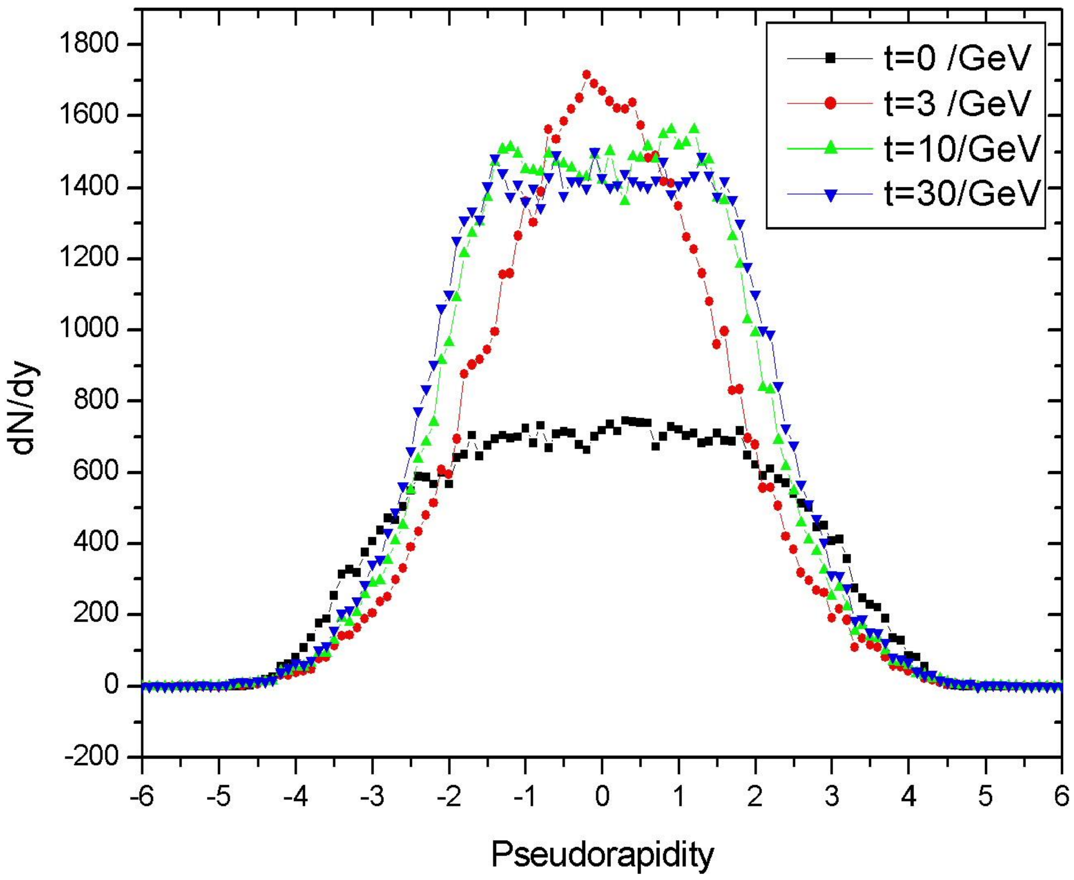
<Energy Density of small sphere(r=1.1fm) at center>



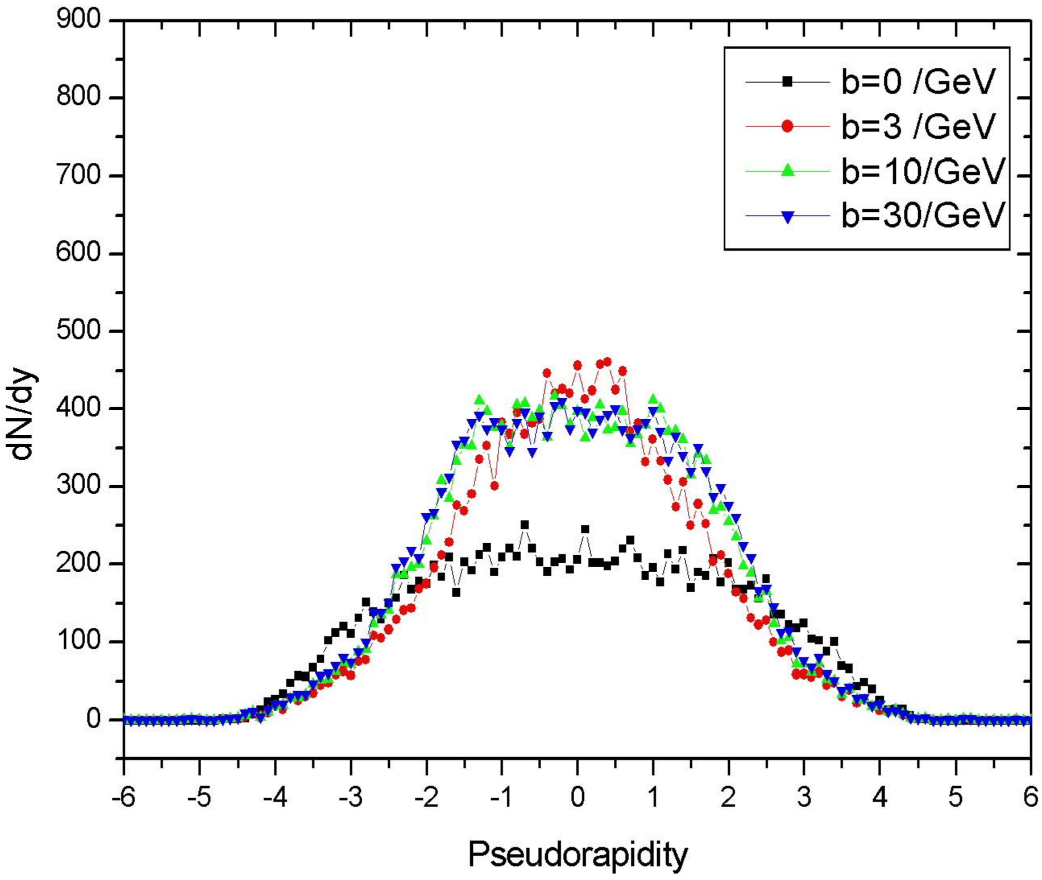
<Number Density of small sphere(r=1.1fm) at center>



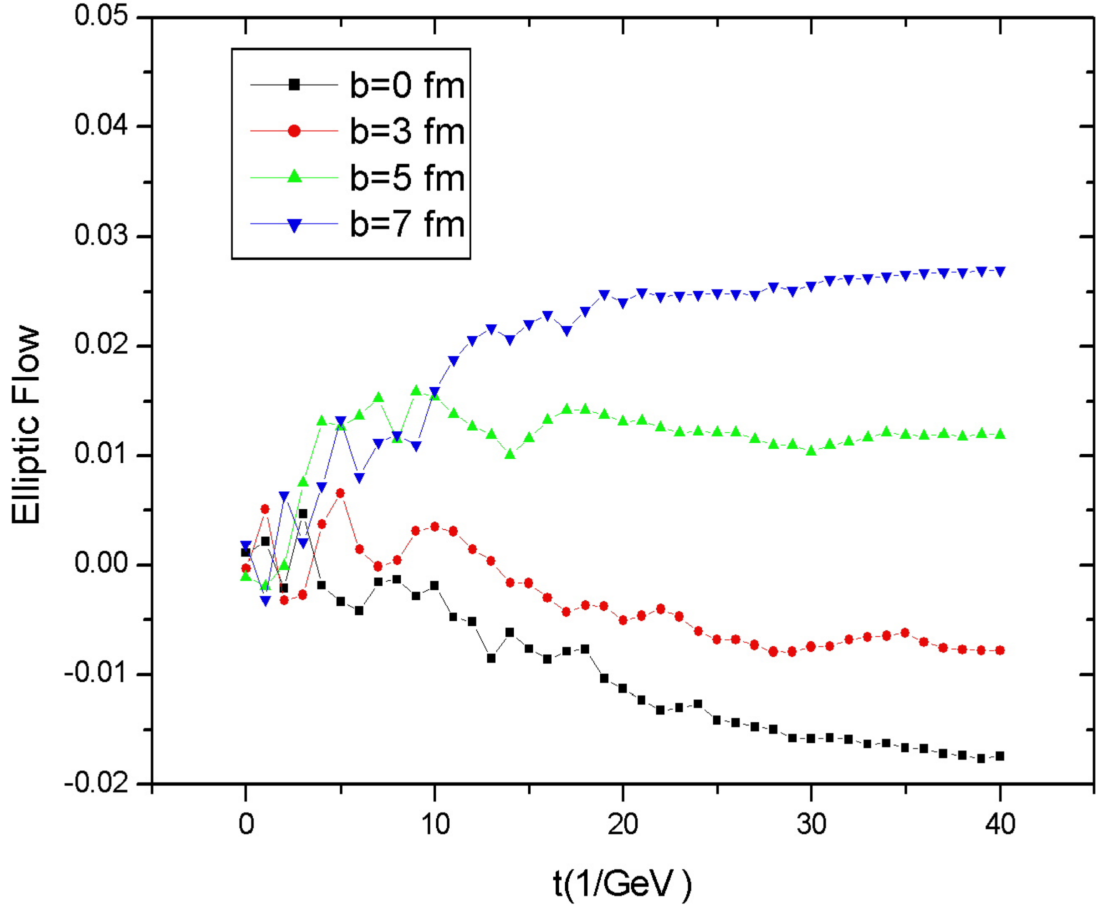
<Isotropicity of small sphere(r=1.1fm) at center>



<Rapidity Distribution: b=0 fm >



<Rapidity Distribution: b=7fm >



<Elliptic Flow for |y| < 2 >

DISCUSSIONS

- **Seems to have ISOTROPIC SYSTEM at b= 0, 3 fm from 1-2 fm/c to 3-4 fm/c at center.**
- **Those system do not show the elliptic flow!**
- **Quite a NON-CENTRAL collision shows the ELLIPTIC FLOW but not ISOTROPIC.**
- **ELLIPTIC FLOW is 2-3% at b=7fm but NEEDS more statistics. Comparable with B. Zhang results for sigma_gg = 10 mb (nucl-th/0309015)**

CONCLUSIONS

- SEEMS to have ENOUGH ENERGY and NUMBER DENSITY, but NOT ISOTROPIC long enough !

- THANK YOU.